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Physics motivation for lepton beam polarization

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- CC cross section
- NC cross section
  - Quark densities functions
  - Axial and vector couplings of u and d quarks
- BSM
  - Right-handed charged currents
  - Contact interactions
  - Leptoquarks
- Summary

Introduction

HERA upgrade: expect $\mathcal{L}_{\text{int}} \approx 1000\text{pb}^{-1}$ in the next years

Spin rotators will be installed for H1 and ZEUS

$\rightarrow$ **Longitudinally polarized leptons**

typical value $|\lambda| = 0.7$, accuracy $\Delta\lambda \approx 0.02$

$\rightarrow$ **Investigate new aspects of *ep* physics with H1**

Note: it will be difficult (or impossible) to operate HERA with the spin-rotators off

$\rightarrow$ **It is crucial to understand the impact of λ and $\Delta\lambda$ on future H1 analyzes**

Charged current cross section

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

- **Significantly enhanced charged current cross section for $\boldsymbol{\lambda = +0.7}$ ($\boldsymbol{e^+}$ beam) and $\boldsymbol{\lambda = -0.7}$ ($\boldsymbol{e^-}$ beam)**

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

- **Significantly reduced charged current cross section for $\boldsymbol{\lambda = -0.7}$ ($\boldsymbol{e^+}$ beam) and $\boldsymbol{\lambda = +0.7}$ ($\boldsymbol{e^-}$ beam)**

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

Impact of $\Delta\lambda$ on the measurement of the charged current cross section

Assume the sign of λ is chosen such that σ^{CC} is maximized.

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

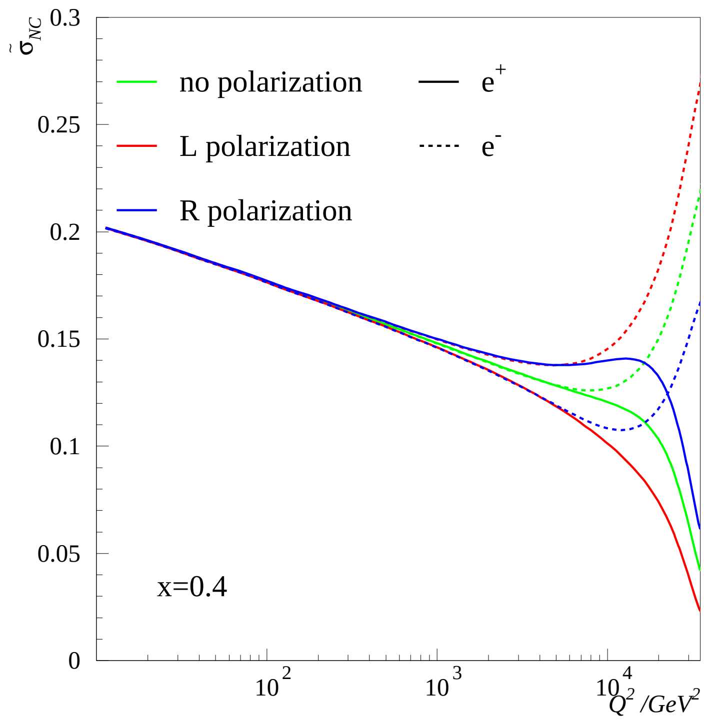
$$\Delta\lambda = (1 + |\lambda|) \times \frac{\Delta\mathcal{L}_{\rm int}}{\mathcal{L}_{\rm int}}$$

Example: left-handed electrons, $\lambda = -0.7$ and 1% relative accuracy on $\mathcal{L}_{\rm int}$

$\rightarrow$ λ needs a precision $\Delta\lambda = 0.017$

$\rightarrow$ For this case (SM CC cross section) the proposed accuracy $\Delta\lambda \approx 0.02$ seems to be just about sufficient.

Neutral current cross section



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

The dependence of $\frac{d^2\sigma}{dx\,dQ^2}$ on λ is large at very high $Q^2 \approx m_{Z^0}$ only

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

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

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

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

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

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

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

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

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

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

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

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 λ

$\rightarrow$ Four independent equations

$\rightarrow$ Disentangle four individual quark densities

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

$\rightarrow$ Or measure the quark axial and vector couplings

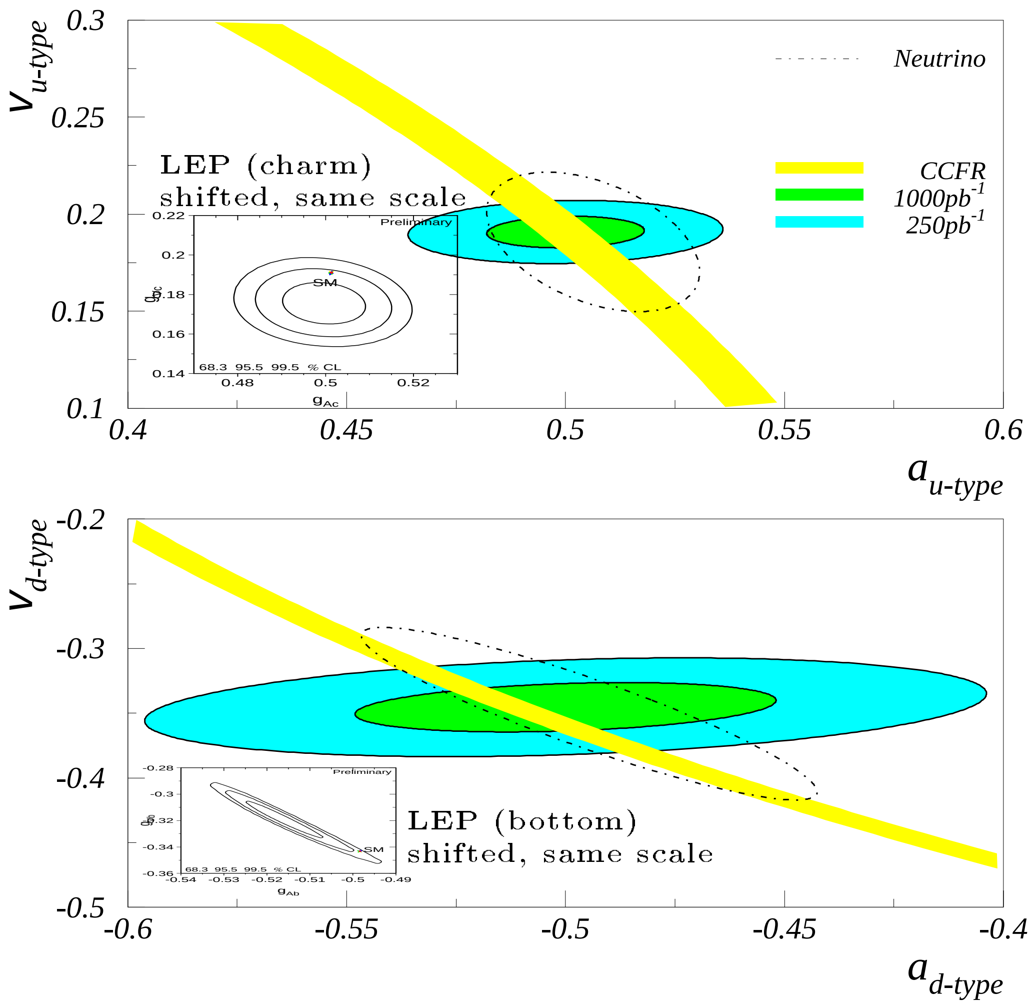
v_u, v_d, a_u, a_d

Precise measurements of $\mathcal{L}_{\text{int}}$ and λ are necessary, as well as high statistics.

Measurement of the weak couplings

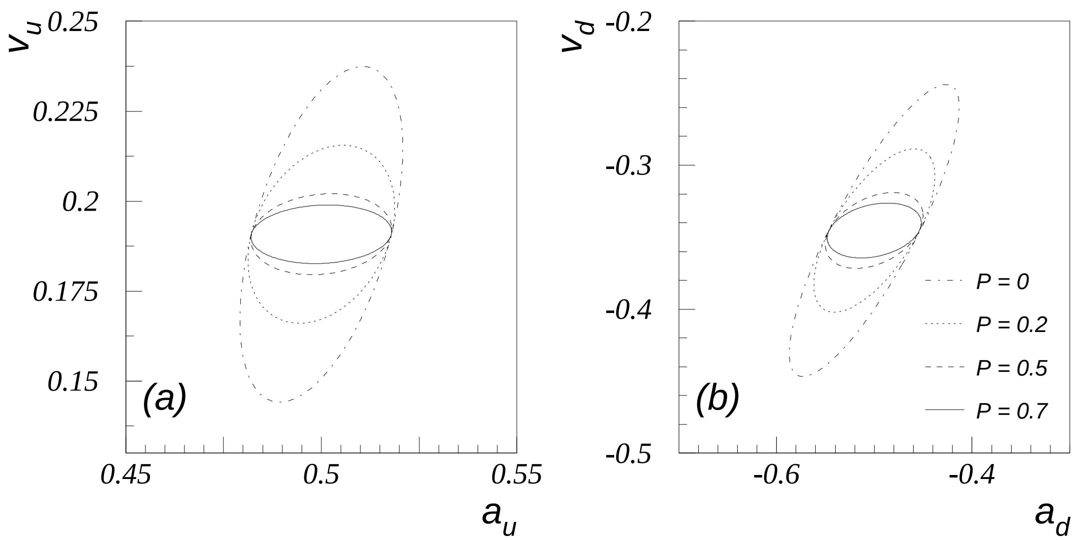
$v_u,\ a_u,\ v_d,\ a_d$

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



Uncertainty of the NC couplings as a function of λ

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



→ **The accuracy of λ is not so critical for this measurement, but high values of the polarization λ are essential.**

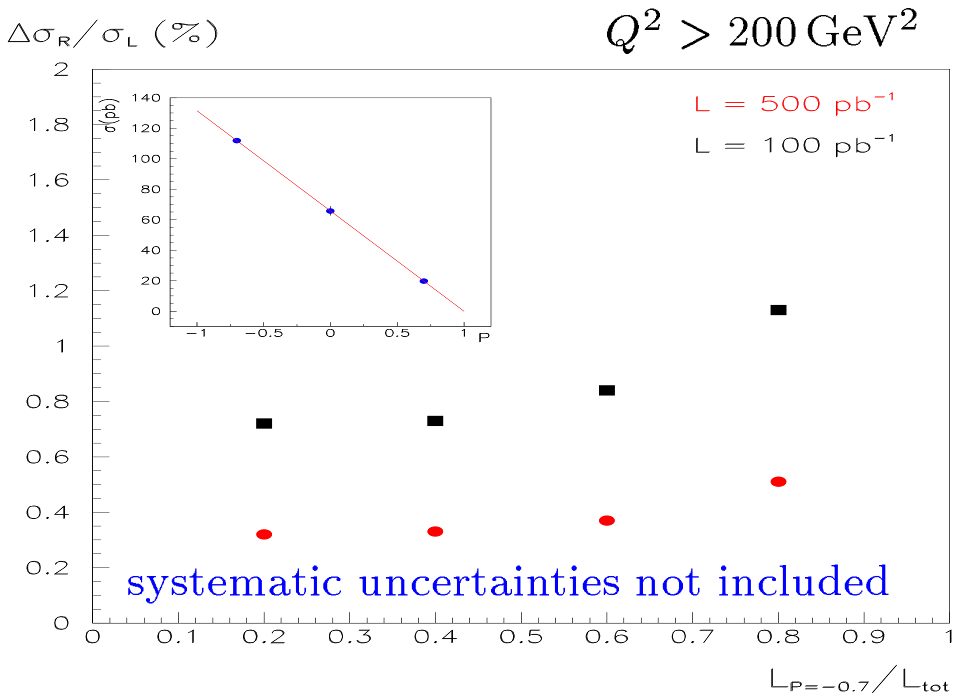
Limits on right-handed charged currents

Cross section for e^- beam

$$\sigma^{\mathrm{CC}} = (1-\lambda)\sigma_{\mathrm{L}}^{\mathrm{CC}} + (1+\lambda)\sigma_{\mathrm{R}}^{\mathrm{CC}}$$

(Reverse sign of λ for e^+)

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



Best measurements of $\boldsymbol{\sigma_{\mathrm{R}}^{\mathrm{CC}}}$ with high luminosity at $\boldsymbol{\lambda = +0.7}$

Systematic uncertainties on $\sigma_{\rm R}^{\rm CC}$ from λ

Assume two points with polarization $\pm\lambda$ are measured

$$\frac{\Delta\sigma_{\rm R}}{\sigma_{\rm L}} \approx \frac{1+|\lambda|}{2|\lambda|}\,\Delta\lambda$$

Assume $|\lambda| = 0.7$, $\Delta\lambda = 0.02$:

$$\boldsymbol{\frac{\Delta\sigma_{\rm R}}{\sigma_{\rm L}} = 2.4\%}$$

→ **Important source of systematic error.**

→ **Precise measurements of $\boldsymbol{\lambda}$ 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.

Contact interactions

Four couplings (left or right handed quarks or leptons). Two sub-cases for destructive/constructive interference

Sensitivities to the compositeness-scale Λ from measuring the **unpolarized** NC cross sections ($\mathcal{L}_{\rm int} = 1000\,{\rm pb}^-1$)

	Limit on Λ in TeV			
	$\eta^+_{\rm LL}$ $\eta^+_{\rm RR}$	$\eta^+_{\rm LR}$ $\eta^+_{\rm RL}$	$\eta^-_{\rm LL}$ $\eta^-_{\rm RR}$	$\eta^-_{\rm LR}$ $\eta^-_{\rm RL}$
e^-	6	2.7	5.2	1.8
e^+	3.3	6	2.6	5
e^- and e^+	6.1	6	5.3	5

$\rightarrow$ **About equal luminosity for either polarization/charge combination is optimal**

Contact interactions and Polarization

The polarized cross sections alone do not give higher sensitivities to Λ than the unpolarized ones.

But they can give some hints on the chiral structure of the underlying interaction, once it is discovered

Basic observable: asymmetry A of left and right handed leptons

$$A = \frac{\sigma(\lambda = -1) - \sigma(\lambda = +1)}{\sigma(\lambda = -1) + \sigma(\lambda = +1)}$$

Nice feature of A: some systematic uncertainties partially cancel out in this ratio (structure functions,...).

Leptoquarks

Scalar leptoquarks:

singlets S_1, $\tilde{S}_1$, doublets R_2, $\tilde{R}_2$, triplet S_3

Vector leptoquarks:

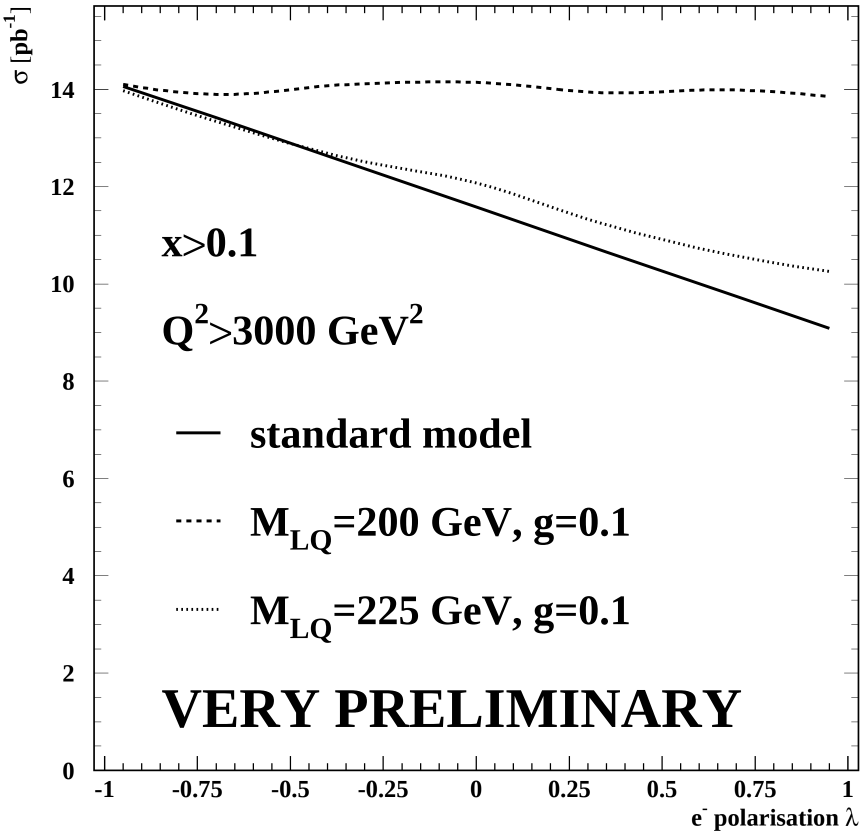
singlets $U_{1\mu}$, $\tilde{U}_{1\mu}$, doublets $V_{2\mu}$, $\tilde{V}_{2\mu}$, triplet $U_{3\mu}$

General search strategy: "similar" to the case of contact interaction: the polarized cross sections to not contribute much to the discovery potential, as compared to the unpolarized NC cross sections

Once the LQ is discovered, its chiral structure can be probed using the polarized cross sections.

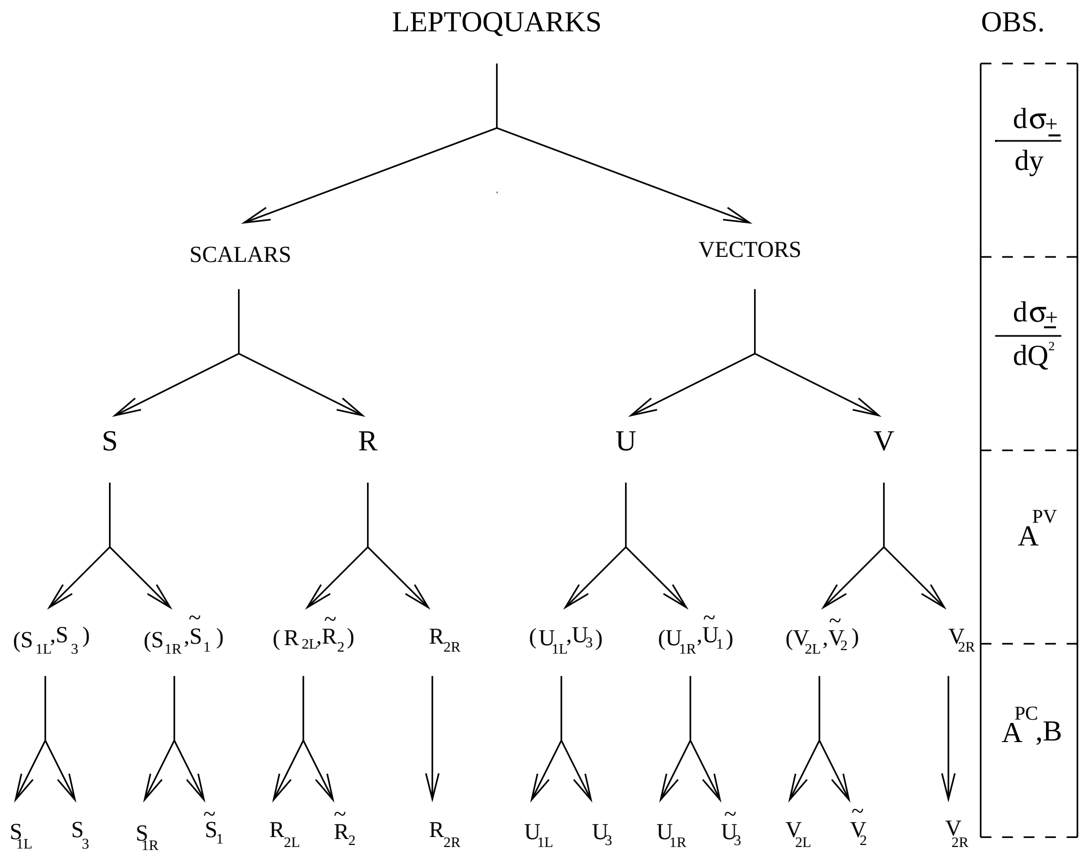
BUT...for some LQs the sensitivity can be enhanced significantly with polarization

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



→ Enhanced signal to background ratio for a positive polarization λ compared to no polarization

Identification of various types of leptoquarks with polarization



- $\frac{d\sigma}{dy}$ separates vector from scalar LQs
- σ_{e^+} and σ_{e^-} separates S and R, U and V
- A separates left and right handed LQs
- polarized protons are needed for the last step

Summary

- H1 with polarized leptons will open a new window to the chiral nature of physics
- An accurate knowledge of the polarization λ is essential for many future H1 analyzes. Start to think about this **NOW**. Don't think You can simply rely on the HERMES data
- Some possible new measurements
  - Right handed charged currents
  - u and d quark and antiquark densities
  - u and d quark axial and vector couplings
  - Exploit polarization to enhance exotic signals compared to the standard-model background
- For many analyzes it is probably most convenient to have equal luminosities with left and right handed leptons available, as this recovers the possibility to work with effectively "unpolarized" data