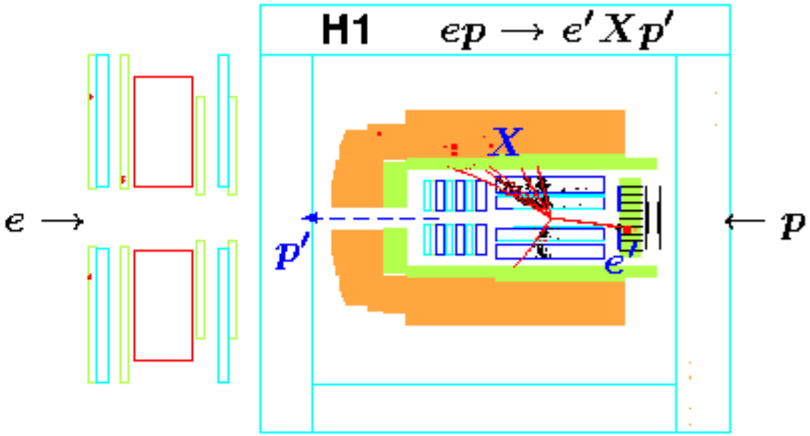
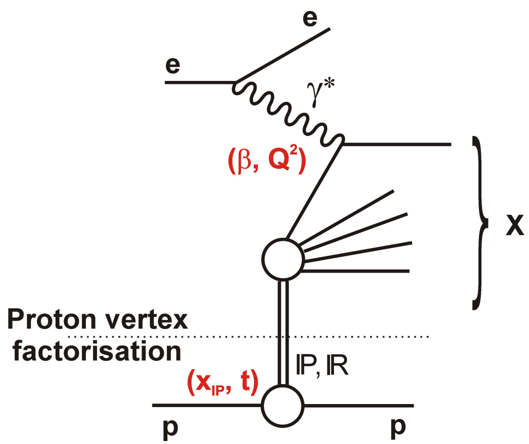
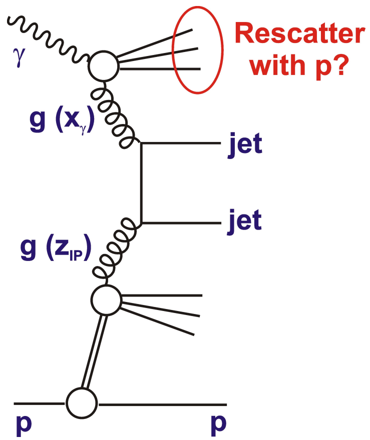
Inclusive Diffraction and Related Topics at HERA







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(University of Birmingham)
representing H1 & ZEUS

ICHEP 2010, Paris
23 July 2010

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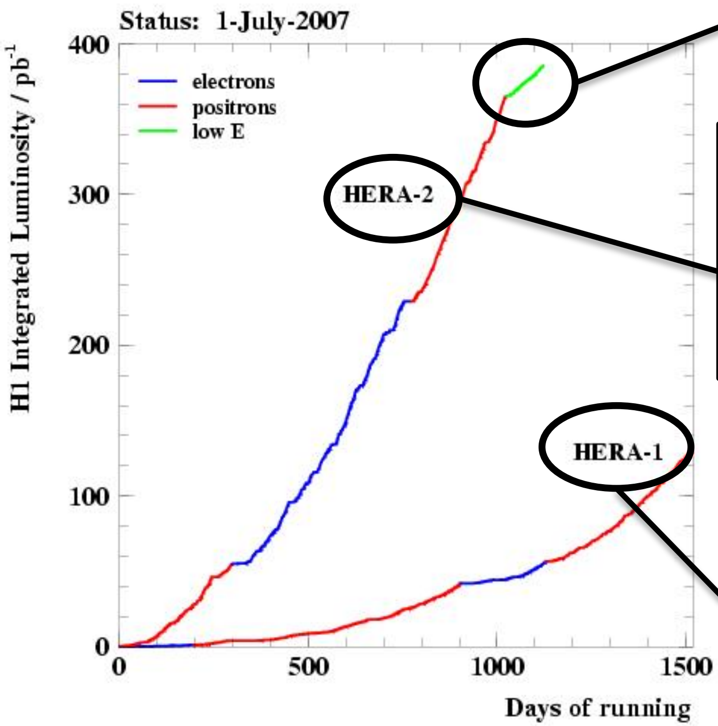


The Longitudinal Diffractive Structure Function, F_L^D [H1]

Inclusive [LRG] Measurement of Diffractive DIS [H1]
Measuring F_2^D with a Very Forward Proton Spectrometer [H1]
Diffractive DIS Cross Sections with a Leading Proton [H1]
Leading Neutron Production in DIS [H1]
Diffractive Jet Production in DIS with a Leading Proton [H1]

DIS with Leading Protons or Large Rapidity Gaps [ZEUS]
A QCD Analysis of ZEUS Diffractive Data [ZEUS]
Diffractive Dijet Photoproduction in ep Collisions [H1]
Leading Proton Production in DIS [ZEUS]
Dijet Photoproduction for Leading Neutron Events [ZEUS]

- Diffractive DIS with Tagged Protons & Rapidity Gaps
- The Soft Proton Vertex and the Pomeron Flux Factor
- Extracting and Testing Diffractive Parton Densities
- Absorptive Effects and Rapidity Gap Survival Probability
- Sub-Leading Exchanges and the Pion Structure Function

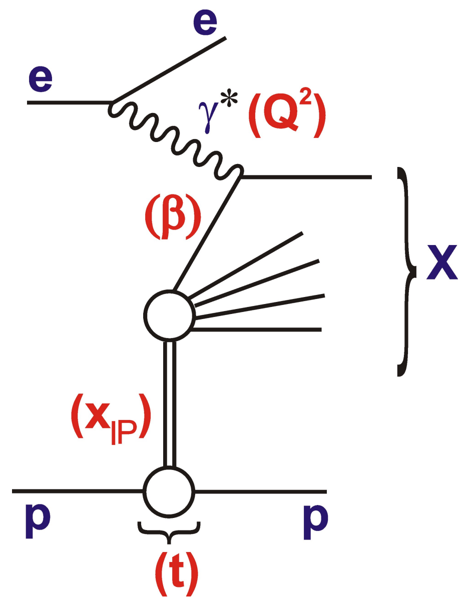
Diffractive DIS Kinematics

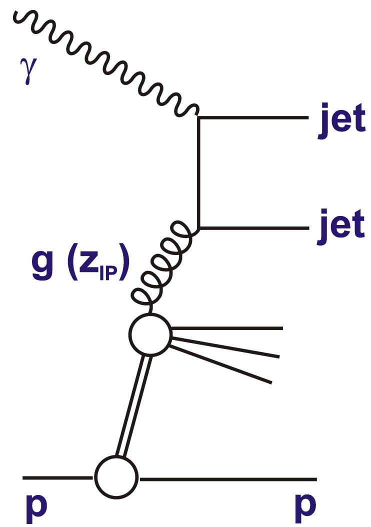
Standard DIS variables ...

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

Additional variables for diffraction:

- **t** = squared 4-momentum transfer at proton vertex
- $x_{IP} = 1 - x_L$ = fractional momentum loss of proton (IP/p)
- $\beta = x / x_{IP}$ = momentum fraction q / IP
- z_{IP} = generalisation of β beyond QPM (momentum fraction g / IP or q / IP)



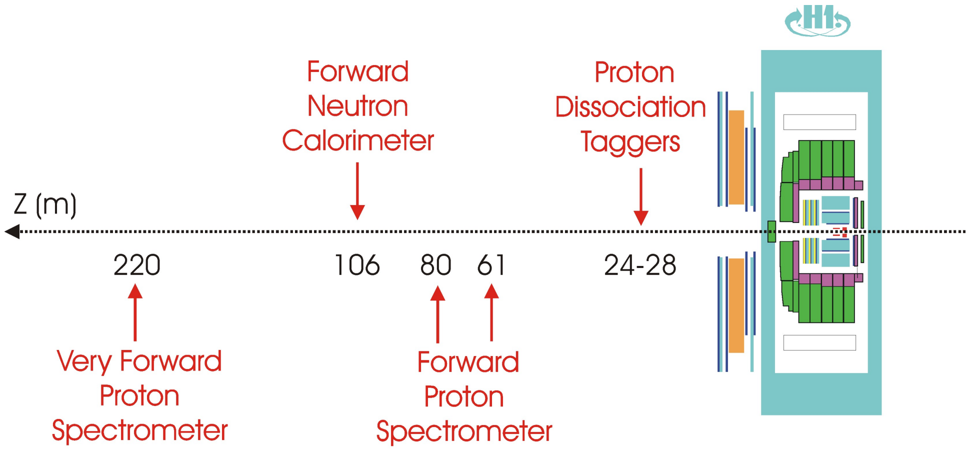


Inclusive data in form of 'reduced' diffractive x-sec ...

$$\sigma_r^{D(4)}(\beta, Q^2, x_{IP}, t) = F_2^{D(4)} - \frac{y^2}{Y_+} F_L^{D(4)} \sim F_2^{D(4)}$$

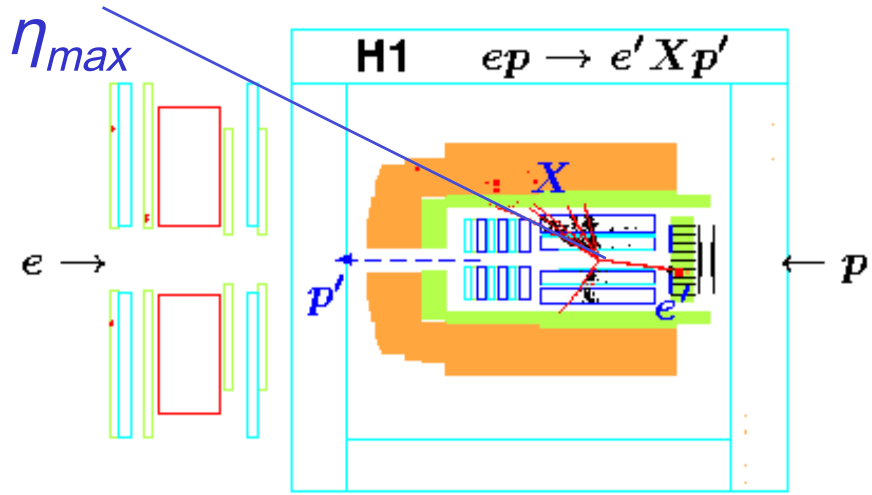
Signatures and Selection Methods

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



Limited by statistics and p-tagging systematics

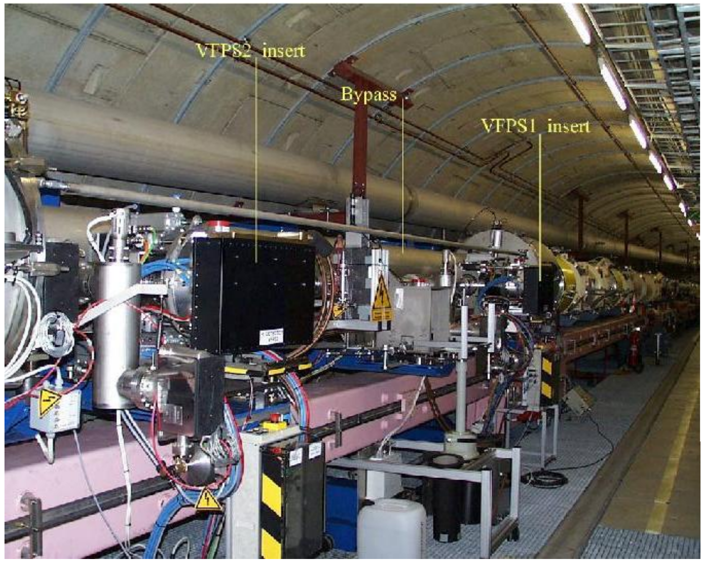
`Large Rapidity Gap' **(LRG)** adjacent to outgoing (untagged) proton

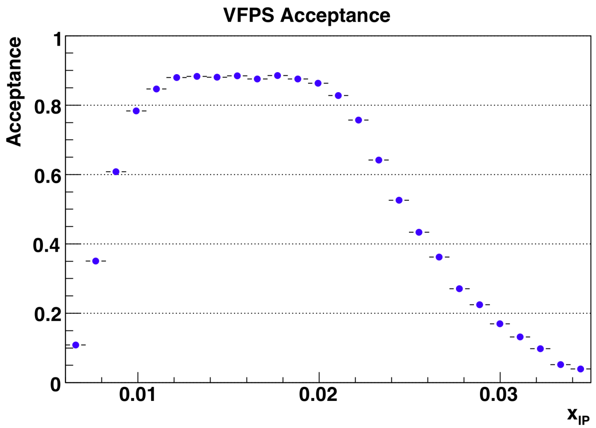


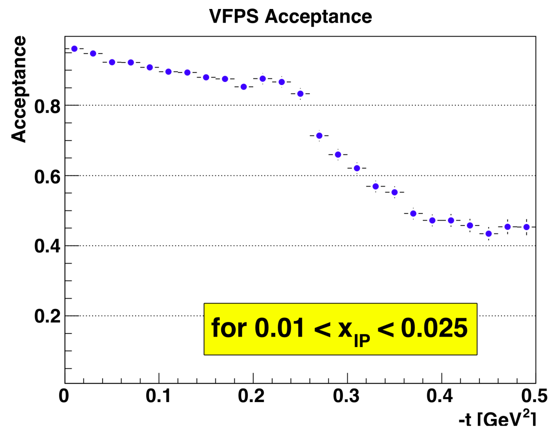
Limited by p-diss systematics

- The 2 methods have very different systematics
- Both experiments also have Zero Degree Calorimeters for forward neutron measurements

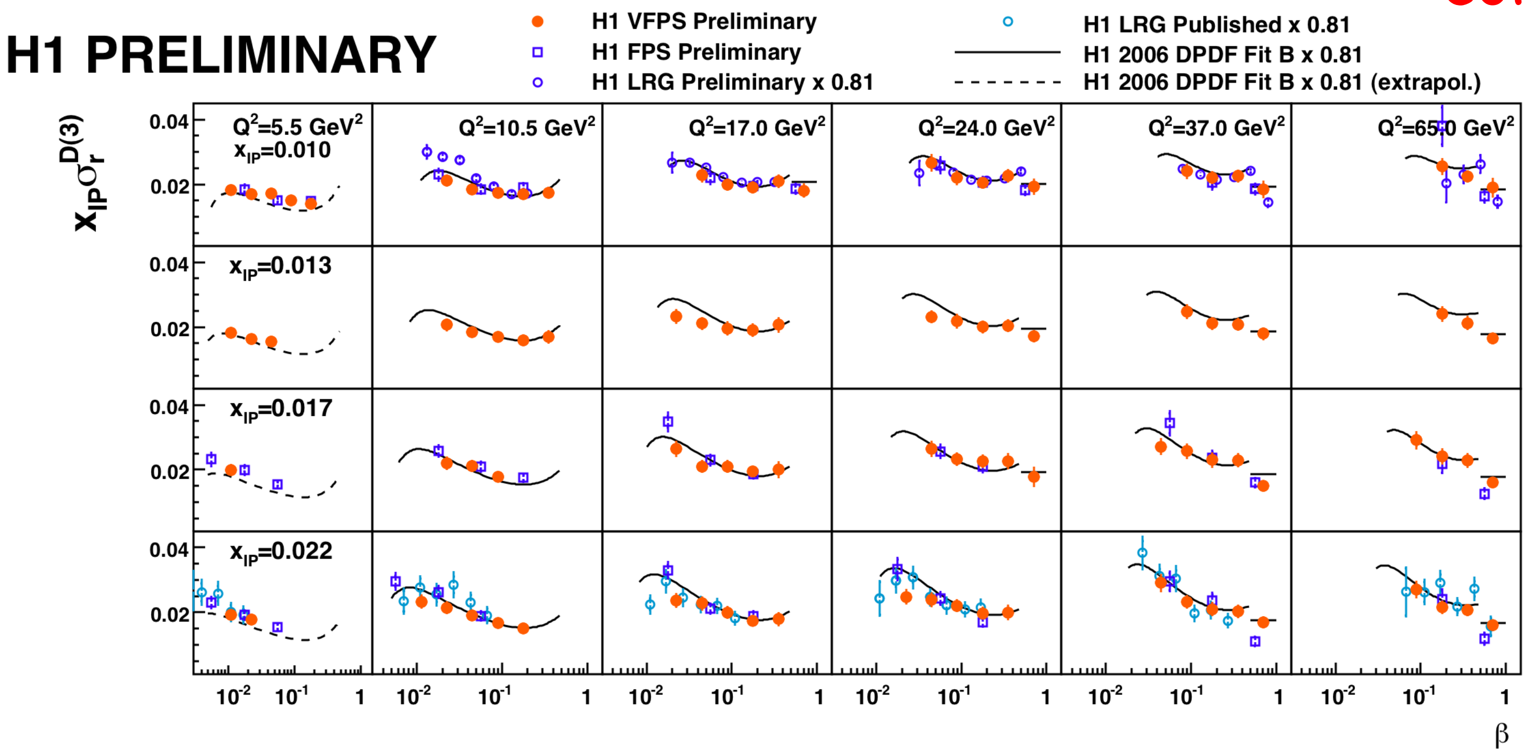
First Physics Results from H1 VFPS







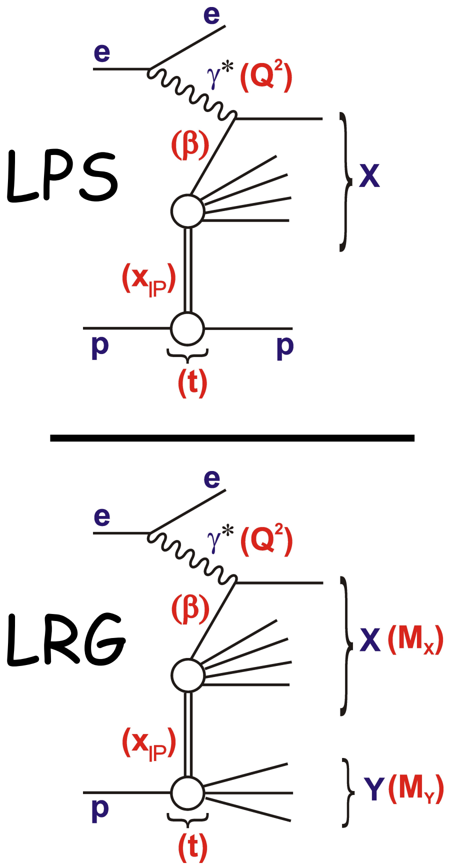
>90% acceptance over wide region - complementary x_{IP} range to LRG

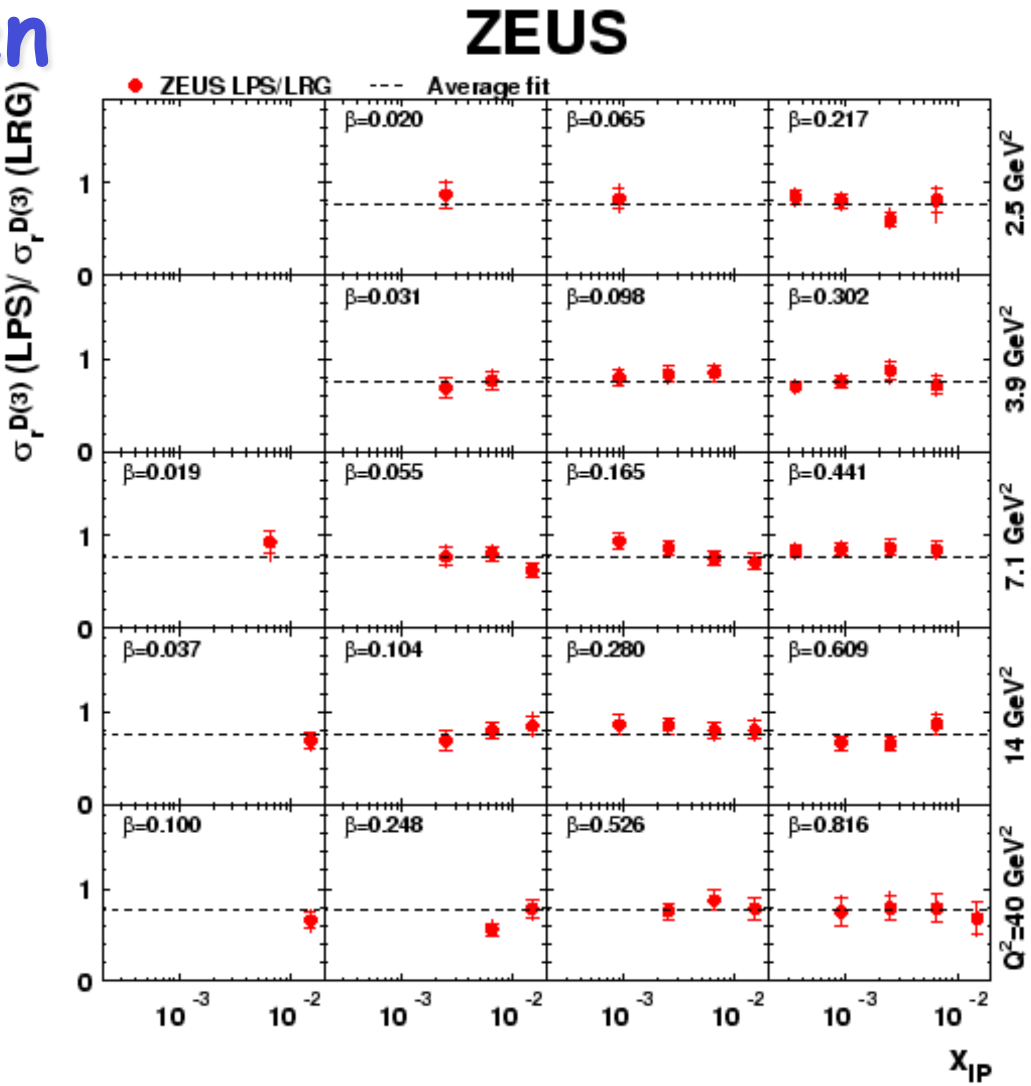


95pb-1

First precise data recently released ...

Comparisons between Methods



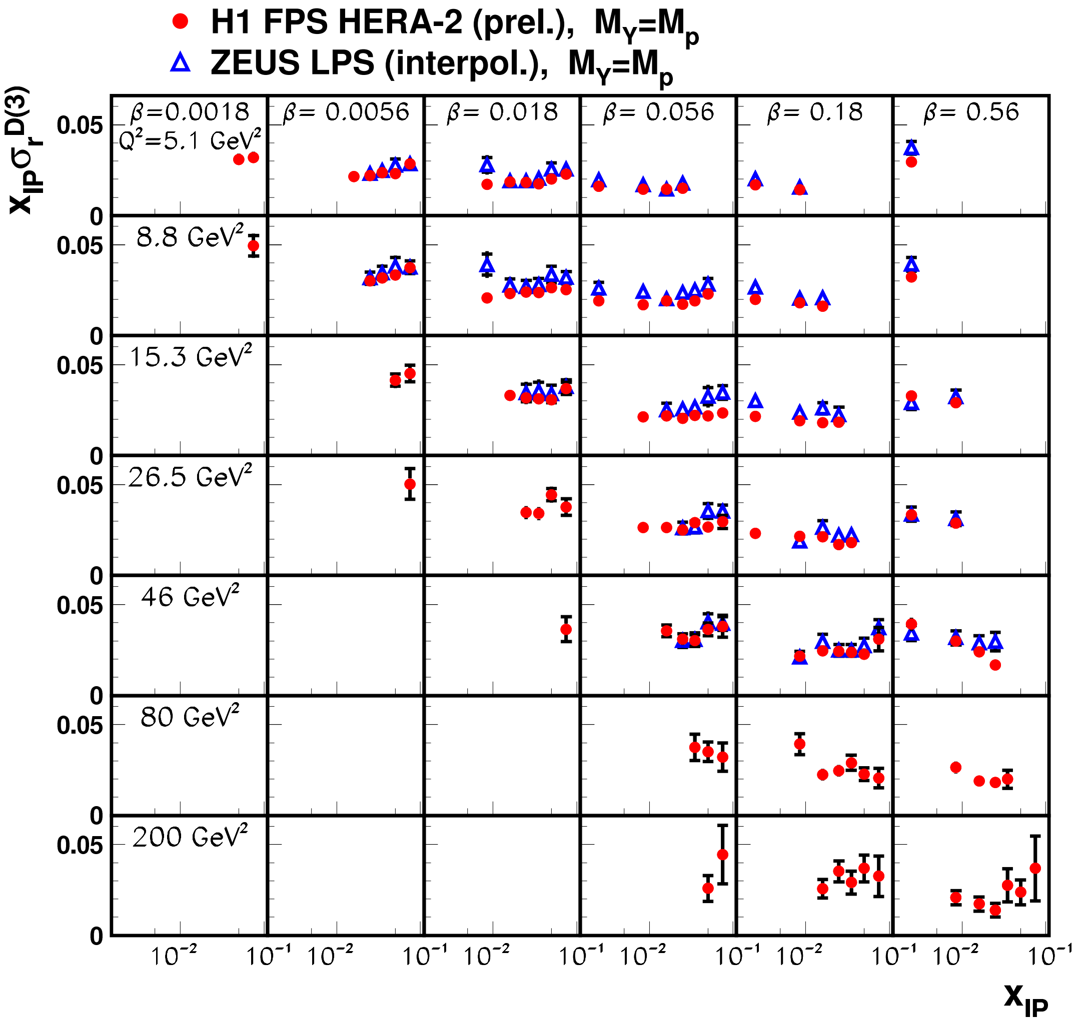


- LRG selections contain typically 20% p diss
- No significant dependence on any variable
- **… well controlled, precise measurements**

ZEUS v H1 Proton-tagged Data

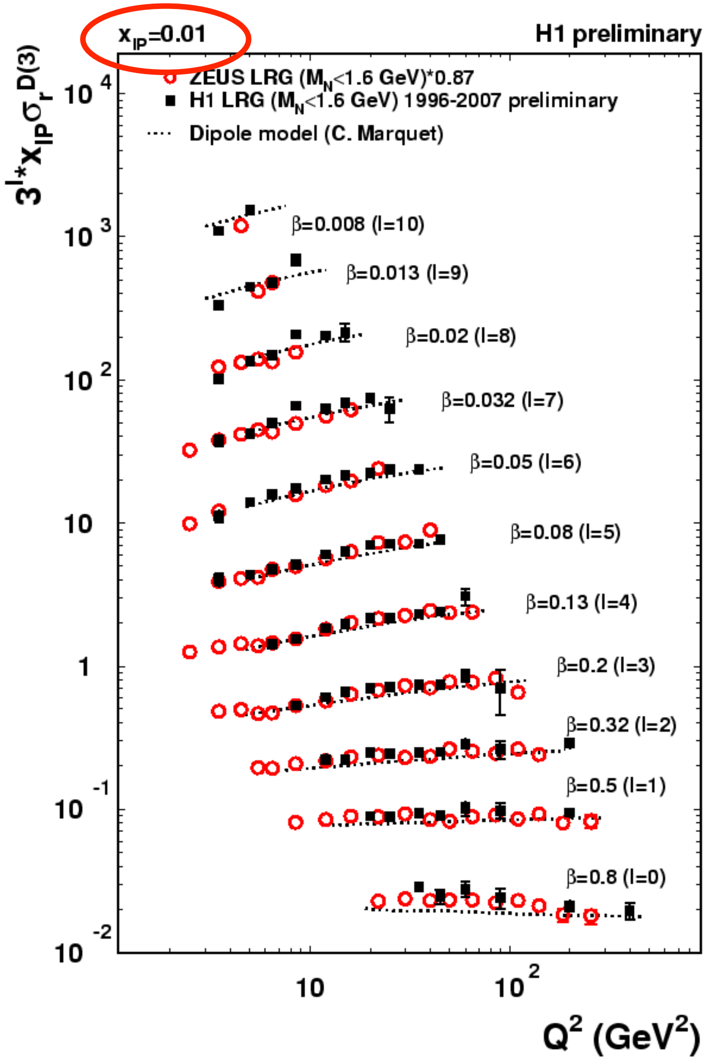
Quadruple-differential cross sections! $\sigma_r^{D(4)}(\beta, Q^2, x_{IP}, t)$

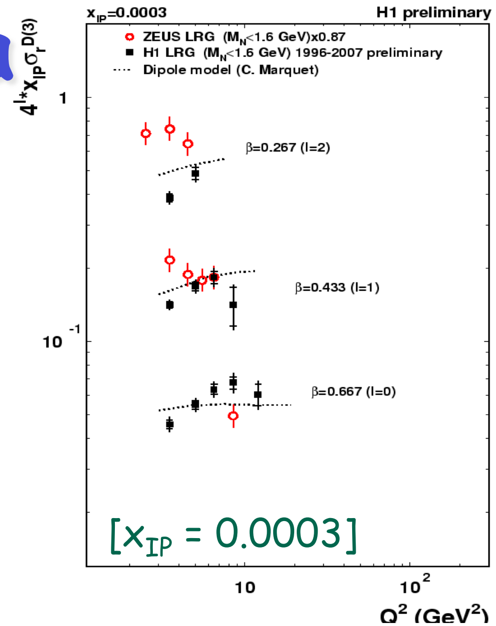
Integrated over t in this example H1-ZEUS comparison

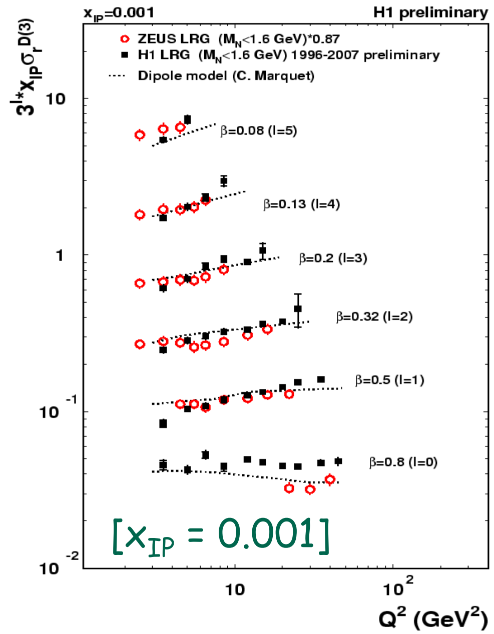


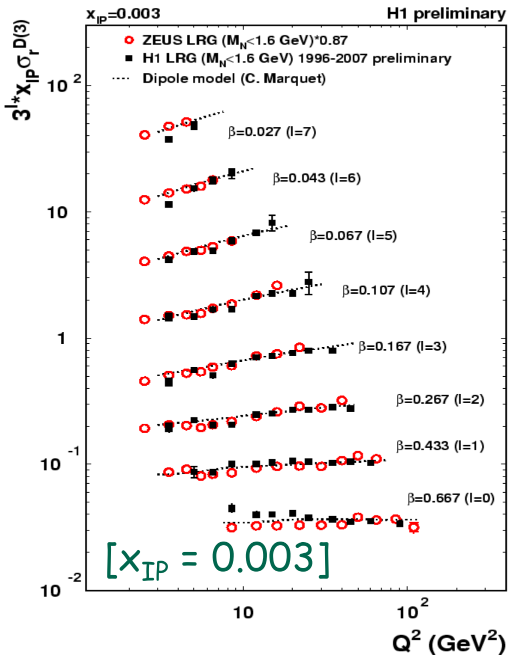
- *All available data used by both collaborations*
  → x_{IP} ~ 0.1
- H1 HERA-II (157 pb^{-1}) yields higher Q^2 data
- Good H1-ZEUS agreement on kinematic dependences
- 15% difference in overall normalisation compatible with uncertainties

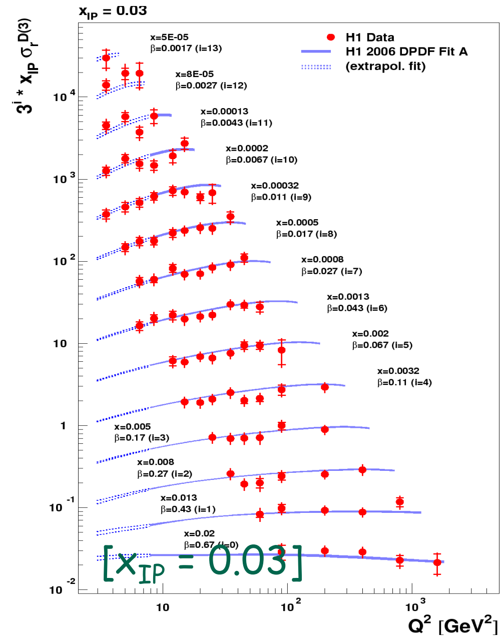
ZEUS v H1 LRG Data







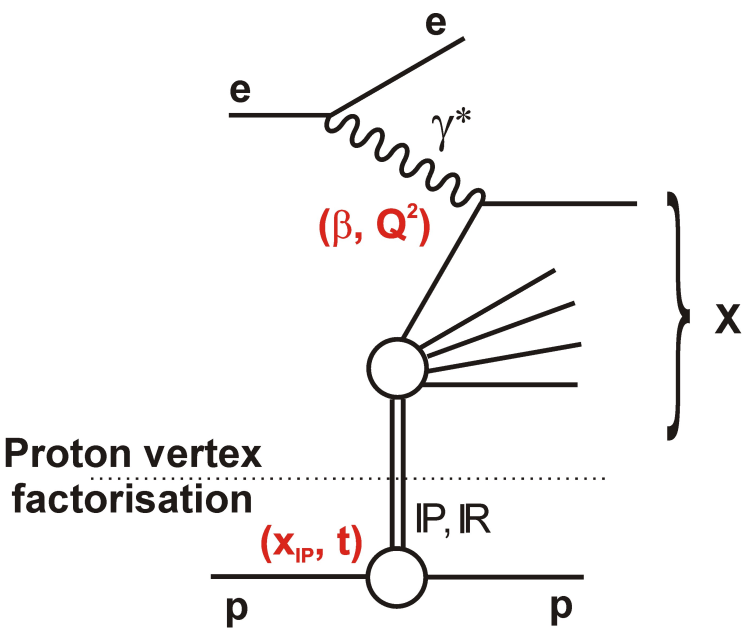




- New H1 data with 370 pb^{-1}
- Few % point-to-point precision over wide kinematic range
- ~13% difference between H1 and ZEUS within norm^n errors

Factorisation Properties of Diffractive DIS

Proton vertex factoris^n hypothesis survived many HERA tests

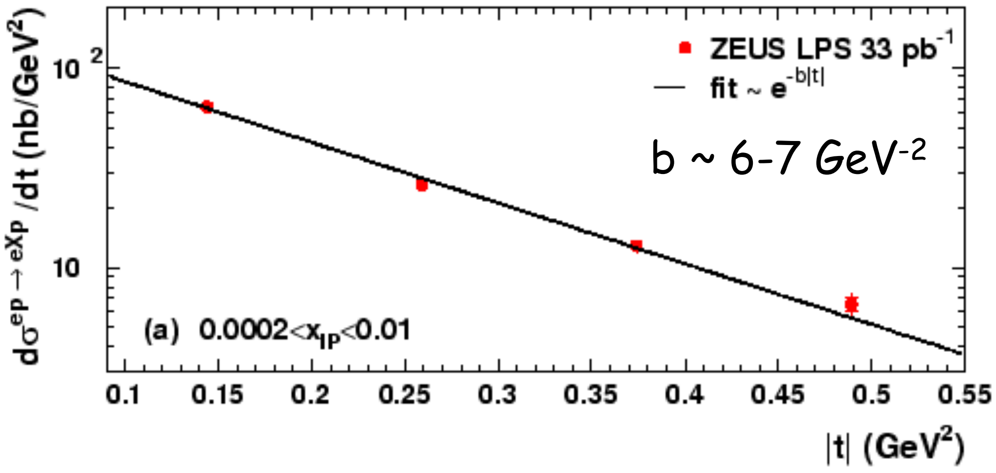


Total electron – pomeron DIS cross section $\sigma(e\, IP \rightarrow eX)$ described in terms of Diffractive Parton Densities (DPDFs), $f_i(\beta, Q^2)$

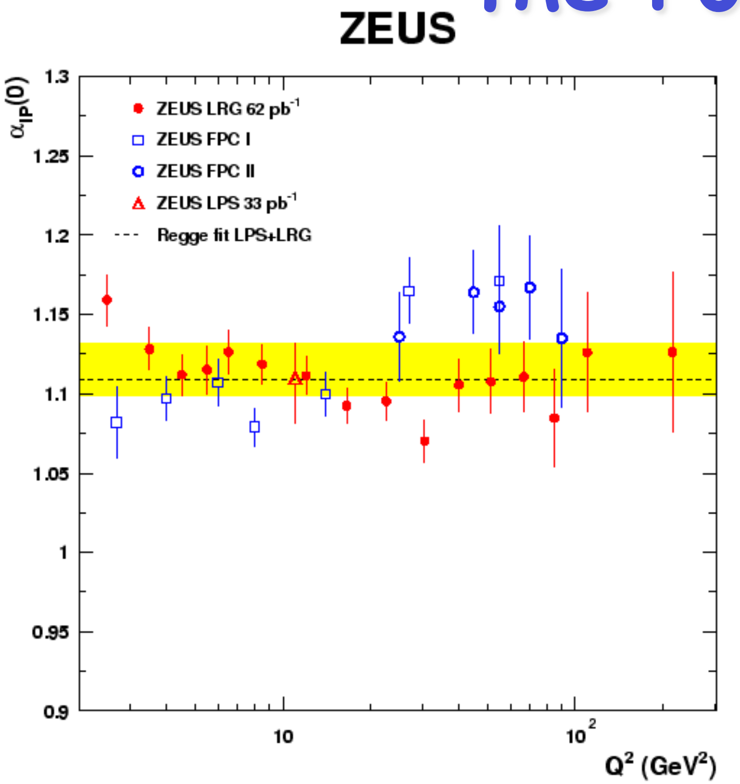
Pomeron flux $f_{IP/p}$ exhibits exponential t dependence
x_{IP} dependence well modelled by Regge phenomenology

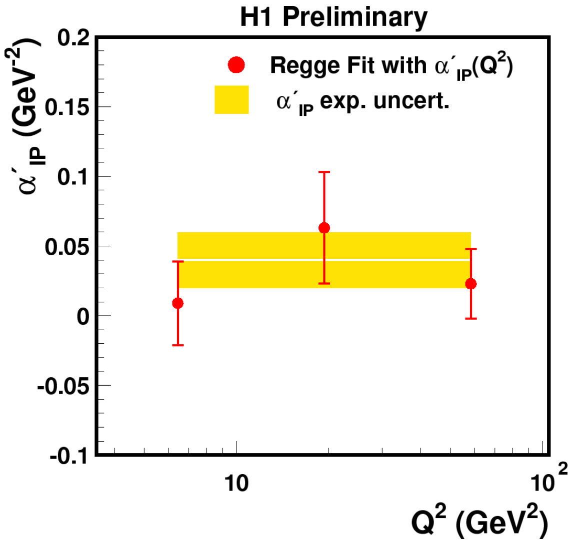
$$f_{IP/p}(x_{IP}, t) = \frac{e^{B_{IP} t}}{x_{IP}^{2\alpha_{IP}(t)-1}}$$

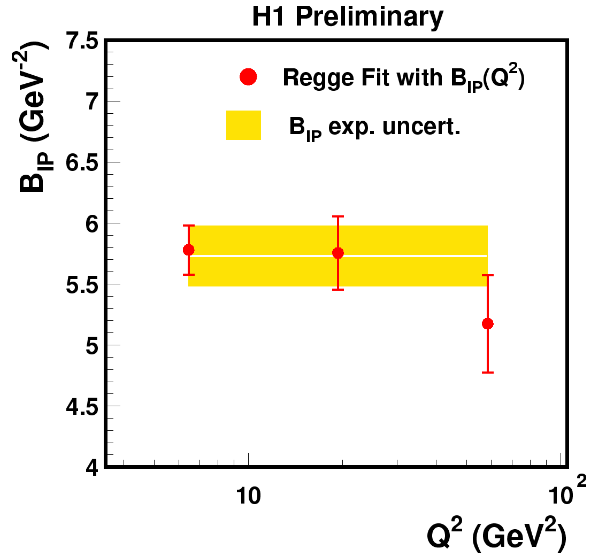
$$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP}\, t$$



Evidence for Proton Vertex Factorisation & the Pomeron Flux Factor







Excellent consistency between experiments and methods.

e.g. From H1 FPS data:

$$\alpha_{IP}(0) = 1.10 \pm 0.02\ (\text{exp.}) \pm 0.03\ (\text{model})$$

$$\alpha'_{IP} = 0.04 \pm 0.02\ (\text{exp.}) \pm 0.03\ (\text{model})\ \text{GeV}^{-2}$$

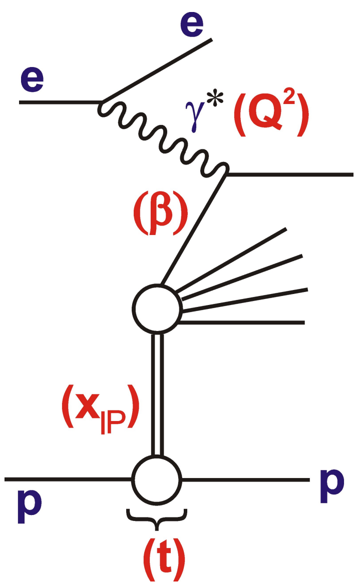
$$B_{IP} = 5.7 \pm 0.3\ (\text{exp.}) \pm 0.6\ (\text{model})\ \text{GeV}^{-2}$$

$\alpha_{IP}(0)$ consistent with soft IP → Dominantly soft exchange

α_{IP}' smaller than soft IP → Absorptive effects?...

Extracting Diffractive Quarks and Gluons

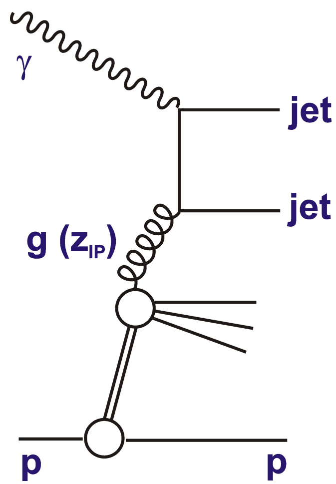
- Fit β and Q^2 dependence at fixed x_{IP}

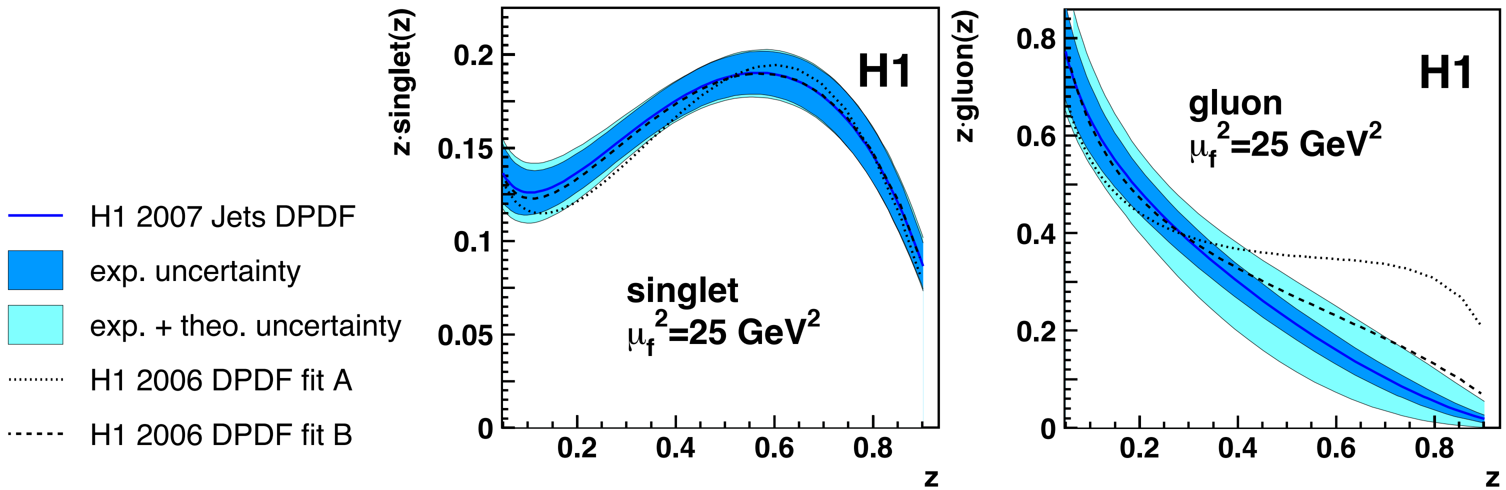


- Parameterise at starting scale Q_0^2 and evolve to higher Q^2 using NLO DGLAP

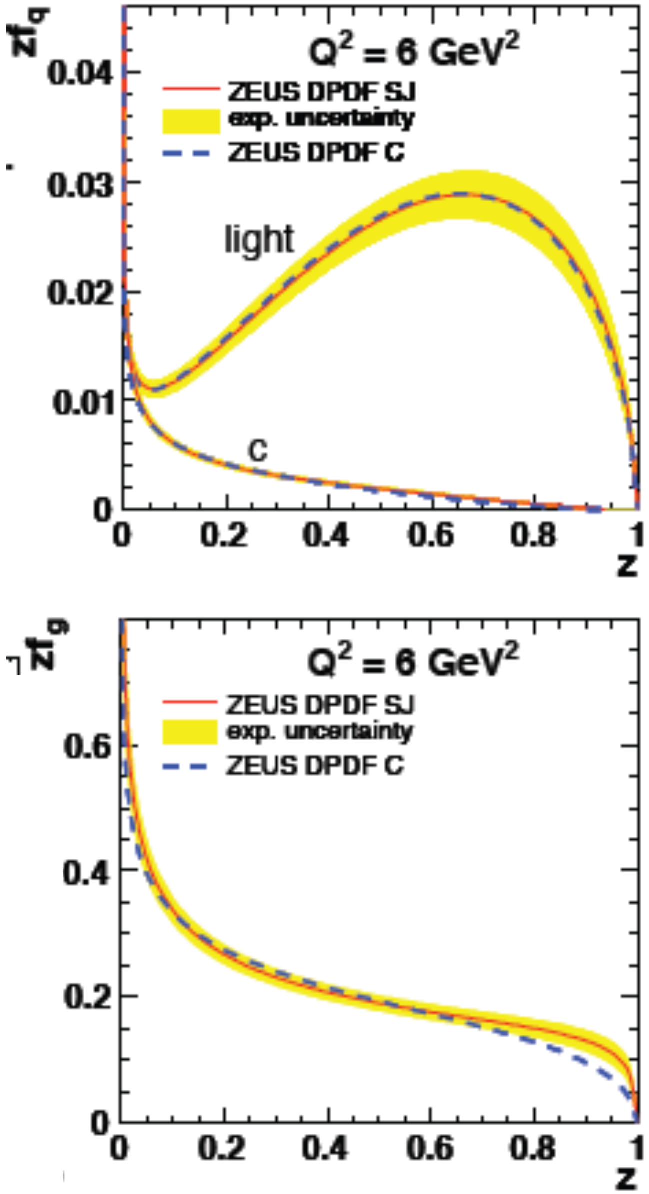
- Exploit proton vertex factorisation to relate data from different x_{IP} values with complementary β, Q^2 coverage.

- Jet cross sections constrain high z gluon

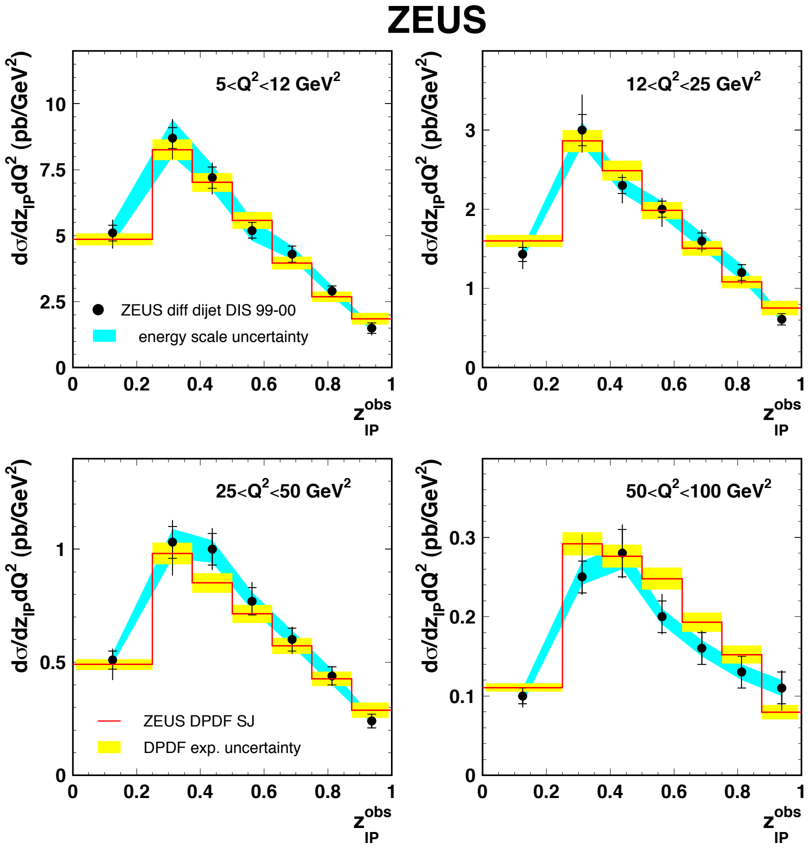


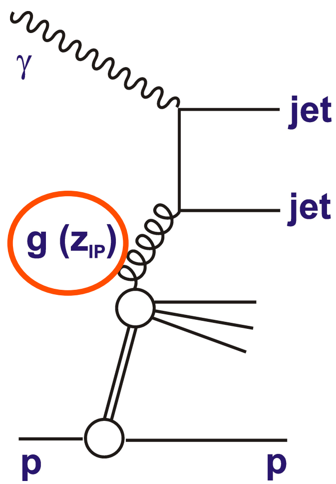


ZEUS DPDFs from Inclusive and Jet Data



- Recent ZEUS fits to high stats LRG & LPS data. – Improved heavy flavour treatment … consistent with previous H1 results up to normalisation factor in data
- Successful descriptions of diffractive final state data in DIS … Jets, Charm …



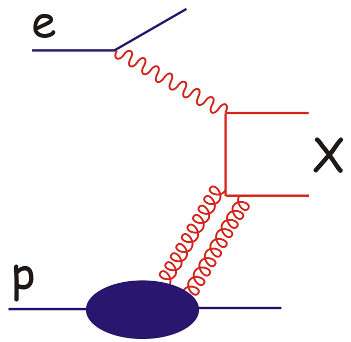


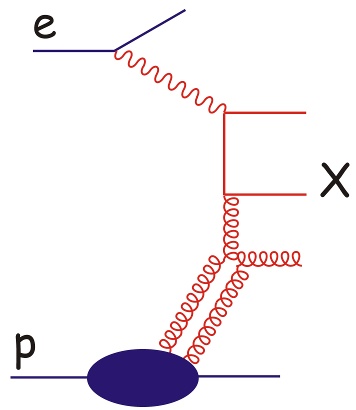
Forward Jets in Diffractive DIS

New H1 analysis with FPS proton tag … extends x_{IP} and η_{jet} ranges … search for 'hard' p QCD-calculable contributions … exclusive 2/3 jets with DGLAP p_t ordering broken?

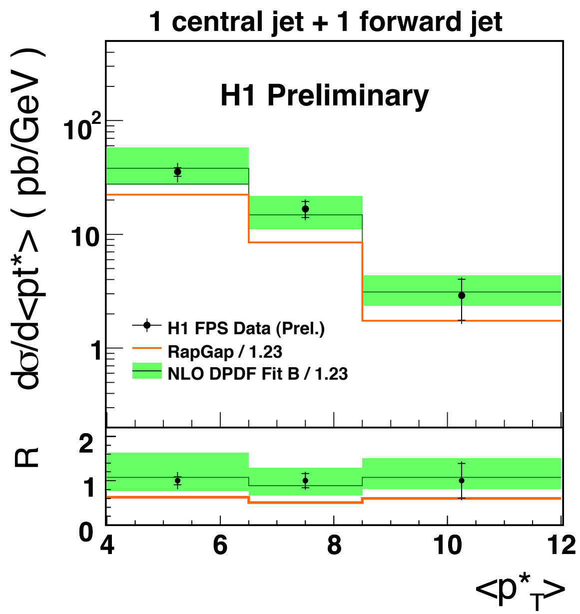
Forward jet: $p_t > 4.5$ GeV, $1 < \eta_{fwd} < 2.8$

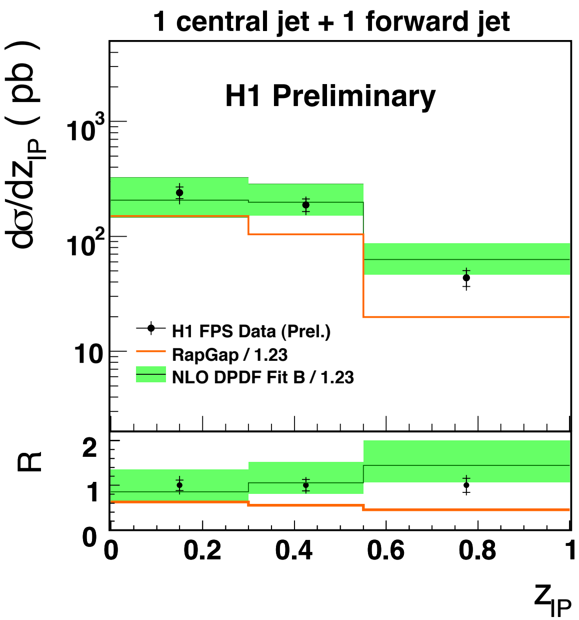
Central jet: $p_t > 3.5$ GeV, $-1 < \eta_{cen} < \eta_{fwd}$

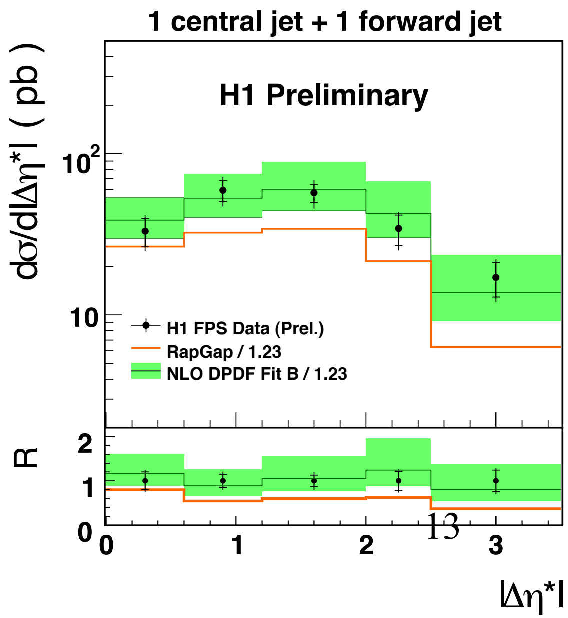


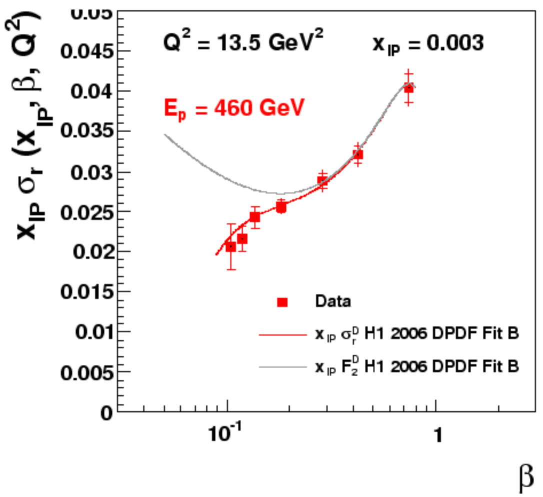


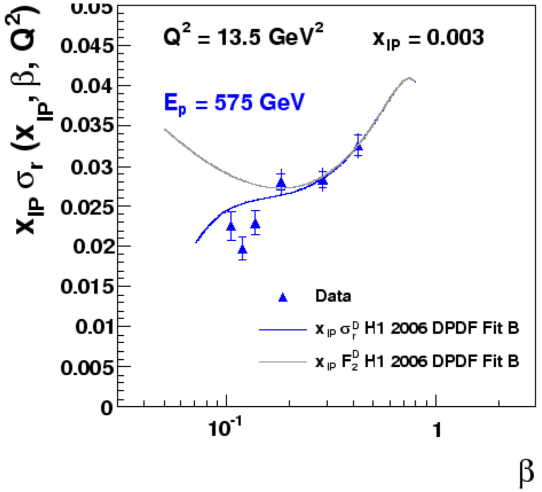
… No evidence for configurations beyond those predicted from NLO DGLAP & DPDFs

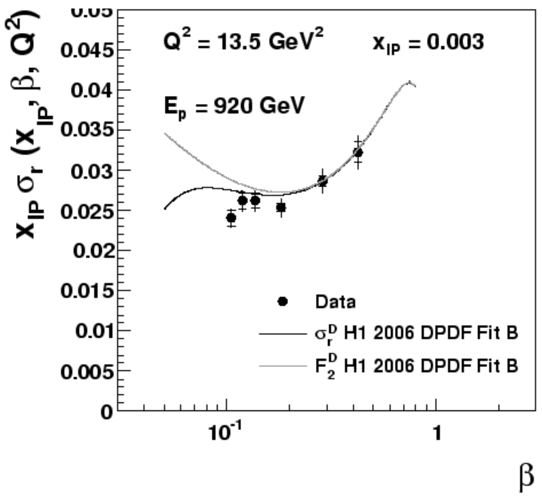












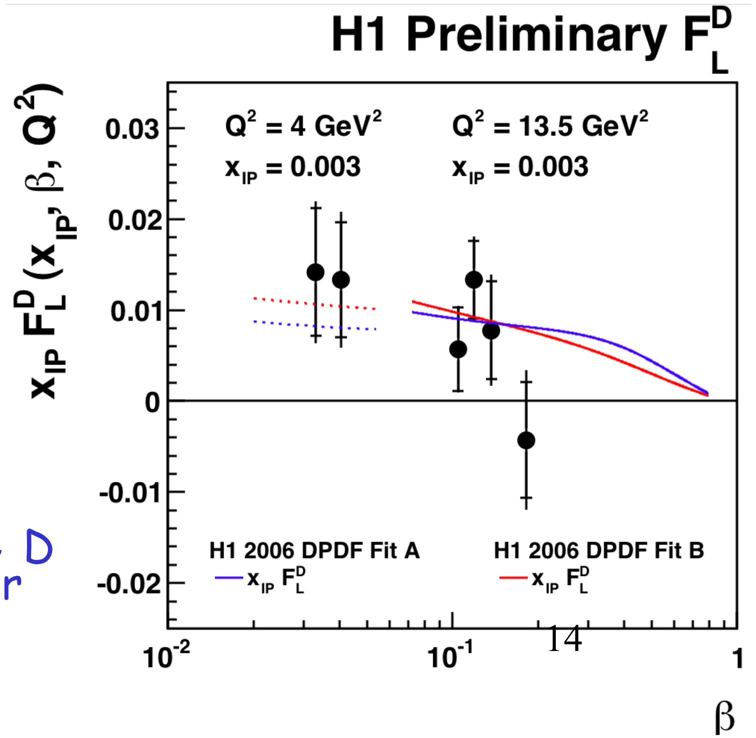
First F_L^D Measurement

Novel test of diffractive gluon density

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

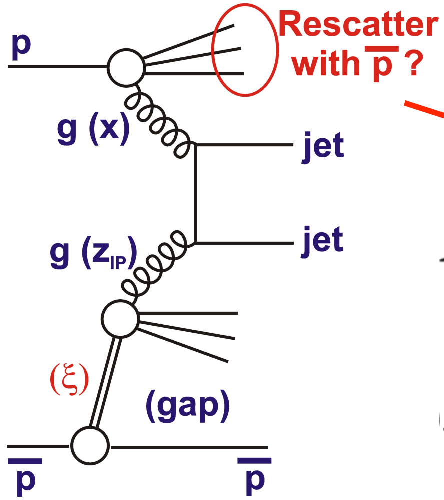
… F_L^D sensitivity @ highest y ($E_e \rightarrow$ 3.4 GeV)
… vary $E_p \rightarrow$ change y at fixed β, x_{IP}, Q^2
… 11pb^{-1} @ 575 GeV, 6pb^{-1} @ 460 GeV, in addition to 820 GeV, 920 GeV data

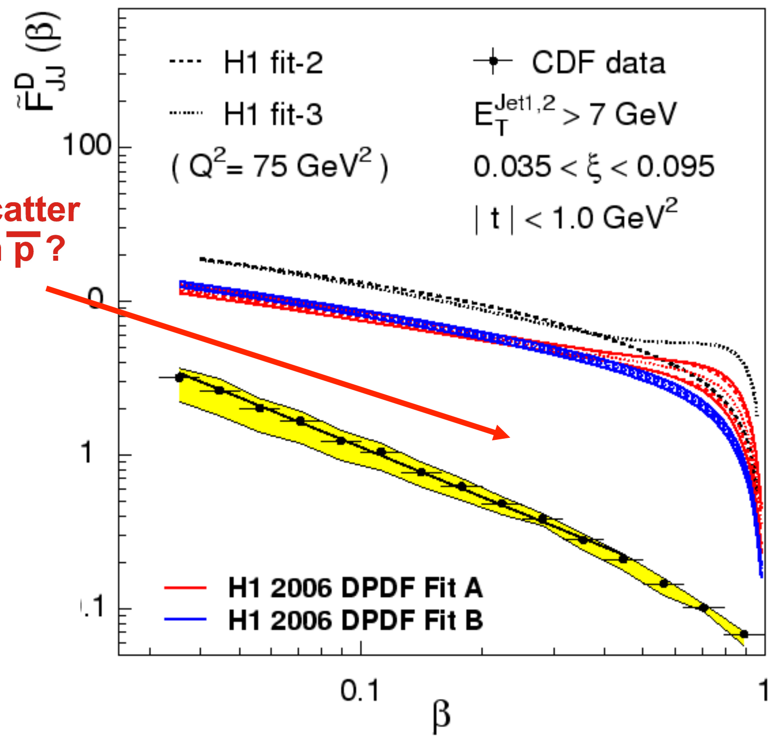
- F_L^D shown to be several σ from zero
- Compatible with all predictions based on NLO DGLAP fits to σ_r^D



.. meanwhile in pp(bar) ...

Strong evidence for absorptive effects in comparing Tevatron diffractive dijets with HERA DPDFs …
`rapidity gap survival probability' $S^2 \sim 0.1$

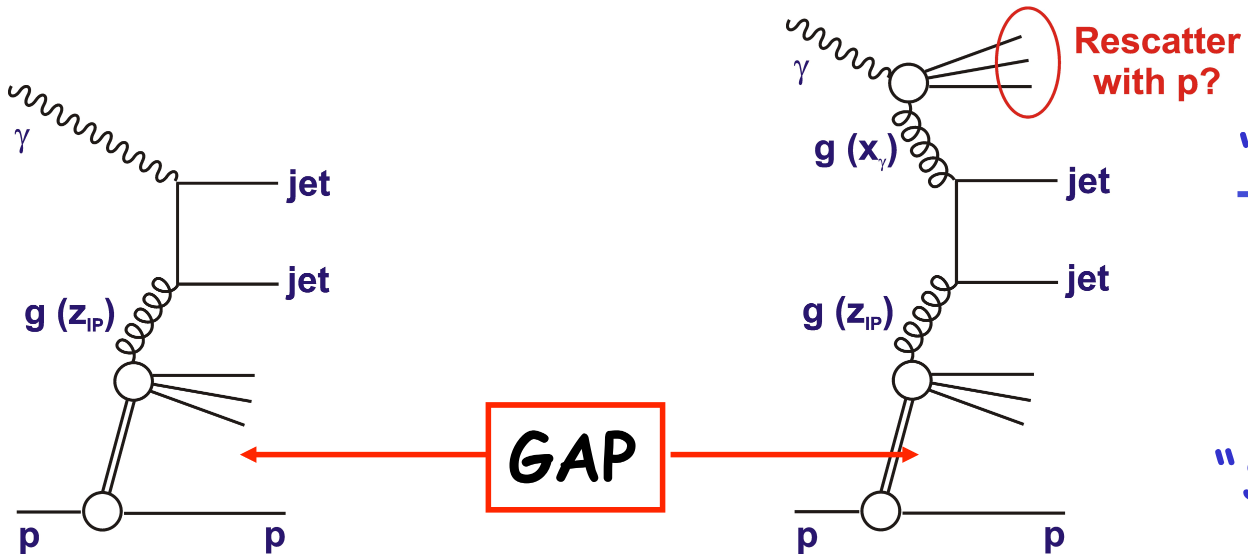




… photoproduction jets as the perfect control experiment?…

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

"$S^2 = 1$"



"Resolved" photon ($x_\gamma < 1$)

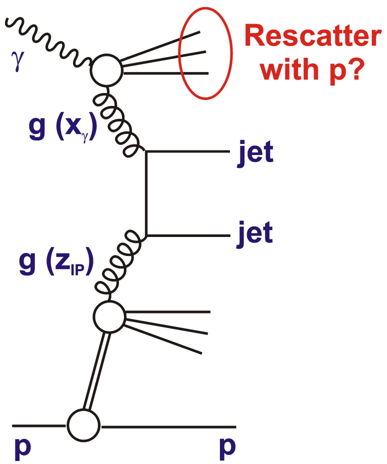
"$S^2 \sim 0.34$?"

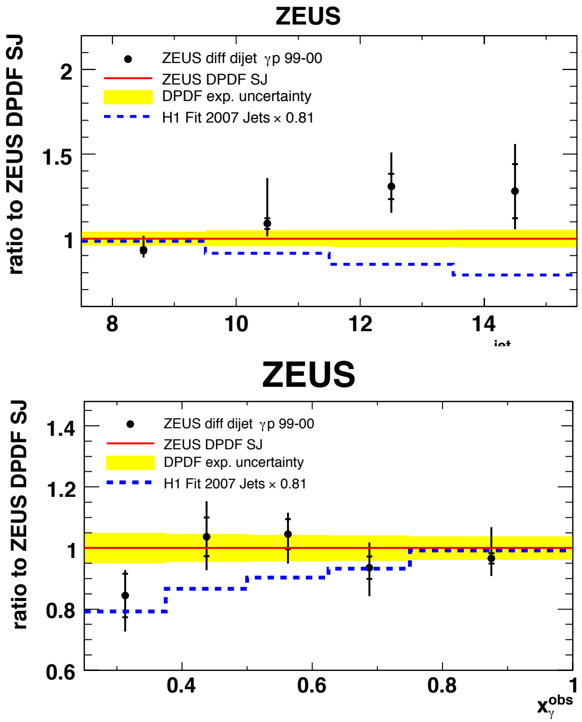
Rapidity Gap Survival Probability in Diffractive Dijet Photoproduction

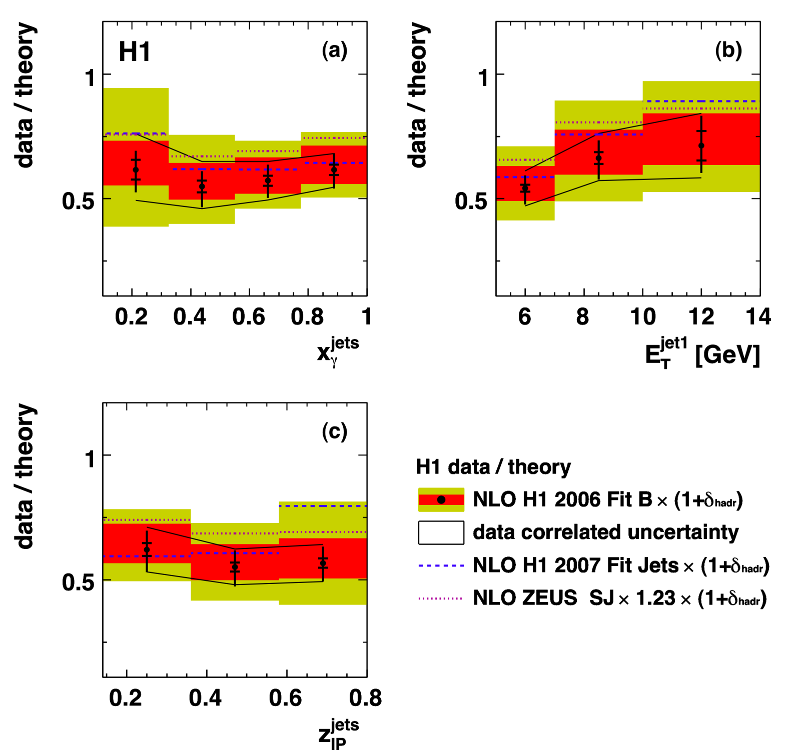
ZEUS [$E_T^1 > 7.5$ GeV]… No evidence for any gap destruction

H1 [$E_T^1 > 5$ GeV]… Survival probability < 1 at 2σ significance

$$\sigma(\text{H1 data}) / \sigma(\text{NLO}) = 0.58 \pm 0.12\ (\text{exp.}) \pm 0.14\ (\text{scale}) \pm 0.09\ (\text{DPDF})$$







- Gap survival unexpectedly has little dependence on x_γ
- Hint of a dependence on jet E_T?

Refined gap Survival Model (KKMR)

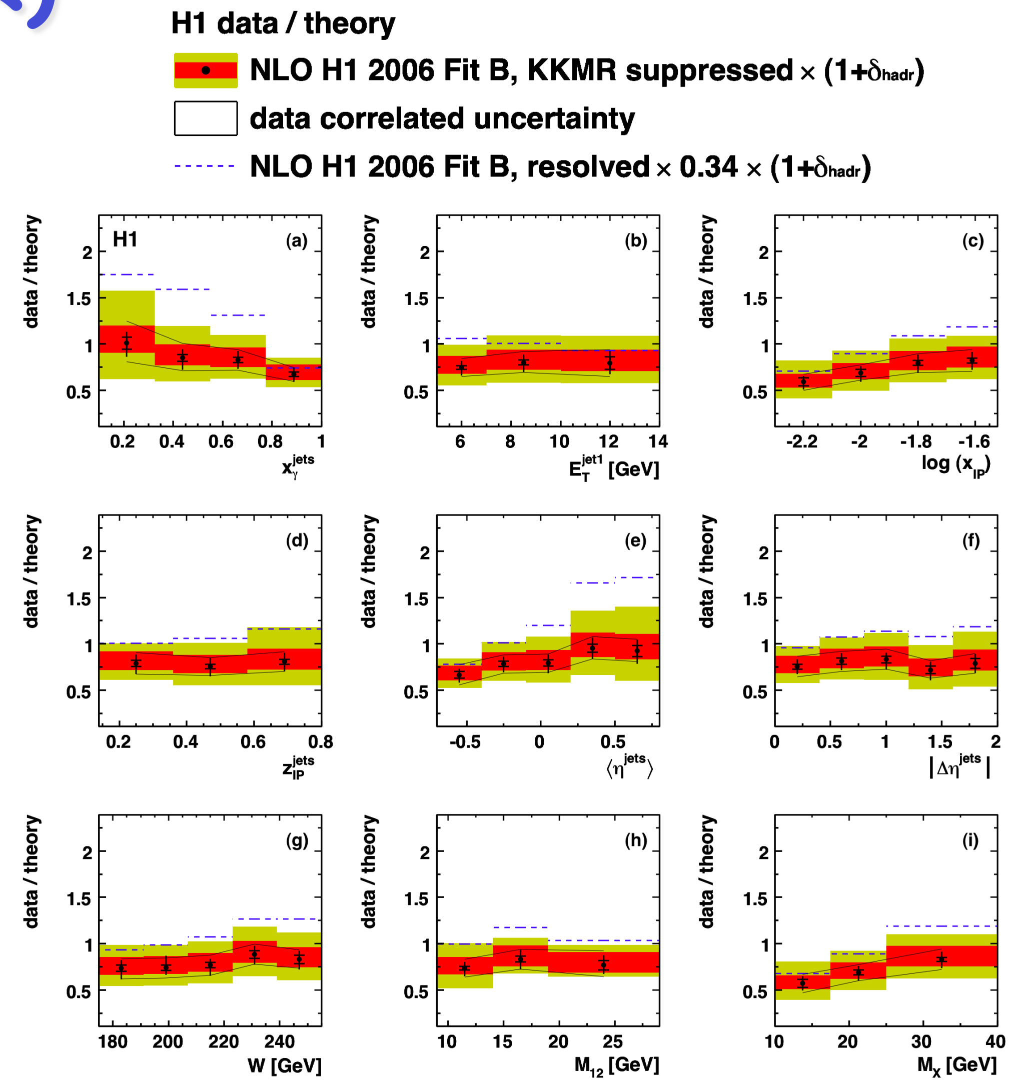
[hep-ph/0911.3716]

Direct contribution remains unsuppressed

Suppression factor 0.34 applies to Hadron-like (VMD) part of photon structure only (low x_γ < 0.1)

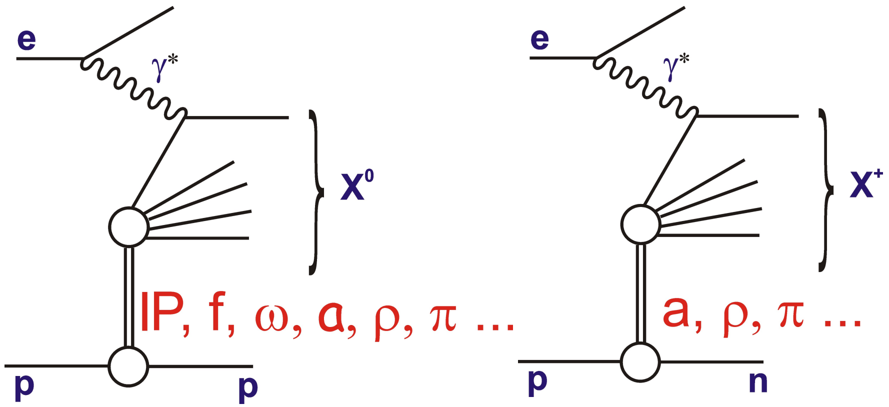
Point-like (anomalous) part of photon structure has less suppression (~0.7-0.8)

Smaller gap destruction effects with some E_T dependence



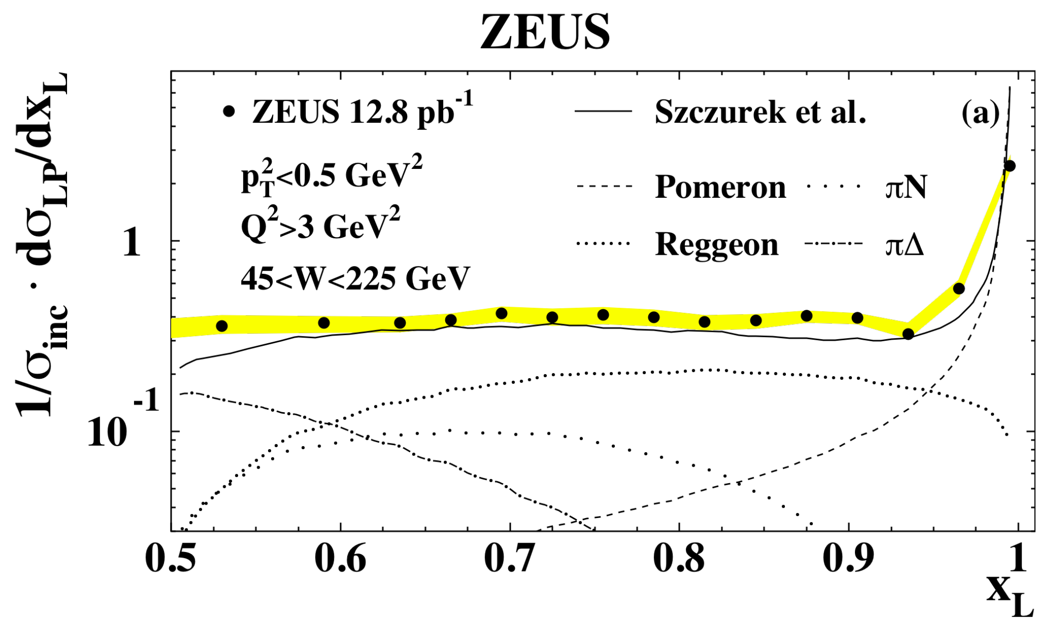
Fair agreement with both H1 and ZEUS data …

Going beyond the diffractive forward peak



As x_L (= 1 - x_{IP}) decreases …
- Sub-leading exchanges important for leading protons
- Leading neutrons produced via charge exchange reactions

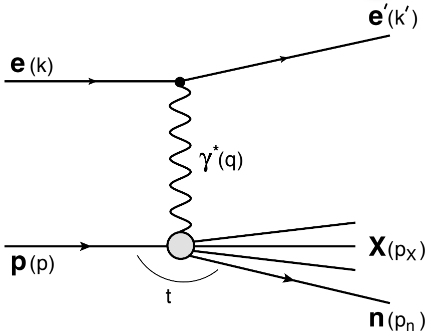
Regge analysis suggest leading proton production beyond diffractive peak dominated by isoscalar meson exchanges with $\alpha_{IR}(0) \sim 0.5 \rightarrow$ ω, f rather than isovector a, ρ

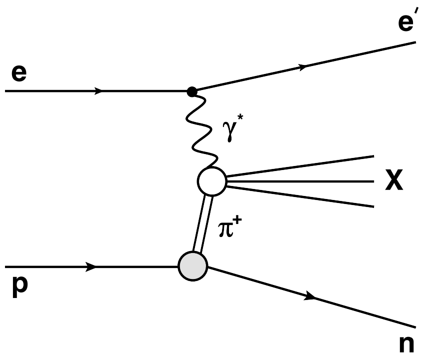


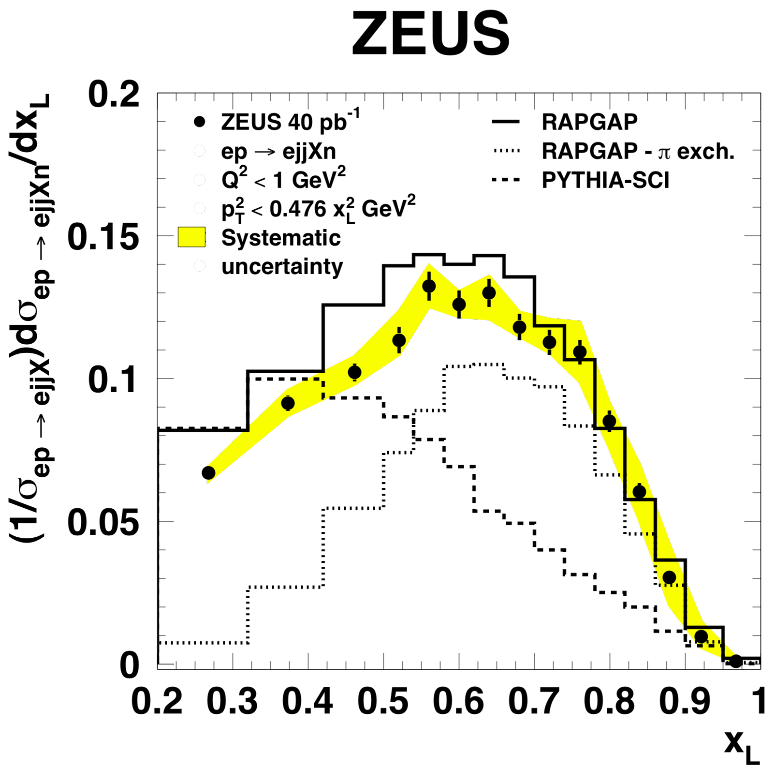
"Large" x_L leading neutron contributions expected to be due to π exchange [$\alpha_\pi(0) \sim 0$] competing with standard baryon fragmentation at lower x_L

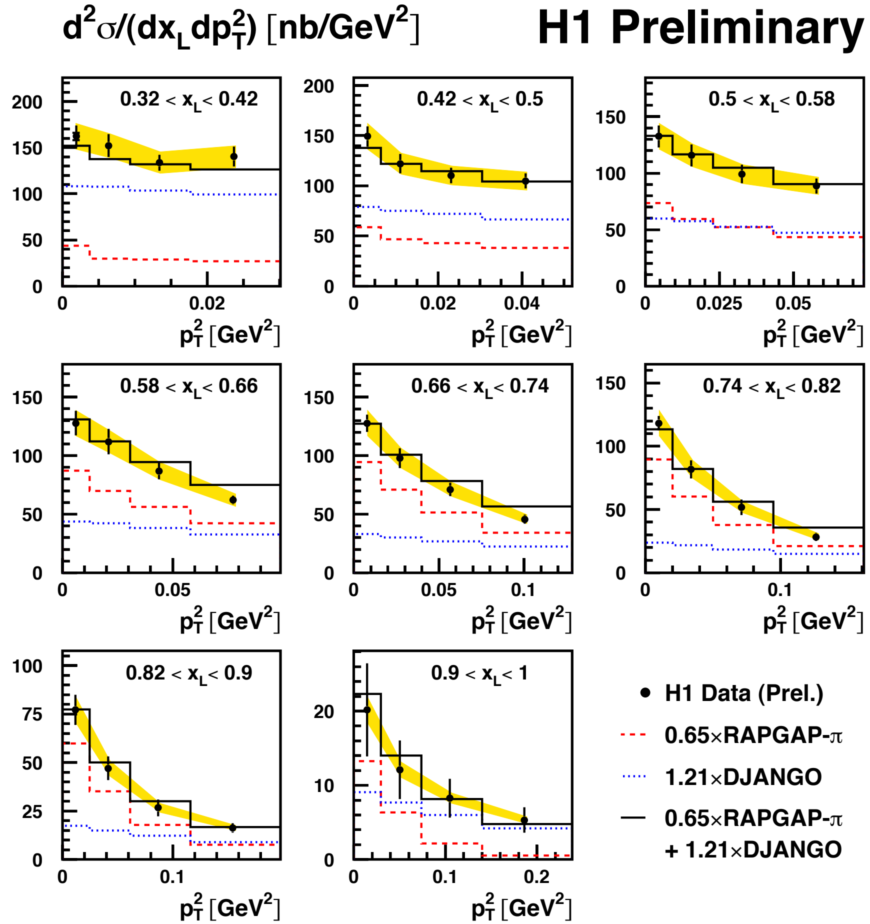
Leading Neutrons at Low x_L: π-exchange & fragmentation

[For π-excahnge, $|t-t_{min}| = p_t^2$]









… mixing MCs describing π-exchange and standard fragmentation gives good description of x_L and p_t dependences for inclusive neutrons and sample accompanied by jets

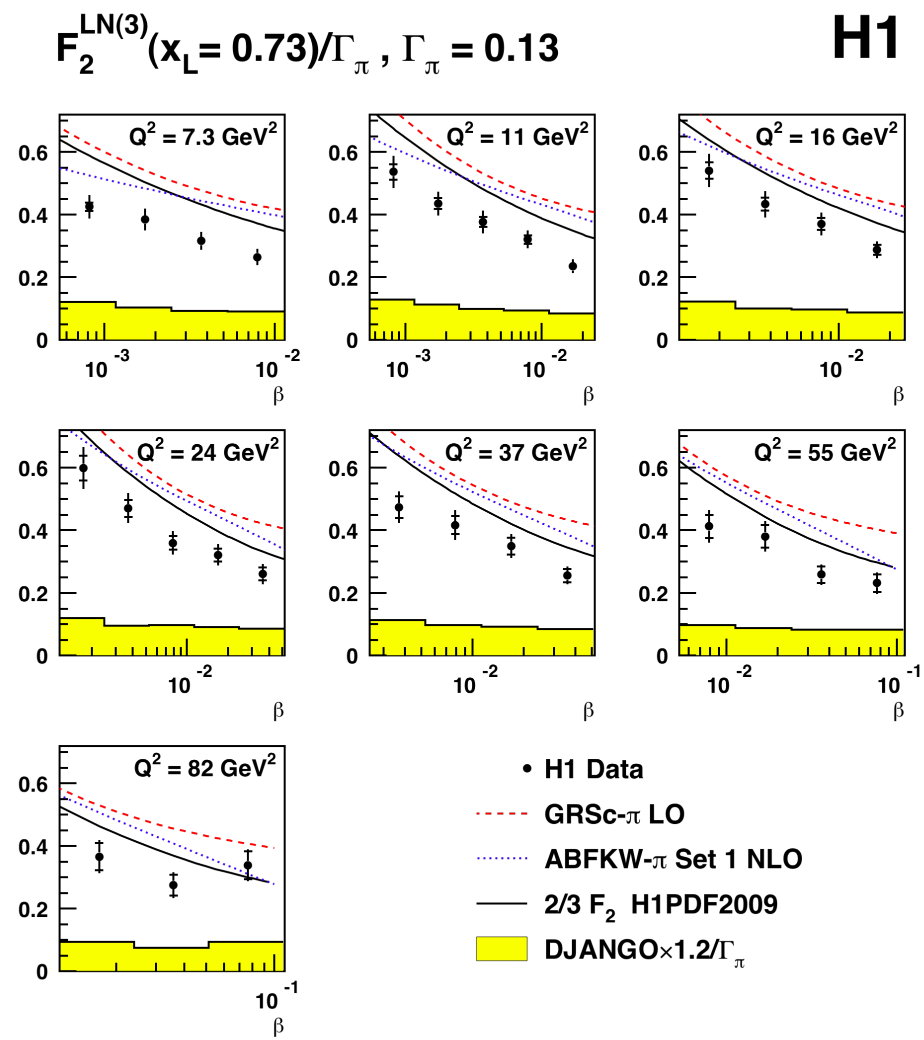
Leading Neutrons and F_2^{π}

… sensitivity at large x_L to pion structure function F_2^{π} after taking out a pion flux factor …

$\Gamma_{\pi} \sim 0.13$ +/- 0.04 (model)

25-35% residual fragmentation component

Other exchanges neglected



Fair agreement with parameterisations of pion structure.

$F_2^{\pi} = 2/3\ F_2^{p}$ (valence quark counting) also in fair agreement

Summary

- New, improved HERA diffractive and related data continue to arrive … unique sensitivity to strong colour-singlet exchange in pQCD regime

- Proton vertex factorisation with $\alpha_{IP}(t) \sim 1.10\ (+\ \delta t)$ & $b \sim 6\ GeV^{-2}$ is good model for the 'soft' physics

- DPDFs well constrained & tested

- Progress in understanding rapidity gap survival in photoproduction

- Leading Neutron Spectra Beyond diffractive peak constrain F_2^{π}

- Input to diffraction, multi-parton interactions, ZDC … @ LHC