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Authors

Albiol, F
Ballester, F
Barbier, G
et al.

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Beam test of the ATLAS silicon detector modules

F. Albiol^a, F. Ballester^a, G. Barbier^b, J. Bernabeu^a, R. Bonino^b, A. Ciocio^c, A.G. Clark^b, C. Couyoumtzelis^b, J. Dane^d, P. Demierre^a, J. DeWitt^e, D.E. Dorfan^e, T. Dubbs^e, J. Emes^c, D. Fasching^f, J. Fuster^a, C. Garcia^a, M.G.D. Gilchriese^c, J. Godlewski^g, S. Gonzalez^f, A. Grewalⁿ, A.A. Grillo^e, C. Haber^c, C. Hackett^d, P. Haeslerⁱ, J.C. Hill^j, S. Holland^c, H. Iwasaki^k, Y. Iwata^l, R. Jared^f, S. Kashigin^e, I. Kipnis^c, U. Koetz^m, T. Kondo^k, R. Kowalewski^b, W. Kroeger^e, A. Lankford^d, J. Lozano Bahilo^c, G. Moorheadⁱ, D. Morgan^u, D.J. Munday^j, W. Murray^{m,n}, R. Nickerson^h, T. Ohsugi^l, V. O'Shea^o, E. Perrin^b, S. Pier^d, P.W. Phillipsⁿ, T. Pulliam^e, J. Richardson^p, W.A. Rowe^e, A. Saavedra^q, H.F.-W. Sadrozinski^{e,*}, J. Salt^a, J. Sanchez^a, B. Schmid^d, A. Seiden^e, P.J. Sellin^u, M. Shapiro^c, J. Siegrist^c, E. Spencer^e, H. Spieler^c, S. Stapnes^r, R. Takashima^s, N. Tamura^t, G. Taylorⁱ, S. Terada^k, Y. Unno^k, B. Vuaridel^b, S.M. Walshⁿ, R. Wastie^h, M. Weber^b, A. Webster^e, R. Wichmann^e, M. Wilder^e

^a IFIC, CSIC-Univ. of Valencia, Valencia, Spain

^b University of Geneva, Geneva, Switzerland

^c Lawrence Berkeley National Laboratory, Berkeley, CA, USA

^d University of California, Irvine, CA, USA

^e SCIPP, University of California, Santa Cruz, CA, USA

^f University of Wisconsin, Madison, WI, USA

^g INP, Krakow, Poland

^h University of Oxford, Oxford, UK

ⁱ University of Melbourne, Melbourne, Australia

^j Cavendish Laboratory, University of Cambridge, Cambridge, UK

^k KEK, Tsukuba, Japan

^l Hiroshima University, Hiroshima, Japan

^m CERN, Geneva, Switzerland

ⁿ Rutherford Appleton Laboratory, Chilton, UK

^o University of Glasgow, Glasgow, UK

^p University of Liverpool, Liverpool, UK

^q University of Sydney, Sydney, Australia

^r University of Oslo, Oslo, Norway

^s Kyoto University of Education, Kyoto, Japan

^t Okayama Univ., Okayama, Japan

^u University of Sheffield, Sheffield, UK

*Corresponding author. Tel.: +1 408 459 4670; fax: +1 408 459 5777; e-mail: hartmut@scipp.ucsc.edu.

Abstract

Results are reported from a beam test of prototype silicon microstrip detectors and front-end electronics developed for use in the LHC detector ATLAS. The detector assemblies (“modules”) were 12 cm long and were read out with binary electronics. Both irradiated and unirradiated modules were measured in a 1.56 T magnetic field for efficiency, noise occupancy, and position resolution as a function of bias voltage, binary hit threshold, and detector rotation angle with respect to the beam direction. © 1998 Elsevier Science B.V. All rights reserved.

1. Introduction

ATLAS is a large general purpose magnetic spectrometer under development for the CERN Large Hadron Collider (LHC) [1]. Precision tracking is achieved with the Semiconductor Tracker (SCT), which is described in detail in Ref. [2]. Based on a series of previous beam tests and experience with binary readout electronics [3–8], the beam test during the Summer of 1996 in the CERN H8 beam line [9] used detectors and electronics designed to meet the ATLAS specifications [2]. Identical 12 cm long modules of n-on-n detectors with 75 μm pitch and binary electronics both before (module # ATT8) and after irradiation (module # ATT7) were measured. Fig. 1 shows the C – V curve of the irradiated module, indicating a depletion voltage of 290 V. In the operation at the LHC, where beneficial annealing takes place and detrimental reverse annealing is suppressed by cooling, this depletion

voltage is expected after an accumulated fluence in excess of 2×10^{14} p/cm². During the beam test, the modules were operated at -10°C in a 1.56 T magnetic field, and scans of the operating parameters: threshold, bias and orientation relative to the B -field, performed.

2. Bias voltage dependence

In order to determine the operating conditions, bias voltage scans were performed with no applied magnetic field and at zero rotation angle. Both detectors show occupancies below 10^{-3} for thresholds above 0.9 fC. Fig. 2 shows the efficiency of both modules, as a function of bias voltage, for several threshold values close to the nominal operating threshold of 1.0 fC. The un-irradiated detector ATT8 needs, as expected for n-on-n detectors before inversion, a certain amount of over-voltage

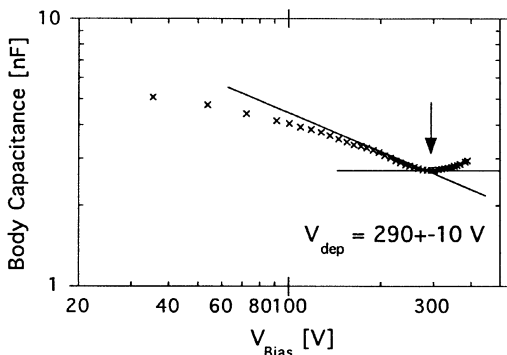


Fig. 1. C – V curve of the irradiated detector. The depletion voltage of 290 V corresponds to a fluence in excess of 2×10^{14} p/cm² after annealing.

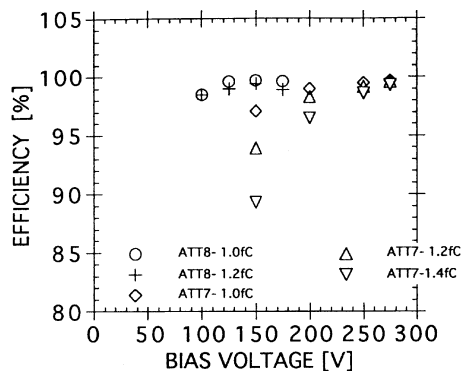


Fig. 2. Efficiency of ATT8 (un-irradiated) and ATT7 (irradiated) as a function of bias voltage, for $V_{\text{th}} = 1.0, 1.2, 1.4$ fC.

beyond the depletion voltage of 70 V. On the other hand, the irradiated detector ATT7 reaches 100% efficiency already at 275 V bias, which is below the depletion voltage, even for 1.4 fC threshold. At lower bias, only a gradual decrease in efficiency is observed. Fig. 2 confirms an effect seen earlier [6,7,9], that at half depletion voltage (150 V), the efficiency of the irradiated detector is above 95% at 1.0 fC threshold. This weak dependence of the n-side efficiency on the bias is the main reason why n-on-n detectors are preferable over p-on-n after severe radiation damage.

3. Efficiency under rotation

For operation in a magnetic field, the orientation of the detectors relative to the beam is important because the Lorentz force tends to spread the collected charge over several strips. Here the strips were parallel to the B -field and the detectors were rotated about the field direction. One expects that the best charge collection and thus efficiency is attained for the case where the detector is rotated by the Lorentz angle, which was $+12^\circ$ for the electrons. Fig. 3 shows the efficiency for a threshold of 1.0 fC for several rotation angles in the magnetic field, with ATT7 biased at 250 V and ATT8 biased at 125 V. The efficiency is uniform as a function of the rotation angle, and the only apparent reduction in efficiency is at -12° rotation. This angle is close to the rotation angle of 27° relative to the Lorentz angle, where all tracks cross three or more strips. It should be noted that both irradiated and un-

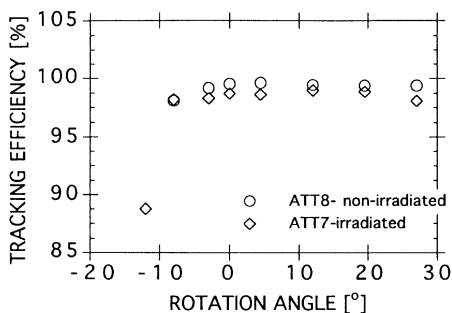


Fig. 3. Efficiency of ATT8 and ATT7 versus angle at 1.0 fC threshold.

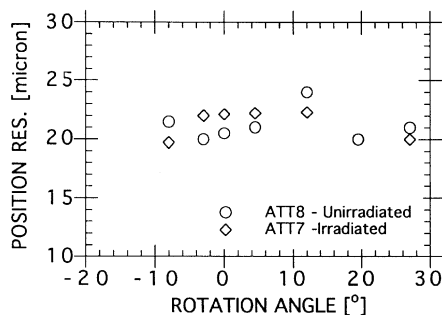


Fig. 4. Position resolution versus angle at 1.0 fC threshold.

irradiated modules show the same efficiency, bearing in mind that they are operated at different bias voltages.

4. Position resolution

In the operation of silicon strip detectors at the LHC, the position resolution could deteriorate due to several reasons: one of them is heavy radiation damage, the other the oblique angle of incidence, simulated here by the rotation in the magnetic field. We compare the position resolution at 1.0 fC threshold of both irradiated and un-irradiated modules in Fig. 4, both as a function of the rotation angle: it is independent of the rotation angle and amounts to about $20 \mu\text{m}$ for both the un-irradiated and irradiated modules, within ATLAS specifications. This value is close to the expected value of $\text{pitch}/\sqrt{12}$, expected for binary readout.

5. Conclusions

Silicon-strip modules for the ATLAS SCT have been tested in a beam under conditions expected for the LHC: radiation damage, magnetic field and tracks with non-normal incidence. When the bias is adjusted for the increased depletion voltage, the irradiated detector shows properties identical to the un-irradiated. This is true for the dependence of the efficiency and position resolution on rotation angle and threshold. In addition, the relatively weak dependence of the efficiency on the bias voltage of the irradiated n-on-n detector was confirmed.

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