HERA Workshop

DESY, 11-13 November 2014

Future prospects in diffraction at HERA

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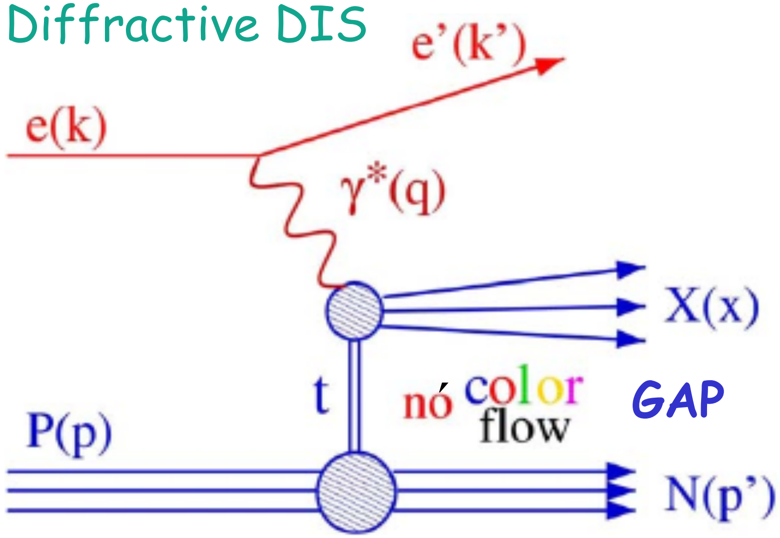
Thanks to Michele Arneodo, Olaf Benkhe, Federico Ceccopieri, Hannes Jung, Sergey Levonian, Paul Newman, Ewald Paul, Alice Valkarova, Matthew Wing for input and discussion

To the memory of Sasha P.

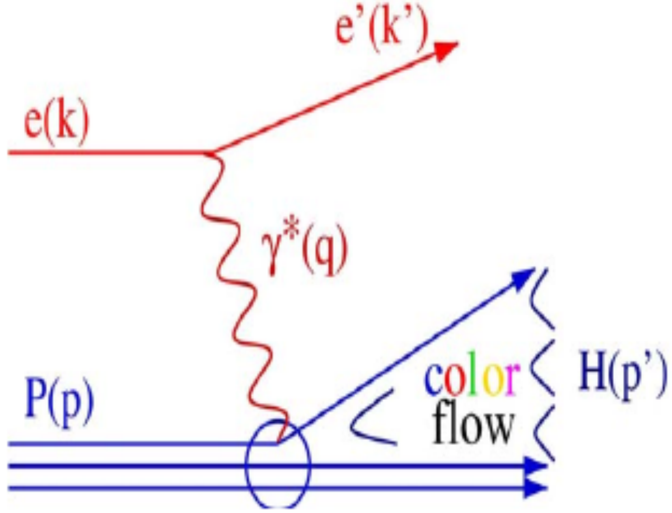
A personal view…

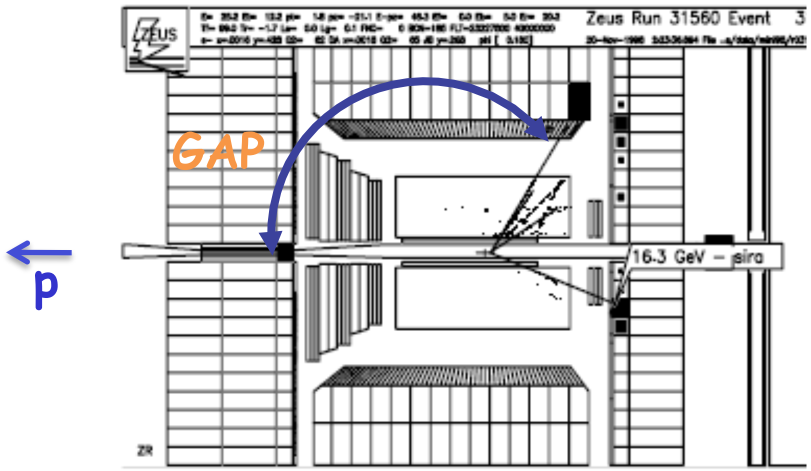
Diffractive dissociation of the (virtual) photon at HERA

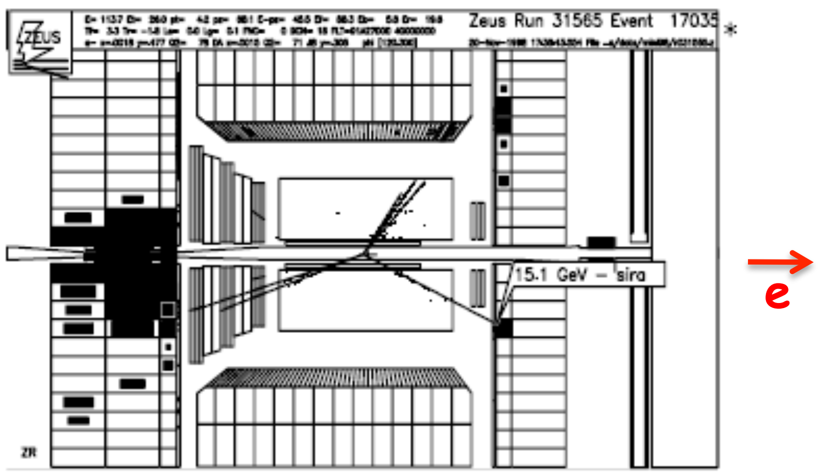
Diffractive DIS



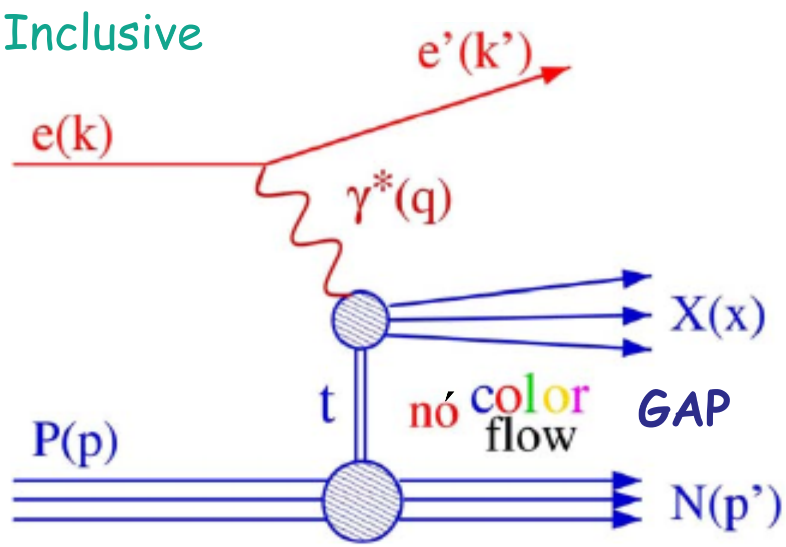
Standard DIS

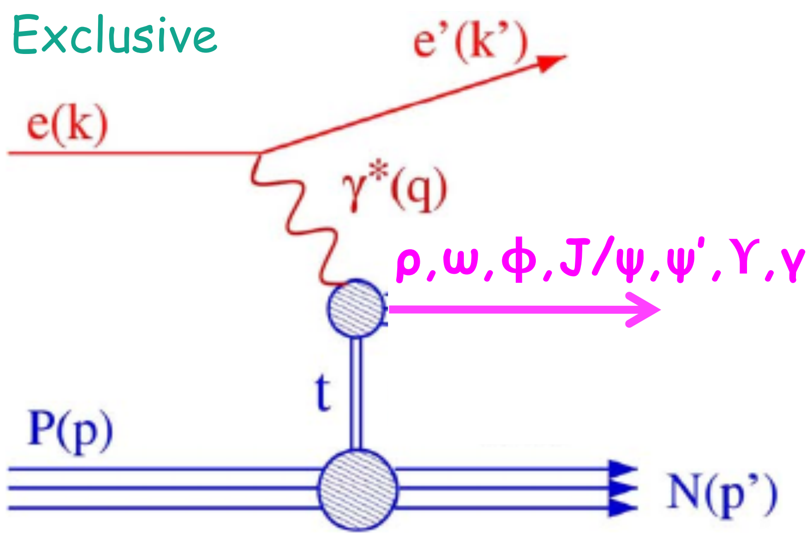






Inclusive and exclusive diffraction





Q^2 = virtuality of photon =
= (4-momentum exchanged at e vertex)^2

W = invariant mass of γ^*-p system

t = (4-momentum exchanged at p vertex)^2
typically: $|t|<1$ GeV^2

M_X = invariant mass of γ^* -IP system

x_{IP} = fraction of proton's momentum carried by IP

ß = Bjorken's variable for the IP
= fraction of IP momentum carried by struck quark
= x/x_{IP}

- Single diffraction/elastic: **N=proton**
- Double diffraction: **proton-dissociative system N**

Brain storming on future prospects

- Diffractive Parton Distribution Functions (DPDFs) fit
- Mechanisms of factorisation breaking
- Proton tagged F_2^b, F_2^c
- π parton density extraction
- Central diffraction
- Pomeron trajectory
- BFKL Pomeron
- Odderon

Brain storming on future prospects

- Diffractive Parton Distribution Functions (DPDFs) fit
- Mechanisms of factorisation breaking

Critical issues

- Proton tagged F_2^b, F_2^c
- π parton density extraction
- Central diffraction

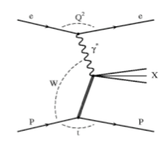
Not done before

- Pomeron trajectory
- BFKL pomeron
- Odderon

High statistics

Critical issues: DPDFs

Inclusive data in diffraction



- **Wealth of inclusive diffractive data** from H1 (HERAI+II) and ZEUS (only HERA I) with different techniques (proton tagging, LRG requirement, Mx method) – good consistency among all data sets!

Statistical and sys uncertainties down to 1% and 5%, overall normalization to 4%,

Proton tagged data H1-ZEUS combined

QCD factorization in hard diffraction

- **Diffractive DIS, like inclusive DIS, is factorisable:**

[Collins (1998); Trentadue, Veneziano (1994); Berera, Soper (1996)...]

universal partonic cross section

$$\sigma\,(\gamma^* p \rightarrow Xp) \;\approx\; f_{i/p}(z,Q^2,x_{IP},t) \;\times\; \sigma_{\gamma^* q}\,(z,Q^2)$$

Diffractive Parton Distribution Function (DPDF)

$f_{i/p}\,(z,Q^2,x_{IP},t)$ expresses the probability to find, with a probe of resolution Q^2, in a proton, parton i with momentum fraction z, under the condition that the proton remains intact, and emerges with small energy loss, x_{IP}, and momentum transfer, t – the DPDFs are a feature of the proton and evolve according to DGLAP

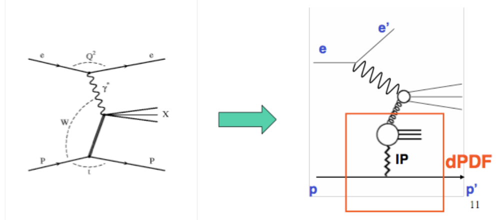
- **Assumption → proton vertex factorisation:**

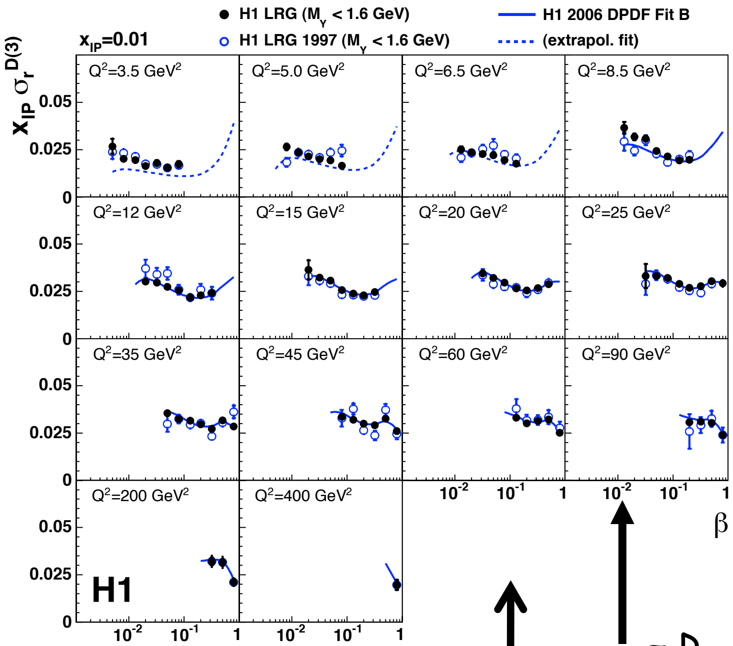
Regge-motivated IP flux

$$\sigma\,(\gamma^* p \rightarrow Xp) \;\approx\; f_{IP/p}(x_{IP},t) \;\times\; f_{i/IP}(z,Q^2) \;\times\; \sigma_{\gamma^* q}\,(z,Q^2)$$

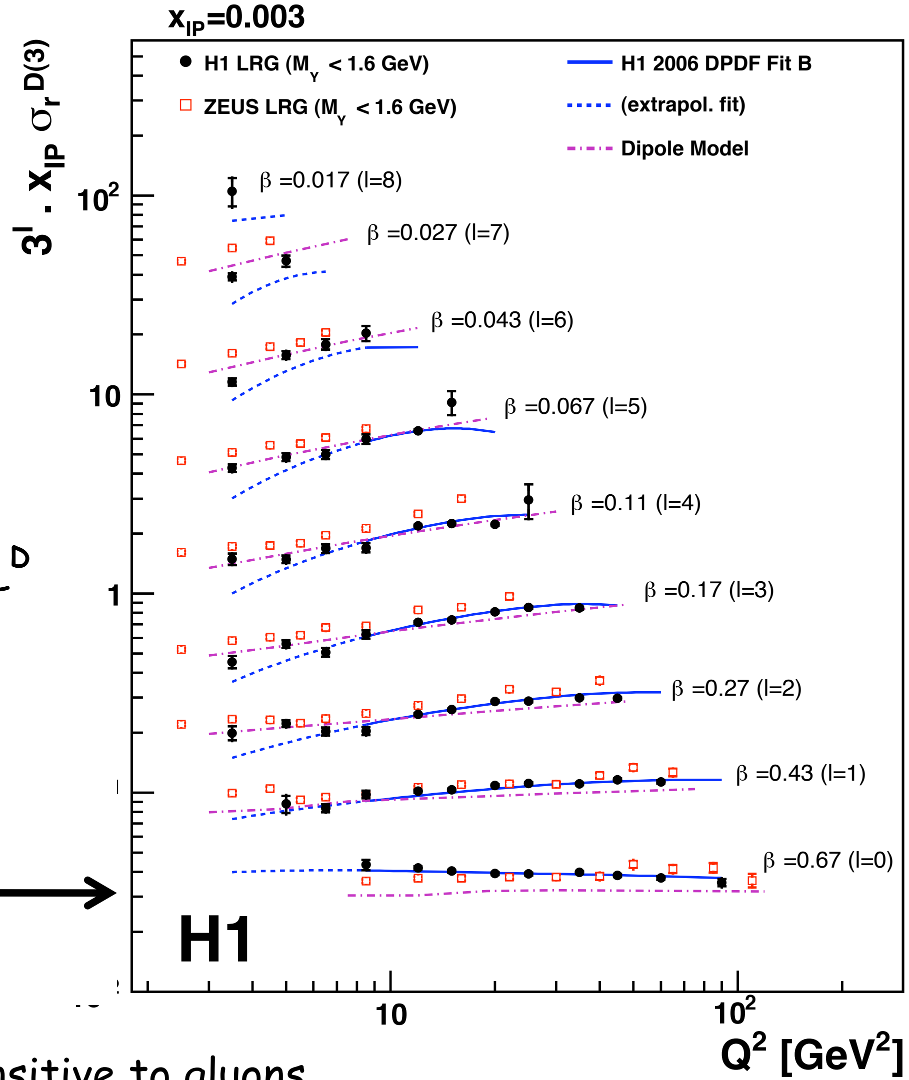
At large x_{IP}, a separately factorisable sub-leading exchange (IR), with different x_{IP} dependence and partonic composition

DPDFs extraction



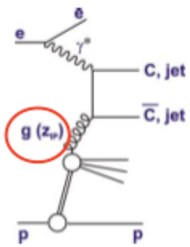


$\sigma_r^D \sim F_2^D - F_L^D$



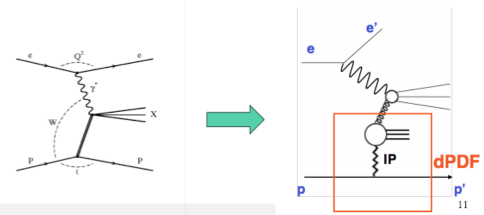
Quark densities constrained by reduced cross section

Gluon density constrained indirectly by scaling violations



Diff dijet data, directly sensitive to gluons, constrains the gluon density @high **z**

Data and DPDF fits



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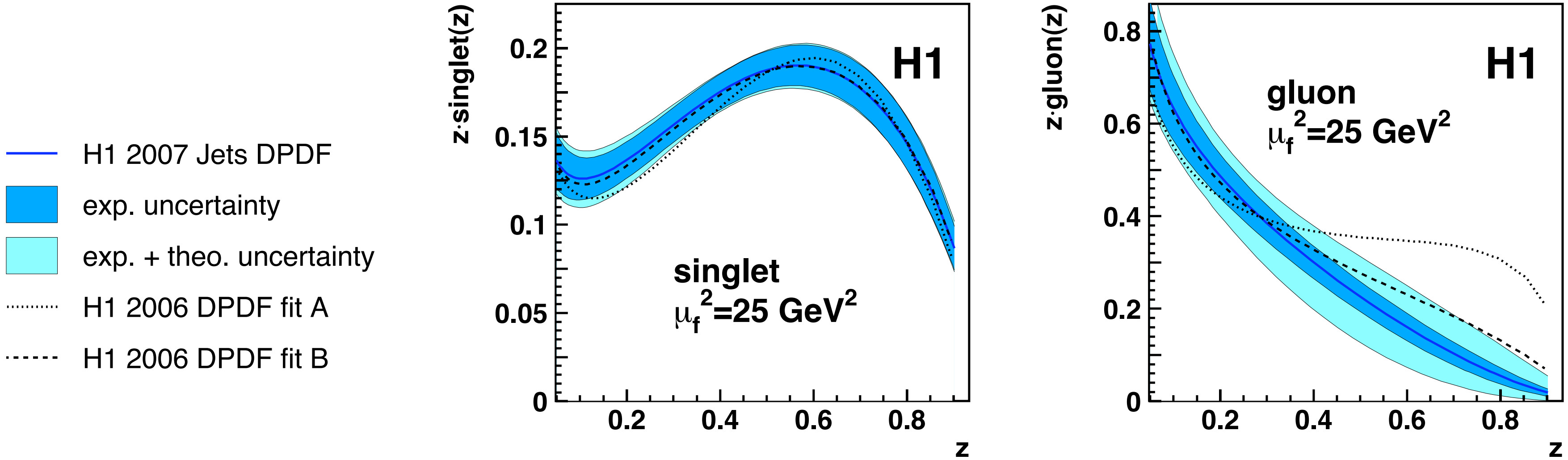
  Statistical and sys uncertainties down to 1% and 5%, overall normalization to 4%,

  Proton tagged data H1-ZEUS combined

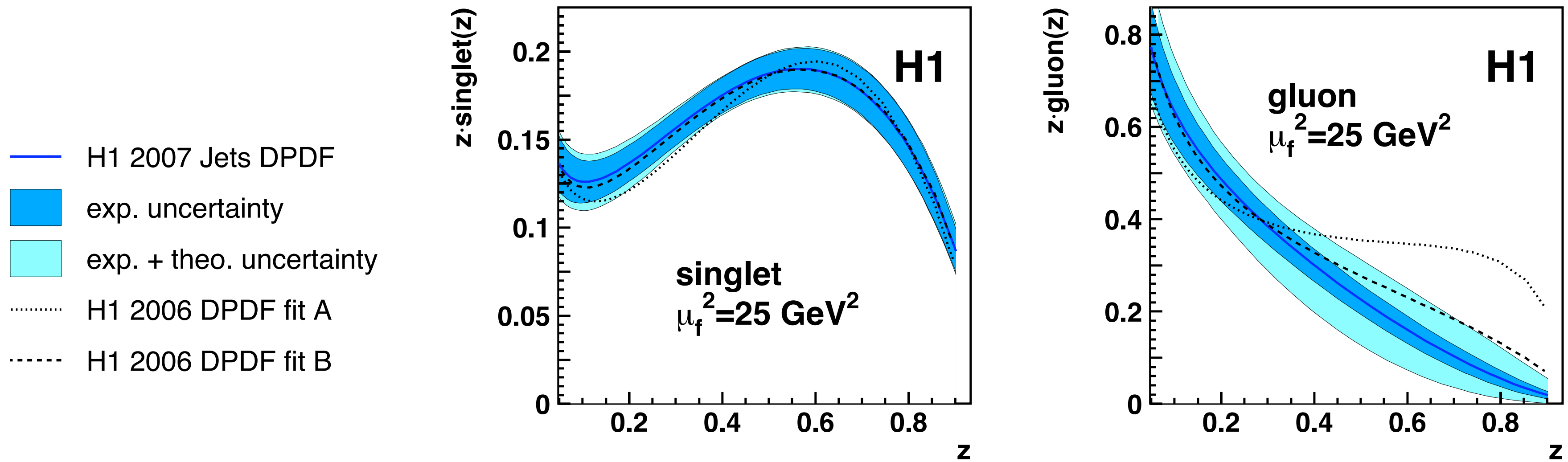
- **A few set of diffractive parton distribution functions** within H1 and ZEUS:
  - H1 Fit A and B (H1 HERA I inclusive LRG data)
  - H1 Jet Fit 2007 (H1 HERA I inclusive LRG +dijet data)
  - ZEUS SJ Fit (ZEUS HERA I inclusive LRG/proton tagged data + dijet data)

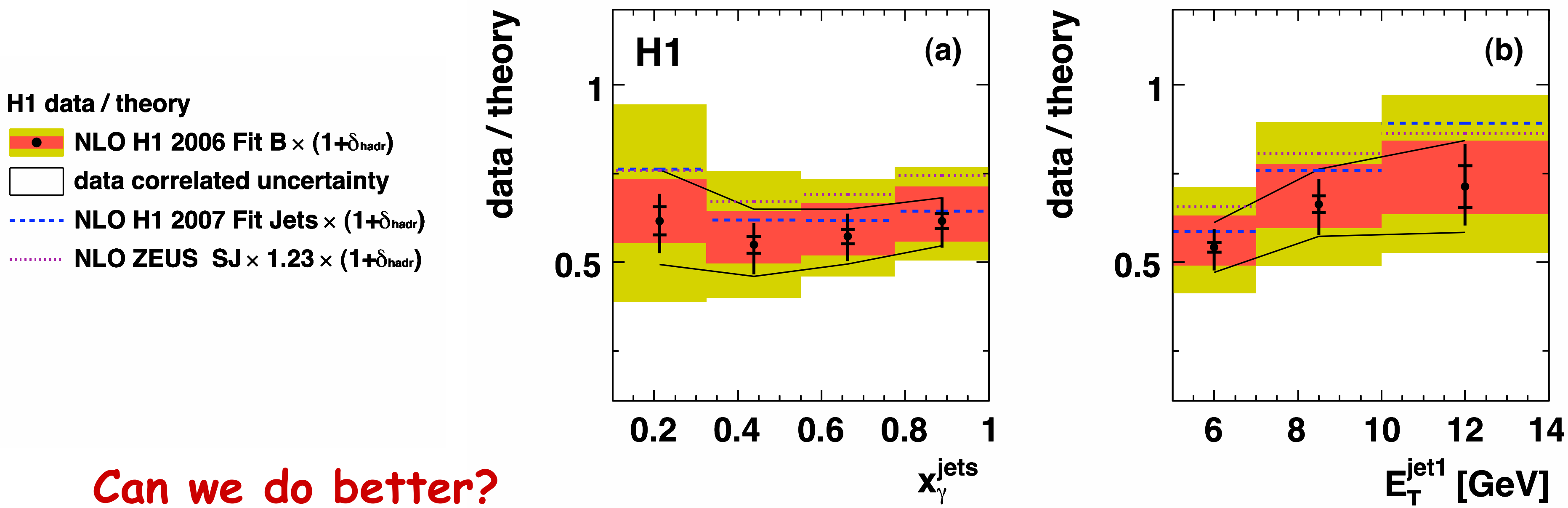
  Regge factorization assumed everywhere

Diffractive parton densities



Diffractive parton densities





Can we do better?

Perspectives for DPDFs

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  Regge factorization assumed everywhere

Global fit to all the inclusive and dijet data available (H1 has brand new high precision dijets in DIS!) would improve precision and set HERA heritage. Statistics is enough to drop vertex factorization assumption

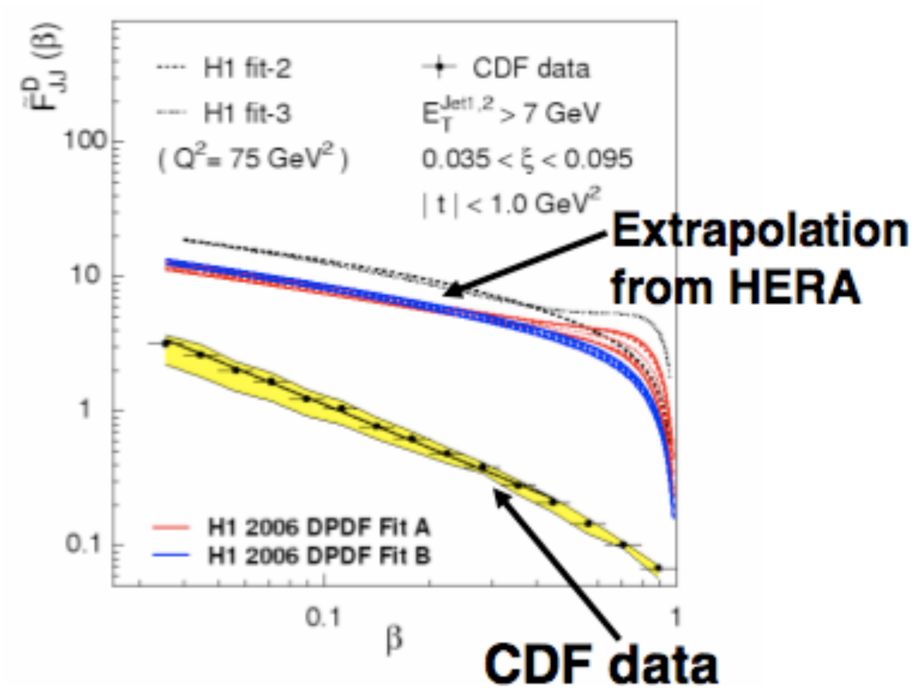
Machinery exists (arXiv:1110.4829v1, ZEUS code in HERAFitter already)

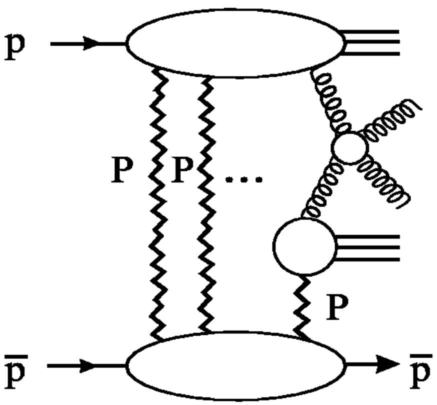
Critical issues: factorization breaking

Factorisation breaking at Tevatron

QCD factorisation not expected to hold in ppbar, pp: indeed it does not!

- **Factor 10 normalisation difference** between extrapolation from HERA data and CDF measurement





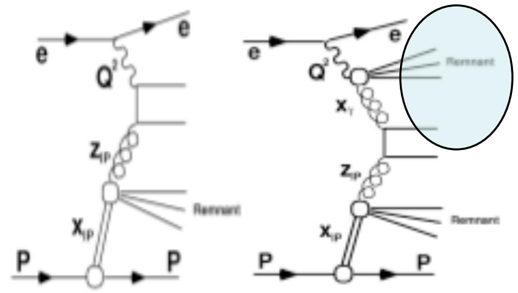
- ☐ Understood in terms of (soft) **rescattering among spectator partons** [Kaidalov, Khoze, Martin, Ryskin] PRL 84 (2000) 5043
- ☐ Lots of different theoretical approaches [Goulianos, Gotsman, Levin, Maor, Ingelman, Enberg, Cox, Forshaw, Lonnblad...]
- ☐ Quantified by **"rapidity gap survival probability", $<|S|^2>$**

Can we learn something from HERA data?

Rescattering effects at HERA?

- **Diffractive dijet photoproduction:**
  direct vs resolved events
  → switch photon remnant on/off:

$$x_\gamma = \frac{\sum_{jets} E - p_z}{\sum_{HFS} E - p_z}$$



$x_\gamma < 0.75$

Rescatter

?

Rescattering effects at HERA?

DIFF DIJET PHOTOPRODUCTION

ZEUS and H1 HERA I data (LRG method) in DIS and photoproduction
H1 HERA II data (proton tag) in DIS and photoproduction
H1 HERA II data (LRG method) in DIS

- **H1: ~0.6 suppression not dependending on x_γ**
  ZEUS compatible with no suppression
  BUT: issue of different proton dissociation contamination
  different y, E_T ranges

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- **H1 in a restricted~ZEUS E_T range → moves towards ZEUS**

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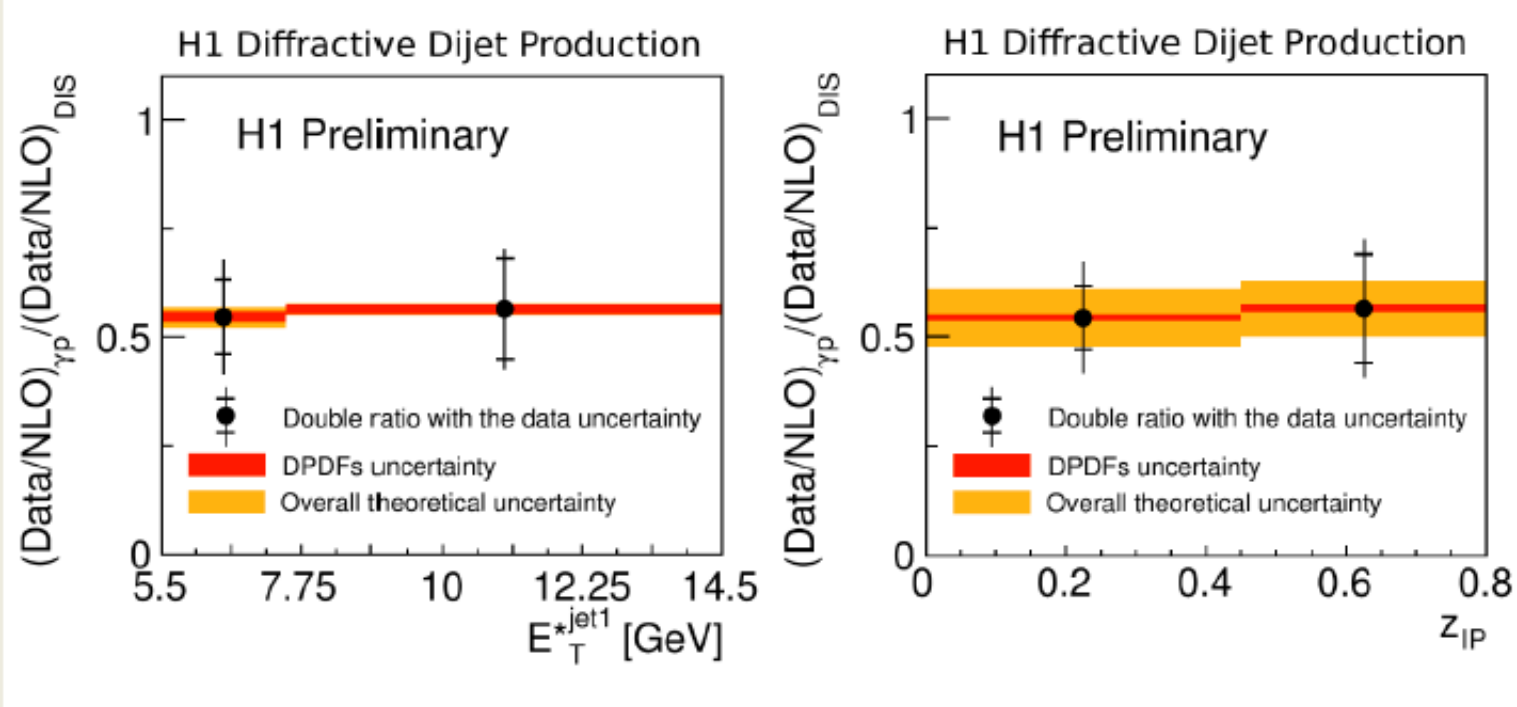
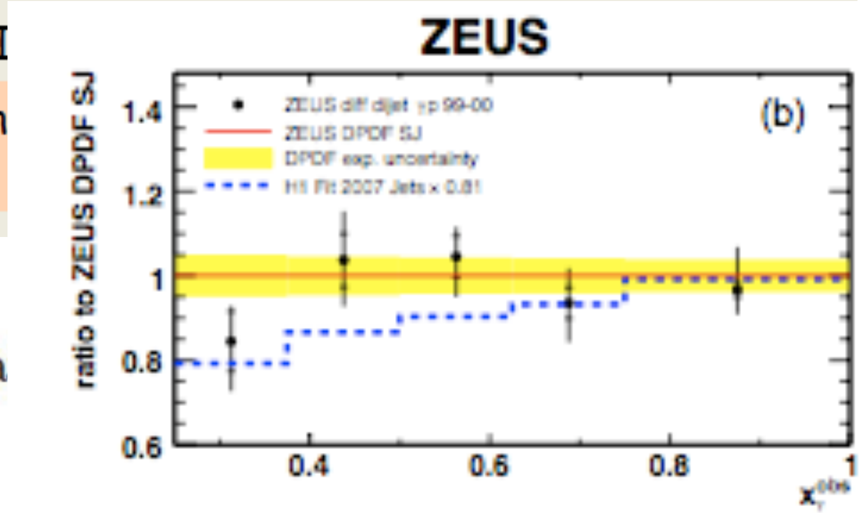


Double ratio photoproduction/DI

Dependence of the suppression on
not observed!

$$\frac{(\mathrm{DATA/NLO})_{\gamma p}}{(\mathrm{DATA/NLO})_{\mathrm{DIS}}} = 0.55 \pm 0.10\,(\mathrm{da}$$



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data vs theory

- **Data seemed to show harder E_T dependence than theory** **not any more ?**
- **Better description with global suppression** rather than with resolved suppressed by 0.34 or treated with ad hoc suppression
  [KKMR, PRL 84 (2000) 5043, KKMR, EPJ C66 (2010) 373]

Not a clear picture...is there something else we can do?

Rescattering effects at HERA?
DIFF DIJET PHOTOPRODUCTION

- **Clarify H1 vs ZEUS**
- **To theorists: where is the onset?**
  Q^2 dependence, where does it start?
- **Exp: spanning Q^2 range in the transition region**

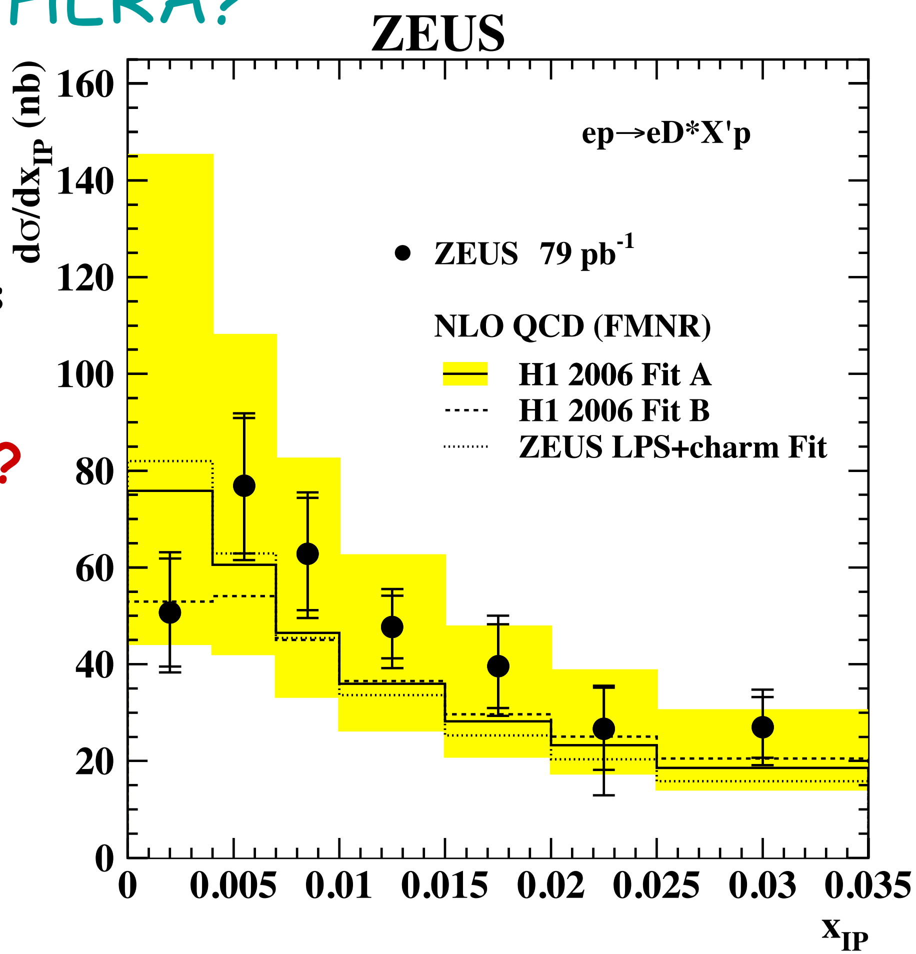
Rescattering effects at HERA?

DIFF CHARM PRODUCTION

H1 and ZEUS HERA I results

No suppression seen within uncertainties

Worth looking at HERA II data?



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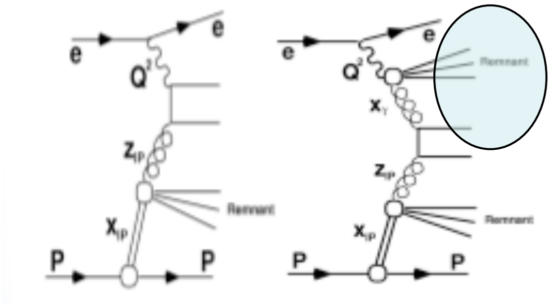
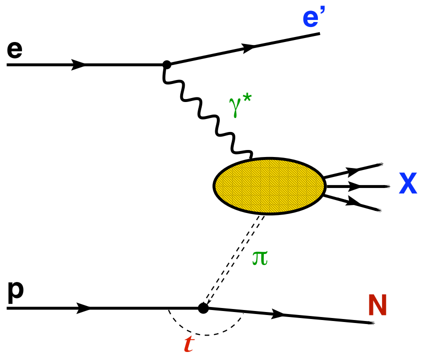


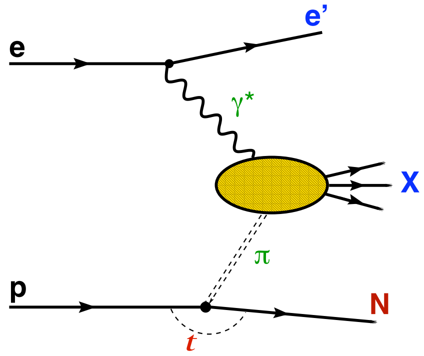
- **Leading baryon production:**
  photoproduction vs DIS
  → change photon size



- **Rapidity gap between jets**

Rescattering effects at HERA?

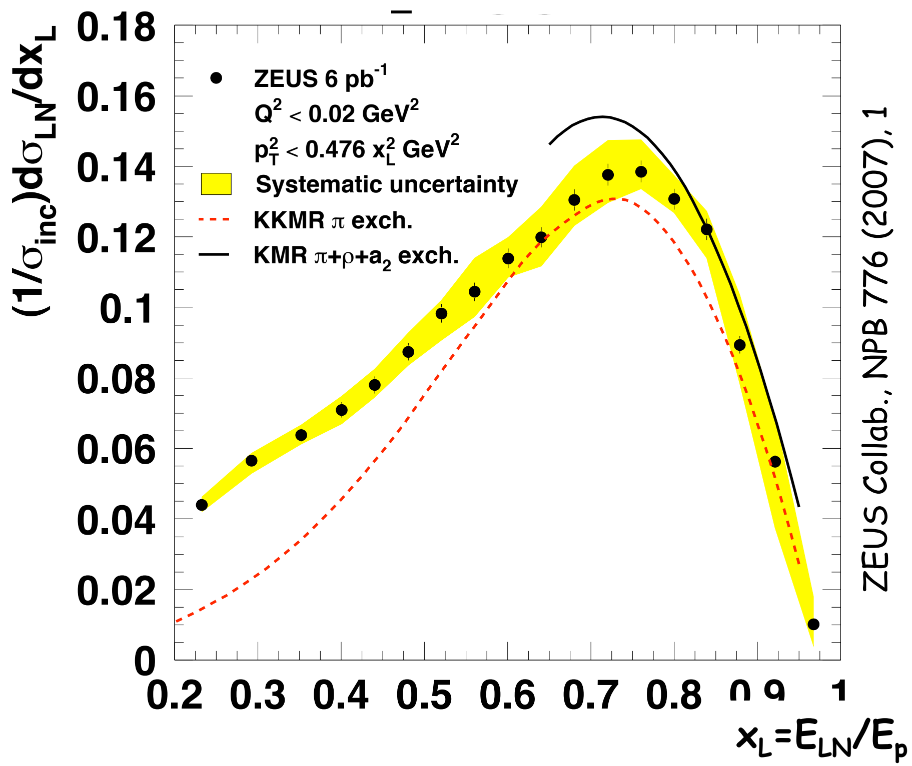
LEADING NEUTRON PRODUCTION



H1 and ZEUS HERA I results

Neutron yield in photoproduction consistent with rescattering:
[Kaidalov et al., EPJ C47 (2006), 385;
EPS C48 (2006), 797]

- Rescattering causes migration of LN to lower x_L, thus acting as absorption at high x_L

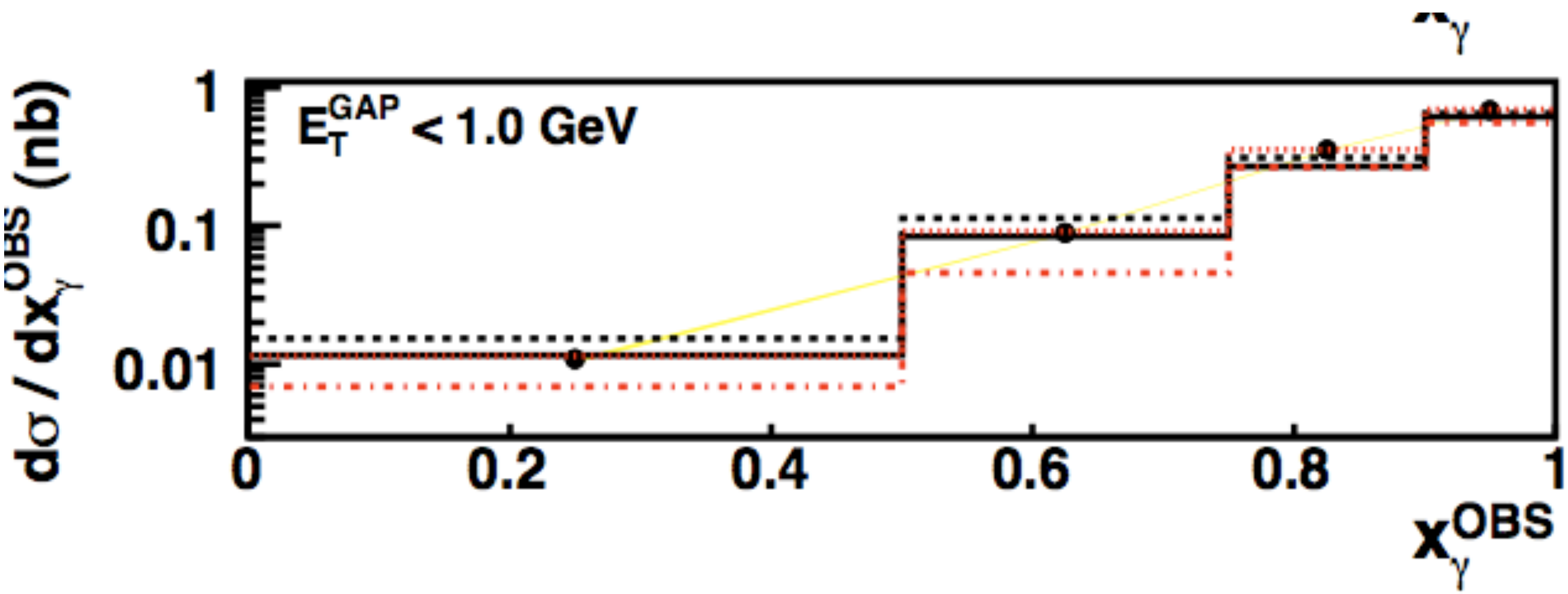


ZEUS Collab., NPB 776 (2007), 1

Rescattering effects at HERA?

RAPIDITY GAP BETWEEN JETS

H1 and ZEUS HERA I results



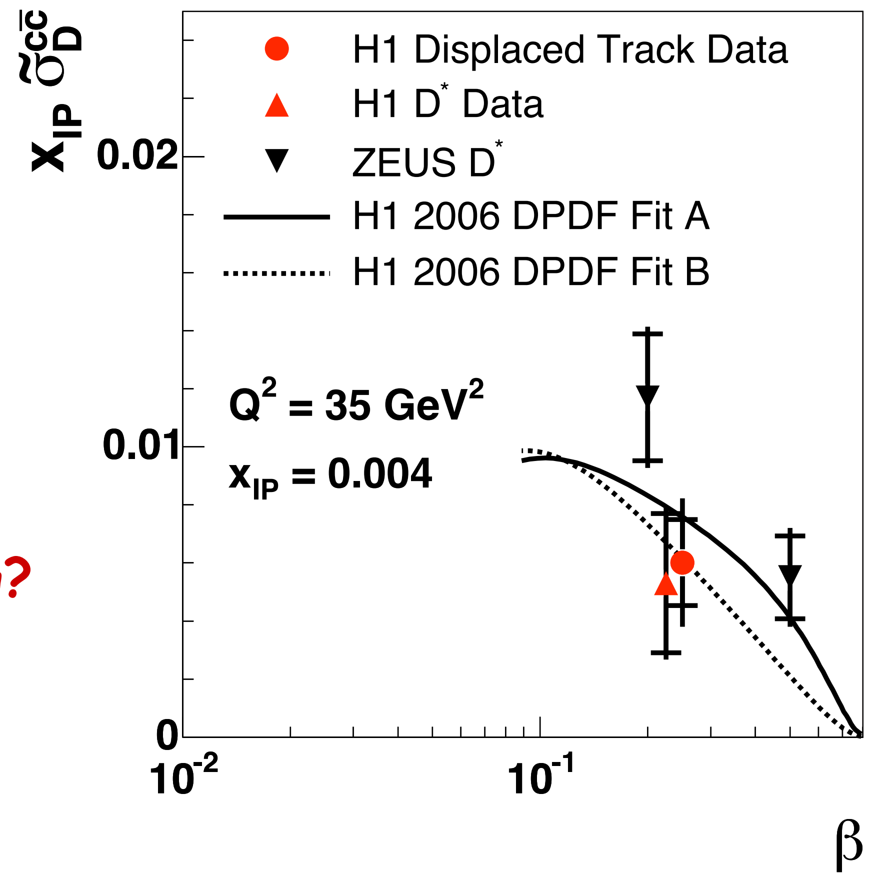
Never done before

F_2^b, F_2^c with proton tag

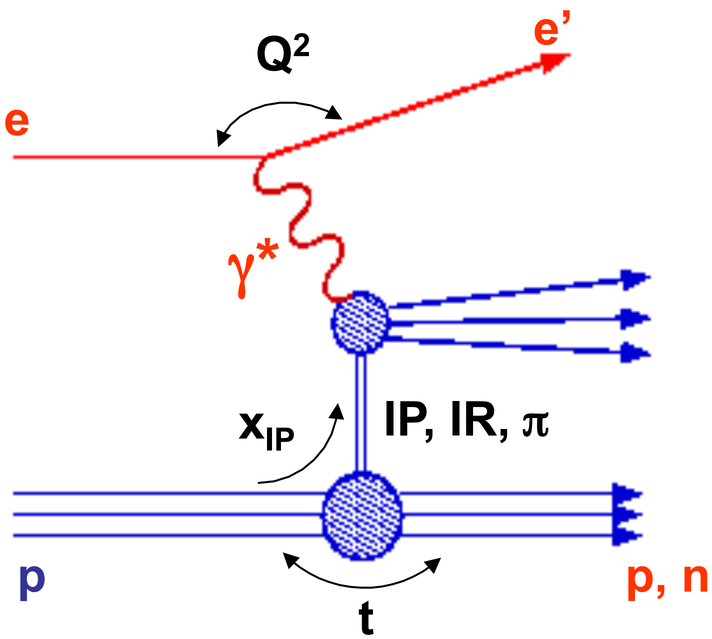
F_2^c measured with LRG
(HERA I data)

Nice ingredients for a global fit

HERA II data: LRG or proton tag?
Statistics has to be good



QCD fit to leading baryon data



Leading proton and neutron spectra important for cosmic ray community and LHC

Yet another way to investigate the proton structure -- measure F_2^{LP}, F_2^{LN} and extract corresponding PDFs

QCD fits to leading neutron data → F_2^π

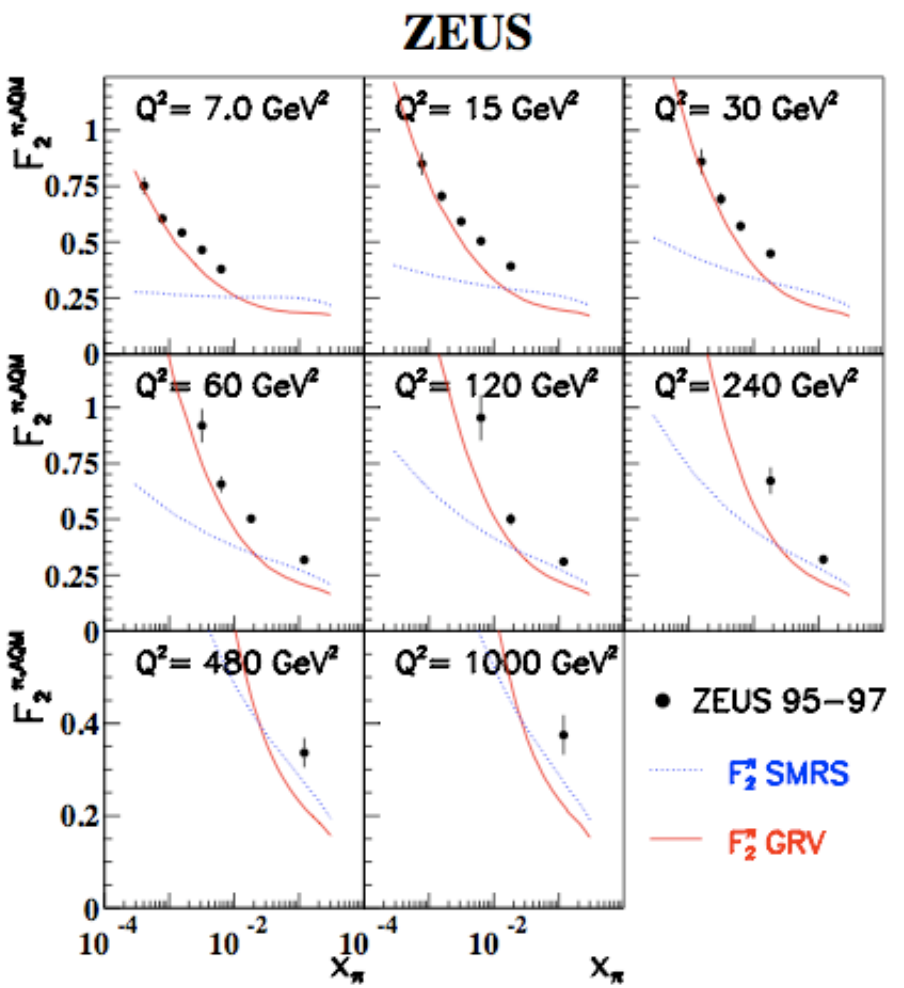


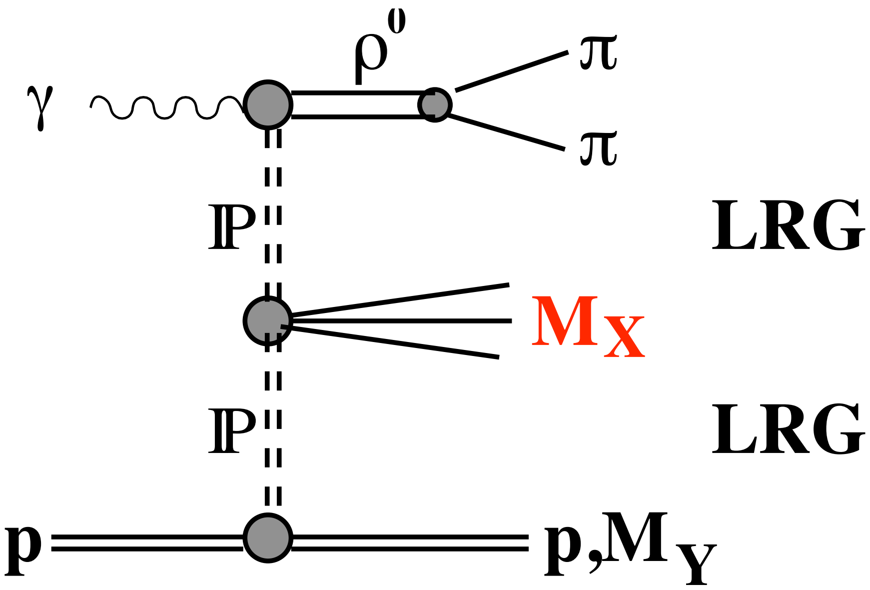
Figure 19: F_2^π as a function of x_π for the pion in bins of Q^2 determined for $0.64 < x_L < 0.82$. The pion flux used to determine F_2^π is the flux obtained using the additive quark model (AQM) of Eq. (21). The uncertainty shown on $F_2^{\pi,AQM}$ arises from the statistical uncertainty due to the leading neutron added in quadrature with the uncertainty on F_2. Not shown are the correlated systematic uncertainties given in Table 1. The solid curves are F_2^π from the GRV parameterisation [76] while the dotted curves are from the Sutton *et al.* parameterisation [77].

H1 and ZEUS HERA I results

F_2^π measured but never fitted

In principle can extract pion PDFs!

Central diffraction



typical Mx range would be
$W\sqrt{(x_{IP}^1 x_{IP}^2)}$ = 1-6 GeV
with the maximum at 2-3 GeV

Intriguing process and mass range, interesting already extablishing it!

Feasibility study needed - no Monte Carlo available (yet) on the market

Odderon searches

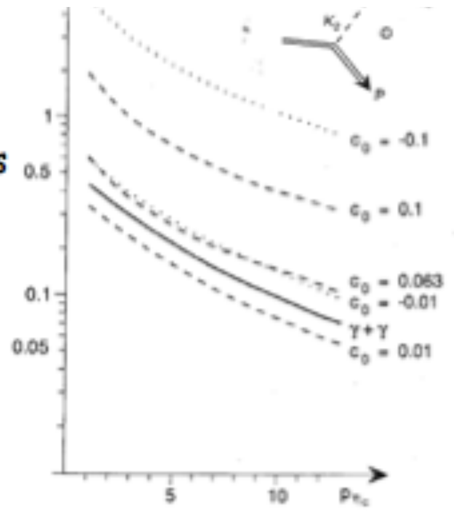
A. Schäfer/L. Mankiewicz/O. Nachtmann:

"The diffractive production of η, η', and η_c can serve as a probe of the odderon, while diffractive J/psi, and psi' production tests the universality of the pomeron. [...] the ratio of η to η' should be a good test for the existence of an odderon. The total cross sections we got are of the order nanobarn and thus should be measurable without too many problems."

-> J/psi and psi' mostly done (H1)/ongoing (ZEUS).

η, η', η_c not yet achieved; should be feasable

-> also see talks R. McNulty, M. Sauter, ...



12. 11. 14 A. Geiser, Future HERA workshop 5

Old measurement by H1 (HERA I), only upper limit

Theretically must be there!

Theorists come up with new idea and models → **Michel Sauter's talk**

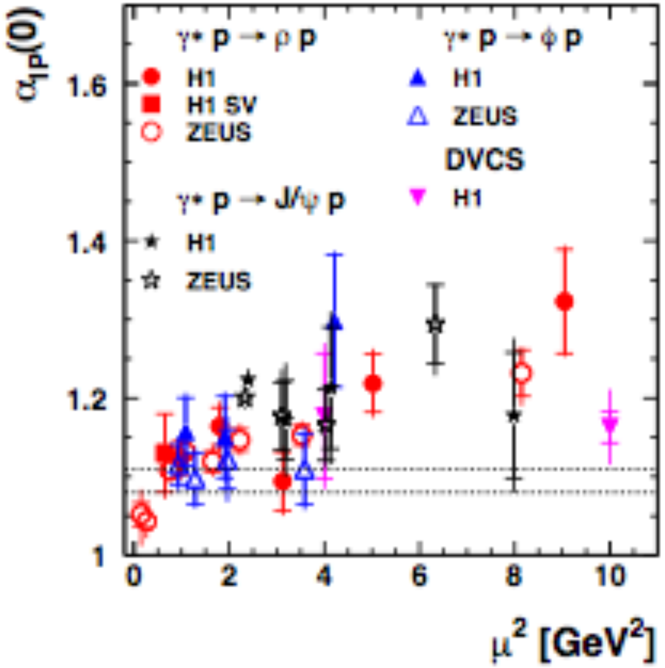
Higher statistics

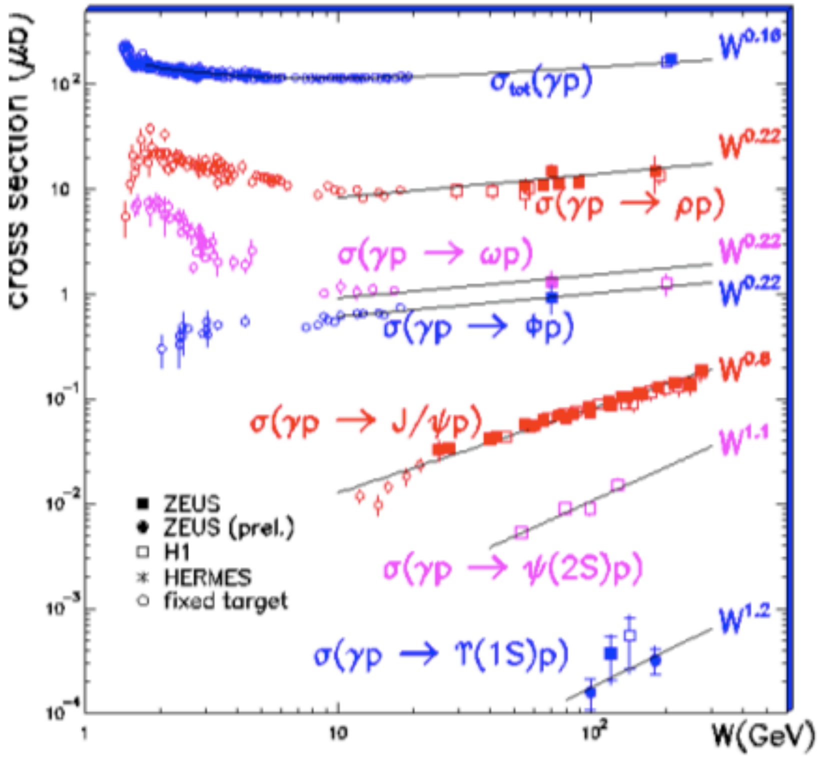
VM production

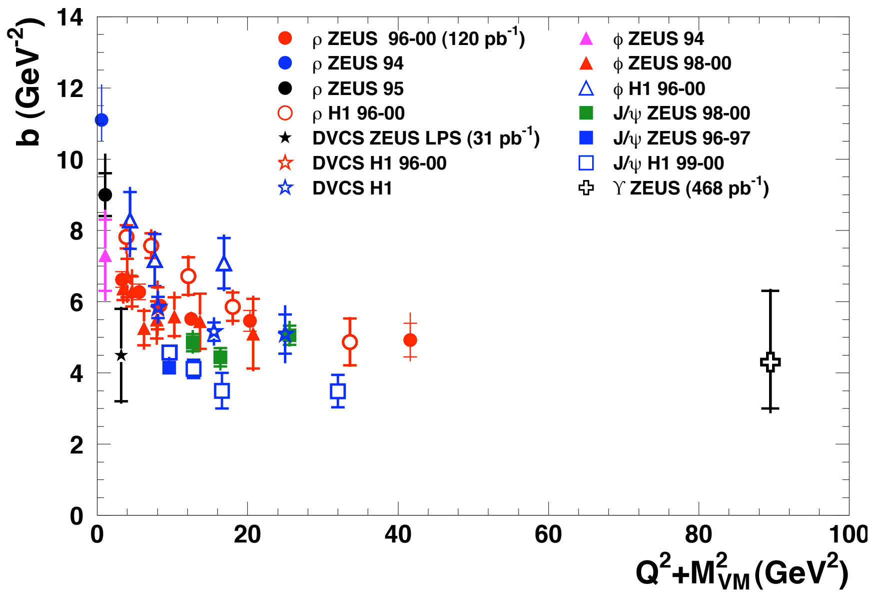
Rich harvest documented by tens of papers

Large W interval

Wide range of several scales (Q^2, t, M_{VM})







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Presently H1 and ZEUS are finalizing analyses of post-upgrade data

- key measurements repeated with full statistics

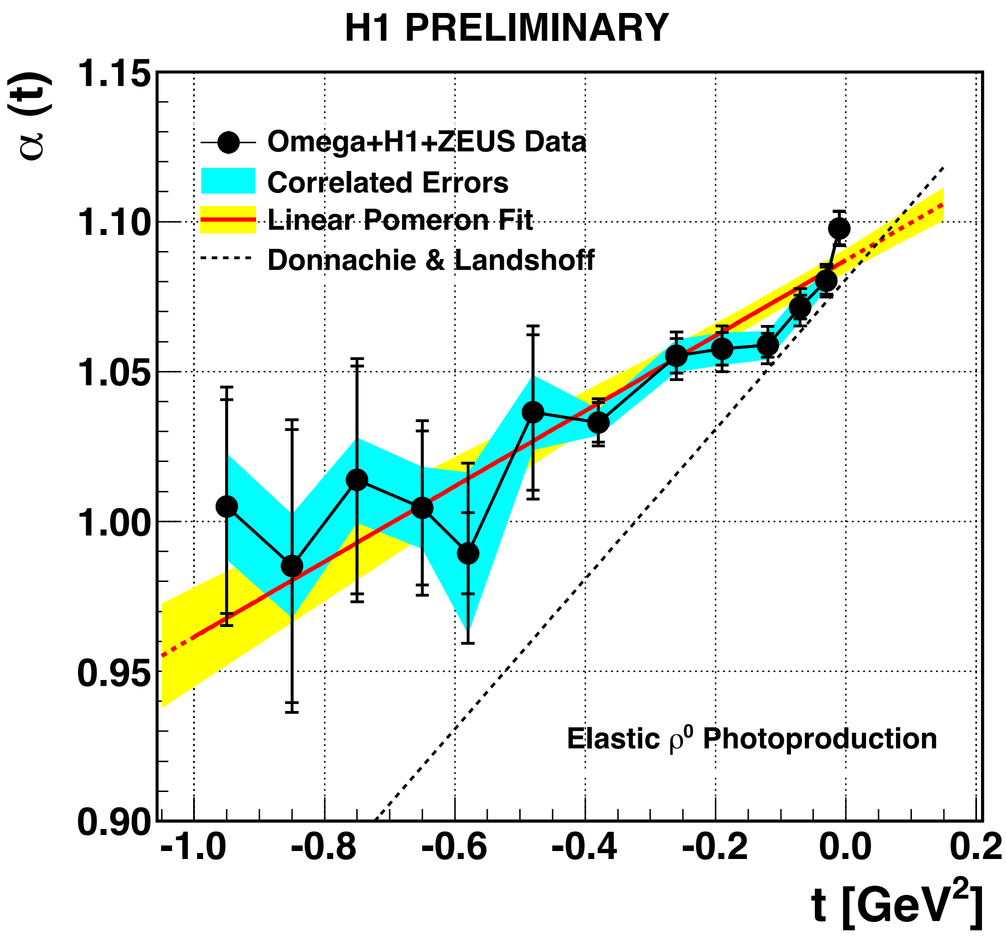
- runs at reduced center of mass energy originally devoted to F_L extraction allow studies with different kinematics

- low cross section processes benefit from higher lumi

Can we consider ourselves satisfied?

Pomeron trajectory

Global fit of H1, ZEUS and OMEGA data, still preliminary



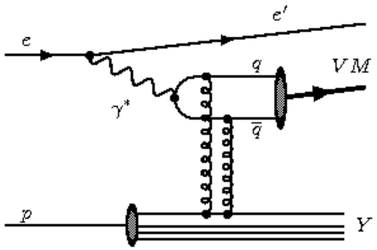
Could add

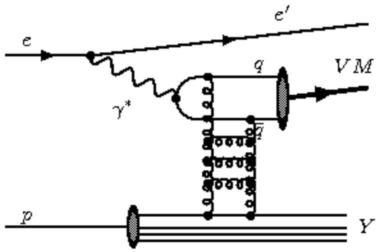
- **latest ZEUS data**
- **low energy HERA II data**

High |t| vector mesons and photons

VM = qqbar dipole, interacts with the proton through the exchange of
2 gluons or a gluon ladder

standard DGLAP or BFKL evolution equations





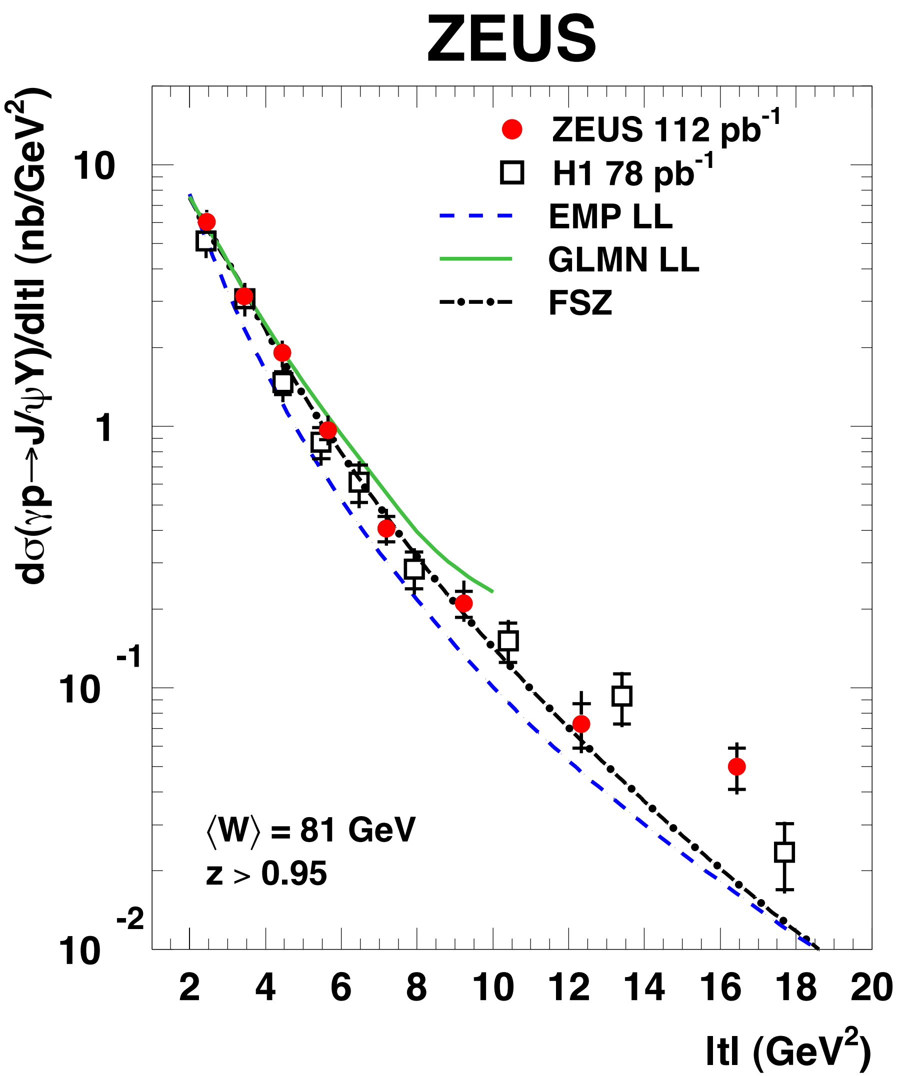
among best processes to see BFKL pomeron

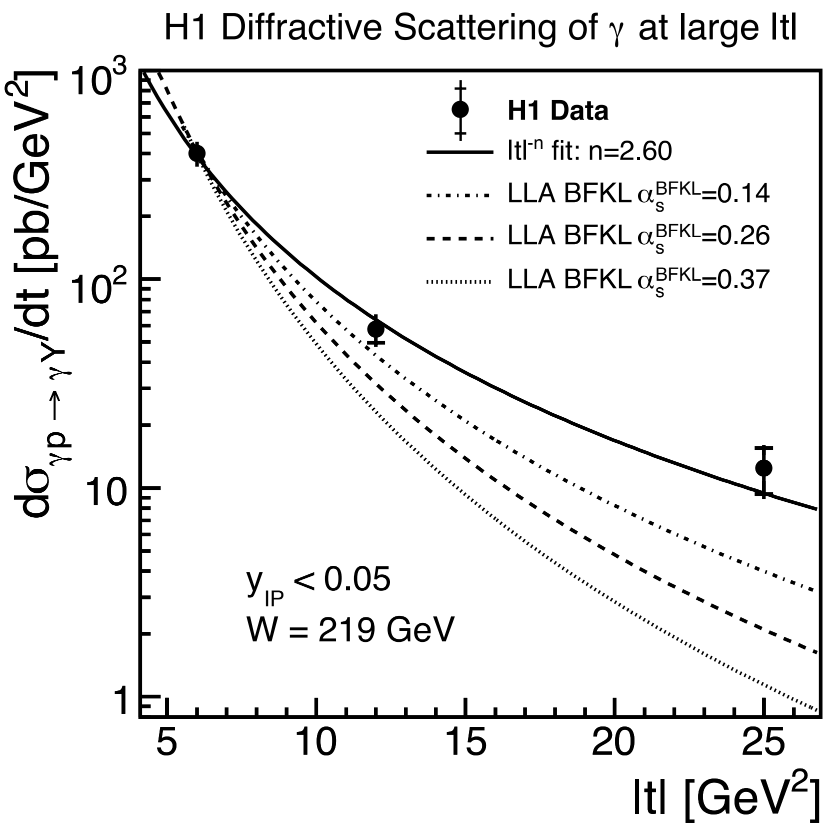
High t domain little explored so far

Proton dissociative processes dominate at high t

ZEUS and H1 results with light VM, J/psi, exclusively produced photons

High |t| vector mesons and photons





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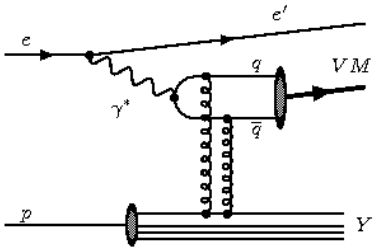
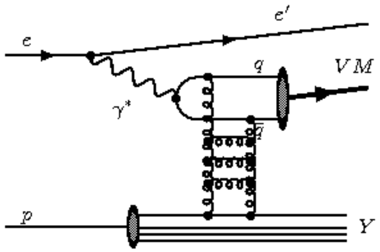
2 gluons or **a gluon ladder**





standard DGLAP or BFKL evolution equations

among best processes to see BFKL pomeron

High t domain little explored so far

Proton dissociative processes dominate at high t

ZEUS and H1 results with light VM, J/psi, exclusively produced photons

HERA II data would greatly improve precision and strenghten conclusion

In summary

- **Diffraction received a great boost from HERA data in the last decade**
  - Many aspects of diffractive DIS can be described by pQCD if a hard scale is present
  - **Diffractive Parton Distribution Functions (DPDFs)** extracted from inclusive and diffractive final state (dijet) data : describe partonic content of proton probed diffractively, mainly gluons
  - Further input from hard vector meson production and DVCS, where precision measurements can constrain the gluon density and their sensitivity to **Generalised Parton Distribution Functions (GPDs)** allows access to parton momenta correlations and trasverse distribution of partons → **scanning the proton at different x** is a unique feature of diffraction!

- **Hard diffraction in hadron-hadron collisions more challenging due to rescattering effects between spectator partons**
  - Need to understand rescattering corrections in terms of QCD – **intimate relation with multiple scattering effects**, great interest in view of the LHC
  - Hint of such effects at HERA, more investigation needed

- **Fundamental links**
  - between the degrees of freedom prevailing in soft interaction - hadrons and Regge trajectories, and those of QCD – quarks and gluons
  - to low-x physics, saturation,...

Brain storming on future prospects

- Diffractive Parton Distribution Functions (DPDFs) fit
- Mechanisms of factorisation breaking

Critical issues

- Proton tagged F_2^b, F_2^c
- π parton density extraction
- Central diffraction

Not done before

- Pomeron trajectory
- BFKL pomeron
- Odderon

High statistics

In short: what are the priorities?

- Diffractive Parton Distribution Functions (DPDFs) fit
- Mechanisms of factorisation breaking

Critical issues

- Proton tagged F2b, F2c
- π parton density extraction
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Not done before

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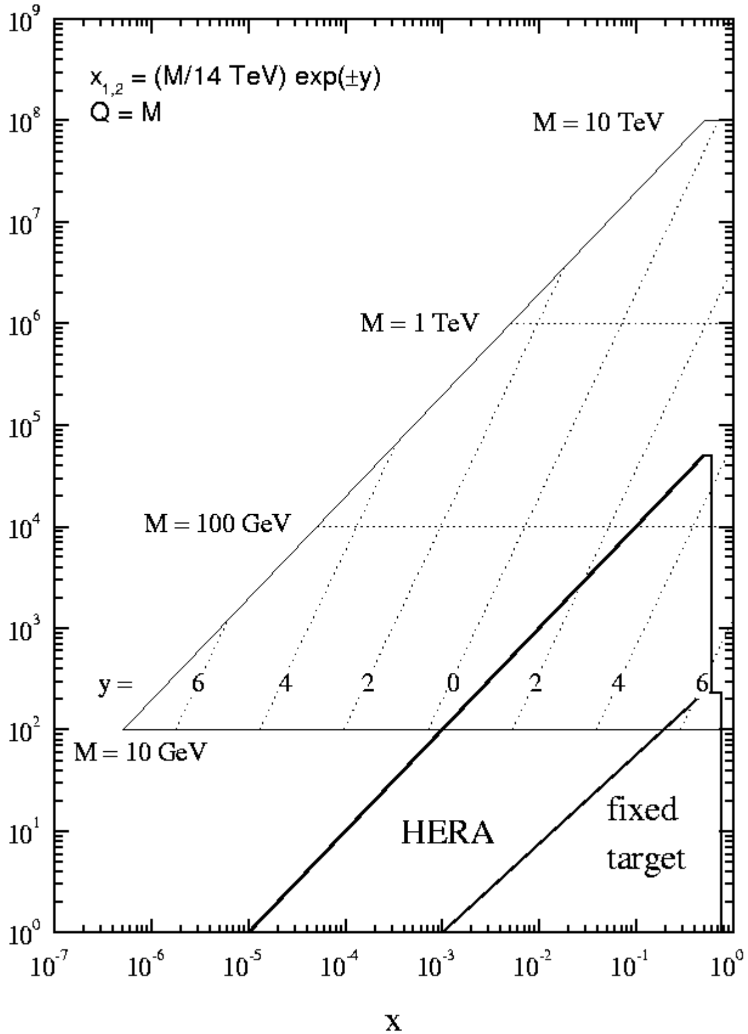
High statistics


LHC parton kinematics
$x_{1,2}$ = (M/14 TeV) exp(±y)
Q = M
M = 10 TeV
M = 1 TeV
M = 100 GeV
M = 10 GeV
y = 6 4 2 0 2 4 6
HERA
fixed target
x
10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^0