Diffraction at HERA

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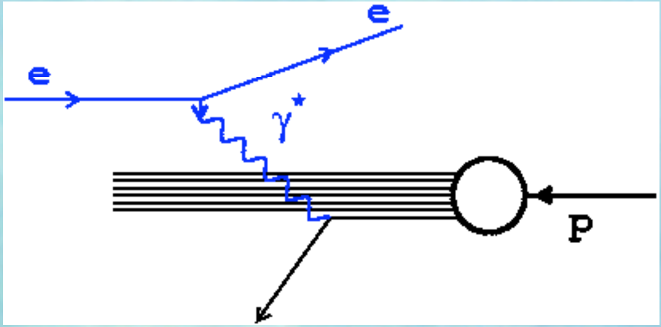
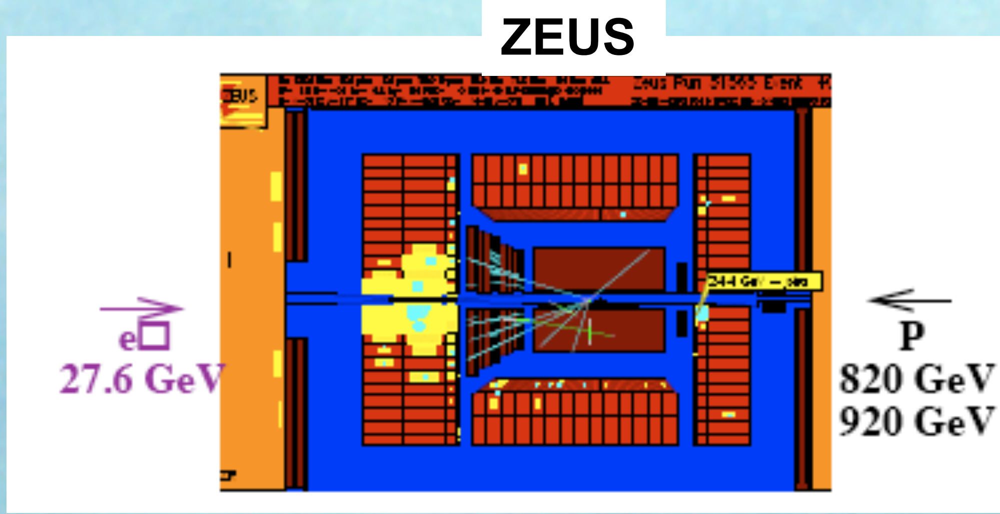
Diffraction 2012, Lanzarote
11th of September, 2012

Surprise of HERA

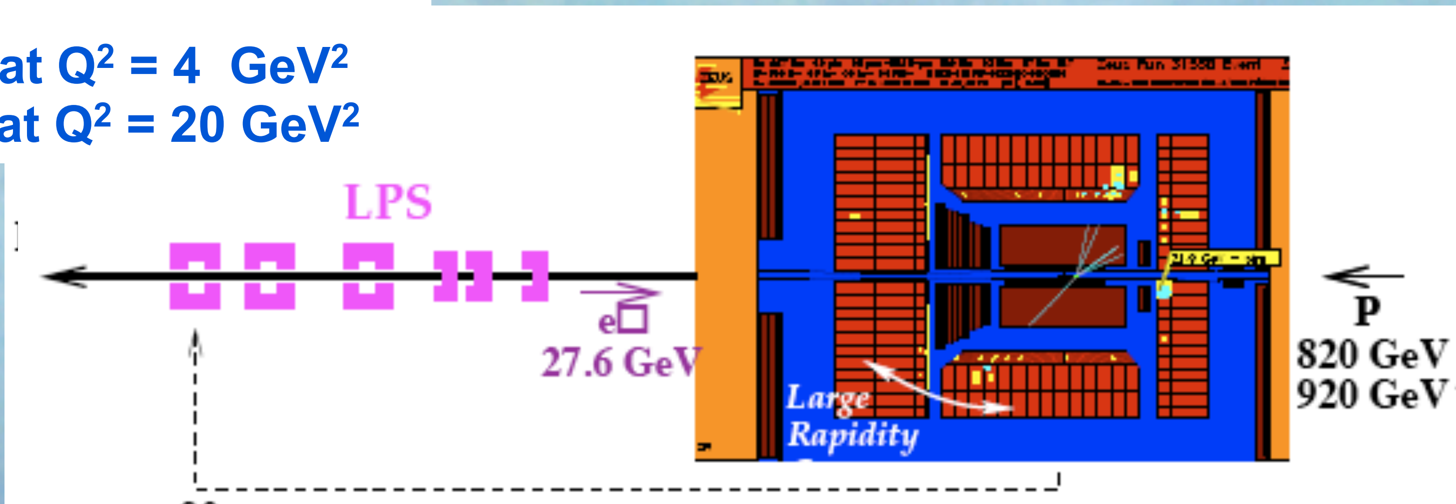
Non-Diffractive Scattering



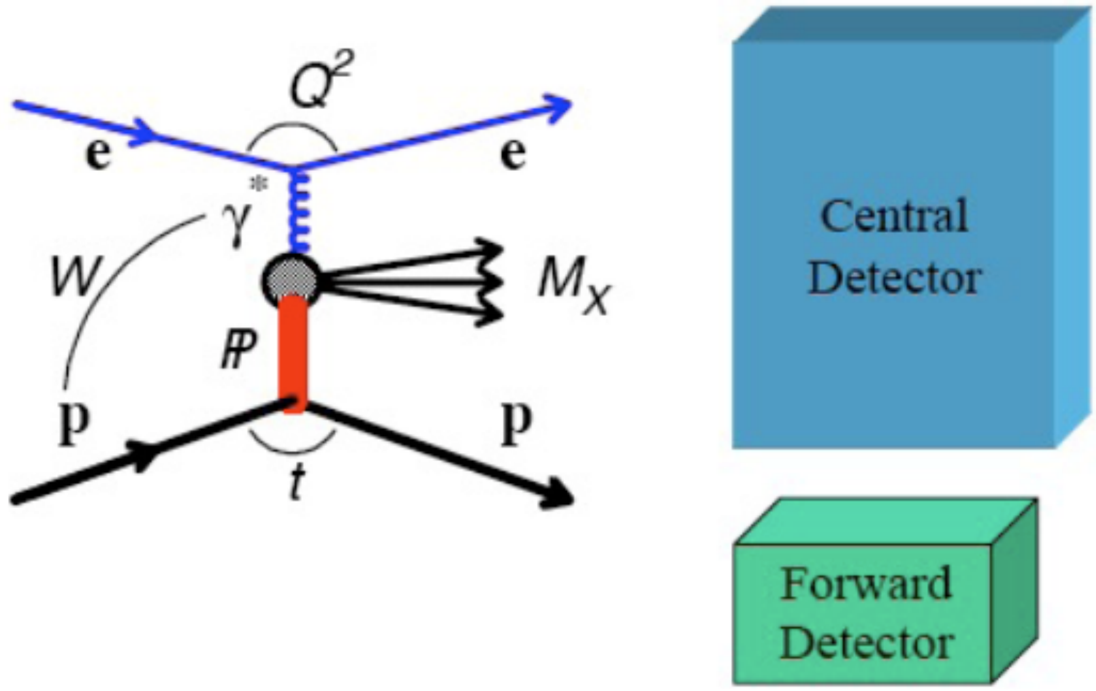


Diffractive Scattering

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

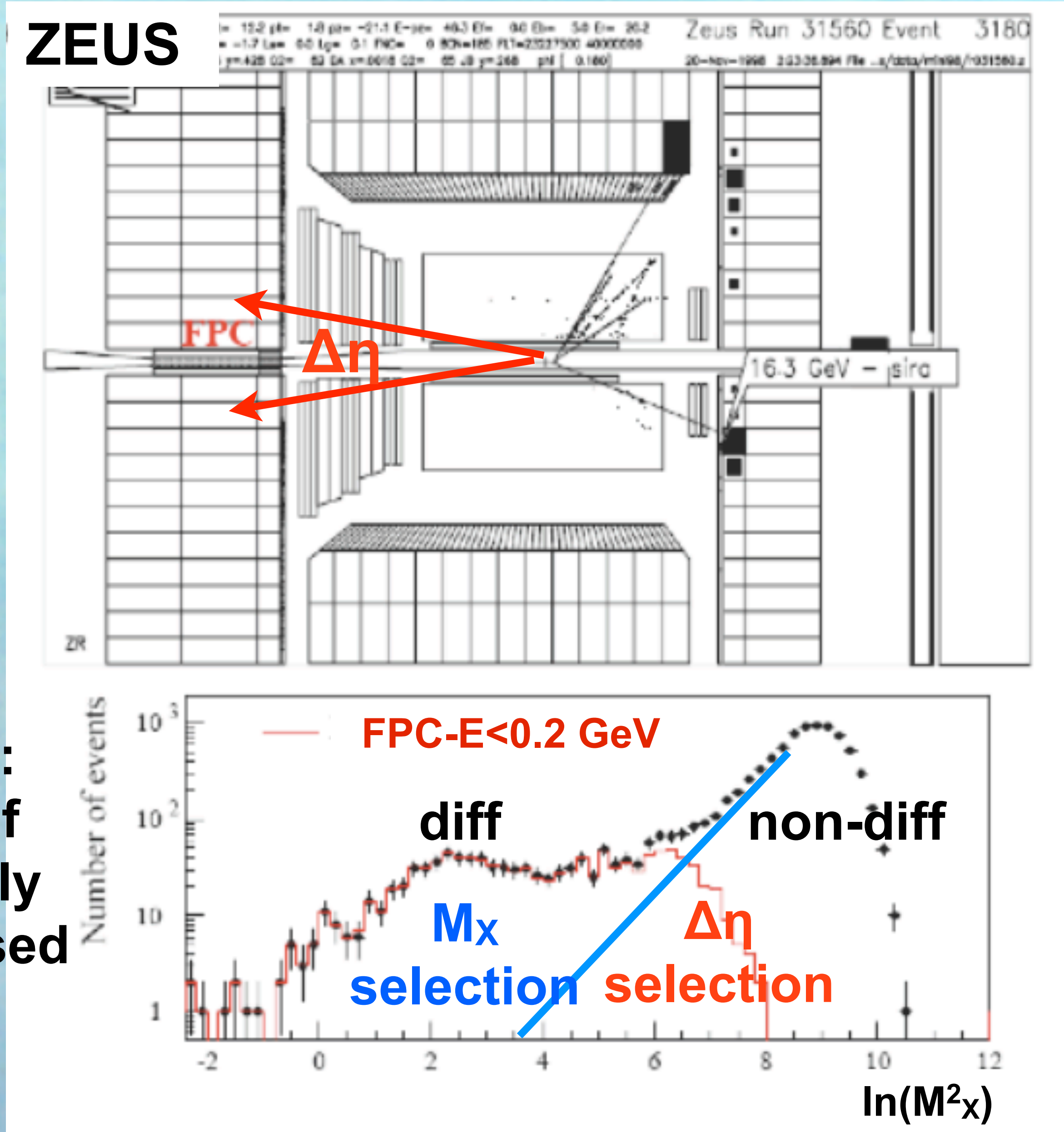
Q^2 - virtuality of the incoming photon
W - CMS energy of the incoming photon-proton system
x - $\approx Q^2/W^2$

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

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

Diffractive Signatures

Large Rapidity Gap - Δη selection



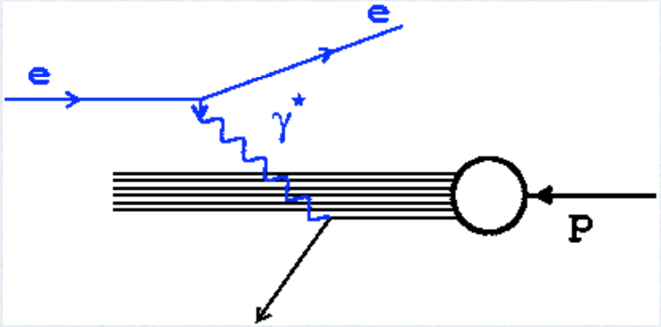
Accidental LRG ?

M_X Method: selection of exponentially nonsuppressed RG

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

Partons vs Dipoles

Infinite momentum frame: Partons

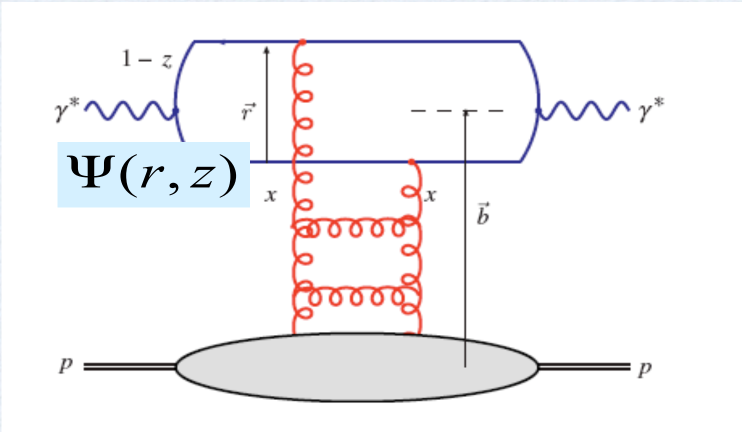


F_2 measures parton density at a scale Q^2

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

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

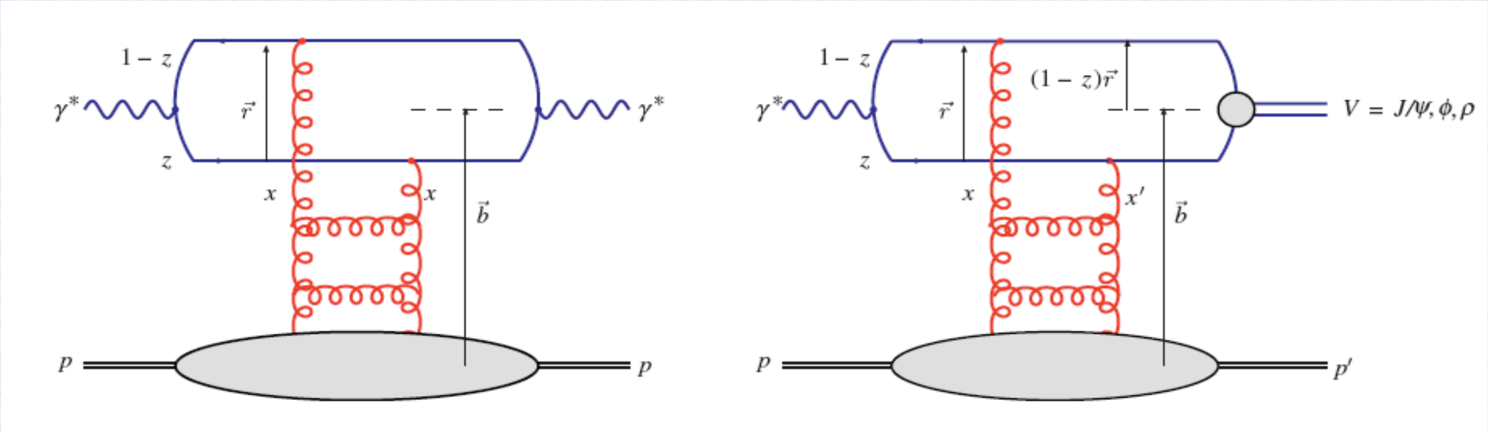
$\sigma_{qq} \sim r^2 \, xg(x,Q^2)$

HERA - F_2 is dominated by the gluon density at low x

➤ the same gluon density determines the exclusive and inclusive diffractive processes,
$\gamma p \Rightarrow J/\psi\, p$, $\gamma p \Rightarrow \varphi p$, $\gamma p \Rightarrow \rho p$, $\gamma p \Rightarrow Xp$,

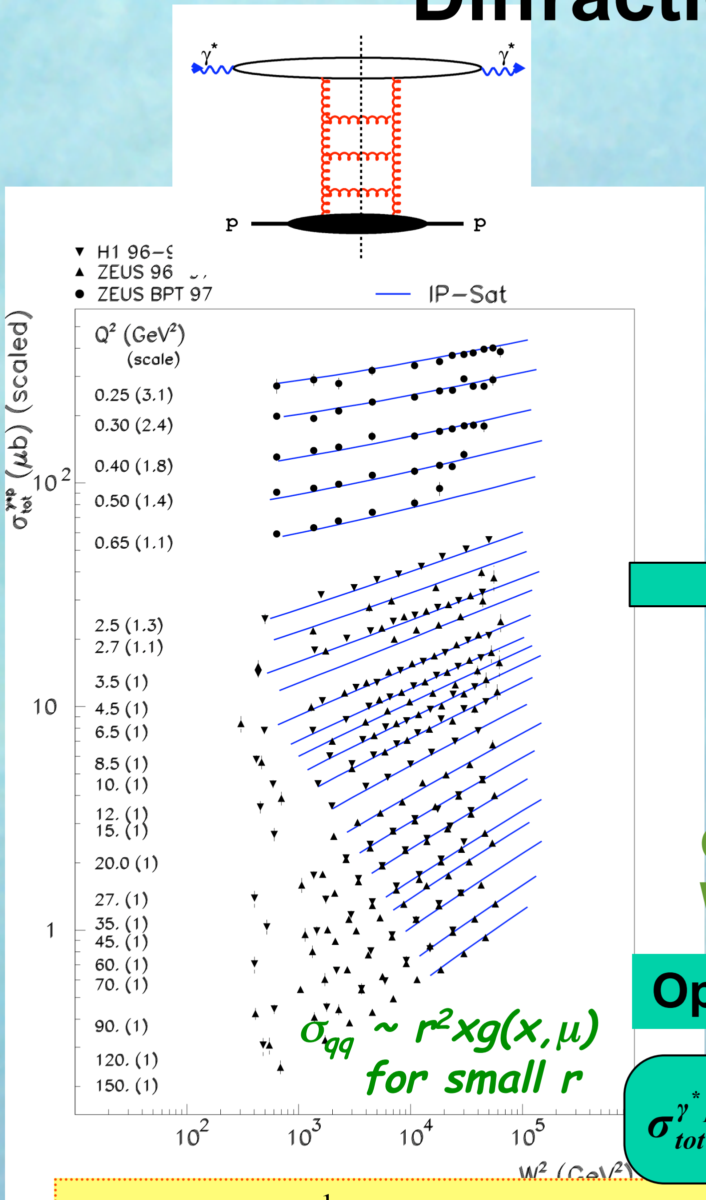
➤ universal gluon density ≡ Pomeron ?

F_2 VM, Diffraction



clear hints for saturation, but here we concentrate on the gluon gluon interactions above the saturation region

Diffraction as a shadow of DIS

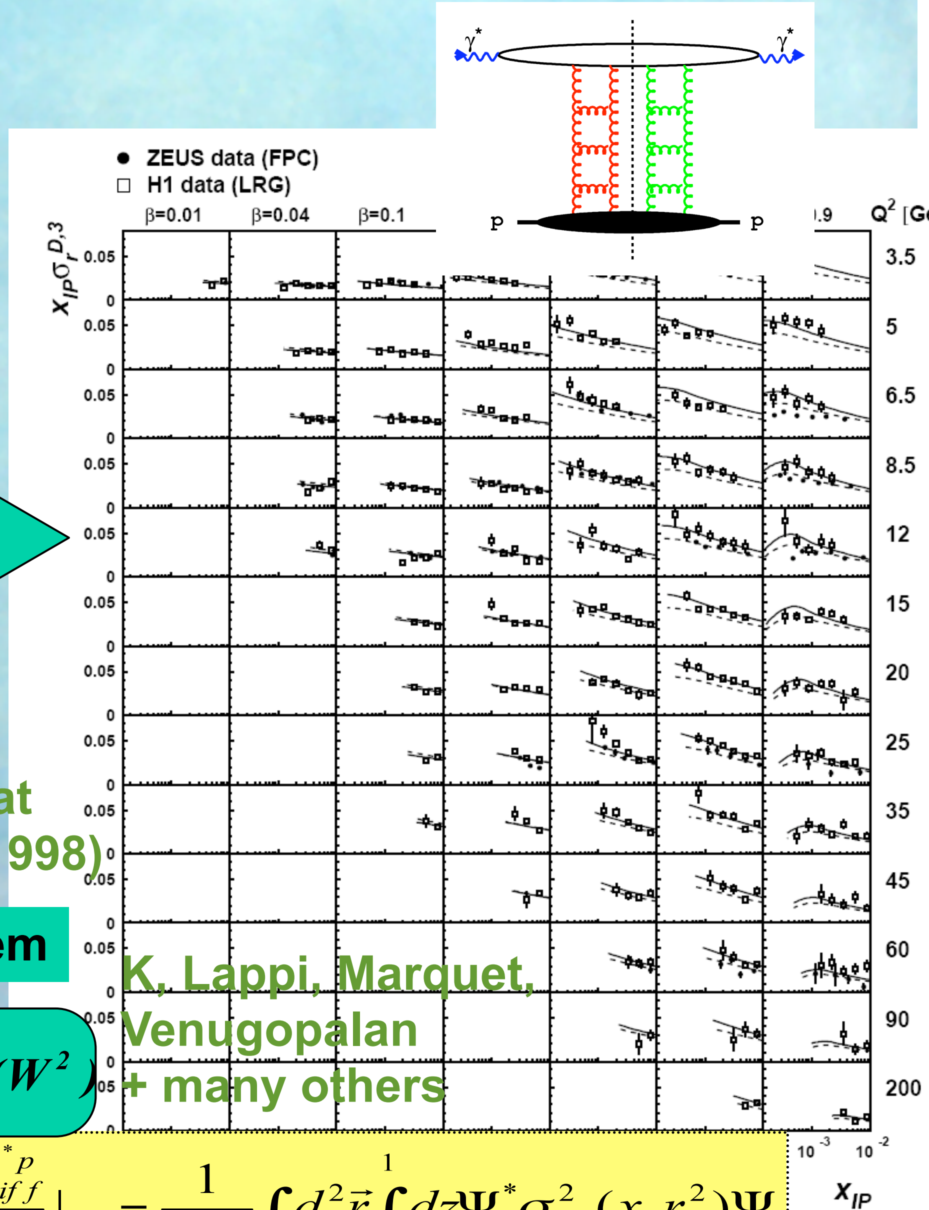


$\sigma_{qq} \sim r^2 xg(x,\mu)$
for small r

Golec-Biernat Wuesthoff (1998)

Optical Theorem

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

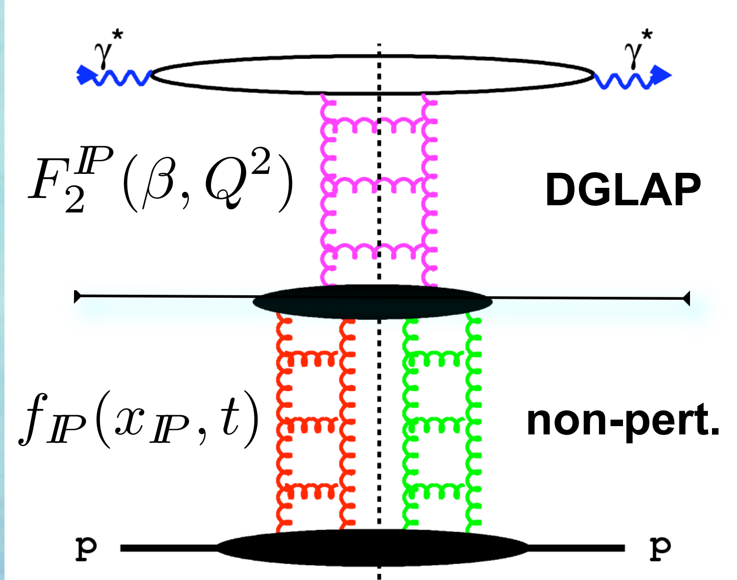


K, Lappi, Marquet, Venugopalan
+ many others

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

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

Diffractive structure function approach

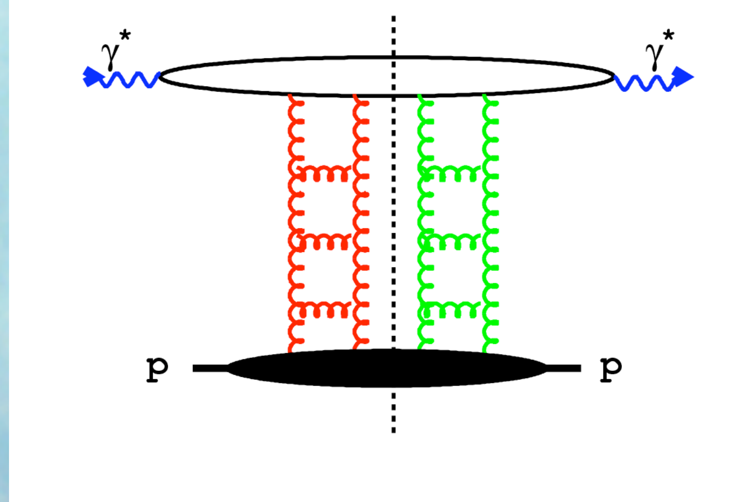


β corresponds to x

$$F_2^D = f_{I\!P}(x_{I\!P}, t)\, F_2^{I\!P}(\beta, Q^2)$$

$$f_{I\!P} = \frac{e^{bt}}{x_{I\!P}^{2\alpha_{I\!P}-1}}$$

Dipole approach



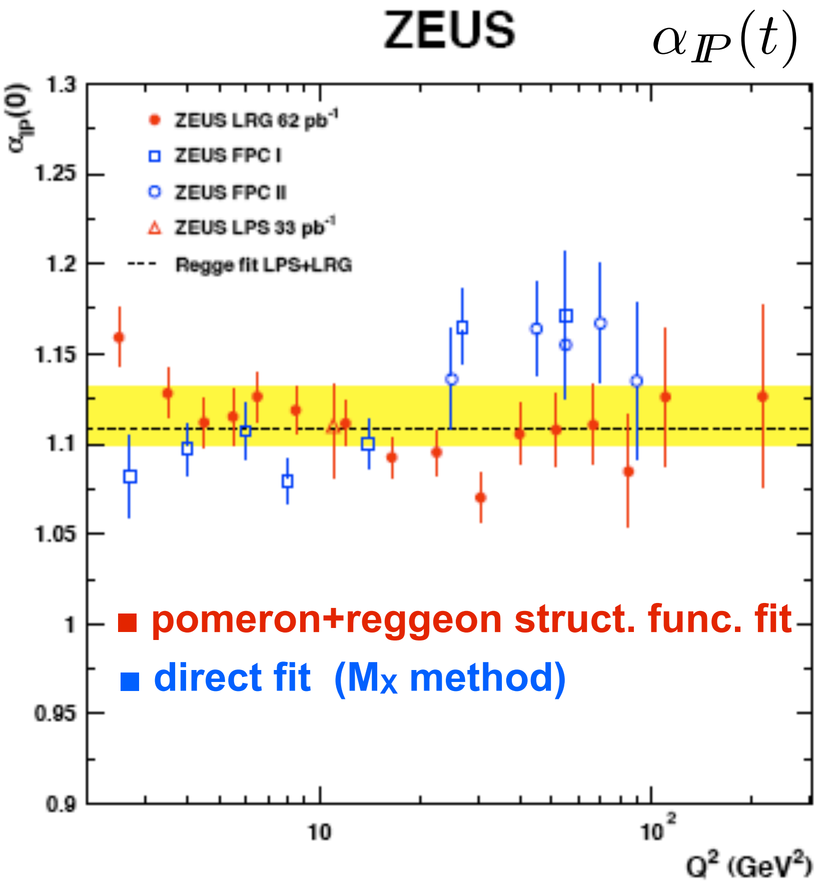
$\sigma_{qq} \approx r^2\, xg(x, \mu^2 = 1/r^2)$

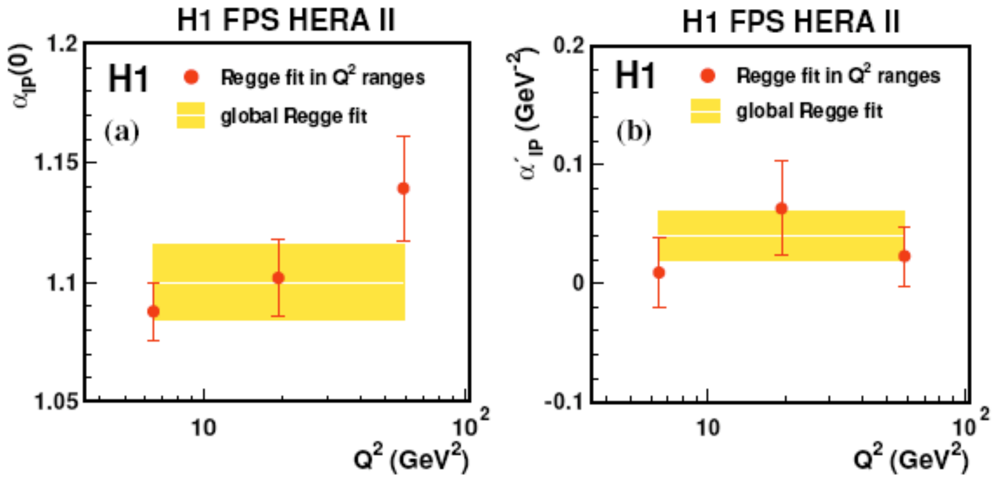
⇒ suppression of small dipoles

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

Pomeron intercept

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





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

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

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

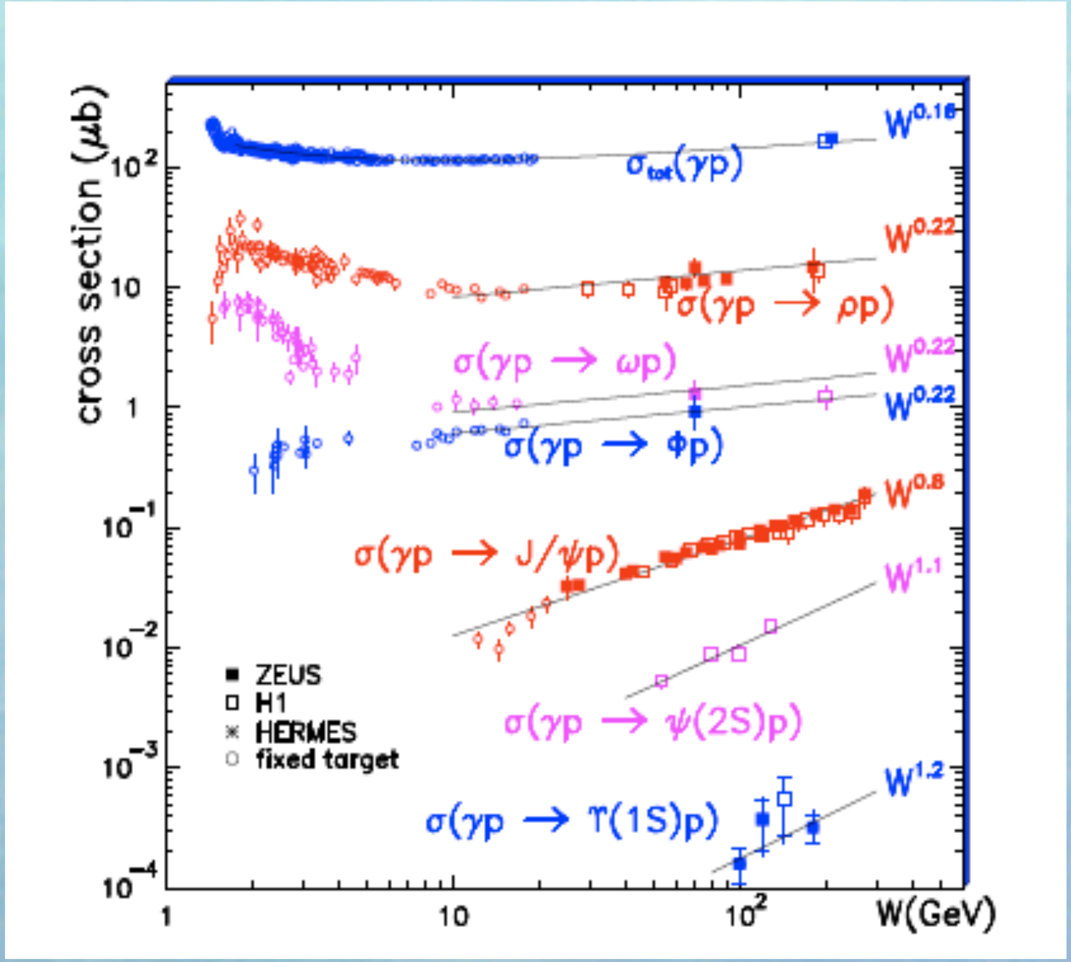
in agreement with the dipole model predictions;
diffraction selects much larger dipoles than non-diff DIS
⇒ much weaker Q^2 dependence than in non-diff DIS

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) ?

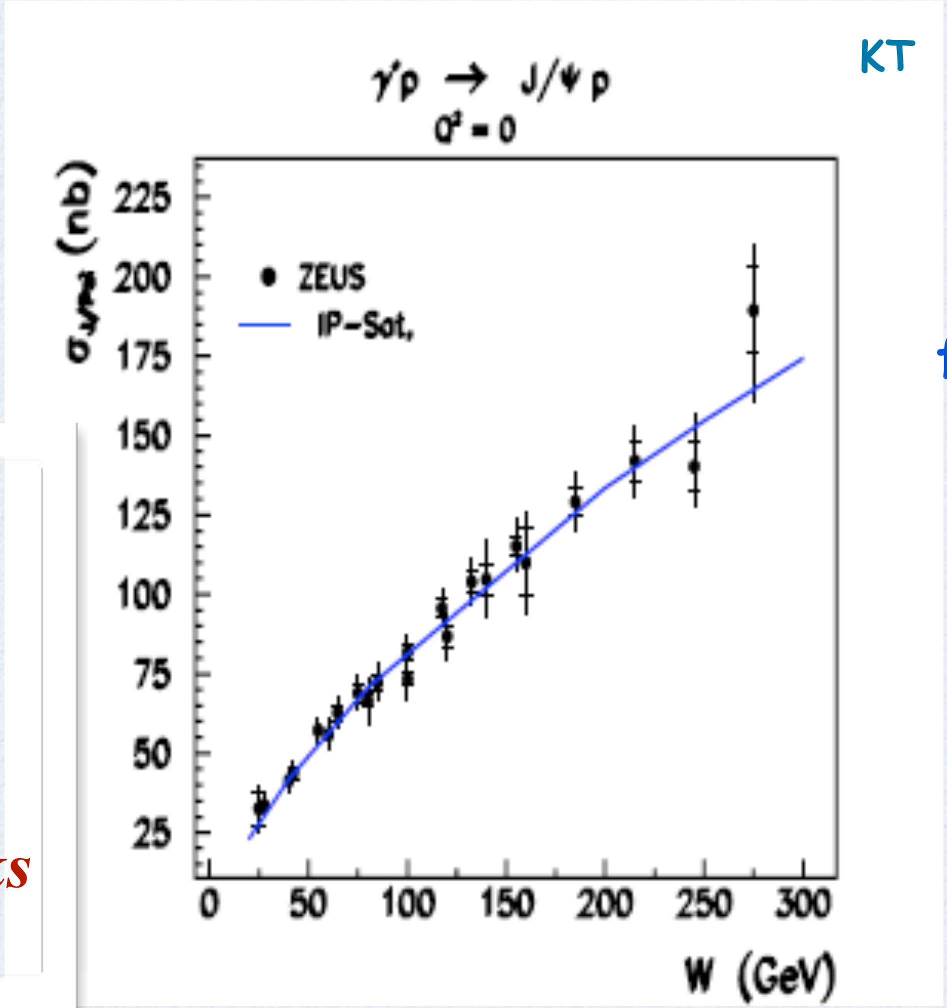
The inclusive diffractive data do not have enough precision to answer it

Clear hints provided by the exclusive vector meson production



In focus: Exclusive J/psi production

educated guess for VM wf is working very well for J/psi and phi and DVCS



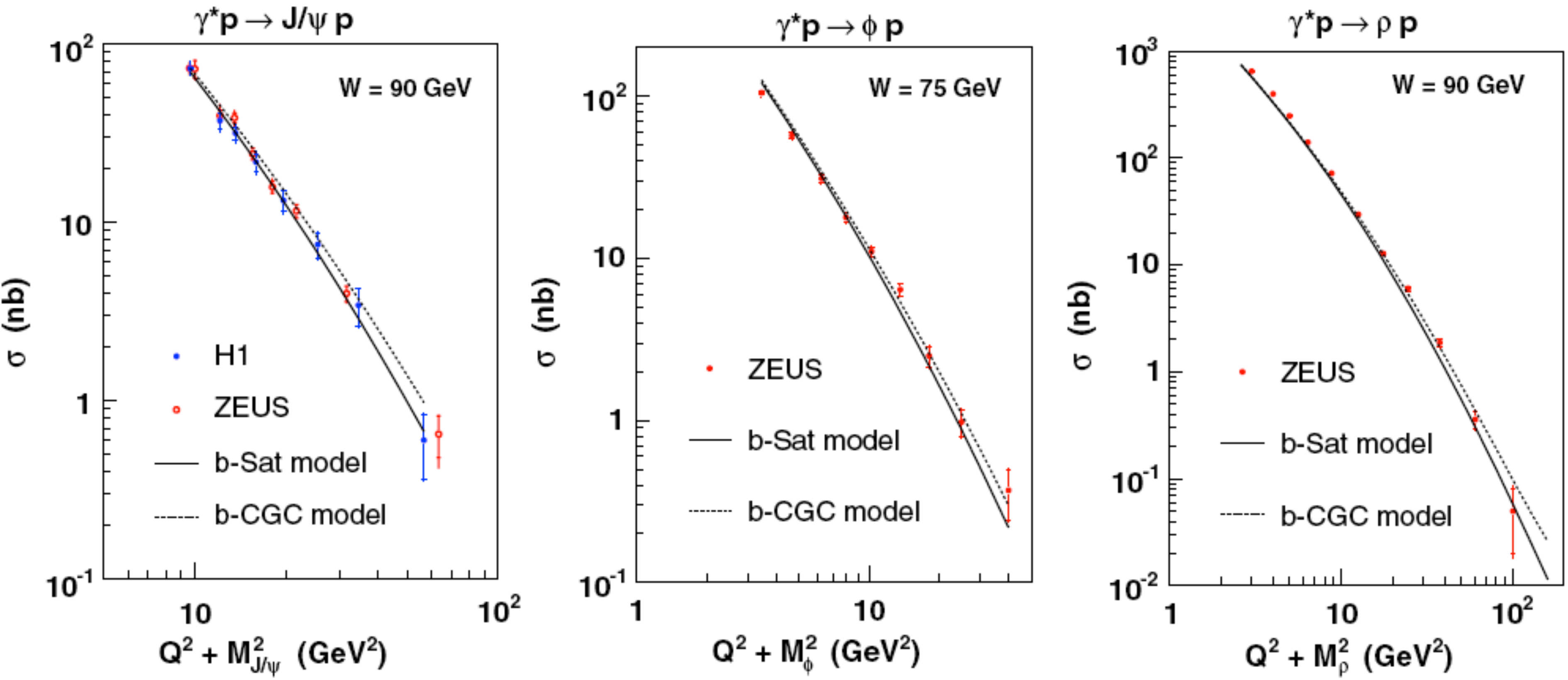
equally good description of Q2 and σ_L/σ_T dependences for J/psi and phi and DVCS

Note:
J/psi x-section grows almost like
$\sigma \propto (x\, g(x,\mu^2))^2$
no valence quarks contribution

➤ **the determination of gluon density with J/psi would be more precise than by F_2 or F_L (MRT) if J/psi measurements would have small systematic errors**

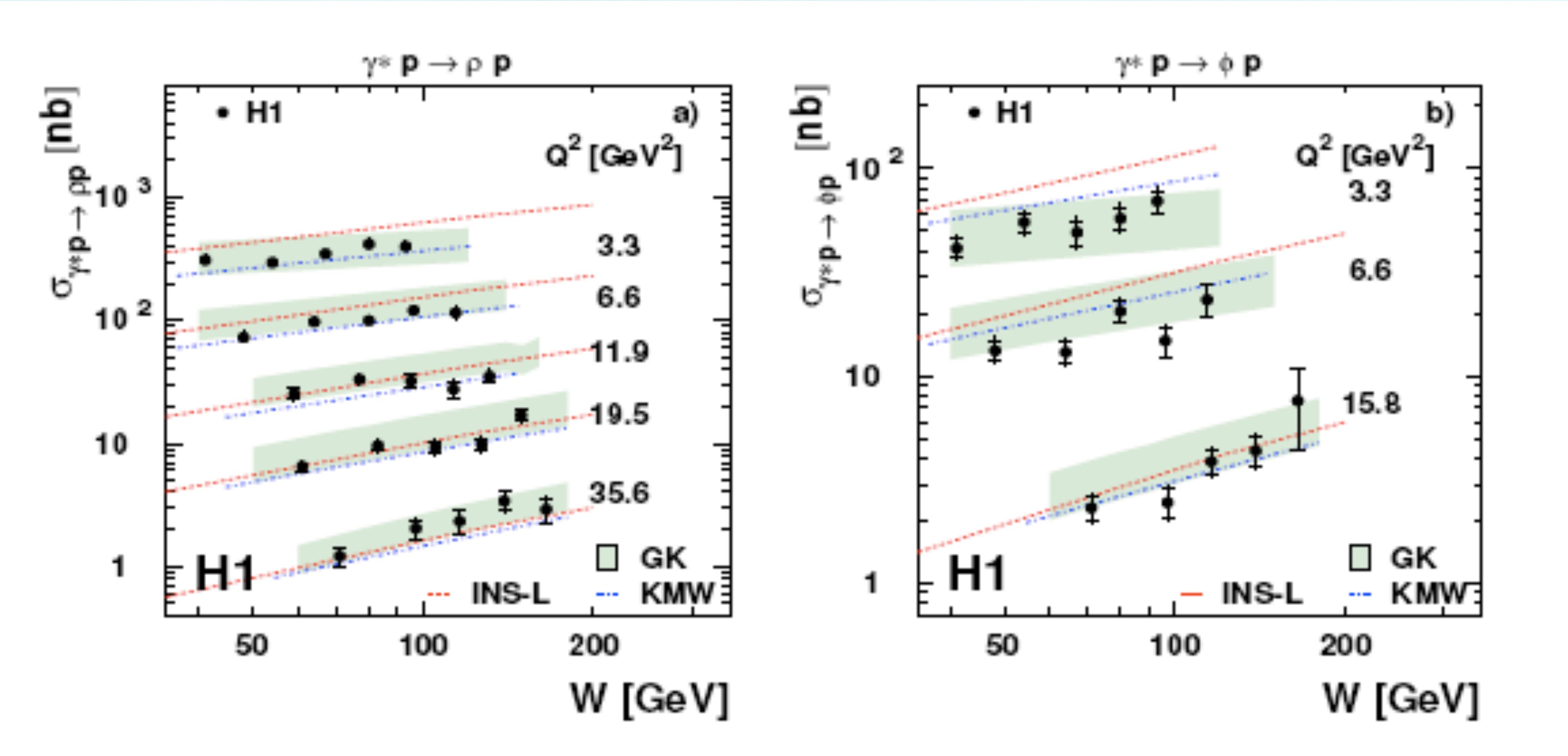
Total VM cross sections from dipole model

KMW Dipole model



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

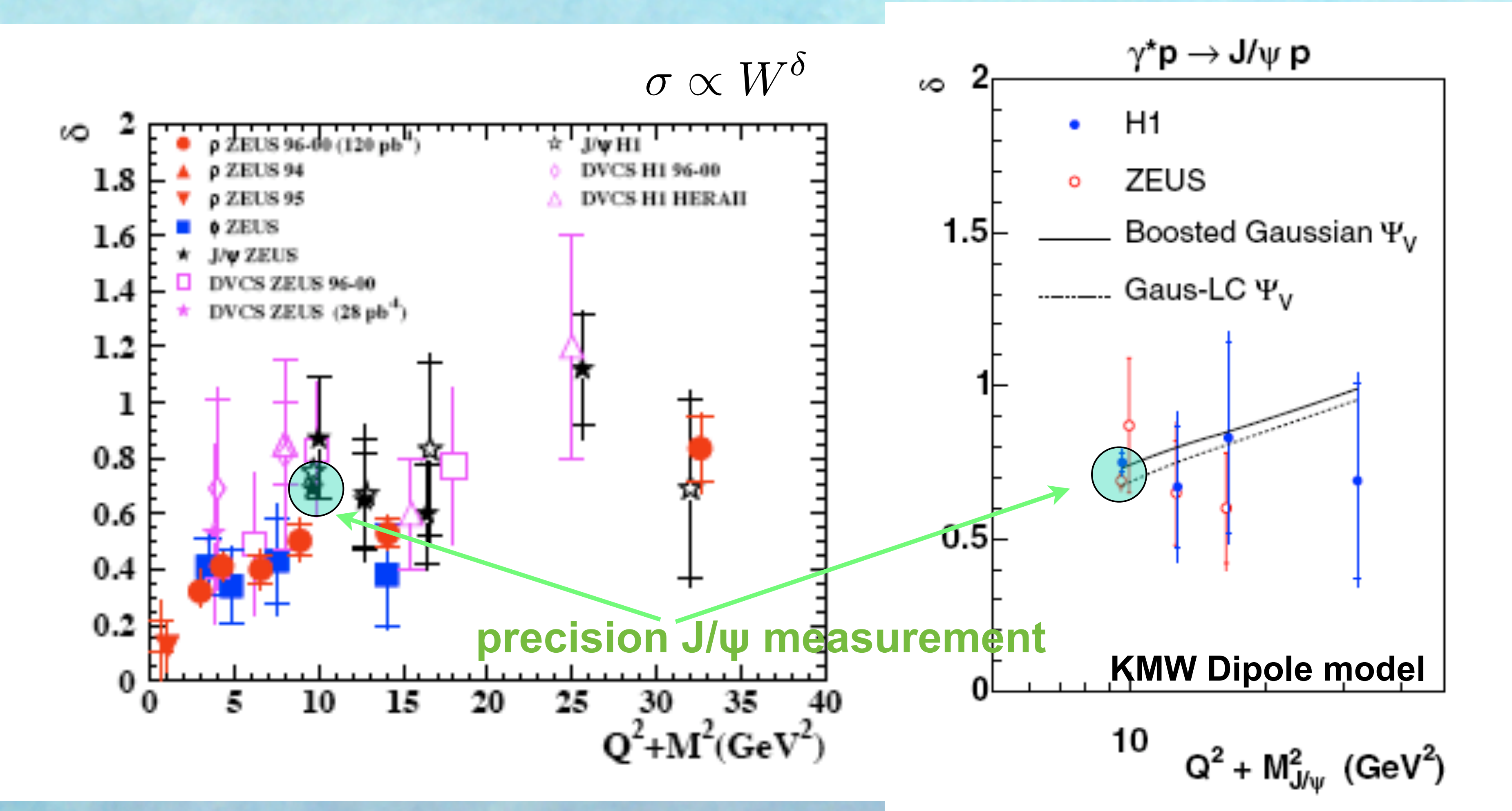
W dependence of exclusive Vector Mesons cross sections



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

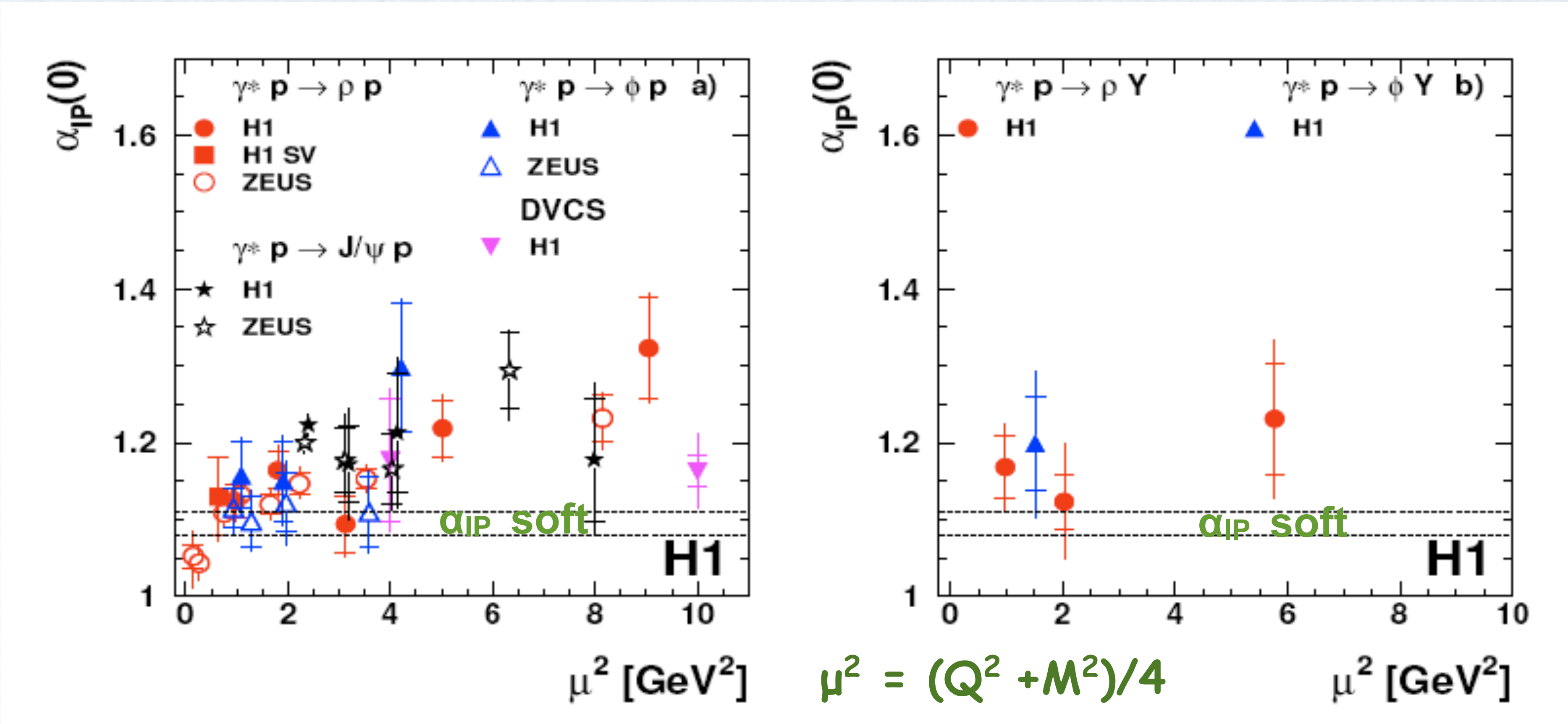
Note: these are absolute predictions obtained from the gluon density determined from F_2

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

α_{IP} in exclusive VM reactions

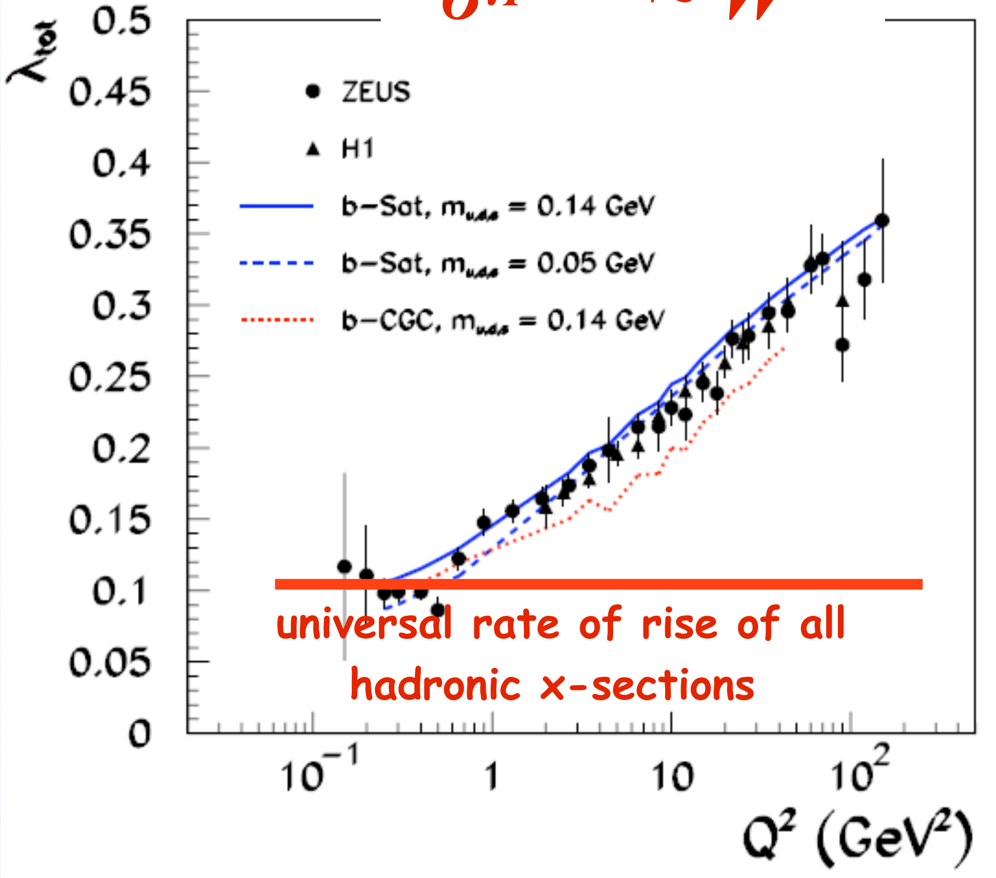


J/ψ and ρ show a clear increase of α_{IP} with the increase of scale

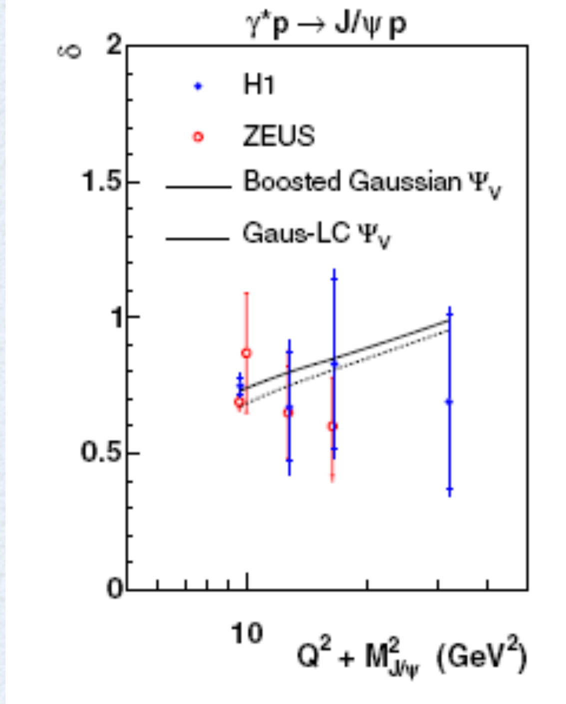
(in agreement with the dipole expectations that $\sigma_{qq} \sim (xg(x,\mu^2))^2$)

Discovery of HERA: the same, universal gluon density describes different reactions - $\gamma^* p \to X$, $\gamma^* p \to J/\psi\, p$ ...

$\sigma^{\gamma p \to X} \sim W^{2\lambda}$



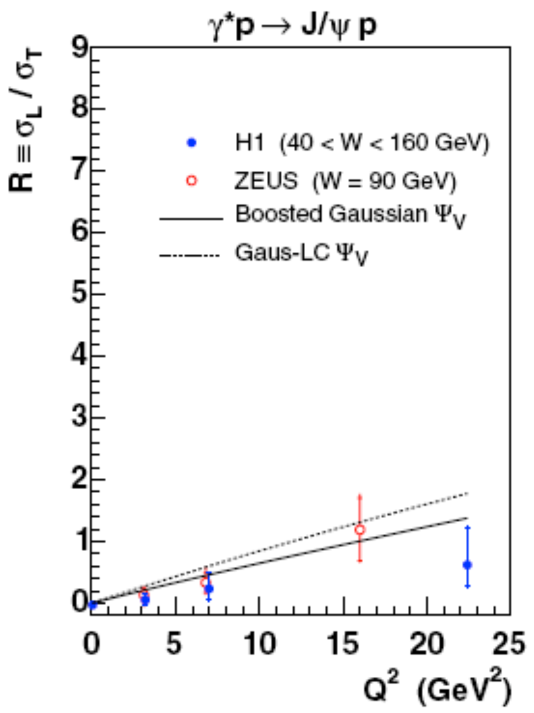
$\sigma^{\gamma p \to J/\psi\, p} \sim W^{\delta}$

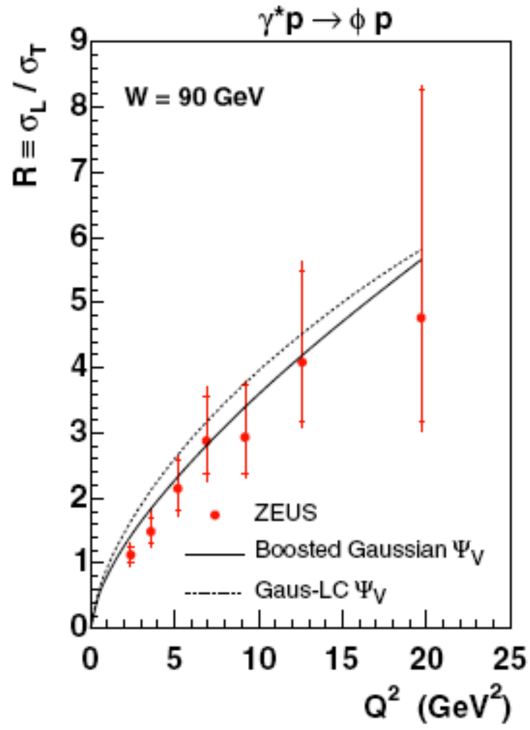


➤ universal, “pomeron like”, QCD object

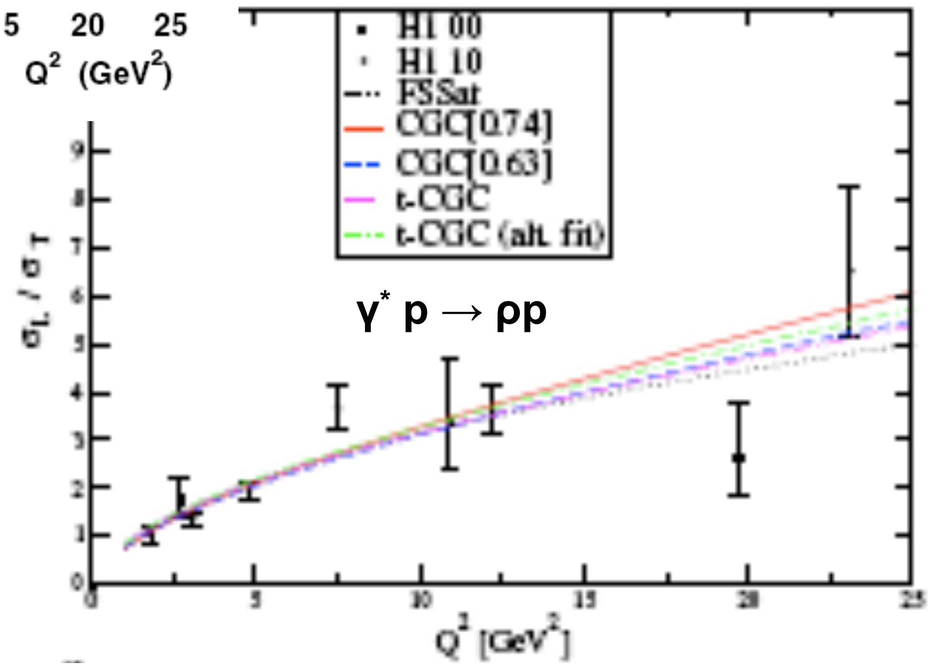
soft and hard pomeron join together

Dipole model description of σ_L / σ_T for VM

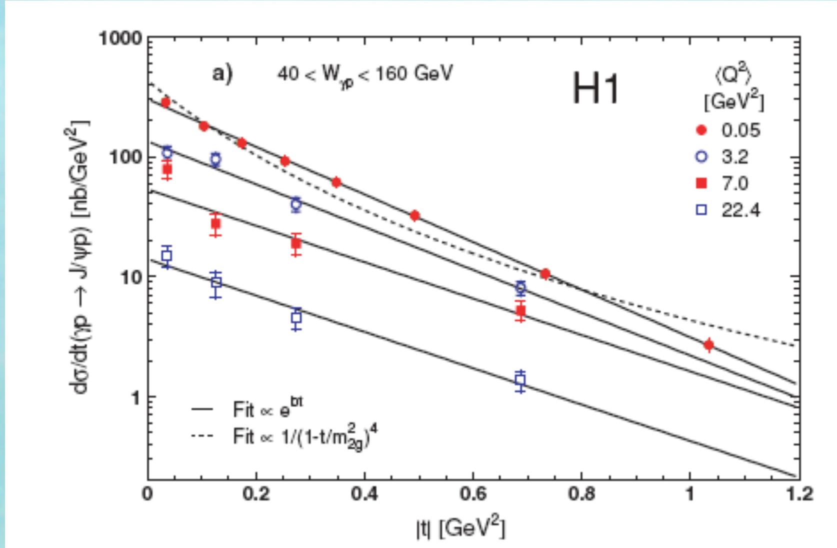




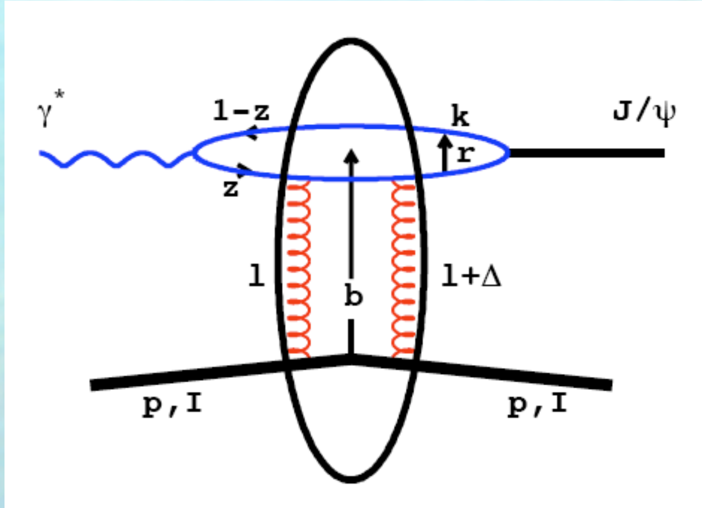
Forshaw and Sandapen improved recently the BG wf by enhancing the end point singularity contributions in the transverse ρ wf



t-distributions



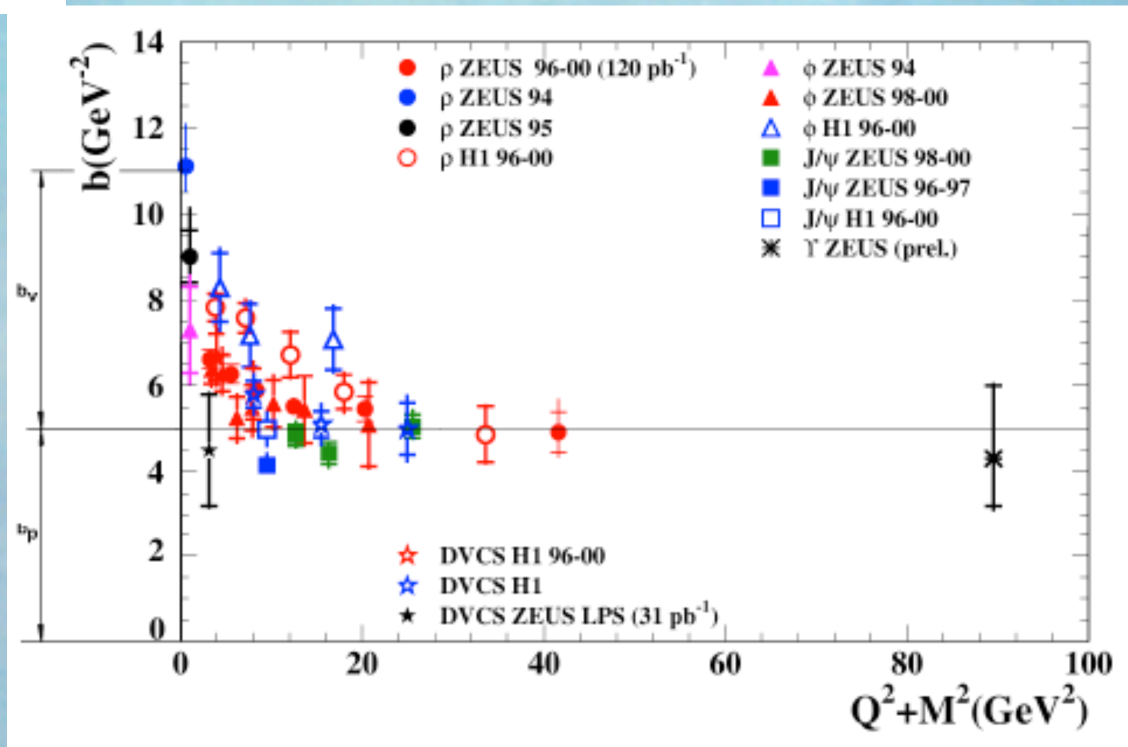
$$\frac{d\sigma}{dt} \sim e^{-b|t|}$$



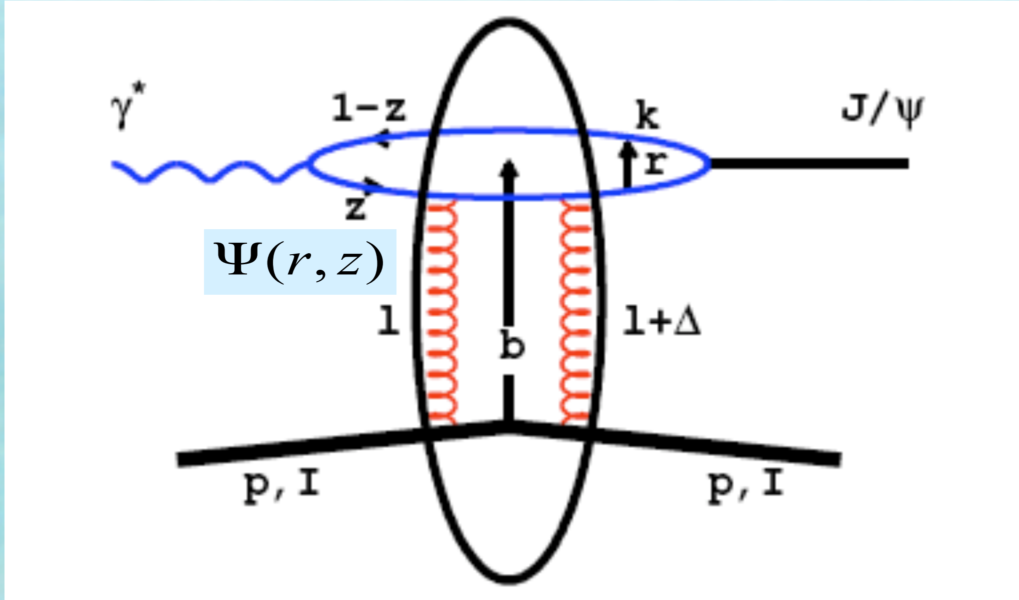
transverse size of the interaction region
$b = b_V + b_p$

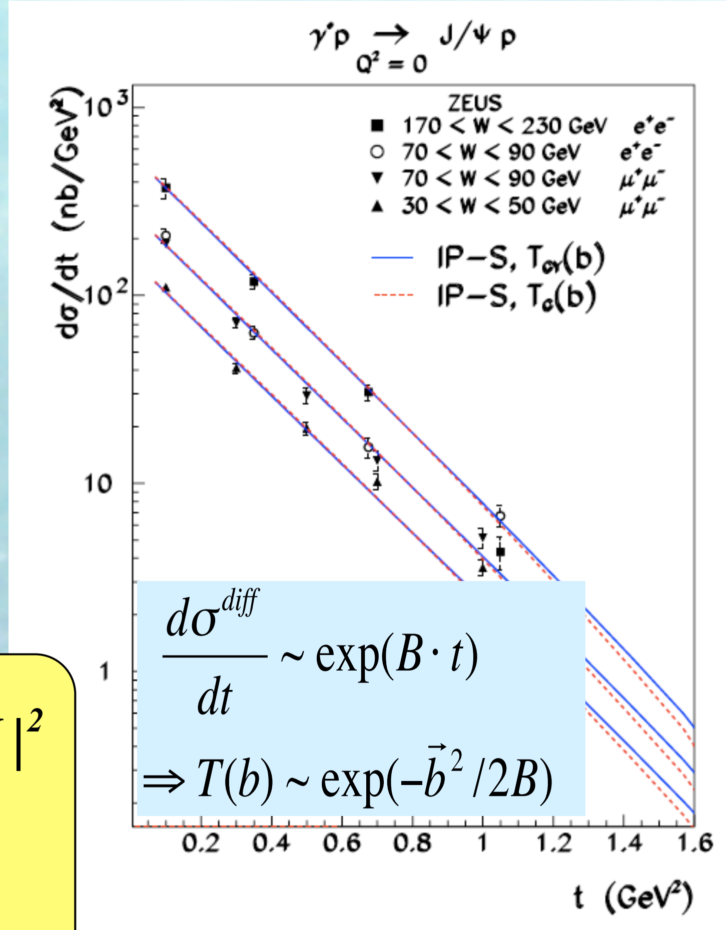
Vector Mesons
$b_V = 1/(Q^2 + M^2)$

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



Extracting Proton Shape using dipoles





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

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

KT, KMW

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

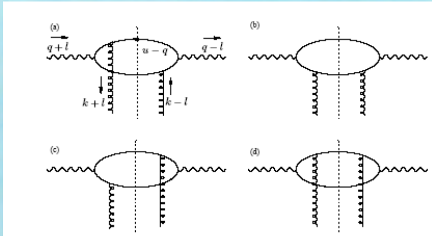
$$\Omega = \frac{\pi^2}{N_C} r^2 \alpha_s(\mu^2) xg(x,\mu^2) T(b)$$

T(b)-proton shape

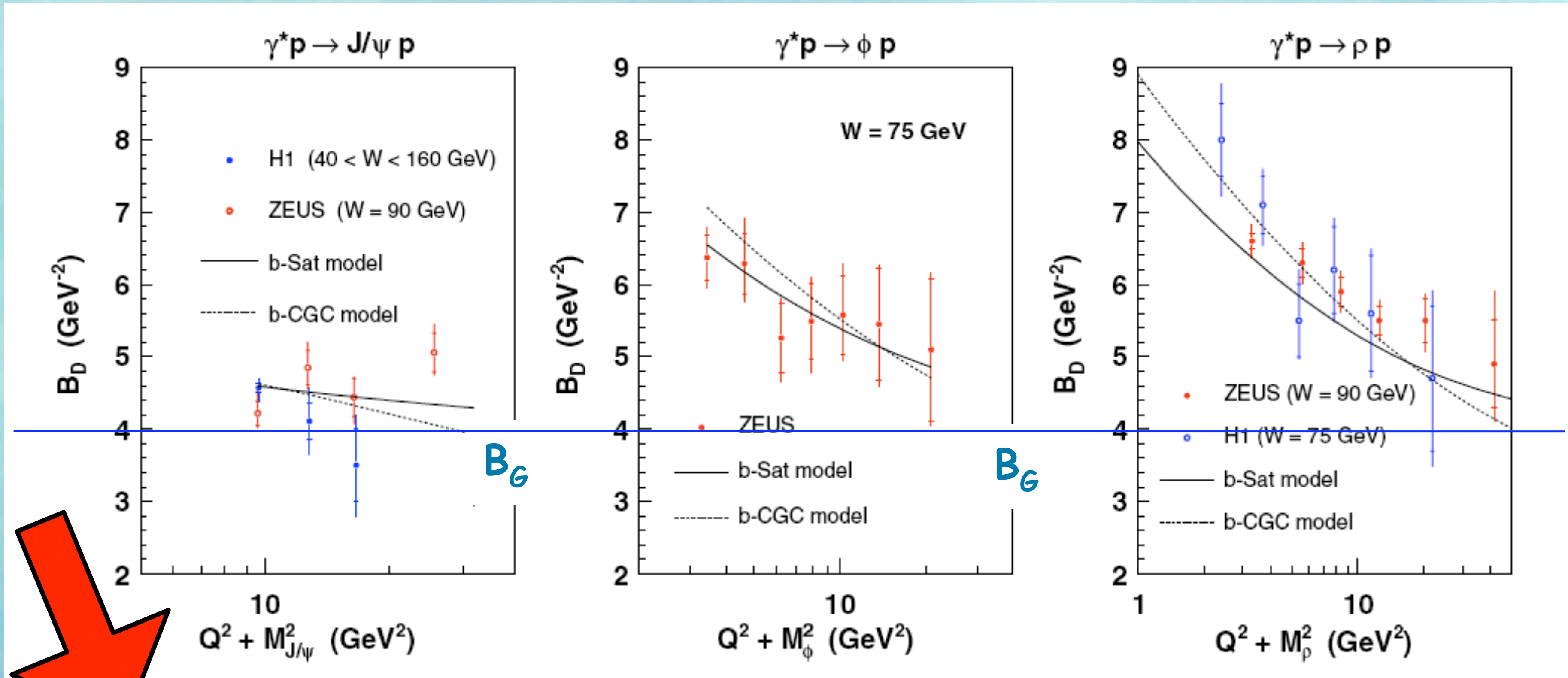
The size of interaction region B for various VM

Modification by Bartels, Golec-Biernat, Peters

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



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.

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 QCD Pomeron

Exclusive Vector Meson processes provide an excellent tool for investigation of the properties of the QCD Pomeron

The QCD Pomeron as described by the BFKL equation may have interesting and unusual properties

→ **see the talk of D. Ross**

Dipole model + valence quarks analysis of HERA data within the HERAFitter framework

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DIFFRACTION 2012, Lanzarote, September 11, 2012

- BGK (Bartels-Golec-Kowalski) parametrization

$$\hat{\sigma}(r,x) = \sigma_0 \left\{1 - \exp\left[-\pi^2 r^2 \alpha_s(\mu^2) x g(x,\mu^2)/(3\sigma_0)\right]\right\}$$

- $\mu^2 = C/r^2 + \mu_0^2$ is the scale of the gluon density
- gluon density is evolved according to the (LO) DGLAP equation

$$xg(x,\mu_0^2) = A_g\, x^{-\lambda_g}\, (1-x)^{C_g}$$

- Dipole model BGK fit without valence quarks

1.1 Dipole model BGK fit without valence quarks for σ_r for H1ZEUS-NC-(e+p) and H1ZEUS-NC-(e-p) data in the range $Q^2 \geq 3.5$ and $Q^2 \geq 8.5$ and $x \leq 0.01$.

No	Q^2	HF Scheme	σ_0	A_g	λ_g	$cBGK$	$eBGK$	Np	χ^2	χ^2/Np
1	$Q^2 \geq 3.5$	RT	40.43	1.596	-0.249	1.529	0.401	197	214.46	1.10
2	$Q^2 \geq 3.5$	ACOT Full	40.43	1.596	-0.249	1.529	0.401	197	214.46	1.10
3	$Q^2 \geq 8.5$	RT	32.48	1.691	-0.256	1.463	0.155	156	125.10	0.80
4	$Q^2 \geq 8.5$	ACOT Full	32.48	1.691	-0.256	1.463	0.155	156	125.10	0.80

HERAPDF fit with valence quarks

1.4 HERAPDF fit with valence quarks for σ_r for H1ZEUS-NC-(e+p), H1ZEUS-NC-(e-p) data in the range $Q^2 \geq 3.5$ and $Q^2 \geq 8.5$. χ^2 is calculated in the region $x \leq 0.01$.

No	Q^2	HF Scheme	Np	χ^2	χ^2/Np
1	$Q^2 \geq 3.5$	RT	197	220.64	1.12
2	$Q^2 \geq 3.5$	ACOT Full	197	206.85	1.05
3	$Q^2 \geq 8.5$	RT	156	131.04	0.84
4	$Q^2 \geq 8.5$	ACOT Full	156	131.04	0.84

Dipole model BGK fit with valence quarks

1.7 Dipole model BGK fit with valence quarks for σ_r for H1ZEUS-NC-(e+p) and H1ZEUS-NC-(e-p) data in the range $Q^2 \geq 3.5$ and $Q^2 \geq 8.5$ and $x \leq 0.01$. ACOT Full HF Scheme.

No	Q^2		σ_0	A_g	λ_g	C_g	$cBGK$	$eBGK$	Np	χ^2	χ^2/Np
1	$Q^2 \geq 3.5$	LO	32.571	2.619	-0.147	4.870	4.0	14.780	196	244.23	1.246
2	$Q^2 \geq 8.5$	LO	26.651	4.732	-0.080	11.569	4.0	17.743	157	129.86	0.827
3	$Q^2 \geq 3.5$	NLO	35.980	1.964	-0.147	3.068	4.0	15.171	196	245.74	1.254
4	$Q^2 \geq 8.5$	NLO	27.820	3.660	-0.076	8.405	4.0	18.188	157	128.92	0.821

Comparison of the BGK fits with different sets of PDFs

- *CTEQ66* valence quarks:
  1) $Q2 > 3.5, \ \chi^2/Np = 1.20$
  2) $Q2 > 8.5, \ \chi^2/Np = 0.81$

- *HERAPDF15NLO* valence quarks:
  1) $Q2 > 3.5, \chi^2/Np = 1.26$
  2) $Q2 > 8.5, \chi^2/Np = 0.82$

- *MSTW2008nlo68* valence quarks:
  1) $Q2 > 3.5, \chi^2/Np = 1.17$
  2) $Q2 > 8.5, \chi^2/Np = 0.81$

Conclusions

- The quality of the fits of the BGK dipole model with valence quarks and without valence quarks are the same.
- The quality of the fits of the BGK dipole model with valence quarks matches the quality of HERAPDF fits in the low x region.