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Precision measurement with the transverse polarimeter at HERA II

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Abstract. The HERA ep–collider provides a longitudinally polarised positron beam to the three experiments HERMES, H1 and ZEUS. The degree of polarisation is determined with two Compton polarimeters, one measuring the transverse polarisation that naturally builds up in a sufficiently planar ring via the Sokolov–Ternov effect, the other one measuring the longitudinal polarisation between the HERMES spin rotators. The future physics program of the collider experiments requires polarimetry with a precision of better than 1%. To meet this goal, the Transverse Polarimeter has been upgraded in 2001 with a new data acquisition system and a silicon strip detector complementing the main calorimeter. A new analysis, which allows an in–situ calibration in parallel to the polarisation measurement without relying on testbeam results obtained under different conditions, is presented in this paper. The new method uses a fit of the double–differential Compton cross section (folded with detector effects) to the measured two–dimensional spectra in energy and position of the scattered photon. In March 2003, HERA succeeded to deliver up to 50% of longitudinal polarisation to all three experiments as well as collisions for H1 and ZEUS. Some first results of the new analysis on polarised HERA II data are shown.

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1 Introduction

In the HERA storage ring at DESY, Hamburg, the electron (or positron) beam can be tuned such that it becomes transversely polarised via the Sokolov–Ternov effect [1]. After HERA had been upgraded for higher luminosity in 2001 (HERA II), not only the HERMES interaction region, but also those of H1 and ZEUS are surrounded by special chains of magnets rotating the spin of the electrons in order to achieve longitudinal polarisation. The future physics program of the two collider experiments requires polarimetry with a precision of 1% or better, which has never been reached before at HERA.

The degree of polarisation is measured by two polarimeters, both making use of the polarisation dependency of Compton scattering. The Transverse Polarimeter (TPOL) is located near the HERA–B interaction region where the polarisation vector is oriented vertically, and the Longitudinal Polarimeter (LPOL) measures between the HERMES spin rotators, where the polarisation vector is oriented along the beam axis. While the LPOL remained more or less unchanged awaiting a later upgrade, the TPOL has been improved substantially during the luminosity upgrade in order to deliver a polarisation measurement of increased precision not only to HERMES, but also to the H1 and ZEUS experiments.

2 The transverse polarimeter

The TPOL has been in operation since 1992 and although its basic properties have already been described in [2], a brief overview will be given here, including the recent changes to the polarimeter. Light of a continuous wave laser is guided into the HERA tunnel and focussed onto the circulating electron beam. The laser power is chosen such that the probability for a Compton interaction per bunch is about 1/1000. The laser beam is circularly polarised to up to 99.5% by a Pockel's cell. The backscattered Compton photons are detected 65 m downstream, where the dipoles of the next arc section bend the electron beam away from the photons. Since transverse polarisation causes an energy dependent asymmetry of the scattering rate with respect to the direction of the polarisation vector, the TPOL needs to measure the vertical position of each single scattered photon. The main detector is a calorimeter which is segmented in an upper and lower half, giving the photon's energy as the sum of both channels, while the energy asymmetry between upper and lower half is a measure for the vertical position. The exact relationship between position and energy asymmetry (also called "η–y–transformation"), which depends delicately on the transverse shower development in the calorimeter, is a priori unknown and used to be the dominant source of systematic uncertainty. Therefore the calorimeter has been complemented by a silicon strip detector, which is intended to calibrate the position measurement by the calorimeter. A new data acquisition system with a much better linearity of the FADCs, online pedestal subtraction and less noiseallows to measure the polarisation for all 220 bunches separately.

The measurement proceeds as follows. For about 20 seconds, the laser beam is interrupted by a shutter, allowing to measure the background which is dominated by bremsstrahlung. For the next 40 seconds, the shutter is opened and the laser polarisation is switched between the left handed and right handed state with a frequency of 90 Hz. Two-dimensional histograms in the photon's total energy E and energy asymmetry η are accumulated separately for the "laser left", "laser right" and "laser off" states. Since the fast online analysis using the analysing power technique described in [2] is not able to achieve the precision required by the physics program of the collider experiments, a new offline analysis has been developed.

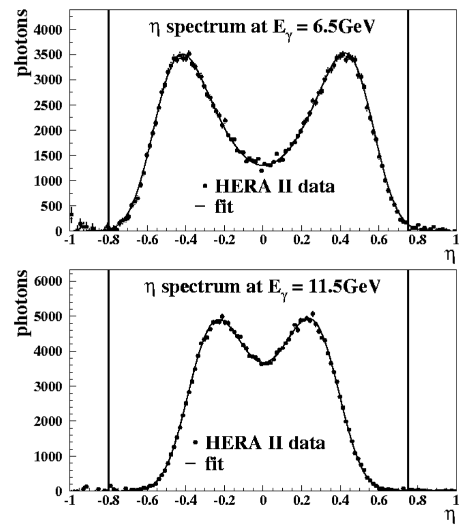

Fig. 1. Calibration fit on HERA II data: two slices in η

3 The offline analysis

For each one–minute measurement cycle the Compton signal is extracted by subtracting the bremsstrahlung background measured when the laser is shut off. After that, the Compton edge in the energy spectrum is used for an absolute energy calibration of the calorimeter. Once the energy scale has been calibrated, the full two–dimesional spectra of η vs E taken with right and left handed circular laser polarisation are fitted by the double–differential cross section for Compton scattering folded with the parametrised effects of the system parameters. The fit proceeds in two steps.

First, the spectra recorded with left and right handed laser polarisation are added. In this sum the effect of the beam polarisation drops out, allowing to perform a calibration fit which is able to determine the up to date values of all relevant system parameters. The calibration fit can be performed in different modi, depending on the number of parameters that are fixed. In the full mode, the fit is allowed to vary all system parameters including those which are expected to change only slowly with time like the η–y–transformation or the energy resolution. The full set of fit parameters comprises the transverse gaussian width of the Compton interaction region, the vertical offset between positron beam axis and center of the calorimeter, the relative miscalibration between the up and down channels of the calorimeter, the five parameters of the η–y–transformation, the energy resolution, the overall normalisation of the histogram, the sum of the linear laser polarisation components of both helicity states and the distance between Compton interaction point and the calorimeter surface.

At first sight it is surprising to see that a fit with 13 parameters actually converges and produces a meaningful result. The first reason that this procedure works is the high statistics that is available. Approximately 2000 η/E bins are used in the fit, each containing on average 300 events. Therefore, approximately 2000 measurements with an accuracy of $1/\sqrt{300} = 6\,\%$ enter the fit. The second reason is that all fit parameters that are used have a unique effect on the shape of the fit function.

In the second step the difference of the same spectra is fitted. In this difference the polarisation independent contribution to the Compton cross–section cancels, while the asymmetry caused by vertical beam polarisation in maximized. The polarisation fit varies only two parameters, namely the difference of linear laser polarisation components of both helicity states and the difference of circular laser polarisation components of both helicity states times the beam polarisation. These parameters can be distinguished easily by the fit, since the corresponding cross section terms are an even function of η (or ϕ) in case of the linear laser polarisation and an odd function in case of the beam polarisation. All other parameters are fixed to their values obtained from (or used in) the calibration fit.

The advantage of this method is that the polarimeter is calibrated in parallel to the actual polarisation measurement. Thus the influence of parameters changing with time is taken into account automatically, whereas a fixed analyzing power is only valid for the conditions under which it was determined.

3.1 Application to data

The new offline fit has been tested on the available HERA II data set and it has been found to describe the data very well. To illustrate its performance, Fig. 1 shows two slices out of a sum spectrum for data of one one–minute cycle (dots with statistical error bars) along with the calibration fit result (full line). The vertical lines indicate the fitted range in η.

The average χ^2/d.o.f. from about 1000 one–minute cycles of a run in March 2003 is 1.02 for the polarisation fits. In case of the calibration fits it is with 1.12 slightly larger, but still very good. Since this slightly higher average χ^2/d.o.f. is not observed in Monte Carlo simulations,

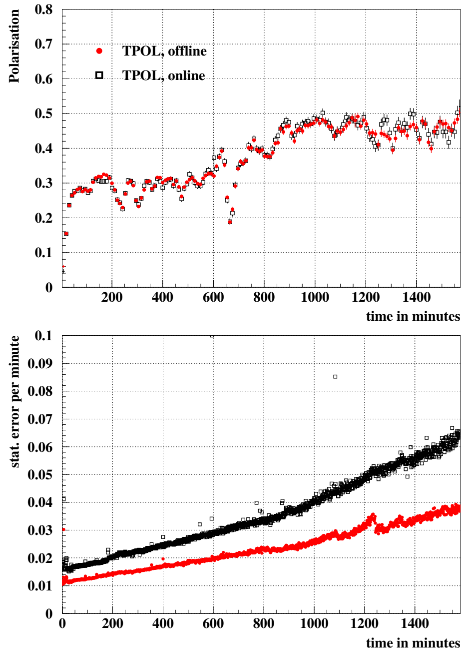

Fig. 2. Polarisation and stat. error as achieved in March 2003

it indicates that the understanding of the polarimeter and thus the precision of the analysis could be improved even further.

The measured polarisation for the same data averaged over five cycles is shown in the upper part of Fig. 2. The online (open squares) and offline analysis (full dots) agree quite well in general, but small differences in both directions can be seen. Note that also the statistical precision is improved by the offline analysis w.r.t. the online method, which is further illustrated by the lower plot. Errors increase with time as the positron current in the ring decreases. Sometimes the Compton luminosity can be increased again by readjusting the laser beam.

3.2 Monte Carlo studies

A number of checks have been performed using Monte Carlo simulations. By varying one of the system parameters and applying online and offline analysis, the influence of each parameter on the beam polarisation measurement can be extracted. As an example of these fits, Fig. 3 shows a simulated polarisation rise over 100 minutes. The dashed line indicates the input values to the simulation, while the full line shows a fit to the values reconstructed by the fit method, which are displayed as black dots with error bars. While the online algorithm shows a significant deviation, the offline fit reproduces the generated values within the statistical error.

4 Summary

With the luminosity upgrade at HERA, a longitudinally polarised lepton beam is provided not only to HERMES, but also to H1 and ZEUS. Since the physics programme

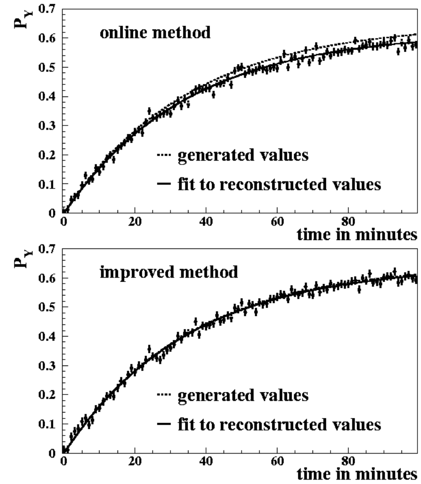

Fig. 3. TPOL analysis upgrade: MC studies comparing online and improved analysis method

of the collider experiments requires a polarisation measurement with a relative precision $\delta P_{\mathrm{Y}}/P_{\mathrm{Y}}$ of 1% or better, the Transverse Polarimeter as been upgraded substancially. Besides a new data acquisition system, and a new silicon strip detector for calibrating the position measurement of the calorimeter, a completely new offline analysis of the calorimeter data has been developed. Its goal is to determine the polarisation without prior assumption on the system parameters, like the η–y–transformation or the beam spot size. This has been achieved by perfoming a fit of the double–differential Compton cross section folded with the detector response to the two–dimensional spectra in energy and position of the scattered photon as by the calorimeter. In a first step, the system parameters are determined from a fit to the sum of the spectra taken with right and left handed circular laser polarisation, in which the effect the beam polarisation cancels. In a second fit to the difference of the same spectra in which the beam polarisation effect is present, all system parameters are fixed to the values found in the first step and only the beam polarisation is varied. The fit has been applied to the data available up to now, especially those taken in March 2003, when HERA delivered up to 50% of longitudinal polarisation to all three experiments after only a few days of tuning. Both the calibration and the polarisation fit describe the data well with an average χ^2/d.o.f. of 1.12 and 1.02, respectively. The performance of the new fit has been studied in detail with Monte Carlo simulations, leading to the preliminary conclusion that the required precision can be achieved. Although these studies have to be repeated with real data, they show that the new analysis presents a substancial improvement in the understanding the polarimeter.

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