Experimental review of diffractive phenomena

$\mathfrak{L}$. *Favart*

I.I.H.E., Université Libre de Bruxelles.

ULB

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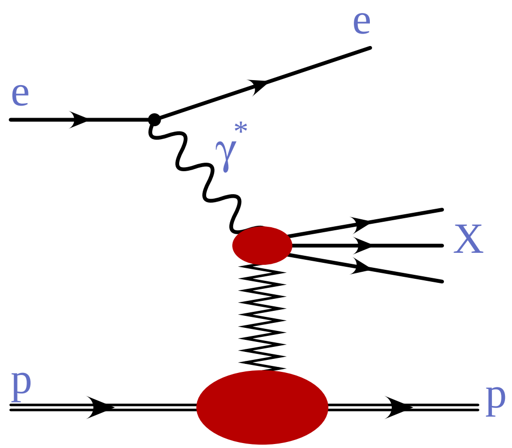
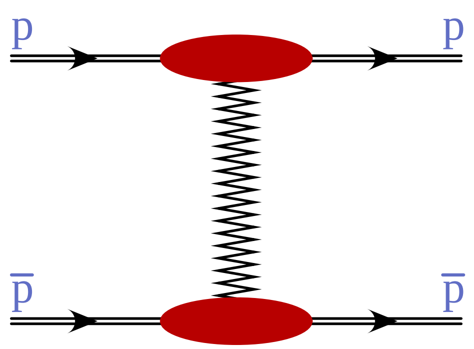
Diffractive processes

- feature of hadron-hadron interactions (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

HERA - Compass



Tevatron

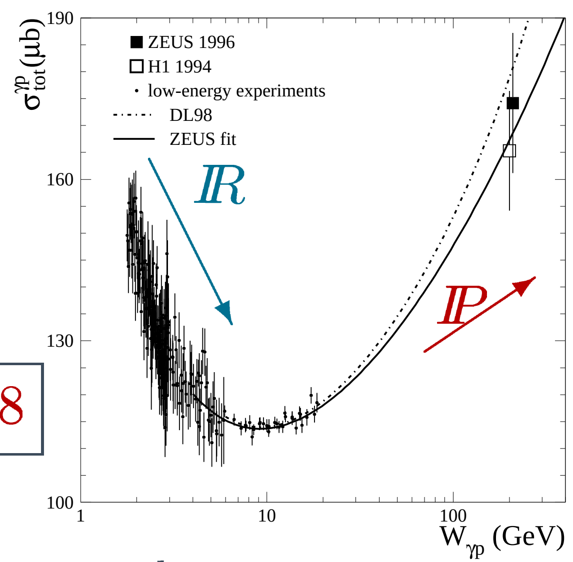


Diffractive processes

- feature of hadron-hadron interactions (30% of σ_{tot})
- t-channel exchange of the vacuum quantum numbers
- Historically (60's) described by a Pomeron exchange in Regge theory

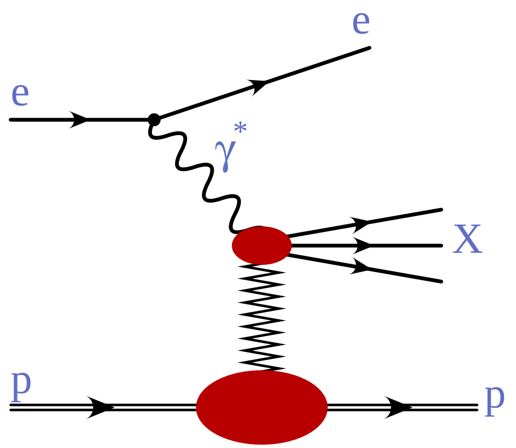
$$\sigma_{Tot} = B\ W^{2(\alpha_{I\!R}-1)} + A\ W^{2(\alpha_{I\!P}-1)}$$

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



Optical theorem: $\sigma_{tot}^2 \sim \frac{d\sigma_{el}}{dt}(t=0)$

HERA - Compass



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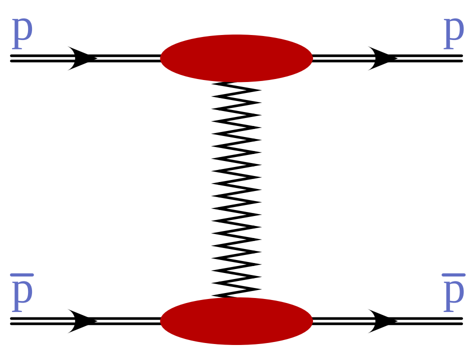
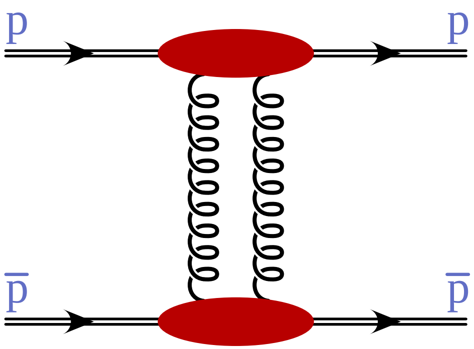


Interest of Hard Diffraction

- Understanding of Diffractive phenomena in terms of QCD
  - → two gluon exchange



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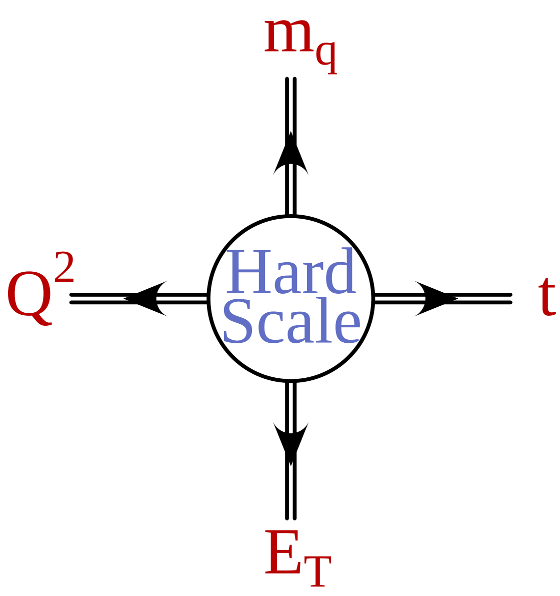
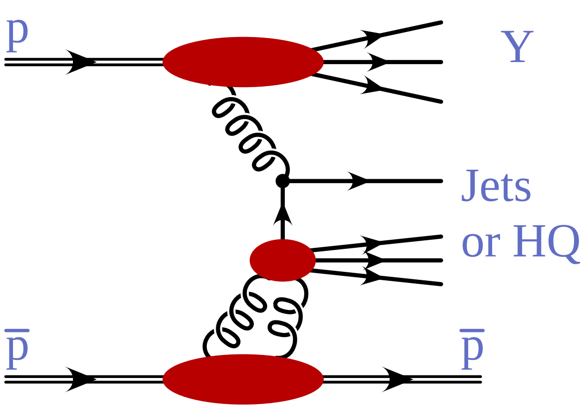
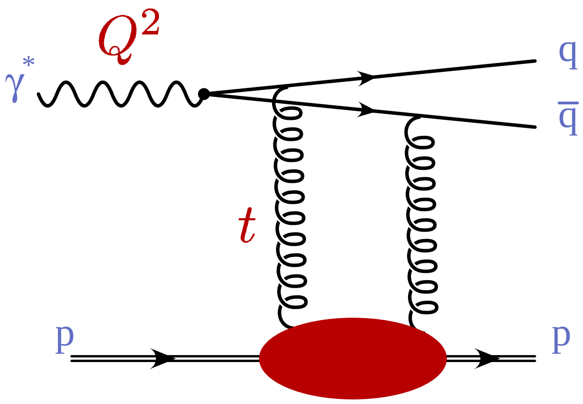
  - → Several possible hard scales

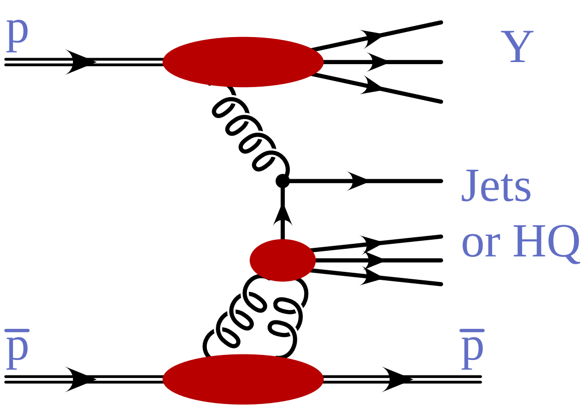


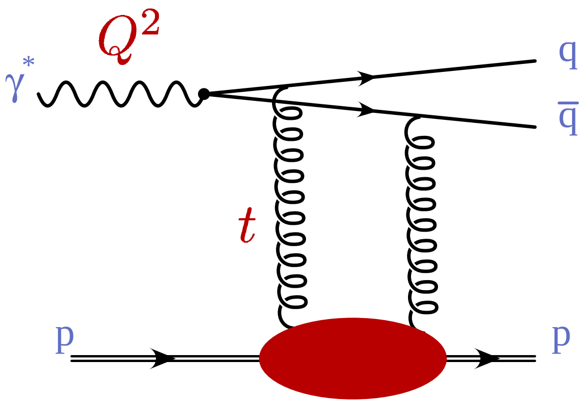




Interest of Hard Diffraction

- Understanding of Diffractive phenomena in terms of QCD
  - two gluon exchange
  - Several possible hard scales
  - probing the exchange partonic structure - like in inclusive structure functions
  - typical signature of hard scale presence: steep rise with W (cms energy)





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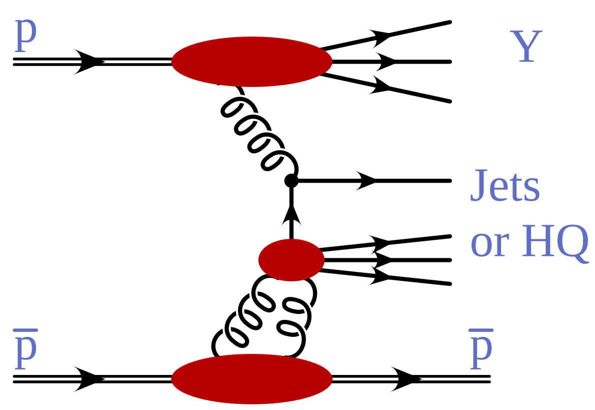
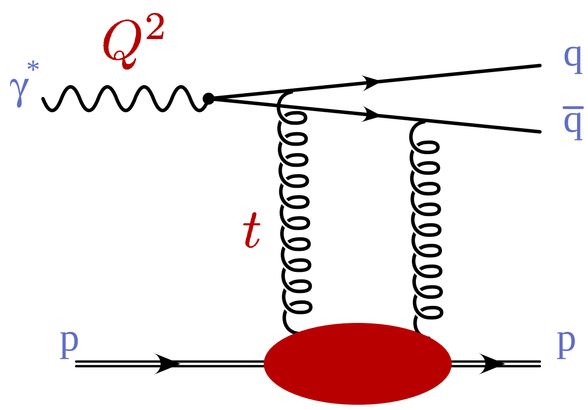
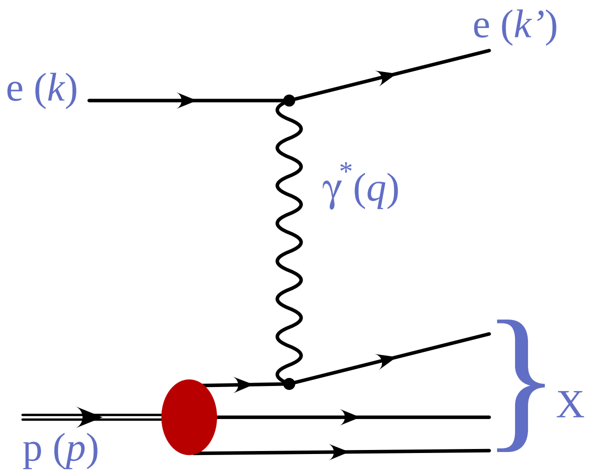
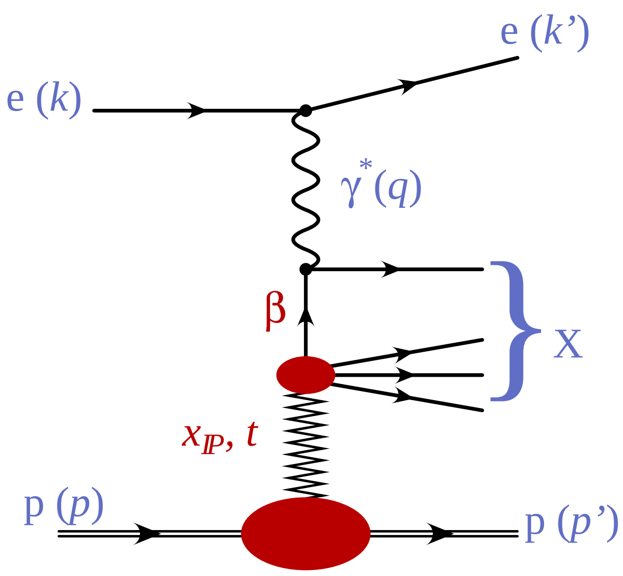


- Access to very low x of nucleon structure function and parton correlations → the Generalized Parton Distributions (GPDs).
- Test of DGLAP and BFKL asymptotic behaviour dynamics
  - → DGLAP: $\log(Q^2)$ → k_T ordering
  - → BFKL: $\log(1/x)$ → $1/x$ ordering
- Colour Dipole model approach: transition 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

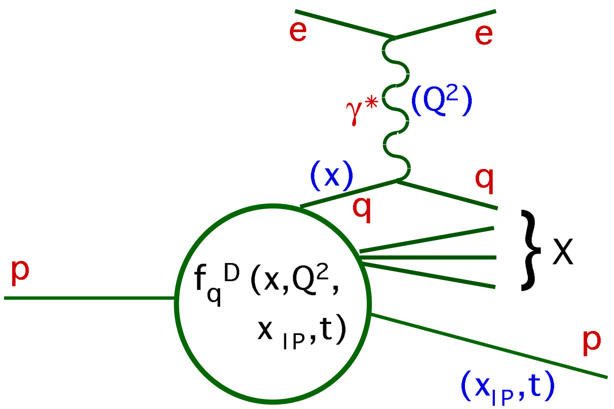
Factorisation Properties

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.

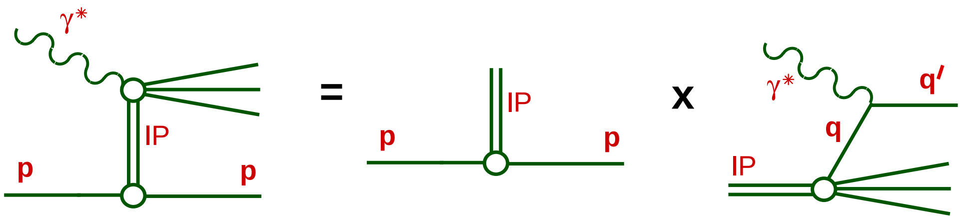


Rigorous for leading Q^2 dependence
but not in hadron-hadron collisions

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

Regge factorisation: β Dependence of F_2^D

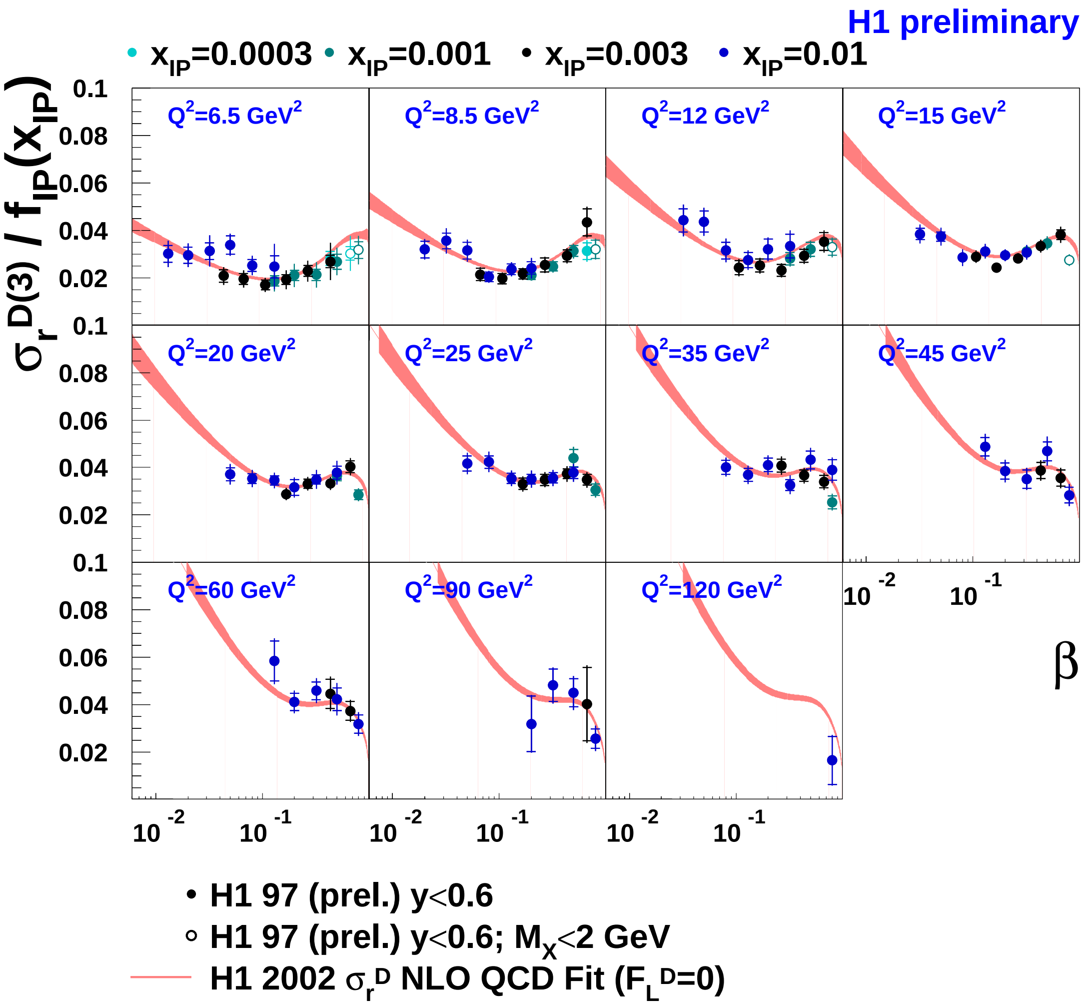
Does Regge factorisation work ?

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, $\alpha(0)$

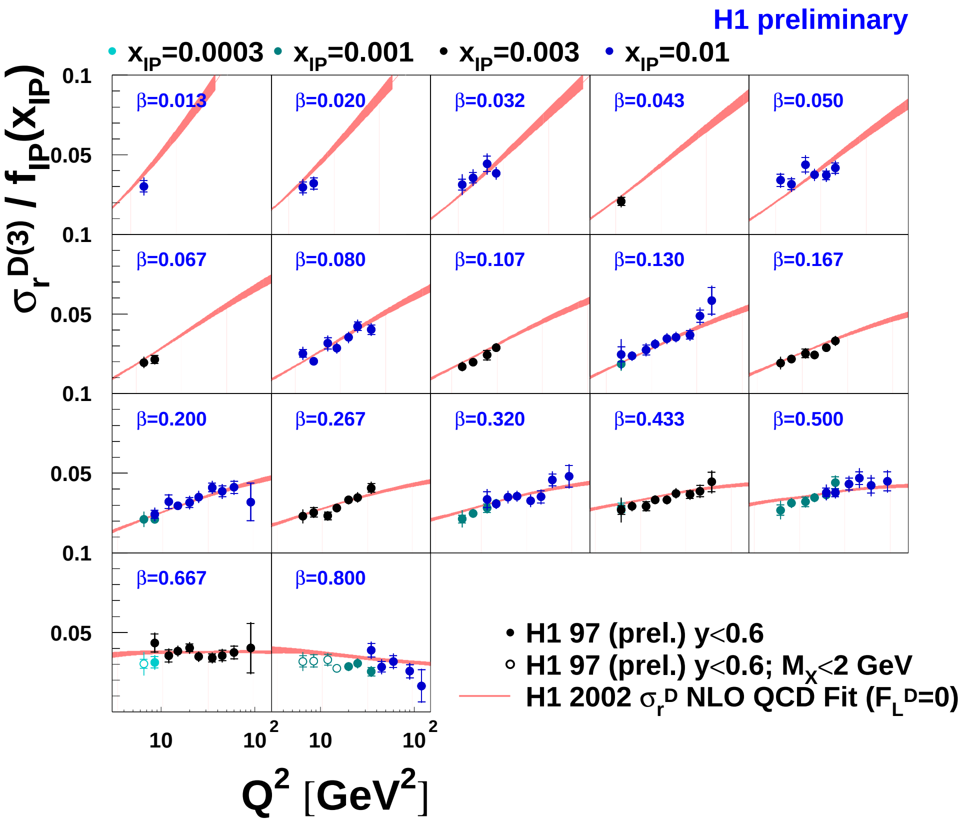
→ Regge factorisation holds !

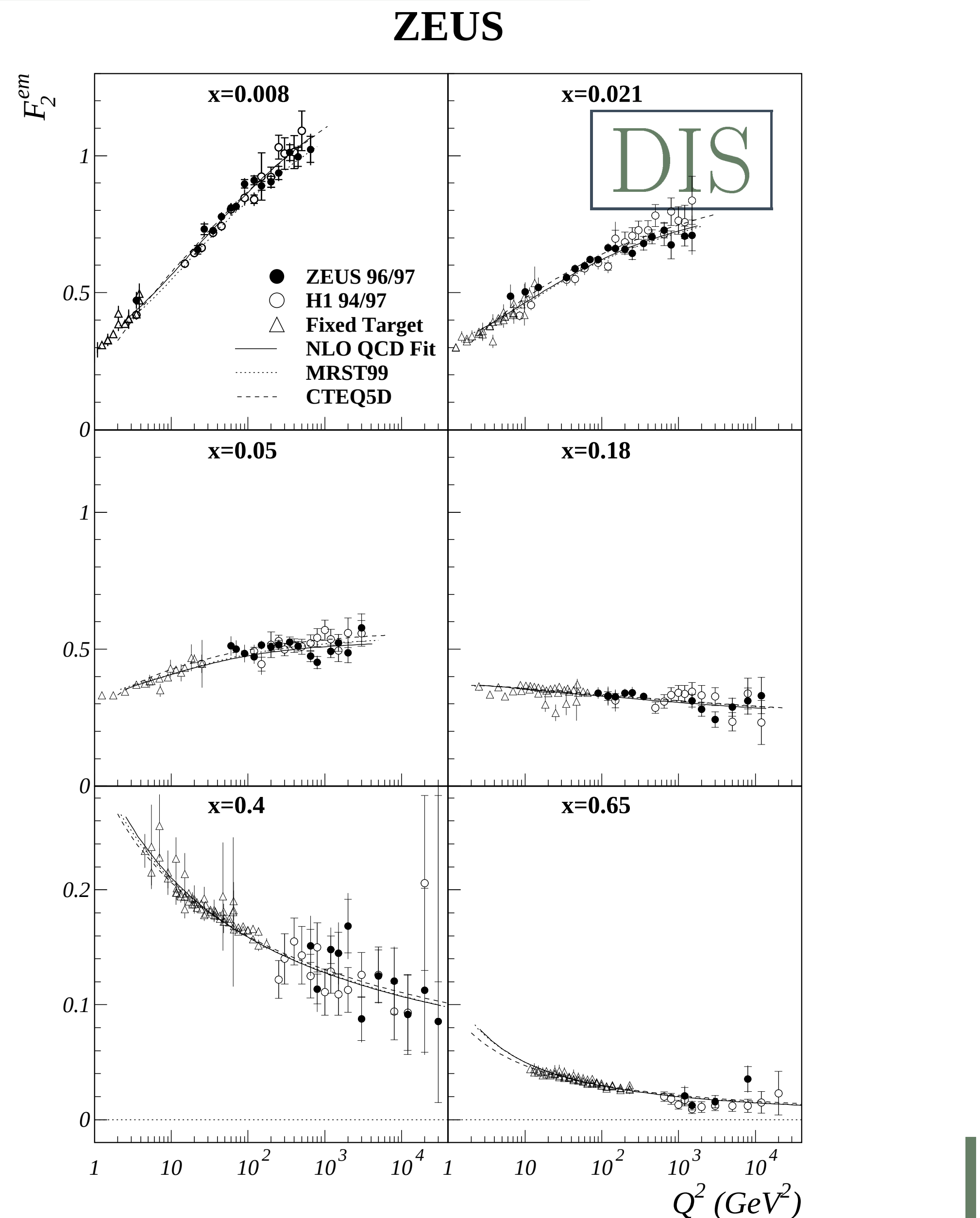


Measures parton density over wide β range.

Q^2 Dependence of F_2^D

Q^2 dependence displays strong scaling violations with positive $\partial\sigma_r^D/\partial \ln Q^2$ up to high β

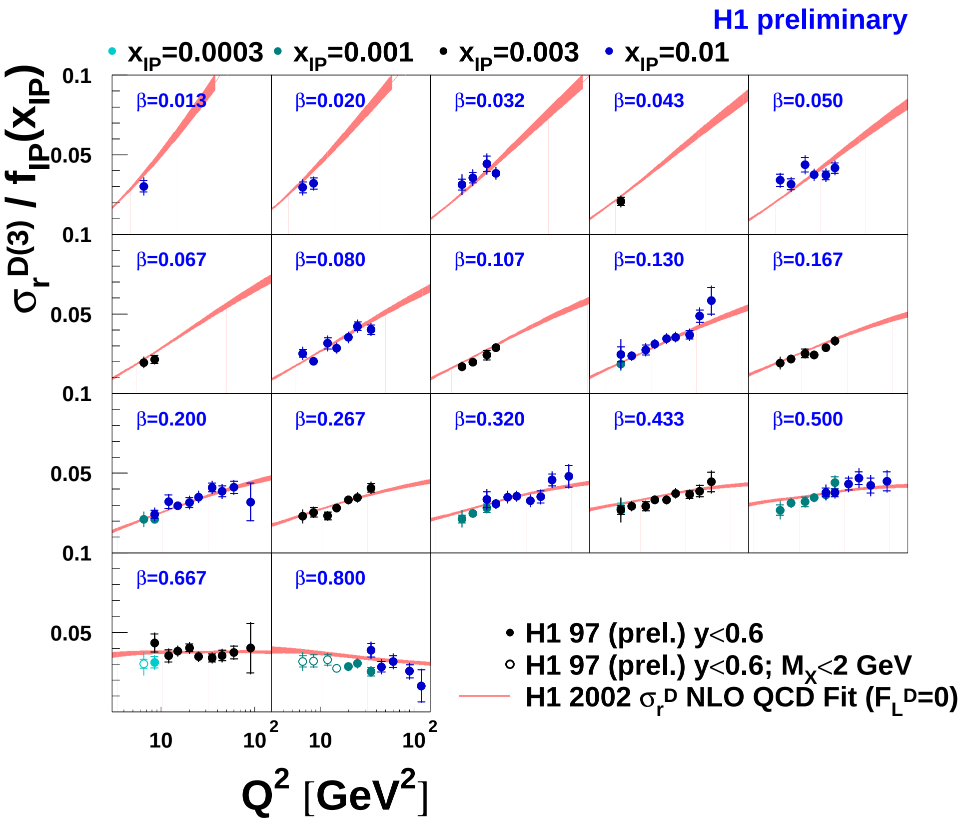


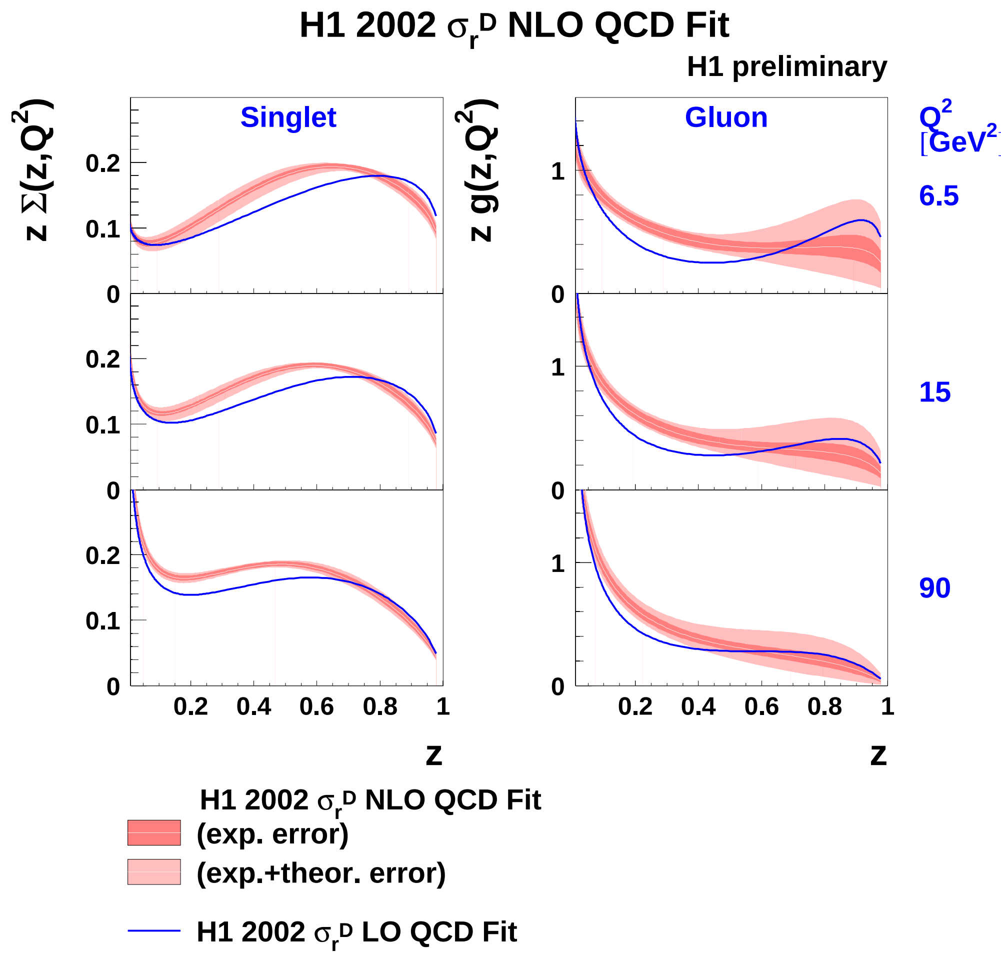


Not like a "normal" hadron

Q^2 Dependence of F_2^D

Q^2 dependence displays strong scaling violations with positive $\partial\sigma_r^D/\partial\ln Q^2$ up to high β





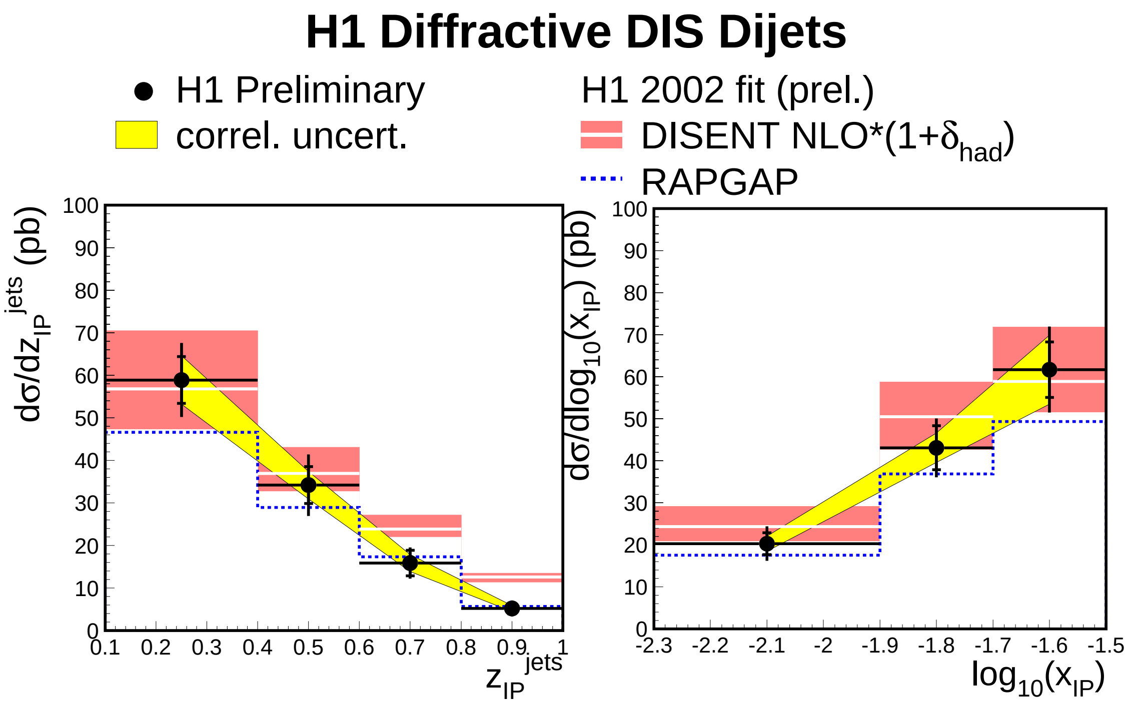
$$\frac{1}{f_{I\!P/p}}\partial\sigma_r^D/\partial\ln Q^2 \sim xG(x)\otimes\alpha_s\otimes P_{qg}$$

- z is the fract. mom. of the parton in $I\!P$
- parametrised at $Q_0^2 = 3$ GeV^2
- DGLAP evolution fit for $Q^2 \geq 6.5$ GeV^2

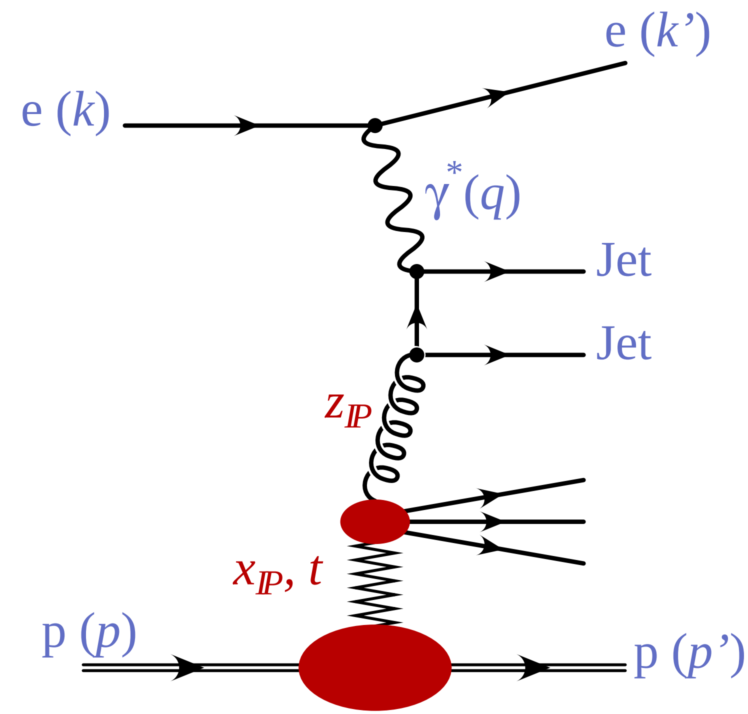
→ a lot of gluons (75 ± 15 % of mom.)

Test of QCD factorisation: Dijet and Charm

Use diff PDFs to predict Dijet production



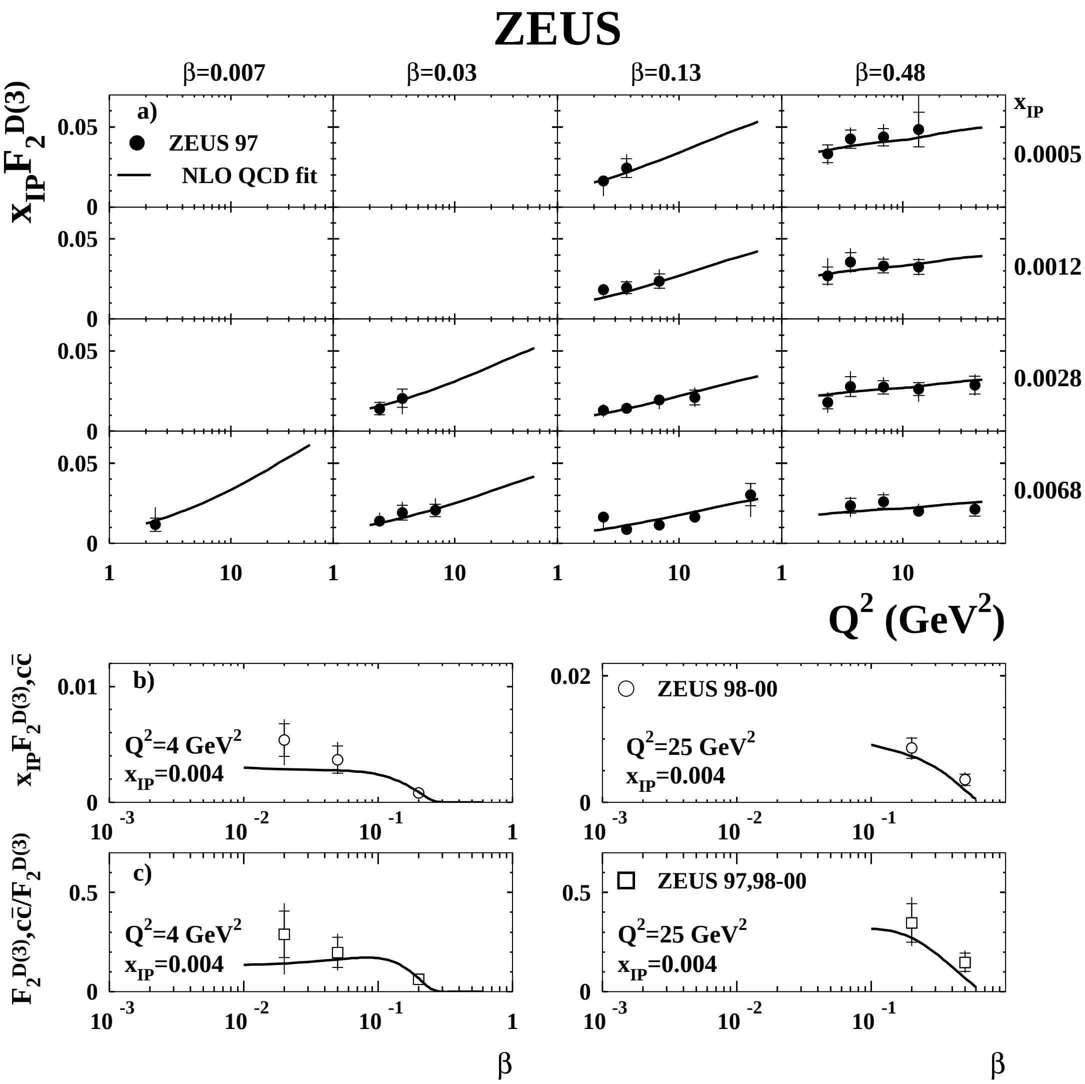
(a) (b)

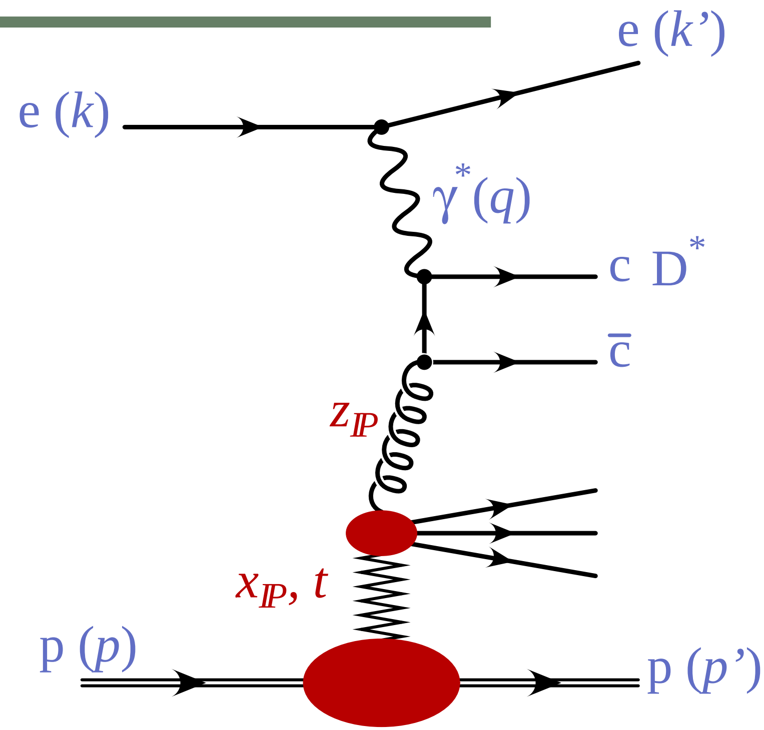


- $Q^2 > 4$ GeV^2, $P_T^{jet1(2)} > 5(4)$ GeV
- Normalisation and shape OK.

→ QCD factorization works within hard Diffraction (in DIS regime)

Test of QCD factorisation: Charm



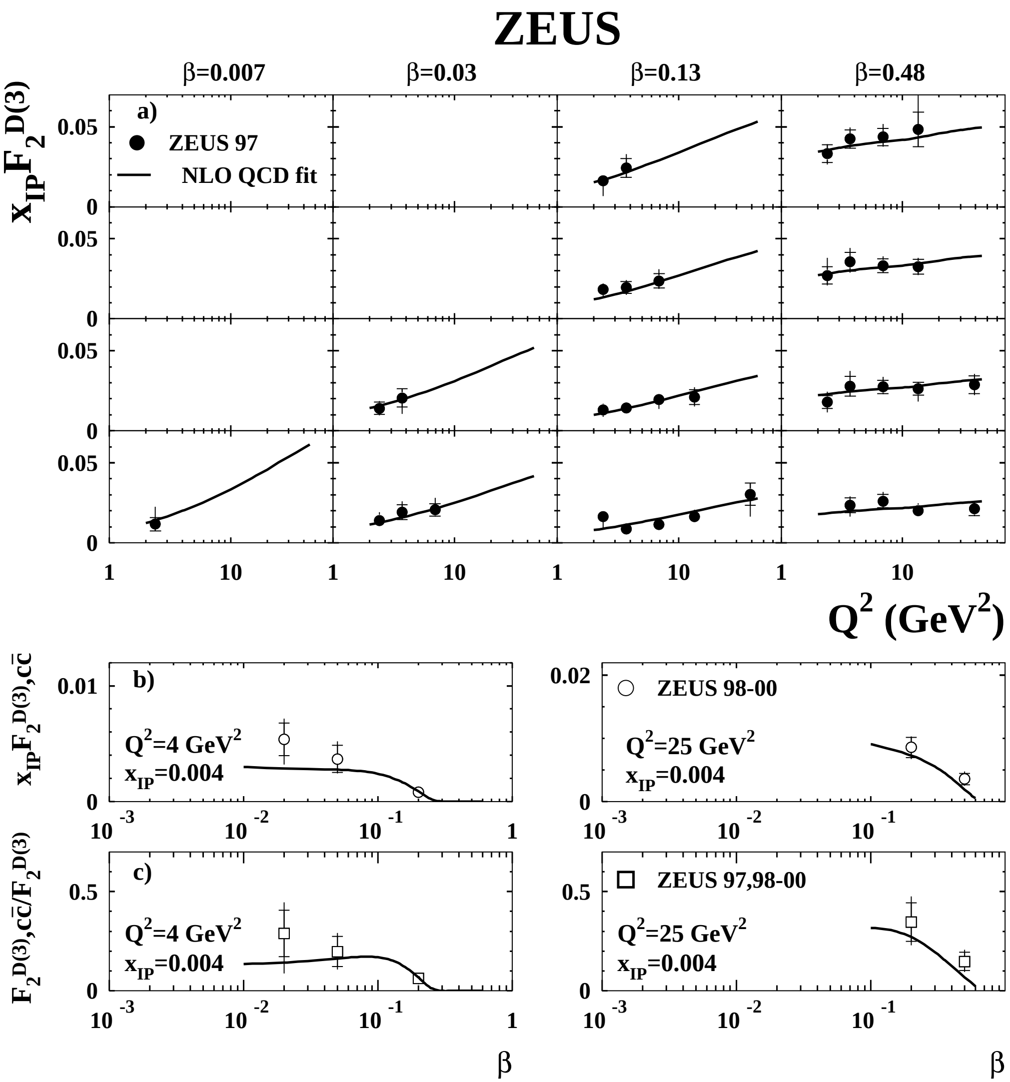


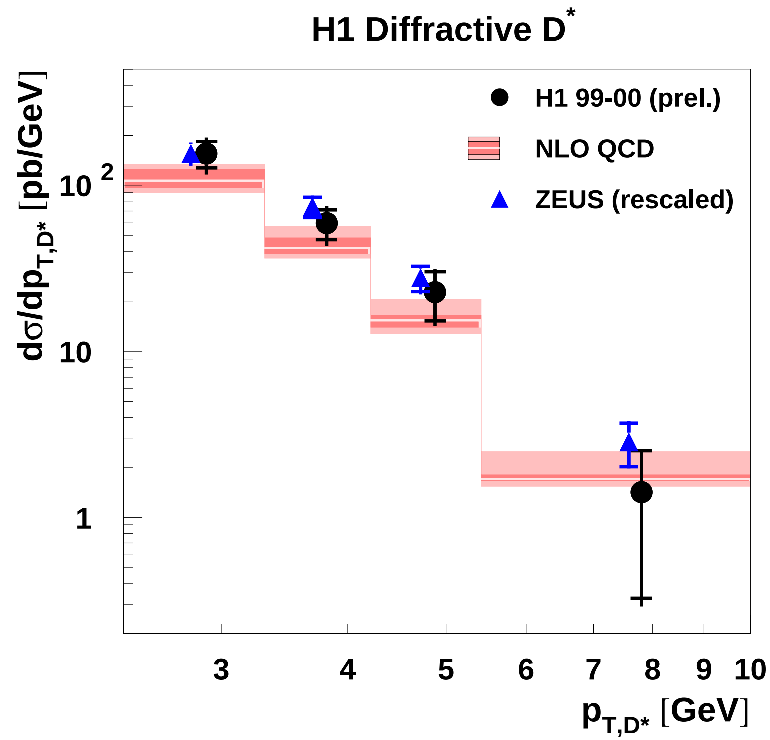
- Data using tagged leading proton
- NLO QCD fit

→ charm prediction

→ QCD factorization works for Charm in Diffraction with $Q^2 > 4$ GeV^2

Test of QCD factorisation: Charm





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→ charm prediction

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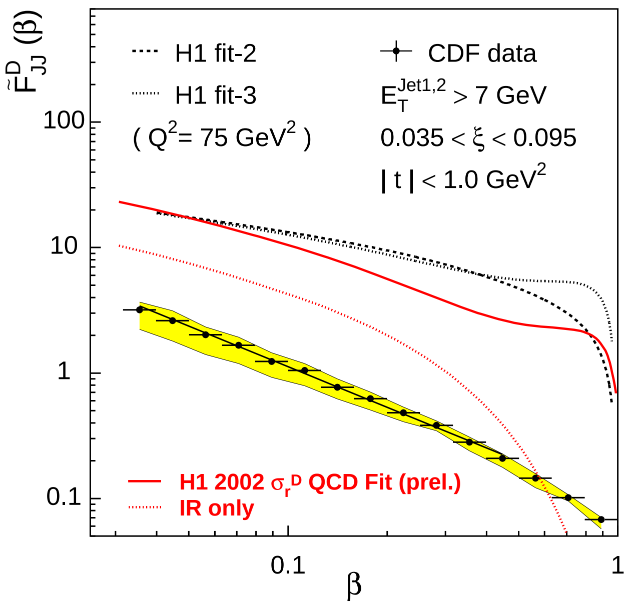
Factorisation breaking at the Tevatron

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



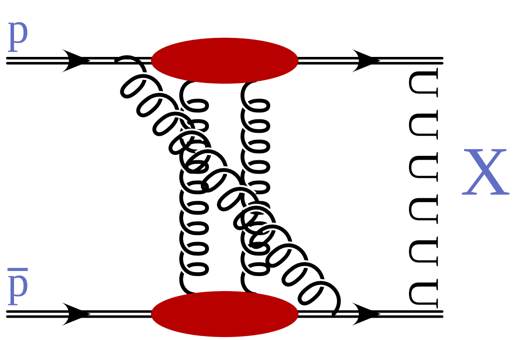
• The prediction based on diffractive PDF's extracted at HERA are one order of magnitude above the measures cross section!

• 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...



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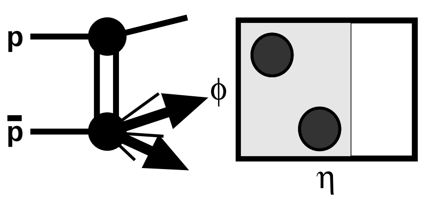
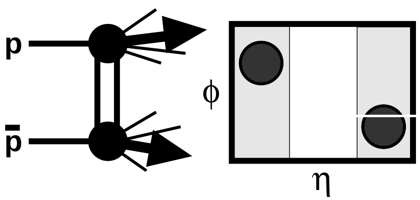
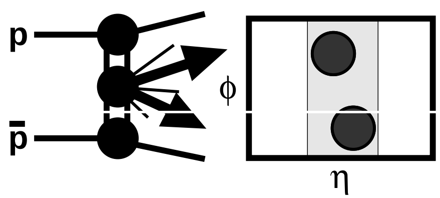


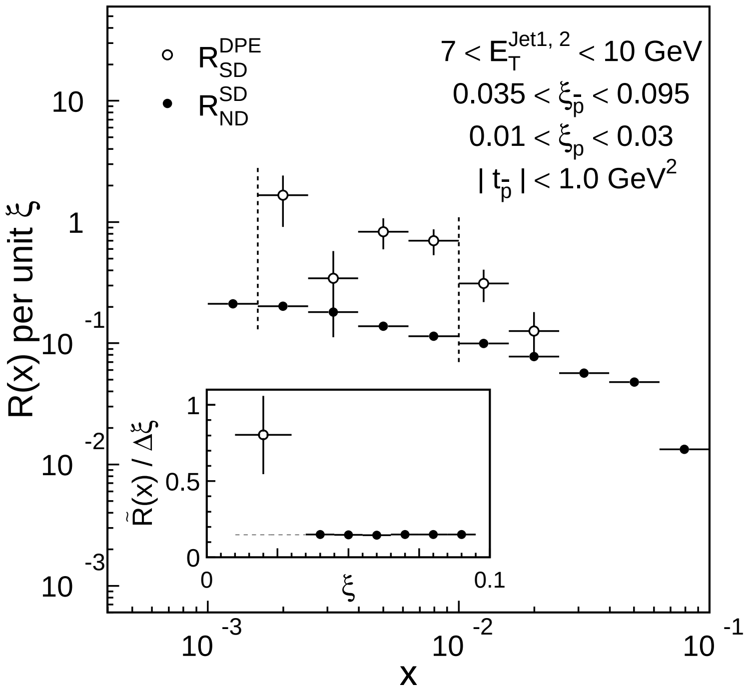
Single Diffraction

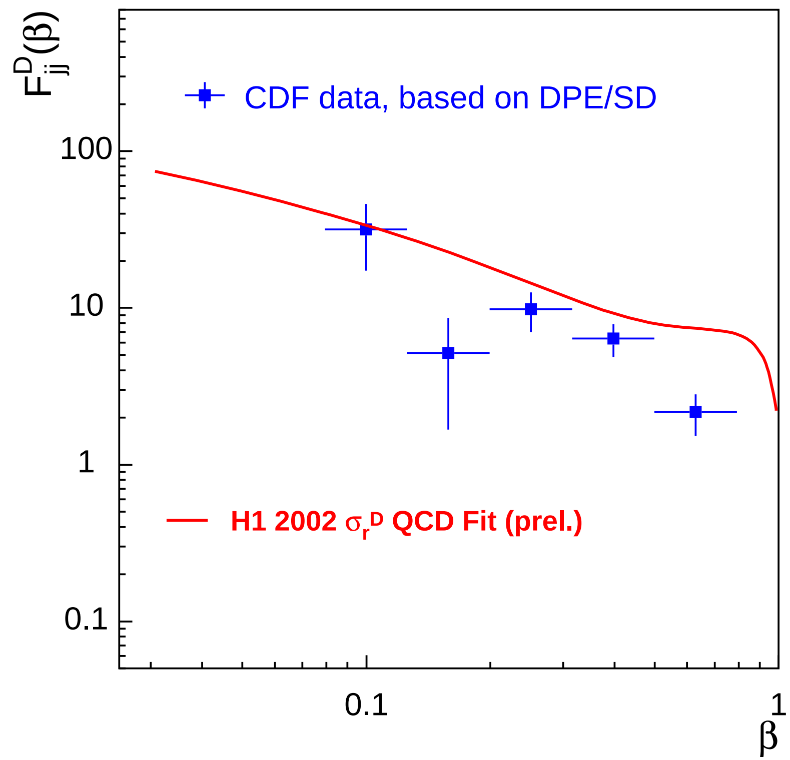


Double Diffraction



Double Pomeron Exchange





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

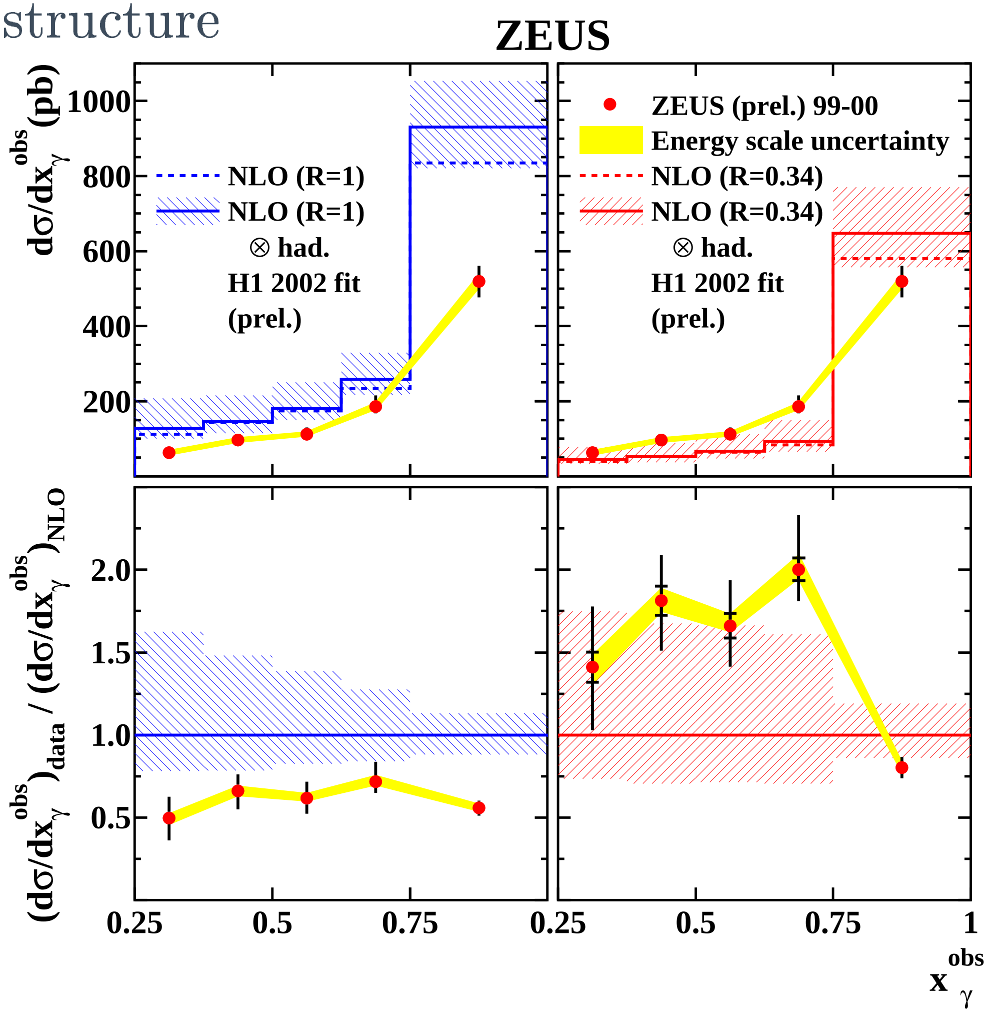
$$R_{ND}^{SD}/R_{SD}^{DPE} = 0.19 \pm 0.07$$

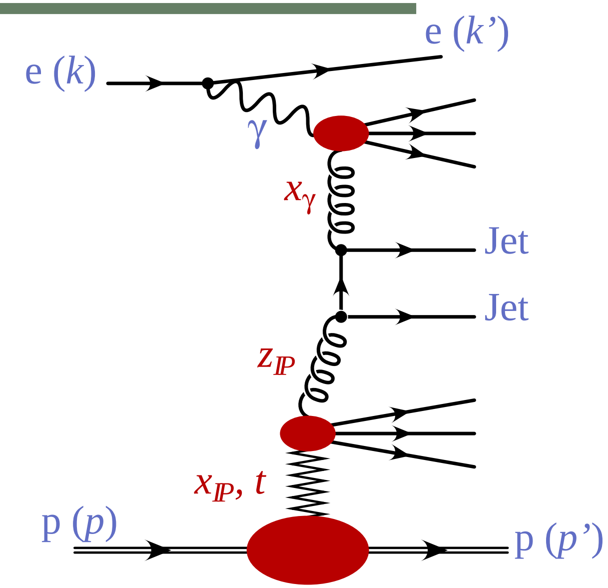
Second gap formation unsuppressed

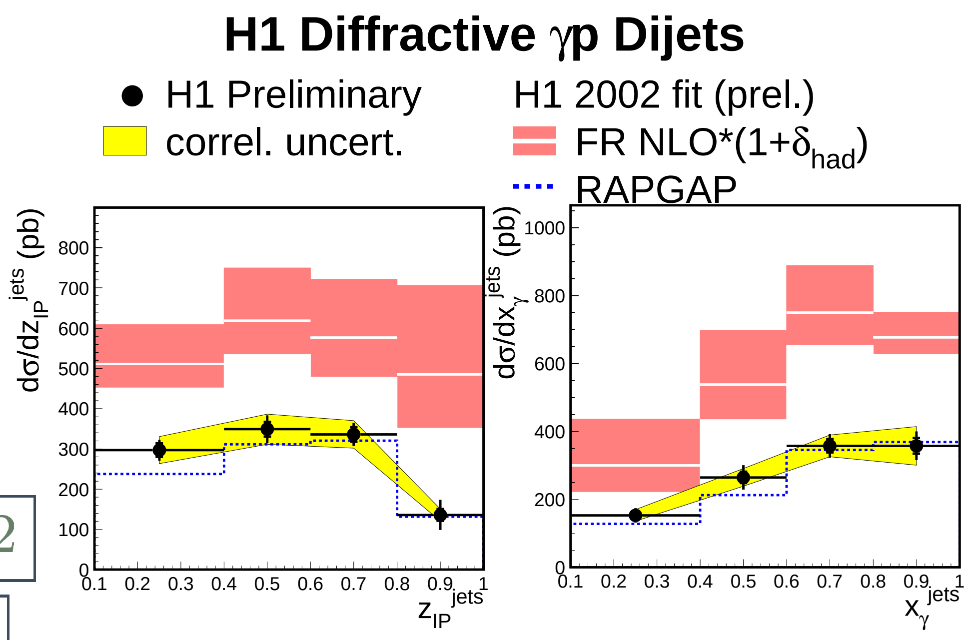
DPE compatible with expectation from H1 PDFs

HERA: Factorisation test: Dijet in Photoproduction

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





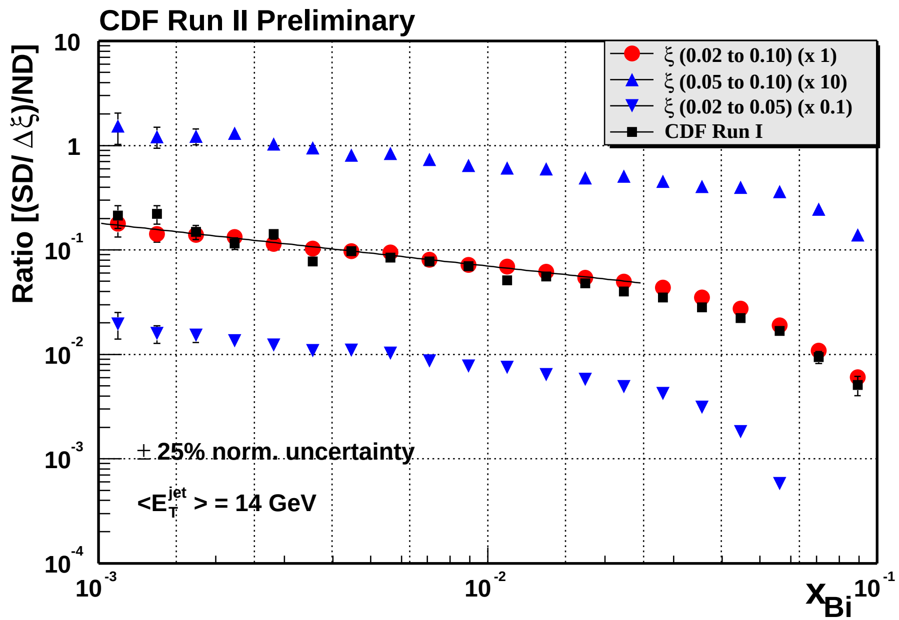


→ NLO prediction above by a factor $\simeq 2$

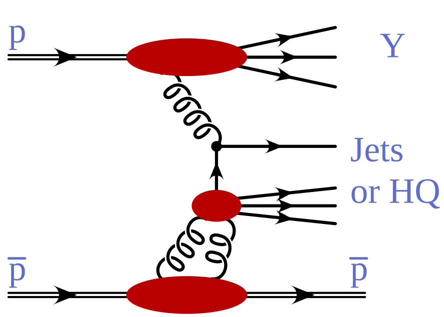
Suppression of both resolved and direct

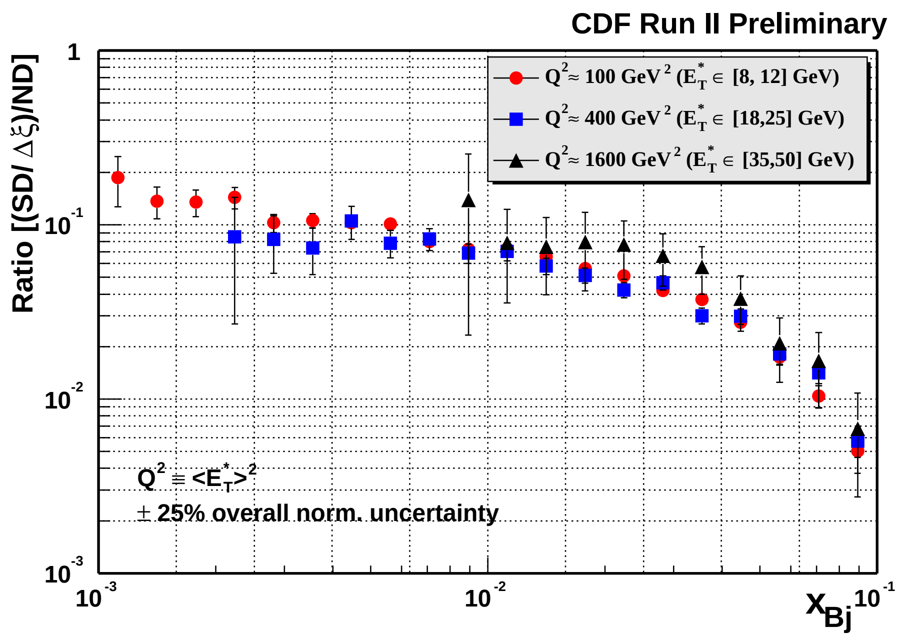
CDF - Run II - Dijet Results

- Slope and normalisation agree with Run I
- no $\xi (= x_{I\!P})$ dependence observed in $0.03 < \xi < 0.1$
  - → Regge fact. also observed
  - → Confirms Run I results



- No $Q^2 (= E_T^2)$ dependence observed in $100 < Q^2 < 1600$ GeV^2
  - → exchange object evolves like a proton





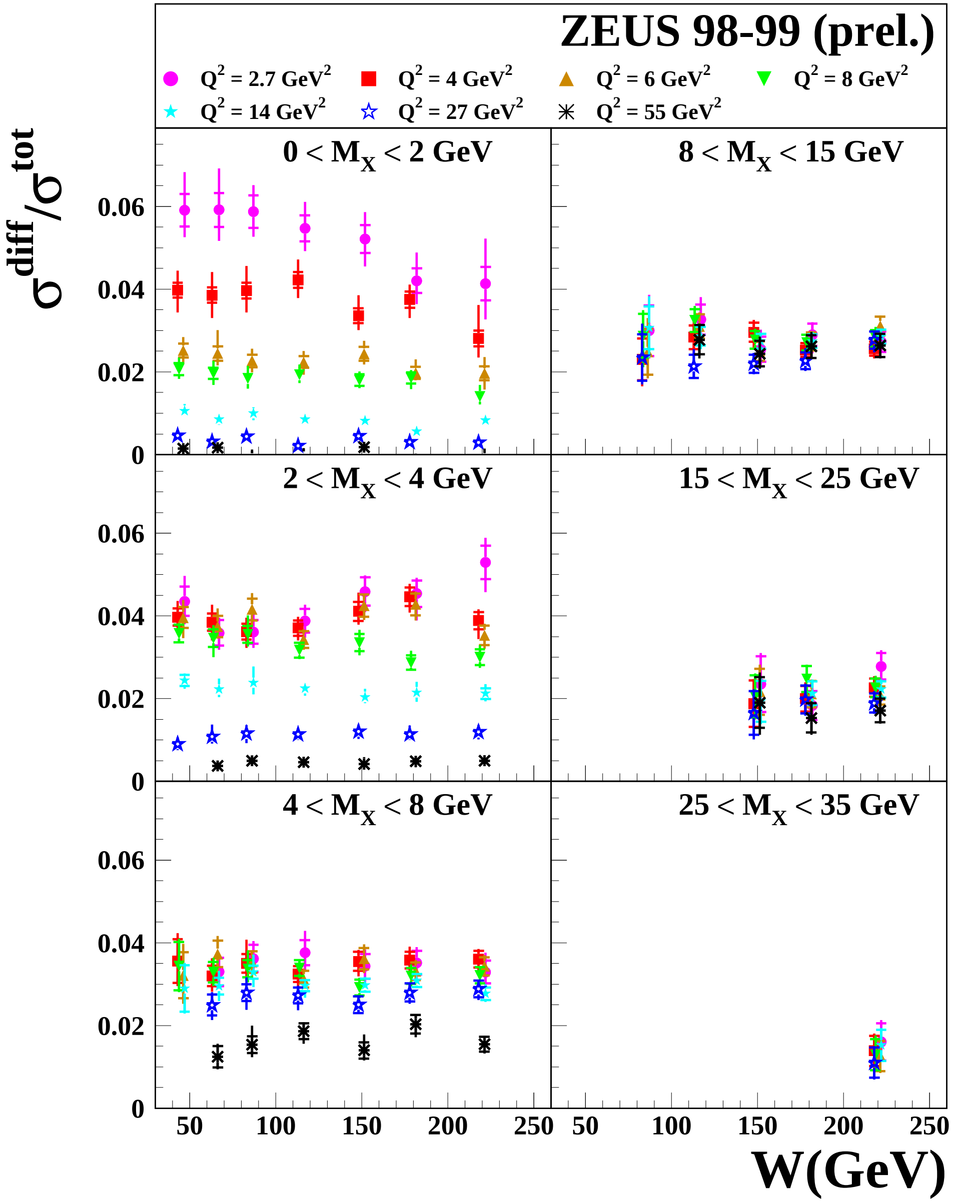
Summary of QCD Factorization tests

- **HERA - Diffraction in DIS regime**
  - → D^* (H1 and ZEUS) validate
  - → Di-jets (H1) validate
- **Tevatron**
  - → Di-jets in single Diff. (CDF) factor 10 lower than expected from HERA PDFs
  - → Double Pomeron exchange (CDF) factor 2-1 lower (OK?)
  - → same in soft and hard diffraction
- **HERA - Diffraction in photoproduction**
  - → Di-jets (H1 and ZEUS) data above NLO QCD by factor 2.
  - → Di-jets: global suppression of both resolved and direct component

=> Description progressing but picture still unclear

=> More work needed (th&exp)

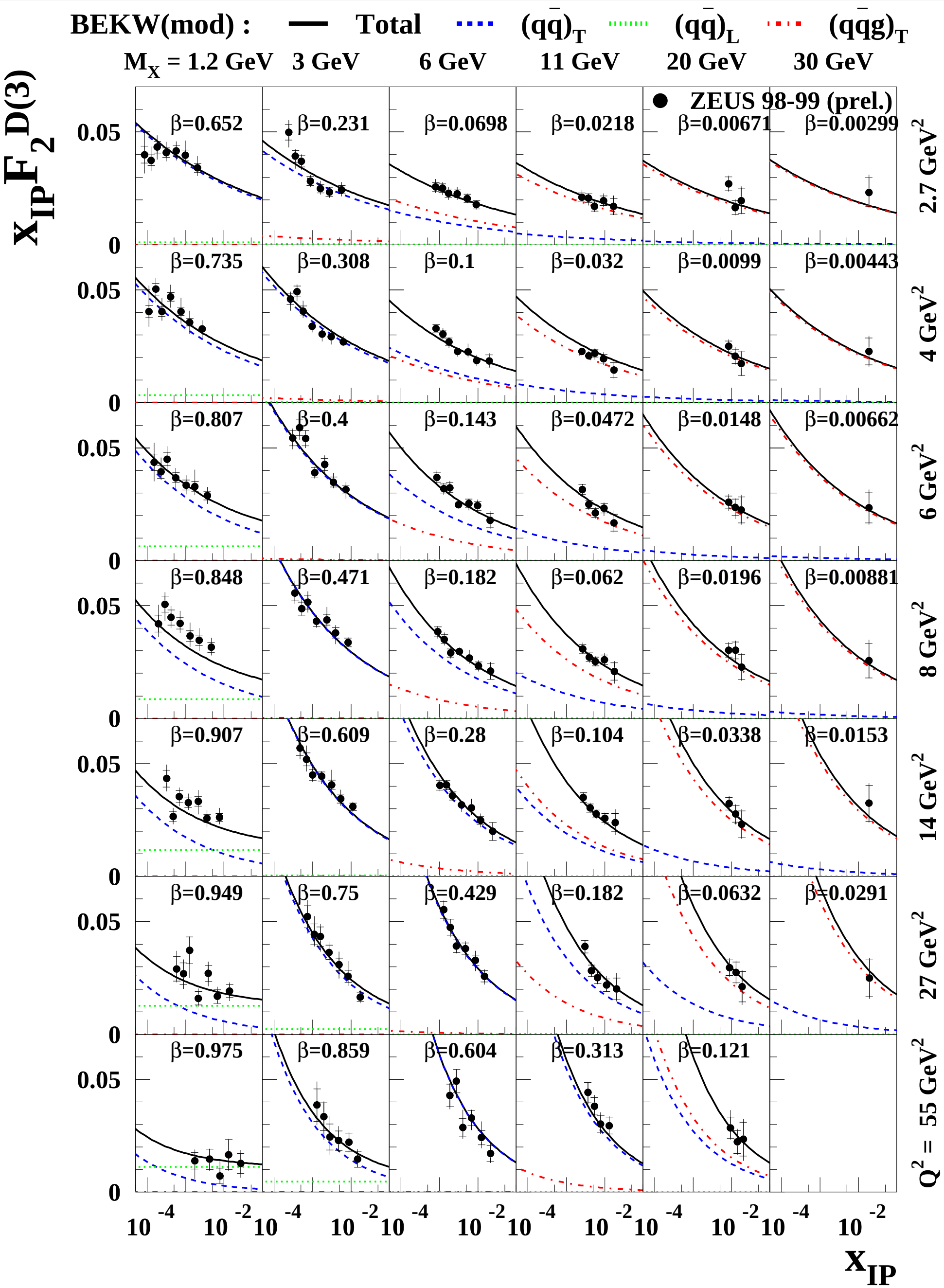
Ratio of Diffractive to inclusive cross-sections

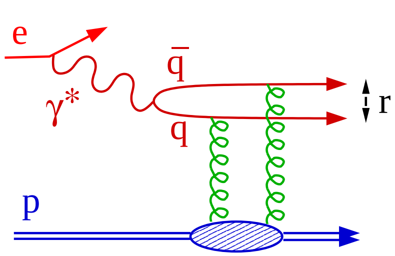


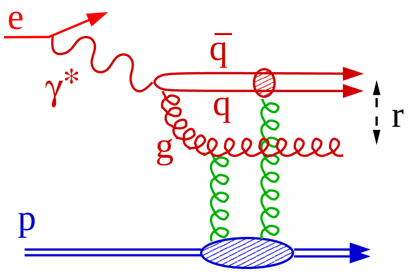
$W^2 \simeq Q^2/x$ $\beta \simeq Q^2/(Q^2 + M_X^2)$

- 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

Colour Dipole approach







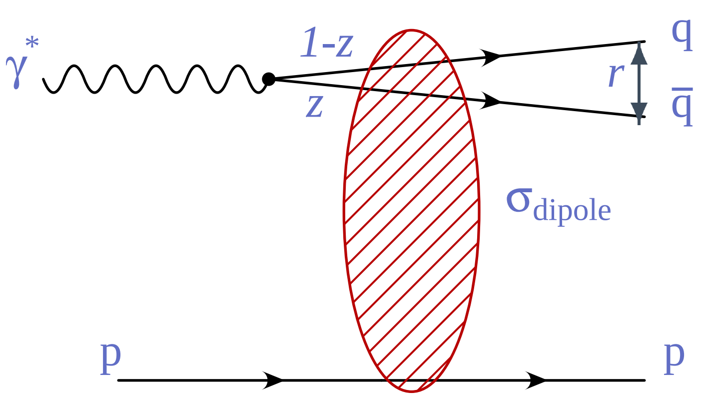
- Dominated by $(q\bar{q}g)_L$ for $\beta < 0.1$
- Dominated by $(q\bar{q})_T$ and $(q\bar{q})_L$ for $\beta > 0.1$
- $\beta \to 1$ → exclusive final state

Exclusive processes

- In presence of a hard scale, (almost) fully calculable in pQCD
- "closed" gluon object → sensitivity to gluon density $\sigma \sim |x\ g(x, Q^2)|^2$
- sensitivity to Generalized Parton Distributions (GPDs)

Two approaches

Colour Dipole



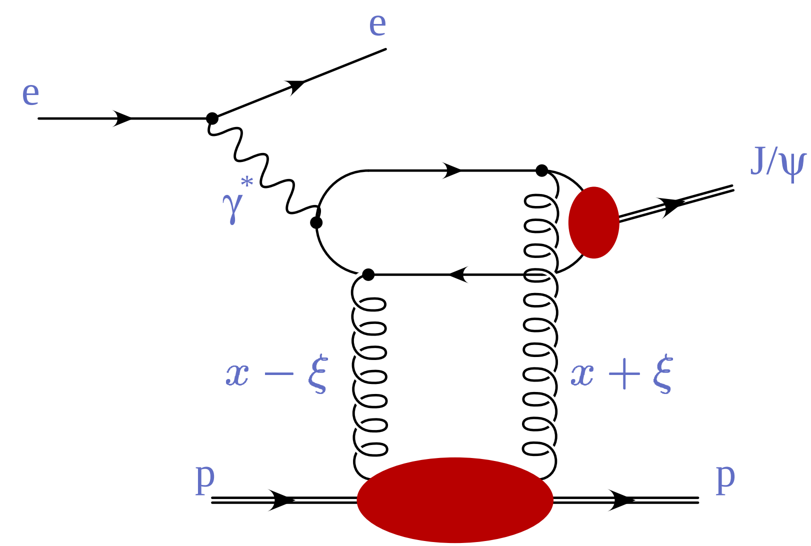
In the proton rest frame:

- γ^* fluctuates in $q\bar{q} + q\bar{q}g + \ldots$

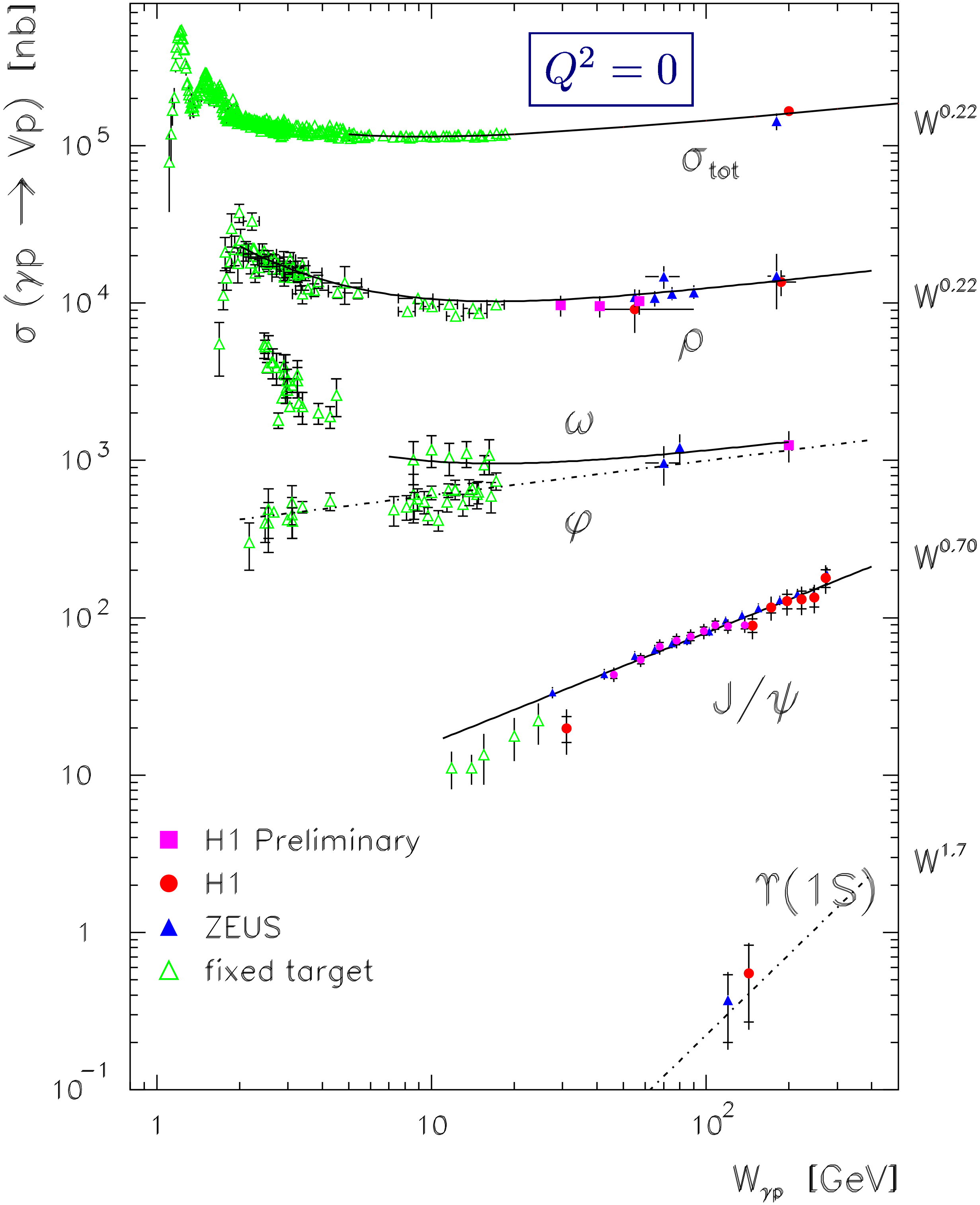
$$\sigma = \int dr^2 \psi^{in}(r, z, Q^2)\ \sigma_{\mathrm{d}}^2\ \psi^{out}(r, z, Q^2)$$

- ψ^{in} calculable
- σ_{d} is modelised (e.g. two gluons)
- integrated over trans. $q\bar{q}$ separation r

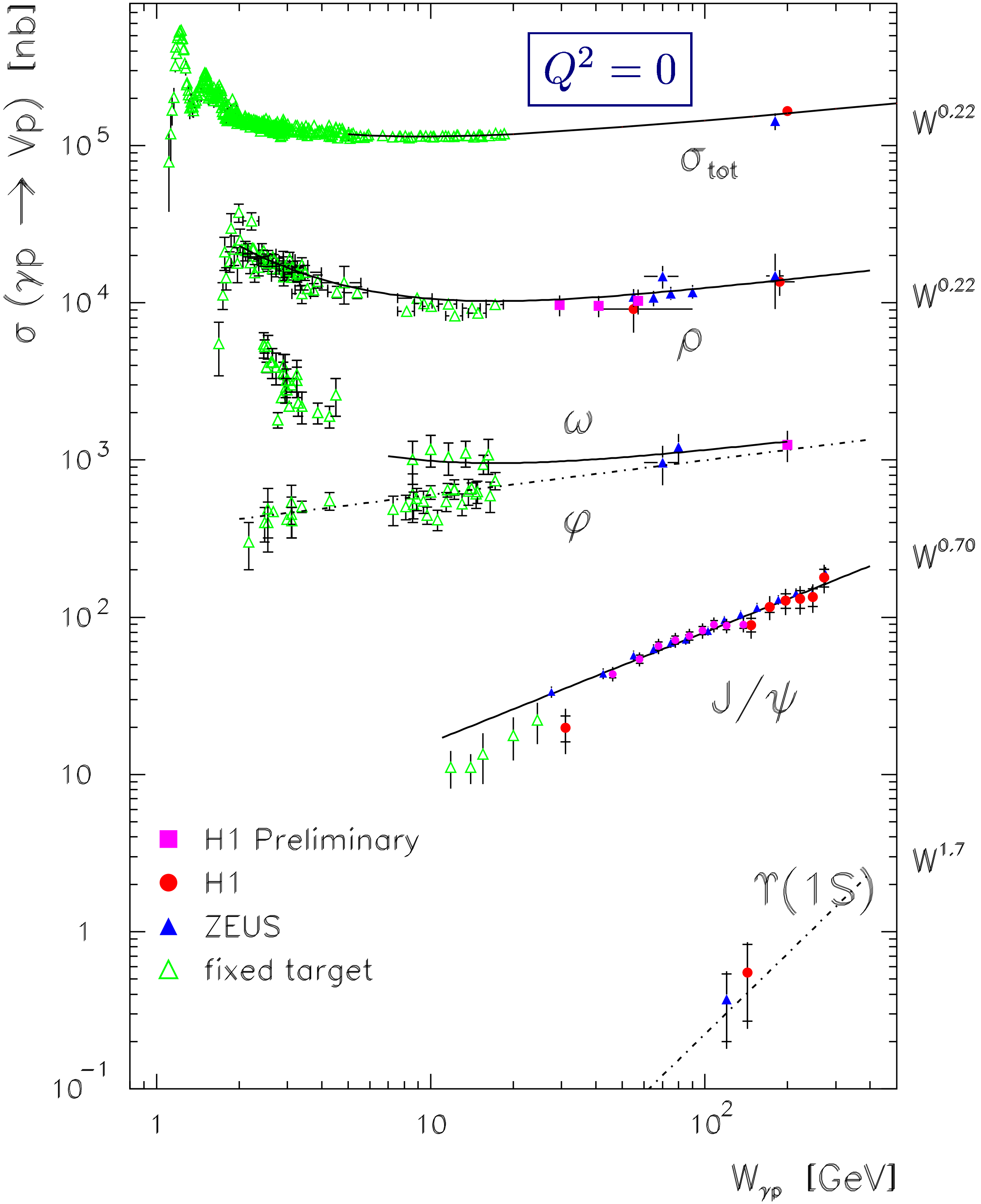
QCD in Breit frame



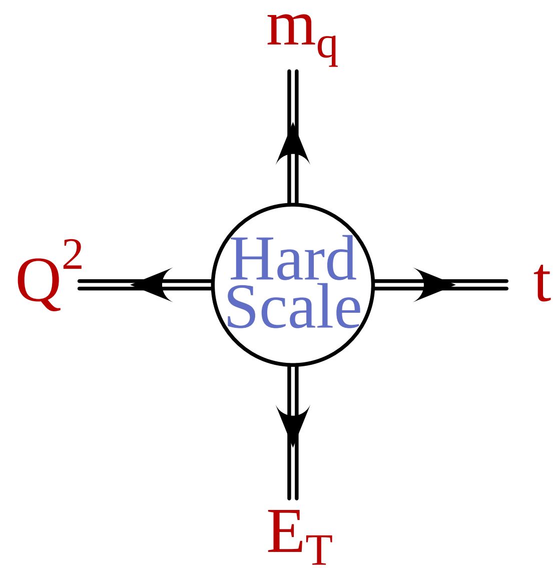
- "exact" QCD calculation possible
- $\int GPD(x, \xi, Q^2)\ dx$
- J/Ψ wave function
- GPDs$(x, \xi, t; \mu)$ build from the PDFs with a skewing effect and a t dependence



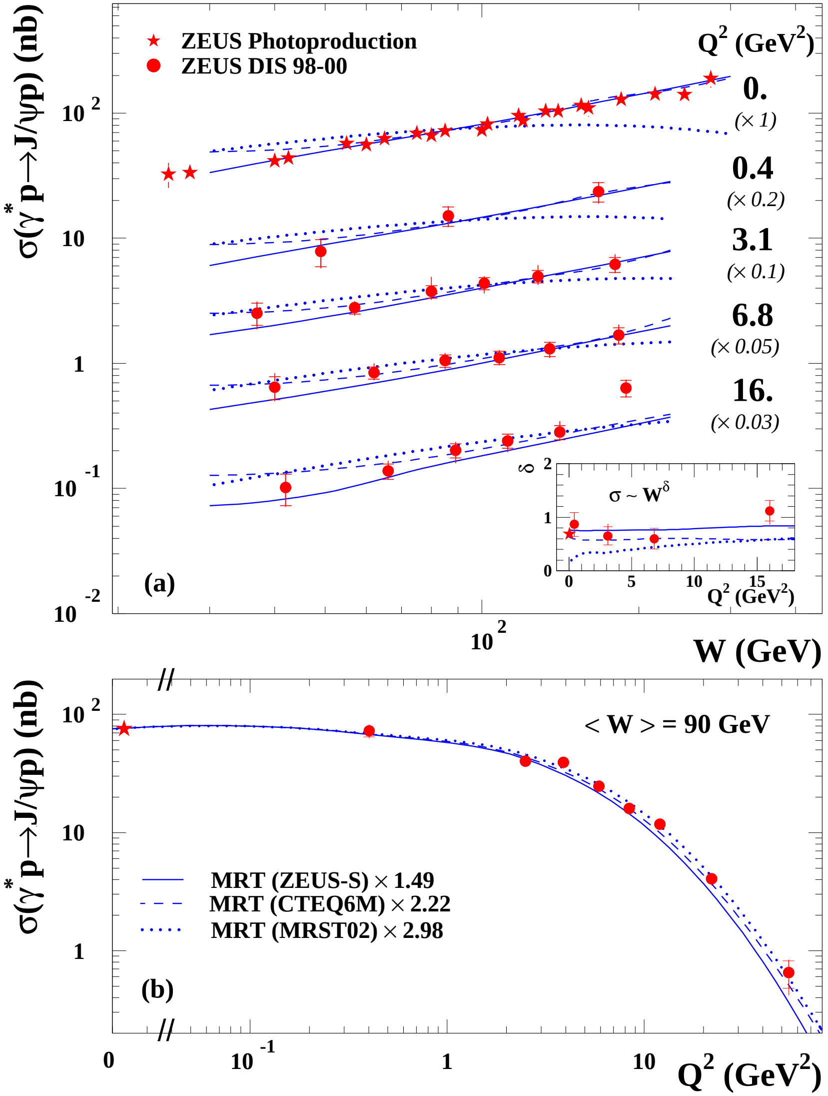
- Low mass (ρ, ϕ, ω; $M_V^2 \simeq 1$ GeV^2): no pert. scale → weak energy dep. (soft regime)
- High mass (J/ψ, υ): pert. scale → strong energy dep. (hard regime)
- similar to F_2 (i.e. the gluon) qualitatively



- 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



Diffractive J/Ψ cross section



- W rise not increasing with Q^2
- hard scale and $\beta = 1$

Dipole approach: e.g. Martin Ryskin and Teubner (MRT)

- confirms $\sigma \simeq |x\ g(x, \mu^2)|^2$

$$\mu^2 = Q^2 + M_V^2$$
$$x = (Q^2 + M_V^2)/W^2$$

- sensitivity to gluon distribution input

- no absolute normalisation prediction (normalised to $Q^2 = 0$)

- no constrains on GPDs

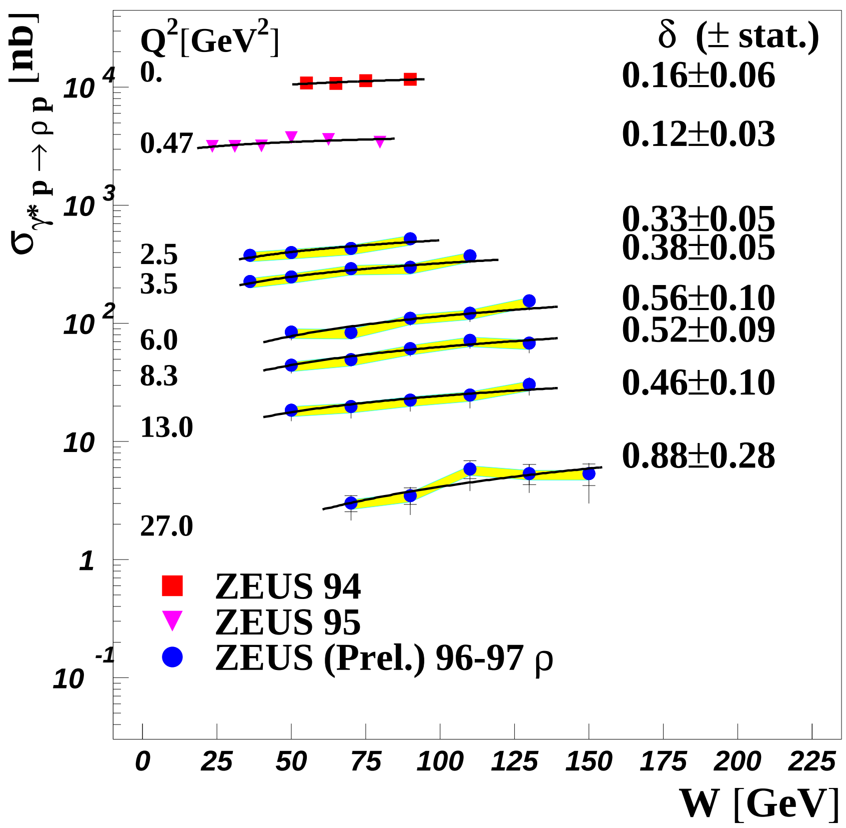
QCD Breit frame approach: Ivanov, Krasnikov and Szymanowski

- Almost finished → to be included in MC.

- Includes GPD input

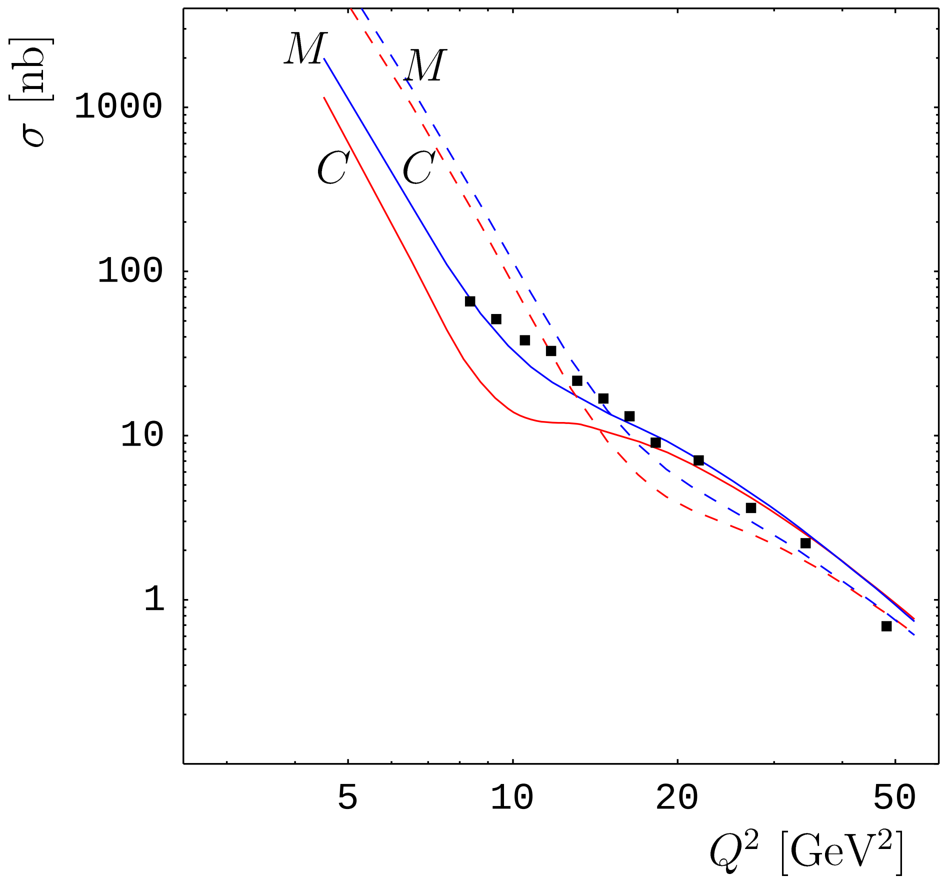
Q^2 evolution of light vector meson Production

$$e\, p \to e\, \rho^o p$$



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

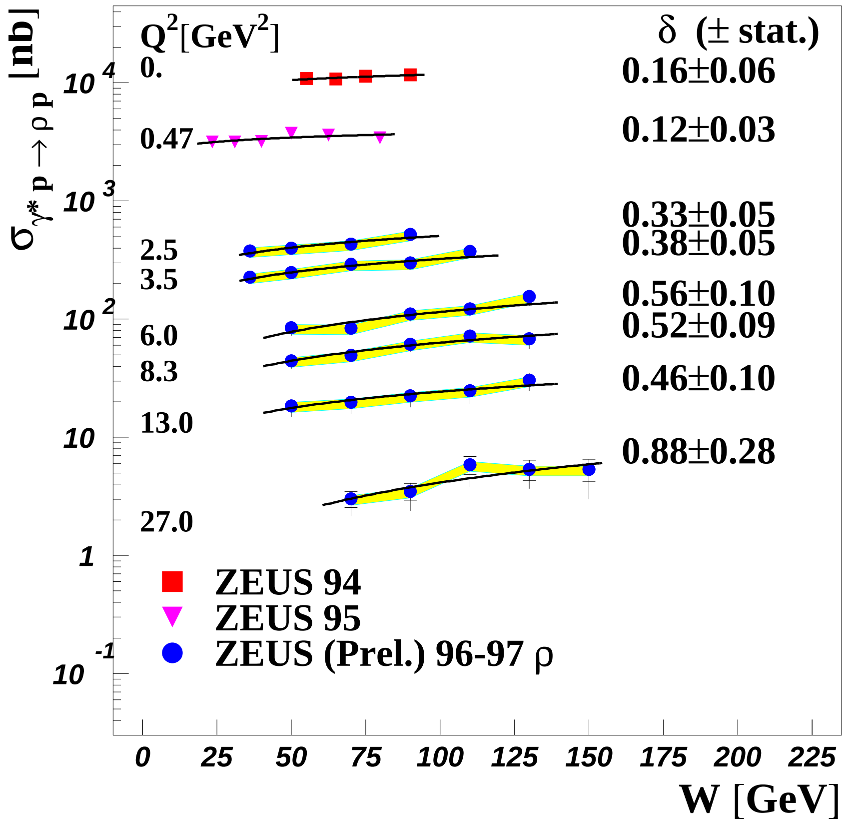
First NLO calculation: Ivanov et al.

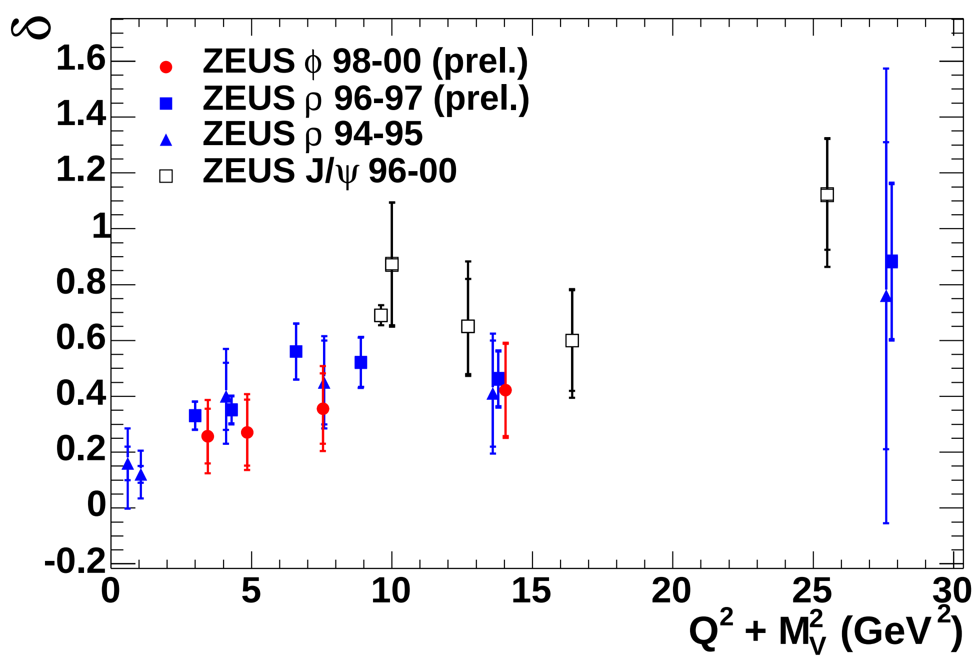


- M=MRST2001 and C=CTEQ6M
- solid line $\mu_R = \mu_F$, dashed line $\mu_R = Q$

Q^2 evolution of light vector meson Production

$$e\ p \rightarrow e\ \rho^o p$$



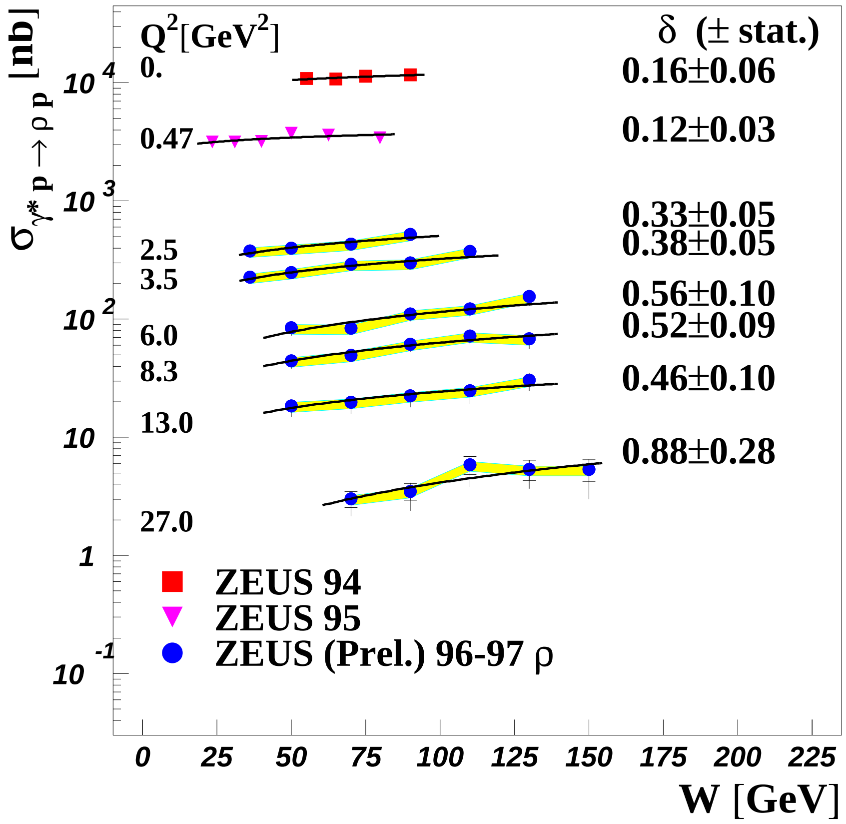


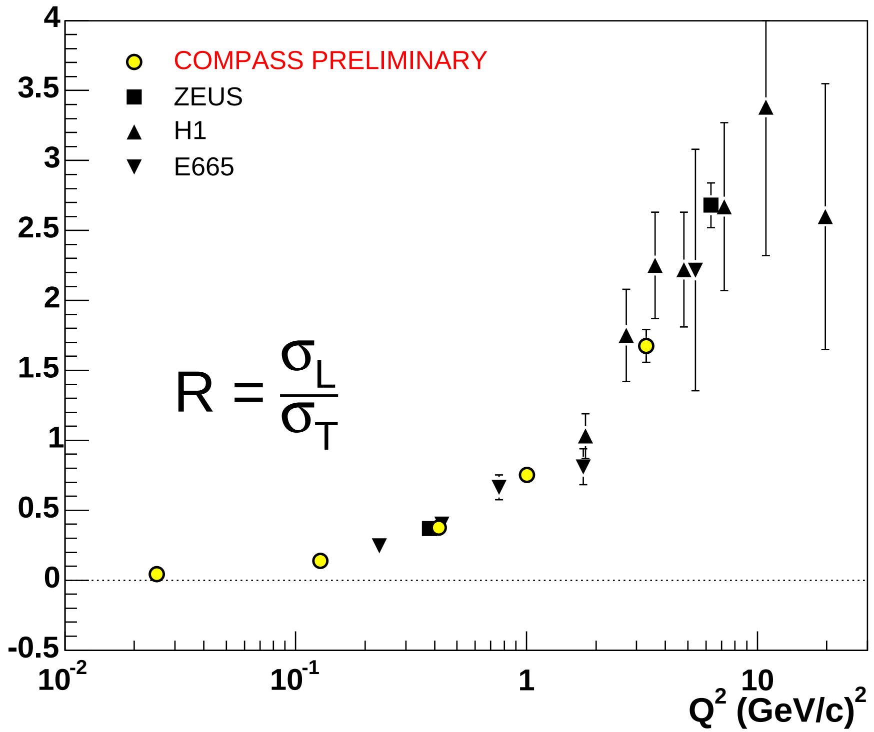
- Universal(?) behaviour for $Q^2 + M_V^2$ scale

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

Q^2 evolution of light vector meson Production

$e\ p \rightarrow e\ \rho^o p$

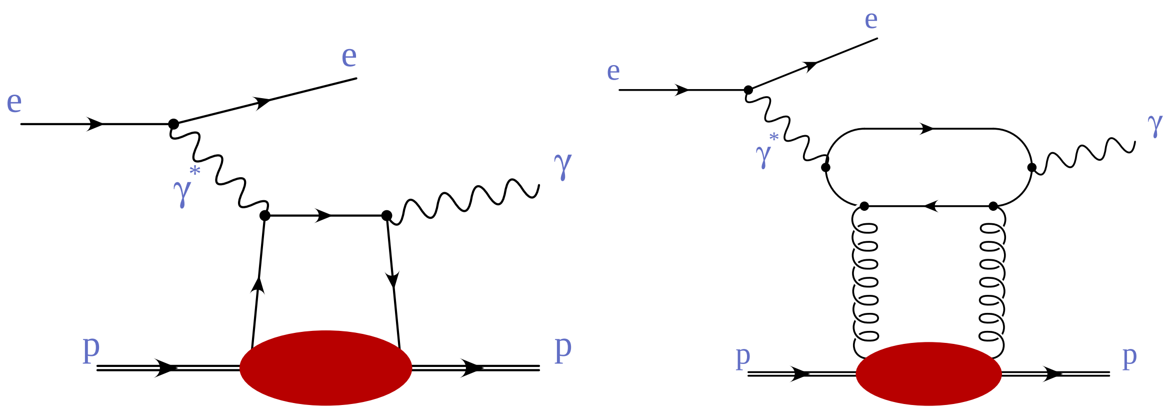


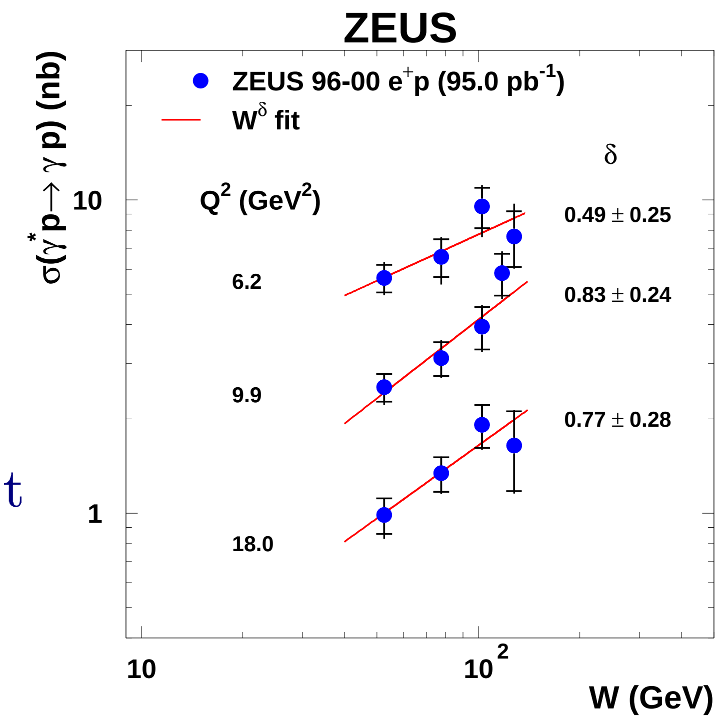


=> see parallel session

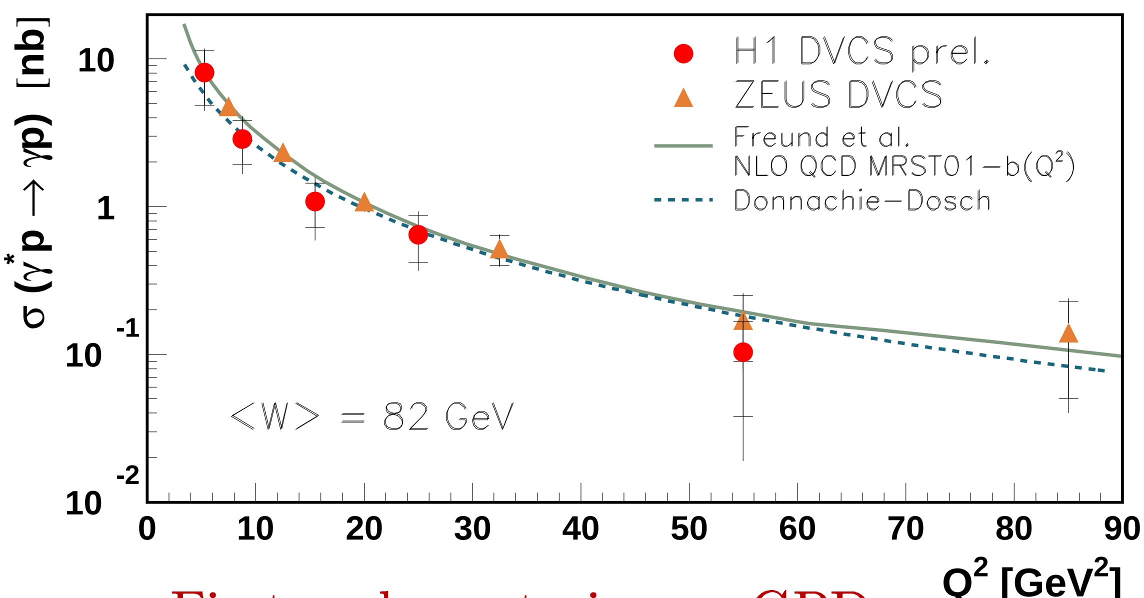
When Q^2 increases, also soft $\rightarrow$ hard transition

Deep Virtual Compton Scattering





fully calculable in pQCD: NLO-Freund & McDermott
Access to the full QCD amplitude using
the interference term with Bethe-Heitler.



First real constrains on GPDs

DGLAP region: $|x| > \xi$

$$\mathcal{H}^q(x,\xi,t;\mu^2) = q(x;\mu^2)\, e^{-b|t|}$$

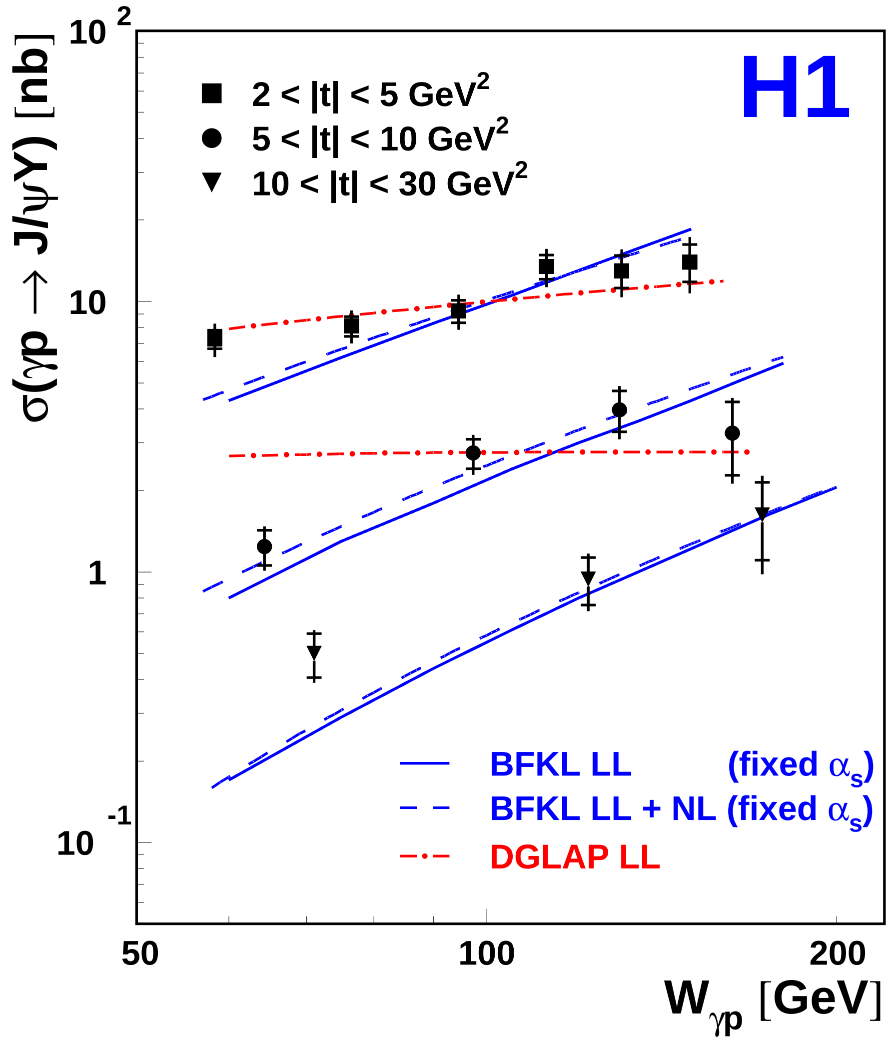
$$\mathcal{H}^g(x,\xi,t;\mu^2) = x\ g(x;\mu^2)\, e^{-b|t|}$$

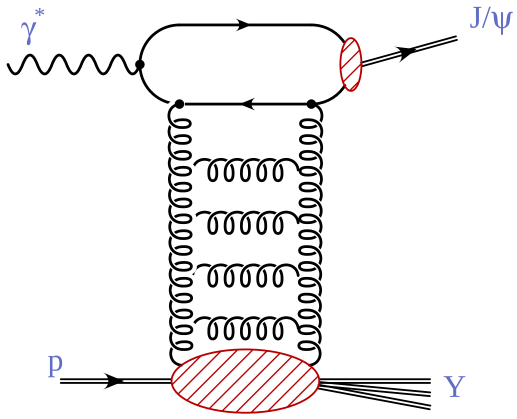
MRST2001 and CTEQ6

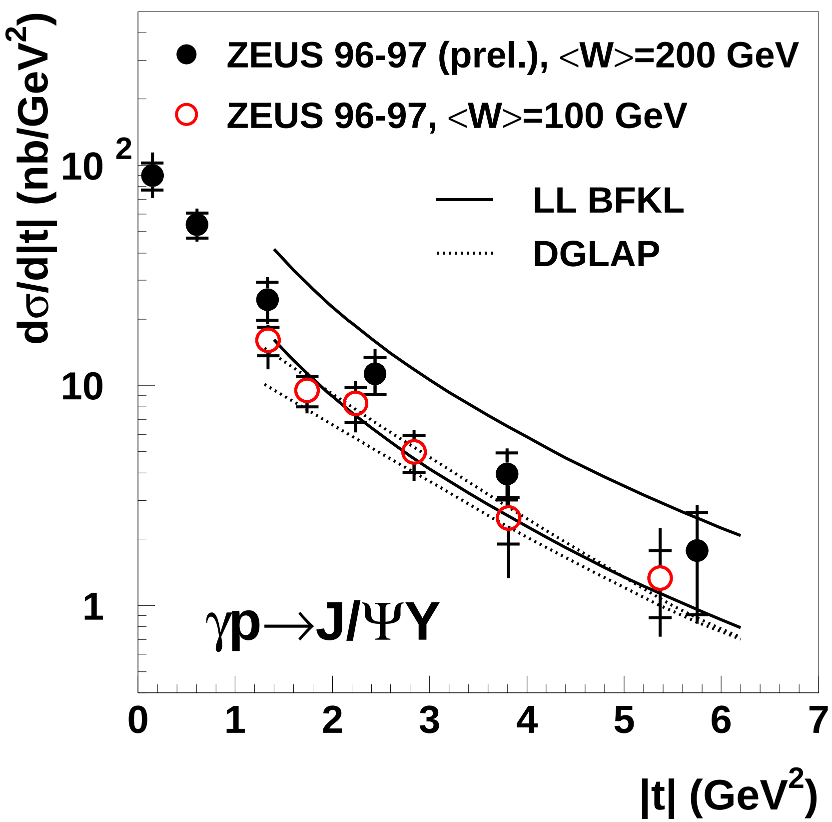
ERBL region: $|x| < \xi$

simple analytic function

Large t: DGLAP vs BFKL

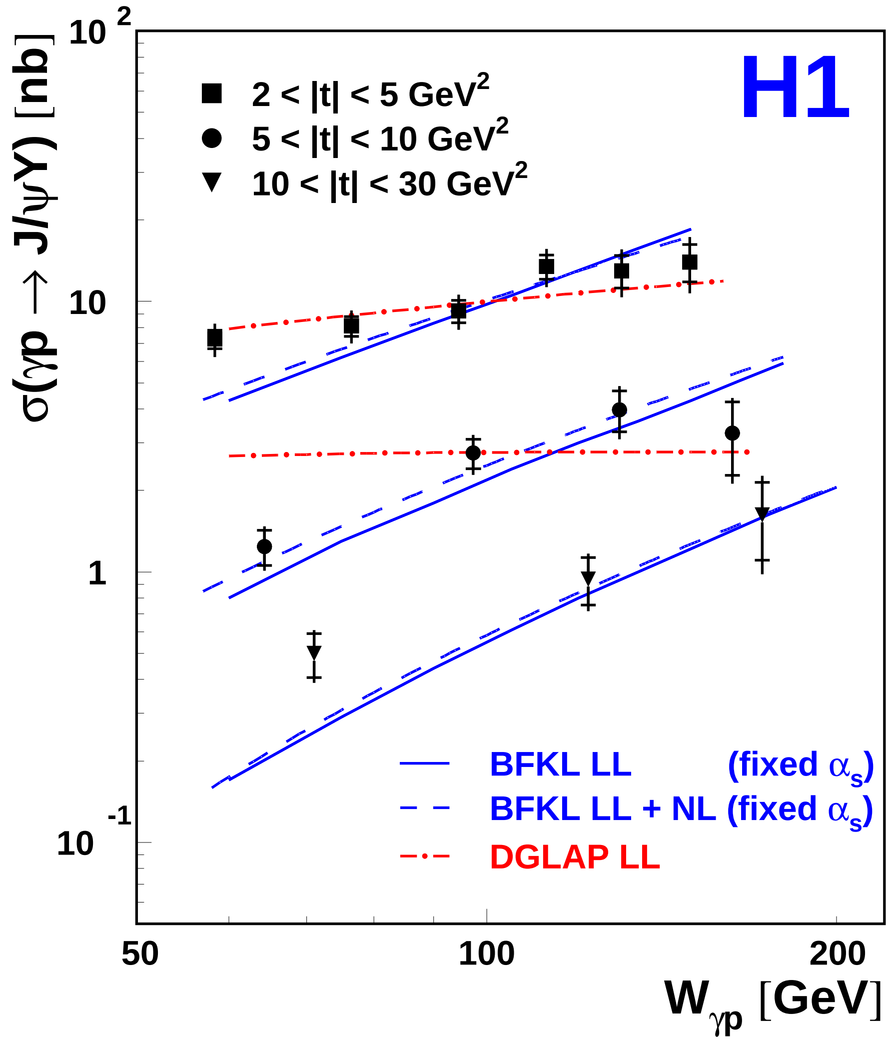


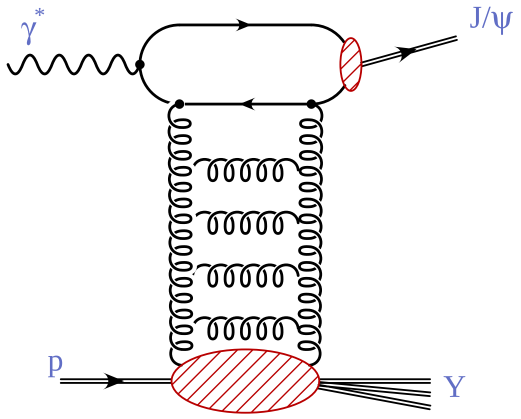


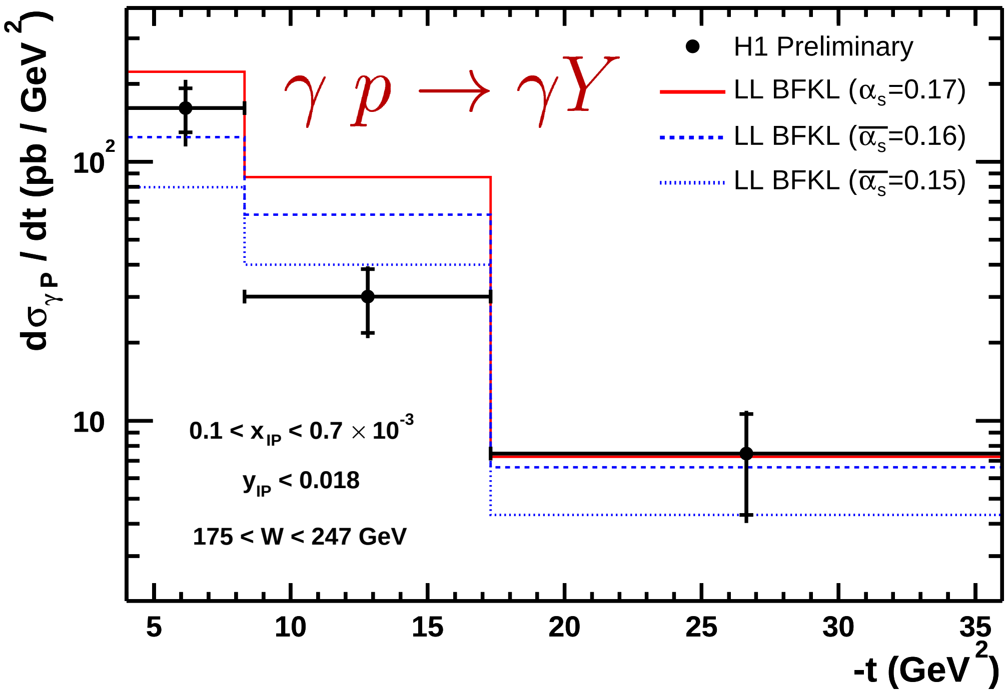


Rise with W not described by DGLAP

Large t: DGLAP vs BFKL







Rise with W not described by DGLAP

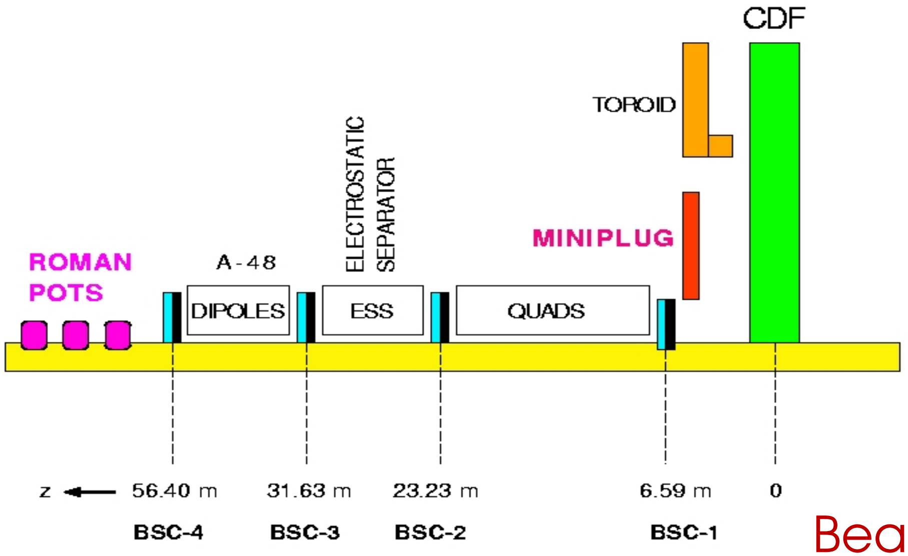
Very close future

- Tevatron Run II started ➜ Upgrades of CDF and D0
- HERA II started ➜ Upgrade of H1
- Compass: - results in parallel session

Less close future

- LHC - see parallel session
- eRHIC...

CDF at Run II



Miniplug calorimeter (new)

high transverse granularity

$3.6 < |\eta| < 5.1$

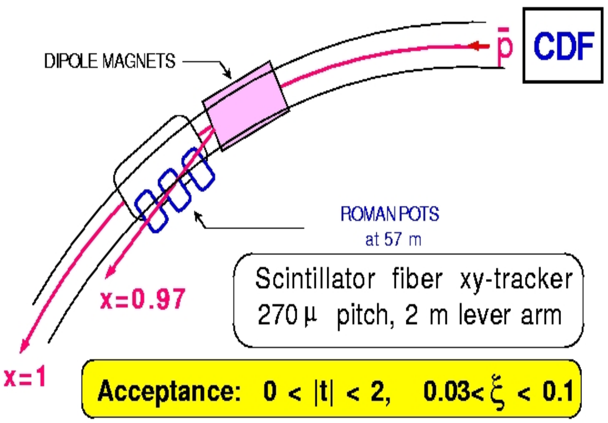
allows larger rapidity gaps to be measured - lower values of ξ_p

Beam Shower Counters (new)

tag forward rapidity gaps

$5.5 < |\eta| < 7.5$

scintillation counters around the beam pipe

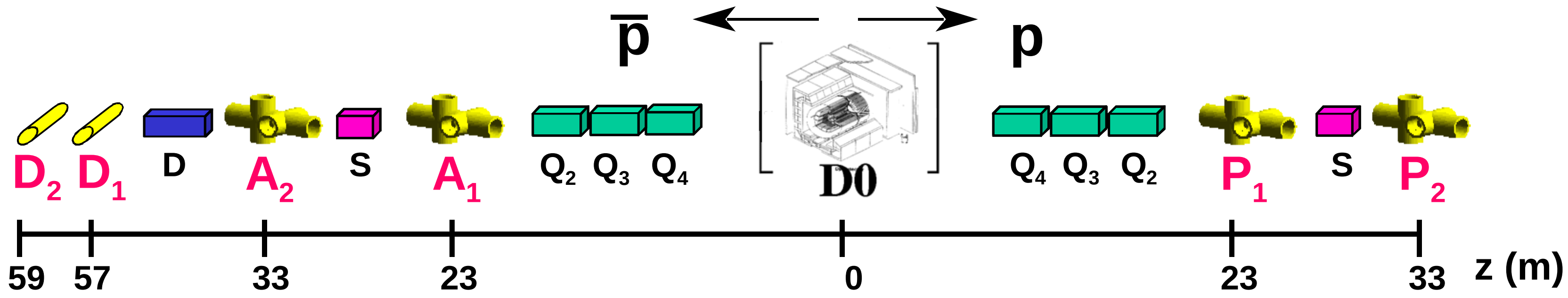


Roman Pot Fibre Tracker (new readout)

tags outgoing anti-proton

$0.02 < \xi < 0.1, 0 < |t| < 2.$

D0 at Run II



9 Momentum Spectrometers composed of 18 Roman Pots

Scintillating fiber detectors installed in Roman Pots can track the scattered protons and antiprotons

The reconstructed track is used to calculate the momentum and scattering angle of protons and antiprotons

Cover a t region ($0 < t < 4.5$ GeV^2) that was never explored before at Tevatron energies

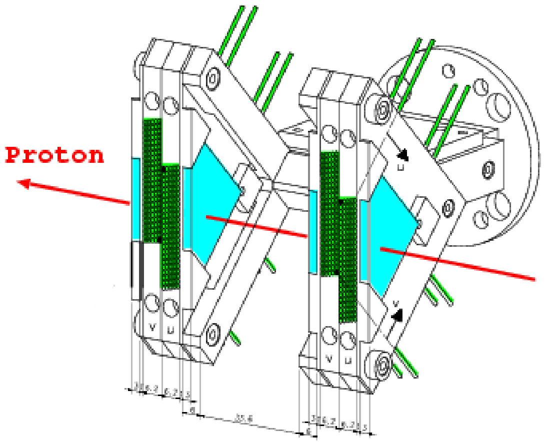
Allows combination of proton tracks with high p_T scattering in the central detector

$$0 < \xi < 0.08$$

PHYSICS PROGRAM

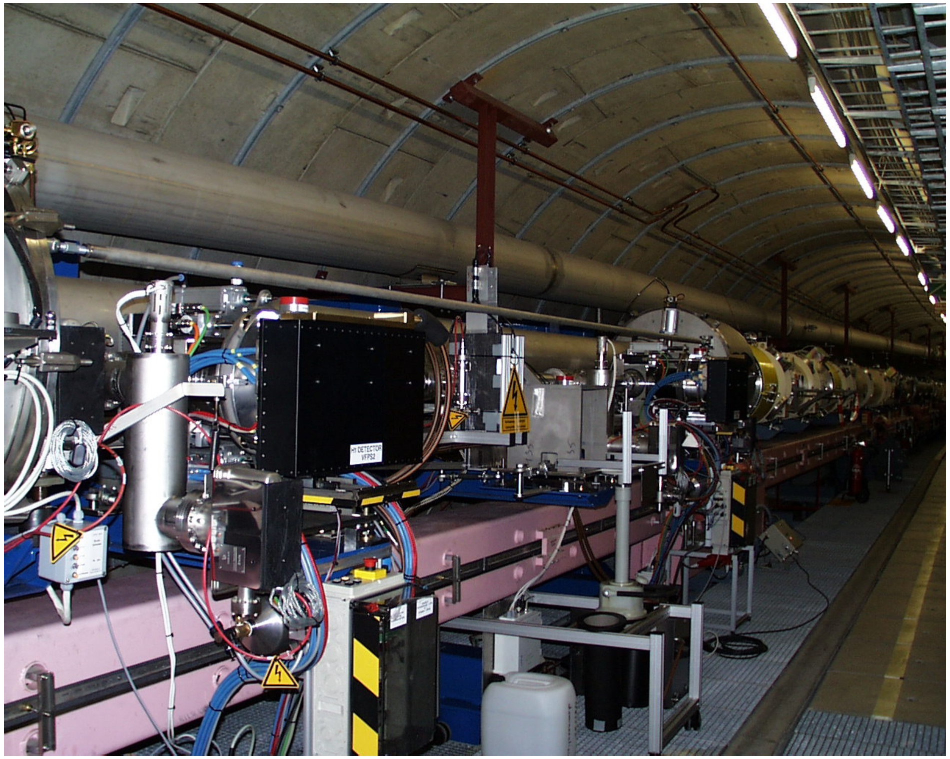
- Hard Double Pomeron reactions
- Diffractive jet production
- Diffractive heavy quark (c, b and t) production
- Diffractive W and Z production
- Glueball searches
- Elastic and Total proton-antiproton cross section
- Inclusive Single Diffraction
- Inclusive Double Pomeron reactions

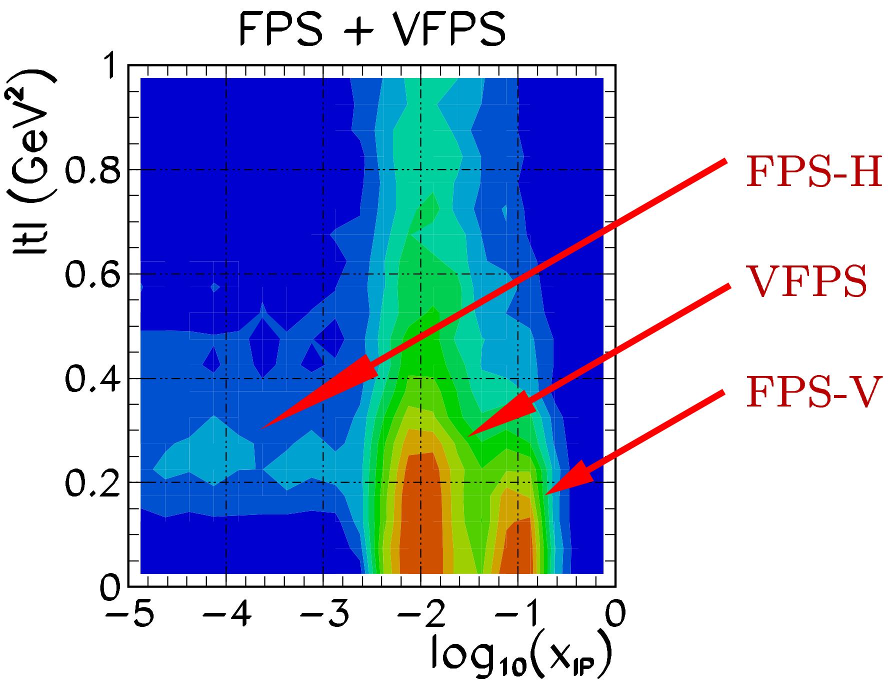
H1 at HERA II



- Scintillating fiber detector
- Free of proton dissociation bkgd
- proton 4-momentum measurement $\rightarrow$ t

$\longrightarrow$ commissioning January 2004





Conclusion

- We are reaching a QCD understanding of diffraction.
- the partonic structure of the exchanged object in diffraction has been measured.
- it is dominated by gluons.
- Diffractive Structure functions can be factorised in DIS regime (large Q^2) in $\gamma^* - p$ interactions
- rescattering corrections in $p - p$
- on the way to understand globally Inclusive and Diffractive scatterings.
- Sensitivity to gluon density and parton correlations (GPDs).
- Test of both DGLAP and BFKL dynamics.
- many results to come...