Inclusive diffraction and leading baryons at HERA

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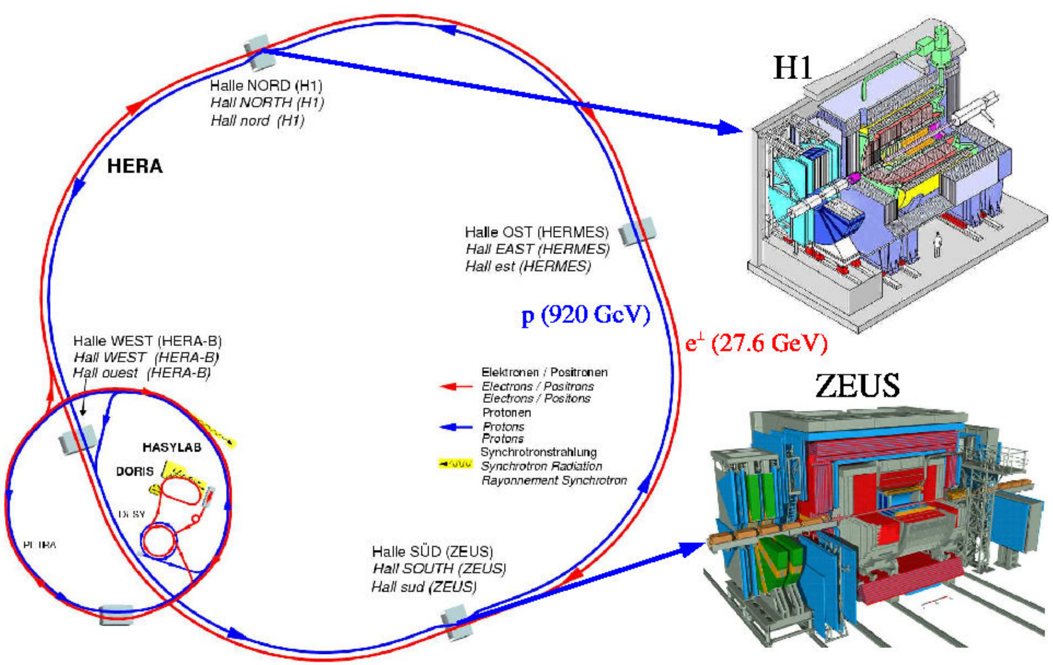
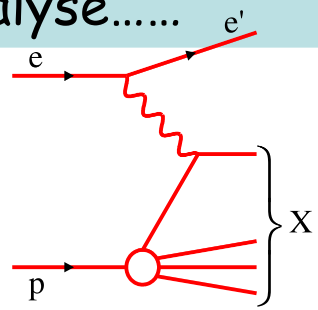
Representing H1 and ZEUS experiments

Low x workshop, Ischia 2009

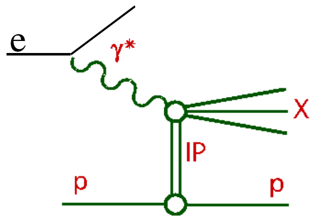
HERA collider experiments

- 27.5 GeV electrons/positrons on 920 GeV protons $\rightarrow \sqrt{s}=318$ GeV
- two experiments: H1 and ZEUS
- HERA I: 16 pb^{-1} e-p, 120 pb^{-1} e+p
- HERA II: ~ 550 pb^{-1}, ~ 40% polarisation of e+,e-
- closed July 2007, still lot of excellent data to analyse……





DIS: Probe structure of proton → F_2

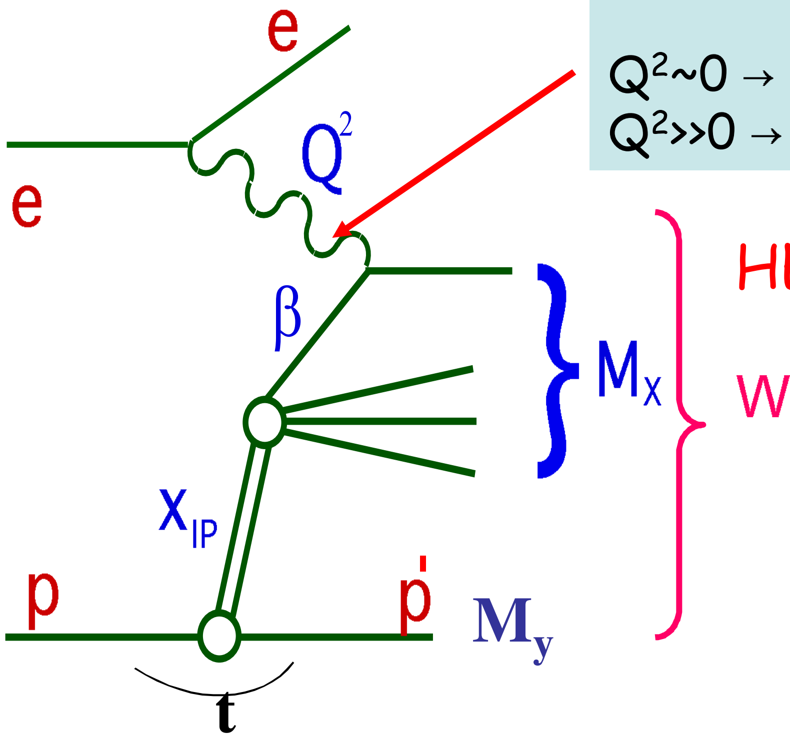


Diffractive DIS: Probe structure of color singlet exchange → F_2^D

Diffraction and diffraction kinematics

Two classes of diffractive events:

$Q^2 \sim 0 \rightarrow$ photoproduction
$Q^2 \gg 0 \rightarrow$ deep inelastic scattering (DIS)



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

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

momentum fraction of color singlet exchange

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

fraction of exchange momentum, coupling to γ*

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

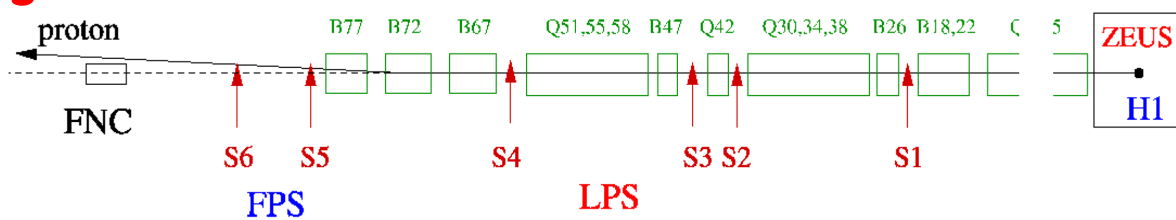
4-momentum transfer squared
(or P_t^2 of proton)

$M_y = m_p$ proton stays intact, needs detector setup to detect protons

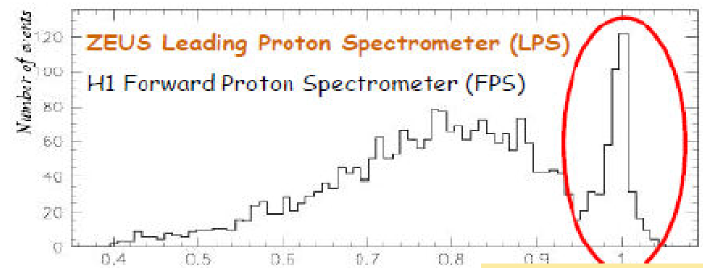
$M_y > m_p$ proton dissociates ⟶ background to be understood and disantangled

Methods of diffractive ev.selection

Proton spectrometers



ZEUS: LPS (1993-2000)
H1: FPS (1995-2007)
t measurement
access to high x_{IP} range
free of p-dissociation background at low x_{IP}
small acceptance → low statistics ☠



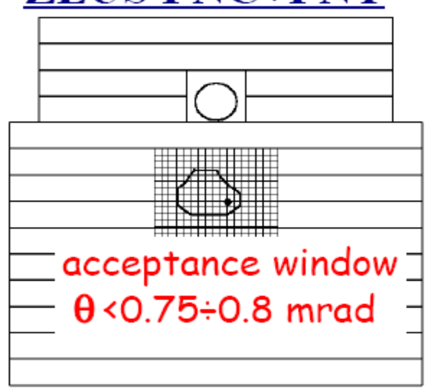
$x_L = p_z'/p_z$

Neutron spectrometers

Acceptance limited by beam apertures and beam size,
P_t resolution dominated by P_t spread of proton beam 50-100 MeV

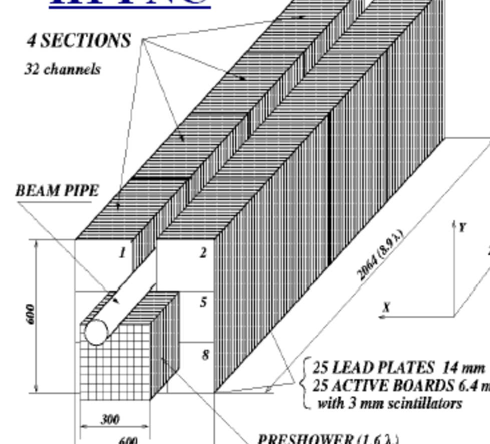
resolution 2-3mm

ZEUS FNC+FNT



14 towers, 17x15 grid of the FNT hodoscopes,
$\sigma_E/E \approx 0.7/\sqrt{E}$

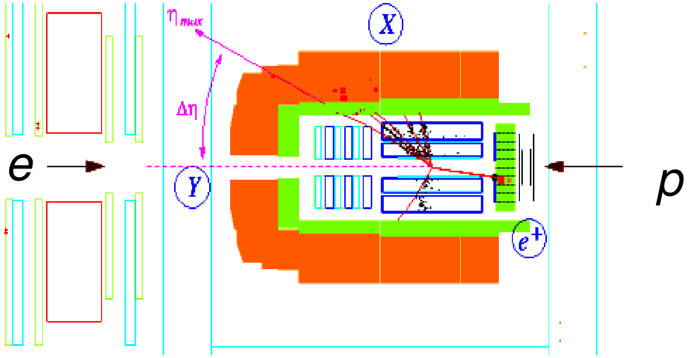
H1 FNC



$\sigma_E/E \approx 0.63/\sqrt{E} \oplus 2\%$

Methods of diffractive ev. selection

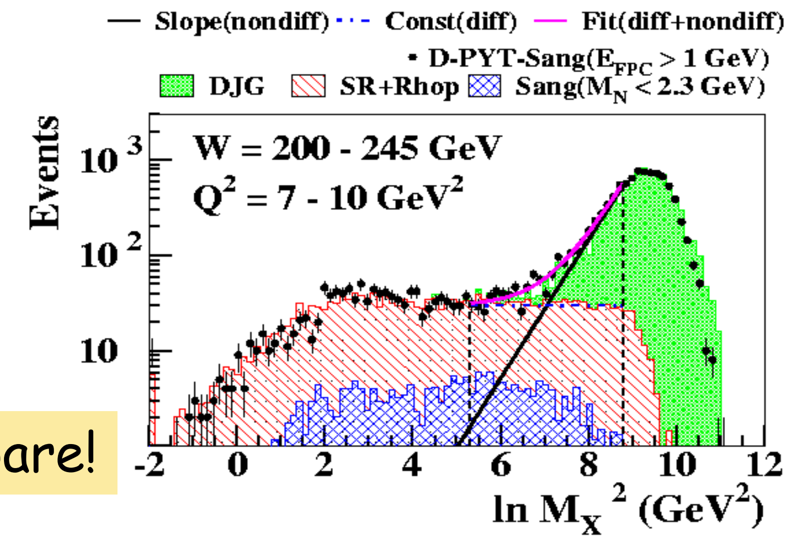
Large Rapidity Gap, H1, ZEUS:
require no activity beyond η_{max}
t not measured,
very good acceptance at low x_{IP}
p-diss background about 20% ☠



$$\eta = -\ln(\tan\tfrac{\theta}{2})$$

M_x method, ZEUS:
diffractive vs non-diffractive: exponential fall off vs constant distribution in $\ln M_x^2$
p-diss background ☠

$$\frac{dN}{d\ln M_x^2} \propto \underbrace{D}_{\text{diff.}} + \underbrace{Ce^{B\ln M_x^2}}_{\text{non-diff}}$$



Different systematics – non-trivial to compare!

Diffractive cross section

$$\frac{d^4\sigma(ep \to eXp)}{d\beta\, dQ^2 dx_P dt} = \frac{4\pi\alpha_{em}^2}{\beta Q^4}(1 - y + \frac{y^2}{2})\ \sigma_R^{D(4)}(\beta, Q^2, x_P, t)$$

$\sigma_R^{D(4)} \rightarrow$ diffractive reduced cross section $\quad \sigma_R^{D(4)} \approx F_2^{D(4)}$ at low y

$$\sigma_R^{D(4)} = F_2^{D(4)} - \frac{y^2}{2(1 - y - \frac{y^2}{2})} F_L^{D(4)}$$

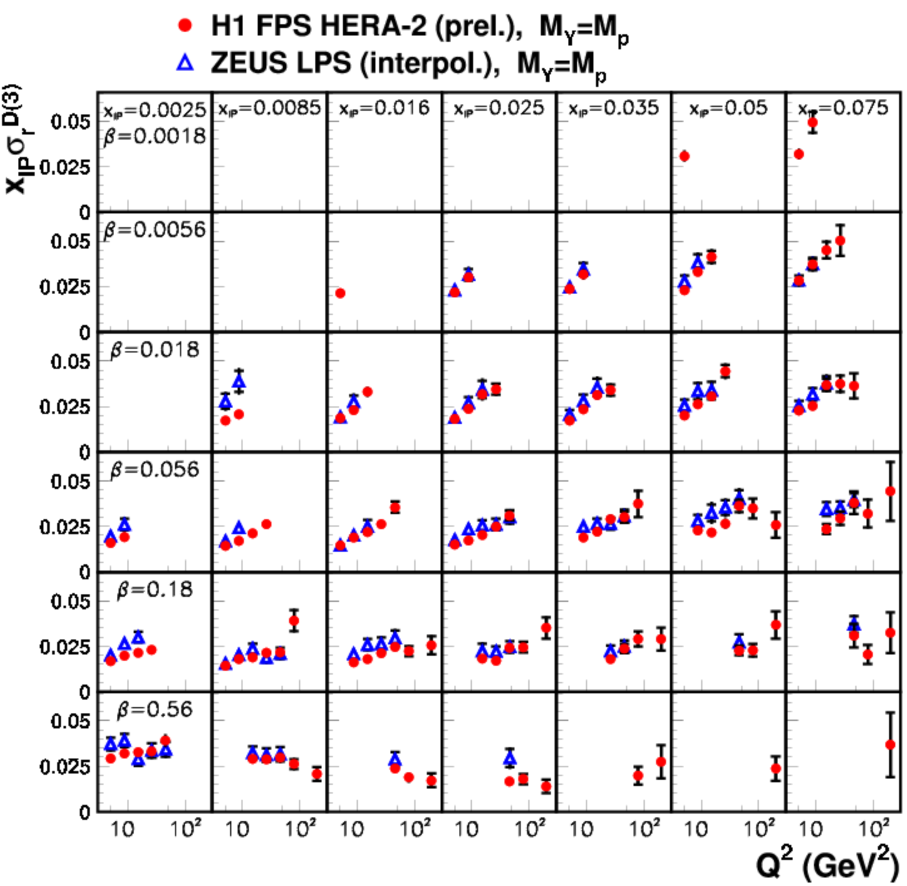
$\sigma_R^{D(4)} = F_2^{D(4)}$ if

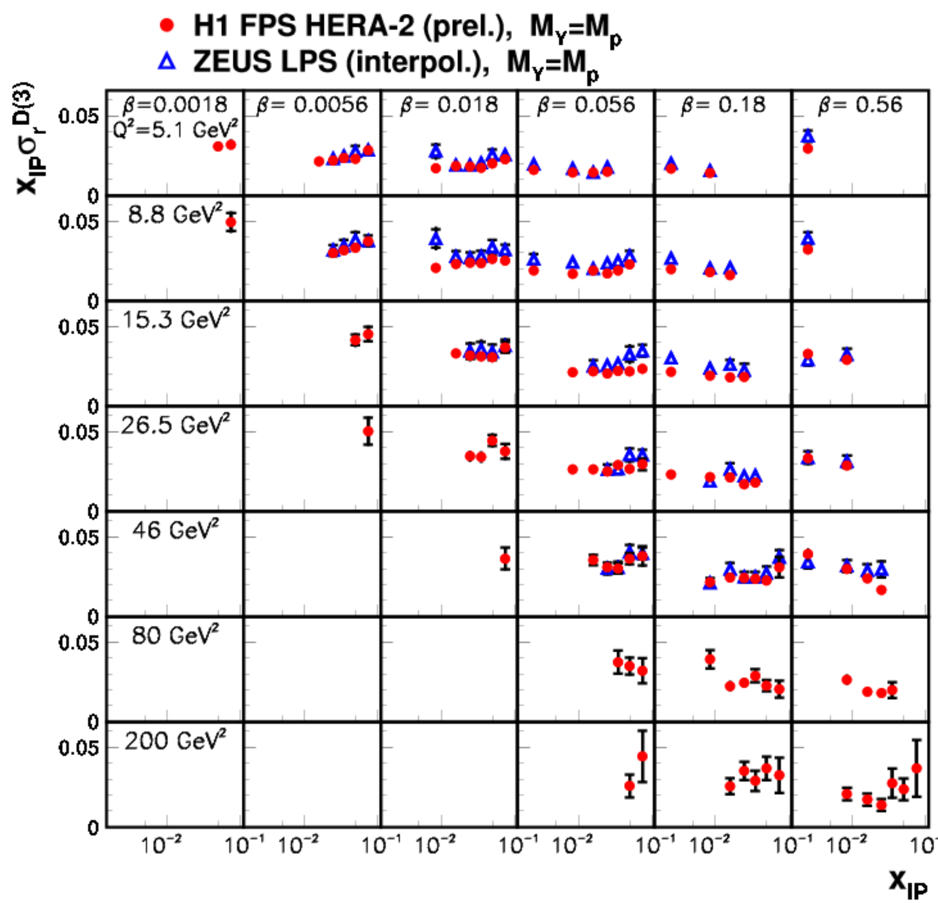
$F_L^{D(4)} = 0$

Integrate over t when proton is not tagged
$\rightarrow \sigma_R^{D(3)}(\beta, Q^2, x_P)$

Comparison H1 FPS & ZEUS LPS

The cleanest comparison, all available data used by both collaborations, H1 HERA II 20 times improved statistics, higher Q^2



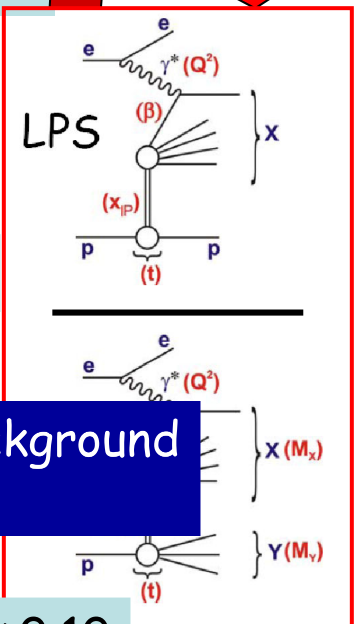


Fair agreement, normalisation uncertainty → LPS~10%, FPS ~6%

Comparison between methods

Are „rapidity gap" and „forward proton" methods compatible?

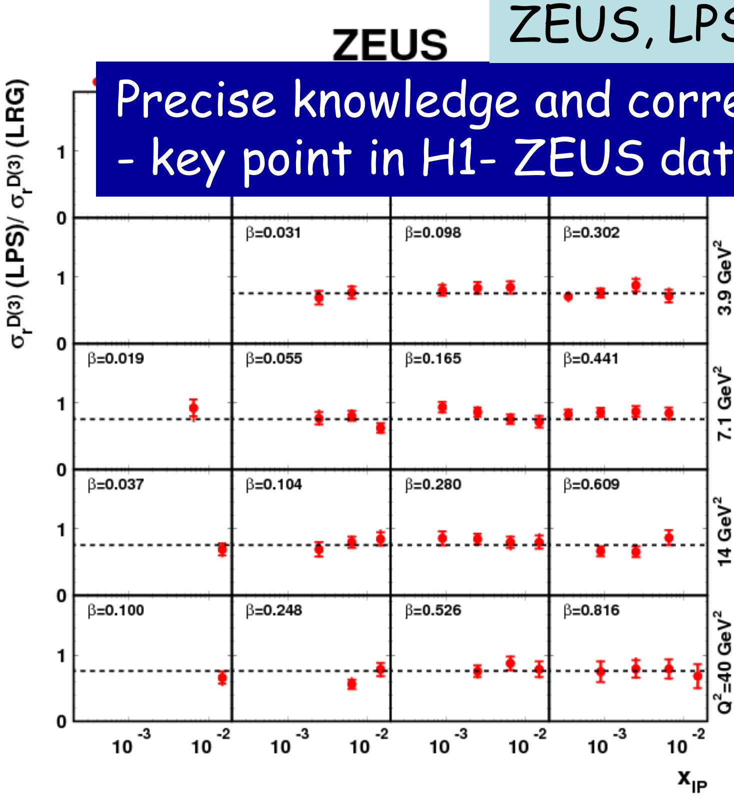
- LRG selection contains about 20% events of proton diss.
- no significant dependence on any variable
- well controlled, precise measurements



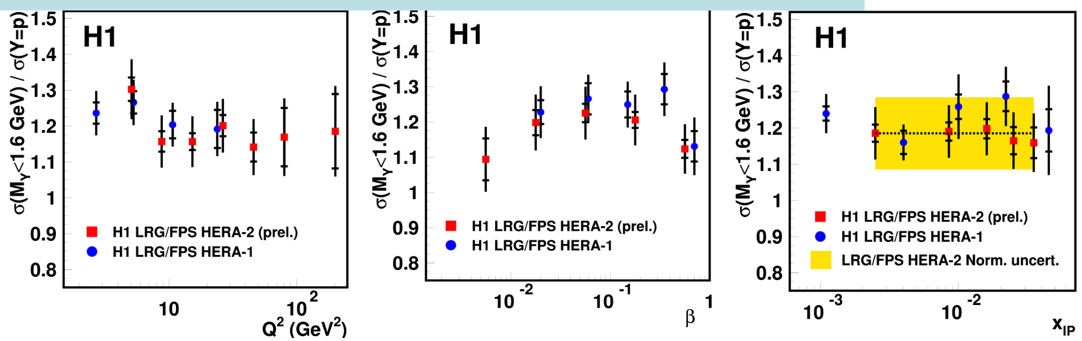
ratio

ZEUS, LPS/LRG = $0.76 \pm 0.01 \pm^{0.03}_{0.02} \pm^{0.08}_{0.05}$

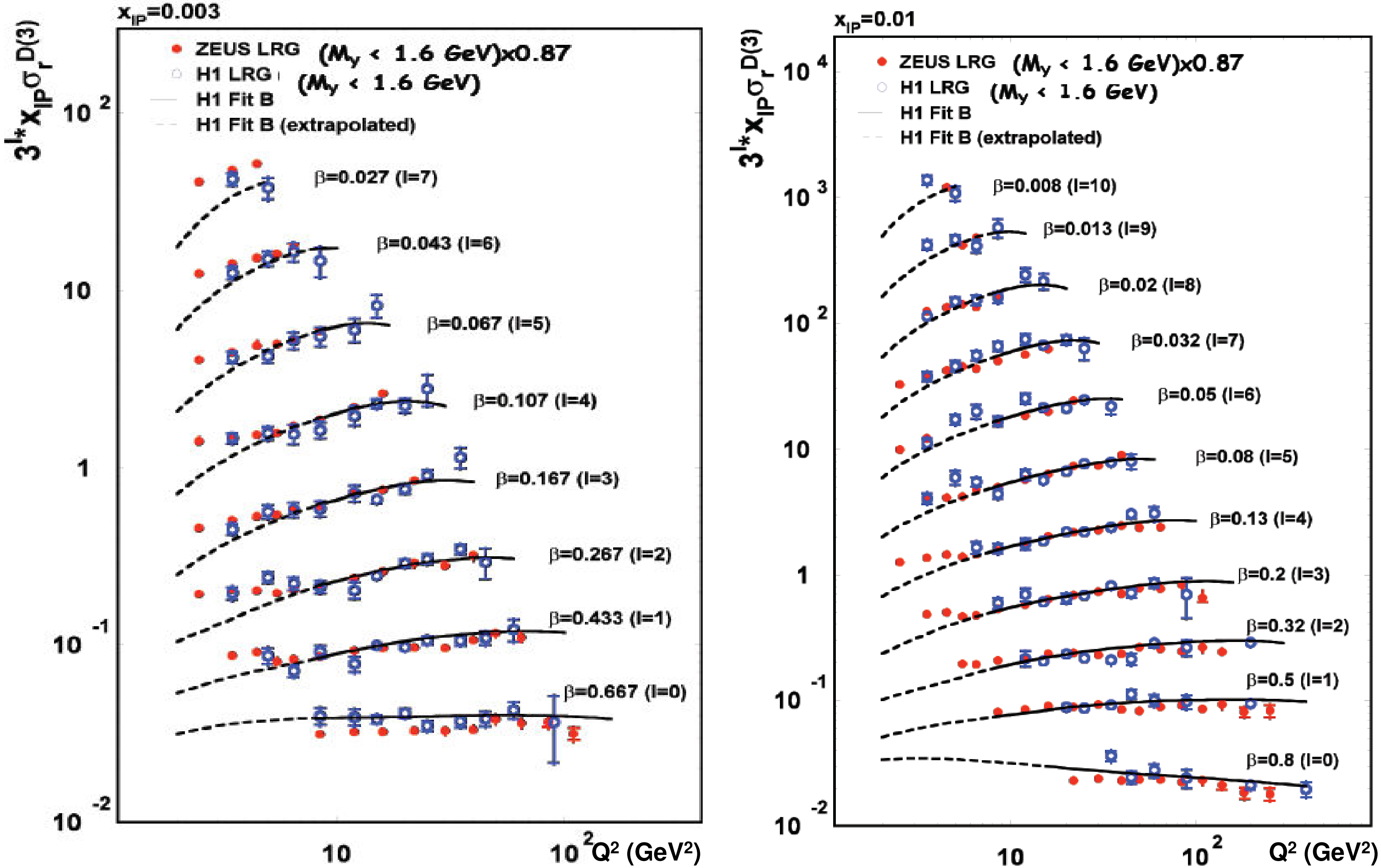
Precise knowledge and corrections for proton dissociation background - key point in H1- ZEUS data comparison



H1, LRG/FPS = $1.18 \pm 0.01 \pm 0.06 \pm 0.10$



H1 & ZEUS inclusive diffraction,LRG

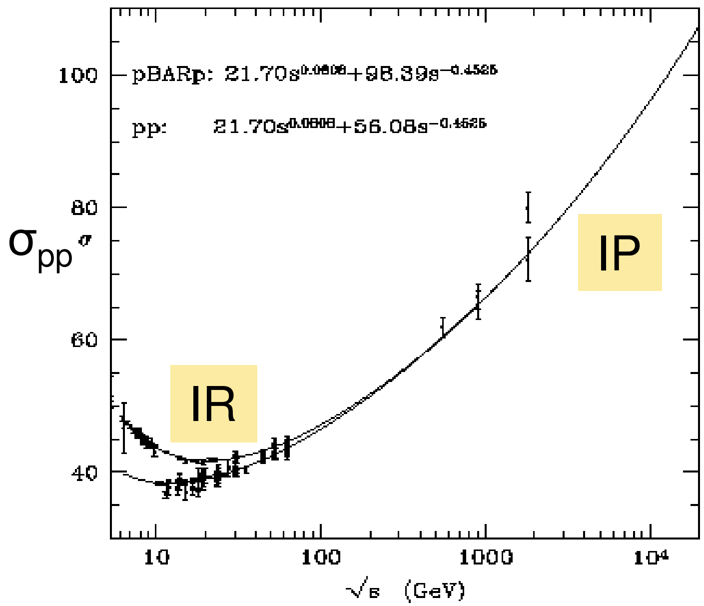


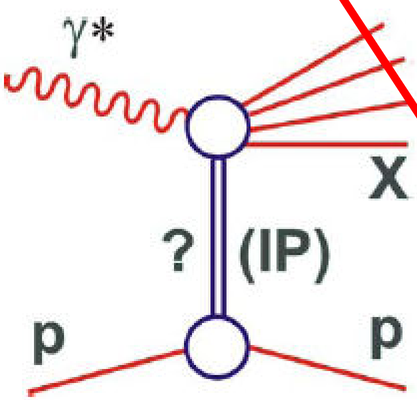
Good agreement between H1 and ZEUS in most of the phase space, (except low Q^2), ZEUS scaled by 0.87, covered by normalisation uncertainty

Soft pomeron, Regge model

Regge model: analytic model of HADRONIC scattering
Exchange of collective states: linear trajectories in the spin-energy (α,t) plane,

$$\alpha_j(t) = \alpha_j(0) + \alpha'_j(t) \quad (j = IR, IP, ..)$$

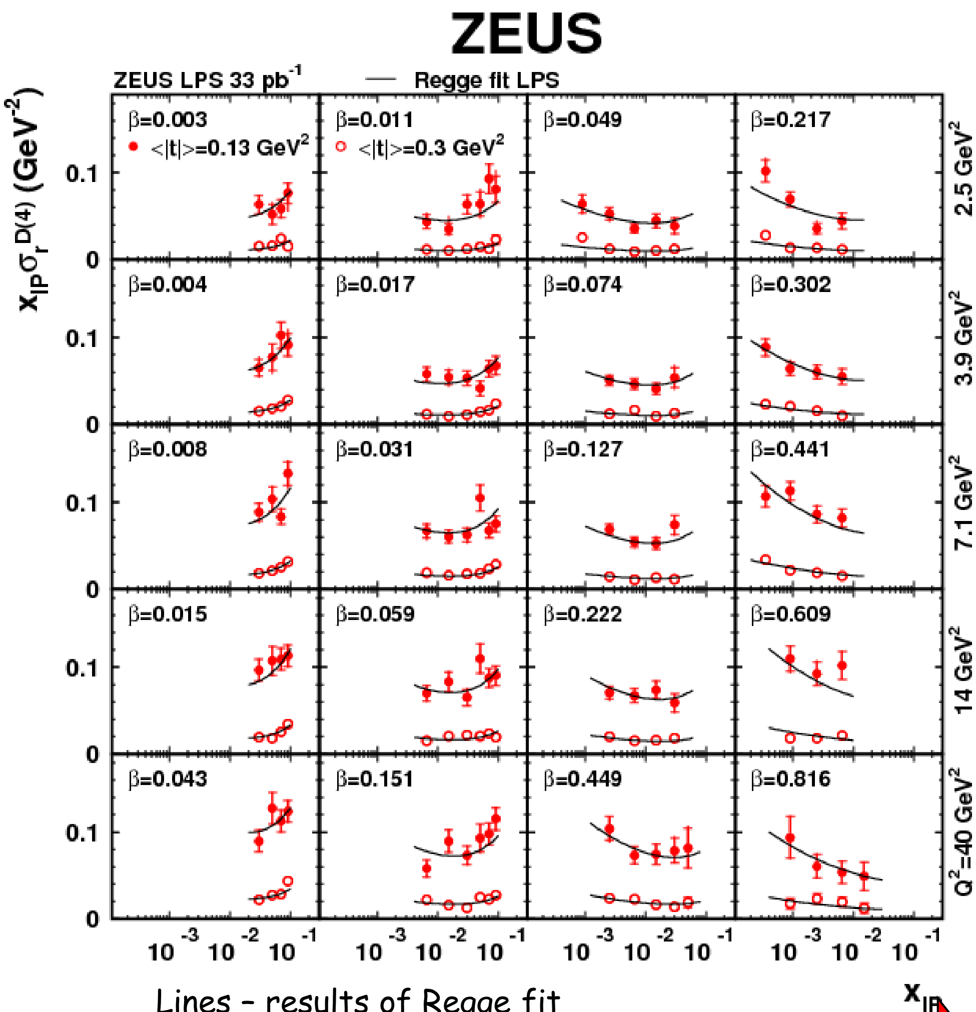




In γ*p→XY virtual photon resolves structure of exchanged object

dominant contribution looks similar to soft pomeron,
we can extract Regge trajectory

x_{IP} dependence for two t values



Lines – results of Regge fit

Regge fit, IP+IR

Reduced cross section measured for the first time at two t values

Low x_{IP} and high β, decrease with increasing x_{IP} →IP-like behaviour

High x_{IP} and low β, increase with increasing x_{IP} → IR-like behaviour

ZEUS $\alpha_{IP}(0)=1.11\pm0.02\pm0.02$

H1 $\alpha_{IP}(0)=1.12\pm0.01\pm0.02$

$\alpha_{IP}(0)$ close to soft 1.08

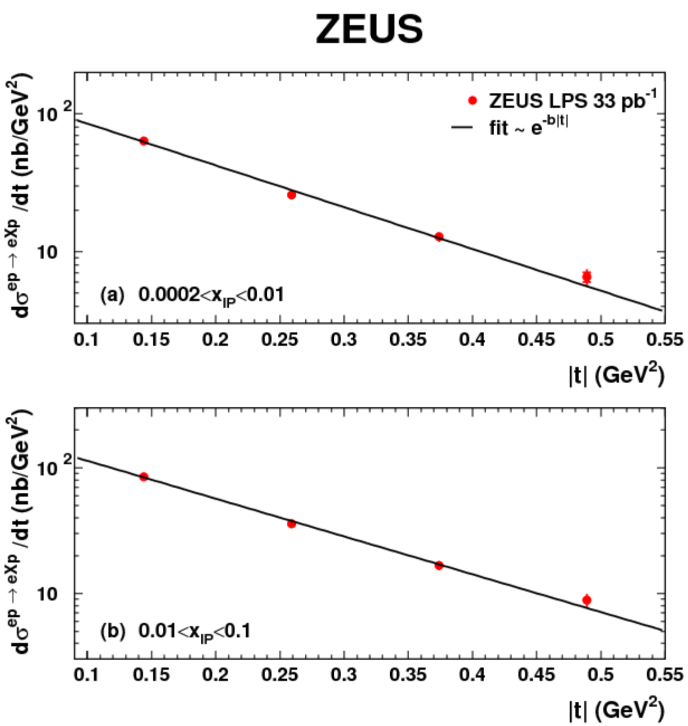
ZEUS $\alpha'_{IP}=-0.01\pm0.06\pm0.05$ GeV^{-2}

H1 $\alpha'_{IP}=0.06\pm0.13$ GeV^{-2}

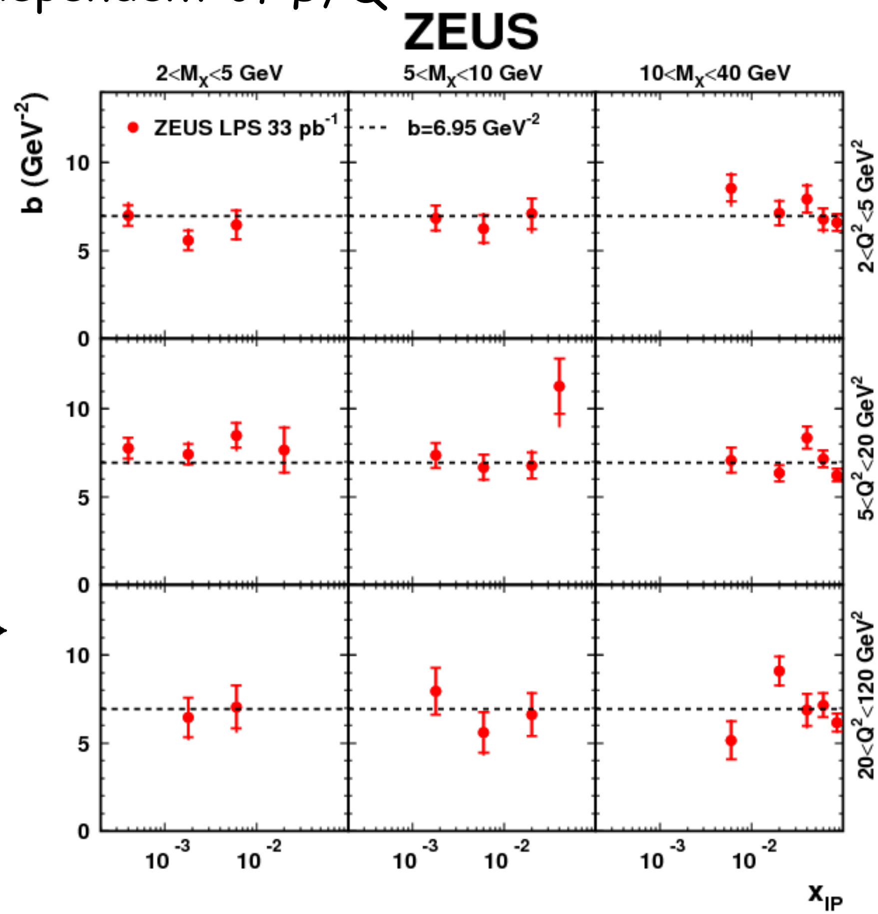
α'_{IP} is not consistent with 0.25 GeV^{-2}

Not soft pomeron, different multi-pomeron absorption effects?

Proton tagged data – t dependence

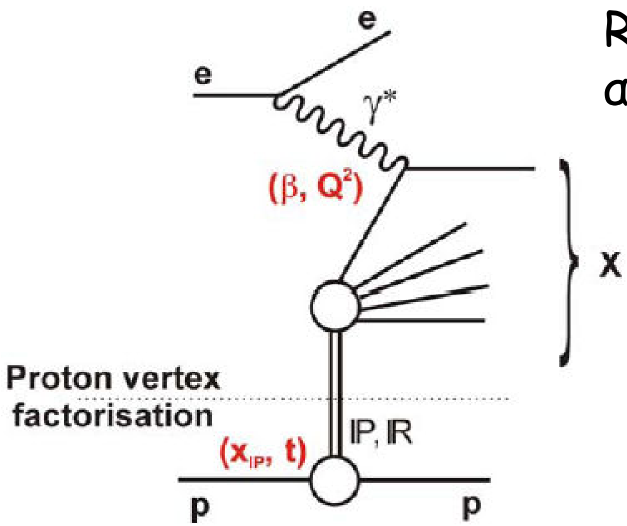


Fitting to e^{-bt} → b ~6-7GeV^{-2} independent of β, Q^2



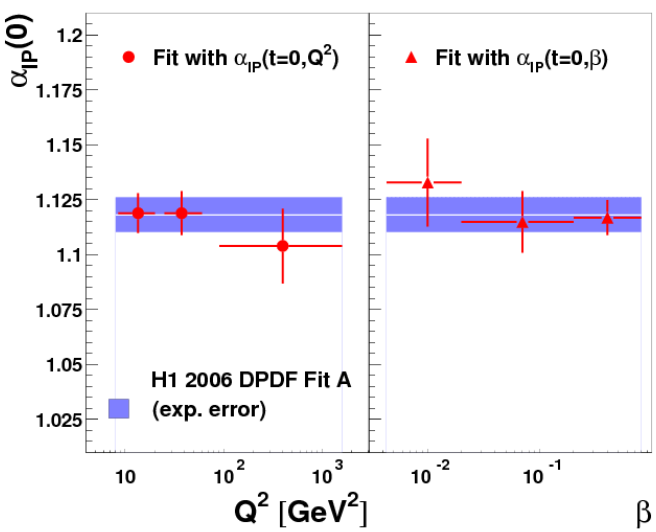
Almost no x_{IP} dependence →

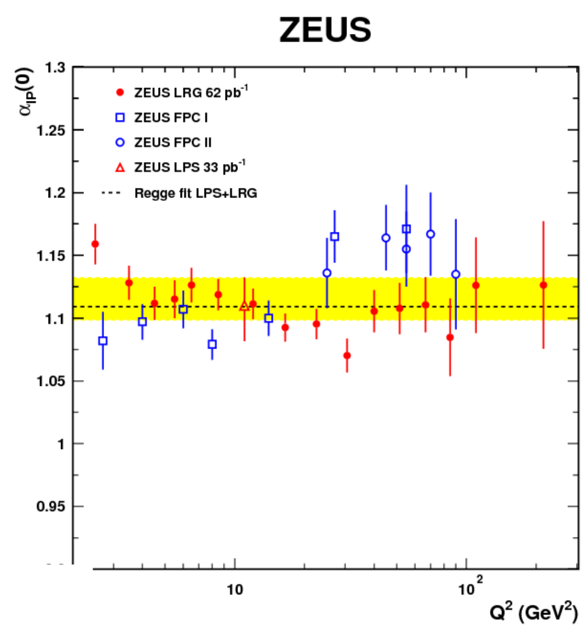
Proton vertex factorisation



Regge fit in different Q^2 bins, no strong evidence for $\alpha_{IP}(0)$ dependence

- Variables (x_{IP},t) describing proton vertex factorise from those at photon vertex (Q^2,β) to good approximation.
  Q^2 and β dependence interpreted in terms of Diffractive Parton Densities (DPDF) → **measurement of partonic structure of exchange, NLO QCD fits –** see next talk of M.Capua





QCD factorisation

Factorisation holds for inclusive and non-inclusive processes when:

- photon is point-like (Q^2 is high enough)
- higher twist corrections are negligible (M_x is high enough)

$$\sigma^D(\gamma^* p \to Xp) = \sum_{parton\_i} f_i^D(x, Q^2, x_{IP}, t) \cdot \sigma^{\gamma^* i}(x, Q^2)$$

$f_i^D \to$ DPDFs – obey DGLAP, universal for diff. ep DIS (inclusive,dijet,charm)

$\sigma^{\gamma^* i} \to$ universal hard scattering cross section (same as in inclusive DIS)

It allows to extract DPDFs from the (DIS) data

H1 and ZEUS –QCD fits assuming Regge factorisation for DPDF

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

$$f_{IP/p}(x_{IP}, t) = \frac{e^{Bt}}{x_{IP}^{2\alpha(t)-1}}$$

pomeron flux factor

pomeron PDF

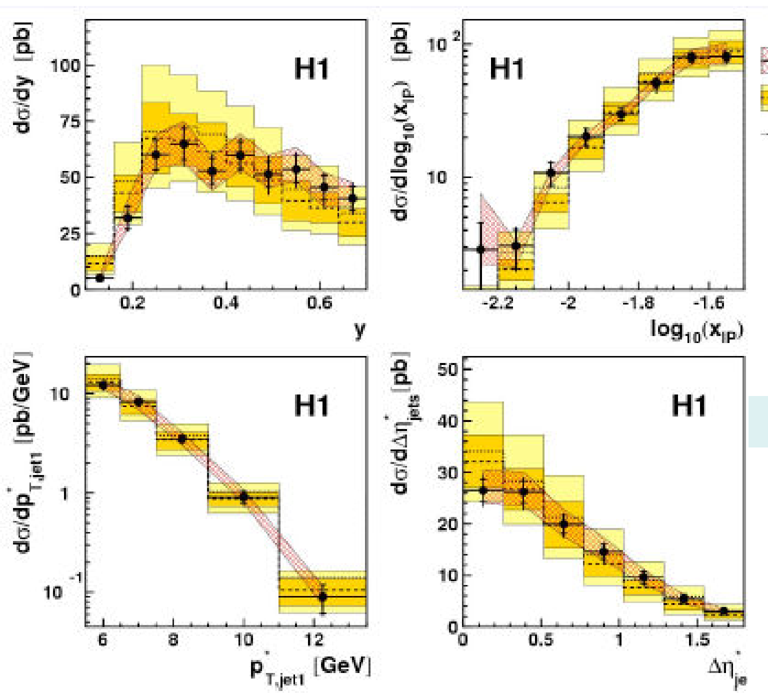
How to profit from factorisation?

- to extract DPDFs from inclusive DIS and to estimate cross sections for dijet and D* production – then compare with data → **tests of factorisation**

- to extract DPDFs from inclusive and semi-inclusive DIS (dijets,D*) – only semi-inclusive data are sensitive to gluon contribution, mainly at large z_{IP}

Used by H1 and ZEUS

semi-inclusive data → dijets in DIS

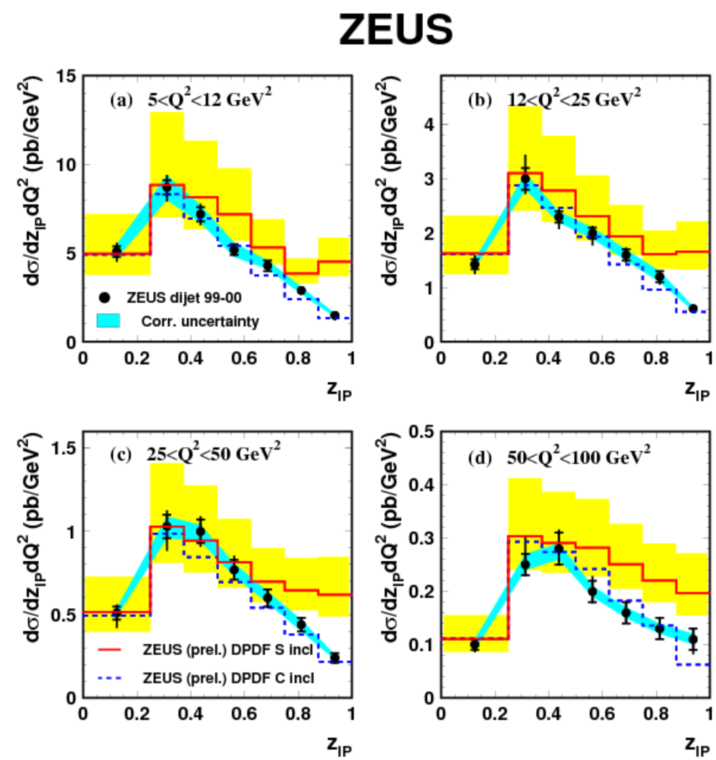


$4 < Q^2 < 80$ GeV^2
$0.1 < y < 0.7$
$x_{IP} < 0.03$

$P^*_{tjet1} > 5.5$ GeV
$P^*_{tjet2} > 4$ GeV
$-3. < \eta^*_{jets} < 0.$

JHEP 0710 042 (2007)

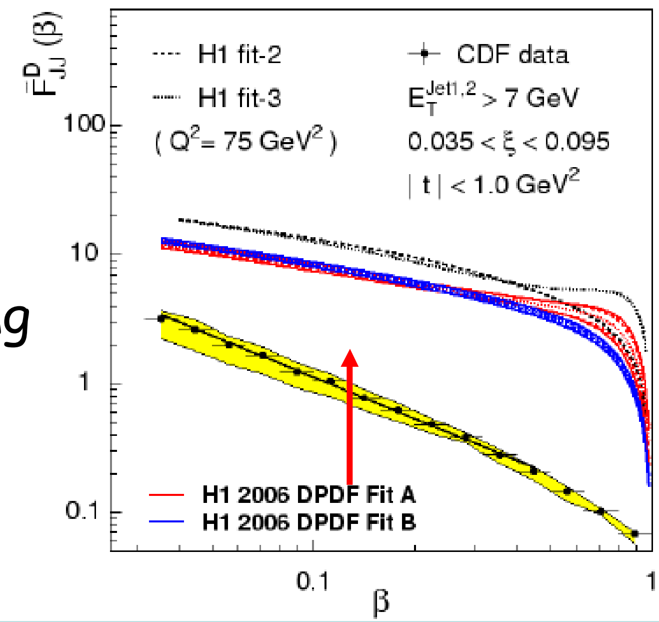
EPJ C52 (2007) 813



Factorisation in hadron-hadron collisions

Factorisation broken by β-dependent factor ~ 10, S ~ 0.1

Exporting DPDFs from HERA to Tevatron.....

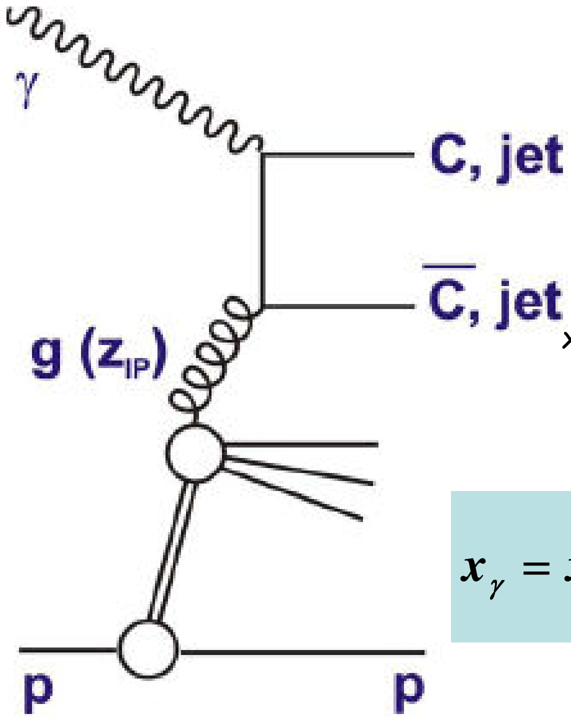


x_{IP} integrated effective DPDFs from CDF single diff. dijets (run I)

Succesfully explained by terms of rescattering and absorption
(see Kaidalov,Khoze,Martin,Ryskin:Phys.Lett.B567 (2003),61)

Must be understood for LHC…e.g. CEP Higgs, (S=1-3%), related to underlying event…..

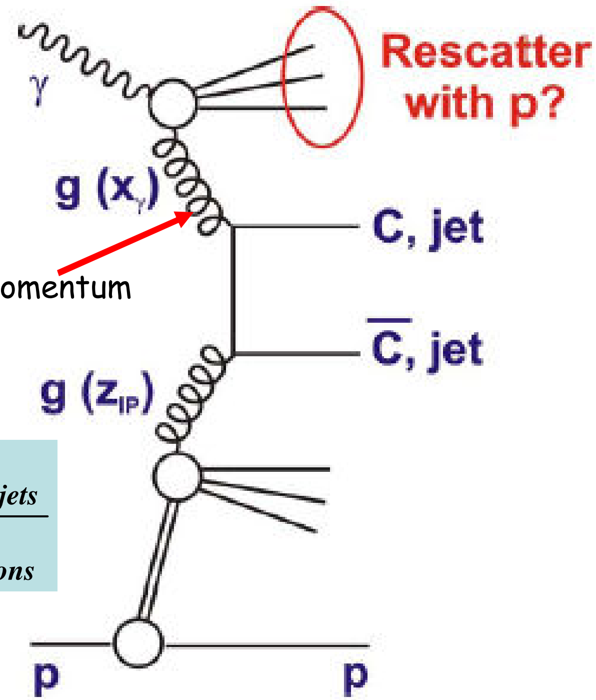
Photoproduction, γ*p, $Q^2 \to 0$



In LO!

x_γ - fraction of photon's momentum in hard subprocess

$$x_\gamma = x_\gamma^{OBS} = \frac{\sum (E - p_z)_{jets}}{(E - p_z)_{hadrons}}$$



direct photoproduction ($Q^2 \simeq 0$):
photon directly involved in hard scattering

$x_\gamma = 1$

(at parton level)

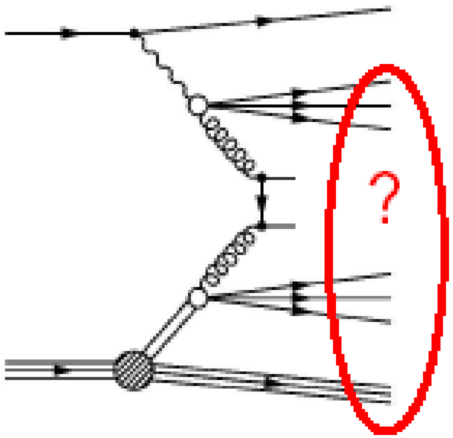
resolved photoproduction ($Q^2 \simeq 0$):
photon fluctuates into hadronic system, which takes part in hadronic scattering, dominant at $Q^2 \simeq 0$

$x_\gamma < 1$

(at parton level)

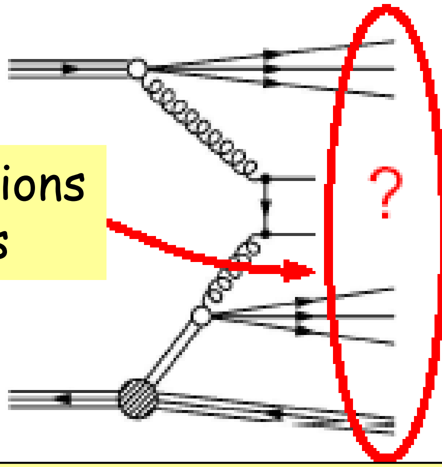
Photoproduction as hadronic process

HERA resolved photoproduction



Secondary interactions between spectators

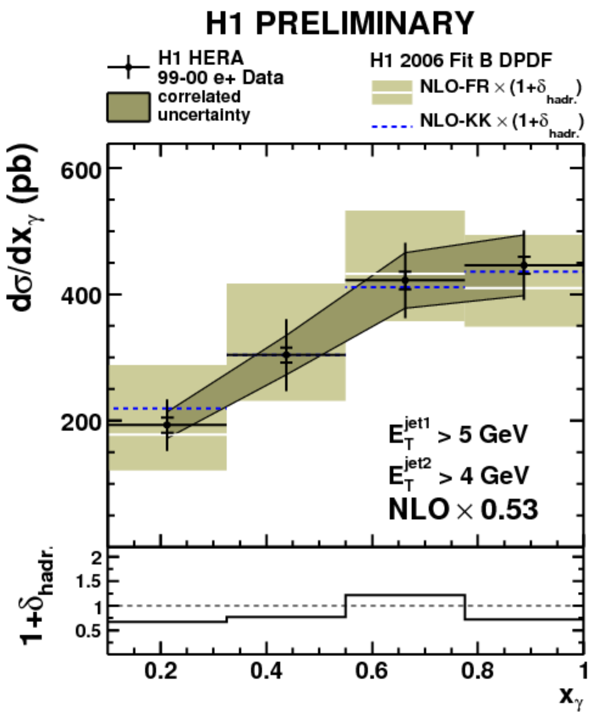
Tevatron

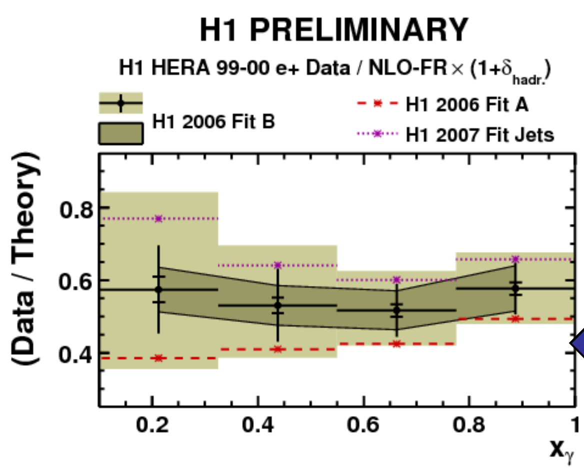


Typical models that describe suppression at Tevatron assume secondary interactions of spectators as the cause:

resolved contribution expected to be suppressed by factor 0.34
see Kaidalov et al.

Lower E_t cut scenario





$E_{tjet1} > 5$ GeV

$$S = \frac{\sigma\,(data)}{\sigma\,(theory)}$$

Integrated survival probabilities (ISP → S)

$$S^{FR}_{fit\,B} = \underline{0.54} \pm 0.01\,(stat.) \pm 0.10\,(syst.)\,^{+0.14}_{-0.13}\,(scale)$$

Good agreement with published H1 results (EPJ C51, (2007),549

$$S^{KK}_{fit\,B} = 0.51 \pm 0.01\,(stat.) \pm 0.10\,(syst.)$$

$$S^{FR}_{fit\,Jets} = 0.65 \pm 0.01\,(stat.) \pm 0.11\,(syst.)$$

$$S^{FR}_{fit\,A} = 0.43 \pm 0.01\,(stat.) \pm 0.10\,(syst.) \qquad 11$$

Within errors no difference in ISP using different DPDFs

No difference in survival probabilities for resolved and direct regions of x_γ, like in previous H1 and ZEUS analyses

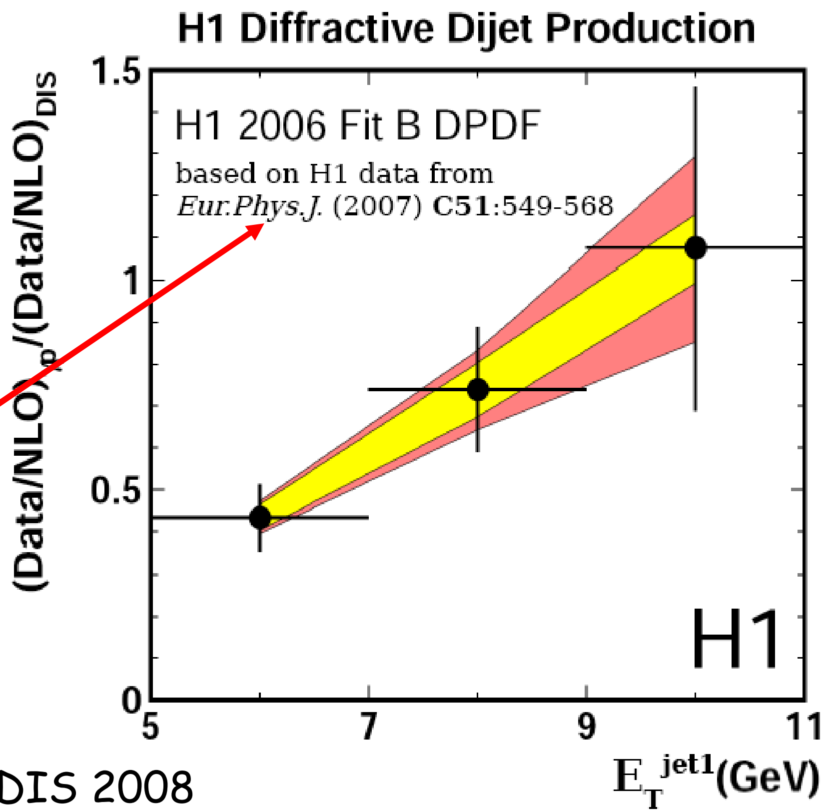
H1 – double ratio, E_t dependence?

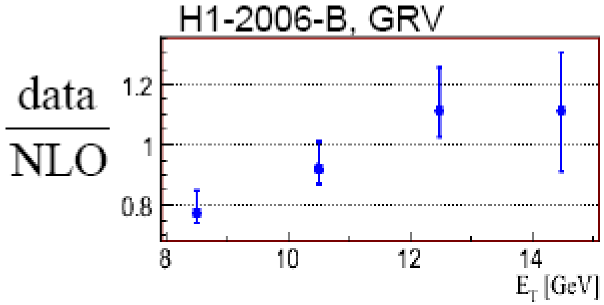
Double ratio of Data/NLO for photoproduction and DIS

→

Very useful – full or partial cancellation of many uncertainties (energy scales for data, DPDFs used…etc).

Figure extracted from published results

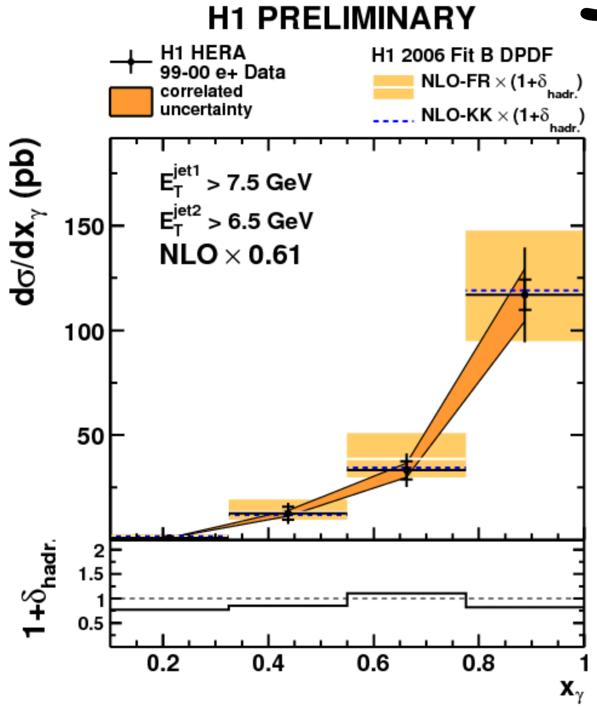


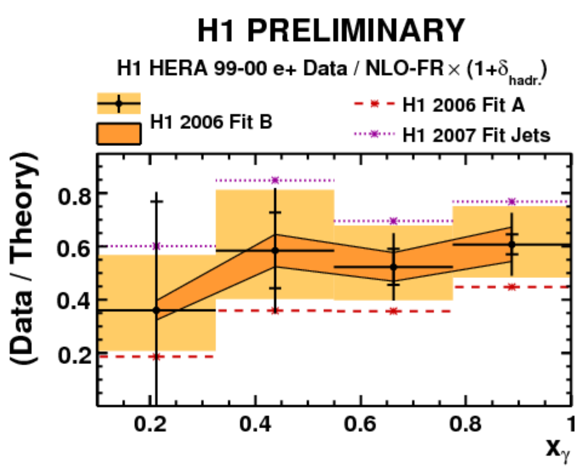


W.Slomiński, ZEUS, DIS 2008

Hint that suppression is within errors E_t dependent!

Higher E_t cut scenario





$E_{t\,jet1} > 7.5$ GeV

Now much more „direct-like“ events than in low E_t analysis, peak at higher x_γ

Integrated survival probabilities (ISP)

$$S^{FR}_{fit\,B} = 0.61 \pm 0.03\,(stat.) \pm 0.13\,(syst.)\,^{+0.16}_{-0.14}\,(scale)$$

$$S^{KK}_{fit\,B} = 0.62 \pm 0.03\,(stat.) \pm 0.14\,(syst.)$$

$$S^{FR}_{fit\,Jets} = 0.79 \pm 0.04\,(stat.) \pm 0.16\,(syst.)$$

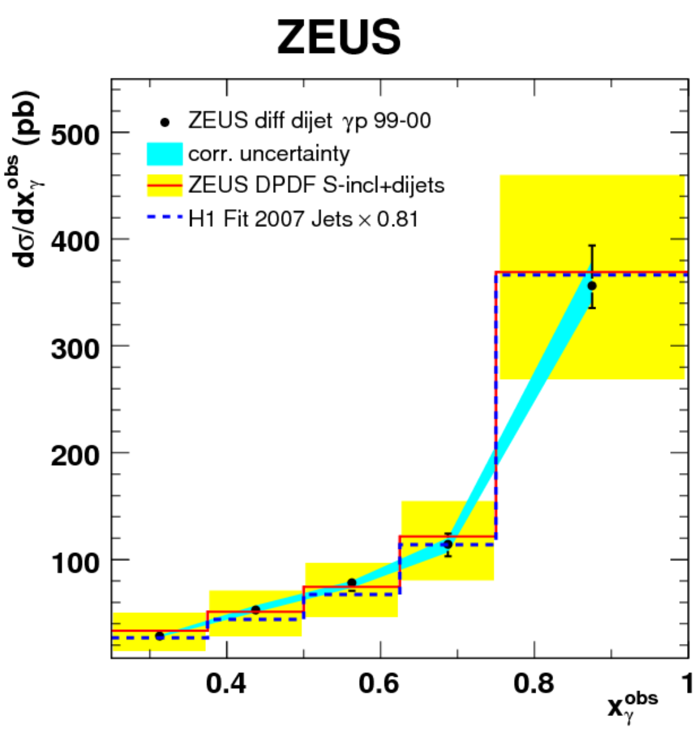
$$S^{FR}_{fit\,A} = 0.44 \pm 0.02\,(stat.) \pm 0.09\,(syst.)$$

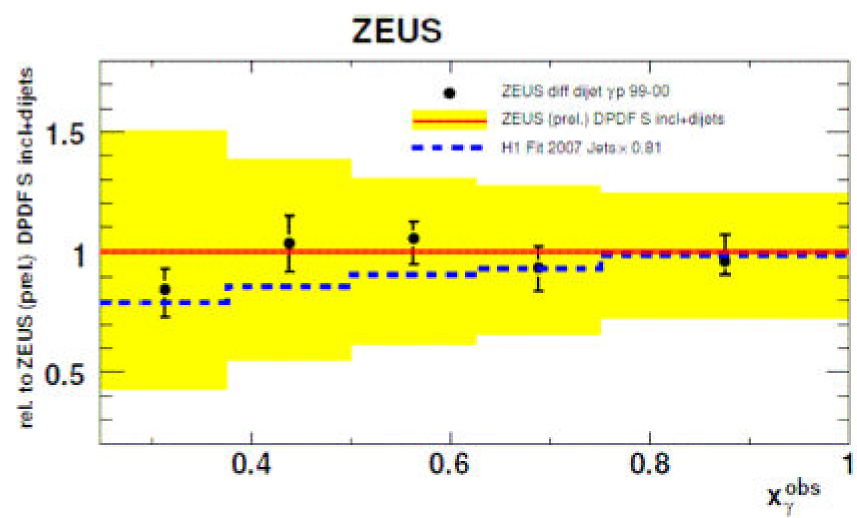
Larger ISP than for lower E_t cut scenario

New ZEUS fit-comparison with old data

Published data: EPJ C55 (2008) 177

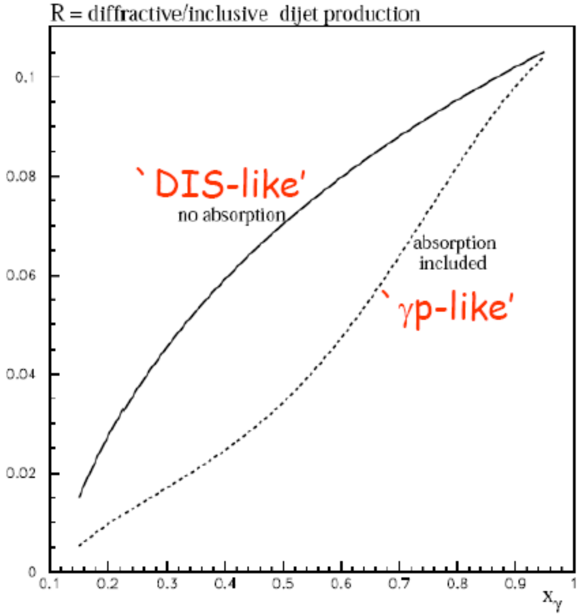
Very good description → no evidence for suppression for ZEUS combined fit and H1 fit jets → ISP ~ 1…..





Ratio diffractive to inclusive

Proposed by Kaidalov et al. Phys.Lett B567 (2003) 61



Full or partial cancellation of PDF uncertainties, scales.....

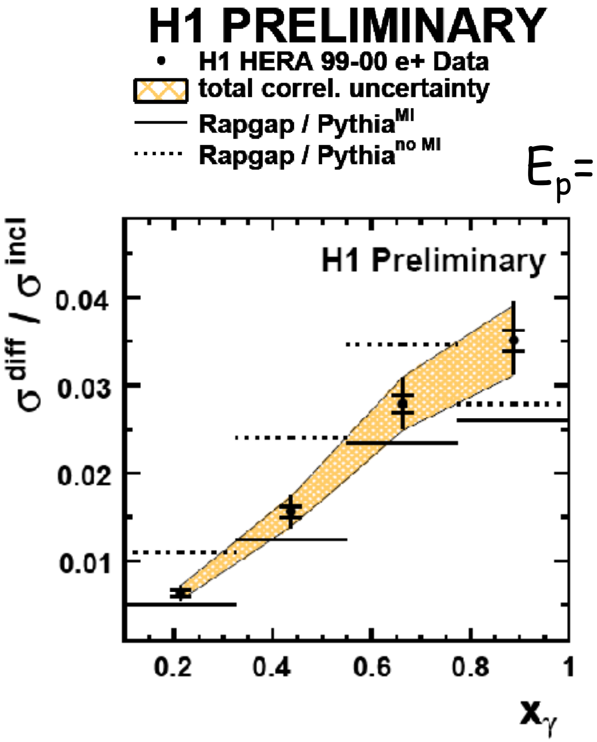
Distribution of x_γ sensitive to gap survival.

H1 - measured in same kinematic range with same method as diffractive cross sections
Acceptance corrections – PYTHIA

Problem → describes low E_t inclusive data with inclusion of multiple interactions only, large hadronisation corrections!

Such a low E_t jets also not properly described by NLO – see eg. H1 inclusive jet paper (EPJ C 129 (2003) 497)

Ratio diffractive to inclusive



E_p=930 GeV

E_p=820 GeV

$p_T^{jet1} > 5$ GeV

$p_T^{jet2} > 4$ GeV

$-1 < \eta_{lab}^{jet1,2} < 2$

$Q^2 < 0.01$ GeV^2

$0.3 < y < 0.6$

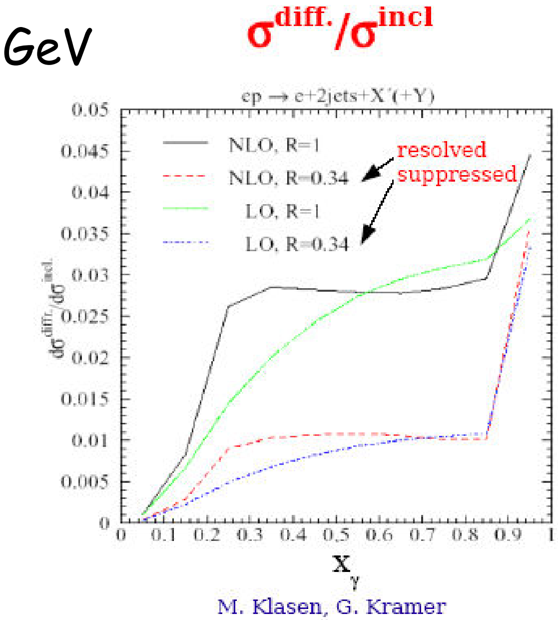
inclusive

$x_{IP} < 0.03$

$M_Y < 1.6$ GeV

$-t < 1$ GeV^2

diffractive

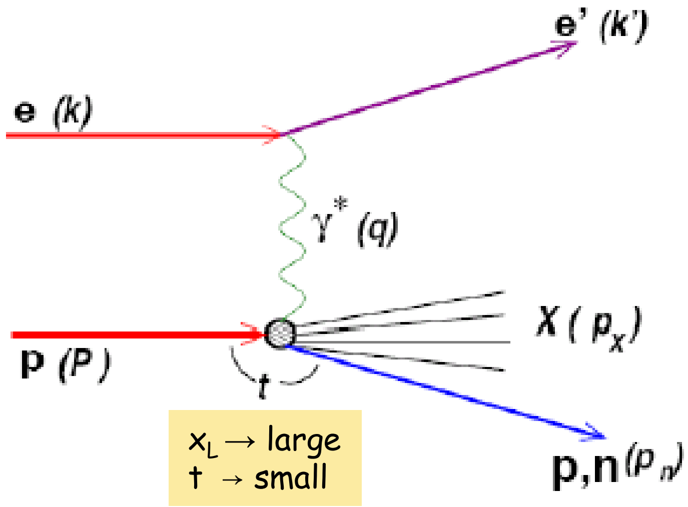


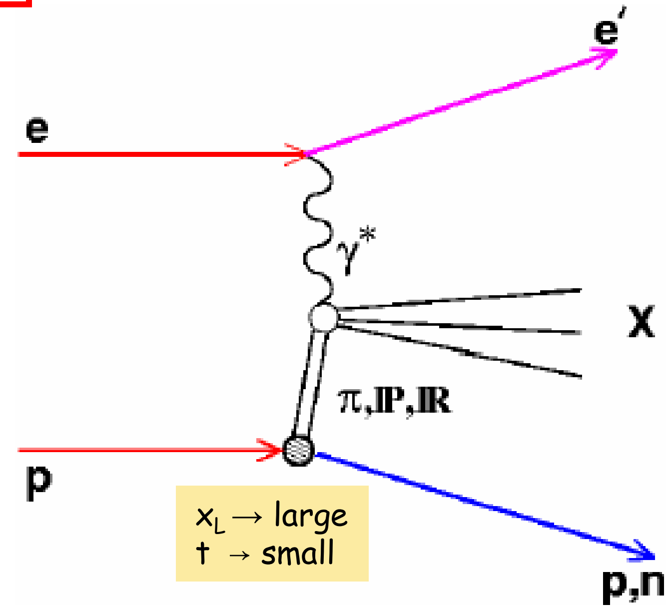
$z_{IP} < 0.8$

- comparison to MC models - RAPGAP/PYTHIA
- very different phase space for incl.& diffractive
- large sensitivity to multiple interactions (MI) for inclusive dijets
- better agreement of data ratio with PYTHIA MI
- due to these facts - interpretation difficult

Leading baryons, production mechanisms

A semi-inclusive reactions: $ep \rightarrow epX$
$ep \rightarrow enX$

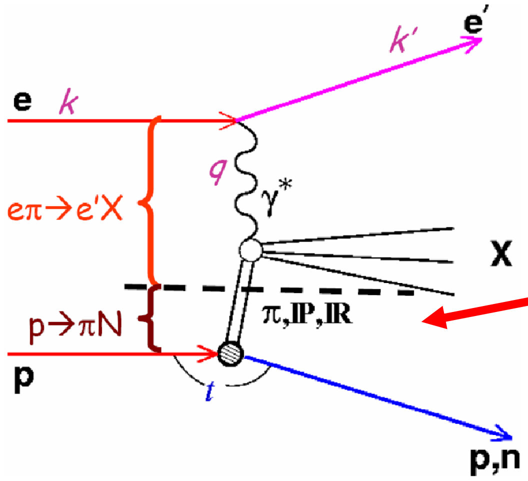




Conventional fragmentation of proton remnant – eg. Lund string model

Exchange of virtual particle → proton: neutral iso-scalar, iso-vector, (π,IR,IP)
neutron: charged iso-vector, (π^+,a_2,rho$^+$)

Vertex factorisation in LB production



Secondary interactions can fill the gap associated with π exchange

In the exchange model the cross sections factorise, e.g. for one pion exchange

$$\sigma(ep\rightarrow e'NX) = f_{\pi/p}(x_L,t) \times \sigma(e\pi\rightarrow e'X)$$

$f_{\pi/p}(x_L,t)$ - pion flux:
probability to emit pion from the photon with given x_L, t

$\sigma(e\pi\rightarrow e'X)$ - cross-section of eπ scattering

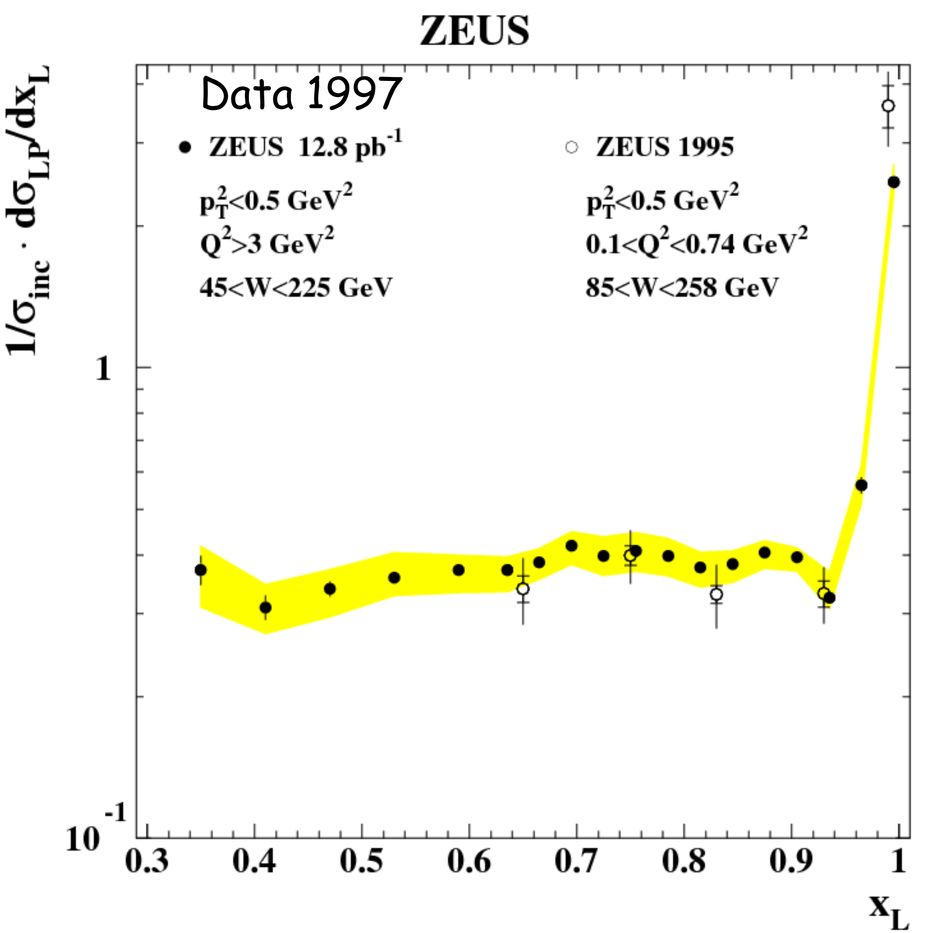
-LB production independent from photon vertex
-probe structure of exchanged particle
-factorisation violation predicted- absorption/rescattering

$d\sigma_{LP}/dx_L$ normalised to inclusive DIS

data 1997

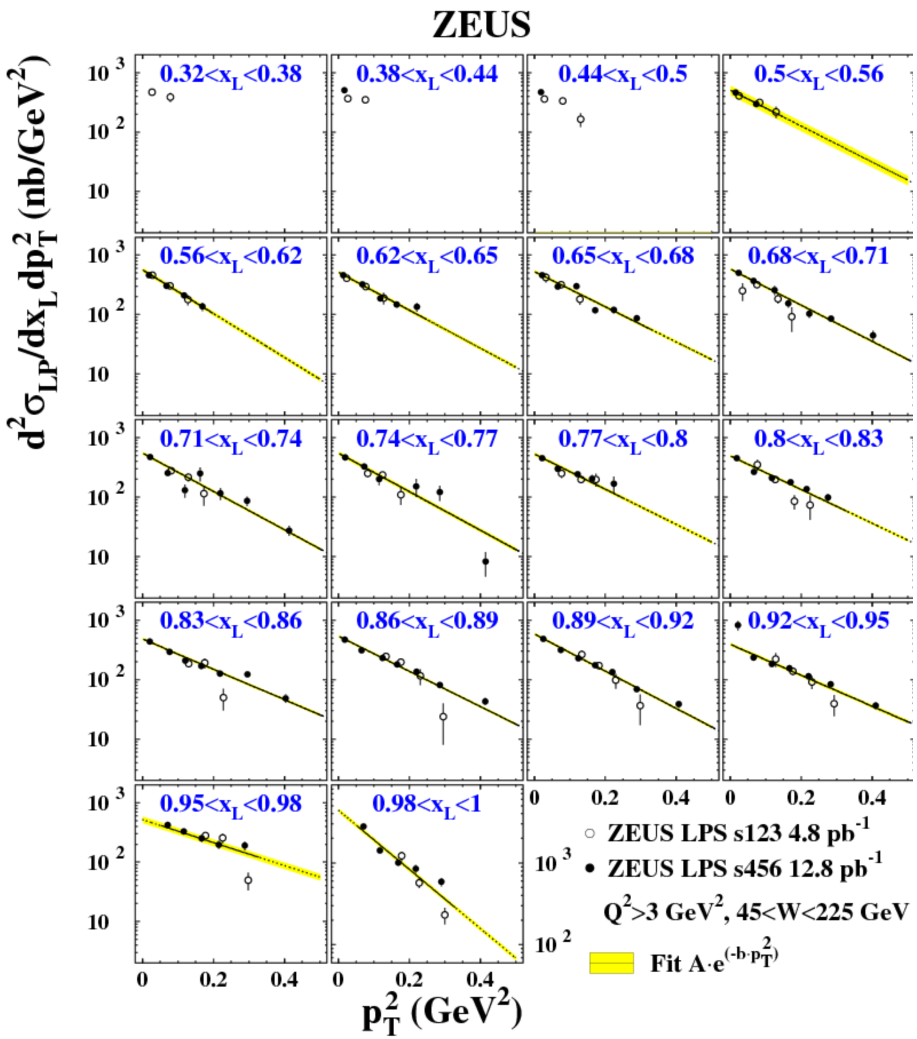
12.8 pb^{-1}
$Q^2 > 3$ GeV^2
$p_T^2 < 0.5$ GeV^2
$45 < W < 225$ GeV
$x_L > 0.32$

two ranges of Q^2

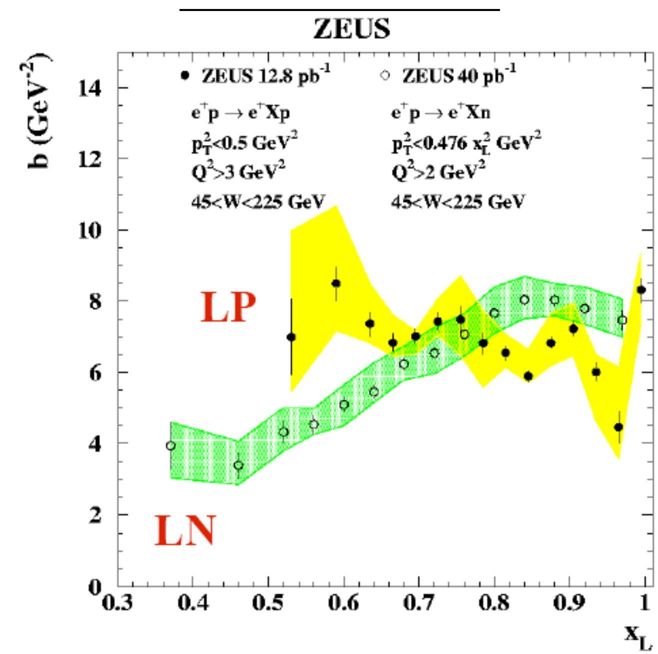


- clear diffractive peak at $x_L \rightarrow 1$
- proton yield flat bellow $x_L < 0.95$
- consistent with previous low Q^2 data (1995)

P_T^2 distribution in x_L bins

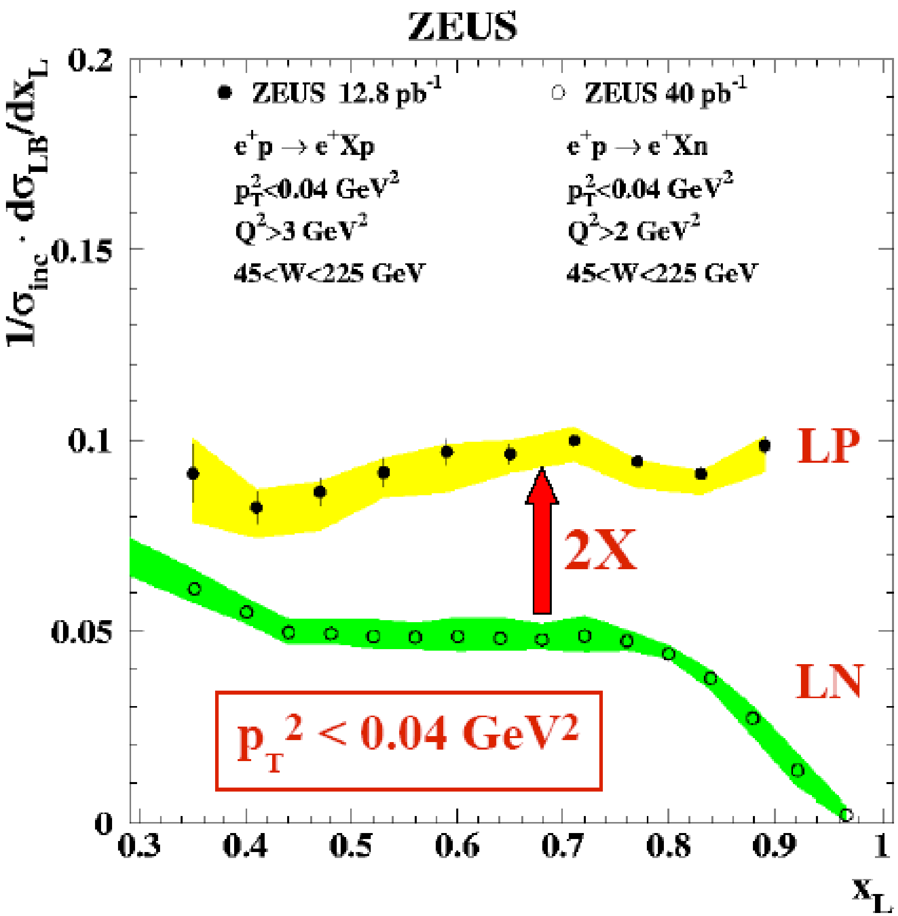


Fit by $$\frac{1}{\sigma_{inc}}\frac{d\sigma_{LP}}{dp_T^2\,dx_L} = a(x_L)\cdot e^{-b(x_L)\,p_T^2}$$



Clear different trends for LP and LN

Comparison of leading proton and neutron yields



Restricted to common p_t^2 range where det.acceptances overlap

- pure isovector (eg.pion) exchange

LP = ½ LN

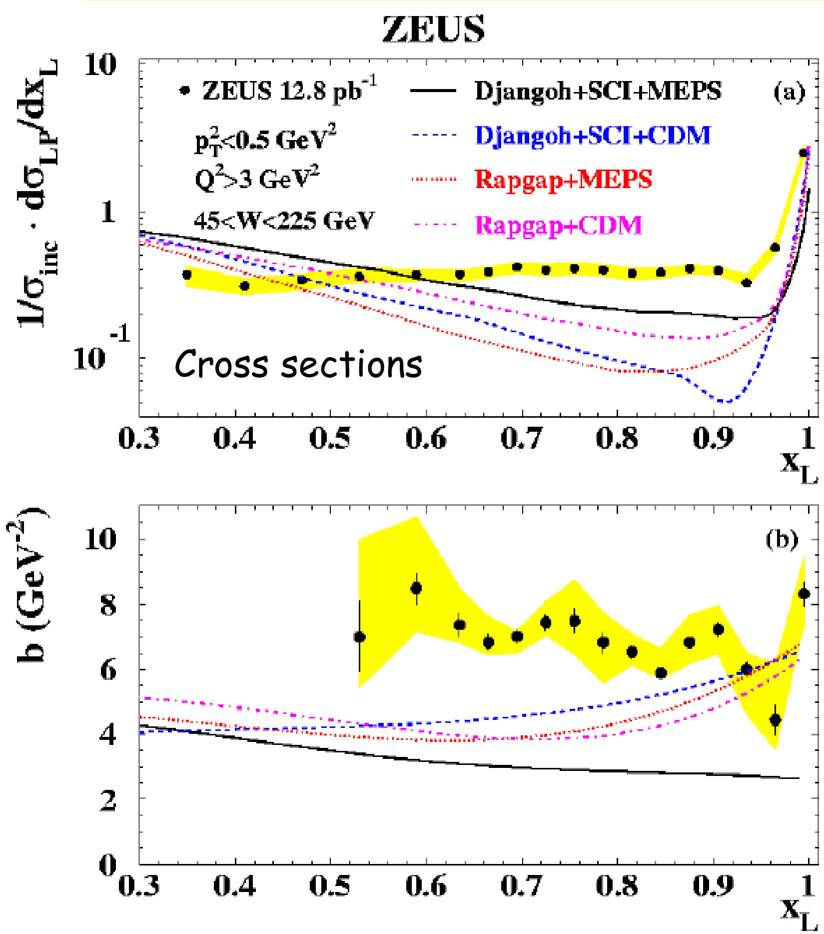
- we observe

LP ~ 2LN

Consistent with quark additive model but not with particle exchange model, additional Regge contributions (isoscalar)to account for observed rates!

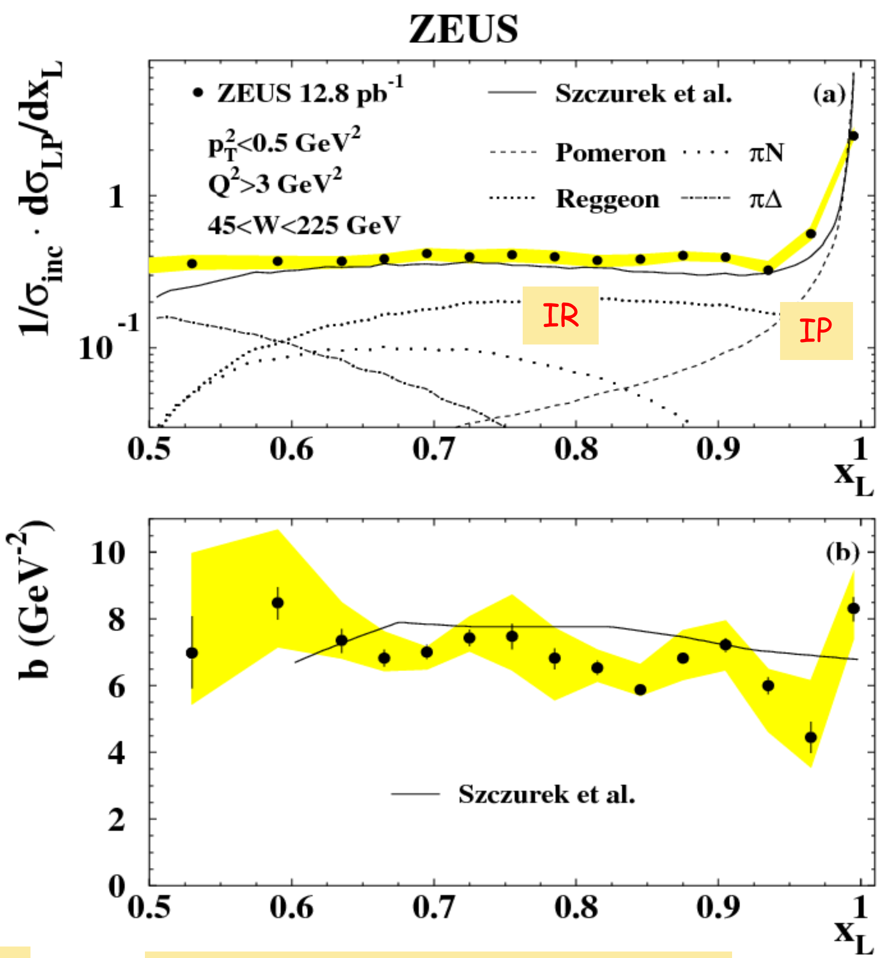
Comparison with models

Standard fragmentation models



Do not describe data out of diff.peak

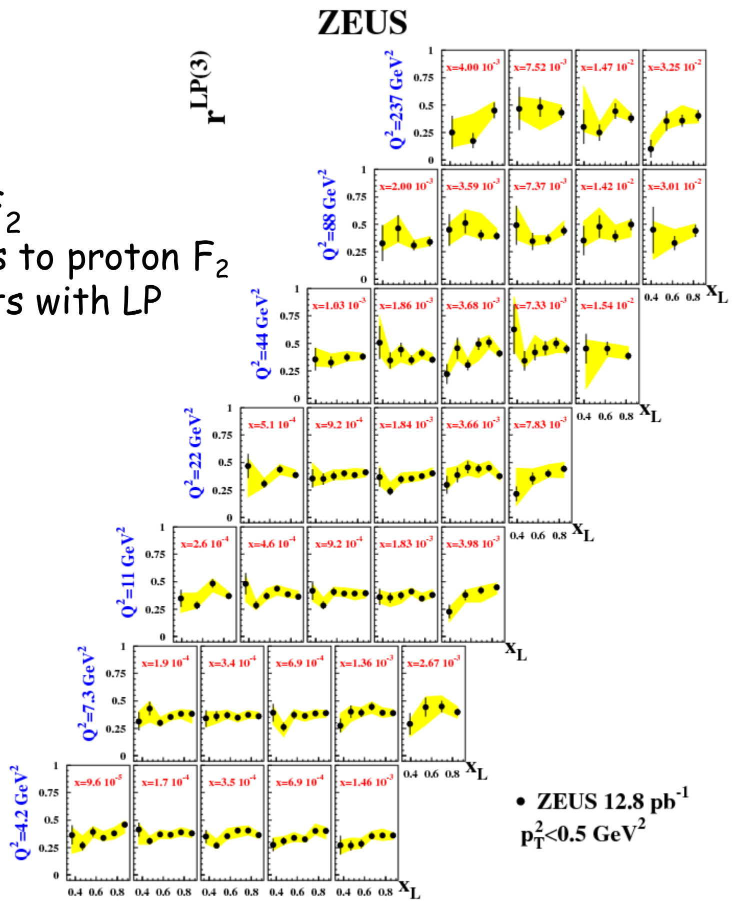
Model with multiple exchange



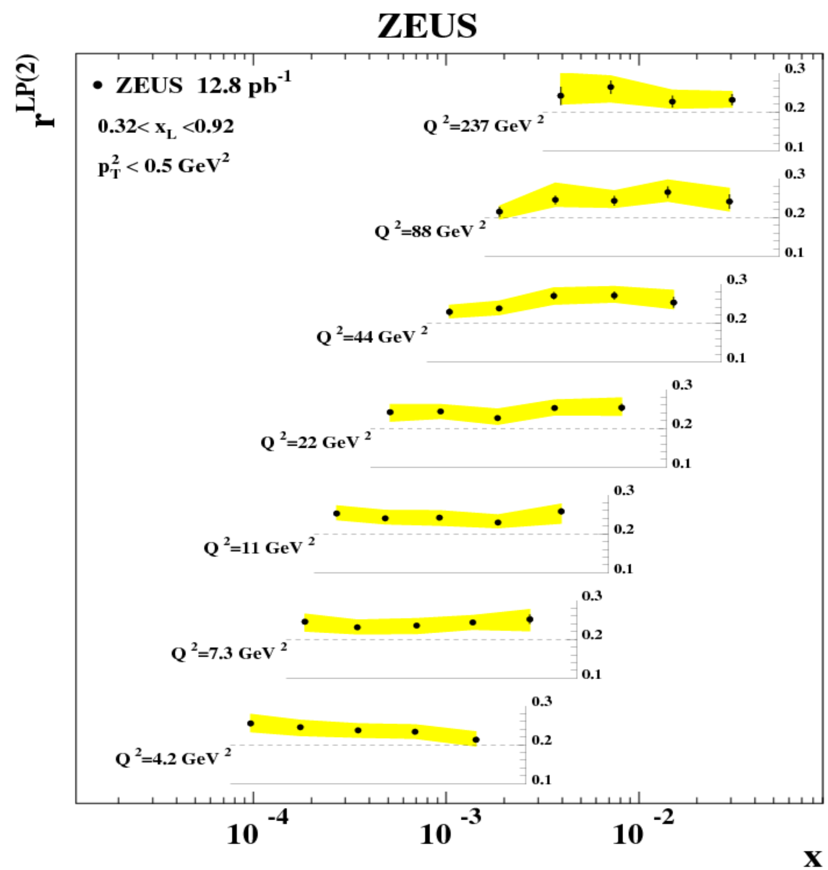
Much better description

Ratios of LP to inclusive DIS yields

$F_2^{LP(4)}/F_2$
analogous to proton F_2
for events with LP



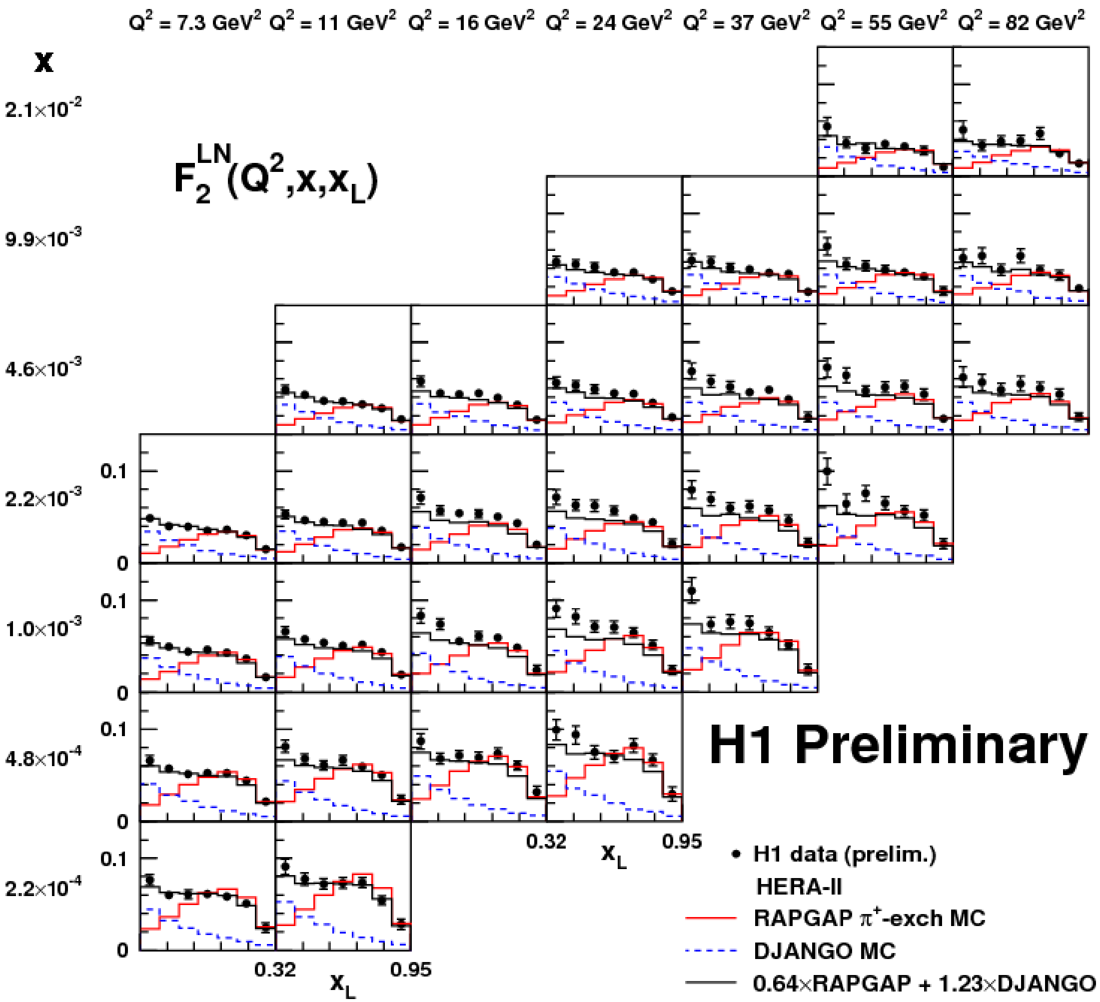
Rates to inclusive DIS



Also a function of x_L and p_T,
but no x_L and p_T dependence….

Rate is approximately constant in Q^2 and x with the value ~ 0.24

Leading neutron production in DIS

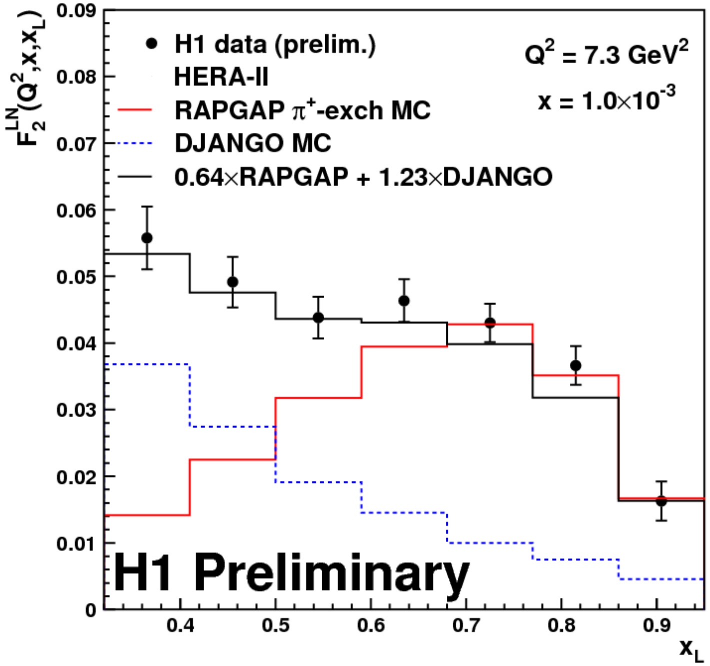


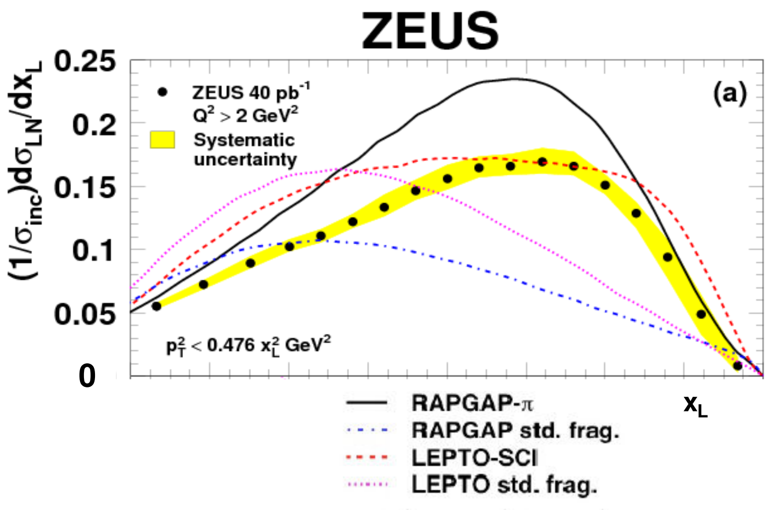
DJANGO – standard fragmentation, too low x-section, diff. x_L

RAPGAP – π^+exchange

Only mixture of RAPGAP and DJANGO MC´s is able to describe the data.

LN cross section - models

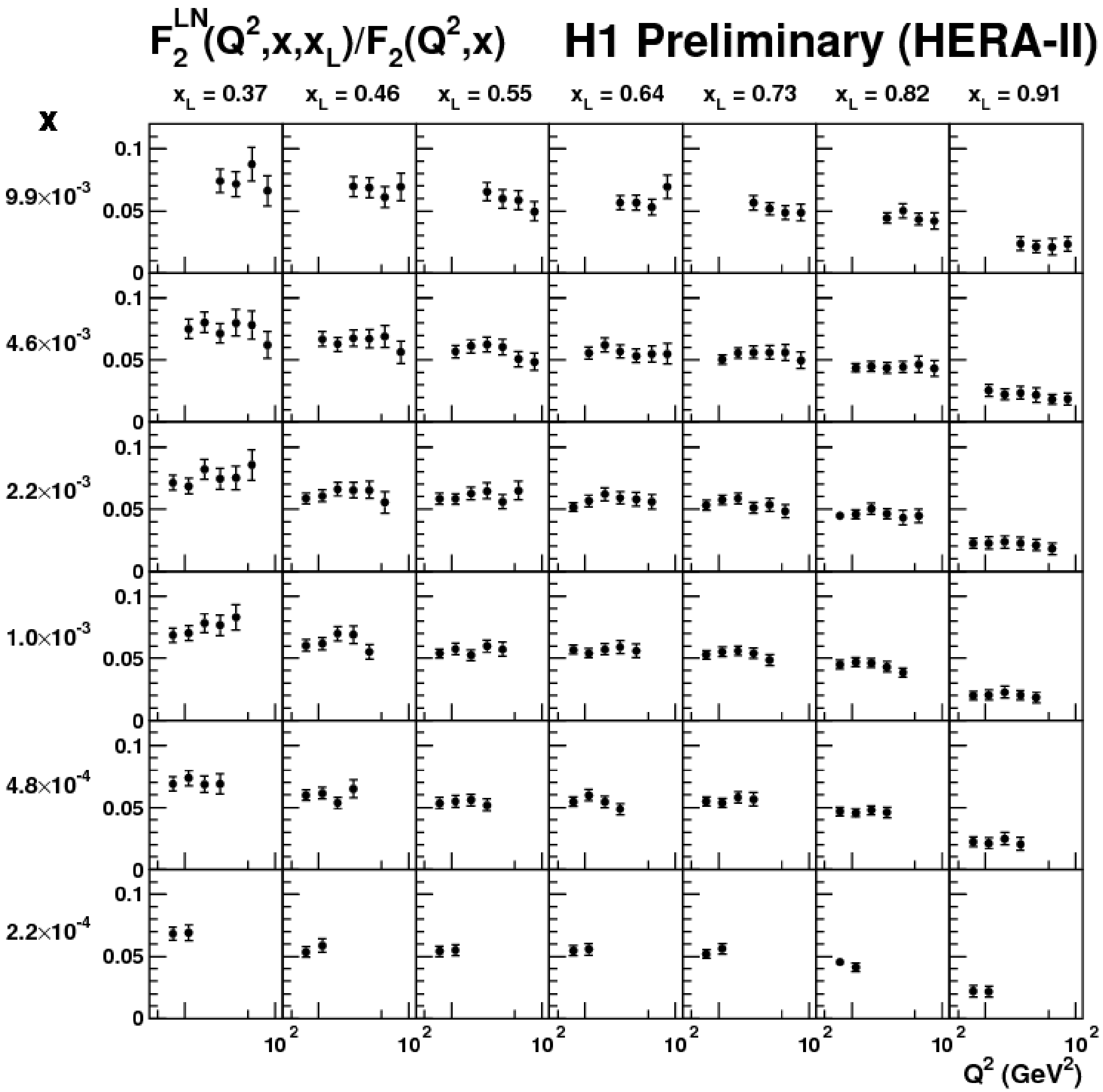




ZEUS coll. Nucl.Phys. B 776, (2007),1

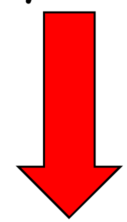
Neither pion exchange nor
standard fragmentation alone can describe LN DIS data.

Ratio $F_2^{LN}(Q^2,x,x_L)/F_2(Q^2,x)$



Ratio $F_2^{LN}(Q^2,x,x_L)/F_2(Q^2,x)$

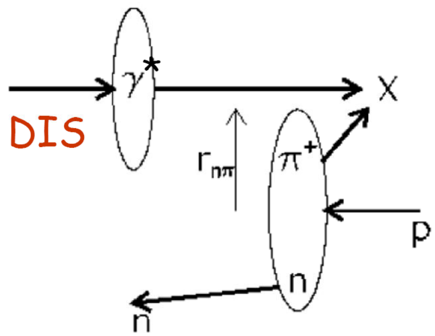
is mostly flat in Q^2 and x



like in Leading Proton measurement (see ZEUS)

Compatible with vertex factorisation hypothesis

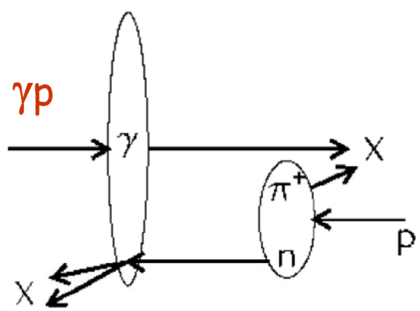
Exchange model refinement: absorptive corrections



Neutron absorption through rescattering:

enhanced when the size of πn system is small,

- neutron breaks up or
- neutron is kicked out to lower x_L and higher p_t (migration) or escapes detector acceptance – (absorption loss)



Size depends on scale Q^2, more absorption in photoproduction than in DIS (larger transverse size of $\gamma\star$)

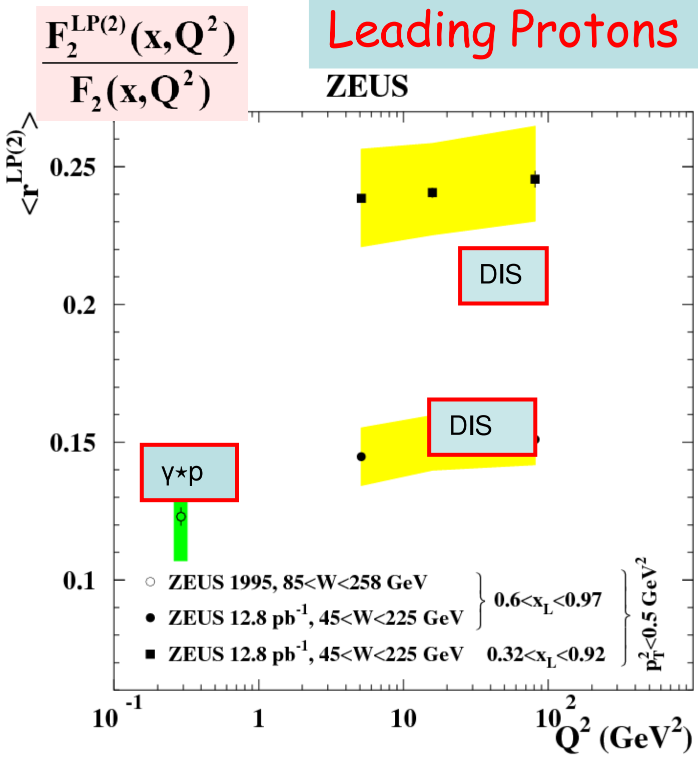
Models without absorption may overestimate the measurements.

Models with absorption and migrations: D´Alessio, Pirner; Nikolaev, Speth, Zakharov; Kaidalov, Khoze, Martin, Ryskin; Kopeliovich, Potashnikova, Schmidt, Soffer

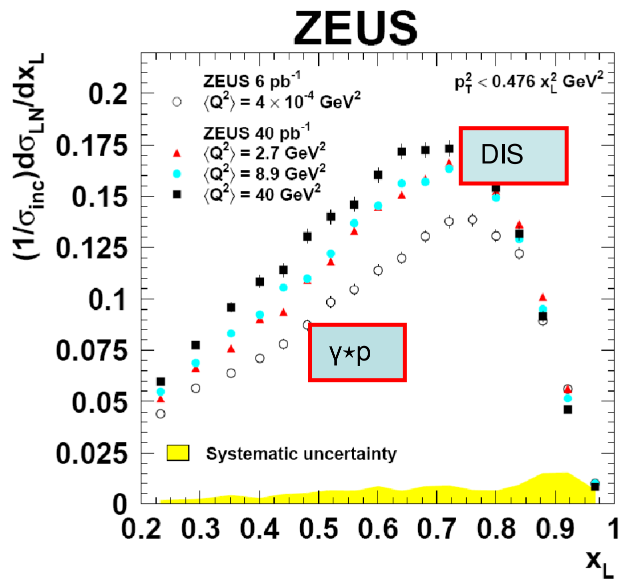
Absorption – key ingredient in calculations of gap survival probability in pp interactions at LHC, critical for hard diffractive processes –eg. diffractive exlusive Higgs production.

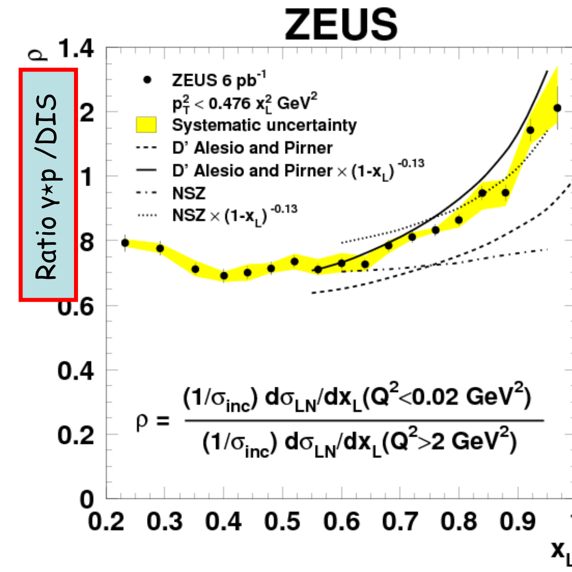
Comparison - photoproduction & DIS

Leading Protons



Leading Neutrons





Increase of LP and LN rates with Q^2

Higher Q^2 → smaller transverse γ⋆ size → less absorption
→ larger event yield

Absorption models are more succesful

Conclusions

- new comparison of methods LRG & proton spectrometers →
  contribution of proton dissociation in LRG sample about 20%,
  methods consistent in shape of diffractive reduce cross section
  consistent results H1 and ZEUS
  consistent with proton vertex factorisation

- dijets in photoproduction – hint that suppression is dependent on E_t of the leading jet → factorisation OK for high E_t?
- in similar kinematic region (and QCD fits which use dijets in DIS) → H1 and ZEUS suppression compatible (H1 ~ 0.8, ZEUS ~ 1)
- suppression is the same for direct enriched and resolved enriched events (in contradiction with theory....)

- precise measurements of leading baryons x_L and p_T^2 provided
- F_2^{LN}/F_2 and F_2^{LP}/F_2 are mostly independent on Q^2 and x
- standard fragmentation models do not describe the data
  - models combining particle exchange and standard fragmentation are more succesful
- increase of proton & neutron yields with Q^2 - absorption should be taken into account