Polarization as a Tool at HERA

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Polarization as a Tool at HERA

- **The HERA Upgrade => HERA II**
- **Polarization at HERA**
- **HERA Polarimeters: LPOL and TPOL**
- **Physics with Polarized Lepton Beams**

  -EW physics

  -G_2 structure function

  -Physics Beyond SM
- **Summary**

HERA II

- **HERA UPGRADE (ep collider): increase luminosity (factor 5) and provide longitudinal lepton beam polarization to the experiments.**
- **Long shutdown, 12 months during 2000-2001, to modify the IP and install spin rotators. Since a few weeks first *e+p* collisions with low currents. Various HERA technical problems caused a late startup.**

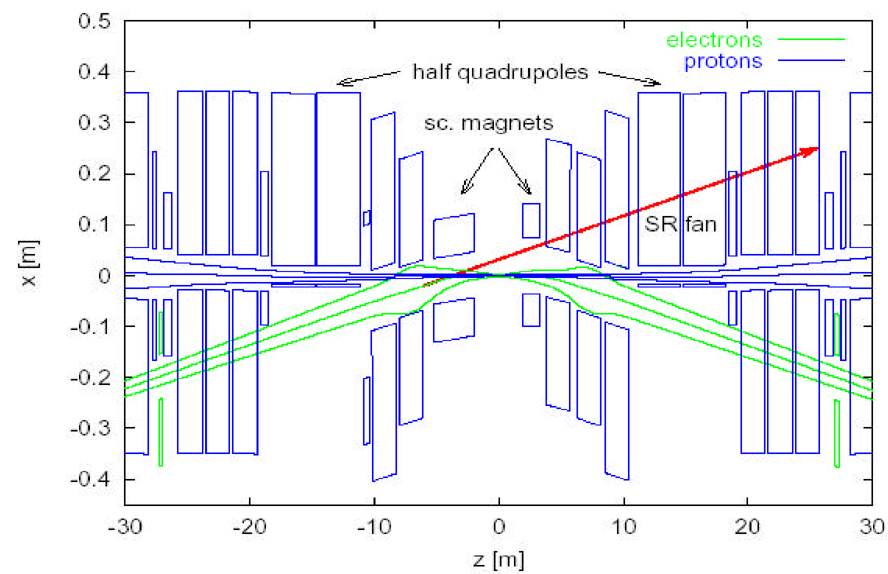
LUMINOSITY UPGRADE

- **Strong focusing at IP: major changes of machine lattice near IP. Sets of superconducting quadrupoles installed close to the H1/ZEUS IP, inside the detectors.**
- **Design luminosity HERA I (achieved):**

$$L = 1.5 \cdot 10^{31} cm^{-2} s^{-1}$$

- **Delivered by HERA I:** L_{INT} @ $180pb^{-1}$ **(during 1992-2000)**
- **Design luminosity HERA II :** $L = 7.5 \cdot 10^{31} cm^{-2} s^{-1}$
- **To be delivered by HERA II by 2006:**

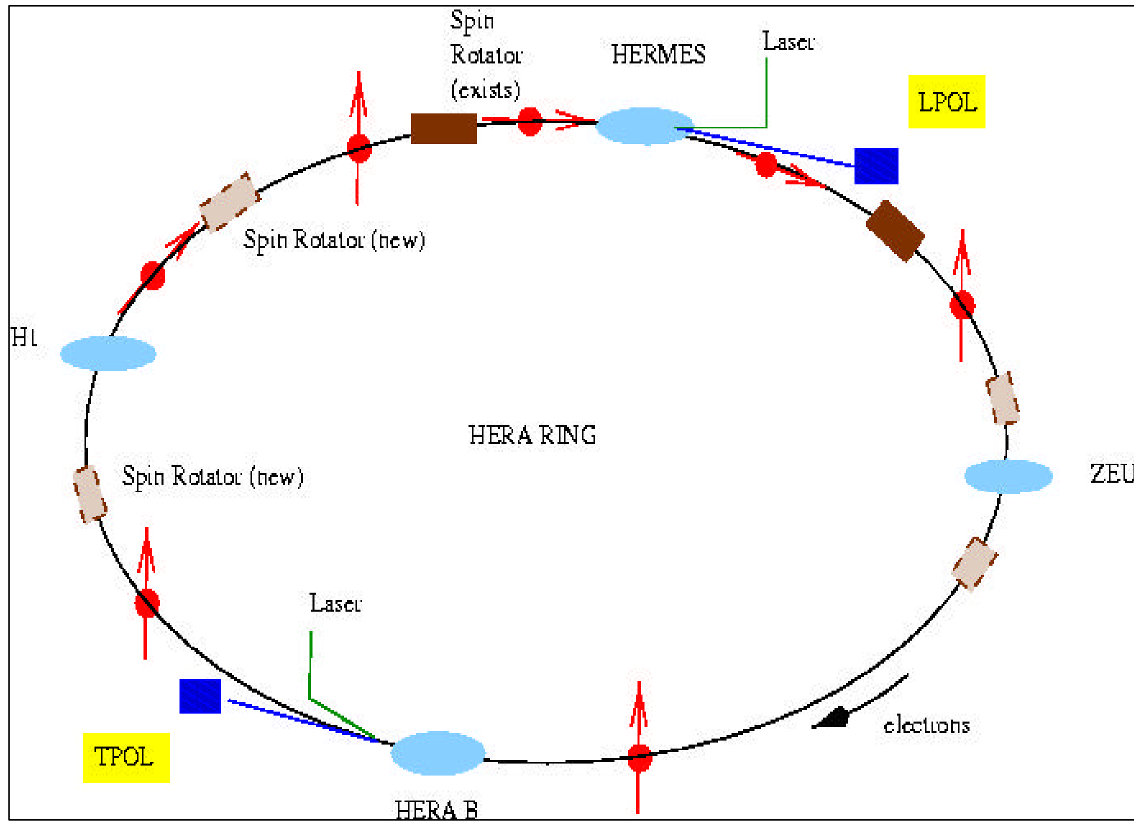
L_{INT} @ $1 fb^{-1}$



HERA II: Polarization

- **In HERA leptons become naturally transversely polarized through the emission of synchrotron radiation (spin flips): Sokolov-Ternov effect.**
- **The transverse polarization is converted into longitudinal polarization at the interaction points by Spin Rotators (HERA I: HERMES; HERA II also H1/ZEUS) .**

- **The lepton beam transverse polarization is measured by the TPOL polarimeter, and the longitudinal polarization is measured at the LPOL polarimeter, independently.**



Polarization

- **Polarization** **is defined as:** $$P = \frac{N_{UP} - N_{DOWN}}{N_{UP} + N_{DOWN}}$$

- **Polarization has to be known at the same level of precision as Total Luminosity, because it enters linearly in the cross section for many processes e.g.:**

$$\sigma^{\pm}_{NC} = \sigma^{\pm}_{NC,unpol} + P\sigma^{\pm}_{NC,pol} \qquad \sigma^{\pm}_{CC} = (1 \pm P)\sigma^{\pm}_{CC,unpol}$$

- **Polarization precision goal for HERA II:** $\Delta P/P \le$ **0.01 (0.03-0.04 for HERA I), needed for polarization physics.**

- **The absolute value of the degree of lepton polarization is the same along the whole ring. The actual location of the polarization measurement is not confined to the experiment IP.** $|P_{Long}| = |P_{Trans}|$

- **Precise measurement from the TPOL/LPOL polarimeters together with machine lattice simulations, will provide confidence of having an accurate measurement at IP.**

Polarization

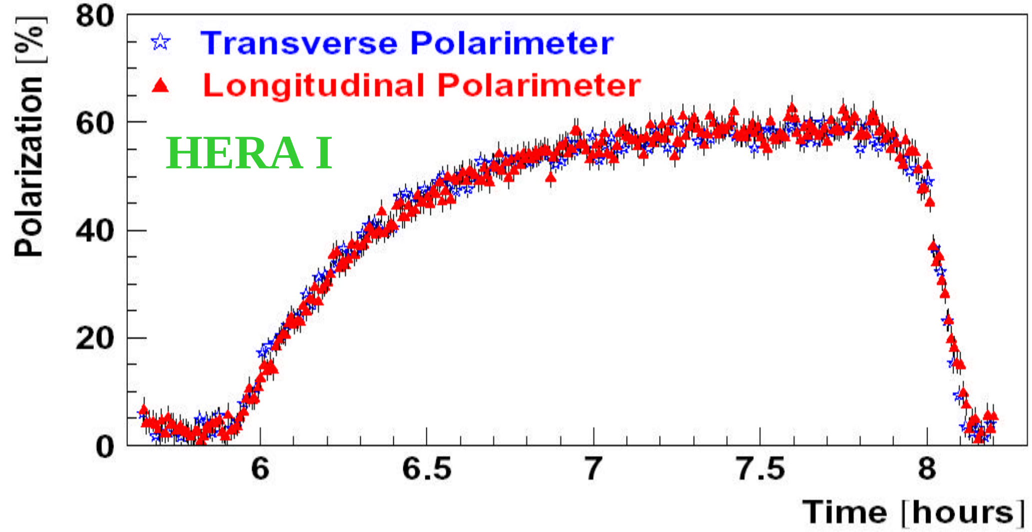
- **Polarization builds up and settles asymptotically to an equilibrium value.**

$$P(t) = P_{eq}(1 - exp^{-t/t})$$

P_{eq} *- asymptotic polarization equilibrium value*

P(t) - polarization value at a given time t

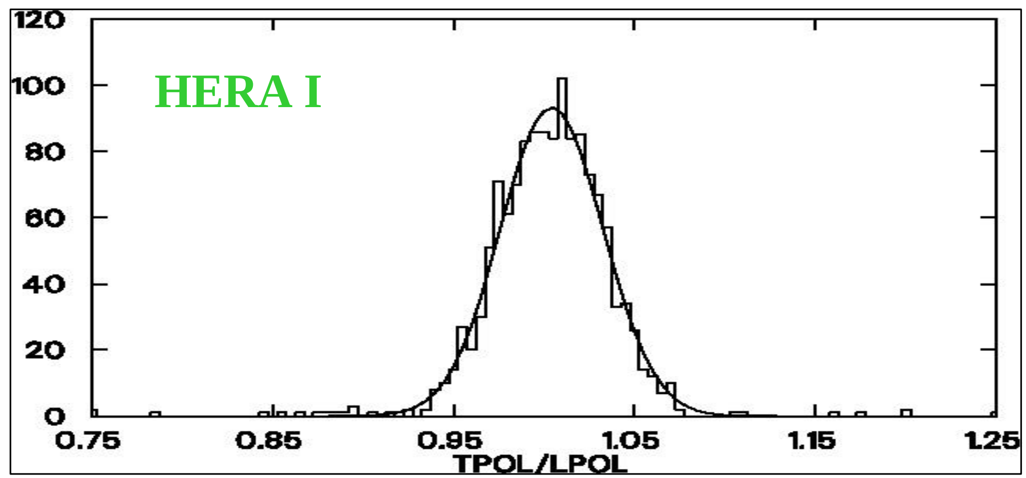
t *- characteristic polarization buildup time » 40min*



•Theoretical max polarization @ 92%, but reduced by counteracting depolarizing effects (dependence on ring parameters).

•HERA I: @ 55%-60% polarization

•HERA II : @ 50% polarization (aim for more)



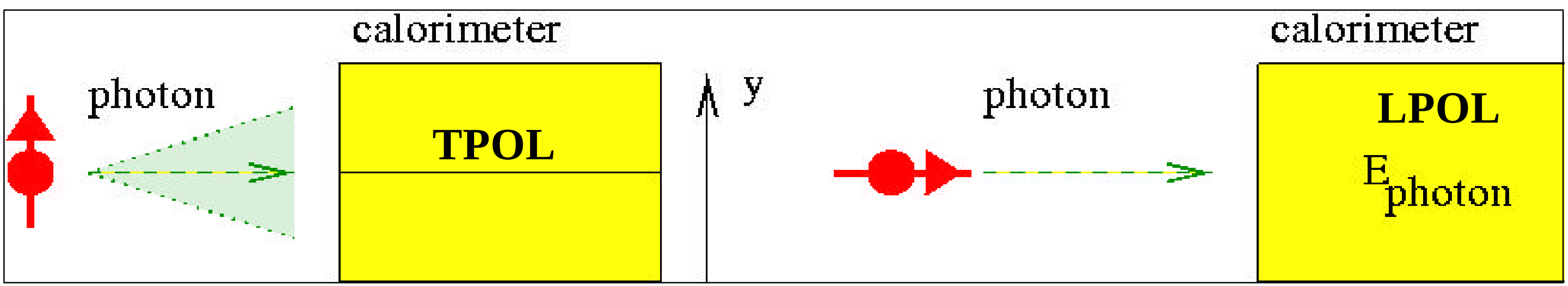
Polarization Measurement

- **The polarimeters make use of the spin-dependent cross section for Compton scattering of polarized photons on polarized leptons(e+/-).**
- **The polarization is determined by measuring asymmetries.**
- **Laser light is scattered off leptons (alternatively L/R circularly polarized). The produced Compton photons are backscattered into a narrow cone centered around the initial lepton direction and are detected by the polarimeter.**

transverse polarization	***longitudinal polarization***
spatial asymmetry	***energy asymmetry***

$$P_T = (\langle Y \rangle_L - \langle Y \rangle_R) K_h$$

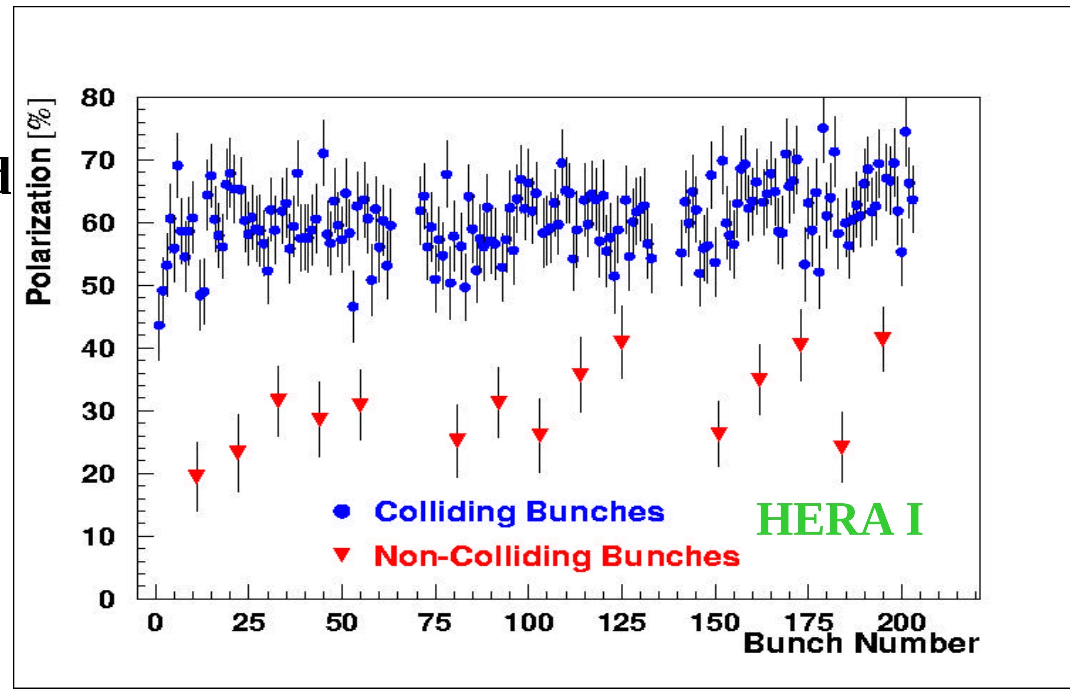
$$P_L = D S_3 P_Z / A(E_g)$$



Polarization Measurement

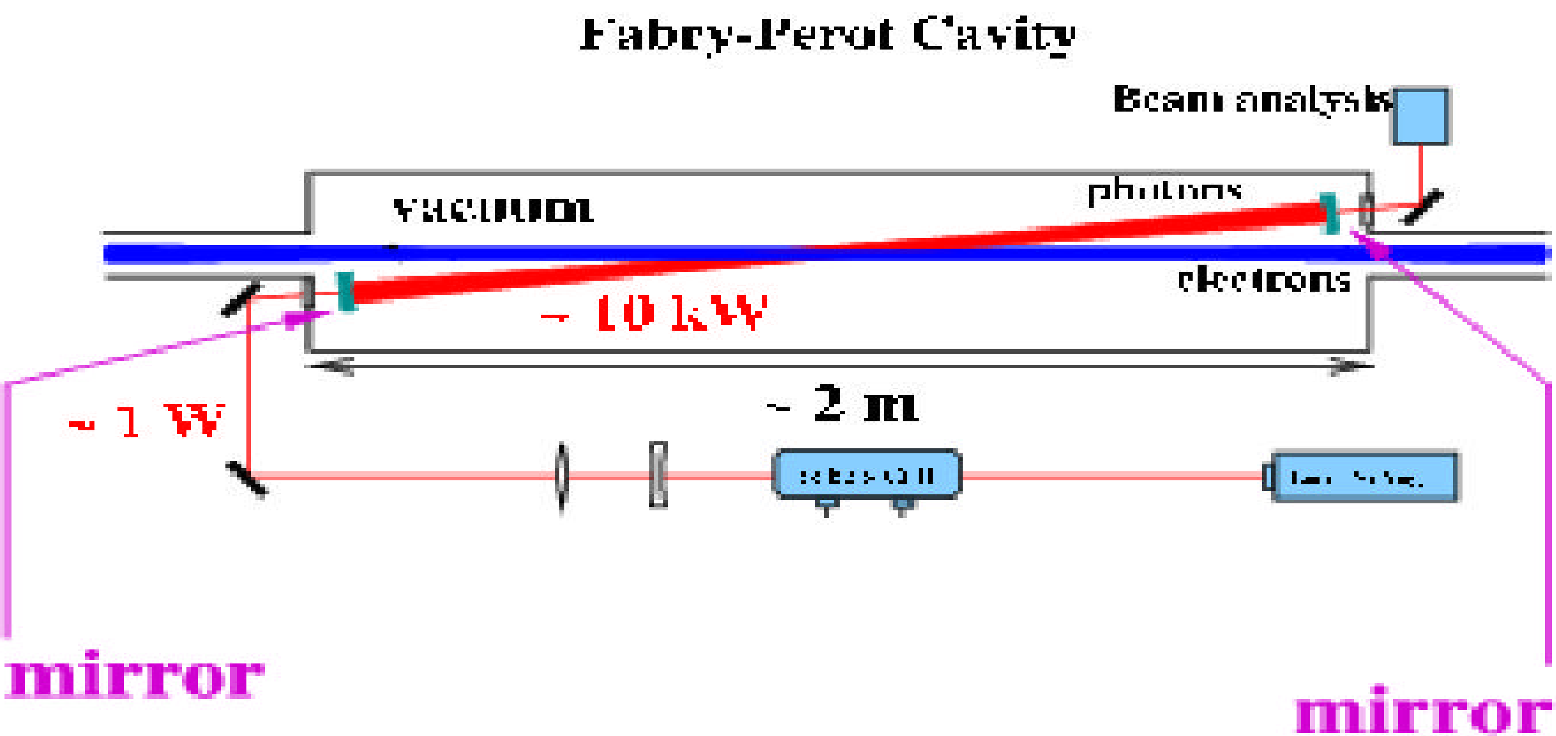
- **Need accurate per bunch per minute polarization measurement Þ LPOL and TPOL upgrade.**

- **The polarization of lepton colliding and non-colliding bunches differs (measured by LPOL at HERA I). Depends on the machine polarization tuning and varies in time (beam-beam effects).**



Polarization: LPOL

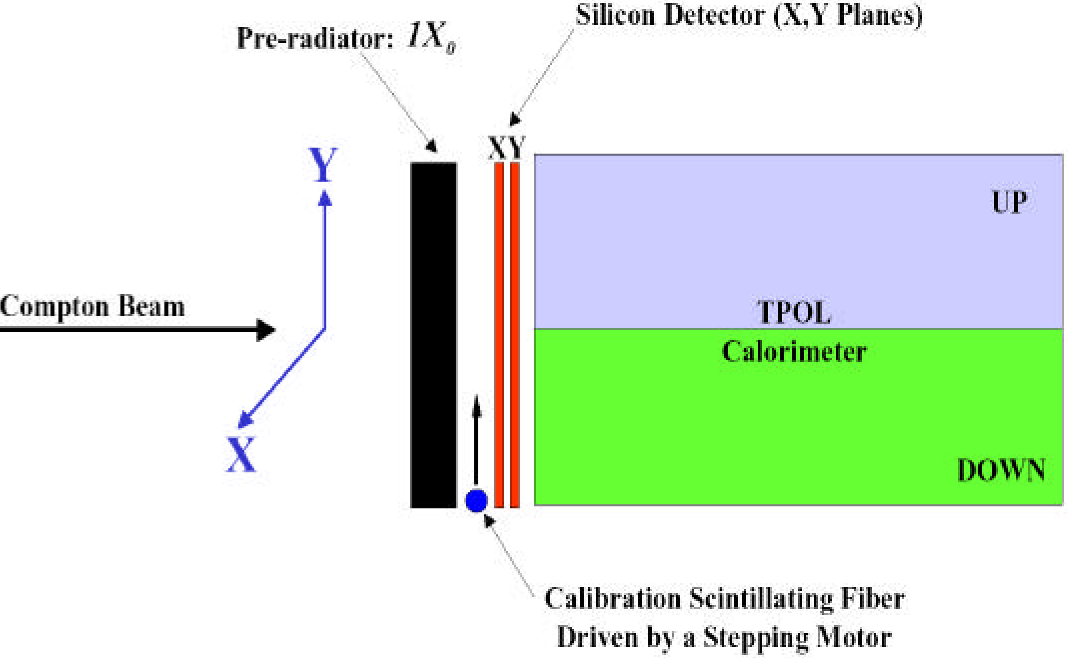
- **LPOL upgrade: New more powerful laser system (Fabry-Perot cavity + new laser) to operate in few photon mode Þ direct calibration with Compton edge.**
- **Laser intensity amplification 10k Þ effective 10kW laser.**
- **Upgrade is not yet completed but the LPOL is anyhow operational.**

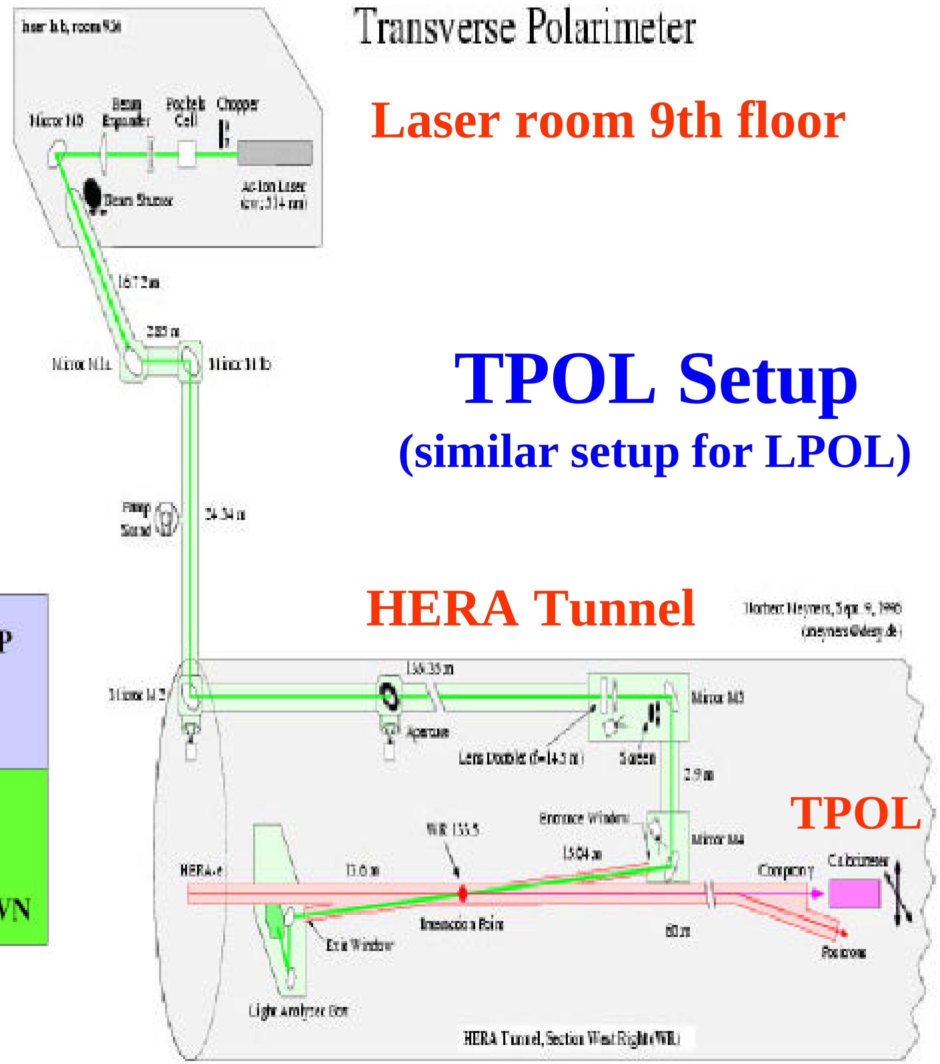


Polarization: TPOL

- **TPOL upgrade completed: Fast DAQ to measure the polarization of individual bunches per minute and radhard silicon position sensitive detector to allow in-situ eta-y calibration.**

$$h = \frac{E_{UP} - E_{DOWN}}{E_{UP} + E_{DOWN}}$$





HERA II: Physics with Polarized Lepton Beams

The study of polarized lepton (e+/e-) proton deep inelastic scattering at high Q^2 will be one of the main physics topics at HERAII. Accurate polarization (P£0.7) measurement together with high luminosity opens a new field for HERA physics at high Q^2 .
Possibility to study the chiral structure of the SM:

-Charged currents: only LH particles interact

-Neutral currents: LH, RH particles interact with Z unequally

- **Electroweak physics: study EW interactions using the 4 possible combinations: e-, e+ with P<0 and P>0.**

  -Polarized NC,CC cross section measurements;

  -Light quark couplings to the Z-boson;

  -Precise measurements of EW parameters.

- **QCD: G2 structure function**
- **Search for new physics: physics beyond SM**

  -Right handed charged currents

  -Leptoquarks

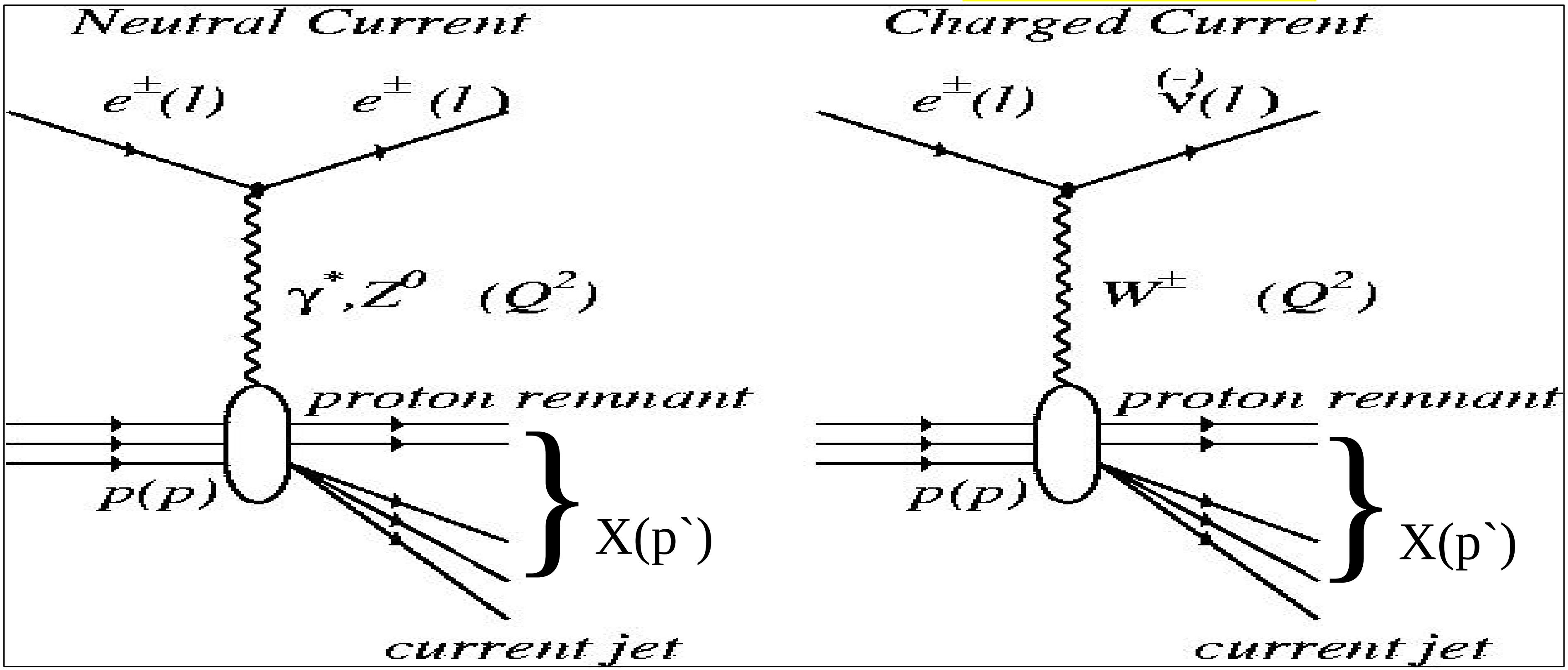
Polarized NC, CC Cross Sections

Investigate EW physics: NC and CC cross section measurements at high Q^2 with P>0, P<0.

Cross sections for NC and CC

$$s^{\pm}_{NC} = s^{\pm}_{NC,unpol} + P s^{\pm}_{NC,pol}$$

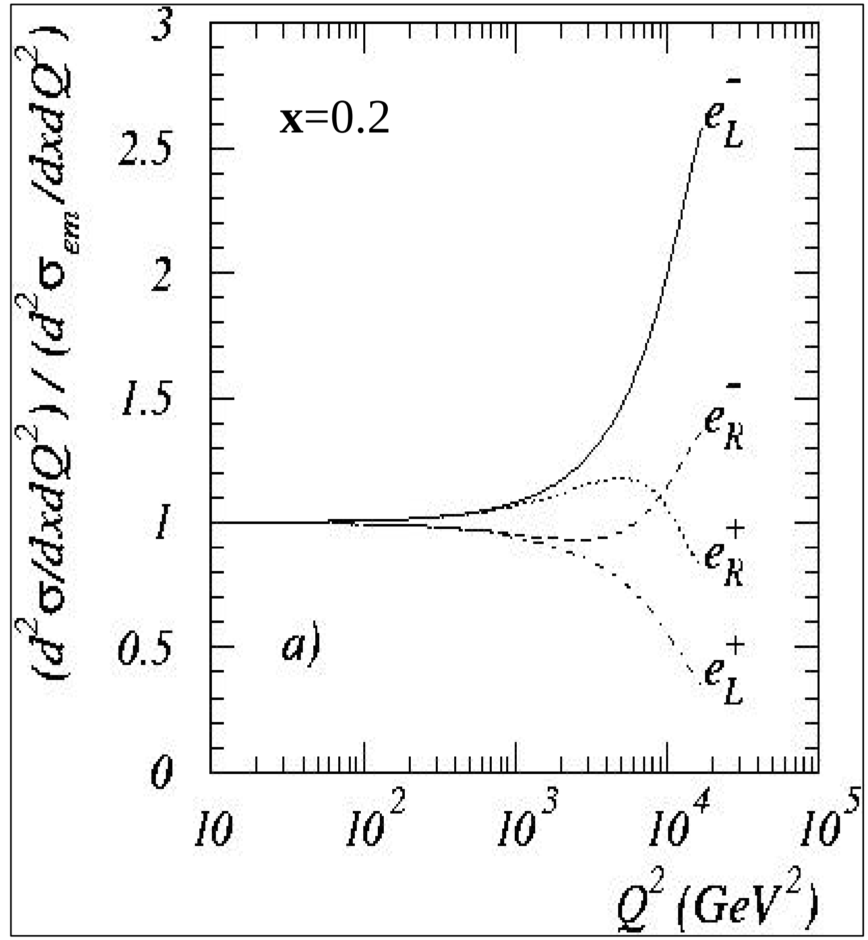
$$s^{\pm}_{CC} = (1 \pm P) s^{\pm}_{CC,unpol}$$



Light Quark Couplings to the Z Boson

- **Polarization effect is large on cross sections**
- **for $Q^2 \gg 10^4 GeV^2$.**
- **Different behavior at high Q^2 due to Z exchange.**
- **Split up to factor 2, at $Q^2 = 10^4 GeV^2$.**
- **Exploit difference to extract the light quark(u,d) couplings to the Z-boson.**

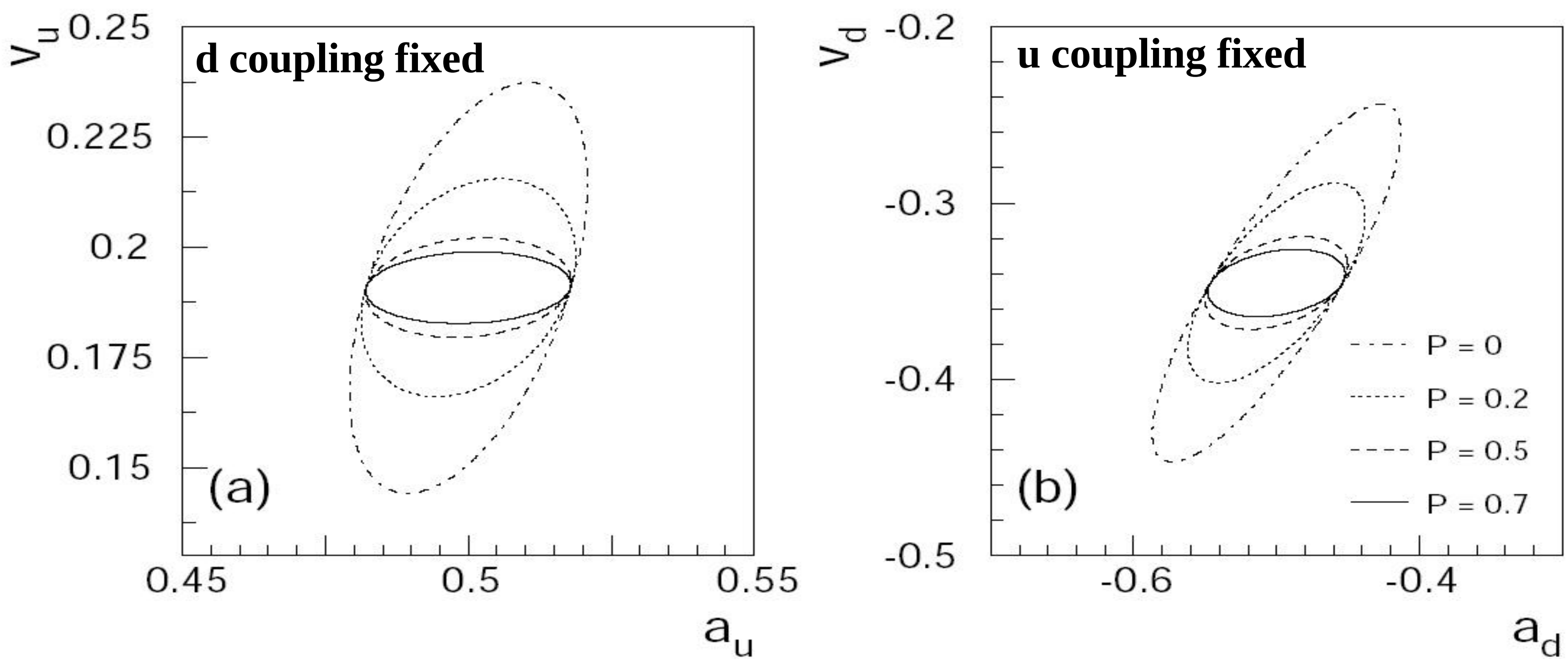
Neutral Current



Light Quark Couplings to the Z Boson

- **Measurement of polarized NC,CC Þ disentangle the light quark(u,d) couplings to Z.**
- **Done by using all four charge/polarization combinations.**
- **Unpolarized DIS with e-/e+ beams Þ axial couplings.**
- **Polarized DIS with the 4 charge/ polarization combinations Þ vector couplings.**

1 s Contours for NC Couplings for Different Polarizations



Light Quark Couplings to the Z Boson

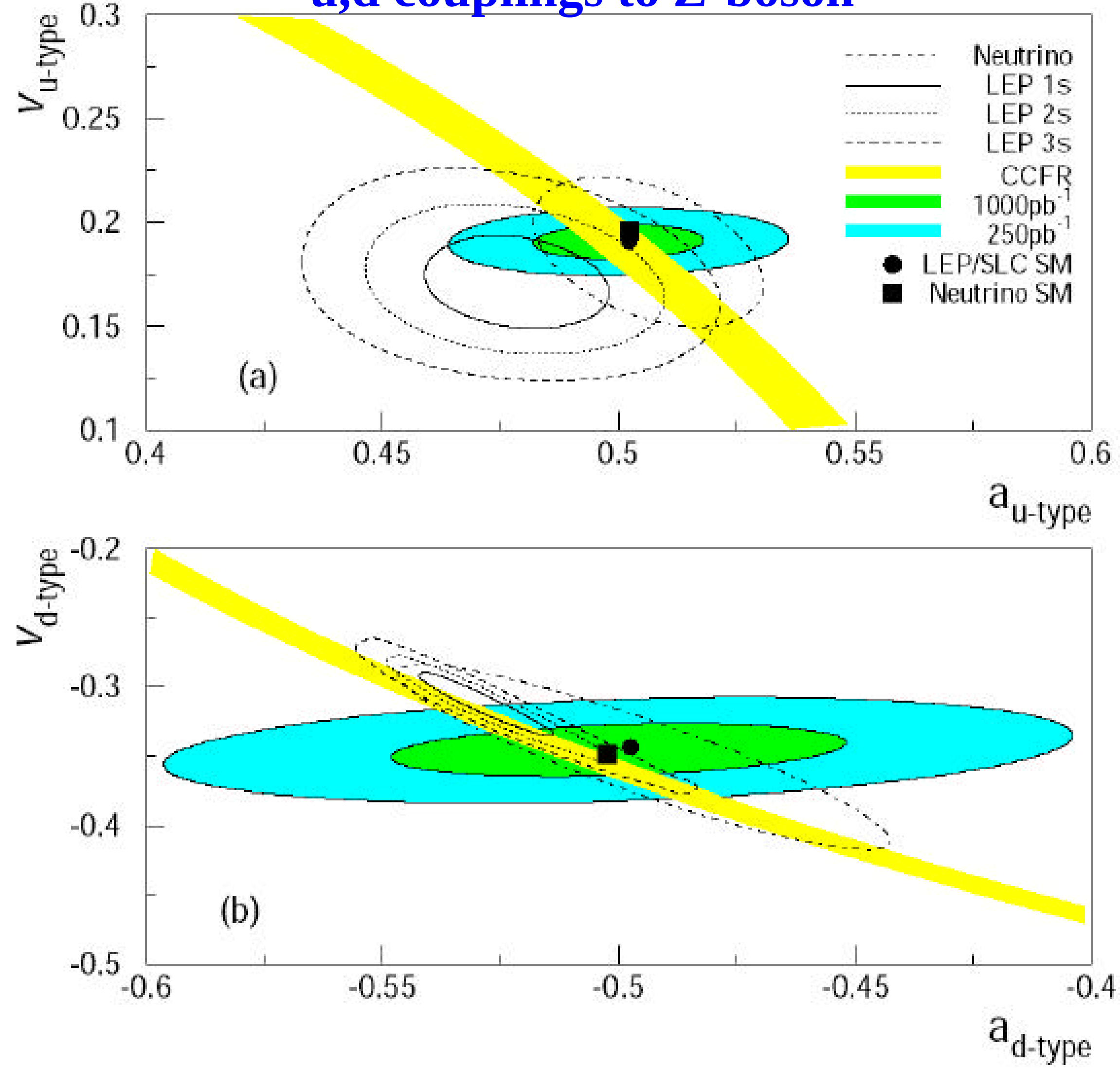
- **With *1 fb*$^{-1}$ of data equally divided between e+/e- and P=±0.7:**

$$d_{v_u} = 13\%; d_{a_u} = 6\%$$

$$d_{v_d} = 17\%; d_{a_u} = 17\%$$

- **Based on full MC simulation; detector improvements would improve precision.**
- **Complementary to LEP measurements with heavy quarks and similar to LEP precision for heavy quarks.**

u,d couplings to Z-boson



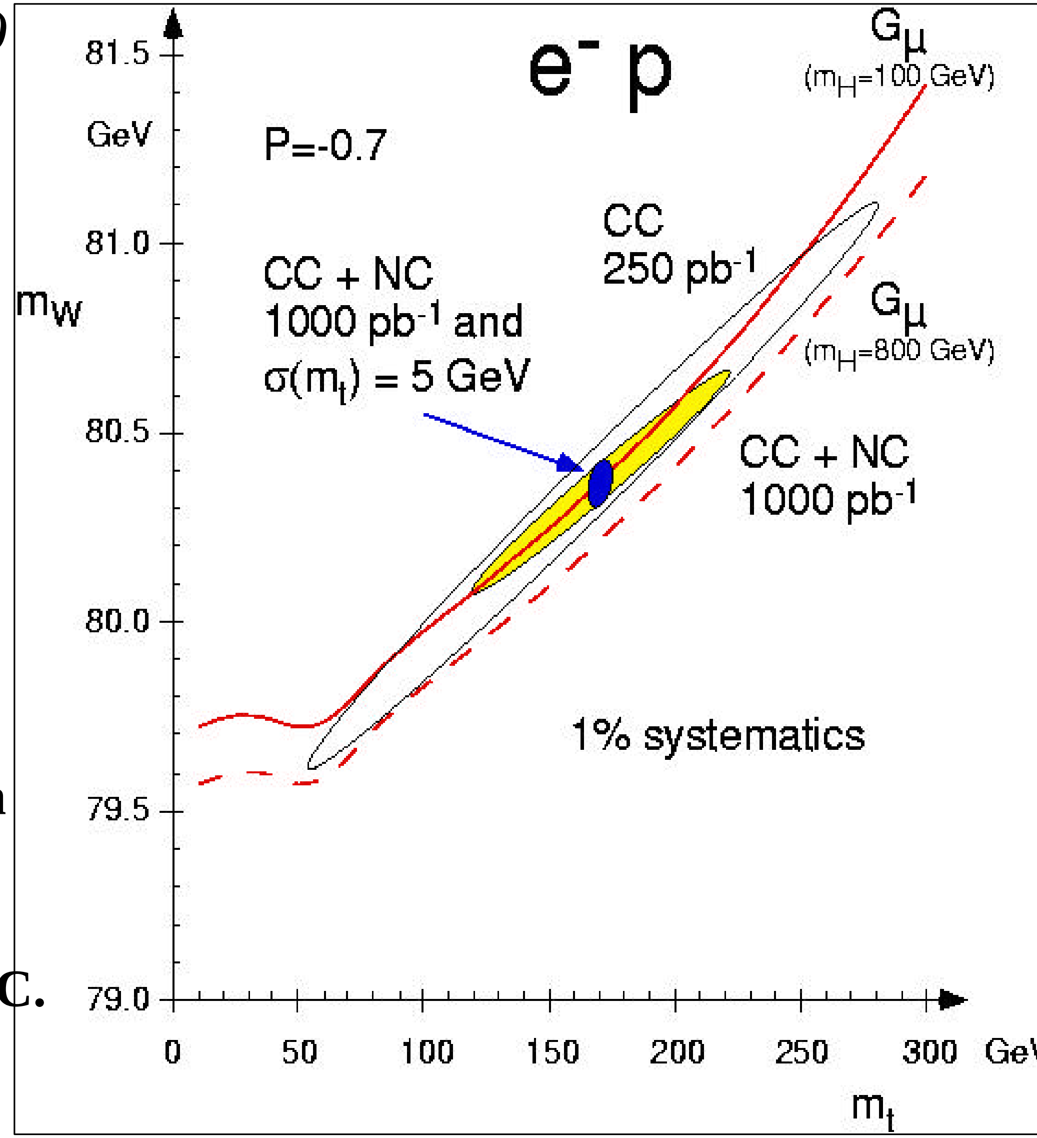
Measurements of EW Parameters: M_W

- **Free parameters in SM** (a, M_Z, M_W, M_H, M_t)
- **Measure** $s^{NC}_{e^-}, s^{CC}_{e^-}$ **constrain** Þ (M_W, M_t)
- *1 fb*$^{-1}$ **data from NC/CC cross sections with beam polarization** $P_{e^-} = -0.7$ Þ

$$From\,Tevatron\; dM_t = \pm 5 GeV$$

$$Þ\; dM_W = \pm 55 MeV$$

- **Test of EW universality.**
- **LH** e^- **gives highest precision: cross section largest.**
- **High Pol. is worth a factor 4 in Lumi for NC.**



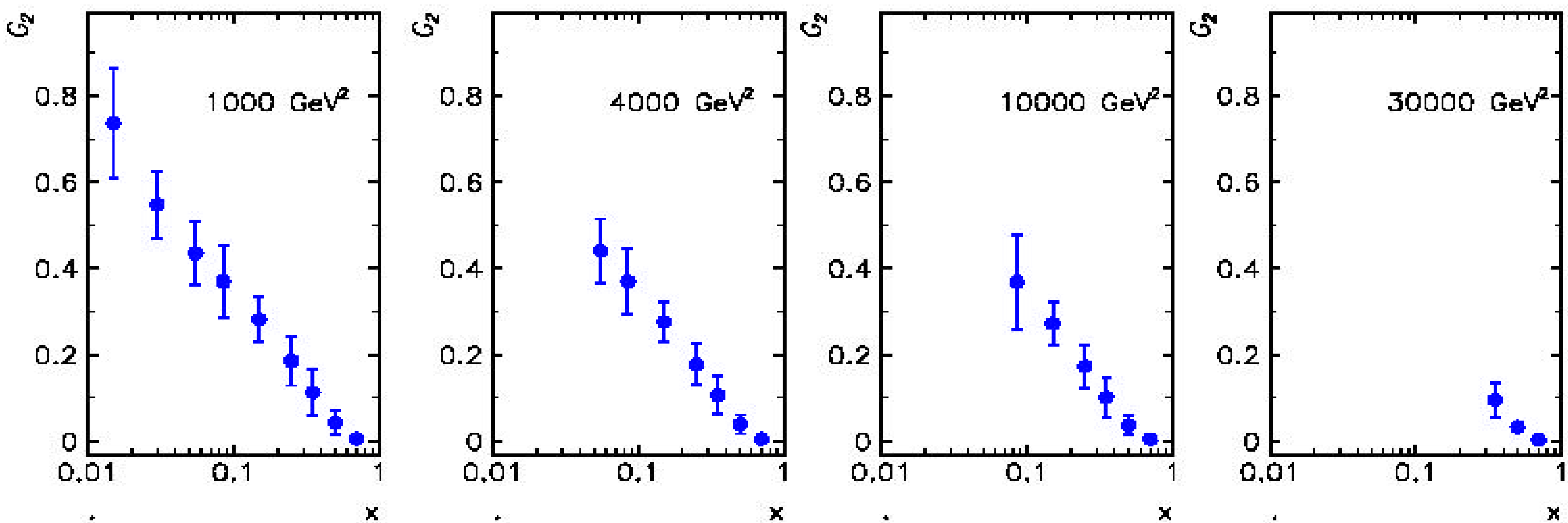
Measure G2 Structure Function

- $G_2 = F^{\gamma Z} = 2x \sum e_q v_q (q + \bar{q})$ **structure function arising from γZ interference.**
- **G2 can be measure from the neutral current parity violating asymmetry** $A^{\pm}$

$$A^{\pm} = \frac{\sigma^{\pm}_{NC}(\lambda) - \sigma^{\pm}_{NC}(-\lambda)}{\sigma^{\pm}_{NC}(\lambda) + \sigma^{\pm}_{NC}(-\lambda)} \simeq \mp\lambda\kappa_z a_e \frac{G_2}{F_2} \xrightarrow[x\to 1]{} \pm\lambda\kappa_z \frac{1 + d_v/u_v}{4 + d_v/u_v}$$

λ = degree of polarization (P)
a_e = axial charge of electron
$\kappa_z \sim 10^{-4}/Q^2[\text{ GeV}^2]$

- **Simulation for P=±50% with** ***200 pb*** $^{-1}$ **for each polarization setting: G2 can be well measured at high** ***x*****.**

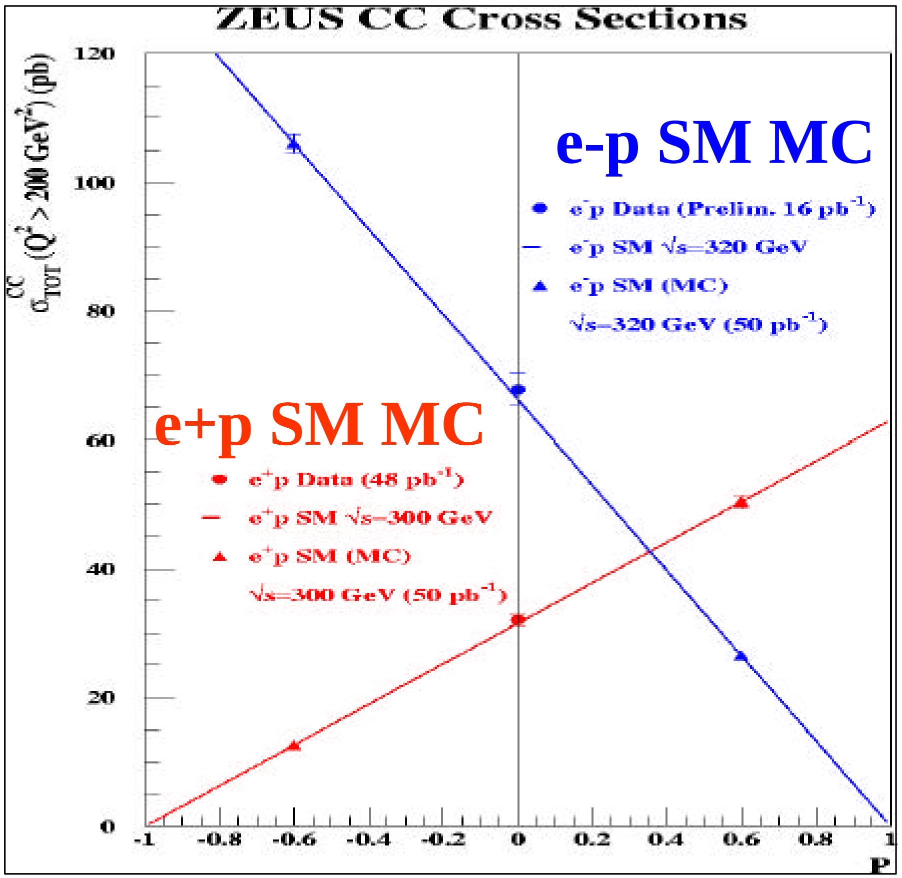


Search for Right Handed CC

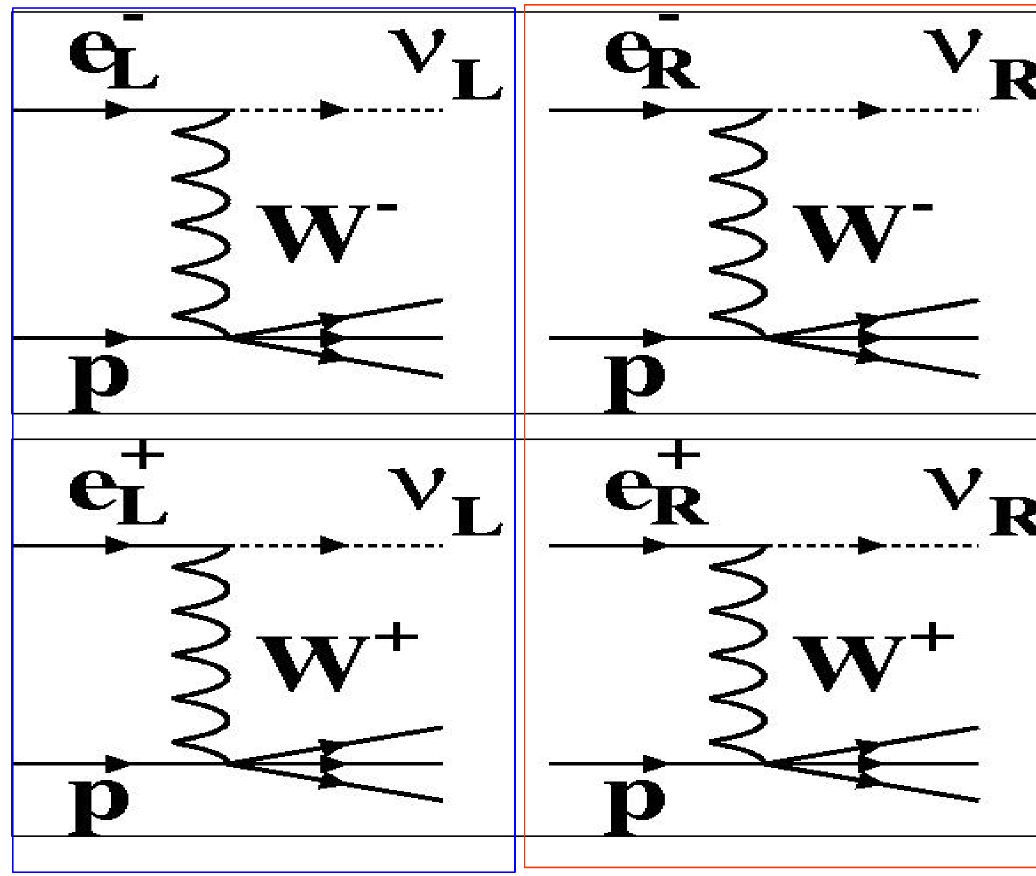
•**Standard model: only LH CC exists, cross section vanishes for purely RH electron with P=+1:**

$$\sigma^{CC}_{e^- p \to \nu X} = (1 - P)\,\sigma^{CC}_{L} + (1 + P)\,\sigma^{CC}_{R}$$

For e+ reverse sign



LHCC **RHCC**

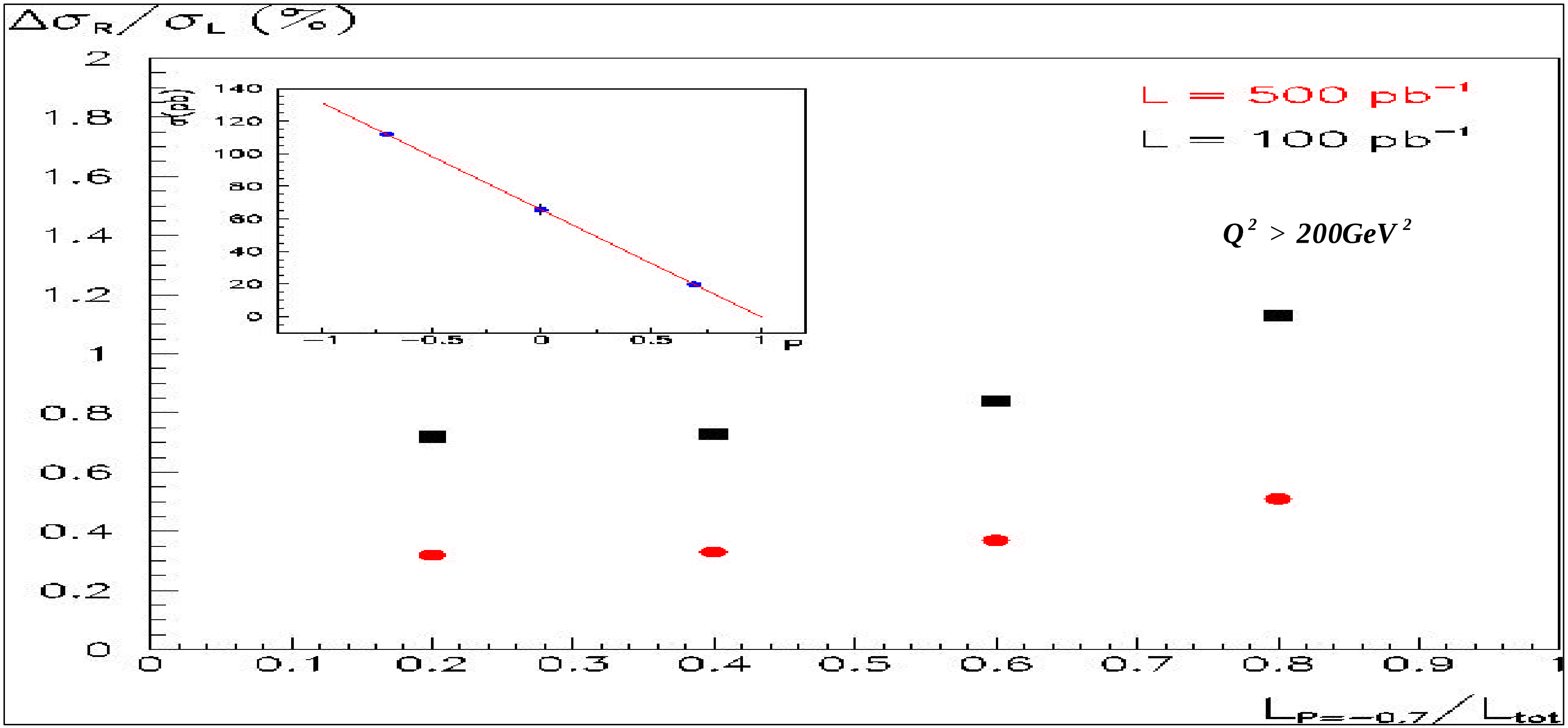


Search for Right Handed CC

- Set a limit on the mass of the hypothetical W^R boson (model dependent).

$$M_{W^R} > 400\,GeV$$

- Direct search and comparable to TEVATRON results.
- Need high polarization ^{3}50%, and precise polarization measurement.



New Physics: Beyond SM

- **Polarization is a useful tool for searching new physics signals. SM backgrounds can be turned off by changing the degree of polarization. If new physics have different couplings, the S/B will be increased.**

Leptoquarks

For Example:

- **On shell leptoquarks can be produced with polarized beams.**
- **In $e^{-}p$ scattering the SM NC cross section decreases as polarization increases.**
- **Scalar leptoquark production cross section is independent of polarization.**

Þ **Increase S/B by switching off SM using polarization of e±.**

Summary

- **HERA has been upgraded Þ HERAII:**

  - luminosity increased by a factor 5: » *1 fb^{-1}* by 2006.

  - lepton beam polarization P ³ 50% with DP/P £ 1%.

- **Two polarimeters LPOL(upgrade to be completed) and TPOL to provide accurate polarization measurements to the HERAII experiments.**
- **The polarimeters will operate independently and cross check one another; together with HERAII machine lattice simulations will provide confidence in the IP polarization value.**
- **New field of HERA physics is opened with polarized lepton beams:**

  -EW tests of SM:

  -Light quark couplings to the Z-boson, W mass;

  -G2 structure function

  -Physics beyond SM:

  -Right handed charged currents, Leptoquarks.