ep-Physics at High Q^2

Recent Results and Future Perspectives
Testing QCD and Electroweak Theory at HERA

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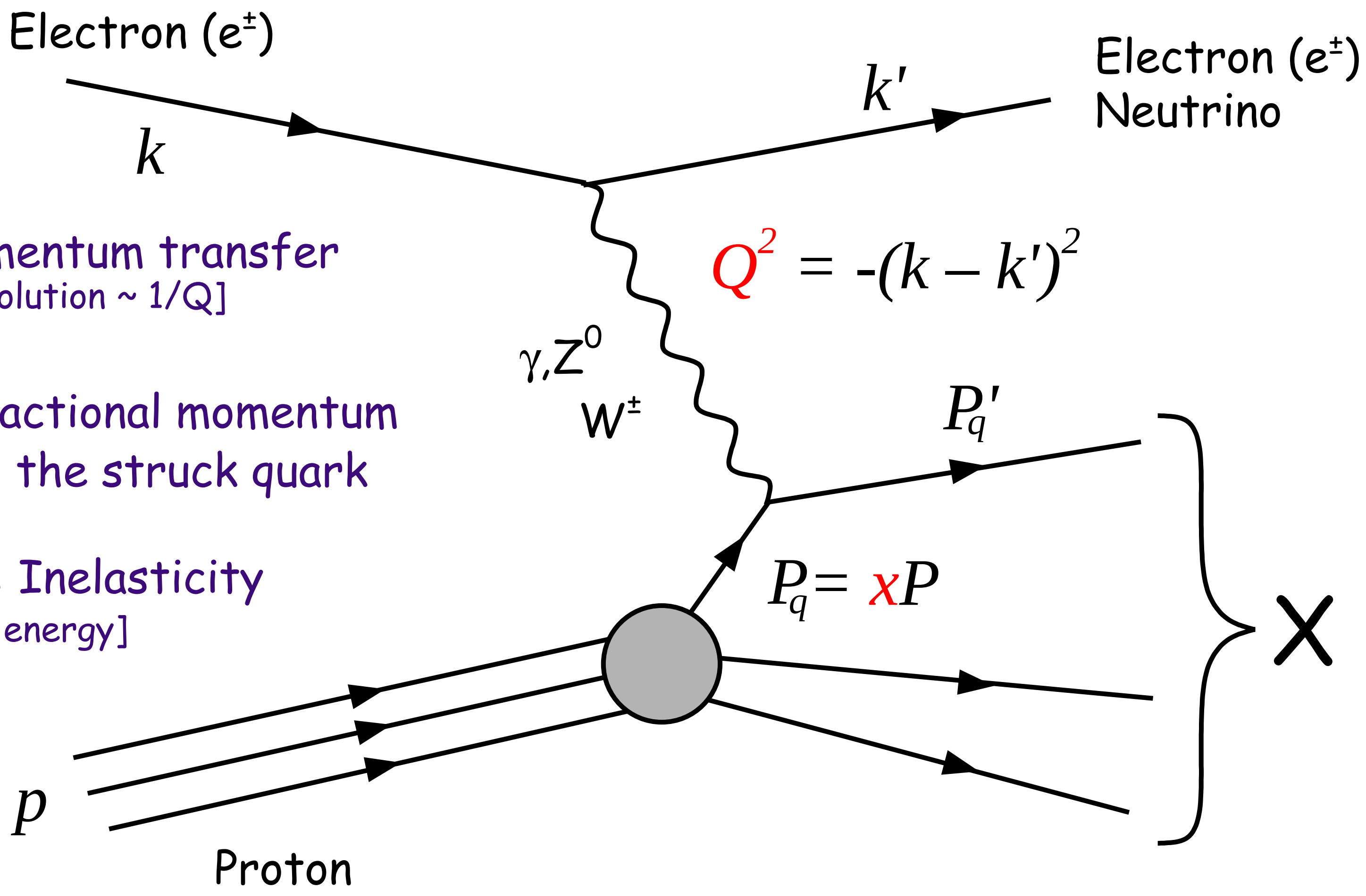
[for the H1 and ZEUS collaboration]

Les Arcs, March 2002

HERA Kinematics

E_e=27.5 GeV



Q^2: four-momentum transfer
[spatial resolution ~ 1/Q]

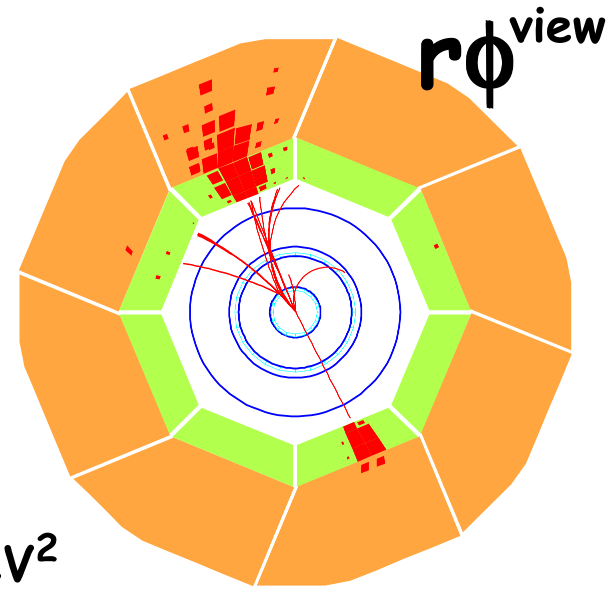
x: fractional momentum of the struck quark

$y = Q^2/sx$: Inelasticity
[$\sqrt{s}$: cms energy]

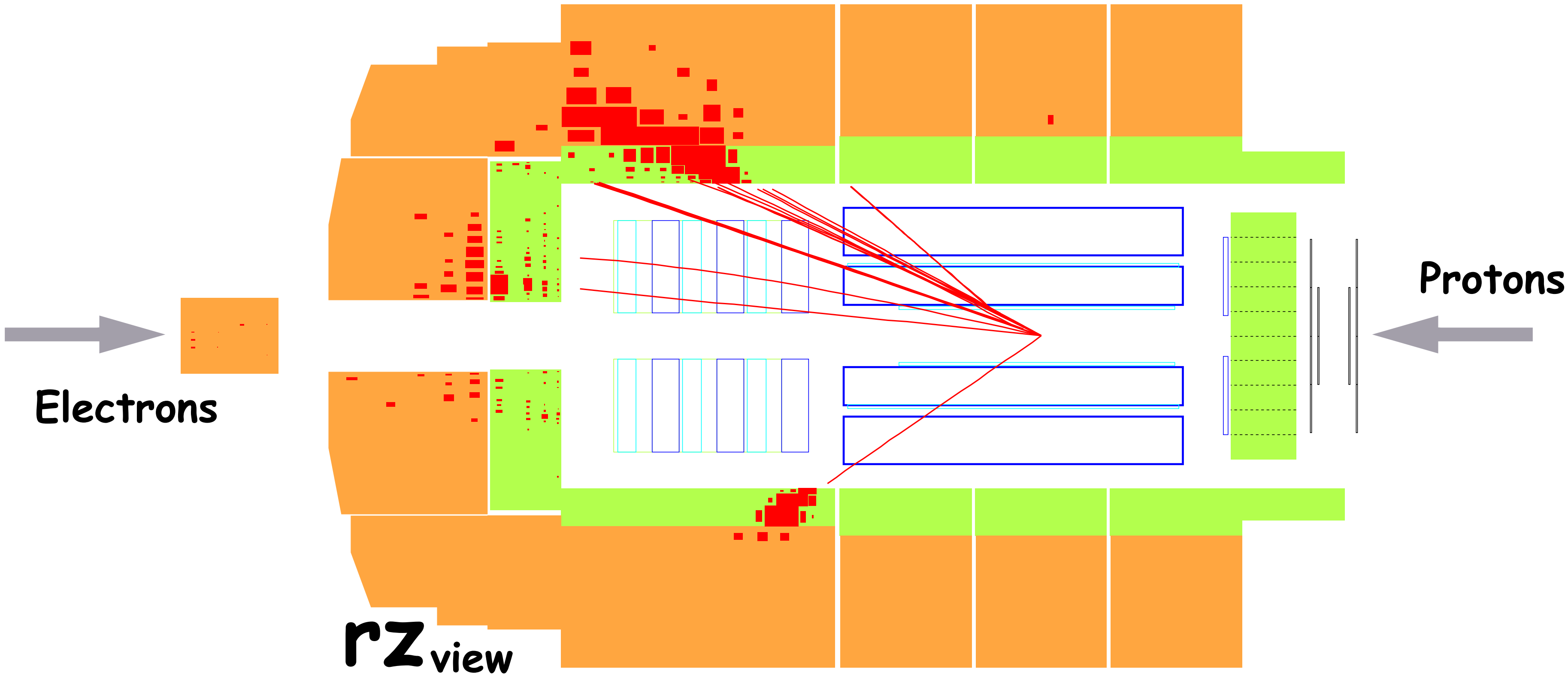
E_p=920 GeV
[before 1998: E_p=820 GeV]

NC DIS Event

[as seen in a typical HERA detector]



$Q^2 = 16950\ GeV^2$



Neutral Current DIS Cross Section

$$\frac{d^2\sigma^{NC}(e^\pm)}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+ \tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2 F_L\right]$$

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

Helicity structure

F_L: influence small
related to gluon density
[contribution only @ high y]
[LO: F_L=0]

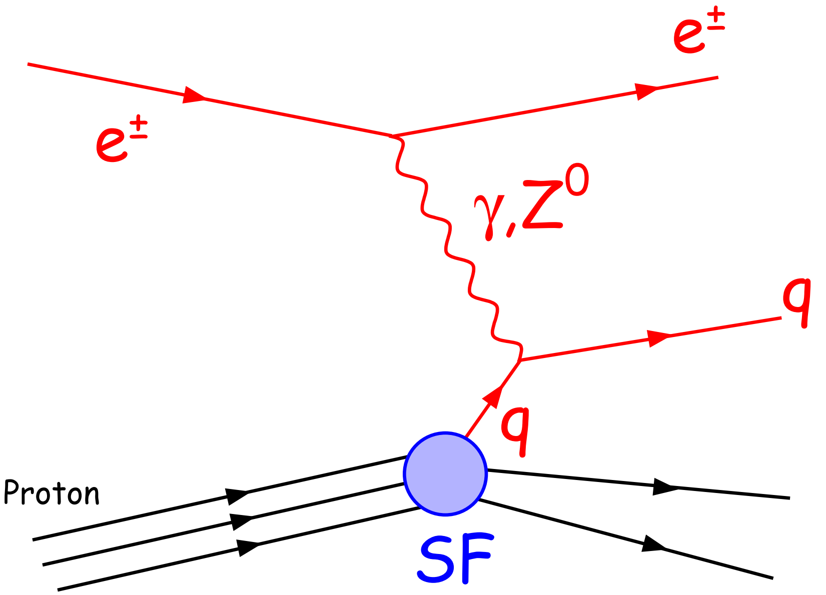
LO picture:

$$\tilde{F}_2 = x\sum_i [q_i(x,Q^2) + \bar{q}_i(x,Q^2)] \cdot \boldsymbol{A_i}$$

$$x\tilde{F}_3 = x\sum_i [q_i(x,Q^2) - \bar{q}_i(x,Q^2)] \cdot \boldsymbol{B_i}$$

Hard process
[electroweak couplings & propagator]

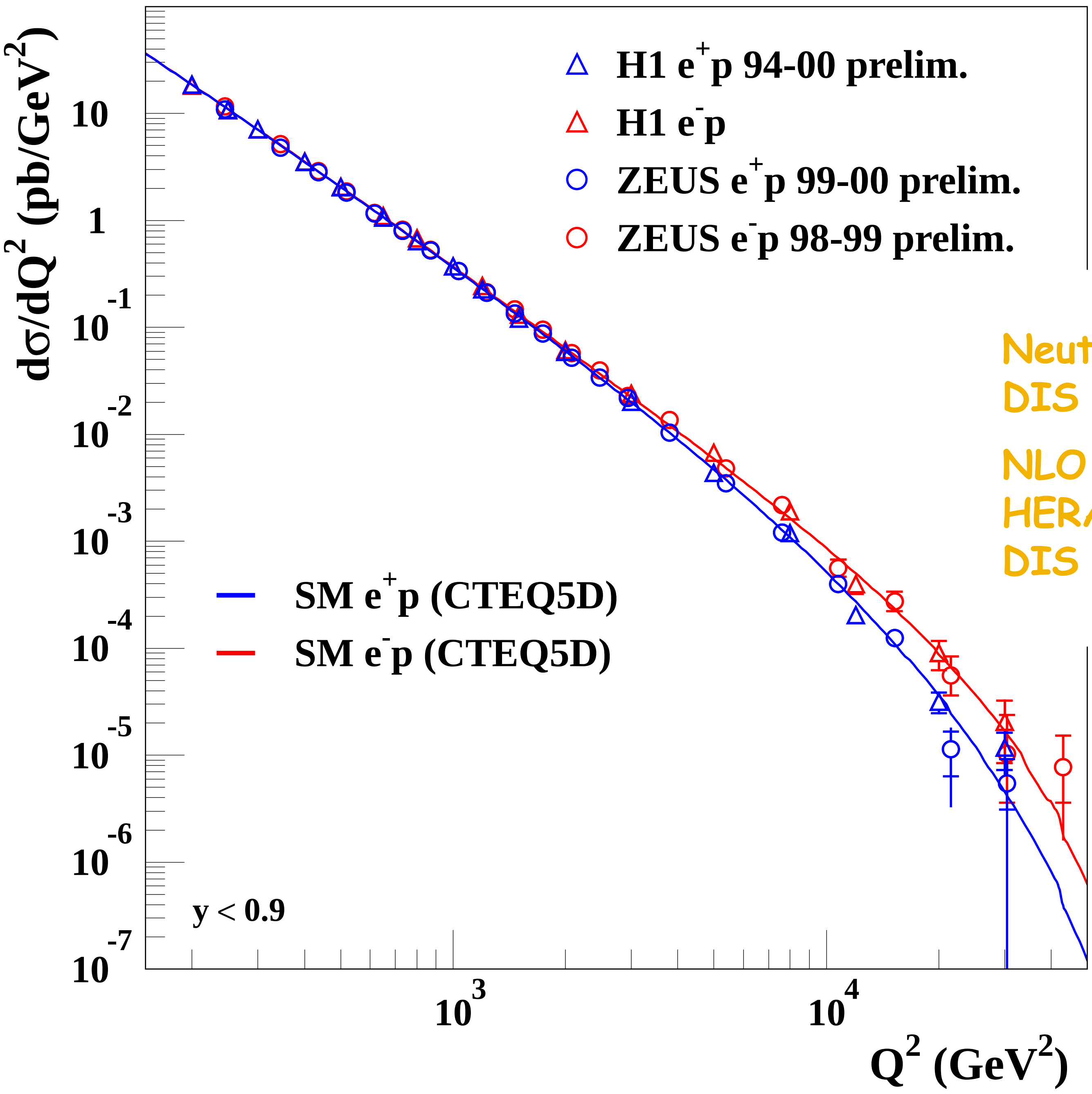
Proton structure
[fitted in NLO]



$$A_i = Q_q^2 - 2Q_q v_e v_q \chi_Z + Q_q v_e v_q \chi_Z + (v_e^2 + a_e^2)(v_q^2 + a_q^2)(\chi_Z)^2$$

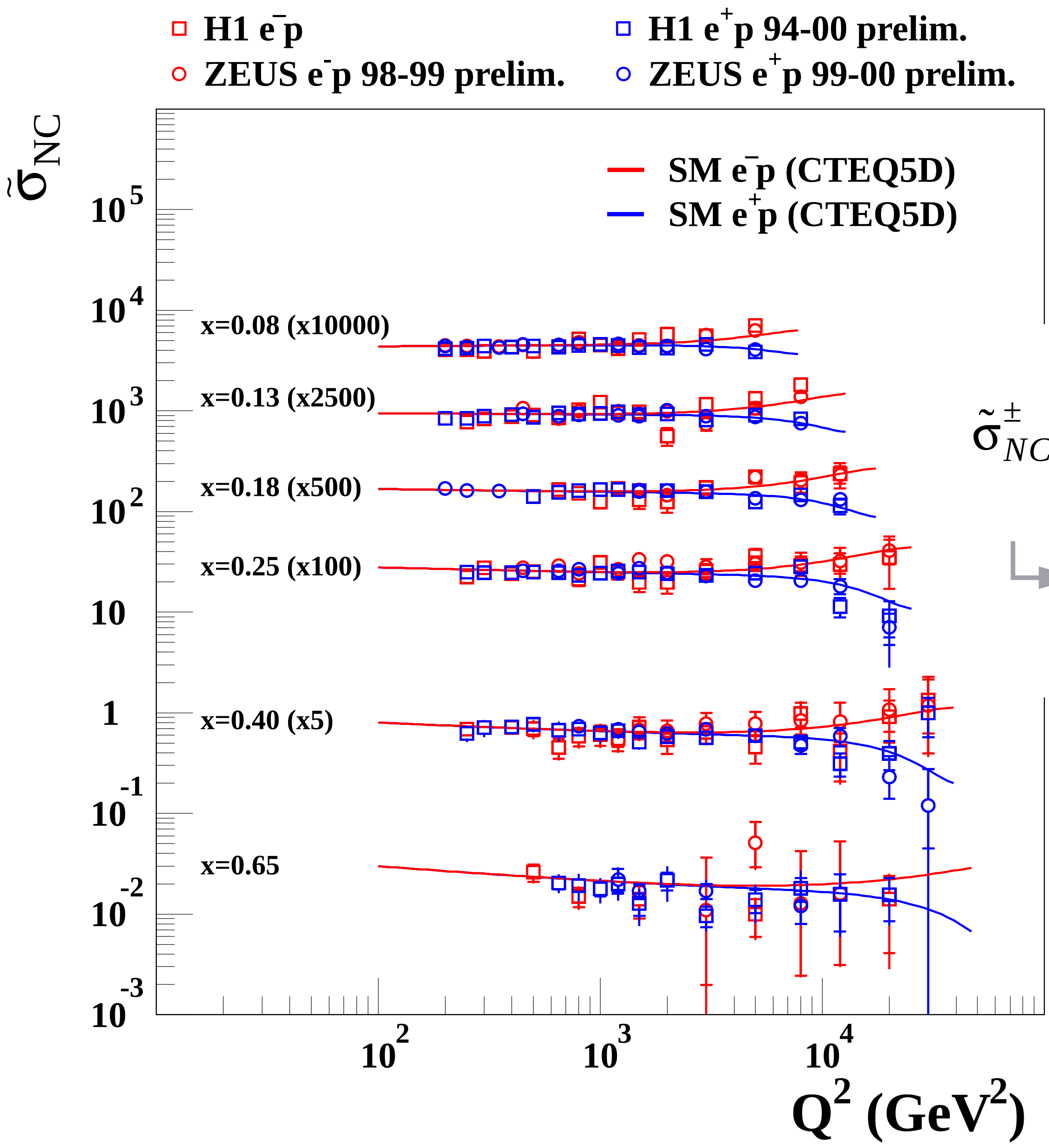
$$B_i = -2Q_q a_e a_q \chi_Z + 4 v_e a_e v_q a_q (\chi_Z)^2$$

$$\chi_Z = \frac{1}{4 s_W^2 c_W^2}\left(\frac{Q^2}{Q^2 + M_Z^2}\right)$$



Neutral Current DIS Cross Section

NLO QCD Fit to HERA & Fixed Target DIS Data etc.



NC 'reduced' Cross Section

$$\tilde{\sigma}^{\pm}_{NC} \equiv \frac{1}{Y_+}\,\frac{xQ^4}{2\pi\alpha^2}\,\frac{d^2\sigma^{NC}(e^\pm)}{dx\,dQ^2}$$

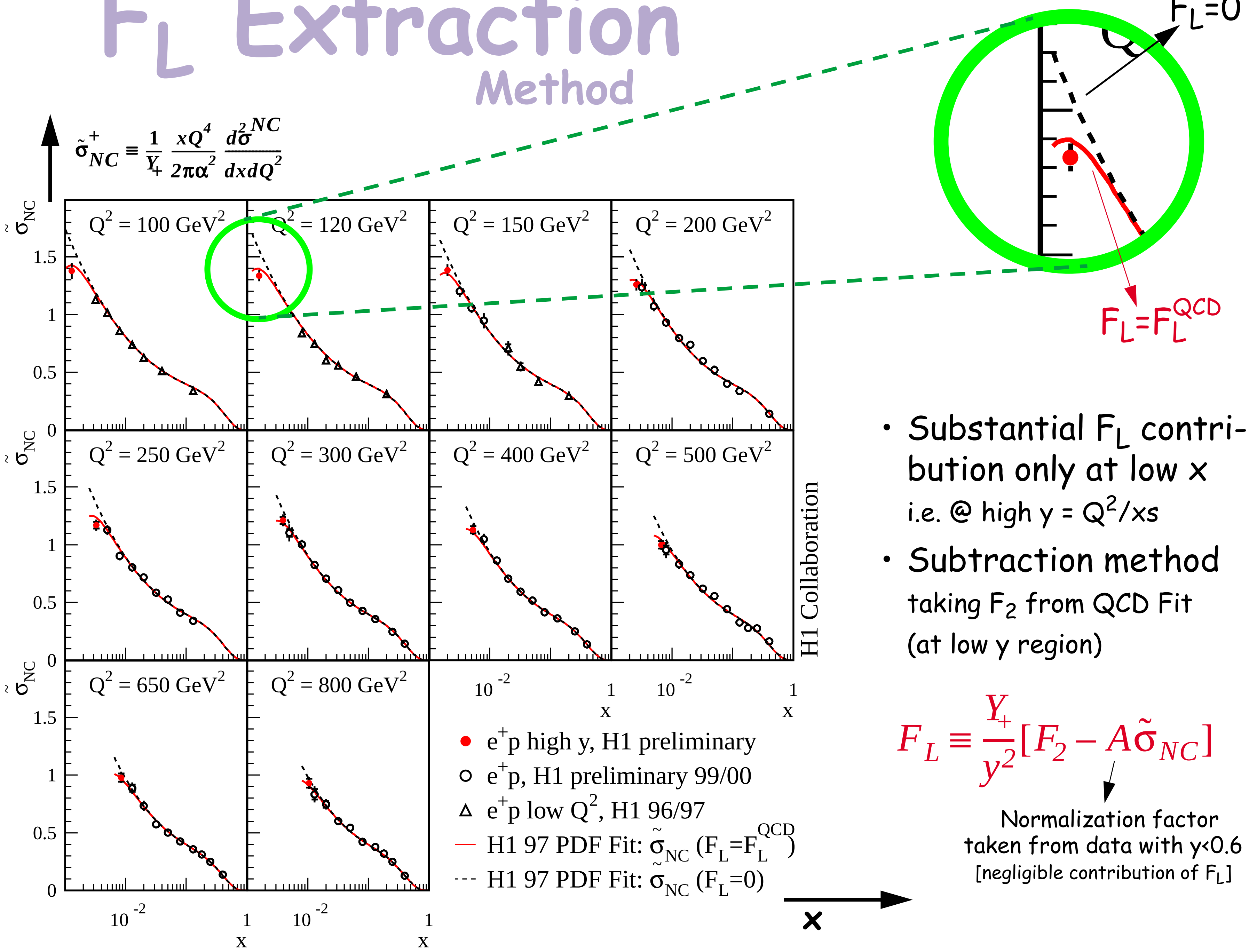
$$\tilde{\sigma}^{\pm}_{NC} = \tilde{F}_2 \mp f(y)\tilde{F}_3 + g(y)F_L$$

Extraction of:

- $x\tilde{F}_3$ (@ large Q^2)
- quark densities

F_L Extraction

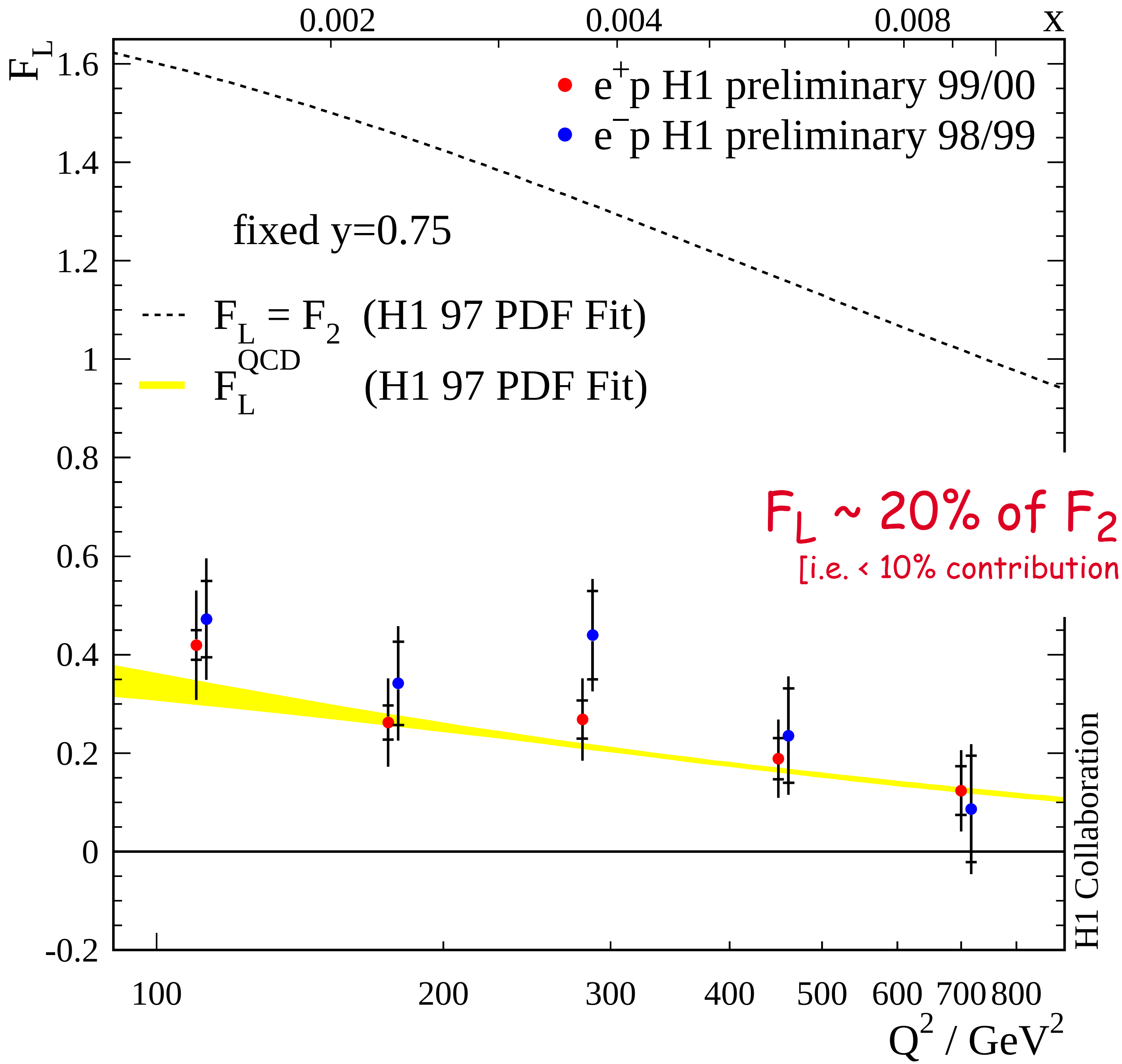
Method



- Substantial F_L contribution only at low x
  i.e. @ high $y = Q^2/xs$
- Subtraction method
  taking F_2 from QCD Fit
  (at low y region)

$$F_L \equiv \frac{Y_+}{y^2}[F_2 - A\tilde{\sigma}_{NC}]$$

Normalization factor taken from data with y<0.6
[negligible contribution of F_L]



$F_L \sim 20\%$ of F_2

[i.e. < 10% contribution for y < 0.6]

$x\tilde{F}_3$ Extraction Method

[Using NC e^+p and e^-p cross section]

$$\tilde{\sigma}^{NC}(e^-) = \frac{1}{Y_+}[Y_+\tilde{F}_2 + Y_- x\tilde{F}_3 - y^2 F_L]$$

$$\tilde{\sigma}^{NC}(e^+) = \frac{1}{Y_+}[Y_+\tilde{F}_2 - Y_- x\tilde{F}_3 - y^2 F_L]$$

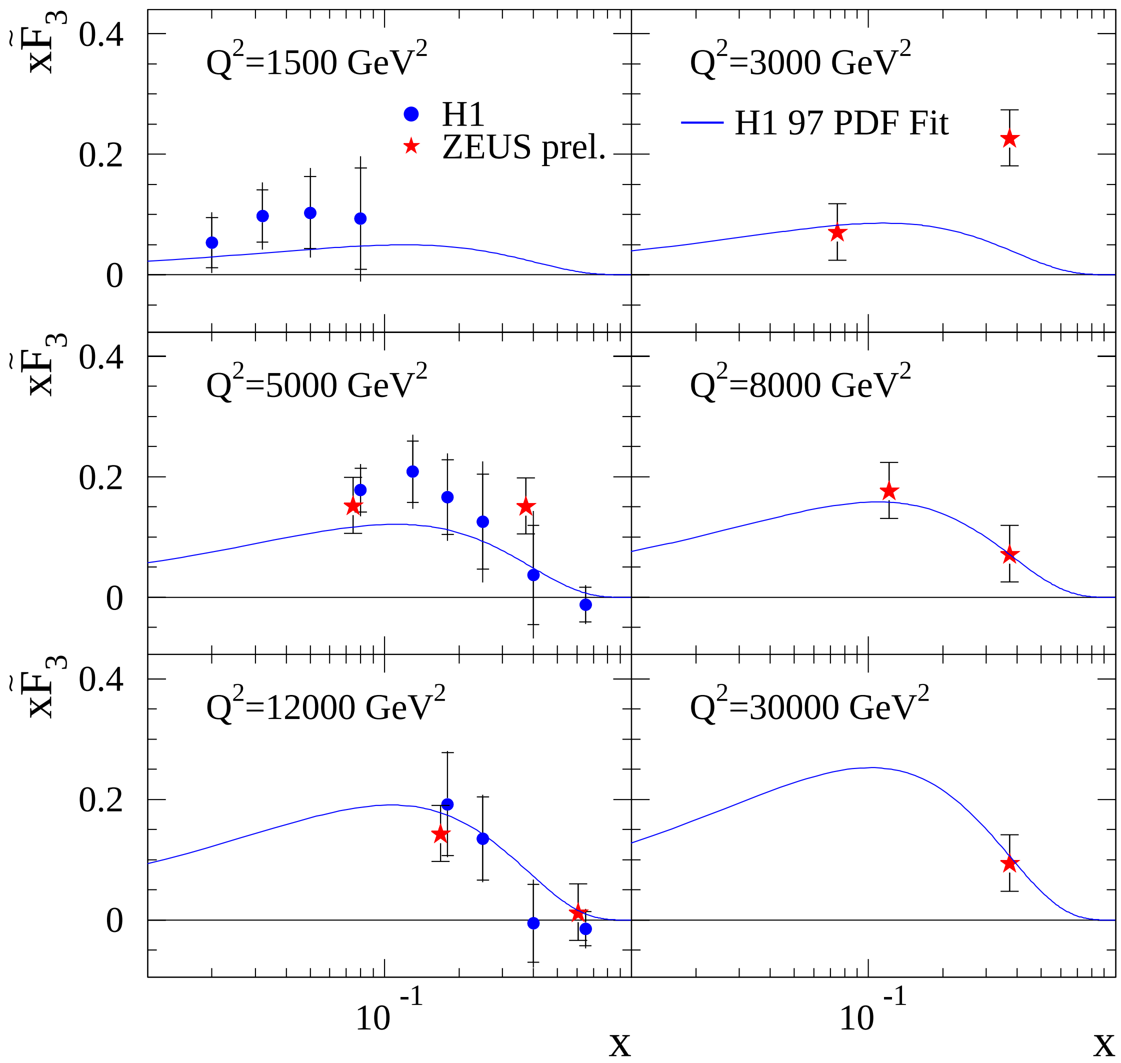
$$x\tilde{F}_3 = \frac{Y_+}{Y_-} \cdot [\tilde{\sigma}^{NC}(e^-) - \tilde{\sigma}^{NC}(e^+)]$$

sensitivity to
valence quark densities

$$x\tilde{F}_3 \sim [q(x,Q^2) - \bar{q}(x,Q^2)]$$

sensitive only @ high Q^2
where γZ interference is sizeable

additional factor needed if
e^+p and e^-p data taken at different beam energies



$x\tilde{F}_3$

- rises with Q^2 (@ fixed x) due to propagator

$$\chi_Z = \frac{1}{4 s_W^2 c_W^2} \left(\frac{Q^2}{Q^2 + M_Z^2} \right)$$

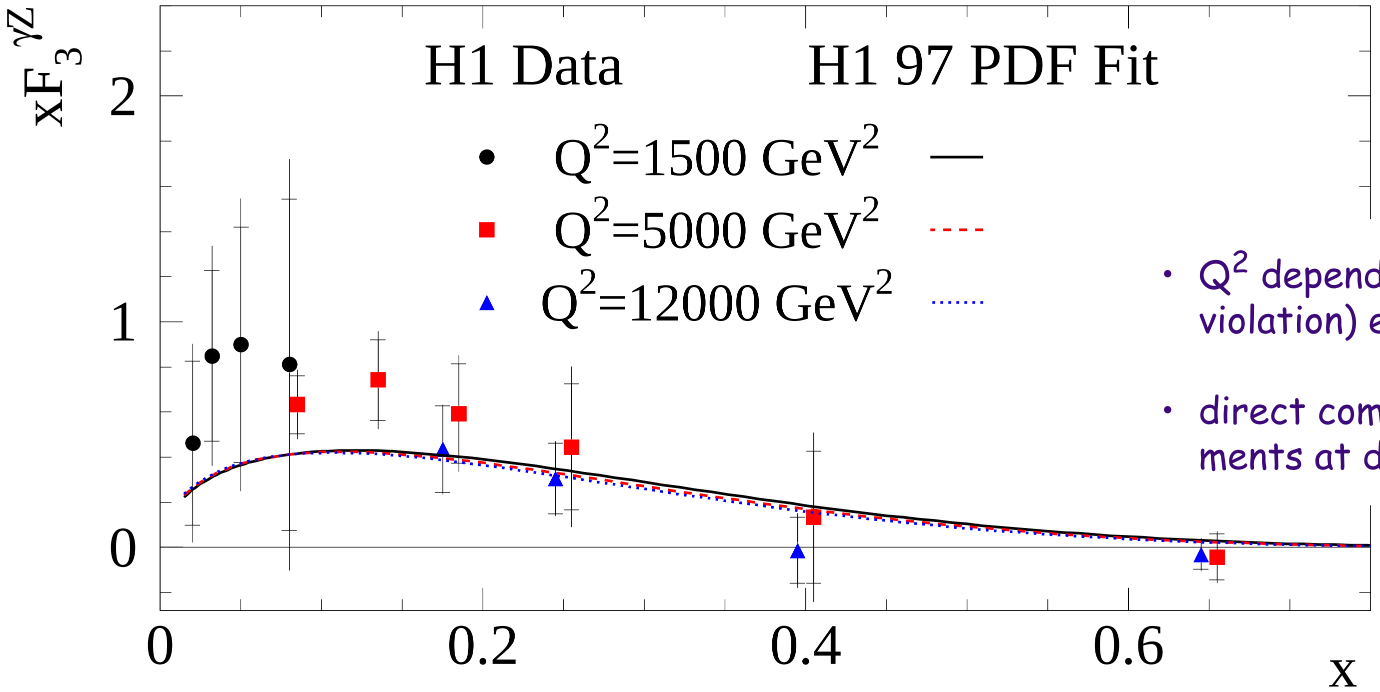
- agreement of data with prediction from QCD fit

contribution to $x\tilde{F}_3$: <3%

$$x\tilde{F}_3 = Q_e a_e \{2Q_q a_q x[q_i - \bar{q}_i]\} \cdot \chi_Z + 2v_e a_e \{2v_q a_q x[q_i - \bar{q}_i]\} \cdot (\chi_Z)^2$$

$$\sim Q_e a_e \{xF_3^{\gamma Z}\} \cdot \chi_Z$$

$xF_3^{\gamma Z}$



- Q^2 dependence (from scaling violation) expected to be small
- direct comparison of measurements at different Q^2 possible

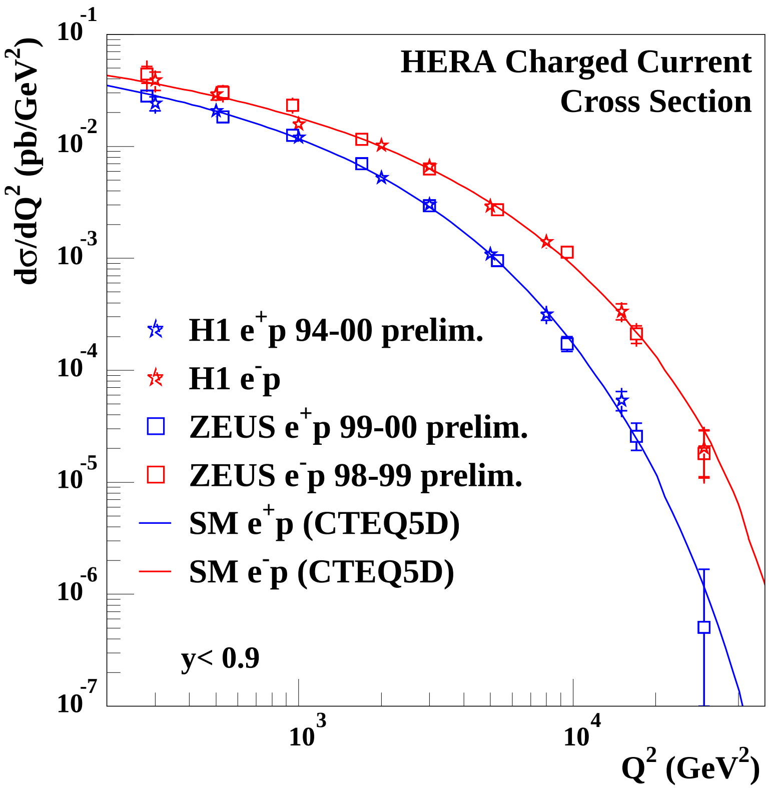
$$\int_0^1 F_3^{\gamma Z} = \int_0^1 2Q_q a_q [q_i - \bar{q}_i] = 2Q_u a_u N_u + 2Q_d a_d N_d = \frac{5}{3} \cdot (1 - \alpha_s/\pi)$$

[sum rule a la Gross Llewellyn-Smith]

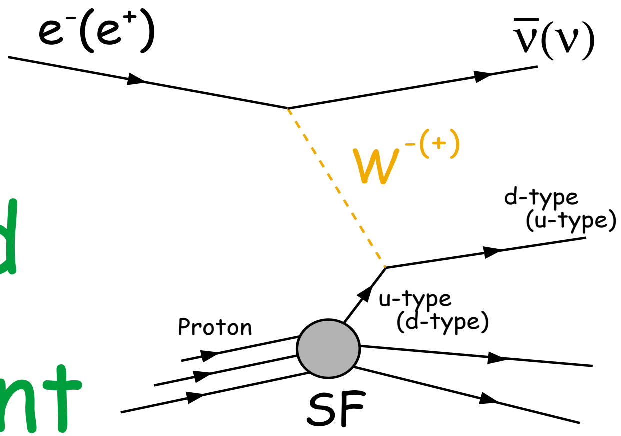
H1 measurement: $\int_{0.02}^{0.65} F_3^{\gamma Z} = 1.88 \pm 0.44$

H1 QCD Fit: $\int_{0.02}^{0.65} F_3^{\gamma Z} = 1.11$

agreement within 2 standard deviations



Charged Current Cross Section



$$\frac{d^2\sigma^{CC}(e^-)}{dx\,dQ^2} = \frac{\pi\alpha^2}{4s_W^2}\frac{1}{(Q^2+M_W^2)^2}\left[u + c - (1-y)^2(\bar{d}+\bar{s})\right]$$

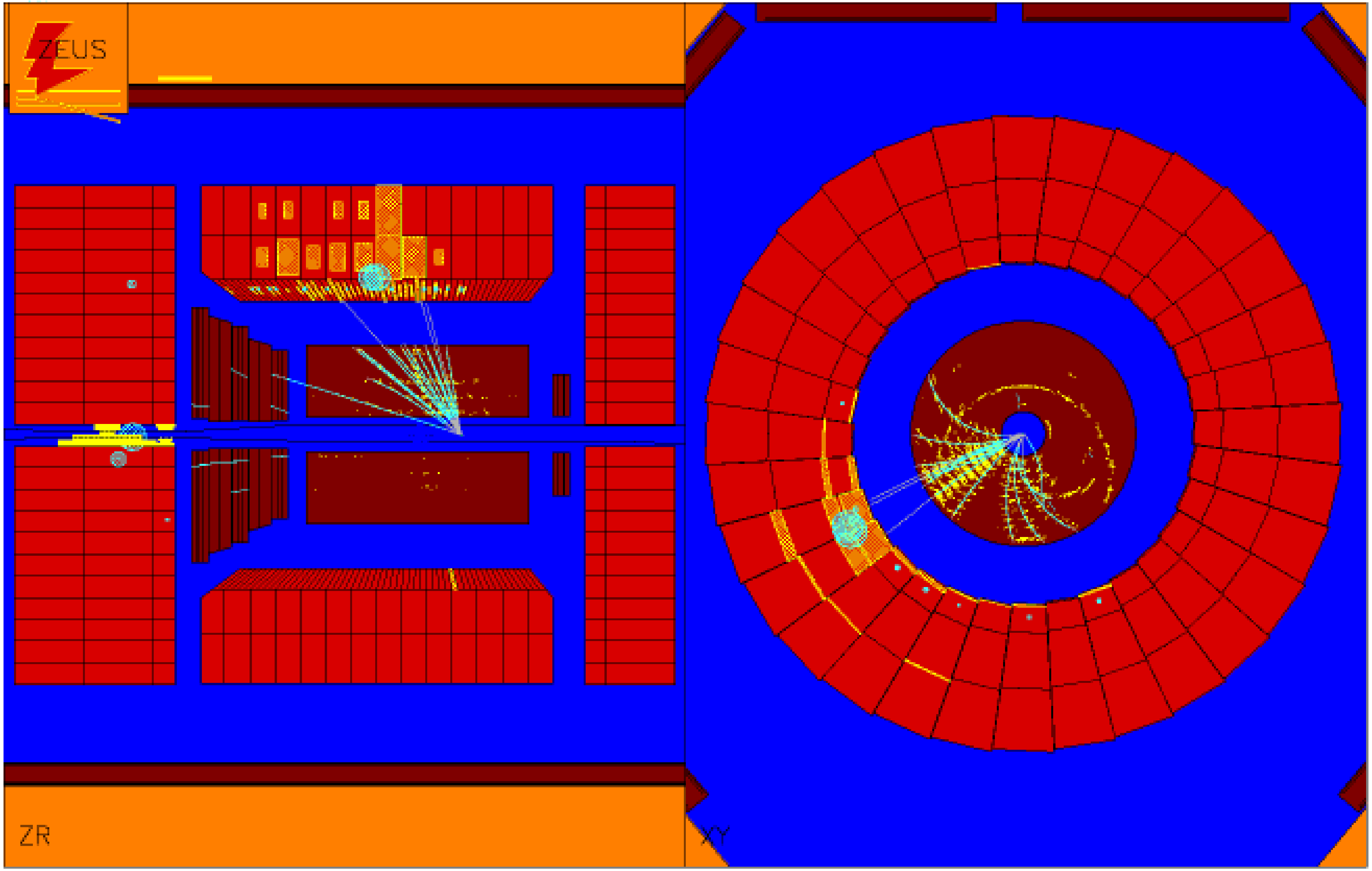
Probes u-quark density

$$\frac{d^2\sigma^{CC}(e^+)}{dx\,dQ^2} = \frac{\pi\alpha^2}{4s_W^2}\frac{1}{(Q^2+M_W^2)^2}\left[\bar{u} + \bar{c} - (1-y)^2(d+s)\right]$$

Probes d-quark density

CC DIS Event

[as seen by the other typical HERA detector]



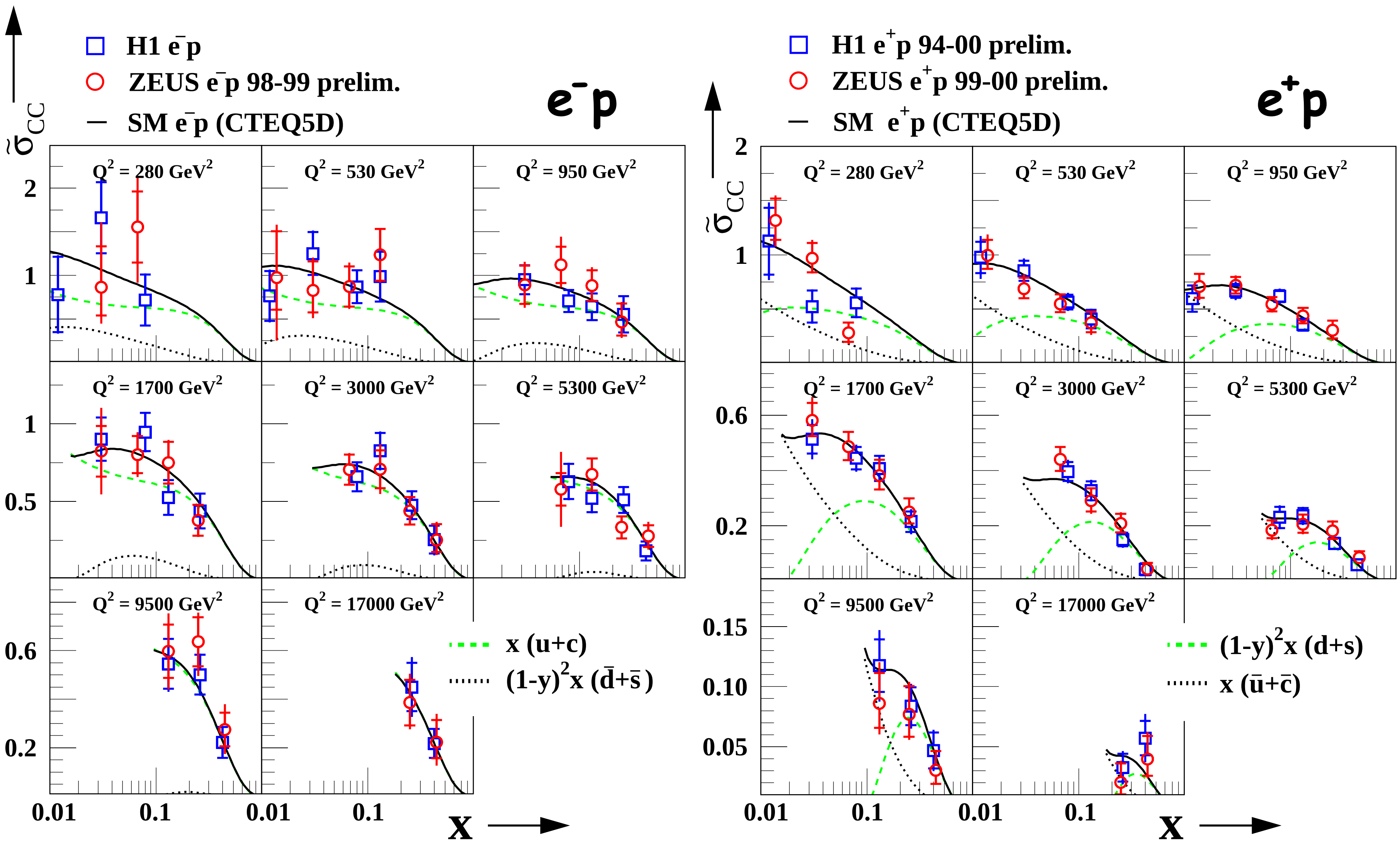
Reduced CC Cross Section

[Sensitivity to u/d quark densities]

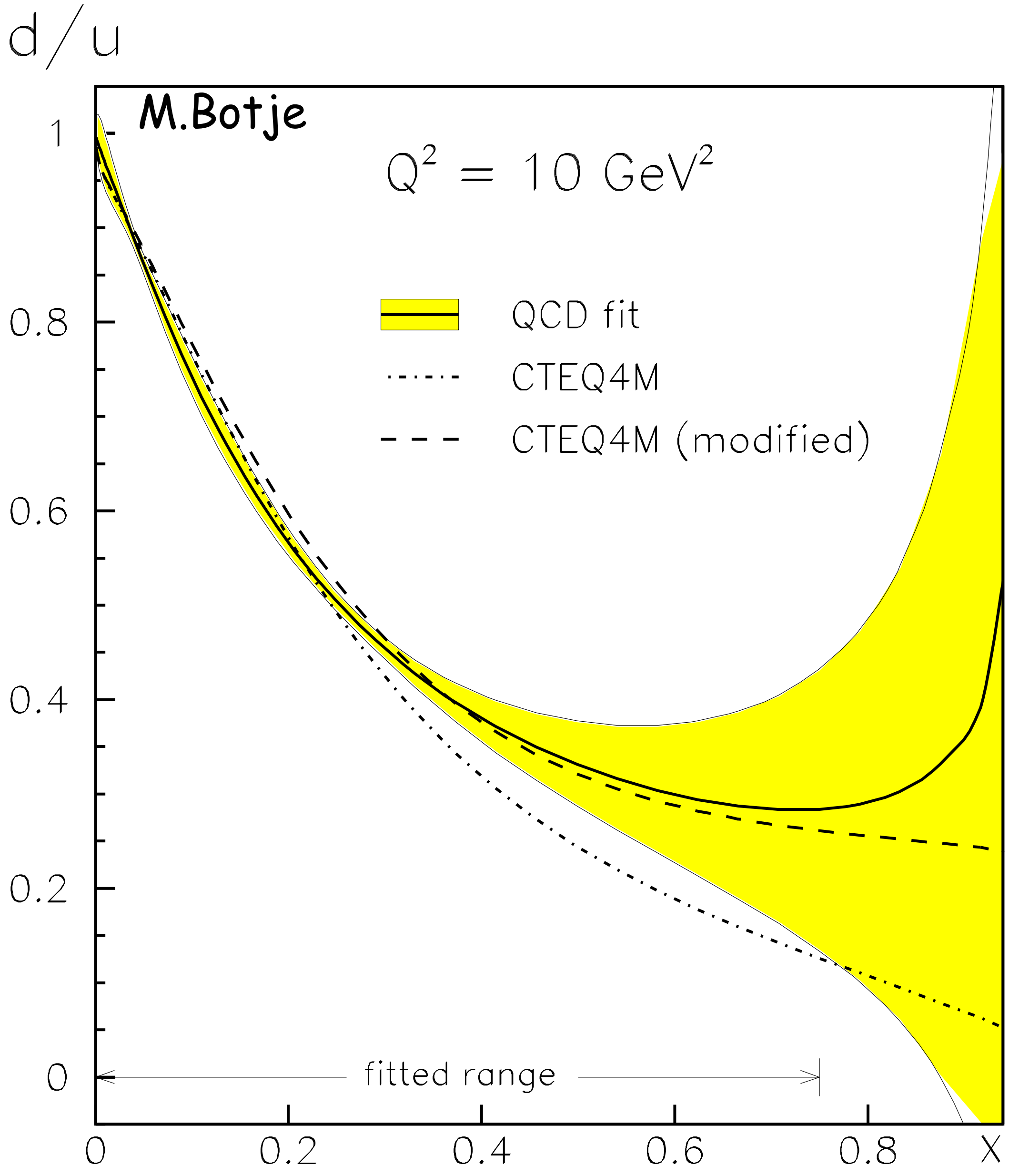
$$\tilde{\sigma}^{\pm}_{CC} = \left[\frac{4s_W^2(Q^2+M_W^2)^2}{\pi\alpha^2}\right]\frac{d\sigma^{2CC}(e^{\pm})}{dxdQ^2}$$

$$\tilde{\sigma}^{-}_{CC} = x[u+c+(1-y)^2(\bar{d}+\bar{s})]$$

$$\tilde{\sigma}^{+}_{CC} = x[\bar{u}+\bar{c}+(1-y)^2(d+s)]$$



Knowledge of d/u Ratio

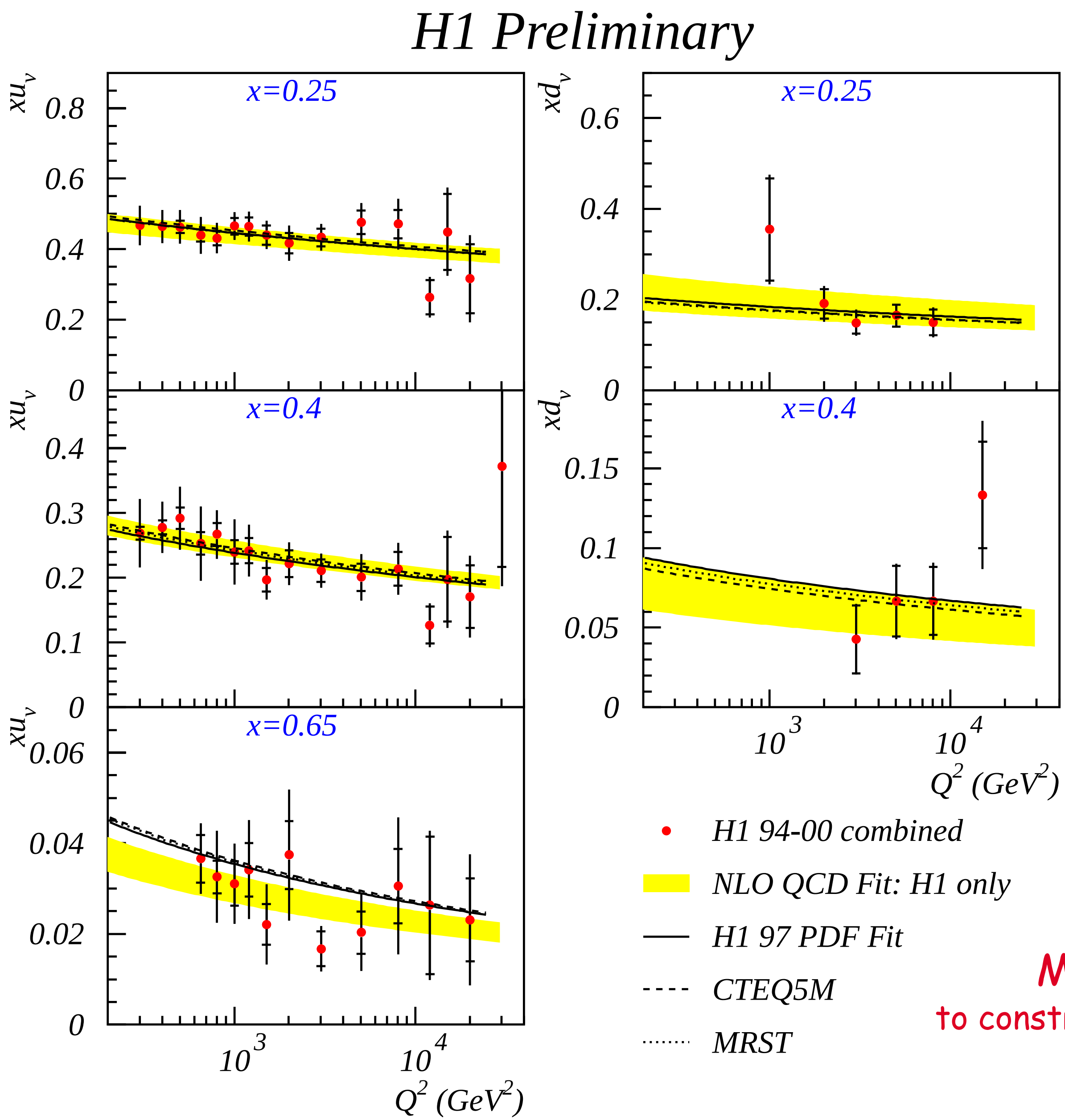


Large uncertainty at high x
[e.g. due to nuclear corrections]

Can be further constrained with NC and CC HERA data.

Valence Quark Distribution

@ high x



NLO QCD fit

using high Q^2, neutral/charged current, e^+p and e^-p data.

Quark densities

determined via local extraction method for data points where the xq_v contribution is >70%.

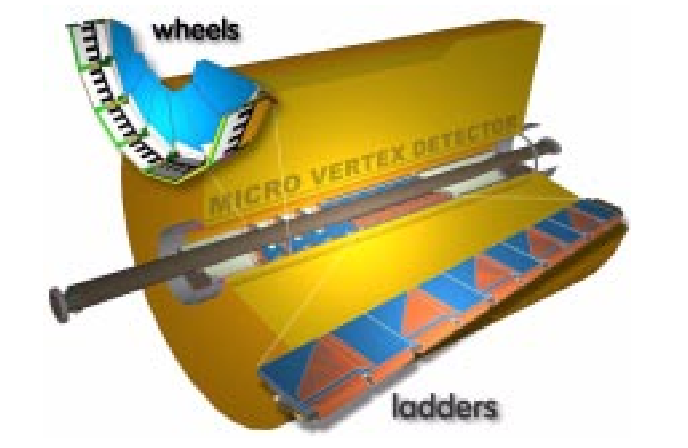
$$xq_v = \sigma_{meas} \cdot \left(\frac{xq_v}{\sigma}\right)_{fit}$$

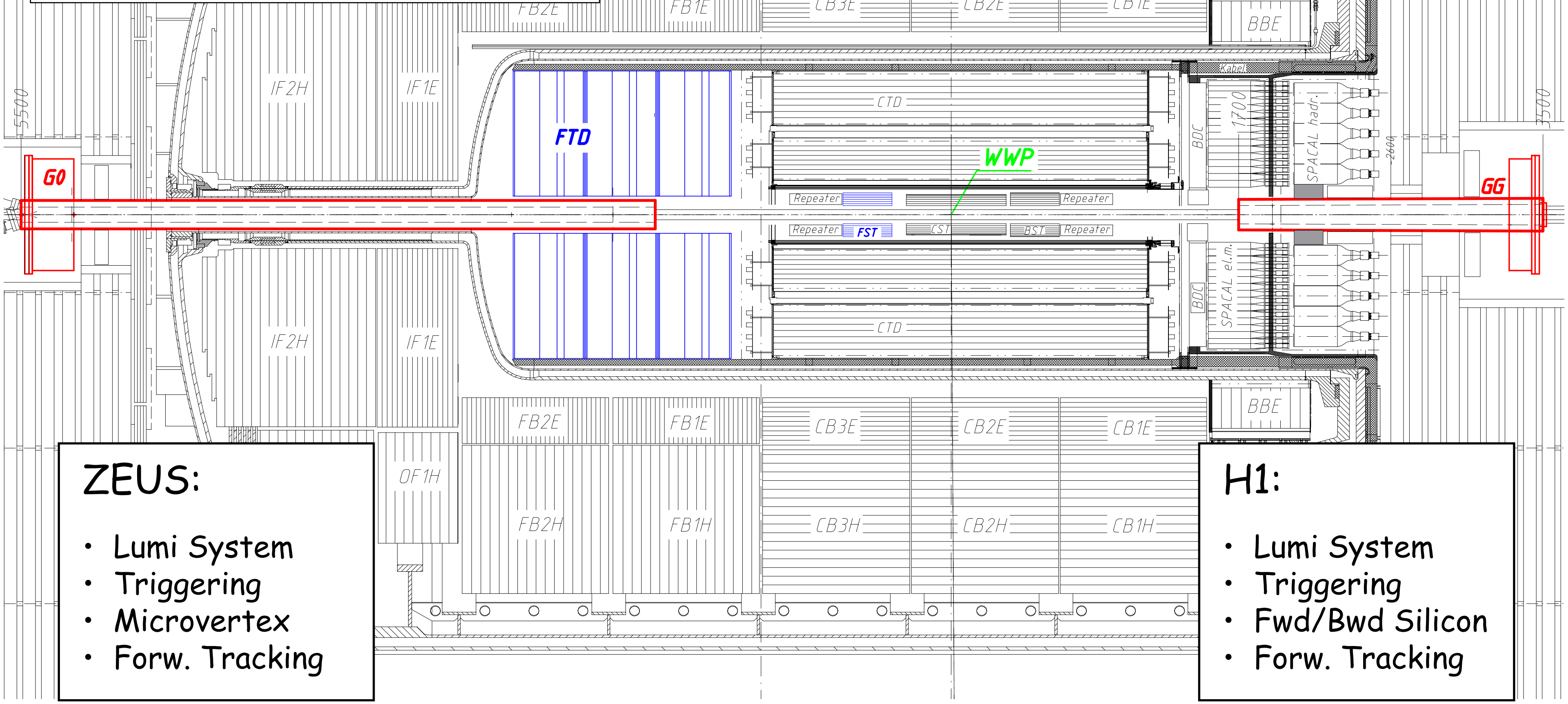
More statistics needed

to constrain behaviour of d/u ratio further.

HERA Upgrade

ZEUS Microvertex Detector





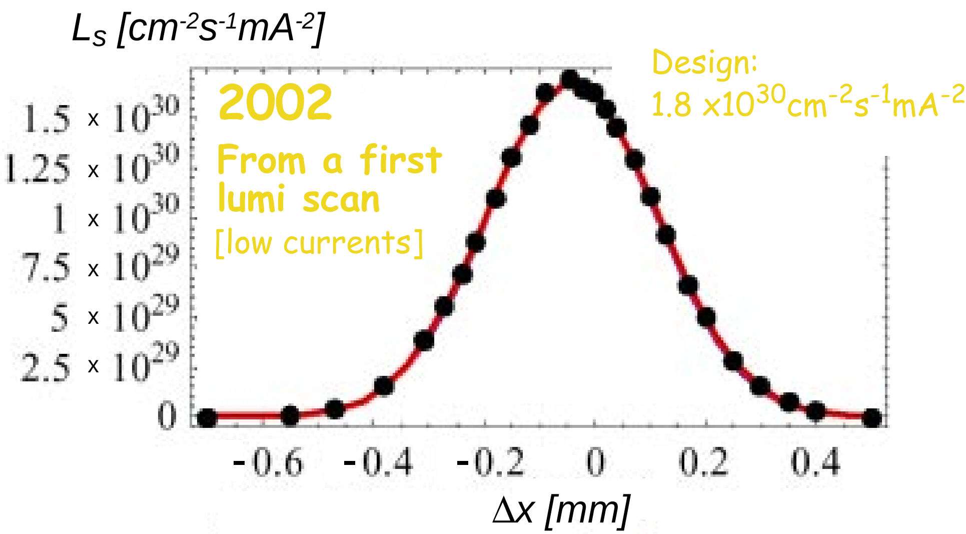
ZEUS:

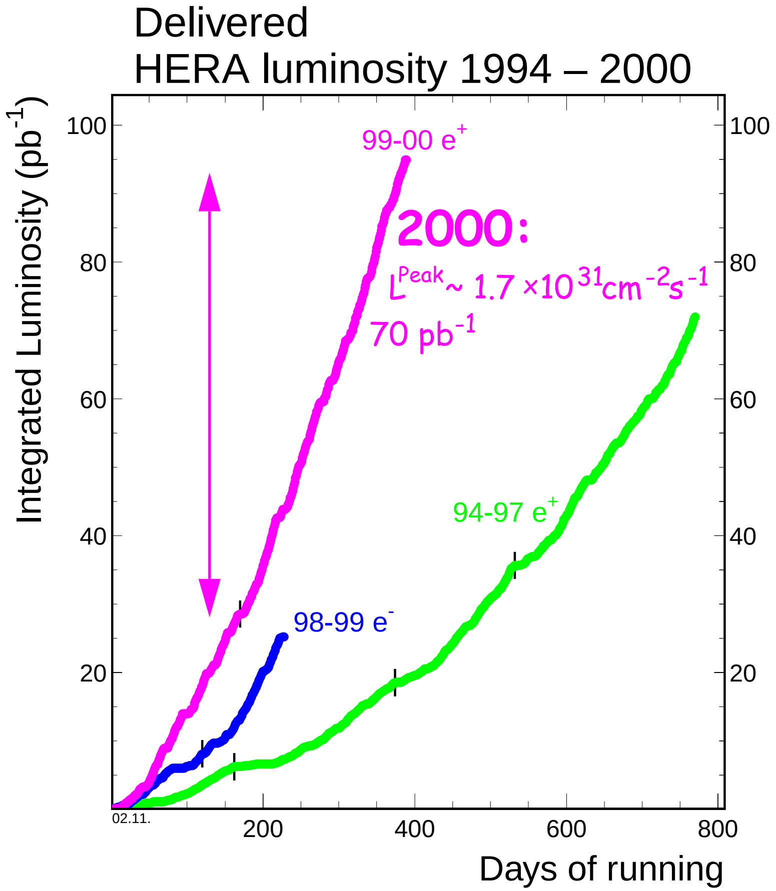
- Lumi System
- Triggering
- Microvertex
- Forw. Tracking

H1:

- Lumi System
- Triggering
- Fwd/Bwd Silicon
- Forw. Tracking

PostUpgrade Luminosity



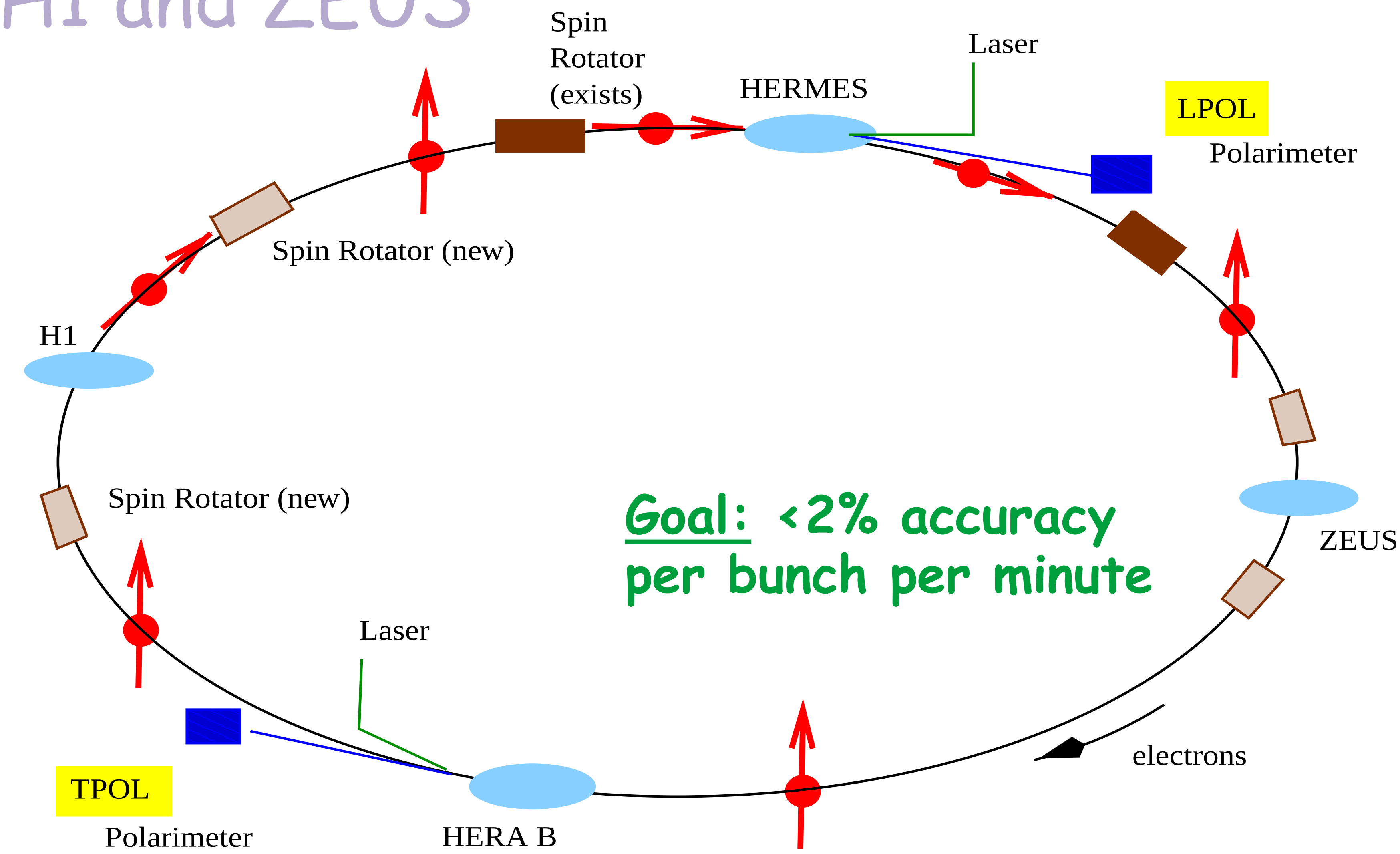


	Peak spec. Lumi [$cm^{-2}s^{-1}mA^{-2}$]	Peak Lumi [$cm^{-2}s^{-1}$]	int. Lumi [pb^{-1}/y]
2000	0.7×10^{30}	1.7×10^{31}	70
	[I_e=50 mA, I_p=100 mA, #Bunches ~200]		
PostUpgr.	1.5×10^{30}	6×10^{31}	240
	[I_e=60 mA, I_p=140 mA, #Bunches ~200]		

New beam optics with stronger focusing provides expected improvement

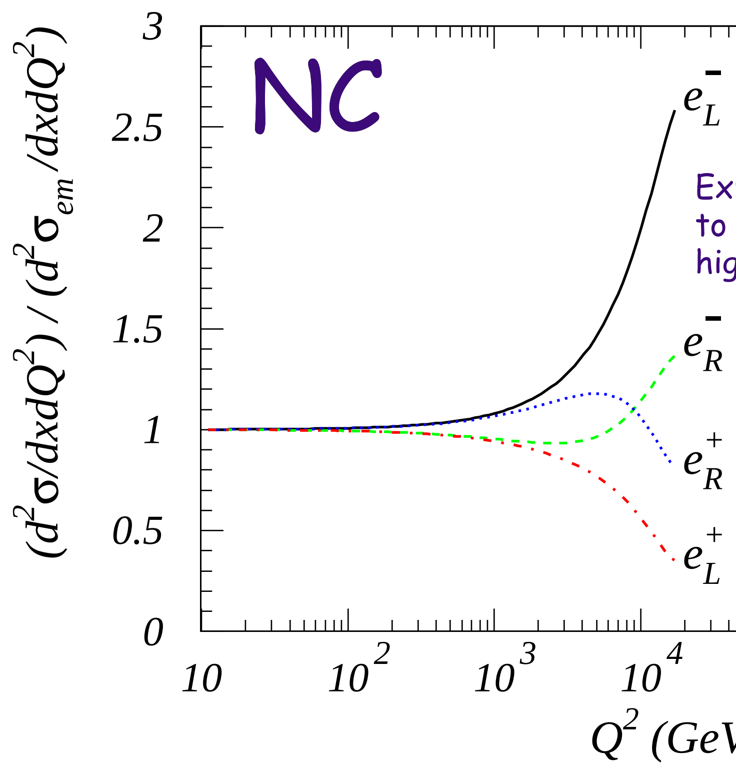
Polarization for H1 and ZEUS

- utilises Compton scattering
- measures energy weighted asymmetry



Goal: <2% accuracy per bunch per minute

- utilises Compton scattering
- measures spatial asymmetry

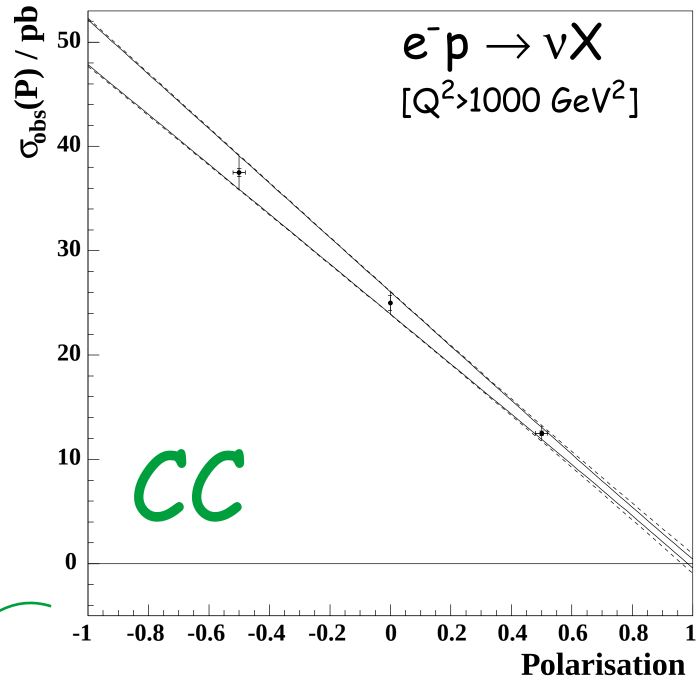


Exploit sensitivity to EW couplings at high Q^2

Utilising Polarisation

$$\tilde{\sigma}^{\pm}_{CC} = (1 \pm P)\tilde{\sigma}^{\pm}_{CC,\,(P=0)}$$

+: Probe d_v quark distribution (P= +1)
-: Probe u_v quark distribution (P= -1)

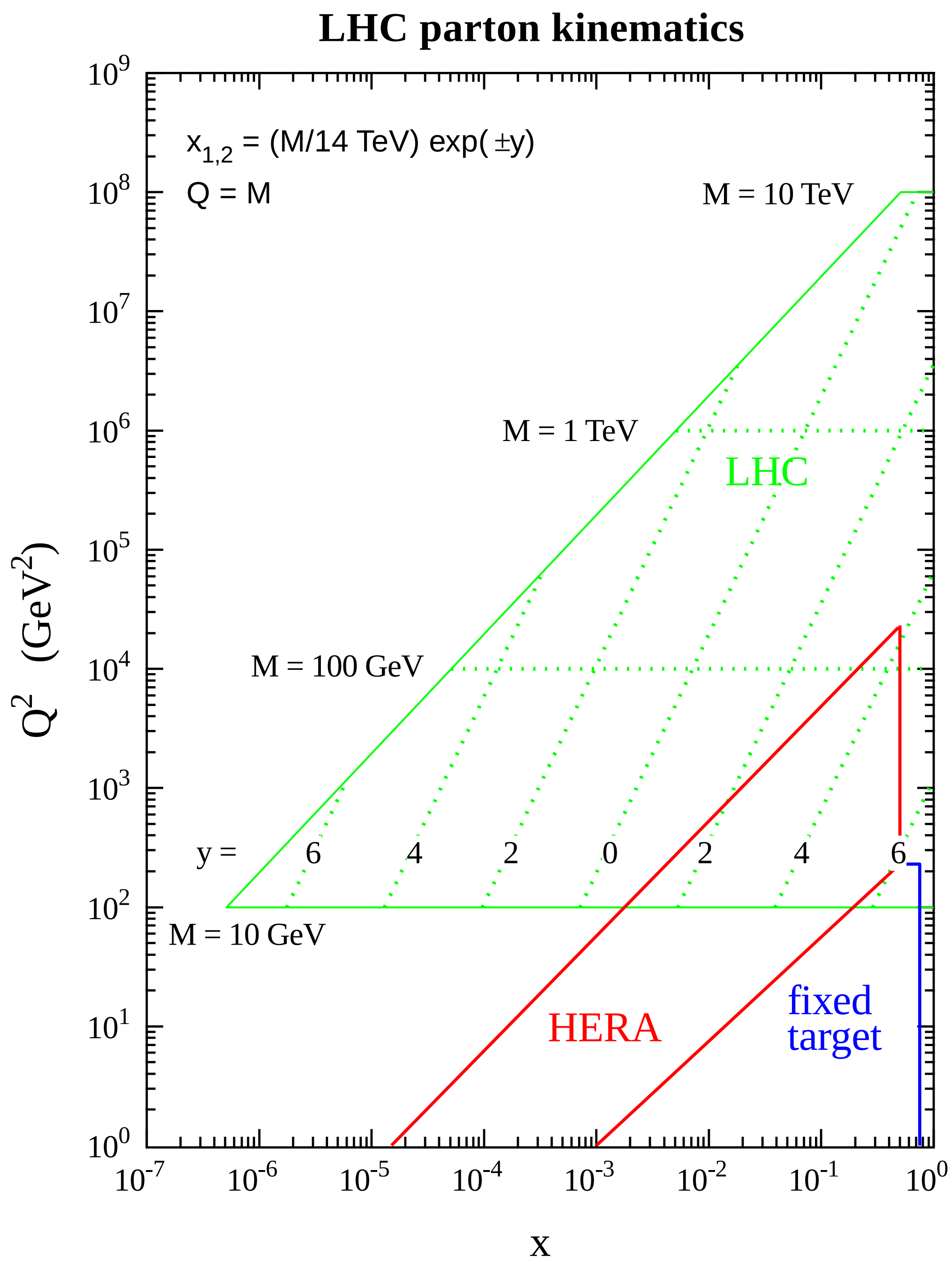


$$\tilde{\sigma}^{\pm}_{NC} = \tilde{\sigma}^{\pm}_{NC,\,0} + P\tilde{\sigma}^{\pm}_{NC,\,P}$$
$$= f(q, \bar{q}, EW\ couplings)$$

Four independent equations one each for $Q_e = \pm 1$ and $P = \pm 1$.

Possibility to

Disentangle individual quark densities
Measure EW couplings v_u, v_d, a_u, a_d

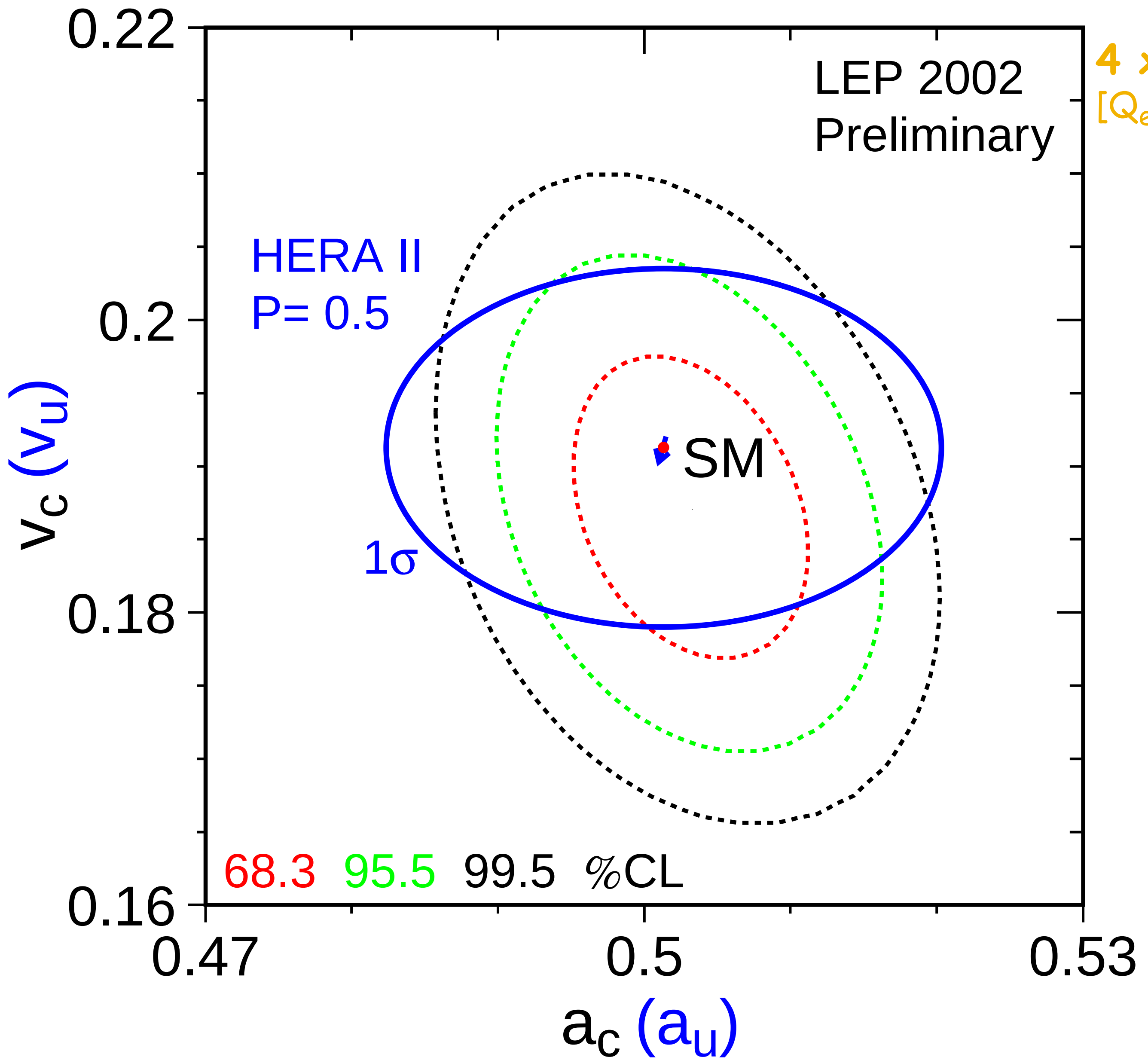


HERA @ high x, high Q^2
\+ Fixed Target

Test of QCD evolution
over 4 order of magnitude.

important for LHC and
e.g. the prediction of
Higgs/W cross sections.

EW Couplings v_u, a_u



4 × 250 pb^{-1}

[Q_e=±1, P=±1]

HERA:

Complementary measurement

[HERA: u,d quark couplings]

[LEP: c,b quark couplings]

Precision compatible with LEP results

Conclusions

Neutral and charged current cross section
consistent with SM

Electroweak effects used as tool to extract
proton structure @ high x

HERA II:
Test of QCD evolution up to highest Q^2
Constrain valence quark distributions at high x
Determine EW couplings v_u, a_u, v_d, a_d