Diffraction and Exclusive Vector Meson Production at HERA

$\mathfrak{L}$. *Favart*

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ULB

On behalf of the H1 and ZEUS Collaborations

BARYONS 2007 - Seoul
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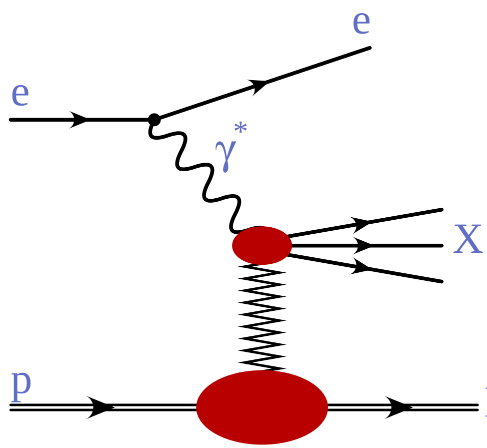
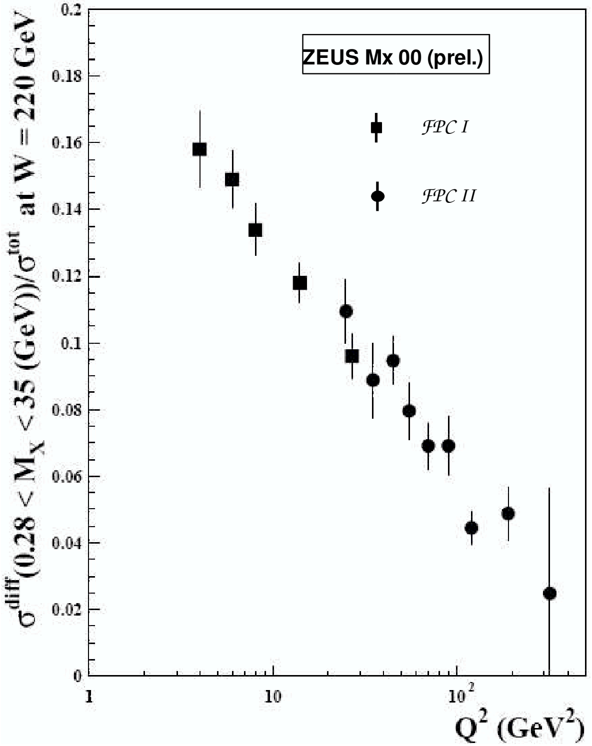
Diffractive processes

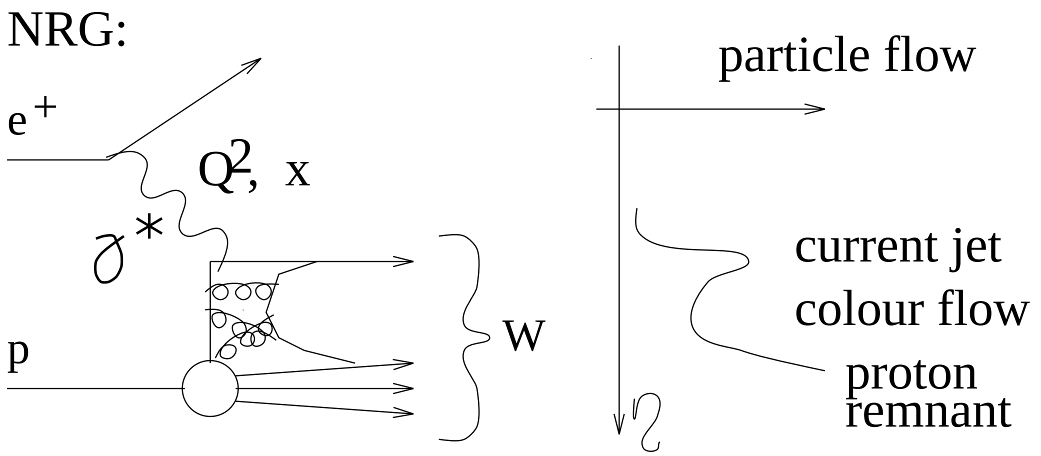
- Feature of hadron-hadron interactions (up to 30% of σ_{tot})
- t-channel exchange of the vacuum quantum numbers
  - Small momentum transfer
    - $t << s$
    - small p momentum loss $x_{I\!P} (= \xi) < 0.05$
  - Final state part. separated by a **Large Rapidity Gap**
  - Beam hadrons scattered elastically or dissociated into a low-mass state (M_Y).
  - QCD: colourless exchange

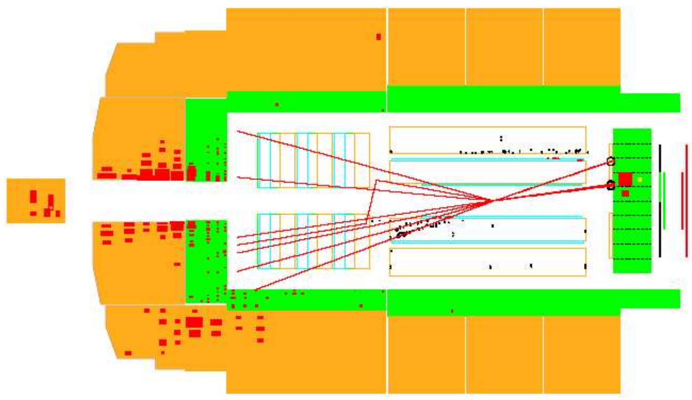




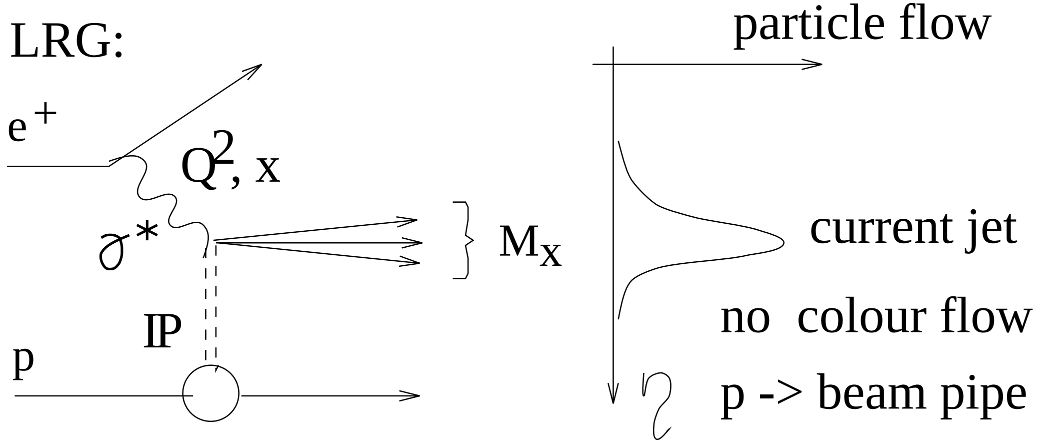
Diffractive Signature

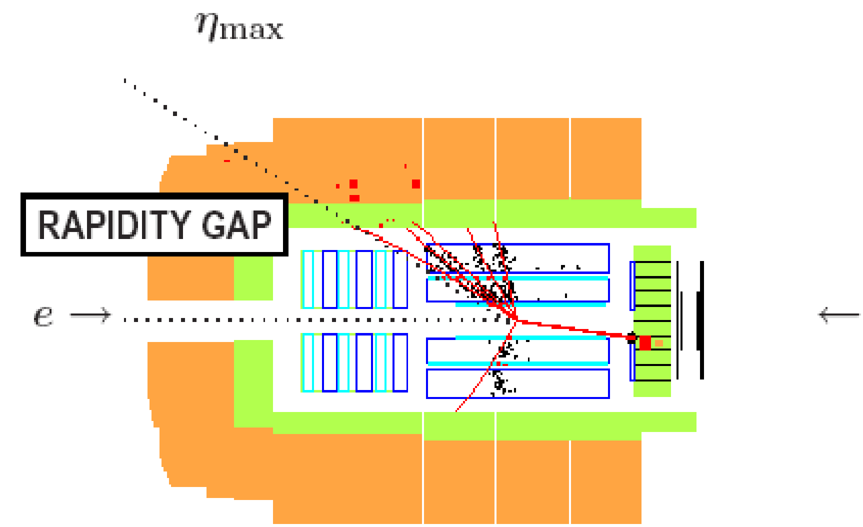
Non-diffractif (DIS)





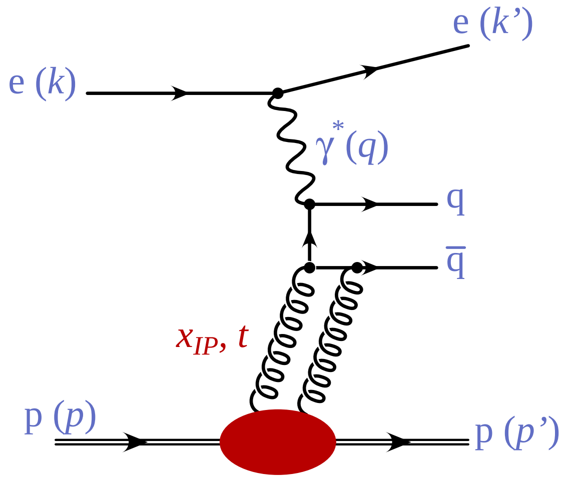
Diffractif (DDIS)

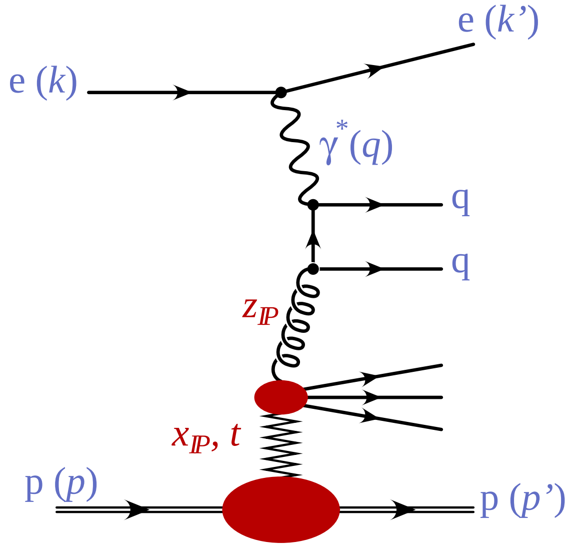




Interest of Hard Diffraction

- Understanding of Diffractive phenomena in terms of QCD
  - → two gluon exchange
  - → Several possible hard scales: Q^2, P_T^{Jet}, t, m_q
  - → probing the exchange partonic structure - like in inclusive structure functions
  - → typical signature of hard scale presence: steep rise with W (cms energy)





Interest of Hard Diffraction

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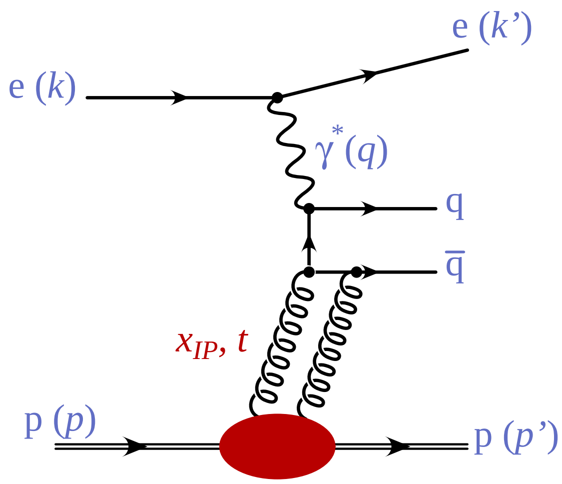
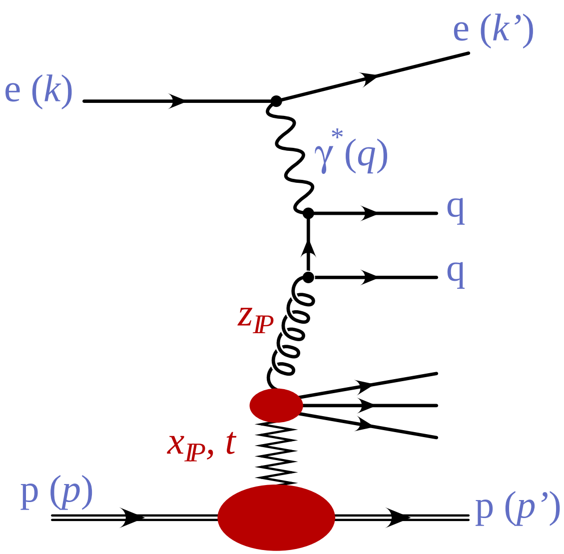
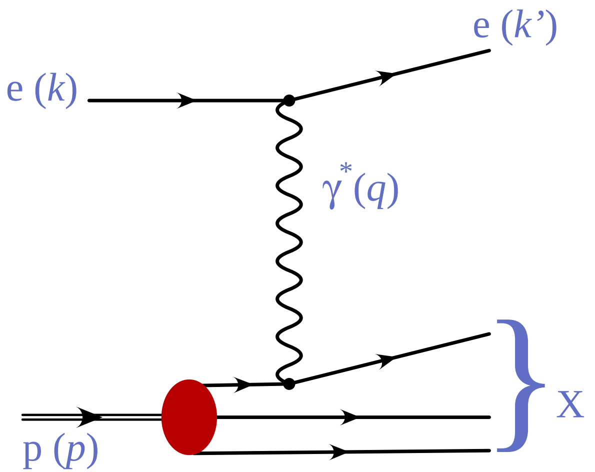
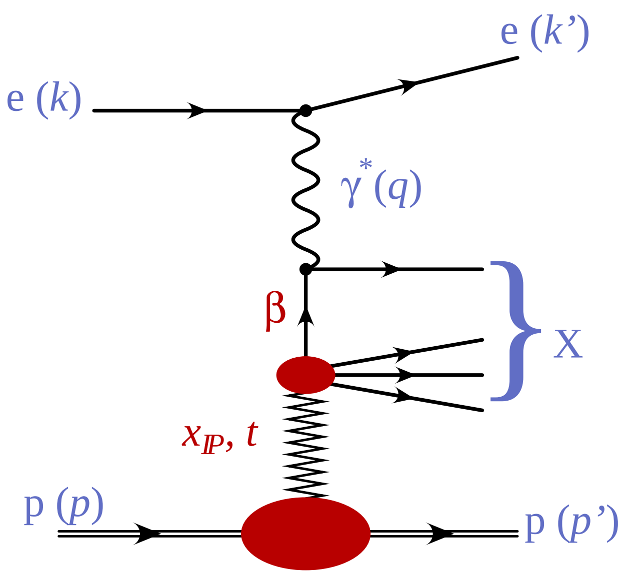
  - ➜ two gluon exchange
  - ➜ Several possible hard scales: Q^2, P_T^{Jet}, t, m_q
  - ➜ probing the exchange partonic structure - like in inclusive structure functions
  - ➜ typical signature of hard scale presence: steep rise with W (cms energy)
- Access to very low x of nucleon structure function and parton correlations ➜ the Generalized Parton Distributions (GPDs).
- Test of DGLAP and BFKL asymptotic behaviour dynamics
  - ➜ DGLAP: $\log(Q^2)$ ➜ k_T ordering
  - ➜ BFKL: $\log(1/x)$ ➜ $1/x$ ordering
- Colour Dipole model approach: transition to non pQCD, saturation





Kinematic





Deep Inelastic Scattering

Q^2 $= -q^2$ - virtuality of the exchanged photon

W $\gamma^* - p$ system energy

x Bjorken-x: fraction of proton's momentum carried by the struck quark

y γ^* inelasticity : $y = Q^2/s\ x$

Diffractive Scattering

$x_{I\!P}$ fraction of proton's momentum of the colour singlet exchange (also named ξ)

$x_{I\!P} \simeq \frac{Q^2+M_X^2}{Q^2+W^2}$

β fraction of $I\!P$ carried by the quark "seen" by the γ^* $\beta = x/x_{I\!P}$

t $= (p-p')^2$, 4-momentum squared at the p vertex

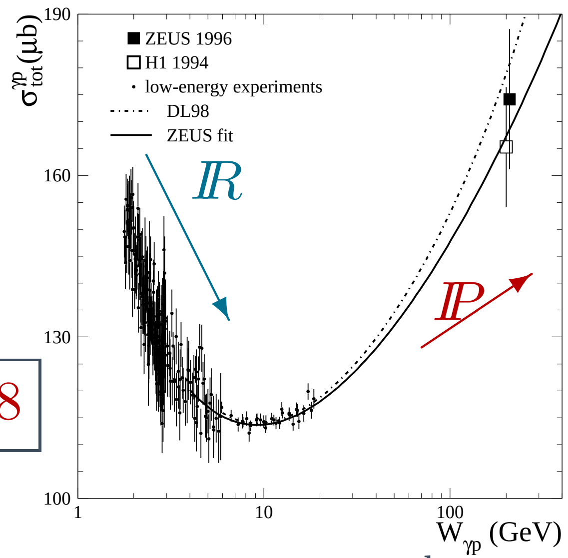
From DIS to Inclusive Diffraction

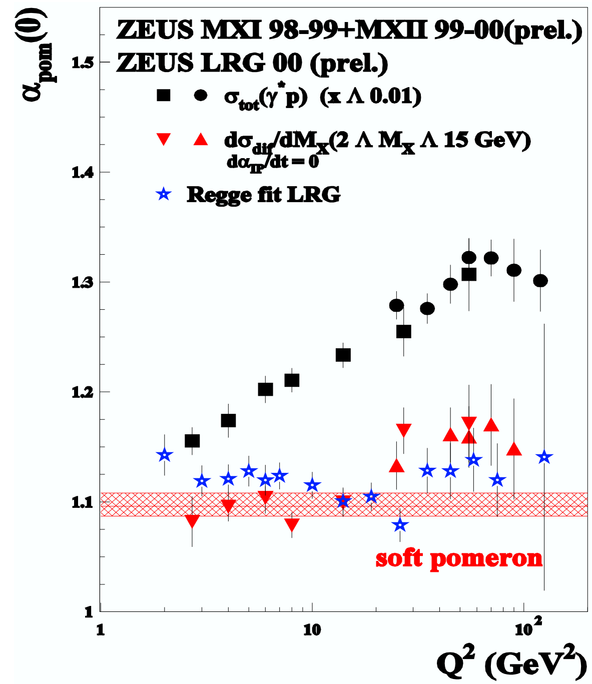
Historically (60's) diffraction is described by a Pomeron exchange in Regge theory

- **Total cross section: $\gamma^* p \to X$**

$$\sigma_{Tot} = B\, W^{2(\alpha_{I\!R}-1)} + A\, W^{2(\alpha_{I\!P}-1)}$$

$$\alpha_{I\!R} = 0.55 \;/\; \alpha_{I\!P} = 1.08$$





Optical theorem: $\sigma^2_{tot}(\gamma^* p \to X) \sim \frac{d\sigma_{el}}{dt}(\gamma^* p \to \gamma^* p)$ at $t = 0$

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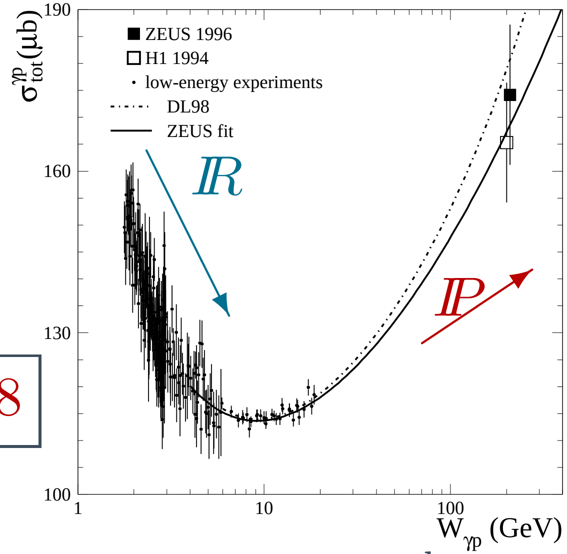
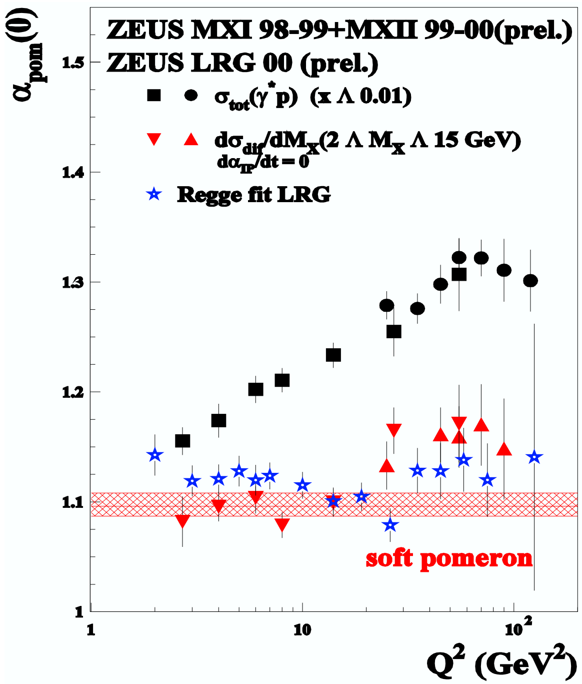
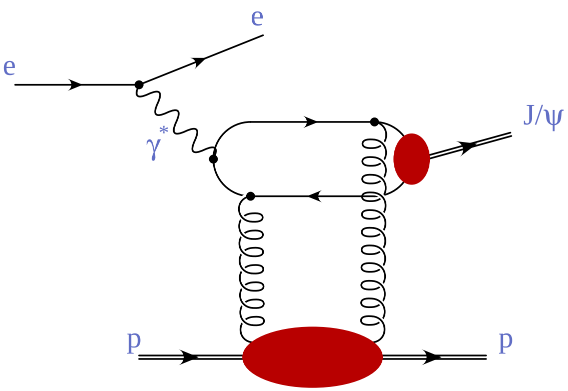




Optical theorem: $\sigma^2_{tot}(\gamma^* p \to X) \sim \frac{d\sigma_{el}}{dt}(\gamma^* p \to \gamma^* p)$ at $t = 0$

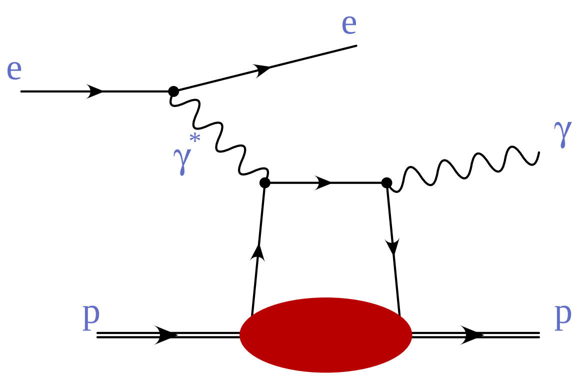
- **DVCS:** extension to off-forward scattering.
  $\gamma^* p \to \gamma p$ at $t \neq 0$ and $\beta = 1$
- **VM production:** $\gamma^* p \to VM\ p$ at $t \neq 0$ and β fixed.
- **Inclusive Diffraction:** $\gamma^* p \to Xp$ any M_X, full β range.

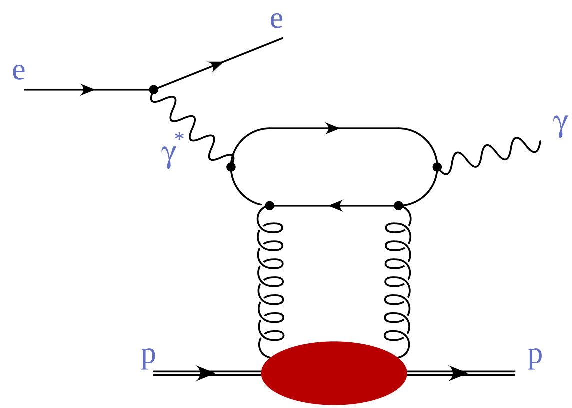


Exclusive processes: DVCS and VM production

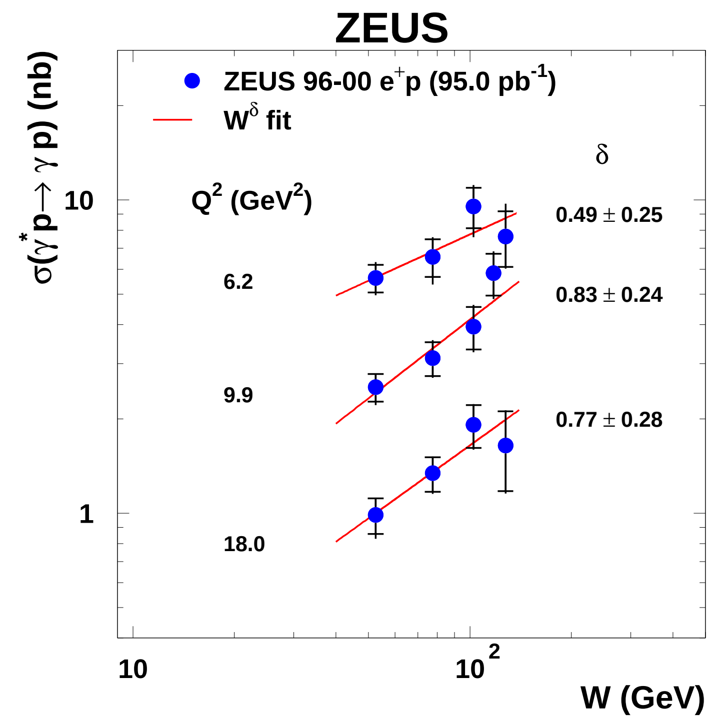
- In presence of a hard scale, (almost) fully calculable in pQCD
  - Is the hard scale present?
- Exclusive final state
  - Can we approximate as $\sigma \sim |x\ g(x, Q^2)|^2$
- Can we constrain Generalized Parton Distributions (GPDs)?

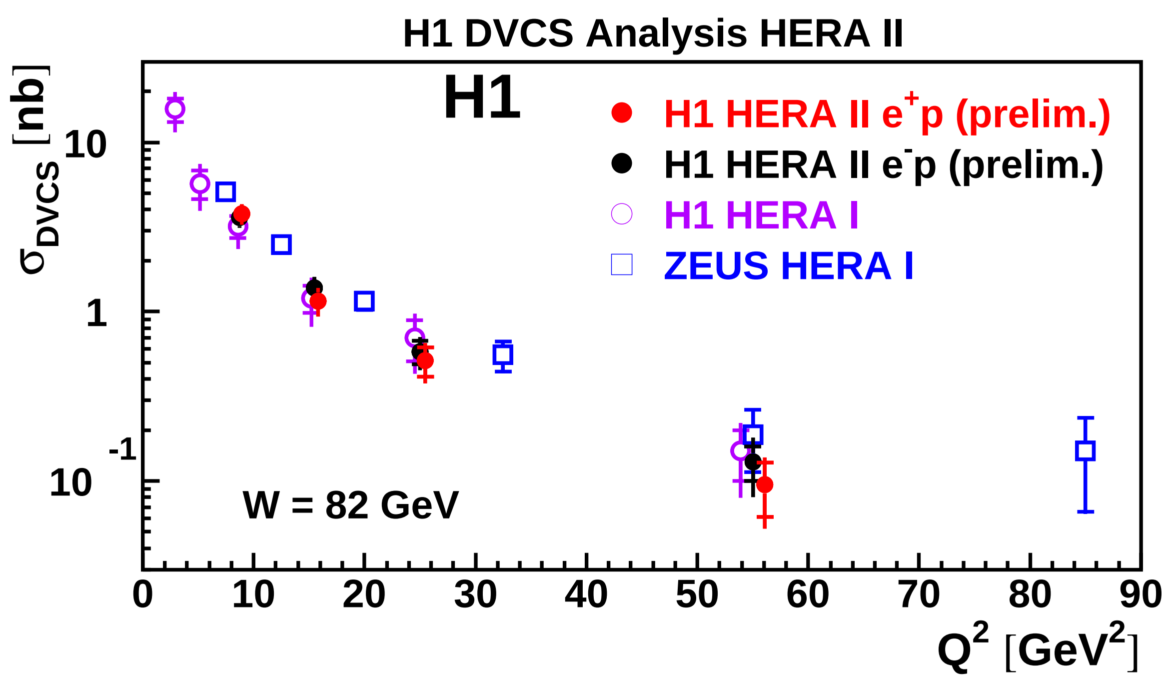
Deep Virtual Compton Scattering

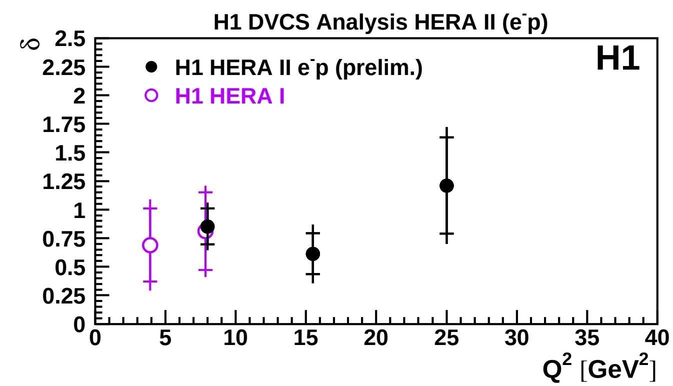




- fully calculable in pQCD
- Access to the full QCD amplitude
- Constrain gluon GPDs







W dependence indicates a hard regime (similar to J/Ψ)

DVCS: t slope and Beam Charge Asymmetry

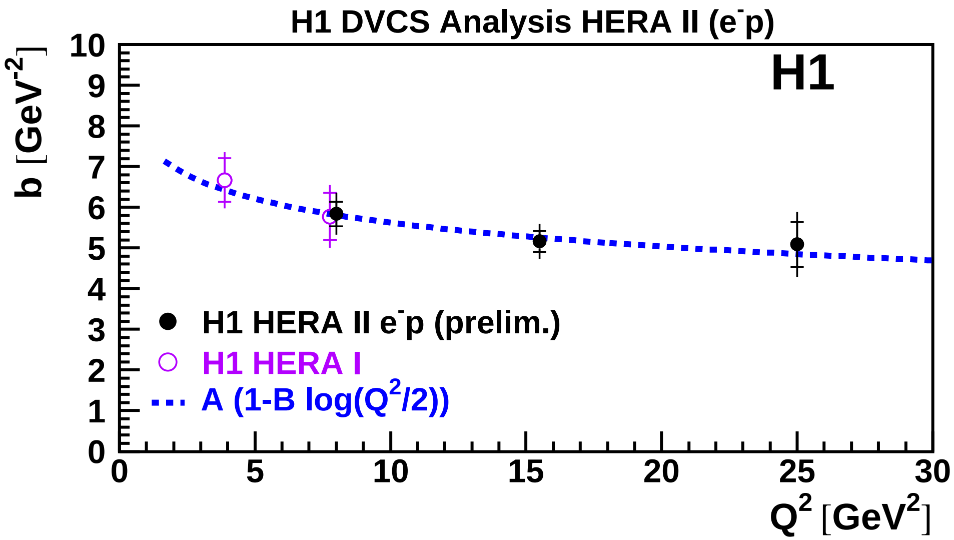
New H1 measurement based on 291 pb^{-1} of HERA II data (e^+ and e^-).

- t slope measured as a function of Q^2

$$b(Q^2) = A\left(1 - B\log(Q^2/2)\right)$$

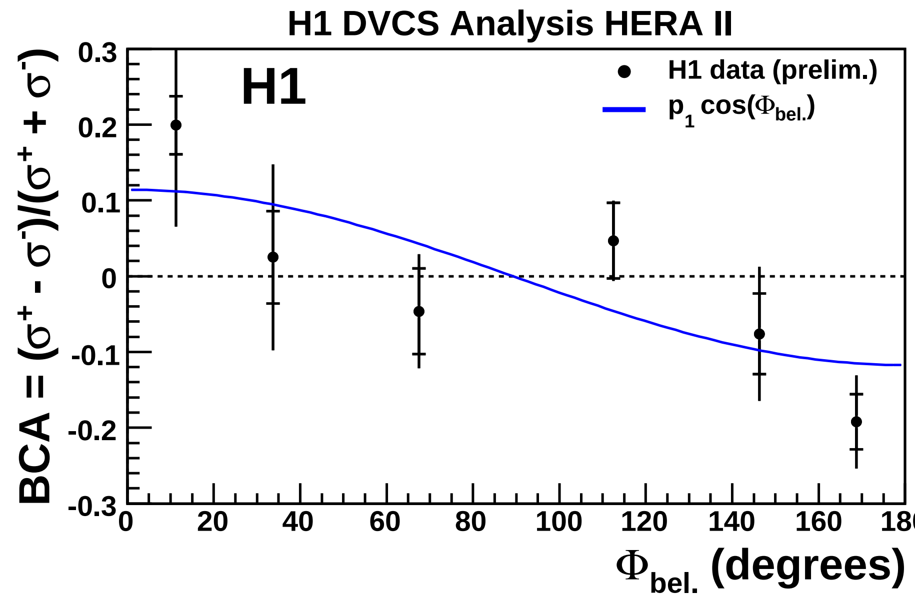
A and B fitted to:
$A = 6.98 \pm 0.54$ GeV^{-2}
$B = 0.12 \pm 0.03$.

$\Rightarrow$ Similar behaviour with VM using the scale $Q^2 + M^2_{VM}$



- First DVCS BCA measured at HERA.

$$BCA \equiv \frac{\sigma(e^+p) - \sigma(e^-p)}{\sigma(e^+p) + \sigma(e^-p)} \sim p_1 cos(\Phi)$$



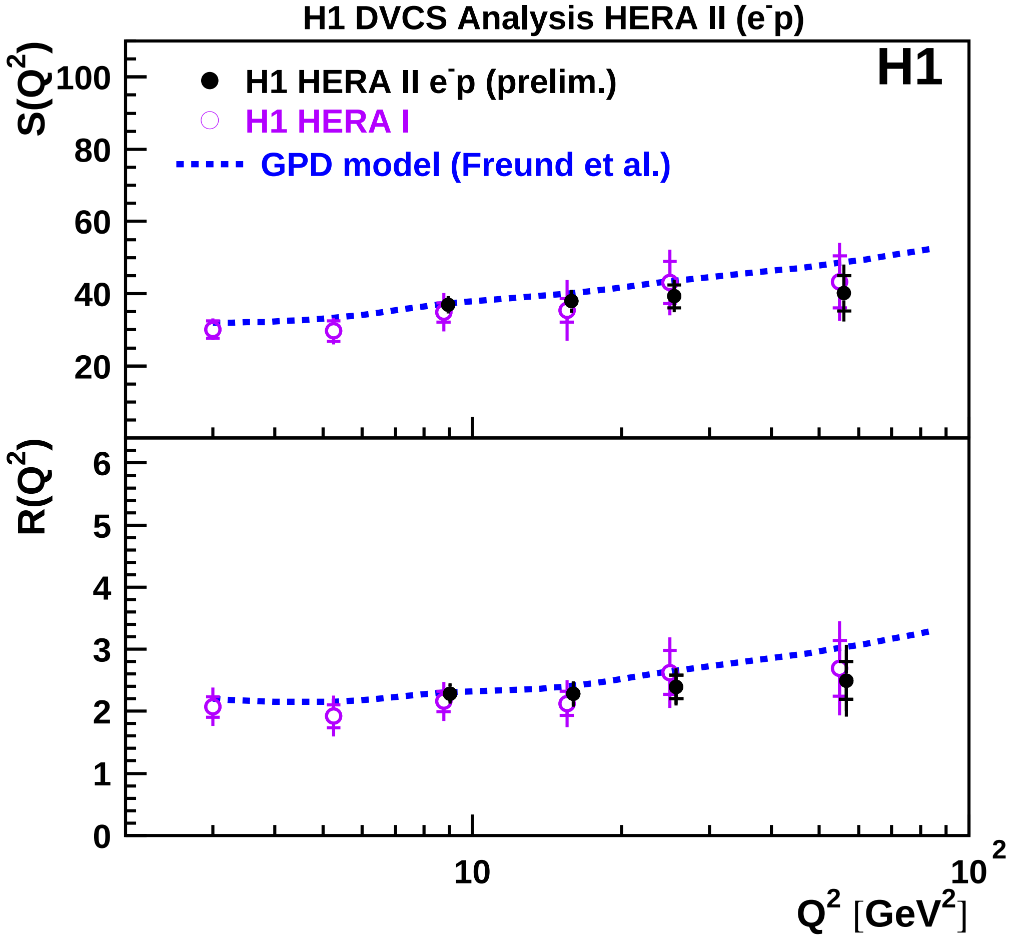
DVCS: QCD interpretation

- correct Q^2 dependence of the propagator and of b in the cross section:

$$S = \sqrt{\frac{\sigma_{DVCS}\ Q^4\ b(Q^2)}{(1+\rho^2)}}$$

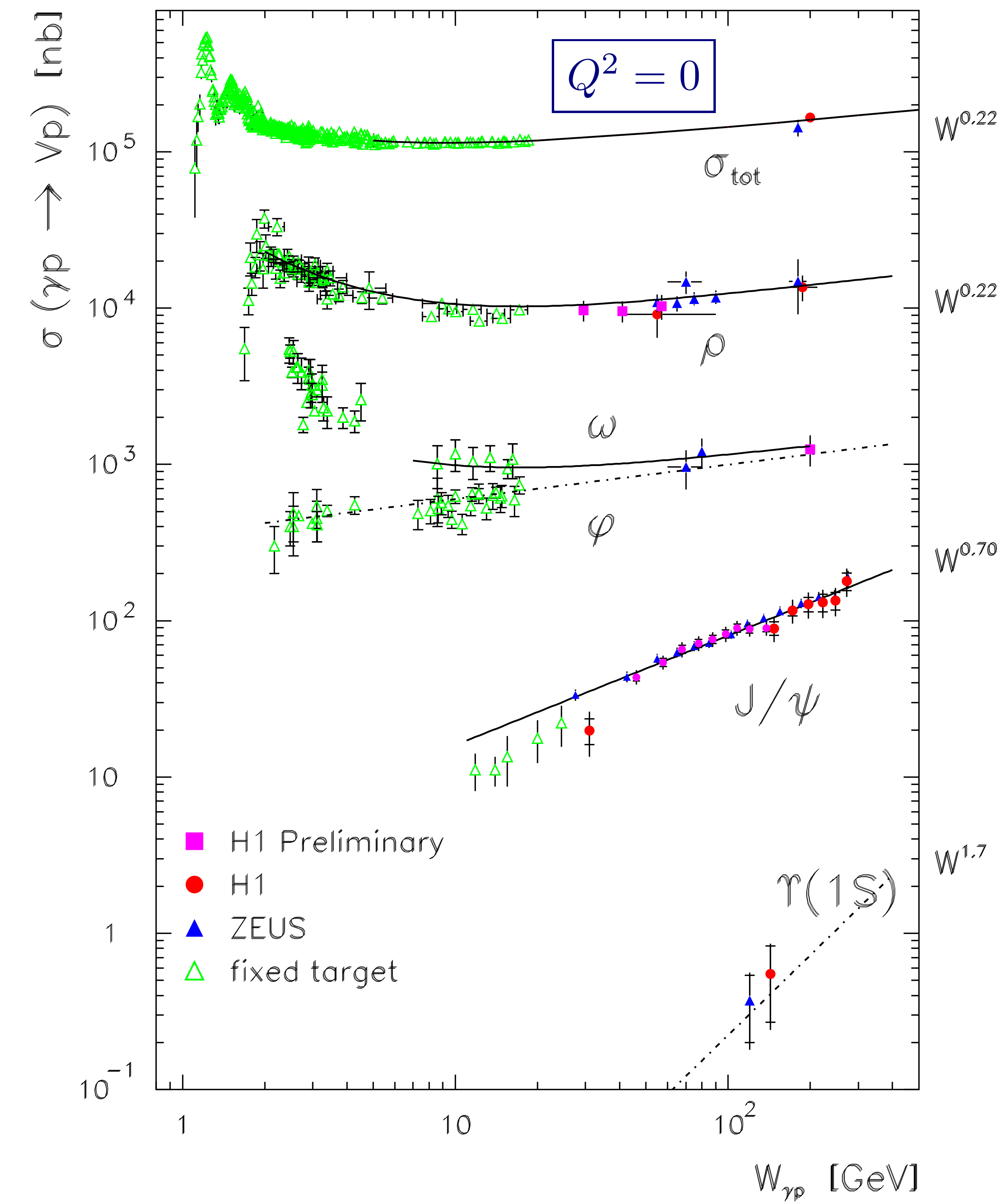
- skewing factor: around 2

$$R = \frac{\mathcal{I}m\ A(\gamma^* p \to \gamma p)}{\mathcal{I}m\ A(\gamma^* p \to \gamma^* p)} = \frac{4\sqrt{\pi\ \sigma_{DVCS}\ b(Q^2)}}{\sigma_T(\gamma^* p \to X)\sqrt{(1+\rho^2)}}$$

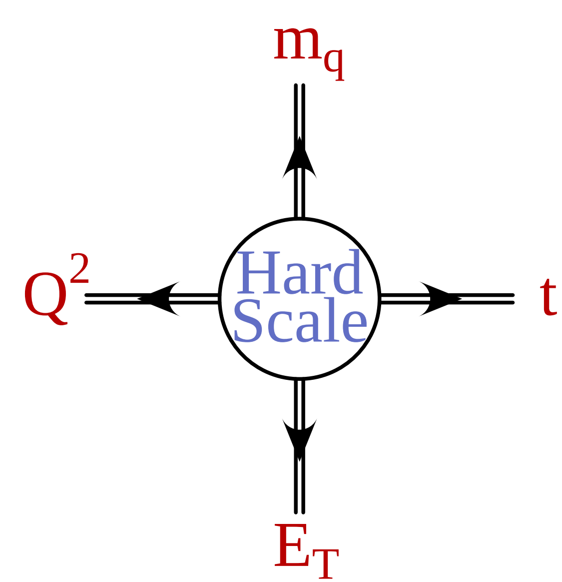


⇒ important skewing factor

⇒ Q^2 evolution close to the one of DIS (pure DGLAP)

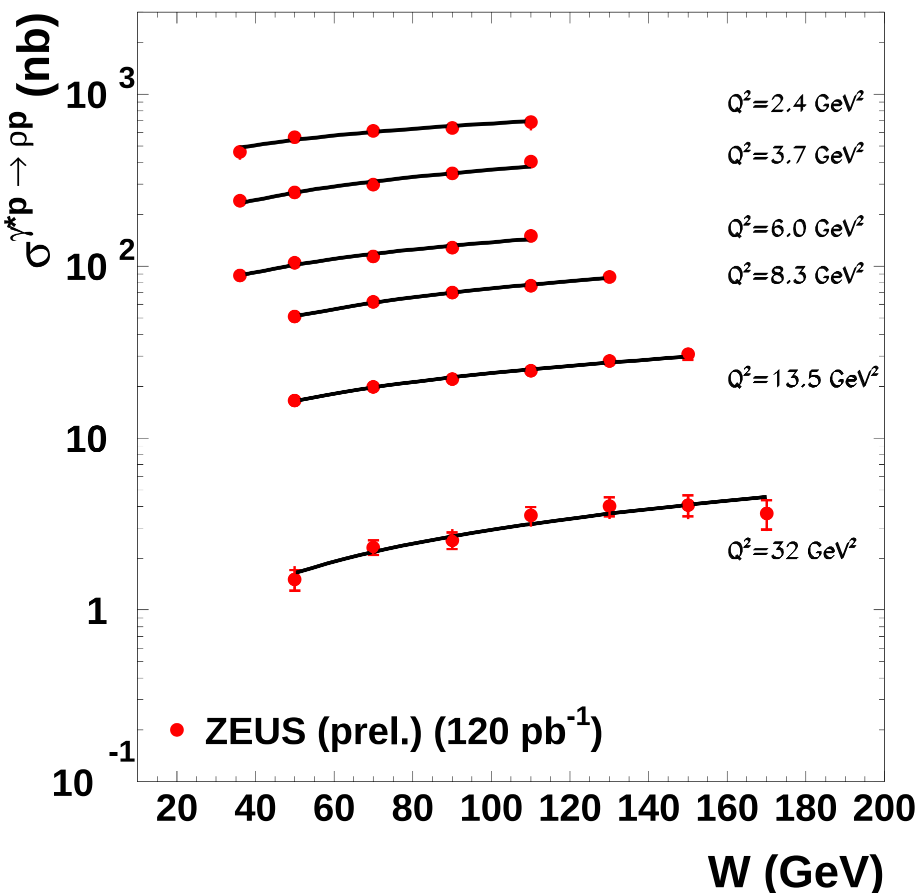


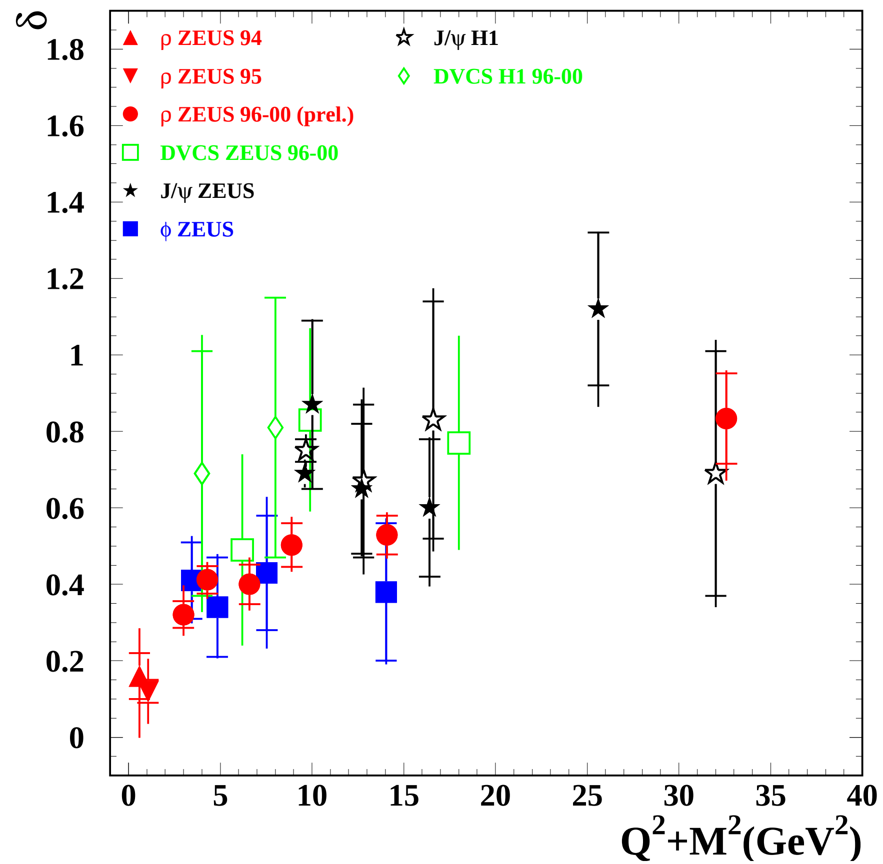
- Low mass (ρ, ϕ, ω; $M_V^2 \simeq 1$ GeV^2): no pert. scale →weak energy dep. (soft regime)
- High mass (J/ψ, υ): pert. scale →strong energy dep. (hard regime)
- similar to F_2 (i.e. the gluon) qualitatively



Q^2 evolution of light vector meson Production

$e\ p \rightarrow e\ \rho^o p$: new ZEUS measurement. $\sigma^{\gamma^* p \rightarrow \rho p} \sim W^\delta$

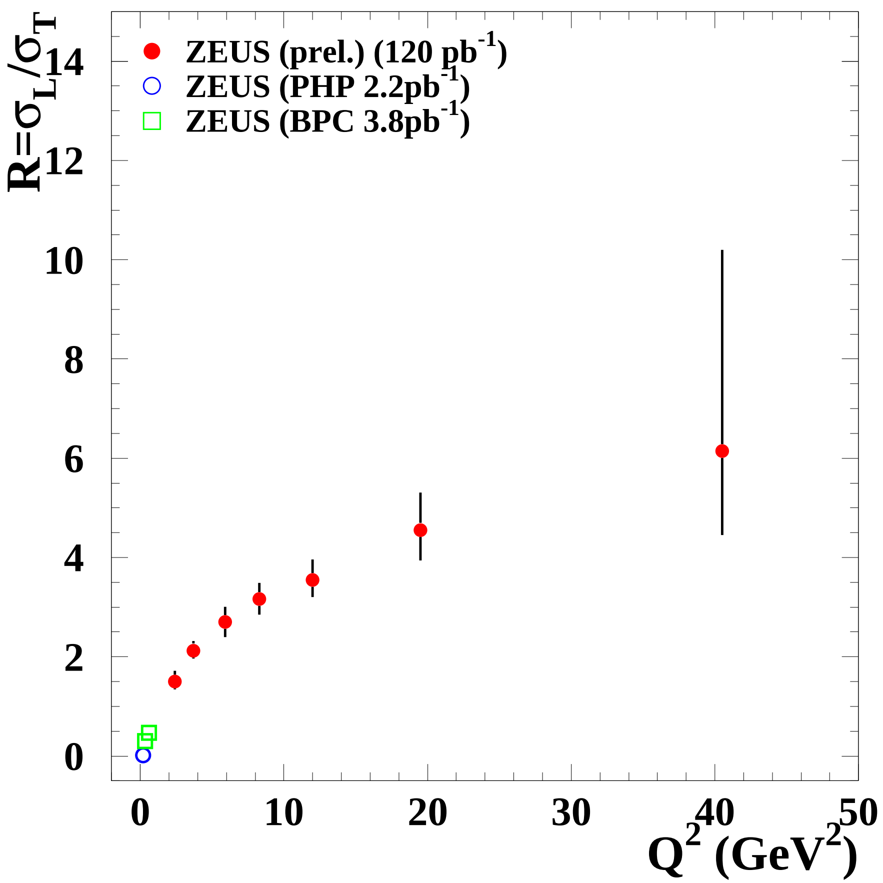


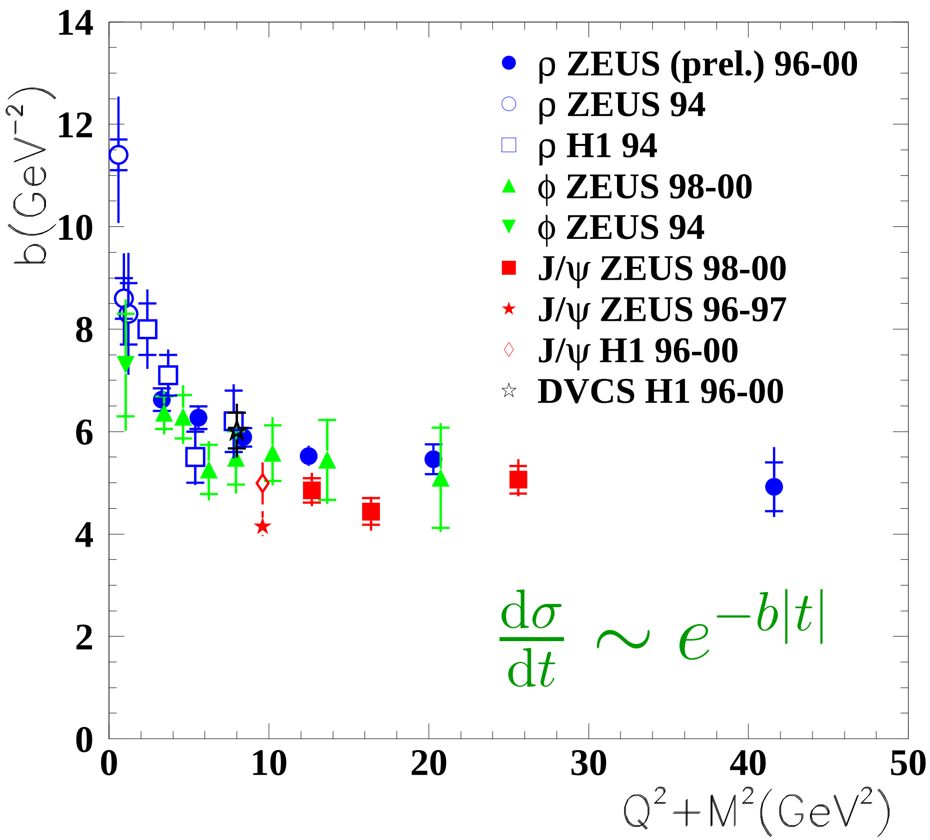


When Q^2 increases, also soft $\rightarrow$ hard transition

- Universal(?) behaviour for $Q^2 + M_V^2$ scale
- seems to saturate ($\neq$ DIS) - Sudakov factor - not pure $|x\ g(x, Q^2)|^2$

Q^2 evolution of light vector meson Production

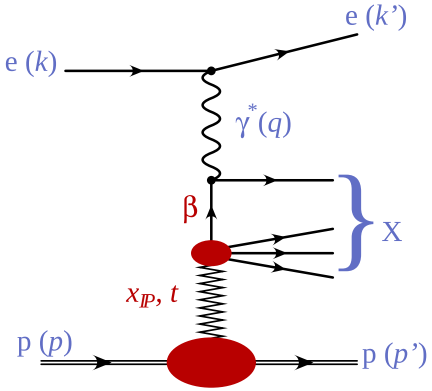




σ_T contains large dipole configuration $\Rightarrow$ non-pert. contribution

σ_L small dipole configuration $\Rightarrow$ pert.

- b reflects the transverse size of the interaction
- Does $b(Q^2)$ reflects the different evolution of q and g in transverse direction.
- Universal(?) behaviour for $Q^2 + M_V^2$ scale



Inclusive and semi-inclusive processes

- gluon radiation are allowed (controlled by β)
  - how does it compare to DIS?
- We can probe the Pomeron structure
  - diffractive parton distributions (DPDF)
  - are DPDF universal?

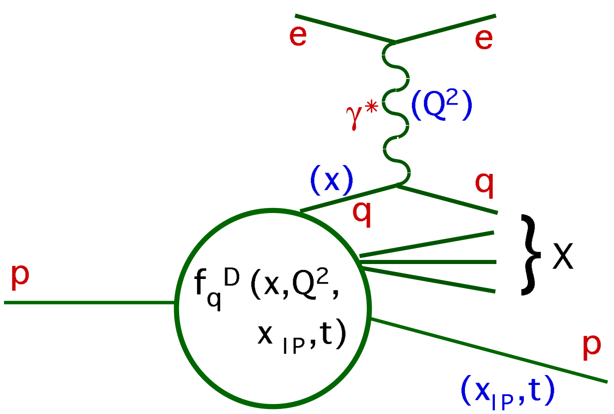
Factorisation Properties

QCD Hard Scattering Fact.

$$\sigma^{\rm Dif}_{\rm DIS} \sim f_q^D(x_{I\!P}, t, x, Q^2) \otimes \hat{\sigma}_{\rm pQCD}$$

Diffractive parton densities $f_q^D(x_{I\!P}, t, x, Q^2)$
$\rightarrow$ *conditional* proton parton probability distributions for particular $x_{I\!P}, t$.

DGLAP applicable for Q^2 evolution.

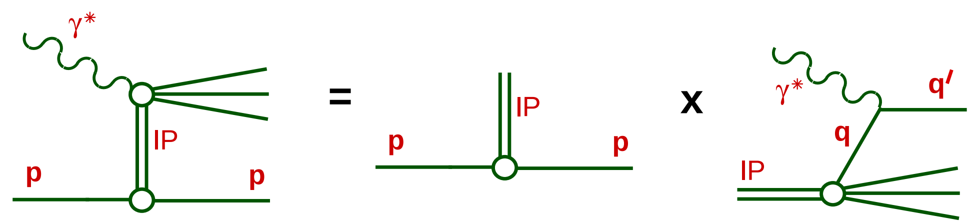


Rigorous for leading Q^2 dependence
but not in hadron-hadron collisions

Regge Factorisation

$$f_q^D(x_{I\!P}, t, x, Q^2) = f_{I\!P/p}(x_{I\!P}, t) \cdot q_{I\!P}(\beta, Q^2)$$

Diffractive parton densities factorise into "pomeron flux factor" and "pomeron parton densities"

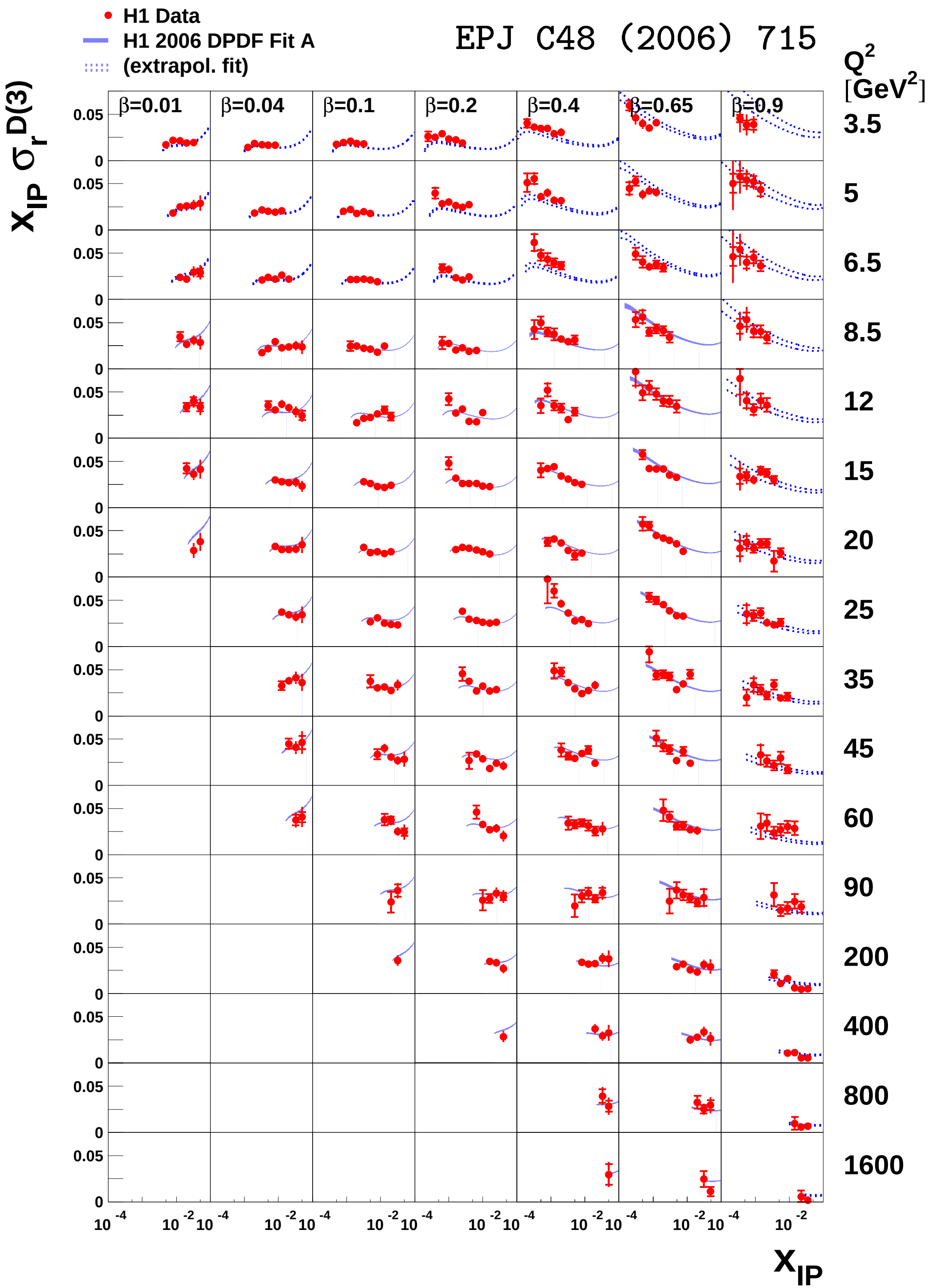


$I\!P$ flux factor from Regge theory …

$f_{I\!P/p}(x_{I\!P}, t) = \frac{e^{Bt}}{x_{I\!P}^{2\alpha(t)-1}}$ where …

$\alpha(t) = \alpha(0) + \alpha' t$

No firm basis in QCD



- precision in best region:

5%(stat), 5%(syst), 6%(norm)

$\alpha_{I\!P}(0) = 1.150 \pm 0.009(\mathrm{exp}) \pm 0.039(\mathrm{th})$

- No Q^2 dependence observed

- larger than soft Pomeron

$\alpha_{I\!P}(0) = 1.08$

- smaller than inclusive DIS

$\alpha_{I\!P}(0) = 1 + 0.048 log(Q^2/0.292)$

NLO QCD fit: H1 Measurement

QCD Fit Technique:

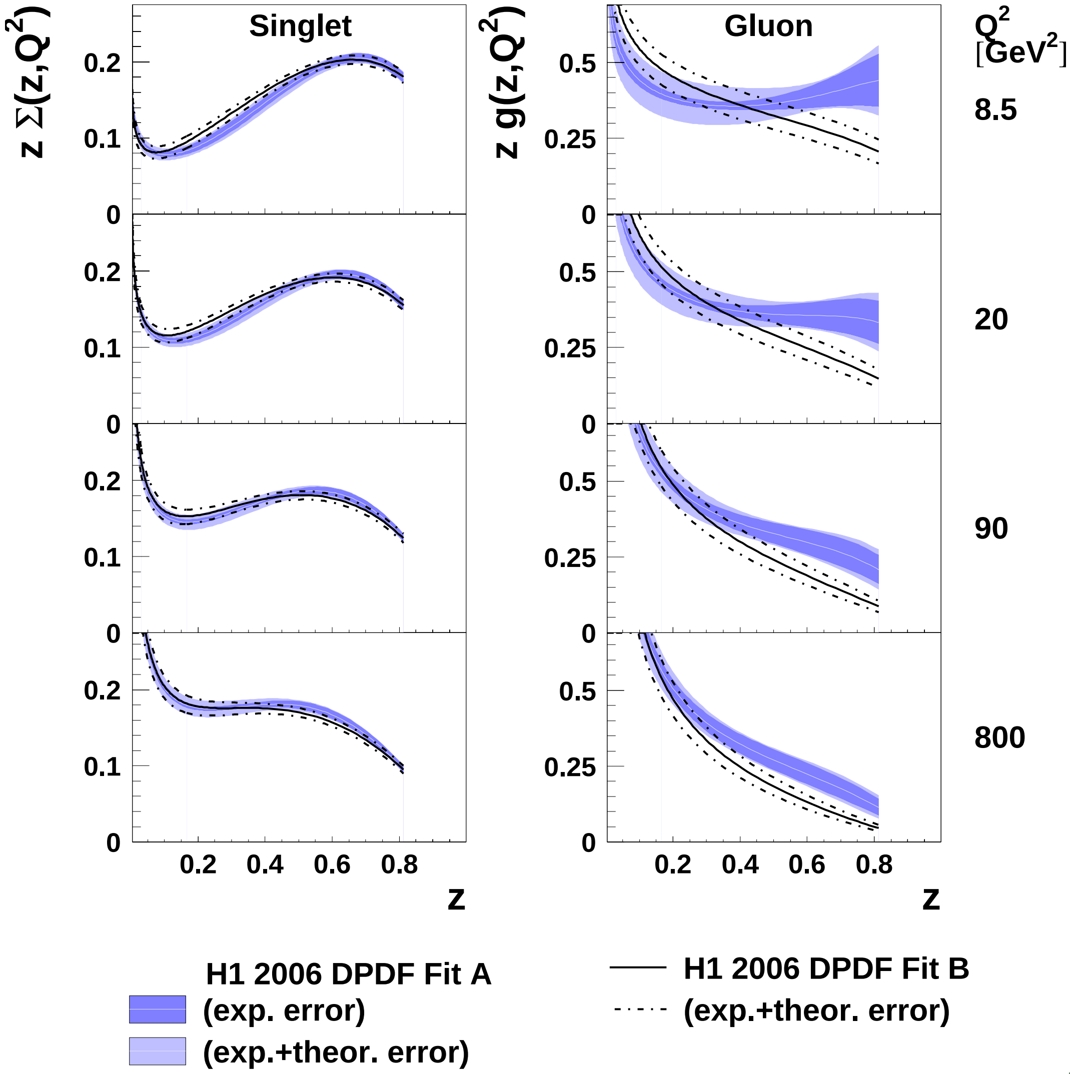
- factorize $f(x_{I\!P})f(z,Q^2)$
- Singet Σ and gluon g
- NLO DGLAP evolution

$$\frac{1}{f_{I\!P/p}}\frac{\partial\sigma_r^D}{\partial\ln Q^2}\sim xg(x)\otimes\alpha_s\otimes P_{qg}$$

- parametrised at $Q_0^2 = 3$ GeV^2
- Fit data for $Q^2 \geq 8.5$ GeV^2, $\beta < 0.8$, $M_X > 2$ GeV
- Two stable solutions: Fit A and Fit B

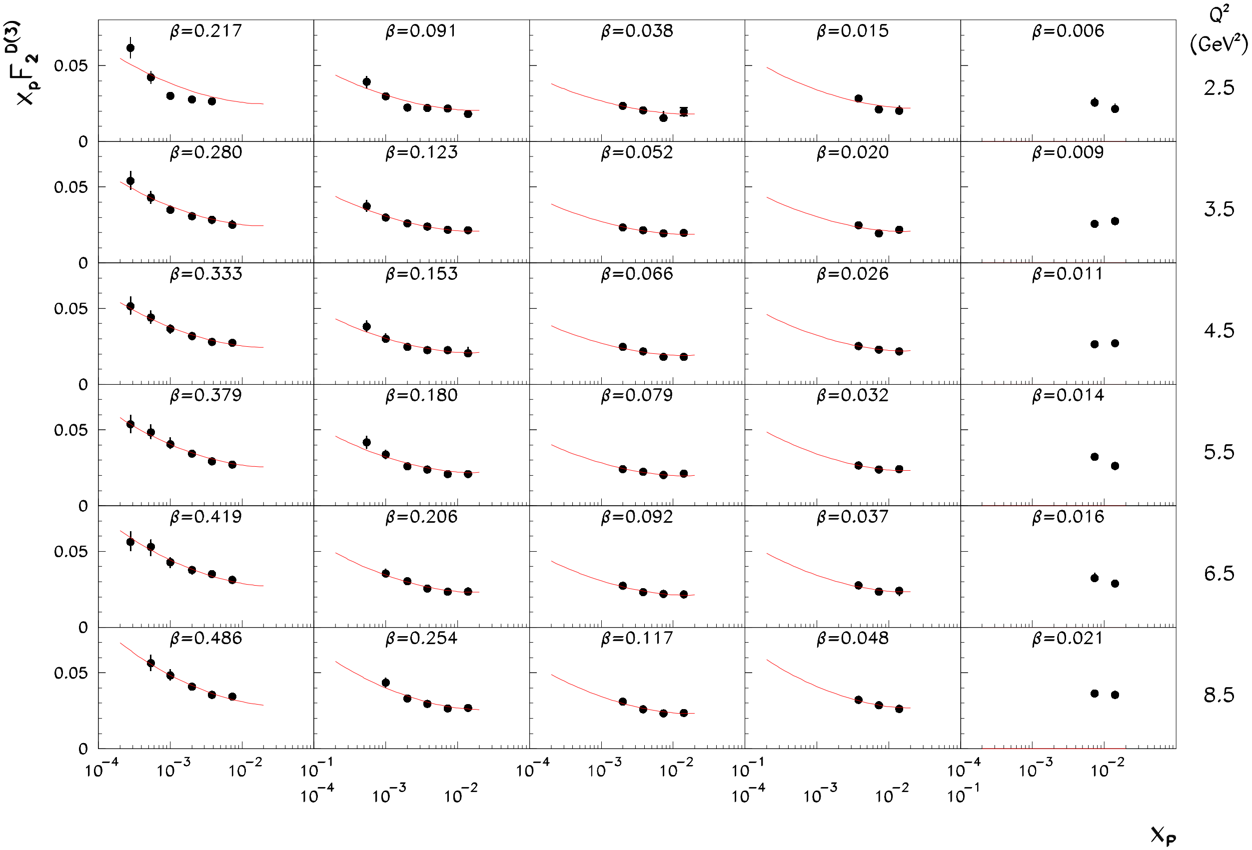
PDF's of Diffractive exchange

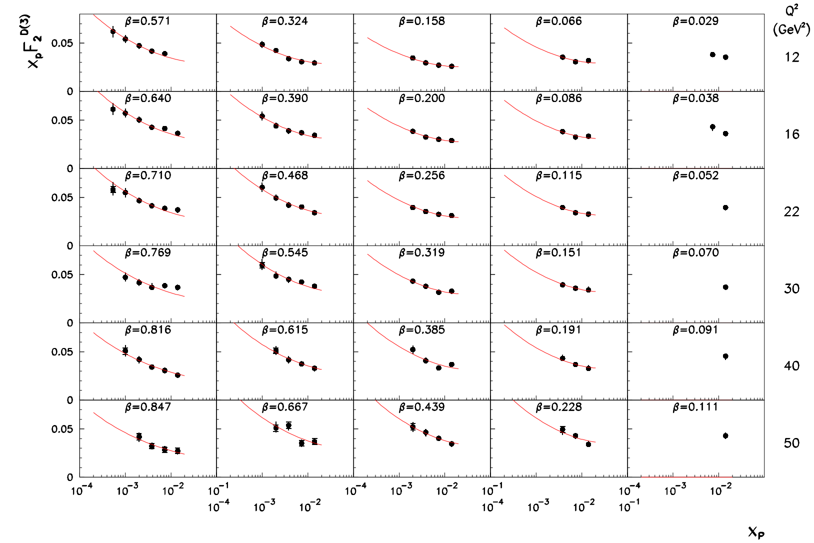
- z is the fract. mom. of the parton in $I\!P$
- Σ well constrained
- a lot of gluons (75 ± 15 % of mom.)

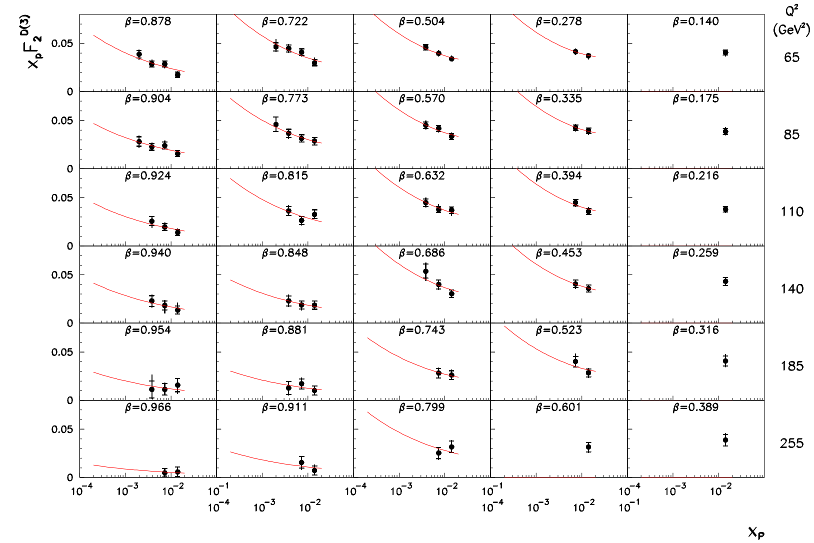


• New ZEUS inclusive diffraction measurements:

$\Rightarrow$ LRG, 45.4 pb^{-1}, 2000 (e^+) data.







$$\alpha_{I\!P}(0) = 1.117 \pm 0.005 \text{ (exp) } {}^{+0.024}_{-0.007} \text{ (model)}$$

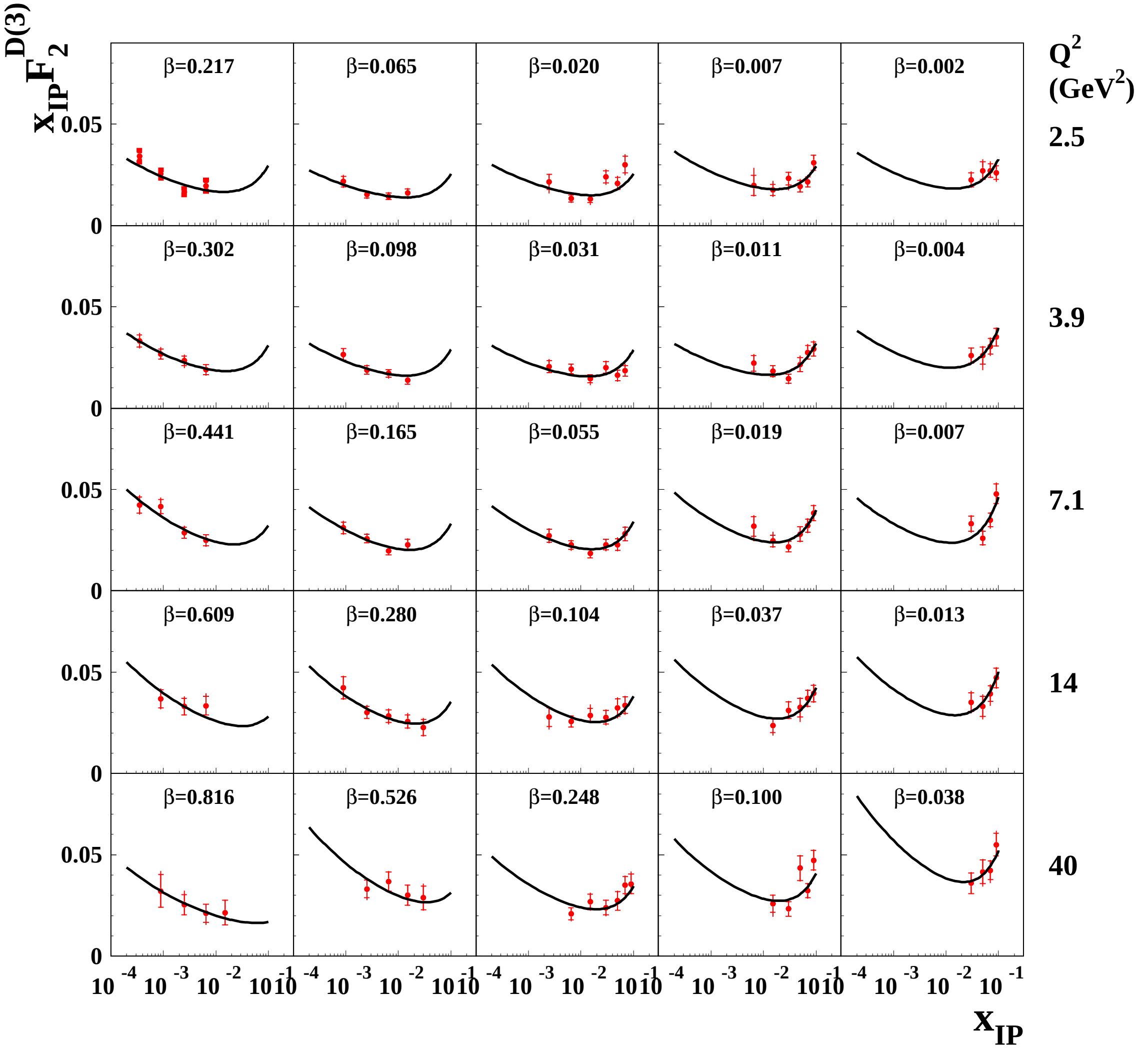
- No Q^2 dependence observed

— Regge Fit

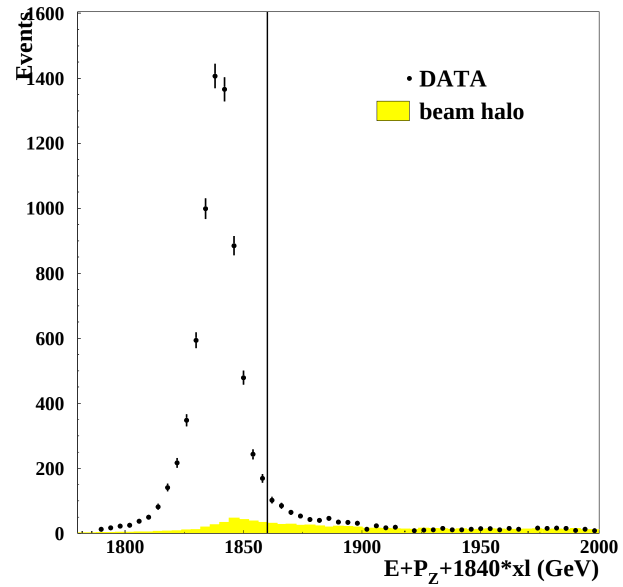
- in good agreement with H1 results

• New ZEUS inclusive diffraction measurements:

⇒ using Leading Proton Spectrometer (32.6 pb^{-1}) 2000 (e^+) data.



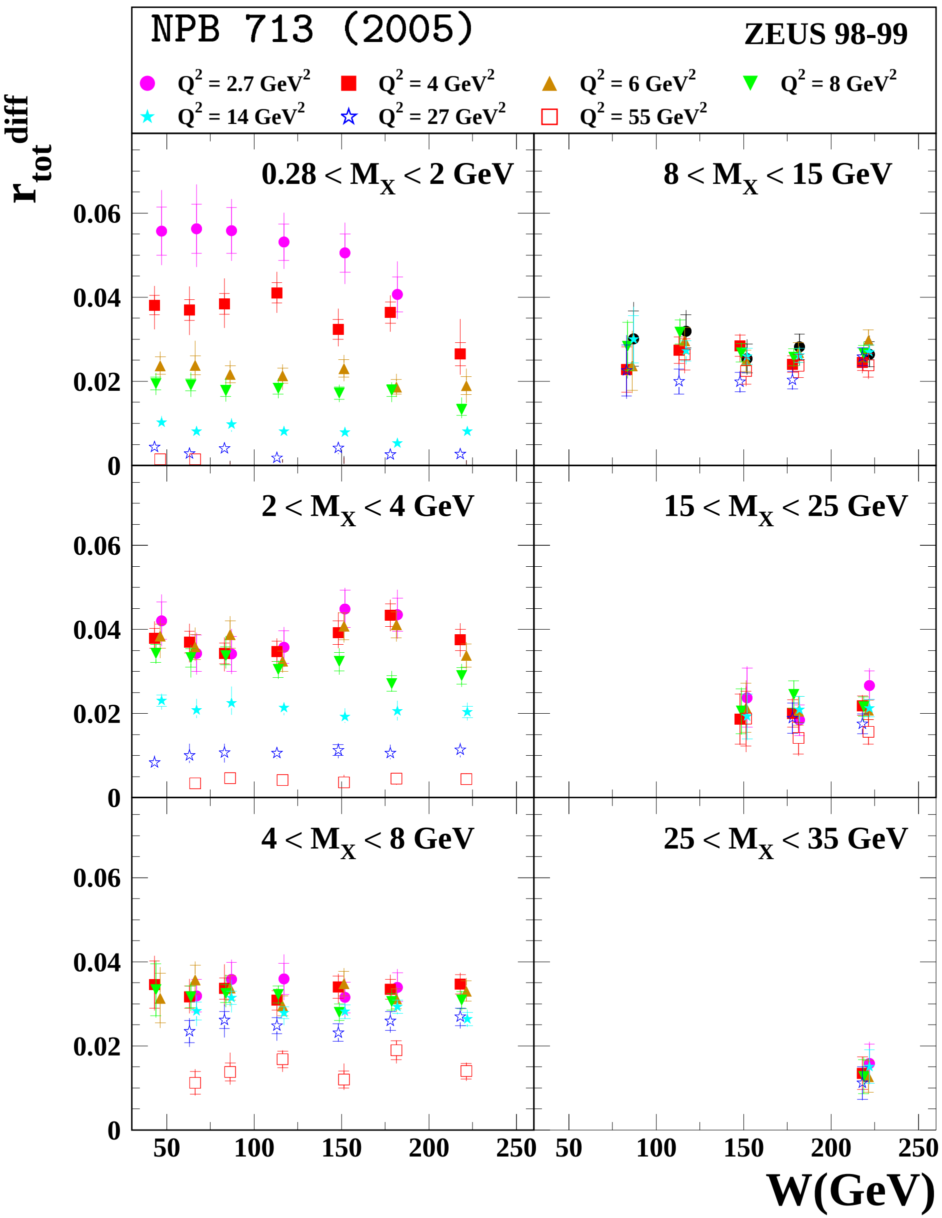
- measures the scattered proton in Roman Pot stations



- results in agreement with H1 FPS

- results in agreement with ZEUS LRG and MX method (not shown)

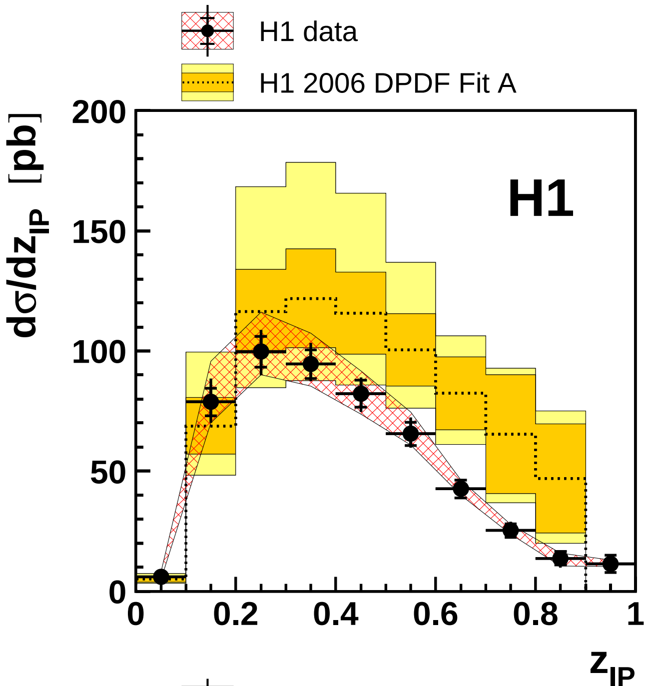
Ratio of Diffractive to inclusive cross-sections

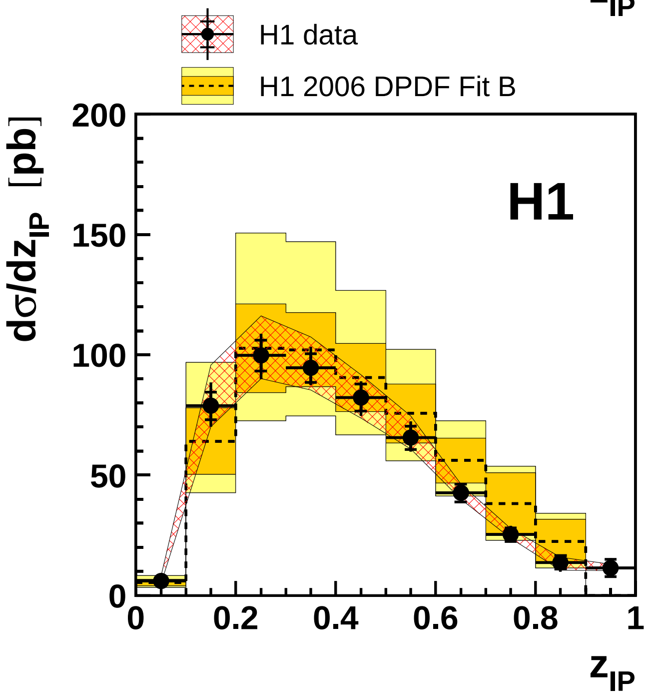


$W^2 \simeq Q^2/x$ $\beta \simeq Q^2/(Q^2 + M_X^2)$

- For $M_X > 2$ GeV: flat in W
  - → same W dependence as σ_{tot}
  - → Not consistent with naive 2 gluon exchange: $R = \frac{|x\ g(x,Q^2)|^2}{x\ g(x,Q^2)} = x\ g(x,Q^2)$
- $M_X > 8$ GeV: no Q^2 dependence
  - → same DGLAP evolution
  - → γ^* sees: 1 gluon that can radiate
- If $M_X \searrow, \beta \nearrow$ → γ^*: more and more of the exchanged object (2 g)
- $M_X < 2$ GeV (large β): falling with W
  - → contribution of Vector Meson production (higher twist)
  - → no g radiation allowed
  - → "closed" gluon object

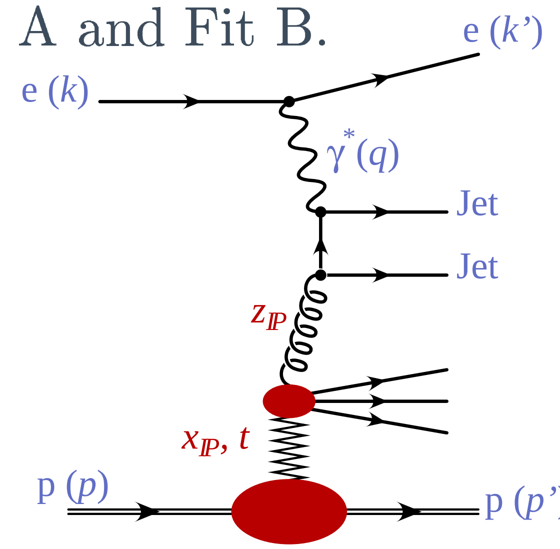
Test of QCD factorisation: H1 Dijet

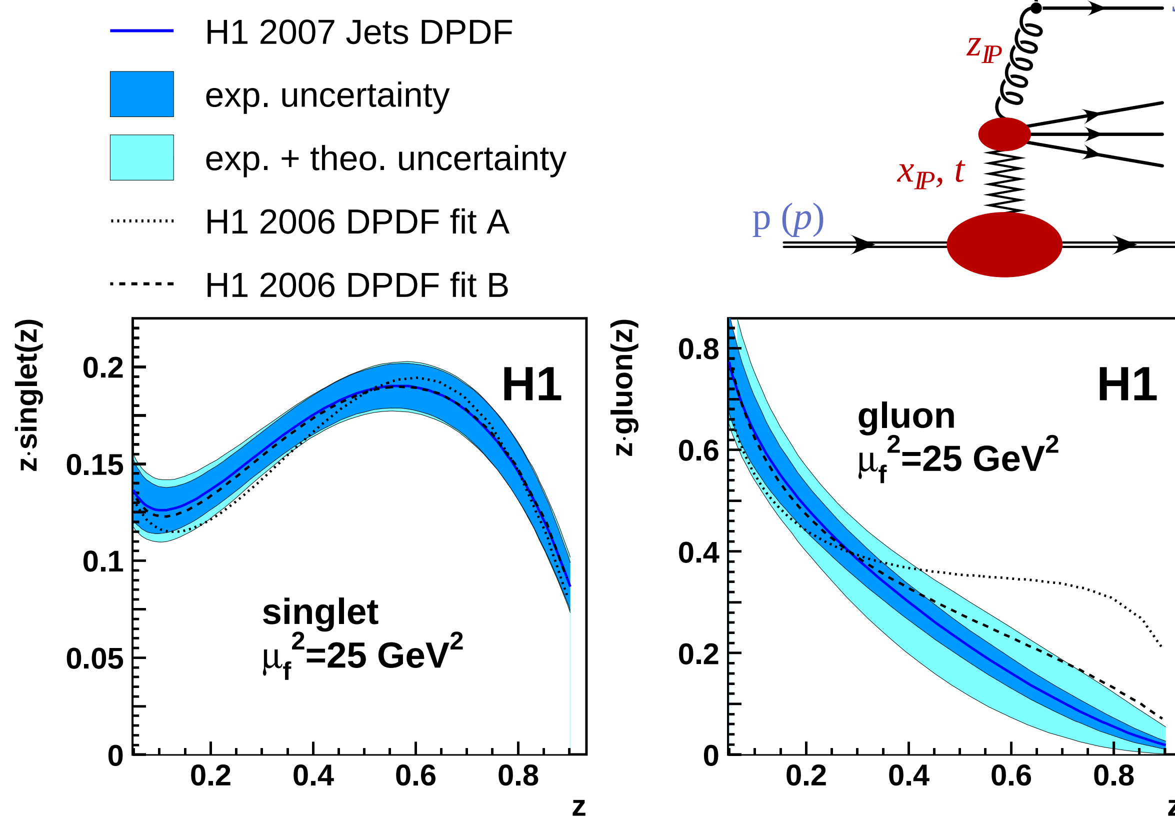




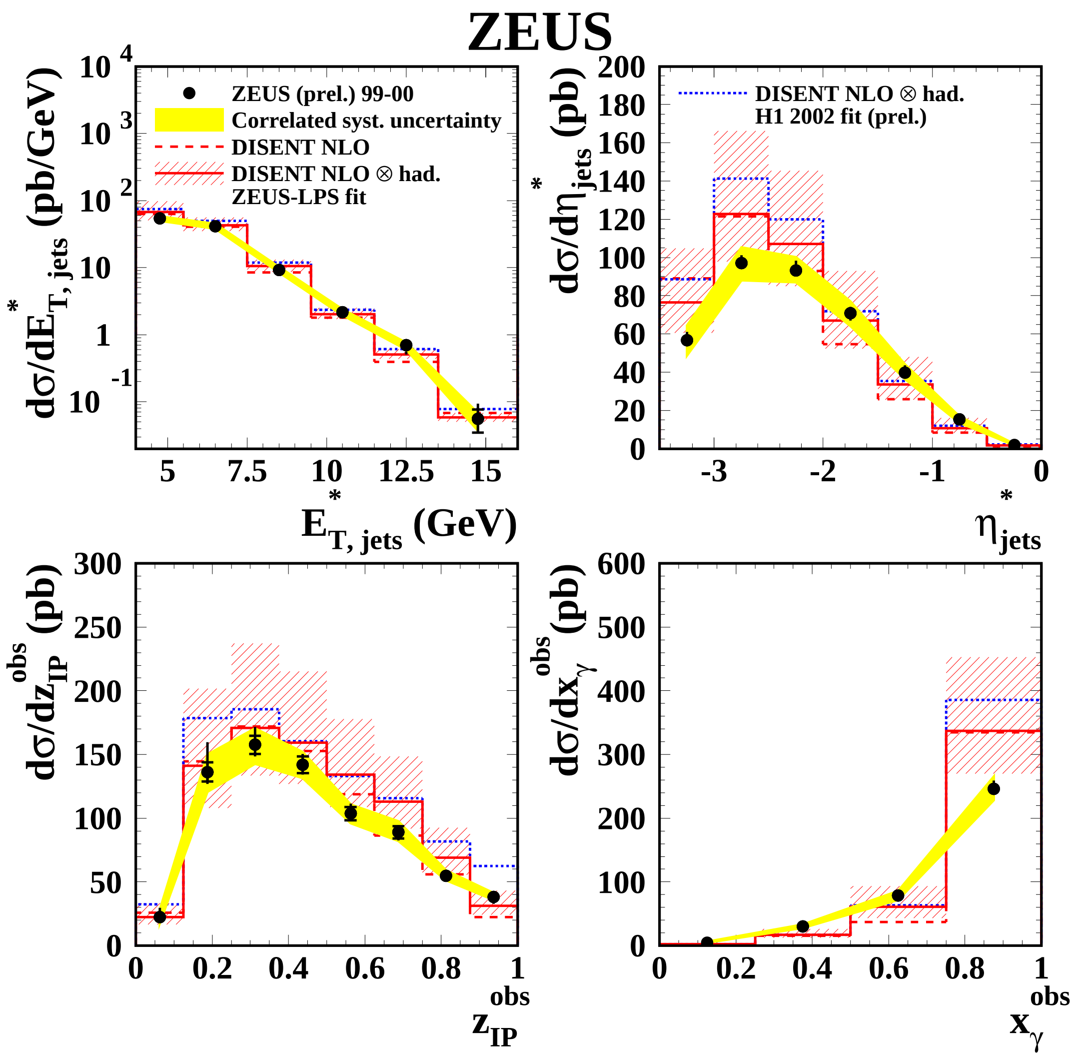
Use diff PDFs to predict Dijet production

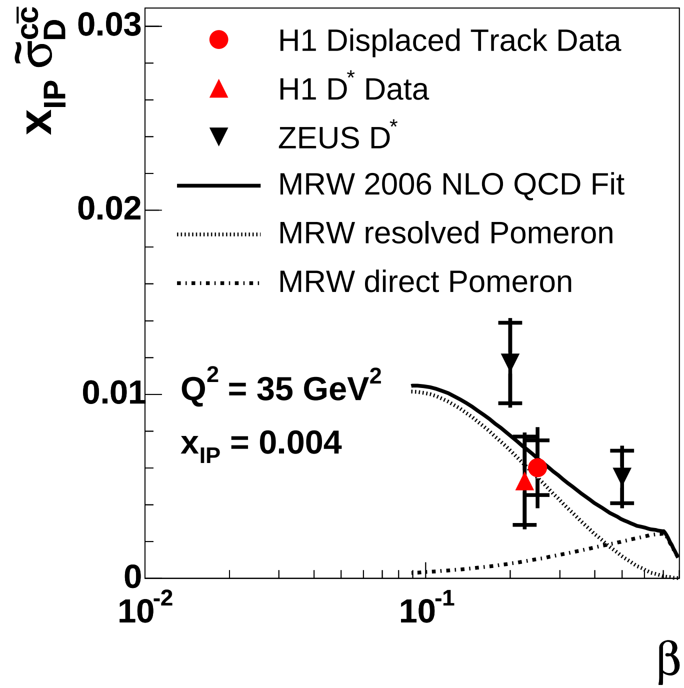
- $Q^2 > 4$ GeV^2, $P_T^{jet1(2)} > 5(4)$ GeV
- can distinguish between Fit A and Fit B.
- Including dijet data in fit yields DPDF with improved precision at large $z_{I\!P}$





Test of QCD factorisation: Dijet and Charm



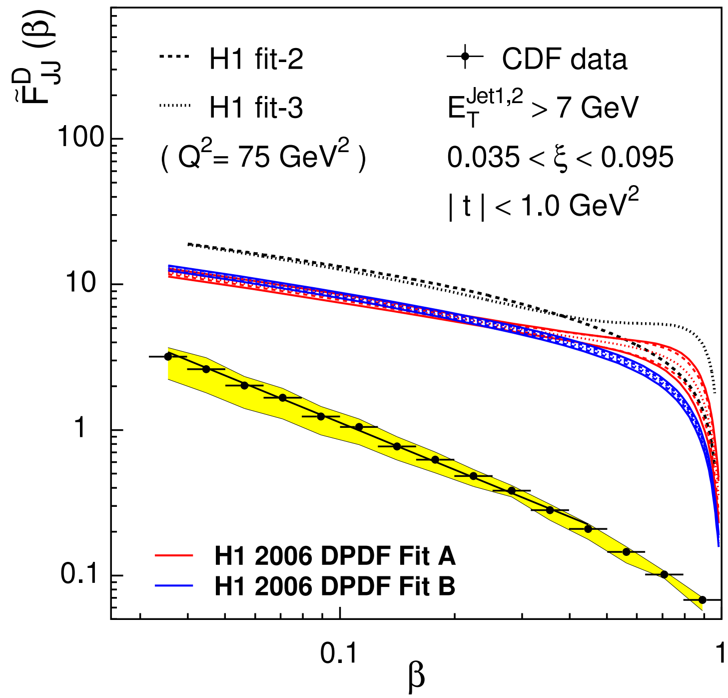


- ZEUS Dijet also in basic agreement
- Charm measured with 2 methods in agreement

→ QCD factorization works for Dijet and Charm in Diff. with $Q^2 > 4\ \mathrm{GeV}^2$

Factorisation breaking at the Tevatron

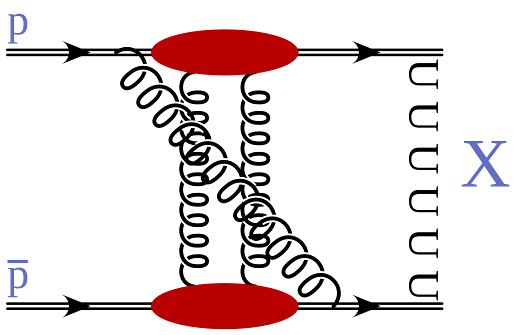
CDF measurement of the diffractive dijet production (using ratio SD/ND):



- The prediction based on diffractive PDF's extracted at HERA are one order of magnitude above the measures cross section!

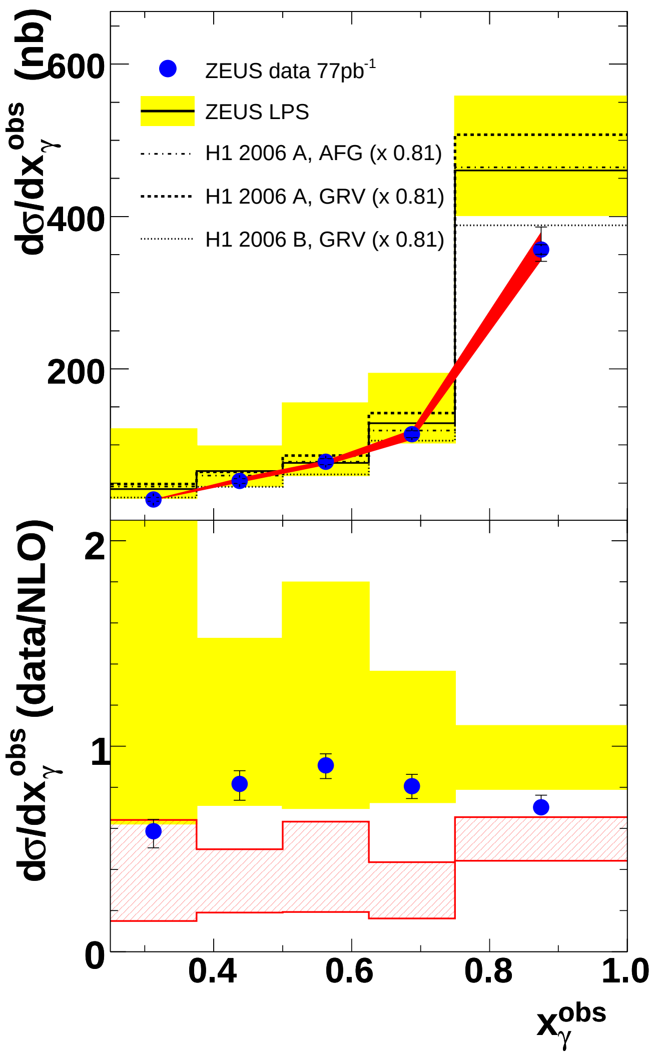
- same to factorisation breaking in soft diffraction (Tevatron RUN I).
- also seen in $W\&Z$ production (sensitive to quark) and J/Ψ and b-mesons (sensitive to gluons)
- Factorization not expected to hold in pp. Violation of factorization understood usually in terms of (soft) rescattering corrections of the spectator partons

But other approaches exist...



HERA: Factorisation test: Dijet in Photoproduction

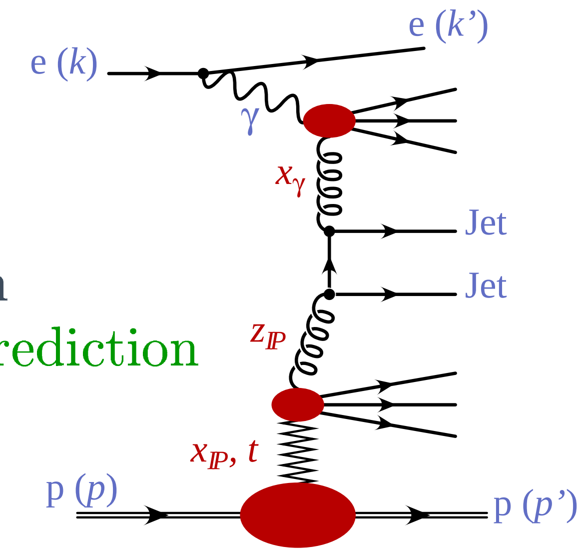
Real photon ($Q^2 \simeq 0$) can develop a hadronic structure

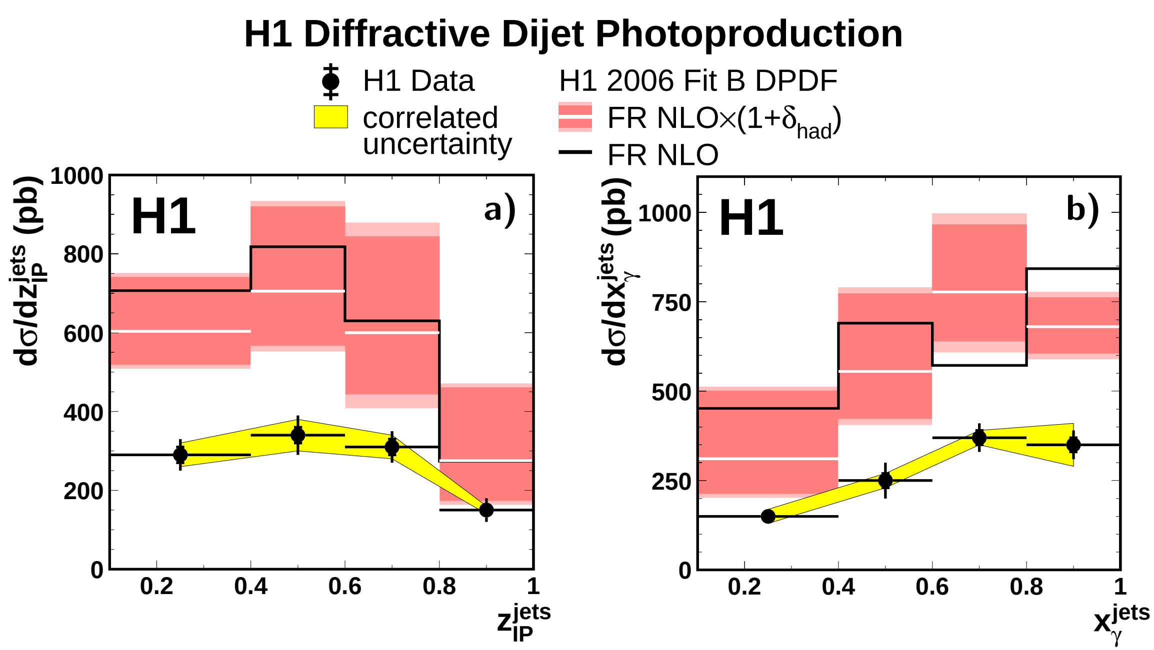


H1: Suppression by factor 2
in direct as well as in resolved

ZEUS: weak (if any) Suppression
on going work to check theory prediction

$E_T^{jet1} > 5$ (H1), 7 (ZEUS) GeV





Conclusion

- Improved precision in DVCS and VM production measurements.
- Sensitivity to very low x gluon density and parton correlations (GPDs).

- Many measurements of inclusive diffraction at HERA.
- Good agreement between methods and Collaborations.
- The partonic structure of the exchanged object in diffraction has been measured with improved precision.

- Diffractive parton distributions can be factorised in DIS regime (large Q^2) in $\gamma^* - p$ interactions
- Photoproduction case needs clarifications
- Rescattering corrections in $p - p$

- Still many HERA results to come...

Back-up Slides

Regge factorisation: β Dependence of F_2^D

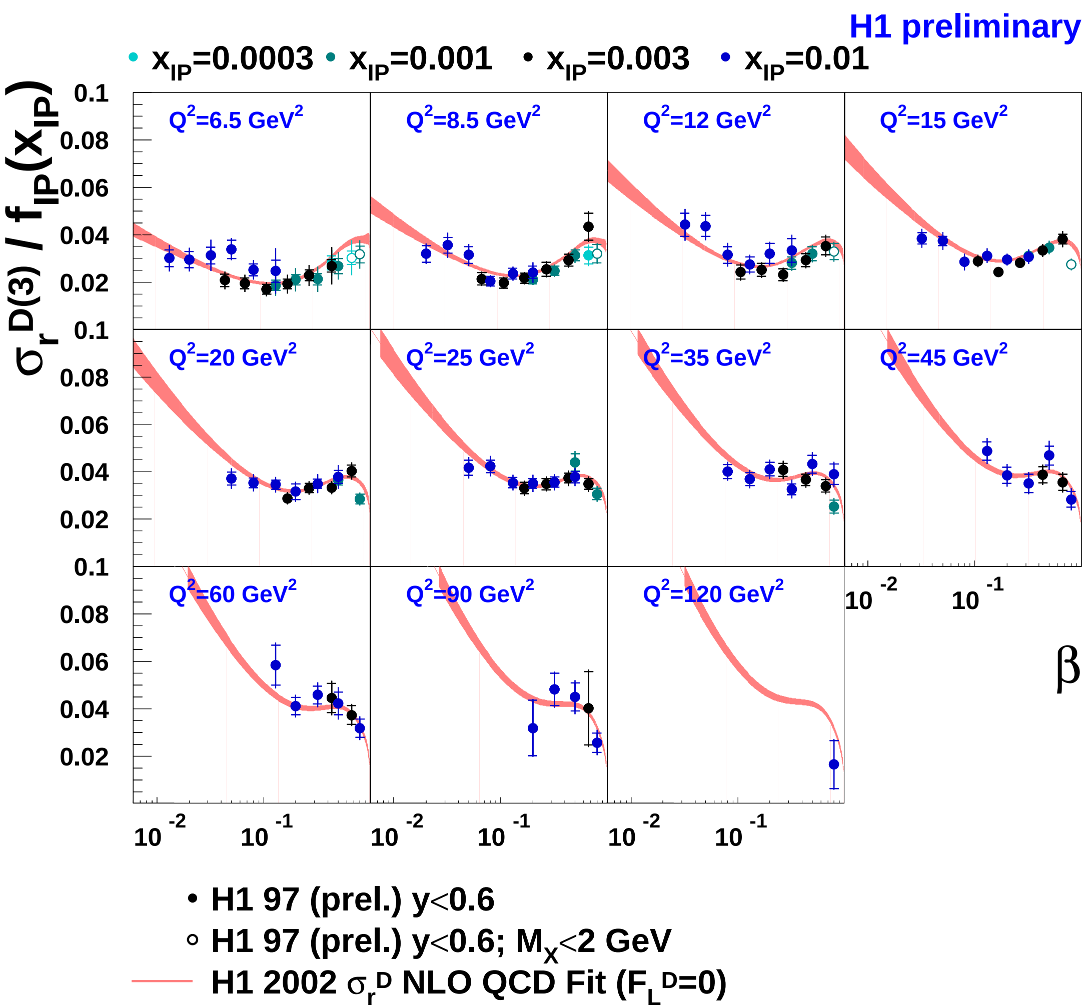
Does Regge factorisation work ?

i.e. is $F(\beta, Q^2)$ dependent of $x_{I\!P}$ after factoring out the flux dependence ?

$$f_{I\!P/p}(x_{I\!P}, t) = \frac{e^{Bt}}{x_{I\!P}^{2\alpha(t)-1}}$$

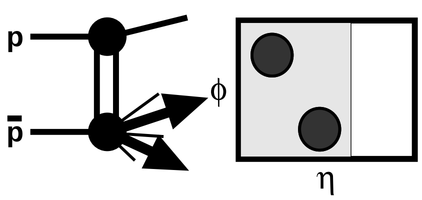
Take experimentally measured B, $\alpha(0)$

→ Regge factorisation holds !

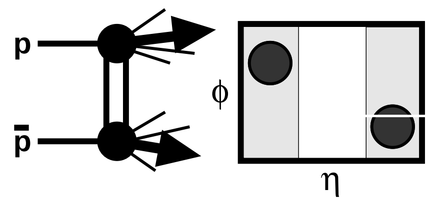


Measures parton density over wide β range.

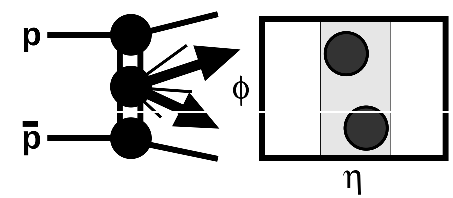
Factorisation breaking at the Tevatron



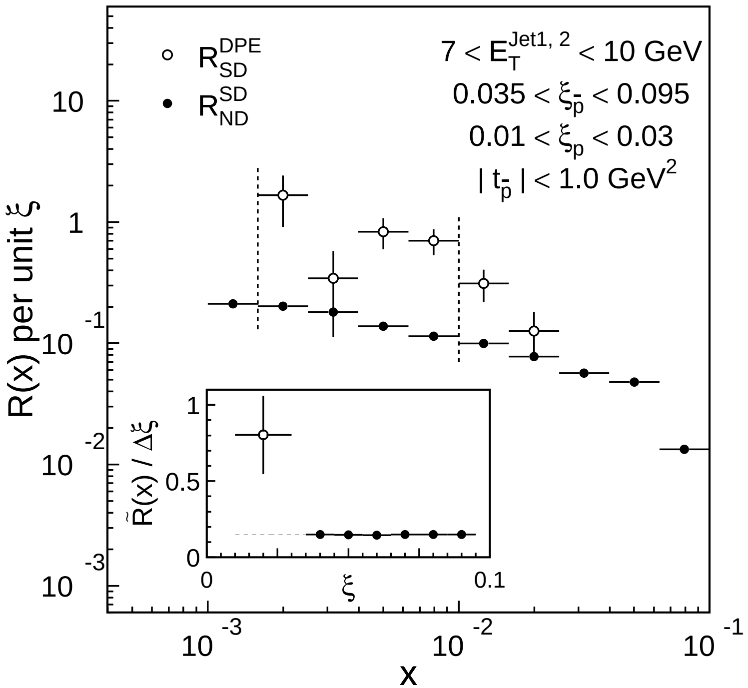
Single Diffraction

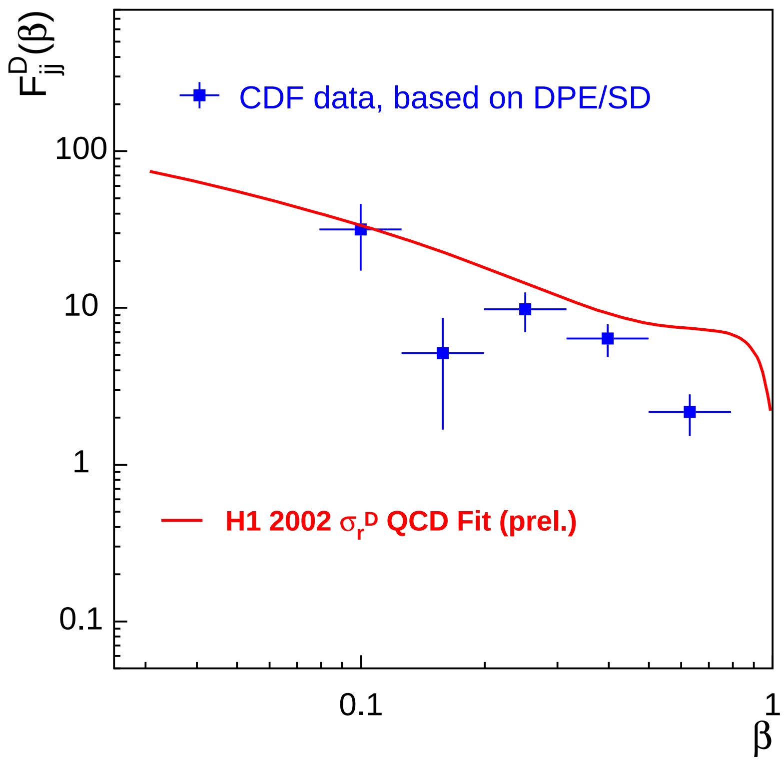


Double Diffraction



Double Pomeron Exchange





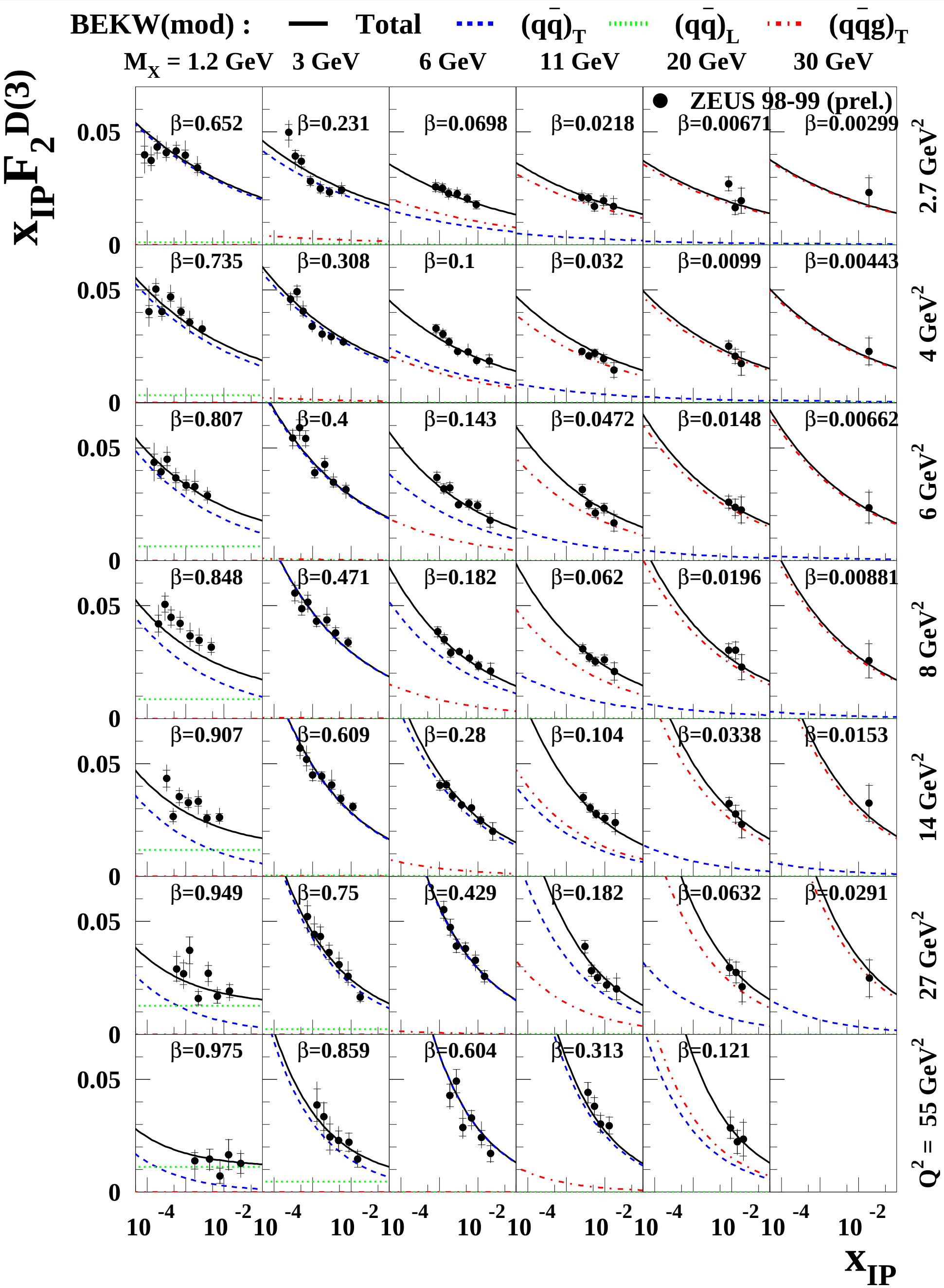
CDF measurement of R_{ND}^{SD} and R_{SD}^{DPE}

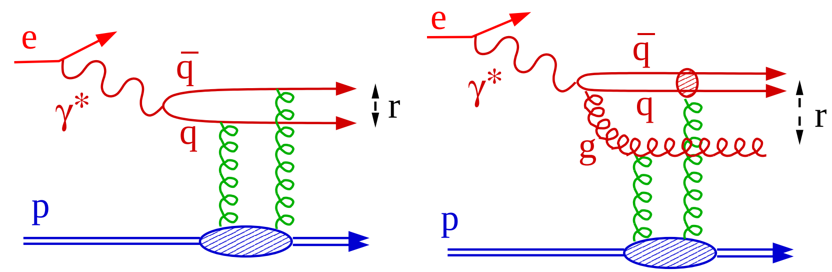
$$R_{ND}^{SD} / R_{SD}^{DPE} = 0.19 \pm 0.07$$

Second gap formation unsuppressed

DPE compatible with expectation from H1 PDFs

Colour Dipole approach





- Dominated by $(q\bar{q}g)_L$ for $\beta < 0.1$
- Dominated by $(q\bar{q})_T$ and $(q\bar{q})_L$ for $\beta > 0.1$
- $\beta \to 1$ → exclusive final state