Silicon microstrip detector for the HERA Transverse Polarimeter
Radiation damage

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The POL2000 collaboration has proposed that the transverse polarimeter, TPOL, be upgraded by the installation of a position sensitive detector behind a passive pre-radiator in order to calibrate the position response of the TPOL calorimeter precisely [1]. An attractive technological solution is provided by the use of a silicon microstrip detector. The detector must withstand the high flux of photons present at the TPOL. The purpose of this document is to explain why the POL2000 collaboration believes that the performance of the proposed silicon microstrip detector will not be compromised given the radiation dose expected.

1. Requirements for the TPOL position detector

The TPOL calorimeter must measure both the energy and the impact position of the back-scattered Compton photon. The position is measured using the spatial, up-down, asymmetry of the energy deposited in the calorimeter via the $\eta(y)$-transformation [2]. The precision with which the transverse polarisation is determined is directly related to the precision with which the impact point of the Compton photon on the calorimeter is measured. Hence, it is important to determine the $\eta(y)$-transformation in-situ during data taking. In order to achieve the required relative precision on the transverse polarisation a pre-shower detector with an intrinsic position resolution of $\sim 50\,\mu\text{m}$ is required [1]. The position detector will also allow the calorimeter to be centred precisely on the Compton photon beam.

The choice of silicon microstrip detector for TPOL was driven by the following considerations:

1. Cost and time-scale: The limited budget and short time-scale for the provision of the position detector precluded the development of a microstrip detector specifically for TPOL. A search was therefore made for detectors of appropriate pitch for which production runs were being planned and for which delivery at the beginning of 2001 could be guaranteed.

2. Active area and resolution: The TPOL calorimeter has an active area of $\sim 10\times 10\,\text{cm}^2$. It was required that the detector covers a significant fraction of this area and that the position resolution be better than $50\,\mu\text{m}$. A search was therefore made for silicon microstrip detectors with an area of at least $\sim 5\times 5\,\text{cm}^2$ with a strip pitch no greater than $150\,\mu\text{m}$.

The POL2000 group therefore proposes to use an ATLAS, single-sided, silicon microstrip detector with a strip pitch of $80\,\mu\text{m}$ and a sensitive area of $6.2\times 6.2\,\text{cm}^2$ [3]. The detector will be read out using amplifier/multiplexer chip developed for the CMS experiment. The intrinsic position resolution of such a device is $\sim 23\,\mu\text{m}$ if the charge is collected on a single strip. Pulse height information from neighbouring strips can be used to improve the resolution.

2. Radiation environment at the TPOL

In order to estimate the dose received by a silicon detector placed after a lead pre-radiator one radiation length thick a GEANT simulation of the TPOL setup was performed [4]. This simulation used the measured Compton photon spectrum together with

an extrapolation to lower photon energy taking bremsstrahlung photons into account. The photon rate at the detector was determined using measurements made with scintillation counters placed in the Compton beam during running in August 2000. The total rate of photons impinging on the TPOL calorimeter was estimated to be 250 kHz. In one year the detector would therefore be exposed to a total fluence of $\sim 3.6\times10^{13}\ \gamma/\mathrm{cm}^{-2}$ and a dose of ~2 Mrad.

3. Effect of high intensity photon radiation on silicon detectors

The effect of photon radiation on silicon detectors has been studied up to doses of ~500 Mrads [5]. The dose required for full compensation of charge carriers is ~215 Mrads, hence type inversion is not a problem for a silicon detector in front of the TPOL calorimeter.

Photon radiation has been observed to increase the leakage current [5, 6]. A damage coefficient of $3.3\times10^{-7}\ \mathrm{A/cm}^2\,/\,\mathrm{Mrad}$ was reported in [5]. For the $80\,\mu\mathrm{m}$ ATLAS silicon detector proposed here this gives an increase in the leakage current for a strip close to the centre of the Compton beam spot of $3\times10^{-3}\ \mathrm{nA/Mrad/strip}$. Hence, over one year the leakage current would be expected to increase by $6\times10^{-3}\ \mathrm{nA/strip}$. This small increase in leakage current should not cause any problems.

4. Differential radiation damage and possible degradation of detector position resolution

The Compton photon beam is highly collimated. This means that the region over which the silicon detector is exposed to radiation is localised to a small area. The localised radiation damage that results from this irradiation may give rise to systematic biases in the position response of the detector. Such an effect has been observed in silicon detectors exposed to 200 GeV pion beam at a fluence of $2.1\times10^{13}\ \pi/\mathrm{cm}^{-2}$ [7]. Systematic deviations as large as $\sim 8\,\mu\mathrm{m}$ were observed and shown to be due to transverse electric fields generated in the silicon by differential radiation damage. In order to ensure that the linearity of the position detector can be monitored and any non-linearity corrected for, a position calibration system based on a single scintillating fibre has been proposed [3]. A schematic diagram of the apparatus is shown in figure 1. A scintillating fibre of diameter $1\,\mathrm{mm}$ will be moved in steps of $2.5\,\mu\mathrm{m}$ across the face of the silicon detector. It has been shown, using GEANT simulation, that this system gives a calibration of the linearity of the system to better than $20\,\mu\mathrm{m}$ [9]. The Pol2000 group is therefore confident that the position response of the silicon microstrip detector can be corrected for any significant systematic non-linearities which may arise. Nevertheless, it is important to estimate the possible size of systematic non-linearty that may arise.

An estimate of the size of the effect may be obtained by comparing the effective cross sections for photon-nucleus interactions to the effective cross section for pion-nucleus interactions. Taking the cross sections given in reference [9] gives a ration of pion-nucleon to photon-nucleon cross section of $\sim 10^{-4}$ when evaluated with a photon energy of 10 GeV and a pion energy of 200 GeV. The mechanisms of radiation damage differ significantly for photons and pions [10]. Large momentum transfer may result in nuclear recoil. The recoil nucleus may cause damage in several adjacent lattice sites. Low momentum transfer processes give rise to single vacancies or single interstitial atoms. Nuclear recoil is more likely to occur with high energy hadron beams than with ~10 GeV photons and so the damage caused by photons is much more localised than for beams of high energy hadrons. These considerations indicate that intense photon beams are intrinsically less harmful than intense high energy hadron beams.

5. Summary and Conclusions

In order to determine the effect of the photon radiation at the TPOL on the performance of a silicon microstrip detector behind a passive pre-radiator a GEANT simulation of the apparatus was performed [4]. The expected annual dose estimated from the simulation was ~2 Mrads. Measurements of the effect of intense photon radiation on silicon microstrip detectors available in the literature indicate that the performance of the device will not be seriously compromised with the levels of radiation expected at TPOL [5]. The literature does not contain detailed studies of the effect of photon radiation on the resolution of silicon microstrip detectors. However, studies of differential damage due to high-energy hadrons have been made and systematic deviations of the position response at the level of $\sim 8\,\mu$m observed [7]. Given the flux of photons expected at TPOL we expect that the linearity of the position response of the proposed silicon strip detector will not be significantly compromised. In order to ensure that the best possible position resolution can be maintained over the lifetime of the device a position calibration system based on a single scintillating fibre will be implemented [8]. These considerations have lead the POL2000 group to conclude that the proposed silicon microstrip detector will meet the specifications required for a position sensitive detector for TPOL.

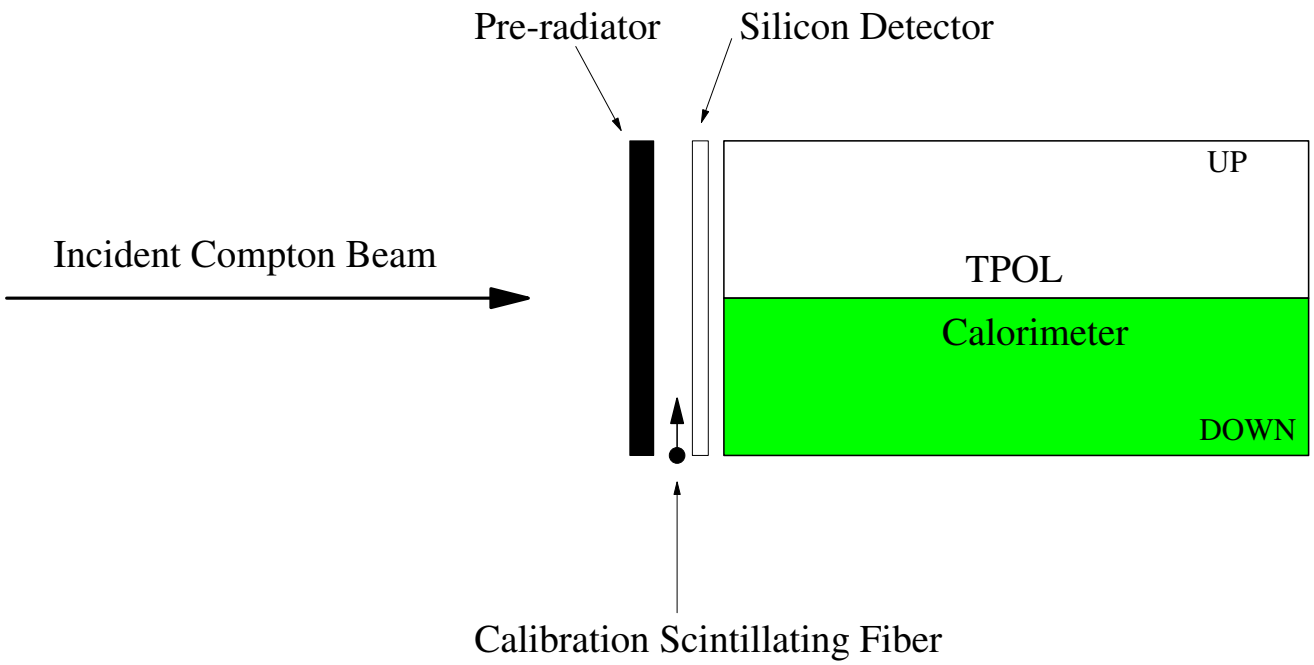

Figure 1: Block diagram of the TPOL calorimeter showing the locations of the proposed silicon microstrip detector, the scintillating fibre which can be moved vertically using a precision stage and which will be used to calibrate the linearity of the silicon detector. The lead pre-radiator is also shown.

References

1. V. Andreev et al., "POL2000: Status and Plans: An appendix to the POL2000 proposal", DESY-PRC-99-05.

2. D.P. Barber et al., "The HERA polarimeter and the first observation of electron spin polarisation at HERA", NIM **A329** 79-111 (1993).

3. ATLAS Inner Detector Technical Design Report, CERN/LHCC/97/17.

4. R. Hamatsu, "Study of radiation dose in the silicon detector of the TPOL polarimeter using GEANT", http://hepmac3.phys.metro-u.ac.jp/StudyOfTPOLDose.html.

5. Z. Li et al., "Study of Bulk Damage in High Resistivity Silicon Detectors Irradiated by High Dose of ^{60}Co γ-Radiation", IEEE Trans. on Nucl. Sci. **44** 834-839 (1997).

6. K. Gill et al., "Radiation damage by neutrons and photons to silicon detectors", NIM **A322** 177-188 (1992).

7. H. Dietl et al., "Radiation damage in silicon strip detectors", NIM **A253** 460-466 (1987).

8. M. Inuzuka, http://www-zeus.desy.de/~inuzuka/pol2000/insitu3.html.

9. D.E. Groom et al., "Particle Data Group: Review of Particle Physics". Euro. Phys. J. **C15**.

10. K. Gill et al., "Bulk damage effects in irradiated silicon detectors due to clustered divacancies", J. Appl. Phys. **82** 1 (1997).