The Photon in Diffraction at HERA

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for H1 and ZEUS

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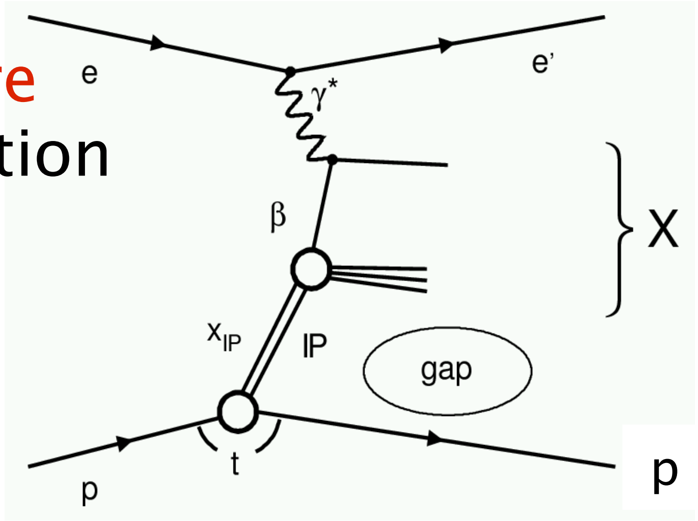
Universality of diffractive proton structure
structure functions, dijets, D* production

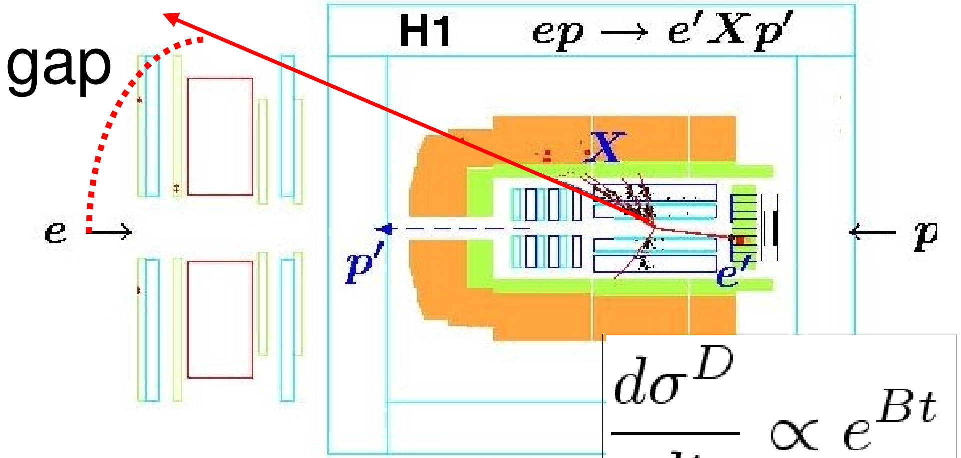
Role of the photon
DIS vs. Photoproduction,
direct vs. resolved photon



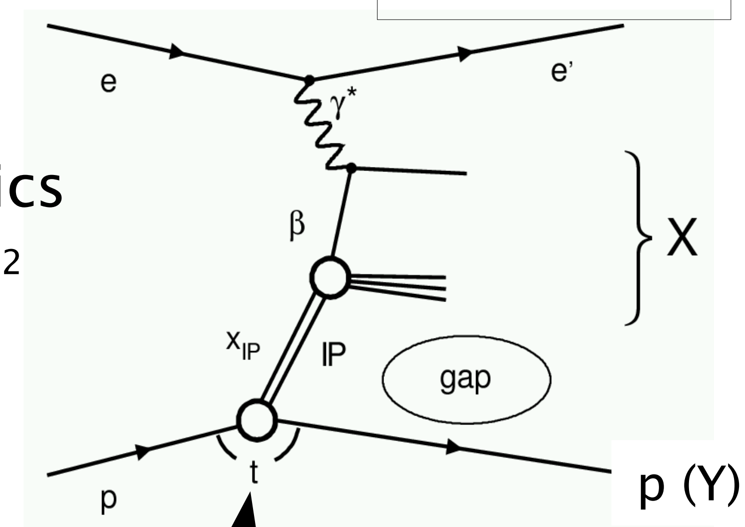
Diffractive HERA Events

≈10% of all HERA events
are diffractive

- proton remains intact
- forward detectors empty
- selection methods:
  - proton tagging
    - Roman pots, low acceptance/statistics
    - measure t dependence: B=5..8 GeV^{-2}
  - rapidity gap (and derived)
    - |t|<1 GeV^2, ≈25% proton dissociation with mass≲2 GeV

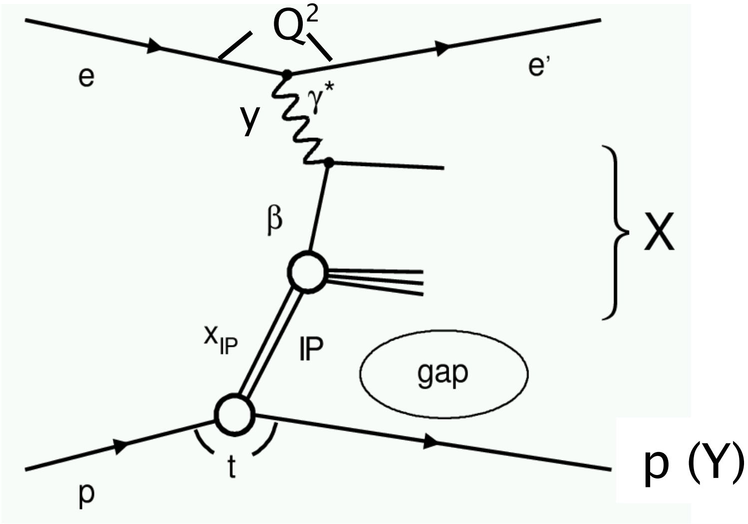


$$\frac{d\sigma^D}{dt} \propto e^{Bt}$$



square of 4-momentum transferred (t<0)

Kinematics



Q^2 photon virtuality, –(4–momentum)^2

β quark momentum fraction

Diffractive variable:

x_{IP} fractional proton momentum loss

small in diffraction (1%)

rapidity gap $\Delta\eta \sim -\ln(x_{I\!P})$

typically >3.5

cross section = $\dfrac{4\pi\alpha^2}{xQ^4} Y_+ \; \sigma_r^D(x, Q^2, x_{I\!P}, t)$

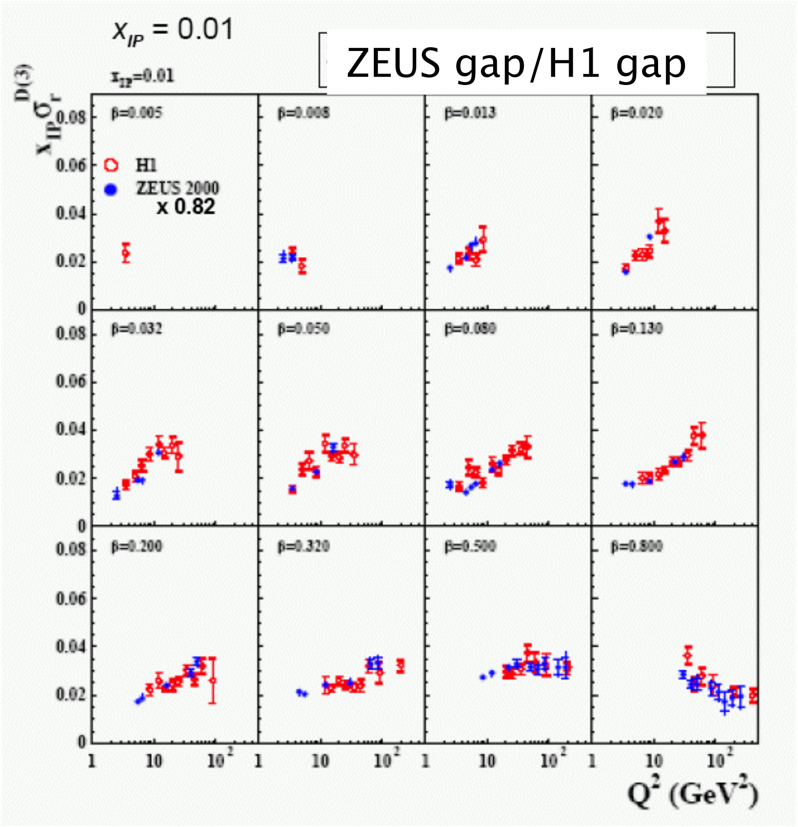
$$\sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D$$

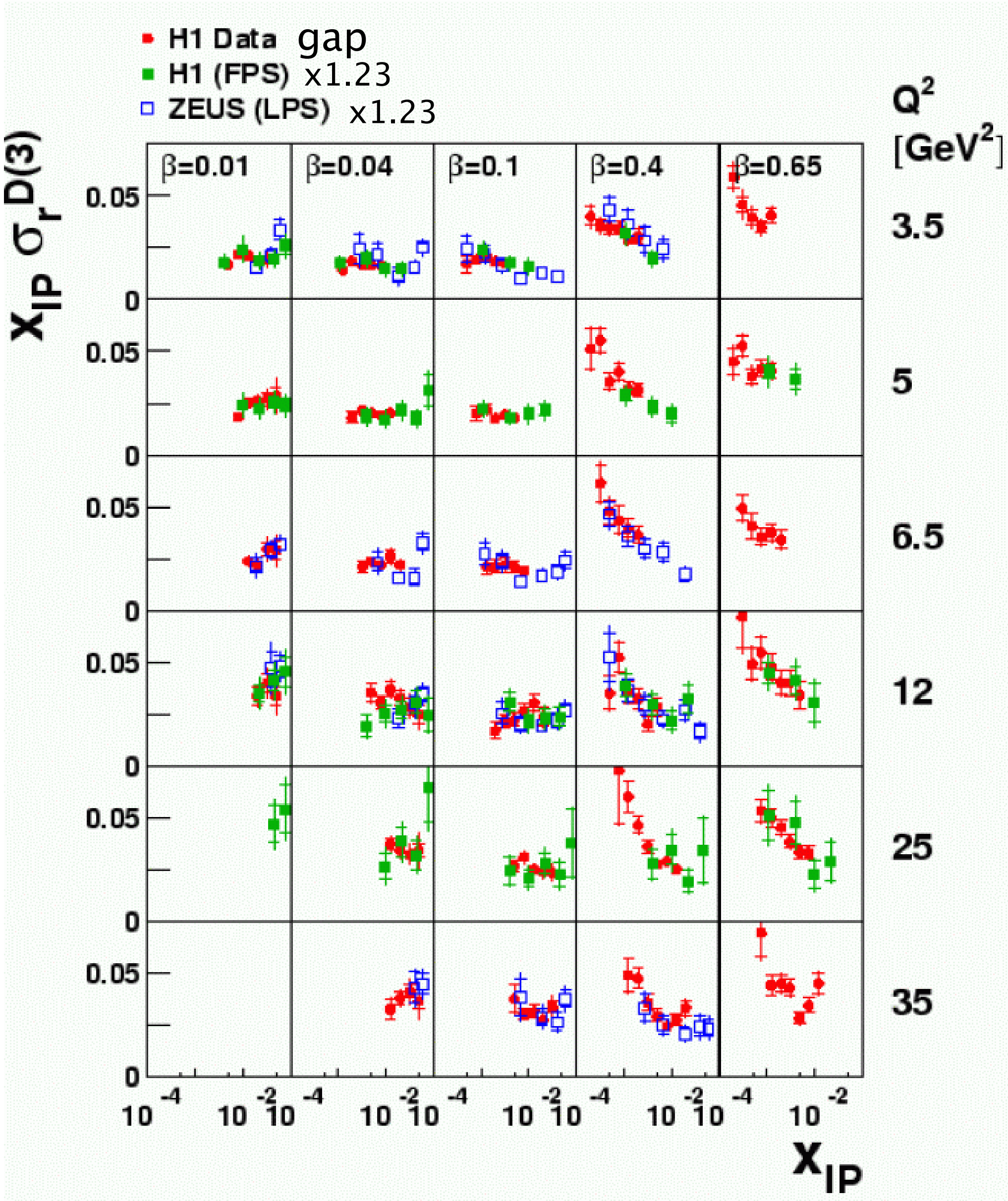
structure functions

F_L only important at high y

$$x = x_{I\!P}\,\beta$$
$$Q^2 = s\,x\,y$$
$$Y_+ = 1 + (1-y)^2$$

Tagged proton vs. Gap



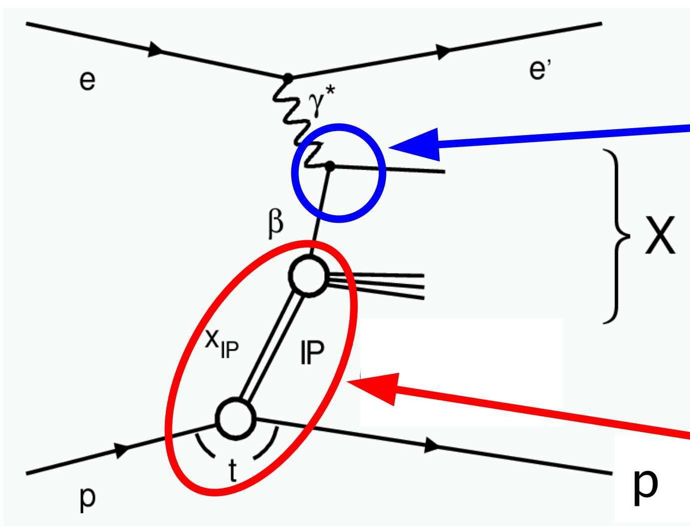


good agreement between methods and experiments

- gap data include ≈25% proton dissociation

Factorisation and PDFs

- fact^n theorem for diffraction in DIS: (Collins et al.)



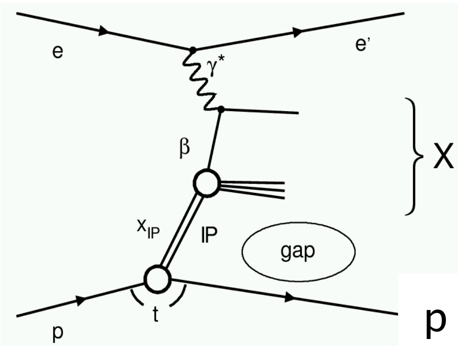
hard parton subprocess

$$\sigma_D^{\gamma^* p} = \sum_{\text{partons } i} f_{i/p}^D \otimes \sigma^{\gamma^* i}$$

DPDF (soft)

- test DPDF universality:
  - extract DPDF from measurement of simplest process: ep→eXp in DIS
  - apply DPDF in calculations for jet and D* production in DIS and photoproduction

Inclusive cross section and fit



- measure quarks directly

$$F_2^D \sim \beta \sum_i e_i^2 \; q_i^{LO}$$

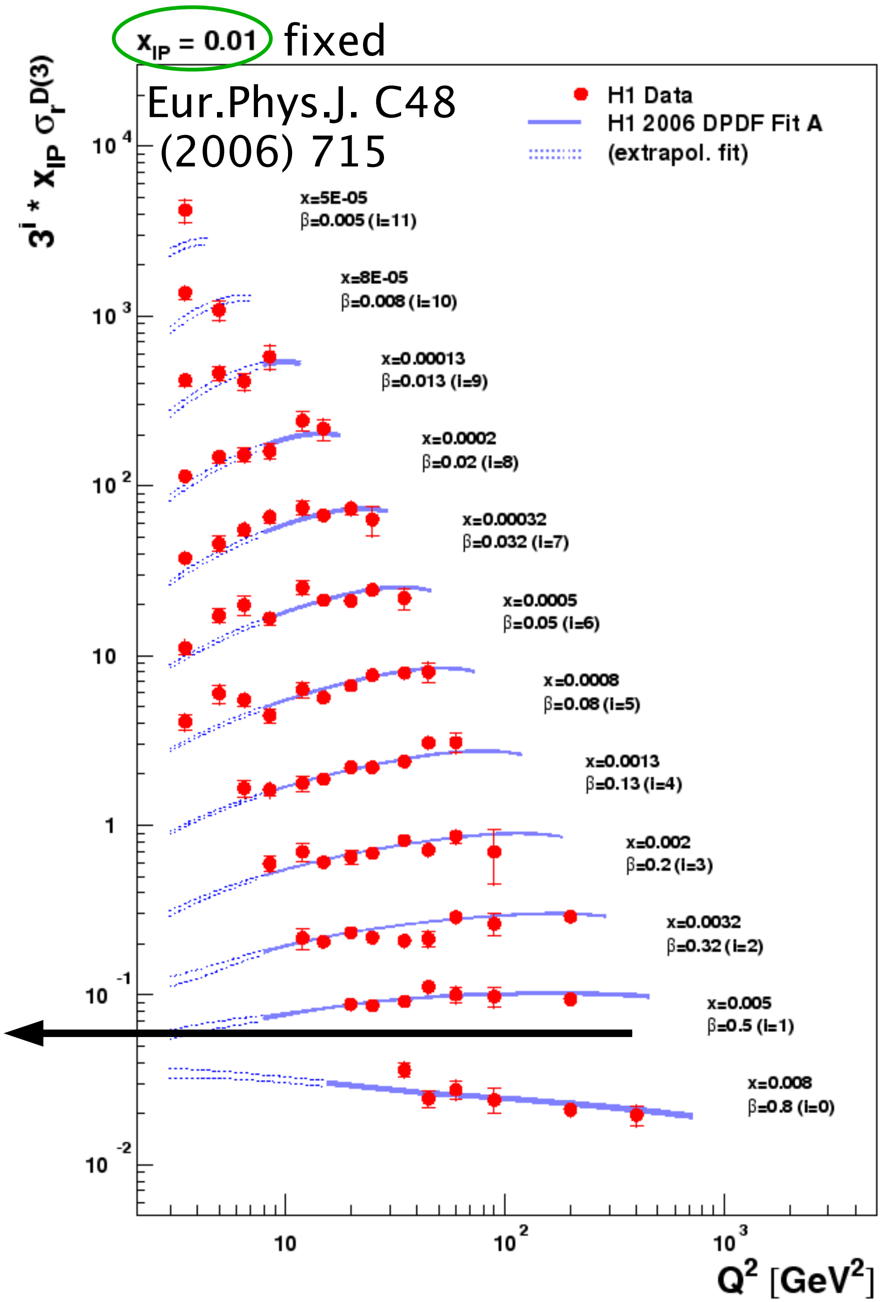
- gluon from scaling violations

$$\partial F_2^D / \partial \ln Q^2 \sim \alpha_s \, g^{LO}$$

positive scaling violations up to $\beta \approx 0.6$

ordinary F_2 rises up to $x_{Bj} \approx 0.1$

large gluon component

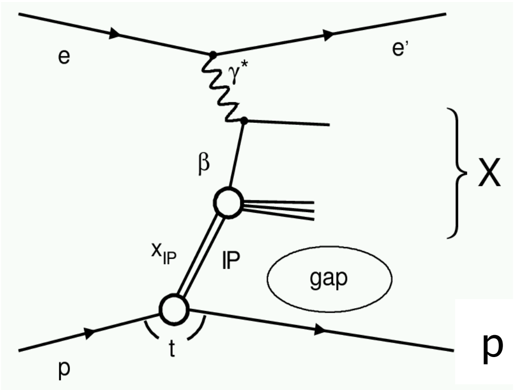


Extraction of parton content

Recipe: (standard procedure, like for F_2)

- measure cross section as a function of Q^2
- parameterise momentum densities q(z), g(z) at starting scale $Q_0^2 \approx 2$ GeV^2
- evolve q,g to measured Q^2 using DGLAP equations
- find parameterisation which fits best throughout Q^2 range

Details:



- not enough data to fit at fixed x_{IP}

  phenomenological Ansatz for densities:

$$f_i^D(\beta, Q^2, x_{I\!P}, t) = f_{I\!P}(x_{I\!P}, t)\, f_{i/I\!P}(\beta, Q^2)$$

$$f_{I\!P} \propto \frac{e^{Bt}}{x_{I\!P}^{2\alpha_{I\!P}(t)-1}}$$ describes data well

Diffractive parton densities

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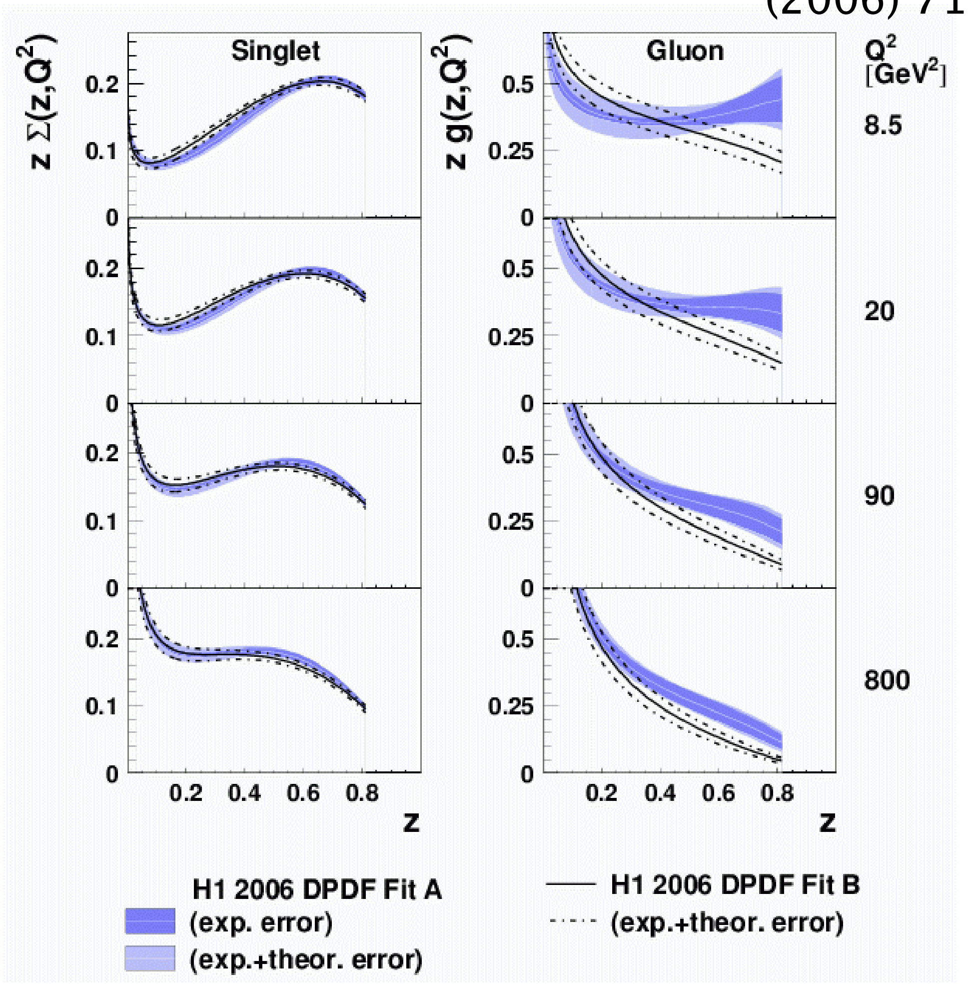
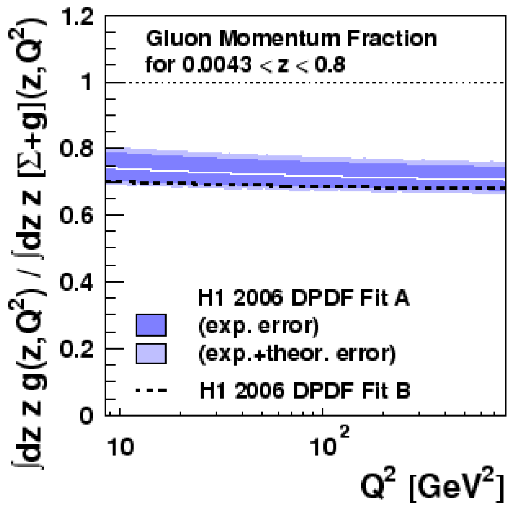
- quark singlet

$$\sum = u + d + s + \bar{u} + \bar{d} + \bar{s}$$

- gluon carries ~70% of momentum
- little sensitivity to gluon at z≳0.5

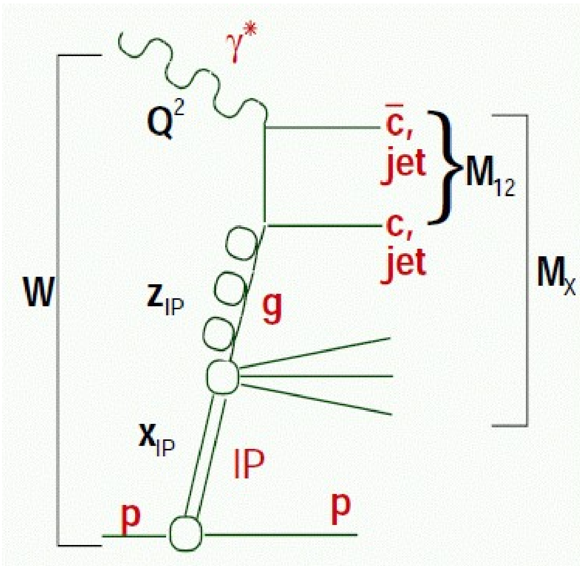




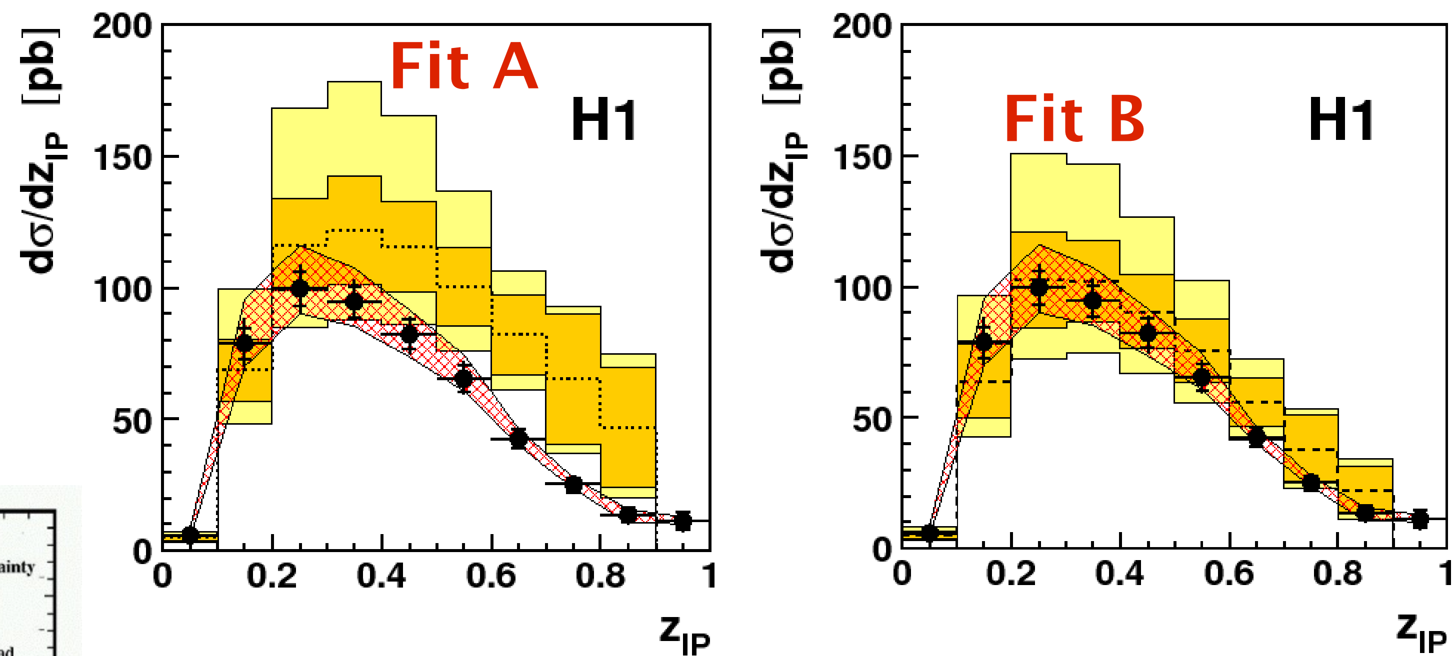
2 different gluons (Fit A and B) describe inclusive diffraction equally well

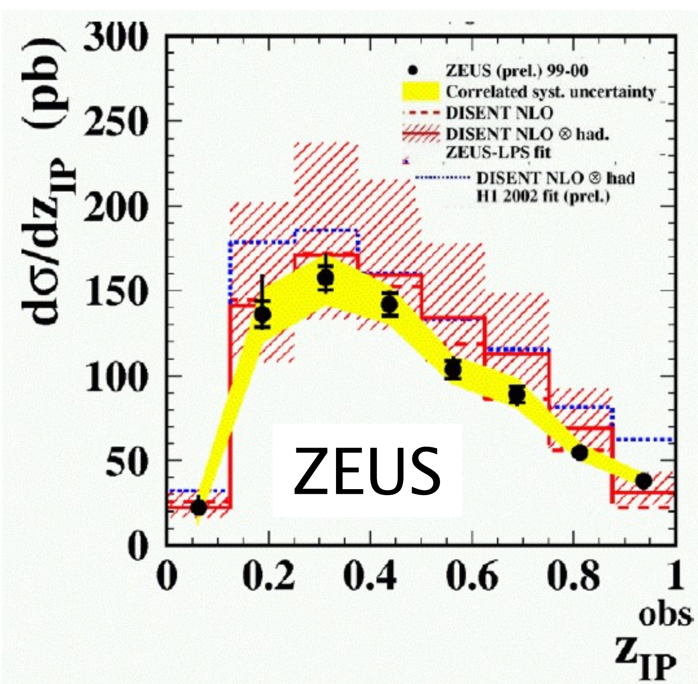
Dijets in DIS

$E_T(1)>5.5$ GeV, $E_T(2)>4$ GeV
$4<Q^2<80$ GeV^2, $x_{IP}<0.03$
$0.1<y<0.7$



directly sensitive
to gluon

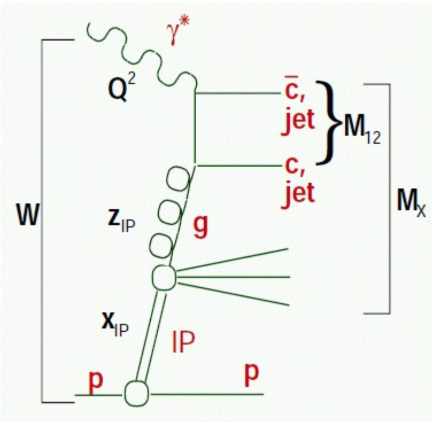


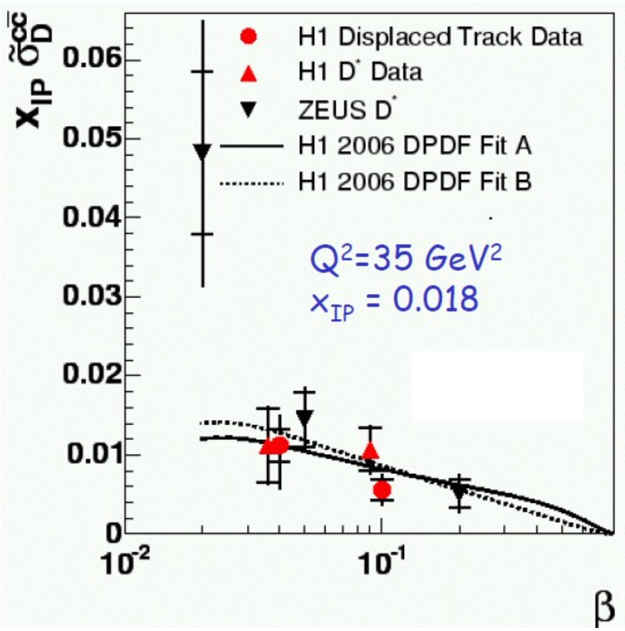


- QCD factorisation holds!
- dijet data clearly favour Fit B

$E_T(1)>5$ GeV, $E_T(2)>4$ GeV
$5<Q^2<100$ GeV^2, $x_{IP}<0.03$
$100<W<250$ GeV

Charm in DIS

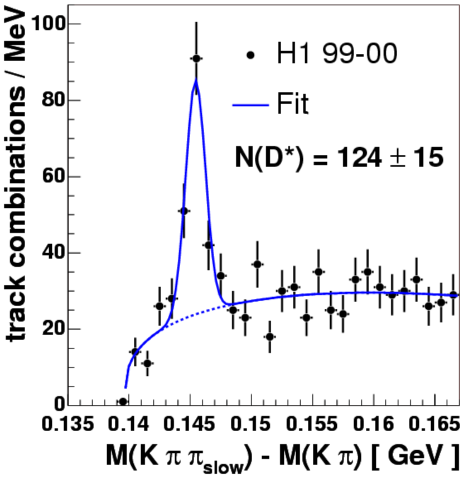




Eur.Phys. J. C50 (2007) 1

$p_T(D^*)>2$ GeV
$2<Q^2<100$ GeV^2
$x_{IP}<0.04$
$0.05<y<0.7$

$D^* \rightarrow K\,\pi\,\pi_s$

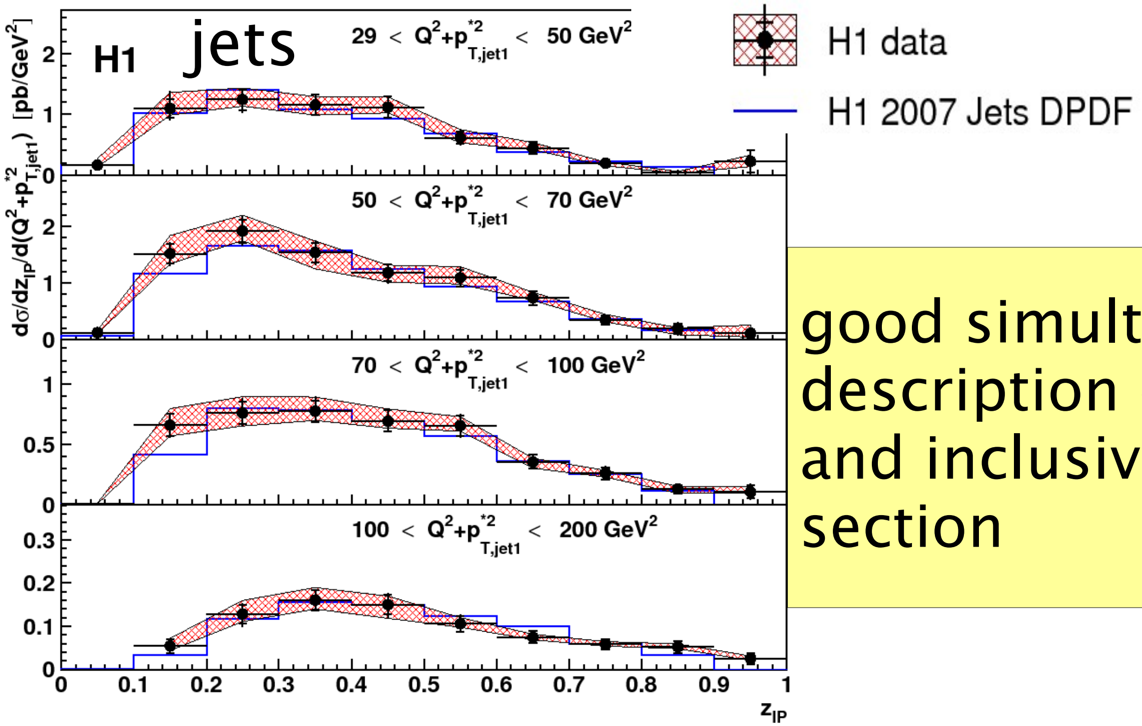


- NLO massive calculation (HVQDIS)
- $\text{scale}^2=(4m_c^{\ 2}+Q^2)$ varied by 1/4, 4

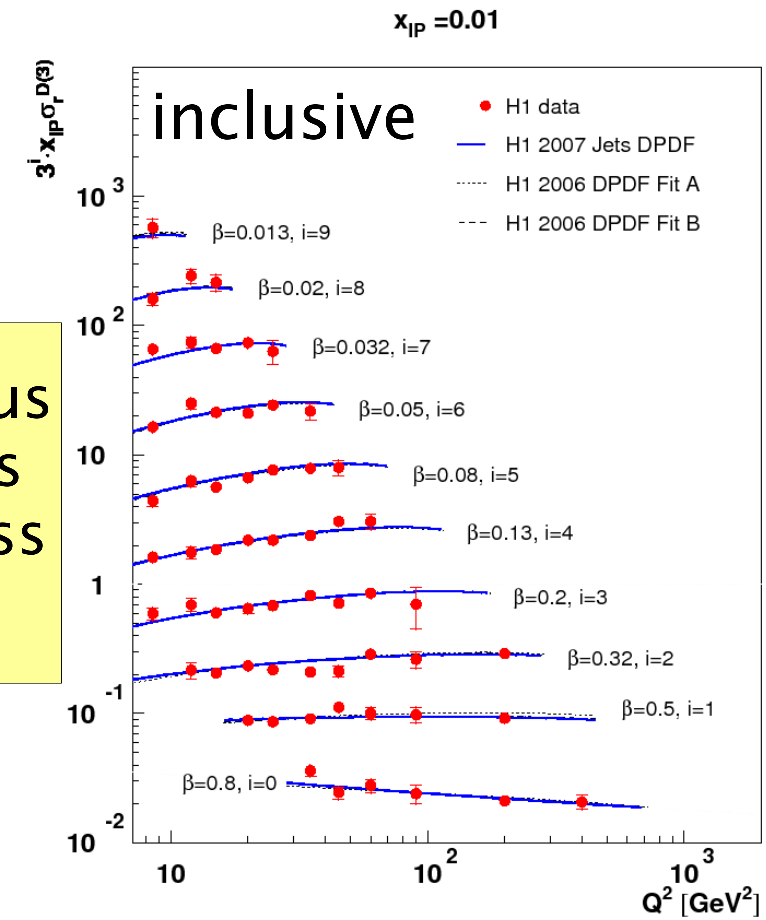
Good description, supports QCD factorisation

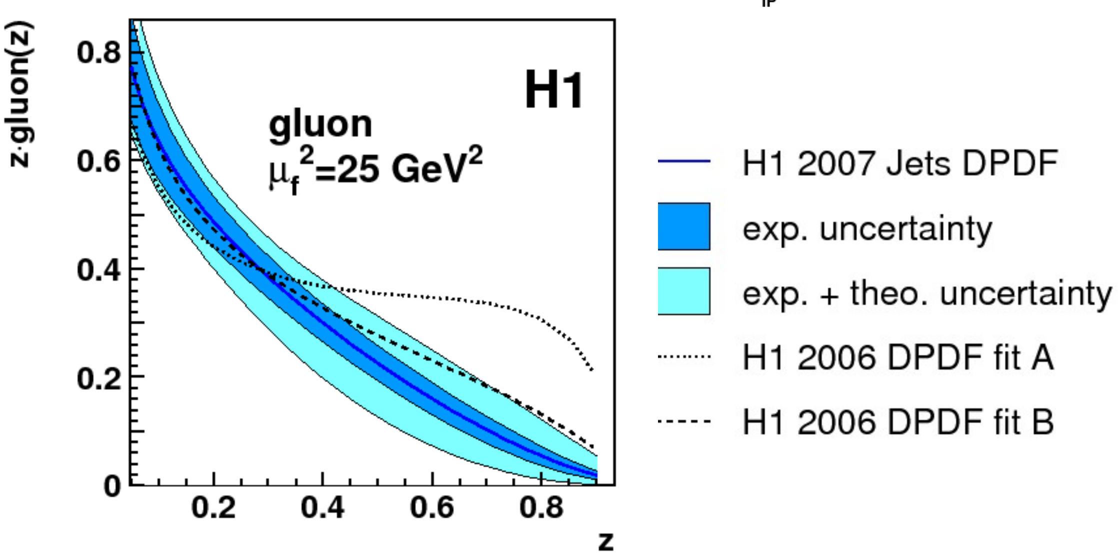
Combined inclusive/jets DPDF

use high z dijet data to constrain gluon



good simultaneous description of jets and inclusive cross section





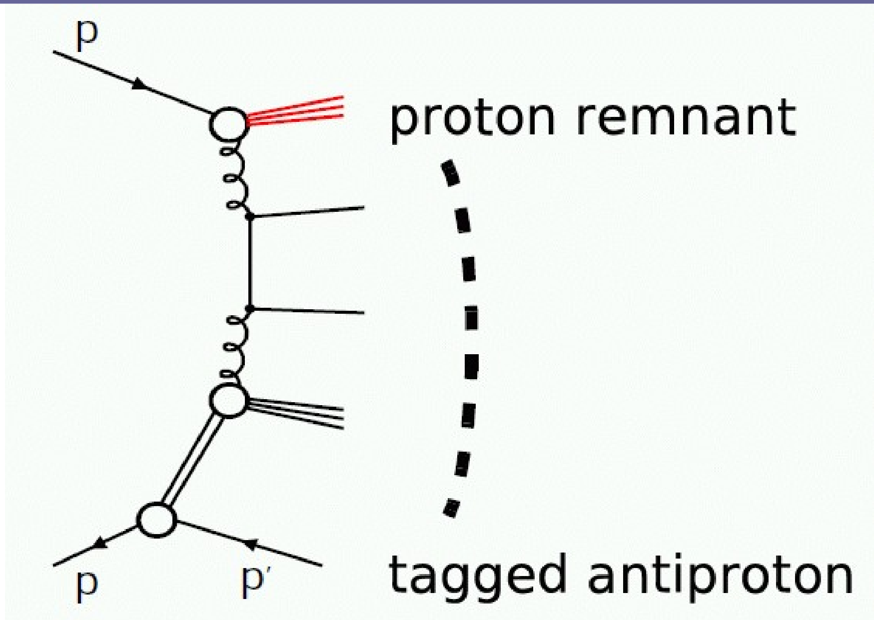
combined DPDF similar to Fit B

Summary DIS

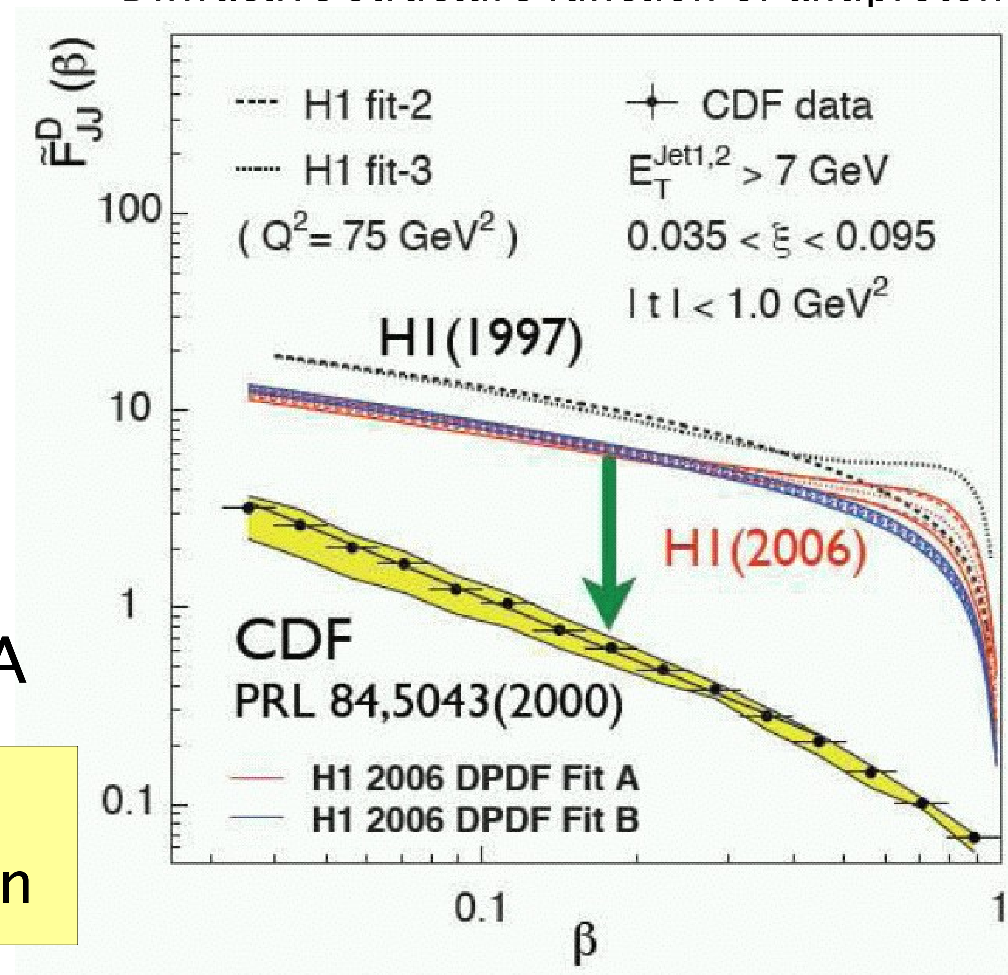
Consistent description of hard diffractive proton interactions in DIS using diffractive parton densities.

DIS ≈ pointlike photon

Tevatron



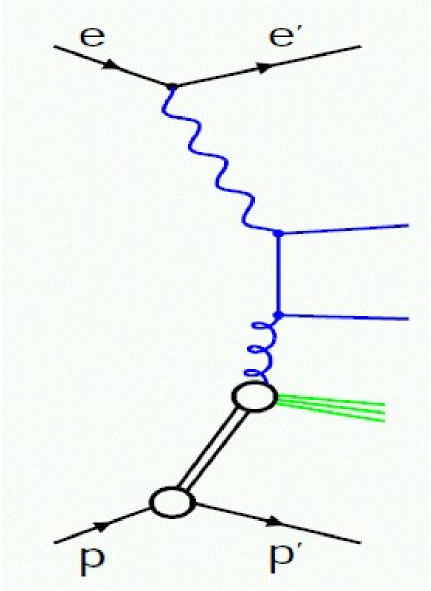
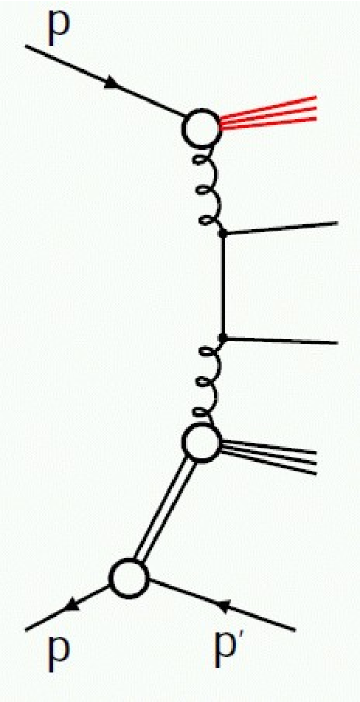
Diffractive structure function of antiproton



leading order comparison
with parton densities from HERA

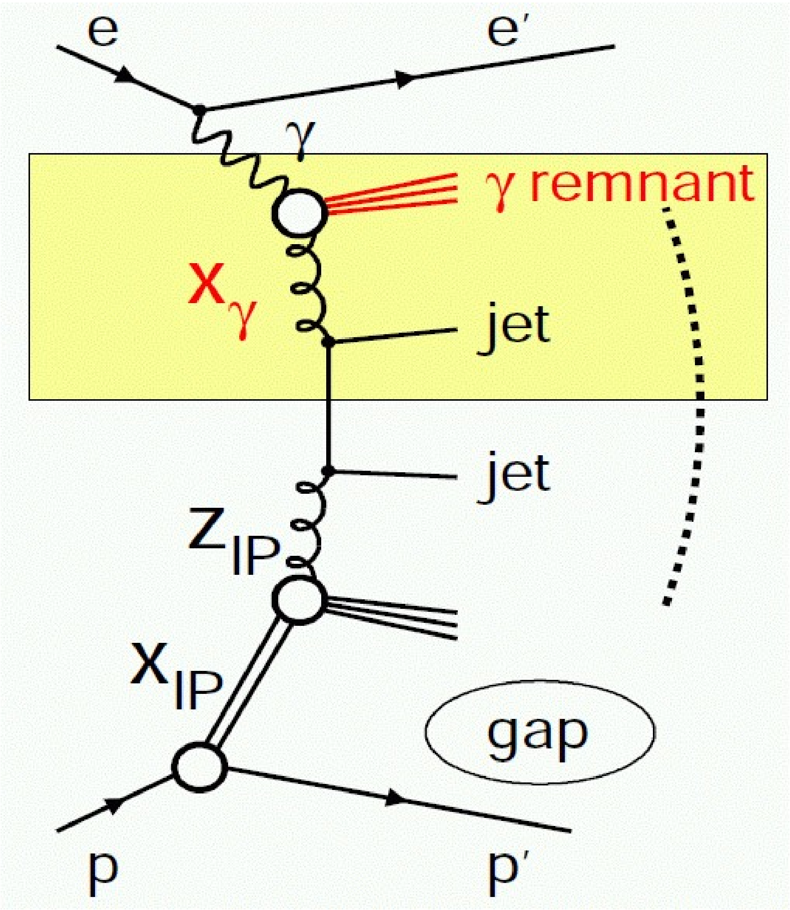
- “gap survival probability”≈0.1
- rescattering due to second proton

γp: Transition from ep to pp

ep (DIS)	γp (Photoproduction)	$p\bar{p}$
 diffractive PDFs universal to all processes (“Factorisation works”)	?	 proton remnant Factorisation broken

Hadronic Photon interactions

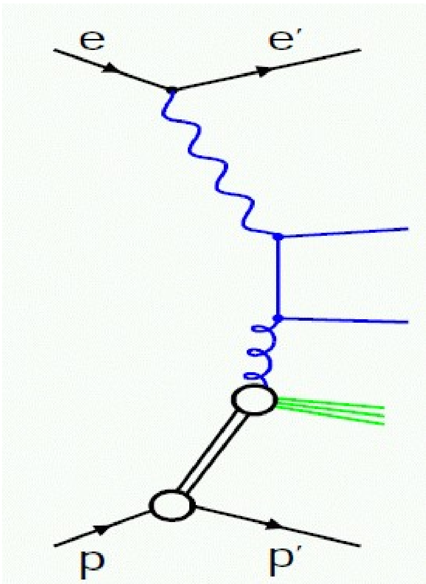
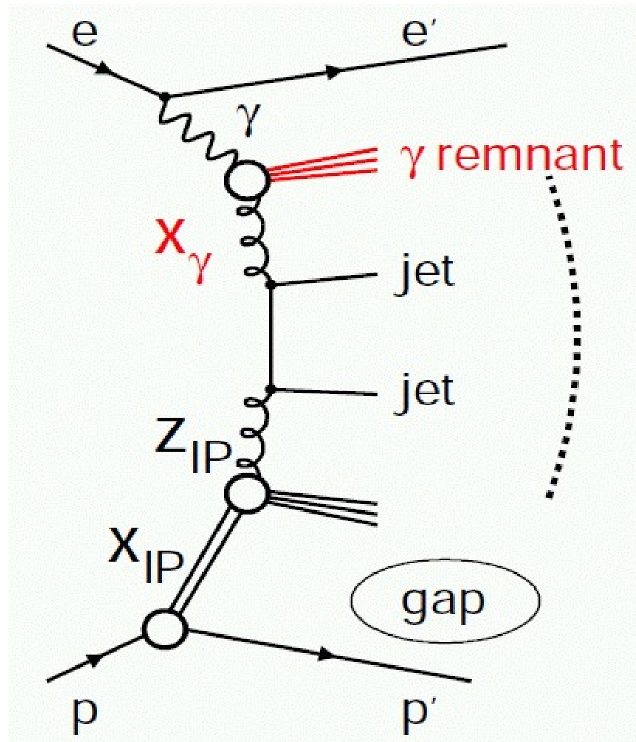
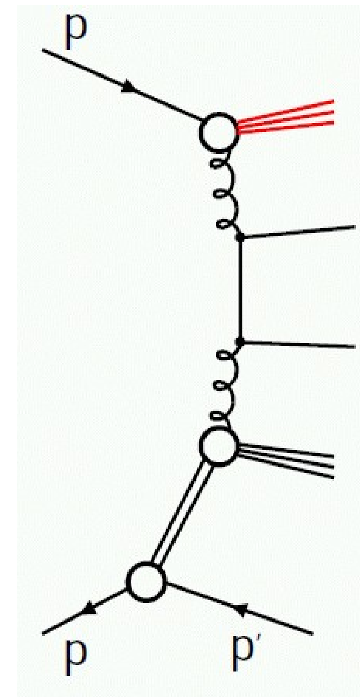
- photon can fluctuate into a hadronic system, of which one parton with momentum fraction x_γ enters the hard scatter
- suppressed with increasing photon virtuality



x_γ<1: photon remnant
$x_\gamma \approx 1$: no remnant

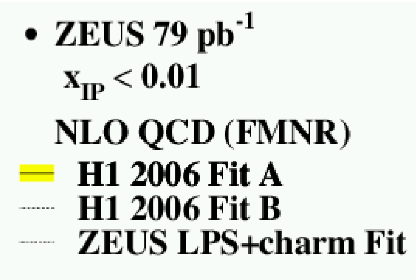
Does the photon remnant affect the gap?

γp: Transition from ep to pp

ep	γp	$p\bar{p}$
		
	$x_\gamma < 1$: photon remnant $x_\gamma \approx 1$: no remnant	proton remnant
Factorisation works	Factorisation?	Factorisation broken

Charm in Photoproduction

$p_T(D^*)>1.9$ GeV
$Q^2<1$ GeV^2, $x_{IP}<0.01$
$130<W<300$ GeV



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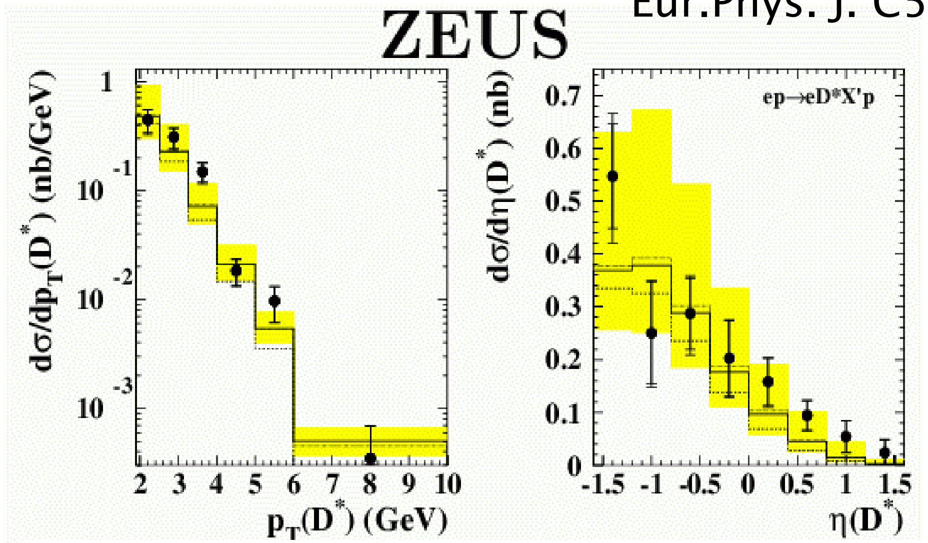
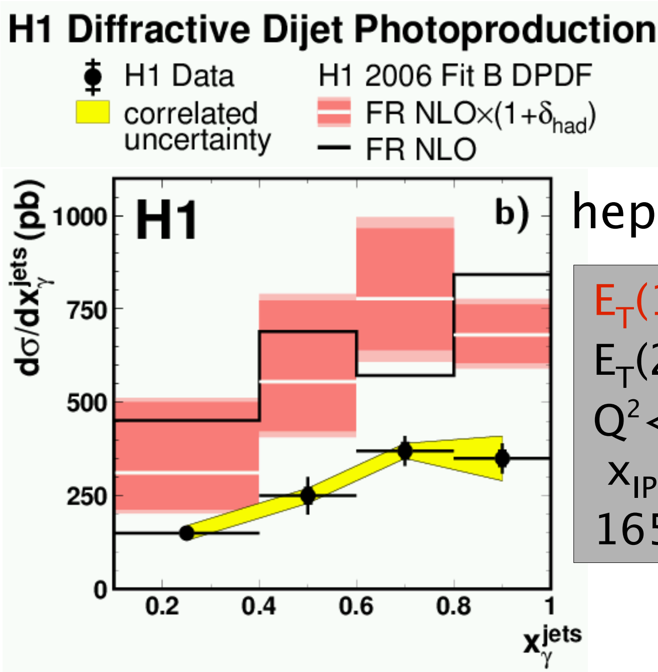


massive charm NLO calculation (FMNR)

Similar result from H1: Eur.Phys. J. C50 (2007) 1

- Good description
- supports QCD factorisation
- large uncertainties

Dijets in Photoproduction



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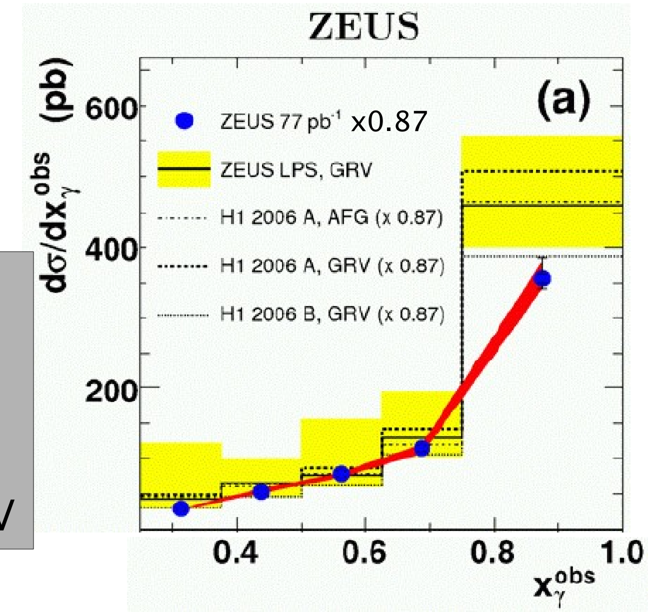
$E_T(1)>5$ GeV
$E_T(2)>4$ GeV
$Q^2<0.01$ GeV^2
$x_{IP}<0.03$
$165<W<242$ GeV

NLO prediction using Frixione/Ridolfi program

- Factorisation is broken
- suppression factor 0.5, independent of x_γ
- direct and resolved photon processes equally suppressed

$E_T(1)>7.5$ GeV
$E_T(2)>6.5$ GeV
$Q^2<1$ GeV^2
$x_{IP}<0.025$
$143<W<295$ GeV



using NLO program from Klasen/Kramer

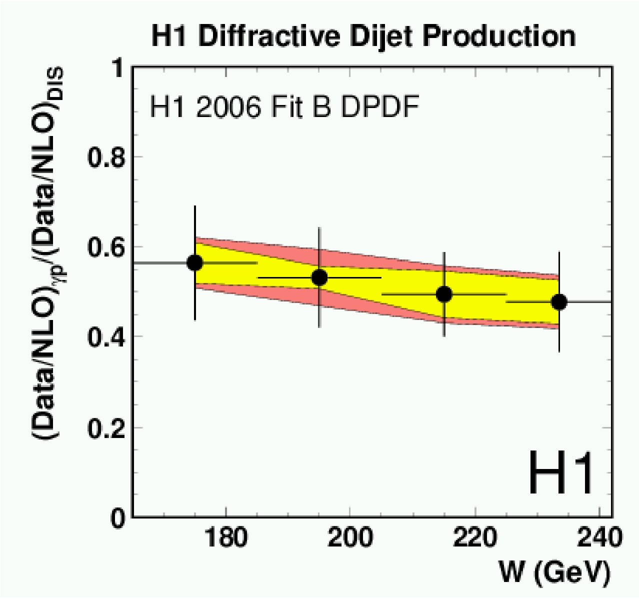
- suppression factor $\approx$0.8 for both direct and resolved
- not significant
- compared to H1:
  - harder jets
  - bigger Q^2

γp Gap Survival Probability

Compare DIS and γp dijets

- identical kinematic range
- same data set
- same DPDFs

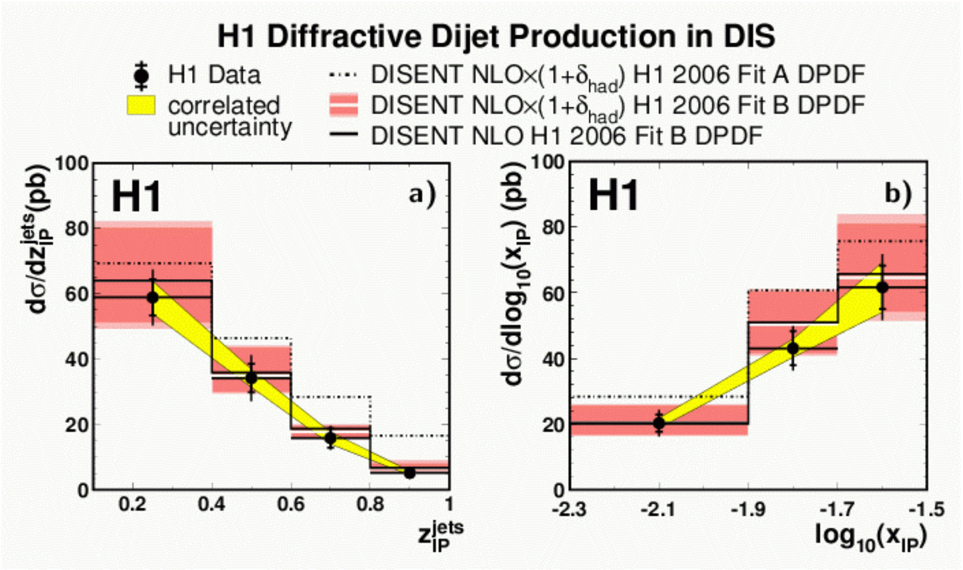
Double ratio $\dfrac{\text{Data/NL} \quad (\gamma p)}{\text{Data/NL} \quad (\text{DIS})}$



γp dijets suppressed by 0.5±0.1

DIS dijets
hep-ex/0703022

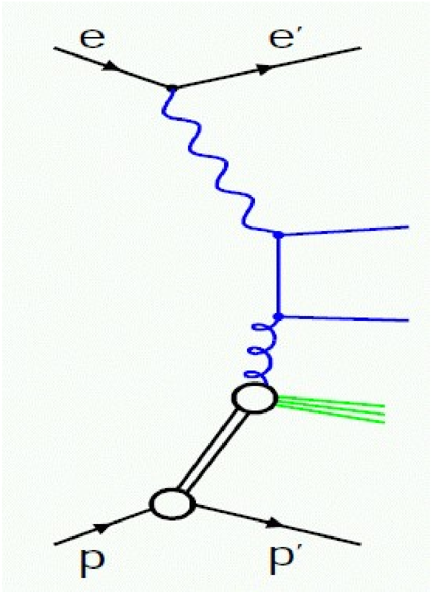
$E_T(1)>5$ GeV, $E_T(2)>4$ GeV
$4<Q^2<80$ GeV^2, $x_{IP}<0.03$
$165<W<242$ GeV



- some theoretical and experimental uncertainties cancel
- independent of used DPDF

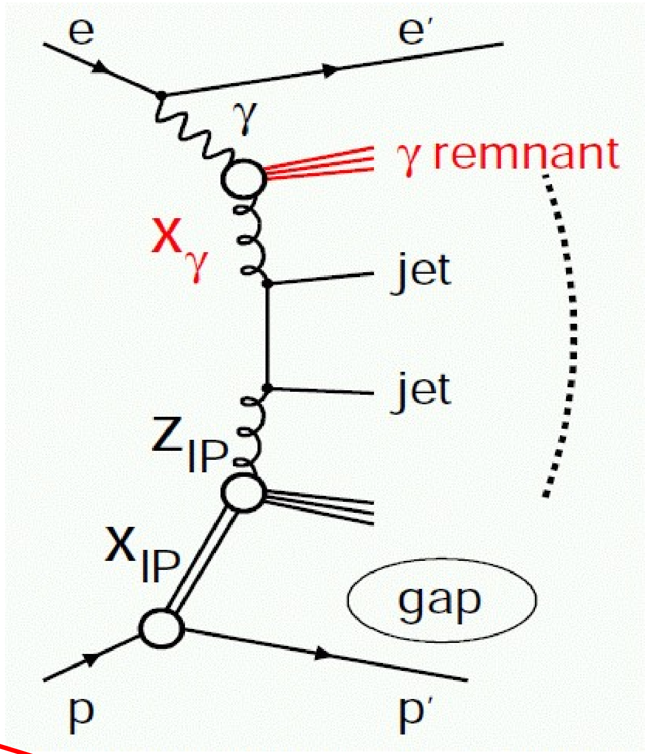
γp: Transition from ep to pp

ep



Factorisation works

γp

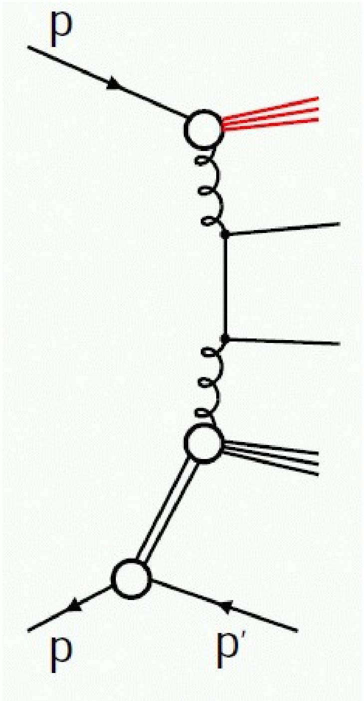


~~$x_\gamma<1$: photon remnant~~

~~$x_\gamma\approx 1$: no remnant~~

Factorisation broken

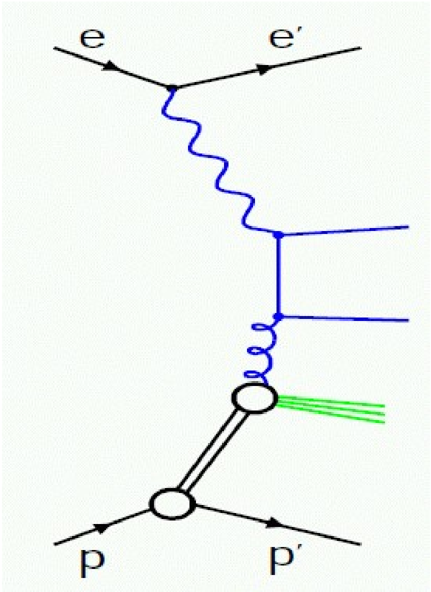
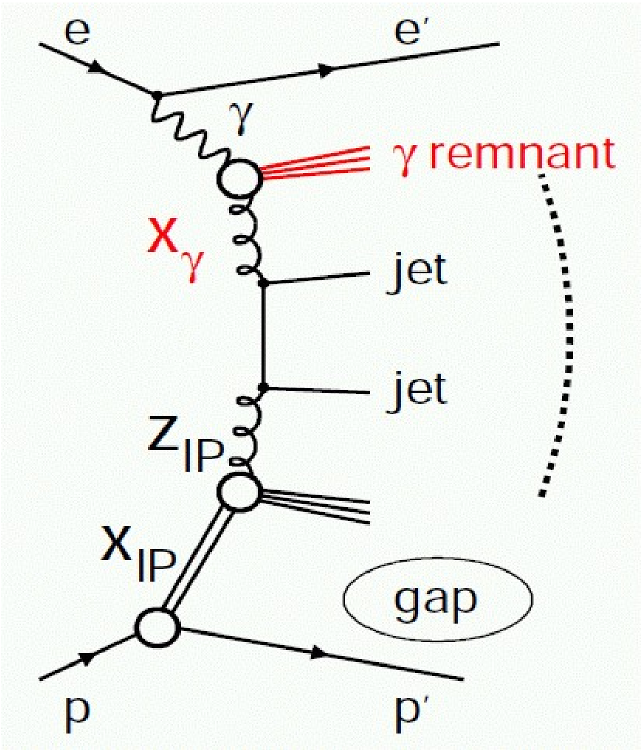
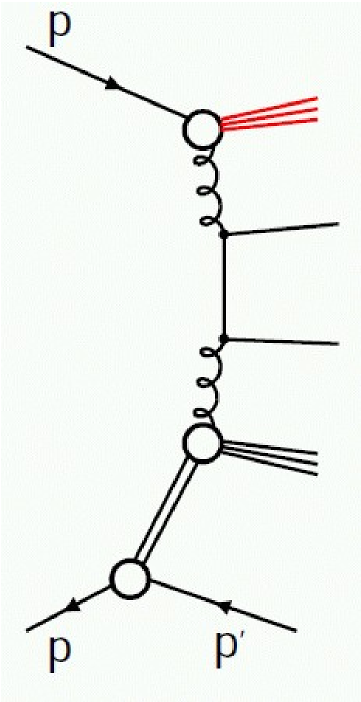
$p\bar{p}$



proton remnant

Factorisation broken

γp: Transition from ep to pp

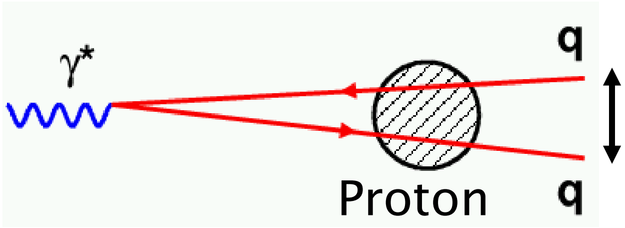
ep	γp	$p\bar{p}$
 Q^2>4 GeV^2	 Q^2≈0	
Factorisation works	Factorisation broken	Factorisation broken

Is the virtuality the key?

Diffractive colour dipole scattering

in proton rest frame:

only my personal naïve speculation...



$R \sim 1/Q$

	Q^2	dipole	Factorisation	
ep	large	small	works	colour transparency
γp	0	large	broken	colour fields overlap → rescattering

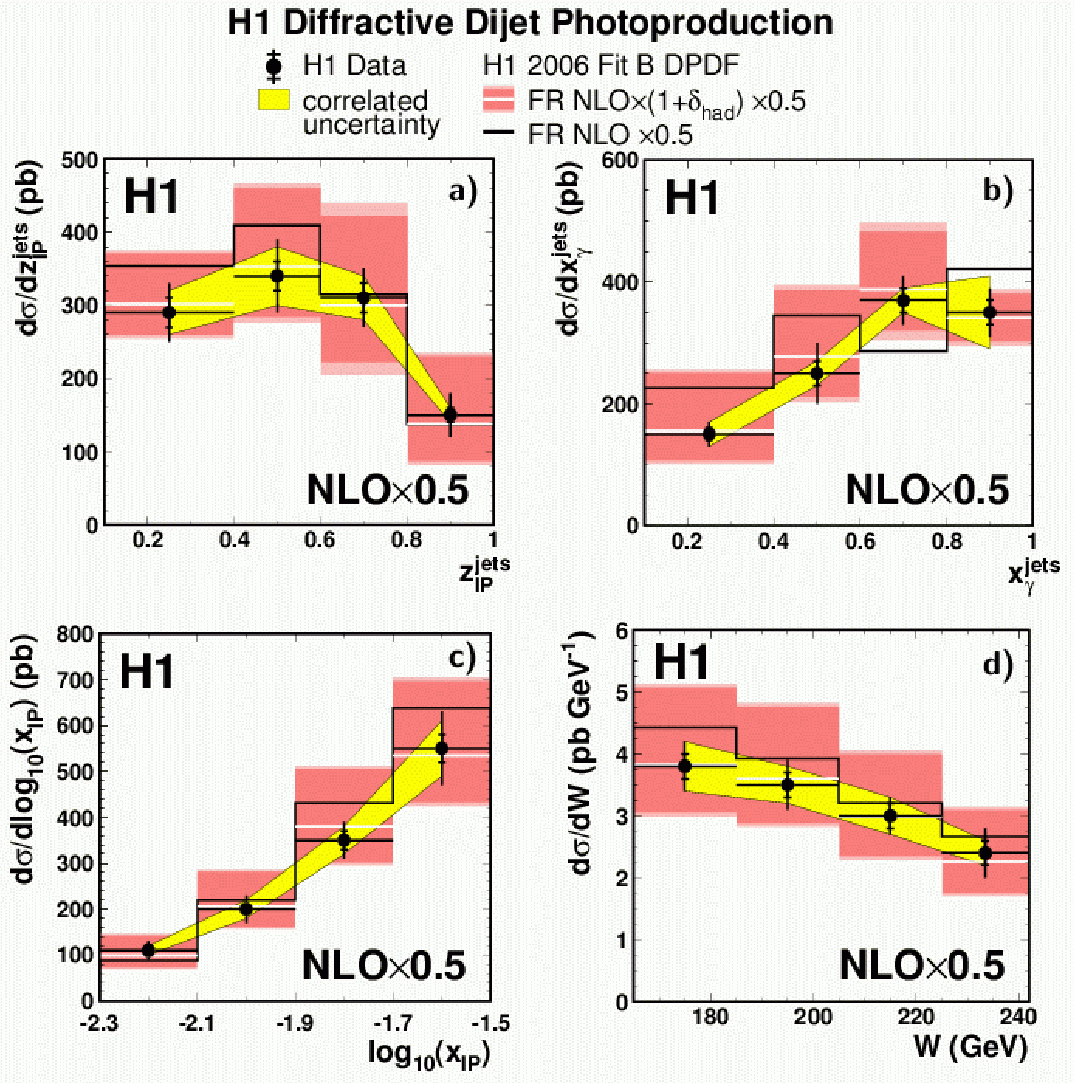
rescattering depends on overlap of dipole and proton colour fields?

Summary

- diffractive parton densities: consistent description of hard diffractive proton interactions in DIS
- Factorisation works for D* photoproduction within large uncertainties
- Dijets in photoproduction
  - $E_T^{(jet)} \gtrsim 5$ GeV:
    - factorisation broken by factor of 0.5
    - gap survival probability=0.5±0.1 w.r.t. to DIS dijets
    - suppression independent of x_γ
  - $E_T^{(jet)} \gtrsim 7.5$ GeV:
    - insignificant suppression (≈0.8)
- Possible explanation of suppression in dipole picture

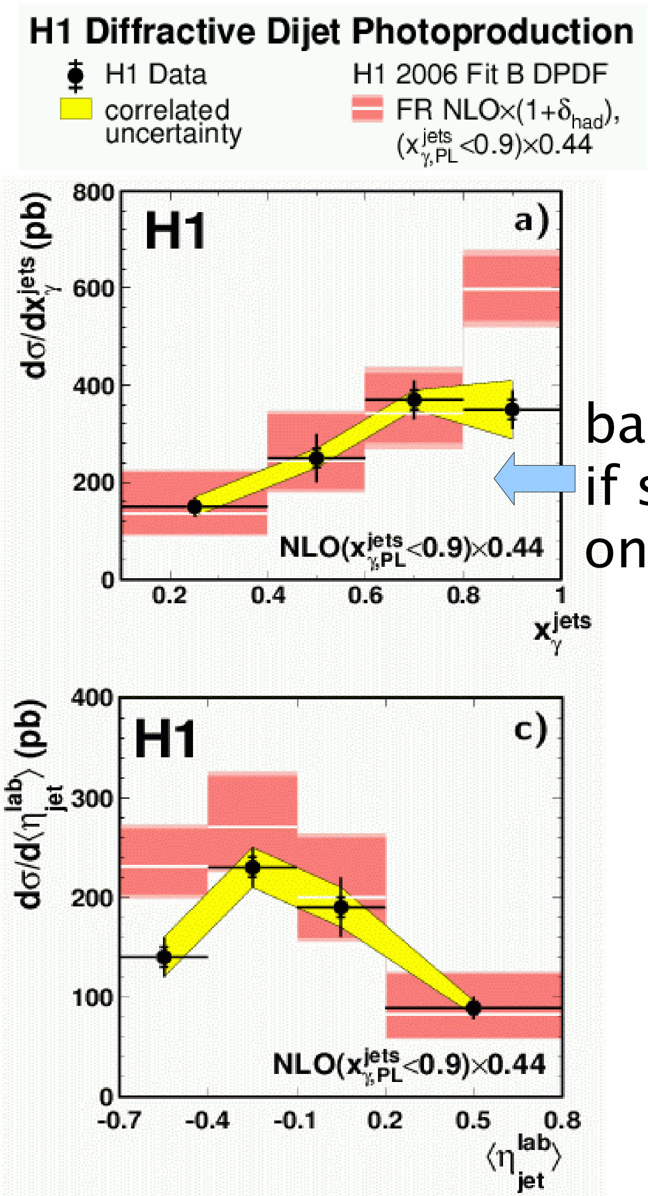
Backup Slides

Global Suppression 0.5



Suppression of direct photon part

At NLO, direct and resolved not cleanly separable
use experimentalists approach based on x_γ



bad description if suppressing only $x_\gamma<0.9$

x_γ (parton level)	Suppression
<0.9	0.47(16)
>0.9	0.53(14)

Suppression independent of x

direct and resolved equally suppressed (within precision)

conceivable in dipole picture
where Q matters (dipole size)

Diffraction?

So far we have parameterised our ignorance of how diffraction occurs in terms of diffractive parton densities.

Alternatives?

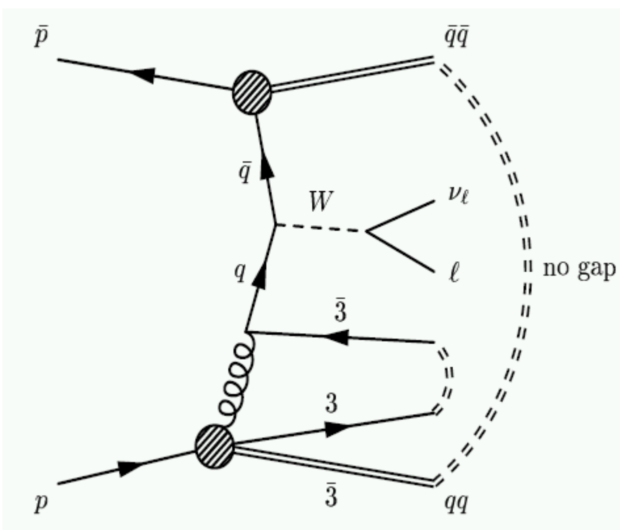
The SCI model

Edin, Ingelman, Rathsman

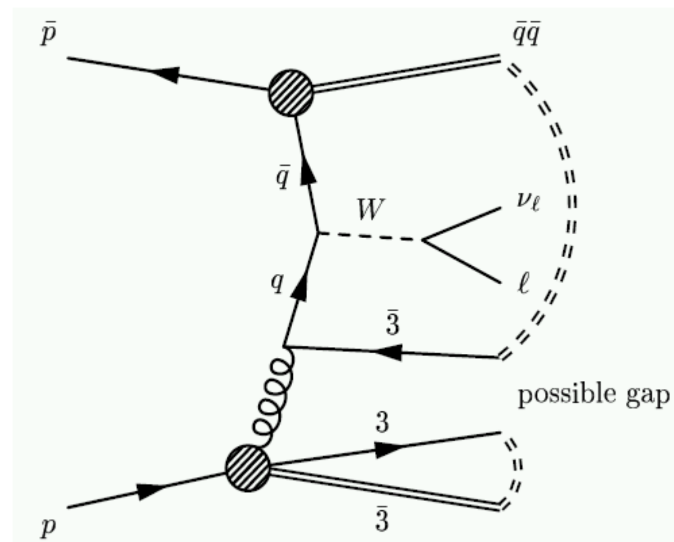
ordinary QCD scattering + final state soft colour reconfiguration

Example W production in $p\bar{p}$ collisions

ordinary scattering



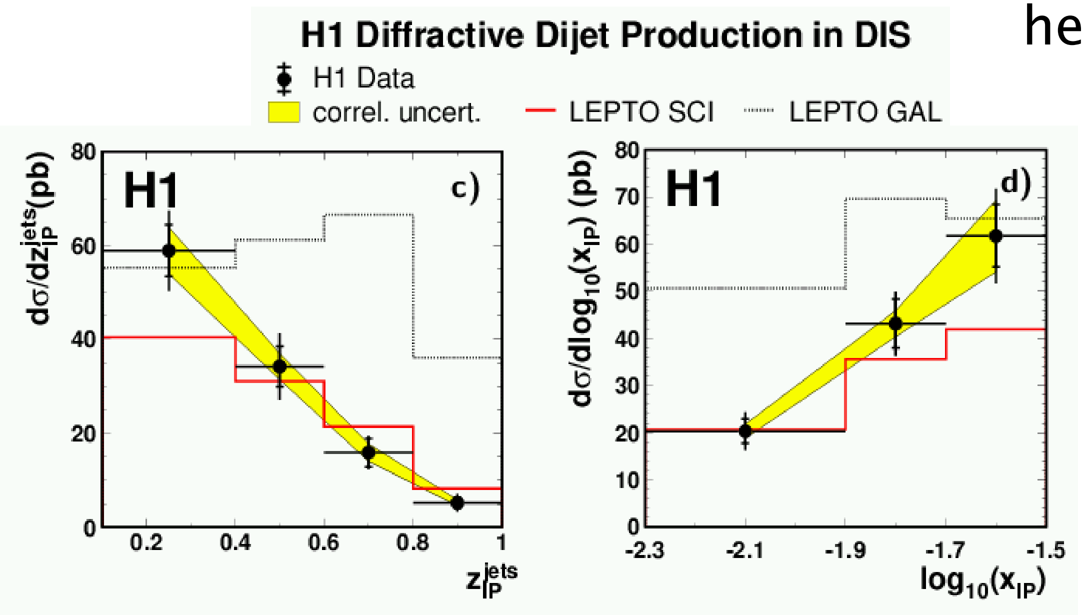
+ soft colour interactions



1 parameter: colour rearrangement probability, tuned to HERA F_2^D

➡ describes diffractive Tevatron data (gap survival ≈0.1)!

Jets in DIS and Photoproduction



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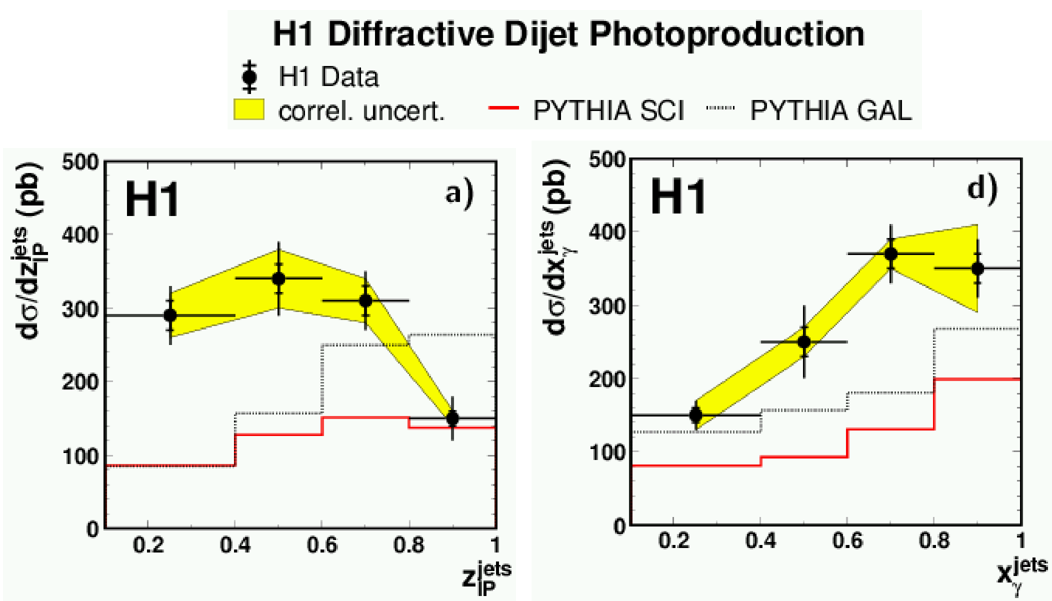

- Leading-order results using LEPTO and PYTHIA (+parton showers)
- proton structure:
  CTEQ5L LO PDF
- SCI
  - reasonable description in DIS
  - fails in photoproduction
- GAL (refined SCI)
  fails in both kinematic regions