Lepton Beam Polarisation at HERA

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Abstract: Longitudinally polarised electron and positron beams enhance the physics potential of the HERA experiments considerably. In this report status and prospects of the production and the measurement of lepton beam polarisation at HERA will be summarised. Polarisation values of 70 % with relative uncertainties of 2 % seem to be feasable and match the requirements for physics measurements. The use of predominantly left and right handed electron beams to measure the polarisation dependence of the charged current cross section, $\sigma(ep \to \nu X)$, is shortly discussed.

1 Introduction

The HERA electron storage ring is operated at a beam energy of 27.5 GeV with typical initial beam currents of 30–40 mA in about 180 bunches. In storage rings electrons become transversely polarised through the emission of synchrotron radiation which is known as the Sokolov-Ternov effect [1]. After the build-up (characteristic time is about 20 minutes at HERA) the polarisation asymptotically settles at an equilibrium value. The degree of polarisation which can be reached is governed by the strength of counteracting depolarising effects which strongly depend on the parameters of the storage ring. The theoretical maximum is 92.4 %. Longitudinal polarisation at an experimental interaction point in a straight section of the ring can then be achieved by the introduction of a pair of spin rotators. This means that the polarisation of the lepton beam is transverse around the ring except at the interaction points equipped with spin rotators. The presence of spin rotators reduces the theoretically achievable polarisation by about 3 % per pair [2]. Since 1994 one pair of spin rotators is installed around the East (HERMES) interaction point. Probably in the HERA shutdown 1997/98 the H1 and ZEUS interaction regions will also be equipped with spin rotators.

2 Measurement and Optimisation of Polarisation

The polarimeter at the HERA electron ring is located in the West Hall and measures the transverse polarisation of the lepton beam [3]. It employs the spin dependent Compton scattering of polarised laser light off the electrons. The most important components are a 10 W continuous argon ion laser and the associated laser beam optics, a calorimeter which measures energy and position of the Compton photons, and a fast data acquisition system. It is the difference in the Compton cross sections for left and right circularly polarised laser light which is exploited for

the electron polarisation measurement. It results in an azimuthal asymmetry of the backscattered photons which also depends on their energy. These quantities are measured with the help of the tungsten-scintillator sandwich calorimeter which is split in an upper and a lower half.

Transverse electron polarisation close to 70 % and longitudinal electron polarisation up to 65 % with one pair of spin rotators installed around the East (HERMES) interaction point has been produced in HERA during special polarisation runs [4, 5]. During 1995 when HERA routinely delivered polarised lepton beams the average asymptotic polarisation value was about 55 %.

With a systematic optimization of machine parameters one can hope to increase the degree of polarisation up to 70 % or even beyond for routine operation. Especially the promising technique of beam-based alignment for the quadrupole magnets has not fully been exploited yet. Since the spin matching procedure for the spin rotators has been proven to work excellently the insertion of two additional pairs of spin rotators for H1 and ZEUS should at most lead to a small decrease — if at all — of the degree of polarisation. Thus a polarisation value of 70 % can be considered a feasable number for physics measurements. This number applies to both electrons and positrons since there are no principal differences for polarisation build-up phenomena.

For typical beam conditions the relative statistical error of the polarisation measurement, $\delta P/P_{\text{stat.}}$, is well below 1 % when averaging the data for e.g. 15 minutes. The most important systematic error is the calibration of the polarisation scale. The assumed polarisation scale which initially was derived from Monte Carlo simulations has been verified within ± 5 % by various cross checks on the data. A direct determination of the polarisation scale is possible by measuring precisely the build-up of the polarisation at the beginning of a fill or after artificial depolarisation. The fitted characteristic rise time then fixes the expected asymptotic polarisation value and therefore the scale [6]. In principal this method is easy to apply. However in order to get meaningful and precise results one needs to have very stable and reproducable conditions for both the HERA machine and the polarimeter itself. Preliminary results from a limited number of rise time measurements suggest that at the moment the polarisation scale is known to ± 3.2 % [7] which leads together with other minor sources to a systematic error $\delta P/P_{\text{syst.}}$ of about 4 %.

Possible improvements on the determination of the polarisation scale are expected with a larger and more consistent set of risetime measurements to be done this year. With partial depolarisation of the beam it will be possible to better control the stability of machine and polarimeter. Further improvements can be done when the HERMES longitudinal polarimeter will be in operation. This polarimeter measures directly the longitudinal beam polarisation at the HERMES interaction point [8] and cross checks between both polarimeters become possible.

Compton polarimeters are also in operation at LEP and at SLC. After some years of operation for physics measurements at SLD the SLC polarimeter group has reached a relative systematic error $\delta P/P_{\text{syst.}}$ of less than 1 % [9]. The CERN group reports a substantially larger uncertainty on the polarisation scale, but no big effort has been made to reduce this value yet. Thus, with the technique of Compton polarimeters it seems possible to measure the beam polarisation of high energetic electron beams to a precision in the order of 1 %.

3 New Longitudinal Polarimeters

For the collider experiments H1 and ZEUS there exists an additional possibility to measure the longitudinal beam polarisation directly at their interaction point [10]: This scheme exploits the fact that bremsstrahlung from longitudinally polarised electrons is circularly polarised, the degree of polarisation depending on the relative energy transfer y from the electron to the photon. The task is to measure the circular polarisation of the bremsstrahlung photons, P_γ^C, and the quantity y. Then the longitudinal electron polarisation P_e^L can be deduced from

$$P_e^L = P_\gamma^C \, \frac{4(1-y)+3y^2}{y(4-y)} \, . \tag{1}$$

For large values of y it follows that $P_e^L \approx P_\gamma^C$. The measurement of P_γ^C is very demanding and involves special crystals for conversion of circular to linear photon polarisation and the subsequent absorption of the photons. The photon absorption depends strongly on the orientation of the crystal axis which must be varied during the measurement. The tagging of high y photons can be done with existing electron detectors close to the beam pipe.

It has been estimated that with this technique a precision of 2 % for the polarisation measurement can be achieved. Therefore this would be a nice cross check for the conventional polarisation measurement of the lepton beam.

4 Limits on Right Handed Charged Current Cross Section

An obvious measurement with polarised lepton beams concerns the polarisation dependence of the cross section for the charged current (CC) reaction, $\sigma(ep \to \nu X)$, which is governed by the exchange of W-bosons. In the standard model it is – for electrons – given by

$$\left.\frac{d^2\sigma}{dxdQ^2}\right|_{CC} = [1-P]\,\frac{G_\mu^2}{2\pi}\left[\frac{M_W^2}{Q^2+M_W^2}\right]^2 \left\{u + c + (1-y)^2\left(\bar{d}+\bar{s}+\bar{b}\right)\right\} . \tag{2}$$

For a definition of the variables refer to [11]. Here we are interested in the polarisation dependent factor $(1-P)$, where P is the degree of longitudinal polarisation and $P=-1$ denotes a fully left handed (i.e. negative helicity) electron beam. Since in the standard model only left handed weak charged currents exist the cross section vanishes for purely right handed electrons ($P=+1$).

A cross section measurement at electron polarisations of $P=-0.7,\ 0,\ +0.7$ could demonstrate the expected polarisation dependence and would give limits for the right handed charged current cross section ($P=+1$). In this study a cross section measurement for $Q^2 > 200\,\mathrm{GeV}^2$ has been assumed with realistic detector acceptance and efficiency values as given in [12]. The possible outcome of such an experiment is given in figure 1. The insert shows the polarisation dependence of the cross section whereas the main plot shows the statistical precision of the extrapolation to the purely right handed charged current cross section at $P=+1$. Depending on the total luminosity and on the distribution to the three different polarisation states the statistical precision for experimental limits on the right handed CC cross section σ_R^{CC} vary between 0.3 % and 1 % of the left handed CC cross section σ_L^{CC}. Including systematic effects

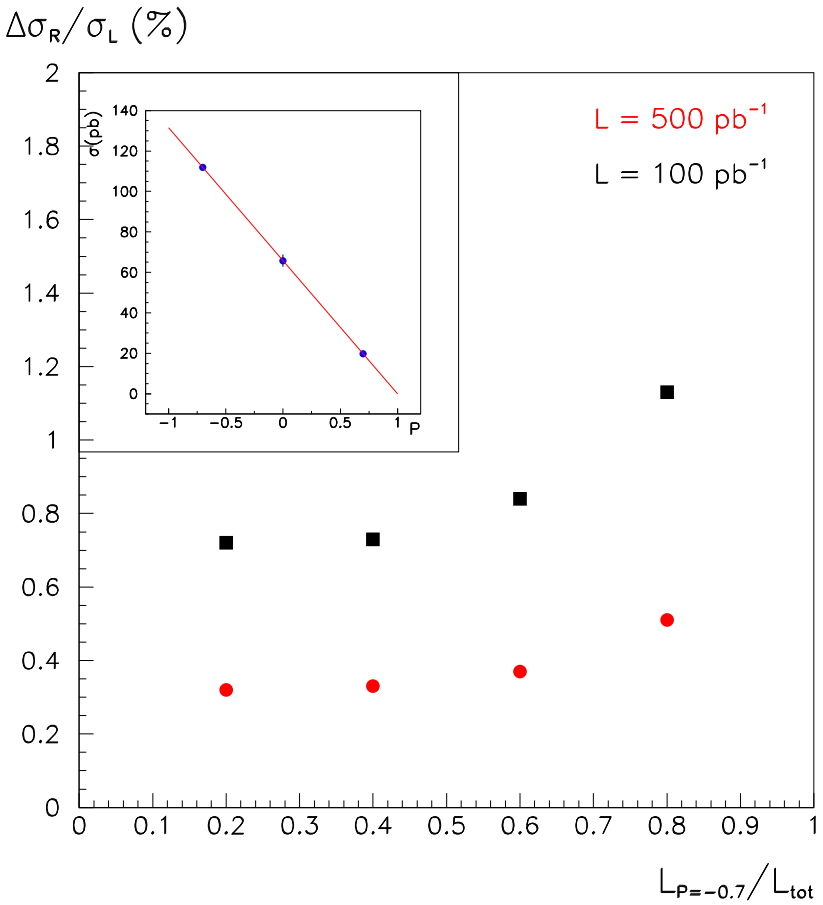

Figure 1: *Limit on the right handed CC cross section normalised to the left handed CC cross section as a function of the luminosity distribution to the different polarisation states ($P = -0.7,\ 0.7$). Shown are the limits based on statistics only for 2 different total luminosities. The insert shows the expected polarisation dependence of the CC cross section.*

(main contributions come from uncertainties in the background substraction for charged current reactions and knowledge of the polarisation scale) these numbers roughly double. At the end a cross section limit of $\sigma_R^{CC}/\sigma_L^{CC} < 0.02$ (95 % C. L.) assuming a total integrated luminosity of 500 pb^{-1} seems to be feasable.

A non-vanishing right handed CC cross section would signal the existence of a right handed W-boson, W_R, and upper limits for the right handed CC cross section can be converted to lower limits on the mass of such a hypothetical right handed W-boson. However these limits heavily depend on the models in which the W_R is incorporated. Some of these models have been already investigated in the Electroweak Working Group of the 1991 HERA Workshop. Rough lower limits for the mass of a hypothetical right handed W-boson of about 300 GeV can be inferred. This is much lower than limits placed recently from $p\bar{p}$ experiments at the Fermilab collider.

5 Conclusion

Currently HERA routinely delivers electron beam polarisation of 50–60 % which can be measured with an uncertainty of $\delta P/P = 4\,\%$. In the course of the year this precision is expected to improve to 2–3 % with the help of more calibration runs and cross checks with the HERMES longitudinal polarimeter. In the long run it may be possible to get close to a 1 % precision

as obtained at SLC. Longitudinal polarimeters for H1 and ZEUS can also be installed using existing luminosity detectors systems. The technique of these devices would be interesting in its own, but also their precision is likely to cope with the more conventional polarimeters. The measurement of the polarisation dependence of the charged current (CC) cross section can be extrapolated to an upper limit for the right handed CC cross section. A cross section limit of $\sigma_R^{CC}/\sigma_L^{CC} < 0.02$ (95 % C. L.) assuming a total integrated luminosity of $500\,\mathrm{pb}^{-1}$ seems to be feasable. Corresponing limits for the mass of a hypothetical right handed W-boson depend on the model considered and are of the order of 300 GeV.

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