64^{th} **Physics Research Committee Meeting**

November 8, 2007

DESY, Hamburg

Deutsches Elektronen-Synchrotron
in der Helmholtz-Gemeinschaft

DESY

ZEUS Status Report

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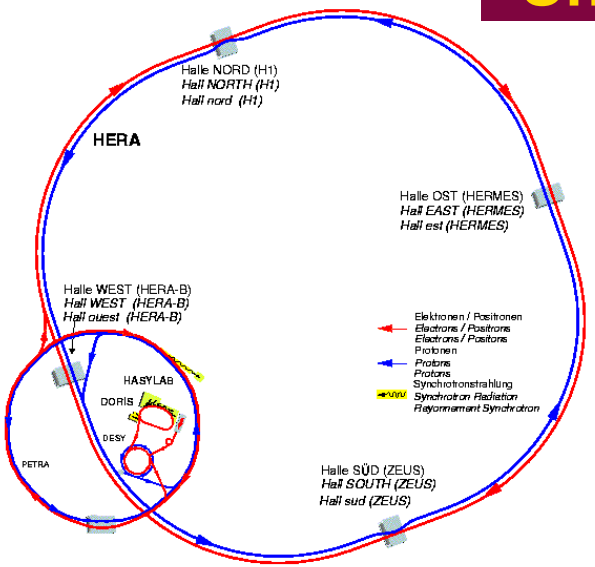
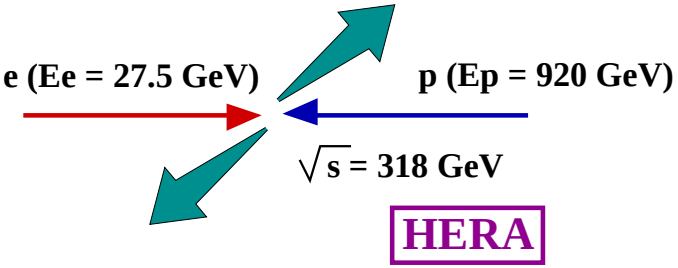
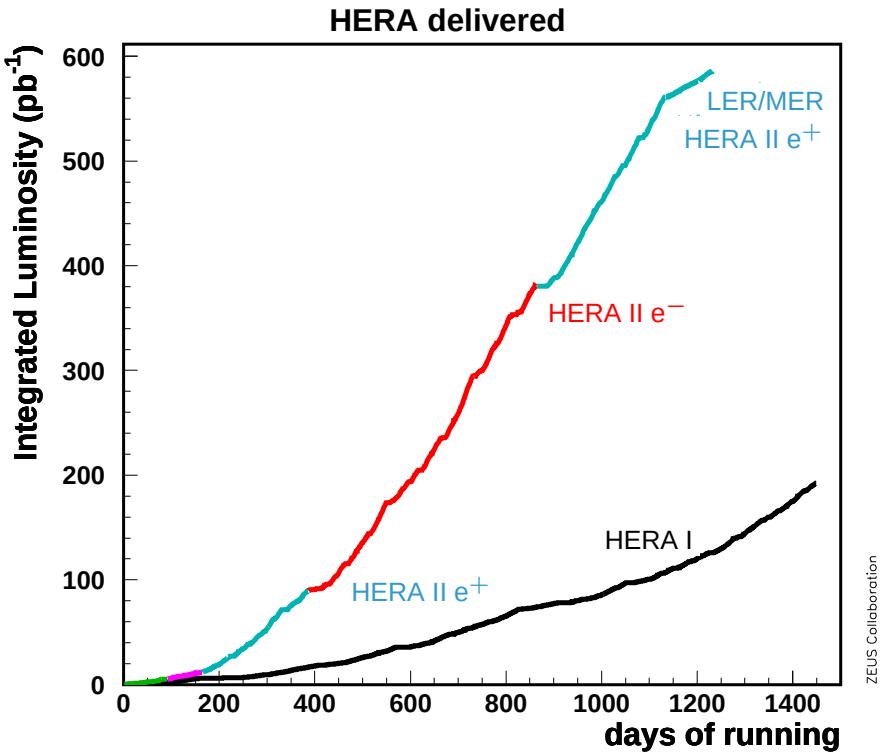
Universidad Autónoma de Madrid

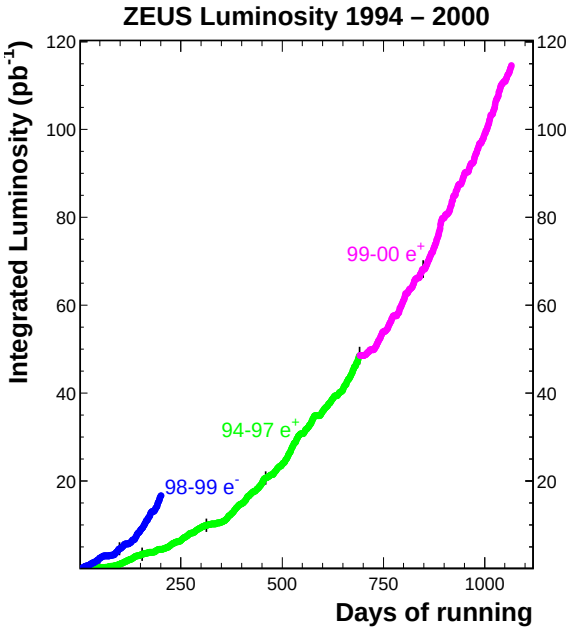


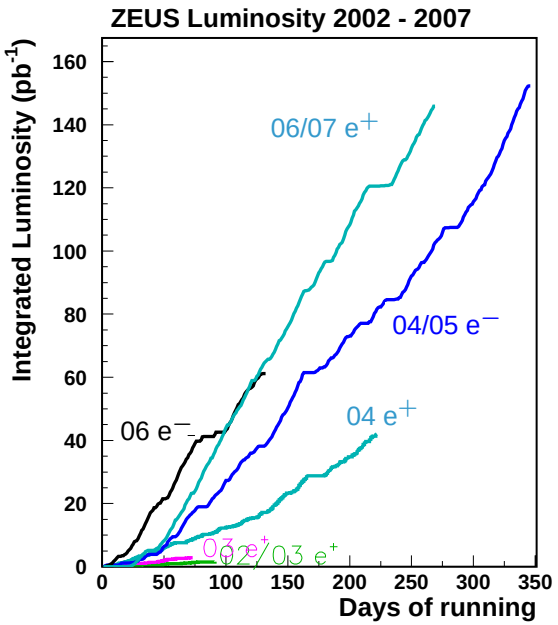


On behalf of the ZEUS Collaboration

HERA and ZEUS luminosity



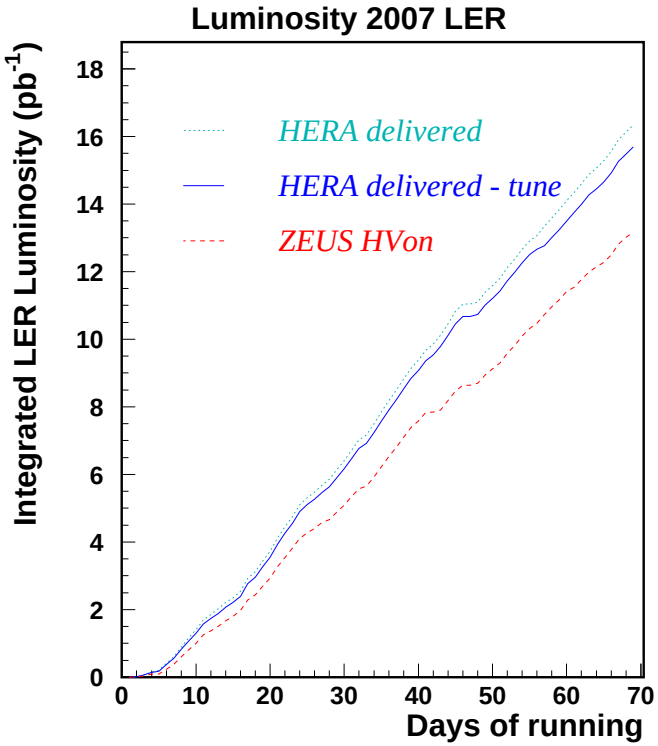




– **Grand total HERA delivered: 0.78 fb^{-1}**
(24 May 1993 - 30 Jun 2007)

→ **Grand total ZEUS gated: 0.5 fb^{-1}**

HERA and ZEUS luminosity

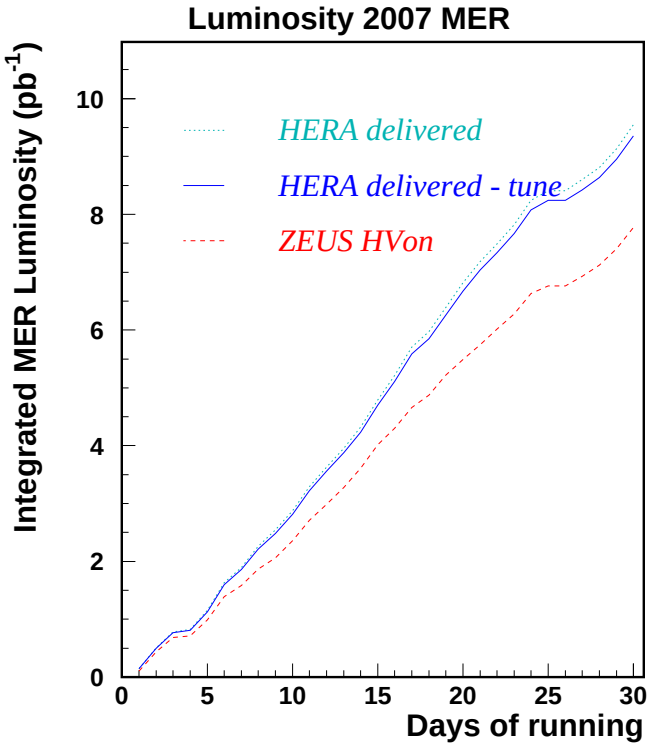


LER ($E_p = 460$ GeV, $\sqrt{s} = 225$ GeV)

– HERA II delivered: 15.7 pb^{-1}

(24 Mar 2007 - 31 May 2007)

→ ZEUS gated: 14 pb^{-1}



MER ($E_p = 575$ GeV, $\sqrt{s} = 252$ GeV)

– HERA II delivered: 9.4 pb^{-1}

(1 Jun 2007 - 30 Jun 2007)

→ ZEUS gated: 7 pb^{-1}

Physics highlights: publications

- **9 ZEUS papers published since May 2007:**
  - ⇝ Multijet production at low x_{Bj} in deep inelastic scattering
    (DESY-07-062, May 2007, NPB 786 (2007) 152)
  - ⇝ Bose-Einstein correlations of charged and neutral kaons in deep inelastic scattering
    (DESY-07-069, May 2007, PLB 652 (2007) 1)
  - ⇝ Measurement of (anti)deuteron and (anti)proton production in DIS
    (DESY-07-070, May 2007, NPB 786 (2007) 181)
  - ⇝ High-E_T dijet photoproduction
    (DESY-07-092, June 2007, PRD 76 (2007) 072011)
  - ⇝ Forward-jet production in deep inelastic ep scattering
    (DESY-07-100, July 2007, accepted by EPJ C)
  - ⇝ Three- and four-jet final states in photoproduction
    (DESY-07-102, July 2007, accepted by NPB)
  - ⇝ Exclusive ρ^0 production in deep inelastic scattering
    (DESY-07-118, August 2007, accepted by PMC A)
  - ⇝ Dijet production in diffractive deep inelastic scattering
    (DESY-07-126, August 2007, accepted by EPJ C)
  - ⇝ Diffractive photoproduction of dijets in ep collisions
    (DESY-07-161, September 2007, submitted to EPJ C)

average of one paper every two weeks

Physics highlights: new results

- **New ZEUS preliminaries in 2007 (presented to EPS07/LP07):**

  → **HERA I:**

  - Beauty production using semileptonic decays into electrons ($b \to e$)
  - Beauty in DIS and measurement of beauty contribution to F_2 ($F_2^{b\bar{b}}$)
  - Deeply virtual Compton scattering (DVCS)
  - Excited charm and charm-strange mesons production (D^0, D^+, D_S^+, D_S^{*+}, D^{*+}, D^{*0})

  → **HERA II:**

  - Multijet cross sections in CC $e^{\pm}p$ DIS
  - Jet substructure in NC DIS
  - High-Q^2 NC DIS cross sections with longitudinally polarised electrons ($e^-_{L/R}$)
  - High-Q^2 CC DIS cross sections with longitudinally polarised positrons ($e^+_{L/R}$)
  - D^* in DIS and measurement of $F_2^{c\bar{c}}$
  - D^+, D^0 cross sections
  - Beauty in dijet photoproduction

Physics highlights: towards final results

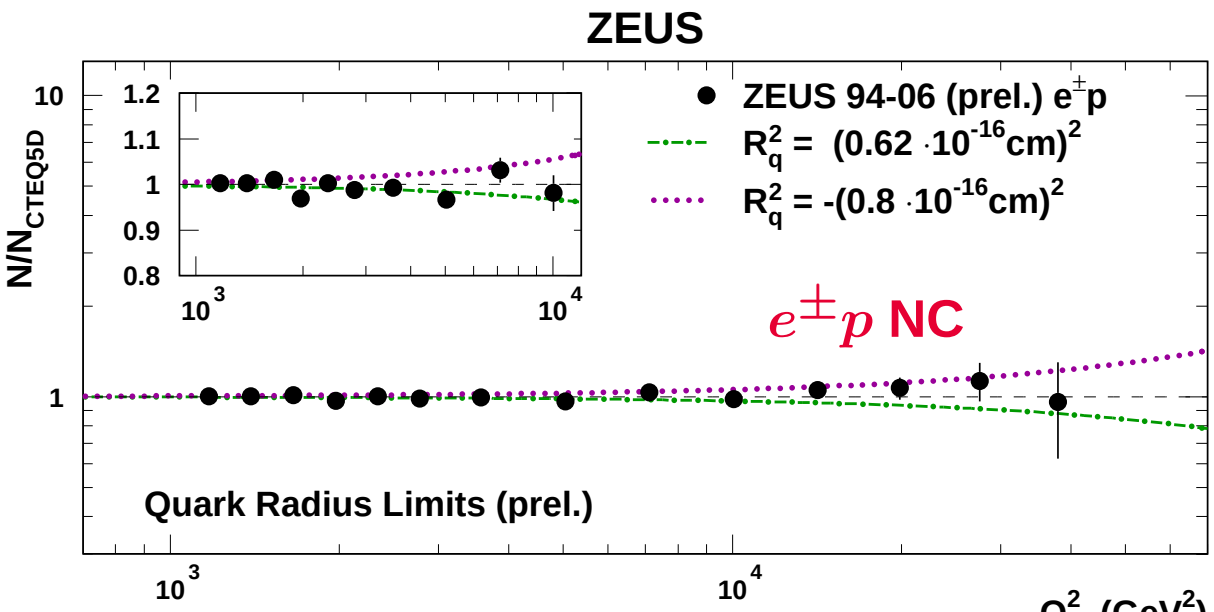
$\longrightarrow$ **New ZEUS measurements combining HERA I + HERA II data:**

- $\rightsquigarrow$ Scaled momentum spectra in the current region of the Breit frame
- $\rightsquigarrow$ $K_s^0 K_s^0$ spectra
- $\rightsquigarrow$ Dijet cross sections in NC DIS
- $\rightsquigarrow$ Isolated high-energy leptons with associated missing transverse momentum
- $\rightsquigarrow$ Multi-lepton production
- $\rightsquigarrow$ Electroweak fits
- $\rightsquigarrow$ PDF fits
- $\rightsquigarrow$ Limits on contact interactions, extra dimensions, heavy leptoquarks
- $\rightsquigarrow$ Inelastic J/ψ
- $\rightsquigarrow$ Exclusive photoproduction of Υ mesons

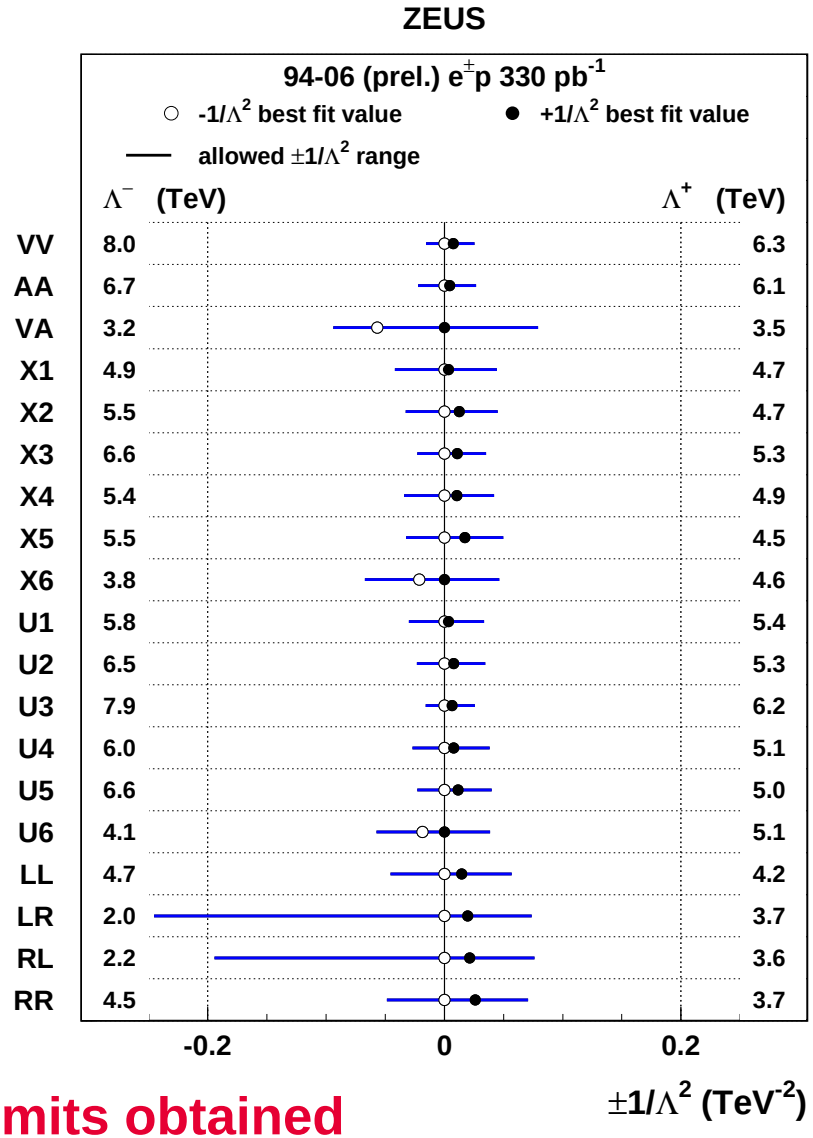
- **NEW!!! $\longrightarrow$ H1 + ZEUS combined results:**
  - $\looparrowright$ α_s from combined HERA I H1 and ZEUS jet measurements
  - $\looparrowright$ Combined NC DIS HERA I reduced cross sections
  - $\looparrowright$ Isolated leptons from HERA I + HERA II
  - $\looparrowright$ Multileptons from HERA I + HERA II

Search for physics beyond the SM

- **Search for signatures of physics beyond the SM using $e^{\pm}p$ HERA I + HERA II data:**
  - ↪ **contact interactions**
  - ↪ **heavy leptoquarks**
  - ↪ **extra dimensions**
  - ↪ **quark radius**



→ **Limit on R_q: $0.62 \cdot 10^{-16}$ cm**

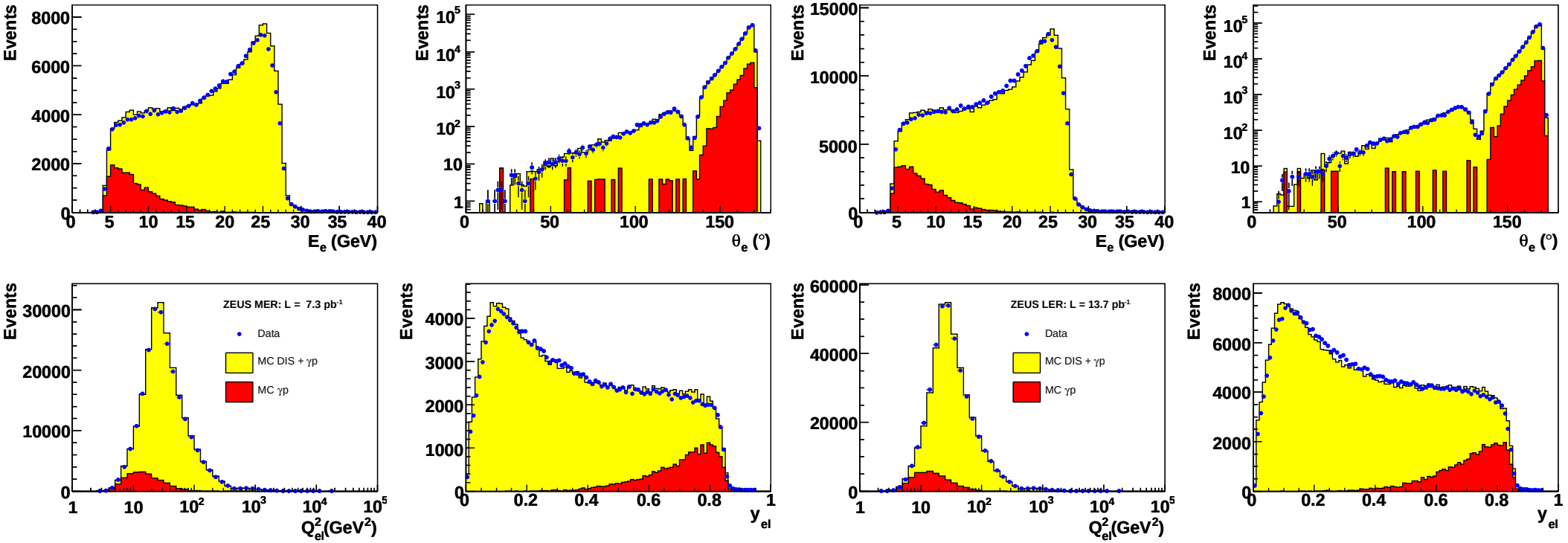


⇒ **No deviations from SM observed → 95% CL limits obtained**

Towards F_L...

- For direct measurement of $F_L \rightarrow$ need NC DIS cross sections at same x and Q^2 but different y
- Measurement of NC DIS cross section with different centre-of-mass energies
  $\rightarrow$ first look at MER/LER data: big progress, but MC still not perfect

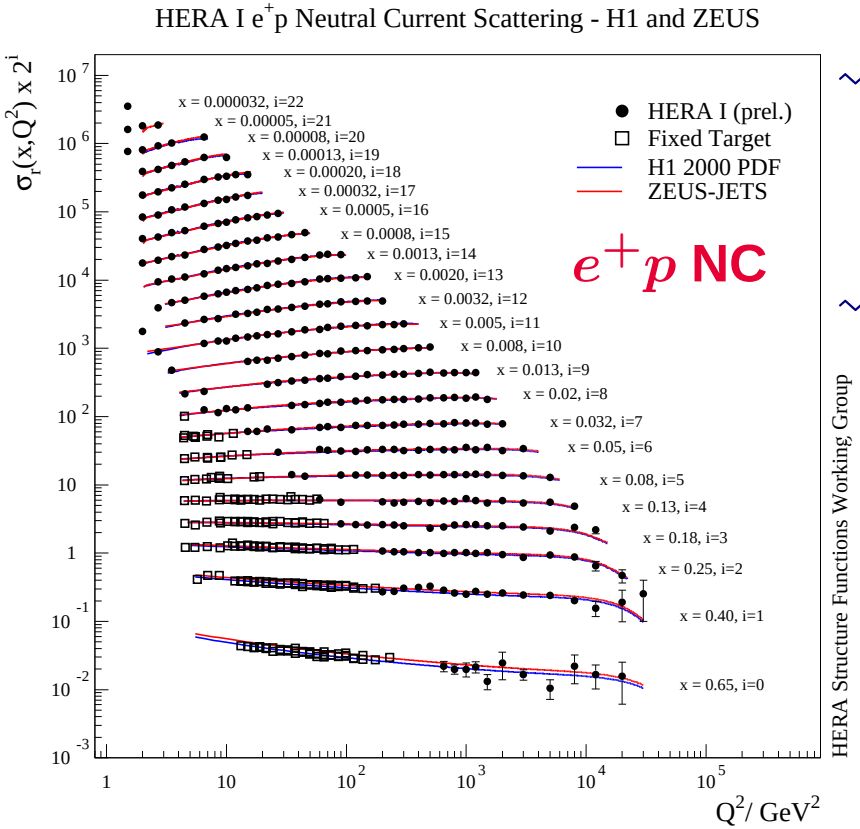
MER ($E_p = 575$ GeV, $\sqrt{s} = 252$ GeV) LER ($E_p = 460$ GeV, $\sqrt{s} = 225$ GeV)



$\Rightarrow$ Collected data during MER and LER together with HER cross sections will allow measurement of F_L

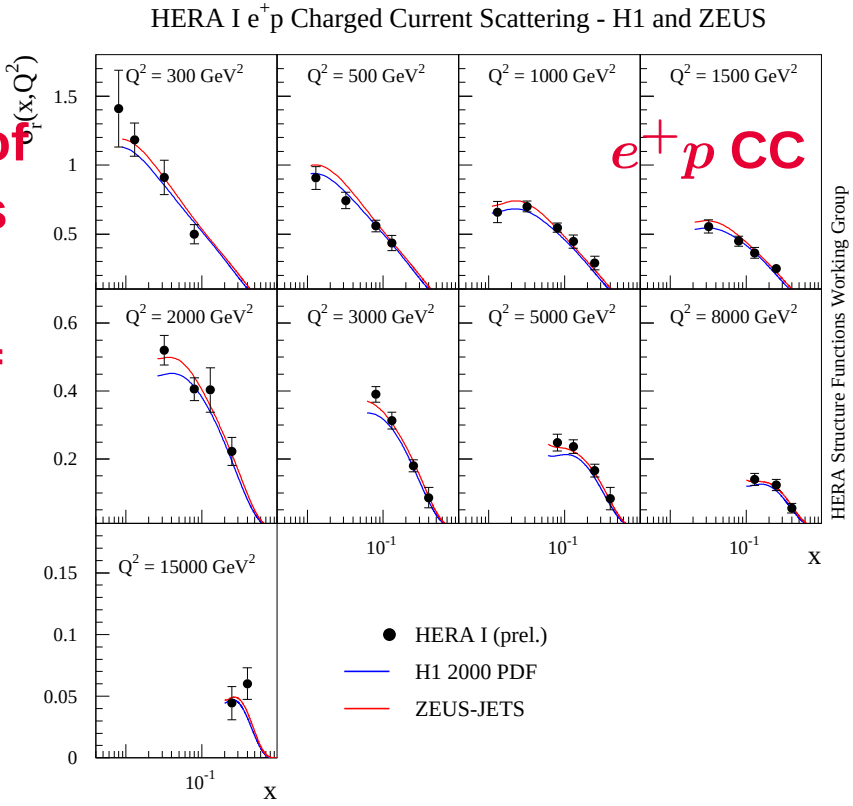
Towards final PDFs from HERA...

- **After 15 years of HERA operation: 1 fb^{-1} of combined H1 + ZEUS data**
  $\rightarrow$ most precise parameterisations of the proton PDFs
- **First step:**
  $\hookrightarrow$ average of $e^{\pm}p$ HERA I NC and CC cross sections ($\sim$ 115 pb^{-1} per experiment)



$\rightsquigarrow$ cross-calibration of experiments

$\rightsquigarrow$ coherent treatment of systematics



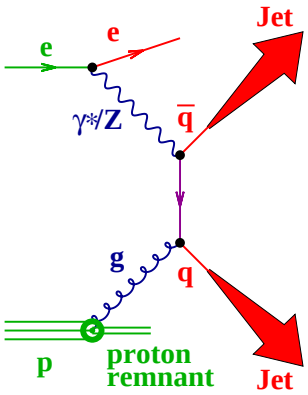
$\Rightarrow$ Reduction of systematic uncertainties $\Rightarrow$ more precise PDFs

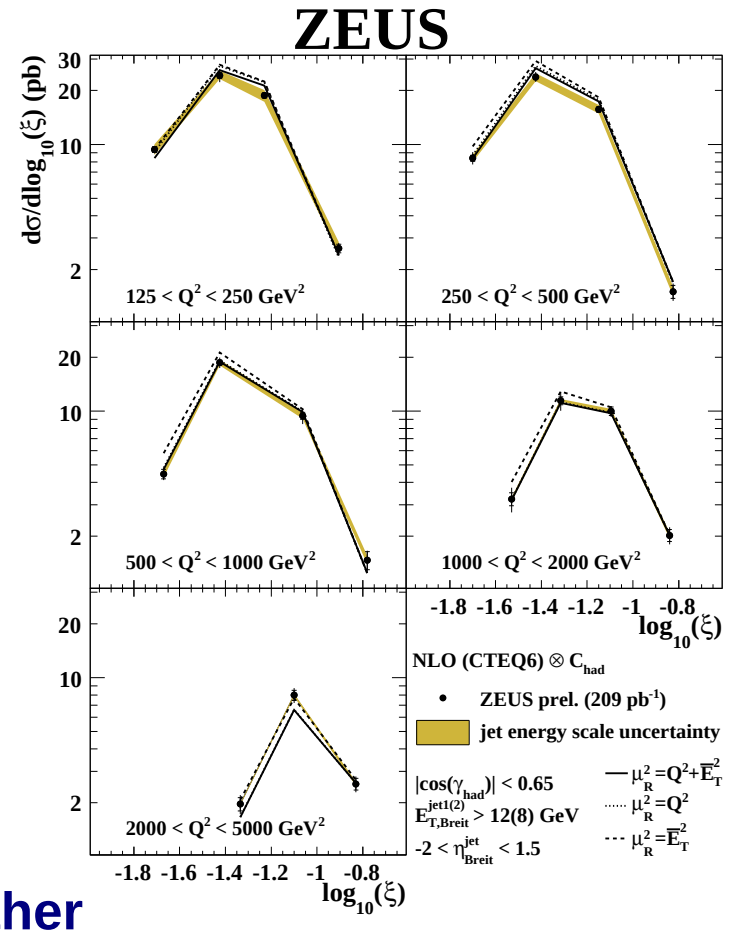
Towards final PDFs from HERA...

- **Model-independent method of combining cross sections allows substantial reduction of uncertainties**
- **Next steps:**
  - **extend combination of H1 and ZEUS data to HERA I + HERA II**
  - **include more data sets**

eg, dijet cross sections in NC DIS (HERA I + HERA II)

→ directly sensitive to gluon PDF





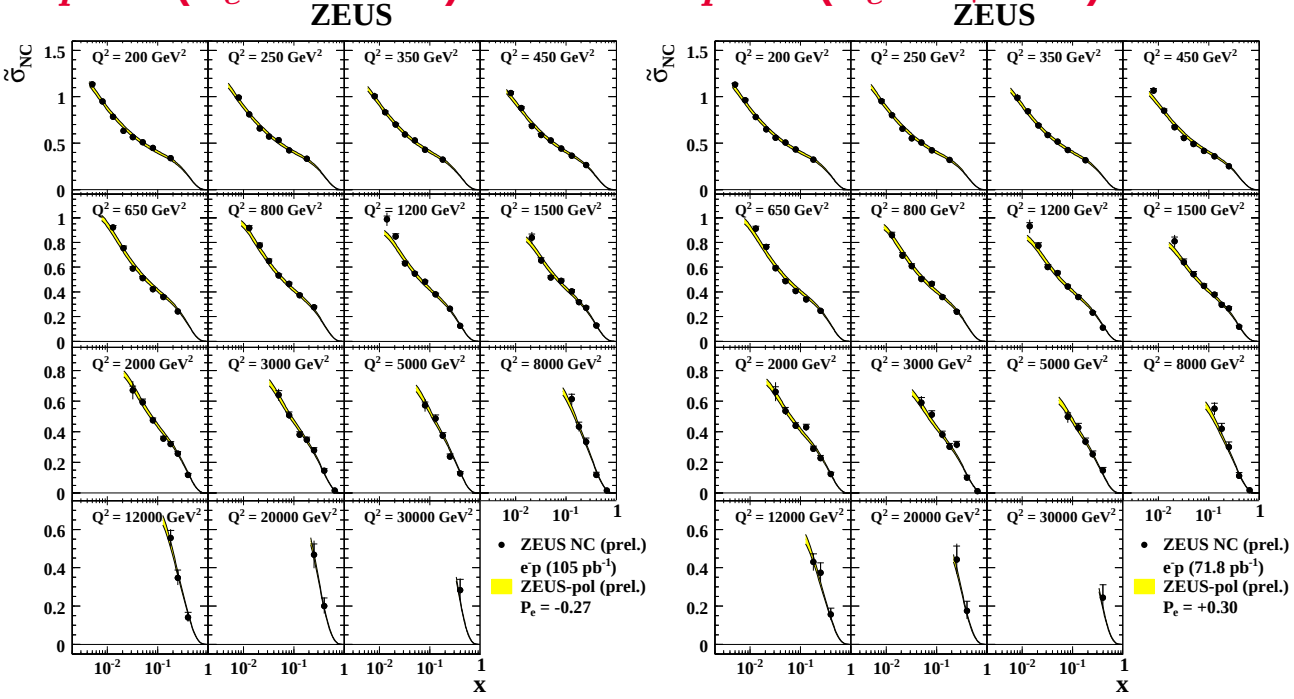
$$\xi = x_{\mathrm{Bj}}\left(1 + \frac{M_{jj}^2}{Q^2}\right)$$

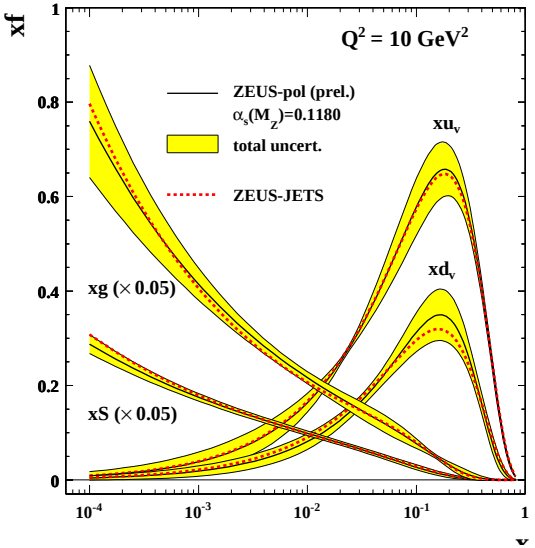
⇒ Constrain gluon PDF further

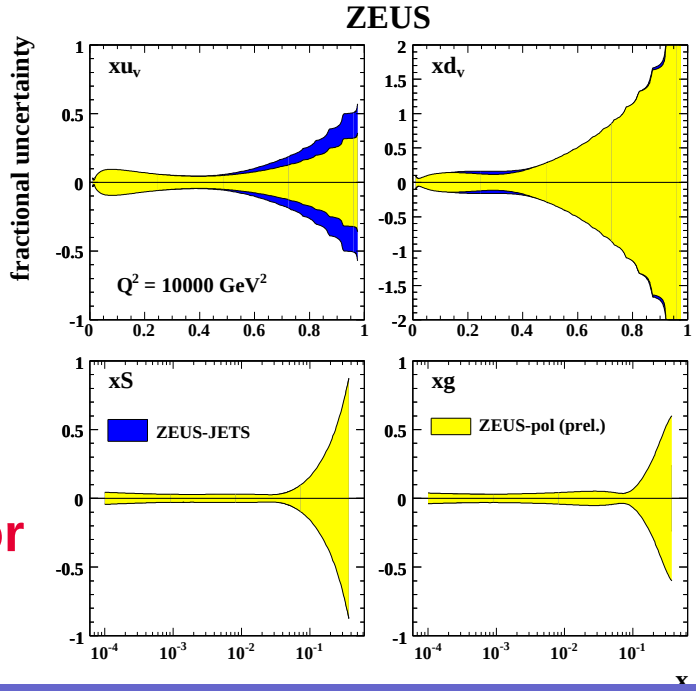
Towards final PDFs from HERA...

- **Update of ZEUS PDF fits → ZEUS-Pol fit:**
  - → polarised NC and CC HERA II data included
  - → NC DIS and PHP jet cross sections included
  - → 4-EW parameters free plus PDF parameters

e^-p NC ($P_e = -0.27$) e^-p NC ($P_e = +0.30$)



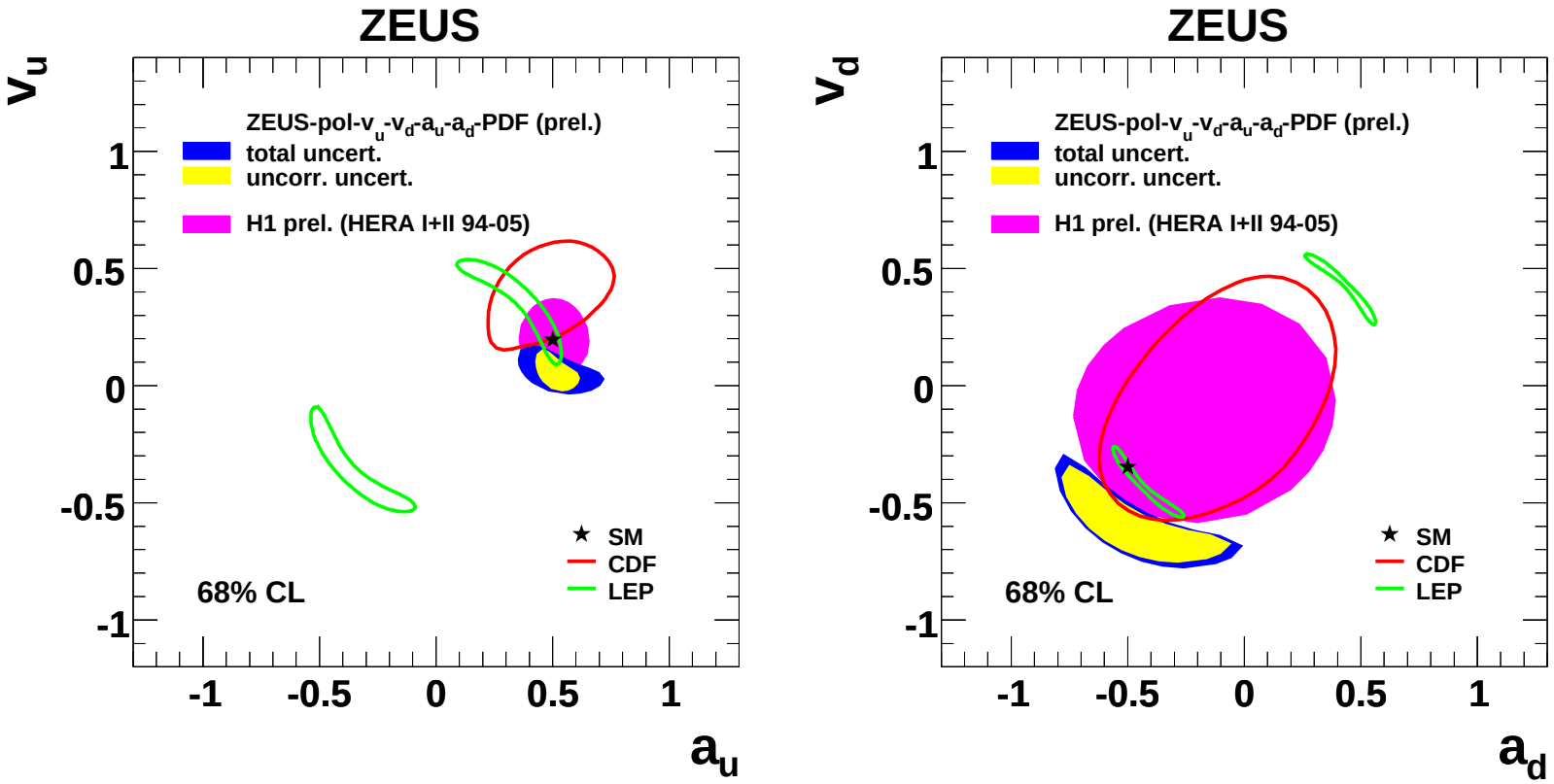




⇒ **ZEUS-Pol vs ZEUS-Jets: uncertainty on u_V much reduced (due to inclusion of e^-p data) at high x for all Q^2 → high Q^2 relevant for LHC physics**

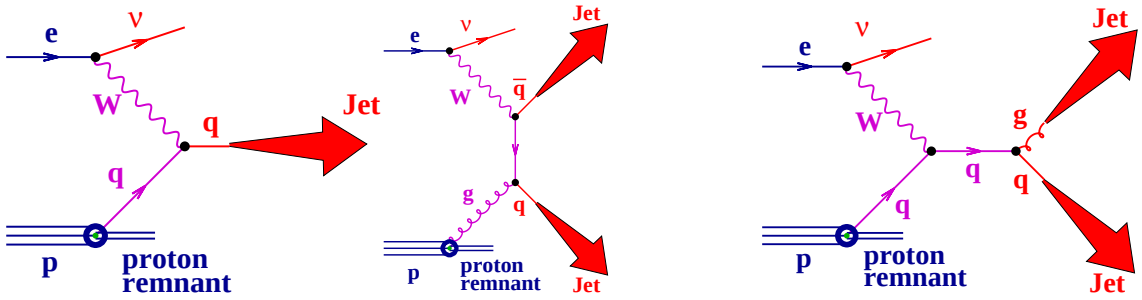
Electroweak analysis

- **Simultaneous extraction of electroweak couplings of quarks and PDF parameters**
  → **in EW, 4-parameter fit: now possible because of HERA II data included**
- **HERA I + HERA II data included: polarised and unpolarised cross sections**
  → **unpolarised xF_3 sensitive to a_i**
  → **polarised F_2 sensitive to v_i**



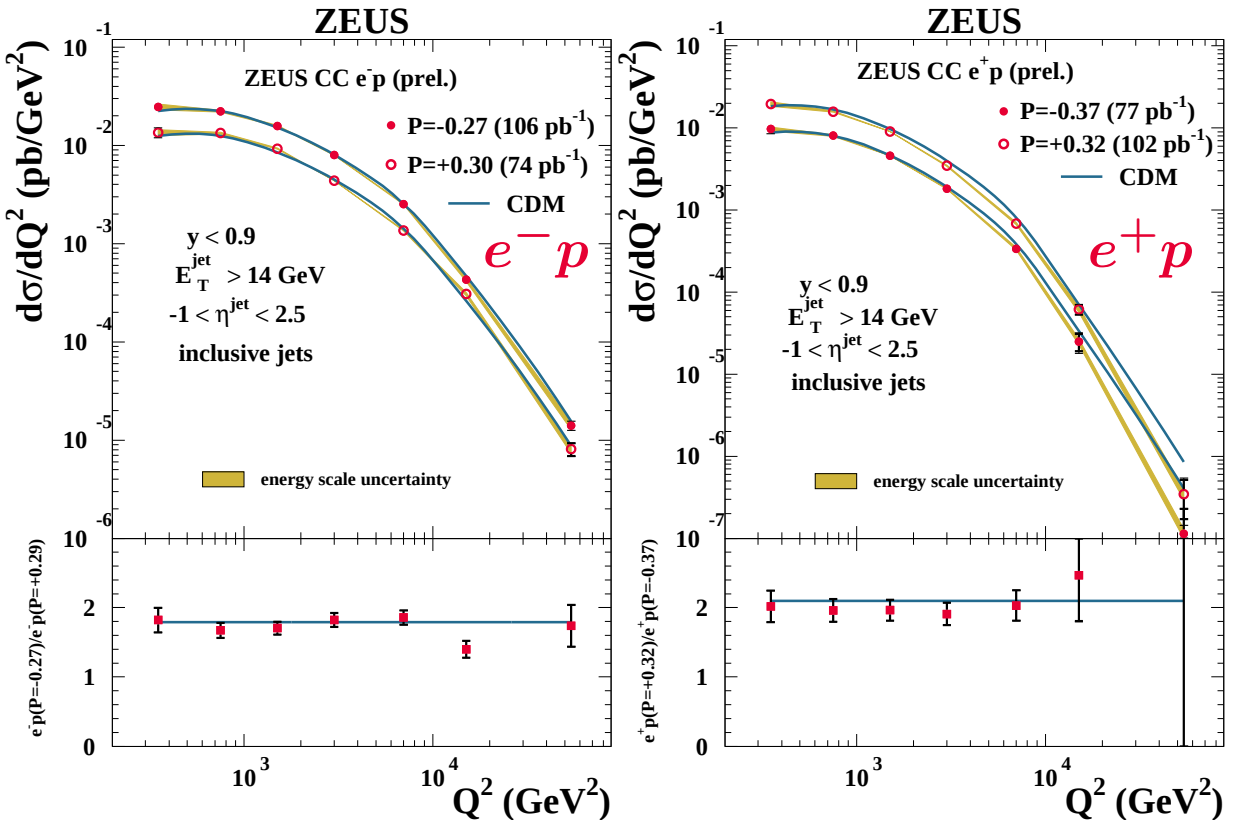
⇒ **Results are very precise: resolved sign in d quark couplings**

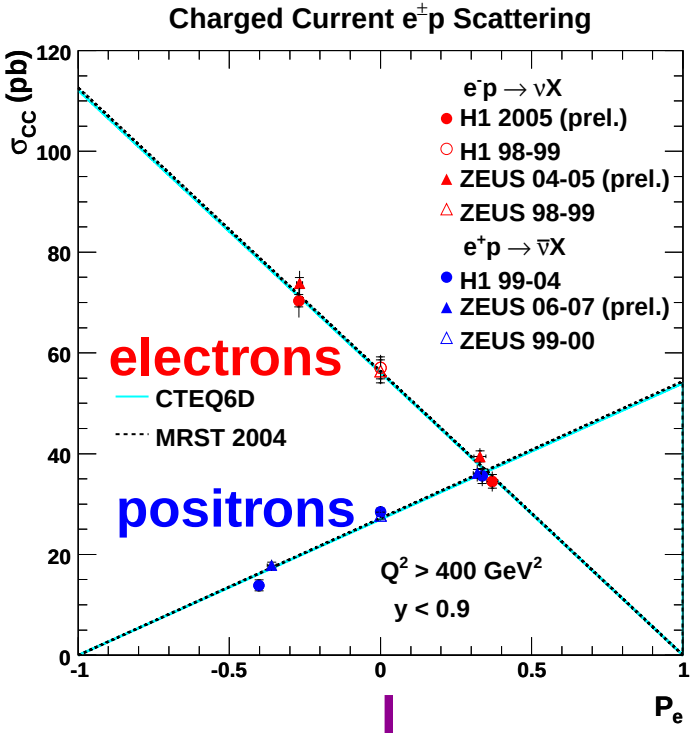
CC DIS and polarisation



HERA II data

$$\sigma^{\pm}_{CC}(P_e) = (1 \pm P_e)\sigma^{0}_{CC}$$





CC $e^{\pm}$ "total" cross section vs P_e

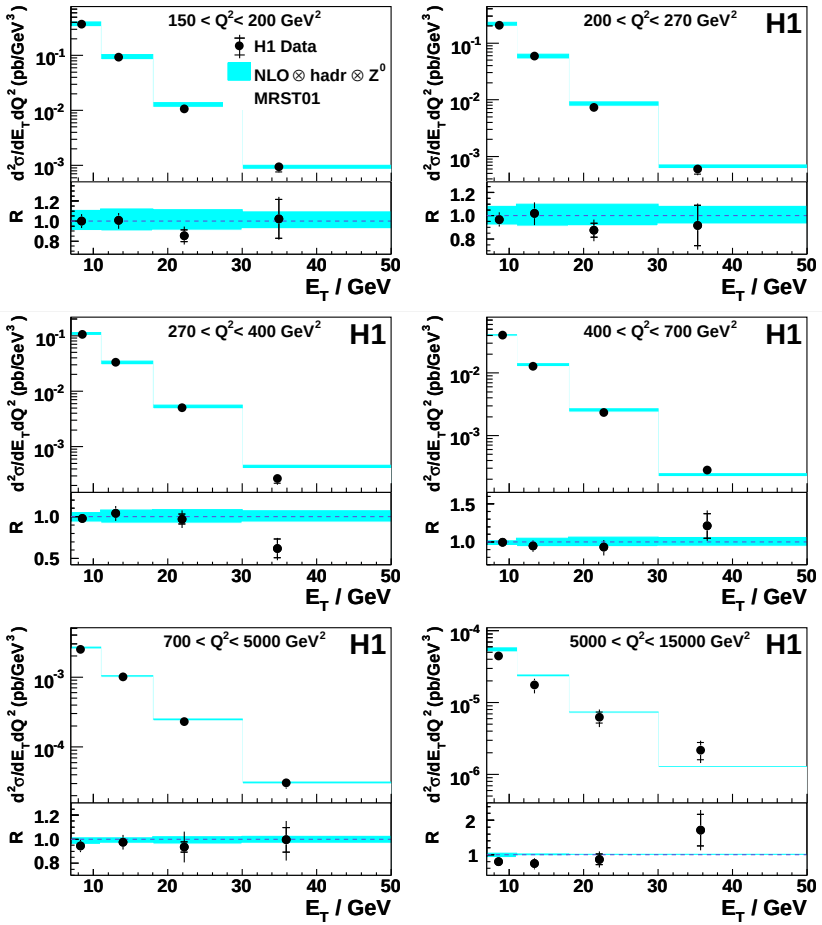
→ **jet cross sections in CC $e^{\pm}$ for different P_e**

⇒ **Good agreement with SM predictions**

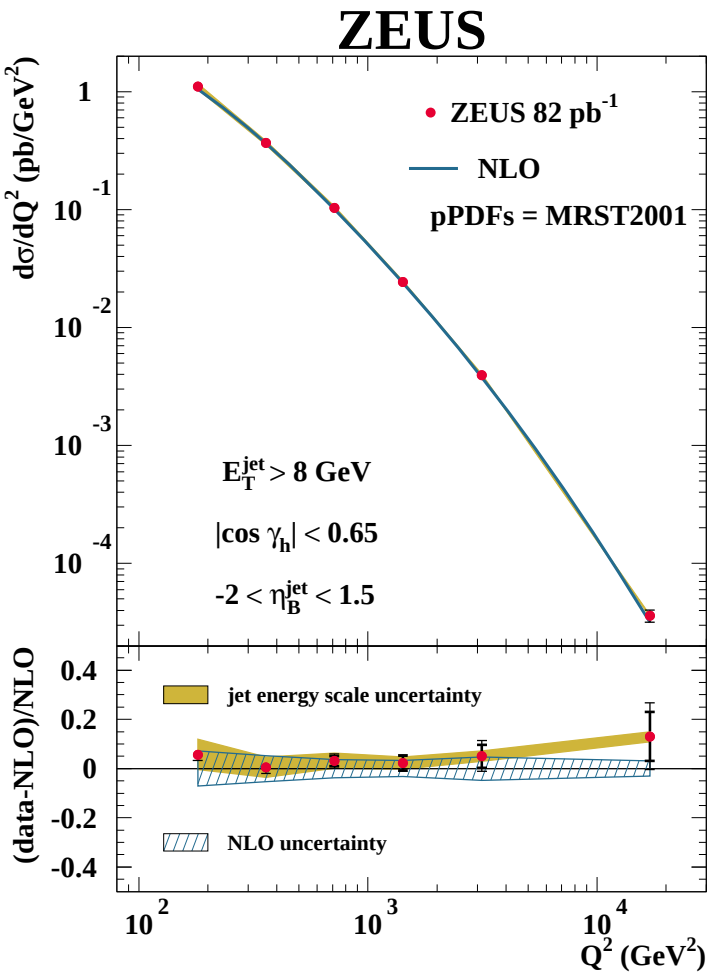
HERA combined 2007 $\alpha_s(M_Z)$

- New $\alpha_s(M_Z)$ combination from inclusive-jet cross sections in NC DIS
  - make simultaneous fit to ZEUS and H1 data sets which yield the most precise $\alpha_s(M_Z)$ values (instead of combining $\alpha_s(M_Z)$ values)

Inclusive Jet Cross Section



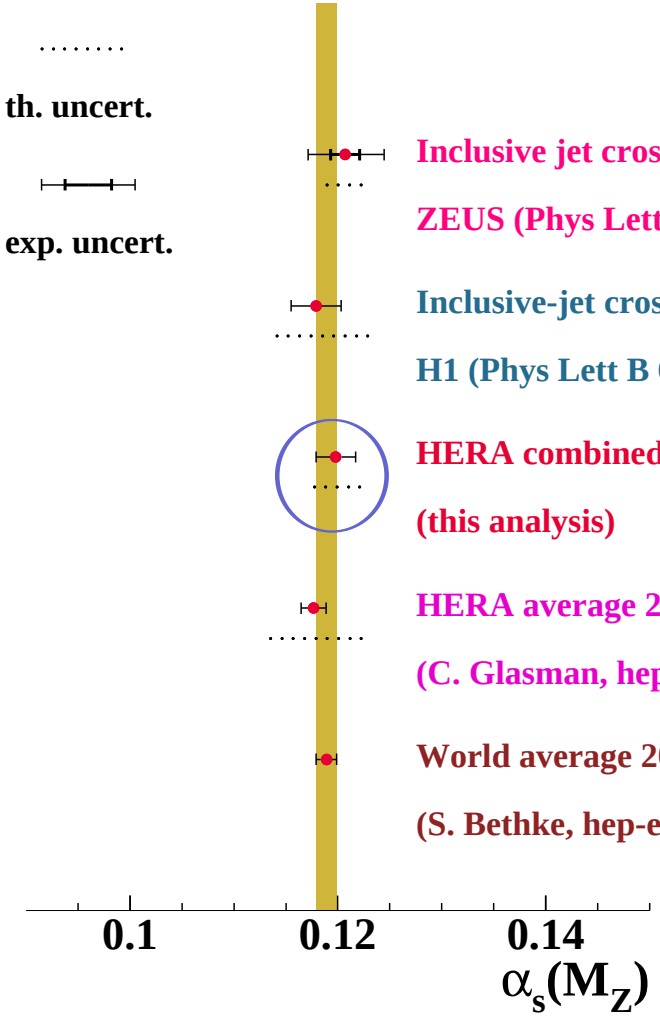
- cross-calibration of experiments
- coherent treatment of systematics
- selection of phase space for smallest theoretical uncertainties

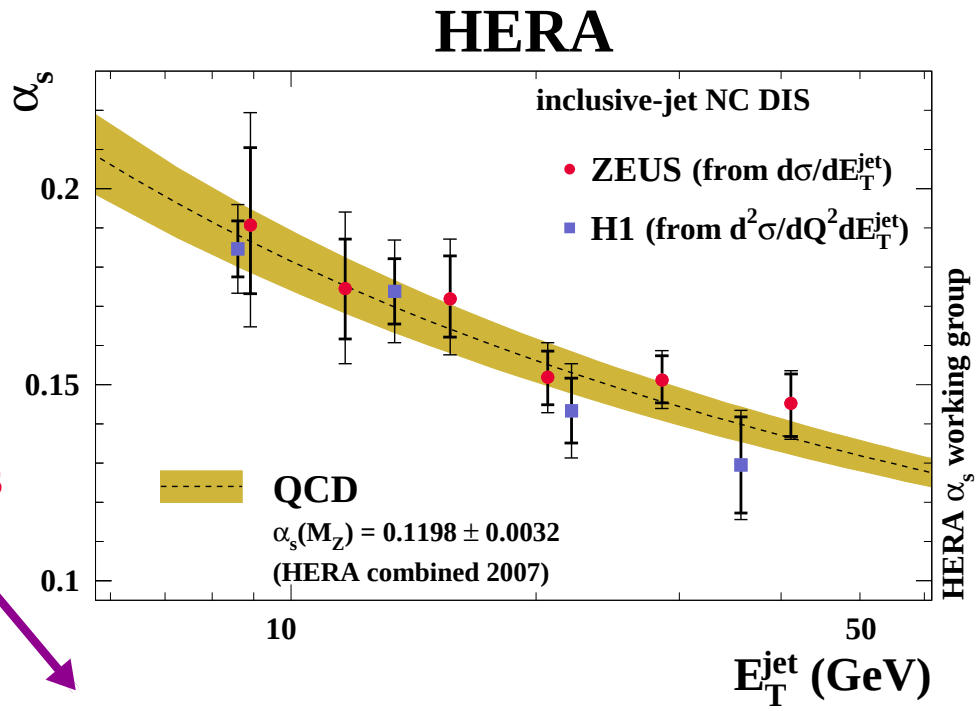


H1 Collab, Phys Lett B 653 (2007) 134

ZEUS Collab, Phys Lett B 649 (2007) 12

HERA combined 2007 $\alpha_s(M_Z)$





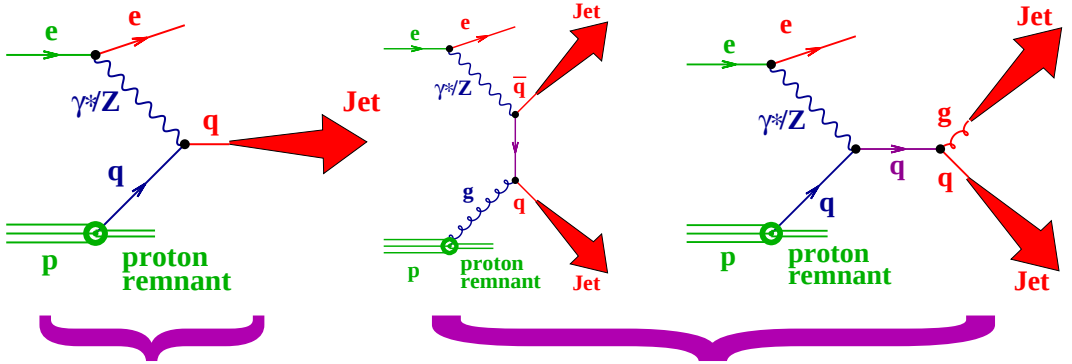
$$\alpha_s(M_Z) = 0.1198 \pm 0.0019\ (\text{exp.}) \pm 0.0026\ (\text{th.})$$

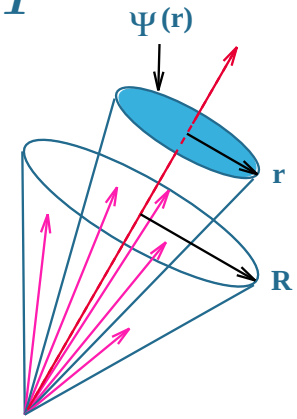
$\Rightarrow$ **Very precise value of $\alpha_s(M_Z)$: 2.7% uncertainty**

$\Rightarrow$ **Observation of the running of α_s in a wide range of E_T^{jet} from HERA jet data alone**

Jet substructure in NC DIS

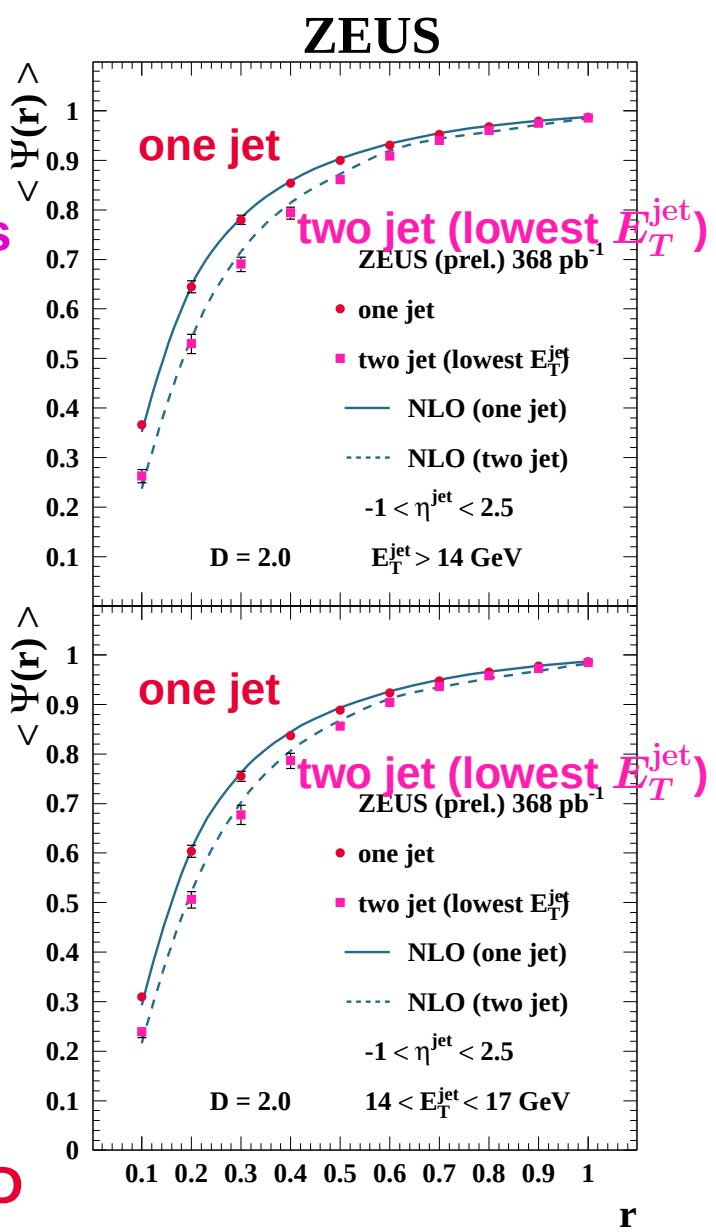
- **Jet substructure:** HERA II data
  - stringent tests of pQCD
  - differences between quark and gluon jets
    - → gluon jets expected to be broader than quark jets
- **Integrated jet shape:** average fraction of E_T^{jet} within $r = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ of jet axis





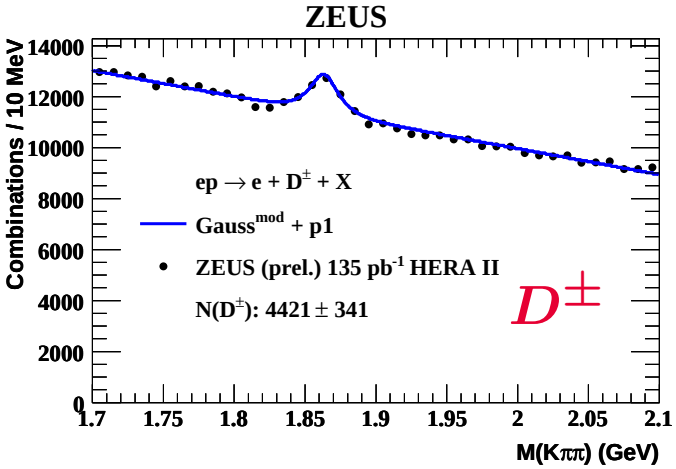
one-jet events enriched in quark jets

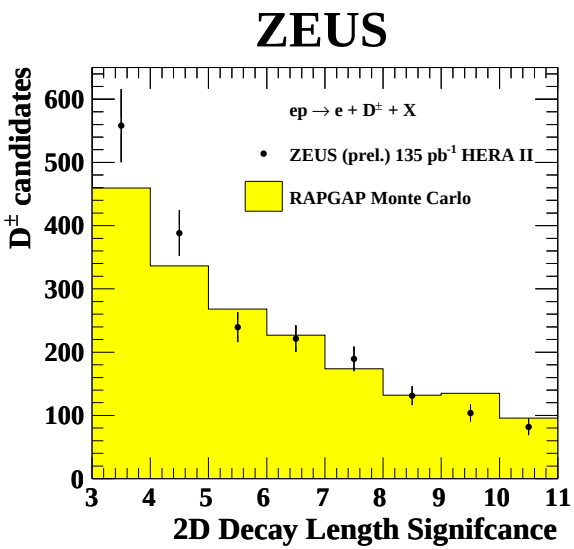
two-jet events higher content of gluon jets

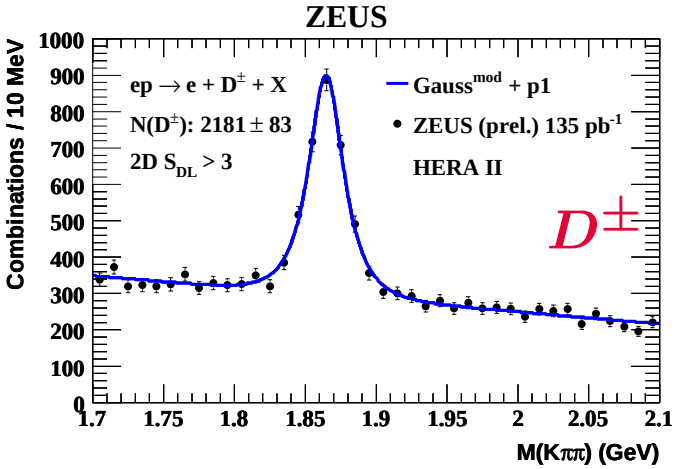


⇒ The lowest-E_T^{jet} jet in the two-jet sample is broader than the one-jet sample: consistent with a higher gluon content in two-jet events, as predicted by pQCD

Charm production with HERA II data



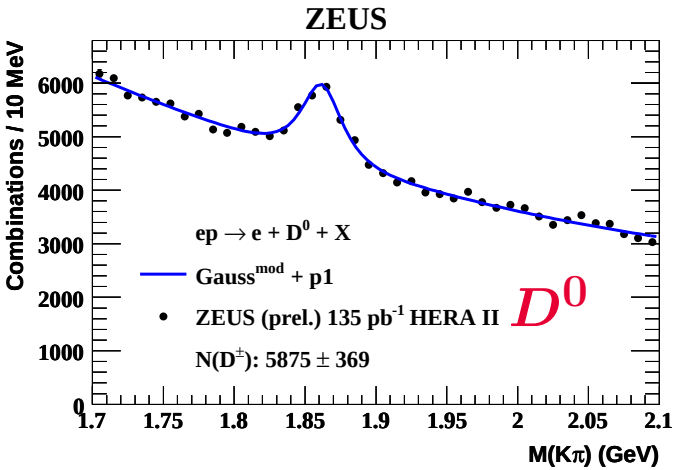


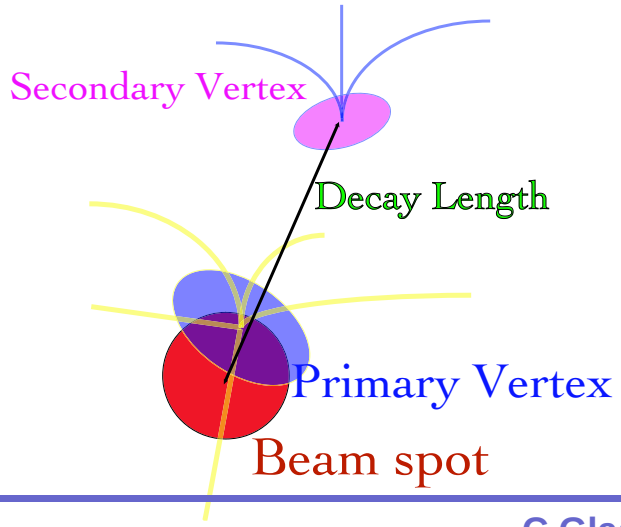


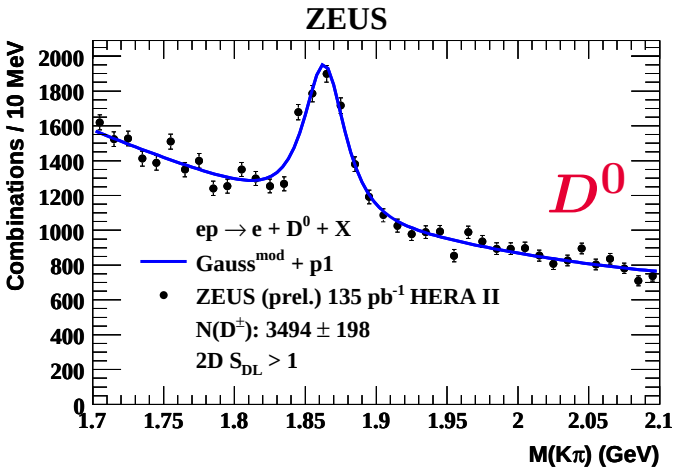
- **Charm-meson production with HERA II data using the silicon Micro Vertex Detector**

- **Better signal to background ratio after cut on decay length significance**

$$S_l = l/\sigma_l$$

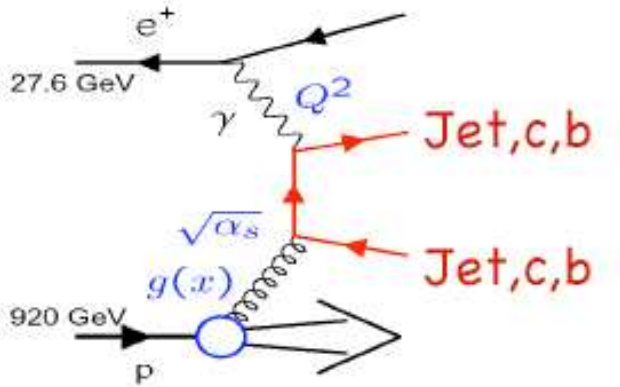




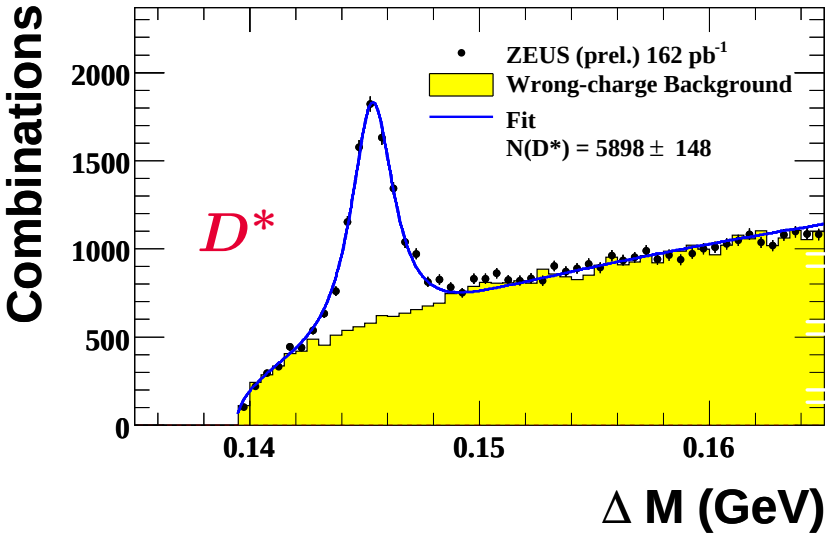


Charm contribution to F_2

- $F_2^{c\bar{c}}$ unfolded from
  – D^+, D^0, D_S^+ and D^* in DIS
  with HERA I + HERA II data

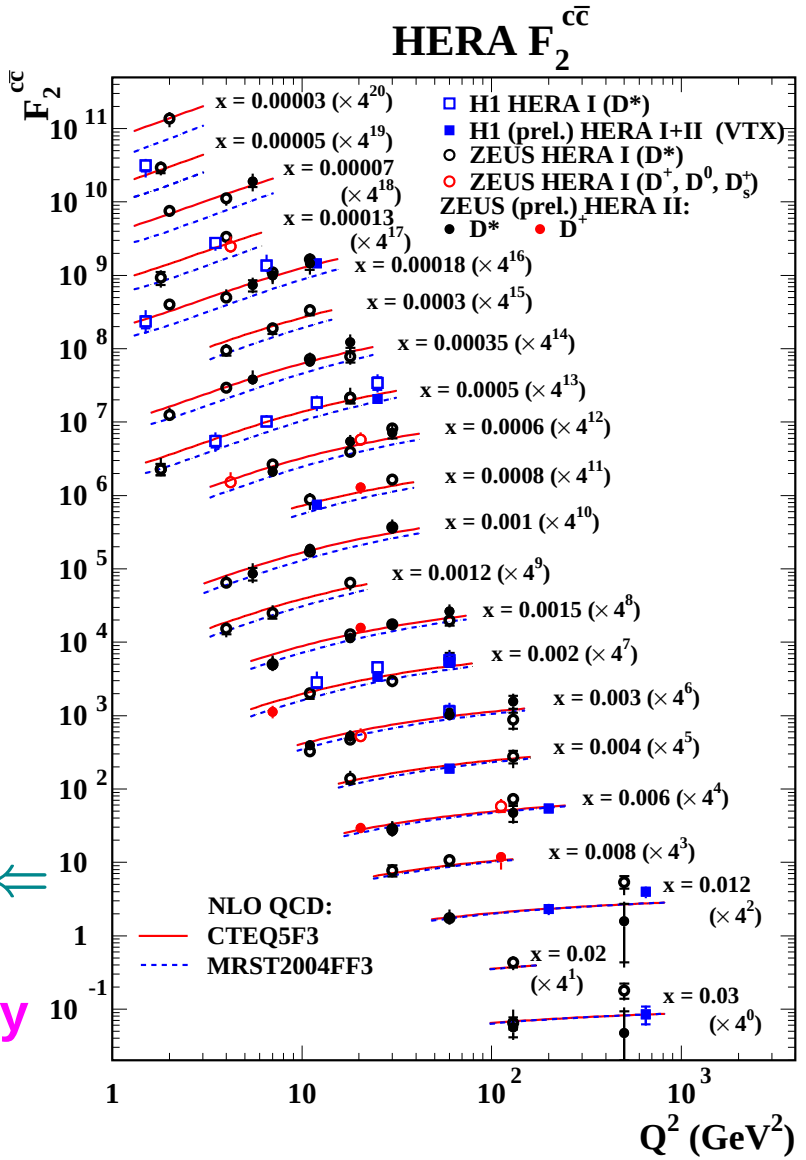


- $F_2^{c\bar{c}} \sim 25\% F_2$



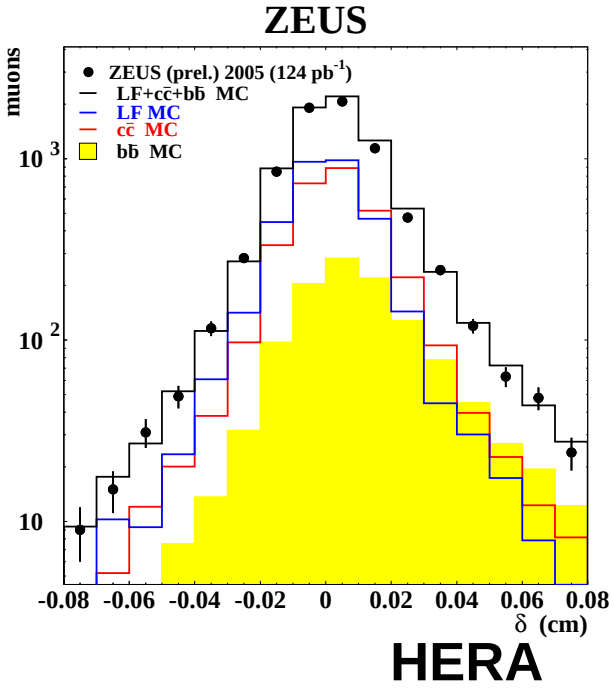
Strong ⇐ scaling violations observed

Observable ⇐ sensitive to gluon density



⇒ **Good precision of measurements:** will help to solve ambiguity in HF scheme

Beauty photoproduction and beauty contribution to F_2



HERA

- Beauty production has been identified in HERA II data in events with jets and muons

← μ impact parameter

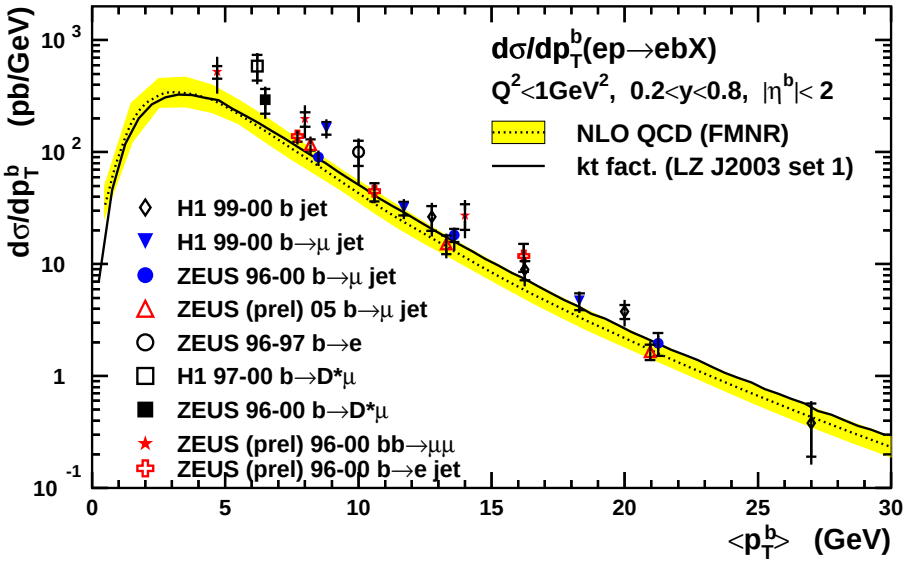
- Beauty signal extracted as

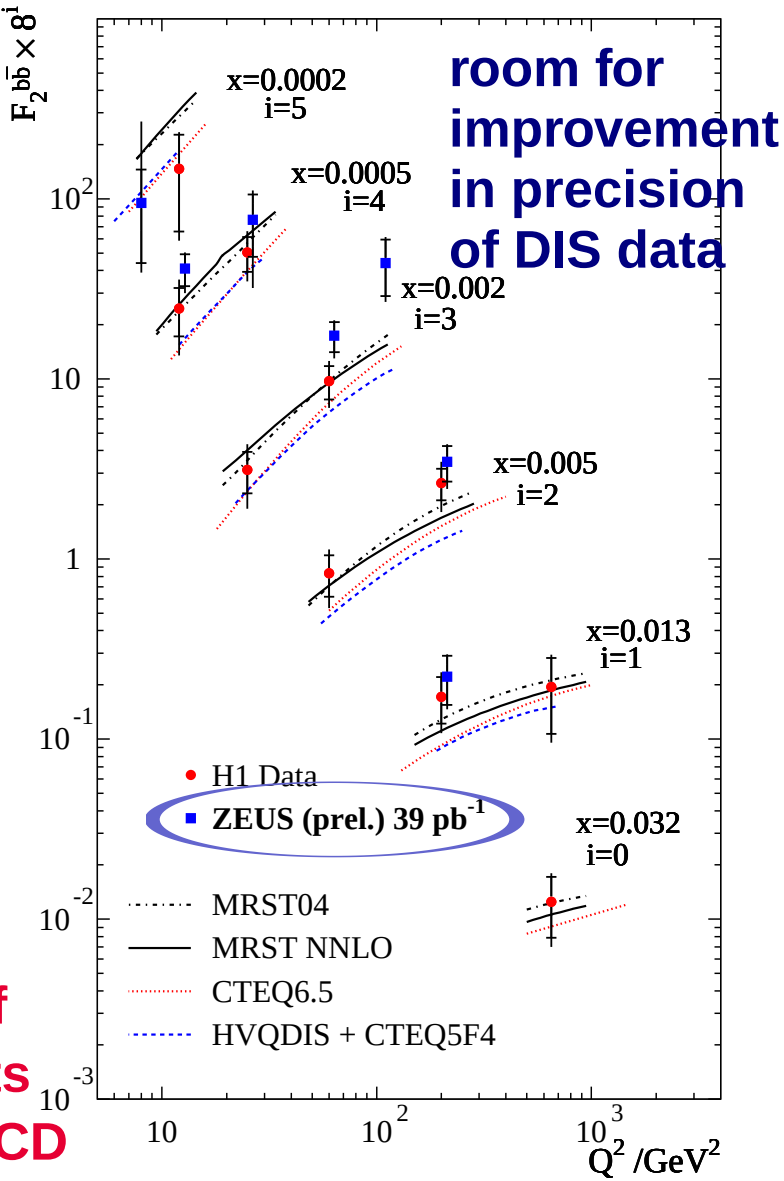
$$N_b = N_{\text{data}} * f_b$$

- $F_2^{b\bar{b}} \sim 1\% F_2$

Strong ⇐ scaling violations observed

⇒ Good description of measurements in PHP by pQCD

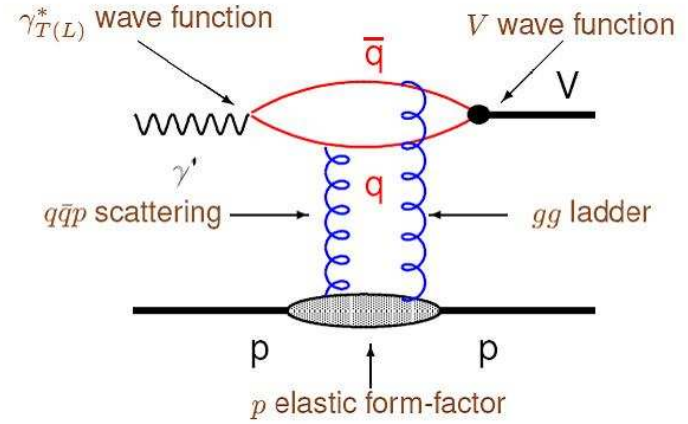


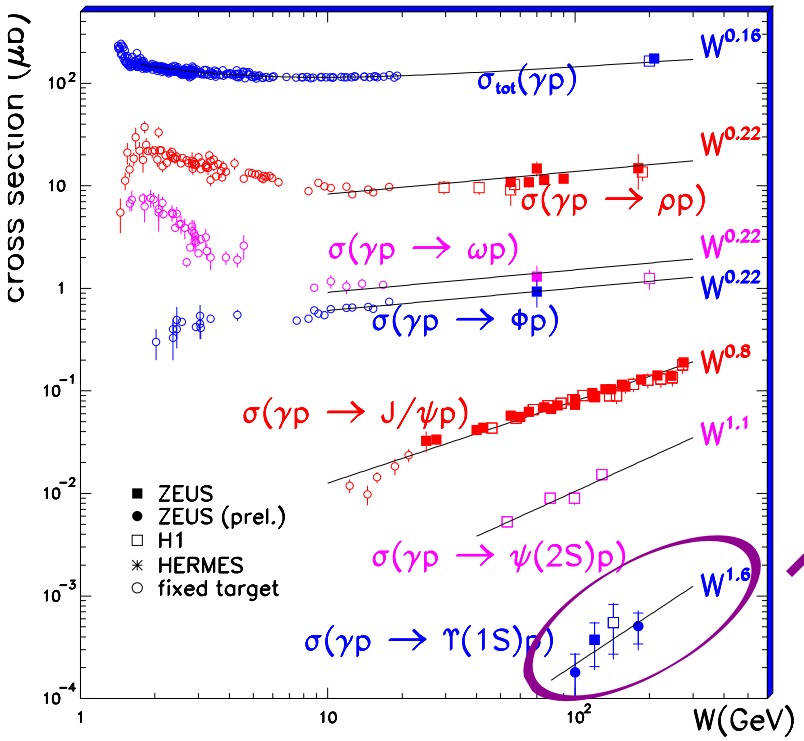


room for improvement in precision of DIS data

Exclusive vector-meson production: Υ photoproduction

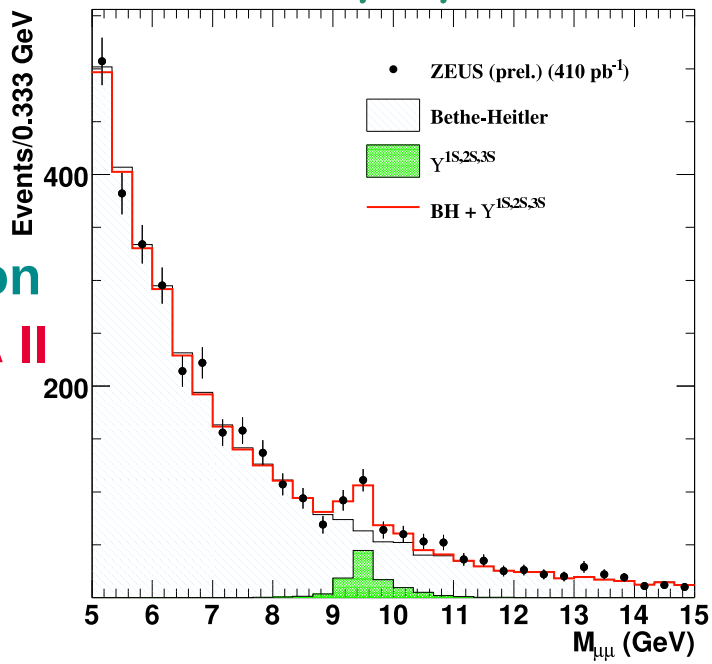
- **Exclusive vector-meson production via two-gluon exchange**





- **Υ in photoproduction with HERA I + HERA II data**

- **Signal searched in $\mu^+\mu^-$ channel**



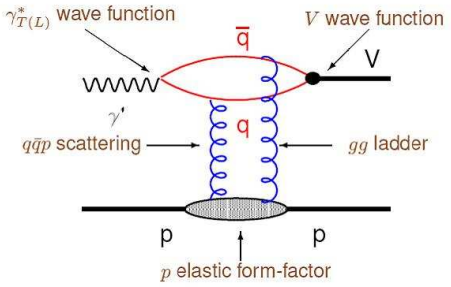
- **5σ Υ signal observed**

$\Rightarrow$ **Fit of cross section vs W for the first time: consistent with a high power of W**

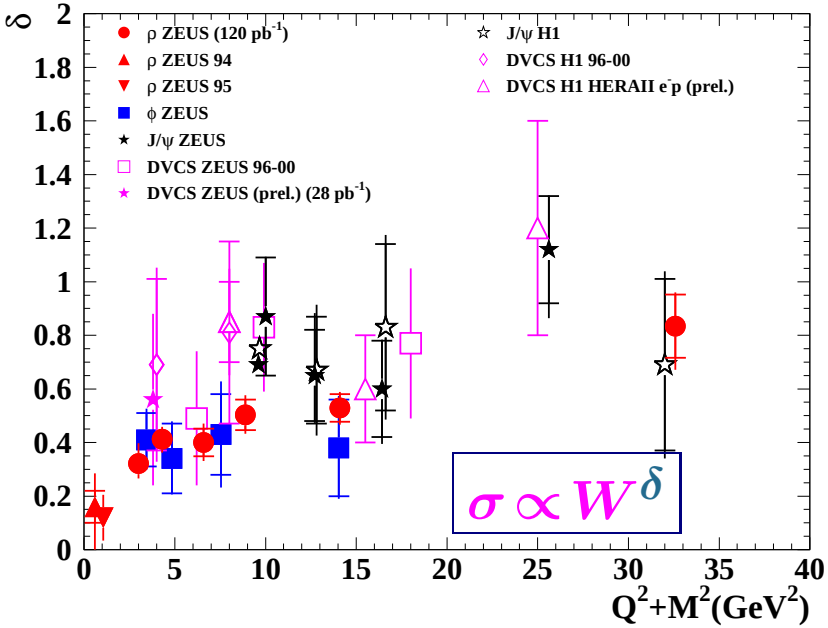
$\Rightarrow$ **Information on generalised parton distributions (GPDs): three-dimensional picture of proton**

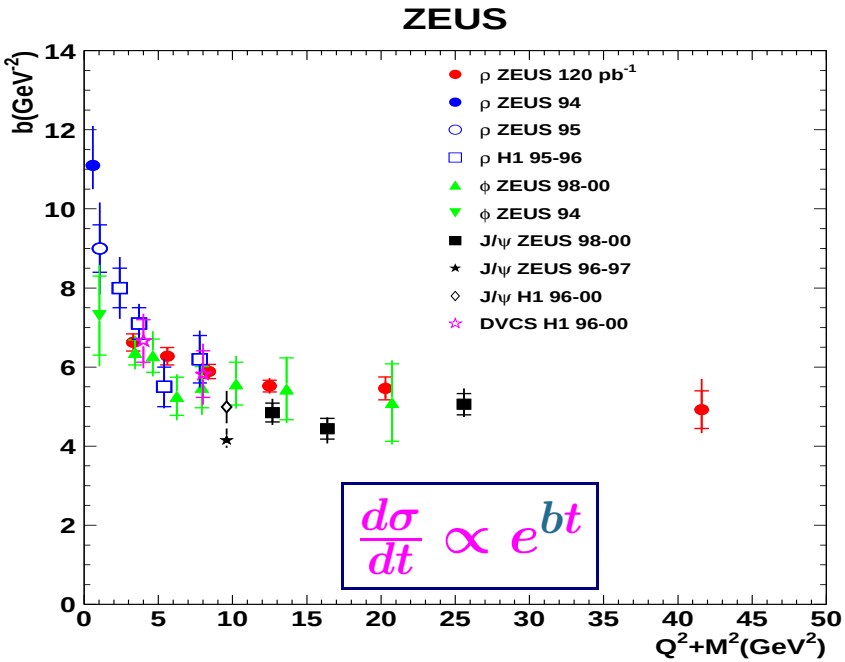
Exclusive vector-meson production: ρ^0 in DIS

- Very precise ρ^0 measurements in DIS from all HERA I data
- Consistent picture of exclusive vector-meson production in PHP and DIS via two-gluon exchange



- Constraints on the gluon and spatial distributions of the proton



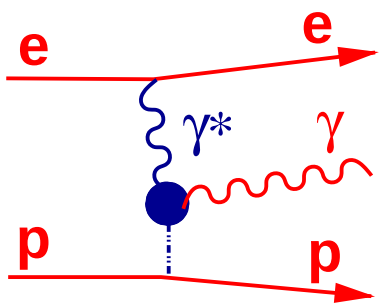


$\Rightarrow$ Value of δ and its dependence with the scale are similar

$\Rightarrow$ Decrease of b with scale and asymptotic value are similar

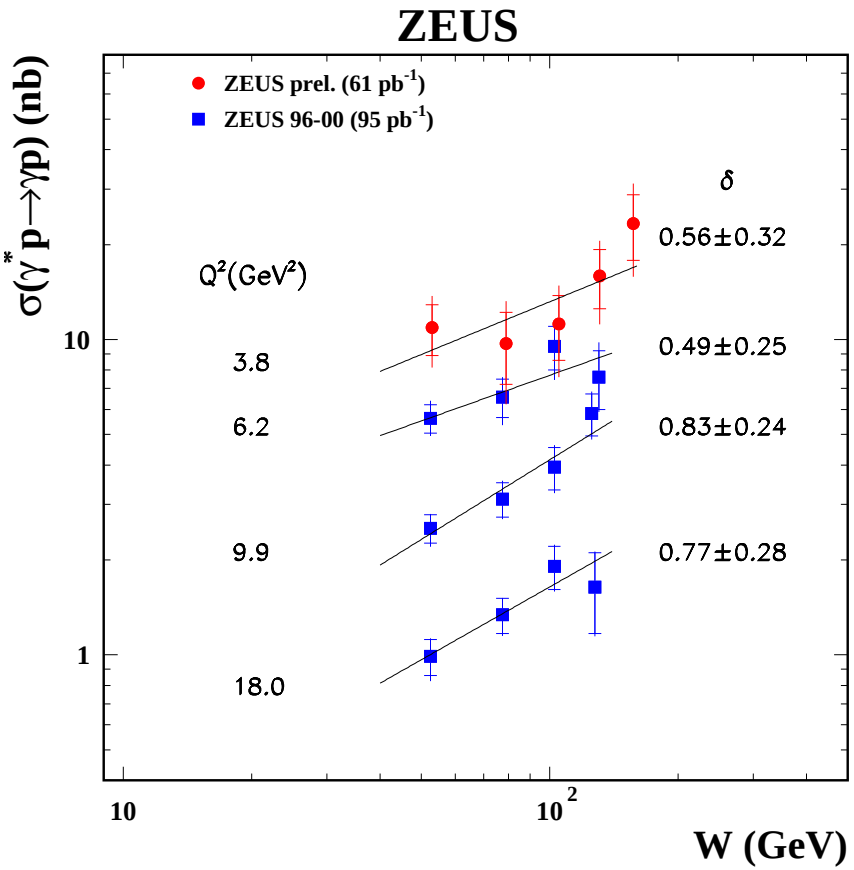
for all exclusive processes

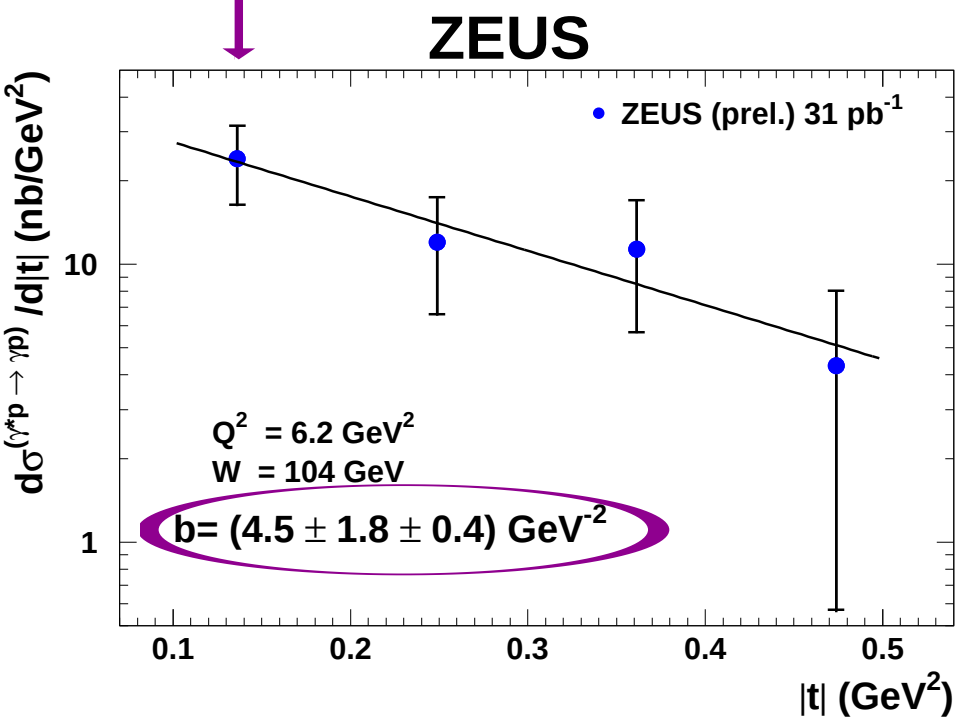
Deeply virtual Compton scattering



QCD colorless exchange

- DVCS predictions depend on the GPDs
  → information about the proton wave function
- Proton tagged in the LPS: first direct measurement of t distribution → information on the impact parameter (b)





⇒ New cross-section measurements vs W at lower Q^2

⇒ More information for constraining models

Conclusions and outlook

- **HERA legacy (1992-2007):**
  → **fifteen years of ZEUS physics results transcend all expectations!**
  - ★ F_2, F_3, $F_2^{c\bar{c}}$, $F_2^{b\bar{b}}$ and PDFs
  - ★ hard diffraction
  - ★ photon structure
  - ★ jets and α_s
  - ★ NC vs CC: unification of EW interactions
  - ★ pushing the limits on leptoquarks

- **ZEUS program with full HERA luminosity and combination with H1 well under way**
- **F_L measurements started**
- **Important progress in heavy flavours and diffraction**
- **Towards final results (ZEUS and H1 with HERA I + HERA II data):**
  - searches
  - PDF fits
  - EW fits
  - α_s

★ ★ ★ **ZEUS rich physics program still ongoing** ★ ★ ★