EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

JHEP 01 (2022) 063
DOI: 10.1007/JHEP01(2022)063

CERN-EP-2021-098
21st February 2022

Search for exotic decays of the Higgs boson into $b\bar{b}$ and missing transverse momentum in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

The ATLAS Collaboration

A search for the exotic decay of the Higgs boson (H) into a $b\bar{b}$ resonance plus missing transverse momentum is described. The search is performed with the ATLAS detector at the Large Hadron Collider using 139 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV. The search targets events from ZH production in an NMSSM scenario where $H \rightarrow \tilde{\chi}_2^0\tilde{\chi}_1^0$, with $\tilde{\chi}_2^0 \rightarrow a\tilde{\chi}_1^0$, where a is a light pseudoscalar Higgs boson and $\tilde{\chi}_{1,2}^0$ are the two lightest neutralinos. The decay of the a boson into a pair of b-quarks results in a peak in the dijet invariant mass distribution. The final-state signature consists of two leptons, two or more jets, at least one of which is identified as originating from a b-quark, and missing transverse momentum. Observations are consistent with Standard Model expectations and upper limits are set on the product of cross section times branching ratio for a three-dimensional scan of the masses of the $\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$ and a boson.

1 Introduction

Since its introduction, the Standard Model (SM) has successfully predicted several new particles, culminating in the discovery of the Higgs boson (H) [1, 2]. The H boson, discovered by ATLAS and CMS at the CERN Large Hadron Collider (LHC) [3], appears to have properties consistent with those predicted by the SM within current experimental uncertainties [4–6]. The 95% confidence level (CL) upper limit on the branching ratio for H boson decays to beyond-the-SM (BSM) particles, from a combined ATLAS and CMS measurement of the Higgs boson couplings, is 34% [6], although this limit comes with some assumptions. A more recent ATLAS measurement, based on 80 fb^{-1} of 13 TeV data [4], set a 95% CL upper limit of 21% on the branching ratio for H boson decays via undetected modes. Given the magnitude of these limits and the assumptions that go into deriving them, direct searches for exotic decays of the Higgs boson remain a high priority [7]. Among the many final states discussed in Ref. [7], this analysis most closely considers a scenario arising in the next-to-minimal supersymmetric SM (NMSSM) [8], a generalization of the minimal supersymmetric SM (MSSM) [9–13].

The MSSM is the simplest extension to the SM that incorporates supersymmetry (SUSY). It predicts four additional Higgs bosons, generally assumed to be heavier than the H boson: two neutral states, the H^0 and A^0 bosons, as well as two charged states, the $H^{\pm}$ bosons. The measured mass of the Higgs boson [14, 15] close to 125 GeV results in the reintroduction of a 'little hierarchy' problem [16] in the MSSM. This hierarchy is alleviated in the NMSSM by allowing for additional contributions to the mass of the Higgs boson from new scalar particles. The NMSSM contains an additional pseudoscalar Higgs boson (a), generally assumed to be less massive than the H boson since its mass is protected by a Peccei–Quinn (PQ) symmetry [8].

Previous searches for exotic Higgs boson decays involving the production of the a boson have focused on the R-symmetry limit [8] of the NMSSM, where the dominant decay channel is $H \to aa$ [17–27]. As proposed in Refs. [28, 29], the present analysis considers instead the region of parameter space near the PQ symmetry limit of the NMSSM. Near this limit, the decay $H \to \tilde{\chi}_2^0 \tilde{\chi}_1^0 \to a \tilde{\chi}_1^0 \tilde{\chi}_1^0$ dominates over $H \to aa$, where $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ are the two lightest neutralinos, which are admixtures of the supersymmetric partners of the Higgs and gauge bosons of the SM. If the decay $a \to b\bar{b}$ is kinematically allowed, it is typically highly favoured. The $\tilde{\chi}_1^0$ is assumed to be stable, as obtained in R-parity conserving SUSY models [11].

The analysis presented in this paper uses 139 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV collected with the ATLAS detector. It targets the $H \to \tilde{\chi}_2^0 \tilde{\chi}_1^0 \to a \tilde{\chi}_1^0 \tilde{\chi}_1^0$ cascade decay, where the $a \to b\bar{b}$ decay dominates, and the H boson is produced in association with a Z boson. The Z boson is required in the analysis selection to decay into a pair of electrons or muons (hereafter referred to as leptons), which provide a signature to trigger upon and which reduce the multijet background.[1] The resulting final state consists of a pair of oppositely charged leptons, two jets, each containing a b-hadron (b-jets), and missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) from the two $\tilde{\chi}_1^0$ neutralinos. The search is performed for a range of m_a values, and for a few sets of fixed values of $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\chi}_2^0}$.

The primary Standard Model backgrounds in this search are Z bosons produced with heavy-flavour (bottom and charm) jets, hereafter labelled Z+HF, and $t\bar{t}$ events; their contributions are estimated from the data in control regions enhanced in these backgrounds. The dijet invariant mass is used as the final discriminant in a binned likelihood fit.

[1] The contribution from $Z \to \tau^+\tau^-$ decays with the subsequent decays of the τ-leptons into light leptons is included in the signal definition and simulation but is suppressed by a factor of at least 2000 due to the event selection requirements.

The search, which compares an expected background shape in the signal region with the measured shape, is also sensitive in principle to other distortions of the dijet invariant mass spectrum arising from BSM physics effects.

2 The ATLAS detector

The ATLAS experiment [30] at the LHC is a multipurpose particle detector with a forward–backward symmetric cylindrical geometry and a near 4π coverage in solid angle.[2] It consists of an inner tracking detector (ID) surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadron calorimeters, and a muon spectrometer. The inner tracking detector covers the pseudorapidity range $|\eta| < 2.5$. It consists of silicon pixel, silicon microstrip, and transition radiation tracking detectors. The insertable B-layer, installed before Run 2 [31, 32], typically provides the innermost hit on a track. Lead/liquid-argon (LAr) sampling calorimeters provide electromagnetic (EM) energy measurements with high granularity. An iron/scintillator hadron calorimeter covers the central pseudorapidity range ($|\eta| < 1.7$). The endcap and forward regions are instrumented with LAr calorimeters for EM and hadronic energy measurements up to $|\eta| = 4.9$. The muon spectrometer surrounds the calorimeters and is based on three large air-core toroidal superconducting magnets with eight coils each. The field integral of the toroids ranges between 2.0 and 6.0 T m across most of the detector. The muon spectrometer includes a system of precision tracking chambers and fast detectors for triggering. A two-level trigger system [33] is used to select events. The first-level trigger is implemented in hardware and uses a subset of the detector information to keep the accepted event rate below 100 kHz. This is followed by a software-based trigger that reduces the accepted event rate to 1 kHz on average depending on the data-taking conditions. An extensive software suite [34] is used for real and simulated data reconstruction and analysis, for operation and in the trigger and data acquisition systems of the experiment.

3 Data and simulated event samples

The data used in this analysis, corresponding to the full Run 2 dataset for pp collisions, were collected at a centre-of-mass energy of 13 TeV during the 2015–2018 running periods using unprescaled single-lepton triggers with a threshold of 26 GeV (transverse energy, E_{T}, for electrons and transverse momentum, p_{T}, for muons) [35, 36]. Events are selected for analysis only if they are of good quality [37] and if all the relevant detector components are known to have been in good operating condition, which corresponds to a total integrated luminosity of 139.0 ± 2.4 fb^{-1} [38]. The recorded events contain an average of 34 inelastic pp collisions per bunch-crossing.

Although the dominant SM backgrounds are modelled using a data-driven technique, Monte Carlo (MC) simulated events provide input to these techniques and are used to model the subdominant backgrounds and the ZH, $H \to \tilde{\chi}_2^0\tilde{\chi}_1^0$ signal process. A summary of all the MC event generator programs used in

[2] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upwards. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z-axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$. The transverse momentum and transverse energy, p_{T} and E_{T}, are defined as $p\sin\theta$ and $E\sin\theta$, respectively.

Table 1: Monte Carlo simulated samples used in this analysis. The top section shows the nominal samples used for SM backgrounds and the potential signal process. The bottom section shows alternative SM samples for evaluating the impact of theoretical systematic uncertainties.

Process	Generator	Parton shower	PDF	Tune	Normalization
Nominal samples					
$t\bar{t}$	Powheg Box v2 [39–43]	Pythia 8.230 [44]	NNPDF3.0nlo [45]	A14 [46], NNPDF2.3lo [47]	NNLO+NNLL [48–54]
Z + jets	Sherpa 2.2.1 [55]	Sherpa [56–59]	NNPDF3.0nnlo [45]	Sherpa	NNLO [60]
Single-top (Wt)	Powheg Box v2 [61]	Pythia 8.230	NNPDF3.0nlo	A14, NNPDF2.3lo	NLO+NNLL [62]
Diboson	Sherpa 2.2.1–2.2.2	Sherpa	NNPDF3.0nnlo	Sherpa	NLO
NMSSM signal	Powheg Box v2	Pythia 8.210	CTEQ6L1 [63]	AZNLO [64]	NNLO(QCD) + NLO(EWK) [65]
Alternative samples					
$t\bar{t}$	Powheg Box v2	Herwig7 [66, 67]	NNPDF3.0nlo	A14, NNPDF2.3lo	NNLO+NNLL
$t\bar{t}$	MadGraph5_aMC@NLO 2.6.0 [68]	Pythia 8.230	NNPDF3.0nlo	A14, NNPDF2.3lo	NNLO+NNLL
Z + jets	MadGraph5_aMC@NLO 2.2.2	Pythia 8.186 [69]	NNPDF3.0nnlo	A14, NNPDF2.3lo	NNLO

the analysis is provided in Table 1. Samples produced with alternative generators are used to estimate systematic uncertainties in the event modelling, as described in Section 6.

In the $H \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^0$ simulated samples, a Higgs boson is produced in association with a Z boson, using Powheg Box, while Pythia 8.210 is used to force the decay chain: $H \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \rightarrow a \tilde{\chi}_1^0$. The Z boson is forced to decay into e^+e^- or $\mu^+\mu^-$ or $\tau^+\tau^-$. Both the Higgs and a bosons have narrow widths, with the Higgs boson width set to its SM value and the a width set to its mass (in GeV) times 10^{-5}. The a boson is then required to decay into a pair of b-quarks. The a width is narrow enough that the experimental resolution dominates the reconstructed dijet invariant mass width for all masses considered here.

All simulated processes are normalized using the most accurate theoretical cross-section predictions currently available and were generated at least to next-to-leading-order QCD accuracy. All samples of simulated background events were passed through the ATLAS detector simulation [70] based on Geant4 [71], while signal samples were passed through a fast simulation [72] based on a parameterization of showers in the ATLAS calorimeters and employing Geant4 elsewhere. The effects of multiple interactions in the same and nearby bunch crossings (pile-up) were modelled by overlaying the hard-scatter events with minimum-bias events simulated using the soft QCD processes of Pythia 8.186 [69] with the A3 [73] set of tuned parameters (tune) and NNPDF2.3LO [47] parton distribution functions (PDF). The minimum-bias samples were reweighted such that the pile-up distribution matches that in the data. For all samples of simulated events, except for those generated using Sherpa [55], the EvtGen 1.6.0 program [74] was used to describe the decays of bottom and charm hadrons.

4 Object and event selection

4.1 Object reconstruction

Tracks measured in the ID [75] are used to reconstruct interaction vertices [76], of which the one with the highest sum of squared transverse momenta of associated tracks is selected as the primary vertex of the hard interaction.

Electrons are reconstructed from clusters of energy deposits [77] in the electromagnetic calorimeter and matched to a track in the ID [78]. One electron must satisfy the *Tight* identification criteria with $E_{\mathrm{T}} > 30$ GeV to be on the trigger efficiency plateau, and be matched to the trigger electron, while the second is required to satisfy the *Medium* identification criteria with $E_{\mathrm{T}} > 20$ GeV [78]. In addition, these electrons must have $|\eta| < 2.47$, be outside the transition region between the barrel and endcap calorimeters ($1.37 < |\eta| < 1.52$), and have small impact parameters:[3] $|d_0/\sigma_{d_0}| < 5$ and $|z_0 \sin(\theta)| < 0.5$ mm. Finally, these electrons are required to pass the *Gradient* isolation requirements [78].

Muons are reconstructed as described in Refs. [79, 80] and required to have $|\eta| < 2.7$. The leading p_{T} muon is required to have $p_{\mathrm{T}} > 30$ GeV so as to be on the trigger efficiency plateau, and must be matched to the trigger muon, while the second muon is required to have $p_{\mathrm{T}} > 20$ GeV. These muons must satisfy the *Medium* identification criteria, pass the *Gradient* isolation requirements [79], and have $|d_0/\sigma_{d_0}| < 3$ and $|z_0 \sin(\theta)| < 0.5$ mm.

In order to veto events with additional leptons, looser selection criteria are employed. Electrons are required to pass the *LooseAndBLayerLLH* requirements with $E_{\mathrm{T}} > 10$ GeV and $|\eta| < 2.47$. Muons are required to satisfy the *Medium* criteria with $p_{\mathrm{T}} > 4$ GeV and $|\eta| < 2.7$.

Jets are reconstructed from energy deposits in clusters of calorimeter cells [77] using the anti-k_t algorithm [81, 82] with radius parameter $R = 0.4$. Jet cleaning criteria are used to identify jets arising from non-collision backgrounds or noise in the calorimeters [83] and events containing such jets are removed. Jets are calibrated using the standard energy scale corrections [84]. Jets are required to have $p_{\mathrm{T}} > 20$ GeV and $|\eta| < 2.4$. A jet vertex tagger [85] at the *Medium* working point is used to remove jets with $20 < p_{\mathrm{T}} < 60$ GeV and $|\eta| < 2.4$ which are identified as not being associated with the primary vertex of the hard interaction. Jets containing a b-hadron are identified as b-jets (b-tagged) using the MV2 multivariate discriminant [86], with the selection tuned to produce an average efficiency of 77% for b-jets, with corresponding light-flavour (u-, d-, s-quark and gluon) and c-jet misidentification efficiencies of 0.9% and 25% respectively, as measured in simulated $t\bar{t}$ events.

Jets and leptons are reconstructed independently. To prevent double counting of these reconstructed objects, an overlap removal procedure for leptons and jets is applied [87]. The looser selection criteria for leptons, as described above, are employed for the overlap removal.

The missing transverse momentum, with magnitude $E_{\mathrm{T}}^{\mathrm{miss}}$, is calculated as the negative vector sum of the transverse momenta of all calibrated selected objects, such as electrons and jets, and is corrected to take into account the transverse momentum of muons. Tracks with $p_{\mathrm{T}} > 500$ MeV, compatible with the primary vertex but not matched to any reconstructed object, are included in the $E_{\mathrm{T}}^{\mathrm{miss}}$ reconstruction to take into account the soft-radiation component that does not get clustered into any hard object [88].

To account for small efficiency differences between simulation and data, simulated events are corrected with scale factors covering lepton reconstruction, identification, isolation and trigger efficiencies, as well as jet pile-up rejection and flavour tagging efficiencies.

[3] Transverse (d_0) and longitudinal (z_0) impact parameters are defined relative to the primary vertex position, where the beam line is used to approximate the primary vertex position in the transverse plane. The uncertainty in d_0 is denoted by σ_{d_0}.

4.2 Event selection

To select events consistent with the decay of the Higgs boson into a $b\bar{b}$ pair plus $E_{\mathrm{T}}^{\mathrm{miss}}$, this analysis focuses on ZH production in which the leptonic decay of the Z boson into electrons or muons provides the trigger signature for the event.

Events are required to have two leptons of the same flavour and opposite charge; events are rejected if any additional leptons are found. Events containing muons that are poorly reconstructed, with $\sigma(q/p)/|q/p| > 0.2$ where q/p is the charge-to-momentum ratio, or muons from cosmic-ray background, with $|d_0| > 0.2$ mm or $|z_0| > 1$ mm, are also rejected.

Events in the signal region (SR) are required to satisfy the following:

- Dilepton invariant mass in the range $81 < m_{\ell\ell} < 101$ GeV
- Dilepton p_{T} with $p_{\mathrm{T}}^{\ell\ell} > 40$ GeV
- At least two jets with $p_{\mathrm{T}} > 20$ GeV
- $E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV
- Dijet invariant mass in the range $20 < m_{jj} < 120$ GeV, based on the two jets with the highest p_{T} in the event, at least one of which must be b-tagged
- A p_{T} fraction ($p_{\mathrm{T}}^{\mathrm{frac}}$), defined [28] as the scalar sum of the p_{T} of the dijet system and $E_{\mathrm{T}}^{\mathrm{miss}}$ divided by the dilepton p_{T}, in the range:

$$0.8 < \frac{p_{\mathrm{T}}^{jj} + E_{\mathrm{T}}^{\mathrm{miss}}}{p_{\mathrm{T}}^{\ell\ell}} < 1.2$$

The requirement on $p_{\mathrm{T}}^{\mathrm{frac}}$ is especially useful in reducing the $t\bar{t}$ background. Requiring only one b-tagged jet is a trade-off between signal acceptance and background rejection. Although the dijet resonance search is mainly sensitive to decays of particles with masses in the range 20–65 GeV, the window for the dijet invariant mass extends to higher values to take into account the tail in the dijet invariant mass distribution that results from choosing a jet that does not come from $a \to b\bar{b}$, and also to better constrain the background shape.

In addition to the SR, two control regions are defined. A control region for Z+HF (CRZ) is defined with the same requirements as the SR except with $60 < E_{\mathrm{T}}^{\mathrm{miss}} < 100$ GeV. A $t\bar{t}$ control region (CRTop) is defined with the same criteria as the SR but with the $m_{\ell\ell}$ requirement inverted (and $m_{\ell\ell} > 50$ GeV). To validate the modelling of $E_{\mathrm{T}}^{\mathrm{miss}}$ for the Z+HF processes, a validation region VRMET is defined with the same criteria as the SR except that the $E_{\mathrm{T}}^{\mathrm{miss}}$ requirement is loosened to $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV and the dijet invariant mass requirement is $m_{jj} > 150$ GeV.

The selection criteria for the signal, control and validation regions are summarized in Table 2. The acceptance times efficiency (for $H \to \tilde{\chi}_2^0\tilde{\chi}_1^0 \to a\tilde{\chi}_1^0\tilde{\chi}_1^0 \to b\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0$) of the selection varies across the three dimensions of m_a, $m_{\tilde{\chi}_1^0}$, and $m_{\tilde{\chi}_2^0}$, but is primarily a function of m_a and varies from approximately 0.4% to 1.1%, depending on the configuration of the three masses.

Table 2: Summary of the event selection criteria for the signal region (SR), Z+jets control region (CRZ), $t\bar{t}$ control region (CRTop), and a validation region for $E_{\mathrm{T}}^{\mathrm{miss}}$ modelling in Z+HF events (VRMET). The first five selection criteria are common to all regions.

	SR	CRZ	CRTop	VRMET
Number of leptons			2	
Number of jets			≥ 2	
Number of b-tagged jets			≥ 1	
Dilepton p_{T} [GeV]			> 40	
p_{T} fraction			[0.8, 1.2]	
Dilepton mass [GeV]	[81, 101]	[81, 101]	[50, 81] or > 101	[81, 101]
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 100	[60, 100]	> 100	> 50
Dijet mass [GeV]	[20, 120]	[20, 120]	[20, 120]	> 150

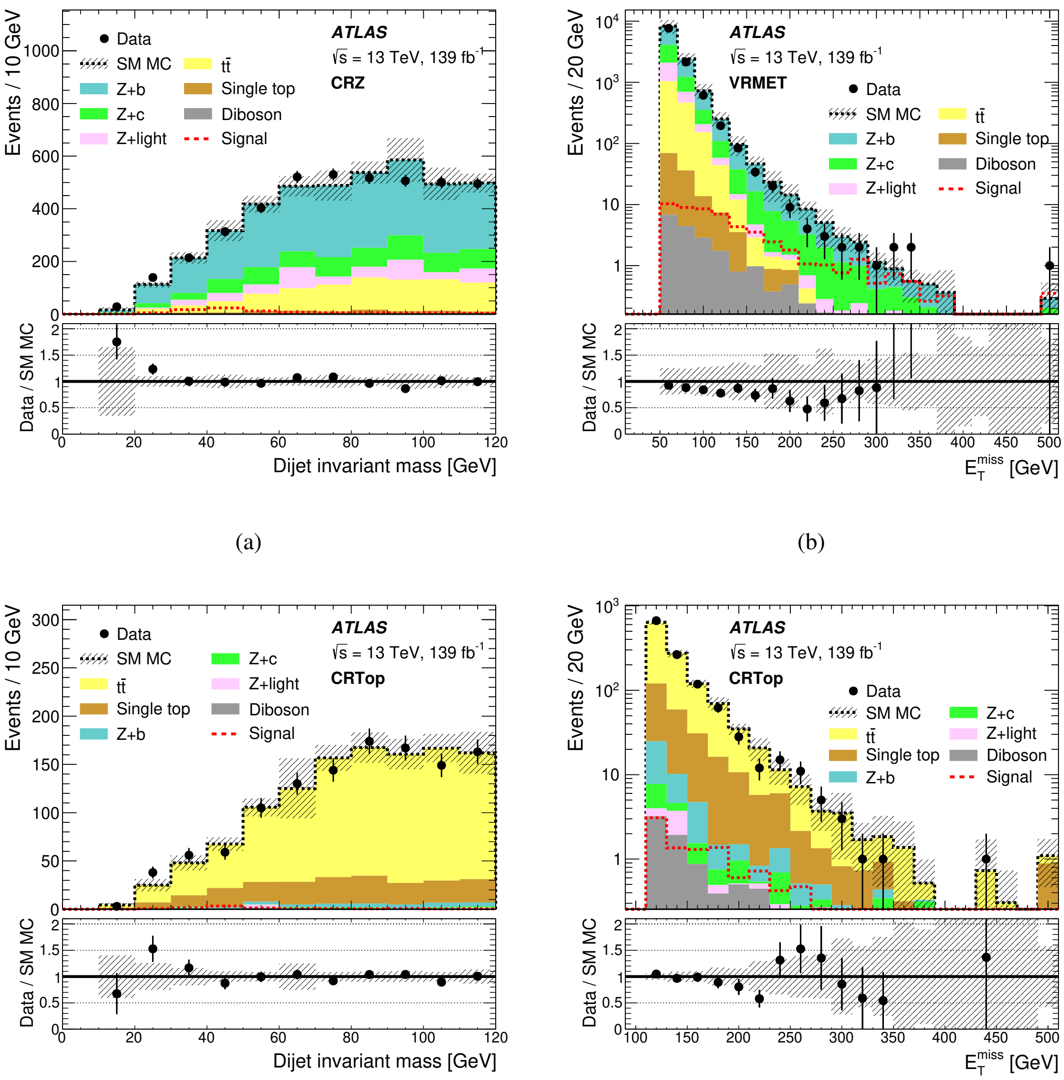
5 Background and statistical model

The background in the SR is primarily composed of Z+HF and $t\bar{t}$, with a small contribution from Z plus light-flavour jets (Z+light), single-top and diboson events. The background from multijet production was studied using same-sign lepton pairs and found to be negligible. The cross sections for Z+HF and $t\bar{t}$ production in the simulation are scaled by normalization factors, $\mu_{\mathrm{Z+HF}}$ and $\mu_{t\bar{t}}$, respectively, determined from a simultaneous fit to the number of events in data and simulation in CRZ and CRTop. Subdominant backgrounds in these regions are normalized to the theoretical cross sections specified in Section 3, while the Z+HF and $t\bar{t}$ components are allowed to float. The calculated scale factors are $\mu_{\mathrm{Z+HF}} = 0.955 \pm 0.032$ and $\mu_{t\bar{t}} = 0.798 \pm 0.033$ where the uncertainties are statistical. Figure 1 shows comparisons between data and simulation in the control and validation regions for a few characteristic observables after applying the Z+HF and $t\bar{t}$ scale factors. The contribution of signal events is less than 1% in CRTop and at most 3% in CRZ for all signal points.

As described below, the background in the SR is modelled using a combination of the m_{jj} distribution shapes from data in CRZ and CRTop to model Z+HF and $t\bar{t}$, respectively, with only a small dependence on the MC simulation. The relatively small contributions of non-Z+HF events to CRZ (approximately 30%) and of non-$t\bar{t}$ events to CRTop (approximately 20%) are derived from MC simulation and subtracted, after applying the scale factors $\mu_{\mathrm{Z+HF}}$ and $\mu_{t\bar{t}}$ to the simulated data. The resulting m_{jj} distributions, assumed to correspond to pure Z+HF and $t\bar{t}$, are referred to as the 'CRZ Z+HF' and 'CRTop $t\bar{t}$' distributions.

The shape of the m_{jj} distribution for Z+HF in CRZ is found to differ slightly from that in the SR, according to the predictions of the Sherpa MC generator. Therefore, the bin-by-bin ratio of the m_{jj} distributions in CRZ and the SR, obtained from MC simulation and denoted by $\mathbf{U}_{\mathrm{Z+HF}}$, is applied to the CRZ Z+HF m_{jj} distribution from the data when assembling the background model. The correction is linear as a function of m_{jj} and ranges from a factor of 0.6 at 20 GeV to just under 1.2 at 120 GeV. A similar comparison via MC simulation between the m_{jj} shapes in CRTop and the SR shows no statistically significant shape difference. Therefore, no shape correction is made for CRTop.

The background model is constructed from the data as a weighted sum of the CRZ Z+HF and CRTop $t\bar{t}$ distributions to which is added the m_{jj} distribution of the subdominant backgrounds in the SR obtained



(a) (b) (c) (d)

Figure 1: Comparison of data and simulation for (a) the dijet invariant mass in CRZ, (b) $E_{\mathrm{T}}^{\mathrm{miss}}$ in VRMET, (c) the dijet invariant mass in CRTop and (d) $E_{\mathrm{T}}^{\mathrm{miss}}$ in CRTop. The Z+HF and $t\bar{t}$ scale factors, described in the text, have been applied to the simulated samples. The lower panels show the ratio of data to SM MC simulation. The total statistical and systematic uncertainties are denoted by the hatched band. Large fluctuations in single bins of the systematic uncertainty band can be caused by high-weight events in the systematic variation samples. The overlaid distribution labelled 'Signal' is for the model with $(m_a, m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0})$ = (45 GeV, 10 GeV, 80 GeV), setting all branching ratios to 100% in the decay chain $H \to \tilde{\chi}_2^0\tilde{\chi}_1^0 \to a\tilde{\chi}_1^0\tilde{\chi}_1^0 \to b\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0$.

from simulation. Signal contamination in the CRs is neglected. The weights for the CRZ and CRTop components, denoted $R_{\text{Z+HF}}$ and $R_{t\bar{t}}$ respectively, are the ratios of the integral event counts from simulation between $m_{jj} = 20$ GeV and 120 GeV in the SR to those in the respective control region. The background model can be described as

$$\mu_{\text{bkg}} N_{\text{SR}}^{\text{model}}\, \hat{\mathbf{f}}_{\text{SR}}^{\text{model}} = \mu_{\text{bkg}} \left(N_{\text{CRTop}}^{\text{data}\ t\bar{t}}\, R_{t\bar{t}} \hat{\mathbf{f}}_{\text{CRTop}}^{\text{data}\ t\bar{t}} + N_{\text{CRZ}}^{\text{data Z+HF}} R_{\text{Z+HF}} \hat{\mathbf{f}}_{\text{CRZ-corr}}^{\text{data Z+HF}} + N_{\text{SR-MC}}^{\text{sub-dom.}}\, \hat{\mathbf{f}}_{\text{SR-MC}}^{\text{sub-dom.}} \right), \tag{1}$$

where N_j^i is the total event count of sample i in region j, and $\hat{\mathbf{f}}_j^i$ is the probability density function as a function of m_{jj} of sample i in region j, both obtained from data in the respective control regions. In particular, $\hat{\mathbf{f}}_{\text{CRZ-corr}}^{\text{data Z+HF}}$ is the normalized product of $\mathbf{U}_{\text{Z+HF}}$ and $\hat{\mathbf{f}}_{\text{CRZ}}^{\text{data Z+HF}}$, where $\mathbf{U}_{\text{Z+HF}}$ is the m_{jj} bin-by-bin shape correction factor described above. The superscript 'subdom.' on the last term in Eq. (1) indicates the subdominant backgrounds (Z+light, single-top, and diboson events) that are derived directly from the Monte Carlo simulation in the signal region, as indicated by the subscript 'SR-MC'.

Because R_i and $\mathbf{U}_{Z+HF}$ are ratios of quantities from the MC samples, they are less sensitive to detector and theory systematic uncertainties. The factor μ_{bkg} is a background normalization parameter whose expected value is close to unity, given that the left-hand side is normalized to $N_{\text{SR}}^{\text{model}}$, the number of background events expected from simulation in the SR, after having applied the Z+HF and $t\bar{t}$ scale factors, $\mu_{\text{Z+HF}}$ and $\mu_{t\bar{t}}$, respectively. To smooth out statistical fluctuations in the background shape, the histogram resulting from the superposition in Eq. (1) is fit with a fourth-order polynomial over the range $m_{jj} \in (20\,\text{GeV}, 120\,\text{GeV})$.

Hypothesis tests for the presence of an exotic Higgs boson decay signal are performed with a multi-bin fit of the m_{jj} distribution in the SR, based on a product of Poisson likelihood terms in a profile likelihood-ratio [89] test statistic. Systematic uncertainties are included as additional terms in the likelihood, assuming Gaussian auxiliary measurements for the nuisance parameters. Upper limits are obtained at 95% CL, based on the CL_s prescription [90].

The model that is fit to the data is the sum of two m_{jj} templates:

- The SM background, whose shape comes from the parameterization described earlier in this section. The normalization is controlled by the nuisance parameter μ_{bkg}.
- The signal, whose shape comes directly from simulation. The signal normalization is controlled by the fit parameter-of-interest, μ_{sig}, which is constrained to be positive. The parameter is scaled to correspond to the branching ratio for the exotic Higgs boson decay, $H \to \tilde{\chi}_2^0 \tilde{\chi}_1^0 \to a \tilde{\chi}_1^0 \tilde{\chi}_1^0$, without constraining the branching ratio to be less than unity, and assuming the Standard Model cross section for ZH associated production and a branching ratio $\text{BR}(a \to b\bar{b}) = 100\%$.

6 Systematic uncertainties

Systematic uncertainties affect our ability to model the shape of the background dijet invariant mass spectrum from simulation, and therefore the background model used in the final fit. Since the background model is built primarily using the data m_{jj} distributions in CRZ and CRTop, the impact of several sources of theoretical and experimental uncertainty is reduced. Nevertheless, the simulated m_{jj} distributions enter through the subdominant backgrounds in both control regions and in the SR, through the predicted yields of Z+HF and $t\bar{t}$ in the three regions, and through the m_{jj} shape correction for Z+HF events, all of which enter into Eq. (1). In addition, the signal acceptance and m_{jj} line shape are subject to theoretical and experimental uncertainties.

Systematic uncertainties are evaluated for detector effects, for theoretical modelling and for variations in the parameterized background model shape arising from the statistical uncertainties in the polynomial fit parameters. In addition, a systematic uncertainty is evaluated to account for the choice of background functional form by comparing the results obtained using the fourth-order polynomial with those from a perfect fit to the data, i.e. the background-model data points themselves. The uncertainty associated with a systematic effect is taken into account by producing a new background m_{jj} distribution that includes the systematic variation. Scale factors for Z+HF and $t\bar{t}$ and the m_{jj} shape correction for Z+HF are recomputed for each systematic variation and the background analysis is fully re-run to determine the size of the effect on the shape of the background model.

The procedure to derive the background model introduces statistical uncertainties when subtracting the subdominant backgrounds. These uncertainties are accounted for in the statistical uncertainty of the background model. However, to avoid double counting of these statistical uncertainties when evaluating the impact of systematic variations, the subtraction of the subdominant backgrounds is omitted; both the nominal distribution and the systematically varied distribution are evaluated without subtracting the subdominant backgrounds. Comparing the shape of the background model with and without the subtraction of the subdominant backgrounds, the difference, measured as the maximum absolute difference between the two background curves, was found to be at most 3%.

Detector-related uncertainties are evaluated for the jet energy scale and resolution [84], the efficiency of the jet vertex tagger [85], the b-tagging performance [86, 91, 92], pile-up reweighting, and lepton reconstruction efficiency, energy/momentum scale, and resolution effects [78, 79]. The jet- and lepton-related uncertainties are propagated to the calculation of $E_{\mathrm{T}}^{\mathrm{miss}}$; an additional uncertainty for the soft-radiation component contributing to $E_{\mathrm{T}}^{\mathrm{miss}}$ is also taken into account [88]. The uncertainty in the combined 2015–2018 integrated luminosity is 1.7% [38], obtained using the LUCID-2 detector [93] for the primary luminosity measurements.

Uncertainties in the theoretical modelling of the dominant background processes (Z+HF and $t\bar{t}$) are evaluated as follows. For Z+HF, the effects of varying the factorization and renormalization scales were evaluated using seven variations in Sherpa [94] each of which changed the renormalization and factorization scales by a factor of 0.5 or 2,[4] leading to a maximum shape difference in the m_{jj} distribution of 4%. Results are also evaluated using an alternative sample based on MadGraph5_aMC@NLO [68] and their difference from those of the nominal Sherpa samples, at most 5%, is assigned as an additional systematic uncertainty.

For $t\bar{t}$ production, uncertainties are estimated by comparing different matrix-element calculations (Powheg Box vs aMC@NLO), different choices of parton-showering model (Pythia8 vs Herwig7), and different amounts of initial-state (ISR) and final-state (FSR) radiation within Pythia8, while leaving all other parameters for each comparison unchanged. The uncertainty due to ISR is estimated by comparing the nominal $t\bar{t}$ sample with two additional samples to simulate higher/lower parton radiation [95]. The impact of FSR is evaluated by varying the renormalization scale for emissions from the parton shower up and down by a factor of two. All of these variations lead to differences compared to the nominal choice of less than 2%.

[4] The pairwise variations applied to the renormalization (μ_{r}) and factorization (μ_{f}) scales are $[\mu_{\mathrm{r}}, \mu_{\mathrm{f}}] \times [0.5, 0.5], [1, 0.5], [0.5, 1], [1, 1], [2, 1], [1, 2], [2, 2]$.

The systematic uncertainty in the ZH cross section is taken from Ref. [65] and includes the effect of QCD scale, PDF, and α_s uncertainties. The impact of theoretical uncertainties on the Higgs boson production kinematics were neglected, based on the studies described in Ref. [96].

7 Results

The m_{jj} distribution in the SR is shown in Figure 2. The observation is consistent with the background model for the SM hypothesis. The long tail on the example signal distribution comes from selecting a jet that does not come from the $a \to b\bar{b}$ decay. For the signal models considered below, which include m_a from 20 GeV to 65 GeV, the smallest p-value [89] is 0.39 for the model with $(m_a, m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0})$ = (50 GeV, 10 GeV, 110 GeV).

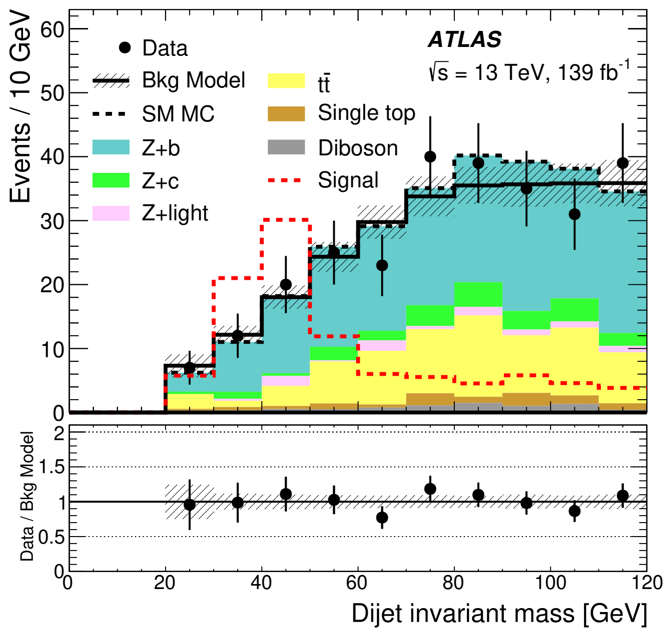


Figure 2: Distribution of the dijet invariant mass in the signal region, shown together with the parameterized background model (labelled ‘Bkg Model’). For reference, the MC prediction for the SM background is also shown (labelled ‘SM MC’). The Z+HF and $t\bar{t}$ scale factors, described in the text, have been applied to the simulated samples. The signal region is defined to have dijet invariant mass > 20 GeV. The total statistical and systematic uncertainties are denoted by the hatched band. The distribution labelled ‘Signal’ is for the model with $(m_a, m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0})$ = (45 GeV, 10 GeV, 80 GeV), setting all branching ratios to 100% in the decay chain $H \to \tilde{\chi}_2^0 \tilde{\chi}_1^0 \to a \tilde{\chi}_1^0 \tilde{\chi}_1^0 \to b\bar{b} \tilde{\chi}_1^0 \tilde{\chi}_1^0$. The long tail on the signal distribution comes from selecting a jet that does not come from the $a \to b\bar{b}$ decay. The lower panel shows the ratio of the observed data to the expectation from the parameterized background model.

The dominant uncertainty limiting the final result is statistical and comes from the limited number of events in the signal region. The dominant systematic uncertainty is again statistical in nature and comes from the normalization of the background shape function to the data observed in the SR; for signal models where this analysis has sensitivity, this uncertainty has a 6%–10% effect on the fitted μ_{sig}. Subdominant systematic uncertainties in this analysis include the theoretical uncertainty of the Z+HF m_{jj} shape correction (2%–3%), the jet energy resolution (1%–3%), the flavour dependence of the jet energy scale (1%–2%), and the statistical uncertainties of the background shape parameters (1%–3%), which arise from the limited number of data events in CRZ and CRTop.

Upper limits at 95% CL on the $pp \to ZH$ cross section times branching ratio for $Z \to \ell^+\ell^-$ (where $\ell = e, \mu$ or τ) and $H \to \tilde{\chi}_2^0\tilde{\chi}_1^0 \to a\tilde{\chi}_1^0\tilde{\chi}_1^0 \to b\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0$ are shown in Figure 3 as a function of m_a for several fixed values of $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\chi}_2^0}$. Assuming the SM value for ZH production, these results can be interpreted as upper limits on the branching ratio for $H \to \tilde{\chi}_2^0\tilde{\chi}_1^0 \to a\tilde{\chi}_1^0\tilde{\chi}_1^0 \to b\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0$. In the region of highest sensitivity, a branching ratio upper limit of 31% is obtained. For comparison between the results at different $\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$ mass points, Figure 4 shows the six 95% CL upper limits of Figure 3 together, without the uncertainty bands.

8 Conclusion

A search for the exotic decay of the Higgs boson (H) into a $b\bar{b}$ resonance plus missing transverse momentum has been performed with the ATLAS detector at the Large Hadron Collider in 139 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV . The search was designed to target Higgs bosons produced in association with a Z boson and was conducted in events with two leptons, two or more jets, at least one of which must be b-tagged, and missing transverse momentum. The analysis was optimized on a model in the Peccei–Quinn symmetry limit of the NMSSM where $H \to \tilde{\chi}_2^0\tilde{\chi}_1^0$, with $\tilde{\chi}_2^0 \to a\tilde{\chi}_1^0$, and a is a new, light pseudoscalar Higgs boson. The decay of the a boson into a pair of b-quarks results in a resonance in the dijet invariant mass. Such models differ from those considered in past searches for exotic Higgs boson decays involving the production of a, where the NMSSM was considered in the R-symmetry limit in which the dominant decay channel is $H \to aa$. Observations are consistent with SM expectations and upper limits on the $pp \to ZH$ cross section times the branching ratio for $Z \to \ell^+\ell^-$ and $H \to \tilde{\chi}_2^0\tilde{\chi}_1^0 \to a\tilde{\chi}_1^0\tilde{\chi}_1^0 \to b\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0$ have been obtained for a three-dimensional scan of masses of the $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and a boson. Assuming the SM cross section for ZH production, and assuming 100% branching ratios for the decays $\tilde{\chi}_2^0 \to a\tilde{\chi}_1^0$ and $a \to b\bar{b}$, an upper limit on the branching ratio BR($H \to \tilde{\chi}_2^0\tilde{\chi}_1^0$) of 31% is obtained at 95% confidence level for a range of m_a values between 35 and 55 GeV for fixed values of $m_{\tilde{\chi}_1^0} = 10$ GeV and $m_{\tilde{\chi}_2^0} = 80$ GeV. These represent the first direct limits on this exotic Higgs boson decay from the LHC.

Acknowledgements

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently.

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; ANID, Chile; CAS, MOST and NSFC, China; Minciencias, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF and MPG, Germany; GSRI, Greece; RGC and Hong Kong SAR, China; ISF and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO,

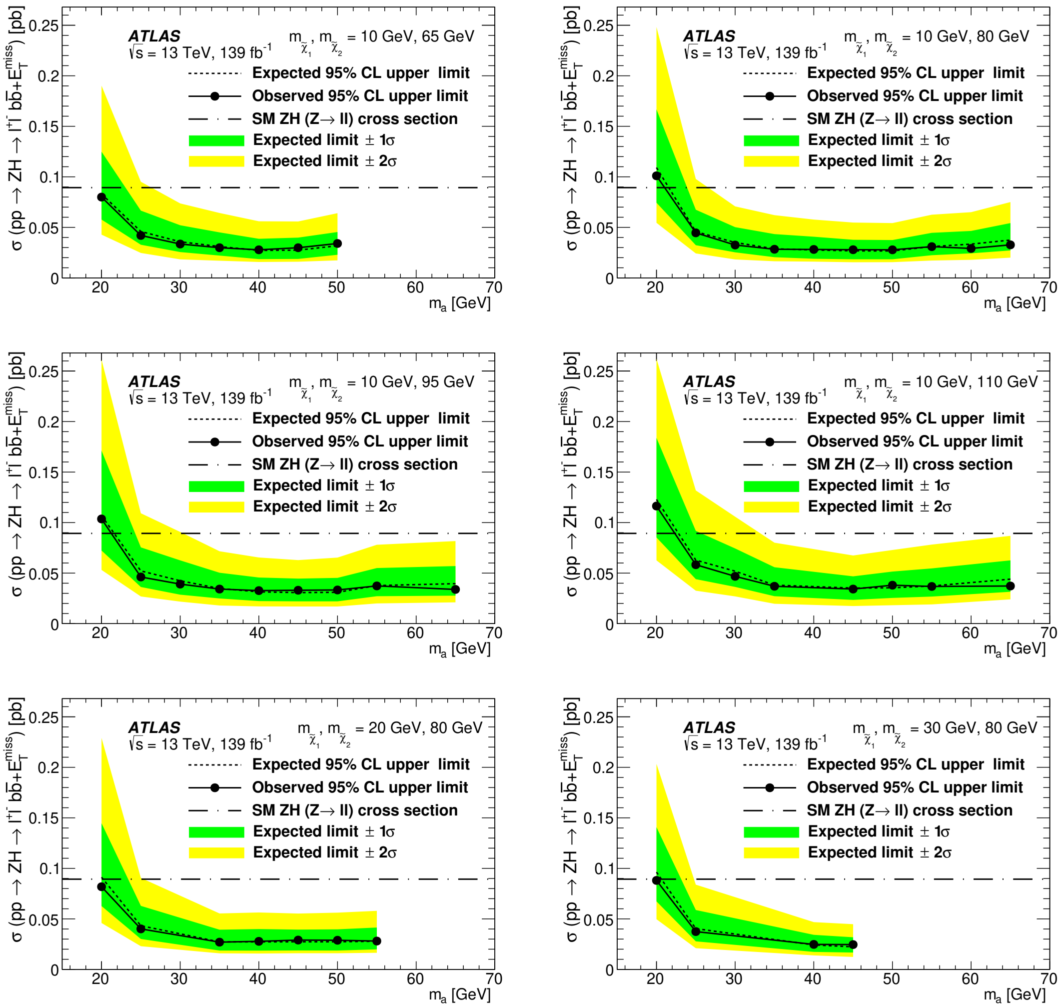


Figure 3: Upper limits at 95% CL on the $pp \to ZH$ cross section times the branching ratio for $Z \to \ell^+\ell^-$ (where $\ell = e, \mu$ or τ) and $H \to \tilde{\chi}_2^0\tilde{\chi}_1^0 \to a\tilde{\chi}_1^0\tilde{\chi}_1^0 \to b\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0$ as a function of m_a for several values of $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\chi}_2^0}$ for the NMSSM scenario described in the text. All branching ratios in the decay chain after the decay $H \to \tilde{\chi}_2^0\tilde{\chi}_1^0$ are set to 100%. The different ranges of m_a points on the horizontal axis reflect differences in the allowed event kinematics. The green and yellow bands show respectively the $\pm 1\sigma$ and $\pm 2\sigma$ ranges for the expected limits. The lines joining the m_a points come from an assumed linear interpolation of the limits. The SM value for the cross section $\sigma(pp \to ZH) \times BR(Z \to \ell^+\ell^-)$ is shown for reference.

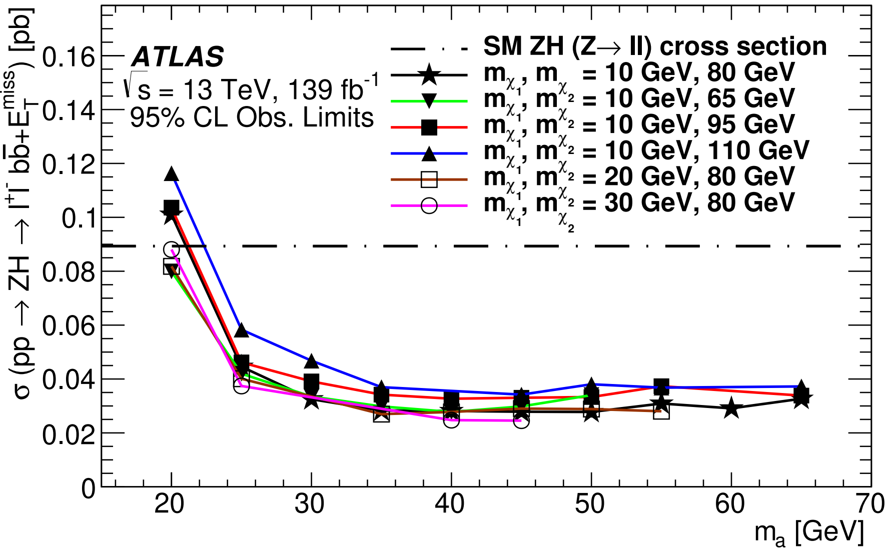


Figure 4: Upper limits at 95% CL on the cross section $pp \to ZH$ times branching ratio for $Z \to \ell^+\ell^-$ (where $\ell = e, \mu$ or τ) and $H \to \tilde{\chi}_2^0\tilde{\chi}_1^0 \to a\tilde{\chi}_1^0\tilde{\chi}_1^0 \to b\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0$ as a function of m_a for several values of $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\chi}_2^0}$ for the NMSSM scenario described in the text. All branching ratios in the Higgs boson decay chain after the decay $H \to \tilde{\chi}_2^0\tilde{\chi}_1^0$ are set to 100%. The different ranges in m_a reflect differences in the allowed event kinematics. The lines joining the m_a points come from an assumed linear interpolation of the limits. The SM value for the cross section $\sigma(pp \to ZH) \times BR(Z \to \ell^+\ell^-)$ is shown for reference.

Netherlands; RCN, Norway; MEiN, Poland; FCT, Portugal; MNE/IFA, Romania; JINR; MES of Russia and NRC KI, Russian Federation; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DSI/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TAEK, Turkey; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, CANARIE, Compute Canada and CRC, Canada; COST, ERC, ERDF, Horizon 2020 and Marie Skłodowska-Curie Actions, European Union; Investissements d'Avenir Labex, Investissements d'Avenir Idex and ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF, Greece; BSF-NSF and GIF, Israel; Norwegian Financial Mechanism 2014-2021, Norway; NCN and NAWA, Poland; La Caixa Banking Foundation, CERCA Programme Generalitat de Catalunya and PROMETEO and GenT Programmes Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [97].

References

[1] ATLAS Collaboration, *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, Phys. Lett. B **716** (2012) 1, arXiv: 1207.7214 [hep-ex].

[2] CMS Collaboration, *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*, Phys. Lett. B **716** (2012) 30, arXiv: 1207.7235 [hep-ex].

[3] L. Evans and P. Bryant, *LHC Machine*, JINST **3** (2008) S08001.

[4] ATLAS Collaboration, *Combined measurements of Higgs boson production and decay using up to* $80\,fb^{-1}$ *of proton–proton collision data at* $\sqrt{s} = 13$ *TeV collected with the ATLAS experiment*, Phys. Rev. D **101** (2020) 012002, arXiv: 1909.02845 [hep-ex].

[5] CMS Collaboration, *Combined measurements of Higgs boson couplings in proton–proton collisions at* $\sqrt{s} = 13$ *TeV*, Eur. Phys. J. C **79** (2019) 421, arXiv: 1809.10733 [hep-ex].

[6] ATLAS and CMS Collaborations, *Measurements of the Higgs boson production and decay rates and constraints on its couplings from a combined ATLAS and CMS analysis of the LHC* pp *collision data at* $\sqrt{s} = 7$ *and* 8 *TeV*, JHEP **08** (2016) 045, arXiv: 1606.02266 [hep-ex].

[7] D. Curtin et al., *Exotic decays of the 125 GeV Higgs boson*, Phys. Rev. D **90** (2014) 075004, arXiv: 1312.4992 [hep-ph].

[8] U. Ellwanger, C. Hugonie and A. M. Teixeira, *The Next-to-Minimal Supersymmetric Standard Model*, Phys. Rept. **496** (2010) 1, arXiv: 0910.1785 [hep-ph].

[9] P. Fayet, *Supersymmetry and weak, electromagnetic and strong interactions*, Phys. Lett. B **64** (1976) 159.

[10] P. Fayet, *Spontaneously broken supersymmetric theories of weak, electromagnetic and strong interactions*, Phys. Lett. B **69** (1977) 489.

[11] G. R. Farrar and P. Fayet, *Phenomenology of the production, decay, and detection of new hadronic states associated with supersymmetry*, Phys. Lett. B **76** (1978) 575.

[12] P. Fayet, *Relations between the masses of the superpartners of leptons and quarks, the goldstino coupling and the neutral currents*, Phys. Lett. B **84** (1979) 416.

[13] S. Dimopoulos and H. Georgi, *Softly broken supersymmetry and SU(5)*, Nucl. Phys. B **193** (1981) 150.

[14] ATLAS Collaboration, *Measurement of the Higgs boson mass in the* $H \rightarrow ZZ^* \rightarrow 4\ell$ *and* $H \rightarrow \gamma\gamma$ *channels with* $\sqrt{s} = 13$ *TeV* pp *collisions using the ATLAS detector*, Phys. Lett. B **784** (2018) 345, arXiv: 1806.00242 [hep-ex].

[15] CMS Collaboration, *A measurement of the Higgs boson mass in the diphoton decay channel*, Phys. Lett. B **805** (2020) 135425, arXiv: 2002.06398 [hep-ex].

[16] R. Barbieri and A. Strumia, *The 'LEP paradox'*, (2000), arXiv: hep-ph/0007265.

[17] ATLAS Collaboration, *Search for Higgs bosons decaying to aa in the $\mu\mu\tau\tau$ final state in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS experiment*, Phys. Rev. D **92** (2015) 052002, arXiv: 1505.01609 [hep-ex].

[18] ATLAS Collaboration, *Search for Higgs boson decays into pairs of light (pseudo)scalar particles in the $\gamma\gamma jj$ final state in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Phys. Lett. B **782** (2018) 750, arXiv: 1803.11145 [hep-ex].

[19] ATLAS Collaboration, *Search for the Higgs boson produced in association with a vector boson and decaying into two spin-zero particles in the $H \to aa \to 4b$ channel in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, JHEP **10** (2018) 031, arXiv: 1806.07355 [hep-ex].

[20] ATLAS Collaboration, *Search for Higgs boson decays into a pair of light bosons in the $bb\mu\mu$ final state in pp collision at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Phys. Lett. B **790** (2019) 1, arXiv: 1807.00539 [hep-ex].

[21] ATLAS Collaboration, *Search for Higgs boson decays into two new low-mass spin-0 particles in the 4b channel with the ATLAS detector using pp collisions at $\sqrt{s} = 13$ TeV*, Phys. Rev. D **102** (2020) 112006, arXiv: 2005.12236 [hep-ex].

[22] CMS Collaboration, *Search for a very light NMSSM Higgs boson produced in decays of the 125 GeV scalar boson and decaying into τ leptons in pp collisions at $\sqrt{s} = 8$ TeV*, JHEP **01** (2016) 079, arXiv: 1510.06534 [hep-ex].

[23] CMS Collaboration, *Search for an exotic decay of the Higgs boson to a pair of light pseudoscalars in the final state of two muons and two τ leptons in proton–proton collisions at $\sqrt{s} = 13$ TeV*, JHEP **11** (2018) 018, arXiv: 1805.04865 [hep-ex].

[24] CMS Collaboration, *Search for an exotic decay of the Higgs boson to a pair of light pseudoscalars in the final state with two b quarks and two τ leptons in proton–proton collisions at $\sqrt{s} = 13$ TeV*, Phys. Lett. B **785** (2018) 462, arXiv: 1805.10191 [hep-ex].

[25] CMS Collaboration, *Search for an exotic decay of the Higgs boson to a pair of light pseudoscalars in the final state with two muons and two b quarks in pp collisions at 13 TeV*, Phys. Lett. B **795** (2019) 398, arXiv: 1812.06359 [hep-ex].

[26] CMS Collaboration, *Search for light pseudoscalar boson pairs produced from decays of the 125 GeV Higgs boson in final states with two muons and two nearby tracks in pp collisions at $\sqrt{s} = 13$ TeV*, Phys. Lett. B **800** (2020) 135087, arXiv: 1907.07235 [hep-ex].

[27] CMS Collaboration, *Search for a light pseudoscalar Higgs boson in the boosted $\mu\mu\tau\tau$ final state in proton–proton collisions at $\sqrt{s} = 13$ TeV*, JHEP **08** (2020) 139, arXiv: 2005.08694 [hep-ex].

[28] J. Huang, T. Liu, L.-T. Wang and F. Yu, *Supersymmetric Exotic Decays of the 125 GeV Higgs Boson*, Phys. Rev. Lett. **112** (2014) 221803, arXiv: 1309.6633 [hep-ph].

[29] J. Huang, T. Liu, L.-T. Wang and F. Yu, *Supersymmetric subelectroweak scale dark matter, the Galactic Center gamma-ray excess, and exotic decays of the 125 GeV Higgs boson*, Phys. Rev. D **90** (2014) 115006, arXiv: 1407.0038 [hep-ph].

[30] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST **3** (2008) S08003.

[31] ATLAS Collaboration, *ATLAS Insertable B-Layer Technical Design Report*, ATLAS-TDR-19; CERN-LHCC-2010-013, 2010, URL: https://cds.cern.ch/record/1291633, Addendum: ATLAS-TDR-19-ADD-1; CERN-LHCC-2012-009, 2012, URL: https://cds.cern.ch/record/1451888.

[32] B. Abbott et al., *Production and integration of the ATLAS Insertable B-Layer*, JINST **13** (2018) T05008, arXiv: 1803.00844 [physics.ins-det].

[33] ATLAS Collaboration, *Performance of the ATLAS trigger system in 2015*, Eur. Phys. J. C **77** (2017) 317, arXiv: 1611.09661 [hep-ex].

[34] ATLAS Collaboration, *The ATLAS Collaboration Software and Firmware*, ATL-SOFT-PUB-2021-001, 2021, URL: https://cds.cern.ch/record/2767187.

[35] ATLAS Collaboration, *Performance of electron and photon triggers in ATLAS during LHC Run 2*, Eur. Phys. J. C **80** (2020) 47, arXiv: 1909.00761 [hep-ex].

[36] ATLAS Collaboration, *Performance of the ATLAS muon triggers in Run 2*, JINST **15** (2020) P09015, arXiv: 2004.13447 [hep-ex].

[37] ATLAS Collaboration, *ATLAS data quality operations and performance for 2015–2018 data-taking*, JINST **15** (2020) P04003, arXiv: 1911.04632 [physics.ins-det].

[38] ATLAS Collaboration, *Luminosity determination in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC*, ATLAS-CONF-2019-021, 2019, URL: https://cds.cern.ch/record/2677054.

[39] S. Frixione, P. Nason and G. Ridolfi, *A positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction*, JHEP **09** (2007) 126, arXiv: 0707.3088 [hep-ph].

[40] P. Nason, *A new method for combining NLO QCD with shower Monte Carlo algorithms*, JHEP **11** (2004) 040, arXiv: hep-ph/0409146.

[41] S. Frixione, P. Nason and C. Oleari, *Matching NLO QCD computations with parton shower simulations: the POWHEG method*, JHEP **11** (2007) 070, arXiv: 0709.2092 [hep-ph].

[42] S. Alioli, P. Nason, C. Oleari and E. Re, *A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX*, JHEP **06** (2010) 043, arXiv: 1002.2581 [hep-ph].

[43] ATLAS Collaboration, *Studies on top-quark Monte Carlo modelling for Top2016*, ATL-PHYS-PUB-2016-020, 2016, URL: https://cds.cern.ch/record/2216168.

[44] T. Sjöstrand et al., *An introduction to PYTHIA 8.2*, Comput. Phys. Commun. **191** (2015) 159, arXiv: 1410.3012 [hep-ph].

[45] R. D. Ball et al., *Parton distributions for the LHC run II*, JHEP **04** (2015) 040, arXiv: 1410.8849 [hep-ph].

[46] ATLAS Collaboration, *ATLAS Pythia 8 tunes to 7 TeV data*, ATL-PHYS-PUB-2014-021, 2014, URL: https://cds.cern.ch/record/1966419.

[47] R. D. Ball et al., *Parton distributions with LHC data*, Nucl. Phys. B **867** (2013) 244, arXiv: 1207.1303 [hep-ph].

[48] M. Beneke, P. Falgari, S. Klein and C. Schwinn,
Hadronic top-quark pair production with NNLL threshold resummation,
Nucl. Phys. B **855** (2012) 695, arXiv: 1109.1536 [hep-ph].

[49] M. Cacciari, M. Czakon, M. Mangano, A. Mitov and P. Nason, *Top-pair production at hadron colliders with next-to-next-to-leading logarithmic soft-gluon resummation*,
Phys. Lett. B **710** (2012) 612, arXiv: 1111.5869 [hep-ph].

[50] P. Bärnreuther, M. Czakon and A. Mitov, *Percent-Level-Precision Physics at the Tevatron: Next-to-Next-to-Leading Order QCD Corrections to $q\bar{q} \to t\bar{t} + X$*,
Phys. Rev. Lett. **109** (2012) 132001, arXiv: 1204.5201 [hep-ph].

[51] M. Czakon and A. Mitov,
NNLO corrections to top-pair production at hadron colliders: the all-fermionic scattering channels,
JHEP **12** (2012) 054, arXiv: 1207.0236 [hep-ph].

[52] M. Czakon and A. Mitov,
NNLO corrections to top pair production at hadron colliders: the quark-gluon reaction,
JHEP **01** (2013) 080, arXiv: 1210.6832 [hep-ph].

[53] M. Czakon, P. Fiedler and A. Mitov,
Total Top-Quark Pair-Production Cross Section at Hadron Colliders Through $O(\alpha_S^4)$,
Phys. Rev. Lett. **110** (2013) 252004, arXiv: 1303.6254 [hep-ph].

[54] M. Czakon and A. Mitov,
Top++: A program for the calculation of the top-pair cross-section at hadron colliders,
Comput. Phys. Commun. **185** (2014) 2930, arXiv: 1112.5675 [hep-ph].

[55] E. Bothmann et al., *Event generation with Sherpa 2.2*, SciPost Phys. **7** (2019) 034,
arXiv: 1905.09127 [hep-ph].

[56] S. Höche, F. Krauss, M. Schönherr and F. Siegert,
A critical appraisal of NLO+PS matching methods, JHEP **09** (2012) 049,
arXiv: 1111.1220 [hep-ph].

[57] S. Höche, F. Krauss, M. Schönherr and F. Siegert,
QCD matrix elements + parton showers. The NLO case, JHEP **04** (2013) 027,
arXiv: 1207.5030 [hep-ph].

[58] S. Catani, F. Krauss, B. R. Webber and R. Kuhn, *QCD Matrix Elements + Parton Showers*,
JHEP **11** (2001) 063, arXiv: hep-ph/0109231.

[59] S. Höche, F. Krauss, S. Schumann and F. Siegert, *QCD matrix elements and truncated showers*,
JHEP **05** (2009) 053, arXiv: 0903.1219 [hep-ph].

[60] C. Anastasiou, L. J. Dixon, K. Melnikov and F. Petriello, *High precision QCD at hadron colliders: Electroweak gauge boson rapidity distributions at next-to-next-to leading order*,
Phys. Rev. D **69** (2004) 094008, arXiv: hep-ph/0312266.

[61] E. Re, *Single-top Wt-channel production matched with parton showers using the POWHEG method*,
Eur. Phys. J. C **71** (2011) 1547, arXiv: 1009.2450 [hep-ph].

[62] N. Kidonakis,
Two-loop soft anomalous dimensions for single top quark associated production with a W^- or H^-,
Phys. Rev. D **82** (2010) 054018, arXiv: 1005.4451 [hep-ph].

[63] J. Pumplin et al.,
New Generation of Parton Distributions with Uncertainties from Global QCD Analysis,
JHEP **07** (2002) 012, arXiv: hep-ph/0201195.

[64] ATLAS Collaboration, *Measurement of the Z/γ^* boson transverse momentum distribution in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector*, JHEP **09** (2014) 145,
arXiv: 1406.3660 [hep-ex].

[65] D. de Florian et al.,
Handbook of LHC Higgs Cross Sections: 4. Deciphering the Nature of the Higgs Sector, (2016),
arXiv: 1610.07922 [hep-ph].

[66] J. Bellm et al., *Herwig 7.0/Herwig++ 3.0 release note*, Eur. Phys. J. C **76** (2016) 196,
arXiv: 1512.01178 [hep-ph].

[67] M. Bähr et al., *Herwig++ physics and manual*, Eur. Phys. J. C **58** (2008) 639,
arXiv: 0803.0883 [hep-ph].

[68] J. Alwall et al., *The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations*, JHEP **07** (2014) 079,
arXiv: 1405.0301 [hep-ph].

[69] T. Sjöstrand, S. Mrenna and P. Skands, *A brief introduction to PYTHIA 8.1*,
Comput. Phys. Commun. **178** (2008) 852, arXiv: 0710.3820 [hep-ph].

[70] ATLAS Collaboration, *The ATLAS Simulation Infrastructure*, Eur. Phys. J. C **70** (2010) 823,
arXiv: 1005.4568 [physics.ins-det].

[71] GEANT4 Collaboration, S. Agostinelli et al., *Geant4 – a simulation toolkit*,
Nucl. Instrum. Meth. A **506** (2003) 250.

[72] ATLAS Collaboration,
The simulation principle and performance of the ATLAS fast calorimeter simulation FastCaloSim,
ATL-PHYS-PUB-2010-013, 2010, URL: https://cds.cern.ch/record/1300517.

[73] ATLAS Collaboration, *The Pythia 8 A3 tune description of ATLAS minimum bias and inelastic measurements incorporating the Donnachie–Landshoff diffractive model*,
ATL-PHYS-PUB-2016-017, 2016, URL: https://cds.cern.ch/record/2206965.

[74] D. J. Lange, *The EvtGen particle decay simulation package*,
Nucl. Instrum. Meth. A **462** (2001) 152.

[75] ATLAS Collaboration,
Performance of the ATLAS track reconstruction algorithms in dense environments in LHC Run 2,
Eur. Phys. J. C **77** (2017) 673, arXiv: 1704.07983 [hep-ex].

[76] ATLAS Collaboration, *Vertex Reconstruction Performance of the ATLAS Detector at $\sqrt{s} = 13$ TeV*,
ATL-PHYS-PUB-2015-026, 2015, URL: https://cds.cern.ch/record/2037717.

[77] ATLAS Collaboration,
Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1,
Eur. Phys. J. C **77** (2017) 490, arXiv: 1603.02934 [hep-ex].

[78] ATLAS Collaboration, *Electron and photon performance measurements with the ATLAS detector using the 2015–2017 LHC proton–proton collision data*, JINST **14** (2019) P12006,
arXiv: 1908.00005 [hep-ex].

[79] ATLAS Collaboration, *Muon reconstruction performance of the ATLAS detector in proton–proton collision data at $\sqrt{s}$ = 13 TeV*, Eur. Phys. J. C **76** (2016) 292, arXiv: 1603.05598 [hep-ex].

[80] ATLAS Collaboration, *Muon reconstruction and identification efficiency in ATLAS using the full Run 2 pp collision data set at $\sqrt{s}$ = 13 TeV*, Eur. Phys. J. C **81** (2021) 578, arXiv: 2012.00578 [hep-ex].

[81] M. Cacciari, G. P. Salam and G. Soyez, *The anti-k_t jet clustering algorithm*, JHEP **04** (2008) 063, arXiv: 0802.1189 [hep-ph].

[82] M. Cacciari, G. P. Salam and G. Soyez, *FastJet user manual*, Eur. Phys. J. C **72** (2012) 1896, arXiv: 1111.6097 [hep-ph].

[83] ATLAS Collaboration, *Selection of jets produced in 13 TeV proton–proton collisions with the ATLAS detector*, ATLAS-CONF-2015-029, 2015, URL: https://cds.cern.ch/record/2037702.

[84] ATLAS Collaboration, *Jet energy scale measurements and their systematic uncertainties in proton–proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector*, Phys. Rev. D **96** (2017) 072002, arXiv: 1703.09665 [hep-ex].

[85] ATLAS Collaboration, *Performance of pile-up mitigation techniques for jets in pp collisions at $\sqrt{s}$ = 8 TeV using the ATLAS detector*, Eur. Phys. J. C **76** (2016) 581, arXiv: 1510.03823 [hep-ex].

[86] ATLAS Collaboration, *ATLAS b-jet identification performance and efficiency measurement with $t\bar{t}$ events in pp collisions at $\sqrt{s}$ = 13 TeV*, Eur. Phys. J. C **79** (2019) 970, arXiv: 1907.05120 [hep-ex].

[87] ATLAS Collaboration, *Search for a scalar partner of the top quark in the jets plus missing transverse momentum final state at $\sqrt{s}$ = 13 TeV with the ATLAS detector*, JHEP **12** (2017) 085, arXiv: 1709.04183 [hep-ex].

[88] ATLAS Collaboration, *Performance of missing transverse momentum reconstruction with the ATLAS detector using proton–proton collisions at $\sqrt{s}$ = 13 TeV*, Eur. Phys. J. C **78** (2018) 903, arXiv: 1802.08168 [hep-ex].

[89] G. Cowan, K. Cranmer, E. Gross and O. Vitells, *Asymptotic formulae for likelihood-based tests of new physics*, Eur. Phys. J. C **71** (2011) 1554, arXiv: 1007.1727 [physics.data-an], Erratum: Eur. Phys. J. C **73** (2013) 2501.

[90] A. L. Read, *Presentation of search results: the CL_S technique*, J. Phys. G **28** (2002) 2693.

[91] ATLAS Collaboration, *Calibration of light-flavour b-jet mistagging rates using ATLAS proton–proton collision data at $\sqrt{s}$ = 13 TeV*, ATLAS-CONF-2018-006, 2018, URL: https://cds.cern.ch/record/2314418.

[92] ATLAS Collaboration, *Measurement of b-tagging efficiency of c-jets in $t\bar{t}$ events using a likelihood approach with the ATLAS detector*, ATLAS-CONF-2018-001, 2018, URL: https://cds.cern.ch/record/2306649.

[93] G. Avoni et al., *The new LUCID-2 detector for luminosity measurement and monitoring in ATLAS*, JINST **13** (2018) P07017.

[94] E. Bothmann, M. Schönherr and S. Schumann, *Reweighting QCD matrix-element and parton-shower calculations*, Eur. Phys. J. C **76** (2016) 590, arXiv: 1606.08753 [hep-ph].

[95] ATLAS Collaboration,
Studies on top-quark Monte Carlo modelling with Sherpa and MG5_aMC@NLO,
ATL-PHYS-PUB-2017-007, 2017, URL: https://cds.cern.ch/record/2261938.

[96] ATLAS Collaboration,
Observation of $H \to b\bar{b}$ decays and VH production with the ATLAS detector,
Phys. Lett. B **786** (2018) 59, arXiv: 1808.08238 [hep-ex].

[97] ATLAS Collaboration, *ATLAS Computing Acknowledgements*, ATL-SOFT-PUB-2021-003,
URL: https://cds.cern.ch/record/2776662.

The ATLAS Collaboration

G. Aad[99], B. Abbott[124], D.C. Abbott[100], A. Abed Abud[34], K. Abeling[51], D.K. Abhayasinghe[91], S.H. Abidi[27], H. Abramowicz[157], H. Abreu[156], Y. Abulaiti[5], A.C. Abusleme Hoffman[142a], B.S. Acharya[64a,64b,p], B. Achkar[51], L. Adam[97], C. Adam Bourdarios[4], L. Adamczyk[81a], L. Adamek[162], S.V. Addepalli[24], J. Adelman[117], A. Adiguzel[11c,ae], S. Adorni[52], T. Adye[139], A.A. Affolder[141], Y. Afik[156], C. Agapopoulou[62], M.N. Agaras[12], J. Agarwala[68a,68b], A. Aggarwal[115], C. Agheorghiesei[25c], J.A. Aguilar-Saavedra[135f,135a,ad], A. Ahmad[34], F. Ahmadov[77], W.S. Ahmed[101], X. Ai[44], G. Aielli[71a,71b], I. Aizenberg[175], S. Akatsuka[83], M. Akbiyik[97], T.P.A. Åkesson[94], A.V. Akimov[108], K. Al Khoury[37], G.L. Alberghi[21b], J. Albert[171], M.J. Alconada Verzini[86], S. Alderweireldt[48], M. Aleksa[34], I.N. Aleksandrov[77], C. Alexa[25b], T. Alexopoulos[9], A. Alfonsi[116], F. Alfonsi[21b,21a], M. Alhroob[124], B. Ali[137], S. Ali[154], M. Aliev[161], G. Alimonti[66a], C. Allaire[34], B.M.M. Allbrooke[152], P.P. Allport[19], A. Aloisio[67a,67b], F. Alonso[86], C. Alpigiani[144], E. Alunno Camelia[71a,71b], M. Alvarez Estevez[96], M.G. Alviggi[67a,67b], Y. Amaral Coutinho[78b], A. Ambler[101], L. Ambroz[130], C. Amelung[34], D. Amidei[103], S.P. Amor Dos Santos[135a], S. Amoroso[44], C.S. Amrouche[52], C. Anastopoulos[145], N. Andari[140], T. Andeen[10], J.K. Anders[18], S.Y. Andrean[43a,43b], A. Andreazza[66a,66b], V. Andrei[59a], S. Angelidakis[8], A. Angerami[37], A.V. Anisenkov[118b,118a], A. Annovi[69a], C. Antel[52], M.T. Anthony[145], E. Antipov[125], M. Antonelli[49], D.J.A. Antrim[16], F. Anulli[70a], M. Aoki[79], J.A. Aparisi Pozo[169], M.A. Aparo[152], L. Aperio Bella[44], N. Aranzabal[34], V. Araujo Ferraz[78a], C. Arcangeletti[49], A.T.H. Arce[47], E. Arena[88], J-F. Arguin[107], S. Argyropoulos[50], J.-H. Arling[44], A.J. Armbruster[34], A. Armstrong[166], O. Arnaez[162], H. Arnold[34], Z.P. Arrubarrena Tame[111], G. Artoni[130], H. Asada[113], K. Asai[122], S. Asai[159], N.A. Asbah[57], E.M. Asimakopoulou[167], L. Asquith[152], J. Assahsah[33d], K. Assamagan[27], R. Astalos[26a], R.J. Atkin[31a], M. Atkinson[168], N.B. Atlay[17], H. Atmani[58b], P.A. Atmasiddha[103], K. Augsten[137], S. Auricchio[67a,67b], V.A. Austrup[177], G. Avner[156], G. Avolio[34], M.K. Ayoub[13c], G. Azuelos[107,ak], D. Babal[26a], H. Bachacou[140], K. Bachas[158], F. Backman[43a,43b], A. Badea[57], P. Bagnaia[70a,70b], H. Bahrasemani[148], A.J. Bailey[169], V.R. Bailey[168], J.T. Baines[139], C. Bakalis[9], O.K. Baker[178], P.J. Bakker[116], E. Bakos[14], D. Bakshi Gupta[7], S. Balaji[153], R. Balasubramanian[116], E.M. Baldin[118b,118a], P. Balek[138], E. Ballabene[66a,66b], F. Balli[140], W.K. Balunas[130], J. Balz[97], E. Banas[82], M. Bandieramonte[134], A. Bandyopadhyay[17], S. Bansal[22], L. Barak[157], E.L. Barberio[102], D. Barberis[53b,53a], M. Barbero[99], G. Barbour[92], K.N. Barends[31a], T. Barillari[112], M-S. Barisits[34], J. Barkeloo[127], T. Barklow[149], B.M. Barnett[139], R.M. Barnett[16], A. Baroncelli[58a], G. Barone[27], A.J. Barr[130], L. Barranco Navarro[43a,43b], F. Barreiro[96], J. Barreiro Guimarães da Costa[13a], U. Barron[157], S. Barsov[133], F. Bartels[59a], R. Bartoldus[149], G. Bartolini[99], A.E. Barton[87], P. Bartos[26a], A. Basalaev[44], A. Basan[97], I. Bashta[72a,72b], A. Bassalat[62], M.J. Basso[162], C.R. Basson[98], R.L. Bates[55], S. Batlamous[33e], J.R. Batley[30], B. Batool[147], M. Battaglia[141], M. Bauce[70a,70b], F. Bauer[140,*], P. Bauer[22], H.S. Bawa[29], A. Bayirli[11c], J.B. Beacham[47], T. Beau[131], P.H. Beauchemin[165], F. Becherer[50], P. Bechtle[22], H.P. Beck[18,r], K. Becker[173], C. Becot[44], A.J. Beddall[11a], V.A. Bednyakov[77], C.P. Bee[151], T.A. Beermann[177], M. Begalli[78b], M. Begel[27], A. Behera[151], J.K. Behr[44], C. Beirao Da Cruz E Silva[34], J.F. Beirer[51,34], F. Beisiegel[22], M. Belfkir[4], G. Bella[157], L. Bellagamba[21b], A. Bellerive[32], P. Bellos[19], K. Beloborodov[118b,118a], K. Belotskiy[109], N.L. Belyaev[109], D. Benchekroun[33a], Y. Benhammou[157], D.P. Benjamin[27], M. Benoit[27], J.R. Bensinger[24], S. Bentvelsen[116], L. Beresford[34], M. Beretta[49], D. Berge[17], E. Bergeaas Kuutmann[167], N. Berger[4], B. Bergmann[137], L.J. Bergsten[24], J. Beringer[16], S. Berlendis[6], G. Bernardi[131], C. Bernius[149], F.U. Bernlochner[22], T. Berry[91], P. Berta[44], A. Berthold[46], I.A. Bertram[87], O. Bessidskaia Bylund[177], S. Bethke[112], A. Betti[40], A.J. Bevan[90], S. Bhatta[151], D.S. Bhattacharya[172], P. Bhattarai[24], V.S. Bhopatkar[5], R. Bi[134], R.M. Bianchi[134], O. Biebel[111], R. Bielski[34], N.V. Biesuz[69a,69b], M. Biglietti[72a], T.R.V. Billoud[137], M. Bindi[51], A. Bingul[11d], C. Bini[70a,70b], S. Biondi[21b,21a], C.J. Birch-sykes[98], G.A. Bird[19,139], M. Birman[175], T. Bisanz[34], J.P. Biswal[2], D. Biswas[176,k], A. Bitadze[98], C. Bittrich[46], K. Bjørke[129], I. Bloch[44], C. Blocker[24], A. Blue[55], U. Blumenschein[90], J. Blumenthal[97], G.J. Bobbink[116], V.S. Bobrovnikov[118b,118a], D. Bogavac[12], A.G. Bogdanchikov[118b,118a], C. Bohm[43a], V. Boisvert[91], P. Bokan[44], T. Bold[81a], M. Bomben[131], M. Bona[90], M. Boonekamp[140], C.D. Booth[91], A.G. Borbély[55], H.M. Borecka-Bielska[107], L.S. Borgna[92], G. Borissov[87], D. Bortoletto[130], D. Boscherini[21b], M. Bosman[12], J.D. Bossio Sola[101], K. Bouaouda[33a], J. Boudreau[134], E.V. Bouhova-Thacker[87], D. Boumediene[36], R. Bouquet[131], A. Boveia[123], J. Boyd[34], D. Boye[27], I.R. Boyko[77], A.J. Bozson[91], J. Bracinik[19], N. Brahimi[58d,58c], G. Brandt[177], O. Brandt[30], F. Braren[44], B. Brau[100], J.E. Brau[127], W.D. Breaden Madden[55], K. Brendlinger[44], R. Brener[175], L. Brenner[34], R. Brenner[167], S. Bressler[175], B. Brickwedde[97], D.L. Briglin[19], D. Britton[55], D. Britzger[112], I. Brock[22], R. Brock[104], G. Brooijmans[37], W.K. Brooks[142d], E. Brost[27], P.A. Bruckman de Renstrom[82], B. Brüers[44], D. Bruncko[26b], A. Bruni[21b], G. Bruni[21b], M. Bruschi[21b], N. Bruscino[70a,70b], L. Bryngemark[149], T. Buanes[15], Q. Buat[151], P. Buchholz[147], A.G. Buckley[55], I.A. Budagov[77], M.K. Bugge[129], O. Bulekov[109], B.A. Bullard[57], T.J. Burch[117], S. Burdin[88], C.D. Burgard[44], A.M. Burger[125], B. Burghgrave[7], J.T.P. Burr[44], C.D. Burton[10], J.C. Burzynski[100], V. Büscher[97], P.J. Bussey[55], J.M. Butler[23], C.M. Buttar[55], J.M. Butterworth[92], W. Buttinger[139], C.J. Buxo Vazquez[104], A.R. Buzykaev[118b,118a], G. Cabras[21b], S. Cabrera Urbán[169], D. Caforio[54], H. Cai[134], V.M.M. Cairo[149], O. Cakir[3a], N. Calace[34], P. Calafiura[16], G. Calderini[131], P. Calfayan[63], G. Callea[55], L.P. Caloba[78b], A. Caltabiano[71a,71b], S. Calvente Lopez[96], D. Calvet[36], S. Calvet[36], T.P. Calvet[99], M. Calvetti[69a,69b], R. Camacho Toro[131], S. Camarda[34], D. Camarero Munoz[96], P. Camarri[71a,71b], M.T. Camerlingo[72a,72b], D. Cameron[129], C. Camincher[171], M. Campanelli[92], A. Camplani[38], V. Canale[67a,67b], A. Canesse[101], M. Cano Bret[75], J. Cantero[125], Y. Cao[168], F. Capocasa[24], M. Capua[39b,39a], A. Carbone[66a,66b], R. Cardarelli[71a], F. Cardillo[169], G. Carducci[39b,39a], T. Carli[34], G. Carlino[67a], B.T. Carlson[134], E.M. Carlson[171,163a], L. Carminati[66a,66b], M. Carnesale[70a,70b], R.M.D. Carney[149], S. Caron[115], E. Carquin[142d], S. Carrá[44], G. Carratta[21b,21a], J.W.S. Carter[162], T.M. Carter[48], D. Casadei[31c], M.P. Casado[12,h], A.F. Casha[162], E.G. Castiglia[178], F.L. Castillo[59a], L. Castillo Garcia[12], V. Castillo Gimenez[169], N.F. Castro[135a,135e], A. Catinaccio[34], J.R. Catmore[129], A. Cattai[34], V. Cavaliere[27], N. Cavalli[21b,21a], V. Cavasinni[69a,69b], E. Celebi[11b], F. Celli[130], K. Cerny[126], A.S. Cerqueira[78a], A. Cerri[152], L. Cerrito[71a,71b], F. Cerutti[16], A. Cervelli[21b], S.A. Cetin[11b], Z. Chadi[33a], D. Chakraborty[117], M. Chala[135f], J. Chan[176], W.S. Chan[116], W.Y. Chan[88], J.D. Chapman[30], B. Chargeishvili[155b], D.G. Charlton[19], T.P. Charman[90], M. Chatterjee[18], S. Chekanov[5], S.V. Chekulaev[163a], G.A. Chelkov[77,ag], A. Chen[103], B. Chen[157], C. Chen[58a], C.H. Chen[76], H. Chen[13c], H. Chen[27], J. Chen[58a], J. Chen[37], J. Chen[24], S. Chen[132], S.J. Chen[13c], X. Chen[58c], X. Chen[13b], Y. Chen[58a], Y-H. Chen[44], C.L. Cheng[176], H.C. Cheng[60a], H.J. Cheng[13a], A. Cheplakov[77], E. Cheremushkina[44], R. Cherkaoui El Moursli[33e], E. Cheu[6], K. Cheung[61], L. Chevalier[140], V. Chiarella[49], G. Chiarelli[69a], G. Chiodini[65a], A.S. Chisholm[19], A. Chitan[25b], I. Chiu[159], Y.H. Chiu[171], M.V. Chizhov[77,t], K. Choi[10], A.R. Chomont[70a,70b], Y. Chou[100], Y.S. Chow[116], L.D. Christopher[31f], M.C. Chu[60a], X. Chu[13a,13d], J. Chudoba[136], J.J. Chwastowski[82], D. Cieri[112], K.M. Ciesla[82], V. Cindro[89], I.A. Cioară[25b], A. Ciocio[16], F. Cirotto[67a,67b], Z.H. Citron[175,l], M. Citterio[66a], D.A. Ciubotaru[25b], B.M. Ciungu[162], A. Clark[52], P.J. Clark[48], J.M. Clavijo Columbie[44], S.E. Clawson[98], C. Clement[43a,43b], L. Clissa[21b,21a], Y. Coadou[99], M. Cobal[64a,64c], A. Coccaro[53b], J. Cochran[76], R.F. Coelho Barrue[135a], R. Coelho Lopes De Sa[100], S. Coelli[66a], H. Cohen[157], A.E.C. Coimbra[34], B. Cole[37], J. Collot[56], P. Conde Muiño[135a,135h], S.H. Connell[31c], I.A. Connelly[55], E.I. Conroy[130], F. Conventi[67a,al], H.G. Cooke[19], A.M. Cooper-Sarkar[130], F. Cormier[170], L.D. Corpe[34], M. Corradi[70a,70b], E.E. Corrigan[94], F. Corriveau[101,aa], M.J. Costa[169], F. Costanza[4], D. Costanzo[145], B.M. Cote[123], G. Cowan[91], J.W. Cowley[30], J. Crane[98], K. Cranmer[121], R.A. Creager[132], S. Crépé-Renaudin[56], F. Crescioli[131], M. Cristinziani[147], M. Cristoforetti[73a,73b,b], V. Croft[165], G. Crosetti[39b,39a], A. Cueto[4], T. Cuhadar Donszelmann[166], H. Cui[13a,13d], A.R. Cukierman[149], W.R. Cunningham[55], S. Czekierda[82], P. Czodrowski[34], M.M. Czurylo[59b], M.J. Da Cunha Sargedas De Sousa[58a], J.V. Da Fonseca Pinto[78b],

C. Da Via[98], W. Dabrowski[81a], T. Dado[45], S. Dahbi[31f], T. Dai[103], C. Dallapiccola[100], M. Dam[38], G. D'amen[27], V. D'Amico[72a,72b], J. Damp[97], J.R. Dandoy[132], M.F. Daneri[28], M. Danninger[148], V. Dao[34], G. Darbo[53b], S. Darmora[5], A. Dattagupta[127], S. D'Auria[66a,66b], C. David[163b], T. Davidek[138], D.R. Davis[47], B. Davis-Purcell[32], I. Dawson[90], K. De[7], R. De Asmundis[67a], M. De Beurs[116], S. De Castro[21b,21a], N. De Groot[115], P. de Jong[116], H. De la Torre[104], A. De Maria[13c], D. De Pedis[70a], A. De Salvo[70a], U. De Sanctis[71a,71b], M. De Santis[71a,71b], A. De Santo[152], J.B. De Vivie De Regie[56], D.V. Dedovich[77], J. Degens[116], A.M. Deiana[40], J. Del Peso[96], Y. Delabat Diaz[44], F. Deliot[140], C.M. Delitzsch[6], M. Della Pietra[67a,67b], D. Della Volpe[52], A. Dell'Acqua[34], L. Dell'Asta[66a,66b], M. Delmastro[4], P.A. Delsart[56], S. Demers[178], M. Demichev[77], S.P. Denisov[119], L. D'Eramo[117], D. Derendarz[82], J.E. Derkaoui[33d], F. Derue[131], P. Dervan[88], K. Desch[22], K. Dette[162], C. Deutsch[22], P.O. Deviveiros[34], F.A. Di Bello[70a,70b], A. Di Ciaccio[71a,71b], L. Di Ciaccio[4], C. Di Donato[67a,67b], A. Di Girolamo[34], G. Di Gregorio[69a,69b], A. Di Luca[73a,73b], B. Di Micco[72a,72b], R. Di Nardo[72a,72b], C. Diaconu[99], F.A. Dias[116], T. Dias Do Vale[135a], M.A. Diaz[142a], F.G. Diaz Capriles[22], J. Dickinson[16], M. Didenko[169], E.B. Diehl[103], J. Dietrich[17], S. Díez Cornell[44], C. Diez Pardos[147], A. Dimitrievska[16], W. Ding[13b], J. Dingfelder[22], I-M. Dinu[25b], S.J. Dittmeier[59b], F. Dittus[34], F. Djama[99], T. Djobava[155b], J.I. Djuvsland[15], M.A.B. Do Vale[143], D. Dodsworth[24], C. Doglioni[94], J. Dolejsi[138], Z. Dolezal[138], M. Donadelli[78c], B. Dong[58c], J. Donini[36], A. D'onofrio[13c], M. D'Onofrio[88], J. Dopke[139], A. Doria[67a], M.T. Dova[86], A.T. Doyle[55], E. Drechsler[148], E. Dreyer[148], T. Dreyer[51], A.S. Drobac[165], D. Du[58b], T.A. du Pree[116], F. Dubinin[108], M. Dubovsky[26a], A. Dubreuil[52], E. Duchovni[175], G. Duckeck[111], O.A. Ducu[34,25b], D. Duda[112], A. Dudarev[34], M. D'uffizi[98], L. Duflot[62], M. Dührssen[34], C. Dülsen[177], A.E. Dumitriu[25b], M. Dunford[59a], S. Dungs[45], K. Dunne[43a,43b], A. Duperrin[99], H. Duran Yildiz[3a], M. Düren[54], A. Durglishvili[155b], B. Dutta[44], D. Duvnjak[1], G.I. Dyckes[132], M. Dyndal[81a], S. Dysch[98], B.S. Dziedzic[82], B. Eckerova[26a], M.G. Eggleston[47], E. Egidio Purcino De Souza[78b], L.F. Ehrke[52], T. Eifert[7], G. Eigen[15], K. Einsweiler[16], T. Ekelof[167], Y. El Ghazali[33b], H. El Jarrari[33e], A. El Moussaouy[33a], V. Ellajosyula[167], M. Ellert[167], F. Ellinghaus[177], A.A. Elliot[90], N. Ellis[34], J. Elmsheuser[27], M. Elsing[34], D. Emeliyanov[139], A. Emerman[37], Y. Enari[159], J. Erdmann[45], A. Ereditato[18], P.A. Erland[82], M. Errenst[177], M. Escalier[62], C. Escobar[169], O. Estrada Pastor[169], E. Etzion[157], G. Evans[135a], H. Evans[63], M.O. Evans[152], A. Ezhilov[133], F. Fabbri[55], L. Fabbri[21b,21a], V. Fabiani[115], G. Facini[173], V. Fadeyev[141], R.M. Fakhrutdinov[119], S. Falciano[70a], P.J. Falke[22], S. Falke[34], J. Faltova[138], Y. Fan[13a], Y. Fang[13a], Y. Fang[13a], G. Fanourakis[42], M. Fanti[66a,66b], M. Faraj[58c], A. Farbin[7], A. Farilla[72a], E.M. Farina[68a,68b], T. Farooque[104], S.M. Farrington[48], P. Farthouat[34], F. Fassi[33e], D. Fassouliotis[8], M. Faucci Giannelli[71a,71b], W.J. Fawcett[30], L. Fayard[62], O.L. Fedin[133,q], M. Feickert[168], L. Feligioni[99], A. Fell[145], C. Feng[58b], M. Feng[13b], M.J. Fenton[166], A.B. Fenyuk[119], S.W. Ferguson[41], J. Ferrando[44], A. Ferrari[167], P. Ferrari[116], R. Ferrari[68a], D. Ferrere[52], C. Ferretti[103], F. Fiedler[97], A. Filipčič[89], F. Filthaut[115], M.C.N. Fiolhais[135a,135c,a], L. Fiorini[169], F. Fischer[147], W.C. Fisher[104], T. Fitschen[19], I. Fleck[147], P. Fleischmann[103], T. Flick[177], B.M. Flierl[111], L. Flores[132], L.R. Flores Castillo[60a], F.M. Follega[73a,73b], N. Fomin[15], J.H. Foo[162], G.T. Forcolin[73a,73b], B.C. Forland[63], A. Formica[140], F.A. Förster[12], A.C. Forti[98], E. Fortin[99], M.G. Foti[130], D. Fournier[62], H. Fox[87], P. Francavilla[69a,69b], S. Francescato[70a,70b], M. Franchini[21b,21a], S. Franchino[59a], D. Francis[34], L. Franco[4], L. Franconi[18], M. Franklin[57], G. Frattari[70a,70b], A.C. Freegard[90], P.M. Freeman[19], B. Freund[107], W.S. Freund[78b], E.M. Freundlich[45], D. Froidevaux[34], J.A. Frost[130], Y. Fu[58a], M. Fujimoto[122], E. Fullana Torregrosa[169], J. Fuster[169], A. Gabrielli[21b,21a], A. Gabrielli[34], P. Gadow[44], G. Gagliardi[53b,53a], L.G. Gagnon[16], G.E. Gallardo[130], E.J. Gallas[130], B.J. Gallop[139], R. Gamboa Goni[90], K.K. Gan[123], S. Ganguly[175], J. Gao[58a], Y. Gao[48], Y.S. Gao[29,n], F.M. Garay Walls[142a], C. García[169], J.E. García Navarro[169], J.A. García Pascual[13a], M. Garcia-Sciveres[16], R.W. Gardner[35], D. Garg[75], S. Gargiulo[50], C.A. Garner[162], V. Garonne[129], S.J. Gasiorowski[144], P. Gaspar[78b], G. Gaudio[68a], P. Gauzzi[70a,70b], I.L. Gavrilenko[108], A. Gavrilyuk[120], C. Gay[170], G. Gaycken[44], E.N. Gazis[9], A.A. Geanta[25b], C.M. Gee[141], C.N.P. Gee[139], J. Geisen[94], M. Geisen[97], C. Gemme[53b], M.H. Genest[56],

S. Gentile[70a,70b], S. George[91], W.F. George[19], T. Geralis[42], L.O. Gerlach[51], P. Gessinger-Befurt[97], M. Ghasemi Bostanabad[171], M. Ghneimat[147], A. Ghosh[166], A. Ghosh[75], B. Giacobbe[21b], S. Giagu[70a,70b], N. Giangiacomi[162], P. Giannetti[69a], A. Giannini[67a,67b], S.M. Gibson[91], M. Gignac[141], D.T. Gil[81b], B.J. Gilbert[37], D. Gillberg[32], G. Gilles[116], N.E.K. Gillwald[44], D.M. Gingrich[2,ak], M.P. Giordani[64a,64c], P.F. Giraud[140], G. Giugliarelli[64a,64c], D. Giugni[66a], F. Giuli[71a,71b], I. Gkialas[8,i], E.L. Gkougkousis[12], P. Gkountoumis[9], L.K. Gladilin[110], C. Glasman[96], G.R. Gledhill[127], M. Glisic[127], I. Gnesi[39b,d], M. Goblirsch-Kolb[24], D. Godin[107], S. Goldfarb[102], T. Golling[52], D. Golubkov[119], J.P. Gombas[104], A. Gomes[135a,135b], R. Goncalves Gama[51], R. Gonçalo[135a,135c], G. Gonella[127], L. Gonella[19], A. Gongadze[77], F. Gonnella[19], J.L. Gonski[37], S. González de la Hoz[169], S. Gonzalez Fernandez[12], R. Gonzalez Lopez[88], C. Gonzalez Renteria[16], R. Gonzalez Suarez[167], S. Gonzalez-Sevilla[52], G.R. Gonzalvo Rodriguez[169], R.Y. González Andana[142a], L. Goossens[34], N.A. Gorasia[19], P.A. Gorbounov[120], H.A. Gordon[27], B. Gorini[34], E. Gorini[65a,65b], A. Gorišek[89], A.T. Goshaw[47], M.I. Gostkin[77], C.A. Gottardo[115], M. Gouighri[33b], V. Goumarre[44], A.G. Goussiou[144], N. Govender[31c], C. Goy[4], I. Grabowska-Bold[81a], K. Graham[32], E. Gramstad[129], S. Grancagnolo[17], M. Grandi[152], V. Gratchev[133], P.M. Gravila[25f], F.G. Gravili[65a,65b], H.M. Gray[16], C. Grefe[22], I.M. Gregor[44], P. Grenier[149], K. Grevtsov[44], C. Grieco[12], N.A. Grieser[124], A.A. Grillo[141], K. Grimm[29,m], S. Grinstein[12,x], J.-F. Grivaz[62], S. Groh[97], E. Gross[175], J. Grosse-Knetter[51], Z.J. Grout[92], C. Grud[103], A. Grummer[114], J.C. Grundy[130], L. Guan[103], W. Guan[176], C. Gubbels[170], J. Guenther[34], J.G.R. Guerrero Rojas[169], F. Guescini[112], D. Guest[17], R. Gugel[97], A. Guida[44], T. Guillemin[4], S. Guindon[34], J. Guo[58c], L. Guo[62], Y. Guo[103], R. Gupta[44], S. Gurbuz[22], G. Gustavino[124], M. Guth[50], P. Gutierrez[124], L.F. Gutierrez Zagazeta[132], C. Gutschow[92], C. Guyot[140], C. Gwenlan[130], C.B. Gwilliam[88], E.S. Haaland[129], A. Haas[121], M. Habedank[17], C. Haber[16], H.K. Hadavand[7], A. Hadef[97], M. Haleem[172], J. Haley[125], J.J. Hall[145], G. Halladjian[104], G.D. Hallewell[99], L. Halser[18], K. Hamano[171], H. Hamdaoui[33e], M. Hamer[22], G.N. Hamity[48], K. Han[58a], L. Han[13c], L. Han[58a], S. Han[16], Y.F. Han[162], K. Hanagaki[79,v], M. Hance[141], M.D. Hank[35], R. Hankache[98], E. Hansen[94], J.B. Hansen[38], J.D. Hansen[38], M.C. Hansen[22], P.H. Hansen[38], K. Hara[164], T. Harenberg[177], S. Harkusha[105], Y.T. Harris[130], P.F. Harrison[173], N.M. Hartman[149], N.M. Hartmann[111], Y. Hasegawa[146], A. Hasib[48], S. Hassani[140], S. Haug[18], R. Hauser[104], M. Havranek[137], C.M. Hawkes[19], R.J. Hawkings[34], S. Hayashida[113], D. Hayden[104], C. Hayes[103], R.L. Hayes[170], C.P. Hays[130], J.M. Hays[90], H.S. Hayward[88], S.J. Haywood[139], F. He[58a], Y. He[160], Y. He[131], M.P. Heath[48], V. Hedberg[94], A.L. Heggelund[129], N.D. Hehir[90], C. Heidegger[50], K.K. Heidegger[50], W.D. Heidorn[76], J. Heilman[32], S. Heim[44], T. Heim[16], B. Heinemann[44,ai], J.G. Heinlein[132], J.J. Heinrich[127], L. Heinrich[34], J. Hejbal[136], L. Helary[44], A. Held[121], S. Hellesund[129], C.M. Helling[141], S. Hellman[43a,43b], C. Helsens[34], R.C.W. Henderson[87], L. Henkelmann[30], A.M. Henriques Correia[34], H. Herde[149], Y. Hernández Jiménez[151], H. Herr[97], M.G. Herrmann[111], T. Herrmann[46], G. Herten[50], R. Hertenberger[111], L. Hervas[34], N.P. Hessey[163a], H. Hibi[80], S. Higashino[79], E. Higón-Rodriguez[169], K.K. Hill[27], K.H. Hiller[44], S.J. Hillier[19], M. Hils[46], I. Hinchliffe[16], F. Hinterkeuser[22], M. Hirose[128], S. Hirose[164], D. Hirschbuehl[177], B. Hiti[89], O. Hladik[136], J. Hobbs[151], R. Hobincu[25e], N. Hod[175], M.C. Hodgkinson[145], B.H. Hodkinson[30], A. Hoecker[34], J. Hofer[44], D. Hohn[50], T. Holm[22], T.R. Holmes[35], M. Holzbock[112], L.B.A.H. Hommels[30], B.P. Honan[98], J. Hong[58c], T.M. Hong[134], J.C. Honig[50], A. Hönle[112], B.H. Hooberman[168], W.H. Hopkins[5], Y. Horii[113], P. Horn[46], L.A. Horyn[35], S. Hou[154], J. Howarth[55], J. Hoya[86], M. Hrabovsky[126], A. Hrynevich[106], T. Hryn'ova[4], P.J. Hsu[61], S.-C. Hsu[144], Q. Hu[37], S. Hu[58c], Y.F. Hu[13a,13d,am], D.P. Huang[92], X. Huang[13c], Y. Huang[58a], Y. Huang[13a], Z. Hubacek[137], F. Hubaut[99], M. Huebner[22], F. Huegging[22], T.B. Huffman[130], M. Huhtinen[34], R. Hulsken[56], N. Huseynov[77,ab], J. Huston[104], J. Huth[57], R. Hyneman[149], S. Hyrych[26a], G. Iacobucci[52], G. Iakovidis[27], I. Ibragimov[147], L. Iconomidou-Fayard[62], P. Iengo[34], R. Ignazzi[38], R. Iguchi[159], T. Iizawa[52], Y. Ikegami[79], A. Ilg[18], N. Ilic[162,162], H. Imam[33a], T. Ingebretsen Carlson[43a,43b], G. Introzzi[68a,68b], M. Iodice[72a], V. Ippolito[70a,70b], M. Ishino[159], W. Islam[125], C. Issever[17,44], S. Istin[11c,an], J.M. Iturbe Ponce[60a], R. Iuppa[73a,73b], A. Ivina[175], J.M. Izen[41], V. Izzo[67a], P. Jacka[136], P. Jackson[1], R.M. Jacobs[44], B.P. Jaeger[148], C.S. Jagfeld[111], G. Jäkel[177], K.B. Jakobi[97], K. Jakobs[50], T. Jakoubek[175], J. Jamieson[55], K.W. Janas[81a], G. Jarlskog[94], A.E. Jaspan[88], N. Javadov[77,ab], T. Javůrek[34], M. Javurkova[100], F. Jeanneau[140], L. Jeanty[127], J. Jejelava[155a,ac], P. Jenni[50,e], S. Jézéquel[4], J. Jia[151], Z. Jia[13c], Y. Jiang[58a], S. Jiggins[50], J. Jimenez Pena[112], S. Jin[13c], A. Jinaru[25b], O. Jinnouchi[160], H. Jivan[31f], P. Johansson[145], K.A. Johns[6], C.A. Johnson[63], D.M. Jones[30], E. Jones[173], R.W.L. Jones[87], T.J. Jones[88], J. Jovicevic[51], X. Ju[16], J.J. Junggeburth[34], A. Juste Rozas[12,x], A. Kaczmarska[82], M. Kado[70a,70b], H. Kagan[123], M. Kagan[149], A. Kahn[37], C. Kahra[97], T. Kaji[174], E. Kajomovitz[156], C.W. Kalderon[27], A. Kaluza[97], A. Kamenshchikov[119], M. Kaneda[159], N.J. Kang[141], S. Kang[76], Y. Kano[113], J. Kanzaki[79], D. Kar[31f], K. Karava[130], M.J. Kareem[163b], I. Karkanias[158], S.N. Karpov[77], Z.M. Karpova[77], V. Kartvelishvili[87], A.N. Karyukhin[119], E. Kasimi[158], C. Kato[58d], J. Katzy[44], K. Kawade[146], K. Kawagoe[85], T. Kawaguchi[113], T. Kawamoto[140], G. Kawamura[51], E.F. Kay[171], F.I. Kaya[165], S. Kazakos[12], V.F. Kazanin[118b,118a], Y. Ke[151], J.M. Keaveney[31a], R. Keeler[171], J.S. Keller[32], D. Kelsey[152], J.J. Kempster[19], J. Kendrick[19], K.E. Kennedy[37], O. Kepka[136], S. Kersten[177], B.P. Kerševan[89], S. Ketabchi Haghighat[162], M. Khandoga[131], A. Khanov[125], A.G. Kharlamov[118b,118a], T. Kharlamova[118b,118a], E.E. Khoda[170], T.J. Khoo[17], G. Khoriauli[172], E. Khramov[77], J. Khubua[155b], S. Kido[80], M. Kiehn[34], A. Kilgallon[127], E. Kim[160], Y.K. Kim[35], N. Kimura[92], A. Kirchhoff[51], D. Kirchmeier[46], J. Kirk[139], A.E. Kiryunin[112], T. Kishimoto[159], D.P. Kisliuk[162], V. Kitali[44], C. Kitsaki[9], O. Kivernyk[22], T. Klapdor-Kleingrothaus[50], M. Klassen[59a], C. Klein[32], L. Klein[172], M.H. Klein[103], M. Klein[88], U. Klein[88], P. Klimek[34], A. Klimentov[27], F. Klimpel[34], T. Klingl[22], T. Klioutchnikova[34], F.F. Klitzner[111], P. Kluit[116], S. Kluth[112], E. Kneringer[74], T.M. Knight[162], A. Knue[50], D. Kobayashi[85], M. Kobel[46], M. Kocian[149], T. Kodama[159], P. Kodys[138], D.M. Koeck[152], P.T. Koenig[22], T. Koffas[32], N.M. Köhler[34], M. Kolb[140], I. Koletsou[4], T. Komarek[126], K. Köneke[50], A.X.Y. Kong[1], T. Kono[122], V. Konstantinides[92], N. Konstantinidis[92], B. Konya[94], R. Kopeliansky[63], S. Koperny[81a], K. Korcyl[82], K. Kordas[158], G. Koren[157], A. Korn[92], S. Korn[51], I. Korolkov[12], E.V. Korolkova[145], N. Korotkova[110], B. Kortman[116], O. Kortner[112], S. Kortner[112], V.V. Kostyukhin[145,161], A. Kotsokechagia[62], A. Kotwal[47], A. Koulouris[34], A. Kourkoumeli-Charalampidi[68a,68b], C. Kourkoumelis[8], E. Kourlitis[5], O. Kovanda[152], R. Kowalewski[171], W. Kozanecki[140], A.S. Kozhin[119], V.A. Kramarenko[110], G. Kramberger[89], D. Krasnopevtsev[58a], M.W. Krasny[131], A. Krasznahorkay[34], J.A. Kremer[97], J. Kretzschmar[88], K. Kreul[17], P. Krieger[162], F. Krieter[111], S. Krishnamurthy[100], A. Krishnan[59b], M. Krivos[138], K. Krizka[16], K. Kroeninger[45], H. Kroha[112], J. Kroll[136], J. Kroll[132], K.S. Krowpman[104], U. Kruchonak[77], H. Krüger[22], N. Krumnack[76], M.C. Kruse[47], J.A. Krzysiak[82], A. Kubota[160], O. Kuchinskaia[161], S. Kuday[3b], D. Kuechler[44], J.T. Kuechler[44], S. Kuehn[34], T. Kuhl[44], V. Kukhtin[77], Y. Kulchitsky[105,af], S. Kuleshov[142b], M. Kumar[31f], N. Kumari[99], M. Kuna[56], A. Kupco[136], T. Kupfer[45], O. Kuprash[50], H. Kurashige[80], L.L. Kurchaninov[163a], Y.A. Kurochkin[105], A. Kurova[109], M.G. Kurth[13a,13d], E.S. Kuwertz[34], M. Kuze[160], A.K. Kvam[144], J. Kvita[126], T. Kwan[101], C. Lacasta[169], F. Lacava[70a,70b], H. Lacker[17], D. Lacour[131], N.N. Lad[92], E. Ladygin[77], R. Lafaye[4], B. Laforge[131], T. Lagouri[142c], S. Lai[51], I.K. Lakomiec[81a], N. Lalloue[56], J.E. Lambert[124], S. Lammers[63], W. Lampl[6], C. Lampoudis[158], E. Lançon[27], U. Landgraf[50], M.P.J. Landon[90], V.S. Lang[50], J.C. Lange[51], R.J. Langenberg[100], A.J. Lankford[166], F. Lanni[27], K. Lantzsch[22], A. Lanza[68a], A. Lapertosa[53b,53a], J.F. Laporte[140], T. Lari[66a], F. Lasagni Manghi[21b], M. Lassnig[34], V. Latonova[136], T.S. Lau[60a], A. Laudrain[97], A. Laurier[32], M. Lavorgna[67a,67b], S.D. Lawlor[91], M. Lazzaroni[66a,66b], B. Le[98], B. Leban[89], A. Lebedev[76], M. LeBlanc[34], T. LeCompte[5], F. Ledroit-Guillon[56], A.C.A. Lee[92], C.A. Lee[27], G.R. Lee[15], L. Lee[57], S.C. Lee[154], S. Lee[76], L.L. Leeuw[31c], B. Lefebvre[163a], H.P. Lefebvre[91], M. Lefebvre[171], C. Leggett[16], K. Lehmann[148], N. Lehmann[18], G. Lehmann Miotto[34], W.A. Leight[44], A. Leisos[158,w], M.A.L. Leite[78c], C.E. Leitgeb[44], R. Leitner[138], K.J.C. Leney[40], T. Lenz[22], S. Leone[69a], C. Leonidopoulos[48], A. Leopold[131], C. Leroy[107], R. Les[104], C.G. Lester[30], M. Levchenko[133], J. Levêque[4], D. Levin[103], L.J. Levinson[175], D.J. Lewis[19], B. Li[13b], B. Li[58b], C. Li[58a], C-Q. Li[58c,58d], H. Li[58a], H. Li[58b], J. Li[58c], K. Li[144], L. Li[58c], M. Li[13a,13d], Q.Y. Li[58a], S. Li[58d,58c,c], X. Li[44], Y. Li[44], Z. Li[58b], Z. Li[130], Z. Li[101], Z. Li[88], Z. Liang[13a], M. Liberatore[44],

B. Liberti[71a], K. Lie[60c], K. Lin[104], R.A. Linck[63], R.E. Lindley[6], J.H. Lindon[2], A. Linss[44], A.L. Lionti[52], E. Lipeles[132], A. Lipniacka[15], T.M. Liss[168,aj], A. Lister[170], J.D. Little[7], B. Liu[13a], B.X. Liu[148], J.B. Liu[58a], J.K.K. Liu[35], K. Liu[58d,58c], M. Liu[58a], M.Y. Liu[58a], P. Liu[13a], X. Liu[58a], Y. Liu[44], Y. Liu[13c,13d], Y.L. Liu[103], Y.W. Liu[58a], M. Livan[68a,68b], A. Lleres[56], J. Llorente Merino[148], S.L. Lloyd[90], E.M. Lobodzinska[44], P. Loch[6], S. Loffredo[71a,71b], T. Lohse[17], K. Lohwasser[145], M. Lokajicek[136], J.D. Long[168], R.E. Long[87], I. Longarini[70a,70b], L. Longo[34], R. Longo[168], I. Lopez Paz[12], A. Lopez Solis[44], J. Lorenz[111], N. Lorenzo Martinez[4], A.M. Lory[111], A. Lösle[50], X. Lou[43a,43b], X. Lou[13a], A. Lounis[62], J. Love[5], P.A. Love[87], J.J. Lozano Bahilo[169], G. Lu[13a], M. Lu[58a], S. Lu[132], Y.J. Lu[61], H.J. Lubatti[144], C. Luci[70a,70b], F.L. Lucio Alves[13c], A. Lucotte[56], F. Luehring[63], I. Luise[151], L. Luminari[70a], O. Lundberg[150], B. Lund-Jensen[150], N.A. Luongo[127], M.S. Lutz[157], D. Lynn[27], H. Lyons[88], R. Lysak[136], E. Lytken[94], F. Lyu[13a], V. Lyubushkin[77], T. Lyubushkina[77], H. Ma[27], L.L. Ma[58b], Y. Ma[92], D.M. Mac Donell[171], G. Maccarrone[49], C.M. Macdonald[145], J.C. MacDonald[145], R. Madar[36], W.F. Mader[46], M. Madugoda Ralalage Don[125], N. Madysa[46], J. Maeda[80], T. Maeno[27], M. Maerker[46], V. Magerl[50], J. Magro[64a,64c], D.J. Mahon[37], C. Maidantchik[78b], A. Maio[135a,135b,135d], K. Maj[81a], O. Majersky[26a], S. Majewski[127], N. Makovec[62], B. Malaescu[131], Pa. Malecki[82], V.P. Maleev[133], F. Malek[56], D. Malito[39b,39a], U. Mallik[75], C. Malone[30], S. Maltezos[9], S. Malyukov[77], J. Mamuzic[169], G. Mancini[49], J.P. Mandalia[90], I. Mandić[89], L. Manhaes de Andrade Filho[78a], I.M. Maniatis[158], M. Manisha[140], J. Manjarres Ramos[46], K.H. Mankinen[94], A. Mann[111], A. Manousos[74], B. Mansoulie[140], I. Manthos[158], S. Manzoni[116], A. Marantis[158,w], L. Marchese[130], G. Marchiori[131], M. Marcisovsky[136], L. Marcoccia[71a,71b], C. Marcon[94], M. Marjanovic[124], Z. Marshall[16], S. Marti-Garcia[169], T.A. Martin[173], V.J. Martin[48], B. Martin dit Latour[15], L. Martinelli[70a,70b], M. Martinez[12,x], P. Martinez Agullo[169], V.I. Martinez Outschoorn[100], S. Martin-Haugh[139], V.S. Martoiu[25b], A.C. Martyniuk[92], A. Marzin[34], S.R. Maschek[112], L. Masetti[97], T. Mashimo[159], J. Masik[98], A.L. Maslennikov[118b,118a], L. Massa[21b], P. Massarotti[67a,67b], P. Mastrandrea[69a,69b], A. Mastroberardino[39b,39a], T. Masubuchi[159], D. Matakias[27], T. Mathisen[167], A. Matic[111], N. Matsuzawa[159], J. Maurer[25b], B. Maček[89], D.A. Maximov[118b,118a], R. Mazini[154], I. Maznas[158], S.M. Mazza[141], C. Mc Ginn[27], J.P. Mc Gowan[101], S.P. Mc Kee[103], T.G. McCarthy[112], W.P. McCormack[16], E.F. McDonald[102], A.E. McDougall[116], J.A. Mcfayden[152], G. Mchedlidze[155b], M.A. McKay[40], K.D. McLean[171], S.J. McMahon[139], P.C. McNamara[102], R.A. McPherson[171,aa], J.E. Mdhluli[31f], Z.A. Meadows[100], S. Meehan[34], T. Megy[36], S. Mehlhase[111], A. Mehta[88], B. Meirose[41], D. Melini[156], B.R. Mellado Garcia[31f], F. Meloni[44], A. Melzer[22], E.D. Mendes Gouveia[135a], A.M. Mendes Jacques Da Costa[19], H.Y. Meng[162], L. Meng[34], S. Menke[112], M. Mentink[34], E. Meoni[39b,39a], S.A.M. Merkt[134], C. Merlassino[130], P. Mermod[52,*], L. Merola[67a,67b], C. Meroni[66a], G. Merz[103], O. Meshkov[110,108], J.K.R. Meshreki[147], J. Metcalfe[5], A.S. Mete[5], C. Meyer[63], J-P. Meyer[140], M. Michetti[17], R.P. Middleton[139], L. Mijović[48], G. Mikenberg[175], M. Mikestikova[136], M. Mikuž[89], H. Mildner[145], A. Milic[162], C.D. Milke[40], D.W. Miller[35], L.S. Miller[32], A. Milov[175], D.A. Milstead[43a,43b], A.A. Minaenko[119], I.A. Minashvili[155b], L. Mince[55], A.I. Mincer[121], B. Mindur[81a], M. Mineev[77], Y. Minegishi[159], Y. Mino[83], L.M. Mir[12], M. Miralles Lopez[169], M. Mironova[130], T. Mitani[174], V.A. Mitsou[169], M. Mittal[58c], O. Miu[162], P.S. Miyagawa[90], Y. Miyazaki[85], A. Mizukami[79], J.U. Mjörnmark[94], T. Mkrtchyan[59a], M. Mlynarikova[117], T. Moa[43a,43b], S. Mobius[51], K. Mochizuki[107], P. Moder[44], P. Mogg[111], A.F. Mohammed[13a], S. Mohapatra[37], G. Mokgatitswane[31f], B. Mondal[147], S. Mondal[137], K. Mönig[44], E. Monnier[99], A. Montalbano[148], J. Montejo Berlingen[34], M. Montella[123], F. Monticelli[86], N. Morange[62], A.L. Moreira De Carvalho[135a], M. Moreno Llácer[169], C. Moreno Martinez[12], P. Morettini[53b], M. Morgenstern[156], S. Morgenstern[173], D. Mori[148], M. Morii[57], M. Morinaga[159], V. Morisbak[129], A.K. Morley[34], A.P. Morris[92], L. Morvaj[34], P. Moschovakos[34], B. Moser[116], M. Mosidze[155b], T. Moskalets[50], P. Moskvitina[115], J. Moss[29,o], E.J.W. Moyse[100], S. Muanza[99], J. Mueller[134], R. Mueller[18], D. Muenstermann[87], G.A. Mullier[94], J.J. Mullin[132], D.P. Mungo[66a,66b], J.L. Munoz Martinez[12], F.J. Munoz Sanchez[98], M. Murin[98], P. Murin[26b], W.J. Murray[173,139], A. Murrone[66a,66b], J.M. Muse[124], M. Muškinja[16], C. Mwewa[27], A.G. Myagkov[119,ag], A.A. Myers[134], G. Myers[63], M. Myska[137], B.P. Nachman[16], O. Nackenhorst[45], A.Nag Nag[46], K. Nagai[130], K. Nagano[79], J.L. Nagle[27], E. Nagy[99], A.M. Nairz[34], Y. Nakahama[113], K. Nakamura[79], H. Nanjo[128], F. Napolitano[59a], R. Narayan[40], I. Naryshkin[133], M. Naseri[32], C. Nass[22], T. Naumann[44], G. Navarro[20a], J. Navarro-Gonzalez[169], R. Nayak[157], P.Y. Nechaeva[108], F. Nechansky[44], T.J. Neep[19], A. Negri[68a,68b], M. Negrini[21b], C. Nellist[115], C. Nelson[101], K. Nelson[103], M.E. Nelson[43a,43b], S. Nemecek[136], M. Nessi[34,g], M.S. Neubauer[168], F. Neuhaus[97], J. Neundorf[44], R. Newhouse[170], P.R. Newman[19], C.W. Ng[134], Y.S. Ng[17], Y.W.Y. Ng[166], B. Ngair[33e], H.D.N. Nguyen[99], T. Nguyen Manh[107], R.B. Nickerson[130], R. Nicolaidou[140], D.S. Nielsen[38], J. Nielsen[141], M. Niemeyer[51], N. Nikiforou[10], V. Nikolaenko[119,ag], I. Nikolic-Audit[131], K. Nikolopoulos[19], P. Nilsson[27], H.R. Nindhito[52], A. Nisati[70a], N. Nishu[2], R. Nisius[112], T. Nitta[174], T. Nobe[159], D.L. Noel[30], Y. Noguchi[83], I. Nomidis[131], M.A. Nomura[27], M.B. Norfolk[145], R.R.B. Norisam[92], J. Novak[89], T. Novak[44], O. Novgorodova[46], L. Novotny[137], R. Novotny[114], L. Nozka[126], K. Ntekas[166], E. Nurse[92], F.G. Oakham[32,ak], J. Ocariz[131], A. Ochi[80], I. Ochoa[135a], J.P. Ochoa-Ricoux[142a], K. O'Connor[24], S. Oda[85], S. Odaka[79], S. Oerdek[167], A. Ogrodnik[81a], A. Oh[98], C.C. Ohm[150], H. Oide[160], R. Oishi[159], M.L. Ojeda[162], Y. Okazaki[83], M.W. O'Keefe[88], Y. Okumura[159], A. Olariu[25b], L.F. Oleiro Seabra[135a], S.A. Olivares Pino[142c], D. Oliveira Damazio[27], D. Oliveira Goncalves[78a], J.L. Oliver[166], M.J.R. Olsson[166], A. Olszewski[82], J. Olszowska[82], Ö.O. Öncel[22], D.C. O'Neil[148], A.P. O'neill[130], A. Onofre[135a,135e], P.U.E. Onyisi[10], H. Oppen[129], R.G. Oreamuno Madriz[117], M.J. Oreglia[35], G.E. Orellana[86], D. Orestano[72a,72b], N. Orlando[12], R.S. Orr[162], V. O'Shea[55], R. Ospanov[58a], G. Otero y Garzon[28], H. Otono[85], P.S. Ott[59a], G.J. Ottino[16], M. Ouchrif[33d], J. Ouellette[27], F. Ould-Saada[129], A. Ouraou[140,*], Q. Ouyang[13a], M. Owen[55], R.E. Owen[139], V.E. Ozcan[11c], N. Ozturk[7], S. Ozturk[11c], J. Pacalt[126], H.A. Pacey[30], K. Pachal[47], A. Pacheco Pages[12], C. Padilla Aranda[12], S. Pagan Griso[16], G. Palacino[63], S. Palazzo[48], S. Palestini[34], M. Palka[81b], P. Palni[81a], D.K. Panchal[10], C.E. Pandini[52], J.G. Panduro Vazquez[91], P. Pani[44], G. Panizzo[64a,64c], L. Paolozzi[52], C. Papadatos[107], S. Parajuli[40], A. Paramonov[5], C. Paraskevopoulos[9], D. Paredes Hernandez[60b], S.R. Paredes Saenz[130], B. Parida[175], T.H. Park[162], A.J. Parker[29], M.A. Parker[30], F. Parodi[53b,53a], E.W. Parrish[117], J.A. Parsons[37], U. Parzefall[50], L. Pascual Dominguez[157], V.R. Pascuzzi[16], F. Pasquali[116], E. Pasqualucci[70a], S. Passaggio[53b], F. Pastore[91], P. Pasuwan[43a,43b], J.R. Pater[98], A. Pathak[176], J. Patton[88], T. Pauly[34], J. Pearkes[149], M. Pedersen[129], L. Pedraza Diaz[115], R. Pedro[135a], T. Peiffer[51], S.V. Peleganchuk[118b,118a], O. Penc[136], C. Peng[60b], H. Peng[58a], M. Penzin[161], B.S. Peralva[78a], M.M. Perego[62], A.P. Pereira Peixoto[135a], L. Pereira Sanchez[43a,43b], D.V. Perepelitsa[27], E. Perez Codina[163a], M. Perganti[9], L. Perini[66a,66b], H. Pernegger[34], S. Perrella[34], A. Perrevoort[116], K. Peters[44], R.F.Y. Peters[98], B.A. Petersen[34], T.C. Petersen[38], E. Petit[99], V. Petousis[137], C. Petridou[158], P. Petroff[62], F. Petrucci[72a,72b], M. Pettee[178], N.E. Pettersson[34], K. Petukhova[138], A. Peyaud[140], R. Pezoa[142d], L. Pezzotti[68a,68b], G. Pezzullo[178], T. Pham[102], P.W. Phillips[139], M.W. Phipps[168], G. Piacquadio[151], E. Pianori[16], F. Piazza[66a,66b], A. Picazio[100], R. Piegaia[28], D. Pietreanu[25b], J.E. Pilcher[35], A.D. Pilkington[98], M. Pinamonti[64a,64c], J.L. Pinfold[2], C. Pitman Donaldson[92], D.A. Pizzi[32], L. Pizzimento[71a,71b], A. Pizzini[116], M.-A. Pleier[27], V. Plesanovs[50], V. Pleskot[138], E. Plotnikova[77], P. Podberezko[118b,118a], R. Poettgen[94], R. Poggi[52], L. Poggioli[131], I. Pogrebnyak[104], D. Pohl[22], I. Pokharel[51], G. Polesello[68a], A. Poley[148,163a], A. Policicchio[70a,70b], R. Polifka[138], A. Polini[21b], C.S. Pollard[44], Z.B. Pollock[123], V. Polychronakos[27], D. Ponomarenko[109], L. Pontecorvo[34], S. Popa[25a], G.A. Popeneciu[25d], L. Portales[4], D.M. Portillo Quintero[56], S. Pospisil[137], P. Postolache[25c], K. Potamianos[130], I.N. Potrap[77], C.J. Potter[30], H. Potti[1], T. Poulsen[44], J. Poveda[169], T.D. Powell[145], G. Pownall[44], M.E. Pozo Astigarraga[34], A. Prades Ibanez[169], P. Pralavorio[99], M.M. Prapa[42], S. Prell[76], D. Price[98], M. Primavera[65a], M.A. Principe Martin[96], M.L. Proffitt[144], N. Proklova[109], K. Prokofiev[60c], F. Prokoshin[77], S. Protopopescu[27], J. Proudfoot[5], M. Przybycien[81a], D. Pudzha[133], P. Puzo[62], D. Pyatiizbyantseva[109], J. Qian[103], Y. Qin[98], A. Quadt[51], M. Queitsch-Maitland[34], G. Rabanal Bolanos[57], F. Ragusa[66a,66b],

G. Rahal[95], J.A. Raine[52], S. Rajagopalan[27], K. Ran[13a,13d], D.F. Rassloff[59a], D.M. Rauch[44], S. Rave[97], B. Ravina[55], I. Ravinovich[175], M. Raymond[34], A.L. Read[129], N.P. Readioff[145], D.M. Rebuzzi[68a,68b], G. Redlinger[27], K. Reeves[41], D. Reikher[157], A. Reiss[97], A. Rej[147], C. Rembser[34], A. Renardi[44], M. Renda[25b], M.B. Rendel[112], A.G. Rennie[55], S. Resconi[66a], E.D. Resseguie[16], S. Rettie[92], B. Reynolds[123], E. Reynolds[19], M. Rezaei Estabragh[177], O.L. Rezanova[118b,118a], P. Reznicek[138], E. Ricci[73a,73b], R. Richter[112], S. Richter[44], E. Richter-Was[81b], M. Ridel[131], P. Rieck[112], P. Riedler[34], O. Rifki[44], M. Rijssenbeek[151], A. Rimoldi[68a,68b], M. Rimoldi[44], L. Rinaldi[21b,21a], T.T. Rinn[168], M.P. Rinnagel[111], G. Ripellino[150], I. Riu[12], P. Rivadeneira[44], J.C. Rivera Vergara[171], F. Rizatdinova[125], E. Rizvi[90], C. Rizzi[52], B.A. Roberts[173], S.H. Robertson[101,aa], M. Robin[44], D. Robinson[30], C.M. Robles Gajardo[142d], M. Robles Manzano[97], A. Robson[55], A. Rocchi[71a,71b], C. Roda[69a,69b], S. Rodriguez Bosca[59a], A. Rodriguez Rodriguez[50], A.M. Rodríguez Vera[163b], S. Roe[34], J. Roggel[177], O. Røhne[129], R.A. Rojas[142d], B. Roland[50], C.P.A. Roland[63], J. Roloff[27], A. Romaniouk[109], M. Romano[21b], A.C. Romero Hernandez[168], N. Rompotis[88], M. Ronzani[121], L. Roos[131], S. Rosati[70a], G. Rosin[100], B.J. Rosser[132], E. Rossi[162], E. Rossi[4], E. Rossi[67a,67b], L.P. Rossi[53b], L. Rossini[44], R. Rosten[123], M. Rotaru[25b], B. Rottler[50], D. Rousseau[62], D. Rousso[30], G. Rovelli[68a,68b], A. Roy[10], A. Rozanov[99], Y. Rozen[156], X. Ruan[31f], A.J. Ruby[88], T.A. Ruggeri[1], F. Rühr[50], A. Ruiz-Martinez[169], A. Rummler[34], Z. Rurikova[50], N.A. Rusakovich[77], H.L. Russell[34], L. Rustige[36], J.P. Rutherfoord[6], E.M. Rüttinger[145], M. Rybar[138], E.B. Rye[129], A. Ryzhov[119], J.A. Sabater Iglesias[44], P. Sabatini[169], L. Sabetta[70a,70b], H.F-W. Sadrozinski[141], R. Sadykov[77], F. Safai Tehrani[70a], B. Safarzadeh Samani[152], M. Safdari[149], P. Saha[117], S. Saha[101], M. Sahinsoy[112], A. Sahu[177], M. Saimpert[140], M. Saito[159], T. Saito[159], D. Salamani[52], G. Salamanna[72a,72b], A. Salnikov[149], J. Salt[169], A. Salvador Salas[12], D. Salvatore[39b,39a], F. Salvatore[152], A. Salzburger[34], D. Sammel[50], D. Sampsonidis[158], D. Sampsonidou[58d,58c], J. Sánchez[169], A. Sanchez Pineda[4], V. Sanchez Sebastian[169], H. Sandaker[129], C.O. Sander[44], I.G. Sanderswood[87], J.A. Sandesara[100], M. Sandhoff[177], C. Sandoval[20b], D.P.C. Sankey[139], M. Sannino[53b,53a], Y. Sano[113], A. Sansoni[49], C. Santoni[36], H. Santos[135a,135b], S.N. Santpur[16], A. Santra[175], K.A. Saoucha[145], A. Sapronov[77], J.G. Saraiva[135a,135d], J. Sardain[99], O. Sasaki[79], K. Sato[164], C. Sauer[59b], F. Sauerburger[50], E. Sauvan[4], P. Savard[162,ak], R. Sawada[159], C. Sawyer[139], L. Sawyer[93], I. Sayago Galvan[169], C. Sbarra[21b], A. Sbrizzi[64a,64c], T. Scanlon[92], J. Schaarschmidt[144], P. Schacht[112], D. Schaefer[35], L. Schaefer[132], U. Schäfer[97], A.C. Schaffer[62], D. Schaile[111], R.D. Schamberger[151], E. Schanet[111], C. Scharf[17], N. Scharmberg[98], V.A. Schegelsky[133], D. Scheirich[138], F. Schenck[17], M. Schernau[166], C. Schiavi[53b,53a], L.K. Schildgen[22], Z.M. Schillaci[24], E.J. Schioppa[65a,65b], M. Schioppa[39b,39a], B. Schlag[97], K.E. Schleicher[50], S. Schlenker[34], K. Schmieden[97], C. Schmitt[97], S. Schmitt[44], L. Schoeffel[140], A. Schoening[59b], P.G. Scholer[50], E. Schopf[130], M. Schott[97], J. Schovancova[34], S. Schramm[52], F. Schroeder[177], H-C. Schultz-Coulon[59a], M. Schumacher[50], B.A. Schumm[141], Ph. Schune[140], A. Schwartzman[149], T.A. Schwarz[103], Ph. Schwemling[140], R. Schwienhorst[104], A. Sciandra[141], G. Sciolla[24], F. Scuri[69a], F. Scutti[102], C.D. Sebastiani[88], K. Sedlaczek[45], P. Seema[17], S.C. Seidel[114], A. Seiden[141], B.D. Seidlitz[27], T. Seiss[35], C. Seitz[44], J.M. Seixas[78b], G. Sekhniaidze[67a], S.J. Sekula[40], L.P. Selem[4], N. Semprini-Cesari[21b,21a], S. Sen[47], C. Serfon[27], L. Serin[62], L. Serkin[64a,64b], M. Sessa[58a], H. Severini[124], S. Sevova[149], F. Sforza[53b,53a], A. Sfyrla[52], E. Shabalina[51], R. Shaheen[150], J.D. Shahinian[132], N.W. Shaikh[43a,43b], D. Shaked Renous[175], L.Y. Shan[13a], M. Shapiro[16], A. Sharma[34], A.S. Sharma[1], S. Sharma[44], P.B. Shatalov[120], K. Shaw[152], S.M. Shaw[98], P. Sherwood[92], L. Shi[92], C.O. Shimmin[178], Y. Shimogama[174], J.D. Shinner[91], I.P.J. Shipsey[130], S. Shirabe[52], M. Shiyakova[77], J. Shlomi[175], M.J. Shochet[35], J. Shojaii[102], D.R. Shope[150], S. Shrestha[123], E.M. Shrif[31f], M.J. Shroff[171], E. Shulga[175], P. Sicho[136], A.M. Sickles[168], E. Sideras Haddad[31f], O. Sidiropoulou[34], A. Sidoti[21b], F. Siegert[46], Dj. Sijacki[14], M.V. Silva Oliveira[34], S.B. Silverstein[43a], S. Simion[62], R. Simoniello[34], S. Simsek[11b], P. Sinervo[162], V. Sinetckii[110], S. Singh[148], S. Sinha[44], S. Sinha[31f], M. Sioli[21b,21a], I. Siral[127], S.Yu. Sivoklokov[110], J. Sjölin[43a,43b], A. Skaf[51], E. Skorda[94], P. Skubic[124], M. Slawinska[82], K. Sliwa[165], V. Smakhtin[175], B.H. Smart[139], J. Smiesko[138], S.Yu. Smirnov[109], Y. Smirnov[109], L.N. Smirnova[110,s], O. Smirnova[94], E.A. Smith[35], H.A. Smith[130], M. Smizanska[87], K. Smolek[137], A. Smykiewicz[82], A.A. Snesarev[108], H.L. Snoek[116], S. Snyder[27], R. Sobie[171,aa], A. Soffer[157], F. Sohns[51], C.A. Solans Sanchez[34], E.Yu. Soldatov[109], U. Soldevila[169], A.A. Solodkov[119], S. Solomon[50], A. Soloshenko[77], O.V. Solovyanov[119], V. Solovyev[133], P. Sommer[145], H. Son[165], A. Sonay[12], W.Y. Song[163b], A. Sopczak[137], A.L. Sopio[92], F. Sopkova[26b], S. Sottocornola[68a,68b], R. Soualah[64a,64c], A.M. Soukharev[118b,118a], Z. Soumaimi[33e], D. South[44], S. Spagnolo[65a,65b], M. Spalla[112], M. Spangenberg[173], F. Spanò[91], D. Sperlich[50], T.M. Spieker[59a], G. Spigo[34], M. Spina[152], D.P. Spiteri[55], M. Spousta[138], A. Stabile[66a,66b], B.L. Stamas[117], R. Stamen[59a], M. Stamenkovic[116], A. Stampekis[19], M. Standke[22], E. Stanecka[82], B. Stanislaus[34], M.M. Stanitzki[44], M. Stankaityte[130], B. Stapf[44], E.A. Starchenko[119], G.H. Stark[141], J. Stark[99], D.M. Starko[163b], P. Staroba[136], P. Starovoitov[59a], S. Stärz[101], R. Staszewski[82], G. Stavropoulos[42], P. Steinberg[27], A.L. Steinhebel[127], B. Stelzer[148,163a], H.J. Stelzer[134], O. Stelzer-Chilton[163a], H. Stenzel[54], T.J. Stevenson[152], G.A. Stewart[34], M.C. Stockton[34], G. Stoicea[25b], M. Stolarski[135a], S. Stonjek[112], A. Straessner[46], J. Strandberg[150], S. Strandberg[43a,43b], M. Strauss[124], T. Strebler[99], P. Strizenec[26b], R. Ströhmer[172], D.M. Strom[127], L.R. Strom[44], R. Stroynowski[40], A. Strubig[43a,43b], S.A. Stucci[27], B. Stugu[15], J. Stupak[124], N.A. Styles[44], D. Su[149], S. Su[58a], W. Su[58d,144,58c], X. Su[58a], N.B. Suarez[134], K. Sugizaki[159], V.V. Sulin[108], M.J. Sullivan[88], D.M.S. Sultan[52], S. Sultansoy[3c], T. Sumida[83], S. Sun[103], S. Sun[176], X. Sun[98], O. Sunneborn Gudnadottir[167], C.J.E. Suster[153], M.R. Sutton[152], M. Svatos[136], M. Swiatlowski[163a], T. Swirski[172], I. Sykora[26a], M. Sykora[138], T. Sykora[138], D. Ta[97], K. Tackmann[44,y], A. Taffard[166], R. Tafirout[163a], E. Tagiev[119], R.H.M. Taibah[131], R. Takashima[84], K. Takeda[80], T. Takeshita[146], E.P. Takeva[48], Y. Takubo[79], M. Talby[99], A.A. Talyshev[118b,118a], K.C. Tam[60b], N.M. Tamir[157], A. Tanaka[159], J. Tanaka[159], R. Tanaka[62], Z. Tao[170], S. Tapia Araya[76], S. Tapprogge[97], A. Tarek Abouelfadl Mohamed[104], S. Tarem[156], K. Tariq[58b], G. Tarna[25b,f], G.F. Tartarelli[66a], P. Tas[138], M. Tasevsky[136], E. Tassi[39b,39a], G. Tateno[159], Y. Tayalati[33e], G.N. Taylor[102], W. Taylor[163b], H. Teagle[88], A.S. Tee[176], R. Teixeira De Lima[149], P. Teixeira-Dias[91], H. Ten Kate[34], J.J. Teoh[116], K. Terashi[159], J. Terron[96], S. Terzo[12], M. Testa[49], R.J. Teuscher[162,aa], N. Themistokleous[48], T. Theveneaux-Pelzer[17], O. Thielmann[177], D.W. Thomas[91], J.P. Thomas[19], E.A. Thompson[44], P.D. Thompson[19], E. Thomson[132], E.J. Thorpe[90], Y. Tian[51], V.O. Tikhomirov[108,ah], Yu.A. Tikhonov[118b,118a], S. Timoshenko[109], P. Tipton[178], S. Tisserant[99], S.H. Tlou[31f], A. Tnourji[36], K. Todome[21b,21a], S. Todorova-Nova[138], S. Todt[46], M. Togawa[79], J. Tojo[85], S. Tokár[26a], K. Tokushuku[79], E. Tolley[123], R. Tombs[30], M. Tomoto[79,113], L. Tompkins[149], P. Tornambe[100], E. Torrence[127], H. Torres[46], E. Torró Pastor[169], M. Toscani[28], C. Tosciri[35], J. Toth[99,z], D.R. Tovey[145], A. Traeet[15], C.J. Treado[121], T. Trefzger[172], A. Tricoli[27], I.M. Trigger[163a], S. Trincaz-Duvoid[131], D.A. Trischuk[170], W. Trischuk[162], B. Trocmé[56], A. Trofymov[62], C. Troncon[66a], F. Trovato[152], L. Truong[31c], M. Trzebinski[82], A. Trzupek[82], F. Tsai[151], A. Tsiamis[158], P.V. Tsiareshka[105,af], A. Tsirigotis[158,w], V. Tsiskaridze[151], E.G. Tskhadadze[155a], M. Tsopoulou[158], I.I. Tsukerman[120], V. Tsulaia[16], S. Tsuno[79], O. Tsur[156], D. Tsybychev[151], Y. Tu[60b], A. Tudorache[25b], V. Tudorache[25b], A.N. Tuna[34], S. Turchikhin[77], D. Turgeman[175], I. Turk Cakir[3b,u], R.J. Turner[19], R. Turra[66a], P.M. Tuts[37], S. Tzamarias[158], P. Tzanis[9], E. Tzovara[97], K. Uchida[159], F. Ukegawa[164], G. Unal[34], M. Unal[10], A. Undrus[27], G. Unel[166], F.C. Ungaro[102], K. Uno[159], J. Urban[26b], P. Urquijo[102], G. Usai[7], R. Ushioda[160], M. Usman[107], Z. Uysal[11d], V. Vacek[137], B. Vachon[101], K.O.H. Vadla[129], T. Vafeiadis[34], C. Valderanis[111], E. Valdes Santurio[43a,43b], M. Valente[163a], S. Valentinetti[21b,21a], A. Valero[169], L. Valéry[44], R.A. Vallance[19], A. Vallier[99], J.A. Valls Ferrer[169], T.R. Van Daalen[12], P. Van Gemmeren[5], S. Van Stroud[92], I. Van Vulpen[116], M. Vanadia[71a,71b], W. Vandelli[34], M. Vandenbroucke[140], E.R. Vandewall[125], D. Vannicola[70a,70b], L. Vannoli[53b,53a], R. Vari[70a], E.W. Varnes[6], C. Varni[16], T. Varol[154], D. Varouchas[62], K.E. Varvell[153], M.E. Vasile[25b], L. Vaslin[36], G.A. Vasquez[171], F. Vazeille[36], D. Vazquez Furelos[12], T. Vazquez Schroeder[34], J. Veatch[51], V. Vecchio[98], M.J. Veen[116], I. Veliscek[130], L.M. Veloce[162], F. Veloso[135a,135c], S. Veneziano[70a], A. Ventura[65a,65b], A. Verbytskyi[112], M. Verducci[69a,69b], C. Vergis[22], M. Verissimo De Araujo[78b], W. Verkerke[116], A.T. Vermeulen[116], J.C. Vermeulen[116], C. Vernieri[149], P.J. Verschuuren[91], M.L. Vesterbacka[121], M.C. Vetterli[148,ak], N. Viaux Maira[142d], T. Vickey[145], O.E. Vickey Boeriu[145], G.H.A. Viehhauser[130], L. Vigani[59b], M. Villa[21b,21a], M. Villaplana Perez[169], E.M. Villhauer[48], E. Vilucchi[49], M.G. Vincter[32], G.S. Virdee[19], A. Vishwakarma[48], C. Vittori[21b,21a], I. Vivarelli[152], V. Vladimirov[173], E. Voevodina[112], M. Vogel[177], P. Vokac[137], J. Von Ahnen[44], S.E. von Buddenbrock[31f], E. Von Toerne[22], V. Vorobel[138], K. Vorobev[109], M. Vos[169], J.H. Vossebeld[88], M. Vozak[98], L. Vozdecky[90], N. Vranjes[14], M. Vranjes Milosavljevic[14], V. Vrba[137,*], M. Vreeswijk[116], N.K. Vu[99], R. Vuillermet[34], I. Vukotic[35], S. Wada[164], C. Wagner[100], P. Wagner[22], W. Wagner[177], S. Wahdan[177], H. Wahlberg[86], R. Wakasa[164], M. Wakida[113], V.M. Walbrecht[112], J. Walder[139], R. Walker[111], S.D. Walker[91], W. Walkowiak[147], A.M. Wang[57], A.Z. Wang[176], C. Wang[58a], C. Wang[58c], H. Wang[16], J. Wang[60a], P. Wang[40], R.-J. Wang[97], R. Wang[57], R. Wang[117], S.M. Wang[154], S. Wang[58b], T. Wang[58a], W.T. Wang[58a], W.X. Wang[58a], X. Wang[13c], X. Wang[168], Y. Wang[58a], Z. Wang[103], C. Wanotayaroj[34], A. Warburton[101], C.P. Ward[30], R.J. Ward[19], N. Warrack[55], A.T. Watson[19], M.F. Watson[19], G. Watts[144], B.M. Waugh[92], A.F. Webb[10], C. Weber[27], M.S. Weber[18], S.A. Weber[32], S.M. Weber[59a], C. Wei[58a], Y. Wei[130], A.R. Weidberg[130], J. Weingarten[45], M. Weirich[97], C. Weiser[50], T. Wenaus[27], B. Wendland[45], T. Wengler[34], S. Wenig[34], N. Wermes[22], M. Wessels[59a], K. Whalen[127], A.M. Wharton[87], A.S. White[57], A. White[7], M.J. White[1], D. Whiteson[166], W. Wiedenmann[176], C. Wiel[46], M. Wielers[139], N. Wieseotte[97], C. Wiglesworth[38], L.A.M. Wiik-Fuchs[50], D.J. Wilbern[124], H.G. Wilkens[34], L.J. Wilkins[91], D.M. Williams[37], H.H. Williams[132], S. Williams[30], S. Willocq[100], P.J. Windischhofer[130], I. Wingerter-Seez[4], F. Winklmeier[127], B.T. Winter[50], M. Wittgen[149], M. Wobisch[93], A. Wolf[97], R. Wölker[130], J. Wollrath[166], M.W. Wolter[82], H. Wolters[135a,135c], V.W.S. Wong[170], A.F. Wongel[44], S.D. Worm[44], B.K. Wosiek[82], K.W. Woźniak[82], K. Wraight[55], J. Wu[13a,13d], S.L. Wu[176], X. Wu[52], Y. Wu[58a], Z. Wu[140,58a], J. Wuerzinger[130], T.R. Wyatt[98], B.M. Wynne[48], S. Xella[38], J. Xiang[60c], X. Xiao[103], X. Xie[58a], I. Xiotidis[152], D. Xu[13a], H. Xu[58a], H. Xu[58a], L. Xu[58a], R. Xu[132], T. Xu[58a], W. Xu[103], Y. Xu[13b], Z. Xu[58b], Z. Xu[149], B. Yabsley[153], S. Yacoob[31a], N. Yamaguchi[85], Y. Yamaguchi[160], M. Yamatani[159], H. Yamauchi[164], T. Yamazaki[16], Y. Yamazaki[80], J. Yan[58c], S. Yan[130], Z. Yan[23], H.J. Yang[58c,58d], H.T. Yang[16], S. Yang[58a], T. Yang[60c], X. Yang[58a], X. Yang[13a], Y. Yang[159], Z. Yang[103,58a], W-M. Yao[16], Y.C. Yap[44], H. Ye[13c], J. Ye[40], S. Ye[27], I. Yeletskikh[77], M.R. Yexley[87], P. Yin[37], K. Yorita[174], K. Yoshihara[76], C.J.S. Young[34], C. Young[149], R. Yuan[58b,j], X. Yue[59a], M. Zaazoua[33e], B. Zabinski[82], G. Zacharis[9], E. Zaffaroni[52], A.M. Zaitsev[119,ag], T. Zakareishvili[155b], N. Zakharchuk[32], S. Zambito[34], D. Zanzi[50], S.V. Zeißner[45], C. Zeitnitz[177], G. Zemaityte[130], J.C. Zeng[168], O. Zenin[119], T. Ženiš[26a], S. Zenz[90], S. Zerradi[33a], D. Zerwas[62], M. Zgubič[130], B. Zhang[13c], D.F. Zhang[13b], G. Zhang[13b], J. Zhang[5], K. Zhang[13a], L. Zhang[13c], M. Zhang[168], R. Zhang[176], S. Zhang[103], X. Zhang[58c], X. Zhang[58b], Z. Zhang[62], P. Zhao[47], Y. Zhao[141], Z. Zhao[58a], A. Zhemchugov[77], Z. Zheng[149], D. Zhong[168], B. Zhou[103], C. Zhou[176], H. Zhou[6], N. Zhou[58c], Y. Zhou[6], C.G. Zhu[58b], C. Zhu[13a,13d], H.L. Zhu[58a], H. Zhu[13a], J. Zhu[103], Y. Zhu[58a], X. Zhuang[13a], K. Zhukov[108], V. Zhulanov[118b,118a], D. Zieminska[63], N.I. Zimine[77], S. Zimmermann[50,*], M. Ziolkowski[147], L. Živković[14], A. Zoccoli[21b,21a], K. Zoch[52], T.G. Zorbas[145], O. Zormpa[42], W. Zou[37], L. Zwalinski[34].

[1]Department of Physics, University of Adelaide, Adelaide; Australia.
[2]Department of Physics, University of Alberta, Edmonton AB; Canada.
[3(a)]Department of Physics, Ankara University, Ankara;[(b)]Istanbul Aydin University, Application and Research Center for Advanced Studies, Istanbul;[(c)]Division of Physics, TOBB University of Economics and Technology, Ankara; Turkey.
[4]LAPP, Univ. Savoie Mont Blanc, CNRS/IN2P3, Annecy ; France.
[5]High Energy Physics Division, Argonne National Laboratory, Argonne IL; United States of America.
[6]Department of Physics, University of Arizona, Tucson AZ; United States of America.
[7]Department of Physics, University of Texas at Arlington, Arlington TX; United States of America.

[8]Physics Department, National and Kapodistrian University of Athens, Athens; Greece.
[9]Physics Department, National Technical University of Athens, Zografou; Greece.
[10]Department of Physics, University of Texas at Austin, Austin TX; United States of America.
[11(a)]Bahcesehir University, Faculty of Engineering and Natural Sciences, Istanbul;[(b)]Istanbul Bilgi University, Faculty of Engineering and Natural Sciences, Istanbul;[(c)]Department of Physics, Bogazici University, Istanbul;[(d)]Department of Physics Engineering, Gaziantep University, Gaziantep; Turkey.
[12]Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona; Spain.
[13(a)]Institute of High Energy Physics, Chinese Academy of Sciences, Beijing;[(b)]Physics Department, Tsinghua University, Beijing;[(c)]Department of Physics, Nanjing University, Nanjing;[(d)]University of Chinese Academy of Science (UCAS), Beijing; China.
[14]Institute of Physics, University of Belgrade, Belgrade; Serbia.
[15]Department for Physics and Technology, University of Bergen, Bergen; Norway.
[16]Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA; United States of America.
[17]Institut für Physik, Humboldt Universität zu Berlin, Berlin; Germany.
[18]Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern; Switzerland.
[19]School of Physics and Astronomy, University of Birmingham, Birmingham; United Kingdom.
[20(a)]Facultad de Ciencias y Centro de Investigaciónes, Universidad Antonio Nariño, Bogotá;[(b)]Departamento de Física, Universidad Nacional de Colombia, Bogotá; Colombia.
[21(a)]Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna;[(b)]INFN Sezione di Bologna; Italy.
[22]Physikalisches Institut, Universität Bonn, Bonn; Germany.
[23]Department of Physics, Boston University, Boston MA; United States of America.
[24]Department of Physics, Brandeis University, Waltham MA; United States of America.
[25(a)]Transilvania University of Brasov, Brasov;[(b)]Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest;[(c)]Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi;[(d)]National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca;[(e)]University Politehnica Bucharest, Bucharest;[(f)]West University in Timisoara, Timisoara; Romania.
[26(a)]Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava;[(b)]Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice; Slovak Republic.
[27]Physics Department, Brookhaven National Laboratory, Upton NY; United States of America.
[28]Departamento de Física (FCEN) and IFIBA, Universidad de Buenos Aires and CONICET, Buenos Aires; Argentina.
[29]California State University, CA; United States of America.
[30]Cavendish Laboratory, University of Cambridge, Cambridge; United Kingdom.
[31(a)]Department of Physics, University of Cape Town, Cape Town;[(b)]iThemba Labs, Western Cape;[(c)]Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg;[(d)]National Institute of Physics, University of the Philippines Diliman (Philippines);[(e)]University of South Africa, Department of Physics, Pretoria;[(f)]School of Physics, University of the Witwatersrand, Johannesburg; South Africa.
[32]Department of Physics, Carleton University, Ottawa ON; Canada.
[33(a)]Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca;[(b)]Faculté des Sciences, Université Ibn-Tofail, Kénitra;[(c)]Faculté des Sciences

Semlalia, Université Cadi Ayyad, LPHEA-Marrakech;[(d)] LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda;[(e)] Faculté des sciences, Université Mohammed V, Rabat; Morocco.
[34] CERN, Geneva; Switzerland.
[35] Enrico Fermi Institute, University of Chicago, Chicago IL; United States of America.
[36] LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand; France.
[37] Nevis Laboratory, Columbia University, Irvington NY; United States of America.
[38] Niels Bohr Institute, University of Copenhagen, Copenhagen; Denmark.
[39(a)] Dipartimento di Fisica, Università della Calabria, Rende;[(b)] INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati; Italy.
[40] Physics Department, Southern Methodist University, Dallas TX; United States of America.
[41] Physics Department, University of Texas at Dallas, Richardson TX; United States of America.
[42] National Centre for Scientific Research "Demokritos", Agia Paraskevi; Greece.
[43(a)] Department of Physics, Stockholm University;[(b)] Oskar Klein Centre, Stockholm; Sweden.
[44] Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen; Germany.
[45] Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund; Germany.
[46] Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden; Germany.
[47] Department of Physics, Duke University, Durham NC; United States of America.
[48] SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh; United Kingdom.
[49] INFN e Laboratori Nazionali di Frascati, Frascati; Italy.
[50] Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany.
[51] II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen; Germany.
[52] Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
[53(a)] Dipartimento di Fisica, Università di Genova, Genova;[(b)] INFN Sezione di Genova; Italy.
[54] II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen; Germany.
[55] SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow; United Kingdom.
[56] LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble; France.
[57] Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA; United States of America.
[58(a)] Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei;[(b)] Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao;[(c)] School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai;[(d)] Tsung-Dao Lee Institute, Shanghai; China.
[59(a)] Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg;[(b)] Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; Germany.
[60(a)] Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong;[(b)] Department of Physics, University of Hong Kong, Hong Kong;[(c)] Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong; China.
[61] Department of Physics, National Tsing Hua University, Hsinchu; Taiwan.
[62] IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay; France.
[63] Department of Physics, Indiana University, Bloomington IN; United States of America.
[64(a)] INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine;[(b)] ICTP, Trieste;[(c)] Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine; Italy.
[65(a)] INFN Sezione di Lecce;[(b)] Dipartimento di Matematica e Fisica, Università del Salento, Lecce; Italy.
[66(a)] INFN Sezione di Milano;[(b)] Dipartimento di Fisica, Università di Milano, Milano; Italy.
[67(a)] INFN Sezione di Napoli;[(b)] Dipartimento di Fisica, Università di Napoli, Napoli; Italy.
[68(a)] INFN Sezione di Pavia;[(b)] Dipartimento di Fisica, Università di Pavia, Pavia; Italy.

[69(a)]INFN Sezione di Pisa;[(b)]Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy.
[70(a)]INFN Sezione di Roma;[(b)]Dipartimento di Fisica, Sapienza Università di Roma, Roma; Italy.
[71(a)]INFN Sezione di Roma Tor Vergata;[(b)]Dipartimento di Fisica, Università di Roma Tor Vergata, Roma; Italy.
[72(a)]INFN Sezione di Roma Tre;[(b)]Dipartimento di Matematica e Fisica, Università Roma Tre, Roma; Italy.
[73(a)]INFN-TIFPA;[(b)]Università degli Studi di Trento, Trento; Italy.
[74]Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck; Austria.
[75]University of Iowa, Iowa City IA; United States of America.
[76]Department of Physics and Astronomy, Iowa State University, Ames IA; United States of America.
[77]Joint Institute for Nuclear Research, Dubna; Russia.
[78(a)]Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora;[(b)]Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro;[(c)]Instituto de Física, Universidade de São Paulo, São Paulo; Brazil.
[79]KEK, High Energy Accelerator Research Organization, Tsukuba; Japan.
[80]Graduate School of Science, Kobe University, Kobe; Japan.
[81(a)]AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow;[(b)]Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow; Poland.
[82]Institute of Nuclear Physics Polish Academy of Sciences, Krakow; Poland.
[83]Faculty of Science, Kyoto University, Kyoto; Japan.
[84]Kyoto University of Education, Kyoto; Japan.
[85]Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka ; Japan.
[86]Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata; Argentina.
[87]Physics Department, Lancaster University, Lancaster; United Kingdom.
[88]Oliver Lodge Laboratory, University of Liverpool, Liverpool; United Kingdom.
[89]Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana; Slovenia.
[90]School of Physics and Astronomy, Queen Mary University of London, London; United Kingdom.
[91]Department of Physics, Royal Holloway University of London, Egham; United Kingdom.
[92]Department of Physics and Astronomy, University College London, London; United Kingdom.
[93]Louisiana Tech University, Ruston LA; United States of America.
[94]Fysiska institutionen, Lunds universitet, Lund; Sweden.
[95]Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne; France.
[96]Departamento de Física Teorica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid; Spain.
[97]Institut für Physik, Universität Mainz, Mainz; Germany.
[98]School of Physics and Astronomy, University of Manchester, Manchester; United Kingdom.
[99]CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France.
[100]Department of Physics, University of Massachusetts, Amherst MA; United States of America.
[101]Department of Physics, McGill University, Montreal QC; Canada.
[102]School of Physics, University of Melbourne, Victoria; Australia.
[103]Department of Physics, University of Michigan, Ann Arbor MI; United States of America.
[104]Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America.
[105]B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk; Belarus.
[106]Research Institute for Nuclear Problems of Byelorussian State University, Minsk; Belarus.

[107]Group of Particle Physics, University of Montreal, Montreal QC; Canada.
[108]P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow; Russia.
[109]National Research Nuclear University MEPhI, Moscow; Russia.
[110]D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow; Russia.
[111]Fakultät für Physik, Ludwig-Maximilians-Universität München, München; Germany.
[112]Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München; Germany.
[113]Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya; Japan.
[114]Department of Physics and Astronomy, University of New Mexico, Albuquerque NM; United States of America.
[115]Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen; Netherlands.
[116]Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam; Netherlands.
[117]Department of Physics, Northern Illinois University, DeKalb IL; United States of America.
[118(a)]Budker Institute of Nuclear Physics and NSU, SB RAS, Novosibirsk;[(b)]Novosibirsk State University Novosibirsk; Russia.
[119]Institute for High Energy Physics of the National Research Centre Kurchatov Institute, Protvino; Russia.
[120]Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of National Research Centre "Kurchatov Institute", Moscow; Russia.
[121]Department of Physics, New York University, New York NY; United States of America.
[122]Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo; Japan.
[123]Ohio State University, Columbus OH; United States of America.
[124]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK; United States of America.
[125]Department of Physics, Oklahoma State University, Stillwater OK; United States of America.
[126]Palacký University, Joint Laboratory of Optics, Olomouc; Czech Republic.
[127]Institute for Fundamental Science, University of Oregon, Eugene, OR; United States of America.
[128]Graduate School of Science, Osaka University, Osaka; Japan.
[129]Department of Physics, University of Oslo, Oslo; Norway.
[130]Department of Physics, Oxford University, Oxford; United Kingdom.
[131]LPNHE, Sorbonne Université, Université de Paris, CNRS/IN2P3, Paris; France.
[132]Department of Physics, University of Pennsylvania, Philadelphia PA; United States of America.
[133]Konstantinov Nuclear Physics Institute of National Research Centre "Kurchatov Institute", PNPI, St. Petersburg; Russia.
[134]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA; United States of America.
[135(a)]Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa;[(b)]Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa;[(c)]Departamento de Física, Universidade de Coimbra, Coimbra;[(d)]Centro de Física Nuclear da Universidade de Lisboa, Lisboa;[(e)]Departamento de Física, Universidade do Minho, Braga;[(f)]Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain);[(g)]Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica;[(h)]Instituto Superior Técnico, Universidade de Lisboa, Lisboa; Portugal.
[136]Institute of Physics of the Czech Academy of Sciences, Prague; Czech Republic.
[137]Czech Technical University in Prague, Prague; Czech Republic.
[138]Charles University, Faculty of Mathematics and Physics, Prague; Czech Republic.

[139]Particle Physics Department, Rutherford Appleton Laboratory, Didcot; United Kingdom.
[140]IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France.
[141]Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA; United States of America.
[142][(a)]Departamento de Física, Pontificia Universidad Católica de Chile, Santiago;[(b)]Universidad Andres Bello, Department of Physics, Santiago;[(c)]Instituto de Alta Investigación, Universidad de Tarapacá, Arica;[(d)]Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso; Chile.
[143]Universidade Federal de São João del Rei (UFSJ), São João del Rei; Brazil.
[144]Department of Physics, University of Washington, Seattle WA; United States of America.
[145]Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom.
[146]Department of Physics, Shinshu University, Nagano; Japan.
[147]Department Physik, Universität Siegen, Siegen; Germany.
[148]Department of Physics, Simon Fraser University, Burnaby BC; Canada.
[149]SLAC National Accelerator Laboratory, Stanford CA; United States of America.
[150]Department of Physics, Royal Institute of Technology, Stockholm; Sweden.
[151]Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY; United States of America.
[152]Department of Physics and Astronomy, University of Sussex, Brighton; United Kingdom.
[153]School of Physics, University of Sydney, Sydney; Australia.
[154]Institute of Physics, Academia Sinica, Taipei; Taiwan.
[155][(a)]E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi;[(b)]High Energy Physics Institute, Tbilisi State University, Tbilisi; Georgia.
[156]Department of Physics, Technion, Israel Institute of Technology, Haifa; Israel.
[157]Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv; Israel.
[158]Department of Physics, Aristotle University of Thessaloniki, Thessaloniki; Greece.
[159]International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo; Japan.
[160]Department of Physics, Tokyo Institute of Technology, Tokyo; Japan.
[161]Tomsk State University, Tomsk; Russia.
[162]Department of Physics, University of Toronto, Toronto ON; Canada.
[163][(a)]TRIUMF, Vancouver BC;[(b)]Department of Physics and Astronomy, York University, Toronto ON; Canada.
[164]Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba; Japan.
[165]Department of Physics and Astronomy, Tufts University, Medford MA; United States of America.
[166]Department of Physics and Astronomy, University of California Irvine, Irvine CA; United States of America.
[167]Department of Physics and Astronomy, University of Uppsala, Uppsala; Sweden.
[168]Department of Physics, University of Illinois, Urbana IL; United States of America.
[169]Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia; Spain.
[170]Department of Physics, University of British Columbia, Vancouver BC; Canada.
[171]Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada.
[172]Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg; Germany.
[173]Department of Physics, University of Warwick, Coventry; United Kingdom.
[174]Waseda University, Tokyo; Japan.
[175]Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot; Israel.
[176]Department of Physics, University of Wisconsin, Madison WI; United States of America.

[177]Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany.
[178]Department of Physics, Yale University, New Haven CT; United States of America.
[a] Also at Borough of Manhattan Community College, City University of New York, New York NY; United States of America.
[b] Also at Bruno Kessler Foundation, Trento; Italy.
[c] Also at Center for High Energy Physics, Peking University; China.
[d] Also at Centro Studi e Ricerche Enrico Fermi; Italy.
[e] Also at CERN, Geneva; Switzerland.
[f] Also at CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France.
[g] Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
[h] Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona; Spain.
[i] Also at Department of Financial and Management Engineering, University of the Aegean, Chios; Greece.
[j] Also at Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America.
[k] Also at Department of Physics and Astronomy, University of Louisville, Louisville, KY; United States of America.
[l] Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva; Israel.
[m] Also at Department of Physics, California State University, East Bay; United States of America.
[n] Also at Department of Physics, California State University, Fresno; United States of America.
[o] Also at Department of Physics, California State University, Sacramento; United States of America.
[p] Also at Department of Physics, King's College London, London; United Kingdom.
[q] Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg; Russia.
[r] Also at Department of Physics, University of Fribourg, Fribourg; Switzerland.
[s] Also at Faculty of Physics, M.V. Lomonosov Moscow State University, Moscow; Russia.
[t] Also at Faculty of Physics, Sofia University, 'St. Kliment Ohridski', Sofia; Bulgaria.
[u] Also at Giresun University, Faculty of Engineering, Giresun; Turkey.
[v] Also at Graduate School of Science, Osaka University, Osaka; Japan.
[w] Also at Hellenic Open University, Patras; Greece.
[x] Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona; Spain.
[y] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg; Germany.
[z] Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest; Hungary.
[aa] Also at Institute of Particle Physics (IPP); Canada.
[ab] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
[ac] Also at Institute of Theoretical Physics, Ilia State University, Tbilisi; Georgia.
[ad] Also at Instituto de Fisica Teorica, IFT-UAM/CSIC, Madrid; Spain.
[ae] Also at Istanbul University, Dept. of Physics, Istanbul; Turkey.
[af] Also at Joint Institute for Nuclear Research, Dubna; Russia.
[ag] Also at Moscow Institute of Physics and Technology State University, Dolgoprudny; Russia.
[ah] Also at National Research Nuclear University MEPhI, Moscow; Russia.
[ai] Also at Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany.
[aj] Also at The City College of New York, New York NY; United States of America.
[ak] Also at TRIUMF, Vancouver BC; Canada.
[al] Also at Universita di Napoli Parthenope, Napoli; Italy.
[am] Also at University of Chinese Academy of Sciences (UCAS), Beijing; China.

[an] Also at Yeditepe University, Physics Department, Istanbul; Turkey.
[*] Deceased