Athena Exclusive&Diffractive meeting

25th June 2021

Prospects from diffraction at HERA

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Pretious input on the implications to EIC from

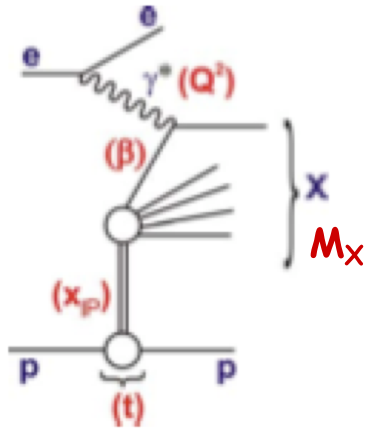
Paul Newman https://indico.bnl.gov/event/11970/

Krzysztof Piotrzkowski https://indico.bnl.gov/event/12229/

Which HERA topics call for further development?

- **Unanswered questions**
- **Lack of statistics**
- **Not fully addressed**

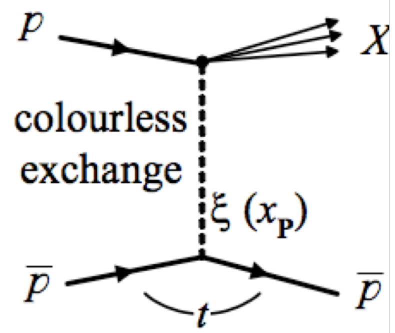
HERA Legacy in diffraction



- Rapidity gaps at HERA unexpected!

- Diffractive Parton Distribution Functions (DPDFs)

- Mechanisms of factorization breaking in lepton-hadron vs hadron-hadron collisions – rescattering effects



- Towards Generalised Parton Distribution Functions (GPDs): a 3d picture of the proton

- Vector meson production: a window on the soft-hard transition

Diffractive PDFs

QCD factorization in hard diffraction

- **Diffractive DIS, like inclusive DIS, is factorisable:**
  [Collins (1998); Trentadue, Veneziano (1994); Berera, Soper (1996)…]

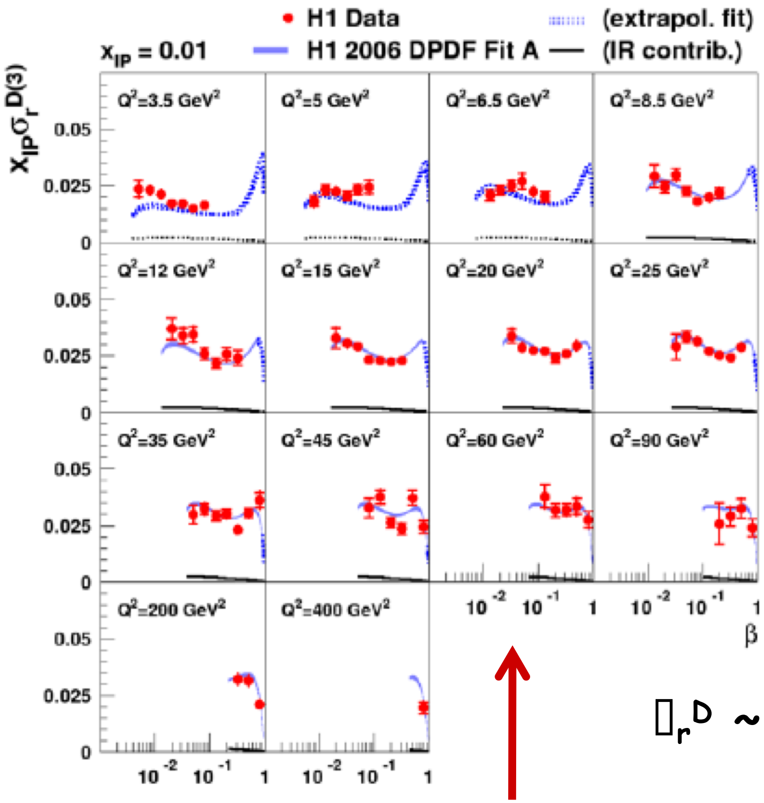
universal partonic cross section

$$\sigma(\gamma^* p \rightarrow Xp) \approx f_{i/p}(z,Q^2,x_{IP},t) \times \sigma_{\gamma^* q}(z,Q^2)$$

Diffractive Parton Distribution Function (DPDF)

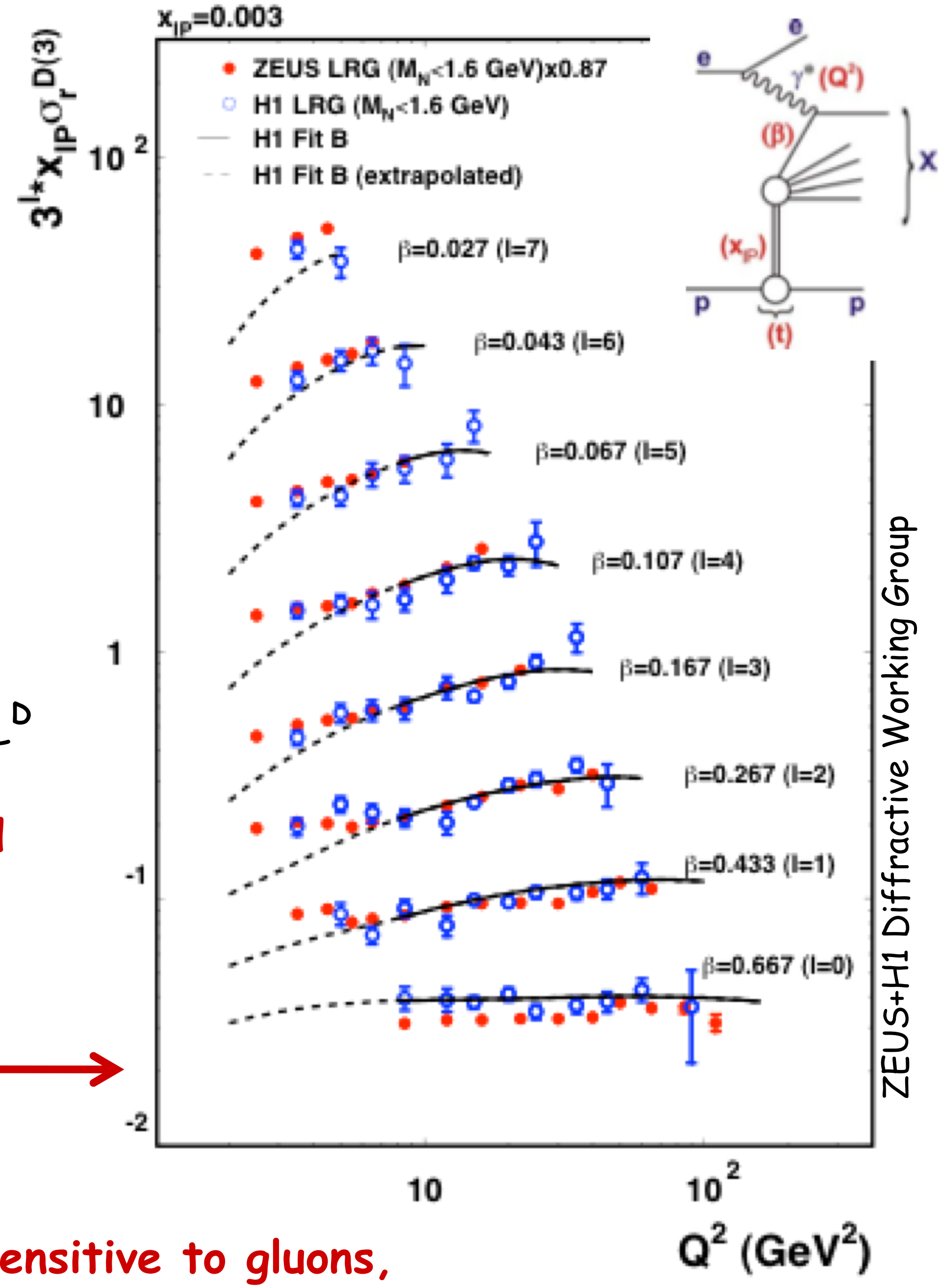
$f_{i/p}(z,Q^2,x_{IP},t)$ expresses the probability to find, with a probe of resolution Q^2, in a proton, parton i with momentum fraction z, under the condition that the proton remains intact, and emerges with small energy loss, x_{IP}, and momentum transfer, t – the DPDFs are a feature of the proton and evolve according to DGLAP

DPDFs extraction



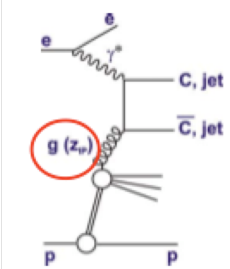
H1 Collab., EPJ C48 (2006), 715

$\sigma_r^D \sim F_2^D - F_L^D$



Quark densities constrained by reduced cross section

Gluon density constrained indirectly by scaling violations



Diff dijet data, directly sensitive to gluons, constrains the gluon density @high z

QCD factorization in hard diffraction

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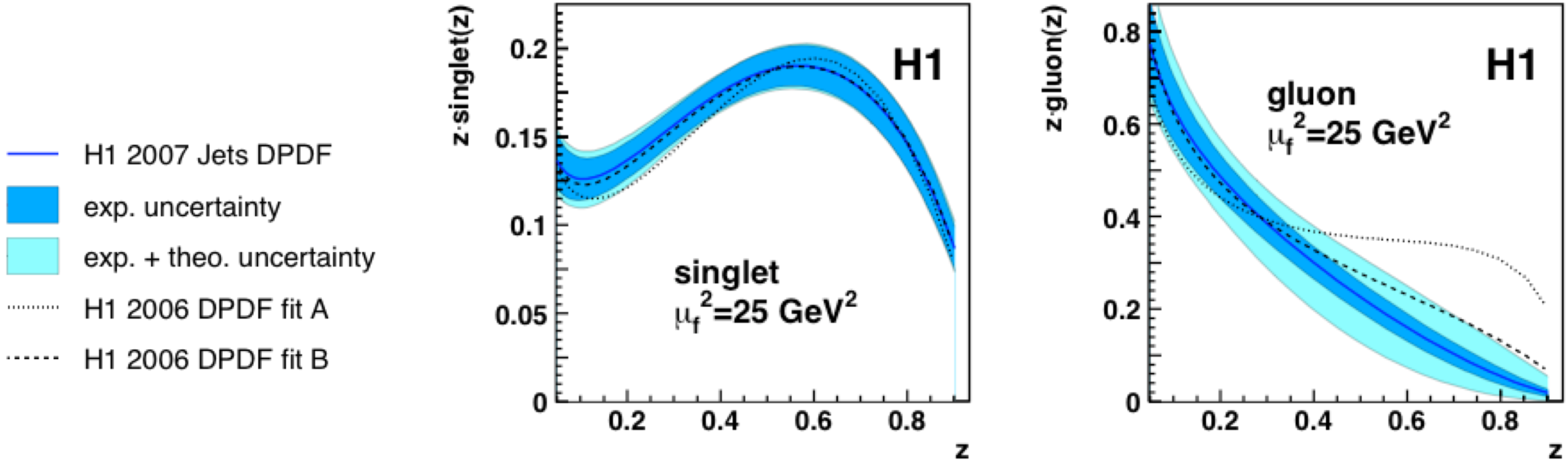
- **Assumption → proton vertex factorisation:**

Regge-motivated IP flux

$$\sigma\,(\gamma^{*}p \rightarrow Xp) \approx f_{IP/p}(x_{IP},t) \times f_{i/IP}(z,Q^2) \times \sigma_{\gamma^{*}q}\,(z,Q^2)$$

At large x_{IP}, a separately factorisable sub-leading exchange (IR), with different x_{IP} dependence and partonic composition

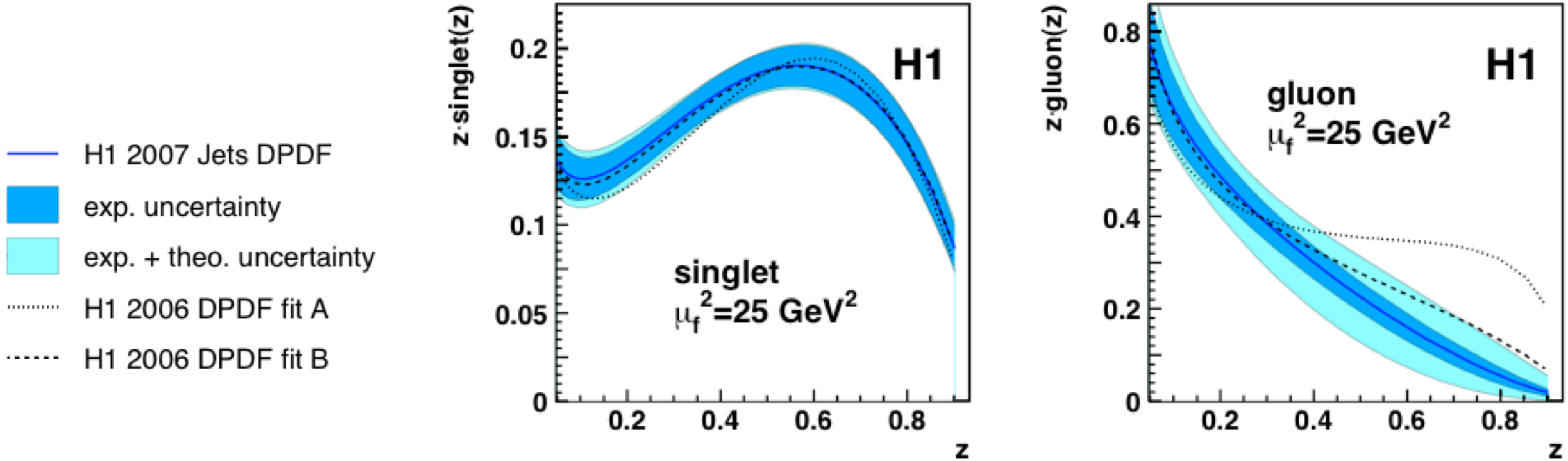
Diffractive parton densities



Room for improvement!

- **Fits fail at low Q2 → additional corrections needed to DGLAP evolution**
- **Uncertanties (high z)**
- **Discrepancies between data sets**
- **Fitting without proton vertex factorization assumption**

Diffractive parton densities



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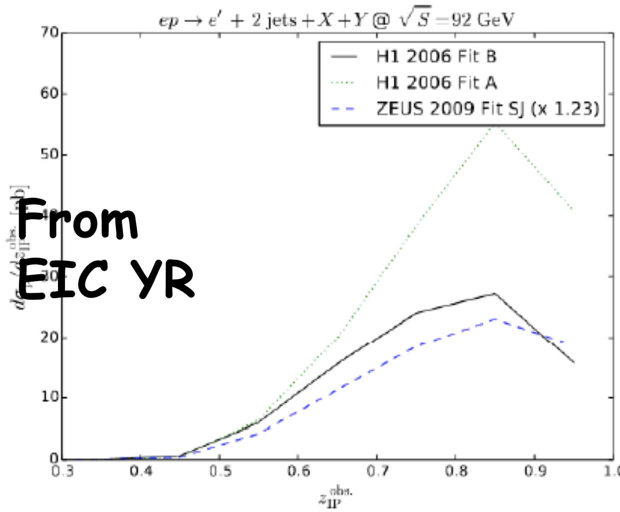


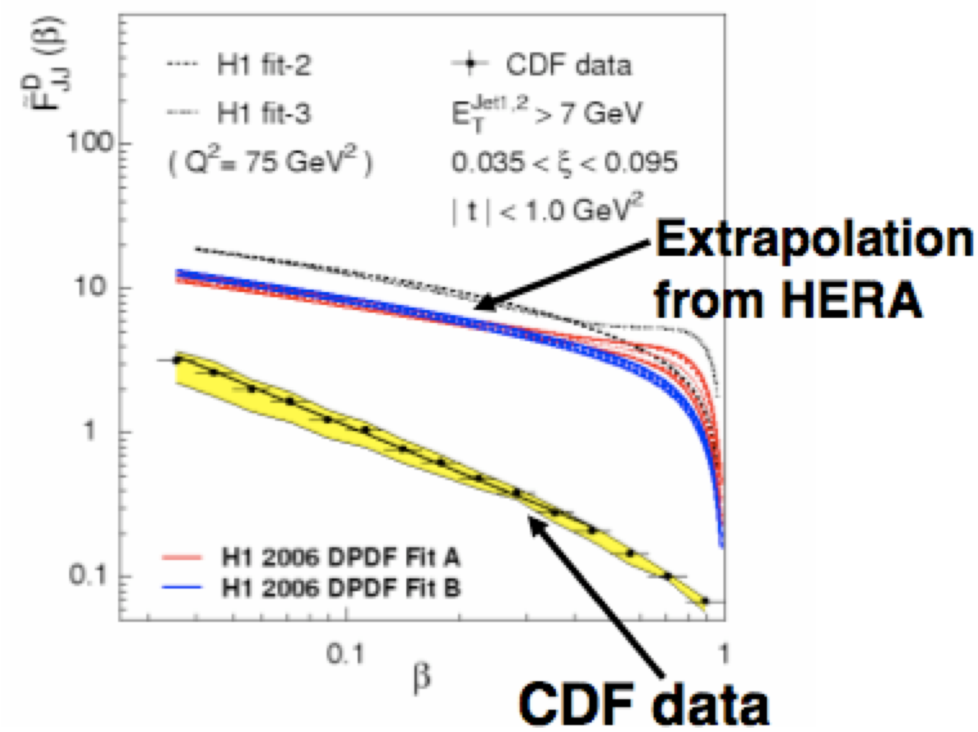
Figure 7.34: NLO QCD predictions for the z_P^{obs}-dependence using three different sets of diffractive PDFs: H1 2006 Fit B (full black), Fit (dotted green), both from Ref. [276], and ZEUS 2009 Fit SJ (dashed blue curves) from Ref. [277]. The rescaling for the calculation using the ZEUS SJ fit is needed to take into account the contribution of proton dissociation, which has been included in the H1 fits and B.

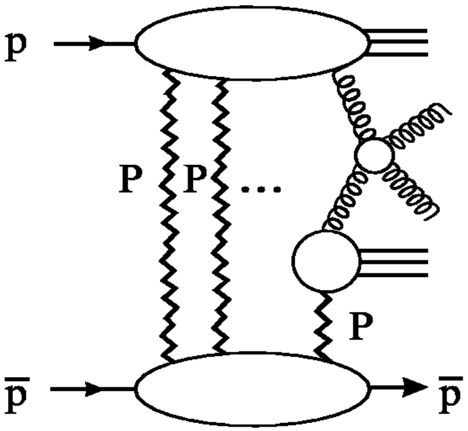
Factorization breaking

Factorisation breaking at Tevatron

QCD factorisation not expected to hold in ppbar, pp: indeed it does not!

- **Factor 10 normalisation difference** between extrapolation from HERA data and CDF measurement





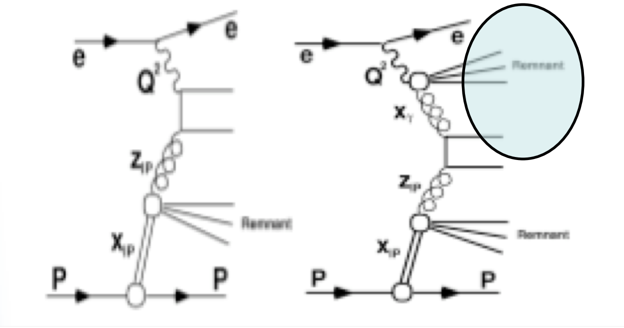
☐ Understood in terms of (soft) **rescattering among spectator partons** [Kaidalov, Khoze, Martin, Ryskin] PRL 84 (2000) 5043

☐ Lots of different theoretical approaches
[Goulianos, Gotsman, Levin, Maor, Ingelman, Enberg, Cox, Forshaw, Lonnblad…]

☐ Quantified by **"rapidity gap survival probability", <|S|²>**

Rescattering effects at HERA?

- **Diffractive dijet photoproduction:** direct vs resolved events → switch photon remnant on/off:



$$x_\gamma = \frac{\sum_{jets} E - p_z}{\sum_{HFS} E - p_z}$$

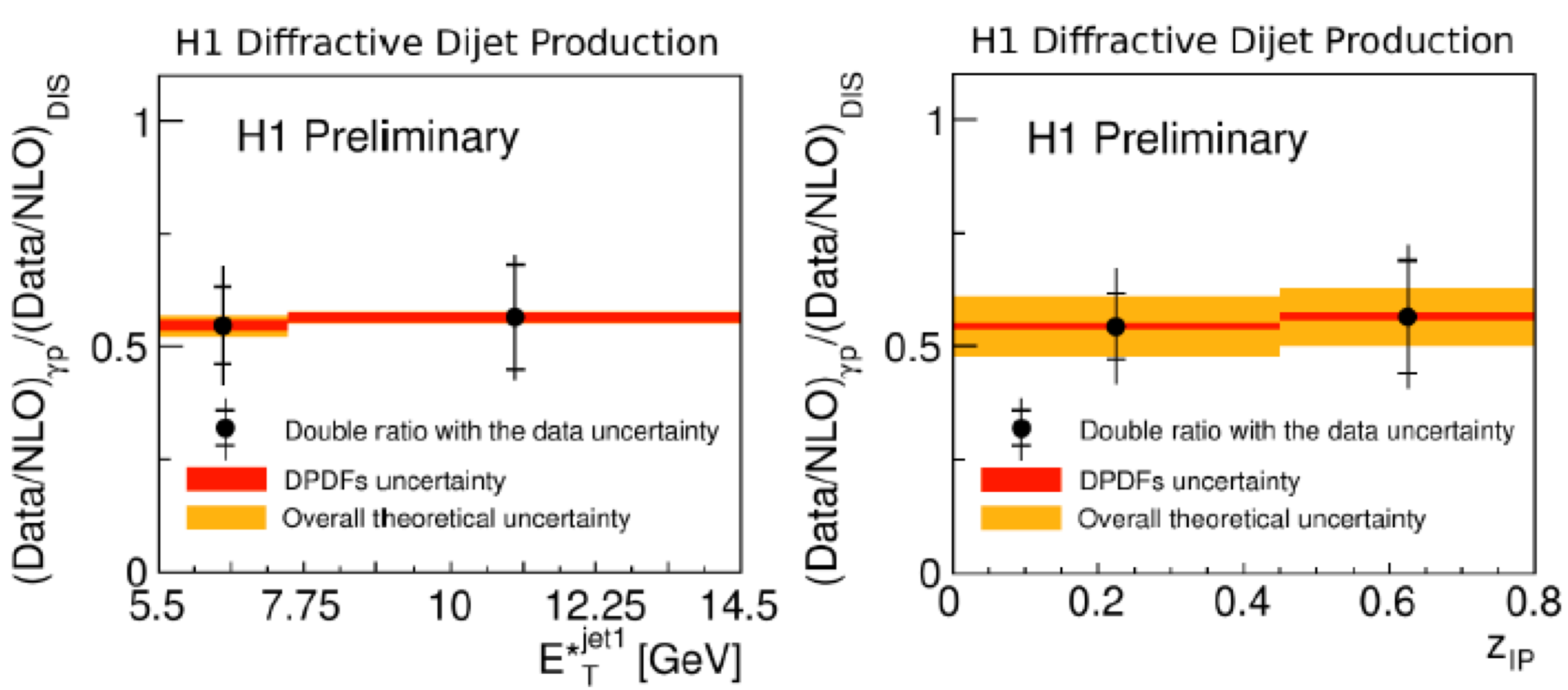
$x_\gamma < 0.75$

Rescatter

?

Rescattering effects at HERA?

DIFF DIJET PHOTOPRODUCTION



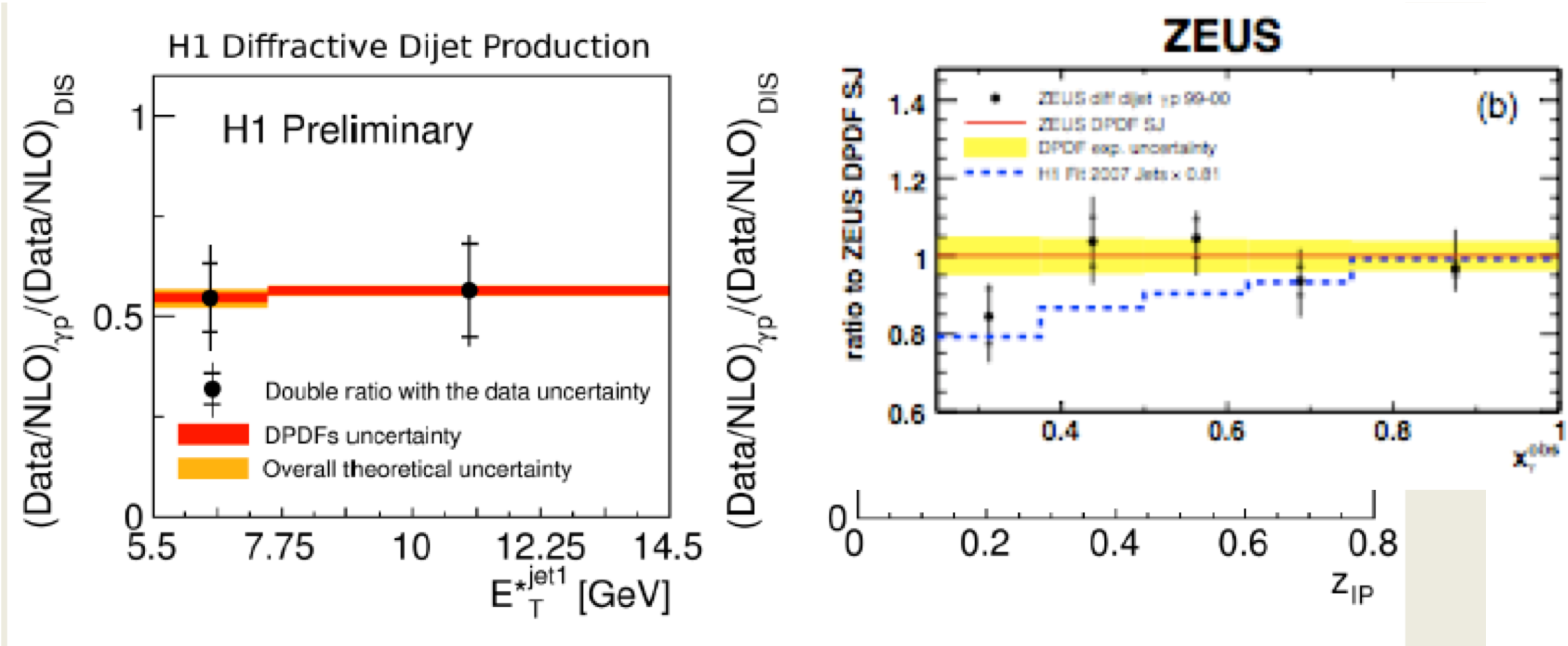
Double ratio photoproduction/DIS – uncertainites reduced!

Dependence of the suppression on E_T of the leading jet and z_{IP} not observed!

$$\frac{(\mathrm{DATA/NLO})_{\gamma p}}{(\mathrm{DATA/NLO})_{\mathrm{DIS}}} = 0.55 \pm 0.10\,(\mathrm{data}) \pm 0.02\,(\mathrm{theor.})$$

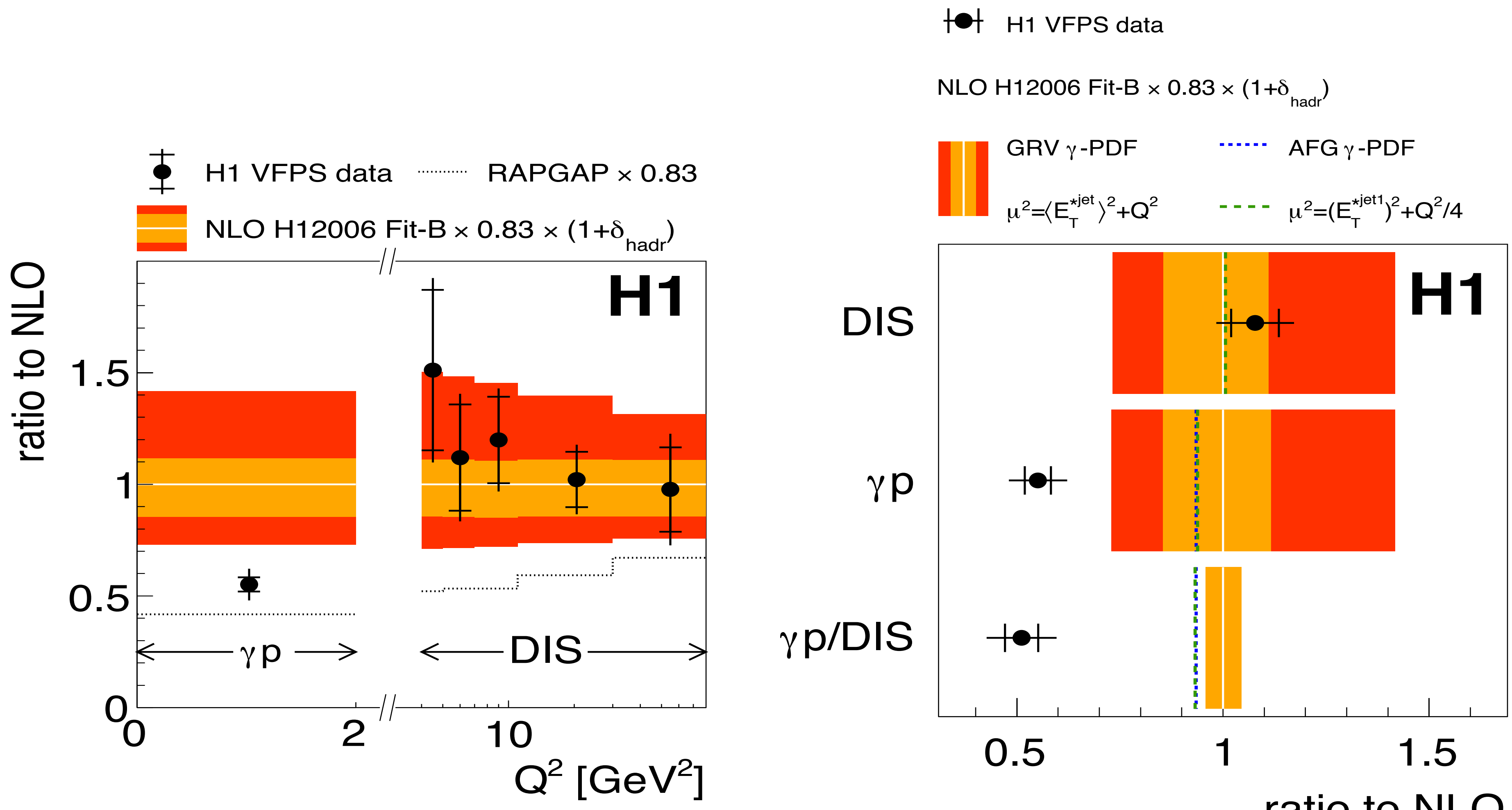
Rescattering effects at HERA?

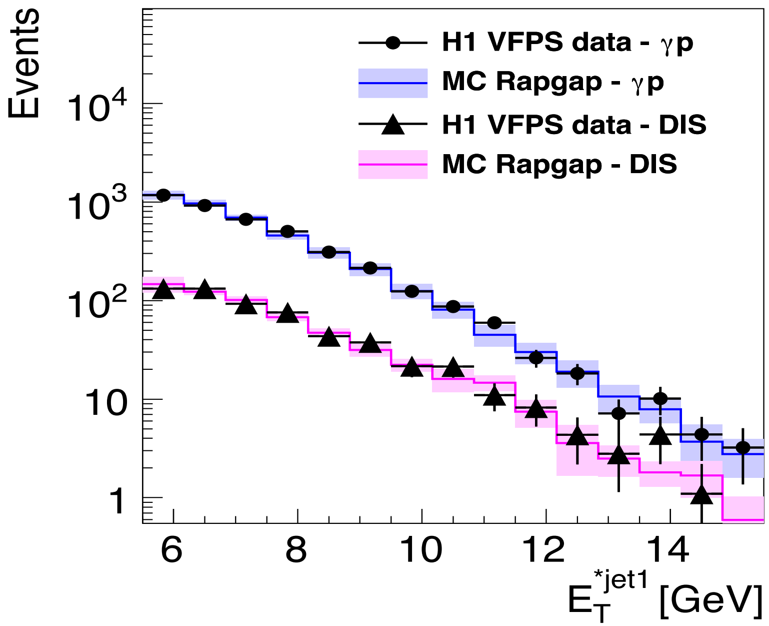
DIFF DIJET PHOTOPRODUCTION

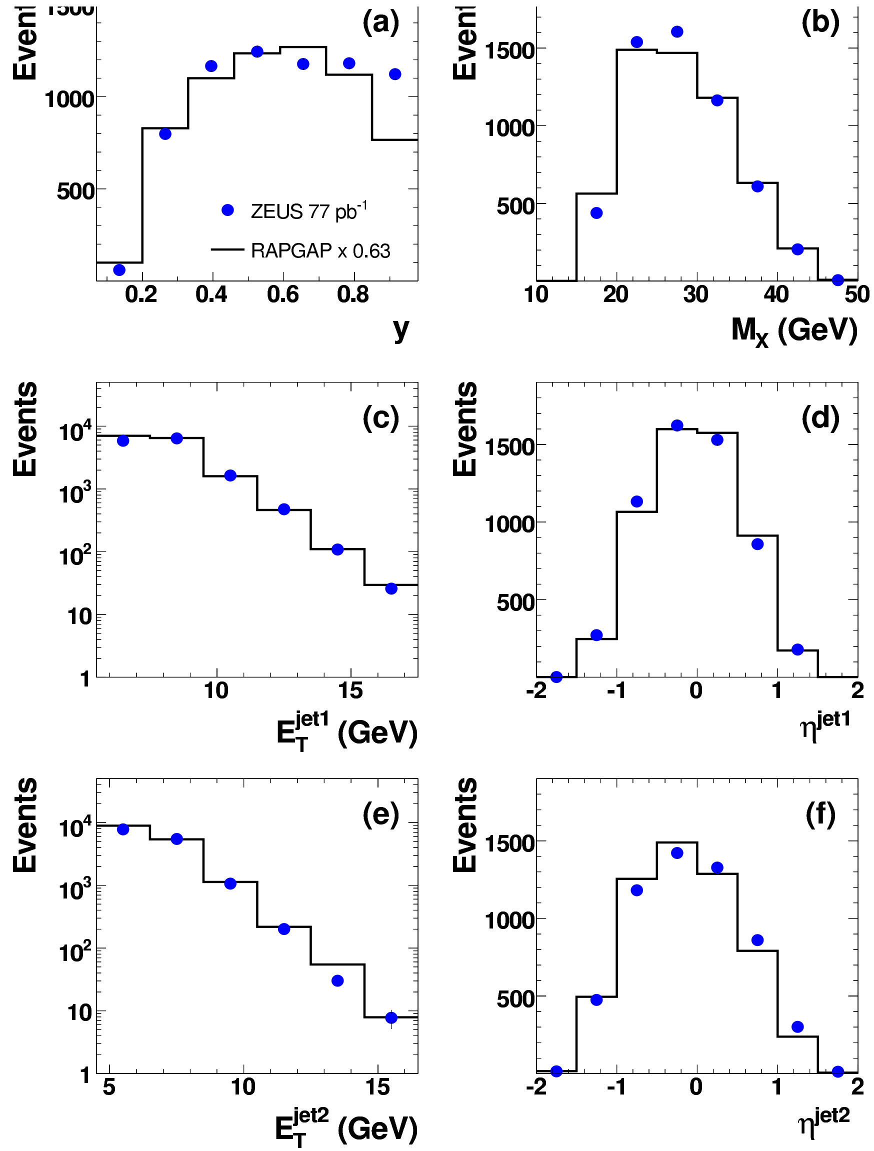


Never-ending discussion on diffractive dijet production at HERA…is it photon issue or rather survival probability issue?

Needed measurement of gap survival probability


H1 VFPS data
RAPGAP × 0.83
NLO H12006 Fit-B × 0.83 × (1+δ_hadr)
H1
ratio to NLO
1.5
1
0.5
0
γp
DIS
0
2
10
Q² [GeV²]
H1 VFPS data
NLO H12006 Fit-B × 0.83 × (1+δ_hadr)
GRV γ-PDF
AFG γ-PDF
μ²=⟨E_T^*jet⟩²+Q²
μ²=(E_T^*jet1)²+Q²/4
H1
DIS
γp
γp/DIS
0.5
1
1.5
ratio to NLO


H1 VFPS data - γp
MC Rapgap - γp
H1 VFPS data - DIS
MC Rapgap - DIS
Events
E_T^{*jet1} [GeV]

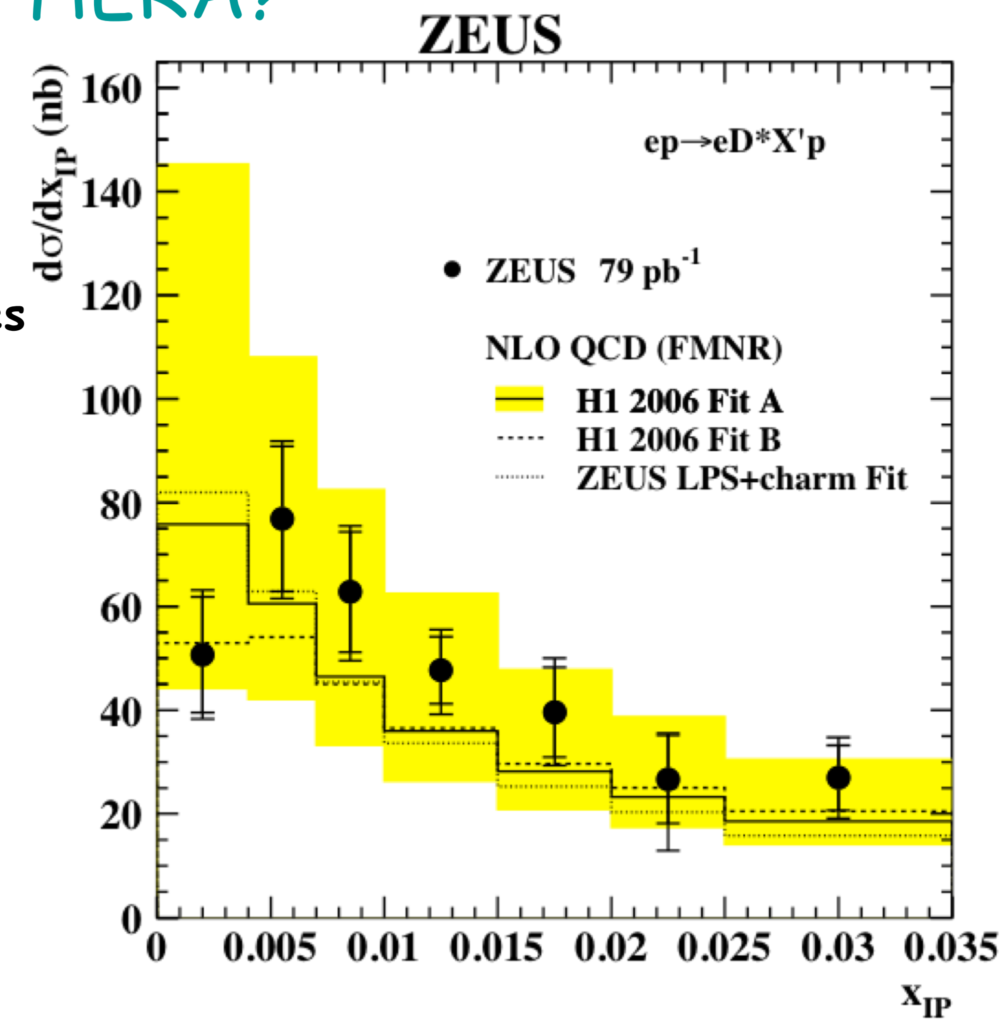

(a)
(b)
(c)
(d)
(e)
(f)
ZEUS 77 pb^{-1}
RAPGAP x 0.63
Events
y
M_X (GeV)
E_T^{jet1} (GeV)
η^{jet1}
E_T^{jet2} (GeV)
η^{jet2}

Rescattering effects at HERA?

DIFF CHARM PRODUCTION

H1 and ZEUS HERA I results

No suppression seen within uncertainties



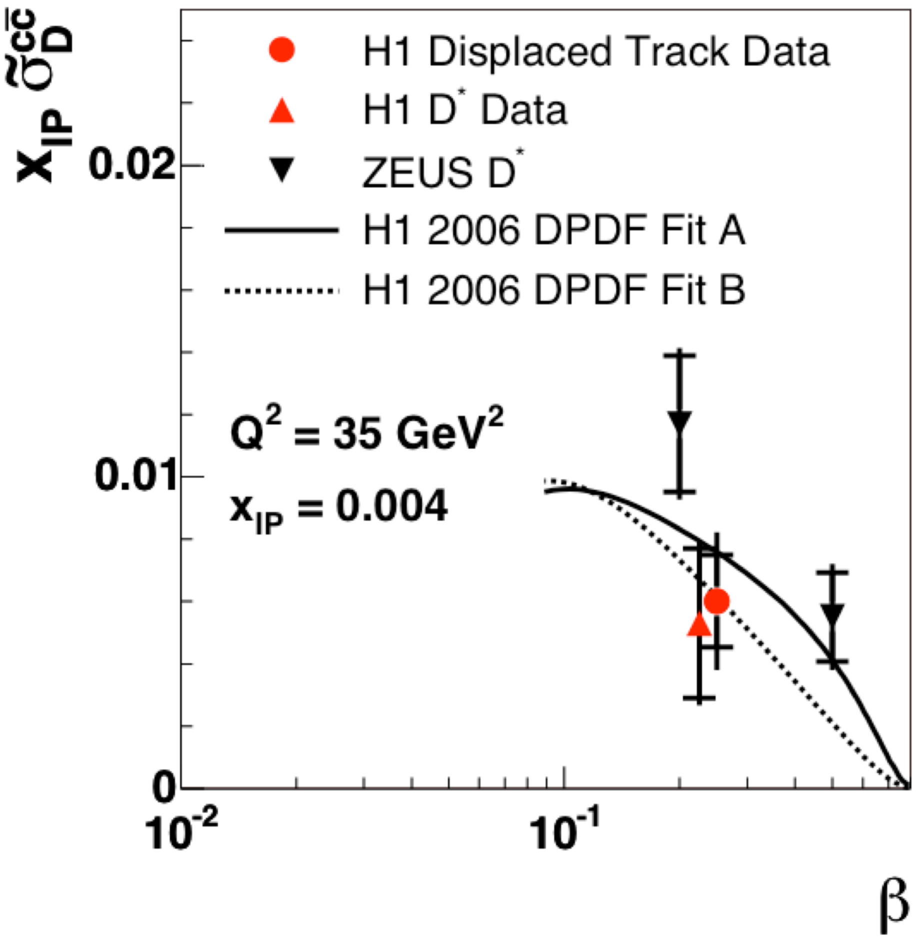
Large experimental and theoretical uncertainties

Not done

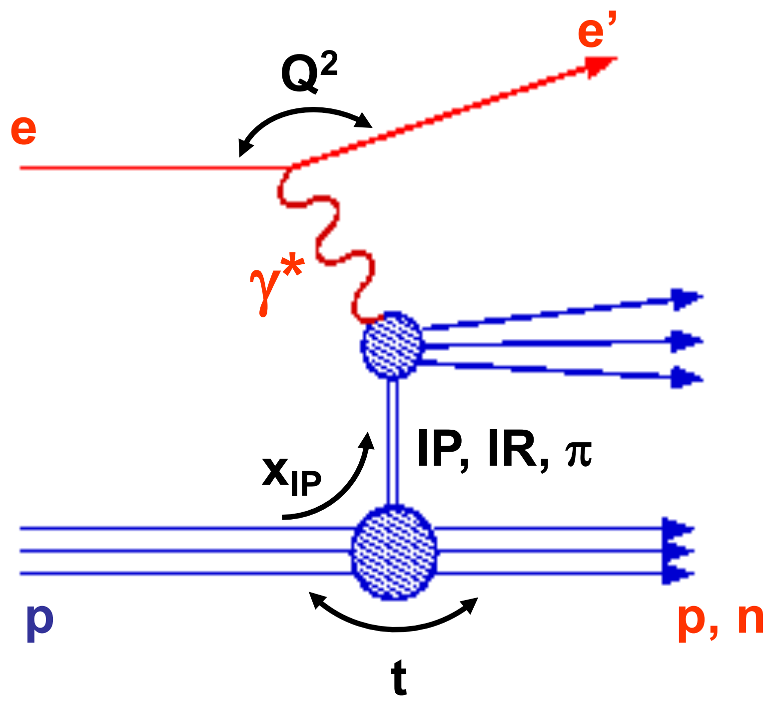
F_2^b, F_2^c with proton tag

F_2^c measured with LRG
(HERA I data)

Nice ingredients for a global fit



QCD fit to leading baryon data



Leading proton and neutron spectra important for cosmic ray community

Yet another way to investigate the proton structure -- measure F_2^{LP}, F_2^{LN} and extract corresponding PDFs

QCD fits to leading neutron data → F_2^π

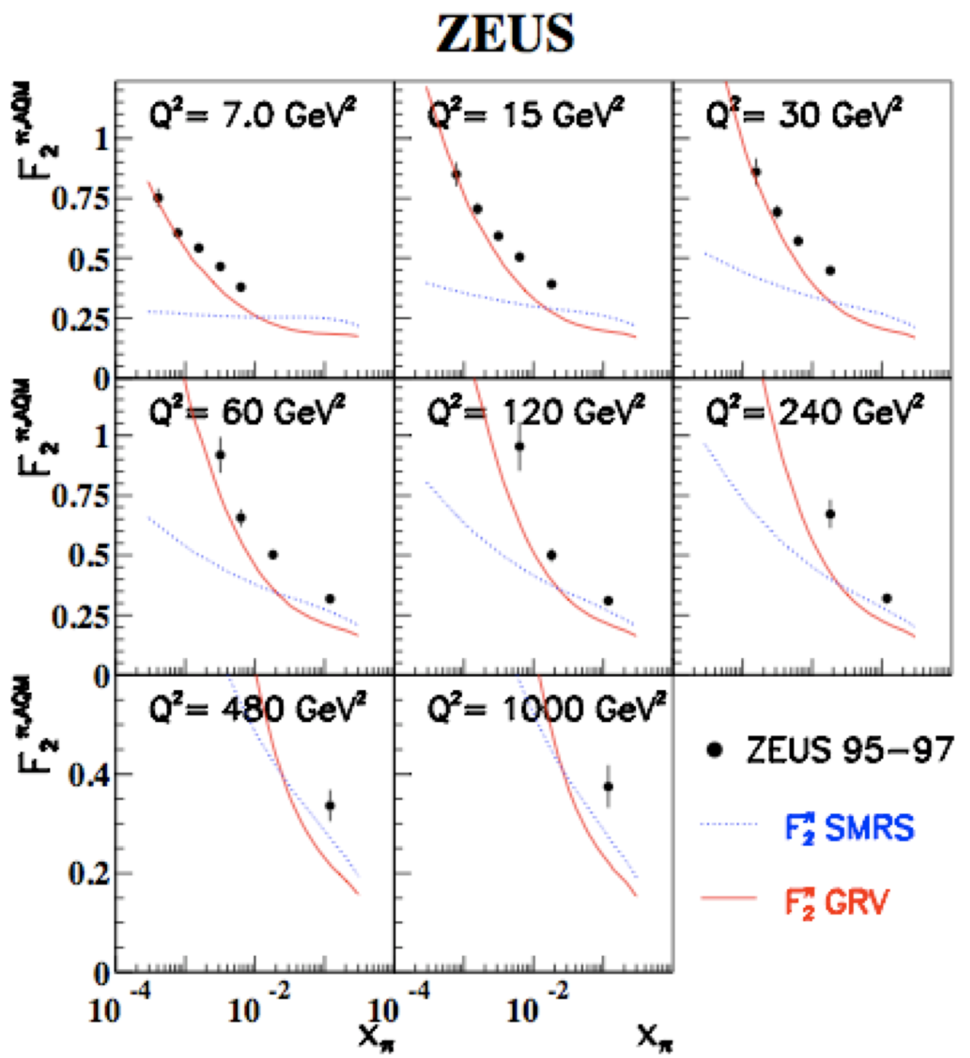


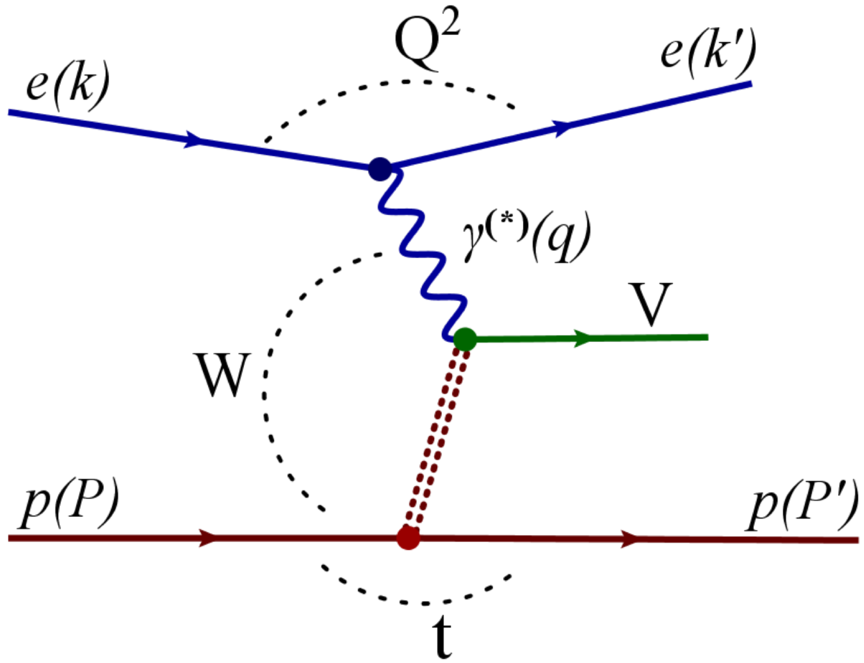
Figure 19: F_2^π as a function of x_π for the pion in bins of Q^2 determined for $0.64 < x_L < 0.82$. The pion flux used to determine F_2^π is the flux obtained using the additive quark model (AQM) of Eq. (21). The uncertainty shown on $F_2^{\pi,AQM}$ arises from the statistical uncertainty due to the leading neutron added in quadrature with the uncertainty on F_2. Not shown are the correlated systematic uncertainties given in Table 1. The solid curves are F_2^π from the GRV parameterisation [76] while the dotted curves are from the Sutton *et al.* parameterisation [77].

H1 and ZEUS HERA I results

F_2^π measured but never fitted

In principle can extract pion PDFs!

Vector meson (VM) production

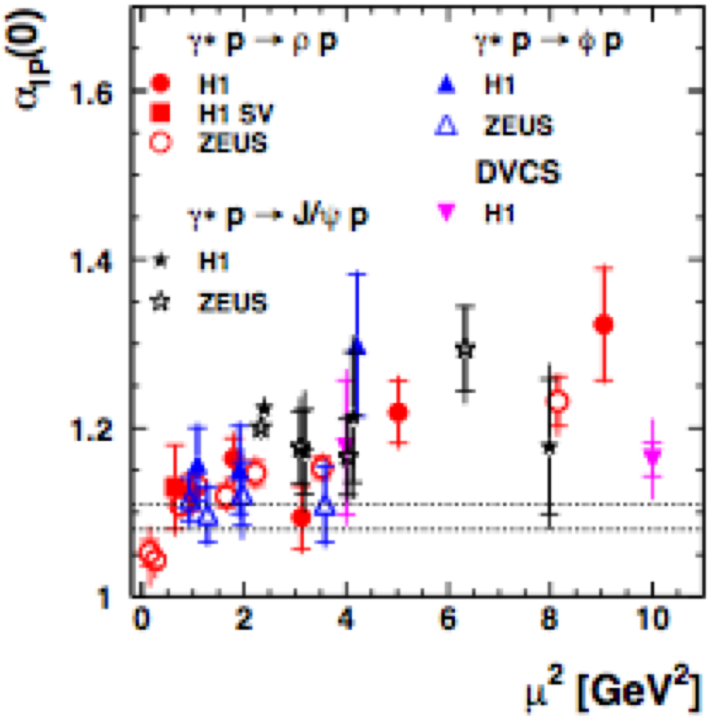


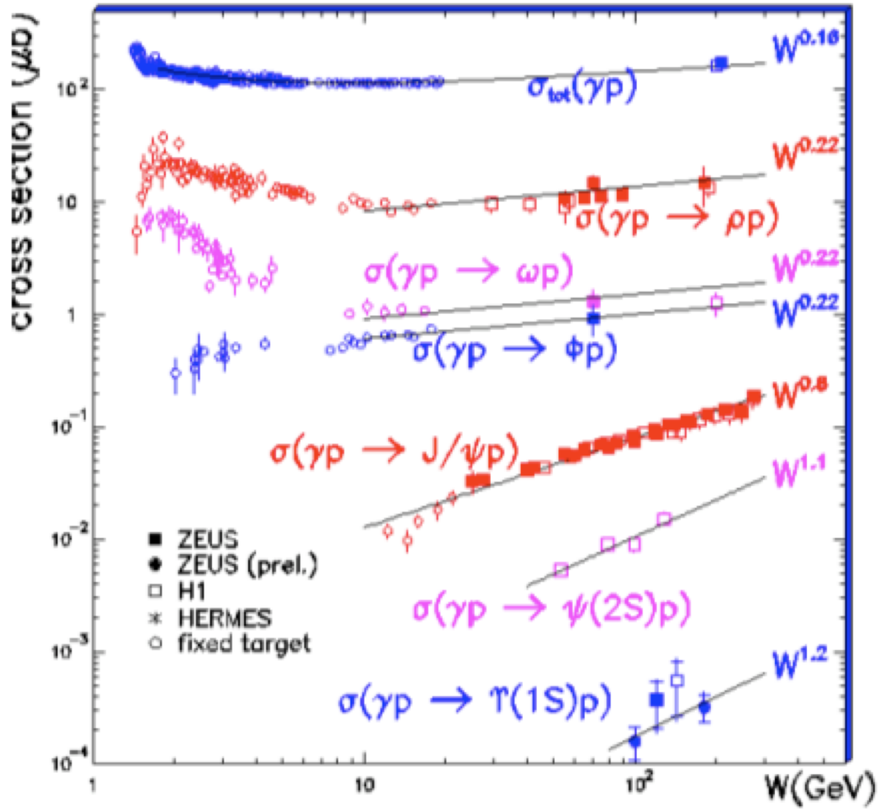
VM production

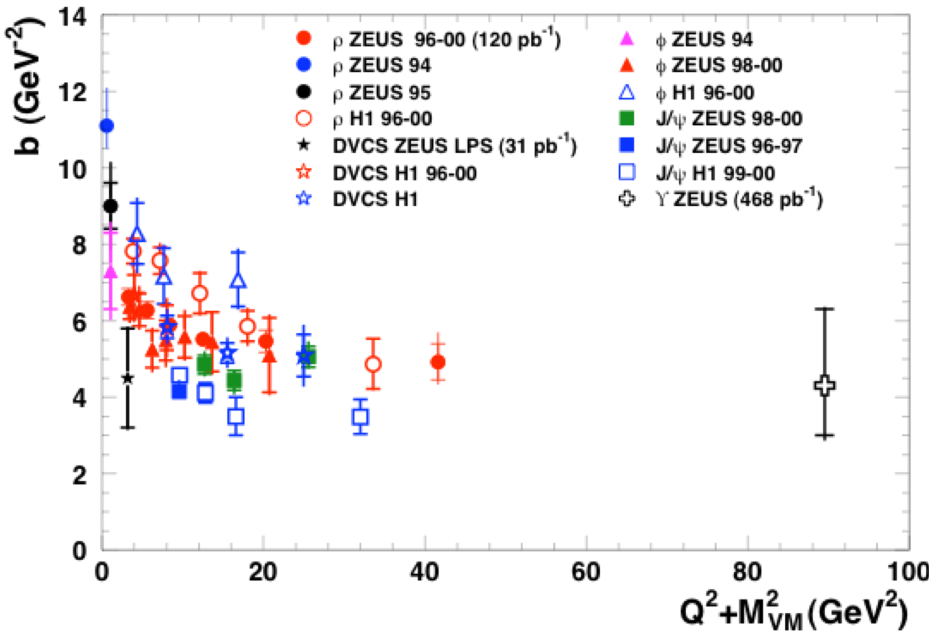
Rich harvest documented by tens of papers

Large W interval

Wide range of several scales (Q^2, t, M_{VM})

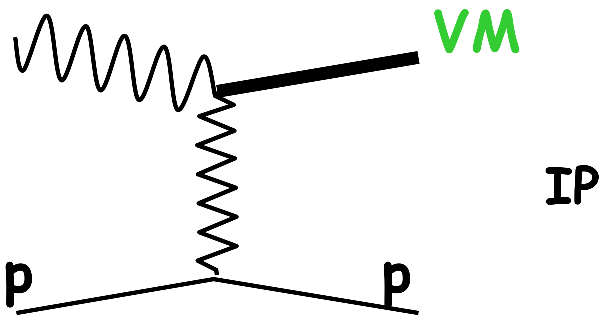




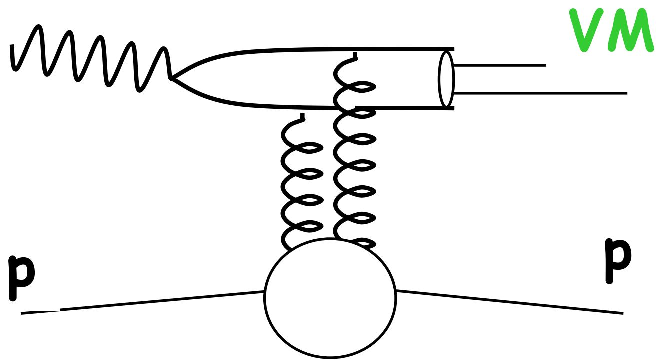


Transition soft → hard

Soft - Regge



Hard - QCD



VM ($J^{PC}=1^{--}$): γ, ρ, ϕ, J/ψ, Υ,...

With increasing scale (Q^2, M_{VM}, t)

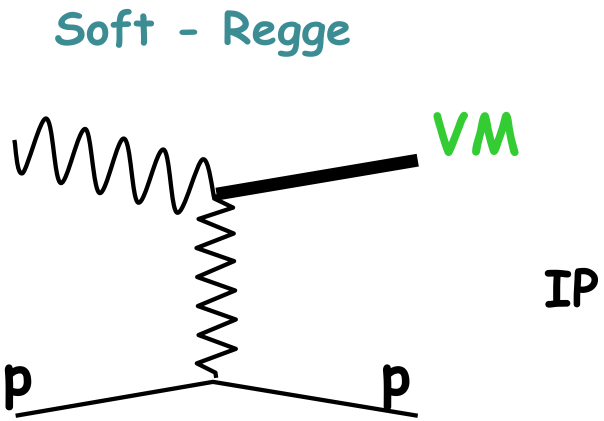
$$\sigma(W) \propto W^{\delta}$$

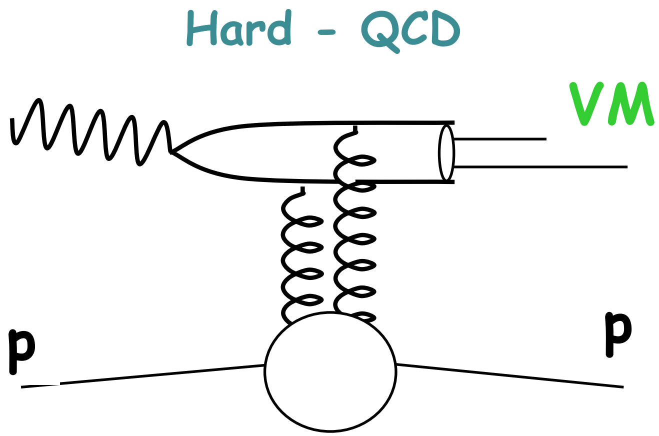
- Expect δ to increase from soft (~0.2, 'soft Pomeron' value) to hard (~0.8, reflecting large gluon density at low x)

$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

- Expect b to decrease from soft (~10 GeV^{-2}) to hard (~4-5 GeV^{-2})

Transition soft → hard





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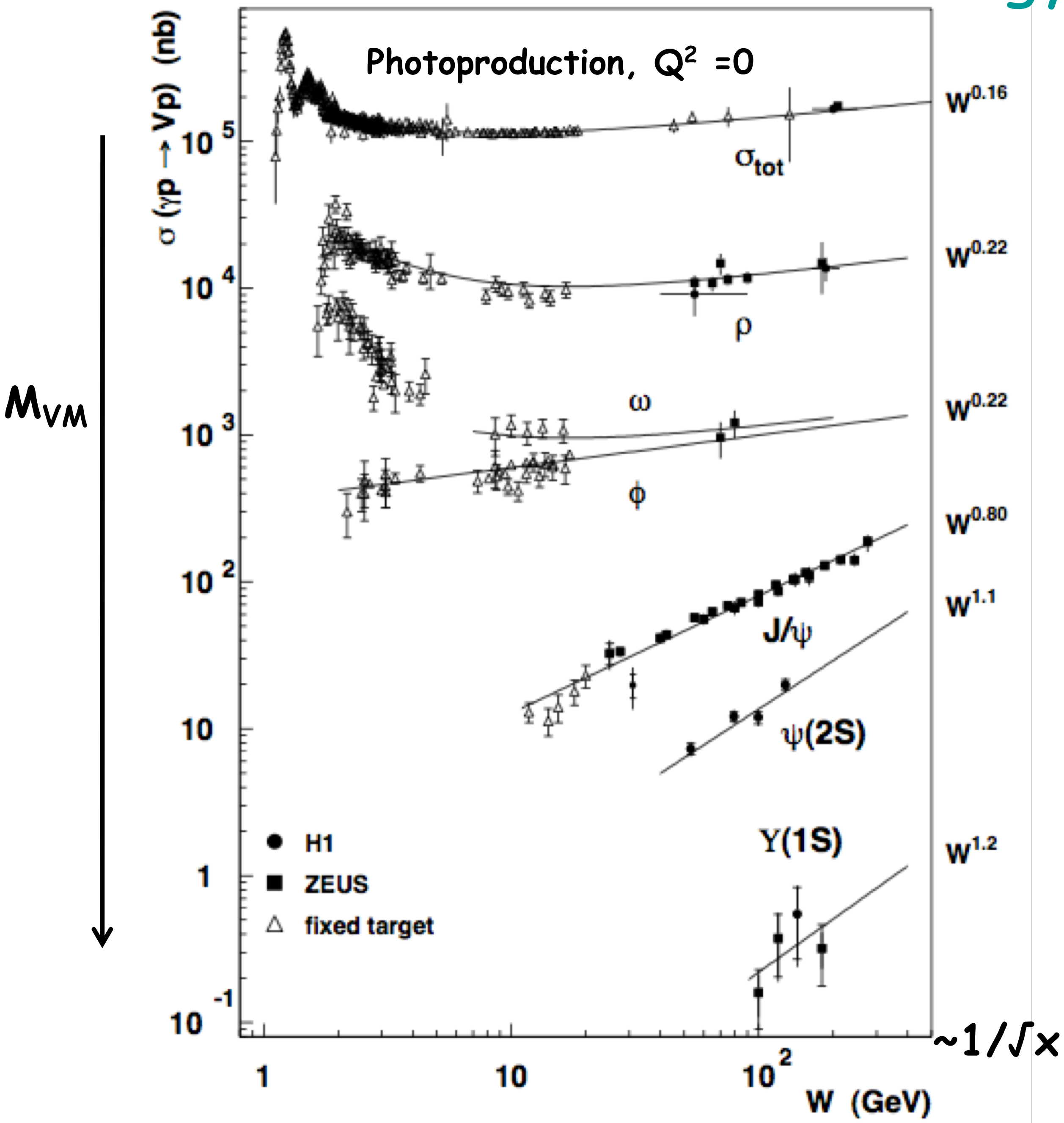
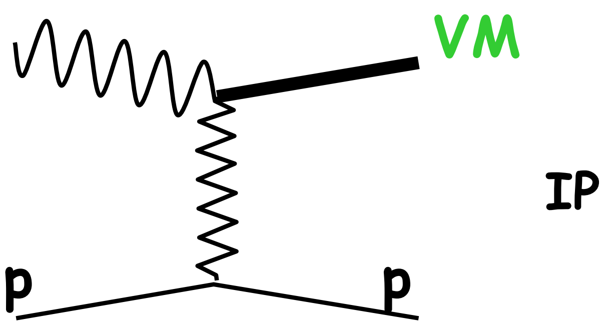
Transition soft → hard: energy dependence



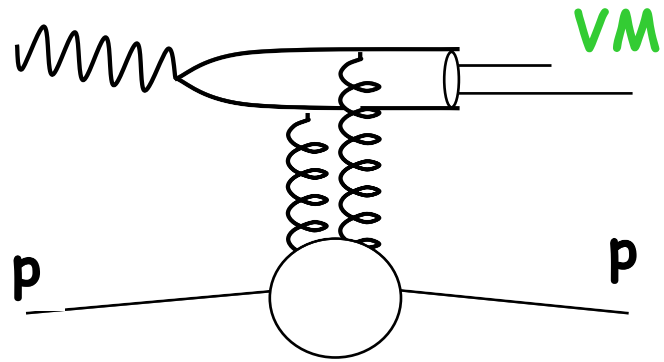
Here scale is M_{VM} – same observed when varying Q^2 for a given VM

Transition soft → hard

Soft - Regge



Hard - QCD



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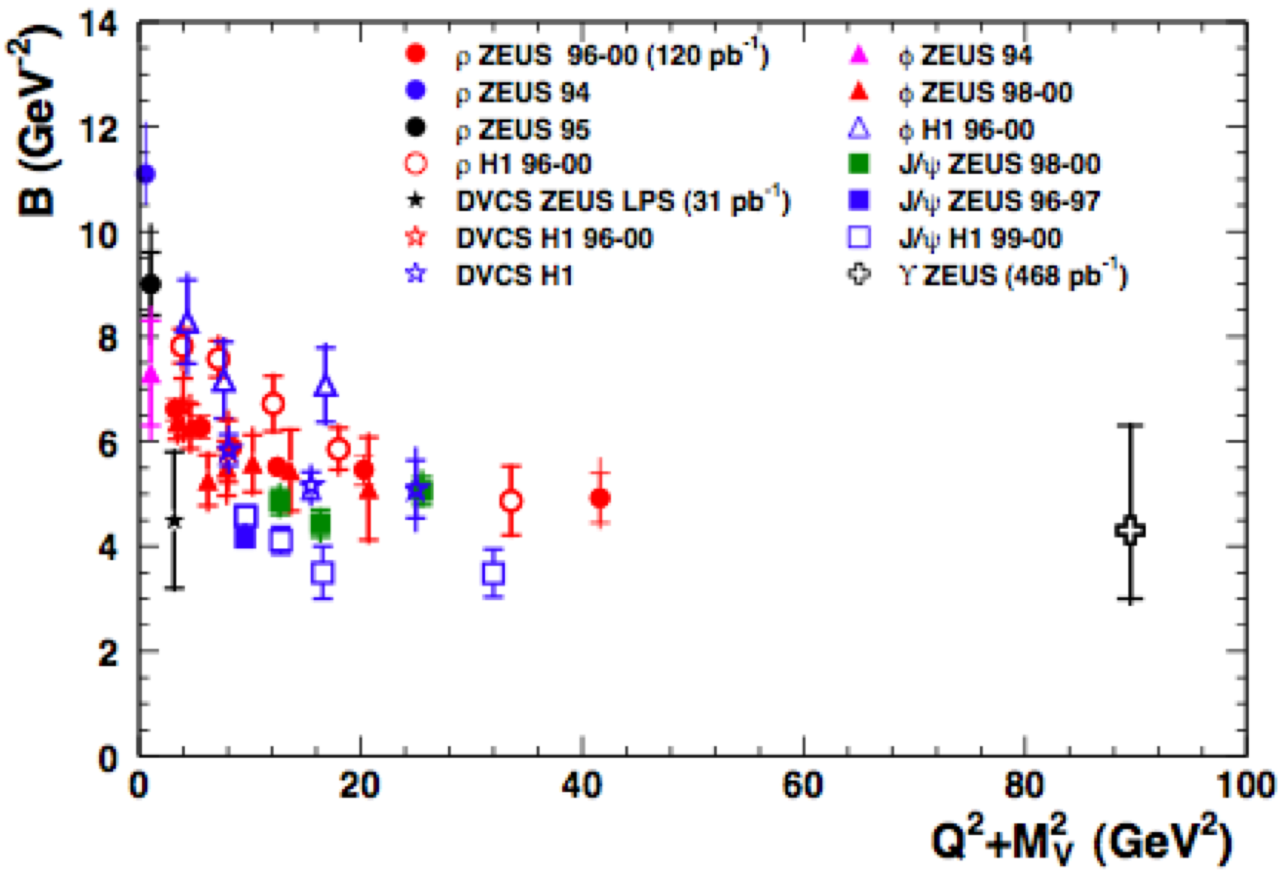
Transition soft → hard: t-slope dependence



$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

As in optical diffraction, size of diffractive cone related to size of interacting objects

b ≈ b_{VM} + b_{ps}

For p.diss. proton breaks → $b_{p.diss.}$ smaller than $b_{el.}$

Inclusive and semi-inclusive opportunities at EIC

- Leading proton in a much wider range of t and xL
- t dependence of IR contribution csi > 0.1
- FLD promising (high luminosity variable cme)
- Unique opportunity to improve DPDF extraction at high z, Fig. 7.33

What about dijets? Lower average energy than at HERA