



Gap survival probability and rescattering at HERA



A.Solano

Univ. of Torino and INFN

On behalf of the H1 and ZEUS Collaborations

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Outline:

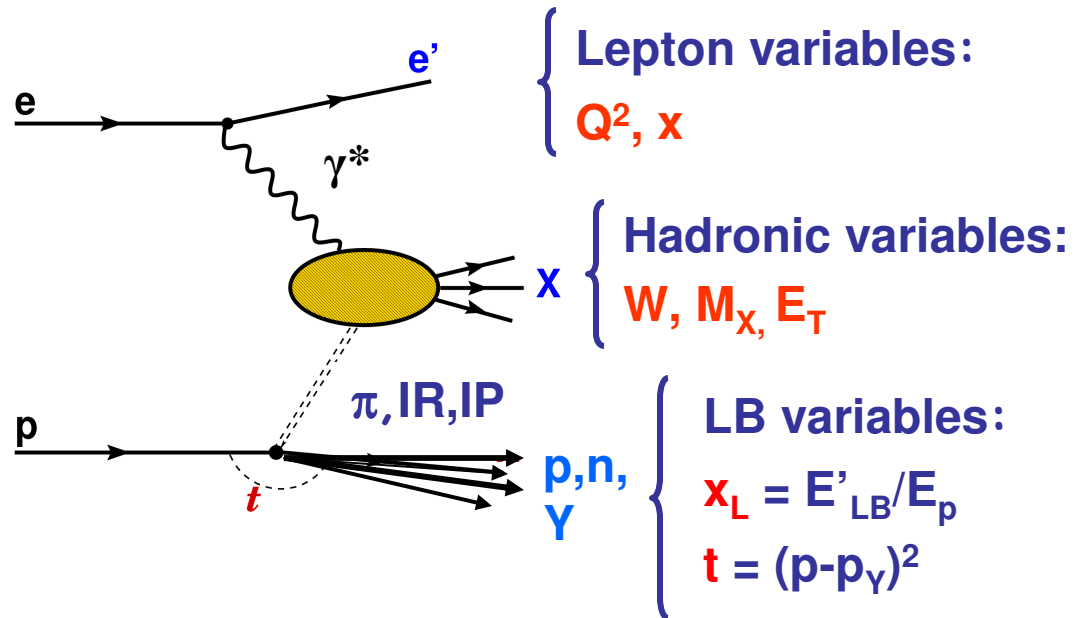
- Introduction
- Diffractive dijets in photoproduction: gap survival probability and its E_T dependence
- Leading neutrons: rescattering and absorption
- Conclusions



Introduction



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



- $Q^2 \gg 0$:

Deep inelastic scattering (**DIS**)

- $Q^2 \sim 0$:

Photoproduction (γp)

Quasi-real $\gamma \sim$ hadron

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

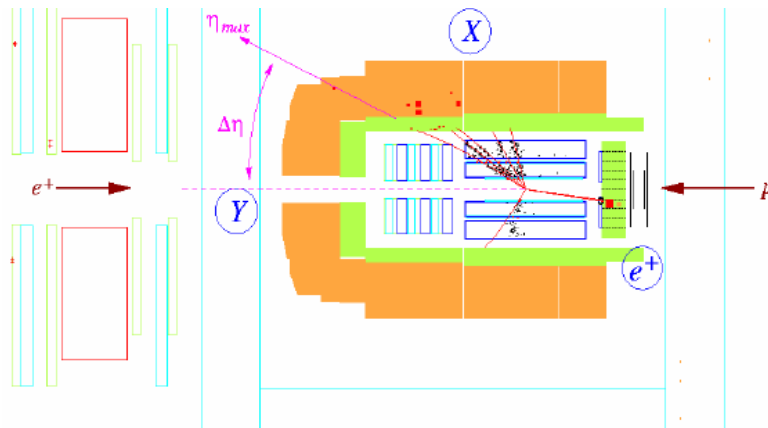
- In diffraction, rapidity gaps may be destroyed by secondary particles generated by rescattering processes between the hadronic final state and the proton remnant
- Leading neutron yields and distributions may be effected by rescattering



Event selection



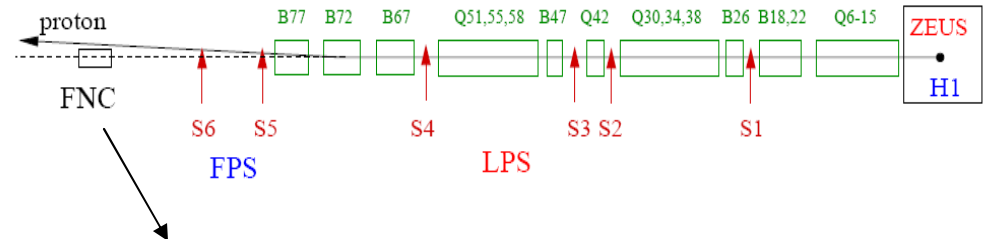
Diffractive events:



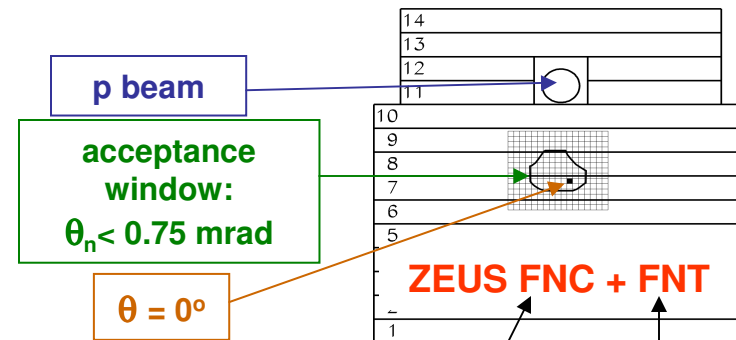
'Large rapidity gap' method:

- 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

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

Hard subprocess ME

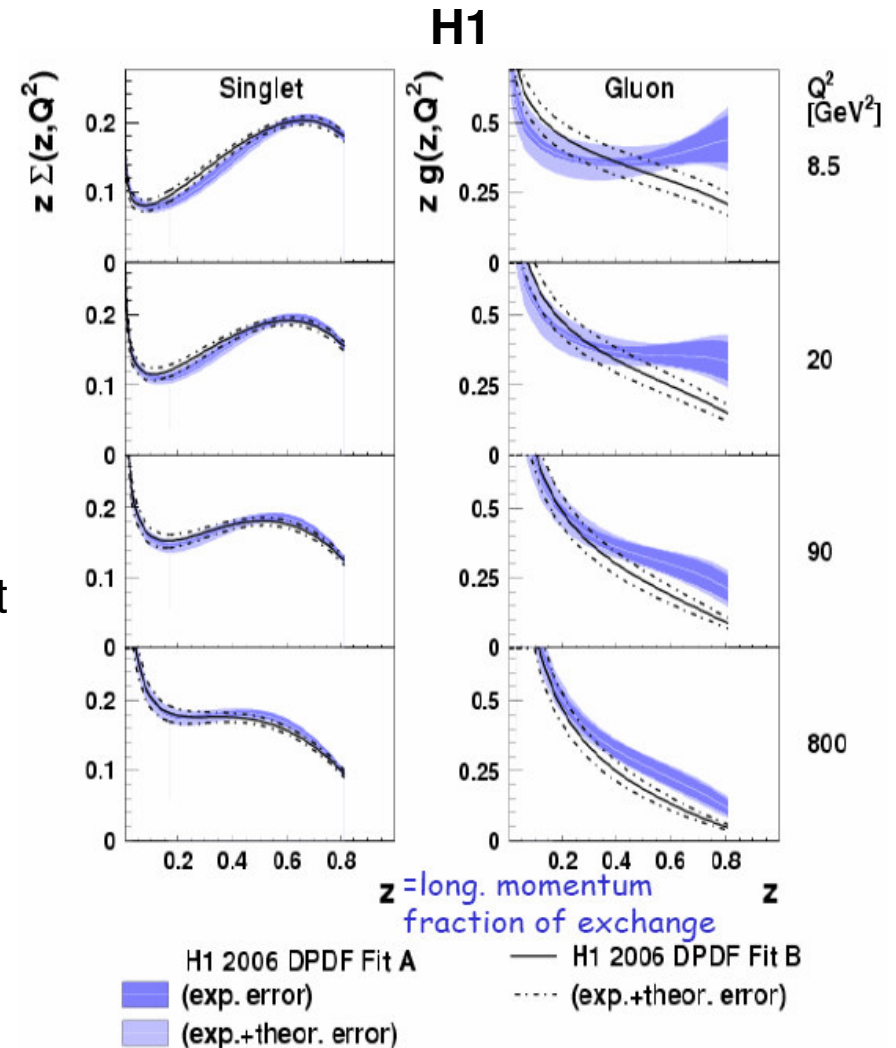
pQCD calculable

Diffractive PDFs

=

std proton PDFs +
diffractive requirement

Diffractive PDFs extracted via NLO DGLAP fit
from inclusive diffractive data





D* and dijets in diffractive DIS

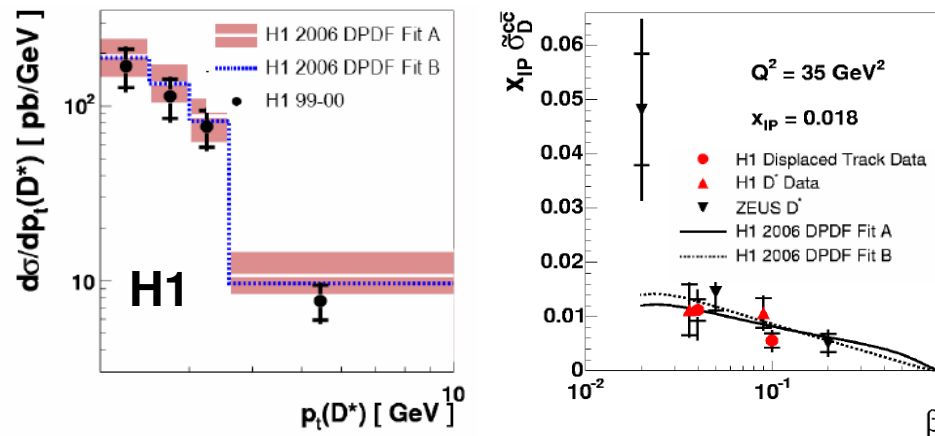


Use DPDFs extracted from inclusive DDIS for calculating NLO predictions to semi-inclusive final states: **test universality of DPDFs**

→ 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



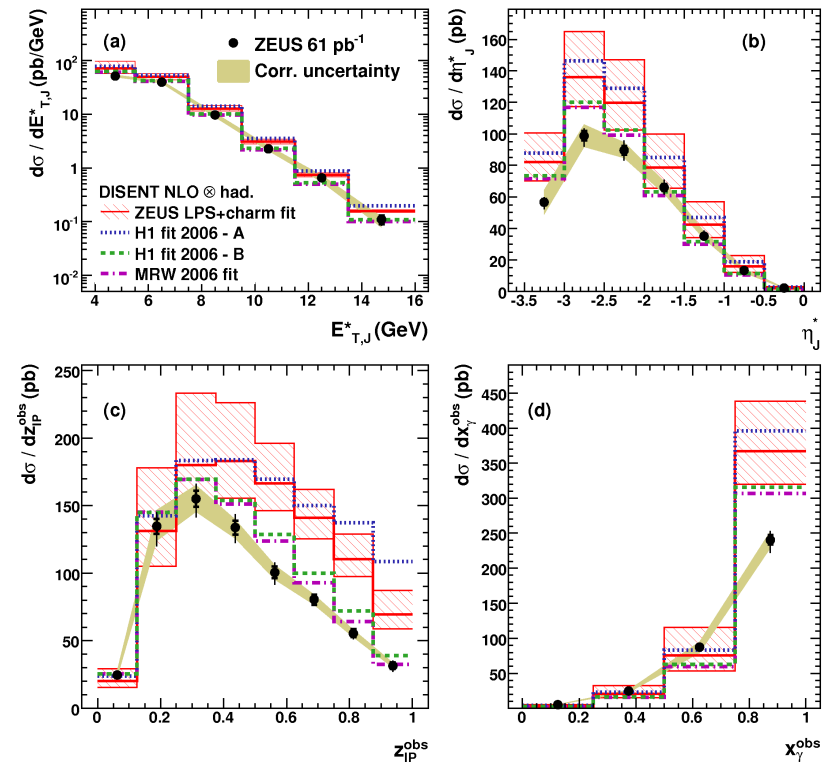
H1 and ZEUS data agree with NLO predictions within uncertainties

→ **QCD factorization holds in DDIS!**

Use D* and jet data to better constrain DPDFs

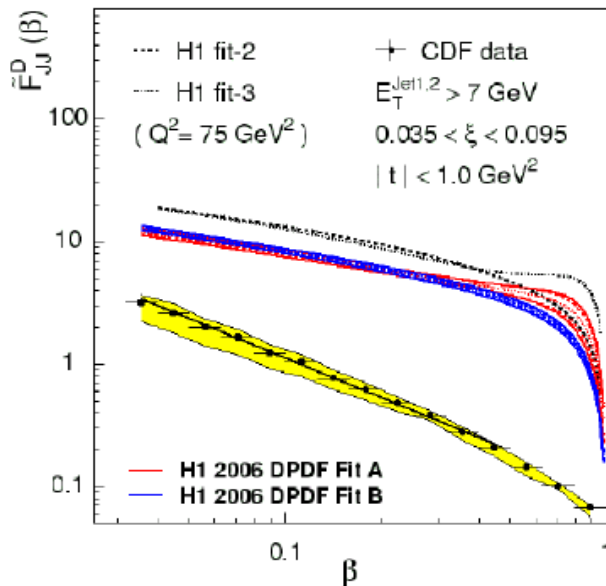
Dijets:

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





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 \leftrightarrow '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

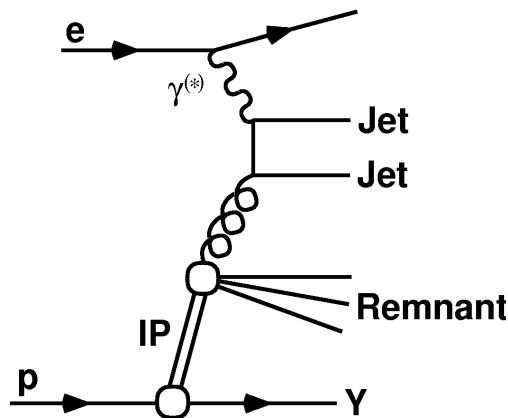


At HERA we have something similar to a hadron:
quasi-real photons ($Q^2 \sim 0$) can develop a **hadronic structure**

Direct photon ($x_\gamma \sim 1$)

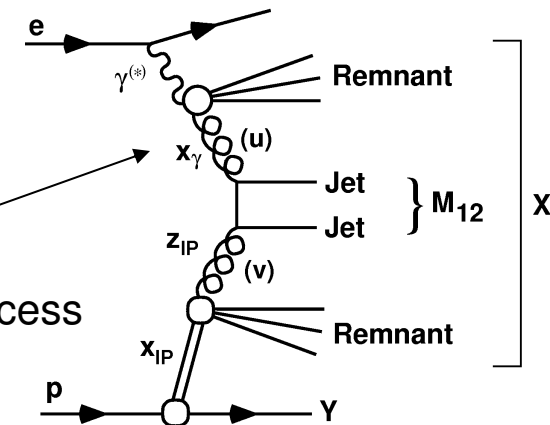
(at LO)

Resolved photon ($x_\gamma < 1$)



**High E_T of the jets
provides the hard scale**

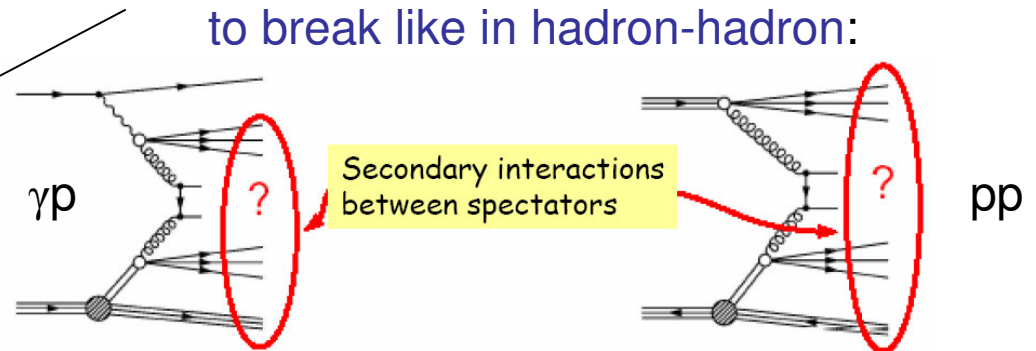
x_γ = fraction of photon's
momentum in hard subprocess



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]**



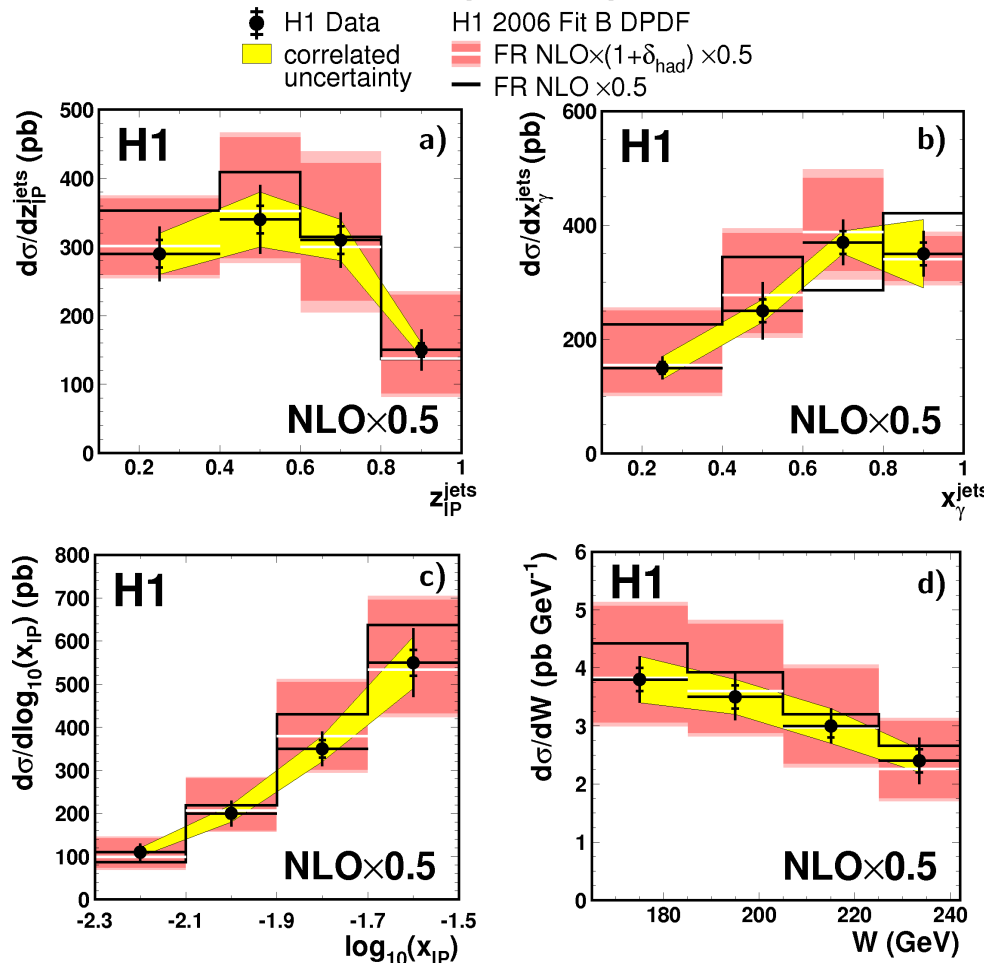


Dijets in diffractive photoproduction



H1 Diffractive Dijet Photoproduction

H1, EPJ C51 (2007) 549



- $E_{T^{\text{jet1}}} > 5 \text{ GeV}$, $E_{T^{\text{jet2}}} > 4 \text{ GeV}$
- Cross section include p dissoci. with $M_Y < 1.6 \text{ GeV}$
- 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 $p\bar{p}$

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

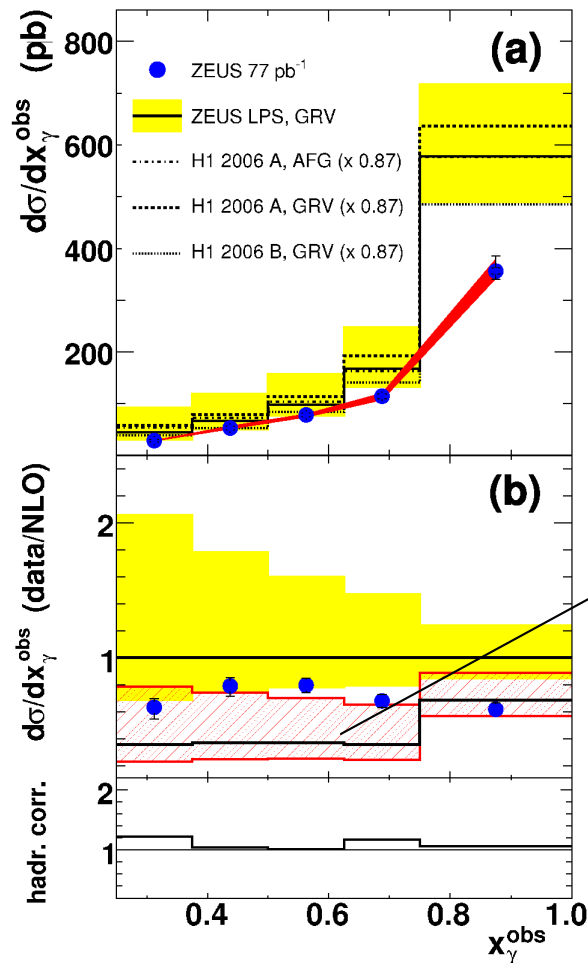


Dijets in diffractive photoproduction



ZEUS

ZEUS, EPJ C55 (2008) 177



• $E_{T}^{jet1} > 7.5 \text{ GeV}$, $E_{T}^{jet2} > 6.5 \text{ GeV}$

• Cross section scaled down for p-dissoc. contribution: $(16 \pm 4)\%$

• 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!

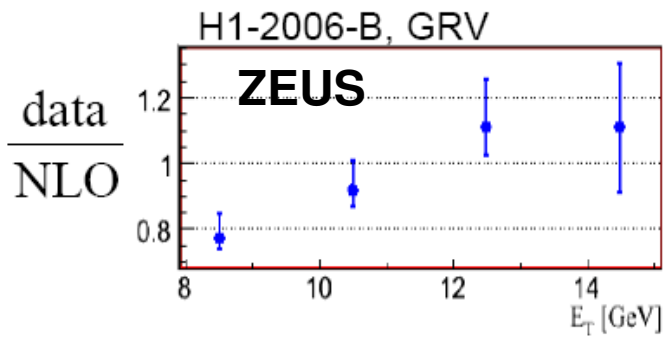
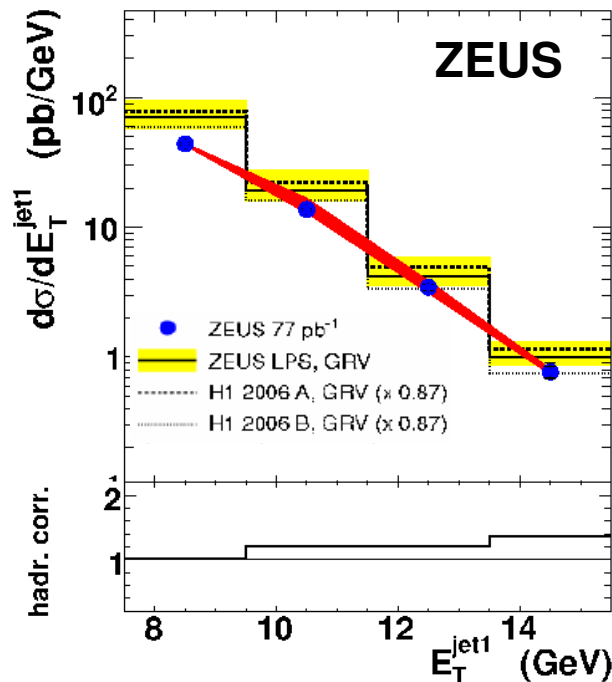
NLO predictions assuming factorization with Klasen & Kramer program [EPJ C38 (2004) 9]



E_T dependence of suppression?



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



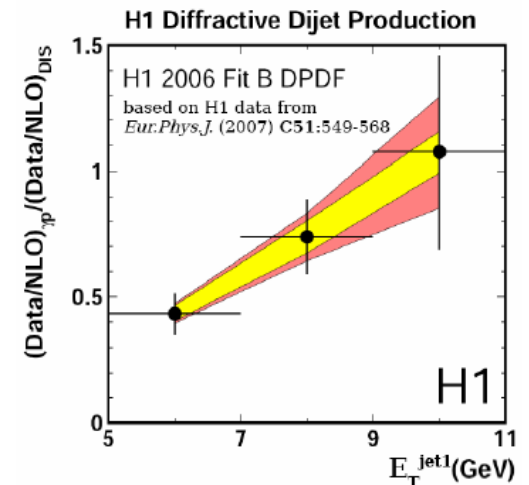
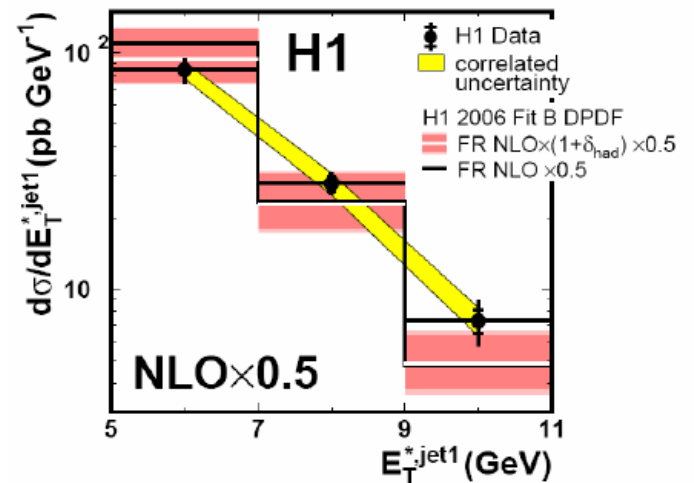
Data have a harder E_T slope than NLO

Better seen with

$$\text{Double ratio} = \frac{(Data / NLO)_p}{(Data / NLO)_{DIS}}$$

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)

$$E_T^{\text{jet1}} > 5 \text{ GeV}$$

$$E_T^{\text{jet2}} > 4 \text{ GeV}$$

$$-1 < \eta^{\text{jet1,jet2}} < 2$$

$$x_{\text{IP}} < 0.03$$

$$0.3 < y_e < 0.65$$

$$Q^2 < 0.01 \text{ GeV}^2$$

$$|t| < 1 \text{ GeV}^2$$

$$M_Y < 1.6 \text{ GeV}$$

High E_T scenario

(similar to ZEUS kinematic region)

$$E_T^{\text{jet1}} > 7.5 \text{ GeV}$$

$$E_T^{\text{jet2}} > 6.5 \text{ GeV}$$

$$-1.5 < \eta^{\text{jet1,jet2}} < 1.5$$

$$x_{\text{IP}} < 0.025$$

$$0.3 < y_e < 0.65$$

$$Q^2 < 0.01 \text{ GeV}^2$$

$$|t| < 1 \text{ GeV}^2$$

$$M_Y < 1.6 \text{ GeV}$$

ZEUS:

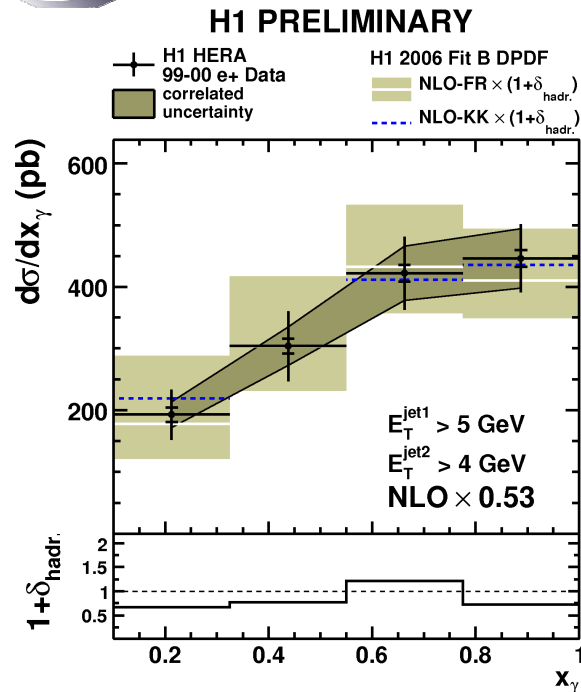
$$0.3 < y_{\text{JB}} < 0.85$$

$$Q^2 < 1 \text{ GeV}^2$$

No p dissociation



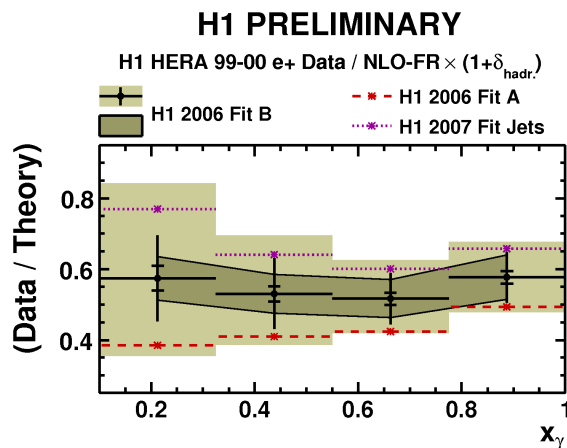
Low E_T scenario



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

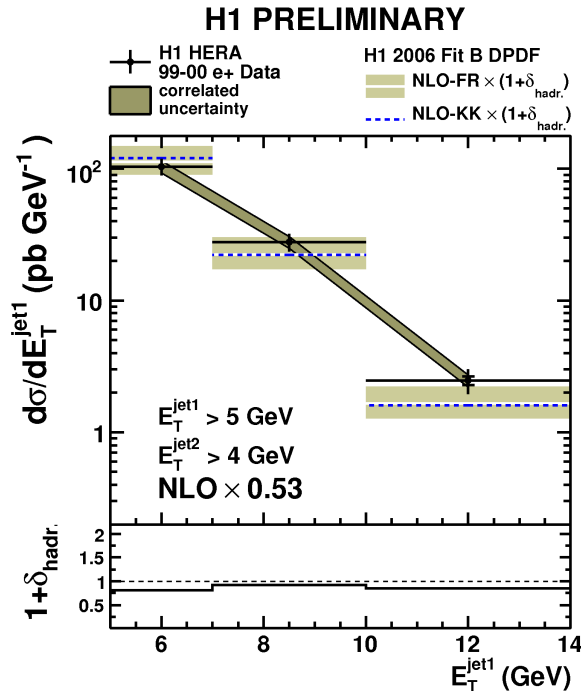
Three sets of DPDFs: H1-2006 Fit A, Fit B, Fit Jets

**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

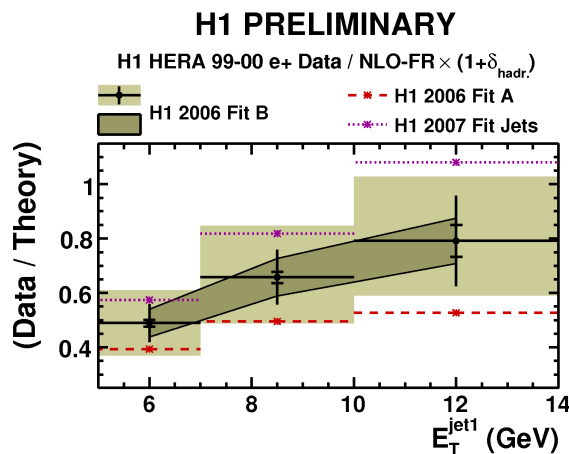
Survival probabilities in range 0.43 – 0.65, depending on DPDFs
(always compatible within uncertainties):

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

$$S_{\text{fitB}}^{\text{KK}} = 0.51 \pm 0.01(\text{stat.}) \pm 0.10(\text{syst.})$$

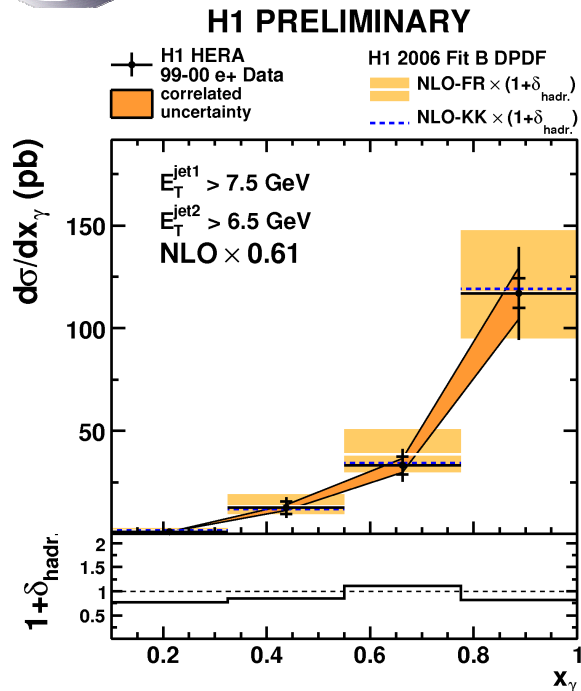
$$S_{\text{fitA}}^{\text{FR}} = 0.43 \pm 0.01(\text{stat.}) \pm 0.10(\text{syst.})$$

$$S_{\text{fitJets}}^{\text{FR}} = 0.65 \pm 0.01(\text{stat.}) \pm 0.11(\text{syst.})$$





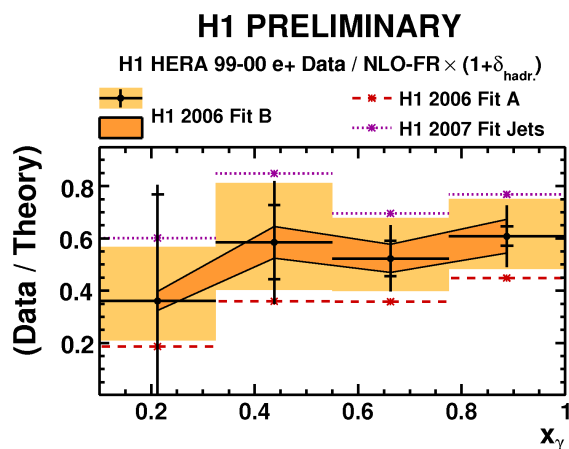
High E_T scenario



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!**



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

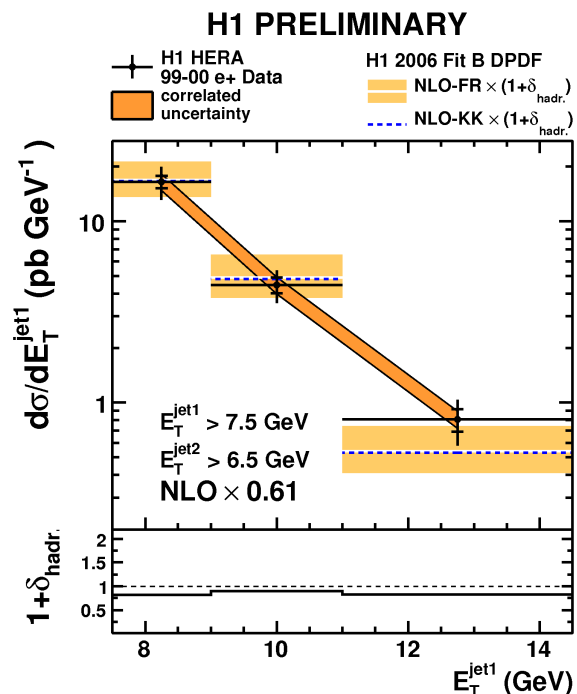
$$S_{\text{fitB}}^{\text{KK}} = 0.62 \pm 0.03(\text{stat.}) \pm 0.14(\text{syst.})$$

$$S_{\text{fitA}}^{\text{FR}} = 0.44 \pm 0.02(\text{stat.}) \pm 0.09(\text{syst.})$$

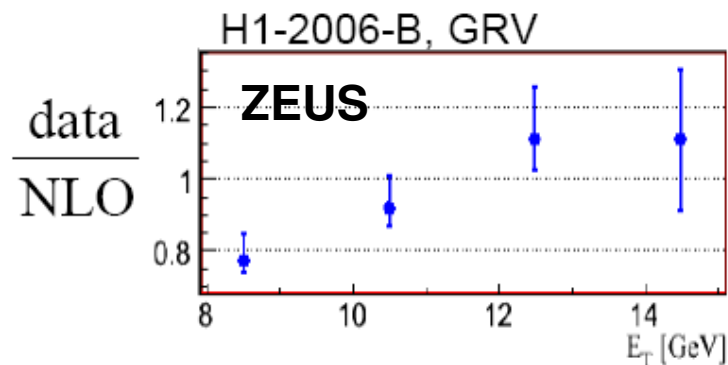
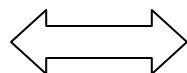
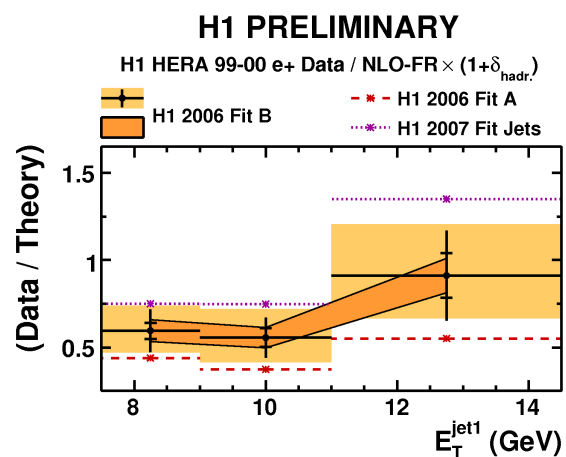
$$S_{\text{fitJets}}^{\text{FR}} = 0.79 \pm 0.04(\text{stat.}) \pm 0.16(\text{syst.})$$



High E_T scenario

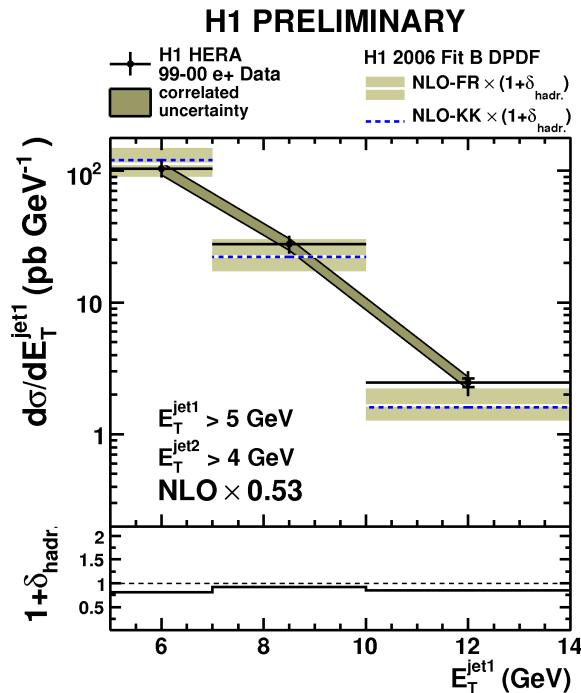


Also in high E_T scenario hint of an E_T spectrum harder in data than in NLO calculations



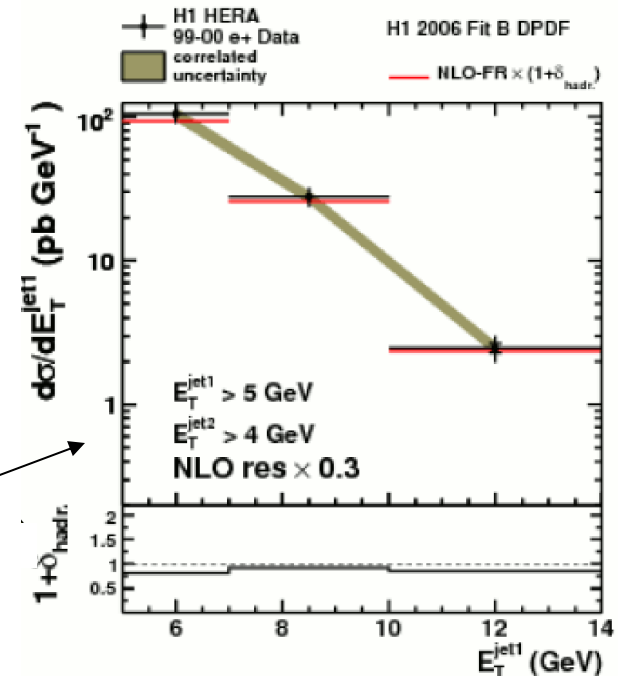


Global or resolved-only suppression?

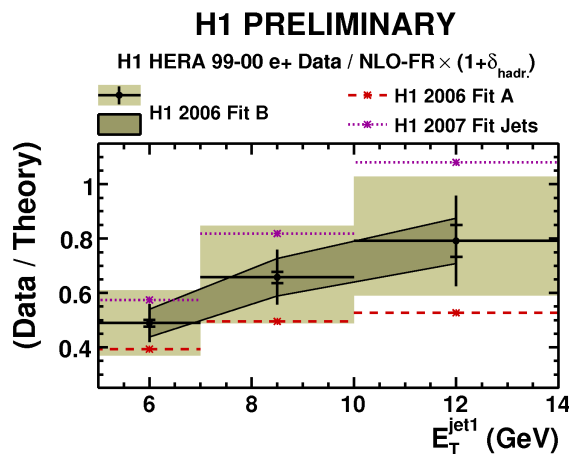


Global suppression
by 0.53

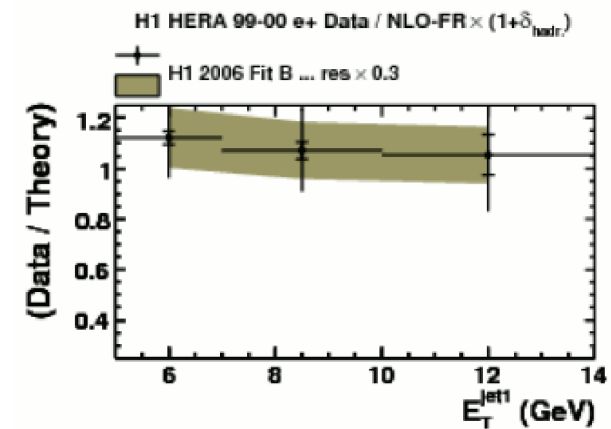
Resolved-only
suppression by 0.3



Data / Theory

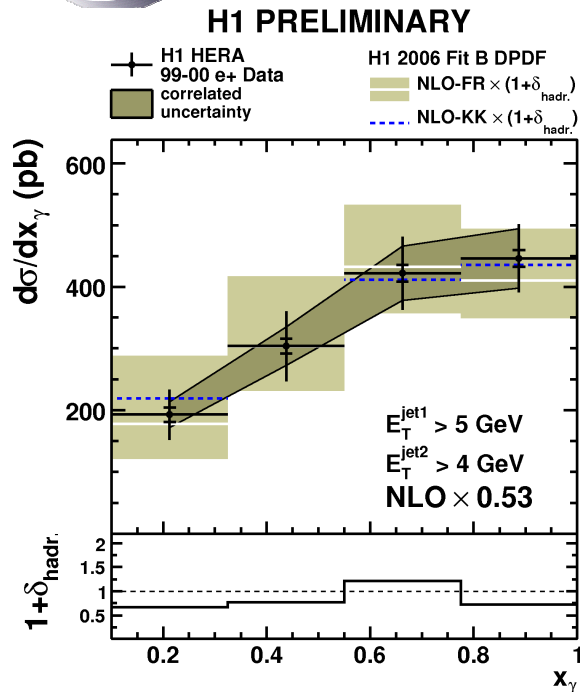


No E_T dependence
with resolved-only
suppression





Global or resolved-only suppression?



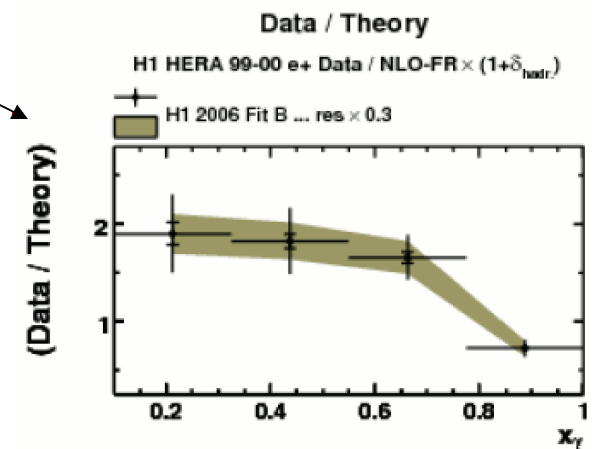
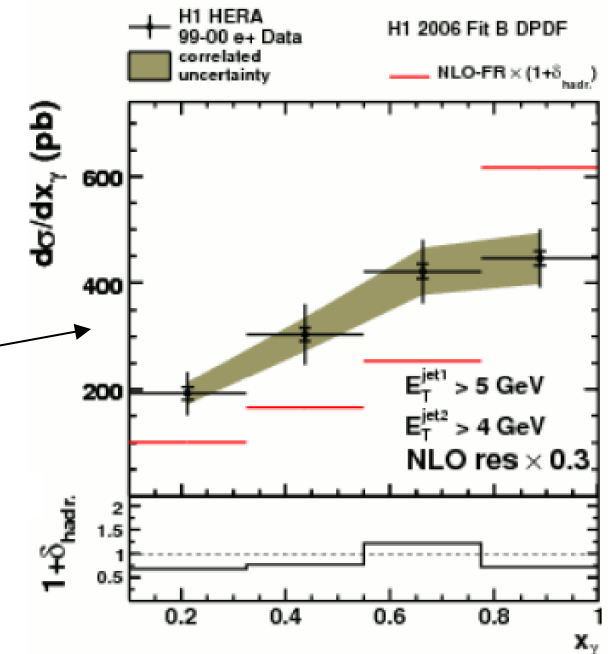
Global suppression
by 0.53

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





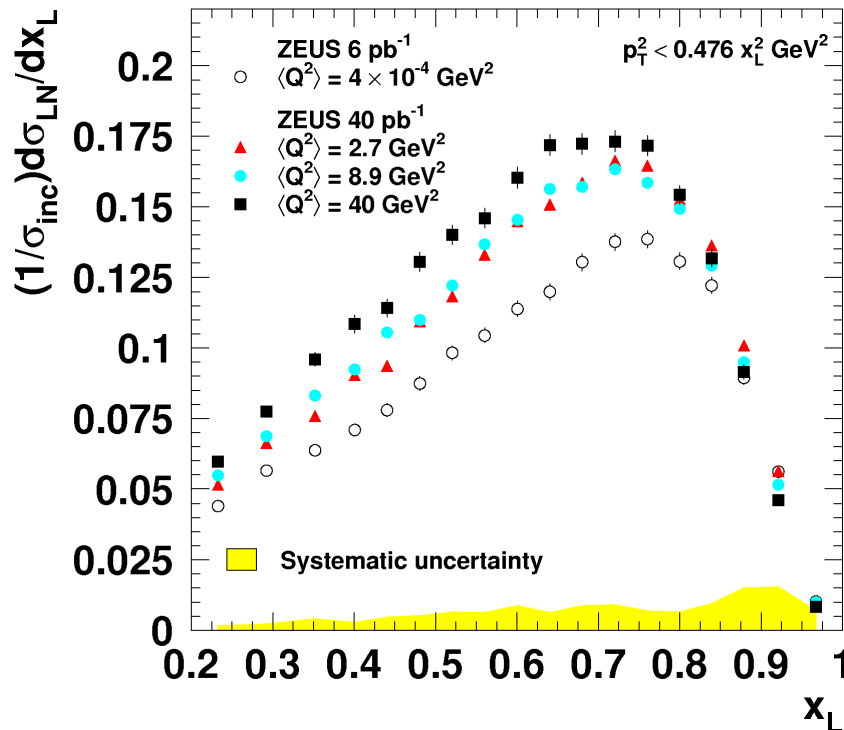
Leading neutron data: γp vs DIS



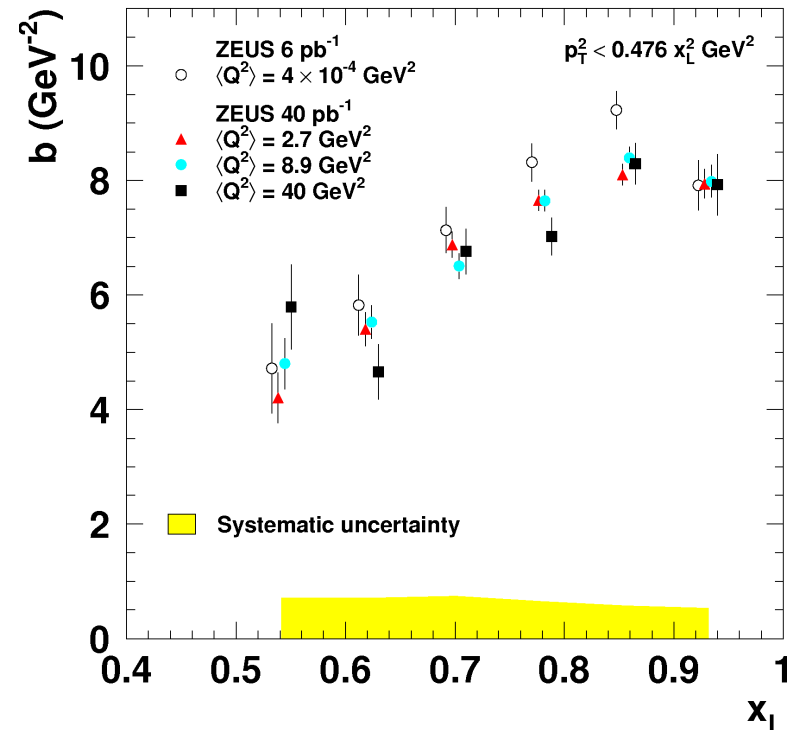
ZEUS, NP B776 (2007) 1

DIS (3 Q^2 bins) and γp

p_T^2 distributions fitted exponentially:



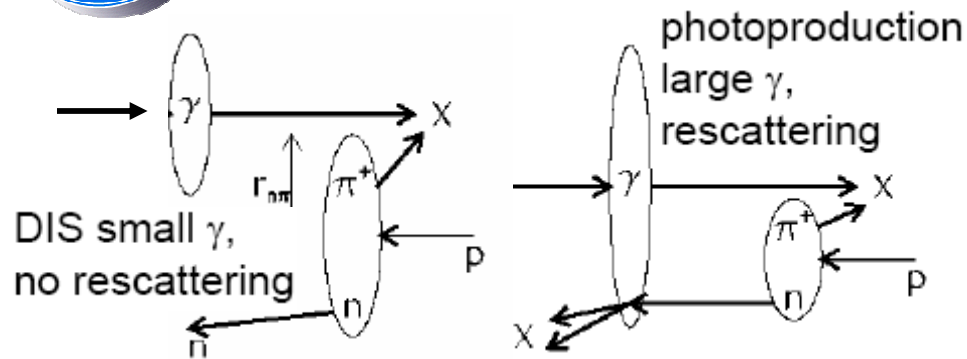
- Yield increases from γp to DIS
- Small but significant increase from mid to high Q^2



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



Absorption models: LN via π exchange



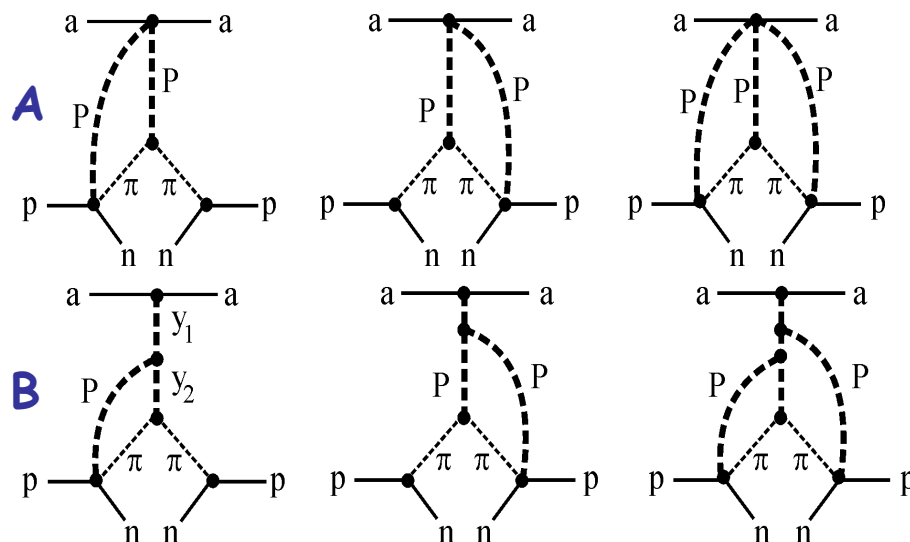
D'Alesio and Pirner, EPJ A7 (2000) 109

- 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



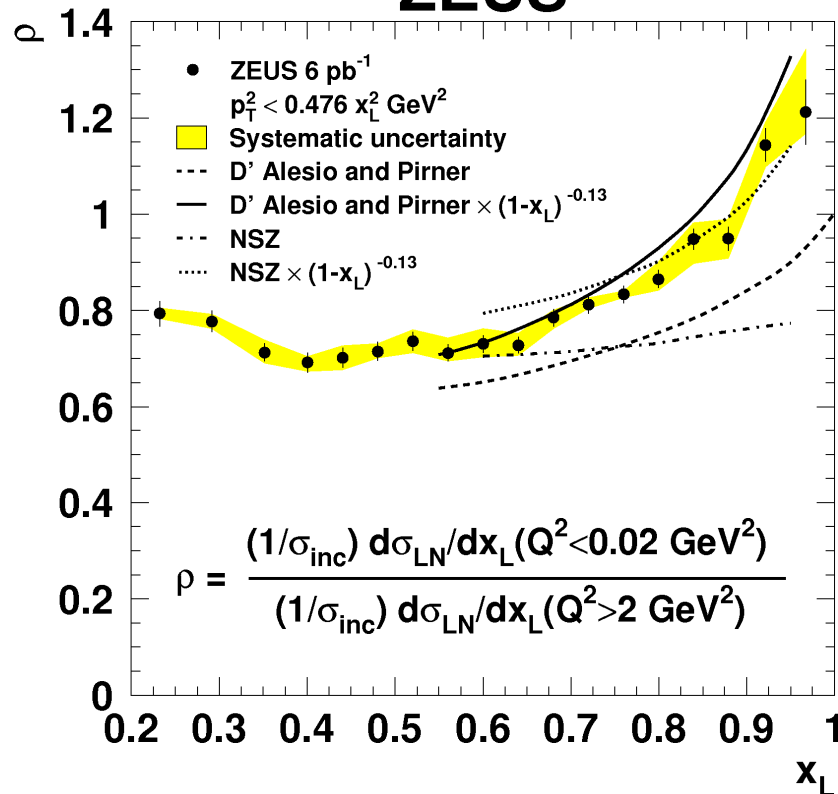
- evaluate correction due to enhanced absorptive diagrams B (small, $\sim 15\%$)
- show importance of distortion of energy spectra (migration) due to rescattering for $x_L < 0.8$
- include effects of ρ , a_2 exchange
- estimate the gap survival factor S^2 (important for LHC!) which takes into account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



Comparison with π exch. + absorption



ZEUS



Ratio $\gamma p/\text{DIS}$ 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 $r_{n\pi} \rightarrow$ **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

$$\sigma_{\gamma\pi}/\sigma_{\gamma^*\pi} \sim (1-x_L)^{-0.13}$$

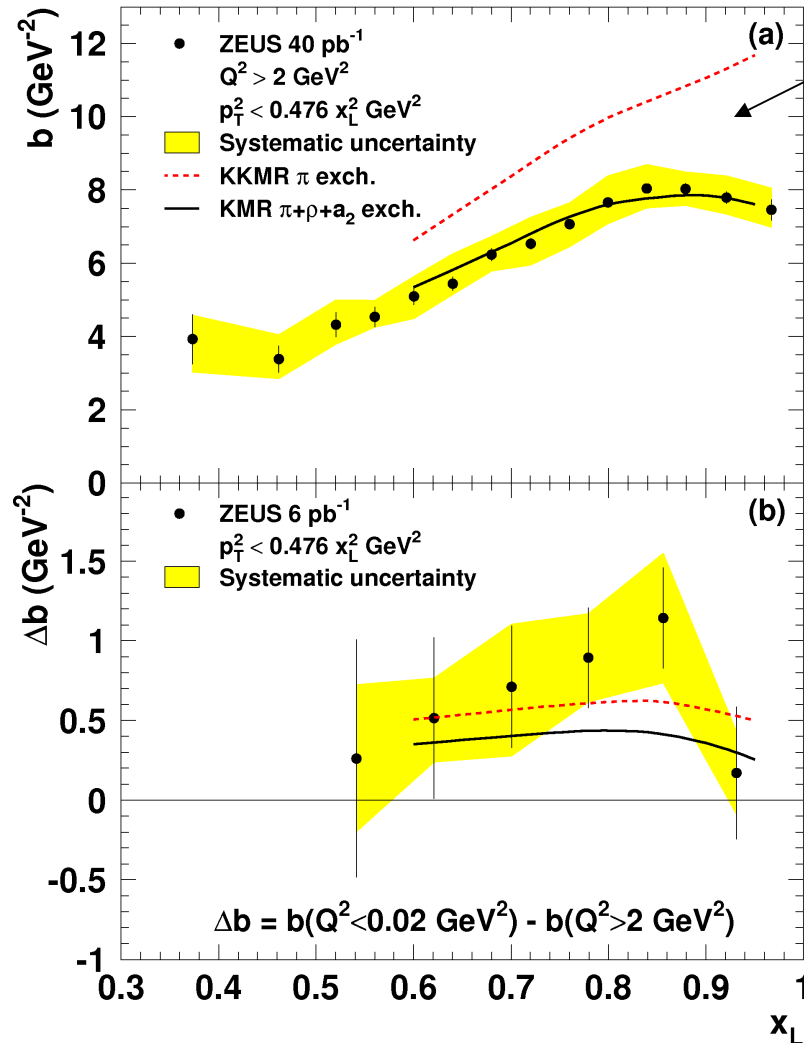
\rightarrow absorption ratio scaled by $(1-x_L)^{-0.13}$



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



ZEUS



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

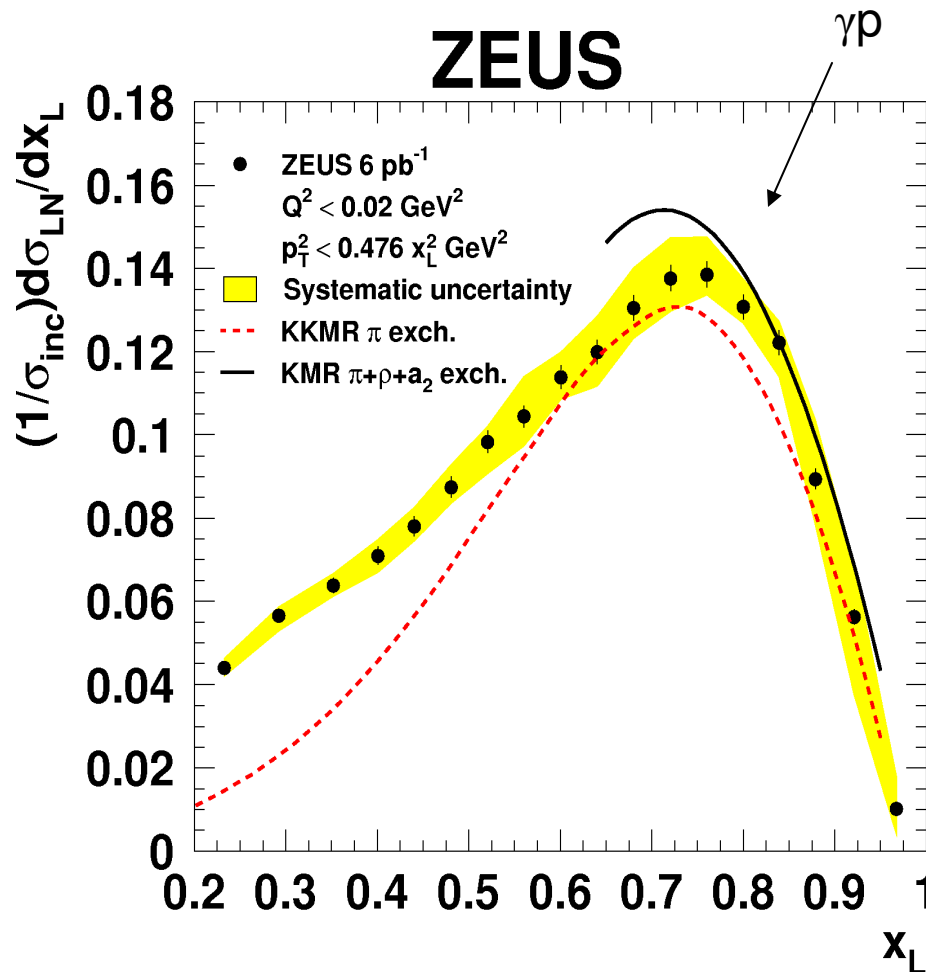
→ including secondary (ρ , a_2) exchanges (KMR) allows a good description of b slopes of LN p_T^2 distributions

Size of (n - π) system proportional to $1/p_{T \text{ neutron}}$

→ **rescattering removes n's with high p_T** : the bigger absorption for small (n - π) systems causes 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 $\sim 15\%$
- **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



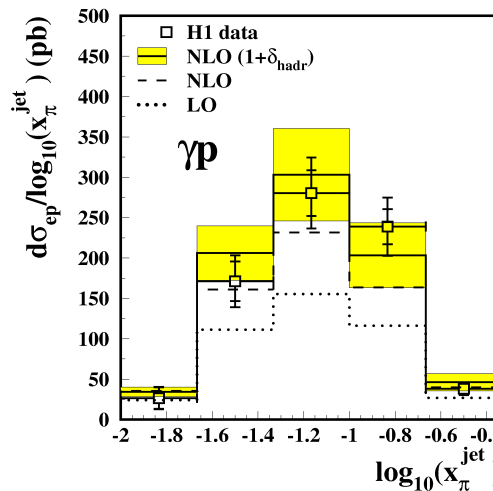
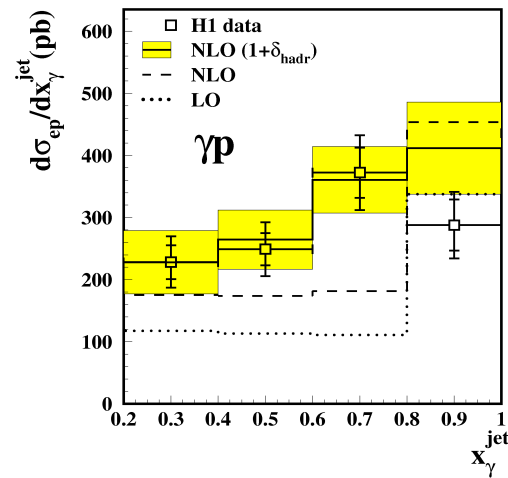
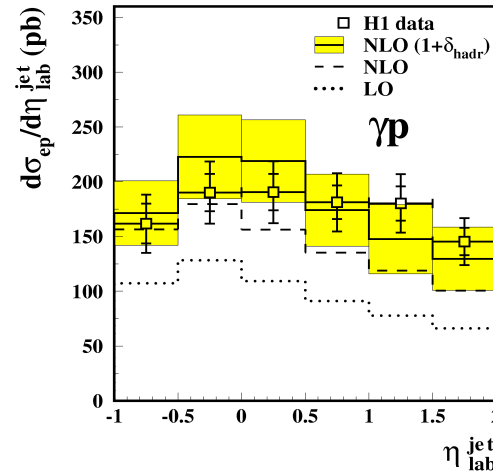
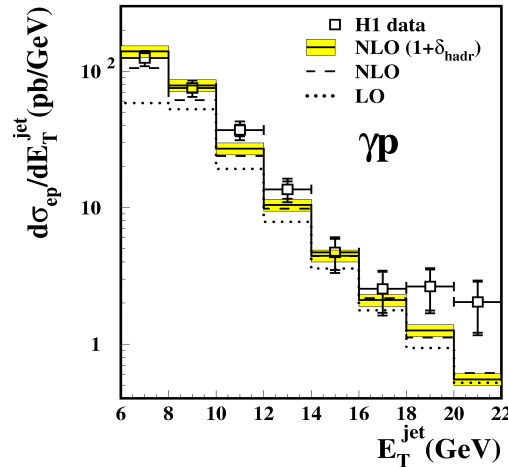
H1, EPJ C41 (2005) 273

H1

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

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



- **Diffraction dijet photoproduction** has been studied to test possible factorization breaking as in proton-antiproton collisions at Tevatron
Gap survival probabilities $\sim 0.4 - 0.9$, higher than in $p\bar{p}$, 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 !