Diffractive PDFs at HERA and implications for LHC energies

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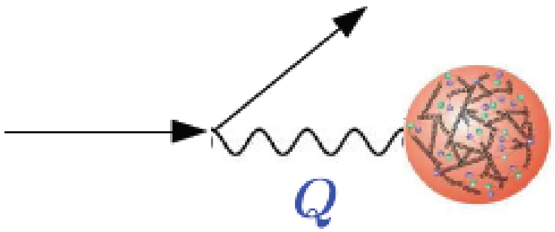
First part: precise introduction on diffractive PDFs: what they are? How they are extracted from data? At which uncertainties?
Are shapes of diffractive PDFs common (universal)?

Then, we show that this is reasonnable to assume a continuity (in a sense defined later) between HERA results at $W_{\gamma p}$~100 GeV and much larger energies… *The rest of the talk is done in this context: we assume the validity of HERA results…*

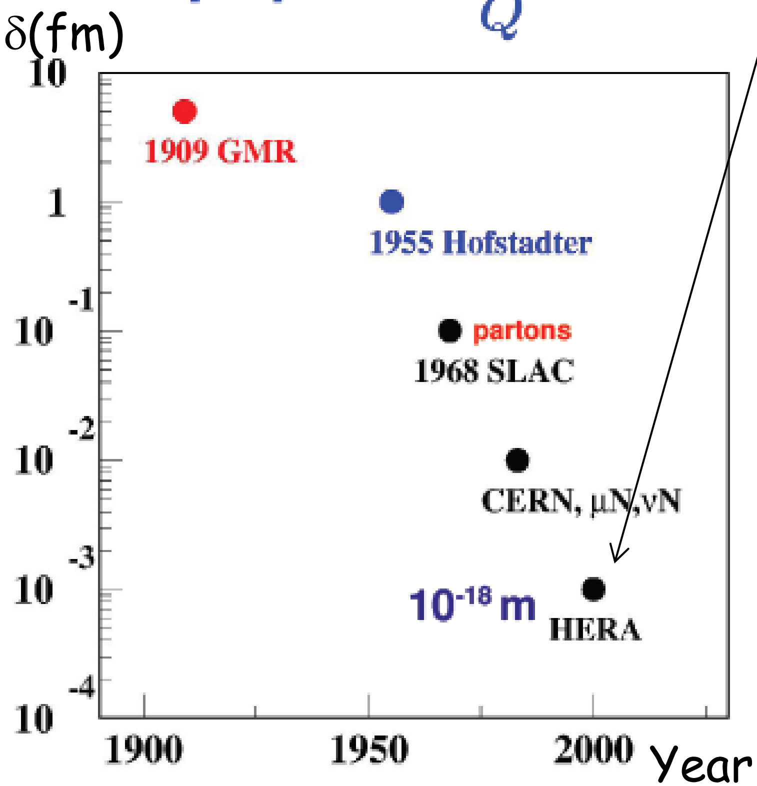
Second part: implications for DPE dijets production at the LHC

Diffractive events at HERA



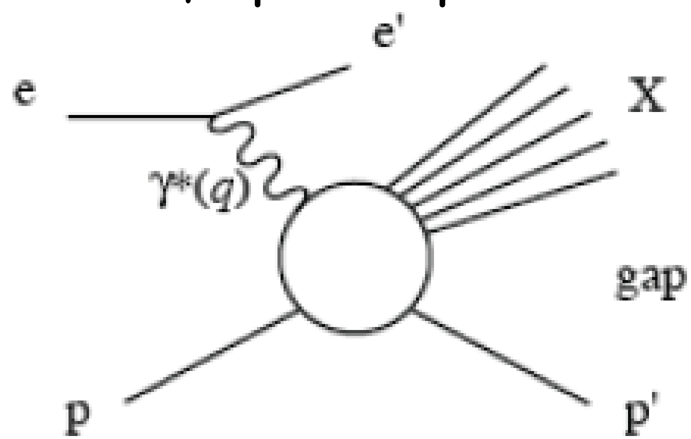
Probe the proton with a lepton beam
=> Virtual photon (γ^*) of resolution ~1/Q

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



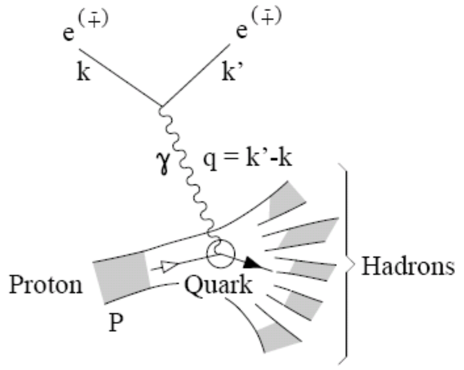
Diffraction of subnuclear waves (γ^*) at HERA [E_{cm}=320 GeV]

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

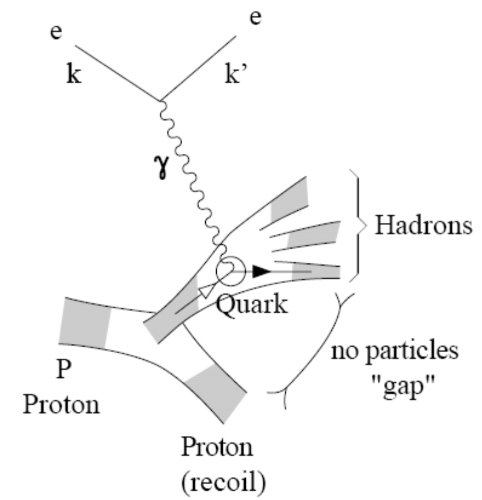


The proton is left intact (or quasi-intact)
** Color singlet exchange
** Presence of a GAP in rapidity
(between X and p')

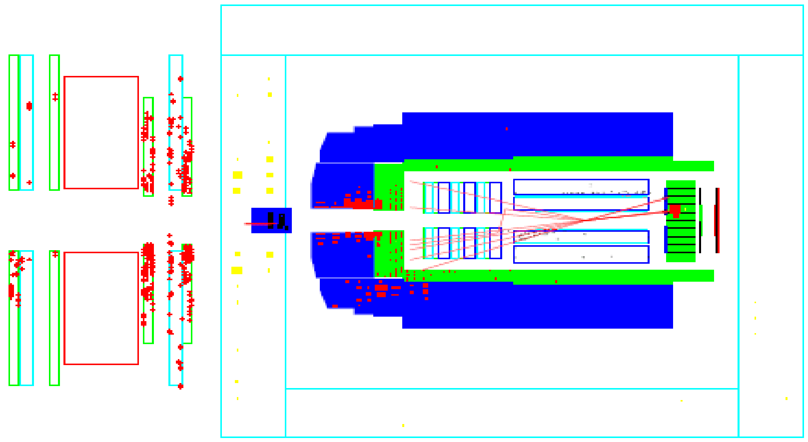
Diffractive events are observed

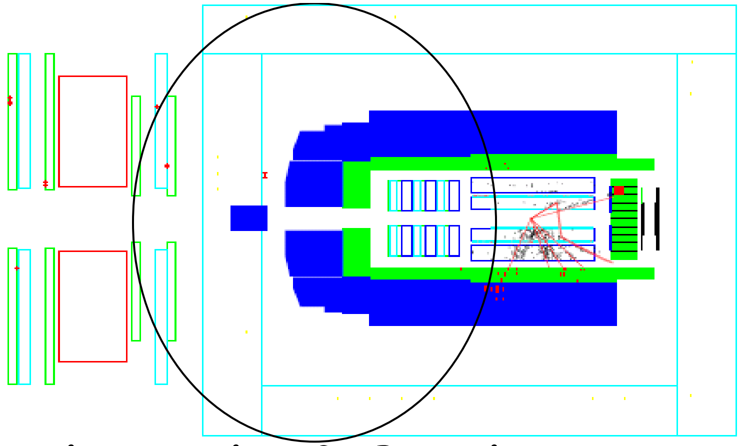


Deep Inelastic Scattering (DIS) => F_2



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

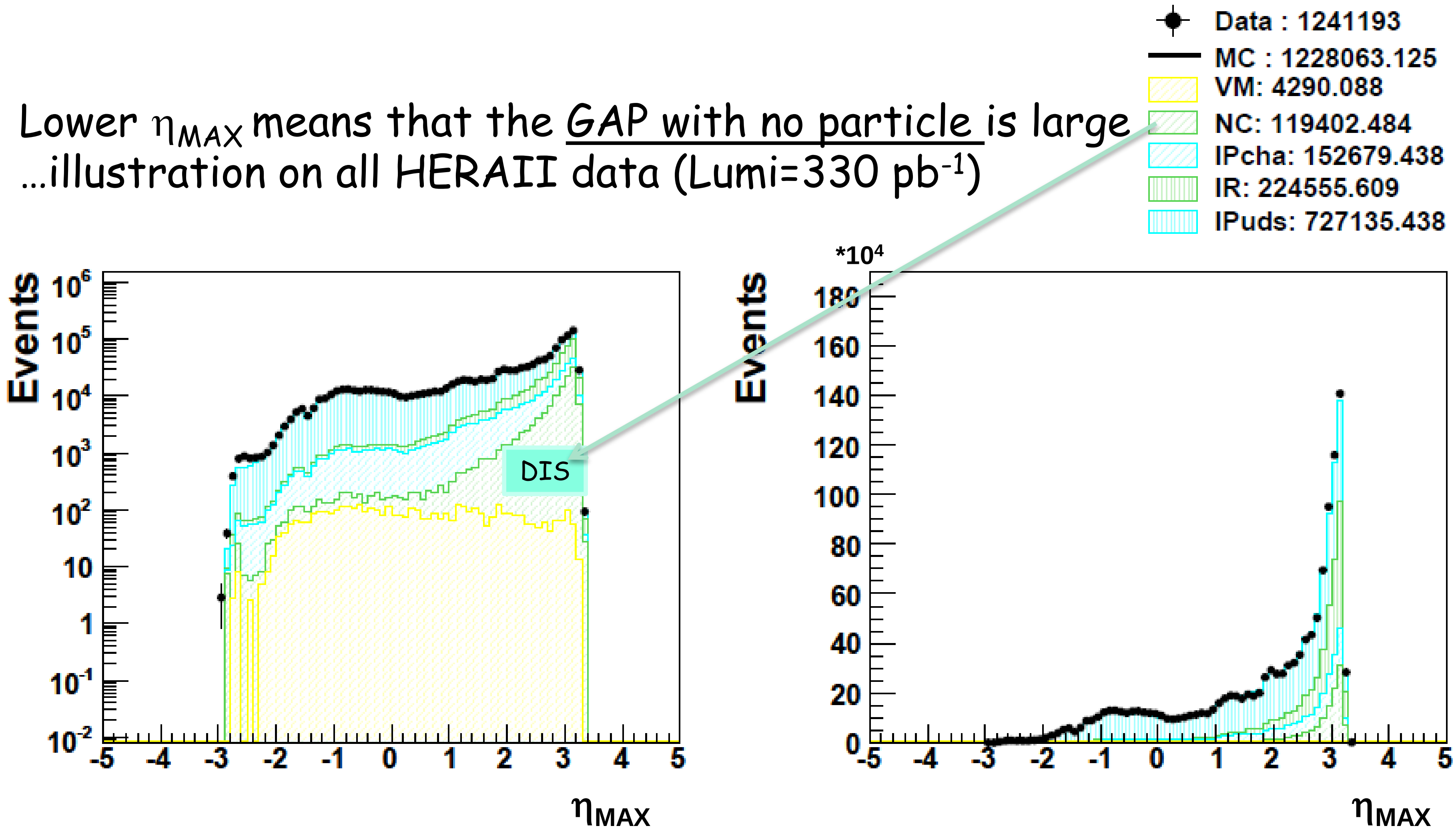




This is the GAP with no particle

…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})



Kinematics and notations

Standard DIS variables …

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

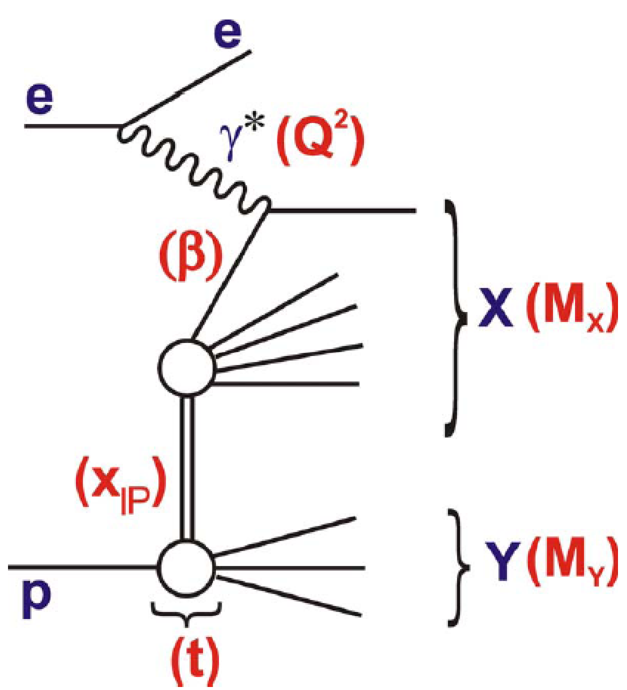
Additional variables for diffraction …

t = squared 4-momentum transfer at proton vertex

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

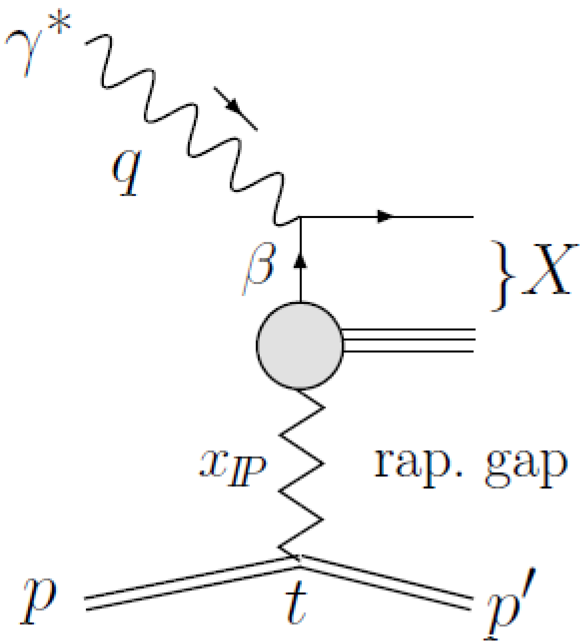
$\beta = x / x_{IP}$ (momentum fraction q / IP)

Most generally ep→eXY …



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

Diffractive cross sections (definition)

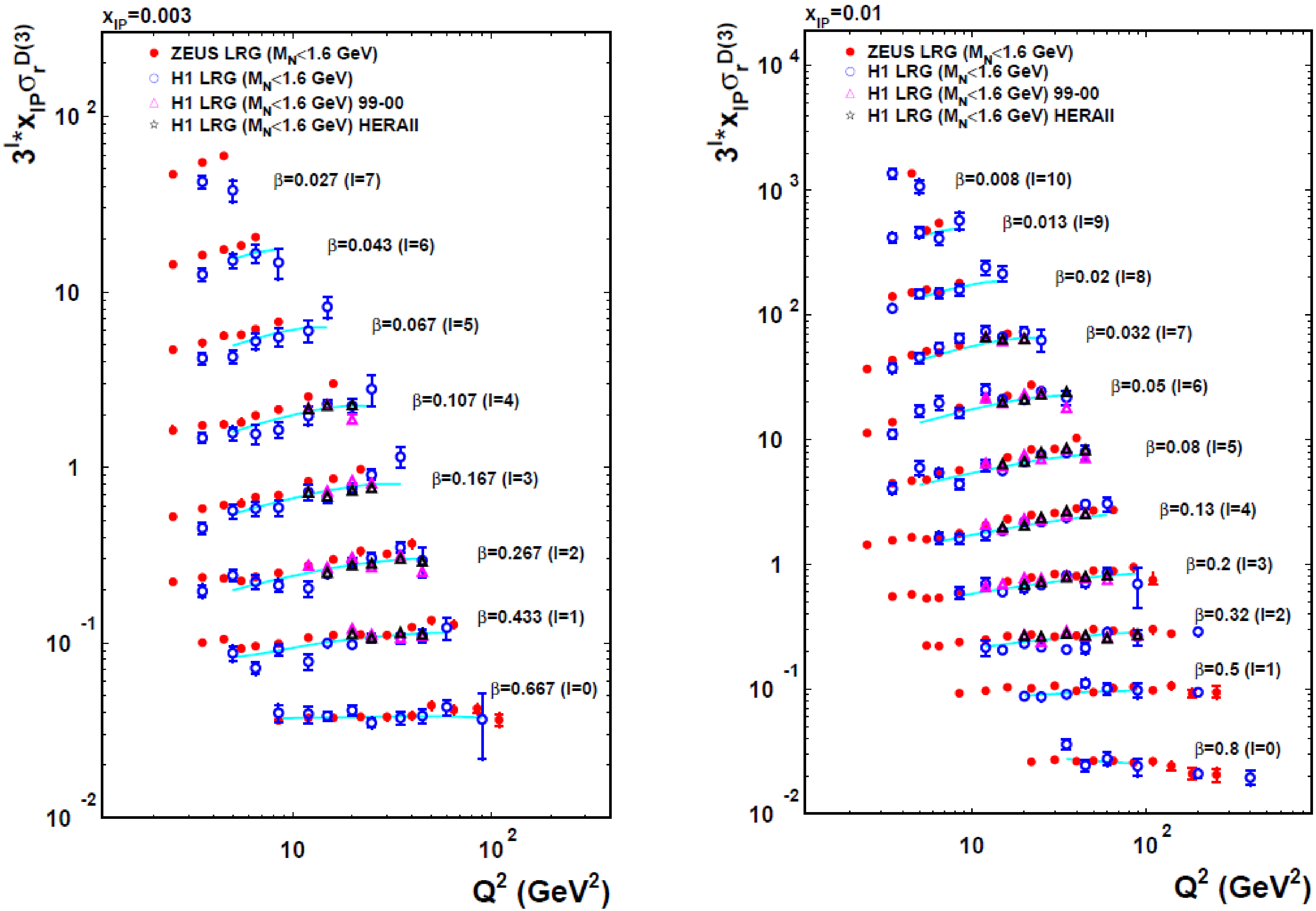


Select diffractive events
Correct for detector effects
Derive cross sections (// F2)

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

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

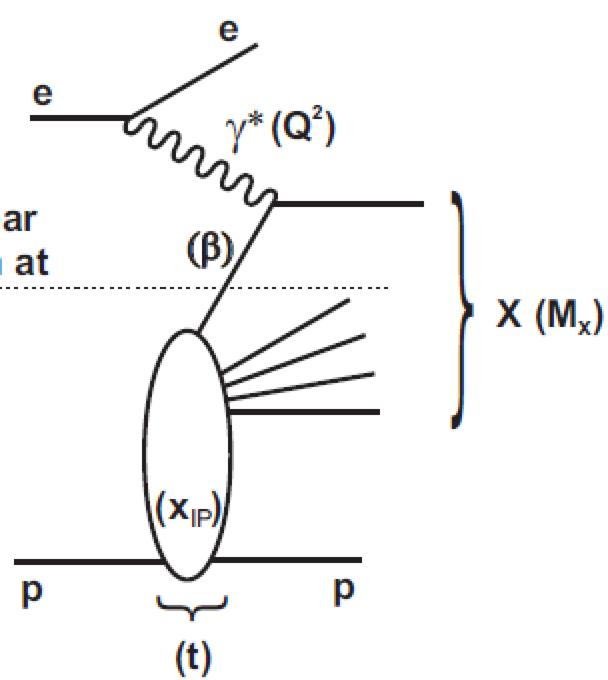
Results (x_{IP} F_2^D) for 2 x_{IP} values



QCD and diffraction (a)

Colinear factorisation in inclusive diffraction [Collins '98]

(a)



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

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

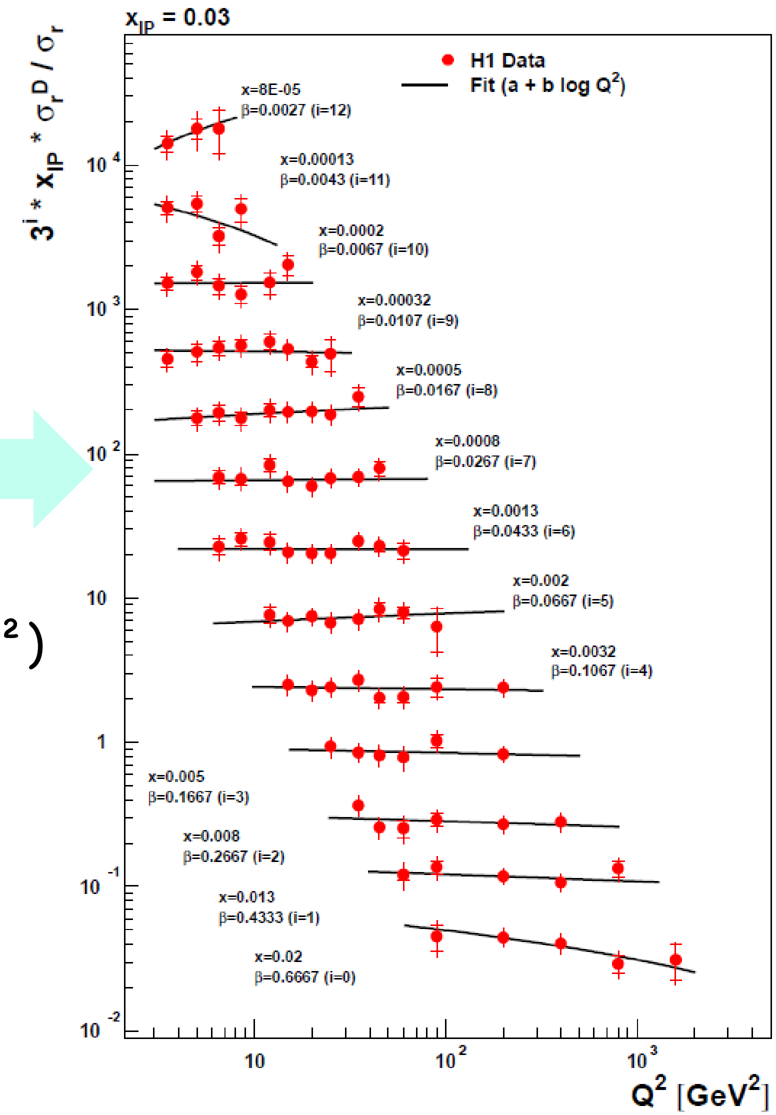
$a^D = zq^D$ or zg^D satisfy DGLAP evolution in Q^2

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

experimental support of the Collins factorisation

Look at the ratio of the diffractive to inclusive cross section

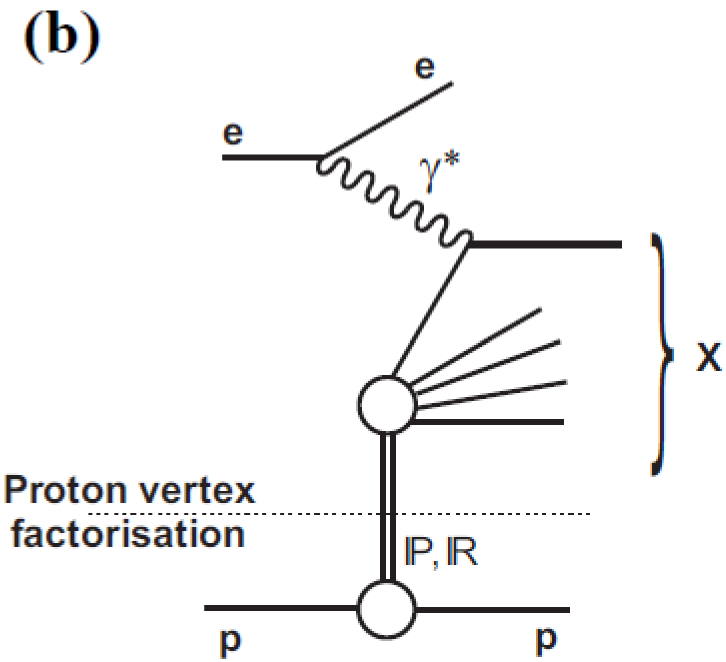
Observation: Q^2 dependence approximately similar for diff and incl…



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:

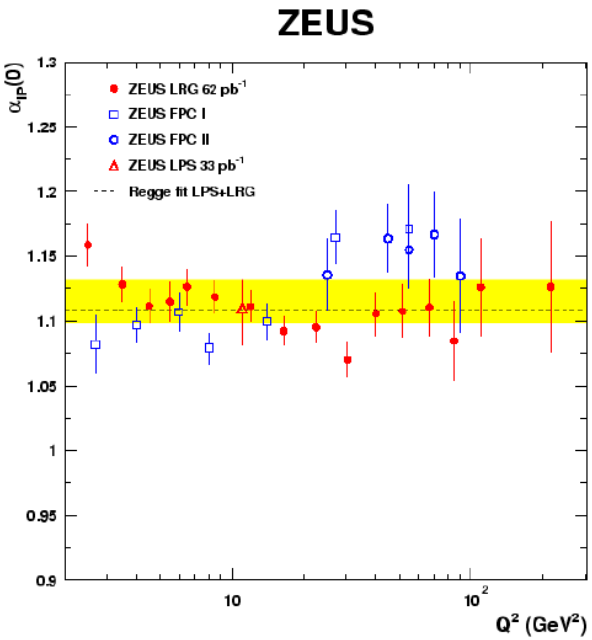
$$a^{D}(x_{\mathbb{P}}, z, Q^2) = f_{\mathbb{P}}(x_{\mathbb{P}})\, a^{\mathbb{P}}(z, Q^2)$$

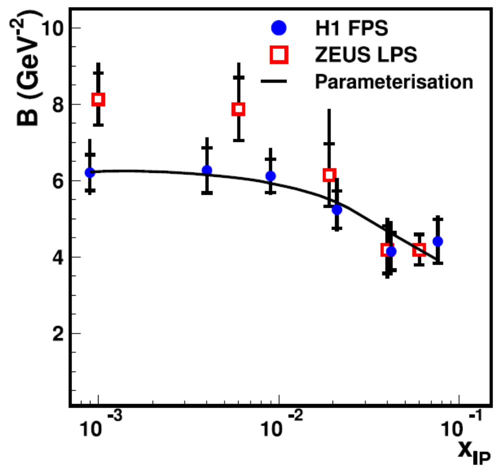
with

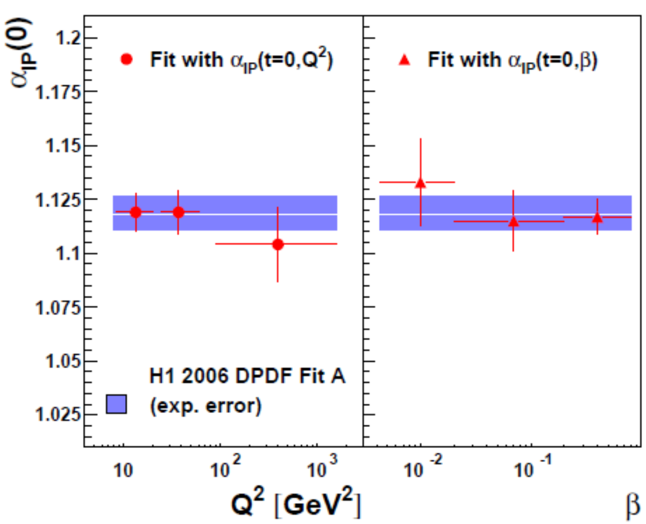
$$f_{\mathbb{P}}(x_{\mathbb{P}}) = \int_{t_{\mathrm{cut}}}^{t_{\mathrm{min}}} \mathrm{d}t\; \mathrm{e}^{B_{\mathbb{P}}\, t}\; x_{\mathbb{P}}^{1-2\alpha_{\mathbb{P}}(t)}$$

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







IP flux parameter: $\alpha_{IP}(t)= \alpha_{IP}(0)+\alpha' t$

$\alpha_{IP}(0)=1.11\pm0.02\pm0.02$

(consistent betw H1/ZEUS)

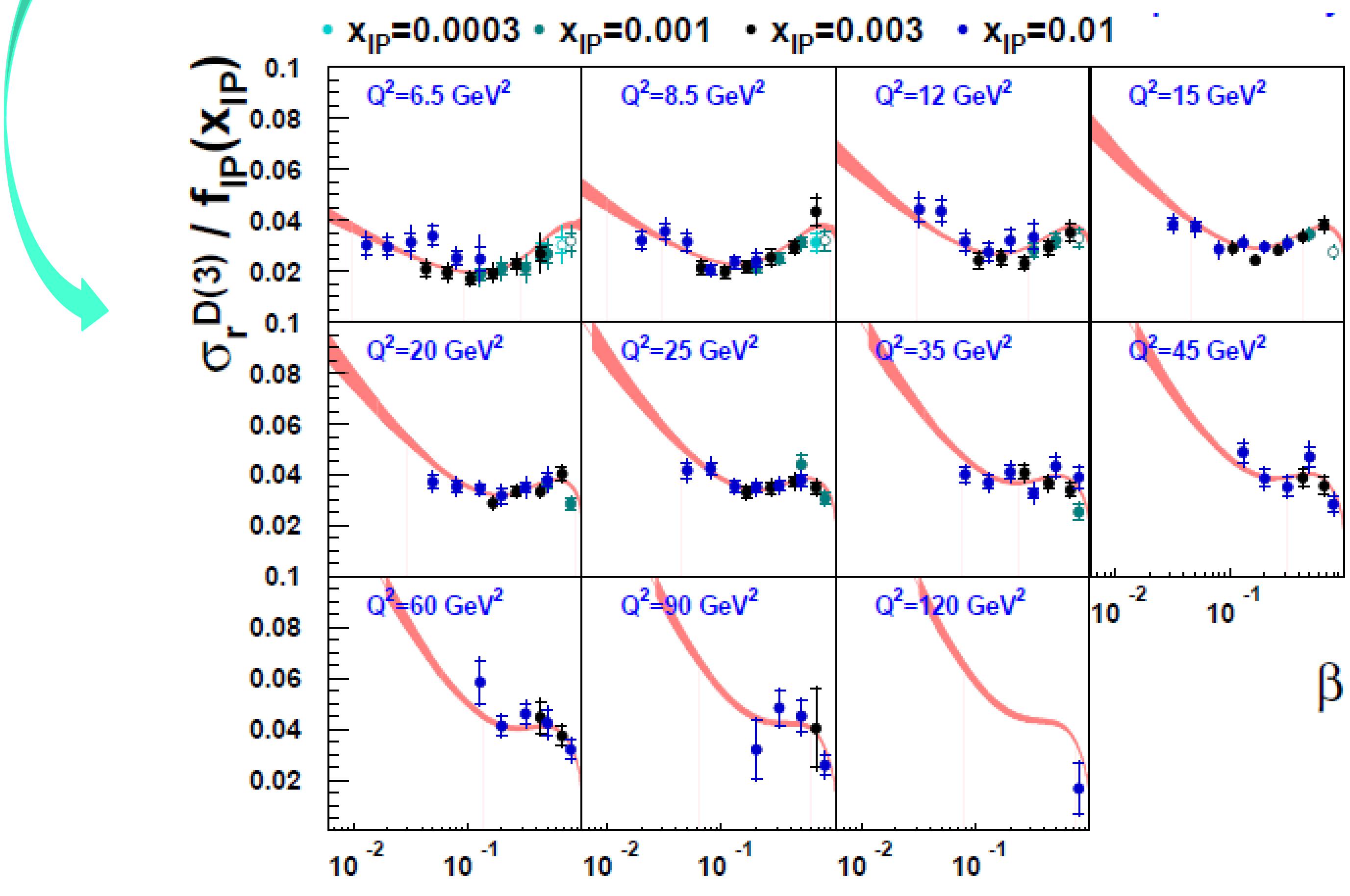
and α' compatible with !

B (low x_{IP})~6-7 GeV^{-2} for H1 and ZEUS

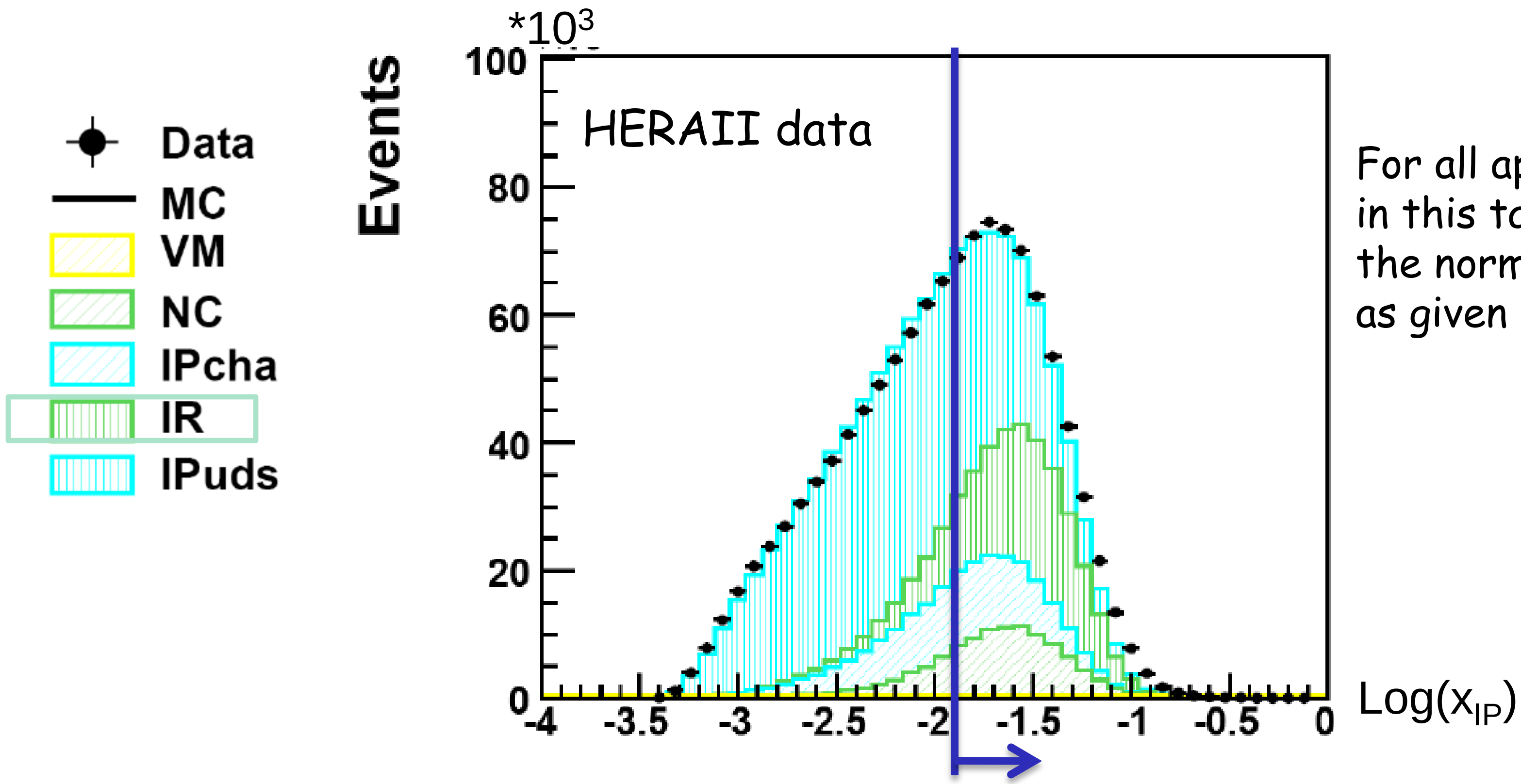
Why the « Regge » factorisation is reasonable?

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

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



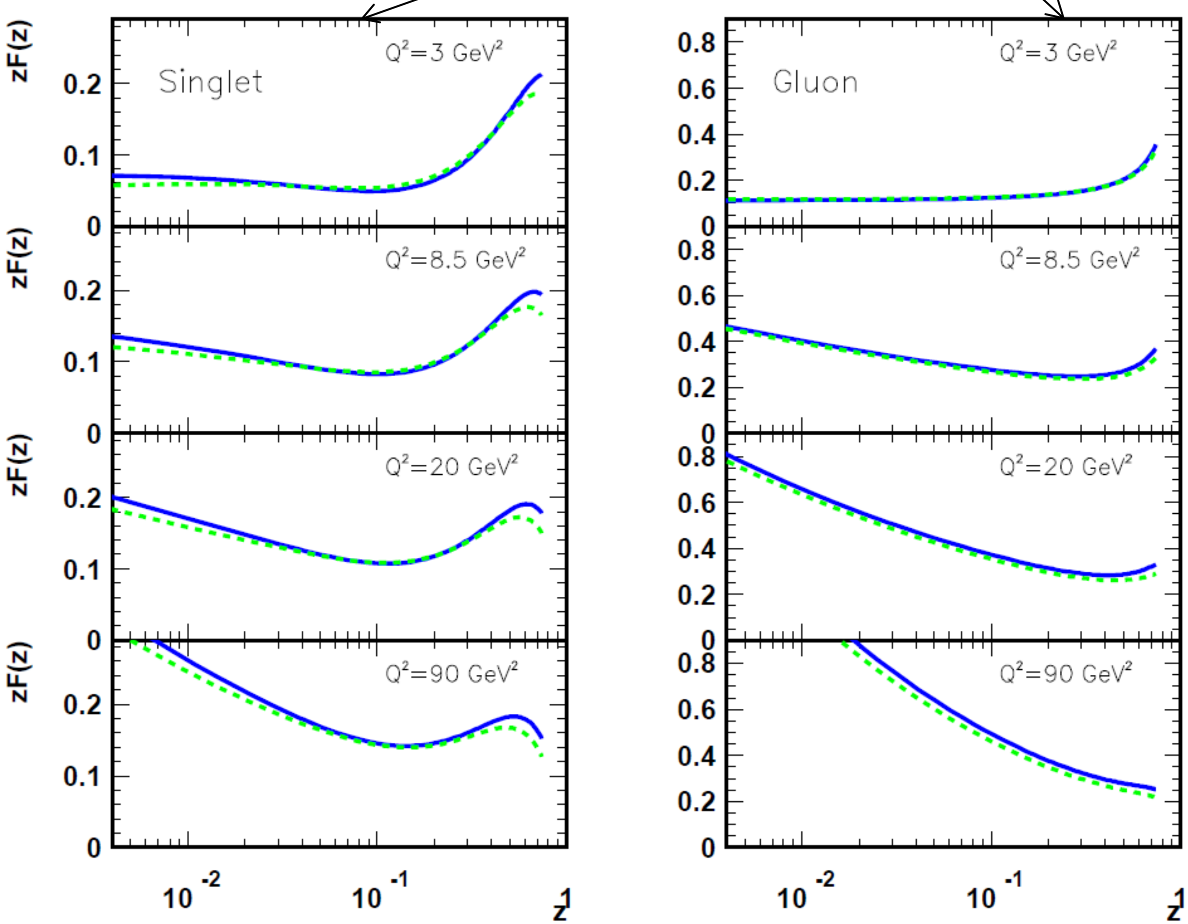
For all applications in this talk, we keep the normalisation of IR as given in this plot

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

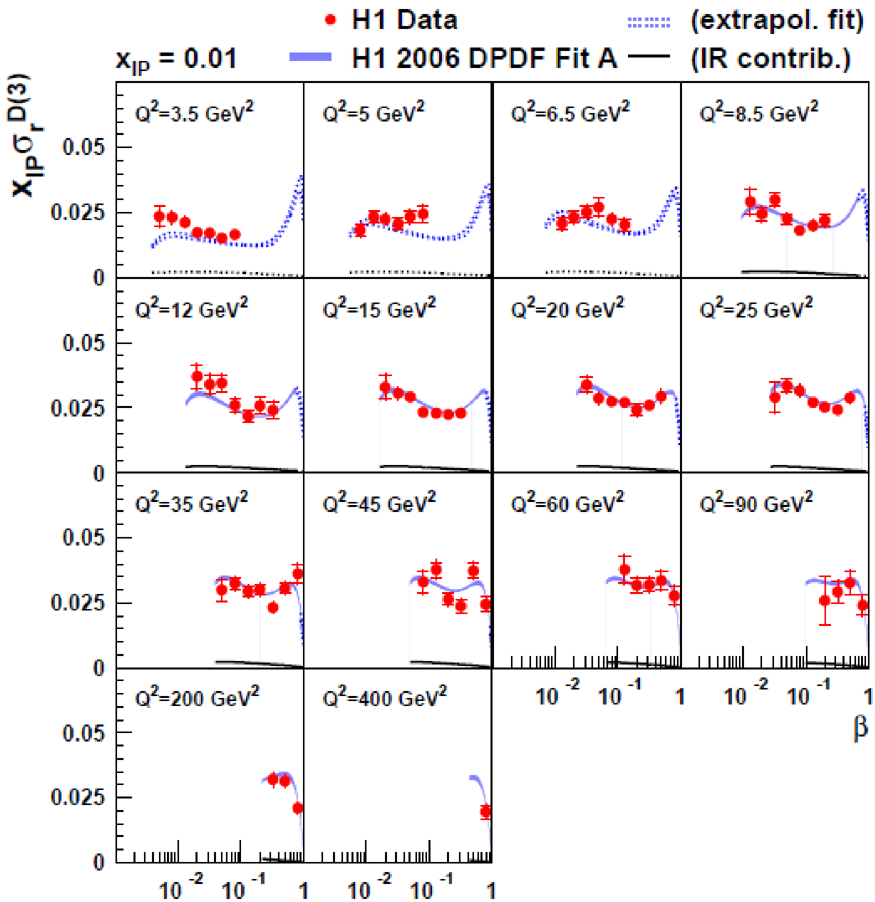
$$F_2^{D(3)} = \sum_{a=q,g} C_{2,a} \otimes a^D + \mathcal{O}(1/Q)$$ *+ sub-leading exchange*



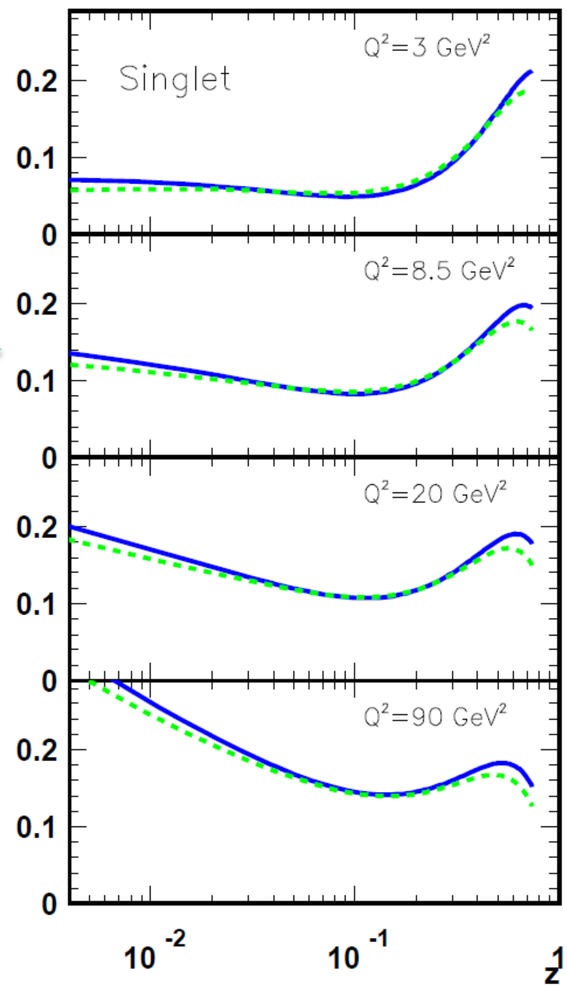
Large gluon fraction
~70% for Q^2>10 GeV^2
(integrated over z)

Fit results[β]

for x_{IP}=0.01



Shapes(β) compatible
as it must be



Diffractive PDFs (comments)

Fit of all F2D data:

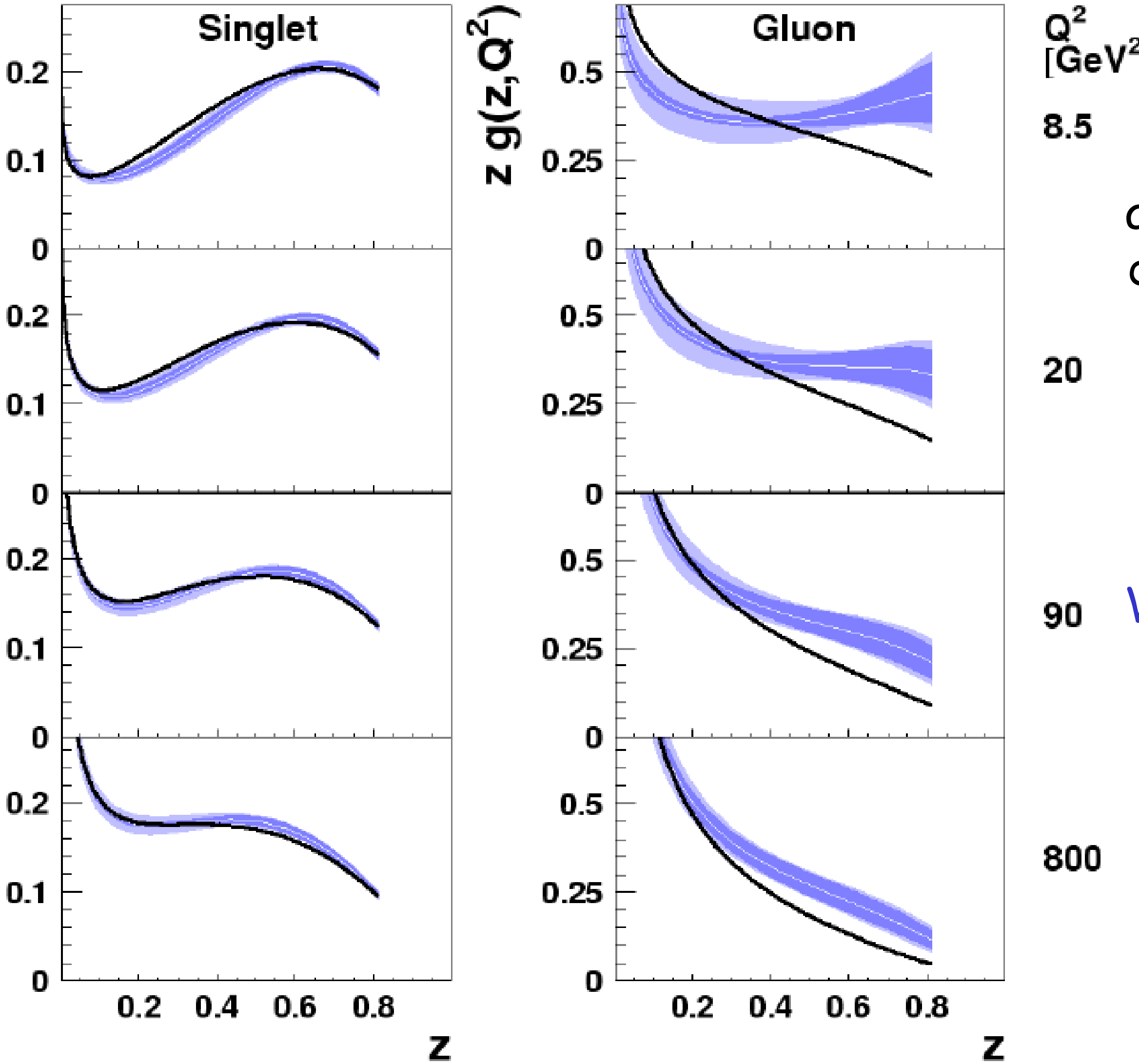
The uncertainties are ~3 to 4% on quarks
and <10% on the gluon at low z
(reaching 20% at highest z values z~0.8)…

Good compatiblity between both experiments (H1 ans ZEUS)

The important fact is the good description of the data
=> validation of the « factorisation theorem » + method

The global ratio ∫dz zG / ∫dz [zG+zS] ~0.7 => <G>/<S> ~ 70%/30%
similar fraction for DIS…
Indeed, diffraction in DIS is a leading twist process (low/medium β)
$d(\sigma_{diff}/\sigma_{incl})/d\log Q^2 \sim 0 \Rightarrow G_{diff}/Q_{diff} \approx G_{incl}/Q_{incl}$

Diffractive PDFs (H1)



As mentioned before:
at large z, F2D fata alone does not give a sufficient constraint on the gluon density

=>

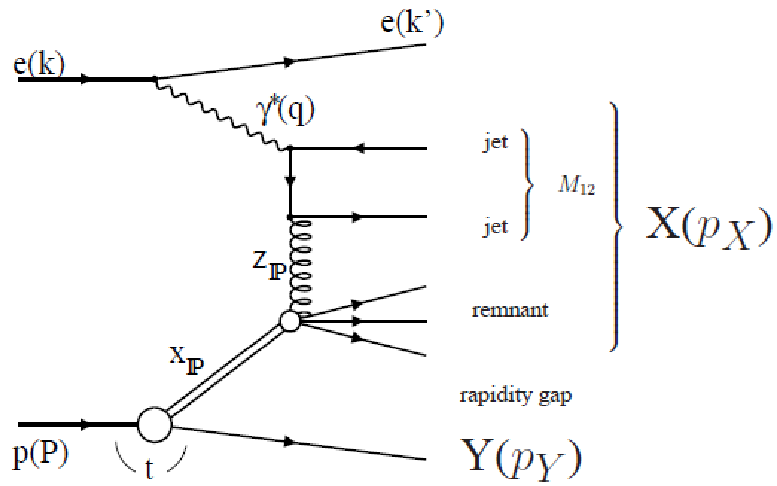
We need to include dijets cross section

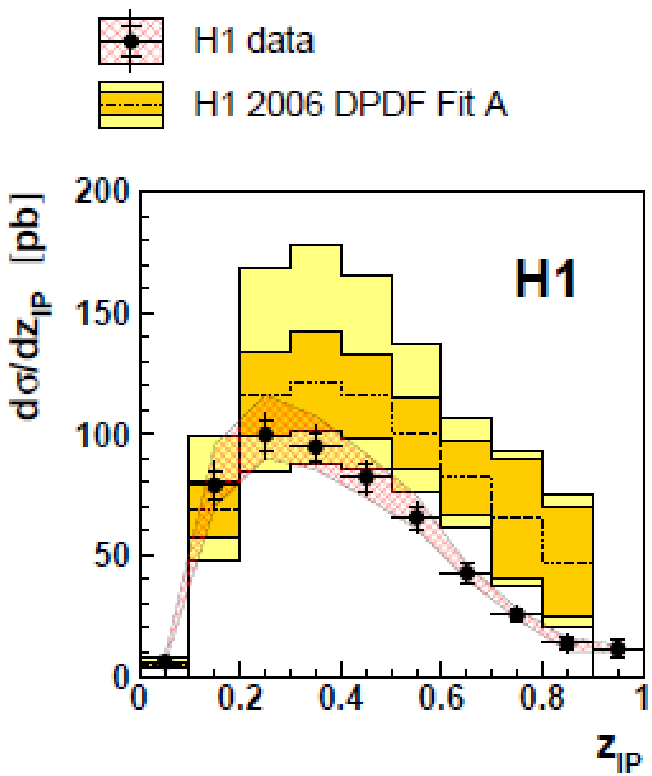
Diffractive dijets at HERA

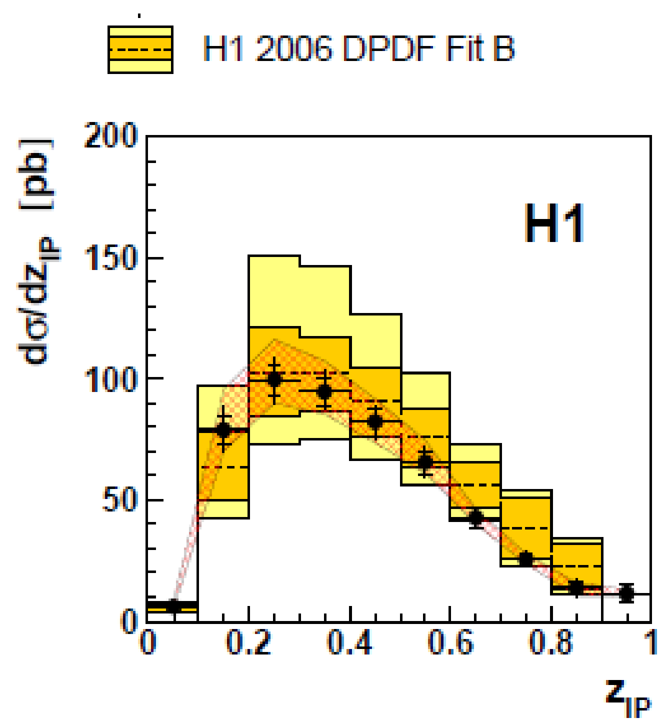
Clear sensitivity to the
zG hypothesis:

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

Fit B: smaller 'zG' at large z

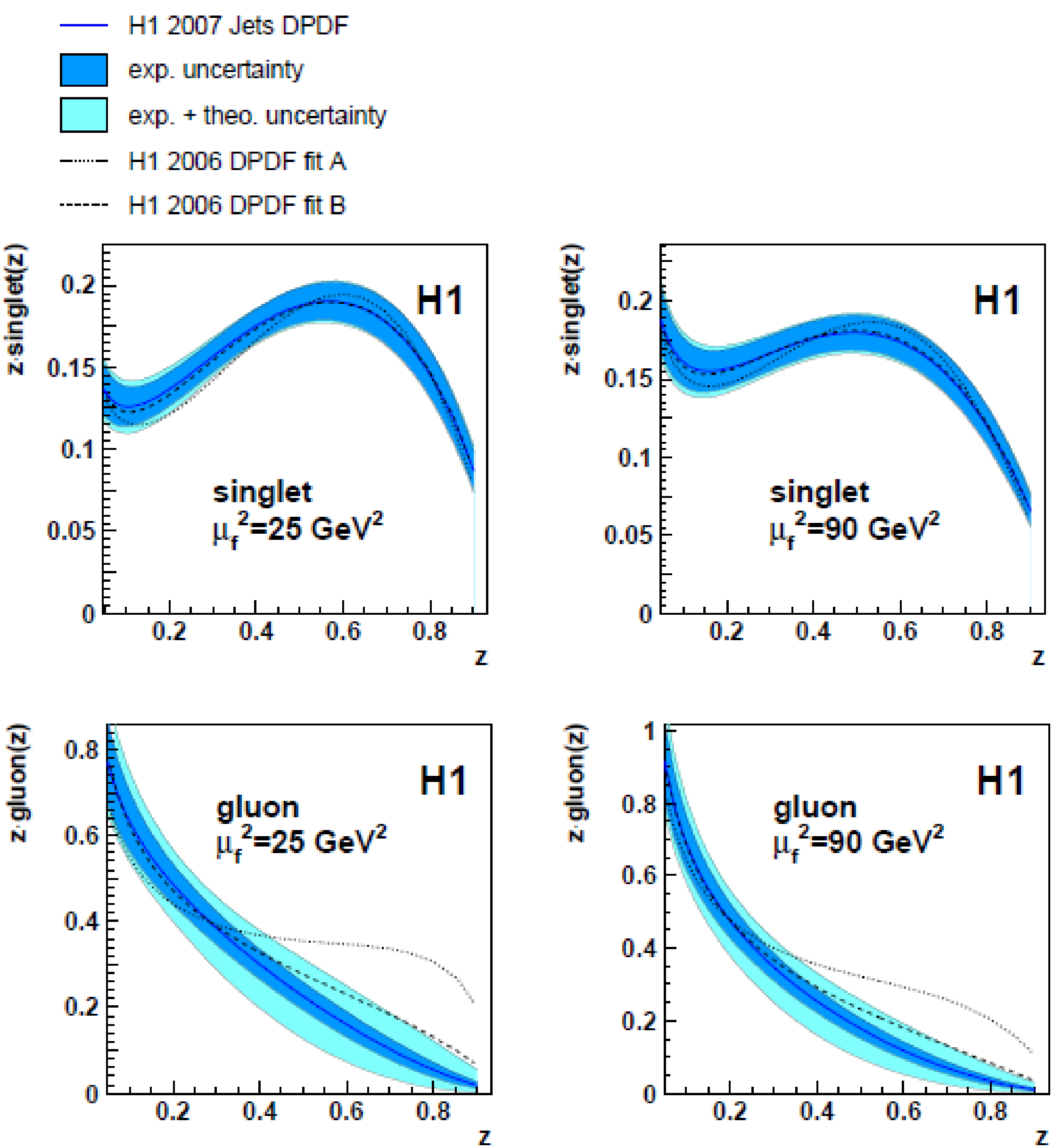






Use these data
in the QCD fit
in addition to F2D

Diffractive PDFs including jets



Now zG is well constrained at large z

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

If we write:
$zG = zG \, . \, (1-z)^{\alpha}$
then, $\delta\alpha < 0.2$

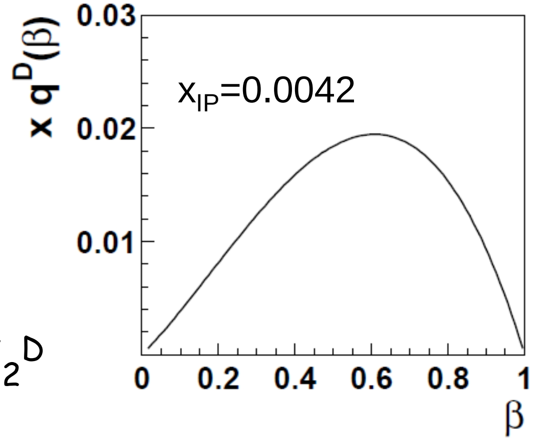
Note: Links between dPDFs and dipole models

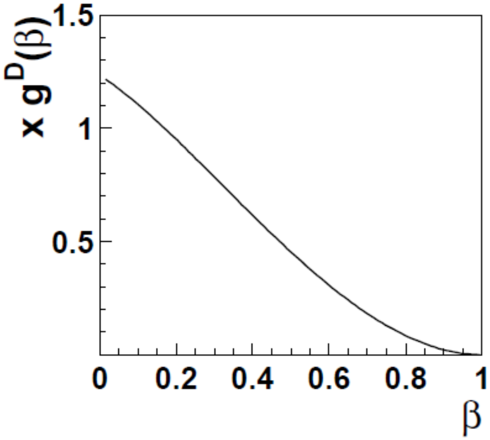
The dipole approach gives a simple and efficient parameterisation of F2D data
Quantitatively almost as good as diffractive PDFs (see Nucl.Phys.B781:1-31,2007)

It contains naturally the 'Regge' factorisation observed in data and assumed in QCD fits

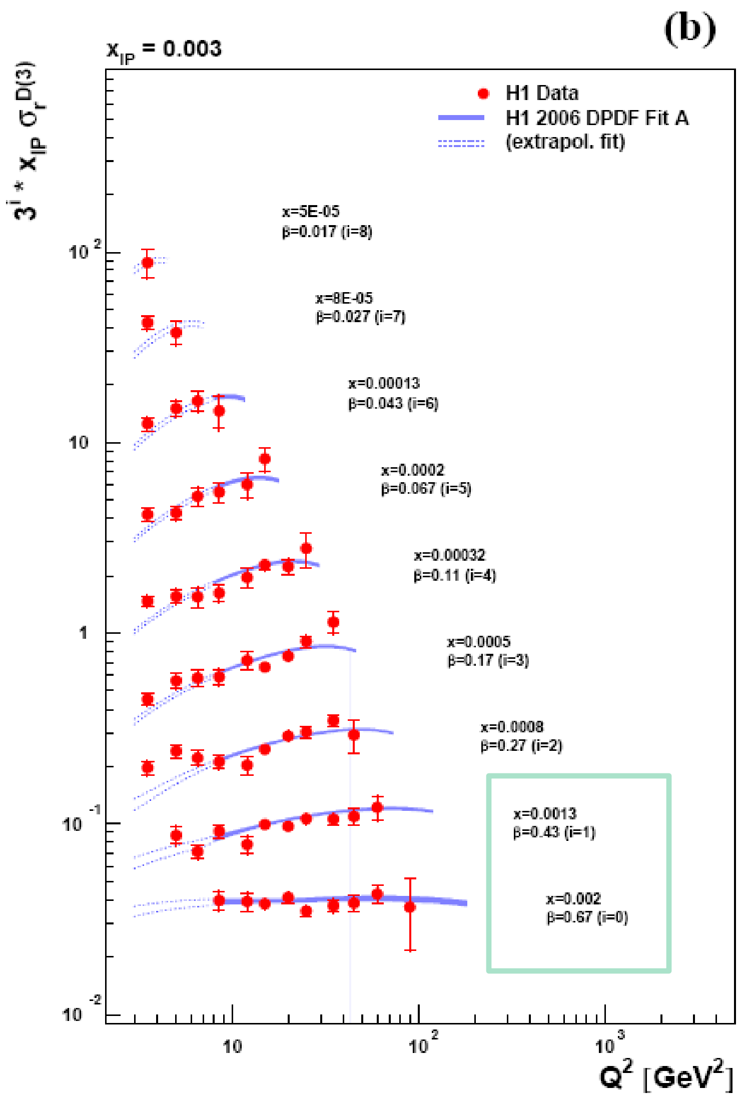
This is not yet a work completed but the dipole approach could give the inputs for diffractive PDFs (initial conditions @ Q_0^2)… if we follow our discussion:
Dipole approach => $x_{IP}F_2^D \sim Qs^2(x_{IP}) \Sigma e_q^2 \beta q(\beta;Q^2)$

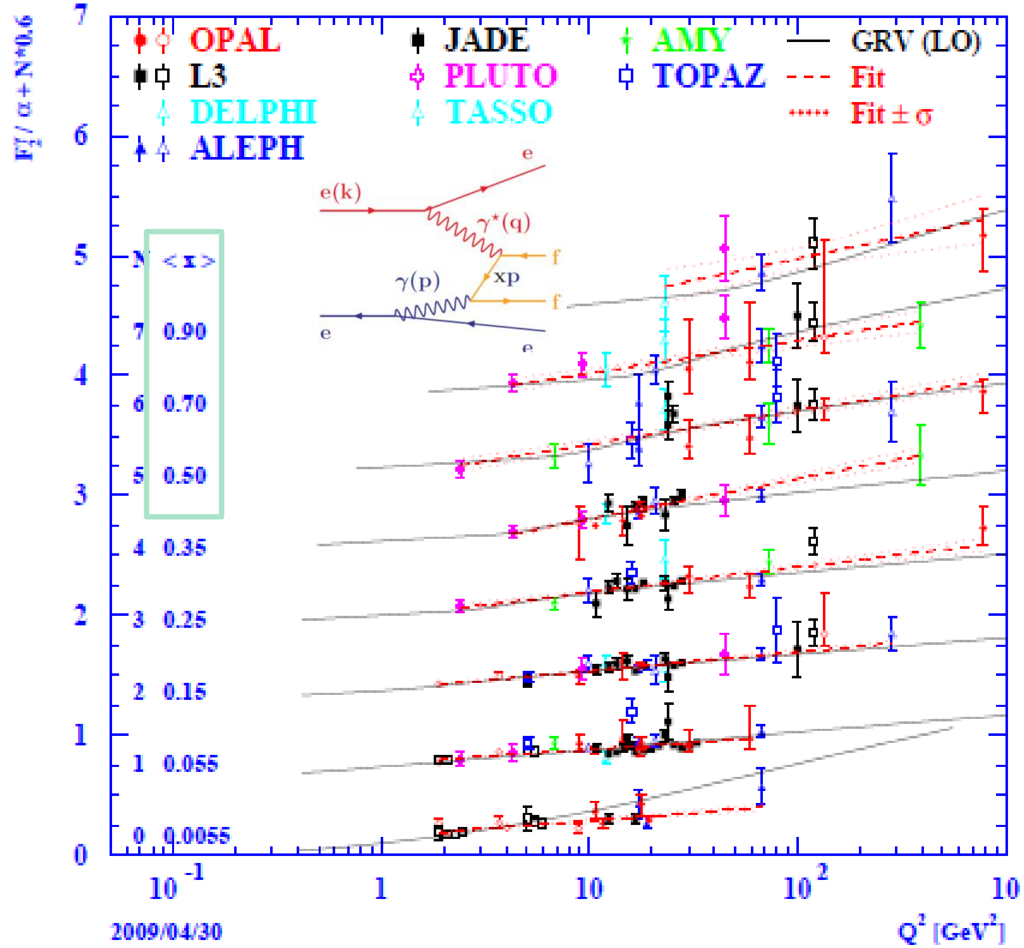
Example from
Golec-Biernat et al. 2001
« Equivalent dPDFs » derived
from the dipole formulae for F_2^D





An interesting parallel: observation



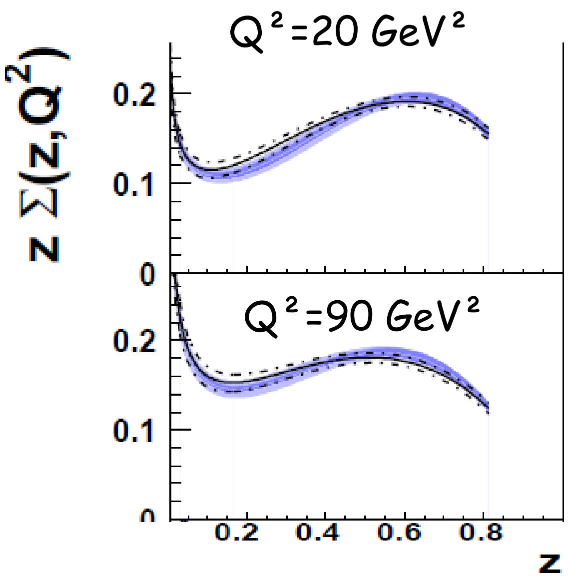


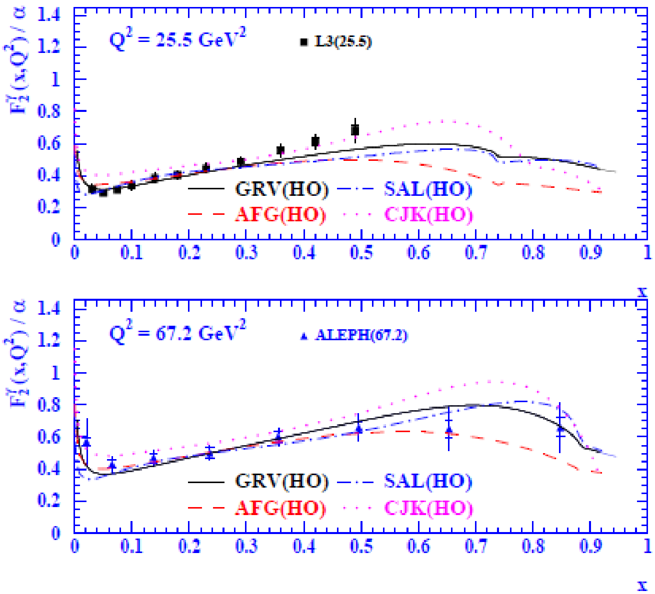
Photon structure function F_2^{γ}

Positive scaling violation till largest x values // $F_2^D(\beta,Q^2)$

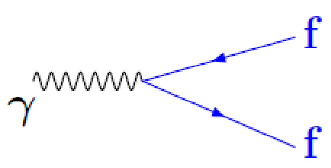
An interesting parallel: consequence (1)

The shapes in x //β for F_2^γ// F_2^D are also compatible…

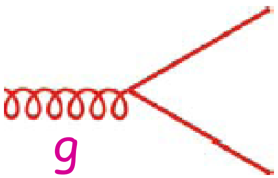




In case of F2γ, the explanation of the x shape is well known: The loss of quarks at large x due to gluon radiation (QCD) is over-compensated by the creation of quarks at large x to the point like coupling of γ to quarks.

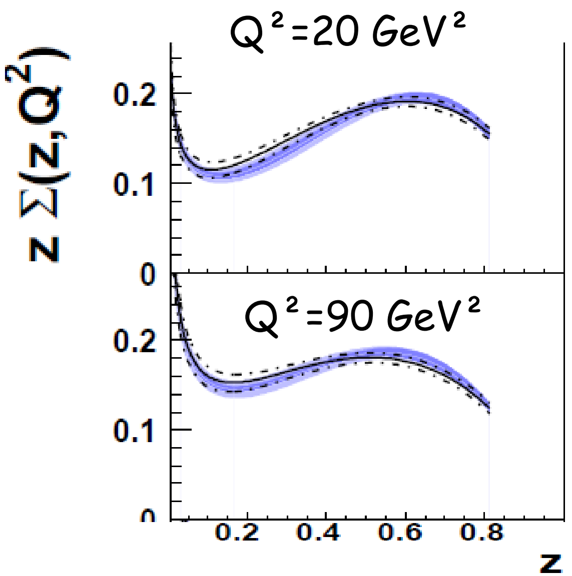


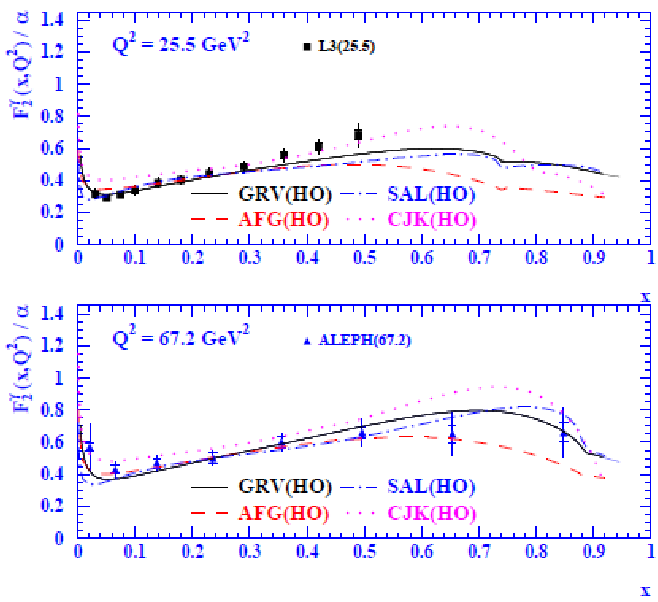
Something similar happens for F2D, via the coupling of q to q. But it works only if the gluon density is large at large x at the initial scale… During the evolution, it is driven to lower and lower x but the mechanism is visible till <x> is not too small…



An interesting parallel: consequence (2)

The shapes in x //β for F_2^{γ}// F_2^D are also compatible…

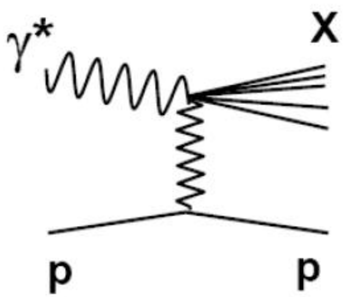


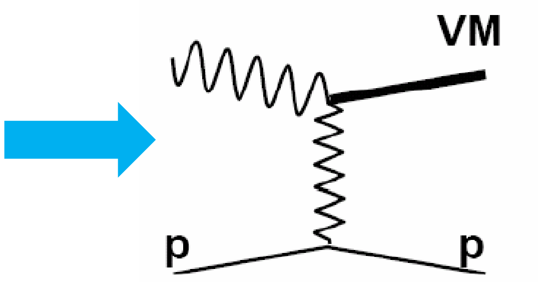


This is not unreasonnable to conclude from the previous 2 slides that the size and shape of diffractive PDFs are more universal that it seems to be at first look.

They are related to a very fundamental mechanism a parton level AND this mechanism is most probably also valid at larger energies (w.r.t. HERA results): this is a default assumption that we can already confront to some data… (next slide)

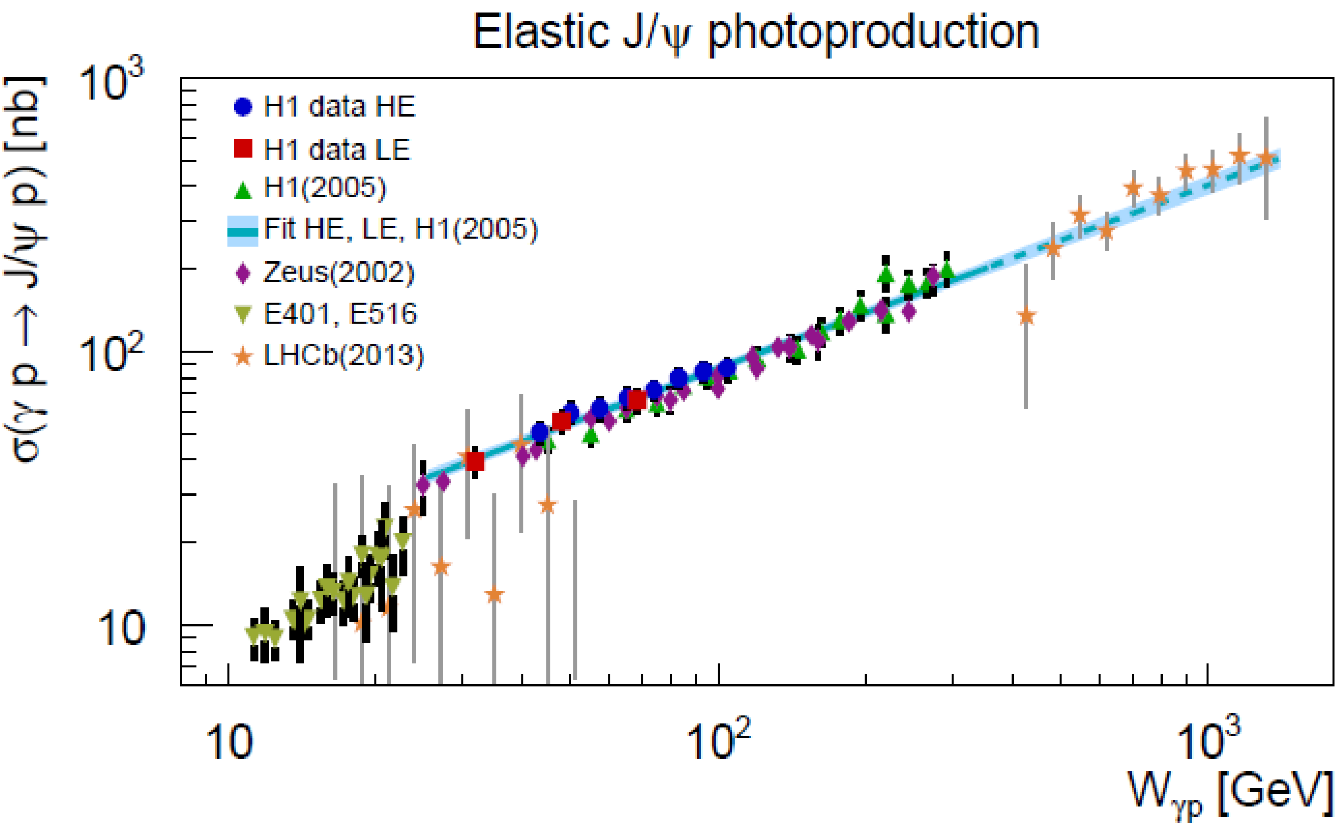
Compatibility of HERA results on DIFF with LHCb (at much larger energies)





The generic mechanism for diffraction can be tested for VM production

This is a huge field of interest at HERA…

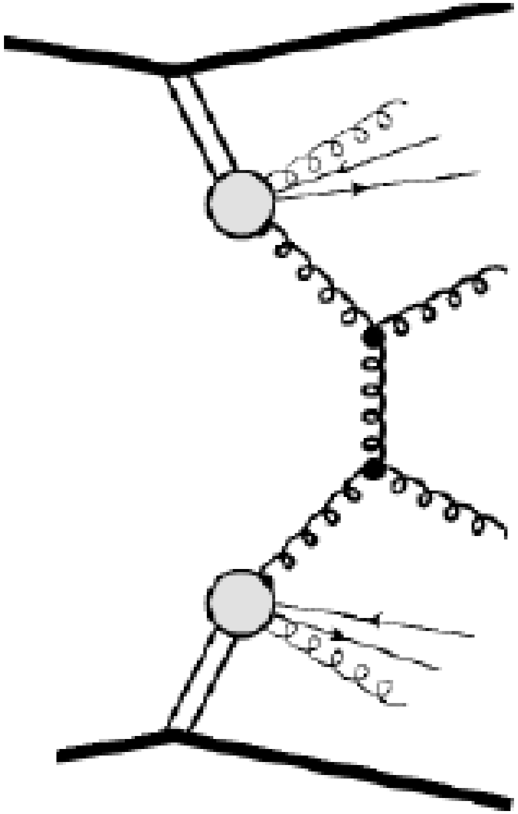


We can compare directly for the same process xs at HERA w.r.t. LHCb at larger energies;

The compatibility is nicely shown on the figure;

A reasonnable assumption is that « *in general diffractive results from HERA can be extended at the LHC* »

DPE in pp scattering (LHC)



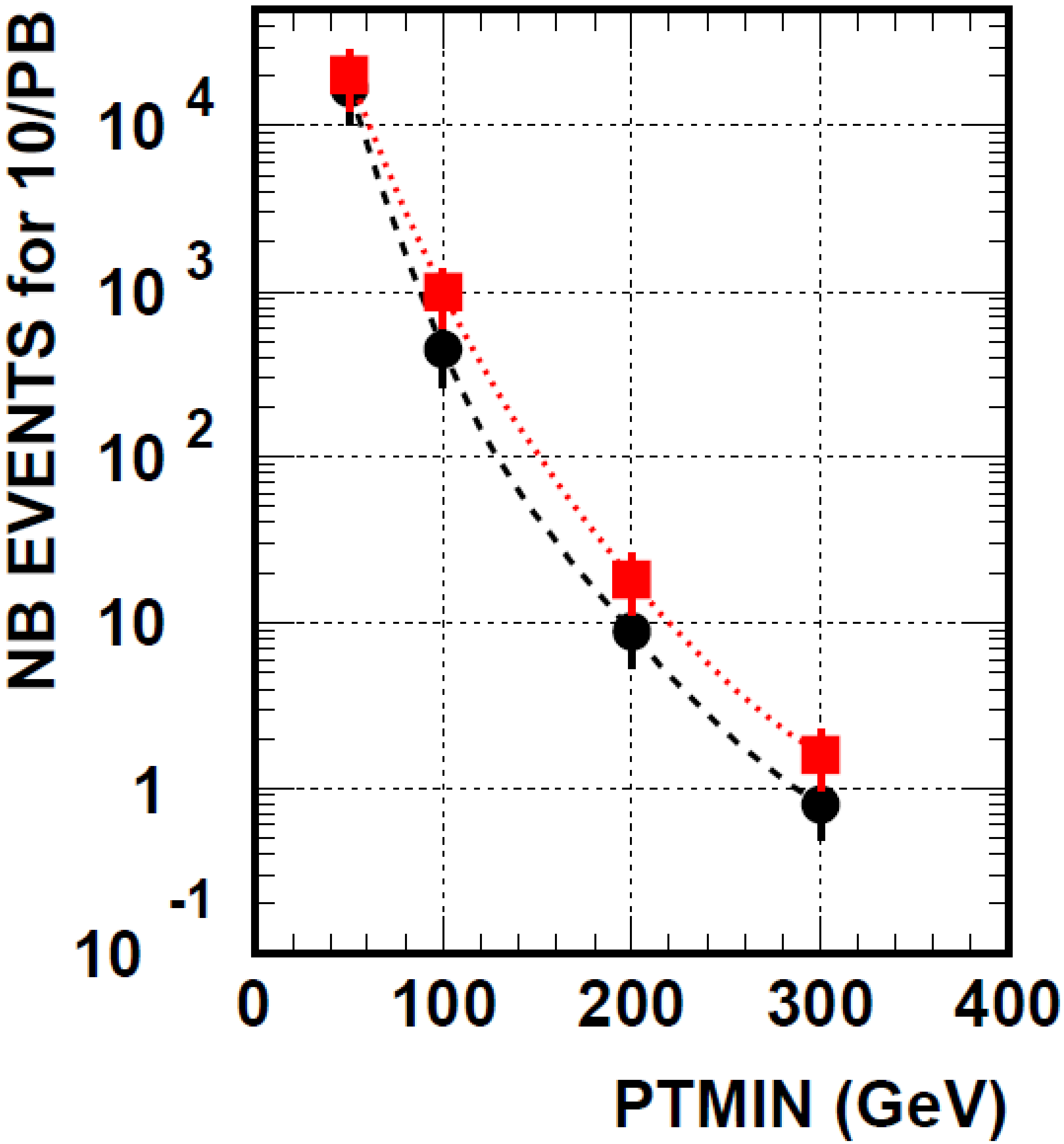
DPE dijets production:

Such a process exhibits *a priori* a sensitivity to the diffractive gluon density;

The idea is thus to check if we can gain a better understanding of zG at large z; *as we know that from HERA diffractive dijets have already been an important input*

Note:
We consider a survival gap probability of 0.03 (fixed)
See other talks of this session…

DPE in pp scattering: for L=10 pb^{-1} in $\xi := x_{IP} \in [0.015;0.2]$



Here, we have:
(i) subtracted the IR content
(ii) propagated normalisation uncertainties
(except on the survival gap probability:=0.03)

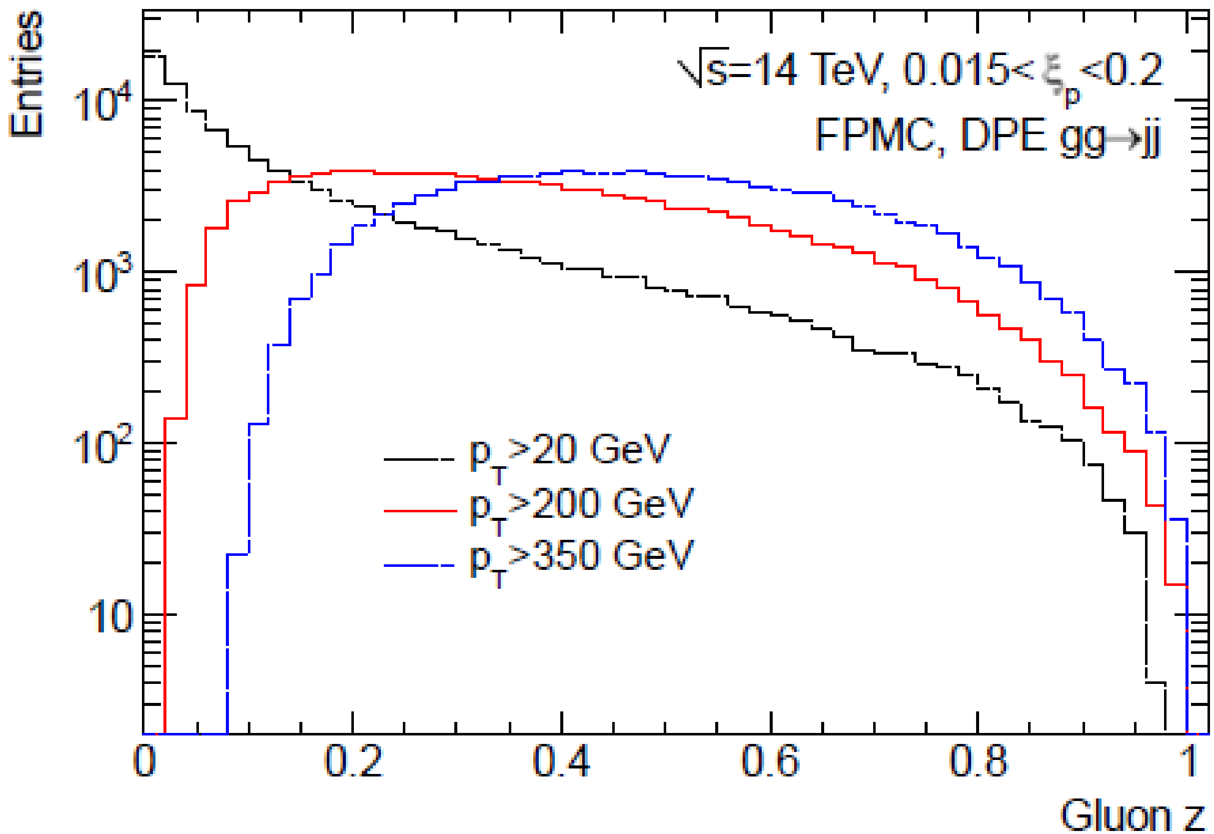
(iii) Consider the 2 zG solutions: with a bump or not at large z *(see slides 17,18,19)*

Conclusion: in the kin domain where we see a potential sensitivity to zG shape at large z, we are left with only a few events, and large normalisation uncertainties…

DPE in pp scattering (LHC): comments

At low PTMIN, the dominant sensitivity is at low z gluon
=> no sizable difference between zG hypothesis
The sensitivity (to large z) is relevant at large PTMIN>200 GeV but in this case, we are left with only a few events (picobarn cross section)!
Also the normalisation uncertainties damp off the sensitivity

=> conclusion: difficult to claim a discrimination between zG hypothesis



Conclusions

After 15 years of data taking and analysis, we get diffractive PDFs from HERA data in addition to precise results on IP and IR flux; **Uncertainties on diffractive PDFs: for quarks: <5%, for gluons: <10%**

Similar functions exist for other physics cases => their shapes are not unique and rooted in deep physics mechanism…

There are already many results at large $W_{\gamma p}$, which tends to show that HERA results on the dynamics of (hard) diffraction can be propagated to larger energies (LHCb)…

DPE dijets at LHC could be interesting to study… to understand the global normalisation of inclusive diffractive processes at the LHC (at low PTMIN); constraining the shape of diffractive zG at large z seems to be difficult.