ZEUS-UK Collaboration Status Report — Part II

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ZEUS-UK Physics

- Understanding QCD
  - photon structure
  - 4-jet production
  - virtual photon structure
  - Determining α_s
  - Measurements of $F_2(x, Q^2)$
  - NLO-QCD fits of F_2 data
  - Λ and K_s^0 production
  - rapidity gaps between jets
  - azimuthal asymmetries
  - prompt γ production
  - Jet production in charged current
  - Scaling violations in γp
  - $F_2(ISR)$ & F_L
  - High mass dijet photoproduction
  - High Q^2 dijet production
- Testing Electroweak theory
  - High Q^2 Neutral current cross sections
  - Charged current cross sections
- Physics beyond the Standard Model
  - Single top production
- Heavy Flavour Physics
  - see previous talk
  - charm in jets

QCD at HERA

- ▷ HERA bridges the gap between e^+e^- and $p\bar{p}$ collisions
- ▷ Generic QCD cross section at HERA

$$\sigma = \mathbf{f_p} \otimes \mathbf{f}_\gamma \otimes \hat{\sigma}$$

subprocess cross section
calculable in pQCD

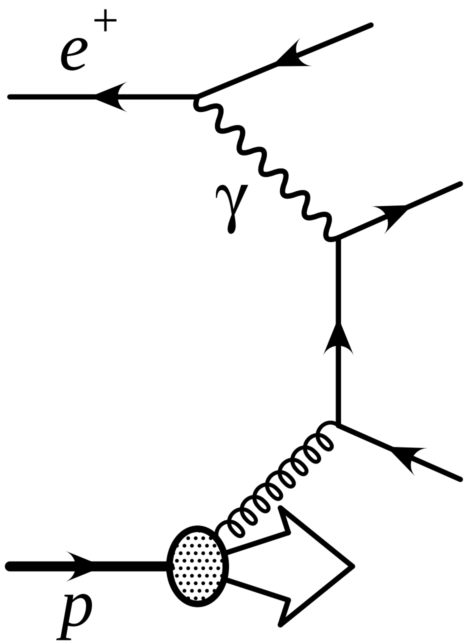
photon parton densities

proton parton densities

- ▷ Probe proton and photon structure at high scales
- ▷ test QCD calculations
- ▷ Measure fundamental parameters ($\alpha_\mathbf{s}$)

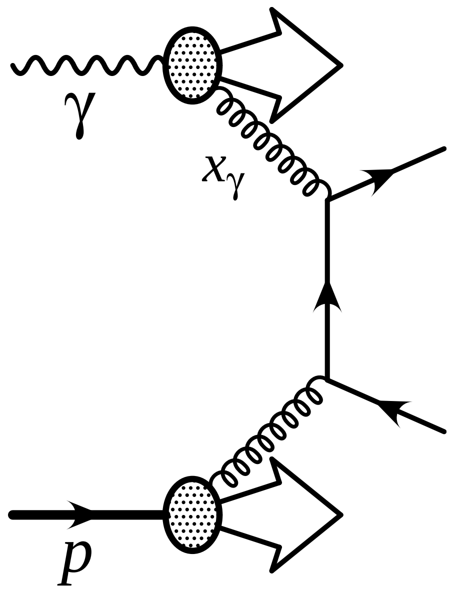
Dijet photoproduction at HERA

▷ *At lowest order, two processes contribute*



▷ *"direct" processes*

- *high* x_γ^{obs}



▷ *"resolved" processes*

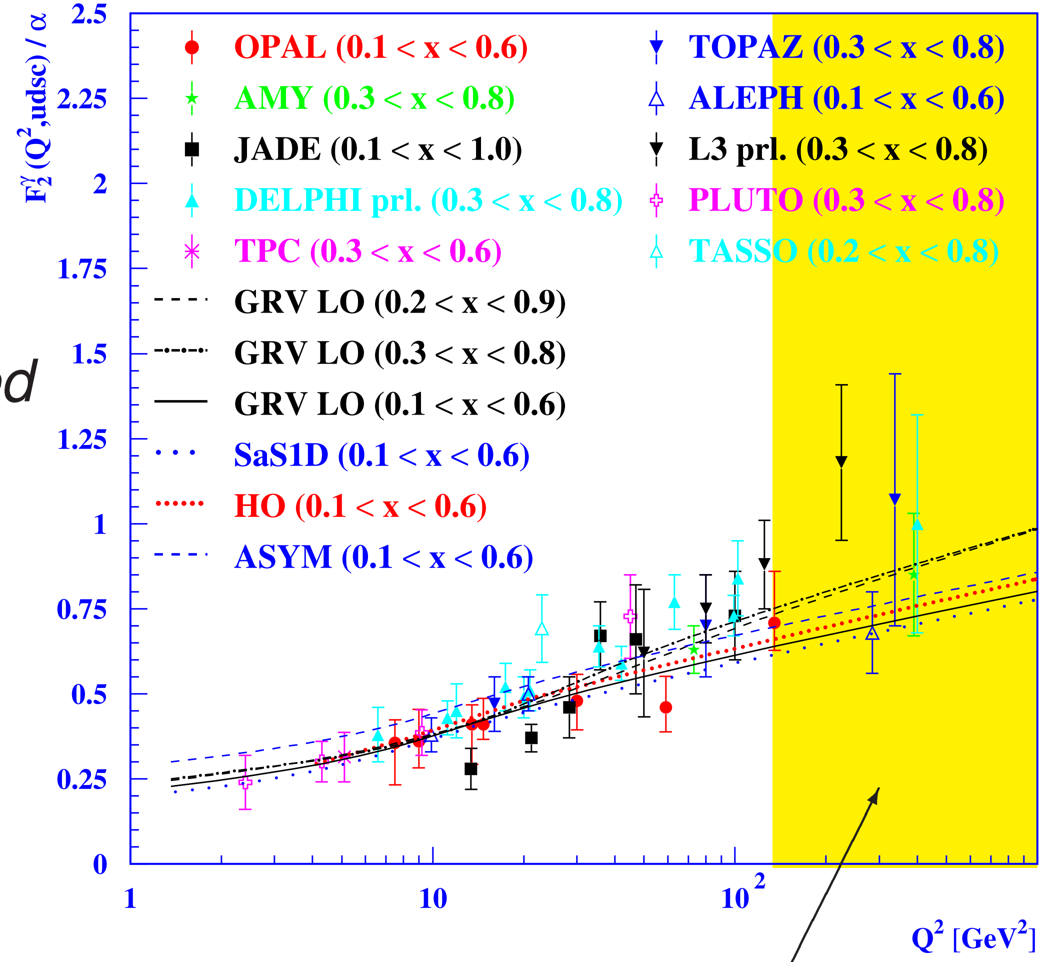
- *low* x_γ^{obs}

$$\boxed{x_\gamma^{\mathrm{obs}} = \sum_{jets} \frac{E_T e^{-\eta}}{2yE_e}}$$

▷ *defined to all orders*

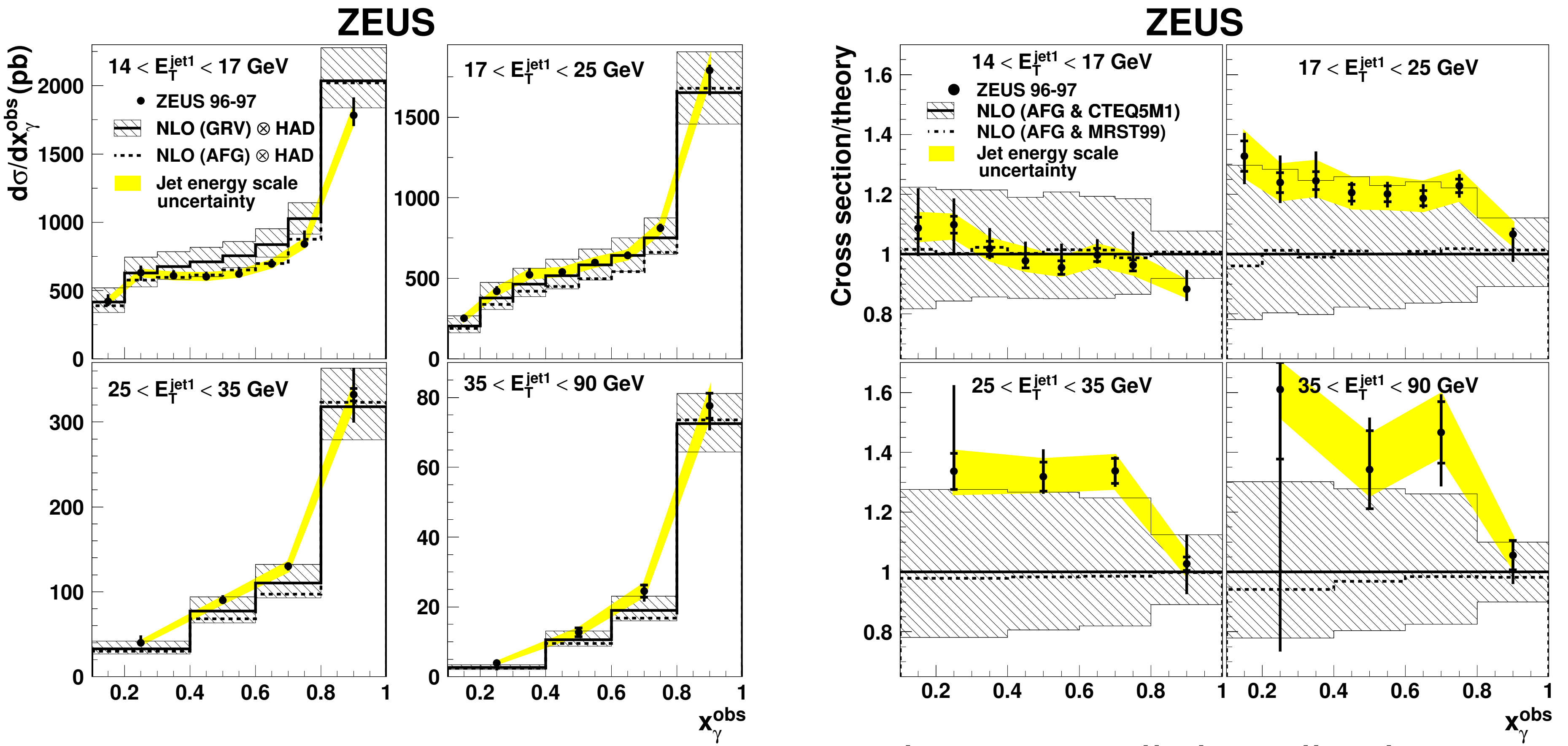
Real Photon Structure

- ▷ photoproduction $Q^2 \approx 0\ \mathrm{GeV}^2$
- ▷ high E_T jets
  - $E_T^2 \gg Q^2$
  - implies moderate to high x
  - proton structure well-constrained
- ▷ sensitive to quarks & gluons in γ at LO
  - gluons dominate σ at low x_γ^{obs}
- ▷ HERA data can probe γ at higher scales than anywhere else !



HERA sensitive region

Real Photon Structure (II)



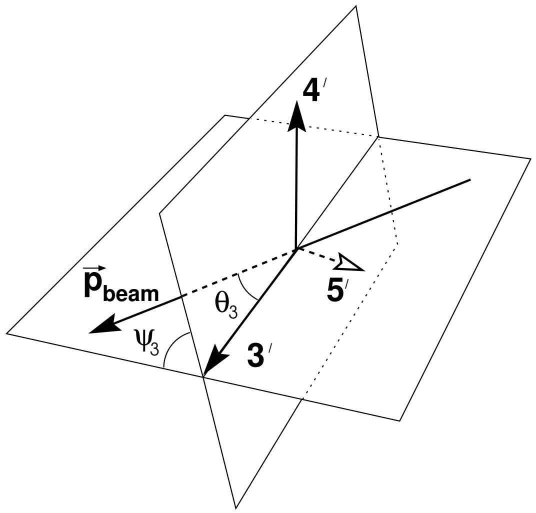
- ▷ *reasonable description* $x_\gamma^{\rm obs} > 0.8$
- ▷ *theory below data*

  for $E_T > 17$ GeV

- ▷ *data not well-described . . .*
  - *parameterisation inadequate ?*
  - *HO corrections ?*

More jets . . .

- ▷ *study 3- and 4-jet events*
- ▷ *testing QCD at intrinsically higher orders*
- ▷ *study "underlying event"*
    - *multi-parton interactions ?*

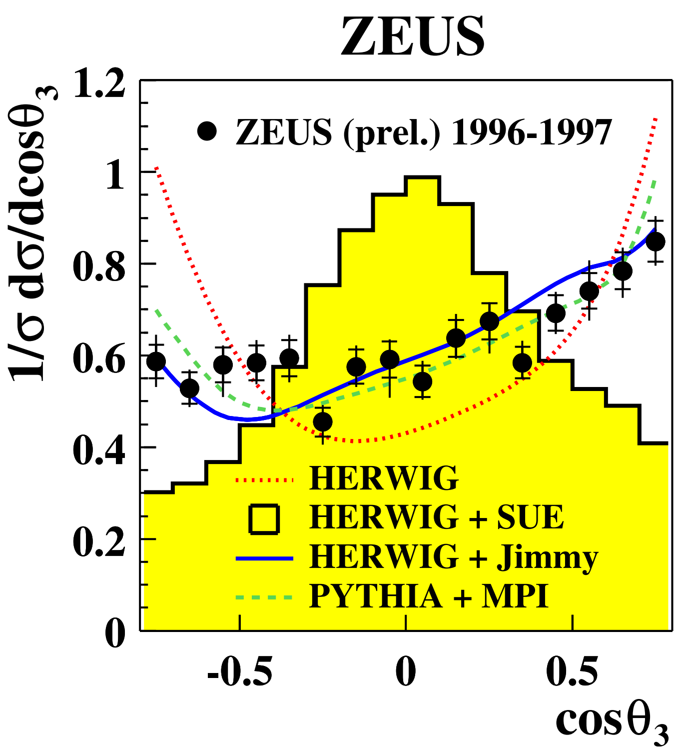


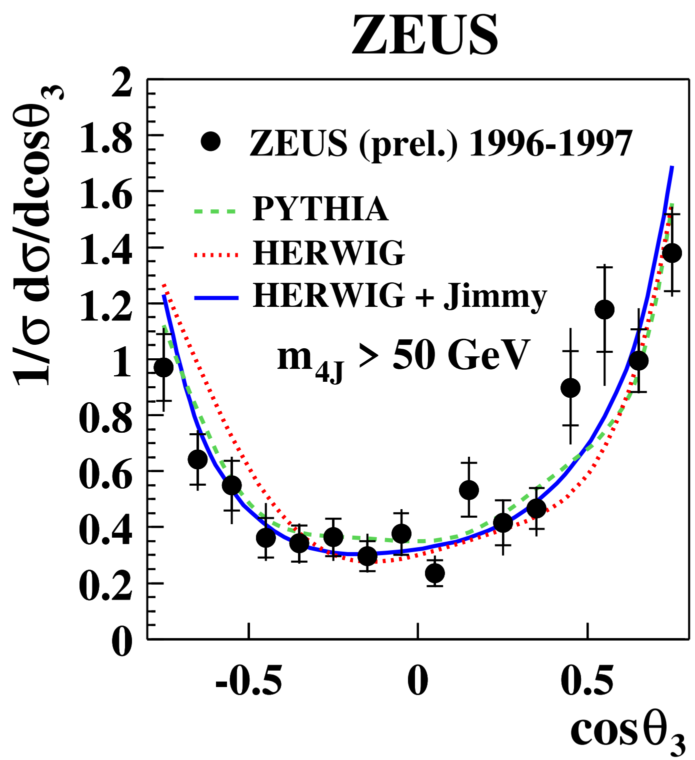
- ▷ *Use scheme of S. Geer & T. Asakawa*
    - *Phys. Rev.* ***D53*** *(1996) 4793*
- ▷ *In 4-jet case*
    - *combine 2 jets with lowest invariant mass*
    - *Directly compare 3- and 4-jet results*

- ▷ *Define variables in multi-jet rest frame*
    - ▷ $1+2 \to 3+4+5(+6)$
    - ▷ $E_3 > E_4 > E_5 (> E_6)$

$$\boxed{\cos\theta_3 = \frac{\vec{p}_{beam} \cdot \vec{p}_3}{|\vec{p}_{beam}| \cdot |\vec{p}_3|}}$$

Multi-jet Production





- ▷ *Jimmy/MPI*

  = multi-parton interaction models
- ▷ *"Soft underlying event" model strongly disfavoured*

- ▷ *QCD is working . . .*
- ▷ *ZEUS data favour multi-parton interactions*

Virtual Photon Structure

- ▷ *virtual photons also have two components*

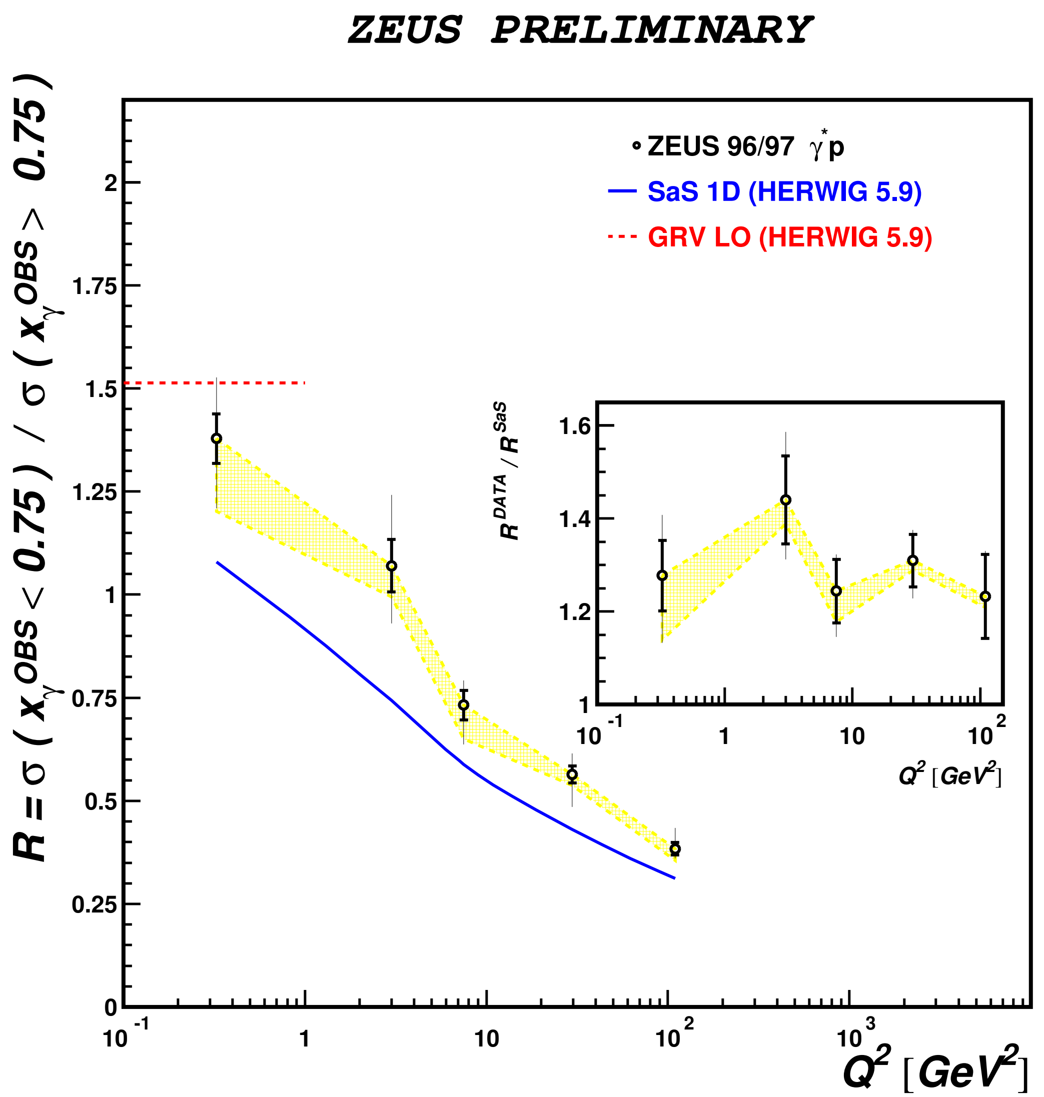
  $|\gamma^* >= |dir > +|res >$

- ▷ *resolved component*

  suppressed with increasing Q^2

- ▷ *Why treat* γ^* *as pointlike*

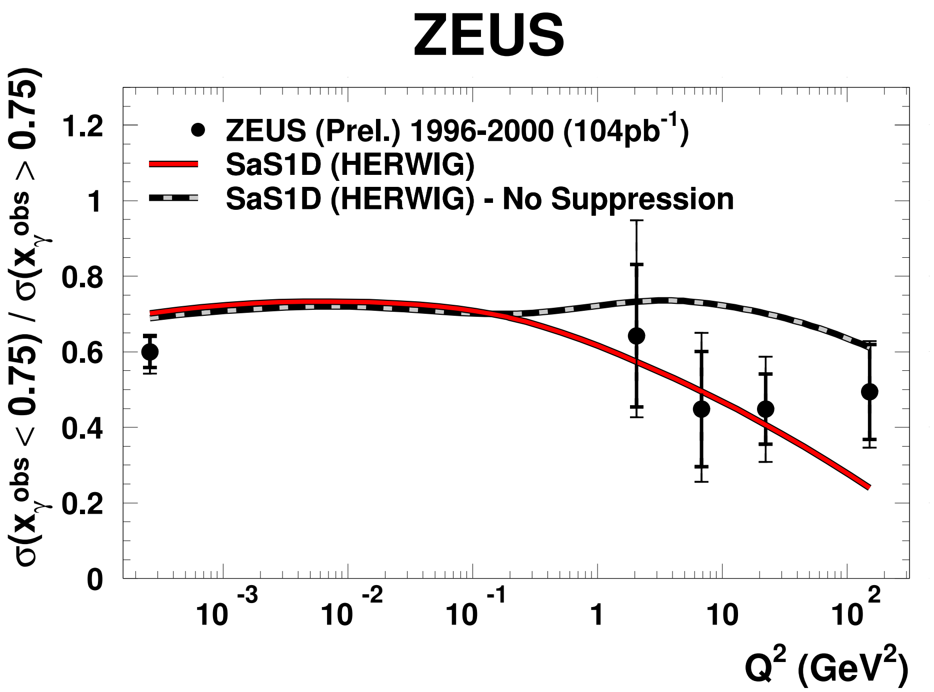
  when $R \neq 0$ *at high* Q^2 *?*



Virtual Photon Structure (II)

▷ Two scales involved: Q^2 and $(\overline{E_T})^2$
- If $Q^2 > (\overline{E_T})^2$: pointlike γ^*
- If $Q^2 < (\overline{E_T})^2$: partonic structure

▷ Consider charm in dijet production



▷ Need to consider:
- Q^2, $(\overline{E_T})^2$ and charm mass

▷ See different behaviour with charm

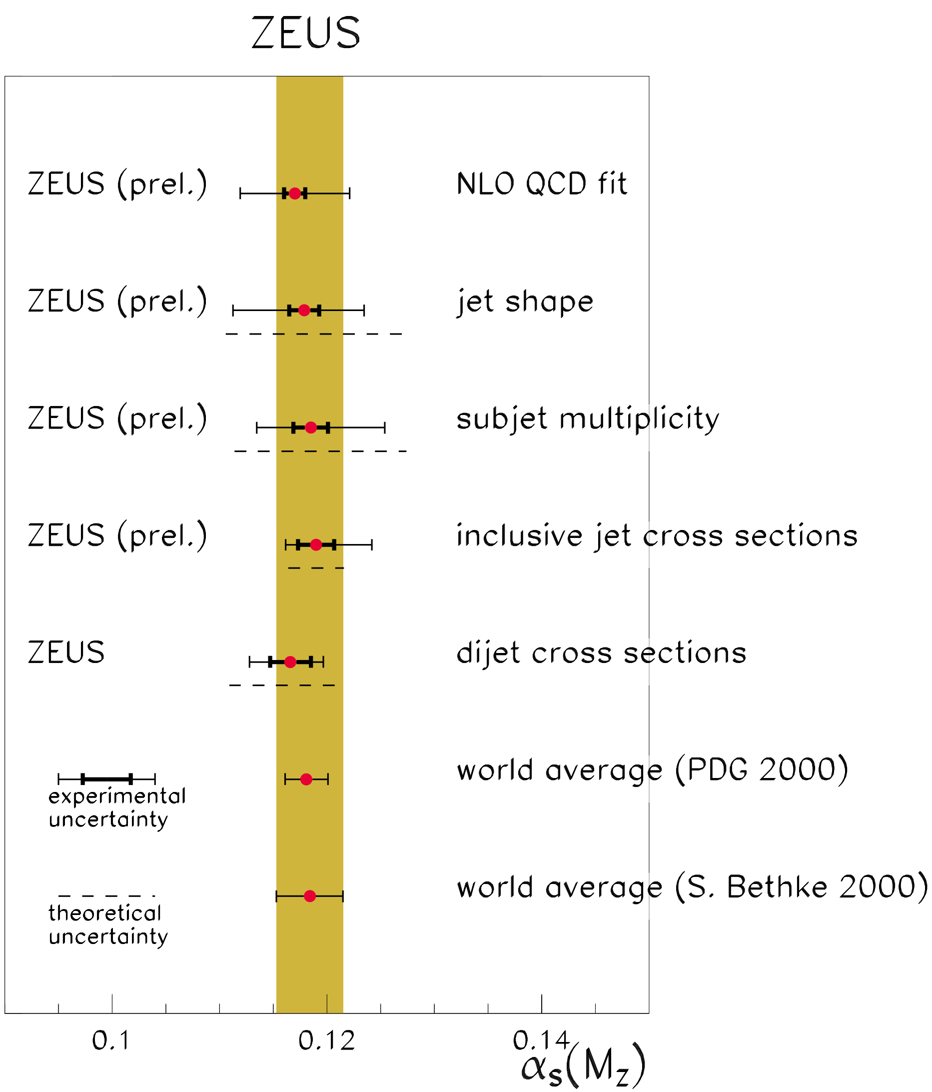
▷ unique opportunity to study inter-play of QCD hard scales

Determination of α_s

- Several methods available:
- NLO-QCD fits of F_2 data — details later
- Jet substructure
  - partonic radiation $\rightarrow$ sensitive to α_s
  - Integrated E_T in cone, radius $r < R$

$$\Psi(r) = \frac{1}{N} \sum_{jets} \frac{E_T^{jets}(r)}{E_T^{jets}(R)}$$

- Consistent with world average
- Uncertainties competitive
- dominated by theory uncertainty



NLO QCD Fits and $\mathrm{F_2(x, Q^2)}$

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

▷ $Y_{\pm} = 1 \pm (1-y)^2$

▷ $F_L =$ *longitudinal structure function*

- $F_L = 0$ *at LO*

▷ *sensitive to gluons*

▷ $xF_3 =$ *parity violating structure function*

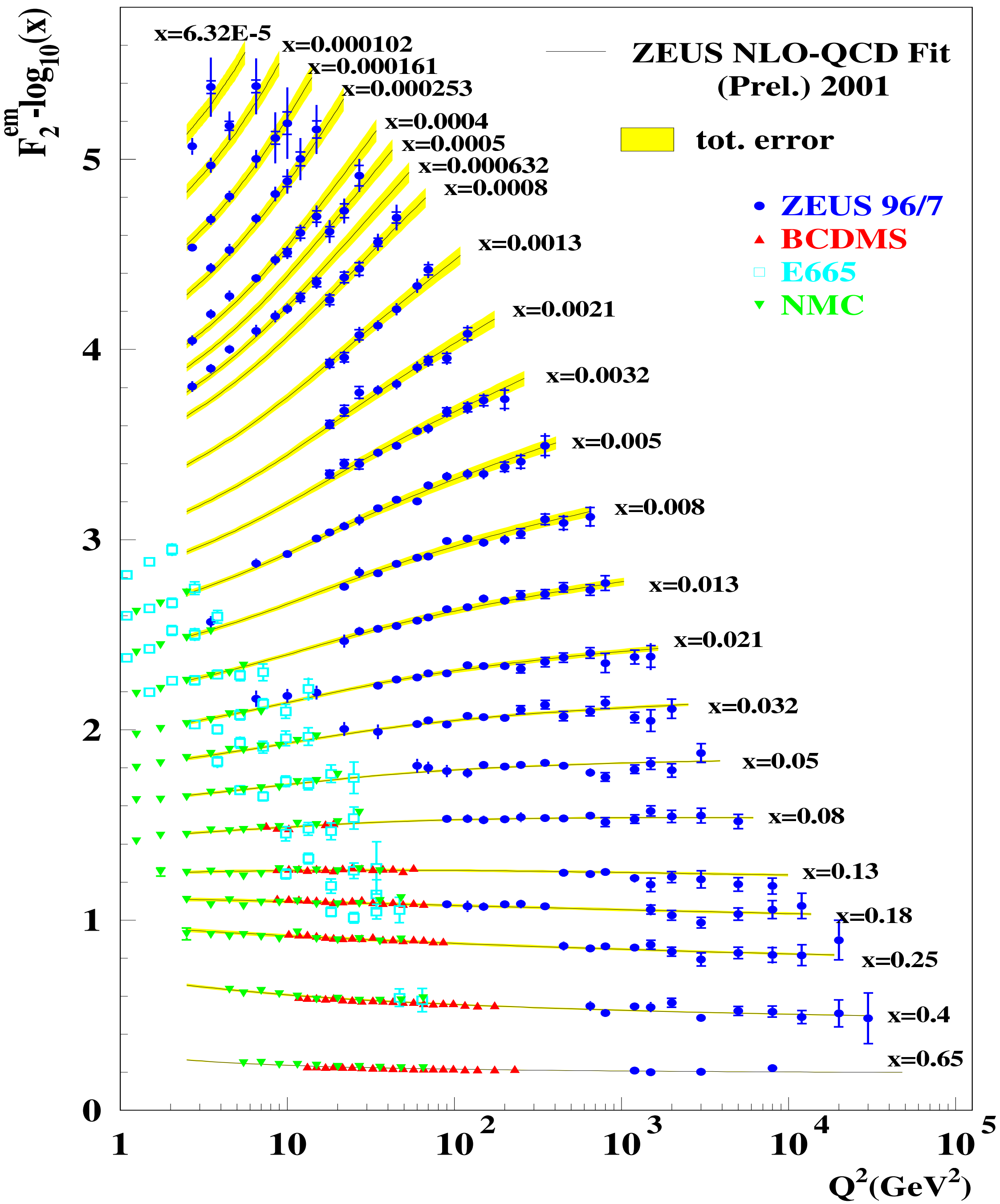
▷ *At LO*
$xF_3 = \Sigma_q B(Q^2)(q - \bar{q})$

▷ $F_2 =$ *short range interaction* $\otimes$ *PDFs*

- *evolution with* $Q^2 \rightarrow$ *DGLAP equations*
- *use data to constrain input distributions at* Q_0^2
- *At LO* $F_2 = \Sigma_q A(Q^2)(q + \bar{q})$

Summary of $\mathrm{F_2(x, Q^2)}$ *data*

- *Measurements very precise*
- *Span 5 orders of magnitude*
- *scaling violations clearly visible*

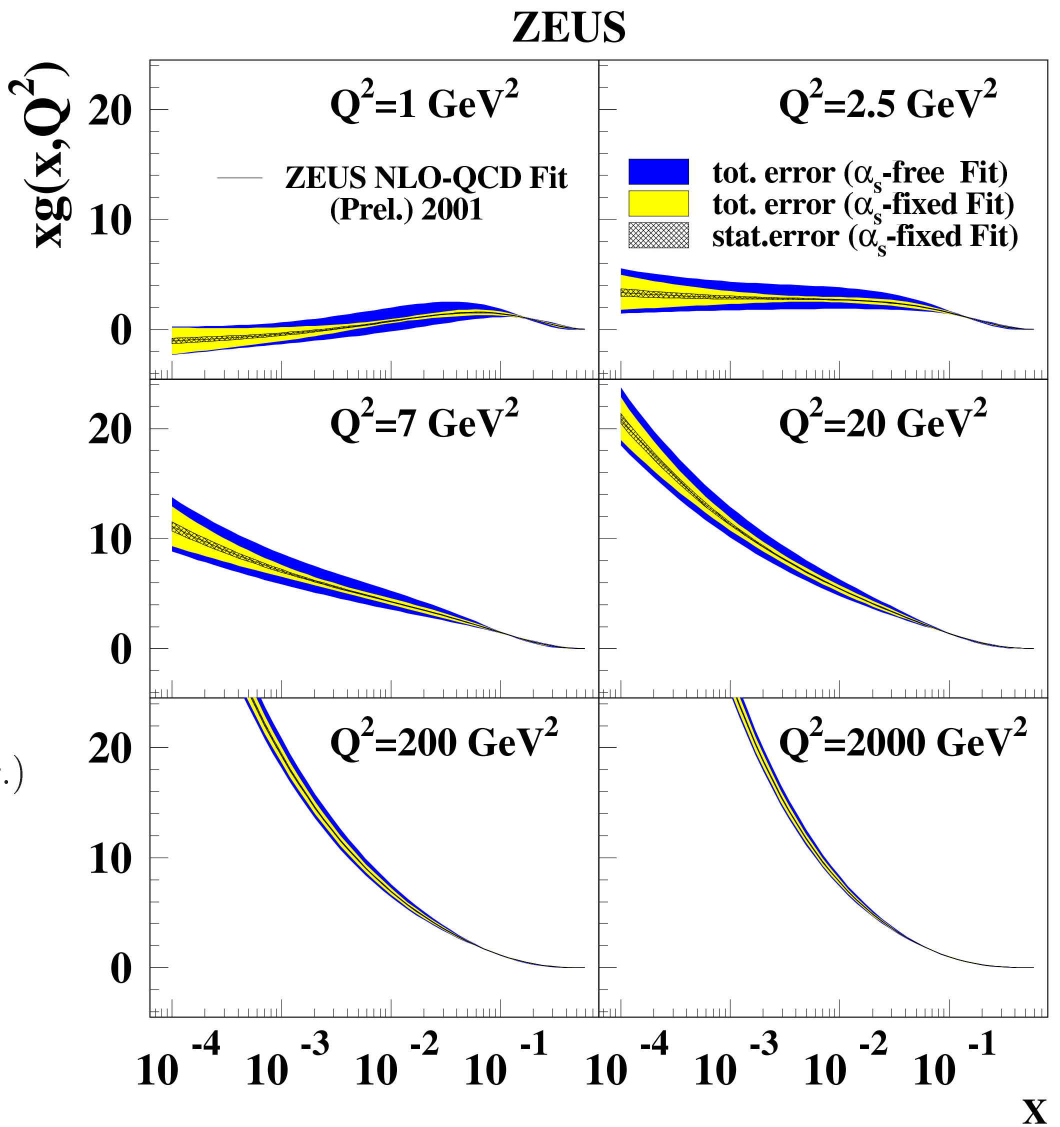


NLO QCD Fits of F_2

- ▷ Fit ZEUS plus BCDMS, E665 and NMC data
- ▷ Assume form at $Q_0^2 = 7\ \mathrm{GeV}^2$

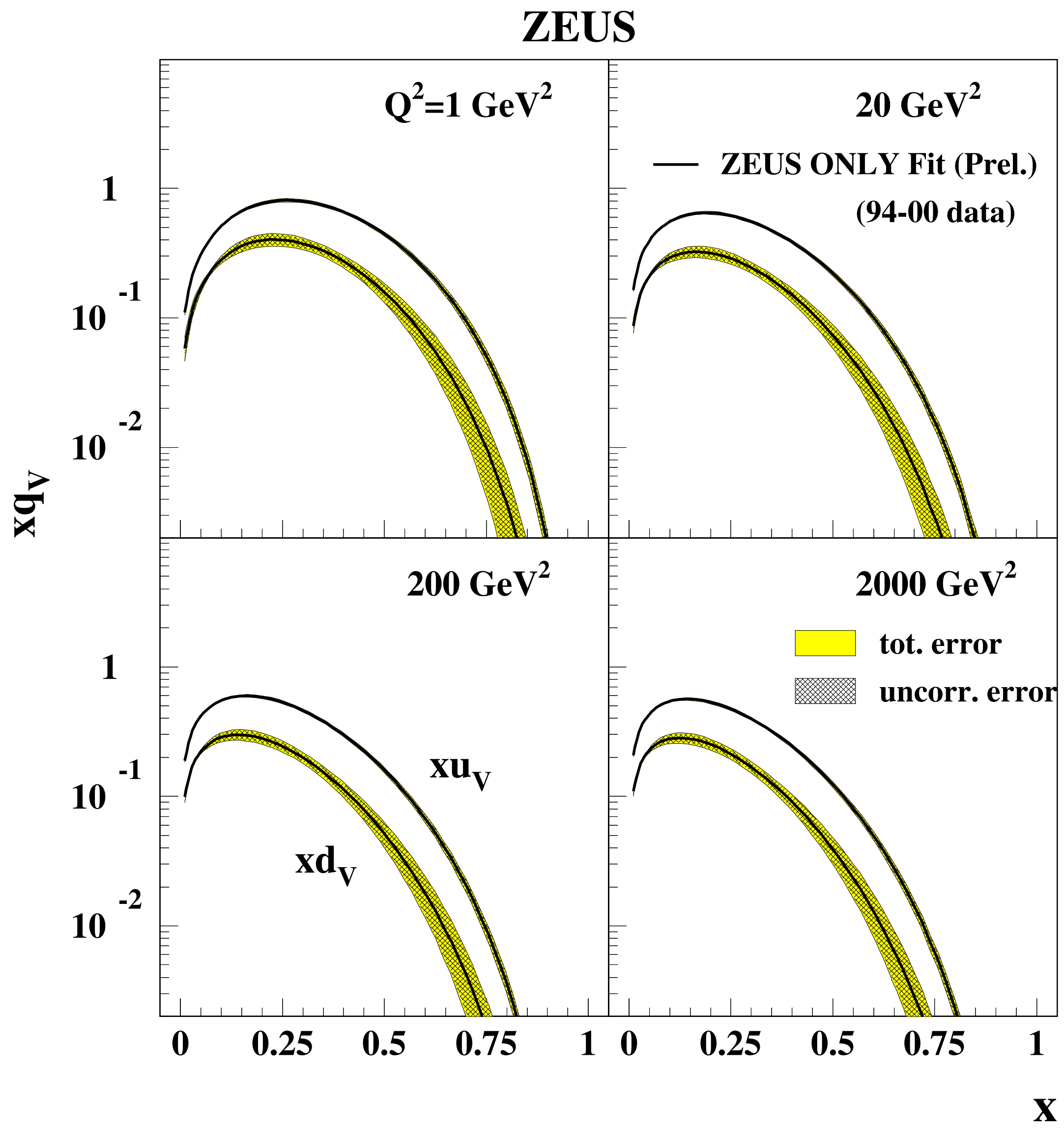
$$f = p_1 x^{p_2}(1-x)^{p_3}(1+p_5 x)$$

- ▷ Heavy quarks:
  - RT-variable flavour number scheme
- ▷ $\alpha_s(\mathrm{M_Z}) = 0.1166 \pm 0.0008(\mathrm{uncorr.}) \pm 0.0032(\mathrm{corr.}) \pm 0.0036(\mathrm{norm.}) \pm 0.0018(\mathrm{model})$
- ▷ gluon very precise at high Q^2
- ▷ steep rise observed



NLO QCD Fits of F_2 (II)

- *Valence quarks from ZEUS-only fit*
- *HERA II data will constrain even more at high x !*

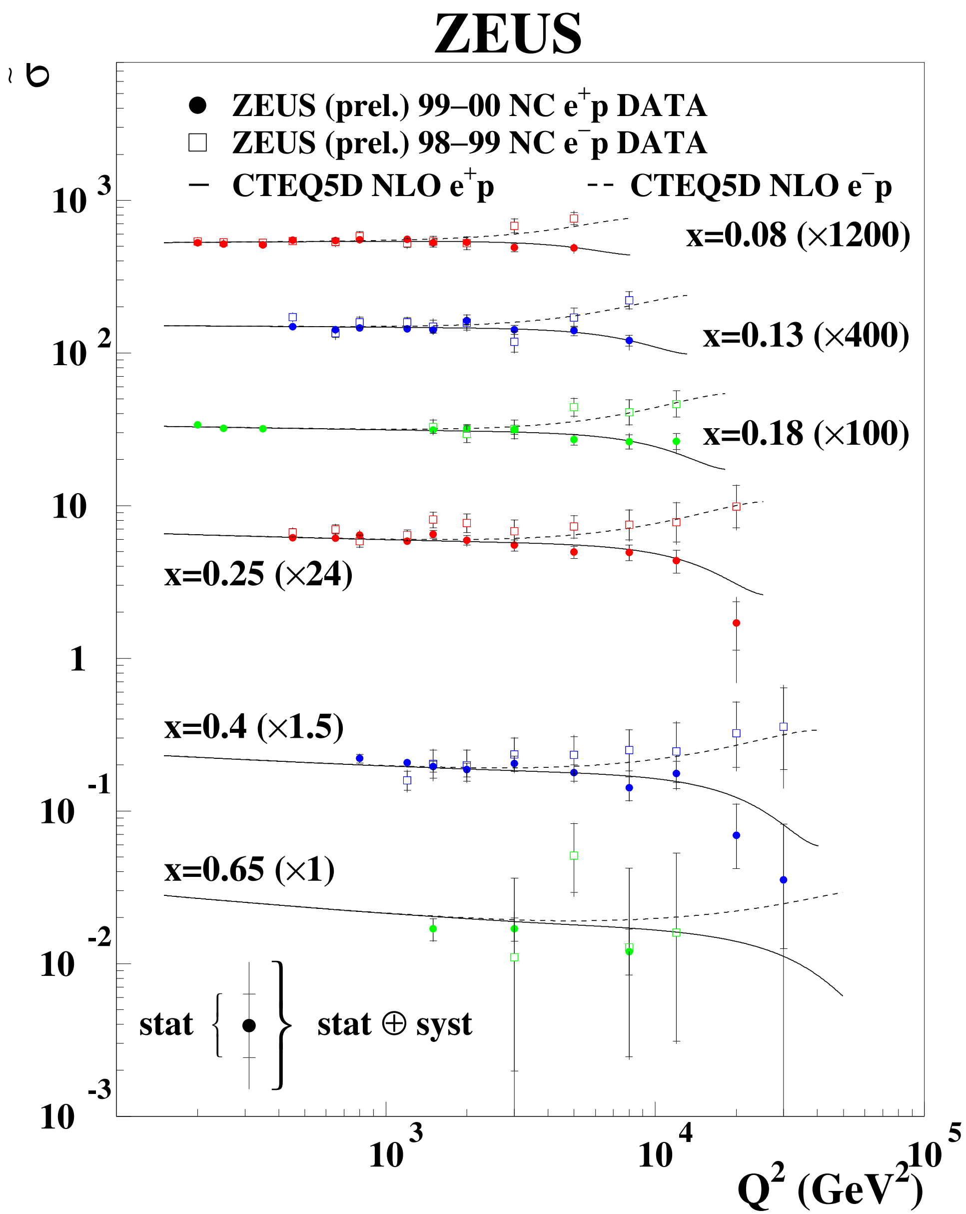


High Q^2 NC cross sections

- ▷ *move to high Q^2 . . .*
  - *F_L becomes negligible*
  - *Z^0 exchange important*

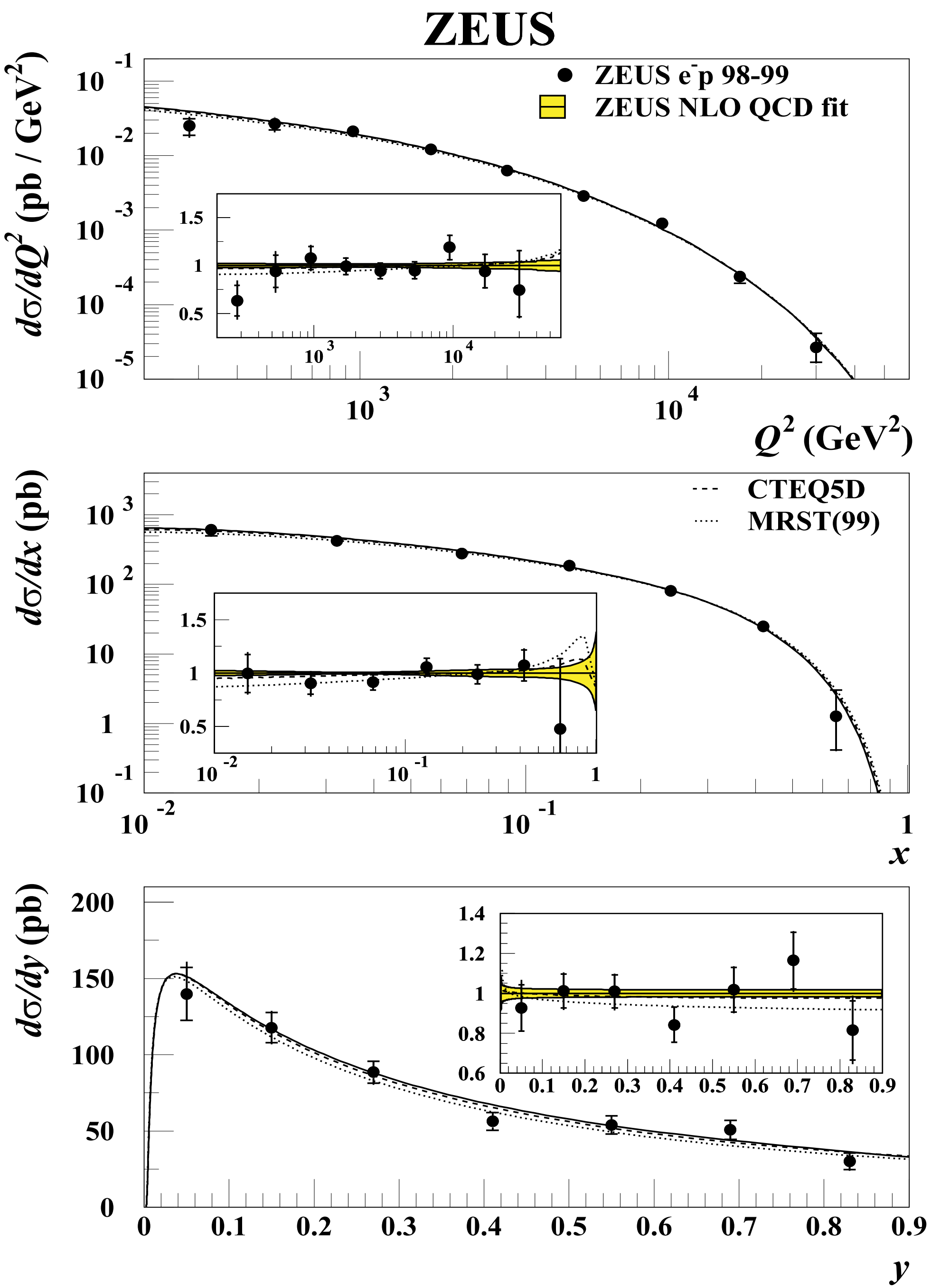
$$\tilde{\sigma} = \frac{1}{Y_+} \cdot \frac{Q^4 x}{2\pi\alpha^2} \cdot \frac{d^2\sigma}{dx dQ^2}$$

- ▷ *effect of Z^0 clearly seen*
- ▷ *Close to publication*



Charged Current Cross sections

- ▷ $e^- p \rightarrow \nu_e X$



- ▷ *Good agreement with SM*
- ▷ *data still statistically limited*
- ▷ *Will benefit from HERA II data*

Charged Current Cross sections (II)

▷ Reduced cross section

$$\tilde{\sigma} = \left[\frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\right]^{-1}\frac{d^2\sigma}{dx\,dQ^2}$$

▷ Chiral structure of SM

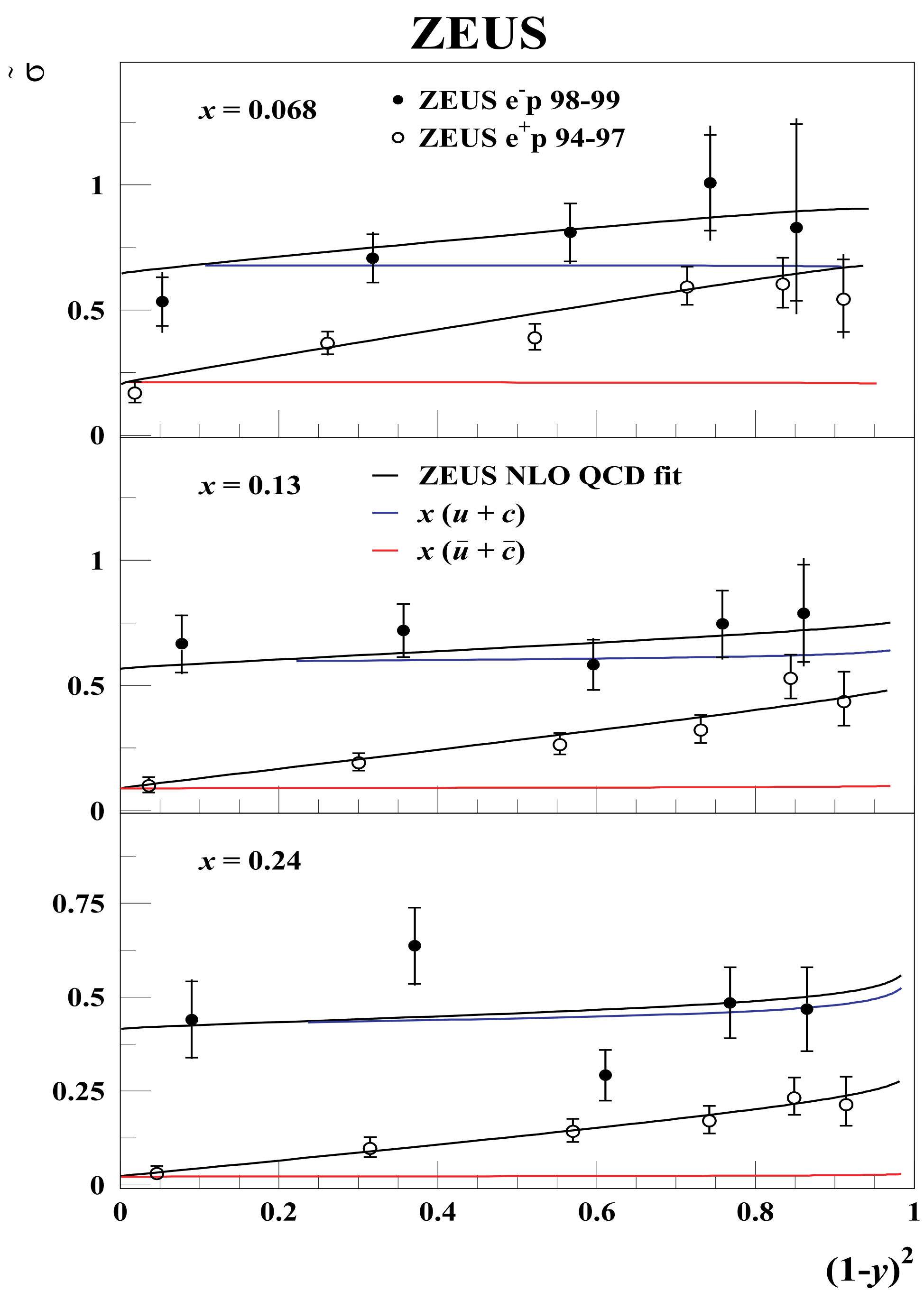
▷ QPM $\Rightarrow$ angular behaviour

- $(1+\cos\theta^*)^2 \propto (1-y)^2$

▷ Data agree with SM

▷ flavour decomposition of proton . . .

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

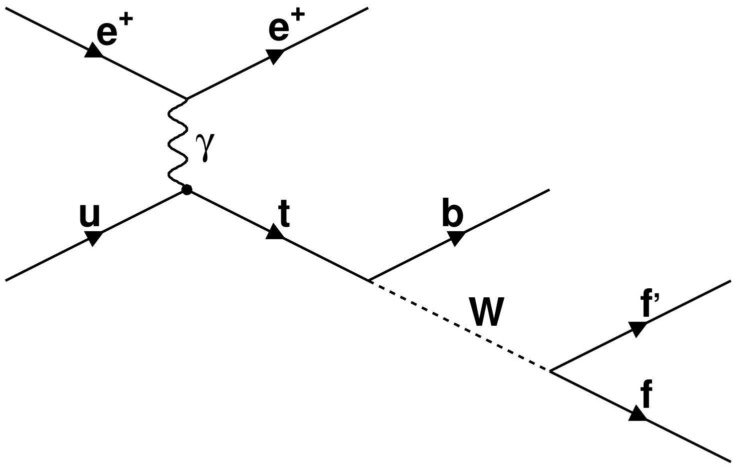


Single Top Production

▷ SM t production: $\sigma \sim 1$ fb

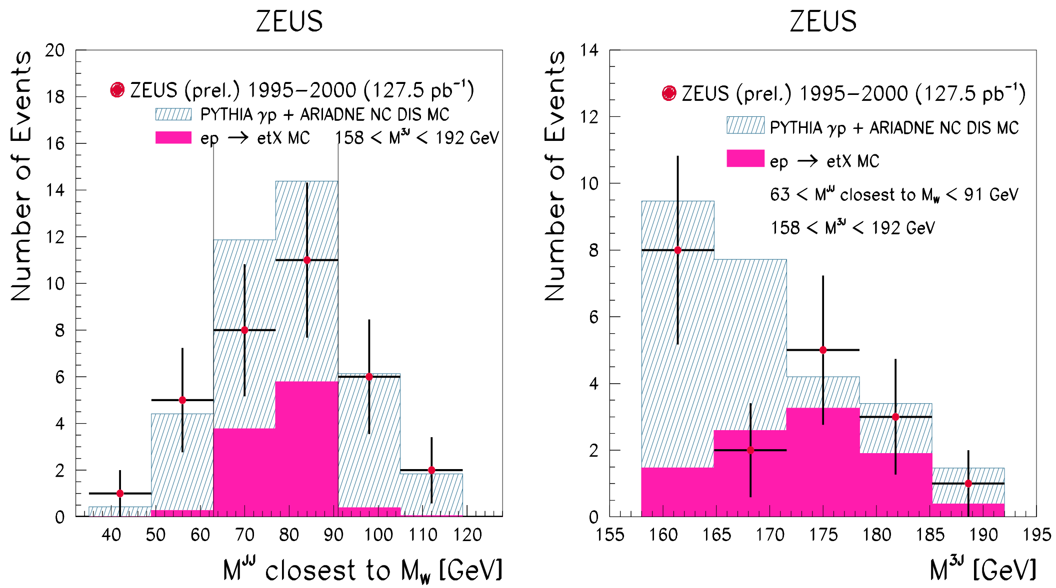
- not visible at HERA

▷ SM extensions (SUSY) predict single t production through FCNC



▷ look for $W \to q\bar{q}$ decay chain

- $W \to l\nu$ also studied



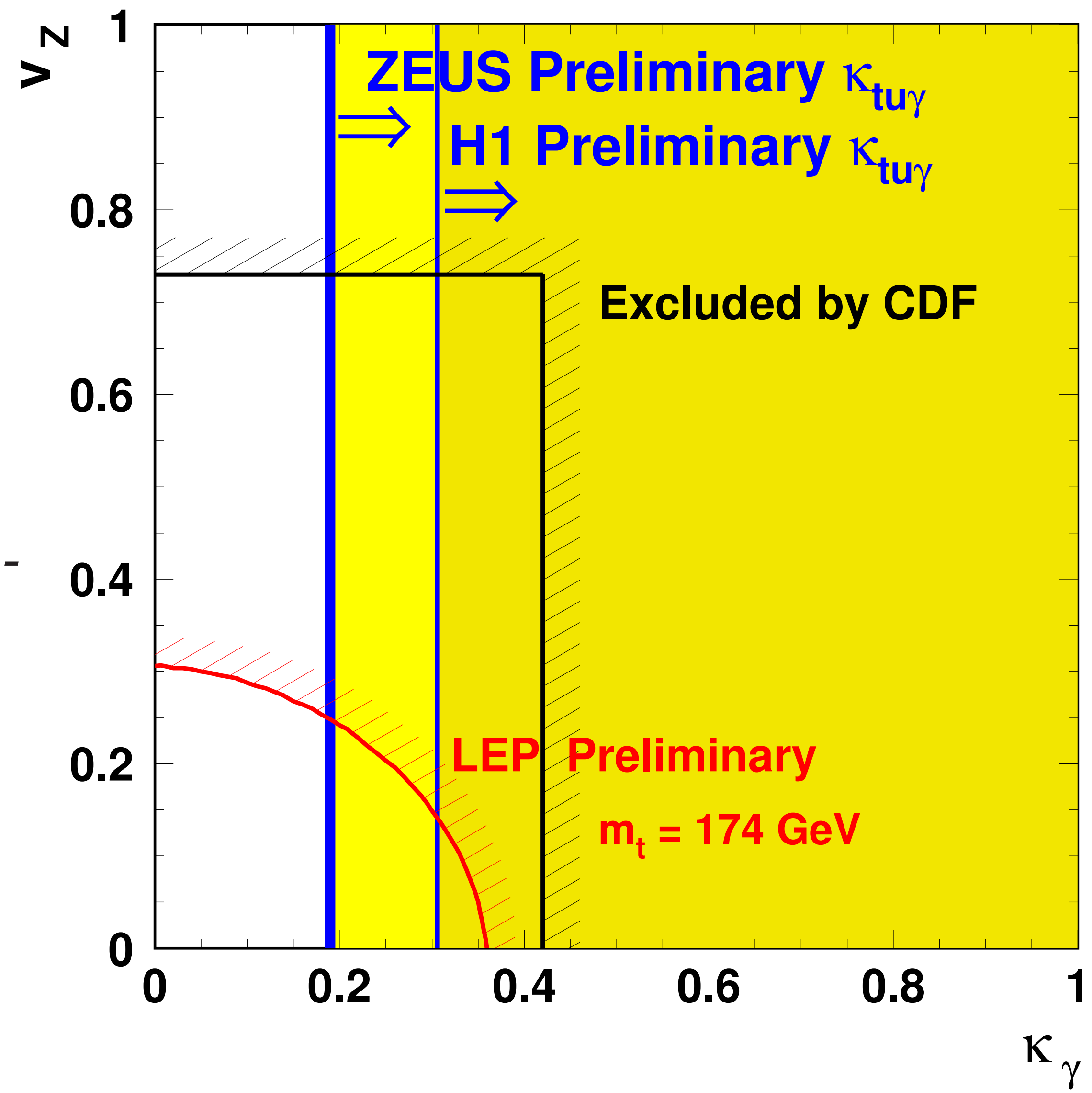
▷ 3-jet final state $\to bq\bar{q}$

- $M_{jj} \simeq M_W$
- $M_{3j} \simeq M_t$

▷ No excess observed

Single Top Production (II)

- ▷ *set limit on:*
  - $\kappa_\gamma =$ *coupling to photon*
- ▷ $V_Z =$ *vector coupling to* Z^0
- ▷ *include result on* $W \rightarrow l\nu$
- ▷ *complementary to LEP and Tevatron limits*
- ▷ *best limit on* κ_γ *set by ZEUS !*



Physics at HERA II

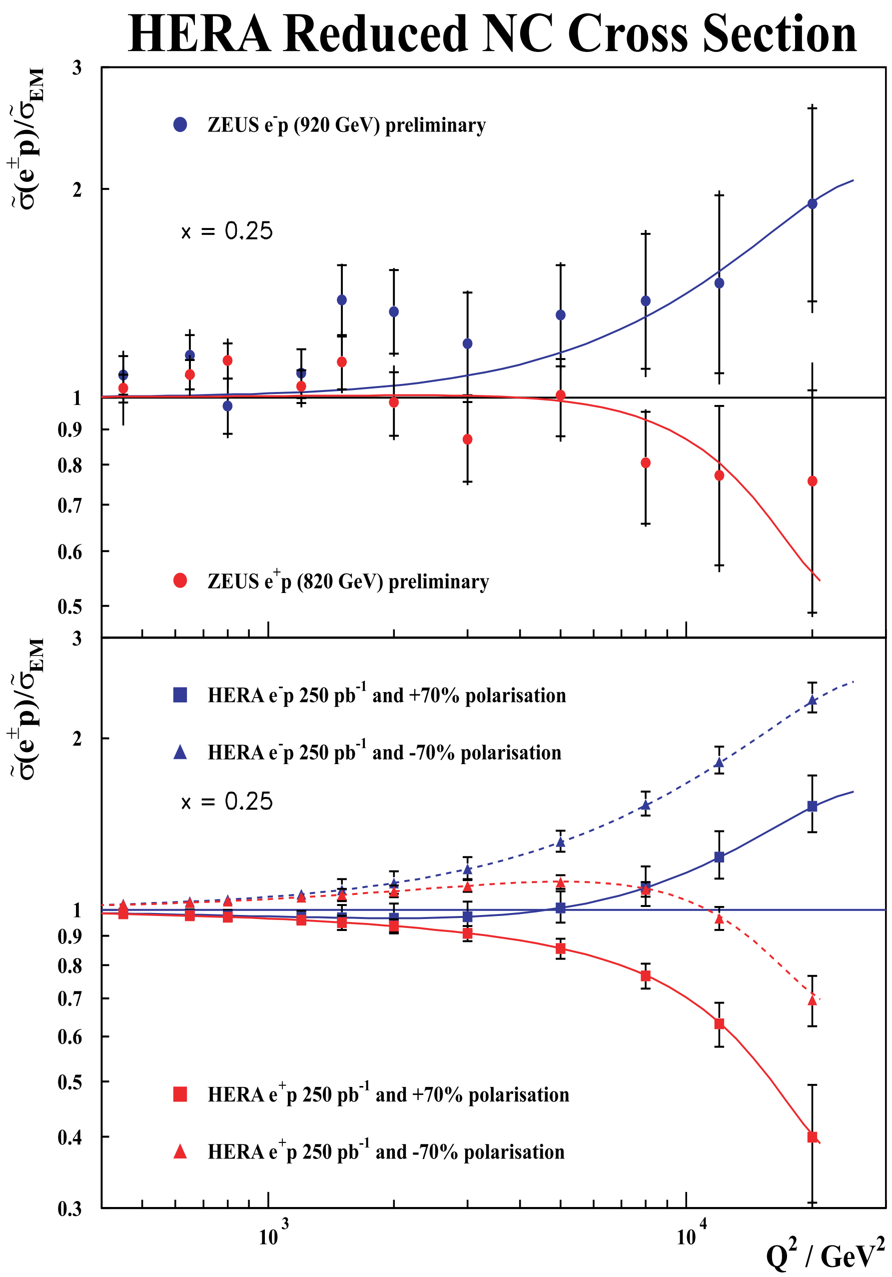
▷ *Exploitation of new detectors, high luminosity & polarisation:*

▷ *polarised NC & CC measurements*

▷ *high x parton distributions*

▷ *high precision beauty and charm measurements*

▷ *and much, much more . . .*



Financial Summary

- ▷ PPARC money and our effort invested regularly in the CTD over many years
  - CTD has consistently performed well
- ▷ In recent years, have also invested heavily in new hardware
  - MVD, TPOL . . .
- ▷ Time has come to reap the full benefits of this new investment
- ▷ SCP4 25% reduction in ZEUS-UK budget — will have consequences
  - Must maintain commitments to Collaboration
  - physics output will suffer

25% reduction in funding will produce a disproportionate reduction in physics output

Conclusions

- ▷ *HERA & ZEUS upgrade complete*
- ▷ *ZEUS has taken upgrade data*
  - *Working closely with HERA to understand backgrounds*
- ▷ *ZEUS publications continue to be highly cited*
- ▷ *Enormous range of physics topics to study at HERA*
  - *Will maintain strong physics output by the ZEUS Collaboration while new data is collected*
- ▷ *Looking forward to*
  - *increase in luminosity and polarisation from HERA II*
  - *data from new detectors*