Recent Results from HERA

Measurements of Proton Structure at Low Q^2

The High Q^2 regime Neutral and Charged Current Processes

QCD: Partons in the Proton, Jets and α_s

First Polarised Measurements from HERA

Heavy Quark Structure Functions and Jets

Seaches for new physics

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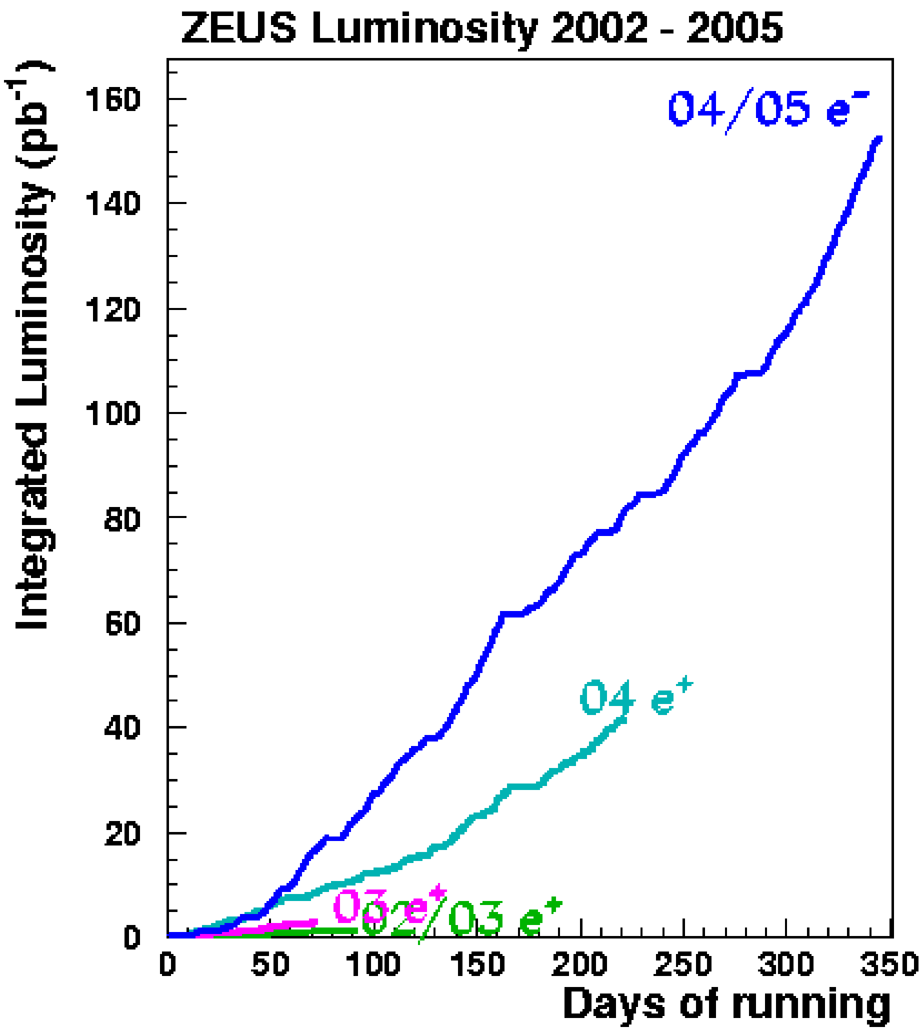
Introduction

- HERA is world's first and only ep collider
- Collision energy $\sqrt{s}$=320 GeV
- Can collide e^+ or e^- with longitudinal polarisation
- Enormous impact on world parton distribution functions
- Tests EW sector of Standard Model
- Charm factory
- Many possible SM extensions show up at HERA

Will only show a personal selection of a few of the hundreds of results. Many important topics skipped altogether

HERA II



- 5 fold lumi increase achieved by focusing magnets and higher beam currents
- Slow start up 2002-03
- Problems with high beam related backgrounds
- Now solved. Best ever HERA performance
- Looking forward to 2006-07 run

HERA collides e and p

Study strong, electromagnetic & weak forces through Deep Inelastic Scattering

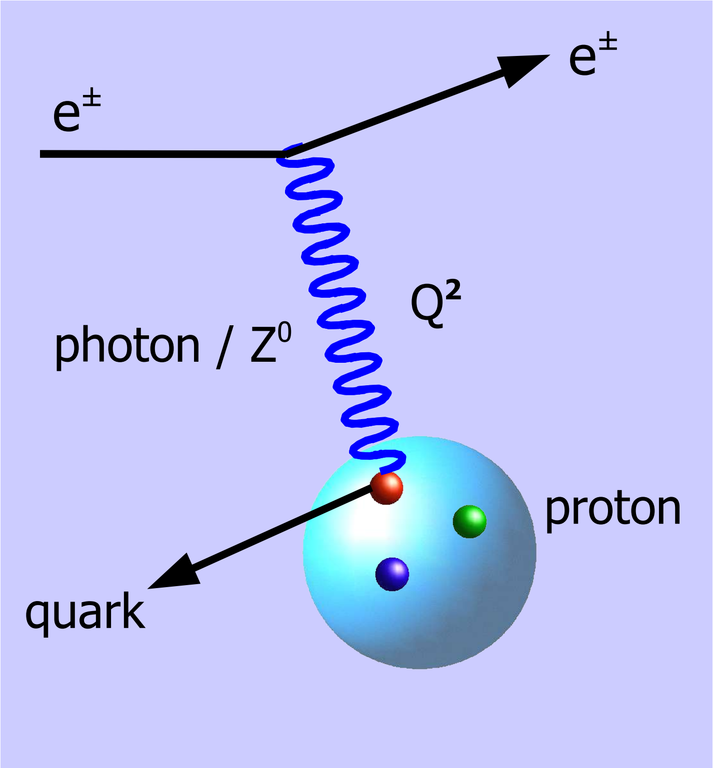
At fixed $\sqrt{s}$: two kinematic variables:

x & Q^2

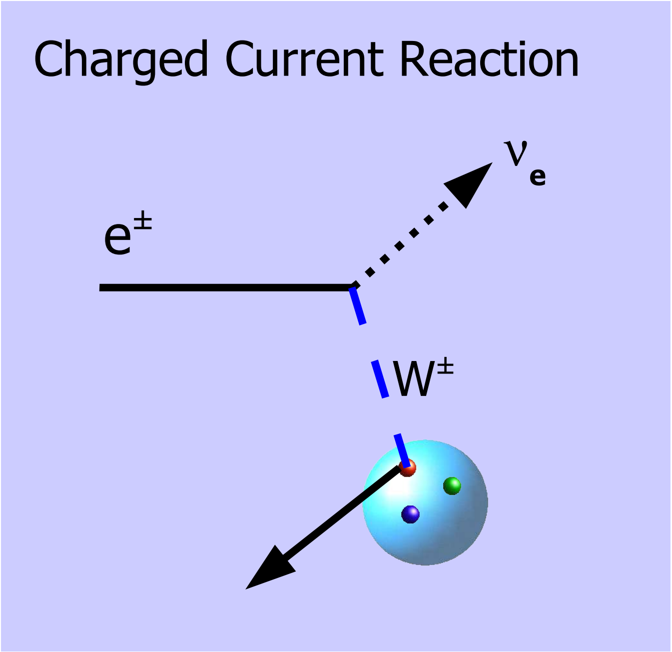
$Q^2 = s \times y$

Q^2 = "resolving power" of probe

High Q^2 : resolve 1/1000th size of proton



Neutral Current Reaction



x = momentum fraction of proton carried by quark

HERA: $\sim 10^{-6}$ - 1

$$\frac{d\sigma^{\pm}_{NC}}{dxdQ^2} \approx \frac{e^4}{8\pi x} \left[\frac{1}{Q^2}\right]^2 \left[Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2\tilde{F}_L\right]$$

Modified at high Q^2 by Z propagator

$$\frac{d\sigma^{\pm}_{CC}}{dxdQ^2} \approx \frac{g^4}{64\pi x} \left[\frac{1}{M_W^2 + Q^2}\right]^2 \left[Y_+\tilde{W}_2^{\pm} \mp Y_- x\tilde{W}_3^{\pm} - y^2\tilde{W}_L^{\pm}\right]$$

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

$\tilde{F}_2 \propto \sum(xq_i + x\bar{q}_i)$ Dominant Contribution

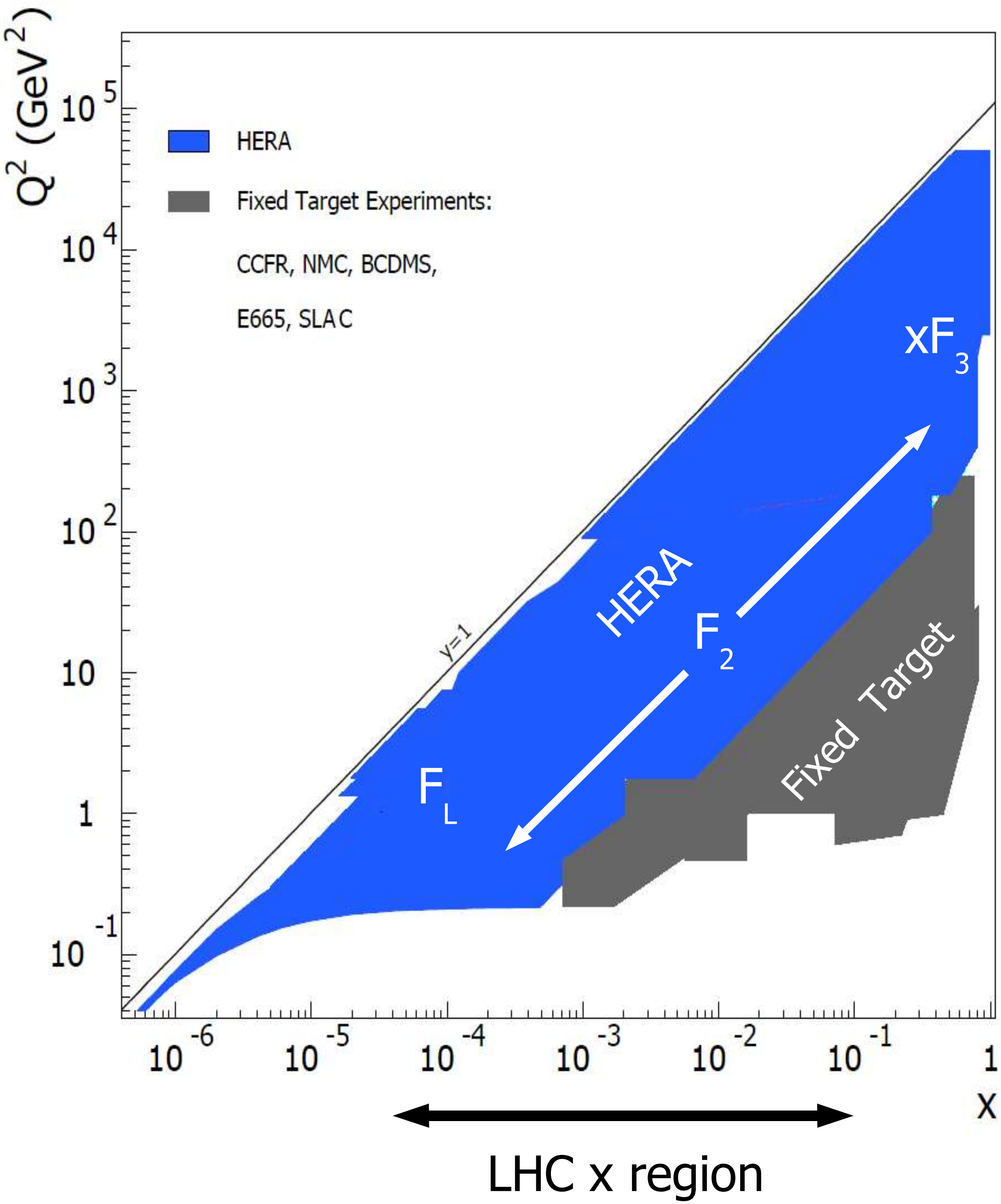
$x\tilde{F}_3 \propto \sum(xq_i - x\bar{q}_i)$ Contributes when $Q^2 \simeq M^2_Z$

$\tilde{F}_L \propto \alpha_s \cdot xg(x,Q^2)$ Contributes only at high y

similarly for $W_2^{\pm}$, $xW_3^{\pm}$ and $W_L^{\pm}$

$$\tilde{\sigma}_{NC} = \frac{Q^2 x}{2\alpha\pi^2} \frac{1}{Y_+} \frac{d^2\sigma}{dxdQ^2}$$

$$\tilde{\sigma} = \tilde{F}_2 \quad \text{when} \quad \tilde{F}_L \equiv x\tilde{F}_3 \equiv 0$$



Conventional QCD evolution only tells us Q^2 dependence

x dependence must come from data

Method:

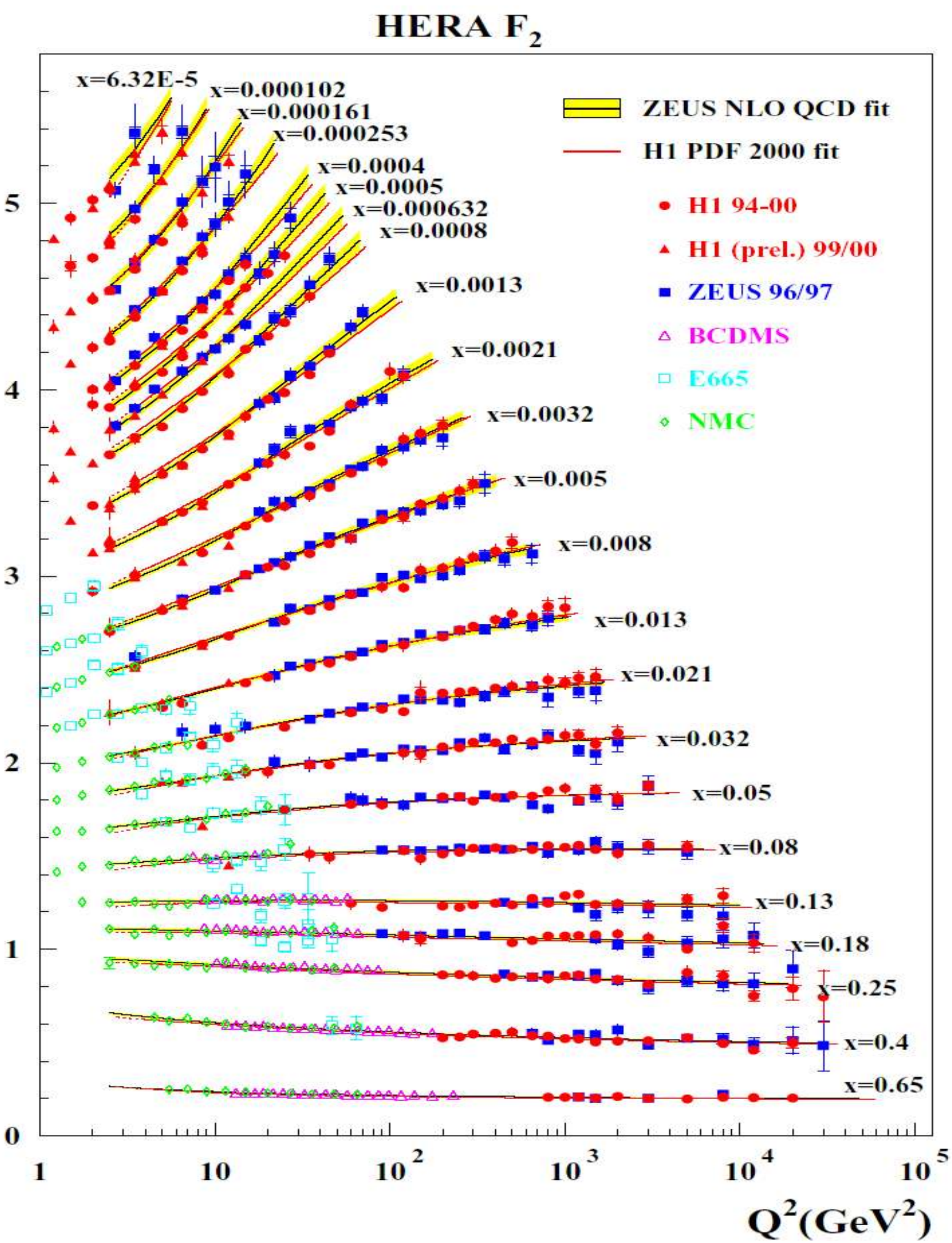
Measure cross sections

Fit data – extract x dep. of partons

HERA PDFs extrapolate into LHC region

LHC probes proton structure where gluon dominates (gluon collider)

HERA data crucial in calculations of new physics & measurements at LHC



F_2 dominates cross-section

Range in x: 0.00001 – 1

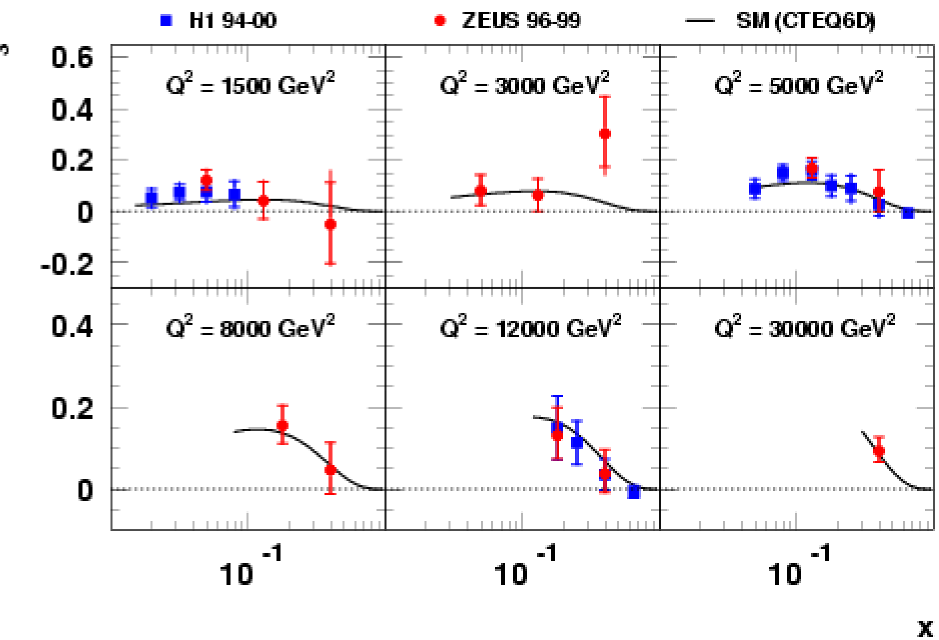
Range in Q^2 ~1 - 30000 GeV^2

Measured with ~2-3% precision

Directly sensitive to sum of all quarks and anti-quarks

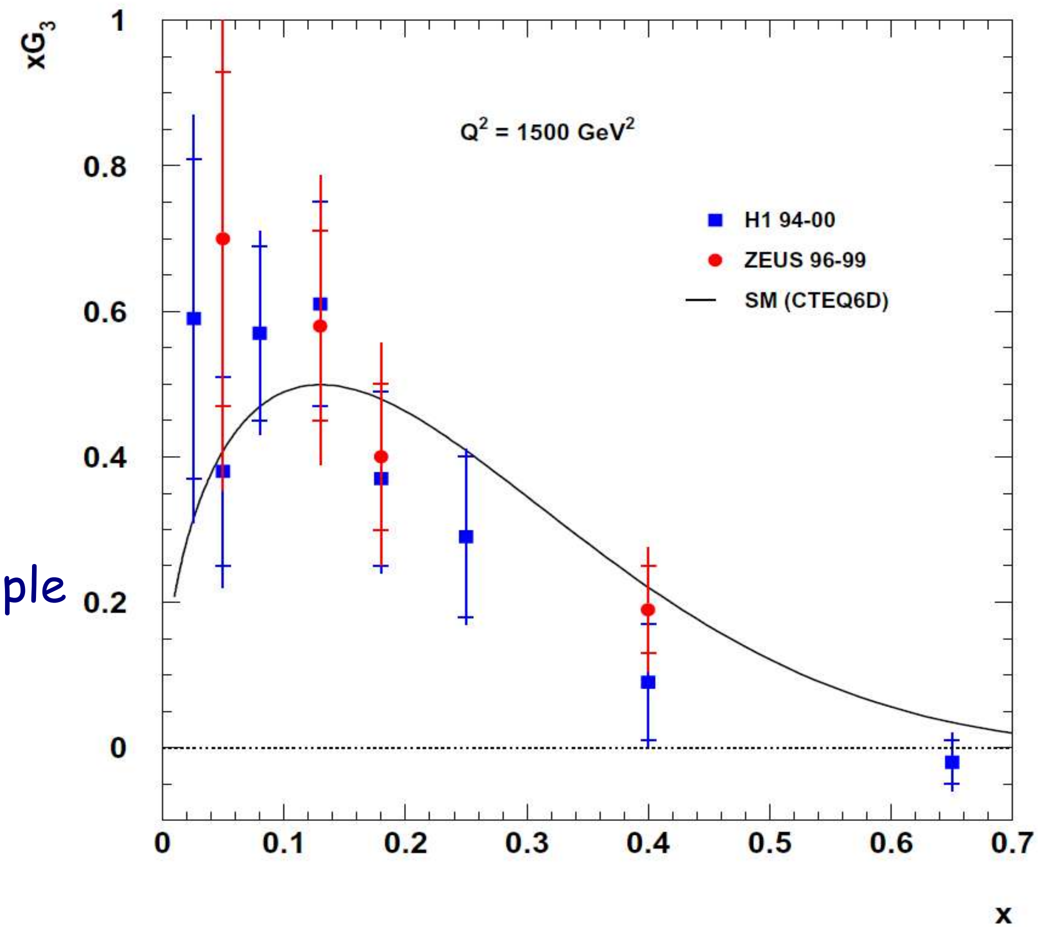
Indirectly sensitive to gluons via QCD radiation - scaling violations

At high Q2 NC cross sections for e^+ and e^- deviate



$$\tilde{\sigma}^{\pm}_{NC} \sim \tilde{F}_2 \mp \frac{Y_-}{Y_+} x\tilde{F}_3$$

Subtract NC positron from electron cross section



HERA confirm valence quark structure

Errors dominated by stat. error of e- sample

HERA II e- run 2005-06 x10 in stats

Much better precision

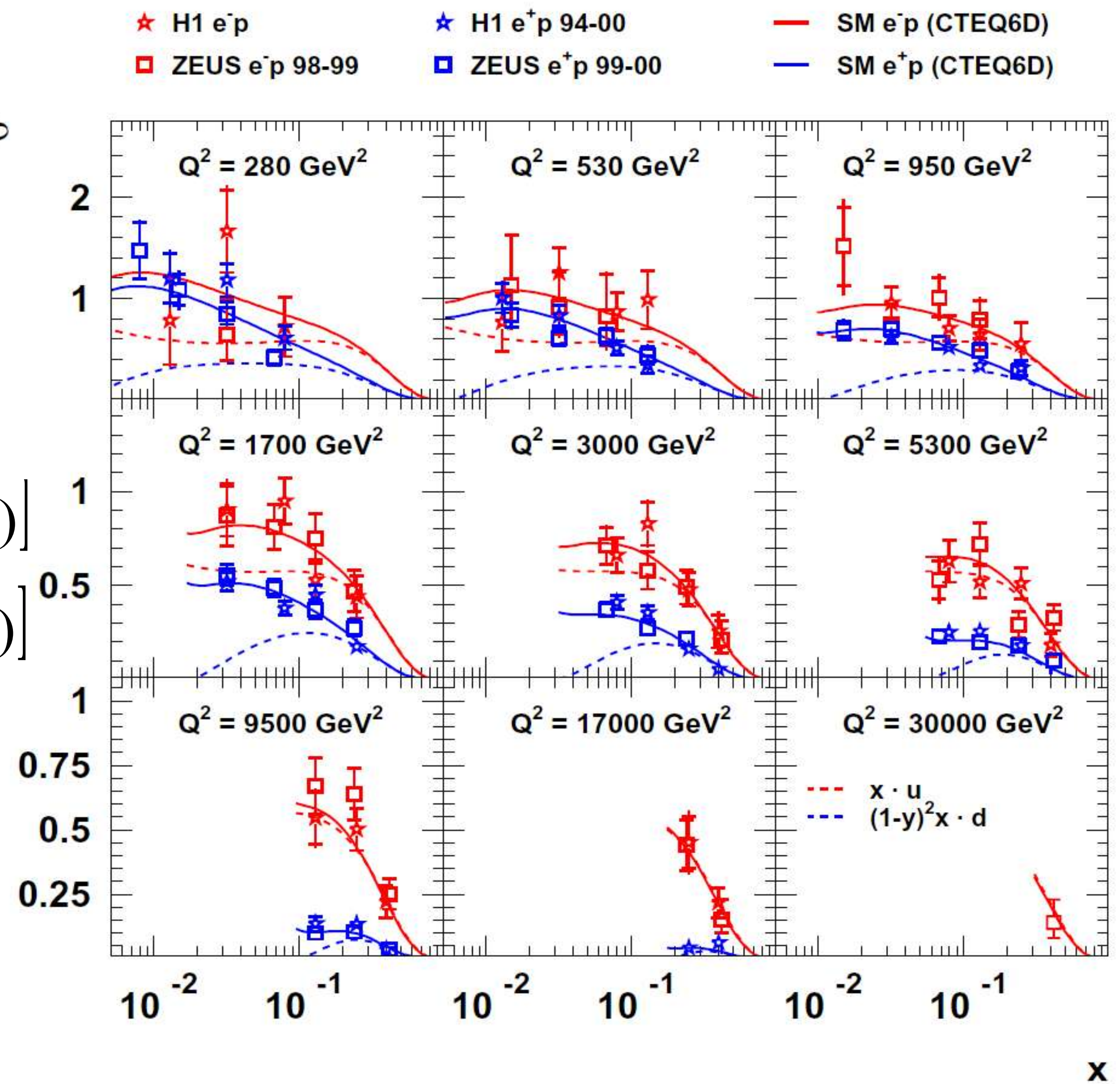
Charged current process provides sensitivity to quark flavour

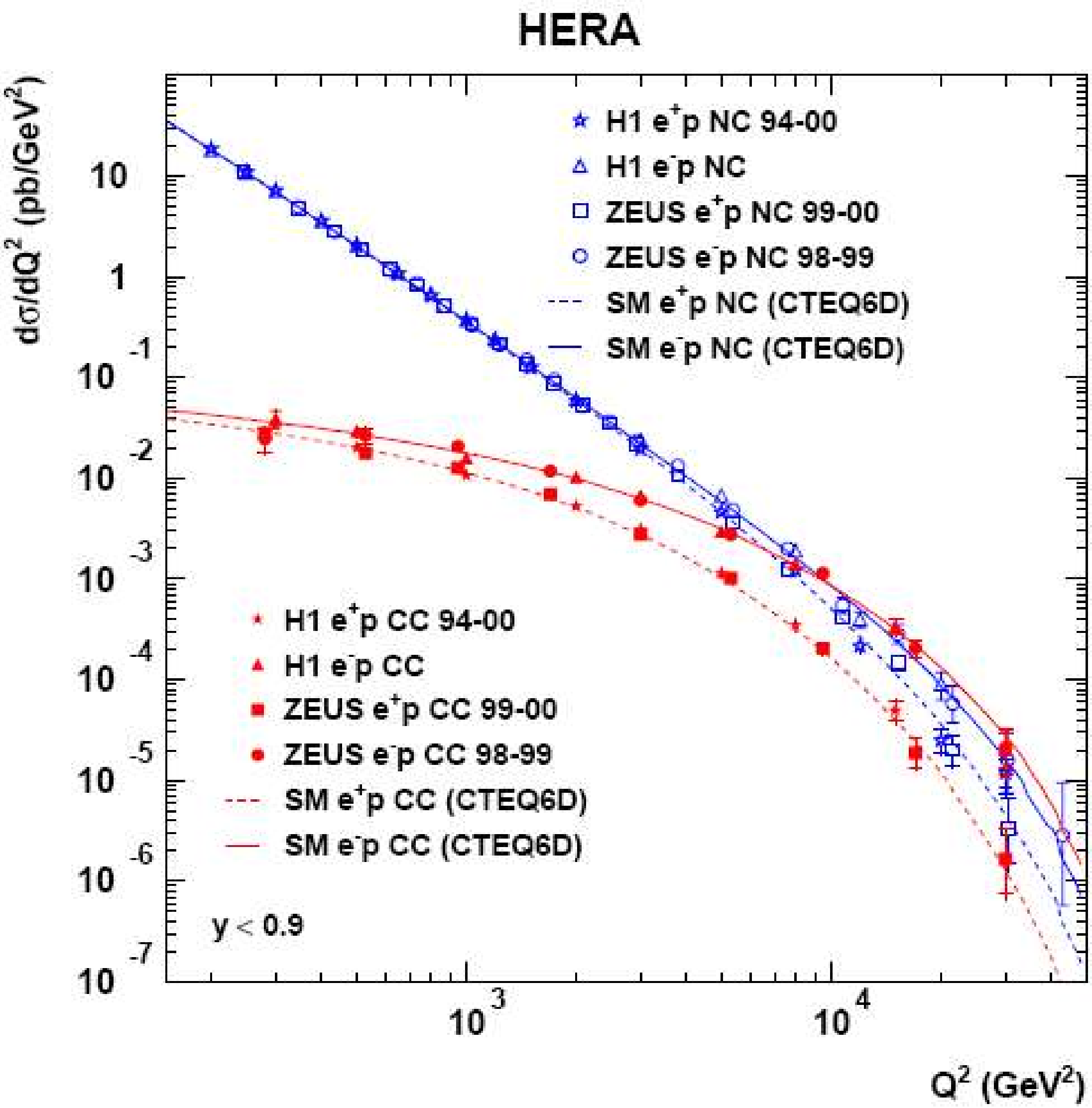
Cross sections small due to large W mass in propagator

At high x (low y) lepton charge separates u from d

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

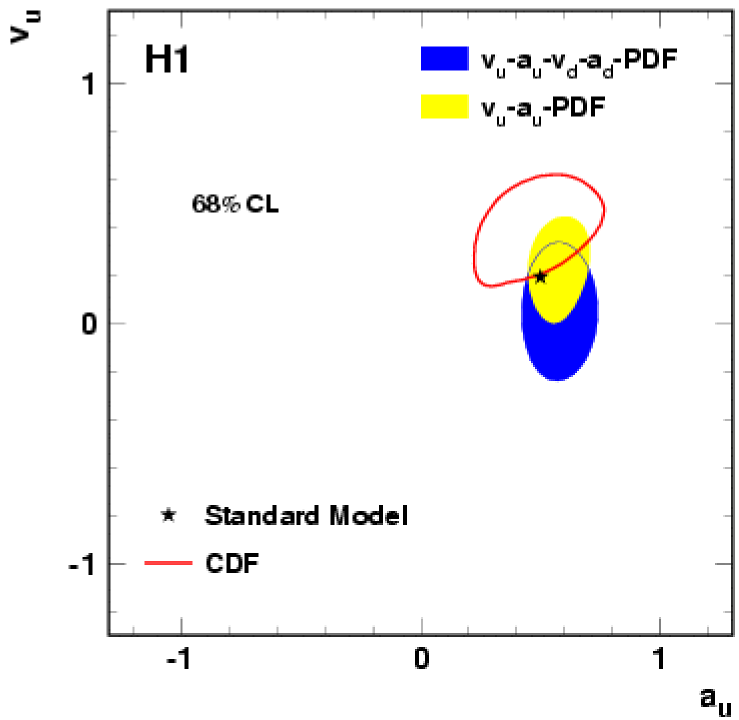
$$\sigma^{-}_{cc} \approx x\left[u + c + (1-y)^2 (\bar{d} + \bar{s})\right]$$

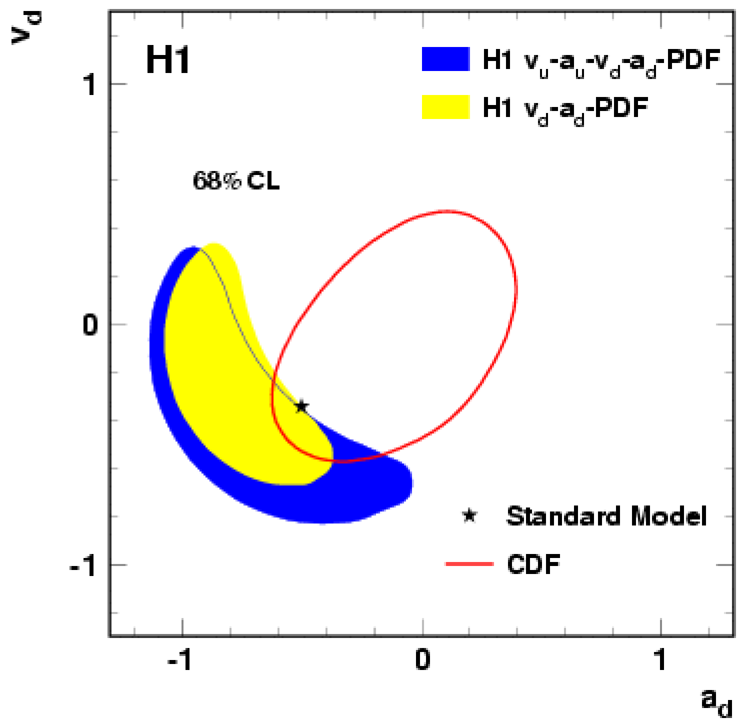




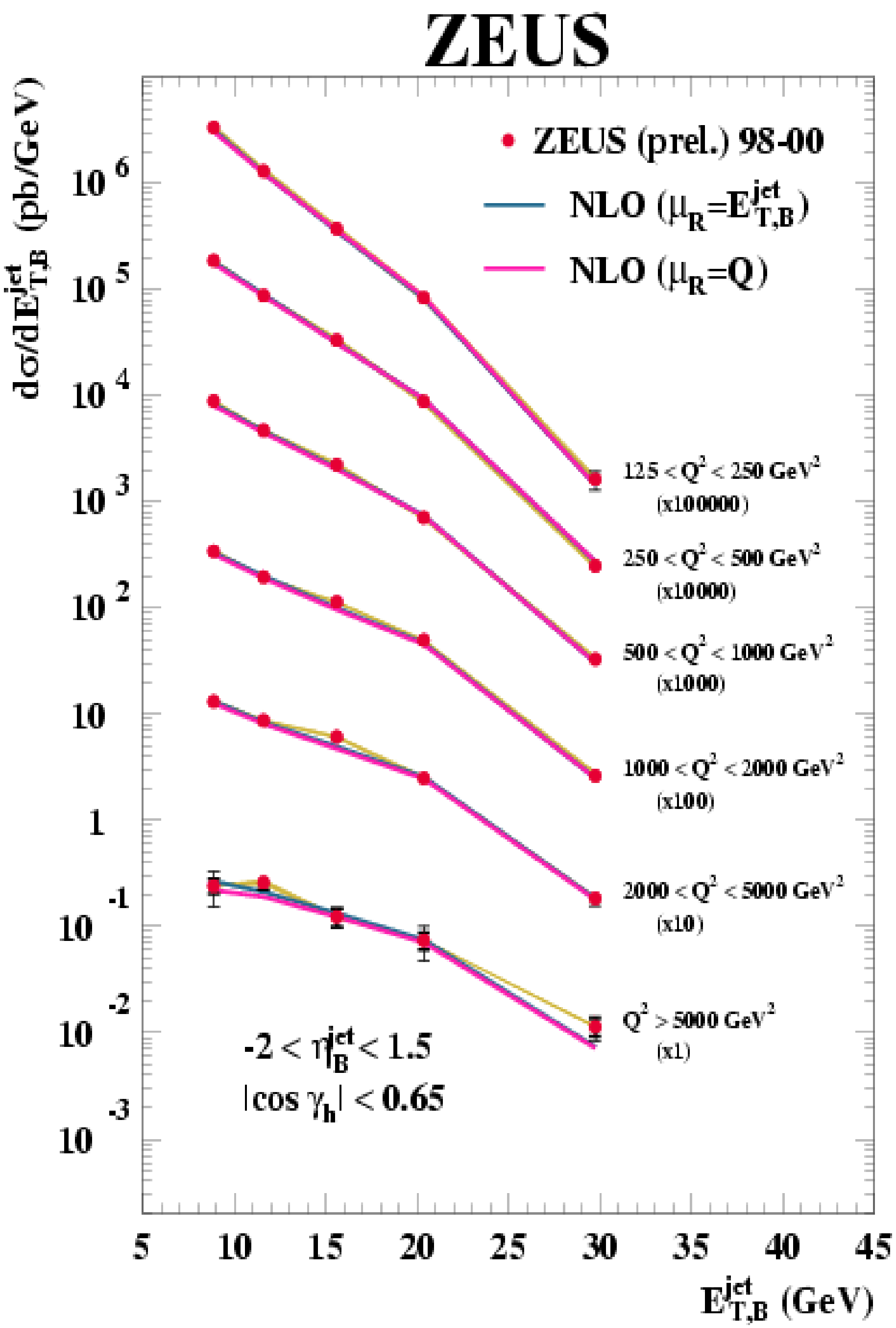
- Cross sections measured over 3 orders of magnitude in Q^2
- CC cross section supressed at low Q^2 by W propagator
- At high Q^2 NC+CC cross sections comparable
- electroweak unification

Extraction of light quark couplings to Z





- Take NC+CC cross sections and fit with extra parameters
- H1 data competetive with world's best
- Standard Model looks in good shape so far



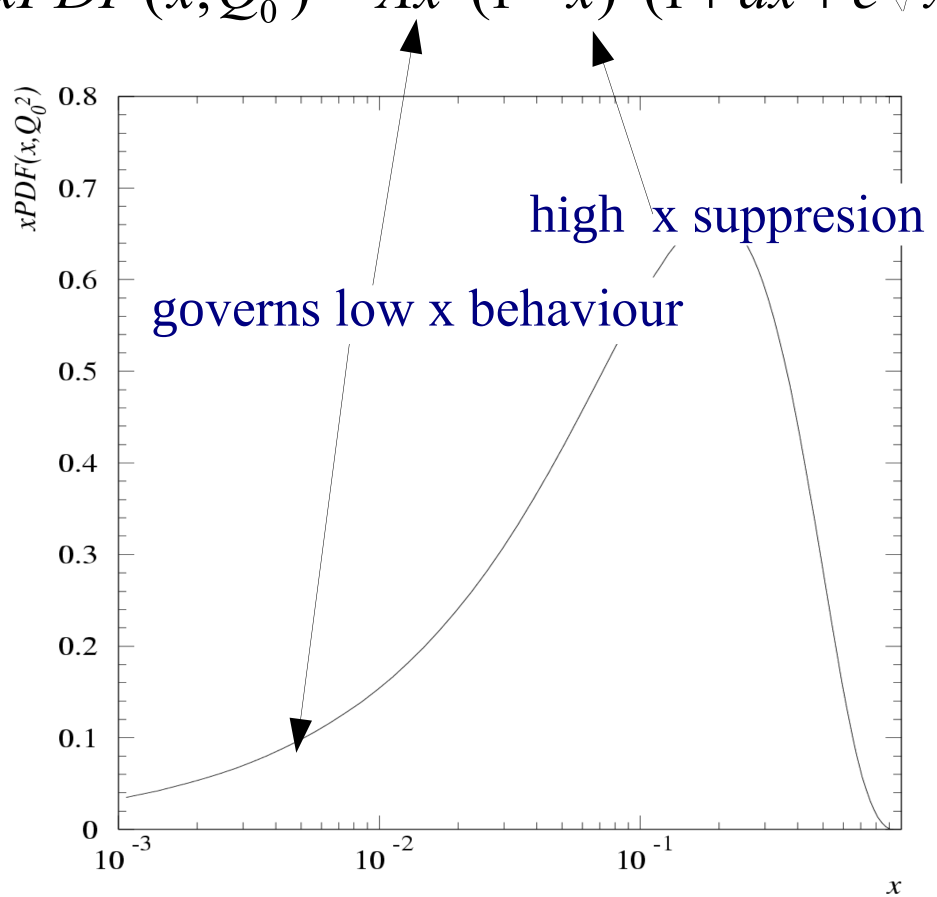
Jet Cross Sections

- Many different measurements in DIS+photoproduction
- Precision of few % achieved over much of phase space
- Good agreement with NLO QCD
- Used to measure α_s from jets alone or in a QCD fit $\Rightarrow$

NLO QCD Fits

PDFs parameterised at starting scale Q_0^2 and use DGLAP to evolve to higher Q^2

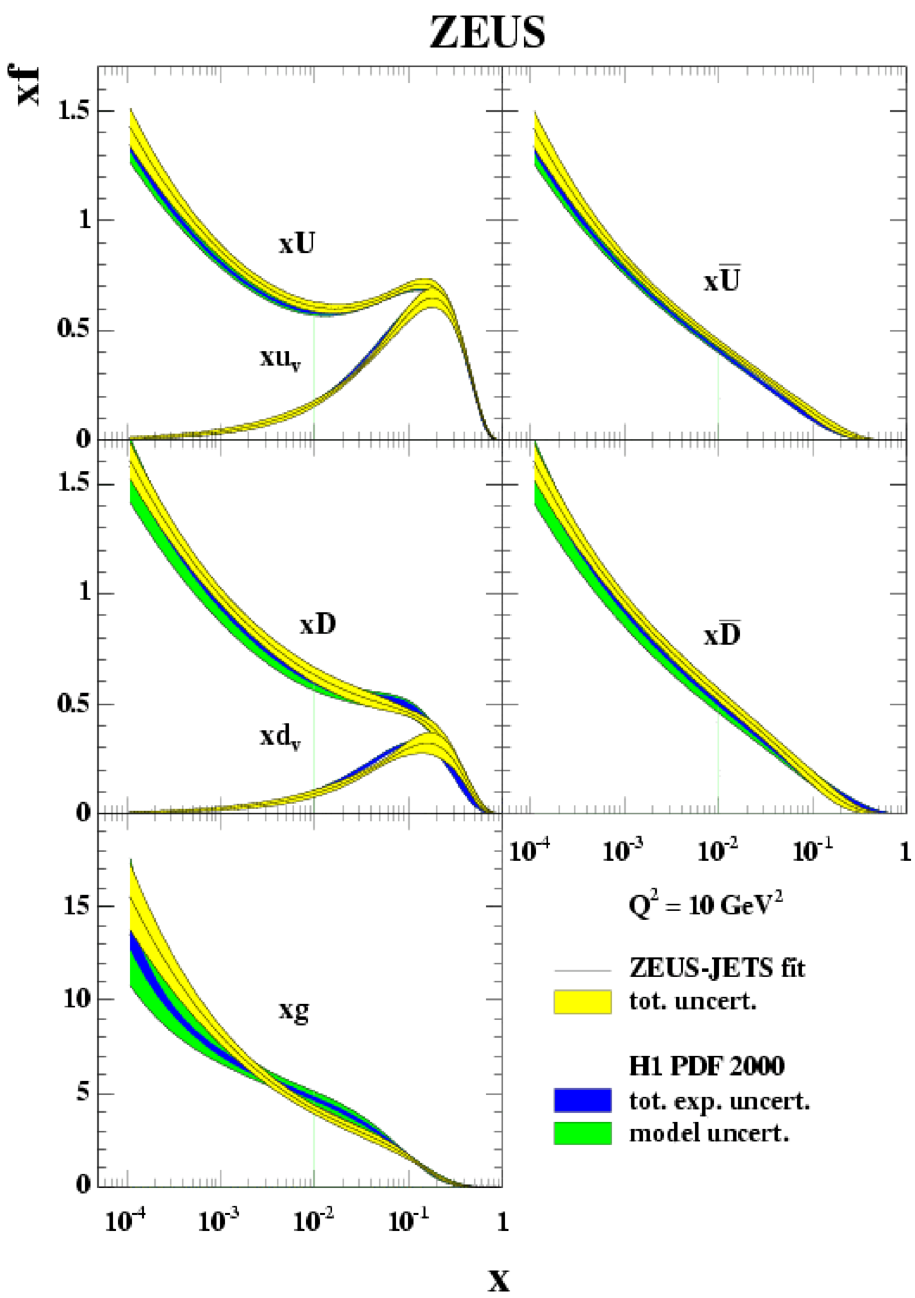
$$xPDF(x,Q_0^2) = Ax^b(1-x)^c(1+dx+e\sqrt{x}+fx^2+gx^3)$$



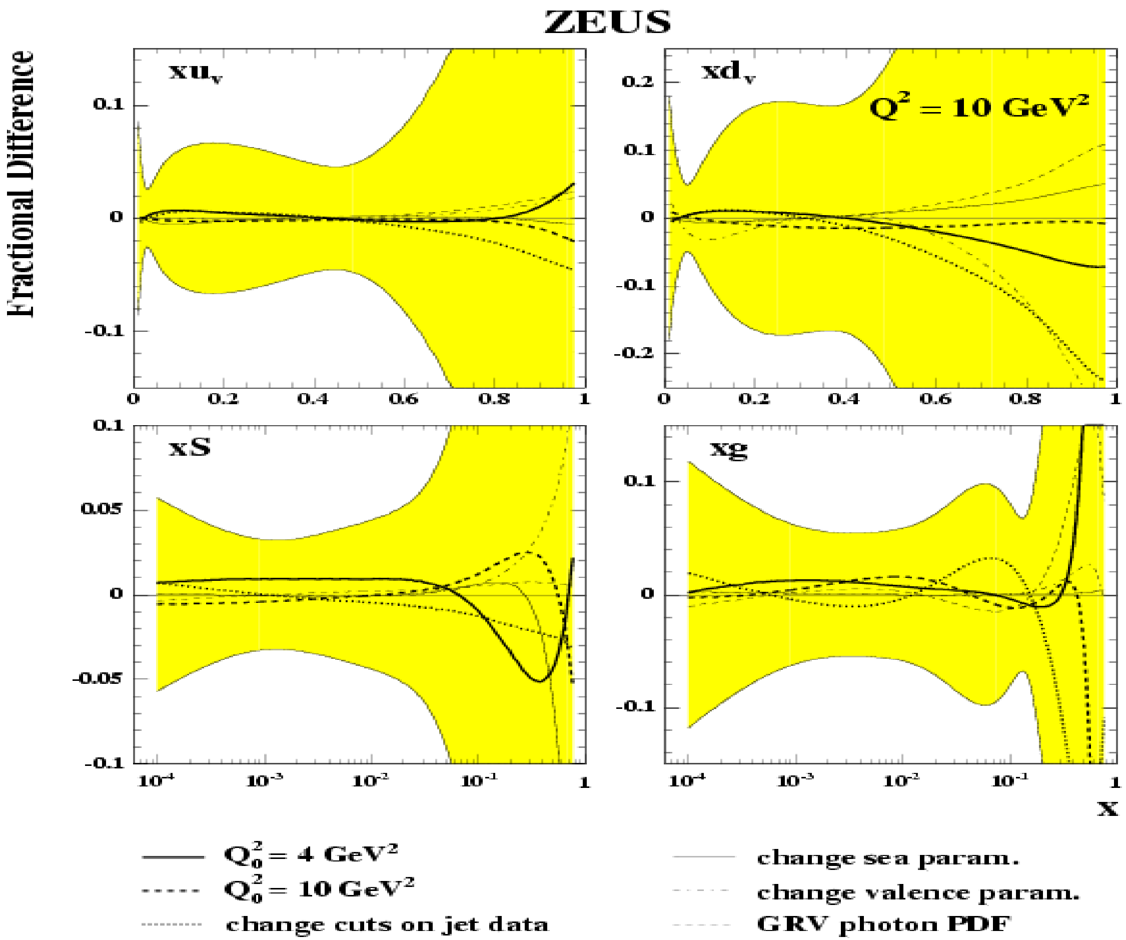
parameters A,b,c,d,e,f optimised in fit for each PDF

some parameters constrained by sum rules e.g. momentum sum = 1

$$\int u_v\,dx = 2 \qquad \int d_v\,dx = 1$$



- ZEUS also use jets to extract PDFs w/o external input
- H1/ZEUS broadly agree but some difference at medium x
- Reasonable agreement with MRSTglobal fit
- Errors still large on d and g at high x

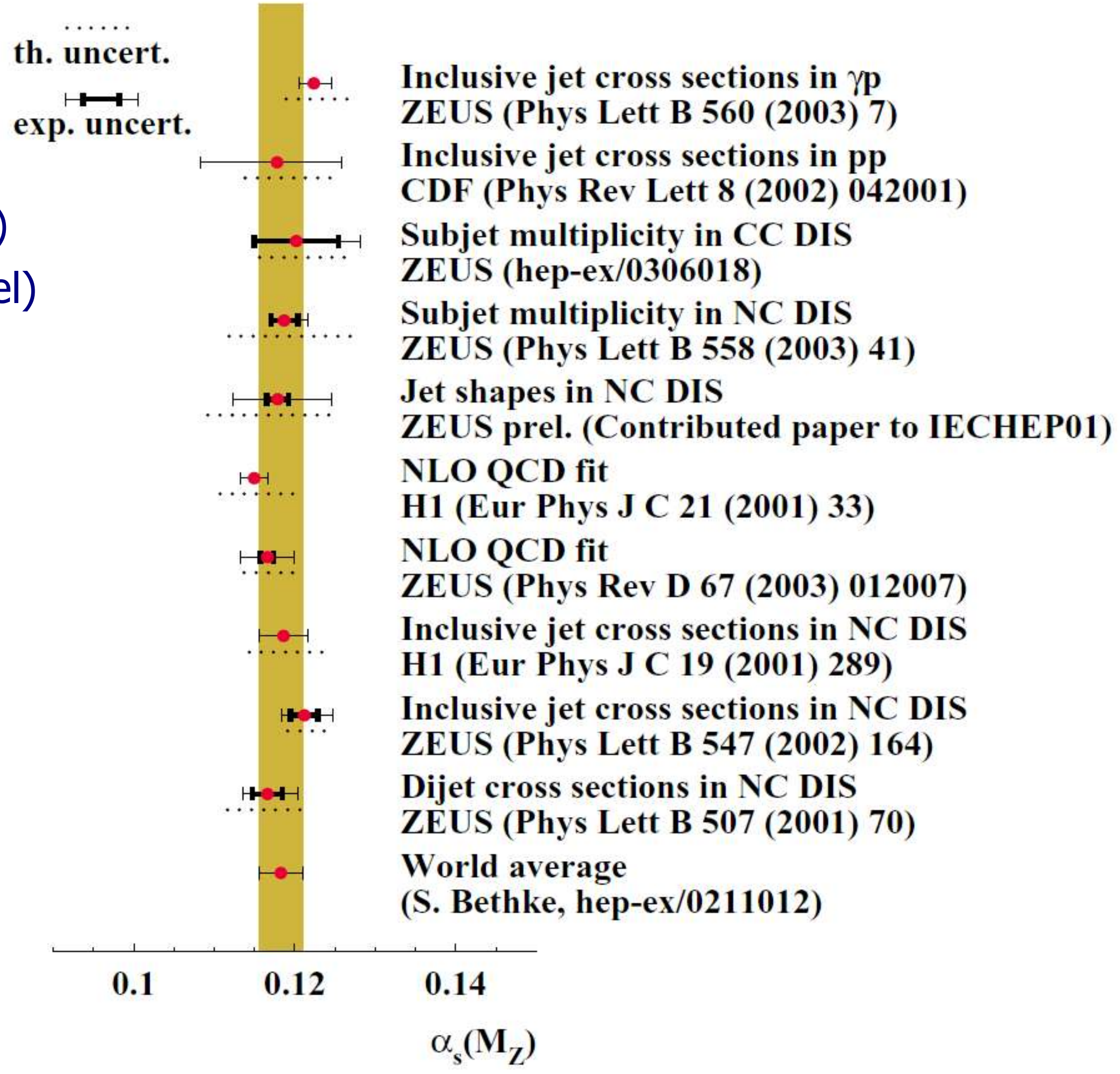


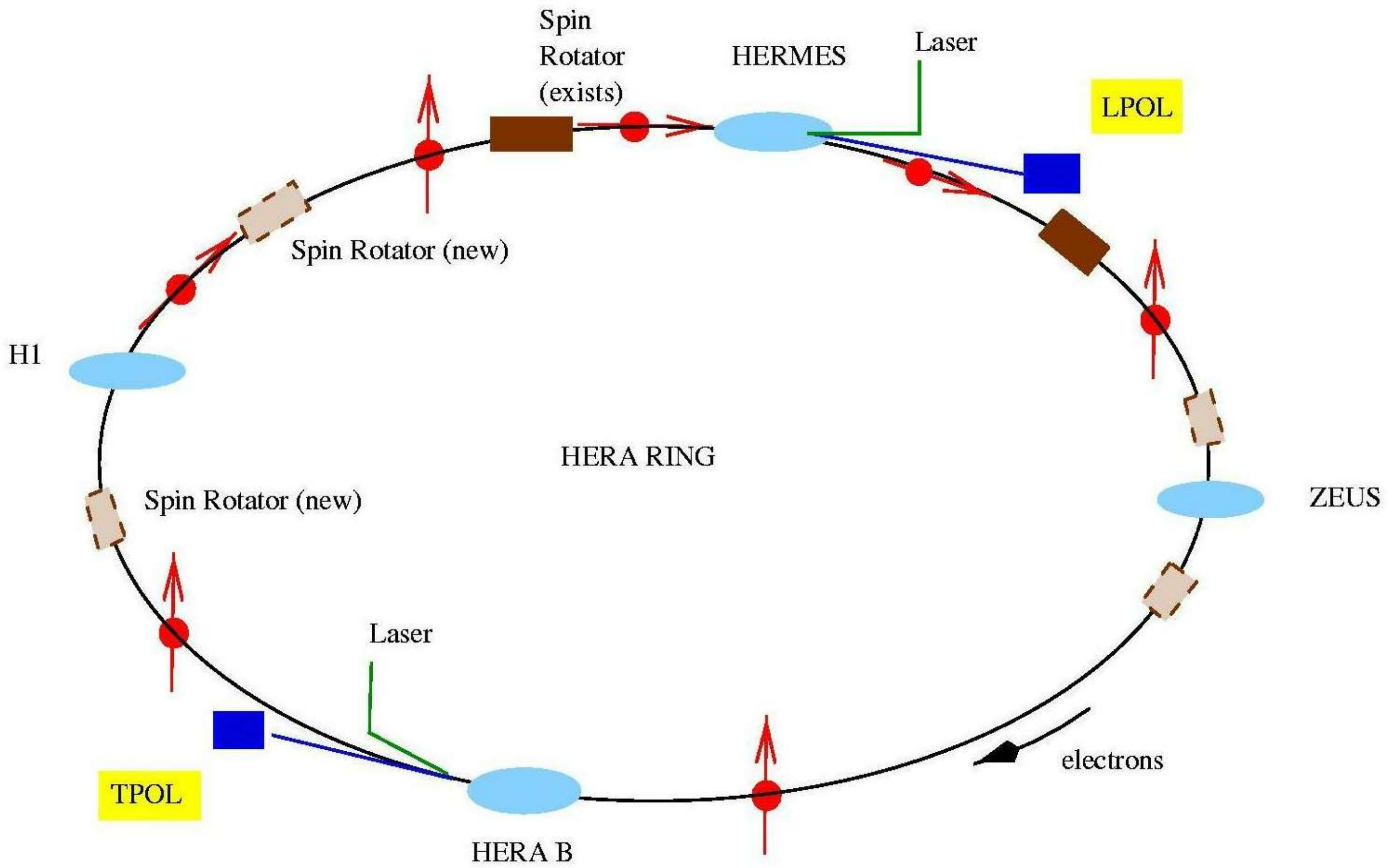
α_s from NLO QCD fits to DIS inclusive and jet data

H1: 0.1150 ±0.0017(exp) ±0.0008(model)
±0.005 (scale)

ZEUS: 0.1166 ±0.0008(unc) ±0.0032(corr)
±0.0036(norm) ±0.0018(model)
±0.004 (scale)

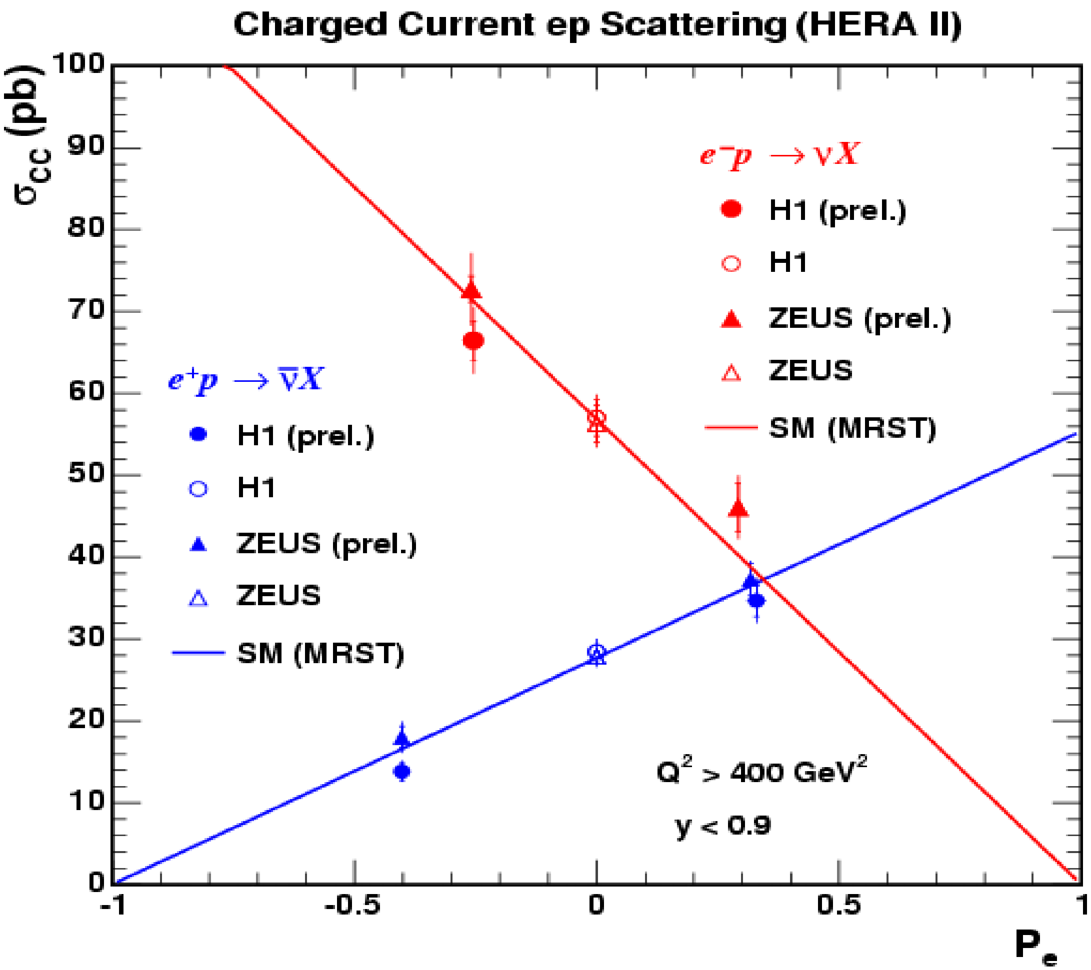
- Experimental errors competitive with world average
- Largest error from renormalisation scale uncertainty (changed by factor 4 H1, 2 ZEUS)
- NNLO analysis should reduce the scale uncertainty by factor 2-4





- Electron beam naturally transversely polarised
- Spin Rotators at IP give longitudinal polarisation
- Polarimeters provide independent polarisation measurements

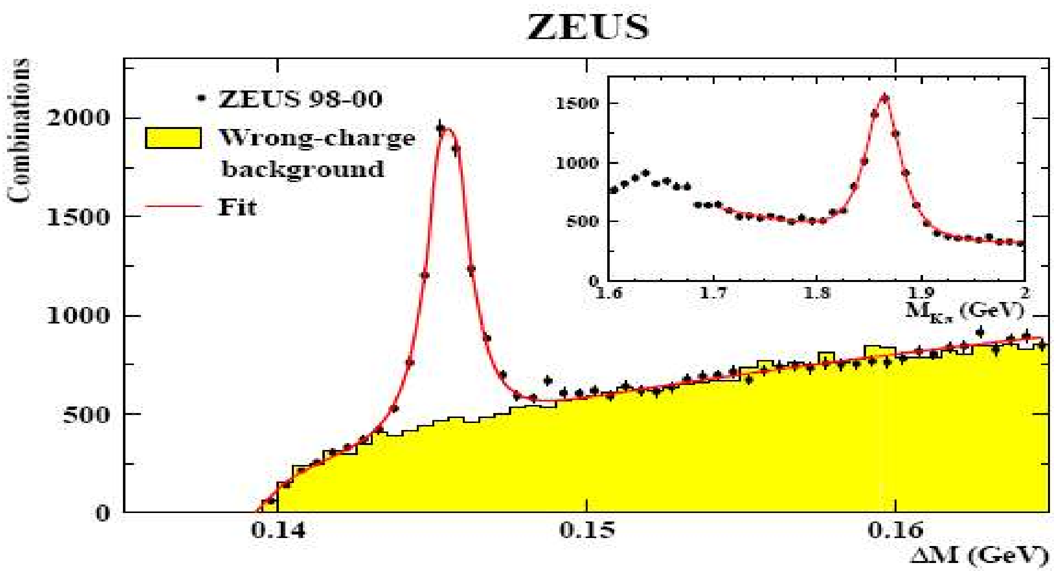
No RH charged currents in SM. Expect a linear dependence



- First Measurement of helicity dependence of ep $\to \nu$ X
- Expect a linear dependence from SM
- ZEUS+H1 measurements in agreement + with SM

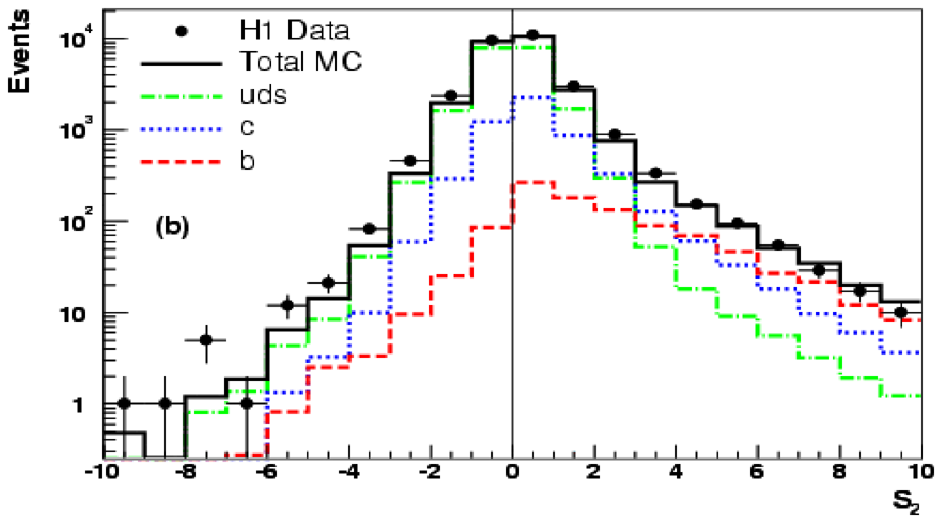
Deviation from straight line means new physics independent of all SM parameters!

Measurement of $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$

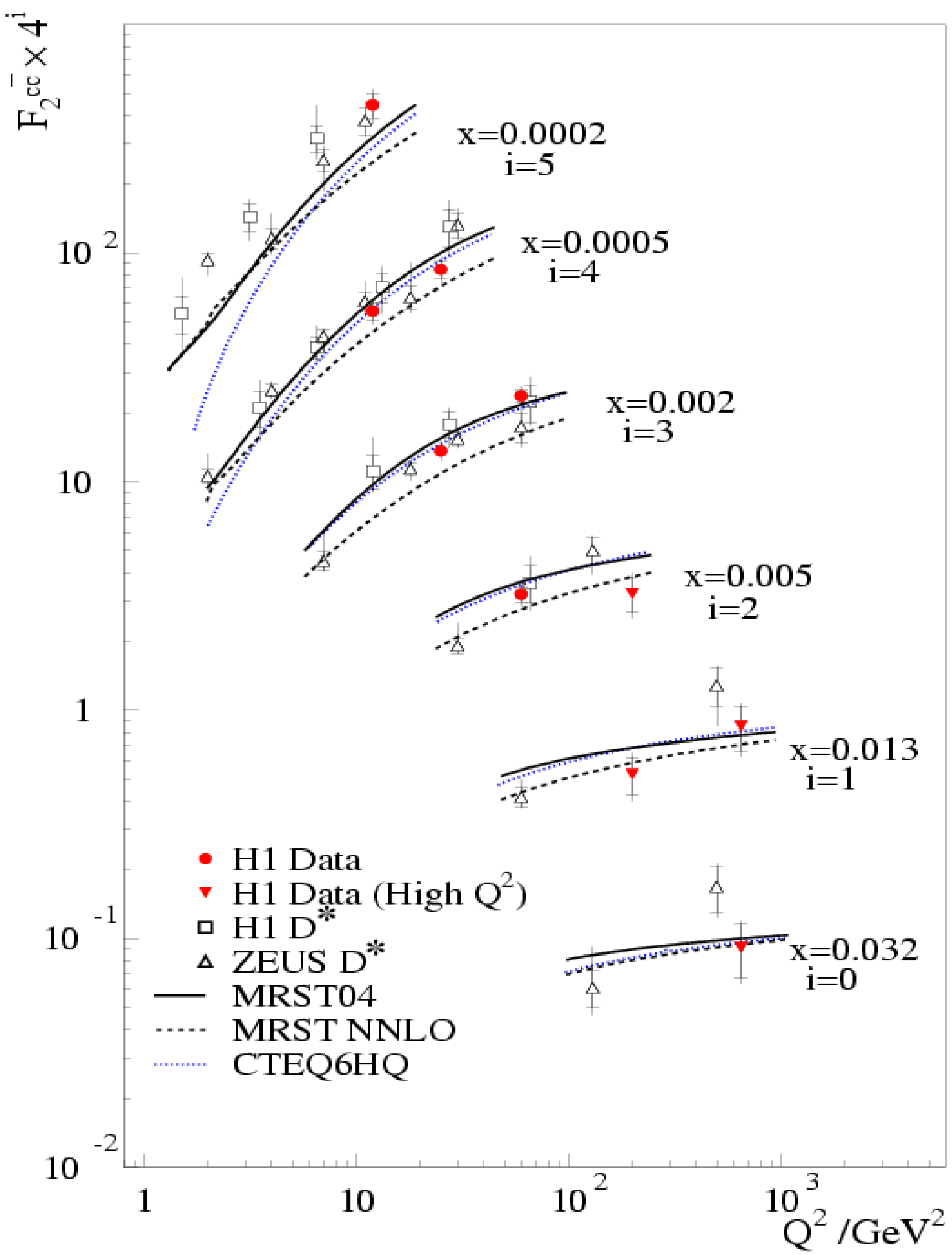


Method 1: D^*

- Access charm by $c \to D^{*\pm} \to K^{\pm}\pi^{\pm}\pi^{\mp}$
- Correct for branching fractions and unseen phase space (low P_T of D^*)
- Only used for $F_2^{c\bar{c}}$



- Use S=DCA/σ(DCA) of track to vertex
- Make use of silicon tracker
- Minimal extrapolation needed to extract $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$



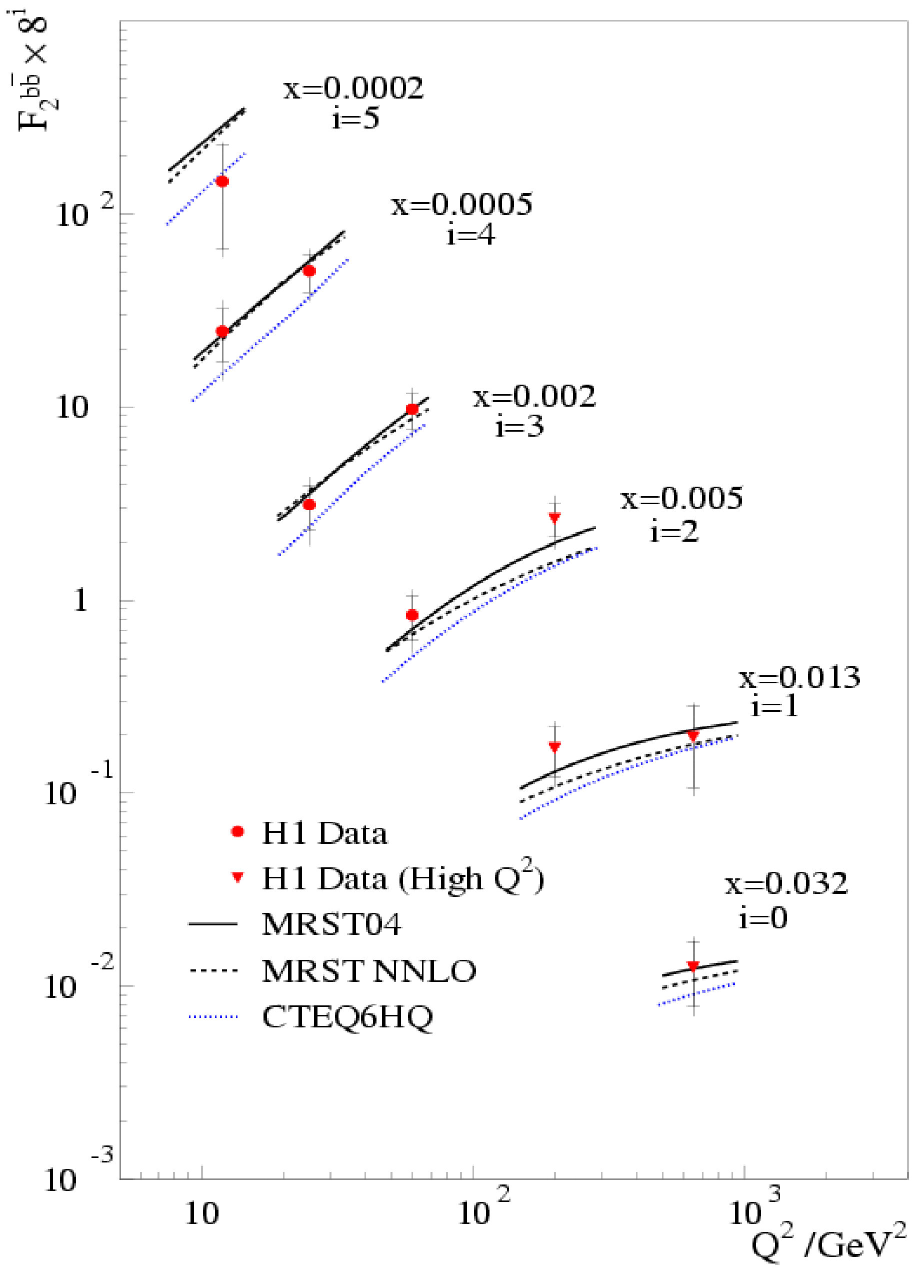
$F_2^{c\bar{c}}$ from D* and displaced track methods

Measured over wide kinematic range

Good agreement H1/ZEUS

Good agreement both methods

Good agreement with SM

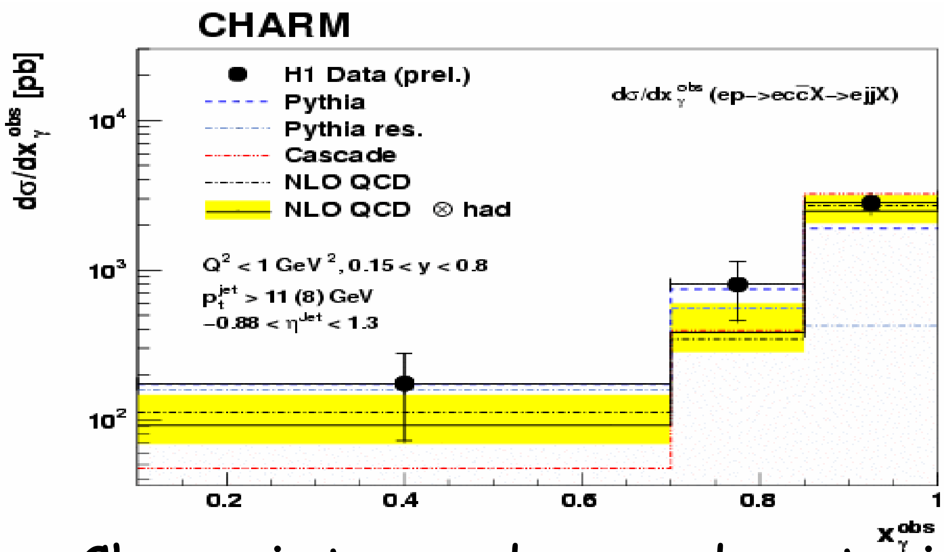


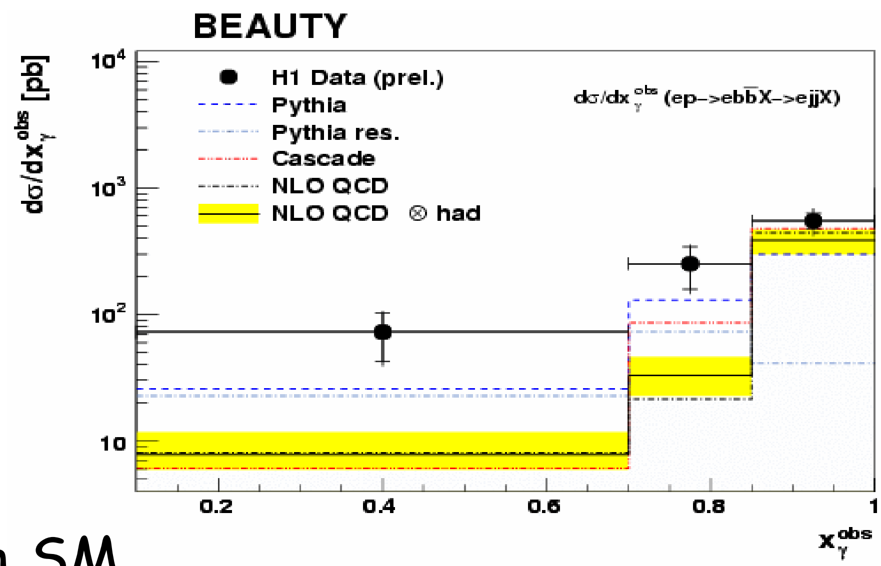
$F_2^{b\bar{b}}$ from displaced tracks only

- First mesurement of $F_2^{b\bar{b}}$
- Good agreement with SM
  - no evidence for excess
- Agreement also good with different QCD models (massive/massless/ VFNS) + PDFs

Large difference CTEQ+MRST at low Q^2

c+b jets in photoproduction +DIS



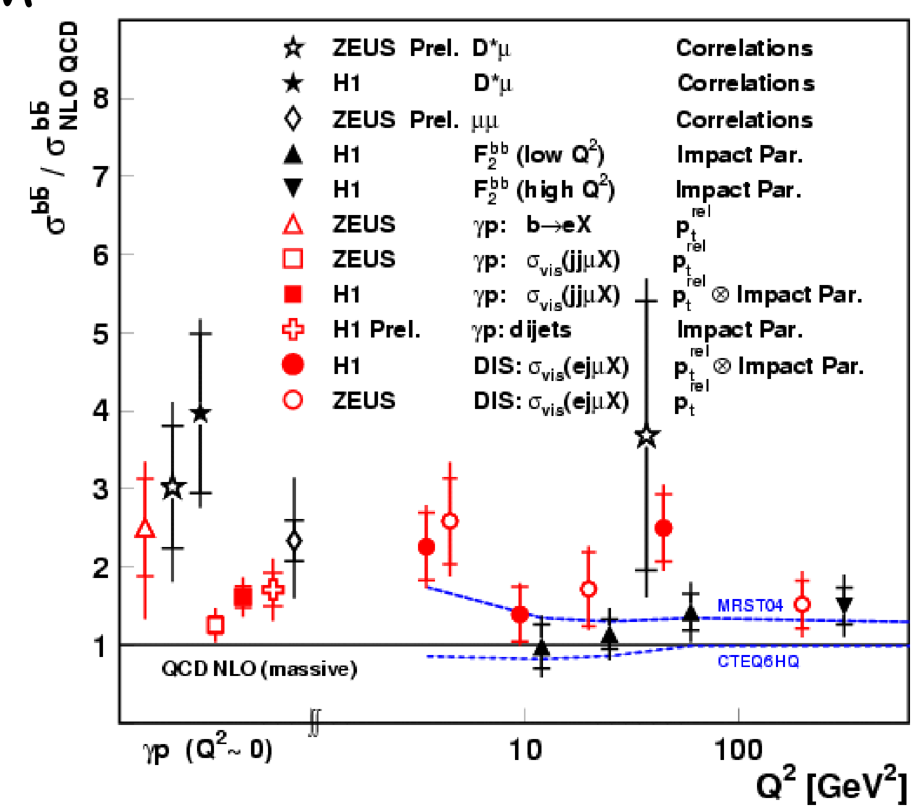


- Charm jets good agreement with SM

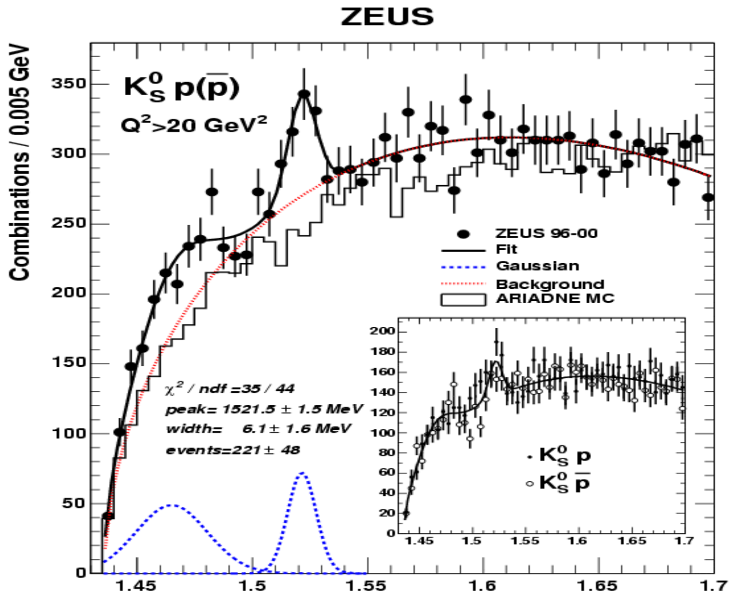
- Many measurements of b production in DIS +photoproduction

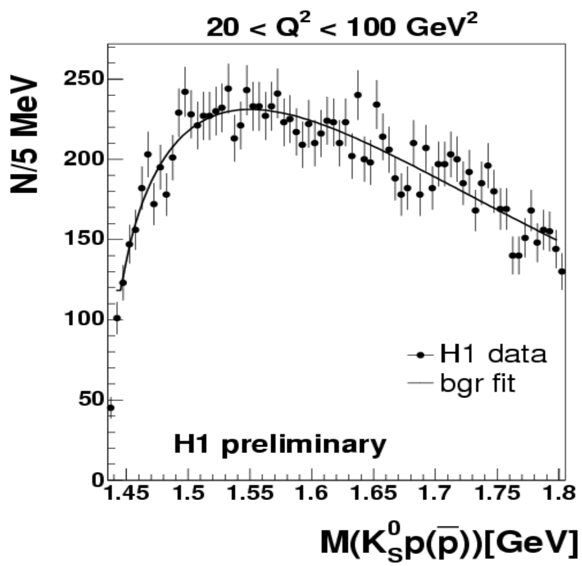
- In DIS data ok within differences in QCD parameterisations

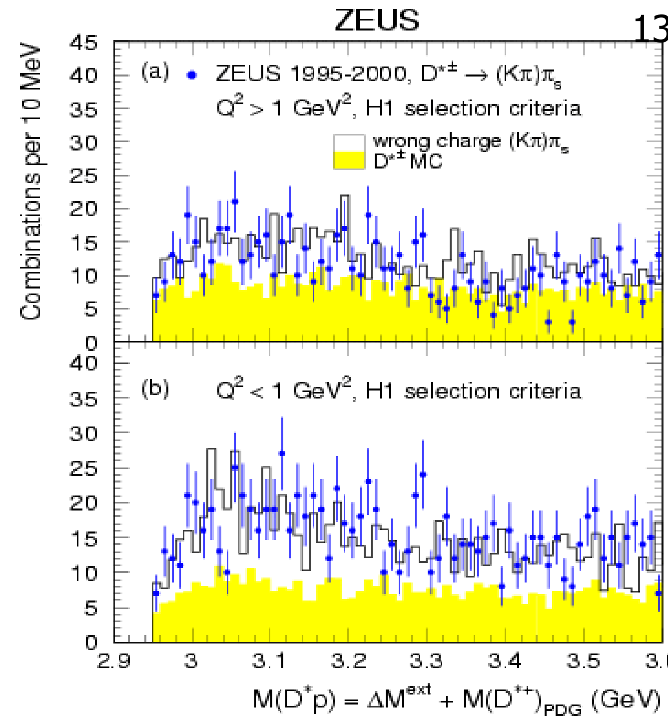
- Excess seen in γp.

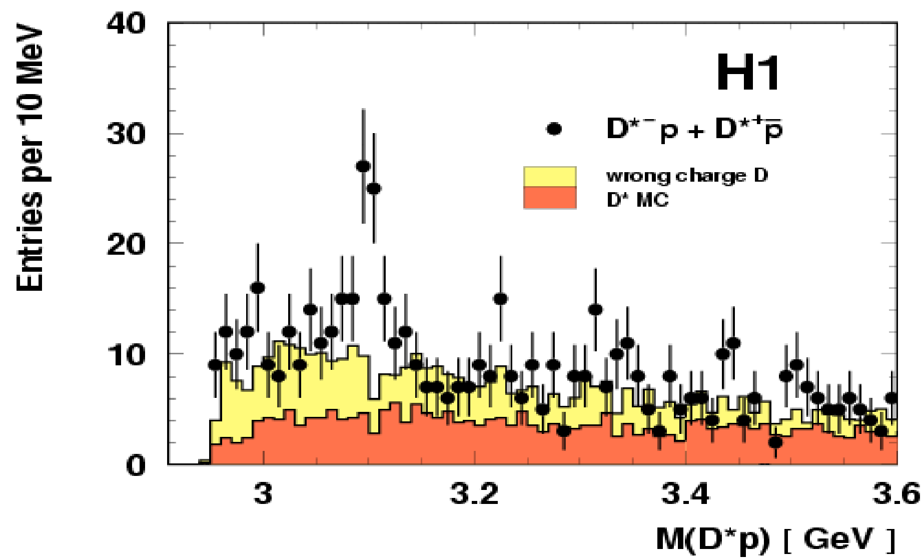


Pentaquarks?

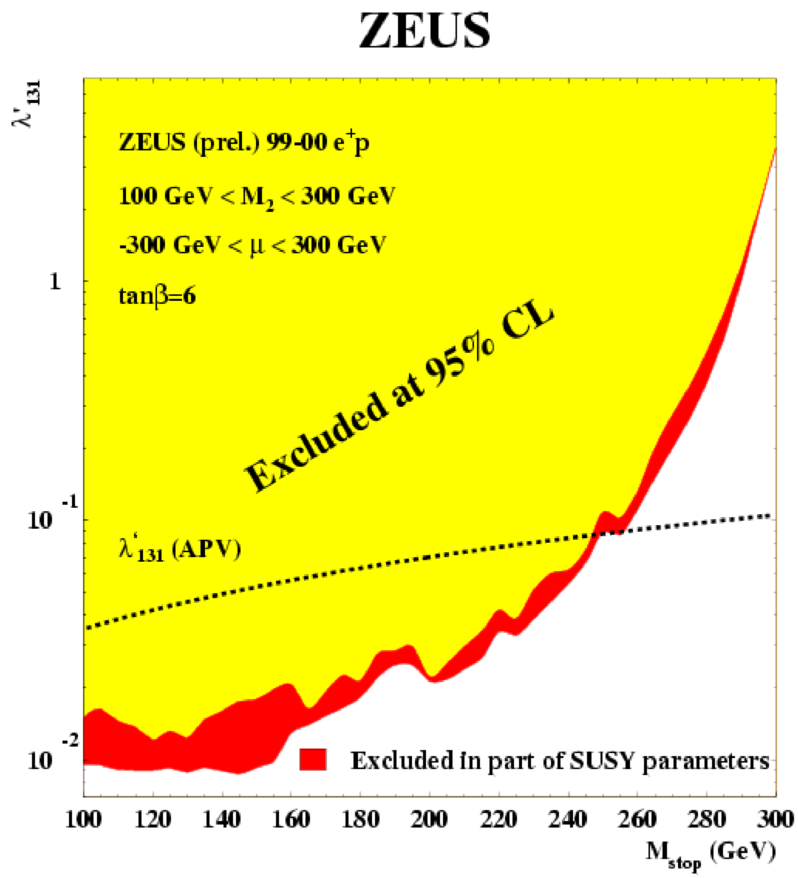


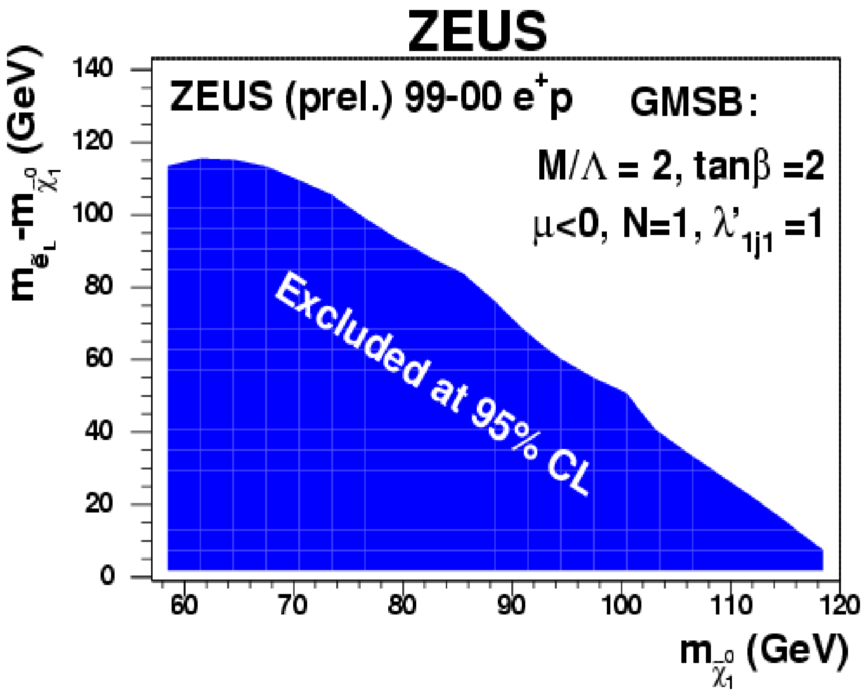






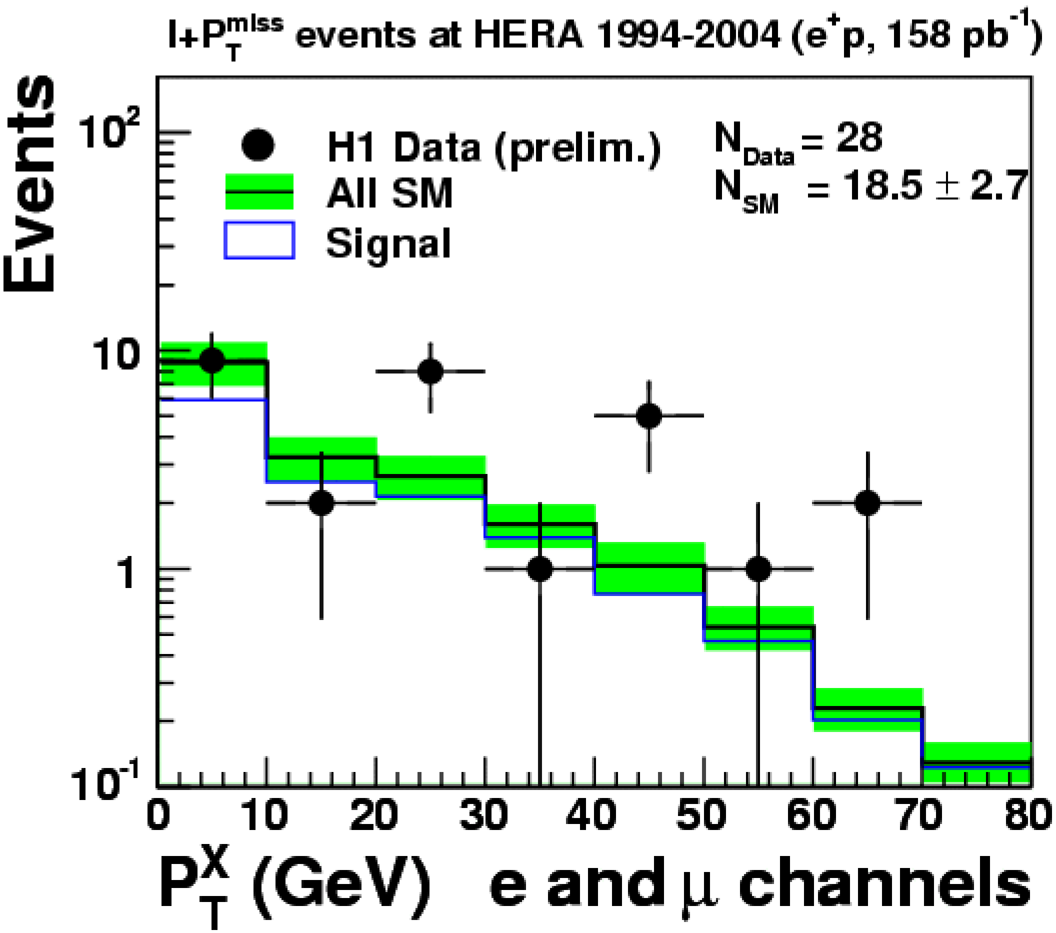
Observations by one experiment not confirmed by other





- Many searches performed for SUSY R parity violating models
- HERA has world's best limits in large areas of phase space

H1Events with Isolated e or μ and missing P_T



Excess of events seen in e^+p HERA I and HERA II data for H1

Events at high hadronic P_T

No excess seen in ZEUS HERA I or H1 e^-p

Await ZEUS HERA II and 2006-2007 data to see if new physics

Summary

Inclusive mesurements from HERA great add to our understanding of proton structure Essential for LHC physics

- Parton distribution functions have errors of a few % over most of the x range
- HERA measurements have achieved a very competative measurements of α_s
- First measurements of polarised CC cross section consistent with a linear dependence as in SM
- Semi-inclusive charm and bottom show we have a good understanding of QCD and the PDFs
- Many searches underway looking for physics beyond the Standard Model