DESY

July 15th, 2003

New results from the ZEUS Experiment

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⇒ 51 Abstracts sent to EPS 2003

- → Structure Functions
- → Searches for New Physics
- → Heavy Quarks
- → Diffraction
- → Hadronic Final States

Abstracts from ZEUS to EPS 2003

$\Rightarrow$ 51 Abstracts

- **Final Results $\Rightarrow$ 13**
- **New for this summer $\Rightarrow$ 11**
- **New for EPS 2003 $\Rightarrow$ 15**

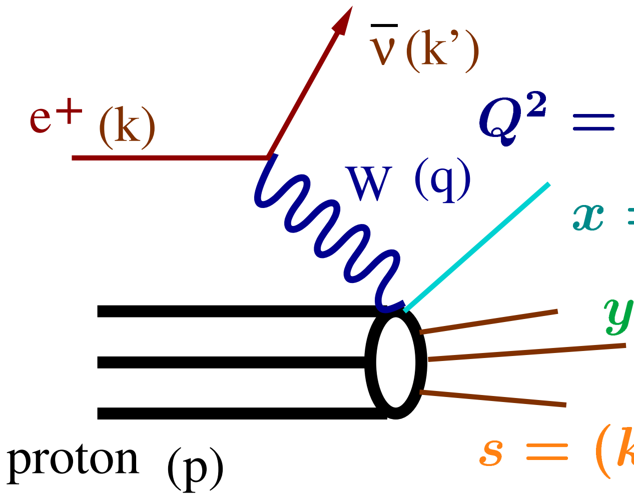
  $\rightarrow$ Measurement of the electromagnetic component of photon light-cone wave function at HERA

  $\rightarrow$ Measurement of proton-dissociative diffractive photoproduction of J/Ψ mesons at HERA

  $\rightarrow$ Measurement of open beauty production in deep inelastic scattering at HERA using a D^* plus muon tag

Structure Functions

High-Q^2 Charged Current Cross Sections in e^+p DIS



$$Q^2 = -q^2 = -(k-k')^2$$

$$x = Q^2/(2p \cdot q)$$

$$y = (p \cdot q)/(p \cdot k)$$

$$s = (k+p)^2 = Q^2/(xy)$$

$$\frac{d\sigma(e^+p)}{dx\,dQ^2} = \frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2 \times$$

$$\times\{Y_+F_2^{CC} - Y_-F_3^{CC} - y^2F_L^{CC}\}$$

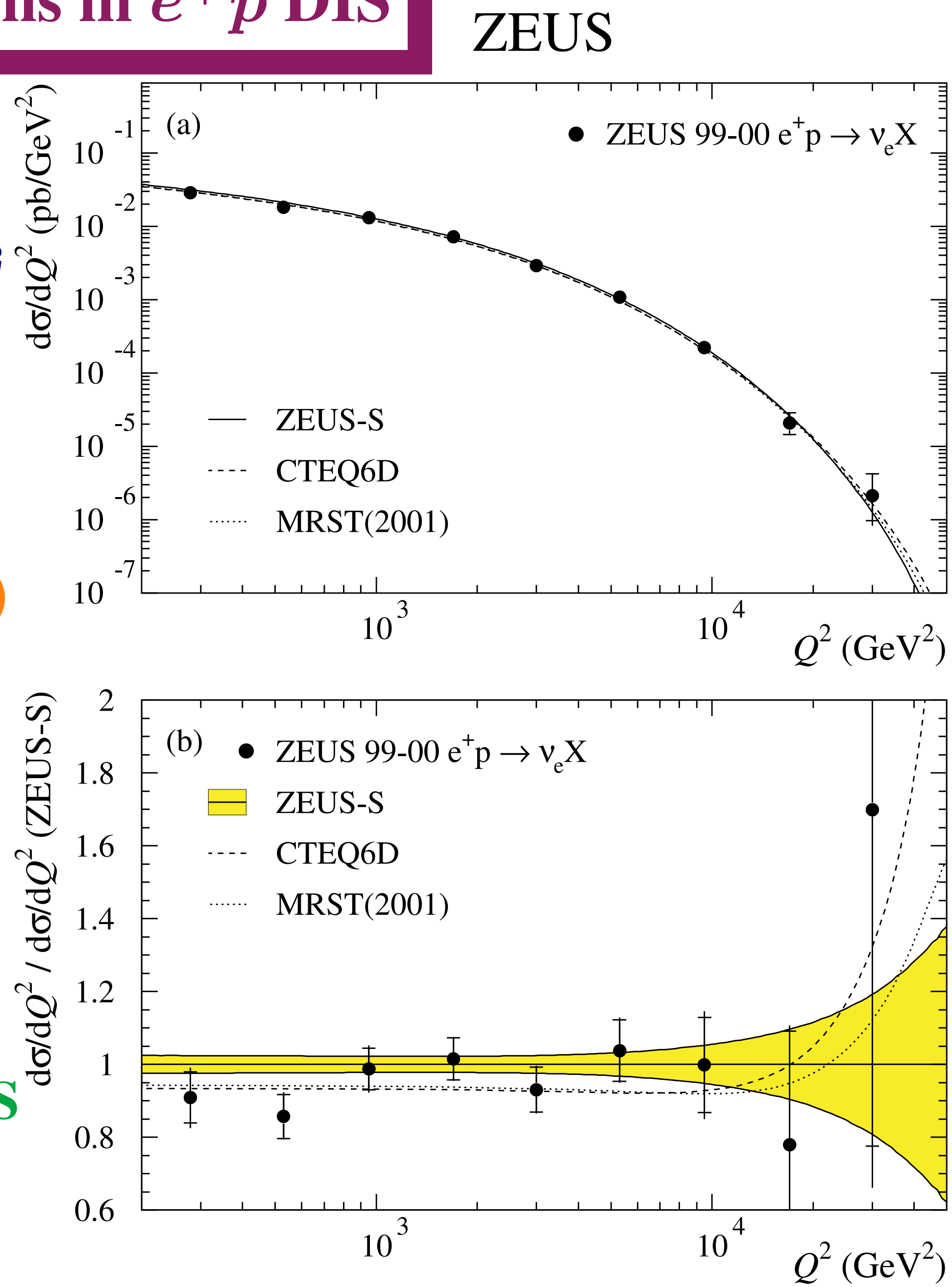
$\rightarrow F_2^{CC} = x\{d + s + \bar{u} + \bar{c}\}$

$\rightarrow xF_3^{CC} = x\{d + s - \bar{u} - \bar{c}\}$

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

- **Measurements of cross sections in CC e^+p DIS at $\sqrt{s} = 318$ GeV using 61 pb^{-1}**

$\rightarrow$ Well described by SM predictions



High-Q^2 Charged Current Cross Sections in e^+p DIS

- **Reduced double-differential cross section**

$$\hat{\sigma} = \left\{\frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2\right\}^{-1} \cdot \frac{d\sigma(e^+p)}{dxdQ^2}$$

LO QCD $\rightarrow \hat{\sigma} = x\{\bar{u} + \bar{c} + (1-y)^2(d+s)\}$

- **Measurement in the kinematic region**

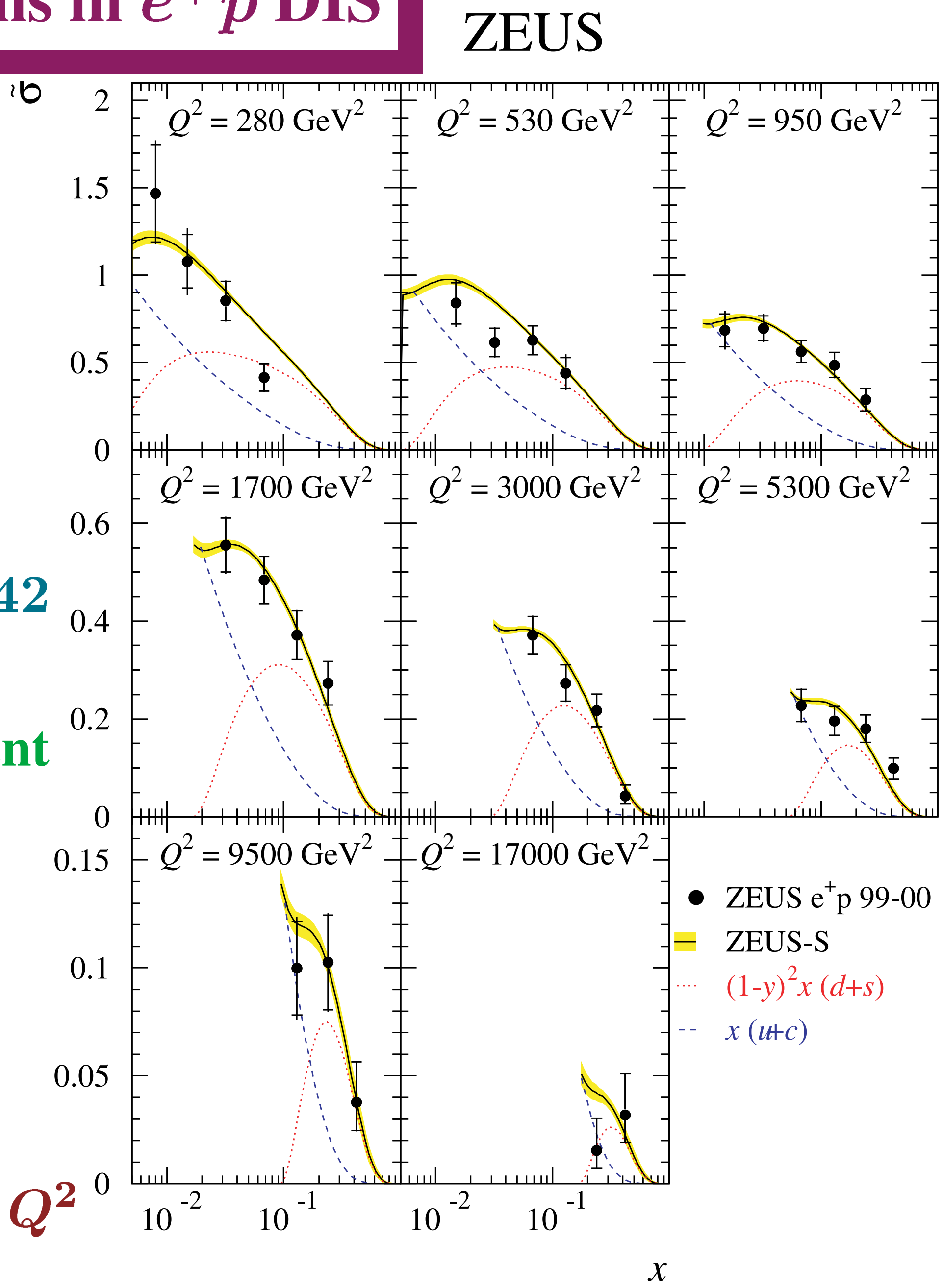
$280 < Q^2 < 17000\ \mathrm{GeV}^2, 8 \cdot 10^{-3} < x < 0.42$

$\rightarrow$ **Well described by SM predictions using current parametrisations of the proton PDFs**

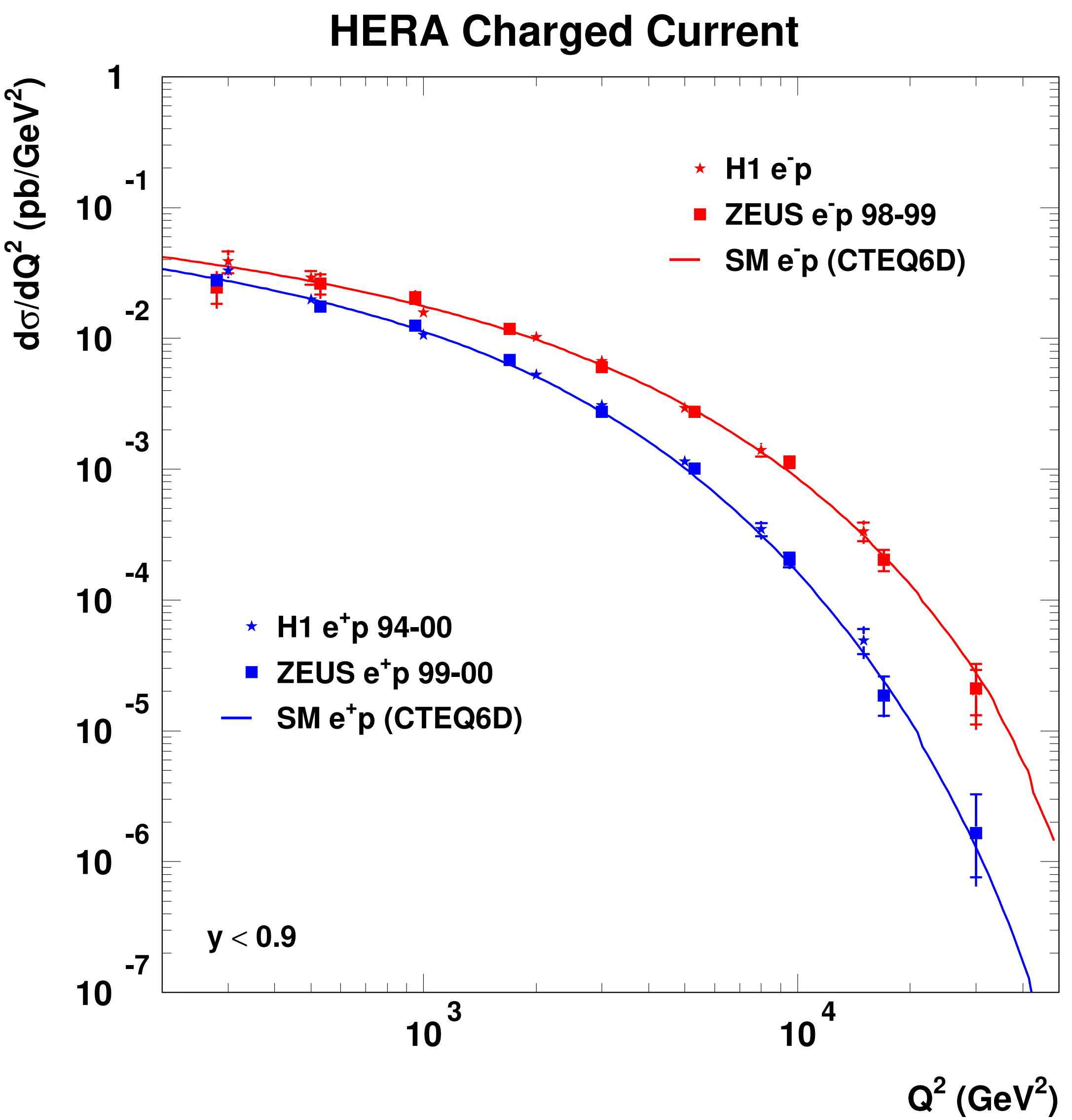
$\rightarrow x(\bar{u} + \bar{c})$ **dominant at low** x

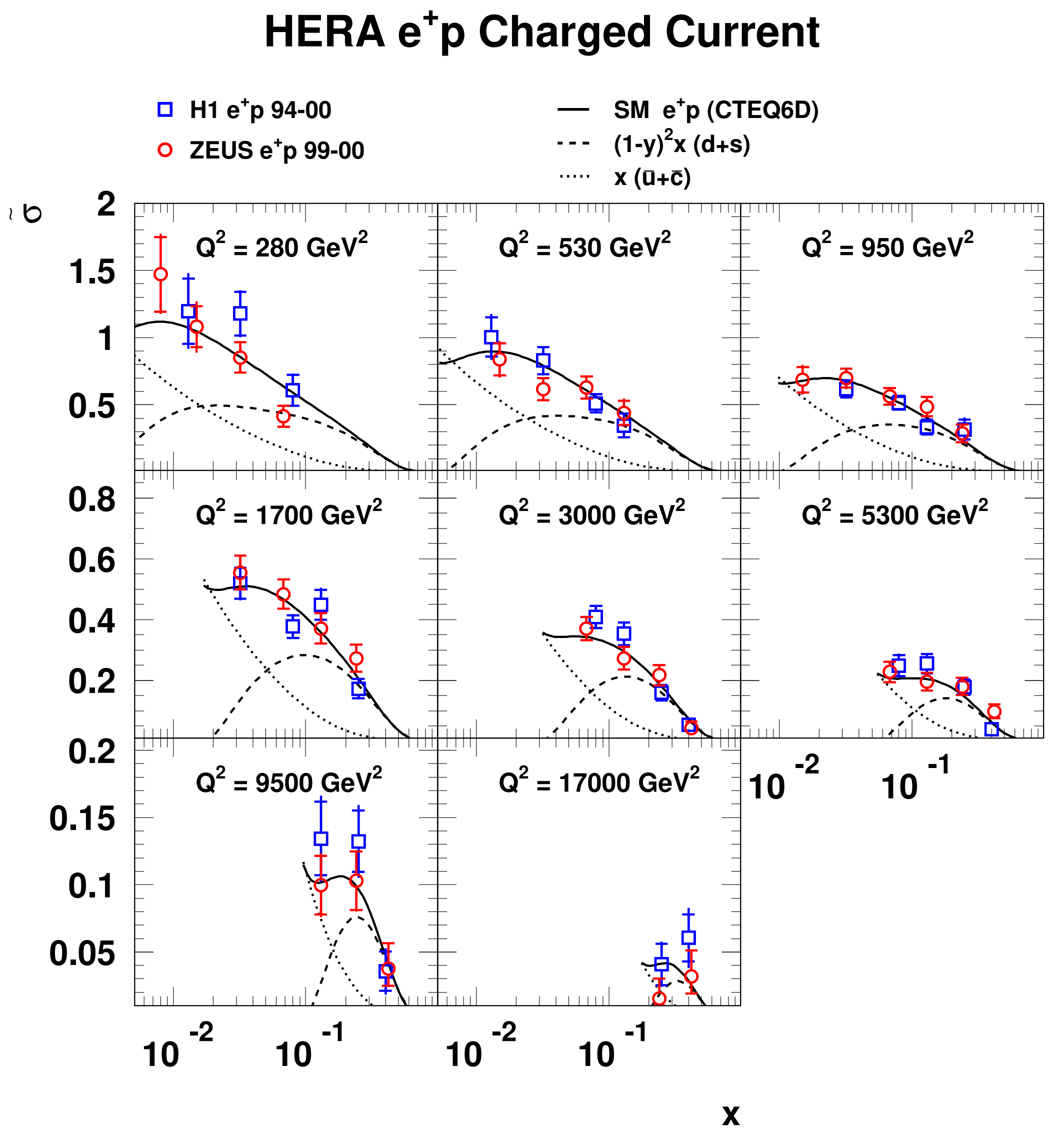
$\rightarrow (1-y)^2 x(d+s)$ **dominant at high** x

$\rightarrow$ **Confirmation of the decomposition of the proton momentum into different quark flavours (specifically** d**) and the evolution of PDFs at high** Q^2



High-Q^2 Charged Current Cross Sections in DIS





Charged Current Structure Function F_2^{CC}

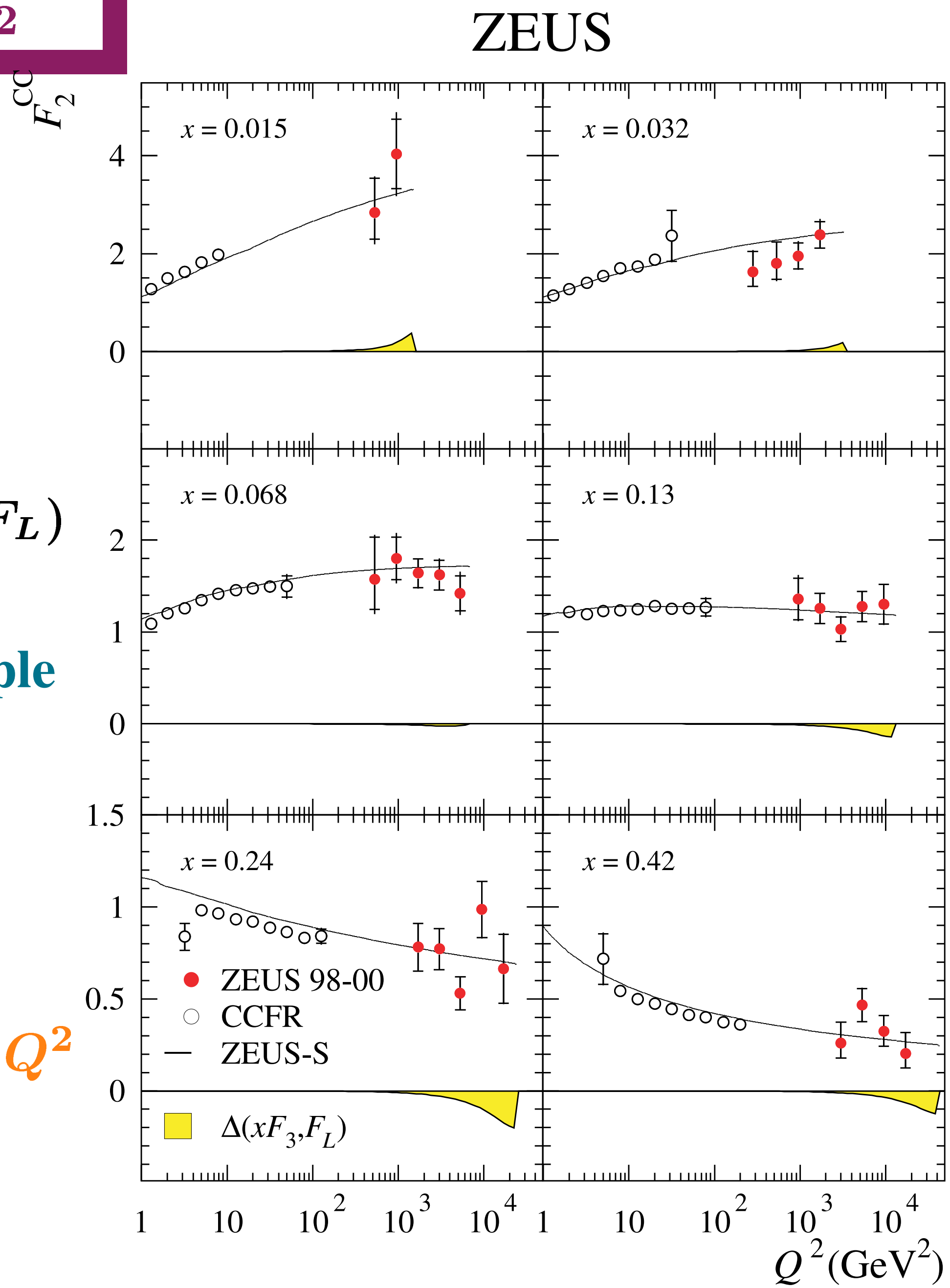
- First (!) extraction of the structure function F_2^{CC} by combining the measurements of cross section in CC e^+p and CC e^-p DIS

$$F_2^{CC} = \frac{2}{Y_+}\left\{\frac{d\sigma(e^+p)}{dxdQ^2} + \frac{d\sigma(e^-p)}{dxdQ^2}\right\} + \Delta(xF_3, F_L)$$

→ Dominant uncertainty: statistics of e^-p sample

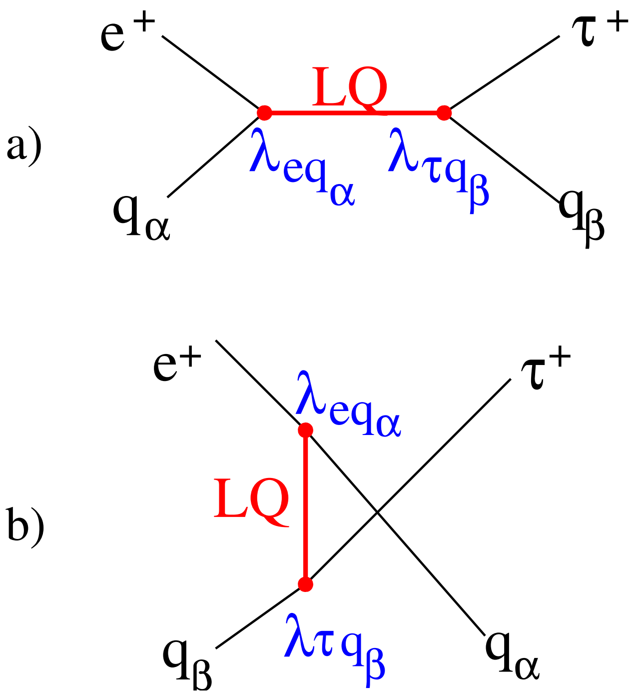
→ This determination extends previous measurements (CCFR; νFe) to higher Q^2

→ The results span four orders of magnitude in Q^2 and are well described by the SM calculations



Searches for New Physics

Search for lepton-flavour violation in τ production by ep collisions



$e^+ q_\alpha \to \tau^+ q_\beta$ **can be mediated by lepto-quarks (LQ)**

$\to$ **Discovery potential when higher-generation quarks are involved**

$\to$ **Signature: high-transverse momentum isolated τ balanced by a jet in the transverse plane**

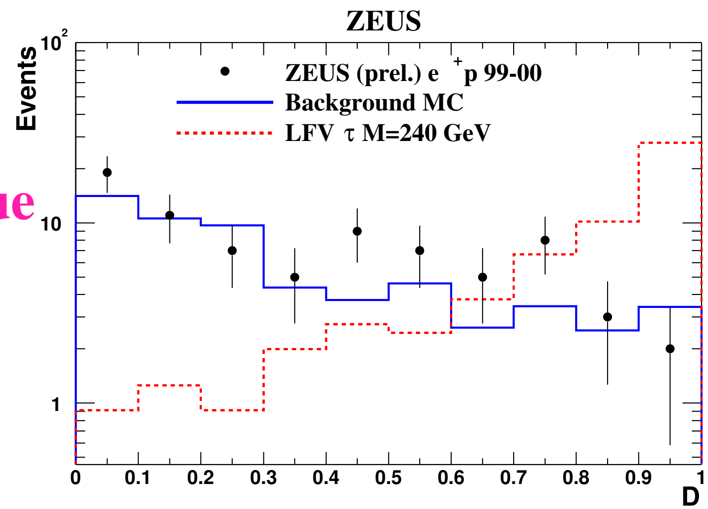
- **Search in e^+p collisions ($\sqrt{s} = 318$ GeV) using 66 pb^{-1}**

$\to$ **Leptonic τ decay ($\tau \to l\nu_l\nu_\tau, l = e, \mu$)**

$E_T > 50$ **GeV, isolated lepton,** $P_T^{miss} > 15(20)$ **GeV for** e **(**μ**) and aligned with the lepton**

$\to$ **Hadronic τ decay ($\tau \to$ hadrons ν_τ)**

$E_T > 50$ **GeV,** $P_T^{miss} > 12$ **GeV, τ-jet candidate with** $P_T^\tau > 15$ **GeV aligned with** P_T^{miss}**; discriminant technique to select pencil-like jets** $\Rightarrow D > 0.9$



No candidate found **(0.8 ± 0.3 expected from SM backg.)**

$\Rightarrow$ **95% C.L. limits**

Search for lepton-flavour violation in τ production by ep collisions

- Resonant LQ production ($M_{LQ} < \sqrt{s}$)

$\rightarrow$ limits on $\lambda_{eq_1} \cdot \sqrt{\beta_{\tau q}}$ (any q except t) as a function of M_{LQ} (scalar and vector)

$\rightarrow$ comparison with low-energy experiments (generation specific) assuming $\lambda_{eq_1} = \lambda_{\tau q}$

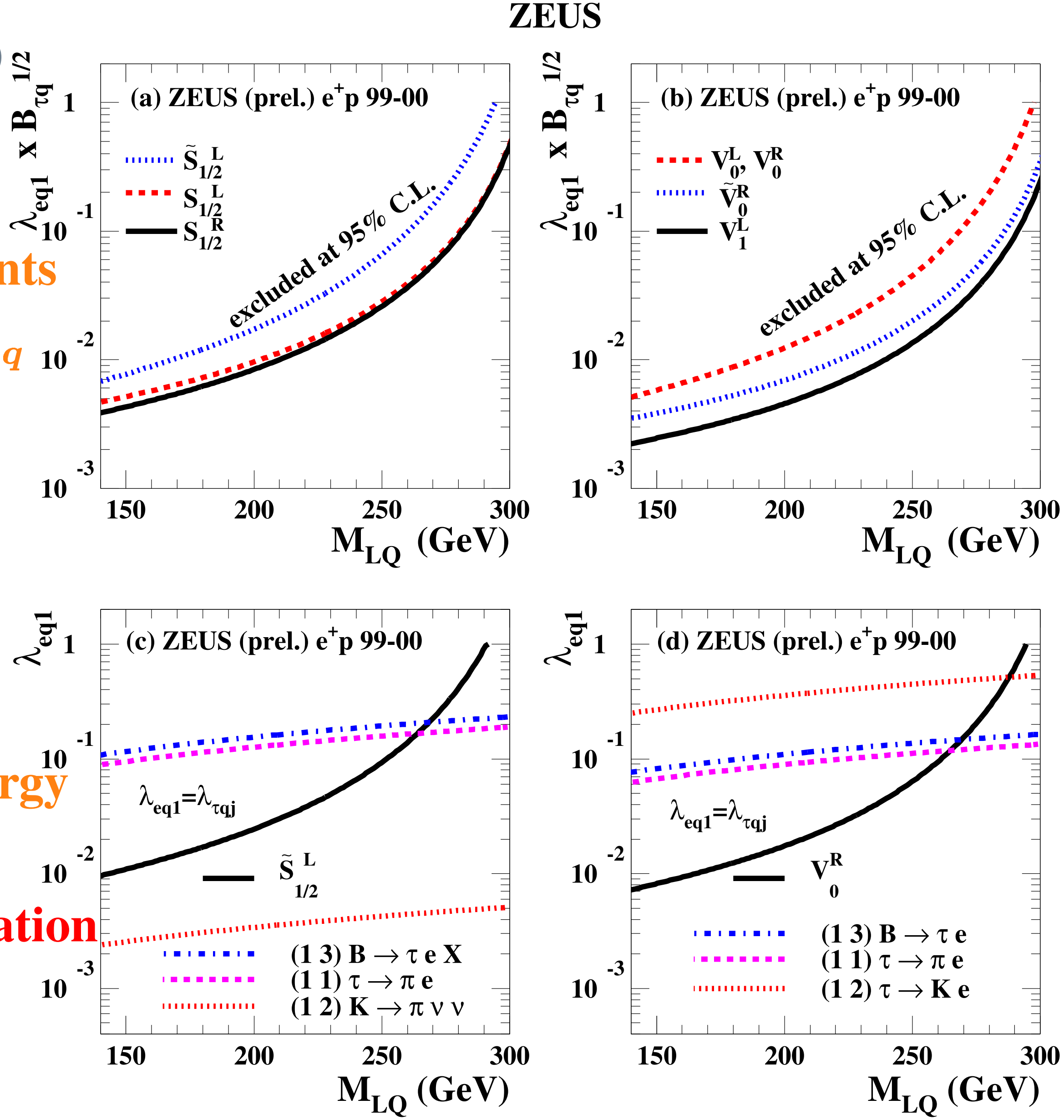
$\rightarrow$ assuming electromagnetic strength

LQs masses up to 299 GeV are excluded

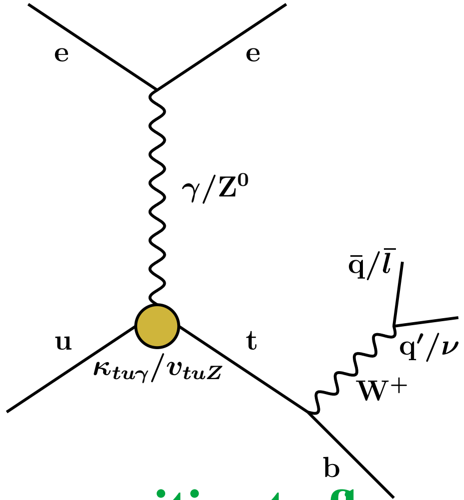
- Virtual LQ effects ($M_{LQ} > \sqrt{s}$)

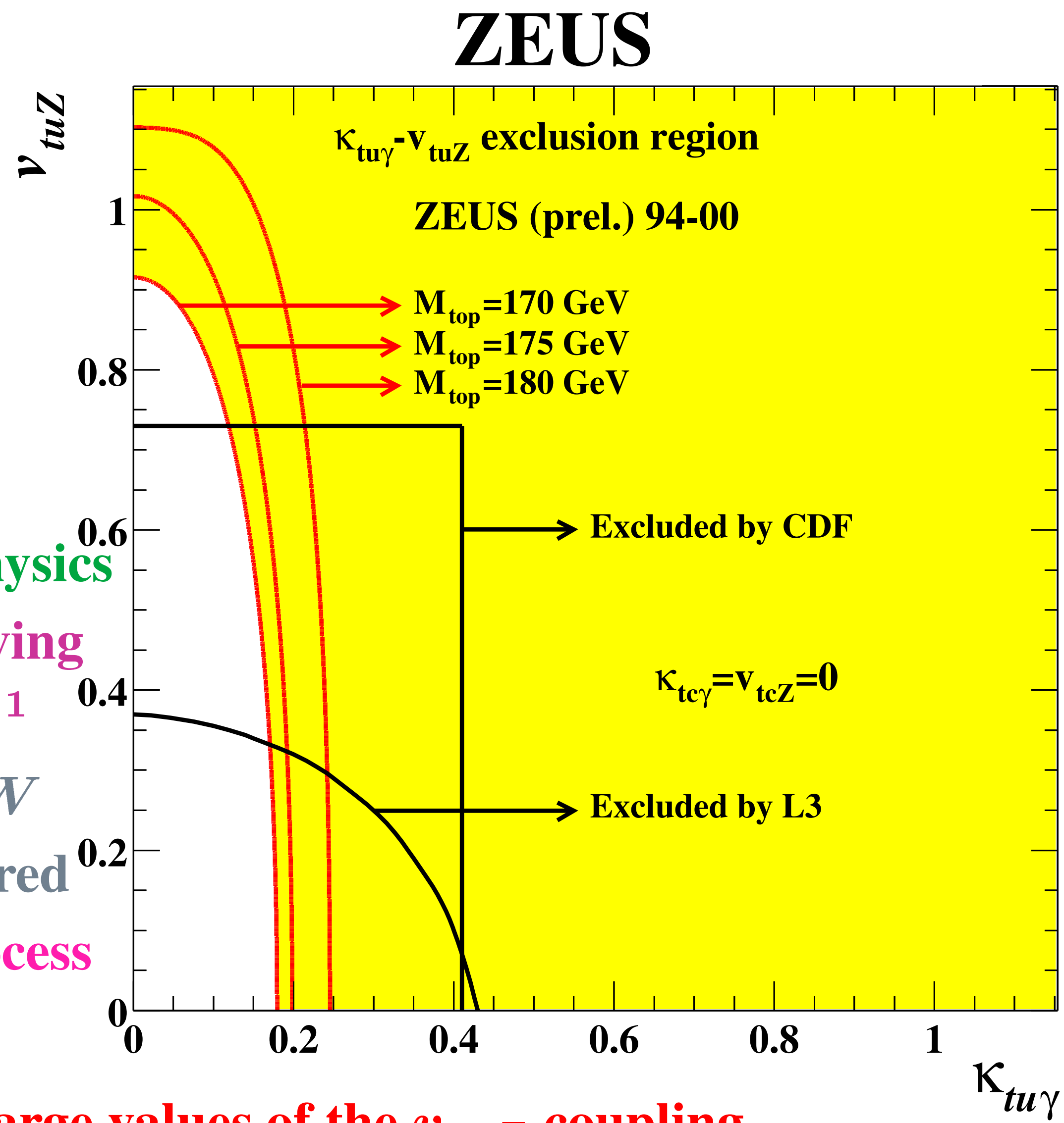
$\rightarrow$ limits on $\lambda_{eq_\alpha} \lambda_{\tau q_\beta} / M_{LQ}^2$

$\rightarrow$ comparison with bounds from low-energy experiments $\Rightarrow$ in many cases the ZEUS limits are most stringent for higher-generation quarks



Search for single-top production in *ep* collisions





- Observables sensitive to flavour-changing neutral currents (FCNC) $\Rightarrow$ probes of new physics

$\rightarrow$ Search for FCNC-induced couplings involving the top quark, $\kappa_{tu\gamma}$ and v_{tuZ}, using 130 pb^{-1}

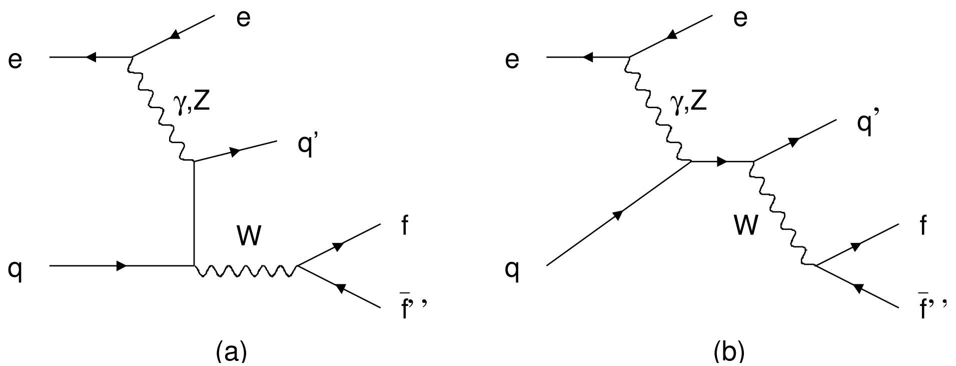
$\rightarrow$ Both leptonic and hadronic decays of the W or Z coming from the top decay were considered

- Improved simulation of the Z-exchange process provides stronger sensitivity for large v_{tuZ}

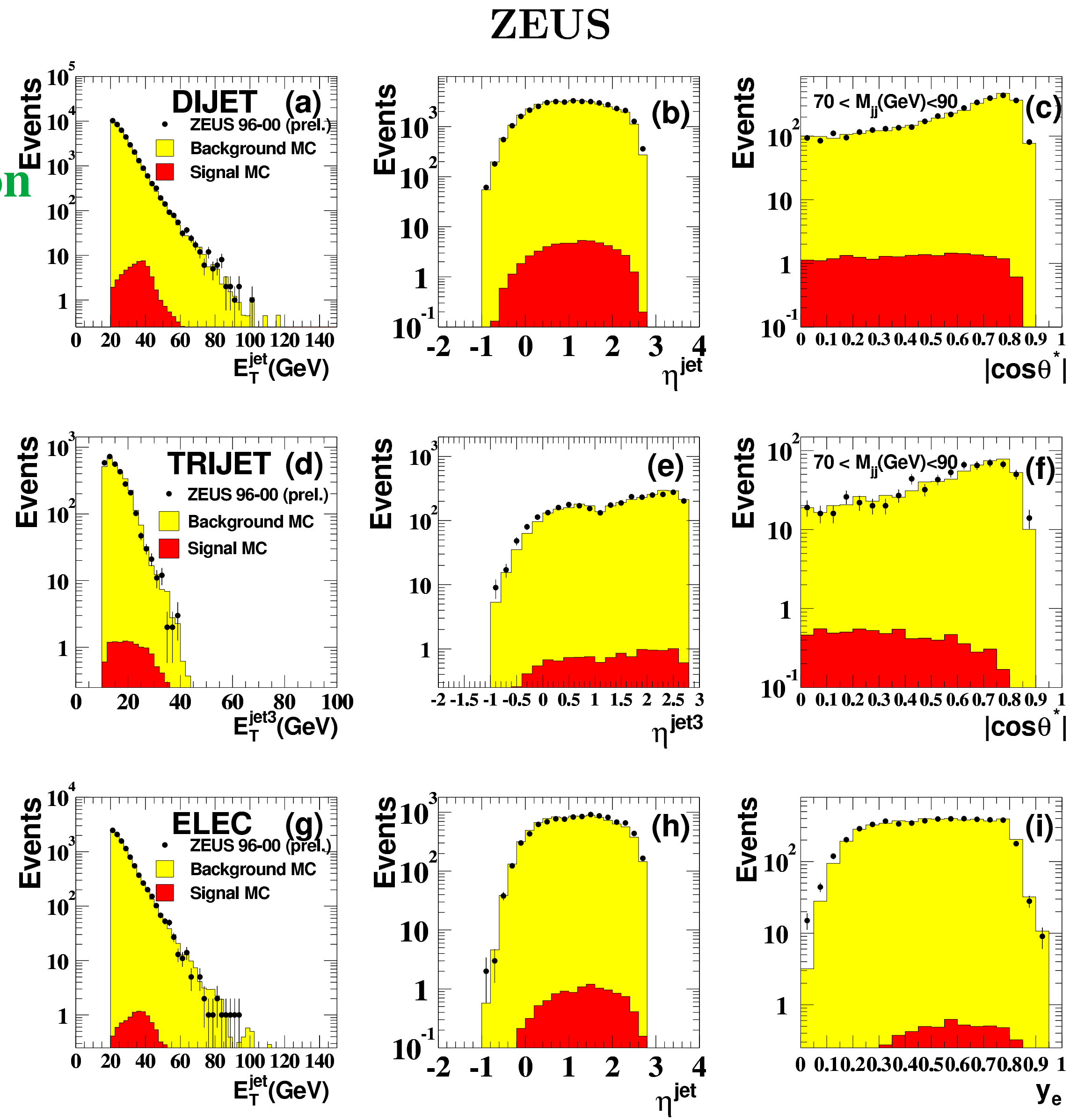
$\Rightarrow$ substantial improvement of the limits for large values of the v_{tuZ} coupling

Search for $W\,(\rightarrow \text{jets})$ production in ep collisions

- H1 observation of an excess of events with isolated μ or e and high P_T^{miss}, kinematically consistent with W production



- Search for $ep \rightarrow eW\,(\rightarrow \text{jets})\,X$ using 120 pb^{-1}; complementary study
- Three event topologies considered:
  - DIJET: two jets with $E_T^{jet} > 20$ GeV, $-1 < \eta^{jet} < 2.75$, no e candidate
  - TRIJET: three jets with $E_T^{jet} > 20$ GeV, $-1 < \eta^{jet} < 2.75$
  - ELEC: as DIJET but with an isolated e
- Good description of the data by the SM background processes



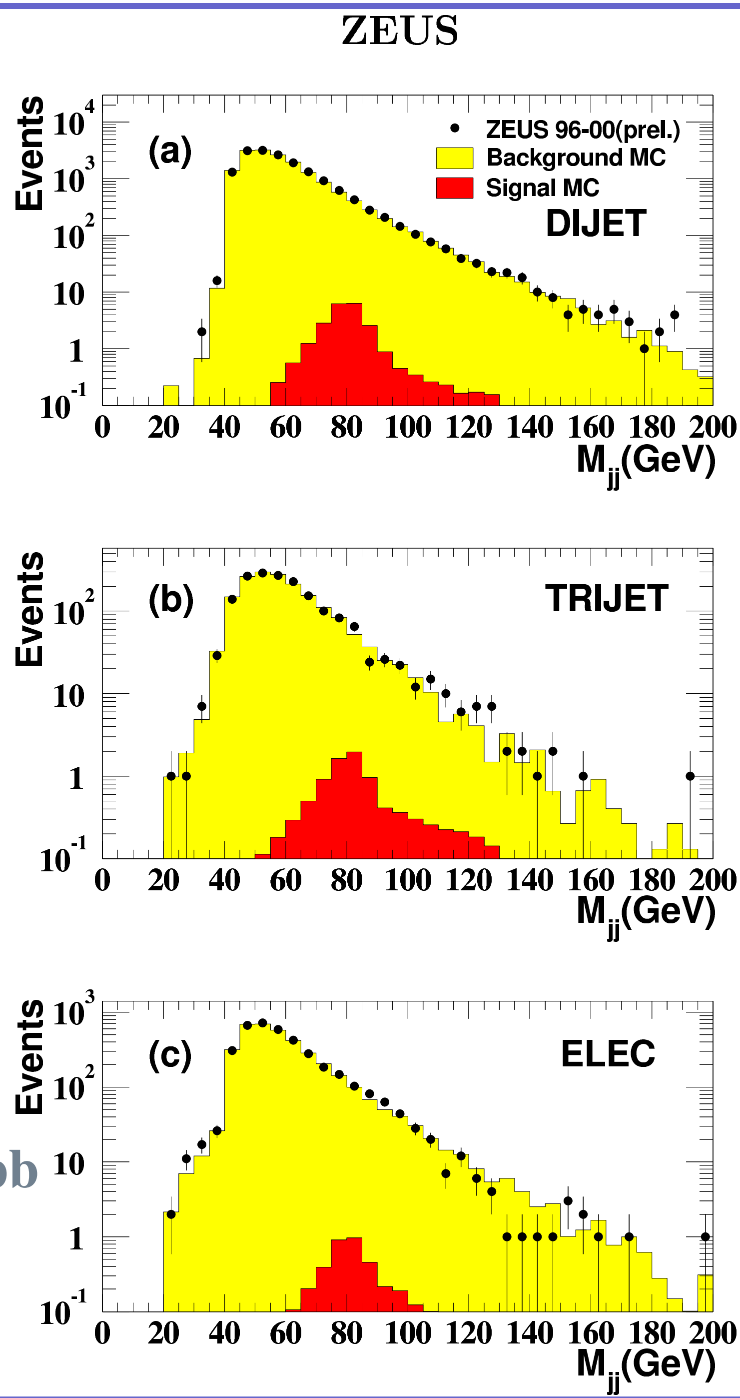
Search for $W(\rightarrow \text{jets})$ production

- Cuts were applied on $|\cos\theta^*|$ and y_e (ELEC) to enhance the signal from W production

- Invariant mass spectra of the two highest E_T^{jet} jets $\rightarrow$ still background dominated

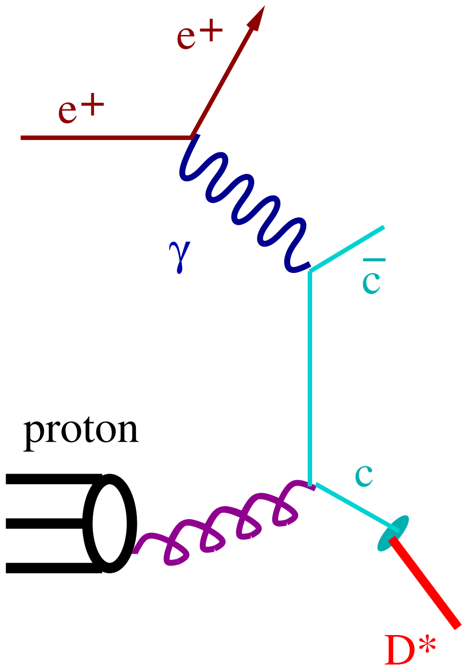
- Estimation of the cross section for W production using a binned χ^2 fit of the invariant mass spectra for signal and background to data in the mass window $60 < M_{jj} < 130$ GeV $\rightarrow$
$\sigma(ep \rightarrow eWX) = 2.97 \pm 2.51(\text{stat.})^{+1.75}_{-0.53}(\text{syst.})$ pb

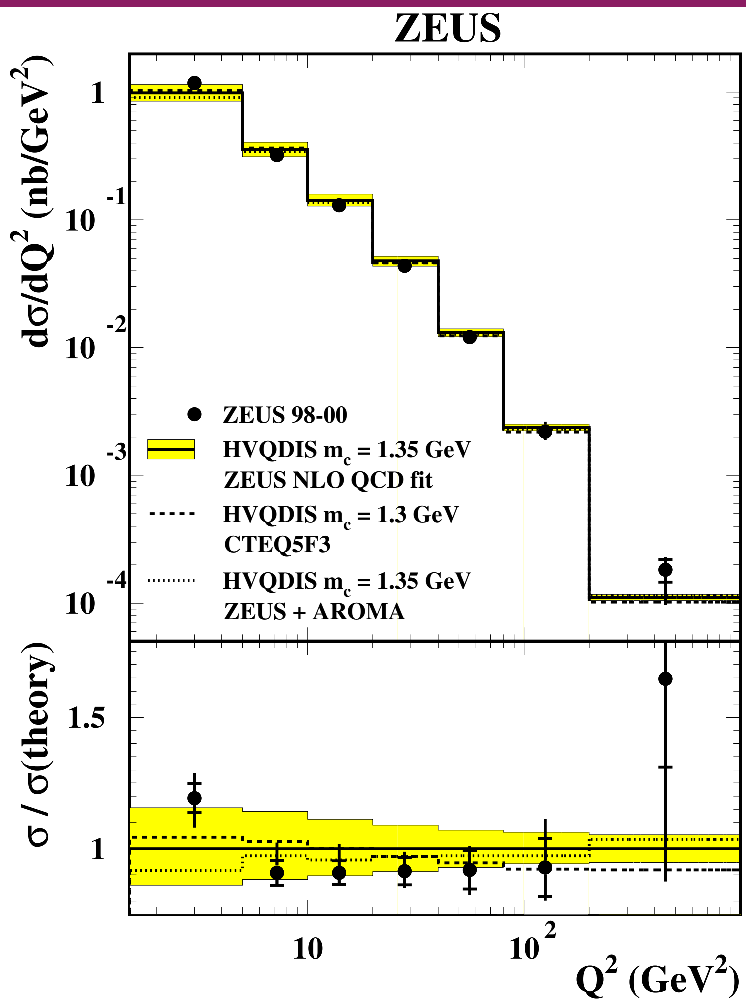
- 95% CL limit: $\sigma(ep \rightarrow eWX) < 8.3$ pb

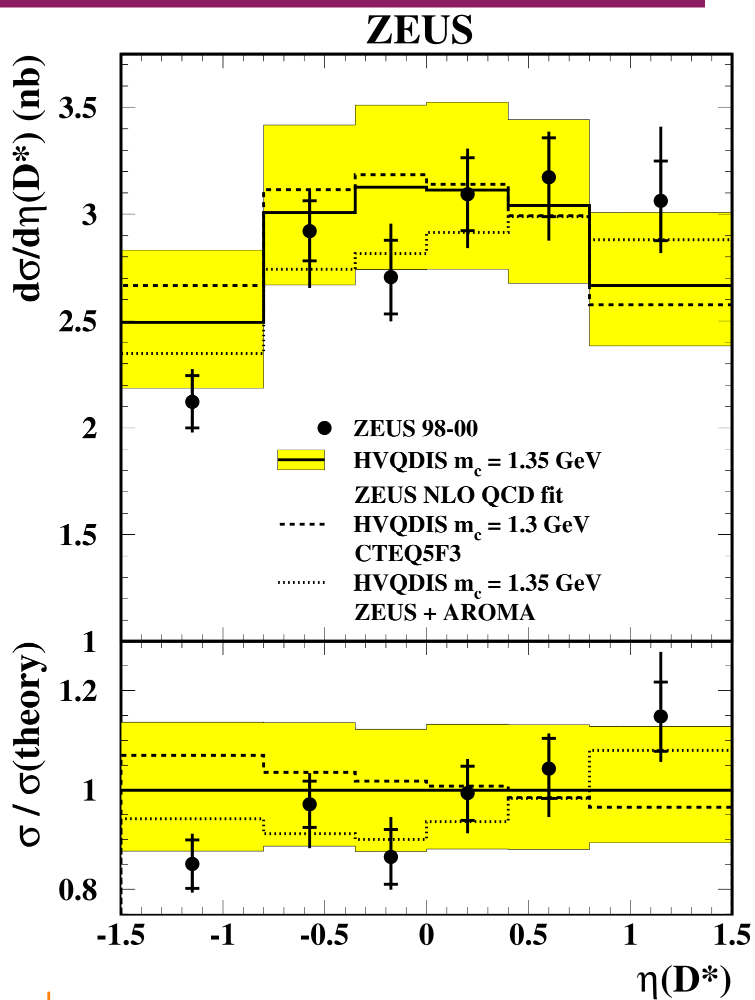


Heavy Quarks

$D^{*\pm}$ production in Neutral Current DIS ($1.5 < Q^2 < 1000$ GeV^2)







Luminosity 82 pb^{-1}

Sensitive to gluon density in the proton

- **Precise measurements of differential cross sections for $D^{*\pm}$ production are reasonably well described by NLO QCD calculations with the parametrisations of the proton PDFs as determined by the ZEUS NLO QCD fit (FFNS) ⇒ Input for future QCD fits of the p PDFs**

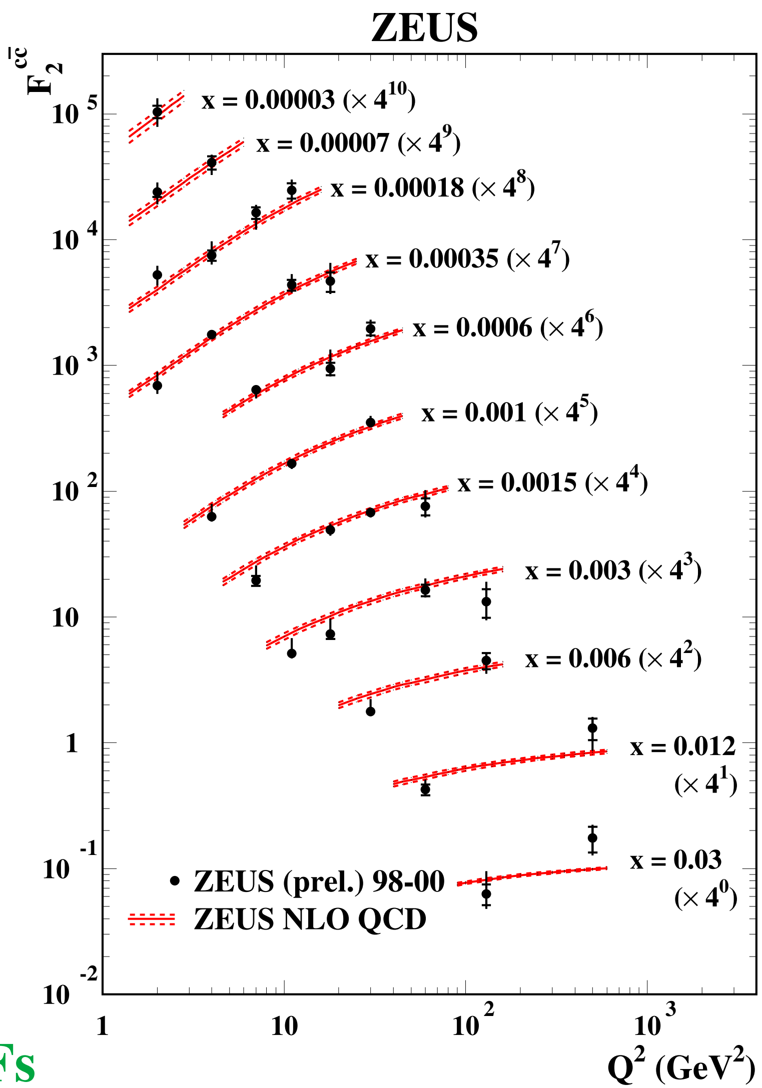
Open-charm contribution to F_2(proton) $(1.5 < Q^2 < 1000\ \mathrm{GeV}^2)$

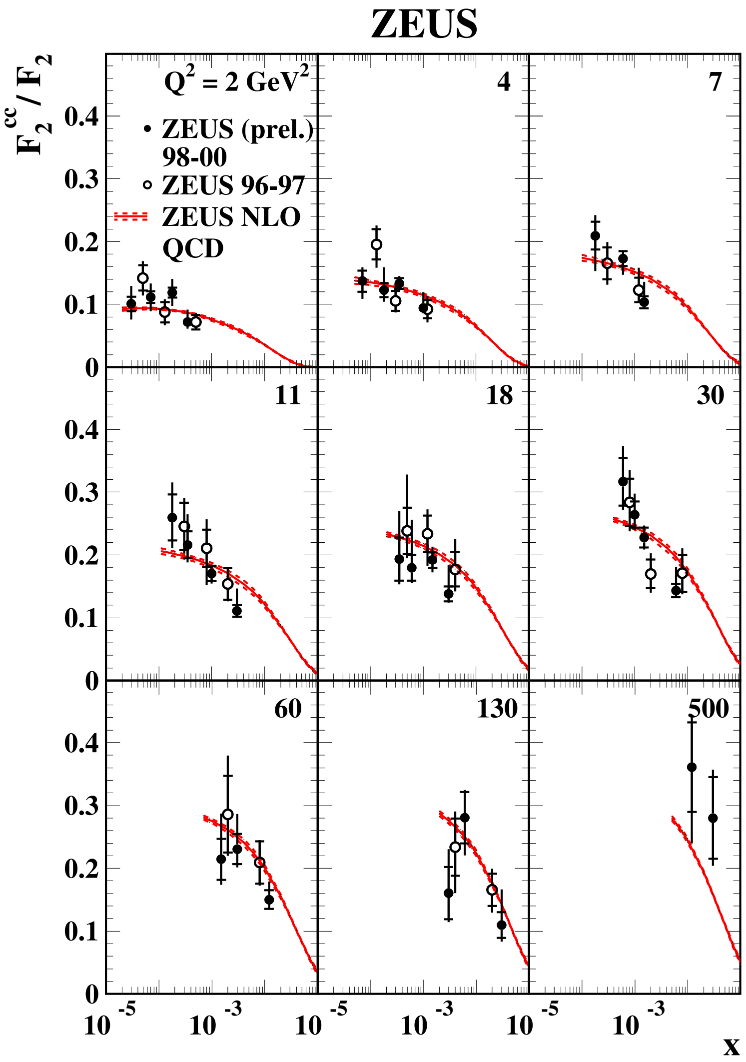
Measured cross sections for $D^{*\pm}$ in the visible range and in (Q^2, y) bins were extrapolated to the full phase space using NLO QCD calculations

- Increased precision and coverage (higher) in Q^2

$\rightarrow$ Steep rise at low x

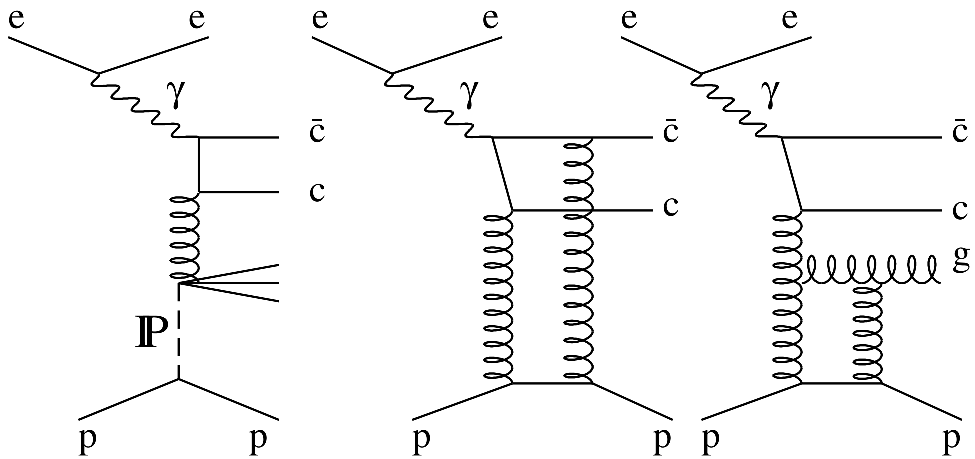
- $F_2^{c\bar{c}}$ data are generally well described by the prediction of the ZEUS NLO QCD fit of the p PDFs

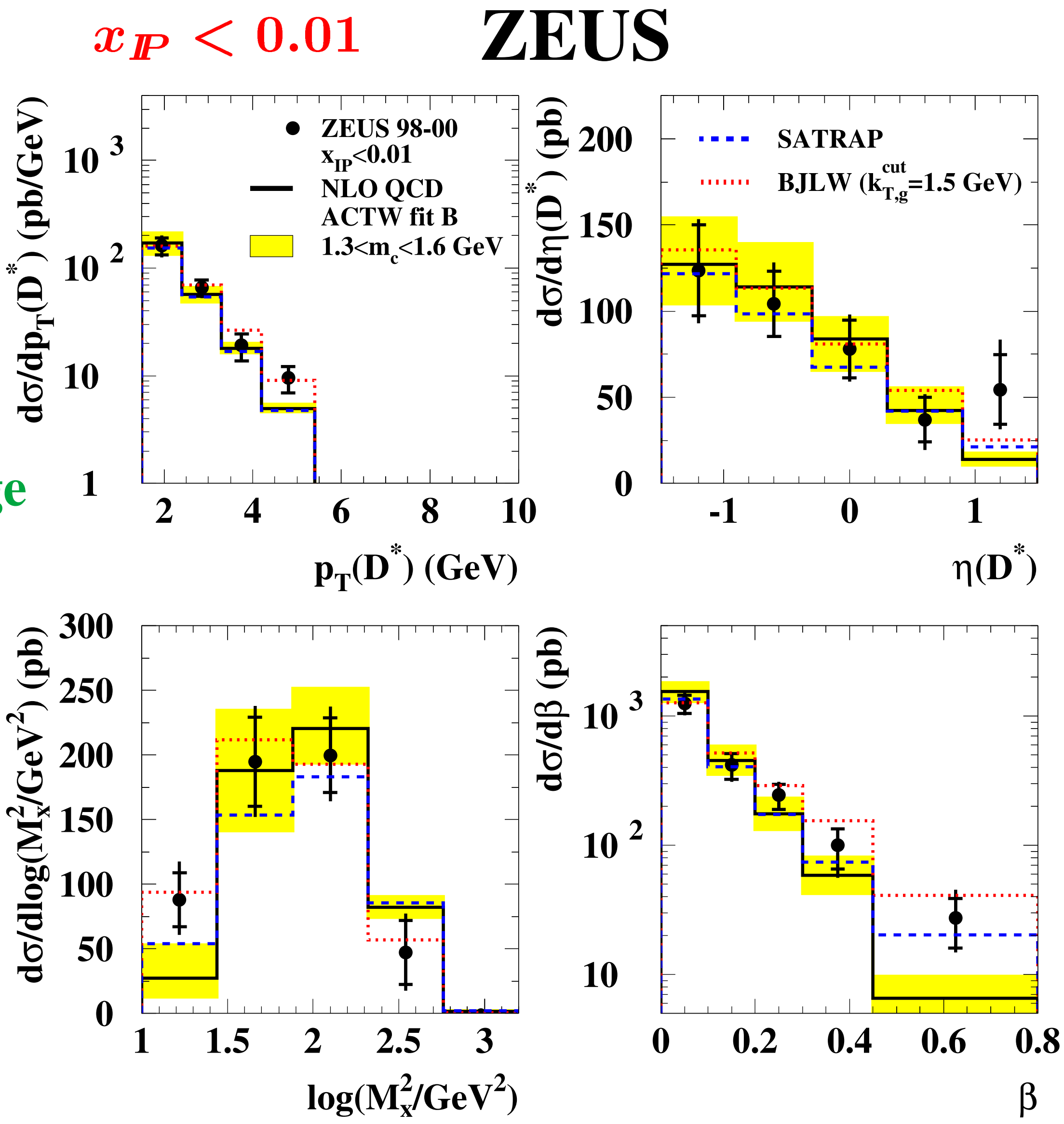




Open-charm contribution to F_2(proton) at low x and high Q^2 $\rightarrow F_2^{c\bar{c}}/F_2 \sim 30\%$

$D^{*\pm}$ production in diffractive NC DIS ($1.5 < Q^2 < 200$ GeV^2)

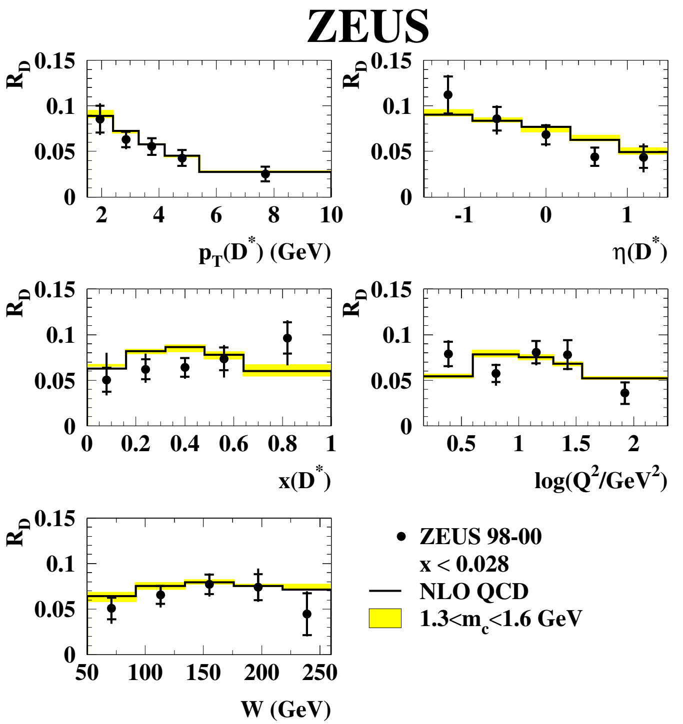


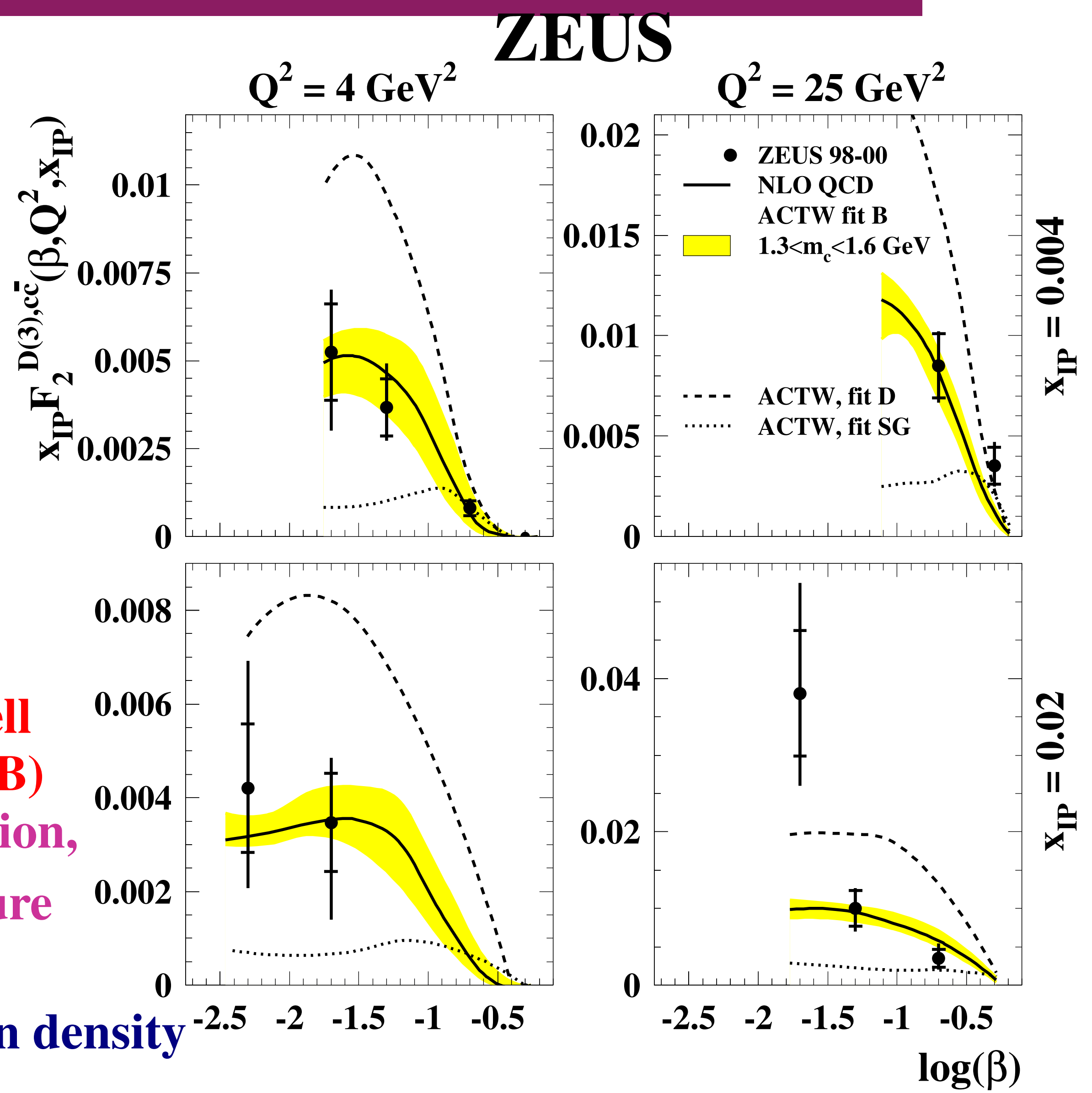


→ Sensitivity to gluon content of the exchange in diffractive interactions

- Increased luminosity (82 pb^{-1}) and rapidity acceptance (Forward Plug Cal.)
- Two-gluon exchange (SATRAP, BJLW) and resolved-Pomeron (Ingelman, Schlein) using NLO QCD $\mathbb{P}$ PDFs with a large gluon content (ACTW, set B) describe the data ($x_{\mathbb{P}} < 0.01$) reasonably well

$D^{*\pm}$ production in diffractive NC DIS ($1.5 < Q^2 < 200$ GeV^2)



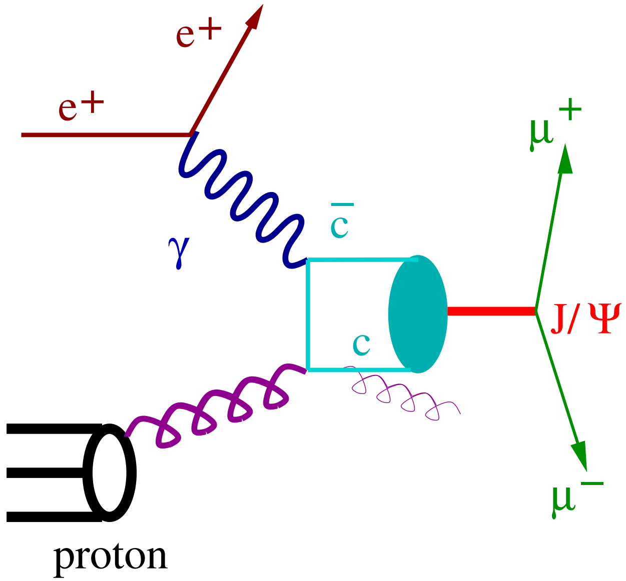


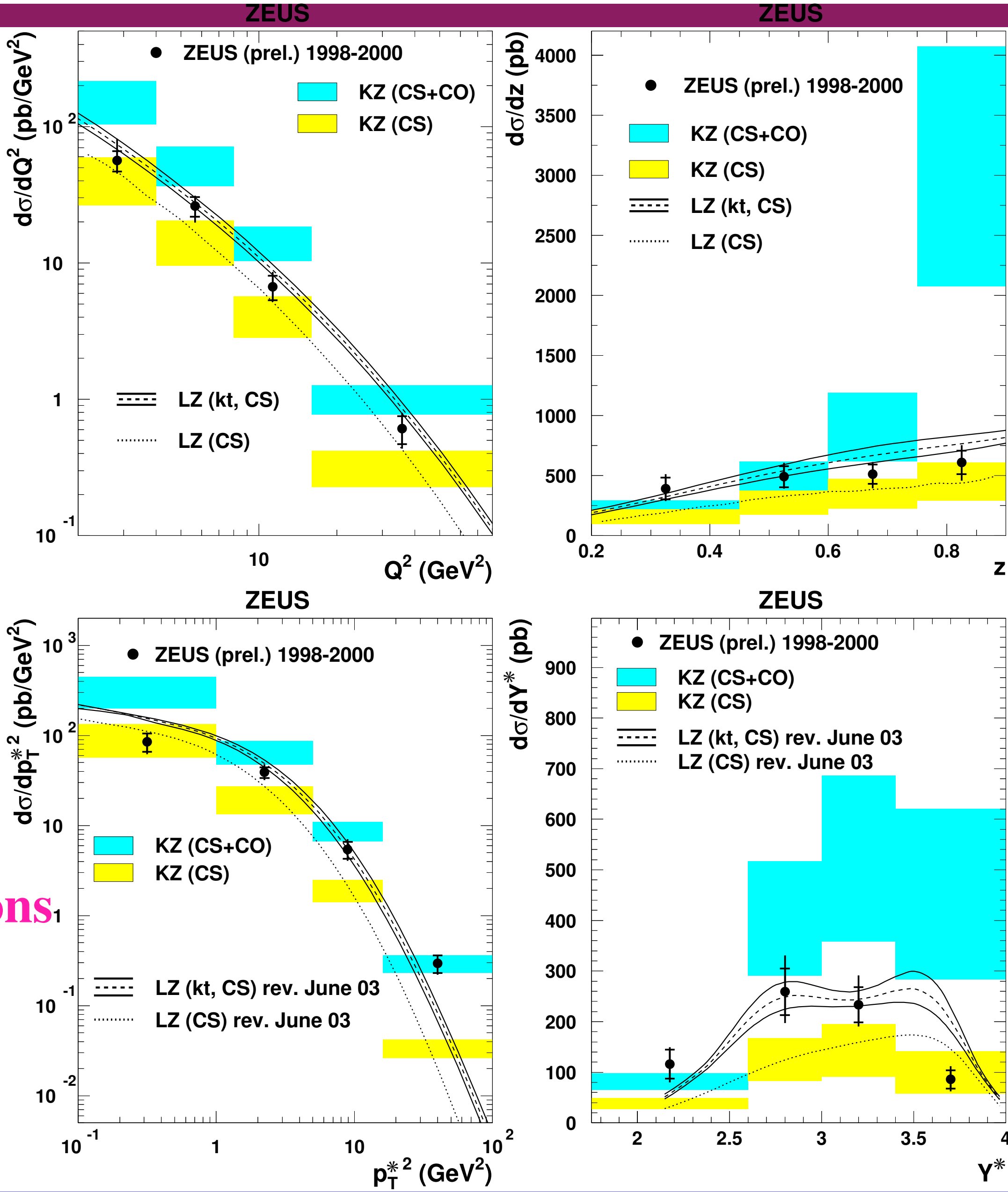
- Ratio of diffractive to inclusive $D^{*\pm}$ well described by NLO QCD calculations (set B)
- Extraction of the open-charm contribution, $F_2^{D(3),c\bar{c}}$, to the diffractive proton structure function: rise as β decreases

→ Powerful constrain on diffractive gluon density

→ Consistent description of inclusive diffraction and diffractive charm production in DIS

Inelastic J/Ψ production in Neutral Current DIS $2 < Q^2 < 80$ GeV^2





Investigation of the $c\bar{c}$-pair production and $c\bar{c}$ bound state formation

$\rightarrow z = E^*_{\Psi} / E^*_{\gamma}$ **in proton rest frame**

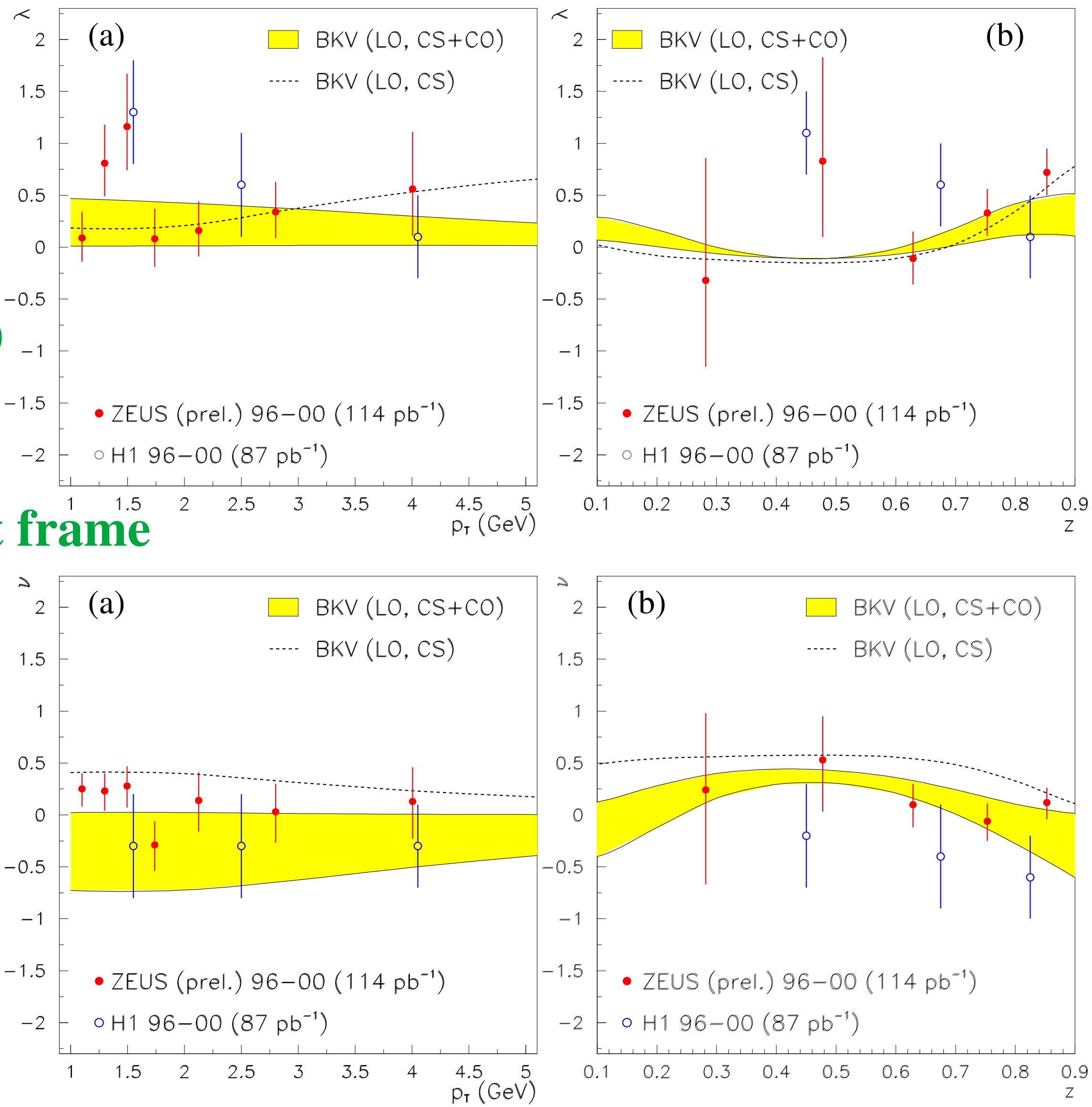
- **LO colour-singlet (CS) predictions below the data (specially at high p_T)**
- **Inclusion of colour-octet (CO) contributions overshoots the data (specially at high z)**

Large uncertainties $\rightarrow$ NLO corrections?

- **CS calculation in the k_T-factorization approach provides a better description**

Inelastic J/Ψ helicity distributions in photoproduction

- The J/Ψ helicity distributions predicted by the CS and CO models have a different p_T dependence
- Shape measurements $\rightarrow$ less sensitive to higher-order corrections (small uncert.)
$\rightarrow$ stringent test of CS and CO models
- Luminosity 114 pb^{-1}

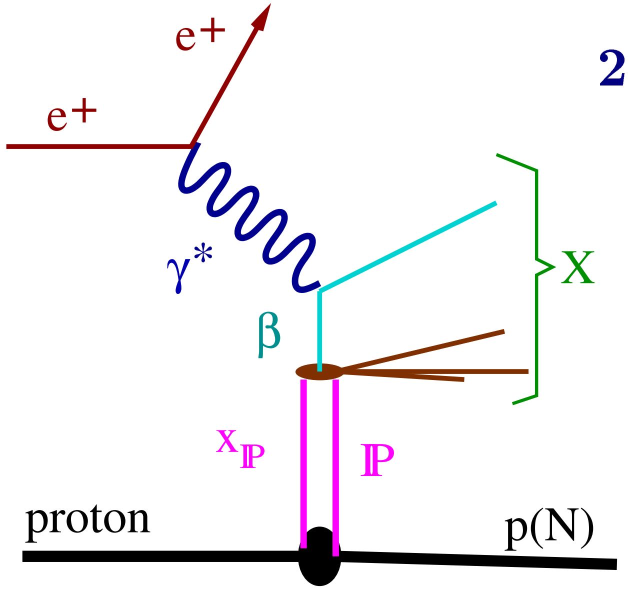


- Decay angular distributions in J/Ψ rest frame
$\rightarrow$ θ^* angle of μ^+ respect to z' (direction opposite to that of proton)
$1/\sigma \cdot d\sigma/d\cos\theta^* \propto 1 + \lambda\cos^2\theta^*$
($\lambda = +1$ (T polaris.), -1 (L polaris.))
- As a function of p_T for $z > 0.4$
- As a function of z for $p_T > 1$ GeV
$\rightarrow$ Measured azimuthal distribution in the region $0.6 < z < 0.8$ disfavours colour-singlet only picture
$\rightarrow$ Firmer conclusion needs explicit calculation of theoretical uncertainty

Diffraction

Diffractive DIS with the Forward Plug Calorimeter

- Measurement of diffractive DIS over a larger kinematic range by using the Forward Plug Cal. and the M_X method

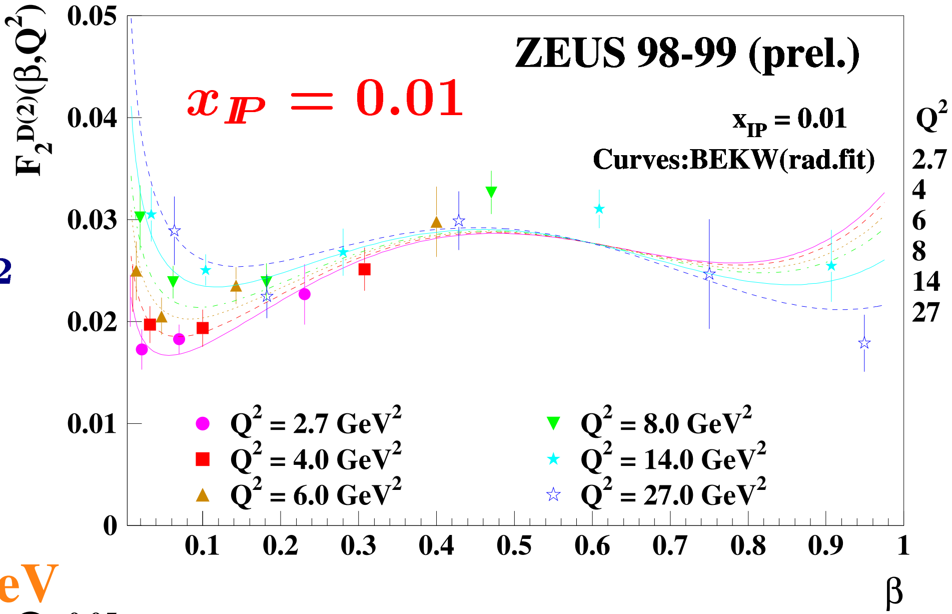


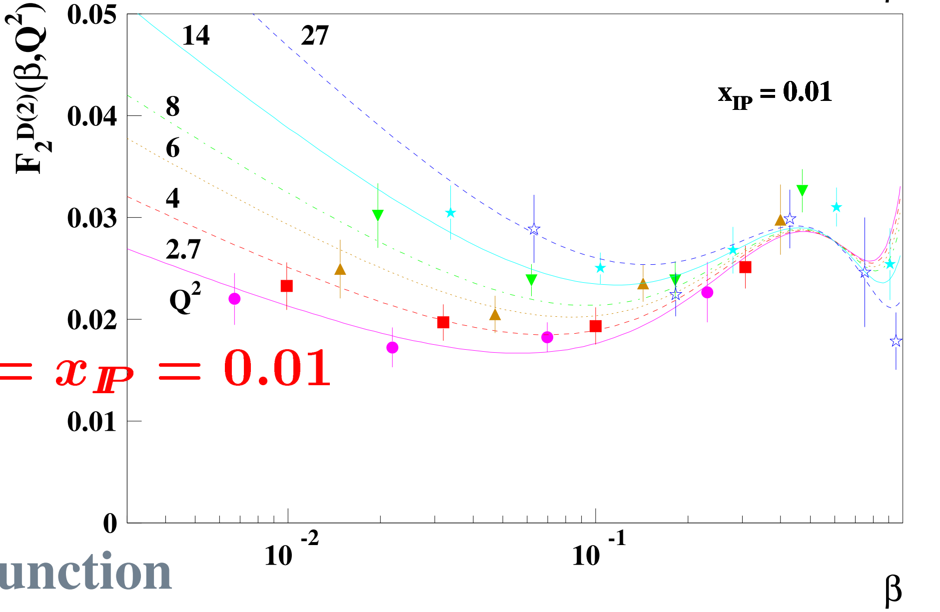
$2.2 < Q^2 < 80$ GeV^2

$M_X < 35$ GeV

$37 < W < 245$ GeV

$M_N < 2.3$ GeV





- Increased statistics allows determination of the diffractive structure function at a given $x_{I\!P}$

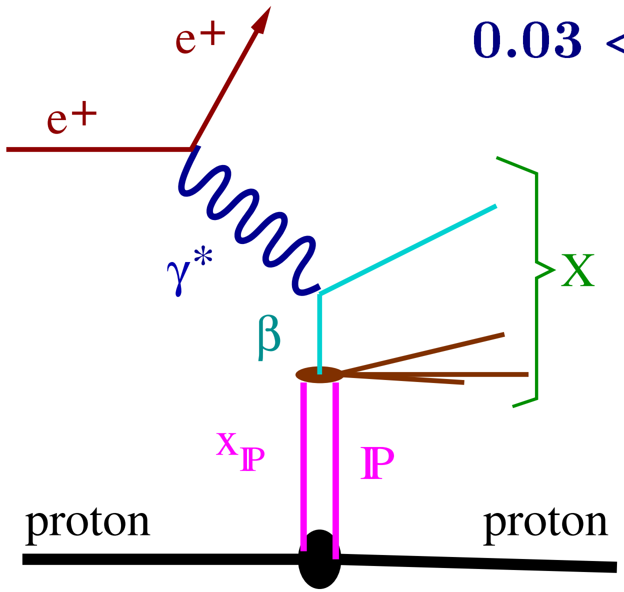
$F_2^{D(2)}(\beta, Q^2) \equiv x_0 \cdot F_2^{D(3)}(x_0, \beta, Q^2)$ at $x_0 = x_{I\!P} = 0.01$

$\rightarrow$ Mild evolution with Q^2 at large β

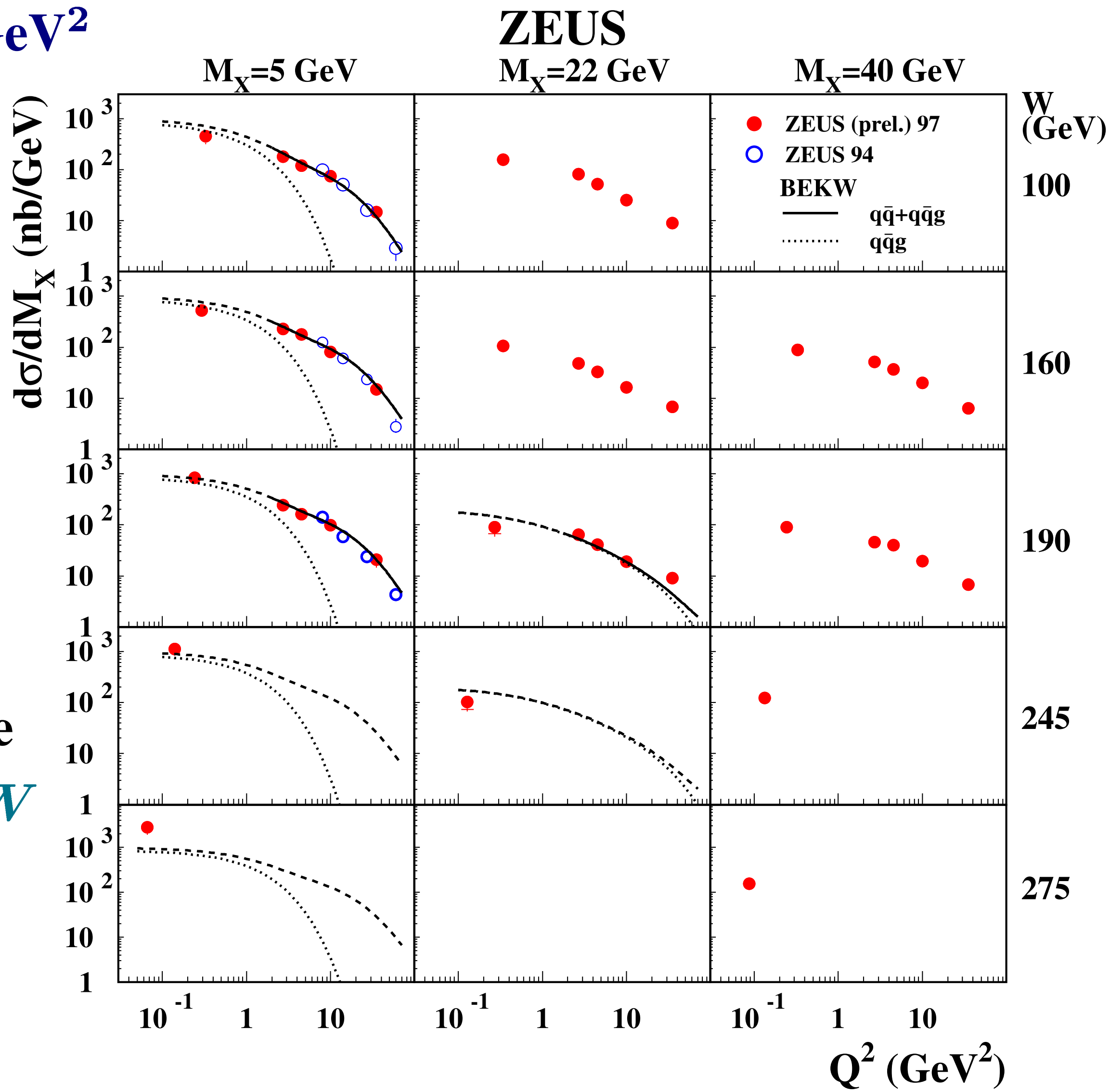
$\rightarrow$ Rapid evolution with Q^2 at small β

$\Rightarrow$ pQCD-like evolution of diffractive structure function

Diffractive DIS with the Leading Proton Spectrometer



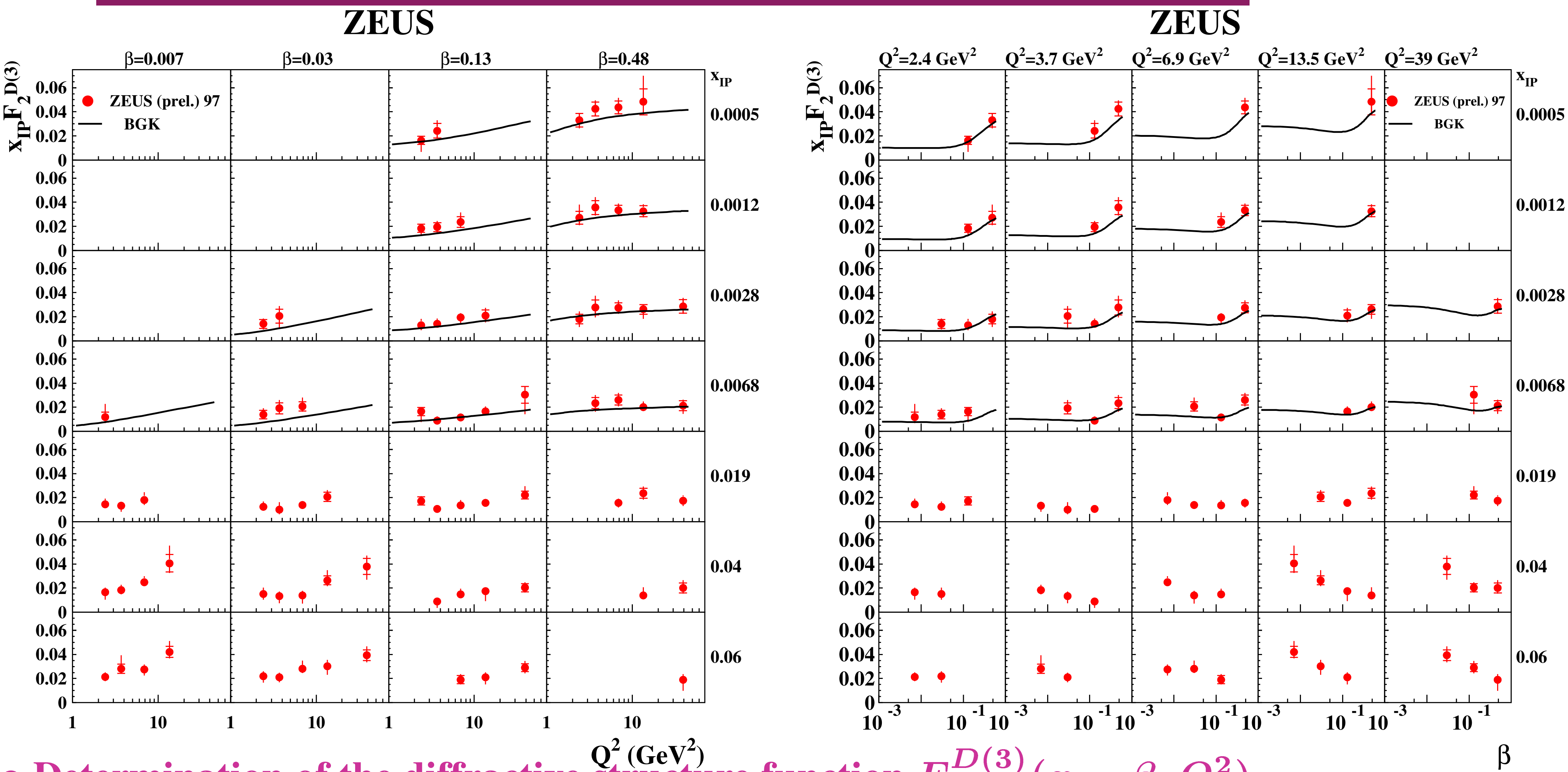
$0.03 < Q^2 < 100$ GeV^2



- Measurement of diffractive dissociation of virtual photons $\gamma^* p \to Xp$ with a leading proton ($x_L > 0.9$) in the final state
- Extended kinematic range in Q^2, M_X, W $\to$ higher $x_{\mathbb{P}}$ values
- The measured diffractive cross section $d\sigma^D_{\gamma^* p}/dM_X$ exhibits a behaviour similar to that of the total $\gamma^* p$ cross section:

$\to$ mild dependence at low Q^2 and rapid decrease at high Q^2

Diffractive DIS with the Leading Proton Spectrometer

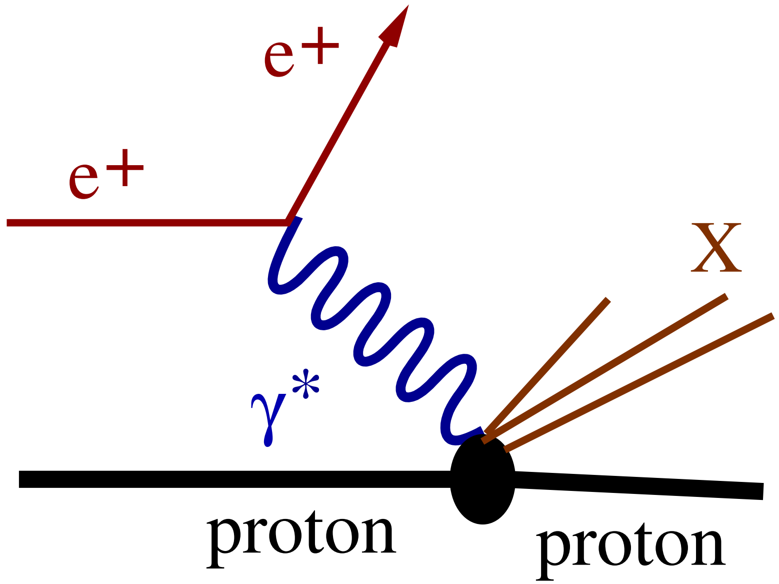


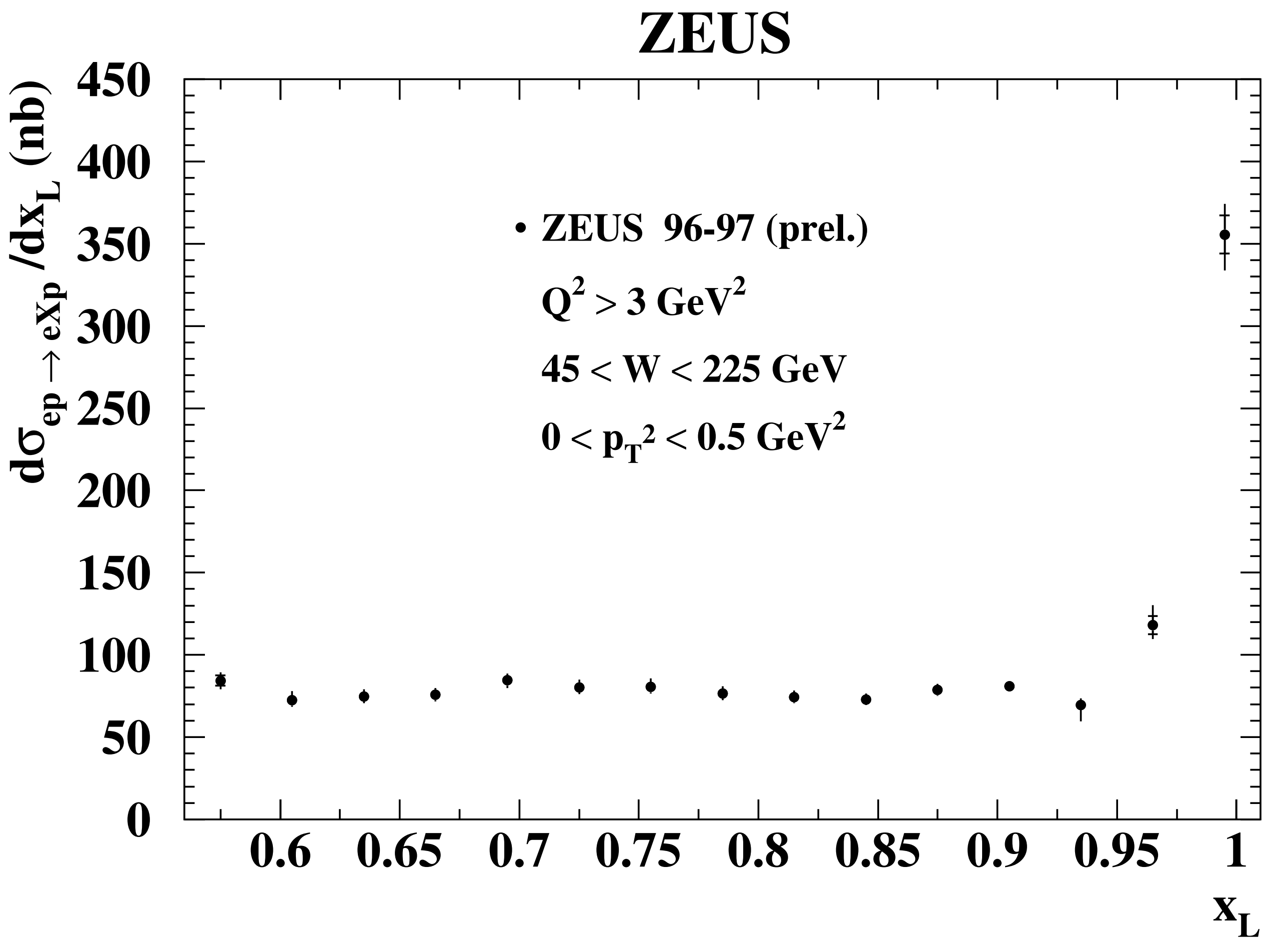
- Determination of the diffractive structure function $F_2^{D(3)}(x_{I\!P}, \beta, Q^2)$

$\rightarrow$ positive scaling violations in the accesible kinematic region

$\rightarrow$ different β spectrum at low (high) $x_{I\!P}$

Leading-proton production in DIS



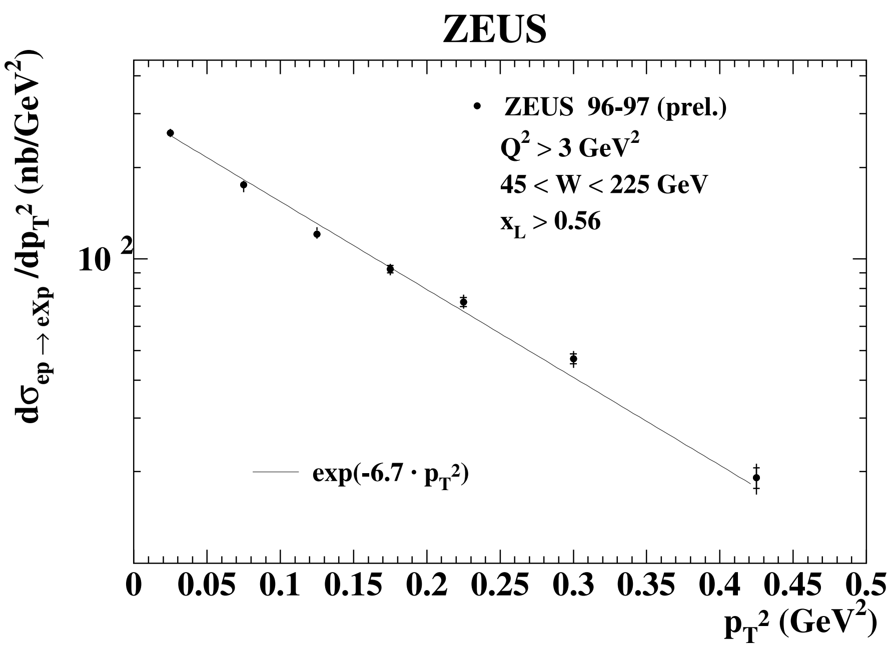


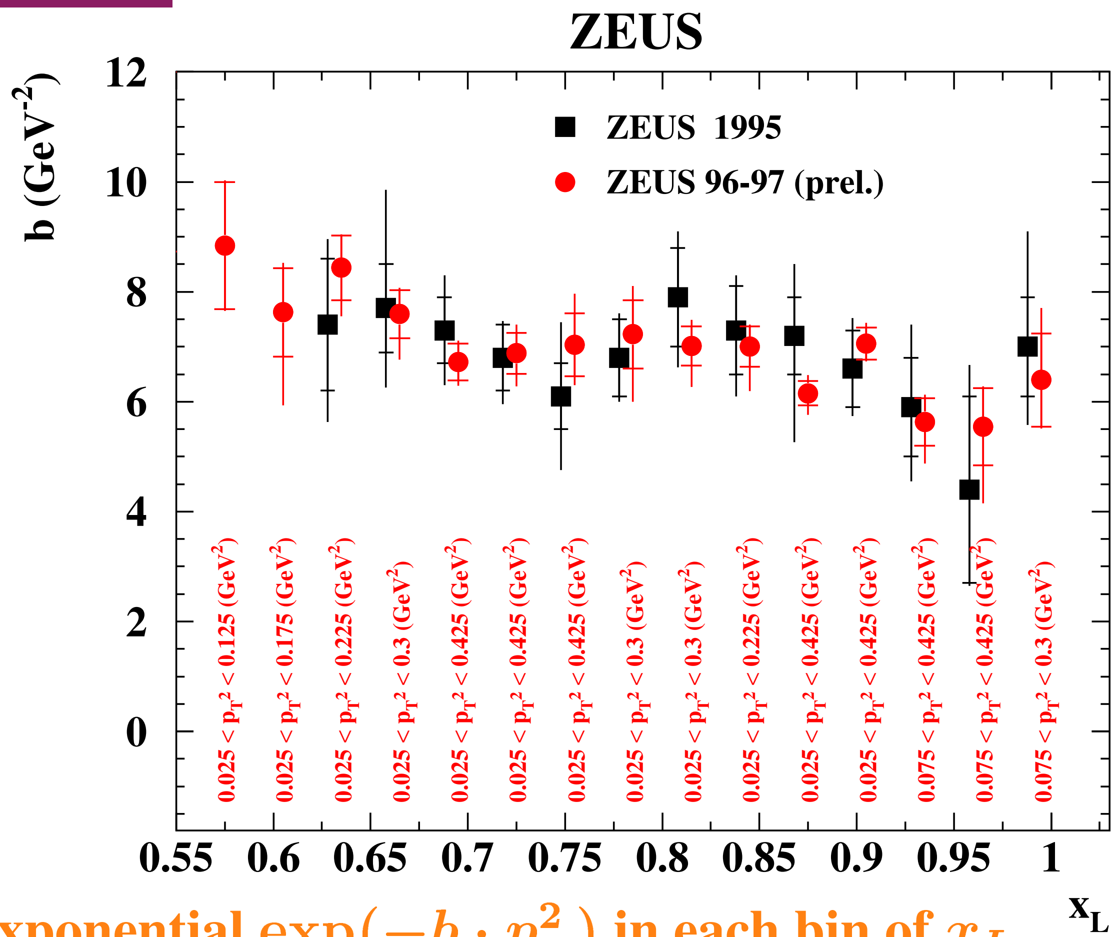
- **High-statistics study of the production of leading protons in DIS:**

$Q^2 > 3$ GeV^2, $45 < W < 225$ GeV, $x_L > 0.56$, $0 < p_T^2 < 0.5$ GeV^2

$\rightarrow d\sigma_{ep\rightarrow eXp}/dx_L$ **flat as a function of** x_L **up to** 0.95

Leading-proton production in DIS





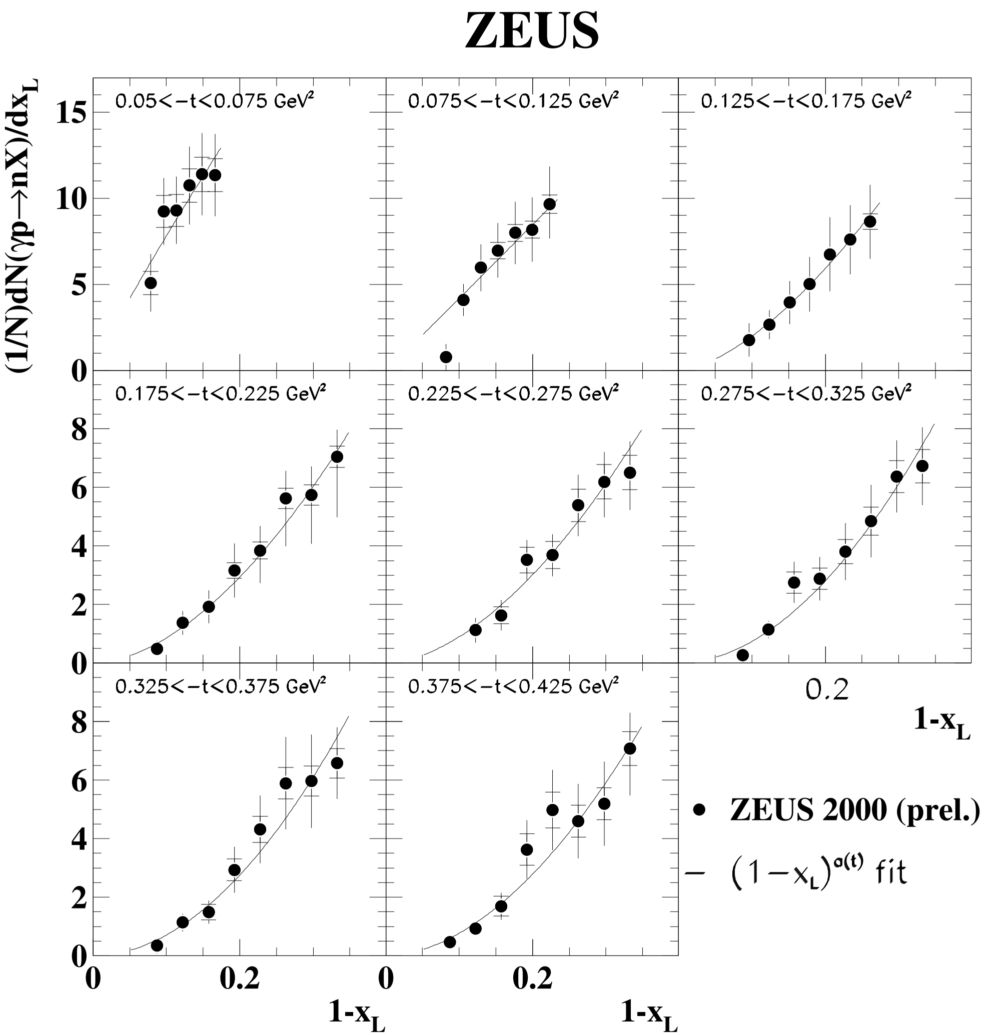
$\rightarrow d\sigma_{ep\rightarrow eXp}/dp_T^2$ fitted with a single exponential $\exp(-b \cdot p_T^2)$ in each bin of x_L

(not a good representation for the differential cross section integrated over $x_L > 0.56$)

$\rightarrow$ Precise determination of the p_T^2-slope versus x_L

(the observed structure comes from the variation of the p_T range)

Leading-neutron production in γp: the pion trajectory

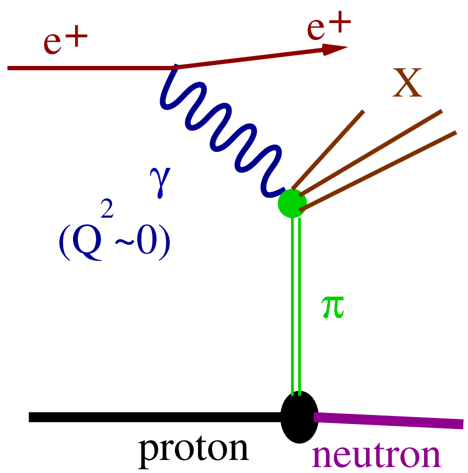


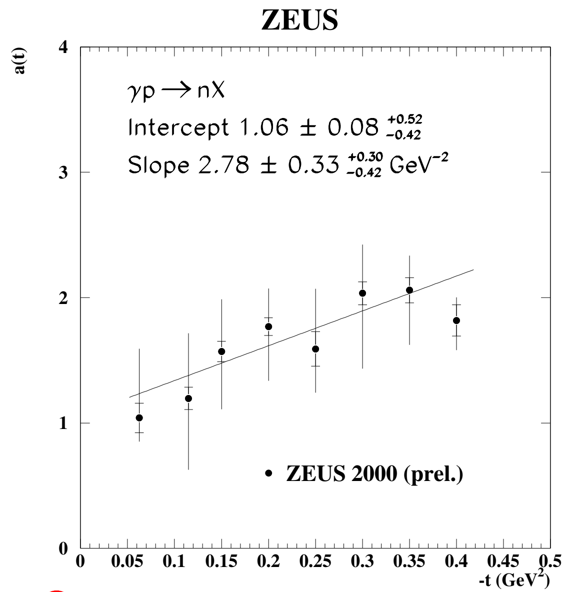
- Measurement of the x_L distribution for leading neutron ($x_L > 0.6$) production as a function of t ($|t| < 0.425$ GeV^2) in γp collisions ($Q^2 \approx 0$)

$\rightarrow$ approximate power-law behaviour observed

$$dN/dx_L \sim (1 - x_L)^{a(t)}$$

with the powers $a(t)$ lying on a linear trajectory in t



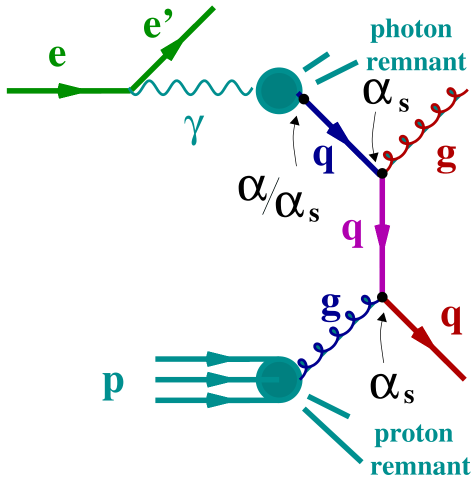


$a(t) = a - b \cdot t$ with $a = 1.06 \pm 0.08(\text{stat})^{+0.52}_{-0.42}(\text{syst})$
and $b = 2.78 \pm 0.33(\text{stat})^{+0.30}_{-0.42}(\text{syst})$ GeV^{-2}

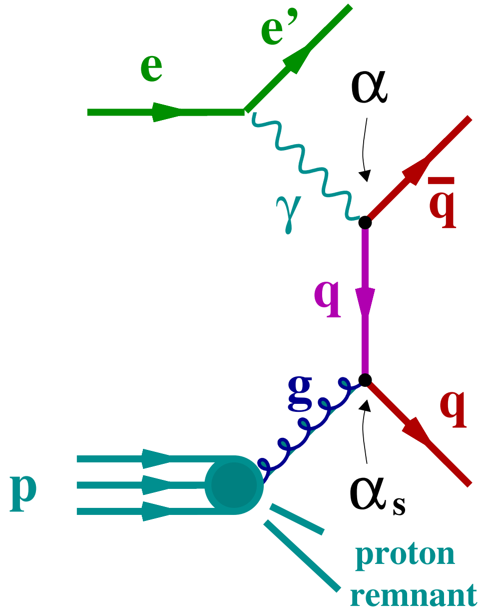
$\Rightarrow$ Consistent with expectations from pion exchange $b = 2\alpha'_\pi \approx 2$

Hadronic Final States

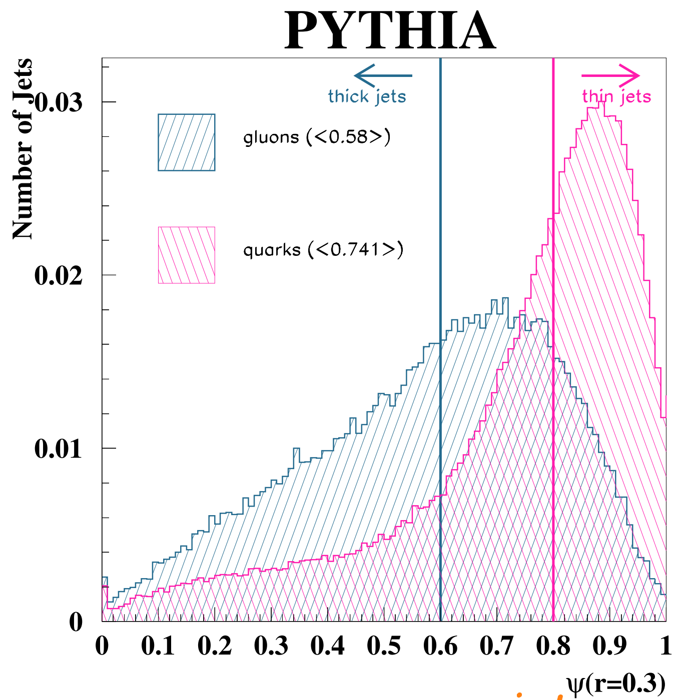
Substructure Dependence of Jet Cross Sections in Photoproduction



Resolved Process

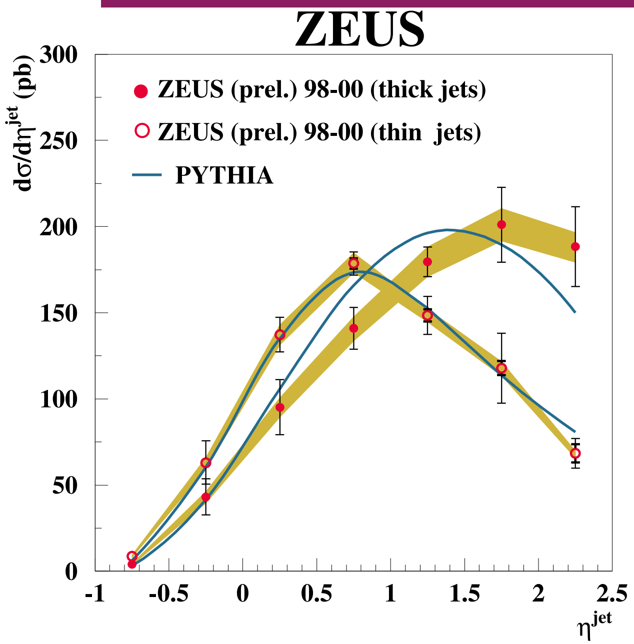


Direct Process



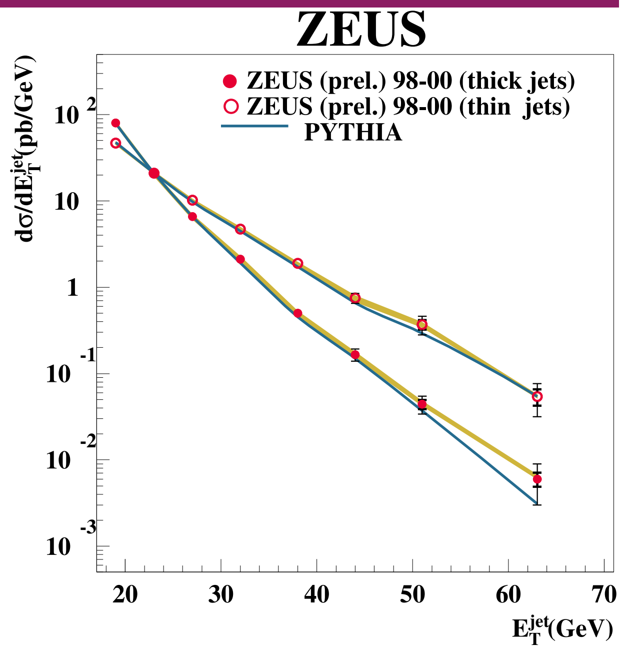
- **The (expected) dominant mechanisms for jet production at high E_T ($E_T^{jet} > 17$ GeV) in γp interactions: $q_\gamma g_p \rightarrow q\ g$ (resolved) and $\gamma g \rightarrow q\bar{q}$ (direct)**
  - **$\Rightarrow$ Majority of quark-initiated jets in $\eta_{jet} < 0$**
  - **$\Rightarrow$ increasing fraction of gluon-initiated jets as η_{jet} increases**
- **Tagging quark and gluon jets to disentangle/study the underlying hard processes**
  - **$\rightarrow$ Gluon (“THICK”) jets: jet shape $\Psi(r = 0.3) < 0.6$ and $n_{sbj}(y_{cut} = 0.0005) \geq 6$**
  - **$\rightarrow$ Quark (“THIN”) jets: jet shape $\Psi(r = 0.3) > 0.8$ and $n_{sbj}(y_{cut} = 0.0005) < 4$**

Substructure Dependence of Jet Cross Sections in Photoproduction



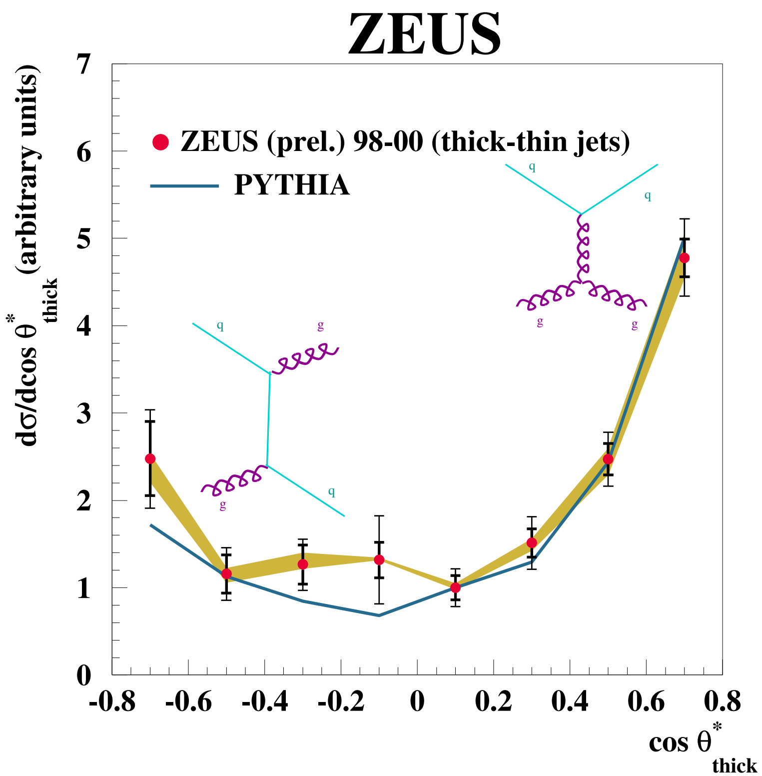
Measurements of inclusive jet cross sections $d\sigma/d\eta_{jet}$ and $d\sigma/dE_T^{jet}$ for "THICK" jets and "THIN" jets

→ MC: shape comparison



Dynamics of qg final states: angular distribution of dijet events ("THIN"-"THICK")

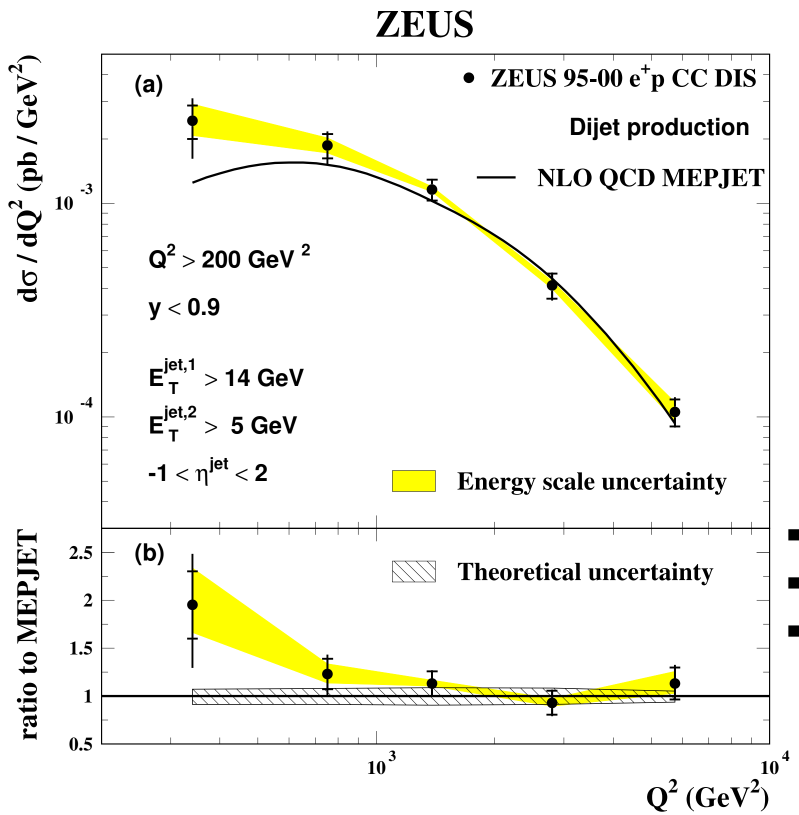
$\Rightarrow d\sigma/d\cos\theta_{THICK}$

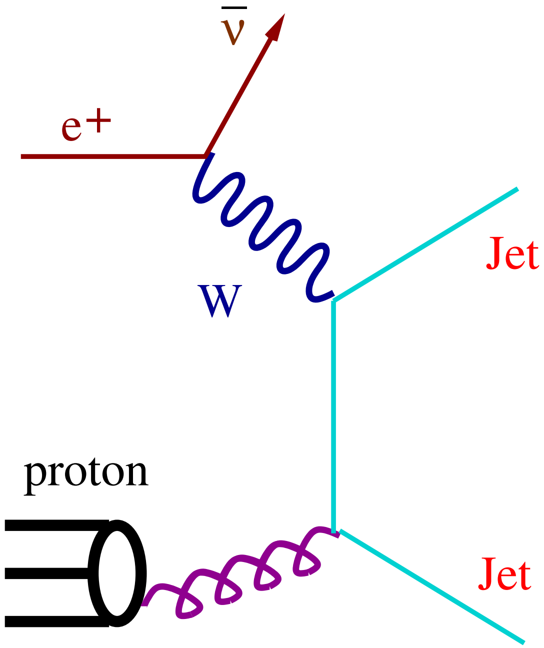


Asymmetric distribution: steeper as $\cos\theta_{thick} \rightarrow +1$ (gluon exchange) than as $\cos\theta_{thick} \rightarrow -1$ (quark exchange)

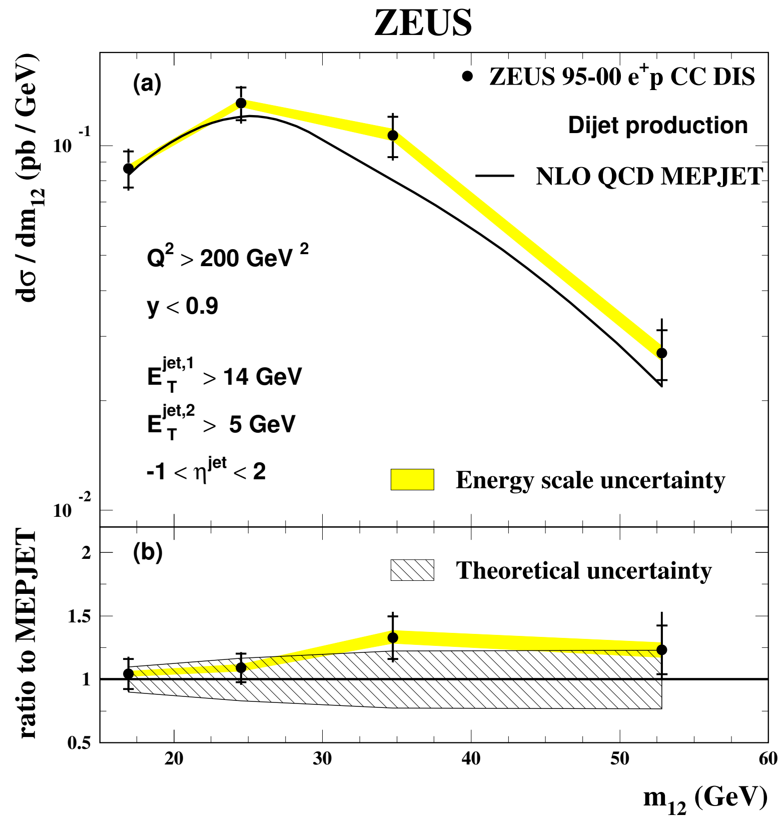
Luminosity 82 pb^{-1}

Dijet Production in Charged Current DIS





- Test of perturbative QCD at $\mathcal{O}(\alpha_s^2)$ in charged current DIS at large Q^2 ($Q^2 > 200$ GeV^2)

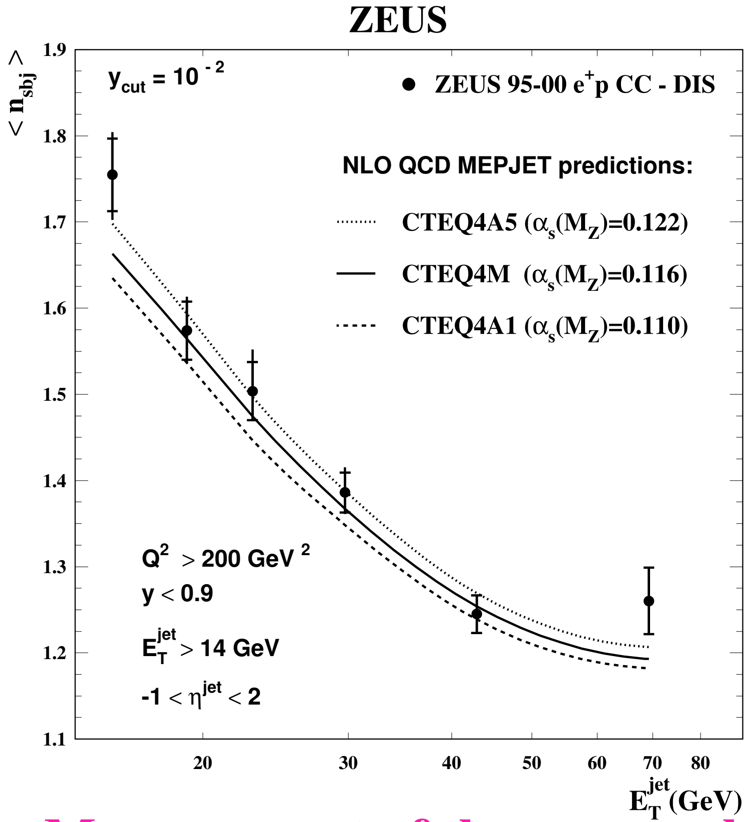


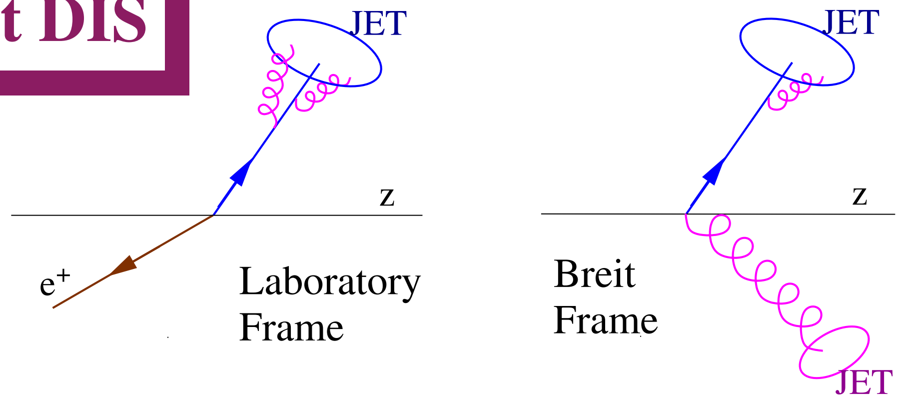
- Measurement of the differential cross sections $d\sigma/dQ^2$ and $d\sigma/dM_{12}$ for dijet production in CC DIS satisfying $E_T^{jet,1} > 14$ GeV and $E_T^{jet,1} > 5$ GeV

NLO QCD calculations describe the data reasonably well

Luminosity 111 pb^{-1}

Jet Substructure in Charged Current DIS





- **Measurements of jet substructure provide:**

  $\rightarrow$ a stringent test of pQCD calculations beyond LO

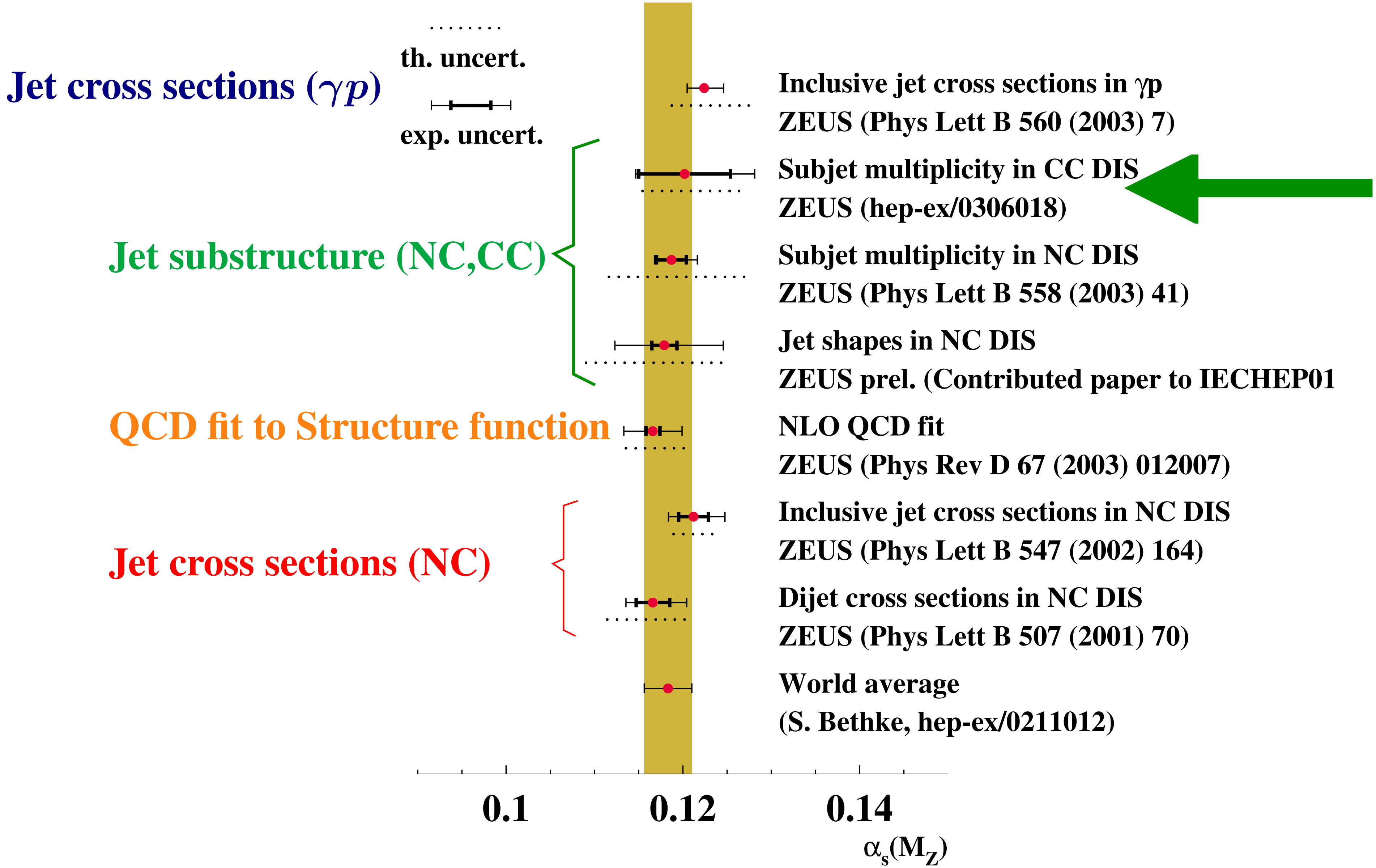
  $\rightarrow$ a determination of α_s

- **NLO QCD calculations of jet substructure possible in the laboratory frame (3 partons in the same jet)**

- **Measurement of the mean subjet multiplicity $\rightarrow < n_{sbj} >$ for an inclusive sample of jets with $E_T^{jet} > 14$ GeV in CC DIS at $Q^2 > 200$ GeV^2 (Luminosity 111 pb^{-1})**
- **Perturbative QCD ($\mathcal{O}(\alpha_s^2)$) calculations describe the data well ($\rightarrow$ sensitivity to α_s)**
- **Extraction of $\alpha_s(M_Z)$ from the measured of $\langle n_{sbj} \rangle (y_{cut} = 10^{-2})$ for $E_T^{jet} > 25$ GeV:**

$$\boxed{\alpha_s(M_Z) = 0.1202 \pm 0.0052\,(\text{stat.})\,^{+0.0060}_{-0.0019}\,(\text{exp.})^{+0.0065}_{-0.0053}\,(\text{th.})}$$

Determinations of $\alpha_s(M_Z)$ by ZEUS



Last Remarks

→ **Rich programme**

→ **High precision**

→ **Full (exhaustive) use of HERA I**

→ **Looking forward to**
the new data taking period