

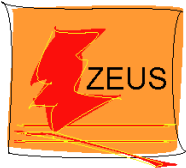
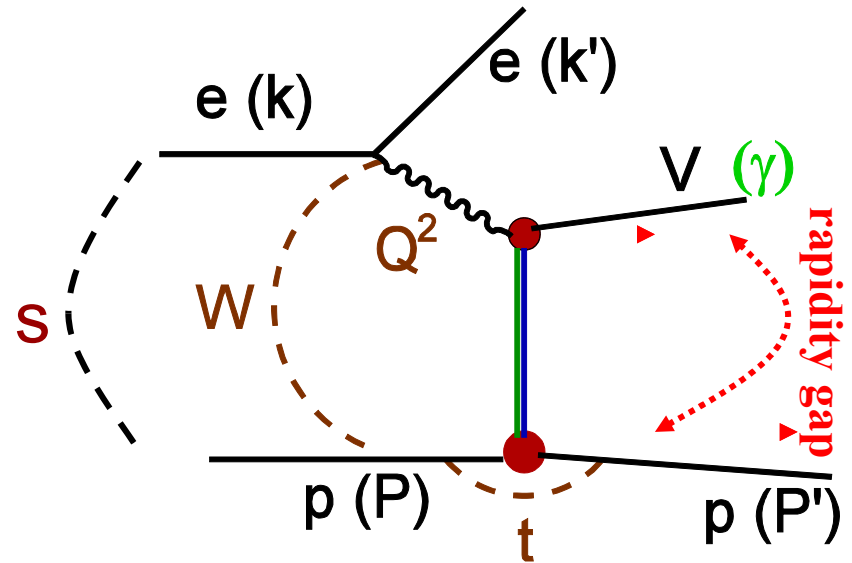
Vector meson production and DVCS at HERA



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on behalf of the ZEUS and H1 Collaborations



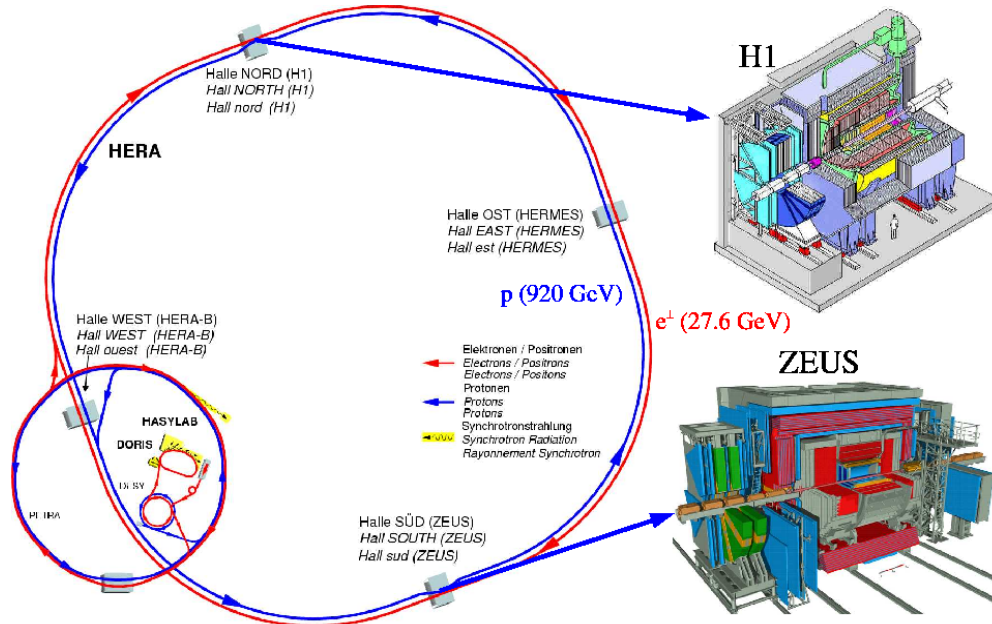
Low-x 2010

Kavala (Greece), June 23 – 27, 2010

HERA colliding experiments

- 27.5 GeV electrons/positrons on 920 GeV protons $\rightarrow \sqrt{s}=318$ GeV
- 2 collider experiments: **H1** and **ZEUS**
- HERA I: $16 \text{ pb}^{-1} \text{ e-p}$, $120 \text{ pb}^{-1} \text{ e+p}$
HERA II (after lumi upgrade): $\sim 400 \text{ pb}^{-1}$, polarisation of e^+, e^-

Closed July 2007, still lot of excellent data to analyse...

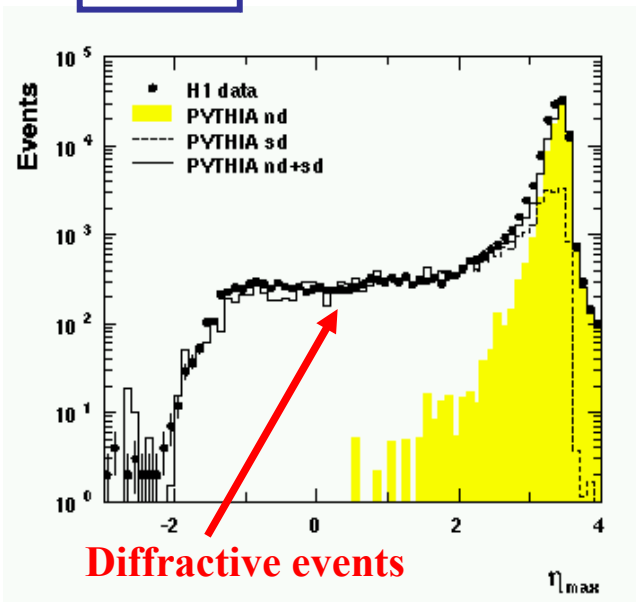
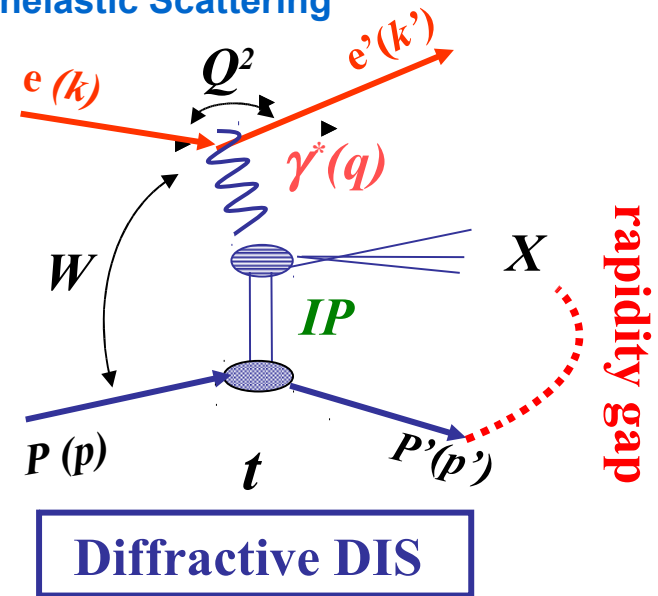
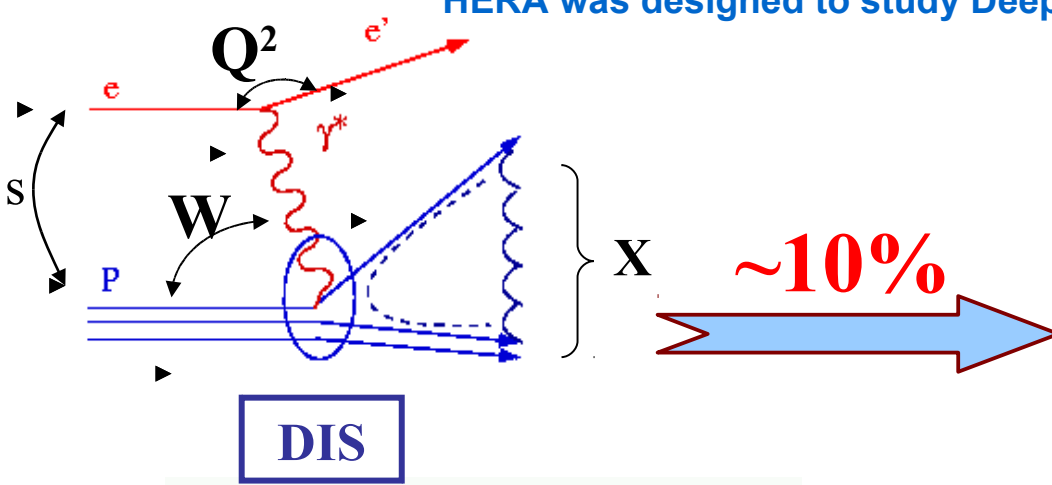


Detectors not originally designed for forward physics, although a lot of results achieved in diffraction at HERA!

Forward instrumentation added later (@ ZEUS for HERA I only)

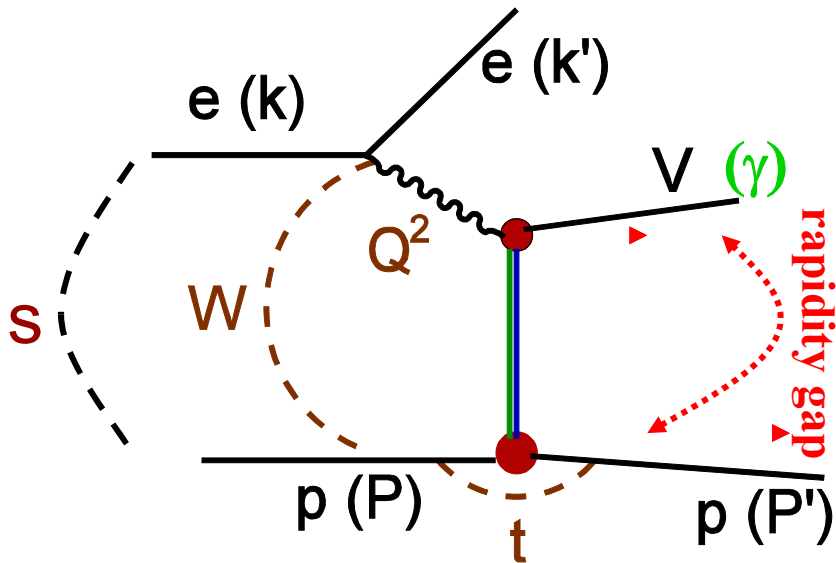
Diffraction in ep collisions at HERA

HERA was designed to study Deep Inelastic Scattering



- p escapes in the beam pipe
- no quantum numbers exchanged btw γ^* and p
 - no colour flux → large rapidity gap
- Providing a perturbative QCD motivated description of strong interactions

Exclusive diffraction



Main kinematic variables

photon virtuality:

$$Q^2 = -q^2 = -(k - k')^2 \approx 4 E_e E_e' \sin^2 \frac{\theta}{2}$$

photon-proton centre-of-mass energy:

$$W^2 = (q + p)^2, \text{ where: } m_p < W < \sqrt{s}$$

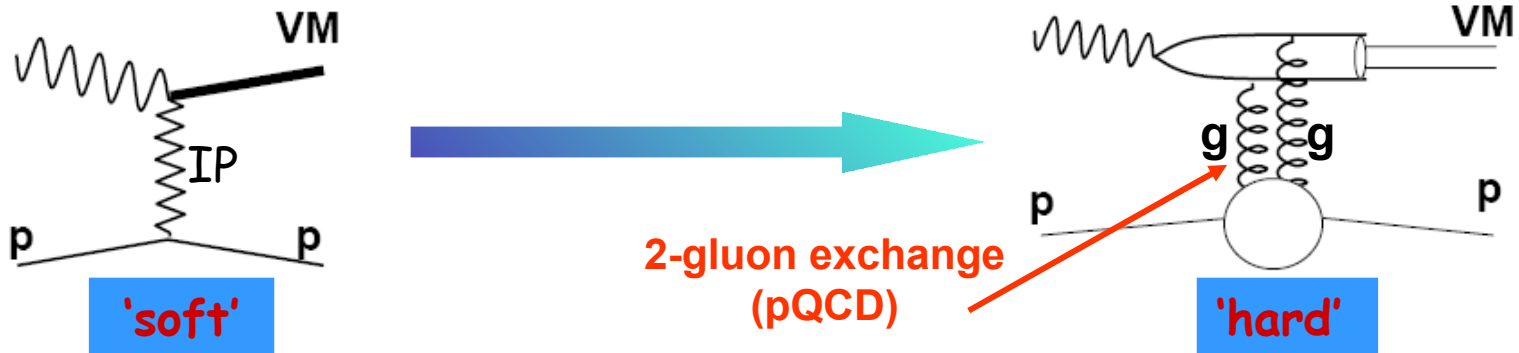
square 4-momentum at the p vertex:

$$t = (p' - p)^2$$

- Vector Mesons production in diffraction
- Deeply Virtual Compton Scattering
- W , Q^2 and t cross section dependence for exclusive processes
- Azimuthal asymmetries in DVCS
- Pomeron trajectory

Soft and hard diffraction

Vector Meson production ($\rho, \phi, J/\psi, Y, \gamma$)



Pomeron trajectory: $\alpha^0 + \alpha't$

Cross section proportional to probability of finding 2 gluons in the proton

$$\begin{cases} \sigma \propto [X g(x, \mu^2)]^2 \\ \mu^2 \propto (Q^2 + M_V^2) \end{cases}$$

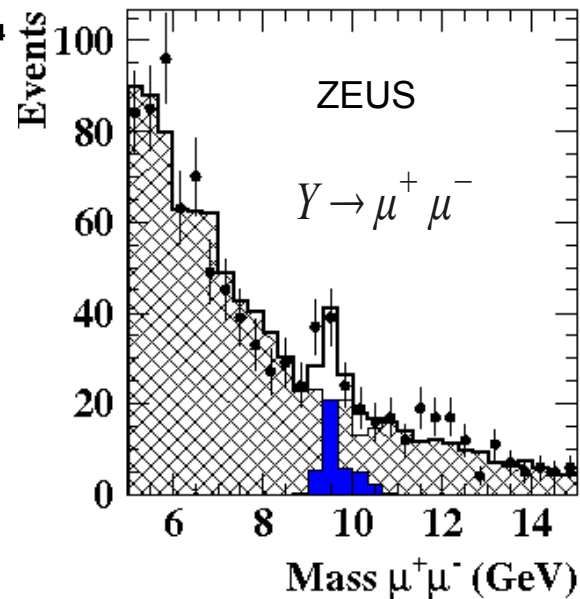
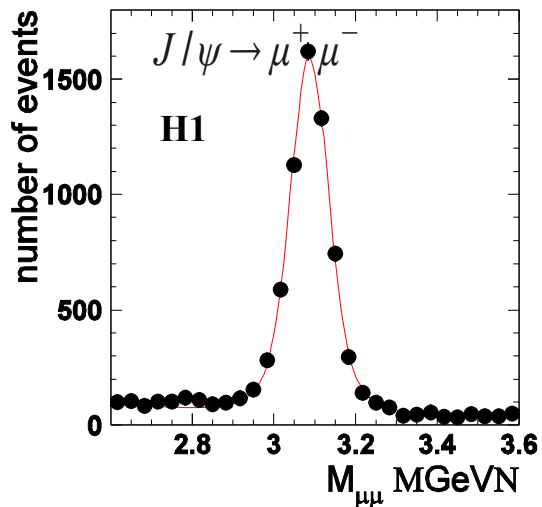
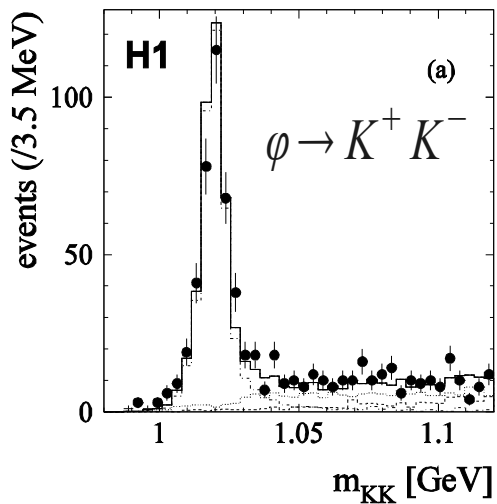
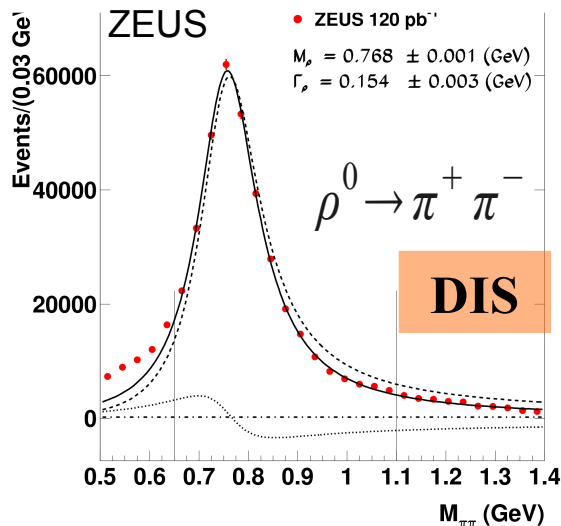
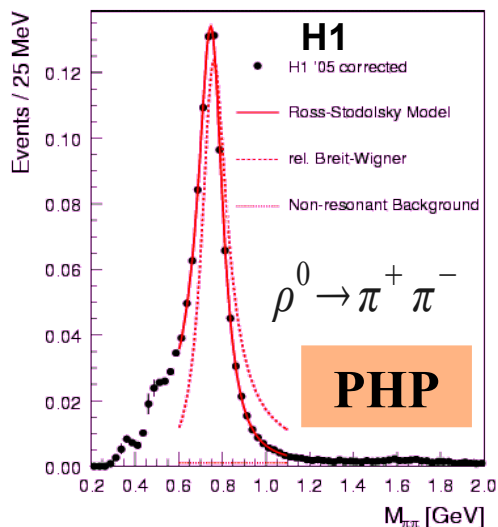
Gluon density in the proton

$\sigma(W) \propto W^\delta$ \rightarrow δ Expected to increase from soft (~ 0.2 , "soft Pomeron") to hard ($\sim 1.$, "hard Pomeron")

$\frac{d\sigma}{dt} \propto e^{-b|t|}$ \rightarrow b expected to decrease from soft ($\sim 10 \text{ GeV}^{-2}$) to hard ($\sim 4-5 \text{ GeV}^{-2}$)

VM mass distributions

Large variety of processes to study dynamics versus scales: M_V^2 , Q^2 , t

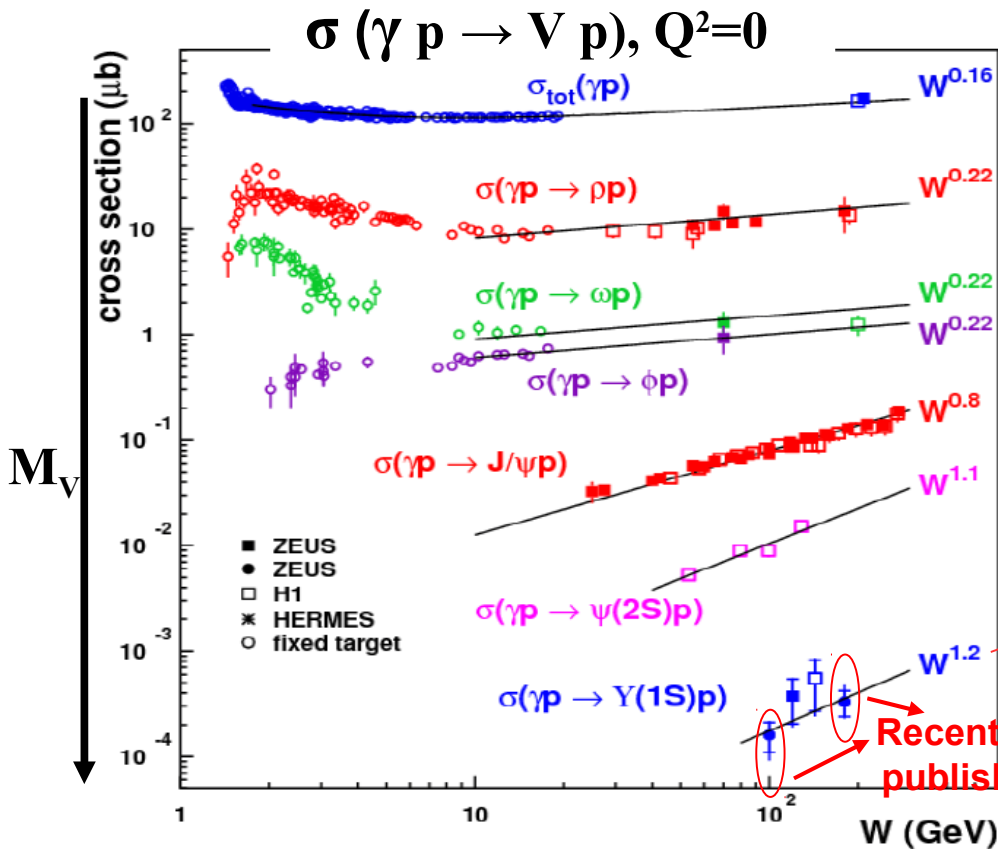


VM photoproduction: W-dependence

Large M_V supplies a scale for hard processes \rightarrow apply pQCD models

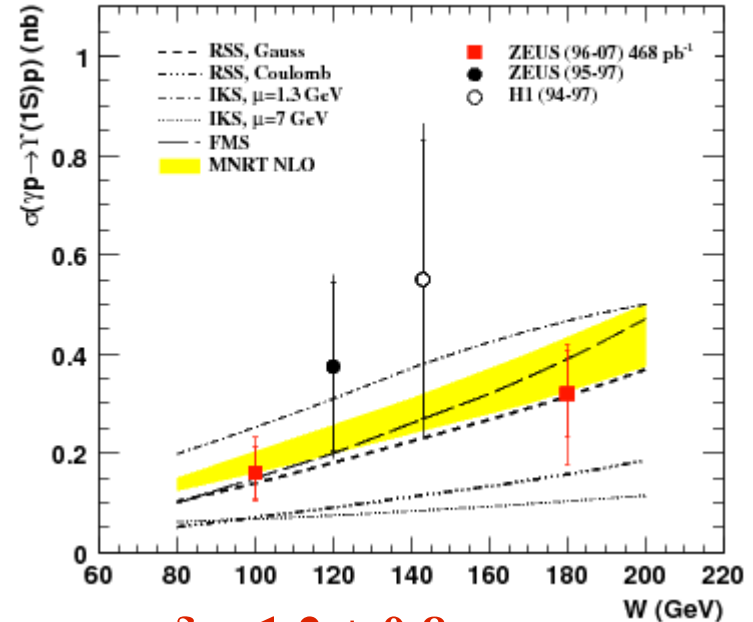
Υ php ($M_\Upsilon = 9.46 \text{ GeV}^2$)

ZEUS



Fit: $\sigma \sim W^\delta$

Recently published



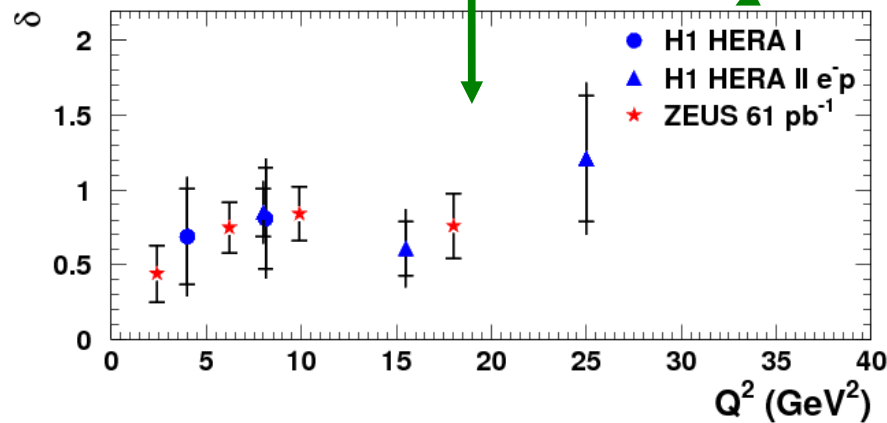
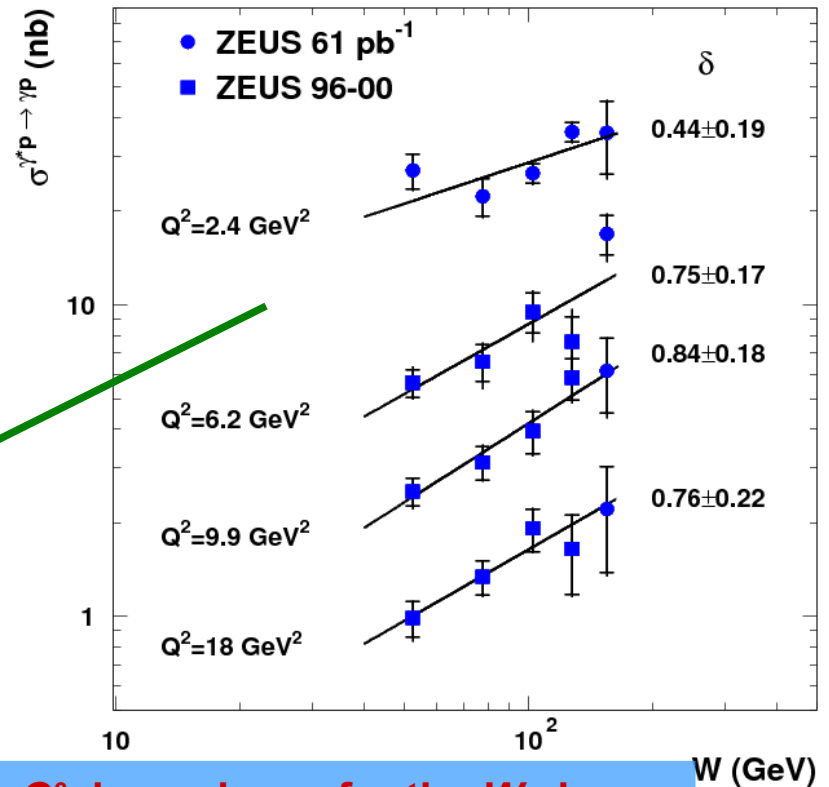
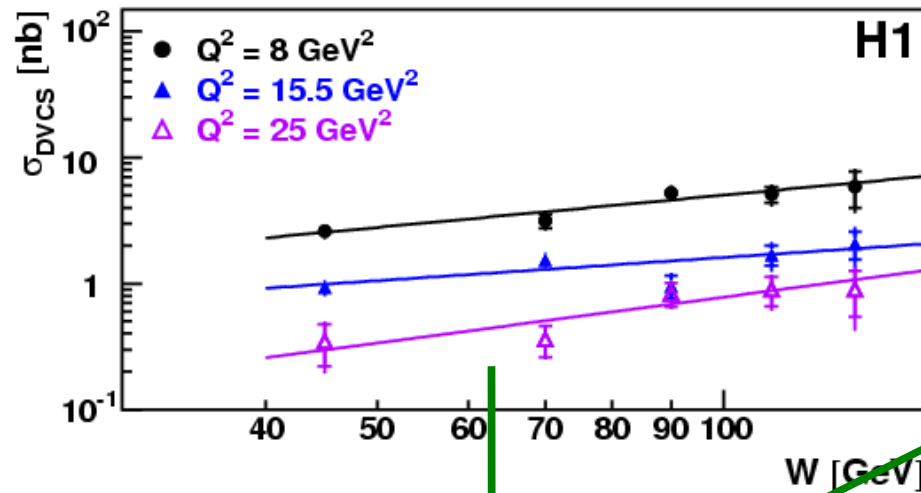
$\delta = 1.2 \pm 0.8$

- Υ sensitive to VM wave function: Gauss preferred to Coulomb
- pQCD models: compatible with FMS LO ($\delta=1.7$) and NLO ($\delta=1.2$)

Phys. Lett. B 680 (2009) 4-12

DVCS: W -dependence

Scale: $Q^2 + M^2$ $\xleftarrow{M_\gamma = 0}$ Q^2 ZEUS Fit: $\sigma \sim W^\delta$



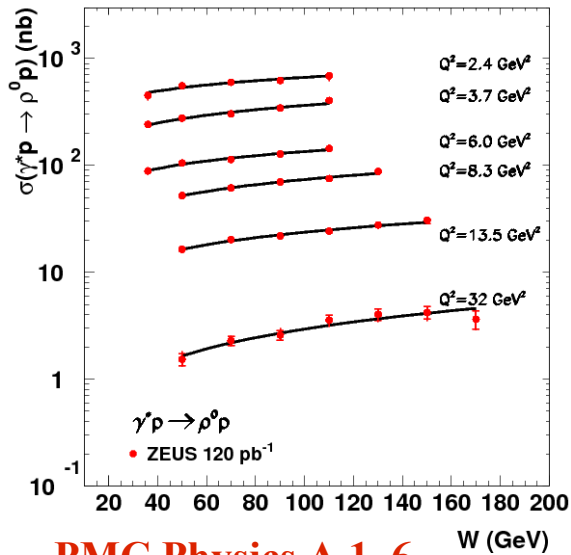
Q^2 dependence for the W slope not clear within the uncertainties!

ZEUS: JHEP05(2009)108

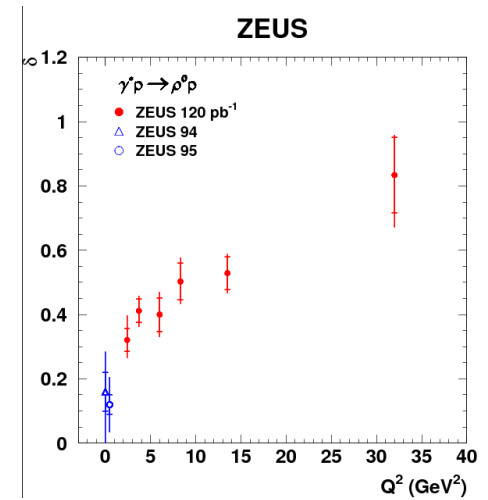
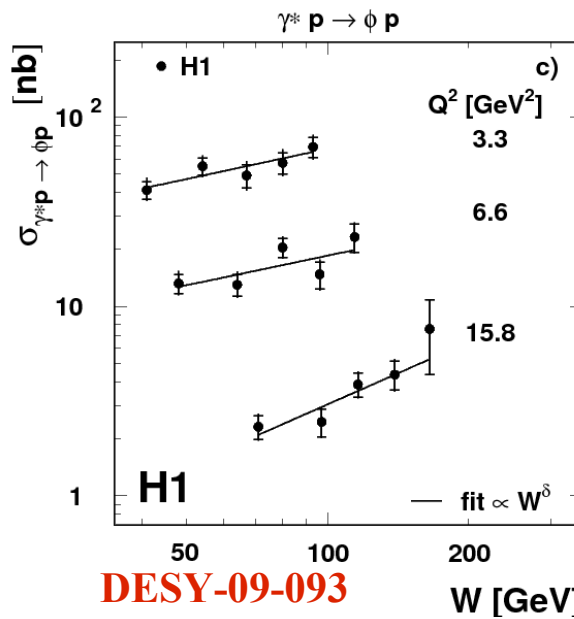
H1: Phys.Lett.B659:796-806,2008

VM electroproduction: W-dependence

ZEUS



Light VM (rho and phi)

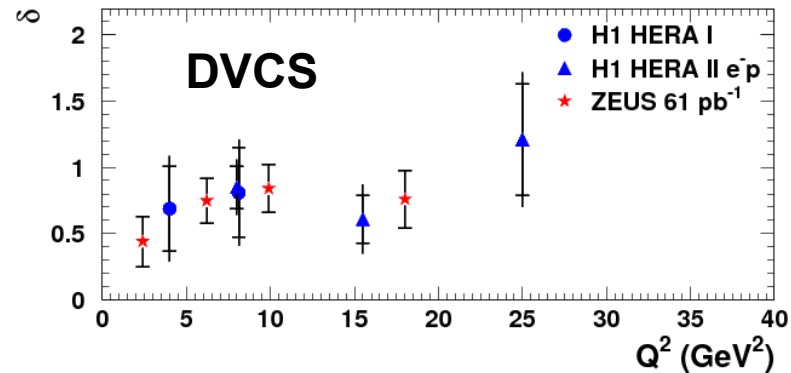


PMC Physics A 1, 6

DESY-09-093

Fit: $\sigma \sim W^\delta$

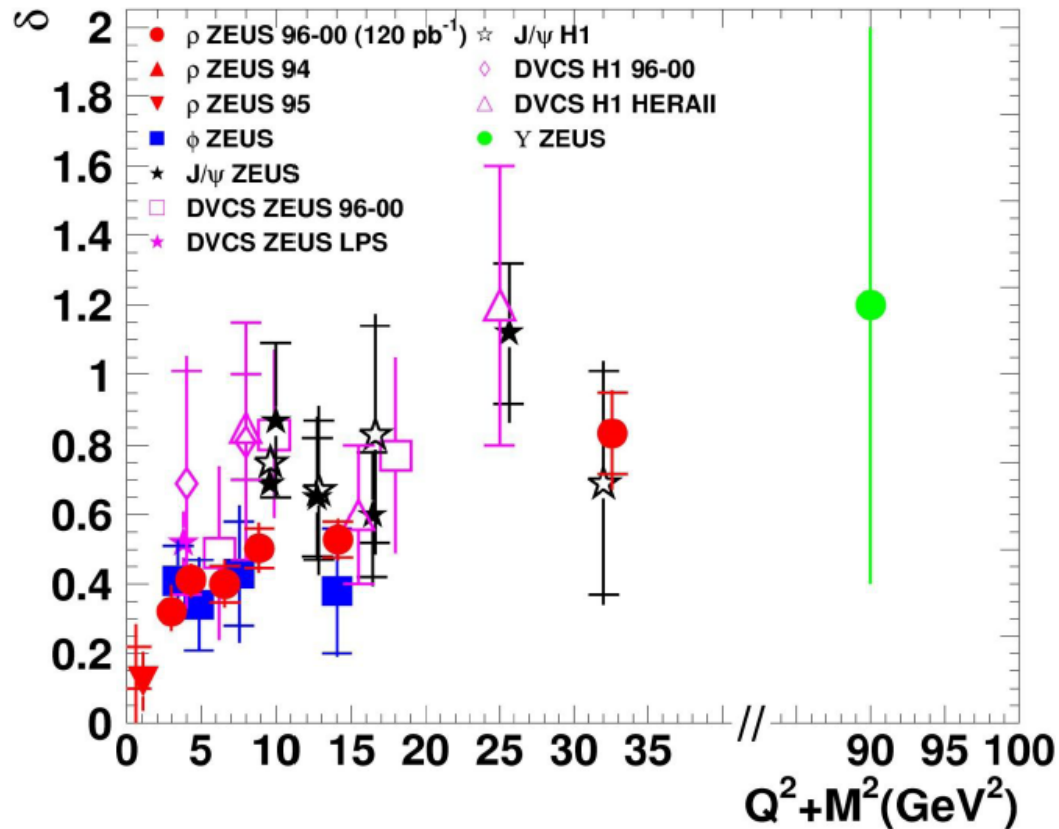
- Similar behavior for light VMs (ρ and ϕ) $\rightarrow \delta$ rises with Q^2 from soft to hard regime
- DVCS shows a “hard” behavior



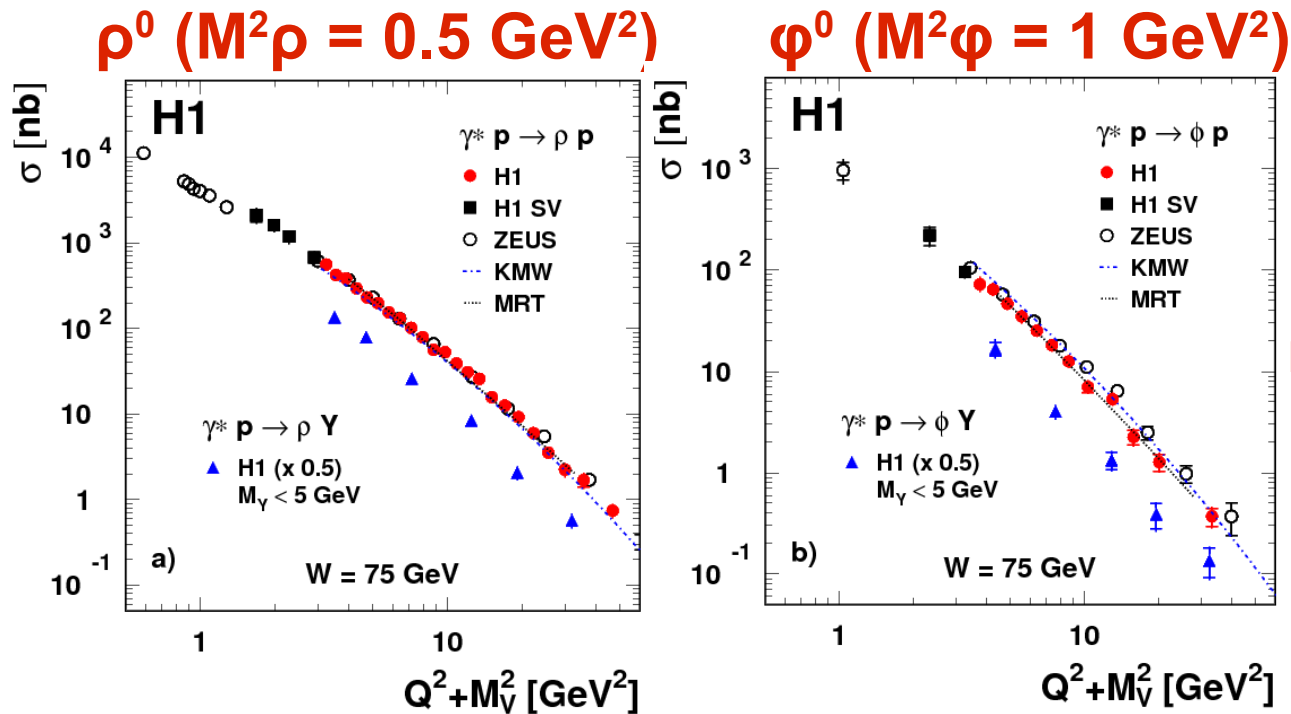
summary: W -dependence

Fit: $\sigma \sim W^\delta$

W -slope is $(Q^2 + M_V^2)$ scale dependent



Q²-dependence



$\sigma \propto (Q^2 + M^2)^{-n}$

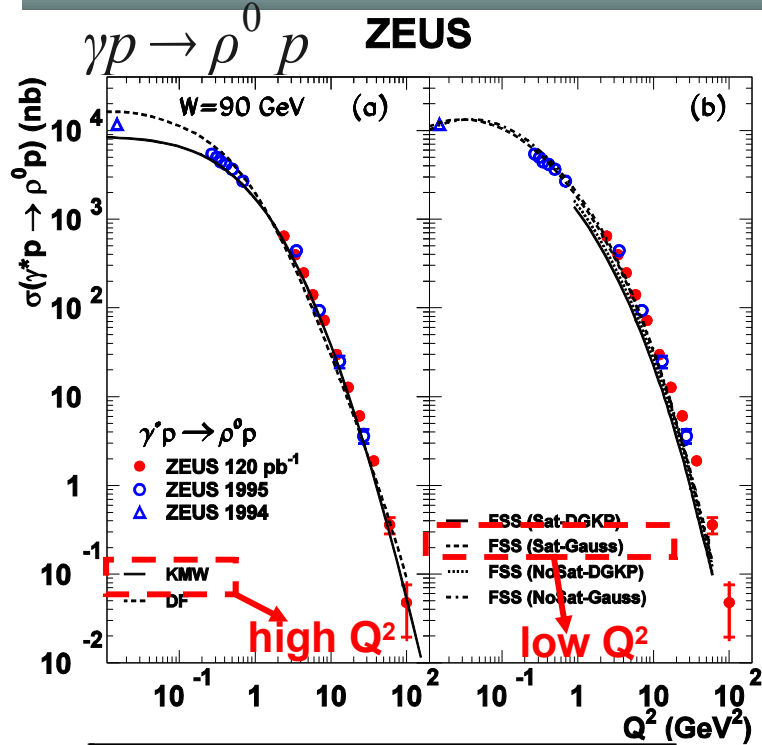
Fit to whole Q^2 range gives bad χ^2/df

Good H1/ZEUS agreement

- $Q^2 \geq 0 \text{ GeV}^2$, $n \approx 2.00 \pm 0.01$, $\chi^2/\text{ndf} \sim 10$ ($n \neq \text{const}$)
- $Q^2 \geq 10 \text{ GeV}^2$, $n \approx 2.50 \pm 0.02$, $\chi^2/\text{ndf} \sim 1.5$

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Q²-dependence

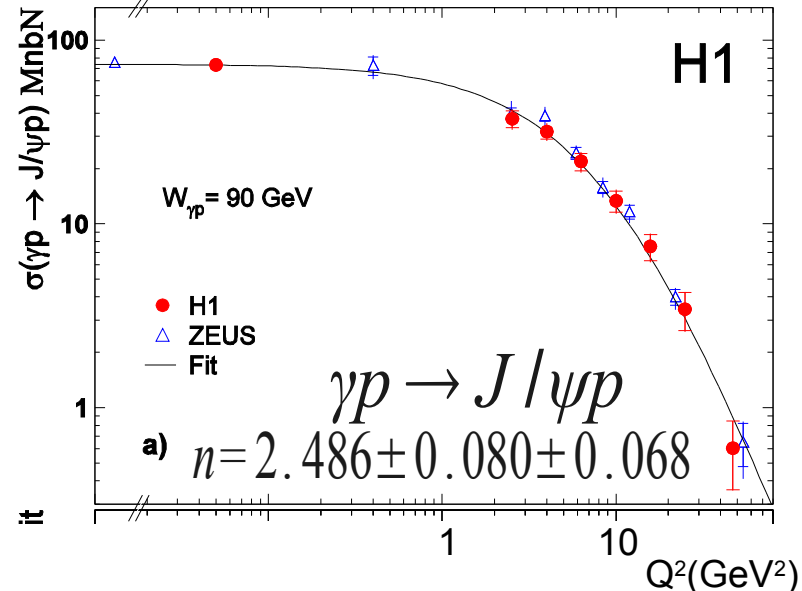
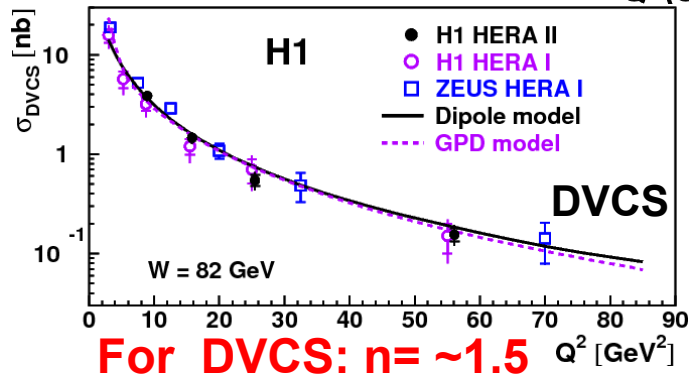


$$\sigma \propto (Q^2 + M^2)^{-n}$$

Fit to whole Q² range gives bad χ^2/df (~70)



n increasing with Q² appears to be favored

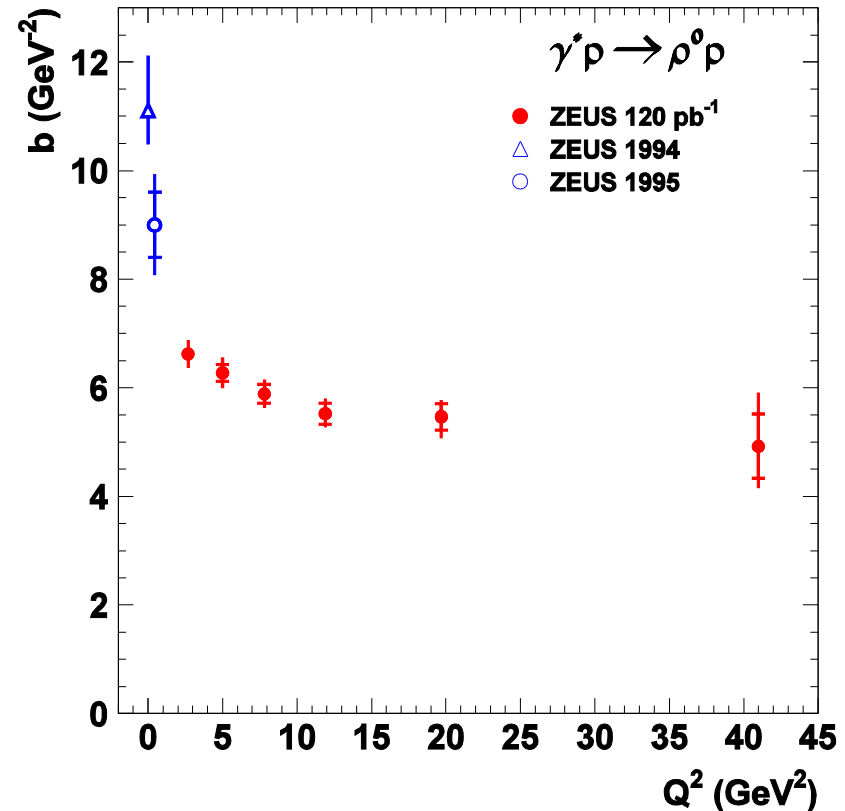
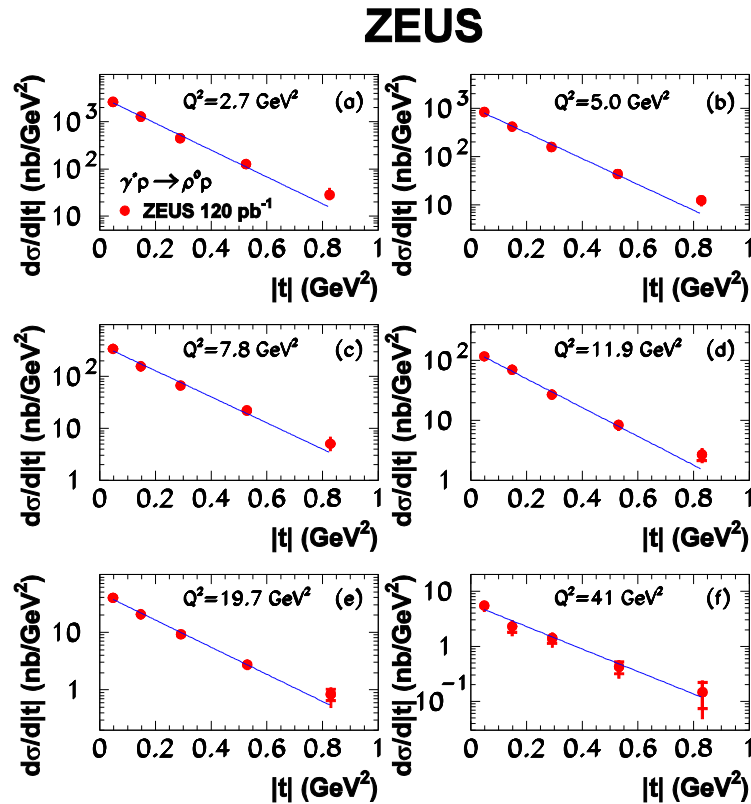


ρ^0 : t dependence

$$\gamma p \rightarrow \rho^0 p$$

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

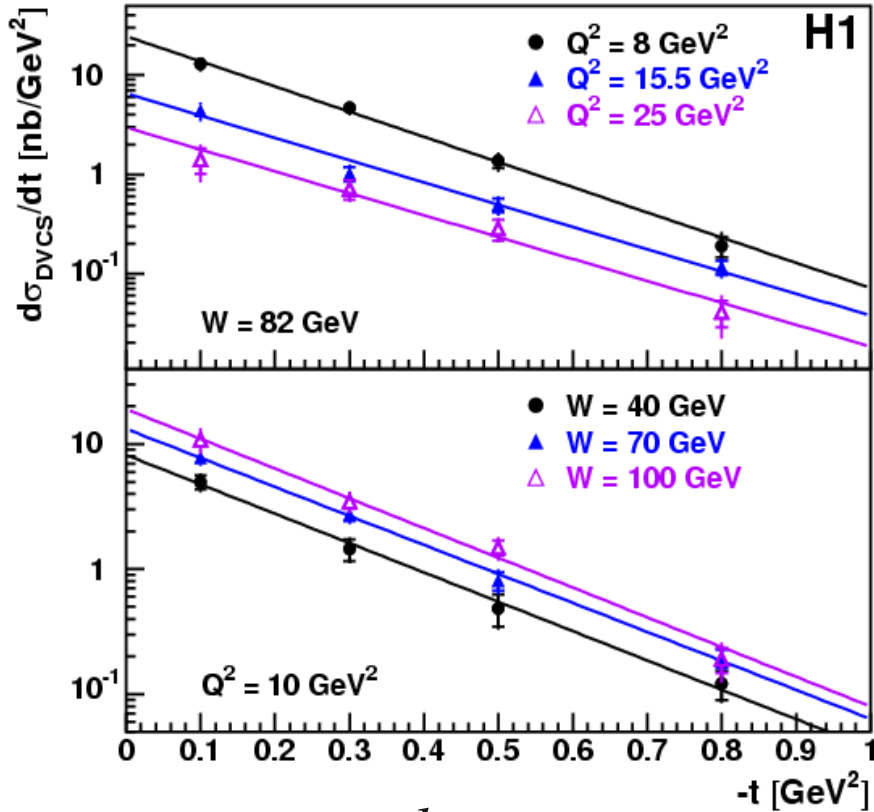
ZEUS



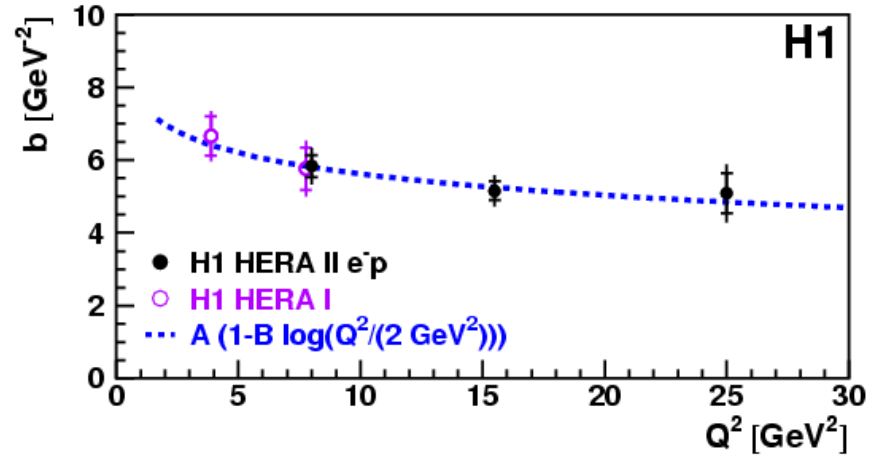
b decreases from soft values to pQCD expected values ($\sim 4-5 \text{ GeV}^{-2}$)

DVCS: t dependence

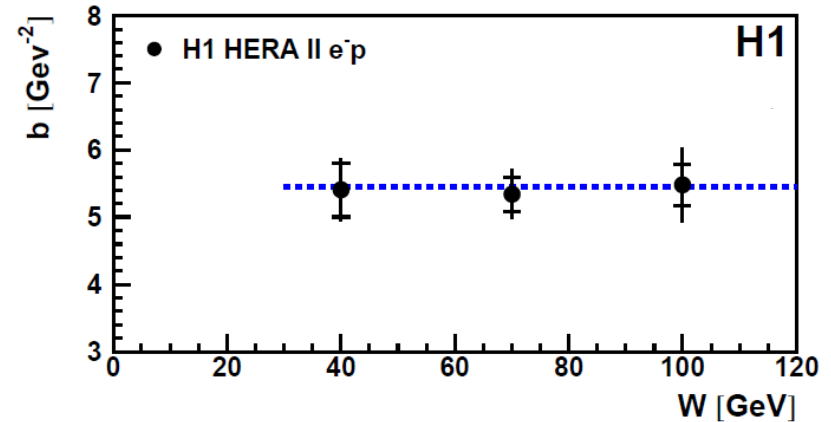
H1 DVCS



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

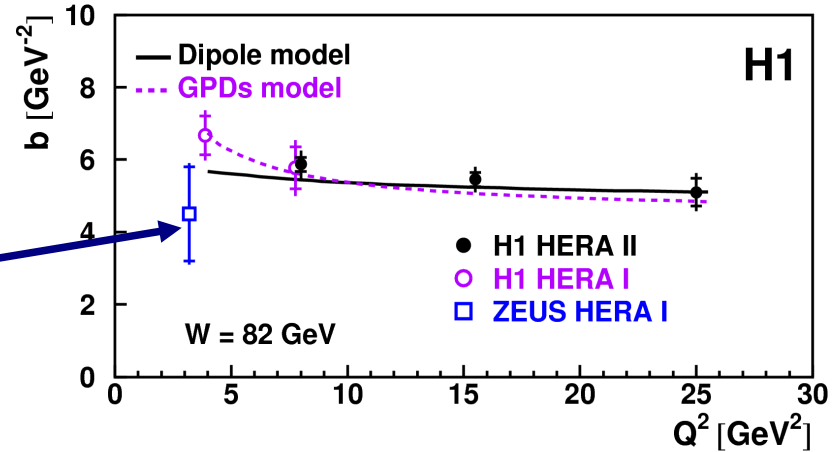
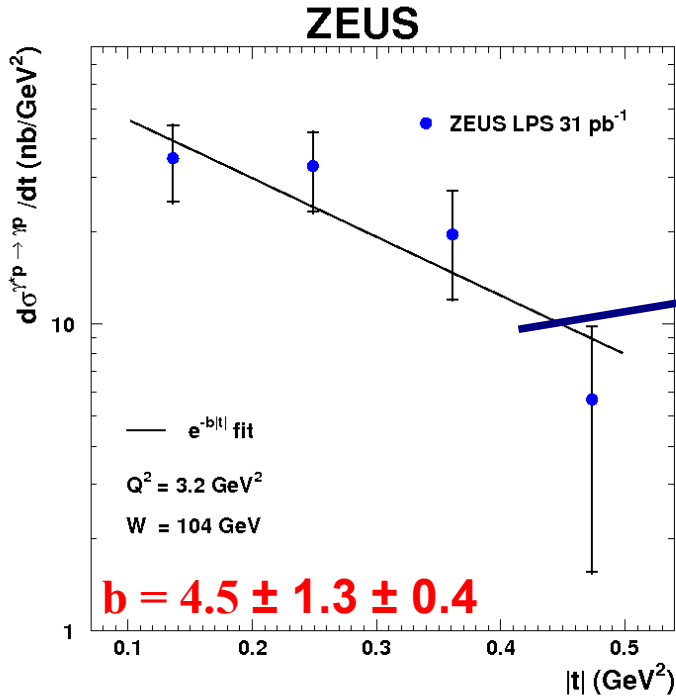


b decreases with increasing Q^2



No evidence for W dependence of b

DVCS: t dependence

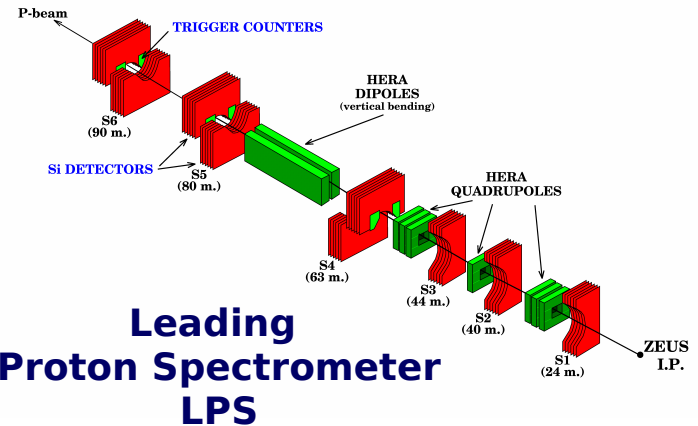


The ZEUS result is compatible with H1

At ZEUS $d\sigma/dt$ measured for the first time by a direct measurement of the outgoing proton 4-momentum using the LPS spectrometer

No p dissociation background → Clean measurement

Low detector acceptance → low statistics



VM and DVCS: t dependence

Same slope for all VM
vs $(Q^2 + M^2)$

Size of the gluons:

$$\langle r^2 \rangle = 2 \cdot b \cdot (\hbar c)^2$$

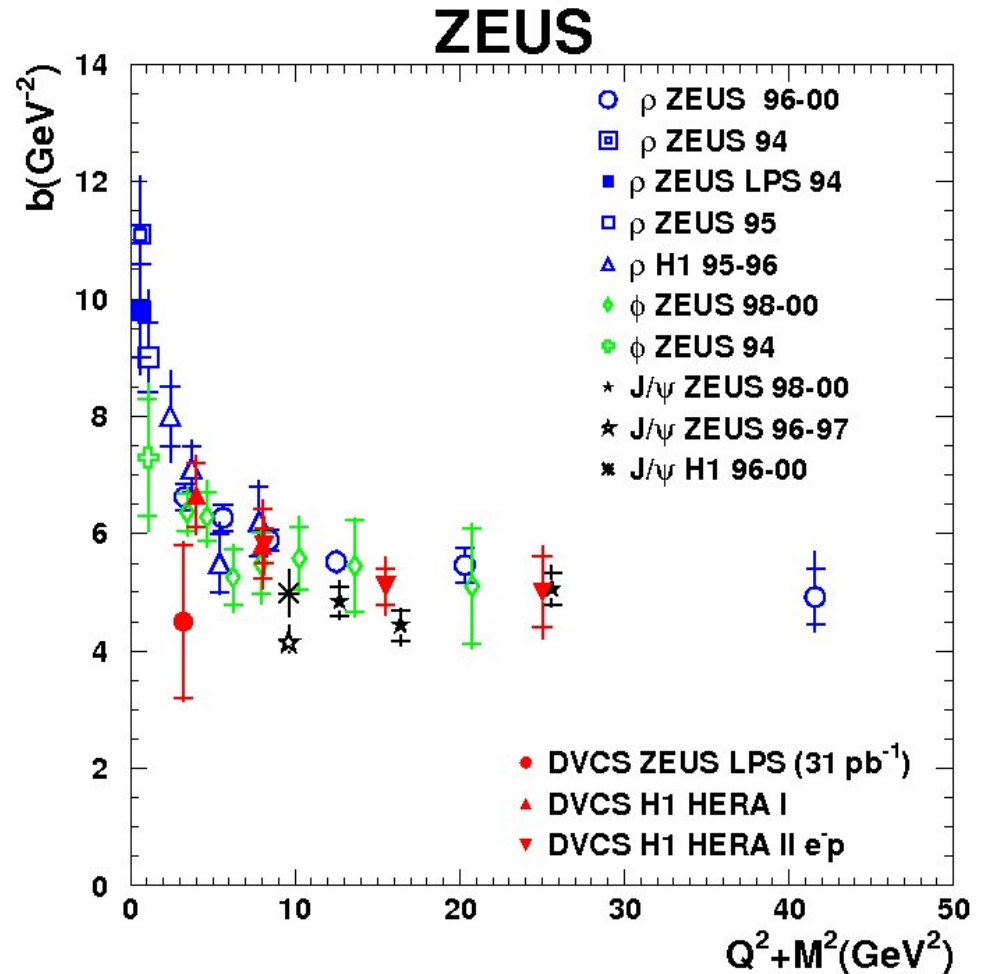
$$r_{glue} = 0.56 \text{ fm}$$

Proton radius:

$$r_{proton} = 0.8 \text{ fm}$$

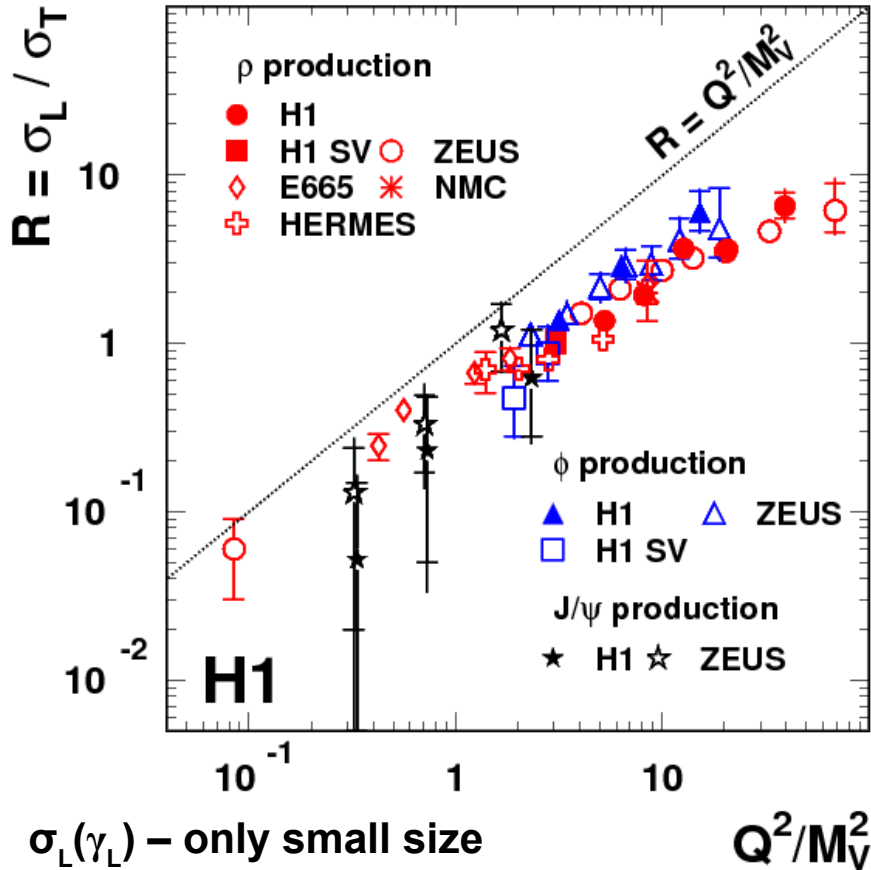


Gluons confinement area
is smaller than proton



VM: σ_L/σ_T

VM production



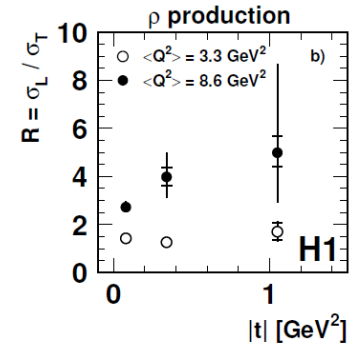
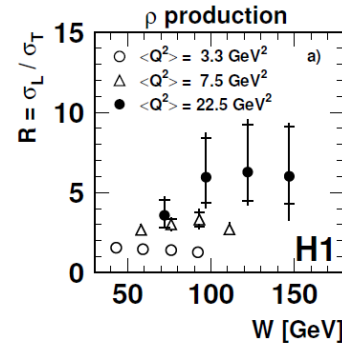
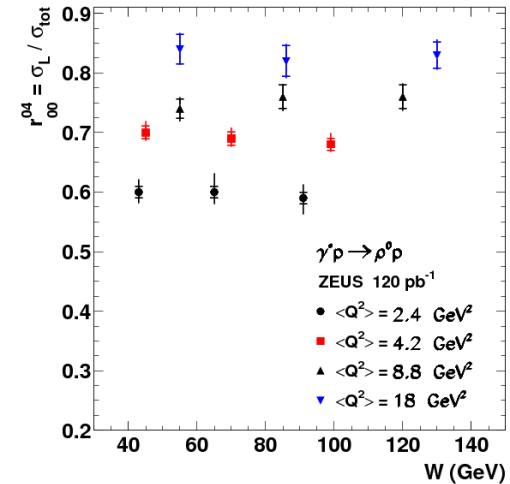
$\sigma_L(\gamma_L)$ – only small size

configurations

$\sigma_T(\gamma_T)$ – small and large size

configurations

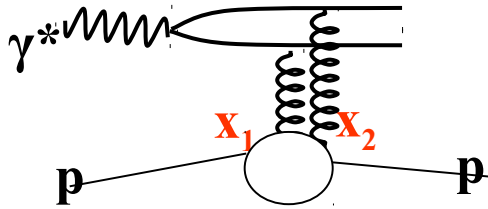
ZEUS



$$R = \sigma_L / \sigma_T$$

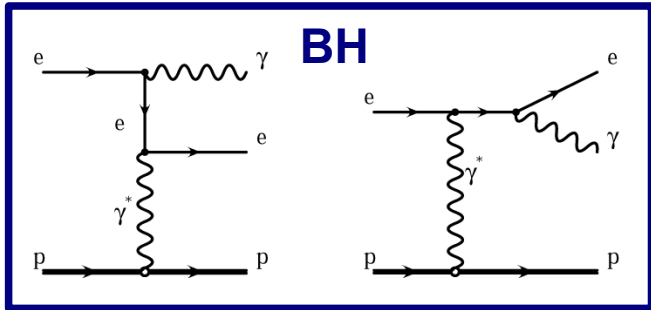
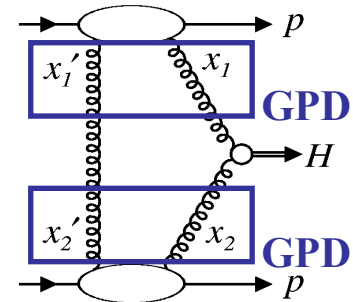
does it depend on W and t ?

The DVCS and GPDs



$x_1 \neq x_2 \rightarrow$ **Generalized Parton Distributions:**
sensitive to the correlations in the proton

GPDs are important also for the diffractive Higgs production
at the future LHC experiments at CERN in Geneva



$$|A|^2 = |A_{DVCS}|^2 + |A_{BH}|^2 + |A_I|^2$$

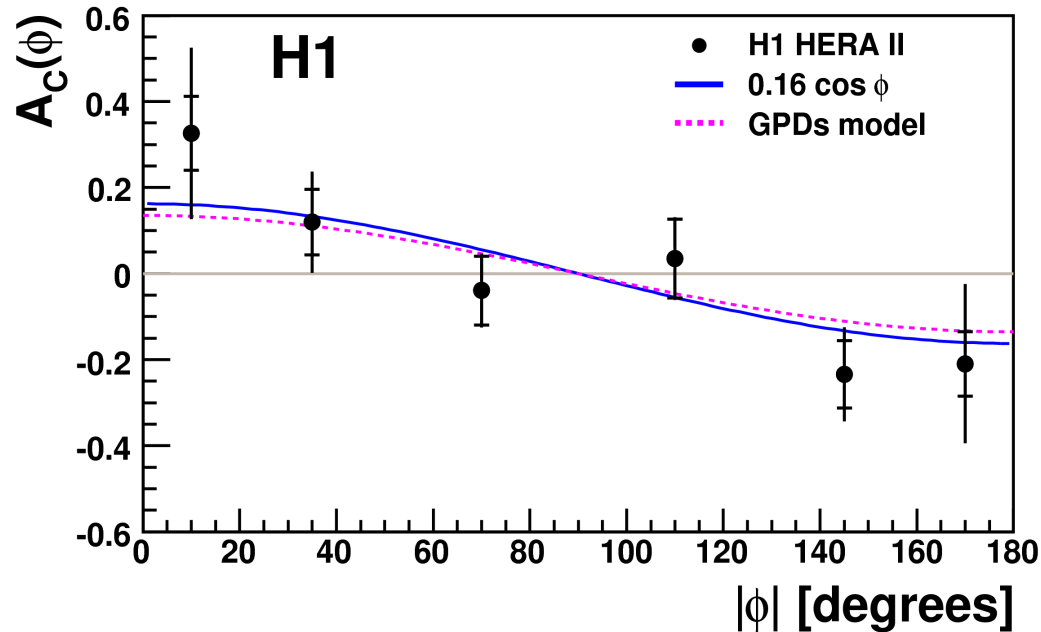
DVCS and BH: identical final state \rightarrow they Interfere

Interference term: $A_I \propto \text{Re}(A_{DVCS}) + \text{Im}(A_{DVCS})$

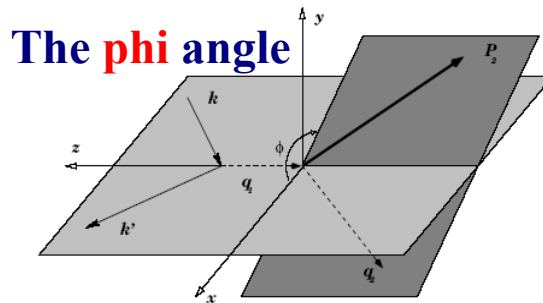
Beam charge asymmetry: $A_C = \frac{d\sigma^{+\cdot} - d\sigma^{-\cdot}}{d\sigma^{+\cdot} + d\sigma^{-\cdot}} \propto \text{Re}(A_{DVCS})$

DVCS: the beam-charge asymmetry

The beam charge asymmetry as a function of ϕ

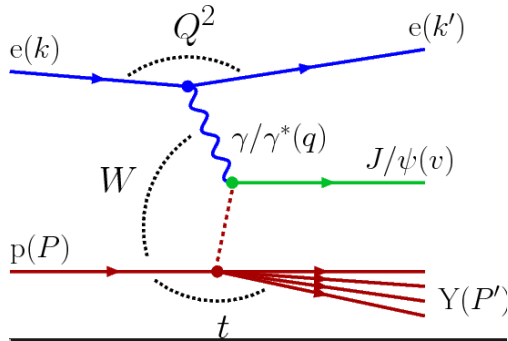


$$A_C \equiv \frac{d\sigma^{+} - d\sigma^{-}}{d\sigma^{+} + d\sigma^{-}}$$

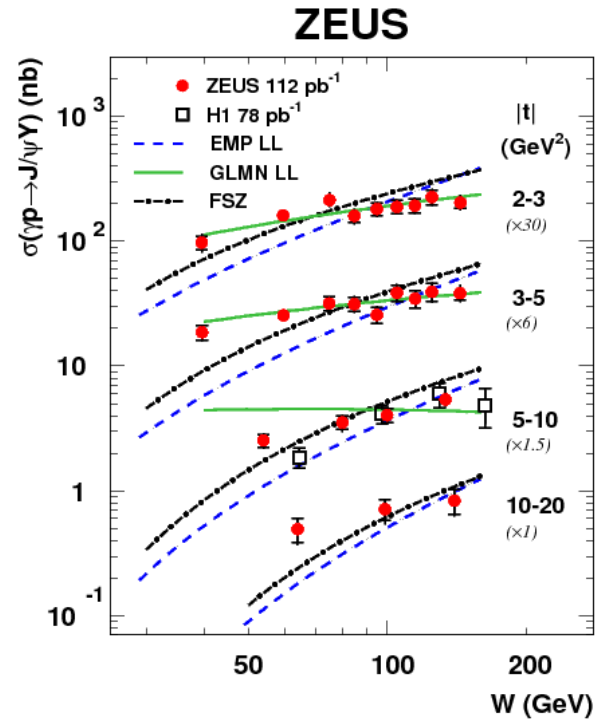
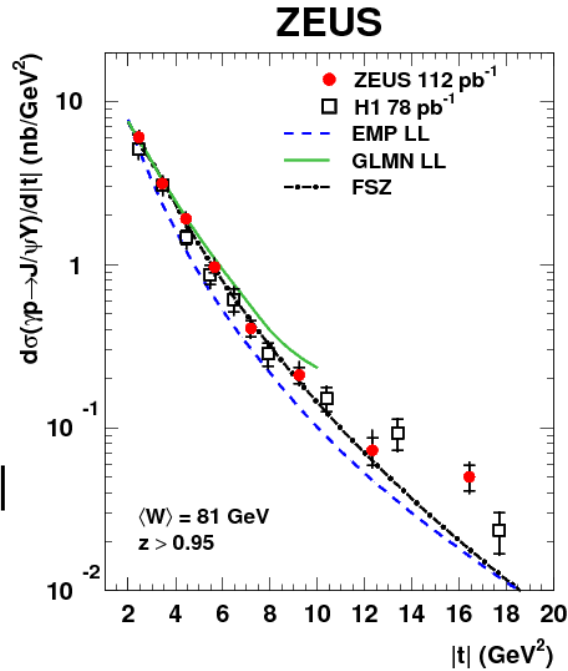


GPDs based model compatible with data

High $|t|$ measurement of J/ψ



- Exclusive process
- Hard scale provided by $|t|$
- t dependence no longer exponential
- None of the models describes the data



DESY-09-137

$$\frac{d\sigma}{d|t|} \sim t^n \quad \rightarrow$$

$$n = -1.9 \pm 0.1, \quad 2 < |t| < 4 \text{ GeV}^2$$

$$n = -3.0 \pm 0.1, \quad 4 < |t| < 16 \text{ GeV}^2$$

Pomeron trajectory in ep collisions

From **SOFT** to **HARD**.....

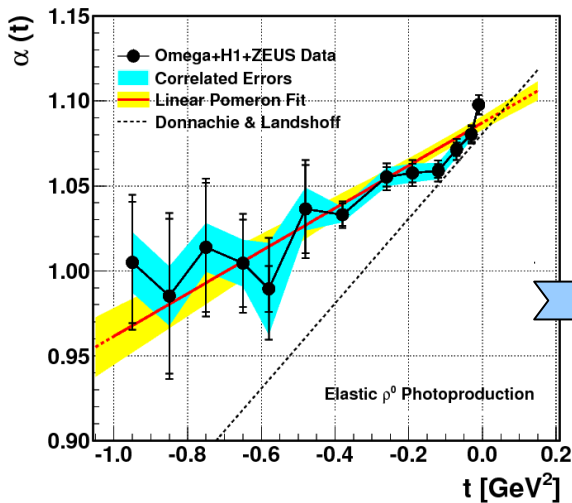
$$\alpha(t) = \alpha(0) + \alpha' t$$

$$\alpha_{IP}(t) = 1.08 + 0.25t \quad \text{measured in hh scattering}$$

In electron-proton interactions:
As the scale gets harder the intercept
grows up to **1.2**

The Pomeron slope is around **~ 0.1**

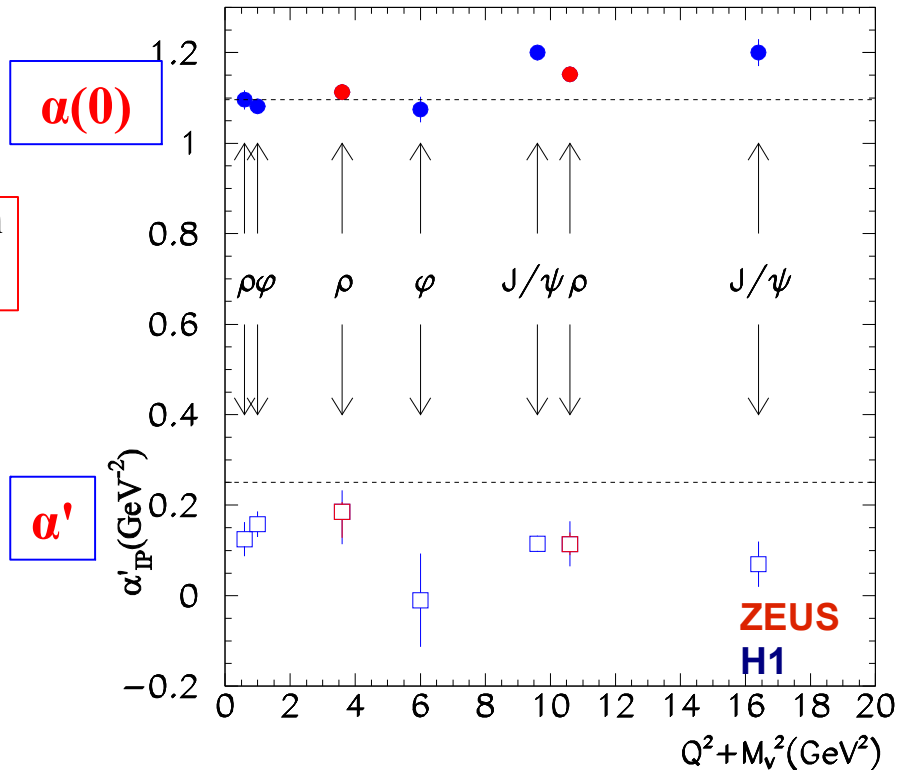
H1 PRELIMINARY



ρ (light VM); elastic production (low $|t|$):

$$\alpha(0) = 1.087 \pm 0.003 \pm 0.003$$

$$\alpha' = 0.126 \pm 0.013 \pm 0.012 \text{ GeV}^{-2}$$



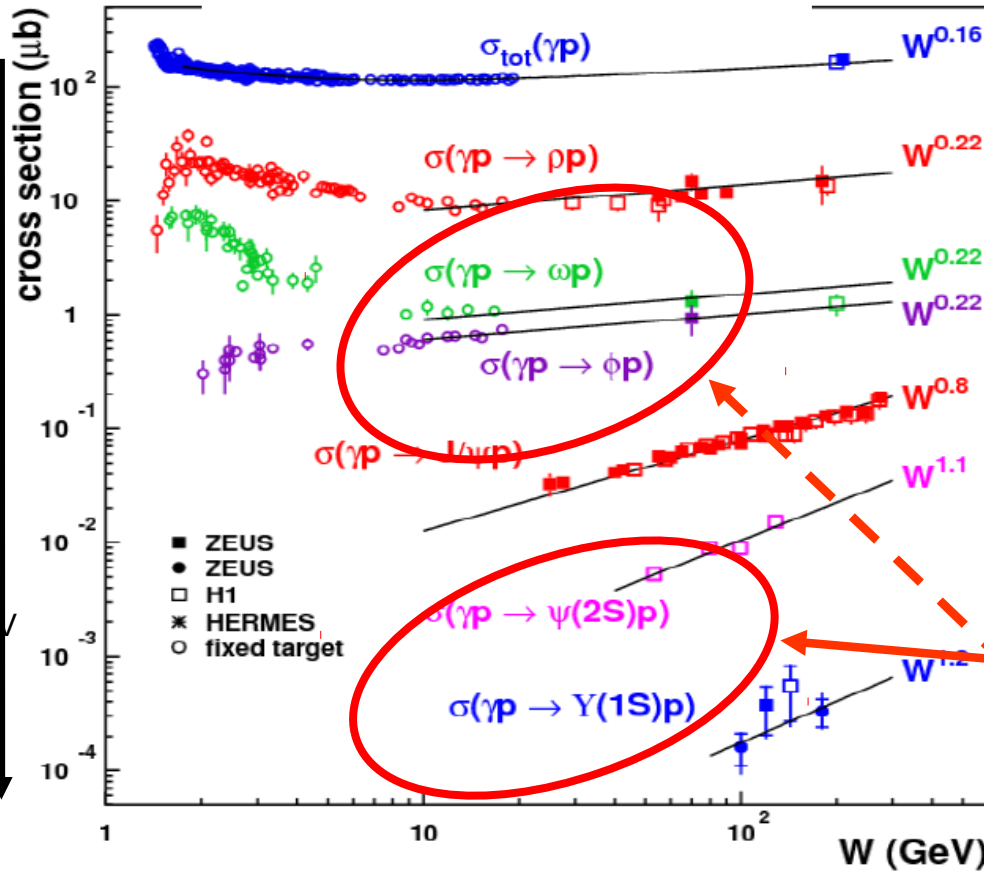
Summary

- ❖ HERA studied a large variety of VMs in a wide kinematic range
- ❖ The measurements allow the study the transition from the soft to the hard regime
- ❖ Many new measurements: Q^2 , W , $|t|$ dependencies from real photons and light VMs up to Ypsilon
- ❖ pQCD expectations are in general compatible with the data, but still a lot to be understood.
- ❖ DVCS asymmetries and $|t|$ slope measurements provide access to GPDs
- ❖ Effective Pomeron trajectory differs from “soft” Pomeron

Back up

VM: sensitivity to gluons in proton

$\sigma(\gamma p \rightarrow Vp), Q^2=0$

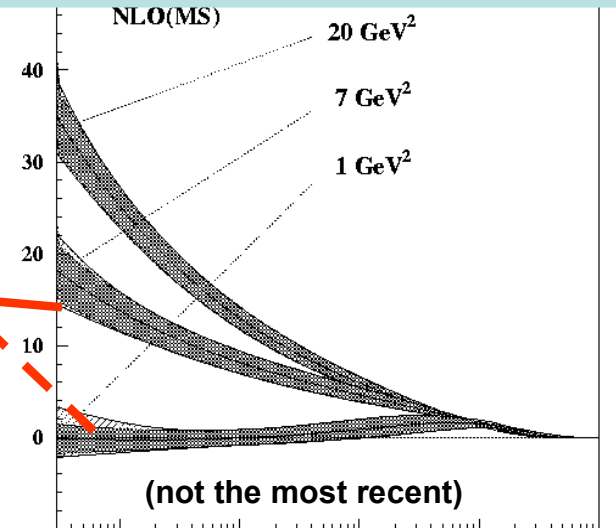


Fit: $\sigma \sim W^\delta$ with $\delta = 4(\alpha_p(0) - 1)$

W -dependence steeper with M_V^2 :

$$\delta_\rho \sim 0.2 \quad \rightarrow \quad \delta_{\psi(2S)} \sim 1.0$$

Large M_V supplies a scale for hard processes \rightarrow apply pQCD models

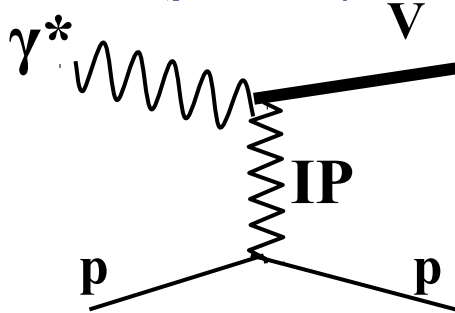


(not the most recent)

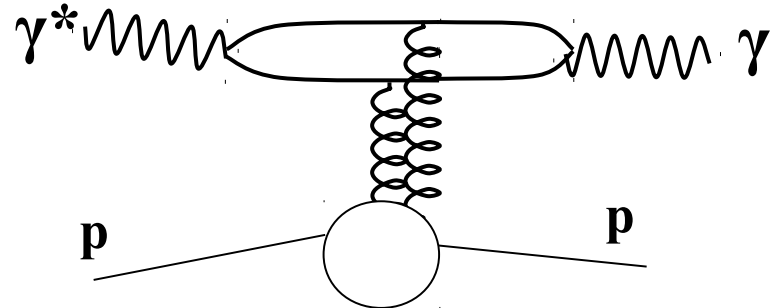
$$W \propto 1/\sqrt{x}$$

Deeply Virtual Compton Scattering

VM ($\rho, \omega, \phi, J/\psi, Y$)



DVCS (γ)



Scale: $Q^2 + M^2$ \longleftrightarrow Q^2

DVCS properties:

- Similar to VM production, but γ instead of VM in the final state
- No VM wave-function involved
- Important to determine Generalized Parton Distributions sensible to the correlations in the proton
- GPD_s are an ingredient for estimating diffractive cross sections at LHC

