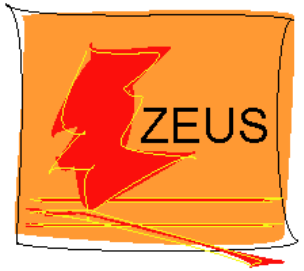


Recent Diffractive Studies at HERA

Dr. Prabhdeep Kaur (SLIET, Longowal)

on behalf of H1 and ZEUS Collaborations

9th International Workshop on Multiple Partonic Interactions at the LHC

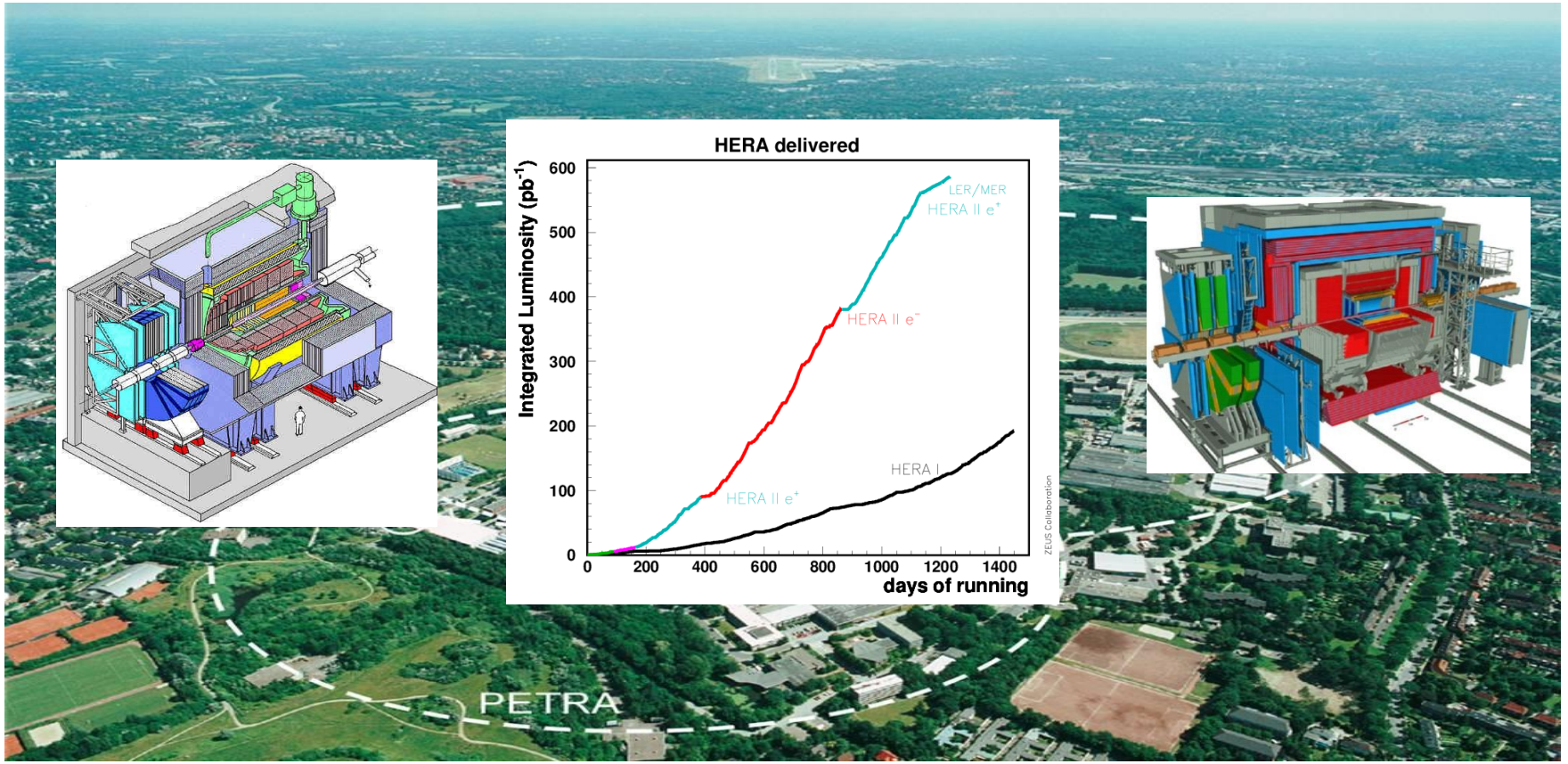
11-15 December 2017 , Hotel Peterhoff, Shimla, India

Outline

- Brief overview of HERA
- Short introduction to diffraction in ep scattering at HERA
- Recent results:
  - D* production in diffractive Deep Inelastic Scattering (DIS) [H1 Collaboration]
  - Ratio of $\sigma_{\psi(2s)}/\sigma_{J/\psi(1S)}$ in diffractive DIS [ZEUS Collaboration]
  - Diffractive photoproduction of Isolated Photons [ZEUS Collaboration]

HERA: ep Collider (1992 – 2007)

- **The world's only electron(positron)-proton** collider at DESY, Hamburg
- **Two collider experiments: H1 and ZEUS**
- **Total luminosity ~ 0.5 fb^{-1} per experiment**



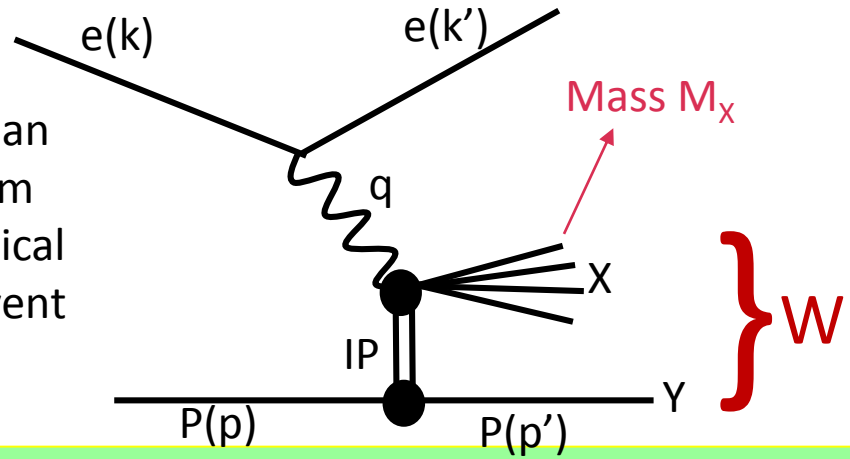
E_{COM}=318 GeV
For the results presented here

- **E_e = 27.6 GeV, E_p=820 GeV** HERA-I , **E_p = 920 GeV HERA-II (**460, 575 GeV**)**

Diffraction at HERA

HERA: ~10% of low-x DIS events are diffractive

Feynman Diagram for typical diff. event



DIS Kinematic variables :

- $Q^2 = -q^2 = -(k-k')^2$: virtuality of the photon
  - $Q^2 \cong 0$ GeV^2 for photoproduction,
  - $Q^2 > 0$ GeV^2 for DIS
- W =photon-proton Centre of Mass Energy
- $x = \frac{Q^2}{2p.q}$ =Bjorken-x: fraction of proton's momentum carried by struck quark
- $y = \frac{p.q}{p.k}$ =inelasticity

Why to study diffraction at HERA?

- **Fundamental aim**:

-To understand high energy limit of QCD (gluon-dynamics)

-To probe partonic structure of diffractive exchange for the first time

- **Practical motivations**:

-To study factorization properties of diffraction – try to transport to **hadron-hadron** scattering (e.g. predict diffractive Higgs production at LHC)

- **Relevance to MPI:** At low Q^2 (photoproduction) there is an **effective hadron-hadron collision** as the photon becomes resolved

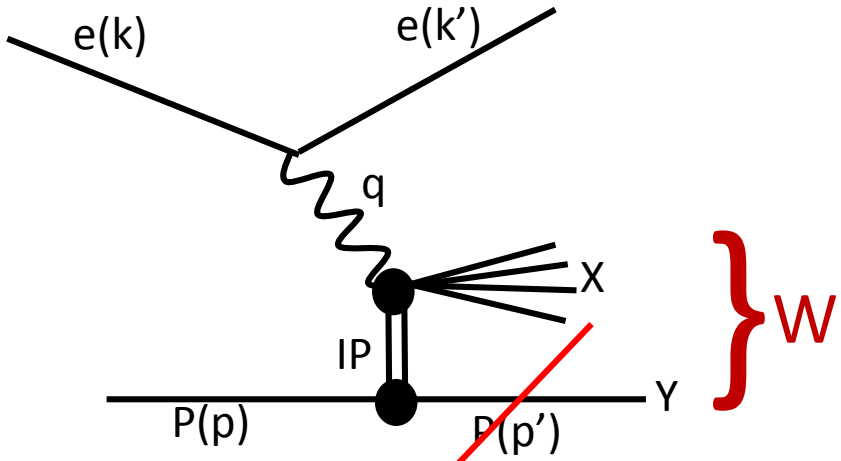
$$x_{IP} = \frac{q\cdot(p-p')}{q\cdot p} \approx \frac{Q^2 + M_X{}^2}{Q^2 + W^2}$$

momentum fraction (of colored or color singlet exchange) w.r.t. proton

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

4-momentum transfer Squared at proton vertex

Kinematic Variables for the Presented Studies



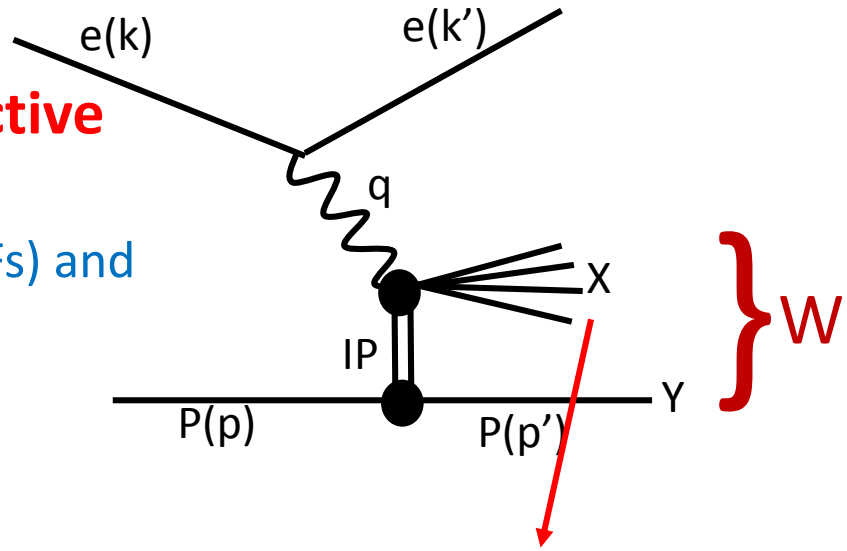
DIS

S.No	Publication	Q^2	X	Y
1.	D* production in DDIS [Eur.Phys.J.C77 (2017), 340]	> 0 GeV^2	D* +anything	P
2.	Diffractive photoproduction of Isolated Photons [Phys. Rev. D 96 (2017) 032006]	$\cong$ 0 GeV^2	γ+jet+anything	P
3.	$\sigma_{\psi(2s)}/\sigma_{J/\psi(1S)}$ in diffractive DIS [Nucl. Phys. B 909 (2016) 934]	> 0 GeV^2	ψ(2s) or J/ψ(1S)	P

Diffraction Predictions for Results Presented

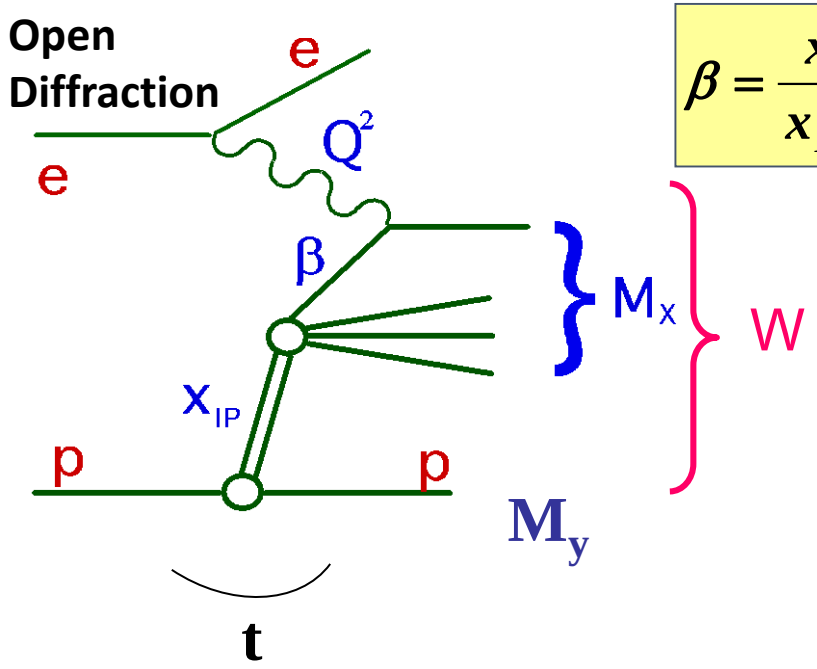
Many methods exist to predict diffractive cross sections:

- Diffractive Parton Density Functions (DPDFs) and hard matrix elements
- Dipole Models
- Regge Phenomenology



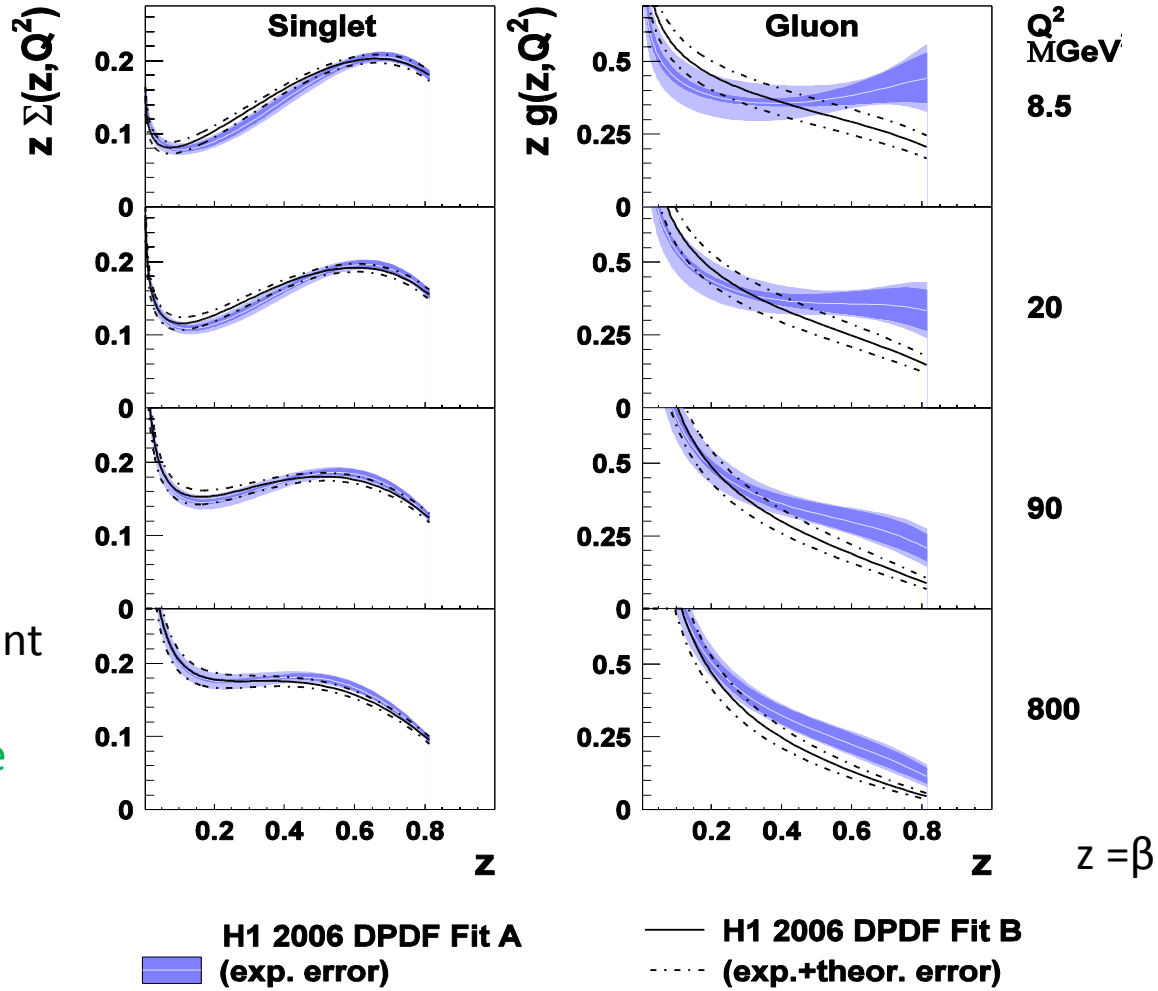
S. No	Publication	Q^2	X	Y	Prediction Model
1.	D* production in DDIS	> 0 GeV^2	D* +anything	P	DPDF +NLO MC
2.	Diffractive photoproduction of Isolated Photons	≅ 0 GeV^2	γ+jet+anything	P	DPDF+LO MC
3.	$\sigma_{\psi(2s)}/\sigma_{J/\psi(1S)}$ in diffractive DIS	> 0 GeV^2	$\psi(2s)$ or $J/\psi(1S)$	P	Dipole Models

Diffractive Parton Densities



$$\beta = \frac{x}{x_{IP}} \approx \frac{Q^2}{Q^2 + M_X^2}$$

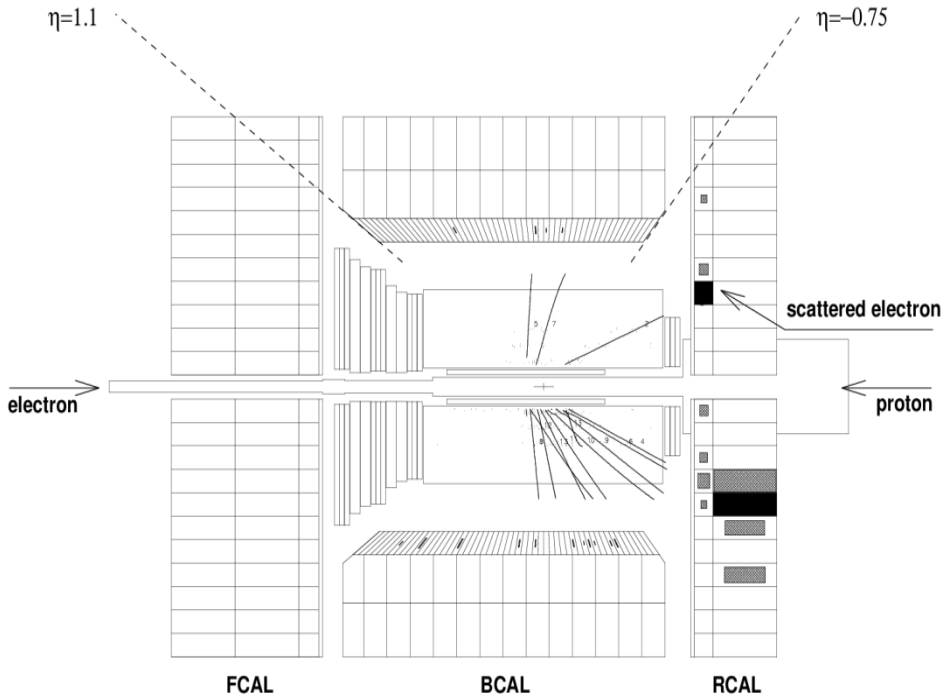
fraction of exchange momentum, carried by the parton "seen" by photon

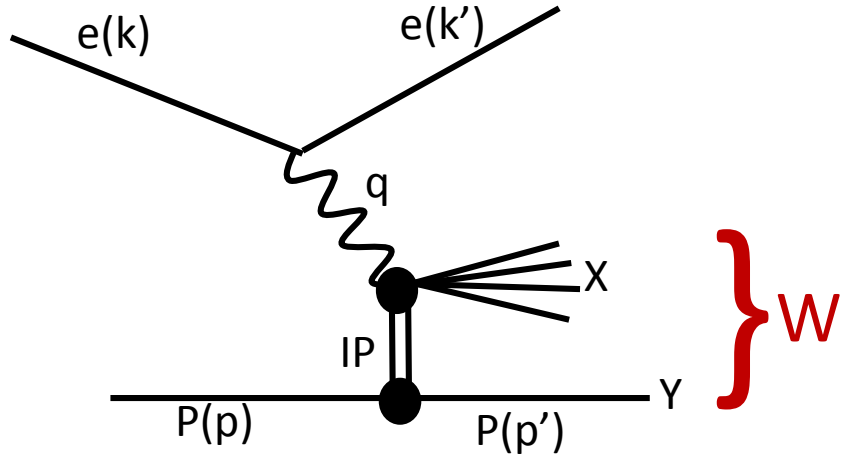


- Diffractive PDFs: extracted by QCD fit through slope of scaling violations
- DPDFs dominated by gluons, but a significant quark content may also be present (singlet part)
- Gluon densities have large uncertainties in shape, and are used in **theoretical predictions compared to the results** shown later in this talk

Eur.Phys.J.C48 (2006) 715-748

Experimental Methods

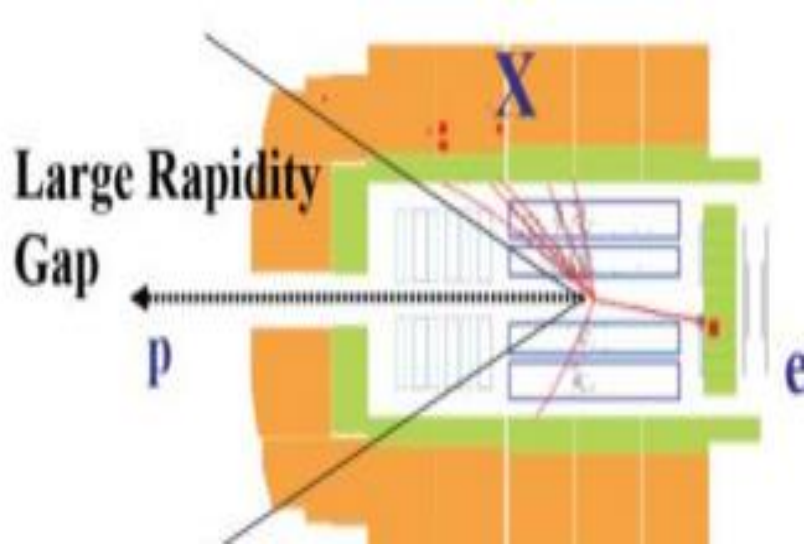




- Diffractive events at HERA are characterised by a Large Rapidity Gap in X and Y.

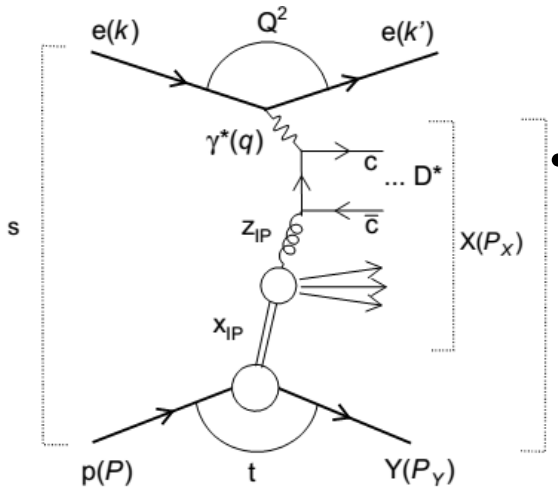
•May contain proton dissociative background
-(could be estimated by proton spectrometer)

•High statistics

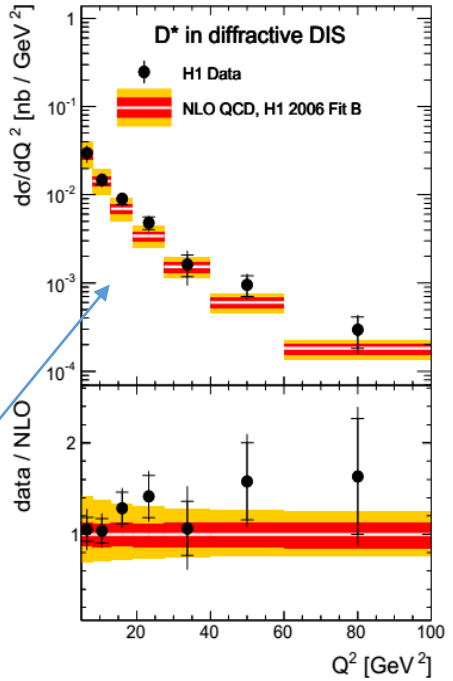


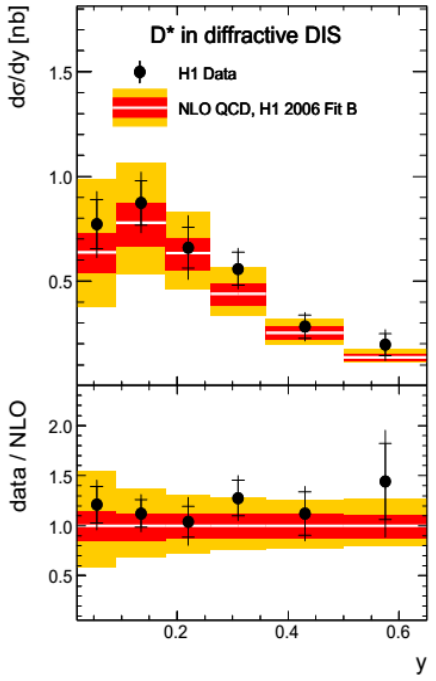
H1 event display

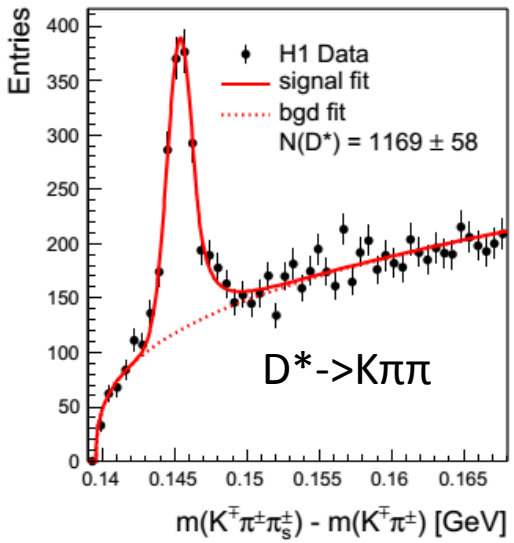
D* Production in Diffractive DIS



- D*: charm quark fragmentation
  - "c" produced via boson-gluon fusion
  - process is sensitive to gluons

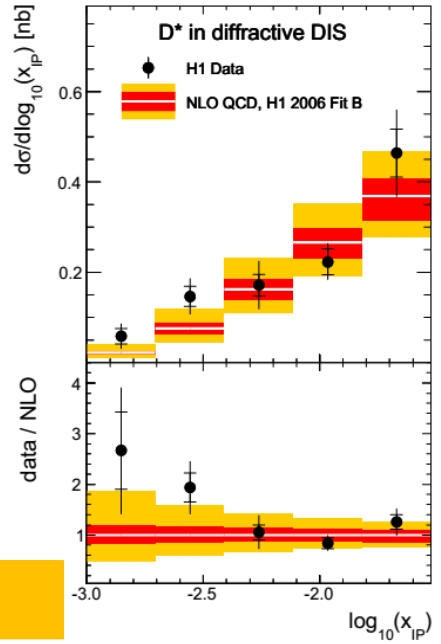


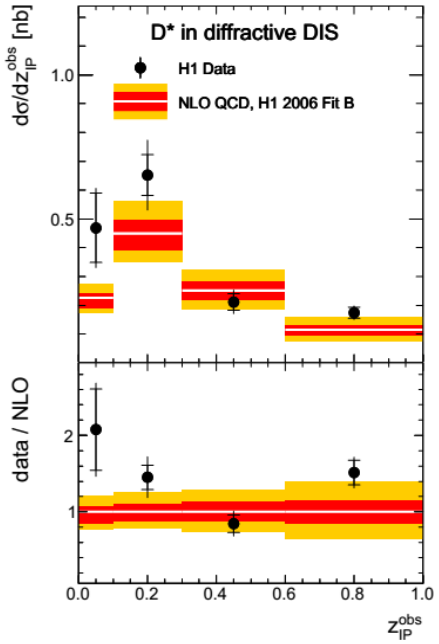




Theory predictions include:
DPDFs(determined from inclusive diffraction data)
+ massive NLO matrix elements for charm production
+ D* fragmentation function

Fair agreement

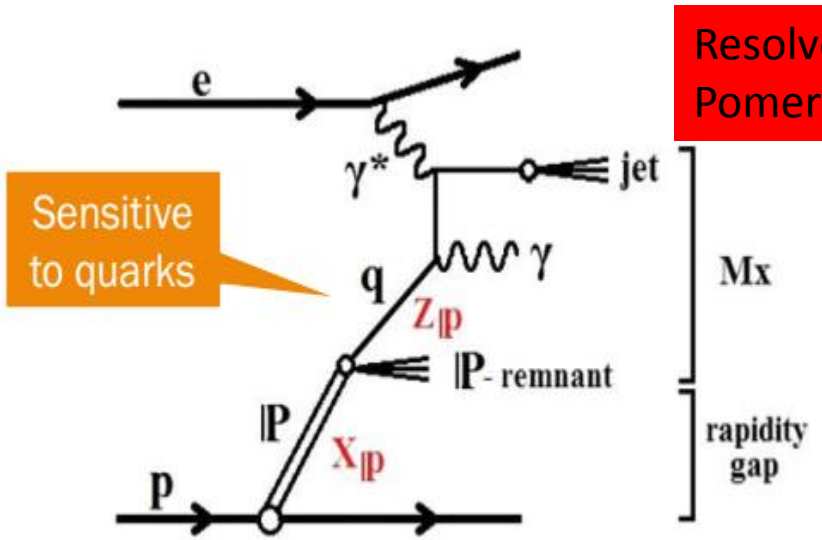




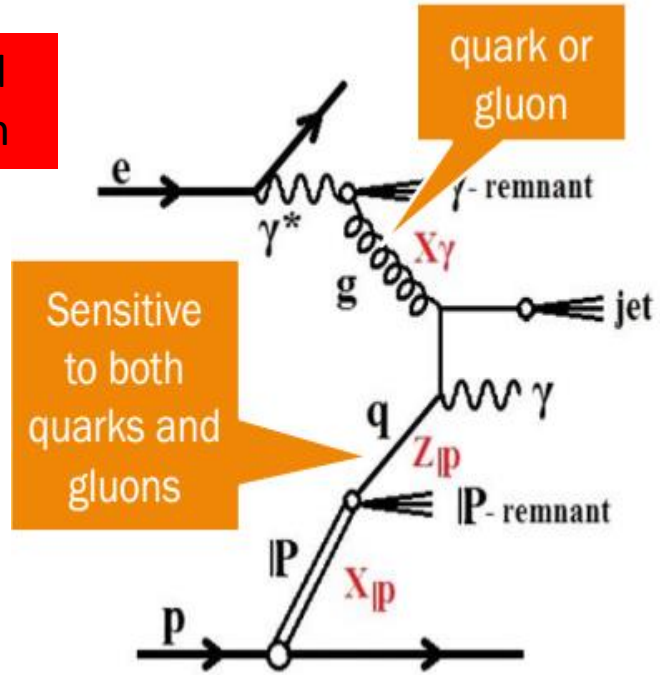
Data consistent with factorisation in diffractive DIS

Isolated Photon in Diffractive Photoproduction

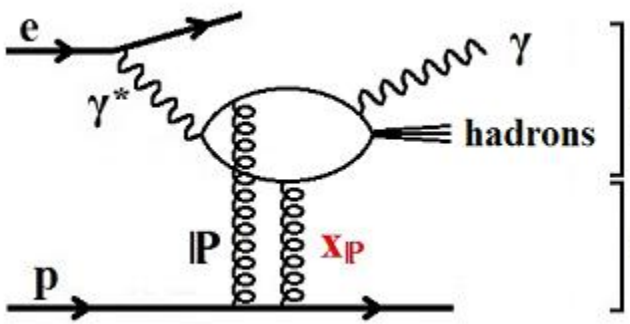
Direct photoproduction



Resolved photoproduction
(absorptive effects may be present)



Resolved Pomeron



Direct Photon and Pomeron

Prompt (hard isolated) photon, from a charged parton emitted =>

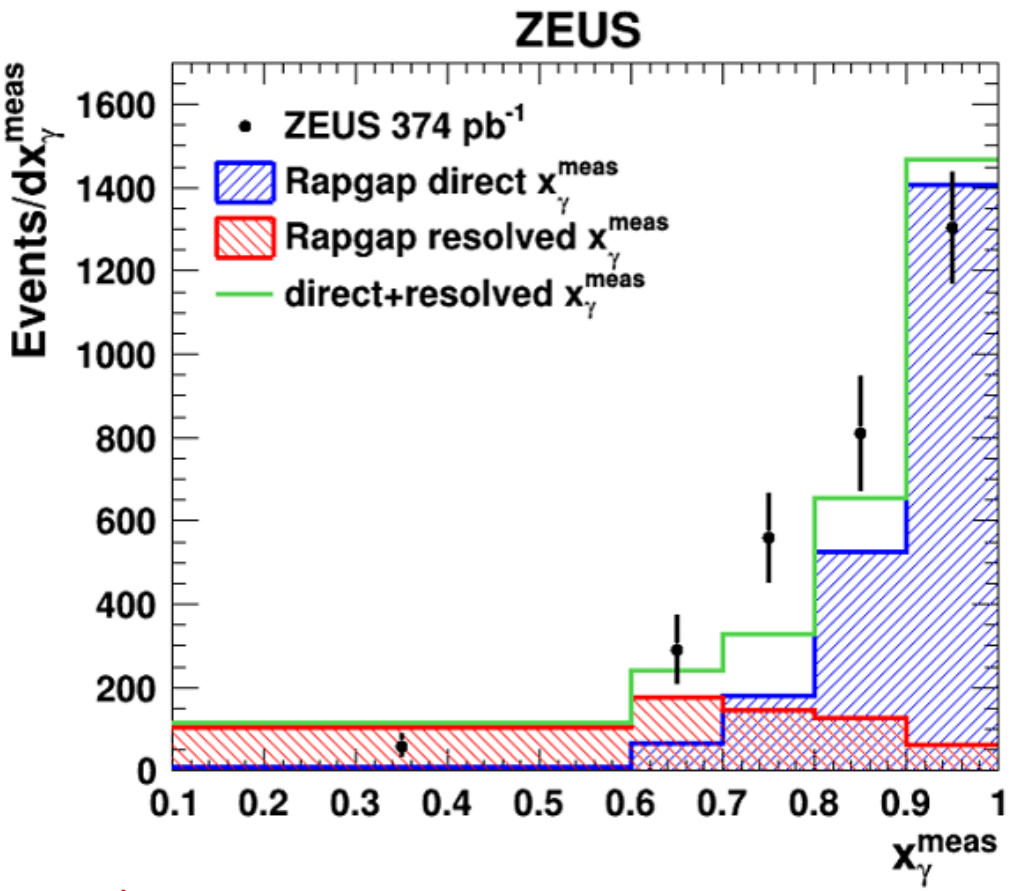
- Either quark/anti-quark are present in Pomeron
- Or higher order processes in which both Pomeron and photon couple to quarks.

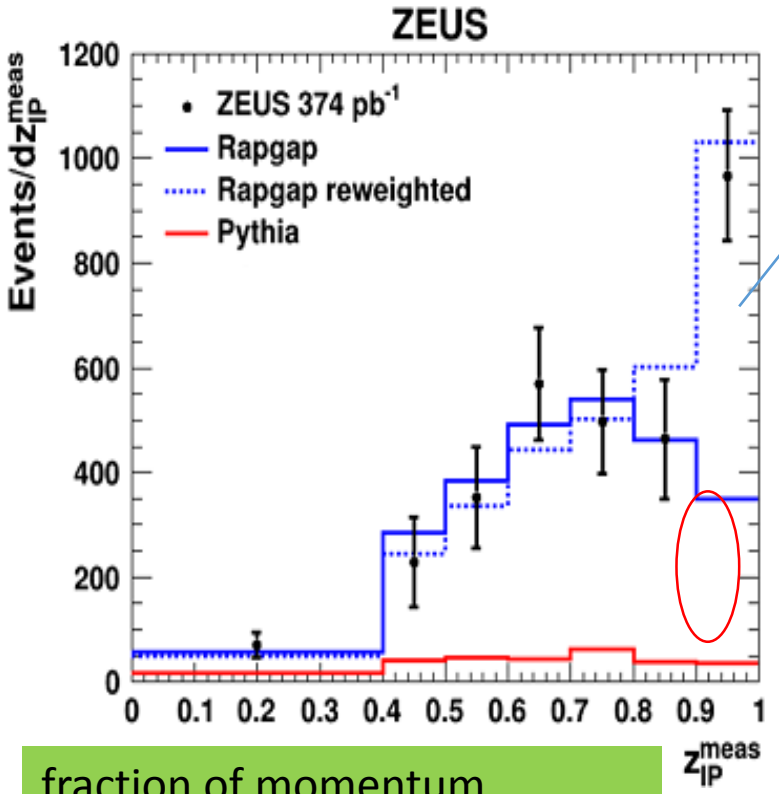
$$x_\gamma^{\mathrm{meas}} = \frac{E^\gamma + E^{\mathrm{jet}} - p_Z^\gamma - p_Z^{\mathrm{jet}}}{E^{\mathrm{all}} - p_Z^{\mathrm{all}}},$$

$$x_{I\!P} = (E^{\mathrm{all}} + p_Z^{\mathrm{all}})/2E_p.$$

$$z_{I\!P}^{\mathrm{meas}} = \frac{E^\gamma + E^{\mathrm{jet}} + p_Z^\gamma + p_Z^{\mathrm{jet}}}{E^{\mathrm{all}} + p_Z^{\mathrm{all}}},$$

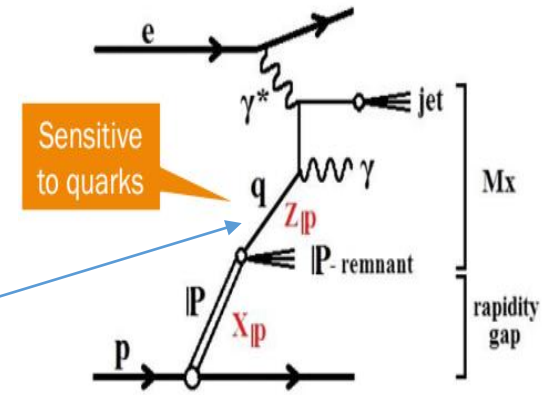
Data Vs MC Predictions: x_γ and z_{IP} spectrum





Data shows a Peak near unity (z_{IP}>0.9),

fraction of momentum, carried by the parton "seen" by direct or resolved photon



- Prediction: RAPGAP LO MC

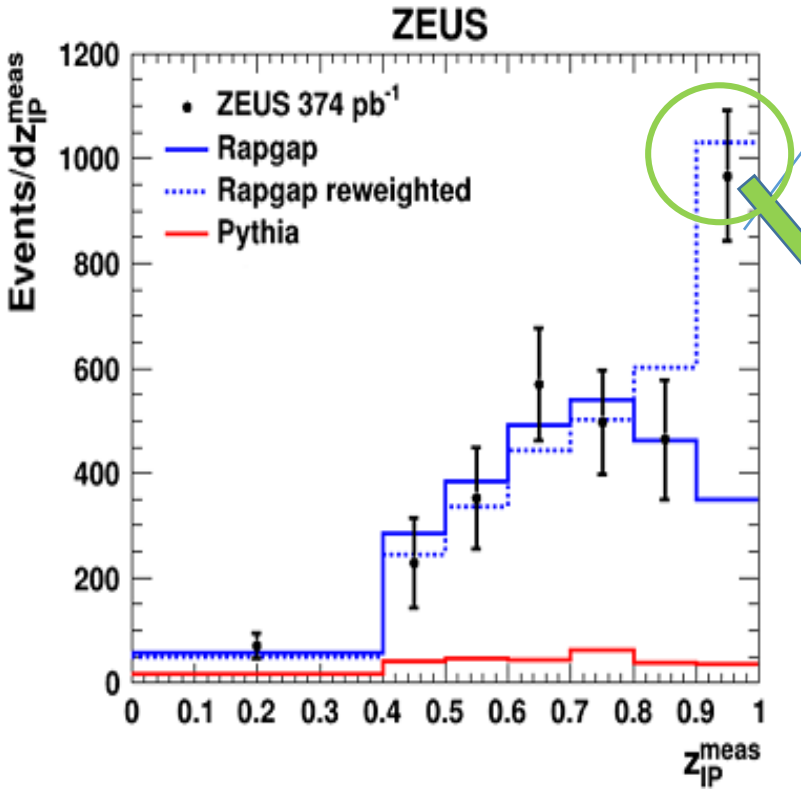
-with LO photon PDF (SaSG 1D) and **DPDF (H1 2006 Fit B)**

- **Resolved:Direct photon = 30:70** to describe the data

(default RAPGAP predicts higher resolved fraction)

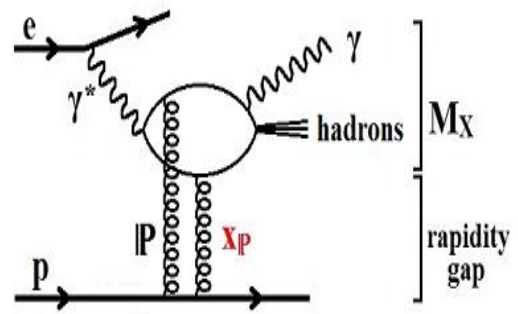
- For z_{IP}>0.9, measurements made **for the first time in inclusive diffraction**
- DPDFs used are **determined only for z_{IP}<0.8**
- For predictions in the region z_{IP}>0.8, DPDFs were **extrapolated in RAPGAP** on basis of resolved pomeron model.

z_{IP} Spectrum: Re-weighting Direct Vs Resolved Component

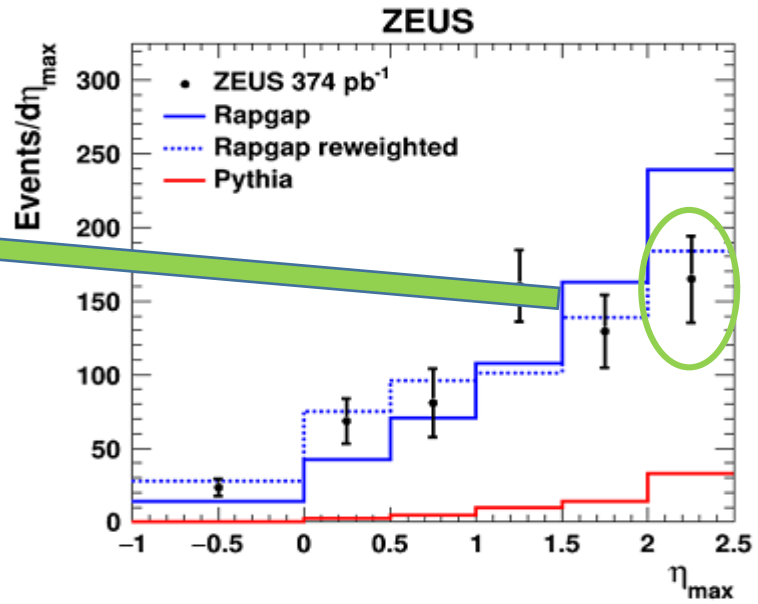


Peak near unity

- no background source identified
- "Super-hard" component in Pomeron?
- RAPGAP was reweighted for additional (7%) direct component of photon, which describes the data well, which supports direct photon and Pomeron interaction

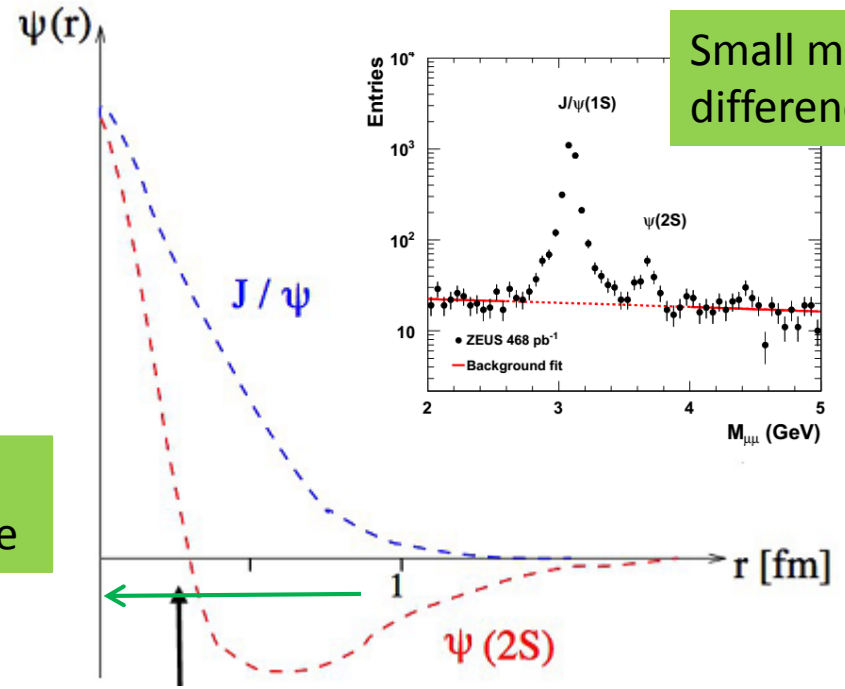


Good agreement between data and predictions after MC additional re-weighting for direct process



Ratio of $\sigma_{\psi(2s)}/\sigma_{J/\psi(1S)}$ in Diffractive DIS

ψ(2s) & J/ψ(1S) have same quark content (c ,cbar), but different radial distributions of the wave functions:

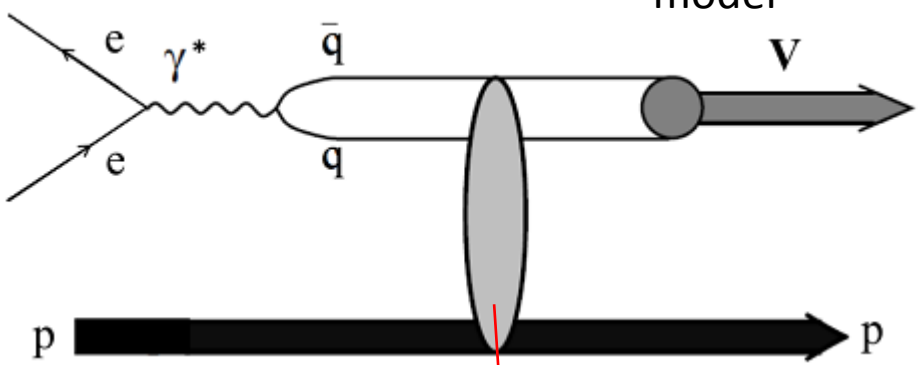


Small mass difference

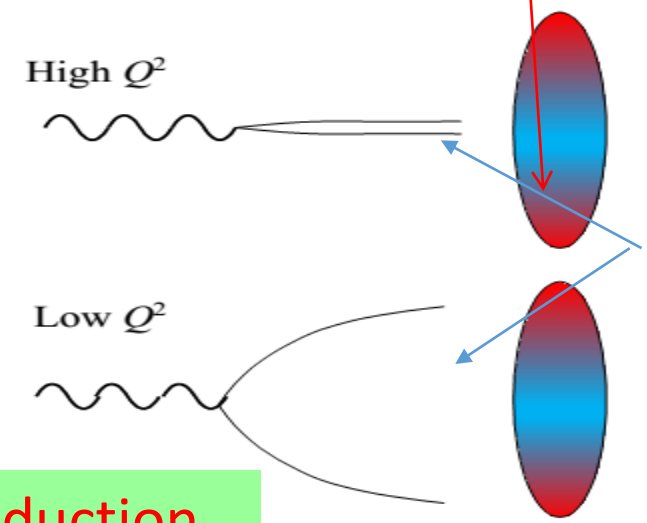
DIS Regime

Node at r ~ 0.35 fm

Predicted by dipole model



q,qbar interact with proton via a color neutral exchange e.g. g-g ladder

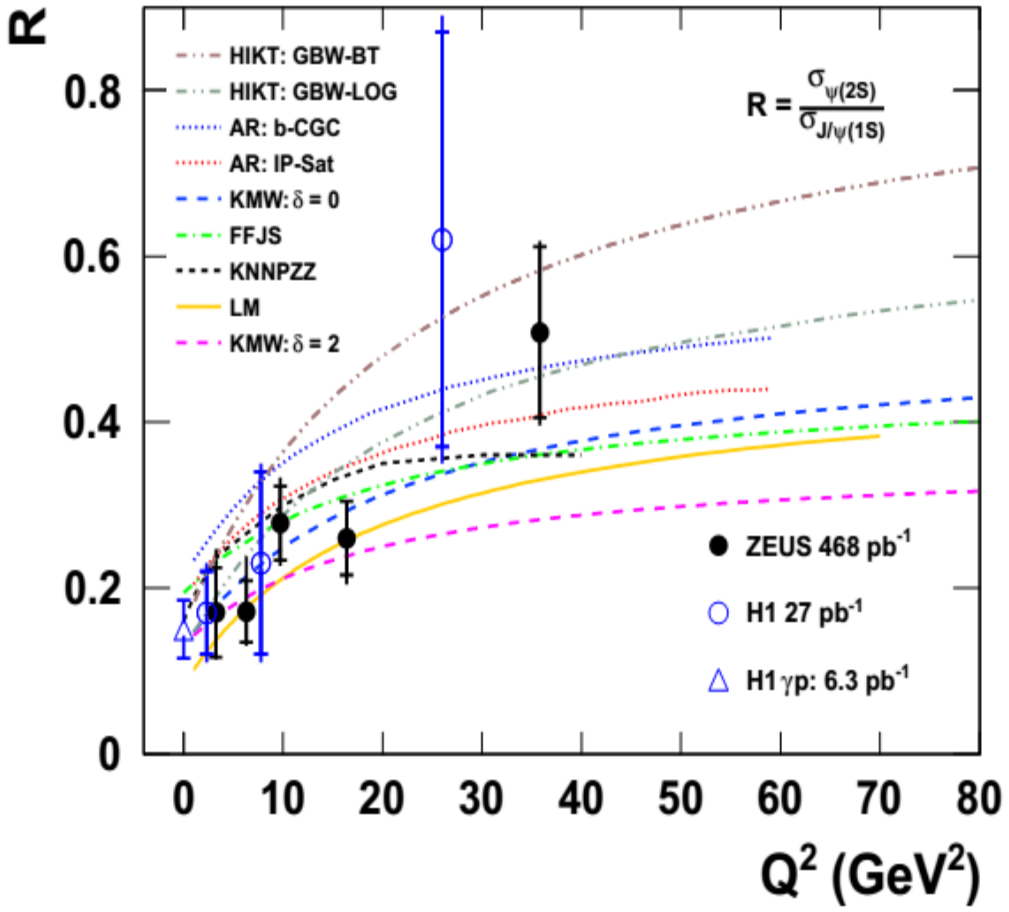


Dipole Model

Photon (or $q\bar{q}$) "transverse size"
– Small for high-Q^2 DIS $\ll$ 1fm
- Large for photoproduction O(1fm)

Prediction: the ratio of psi to j/psi production cross section (R) increases with Q^2

Mass Distribution and R Vs Q^2



Steep increase in R with Q^2 from photoproduction to DIS regime

- Measured R is compared to:

-- previous H1 Results: both are in good agreement

-- various theoretical predictions of QCD inspired models of exclusive vector-meson production

- Models with very slow increase in R with Q^2 are not favoured

Summary

- D* in DIS:

➢ Diffractive factorisation in DIS further supported

- Jet + direct γ in photoproduction:

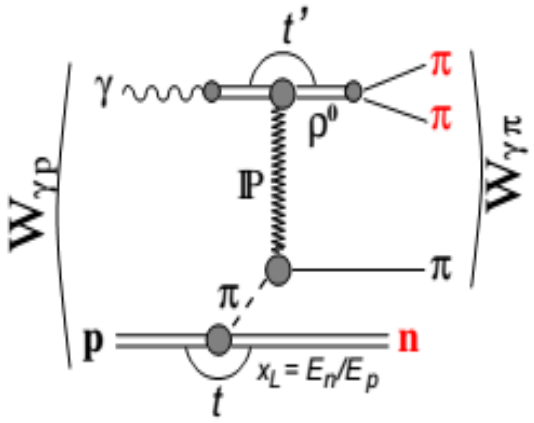
➢ Hard (quark) component in diffraction (?)

- ψ(2s), J/ψ(1S) production:

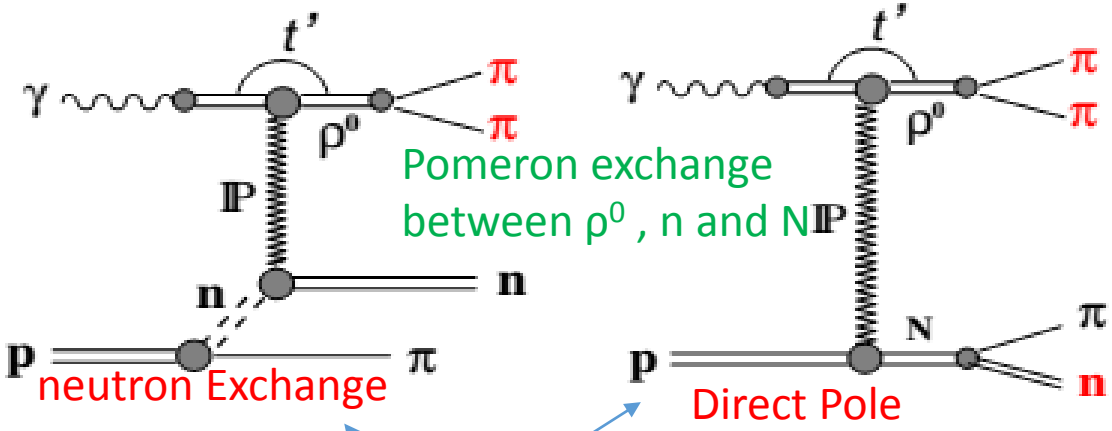
➢ Insight to charmonium production

THANKS !!

ρ^0 Photoproduction with a Leading Neutron



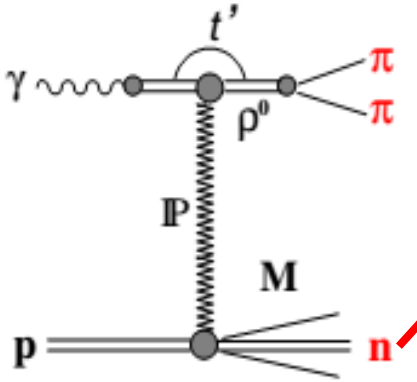
One pion Exchange (OPE)
dominant for large x_L



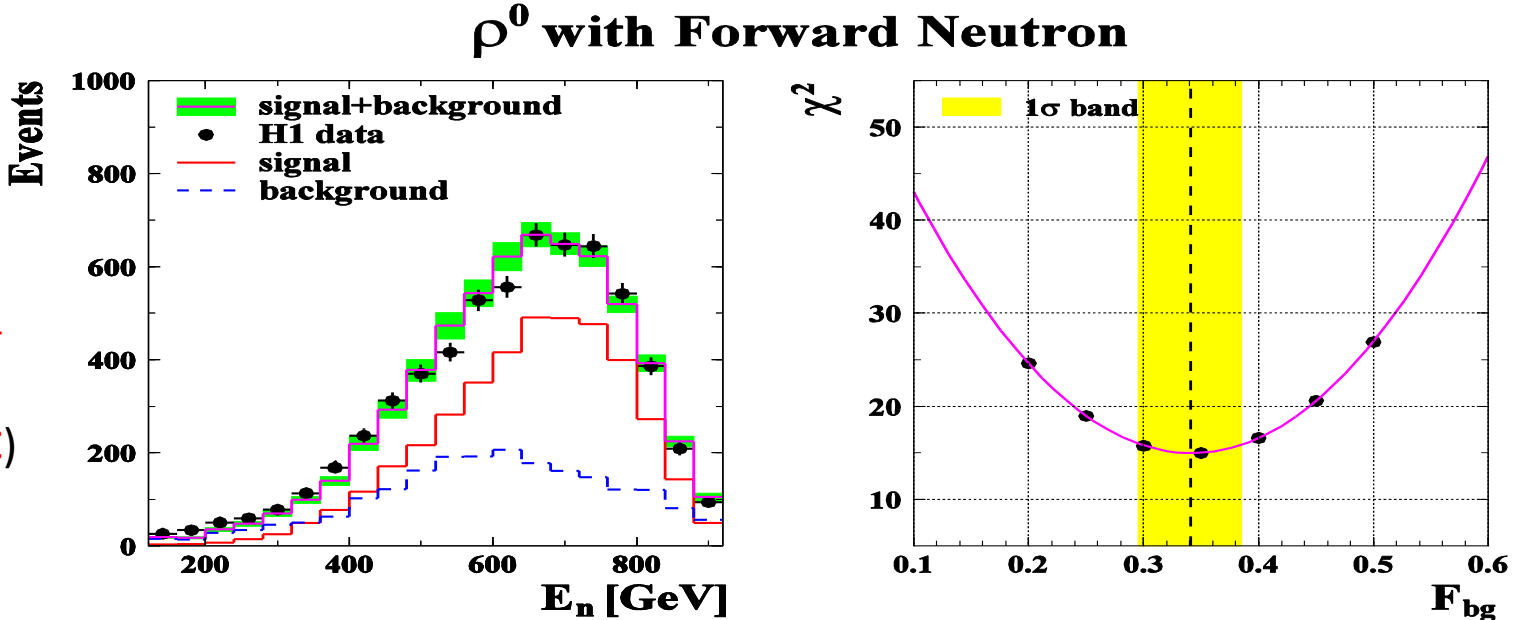
Pomeron exchange
between ρ^0 , n and N

at small t, cancel each other (scattering amplitude same in mag. But opp. In sign)

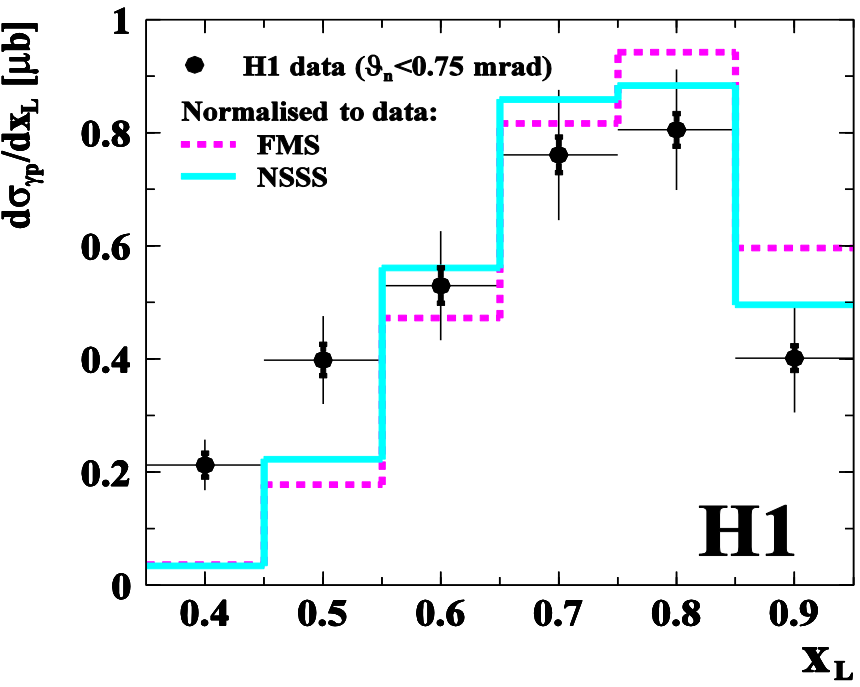
γp-> ρ^0 π^+ n, π^+->undetected
=>BG from other type of events
with leading neutron, eg. Proton dissociation

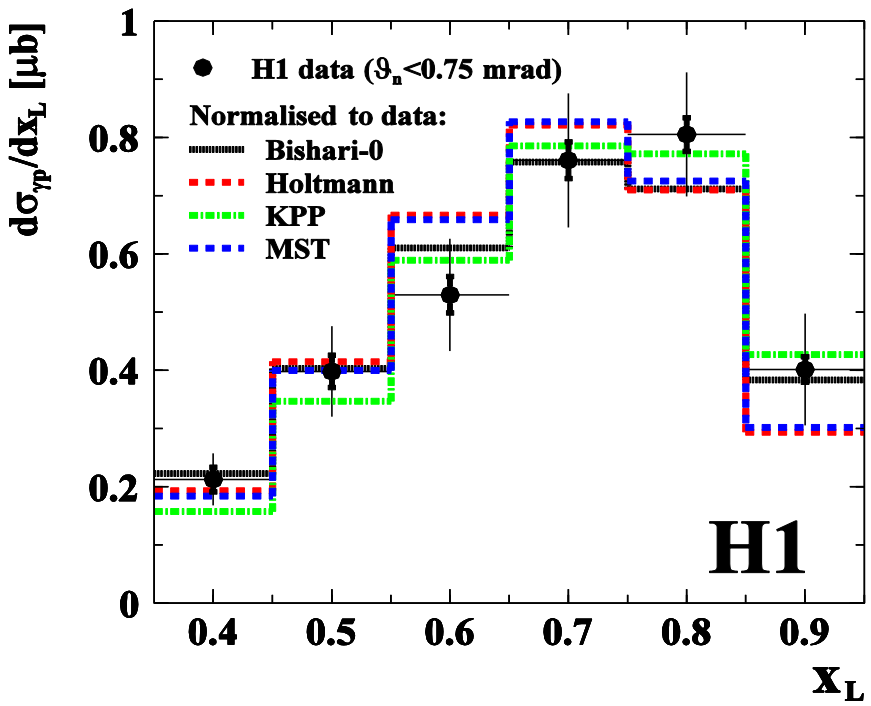


detected in zero-degree calorimeter (FNC)



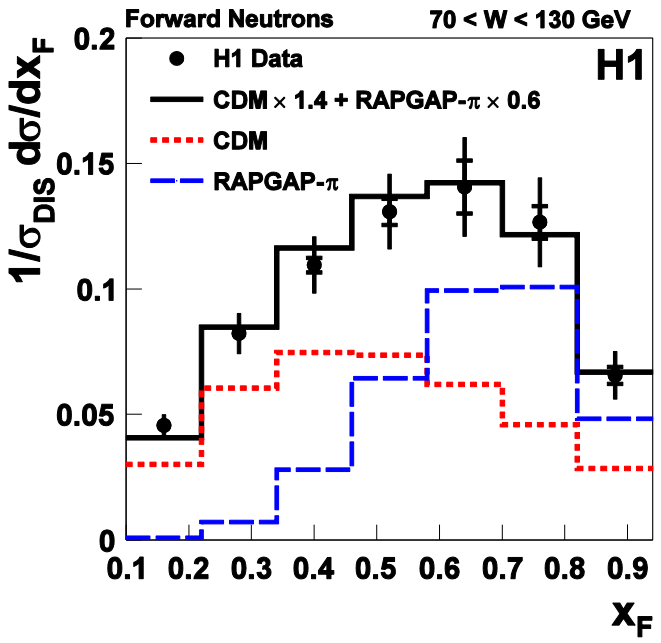
ρ^0+n: γp Cross Sections





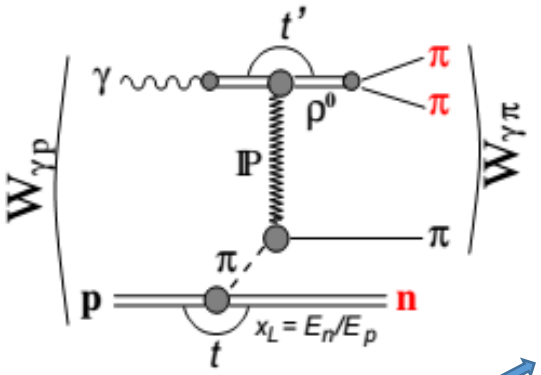
Present analysis
$0.35<x_L<0.95$
$t'<1GeV^2$

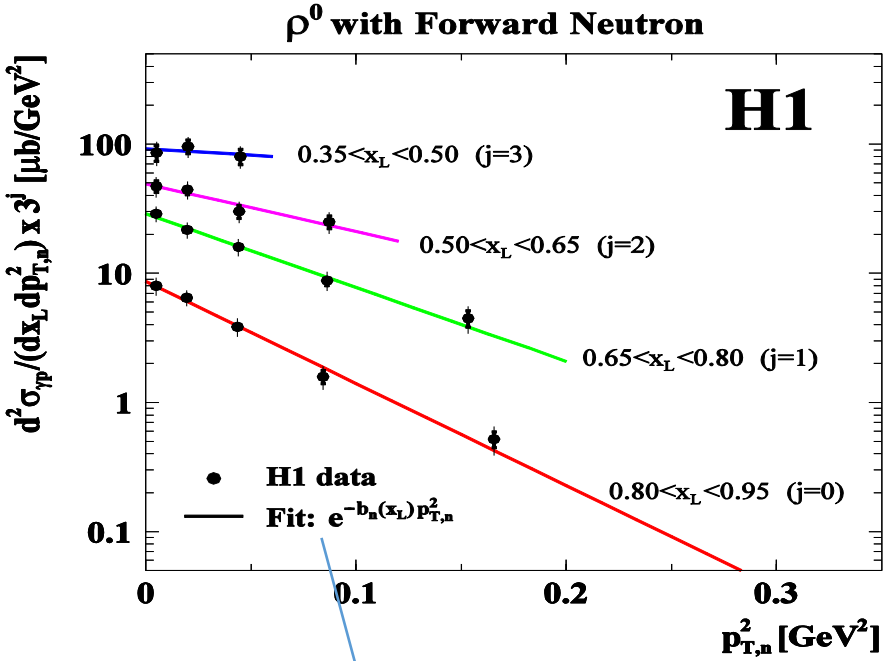
DESY-14-035



- Similar shape **as the inclusive neutron**
  - **supports factorisation** at proton-neutron vertex
- Well described by many of models
  - except for FMS and NSSS

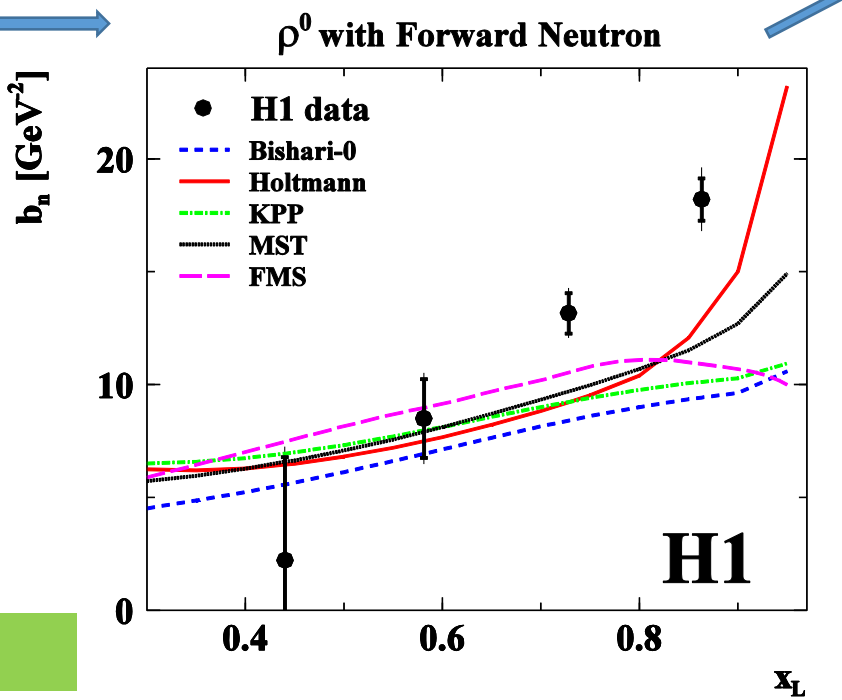
ρ^0+n: t-Slope Measurement





$P_{T,n}^2 = -t$

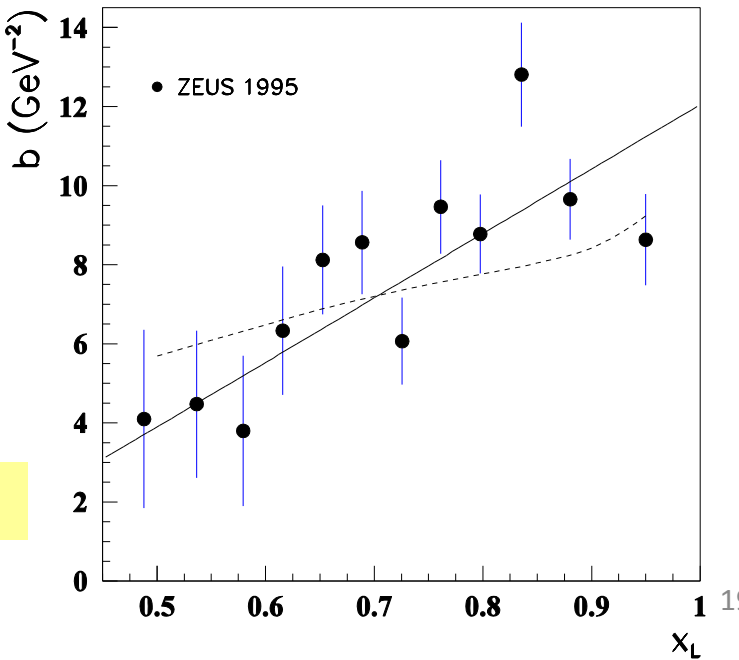
Fit function used for each $x_L = \exp(-b_n . P_{T,n}^2)$



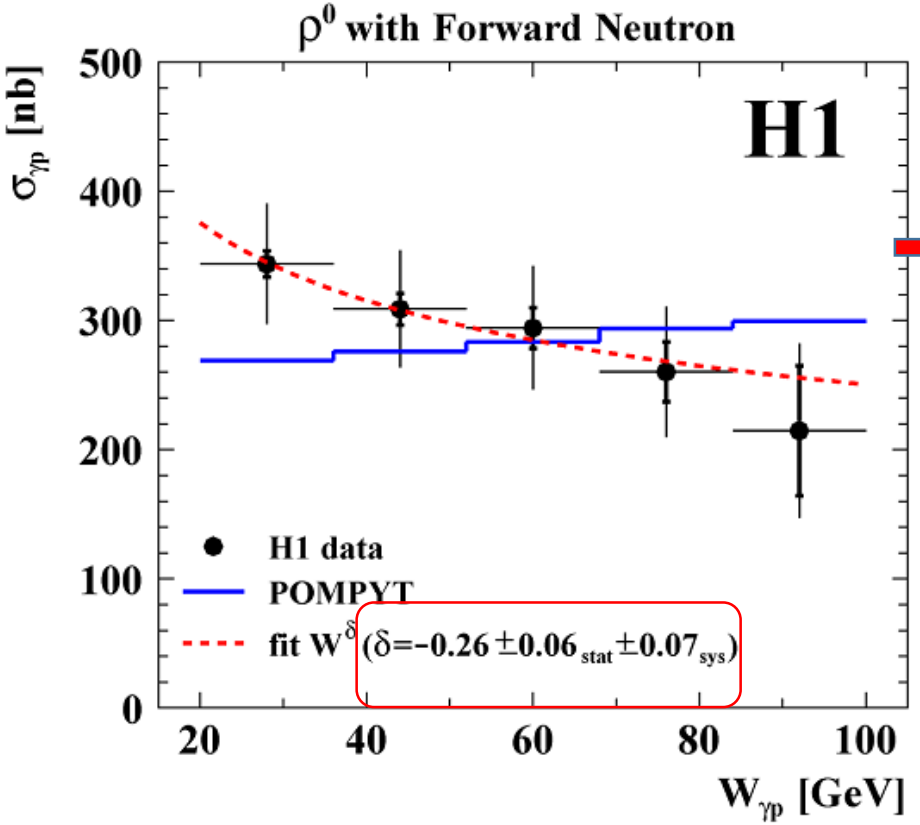
Impact parameter =2b . $(hc/2\pi)^2$

Data has high b parameter at very high x_L

Similar behaviour but less pronounced steepness for inclusive leading neutron production (DESY-02-039)

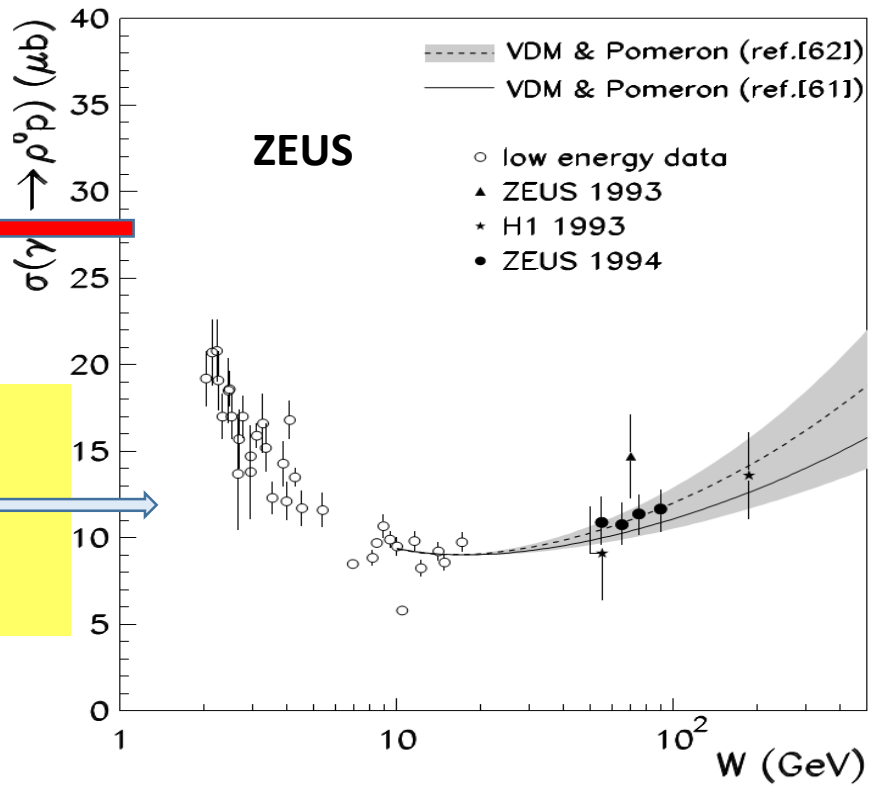


ρ^0+n: Energy$_{(\gamma p)}$ Dependence of Cross Section



Different behaviour

DESY 97-237(elastic and proton dissociative ρ^0 photoproduction



- In POMPYT energy dependence is driven by Pomeron exchange only
- Fit ----- is Regge Motivated power law

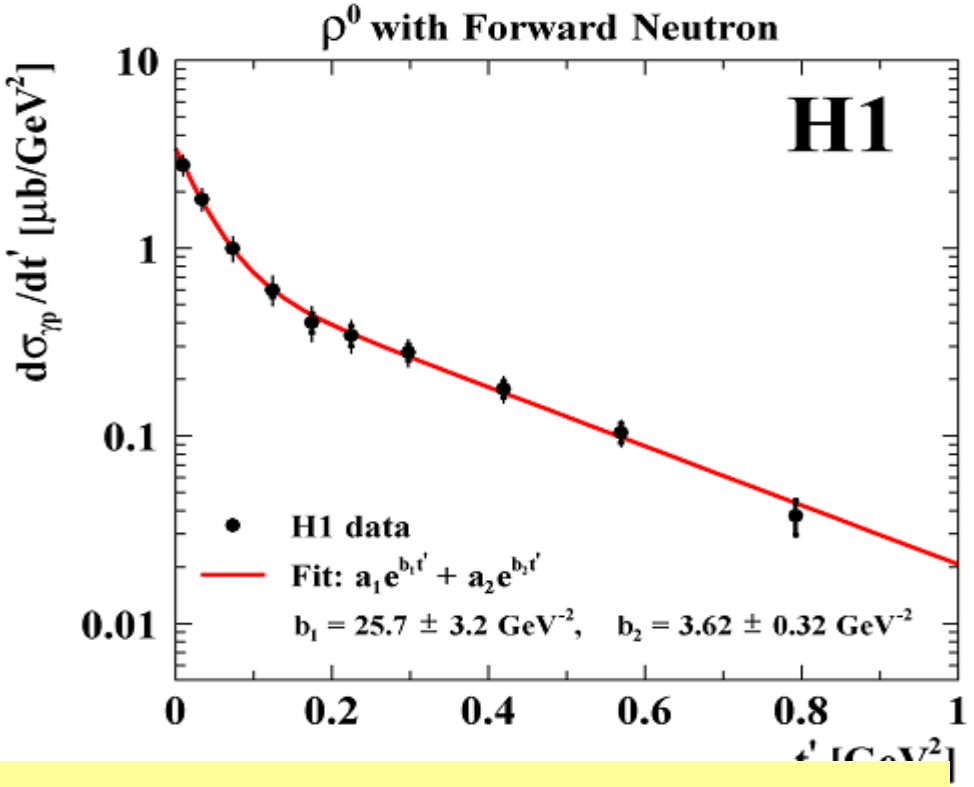
$r_{el}=\sigma_{el}^{\gamma\pi}/\sigma_{el}^{\gamma p} \cong 0.25$ at <W>=24 GeV

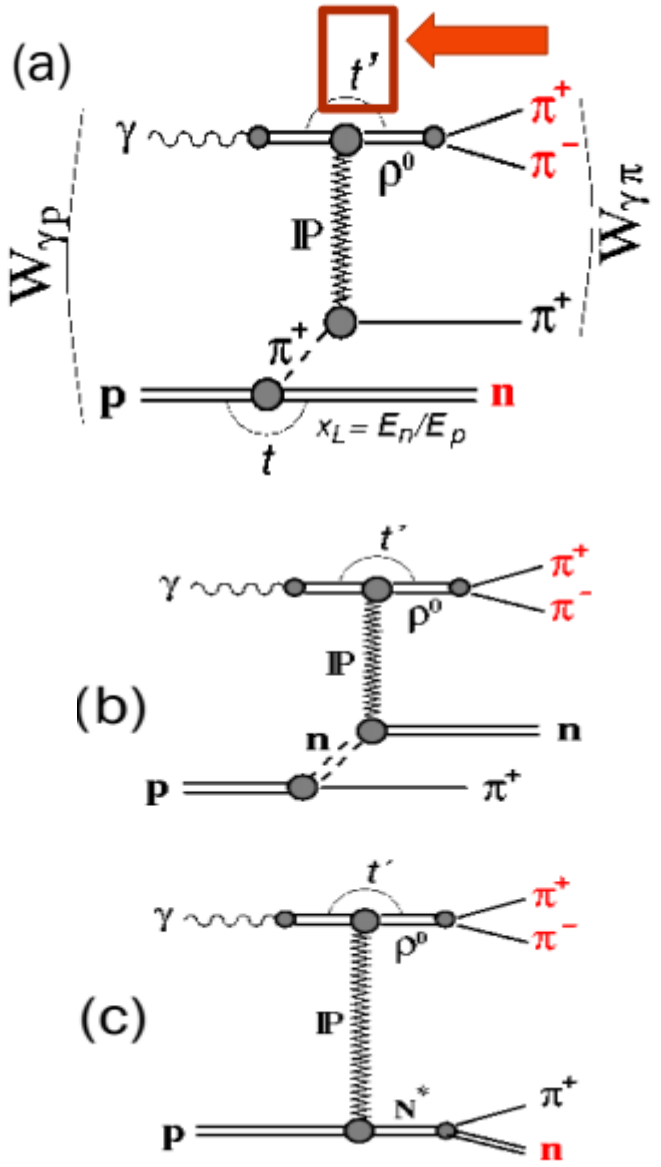
$r_{tot}=\sigma_{tot}^{\gamma\pi}/\sigma_{tot}^{\gamma p} \cong 0.32$ at <W>=107 GeV (DESY-02-039)

– smaller than additive quark model ($\simeq 0.6$)

– May be attributed to absorption/rescattering

ρ^0+n: t' Dependence of Cross Section





b1≅25.7

- impact parameter ≅ (1.6 R_p)^2
- Very peripheral scattering, hinting at:

- change of slope is due to interference between various diagrams (a),(b),(c) according to double-peripheral process (π, IP)
- "Pion dissociation" component?

$\rho^0 + n$: diffractive “γ π” scattering

- Factorisation between γ and proton vertex is supported
- One-pion exchange describes most of the feature of the data
- Hints at absorption effects

Factorisation

- QCD factorisation

$$\sigma^D(\gamma^* p \to X p) \sim f_i^D(x, Q^2, x_{IP}, t) \cdot \sigma_{\gamma^* i}(x, Q^2)$$

DPDFs – obey DGLAP, universal for diff. ep DIS

hard scattering cross section

- Proton vertex factorisation - conjecture

$$f_i^D(x, Q^2, x_{IP}, t) \sim f_{IP/p}(x_{IP}, t) f_{i/IP}^D(\beta, Q^2)$$

pomeron flux factor

pomeron PDF

Outline

- D* production in diffractive Deep Inelastic Scattering (DIS) [H1 Collaboration]
- (287 pb^{-1}) ($5<Q^2<100$ GeV^2)

- Ratio of $\sigma_{\psi(2s)}/\sigma_{J/\psi(1S)}$ in diffractive DIS [ZEUS Collaboration] (114 pb^{-1})
- ($2<Q^2<80$ GeV^2, $30<W<210$ GeV) (HERAI and II)

- Diffractive photoproduction of Isolated Photons [ZEUS Collaboration]
- (456 pb^{-1})

-1.5 <Eta jet<1.8