

Perspectives for polarized antiprotons

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MENU 2013 - Rome, September 3rd 2013

Motivation

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- The PAX collaboration proposed to investigate Drell Yan processes in scattering of polarized proton - antiproton beams at the HESR (FAIR).
- Annihilation of valence quark with an antiquark allows direct access to: transversity, ...

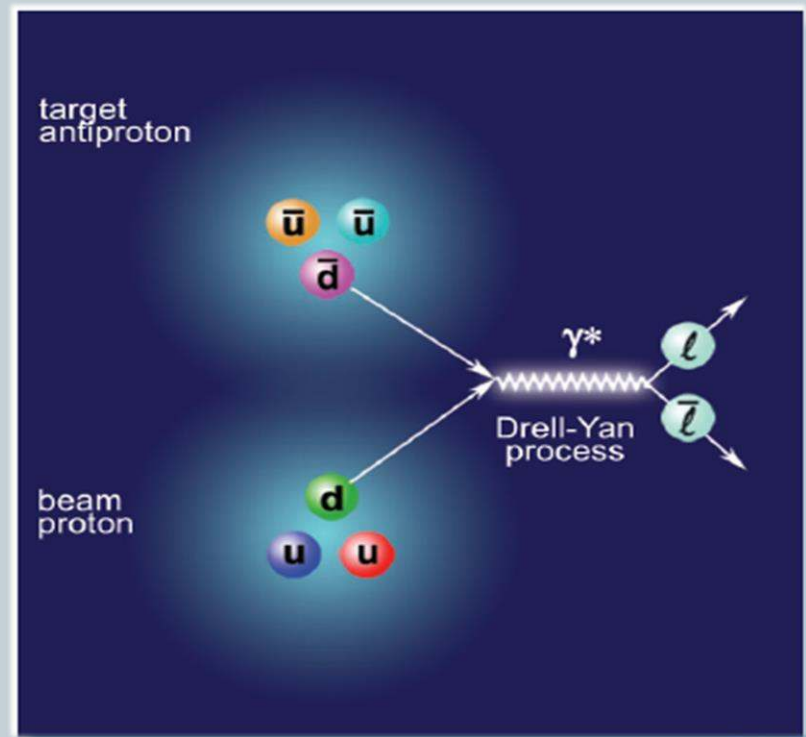
$$A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} = \hat{a}_{TT} \frac{\sum_q e_q^2 h_1^q(x_1, M^2) h_1^{\bar{q}}(x_2, M^2)}{\sum_q e_q^2 q(x_1, M^2) \bar{q}(x_2, M^2)}$$

- Requirements:

Polarized proton beam

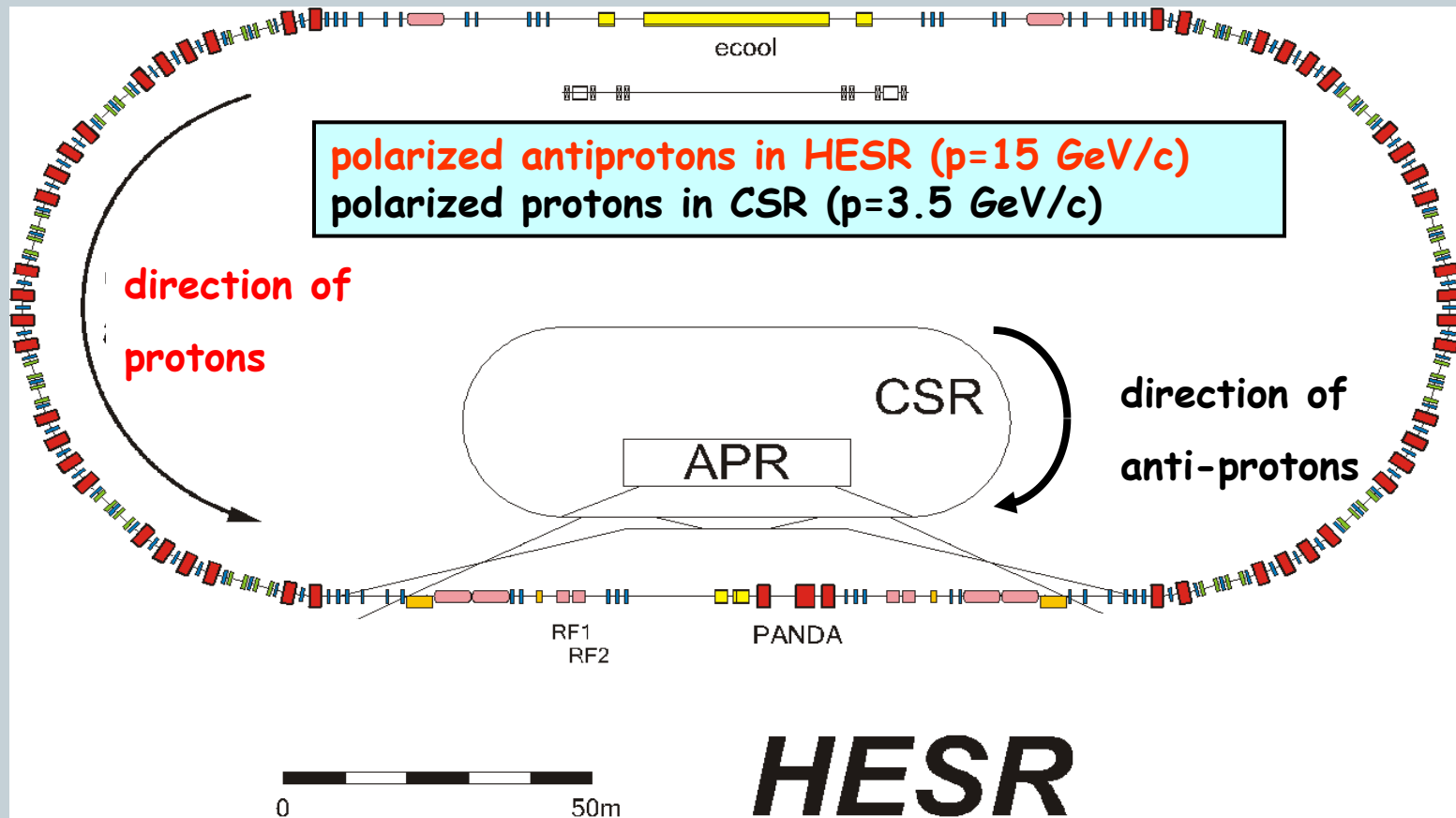


Polarized antiproton beam



A polarized Proton-Antiproton Collider at FAIR

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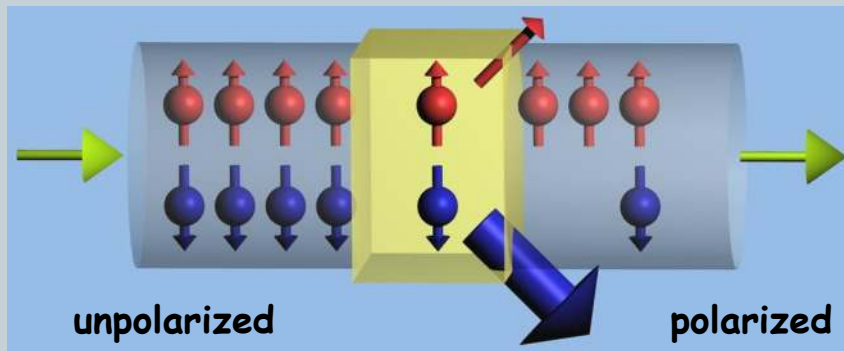


How to Polarize Antiprotons?

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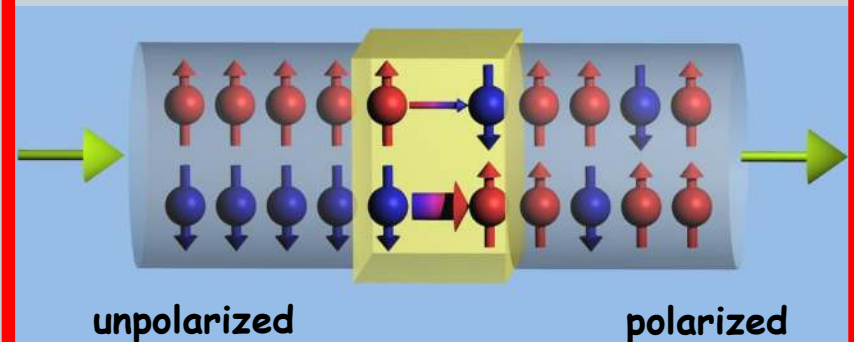
- Spin-1/2 particles \longrightarrow 2 states

selective removal



- Reduces beam intensity

selective flip



- Does not affect intensity

Selective-flip: a proposal

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A surprising method for polarising antiprotons.

Th. Walcher^{1,2}, H. Arenhövel¹, K. Aulenbacher¹, R. Barday¹ and A. Jankowiak¹

¹ Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, D-55099 Mainz, Germany

² Laboratori Nazionali di Frascati, Istituto Nazionale di Fisica Nucleare, I-00044 Frascati (Rome), Italy

Received: date / Revised version: date

Abstract. We propose a method for polarising antiprotons in a storage ring by means of a polarised positron beam moving parallel to the antiprotons. If the relative velocity is adjusted to $v/c \approx 0.002$ the cross section for spin-flip is as large as about $2 \cdot 10^{13}$ barn as shown by new QED-calculations of the triple spin-cross sections. Two possibilities for providing a positron source with sufficient flux density are presented. A polarised positron beam with a polarisation of 0.70 and a flux density of approximately $1.5 \cdot 10^{10}/(\text{mm}^2 \text{ s})$ appears to be feasible by means of a radioactive ^{11}C dc-source. A more involved proposal is the production of polarised positrons by pair production with circularly polarised photons. It yields a polarisation of 0.76 and requires the injection into a small storage ring. Such polariser sources can be used at low (100 MeV) as well as at high (1 GeV) energy storage rings providing a time of about one hour for polarisation build-up of about 10^{10} antiprotons to a polarisation of about 0.18. A comparison with other proposals show a gain in the figure-of-merit by a factor of about ten.

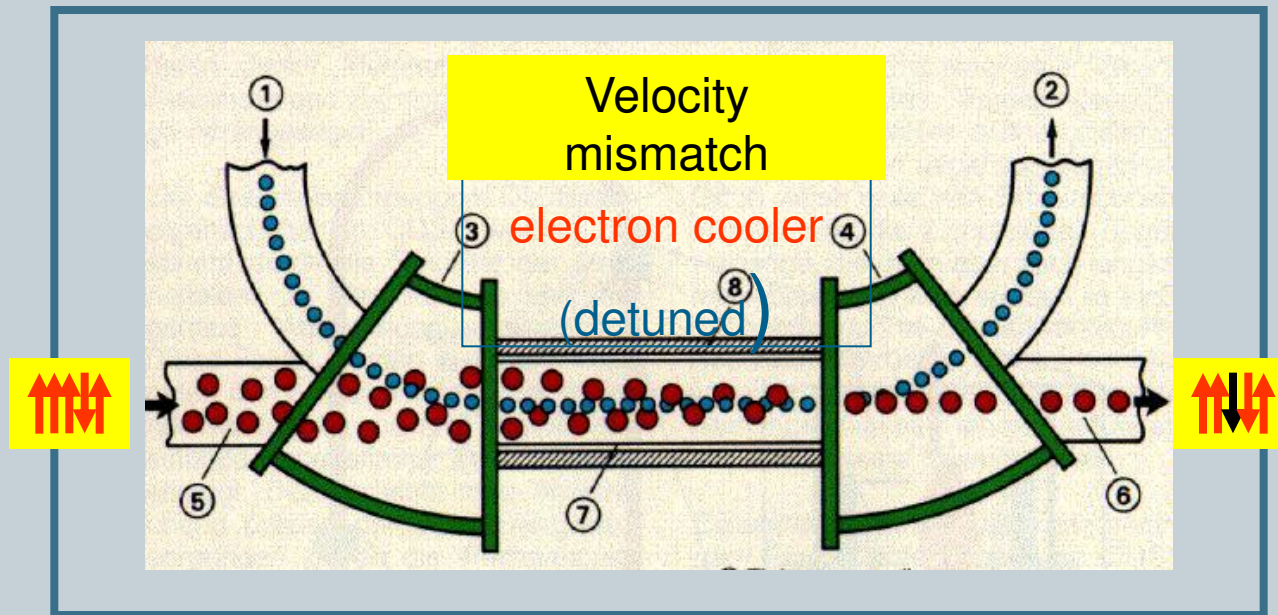
PACS. 13.88.+e Polarisation in interactions and scattering – 29.20.Dh Storage rings – 29.25.Bx Electron sources – 29.27.Hj Polarised beams

Eur. Phys. J. A 34, 447 (2007)

Spin-flip studies at COSY

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- Use **proton** beam and co-moving **electrons**
- Turn experiment around: $p \vec{e} \rightarrow \bar{p} e$ into $\bar{p} e \rightarrow p \vec{e}$
i.e. observe **depolarization** of a polarized proton beam



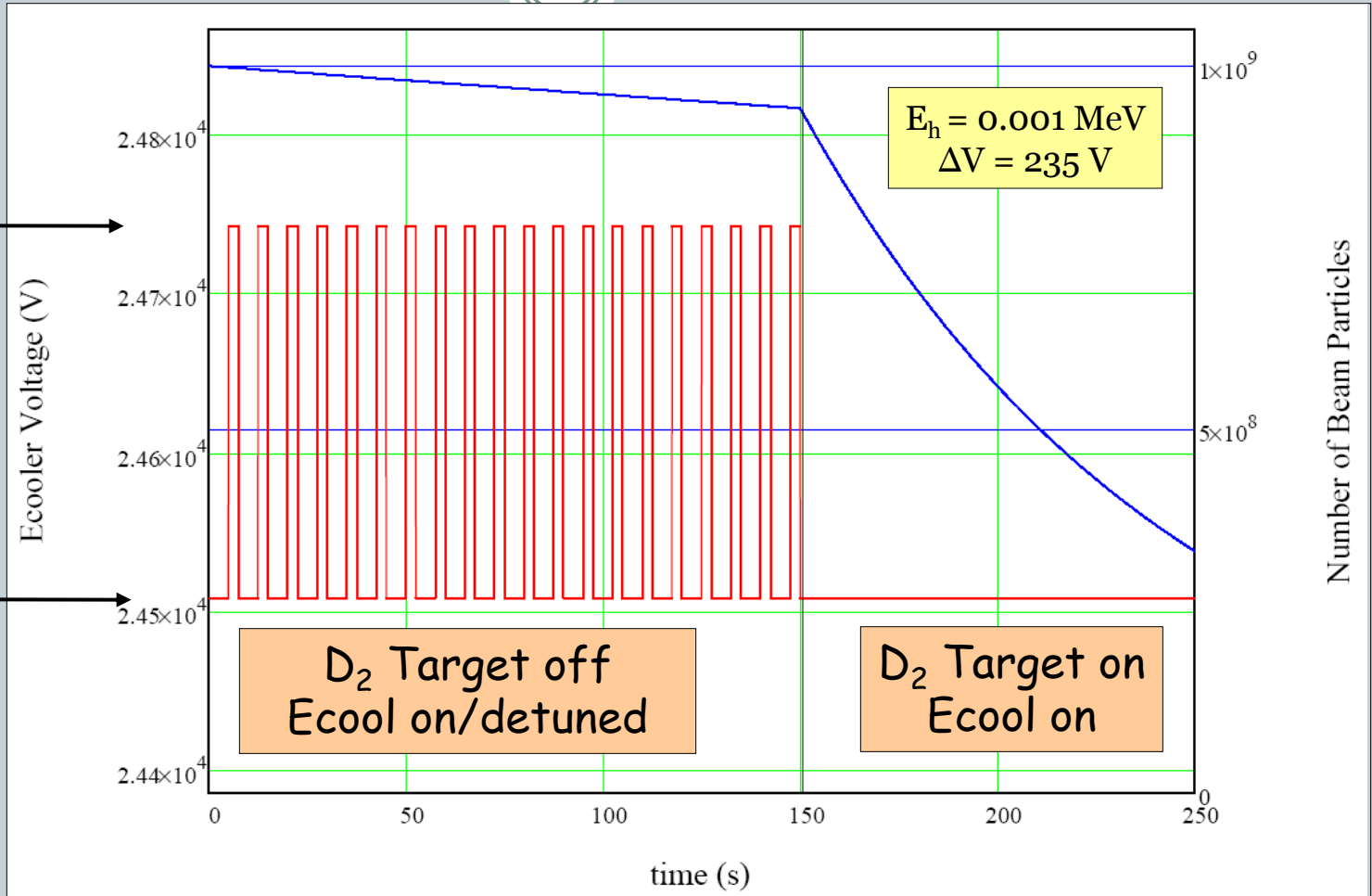
Measurement cycle

7

Detuned Cooler Voltage
 $T_{\text{detuned}} = 50 \text{ s}$

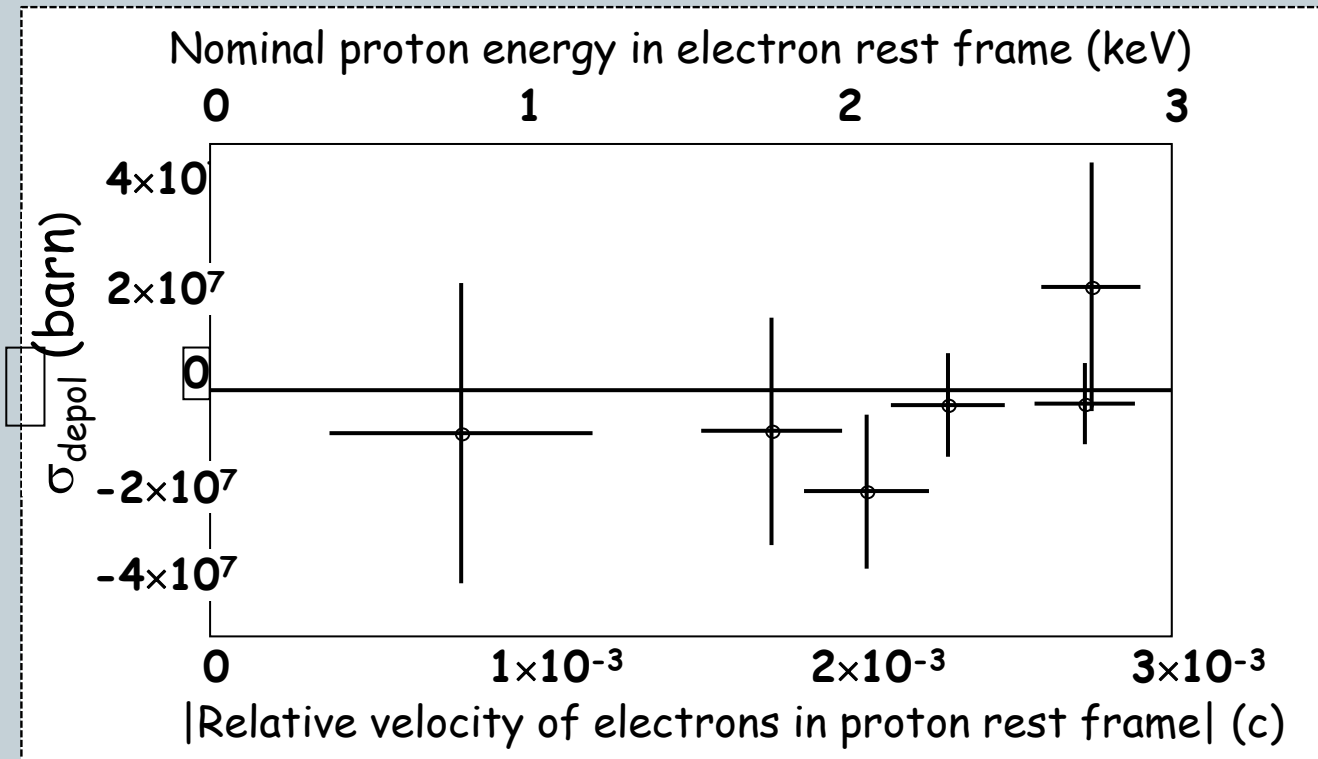
Nominal Cooler Voltage
 $T_{\text{nominal}} = 100 \text{ s}$

$$\frac{T_{\text{nominal}}}{T_{\text{detuned}}} = 2$$



Spin-flip: results

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$$\sigma_{\parallel} < 3.2 \times 10^7 \text{ b}$$
$$\sigma_{\perp} < 1.7 \times 10^7 \text{ b}$$

D.Oellers et al., Physics Letters B 674 (2009) 269

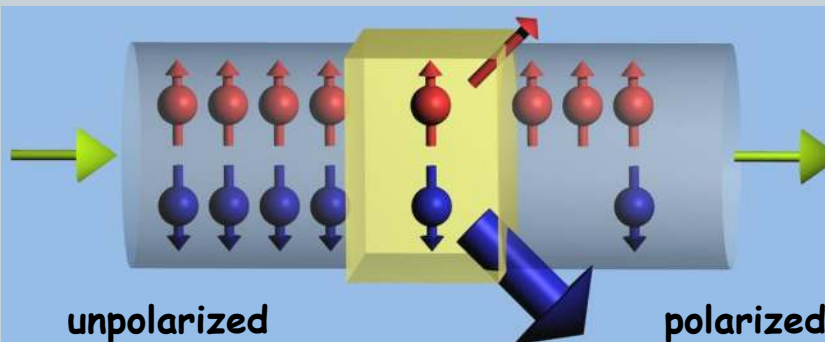
RESULT: Selective flip: e^+ pbar spin-flip cross-section is too low

How to Polarize Antiprotons?

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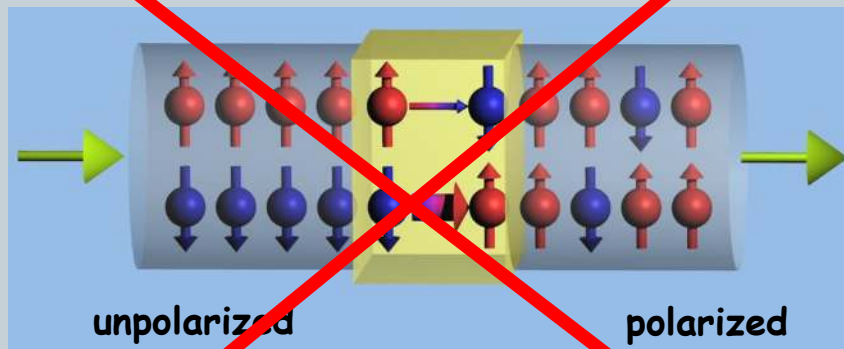
- Spin-1/2 particles \longrightarrow 2 states

selective removal



- Reduces beam intensity

selective flip

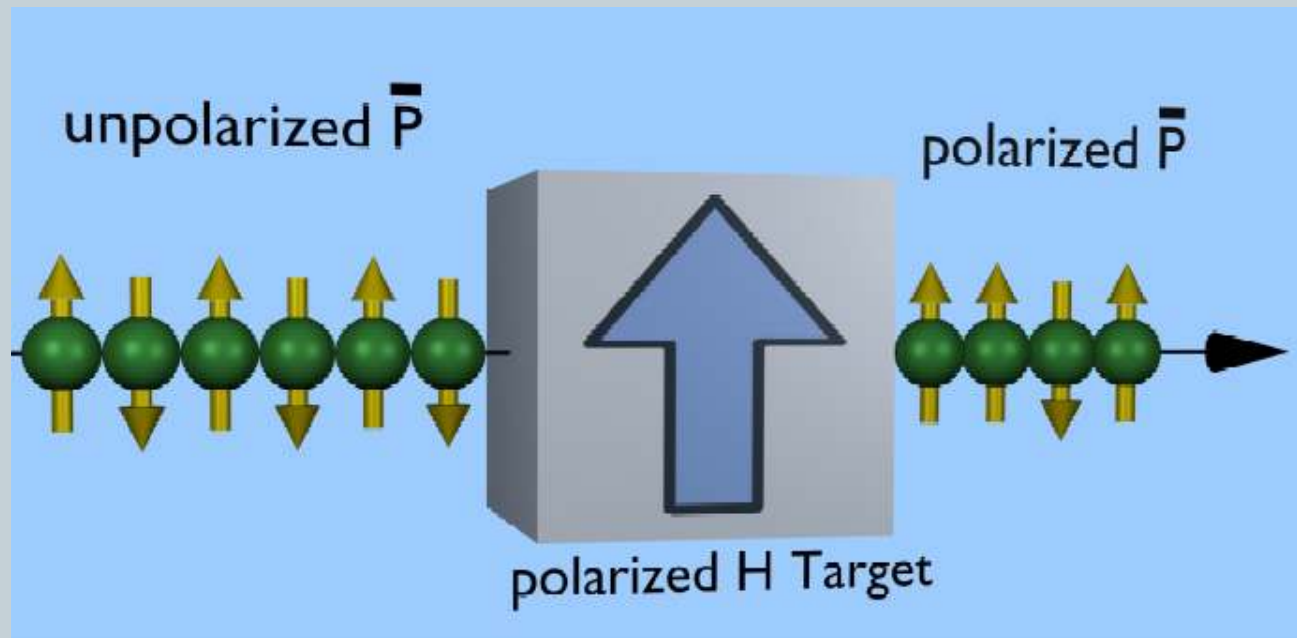


- Does not affect intensity

Spin-filtering

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Polarization build-up of a circulating particle beam by interaction with a polarized gas target



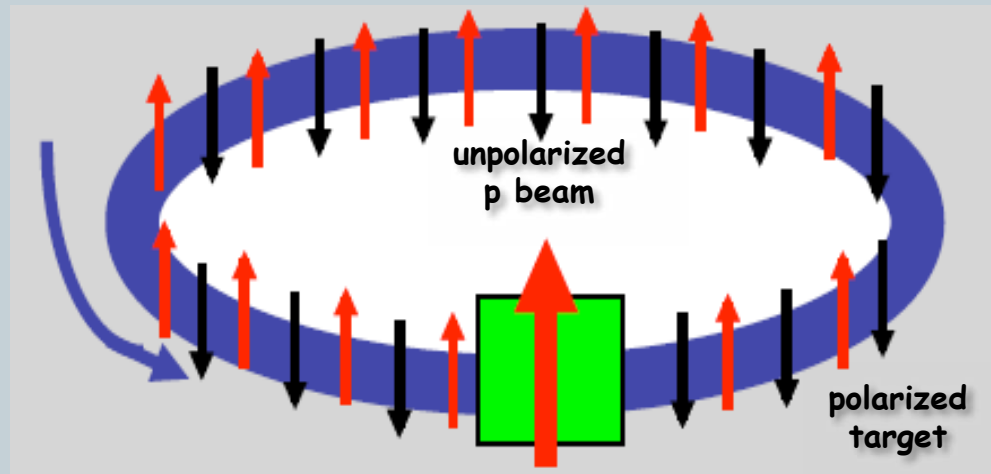
Spin-filtering

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$$\sigma_{tot} = \sigma_0 + \sigma_1(\vec{P} \cdot \vec{Q}) + \sigma_2(\vec{P} \cdot \hat{k})(\vec{Q} \cdot \hat{k})$$

P...beam particle spin orientation
Q...target particle spin orientation
k || beam direction

$$P(t) = \frac{N_{\uparrow} - N_{\downarrow}}{N_{\uparrow} + N_{\downarrow}} = \tanh\left(\frac{t}{\tau_1}\right) \approx t \cdot \tilde{\sigma}_1 \cdot Q \cdot d_t \cdot f$$



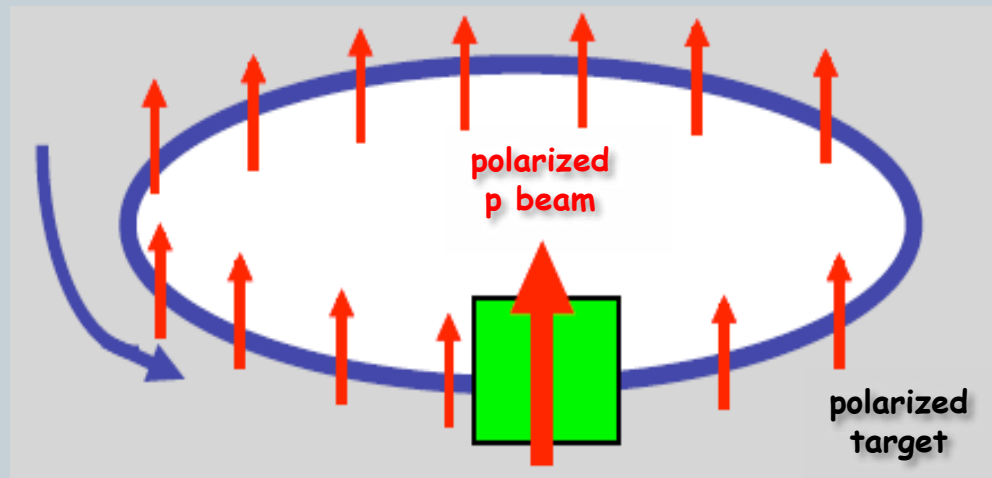
Spin-filtering

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$$\sigma_{tot} = \sigma_0 + \sigma_1(\vec{P} \cdot \vec{Q}) + \sigma_2(\vec{P} \cdot \hat{k})(\vec{Q} \cdot \hat{k})$$

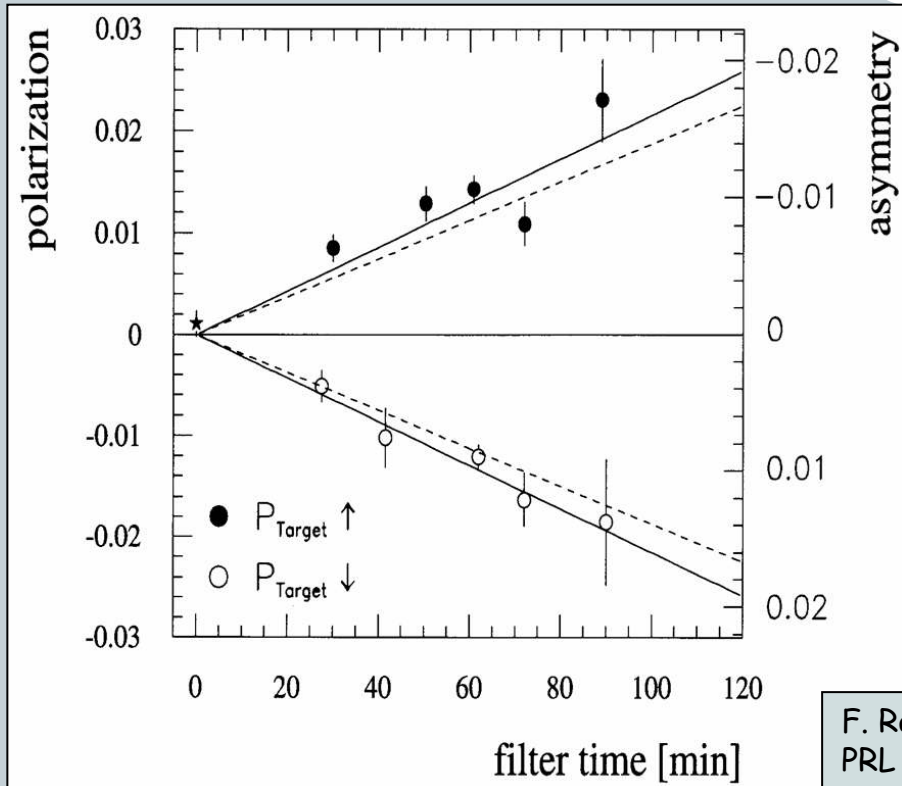
P...beam particle spin orientation
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k || beam direction

$$P(t) = \frac{N_{\uparrow} - N_{\downarrow}}{N_{\uparrow} + N_{\downarrow}} = \tanh\left(\frac{t}{\tau_1}\right) \approx t \cdot \tilde{\sigma}_1 \cdot Q \cdot d_t \cdot f$$



1992: Filter Test at TSR with protons

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F. Rathmann. et al.,
PRL 71, 1379 (1993)

Spin filtering works
for protons

PAX submitted new proposal to find out how well does spin filtering work for antiprotons

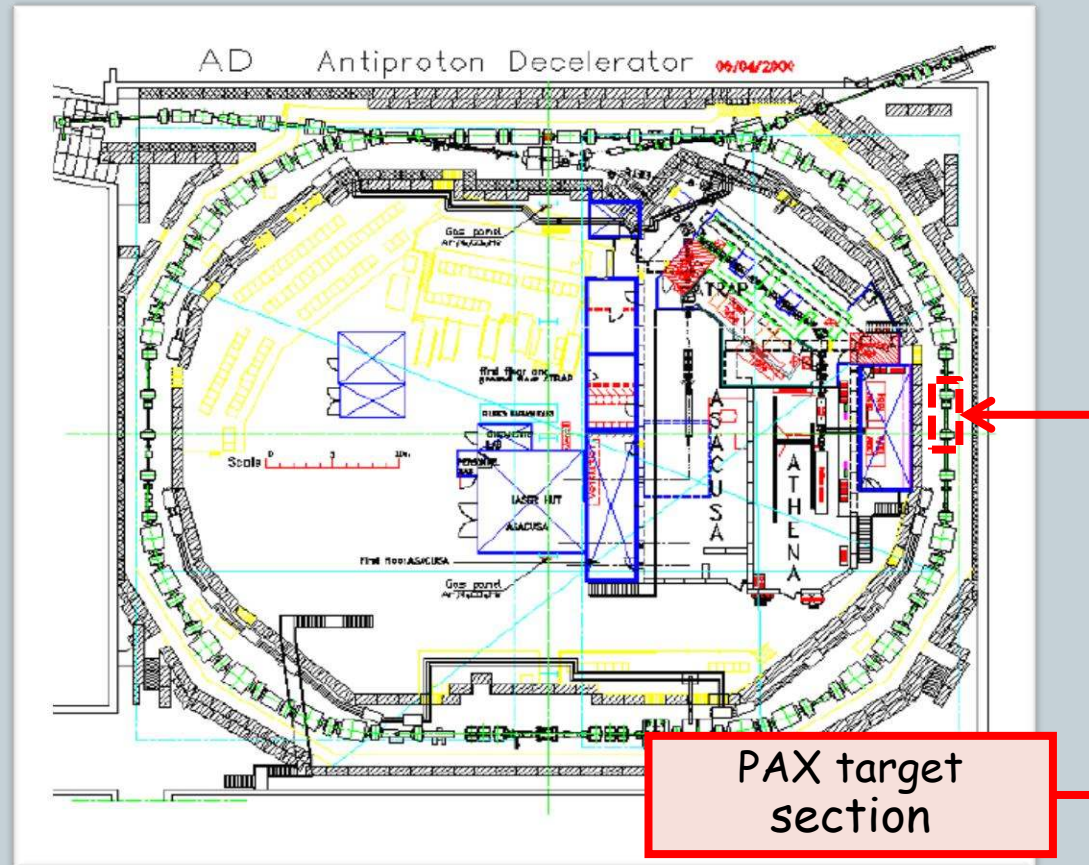
Measurement of the Spin-Dependence of the pp Interaction at the AD Ring

(CERN-SPSC-2009-012 / SPSC-P-337)

Measurements at AD (CERN)

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- Aim: 1st measurement of the spin-dependence of the $p\bar{p}$ cross section
- Method: measurement of polarization build-up by spin-filtering



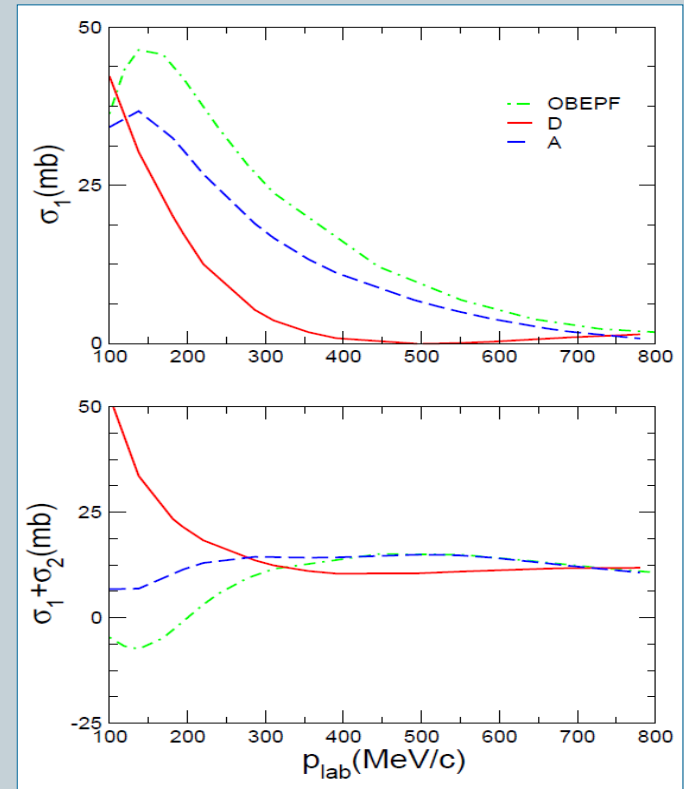
Spin-dependence of the \bar{p} - p interaction

15

Model A: T. Hippchen et al., Phys. Rev. C 44, 1323 (1991).

Model OBEPF: J. Haidenbauer, K. Holinde, A.W. Thomas, Phys. Rev. C 45, 952 (1992).

Model D: V. Mull, K. Holinde, Phys. Rev. C 51, 2360 (1995).



Oct. 2009 SPS Committee:

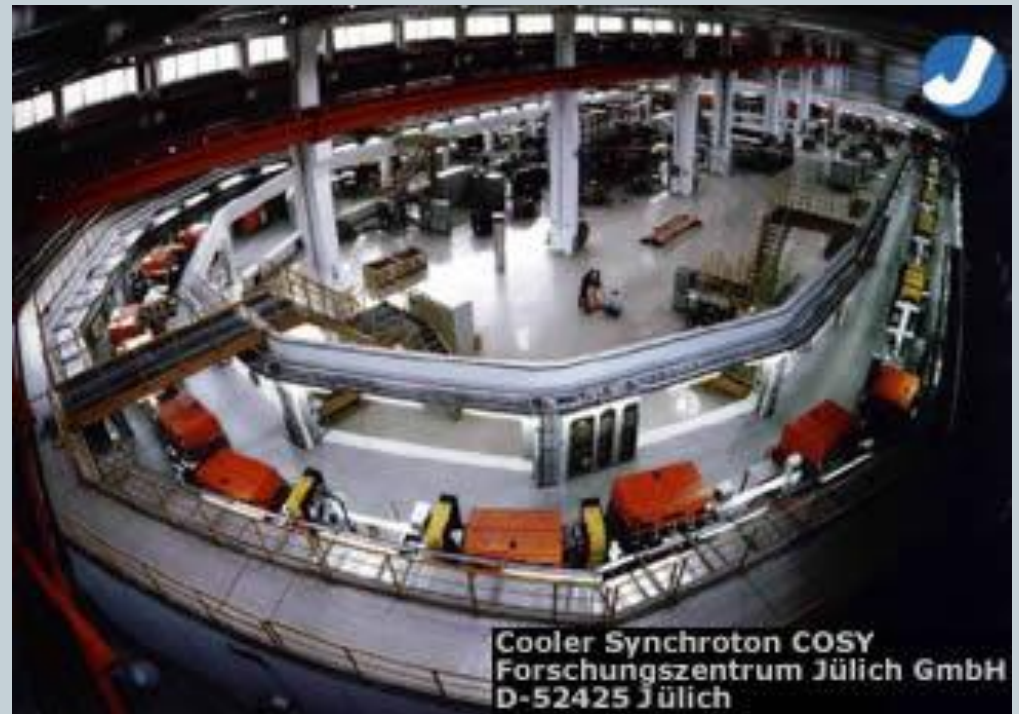
... Taking into account the timeline and constraints of the various projects concerned, the SPSC **encourages the PAX Collaboration to first perform their spin filtering measurements at COSY...**

Spin Filtering at COSY

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Spin filtering with protons for better understanding of the underlying processes and commissioning of the experimental setup

- Length: 183.4 m
- Injection energy: 45 MeV
- Electron cooling for long lifetimes up to 600 MeV/c (p)

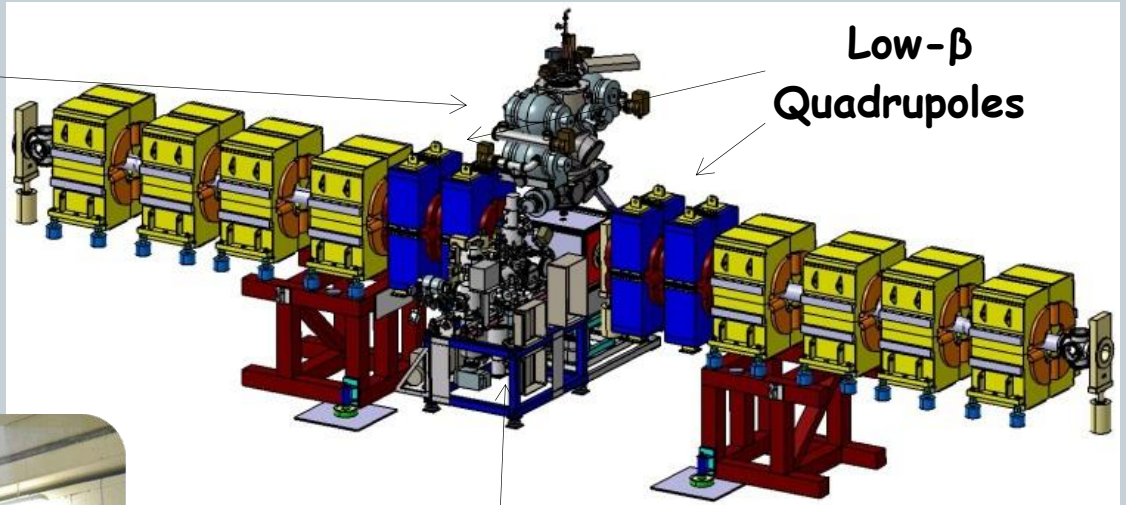


Experimental setup at PAX-IT

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ABS

Low- β
Quadrupoles



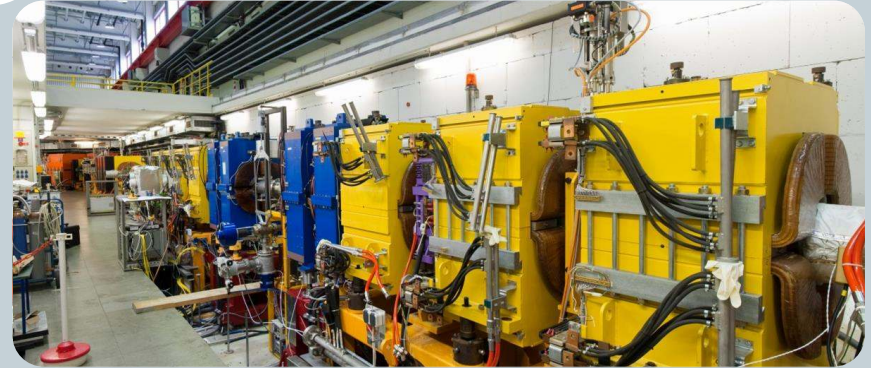
Target
Chamber

Low- β section

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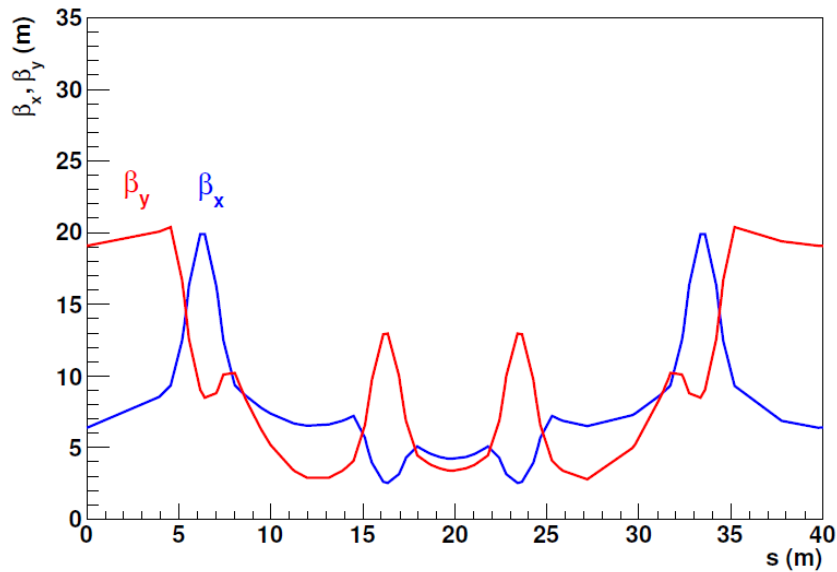
Beam lifetime τ :

$$\tau \propto \frac{1}{d_t \cdot \beta}$$



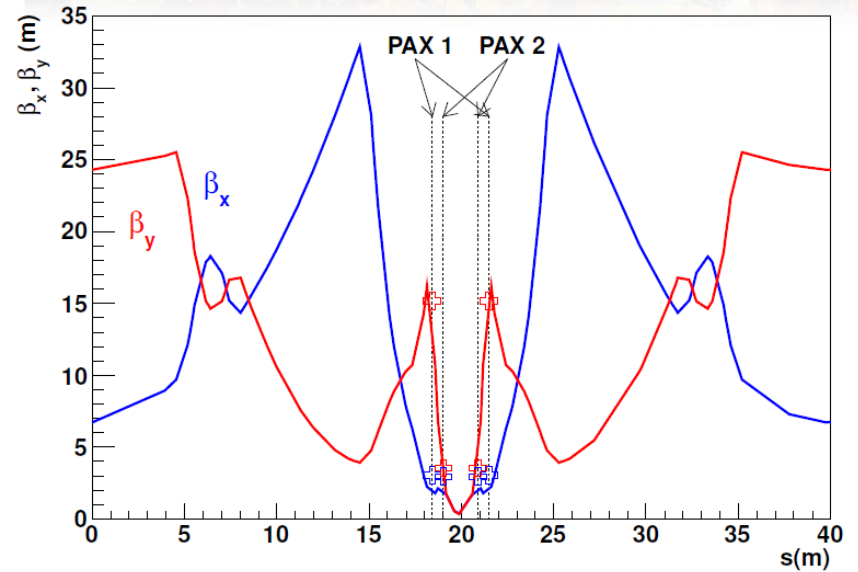
Low- β section off

PAX OFF



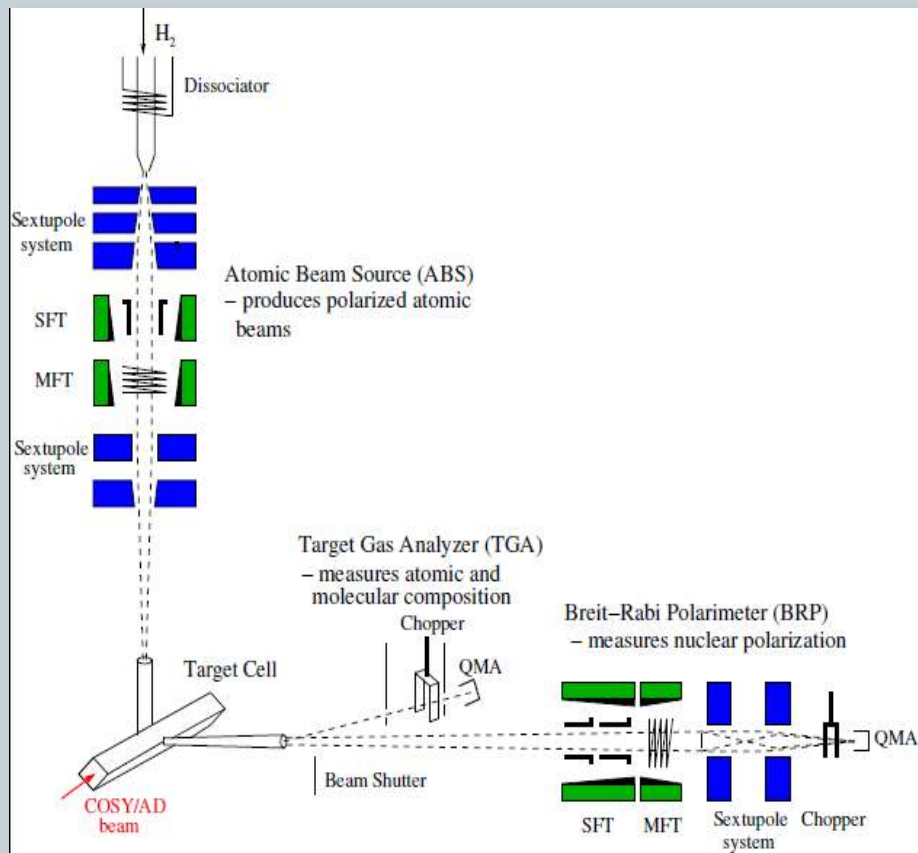
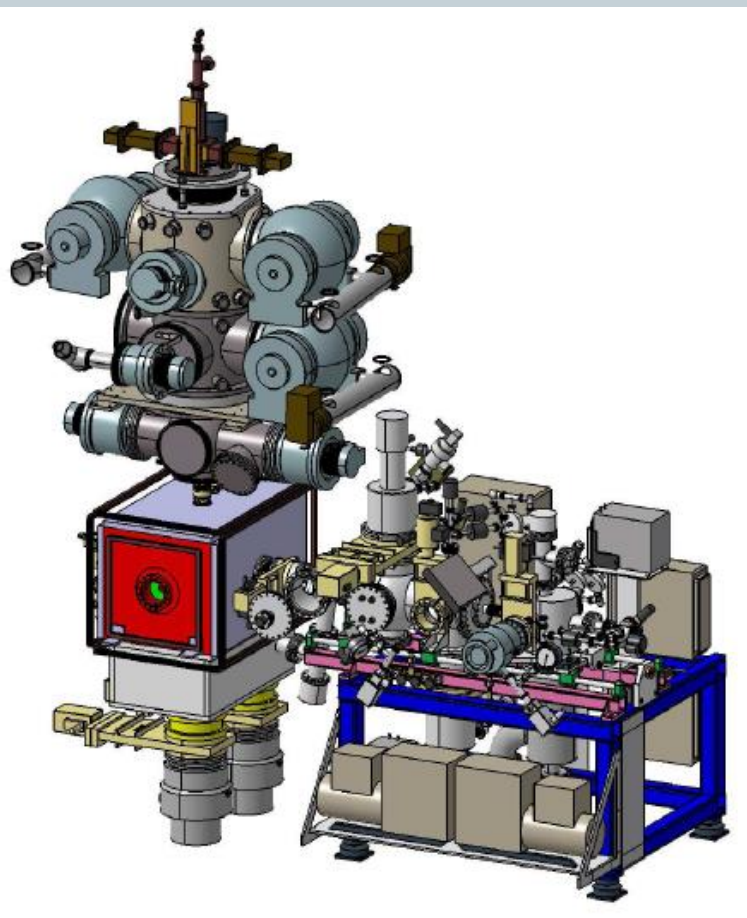
Low- β section on

PAX ON



Atomic Beam Source

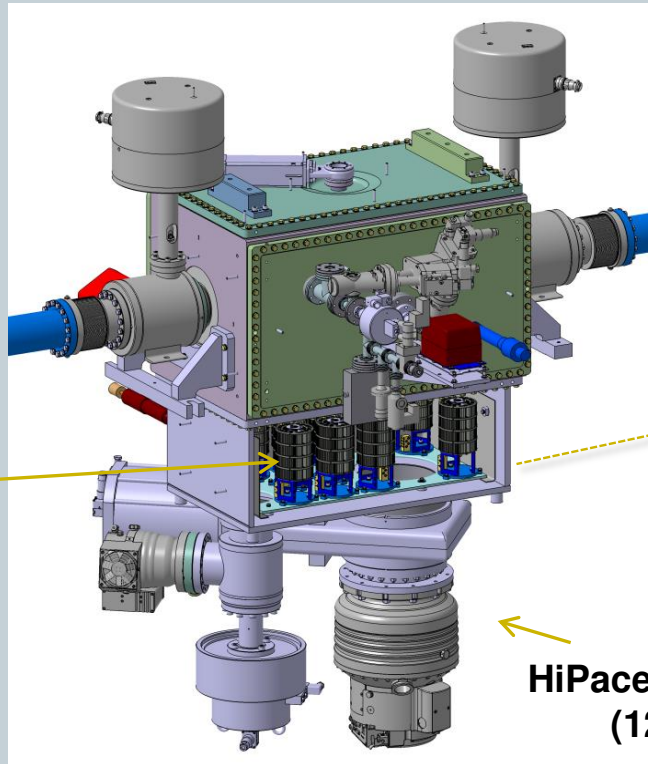
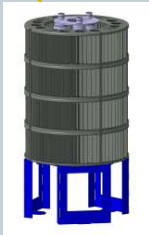
19



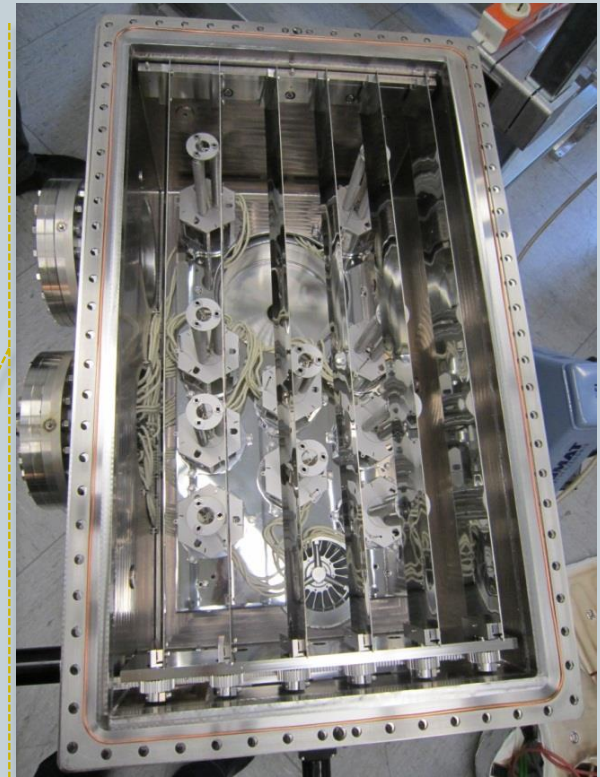
Target chamber

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SAES getter pump
(each 1900 l/s)



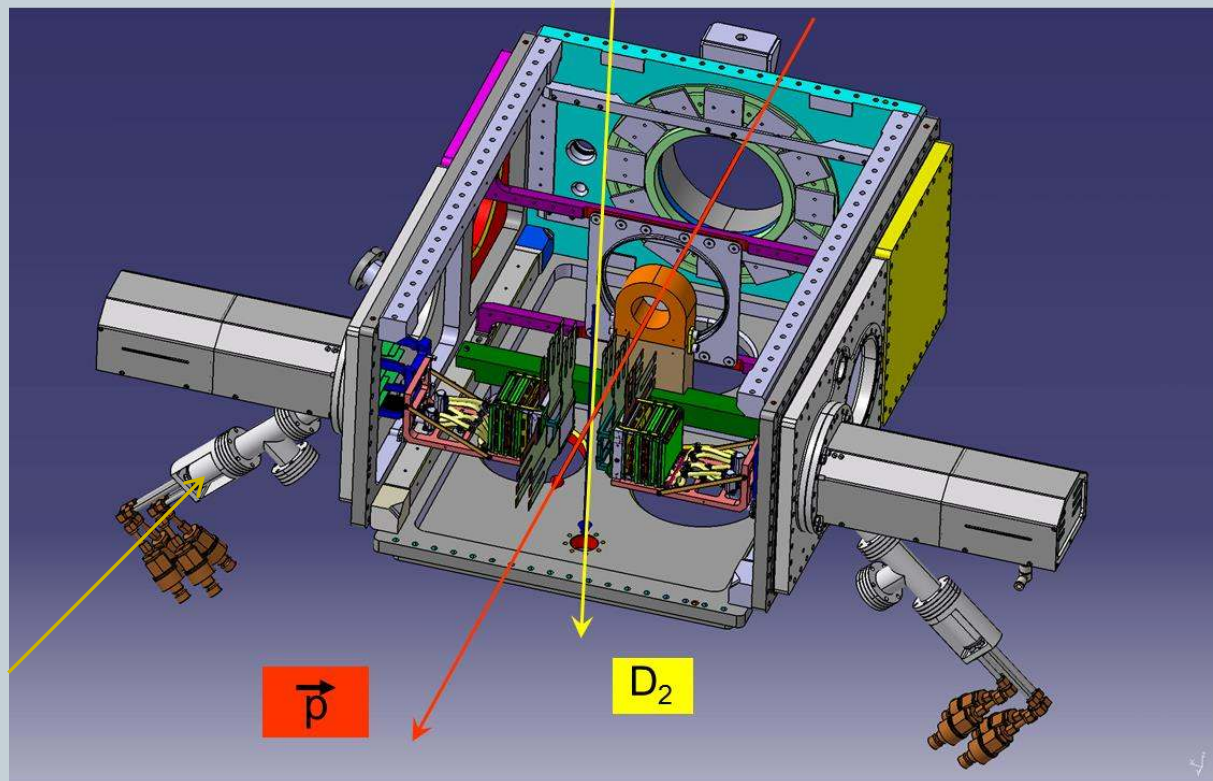
HiPace 1800 turbo
(1200 l/s)



Beam polarimeter

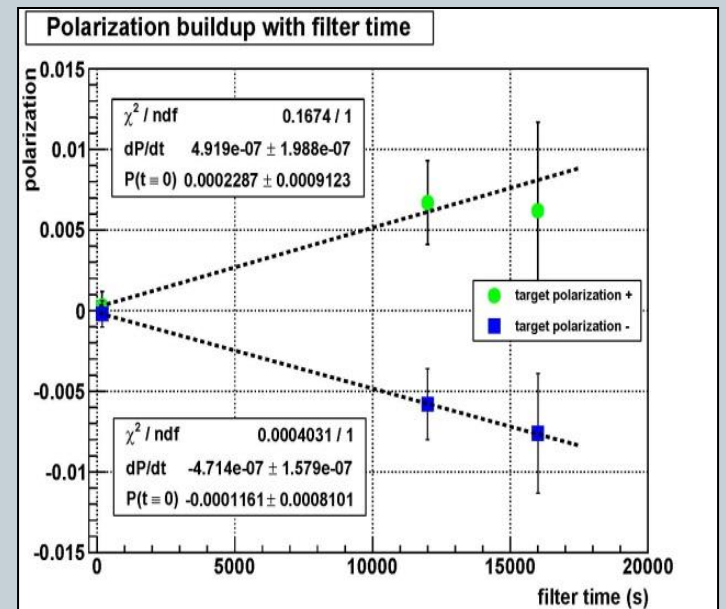
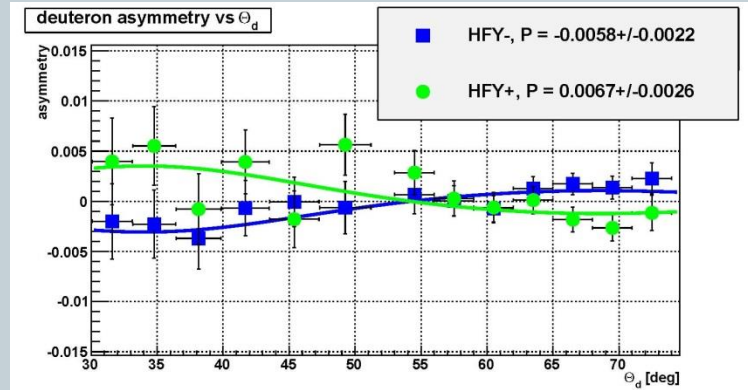
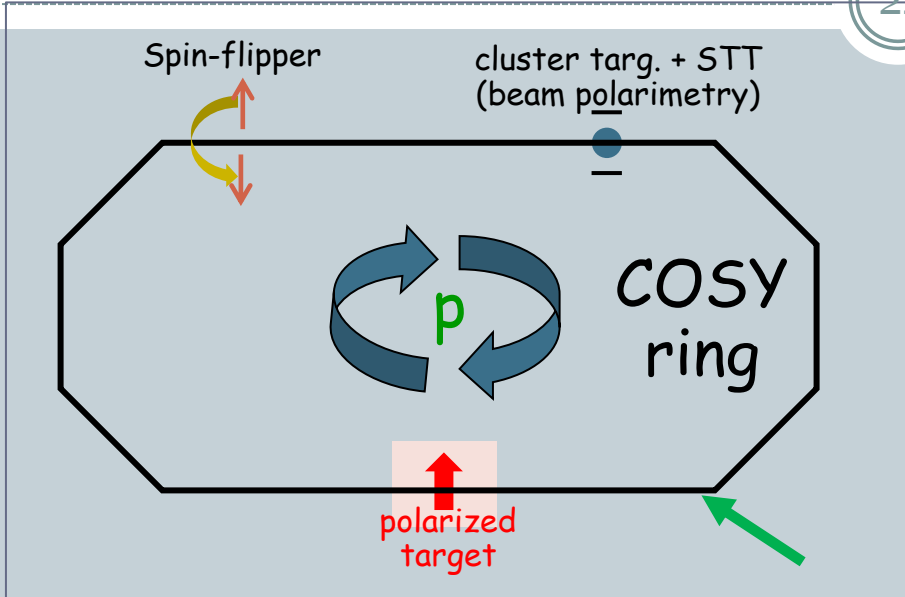
21

- Measurement of asymmetry in pd-elastic scattering
- 2 Silicon Tracking Telescopes left and right of the COSY beam
- Deuterium Cluster Target ($d_t = 10^{14}$ atoms/cm²)



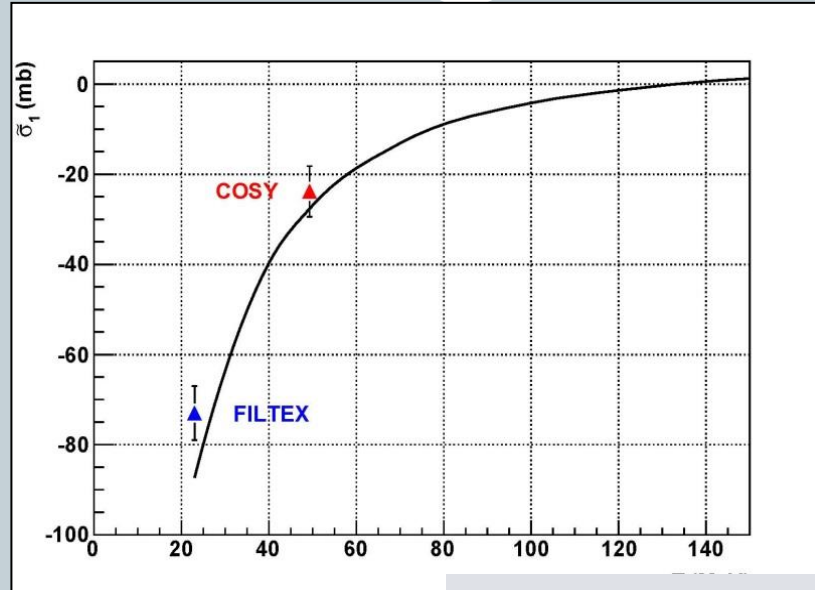
Spin-filtering cycle

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Spin-filtering: result

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W. Augustyniak et al., Phys. Lett. B 712 (2012) 64

▪ Milestone for the field

- Confirms understanding of spin-filtering as a viable method to polarize a stored beam.
- Confirms complete control of the systematics of the experiment.

Mar. 2012 SPS Committee:

... many positive developments have occurred at the AD, leading to an updated program for the coming years **We consider that PAX is now incompatible with this program.**

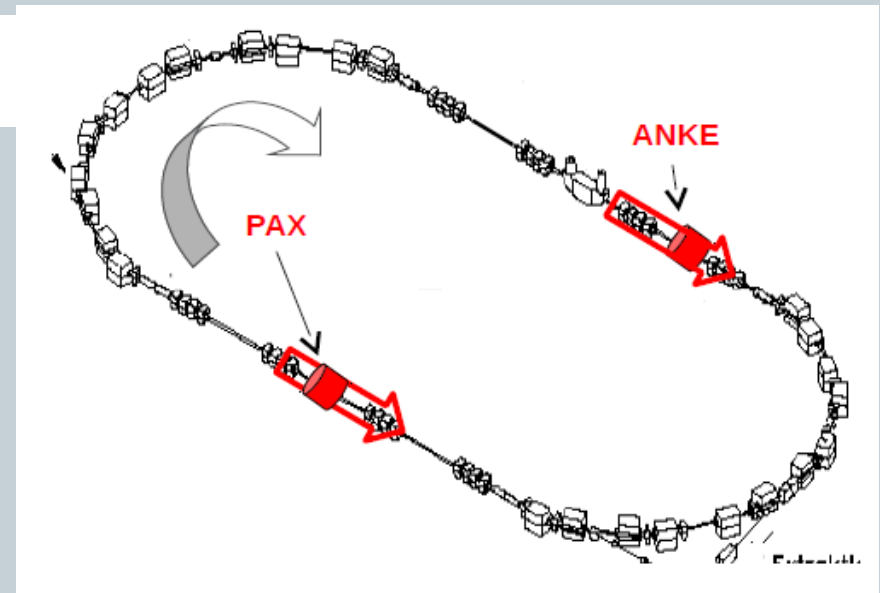
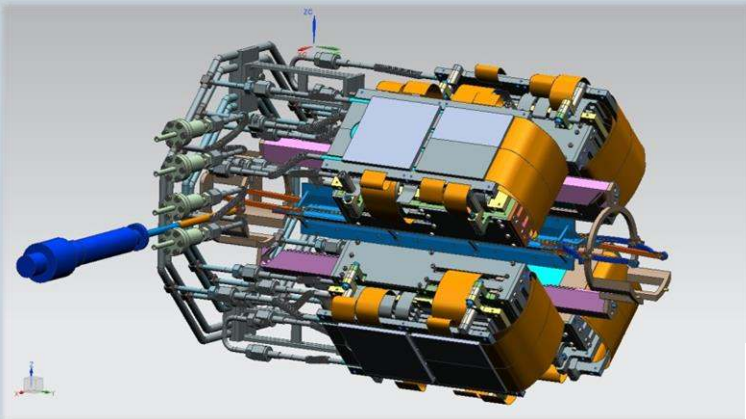
Future plans

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Waiting for approval at CERN (or construction of FAIR facility)

Longitudinal spin-filtering test at *COSY*

Superconducting 4.7 Tm solenoid ordered



Longitudinal beam polarimeter in preparation

Summary

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Status:

- Successful spin filtering measurement at COSY on transverse polarized target.
- Excellent agreement with theoretical predictions for protons
- Successful commissioning of experimental setup for experiments with antiproton

Future plans at COSY

- Spin filtering with protons and a longitudinally polarized gas target at COSY at $T_p = 130$ MeV ($\vec{p}\vec{p}$ scattering)

Still pending:

- Spin-filtering experiments at AD exploring the systems $p(\bar{p})p$, $p(\bar{p})d$, $(p(\bar{p})^3\text{He})$ (transverse and longitudinal polarization)

Thank you!

Additional Slides

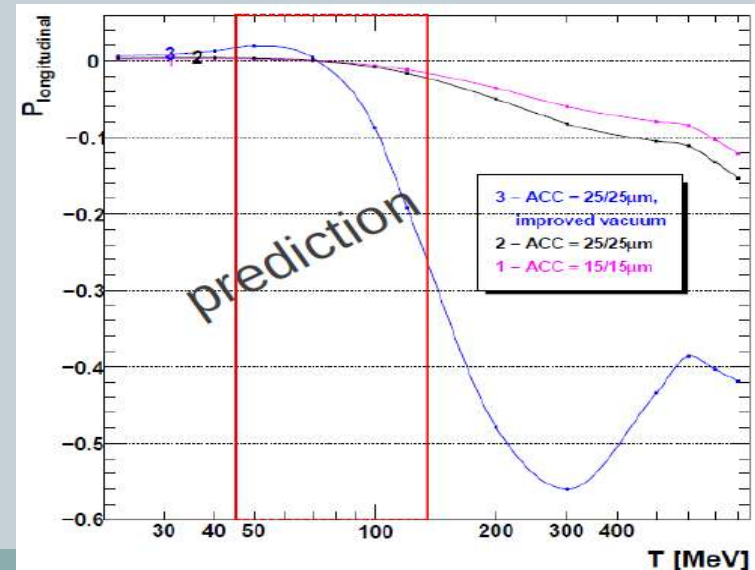
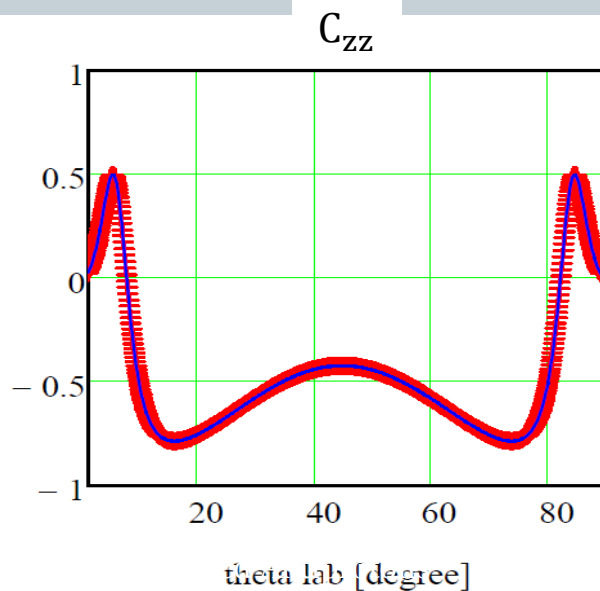
26

Spin Filtering with Longitudinal Polarization

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- Buildup of longitudinal beam polarization due to repeated interaction with a longitudinally polarized hydrogen target
- $T_p \approx 45 - 130$ MeV kinetic proton energy
- Detector: Measurement of longitudinal beam polarization using $\vec{p}\vec{p}$ elastic scattering
 - Measurement during filtering with hydrogen target possible
 - Spin correlation coefficient (~ 0.5)
 - No background

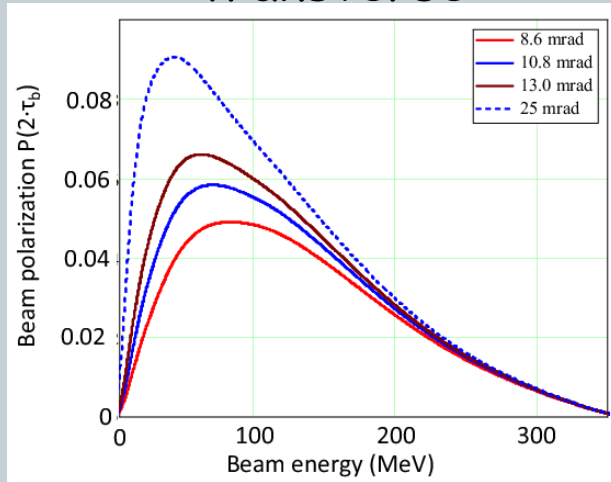
$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} (1 + C_{ZZ} \cdot P_Z Q_Z)$$



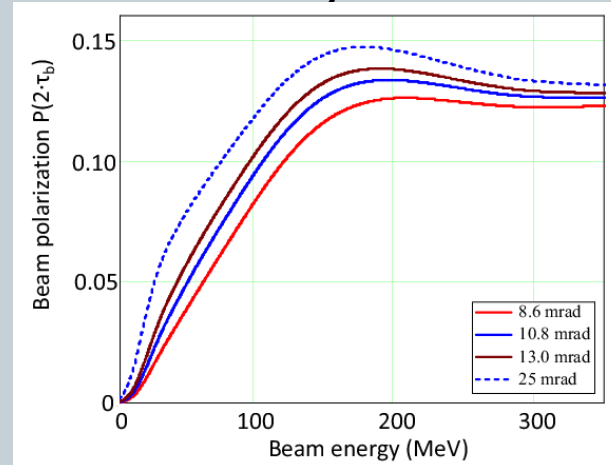
Expected polarizations after filtering for two lifetimes

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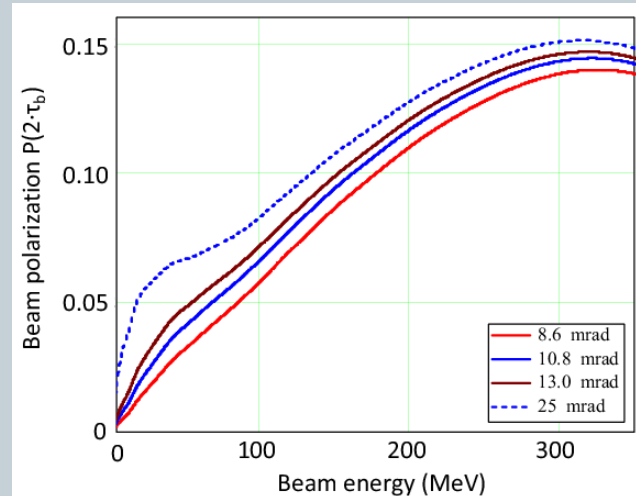
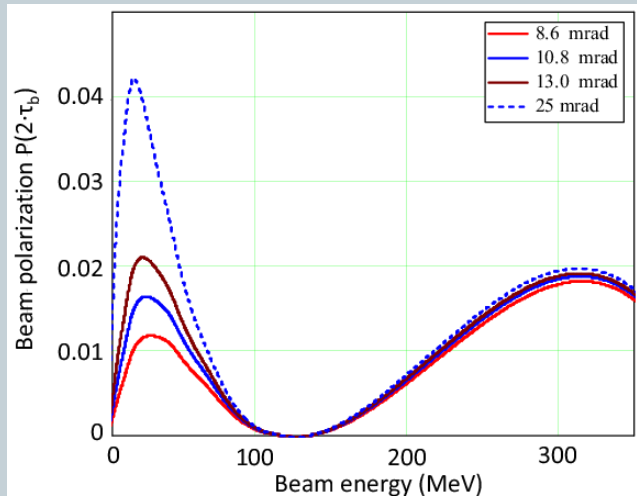
transverse



longitudinal



A



D

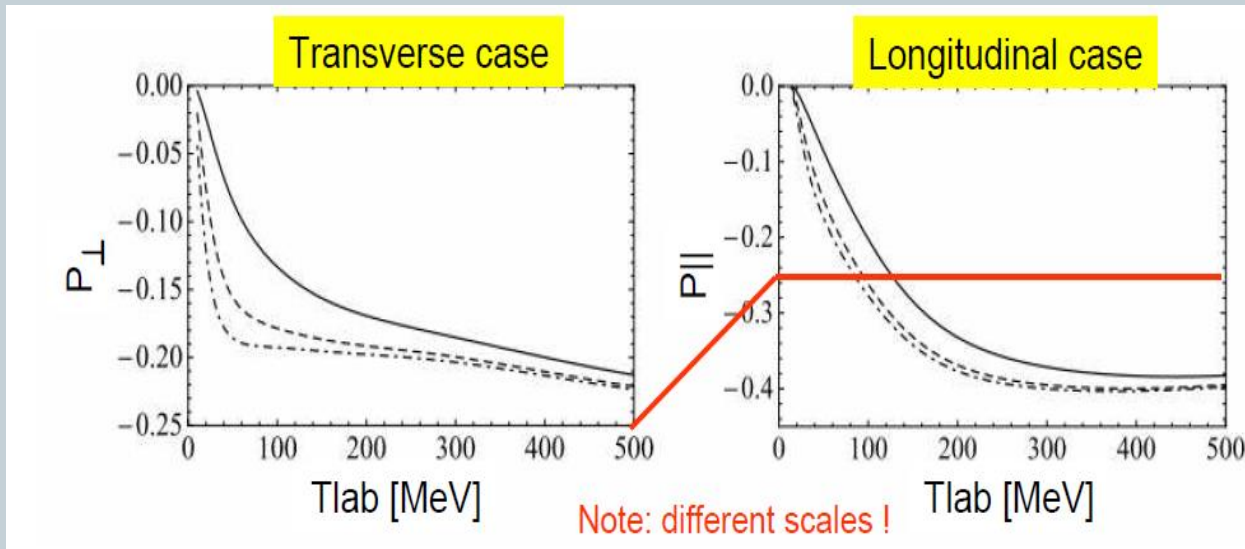
Additional calculations...

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Spin-dependent part of $p\bar{p}$ interaction cross section and Nijmegen potential

V.F. Dmitriev^{a,b}, A.I. Milstein^{a,b}, S.G. Salnikov^{a,b,*}

PLB 690 (2010)

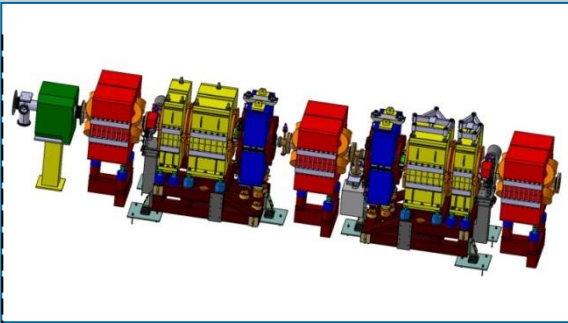


Projected
polarizations

Stages of installation at AD

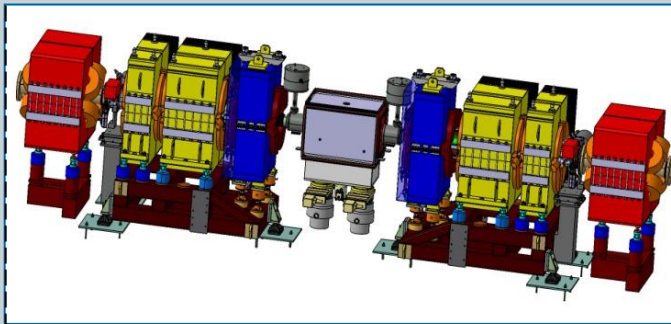
30

Phase 1



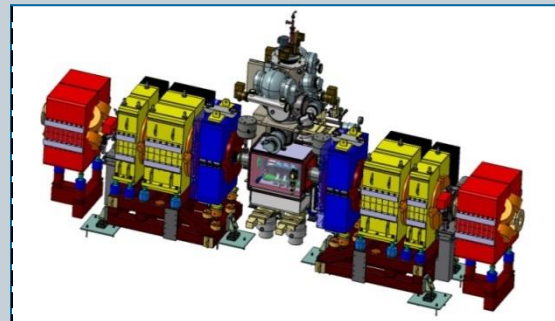
Installation of six magnets for the low- β insertion

Phase 2



Installation of the target chamber: Machine acceptance studies. Stacking studies

Phase 3



Spin-filtering measurements up to 70 MeV with transverse beam polarization