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MONTE CARLO STUDIES OF THE CALORIMETER AND POSITION SENSITIVE DETECTOR OF THE TPOL.

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Results of Monte Carlo studies for the present TPOL calorimeter are presented. The possibility of having a position sensitive detector in front of the calorimeter has also been studied.

1 Introduction

In storage rings electrons become transversely polarized [1]. Compton laser polarimeters [2] utilize the spin dependent cross section for Compton scattering of polarized photons off electrons to measure the degree of electron polarization. The scattering of circularly polarized photons (from a laser) off vertically polarized electrons is asymmetric with respect to the orbital plane of the electrons, and the magnitude of the asymmetry is proportional to the vertical polarization of the electrons.

The TPOL is a polarimeter installed at the HERA electron ring. It is a calorimeter with 12 alternating layers of tungsten and scintillator. Each layer consists of a single absorber plate and two optically decoupled scintillator plates. Conceptually, it can be considered as consisting of two calorimeters, one on top of the other. The scintillation light from each half is collected with wavelength shifters (WLS). Photomultiplier tubes transform the light from the WLS into electrical signals. The split calorimeter allows the reconstruction of the impact point of the backscattered Compton photon with good precision, and thus the reconstruction of the degree of polarization in the machine. In addition wavelenght shifters are glued to the sides of the scintillator plates, thus allowing to read out the sum of the deposited energy in the upper and lower halves of the calorimeter.

2 The calorimeter

2.1 Energy Resolution

The energy resolution of this calorimeter is calculated using the Monte Carlo simulation programm GEANT [3], and is compared[a] to results from a test-beam study. A simplified model was used to describe the collection of light and the associated efficiencies. The following assumptions were made:

- photon yields in scintillator - 1 photon per 100 eV of energy deposit
- quantum efficiency of WLS - 0.4
- light collection efficiency of scintillator and WLS - 0.075
- quantum efficiency of photomultiplier - 0.25.

The yield of photons is described with Poisson Statistics.

In Figure 1 the energy resolution as a function of the energy of the incident particle is shown for data [4] and simulation. Reasonable agreement is observed. The energy resolution of the calorimeter can be described as follows:

$$\frac{\sigma E}{E} = \frac{23.3\%}{\sqrt{E}} + 1.8\%.$$

2.2 Spatial Resolution

The position of the incident photon on the face of the calorimeter is reconstructed from the ratio of energies deposited in the upper and lower halves of the calorimeter.

The measured energy asymmetry η is defined as

$$\eta(y) = \frac{E_u - E_d}{E_u + E_d}$$

where E_u and E_d are the energies deposited in the upper and lower halves of the detector, respectively. The vertical coordinate y of the photon impact point is related to η via a transformation function, which is in general non-linear and a property of the calorimeter. The knowledge of this transformation function is of central importance for the determination of the polarization.

[a] The program was operated with the following switches: LOSS 2, MULS 1, BREM 1, PAIR 1, COMP 1, ANNI 1, PHOT 1. Particles were tracked until their energy dropped below 10 keV.

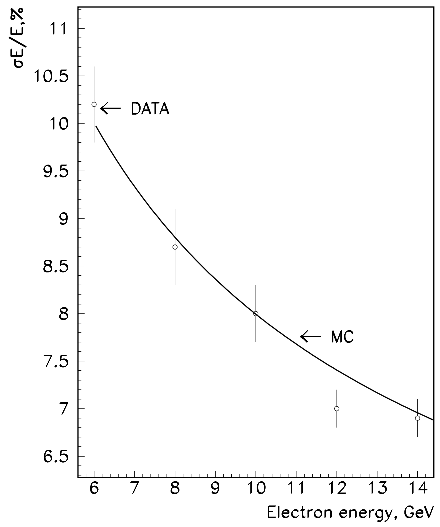

Figure 1: Simulated (solid line) and measured (points with error bars) energy resolution as a function of the incident particle energy, for the TPOL calorimeter.

In Figure 2(a) the $\eta - y$ transformation function is shown. The solid line is the simulated transformation function, the dotted lines indicate the 1σ band of the measured transformation function. Good agreement between the simulation and the data is observed.

In figure 2(b) the vertical position resolution of the calorimeter is shown. Depending on the impact point of the photon it ranges from 800 μm to 1.5 mm. The solid curve shows the result from the simulation. Note that the quoted resolution values do include a contribution from the test beam of 630 μm for particles at this energy. Also included in the simulation is a simple model of the light attenuation in the scintillator as a function of the impact position. This changes the resolution by at most 6 % of its central value.

There are some clear discrepancies between data and simulation once the impact point is more than 2 mm away from the center of the calorimeter. The source of this discrepancy is not yet understood.

For the measurements in the test beam the positions of the particles at the front face of the calorimeter were reconstructed with a Silicon hodoskop,

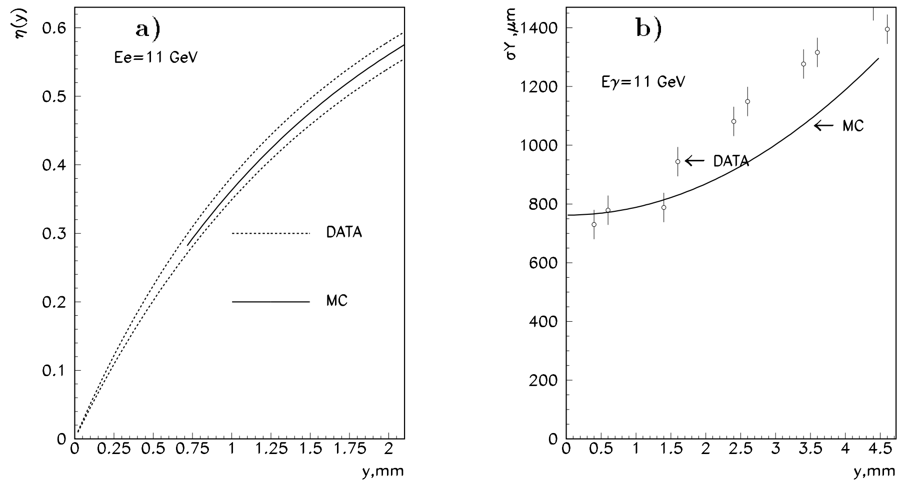

Figure 2: a) Measured (dotted lines) and simulated (solid line) $\eta - y$ calorimeter transformation function, for 11 GeV electrons. b) Spatial resolution of the calorimeter as function of the vertical coordinate y, measured in the test beam (points with error bars) and simulated (solid line).

located some distance in front of the test calorimeter. This allowed the reconstruction of the impact point on the calorimeter front face with a precision of around 600 μm. This number is dominated by multiple scattering. To explore the influence of this uncertainty on the determination of the transformation function its size has been changed in the simulation, varying between 0 and 780 μm. The influence of this change of spatial resolution σ_y on the $\eta - y$ calorimeter transformation function is shown in Figure 3, for three values of σ_y.

3 A Position Sensitive Detector for the TPOL

In the present TPOL the measurement of the impact point of the photon and the measurement of the deposited energy is done by the same device. It might be advantageous for the TPOL to separate these two functions, and to measure the position of the photon impact point separately. There are two different approaches one can take. In the most ambitious scenario these two functions are fully separated, and a high resolution position sensitive detector

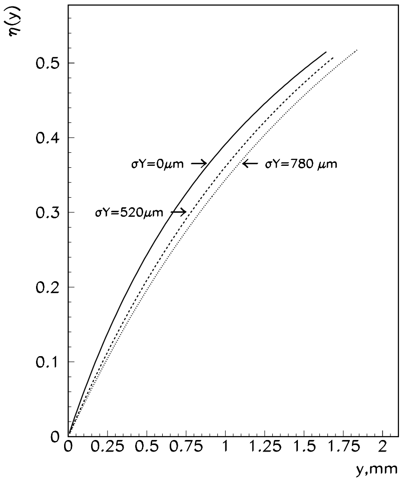

Figure 3: Simulated $\eta - y$ transformation function for three different values of the resolution σ_y, with which the true impact position of the photon on the face of the calorimeter is known.

measures the photon position for every photon incident on the calorimeter. This approach will probably yield theoretically the best results, however it is faced with a number of significant technical problems. Prominent among these is the fact that in order to measure the photon position for every event, the detection efficiency must be very high. This in turn implies that a thick pre-radiator is installed in front of the detector, which degrades the resolution of both the position measurement and the energy measurement.

A less ambitious approach is to use a high precision position sensitive detector to determine independently the $\eta - y$ transformation function of the calorimeter. This function, if it can be measured with adequate precision, can then be used in the calculation of the polarization and help to control and reduce the systematic errors.

The following study is geared towards the second, less ambitious option. The goal is to understand the required performance of such a position sensitive detector.

In contrast to some other polarimeters installed at different machines, the TPOL measures the Compton photon instead of the recoil electron. A posi-

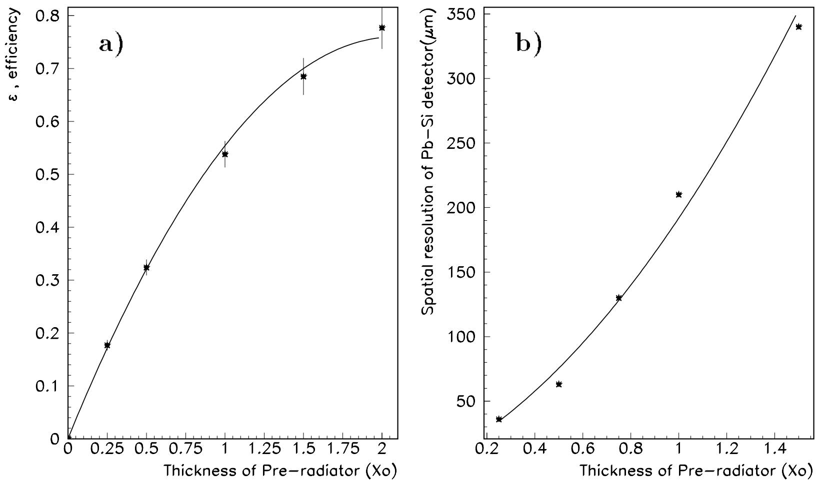

Figure 4: a) Probability with which a 11 GeV photon will convert in a pre-radiator, as a function of pre-radiator thickness in radiation lengths. b) Spatial resolution of a Silicon detector with a strip pitch of 50 μm, mounted behind a pre-radiator, as a function of pre-radiator thickness in radiation length. The energy of the incident photons is 11 GeV.

tion measurement of this Compton photon can only be done after the photon converted into an e^+e^- pair. Therefore a position sensitive detector has to be installed behind a pre-radiator. In Figure 4(a) the fraction of photons for which a conversion occurred is shown as a function of the pre-radiator thickness. Figure 4(b) shows the resolution, which can be obtained from a Silicon detector with a strip pitch of 50 μm, when this device is mounted behind a pre-radiator. It should be noted that no sophisticated clustering algorithm was used for this estimate, so significant improvements in resolution can be expected with more refined analysis techniques.

Figures 4 (a, b) clearly demonstrate that it is feasible to operate a position sensitive device in the photon beam, and to obtain both an acceptable position resolution and an acceptable efficiency.

As discussed above the device can be used to provide in-situ calibration data and to determine the $\eta - y$ transformation with good accuracy simultaneously with the actual data taking. To estimate the precision needed for a sensible calibration an attempt was made to calculate the systematic error due to the knowledge of the $\eta - y$ transformation. From the data taken with the position sensitive detector the parameters of the $\eta - y$ transformation are determined with a certain accuracy. The errors on these parameters are propagated through to the determination of the polarization, under the assumption that the analyzing power of the calorimeter is determined from this $\eta - y$ transformation. This procedure is repeated for different assumed resolutions of the position sensitive device. Its determination is based on a sample of 100000 simulated events.

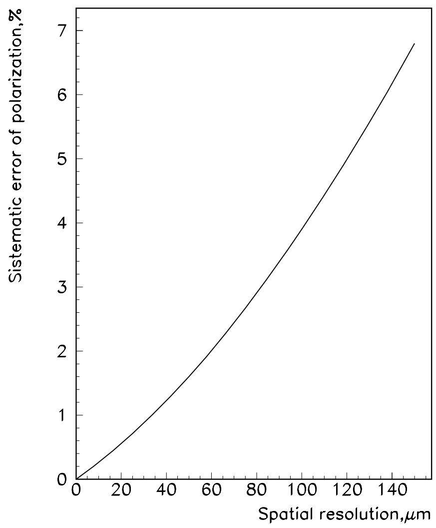

Figure 5: Expected systematic error of the polarization due to the knowledge of the $\eta - y$ transformation, as function of the spatial resolution of a position sensitive detector, used to determine the $\eta - y$ transformation.

In Figure 5 the estimated systematic error of the polarization is shown as a function of the assumed spatial resolution. From this plot and under the assumptions given above one concludes that a device with a spatial resolution of 50 μm is able to determine the $\eta - y$ transformation with a precision sufficient for measuring the polarization with a precision of 1%. It should be pointed out that this estimate does not take into account any additional systematic errors which might be present in the position sensitive detector. In particular any nonlinear effects in the position reconstruction are not contained in this error estimate.

4 Background sources

The position sensitive detector is exposed to several sources of radiation: bremsstrahlung off gas molecules, Compton scattering off thermal photons, and synchrotron radiation. The polarimeter is installed at the HERA electron ring in a specially optimized position. It "sees" a straight beampipe section which is only about 10 m long. In addition at the beginning of the straight section a soft bending magnet is installed, which is producing synchrotron radiation, part of which might hit the detector. In the following an estimate of the rate of the different background sources is attempted.

The planned electron intensity in HERA after the luminosity upgrade is 56 mA. This number was used for the calculation of the intensity of the background photons. The total bremsstrahlung cross-section for photons above 100 keV is 10.3 b. For a vacuum pressure of $1.6 \cdot 10^{-9}$ mbar the average number of bremsstrahlung photons is equal to $3 \cdot 10^{5}$ s^{-1}. The total Compton cross-section [5] is 0.7 b. For a temperature of 350 K [2] the average number of the Compton thermal photons is equal to $8.7 \cdot 10^{8}$ cm^{-3}. For these parameters the average number of Compton scattered photons is equal to $2 \cdot 10^{5}$ s^{-1}.

An electron produces many synchrotron photons in each pass through the detector aperture. With 27.55 GeV electrons the radiation from the weak dipoles (type BC with $\rho = 3215$ m) [2] has a critical energy of 13 keV. For a horizontal size of the position sensitive detector of 4 cm, synchrotron radiation is produced over a length of 4 m. We calculate this source of radiation using GEANT and formulas from Refs. 6 and 7. The photon spectrum of the synchrotron radiation for these parameters is shown in Figure 6(a). Here the dashed line gives the spectrum of the photons after 0.5 X_0 of Tungsten pre-radiator. The energy attenuation with 0.5 X_0 of Lead, Carbon and Tungsten is shown in Figure 6(b). A fraction of these photons is absorbed in the position sensitive detector. For a 300 μm thick Silicon detector, this fraction is about $1.6 \cdot 10^{-2}$ for a photon energy of 65 keV and $3 \cdot 10^{-3}$ for 150 keV. Thus, the Silicon position sensitive detector will have a background hit rate $8 \cdot 10^{7} c^{-1}$ for 65 keV photons and $6 \cdot 10^{6} c^{-1}$ for 150 keV photons.

5 Conclusions

In this note the Monte Carlo simulation of the TPOL calorimeter has been investigated and compared with existing beam-test data. Good agreement is found for the energy resolution and, within limits, for the spatial resolution of

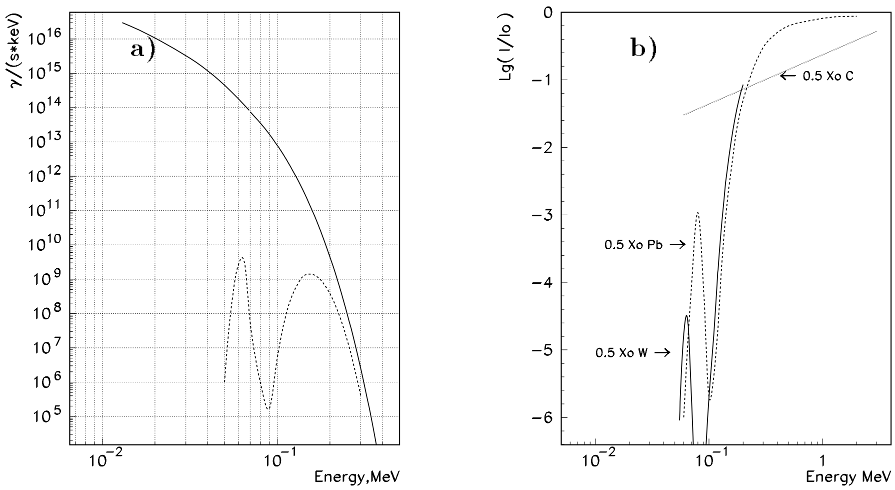

Figure 6: a) Energy spectrum of the synchrotron photons without attenuation (solid line) and after being attenuated by a 0.5 X_0 thick Tungsten pre-radiator (dotted line). b) Attenuation factor for different materials.

the device. This simulation has then been used to determine the characteristic energy-position transformation function of the device. A way has been presented to determine this transformation function using a dedicated position sensitive detector in front of the calorimeter, behind 0.5 radiation length of a pre-radiator. It has been shown that such a detector does allow the determination of the transformation with a sufficient accuracy for measuring the polarization with an error of 1 %. Some estimates are presented for the expected background rates in the position sensitive detector from different beam related sources. They appear to contribute at a level of below 1 % to the observed event rate in the detector, thus do not seem to severely limit the performance of the device. This note does not address the technical feasibility of installing a position sensitive detector at the location of the TPOL, with its related problems of radiation damage etc. This will be addressed in further studies.

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