Gap survival probability and rescattering at HERA

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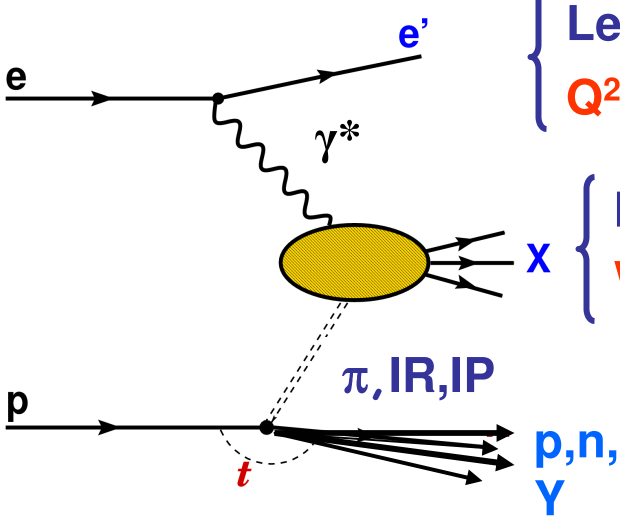
Outline:

- Introduction
- Diffractive dijets in photoproduction: gap survival probability and its E_T dependence
- Leading neutrons: rescattering and absorption
- Conclusions

Introduction

Events with leading baryons (LB) are a large fraction of the HERA cross section



Lepton variables:
Q^2, x

Hadronic variables:
W, M_X, E_T

LB variables:
$x_L = E'_{LB}/E_p$
$t = (p-p_Y)^2$

- $Q^2 >> 0$:

Deep inelastic scattering (**DIS**)

- $Q^2 \sim 0$:

Photoproduction (γ**p**)
Quasi-real γ ~ hadron

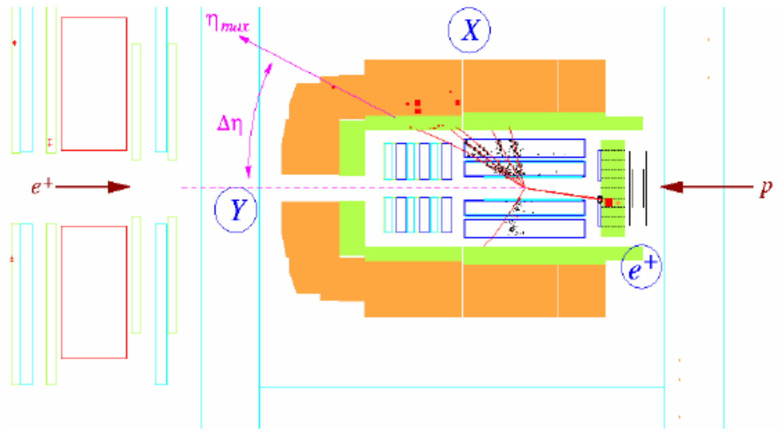
The increasing role of rescattering in the transition from DIS to hadron-hadron can be studied at HERA by comparing DIS with γp:

- In diffraction, rapidity gaps may be destroyed by secondary particles generated by rescattering processes between the hadronic final state and the proton remnant

- Leading neutron yields and distributions may be effected by rescattering

Event selection

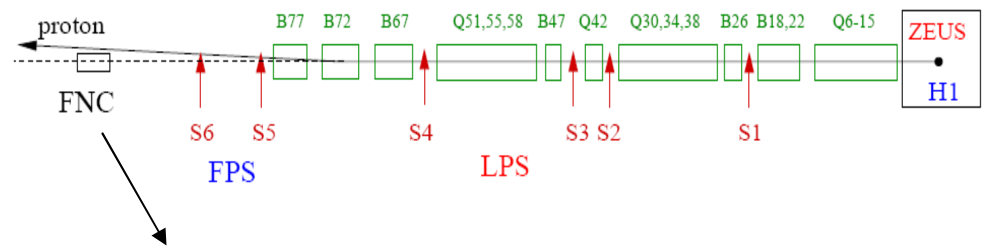
Diffractive events:



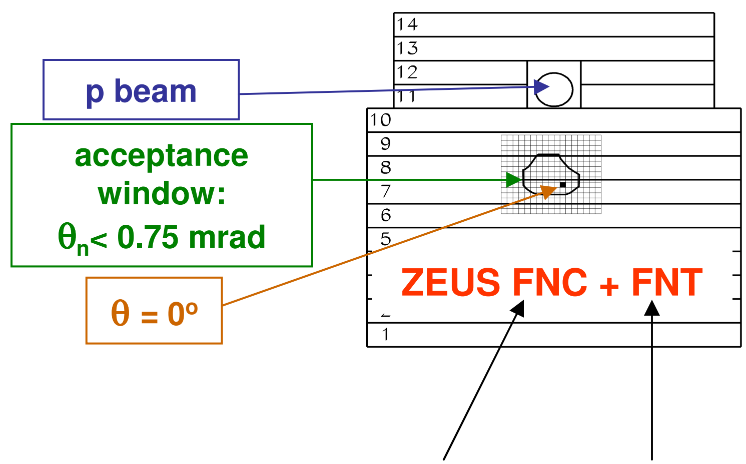
'Large rapidity gap' method:

- Exchange of colourless IP: lack of particle flow in the p direction
- Loss of information about scattered p
- Contribution from p dissociation
- High statistics

Leading neutrons:



Forward neutron calorimeters:



- Measure energy and p_T

QCD factorization in diffraction

H1, EPJ C48 (2006) 715

QCD factorization theorem

proven for DIS by **J.Collins**, **PR D57 (1998) 3051**

$$\sigma^D(\gamma^* p \to Xp) = \sum_i \hat{\sigma} \otimes f_i^D(t, x_{IP}, z, Q^2)$$

Hard subprocess ME

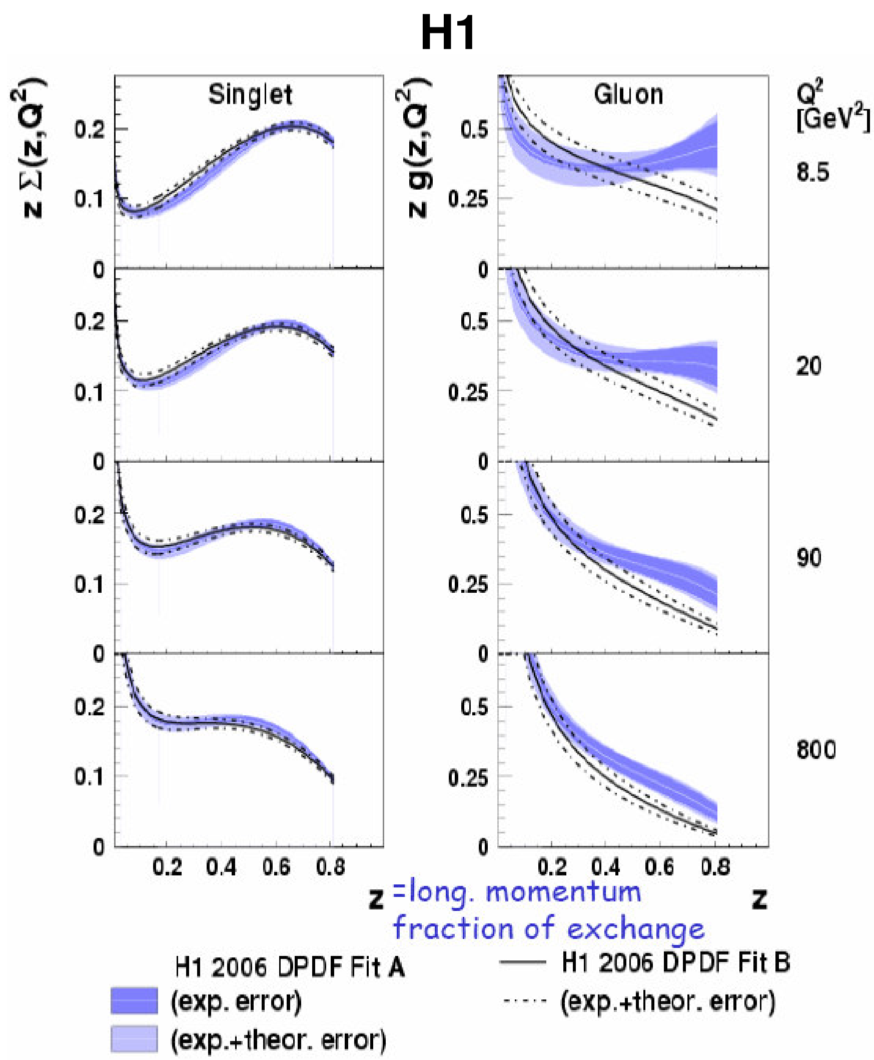
pQCD calculable

Diffractive PDFs

=

std proton PDFs +
diffractive requirement

Diffractive PDFs extracted via NLO DGLAP fit from inclusive diffractive data



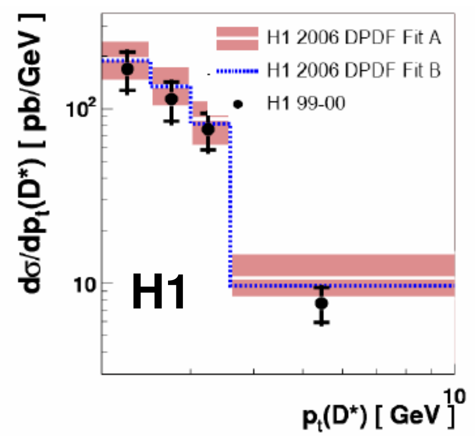
D* and dijets in diffractive DIS

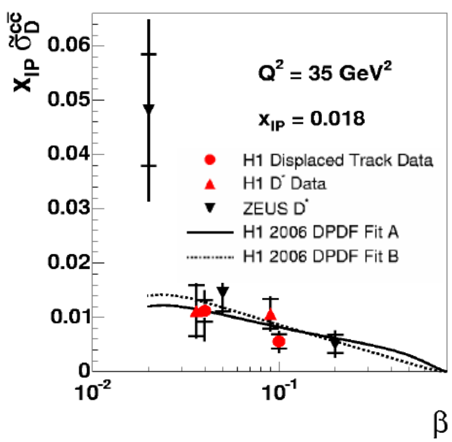
Use DPDFs extracted from inclusive DDIS for calculating NLO predictions to semi-inclusive final states: **test universality of DPDFs**

→ Open charm and dijets in DIS: hard scales in the process ensure use of pQCD

Open charm:

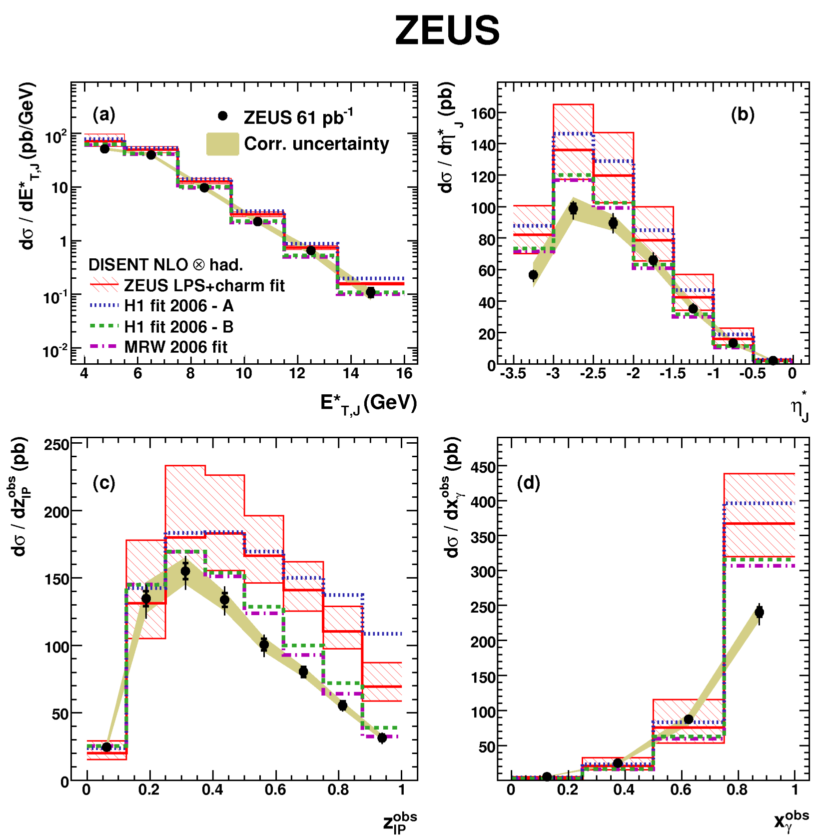
H1, DESY 06-164
ZEUS, NP B672 (2003) 3





Dijets:

H1, JHEP 0710:042 (2007)
ZEUS, EPJ C52 (2007) 813

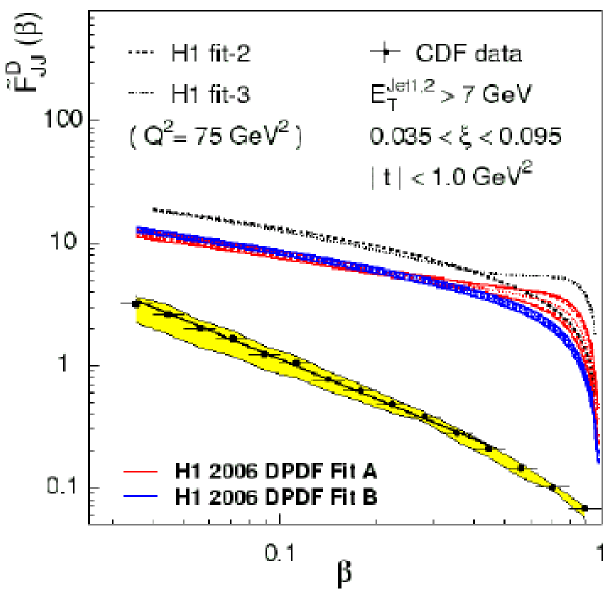


H1 and ZEUS data agree with NLO predictions within uncertainties

→ **QCD factorization holds in DDIS!**

Use D* and jet data to better constrain DPDFs

Factorization breaking at Tevatron and Gap survival probability



CDF, PRL 84 (2000) 5043 + P.Newman/H1

Diffractive dijet measurement in ppbar by CDF

Comparison with NLO predictions with **HERA DPDFs as input**:

Significant **overestimation** (~ factor 10) of the data by NLO calculations and **different shape**

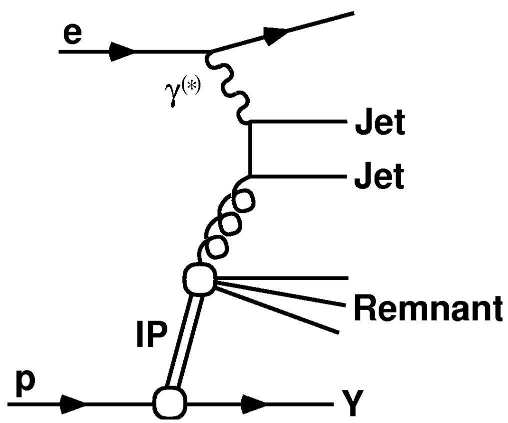
Factorization not expected to hold for diffractive hadron-hadron collisions

- Violation of factorization is understood in terms of (soft) rescattering between the spectator partons, in initial and final states, suppressing the large rapidity gap: suppression ↔ 'rapidity gap survival probability'
- Models including rescattering corrections via multi-pomeron exchanges are able to describe the suppression observed [**KKMR, EPJ C21 (2001) 521**]
- **Of great interest for LHC!**

Hadron-hadron and photoproduction

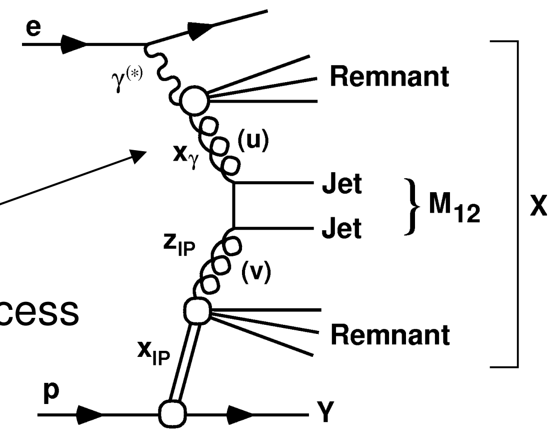
At HERA we have something similar to a hadron:
quasi-real photons ($Q^2 \sim 0$) can develop a **hadronic structure**

Direct photon ($x_\gamma \sim 1$) (at LO) **Resolved photon ($x_\gamma < 1$)**



High E_T of the jets provides the hard scale

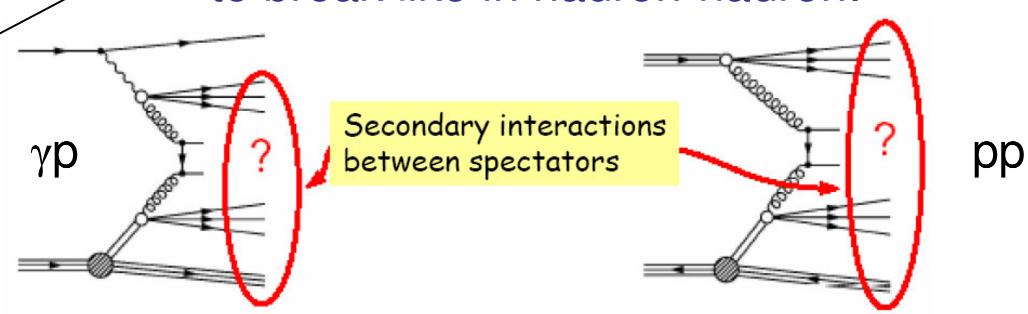
x_γ = fraction of photon's momentum in hard subprocess



QCD factorization is expected to hold like in DIS

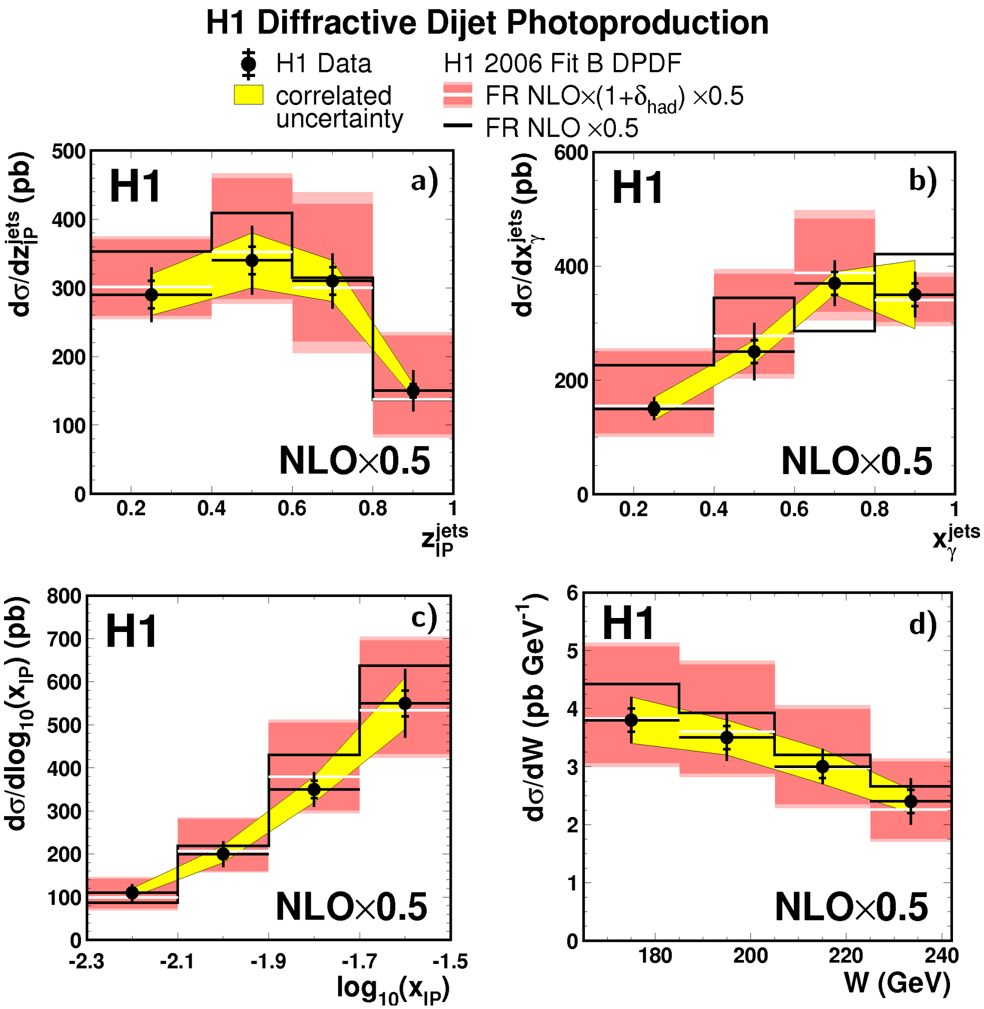
QCD factorization is expected to break like in hadron-hadron:

Expected suppression ~ 0.34 for resolved γ [KKMR, PL B567 (2003) 61]



Dijets in diffractive photoproduction

H1, EPJ C51 (2007) 549



- $E_T^{jet1} > 5$ GeV, $E_T^{jet2} > 4$ GeV
- Cross section include p dissoc. with $M_Y < 1.6$ GeV
- Cross section corrected at hadron level

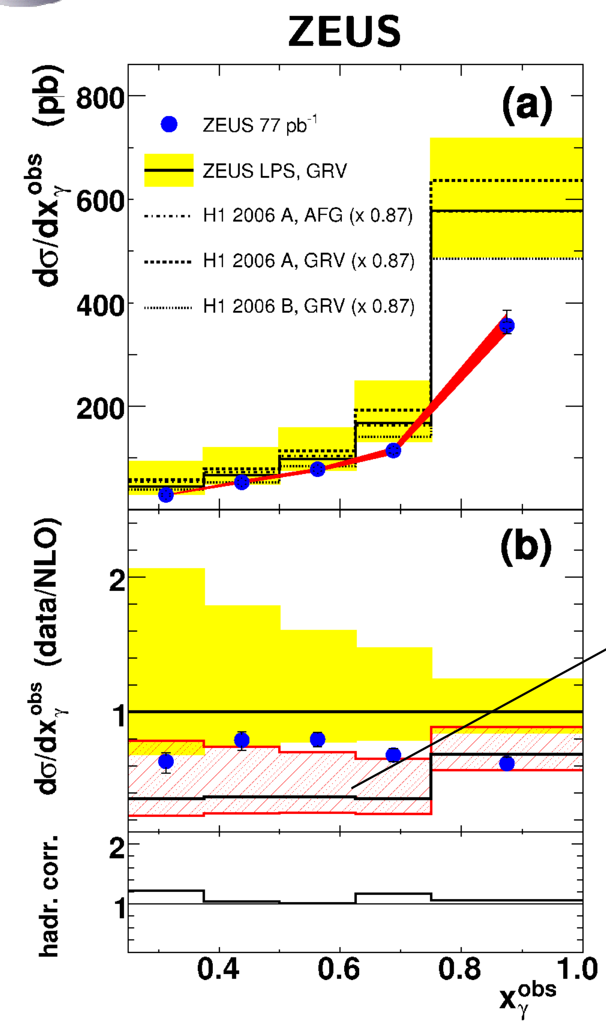
NLO overestimates the measured cross section by a factor ~ 2, both in the direct and resolved region

Suppression in γp is much smaller than in ppbar

NLO predictions assuming factorization with Frixione et al. program [NP B467 (1996) 399; B507 (1997) 295]

Dijets in diffractive photoproduction

ZEUS, EPJ C55 (2008) 177



- $E_T^{jet1} > 7.5$ GeV, $E_T^{jet2} > 6.5$ GeV
- Cross section scaled down for p-dissoc. contribution: (16±4)%
- Cross section corrected at hadron level

Suppression factor 0.34 applied to resolved component only

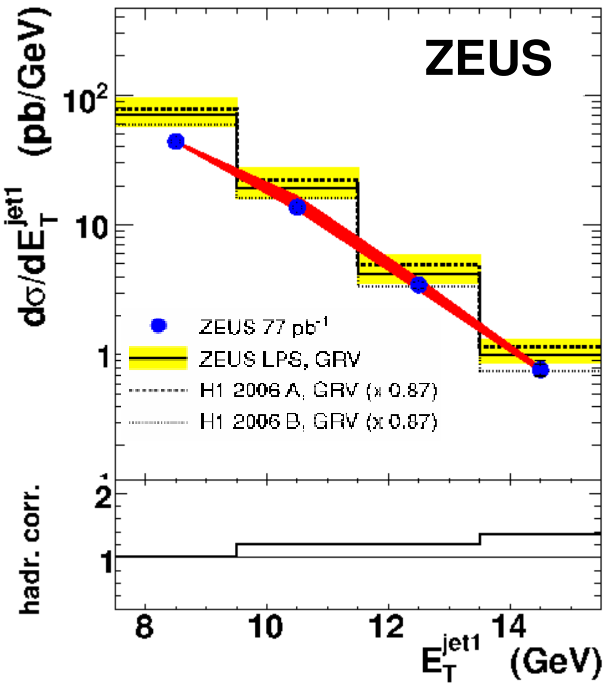
Within uncertainties data show a weak (if any) suppression: 0.6-0.9

ZEUS as H1 do not see any difference between the resolved and direct regions, in contrast to theory!

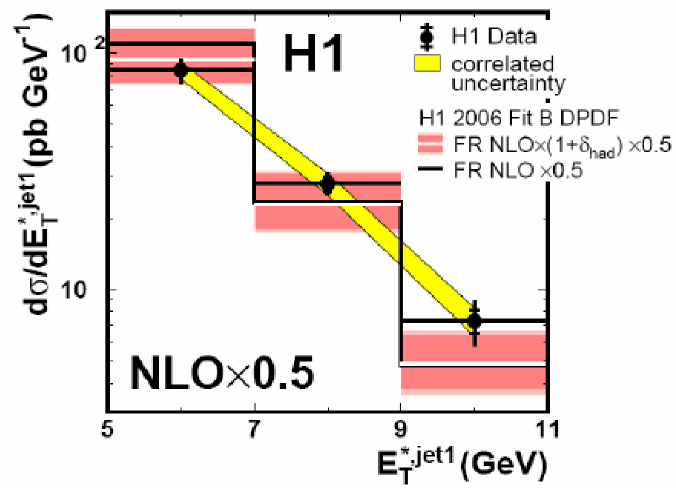
NLO predictions assuming factorization with Klasen & Kramer program [**EPJ C38 (2004) 9**]

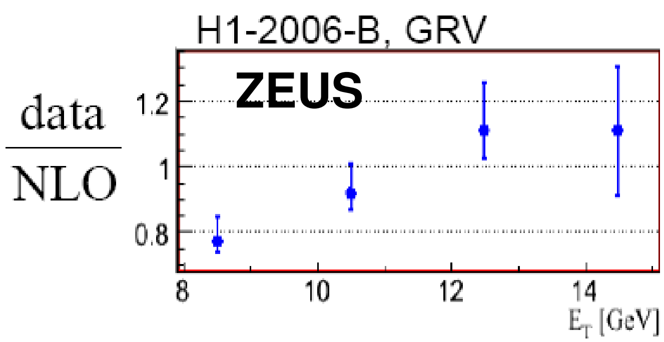
E_T dependence of suppression?

Difference between H1 and ZEUS possibly due to different E_T regions?



Data have a harder E_T slope than NLO



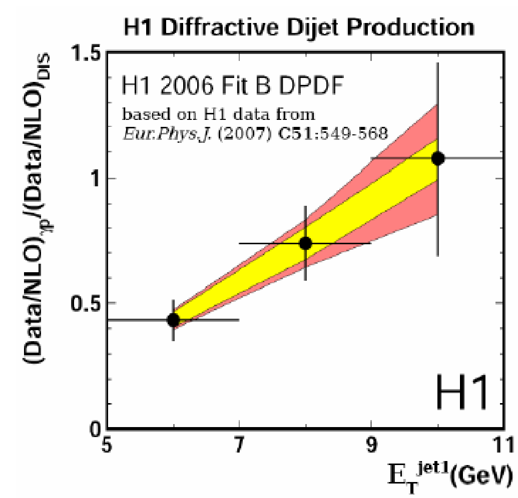


Better seen with

$$\textit{Double ratio} = \frac{(\,Data\,/\,NLO\,)_{\gamma p}}{(\,Data\,/\,NLO\,)_{DIS}}$$

to cancel DPDFs uncertainty

A signal that gap survival probability might increase with E_T



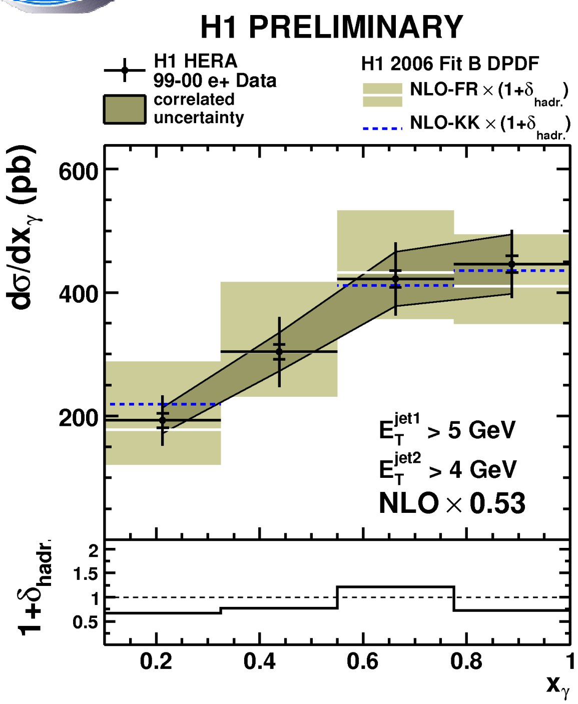
New H1 analysis of dijets in γp

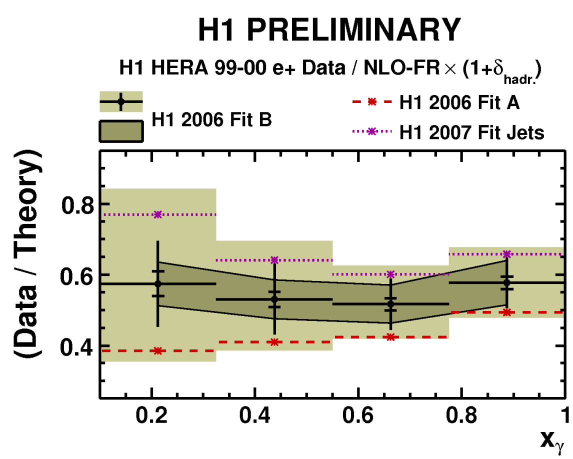
H1 prel-08-012

- 99/00 data: higher luminosity (x3) compared to previous results
- Two E_T cut scenarios:

Low E_T scenario (cross check with previous H1 results)	High E_T scenario (similar to ZEUS kinematic region)	**ZEUS**:
$E_T^{jet1} > 5$ GeV	$E_T^{jet1} > 7.5$ GeV	
$E_T^{jet2} > 4$ GeV	$E_T^{jet2} > 6.5$ GeV	
$-1 < \eta^{jet1,jet2} < 2$	$-1.5 < \eta^{jet1,jet2} < 1.5$	
$x_{IP} < 0.03$	$x_{IP} < 0.025$	
$0.3 < y_e < 0.65$	$0.3 < y_e < 0.65$	$0.3 < y_{JB} < 0.85$
$Q^2 < 0.01$ GeV^2	$Q^2 < 0.01$ GeV^2	$Q^2 < 1$ GeV^2
$\|t\| < 1$ GeV^2	$\|t\| < 1$ GeV^2	
$M_Y < 1.6$ GeV	$M_Y < 1.6$ GeV	No p dissoc.

Low E_T scenario



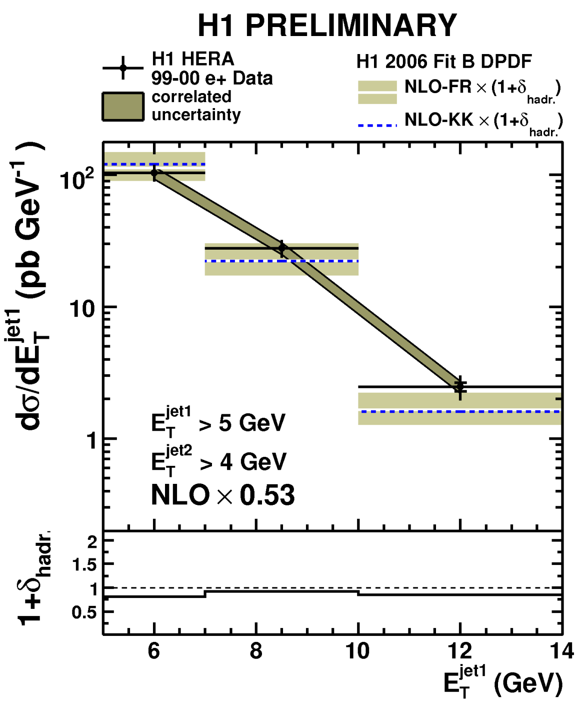


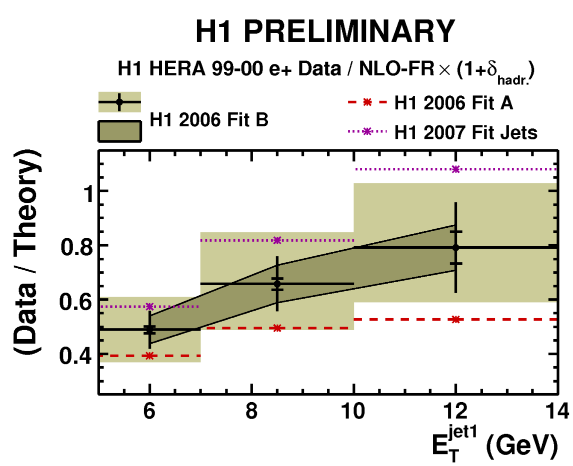
Measurements compared to two NLO calculations: Frixione-Ridolfi and Klasen-Kramer

Three sets of DPDFs: H1-2006 Fit A, Fit B, Fit Jets

No sign of x_γ dependence of the gap survival probability, as in previous H1 and ZEUS analyses

Low E_T scenario





Another hint of an E_T spectrum harder in data than in NLO calculations

Survival probabilities in range 0.43 – 0.65, depending on DPDFs
(always compatible within uncertainties):

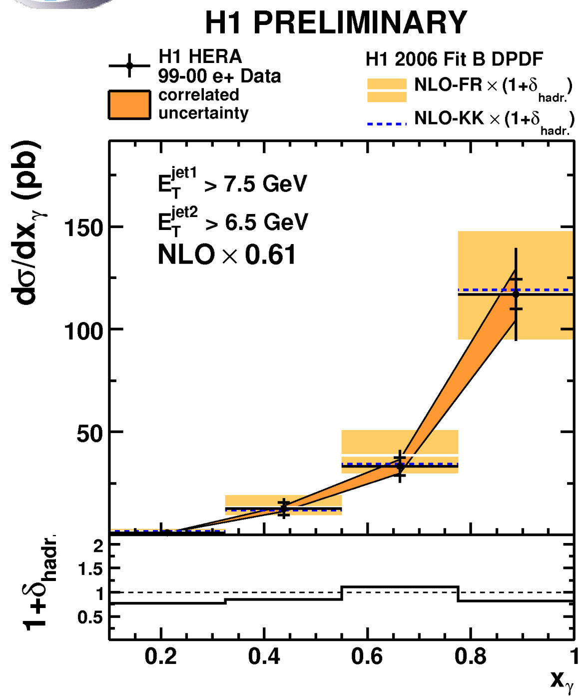
$$S^{FR}_{fitB} = 0.54 \pm 0.01(\,stat.) \pm 0.10(\,syst.)^{+0.14}_{-0.13}(\,scale\,)$$

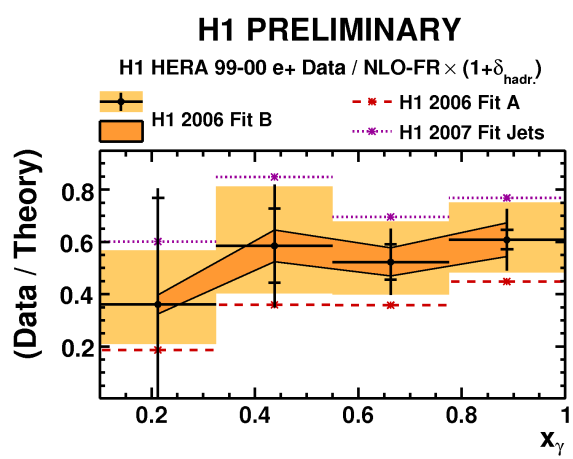
$$S^{KK}_{fitB} = 0.51 \pm 0.01(\,stat.) \pm 0.10(\,syst.)$$

$$S^{FR}_{fitA} = 0.43 \pm 0.01(\,stat.) \pm 0.10(\,syst.)$$

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

High E_T scenario





Higher E_T cut selects more ‘direct-like’ events:
→ appearance of a peak at high x_γ as in ZEUS data

Confirmation that no x_γ dependence of the gap survival probability is observed

Survival probabilities in range 0.44 – 0.79, slightly higher than in low E_T scenario:
→ H1 closer to ZEUS!

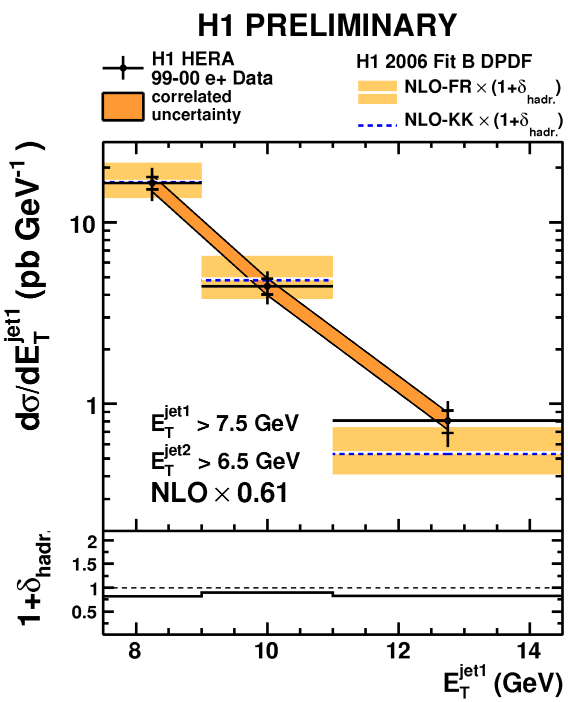
$$S^{FR}_{fitB} = 0.61 \pm 0.03(\,stat.) \pm 0.13(\,syst.)^{+0.16}_{-0.14}(\,scale\,)$$

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

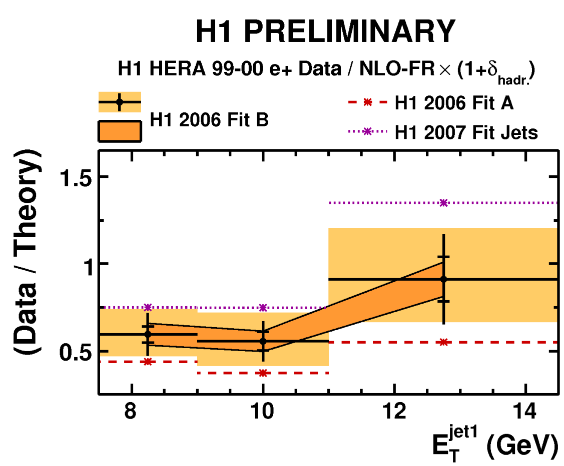
$$S^{FR}_{fitA} = 0.44 \pm 0.02(\,stat.) \pm 0.09(\,syst.)$$

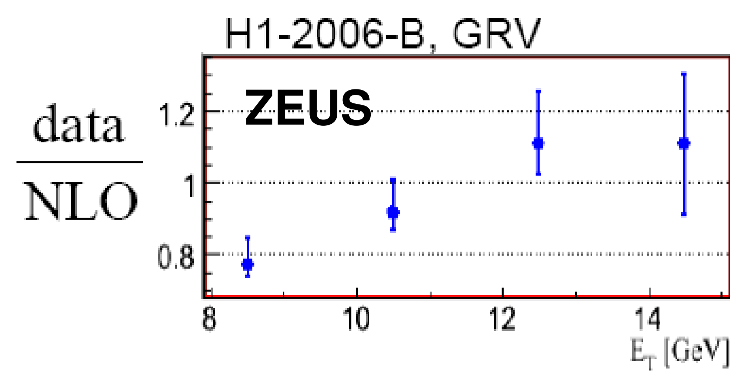
$$S^{FR}_{fitJets} = 0.79 \pm 0.04(\,stat.) \pm 0.16(\,syst.)$$

High E_T scenario

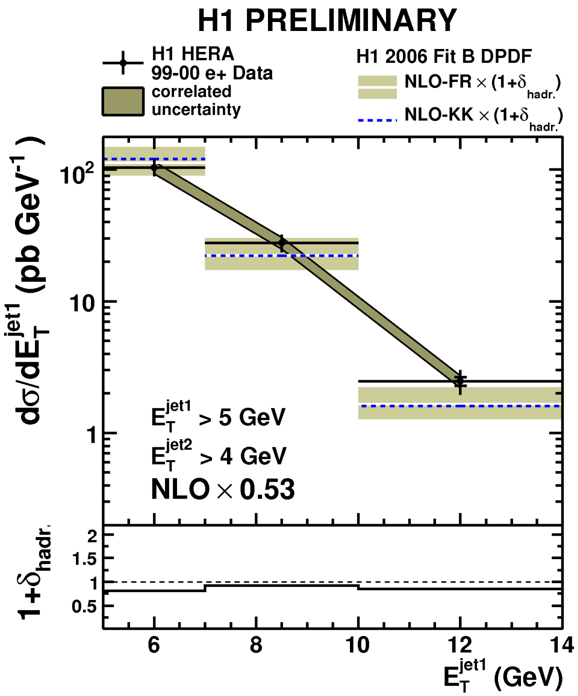


Also in high E_T scenario hint of an E_T spectrum harder in data than in NLO calculations

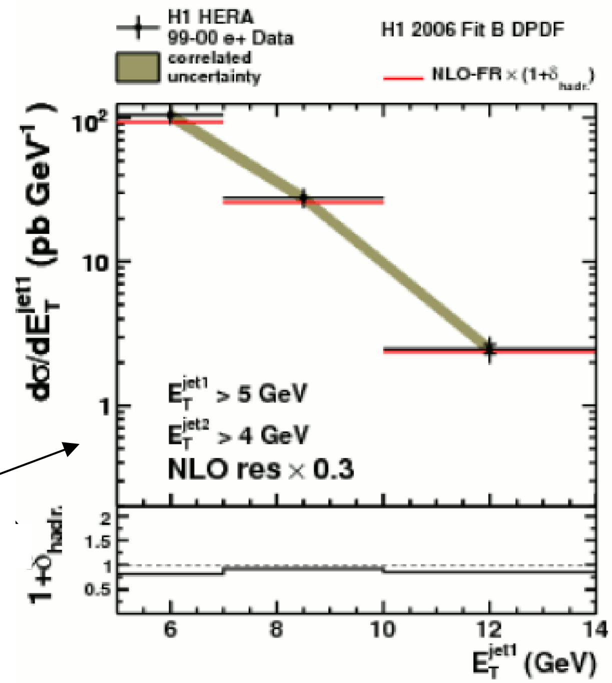




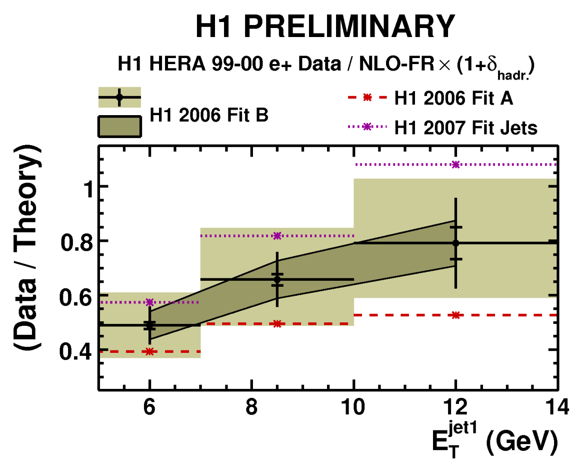
Global or resolved-only suppression?



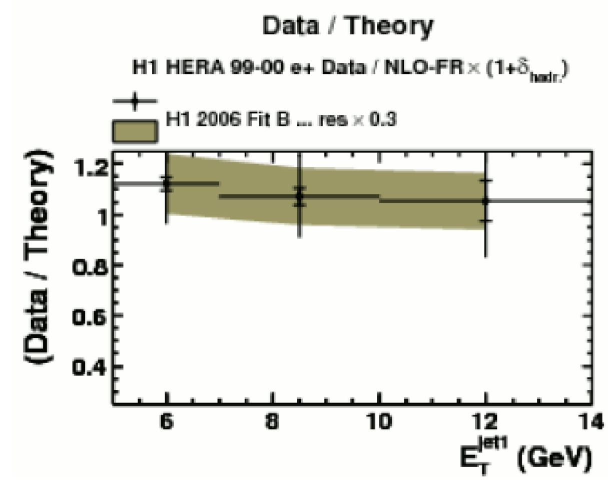
Global suppression by 0.53



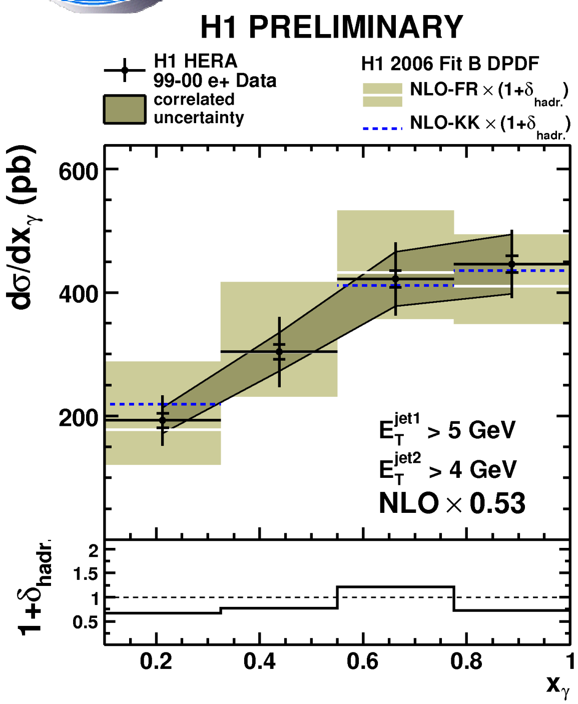
Resolved-only suppression by 0.3

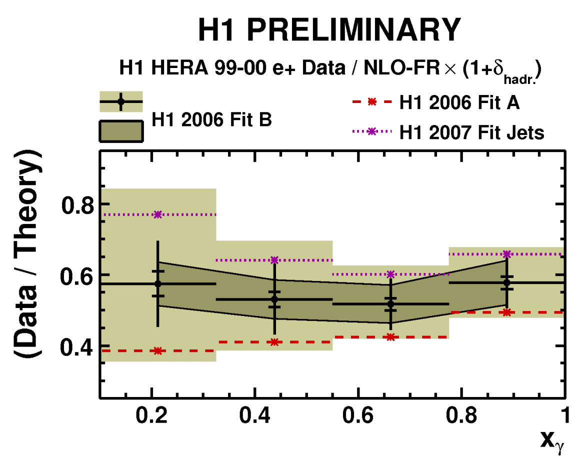


No E_T dependence with resolved-only suppression



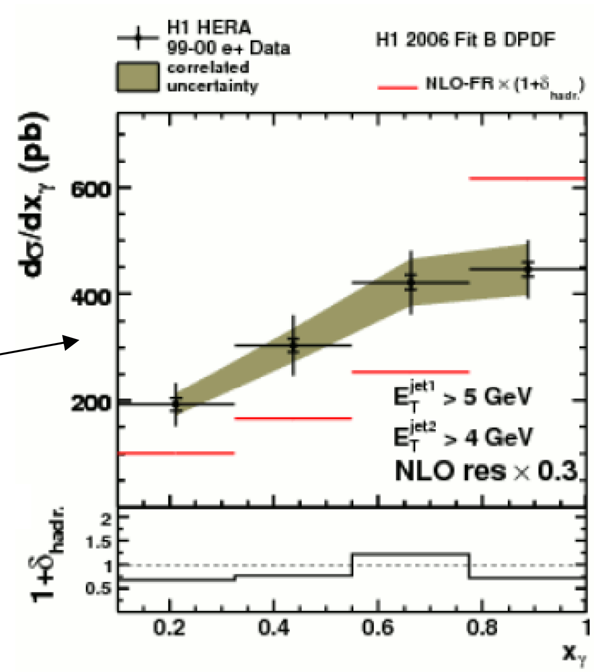
Global or resolved-only suppression?





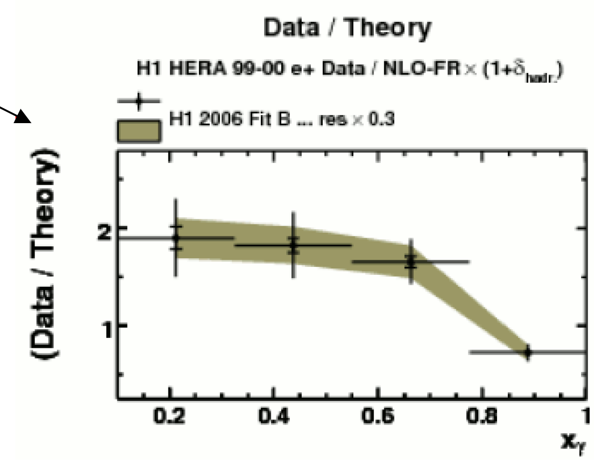
Global suppression by 0.53

Resolved-only suppression by 0.3



With resolved-only suppression much worse agreement in x_γ distribution

→ Experiments seem to prefer global suppression



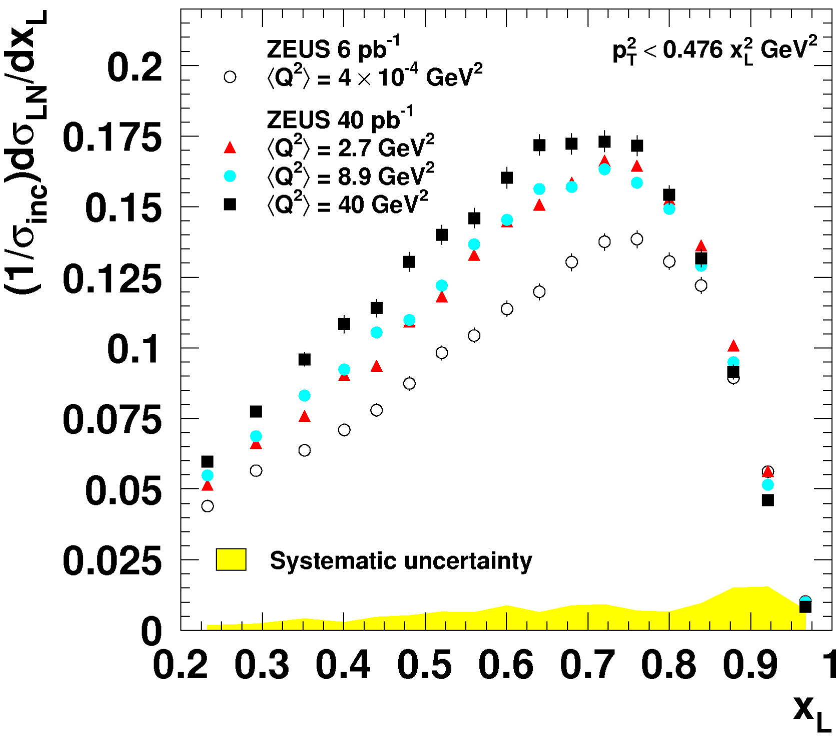
See also Klasen & Kramer DESY 08-074

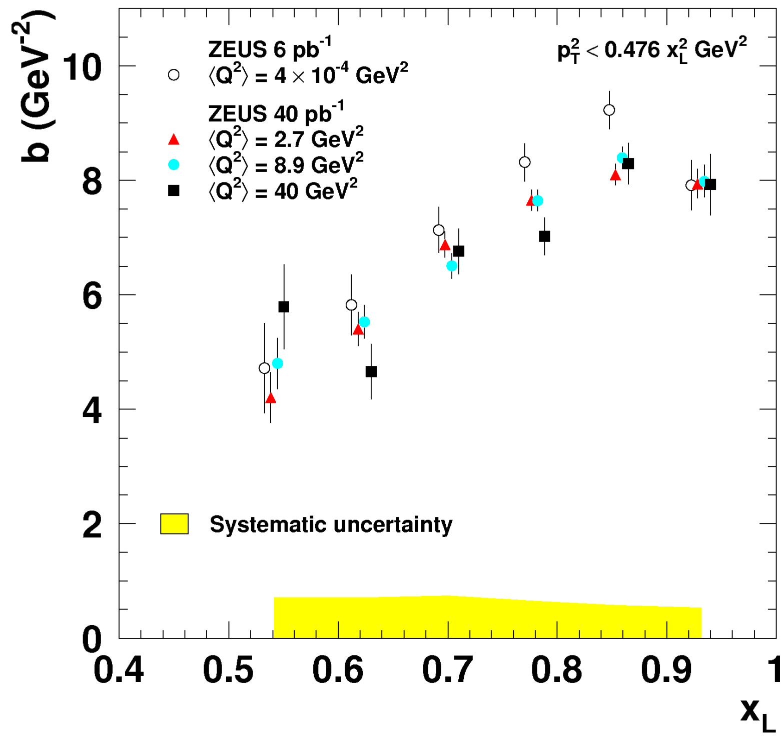
Leading neutron data: γp vs DIS

ZEUS, NP B776 (2007) 1

DIS (3 Q^2 bins) and γp

$p_T{}^2$ distributions fitted exponentially:

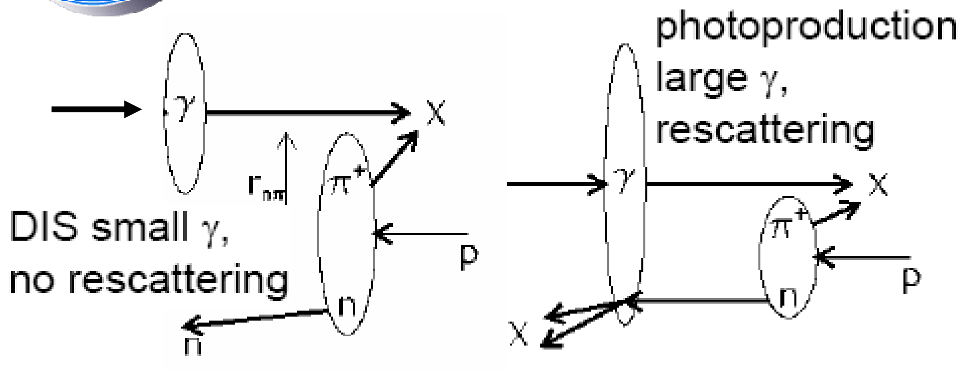




- Yield increases from γp to DIS
- Small but significant increase from mid to high Q^2

- DIS slopes almost equal
- γp slopes higher at intermediate $0.6 < x_L < 0.9$

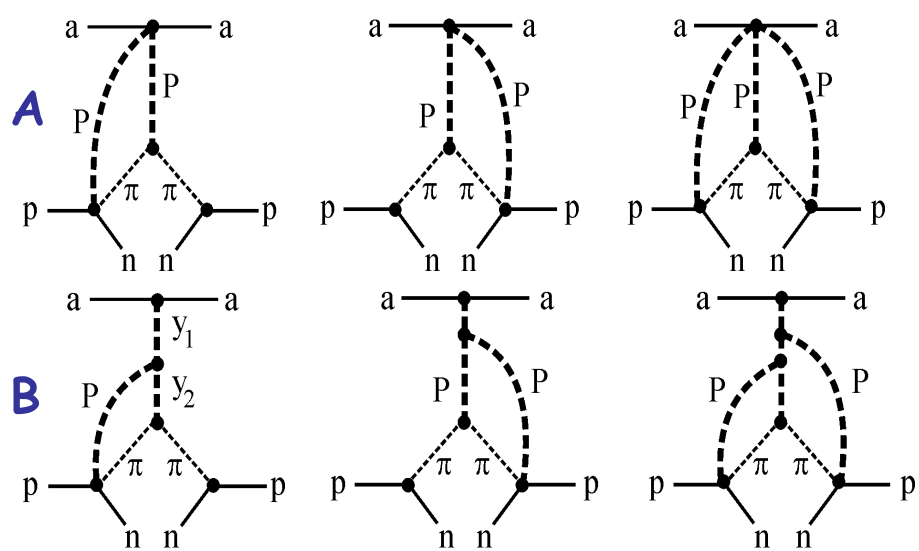
Absorption models: LN via π exchange



D'Alesio and Pirner, EPJ A7 (2000) 109

- the larger the photon, the fewer the n's detected (more absorption in γp than DIS)
- the smaller the n-π system ($r_{n\pi}$), the fewer the n's detected (more absorption at high p_T, low x_L)

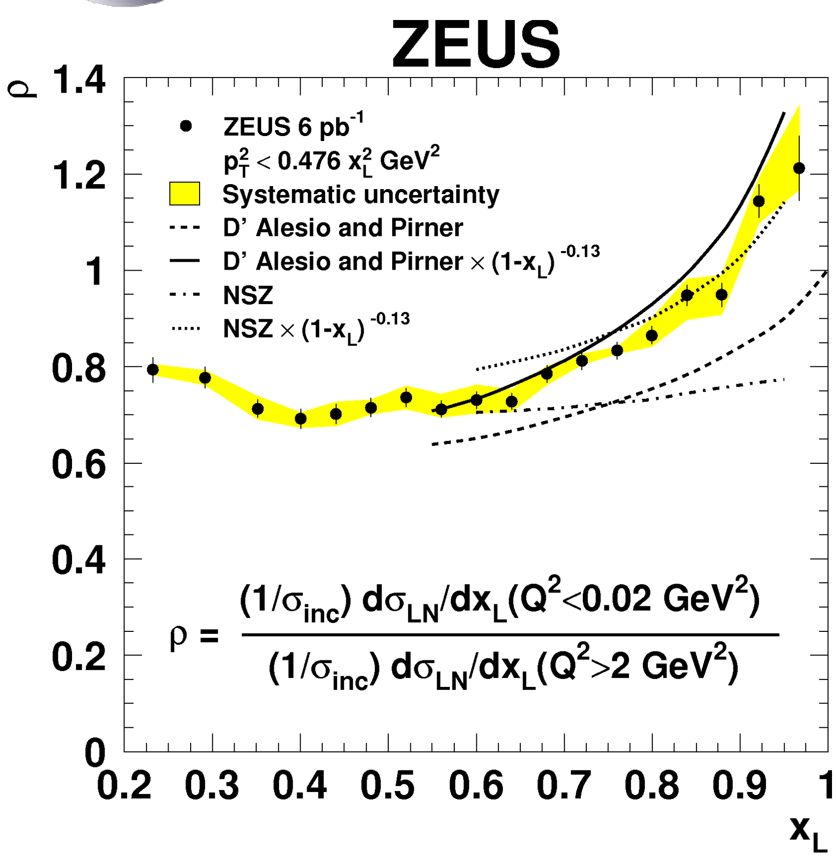
Absorption from additional pomeron exchange:
(Nikolaev, Speth, Zakharov, hep-ph/9708290)



(Kaidalov), Khoze, Martin, Ryskin
EPJ C47 (2006) 385; EPJ C48 (2006) 797

- evaluate correction due to enhanced absorptive diagrams B (small, ~15%)
- show importance of distortion of energy spectra (migration) due to rescattering for $x_L < 0.8$
- include effects of ρ, a_2 exchange
- estimate the gap survival factor S^2 (important for LHC!) which takes into account that rescattering may populate the rapidity gap with secondary particles carrying away energy from the leading neutron

Comparison with π exch. + absorption



Ratio γp/DIS rises with increasing x_L

Consistent with π exchange + geometrical absorption model (D'Alesio and Pirner):

- **more absorption in γp than DIS**
- average n-π separation $r_{n\pi}$ increases with x_L (from pion flux): bigger $r_{n\pi}$ → **less absorption at high x_L**

Consistent with Regge-based model with multi-pomeron exchanges (NSZ)

Note on energy dependence:

Different dependence of $\sigma_{\gamma\pi}$ on c.m. energy

$$s' = (1-x_L)W^2$$

in DIS and γp.

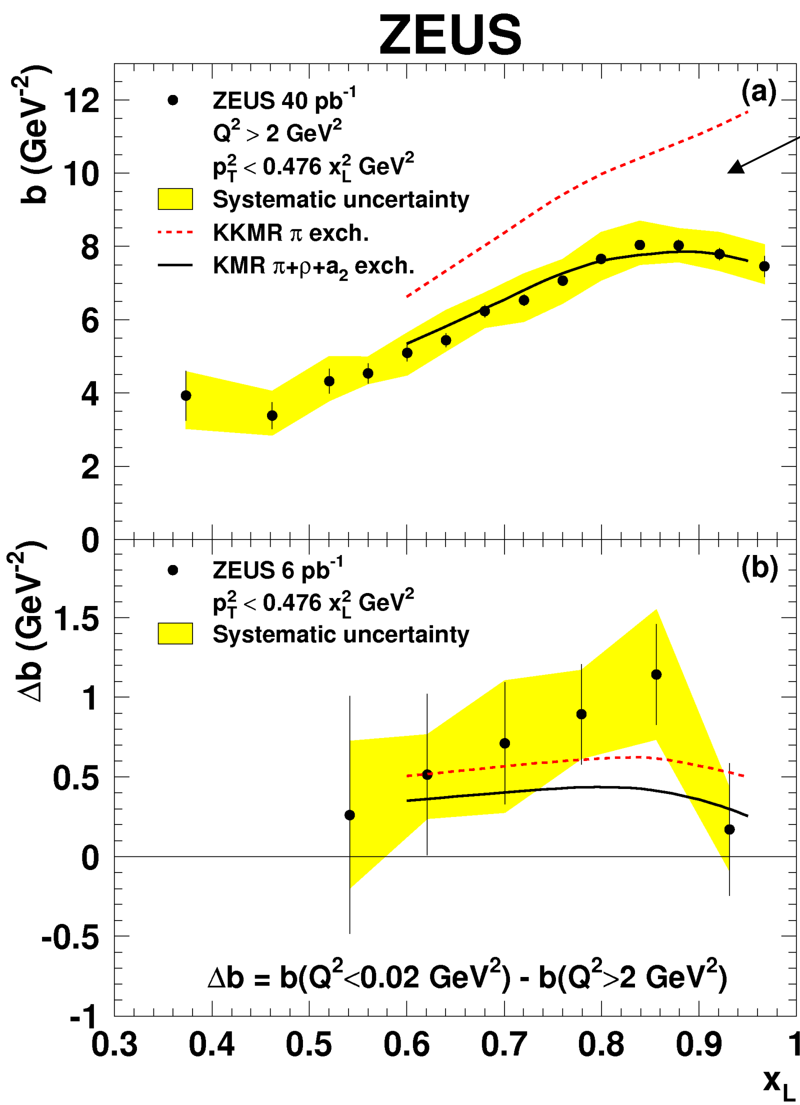
⇨

Assuming same power-law dependence of γp and $\gamma\pi$ cross-sections, at fixed W

$$\sigma^{\gamma\pi}/\sigma^{\gamma^*\pi} \sim (1-x_L)^{-0,13}$$

→ absorption ratio scaled by $(1-x_L)^{-0.13}$

Comparison with enhanced absorption model + secondary exch.: b slopes



All DIS bins combined together

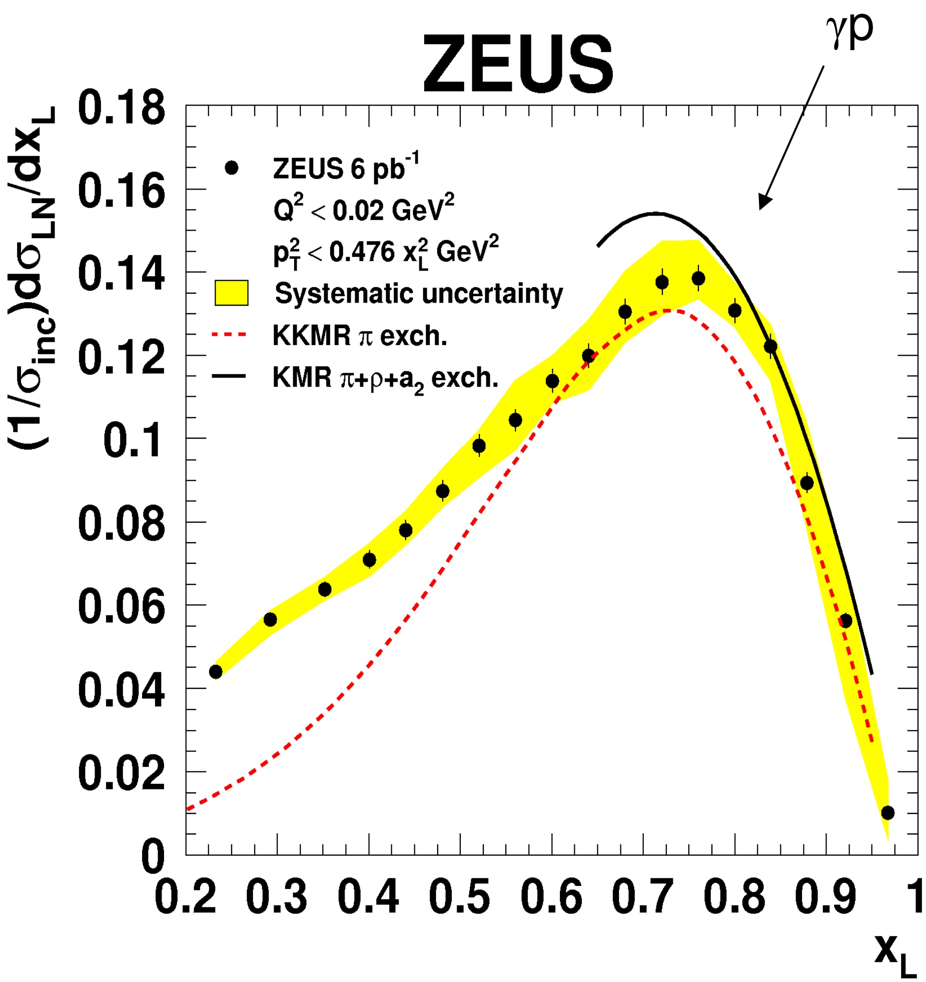
Model by Kaidalov, Khose, Martin, Ryskin (KKMR), including rescattering corrections with migration and absorption, is not enough to describe the data

→ including secondary (ρ, a_2) exchanges (KMR) allows a good description of b slopes of LN $p_T{}^2$ distributions

Size of (n-π) system proportional to $1/p_T^{neutron}$

→ **rescattering removes n's with high p_T**: the bigger absorption for small (n-π) systems casues a depletion of high-p_T neutrons, more in γp than in DIS

Comparison with enhanced absorption model + secondary exch.: x_L spectrum



Model by Kaidalov, Khose, Martin, Ryskin (KKMR):

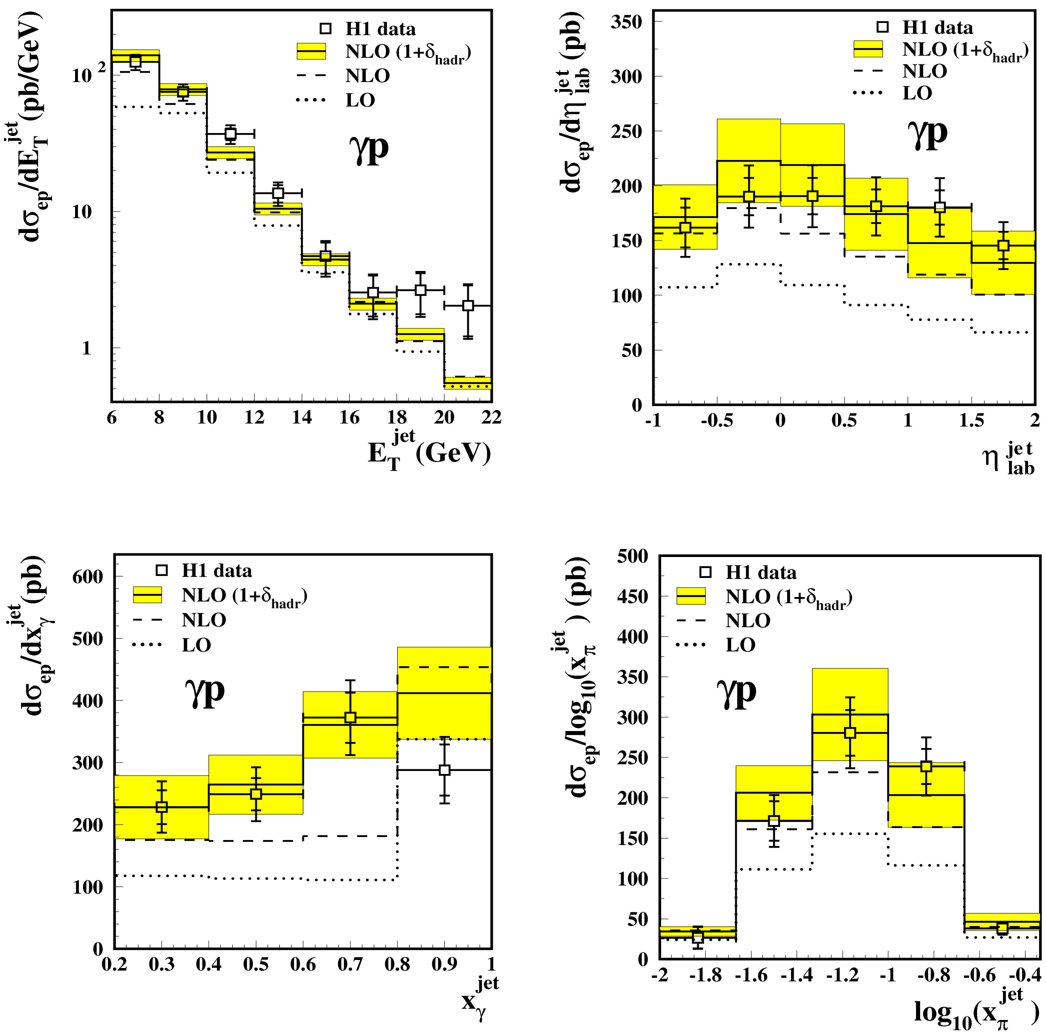
- rescattering causes migration of LN to lower x_L values
- thus at large x_L rescattering acts as absorption
- enhanced abs. corrections small ~15%
- **absorptive effects may be described in terms of gap survival probability**
- including exchanges of secondary reggeons (ρ, a_2) to better describe the p_T distribution (KMR) leads to the prediction of a **gap survival probability ~ 0.4**, in agreement with LN yield in γp

Validity of the model tested on HERA data allows reliable predictions for LHC!

Leading neutrons + dijets in γp

H1, EPJ C41 (2005) 273

H1



$E_T^{jet1} > 7$ GeV, $E_T^{jet2} > 6$ GeV

NLO by Klasen and Kramer reproduces well the data if corrections to hadron level are introduced

→ **no suppression seen**

But see also more recent KK calculation (DESY 06-124) where NLO is first normalized to DIS data:
→ suppression ~ 0.48 for resolved-only and ~ 0.64 for global

Conclusions

- **Diffractive dijet photoproduction** has been studied to test possible factorization breaking as in proton-antiproton collisions at Tevatron

  Gap survival probabilities ~ 0.4 – 0.9, higher than in ppbar, have been measured

  Both H1 and ZEUS data prefer a global suppression for both the direct and resolved components of the photon, with a possible E_T dependence of the suppression factors

- **Leading neutron production data** indicate a suppression in γp @ low x_L, high p_T

  π exchange models with absorptive corrections, including migration and secondary exchanges, describe the data, with a gap survival probability ~ 0.4

  No absorption is seen in presence of high E_T jets

HERA data offer the opportunity of testing and tuning models for LHC !