Diffraction at H1 and Zeus

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Moriond QCD

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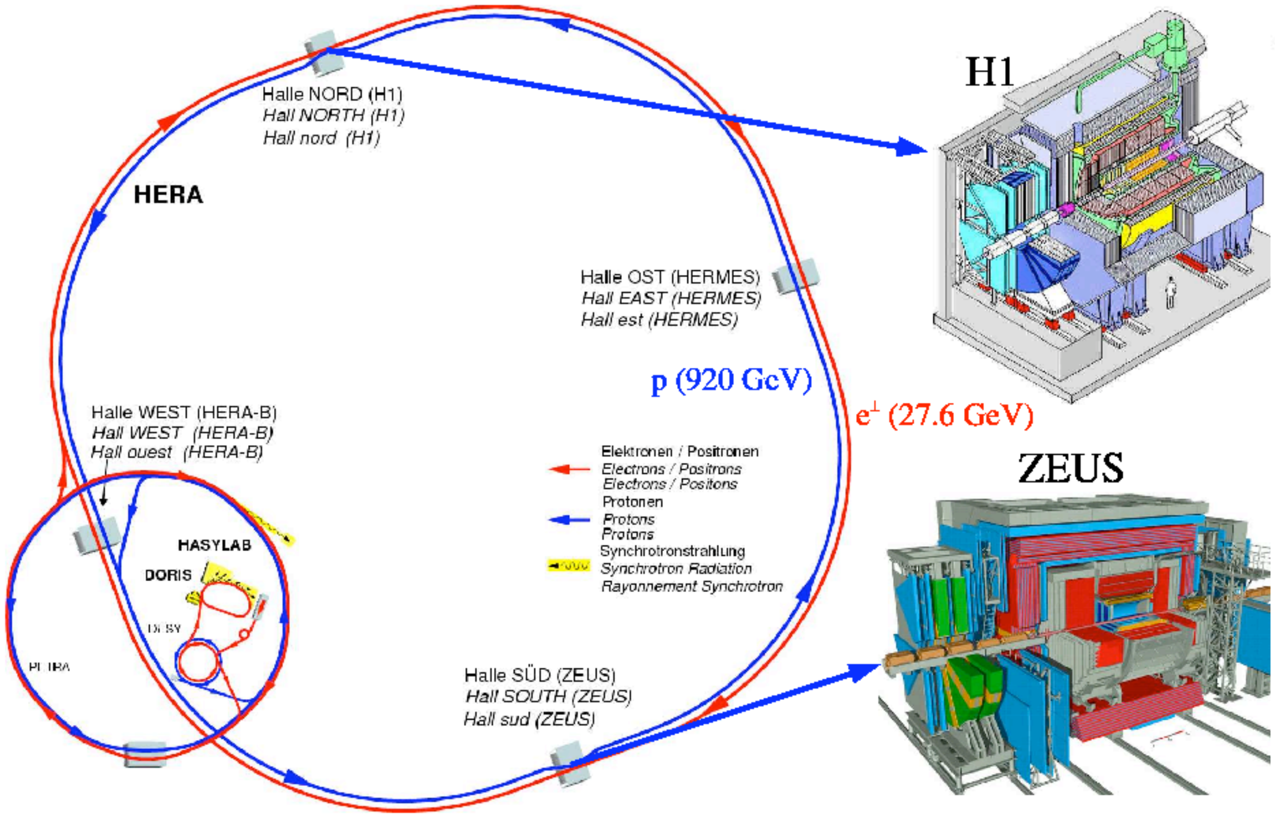
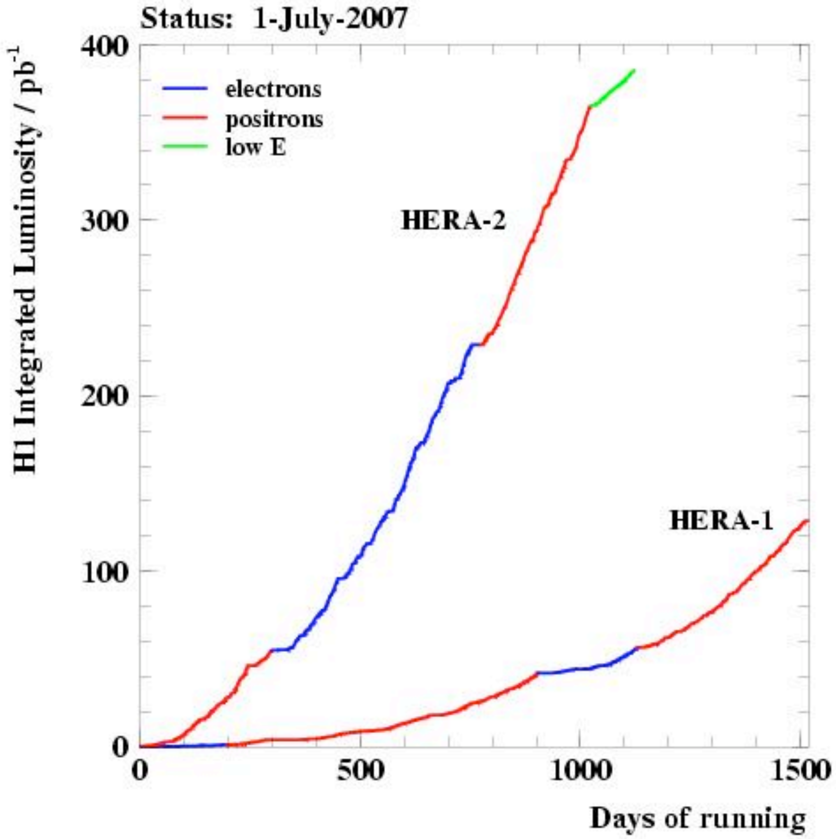
Overview

- Inclusive Diffraction at HERA
- QCD Fits and Diffractive PDFs
- Diffractive Dijets in DIS
- Diffractive Dijets in Photoproduction
- Exclusive Vector Meson Production and DVCS
- Summary

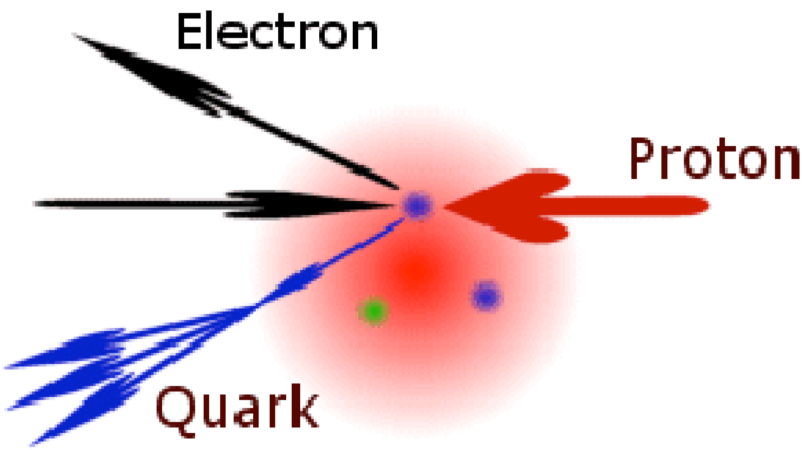
The HERA Harvest

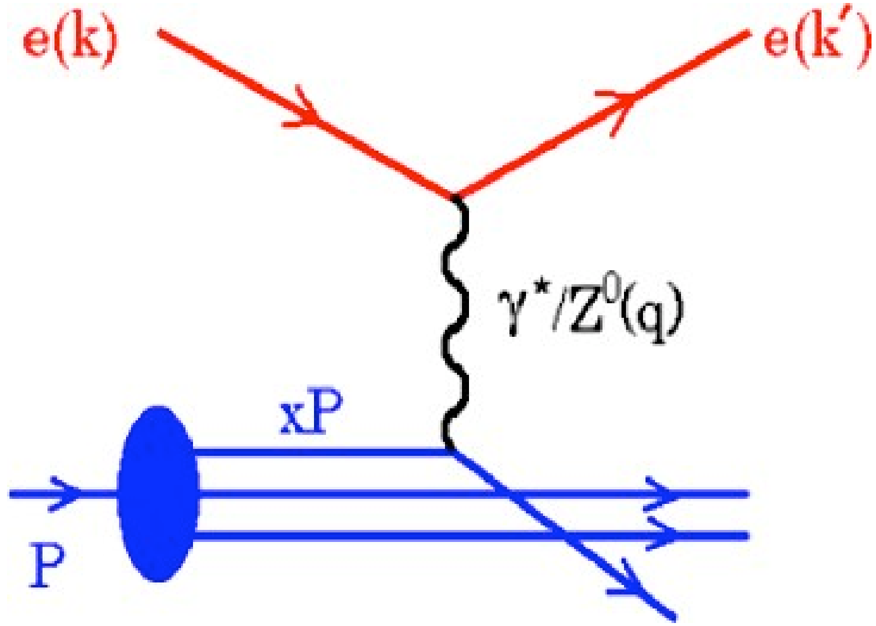




- The unique HERA machine collided 27.5 GeV electrons/positrons with protons of 460, 575, 820 and 920 GeV providing 0.5 fb^{-1} to H1 and Zeus
- Precision tests of QCD and a PDF machine in exactly the right range of parton fractional momentum for LHC experiments
- The final precision analyses of HERA data are underway ***now***

Deep-Inelastic Scattering at HERA



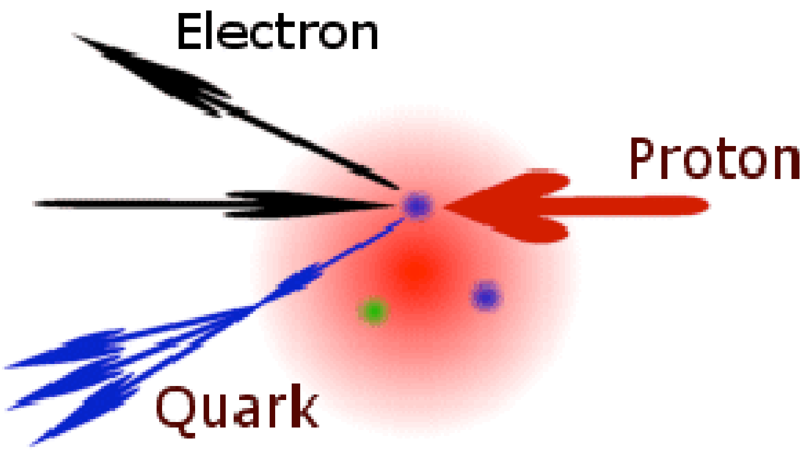


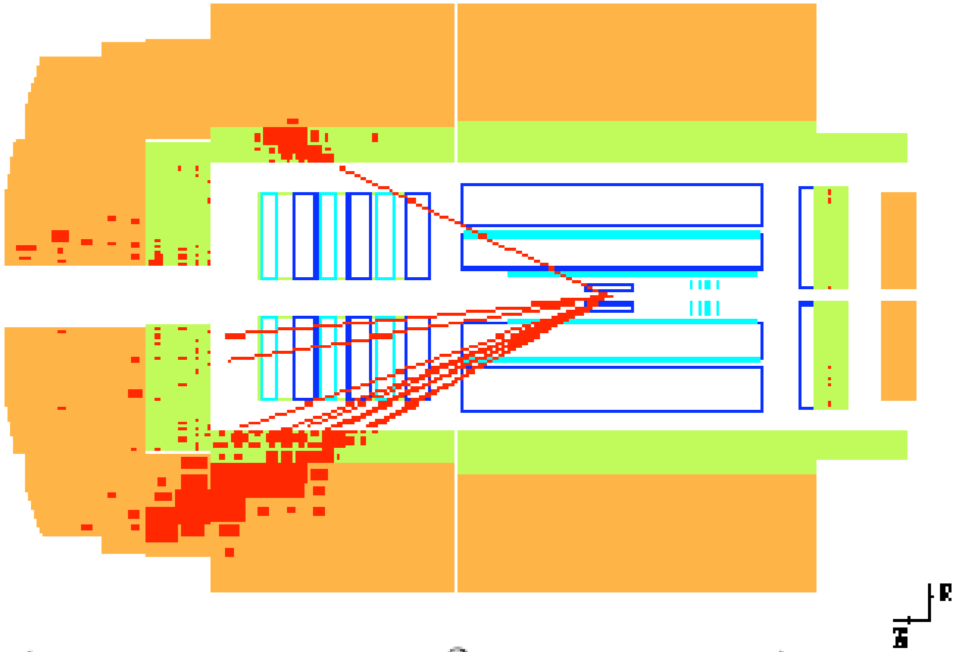
$Q^2 = -q^2 = -(k - k')^2$ *Virtuality / resolving power of the photon*

$x = \frac{Q^2}{2p \cdot q}$ *Momentum fraction of the struck quark*

$y = \frac{p \cdot q}{p \cdot k}$ *Inelasticity of the event*

Deep-Inelastic Scattering at HERA





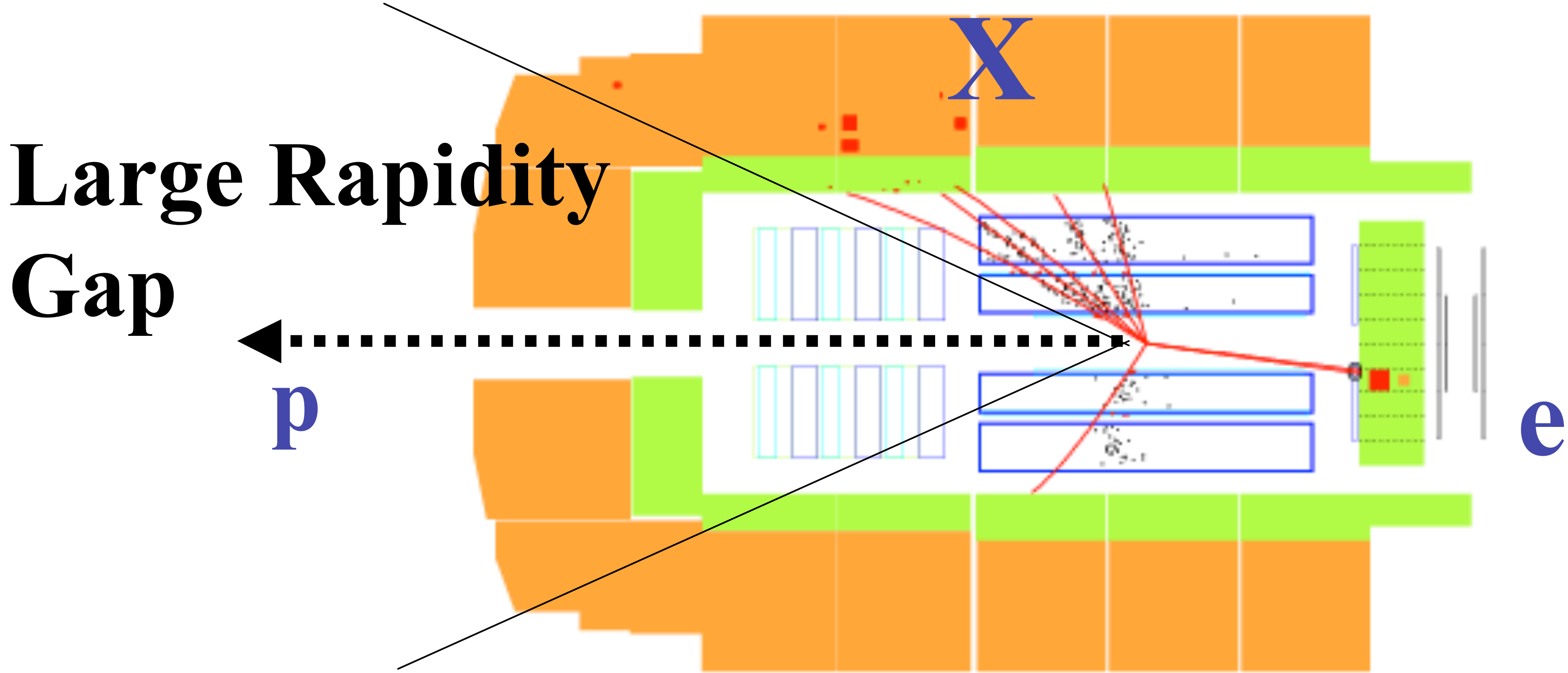
Measure:

$$\frac{d^2\sigma^{ep}_{NC}}{dx\,dQ^2} = \frac{2\pi\alpha^2 Y_+}{xQ^4}\left(F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2)\right)$$

Extract:

- F_2 directly related to (PDFs) quark content: $F_2 \sim x\Sigma e^2(q+q)$
- $dF_2/d\ln Q^2$ (scaling violations) sensitive to gluon content
- F_L only non-zero in higher order QCD – independent access to gluon density and QCD dynamics

Diffractive DIS: $ep \rightarrow eXp$



Unexpectedly (in 1990) we saw that in 10% of DIS events, there is a large gap where there are NO particles produced between the struck quark and the proton

Diffractive DIS was born - electron-Pomeron scattering

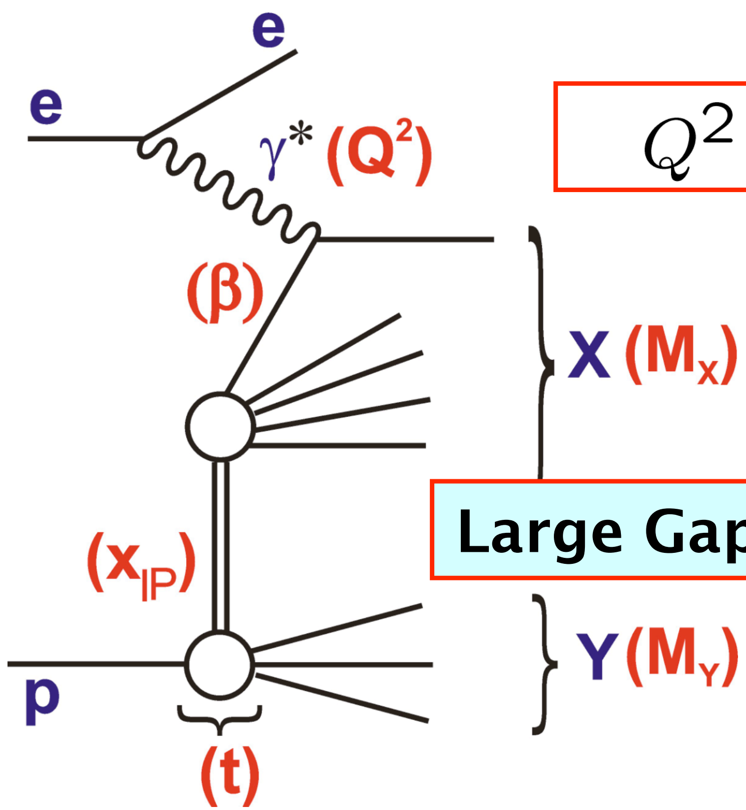
Diffractive DIS Kinematics and Observables

$$x = x_{I\!P}\beta$$

$$\beta = \frac{Q^2}{Q^2+M_X^2}$$

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

$$Y_+ = 1 + (1-y)^2$$



$$Q^2 = sxy$$

Large Gap in Rapidity

Cross section: $$\frac{d^4\sigma^{ep\to eXp}}{dx dQ^2 dx_{I\!P} dt} = \frac{4\pi\alpha^2}{xQ^4} Y_+ \, \sigma_r^{D(4)}(x, Q^2, x_{I\!P}, t)$$

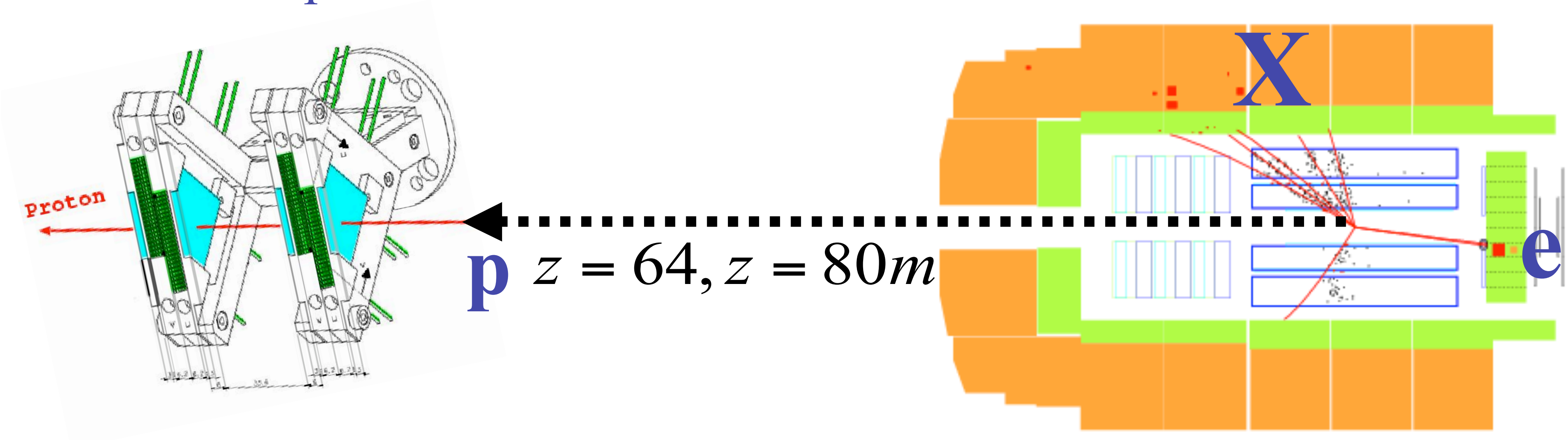
$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{Y_+} F_L^{D(4)}$$

$$\sigma_r^{D(3)} = \int_{-1}^{t_{min}} \sigma_r^{D(4)} dt$$

Experimentally selecting $ep \rightarrow eXp$

Forward/Leading Proton Spectrometer

Central H1 Detector



Measure Leading Proton (FPS/LPS)

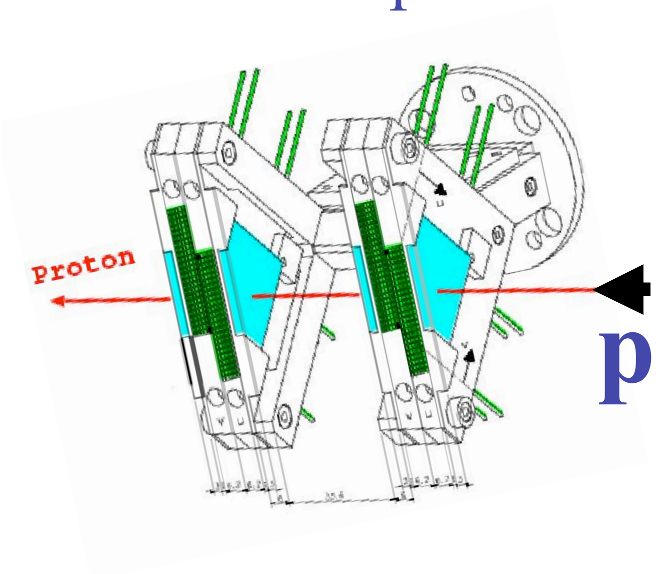
No proton dissociation (pdiss)

Measure the t dependence

Low detector acceptance

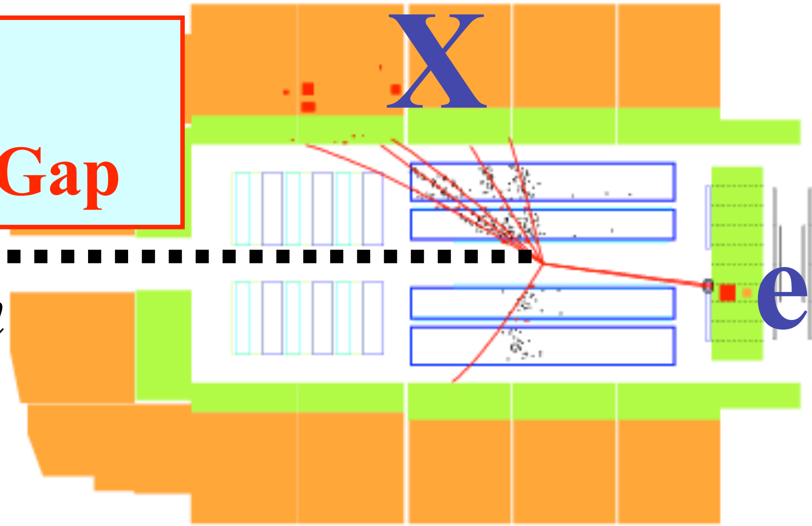
Experimentally selecting $ep \rightarrow eXp$

I Forward/Leading Proton Spectrometer



Central H1 Detector

***II* Large Rapidity Gap**



p $z = 64, z = 80m$

Measure Leading Proton (FPS/LPS)

No proton dissociation (pdiss)

Measure the t dependence

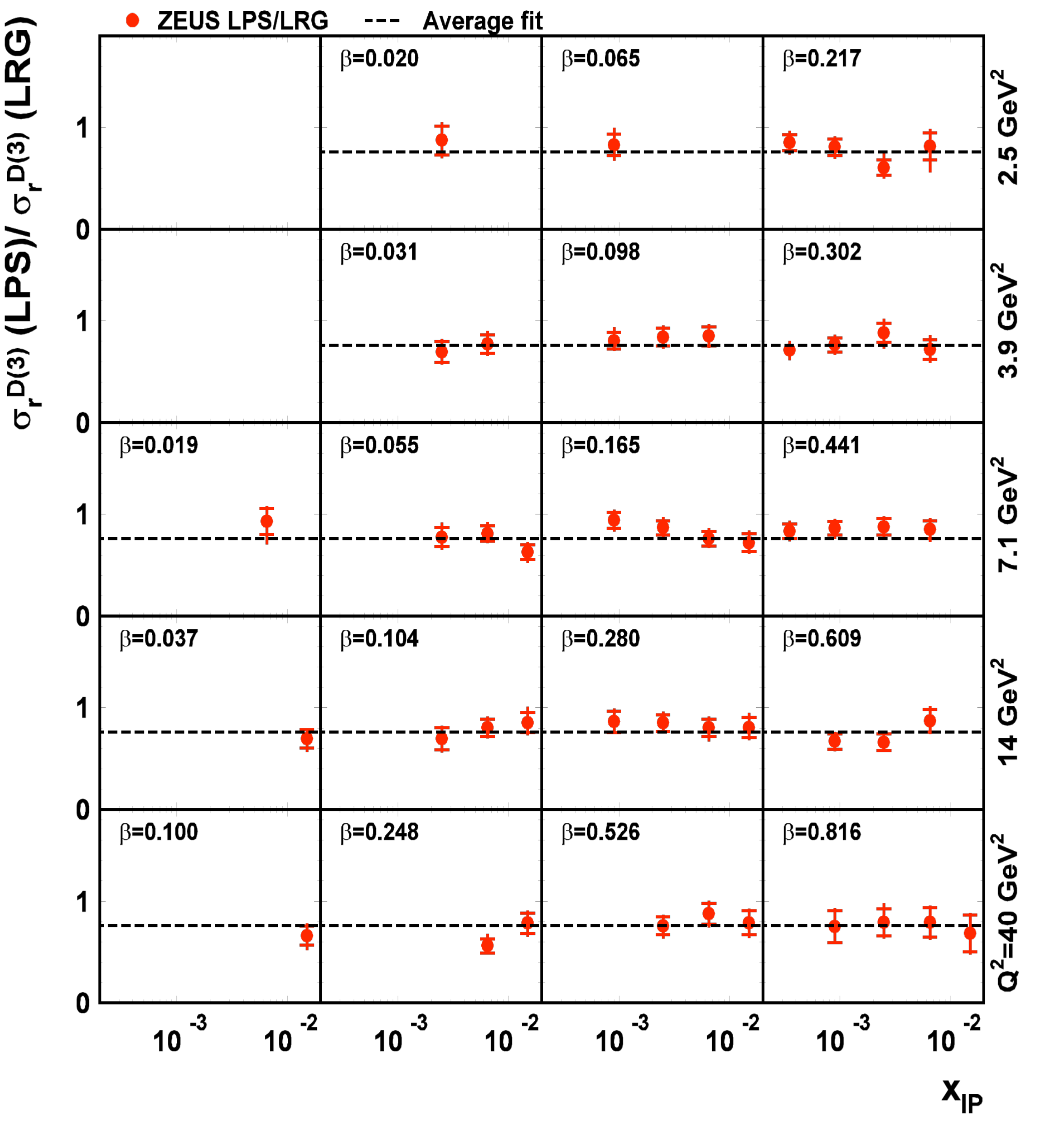
Low detector acceptance

Require Large Rapidity Gap (LRG) spanning at least $3.3 < \eta < \sim 7.5$

Kinematics measured from X system, integrate $|t| < 1.0$ GeV^2, $M_Y < 1.6$ GeV

High detector acceptance → precision

Ratio of Leading Proton / Large Rapidity Gap



The LRG data contains a sizeable proton dissociation background (esimated to be 24% at ZEUS,H1)

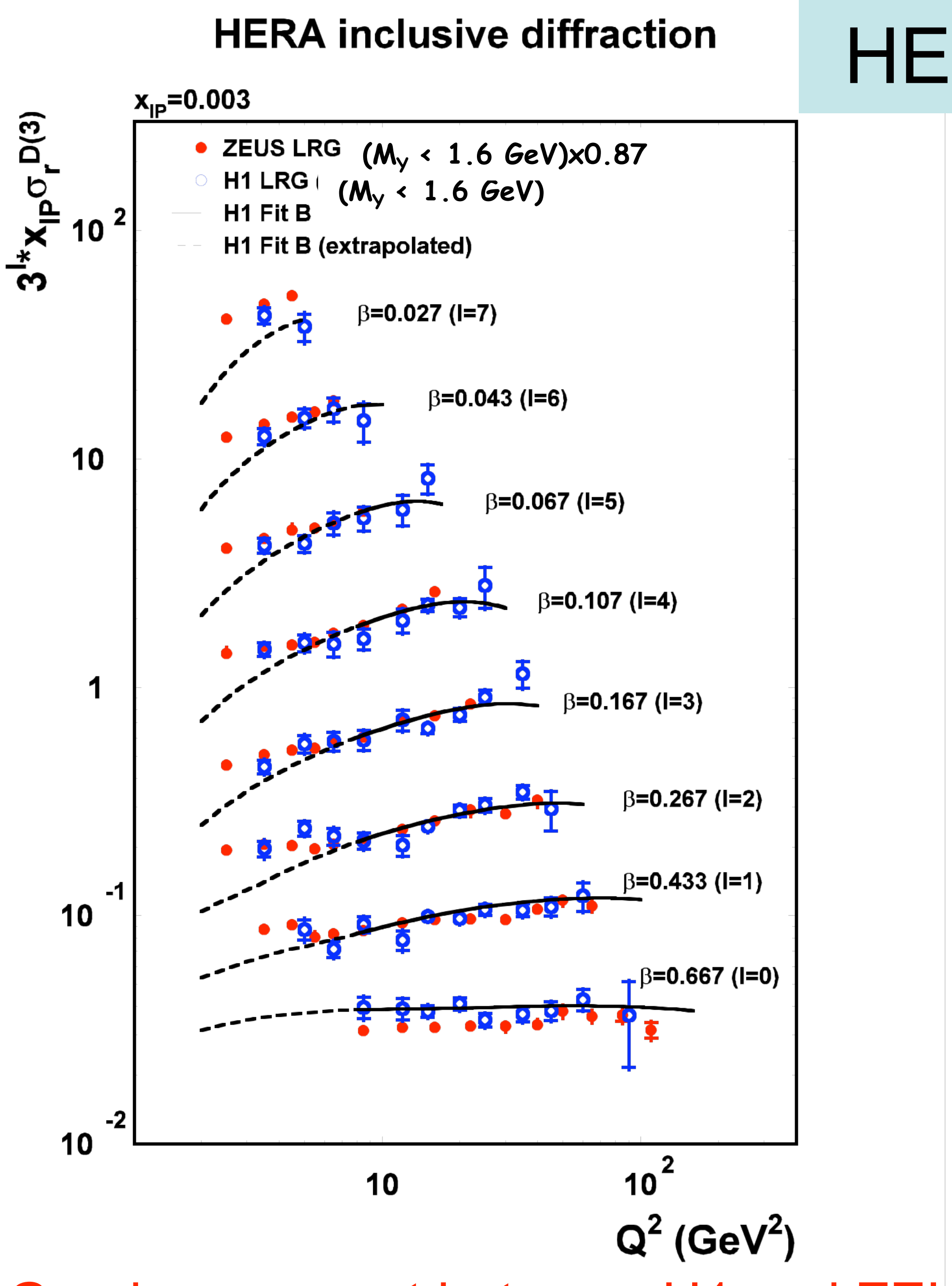
The ratio of leading proton /LRG cross sections is *independent* of Q^2, x_{IP}, β

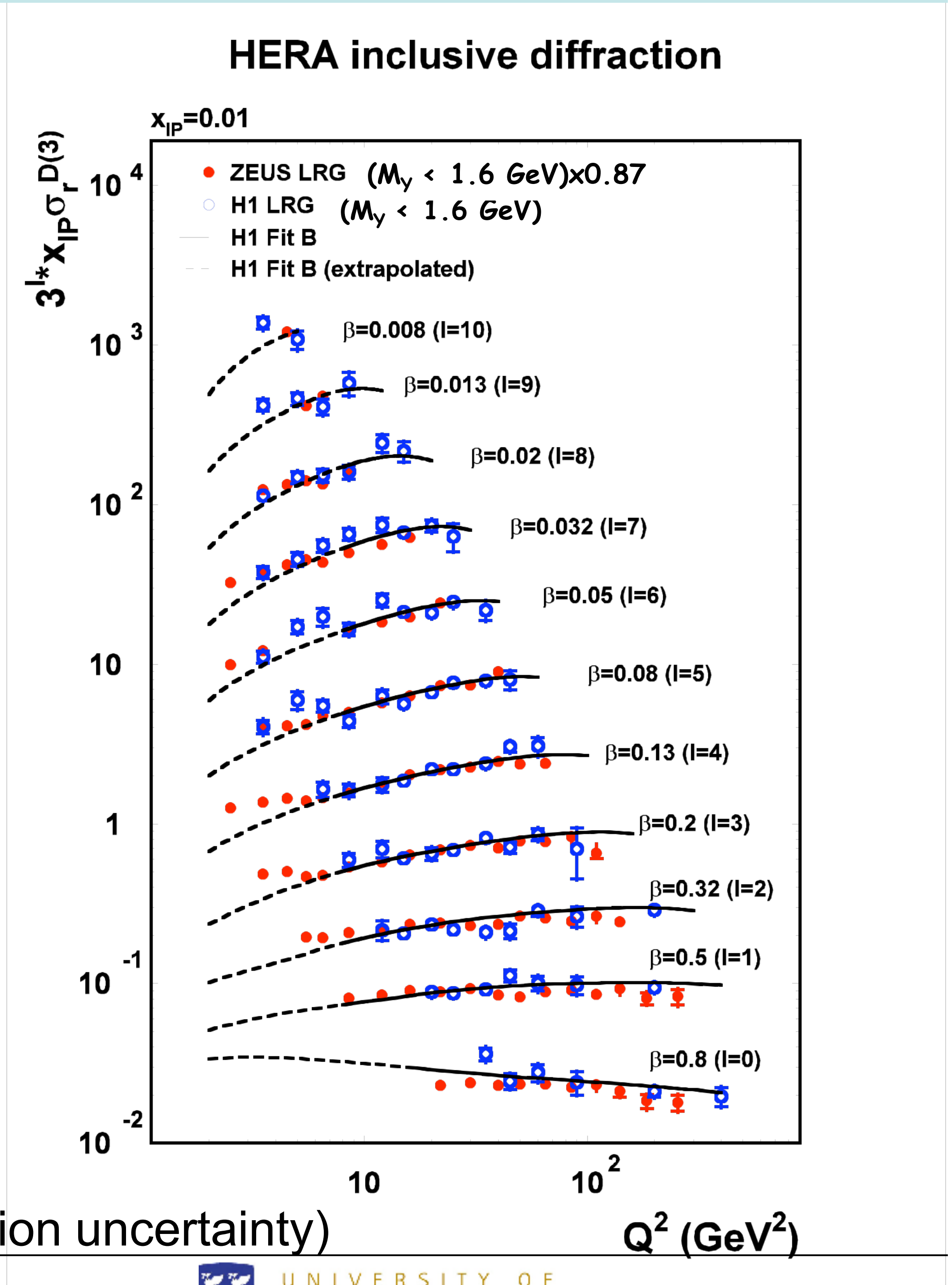
LRG equivalent to Leading Proton up to a normalisation correction to account for pdiss

ZEUS LPS / ZEUS LRG = 0.76 +-0.01(stat) +0.03-0.02(sys) +0.08-0.05 (norm)

→ pdiss background in LRG data: [24 +-1(stat) +2-3(sys) +5-8(norm)]%

HERA Large Rapidity Gap Data

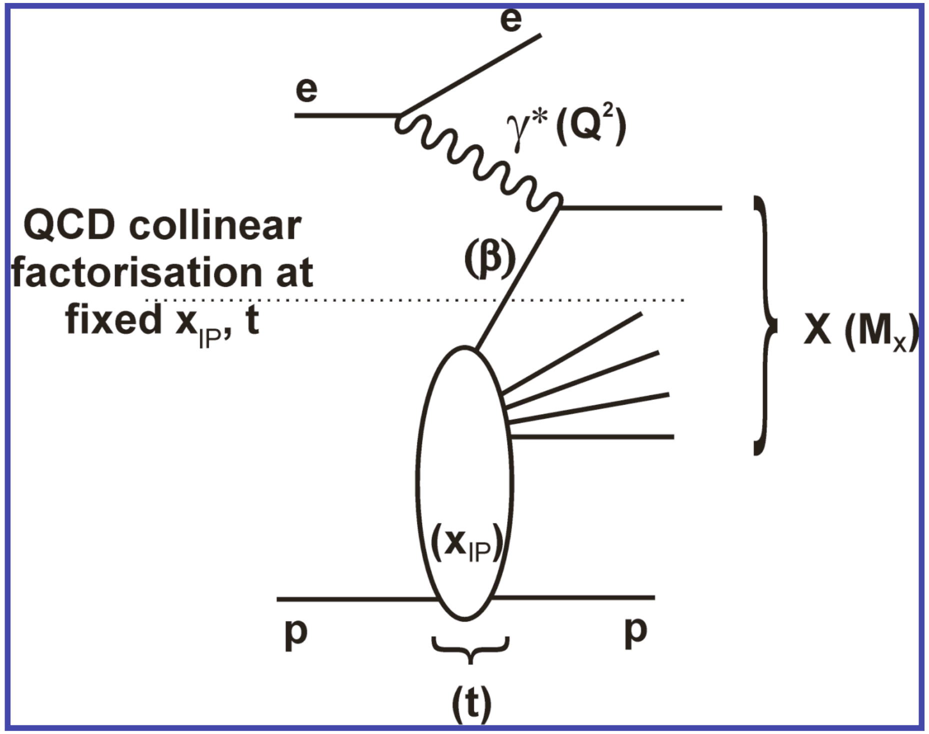




Good agreement between H1 and ZEUS

(ZEUS scaled by 0.87, covered by normalisation uncertainty)

Factorisation in Diffractive DIS

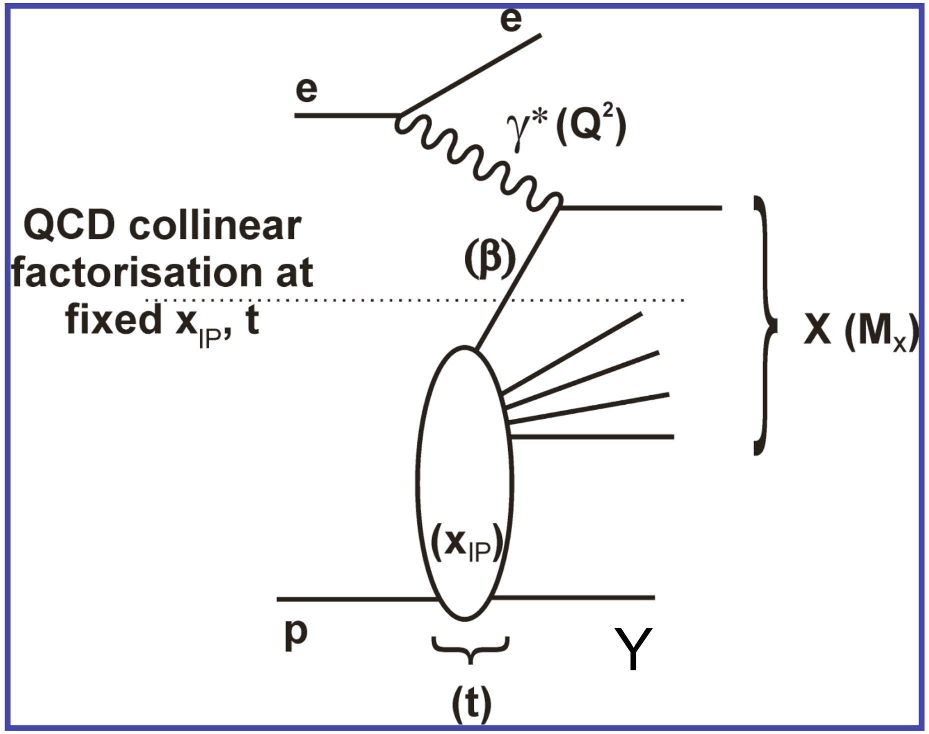


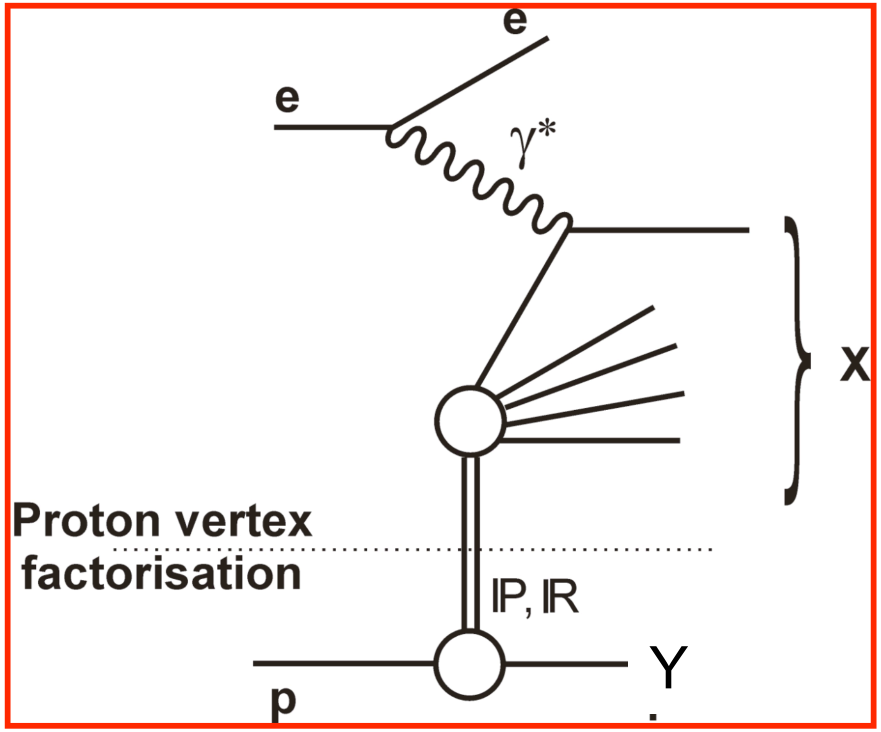
QCD hard scattering collinear factorisation (Collins) at fixed x_{IP} and t

$$d\sigma_{parton\,i}(ep \to eXY) = f_i^D(x, Q^2, x_{I\!P}, t) \otimes d\sigma^{ei}(x, Q^2)$$

Applied after integration over measured M_Y and t ranges

Factorisation in Diffractive DIS





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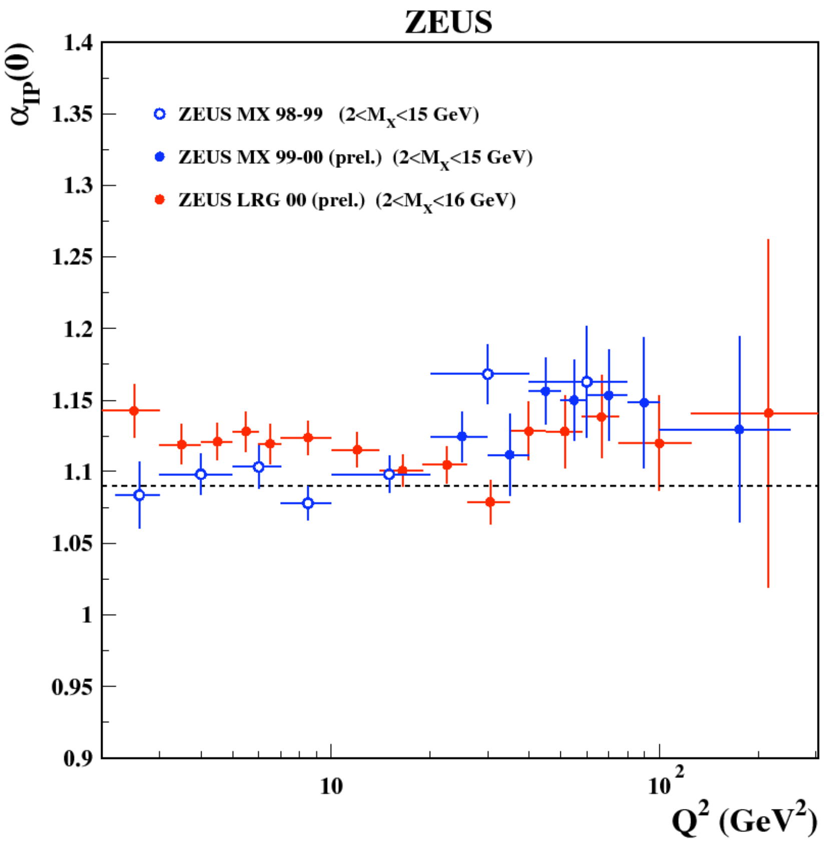
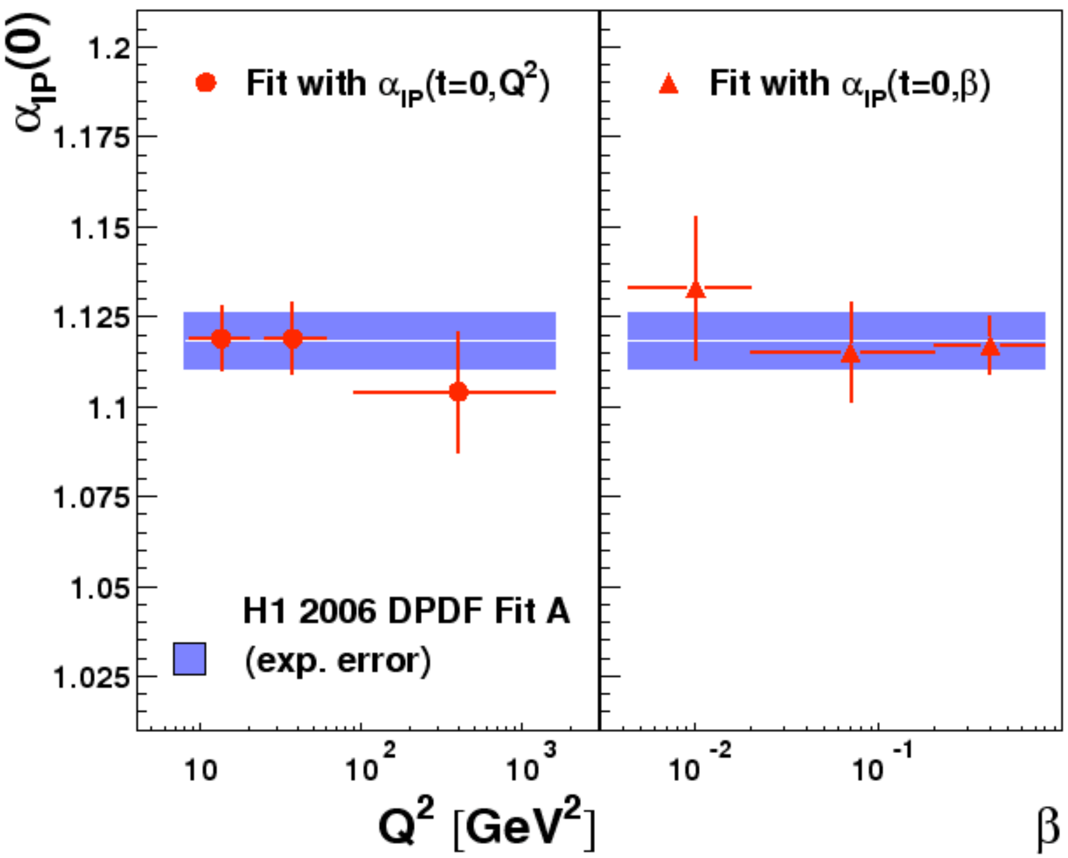
Applied after integration over measured M_Y and t ranges

\`Proton vertex' factorisation of β and Q^2 from x_{IP}, t, and M_Y dependences

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

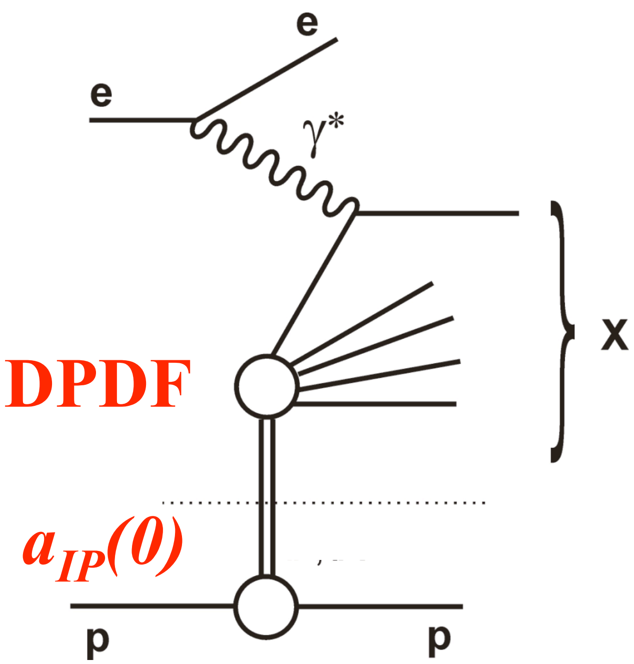
Proton Vertex Factorisation Tests





- Measure the x_{IP} dependence of the data as a function of β and Q^2
- The proton vertex factorisation approximation holds within the experimental precision
- This allows an NLO QCD analysis of the β and Q^2 dependences

NLO QCD Fit Example - H1 2006 DPDF Fit

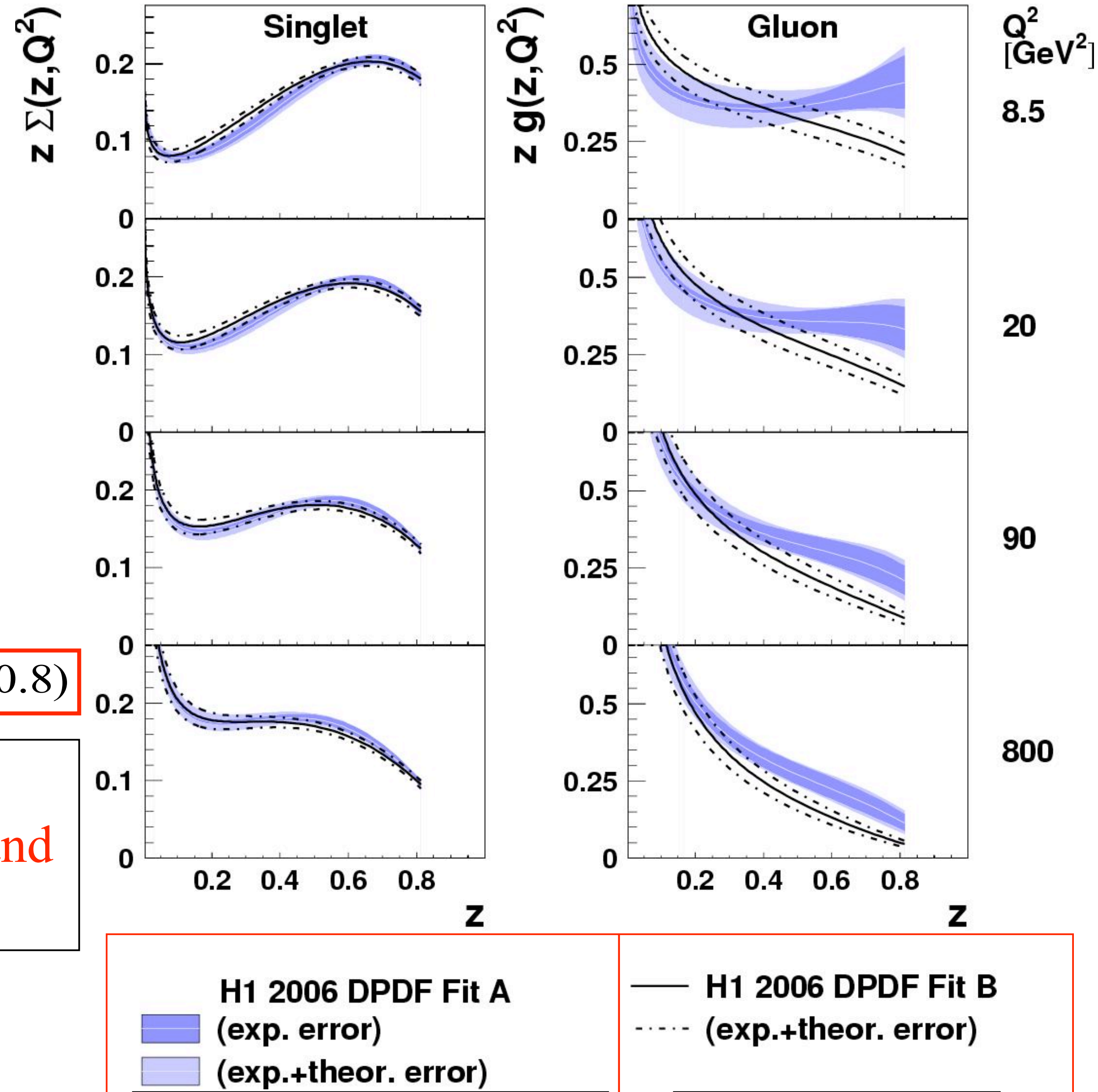


$Q^2 \geq 8.5\ \text{GeV}^2$ (and $M_X > 2$ GeV, $\beta \leq 0.8$)

- Fit $\alpha_{IP}(0)$ (x_{IP} dependence).
- Fit 5(4) parameters of DPDFs (β and Q^2 dependences) using NLO QCD

Singlet: $z\Sigma(z, Q_0^2) = A_q z^{B_q}(1-z)^{C_q}$

Gluon: 2 solutions, Fit A and Fit B:

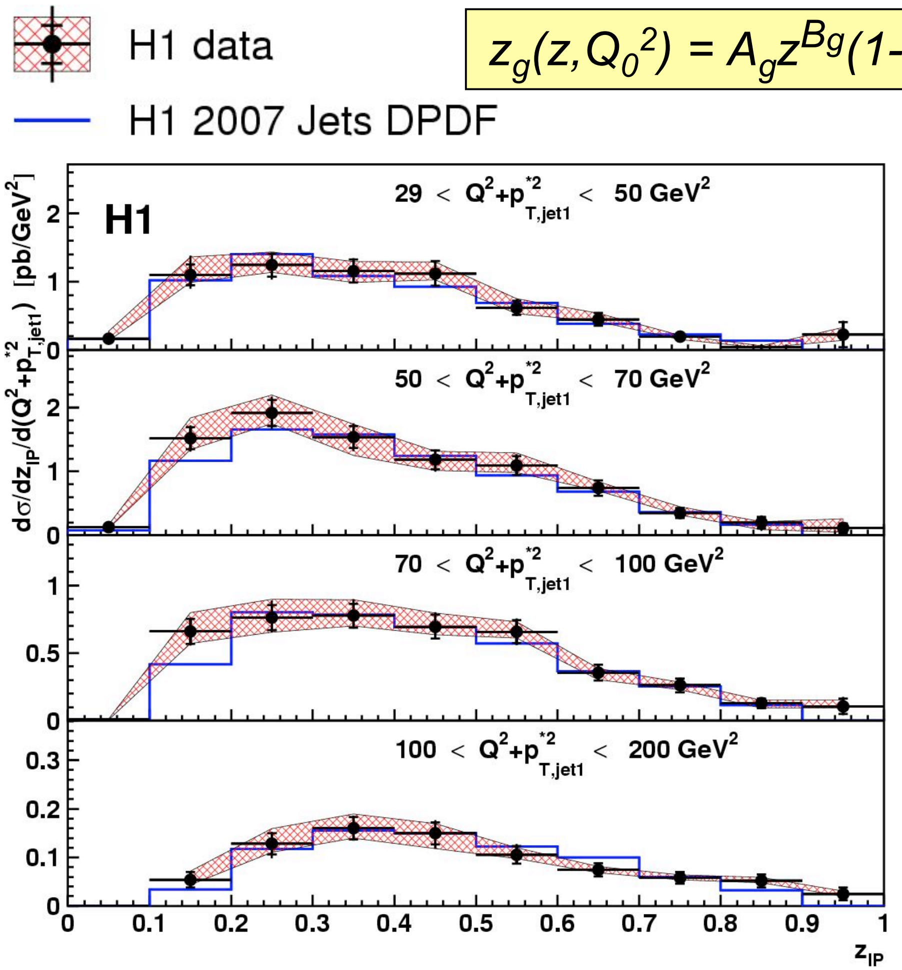


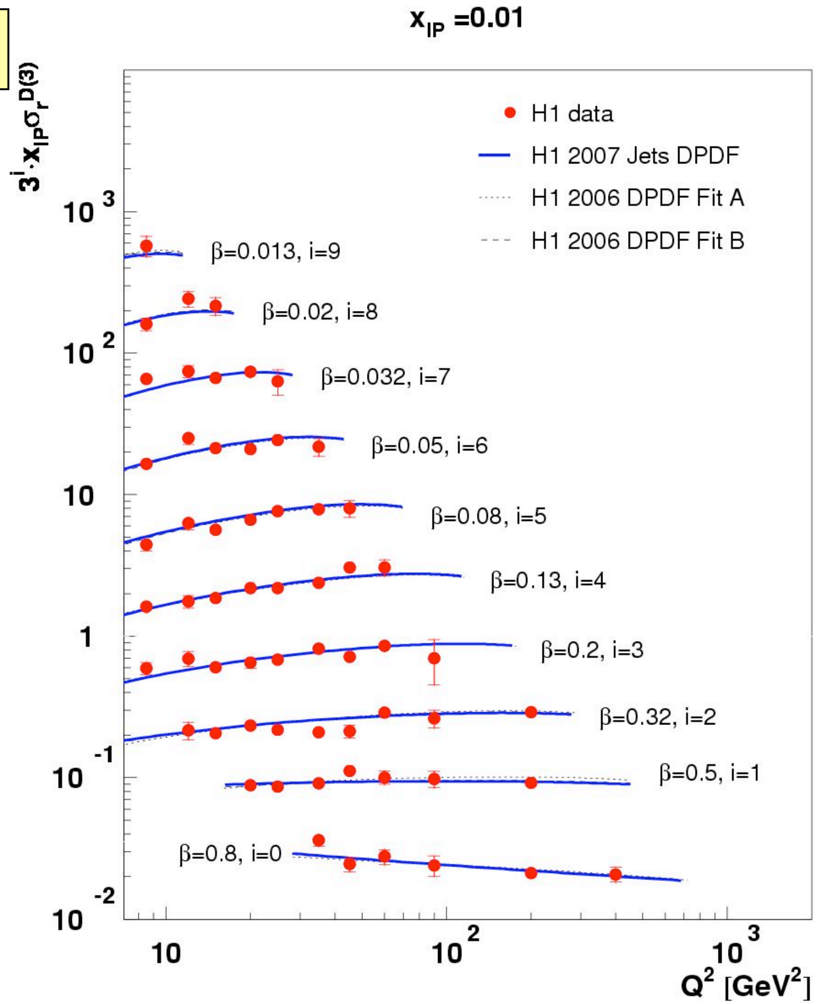
Fit A: $z_g(z, Q_0^2) = A_g(1-z)^{C_g}$

Fit B: $z_g(z, Q_0^2) = A_g$

Combined fit of dijet and inclusive data

$z_g(z,Q_0^2) = A_g z^{B_g}(1-z)^{C_g}$





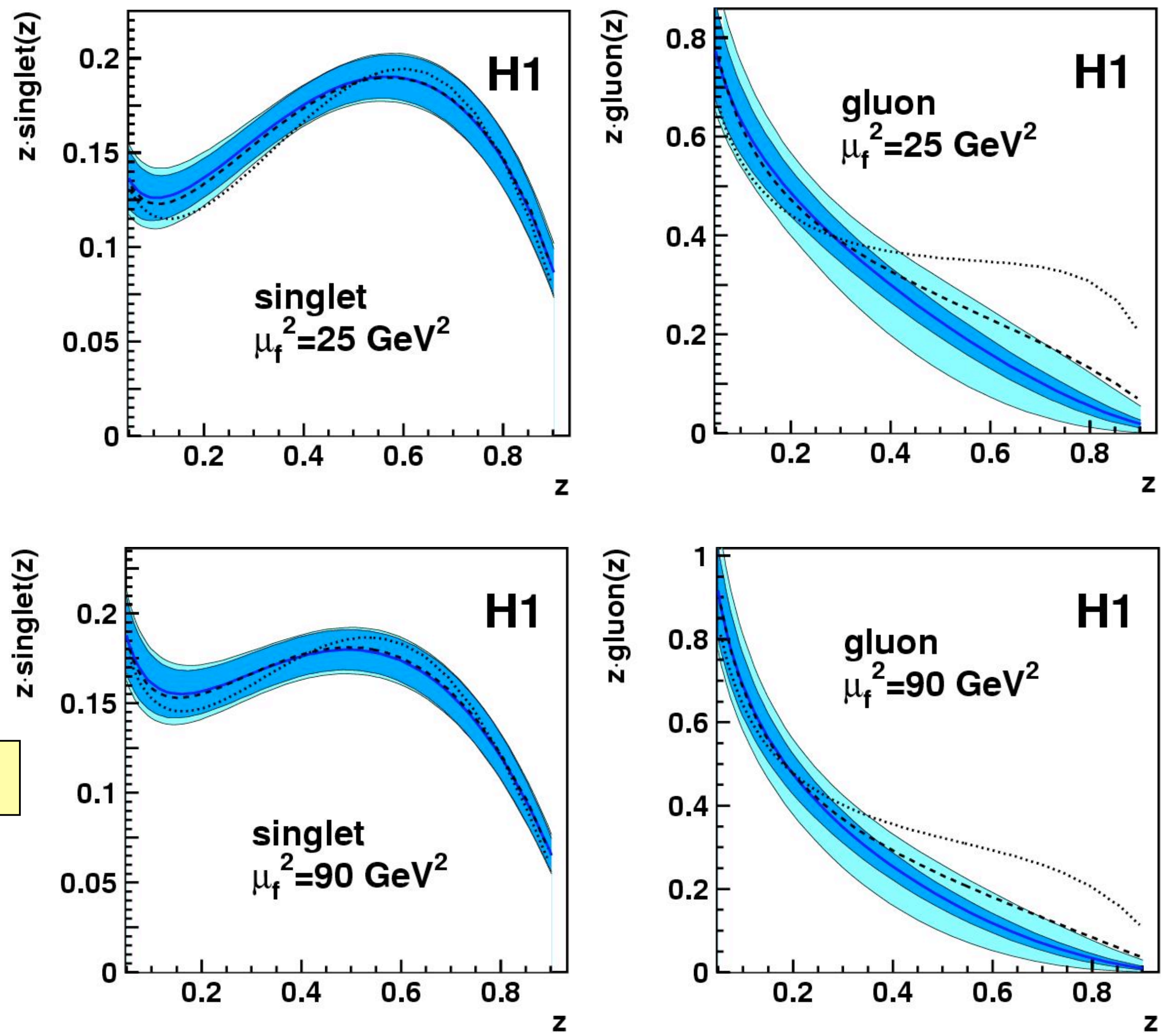
- The diffractive dijet data can be used as an additional constraint in a NLO QCD fit procedure
- Details similar to the inclusive case but can now constrain 3 parameters for the gluon

Very good simultaneous fit of both inclusive and dijet data achieved

Combined fit DPDFs from H1

https://www-h1.desy.de/h1/www/publications/htmlsplit/DESY-07-115.long.html

H1 2007 Jets DPDF
exp. uncertainty
exp. + theo. uncertainty
H1 2006 DPDF fit A
H1 2006 DPDF fit B



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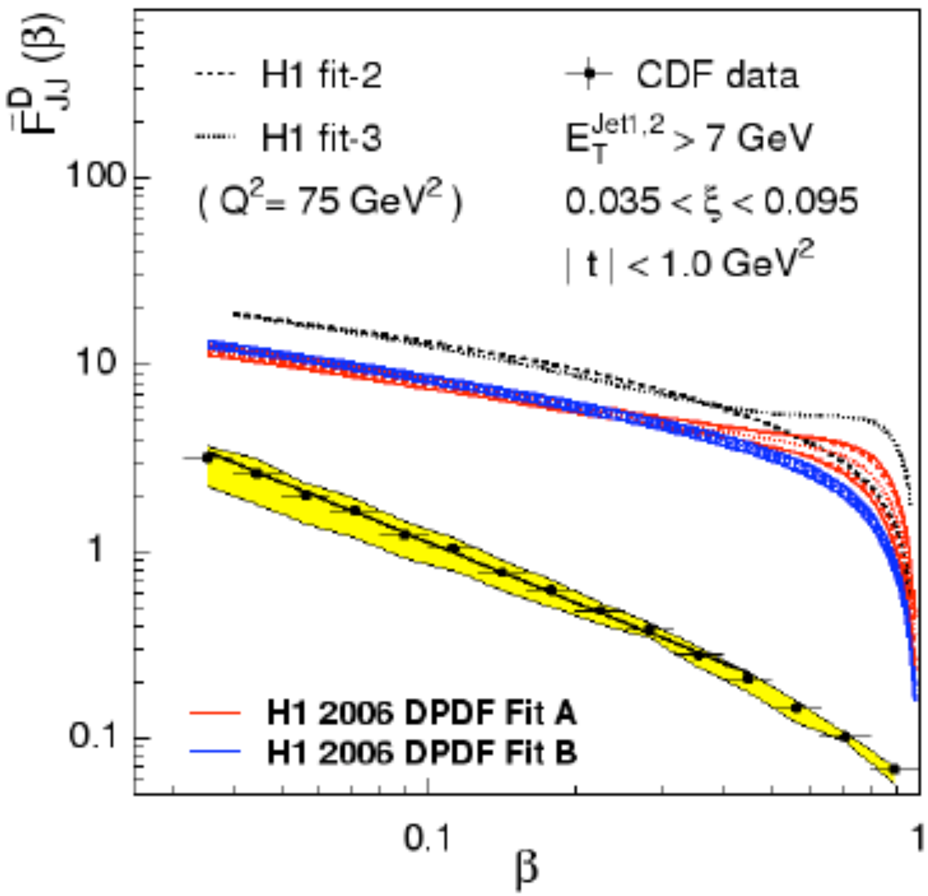
Gluon Fit A: $z_g(z,Q_0^2) = A_g(1-z)^{C_g}$

Fit B: $z_g(z,Q_0^2) = A_g$

Jets: $z_g(z,Q_0^2) = A_g z^{B_g}(1-z)^{C_g}$

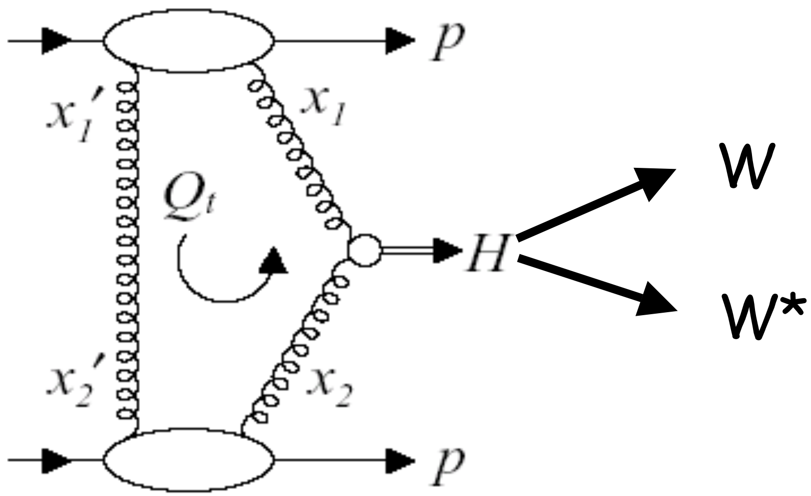
The singlet and gluon are constrained with similar precision across the whole kinematic range

Exporting DPDFs to Hadron-Hadron machines



When trying to use DPDFs extracted at HERA to predict diffractive dijets at CDF…

… it simply doesn't work!

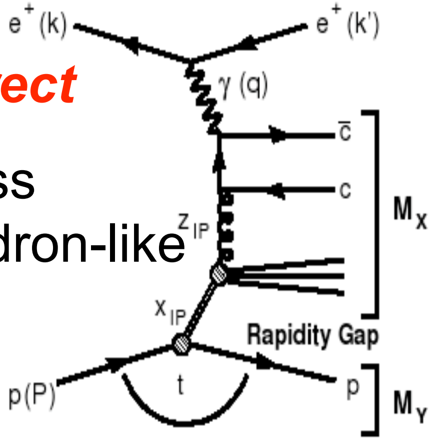


If we want to understand Diffractive Higgs production at the LHC then we need to understand why that is

Factorisation tests at HERA

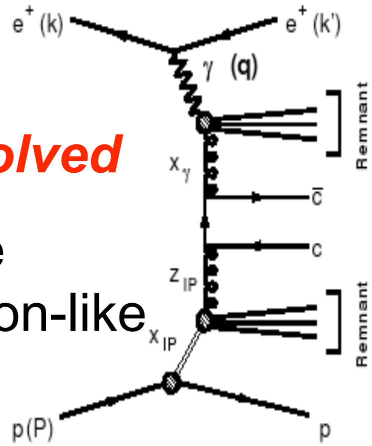
Direct

Less hadron-like



Resolved

More hadron-like



Use photoproduction at HERA as a hadron-hadron collider

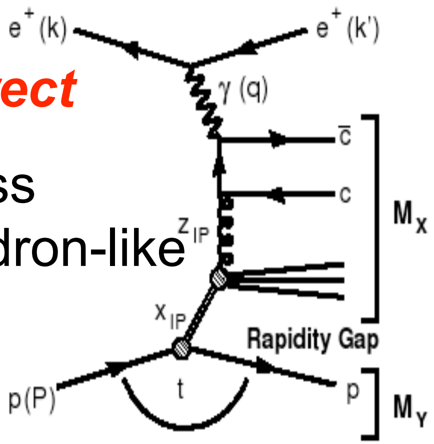
How hadron-like the photon is depends on the x_γ variable

Expect *Resolved* (low x_γ)to be more suppressed than *Direct* (high x_γ)

Factorisation tests at HERA

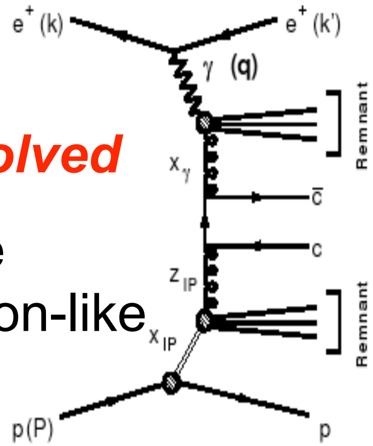
Direct

Less hadron-like



Resolved

More hadron-like



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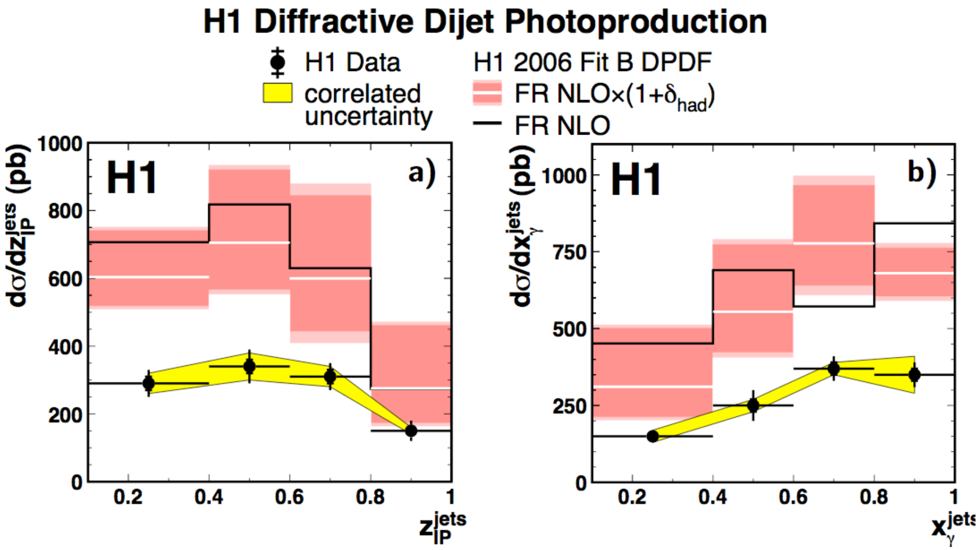
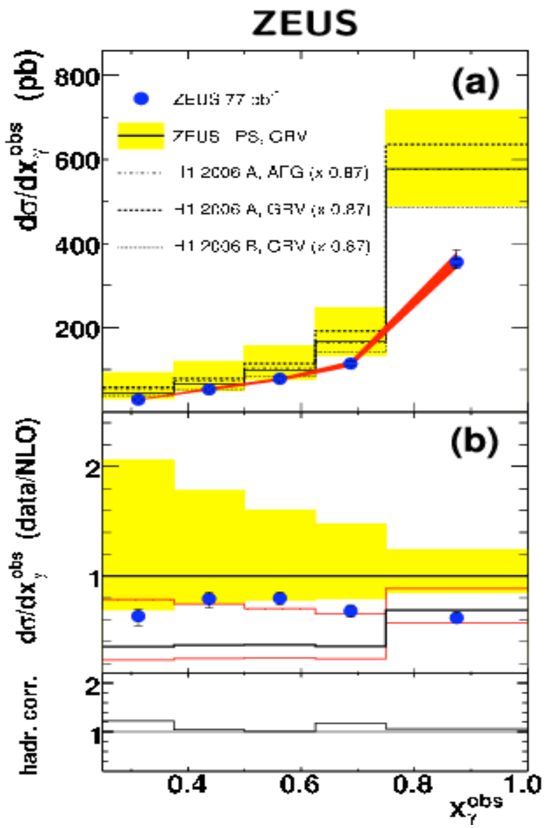


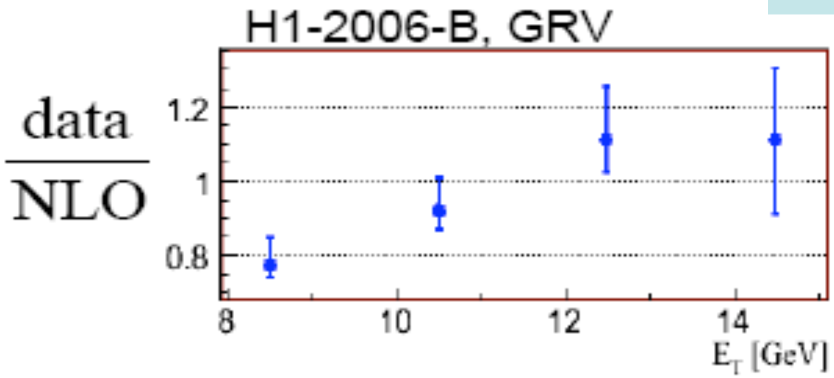


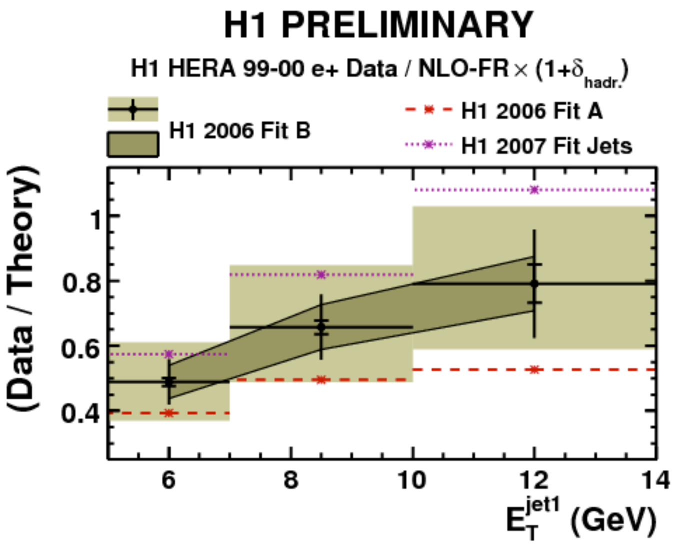
H1 saw that the cross section was suppressed in photoproduction, but independent of x_γ

ZEUS saw consistency with no suppression but did confirm the absence of dependence of x_γ

E_T dependence of the suppression

ZEUS - W.Slomińsk

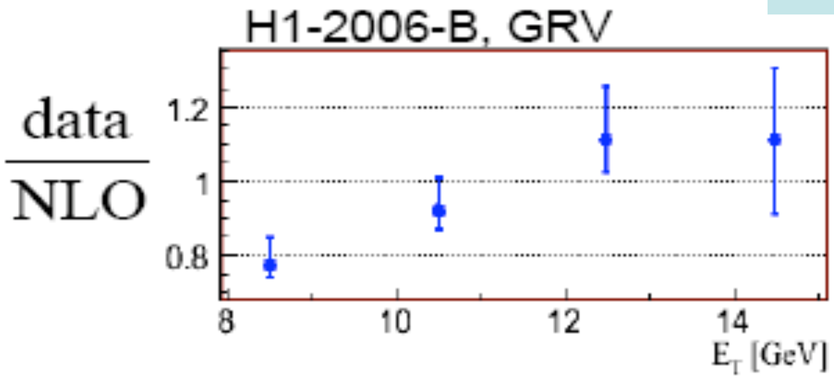




The H1 and ZEUS dijets in photoproduction analyses have different analysis cuts on jet E_T with ZEUS being at higher E_T than H1

Looking at the Data/Theory ratio as a function of jet E_T suggests that there is an *E_T dependence of the suppression*

E_T dependence of the suppression



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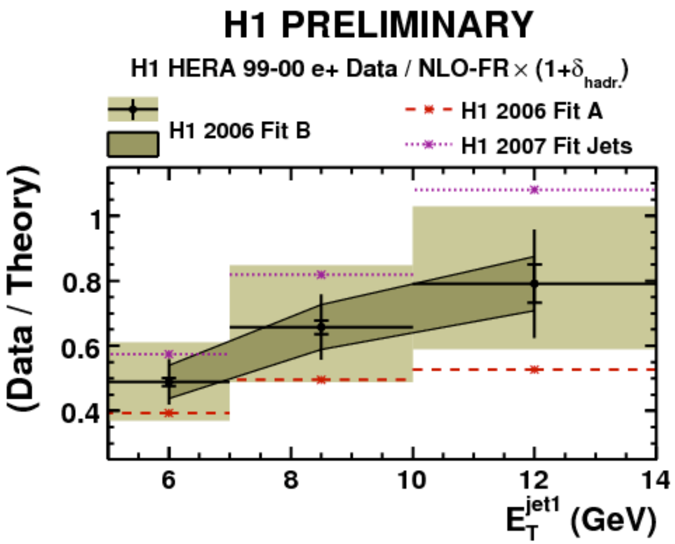
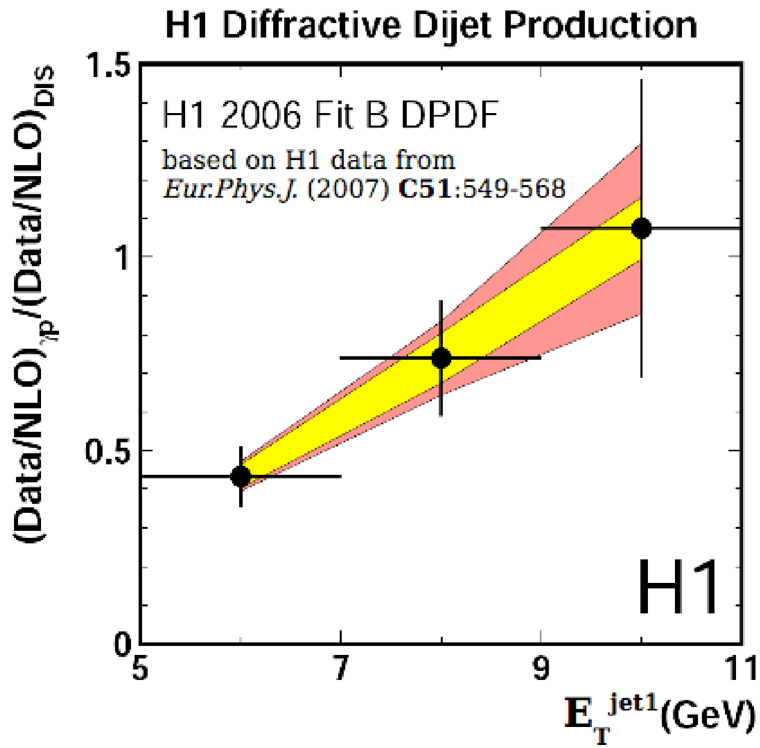
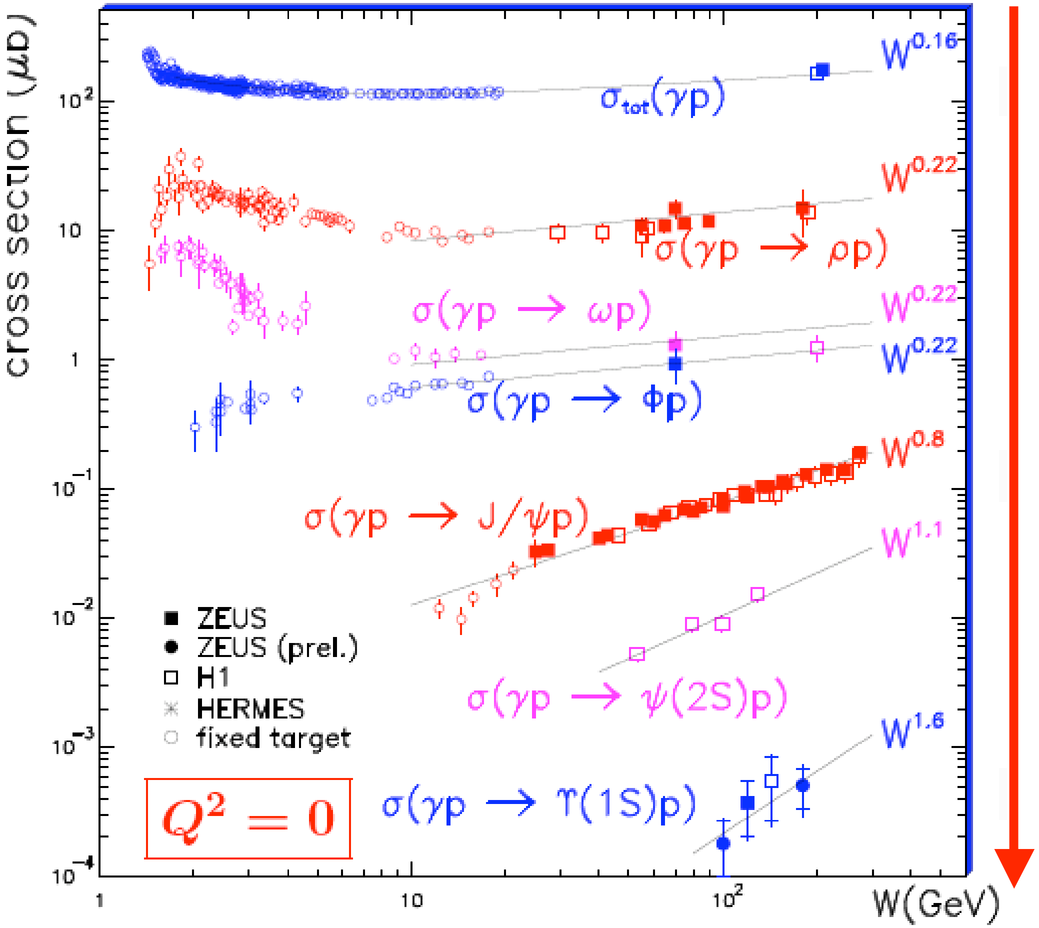
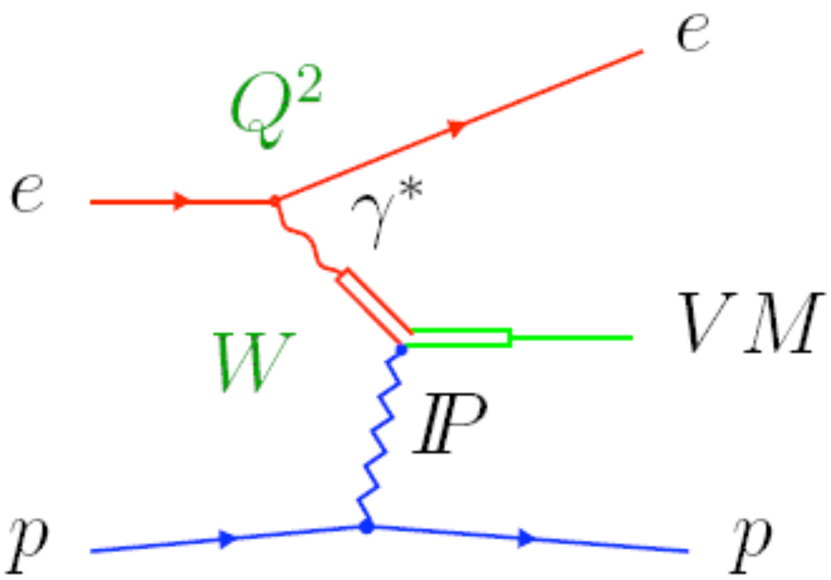




The suggestion of an E_T dependence is even stronger when looking at the double ratio of Data/Theory γp / DIS where some systematic uncertainties cancel

Exclusive Diffraction: *ep → ep VM*

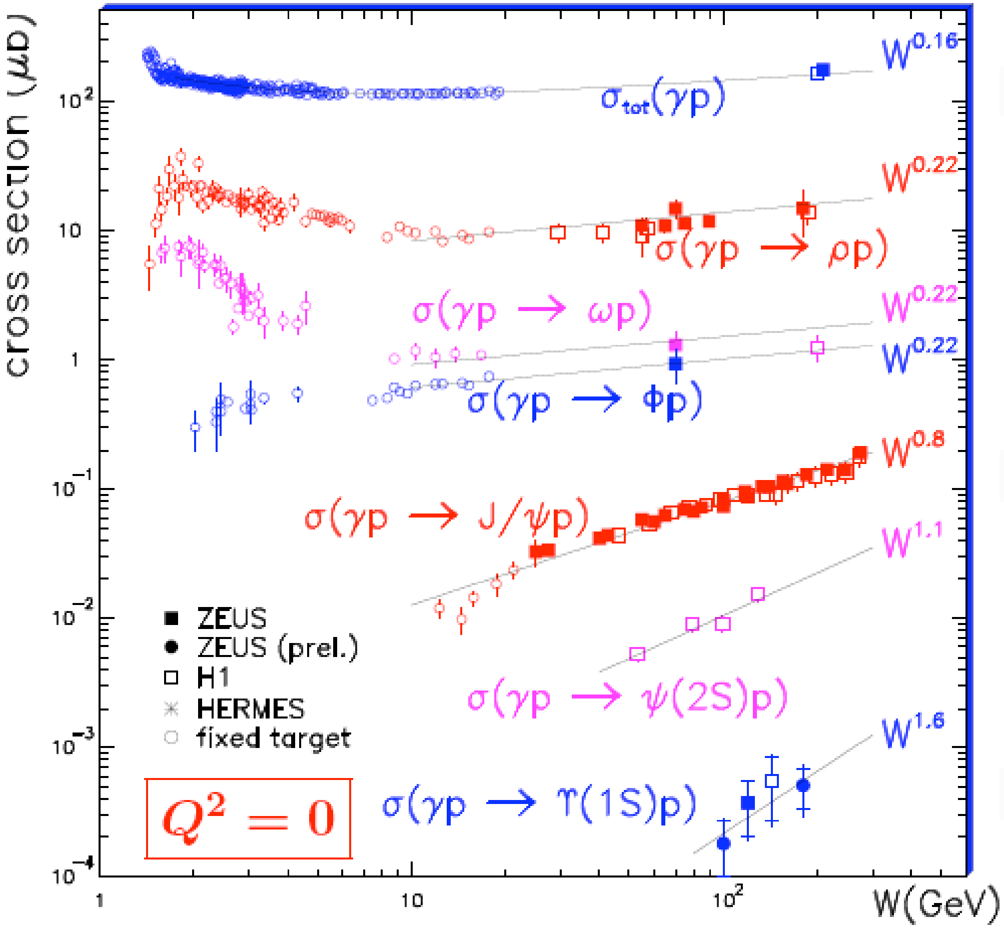


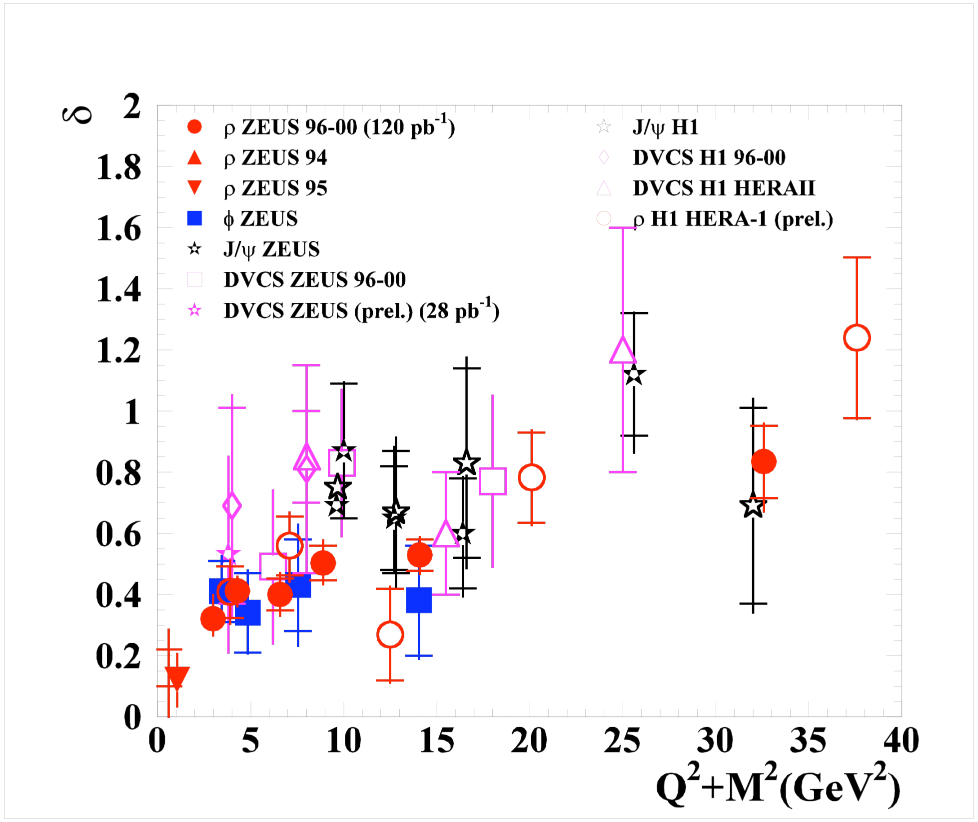


$\sigma \sim W^{\delta}$

As the VM mass increases, the process gets harder

Exclusive Diffraction: *ep → ep VM*





As the VM mass increases, the process gets harder

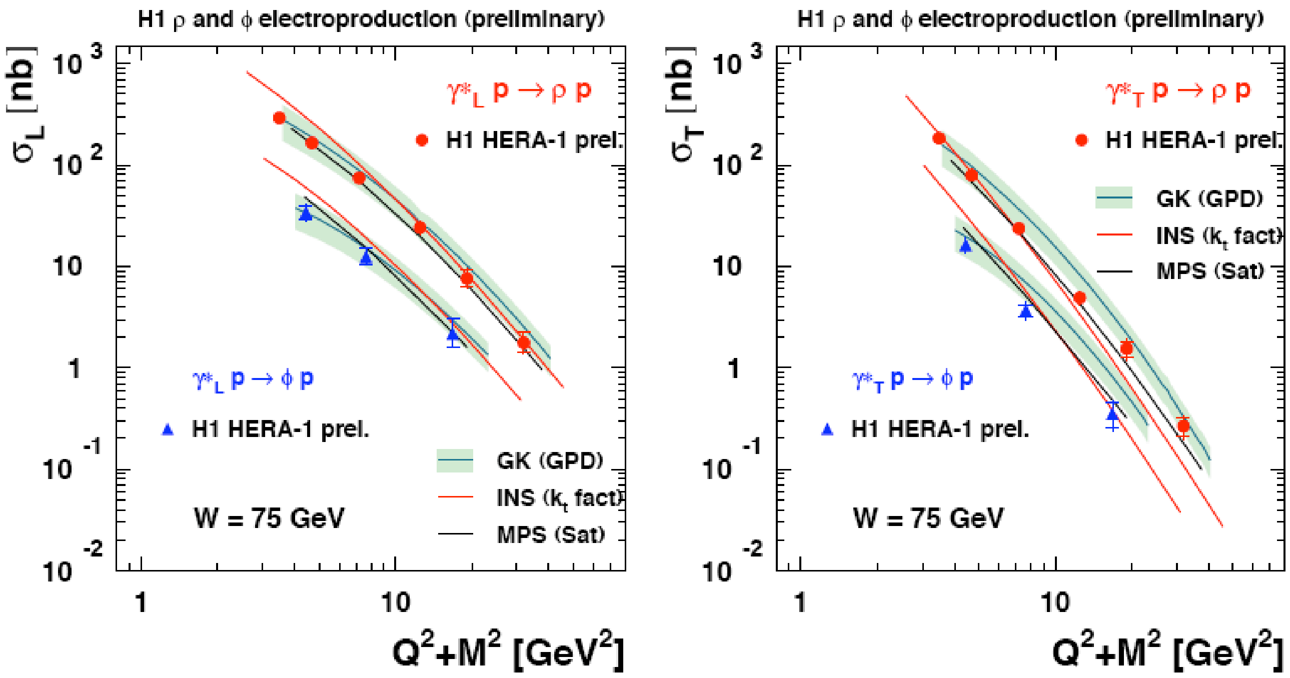
As Q^2 increases, the process gets harder

Many more features, all compatible with predictions of QCD, but no single model can describe them all

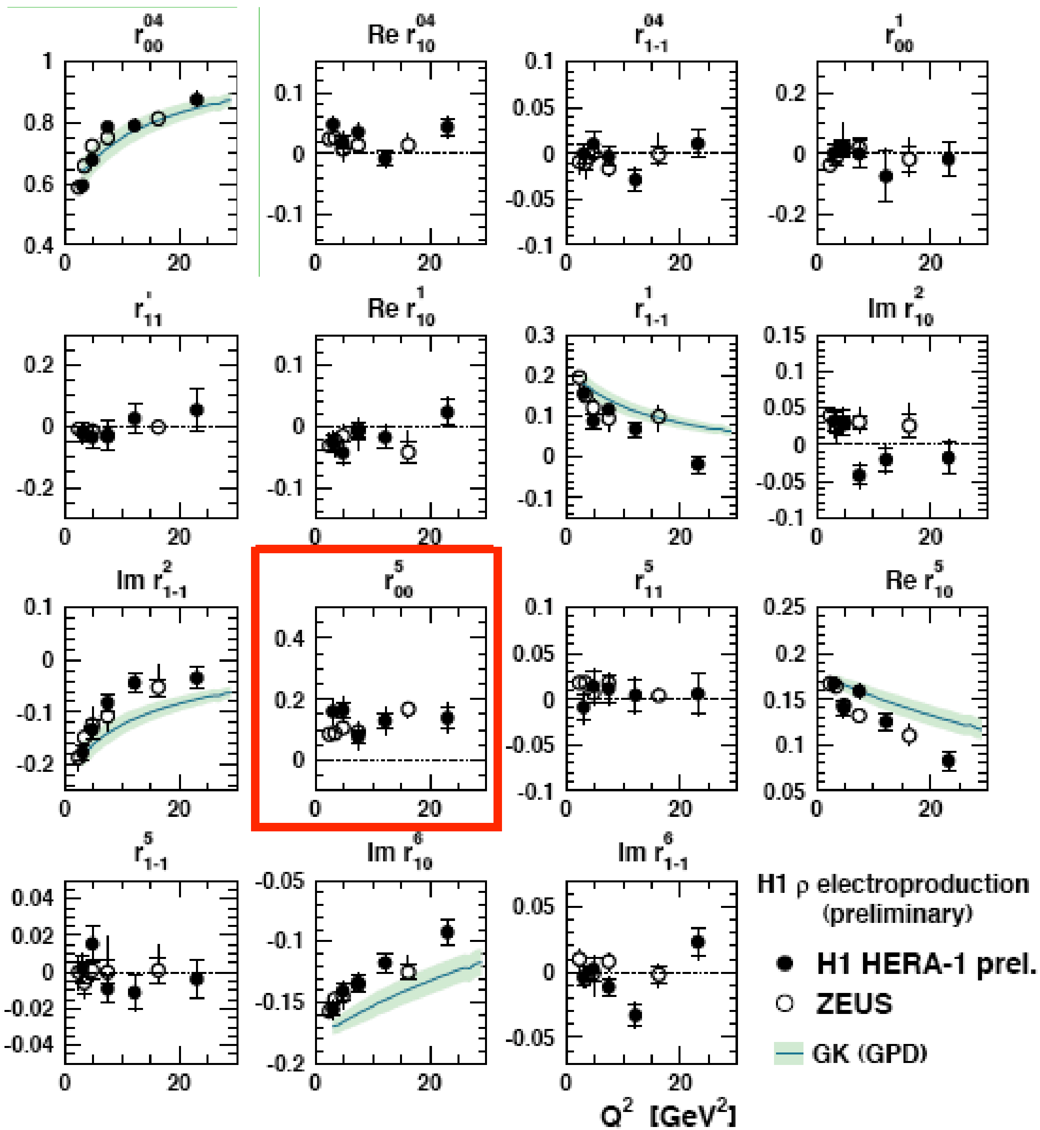
Elastic ρ and ϕ production in DIS

Longitudinal

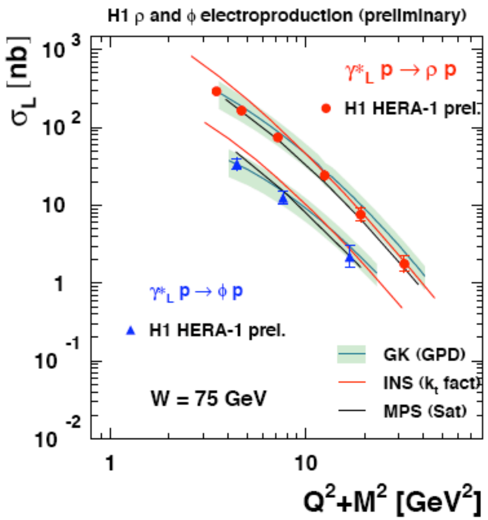
Transverse



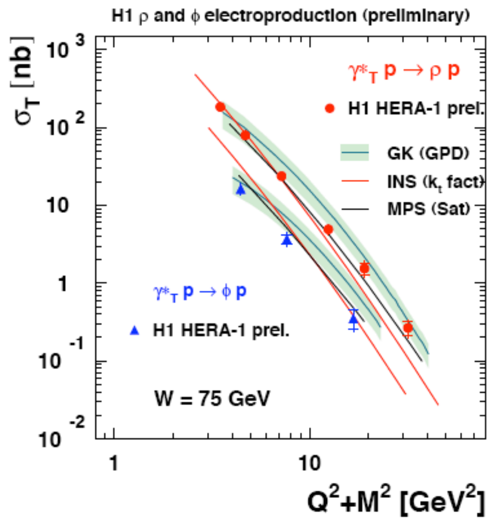
Spin density matrix elements



Longitudinal



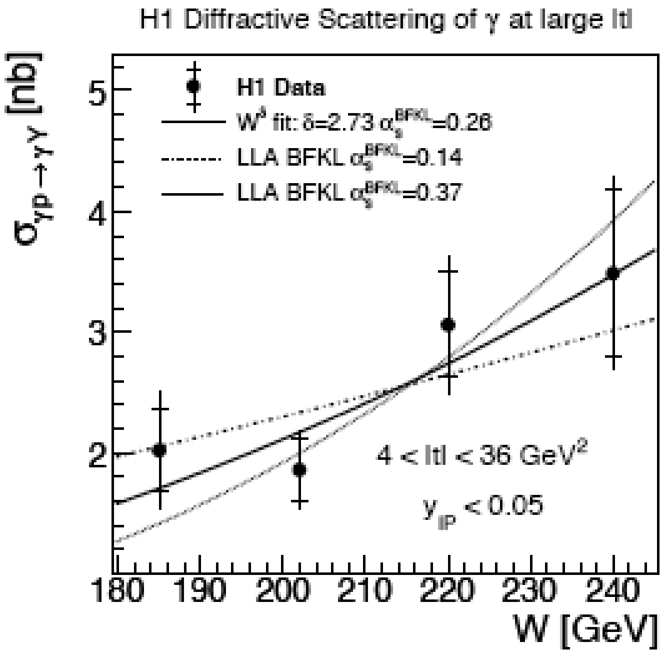
Transverse

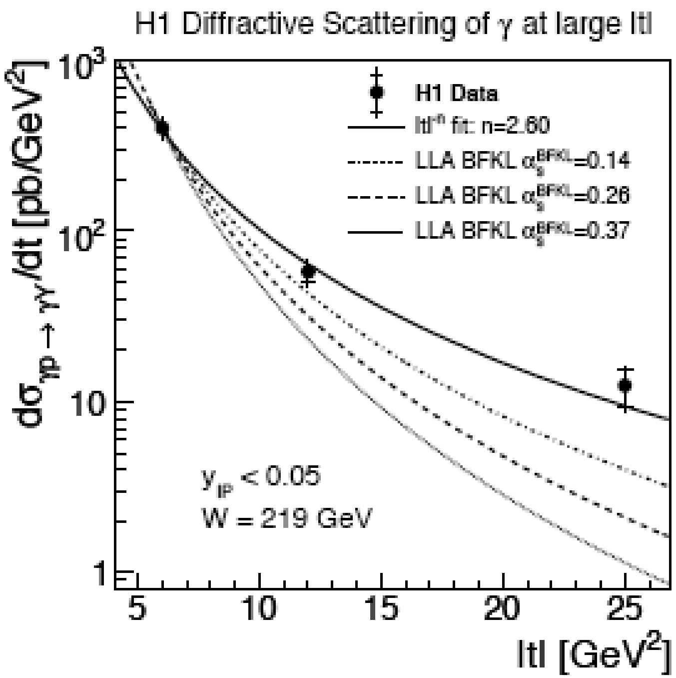


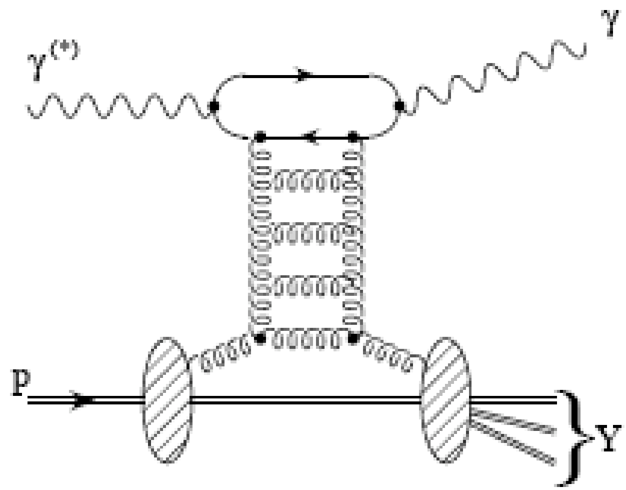
s-channel helicity conservation is violated

The GPD model describes the data to some extent

Diffractive high p_T photons







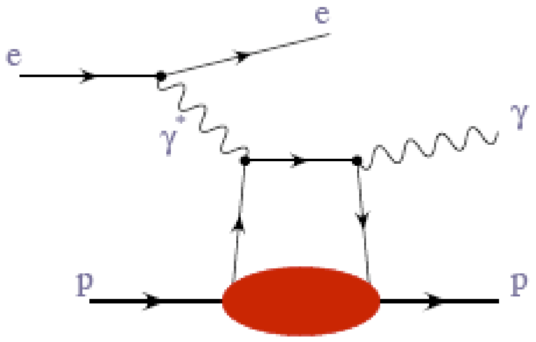
Large t provides a scale for perturbative (BFKL) calculations

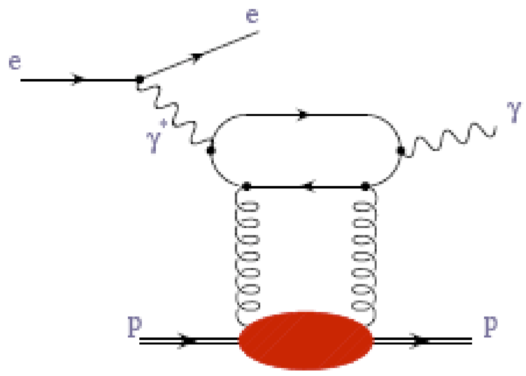
Very hard W dependence

$$W^\delta \text{ fit} \rightarrow \delta = 2.73 \pm 1.02^{+0.56}_{-0.78}$$

BFKL prediction describes the data to some extent

Deeply Virtual Compton Scattering





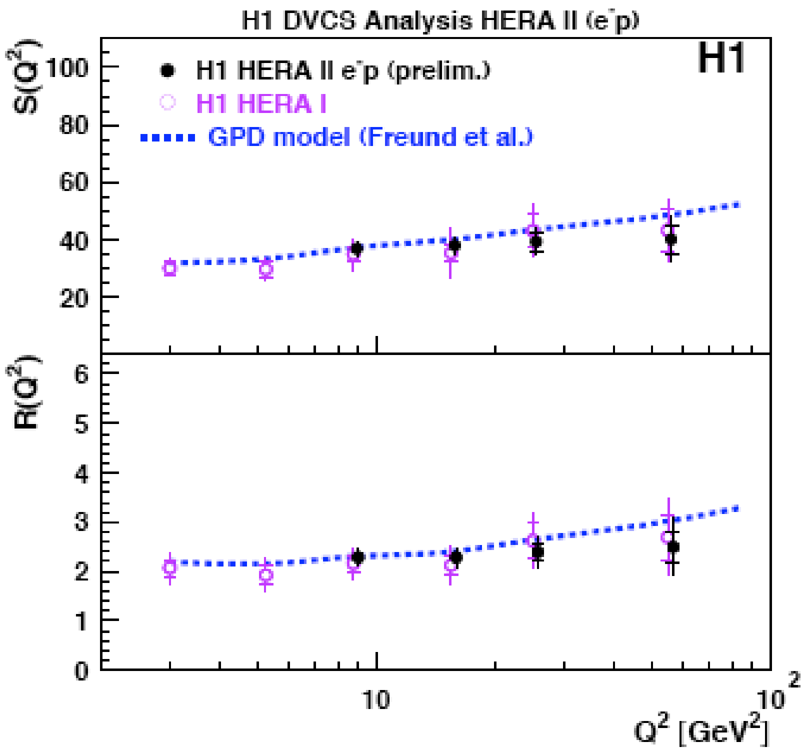
Extract a parton with momentum p_1 and reinsert it with p_2

A fully calculable process sensitive to the transverse correlations of partons - GPDs

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

Ratio of GPD to PDF:

$$R = \frac{\mathcal{I}m\, A(\gamma^* p \to \gamma p)}{\mathcal{I}m\, A(\gamma^* p \to \gamma^* p)}$$



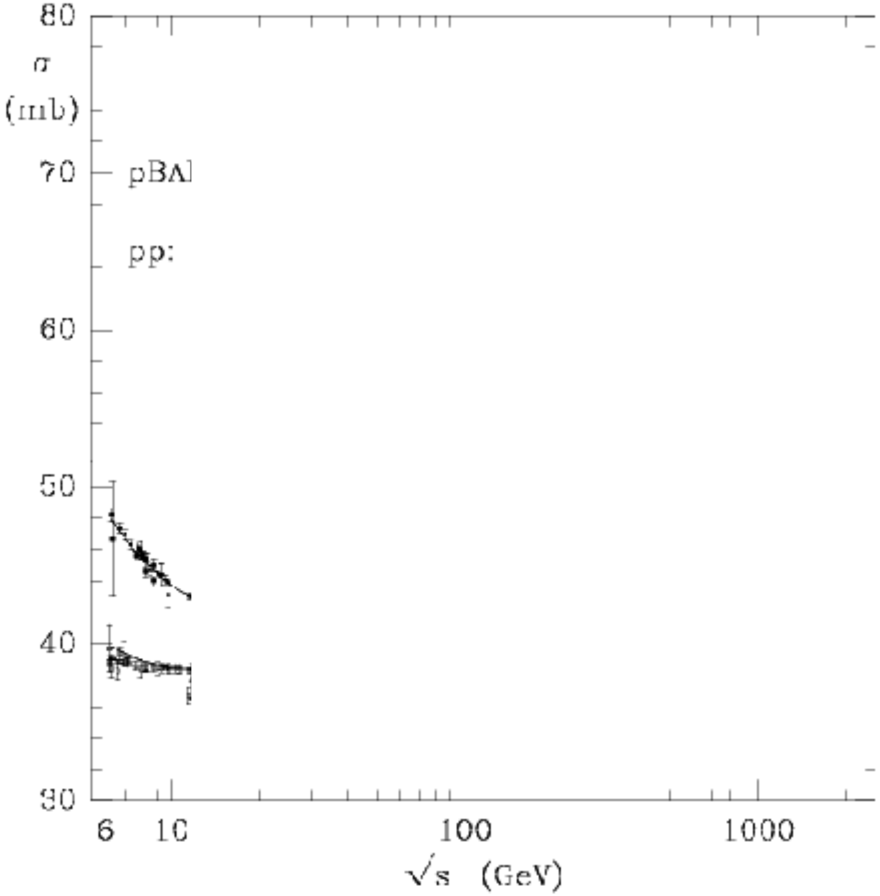
The data are well reproduced by the GPD model prediction

Summary

- A wealth of data from both the H1 and ZEUS collaborations
- Proton vertex factorisation is a good enough approximation of the data to allow extraction of DPDFs from NLO QCD fits to β, Q^2 dependences of inclusive data
- Diffractive dijet data in DIS agree well with predictions of fits to inclusive data
  - Combined fit to inclusive and dijet data constrains both the quark and gluon PDFs to similar good precision
- Diffractive dijet data in photoproduction show evidence of a suppression wrt predictions that is consistent with
  - No x_γ dependence
  - An E_T dependence
- Vector Meson production consistent with predictions of QCD, but no model capable of explaining all of the features
- DVCS data show sensitivity to GPDs

BACK-UP SLIDES FOLLOW

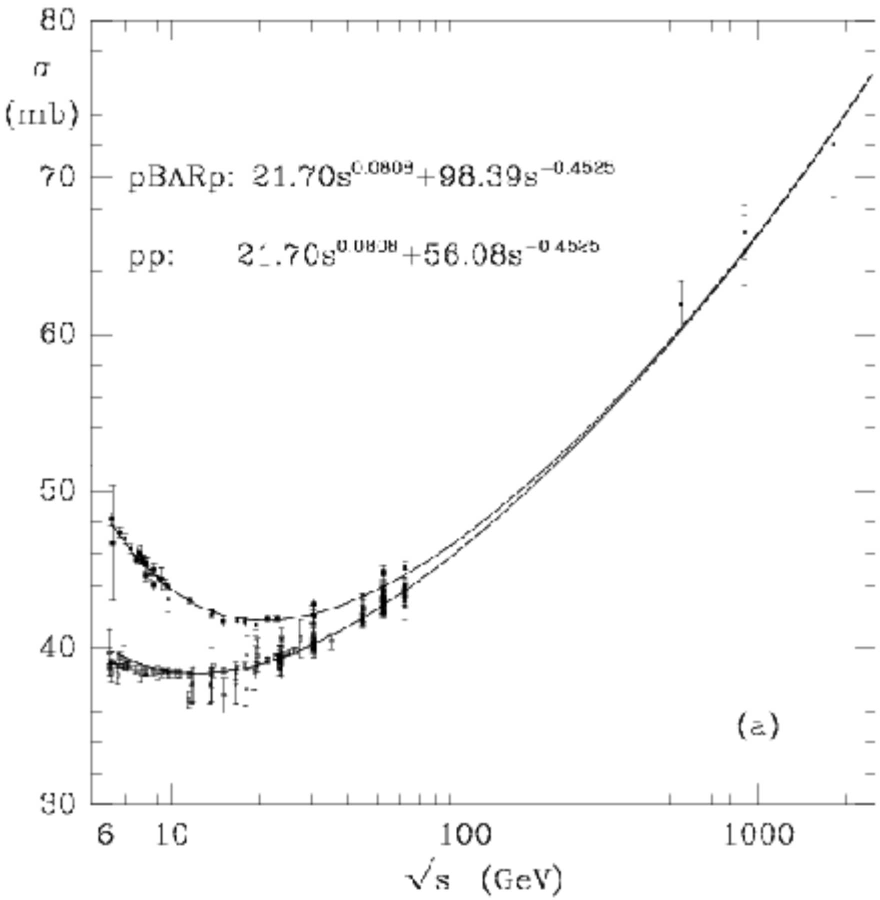
The Pomeron



Pomeranchuk proved that, for any process that involved the exchange of quantum numbers, the cross section σ would decrease with s

Early data bore this out…

The Pomeron



Pomeranchuk proved that, for any process that involved the exchange of quantum numbers, the cross section σ would decrease with s

But at high energy (large s) we saw that the elastic pp scattering σ actually increases with s

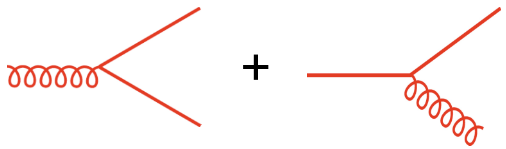
This process must be described by vacuum quantum number exchange

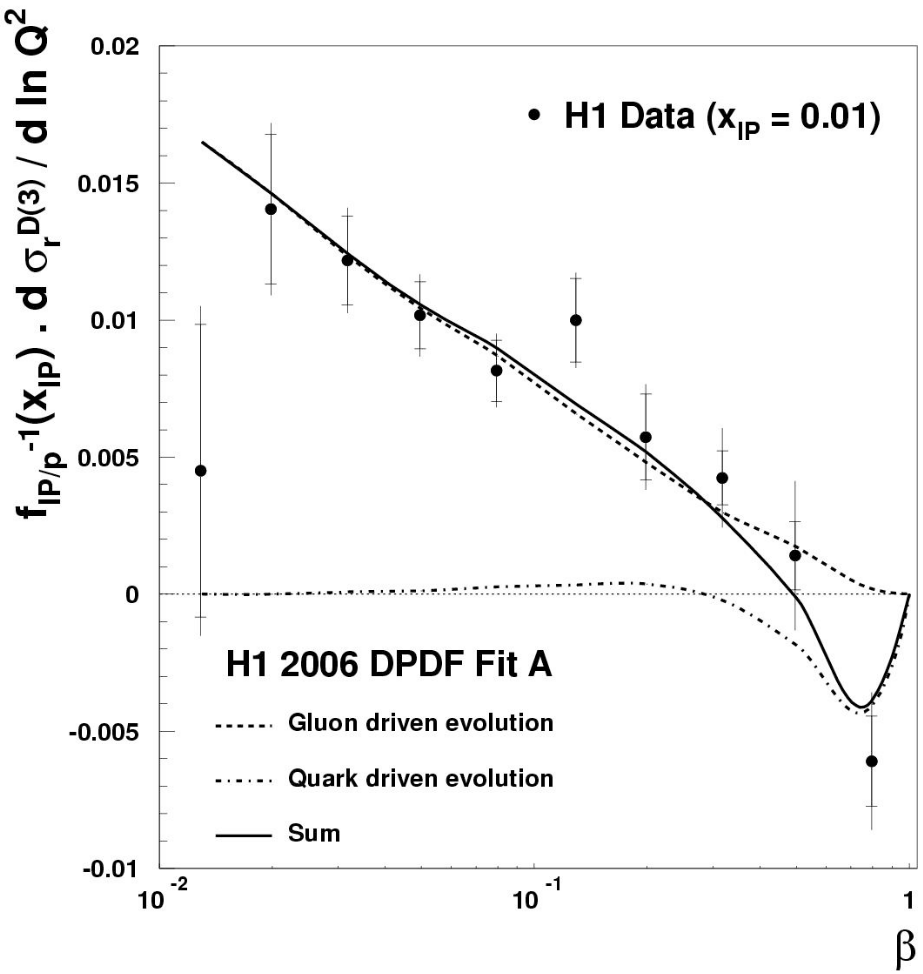
Pomeron is the name given to this exchange

A Closer Look at the High z Region

We have only singlet quarks, so DGLAP evolution equation for F_2^D ….

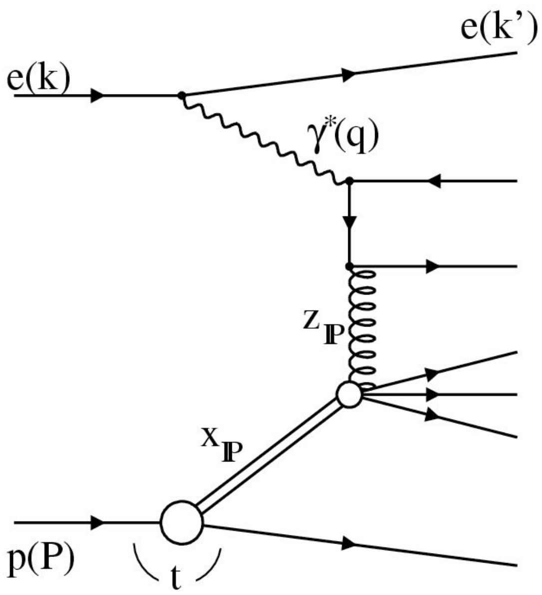
$$\frac{dF_2^D}{d\ln Q^2} \sim \frac{\alpha_s}{2\pi}\left[P_{qg}\otimes g \;+\; P_{qq}\otimes\Sigma\right]$$





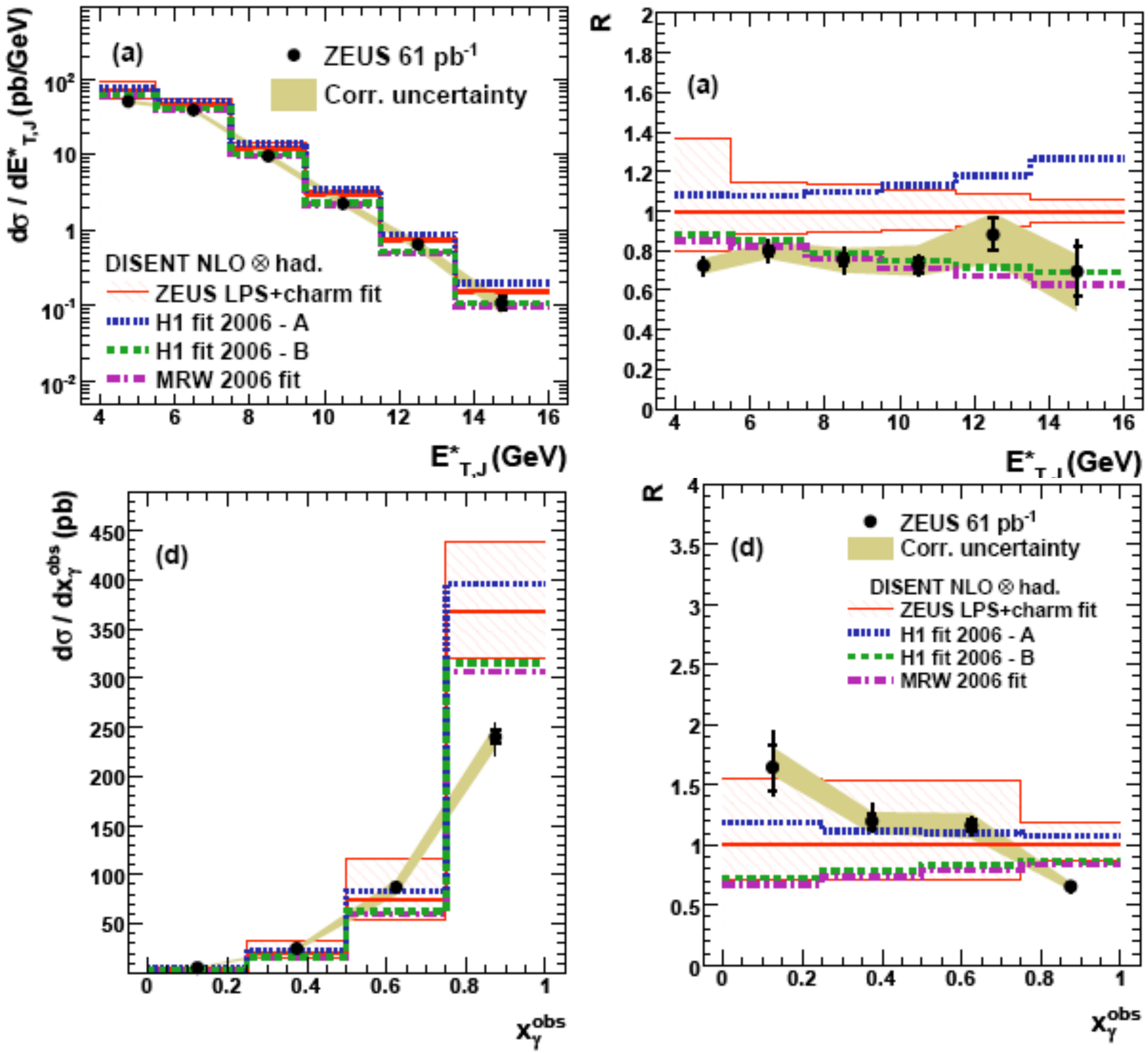
At high β, relative error on derivative grows, $q \rightarrow qg$ contribution to evolution becomes important … sensitivity to gluon is lost

Compare to diffractive dijets in DIS

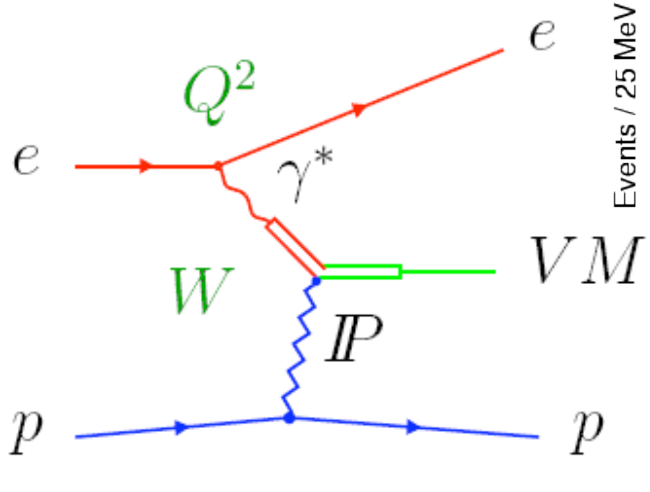


$$z_{IP} = \frac{M_{12}^2 + Q^2}{M_X^2 + Q^2}$$

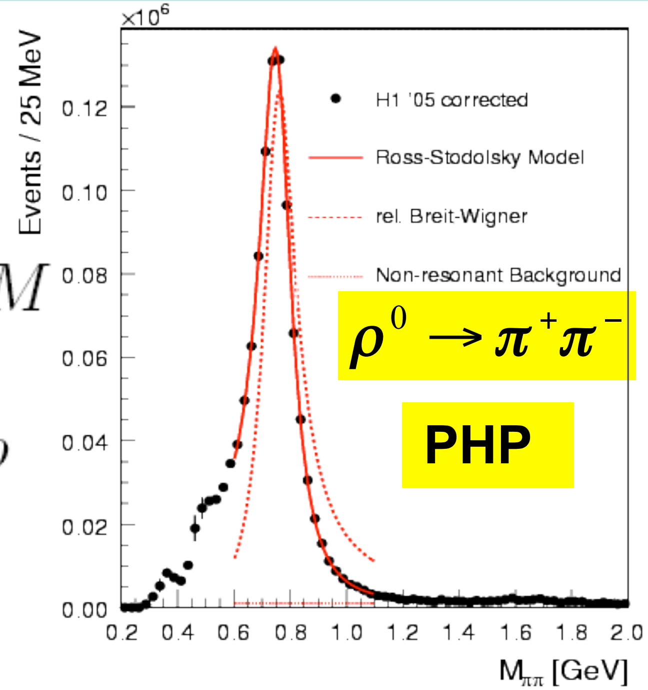
- Compare the ZEUS dijet data to H1 Fit A and Fit B
- Best agreement for H1 Fit B
- ***Factorisation holds in DIS***

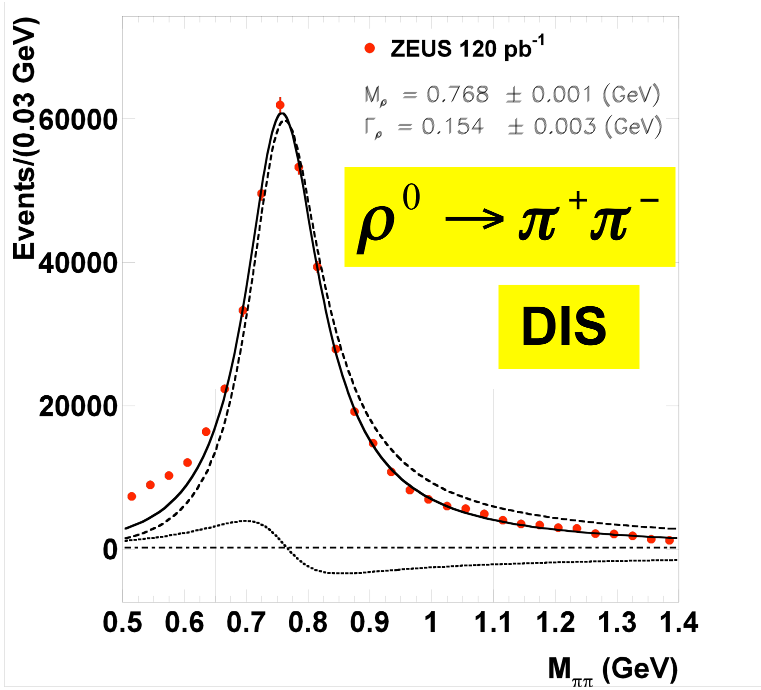


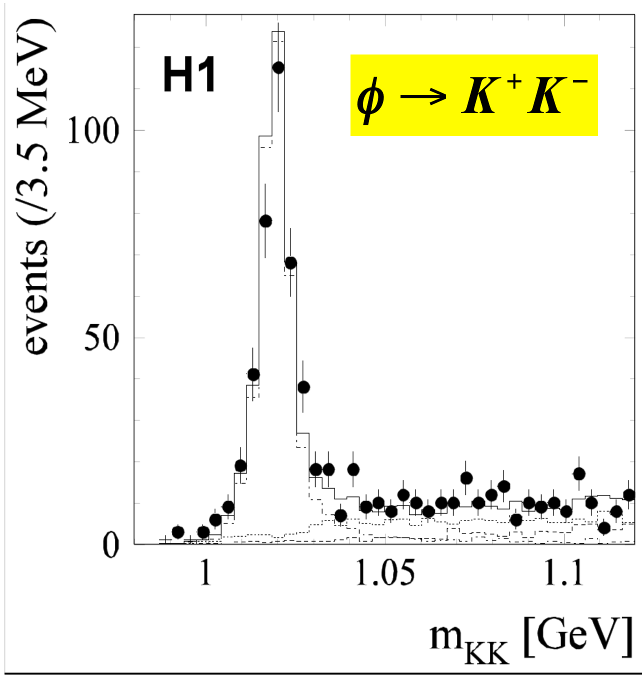
Exclusive Diffraction: *ep* → *ep VM*

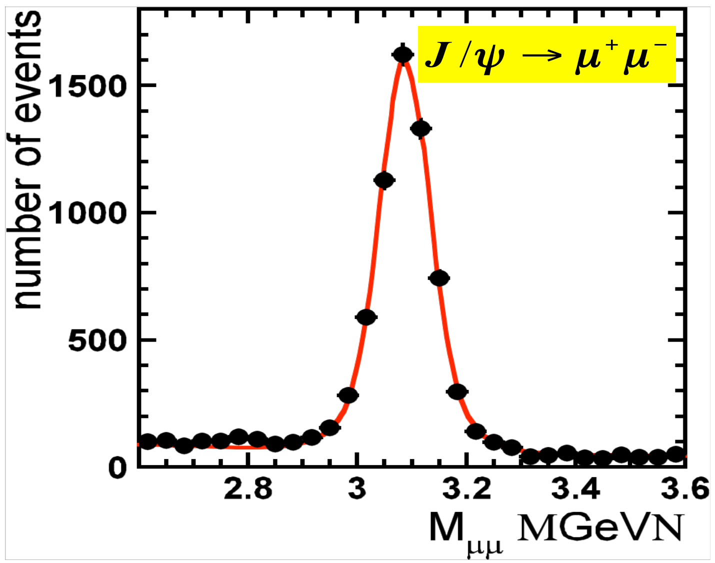


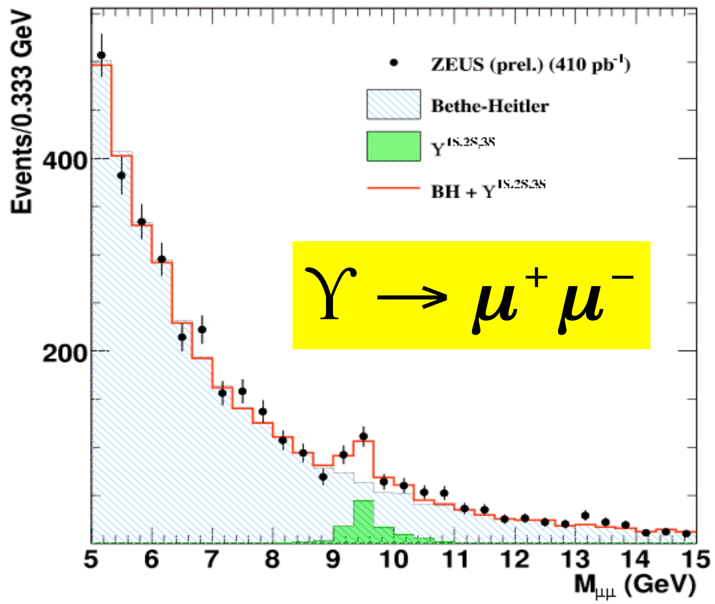
$\sigma \sim W^{\delta}$





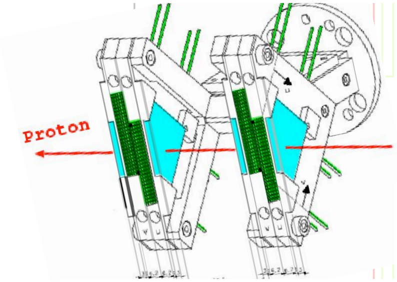




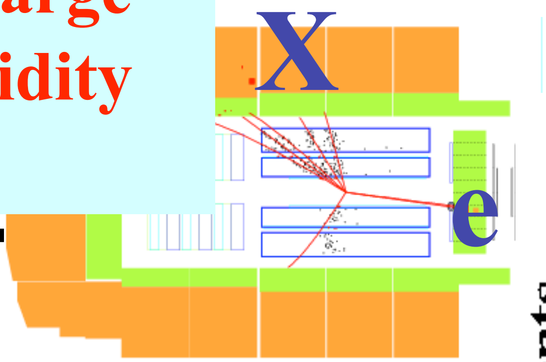


Experimentally selecting $ep \rightarrow eXp$

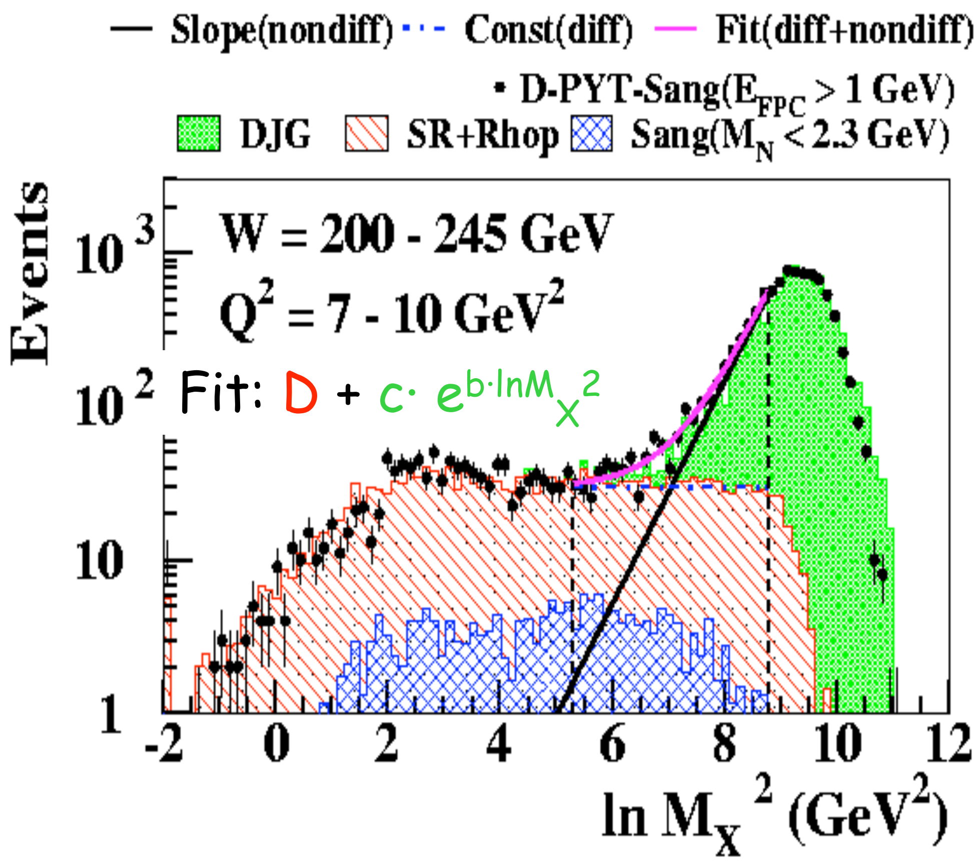
I LPS/FPS



II Large Rapidity Gap



III M_x method



Measure Leading Proton (FPS/LPS)

No proton dissociation

Measure the *t* dependence

Low detector acceptance

Require Large Rapidity Gap (LRG) spanning at least $3.3 < \eta < \sim 7.5$

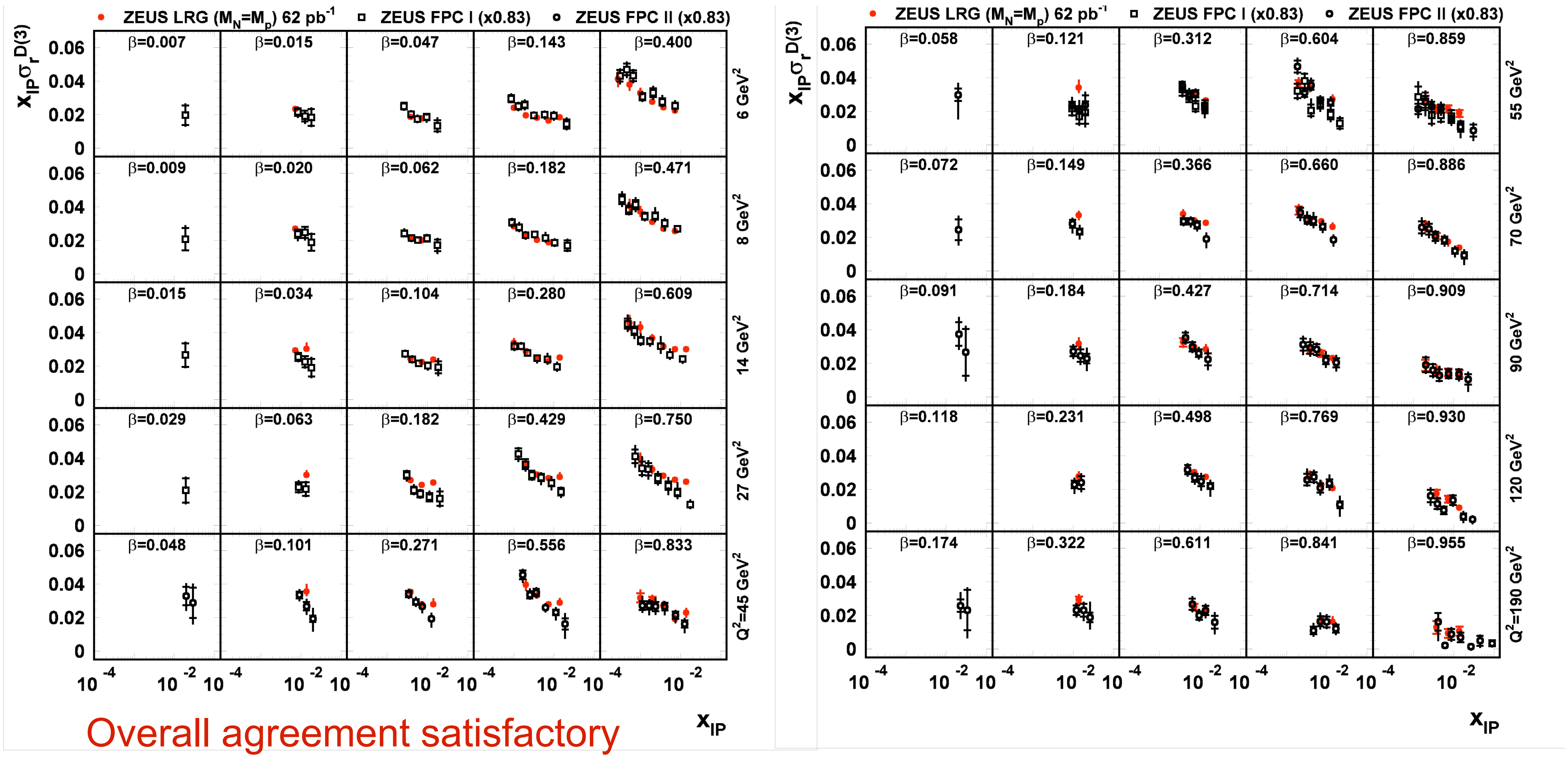
Kinematics measured from *X* system, integrate $|t| < 1.0$ GeV^2, $M_Y < 1.6$ GeV

High detector acceptance → precision

How do the three experimental techniques compare?

ZEUS LRG vs ZEUS M_x

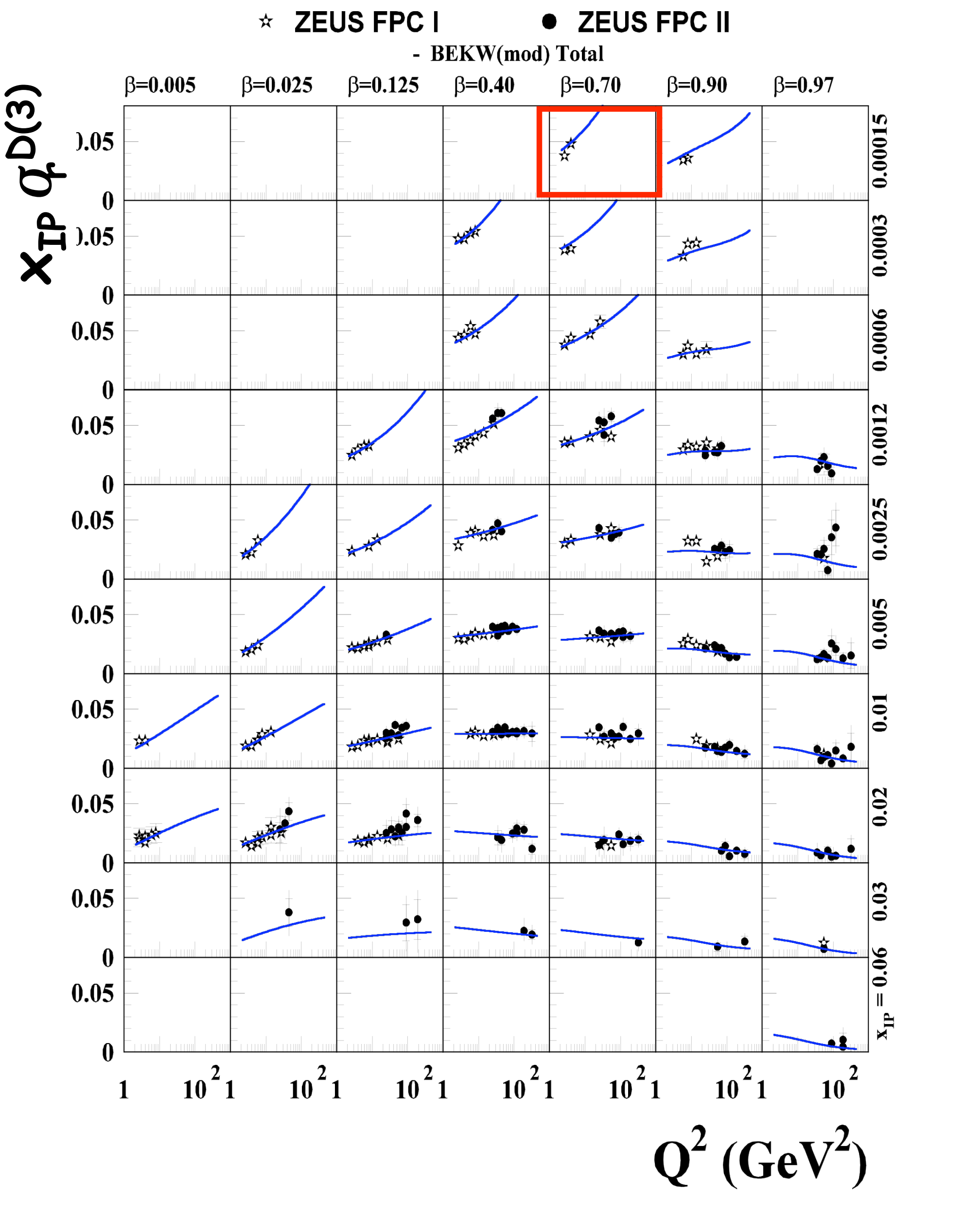
M_x data (M_N < 2.3 GeV) normalised to LRG (M_N=m_p): factor 0.83 ± 0.04 (determined via a global fit) estimates residual p-diss. background in M_x sample

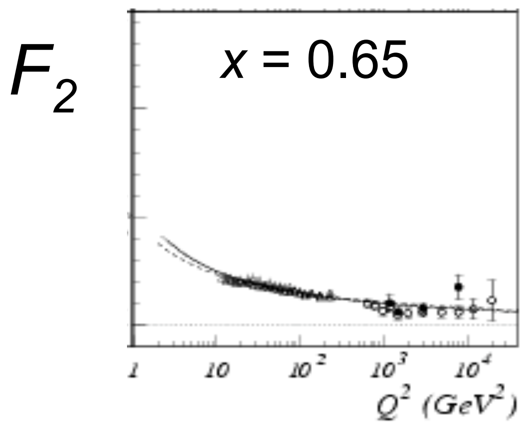


Overall agreement satisfactory

Different x_{IP} dependence ascribed to IR suppressed in M_x data

Q^2 dependence of $\sigma_r^{D(3)}$ ZEUS M_x data



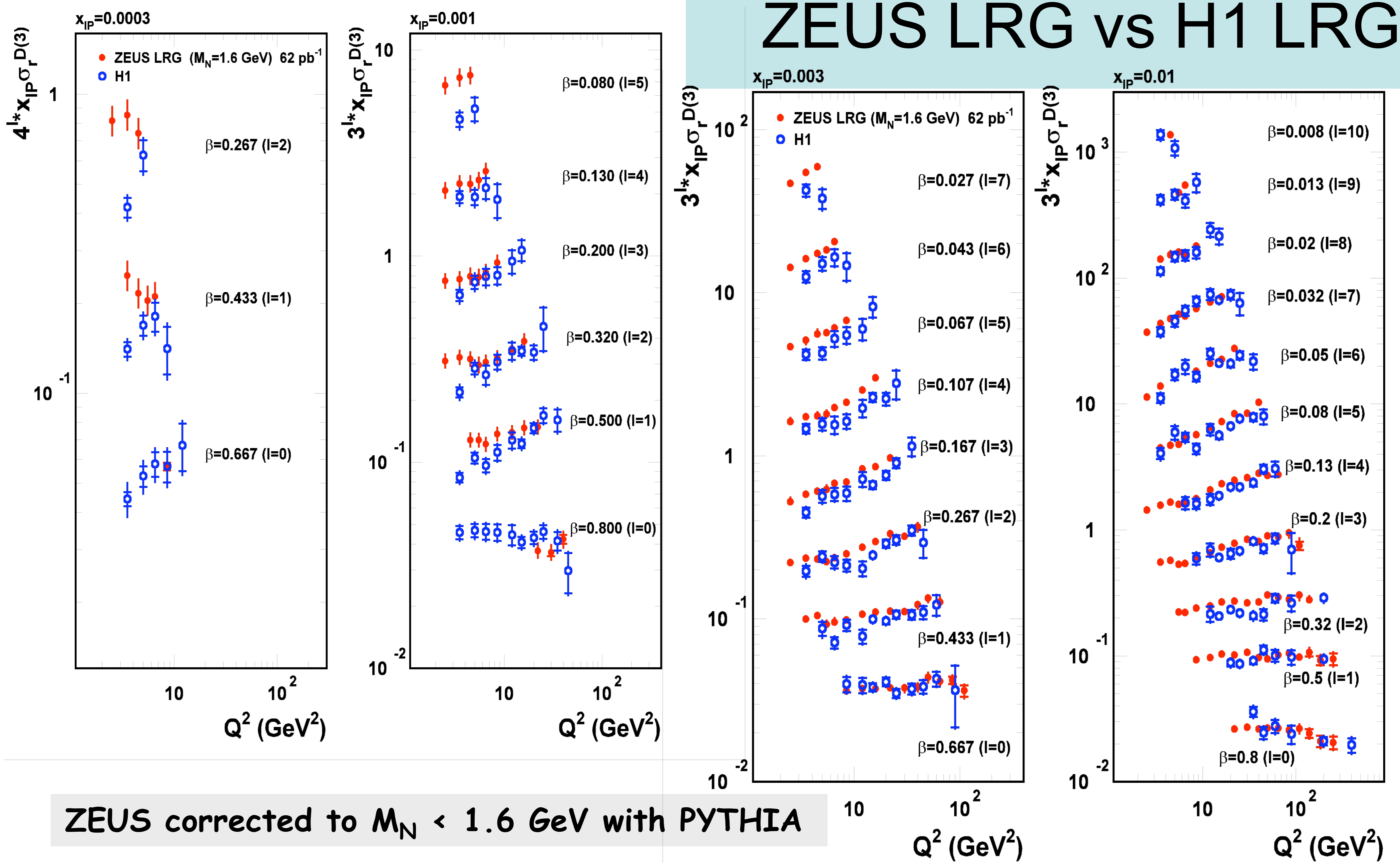


Large positive scaling violations up to high-β values implies that the diffractive exchange is gluon-dominated

At fixed β the reduced cross section depends on x_{IP} - these data seem to contradict Regge factorisation

Regge factorisation is only a useful approximation but fits made thus far are insensitive to this mild breaking

ZEUS LRG vs H1 LRG

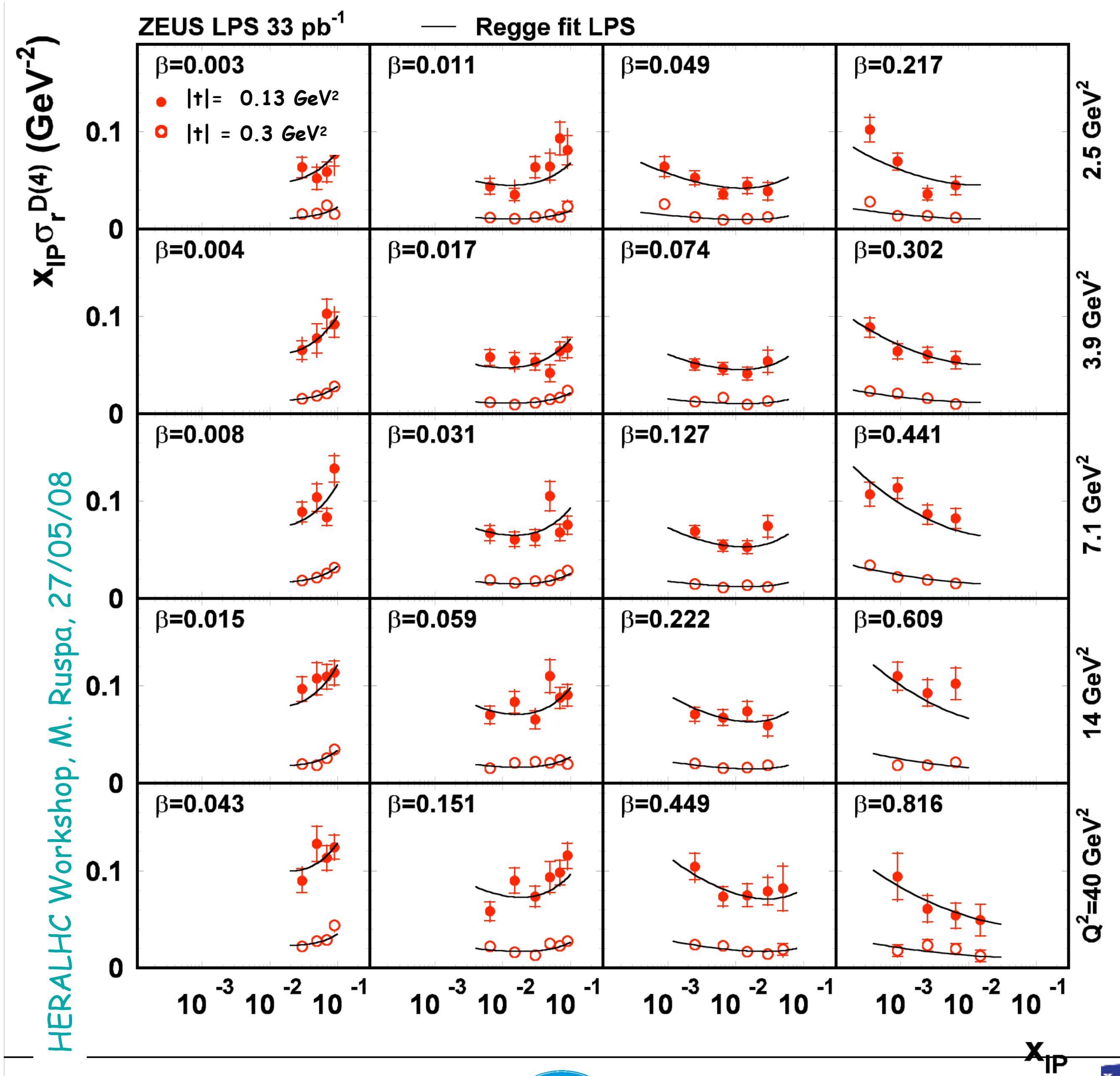


ZEUS corrected to M_N < 1.6 GeV with PYTHIA

→ Remaining normalisation difference of 13% (global fit) covered by uncertainty on p-diss. correction (8%) and relative normalisation uncertainty (7%)

→ Shape agreement ok except low Q^2

x_{IP} dependence of $\sigma_r^{D(4)}$ Leading Proton data



First measurement in two t bins

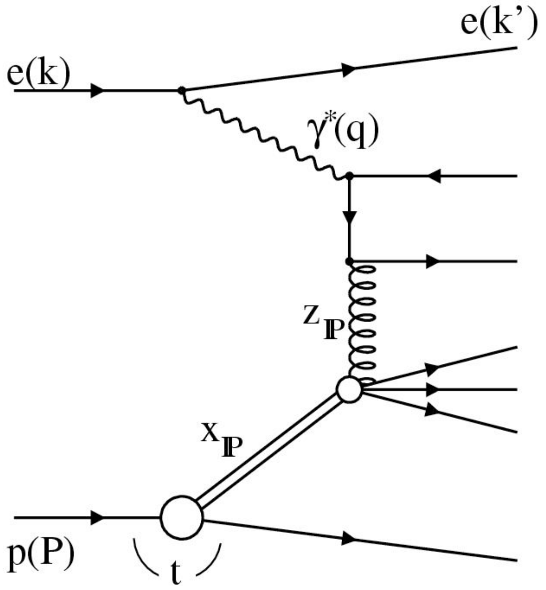
Same x_{IP} dependence in two t bins

Low x_{IP}: $\sigma_r^{D(4)}$ falls with x_{IP} faster than $1/x_{IP}$

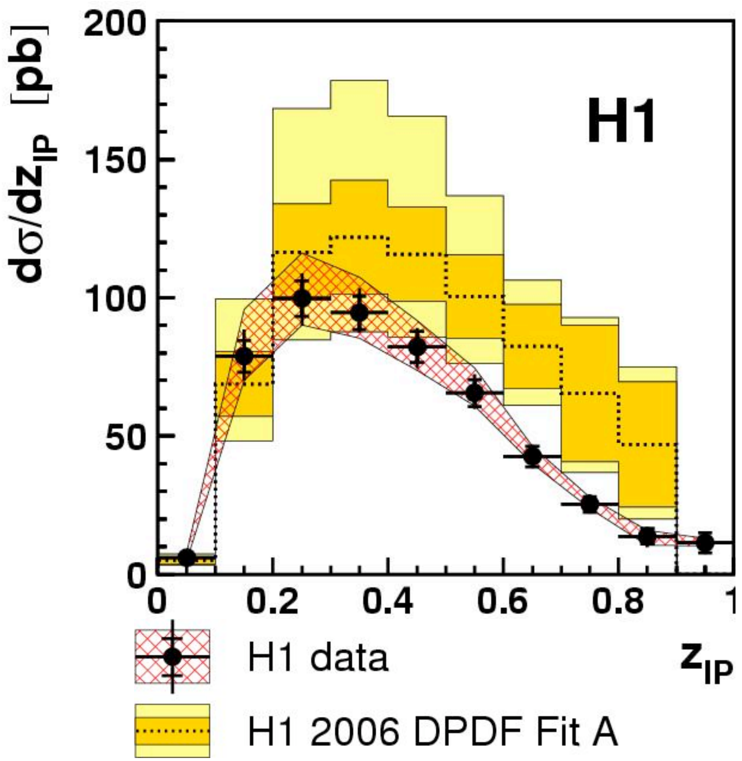
High x_{IP}: $x_{IP}\sigma_r^{D(4)}$ flattens or increases with x_{IP}

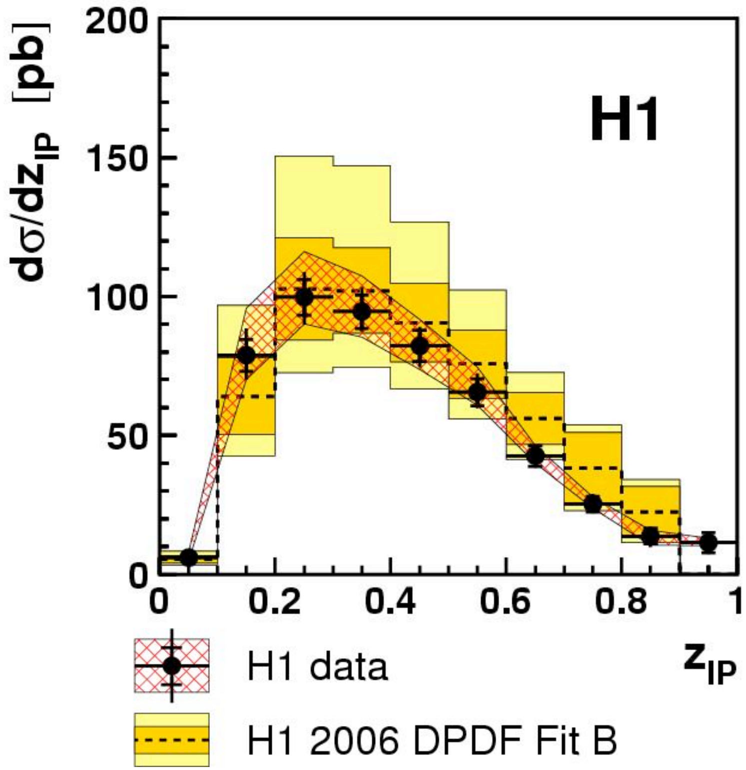
(Reggeon and π)

Factorisation holds in DIS



$$z_{IP} = \frac{M_{12}^2 + Q^2}{M_X^2 + Q^2}$$





At low z_{IP} (< 0.4) Fit A and Fit B are similar

The data are in good agreement with the predictions, consistent with factorisation

At high z_{IP} the data clearly prefer Fit B

Include the diffractive dijet in a combined fit with the inclusive H1 LRG data