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Requirements for the lepton beam polarisation at HERA II

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Abstract

The physics requirements for the lepton beam polarisation and its systematic uncertainty at HERA II are evaluated.

1 Introduction

From 1992 to 2000 (HERA I) the HERA collider experiments accumulated an integrated luminosity of $100 - 150\,\mathrm{pb}^{-1}$. Between 2001 and 2003 the HERA accelerator was upgraded with the objective of providing a fivefold increase in luminosity and longitudinally polarised lepton beams to the collider experiments for the first time (HERA II). The high luminosity running with polarised beams opens up the realm of electroweak physics to the HERA experiments and possible measurements are reviewed below along with other analyses that are expected to benefit from polarised lepton beams. The lepton beam polarisation is measured using two independent polarimeters (LPOL [1] and TPOL [2]) which make use of the spin-dependent cross section for Compton scattering of photons off leptons. During HERA I running the polarisation ($\mathcal{P}$) was measured with a precision of $\delta\mathcal{P}/\mathcal{P} = 1.6\%$ by the LPOL [1] and $\delta\mathcal{P}/\mathcal{P} = 3.4\%$ by the TPOL [3] at average polarisation values of 0.55. In the meantime both polarimeters have been upgraded. The TPOL to provide a more precise and per bunch measurement by installing position sensitive detectors and improving the DAQ system [4] and the LPOL to provide a fast measurement for accelerator tuning purposes [5].

Previous studies of the HERA II physics program with polarised lepton beams have condsidered the case of an integrated luminosity of $1\,\mathrm{fb}^{-1}$ and lepton beam polarisation of ± 0.7 with a fractional uncertainty of $\delta\mathcal{P}/\mathcal{P} = 1\%$ [6]. In this note we reconsider the impact of the beam polarisation value and its systematic uncertainty given the running experience from HERA II in 2003 and 2004. Finally, we suggest optimum fractions of data that should be collected with positively and negatively polarised lepton beams.

2 HERA II luminosity projections

The projections for the total integrated luminosity delivered by HERA from 2003 to mid 2007 are between about 700 and $800\,\mathrm{pb}^{-1}$ [7]. The range in values originates from different possible running scenarios with different fractions of electron-proton and positron-proton collisions (see Table 1). The plan currently being followed predicts an electron-proton luminosity of $300\,\mathrm{pb}^{-1}$ and a positron-proton luminosity of $390\,\mathrm{pb}^{-1}$. During HERA II running to date, an average positron beam polarisation of 0.35 with peak values of around 0.5 has been achieved with an uncertainty similar to that achieved in HERA I running [8, 9].

3 Charged current deep inelastic scattering

The cross section for charged current (CC) deep inelastic scattering (DIS) depends linearly on the longitudinal polarisation of the lepton beam. Since the Standard Model (SM) does not predict right-handed charged currents, the cross section for electron(positron)-proton charged current deep inelastic scattering is predicted to be zero at polarisation of +1(-1). Measuring the total cross section as a function of polarisation allows the Standard Model to be tested through searches for right-handed charged currents and limits on the cross section for right-handed W-boson exchange may be set.

Previous ZEUS measurements of the total cross section for charged current deep inelastic scattering have yielded systematic uncertainties of around 1.5-2.5% [10, 11]. These uncertainties excluded the uncertainty of 1.8-2.5% due to the luminosity measurement.

Assuming positron-proton data with positive and negative polarisation samples of integrated luminosity of 200 pb^{-1} each, the uncertainty on the cross section extrapolated to a polarisation of -1, as a function of polarisation is shown in Fig. 1. It can be seen that the highest possible polarisation is necessary for the best possible test of the Standard Model. For the expected HERA II polarisation of 0.5, the uncertainty on the cross section for $\mathcal{P} = -1$ is insensitive to the polarisation uncertainty below a fractional uncertainty of 2% and there is only a small sensitivity for a fractional polarisation uncertainity of 4%.

The results of another study considering positron-proton and electron-proton data samples with positive and negative polarisations of 0.5 and luminosities of $300\,\text{pb}^{-1}$ and $400\,\text{pb}^{-1}$ for electron-proton and positron proton collisions, repectively, are shown in Fig. 2. The figure shows the statistical uncertainty extrapolated to polarisations of +1 and -1 for electron and positron beams, respectively, as a function of the fraction of data taken with a negatively polarised beam. It can be seen that positron-proton collisions provide the better uncertainty and this is largely insensitive to the fractions of data taken with positively and negatively polarised beams.

In addition to the measurements of polarisation dependence, charged current DIS data is an important input to QCD analyses of proton structure. This is of particular relevance at high x in positron-proton collisions where the charged current process probes the d-quark density in the proton. Since NC DIS is dominated at high x by the u-quark density and fixed-target data suffers from large uncertainties from heavy target corrections, the HERA II charged current data are especially valuable. Given that the electroweak studies are insensitive to the fractions of data taken with positively and negatively polarised beams, there is the opportunity to tune this fraction to give the best possible determination of the proton structure functions. Figure 3 shows the ratio of the statistical uncertainty on the charged current positron-proton cross section measurement for varying fractions of data taken with negatively polarised beams compared to the uncertainty for equal samples, for different beam polarisations. It can be seen that at the expected polarisation values of ± 0.5 the improvement in the statistical uncertainty is up to 20%. Another aspect of using the polarised measurements in QCD analyses is the normalisation uncertainty introduced by the uncertainty in the measured polarisation. The effect of this is shown in Fig. 4 where the quantity $\delta\mathcal{P}/(1+\mathcal{P})$ is shown as a function of polarisation for different values of the polarisation uncertainty. This gives the normalisation uncertainty for a single measurement of the positron-proton CC DIS cross section. It can be seen that for $\mathcal{P} = -0.5$ with an uncertainty of $\delta\mathcal{P}/\mathcal{P} = 2\%$ this introduces a normalisation uncertainty of 2%, which is similar to the normalisation uncertainty from the luminosity measurement.

In summary the charged current electroweak measurements benefit from the highest possible polarisation and are insensitive to the polarisation uncertainty (for a maximum longitudinal polarisation of ± 0.5) and the fractions of data taken with positively and negatively polarised beams. QCD studies show that careful choice of the fractions of positively and negatively polarised data can give only a modest improvement in the statistical uncertainty and a fractional polarisation uncertainty of 2% results in an acceptable normalisation uncertainty for the cross sections.

4 Neutral current deep inelastic scattering

Neutral current (NC) deep inelastic scattering proceeds through the exchange of a photon or a Z^0 boson. Only massive boson exchange is sensitive to the longitudinal polarisation of the incoming lepton beam in collisions with unpolarised protons, therefore only the Z^0 and $Z^0-\gamma$ interference terms in the cross section for NC DIS exhibit polarisation dependence. Such terms are suppressed relative to the photon exchange cross section by the ratio of the propagators. Conseqently Z^0 exchange only makes a significant contribution to the cross section at very high Q^2. The cross section for NC DIS at high Q^2 is small, which leads to a large statistical uncertainty in the measurements in this region. The statistical uncertainty dominates the systematic uncertainties from the polarisation measurement and the luminosity measurement. Figure 5 illustrates this showing the reduced cross section for NC DIS at $x = 0.25$ as a function of Q^2 for all four beam charge-polarisation combinations. It can clearly be seen that the statistical uncertainty of the data dominates the uncertainty from the polarisation measurement.

Previous studies have shown that an equal sharing of the total luminosity between electron, positron and negatively polarised and positvely polarised beams is optimal for NC electroweak studies [12].

5 Searches

Longitudinally polarised lepton beams offer extra sensitivity for some searches for physics beyond the Standard Model since chiral couplings are often involved in the production of new particles. For example models which predict heavy excited leptons require chiral couplings between ordinary left(right)-handed and excited right(left)-handed (anti)leptons. In addition, for excited neutrinos, where W-boson exchange is predicted, extra sensitivity can be gained using polarised lepton beams in the same way as the Standard Model cross section for charged current. Likewise for squark production in R-parity violating SUSY models only left(right)-handed electrons(positrons) contribute, so polarised lepton beams will give increased sensitivity in these searches. Conversely for generic leptoquarks, chiral states with couplings to left or right-handed leptons are possible. In this case different lepton beam polarisations will allow a selective increase in sensitivity for different leptoquark types.

Since these effects are searched for at the smallest distance scales and the highest masses the numbers of events measured are typically very small, and the background from SM processes is likewise small. Therefore the uncertainties are dominated by the statistical uncertainty of the data in the HERA II running scenarios and the effect of increased precision in the polarisation measurement is negligible. Some searches benefit from an equal sharing of data taken with positively and negatively polarised beams, while others will benefit from running with the polarisation that gives the highest cross sections possible to a similar extent that the charged current measurements benefit.

6 Deeply virtual Compton scattering

Longitudinally polarised lepton beams allow the measurement of extra observables in deeply virtual Compton scattering (DVCS), the diffractive production of a real photon in NC DIS. The interference terms between the Bethe-Heitler (BH) and DVCS amplitudes give rise to a beam-spin asymmetry which can be measured with polarised lepton beams. The asymmetry can be measured by considering the ratio of events from positively and negatively polarised lepton beams as a function of the angle between the real photon production plane and the lepton scattering plane. Low-Q^2 measurements of the kinematically integrated asymmetry (A_{LU}) have determined the magnitude to be $\sim \mp 0.2$ for $e^{\pm}$ beams [13] and simulations suggest similar values for the HERA collider kinematic region [14]. Figure 6 shows the statistical uncertainty expected on A_{LU} assuming a DVCS+BH cross section of 30 pb. The statistical uncertainty is plotted as a function of the integrated luminosity per beam charge-polarisation combination. Systematic uncertainties from other sources and the uncertainty in the measured luminosity are expected to cancel in the asymmetry ratio, assuming possible time dependencies for different polarisation states can be controlled. Figure 7 shows the degree to which time dependent efficiencies can produce a false asymmetry and illustrates that a precise control of such effects is essential. The highest possible polarisation value is desirable keeping in mind the goal of double differential asymmetry measurements. The systematic uncertainty of the beam polarisation enters as the main normalisation uncertainty, and hence should be minimised. Balanced samples of electron and positron collisions with positively and negatively longitudinally polarised beams are optimum.

7 Conclusion

A measurement precision of $\delta\mathcal{P}/\mathcal{P} = 2\%$ for a maximum longitudinal polarisation of ± 0.5, given the projected integrated luminosity for HERA II running, is sufficient for the physics goals outlined. There is no significant advantage to be gained by collecting unequal amounts of data with positively and negatively polarised beams.

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References

[1] M. Beckermann et al., Nucl. Inst. Meth. **A 479**, 334 (2002).

[2] D.P. Barber et al., Nucl. Inst. Meth. **A 329**, 79 (1993).

[3] HERMES Coll., A. Airapetian et al., Phys. Lett. **B 442**, 484 (1998).

[4] J. Böhme, Eur. Phys. J. **C 33**, S1067 (2004).

[5] F. Zomer, *A high power Fabry-Perot resonator for precision Compton Polarimetry with the longitudinally polarised lepton beams at HERA*. Habilitation Thesis, Universite de Paris-Sud, Report LAL 03-12, 2003.

[6] *Future Physics at HERA Volumes I and II*, ed. G. Ingelman, A. De Roeck, R. Klanner, 1996.

[7] F. Willeke, *Presented at the XII International Workshop on Deep Inelastic Scattering, DIS 2004, 14 - 18 April 2004*. Strbske Pleso, High Tatras, Slovakia. (2004).

[8] A. Airapetian et al., *Data Quality of LPOL Measurements* (unpublished). 2004.

[9] F. Corriveau et al., *A Calibration of the HERA Transverse Polarimeter for the 2003/2004 Data* (unpublished). 2004.

[10] ZEUS Coll., S. Chekanov et al., Phys. Lett. **B 539**, 197 (2002). Erratum in Phys. Lett. **B 552**, 308 (2003).

[11] ZEUS Coll., S. Chekanov et al., Eur. Phys. J. **C 32**, 1 (2003).

[12] R.J. Cashmore et al., *Proc. the Workshop on Future Physics at HERA*, G. Ingelman, A. De Roeck and R. Klanner (eds.), Vol. 1, p. 163. DESY, Hamburg, Germany (1996).

[13] HERMES Coll., A. Airapetian et al., Phys. Rev. Lett. **87**, 182001 (2001).

[14] A. Freund, Phys. Rev. **D68**, 096006 (2003).

Running scenario	1	2	3	4
Jan - Aug 2004	e^+p	e^+p	e^+p	e^+p
Oct - Dec 2004	e^+p	e^+p	e^-p	e^+p
Jan - Aug 2005	e^+p	e^+p	e^-p	e^-p
Oct - Dec 2005	e^-p	e^-p	e^-p	e^-p
Jan - Aug 2006	e^-p	e^-p	e^-p	e^-p
Oct - Dec 2006	e^+p	e^-p	e^+p	e^+p
Jan - Aug 2007	e^+p	e^-p	e^+p	e^+p
Total e^-p luminosity (pb^{-1})	190	400	300	280
Total e^+p luminosity (pb^{-1})	590	280	390	420
Total luminosity (pb^{-1})	780	680	690	700

Table 1: *HERA II running scenarios.*

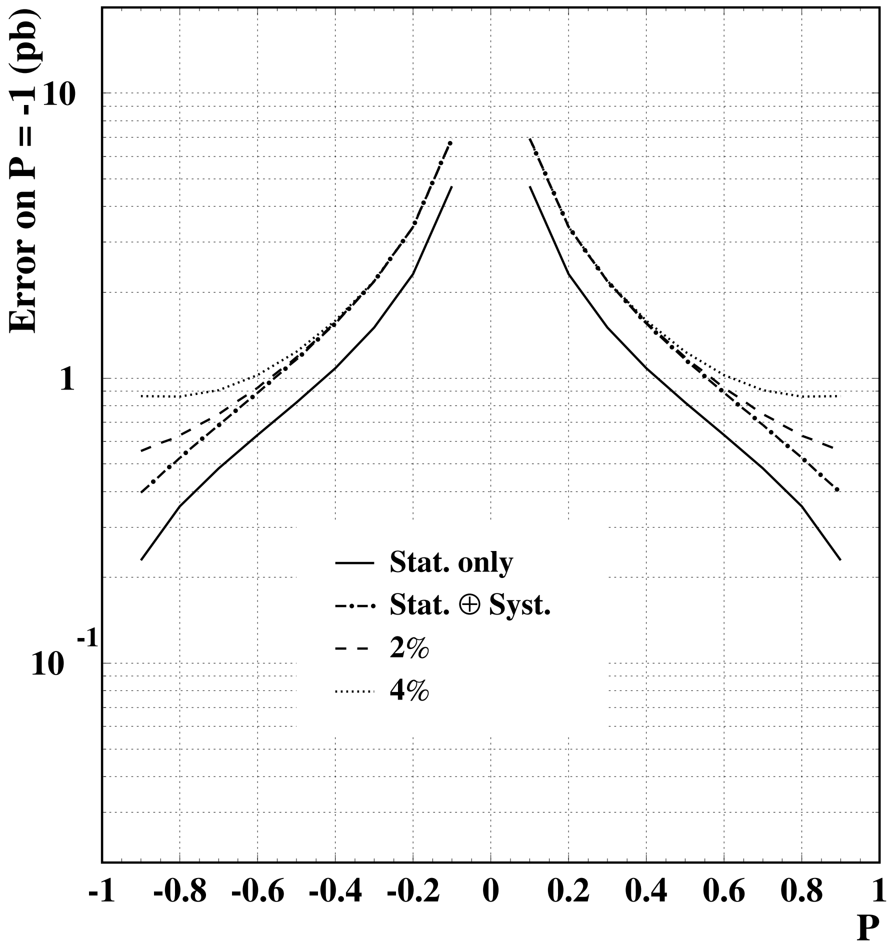

Figure 1: *Extrapolated e^+p charged current cross section uncertainty as a function of longitudinal polarisation. The full line shows the extrpolated uncertainty that may be obtained for statistical uncertainty only, the dot-dashed line for statistical and systematic uncertainies (excluding the uncertainty on the measured polarisation) and the dashed and dotted lines show the extrapolated uncertainties that may be obtained for fractional uncertainities of 2% and 4%, respectively, on the measured polarisation.*

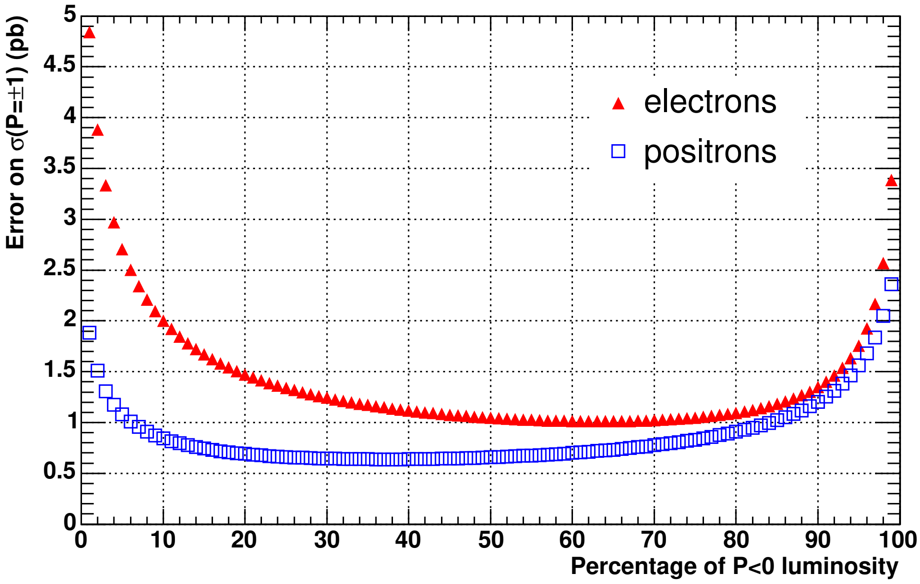

Figure 2: *Extrapolated cross section uncertainty as a function of the percentage of data taken with negatively polarised lepton beams.*

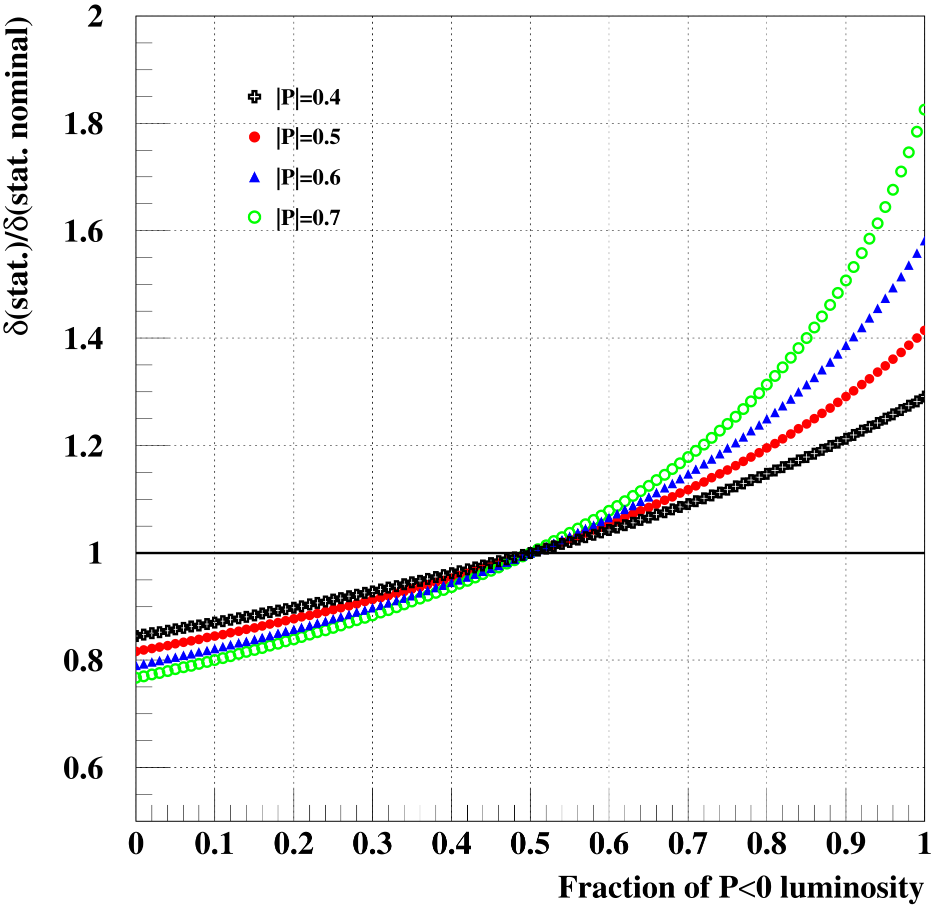

Figure 3: *Relative statistical uncertainty in the e^+p charged current DIS cross section as a function of the fraction of data taken with a negatively polarised positron beam.*

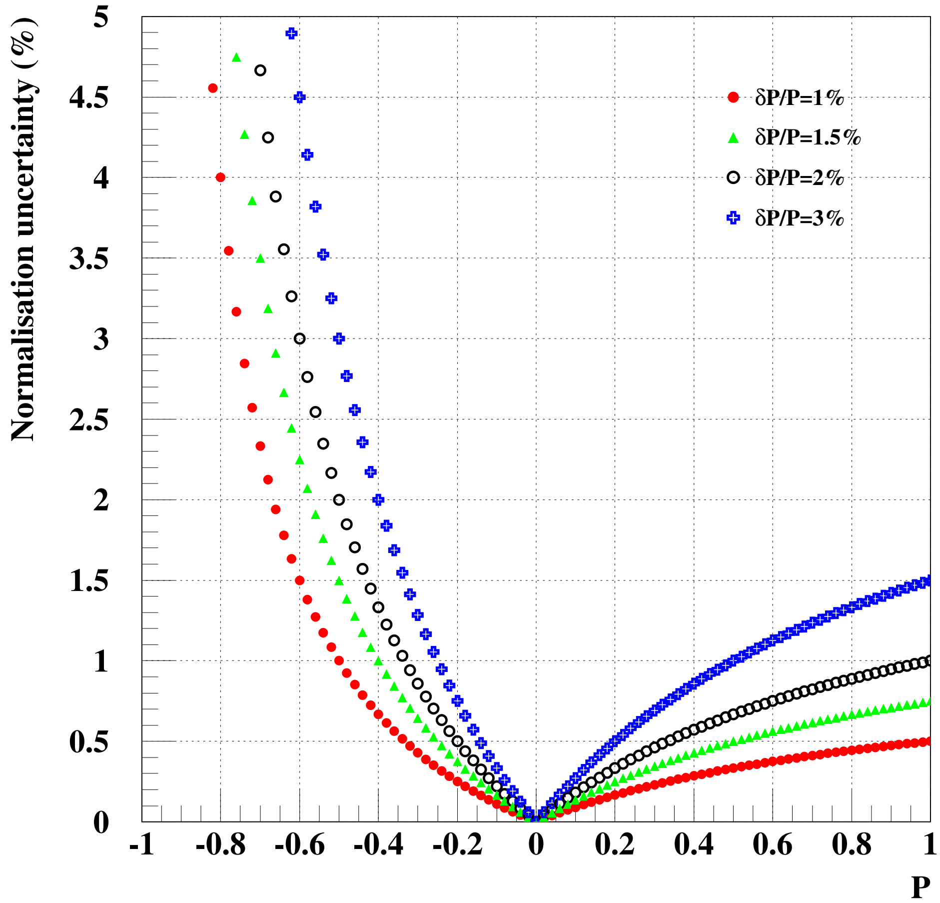

Figure 4: *Normalisation uncertainty introduced in the e^+p charged current DIS cross section by the polarisation uncertainty.*

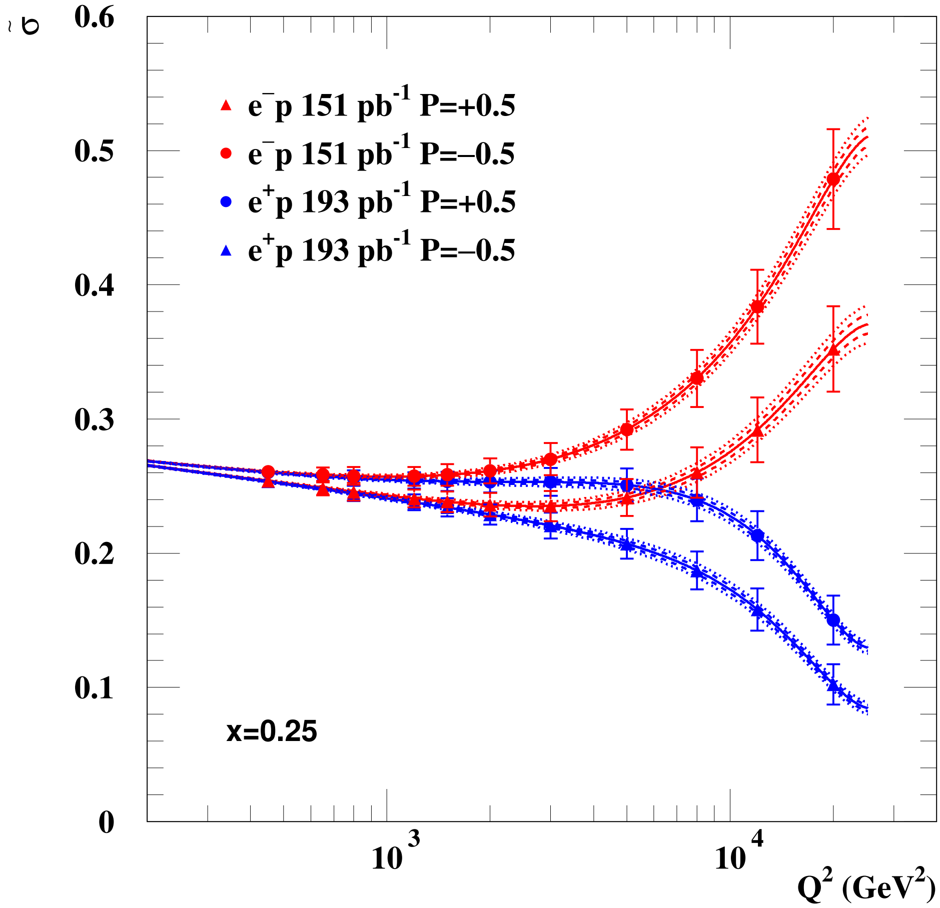

Figure 5: *Simulated neutral current reduced cross section points with the sensitivity to the measured polarisation shown. The error bars show the expected statistical uncertainty from HERA II running. The full lines show the prediction for polarisations of ± 0.5 and dotted and dashed lines show a variation in the polarisation of $\delta\mathcal{P}/\mathcal{P}$=10% and 20%, respectively.*

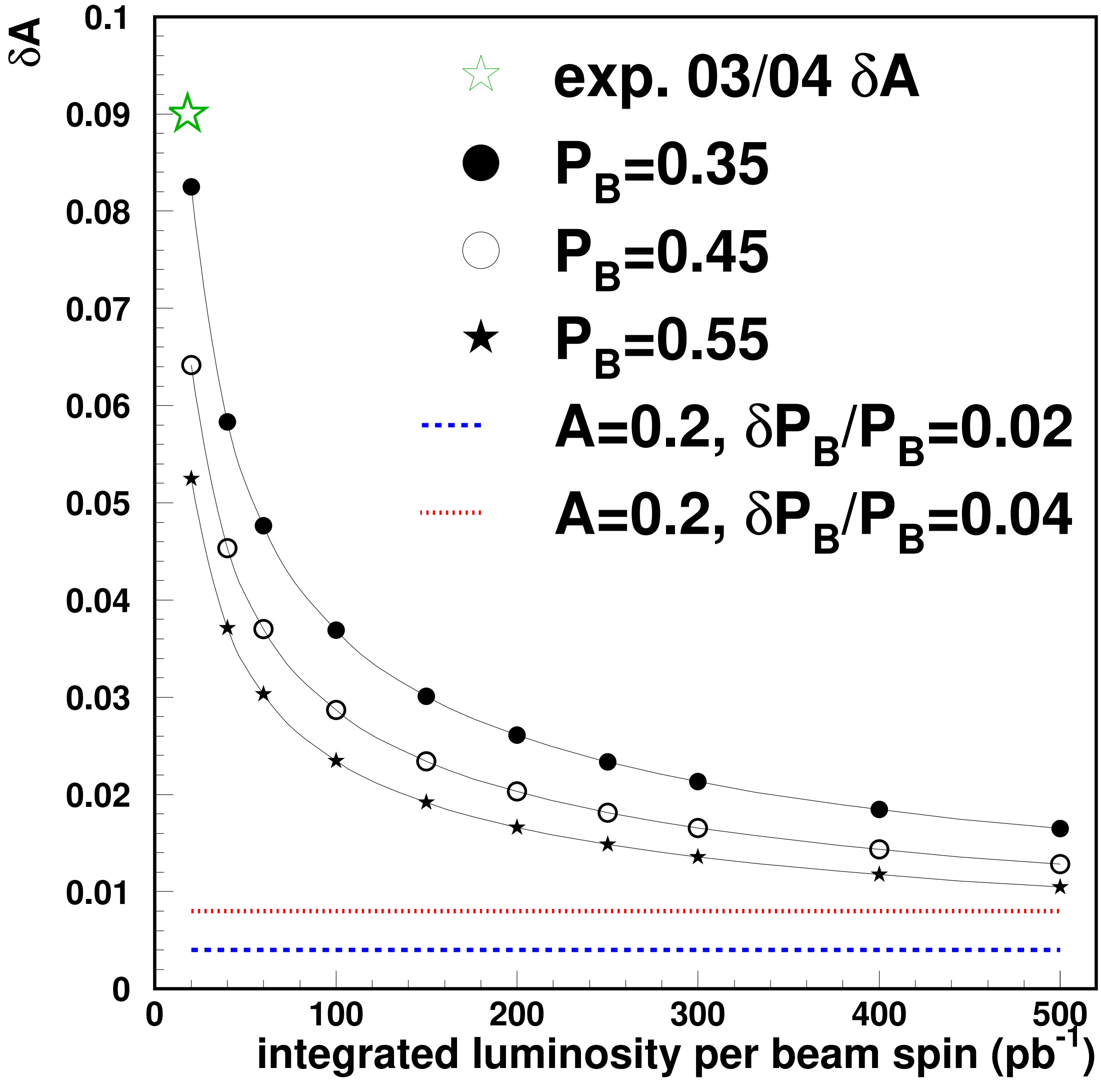

Figure 6: *Statistical uncertainty on the DVCS beam-spin asymmetry. The filled and open circles and stars show the expected uncertainty for different lepton beam polarisations and the dotted and dashed lines show the contribution to the uncertainty for fractional polarisation uncertainties of 2% and 4%, assuming an asymmetry of 0.2.*

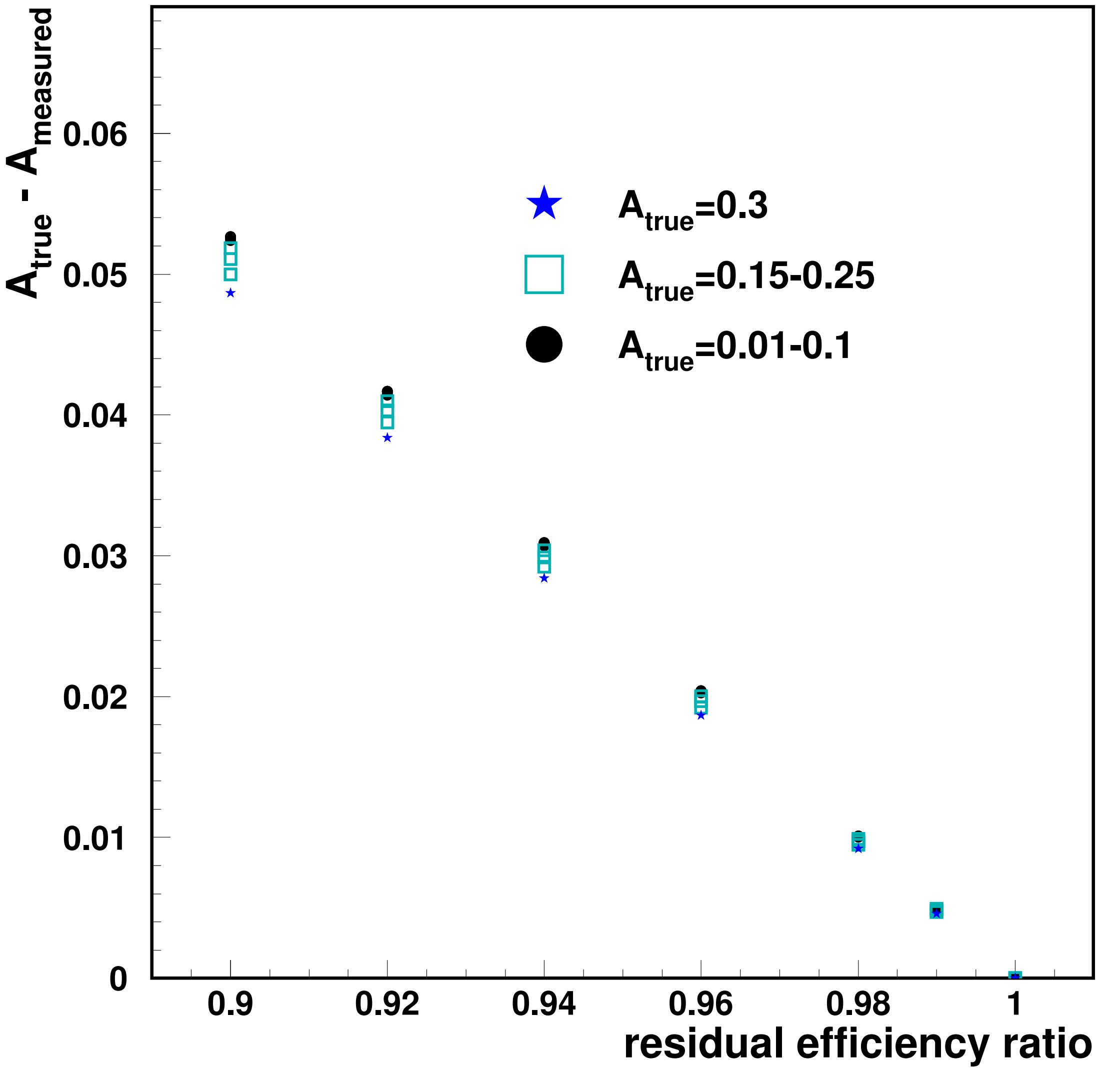

Figure 7: *The difference between the true and measured asymmetry is shown as a function of the residual i.e. non-canceling fraction of the efficiencies, for different values of the true asymmetry. This represents the false asymmetry that may be introduced by limited understanding of time or beam spin dependent effects.*