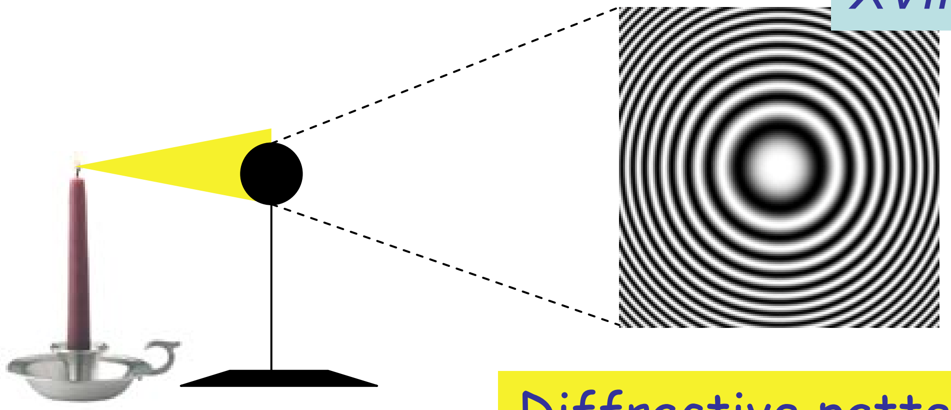
13 August 2007

Diffraction and vector meson production

A.Rostovsev (ITEP, Moscow)

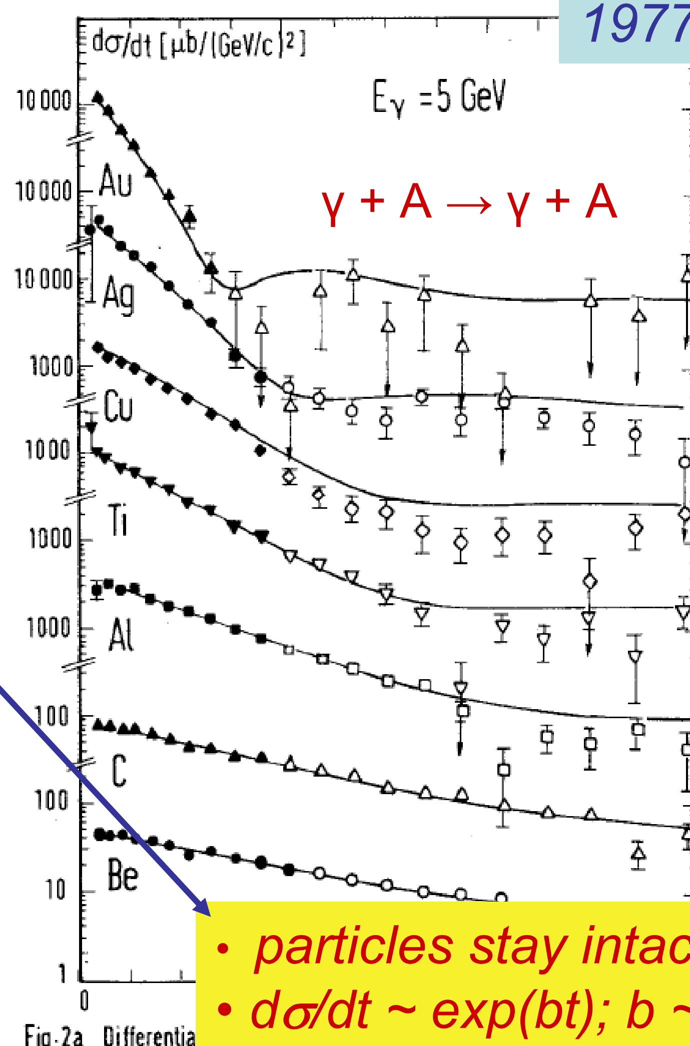
Diffraction phenomena are interesting now?

XVIII c



Diffractive pattern

1977



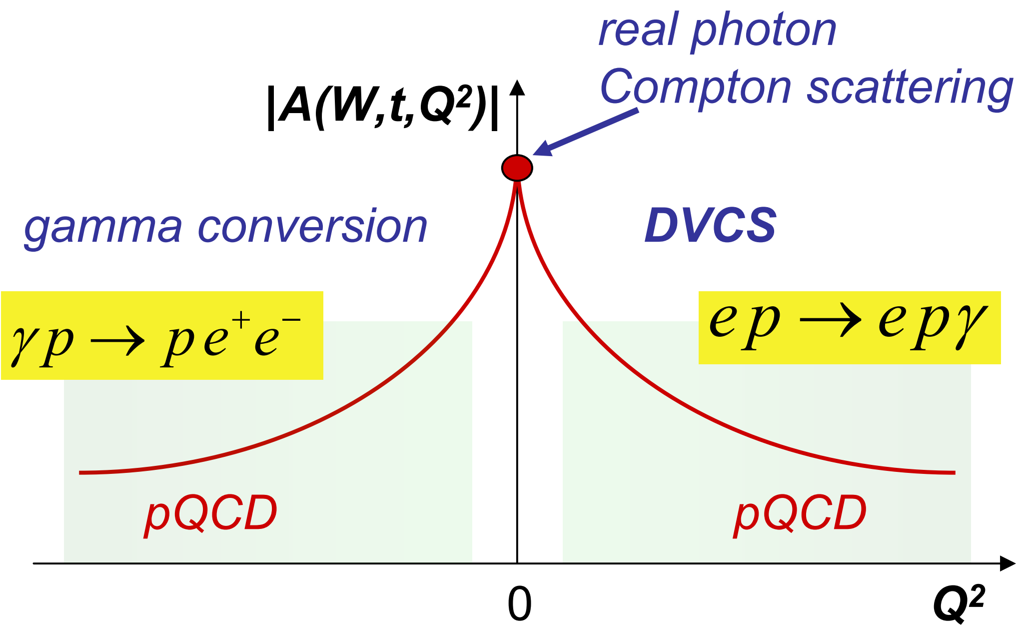
- particles stay intact
- $d\sigma/dt \sim \exp(bt)$; $b \sim r^2$
- $\sigma \sim s^{\alpha-1}$; $\alpha > 1$

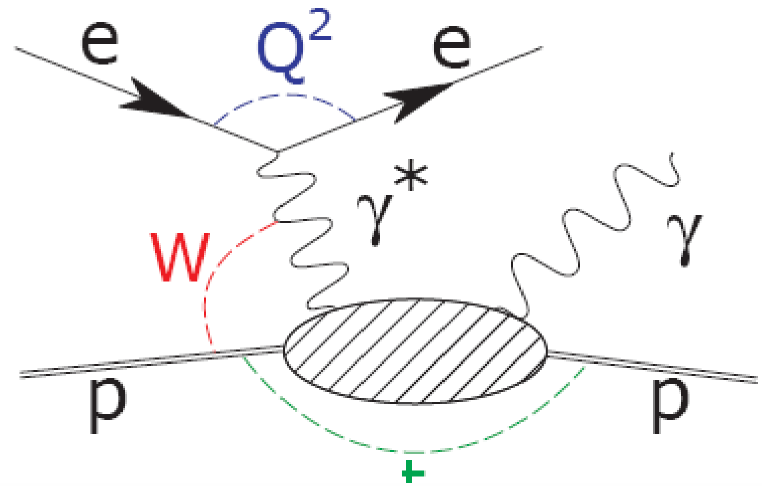
LP 2007

- Spectacular QCD phenomenon
- Challenge for perturbative QCD
- Unique tool :
  - nucleon tomography
  - nucleon angular momentum
  - trajectories / strong forces
  - Higgs boson production

Deeply Virtual Compton Scattering (DVCS)

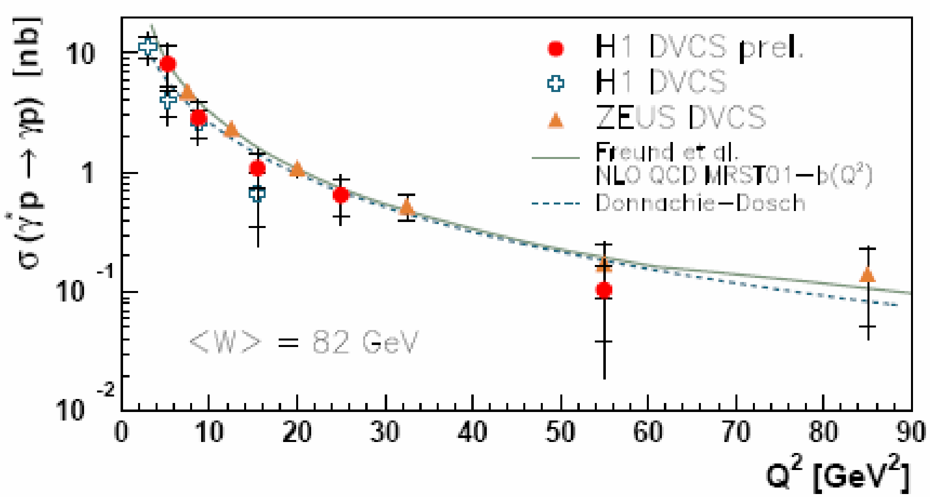
$$\frac{d\sigma_{DVCS}}{d|t|} \propto |A(W,t,Q^2)|^2$$





H1, ZEUS ($x \sim 10^{-2} - 10^{-4}$)

HERMES
JLab
COMPASS
} ($x \sim 10^{-1}$)



- the theoretically cleanest process
- information on GPDs

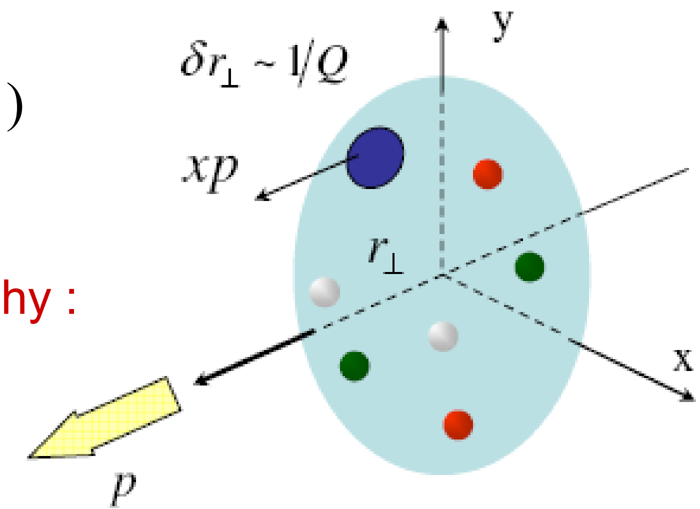
Generalized Parton Distributions (GPDs)

GPDs describe the correlation between two partons ($\boldsymbol{x_1}$, $\boldsymbol{x_2}$) which differ by longitudinal (x_1-x_2) and transverse (t) momentum at the given $\boldsymbol{Q^2}$

GPDs could be reduced to

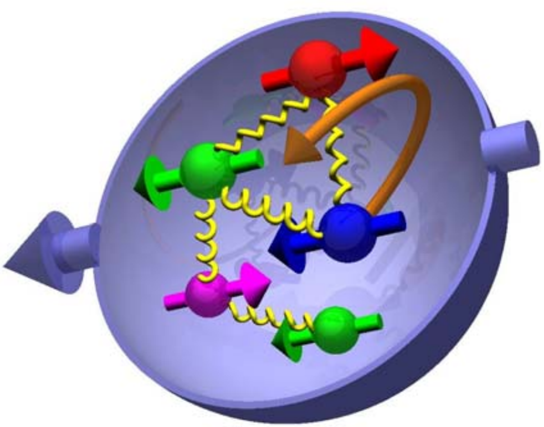
PDFs : $GPD(x_1 = x_2, t = 0) \equiv q(x, Q^2),\ xg(x, Q^2)$

Form Factors : $\int GPD \cdot dx = F(t)$



Nucleon tomography :

$$q(x, r_\perp, Q^2) = \int \frac{d^2\Delta}{(2\pi)^2} e^{-ir\Delta} GPD_q(x, Q^2, t = -\Delta^2)$$



Total angular momentum carried by partons in the nucleon :

Ji's sum rule (1997)

$$J^q = \frac{1}{2}\Delta\Sigma + L^q = \frac{1}{2}\int GPD_q \cdot x dx$$

Total Angular Momentum of u- and d- in Proton

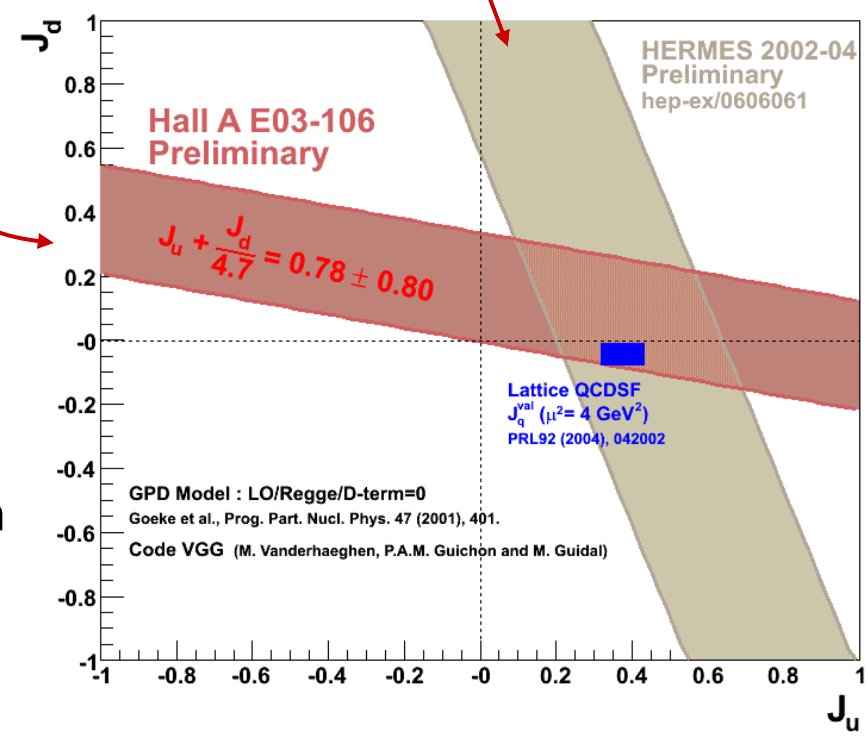
JLAB: *e-beam polarized cross section difference measured on deuteron and proton target.*

HERMES: *transverse proton spin asymmetry with unpolarized e-beam is sensitive to J^u and J^d at high x*

$d\sigma(\overrightarrow{e^-},n) - d\sigma(\overleftarrow{e^-},n) = \mathcal{P}(J^u,J^d)$

$d\sigma(e+,p\uparrow) - d\sigma(e+,p\downarrow) = \mathcal{F}(J^u,J^d)$

$$J^q = \frac{1}{2}\Delta q + L^q$$



HERMES 99

$\Delta u = 0.57 \pm 0.04$

$\Delta d = -0.25 \pm 0.08$

$\Delta s = -0.01 \pm 0.05$

sums up to about 30% of nucleon spin

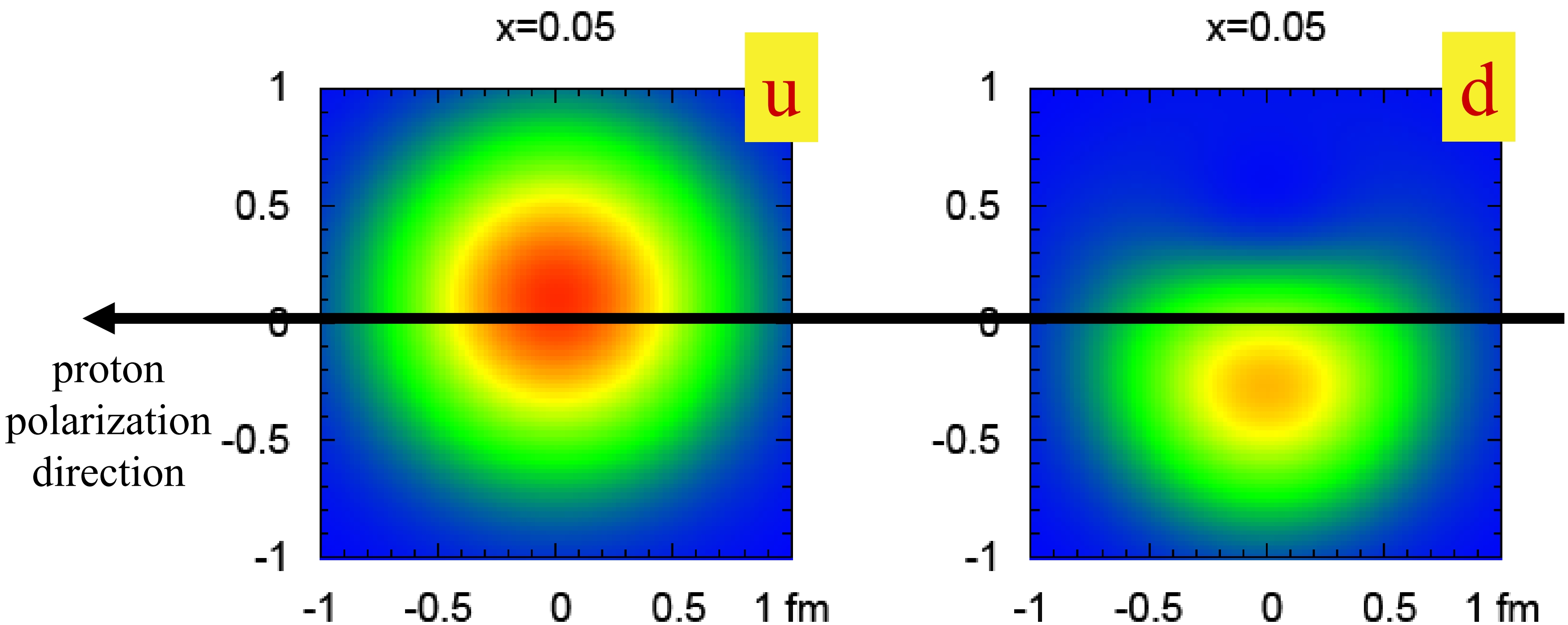
L^q adds about 30% to the proton spin

Tomography picture of proton

Scanning of the nucleon at different x is a unique feature of diffractive reactions

GPDs constrained to the Pauli and Dirac form factors of proton

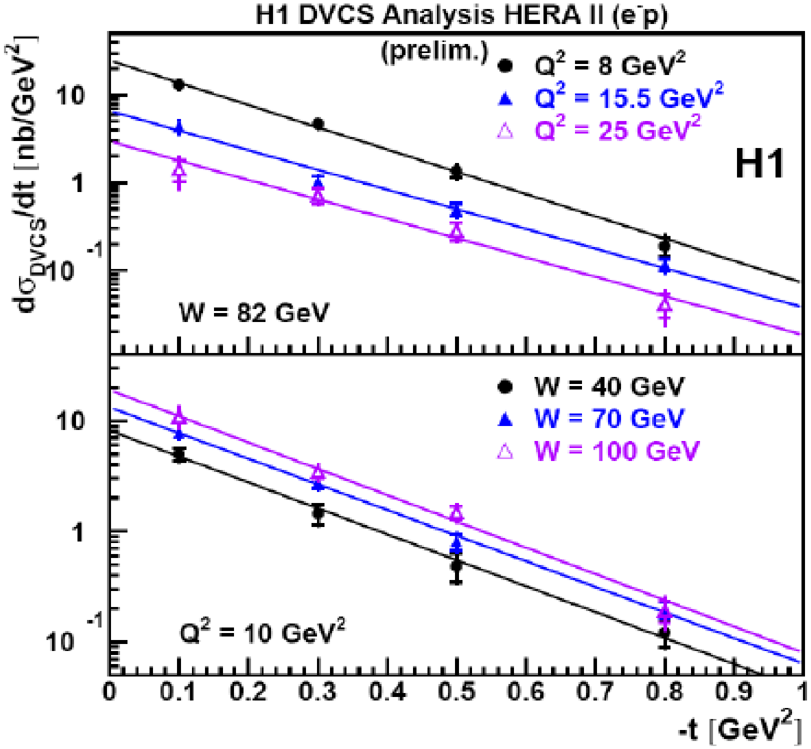
Tomography plots for u- and d- quarks at high x:



M. Diehl, T. Feldmann, R. Jakob and P. Kroll, Eur. Phys. J. C **39**, 1 (2005).

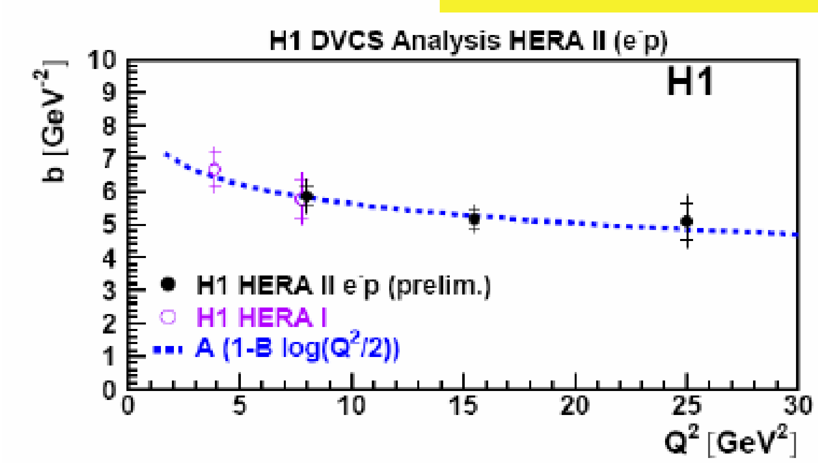
Proton tomography with DVCS at HERA

A measurement of ***t***-dependence of DVCS cross section at different values of **Q^2, W**



Approximated : *$d\sigma/dt \sim exp(bt)$*

t-slope parameter ***b(Q^2) decreases with increasing Q^2***



No W-dependence of t-slope observed.

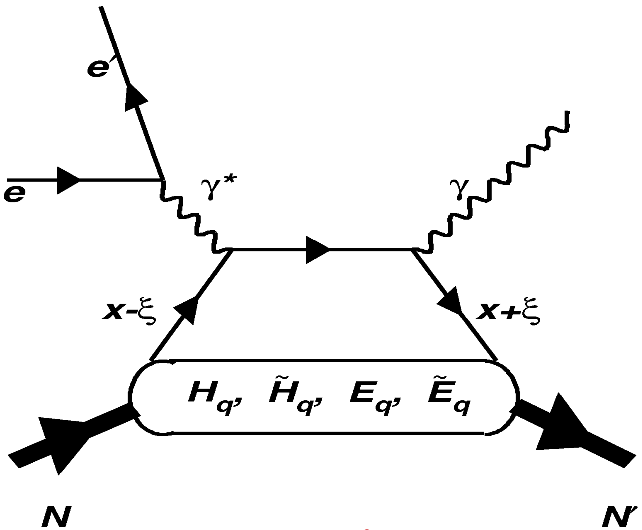
$<r_T> = \sqrt{b} \approx 0.65$ fm dominated by sea and gluons (low-x @ HERA)

*experimental input to GPDs parameterization as function of **t***

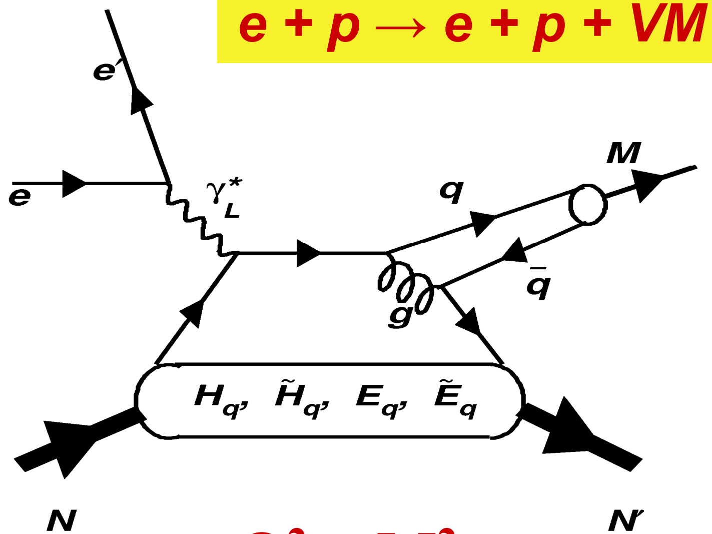
Diffractive Vector Meson Production

Vector Meson (VM) = ρ^0, ω, φ, Ψ, Υ

DVCS



$e + p \rightarrow e + p + VM$



Scale : Q^2 ⟺ $Q^2 + M^2$

No extra α_{em} supression : $\sigma_\rho \sim 10 \cdot \sigma_{DVCS}$
VMs have larger signal to background ratio than DVCS

VM wave function involved : theoretically not that clean as DVCS

Total γ^* + $p \rightarrow$ V + p cross section as function of Q^2

The cross sections were scaled by factors, according to the quark charge content of the vector meson

$$\rho : \omega : \varphi : J/\Psi = 1 : 9 : 9/2 : 9/8$$

Approximated with

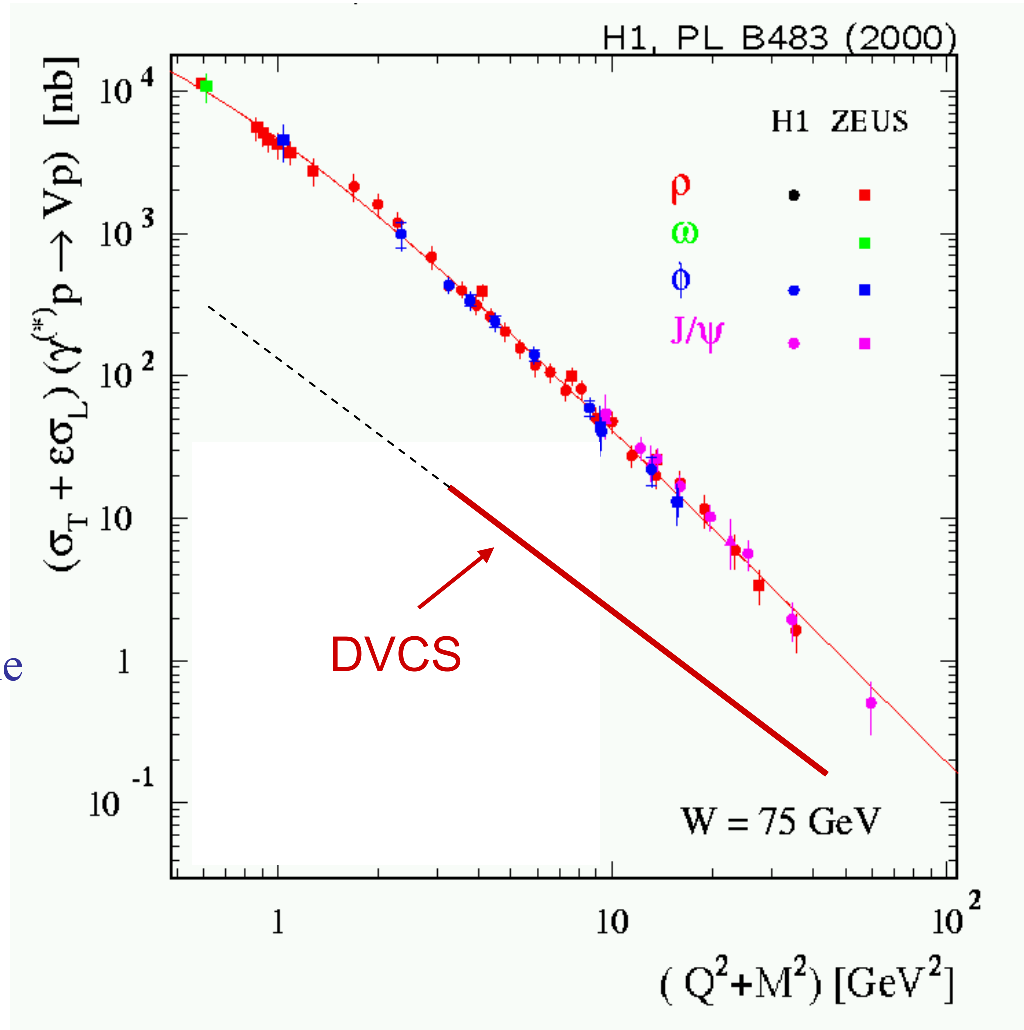
$$\sigma(Q^2) \propto 1/(Q^2 + M^2)^n$$

DVCS : n ≈ 1.5

VM : n ≈ 2.5 extra $(Q^2+M^2)^{-1}$ from the Vm wave function

Details:

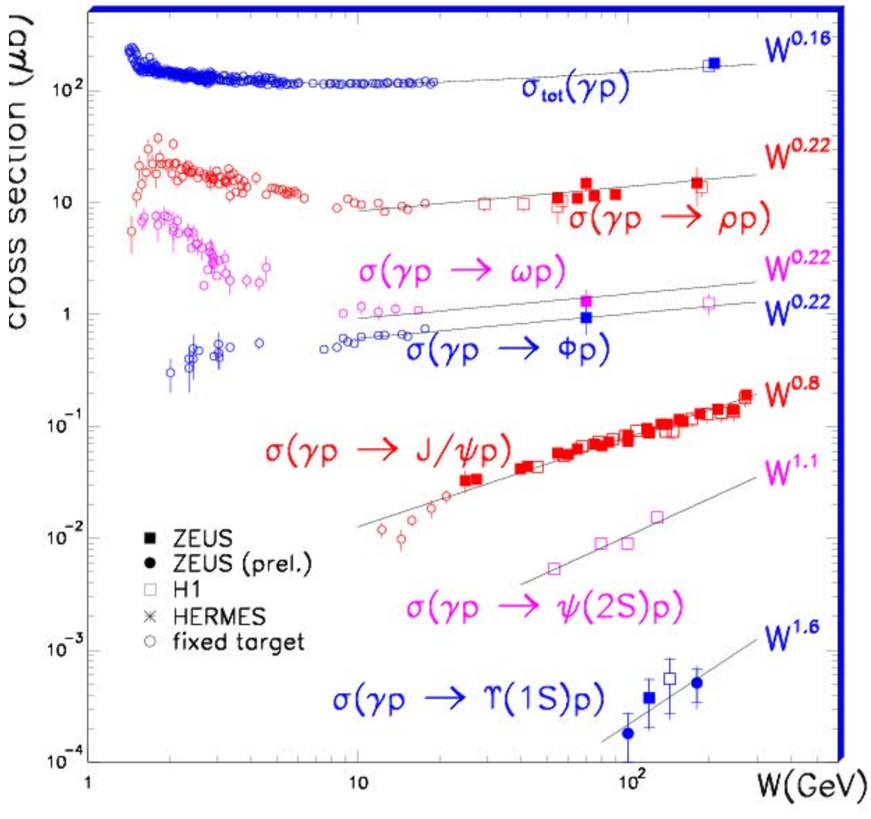
Fit to whole Q^2 range gives bad χ^2/dof



- striking universality in vector meson production.
- The Q2 dependence of $\sigma(\gamma^* p \rightarrow \rho p)$ cannot be described by a simple propagator term.

$\sigma(\gamma^* + p \rightarrow V + p)$. Energy dependence.

Photoproduction ($Q^2 \approx 0$)



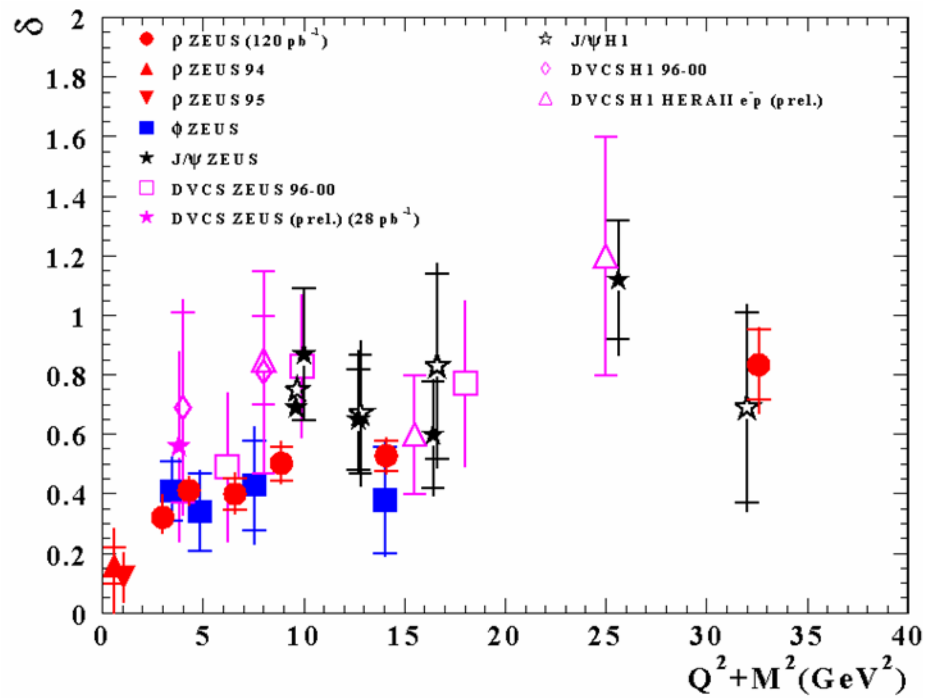
process becomes hard as Q^2+M^2 -scale becomes larger.

Cross section rises with energy.

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

the exponent is Q^2+M^2 scale dependent

$$\delta = \delta_0 + 0.25\ln(Q^2+M^2)$$



$\sigma(\gamma^*+p \rightarrow V+p)$. Energy dependence.

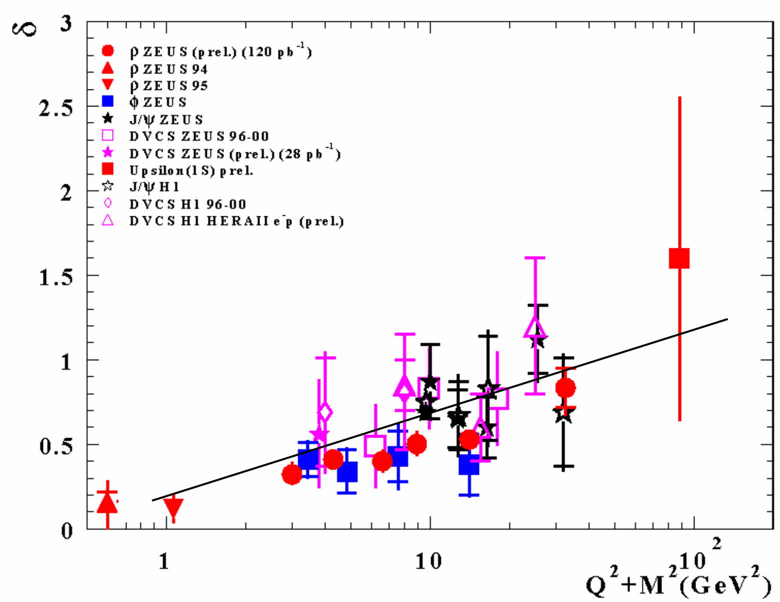
Elastic Vm production c.s. rises fast

$$\sigma(\gamma^*+p \rightarrow V+p) \sim (F_2)^2 \sim W^{\delta}$$

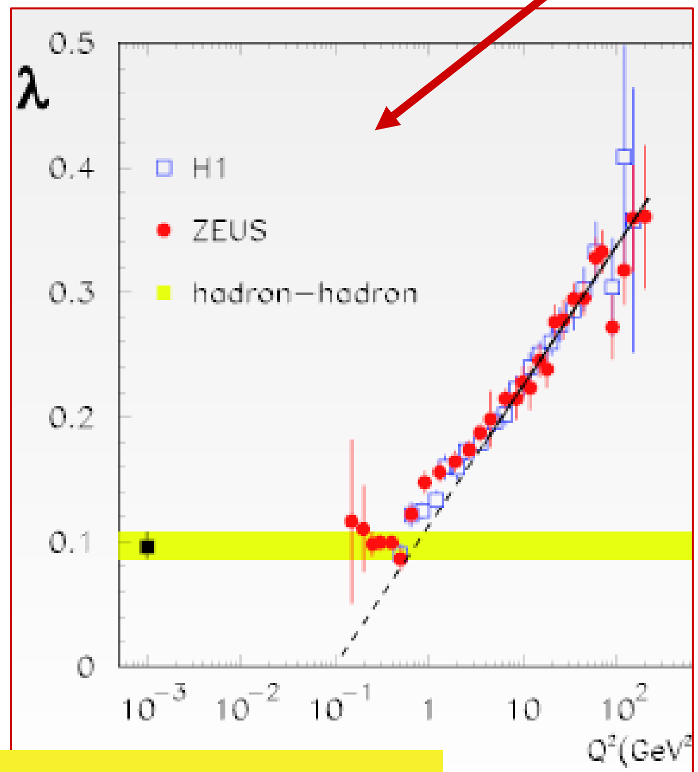
Inclusive c.s. is defined by Structure Function

$$\sigma(\gamma^*+p \rightarrow X) \sim (F_2) \sim W^{2\lambda}$$

$$F_2(x,Q^2) \sim (1/x)^{\lambda}$$



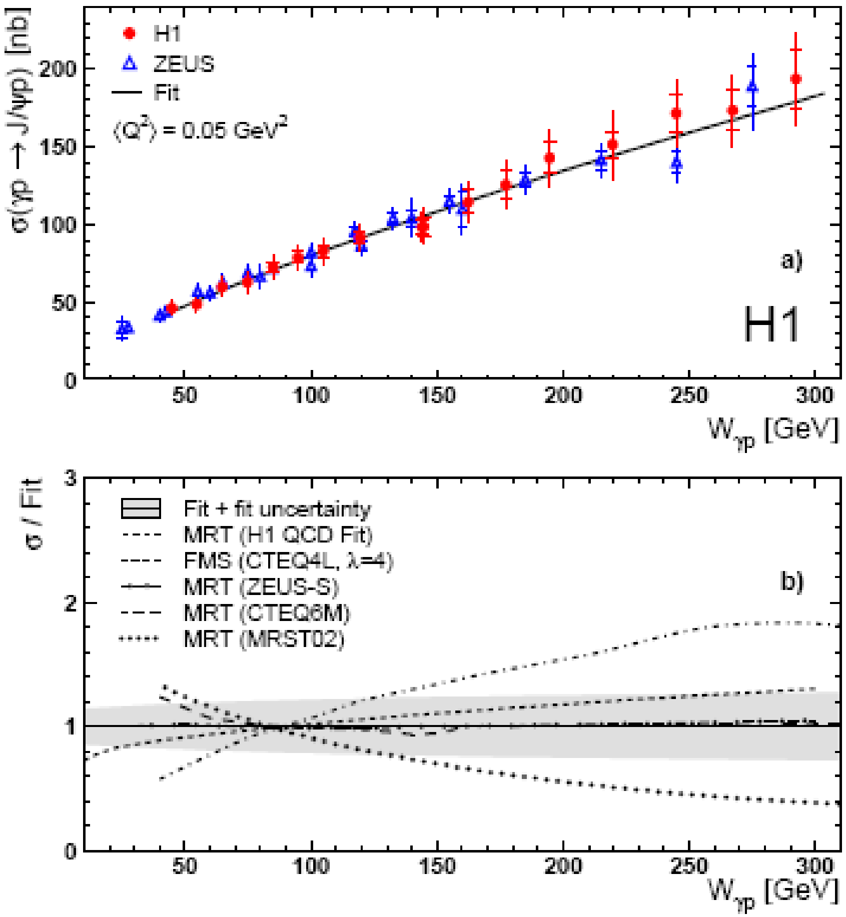
$= 4 \cdot$

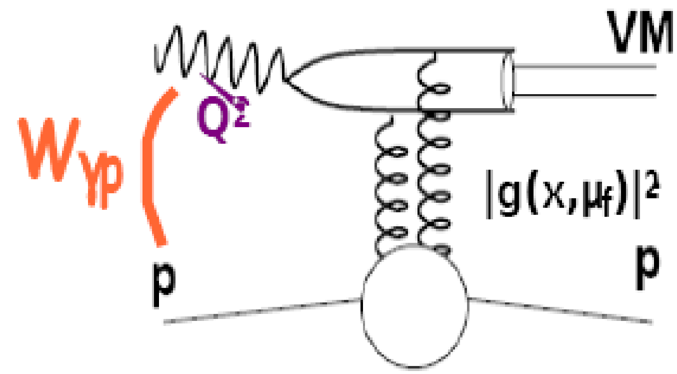


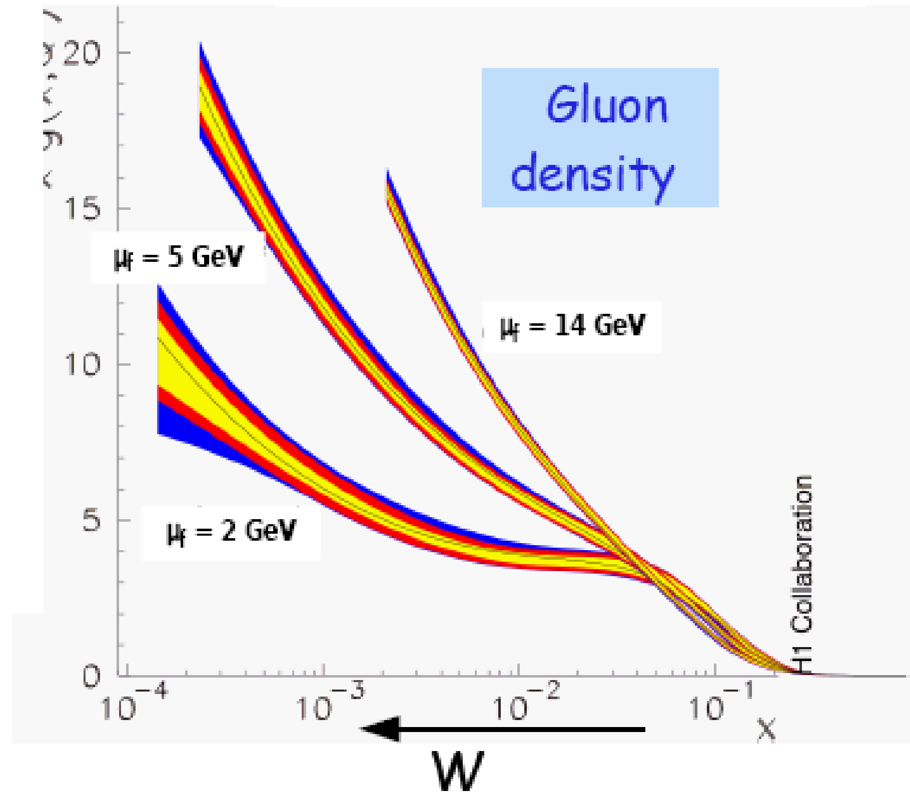
Energy dependence is defined by Structure Function

$$\delta(Q^2+M^2) = 4 \cdot \lambda(Q^2)$$

VM@HERA help to improve PDF parameterizations







High sensitivity to gluon density at low-x

$d\sigma/dt(\gamma^*+p \rightarrow V+p)$. t- dependence.

$$\frac{d\sigma}{dt} \propto F_V^2 F_p^2 \propto (1+a_V t)^{-4}(1+a_p t)^{-4} \Rightarrow \begin{cases} \exp(b \cdot t) & \text{- at low t, } b=4a_V+4a_p \equiv b_V+b_p \\ 1/|t|^n & \text{- at large t, } (4<n<8) \end{cases}$$

t- dependence is defined by Form Factors ($F_V F_p$)

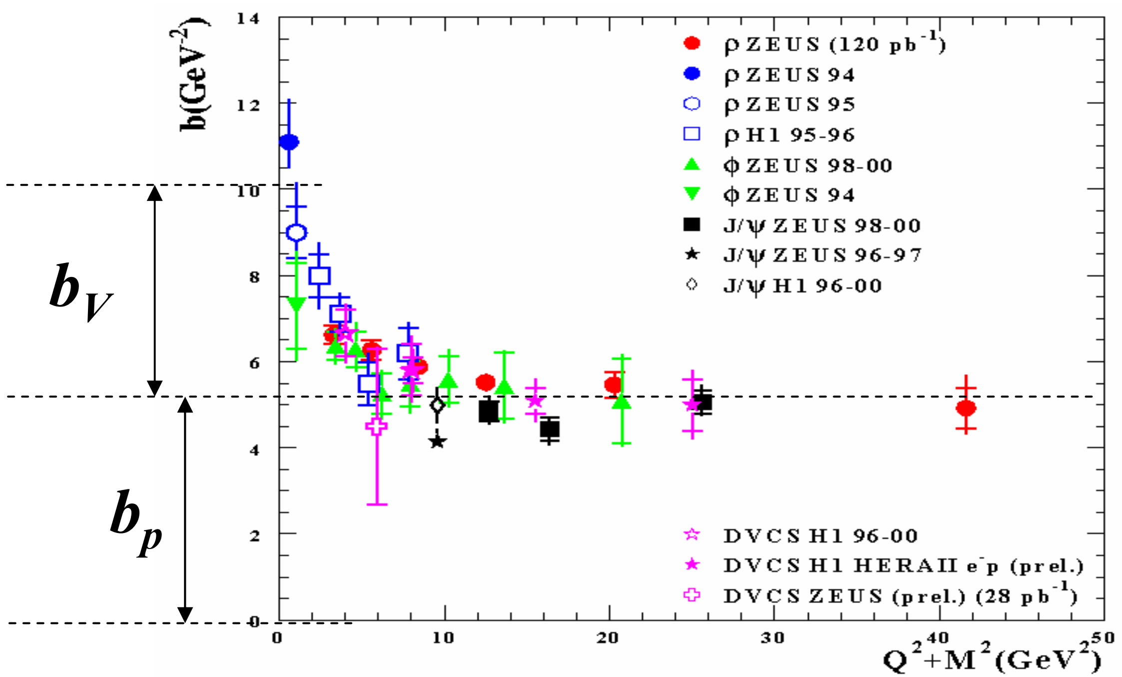
Slope ***b*** is a function of Q^2+M^2 scale

Geometric picture:

$$b = b_p + b_V$$

Size of the scattered vector meson is getting smaller with Q^2+M^2 scale

$$b_V \propto \frac{1}{Q_2 + M_V^2}$$



The exponential slope of the t distribution decreases with Q2 and levels off at about b = 5 GeV-2.

$d\sigma/dt(\gamma^*+p \rightarrow V+p)$. Interplay of t, Q^2

Alternative approach: *Take as a scale $Q^2 + M^2 - t$*

$$\frac{d\sigma}{dt} \propto \frac{\exp(b_0 t)}{(Q^2 + M_V^2 - t)^n} \Rightarrow \exp(b_0 t + \frac{n}{Q^2 + M_V^2} \cdot t)$$

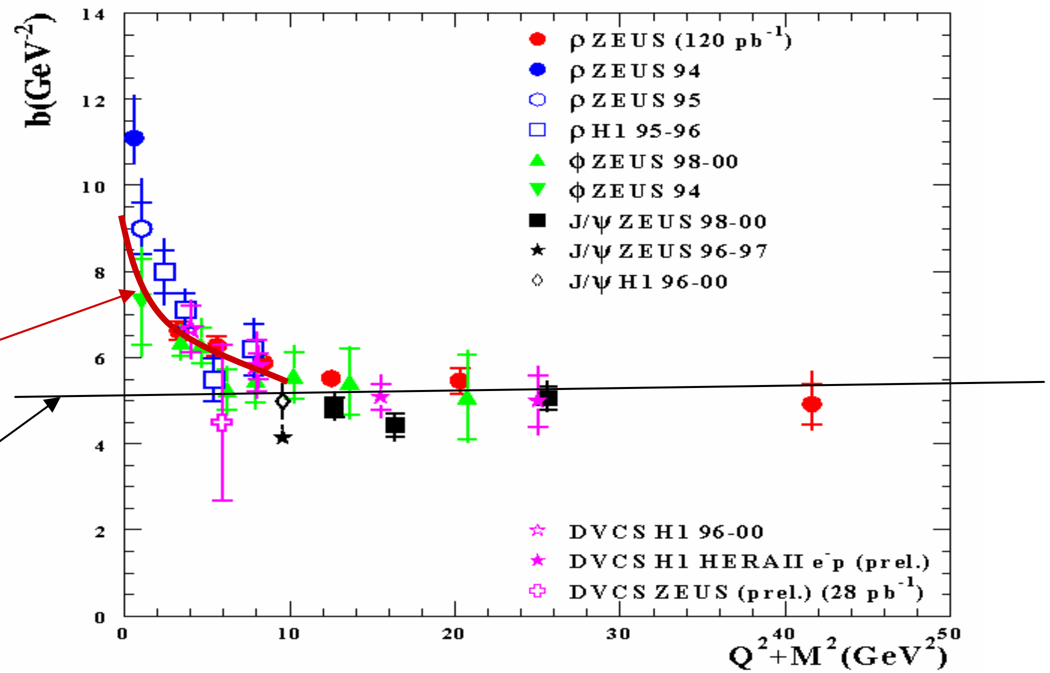
- at low t- values

For n = 2.5

$b_0 = 5\ GeV^{-2}$

effective slope b :

$$b = 5 + \frac{2.5}{Q^2 + M_V^2} \quad GeV^{-2}$$



If so,

Real slope $b_0 \approx 5\ GeV^{-2}$

and

The exponential slope of the t distribution does not change with Q2

$d\sigma/dt(\gamma^*+p \to V+p)$. Interplay of t, W

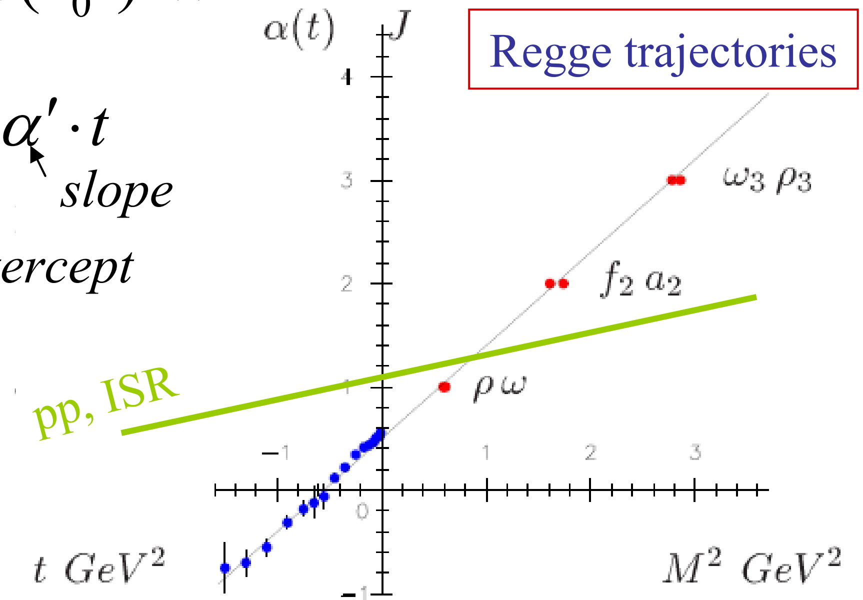
Regge-type anzatz: $$\frac{d\sigma}{dt} \propto \exp(b_0 t) \cdot W^{4\alpha(t)-4}$$

with a trajectory $$\alpha(t) = \alpha(0) + \alpha' \cdot t$$

slope

intercept

α(0) and α' are fundamental parameters represent basic features of strong interactions and hadron spectroscopy.



a(0) determines the energy dependence of total and diffractive cross sections

$$\frac{d\sigma}{dt} \propto \exp(b_0 t) \cdot W^{4\alpha(t)-4} = W^{4\alpha(0)-4} \cdot \exp(bt); \quad b = b_0 + 4\alpha' \ln(W)$$

α' determines the growth with energy of the transverse extension of the scattering system and **characterizes the confinement forces in QCD**

Access to α' only in diffraction

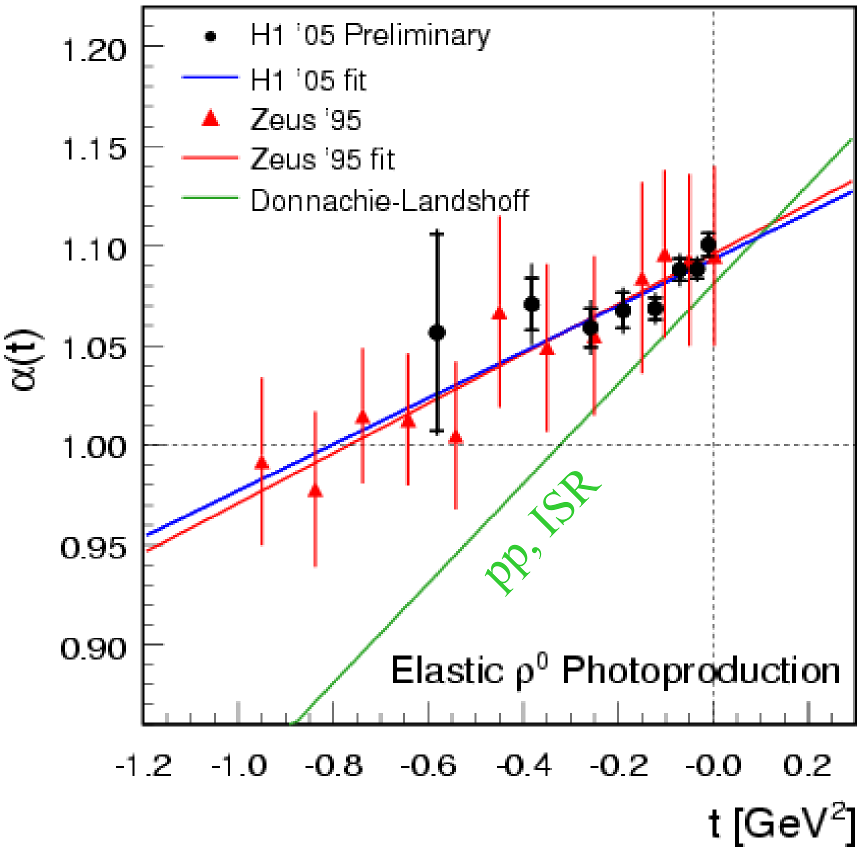
Interplay t and W "coded" in GPDs

Effective Pomeron Trajectory $\gamma p \rightarrow Vp$

$$\frac{d\sigma}{dt} \propto \exp(b_0 t) \cdot W^{4\alpha(t)-4} \qquad \alpha(t) = \alpha(0) + \alpha' \cdot t$$

ρ^0

$$\alpha(0) = 1.093 \pm 0.008$$
$$\alpha' = 0.116 \pm 0.05$$



Elastic ρ^0 photoproduction $(Q^2+M^2) = 0.6$ GeV^2

$a(0)(\gamma p) \approx \alpha(0)(pp)$

But….

$\alpha'(\gamma p) \approx ½\, \alpha'(pp)$

Two different soft Pomeron trajectories?

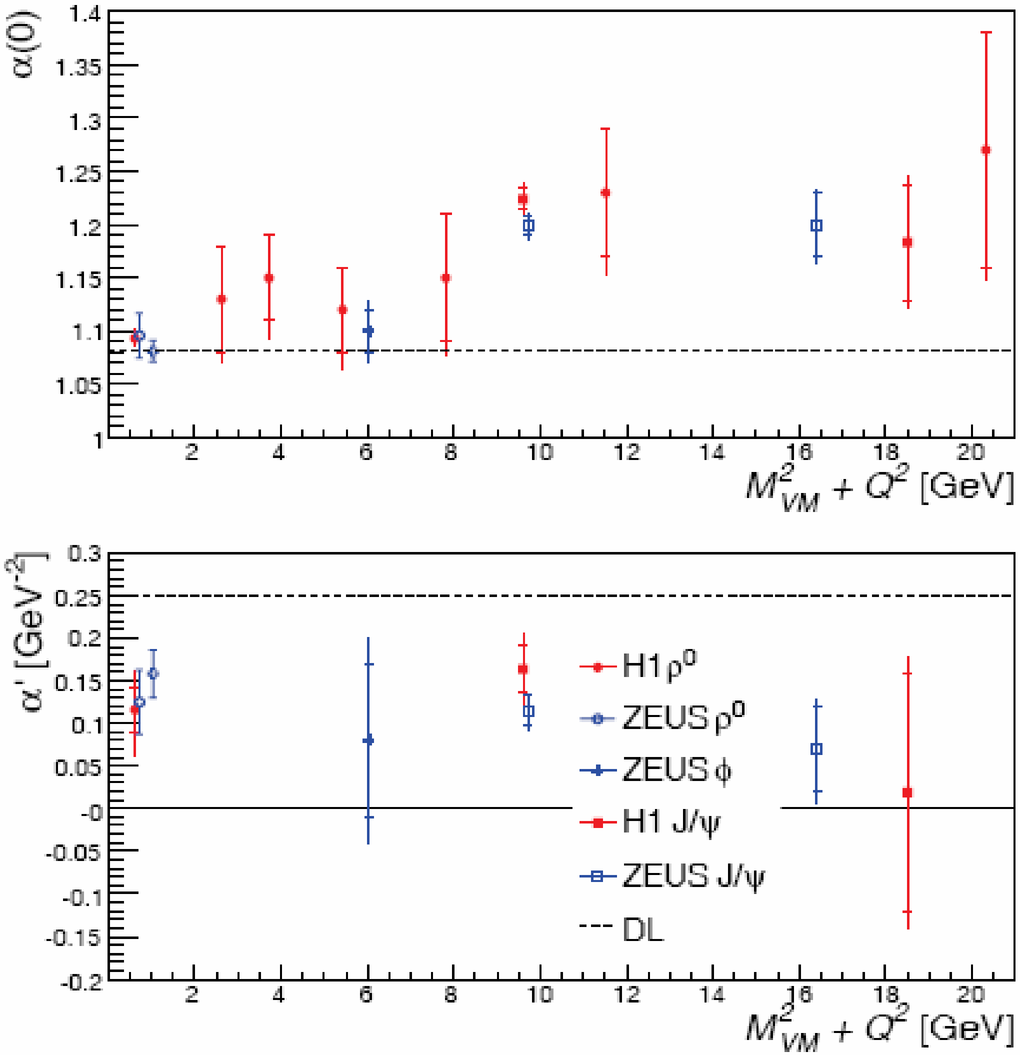
α' reflects the diffusion of partons in impact parameter, b_t, plane during the evolution in rapidity ~ln(s)

Size of 2 proton system in pp scattering grows twice faster with s than a single proton in γp-scattering?

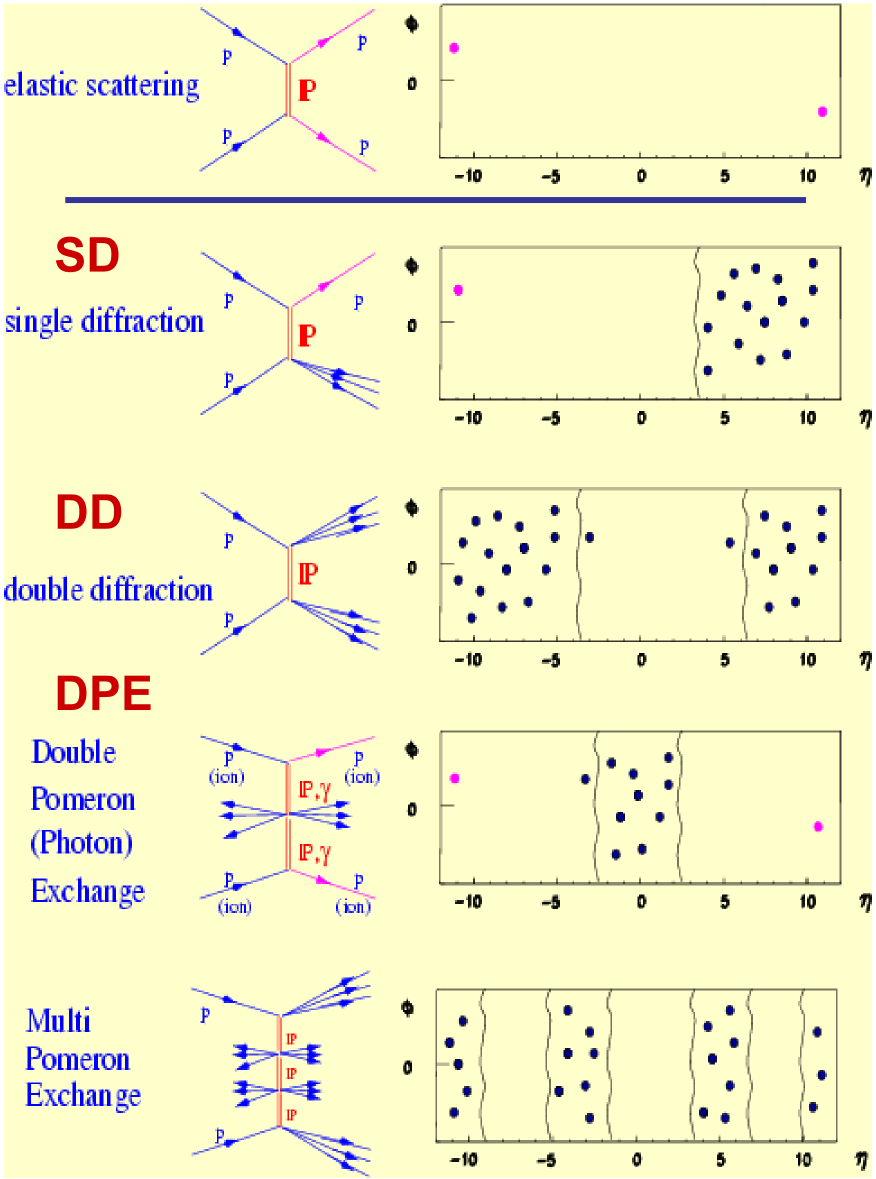
Effective Pomeron Trajectories $\gamma p \to Vp$

As the scale gets harder the intercept grows

The available data do not allow to make a conclusion on the slope evolution with the scale. Need more data!

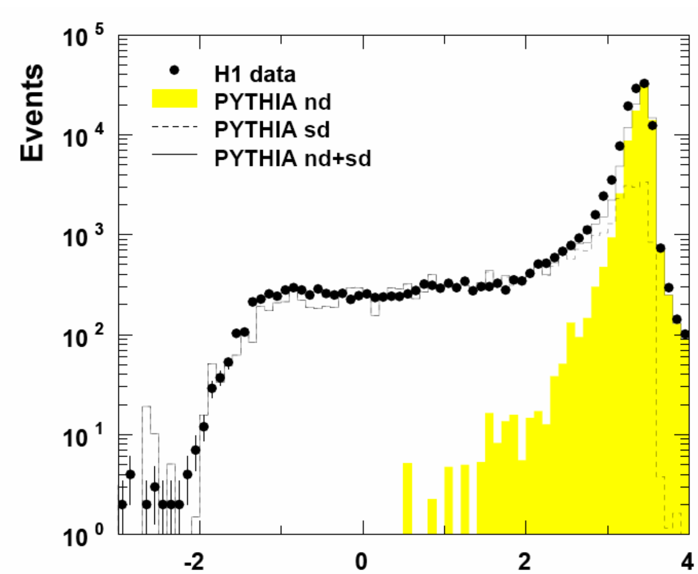


Diffractive dissociation processes



SD: one of colliding particle dissociates
DD: *t-* measurement is not possible

What is the diffraction pattern?

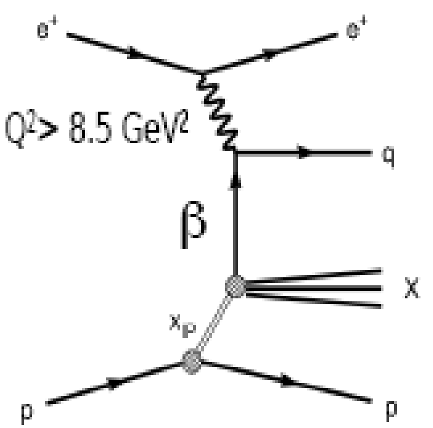


Rapidity Gap → Δy

A class of reactions with non-exponentially suppressed large rapidity gaps is operationally termed diffractive reactions (Bjorken 1994)

Extraction of Diffractive Parton Densities at HERA

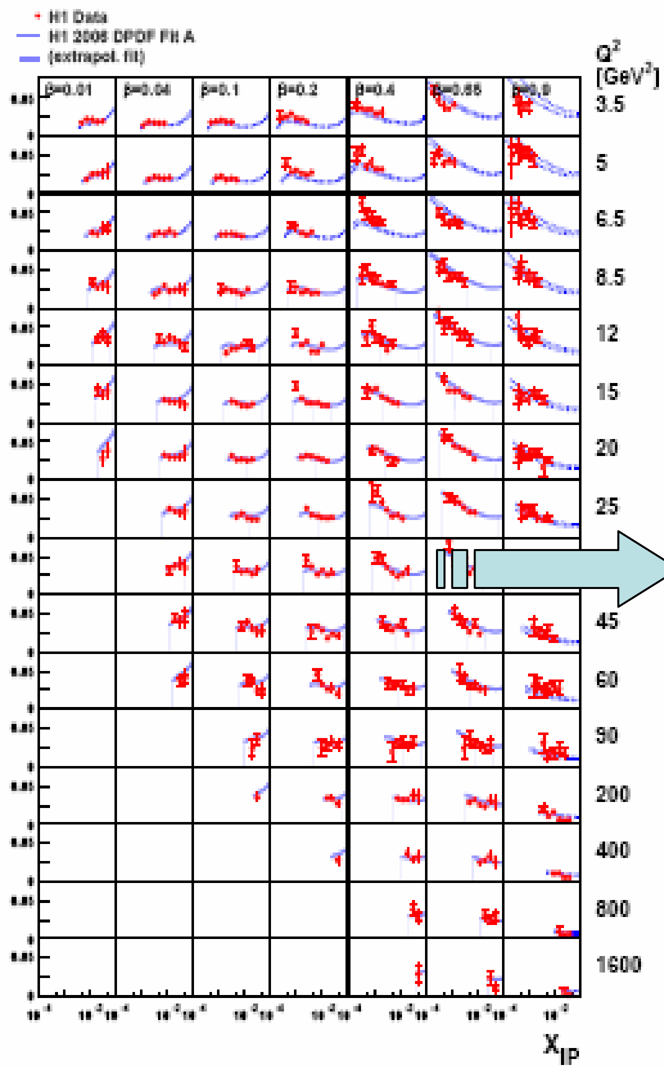
Inclusive diffr.



$$\beta = x / x_P$$

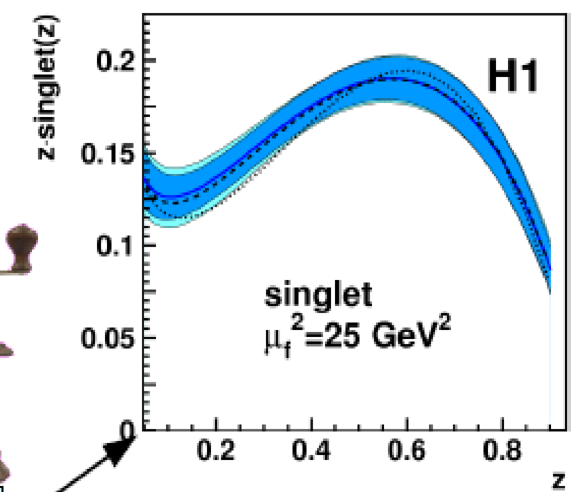
Assuming a factorization one could define and measure parton densities inside an object (Pomeron) exchanged in the diffractive reaction

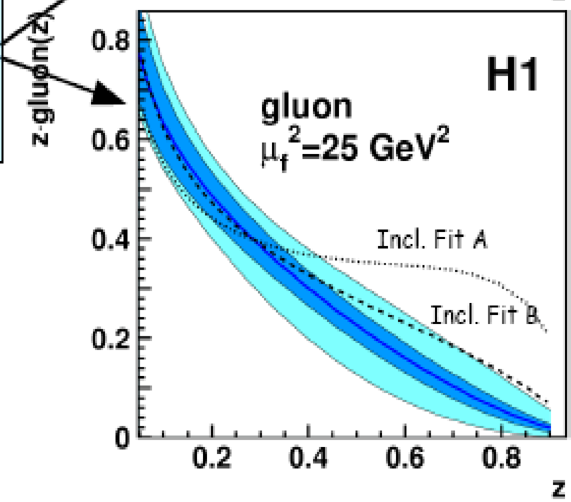
Diffractive x-sections.



NLO FIT

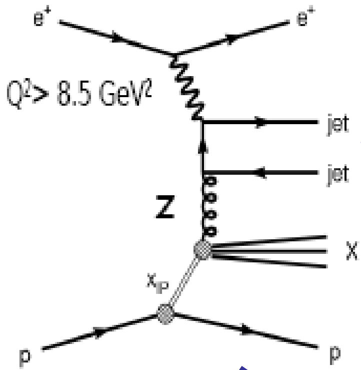
Diffractive PDFs



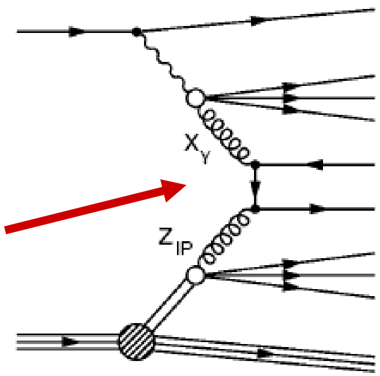


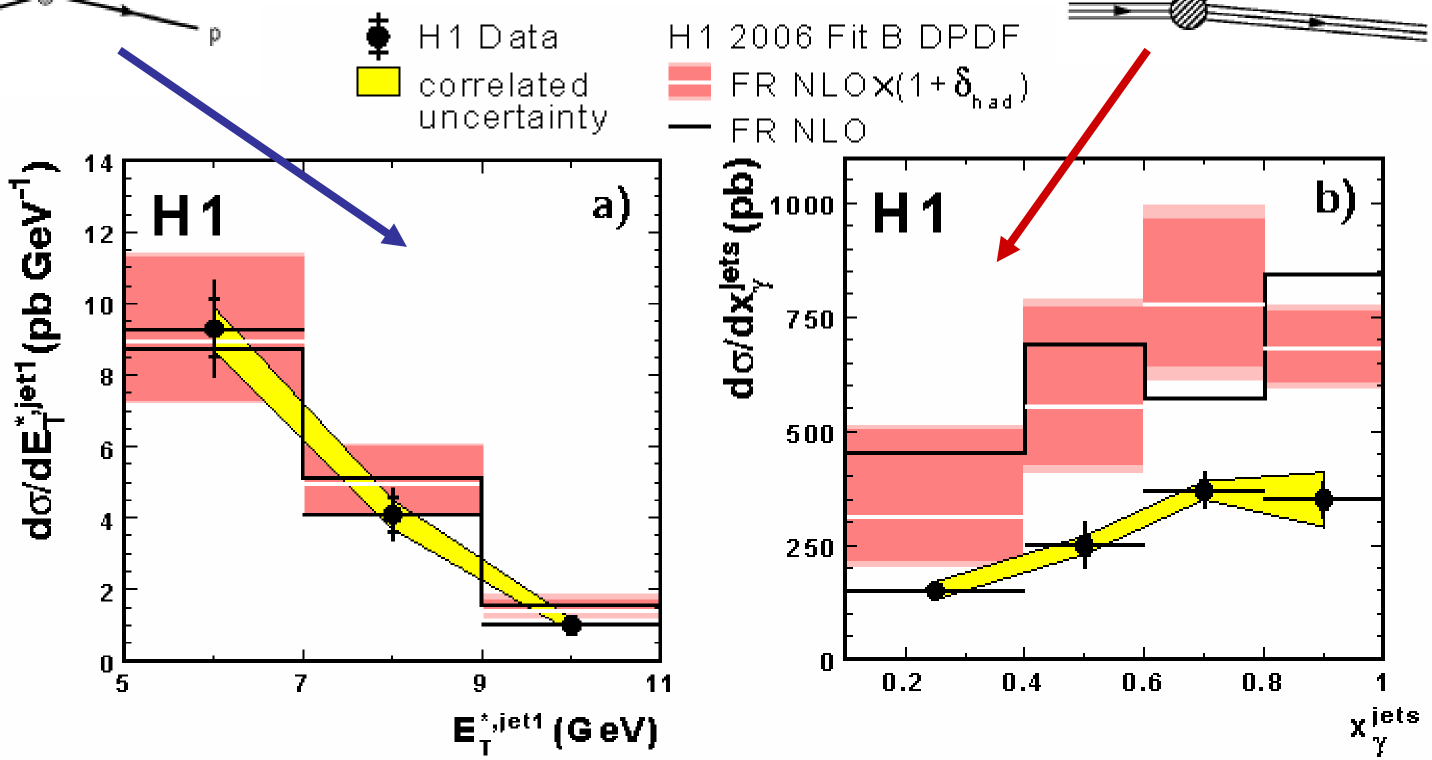
Factorization breaking at HERA

$$\sigma = \text{Diffr. PDF} \otimes \sigma_{\text{hard matrix el.}}$$

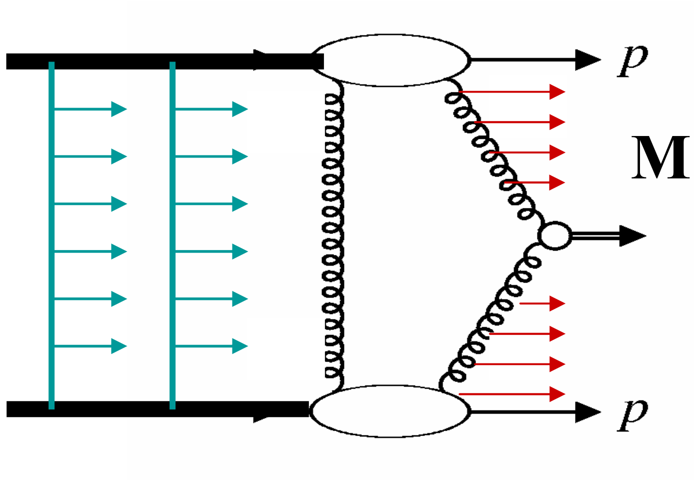


Once factorization is observed in
DIS diffractive di-jet production
it is broken in di-jet photoproduction





Rapidity Gap Survival Probability



Central production of high Mass or di-jets :

$$\sigma^{incl}(M) \otimes T^2 \cdot S^2 = \sigma^{excl}(M)$$

~~σ = Diffr. PDF $\otimes$ $\sigma_{\text{hard matrix el.}}$~~

T^2 – suppression of strong bremsstrahlung when two colour charged gluons ‘annihilate’ into a heavy object (Sudakov form factor)

For higher M the suppression T^2 is higher *(calculated in pQCD)*

S^2 - probablity that rapidity gaps survive against population by secondary hadrons from soft rescattering (responsible for non-factorization).

For higher collision energy the suppression S^2 is higher *(soft process, large uncertainty)*

LHC: *for $M \approx 100$ GeV* $\Longrightarrow$ $S^2 \approx 0.03$; $\dfrac{\sigma^{excl}}{\sigma^{incl}} \approx 10^{-4}$

S^2 suppression at works

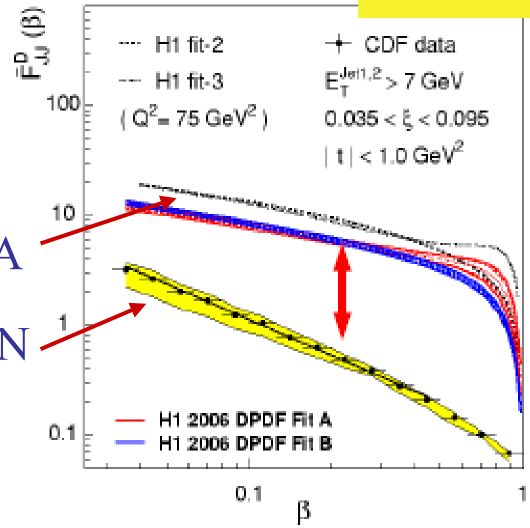
Diffractive di-jets at CDF

Diffractive fractions:

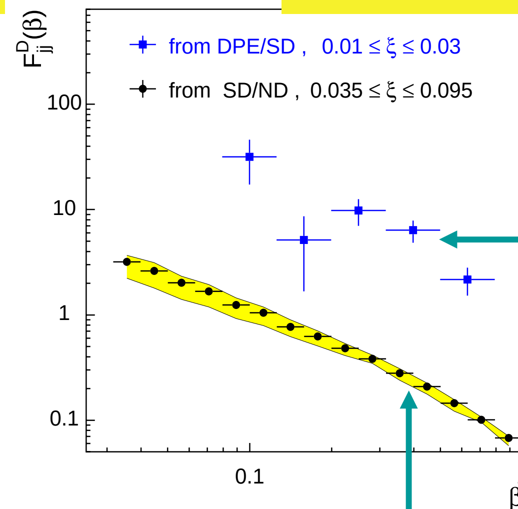
(~10%) as expected from HERA

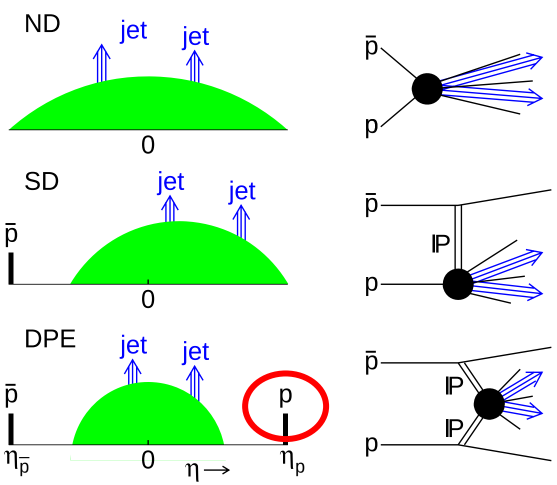
(~1%) measured at TEVATRON

SD / ND



DPE / SD





R(SD/ND) *- suppressed by S^2*

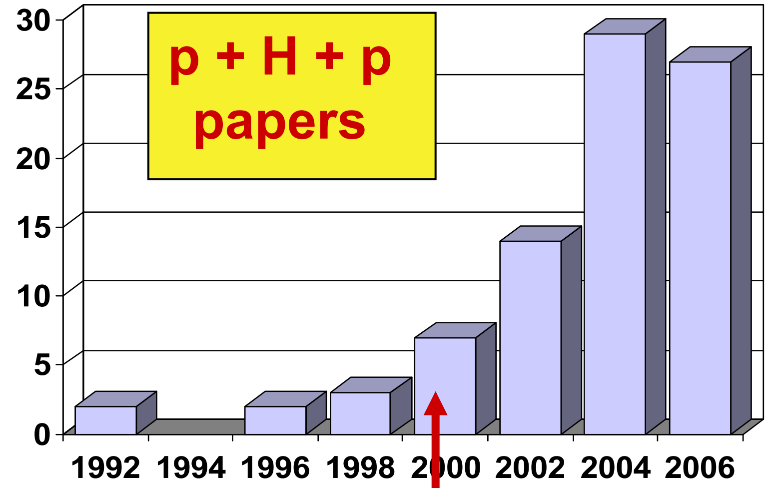
R(DPE/SD) *- non-suppressed*

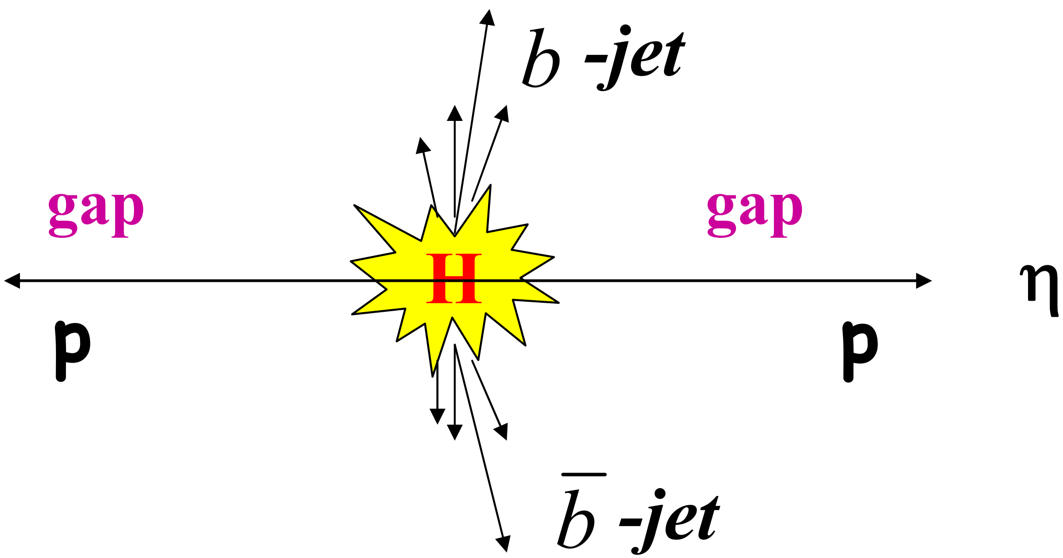
DSF from two/one gap:
factorization restored!

First rapidity gap selects event topologies without soft rescatterings (suppression!)

...but the next gap in the same event is for free!

$pp \to p + H + p$



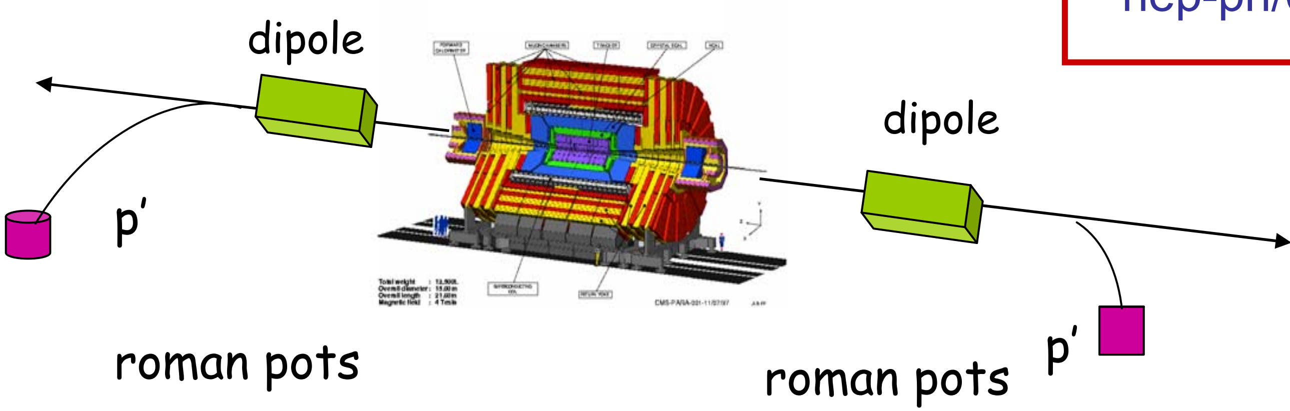


First reliable estimates for exclusive Higgs production hep-ph/0006005.

+

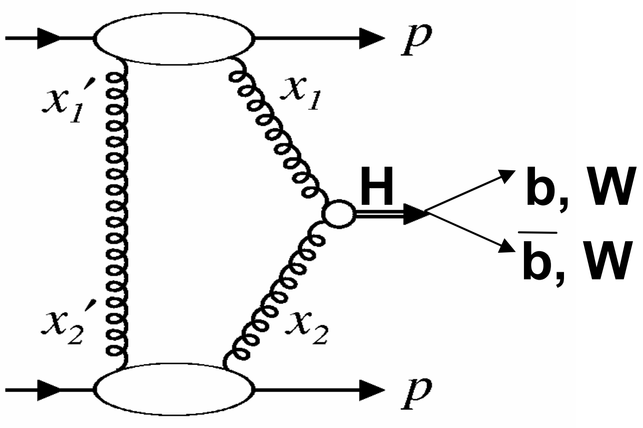
Missing mass method and proton tagging for Higgs hep-ph/0009336.

Missing mass with proton tagging:



$\sigma_{LHC} \sim 3$ fb

Exclusive Higgs boson production at LHC

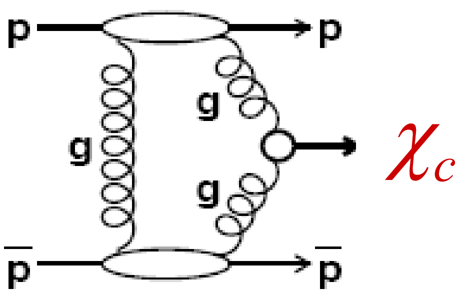


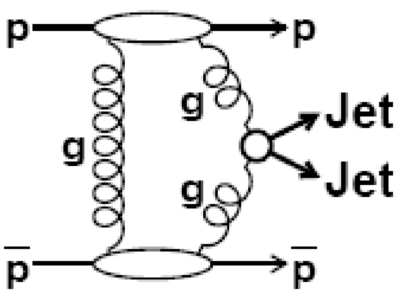
- *missing mass method*
  - ↪ *high mass resolution (2÷4 Gev)*
- *suppression of $b\bar{b}$-pair production*
  - ↪ *high S/B ratio*

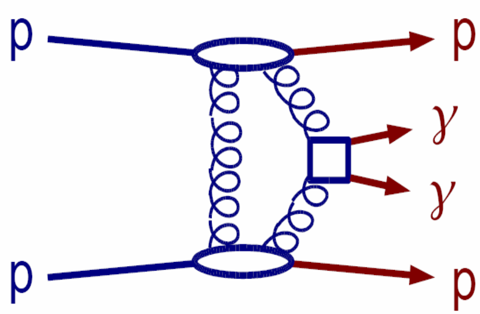
Rapidity gap suppression ⟹ Low cross section

How large is the rapidity gap suppression?
This is tested at TEVATRON:

- exclusive χ_c production ($p + p \rightarrow p + \chi_c + p$)
- exclusive ***di-jet*** production ($p + p \rightarrow p +$ *jet-jet* $+ p$)
- exclusive $\gamma\gamma$ production ($p + p \rightarrow p + \gamma\gamma + p$)



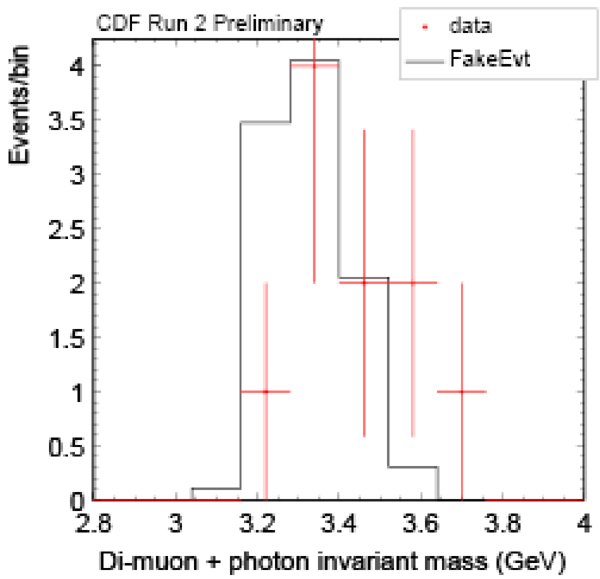




Central Exclusive χ_c production at CDF

Use the decays $\chi_c \to J/\Psi(\mu\mu)\gamma$ within |y|<0.6 central detector

10 events J/Ψ+γ found in the CDF detector and nothing else OBSERVABLE



If assume all 10 events are $\chi_c(0^{++})$

Upper limit of 49 ± 18(stat) ± 39(syst) pb

to be compared with prediction of 70 pb for |y|<0.6 (Khoze, Martin, Ryskin, 2001; uncertainty factor 2÷5)

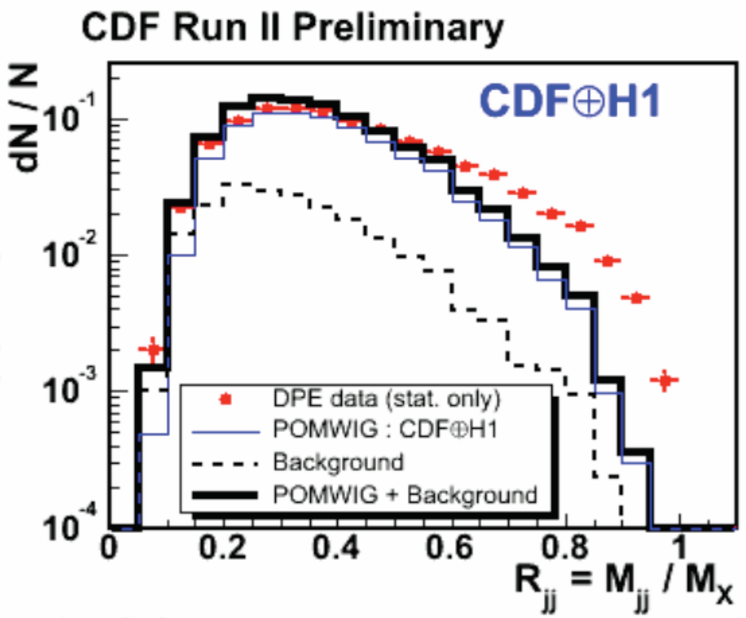
- small fraction of CDF statistics used in analysis
- needs for account of the $\chi_c(2^{++})$ state

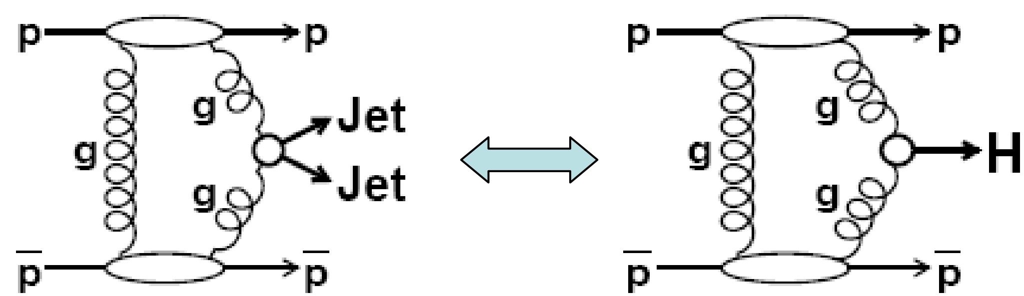
Since $\sigma \sim \Gamma_{gg}$,$\Gamma(2^{++})/\Gamma(0^{++}) \approx 0.13$

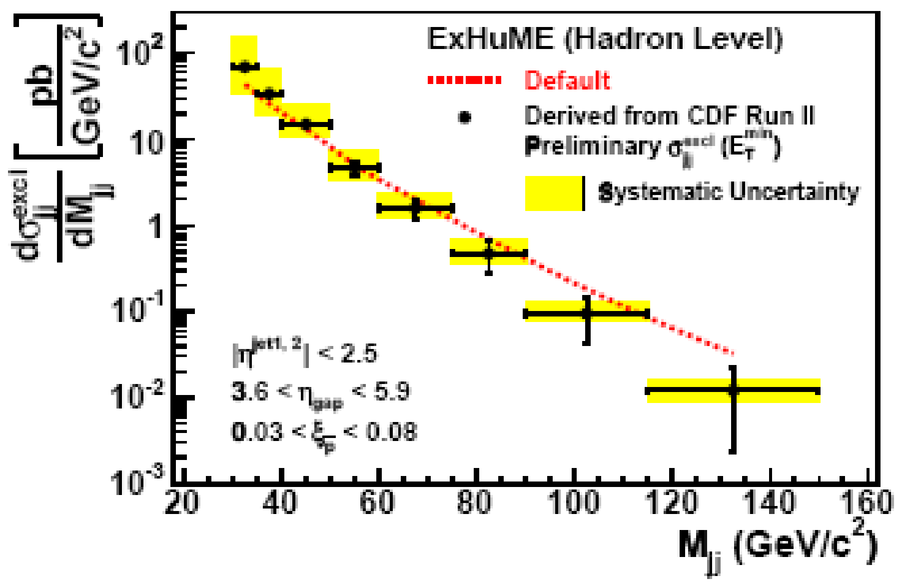
But $BR(\chi \to J/\Psi\gamma)$: $BR(2^{++})/BR(0^{++}) \approx 20$

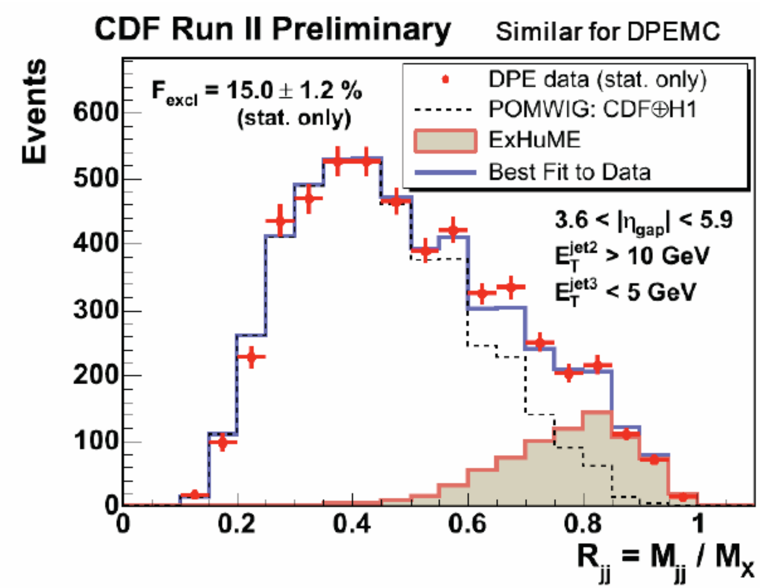
One expects about equal contributions from 0++ and 2++ states

Central exclusive di-jet production at CDF



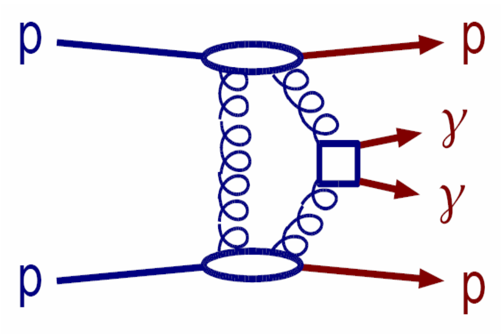






Good agreement with the calculations up to the expected Higgs mass lends credence to the calculation for exclusive Higgs production at LHC.

Central exclusive $\gamma\gamma$ production at CDF



Lumi = 532 pb^{-1}

Search for exclusive $\gamma\gamma$

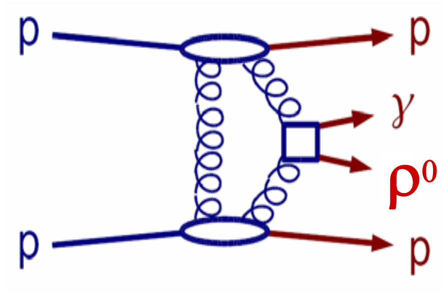
$E_T(\gamma) > 5$ *GeV and* $|\eta|<1$

- ✓ 3 candidate events found
- ✓ 1 (+2/-1) predicted from ExHuME MC
- ➢ estimated ~1 bgd event from $\pi^0\,\pi^0$, $\eta\,\eta$

If assume 3 events are DPE $\gamma\gamma$

Upper limit $\sigma < 410$ *fb*

What Else?



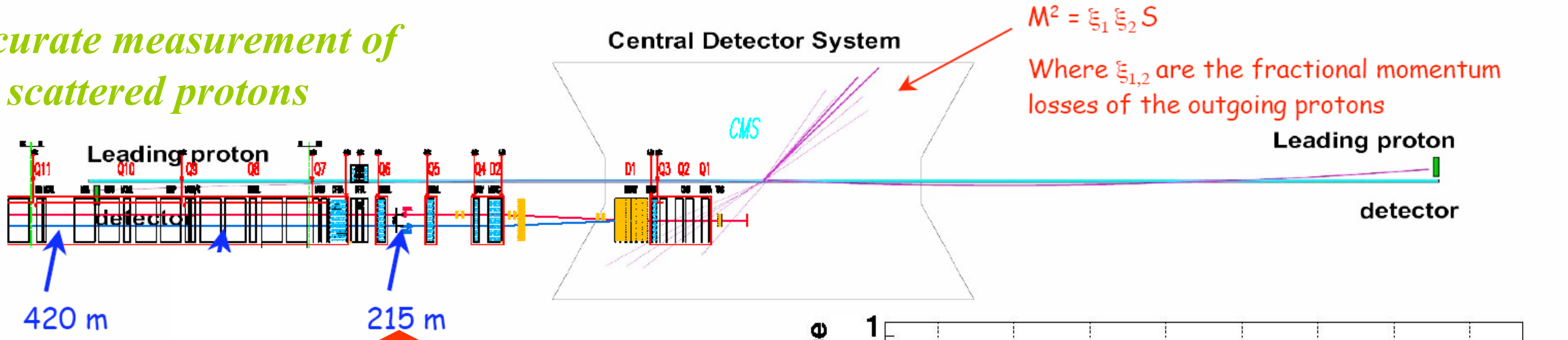
$pp \rightarrow pp + \gamma + \rho^0$

Similarity to VM-production at HERA

$$\sigma(\gamma\rho^0) \approx 10 \cdot \sigma(\gamma\gamma)$$

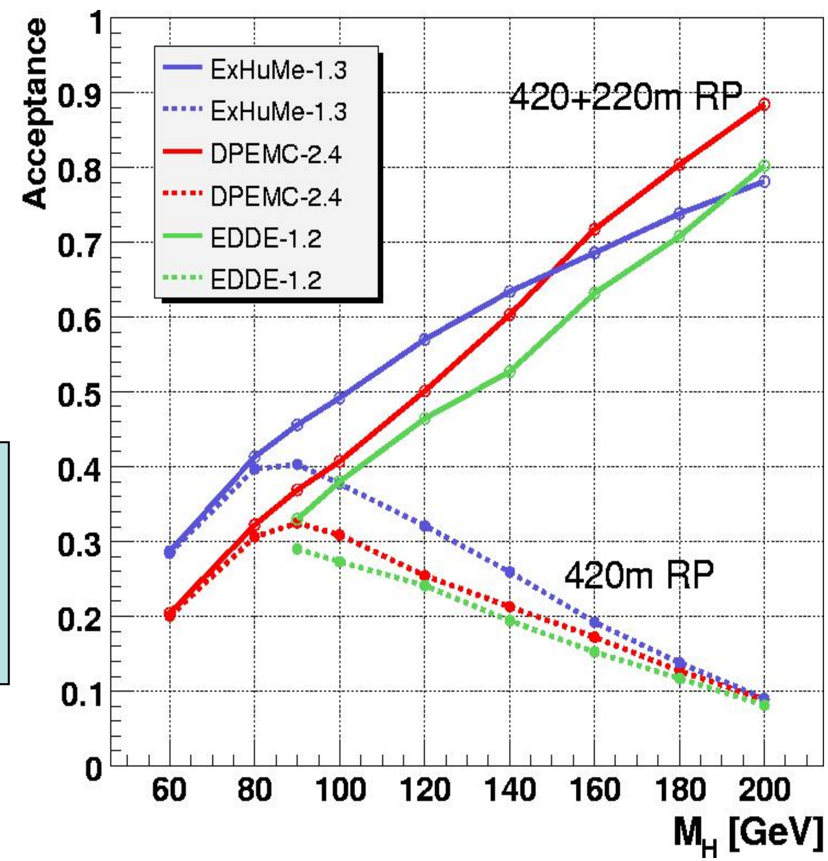
FP420 project at LHC

Accurate measurement of the scattered protons



FP420

TOTEM on CMS side
RP220 on ATLAS side



For L=30 fb-1 one expects to observe

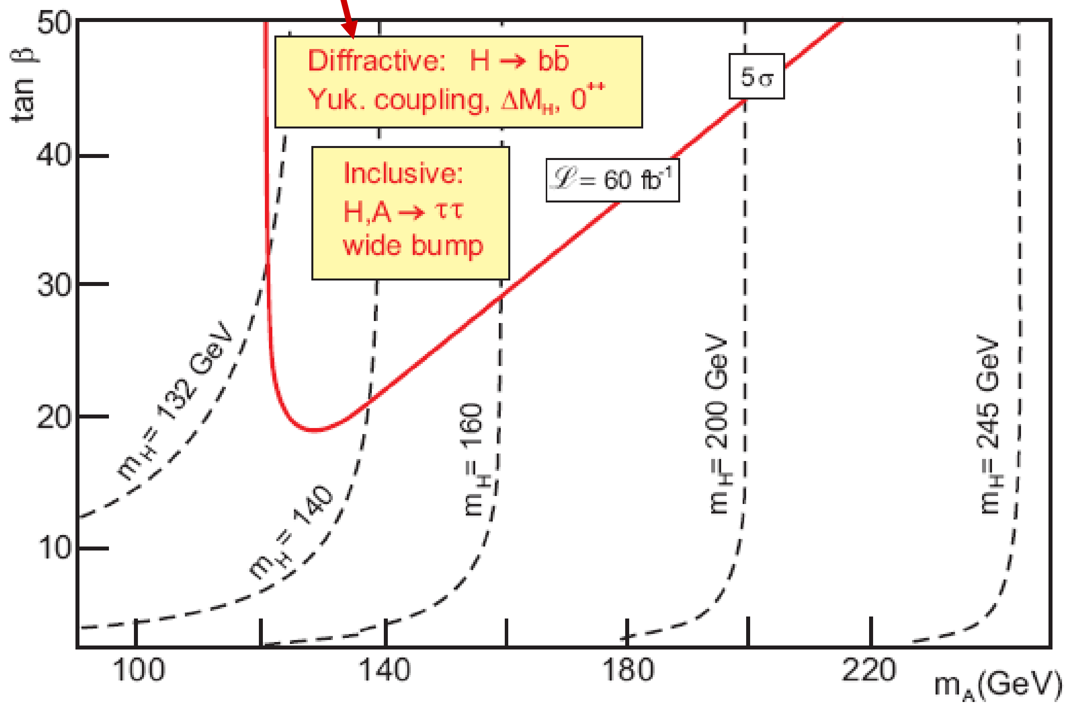
~30 events H→bb

~5 events H→WW (leptonic modes)

MSSM Higgs exclusive production at LHC

For high tan(β) the WW channel is suppressed by H→bb, but the cross section is enhanced.

- need for clean environment to isolate b-jets   exclusive production
  - possibility to separate A and H,h bosons (A is suppressed in DPE)
    - about 1000 proton tagged events are expected for 30 fb^{-1} luminosity



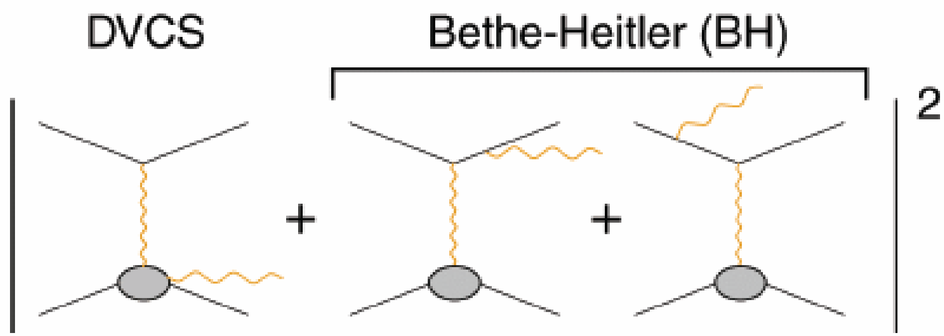
Exclusive H production – discovery channel in certain MSSM scenarios

Summary

- Significant progress in the Experiment and Theory of diffractive processes during last years
- The way to go:
    - Experiment: to make precision measurements (DVCS@high-x, α'@HERA, diffractive exclusive reactions @TEVATRON)
    - Theory: to provide a consistent model for diffraction at all scales
- Diffraction is a powerful instrumental tool in particle physics
- Good luck for FP420 initiative @LHC !

Extraction of GPDs

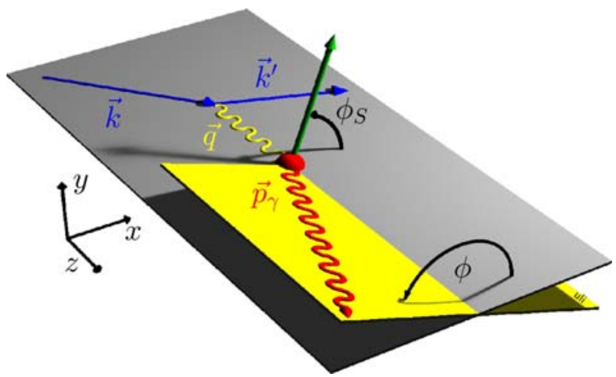
$\sigma(eN \longrightarrow eN\gamma) =$



A

σ_{DVCS} measurement :

$$d\sigma \propto \left|\tau_{DVCS} + \tau_{BH}\right|^2 = \left|\tau_{DVCS}\right|^2 + \left|\tau_{BH}\right|^2 + \left(\tau^*_{DVCS}\tau_{BH} + \tau^*_{BH}\tau_{DVCS}\right)$$

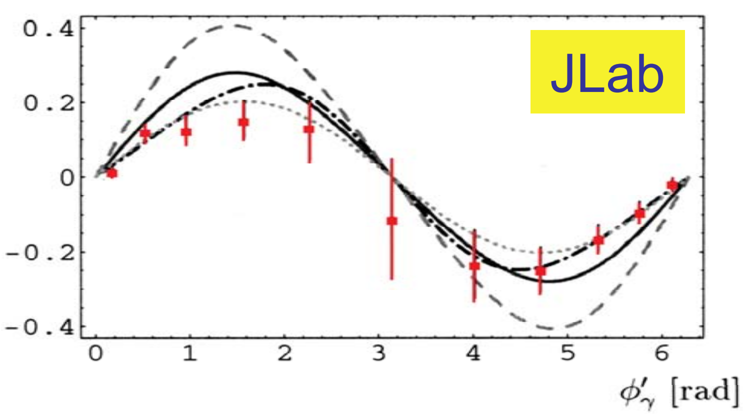


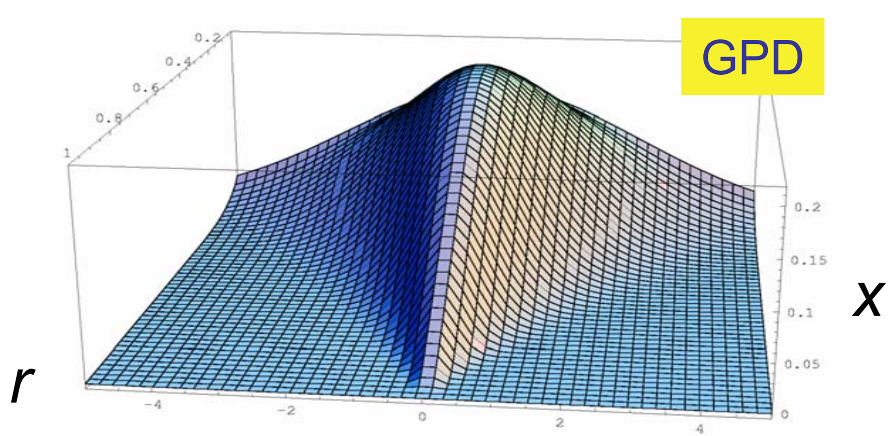
B

Interference term :
azimuthal asymmetry measurement

$$d\sigma_{e^+} - d\sigma_{e^-} \propto \Re(\tau_{DVCS}\tau_{BH})\cos(\varphi_{\gamma^*\gamma})$$

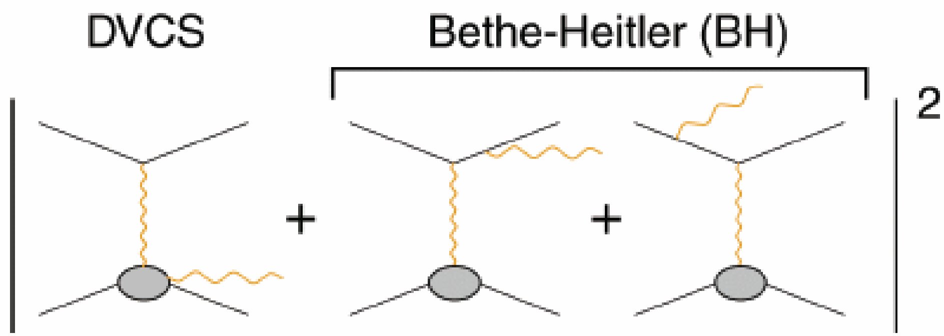
$$d\sigma_{\leftarrow} - d\sigma_{\rightarrow} \propto \Im(\tau_{DVCS}\tau_{BH})\sin(\varphi_{\gamma^*\gamma})$$





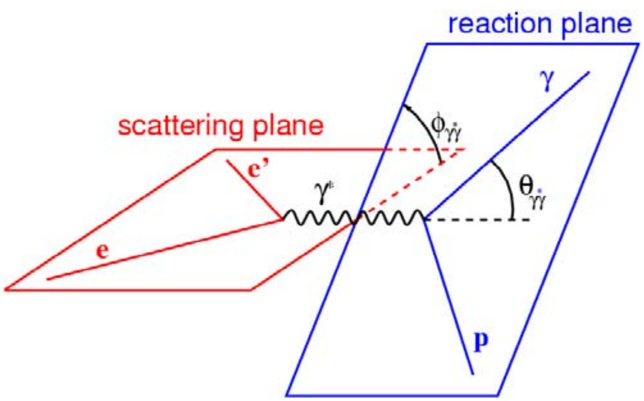
DVCS. Beam Charge Asymmetry at HERA

$\sigma(eN \longrightarrow eN\gamma) =$



σ_{DVCS} measurement :

$$d\sigma \propto \left|\tau_{DVCS} + \tau_{BH}\right|^2 = \left|\tau_{DVCS}\right|^2 + \left|\tau_{BH}\right|^2 + \left(\tau^*_{DVCS}\tau_{BH} + \tau^*_{BH}\tau_{DVCS}\right)$$

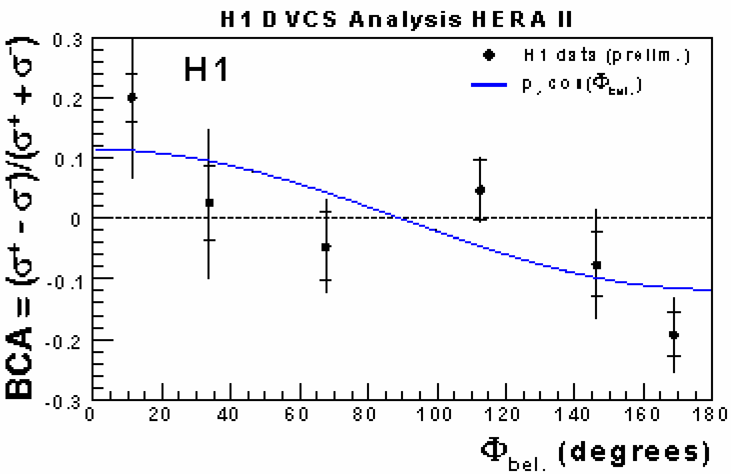


Interference term :
azimuthal asymmetry measurement

$$d\sigma_{e^+} - d\sigma_{e^-} \propto \Re(\tau_{DVCS}\tau_{BH})\cos(\varphi_{\gamma^*\gamma})$$

H1 prelim:

$$BCA = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = (0.17 \pm 0.6)\cdot\cos(\phi)$$



Effective Pomeron Trajectory $\gamma p \rightarrow Vp$

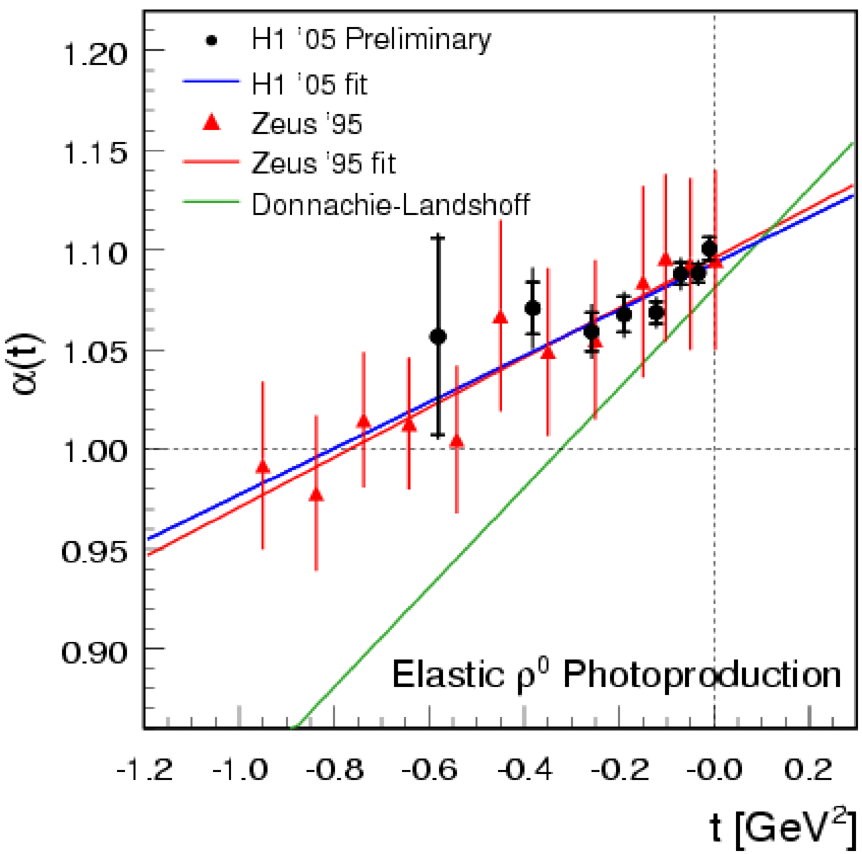
$$\frac{d\sigma}{dt} \propto \exp(b_0 t) \cdot W^{4\alpha(t)-4} \qquad \alpha(t) = \alpha(0) + \alpha' \cdot t$$

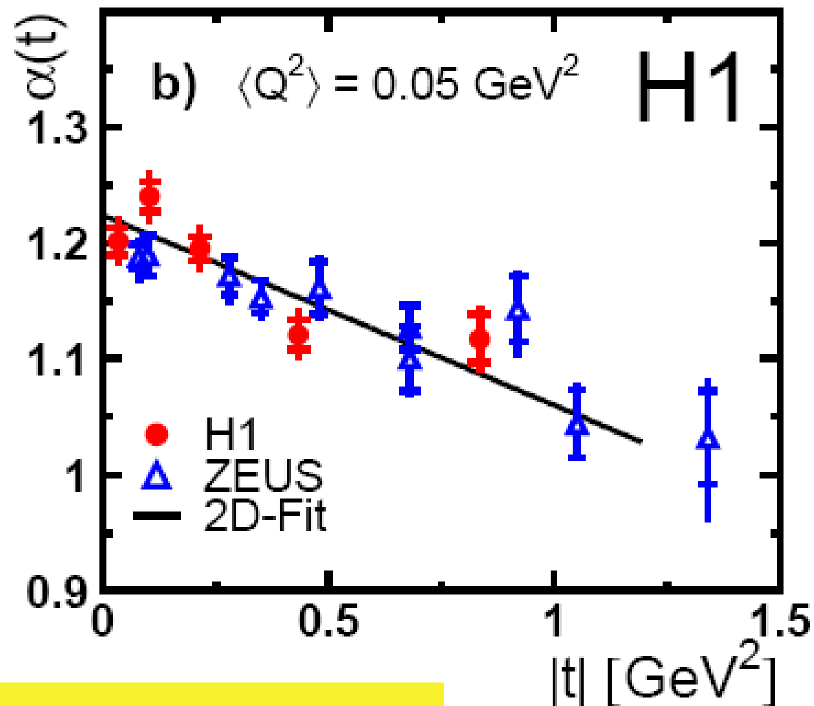
ρ^0

$$\alpha(0) = 1.093 \pm 0.008$$
$$\alpha' \quad = 0.116 \pm 0.05$$

J/Ψ

$$\alpha(0) = 1.224 \pm 0.016$$
$$\alpha' \quad = 0.164 \pm 0.041$$



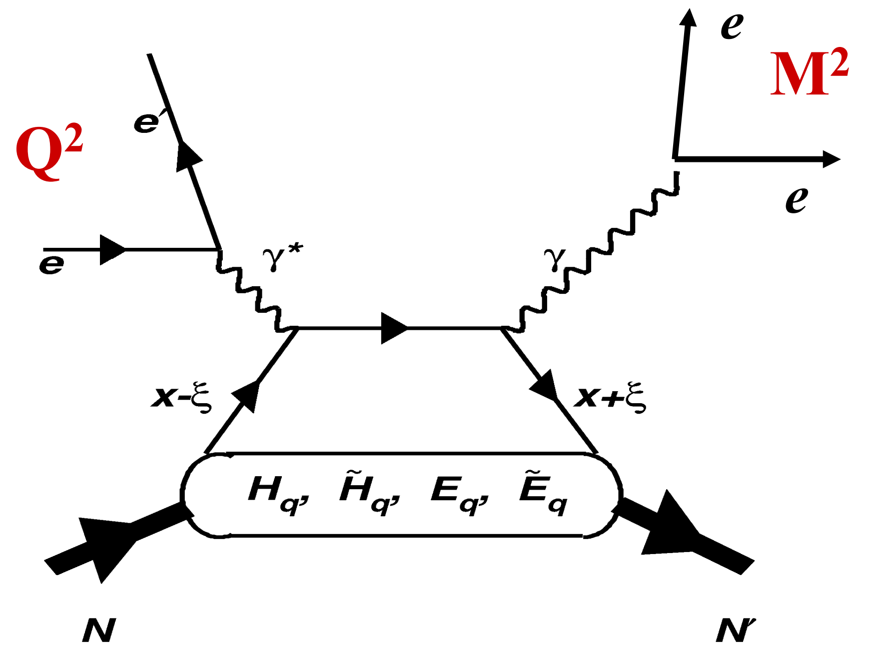


α'(γp) ≈ ½ α'(pp)
α(0)(γp) ≈ α(0)(pp)

Double DVCS

Deep Virtual Photon Lepton Pail Production

$$e + p \rightarrow e' + p + e^{+}e^{-}$$



Scale of the process - $Q^2 + M^2$