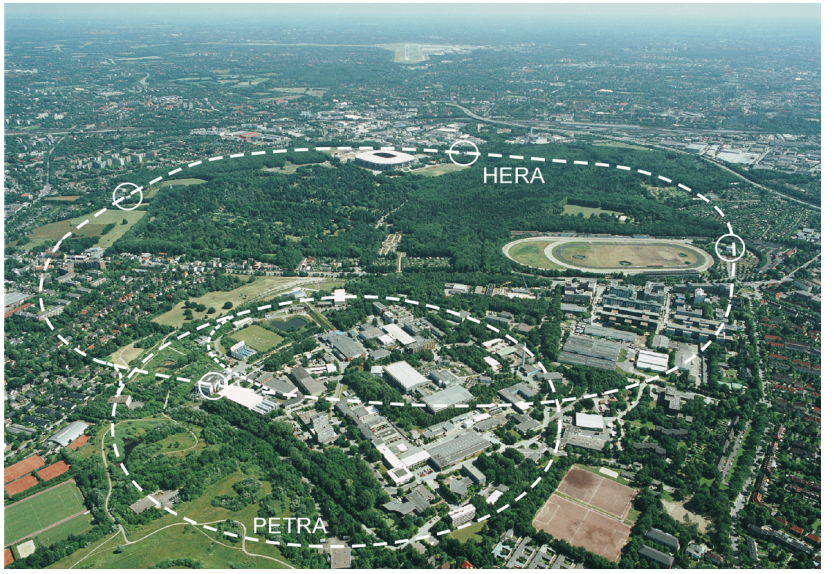
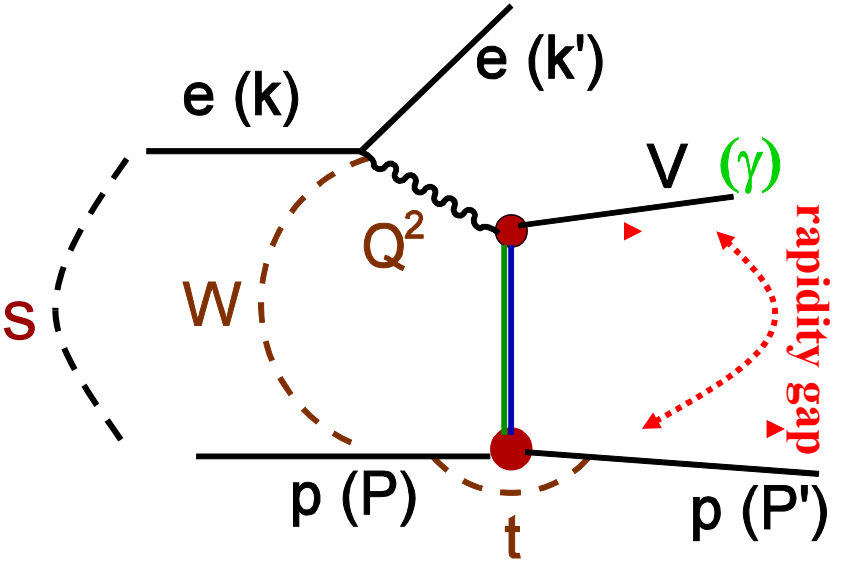
Vector meson production and DVCS at HERA

Università della Calabria
Dipartimento di Fisica

Salvatore Fazio
Calabria University and INFN-Cosenza
Rende (Cosenza), Italy

INFN Istituto Nazionale di Fisica Nucleare





ZEUS

on behalf of the ZEUS and H1 Collaborations

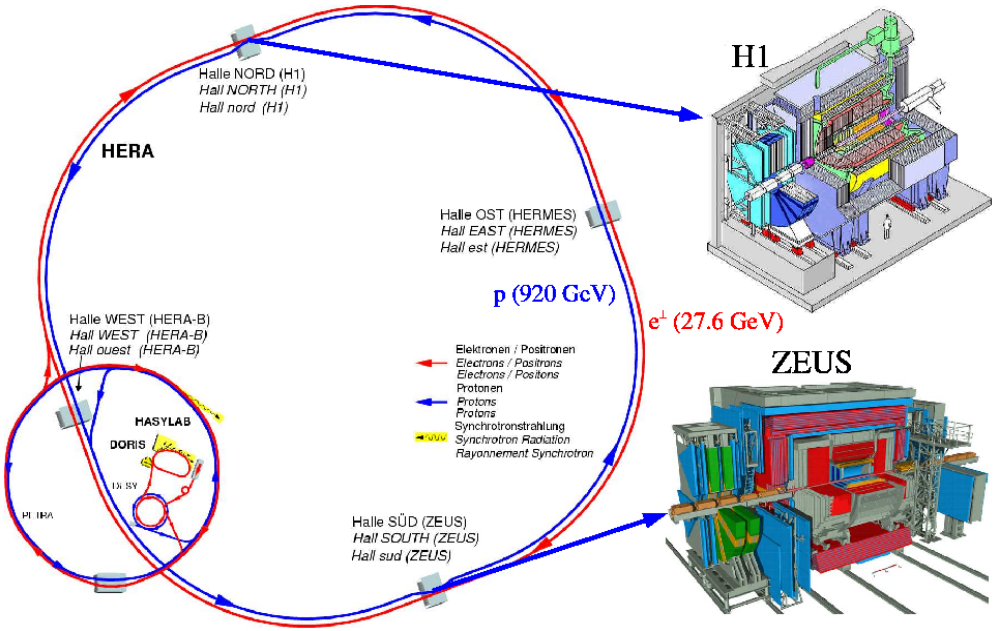
H1

Low-x 2010
Kavala (Greece), *June 23 – 27, 2010*

HERA colliding experiments

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

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

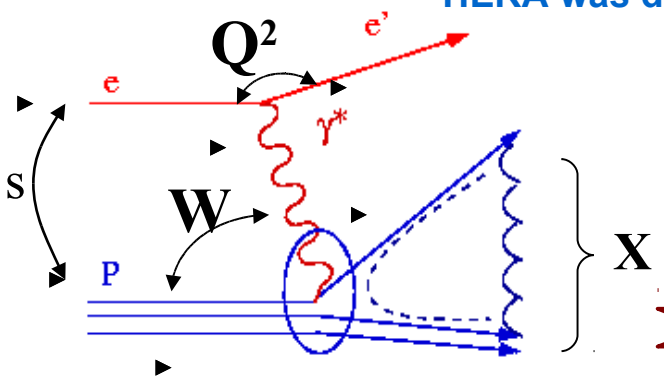


Detectors not originally designed for forward physics, although a lot of results achieved in diffraction at HERA!

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

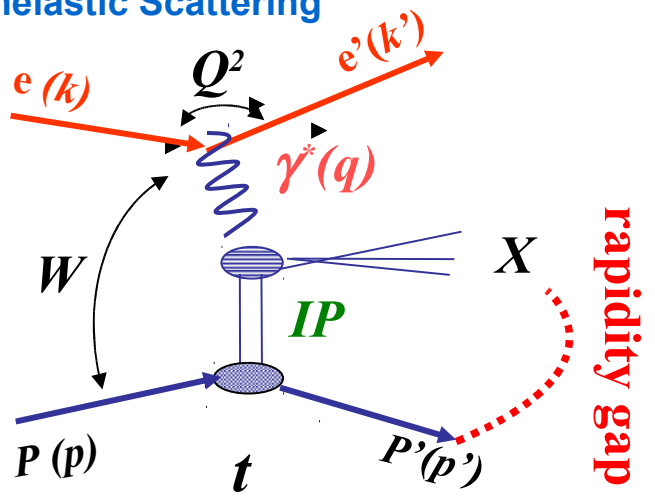
Diffraction in ep collisions at HERA

HERA was designed to study Deep Inelastic Scattering

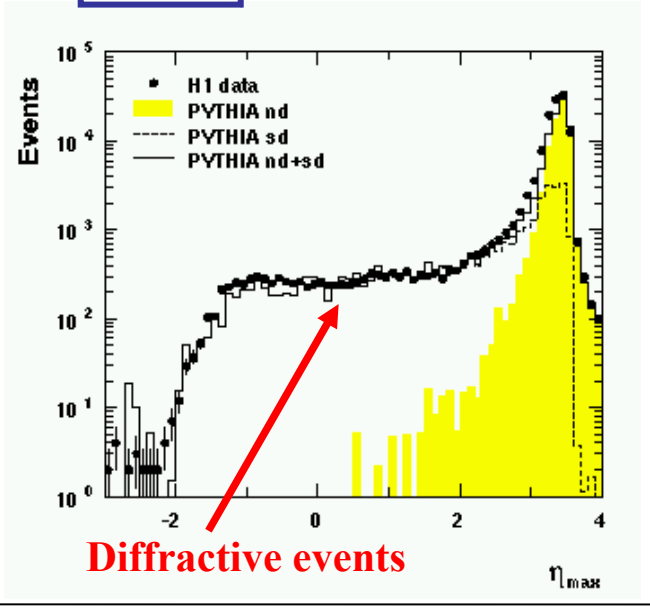


DIS

~10%

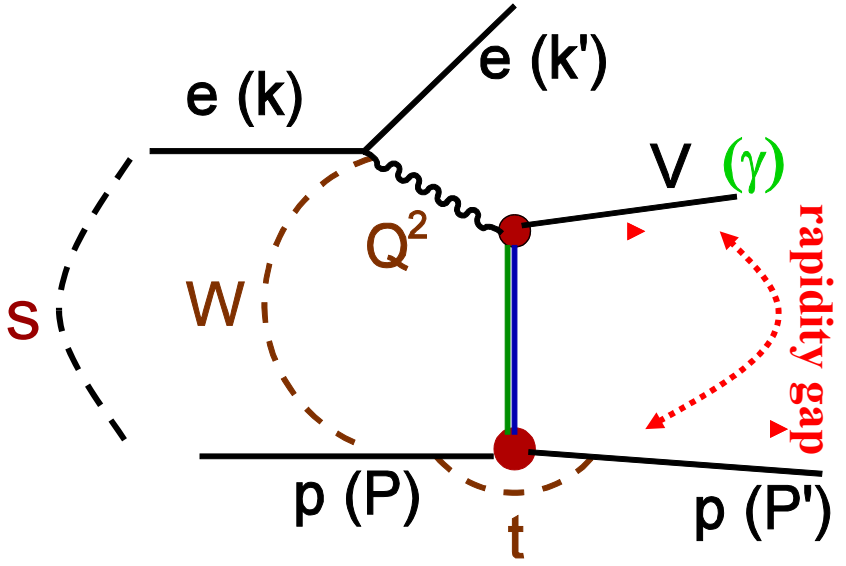


Diffractive DIS



- ***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:

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

photon-proton centre-of-mass energy:

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

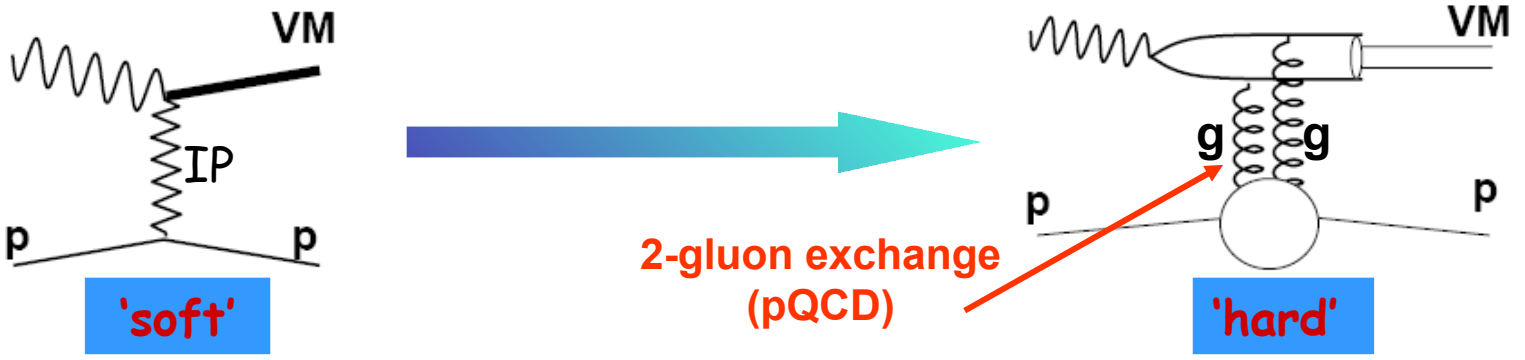
square 4-momentum at the *p* vertex:

$$t = \left(p' - p\right)^2$$

- **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 (ρ, ϕ, J/ψ, Υ, γ)



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

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

Gluon density in the proton

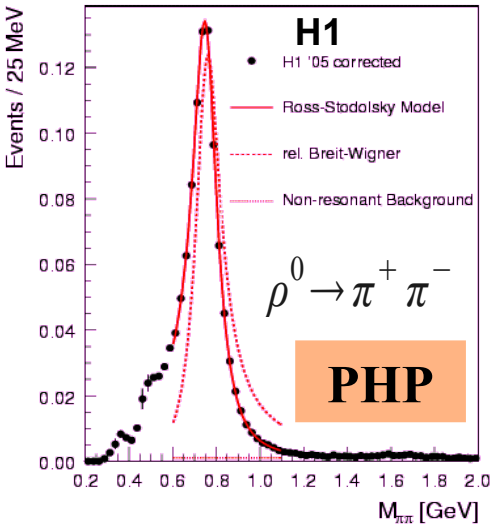
$$\begin{cases} \sigma \propto \left[x\, g(x, \mu^2) \right]^2 \\ \mu^2 \propto (Q^2 + M_V^2) \end{cases}$$

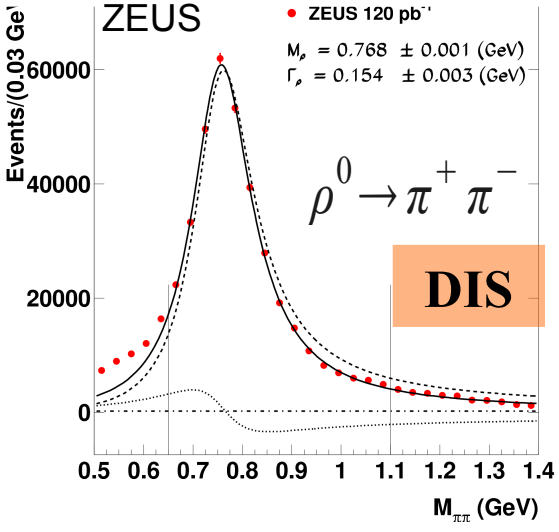
$\sigma(W) \propto W^{\delta}$ ➡ δ Expected to increase from soft (~0.2, "soft Pomeron") to hard (~1., "hard Pomeron")

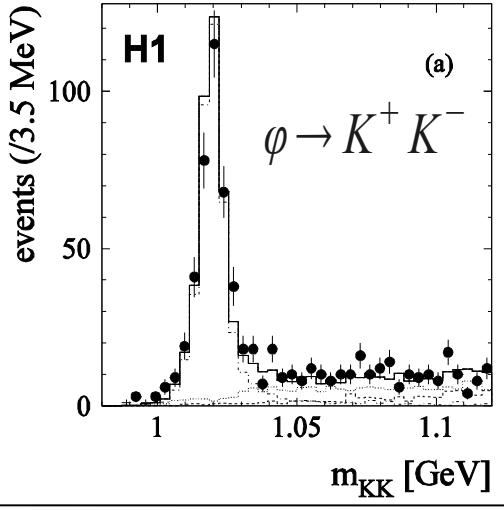
$\frac{d\sigma}{dt} \propto e^{-b|t|}$ ➡ *b* expected to decrease from soft (~10 GeV^{-2}) to hard (~4-5 GeV^{-2})

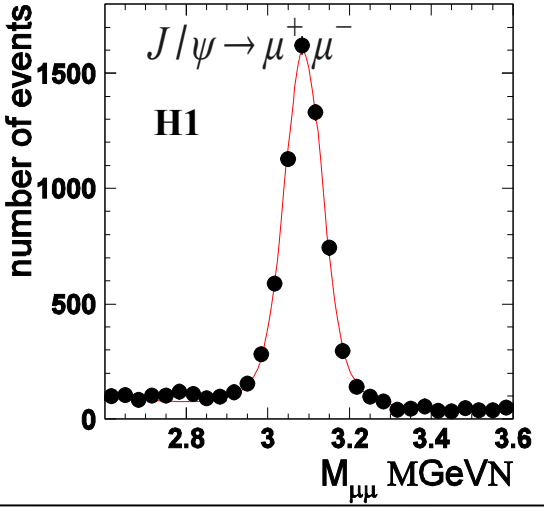
VM mass distributions

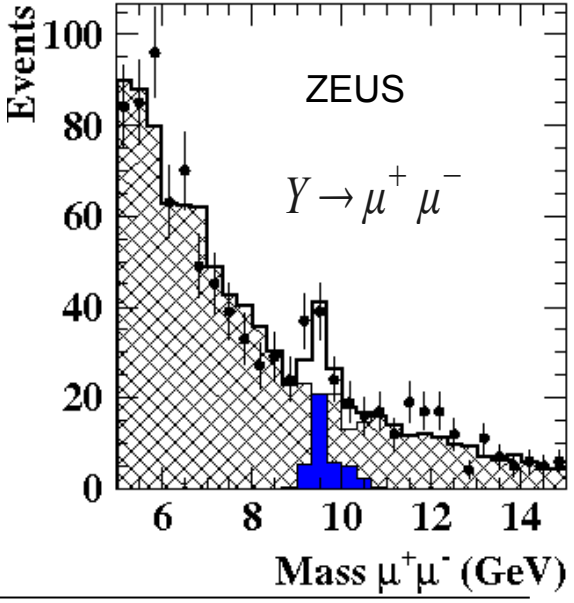
Large variety of processes to study dynamics versus scales: M_V^2, Q^2, t





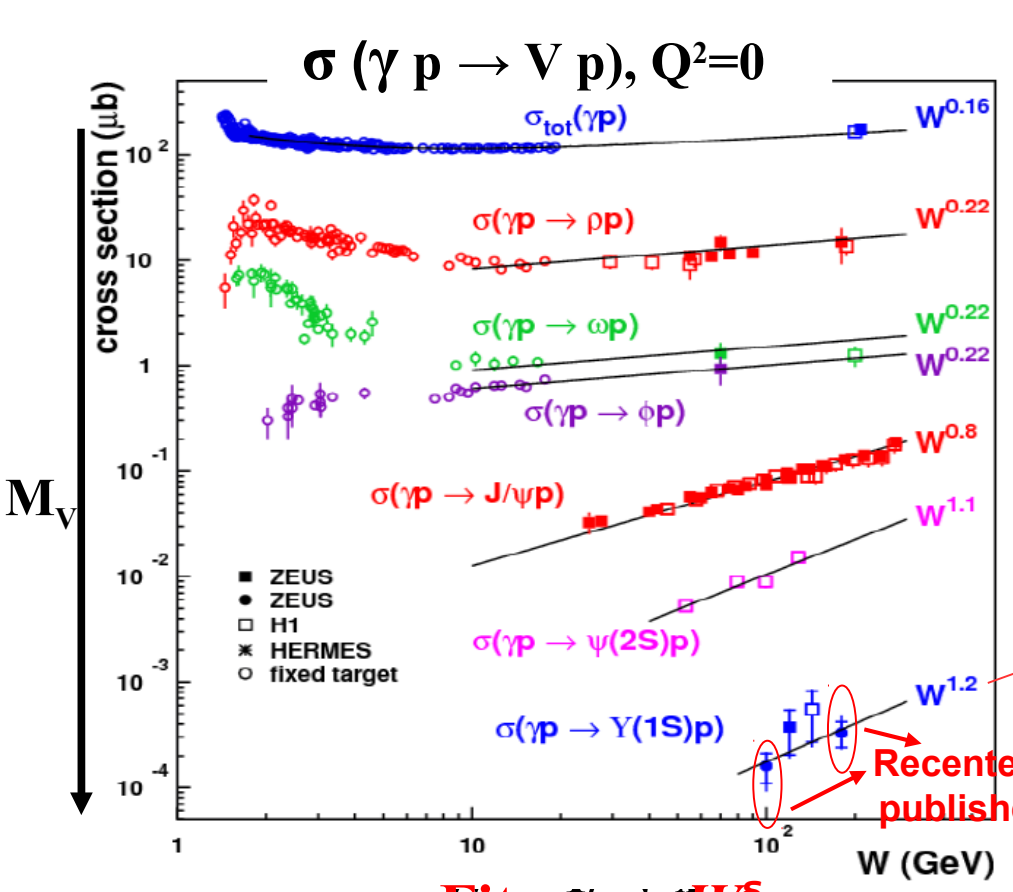






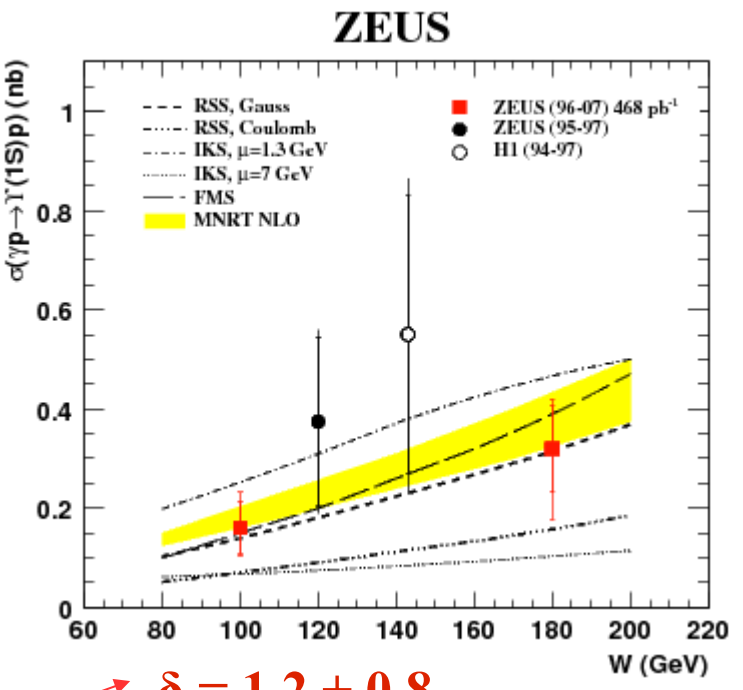
VM photoproduction: W-dependence

Large M_V supplies a scale for hard processes → apply pQCD models



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

Y php (M_Υ = 9.46 GeV²)



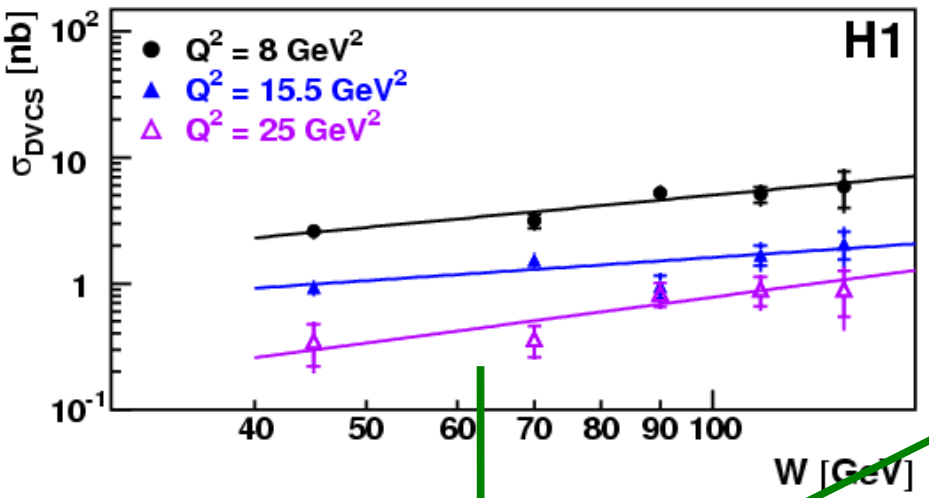
$\delta = 1.2 \pm 0.8$

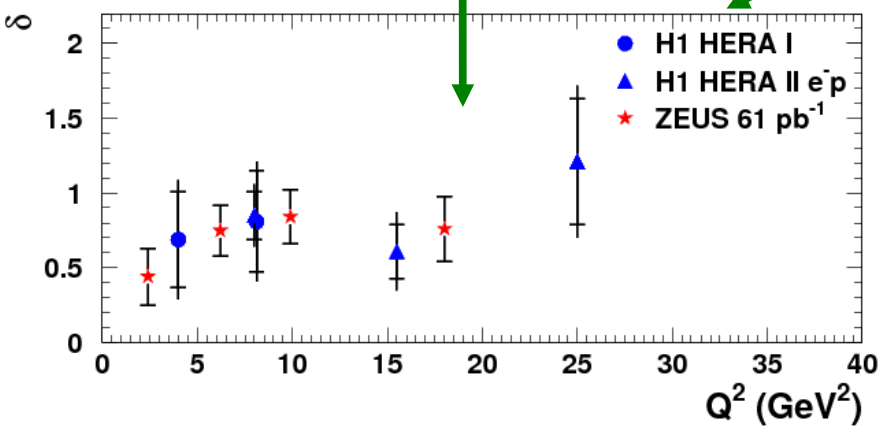
- **Y sensitive to VM wave function: Gauss preferred to Coulomb**
- **pQCD models: compatible with FMS LO (δ=1.7) and NLO (δ=1.2)**

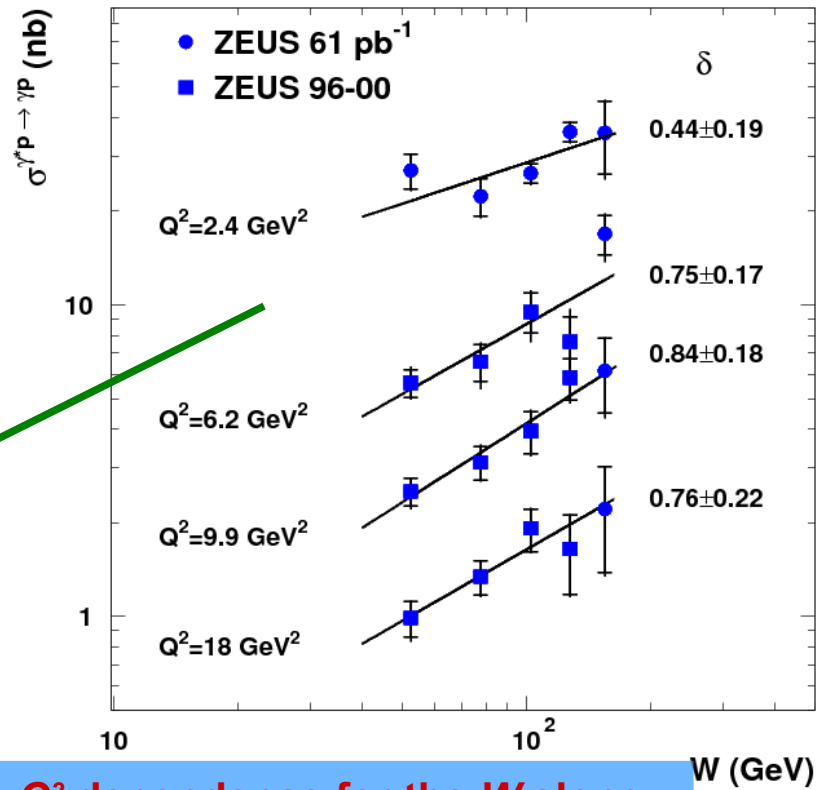
Phys. Lett. B 680 (2009) 4-12

DVCS: *W*-dependence

Scale: $Q^2 + M^2$ ⟵ $M\gamma = 0$ ⟶ Q^2 **Fit:** $\sigma \sim W^{\delta}$



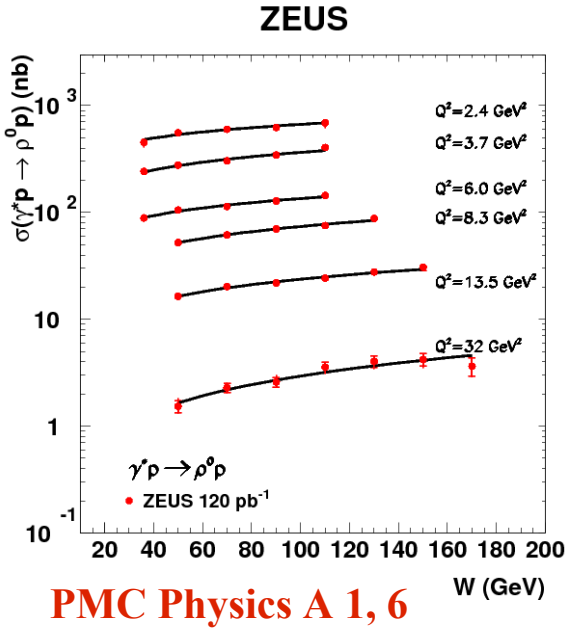




Q^2 dependence for the *W* slope not clear within the uncertainties!

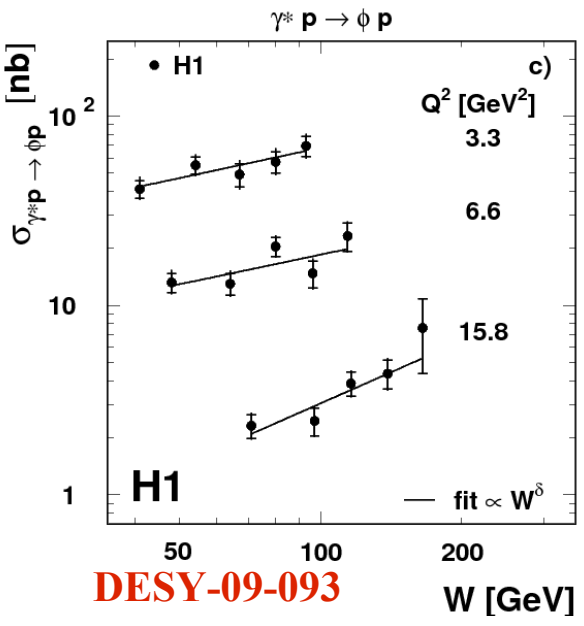
ZEUS: JHEP05(2009)108
H1: Phys.Lett.B659:796-806,2008

VM electroproduction: W-dependence



PMC Physics A 1, 6

Light VM (rho and phi)



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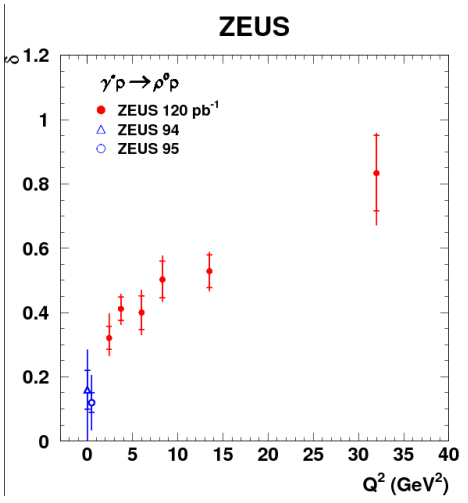
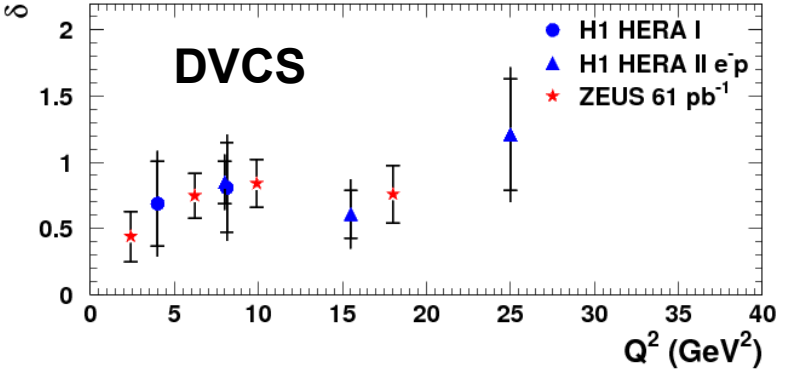


Fit: $\sigma \sim W^{\delta}$

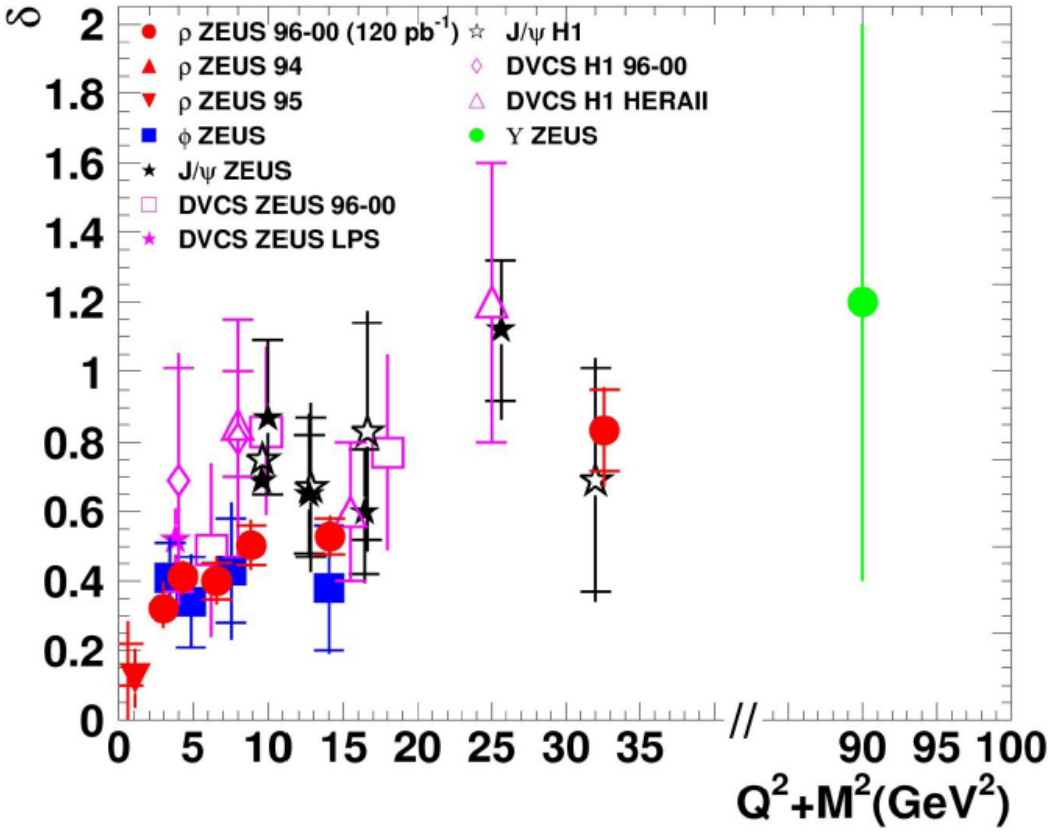
- Similar behavior for light VMs (ρ and φ) -> δ rises with Q^2 from soft to hard regime
- DVCS shows a "hard" behavior



summary: W-dependence

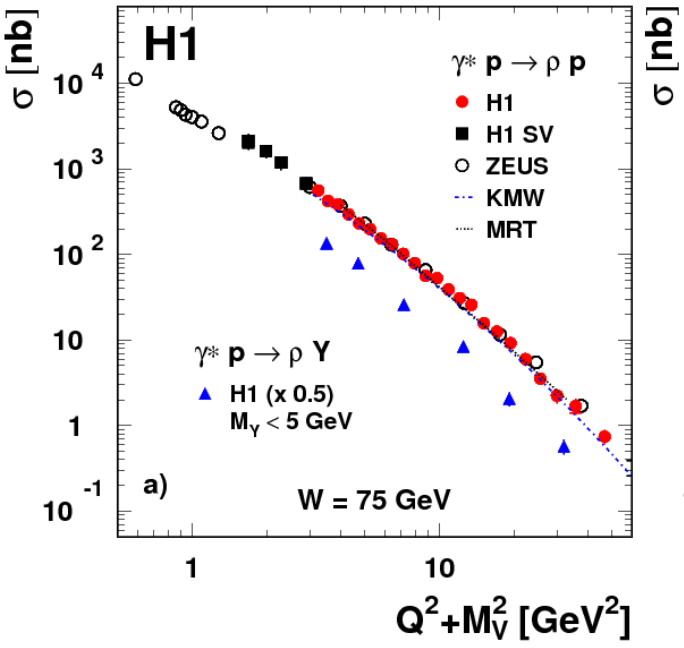
Fit: $\sigma \sim W^{\delta}$

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

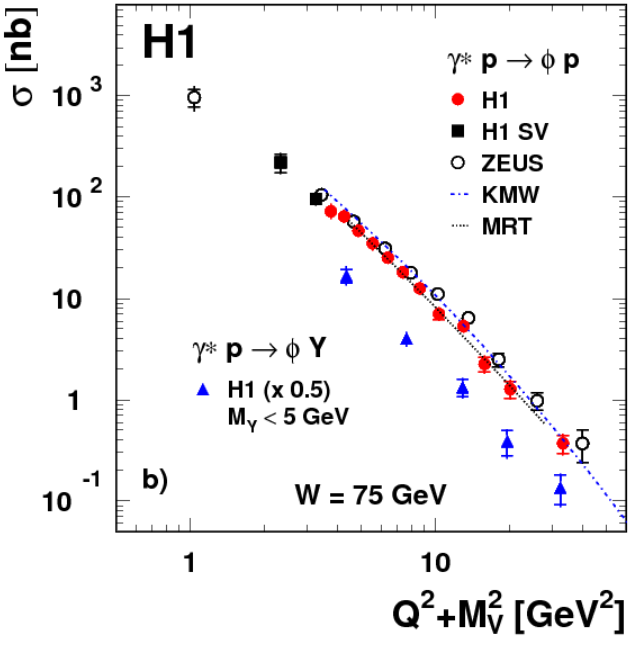


Q^2-dependence

ρ^0 ($M^2\rho$ = 0.5 GeV^2)



φ^0 ($M^2\varphi$ = 1 GeV^2)



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

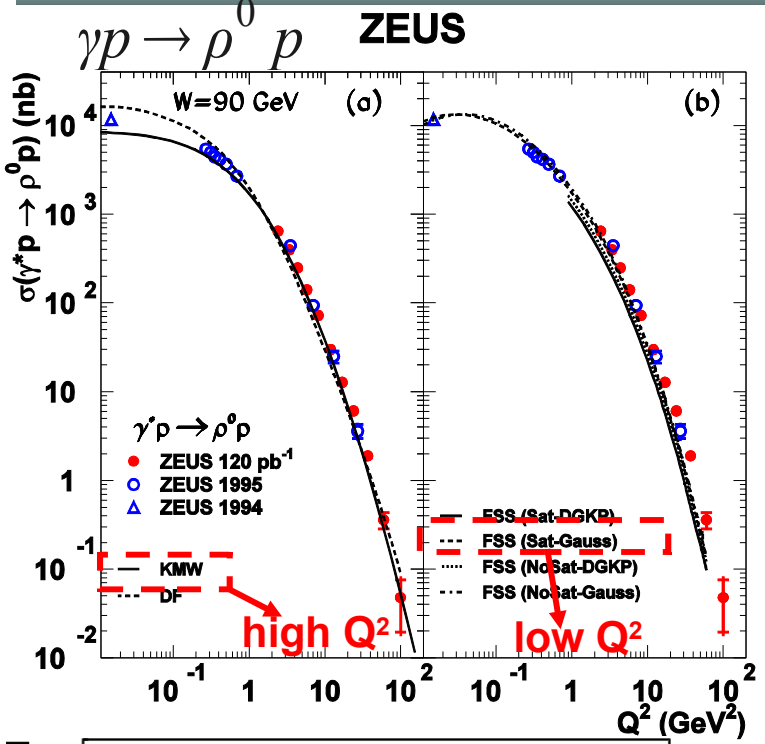
Fit to whole Q^2 range gives bad χ^2/df

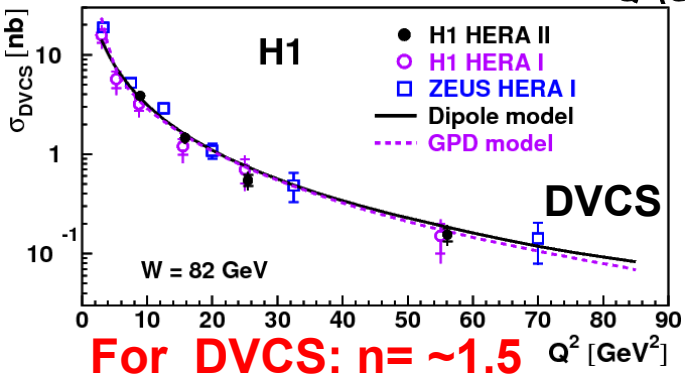
Good H1/ZEUS agreement

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

DESY-09-093

Q^2-dependence



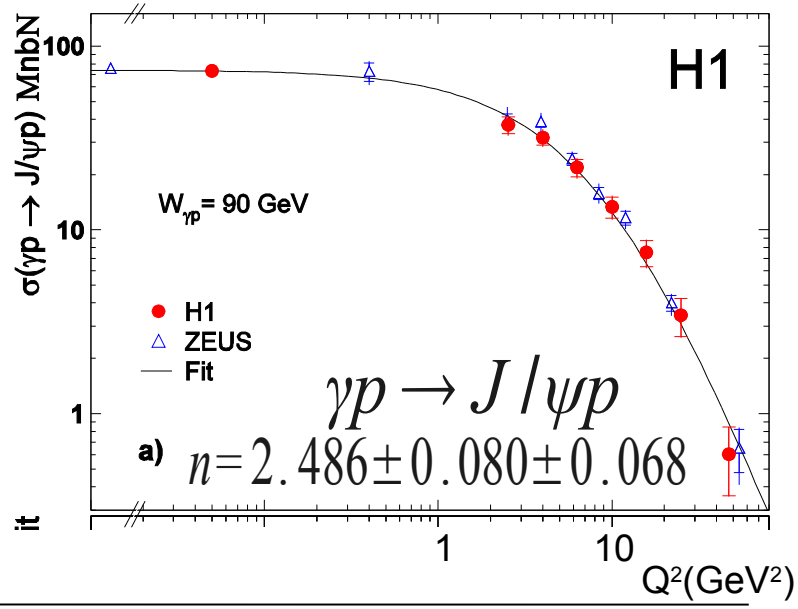


For DVCS: n= ~1.5

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

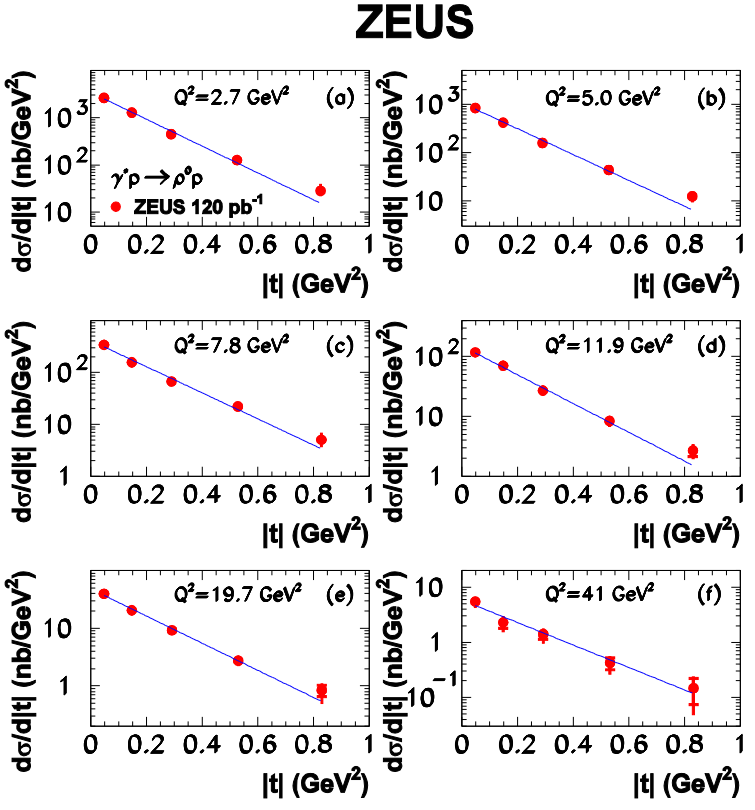
Fit to whole Q^2 range gives bad χ^2/df (~70)

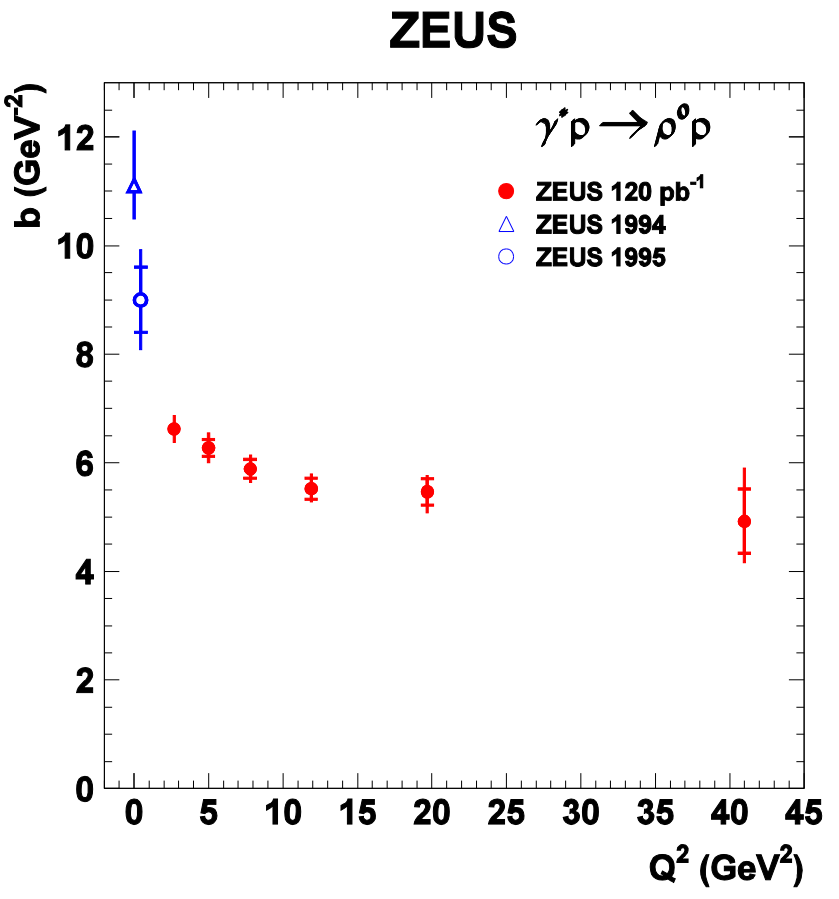
***n* increasing with Q^2 appears to be favored**



ρ^0: t dependence

$$\gamma p \to \rho^0 p \qquad Fit: \frac{d\sigma}{dt} \propto e^{-b|t|}$$

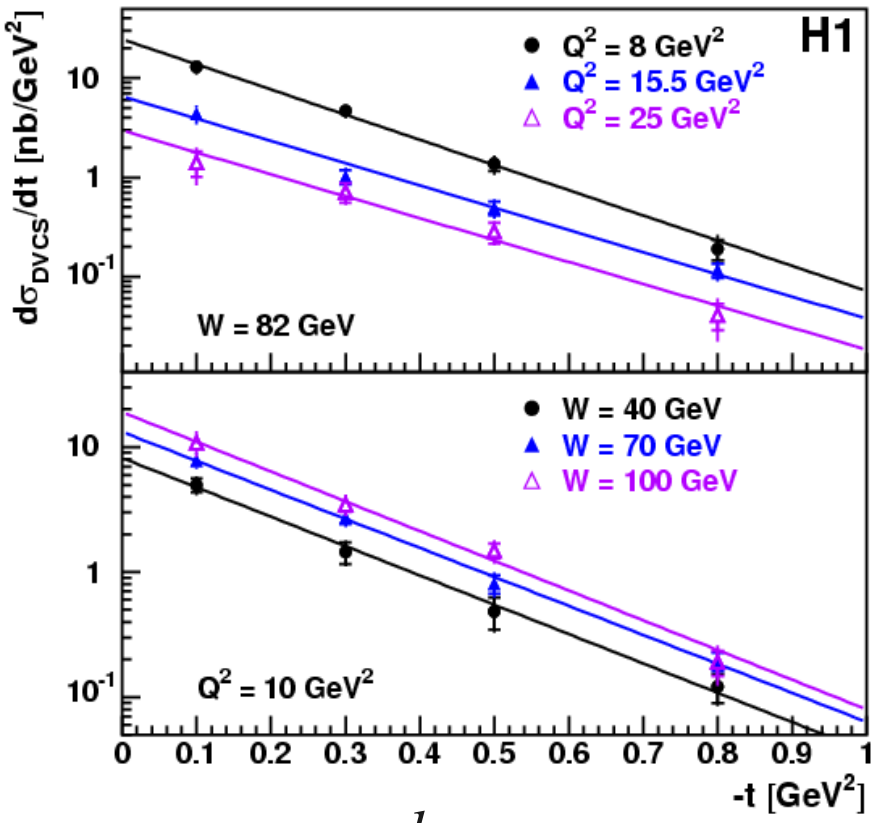




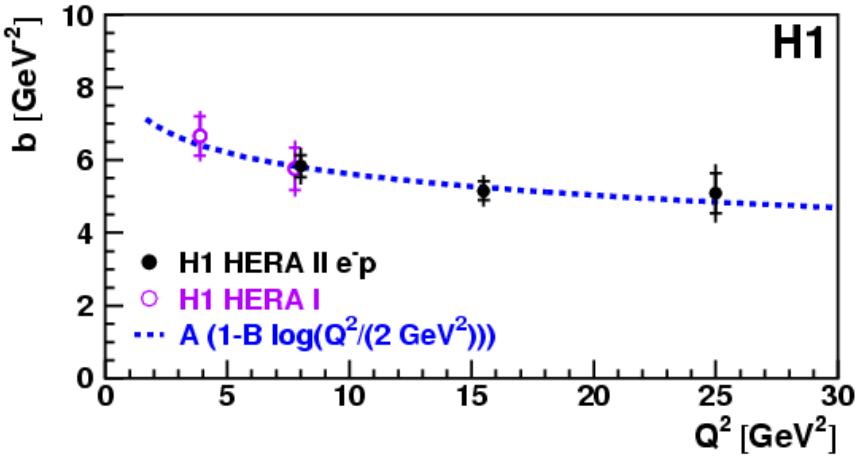
b decreases from soft values to pQCD expected values (~4-5 GeV^{-2})

DVCS: *t* dependence

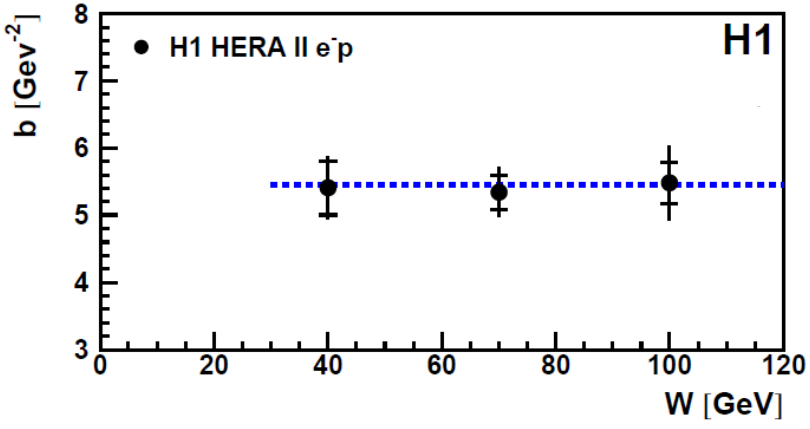
H1 DVCS



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

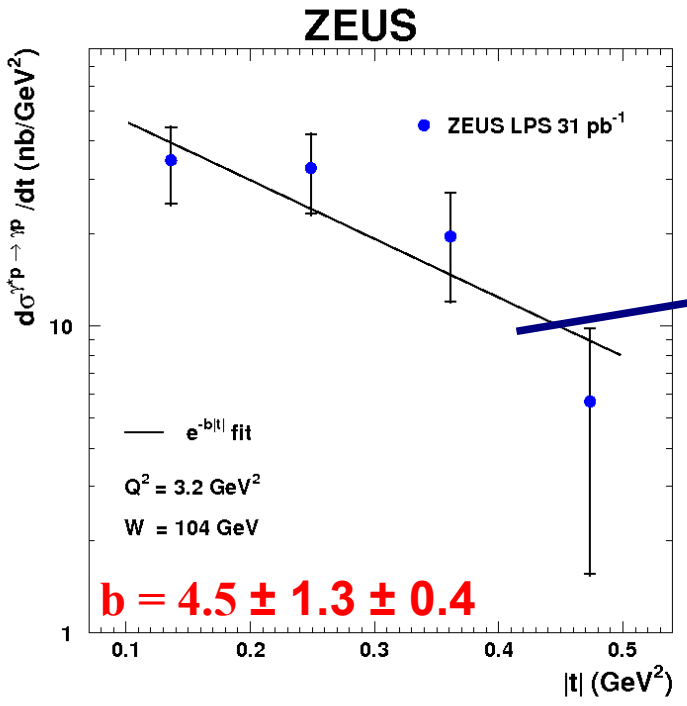


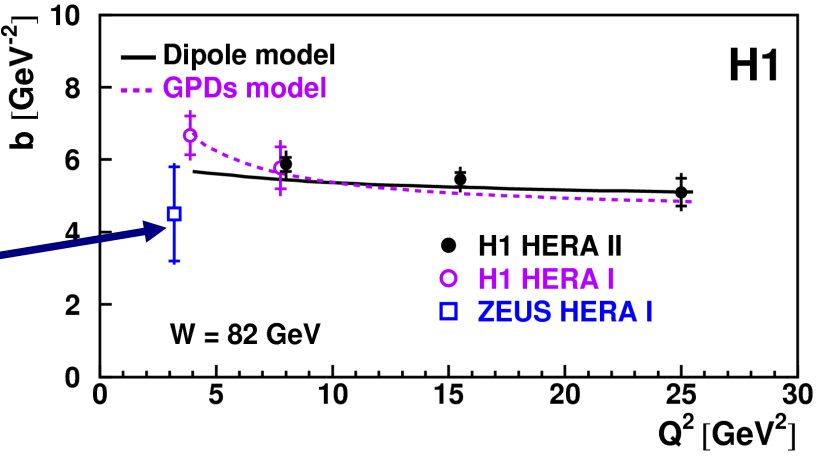
***b* decreases with increasing Q^2**



No evidence for *W* dependence of *b*

DVCS: *t* dependence



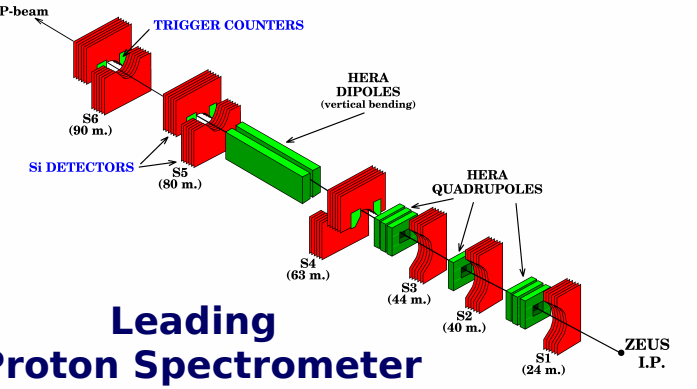


The ZEUS result is compatible with H1

At ZEUS dσ/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



Leading Proton Spectrometer LPS

VM and DVCS: *t* dependence

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

Size of the gluons:

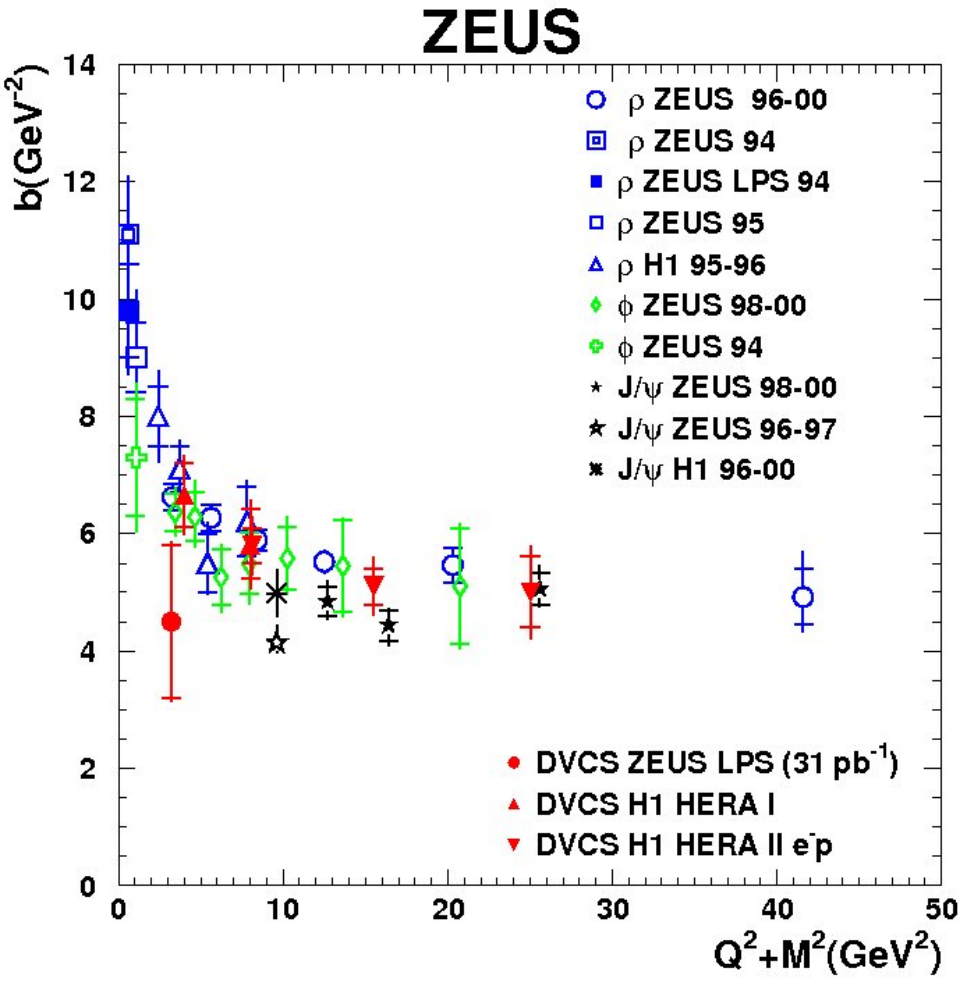
$$\langle r^2 \rangle = 2 \cdot b \cdot (\hbar c)^2$$

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

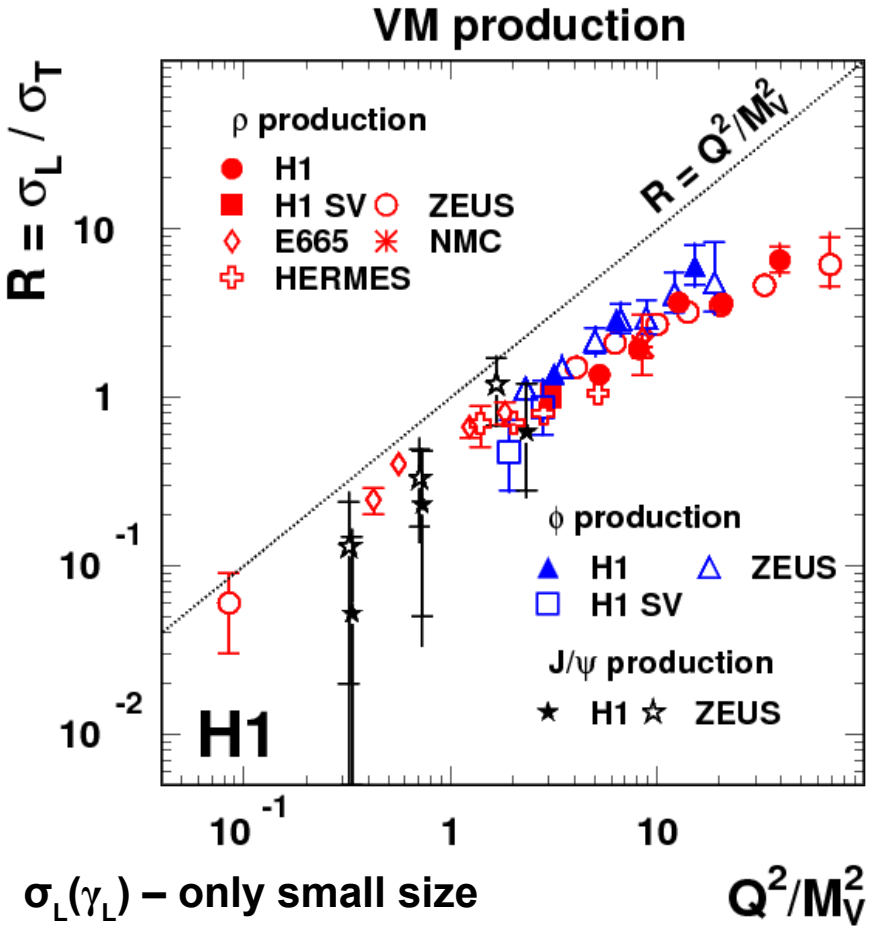
Proton radius:

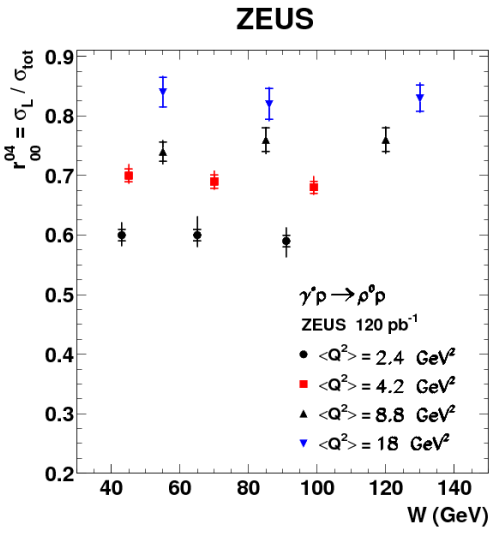
$$r_{proton} = 0.8 \text{ fm}$$

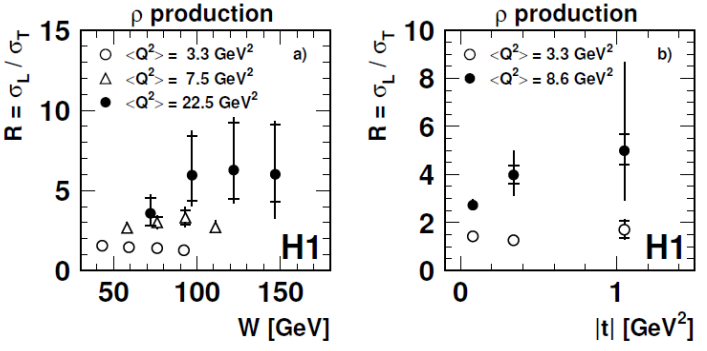
Gluons confinement area is smaller than proton



VM: σ_L/σ_T







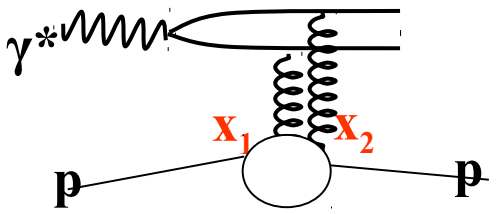
$\sigma_L(\gamma_L)$ – only small size configurations

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

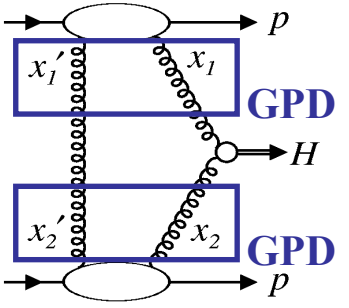
$R = \sigma_L/\sigma_T$

does it depend on W and t ?

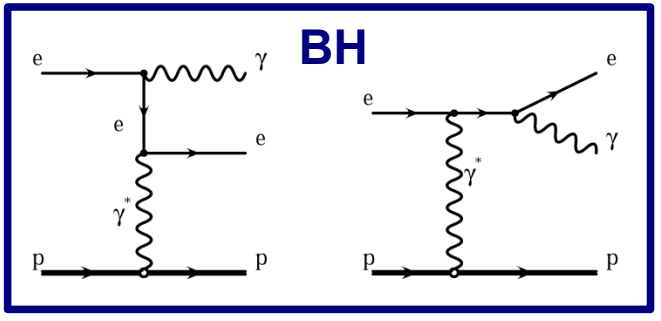
The DVCS and GPDs



x1 ≠ x2 → 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



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

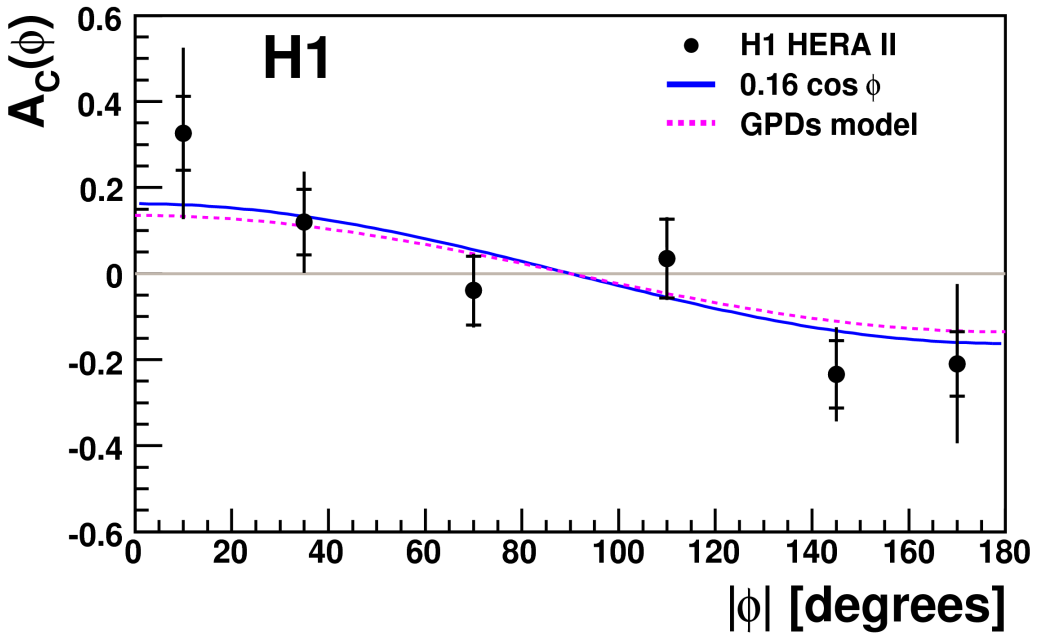
DVCS and BH: identical final state → they Interfere

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

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

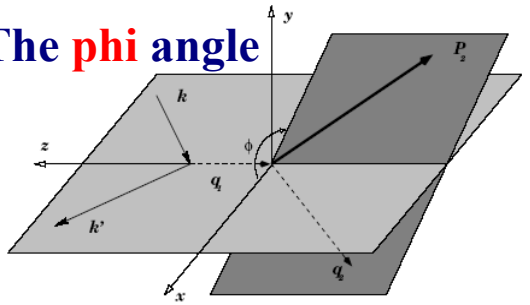
DVCS: the beam-charge asymmetry

The beam charge asymmetry as a function of phi



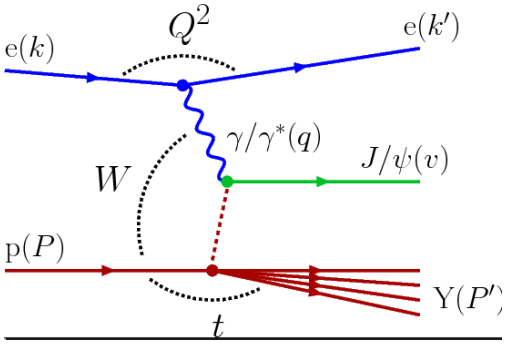
$$A_C = \frac{d\sigma^{+\cdot} - d\sigma^{-\cdot}}{d\sigma^{+\cdot} + d\sigma^{-\cdot}}$$

The phi angle

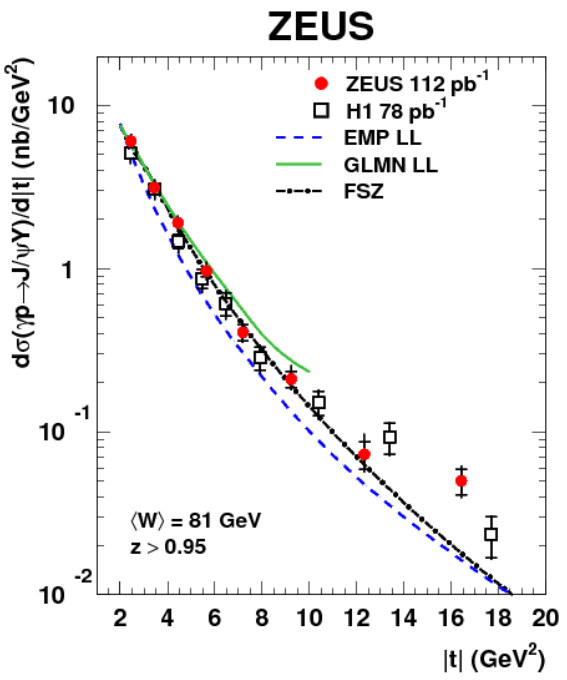


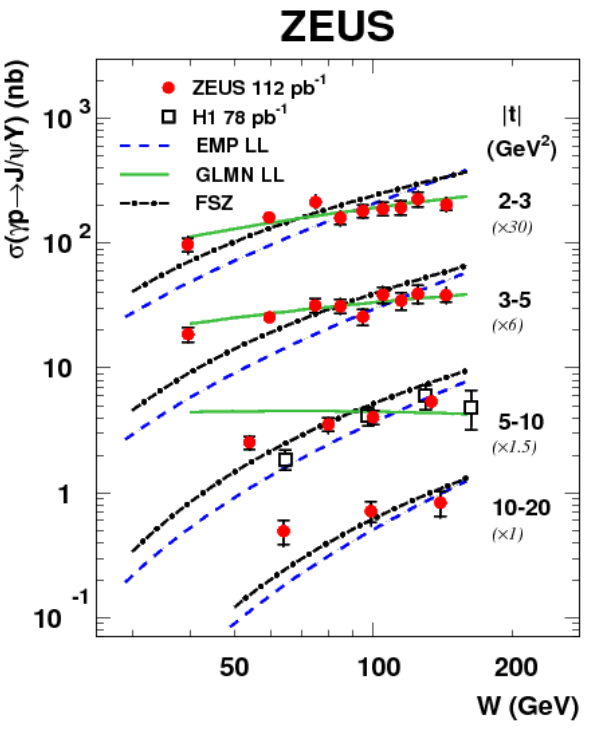
GPDs based model compatible with data

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

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

n = -1.9 ± 0.1, 2 < |t| < 4 GeV²
n = -3.0 ± 0.1, 4 < |t| < 16 GeV²

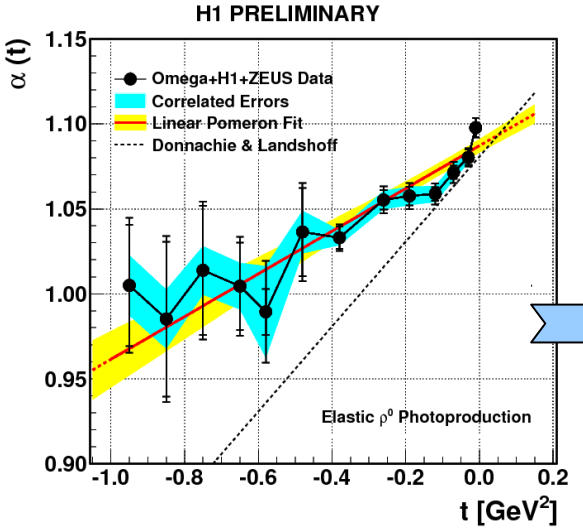
Pomeron trajectory in ep collisions

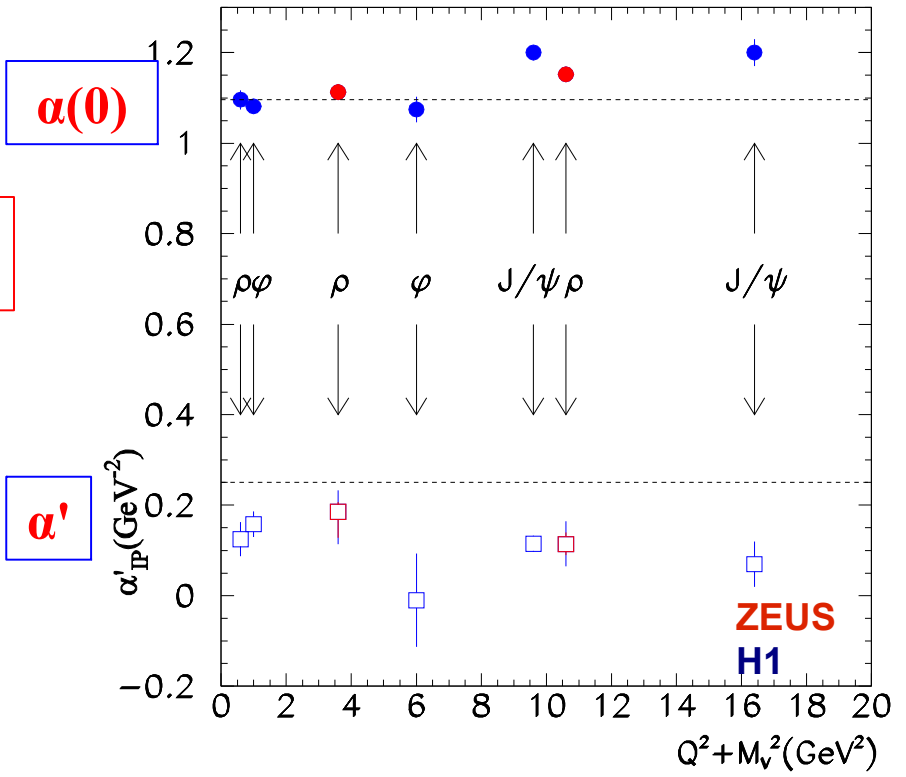
From SOFT to HARD.....

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

$$\alpha_{IP}(t) = 1.08 + 0.25t$$ **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





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

α(0) = 1.087 ± 0.003 ± 0.003
α' = 0.126 ± 0.013 ± 0.012 GeV^{-2}

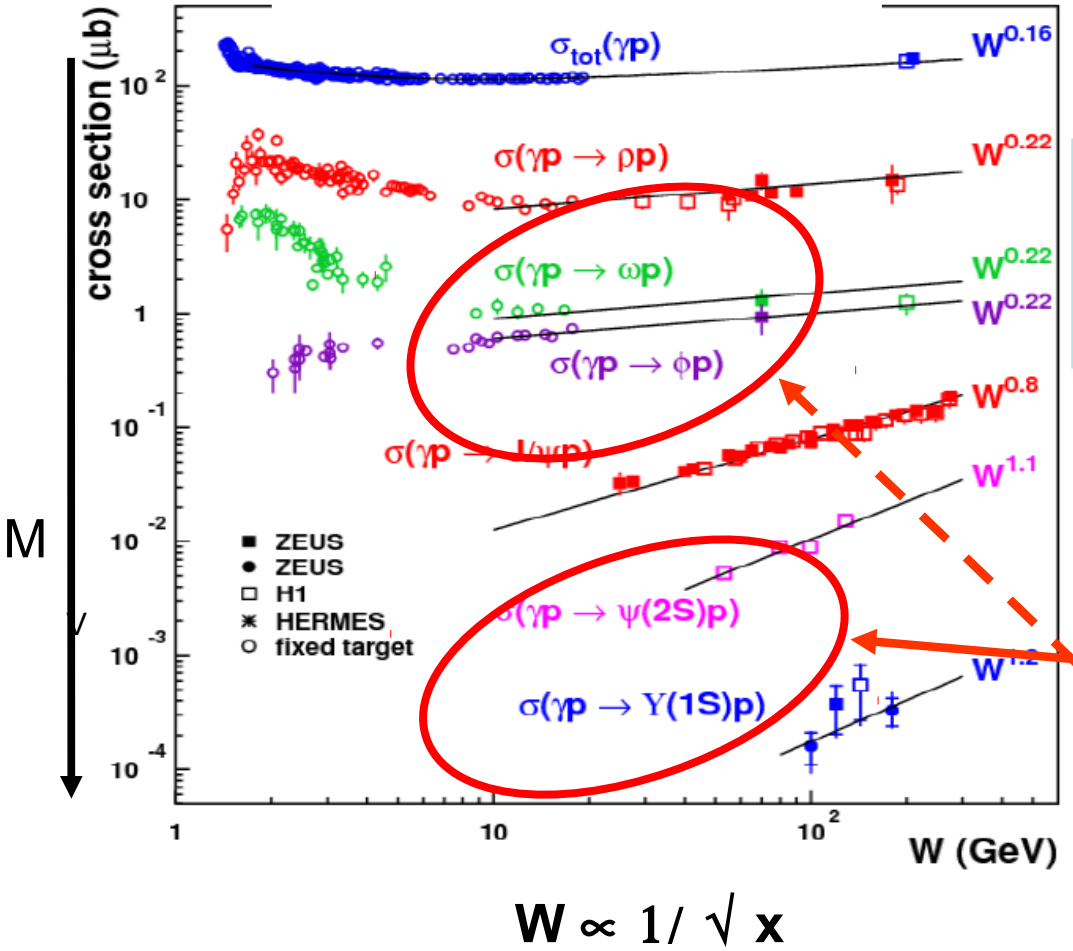
Summary

- 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: Q2, 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

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

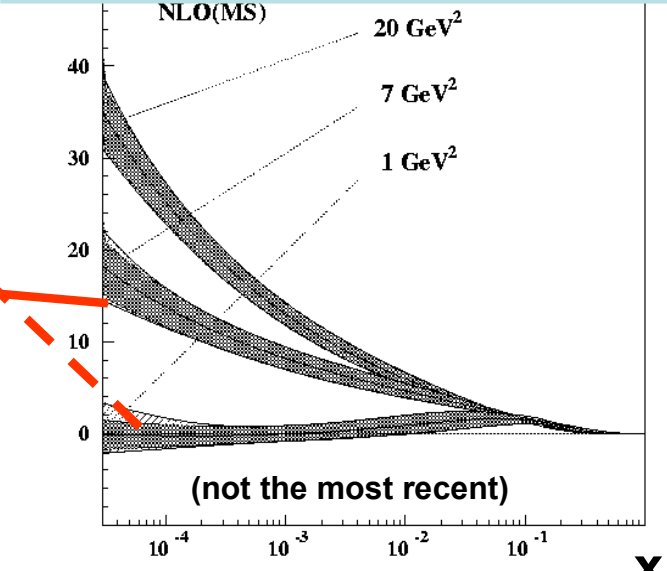


Fit: $\sigma \sim W^{\delta}$ with $\delta = 4(\alpha_P(0) - 1)$

W-dependence steeper with M_V^2:

$\delta_\rho \sim 0.2 \quad \dashrightarrow \quad \delta_{\Psi(2S)} \sim 1.0$

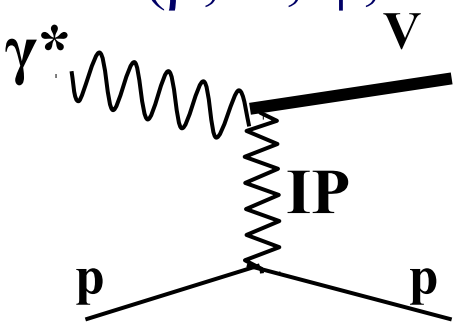
Large M_V supplies a scale for hard processes → apply pQCD models



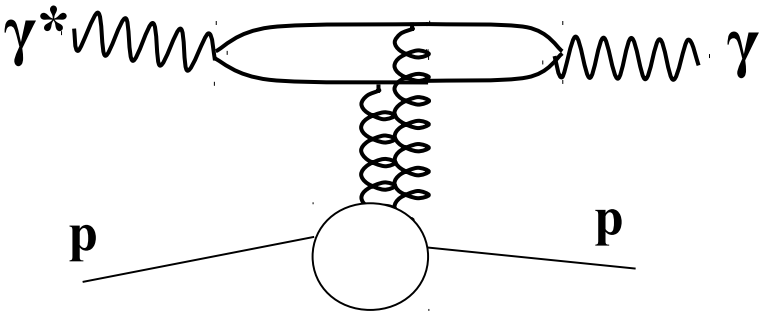
$W \propto 1/\sqrt{x}$

Deeply Virtual Compton Scattering

VM (ρ, ω, φ, J/ψ, Y)



DVCS (γ)



Scale: $Q^2 + M^2$ ⟷ 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**