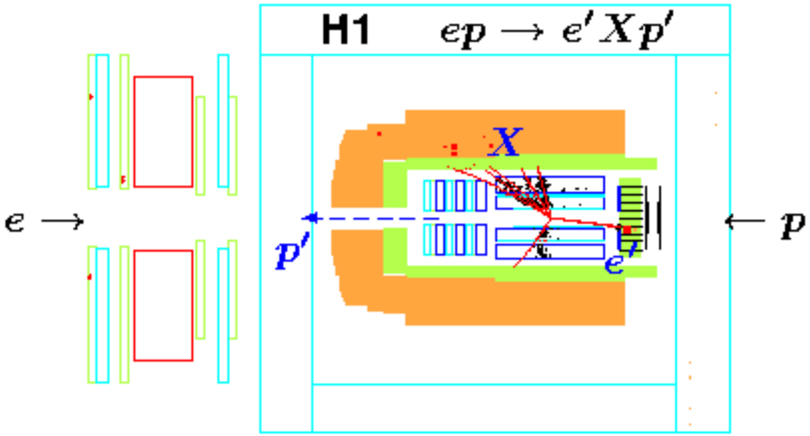
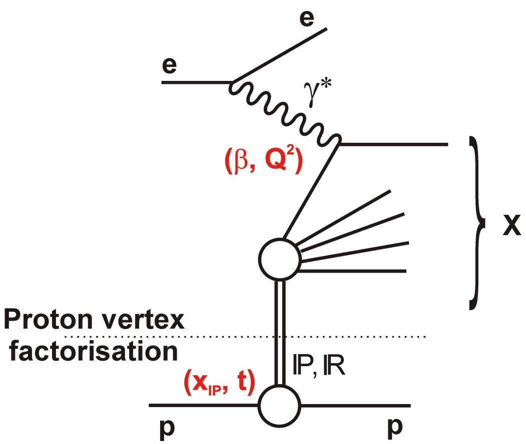
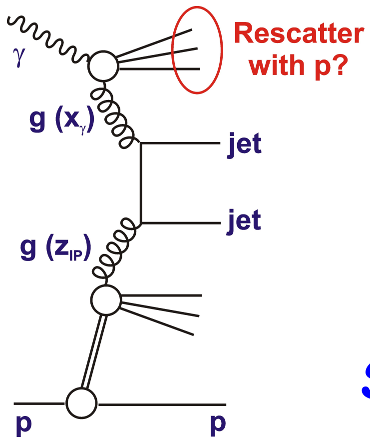
Diffractive Factorisation & Rapidity Gap Survival at HERA



Paul Newman
(University of Birmingham)

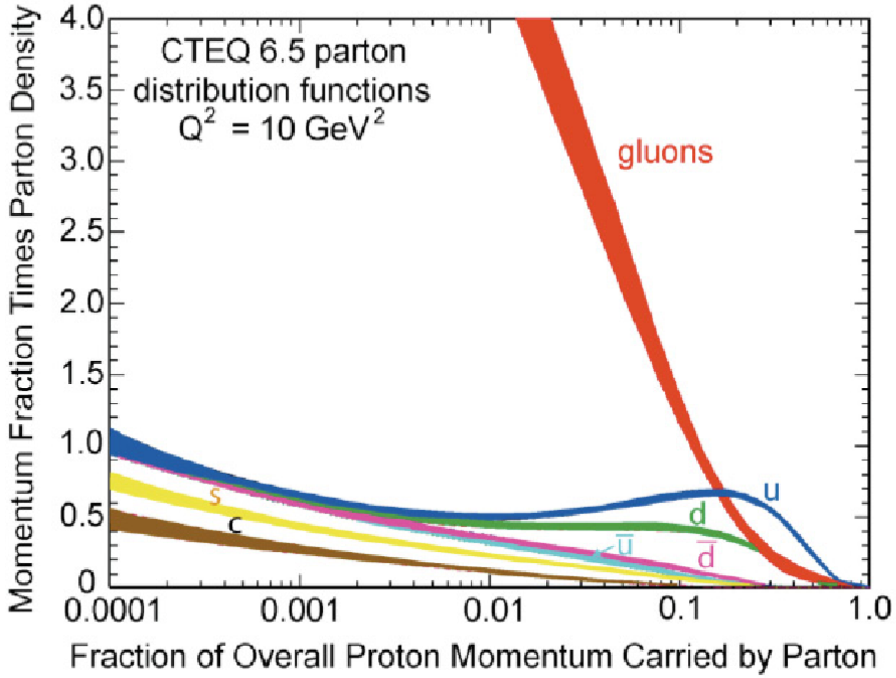




Forward Physics @ LHC
Manchester 14 / 12 / 09

Supported in part by IPPP, Durham

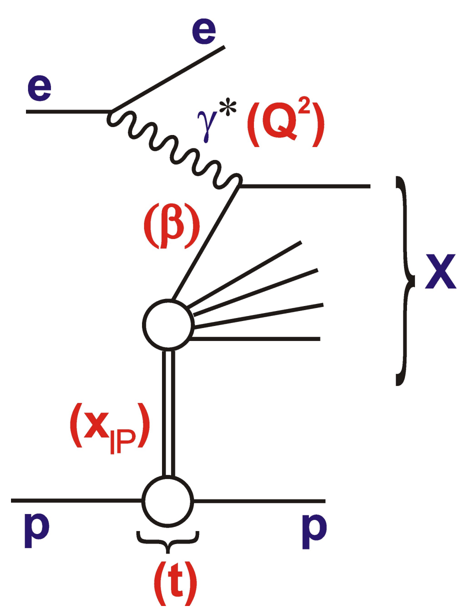
Low x ep Physics & Diffraction



- Low x physics, as revealed by HERA, is the physics of very large gluon densities…

- Associated with a large (> 10%) diffractive content

… partonic structure of diffraction
… tests of new QCD factorisation ideas
… relation to non-linear evolution (low x sat^n)
… related to gap survival / underlying event

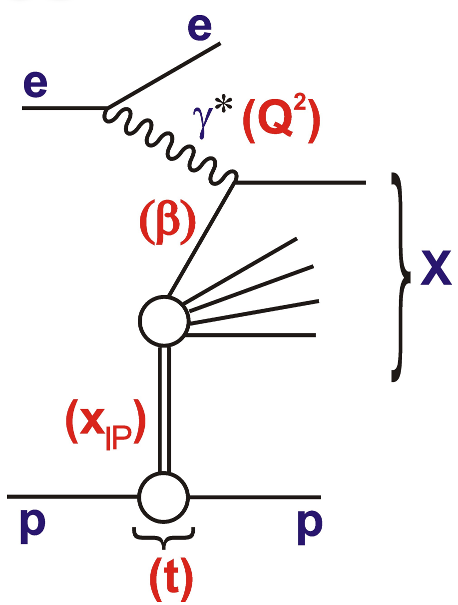


- Vital input to diffraction at the LHC …

Diffractive DIS Kinematics

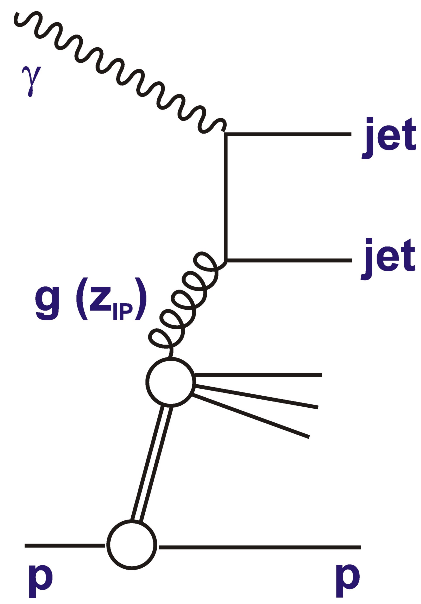
Standard DIS variables …

- x = momentum fraction q/p
- Q^2 = $|\gamma^*$ 4-momentum squared$|$



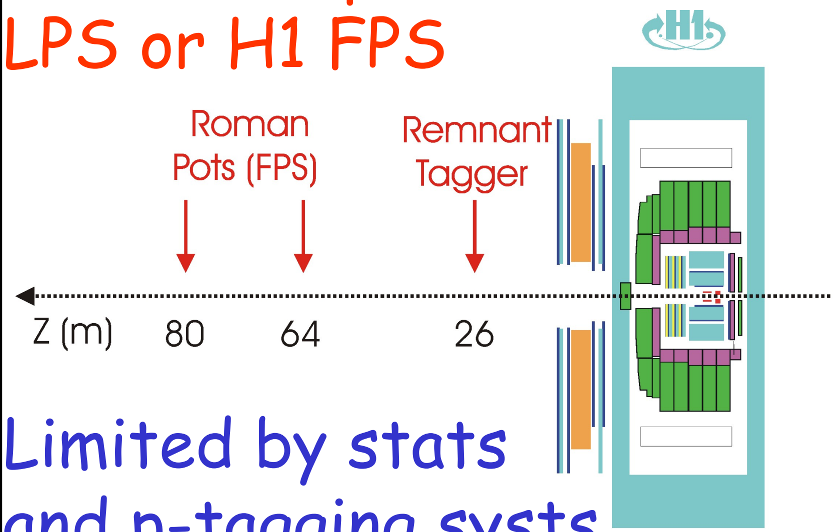
Additional variables for diffraction:

- 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)
- z_{IP} = generalisation of β beyond QPM (momentum fraction g / IP or q / IP)

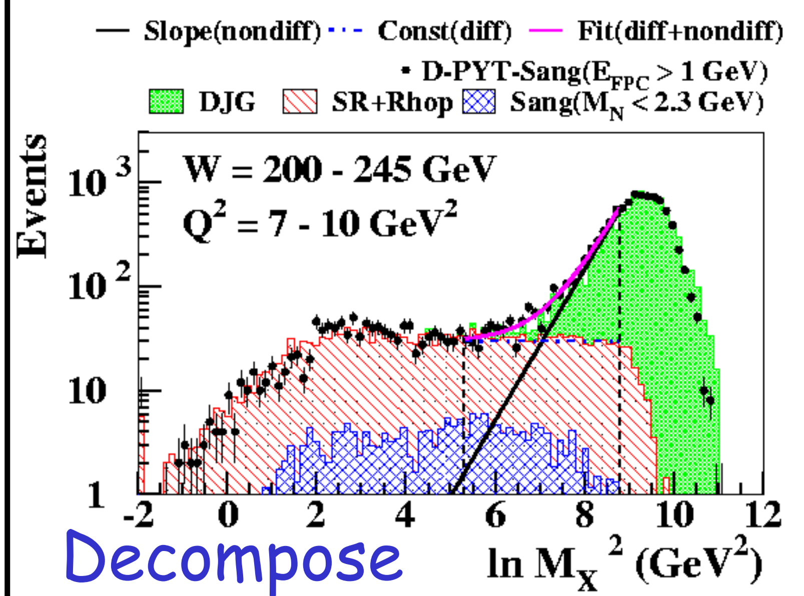


Signatures and Selection Methods

Scattered proton in ZEUS LPS or H1 FPS

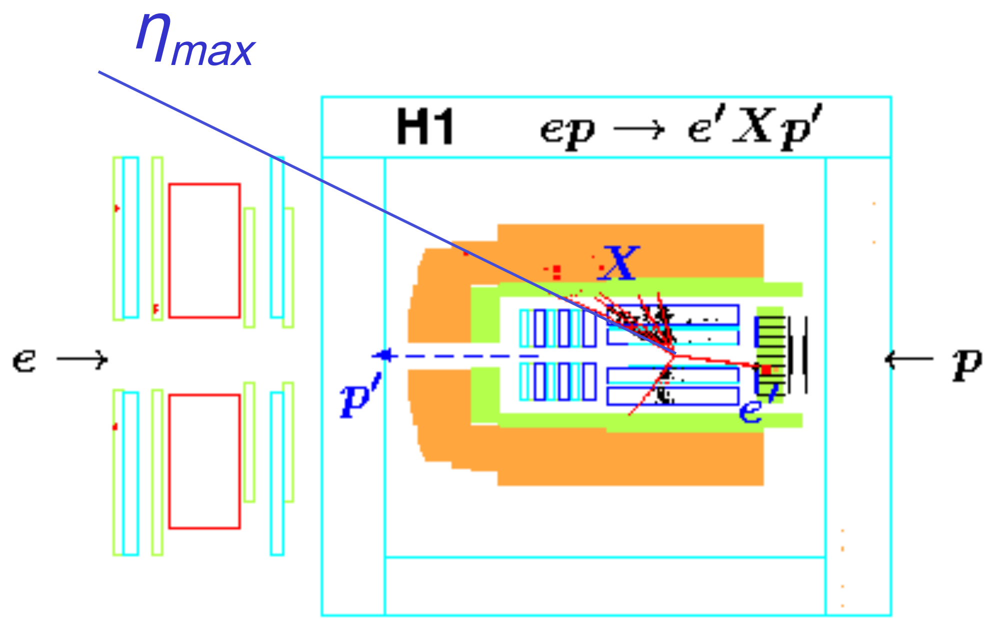


Limited by stats and p-tagging systs



Decompose inclusive $\ln(M_X)$ distn

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

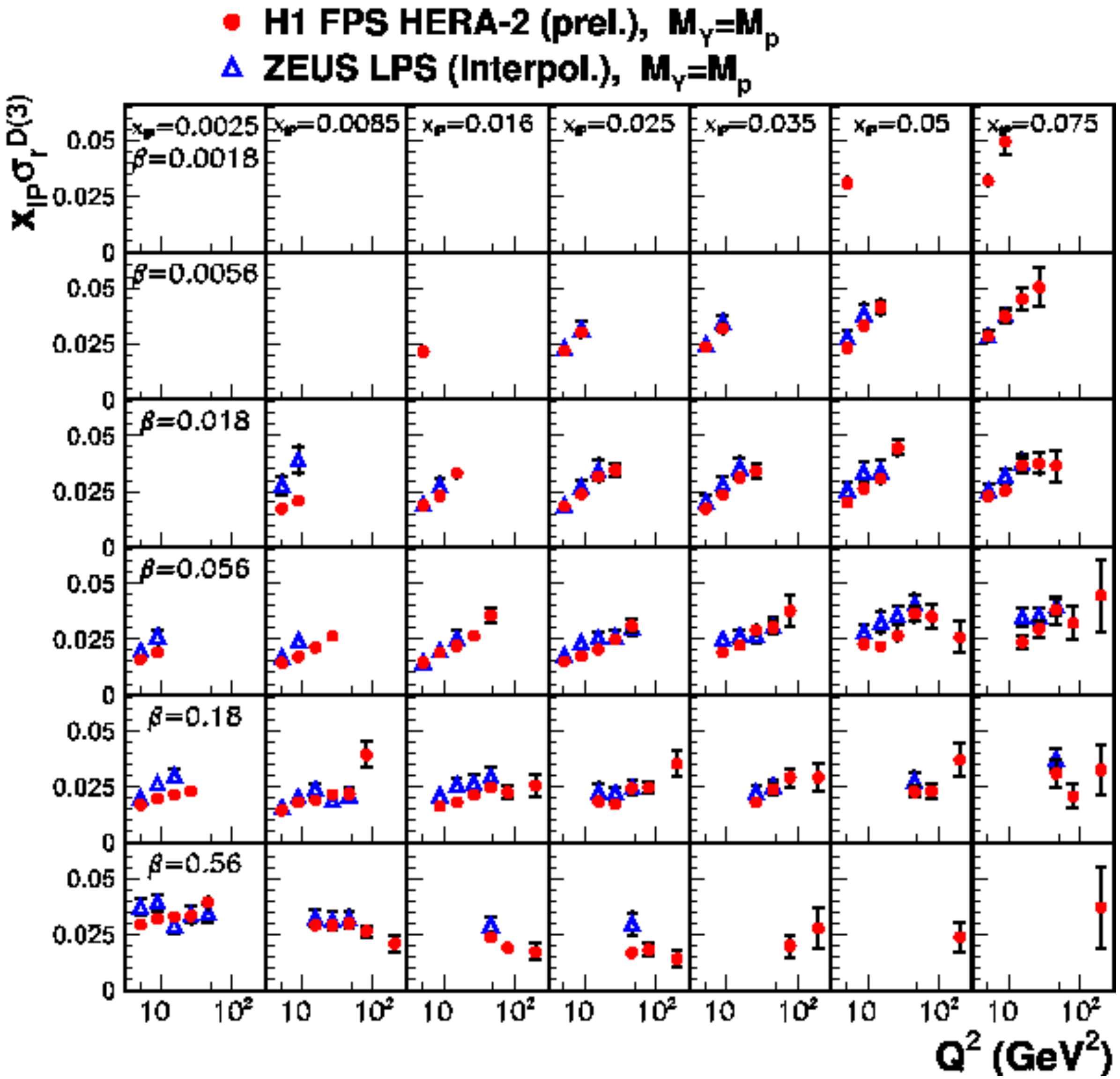


Limited by p-diss systs

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

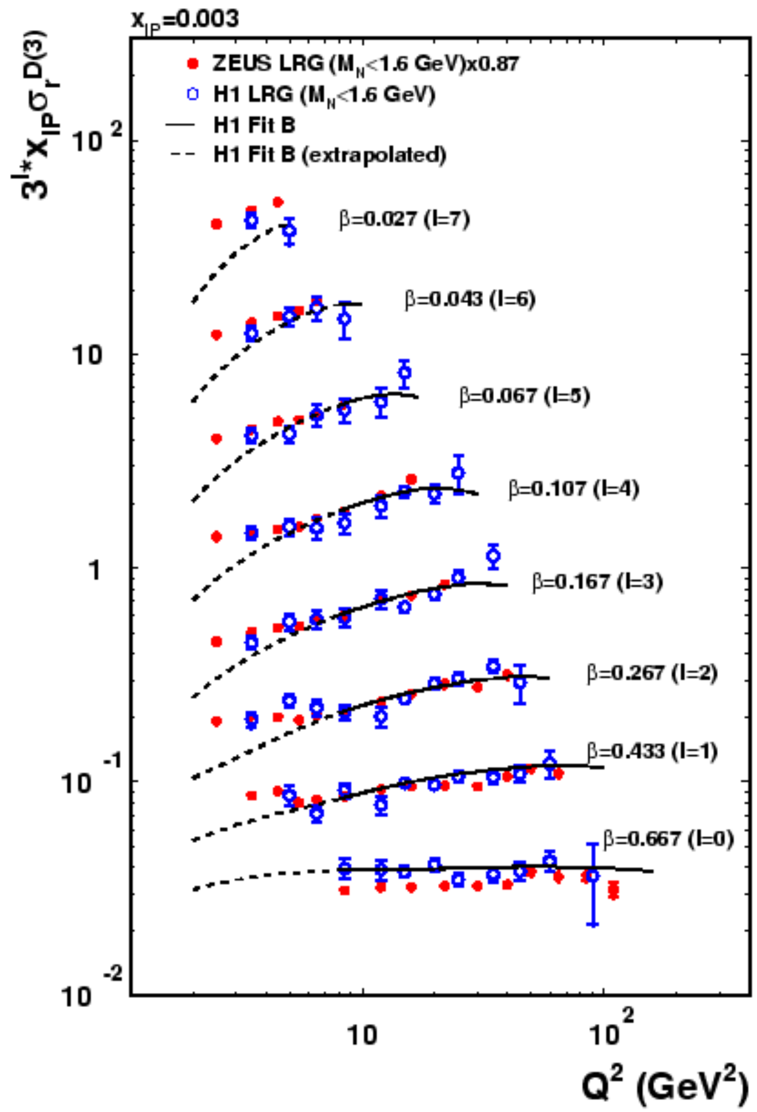
ZEUS v H1 Proton-tagged Data

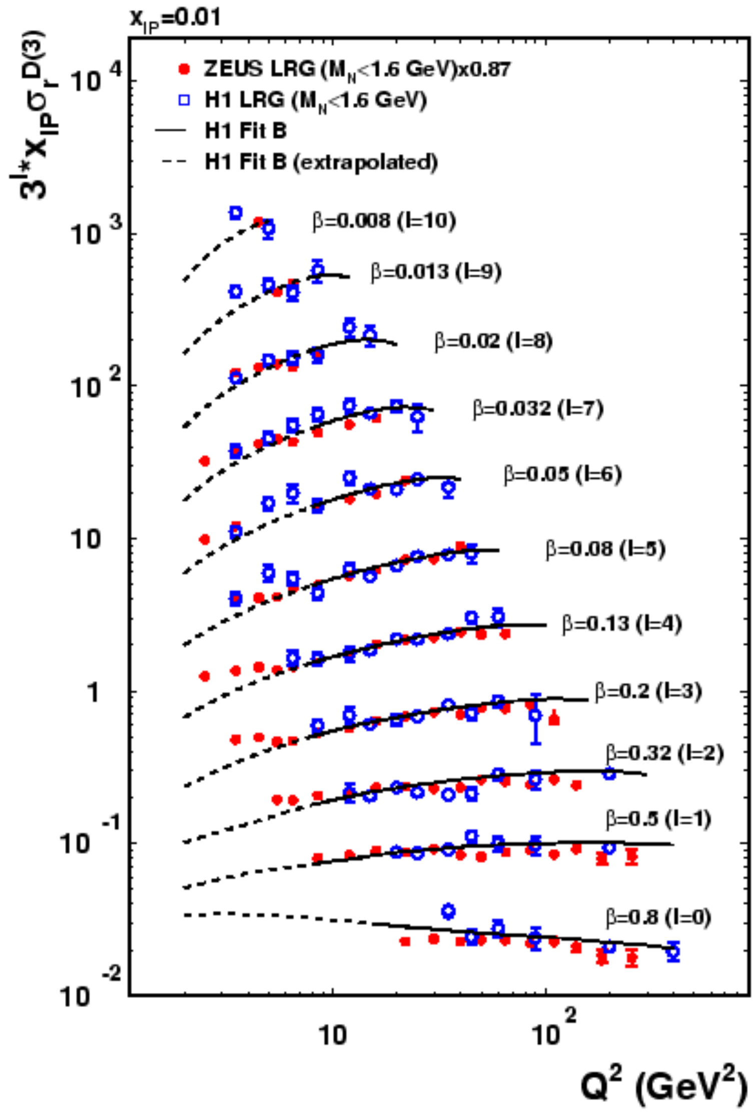
... presented as $\sigma_r^{D(3)}(\beta, Q^2, x_{IP}) = F_2^{D(3)} - \frac{y^2}{Y_+} F_L^{D(3)} \sim F_2^{D(3)}$



- 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%)

Normalised LRG Comparison H1 v ZEUS



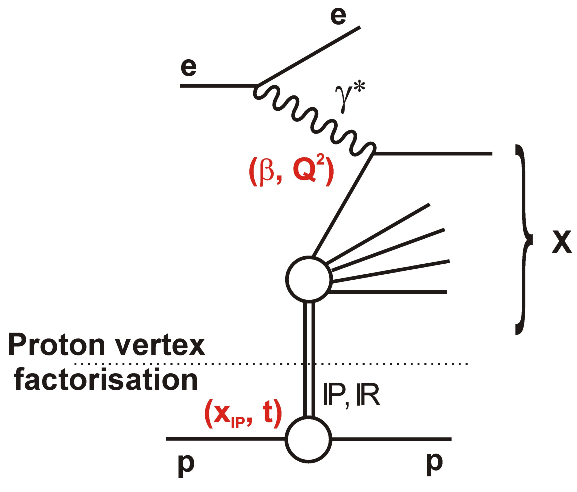


Final ZEUS LRG data (62 pb^{-1}) reach new level of statistical precision

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

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

Proton Vertex Factorisation



- Variables describing proton vertex (x_{IP}, t) factorise from those at photon vertex (β, Q^2) to good approximation for Q^2 >~ 5 GeV^2

- Model proton vertex in terms of effective IP trajectory:

<u>ZEUS</u>

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

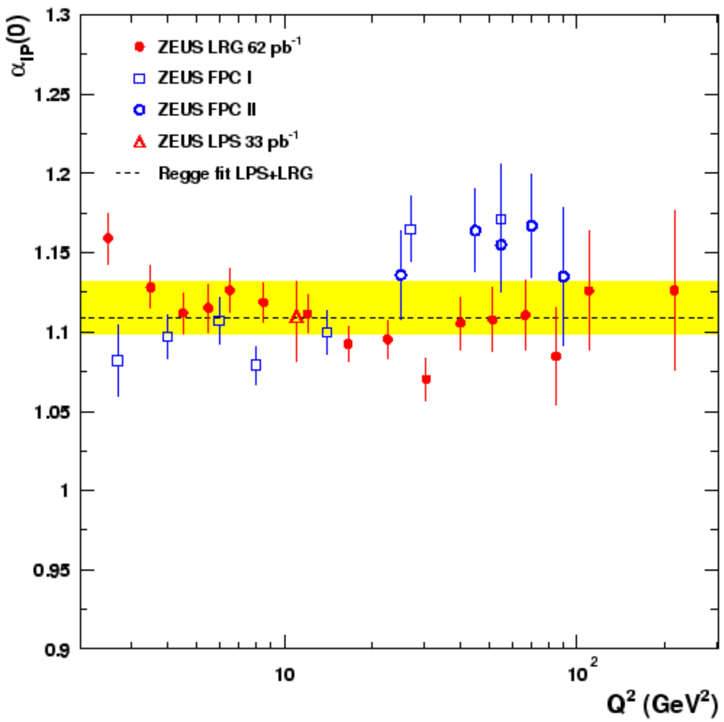
$$\alpha'_{IP} = -0.01 \pm 0.06(\text{stat.}) \pm 0.06(\text{syst.})$$

<u>H1</u>

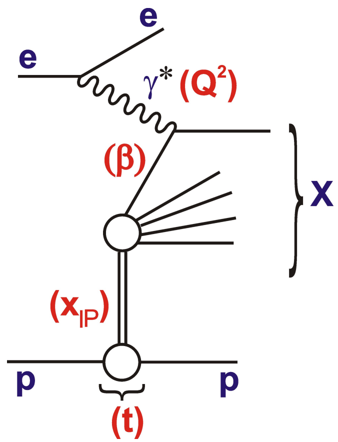
$$\alpha_{IP}(0) = 1.12 \pm 0.01(\text{exp.}) \pm 0.02(\text{model})$$

$$\alpha'_{IP} = 0.06 \pm 0.13$$

ZEUS



$\alpha_{IP}(0)$ consistent with soft pomeron, α_{IP}' smaller



Diffractive Parton Densities

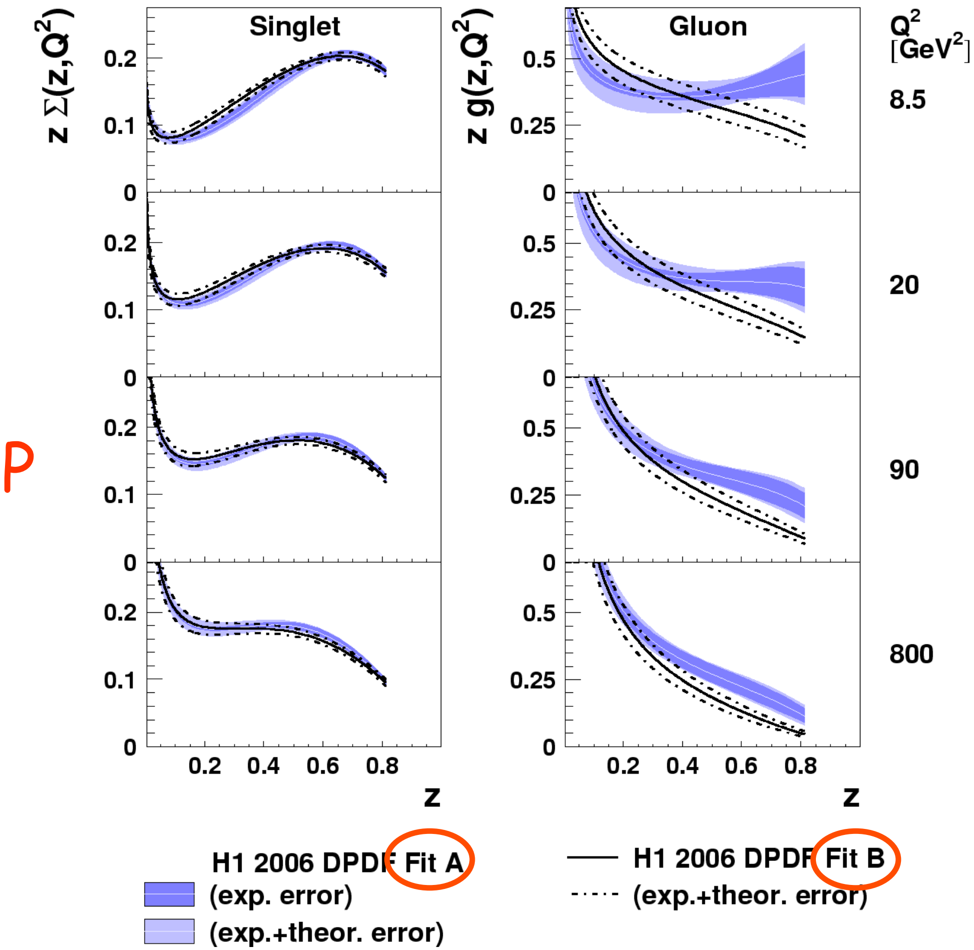
- β, Q^2 dependence interpreted in terms of Diffractive Parton Densities (DPDFs), measuring partonic structure of exchange

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

- Parameterise and fit z_{IP} dependences of DPDFs.
- Q^2 evolution from NLO DGLAP equations with massive charm (H1) or GM VFNS (ZEUS)

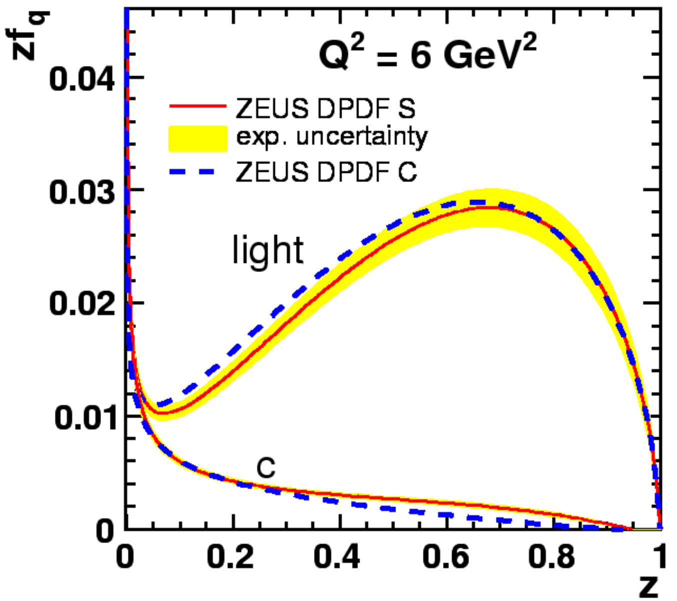
  - Singlet quarks to ~5%,
  - Gluon to ~15% for z <~ 0.1,

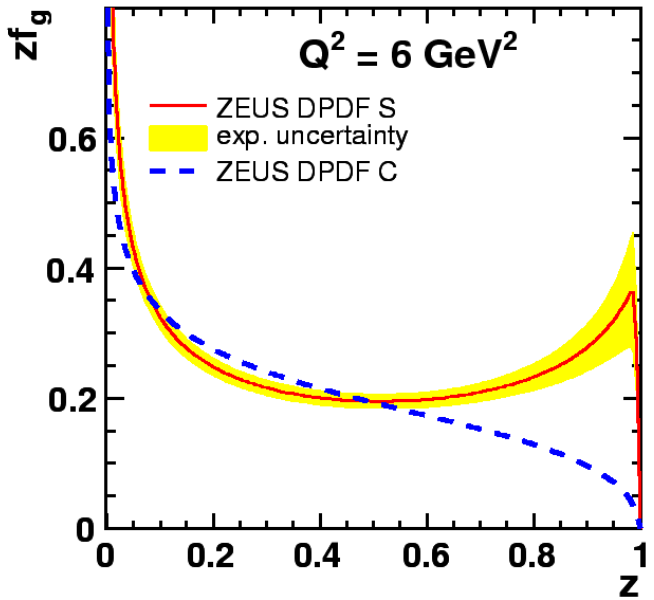
  … growing fast at higher z



[H1, F2D data only]

New ZEUS DPDFs from Inclusive Data





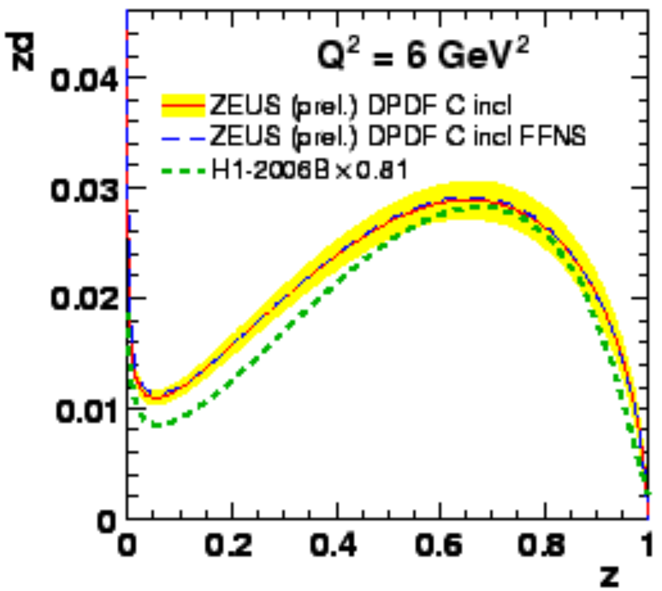
- H1 Fit A / ZEUS fit S

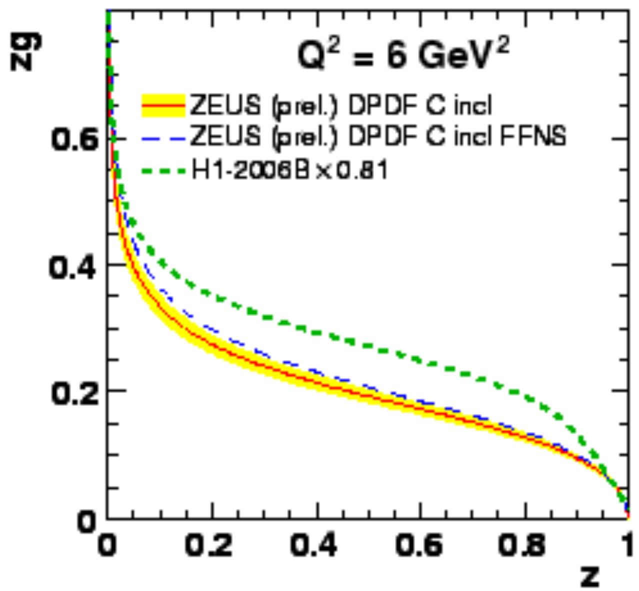
$zg(z,Q_0^2)$ = const

- H1 Fit B / ZEUS Fit C

$zg(z,Q_0^2)$

$= Az^B(1-z)^C$

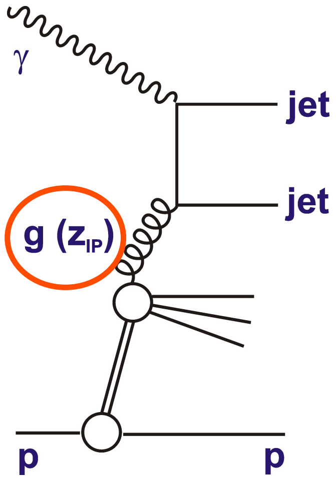


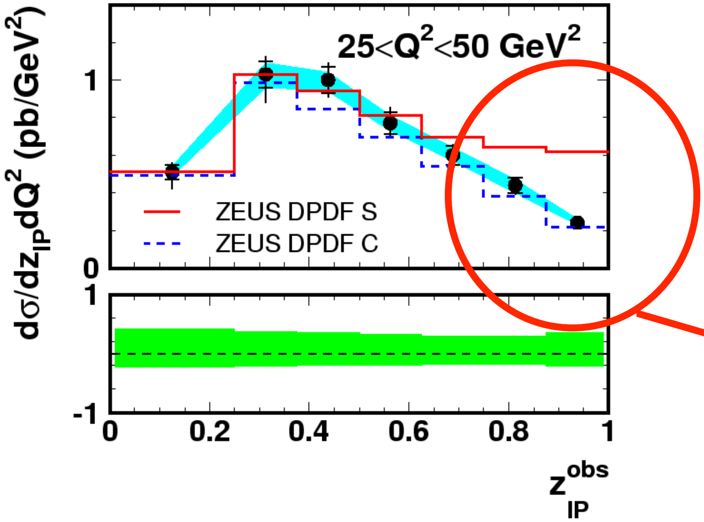


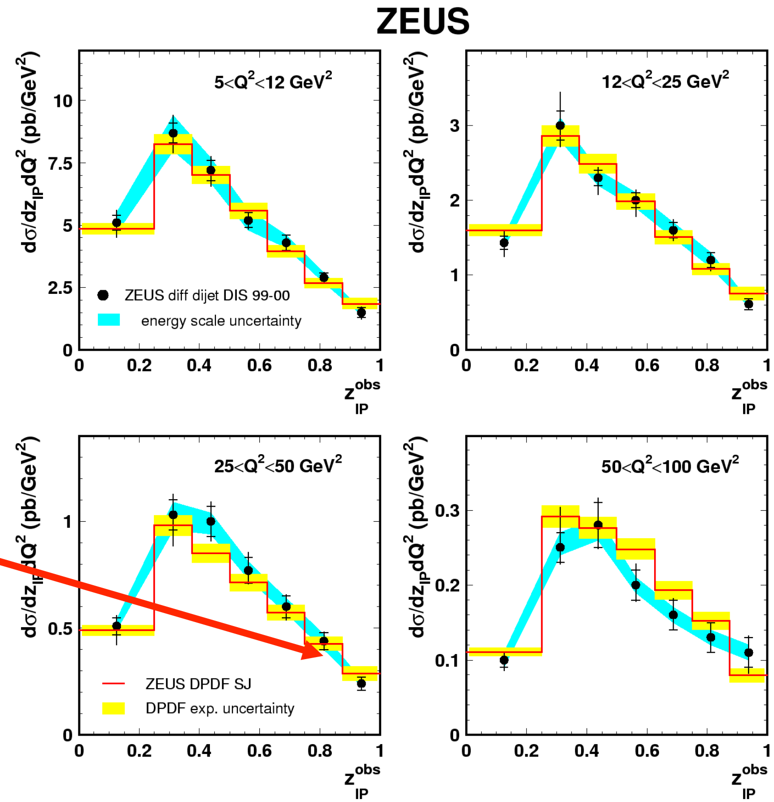
- Gluon dominates

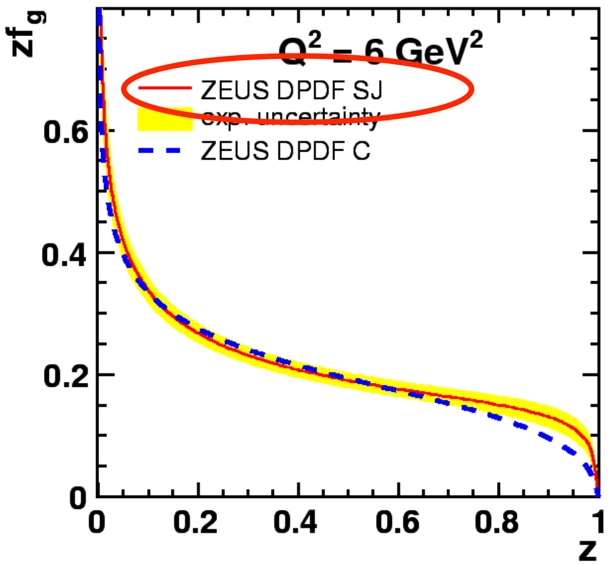
- Reasonable agreement with H1 up to large uncertainty on high z gluon

Dijets in DIS & high z gluons



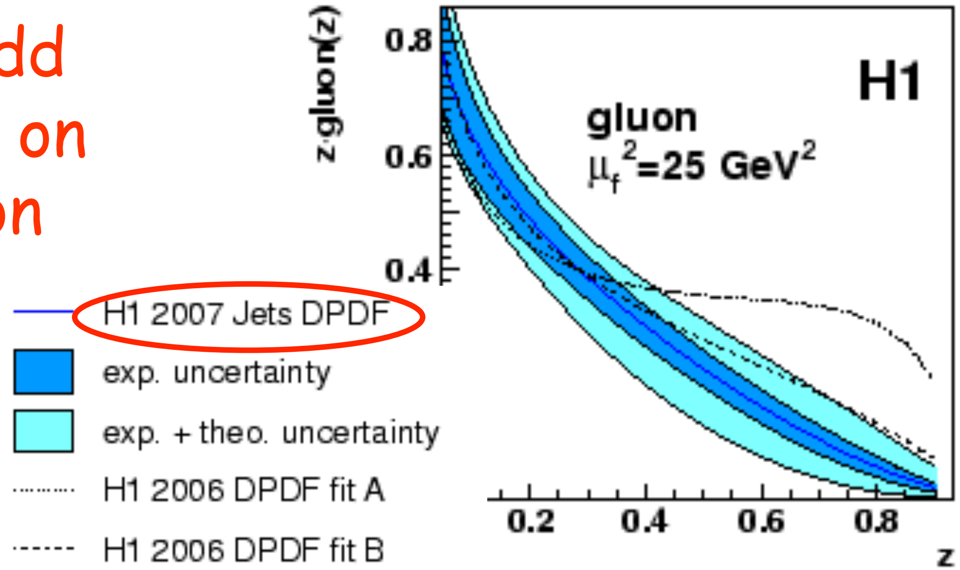






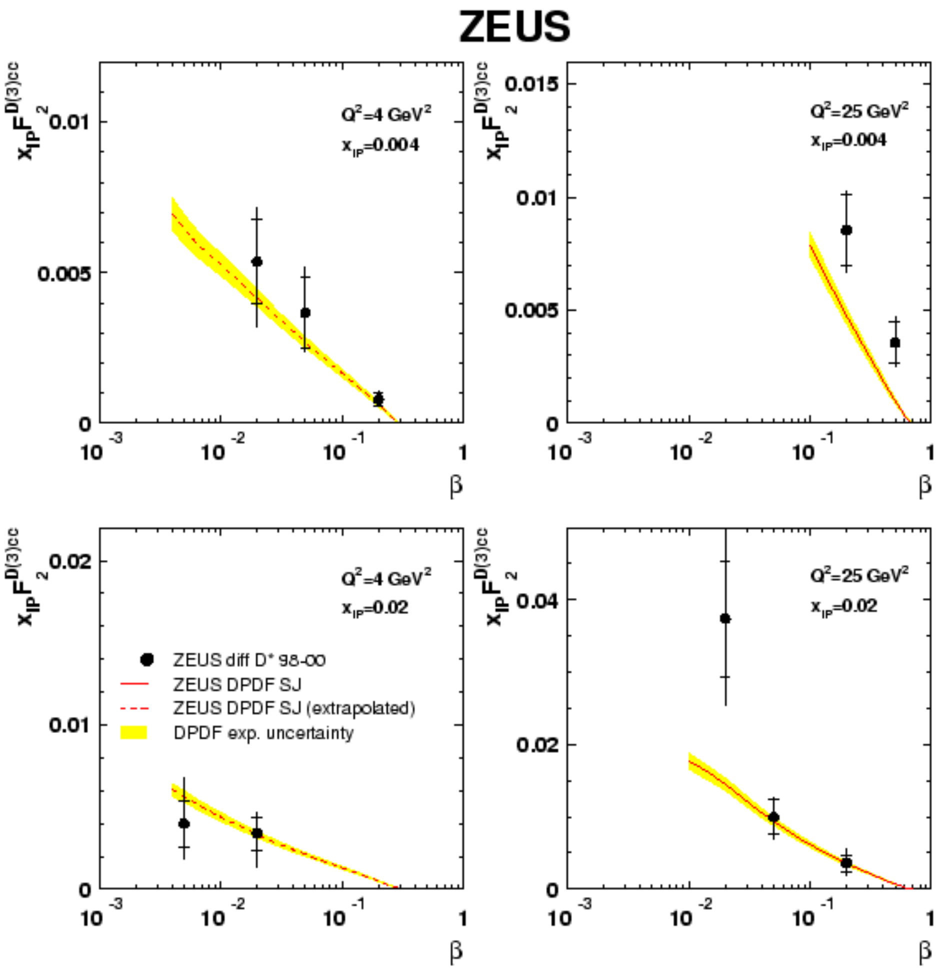
... jet cross sections add constraint on high z gluon in fits:

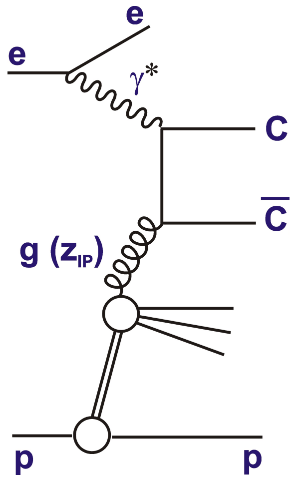
→ More DPDF sets

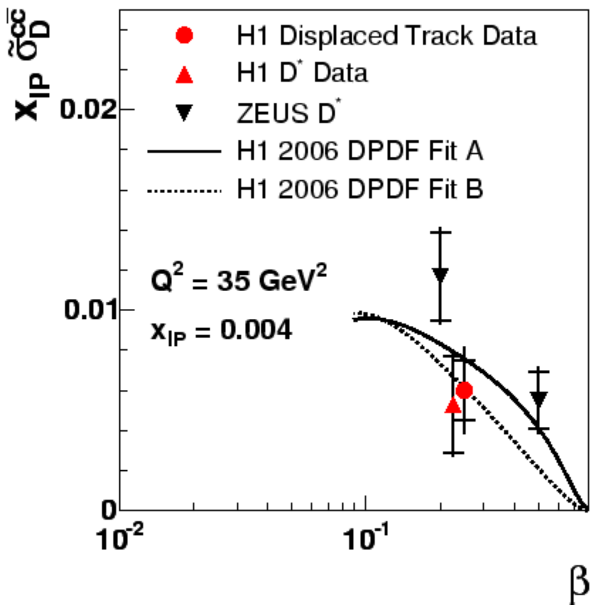


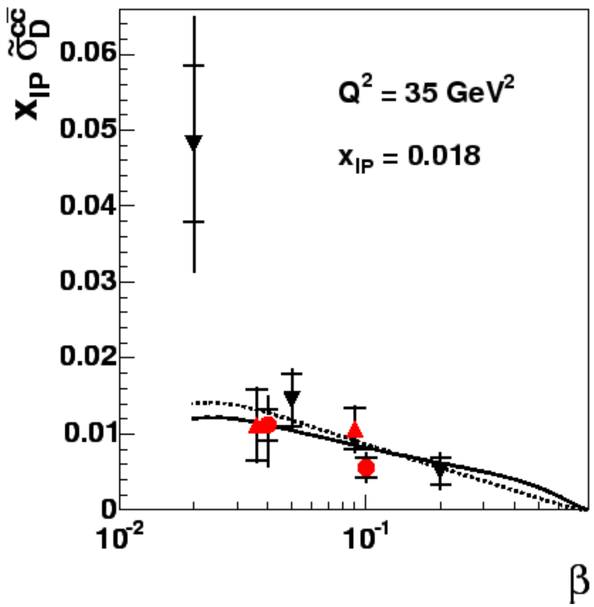
Describing other diffractive DIS processes

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



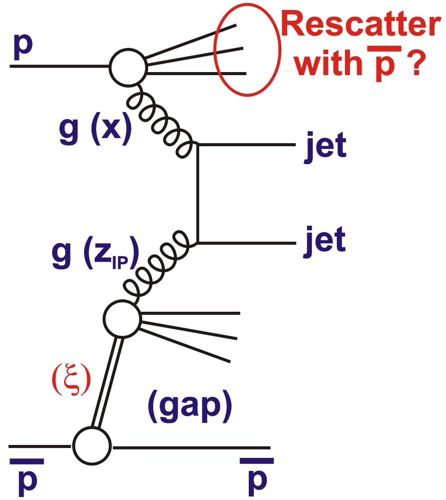


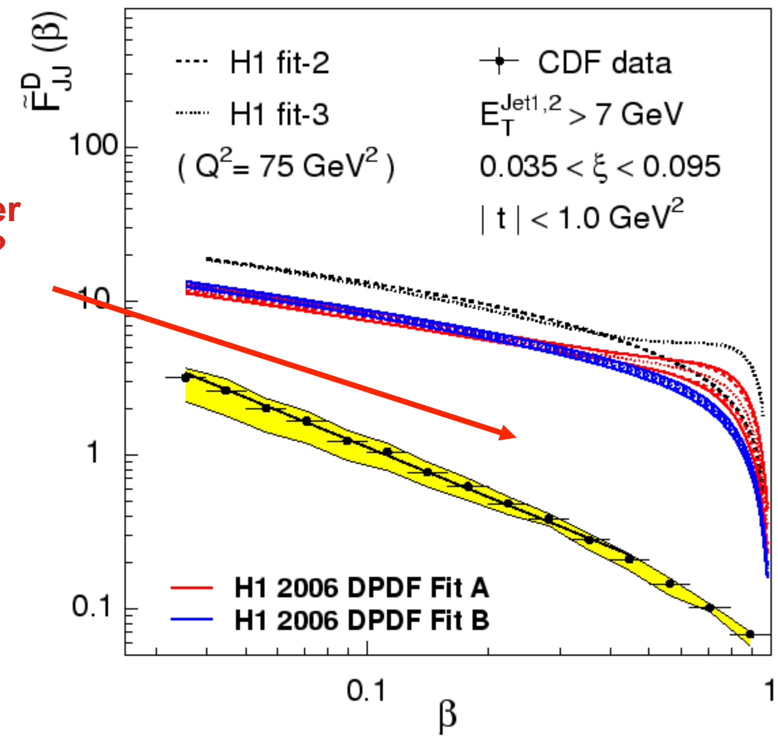




.. meanwhile in pp(bar) …

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



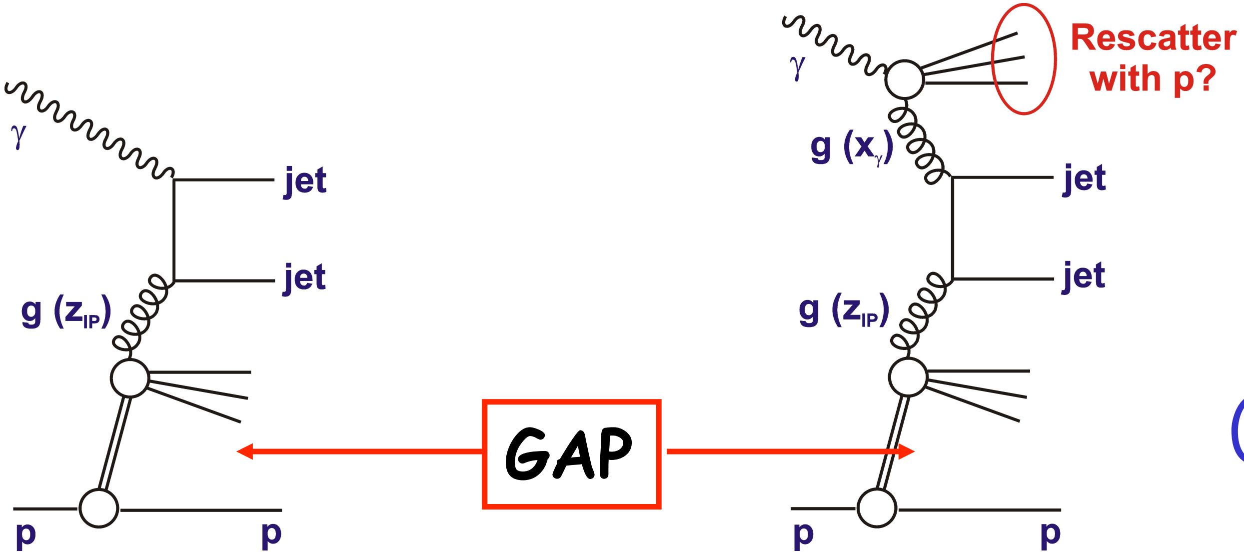


… explained by rescattering / absorption

… photoproduction jets as the perfect control experiment?…

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

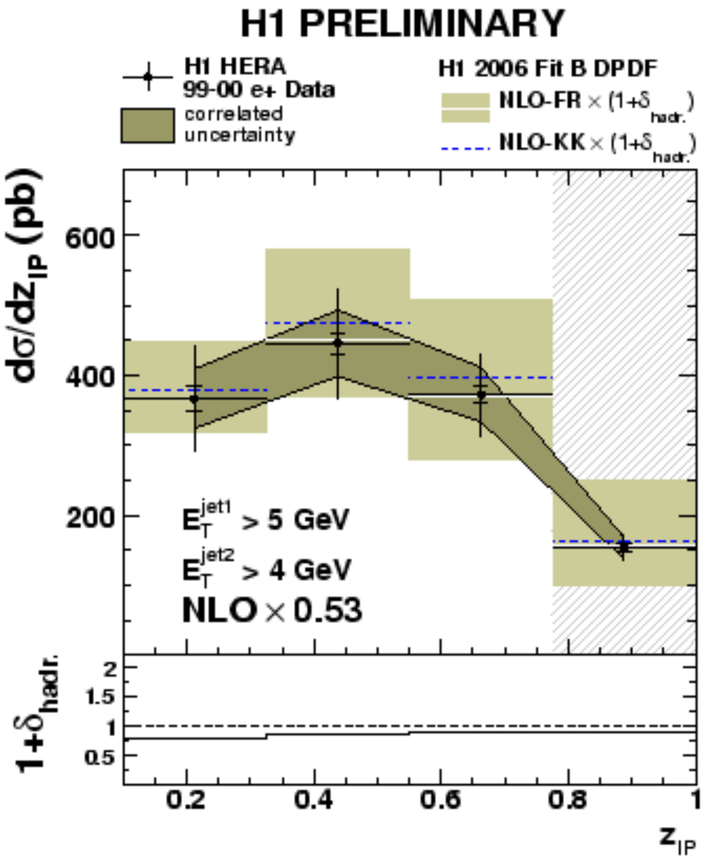
"S^2 = 1"



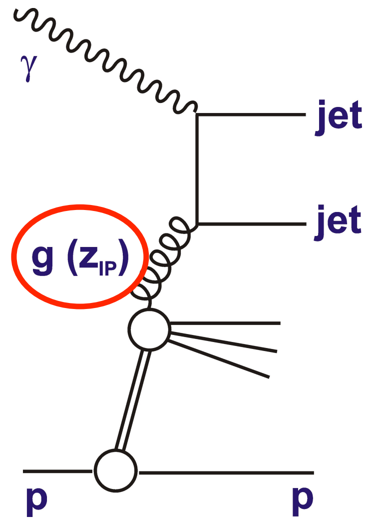
"Resolved" photon
(x_γ < 1)

"$S^2 \sim 0.34$"
(KKMR - but see later…)

x-section Differential in z_{IP}

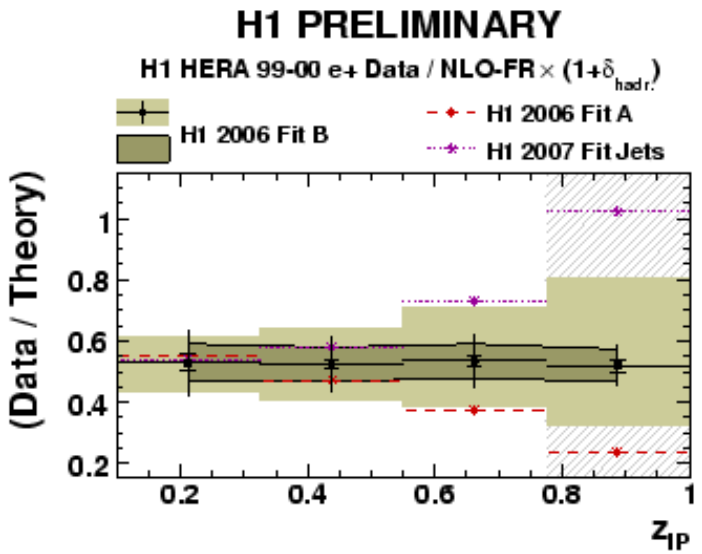


$$z_{IP} = \frac{\sum_{jets}(E + p_z)}{2E_p\ x_{IP}}$$



Global suppression ~0.5 needed for NLO calculations

DPDF uncertainties small at low z_{IP}, but explode at high z_{IP} (highest z_{IP} bin even beyond range of DPDF fits)



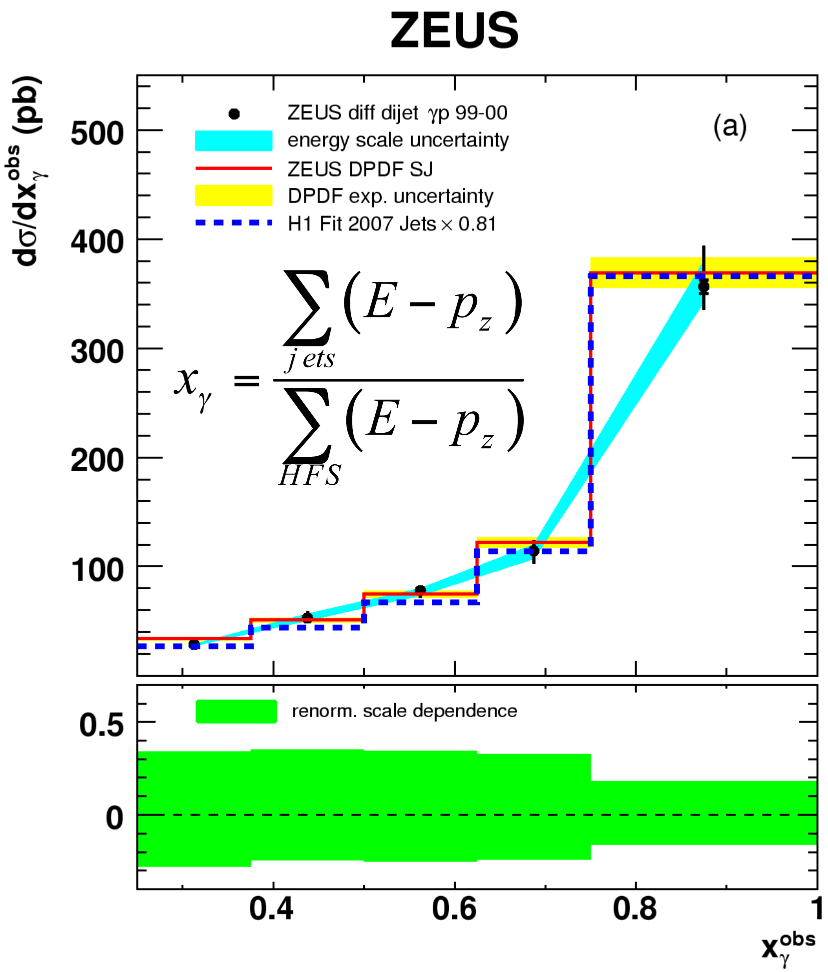
Ratios to H1 Fit B, with μ_f, μ_r = p_t:

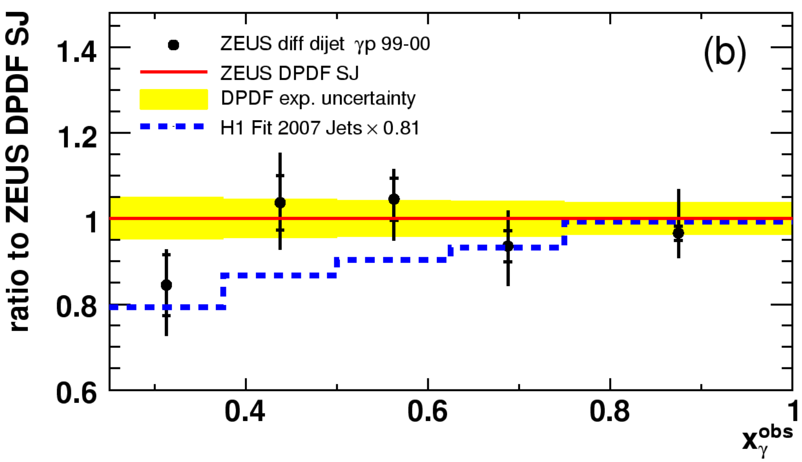
H1: $S^2 = 0.54 \pm 0.01(\text{stat.})$

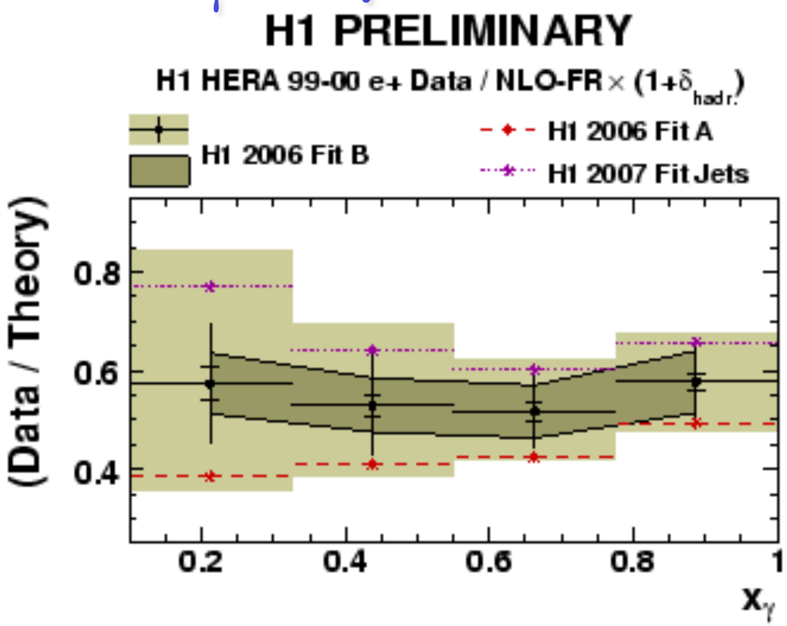
$\pm 0.10(\text{syst.}) \pm 0.13(\text{scale})$

ZEUS: S^2 about 0.9 … hmmm!

x_γ Dependence





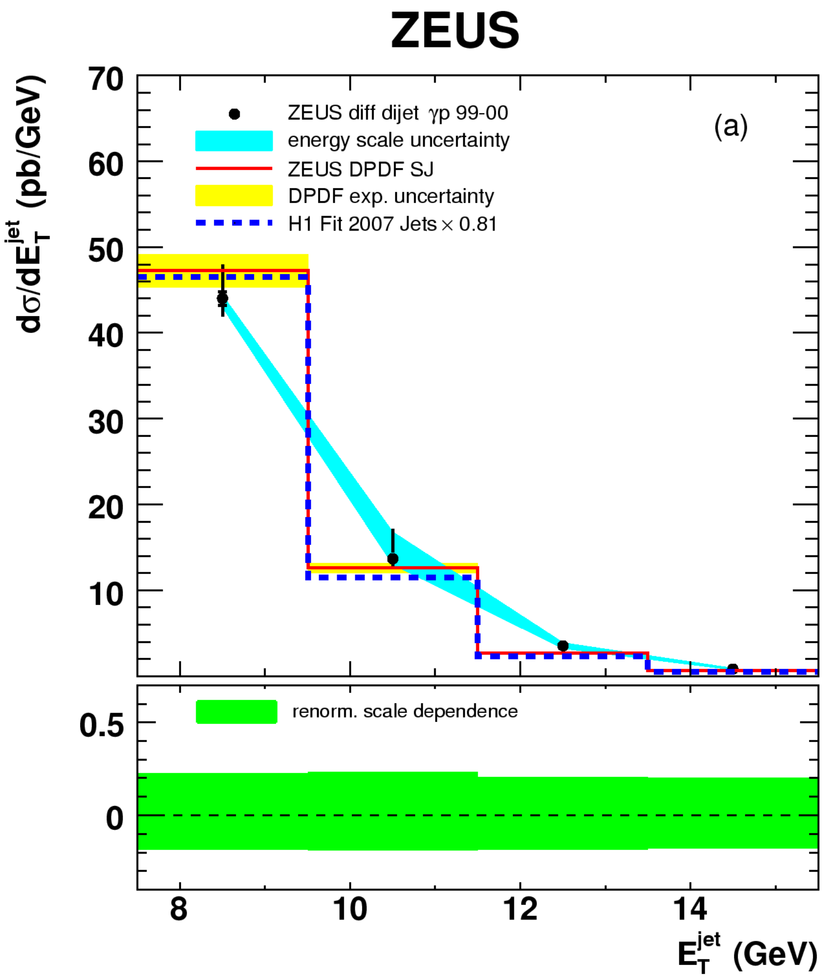


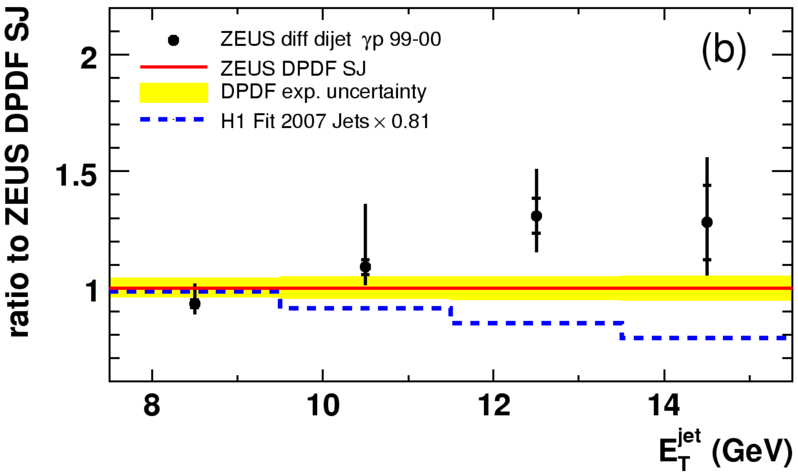
- Good shape description → no significant difference between high / low x_γ !

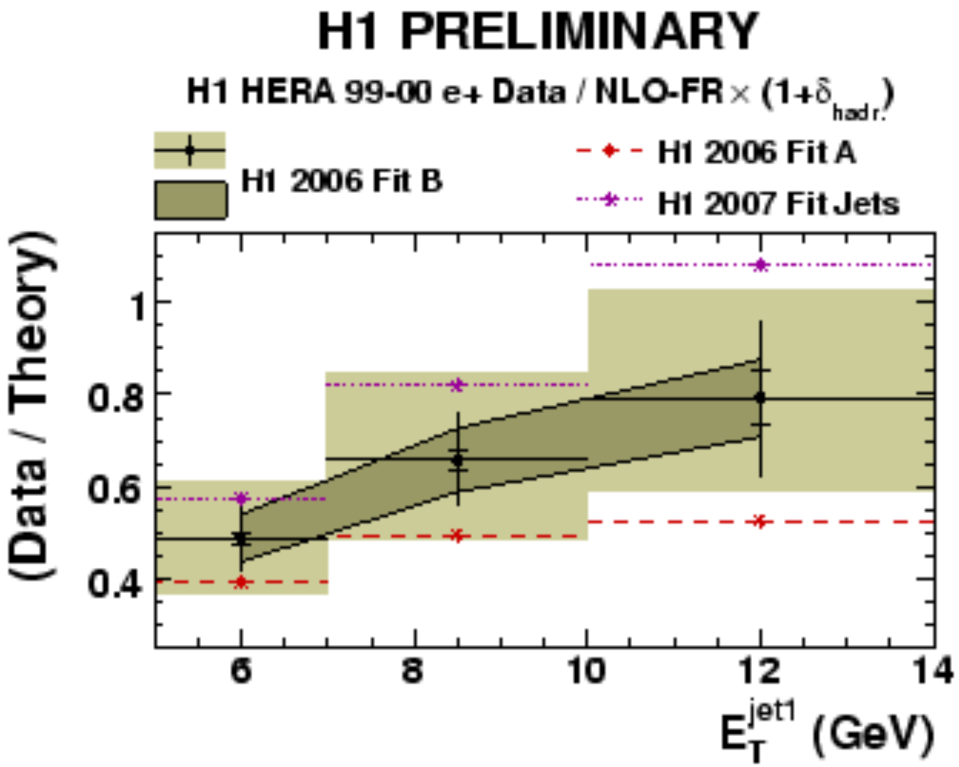
- H1: $E_t^{jet1} > 5$ GeV
... suppression by factor ~2

- ZEUS: $E_t^{jet1} > 7.5$ GeV
... little or no suppression

E_T Dependence



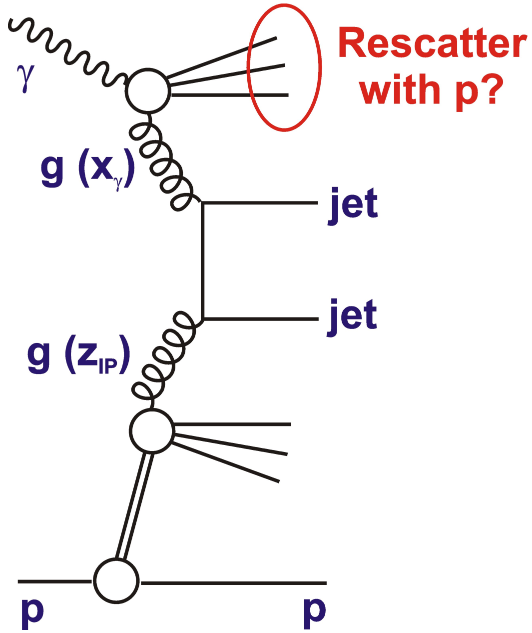




Some evidence for a dependence of gap survival probability on E_T

Both collaborations consistent with no suppression @ E_T > 10 GeV

New KKMR Ideas [hep-ph/0911.3716]



Direct contribution remains unsuppressed (but subject to hadronisation migrations).

Suppression factor 0.34 applies to Hadron-like (VMD) part of photon structure only
→ Expect $S^2 = 0.34$ only at very low $x_\gamma < 0.1$

Point-like (anomalous) part of photon structure has a smaller suppression
→ Expect less suppression at intermediate x_γ
→ Possible mechanism to generate E_T dependence of S^2 via inhomogeneous term in DGLAP E_T evolution (small effect?)

$S^2 \sim 0.75 - 0.85$ for $E_T > 7.5$ GeV
$S^2 \sim 0.7 - 0.8$ for $E_T > 5$ GeV

Agrees better with data … no full quantitative analysis yet

Summary

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

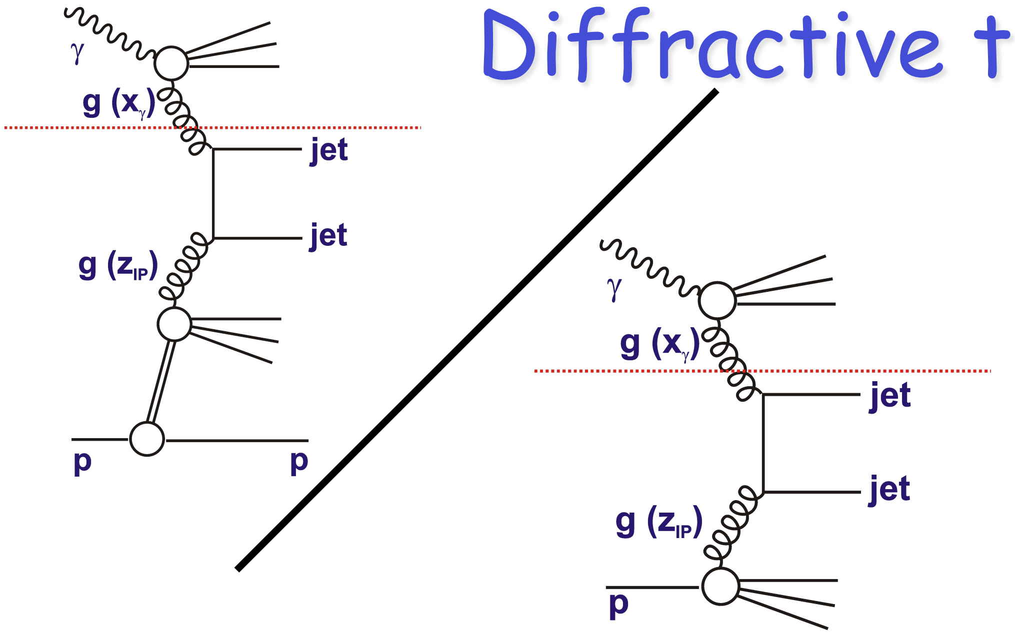
- Proton vertex factorisation with $\alpha_{IP}(t) \sim 1.11\ (+\ \delta t)$ & $b_{IP} \sim 6\ GeV^{-2}$ is good model for the 'soft' physics

- DPDFs well constrained & tested in DIS, can be applied at LHC

- Dijet photoproduction data still provide a challenge to theoretical understanding of gap survival

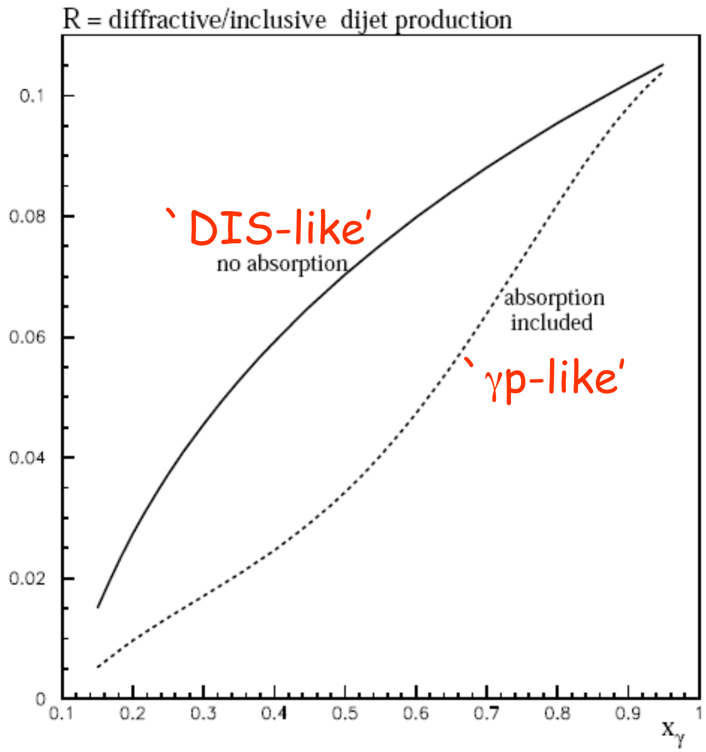
- More precision still expected, especially from HERA-II

Diffractive to Inclusive Ratios



… a la CDF, measures ratio of diffractive gluon (convaluted with flux) to inclusive gluon

… full or partial cancellation of photon PDFs, scale uncertainites, jet energy scales …



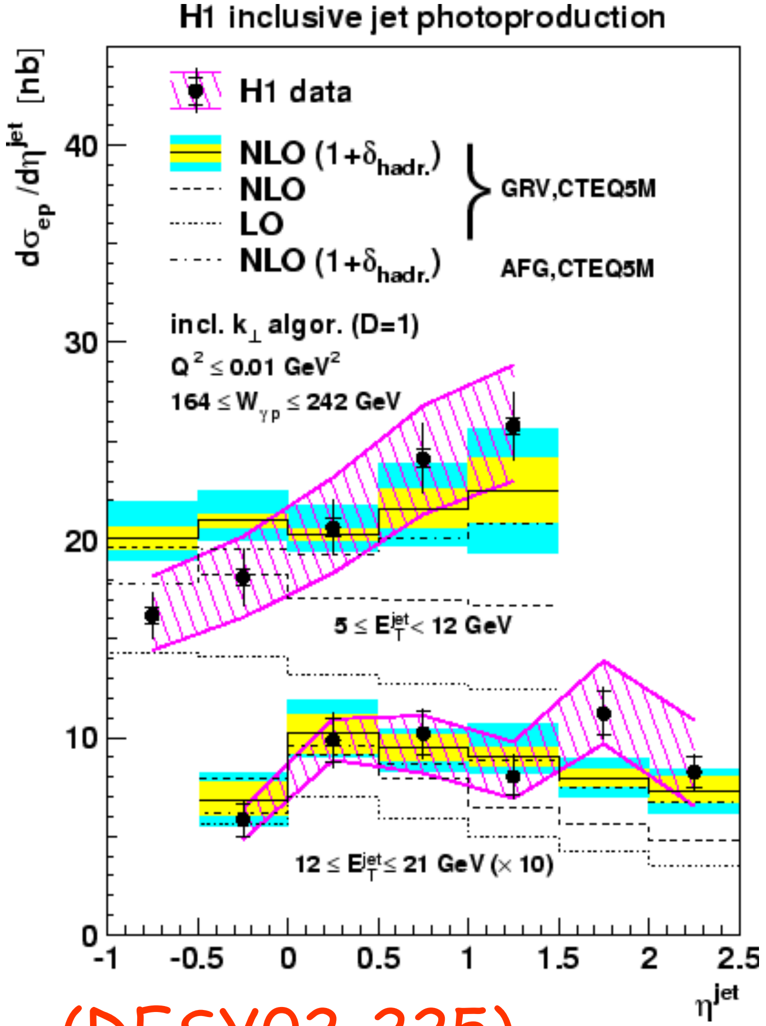
- x_γ dependence sensitive to absorption / gap survival, as well as differences between diffractive and inclusive phase space …

- e.g. Kaidalov et al.

Phys. Lett. **B567** (2003) 61.

Inclusive Photoproduction Dijet Cross Sections

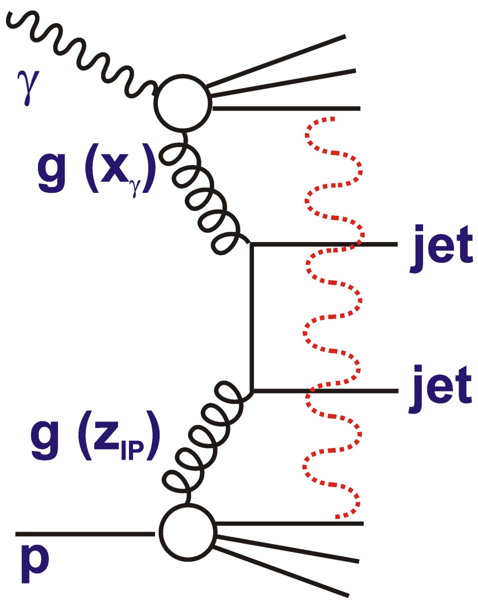
- Measured in same kinematic range with same method as diffractive cross sections
- Acceptance corrections using PYTHIA (CTeQ5L, GRV-G LO)



(DESY02-225)

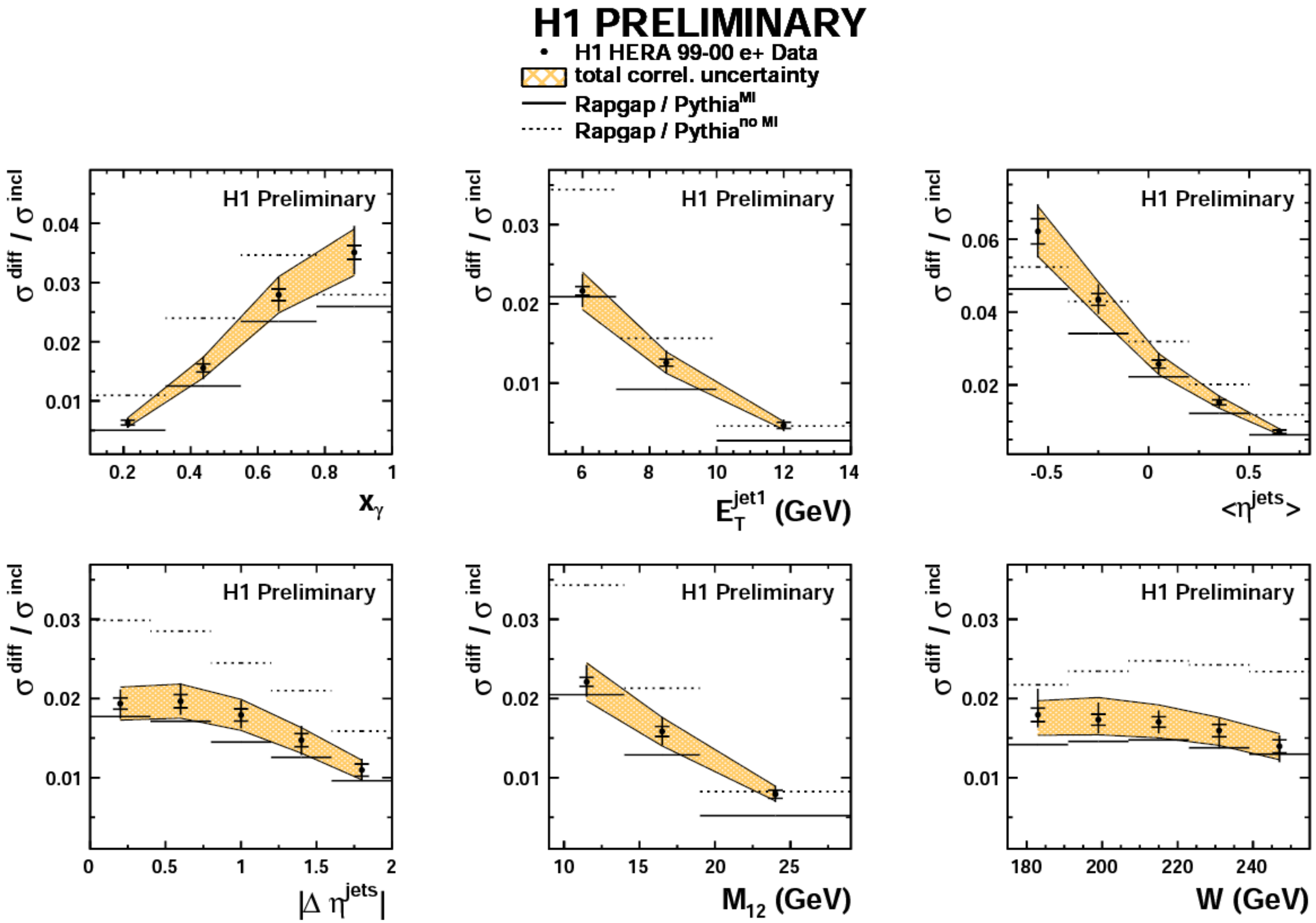
→ describes low E_T data only with inclusion of underlying event model (multiple interactions) & large hadronisation corrections

... introduces a large uncertainty ...



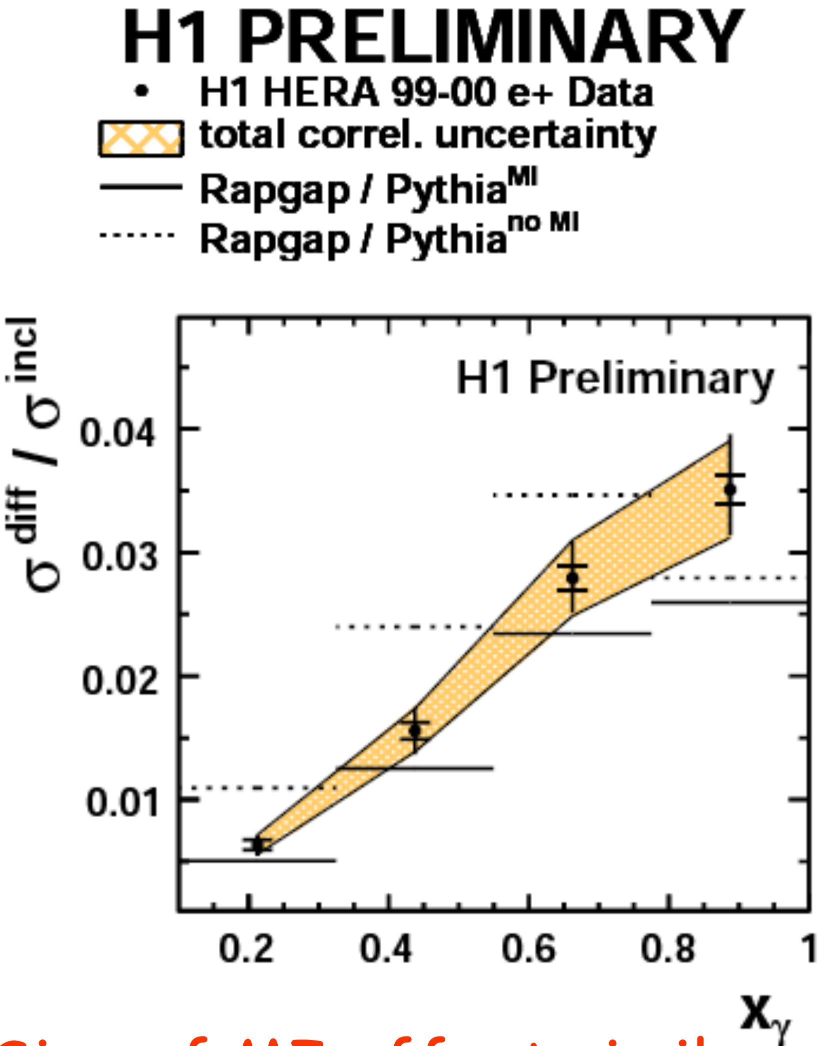
Diffractive to Inclusive Ratios

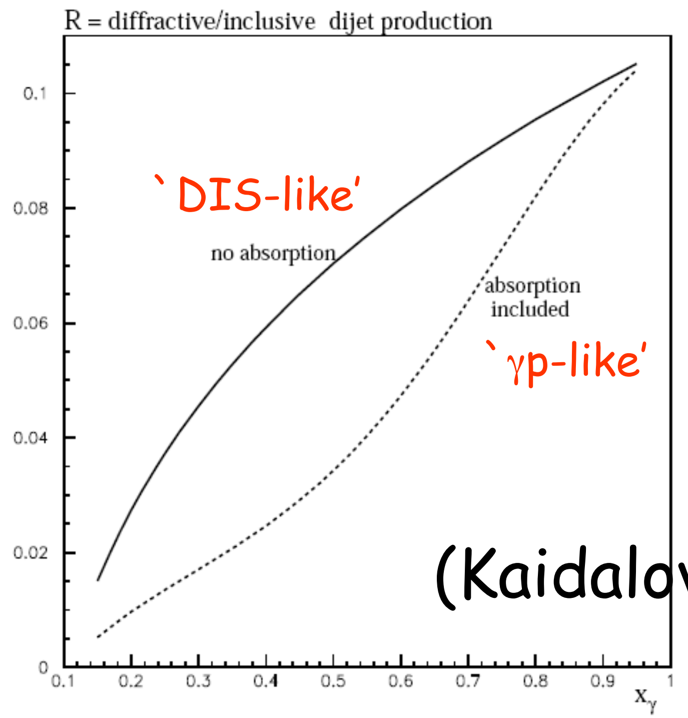
$z_{IP} < 0.8$ cut to reduce sensitivity to DPDF uncertainties



- Comparisons only with RAPGAP/PYTHIA ratios so far
- Dominant feature of distributions is phase space
- Large influence of adding multiple interactions

Diffractive / Inclusive

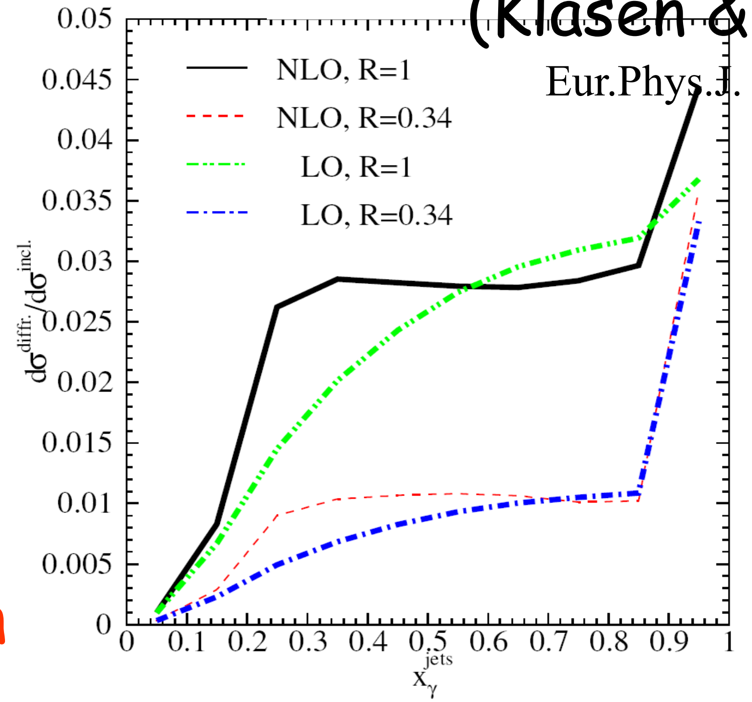




(Kaidalov et al.)

(Klasen & Kramer)

Eur.Phys.J. C38 (2004) 93



inclusive

$p_T^{jet1} > 5$ GeV

$p_T^{jet2} > 4$ GeV

$-1 < \eta_{lab}^{jet1,2} < 2$

$Q^2 < 0.01$ GeV^2

$0.3 < y < 0.6$

diffractive

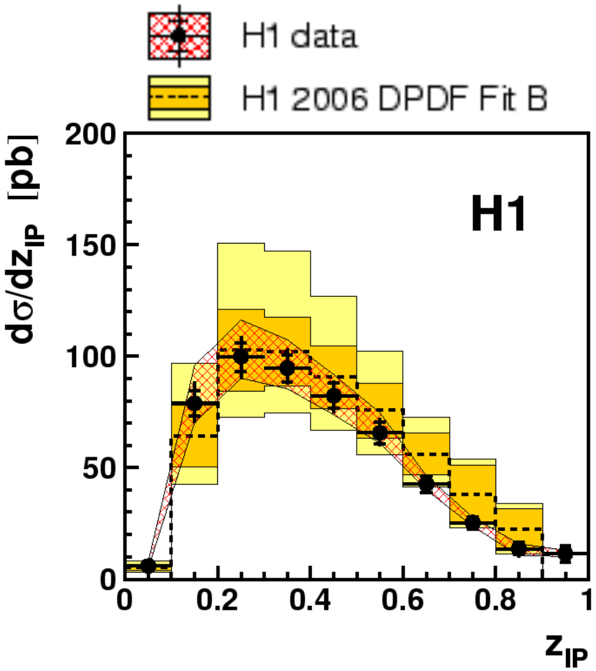
$x_{IP} < 0.03$

$M_Y < 1.6$ GeV

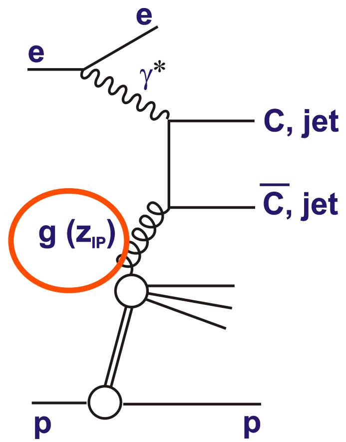
$-t < 1$ GeV^2

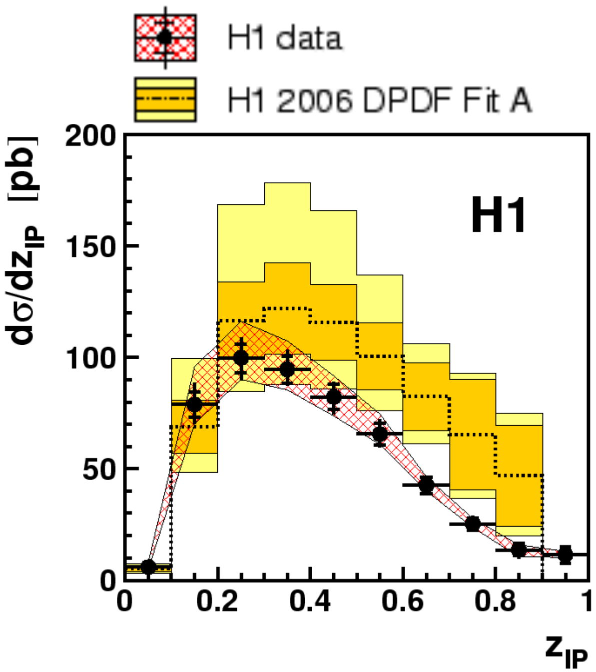
- Size of MI effect similar to that of absorption.
- MI Model → fair description

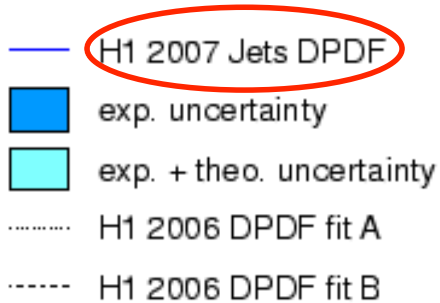
Factorisation, DIS Dijets & the high z Gluon

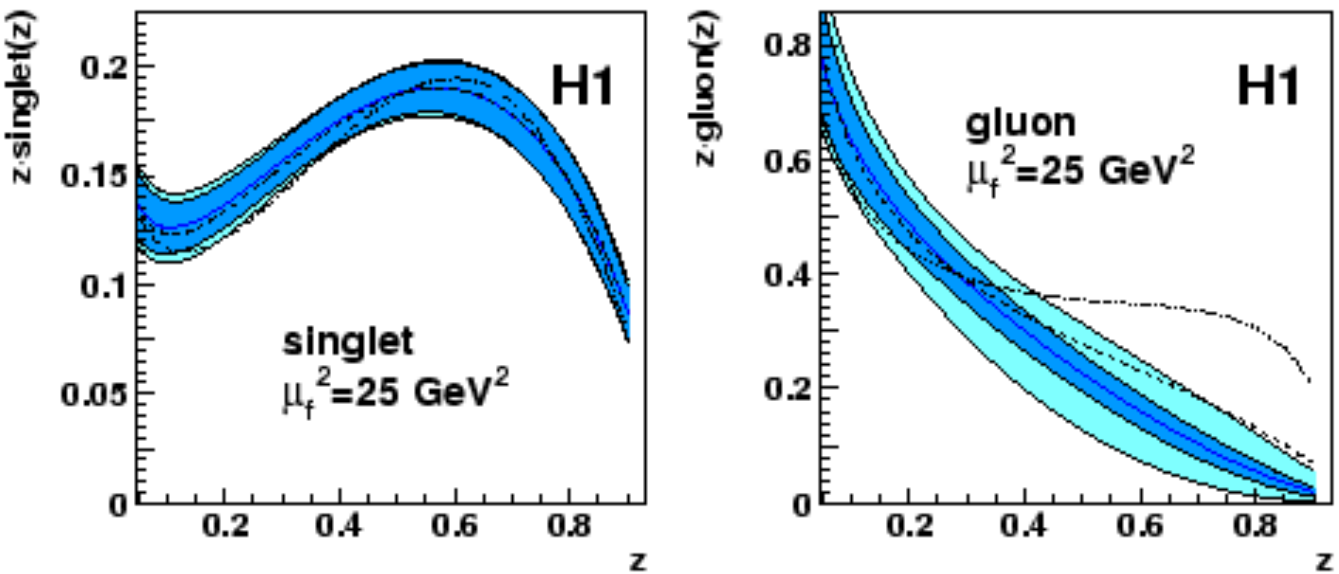


- Fit A, B describe diverse diffractive DIS data
- Dijet data dominantly at large z_{IP} … distinguish between `fit A' & `fit B'
- Include jet data in fit → `H1 2007 Jets' DPDFs

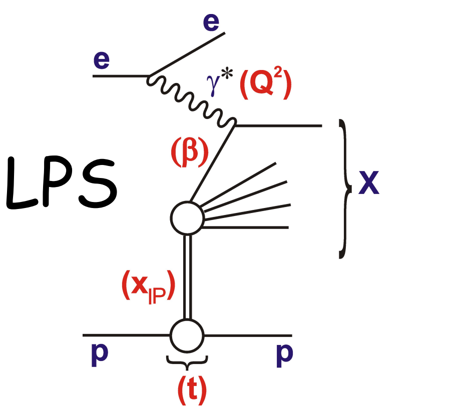


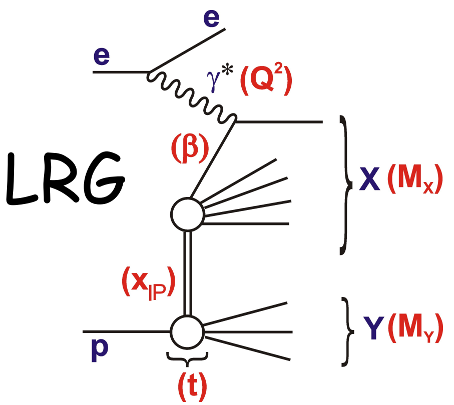


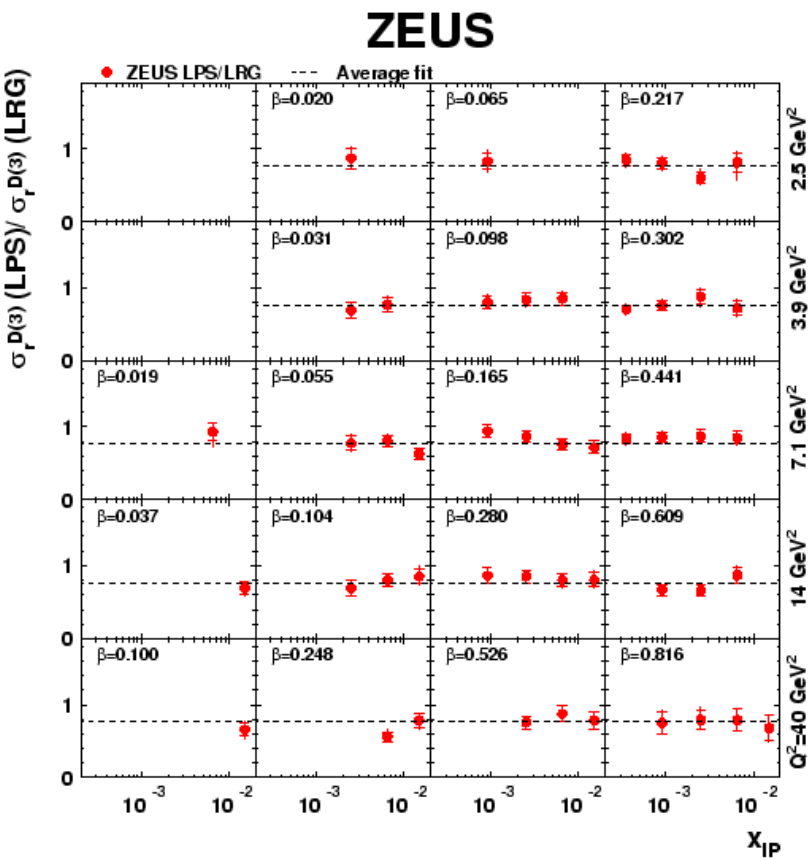


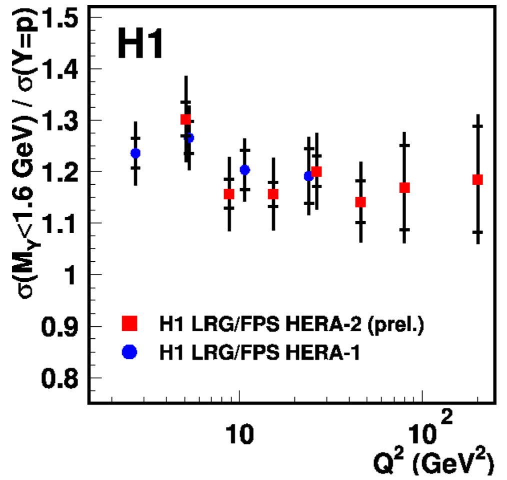


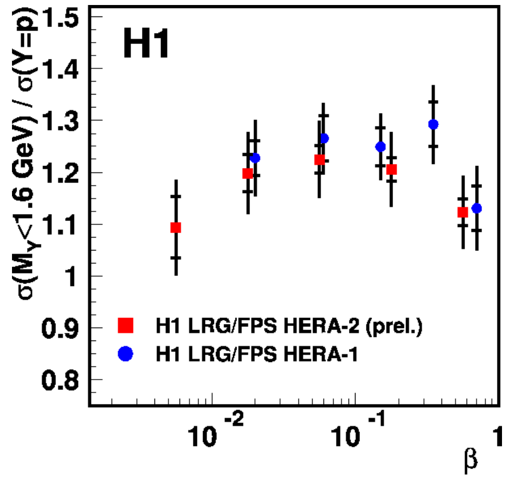
Comparisons between Methods

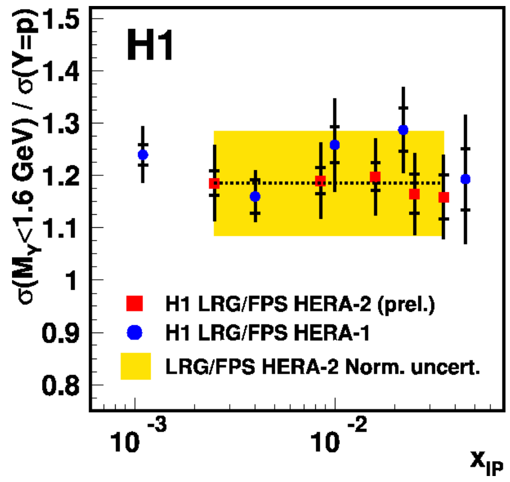








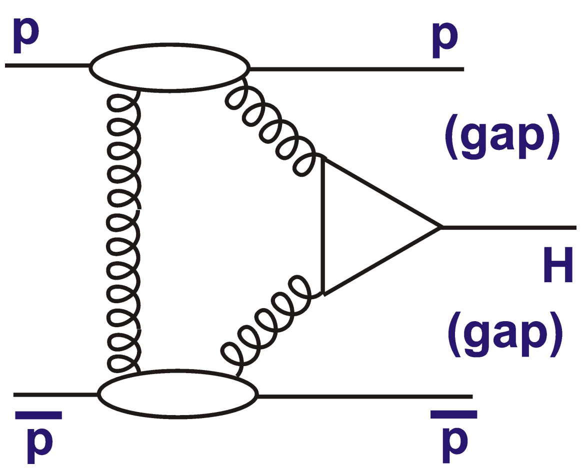


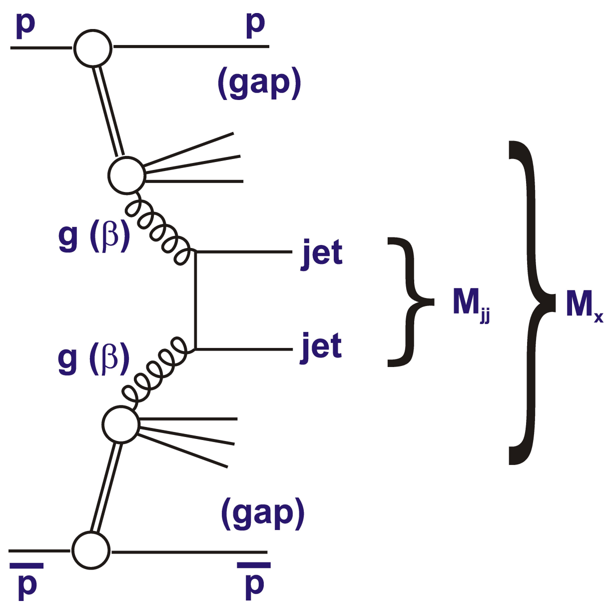


- LRG selections contain typically 20% p diss
- No significant dependence on any variable
- Similar compatibility with Mx method

… **well controlled, precise measurements**

Relation to Central Exclusive Production





HERA input to 'Central Exclusive Production'

-Unintegrated gluon density

- Gap survival constraints

- DPDFs for non-exclusive background