Inclusive Diffraction at HERA

On behalf of H1 and ZEUS collaborations

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Paris, 21rst May 2013

Diffraction on nuclear waves

ELASTIC AND INELASTIC SCATTERING OF 1.37 GeV α-PARTICLES FROM ^{40,42,44,48}Ca

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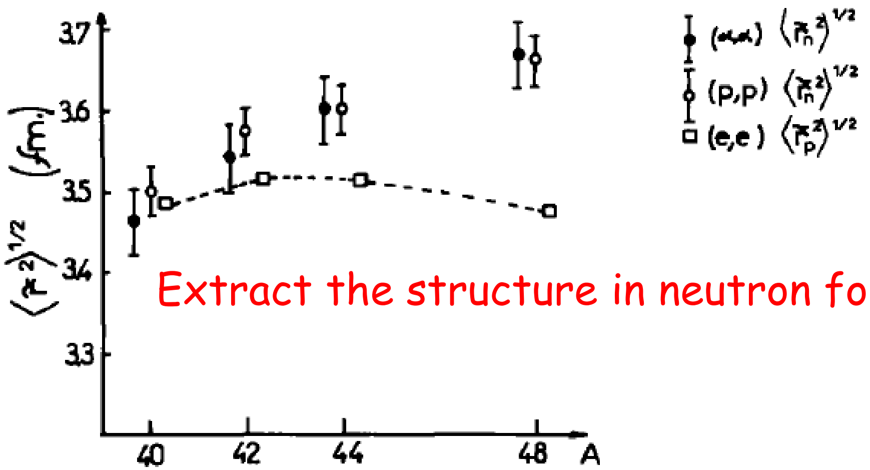
Received 6 October 1976
(Revised 9 December 1976)

ϑ(or $|t|^{1/2}$) dependence presents the standard diffractive pattern (optics)

Amplitude(**q**,k) ~ ik/2π ∫d**b** e^{ibq} D(**b**,k)



Extract the structure in neutron for Calcium

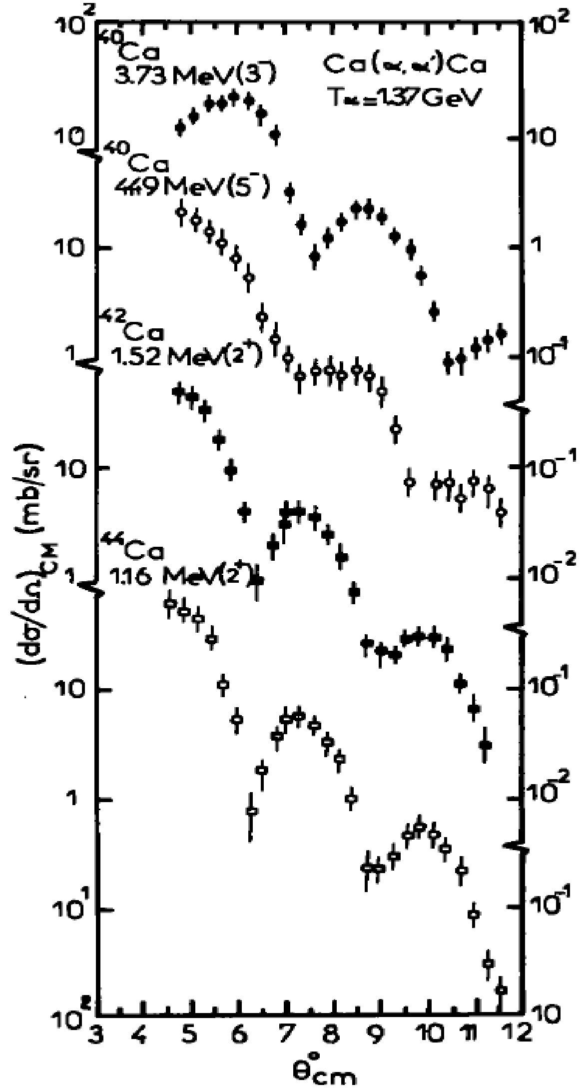
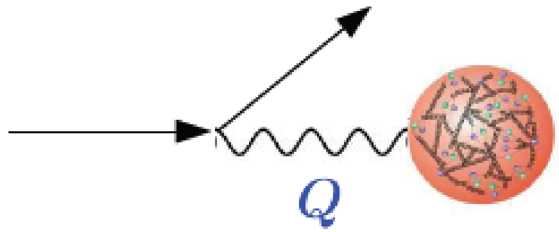


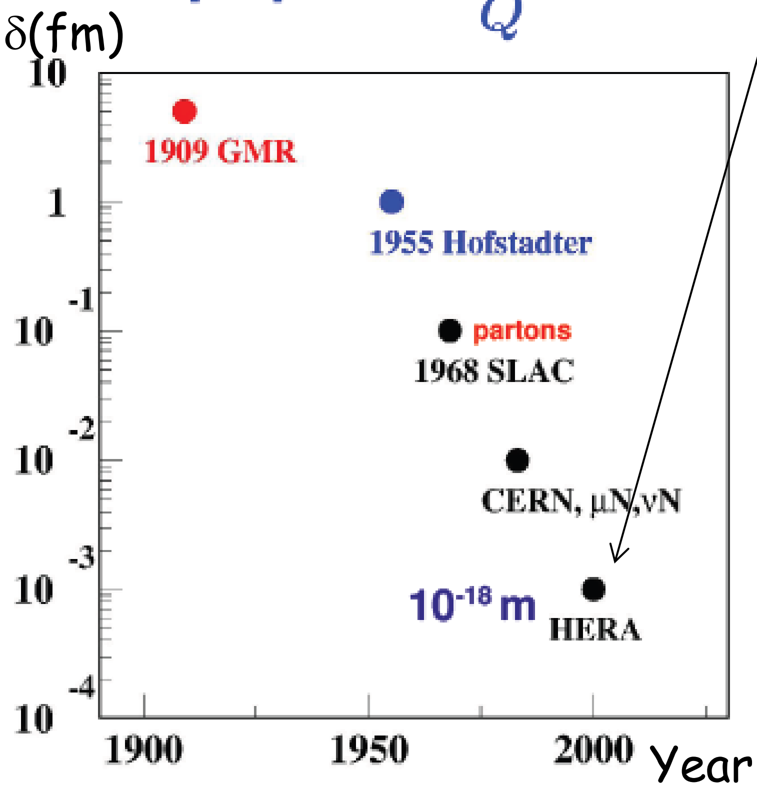
Fig. 3. Differential cross sections of inelastic scattering of 1.37 GeV α-particles from the 3_1^- and 5_1^- states in ^{40}Ca and the 2_1^+ states in ^{42}Ca and ^{44}Ca.

Subnuclear waves



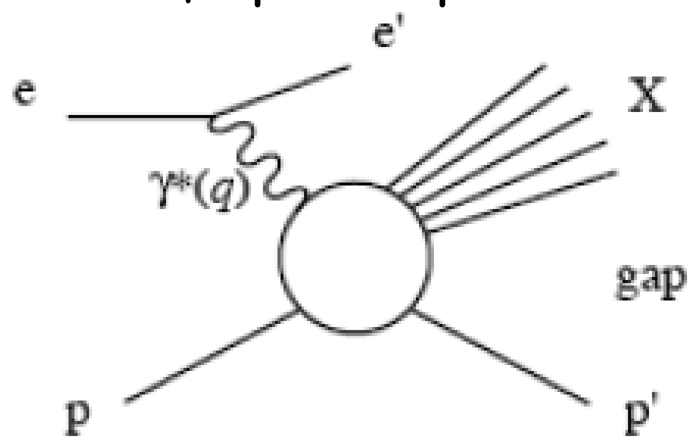
Probe the proton with a lepton beam
=> Virtual photon (γ^*) of resolution ~1/Q

$$\delta \text{ [fm]} \simeq \frac{200 \text{ MeV}}{Q}$$



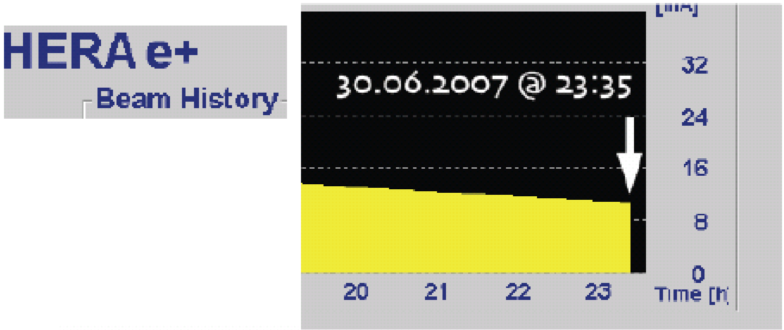
Diffraction of subnuclear waves at HERA [E_{cm}=320 GeV]

$$\gamma^* \, p \rightarrow X \, p$$



The proton is left intact (or quasi-intact)
** Color singlet exchange
** Presence of a GAP in rapidity (between X and p')

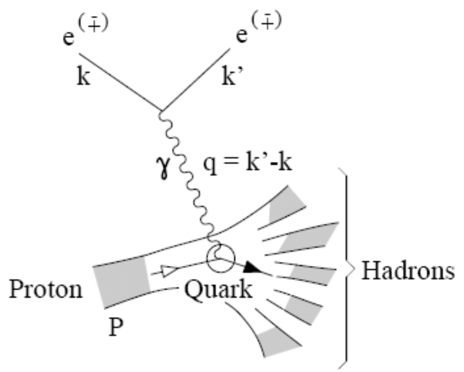
HERA-DESY: 1992-2007



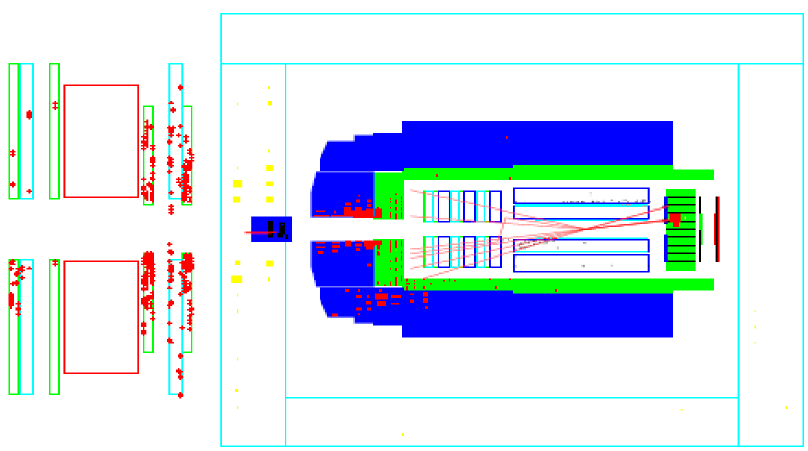
Total luminosity=1 fb^{-1} for H1+ZEUS

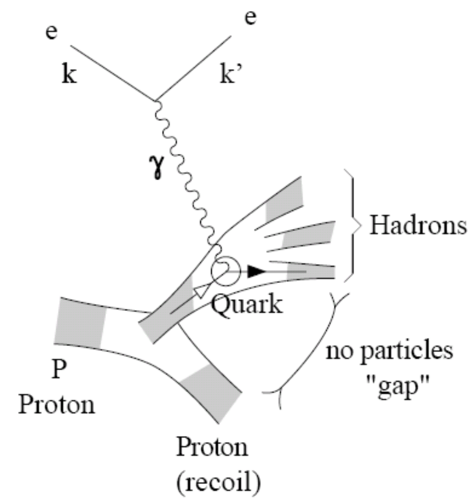
350 collaborators per experiment (H1+ZEUS)
+HERMES

Diffractive events are observed

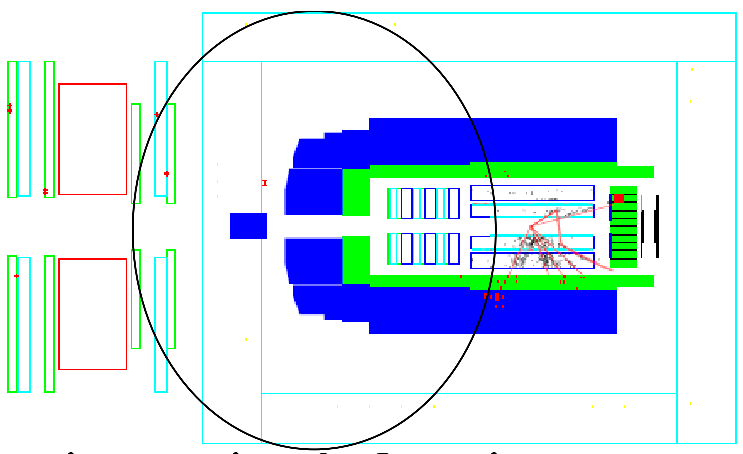


Deep Inelastic Scattering (DIS) => F_2





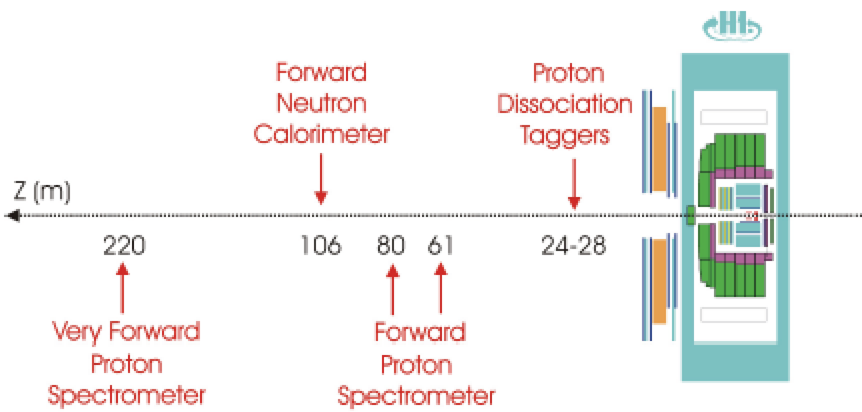
Diffractive Deep Inelastic Scattering (DDIS) => F_2^D



This is the GAP with no particle

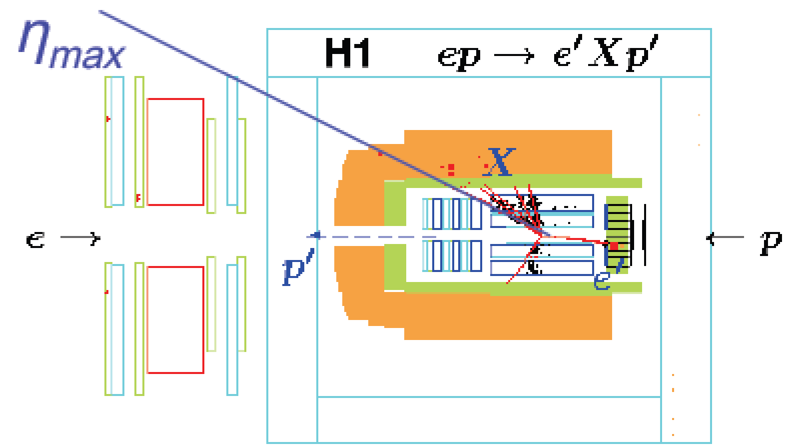
Experimental selection methods

Scattered proton in Leading Proton Spectrometers **(LPS)**



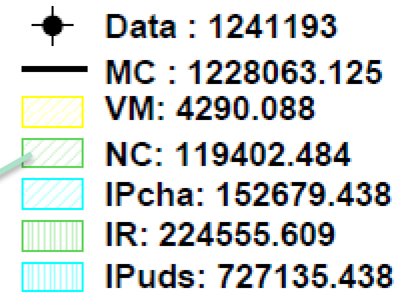
Limited by statistics and p-tagging systematics

\`Large Rapidity Gap' **(LRG)** adjacent to outgoing (untagged) proton

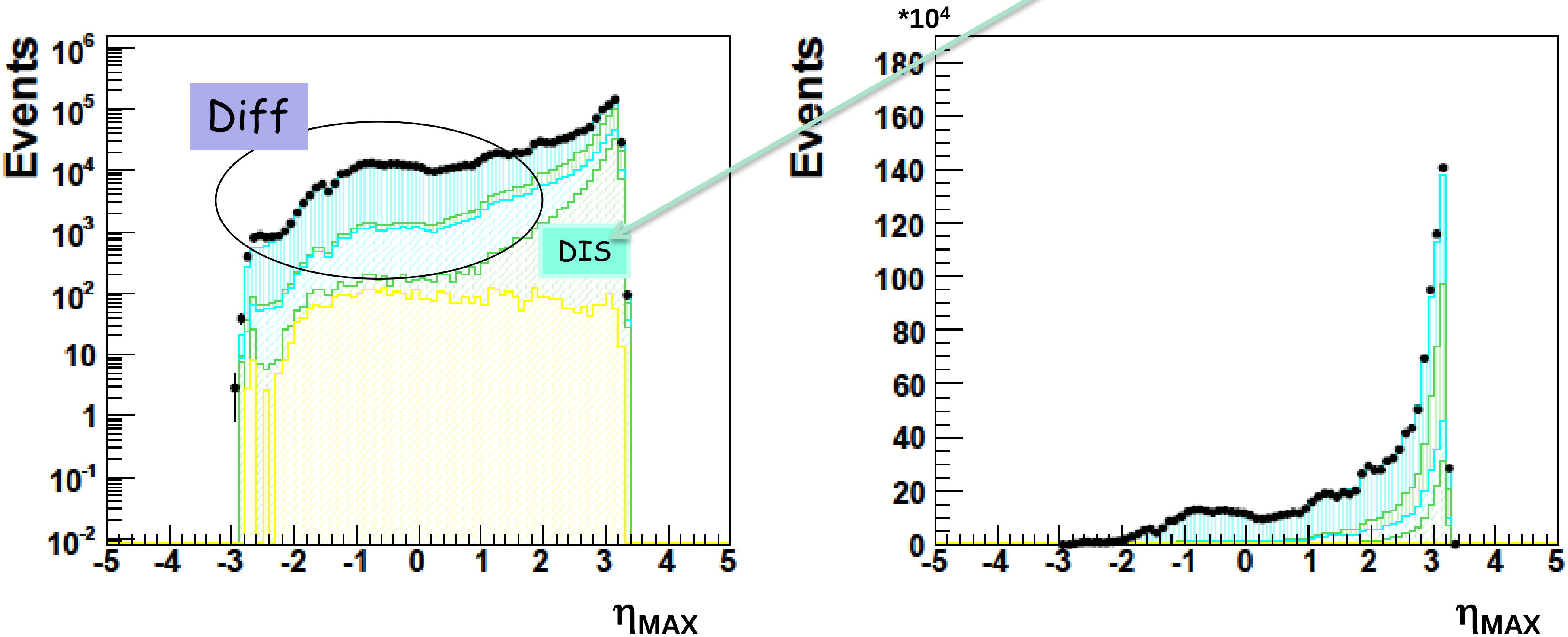


Limited by p-diss systematics

Diff events are produced with a quite large rate



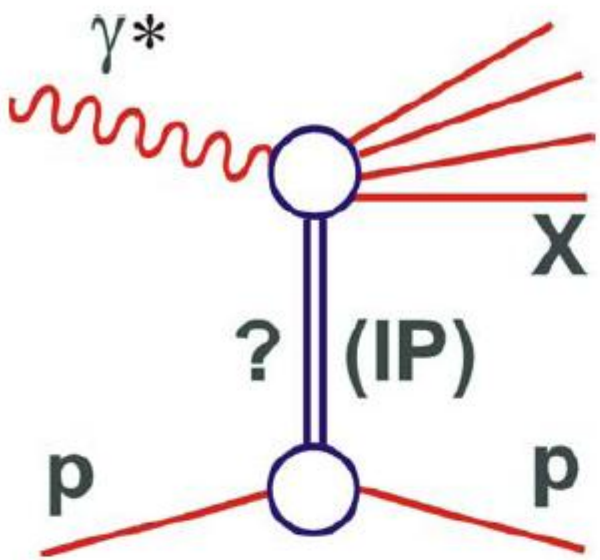
Lower η_{MAX} means that the GAP with no particle is large
…illustration on all HERAII data (Lumi=330 pb^{-1})



Why DIFF rate is large @ HERA (low x)?

...certain (Fock) states of the virtual photon $|\psi_K>$ do not feel the the strong interaction, while others are strongly affected...

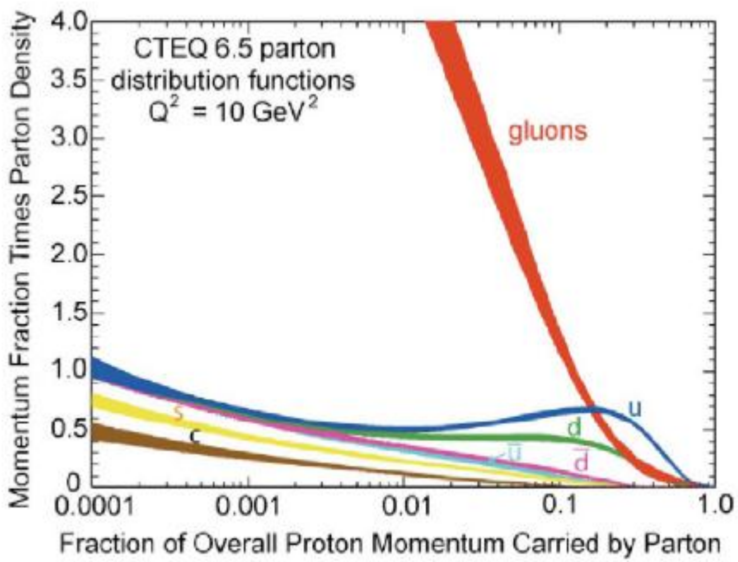
=> Large fluctuations in the absorbption coefficients of these states...



This is (obviously) linked to the dominance of the gluon density at small x.

It finds a natural extension in the dipole approach:

$$T(b) \sim \alpha_S r^2 \, xG(x,1/r^2)/(\pi R^2) \; * \exp(-b^2/b_0^2)$$



Kinematics and notations

Standard DIS variables …

x = momentum fraction q/p
Q^2 = |γ^* 4-momentum squared|

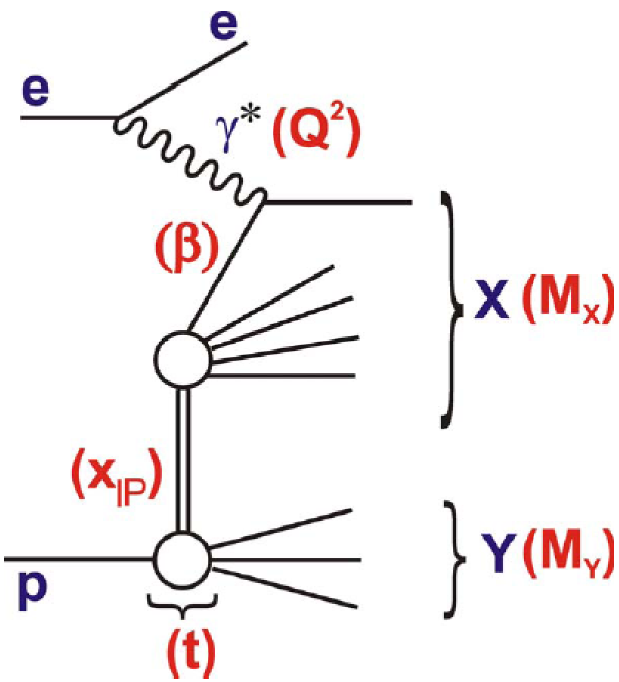
Additional variables
for diffraction …

t = squared 4-momentum
transfer at proton vertex

x_{IP} = fractional momentum
loss of proton
(momentum fraction IP/p)

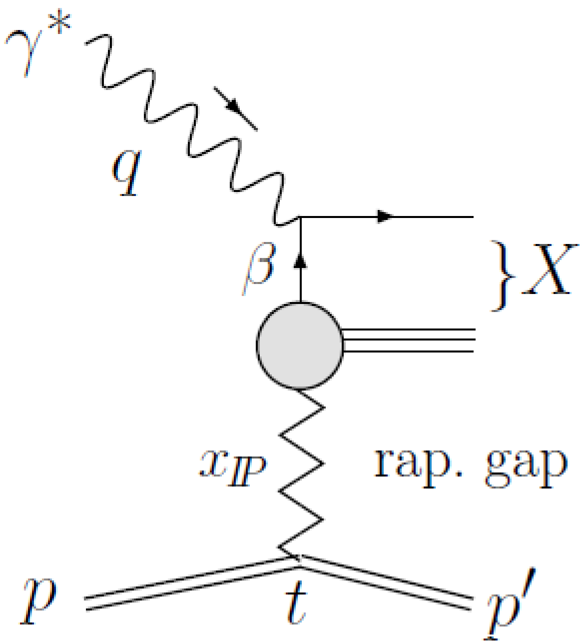
$\beta = x / x_{IP}$
(momentum fraction q / IP)

Most generally ep→eXY …



In most cases here, Y=p,
(small admixture of low
mass excitations)

Diffractive cross sections (definition)

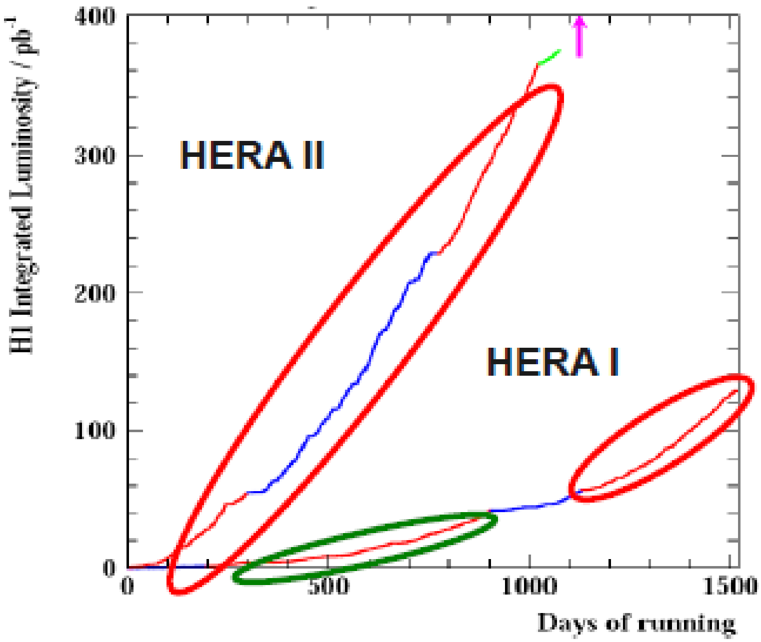


Select diffractive events
Correct for detector effects
Derive cross sections (// F2)

$$\frac{d^3\sigma^D}{dx_{\mathbb{P}}\, d\beta\, dQ^2} = \frac{2\pi\alpha_{em}^2}{\beta\, Q^4}\left[1+(1-y)^2\right]\sigma_r^{D(3)}(x_{\mathbb{P}}, \beta, Q^2)$$

$$\sigma_r^{D(3)} = F_2^{D(3)} - \frac{y^2}{1+(1-y)^2} F_L^{D(3)} \approx F_2^{D(3)}(x_{\mathbb{P}}, \beta, Q^2)$$

H1 LRG samples



Data Set	Q^2 range (GeV^2)	Proton Energy E_p (GeV)	Luminosity (pb^{-1})
New data samples			
1999 MB	$3 < Q^2 < 25$	920	3.5
1999-2000	$10 < Q^2 < 105$	920	34.3
2004-2007	$10 < Q^2 < 105$	920	336.6
Previously published data samples			
1997 MB	$3 < Q^2 < 13.5$	820	2.0
1997	$13.5 < Q^2 < 105$	820	10.6
1999-2000	$133 < Q^2 < 1600$	920	61.6

[H1 Coll. EPJC28 (2006) 715]

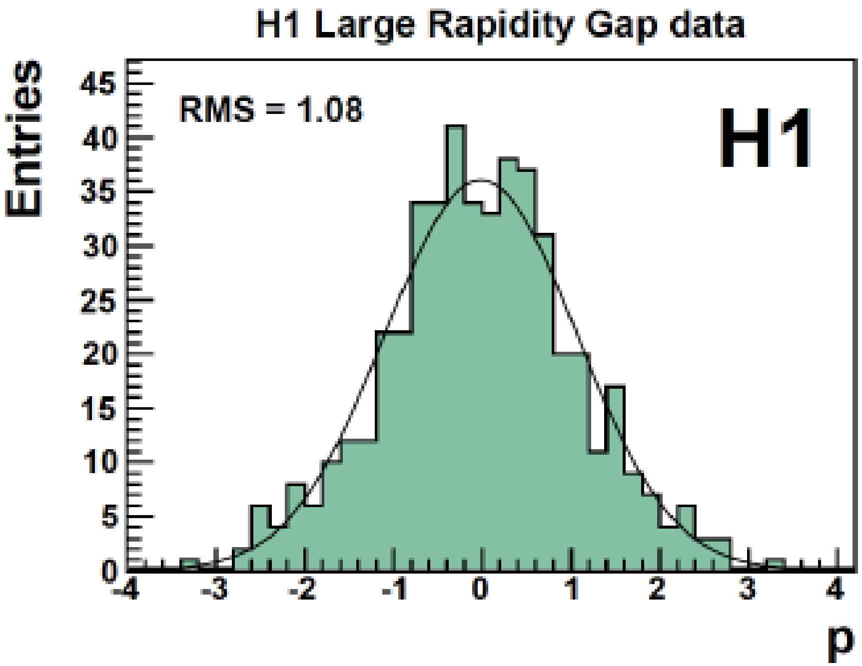
- All H1 data samples now analysed → Increase in statistics of 3 to 30

  - All combined into one single H1 LRG cross section set
  - Total kinematic range:

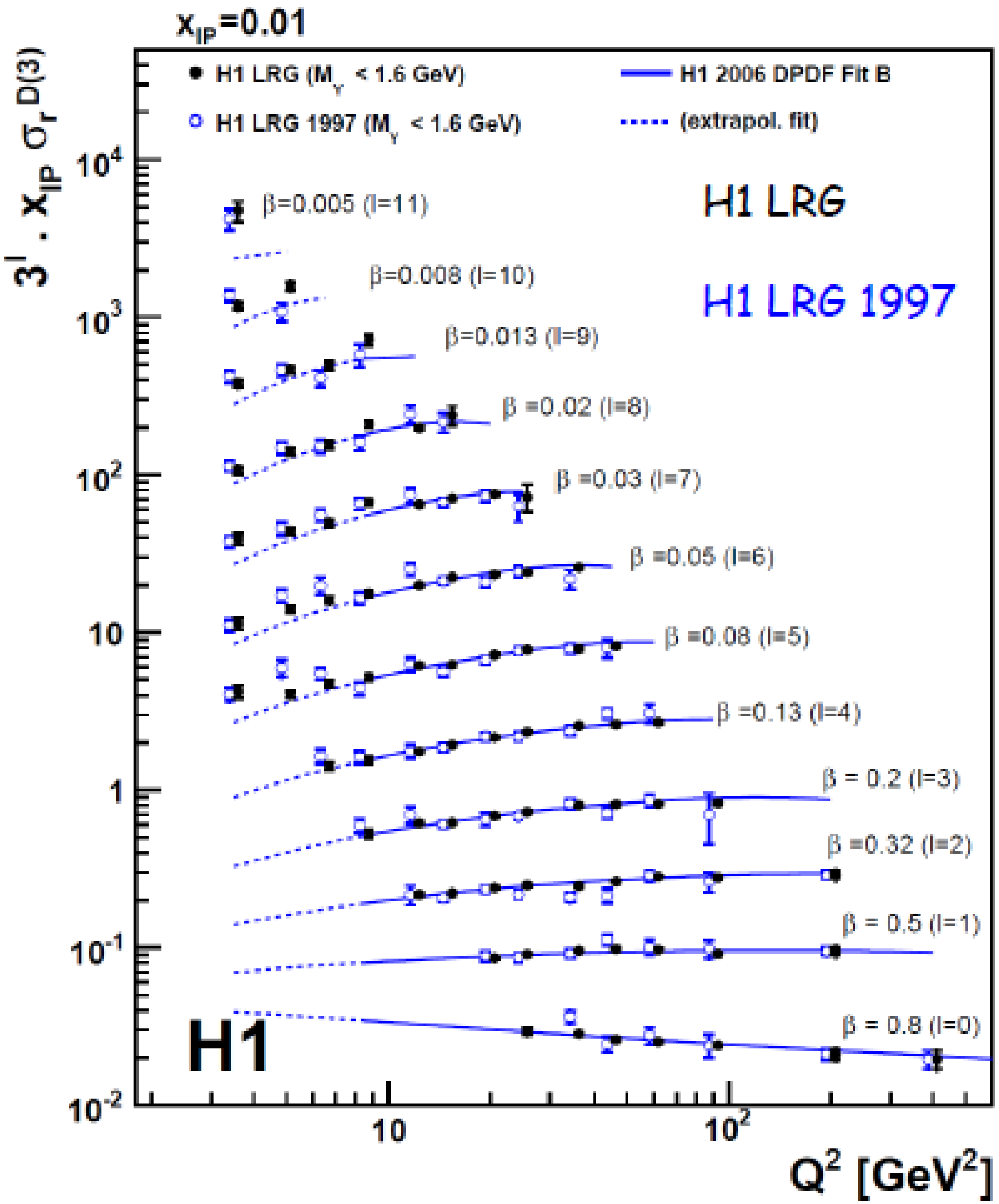
$3.5 < Q^2 < 1600$ GeV^2
$0.0017 < \beta < 0.8$
$0.0003 < x_{IP} < 0.03$

Combination of H1 LRG data

- Combine reduced cross sections from each data period
- Iterative χ^2 minimisation used
- Full error correlations considered
  - ➔ 597 data points averaged to 277 measurements
  - ➔ χ^2 / ndof = 371 / 320
- Pulls of individual points to combined points
  - ➔ No large tension between data sets observed



Combined H1 LRG cross section ($F2^D$)[Q^2]



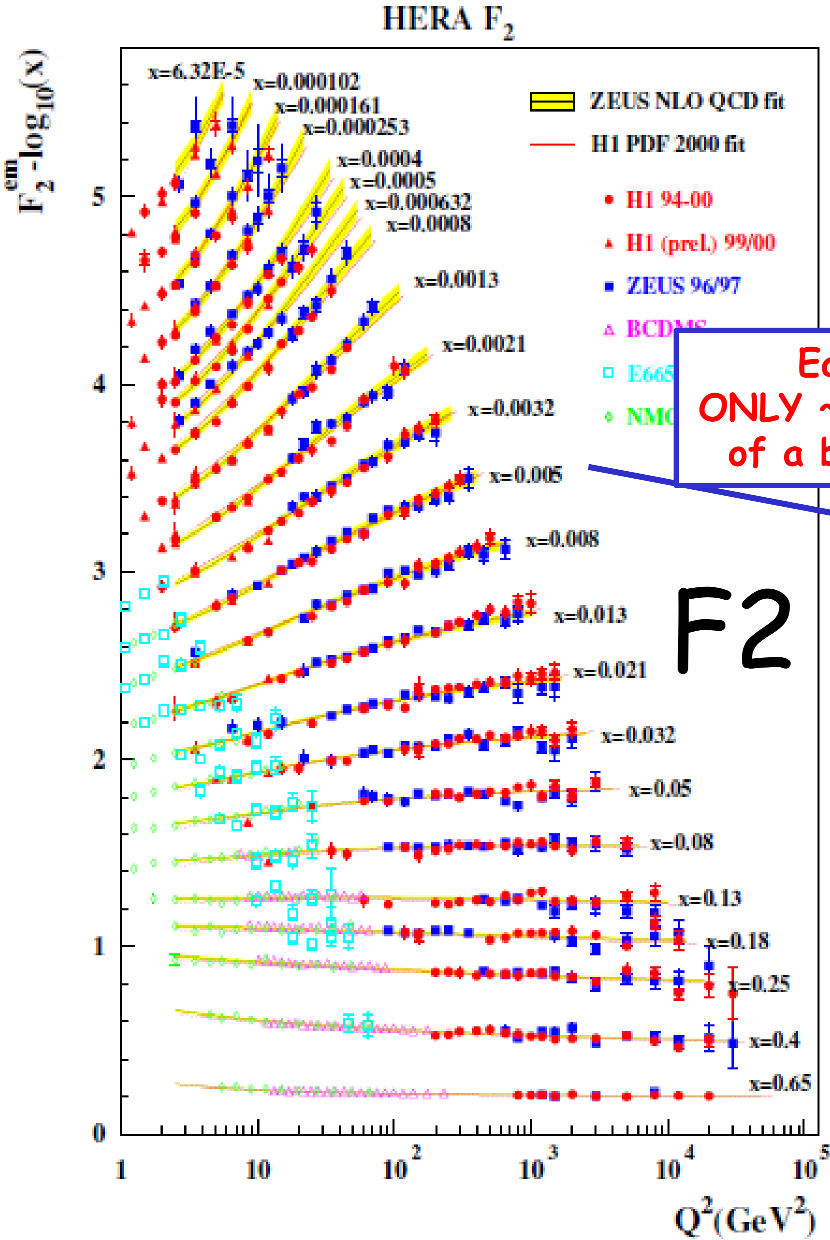
- Example of Q^2 dependence for x_{IP}=0.01

  → Large reduction of statistical errors

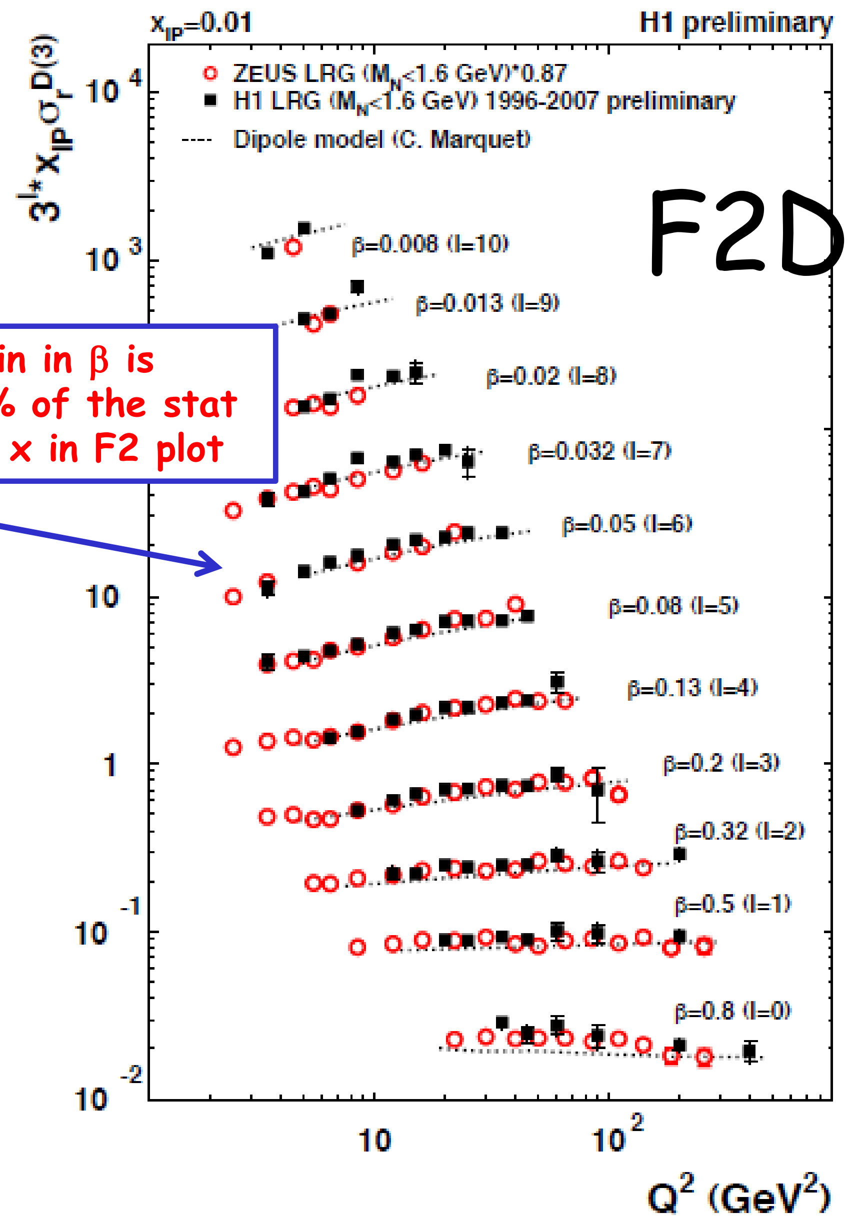
  → Typical precision for Q^2 > 12 GeV^2:

1% (stat.)
5% (sys.)
4% (norm.)

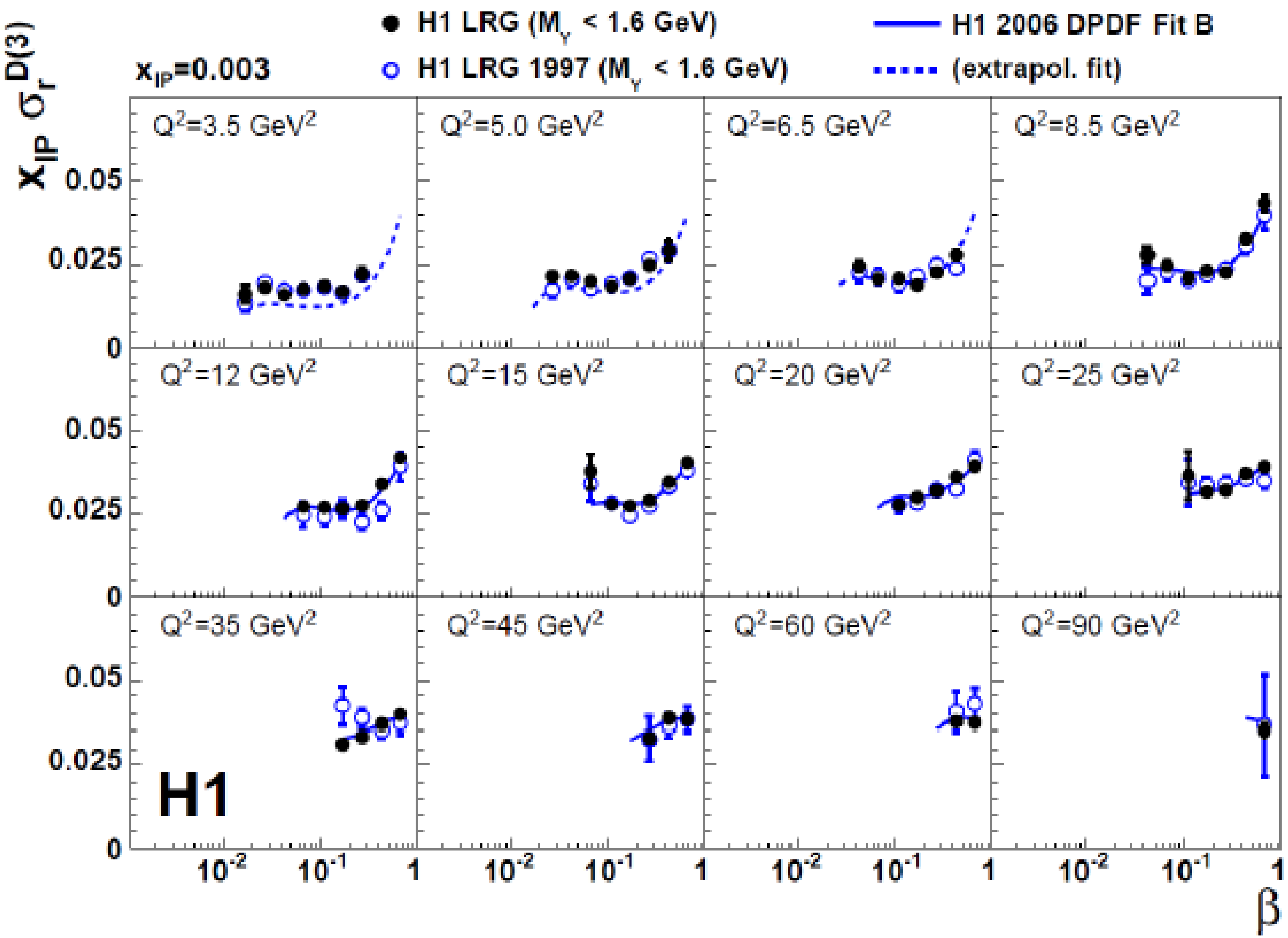
F2 versus F_2^D



Each bin in β is ONLY ~1-2% of the stat of a bin in x in F2 plot



Combined H1 LRG cross section (F2^D)[β]



H1 LRG

H1 LRG 1997

LRG versus p-tagged F2^D

- Compare H1 LRG and FPS cross sections

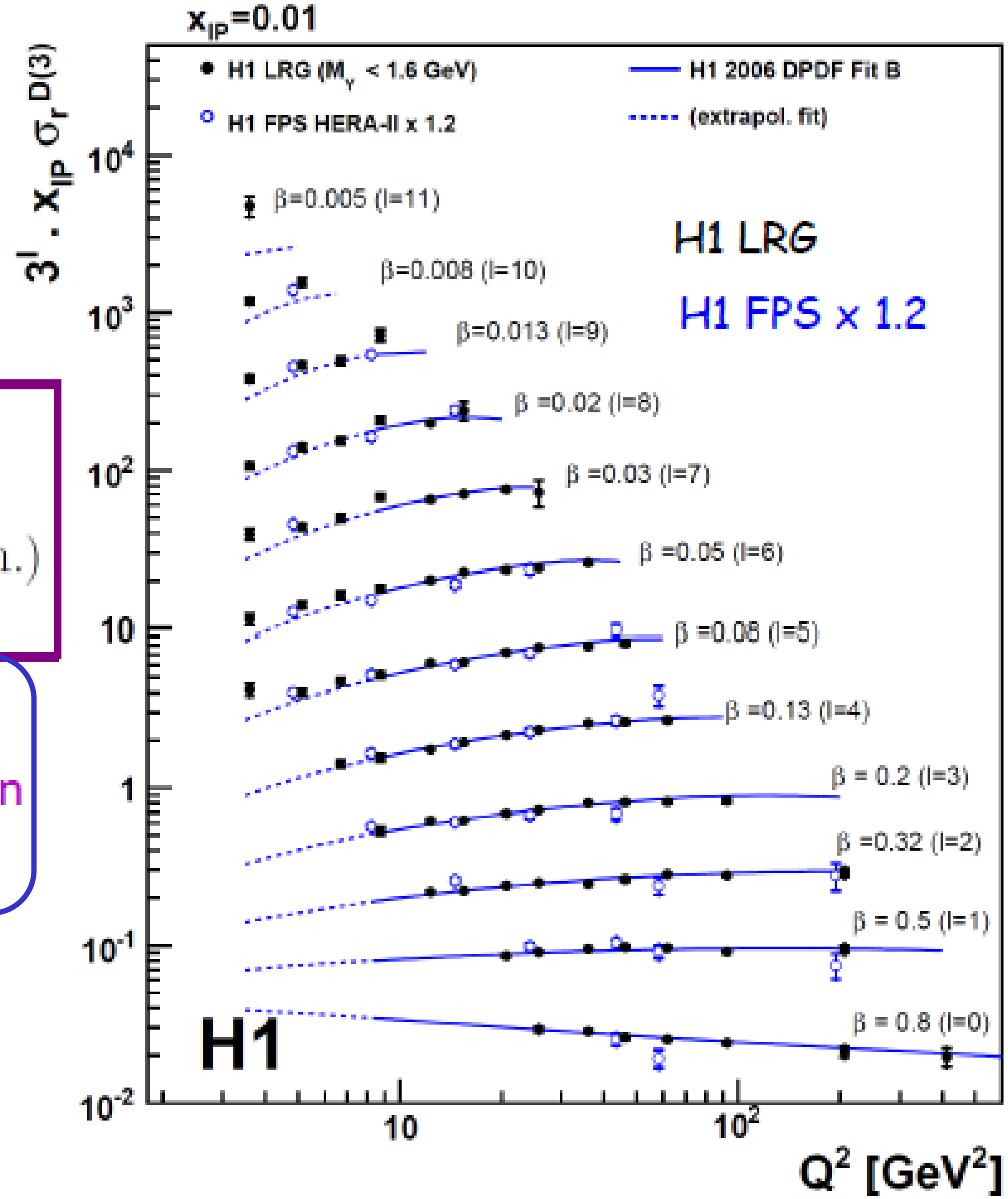
  → Ratio LRG / FPS :

$$\frac{\sigma\,(M_Y < 1.6\,\mathrm{GeV})}{\sigma\,(Y = p)} = 1.203 \pm 0.019(\mathrm{exp.}) \pm 0.087(\mathrm{norm.})$$

(1.6%) (7.2%)

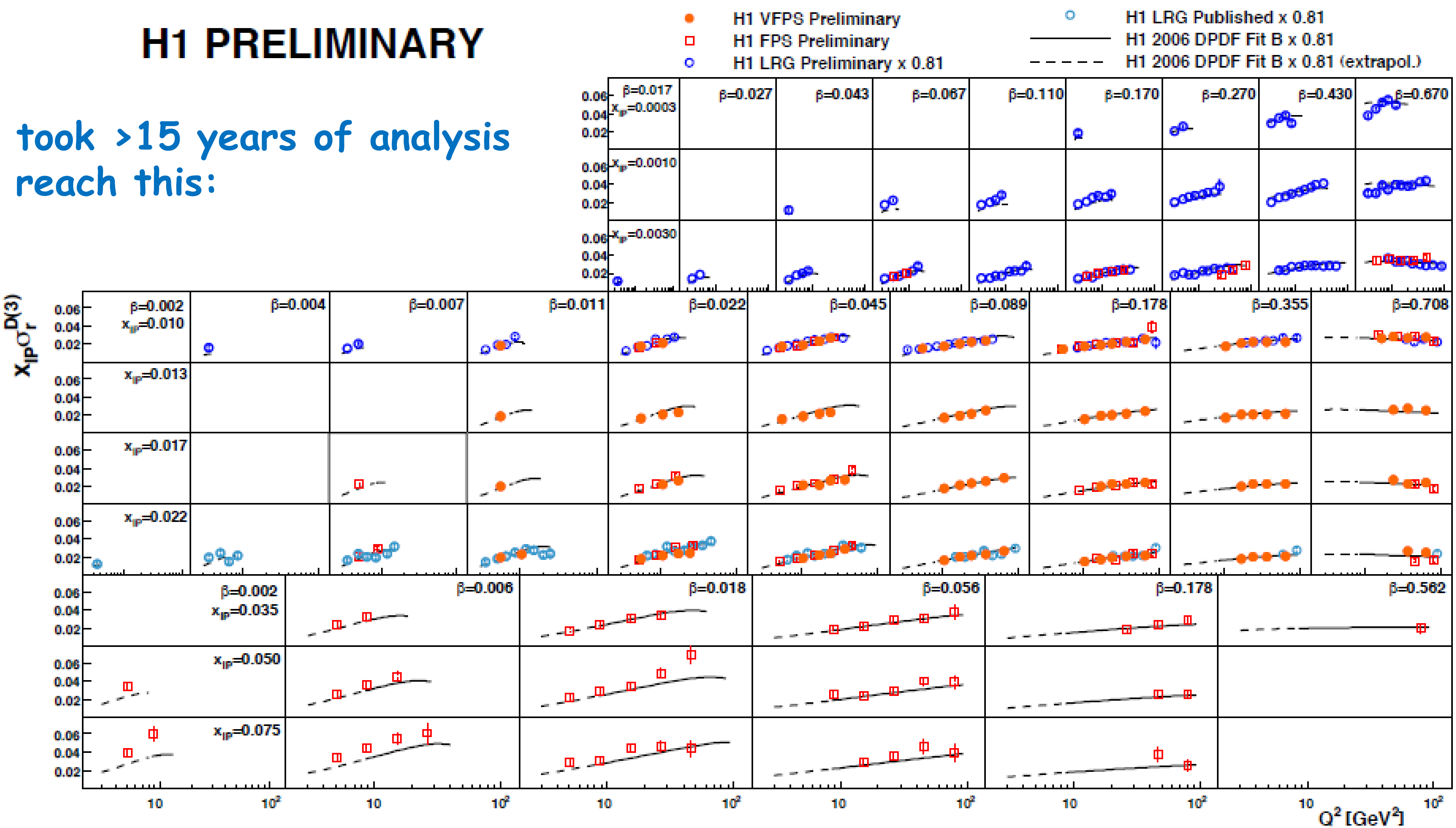
→ Experimental control of the amount of proton dissociation in LRG data

→ No β or Q^2 dependent differences observed

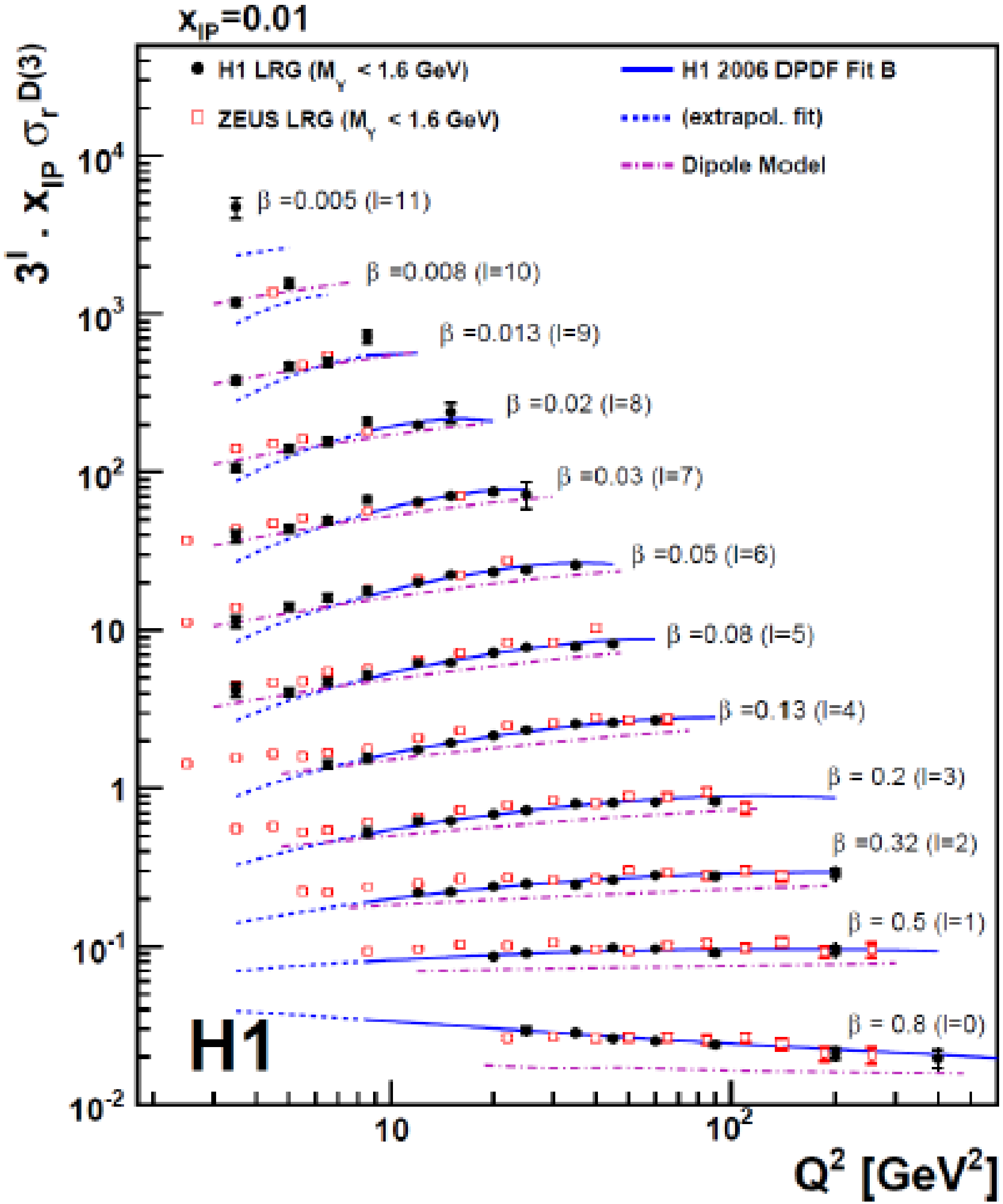


Experimental summary for H1 F_2^D

It took >15 years of analysis to reach this:



H1 and ZEUS data on F2^D



H1 LRG (M_y < 1.6 GeV^2)

ZEUS LRG (M_y < 1.6 GeV^2)

- ZEUS data rescaled to M_y < 1.6 GeV^2

  [ZEUS Coll. NPB816 (2009) 1]

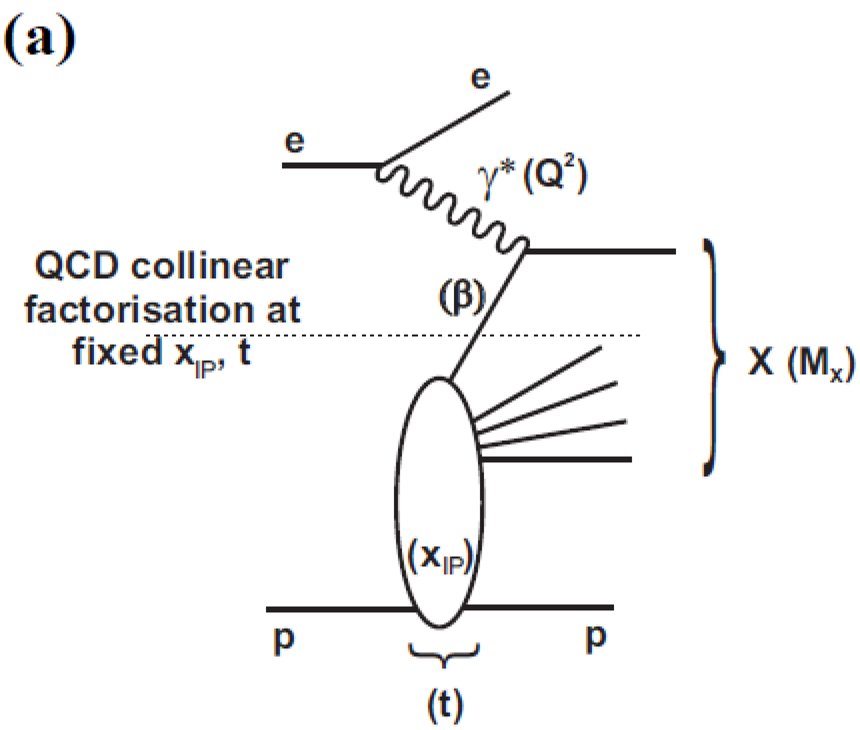
- General overall agreement
- Overall ~10% normalisation difference

  → Within normalisation uncertainties of each measurement

- Comparison sensitive to systematics effect

QCD and diffraction (a)

Colinear factorisation in inclusive diffraction [Collins '98]



$$F_2^{D(3)} = \sum_{a=q,g} C_{2,a} \otimes a^D + \mathcal{O}(1/Q)$$

$C_{2,a}$ are the same coef functions as in inclusive DIS

$a^D = zq^D$ or zg^D satisfy DGLAP evolution in Q^2

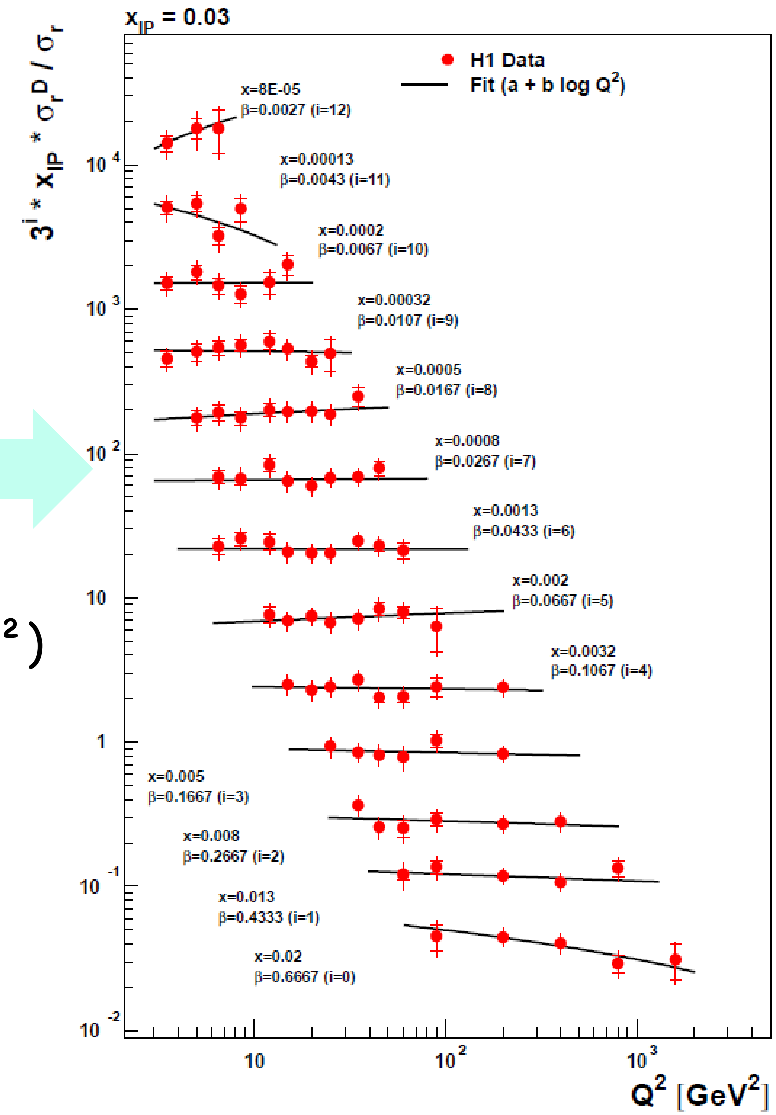
$$\frac{\partial a^D}{\partial \ln Q^2} = \sum_{a'=q,g} P_{aa'} \otimes a'^D$$

experimental support of the Collins factorisation

Look at the ratio of the diffractive
to inclusive cross section

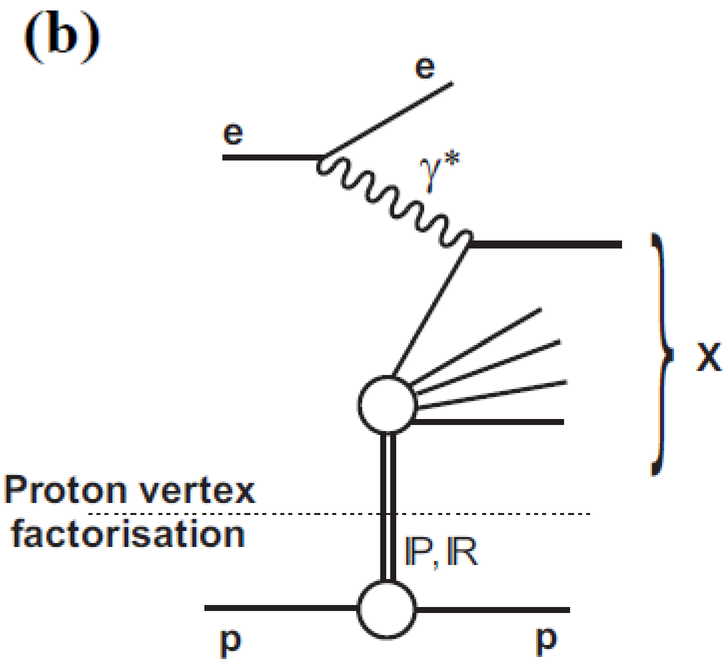
Observation: Q^2 dependence approximately
similar for diff and incl…

Support the fact that evolution equations(Q^2)
can be applied for diff…
(// standard inclusive F2)



QCD and diffraction (b)

'so-called' Regge factorisation (hypothesis) [Ingelman-Schlein]



Assume:

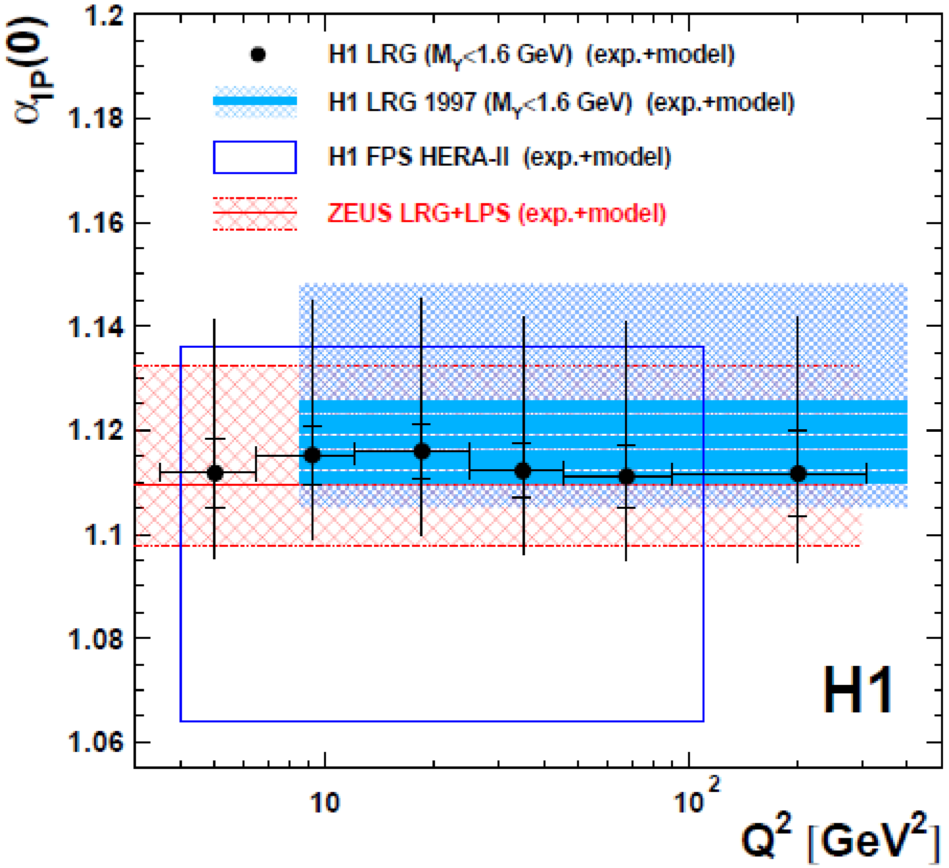
$$a^{D}(x_{\mathbb{P}}, z, Q^2) = f_{\mathbb{P}}(x_{\mathbb{P}})\, a^{\mathbb{P}}(z, Q^2)$$

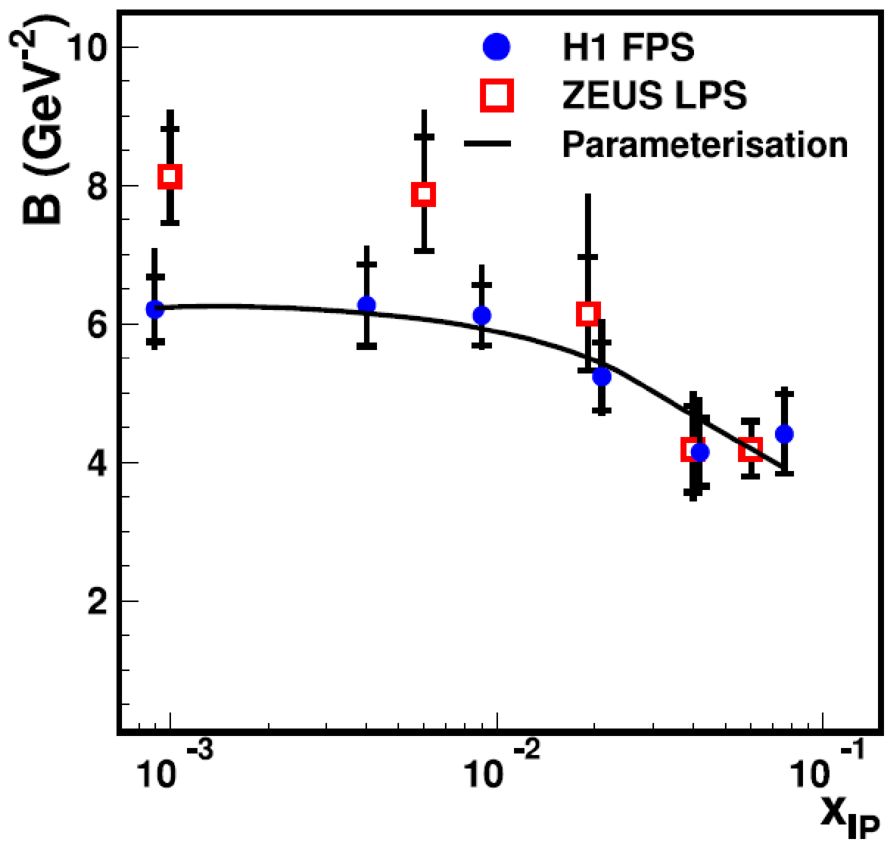
with

$$f_{\mathbb{P}}(x_{\mathbb{P}}) = \int_{t_{\rm cut}}^{t_{\rm min}} \mathrm{d}t\; e^{B_{\mathbb{P}}\, t}\; x_{\mathbb{P}}^{1-2\alpha_{\mathbb{P}}(t)}$$

Parameters of the Pomeron flux function also determined from data…
From data: α_{IP} ~1.11 and B~6 GeV^{-2}

α_{IP} and t-slope determinations

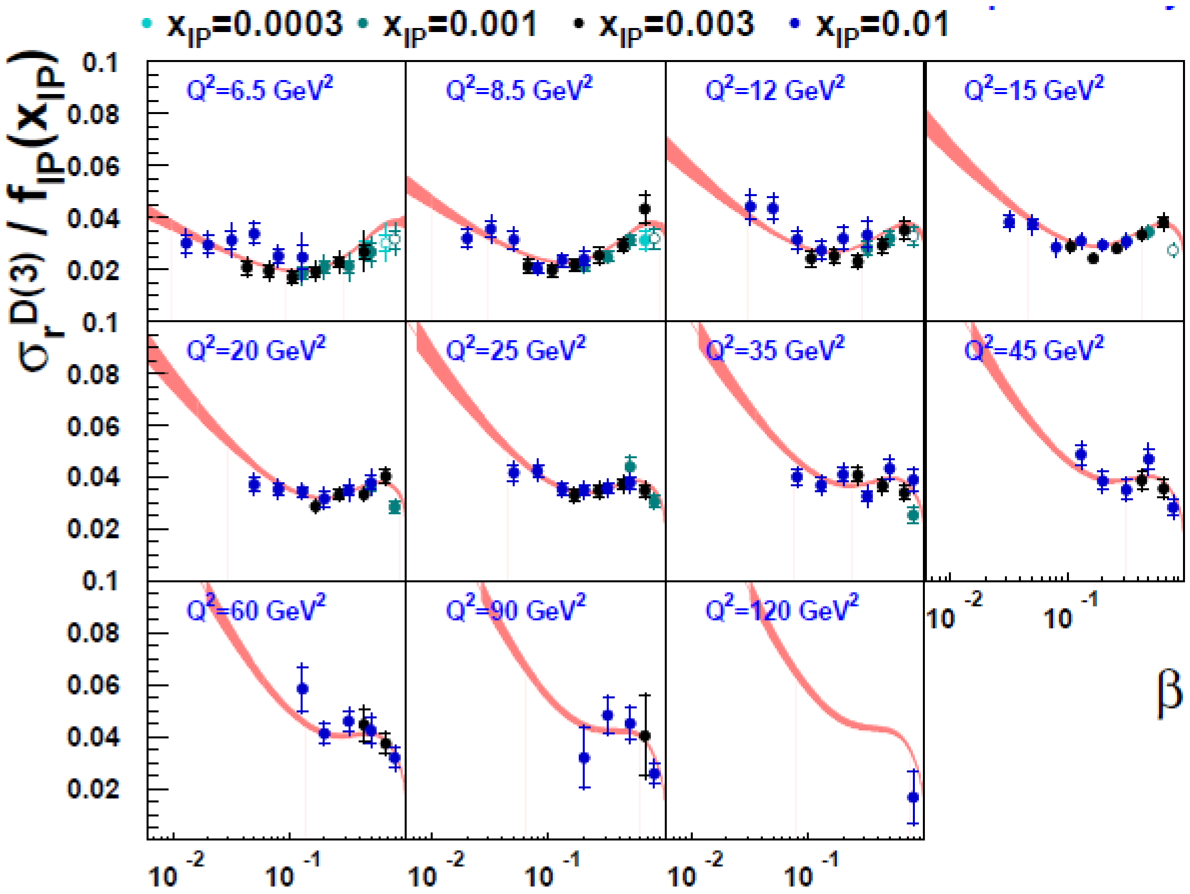




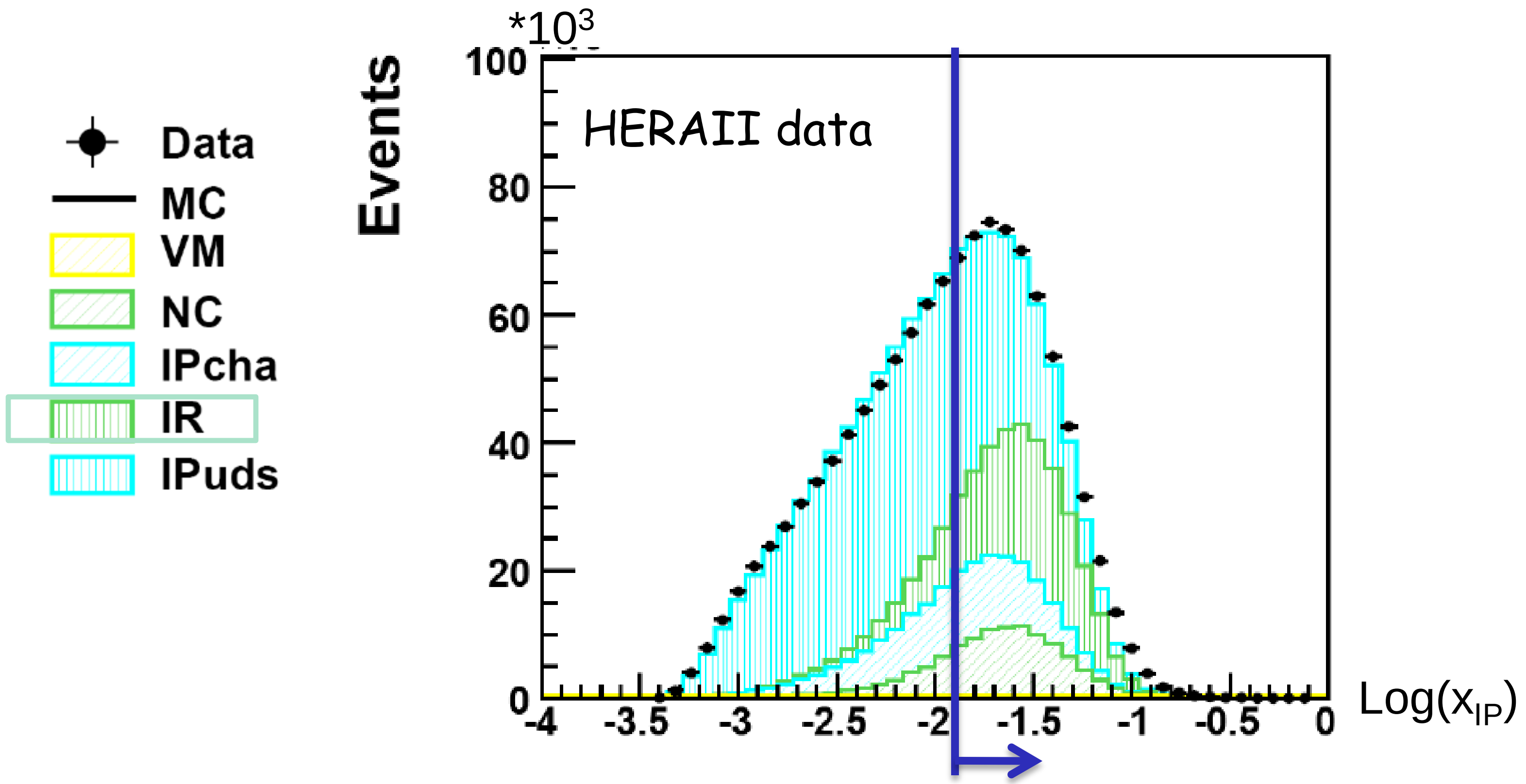
Why the « Regge » factorisation is reasonable?

$$a^{D}(x_{\mathbb{P}}, z, Q^2) = f_{\mathbb{P}}(x_{\mathbb{P}})\, a^{\mathbb{P}}(z, Q^2)$$

This means that if we divide F_2^D by $f_{IP}(x_{IP})$ the dependence in $(z=\beta, Q^2)$ must be the same for all x_{IP} values (small $x_{IP}<10^{-2}$)...



Large x_{IP} and sub-leading exchange

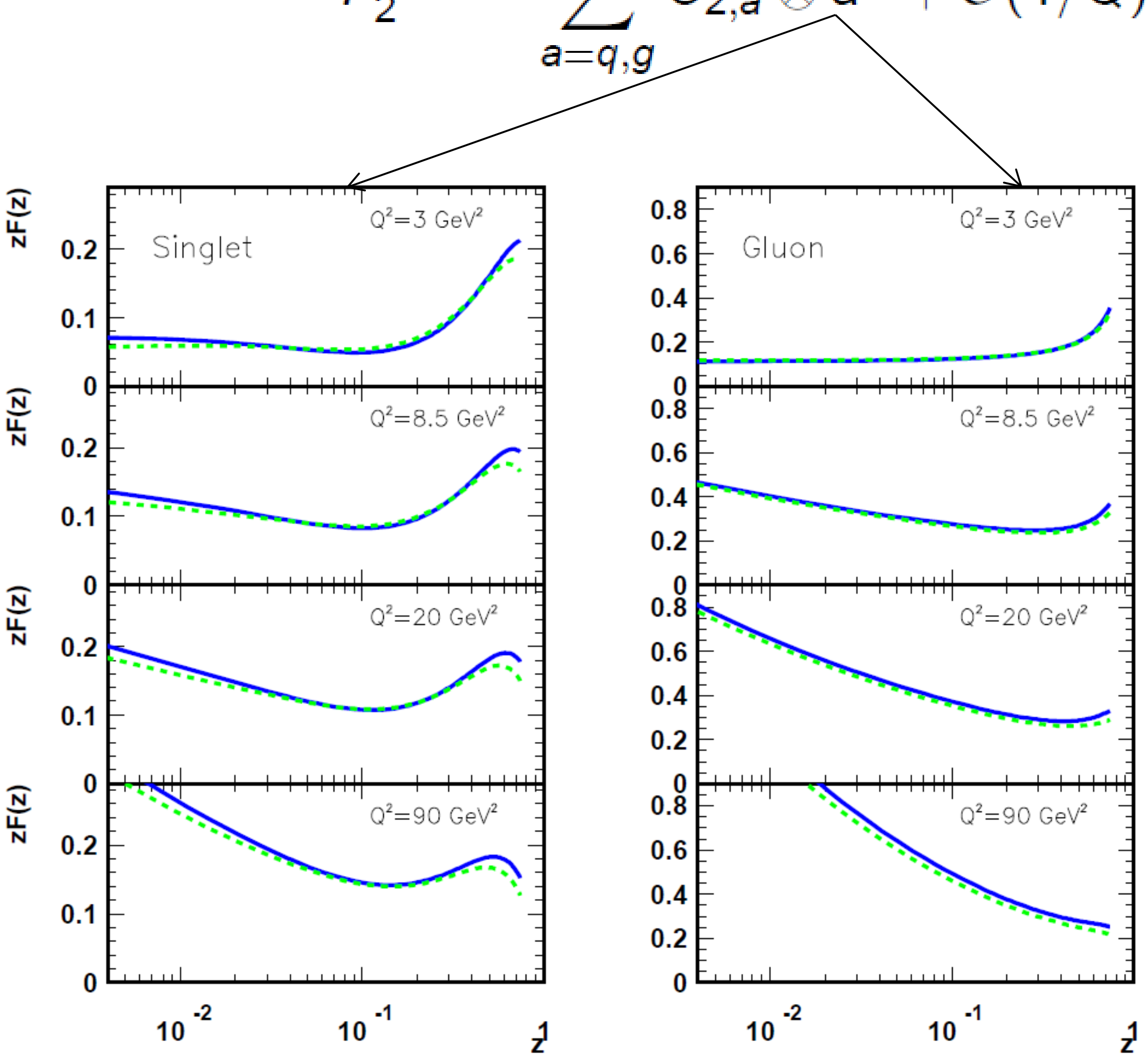


x_{IP}>0.01 => contribution of Reggeons (IR) starts increasing (sub-leading exchange w.r.t. IP)
This is an irreductible background…

These IR lie on the approximately degenerate trajectory $\alpha_{IR}(t) \simeq 0.55 + 0.9t$
…carry the quantum numbers of the ρ,ω,a or f meson
…it is assumed that these exchanges can be expressed as the product of a flux and a meson structure function

Diffractive PDFs

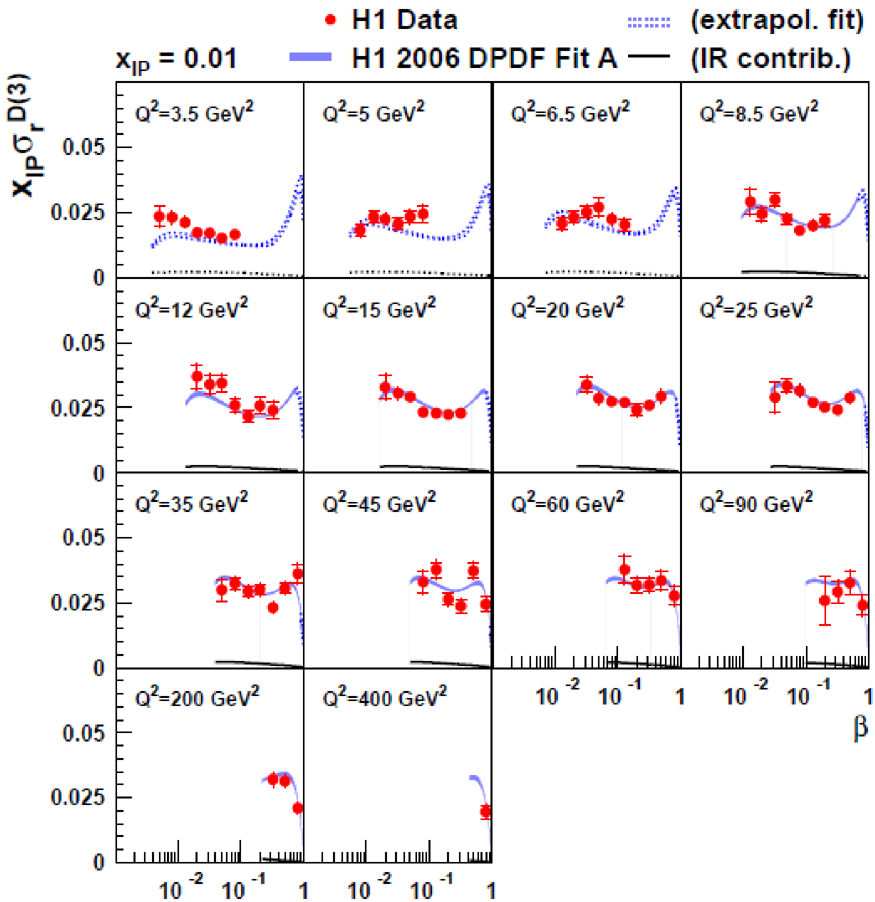
$$F_2^{D(3)} = \sum_{a=q,g} C_{2,a} \otimes a^D + \mathcal{O}(1/Q)$$ + *sub-leading exchange*



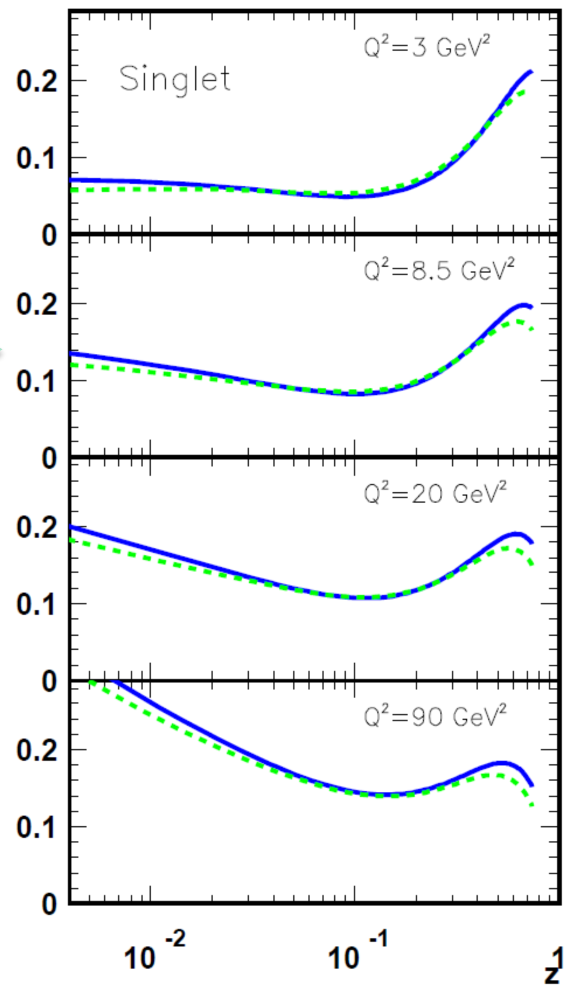
Large gluon fraction
~70% for Q^2>10 GeV^2
(integrated over z)

Fit results[β]

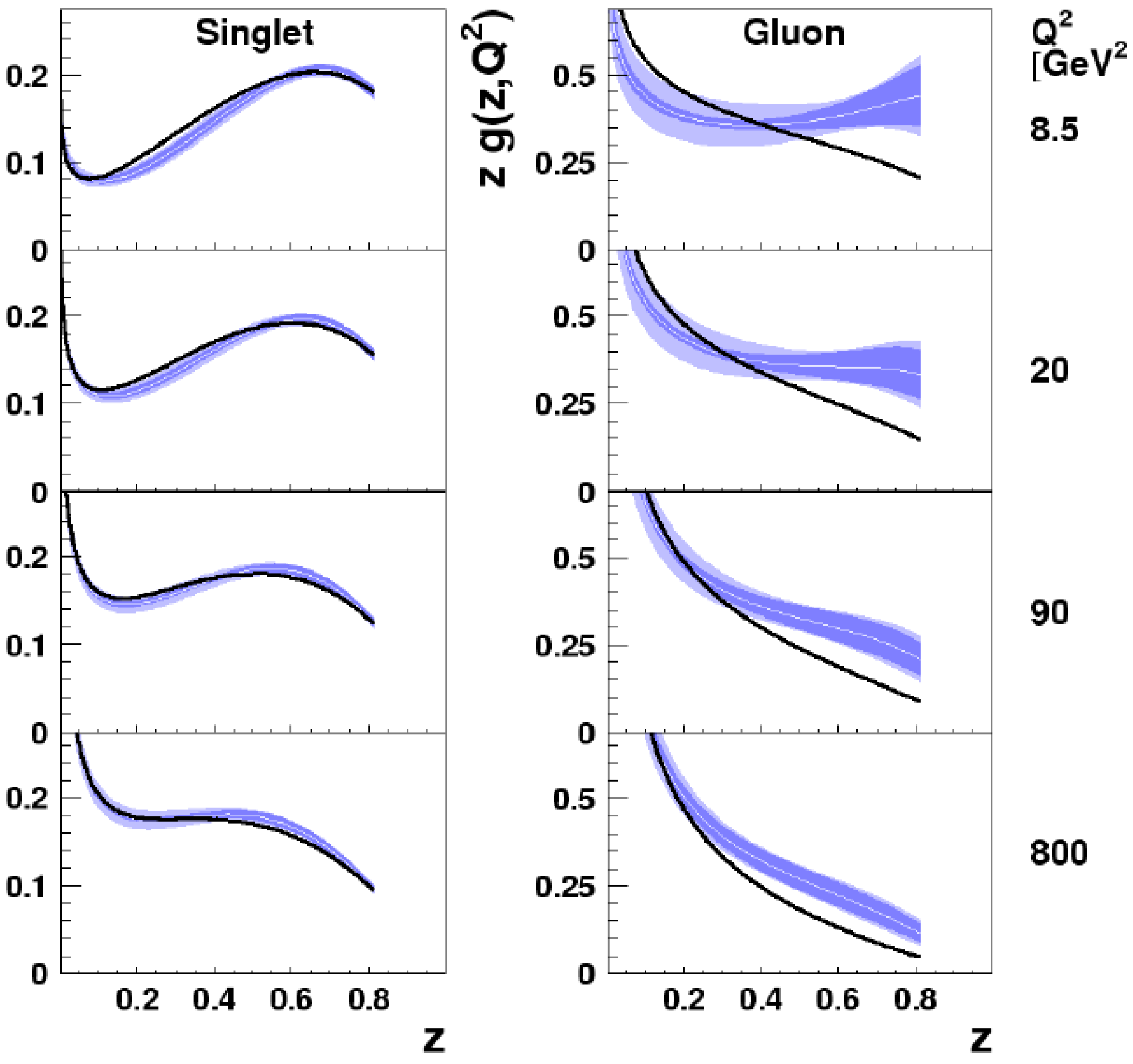
for x_{IP}=0.01



Shapes(β) compatible *as it must be*



Diffractive PDFs (H1) from F2D only



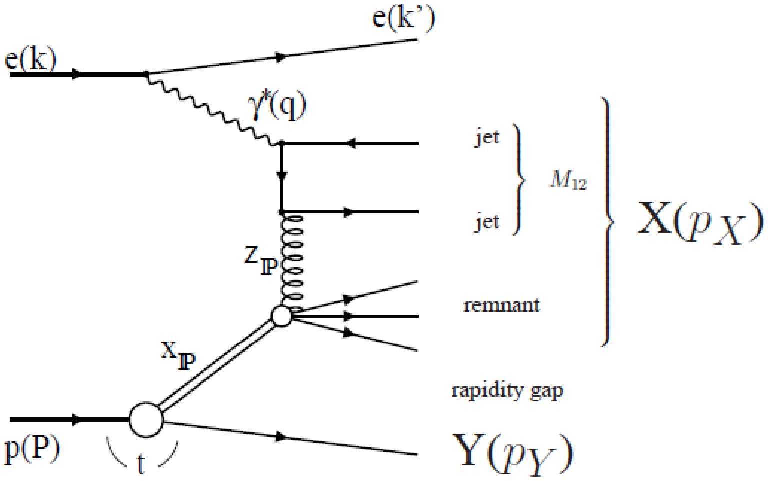
The ambiguity on the gluon distribution can be solved by including Dijets cross sections

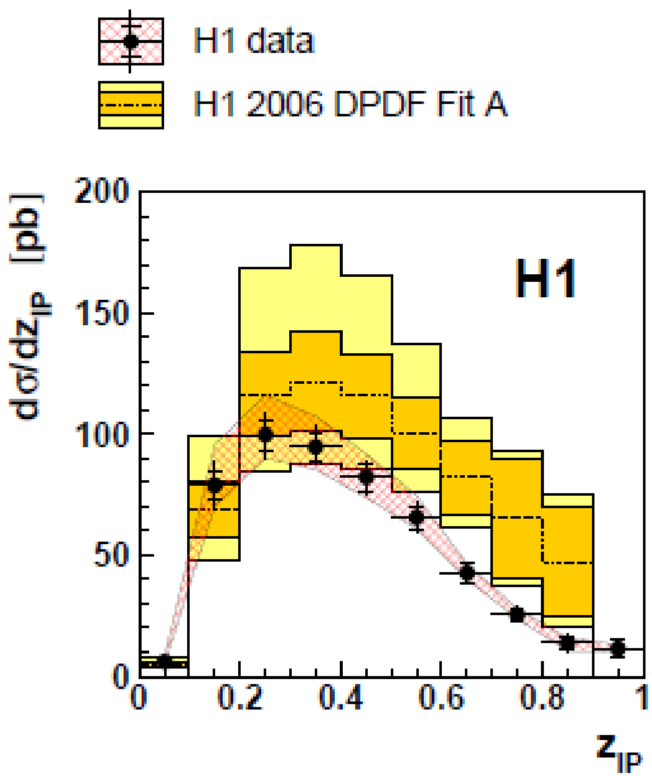
Diffractive dijets at HERA

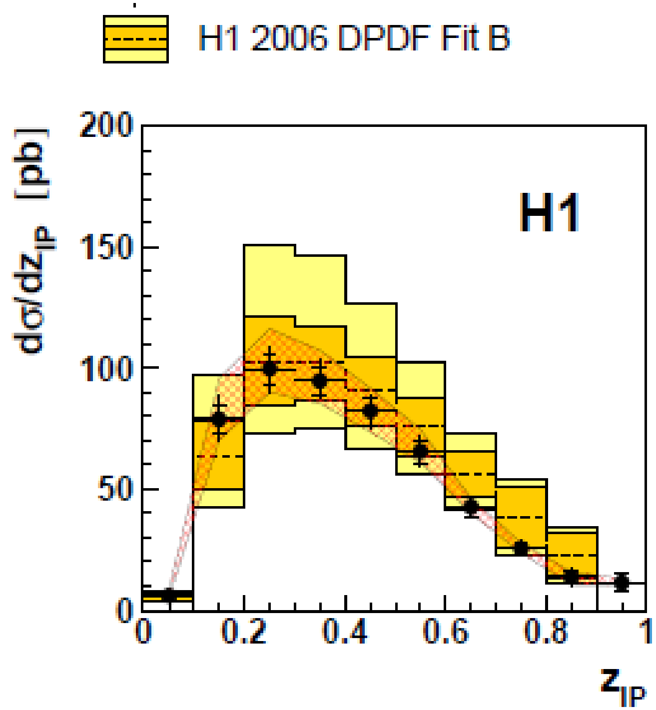
Clear sensitivity to the zG hypothesis:

Fit A: large z 'zG' solution of QCD fits

Fit B: smaller 'zG' at large z

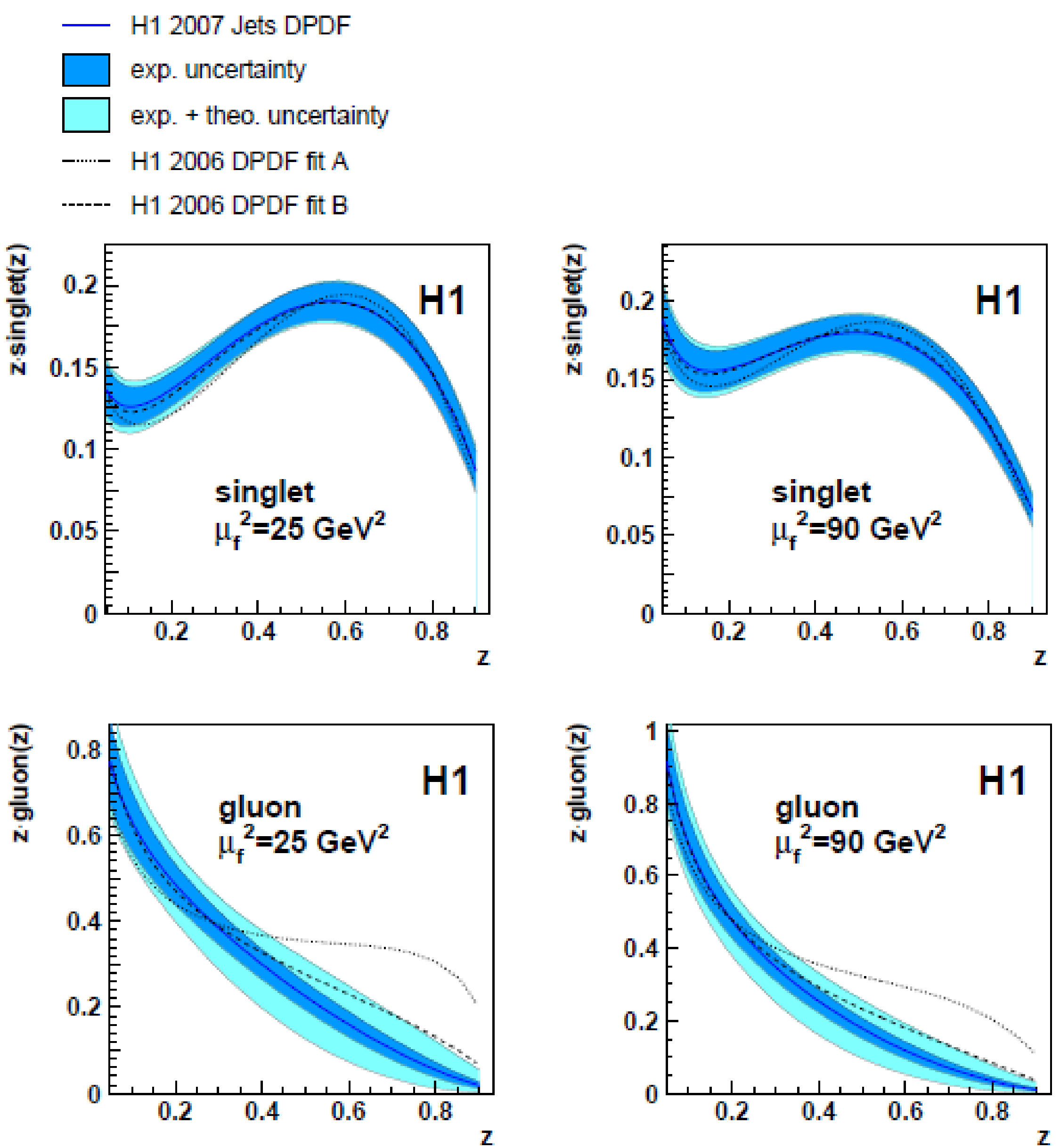






Use these data in the QCD fit in addition to F2D

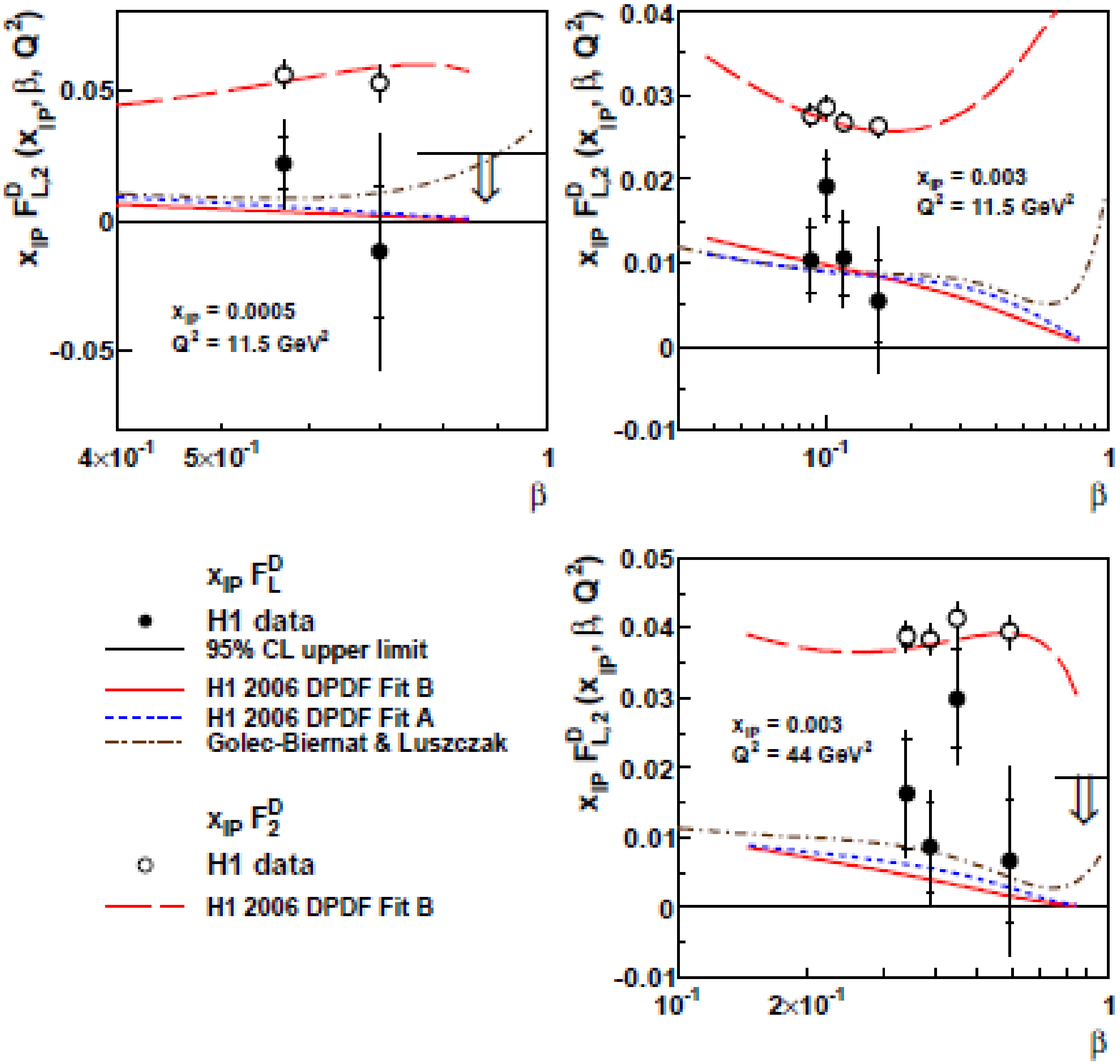
Diffractive PDFs including jets



Now zG is well constrained at large z

Compatibility with dPDFs including F2D only is shown on the figure…

Add-up: FL^D measurements



I can not describe
the measurement,
it would need a
dedicated presentation.

In the context of this
Talk => we can
check the size of FLD
versus F2D and the
good description
by the diffractive
PDFs (thus zG)…

Conclusion -1-

19 years after first HERA diffractive events …
H1 released its final LRG cross section measurement
➔A precision measurement
➔Reduced statistical and systematic errors
[H1 Coll. arXiv:1203.4495]

- Amount of proton dissociation: 20%
- New constraints for QCD models
- Data support the proton-vertex factorisation hypothesis
- Overall general agreement with ZEUS LRG data

Outlook: all HERA LRG data combination ?
this is a nice project that will take time

Still a bunch of results to come from measurements using the VFPS

Conclusion -2-

19 years after first HERA diffractive events …

H1 released its final LRG cross section measurement

➔A precision measurement

➔Reduced statistical and systematic errors

[H1 Coll. arXiv:1203.4495]

Thanks to all H1 members

who worked during years

to make this measurement possible