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Measurements of Inclusive and Exclusive Diffraction at HERA

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Outline:

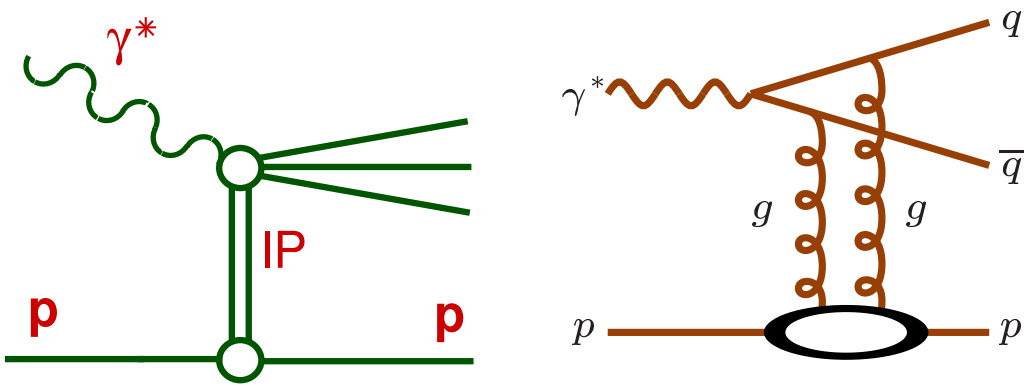
- Introduction
- Vector Meson production
- Inclusive diffraction in DIS
- F_2^D QCD fits
- Dijets and Open Charm
- Conclusions and Outlook

Not covered in this talk:

- Leading baryons
- Odderon searches
- Rap.Gap between Jets
- Event Shapes
- Energy flow
- DVCS
- ...

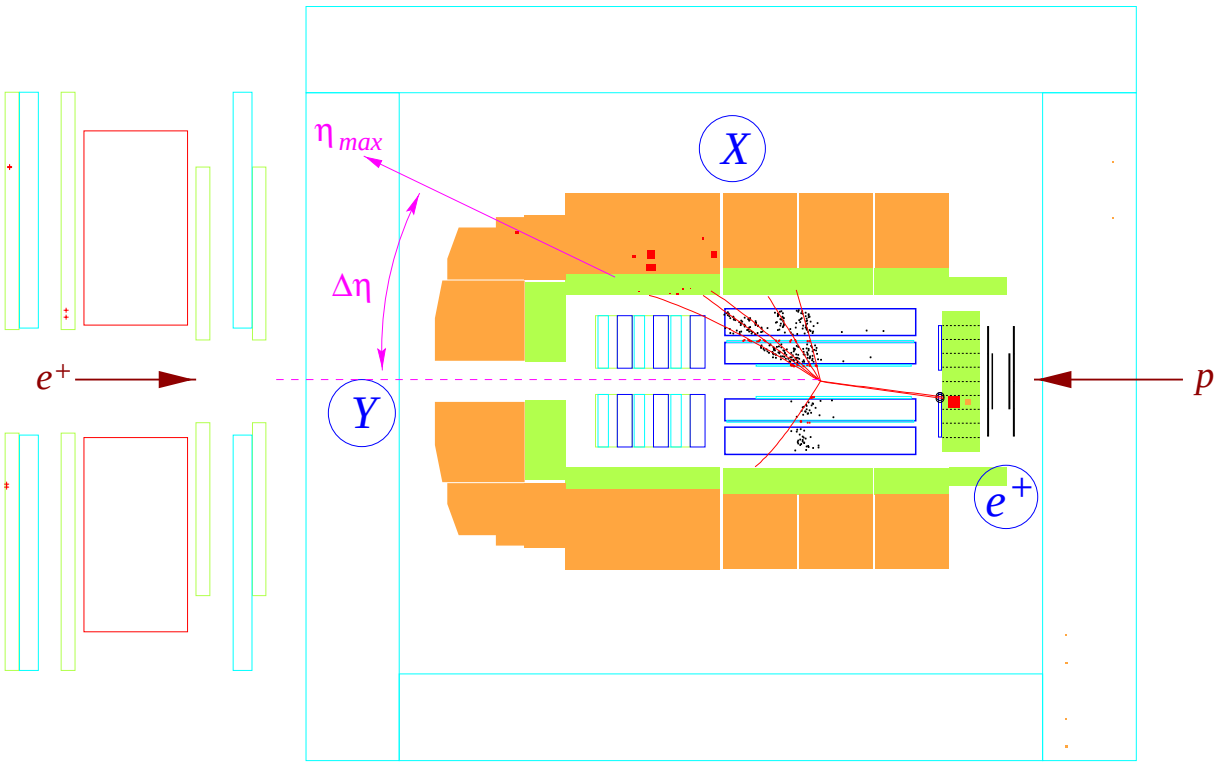
Diffraction at HERA

- no hard scale– $Q^2, |t| \approx 0$: similar to soft hadron-hadron interactions
  - Regge: diffraction is $exchange\ of\ Pomeron$
- large $Q^2, |t|, p_T^{jet}, m_q$: pQCD at $\gamma^* I\!P$ vertex
  - Resolved Pomeron: γ^* probes $I\!P$ structure
  - Colour dipole: diffraction is $exchange\ of\ colour\ singlet\ gluon\ ladder$ between $(\gamma^* \longrightarrow q\bar{q}, q\bar{q}g)$ and proton



HERA– unique facility to
probe partonic content of diffractive exchange and to
study transition from soft to hard regime

Selection of diffractive events



A: Leading Proton Tag

- scattered proton is measured in very forward detectors
  $\Longrightarrow M_Y = M_p$ (pure single diffraction)
- $x_{I\!P} \lesssim 0.03 \div 0.1$

B: Large Rapidity Gap Events

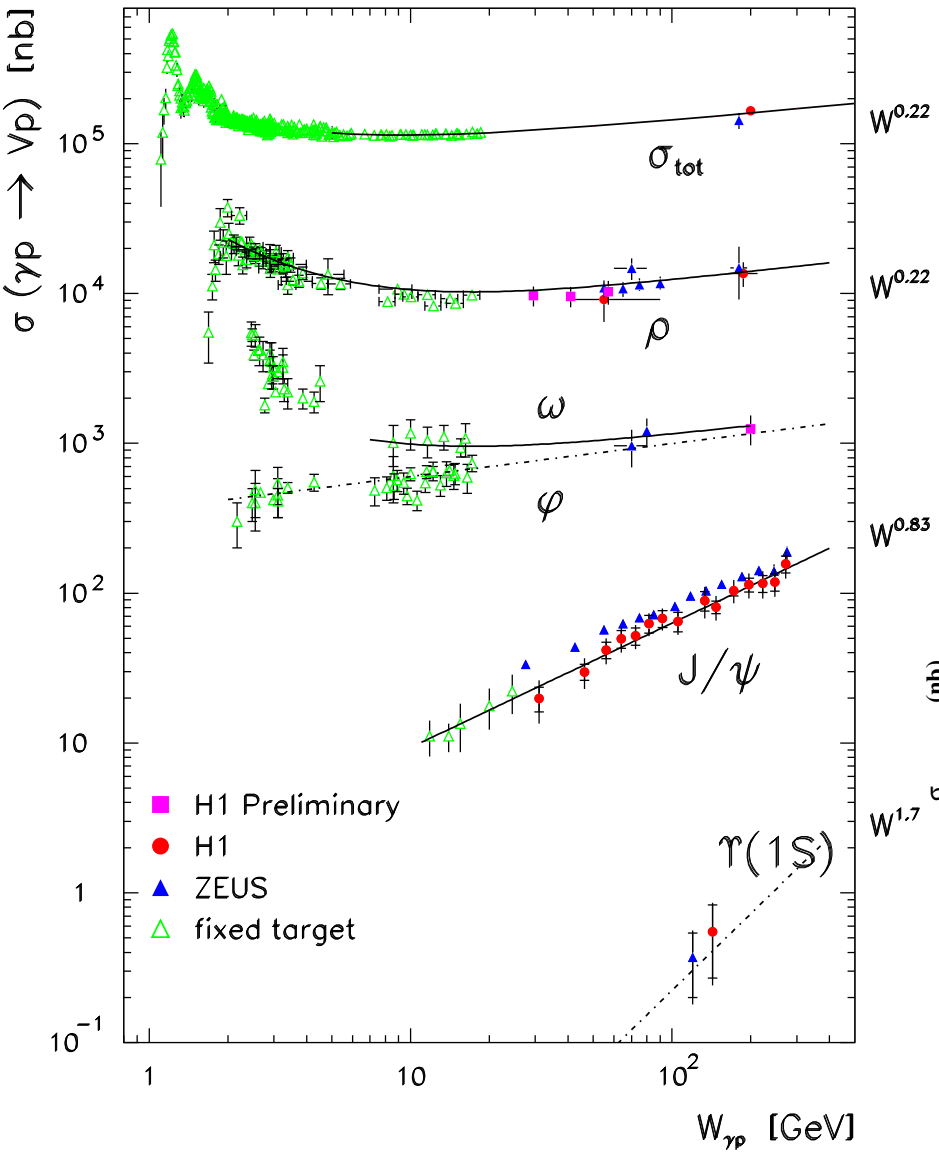
No hadronic activity in the forward part of detector

$\Longrightarrow$ Large Rapidity Gap $\Delta\eta \simeq ln(W^2/M_X^2)$

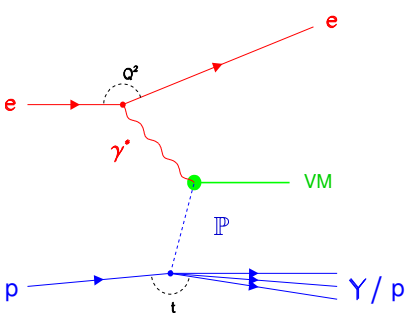
(pseudorapidity $\eta = -ln\ tan\ \theta/2$)

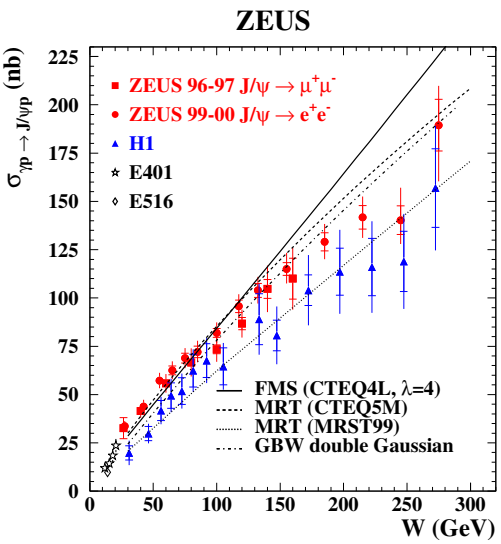
- proton is not directly measured
  $\Longrightarrow M_Y \lesssim 1.6 GeV$
- $x_{I\!P} \lesssim 0.05$

Photoproduction of Vector Mesons



$\gamma p \rightarrow Vp$





- The cross sections of VM photoproduction (and $\sigma_{tot}^{\gamma p}$) indicate a power law behaviour $\sigma \sim W^{\delta}$ for $W > 10\ GeV$
- For ρ, ω, ϕ: $\delta \approx 0.2$, compatible with $\sigma_{tot}^{\gamma p}$
- For J/Ψ: $\delta \approx 0.8$

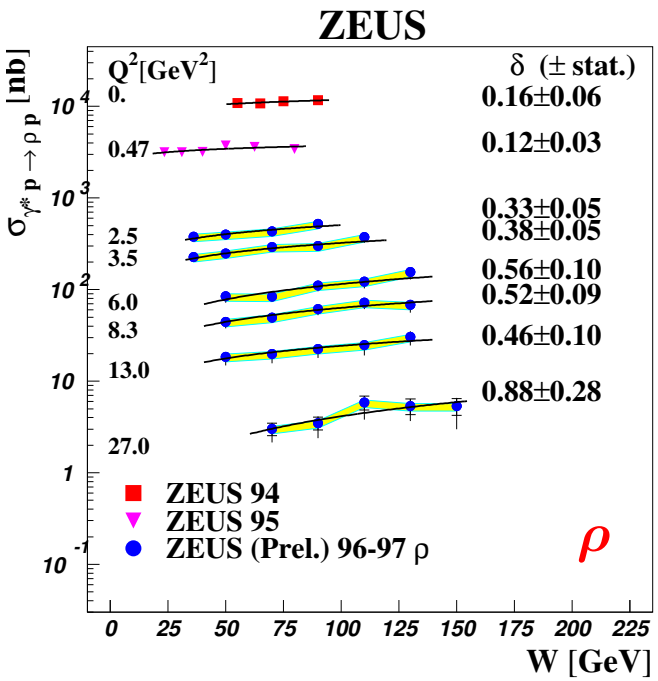
  $\Longrightarrow$ Steeper W dependence for heavy Vector Mesons

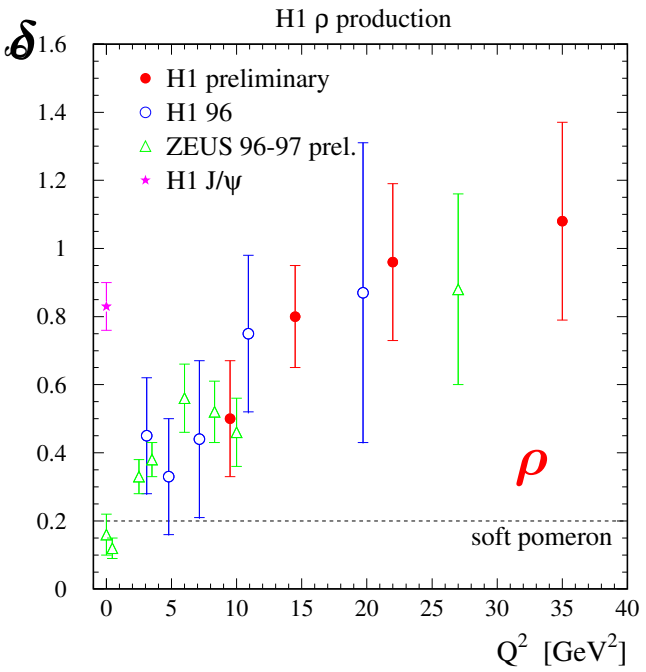
  M_{VM} sets a hard scale for calculation

  pQCD describes steep rise of cross section for J/Ψ

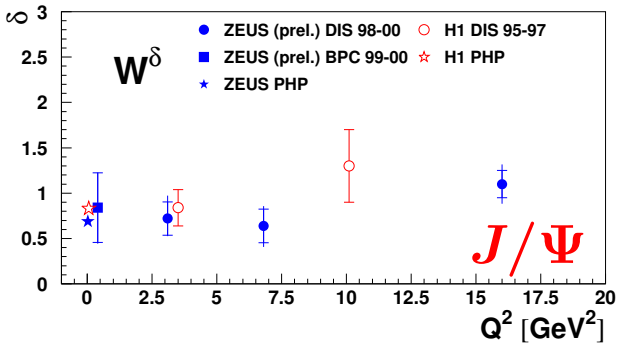
  ($\sigma \propto [xg(x, Q^2)]^2$)

VM-meson Production in DIS





$$\sigma \sim W^{\delta(Q^2)}$$

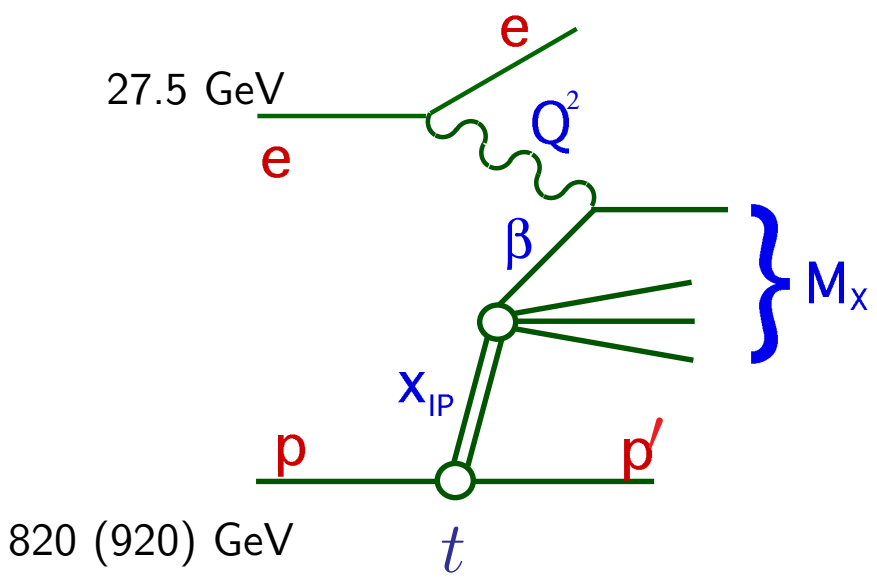


– W dependence steeper for ρ with increasing Q^2

– W dependence for J/Ψ steep already at $Q^2 = 0$

Transition from soft to hard physics as Q^2 increases

Inclusive Diffractive DIS



$t = (p - p')^2$ — 4-momentum transfer squared

$x_{I\!P} = \frac{q\cdot(p-p')}{q\cdot p}$ — fraction of p momentum transferred to $I\!P$ ($x_{I\!P} \simeq 1 - E'_p/E_p$)

$\beta = \frac{Q^2}{2q\cdot(p-p')}$ — fraction of $I\!P$ momentum carried by struck quark

Cross Section:

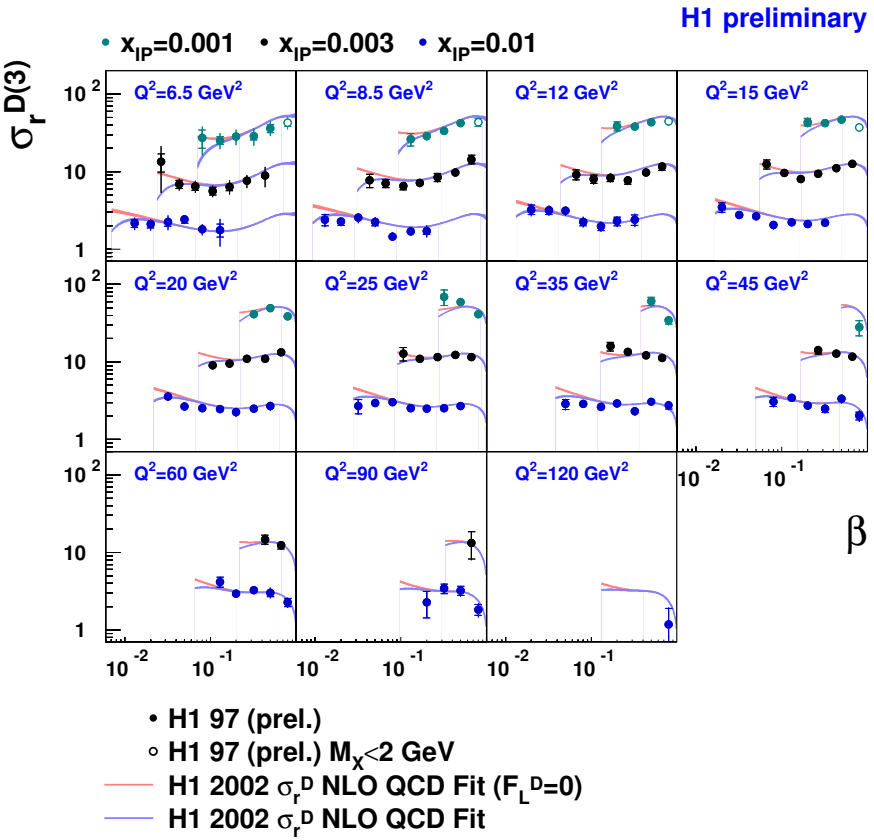
$$\frac{d\sigma^D}{d\beta dQ^2 dx_{I\!P} dt} = \frac{2\pi\alpha}{\beta Q^4}(1 - y + y^2/2) \cdot \sigma_R^{D(4)}(\beta, Q^2, x_{I\!P}, t)$$

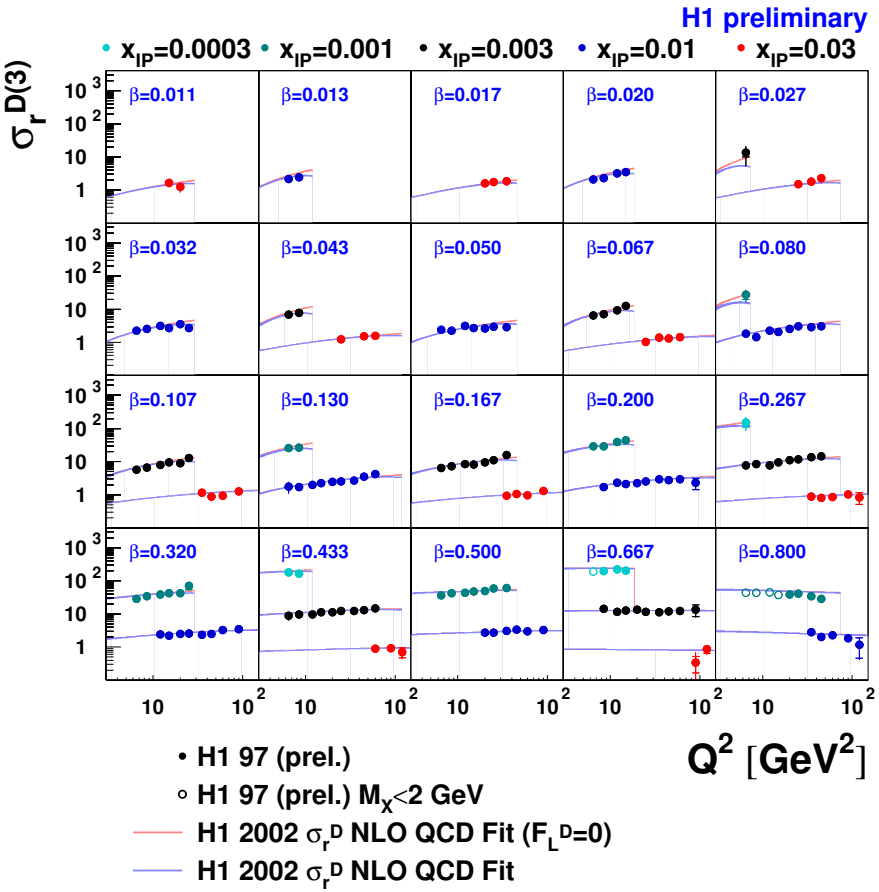
$$\sigma_R^{D(3)}(\beta, Q^2, x_{I\!P}) = \int \sigma_R^{D(4)}(\beta, Q^2, x_{I\!P}, t) \cdot dt$$

Reduced Cross Section:

$$\sigma_R^D = F_2^D - \frac{y^2}{1+(1-y)^2} F_L^D \qquad (\sigma_R^D = F_2^D \text{ if } F_L^D = 0)$$

$x_{I\!P}, \beta, Q^2$ dependence of $F_2^{D(3)}$





– β dependence relatively flat (different from F_2^p)

– scaling violation rising with $ln Q^2$ up to large β

– large gluon contribution needed in diffractive PDFs

– DGLAP evolution based fit describes the data

Factorization Properties of F_2^D

QCD factorization -proven in diffractive ep (Collins 1997)

$$\sigma^D(\gamma^* p \to X p) \sim \sum_i f^D_{i/p}(x_{I\!P}, t, x, Q^2) \otimes \hat{\sigma}_{\gamma^* i}(x, Q^2)$$

Diffractive parton densities $f^D_{i/p}(x_{I\!P}, t, x, Q^2)$:

- at fixed $x_{I\!P}$ and t evolve with x, Q^2 according to DGLAP
- are $universal$ for diffractive DIS

Regge factorization

Additional assumption– diffractive PDFs are independent of $x_{I\!P}$ and t

$$F_2^{D(4)}(x_{I\!P}, t, \beta, Q^2) = f_{I\!P}(x_{I\!P}, t) \times F_2^{D(2)}(\beta, Q^2)$$

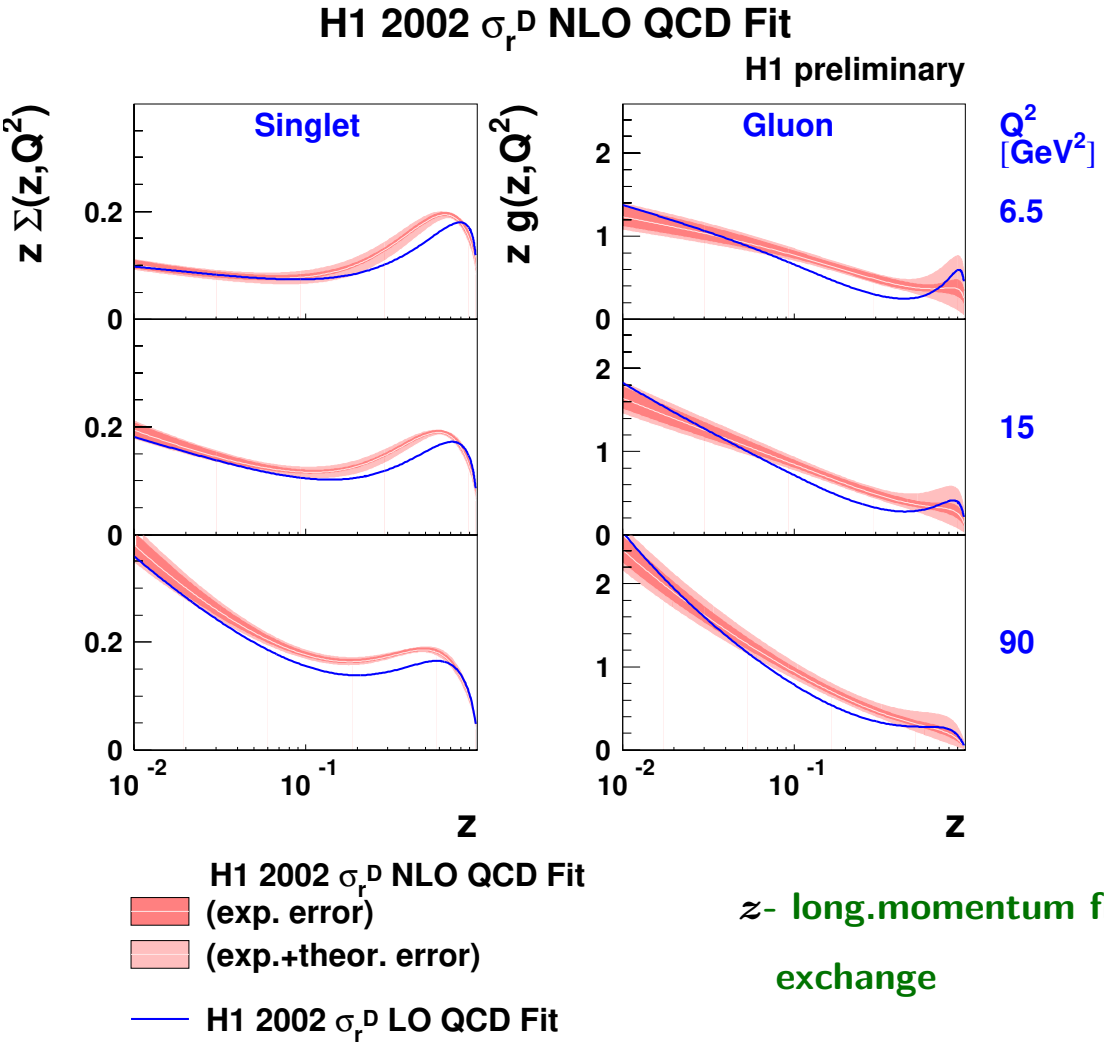
(recall $x = x_{I\!P} \cdot \beta$)

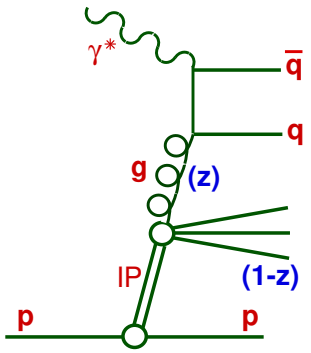
Diffractive Parton Densities from QCD Fit to $F_2^{D(3)}$

Extract diffractive parton densities from F_2^D data and use to predict the diffractive final states $\Longrightarrow$ are these PDFs universal ?

Apply same NLO QCD DGLAP technique to Q^2 and β dependences as for inclusive DIS

- ▷ singlet quark density $\Sigma(z, Q^2)$– directly from F_2^D $(\Sigma = 6u, u = d = s = \bar{u} = \bar{d} = \bar{s})$
- ▷ gluon density $g(z, Q^2)$– from scaling violation

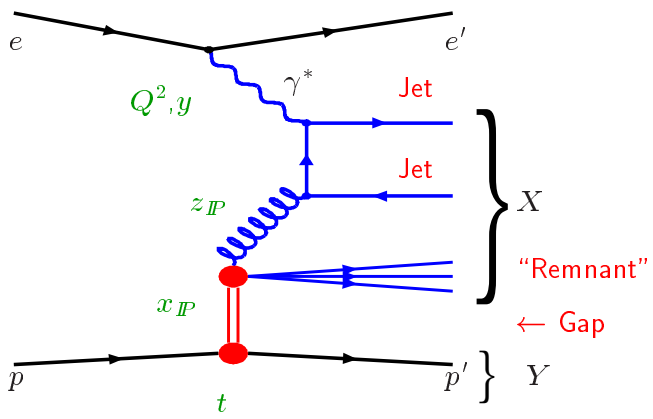




z- long.momentum fraction of the exchange

- low z behaviour similar to F_2^p
- hard gluon distribution extending to high z
- momentum fraction of colour singlet exchange carried by gluons $\sim 75\%$ for $6.5 < Q^2 < 800\ GeV^2$
- large uncertainty for $g(z, Q^2)$ at $z > 0.6$

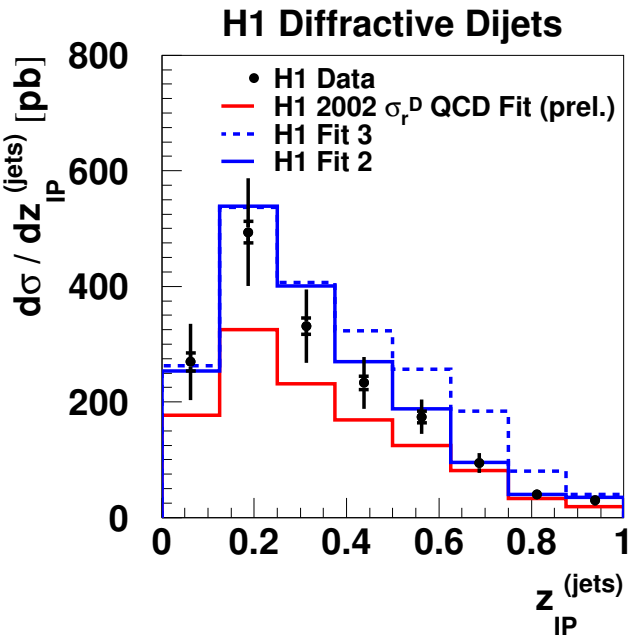
Diffractive Dijet and Open Charm Production

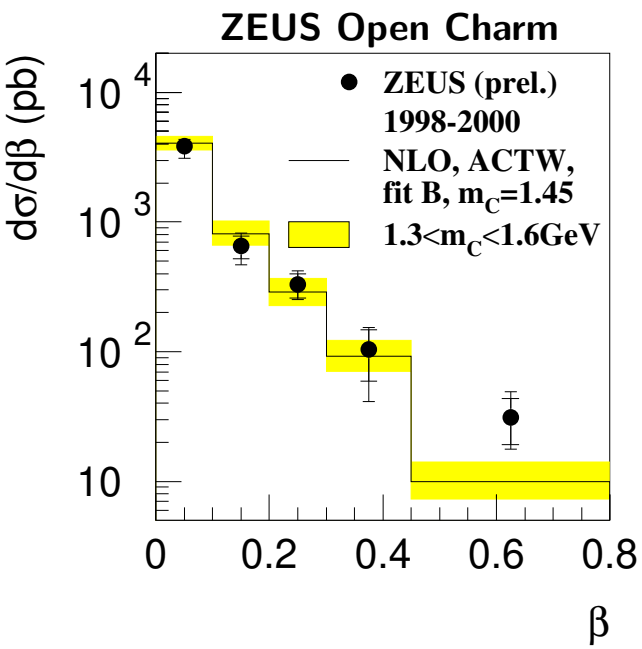


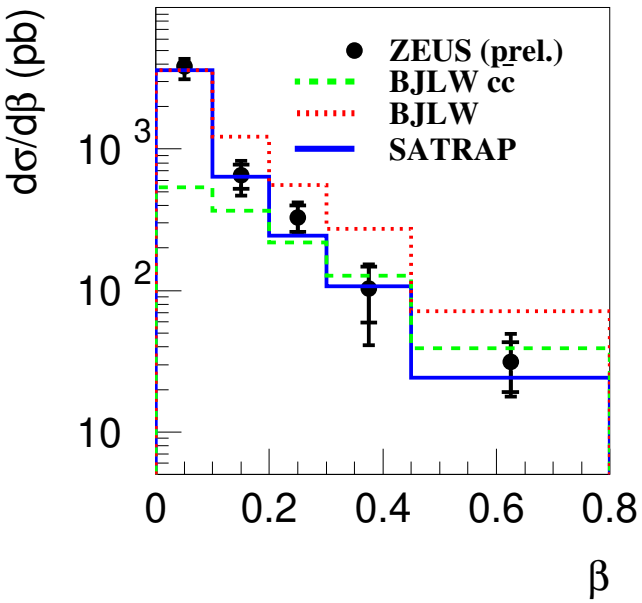
- **Ideal test of underlying dynamics of diffraction:**
  - **Cross-sections are calculable in pQCD**
  - **Production mechanism is directly sensitive to the gluon content of colour singlet exchange**
- **Test universality of parton distributions (extracted from F_2^D)**
- **Test of QCD $factorization$ and theoretical approaches:**
  - ♢ **Resolved Pomeron Model**
  - ♢ **Colour Dipole / 2 gluon exchange models**

Diffractive Dijet and Open Charm Production

Constrain shape and normalization of gluon density in colour singlet exchange





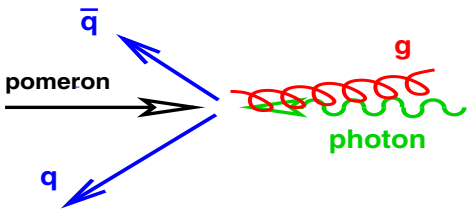


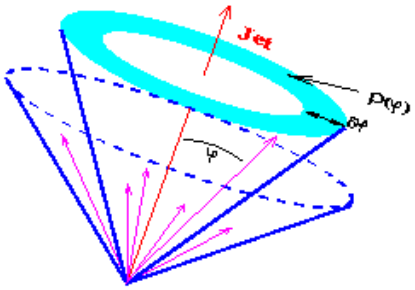
z– long.momentum fraction of the exchange

β– fraction of exchange momentum carried by struck quark

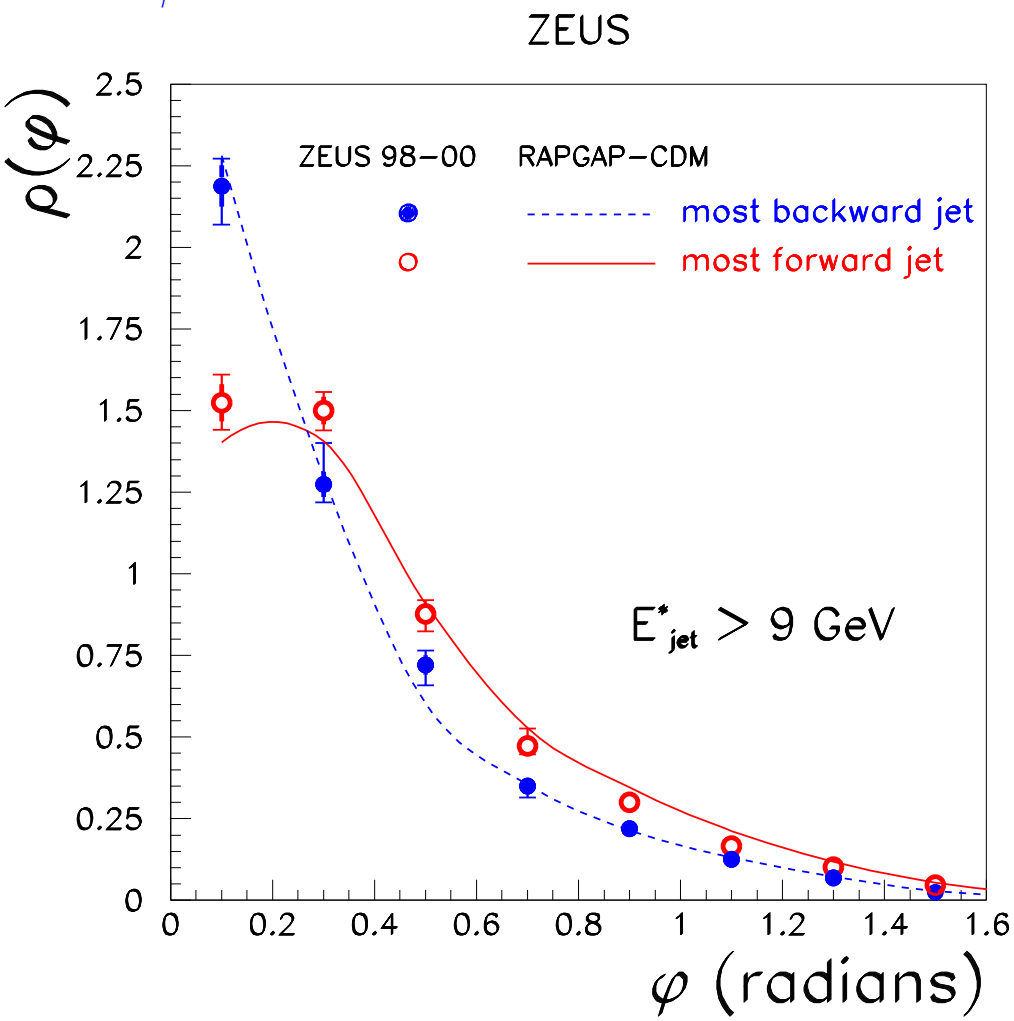
- **Resolved $I\!P$ models with QCD fits describe well the shapes and normalizations of dijet and open charm cross sections.**
  $\Longrightarrow$ Support for QCD factorization and gluon dominated PDFs
- **2g exchange models also describe the measurements if they include a significant contribution of $q\bar{q}g$ in the partonic final state.**
  The data are sensitive to the differences in these models.

Diffractive 3 Jet Production –Jet Shapes





$$\rho(\phi) = \left\langle \frac{1}{\delta\phi} \frac{E^{jet}(\phi \pm \delta\phi/2)}{E^{jet}} \right\rangle$$



- most $forward$ jet ($\mathbb{P}$ direction) is broader than most $backward$ jet (γ^* direction)
- data consistent with gluon emitted in $\mathbb{P}$ direction

Conclusions

- **HERA is an ideal facility to study the transition from soft to hard diffraction, explored using different hard scales (Q^2, M_q, p_T^{jet}, ...)**

- **Measurements of inclusive diffraction and the hadronic final states in diffractive DIS can be described within a consistent picture:**
  - **QCD factorization**
  - **NLO DGLAP evolution**
  - **Diffractive PDFs dominated by gluon contribution ($> 70\%$)**

Outlook

- **Only a small fraction of HERA results were presented in this talk**
- **Many new analyses of HERA-I data are underway**
- **HERA-II – precision measurements on diffraction**
  - **$10\times$ increase of statistics by 2006**
  - **new detectors- H1 VFPS** -Roman Pots at z$\approx$ 200m, 100% acceptance for |t|$\lesssim$ 0.2 GeV^2, 0.01$\lesssim x_{I\!P} \lesssim$ 0.02