H1 & ZEUS

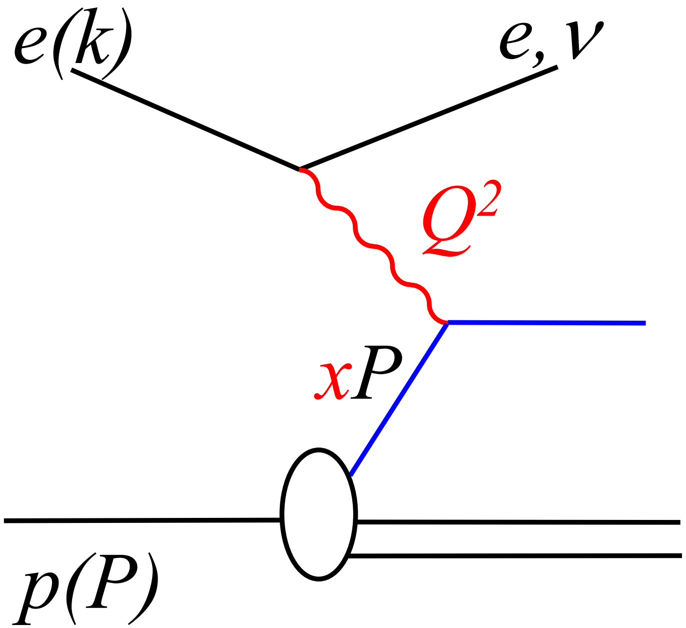
High Q^2 physics and the future physics program at HERA-II

LLWI 2002

- Summary of high Q^2 results from HERA-I
- HERA upgrade
- H1 and ZEUS upgrades
- Physics potential
- Summary

Introduction

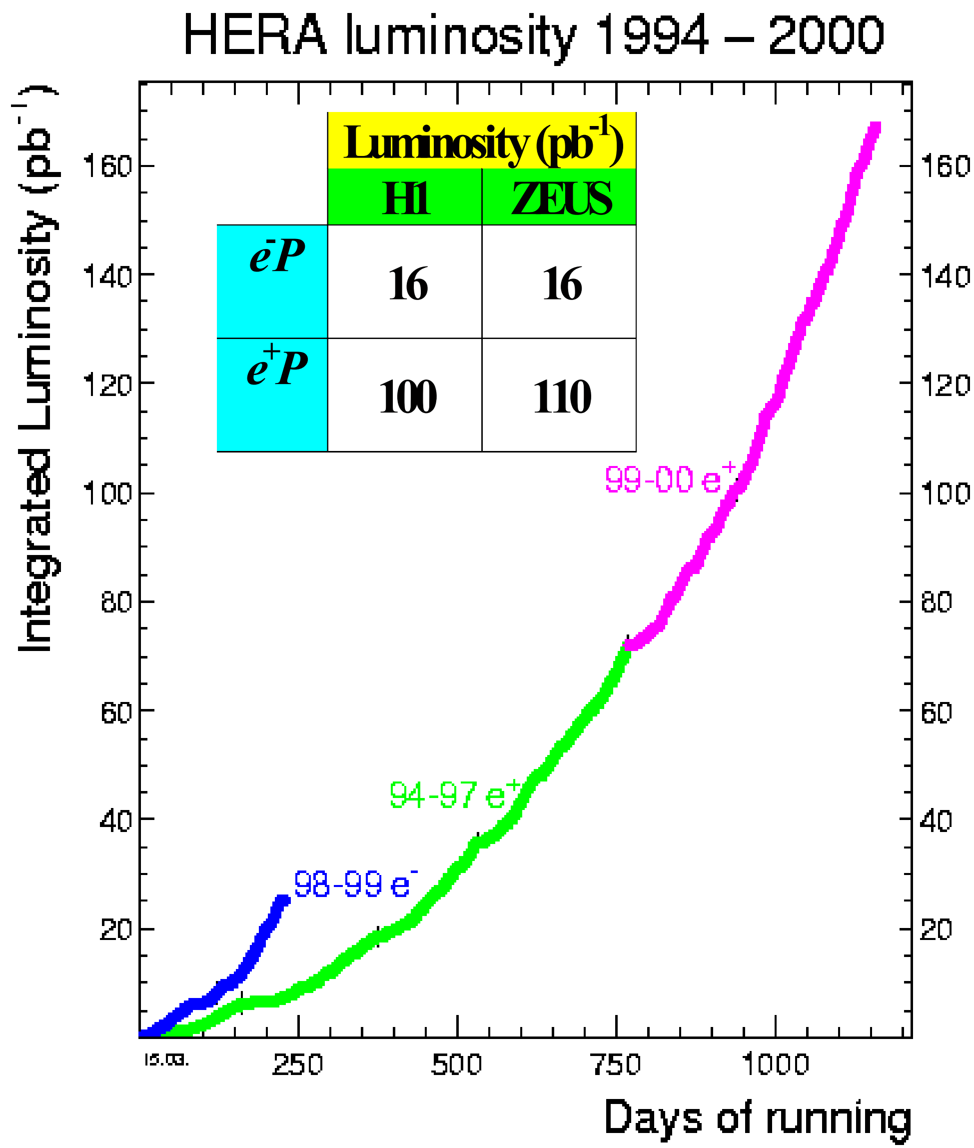
H1 & ZEUS



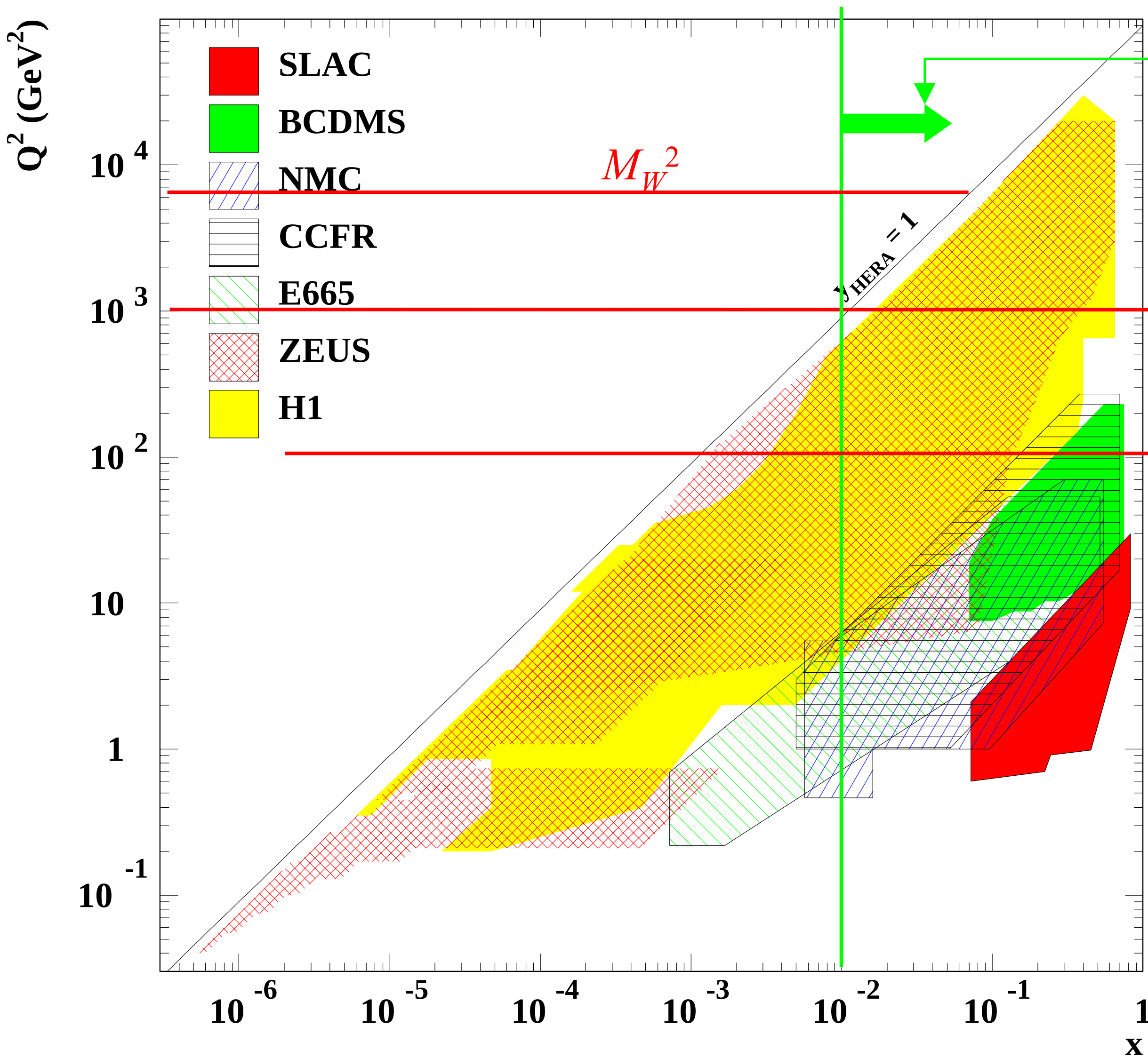
$$Q^2 = sxy$$

s = 300 GeV (94-97)

= 318 GeV (98-00)



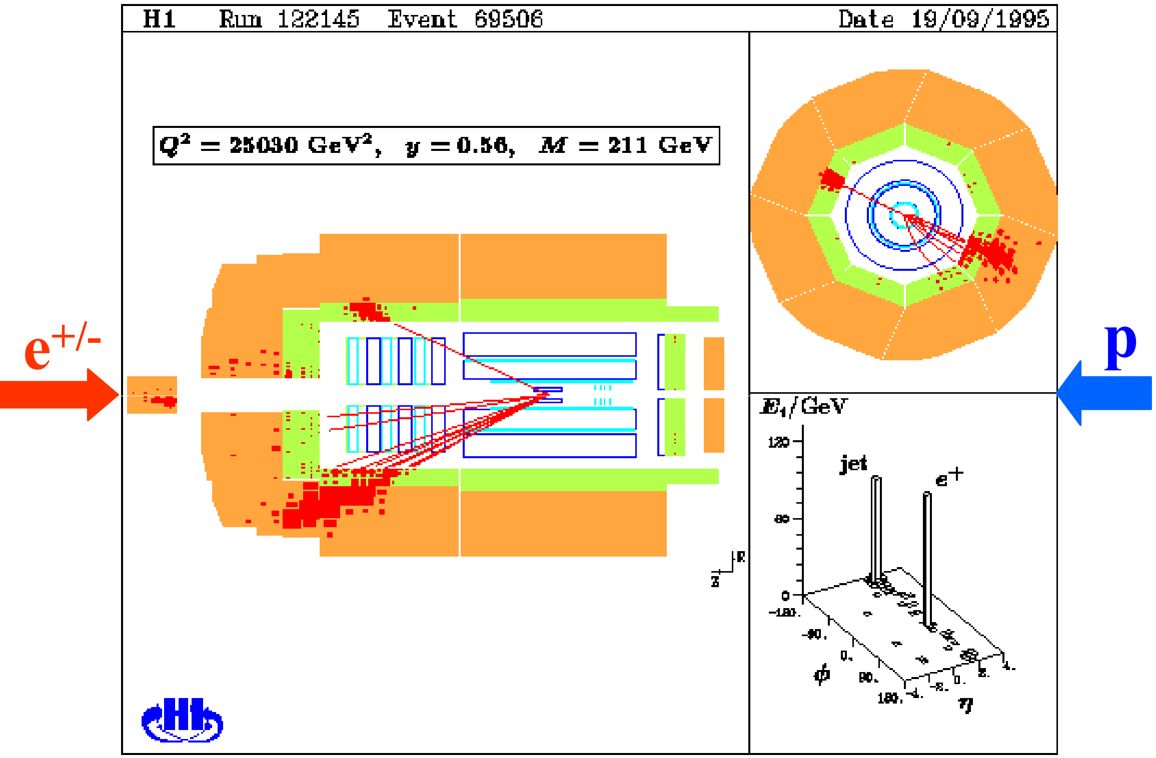
The measurements so far

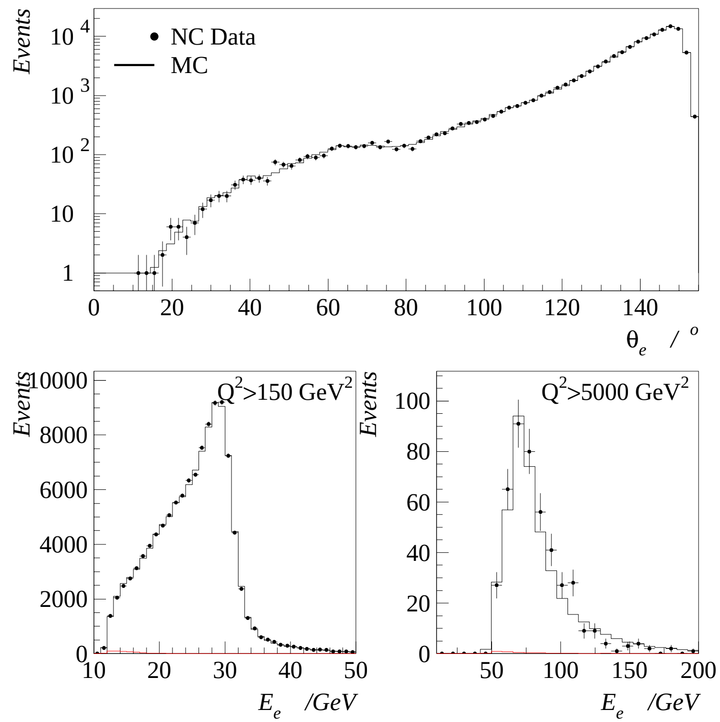


high Q^2 means high x

… but low statistics so far

Fixed target experiments have made good measurements at high x, but at much lower Q^2



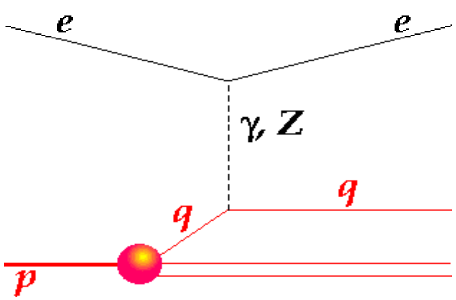


Events easy to recognize: high trigger efficiency, low background

lepton back-scattered, high energy

CC (signature is missing p_T) more difficult at low y

Neutral Current



$$\frac{d^2\sigma_{NC}^{e^\pm p}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\cdot\left[Y_+\cdot F_2\left(x,Q^2\right) \mp Y_-\cdot xF_3\left(x,Q^2\right) - y^2 F_L\left(x,Q^2\right)\right]$$

LO QCD — LO QCD — F_L: small at high Q^2

Parity conserving

$$F_2^{NC} = x\sum_f A_f(Q^2)[q(x,Q^2)+\bar{q}(x,Q^2)]$$

Parity violating

$$xF_3^{NC} = x\sum_f B_f(Q^2)[q(x,Q^2)-\bar{q}(x,Q^2)]$$

$$A_f = e_f^2 \quad - \quad 2v_e v_f e_f \chi_Z \quad + \quad (v_e^2+a_e^2)(v_f^2+a_f^2)\chi_Z^2$$

γ exch. — γ -Z interference — Z exch.

$$B_f = \quad - \quad 2a_e a_f e_f \chi_Z \quad + \quad 4v_e a_e v_f a_f \chi_Z^2$$

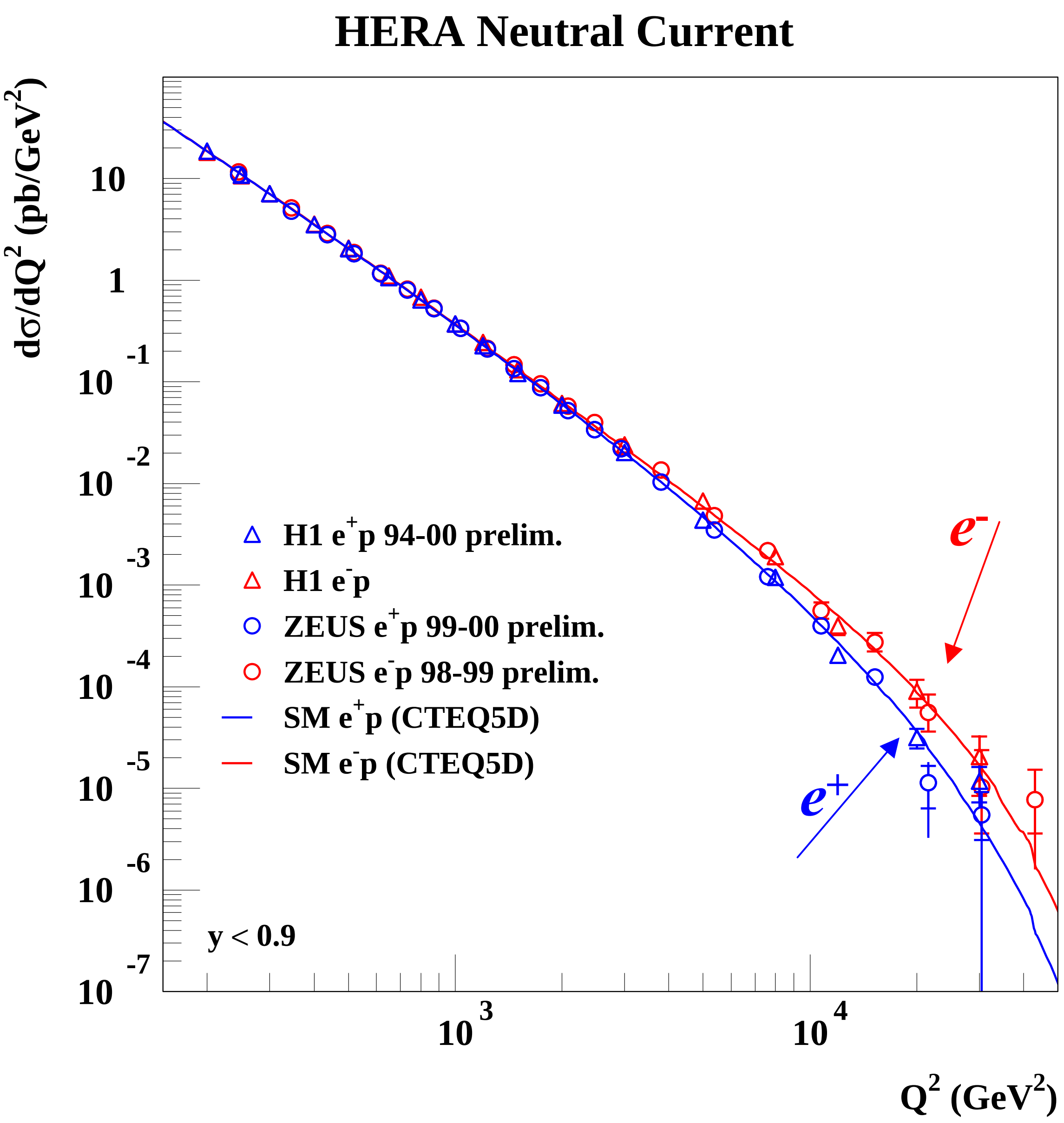
$$\chi_Z = \frac{1}{4\sin^2\vartheta_W \cos^2\vartheta_W}\frac{Q^2}{Q^2+M_Z^2}$$

v_e, a_e, v_f, a_f : weak couplings

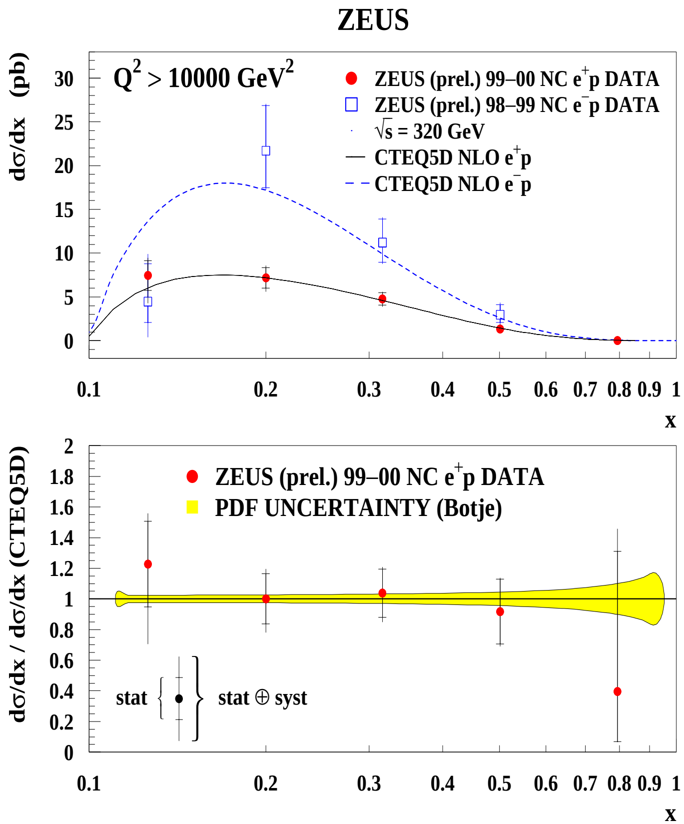
<u>Reduced cross section:</u>

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

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

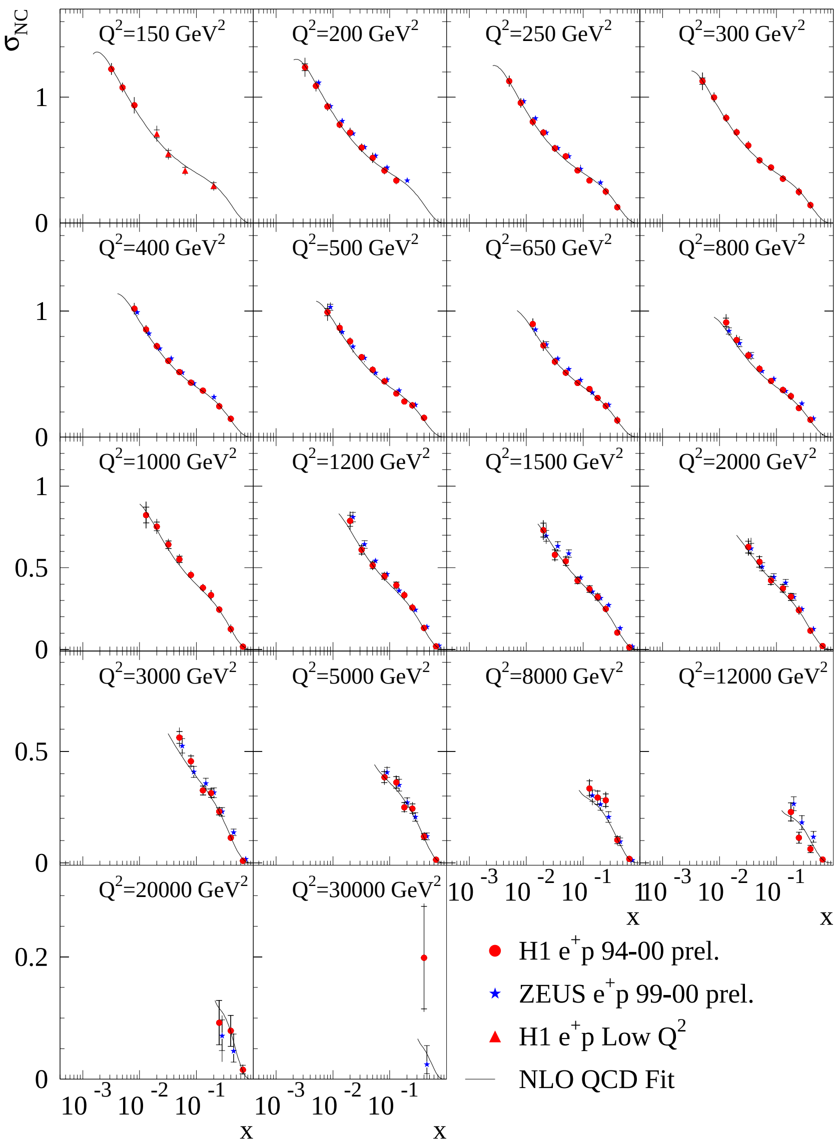


- SM describes shape over 10^6 fall in cross section
- evidence for the effect of γ–Z interference at high Q^2



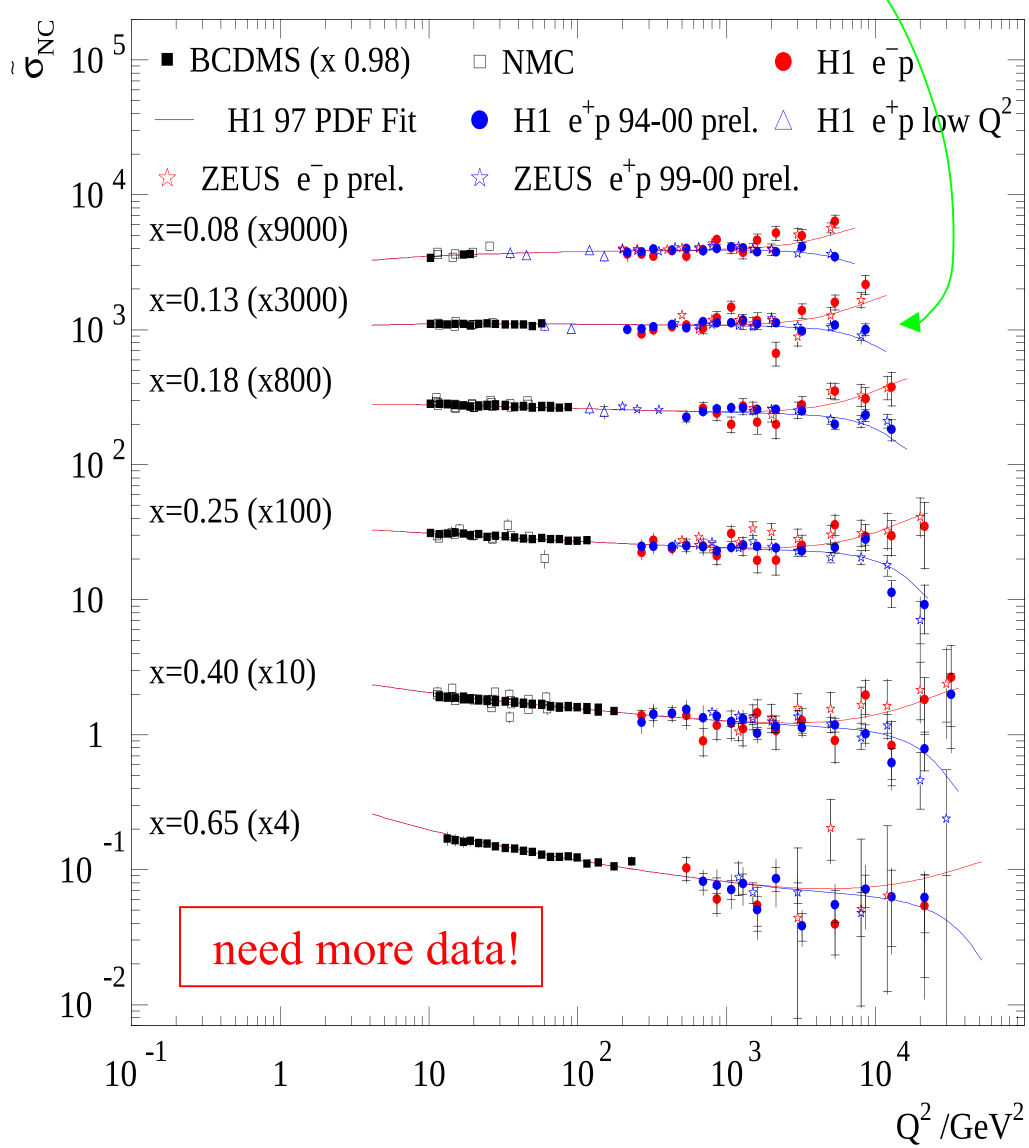
Quality of the data

H1 & ZEUS



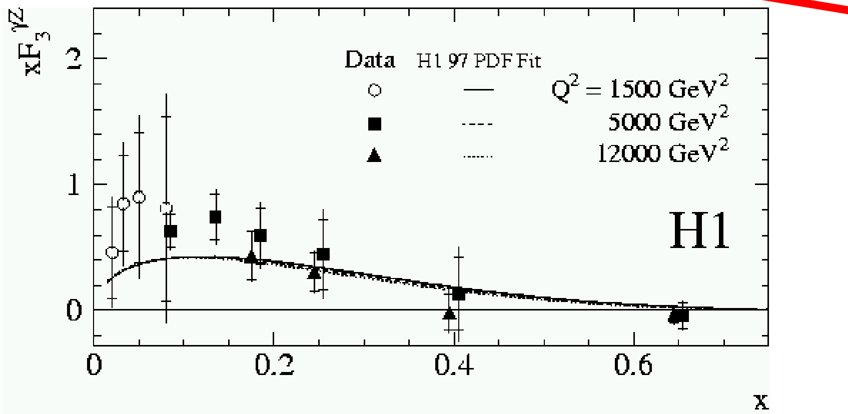
good agreement H1/ZEUS/SM

effect of *Z*-exchange



need more data!

NC: first measurement of xF_3 — H1 & ZEUS



- agrees with QCD: small changes over large range of Q^2 due to QCD scaling violations

- results limited by small e^- sample

- sensitive to valence quarks:

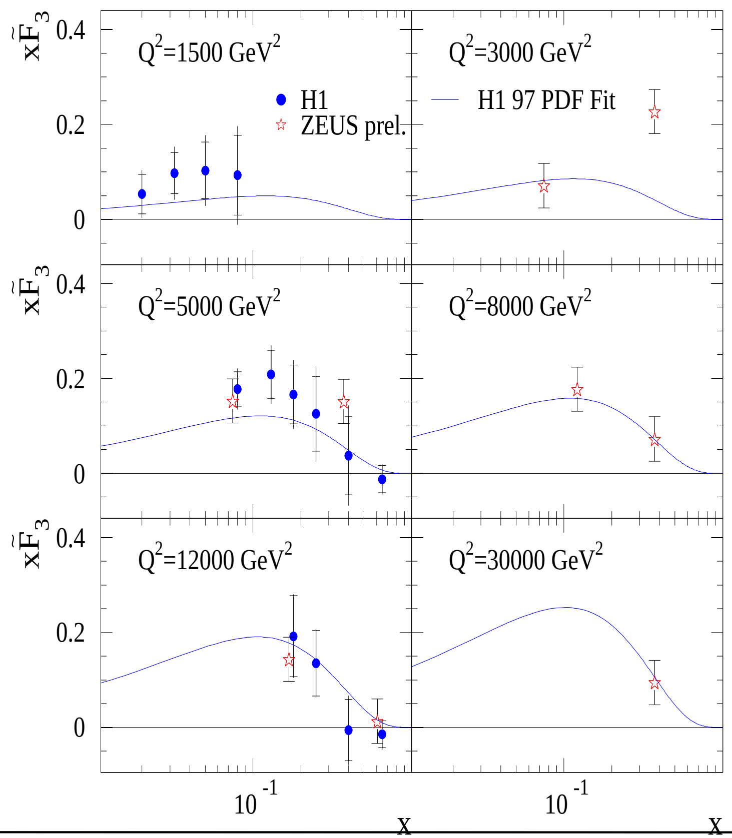
$$xF_3 \propto (q - \bar{q}) = ((q_v + q_{sea}) - \bar{q}_{sea}) \approx q_v$$

- sum rule test:

$$\text{recall:} \quad xF_3^{\gamma-Z} = x \sum_q 2 e_q a_q (q - \bar{q})$$

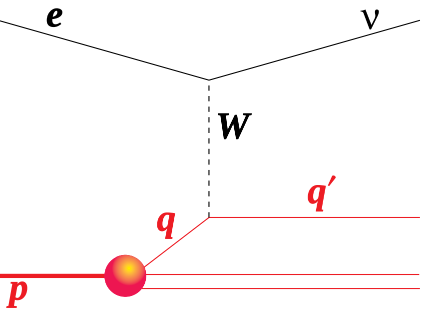
$$\text{then:} \quad \int_0^1 F_3^{\gamma-Z} dx \approx 2 e_u a_u N_u + 2 e_d a_d N_d = 5/3$$

$$\text{H1:} \quad \int_{0.02}^{0.65} F_3^{\gamma-Z} dx = 1.88 \pm 0.35(\text{stat.}) \pm 0.27(\text{syst.})$$



Charged Current

H1 & ZEUS



$$\frac{d^2\sigma_{CC}^{e^\pm p}}{dxdQ^2} = \frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 \left[Y_+ \cdot F_2^{CC}(x,Q^2) \mp Y_- \cdot xF_3^{CC}(x,Q^2) - y^2 F_L^{CC}(x,Q^2)\right]$$

small

$e^- p \rightarrow \nu X$

$$F_2^{CC} = x(q+\bar{q}) = x(u+c+\bar{d}+\bar{s})$$
$$xF_3^{CC} = x(q-\bar{q}) = x(u+c-\bar{d}-\bar{s})$$

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

Probe u valence

$e^+ p \rightarrow \bar{\nu} X$

similarly ...

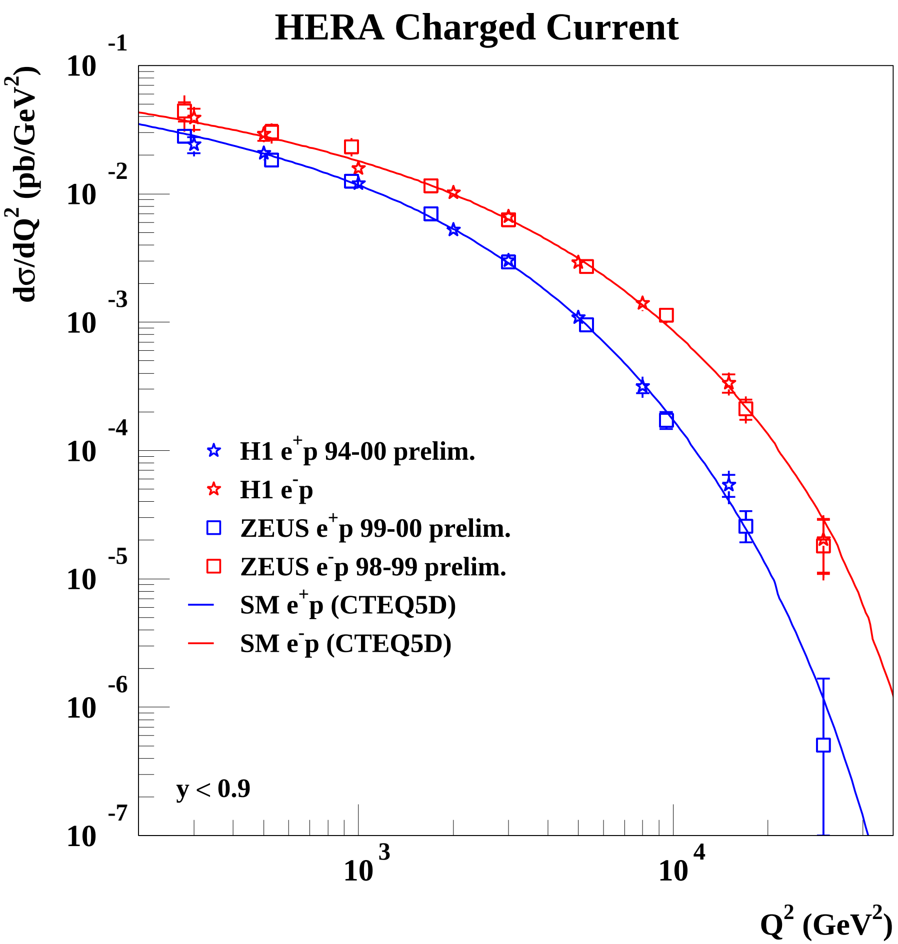
$$\tilde{\sigma}_{CC}^{e^+ p} = \bar{u} + \bar{c} + (1-y)^2(d+s)$$

Probe d valence

- extract individual quark densities
- measure M_W from propagator dependance

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

$$\tilde{\sigma}_{CC} = \frac{2\pi x}{G_F^2}\left[\frac{Q^2+M_W^2}{M_W^2}\right]^2 \frac{d^2\sigma_{CC}}{dxdQ^2}$$



- SM describes shape well:
  - below M_W^2, slow fall with Q^2 due to reduced x phase space
  - above M_W^2, rapid fall due to W propagator
- difference e^- vs e^+:
  - low Q^2, sea important, $\sigma\sim$ same
  - high Q^2, valence dominates:

$$\tilde{\sigma}_{CC}^{e^-p} \approx u$$

$$\tilde{\sigma}_{CC}^{e^+p} \approx (1-y)^2 d$$

so rough expectation:

proton has $2u, 1d$; $\int_0^1 (1-y)^2 dy = 1/3$

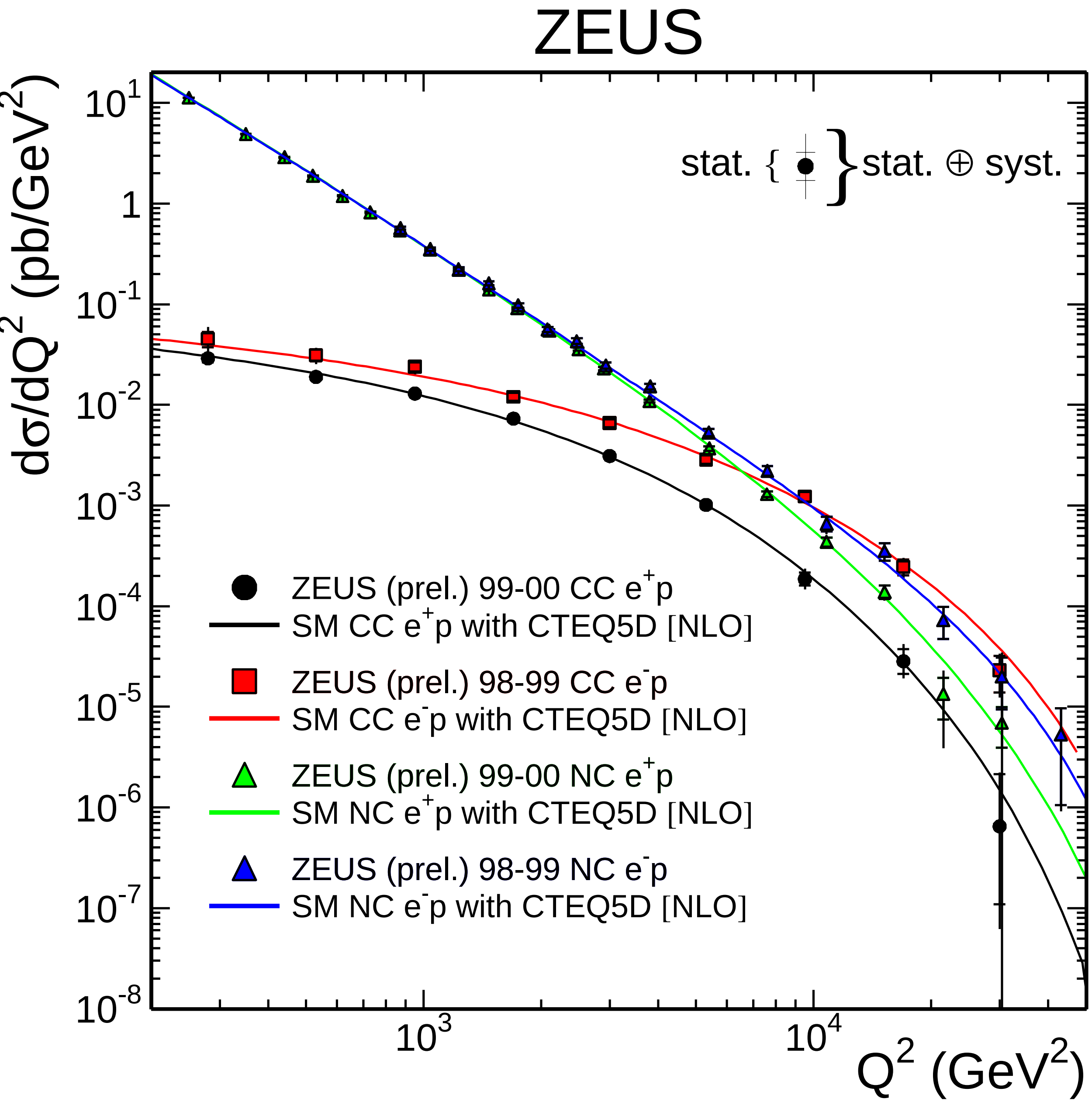
$$\Rightarrow \quad \sigma^{e^-p} / \sigma^{e^+p} \approx 6$$

- d/u critical measurement

Space-like M_W measurement:

H1: $M_W = 80.9 \pm 3.3 \pm 1.7 \pm 3.7$ GeV

ZEUS: $M_W = 81.4 \pm 2.7 \pm 2.0 \pm 3.3$ GeV

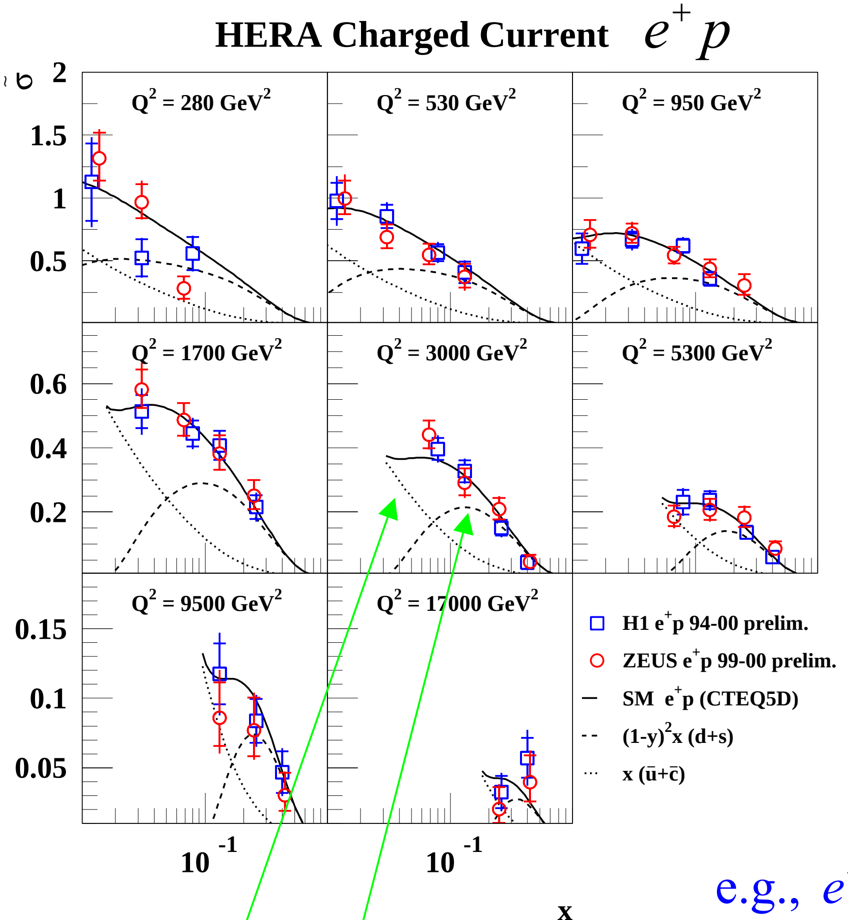


$\sigma_{CC} \approx \sigma_{NC}$

for

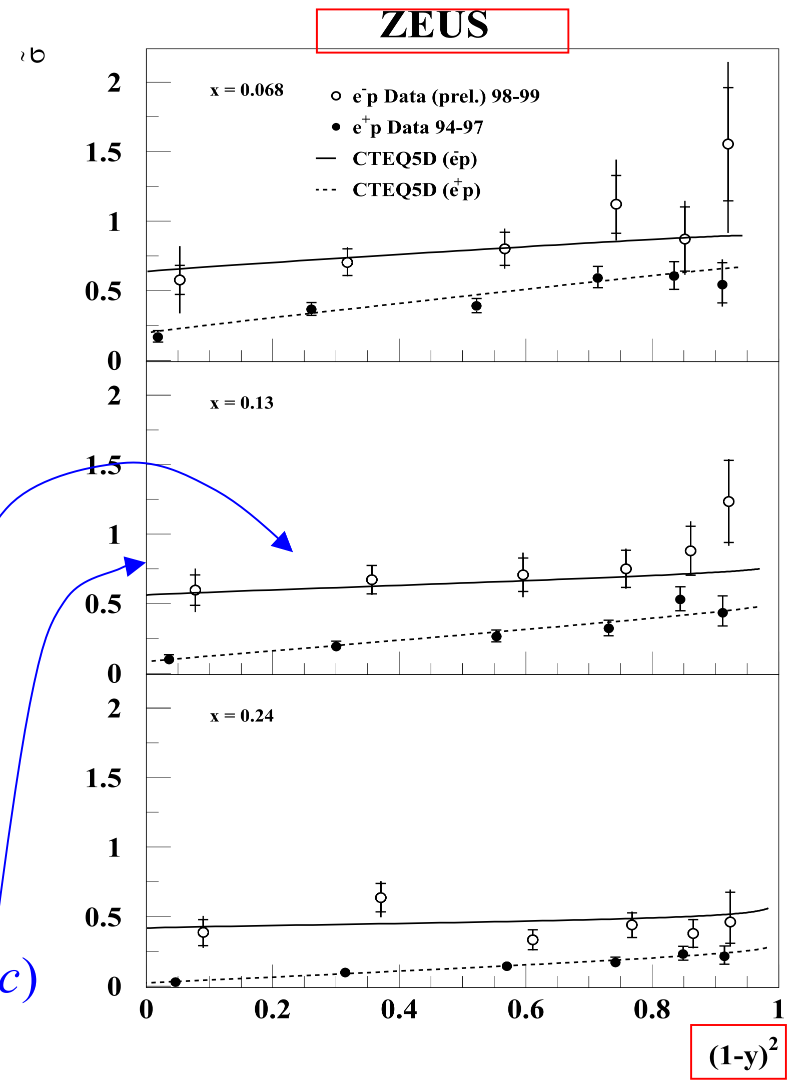
$Q^2 > M_W^2, M_Z^2$

Flavour decomposition with CC



$x(\bar{u}+\bar{c})$

$(1-y)^2 x(d+s)$



e.g., $e^- p$:

slope $= (\bar{d}+\bar{s})$

intercept $= (u+c)$

H1 xu and xd extraction

H1 & ZEUS

- NLO QCD fit to H1 data (yellow)
  - determine xu ~ 6-10%, xd ~20%
  - at x=0.65, xu is lower by ~17% than in MRST, CTEQ5, H197

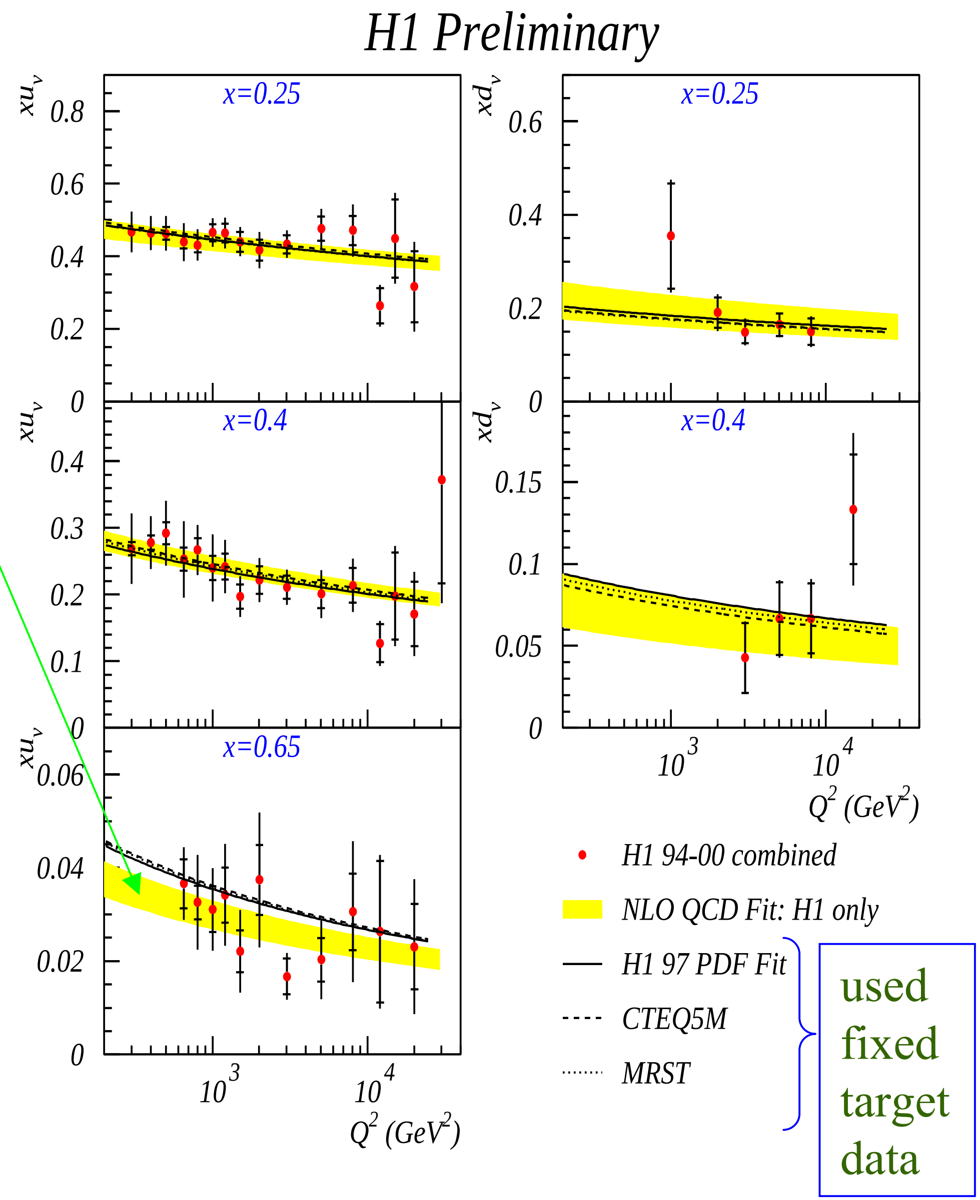
- data points "extracted":

$$xq_v(x,Q^2) = \sigma_{meas}(x,Q^2)\left(\frac{xq_v(x,Q^2)}{\sigma(x,Q^2)}\right)_{fit}$$

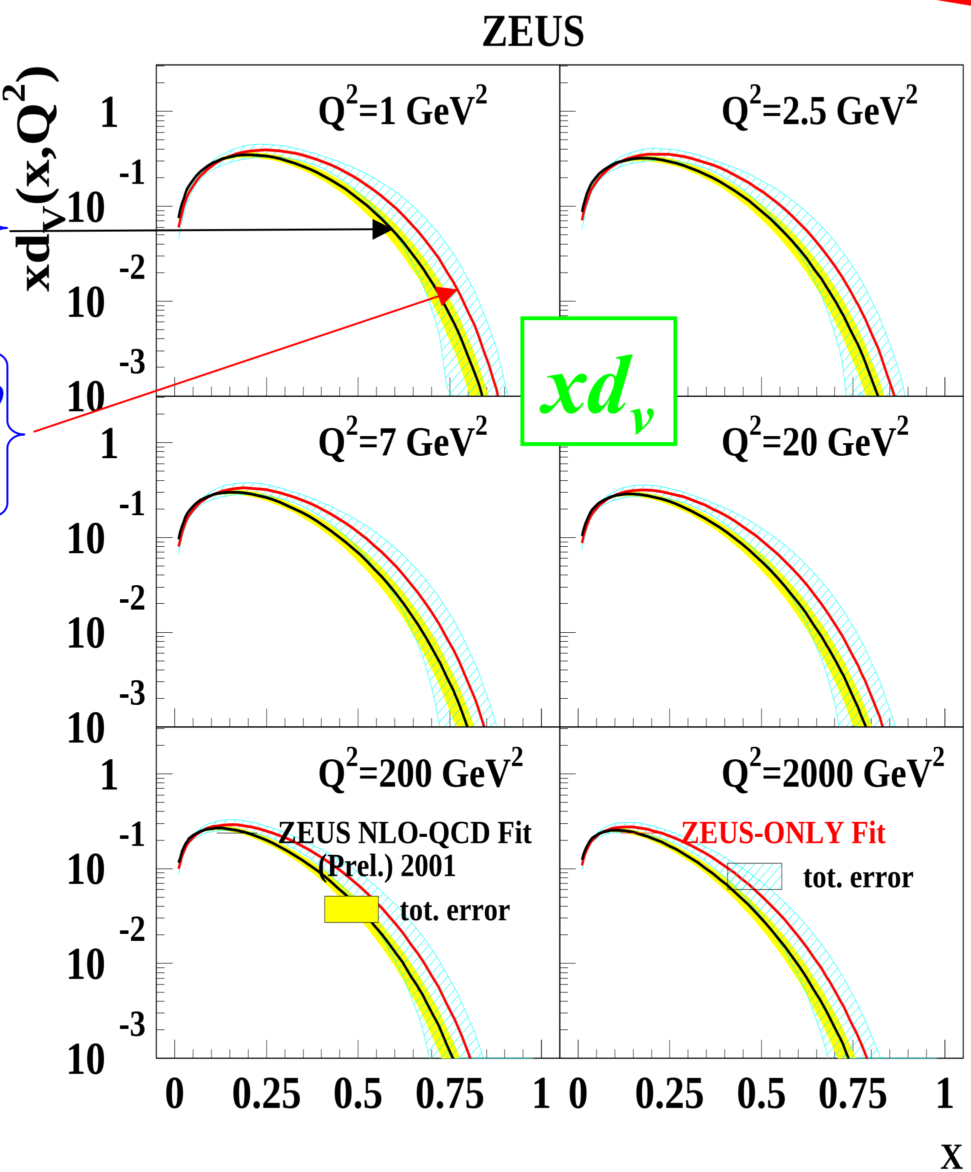
points extracted only for $\left(\frac{xq_v}{\sigma}\right) > 0.7$

$\Rightarrow$ approx. model independent

  - extracted points in good agreement with QCD fits

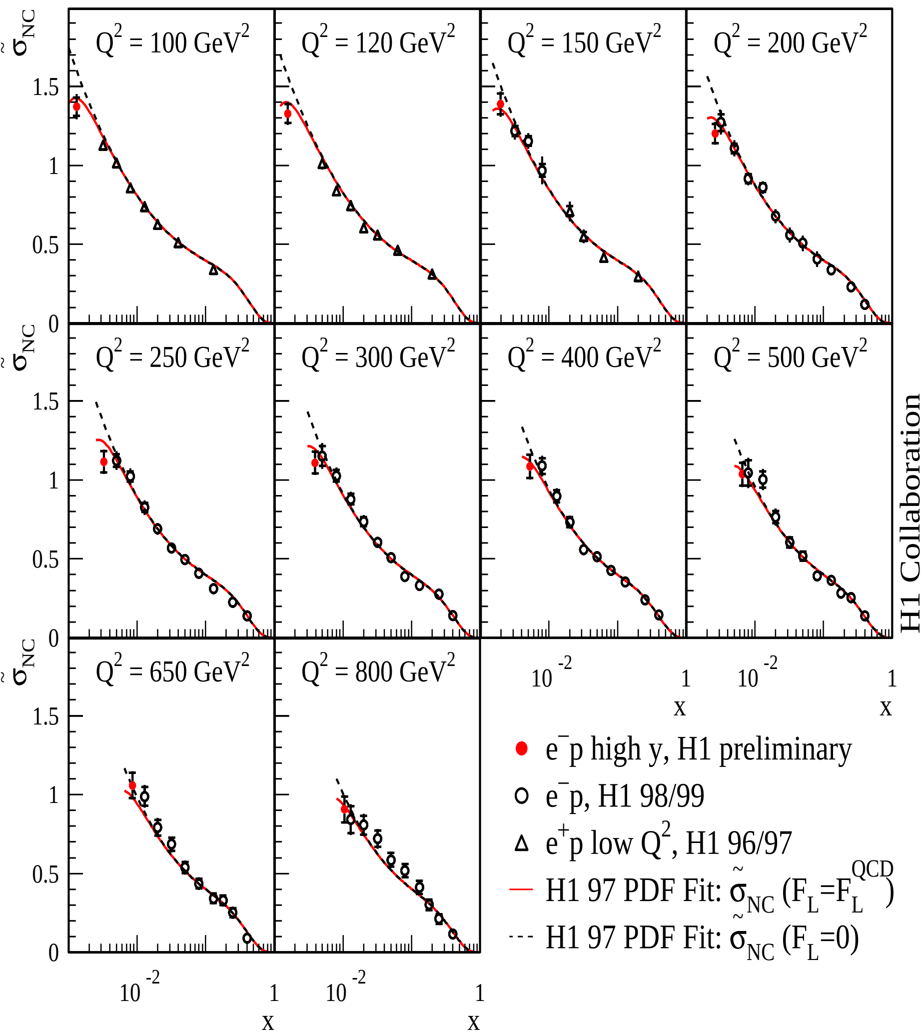


- Uses ZEUS 96-97 e^+p NC data and fixed target data
- ZEUS-ONLY fit uses 96-97 e^+p NC/CC, 98-99 e^-p NC/CC
  - prefers higher xd_v than standard fit
- more HERA data needed: free from heavy target, higher twist, etc. corrections



H1 F_L determination at high Q^2

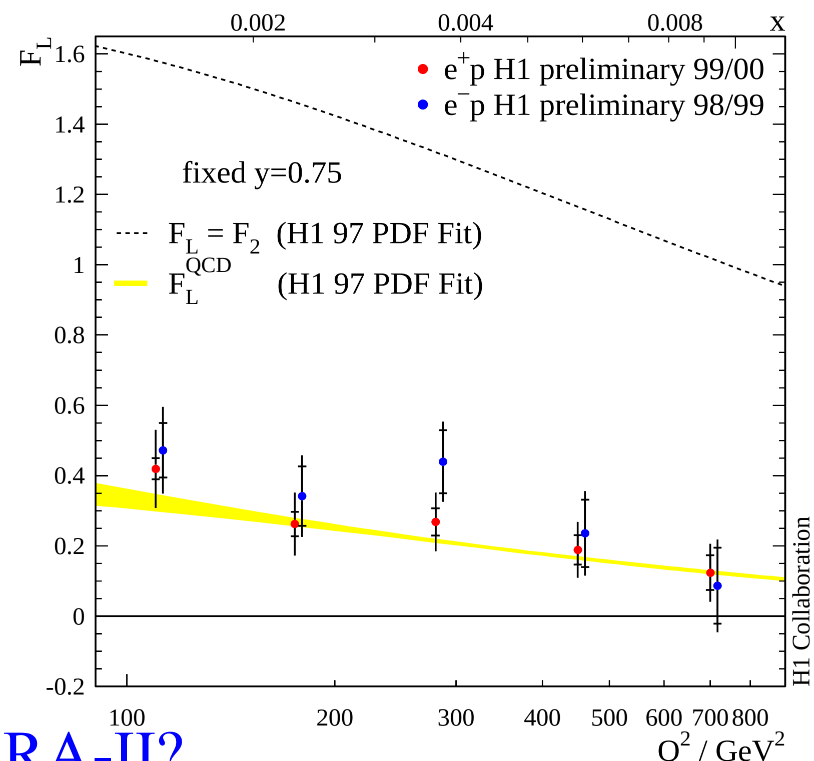
- Extend data at high *y* by lowering cut on scattered *e* from 11 to 6 GeV



$$F_L = \frac{Y_+}{y^2}(F_2^{fit} - \tilde{\sigma})$$

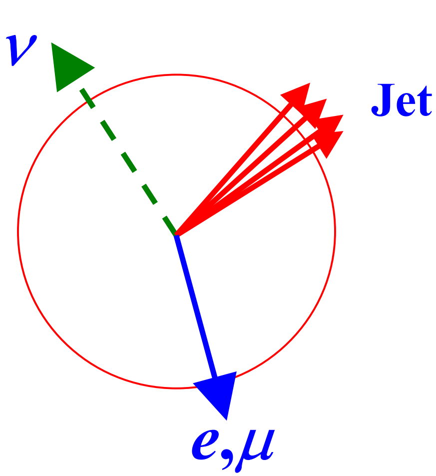
from H1 97 fit

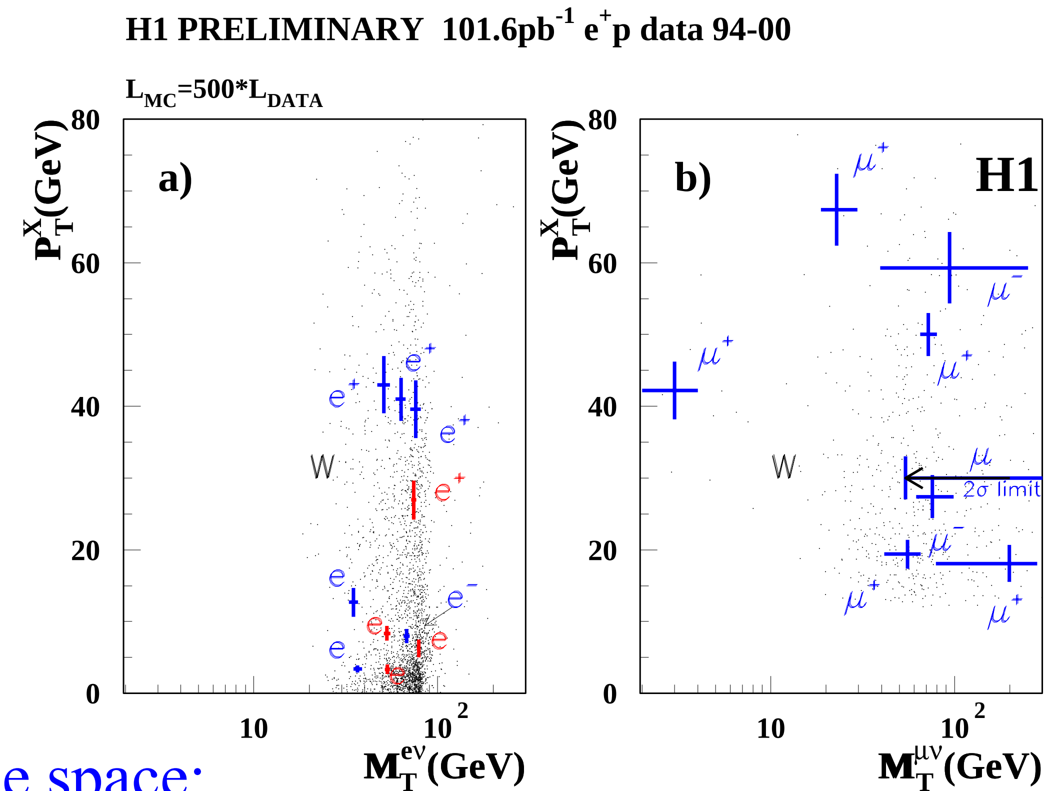
normalized to data y<0.4



- measurement needed at lower E_p : HERA-II?

H1 anomalous events





- SM background mostly *W*

- Compare expts in same phase space:

P^x_T>25 GeV	*e* Obs (exp)	*μ* Obs (exp)	*e+μ* Obs (exp)
H1	**4 (1.3)**	**6 (1.5)**	**10 (2.8+/-0.7)**
ZEUS	**1 (1.1)**	**1 (1.3)**	**2 (2.4+/-0.2)**

H1 sees them, ZEUS doesn't

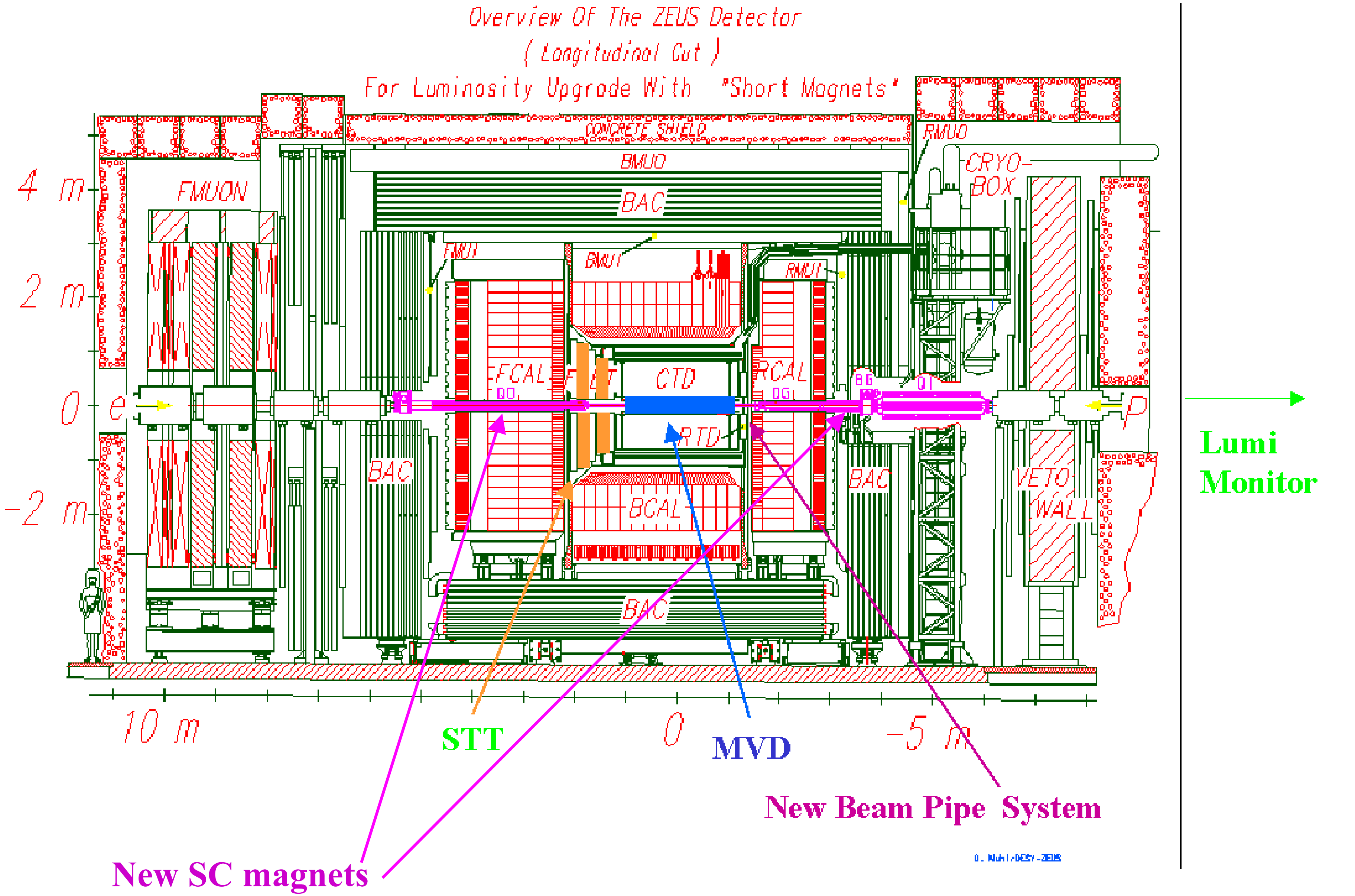
?? puzzle ??

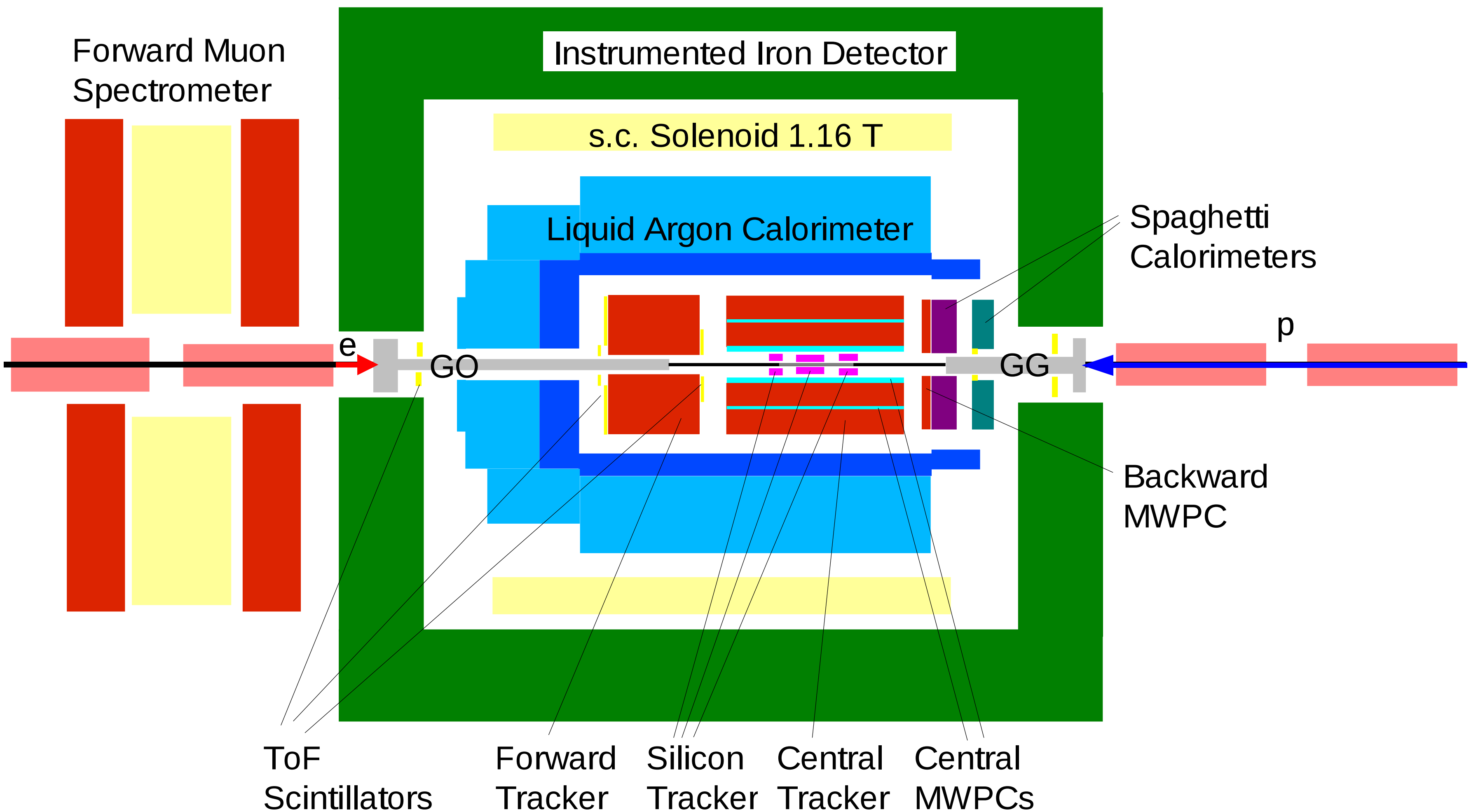
need more data to resolve

- Luminosity upgrade 5x increase → 150-200 pb^{-1}/yr
  - strong focusing inside experiments: SC magnets
  - new magnet arrangement +/- 100 m from experiments
- Longitudinal polarization for H1/ZEUS
  - >50% (70% design goal)
- experiment upgrades:
  - forward tracking, Si vtx detector (new for ZEUS, new fwd. planes for H1)
    - needed for forward jets, high energy scattered electron, heavy quarks
  - online triggers
    - short decays for *b*,*c* ; *D** reconstruction
  - lumi and pol measurement detectors
- HERA-II run until 2006 : goal 1000 pb^{-1}/experiment
  - divided ~ equally $e^+_R, e^+_L, e^-_R, e^-_L$

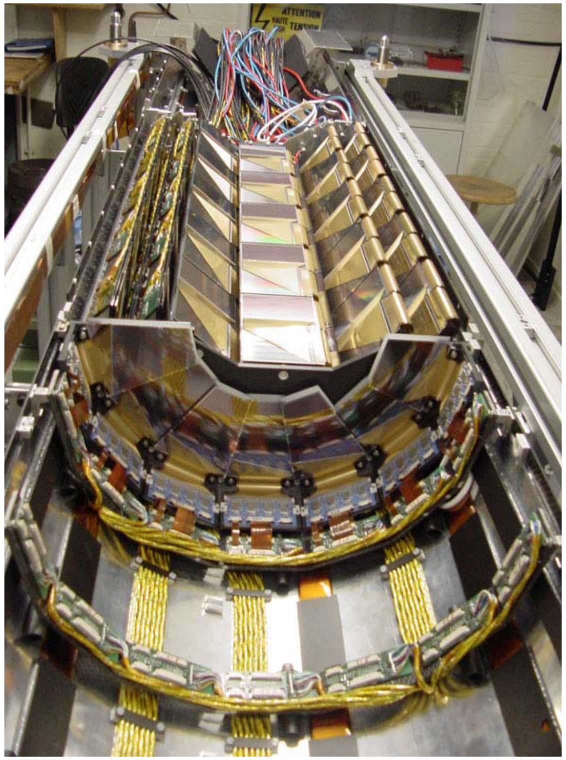
10x current data set

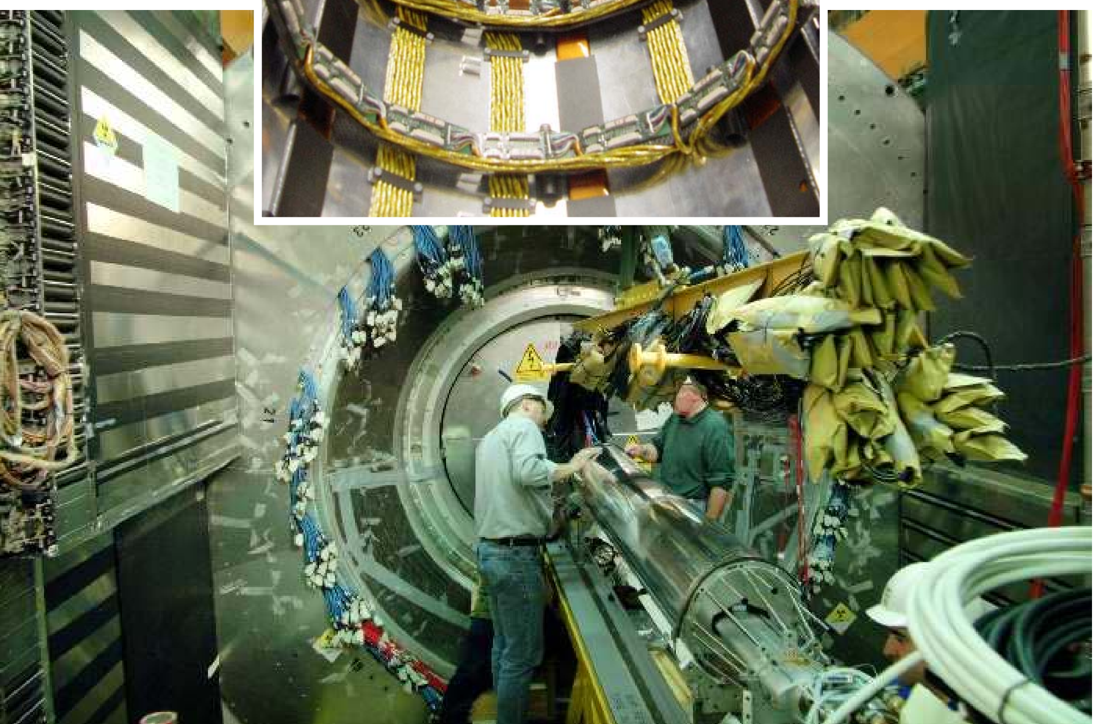
ZEUS upgrades

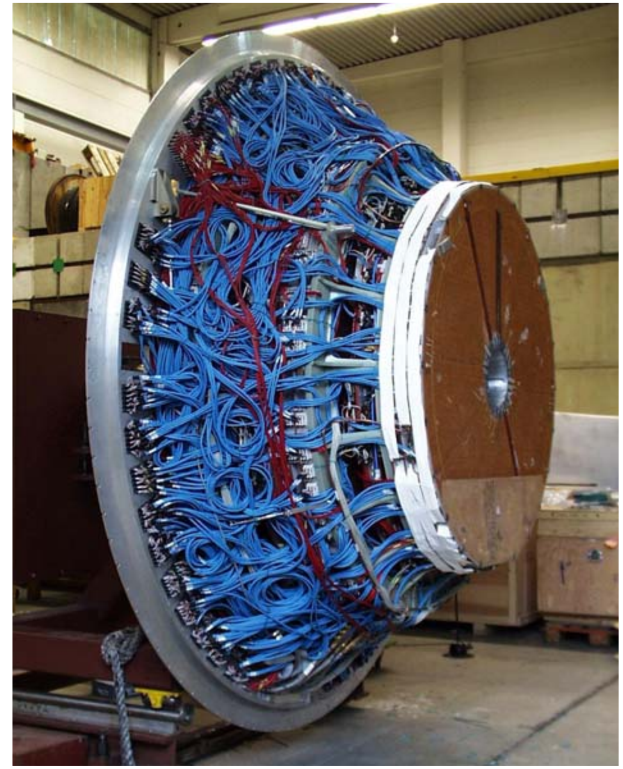



Forward Muon Spectrometer
Instrumented Iron Detector
s.c. Solenoid 1.16 T
Liquid Argon Calorimeter
Spaghetti Calorimeters
e
GO
GG
p
Backward MWPC
ToF Scintillators
Forward Tracker
Silicon Tracker
Central Tracker
Central MWPCs

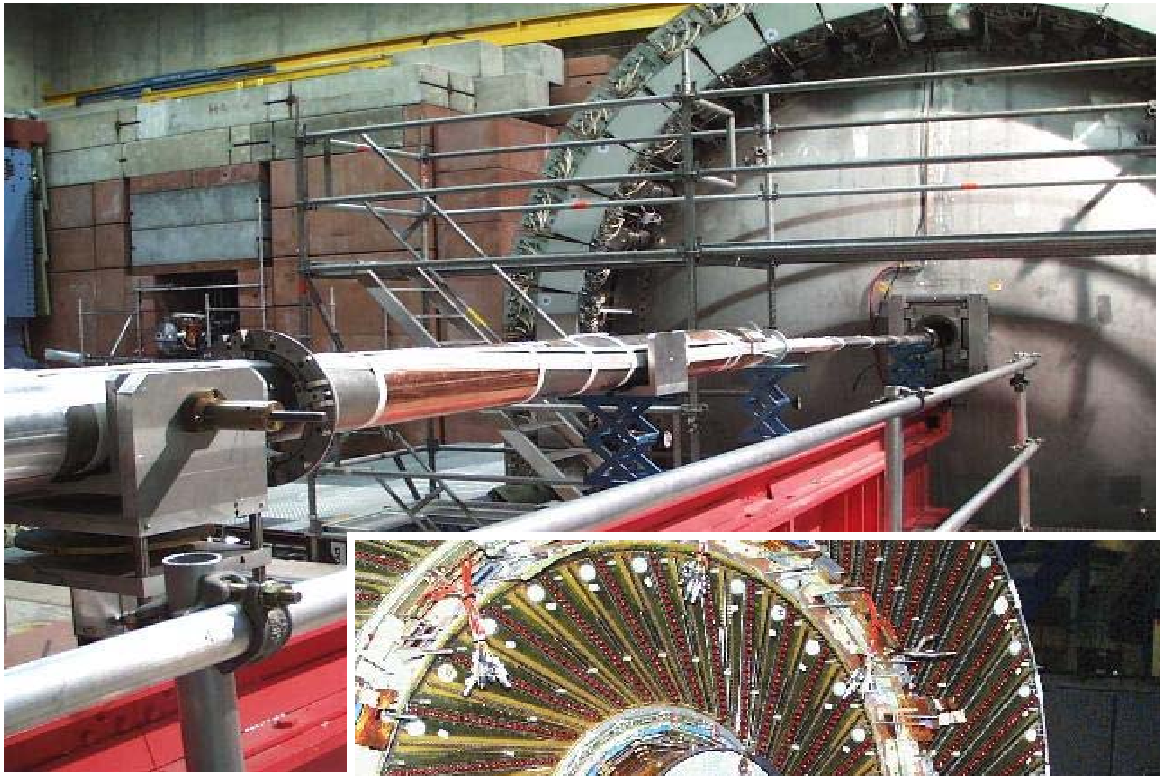
ZEUS MVD and STT

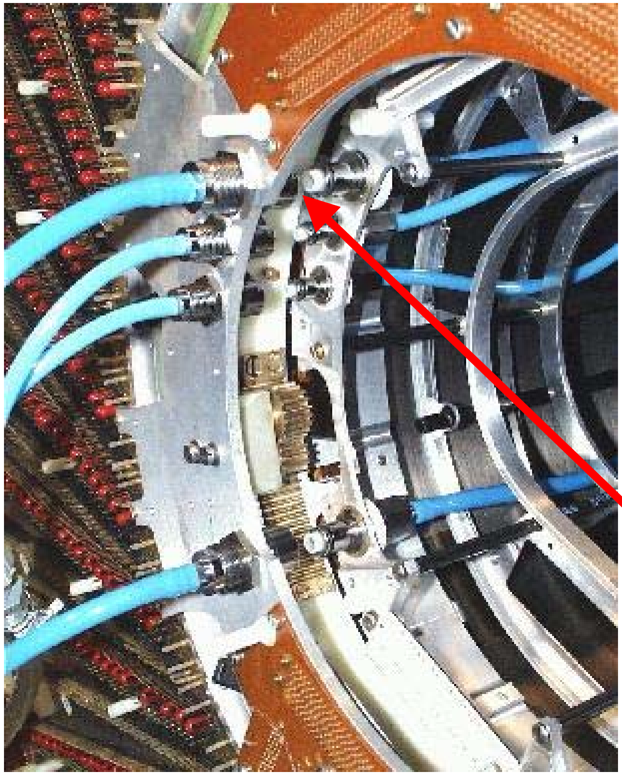




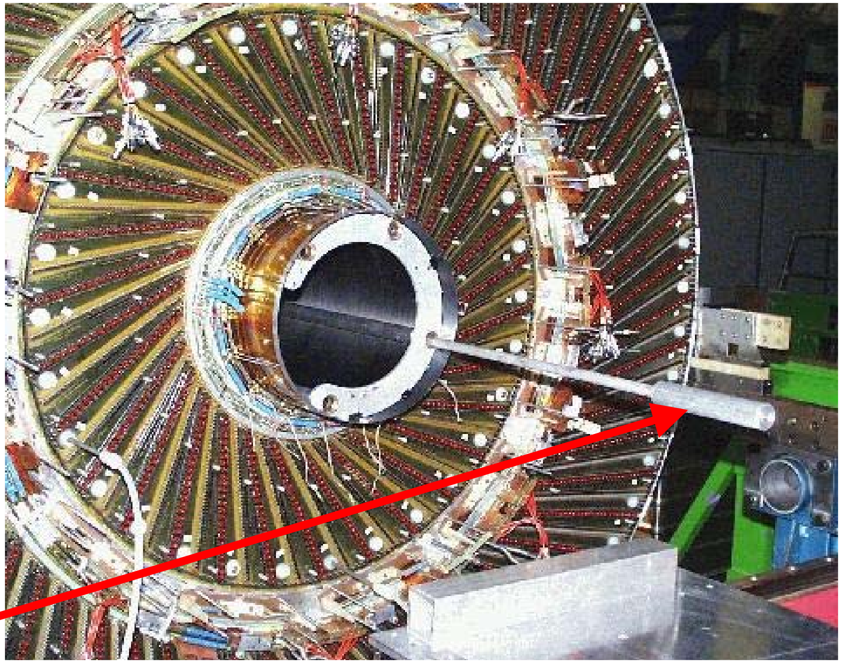


- Very tricky operation … had to be done blind from one end!!



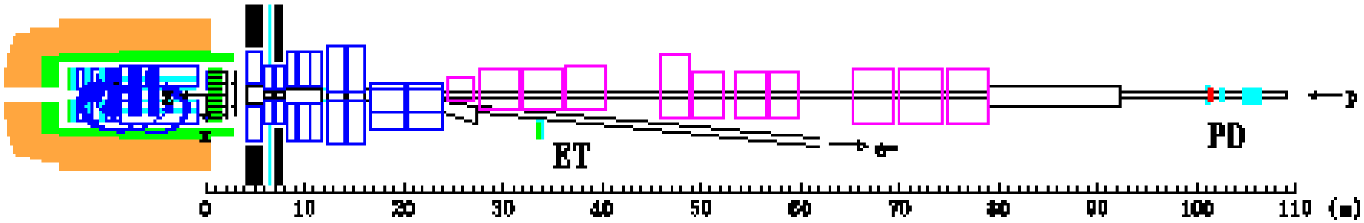


Connectors had to mate inside!

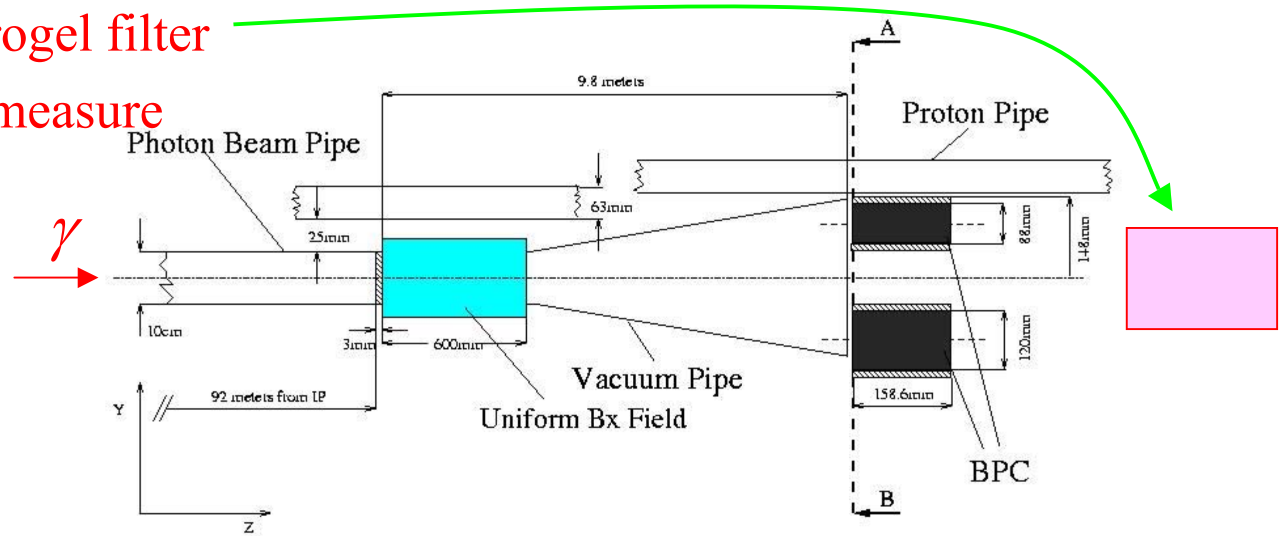


Remote tool

- H1: crystal cerenkov detectors to detect e and γ in $ep \rightarrow ep\gamma$



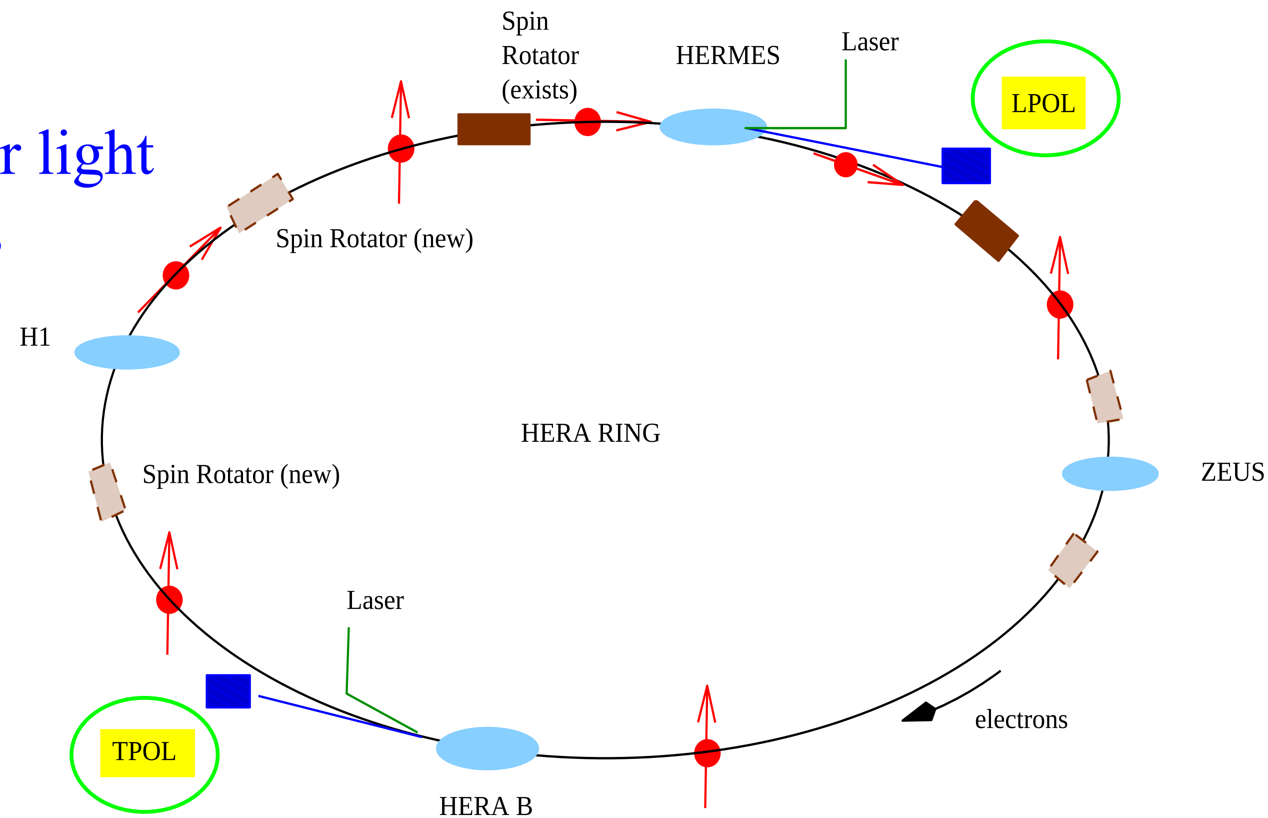
- ZEUS: 2 methods (different systematics) to detect γ
  - calorimeter + active aerogel filter
  - dipole spectrometer to measure e^+e^- conversions
  - scattered electron measured in W/fibre calorimeter at 6 m



- goal: 1%
  - face increased synchrotron background, multiple overlapping γ + physics

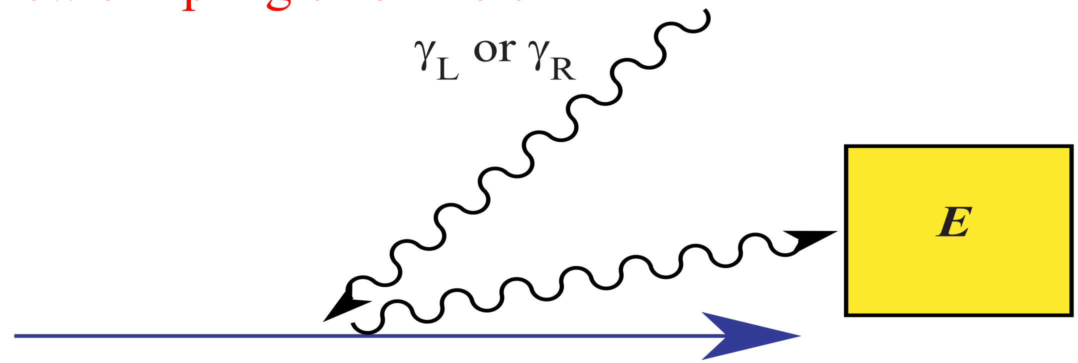
Polarization measurement

- cross-check with accurate measurement of both transverse (TPOL) and longitudinal (LPOL) polarization plus machine lattice simulation
- need short time-scale measurement, ideally bunch-by-bunch
  - challenge in high synchrotron radiation environment
- use back-scattered laser light and precision detectors and DAQ
- goal: 1%
  - was 5% at HERA-I for HERMES

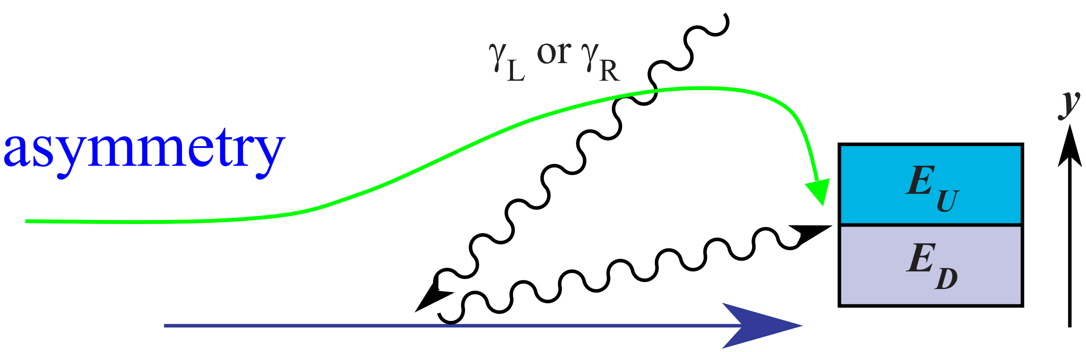


LPOL and TPOL

- Laser beam switched between R and L circular polarization
- LPOL: measure *E* asymmetry of back-scattered Compton photons
  - new Fabry-Perot cavity +laser, new sampling calorimeter
  - high rate 1 γ per bunch
  - calibration on Compton edge



- TPOL: measure position asymmetry
  - pre-radiator + Si detector



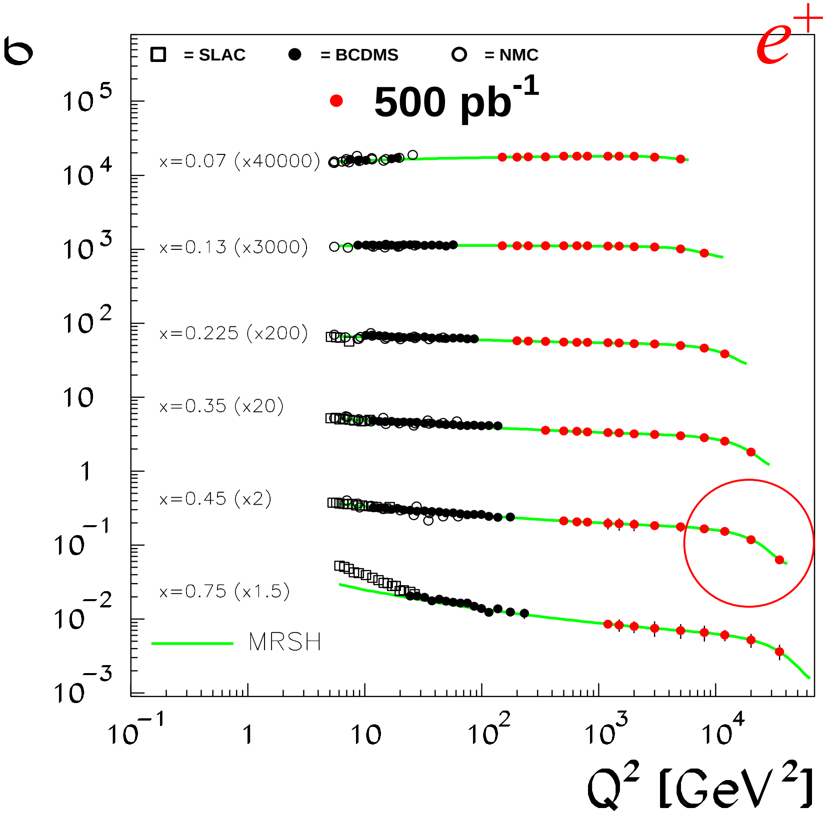
$$P = \left(\langle y \rangle_L - \langle y \rangle_R \right) K_\eta$$

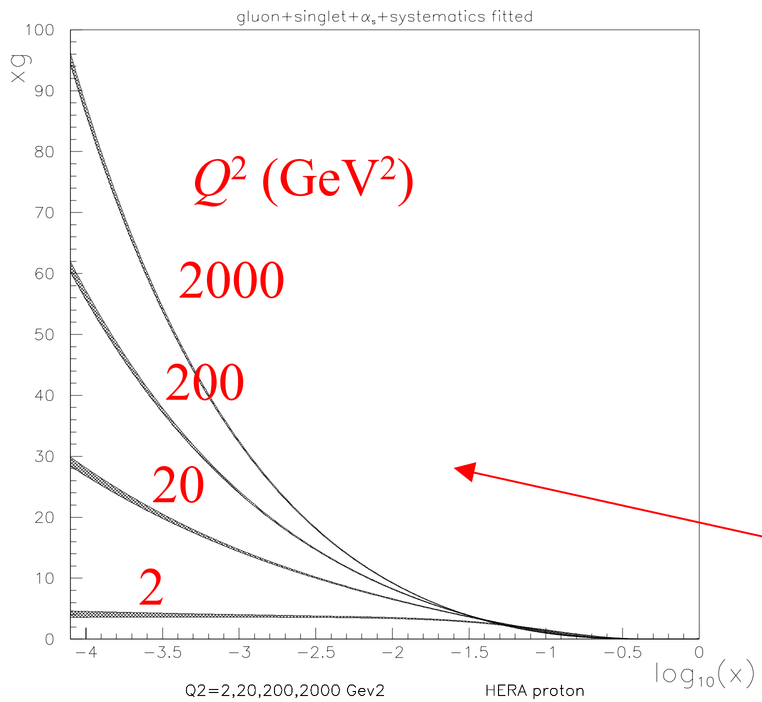
Precision at high Q^2

- High precision (3%) over unprecedented range:

$$2 \cdot 10^{-5} < x < 0.7$$

$$Q^2 < 5 \cdot 10^4 \,\mathrm{GeV}^2$$





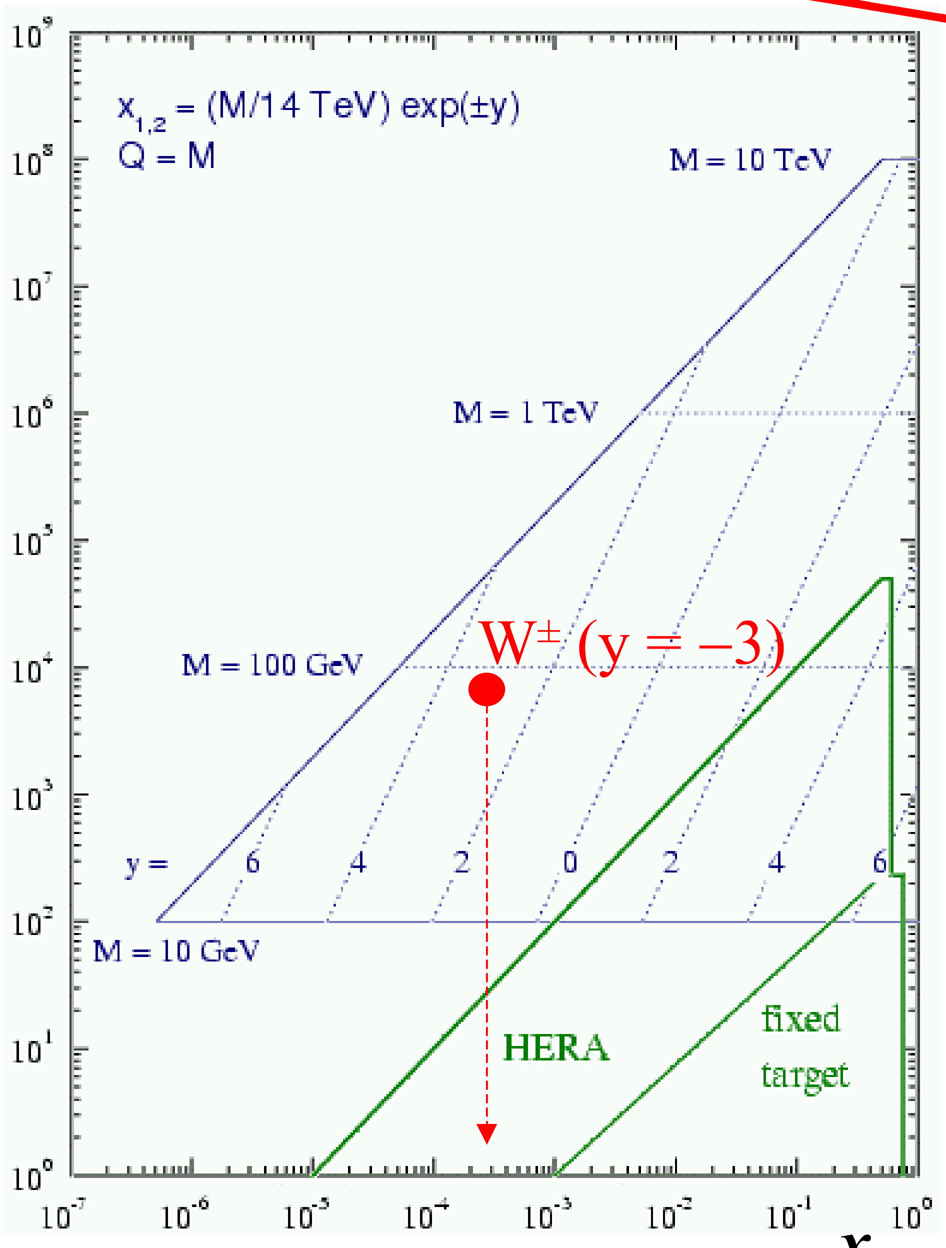
- beyond NLO fit will give:
  - gluon to 3% (important for Higgs)
  - α_s to 0.001

Importance for LHC

H1 & ZEUS

LHC parton kinematics (LO)

- e.g., W production at high y
  - low x = 0.0003
- can the extrapolation to high Q^2 be done reliably??
  - an area of active theoretical research: NNLO, resummation of ln $1/x$ terms, etc.
  - e.g., for F_L, LO → NLO → NNLO converges only for $Q^2 > 5$ GeV^2



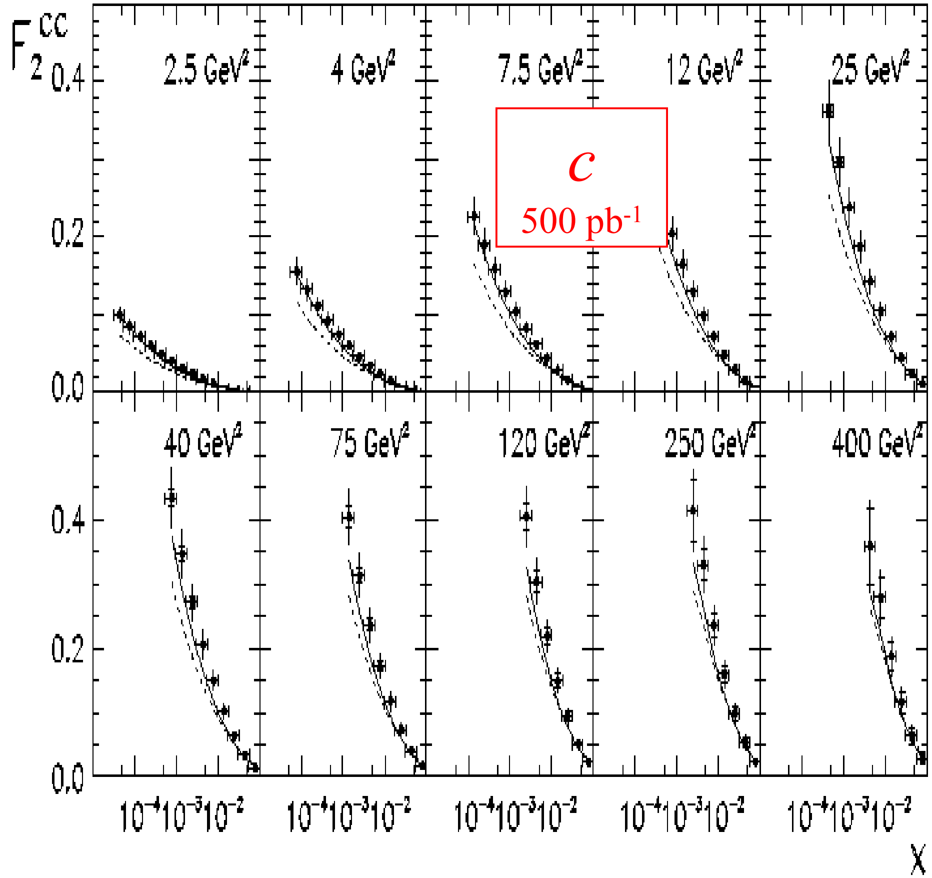
Quark densities

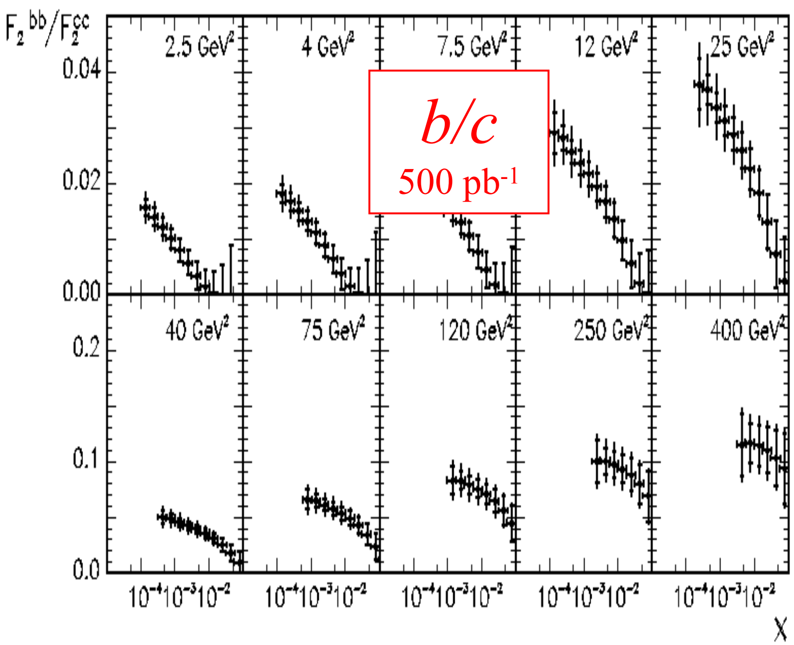
H1 & ZEUS

High $\mathcal{L}$ + short decay tagging
gives *c* and *b* (> x 20 increase)

CC e^+ and e^- gives
u, *d*, *s* (from *Ws* → *c*)

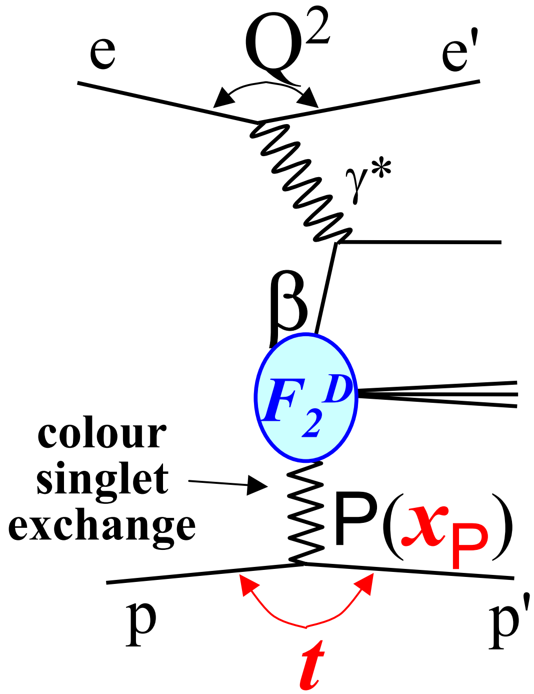
$$\tilde{\sigma}^{+} = x\left[\bar{u} + \bar{c} + (1-y)^2 (d + s)\right]$$
$$\tilde{\sigma}^{-} = x\left[u + c + (1-y)^2 (\bar{d} + \bar{s})\right]$$

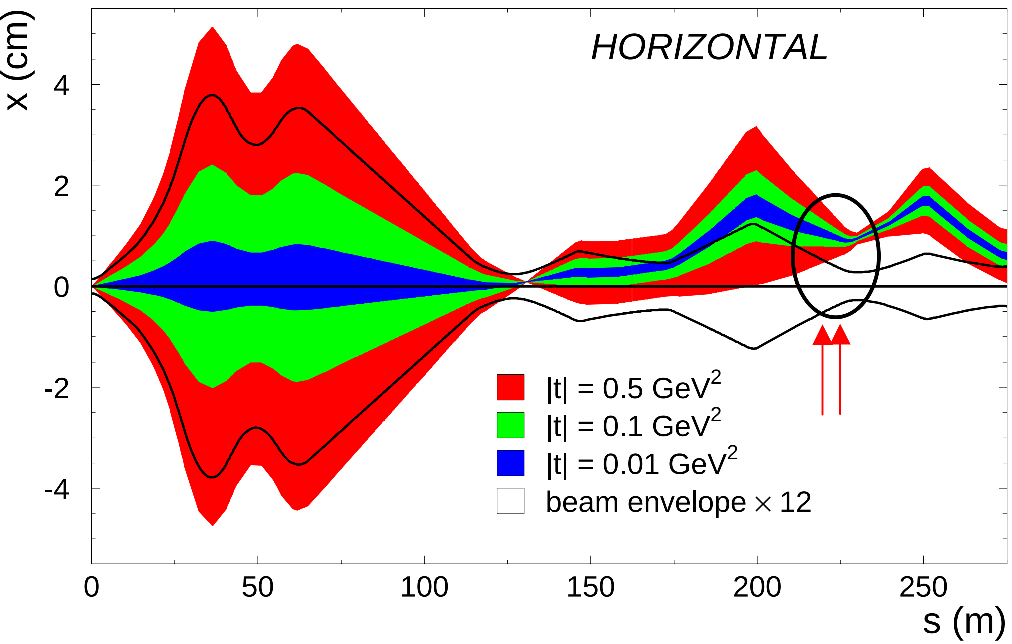




⇒ complete survey of
parton content of the proton!

- QCD understanding of colour singlet exchange still intense field of study
- need more data with jets, VM, charm, with tagged leading *p*





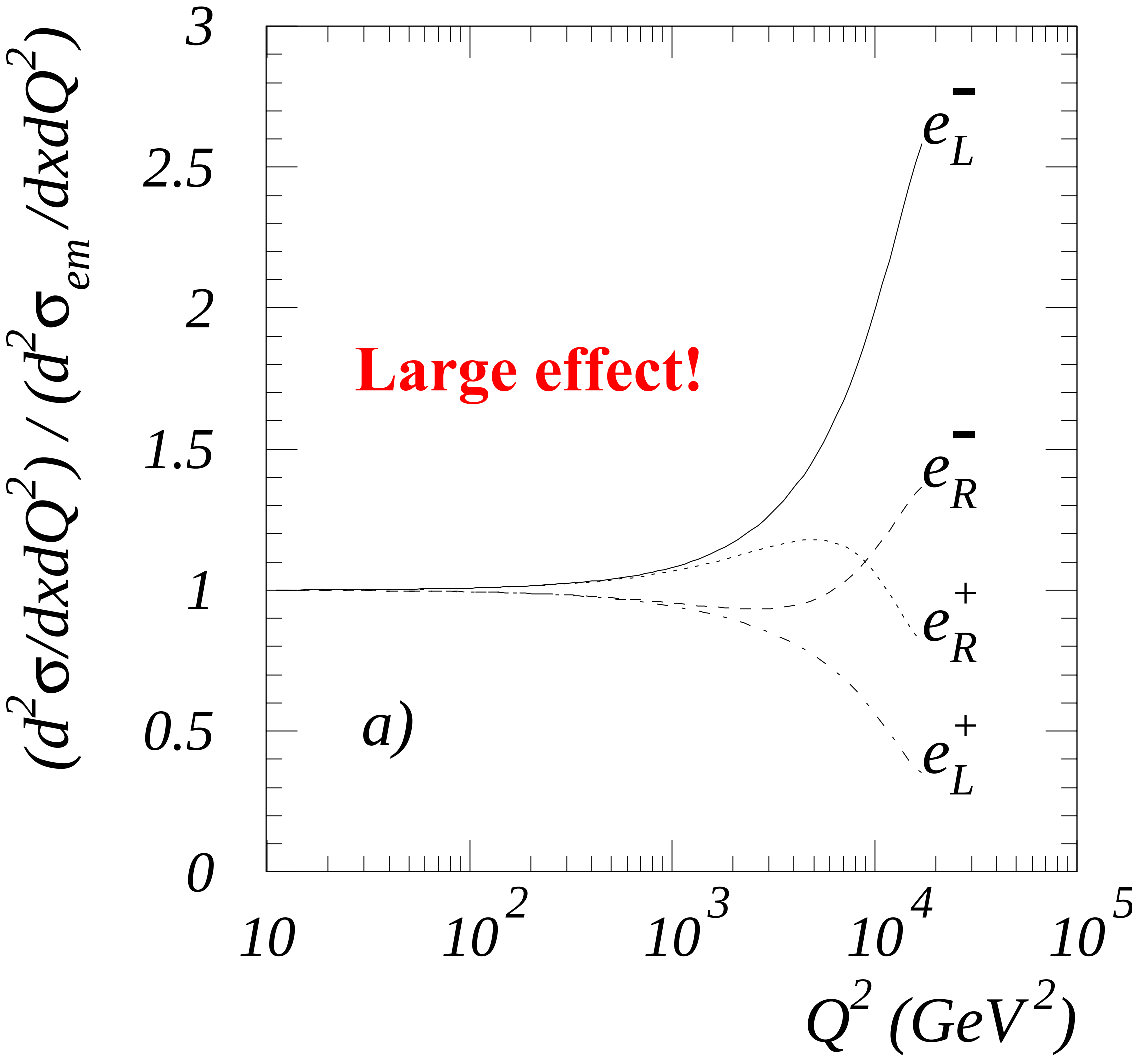
- H1: new spectrometer at 220 m
- measure $-t < 0.5$ GeV^2, resolution ~ 0.2 GeV^2

Polarization important

H1 & ZEUS

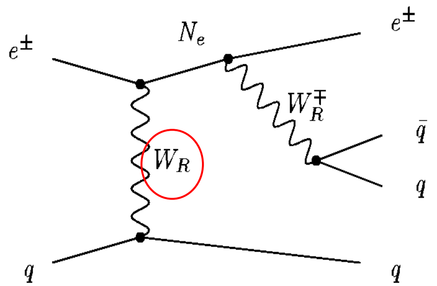
at $Q^2 = 10{,}000\ \mathrm{GeV}^2$, $x = 0.2$,

$$\frac{\sigma(e^-_L)}{\sigma(e^-_R)} \approx 1.7 \pm 0.06(\mathrm{Stat.})$$

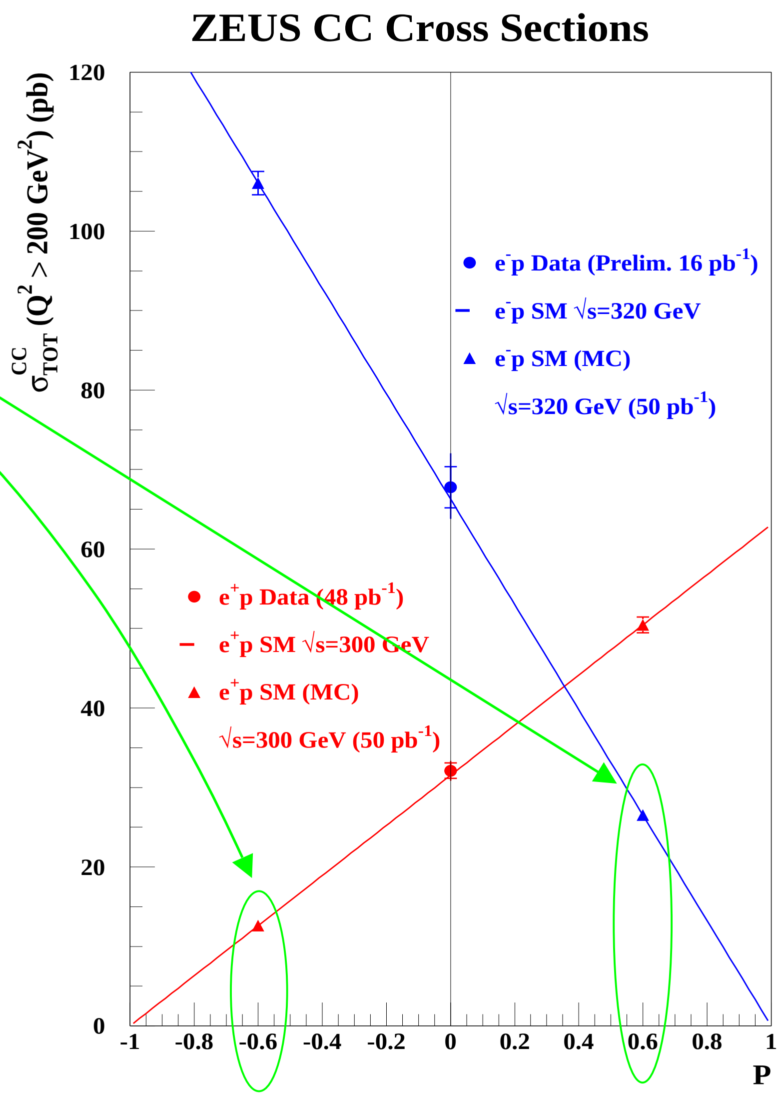


$$\sigma_{CC}^{e^{\pm}p} \propto (1 \pm P)$$

- CC interactions with or e^{+}_{L} or e^{-}_{R}
  - $\Rightarrow$ W_R sensitive to ~ 500-700 GeV
  - sensitive to $M_N \sim 150$ GeV



- in general, vary polarization to reduce SM backgrounds
  - $\Rightarrow$ enhance S/B for new physics with different couplings



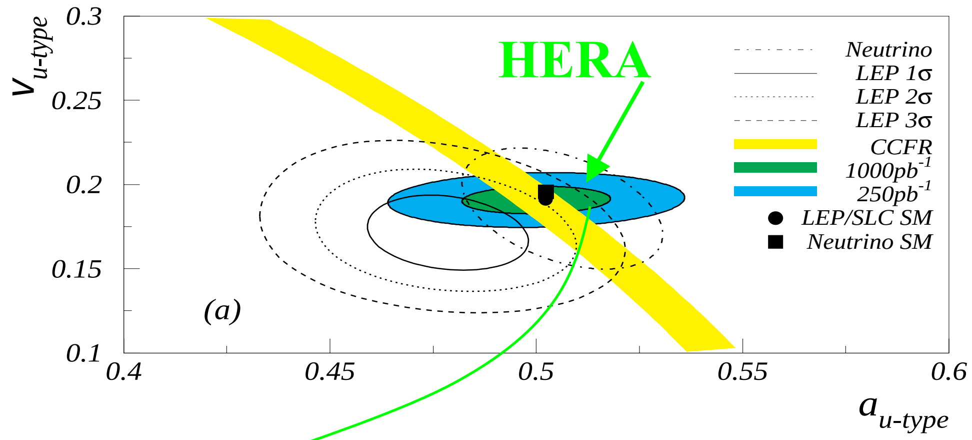
Polarization examples

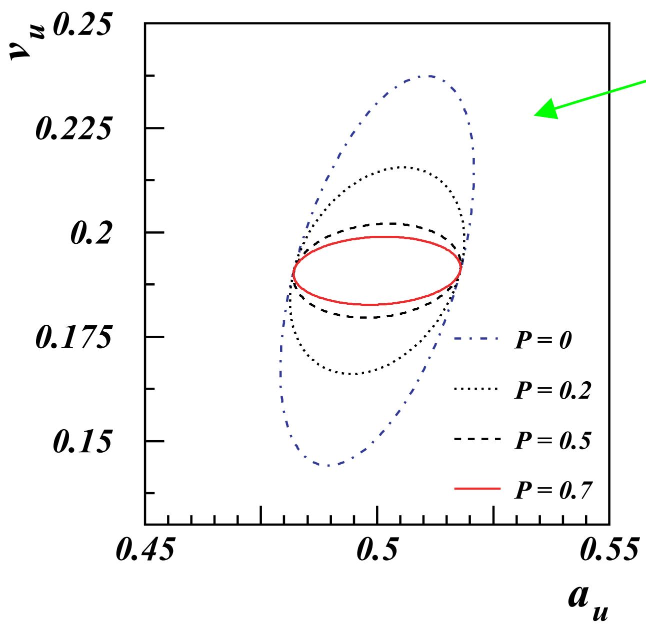
Measure:

v_u to ~ 13%

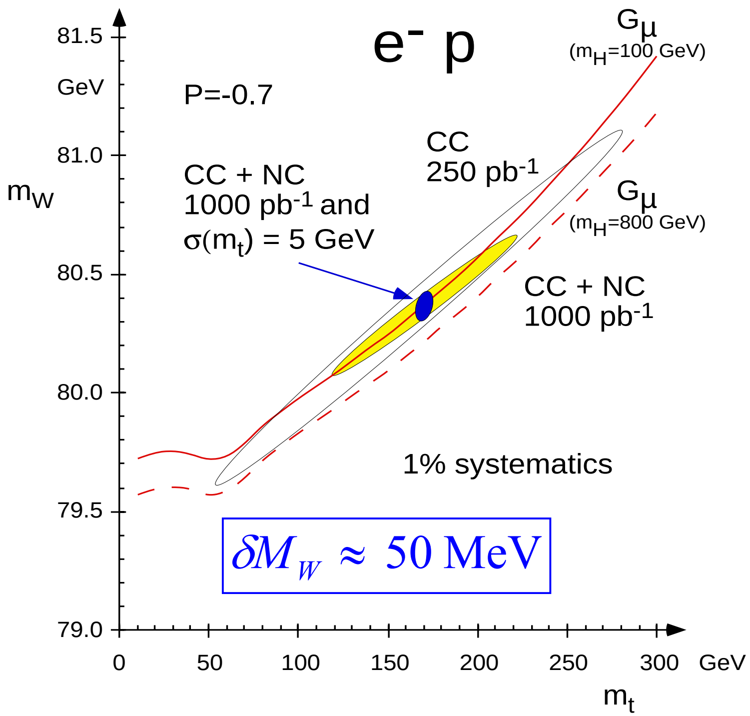
a_u to ~ 7%

(*cf.* LEP c and b)





Sensitivity to beam polarization



$\delta M_W \approx 50$ MeV

New physics ?

– Rp violating SUSY
– lepton flavour violation
– excited fermions
– contact interactions

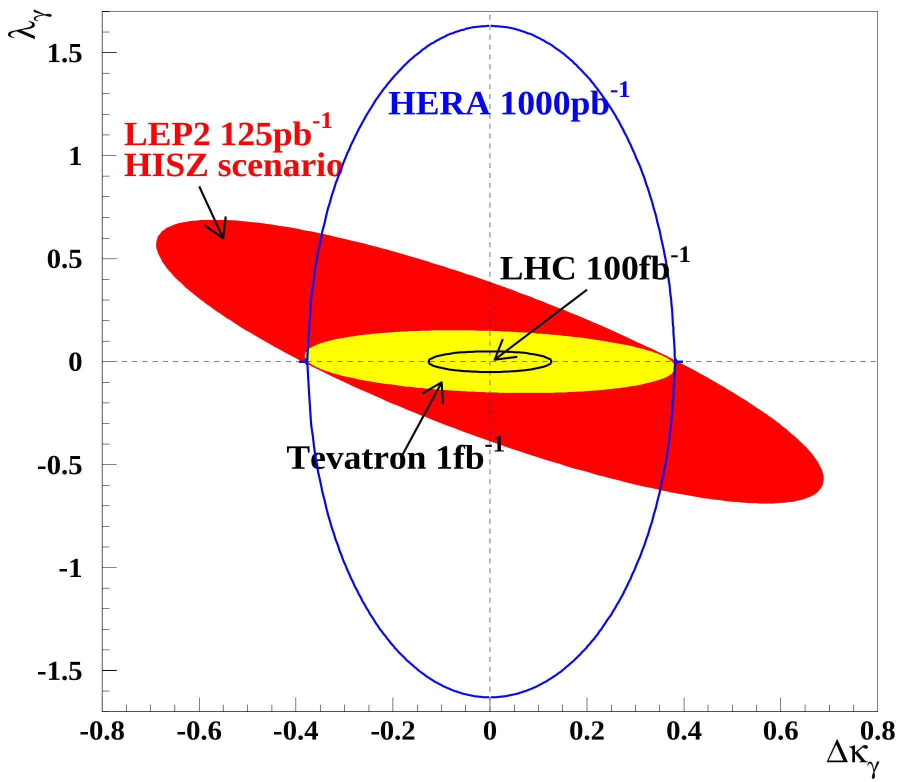
In many regions of "search phase space" HERA already sets the best limits (see Corradi). Large luminosity increase will further enhance the sensitivity.

e-polarization: improve S/B

Sensitivity to $WW\gamma$ vertex:

anomalous couplings

$\Delta\kappa_\gamma$, λ_γ parameterize deviation from SM



Summary

- No time for a summary!

- HERA-II about to begin:
  - first test lumi run in December
  - problems with

proton ring aperture	now fixed
synch. radiation way too high	new collimators being built
	install early March

- first lumi run begins Mar 17
  - experiments are ready
  - start with e^+, switch to e^- in June

- we look forward to exciting physics with high luminosity