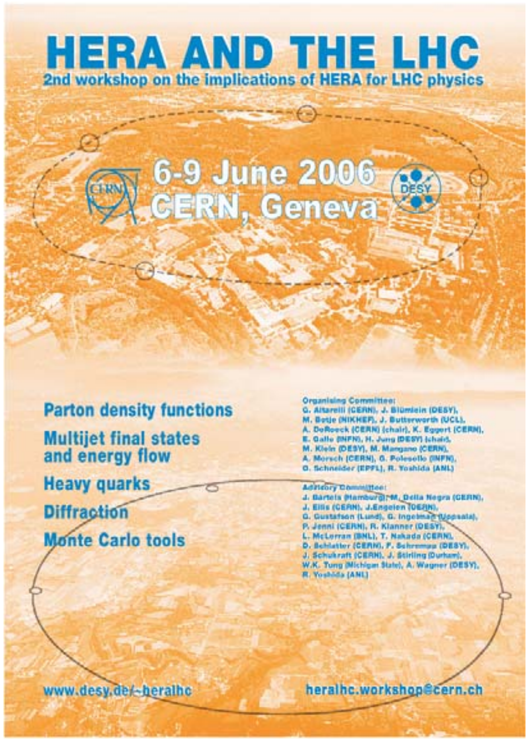
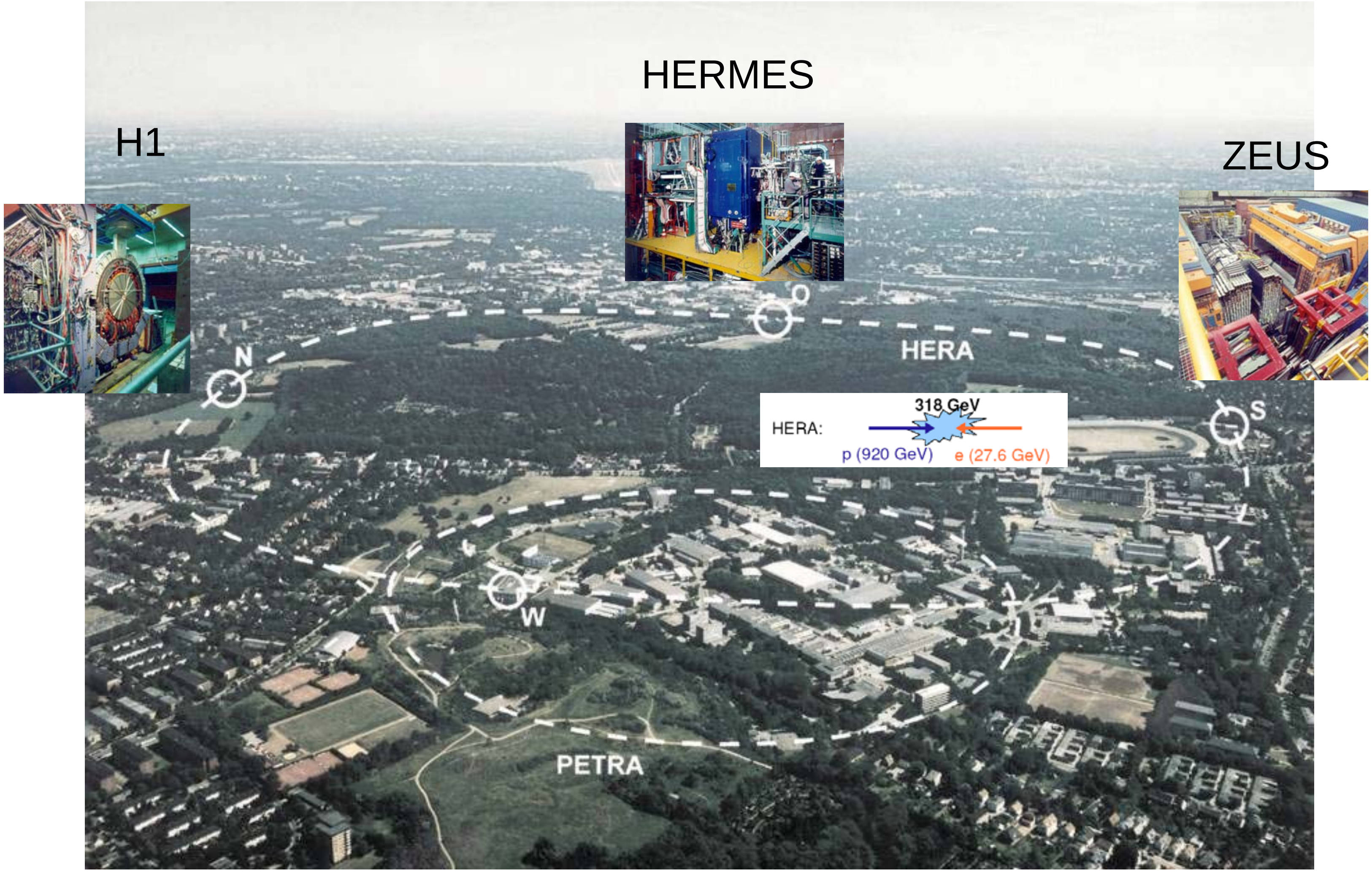
# HERA Program until 2007

Elisabetta Gallo, INFN Firenze

CERN 6/6/2006

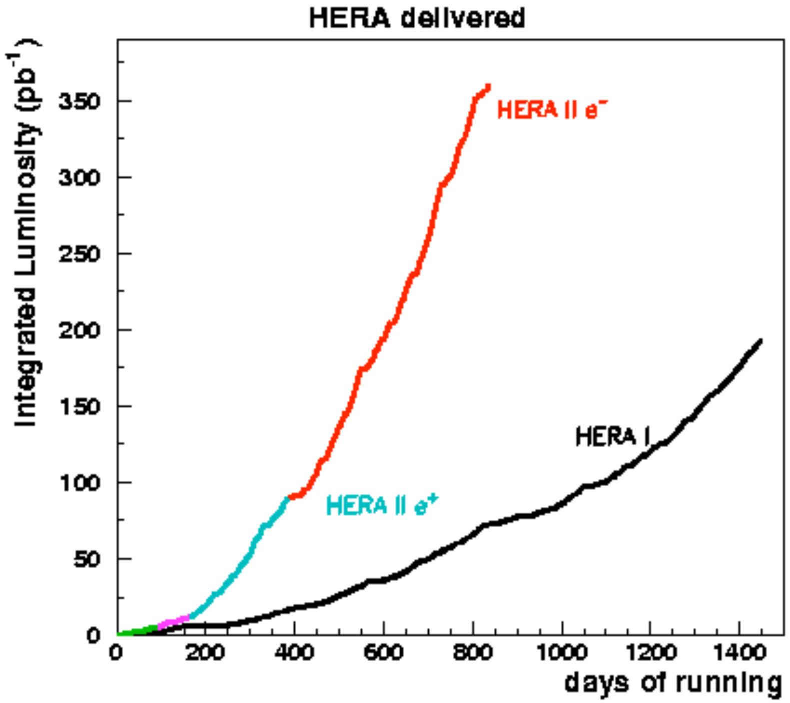


# Three experiments on HERA




Hermes fixed target, spin physics, uses lepton beam, not covered in this talk
H1 and ZEUS ep collisions at $\sqrt{s}$=318 GeV

## Taking data since 1992, run ends end of June 2007



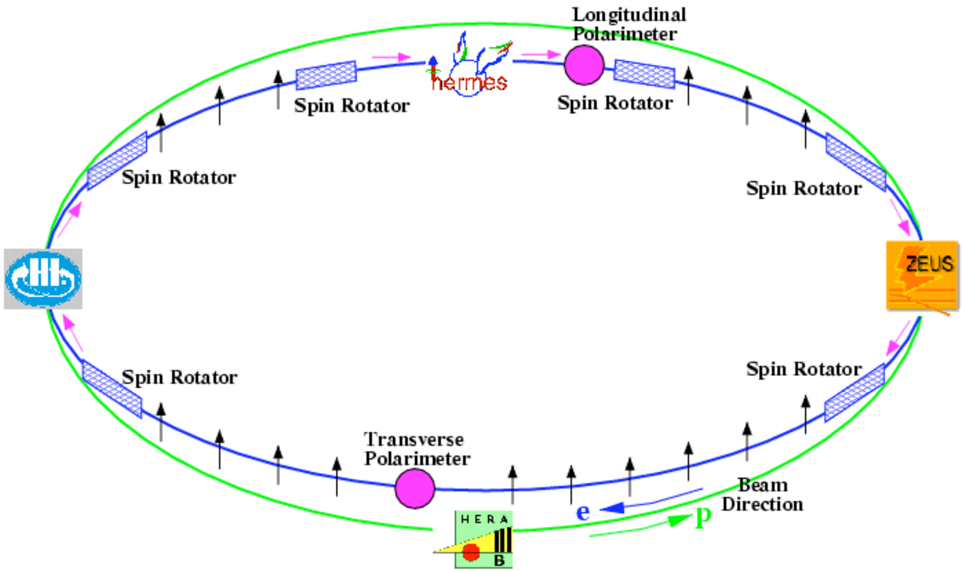

Int. luminosities in $pb^{-1}$ per experiment on tape

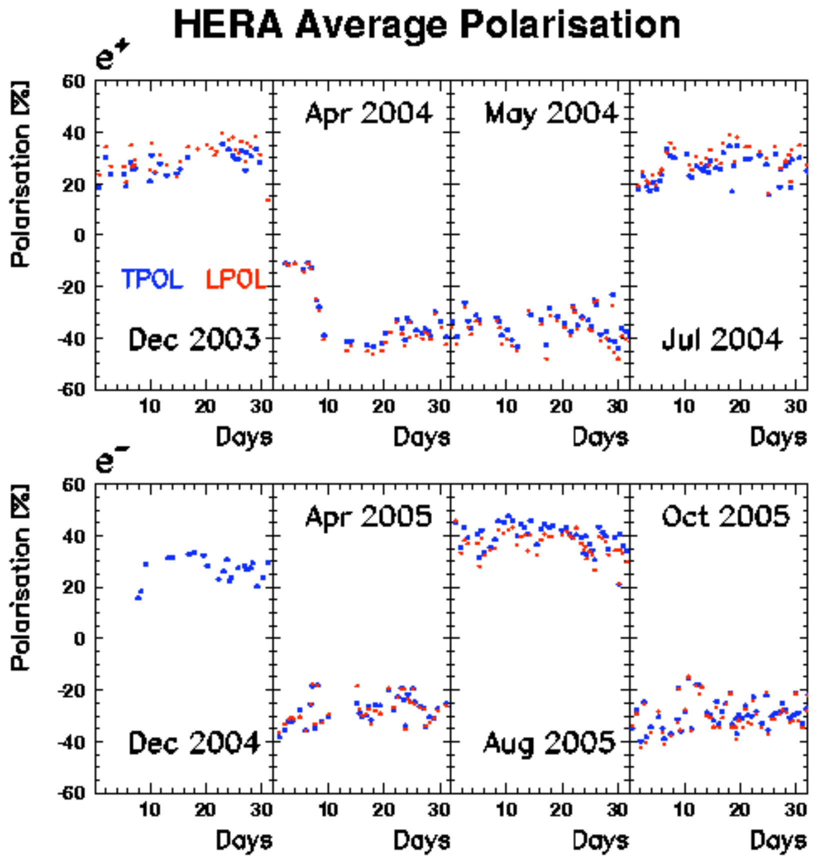
| | | |
|---|---|---|
| Hera I | 110-130 $e^+p$ | 16 $e^-p$ |
| Hera II now<br>Hera II total? | ~ 45 $e^+p$<br>>~ 210 $e^+p$ | ~ 190 $e^-p$<br>~ 210 $e^-p$ |

Schedule more or less decided mid May:

- switch to positrons end of June 2006
- run 3 months at lower proton beam energy (Ep=460 GeV) some time (in 2007 likely) after a long period of stable running

# Polarized electron/positron beams, since the upgrade




Polarization 30-40%

Spin flip every 2-3 months

Measured by three devices Tpol,Lpol and cavity, aim at a precision of 1%, i.e. not contributing significantly to syst. errors

## Outline of my talk

- What do we want to do with a high energy stable running with positrons and electrons, some examples from recent results of measurements which will be pursued

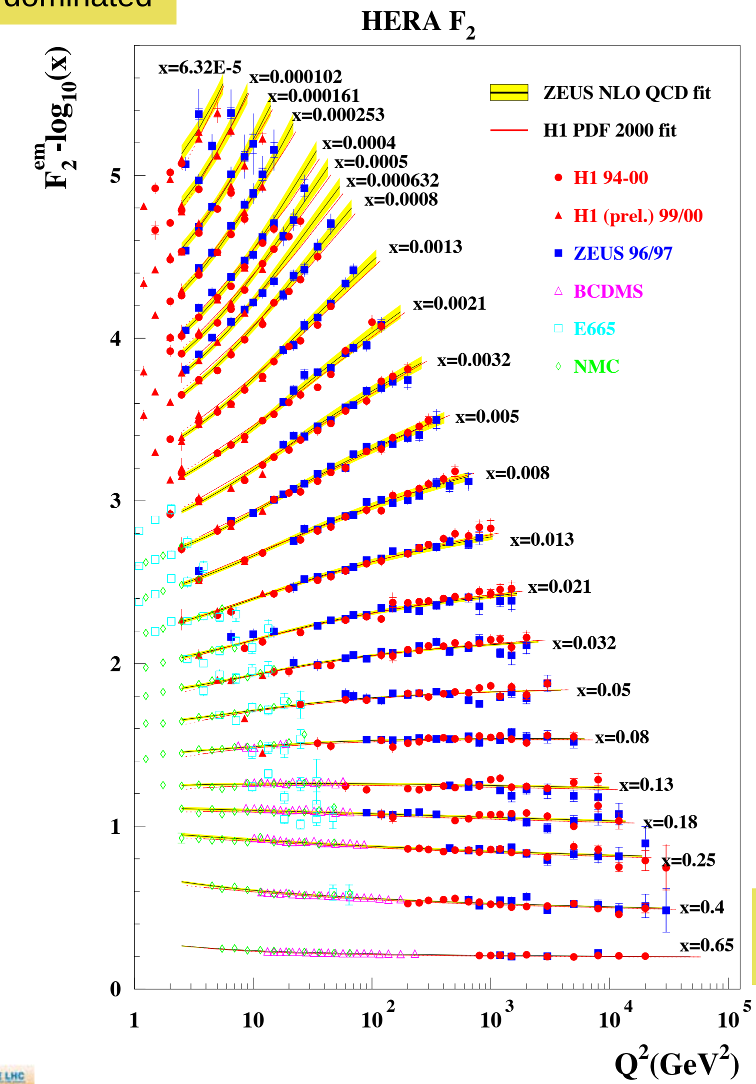
  - structure functions, parton densities
  - jets, $\alpha_S$
  - heavy flavour
  - diffraction
  - Exotics: isolated leptons events, excited neutrinos, leptoquarks

- Why we want to run three months at lower proton beam energy

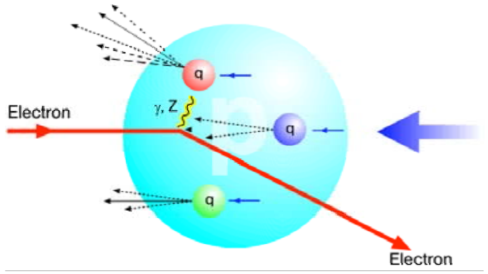
  - measurement of $F_L$, $F^D_{L}$.

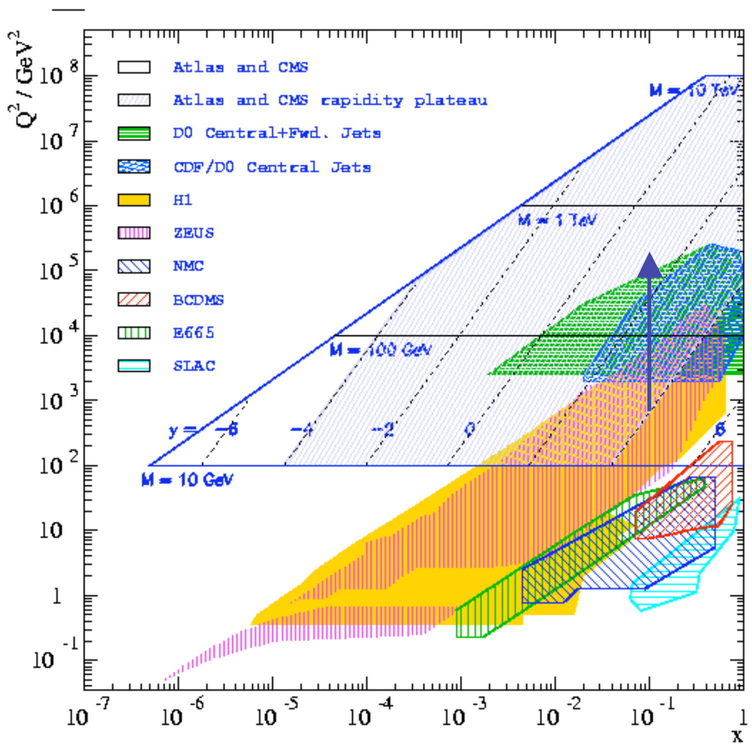
# Structure functions and parton densities

low x, sea dominated



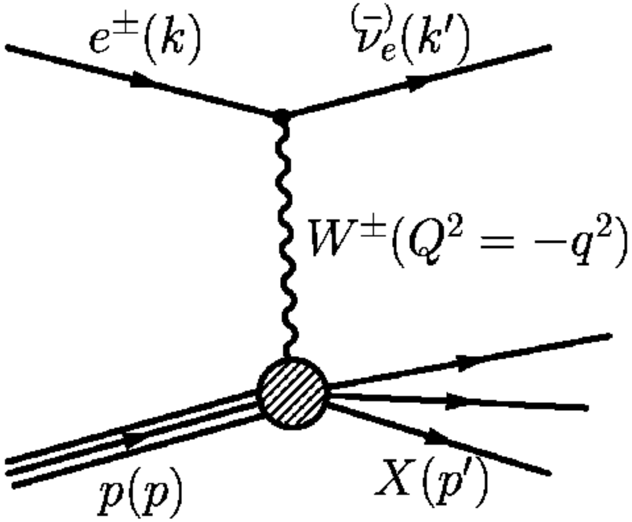

high x, valence q

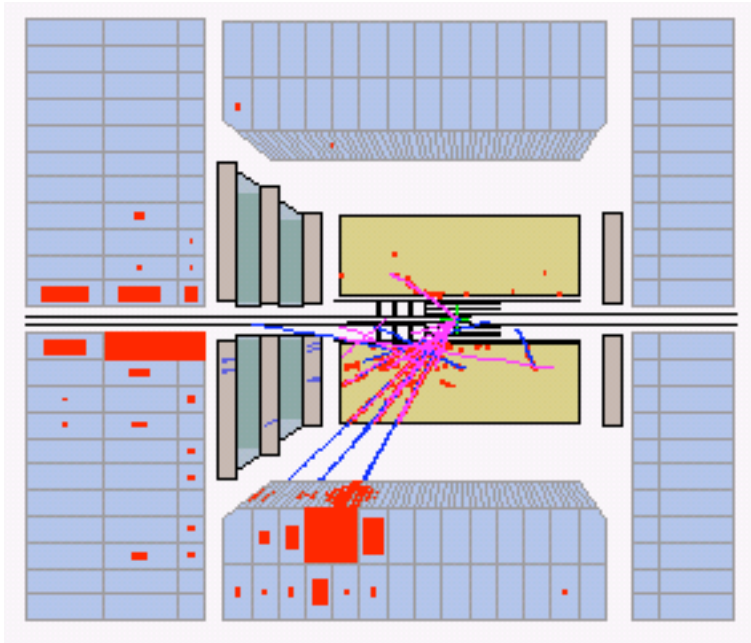



DGLAP

# Charged Current polarized cross-sections

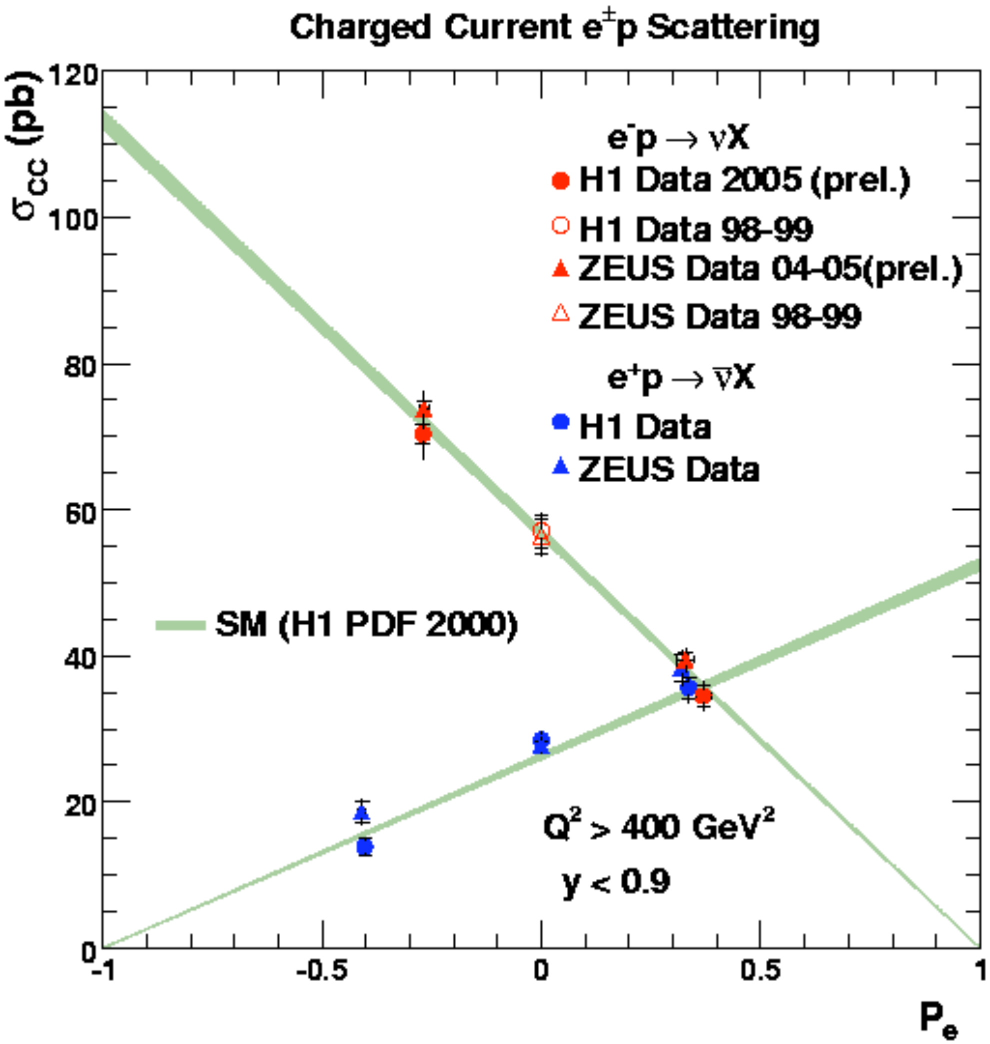


$$\frac{d\sigma^{e^+p}_{unpolCC}}{dQ^2dx} = \frac{G_F}{2\pi}\cdot\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left[\bar{u}_i(Q^2,x) + (1-y)^2 d_i(Q^2,x)\right]$$

$$\frac{d\sigma^{e^-p}_{unpolCC}}{dQ^2dx} = \frac{G_F}{2\pi}\cdot\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left[u_i(Q^2,x) + (1-y)^2 \bar{d}_i(Q^2,x)\right]$$

# Charged Current polarized cross-sections

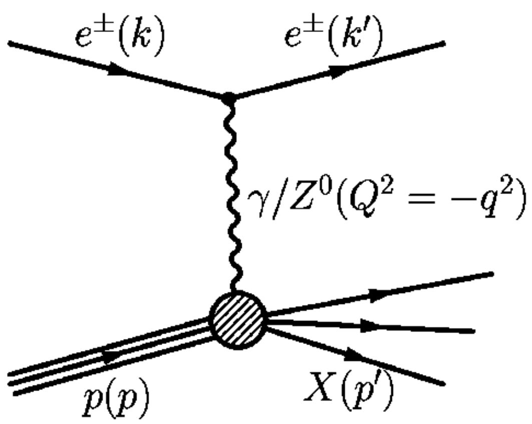


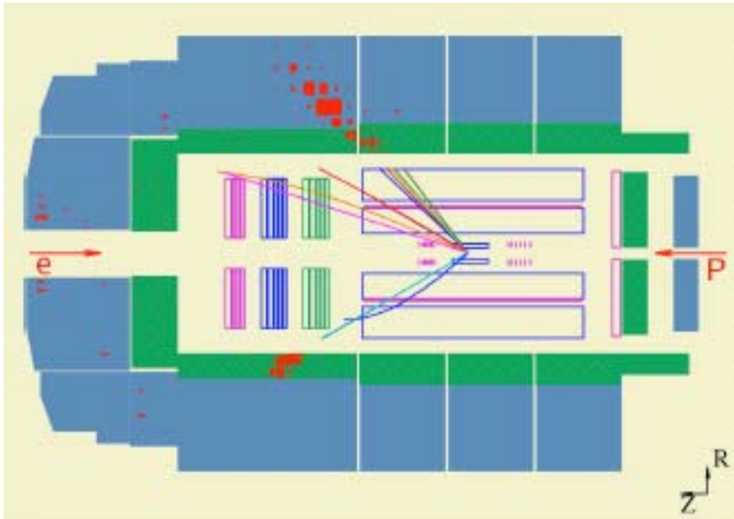

$$\sigma^{e\pm p}_{polCC}(Q^2, x) = \frac{1 \pm P_e}{2} \cdot \sigma^{e\pm p}_{LHCC}(Q^2, x)$$

Textbook plot, absence of RH currents in the CC pure weak interaction.

$M(W_R)$>~180-208 GeV with present accuracy

# Neutral Current cross-sections




$$\sigma(e^{\pm}) \propto Y_+ F_2\,(e^{\pm}) \mp Y_- xF_3\,(e^{\pm})$$

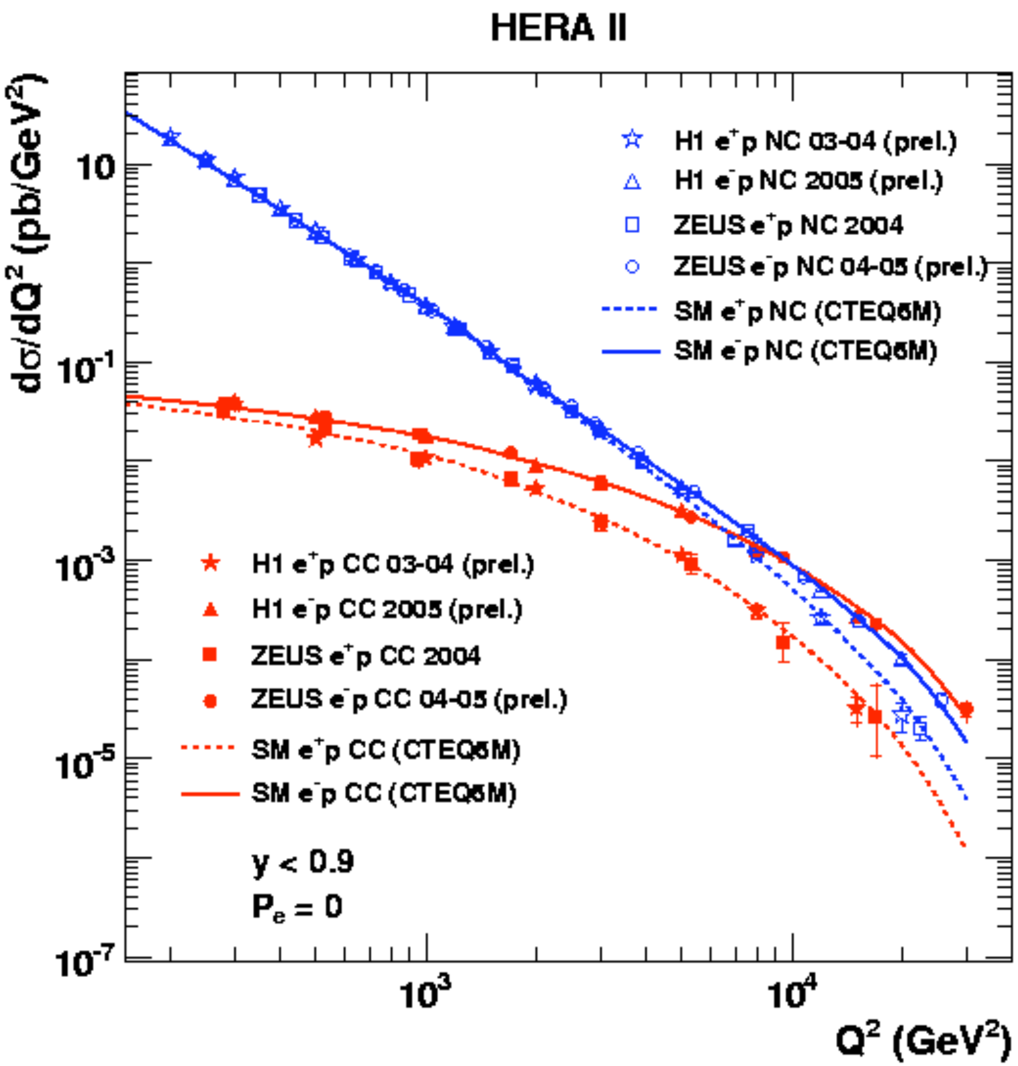
$$F_2^{L,R} = \sum_q [xq(x,Q^2) + x\bar{q}(x,Q^2)] \cdot A_q^{L,R},$$

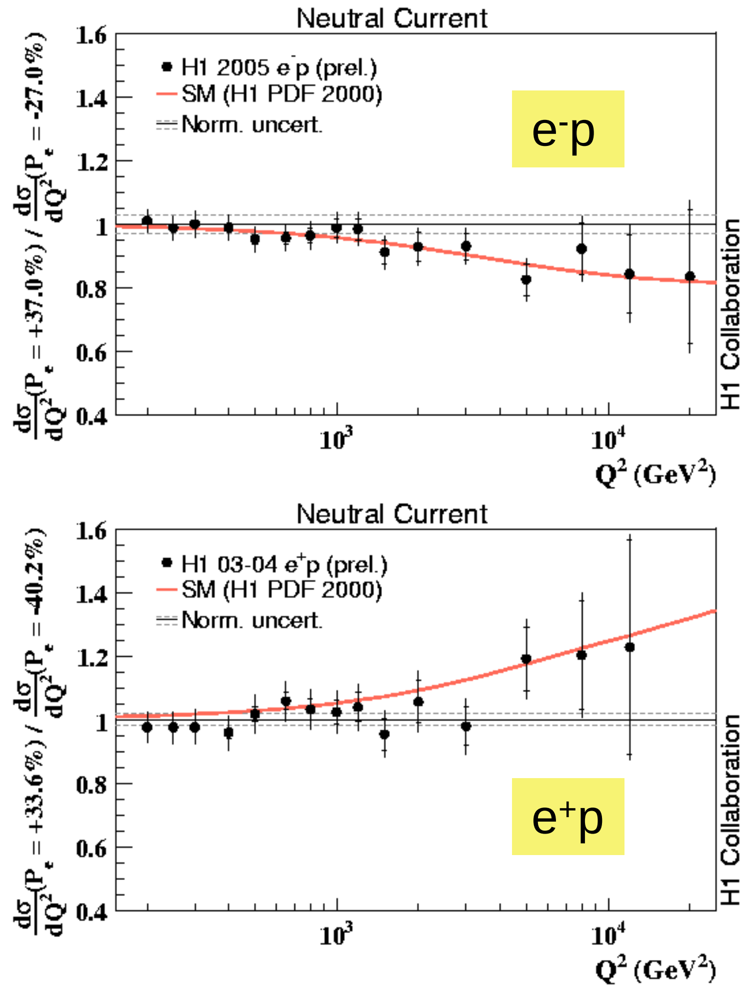
$$xF_3^{L,R} = \sum_q [xq(x,Q^2) - x\bar{q}(x,Q^2)] \cdot B_q^{L,R}.$$

$$A_q^{L,R} = Q_q^2 + 2Q_eQ_q(v_e \pm a_e)v_q\chi_Z + (v_e \pm a_e)^2(v_q^2 + a_q^2)\,(\chi_Z)^2\,,$$

$$B_q^{L,R} = \pm 2Q_eQ_q(v_e \pm a_e)a_q\chi_Z \pm 2(v_e \pm a_e)^2 v_q a_q\,(\chi_Z)^2\,,$$

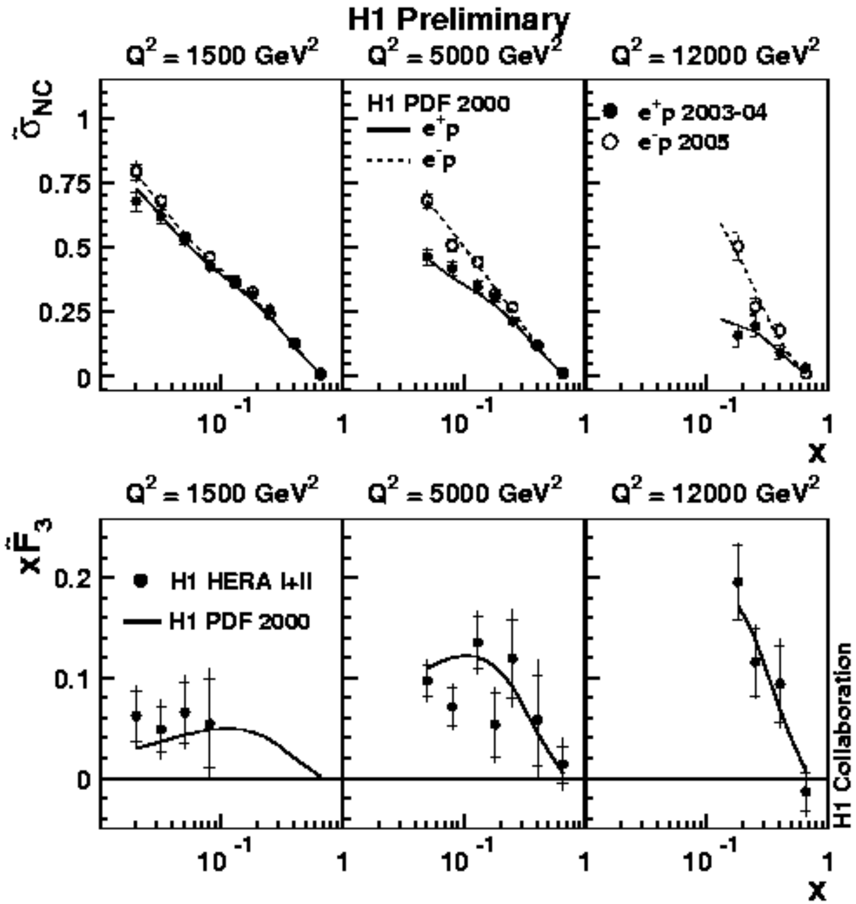
# NC cross sections

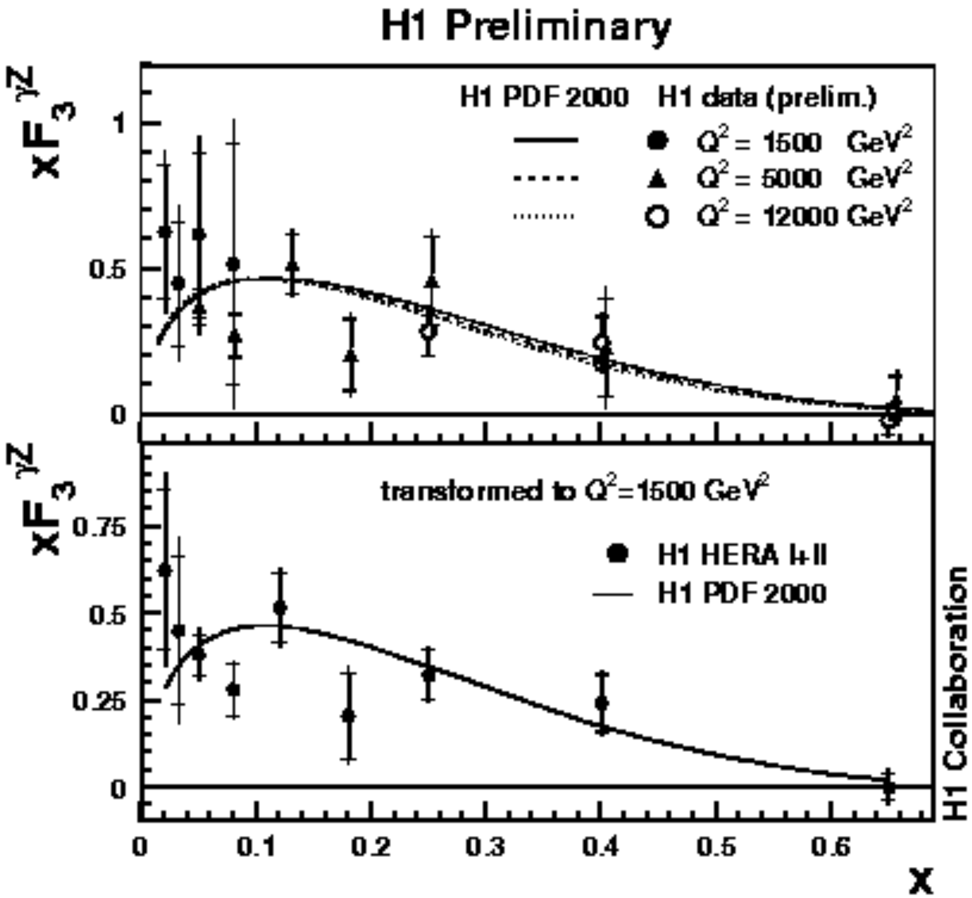



Effect of polarization in NC only visible at very high $Q^2$

# Measurement of $xF_3$




$$xF_3 = (\tilde{\sigma}(e^- p) - \tilde{\sigma}(e^+ p))\ (Y_+/2Y_-)$$

$$xF_3^{\gamma Z} = xF_3 / [-a_e k_w / (Q^2 + M_Z^2)] \sim (2u_v + d_v)$$

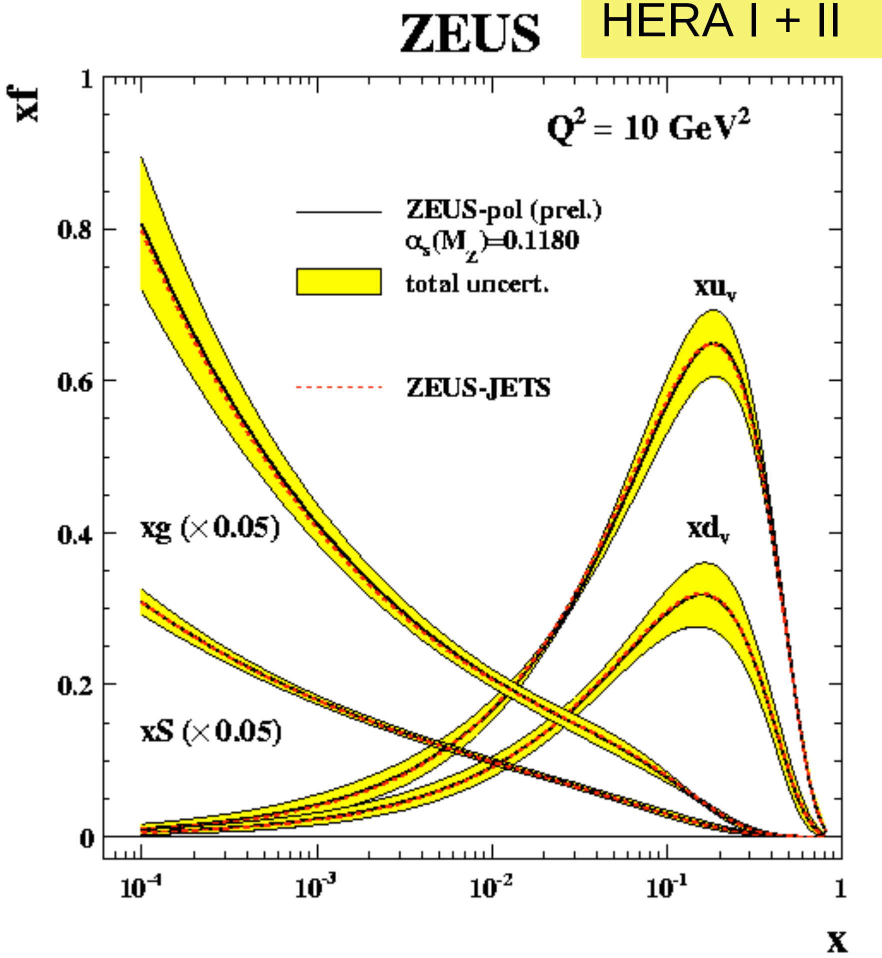
# Combined QCD&EW fits

$$xf(x) = Ax^{b}(1-x)^{c}(1+dx)$$

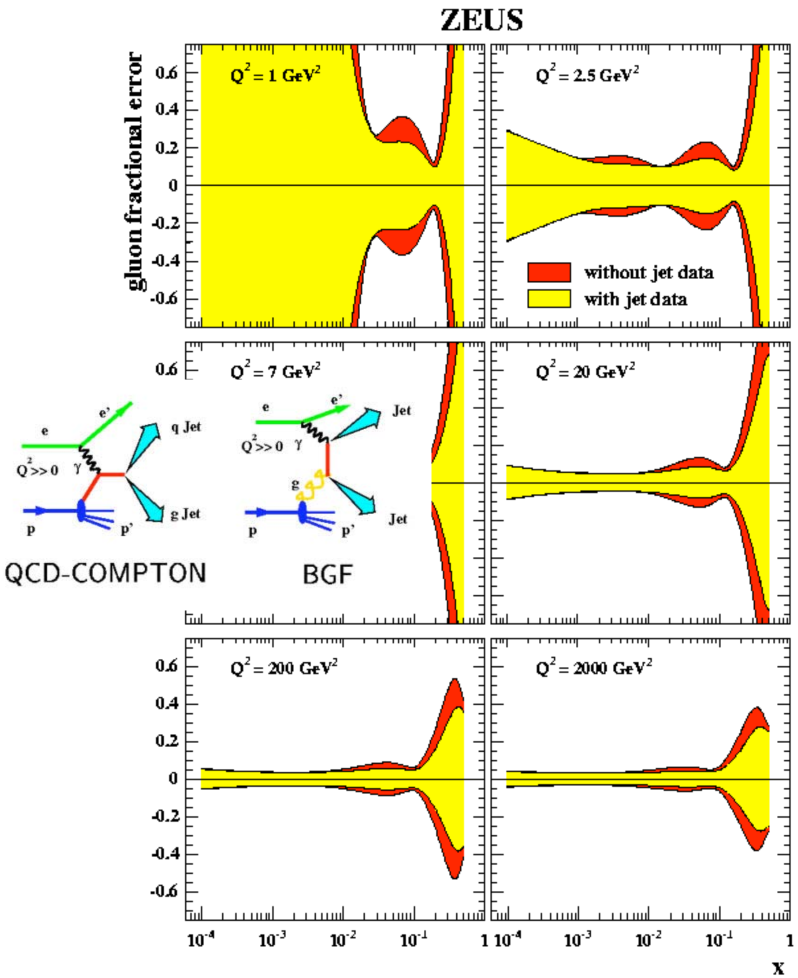
i.e. at ZEUS

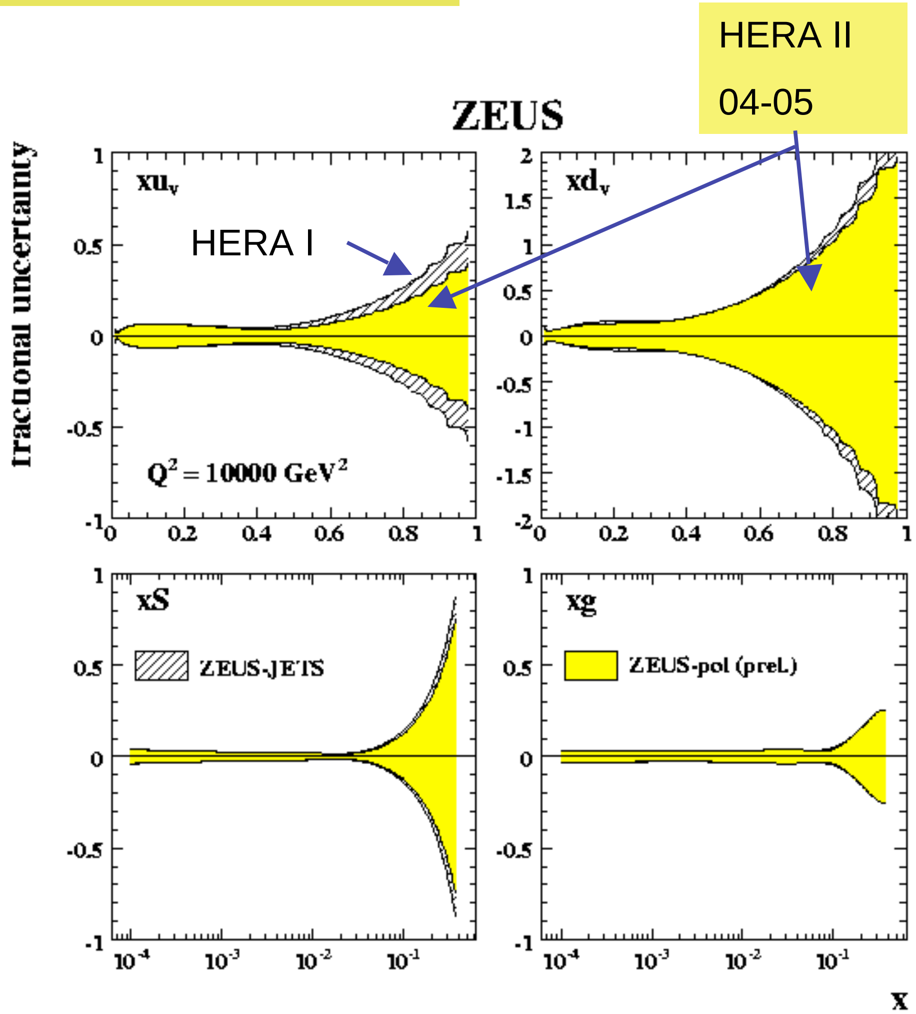
- Parton densities parametrized at $Q_0^2 = 7\ \mathrm{GeV}^2$ for $xu_v$, $xd_v$, $xS$, $xg$, $x\Delta$ and evolved in $Q^2$ with DGLAP
- low $x$ (sea,gluons) constrained by $F_2$ at low $Q^2$
- high $x$ $u,d$ valence constrained by high $Q^2$ NC and CC cross sections ($e^+/e^-$)
- mid $x$ gluon constrained by jet data (DIS and direct photoproduction)
- EW parameters better constrained by HERA II polarized structure functions

HERA I + II



# Combined QCD&EW fits




Central value of PDFs does not change with the new HERA II data, but uncertainty on u-valence much reduced due to more $e^-$ data. In addition it is possible to fit the couplings to the Z for u,d quarks

# Combined QCD&EW fits

$$\sigma_r(e^{\pm}p) = (Y_+F_2^0 \mp Y_-xF_3^0) \mp P(Y_-F_2^P \mp Y_-xF_3^P)$$

Neutral current cross-section

$$F_2^{0,P} = \sum_i A_i^{0,P}(Q^2)[xq_i(x,Q^2) + x\bar{q}(x,Q^2)]$$

$$xF_3^{0,P} = \sum_i B_i^{0,P}(Q^2)[xq_i(x,Q^2) - x\bar{q}(x,Q^2)]$$

Polarized structure functions

$$A^0(Q^2) = -e_i^2 - 2e_iv_iv_eP_Z + (v_e^2 + a_e^2)(v_i^2 + a_i^2)P_Z^2$$

$$B_i^0(Q^2) = \underline{-2e_ia_ia_eP_Z} + 4a_ia_ev_iv_eP_Z^2$$

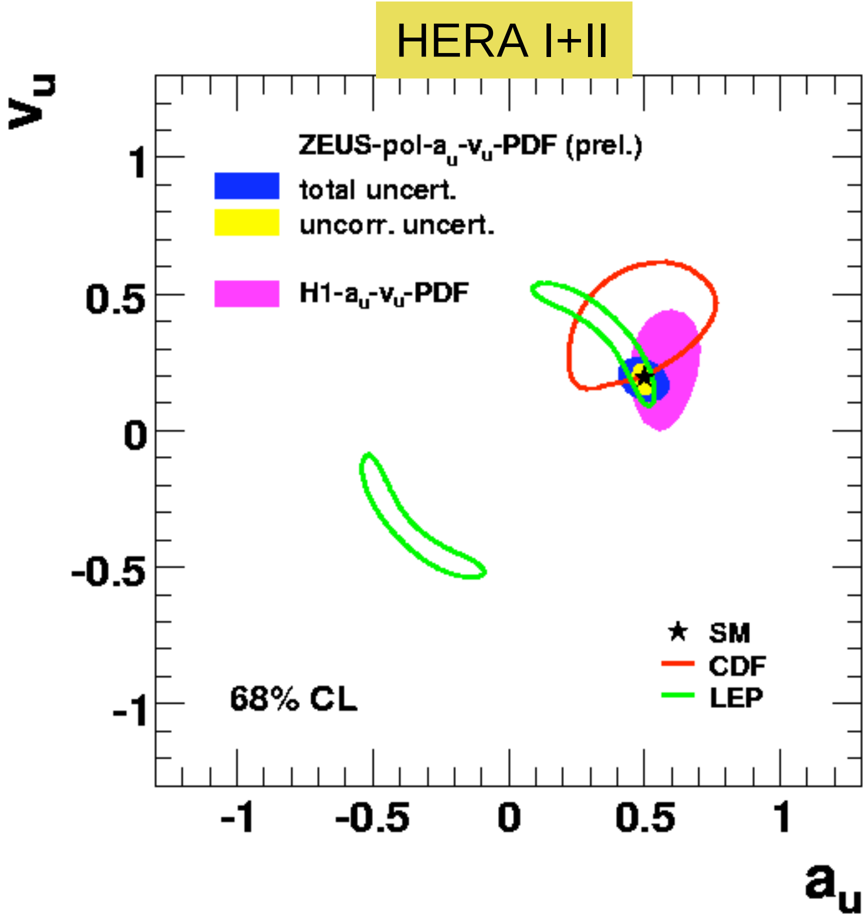
Unpolarized $xF_3$ determines the axial couplings

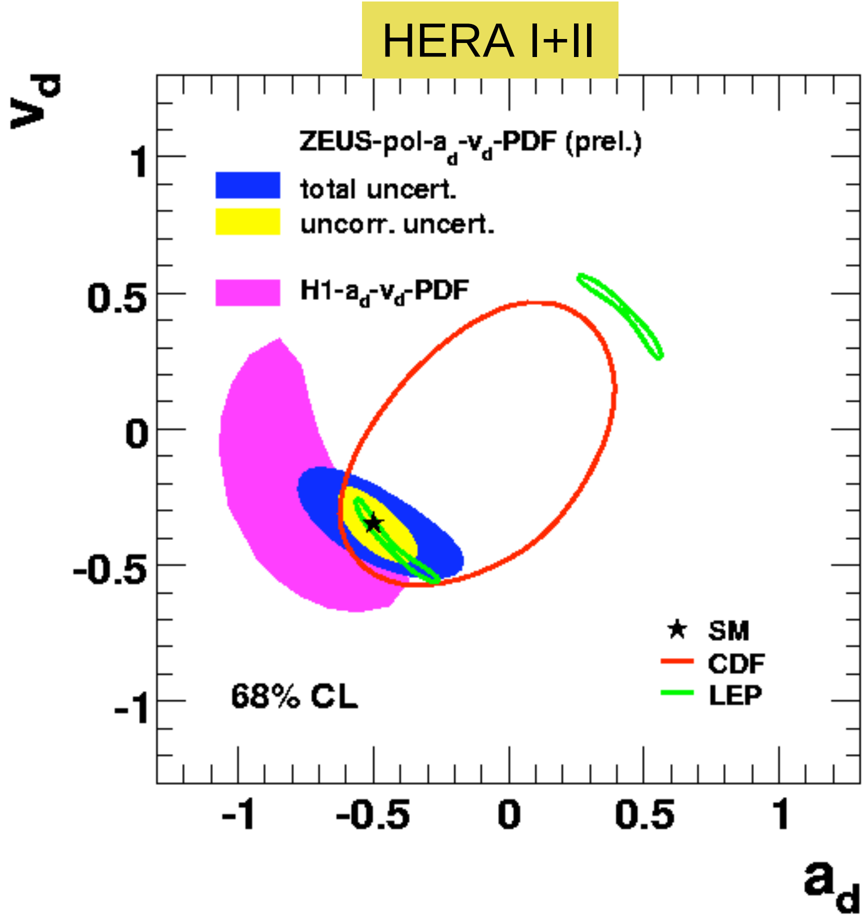
$$A_i^P(Q^2) = \underline{-2e_iv_ia_eP_Z} - 2v_ea_e(v_i^2 + a_i^2)P_Z^2$$

$$B_i^P(Q^2) = -2e_ia_iv_eP_Z - 2v_ia_i(v_e^2 + a_e^2)P_Z^2$$

Polarized $F_2$ determines the vector couplings

# Combined QCD&EW fits

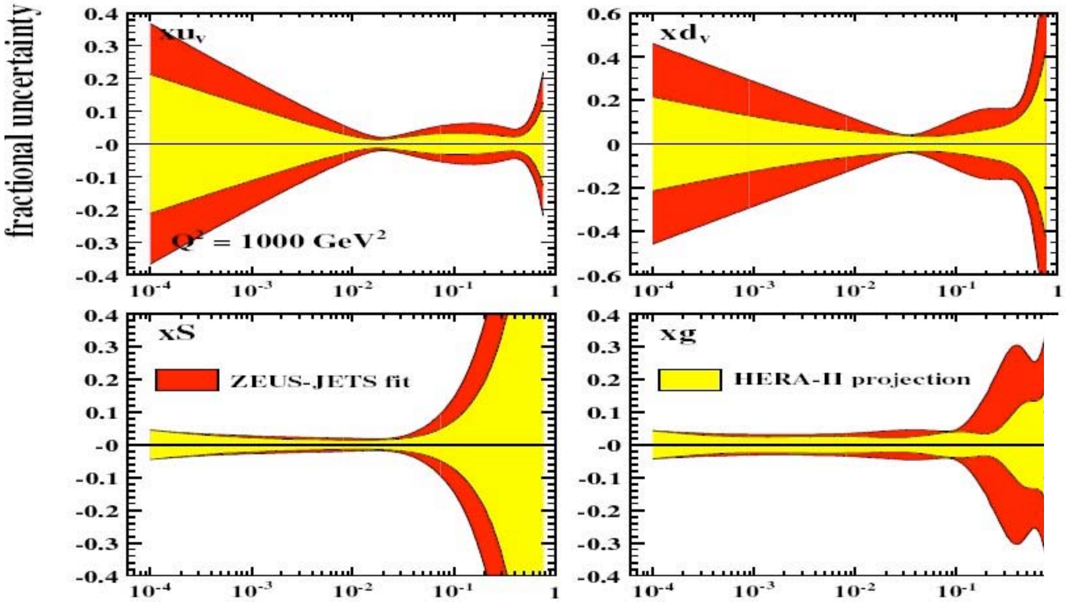


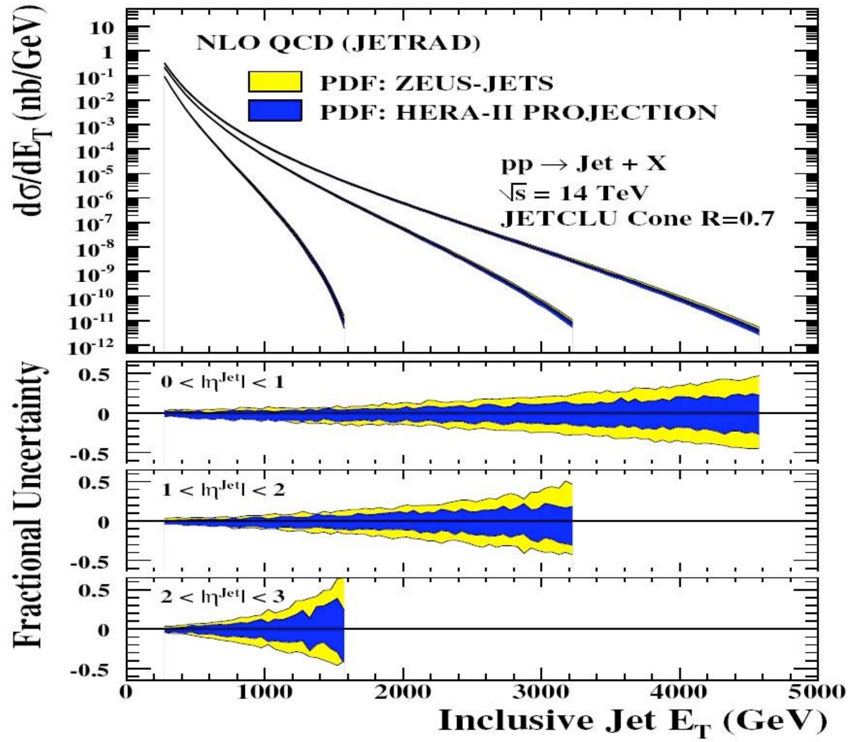

H1: HERA I unpolarized data; ZEUS HERA II polarized data

Axial and vector couplings of u and d quarks determined with good precision and compatible with SM predictions

# QCD fits prospects



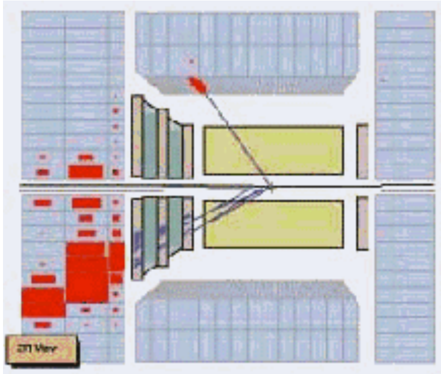

C. Gwenlan, A. Cooper-Sakar, C.Targett-Adams, HERA-LHC proceedings

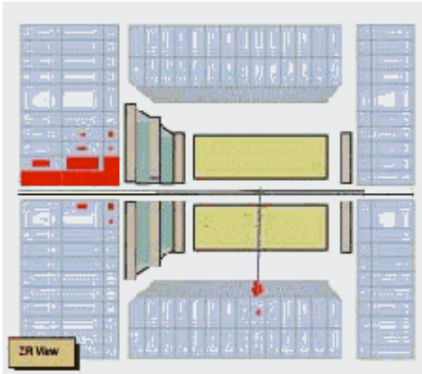



Projection for 500 pb$^{-1}$ of integrated luminosity at HERA II ($e^+$, $e^-$, jets)

Improvement of PDFs at high *x* reflected in jets cross sections at LHC

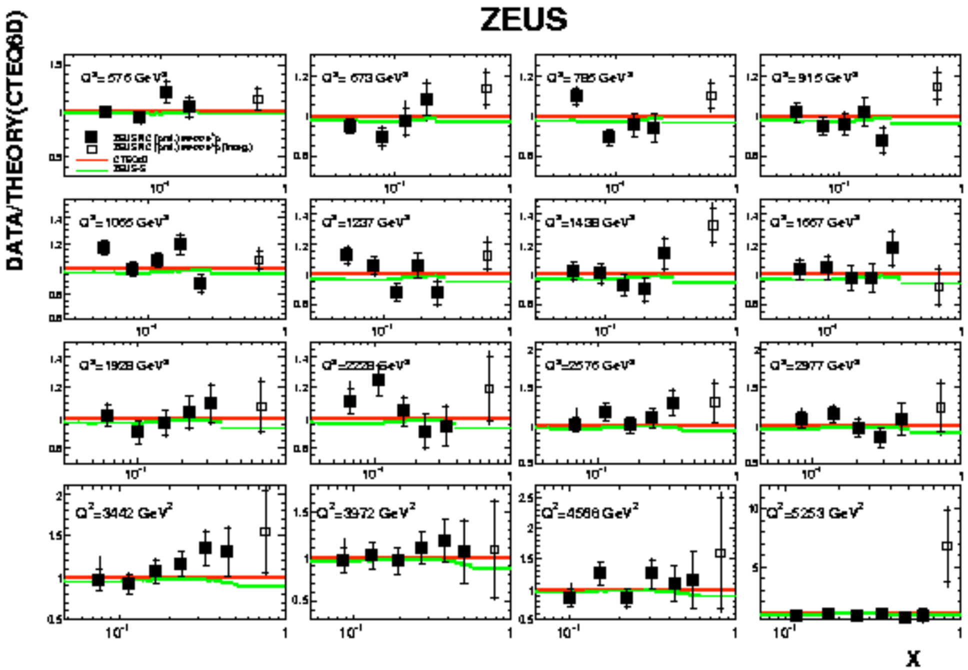
# Cross sections at very high x

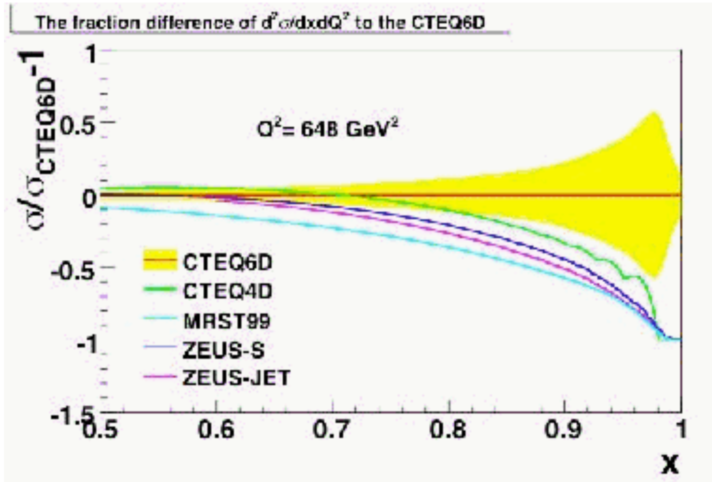




Technique from ZEUS:

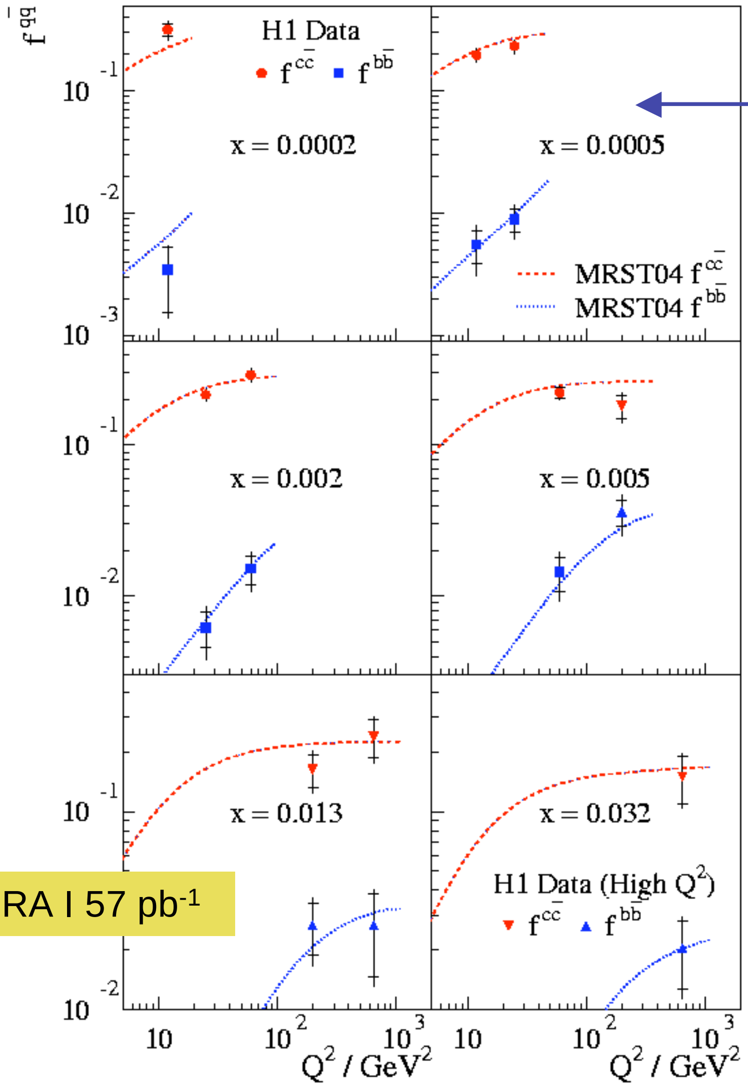
- reconstruct $Q^2$ from electron
- jet in detector, reconstruct *x* from jet
- jet in beampipe, very high-*x*, integrate cross-section up to *x=1*
- Will be further exploited for HERA II




Uncertainties on PDFs at high *x* still high

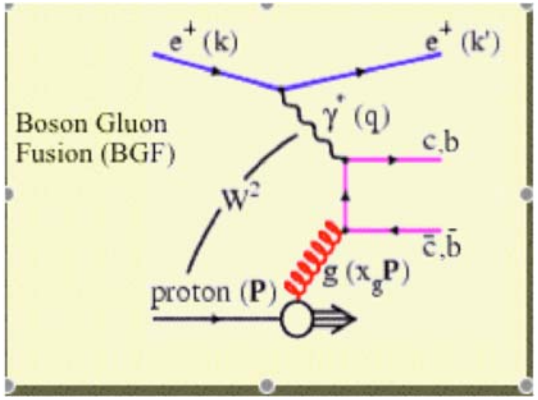
# Measurement of $F_2^{ccbar}$ and $F_2^{bbar}$

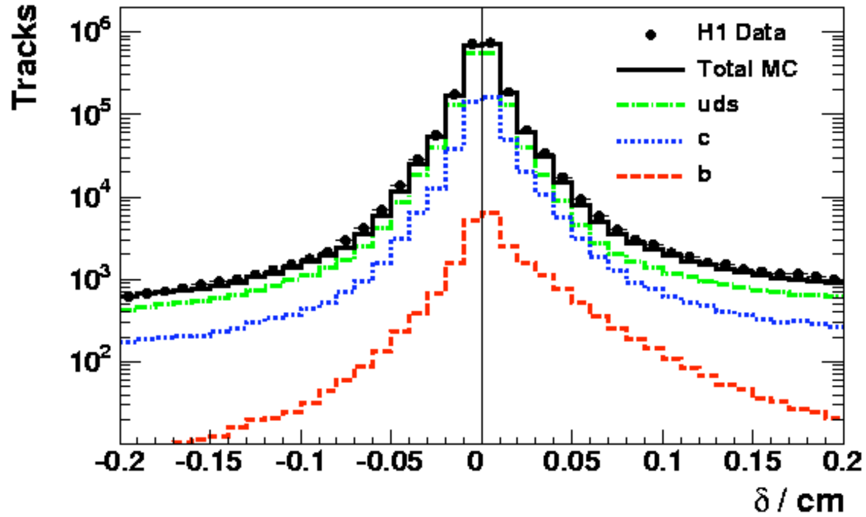



HERA I 57 $pb^{-1}$

Fraction of $F_2^{ccbar}$ and $F_2^{bbar}$ to $F_2$.

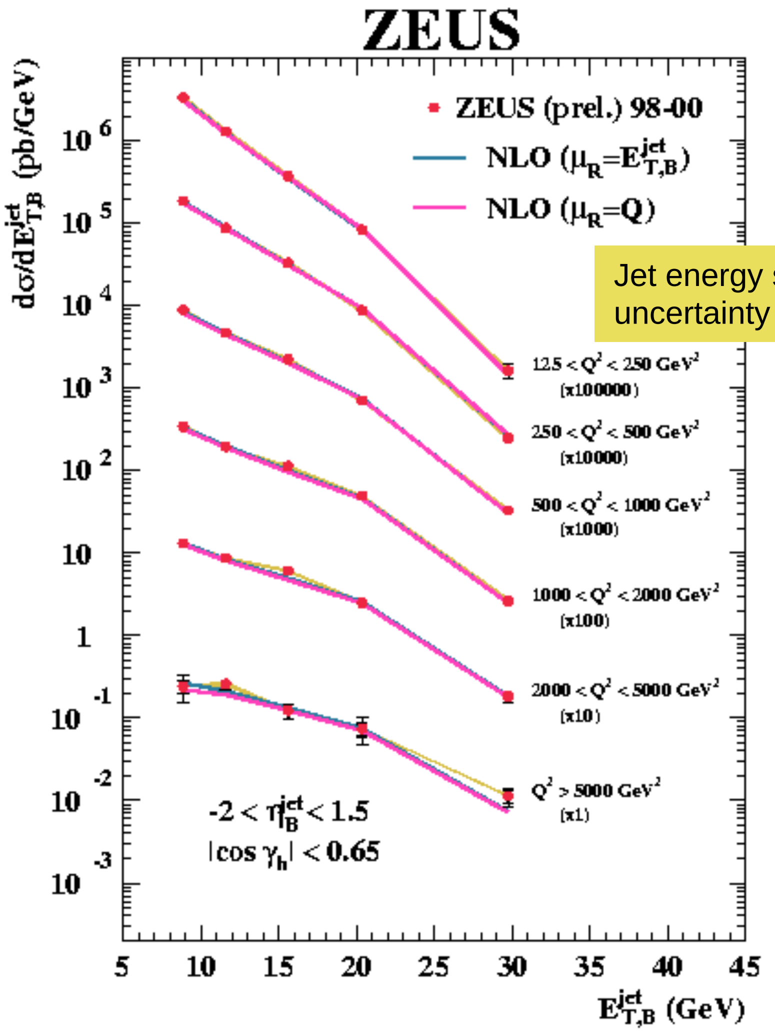
Heavy quark production is a hot QCD topics at hadron colliders, beauty density in the p must be known at LHC



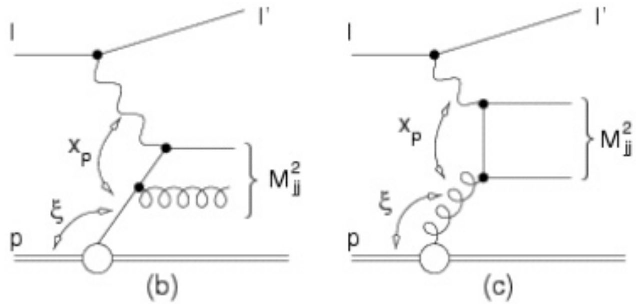



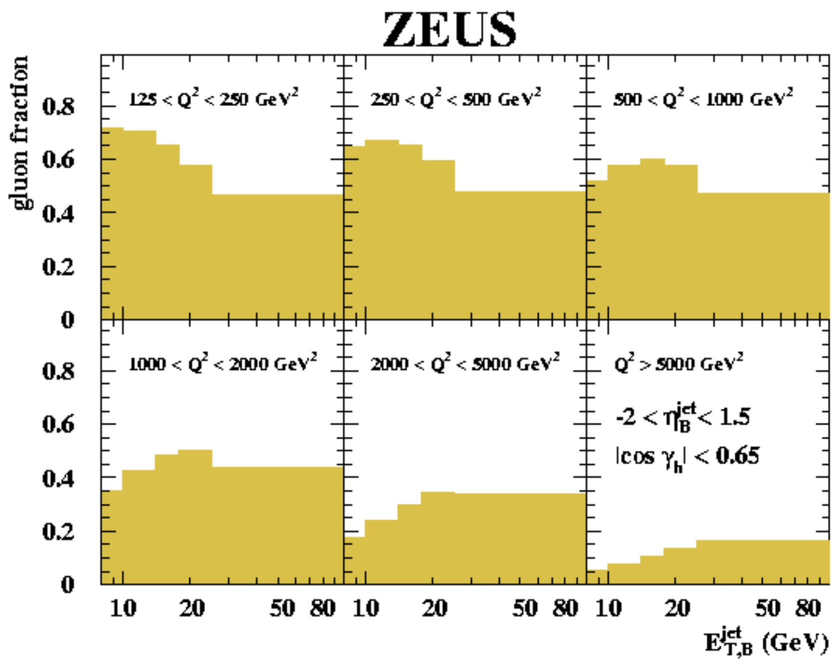

Selection based on impact parameters, using the H1 CST, less extrapolation. For HERA II data also from ZEUS, expect ~450 $pb^{-1}$ per experiment

# Jets and $\alpha_S$



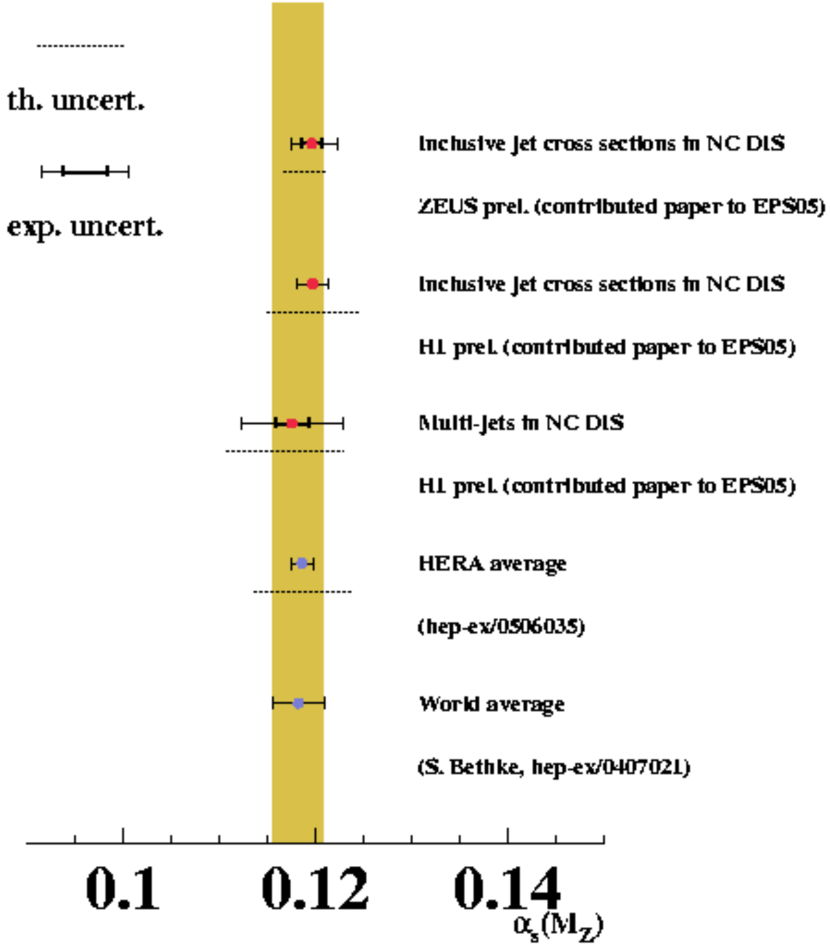

Jet energy scale uncertainty of 1%

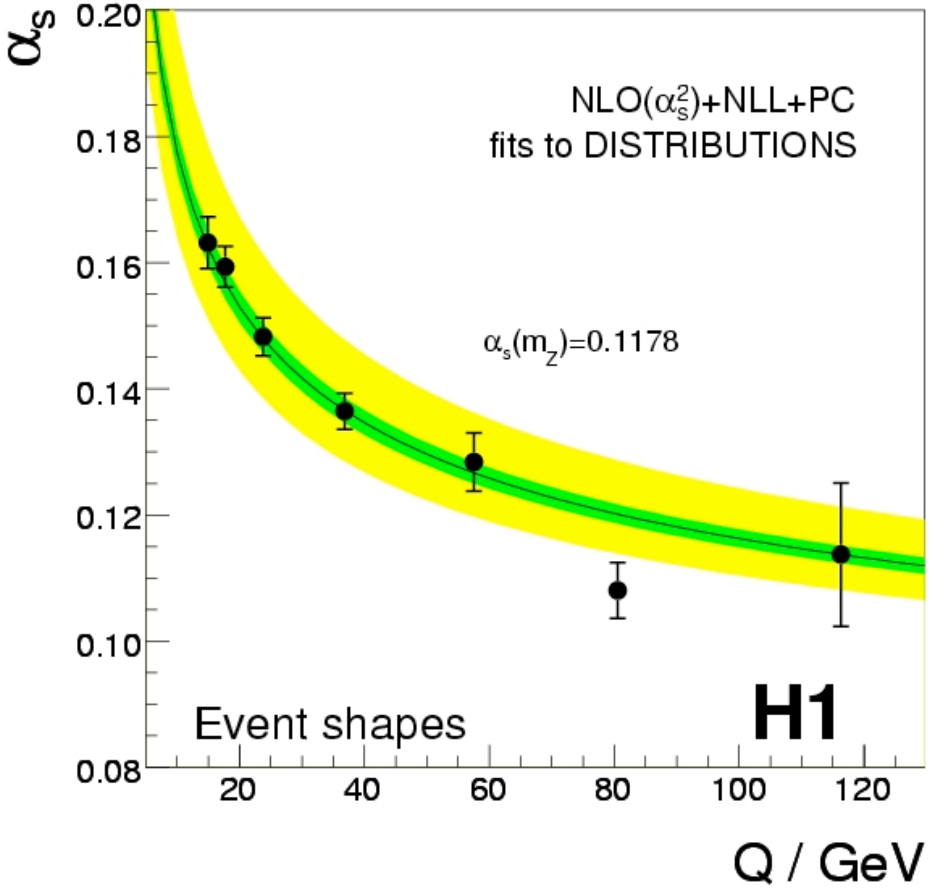



These measurements will provide additional constraints for the gluon distribution at middle *x*; and give a measurement of $\alpha_S$

# Jets and $\alpha_S$

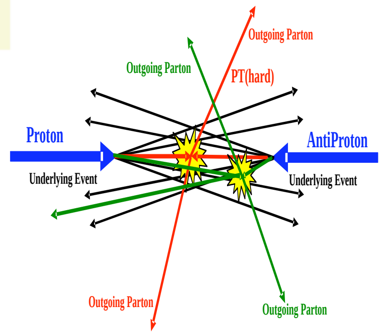


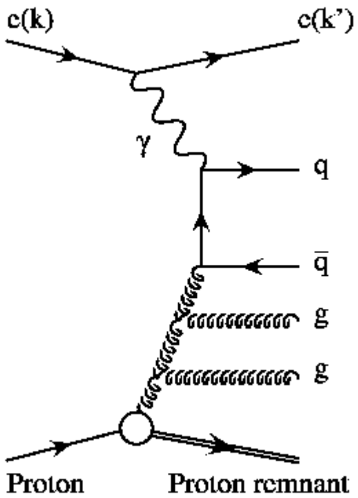

Precise measurement of $\alpha_S$ at HERA, error dominated by theory

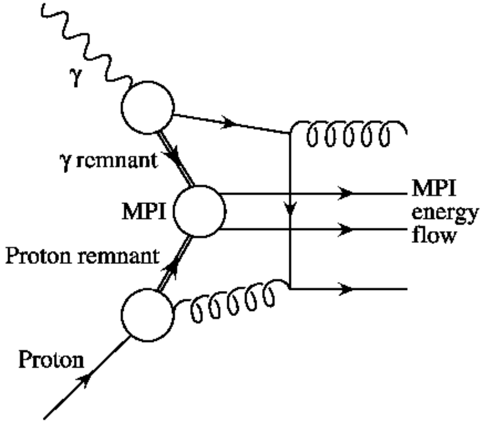
Running measured from jets and event shapes in a single experiment

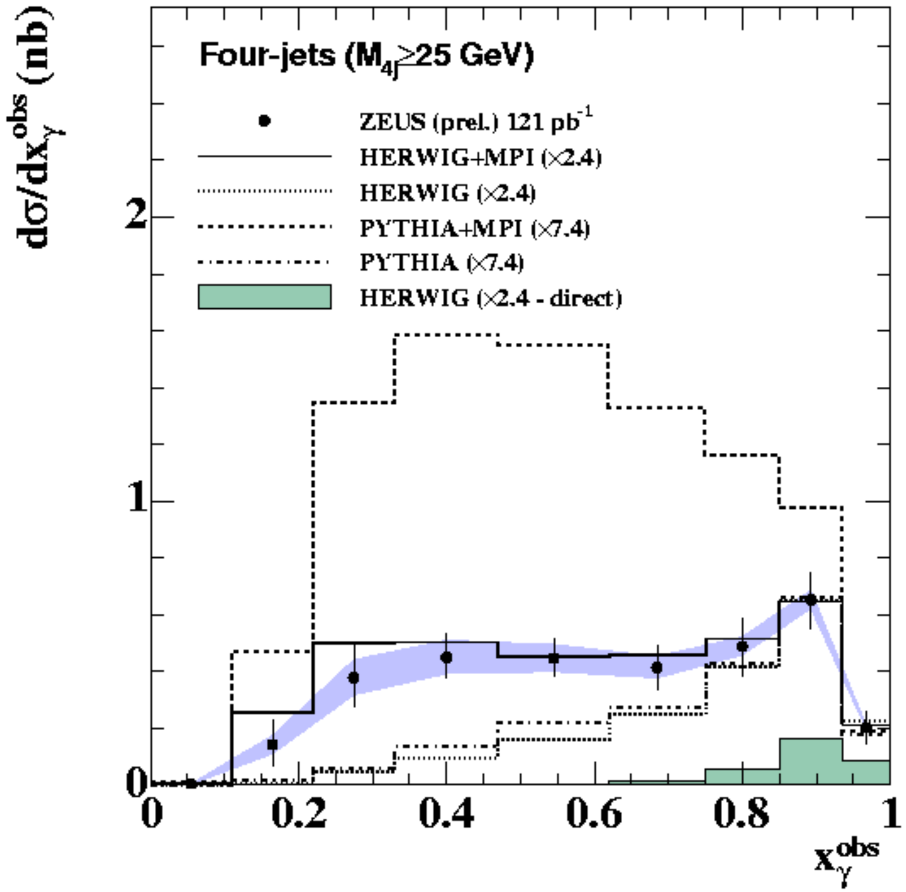
# Multijets in photoproduction




## High statistics: can measure 3,4-jets:



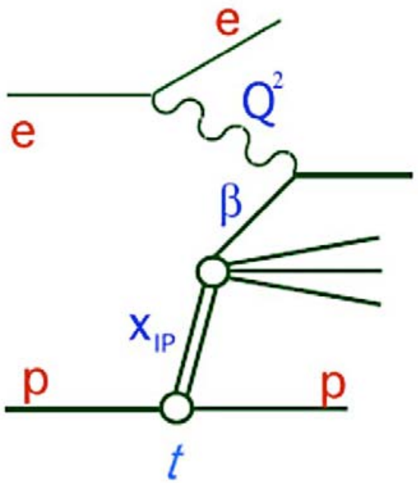

Test of QCD at higher order of $\alpha_S$

NLO calculations available for $O(\alpha\alpha^2_S)$, I.e. 3 jets

4 jets measure $O(\alpha\alpha^3_S)$

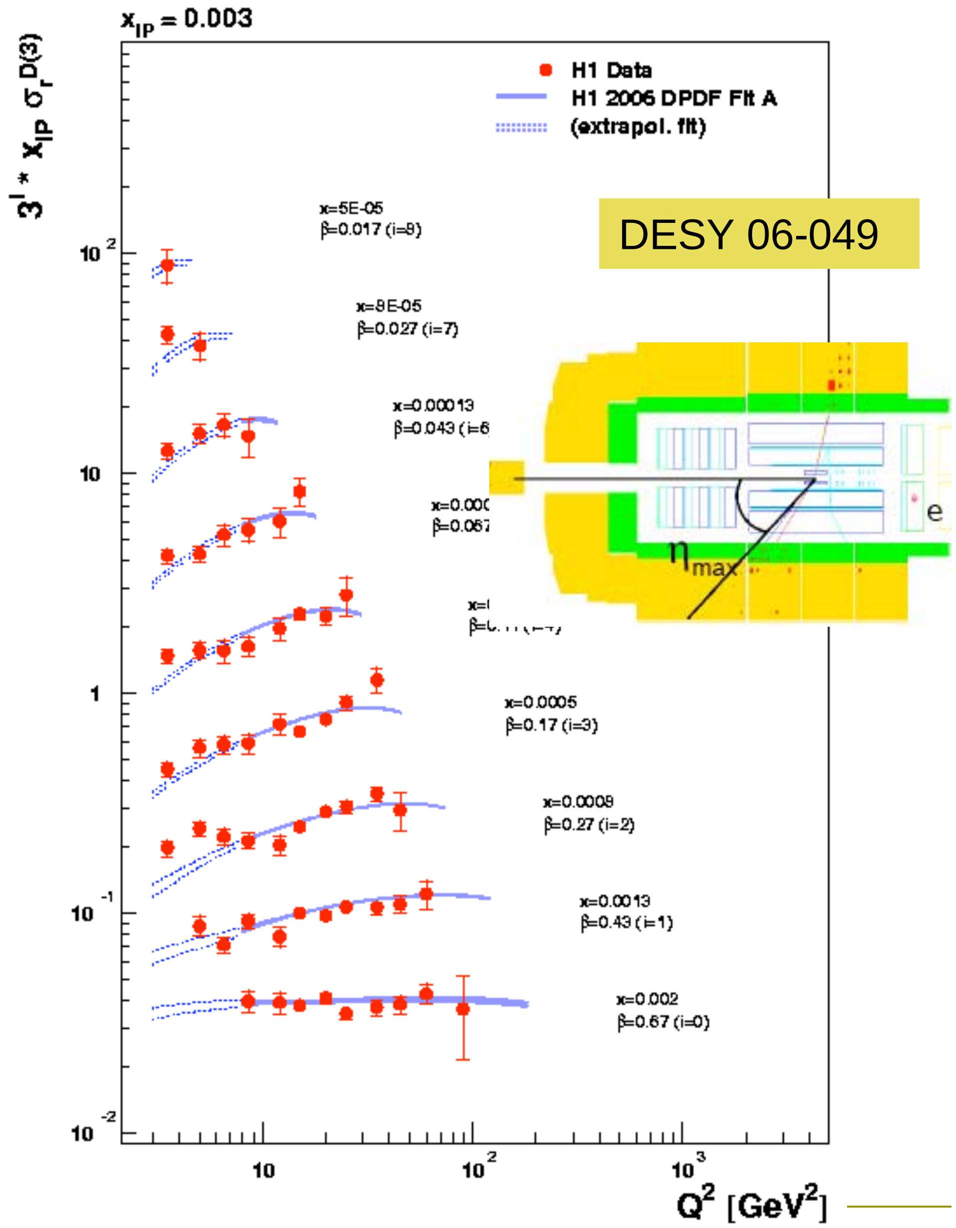
Test of MC models (LO+PS) and Multiple Parton interactions

# Diffractive structure functions

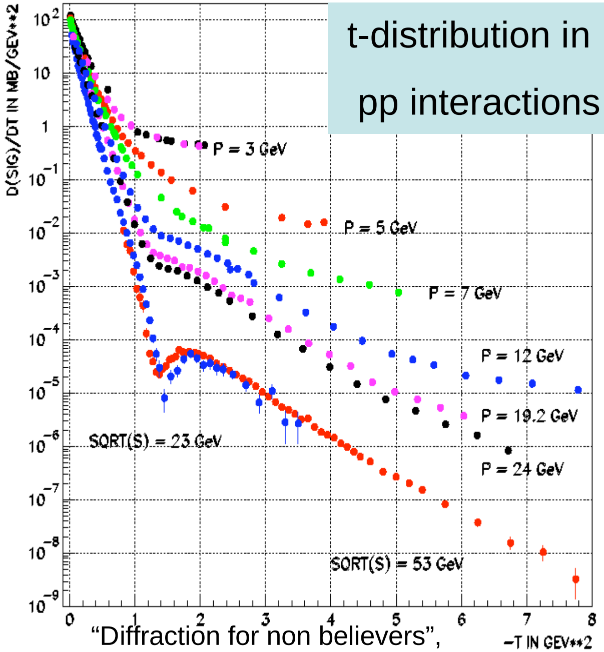



Diffractive events observed in hard interactions at HERA

Final H1 data from HERA I, extract xg(x) and dPDF from scaling violation



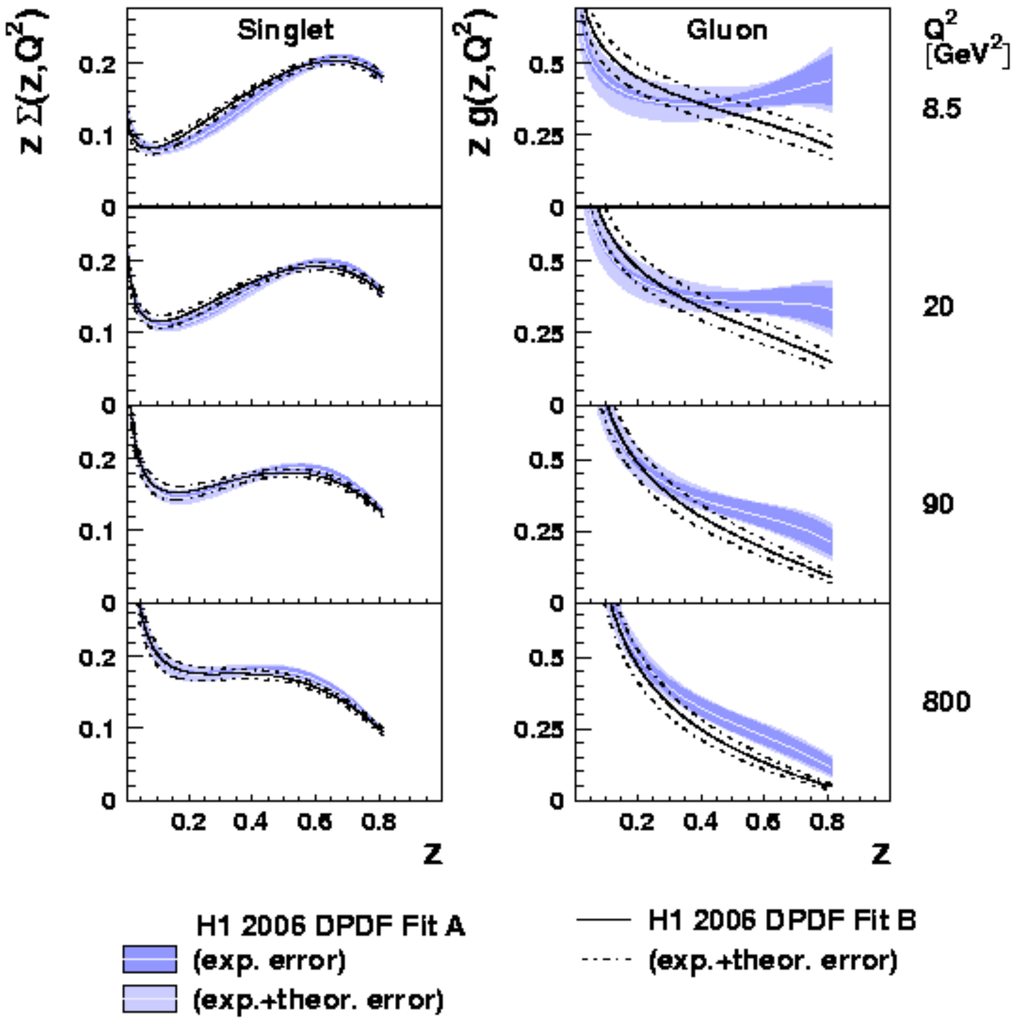

DESY 06-049



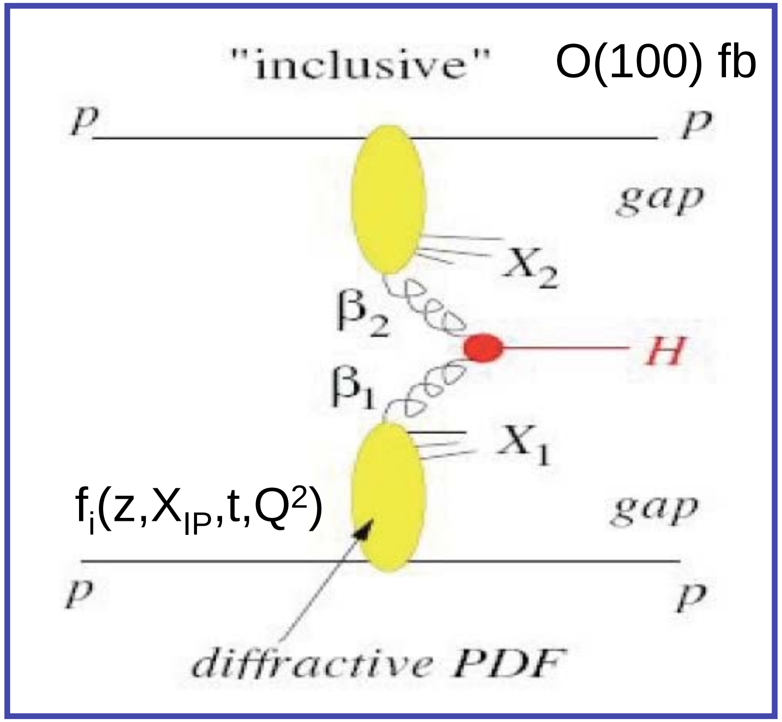

t-distribution in pp interactions

"Diffraction for non believers", M. Arneodo, M. Diehl

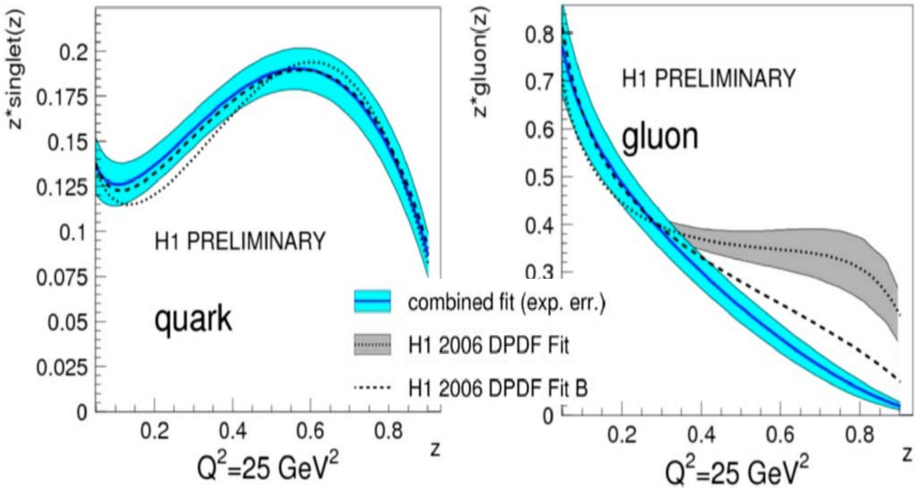
# Diffractive proton parton densities

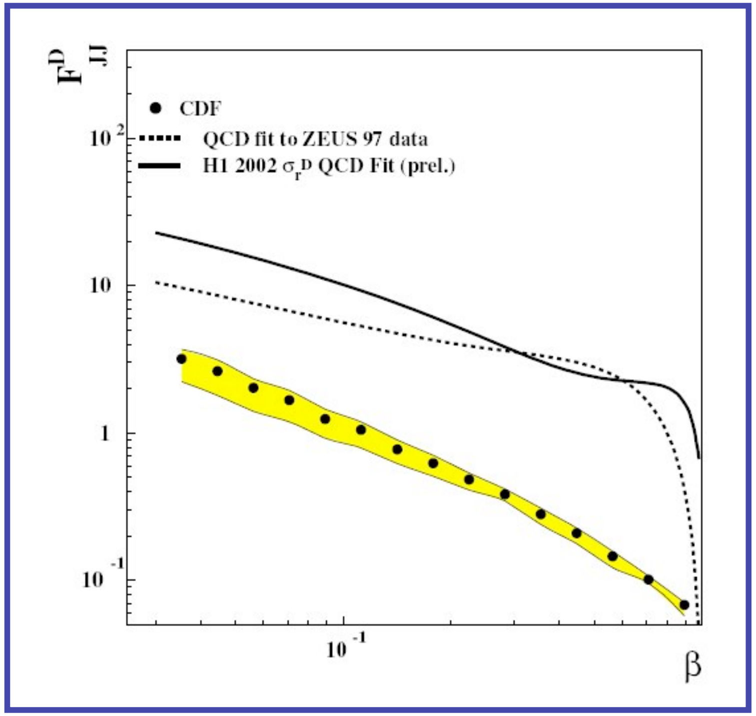



Assume proton vertex factorization and extract dPDF. Gluon carries 70% of the momentum of the colourless exchange



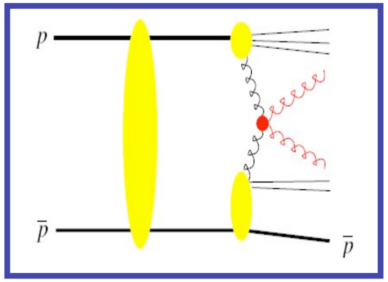
# Diffractive final states

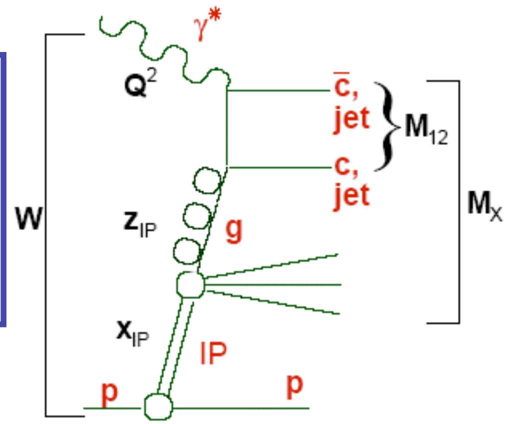



-DPDF fit including dijets in DIS, better determination of the gluon at middle *z*

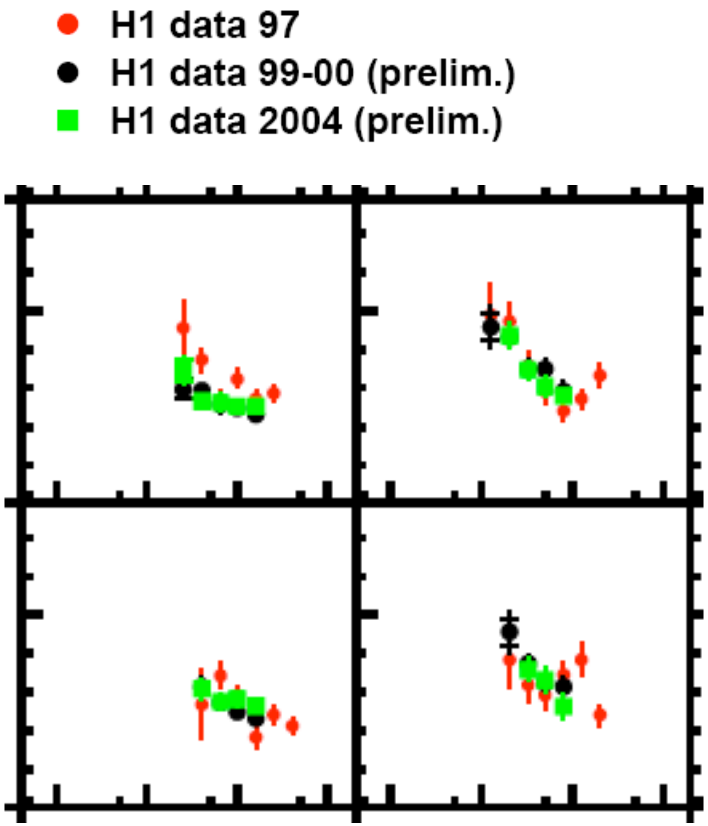
For diffractive jets at *pp* colliders spectator partons interactions are important, can be studied with resolved photon jets



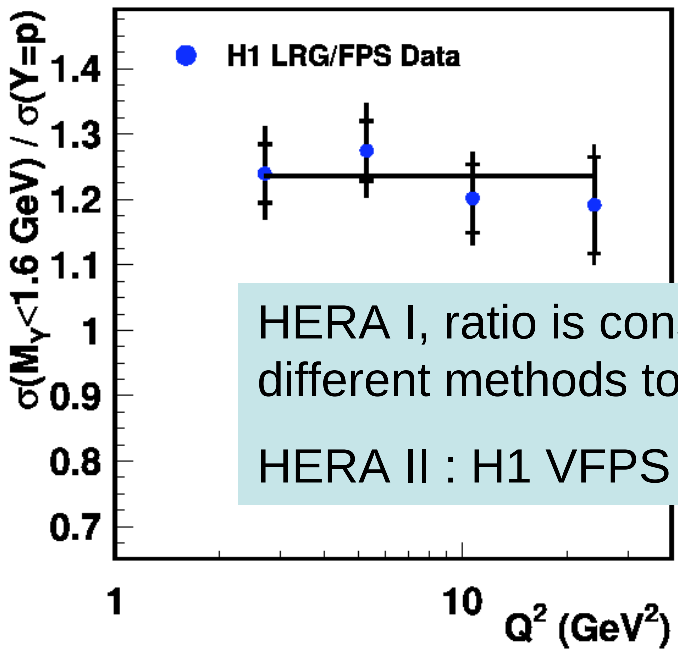



# Diffractive results, prospects

First results on $F_2^D$ from H1 at HERA II, reduced stat errors

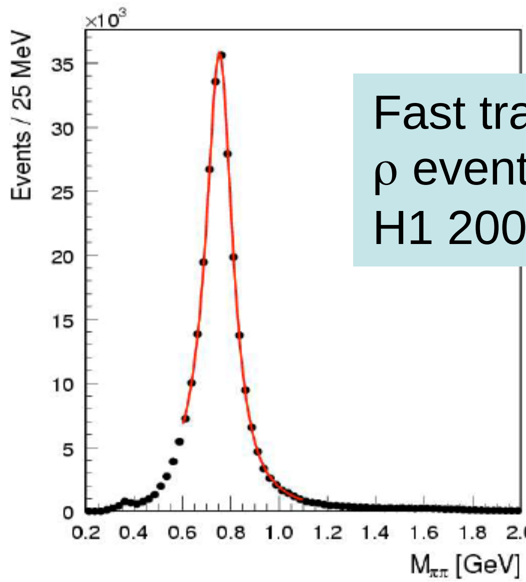



DESY 06-048



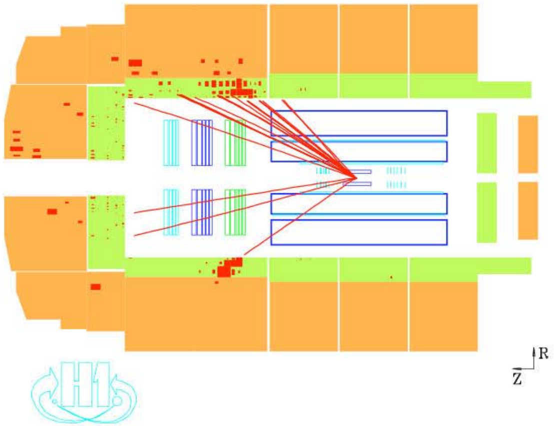

HERA I, ratio is constant, exploit different methods to tag diffraction

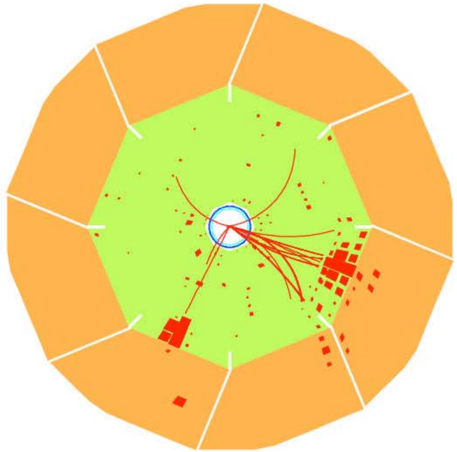
HERA II : H1 VFPS

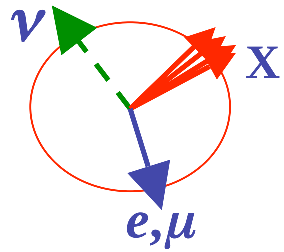


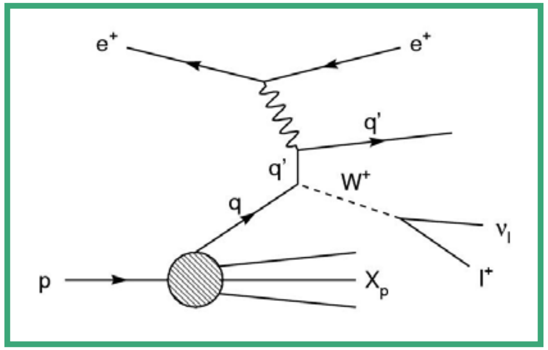

Fast track trigger,300K ρ events selected in H1 2005 data

# Isolated lepton and missing $p_T$ events

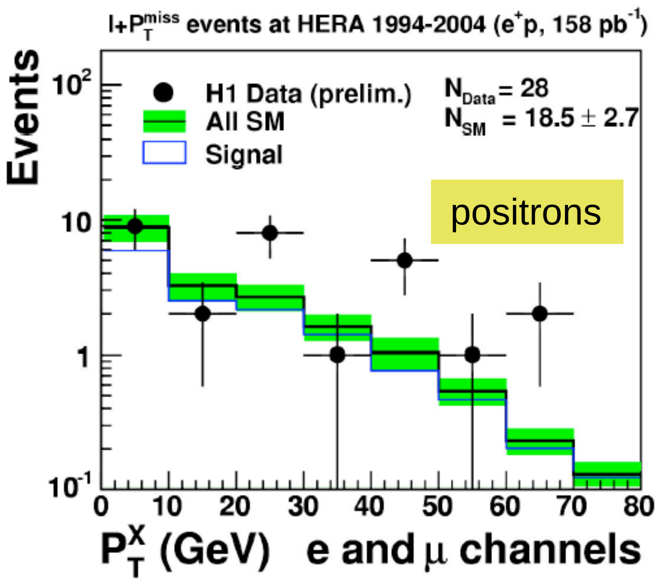


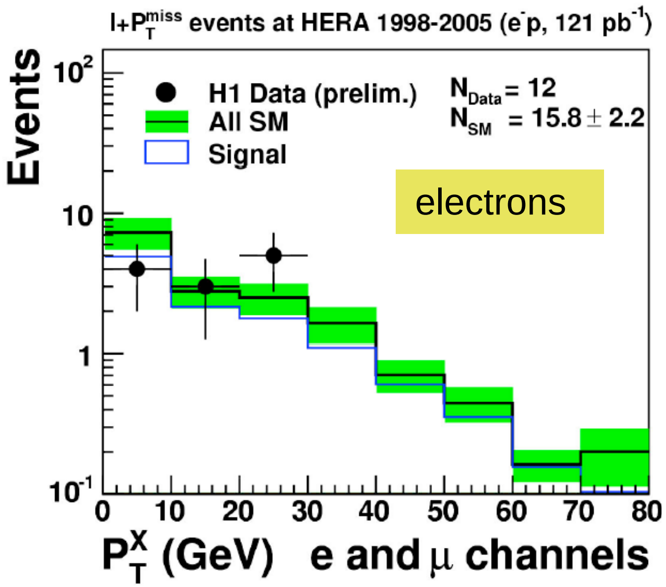






Analysis is optimized for the main SM process which is W production



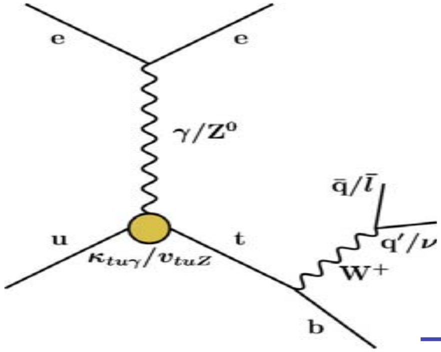

Excess at high $P_T^X$ observed by H1 in $e^+p$ collisions

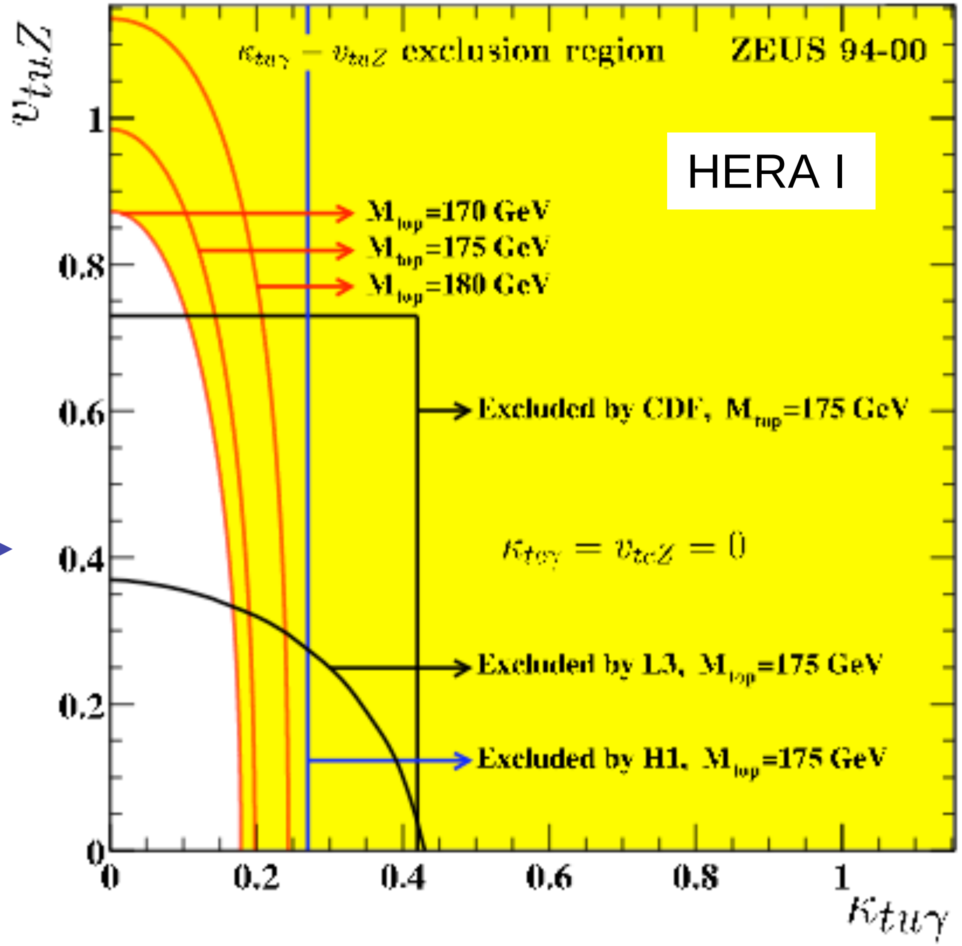
# Isolated lepton and missing $p_T$ events

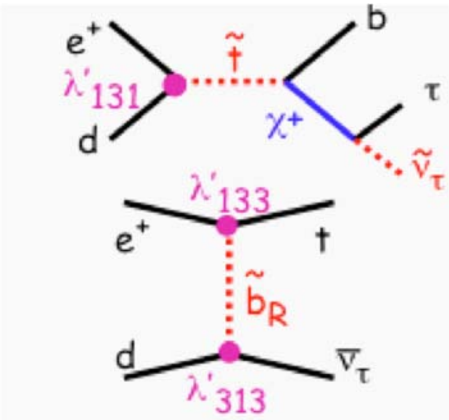
| $P_T^X > 25$ GeV obs/exp. (SM) | e channel | μ channel | Combined e & μ | Tau channel |
|---|---|---|---|---|
| H1 Electrons, 98-05 ~121 $pb^{-1}$ | 2 / 2.4 | 0 / 2.0 | 2 / 4.4 | 3/0.4 |
| H1 Positrons, 94-04 ~158 $pb^{-1}$ | 9 / 2.3 | 6 / 2.3 | 15 / 4.6 | 0/0.4 |
| ZEUS Electrons 98-05 ~143 $pb^{-1}$ | 3/2.9 | 2/1.4 (~ 126 $pb^{-1}$) | ZEUS good agreement with SM | |
| ZEUS Positrons 99-04 ~106 $pb^{-1}$ | 1/1.5 | | ZEUS good agreement with SM | 2/0.2 (120 $pb^{-1}$) |

# Isolated lepton and missing $p_T$ events

Events analyzed in terms of anomalous single top production at HERA I

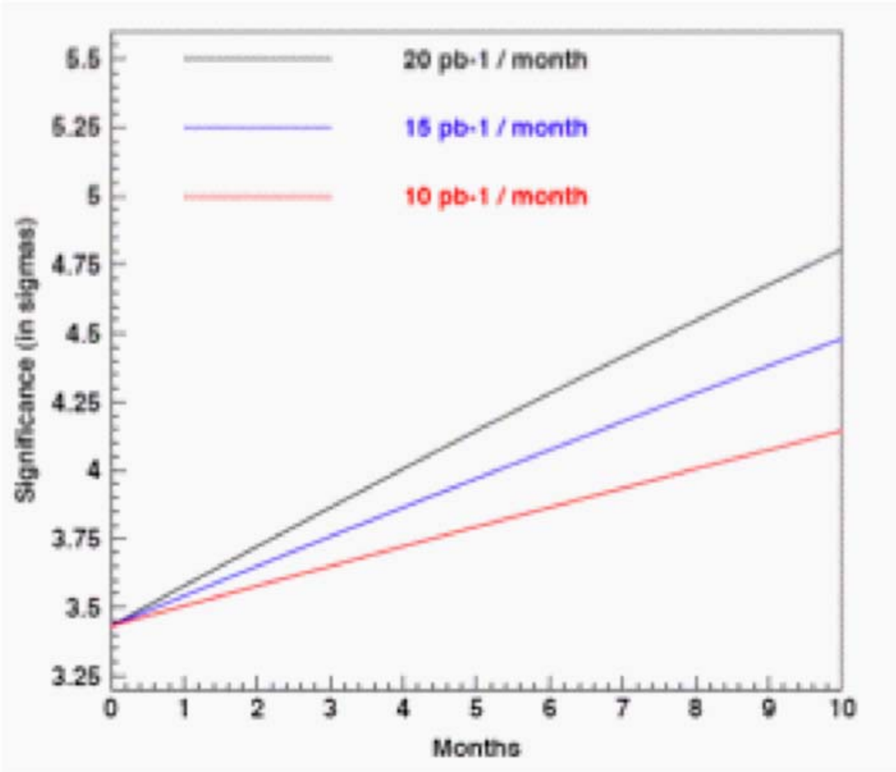


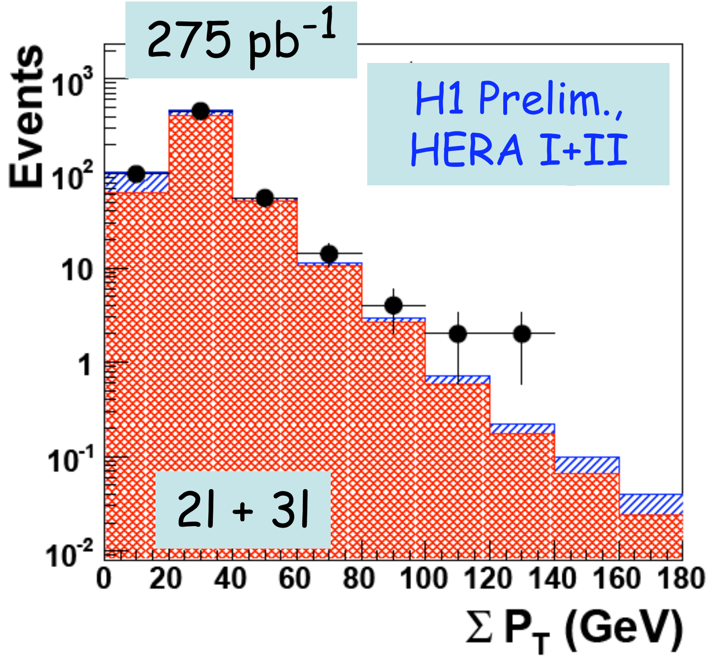

Some possible diagrams in R-parity violation SUSY to explain the H1 excess

# Isolated lepton events, prospects



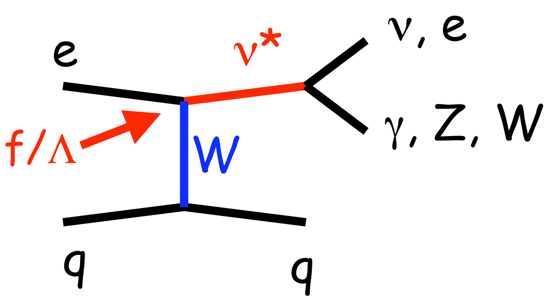

If H1 rate of isolated $e^+$ continues, a 4.5 sigma effect could be reached after 8 months of $e^+$ running at 20 pb-1/month, in H1 (E.Perez, Ringberg05)

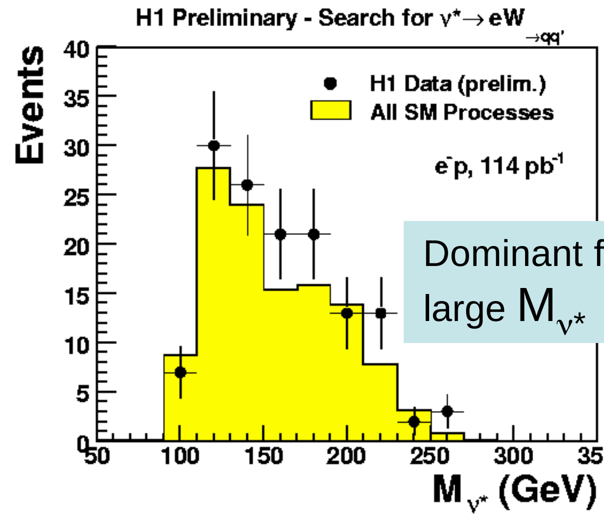
Also multileptons being looked at:




This is why we are interested in a long positron running

# Search for excited neutrinos



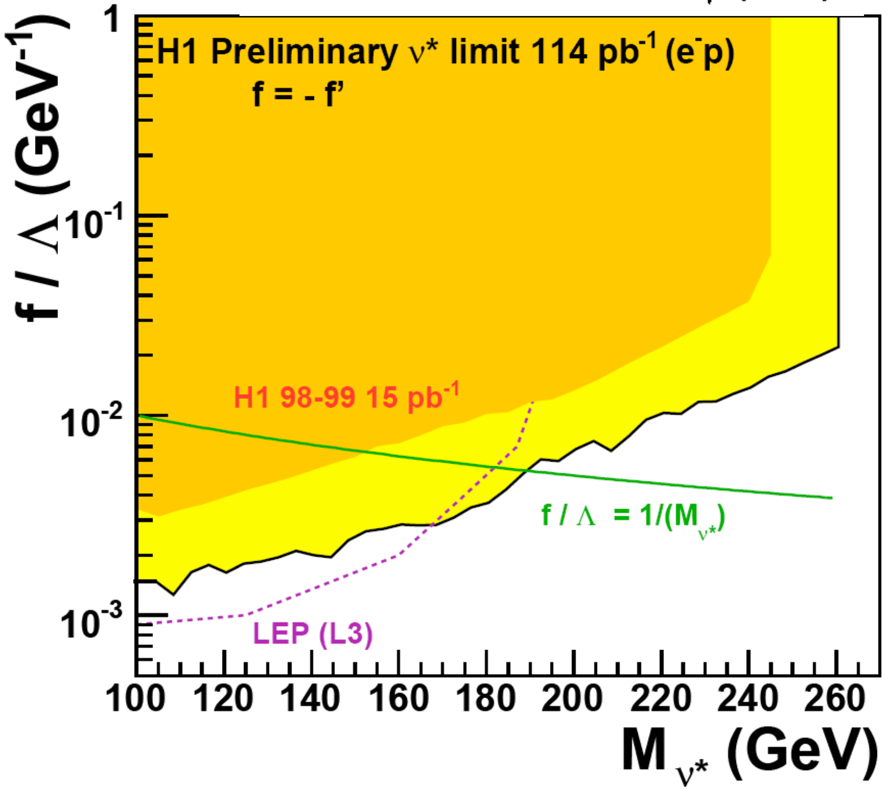




Dominant for large $M_{\nu^*}$

But happy also to have more $e^-$ data

$\sigma(e^-p) \sim 100 \times (e^+p)$

New results with 10xint. Luminosity in HERA II 04-05 compared to HERA I 98-99

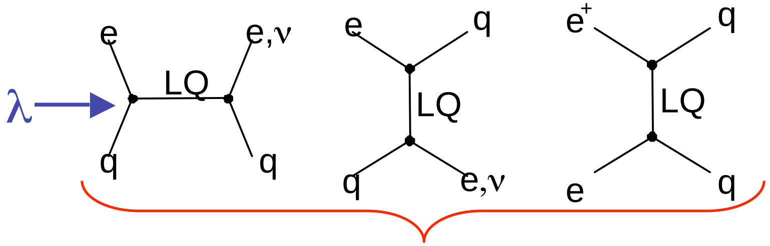


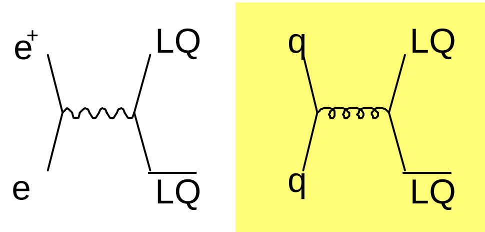

No signal seen from the invariant mass of the final reconstructed states in the 3 decays mode

For $f/\Lambda = 1/M$

$M_{\nu^*} > 188$ GeV

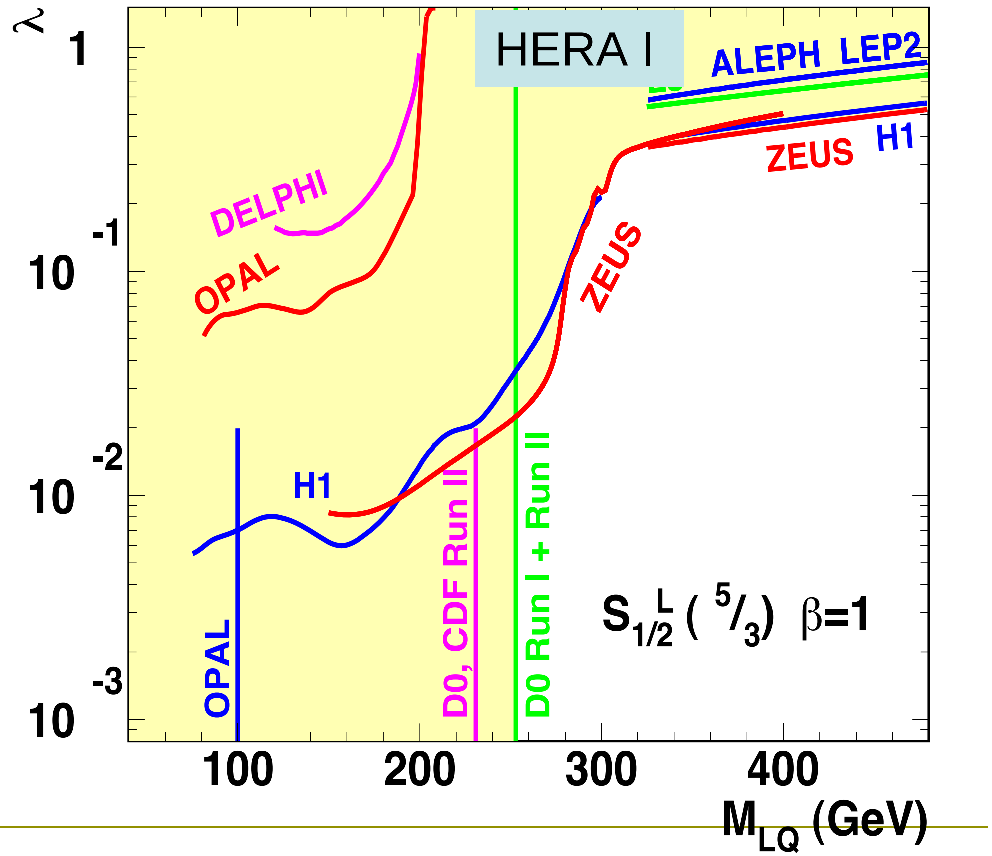
# Prospect for searches for leptoquarks



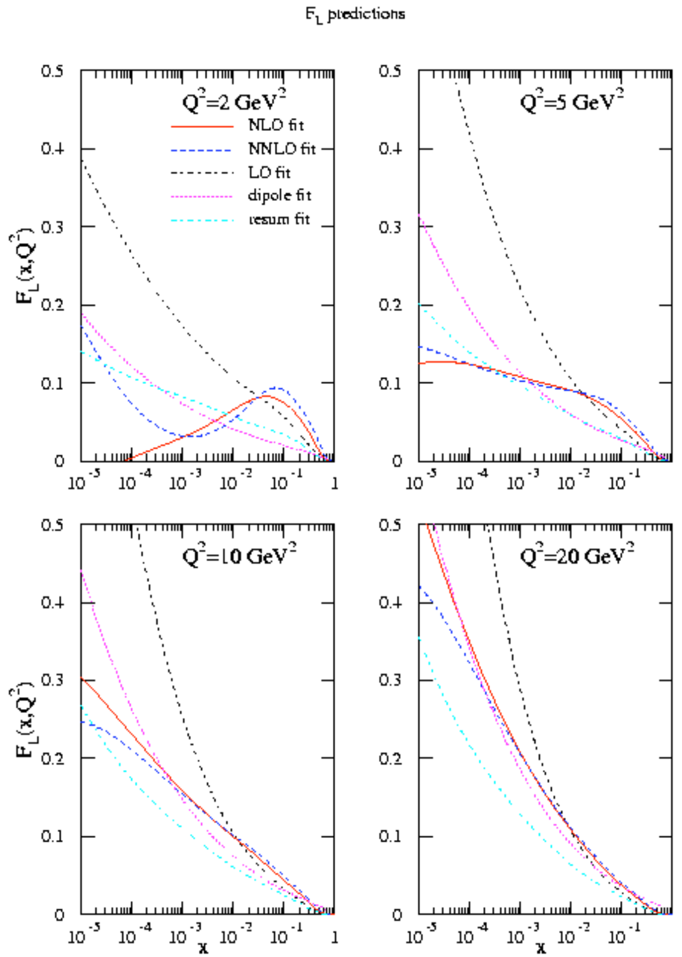

- At HERA II BRW leptoquarks with F=-2 ($e^-q$) still sensitivity (15 $pb^{-1}$ → 210 $pb^{-1}$)
- Still discovery potential at HERA II for a resonance state F=0 (e+p), E. Perez, Ringberg05:

| | $\sigma_{LQ}$=limit | $\sigma_{LQ}$= 0.5 limit |
|---|---|---|
| 350 pb-1 | ~4 sigma | ~ 2.5 sigma |
| 700 pb-1 (H1+ZEUS) | > 5 sigma | ~ 3.5 sigma |



# Measurement of $F_L$

Martin,Stirling,Thorne




$$\frac{d^2\sigma}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+F_2(x,Q^2) - y^2F_L(x,Q^2)\right]$$

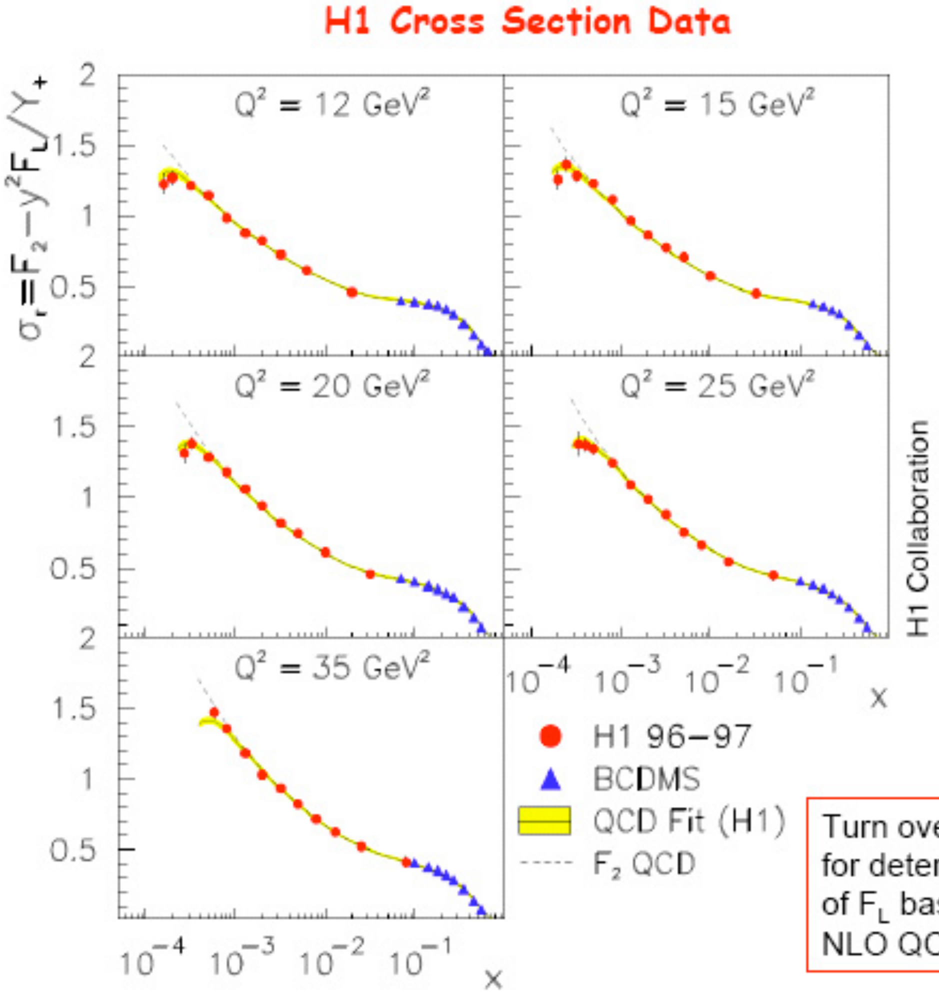
$$Y_+ = \left(1 + (1-y)^2\right)$$

$$F_L = \left(\frac{Q^2}{4\pi^2\alpha}\right)\sigma_L$$

$$F_L = \frac{\alpha_S}{4\pi}x^2\int_x^1\frac{dz}{z^3}\left[\frac{16}{3}F_2 + 8\sum e_q^2(1 - {}^x\!/\!_z)zg\right]$$

Directly connected to the
gluon distribution dominant at low-x
Predictions are still very uncertain

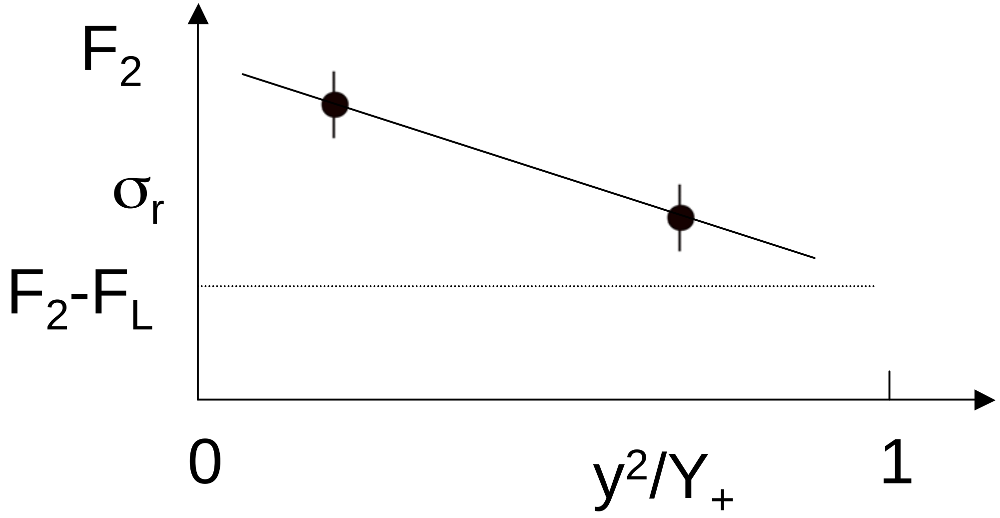
# Measurement of $F_L$




Turn over used for determination of $F_L$ based on NLO QCD $F_2$

- Up to now model dependent extractions
- A determination of $F_L$ requires changing the center of mass energy, i.e. the proton beam energy
- $F_L$ is a fundamental observable in QCD, it is the duty of HERA to measure it at low *x*

# Measurement of $F_L$



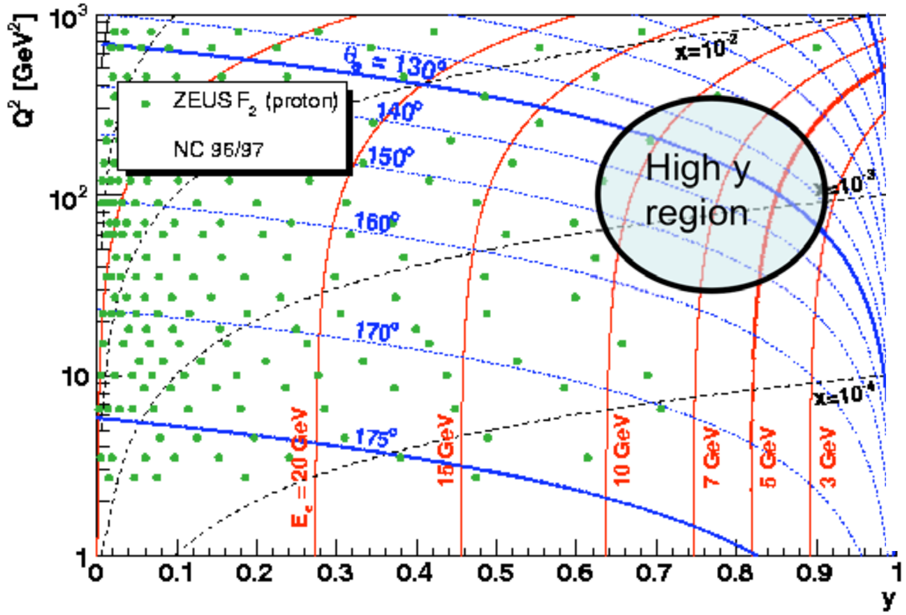

$$\sigma_r = \left(\frac{2\pi\alpha^2 Y_+}{xQ^4}\right)^{-1} \frac{d^2\sigma}{dxdQ^2} = \left[F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2)\right]$$

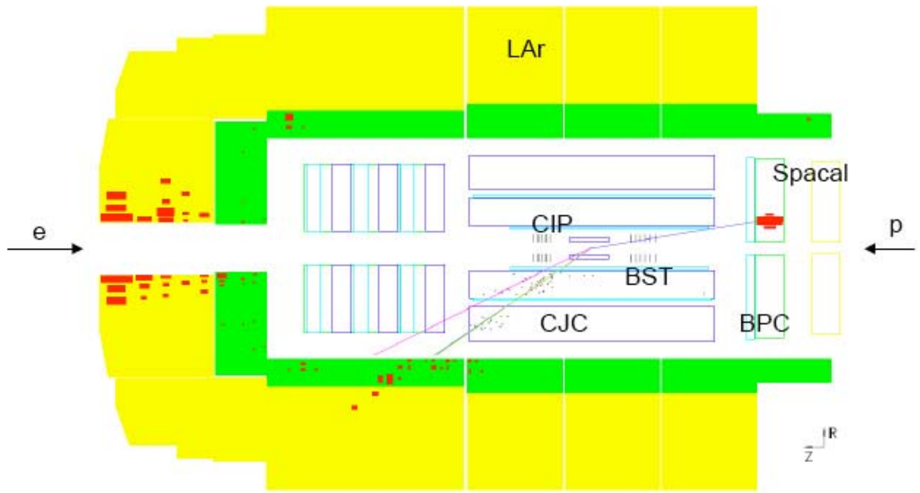
$$F_L(x,Q^2) = \frac{\sigma_r(x,Q^2,y_1) - \sigma_r(x,Q^2,y_2)}{f(y_2) - f(y_1)}$$

$$f(y) = y^2 / Y_+$$

- Need to measure cross sections at same $x,Q^2$ and different $y$.
- To change $y=Q^2/xs$, we change $s$ by lowering $E_p$ to 460 GeV
- The price in integrated luminosity is a factor of 4
- 10 $pb^{-1}$ require two weeks of preparation + running= 3 months

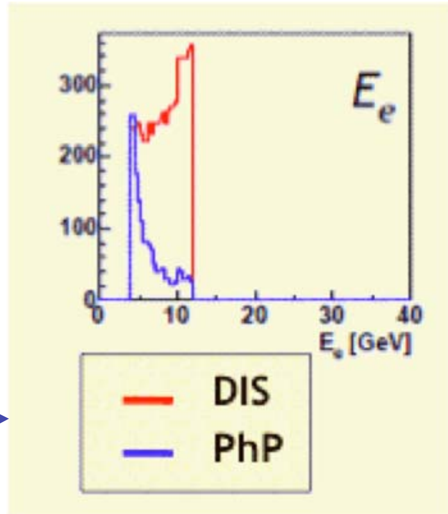
# Measurement of $F_L$




- Challenging for the machine, due to the lower proton energy

- But also challenging for the experiments, need to measure a very low scattered positron energy (down to 3 GeV), huge background from photoproduction at high *y*, low $E_p$

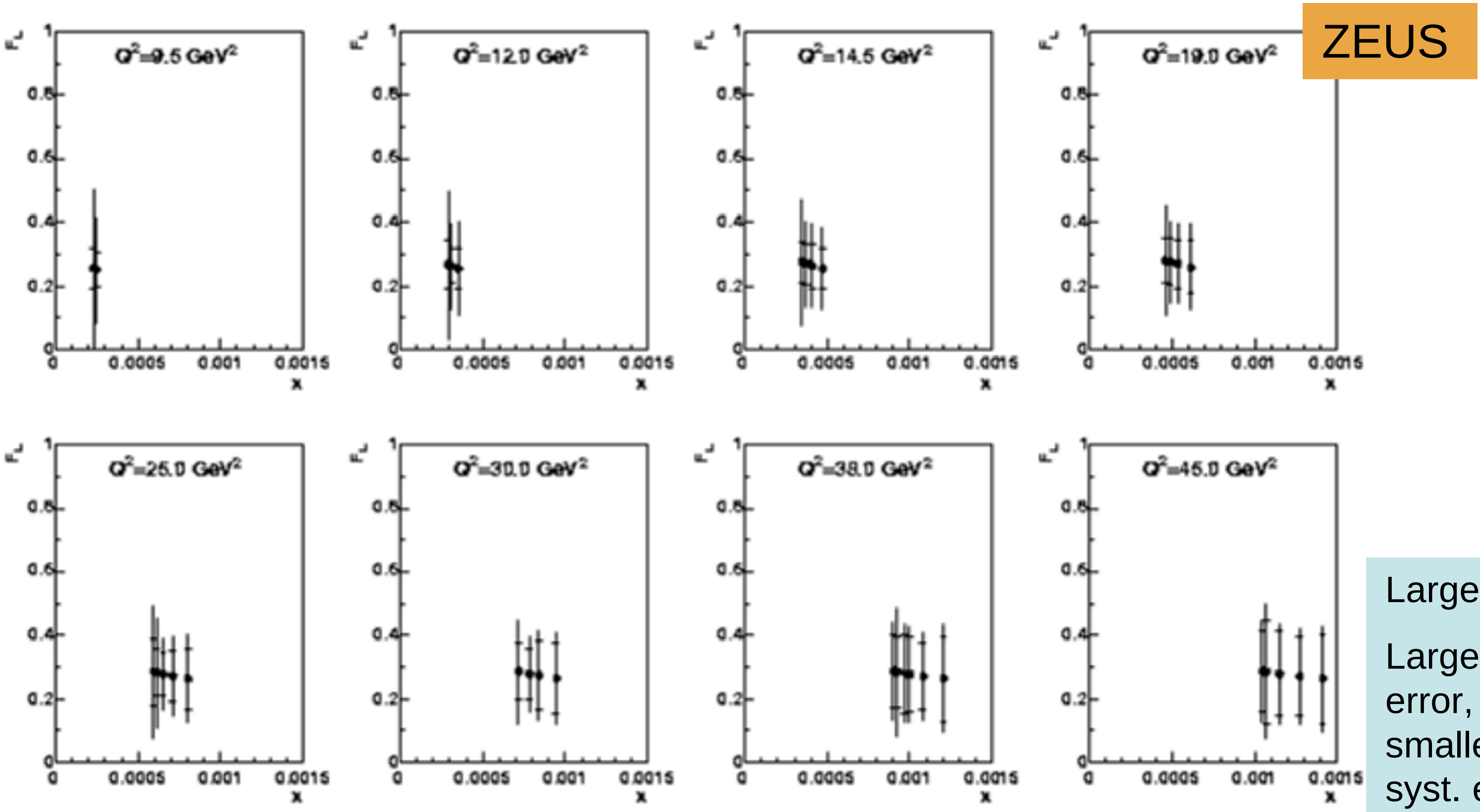


# Measurement of $F_L$

Low $Q^2$, small stat. error, big syst.

10% backg

10% el. efficiency

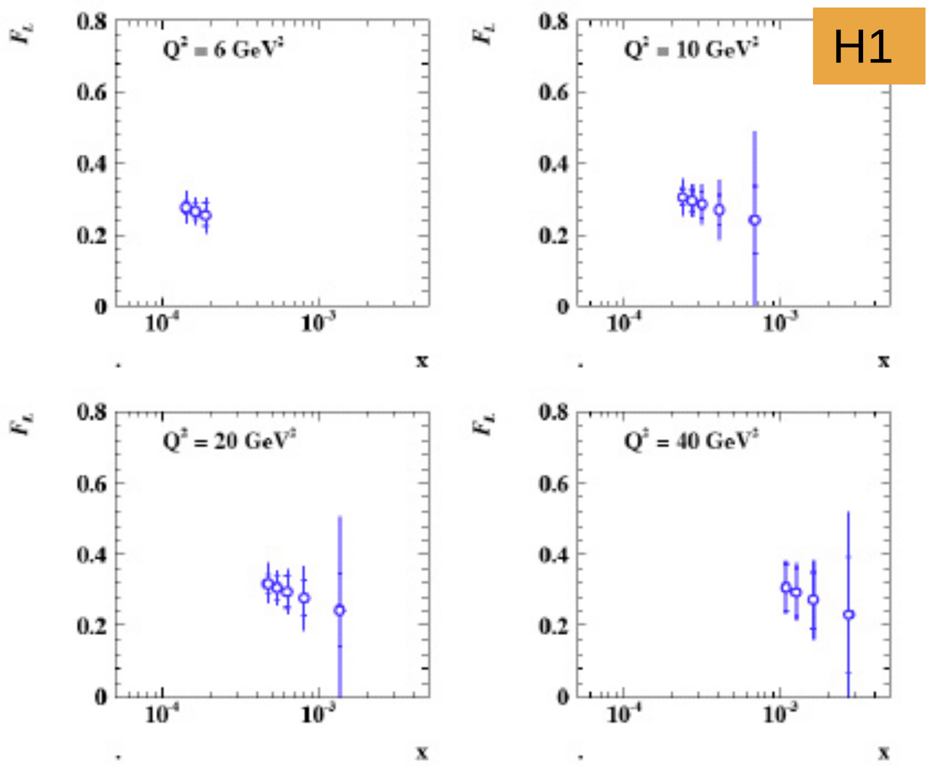



Large $Q^2$,

Large stat error, smaller syst. error

$F_L$ set to 0.2 $F_2$. Full simulation of results with 30 $pb^{-1}$ at $E_p$= 920 GeV and 10 $pb^{-1}$ at $E_p$=460 GeV

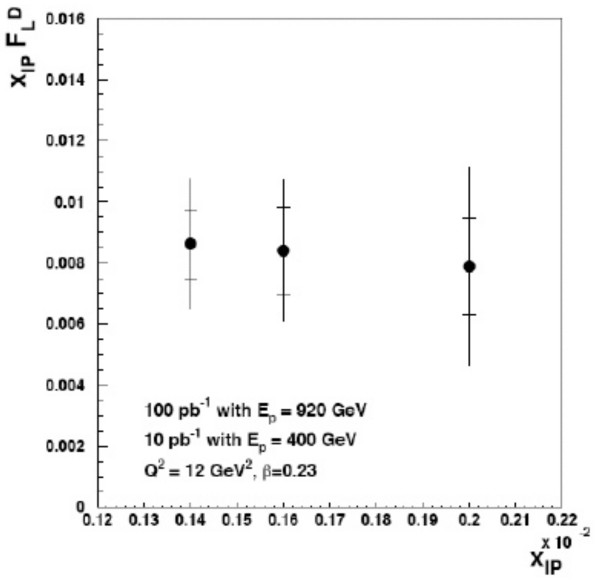
# Measurement of $F_L$




H1 detector better equipped in the backward region, important for low $Q^2$

Smaller errors, can go to lower $Q^2$ and higher y

See also M. Klein, J. Feltesse in HERA-LHC proceedings




In addition the $F_L^D$ measurement will be possible (also VFPS in H1)

See also Paul Newman in HERA-LHC proceedings

# Summary from plans at Hamburg

- HERA I has advanced our knowledge of QCD (steep rise of $F_2$ at low $x$, diffractive events, parton densities, jets etc.)
- HERA II, higher luminosity and polarization, also electroweak studies are open
- Still hope for a discovery, maybe isolated lepton events?
- Will go back to low $x$ at the end of HERA running and measure $F_L$