Stefan Schmitt

Physics requirements on polarization measurements for ZEUS and H1

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Introduction

Why have a longitudinally polarized lepton beams for H1 and ZEUS?

- The couplings to the W and Z boson are different for left and right-handed fermions.

  $\rightarrow$ probe the electroweak interactions of the standard model separately with left and right-handed leptons.

  $\rightarrow$ new physics might also have a chiral structure

Experimentally polarization plays a similar role as luminosity: it enters as a kind of normalization factor

The uncertainty of the luminosity measurement $\Delta\mathcal{L} \approx 1\%$ already is an important contribution to many cross section measurements.

$\rightarrow$ H1 and ZEUS need $\Delta\mathcal{P} \approx 1\%$ for precision electroweak tests.

Charged current cross section

$$\underbrace{\left(\frac{d^2\sigma}{dxdQ^2}\right)_{\mathrm{CC}}}_{\text{prop. to } \frac{N}{\mathcal{L}_{\mathrm{int}}}} = \underbrace{(1 \pm \mathcal{P})}_{e^\pm \text{ polarisation}} \left(\frac{d^2\sigma}{dxdQ^2}\right)_{\mathrm{CC},\,\mathcal{P}=0}$$

- **Significantly enhanced charged current cross section for $\mathcal{P} = +0.6$ (e^+ beam) and $\mathcal{P} = -0.6$ (e^- beam)**

  $\rightarrow$ **Measure couplings and mass of the W boson**

- **Significantly reduced charged current cross section for $\mathcal{P} = -0.6$ (e^+ beam) and $\mathcal{P} = +0.6$ (e^- beam)**

  $\rightarrow$ **New physics with right-handed couplings**

Impact of $\Delta\mathcal{P}$ on the measurement of the SM charged current cross section

Assume the sign of $\mathcal{P}$ is chosen such that σ^{CC} is maximized.

Where are the contributions to the systematic uncertainties from the integrated luminosity $\mathcal{L}_{\mathrm{int}}$ and the polarization $\mathcal{P}$ of equal size?

$$\Delta\mathcal{P} = (1 + |\mathcal{P}|) \times \frac{\Delta\mathcal{L}_{\mathrm{int}}}{\mathcal{L}_{\mathrm{int}}}$$

Example: left-handed electrons, $\mathcal{P} = -0.6$ and 1% relative accuracy on $\mathcal{L}_{\mathrm{int}}$

$\rightarrow$ $\mathcal{P}$ needs a precision $\Delta\mathcal{P} = 0.016$

$\rightarrow$ For this case (SM CC cross section) the proposed accuracy $\Delta\mathcal{P} \approx 0.01$ seems to be sufficient.

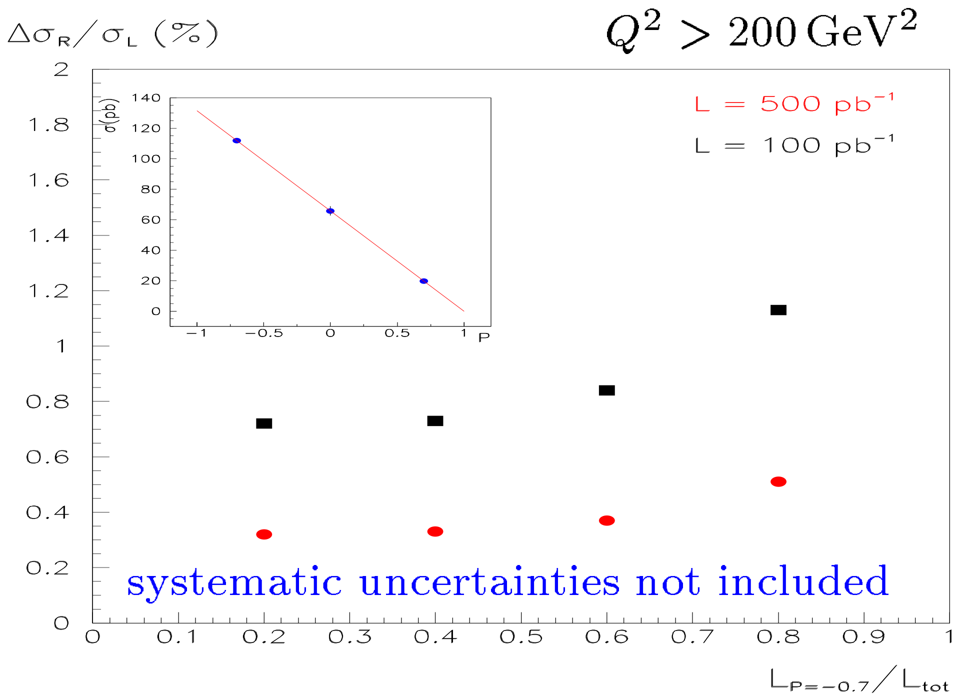
Limits on right-handed charged currents

Cross section for e^- beam

$$\sigma^{\rm CC} = (1-\mathcal{P})\sigma_{\rm L}^{\rm CC} + (1+\mathcal{P})\sigma_{\rm R}^{\rm CC}$$

(Reverse sign of $\mathcal{P}$ for e^+)

Measure σ^{cc} as a function of $\mathcal{P}$ and extrapolate to $\mathcal{P} = +1$.



Best measurements of $\boldsymbol{\sigma_{\rm R}^{\rm CC}}$ with high luminosity at $\boldsymbol{\mathcal{P} = +0.7}$ ($\boldsymbol{e^-}$ case)

Systematic uncertainties on $\sigma_{\mathrm{R}}^{\mathrm{CC}}$ from $\mathcal{P}$

Assume two points with polarization $\pm\mathcal{P}$ are measured

$$\frac{\Delta\sigma_{\mathrm{R}}}{\sigma_{\mathrm{L}}} \approx \frac{1+|\mathcal{P}|}{2|\mathcal{P}|}\,\Delta\mathcal{P}$$

Assume $|\mathcal{P}| = 0.6$, $\Delta\mathcal{P} = 0.15$:

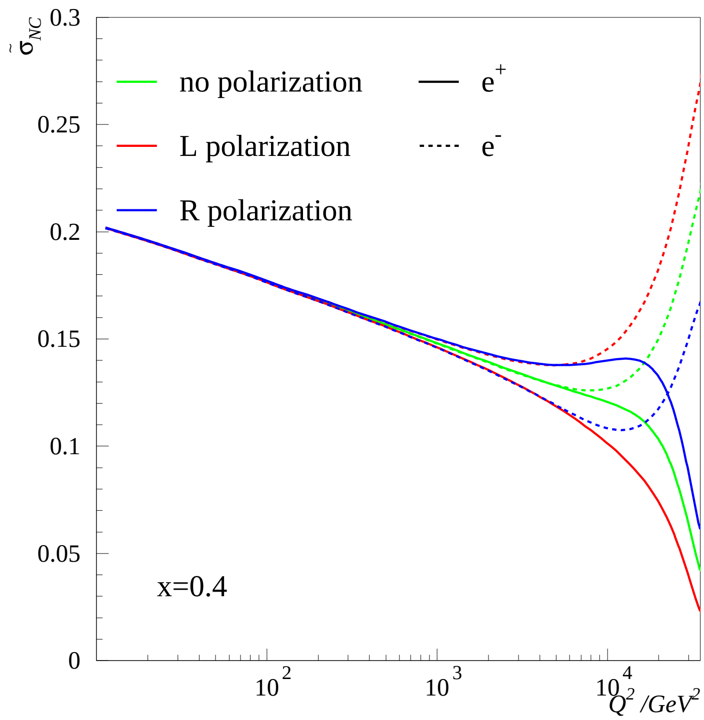
$$\boldsymbol{\frac{\Delta\sigma_{\mathrm{R}}}{\sigma_{\mathrm{L}}} = 2\%}$$

→ **Important source of systematic error.**

→ **Precise measurements of $\mathcal{P}$ are important for this measurement**

Note: limits on m_{W_R} from this measurement could be in the order of 300 GeV (model-dependent). Complementary to direct searches for heavy neutrinos.

Neutral current cross section



$x = 0.4$	$\frac{d^2\sigma}{dxdQ^2}(\mathrm{L}) / \frac{d^2\sigma}{dxdQ^2}(\mathrm{R})$
$Q^2 = 1000\,\mathrm{GeV}^2$	≈ 1.1
$Q^2 = 10000\,\mathrm{GeV}^2$	≈ 1.4

The dependence of $\frac{d^2\sigma}{dxdQ^2}$ on $\mathcal{P}$ is large at very high $Q^2 \approx m_{Z^0}$ only

Differential NC cross section for $e^{\pm}$ scattering

$$\frac{d^2\sigma}{dQ^2dx}(e^{\pm}) = \frac{2\pi\alpha^2}{xQ^4}\left(H_0^{\pm} + \mathcal{P}H_P^{\pm}\right)$$

$$H_{0,P}^{\pm} = Y_+ F_2^{0,P}(x,Q^2) \mp Y_- xF_3^{0,P}(x,Q^2)$$

$$Y_{\pm} = 1 \pm (1-y)^2$$

$$F_2^{0,P} = \sum x(q+\bar{q})A_q^{0,P}$$

$$xF_3^{0,P} = \sum x(q-\bar{q})B_q^{0,P}$$

$$A_q^0 - e_q^2 = -2e_q v_q v_e \chi + ({v_q}^2 + {a_q}^2)(v_e^2 + a_e^2)\chi^2$$

$$B_q^0 = -2e_q a_q a_e \chi + 4v_q a_q v_e a_e \chi^2$$

$$A_q^P = +2e_q v_q a_e \chi - 2({v_q}^2 + {a_q}^2)v_e a_e \chi^2$$

$$B_q^P = +2e_q a_q v_e \chi - 2v_q a_q (v_e^2 + a_e^2)\chi^2$$

$$\chi = \left[\frac{\sqrt{2}G_\mu M_{Z^0}^2}{4\pi\alpha}\right]\frac{Q^2}{M_{Z^0}^2 + Q^2}$$

For a fixed lepton charge and polarization the cross section $\frac{d^2\sigma}{dQ^2dx}$ is

- a linear combination of the quark densities
- a quadratic function of the quark couplings

Measure cross sections for e^+ and e^- scattering with both positive and negative polarization $\mathcal{P}$

$\rightarrow$ Four independent equations

$\rightarrow$ **Disentangle four individual quark densities**

$\boldsymbol{u,\ \bar{u},\ d,\ \bar{d}}$

$\rightarrow$ **Measure the quark axial and vector couplings**

$\boldsymbol{v_u,\ v_d,\ a_u,\ a_d}$

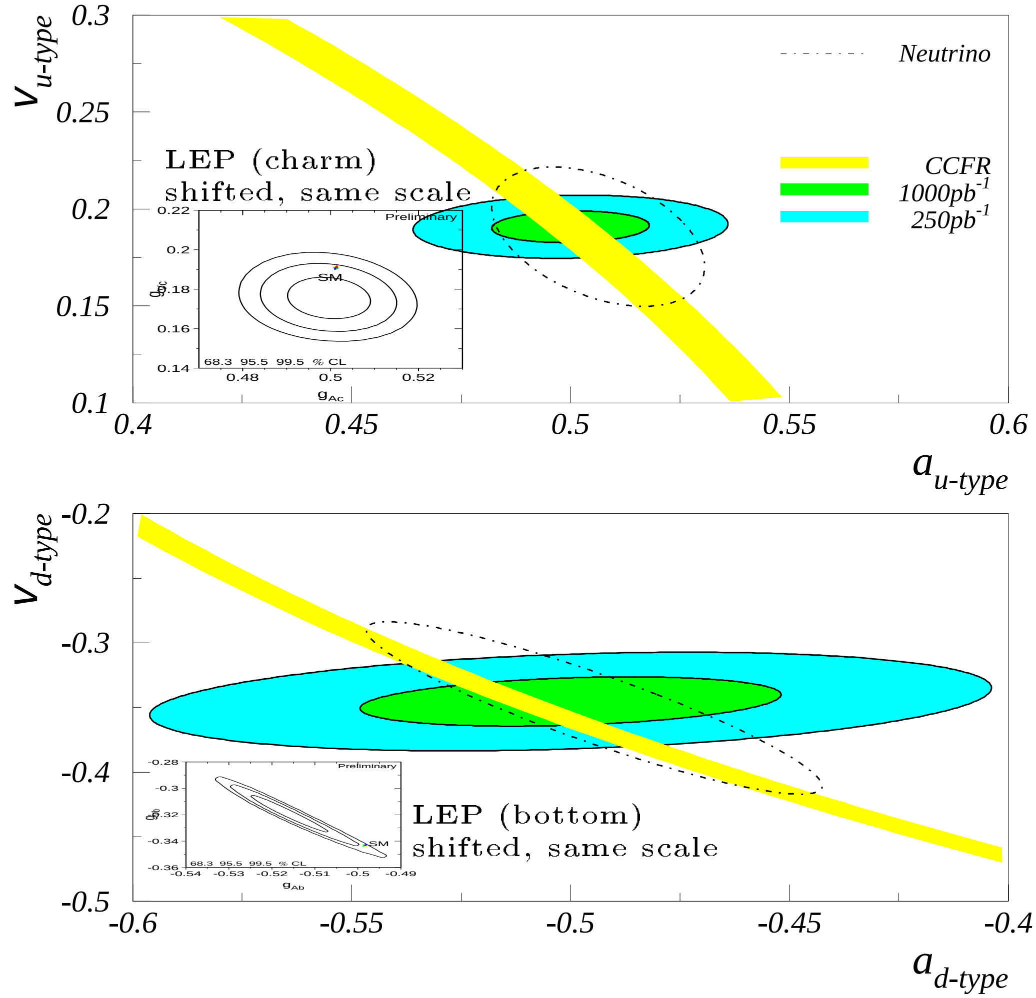
Precise measurements of $\mathcal{L}_{\mathrm{int}}$ and $\mathcal{P}$ are necessary to unfold the quark densities and couplings from

$$\sigma^+(-\mathcal{P}),\ \sigma^+(+\mathcal{P}),\ \sigma^-(-\mathcal{P}),\ \sigma^-(+\mathcal{P})$$

Measurement of the weak couplings

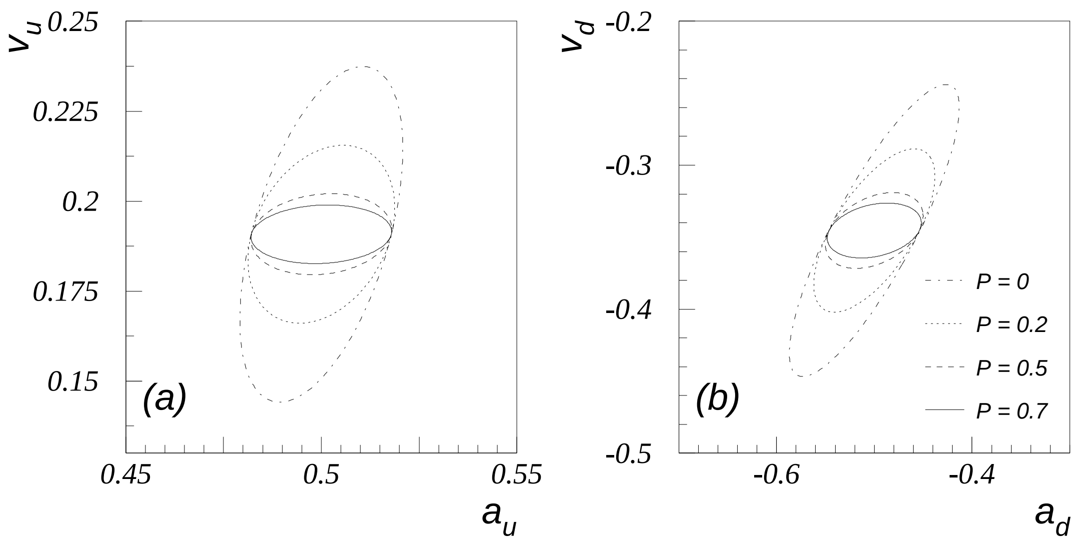
$v_u,\ a_u,\ v_d,\ a_d$

Complementary to LEP/SLD measurements with heavy quarks and to results from neutrino scattering experiments



Uncertainty of the NC couplings as a function of $\mathcal{P}$

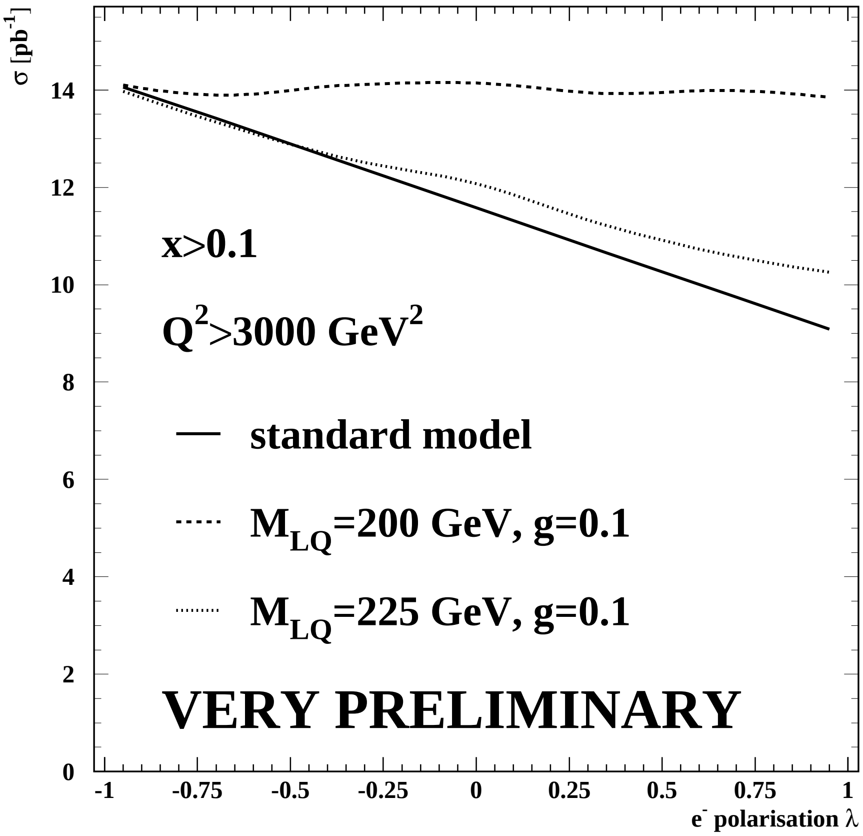
Example: analysis with d or u couplings constrained to the SM.



→ **The accuracy of $\mathcal{P}$ is not so critical for this measurement, but high values of the polarization $\mathcal{P}$ are essential.**

Searches

Example: on-shell production of a scalar Leptoquark with right handed coupling in $e^- p$ scattering



$\rightarrow$ It is possible to enhance exotic signals compared to the SM background for a clever choice of polarization.

Polarization measurement

HERA 2000: Spin rotators for H1 and ZEUS

$\rightarrow$ Longitudinal lepton polarization with $|\mathcal{P}| \approx 0.6$

Polarization measurements in 2001

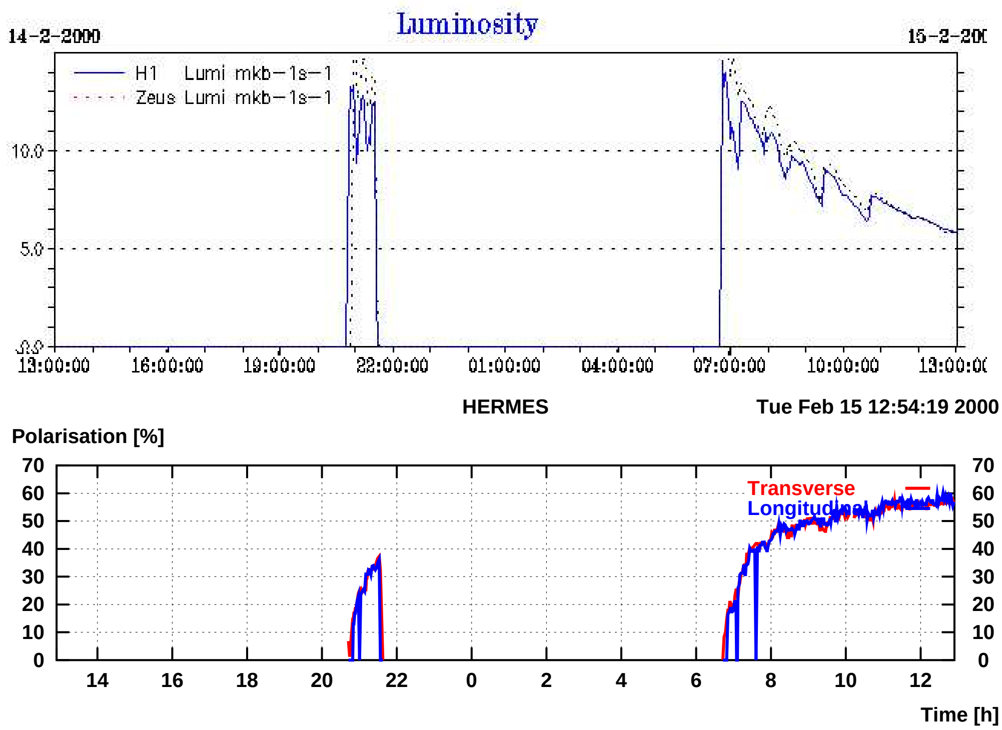
- Upgraded transverse (TPOL) polarimeter and longitudinal (LPOL) polarimeter
- Statistical accuracy $\Delta\mathcal{P} \approx 0.01$ or better per minute for groups of bunches is possible.
- Overall systematic uncertainties are probably in the same order of magnitude.
- Measurements of the polarization of all individual bunches are possible, but on larger time scales

  (upgraded TPOL: $\Delta\mathcal{P} \approx 0.05$ every 10 minutes)

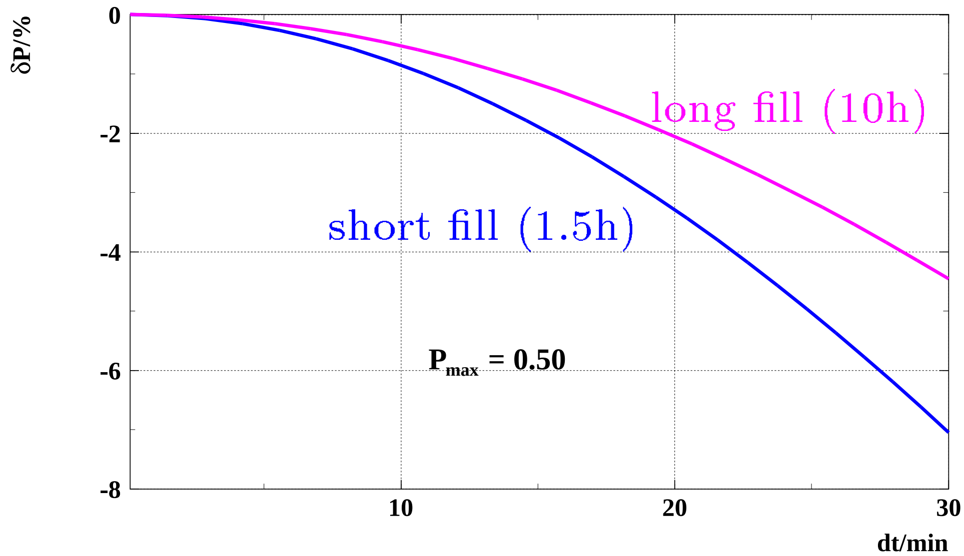
Impact of the Polarization build-up

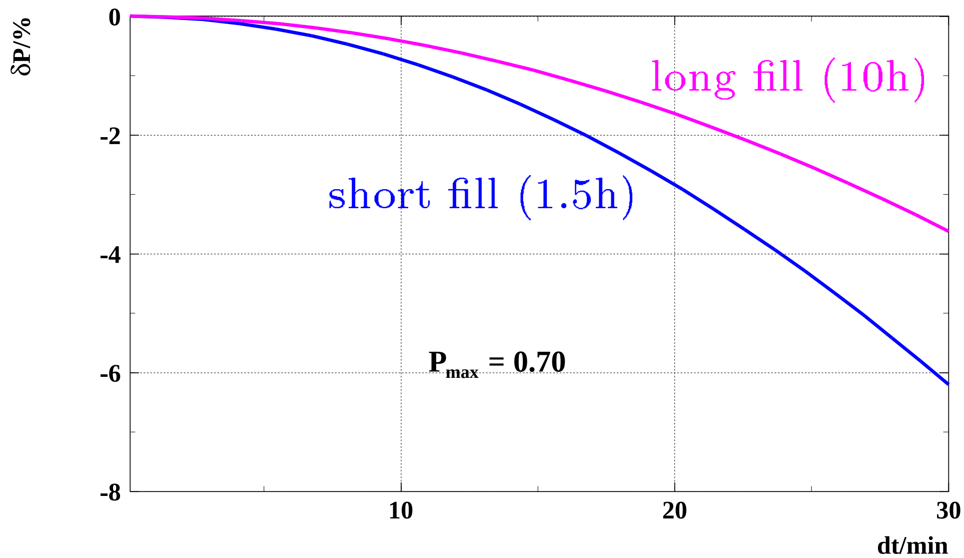
$\approx$ 30 minutes polarization build-up phase at the start of a fill, where the luminosity is high.

ZEUS and H1 want to use this data



Study by Sergey Levonian: fold polarization measurements with luminosity at certain time-intervals (2 min, 5 min, 10 min…) and compare to the case of infinitely small time-intervals.

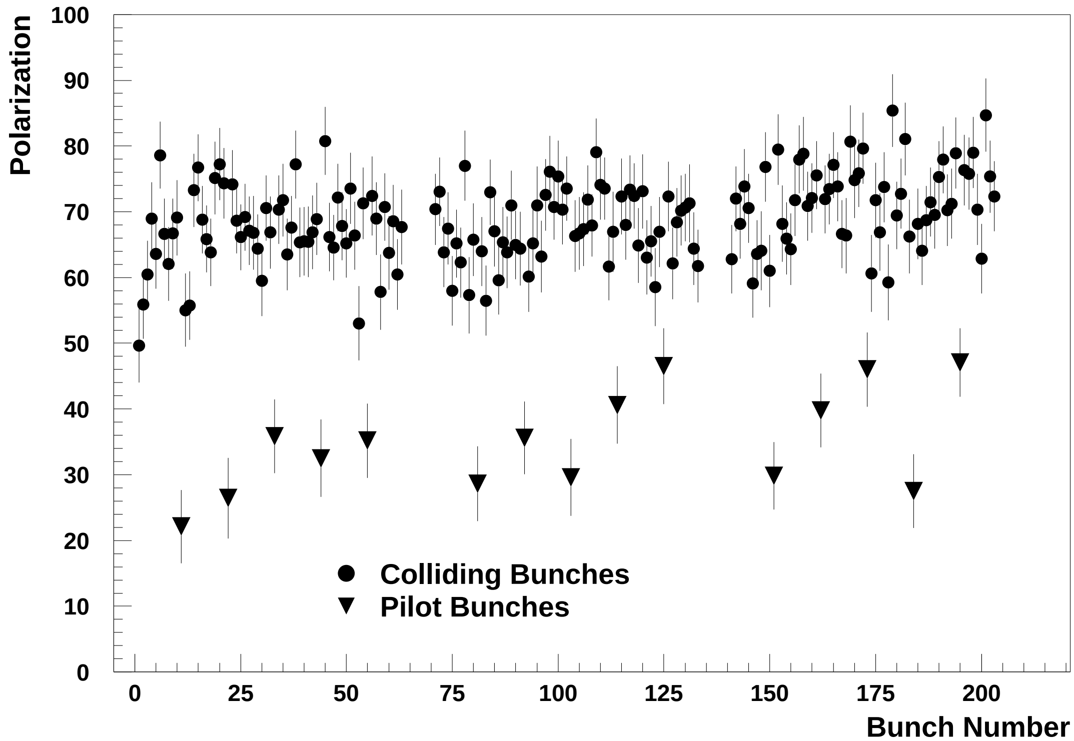




→ Polarization build-up does not introduce large additional systematic uncertainties, when weighting polarization with luminosity on a 1 or 2 minute basis

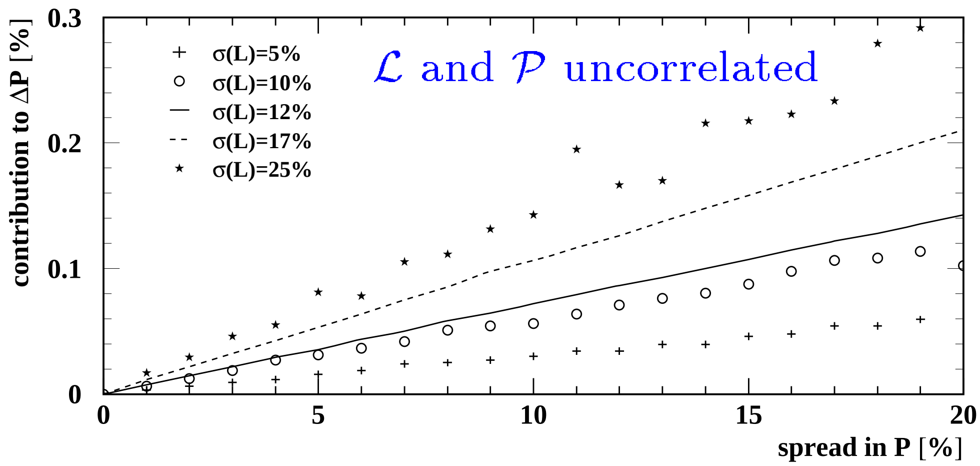
Influence of bunch-to-bunch fluctuations

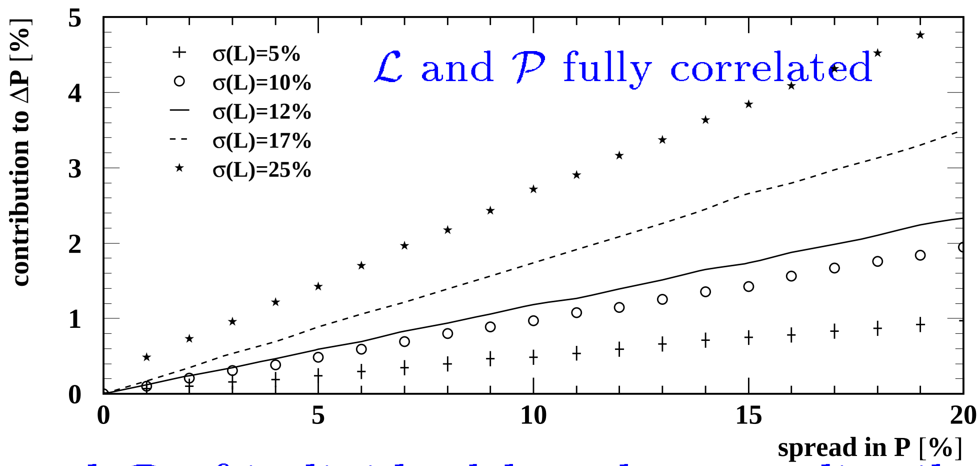
Polarization can vary from bunch to bunch



H1 and ZEUS are interested in $\mathcal{P}$ weighted by the per-bunch luminosity. The polarimeters measure $\mathcal{P}$ weighted by the per-bunch electron current.

Study by Sergey Levonian: compare average polarization to the luminosity-weighted polarization, assuming fluctuations in $\mathcal{P}$ and $\mathcal{L}$ as observed in typical fills. Compare uncorrelated to fully correlated fluctuations.





$\mathcal{L}$ and $\mathcal{P}$ of individual bunches are distributed around the central value with a typical width

$$\sigma(\mathcal{L}) = (12 - 17)\%, \quad \sigma(\mathcal{L}) = (5 - 10)\%$$

→ Worst-case scenario leads to significant systematic uncertainties.

Summary

- Future ZEUS and H1 measurements where $\Delta\mathcal{P}$ is critical
  - Limits on right-handed charged currents
    → Accuracy $\Delta\mathcal{P} \approx 1\%$ limits the systematics (compared to $\Delta\mathcal{L} \approx 1\%$)
  - u and d quark axial and vector couplings
    → Highest possible polarization and good accuracy is necessary

  An accurate knowledge of the polarization $\mathcal{P} \approx 1\%$ or better is essential for many future H1 and ZEUS analyzes.

- **Bunch to bunch fluctuations are potentially dangerous.**
  - Further studies are needed, how the per-bunch measurements from the current LPOL and the upgraded TPOL can help here
  - More uniform bunch currents can also help