Diffraction at HERA

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on behalf of H1 and ZEUS Collaborations
Photon 2011, Spa, Belgium
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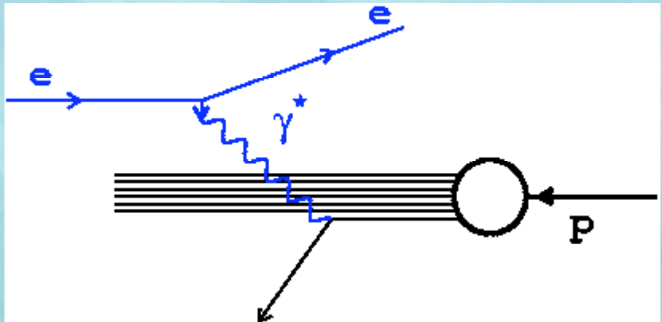
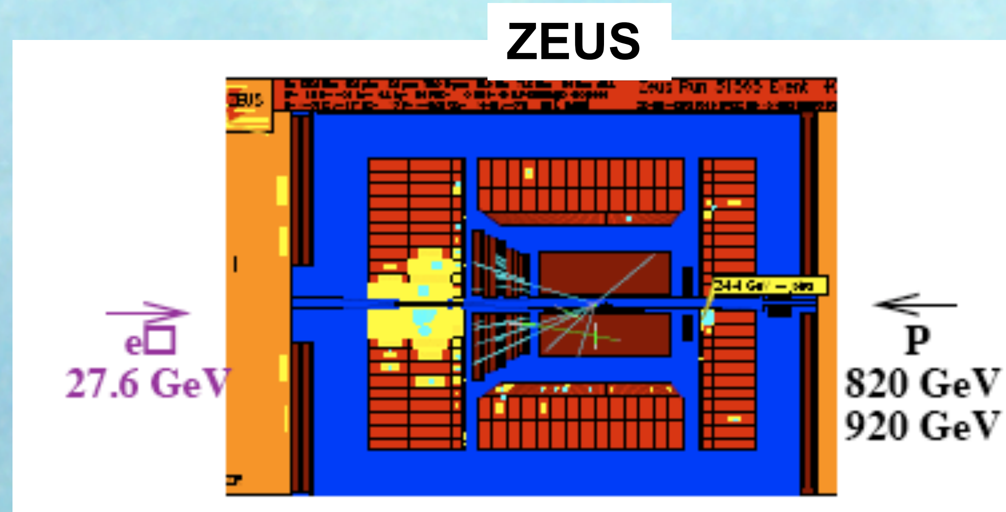
Surprise of HERA

Non-Diffractive Scattering

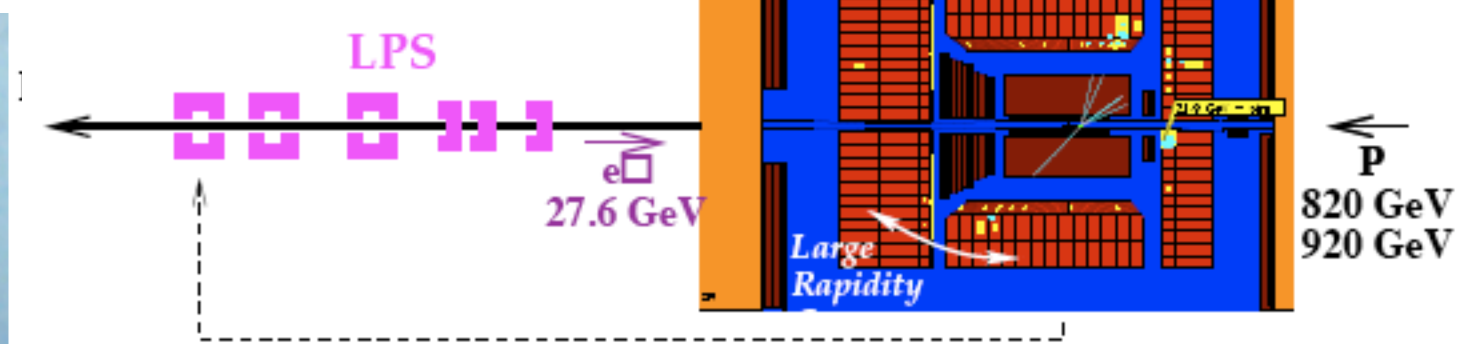




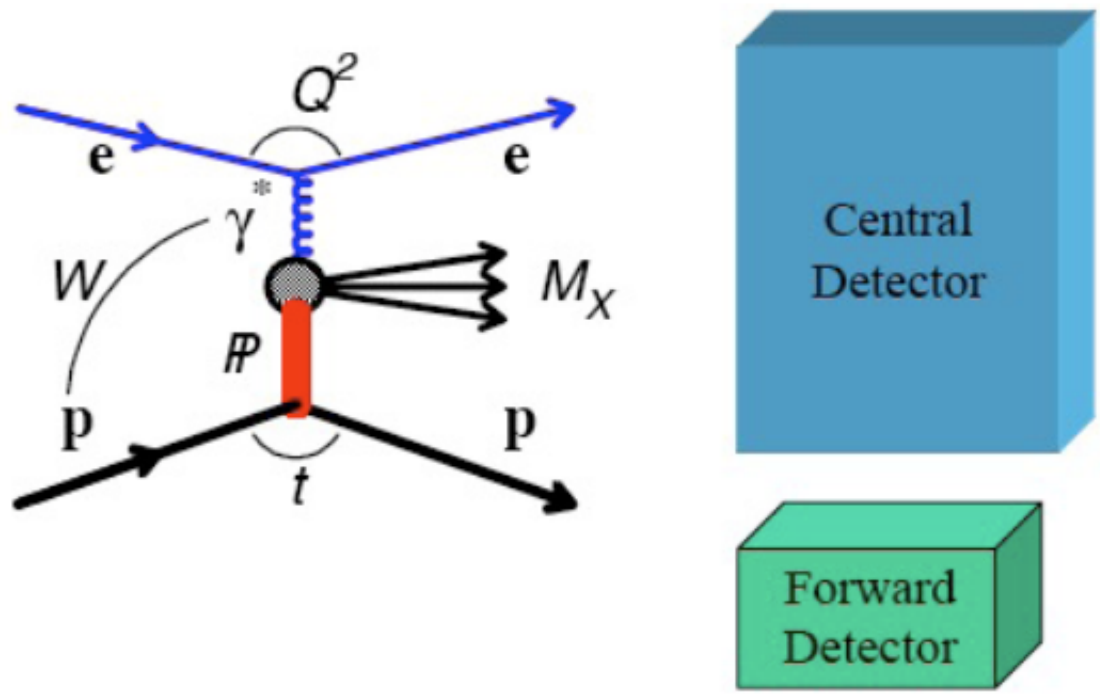
Diffractive Scattering

expectation before HERA
~ 0.01%

seen ~20% at Q^2 = 4 GeV^2
~10% at Q^2 = 20 GeV^2



Diffractive Reactions in DIS



Rapidity Gaps
$\Delta Y = \ln(W^2/M^2_X) \approx \Delta\eta$

Forward protons with $x_L = 1 - x_{IP} > 95\%$
x_L ~ longitudinal fraction of proton momentum

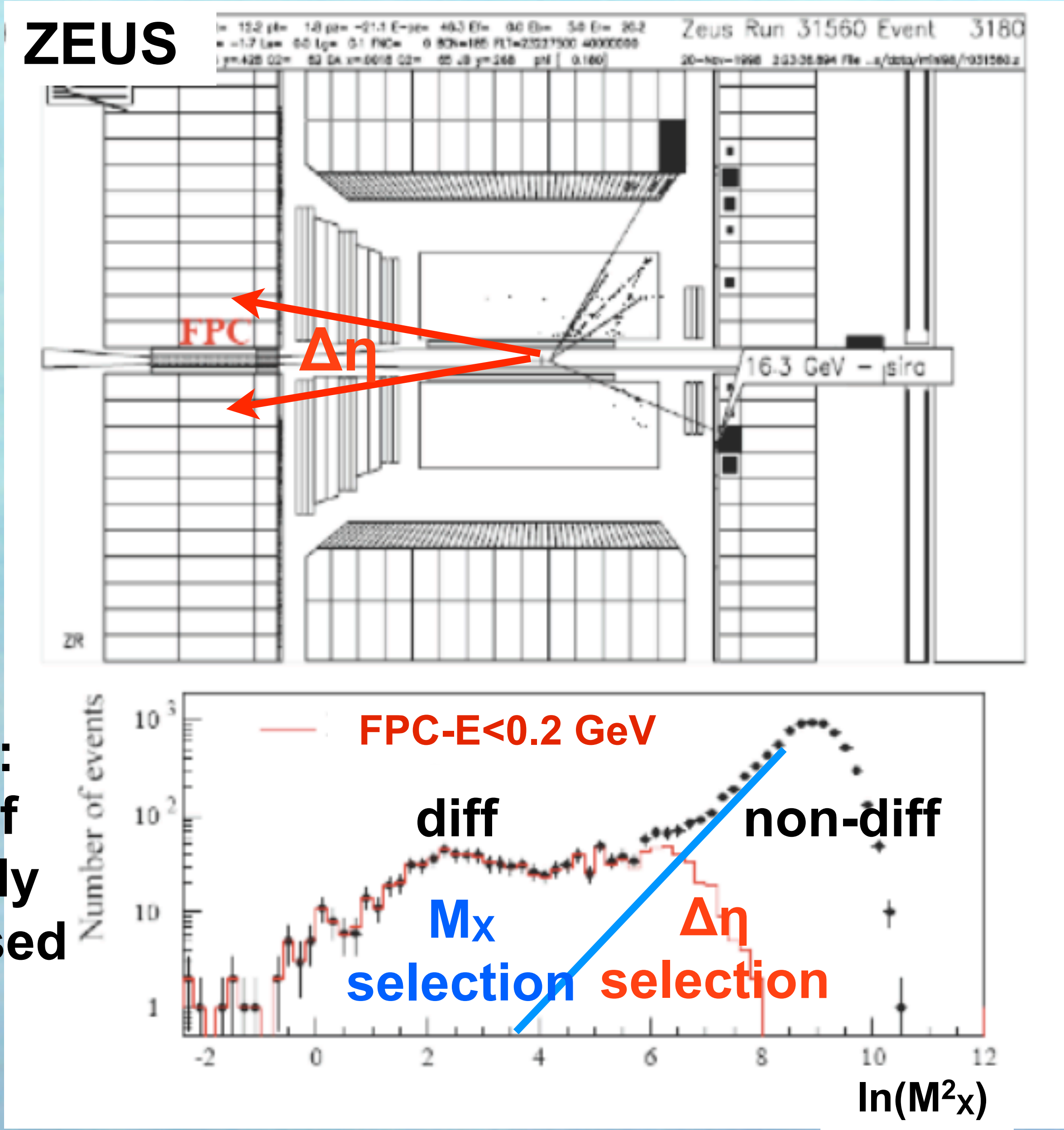
Q^2 - virtuality of the incoming photon
W - CMS energy of the incoming photon-proton system
x - $\approx Q^2/W^2$

M_X - invariant mass of all particles seen in the detector
t - momentum transfer to the diffractively scattered proton

$\beta = Q^2/(Q^2 + M^2)$ $\quad$ $x_{IP} = (Q^2 + M^2)/(W^2 + M^2)$

Diffractive Signatures

Large Rapidity Gap - $\Delta\eta$ selection

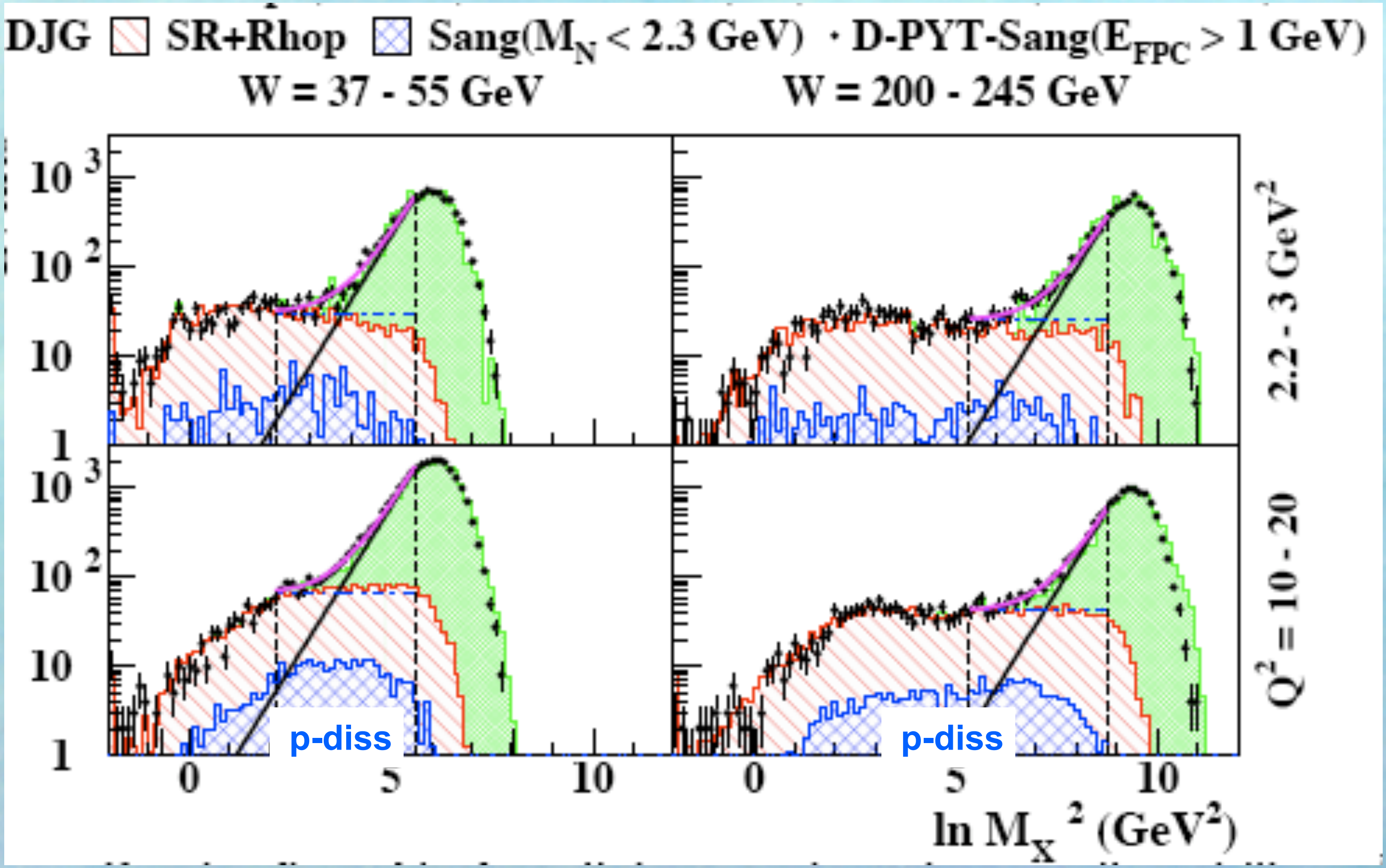


Accidental LRG ?

M_X Method: selection of exponentially nonsuppressed RG

$\Delta\eta \approx \ln(W^2/M^2_X)$

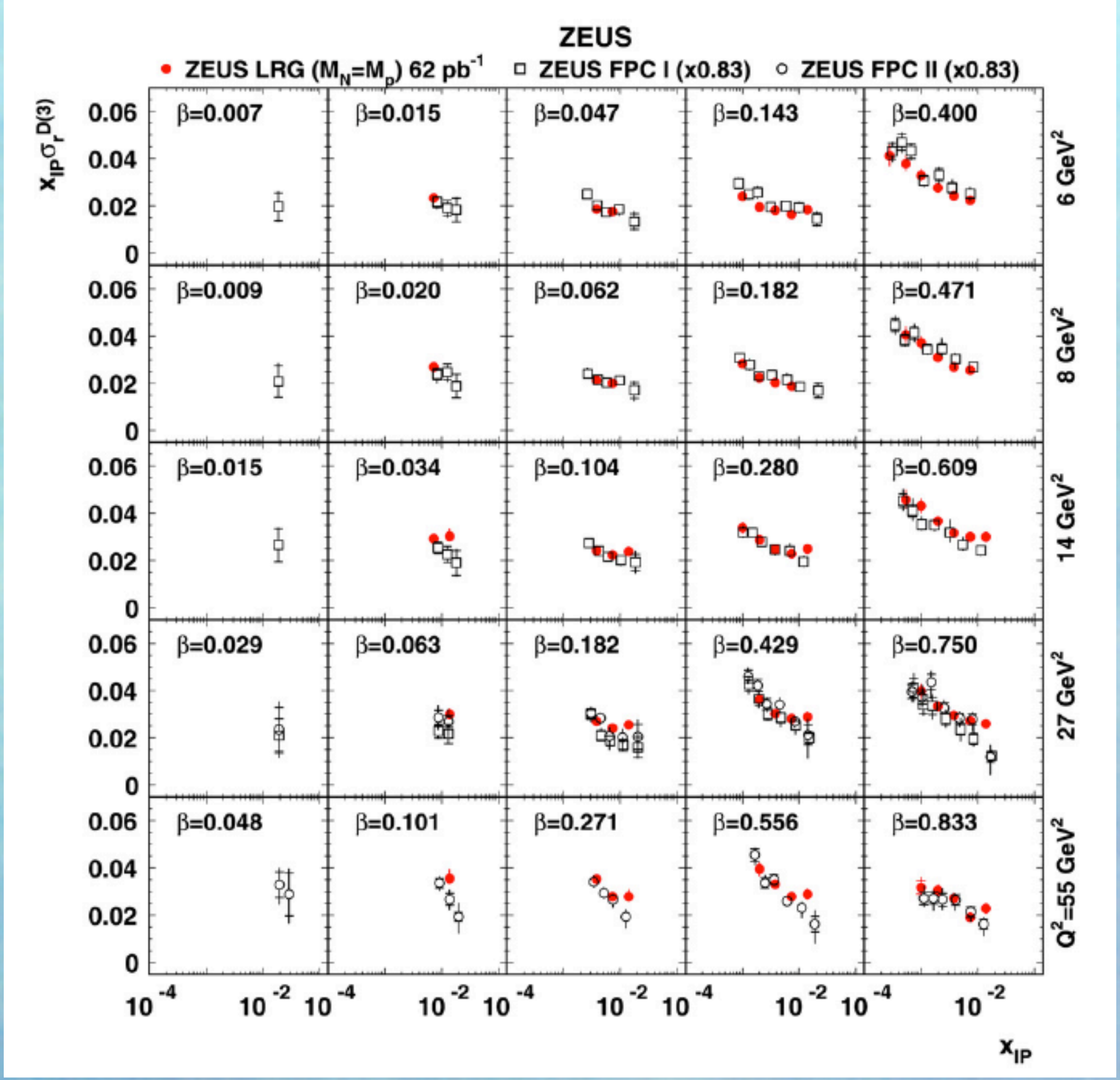
ZEUS



M_X and LRG methods have a different sensitivity to the proton dissociation background

some control over p-diss systematic

LRG vs M_X

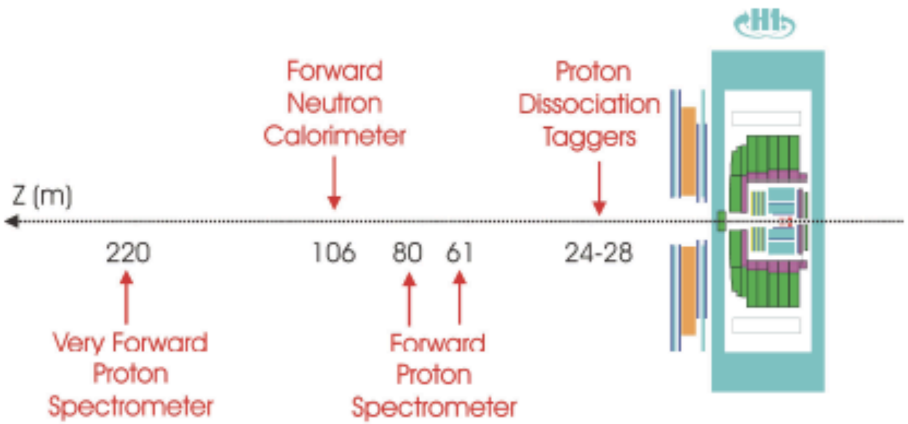


good overall agreement

deviation at large values of x_{IP} are due to different treatment of the reggeon contributions

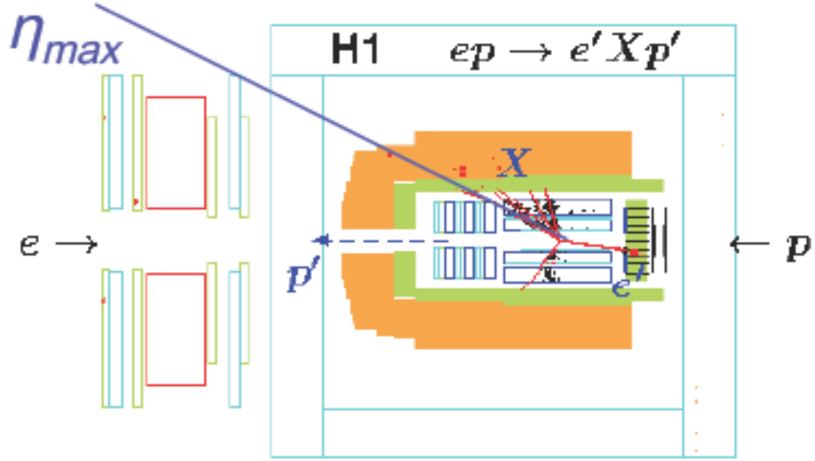
H1 Diffractive Measurements

Scattered proton in Leading Proton Spectrometers **(LPS)**



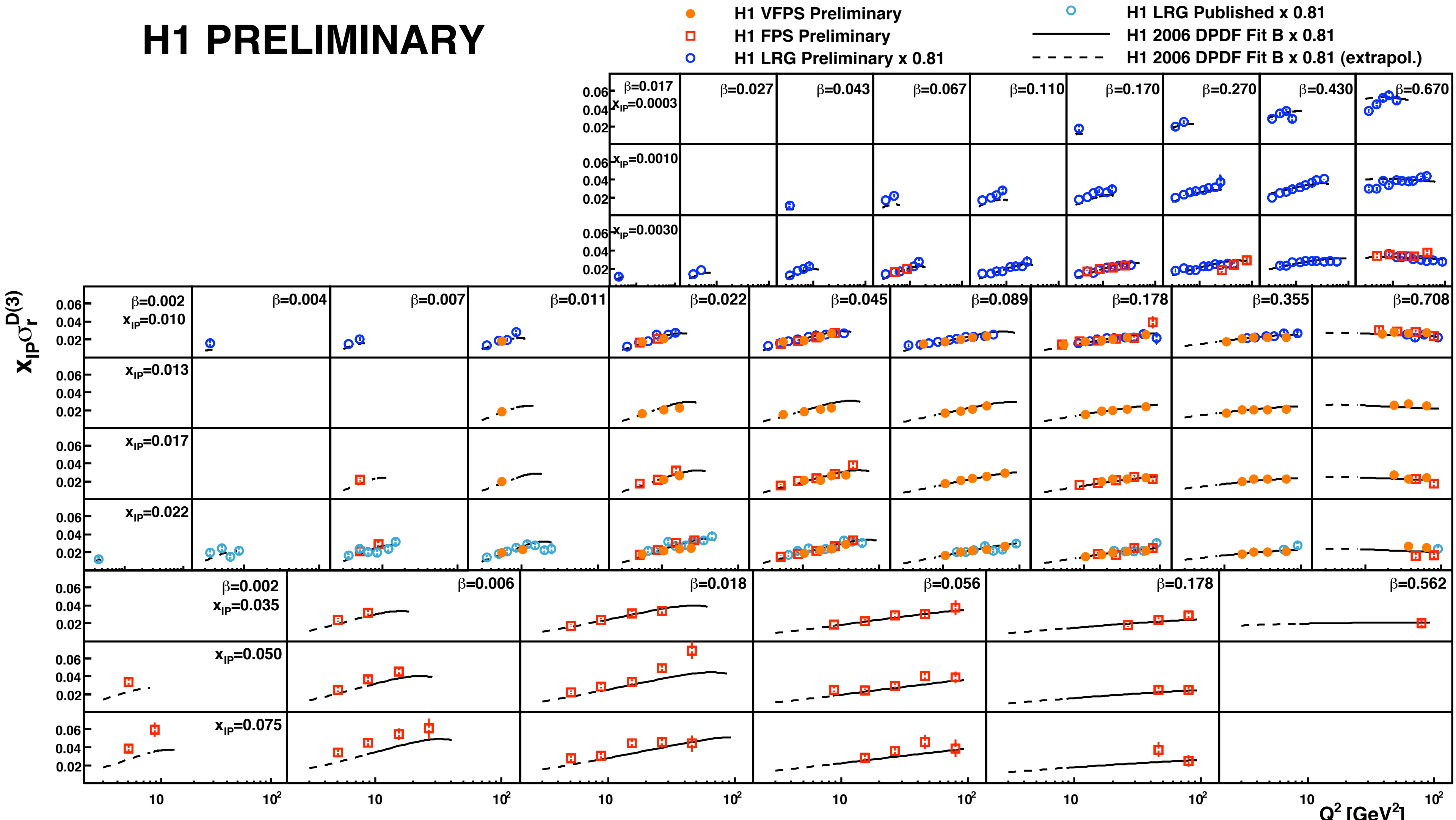
Limited by statistics and p-tagging systematics (as in ZEUS)

`Large Rapidity Gap' **(LRG)** adjacent to outgoing (untagged) proton



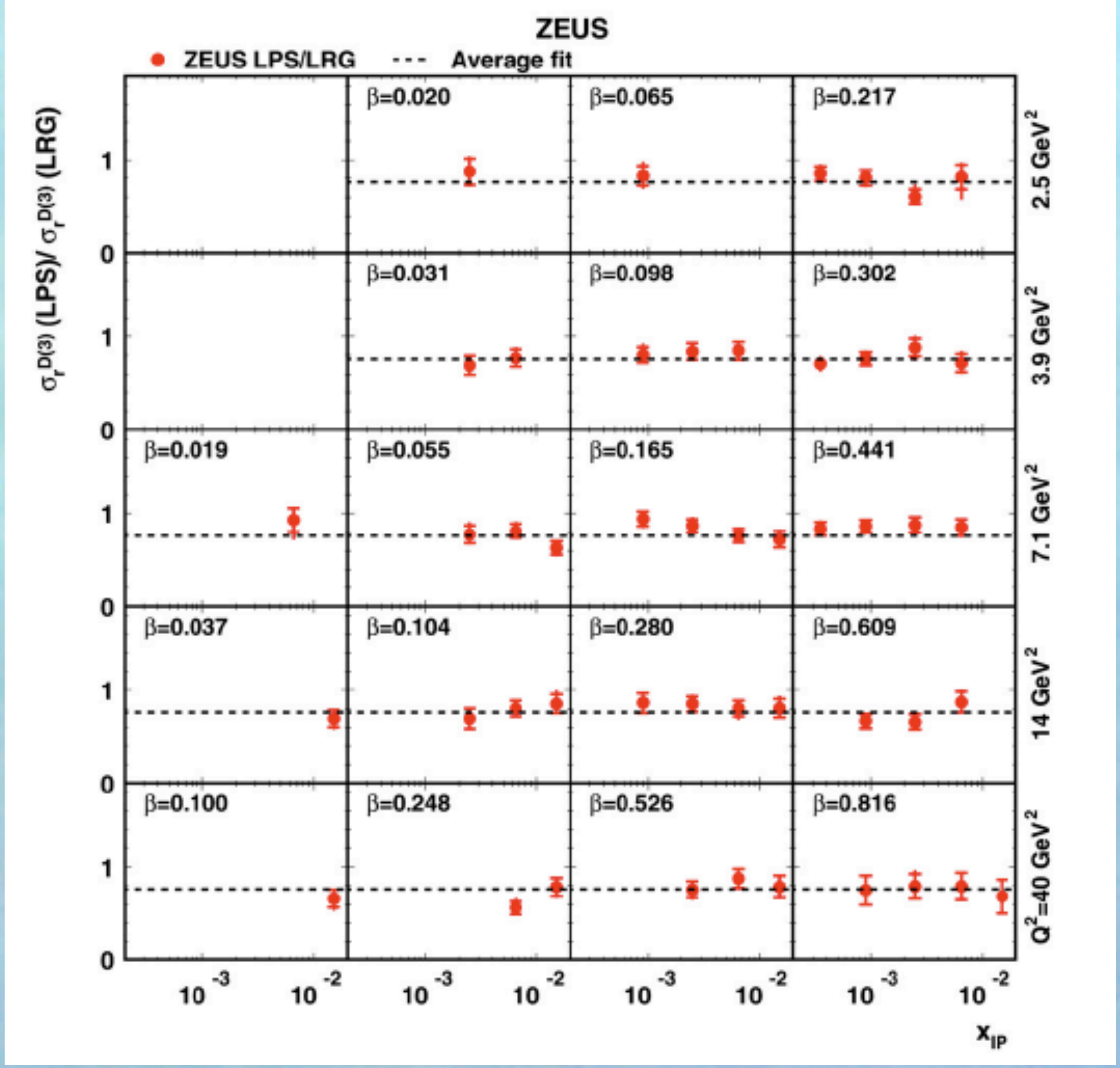
Limited by p-diss systematics (as in ZEUS)

H1 VFPS/FPS/LRG



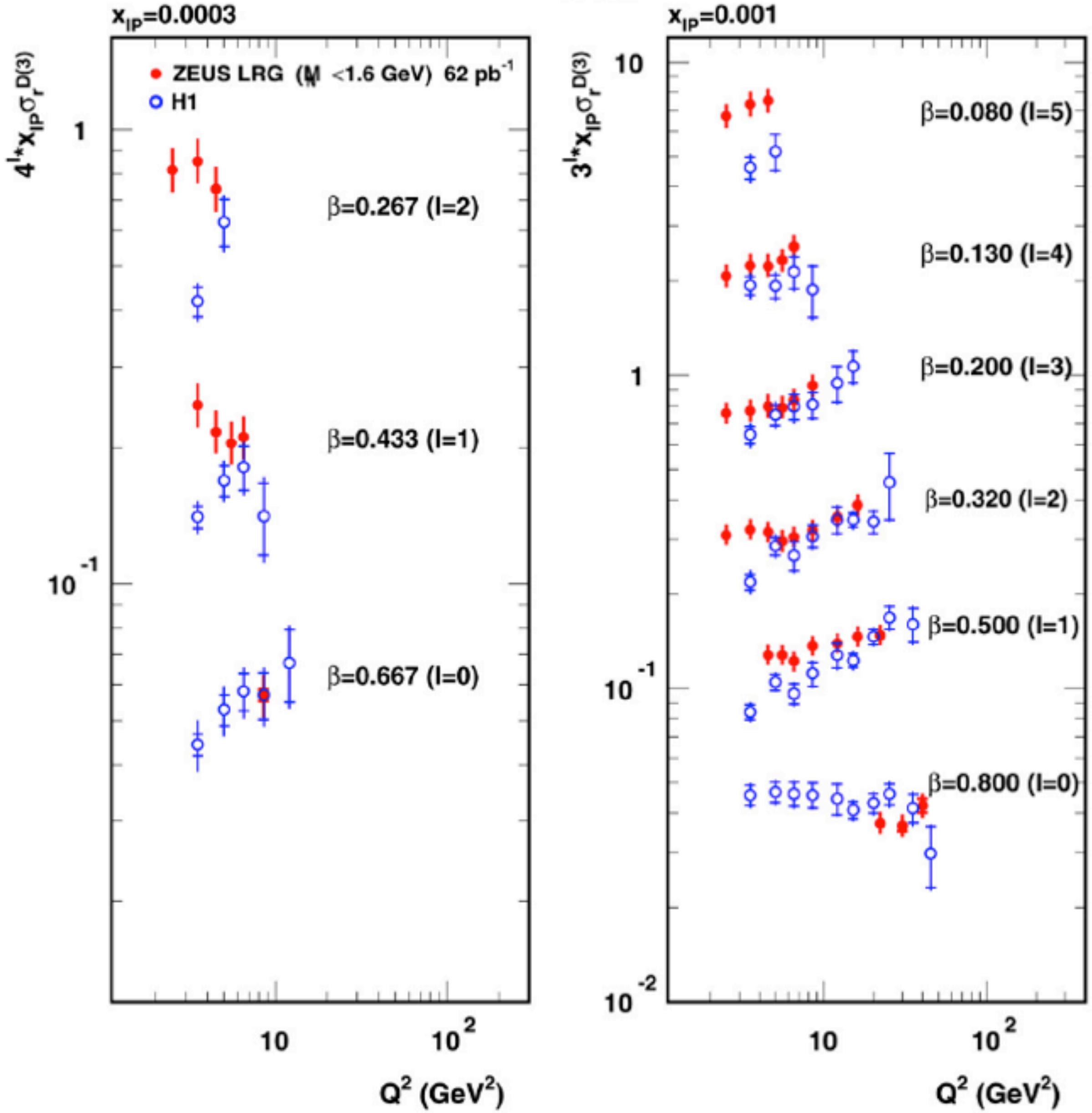
large coverage of phase space and good agreement of the different data sets in regions of mutual coverage

LRG vs LPS



good agreement in shape in regions of mutual coverage from LPS/LRG ⇒ p-diss ~ 20% of LRG for ZEUS and H1

H1-LRG vs ZEUS LRG

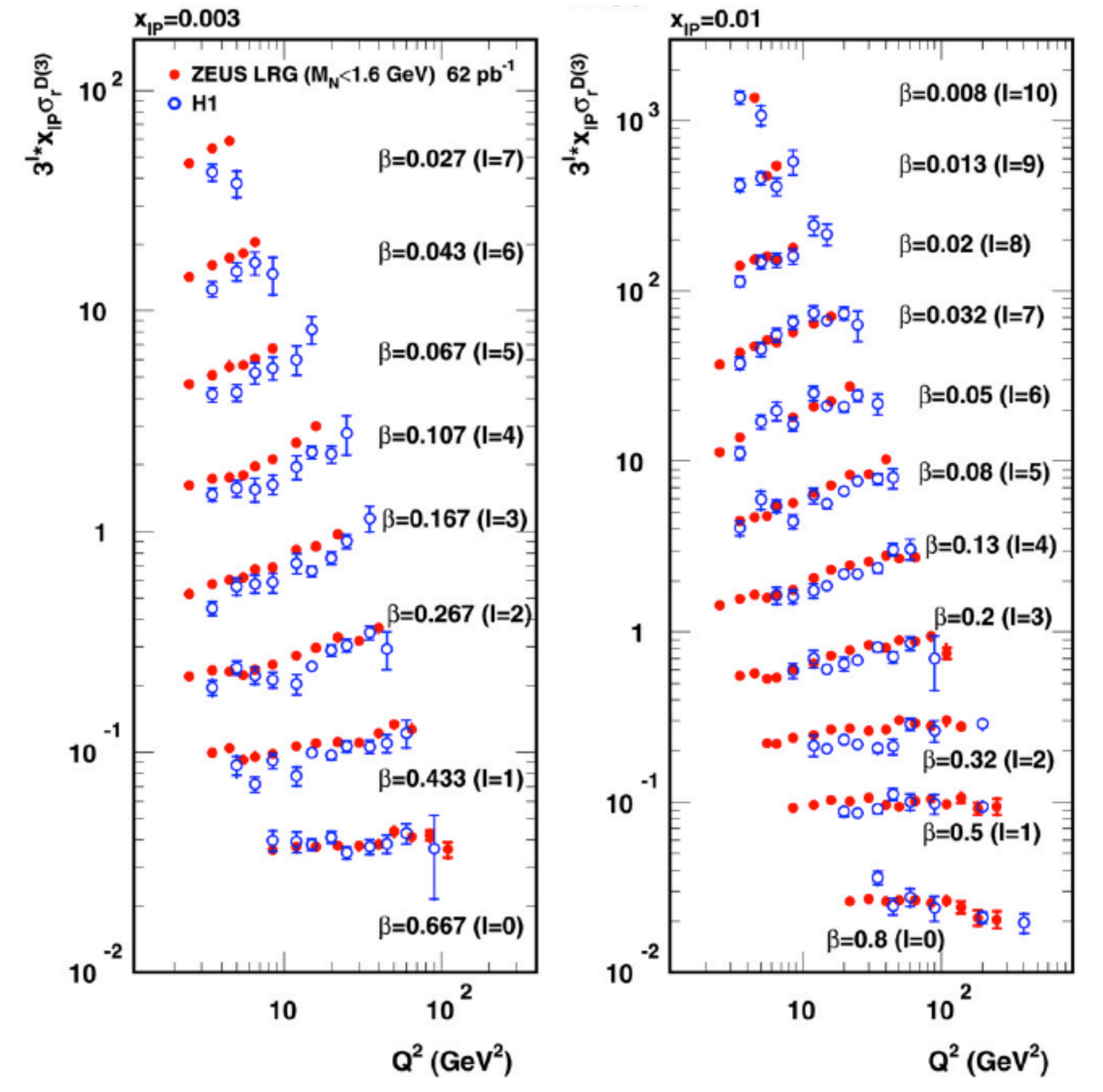


comparison of LRG data is sensitive to systematic effects

F_2 data of H1 and ZEUS agrees very well

p-diss systematic differences?

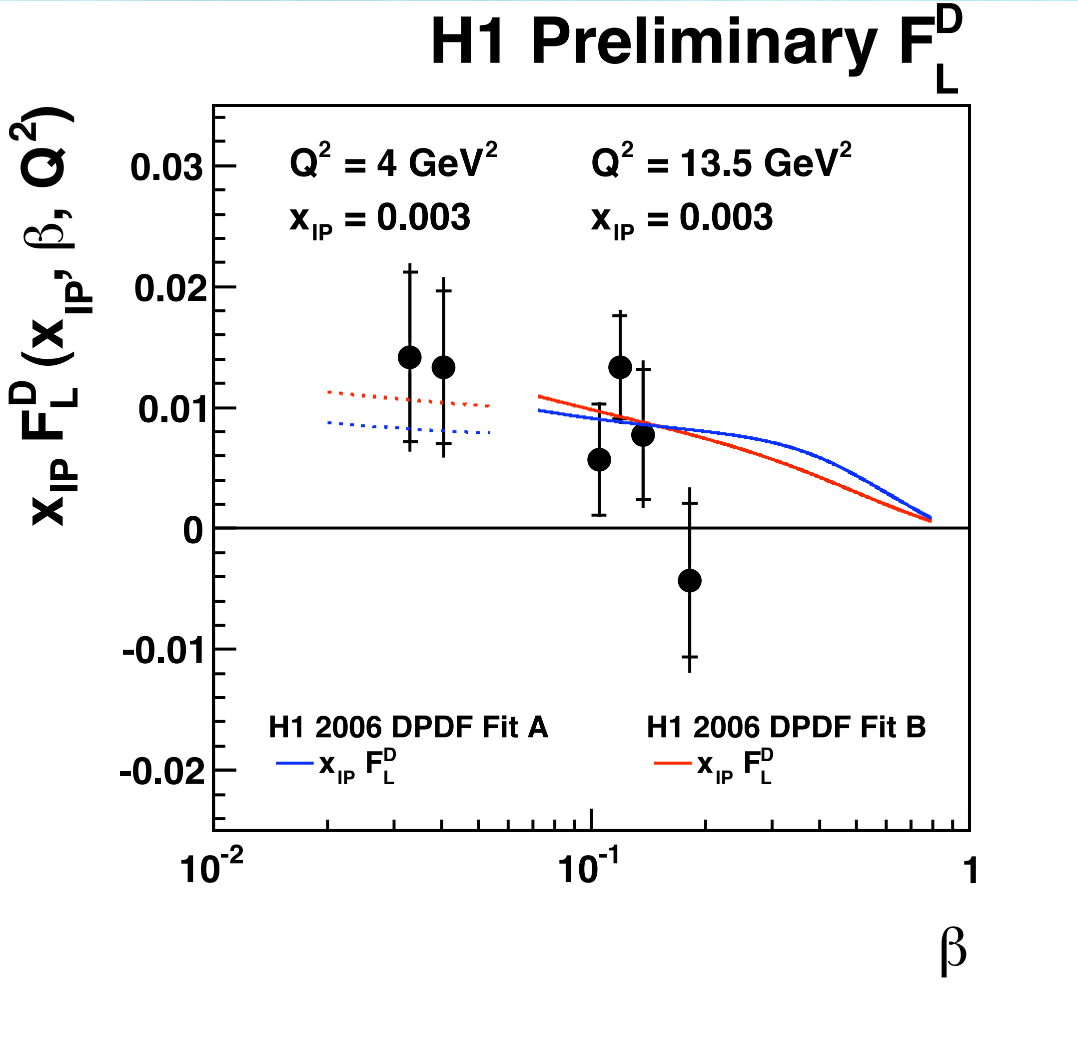
H1-LRG vs ZEUS LRG



general overall agreement

work in progress on understanding systematic differences and on combined H1 and ZEUS inclusive diffraction data

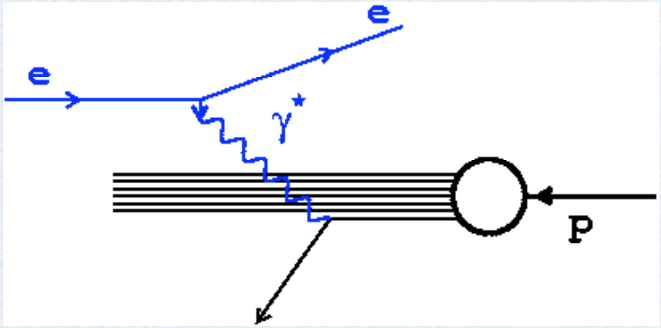
H1 - first measurement of the longitudinal diffractive structure function



possible due to the excellent backward electron measurement in H1

Partons vs Dipoles

Infinite momentum frame: Partons



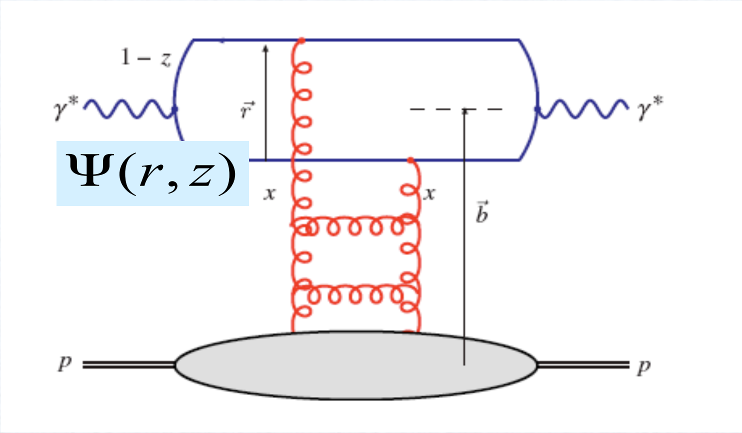
F_2 measures parton density at a scale Q^2

$$F_2 = \Sigma_f \; e_f^2 \; xq(x, Q^2)$$

Proton rest frame: Dipoles - long living quark pair interacts with the gluons of the proton

dipole life time ≈ $1/(m_p\, x)$

$= 10 - 1000$ fm at $x = 10^{-2} - 10^{-4}$

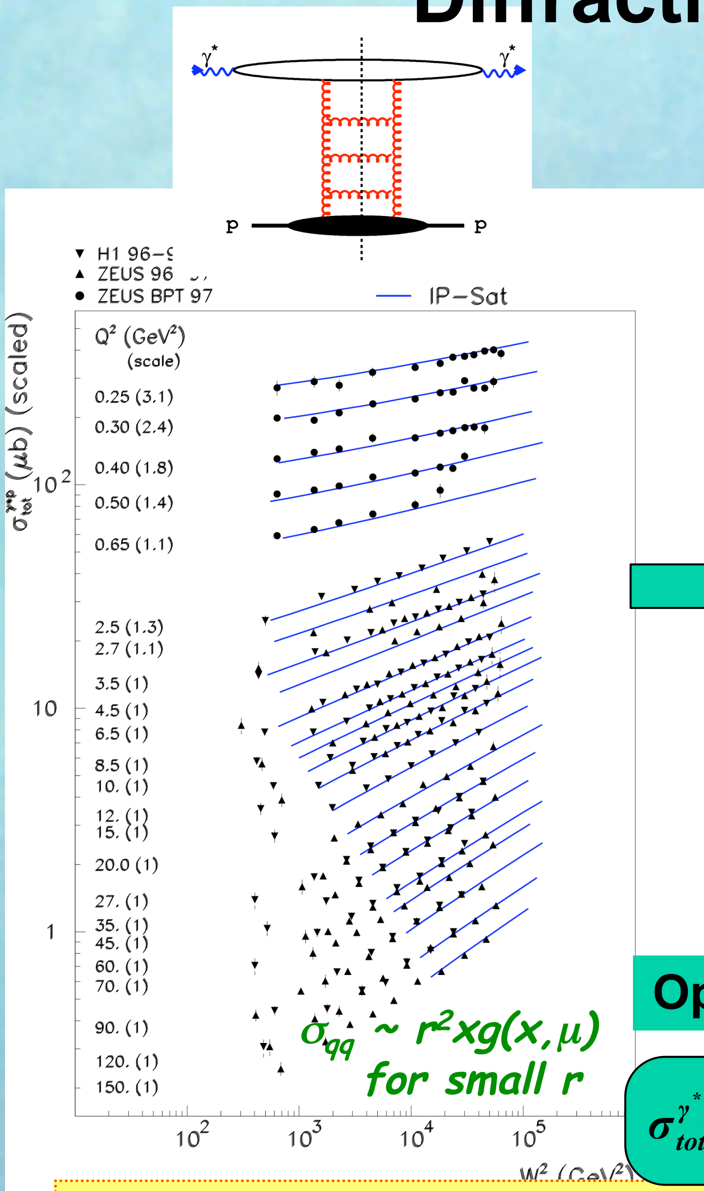


$$\sigma_{tot}^{\gamma^* p} = \int \Psi^* \sigma_{qq} \Psi \; ; \qquad F_2 = \frac{Q^2}{4\pi^2 \alpha_{em}} \sigma_{tot}^{\gamma^* p}$$

for small dipoles, at low-x, dipole picture is equivalent to the QCD parton picture

$\sigma_{qq} \sim r^2 \, xg(x, Q^2)$

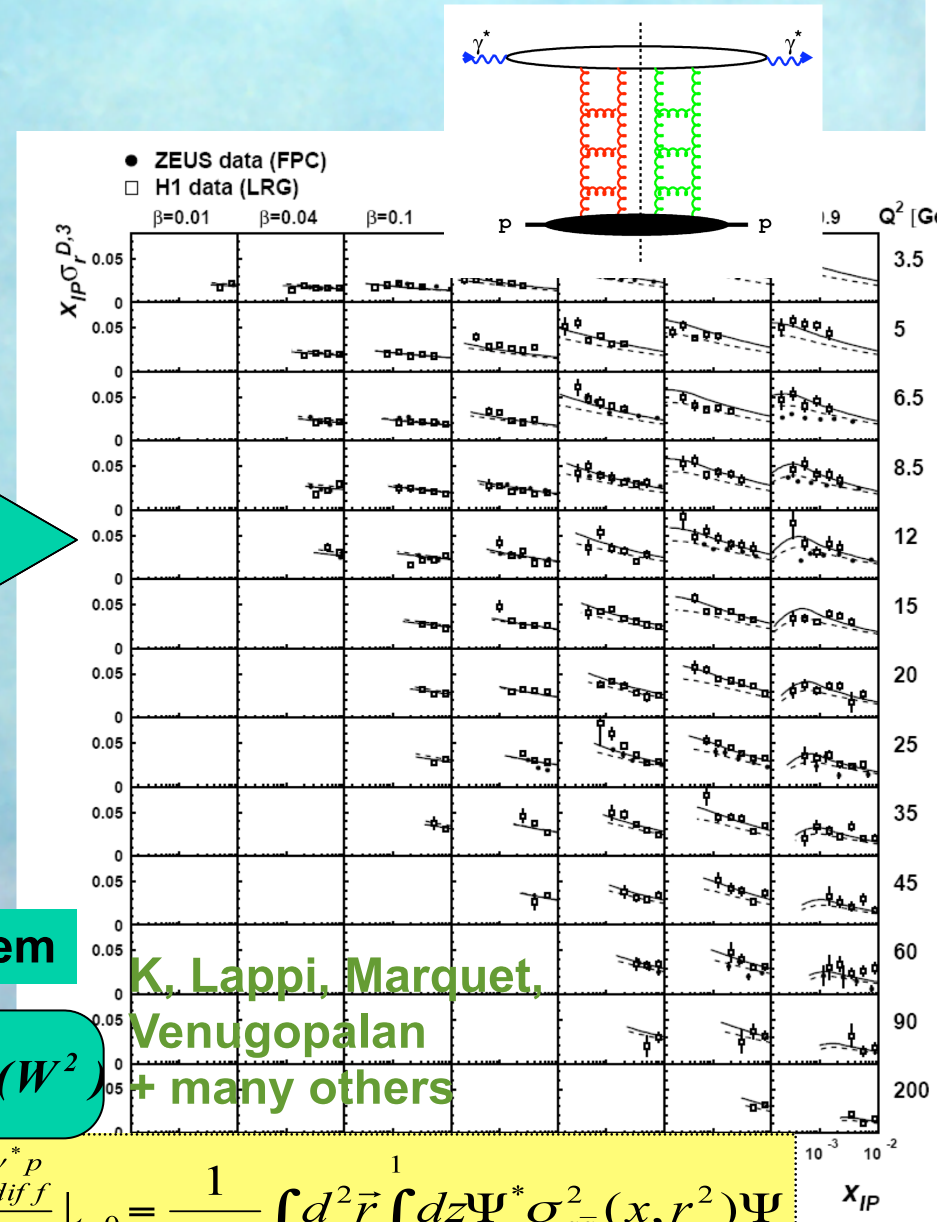
Diffraction as a shadow of DIS



$\sigma_{q\bar{q}} \sim r^2 xg(x,\mu)$ for small r

Optical Theorem

$$\sigma_{tot}^{\gamma^* p} = \frac{1}{W^2} Im A_{el}(W^2)$$

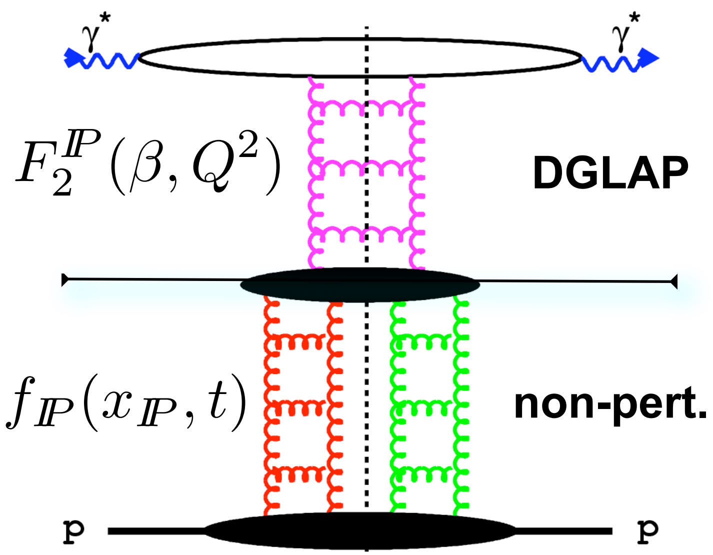


K, Lappi, Marquet, Venugopalan + many others

$$\sigma_{tot}^{\gamma^* p} = \int d^2\hat{\vec{r}} \int_0^1 dz \Psi^* \sigma_{q\bar{q}}(x, r^2) \Psi$$

$$\frac{d\sigma_{diff}^{\gamma^* p}}{dt}\Big|_{t=0} = \frac{1}{16\pi} \int d^2\vec{r} \int_0^1 dz \Psi^* \sigma_{q\bar{q}}^2(x, r^2) \Psi$$

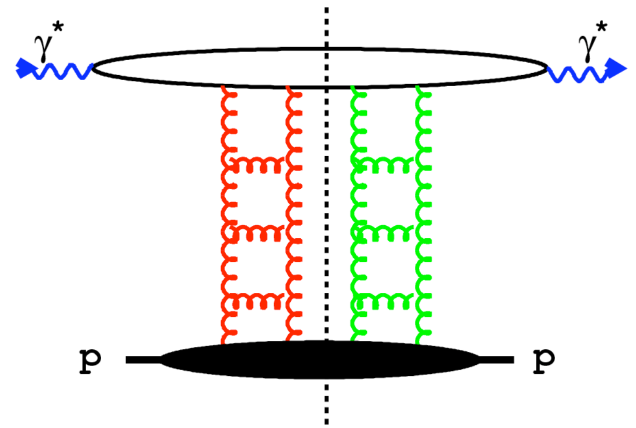
Diffractive structure function approach



β corresponds to x

$$F_2^D = f_{I\!P}(x_{I\!P},t)\,F_2^{I\!P}(\beta,Q^2)$$
$$f_{I\!P} = \frac{e^{bt}}{x_{I\!P}^{2\alpha_{I\!P}-1}}$$

Dipole approach



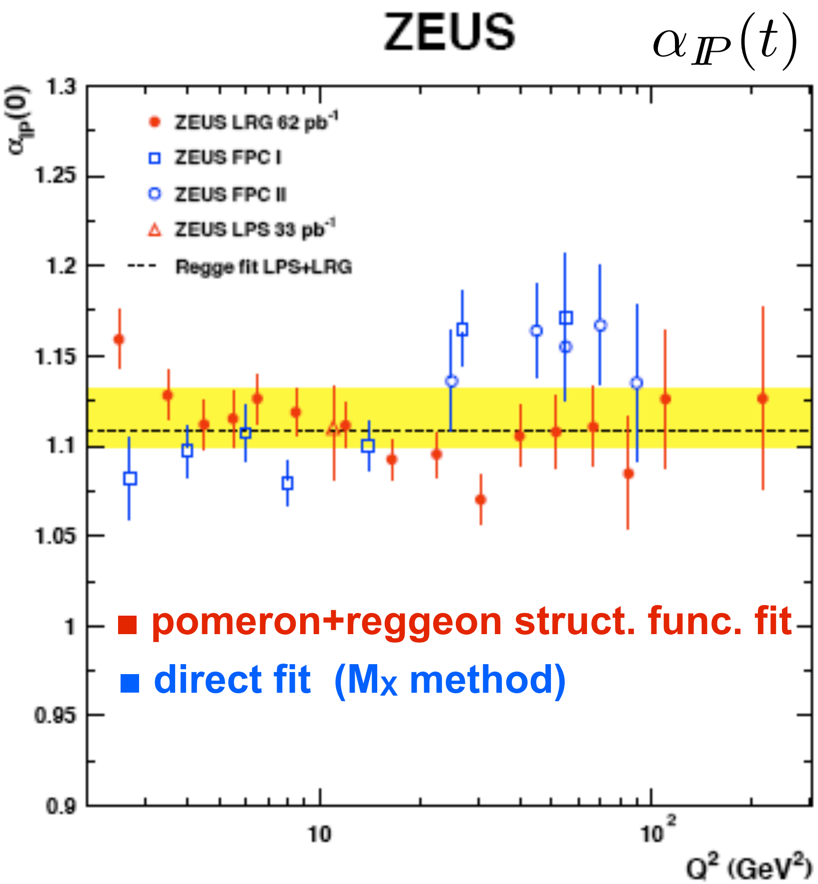
$\sigma_{qq} \approx r^2\, xg(x,\mu^2=1/r^2)$

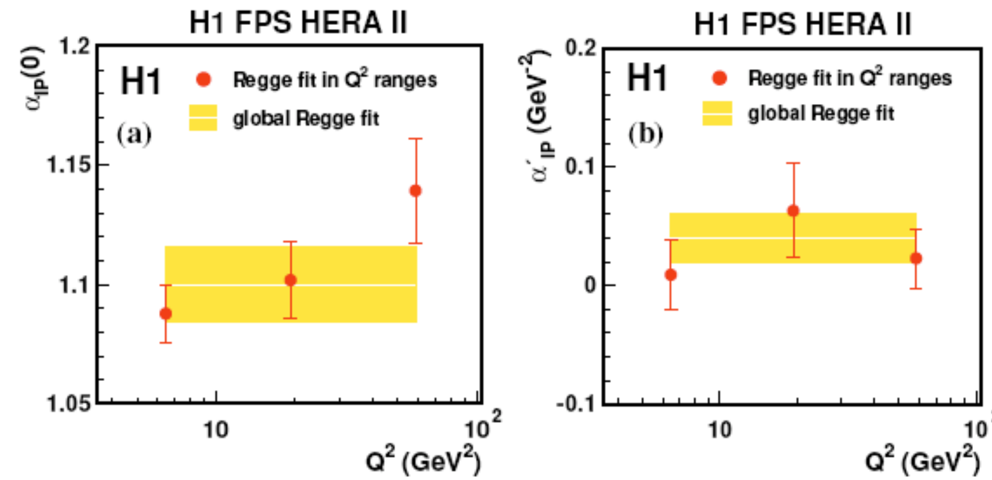
⇒ suppression of small dipoles

$$d\sigma^{\gamma^* p}_{diff}/dt \propto \int dz\,dr^2\,\Psi^* \sigma^2_{qq}(x,r^2,t)\Psi$$

Pomeron intercept

$$\alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha' \cdot t$$





e.g. from H1 FPS - HERA II data:

$$\alpha_{I\!P}(0) = 1.10 \pm 0.02(\mathrm{exp}) \pm 0.03(\mathrm{model})$$

no strong Q^2 dependence of α_{IP} observed
in agreement with the dominance of non-perturbative effects in the pomeron SF

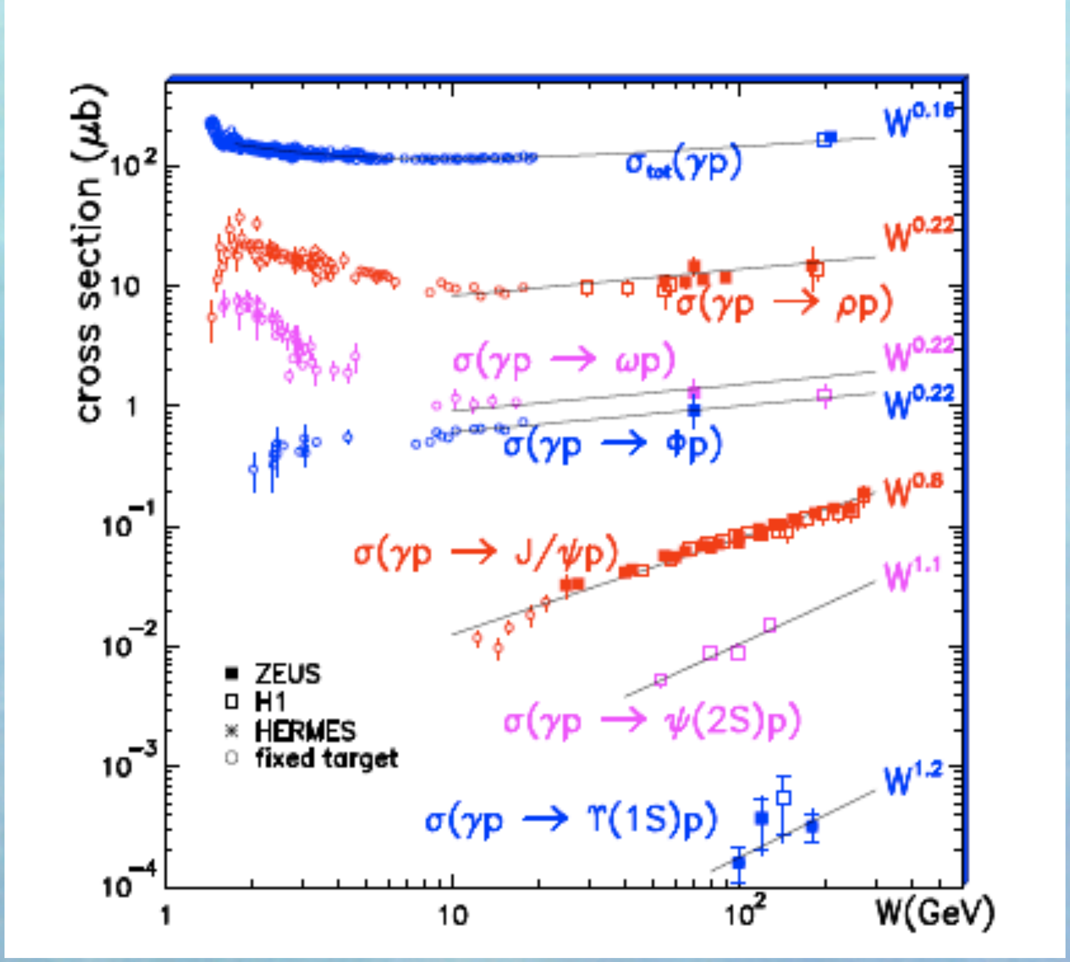
in agreement with the dipole model predictions;
diffraction selects much larger dipoles than non-diff DIS
⇒ much weaker Q^2 dependence than in non-diff DIS

Big question for LHC precision measurements:

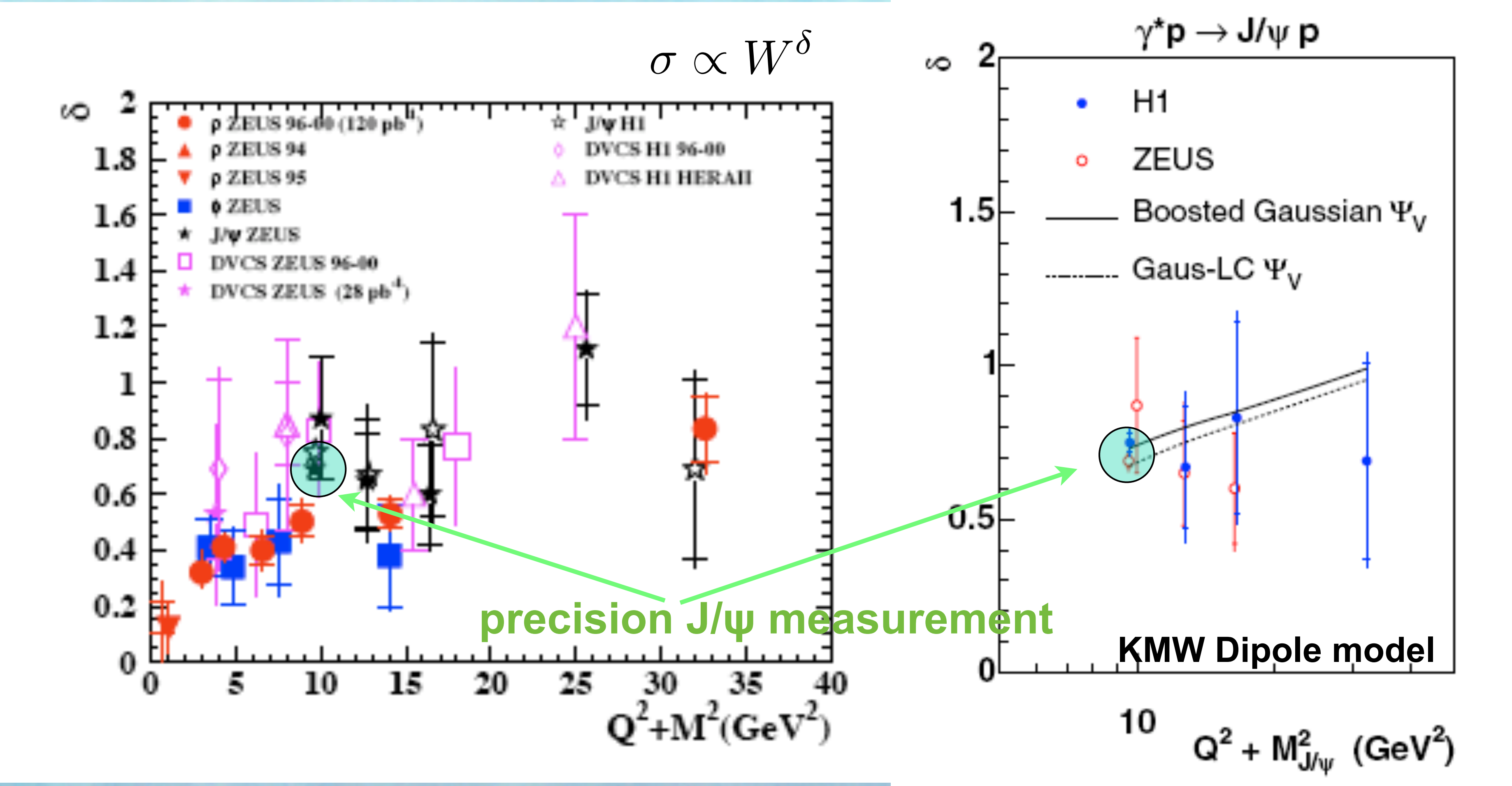
is the inclusive diffractive component evolving with Q^2 like in DGLAP or like in the dipole model (or even in a more involved way) ?

The inclusive diffractive data do not have enough precision to answer it

Clear hints provided by the exclusive vector meson production

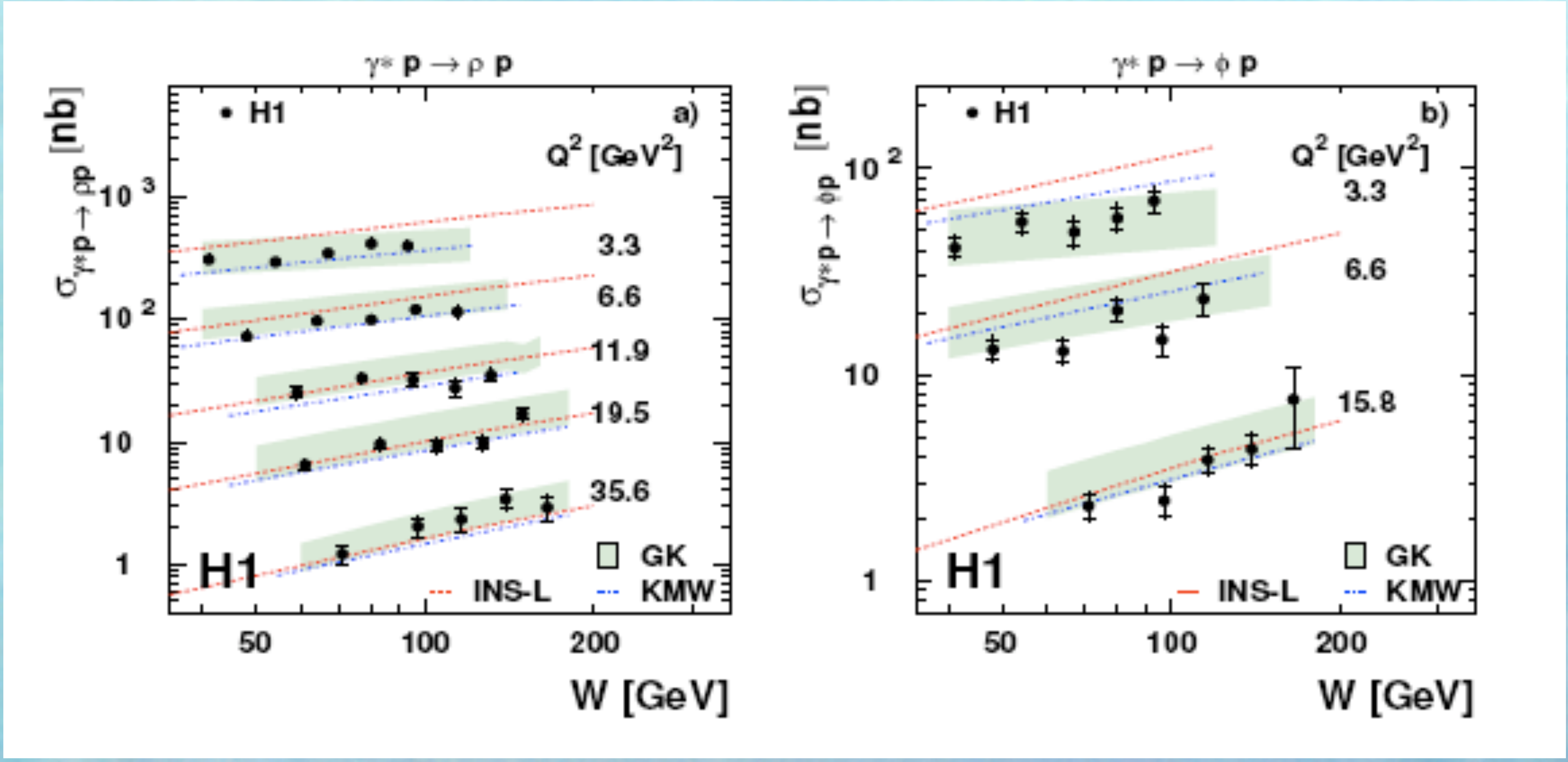


Pomeron intercepts from excl. Vector Mesons



Dipole model with the DGLAP evolution of the gluon density predicts well the δ's for J/ψ, ρ, φ VM and for DVCS

W dependence of exclusive Vector Mesons cross sections

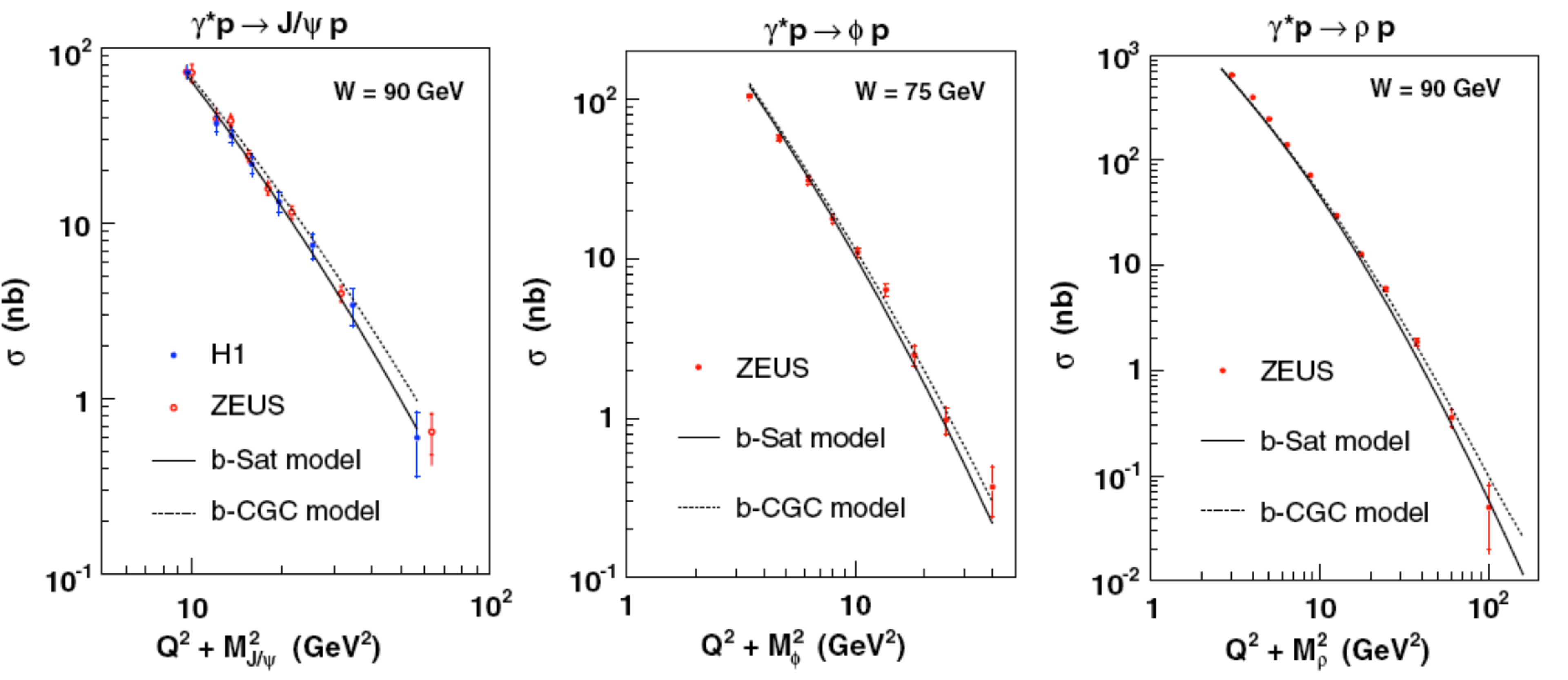


Dipole model with the DGLAP evolution of the gluon density predicts well the rise with W of the ρ and φ VM cross sections

Note: these are absolute predictions obtained from the gluon density determined from F_2

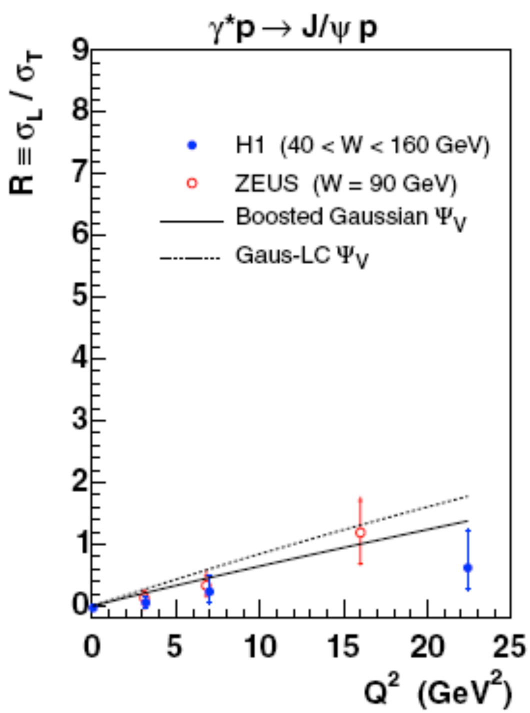
Total VM cross sections from dipole model

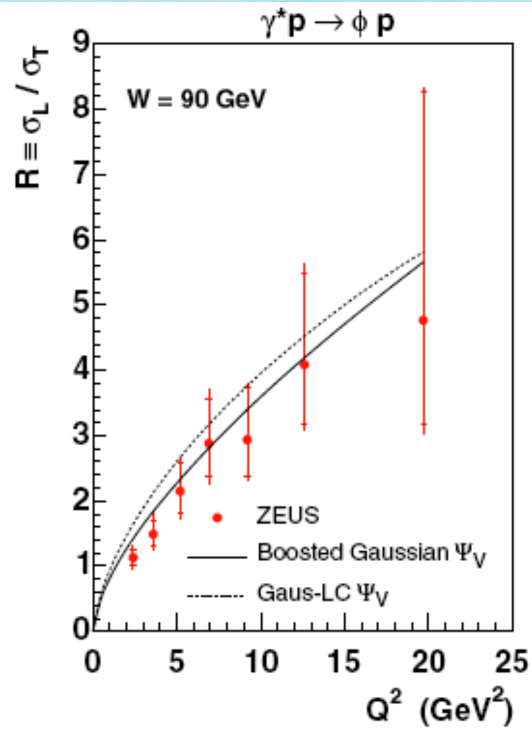
KMW Dipole model



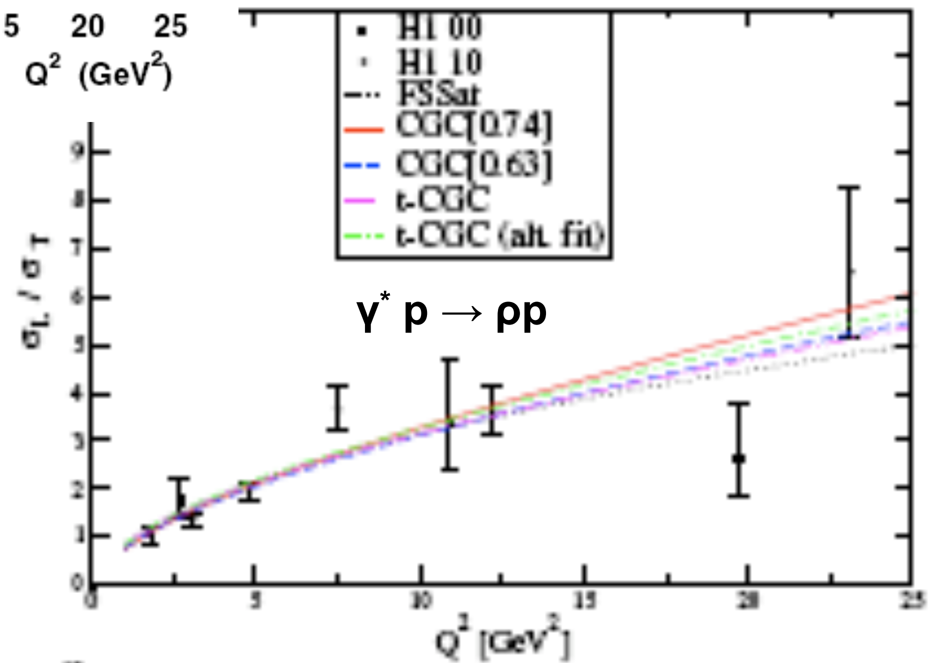
Note: these are absolute predictions obtained from the gluon density determined from F_2

Dipole model description of σ_L / σ_T for VM

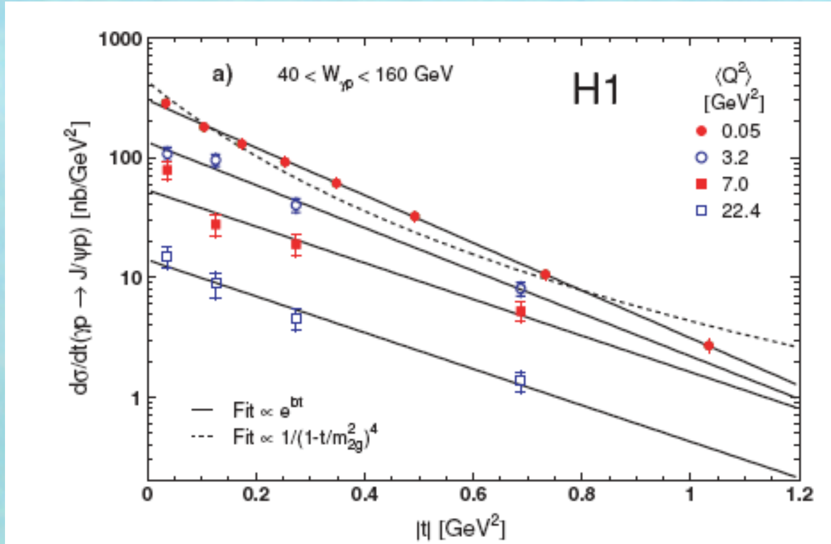




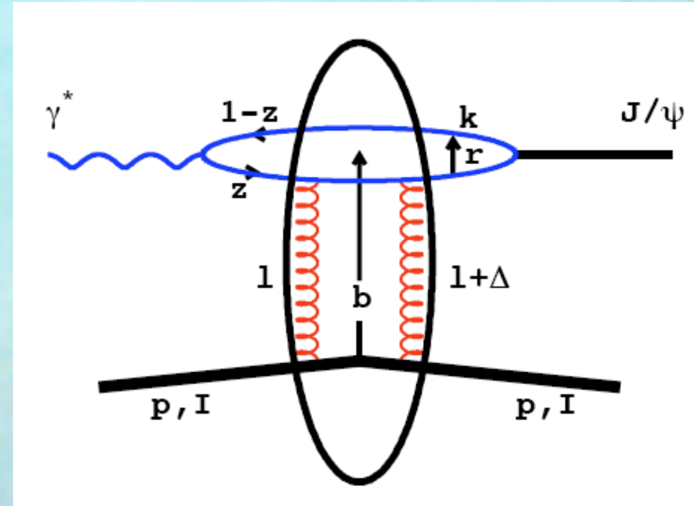
Forshaw and Sandapen improved recently the BG wf by enhancing the end point singularity contributions in the transverse ρ wf



t-distributions



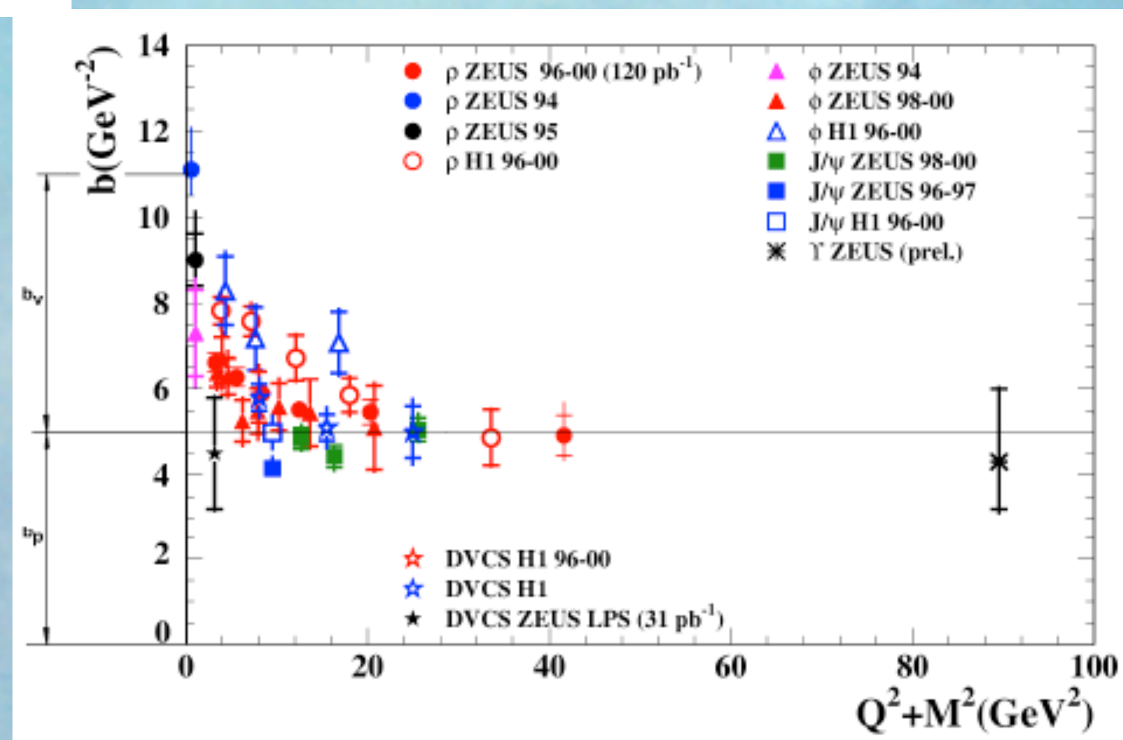
$$\frac{d\sigma}{dt} \sim e^{-b|t|}$$



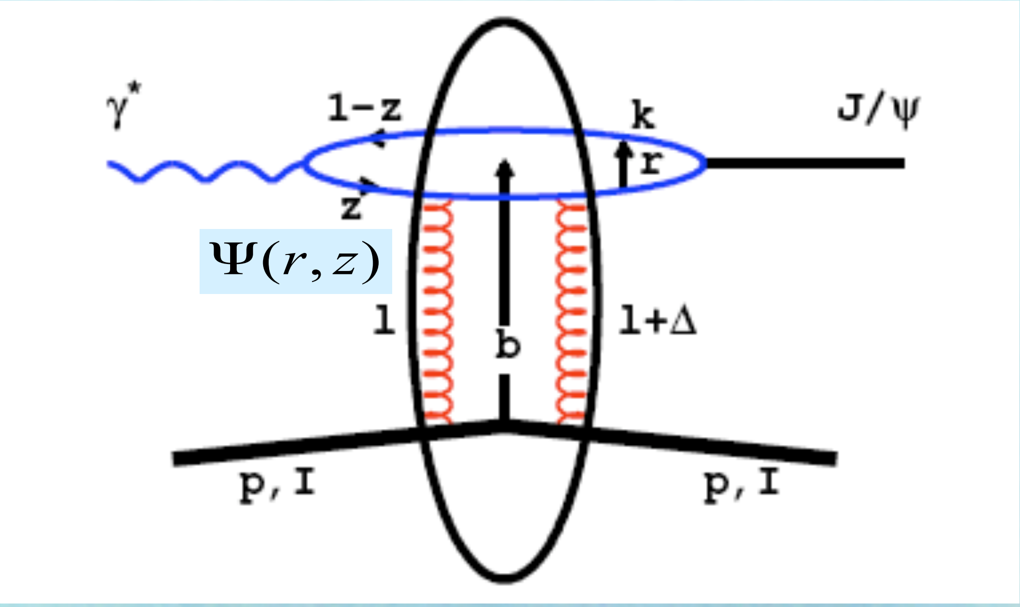
transverse size of the interaction region
$b = b_V + b_p$

Vector Mesons
$b_V = 1/(Q^2 + M^2)$

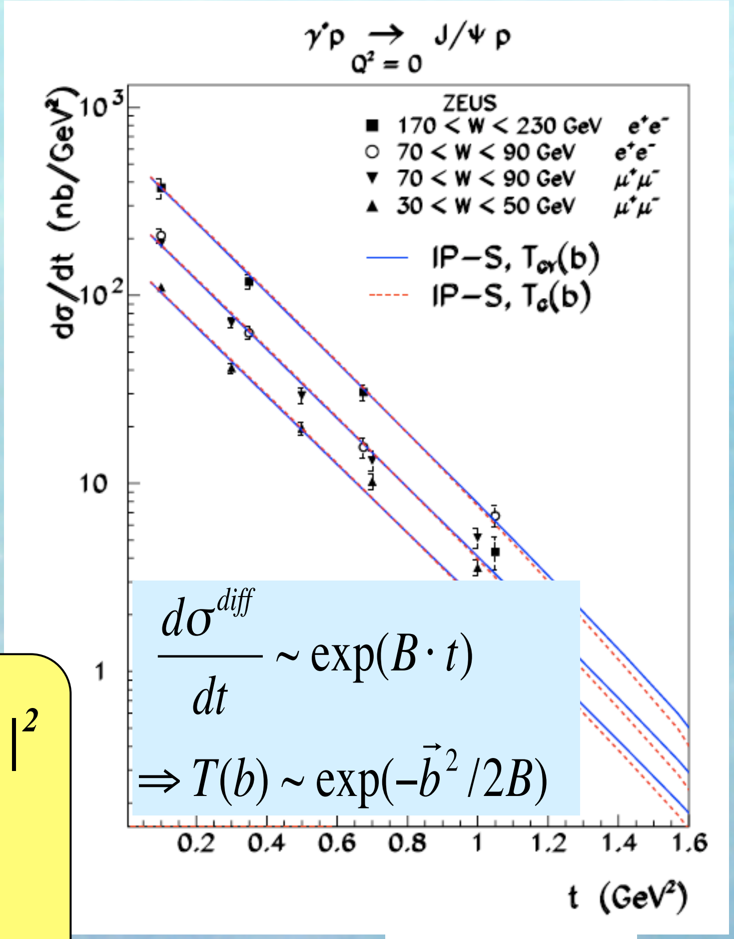
proton
$b_p \sim 5$ GeV
in dip. mod. $b_p \sim 4$ GeV



Extracting Proton Shape using dipoles



$\Psi(r,z)$



$$\frac{d\sigma^{diff}}{dt} \sim \exp(B \cdot t)$$

$$\Rightarrow T(b) \sim \exp(-\vec{b}^2/2B)$$

$$\frac{d\sigma_{VM}^{\gamma^* p}}{dt} = \frac{1}{16\pi} \left| \int e^{-i\vec{b}\cdot\vec{\Delta}} \Psi_{VM}^* 2\left\{1 - exp(-\frac{\Omega}{2})\right\} \Psi \right|^2$$

$$\Omega = \frac{\pi^2}{N_C} r^2 \alpha_s(\mu^2) xg(x,\mu^2) T(b)$$

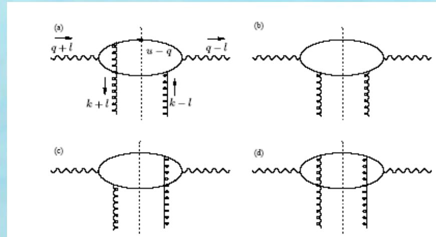
T(b)-proton shape

KT, KMW

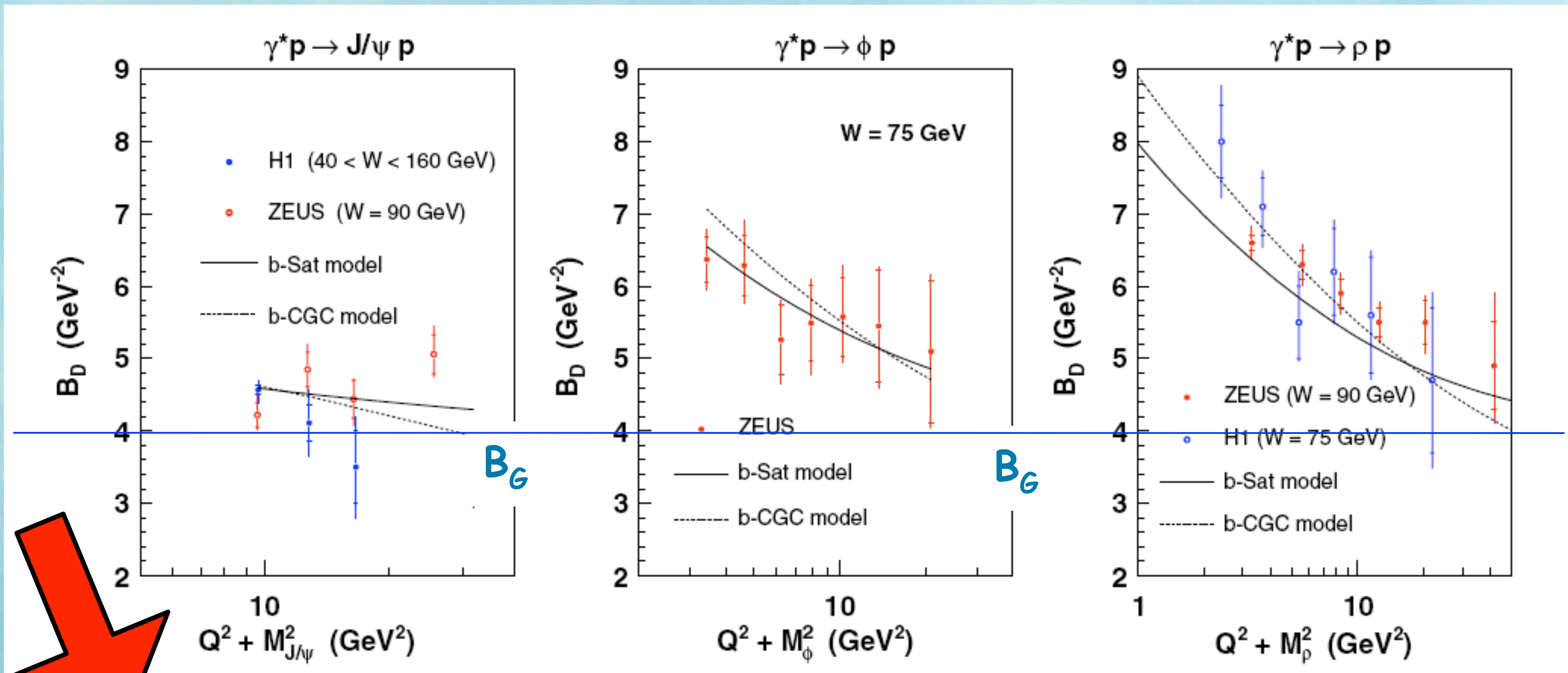
The size of interaction region B for various VM

Modification by Bartels, Golec-Biernat, Peters

$$e^{i\vec{b}\cdot\vec{\Delta}} \Longrightarrow e^{i(\vec{b}+(1-z)\vec{r})\cdot\vec{\Delta}}$$



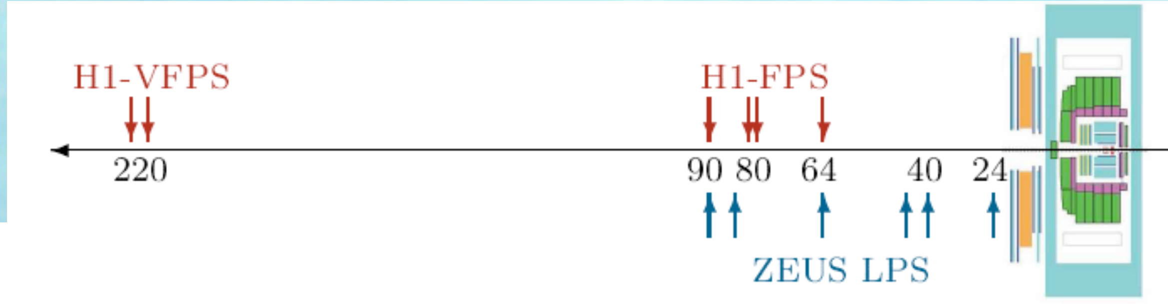
KMW

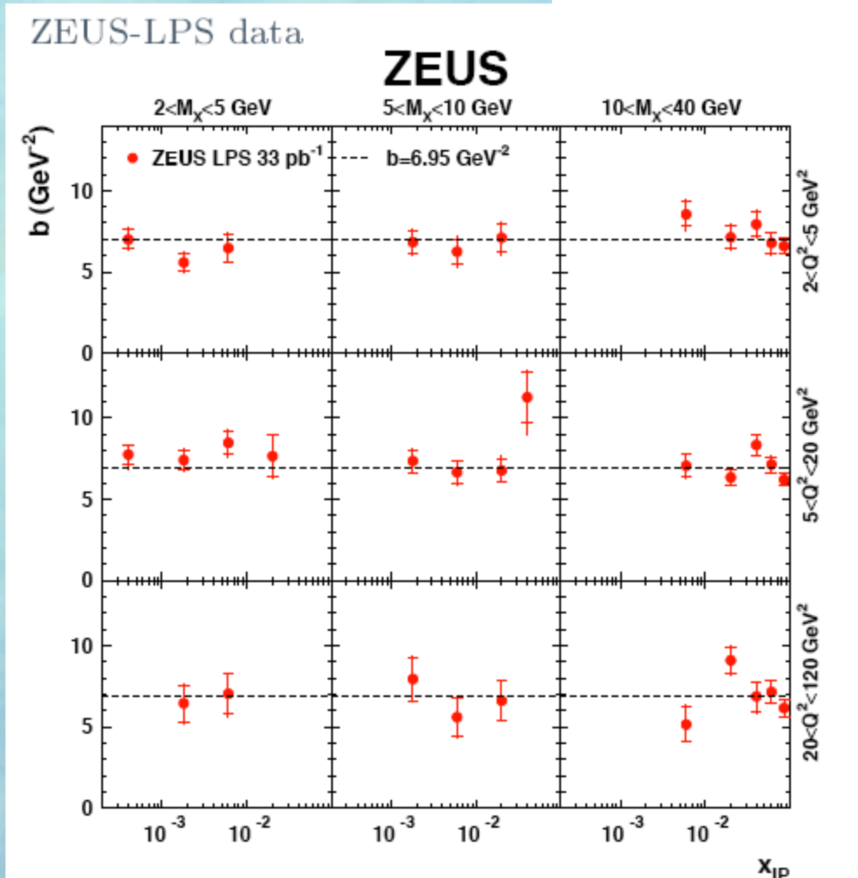


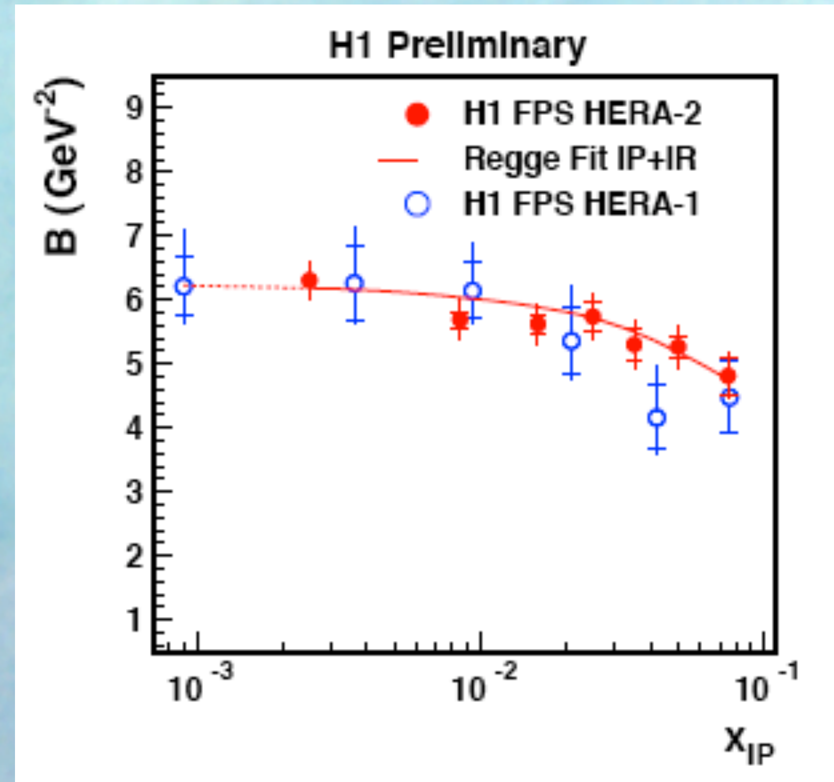
2g proton radius $\sqrt{\langle r^2_{2g}\rangle} = \sqrt{3 \cdot B_G} = 0.61 \pm 0.04$ fm. **charged** $r_p = 0.875 \pm 0.007$ fm.

B in inclusive diffraction

Roman Pot Method

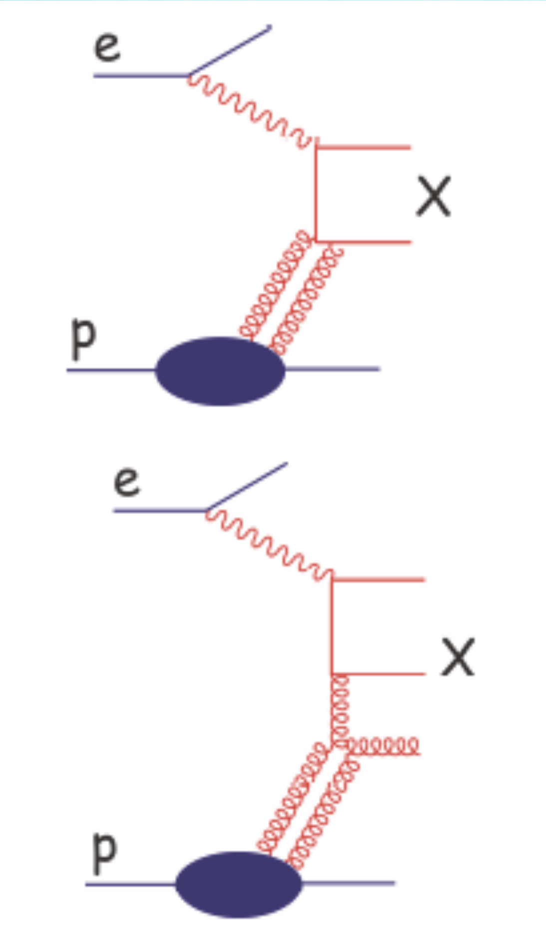


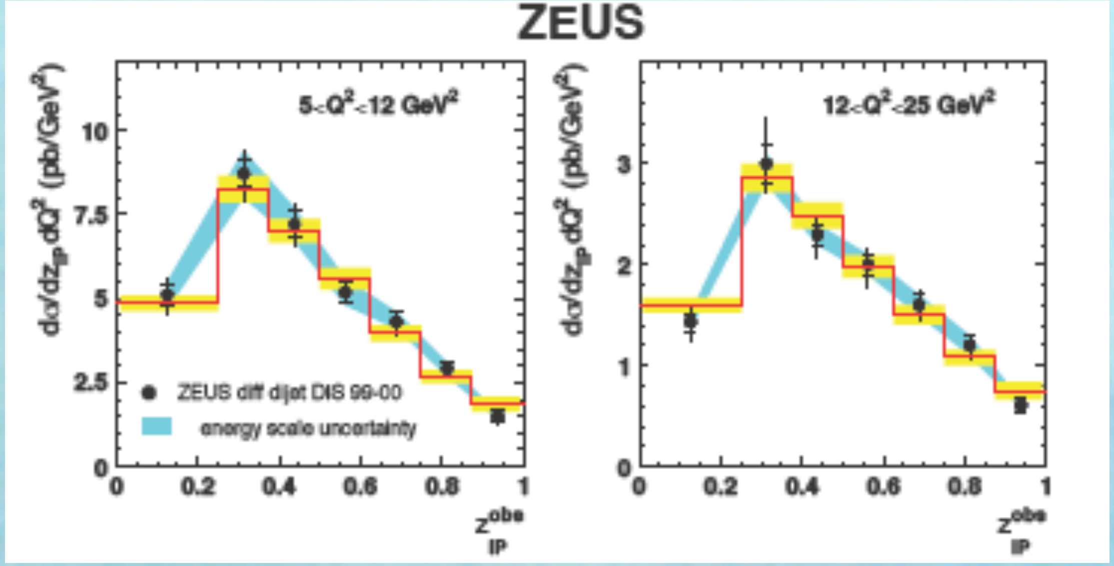


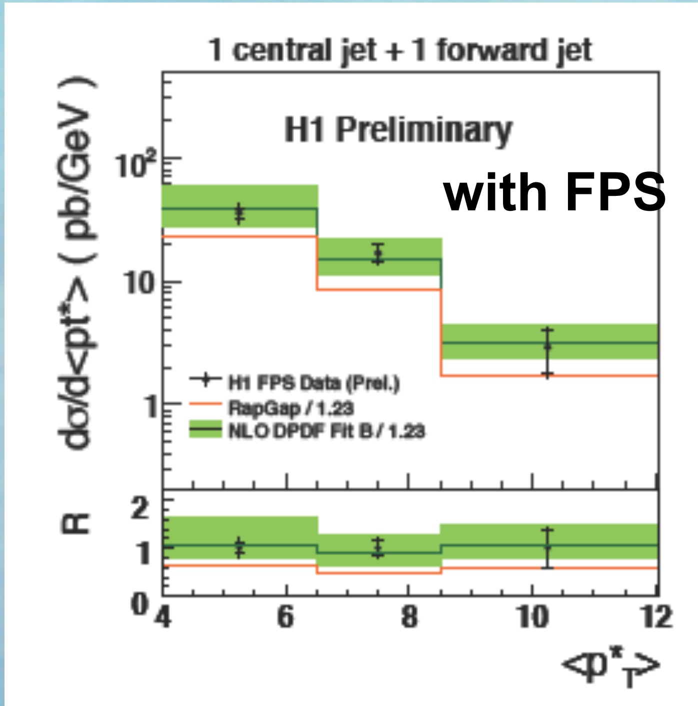


no dependence of B from Q^2 observed
in agreement with the expected dominance of large dipoles?
precise evaluation in dipole model is still missing

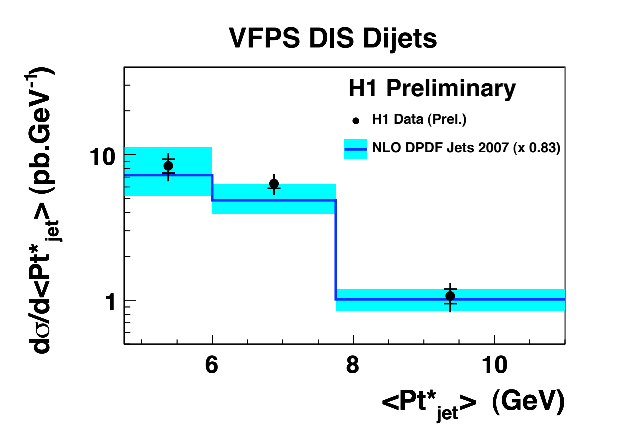
Diffractive jets





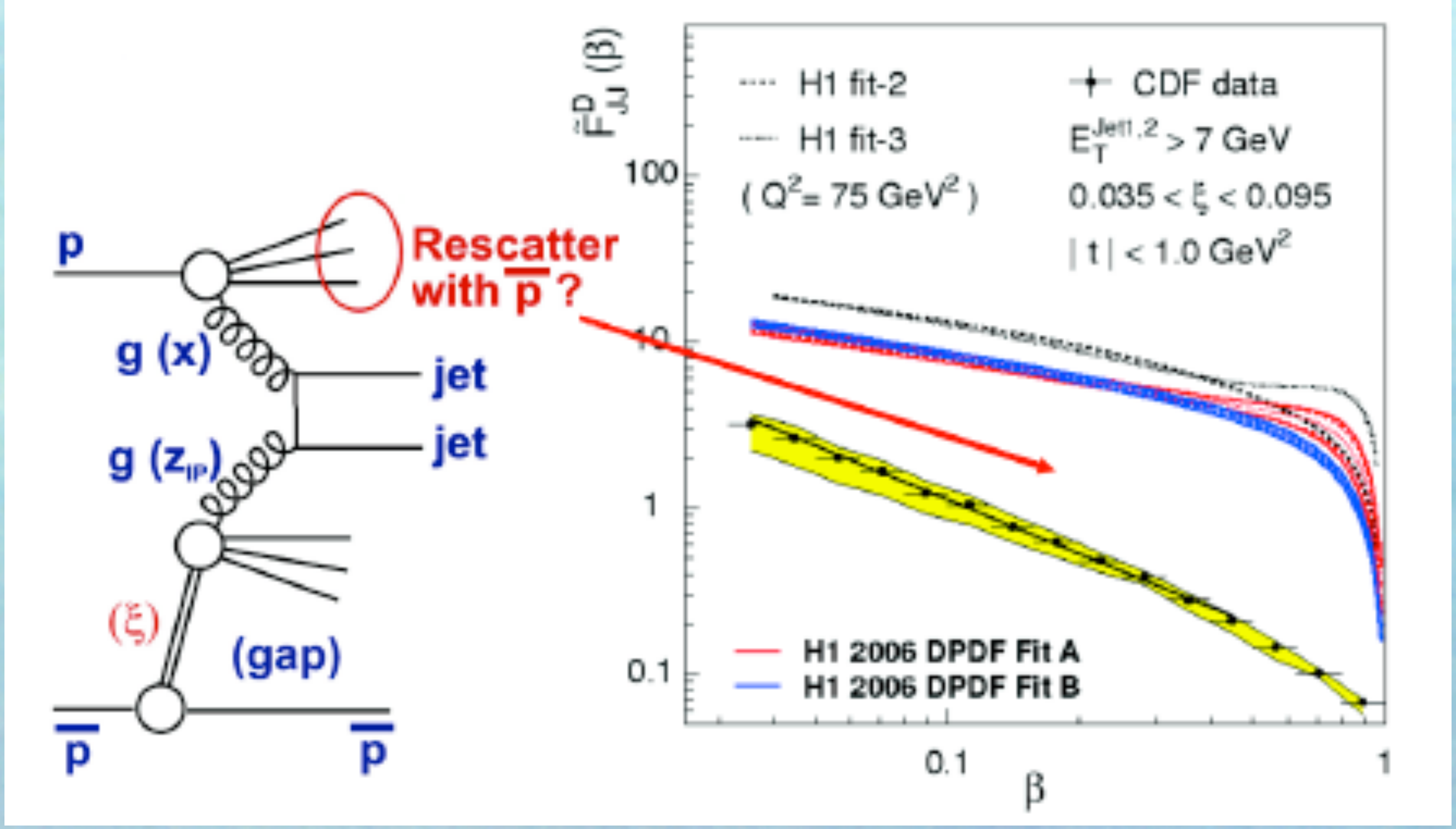


with FPS



good description of diffractive jets with diffractive structure functions, DPDFs

Diffractive jets at pp



Evidence for strong absorptive effects in comparing diffractive jets in pp with HERA DPDFs predictions

S^2 ~ 0.1 at Tevatron,
S^2 is expected to be significantly smaller at LHC

Conclusions

Diffraction is a substantial part of DIS reaction

The success of the dipole description of the vector meson production (based on the gluon density determined in F_2) strongly indicates the existence of an universal hard Pomeron.

Inclusive diffractive data show that this pomeron is also soft, in agreement with the properties of a QCD-BFKL Pomeron which is hard and soft simultaneously

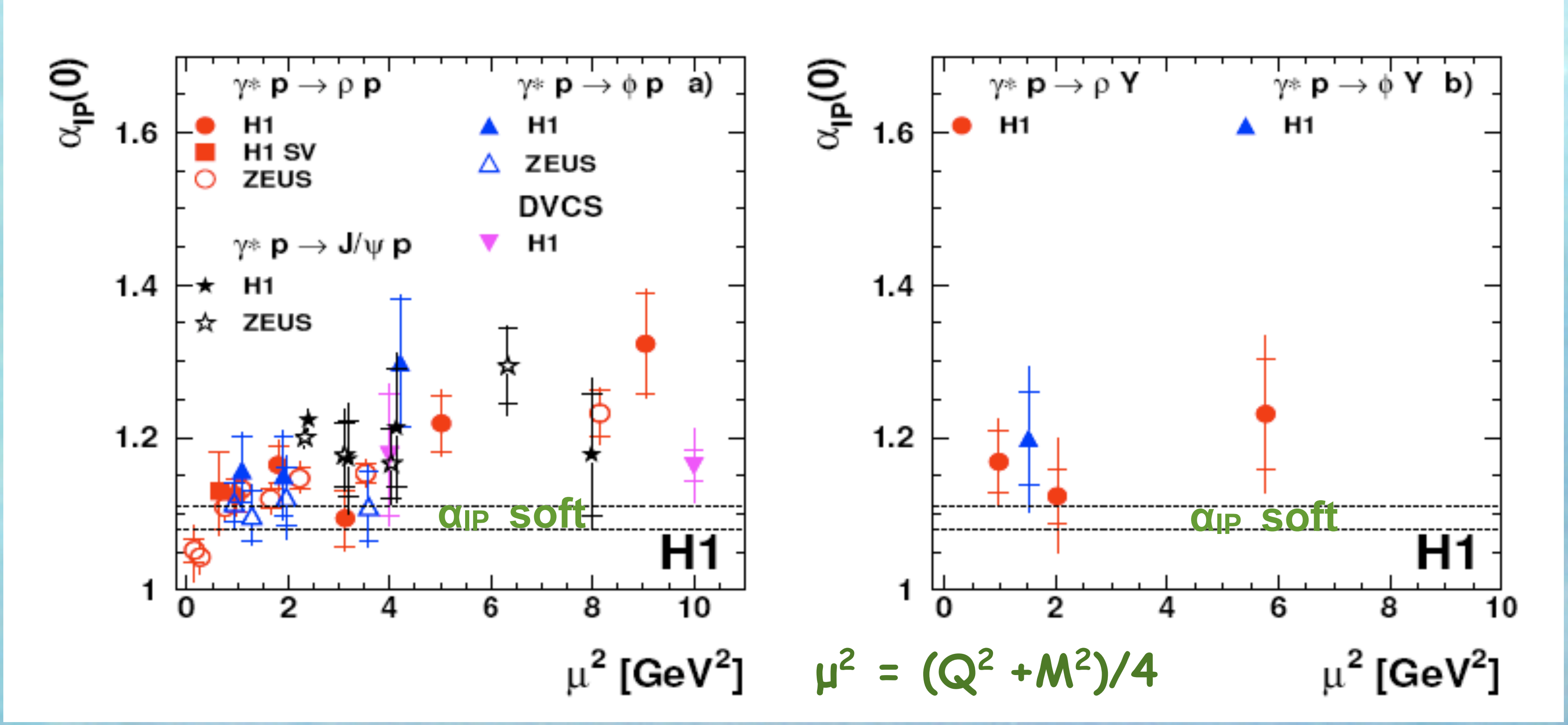
Good agreement of inclusive diffractive jet predictions based on DPDF's together with Tevatron data

strong absorption of hard diffractive processes at LHC

e.g: diffractive Higgs, abundance of MI

Backup slides

α_{IP} in exclusive VM reactions



J/ψ and ρ show a clear increase of α_{IP} with the increase of scale

(in agreement with the dipole expectations that $\sigma_{qq} \sim (xg(x,\mu^2))^2$)