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Diffraction at HERA

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Representing the H1 and ZEUS Collaborations

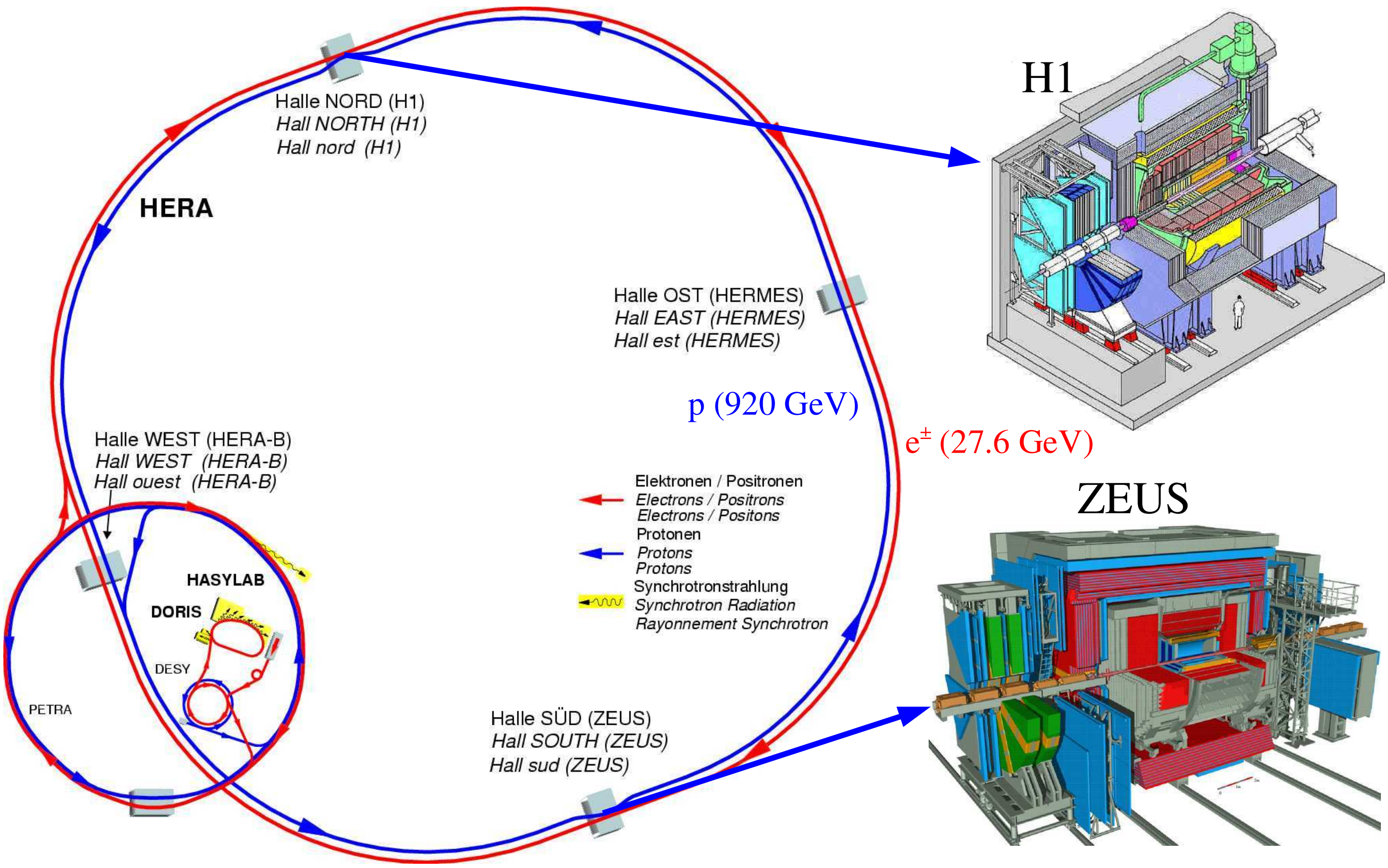
Outline:

- 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
- ...

HERA– the world's only ep collider

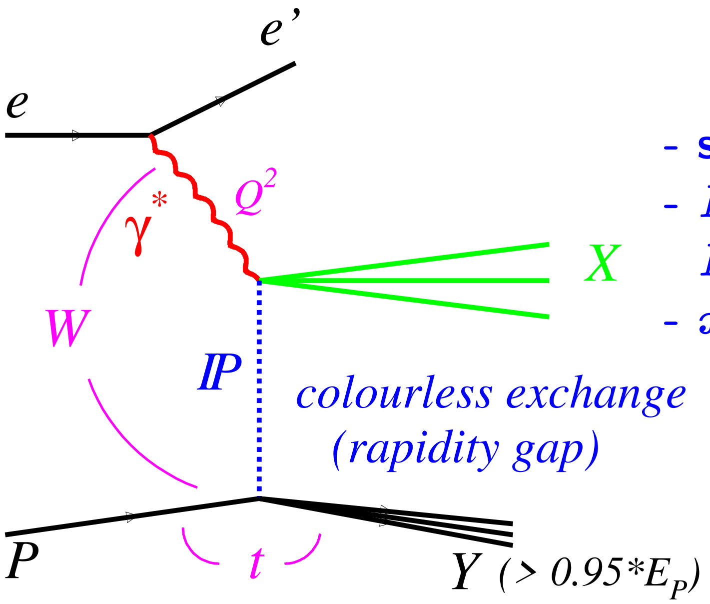


$$\boxed{s = 4E_eE_p \approx 100\ 000\ GeV^2}$$

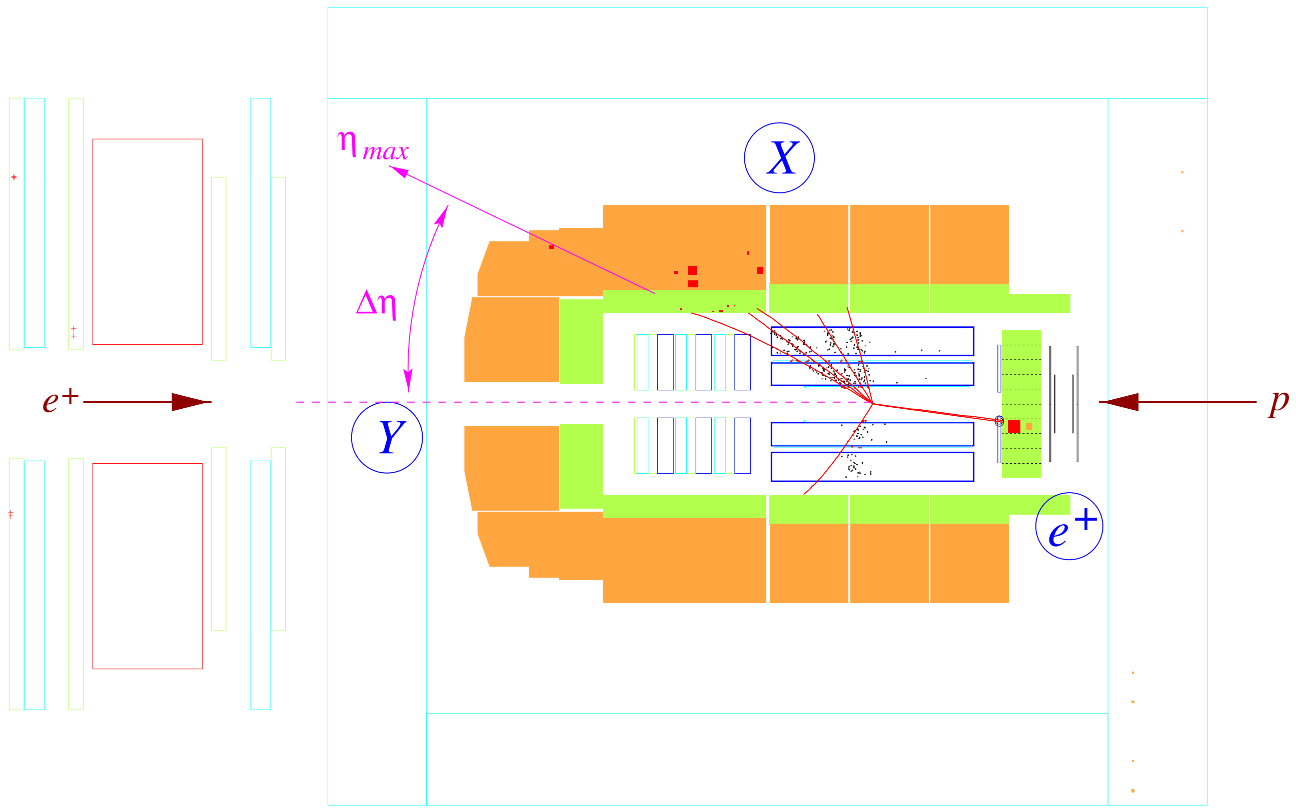
equivalent to 50 TeV fixed target !

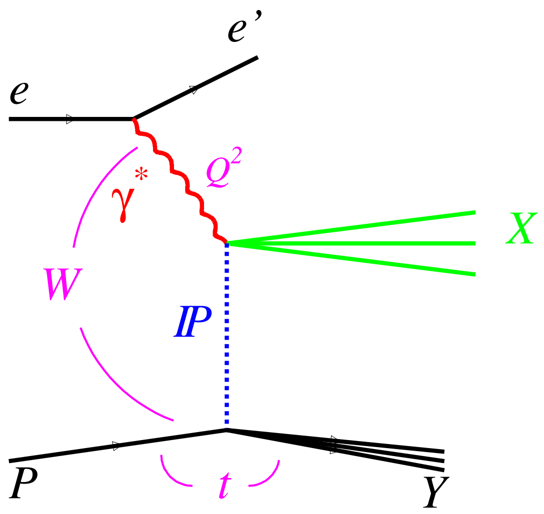
HERA-I (1993-2000): integrated luminosity– more than 100 pb^{-1} per experiment

Diffraction– t-channel exchange of the vacuum quantum numbers



- **small momentum transfer t**
- $M_Y \equiv M_P$ **or** $M_Y \lesssim 1.6\ GeV$
- $x_{I\!P} \simeq 1 - E_Y/E_p \lesssim 0.05$





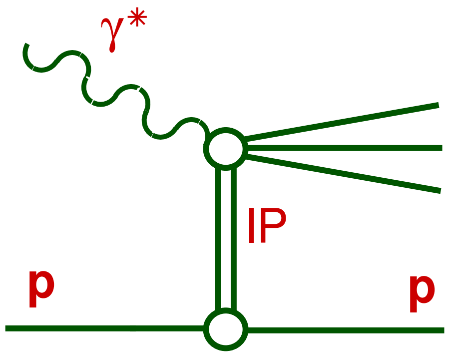
If no hard scale– Q^2, $|t| \approx 0$: similar to <u>soft</u> hadron-hadron interactions

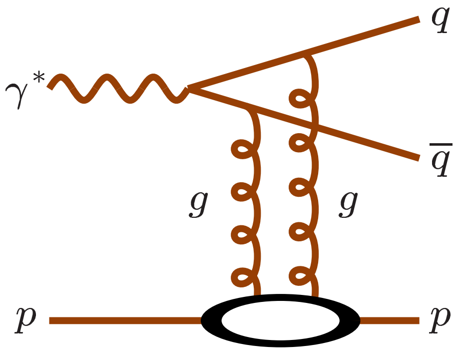
– Regge theory: diffraction is $exchange\ of\ Pomeron$

If large Q^2, $|t|$, p_T^{jet}, m_q: <u>pQCD</u> at $\gamma^* I\!P$ vertex

– Resolved Pomeron: γ^* probes $I\!P$ structure

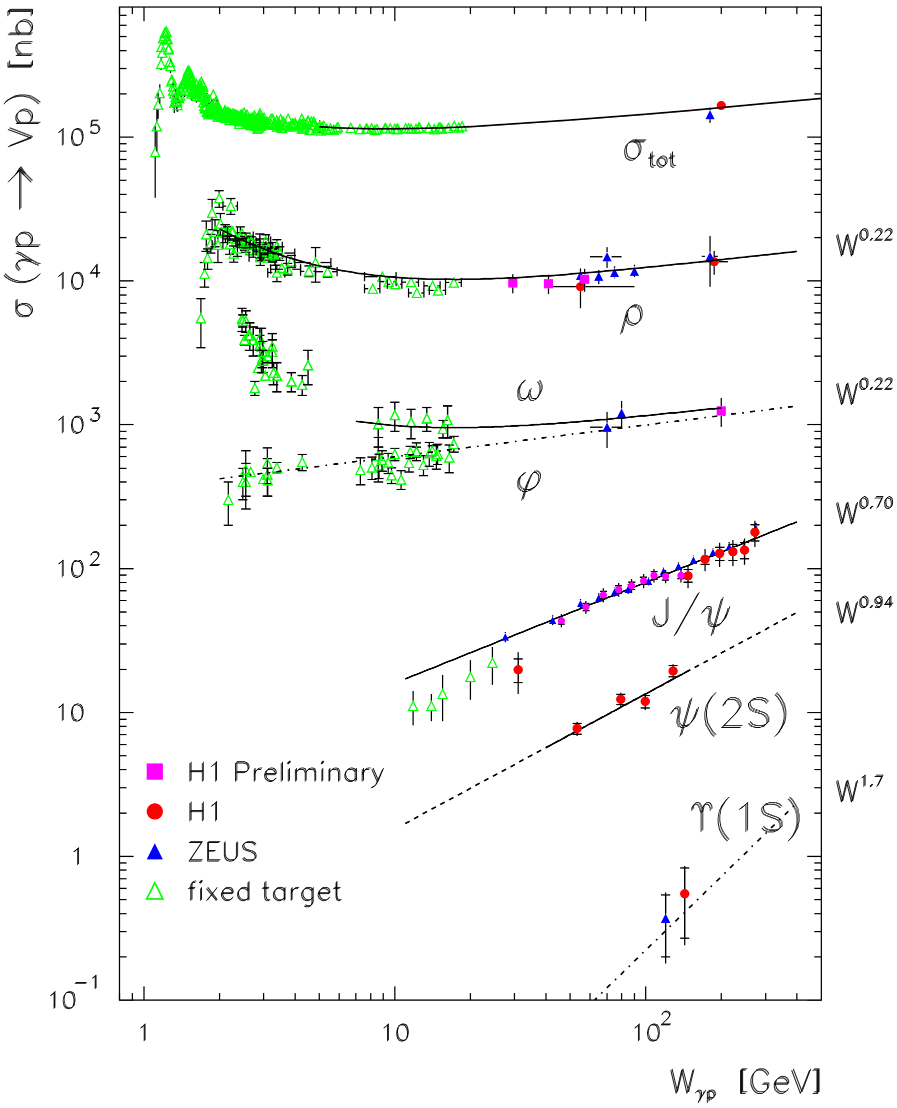
– Colour dipole: diffraction is $exchange\ of\ colour\ singlet\ gluon\ ladder$ between $(\gamma^* \to q\bar{q}, q\bar{q}g)$ and the proton



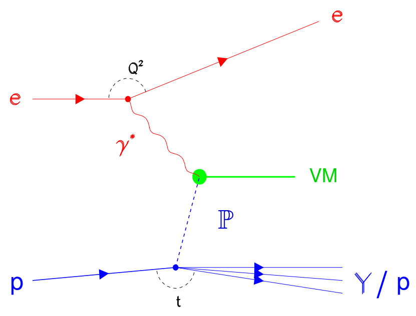


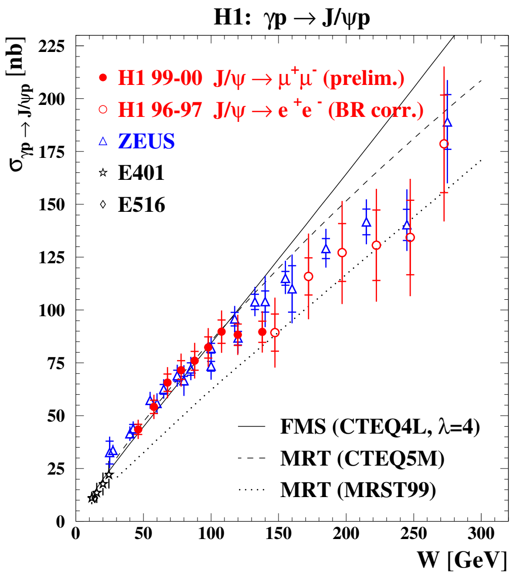
HERA– unique facility to probe partonic content of diffractive exchange and to study transition from soft to hard regime

Photoproduction of Vector Mesons



$\gamma p \longrightarrow Vp$



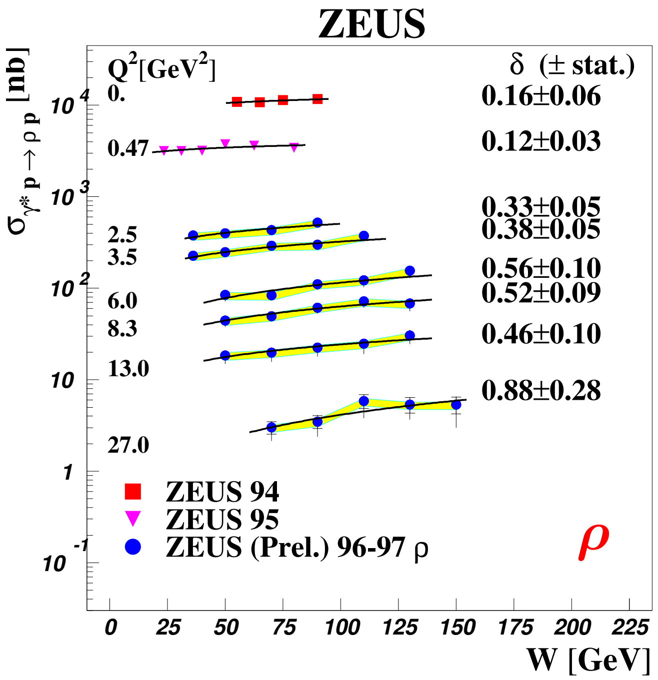


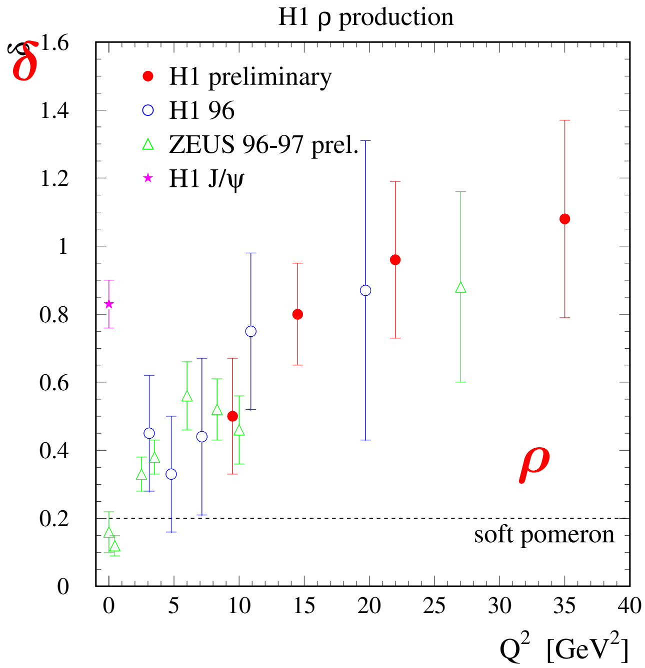
- The cross sections of VM photoproduction (and $\sigma_{tot}^{\gamma p}$) indicate a power law behaviour $\sigma \sim W^{\delta}$ for $W > 10\ GeV$
- For ρ, ω, ϕ: $\delta \approx 0.2$, compatible with $\sigma_{tot}^{\gamma p}$
- For J/Ψ: $\delta \approx 0.8$

$\Longrightarrow$ Steeper W dependence for heavy Vector Mesons, described by pQCD ($\sigma \propto [xg(x, Q^2)]^2$)

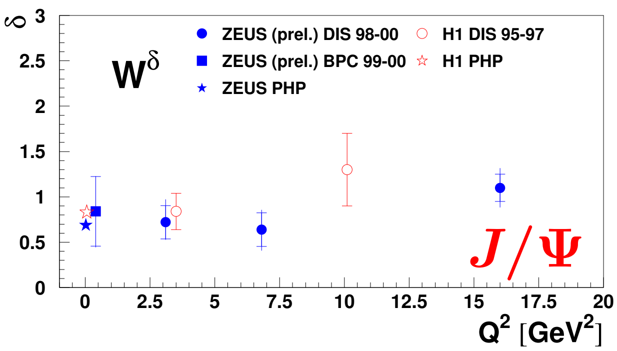
$\Longrightarrow$ M_{VM} sets a hard scale for pQCD calculation !

VM-meson Production in DIS





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



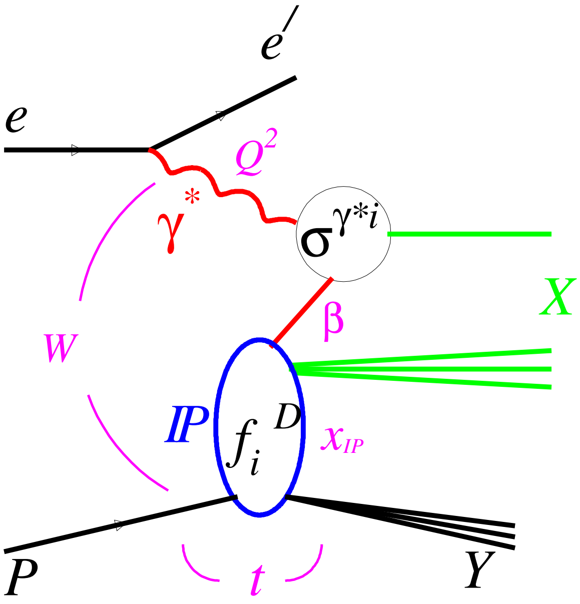
$-W$ dependence steeper for ρ with increasing Q^2

Transition from soft to hard physics as Q^2 increases

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

$\Longrightarrow$ Q^2 and $M_{J/\Psi}$ set a hard scale for pQCD

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 $I\!P$ $(x_{I\!P} \simeq 1 - E_Y/E_P)$

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

Cross Section:

$$\frac{d\sigma^D}{d\beta dQ^2 dx_{I\!P} dt} = \frac{2\pi\alpha}{\beta Q^4}(1 - y + y^2/2)\cdot F_2^{D(3)}(\beta, Q^2, x_{I\!P}, t)$$

Factorization Properties of F_2^D:

QCD factorization -proven in diffractive ep (Collins 1997)

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

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

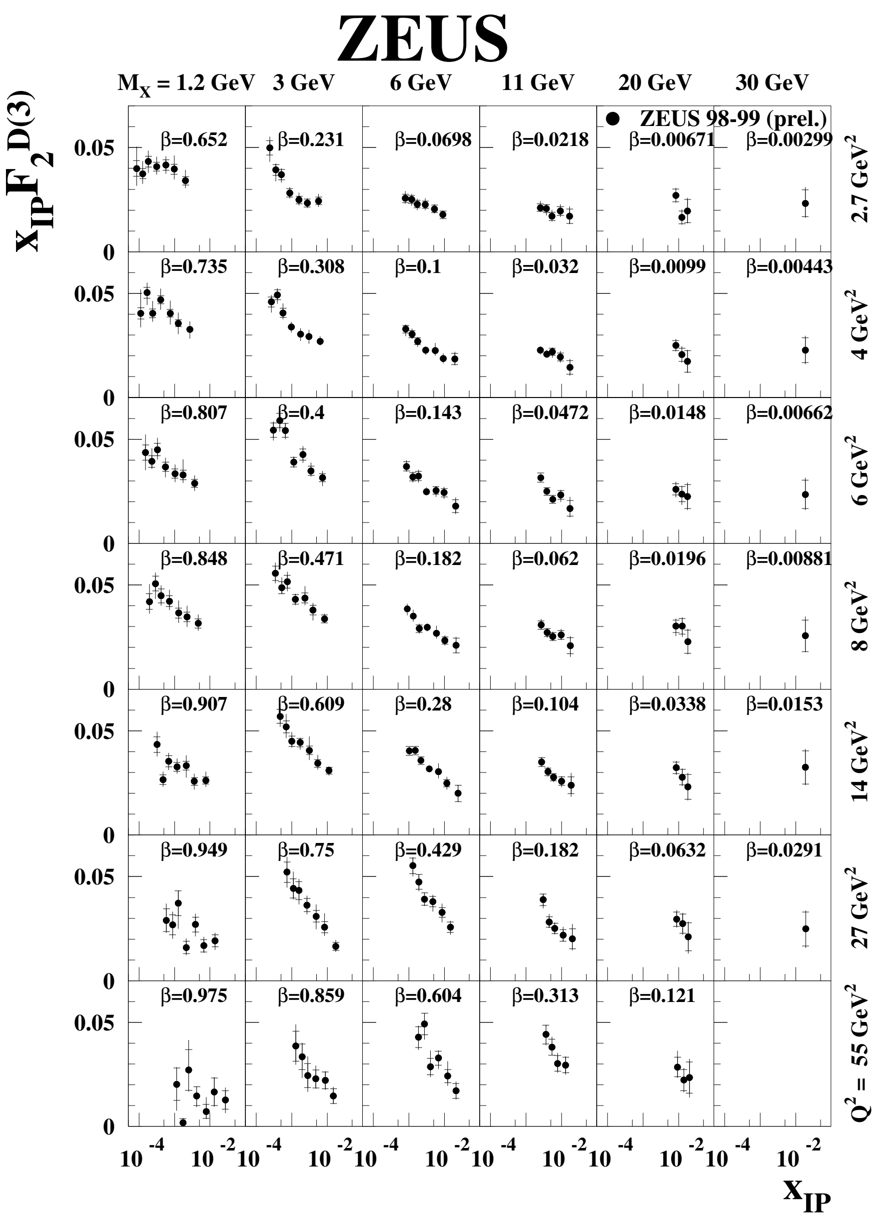
- at fixed $x_{I\!P}$ and t evolve with x, Q^2 according to DGLAP
- are $universal$ for diffractive DIS (!?)

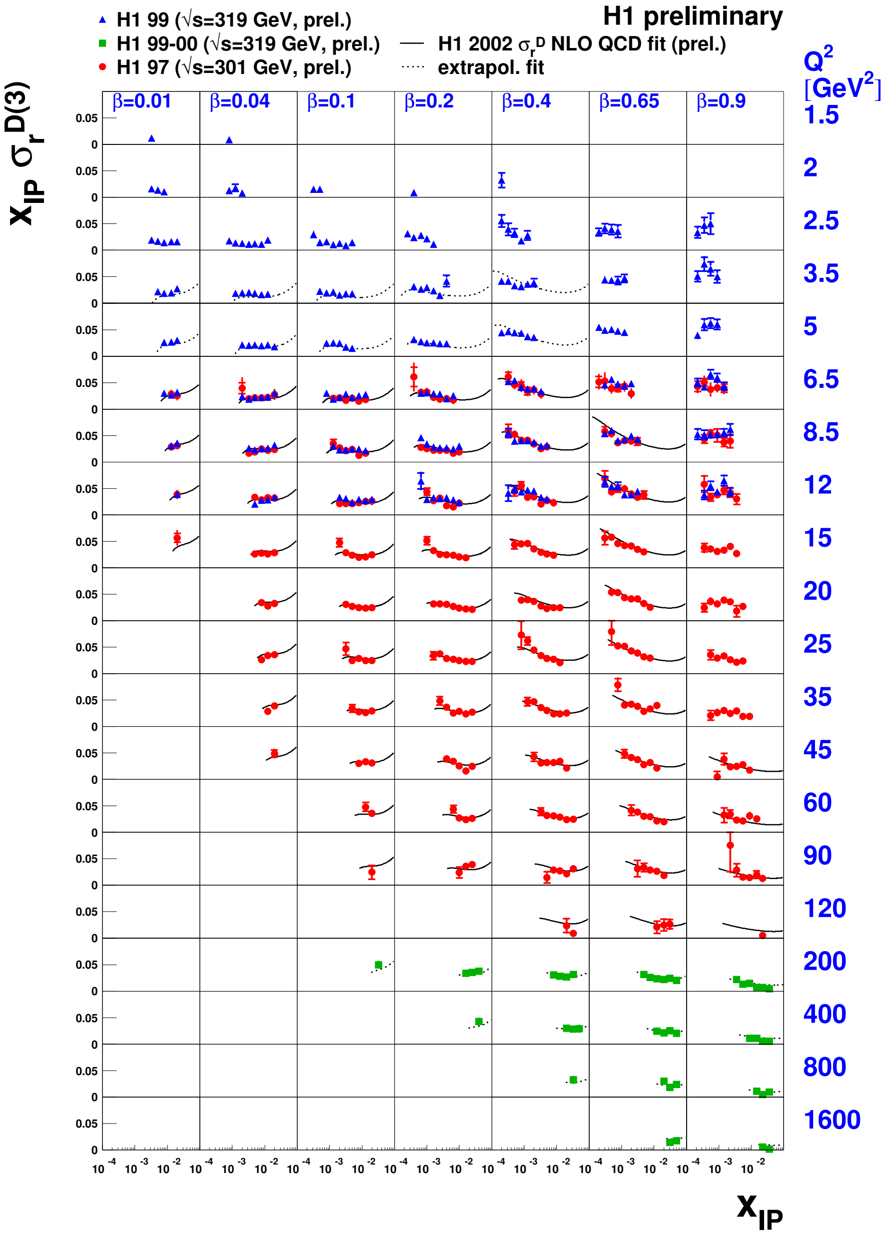
$\Longrightarrow$ extract diffractive parton densities from F_2^D and use to predict the diffractive final states:

- apply NLO QCD DGLAP technique to Q^2 and β dependences as for inclusive DIS
- assume Regge factorization:
  diffractive PDFs are independent of $x_{I\!P}$ and t
  $F_2^{D(4)}(\beta, Q^2, x_{I\!P}, t) = f_{I\!P}(x_{I\!P}, t) \times F_2^{D(2)}(\beta, Q^2)$

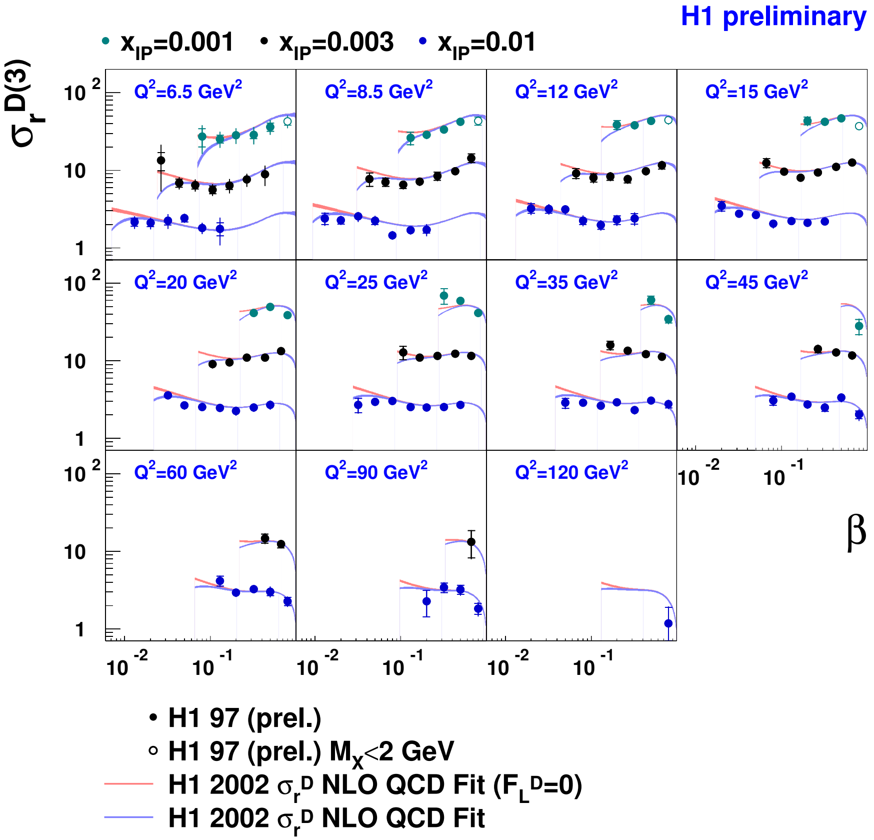
(recall $x = x_{I\!P}\cdot\beta$)

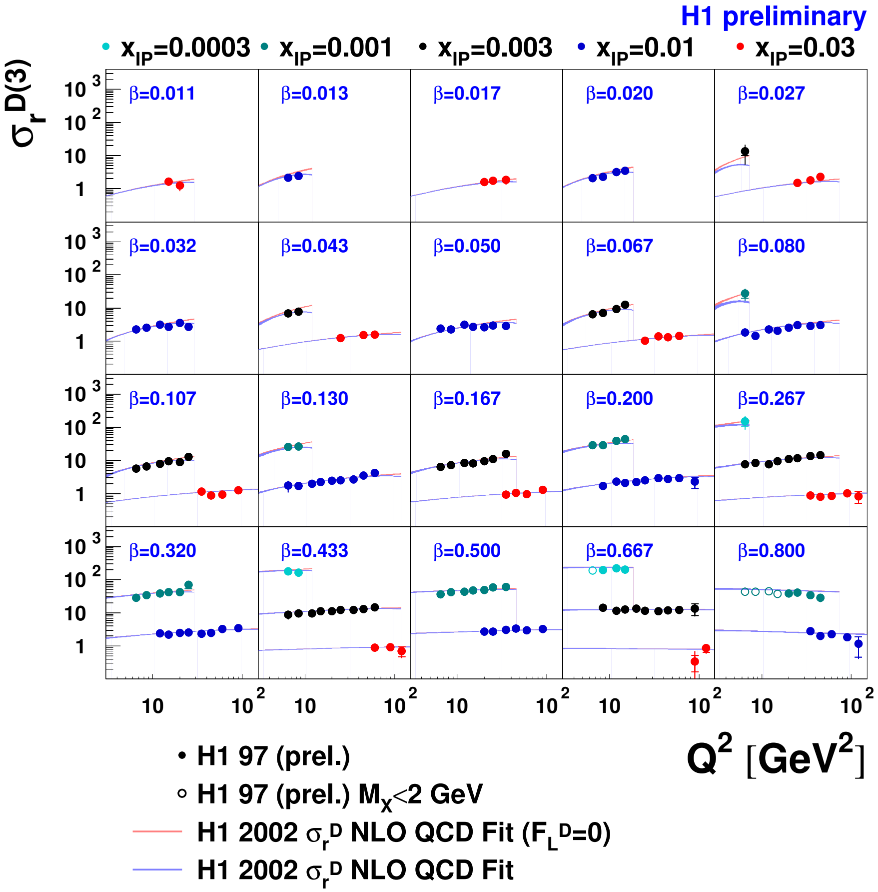
$x_{I\!P}, \beta, Q^2$ dependence of $F_2^{D(3)}$





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





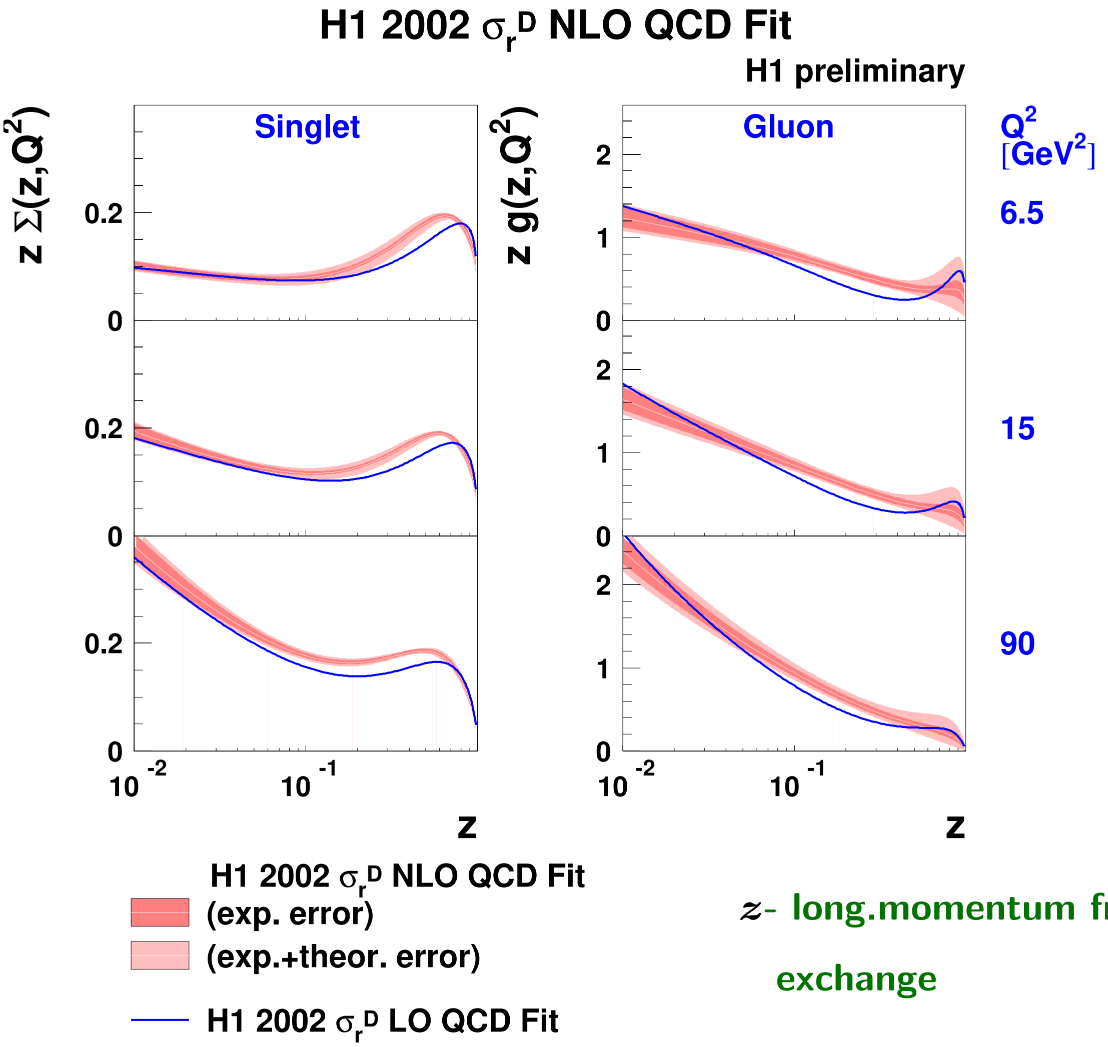
- β dependence relatively flat (different from F_2^p)
- scaling violation rising with lnQ^2 up to large β
- DGLAP evolution based fit describes the data

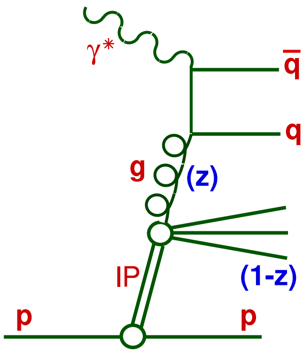
Diffractive Parton Densities from QCD Fit to $F_2^{D(3)}$

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

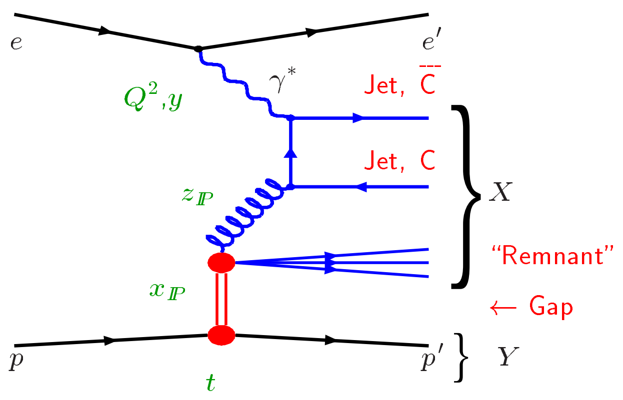




z- long.momentum fraction of the exchange

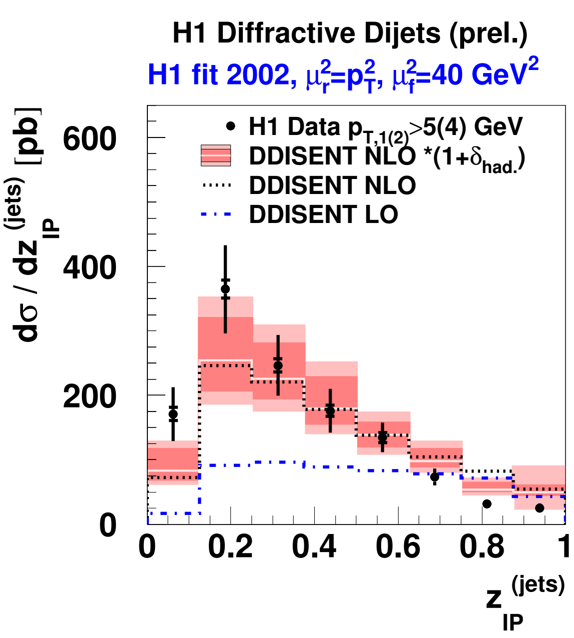
- low z behaviour similar to F_2^p
- hard gluon distribution extending to high z
- momentum fraction of colour singlet exchange carried by gluons $\sim 75\%$ for $6.5 < Q^2 < 800\ GeV^2$
- large uncertainty for $g(z, Q^2)$ at $z > 0.6$

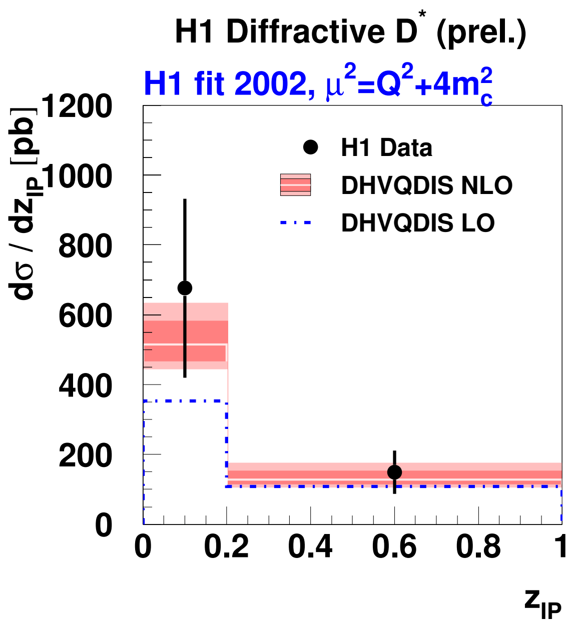
Diffractive Dijets and Open Charm in DIS



Ideal test of underlying dynamics of diffraction:

- Test universality of parton distributions (extracted from F_2^D)
- Production mechanism is directly sensitive to the gluon content of colour singlet exchange $\longrightarrow$ give constrain of shape and normalization of gluon density in diffractive exchange
- Presense of two hard scales (Q^2 and p_T^{jet}, m_Q)



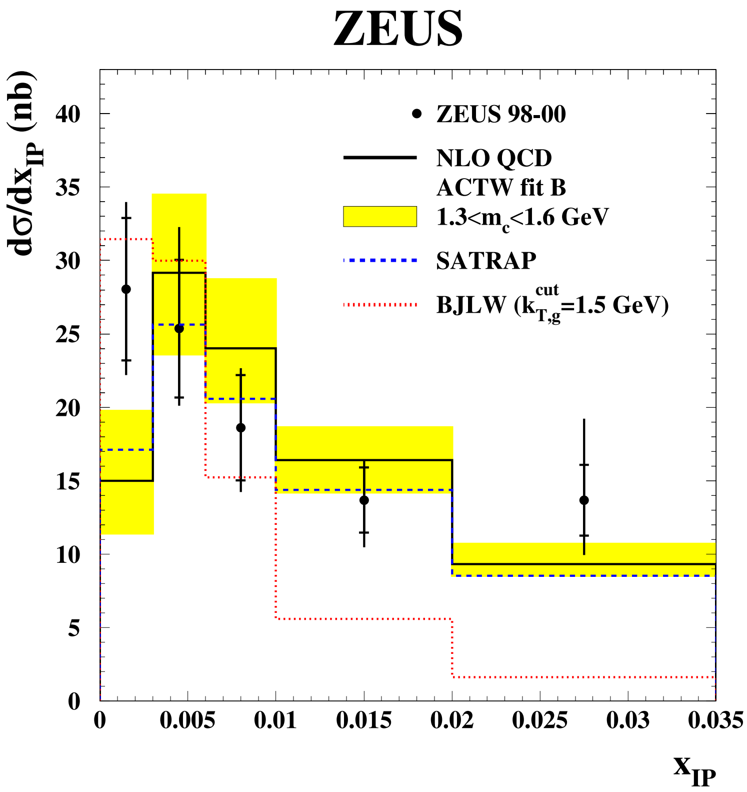


($z_{I\!P}$– momentum fraction of diffr.exchange entering hard scattering)

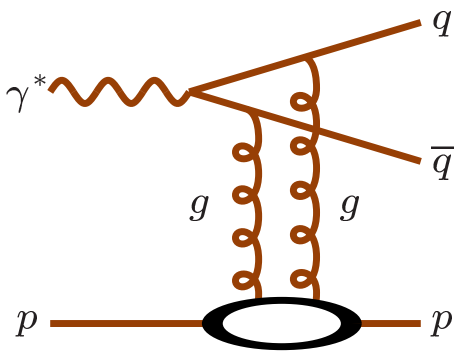
Resolved $I\!P$ models with QCD fits describe well the shapes and normalizations of dijet and open charm cross sections.

$\Longrightarrow$ Support for QCD factorization and gluon dominated PDFs

Open Charm– comparison with calculations



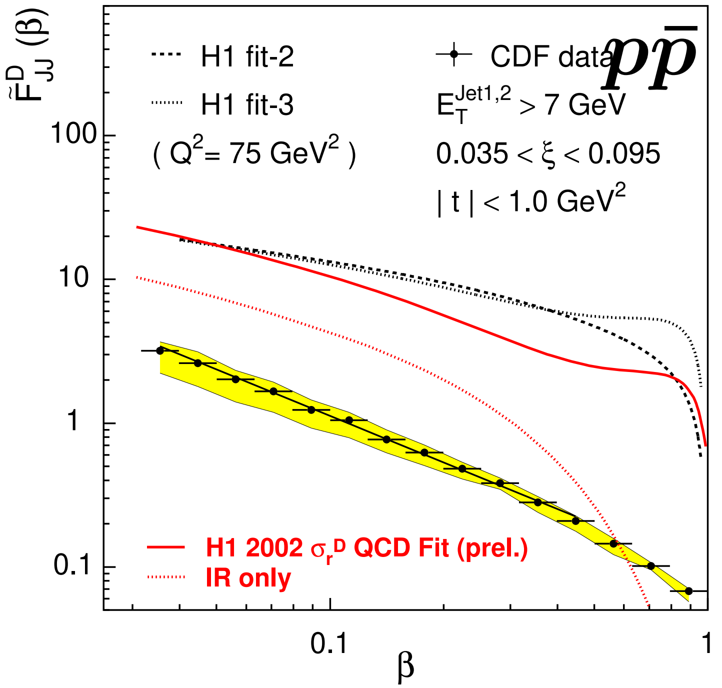
$x_{I\!P}$– long.momentum fraction of diffr. exchange

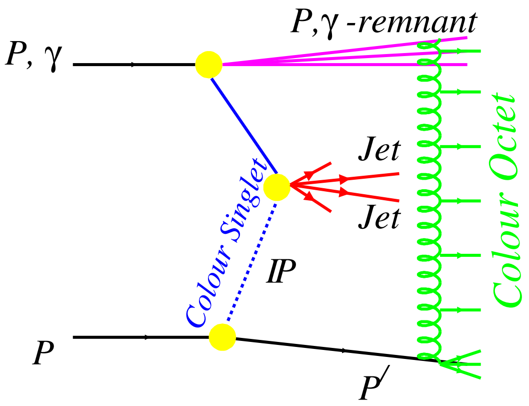


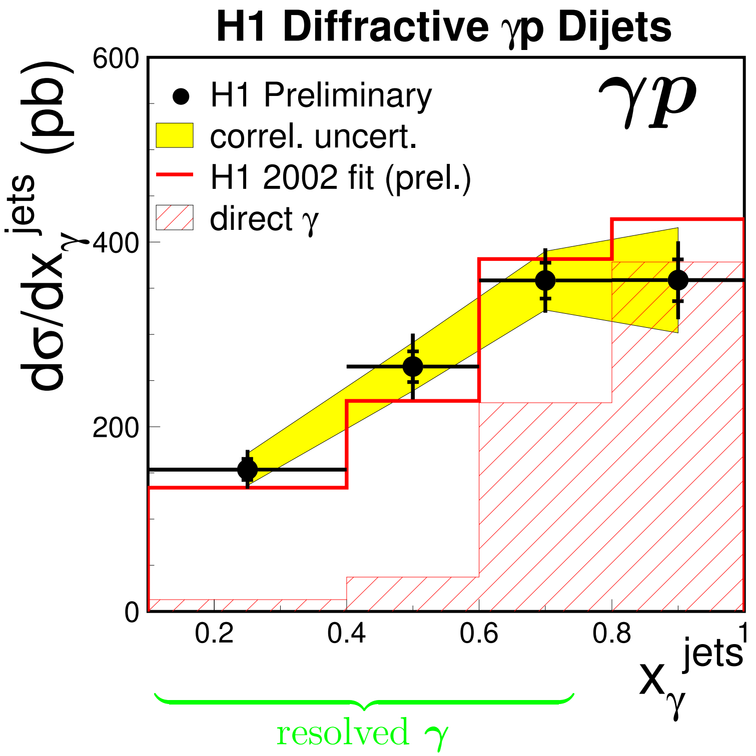
2g exchange models also describe the measurements

The data are sensitive to the differences in these models

Diffractive Dijets at the TeVatron and photoproduction at HERA





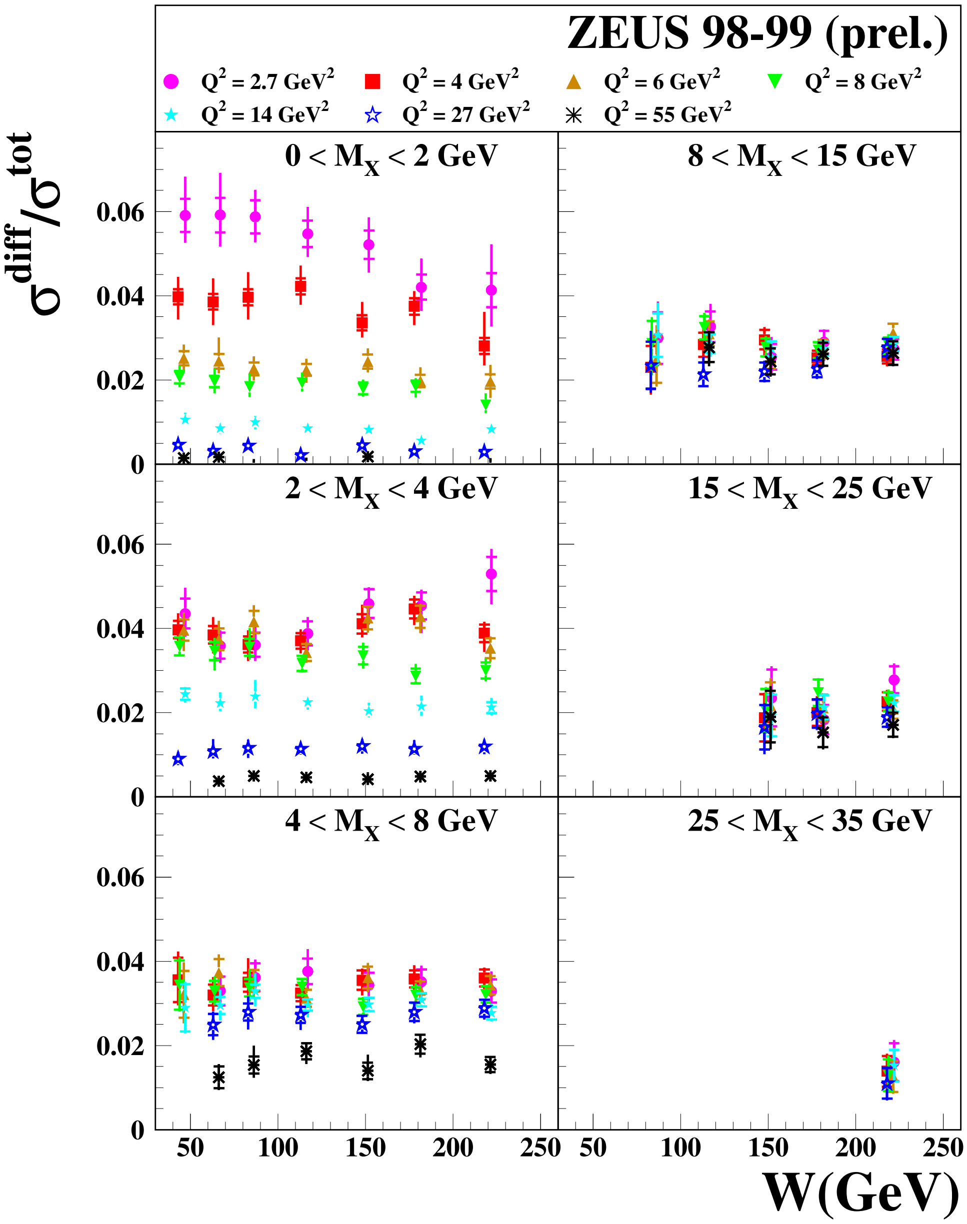


- Hadronic environment– hard scale is given by p_T^{jet}
- Hard diffraction in pp is suppressed w.r.t. predictions using PDFs from HERA (by factor 5-10)

  Rescattering between two remnants !? (Gap survival probability is small)
- No evidence for the suppression of resolved photon processes in photoproduction !

  (Resolved photon ($x_\gamma < 1$) can be regarded as a hadron)

W dependence of $\sigma_{diff}/\sigma_{tot}$ in DIS



$\sigma_{diff}/\sigma_{tot}$ is flat in W ! $\rightarrow$
Same energy behaviour in diffractive and inclusive DIS

Simple view: diffraction is exchange of 2 hard gluons $\rightarrow$
$\sigma_{diff} \propto |xg(x)|^2$, $\rightarrow$ $\sigma_{diff}/\sigma_{tot} \propto xg(x) \propto W^a$
(since $\sigma_{tot} \propto xg(x) \propto W^a$)

Softer than "two hard gluon" exchange !

Conclusions

- **HERA is an ideal facility to investigate the diffractive exchange in terms of pQCD and to study 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 ($> 70\%$)**

- **Open questions (e.g. breakdown of factorization at TeVatron, flat dependence $\sigma_{diff}/\sigma_{tot}$,...)**

Outlook

- **Still more results to come from HERA-I data**
- **HERA-II – new quality of diffractive measurements**
  - **$\times 10$ increase of statistics**
  - **new detectors- H1 VFPS** – $\sim$ 100% acceptance for |t|$\lesssim$ 0.2 GeV^2, 0.01$\lesssim x_{I\!P} \lesssim$ 0.02