Diffractive Dijet and D* Production at ZEUS

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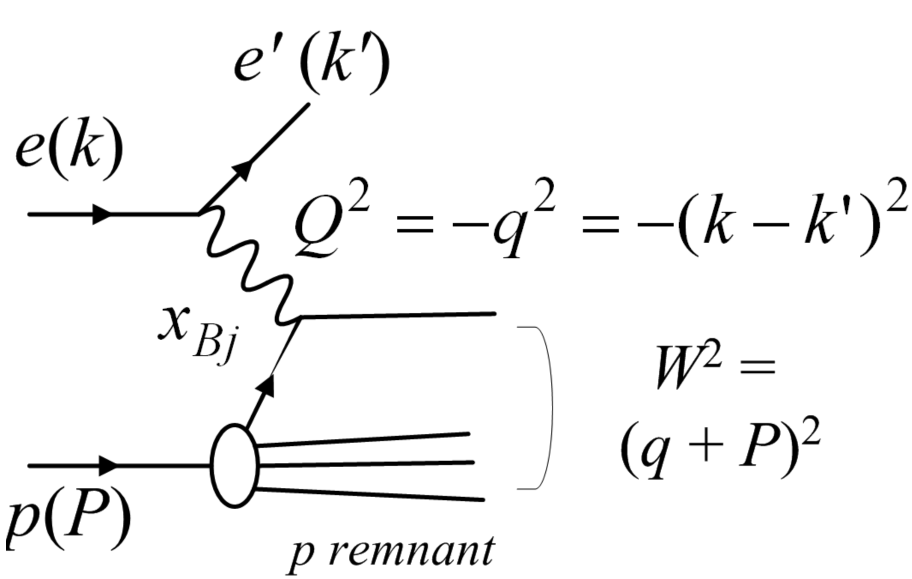
on the behalf of the ZEUS collaboration

Outline

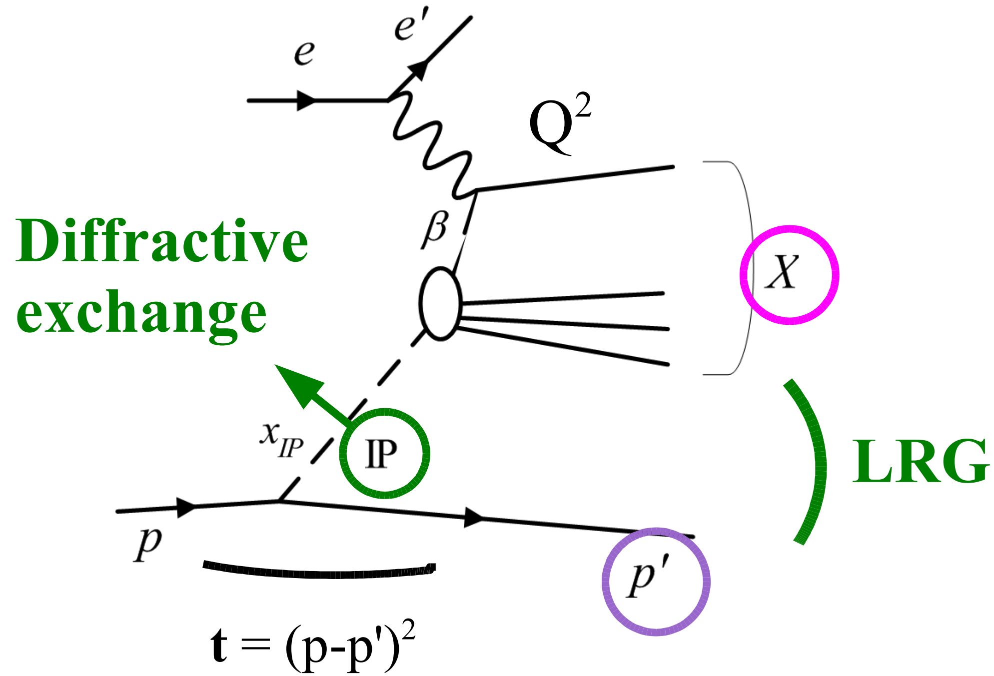
- **Introduction**
- **Dijets in diffractive Deep Inelastic Scattering (dDIS)**
- **D* in diffractive Photoproduction (dPhP)**
- **Conclusions**

Diffraction at HERA

Deep Inelastic Scattering (DIS)



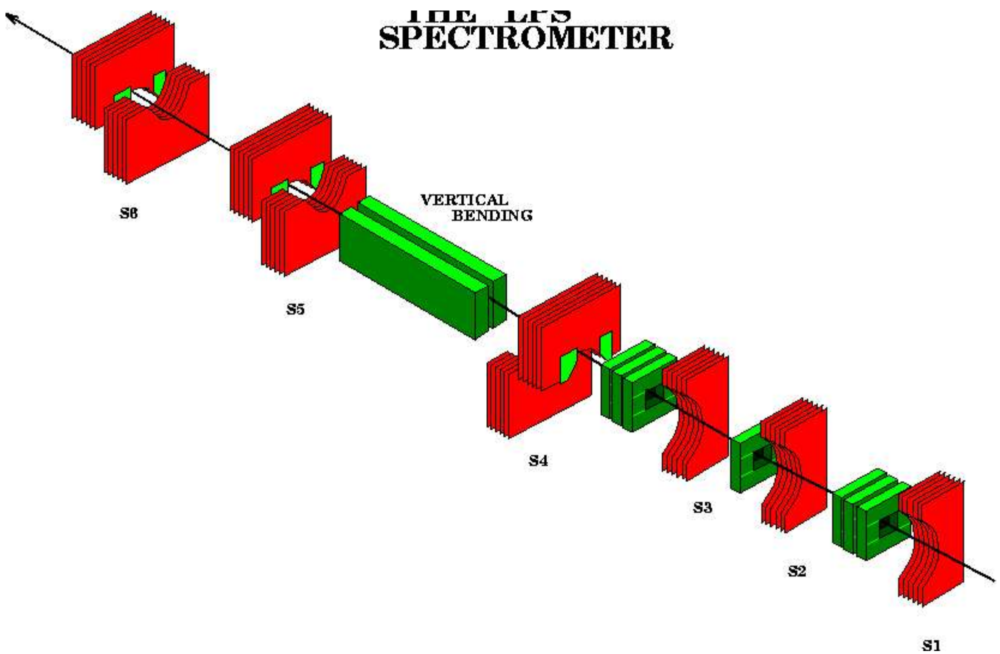
Diffractive DIS (dDIS)



- Proton emerging from the interaction only slightly perturbated
- γ^*p interaction is carried out via the exchange of an object with the vacuum quantum numbers (IP)
- Very characteristic experimental signatures
- Significative contribution to the total DIS cross section

Providing a QCD motivated description of diffraction is important for having a comprehensive understanding of the strong interaction.

Diffraction at ZEUS (1)

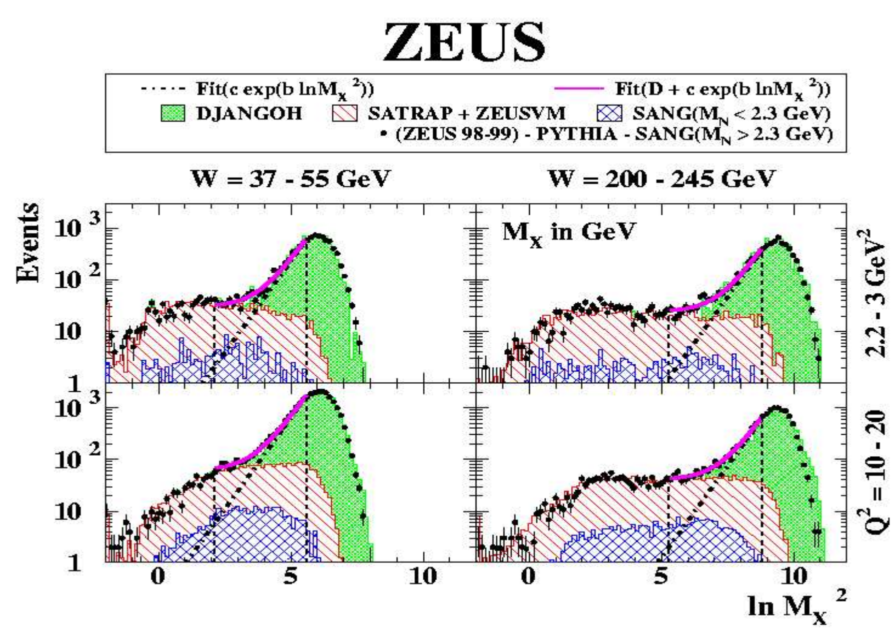


LPS method: Diffractive events can be tagged by detecting directly the scattered proton with the Leading Proton Spectrometer (LPS)

M_x method: Non-exponential fall off of the diffractive $\ln M_X^2$ distribution

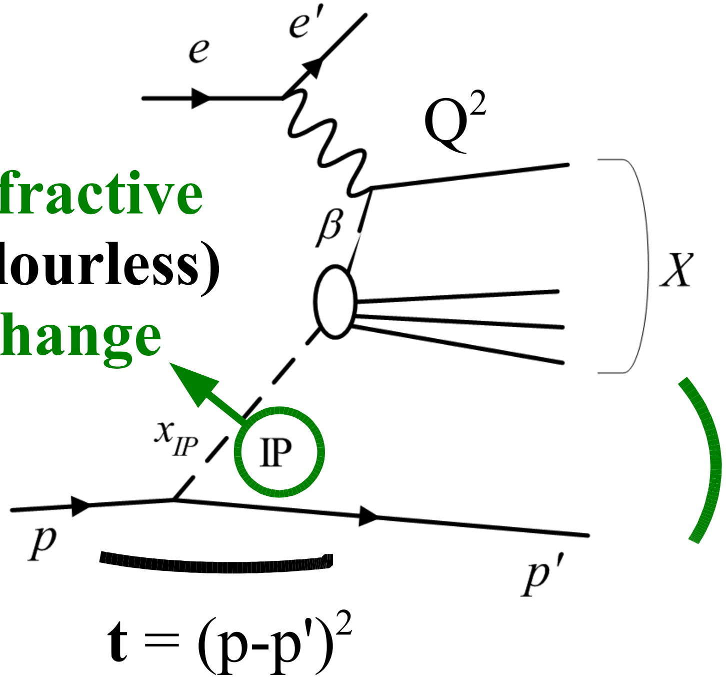
$$\frac{dN}{d\,lnM_X^2} \propto D + C \cdot e^{B*lnM_X^2}$$

Diffr. Non-diffr.



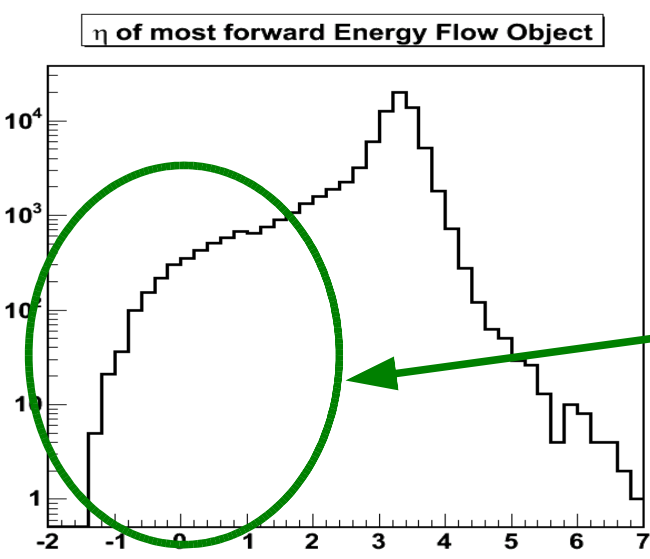
Diffraction at ZEUS (2)

Diffractive (colourless) exchange

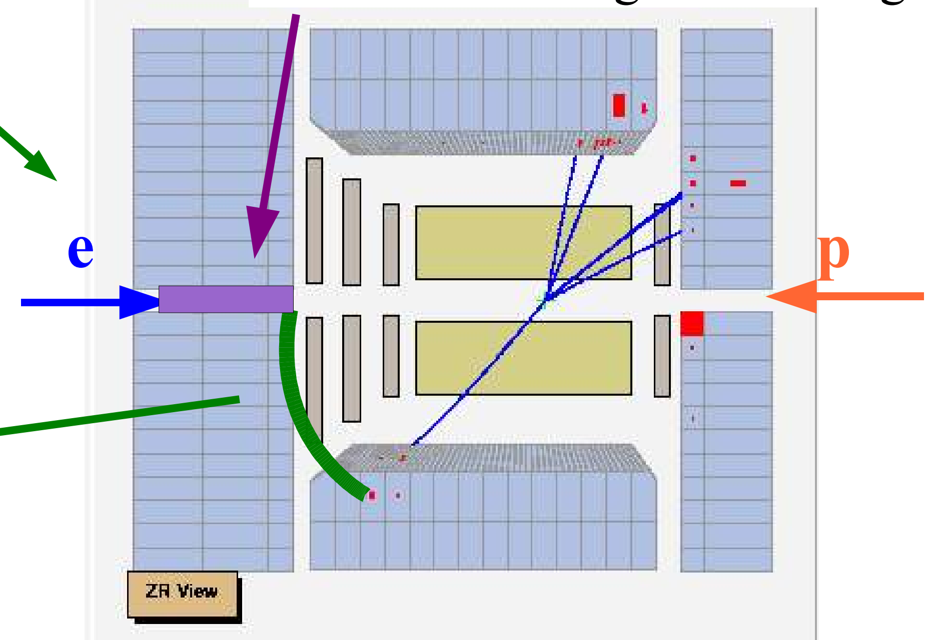


$\mathbf{t} = (p-p')^2$

LRG: Large Rapidity Gap in the direction of the scattered proton with no hadronic activity



FPC extends angular coverage



Diffractive Parton Distribution Functions (dPDFs)

Trying to use QCD theory and tools for describing diffraction

dPDFs:

- Standard parton densities + diffractive interaction
- Obtained from a QCD fit to a set of diffractive events
- "Universality": input for exclusive processes predictions. This is known as **QCD factorisation** theorem and it was proven for diffraction in DIS (1998).

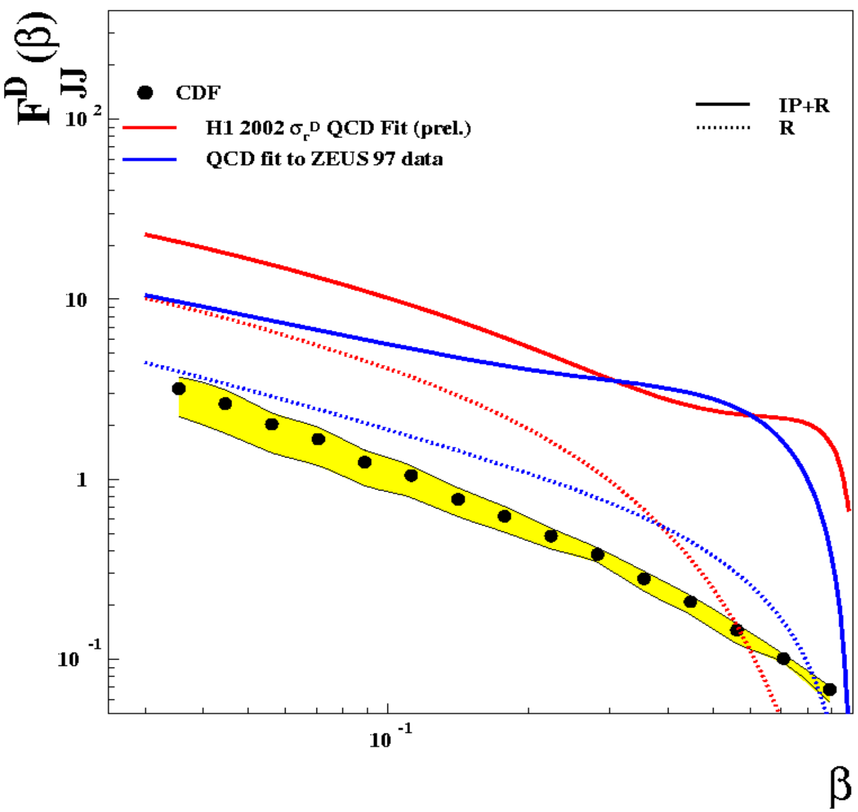
$$\sigma^D_{dijets}(\gamma * p \rightarrow Xp) \simeq \sum_{i=q,g} \hat{\sigma}_{\gamma i \rightarrow jj} f^D_i(t, x_{IP}, \beta, Q^2)$$

Process dependent scattering amplitude

Process indipendent ("universal") dPDF

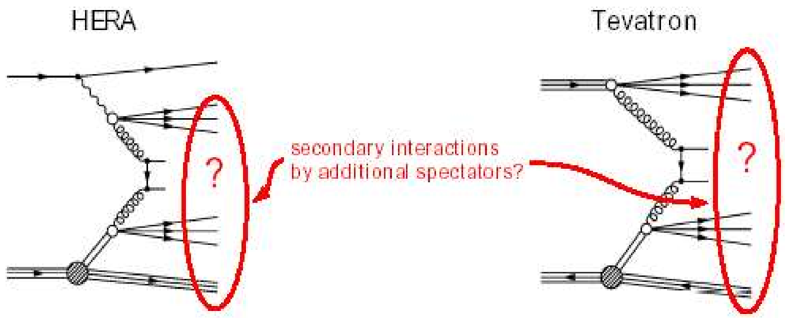
<u>As for the standard PDFs, HERA is the ideal place for extracting the dPDFs</u>

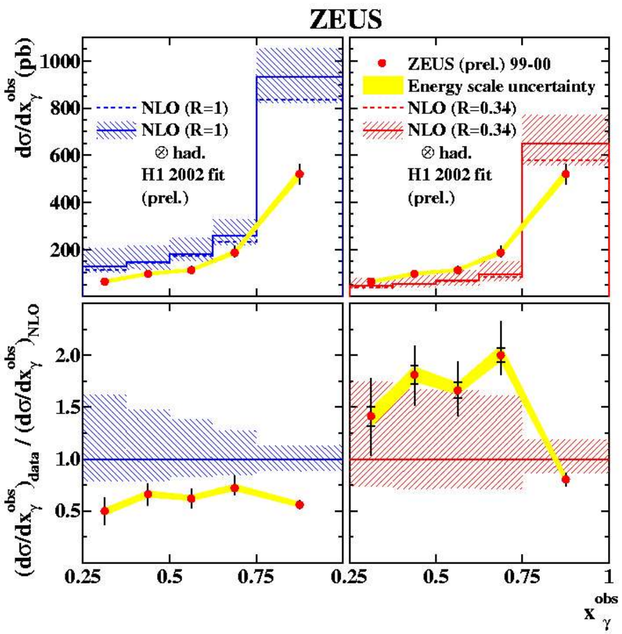
QCD Factorisation breaking



At hadron-hadron colliders this ansatz is violated (soft interactions, LRG survival probability). The same thing is expected to happen for photoproduction ($Q^2 \approx 0$) at ep colliders.

Kaidalov et al., Phys.Lett. B567 (2003),61

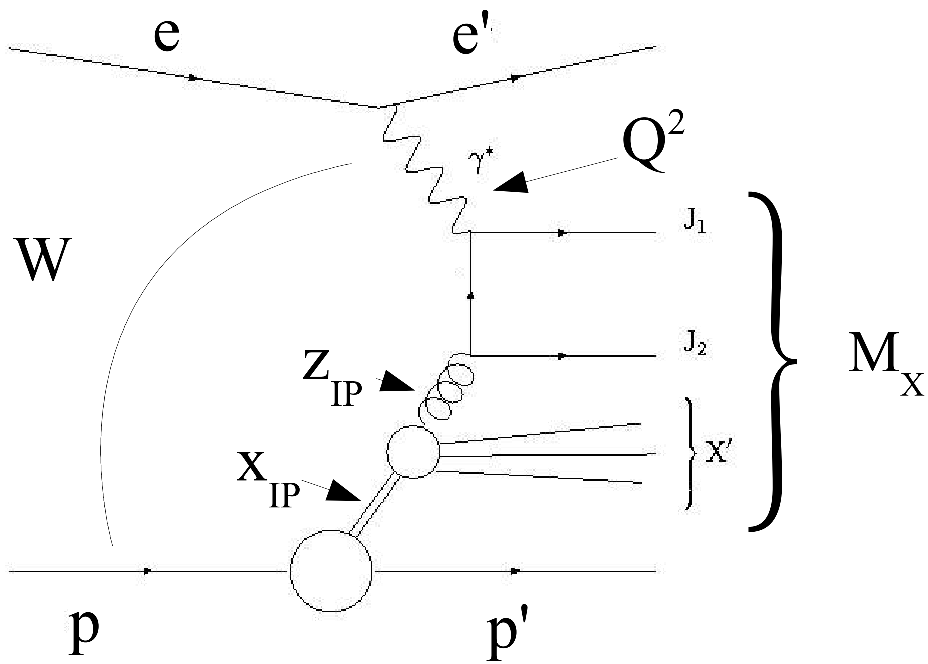




Diffractive exclusive events (e.g. dijets, charmed mesons) at HERA are important:

- verify the validity of the QCD factorisation theorem where it is supposed to work
- verify the presence of the same factorisation breaking seen at TeVatron
- check how well the soft rescatterings can be modelled by the theory

Dijets in diffractive DIS (dDIS)



$$Q^2 = -q^2 = -(e-e')^2 \quad W^2=(p+q)^2$$

$$x_{IP} = \frac{Q^2 + M_X^2}{Q^2 + W^2}, \quad \beta = \frac{x}{x_{IP}} = \frac{Q^2}{Q^2 + M_X^2}$$

$$z_{IP} = \frac{Q^2 + M_{12}^2}{Q^2 + M_X^2}, \quad x_\gamma = \frac{\sum_{\text{dijets}} E - p_z}{\sum_X E - p_z}$$

This process provides:

- ✔ Hard scale (Q^2 & E_T) ⟶ perturbative QCD, Q^2 evolution of PDF
- ✔ Strong sensitivity to gluon content of dPDFs

From this analysis we can obtain

Test of QCD factorisation
Constrain on dPDFs

Event selection

Data sample: 99e-, 99e+, 00e+; total lumi 65.2 pb^{-1}

Kinematic region of definition of the cross section

- **$5 < Q^2 < 100$ GeV^2**
- **$100 < W < 250$ GeV**
- **Njets ≥ 2** (K_T algorithm run on Tracks+Clusters Objects (* $\equiv$ γ-proton c.m.s))
- **$E^*_{T,jet1} > 5$ GeV, $E^*_{T,jet2} > 4$ GeV**
- **$-3.5 < \eta^*_{jets} < 0.0$**
- **$x_{IP} < 0.03$**

Diffractive selections:

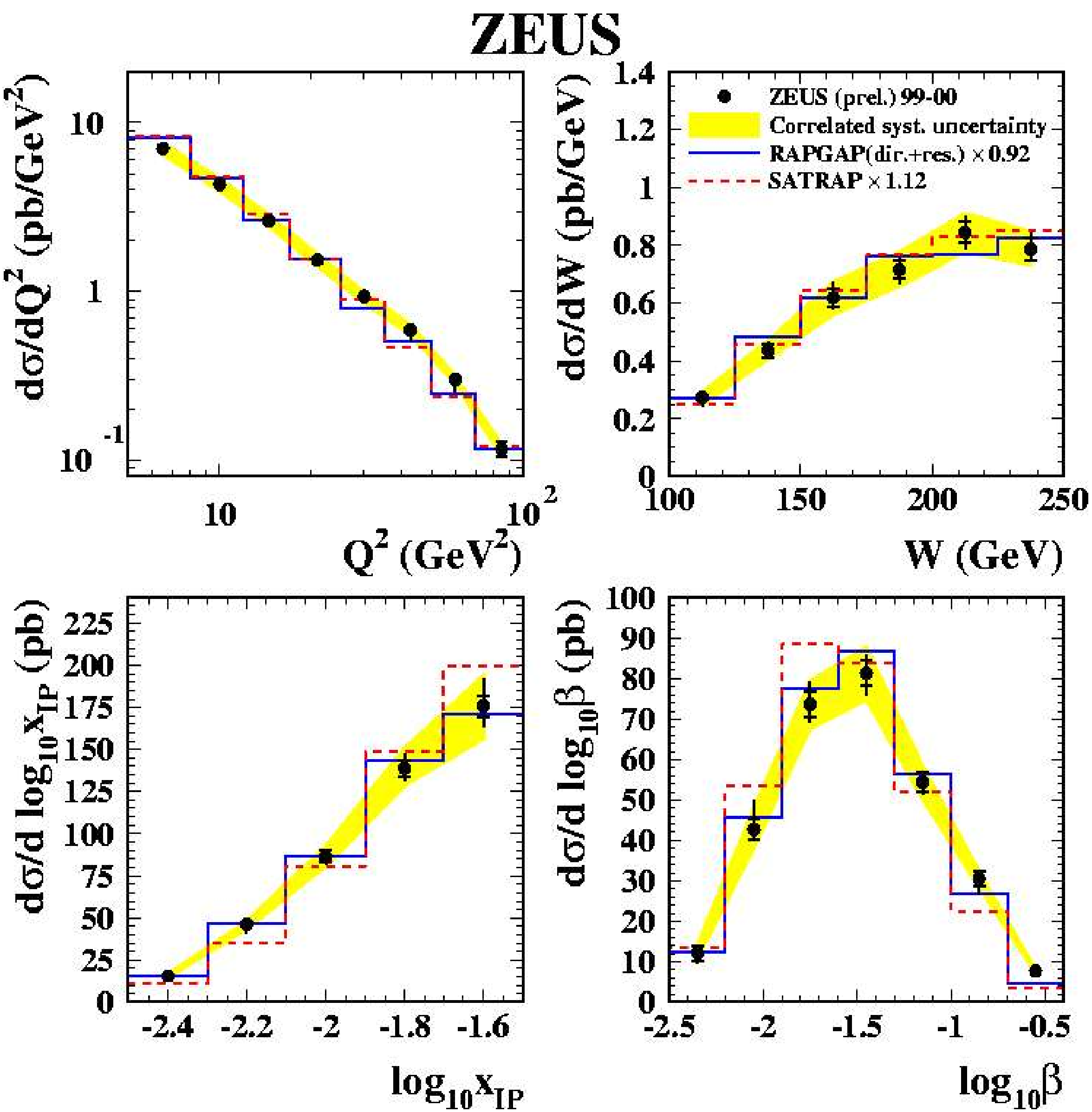
- $E_{FPC} < 1$ GeV
- η of most forward track/cluster with E> 400 MeV $\eta_{MAX} < 2.8$
- $x_{IP} < 0.03$

} Rapidity Gap selection

Leading Order Monte Carlos

- SATRAP
  - Golec-Biernat-Wüsthoff model
  - Color-Dipole-Model parton shower
- RAPGAP
  - Resolved Pomeron model
  - H1 fit 2 dPDFs (IP only)
  - MEPS parton shower
  - Direct + Resolved photon generated separately

Cross Section and LO comparison (1)



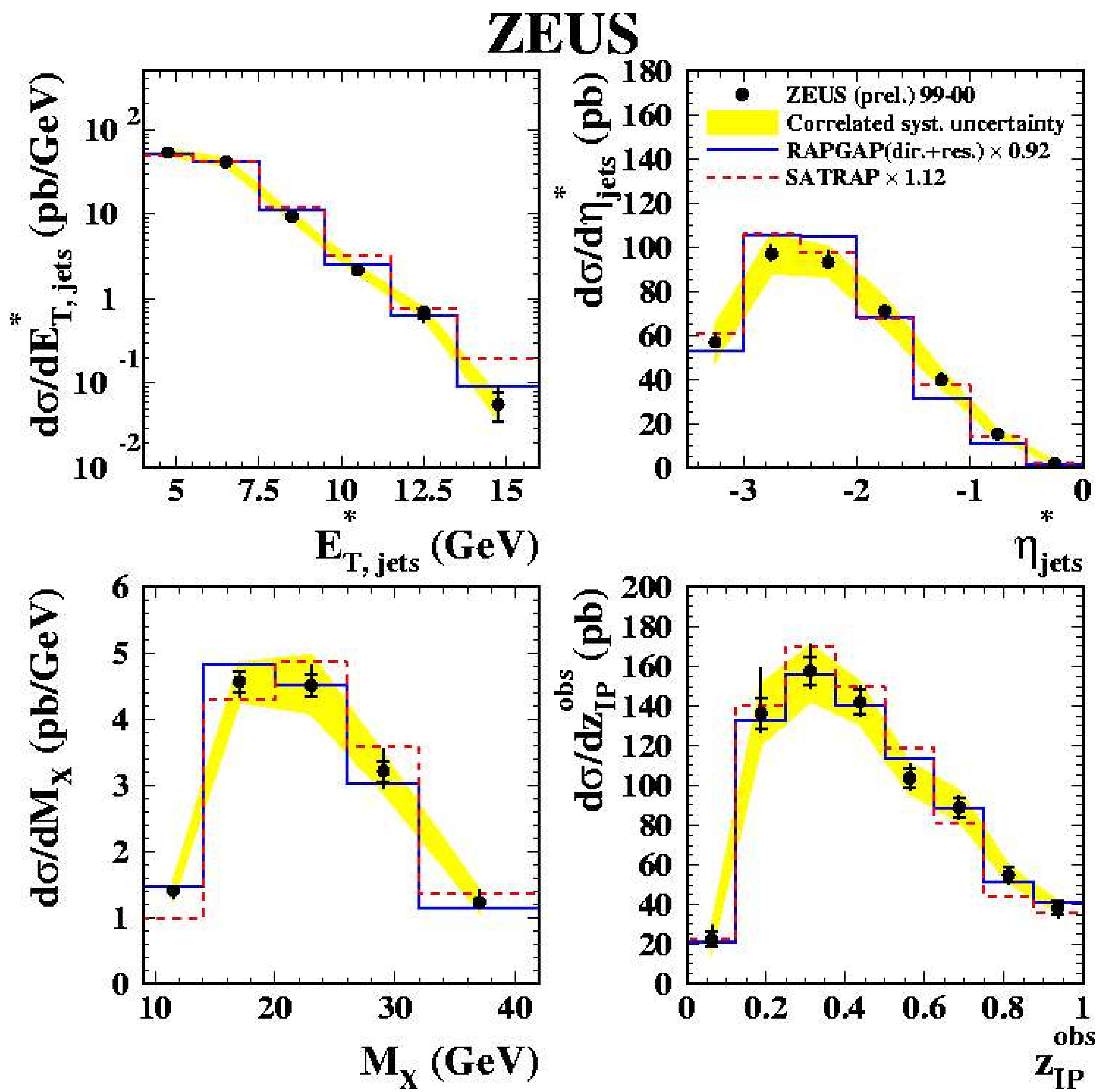
RAPGAP was used for acceptance corrections estimations

Proton dissociation background was subtracted ($16 \pm 4\%$) to the measured cross sections

Good description of the data by both MC.

Total uncertainty on the cross section measurement is typically ~10%

Cross Section and LO comparison (2)



Good description by both MC
RAPGAP better at high jet transverse energies

LO/NLO calculation

- If one has a set of dPDFs one can use them for calculating a NLO prediction of the cross sections. Then one can compare them with the measured cross section and check whether the theory (i.e. QCD factorisation, DGLAP fits) works also for this kind of processes.
- The LO/NLO program DISENT was adapted in order to get the diffractive dijet NLO predictions

  1) Scale the proton beam energy by a factor x_{IP}
  2) Replace the proton PDFs with the dPDFs
  3) Calculate the NLO-predicted cross section
  4) Multiply by a t-integrated pomeron-flux factor
  5) Repeat the passages above for many tiny step of x_{IP} and at the end sum up all the calculated NLO predictions

DISENT settings

- Three different sets of dPDFs exhamined

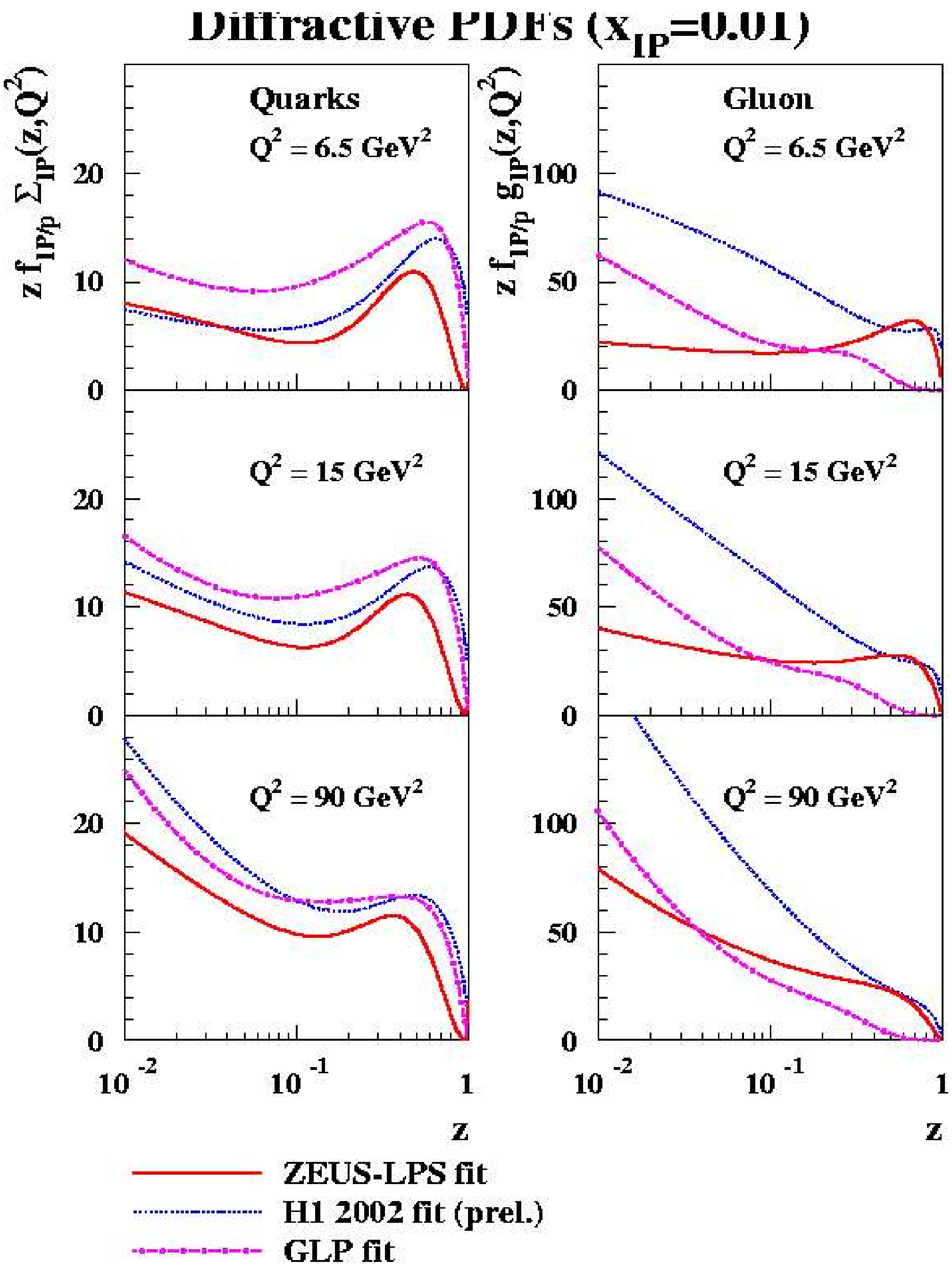
  H1 fit 2002 (prelim.) -> H1 1997 data, LRG
  ZEUS LPS -> ZEUS 1997 data, LPS (+diffr. charm)
  (Eur.Phys.Journ. C38 (2004), 43-67)
  GLP fit -> ZEUS 1998-99 data, Mx
  (HERA-LHC proceedings, CERN-2005-014)

- α_S calculation routine performed with QCDNUM
  - $\alpha_S(M_Z^2) = 0.1085$ for H1fit2002 dPDFs
  - $\alpha_S(M_Z^2) = 0.1180$ for ZEUS-LPS and GLP dPDFs

- Scale choice
  - $\mu_r^2 = E^*_{T,jet1}$
  - $\mu_f^2 = 40$ GeV^2 (average p_T of jets)

- Pomeron flux factor integrated up to $|t| = 10$ GeV^2

The diffractive PDFs



H1 fit 2002 (prelim.) -> H1 1997 data, LRG

ZEUS LPS -> ZEUS 1997 data, LPS (+diffr. charm)

GLP fit -> ZEUS 1998-99 data, Mx

The diffractive exchange is gluon-dominated

Differences in the data sets

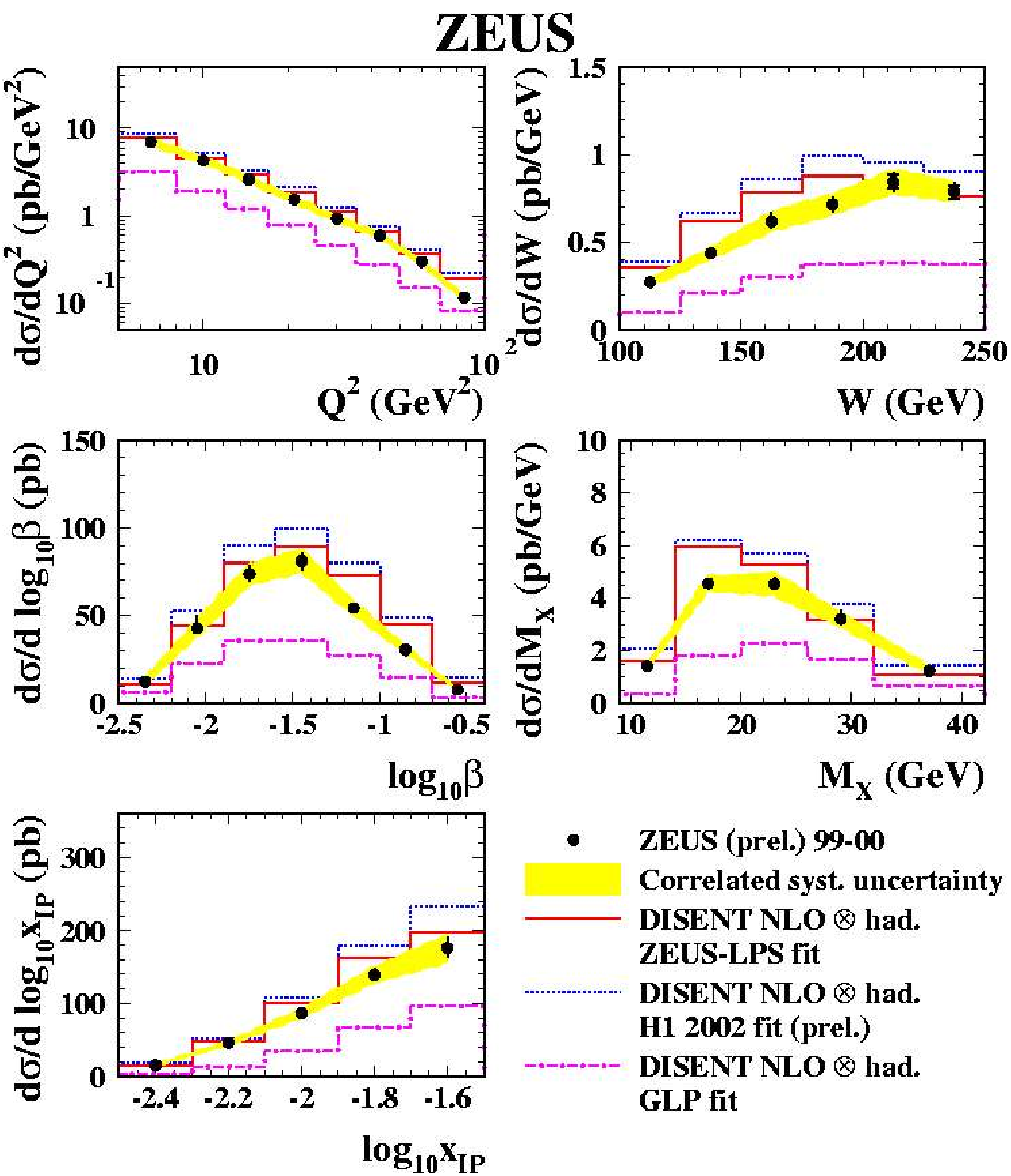
↓

Differences between dPDFs

↓

Understanding these differences is one of the main tasks in the field of diffraction

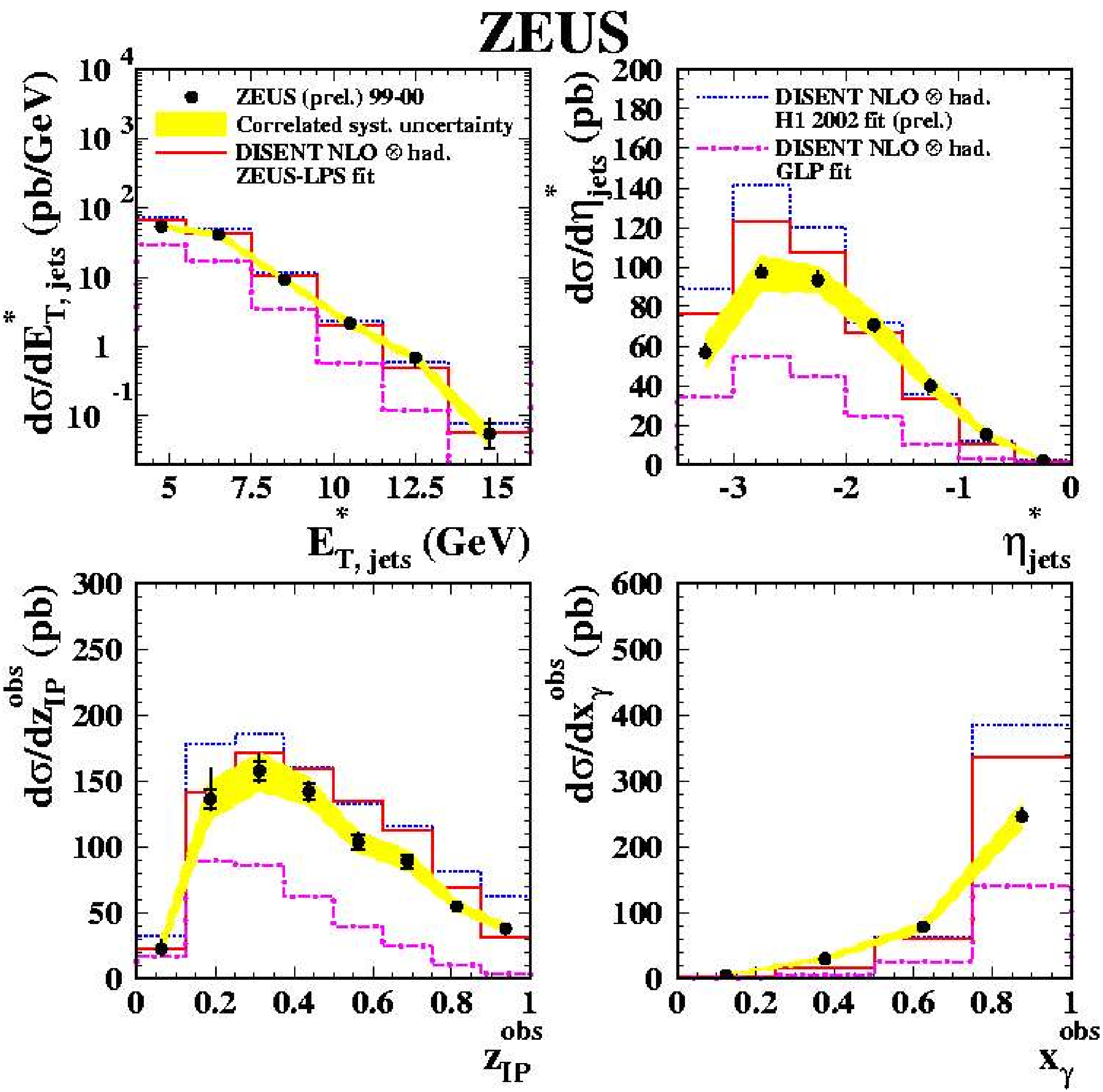
NLO comparison



Scale uncertainties not displayed but large (~20%)

Reasonable description of data (slightly overestimating) by H1fit2002 and ZEUS-LPS calculations

Significant underestimation by GLP fit



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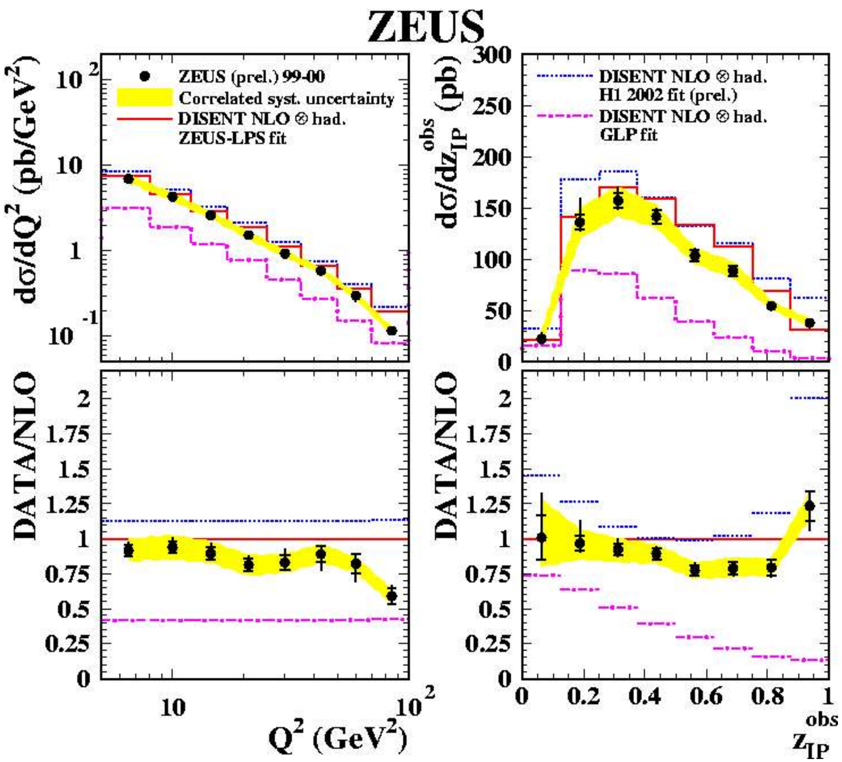
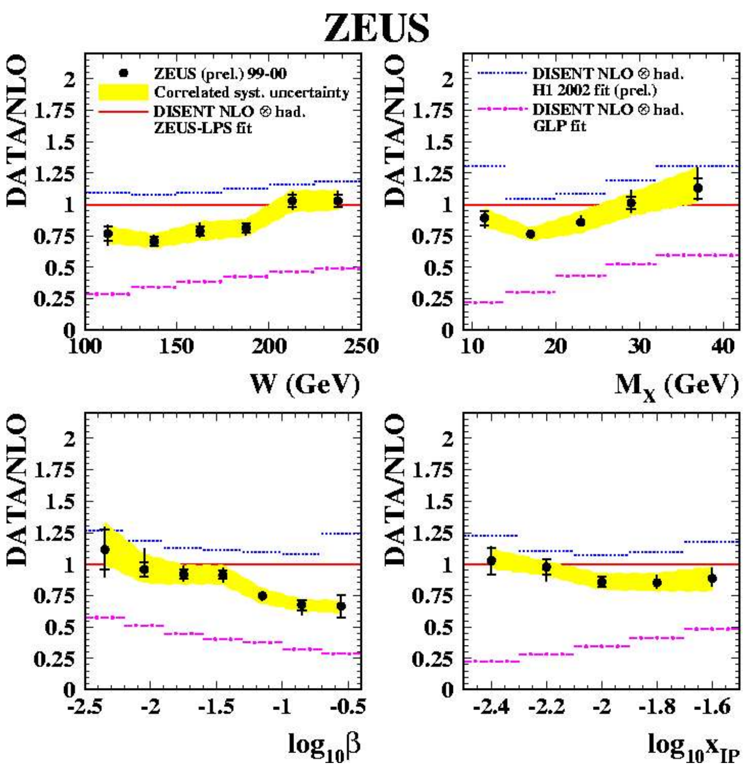


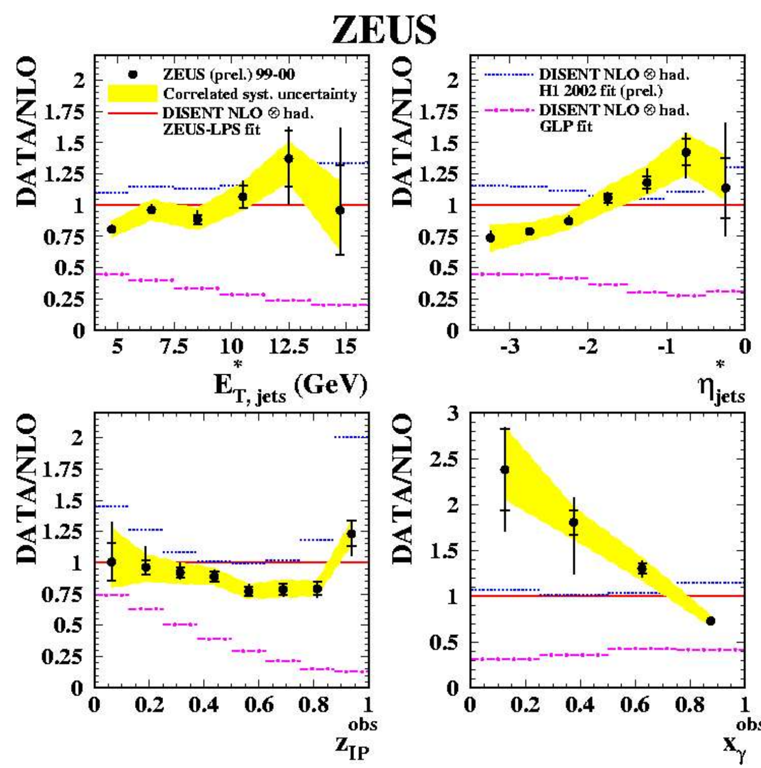
Ratio of DATA/NLO prediction are shown. The ZEUS-LPS NLO calculation is used as reference.
Ratios of the other two NLO predictions to the ZEUS-LPS one are also present.

High Q^2 and high β: discrepancies between data and all the predictions (dPDFs uncertainties)

Resolved photon contribution not included in DISENT: discrepancy at low x

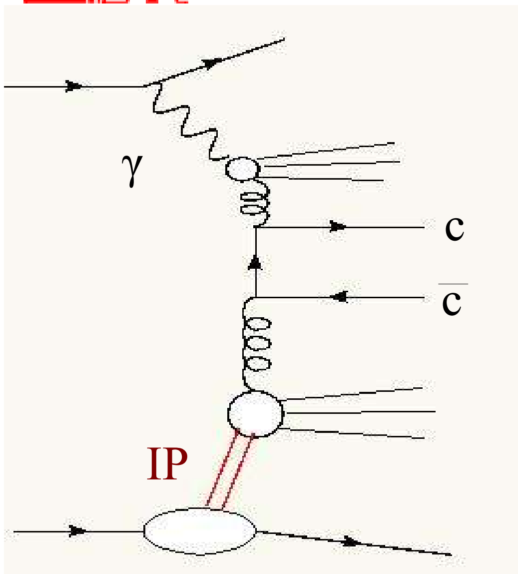
GLP fit miss the description of the shape for many variables





Dijets in dDIS: conclusions

- Diffractive dijets in DIS cross sections have been measured with good precision (~10%).
- Two LO MCs have been compared to the results and they both describe the shape of the data in a reasonable way.
- Three dPDFs were used as inputs for three NLO calculations.
  - Large uncertainties in both the choice of the scale for the calculation and the dPDFs themselves affect the precision of these NLO predictions.
  - Two sets of calculations agree with data, the third one shows big differences.
- A better understanding of the inclusive diffractive data sets and of the theory is needed before making any strong statement about the QCD factorisation theorem for diffraction.
- The dDIS dijets data can be precious inputs for more refined NLO fits to the dPDFs thanks to their precision and their sensitivity to the gluon content of the diffractive exchange.



D*(2010) in diffractive photoproduction (dPhP)

- Similar motivation for dijets in dDIS: QCD analysis of diffractive events
- **Big difference** between dPhP and dDIS: no QCD factorisation expected. Because of its low Q^2, the photon behaves like a hadron and secondary interactions fill the rapidity gap. The NLO comparison using the same dPDFs of before should point out that, as for the TeVatron data

Diffractive D* selection

Data sample: ZEUS 98-99 e-, 99-00e+ data (78.6 pb^{-1})
Monte Carlo:

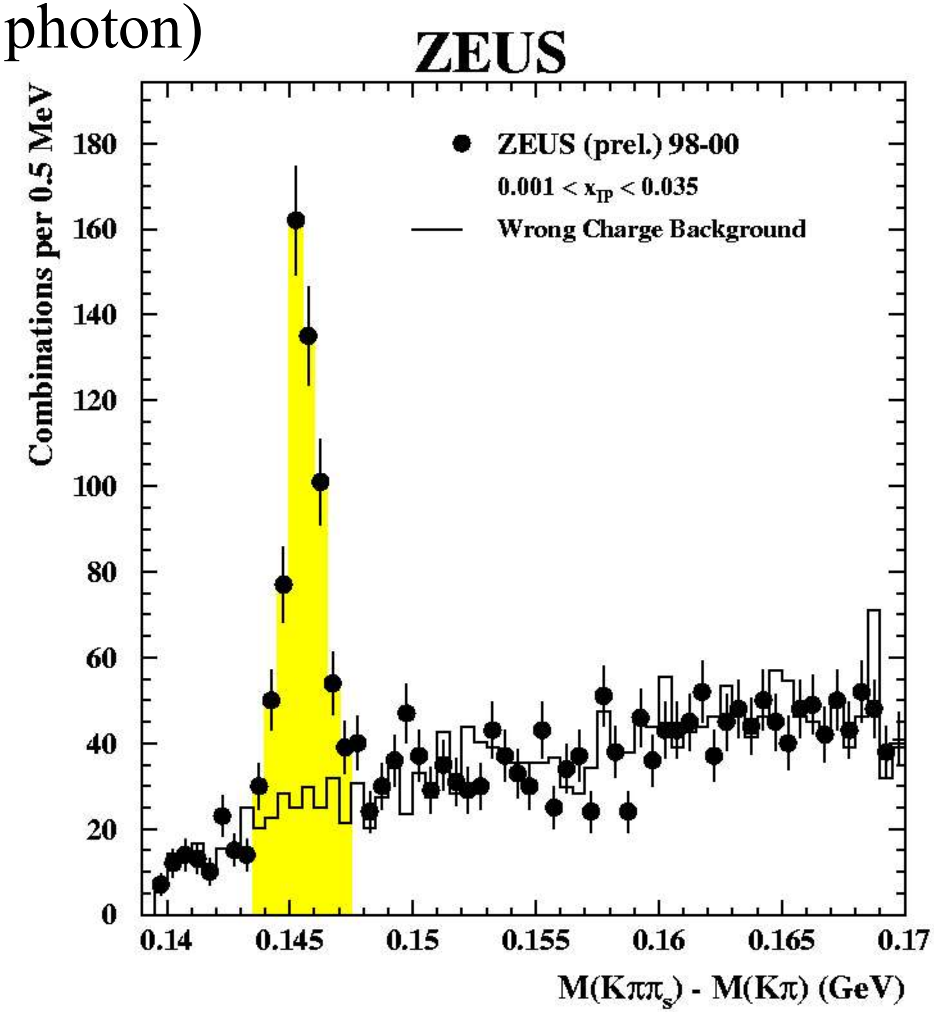
- RAPGAP (IP + IR , direct+resolved photon)

Kinematic region of cross section definition:

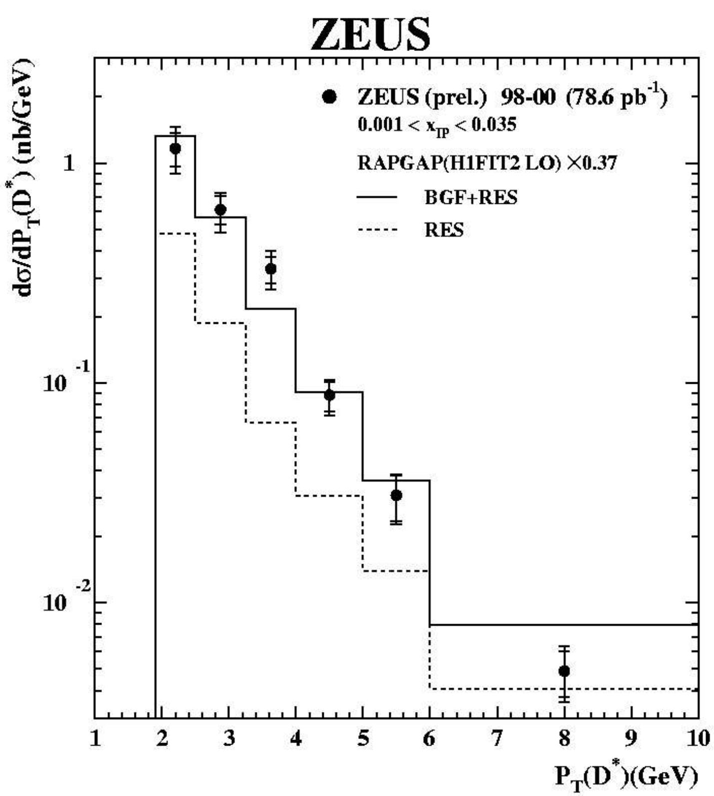
- $Q^2 < 1\ GeV^2$
- $130 < W < 300$ GeV
- $p_{\perp}(D^*) > 1.9$ GeV
- $|\eta(D^*)| < 1.6$
- $x_{IP} < 0.035$

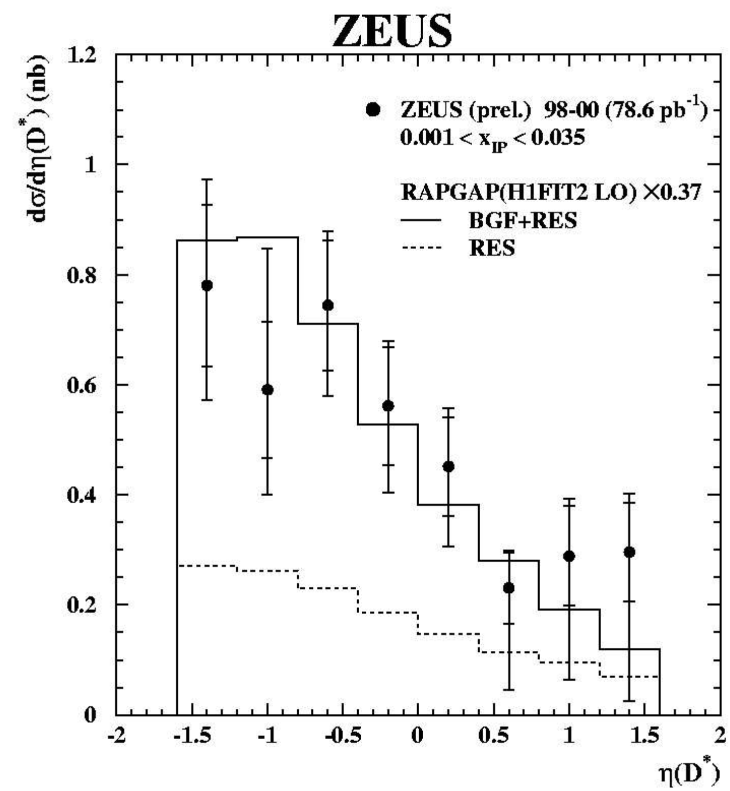
Diffraction selection

- $E_{FPC} < 1.5$ GeV
- $\eta_{max} < 3.0$ for EFOs with E>400 MeV
- $x_{IP} < 0.035$



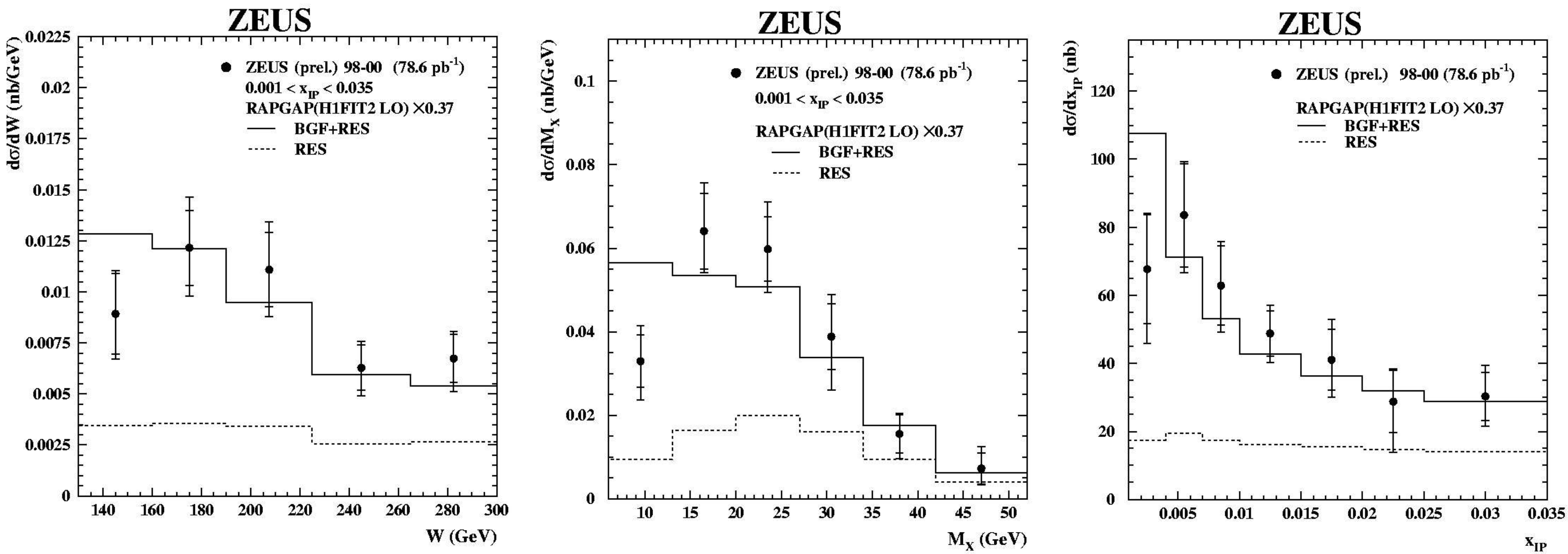
Cross Sections and comparison with LO





Good description of the data provided by the LO MC

Cross Sections and comparison with LO



Good description of the data provided by the LO MC

NLO calculation

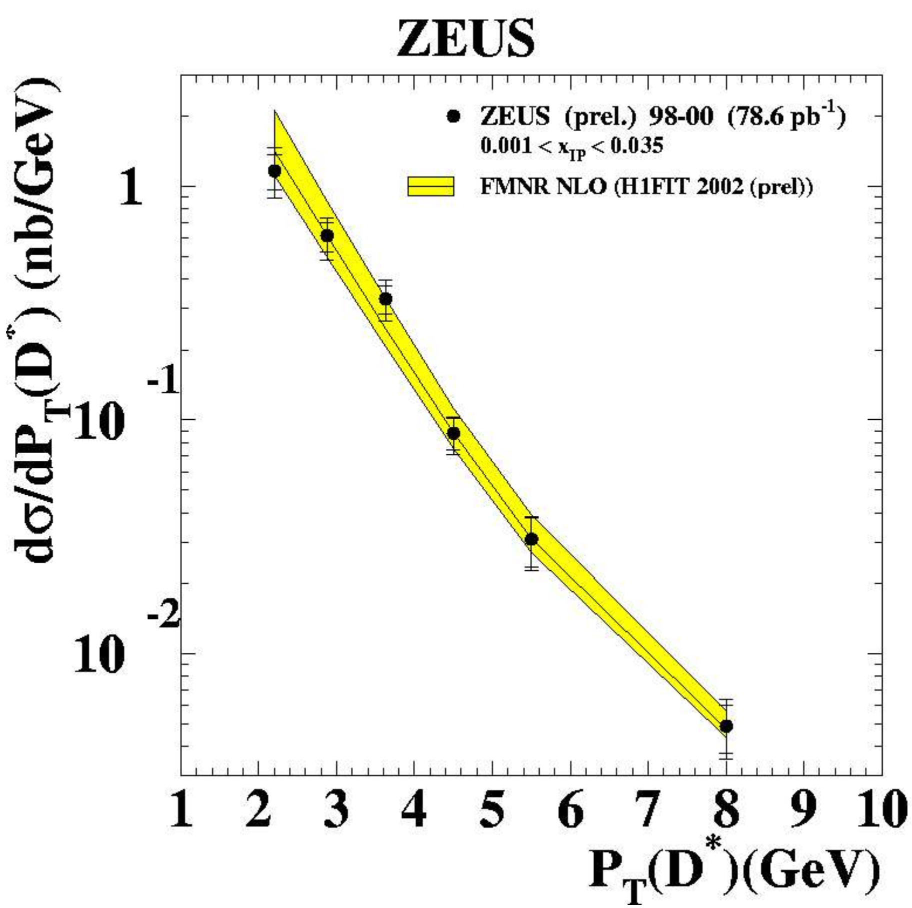
- In order to verify QCD factorisation theorem for diffraction one can compare the previous cross sections to NLO predictions obtained from some dPDFs.
- The FMNR program was used for calculating NLO predictions for D* in dPhP.
- Same procedure described before for DISENT.

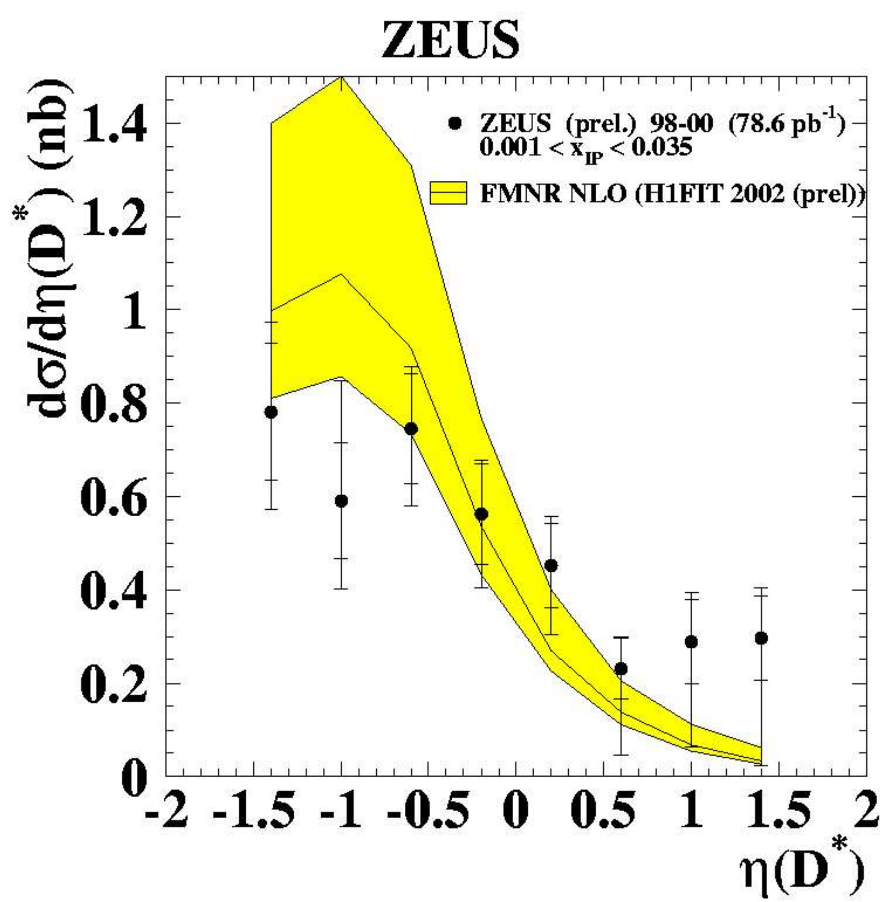
Settings:

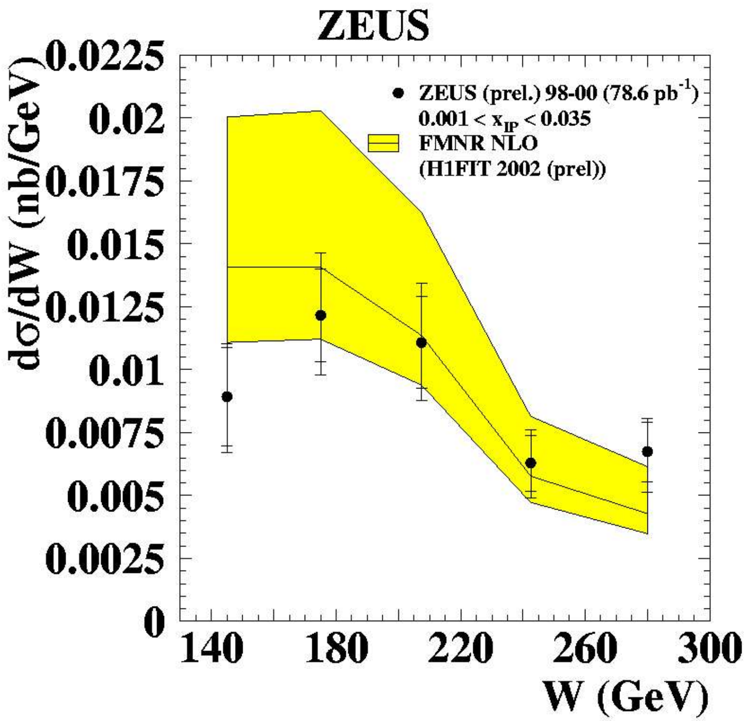
- $m_c = 1.5$ GeV (± 0.2 GeV)
- $\Lambda_5 = 0.2$ GeV
- dPDFs: H1fit2002 (prel.)
- γ PDFs: AFG
- Renormalisation and factorisation scale: $\mu_r = \mu_f = \sqrt{(m_C^2 + p_T^2)}$
- Petersen fragmentation function with $\varepsilon = 0.035$
- Fragmentation fraction: 0.235

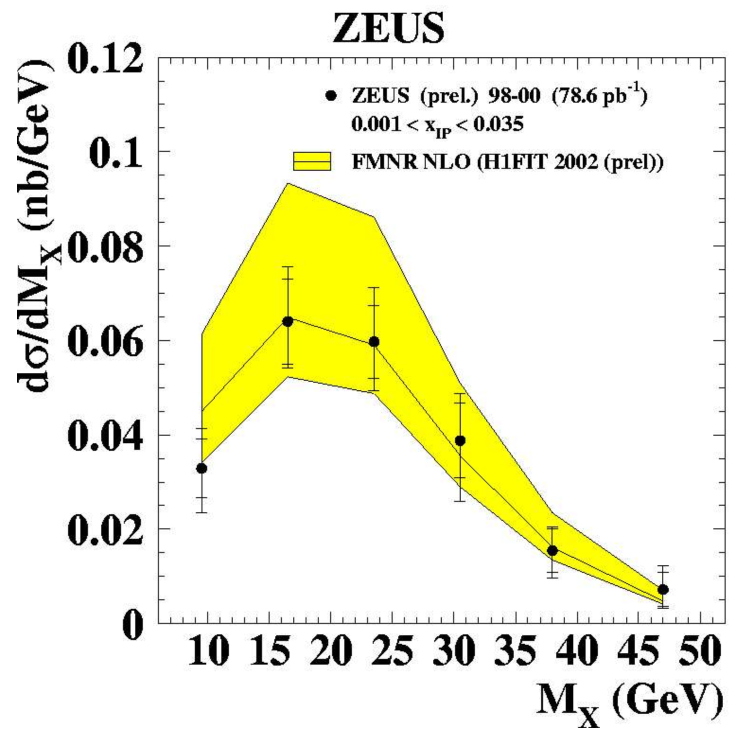
Comparison with NLO

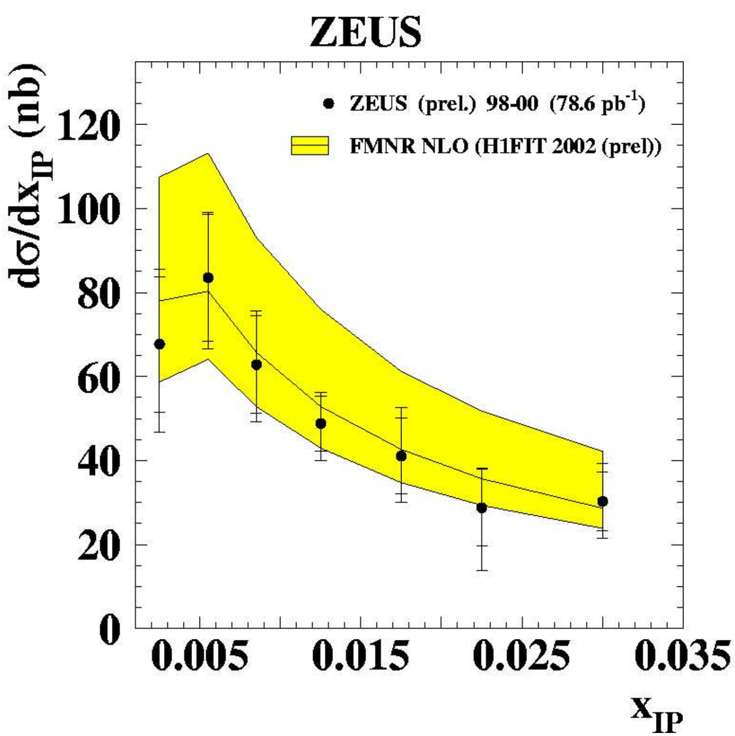
- Calculation performed with the FMNR program using as input the "H1fit2002 (prel.)" fit
- Data and NLO are consistent within the errors











NLO underestimates the inclusive D* data (diff+non-diff.). Such an effect could "mask" the factorisation breaking in the diffractive charm.

In any case the uncertainties on the calculation are again too large for any strong statement.

D* in dPhP: conclusions

- The cross section for diffractive D* production in PhP has been measured for the first time at ZEUS
- The LO MC gives a good description of the shape of the measured cross sections
- The limited precision of the NLO predictions does not allow any conclusion about the factorisation breaking.
- Large theoretical uncertainties (comparable to the experimental ones). Need for more precise theoretical models (i.e. more precise dPDFs, scale choice).

Summary

- In order to verify the QCD factorisation theorem for diffraction many different **dPDFs** have been used for NLO predictions to exclusive processes.
- The sets of dPDFs are very different among them. These differences affect the significance of the results which can be achieved. Need for better understanding of the data and more constraints to the QCD fits.
- These large uncertainties on the theoretical side make impossible a clear test of QCD factorisation breaking in exclusive processes like production of D* in dPhP.
- **Diffractive dijets in DIS can be necessary** for improving our knowledge of the dPDFs, thanks to their precision and their sensitivity to the gluon content of the diffractive exchange.

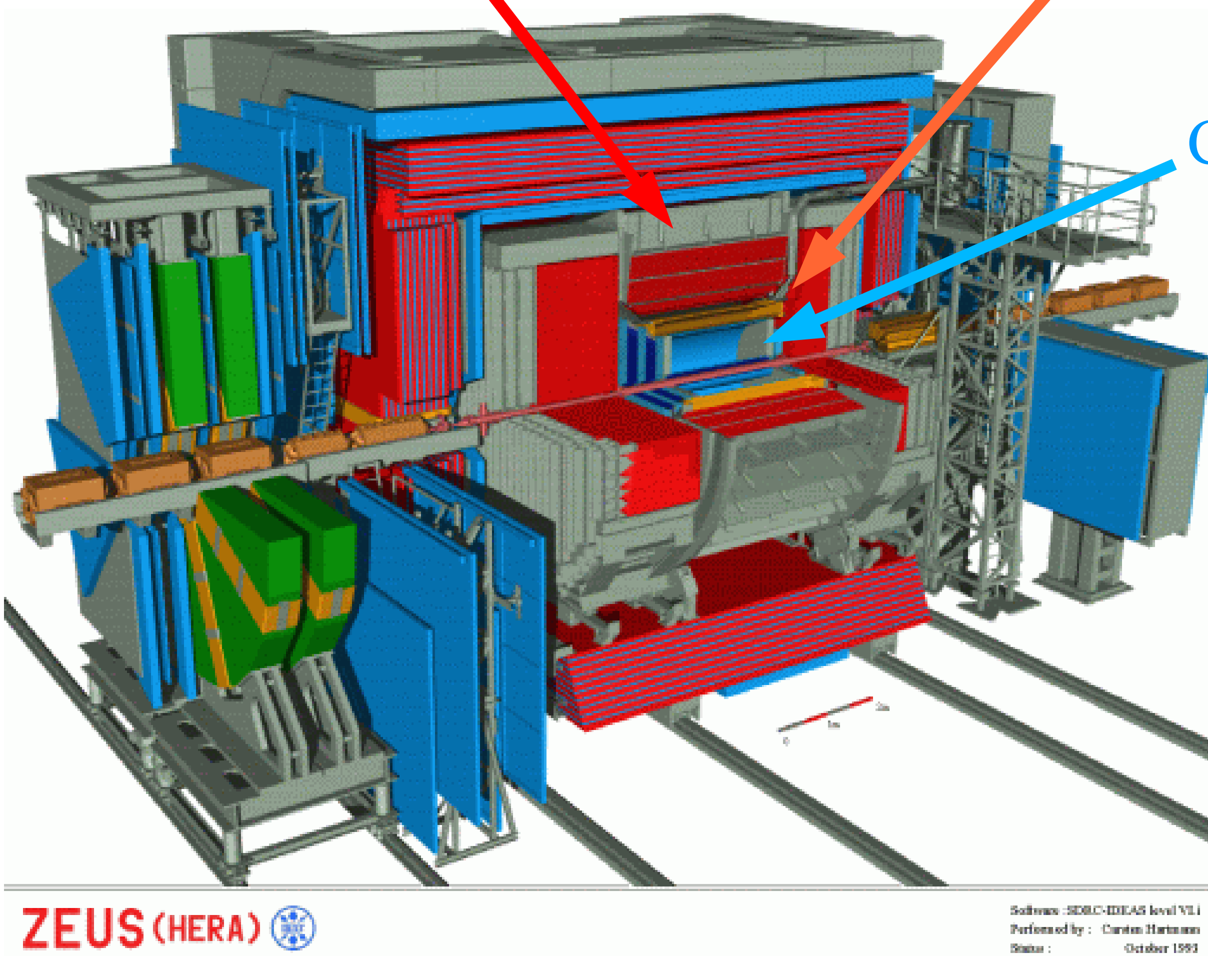
Backup

ZEUS

Hadronic Calorimeter (HAC)

Electromagnetic Calorimeter (EMC)

Central Tracking Detector (CTD)



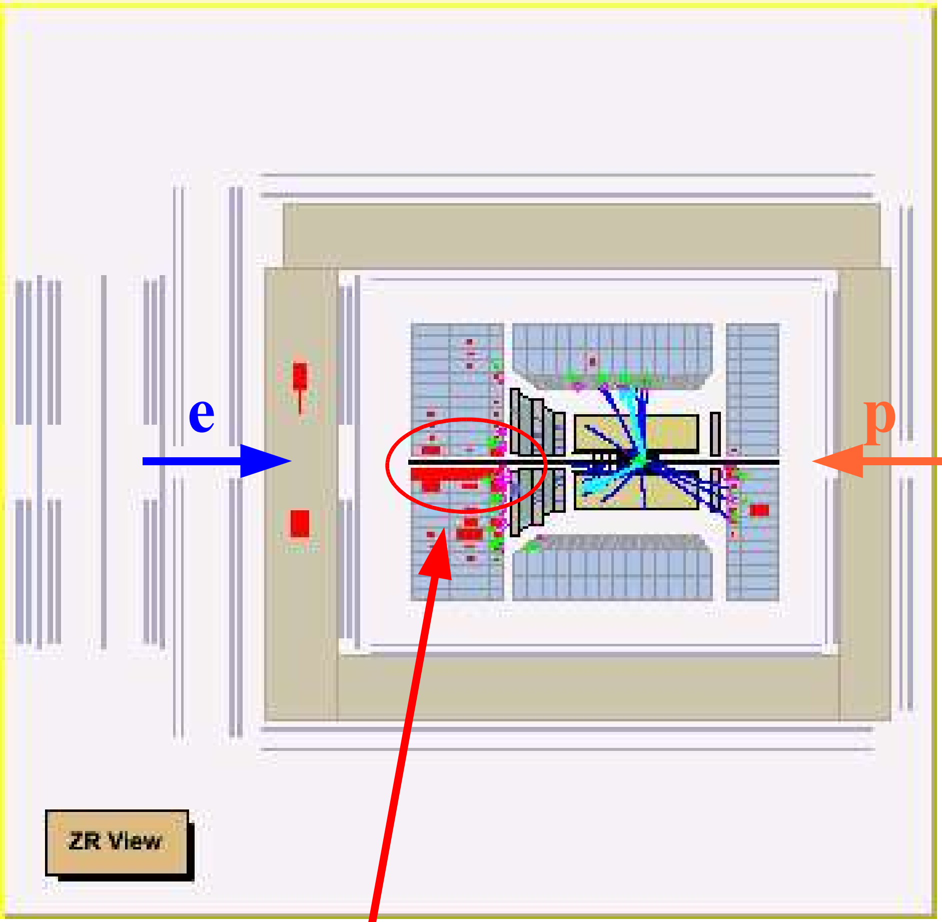
- Multipurpose experiment at HERA (ep-collider at $\sqrt{S}$ ≈320 GeV)
- 12x10x19 m, 3600 t
- 12 nations, 50 institutes, ~400 partecipants

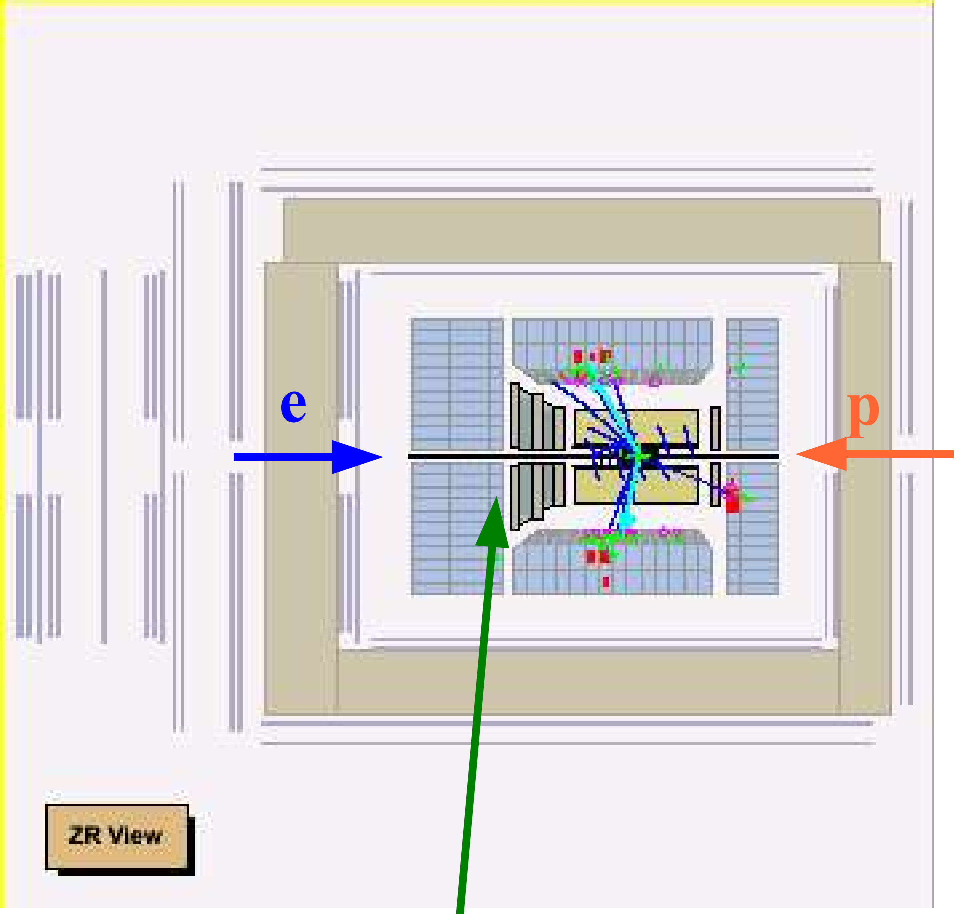
Large spectrum of physics topics:

- Structure functions and α_s
- Jet physics and test of QCD
- Heavy flavour physics
- Searches for new physics
- **Diffraction**

NON-DIFFRACTIVE

DIFFRACTIVE

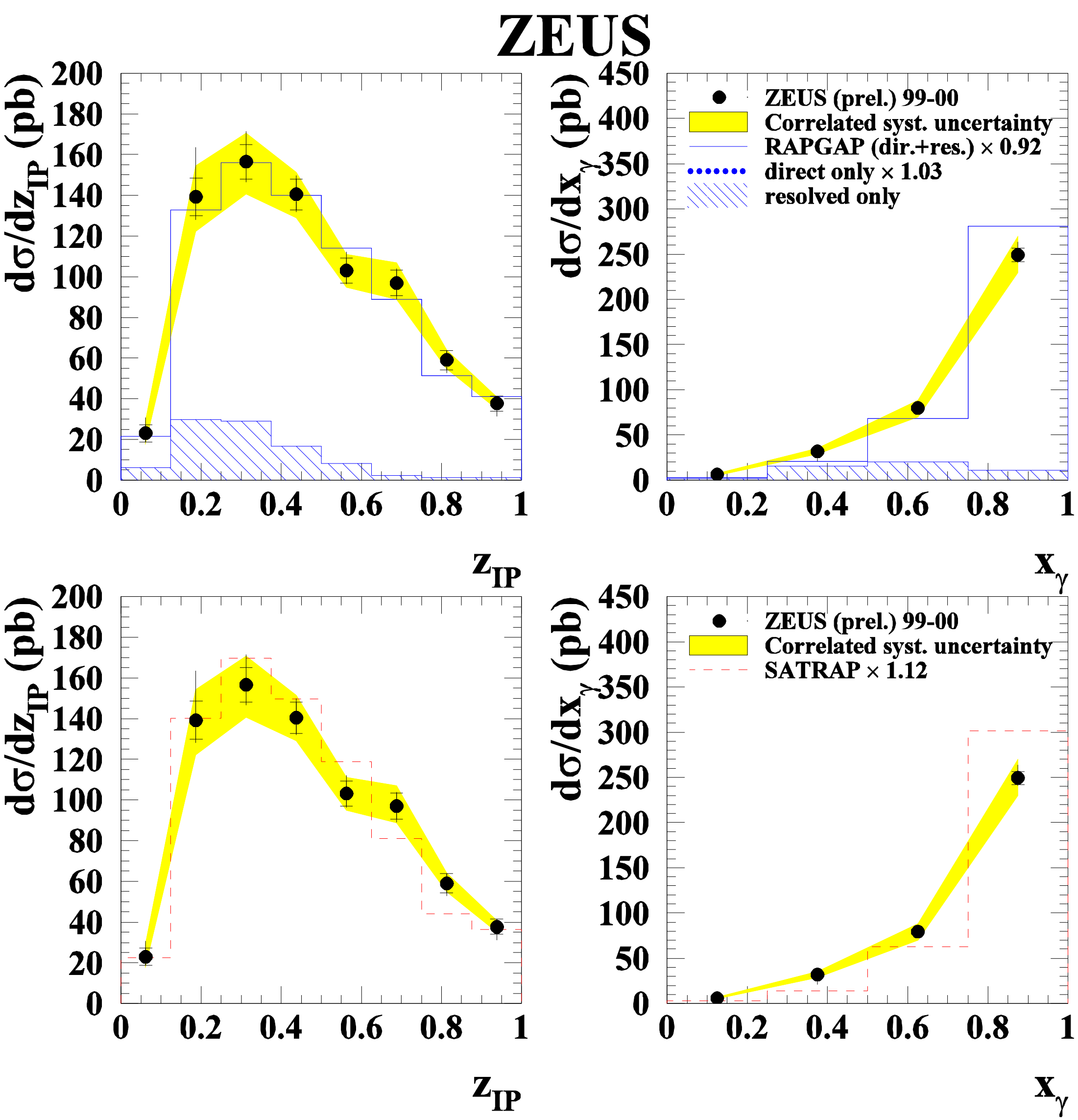




The proton breaks up
Activity in the forward direction

A colourless object is exchanged
No activity in a large rapidity range

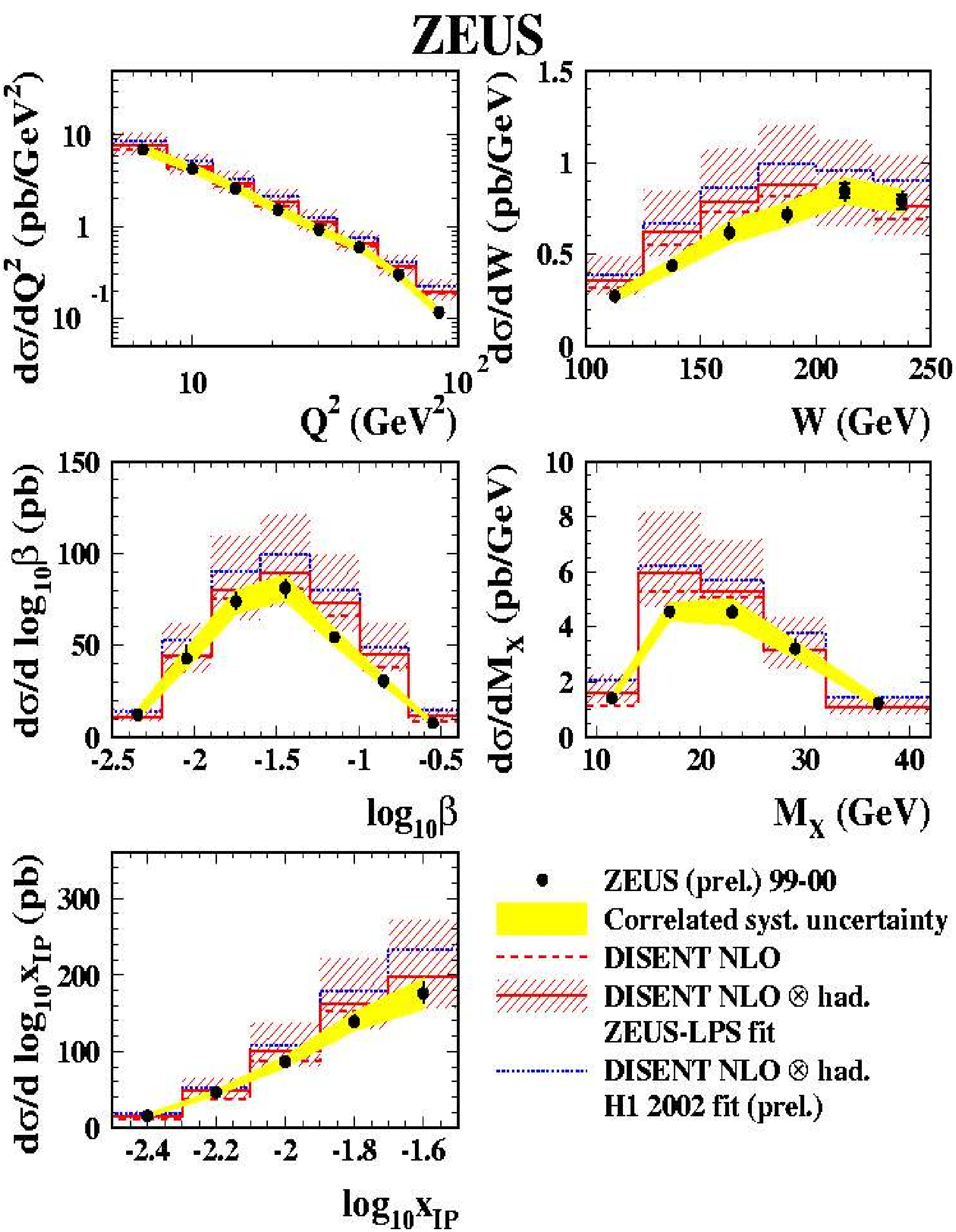
Resolved Photon contribution



Improved description by RAPGAP if the resolved photon is included

Resolved photon is not explicitely calculated in SATRAP

Comparison with NLO (1)



Large uncertanties (~20%) related to the scale choice

dPDFs uncertanties not estimated but comparable to scale uncertanties