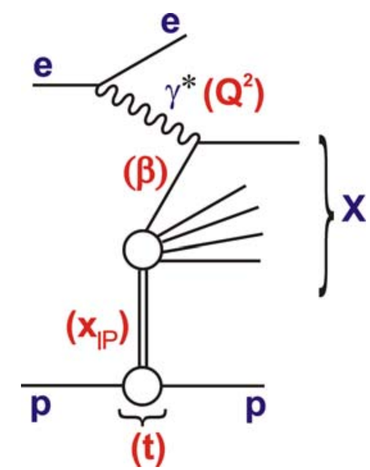
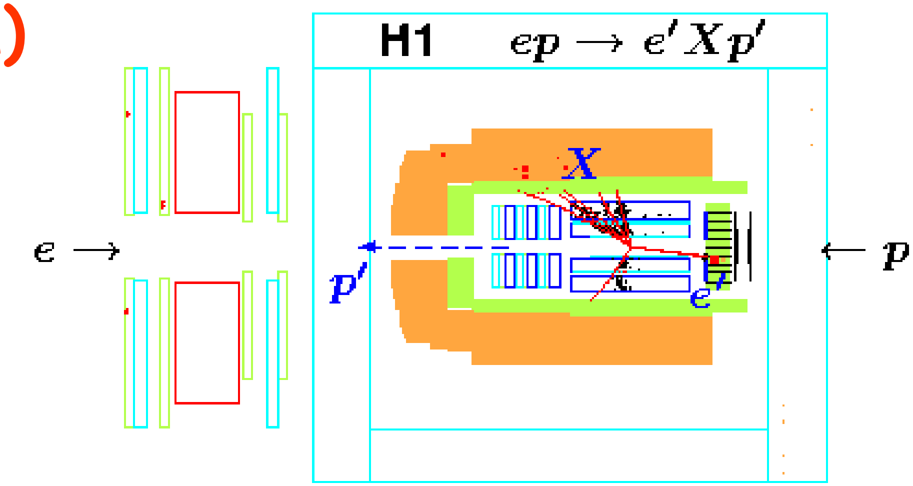
Inclusive Diffraction & Factorisation Tests at HERA

… the quasi-elastic scattering of the virtual photon in the proton colour field …

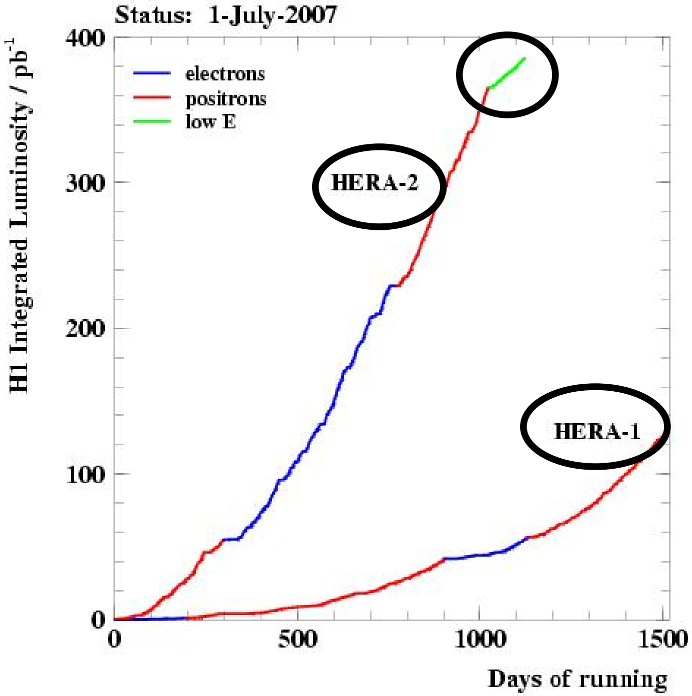


Presented by P.Newman
(University of Birmingham)
on behalf of the H1 & ZEUS Collaborations



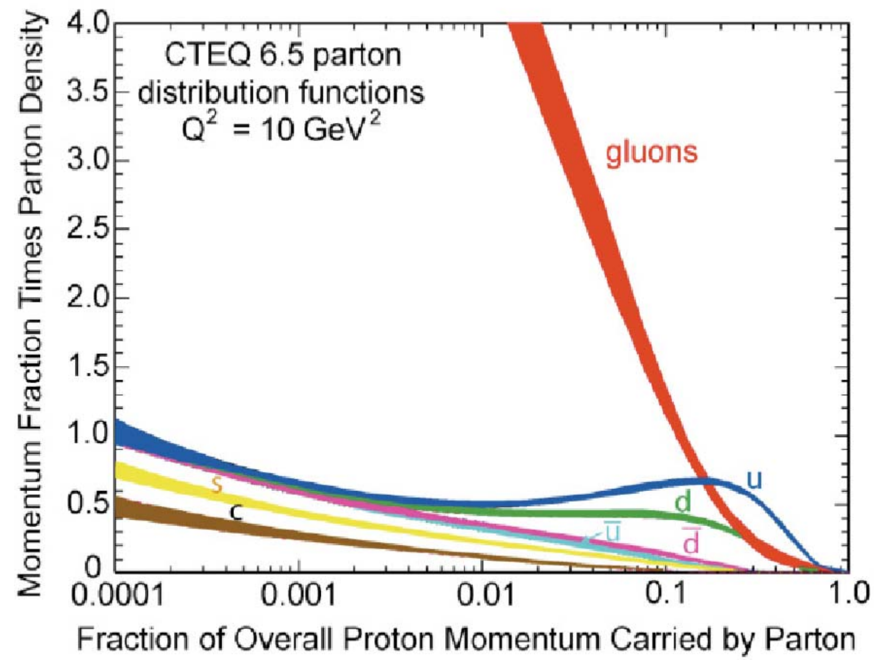
PHOTON '09, DESY
14 May 2009

HERA & Diffraction



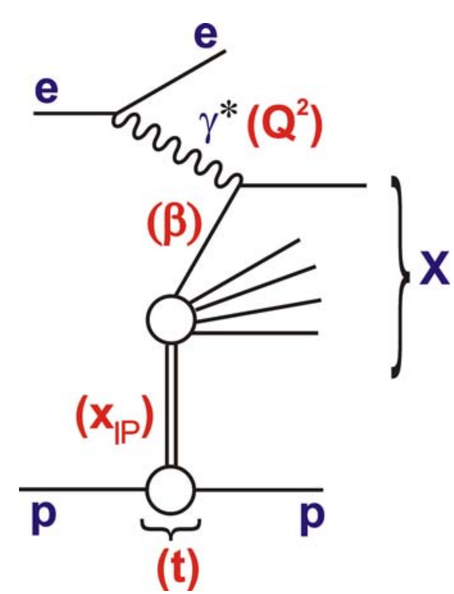
- **Several new (April '09) results with improved precision:**
  - → Final ZEUS HERA-I diffractive DIS data
  - → ZEUS QCD fit → Diffractive Parton Densities
  - → First H1 HERA-II proton (& neutron) tagged data
  - → First H1 F_L^D measurement (E_p = 575, 460 GeV data)

Low x Physics & Diffraction



- Low x physics, as revealed by HERA, is the physics of very large gluon densities…
- Associated with a large (> 10%) diffractive content

… enormous progress in understanding diffraction in terms of partons
… testing new QCD factorisation ideas
… related to non-linear evolution (low x sat^n)
… related (gap survival) to underlying event
… related to confinement …
… see also S. Kananov on vector mesons



Diffractive DIS Kinematics

Standard DIS variables …

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

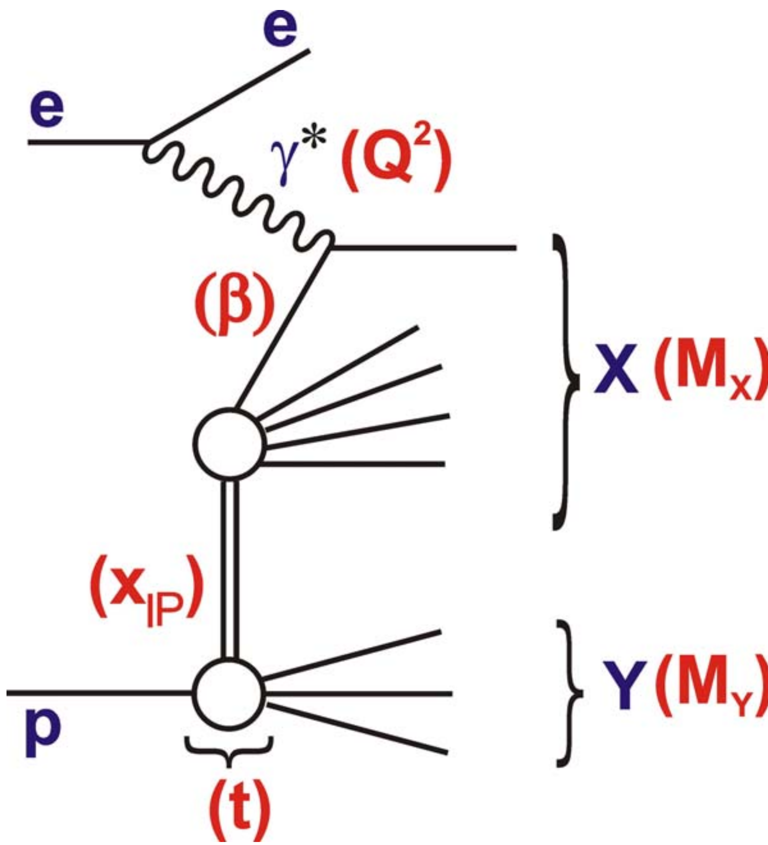
Additional variables for diffraction …

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)

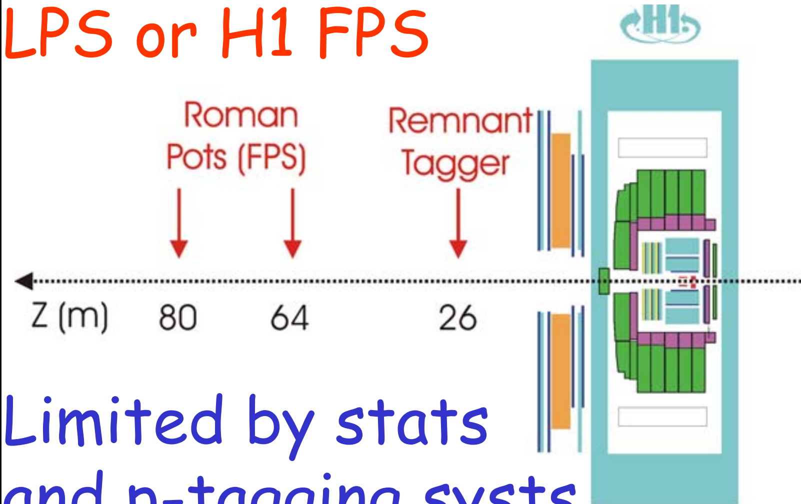
Most generally ep→eXY …



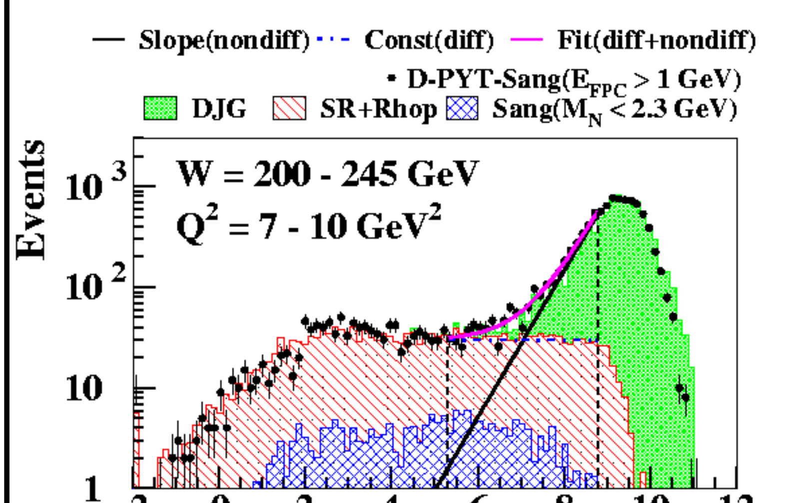
In most cases here, Y=p, (small admixture of low mass excitations)

Signatures and Selection Methods

Scattered proton in ZEUS LPS or H1 FPS

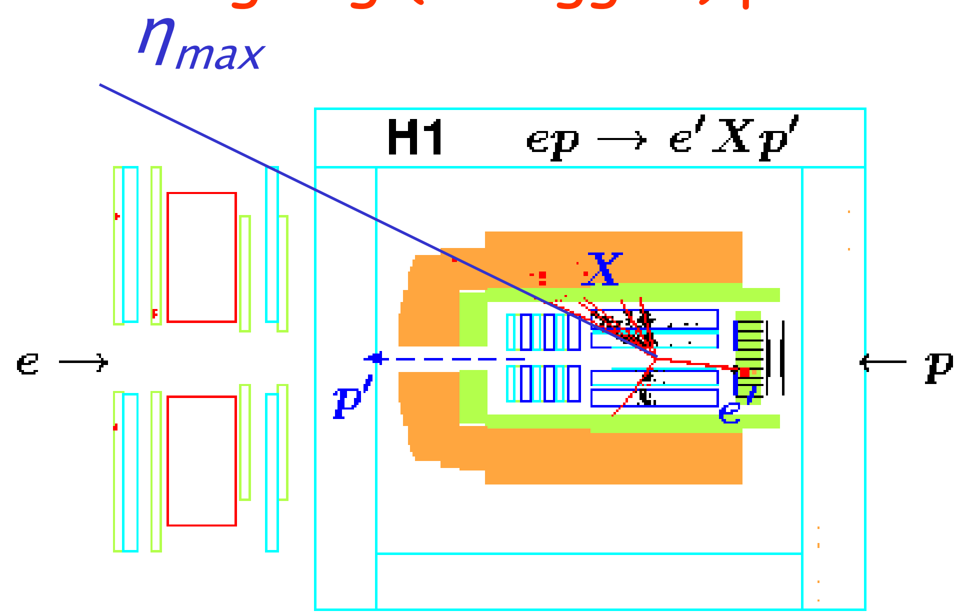


Limited by stats and p-tagging systs



Decompose inclusive $\ln(M_x)$ distn

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

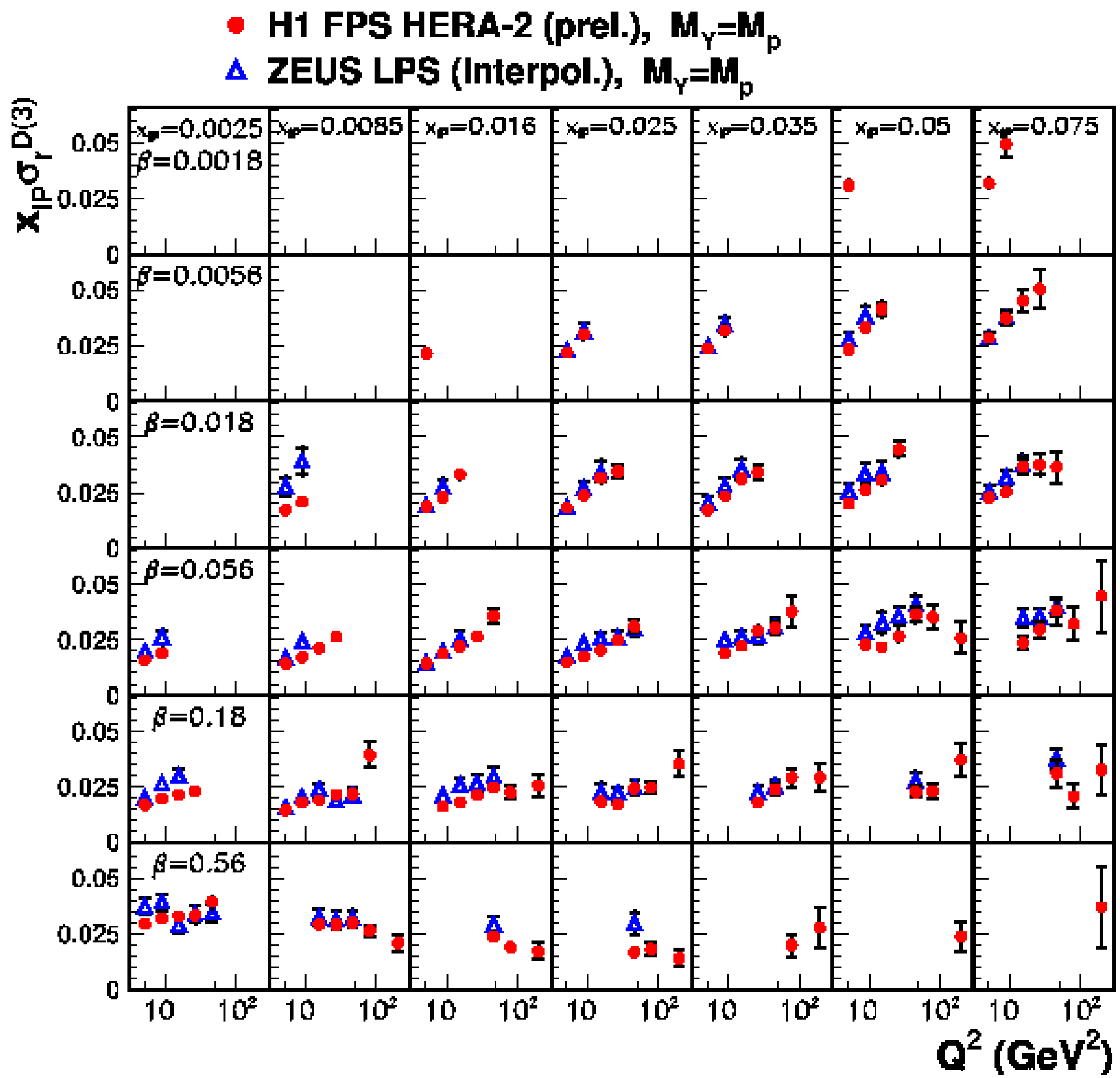


Limited by p-diss systs

<u>**The methods have very different systematics!**</u>

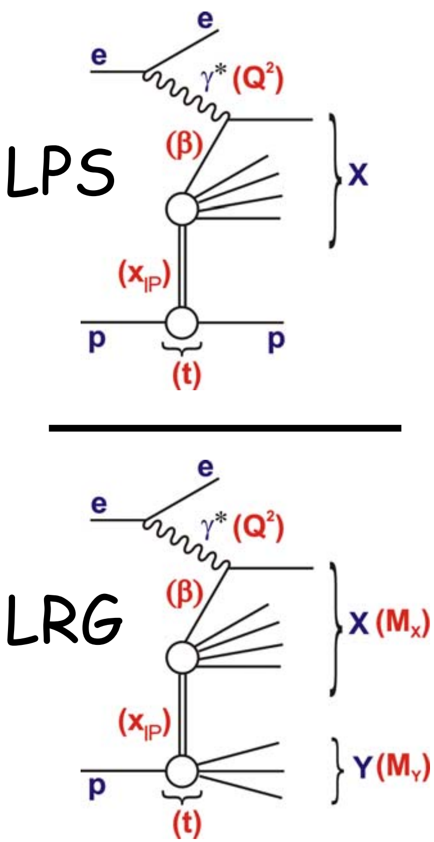
ZEUS v H1 Proton-tagged Data

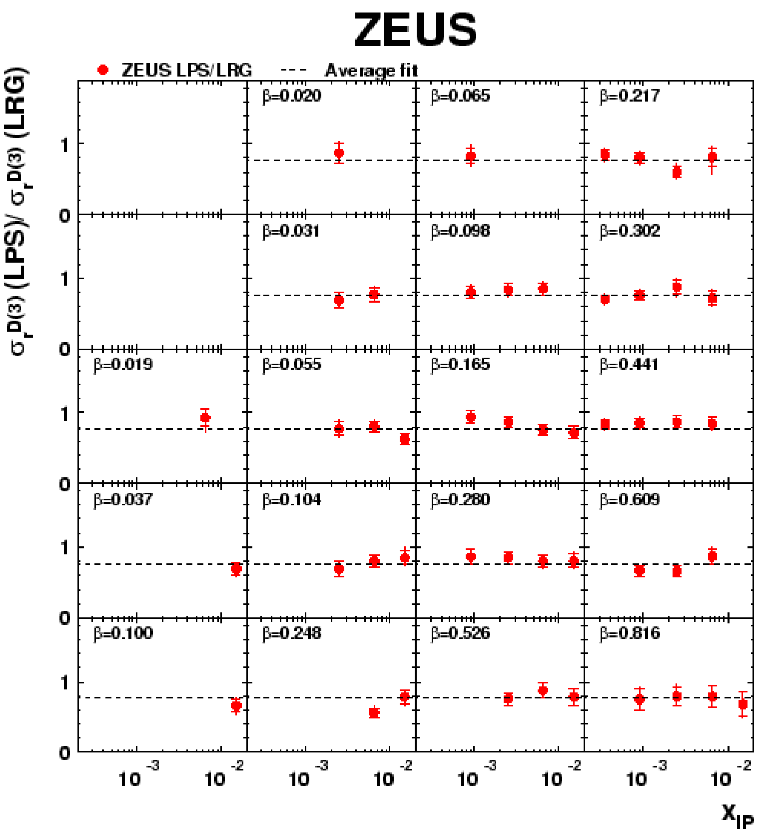
… presented as $\sigma_r^{D(3)}(\beta, Q^2, x_{IP}) = F_2^{D(3)} - \frac{y^2}{Y_+} F_L^{D(3)} \sim F_2^{D(3)}$

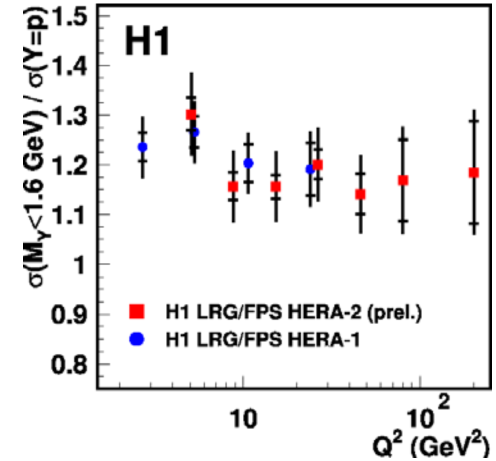


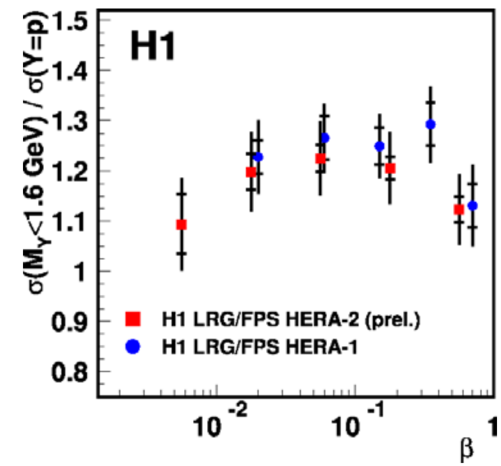
- All available data used by both collaborations
- H1 HERA-II data (156 pb^{-1}) improve stats by factor of 20 and reach higher Q^2
- Fair agreement (combined norm uncertainty ~10%)

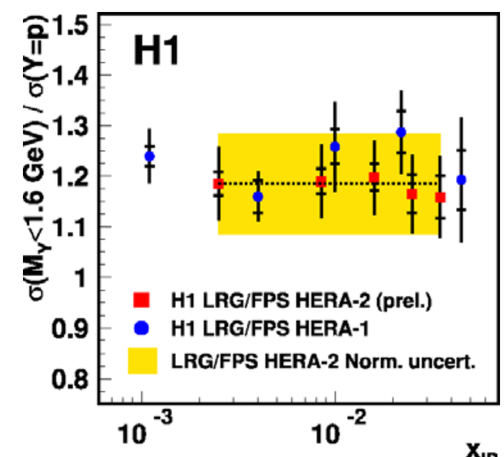
Comparisons between Methods







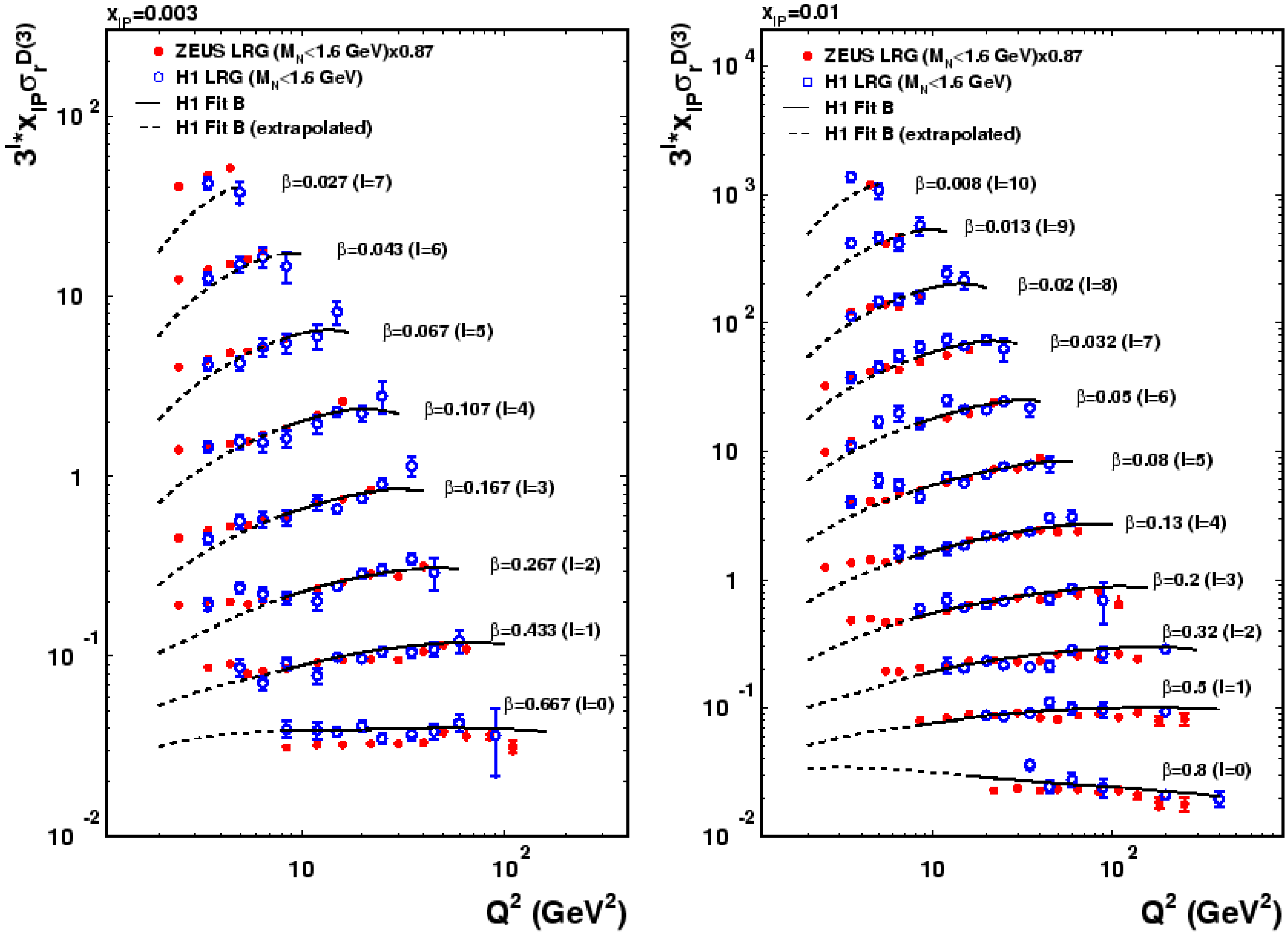




- LRG selections contain typically 20% p diss
- No significant dependence on any variable
- Similar compatibility with Mx method

… **well controlled, precise measurements**

Normalised LRG Comparison H1 v ZEUS



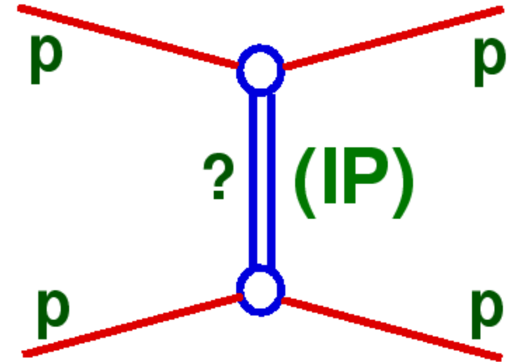
Final ZEUS LRG data ($62\ pb^{-1}$) reach new level of statistical precision

… Overall 13% H1-ZEUS difference within normalis^n errors

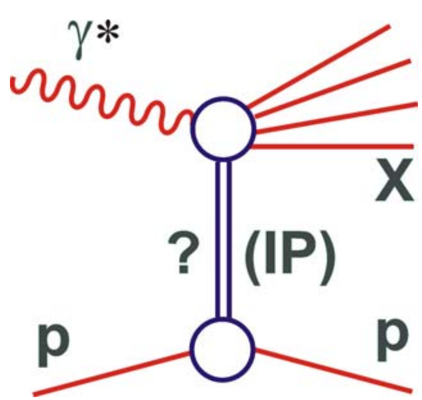
… Good shape agreement in most of phase space (high, low β?)

(x_{IP},t) Dependences: Exchanging `Nothing'

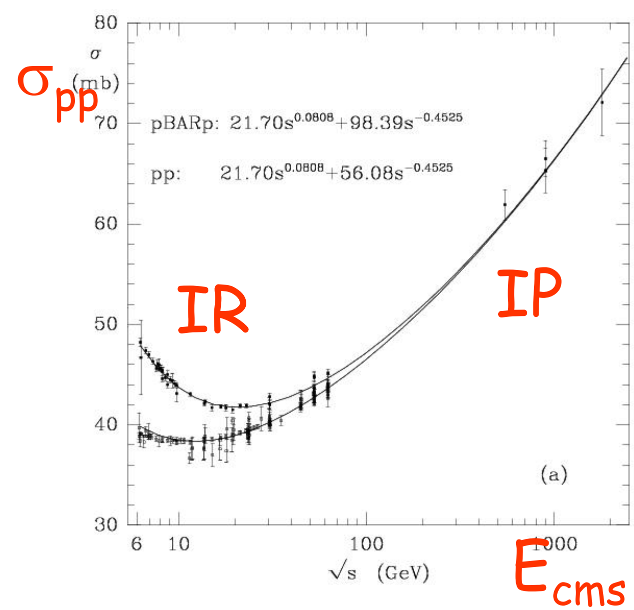
- Diffractive DIS reminiscent of (soft) diffractive hadronic scattering
- **Vacuum exchange `pomeron' (IP)** introduced in Regge theory context



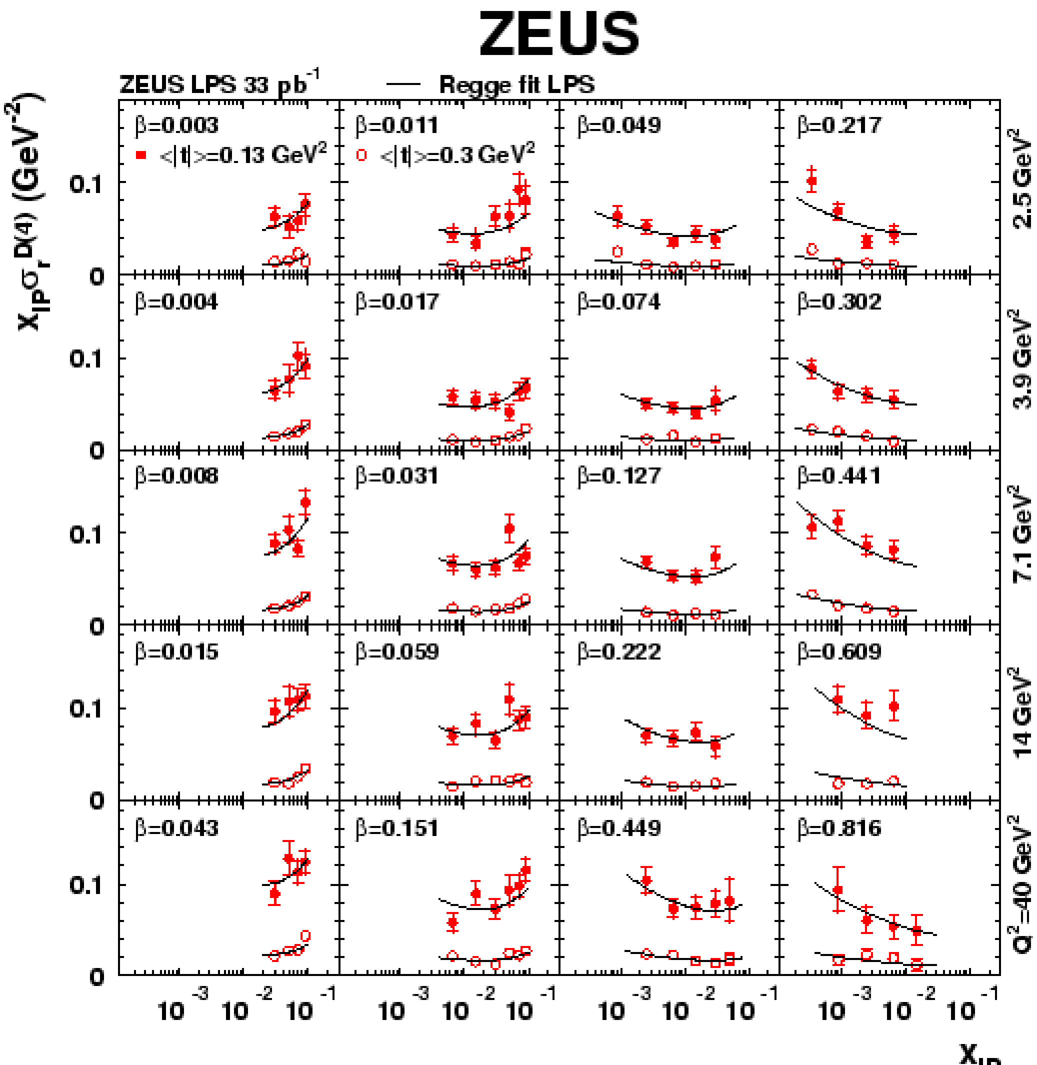
- In $\gamma^*p \rightarrow XY$, virtual photon resolves structure of exchange … dominant contribution looks similar to soft IP



- Often discussed loosely in this language … can extract effective IP trajectory: $\alpha_{IP}(0) + \alpha'_{IP} t$



x_{IP} Dependence (ZEUS Leading Proton Data)



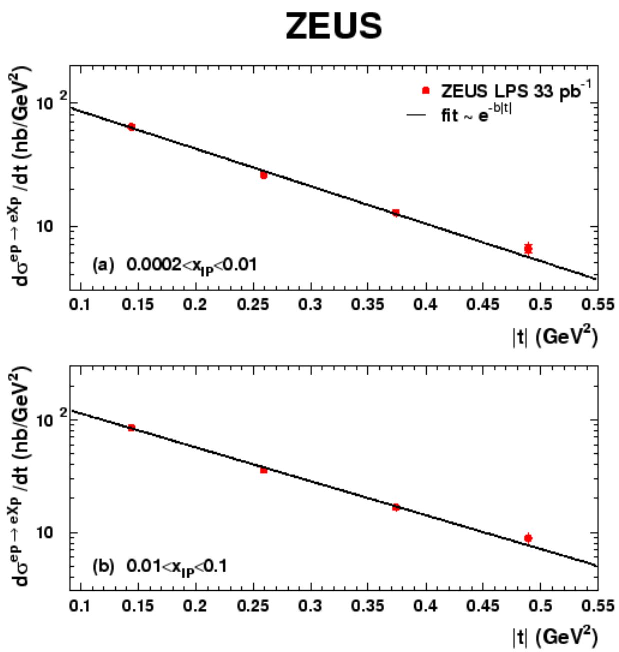
- 1st diffractive structure function measurement at multiple t values
- Low x_{IP} / high β … falling (IP-like) behaviour
- High x_{IP} / low β … rising (IR-like) behaviour
- Compatible x_{IP} dependence in each t bin

ZEUS $\alpha_{IP}(0) = 1.11 \pm 0.02(\text{stat.}) \pm 0.02(\text{syst.}) \pm 0.02(\text{model})$

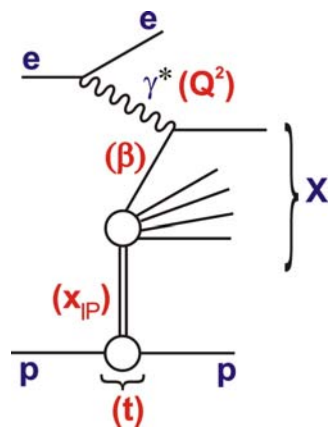
c.f. H1 $\alpha_{IP}(0) = 1.12 \pm 0.01(\text{exp.}) \pm 0.02(\text{model})$

Consistent with soft IP intercept

t Dependence from LPS / FPS



Fitting to e^{bt} yields $b = 6\text{-}7\ \mathrm{GeV}^{-2}$, independently of β, Q^2

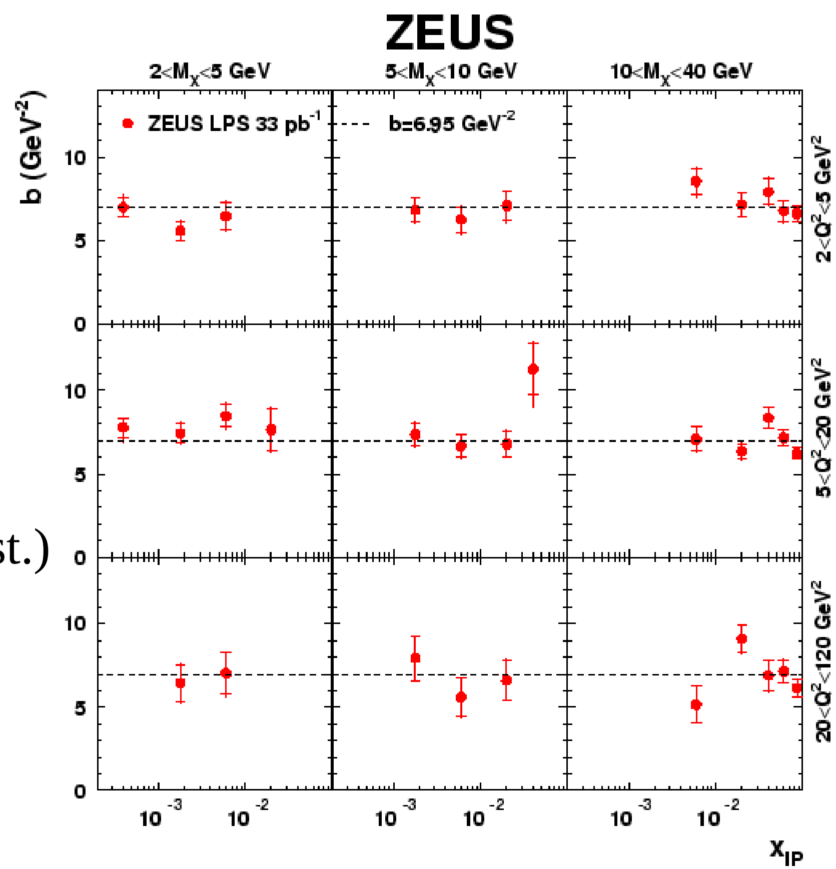


Also very little x_{IP} dependence:

ZEUS LPS:

$$\alpha'_{IP} = -0.01 \pm 0.06(\text{stat.}) \pm 0.06(\text{syst.})$$

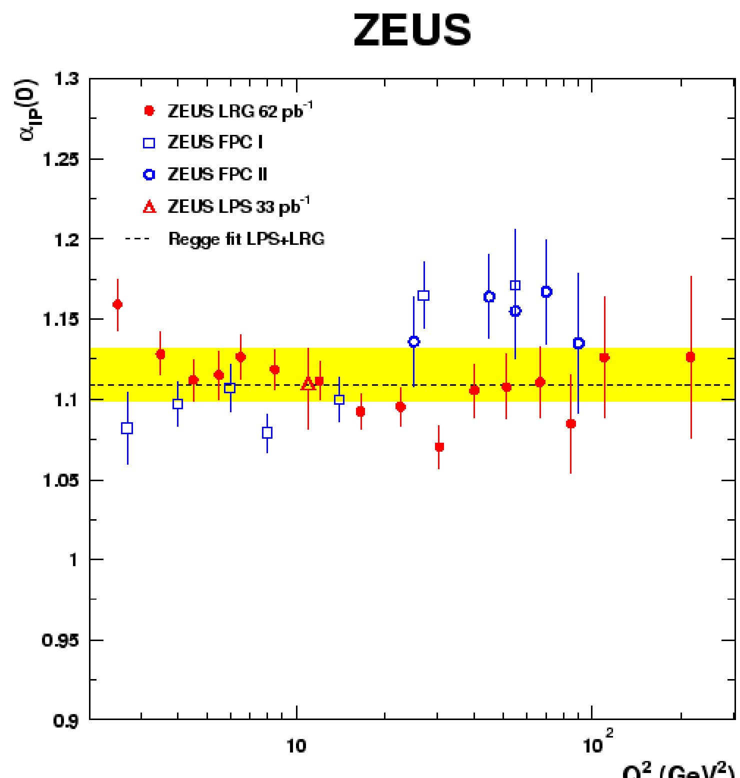
c.f. H1: $\alpha'_{IP} = 0.06 \pm 0.13$



… not soft IP → different multi IP / absorption effects…?

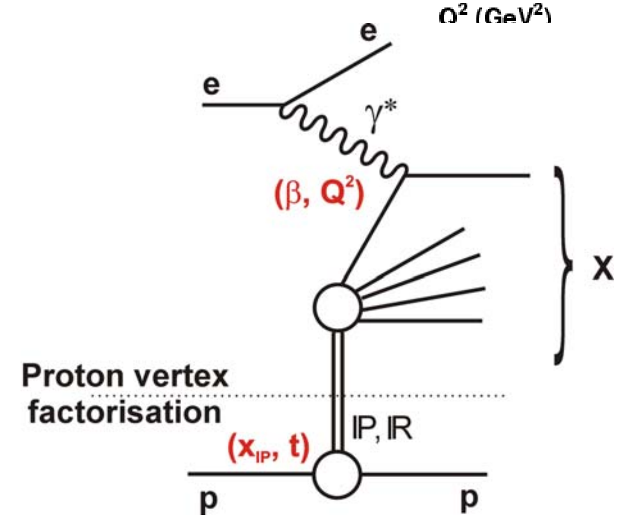
Proton Vertex Factorisation & Partons

• Variables describing proton vertex (x_{IP}, t) factorise from those at photon vertex (β, Q^2) to good approximation …



• β,Q^2 dependence interpreted in terms of **Diffractive Parton Densities (DPDFs)**, measuring partonic structure of exchange

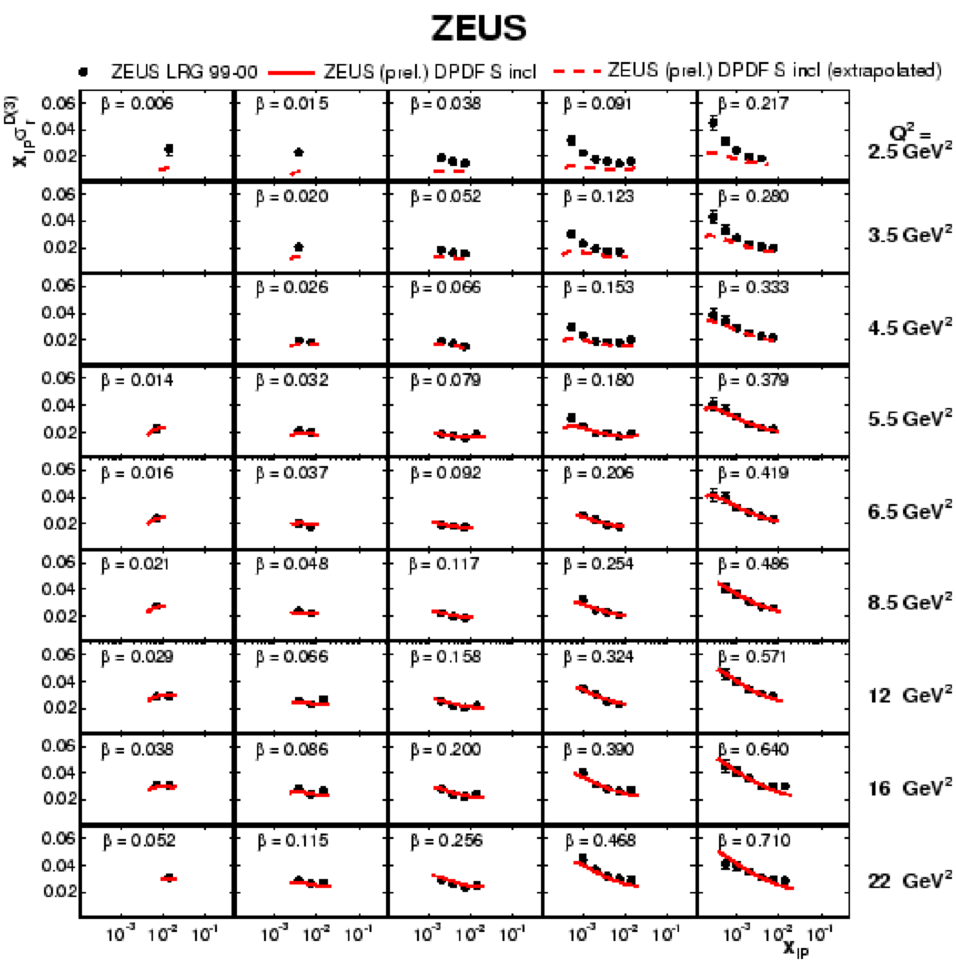
• Parameterise and fit β dependences of DPDFs. For Q^2 evolution, use NLO DGLAP equations with massive charm (H1) or GM VFNS (ZEUS)

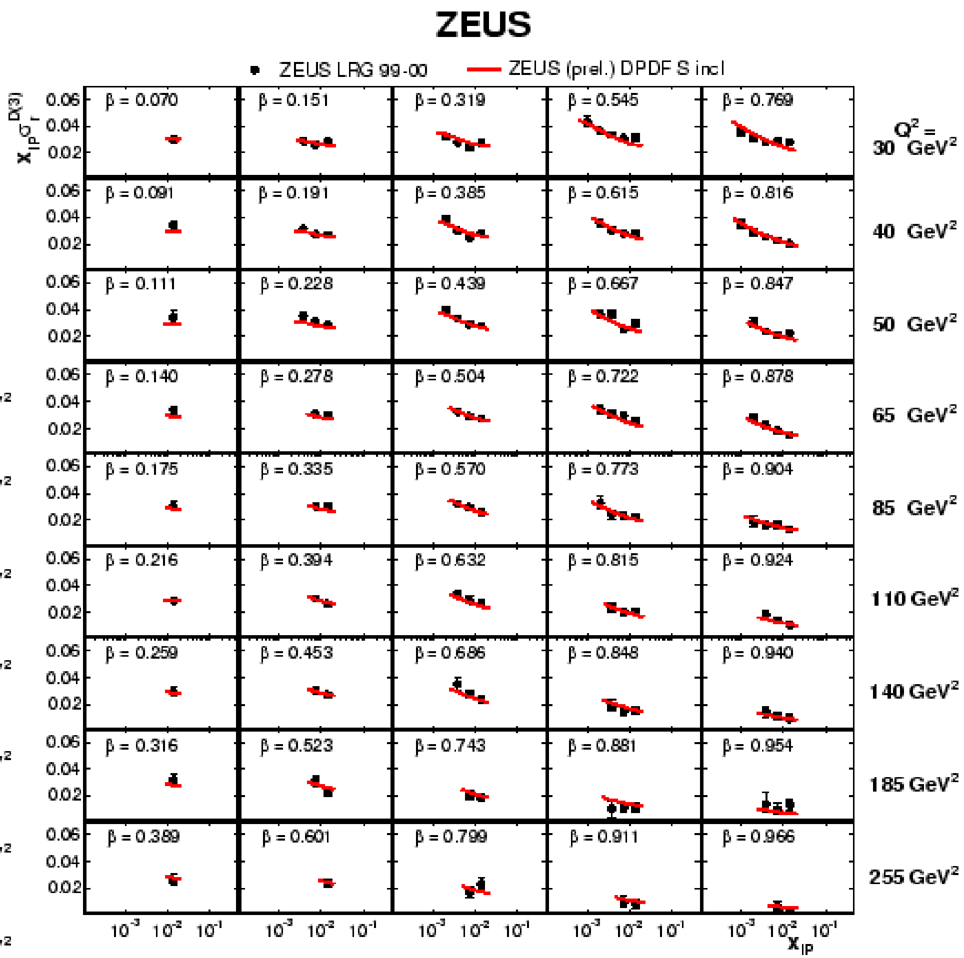


• Exclude data with low M_X (higher twists) or low Q^2 (NLO insufficient?)

QCD Fits to New ZEUS LRG Data

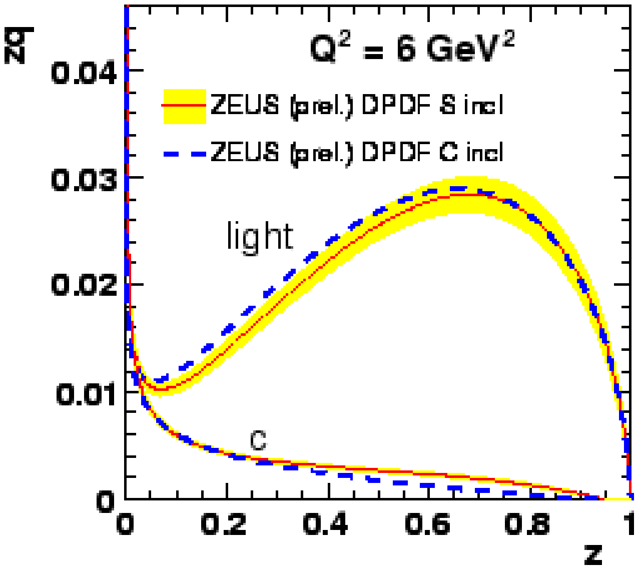
- At fixed x_{IP}, F_2^D measures quarks, dF_2^D / $d\ln Q^2$ gluons

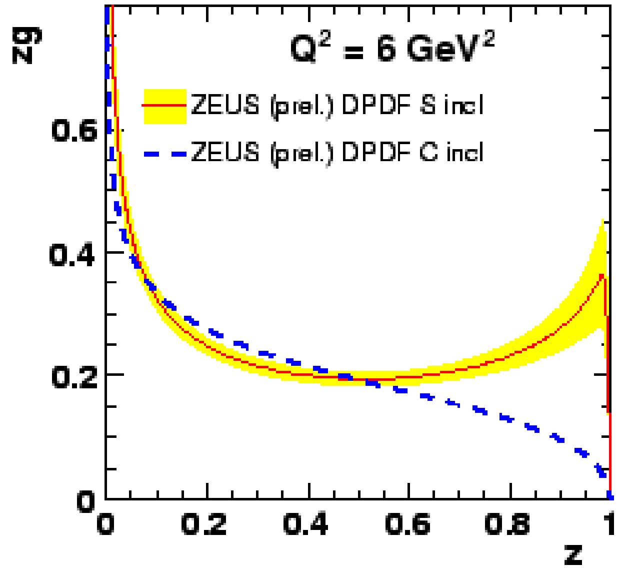




Good description of all data with (fitted) $Q^2 > 5$ GeV^2

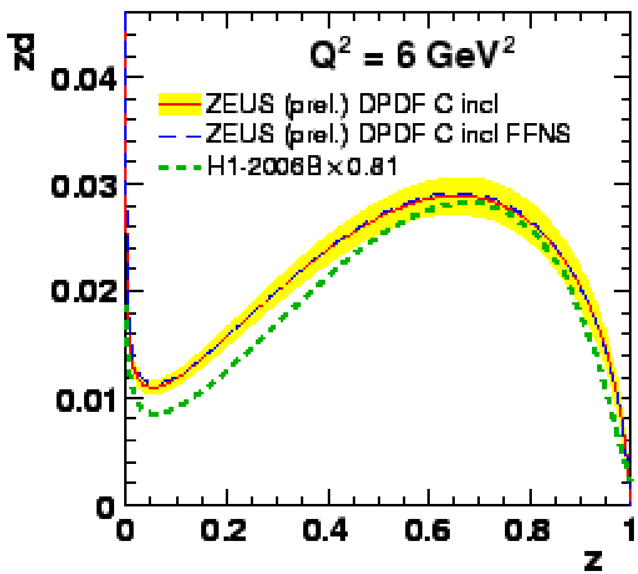
New ZEUS DPDFs from Inclusive Data

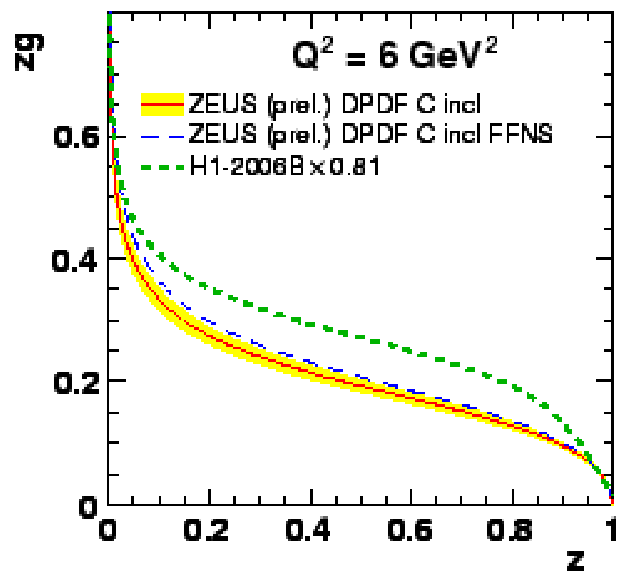




- z = incoming momentum fraction of parton (= β for quarks, > β for gluons)

- Quarks & low z gluons to few %, poor high z gluon constraint.

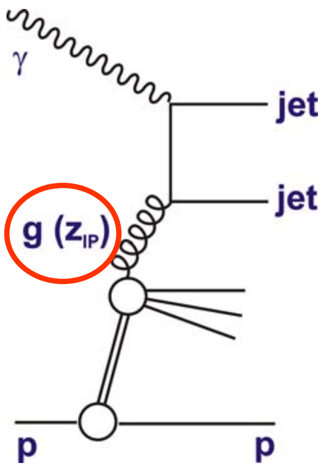


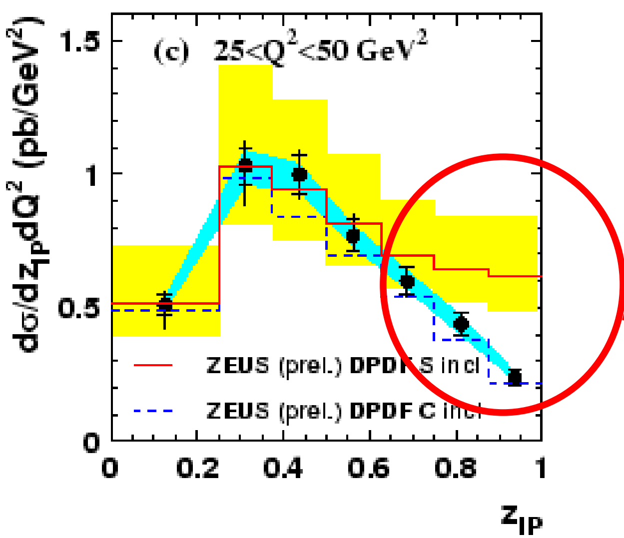


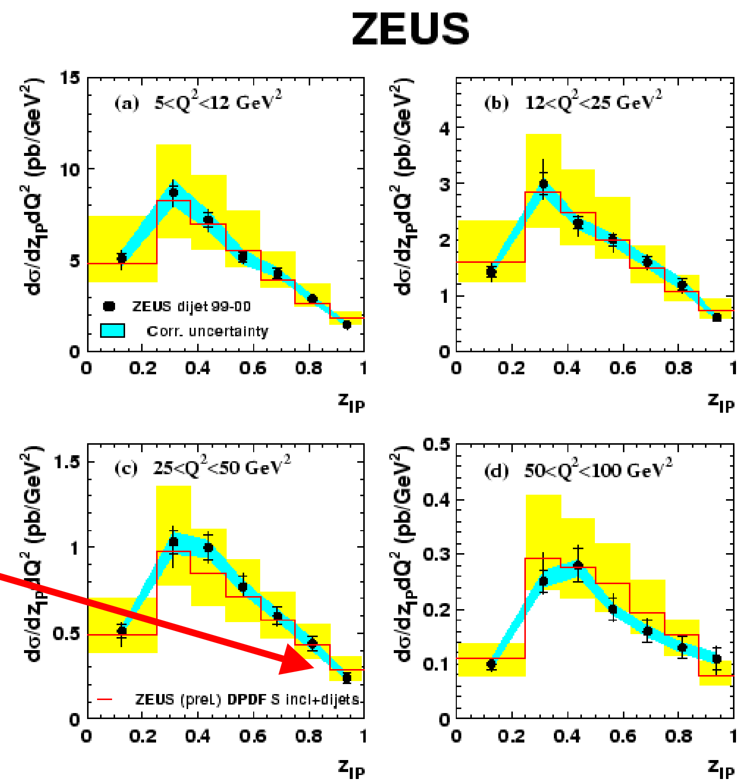
- Gluon dominates

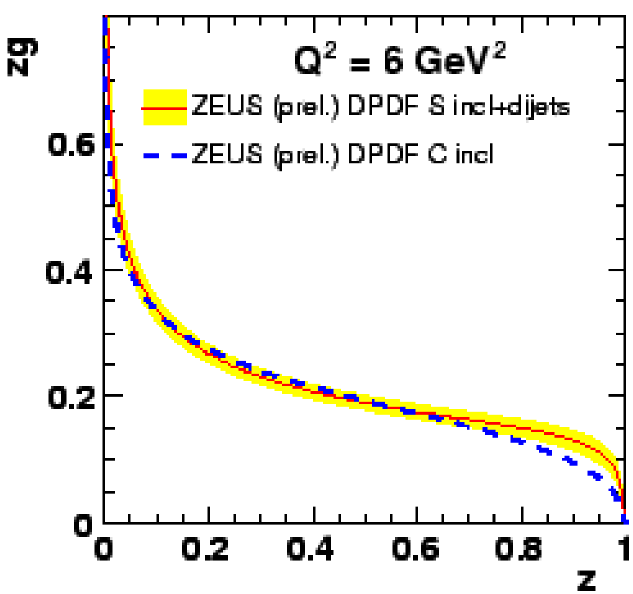
- Reasonable agreement with H1 up to large uncertainty on high z gluon

Dijets in DIS & high z gluons

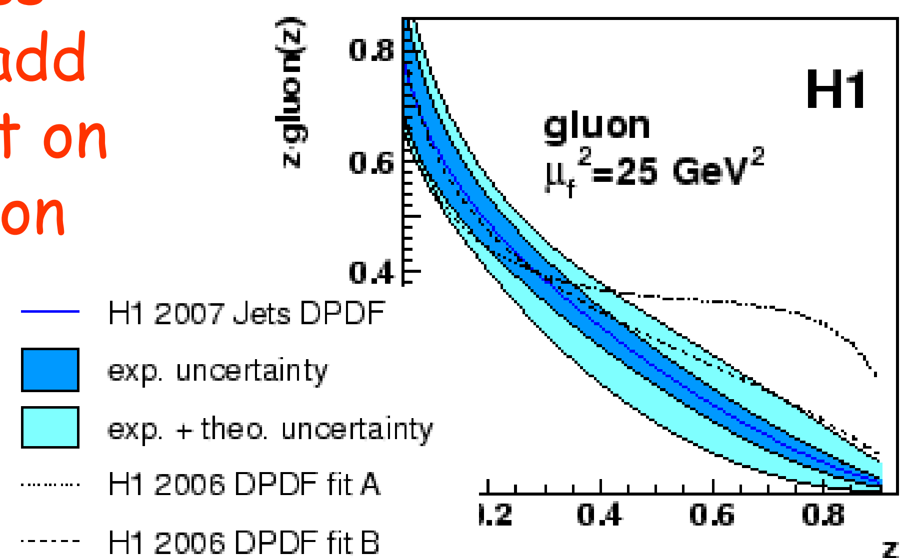






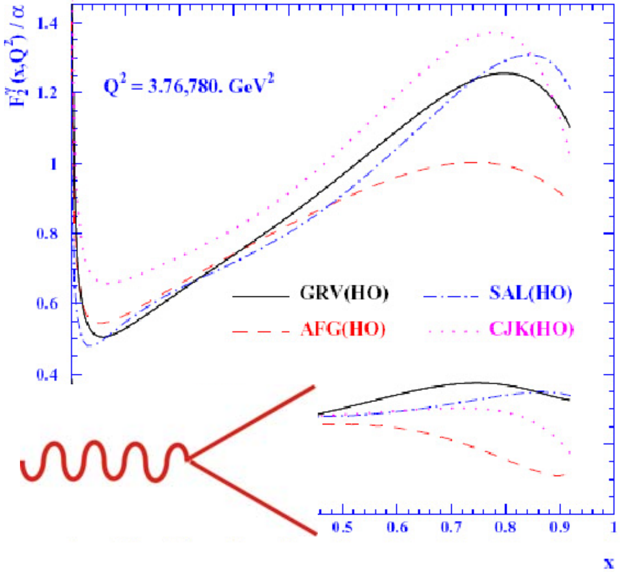


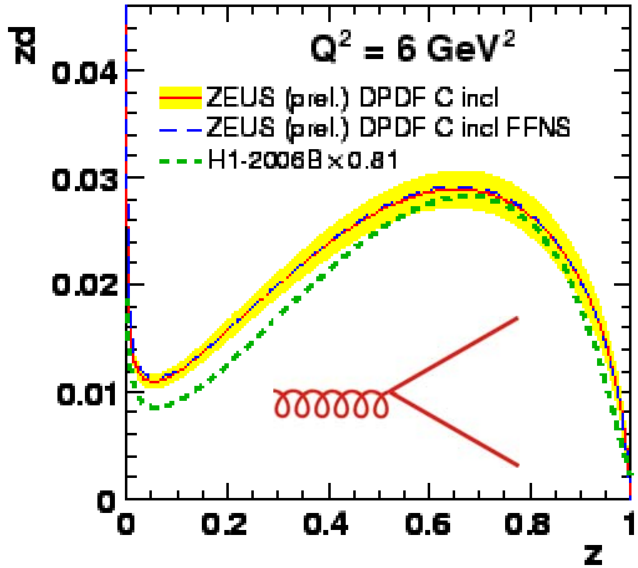
... jet cross sections add constraint on high z gluon in fits...



Some Features of the DPDFs

[R Nissius]

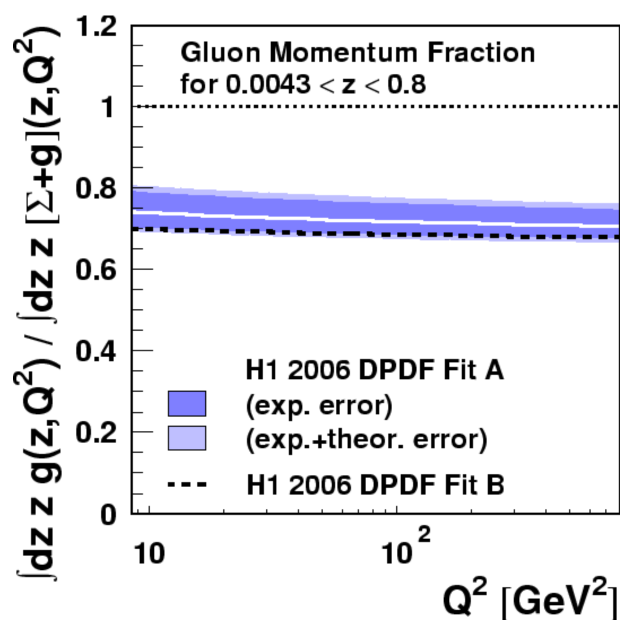




- **High z** behaviour of quarks looks similar to photon structure function

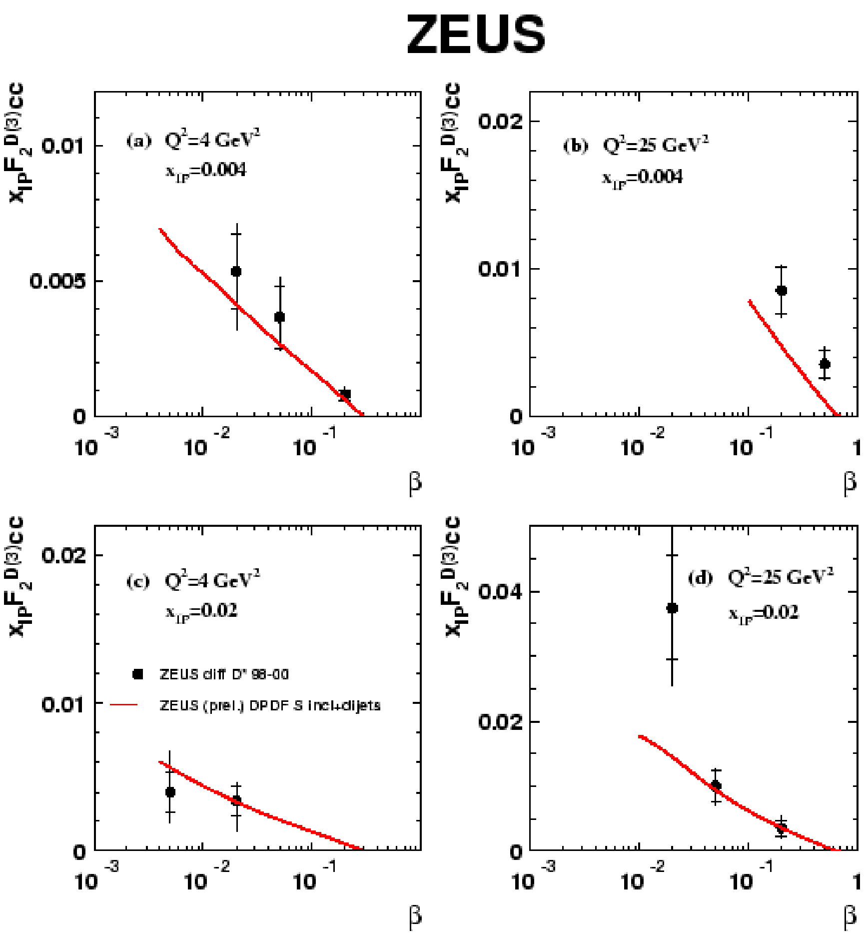
- **Overall ratio of quarks to gluons** is about 70:30, similar to inclusive PDFs at low x

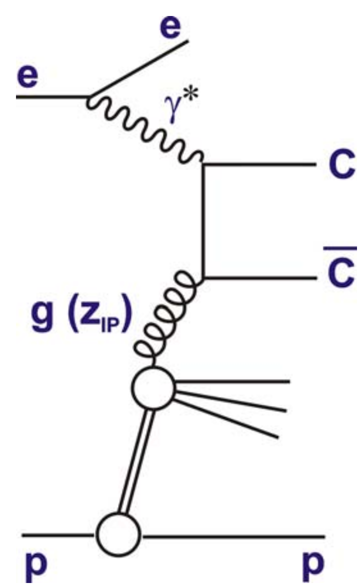
- Diffractive and (low x) inclusive DIS give complementary windows of the QCD vacuum consequences of an underlying gluon exchange?

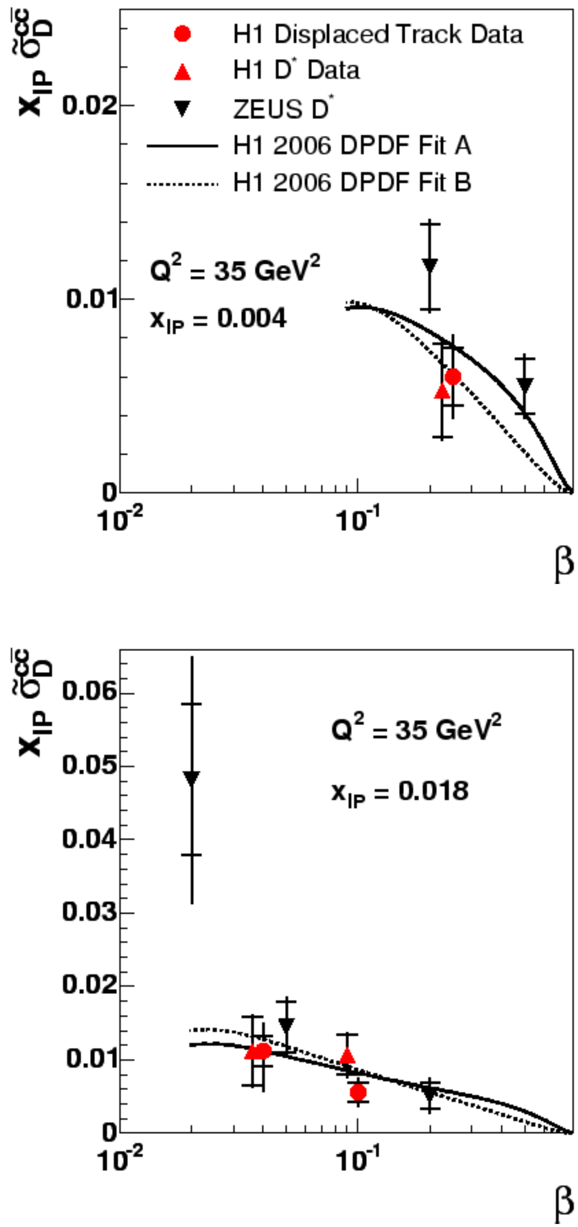


Describing other diffractive DIS processes

As well as inclusive x-sections and jets in DIS, DPDFs describe diffractive charged current, charm, particle flow & spectra …







First F_L^D Measurement

A new test of the diffractive gluon density in DIS …

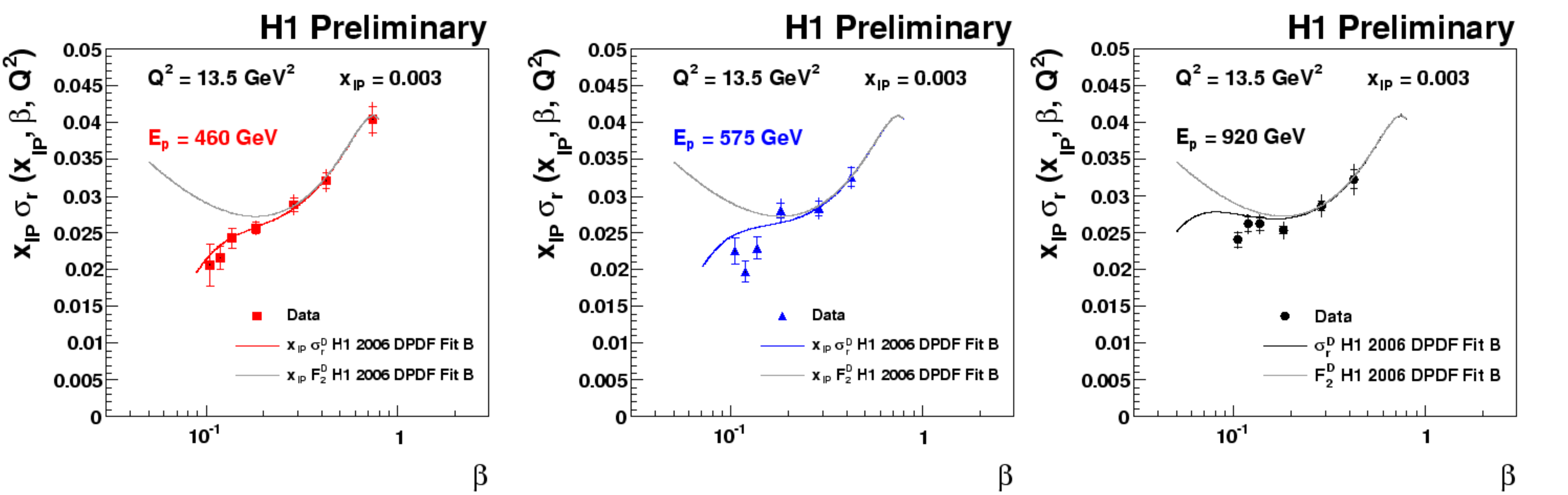
$$\sigma_r^{D(3)}(\beta, Q^2, x_{IP}) = F_2^{D(3)} - \frac{y^2}{Y_+} F_L^{D(3)} \qquad F_L^{D(3)} \sim \alpha_S \, xg(x) + \delta q(x)$$

… sensitivity to F_L^D @ highest y (lowest β)

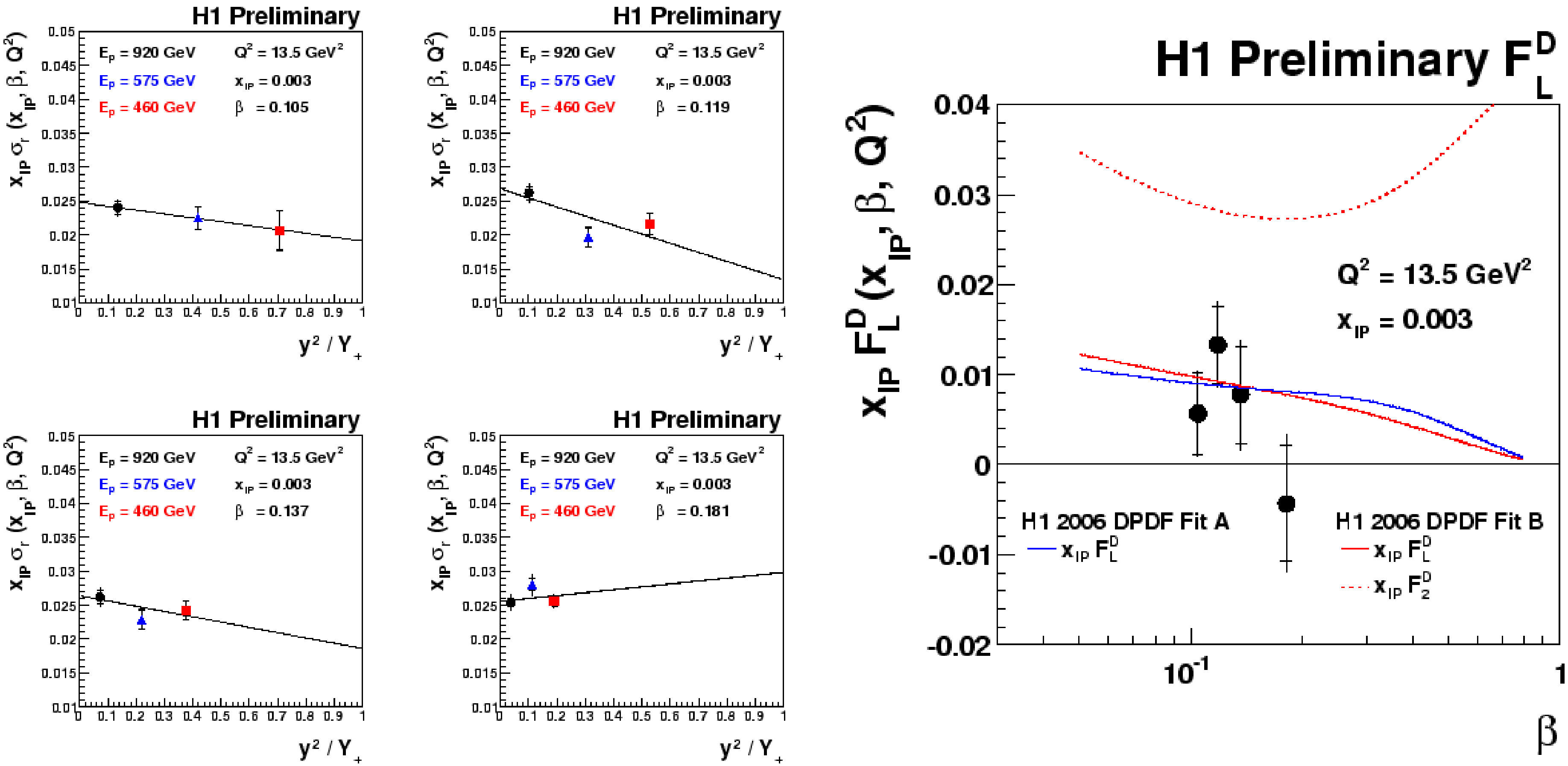
… vary beam energy to change y at fixed β, x_{IP}, Q^2

… 21 pb^{-1} @ Ep = 920 GeV, 11pb^{-1} @ 575 GeV, 6pb^{-1} @ 460 GeV

… y < 0.9 → scattered electron energy cut → 3.4 GeV!



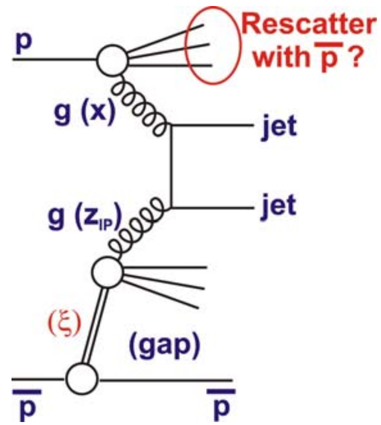
First F_L^D Measurement

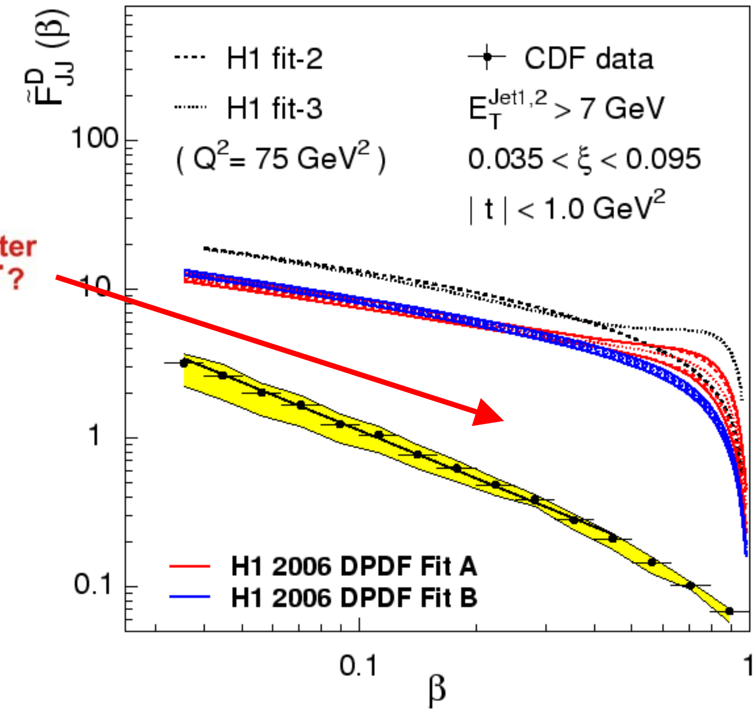


- F_L^D measured ~ 3σ from zero
- Compatible with all predictions based on DGLAP fits to F_2^D
- F_L^D / F_2^D (~ g / q) compatible with F_L / F_2 @ low x?
- $R^D = \sigma_L/\sigma_T = F_L^D / (F_2^D - F_L^D)$ ~ 0.5 with big errors

.. meanwhile in pp(bar) ...

Tevatron effective DPDFs from dijets show strong factor^{n} breaking compared with HERA DPDFs ... `gap survival' factor $S^2 \sim 0.1$



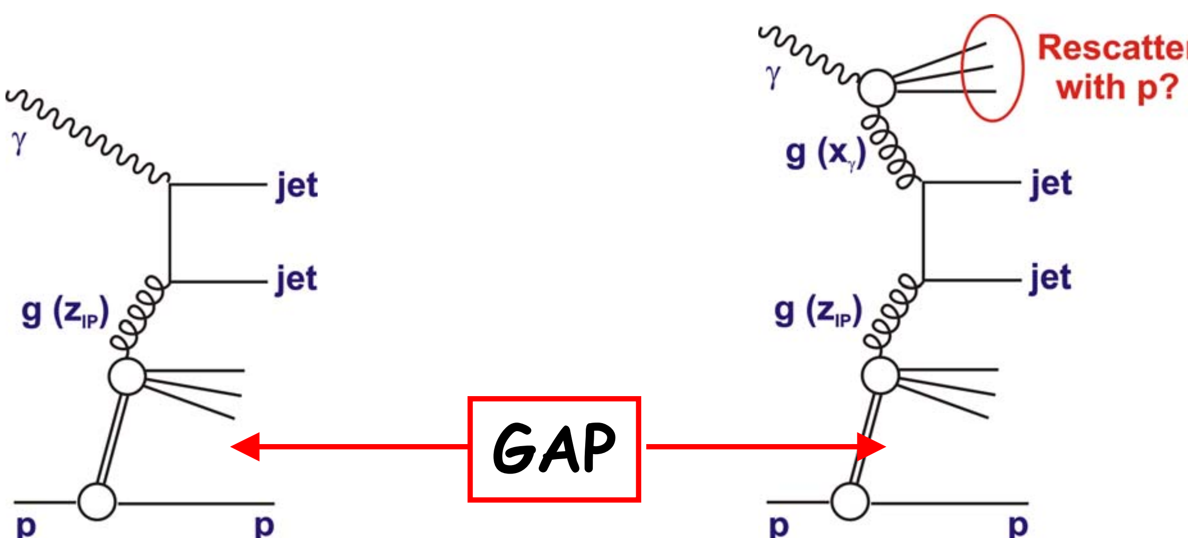


... explained by rescattering / absorption

... photoproduction jets as the perfect control experiment?...

"Direct" photon ($x_\gamma \rightarrow 1$)

"$S^2 = 1$"

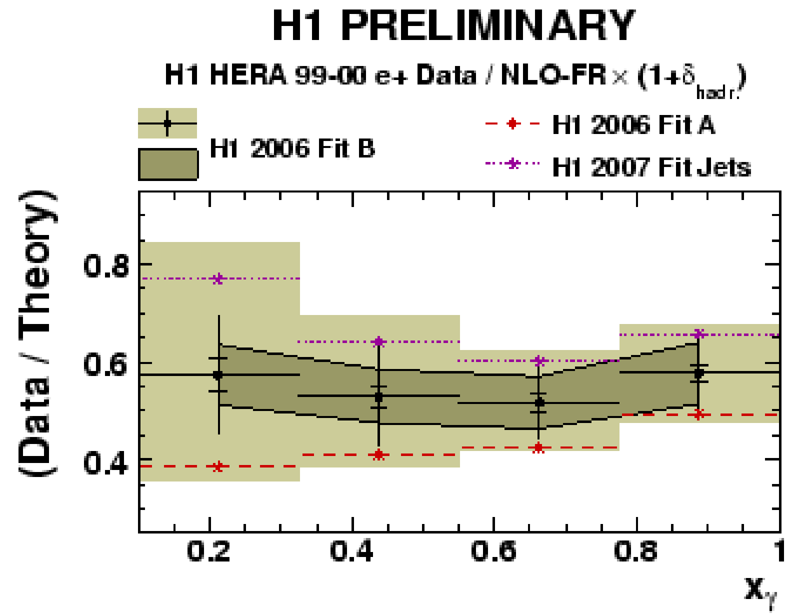


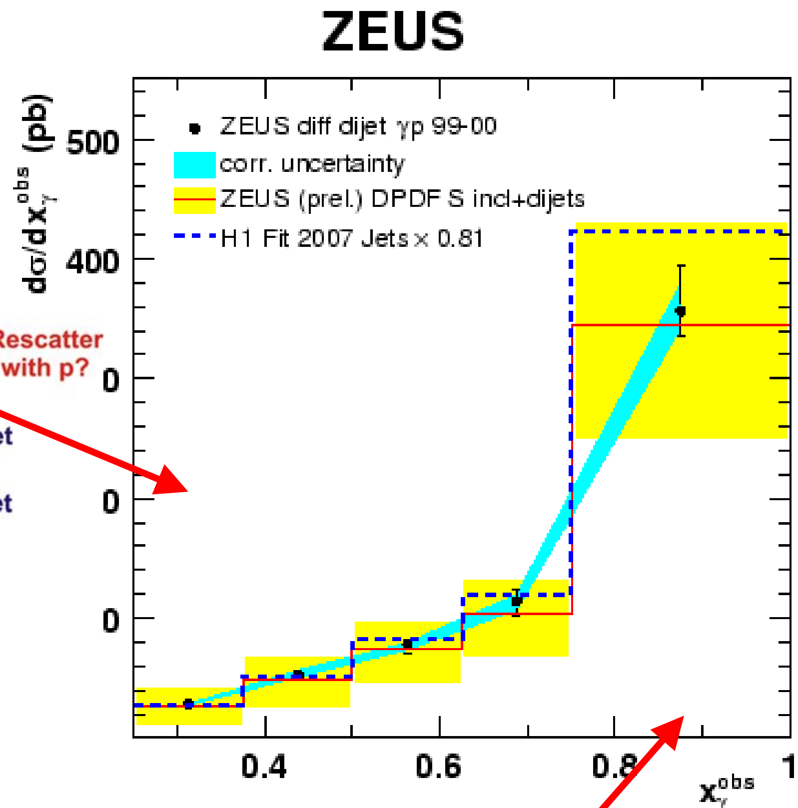
"Resolved" photon (x_γ < 1)

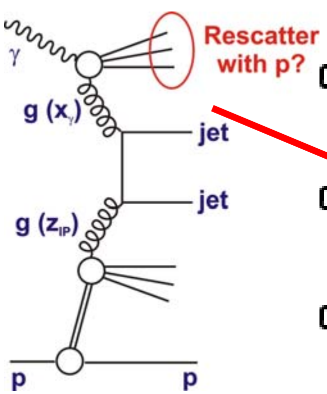
"$S^2 \sim 0.34$" (KKMR)

X-Sec Differential in x_γ

… a surprise!…

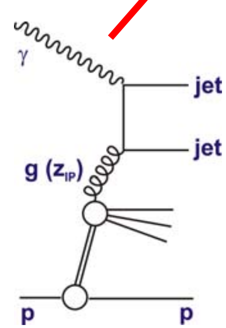






- Good shape description → no significant difference between high / low x_γ !

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



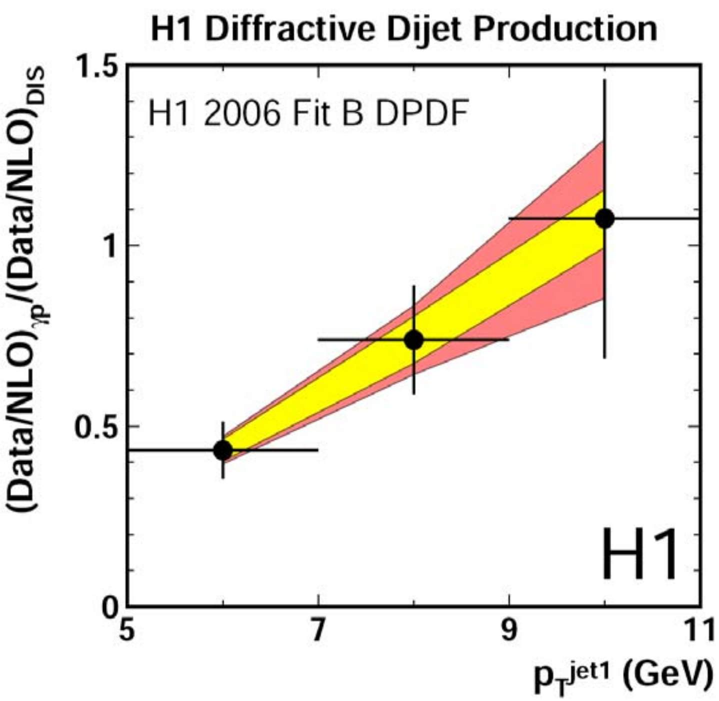
- H1: $E_t^{jet1} > 5$ GeV

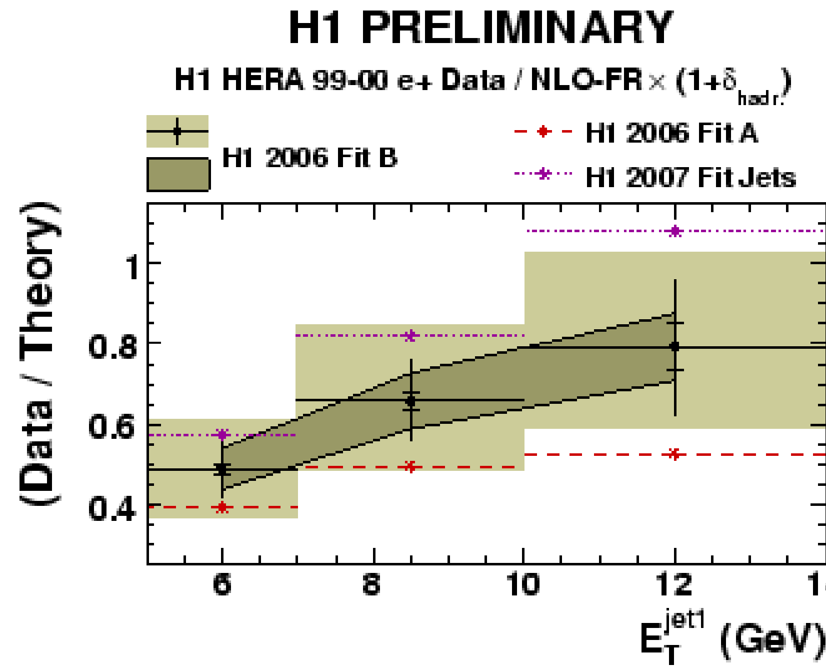
… suppression by factor ~2

- ZEUS: $E_t^{jet1} > 7.5$ GeV

… little or no suppression

Cross Section Differential in E_T





- Suggestions of harder Et dependence in data than NLO theory … thus of E_t dependent gap survival probability

- Could rescattering effects for photon depend on Et, not x_γ?

- Non-trivial kinematic correlations … final conclusion pending!

Summary

• After 15 years of running, HERA provided unique diffractive data.

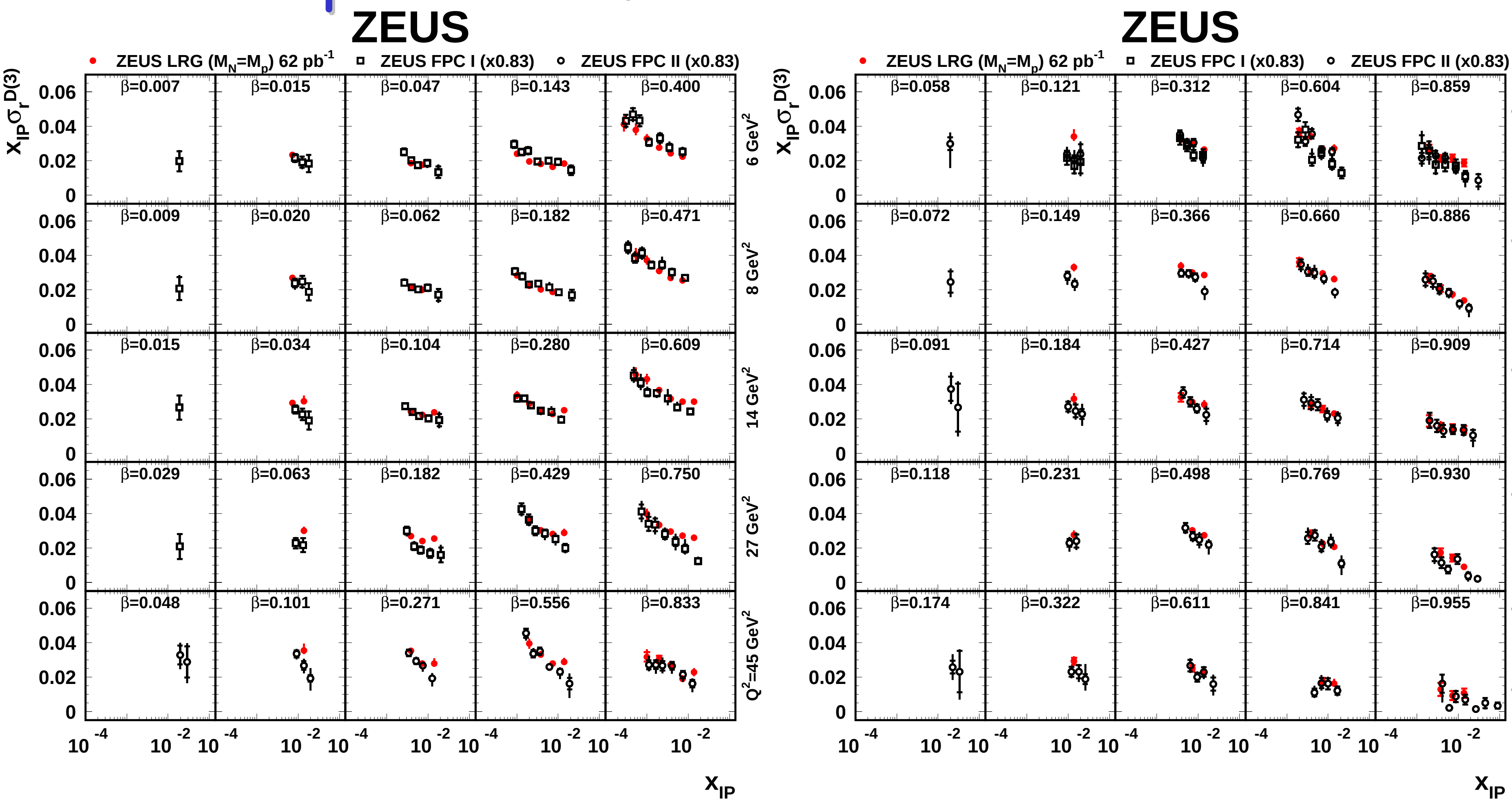
• Agreement in detail between different analysis methods

• Proton vertex factorisation with $\alpha_{IP}(t) \sim 1.11$ (+ δt) & $b_{IP} \sim 6$ GeV^{-2} is good model for the 'soft' physics

• DPDFs well constrained & tested … measuring the QCD vacuum development of a basic `hard' gluon exchange?

• Solid conclusions on diffractive dijet photoproduction will lead to new insights on gap survival / photons

Comparison of ZEUS LRG v Mx Data

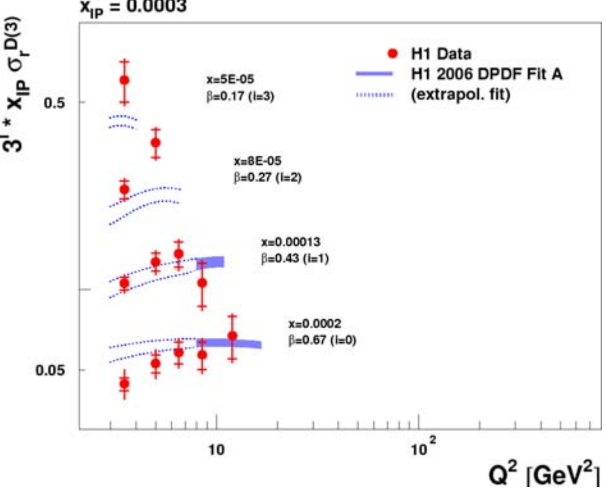


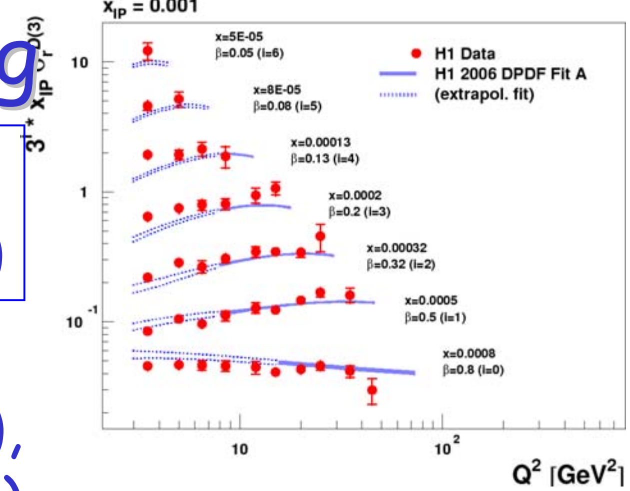
- Global fit of LRG (at My = mp) v FPC normalisation yields factor 0.83 +- 0.04, compatible with (tuned) MC expectations
- Acceptable agreement after applying this factor (despite differently defined x-secs at high M_x)

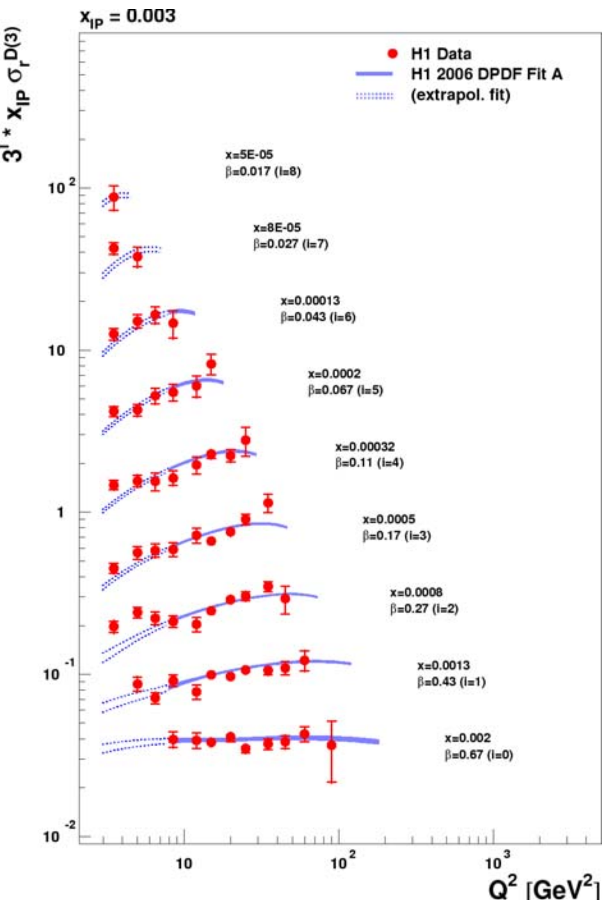
Fixed x_{IP} binning

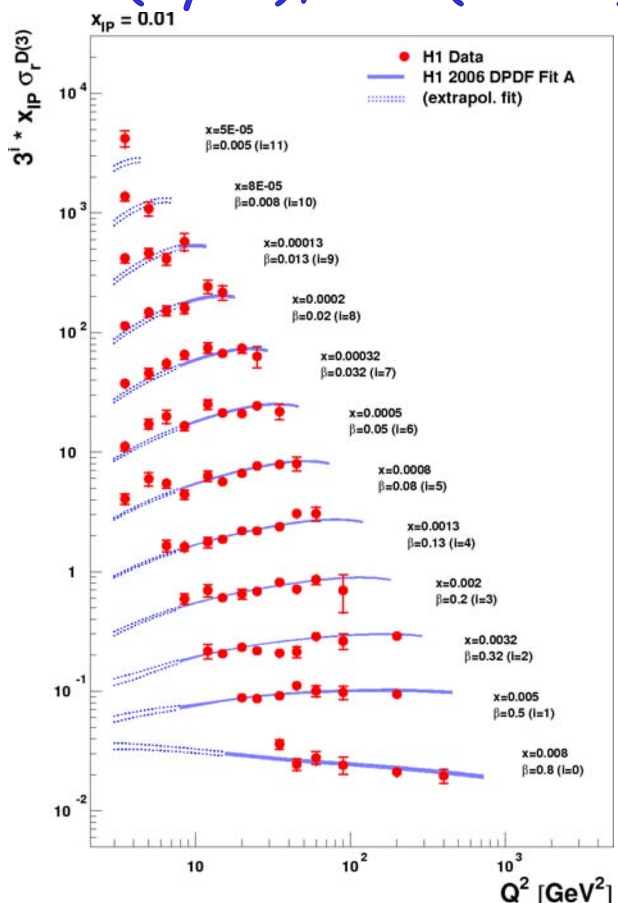
x, x_{IP}, Q^2 binning
(new presentation)

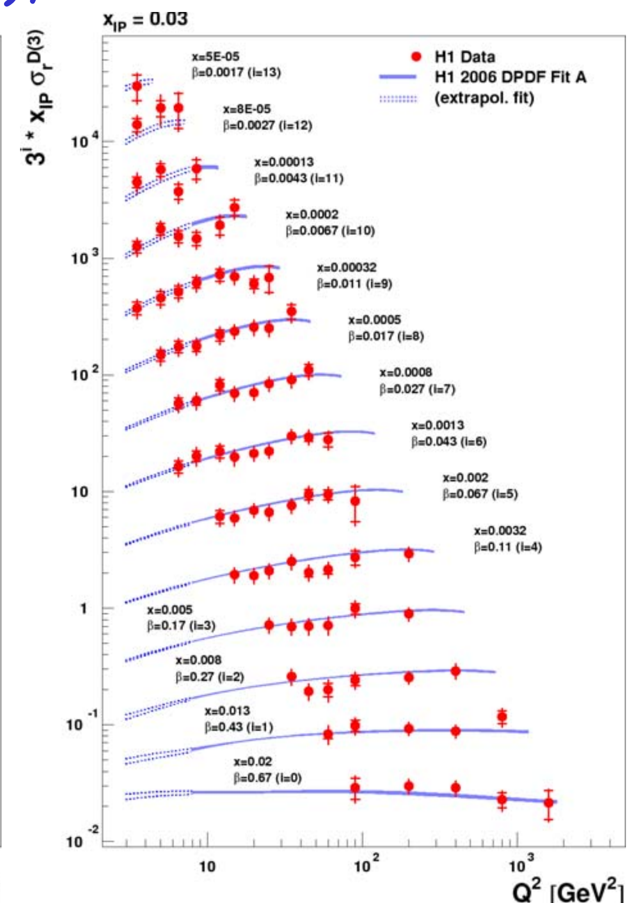
In best regions,
precision ~5% (stat),
5% (syst), 6% (norm),



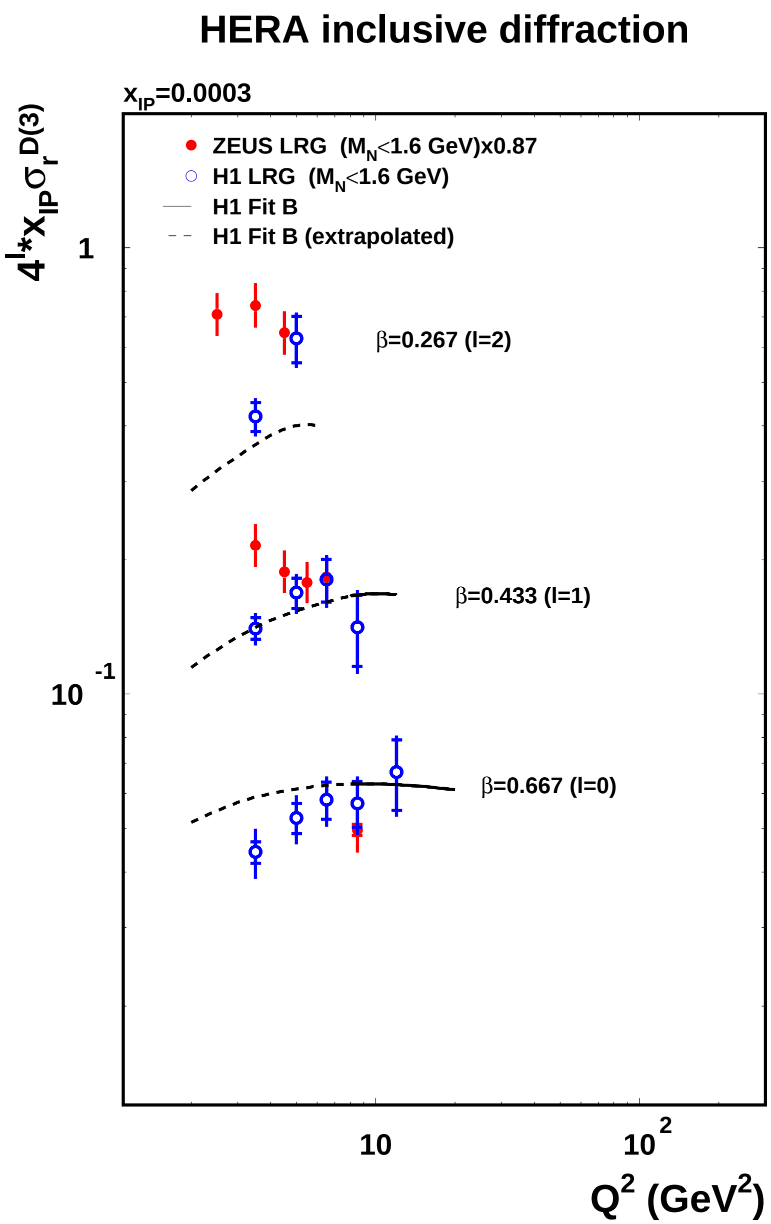


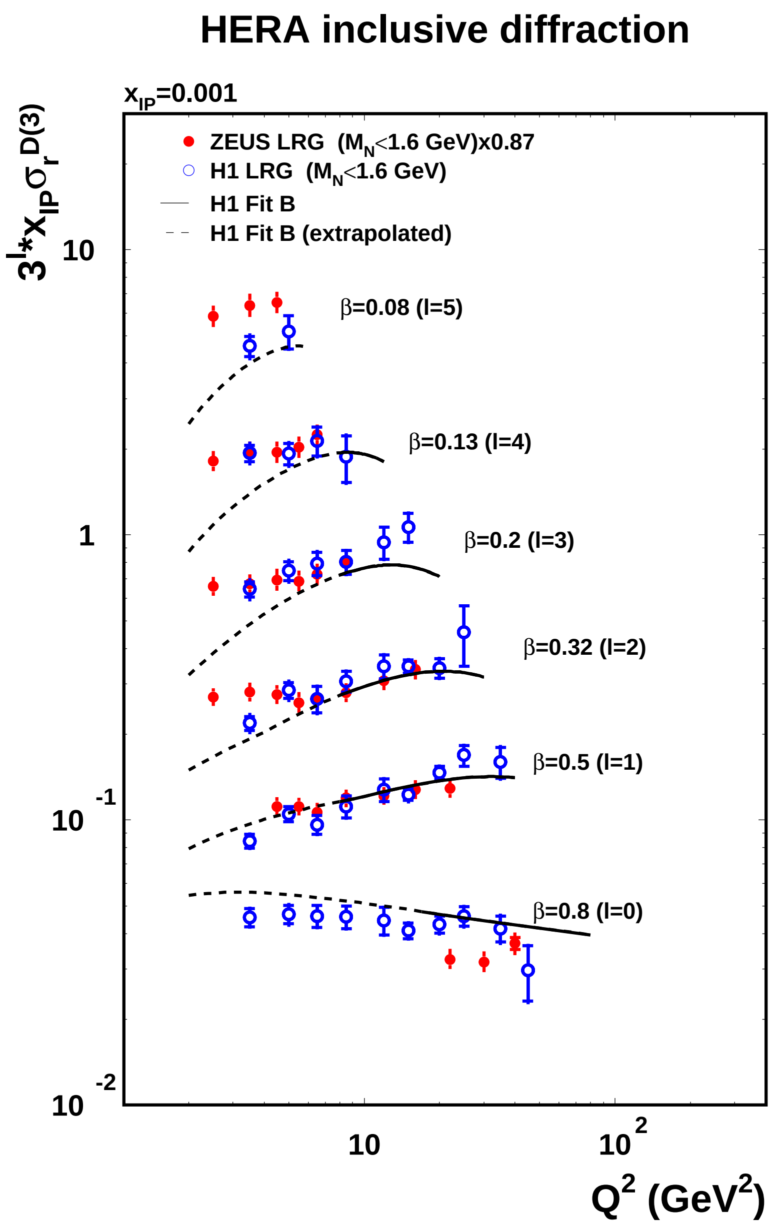






Normalised LRG Comparison H1 v ZEUS



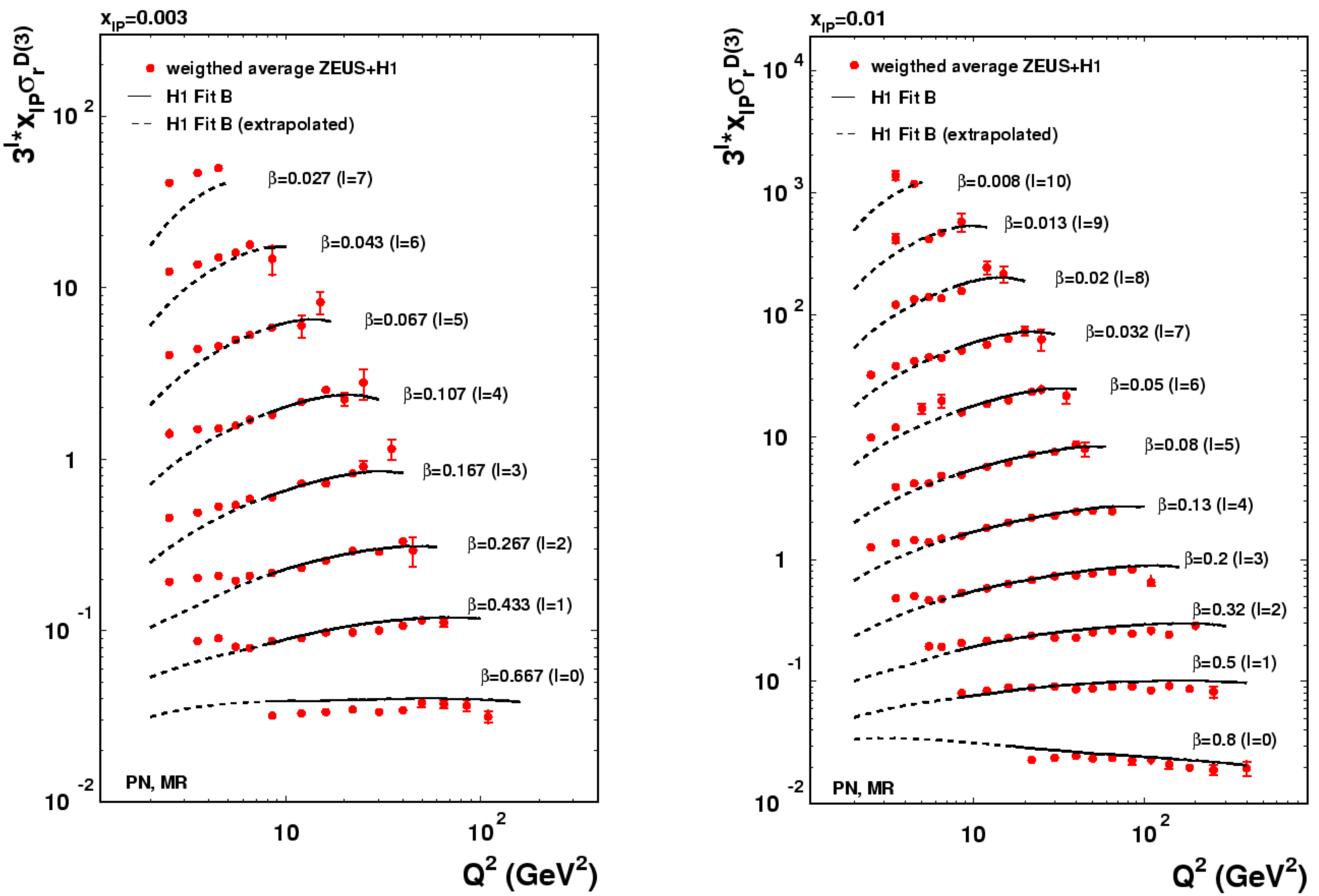


First Step towards Combined LRG Data

- Set normalisation (arbitrarily) to H1 → >10% uncertainty
- Swim H1 points to ZEUS Q^2 values using H1 fit B
- Pending correlated systematic details in ZEUS data, make a simple weighted average of H1 / ZEUS at each data point based on quadratic sum of stat and (non-norm) syst errors
- (For now) restrict to x_{IP} = 0.003, 0.01 (best agreement)

… results generally pulled towards more precise ZEUS data
… many points have 3-4% precision (excluding normalisation)

First Combined LRG Data (Newman, Ruspa)



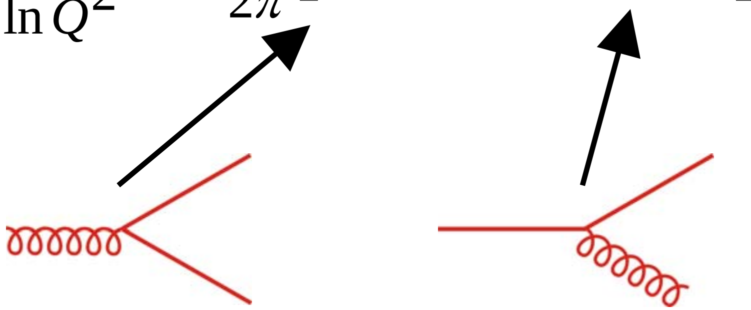
No big conflicts with existing DPDFs (quarks @ low, high β?)

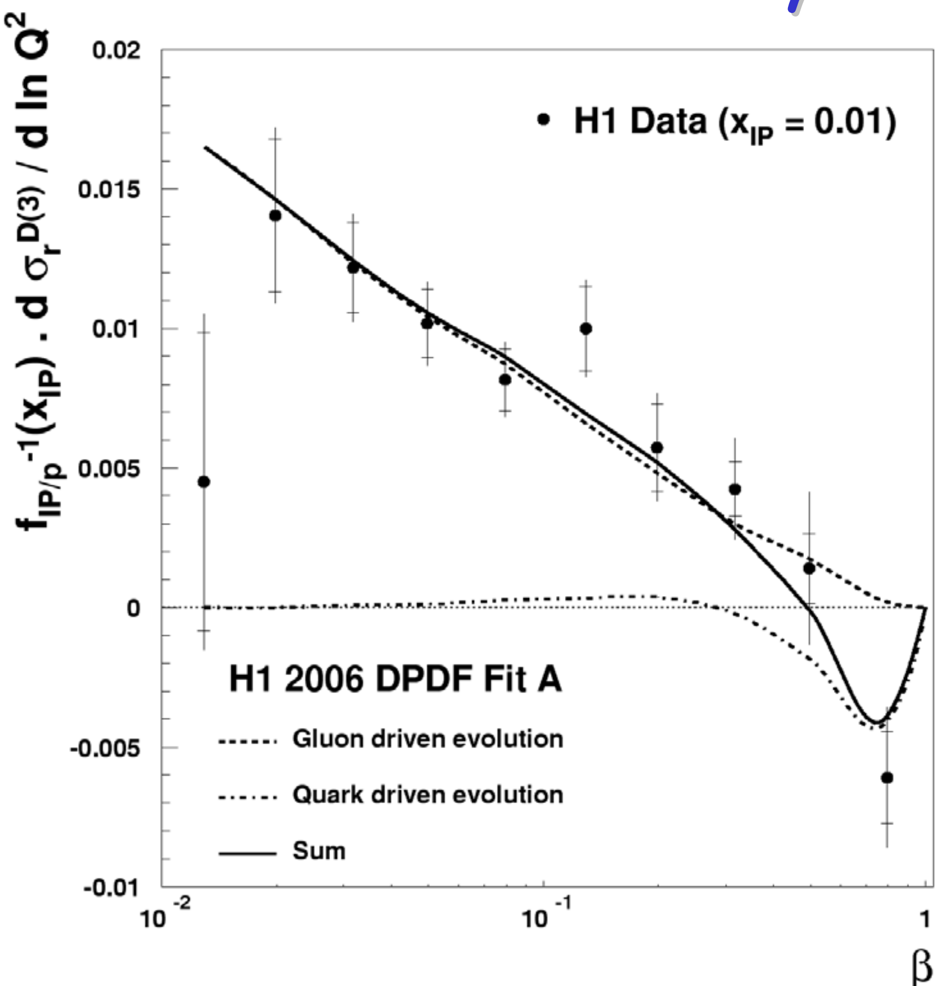
Q^2 Dependence and the Gluon Density

$\sigma_r^{D(3)}$ measures diffractive quark density.

Its dependence on Q^2 is sensitive to diffractive gluon density.

$$\frac{d\sigma_r^D}{d\ln Q^2} \sim \frac{\alpha_s}{2\pi}\left[P_{qg}\otimes g \;+\; P_{qq}\otimes q\right]$$

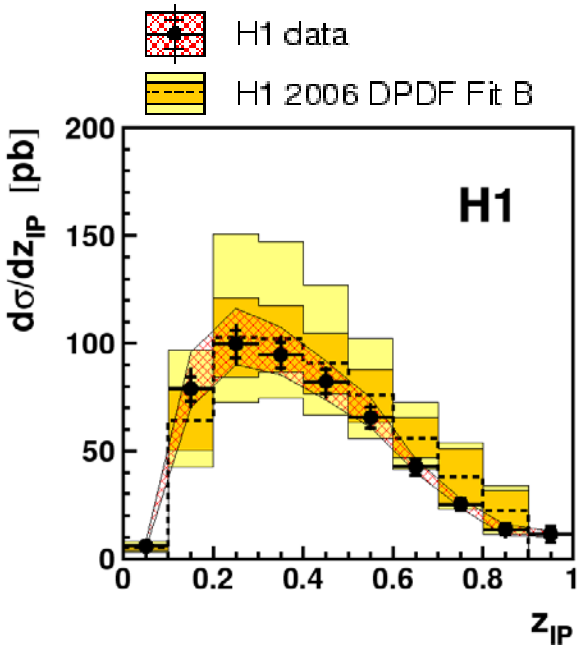




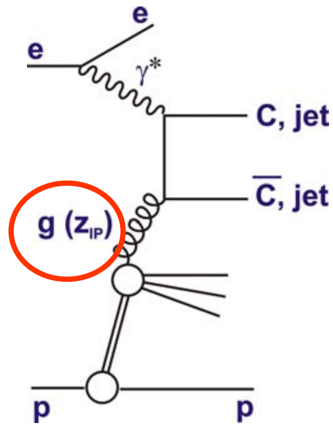
Extract $d\sigma_r^D/d\ln Q^2$ by fitting data at fixed x, x_{IP}

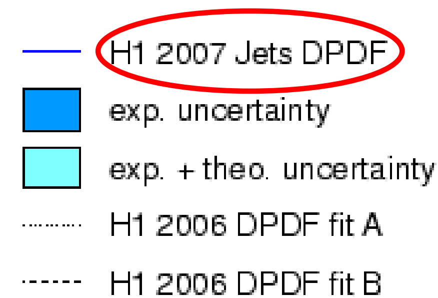
- Low β evolution driven by $g \to q\bar{q}$ … strong sensitivity to gluon
- High β, relative error on derivative grows, $q \to qg$ contribution to evolution becomes dominant … sensitivity to gluon is lost!

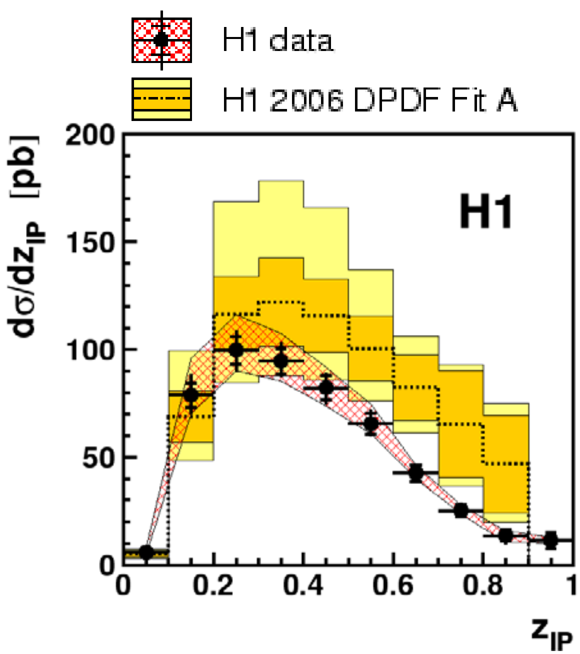
Factorisation, DIS Dijets & the high z Gluon

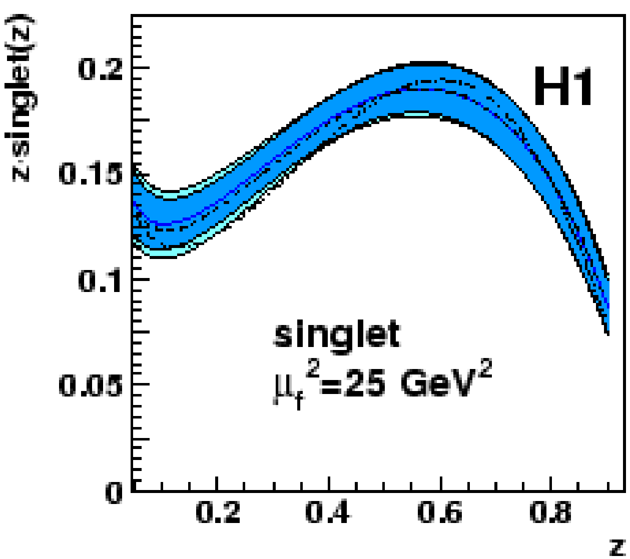


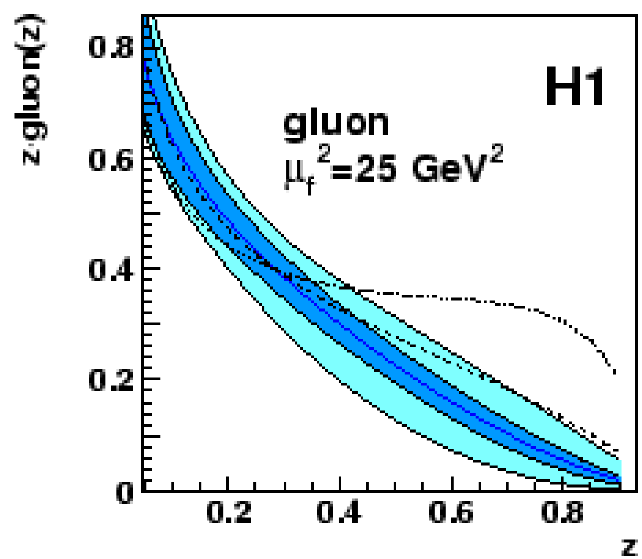
- Fit A, B describe diverse diffractive DIS data
- Dijet data dominantly at large z_{IP} … distinguish between `fit A' & `fit B'
- Include jet data in fit → `H1 2007 Jets' DPDFs



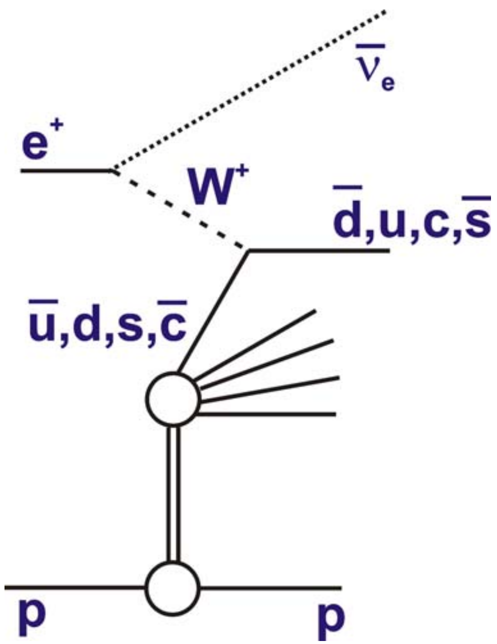


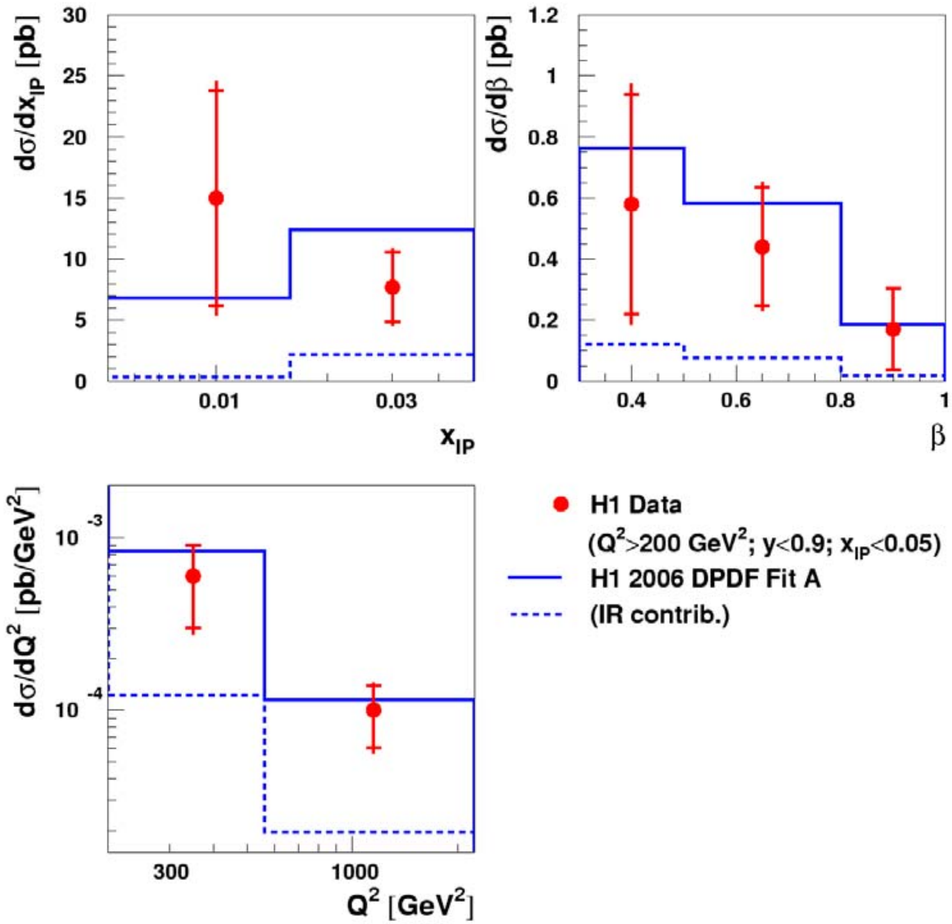






Diffractive Charged Current Cross Section

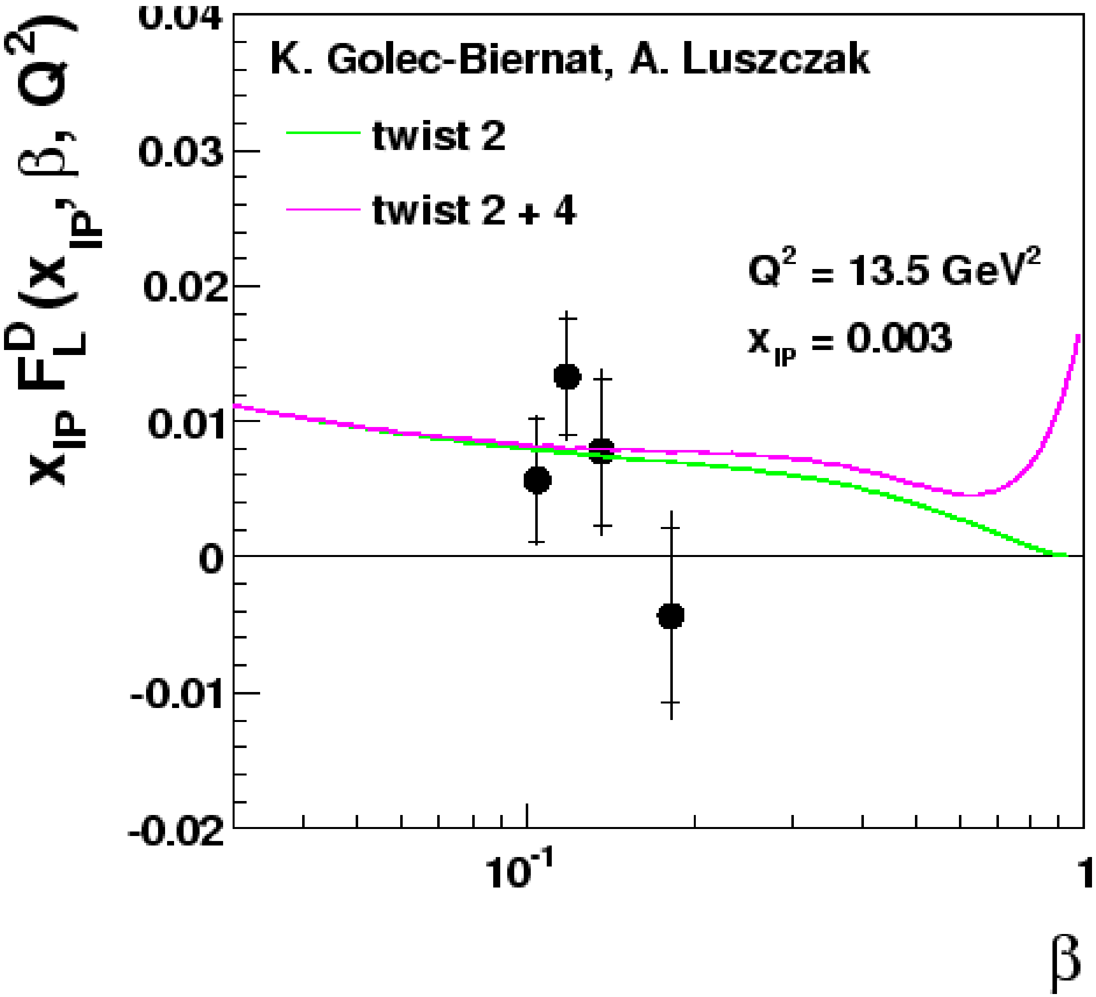




Very similar method of measurement to Neutral Current case.

Good agreement with fit prediction (assumes $u = d = s = \bar{u} = \bar{d} = \bar{s}$ and c from BGF) though statistical precision limited so far

F_L^D and Higher Twist at High β?



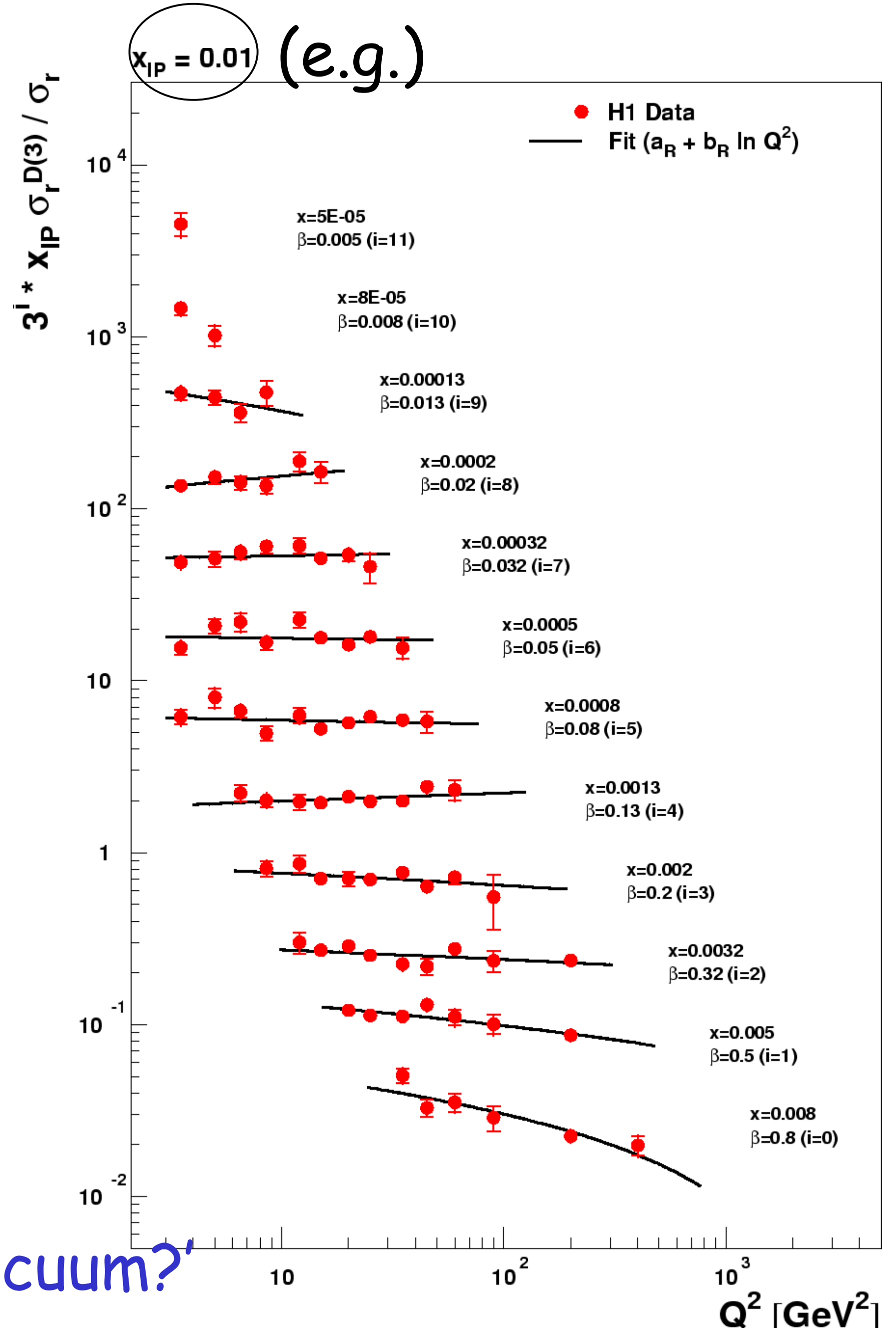
So far no sensitivity …

Low x similarity of diffractive & inclusive PDFs

• Similar ratios of quarks to gluons reflected in similar Q^2 evolution of inclusive and diffractive cross sections at low x…

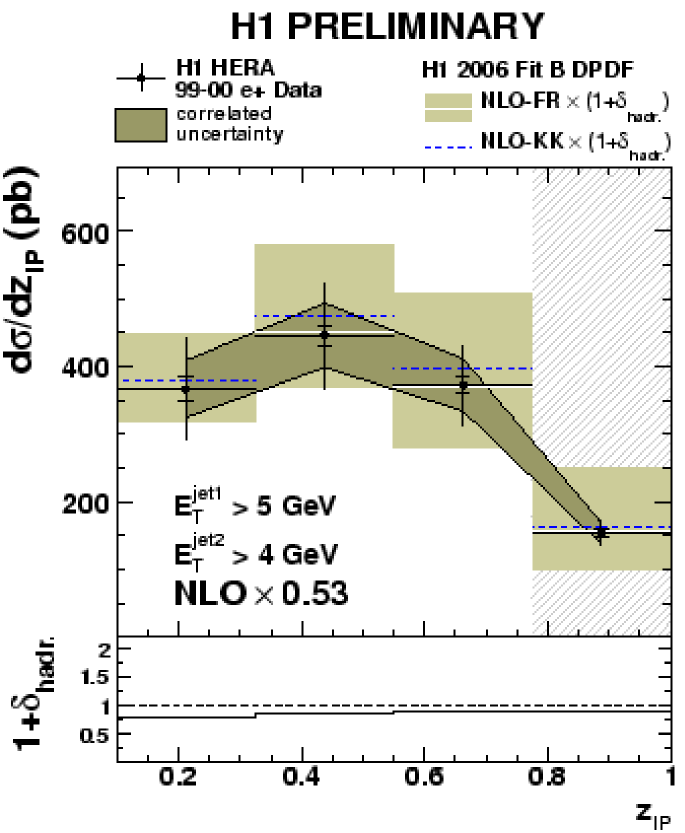
• …Ratio σ_r^D/σ_r ~ independent of Q^2 at fixed x_{IP} and x.

• … away from the influence of valence quarks, PDFs and their evolution is driven only by QCD … same for proton, pomeron, pion, photon …?

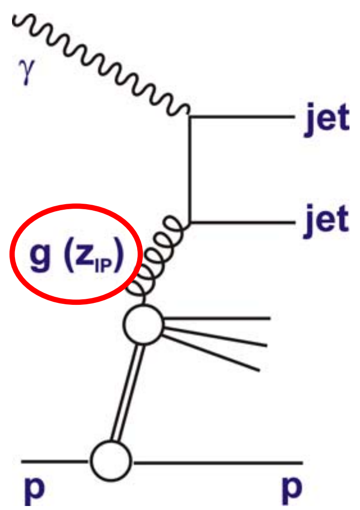


…`universal structure of QCD vacuum?'

X-Section Differential in z_{IP}

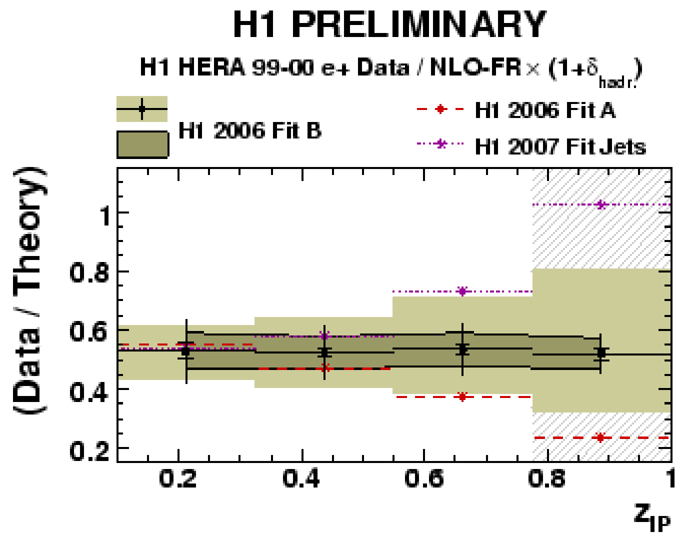


$$z_{IP} = \frac{\sum_{jets} (E + p_z)}{2E_p \; x_{IP}}$$



Global suppression ~0.5 needed for NLO calculations … confirms previous result

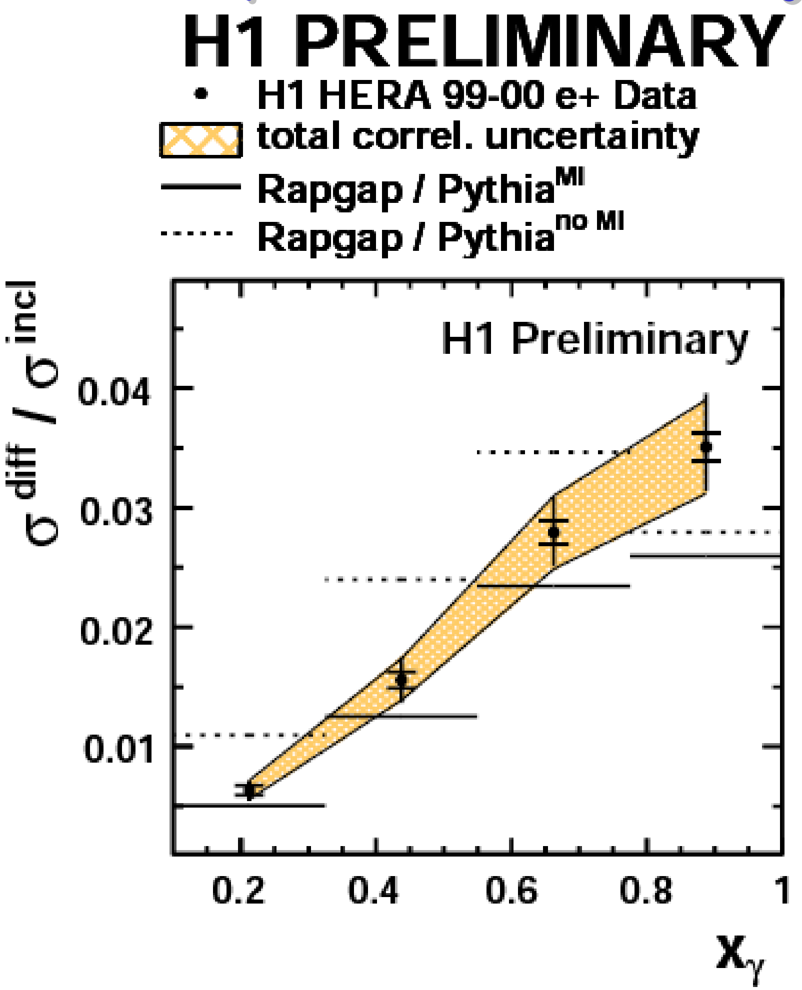
Best shape description from Fit B

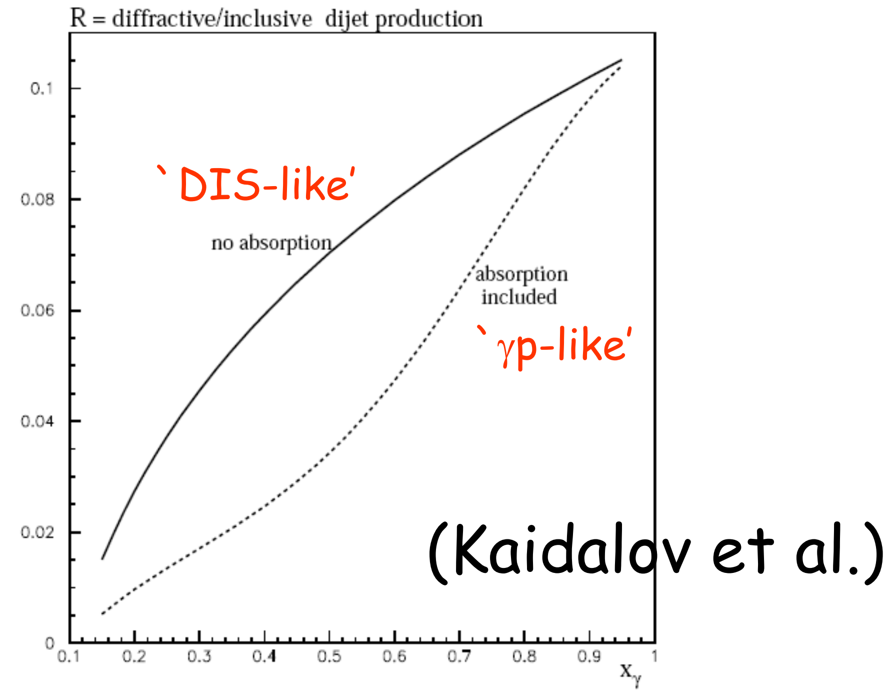


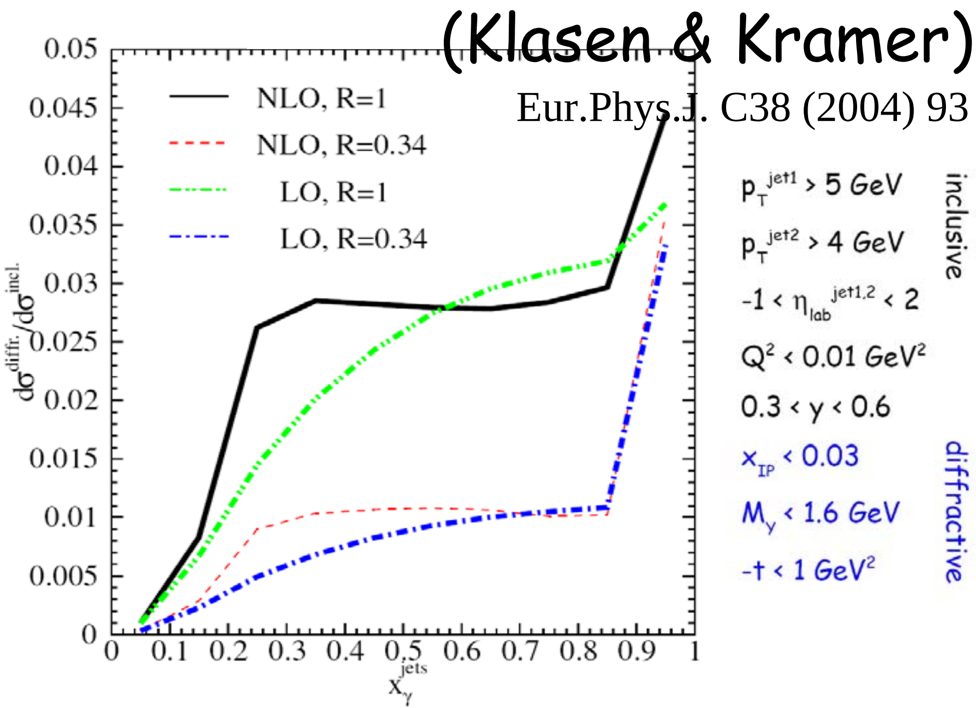
DPDF uncertainties small at low z_{IP}, but explode at high z_{IP} !

Highest z_{IP} bin is even beyond the range of DPDF fits, so predictions should be taken very cautiously

Diffractive / Inclusive Photoproduction Dijets







- Size of MI effect similar to that of absorption.
- MI Model → fair description