Diffractive PDFs and factorization tests at HERA

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Talk Outline

Diffraction at HERA

Kinematics

- Q^2 4-momentum exchange
- W γ p center-of-mass energy
- x fraction of p momentum carried by the struck quark
- x_{IP} fraction of p momentum carried by IP

$$x_{IP} = \frac{q \cdot (p - p')}{q \cdot p} \sim \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

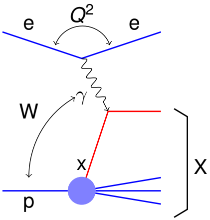
- β fraction of IP momentum carried by the struck quark

$$\beta = \frac{Q^2}{2q \cdot (p - p')} \sim \frac{Q^2}{Q^2 + M_X^2}$$

$$x = \beta x_{IP}$$

- t 4-momentum transfer at p vertex

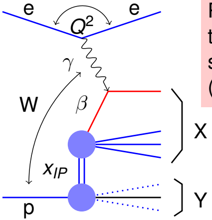
$$t = (p - p')^2$$



$ep \to eX$

Probe partonic structure of the proton $\to F_2$

Inclusive DIS



$ep \to eXY$

Probe structure of the exchanged color singlet (Pomeron IP) $\to F_2^D$

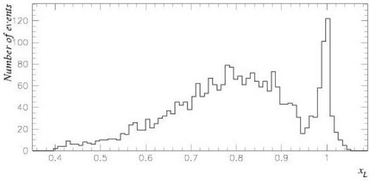
Diffractive DIS

Experimental Selection of Diffraction

LPS/FPS

Tag and reconstruct the final state proton:

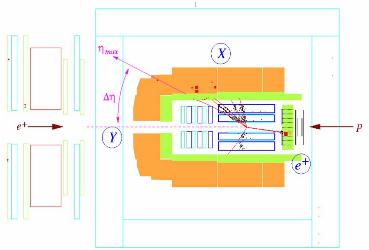
- clean, no p-diss. background;
- measure $|t|$;
- access high x_{IP} region;
- low acceptance, low statistics.



LRG

Select events with a Large Rapidity Gap:

- measure all hadrons comprising X;
- some p-diss. background;
- very good acceptance at low x_{IP}.



Diffractive Structure Functions

- Diffractive Cross Section

$$\frac{d\sigma^D_{\gamma^* p}}{dM_X} = \frac{\pi Q^2 W}{\alpha(1+(1-y)^2)} \cdot \frac{d^3\sigma^D_{ep\to eXp}}{dQ^2 dM_X dW}$$

- Diffractive structure function $F_2D(4)$ and reduced cross section $\sigma_r^{D(4)}$

$$\frac{d^4\sigma^D_{ep\to eXp}}{d\beta dQ^2 dx_{IP} dt} = \frac{4\pi\alpha^2}{\beta Q^2}\left[1 - y + \frac{y^2}{2(1+R^D)}\right] F_2^{D(4)}\left(\beta, Q^2, x_{IP}, t\right)$$

$$= \frac{4\pi\alpha^2}{\beta Q^2}\left[1 - y + \frac{y^2}{2}\right] \sigma_r^{D(4)}\left(\beta, Q^2, x_{IP}, t\right)$$

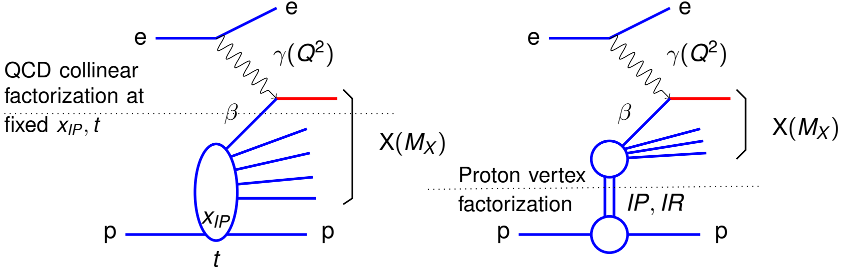
- when t is not measured

$$\sigma_r^{D(3)} = \int \sigma_r^{D(4)}\left(\beta, Q^2, x_{IP}, t\right) dt$$

- $R^D = \sigma_L(\gamma^* p \to Xp)/\sigma_T(\gamma^* p \to Xp)$
- $\sigma_r^D \sim F_2^D$ when $R^D \sim 0$

QCD and Vertex Factorization

- Two levels of factorization:



- QCD factorization theorem (Collins et al.) at fixed x_{IP} and t:

$$d\sigma\left(\gamma^{*}p \rightarrow Xp\right) = f_i^D\left(x, Q^2, x_{IP}, t\right) \times d\hat{\sigma}_{\gamma^{*}q}\left(x, Q^2\right)$$

- Proton Vertex factorization (Regge theory):

$$f_i^D\left(x, Q^2, x_{IP}, t\right) = f_{IP}\left(x_{IP}, t\right) \cdot f_i^{IP}\left(\beta = x/x_{IP}, Q^2\right)$$

NLO QCD Fits to Inclusive DDIS data

- use DGLAP evolution equations to get quark and gluon distrib, $f_i(z, Q^2)$, with DPDFs parametrized versus z at a staring scale Q_0^2.
- Heavy quark contributions trated in VFNS of Thorne and Roberts (ZEUS only)
- Starting scale $Q_0^2 = 1.8$ GeV^2

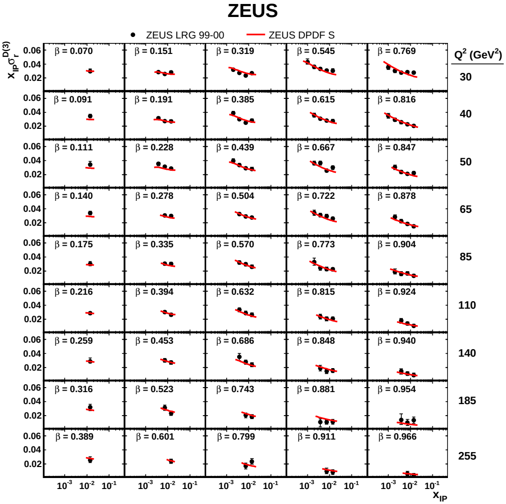
quark singlet $q = \sum_q (f_q + f_{\bar{q}})$ (light quarks, no intrinsic charm or bottom).
$zq(z, Q_0^2) = A_q \cdot z^{B_q} \cdot (1-z)^{C_q}$

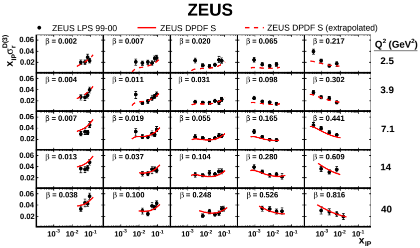
gluon (2 fits)
$zg(z, Q_o^2) = A_g \cdot z^{B_g} \cdot (1-z)^{C_g}$

  - "Standard" : Fit S with B_g and C_g fitted
  - "Constant" : Fit C with $B_g = C_g = 0$ (as in H1-2006 B)

- use Proton Vertex Factorization assumptions:
  x_{IP} dependence parametrized with Regge inspired Pomeron and Reggeon fluxes (with linear trajectories)
- Free parameters in the fit: 9
- H1 performed similar fits

ZEUS QCD Fit to Inclusive Diffraction

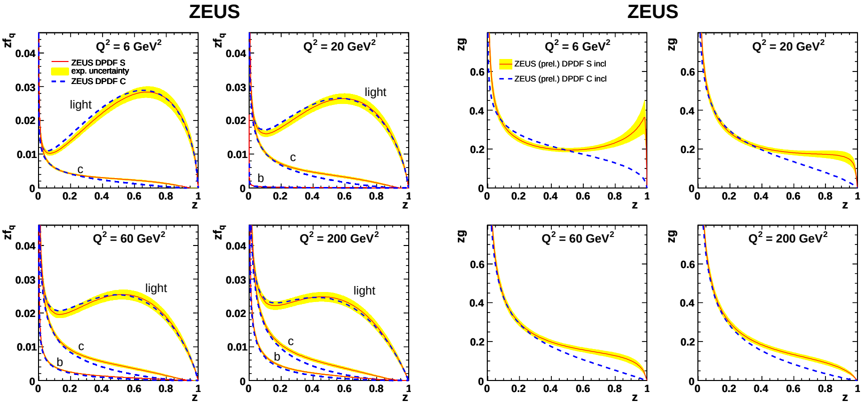




Simultaneous fit to LRG and LPS data

Only data with $Q^2 > 5$ GeV^2 fitted.

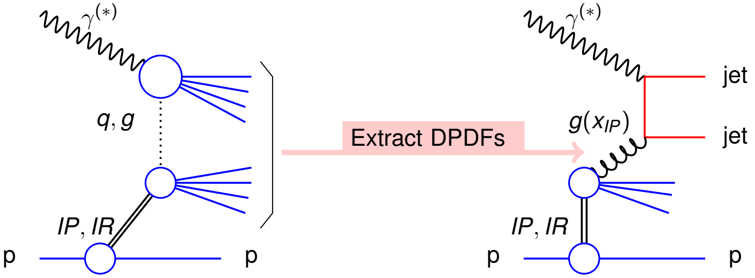
ZEUS Quark and Gluon distributions



- Both Fit S and C describe the data.
- . . . but large discrepancy between the fits for zg → low sensitivity of inclusive data to gluons.
- Very large uncertainty for gluons at high z

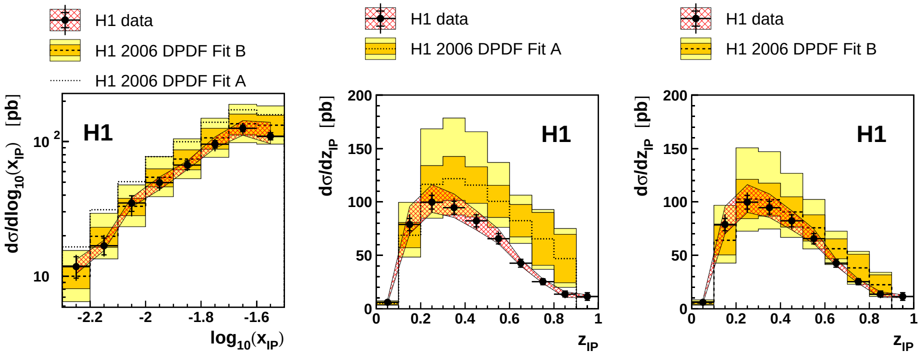
From Inclusive Diffraction to Diffractive Dijets

- Boson-Gluon Fusion is the main mechanism → sensitive to the gluon content



- extract DPDFs from inclusive diffractive data;
- test of factorization in dijet and heavy quark (charm) diffractive data.

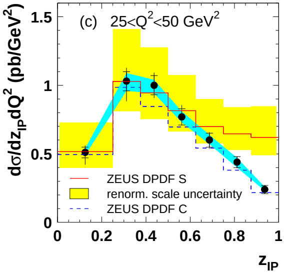
H1 Diffractive Dijets (in DIS)

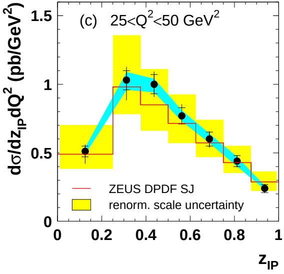


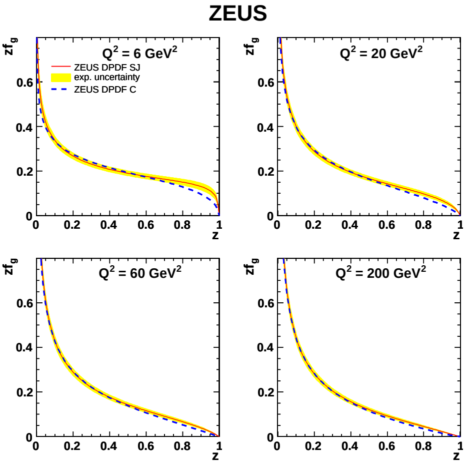
- Good agreement in x_{IP} $\rightarrow$ Pomeron flux similar to that of inclusive diffraction;
- large uncertainties in the NLO QCD predictions (with H1 DPDF Fits).
- discrepancy between Fit A and B evident at high z_{IP}.
- high sensitivity of dijet data to the gluon density for $z_{IP} > 0.4$.

$$z_{IP} = \frac{M_{12}^2 + Q^2}{M_X^2 + Q^2}$$

ZEUS Diffractive Dijets (in DIS)

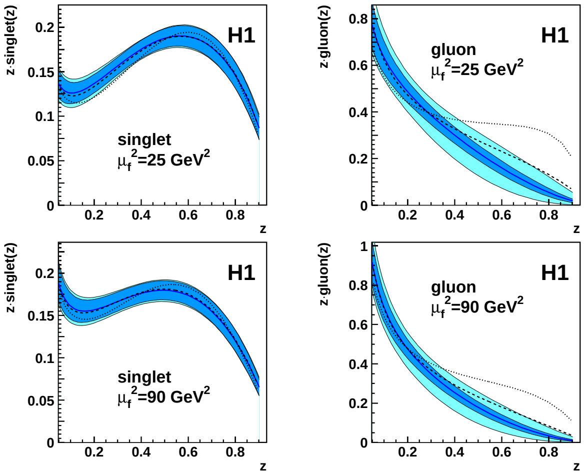






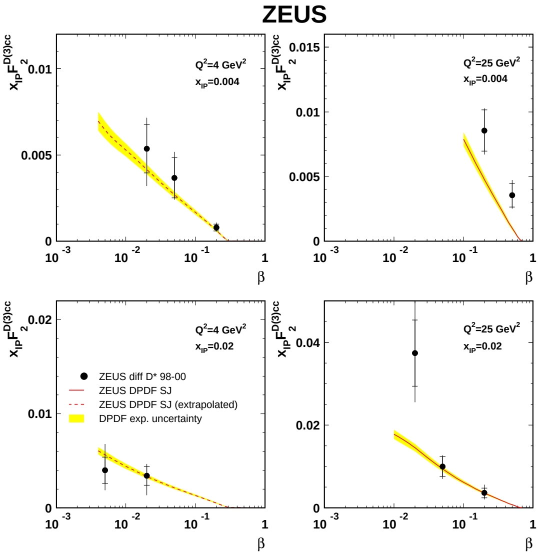
- Combining inclusive and dijet diffractive data → gluon and quark densities constrained with comparable precisions across the whole *z* range.

H1 Diffractive Singlet and Gluon distributions



Better constraint of gluons over a wider range ($0.05 < z_{IP} < 0.9$).

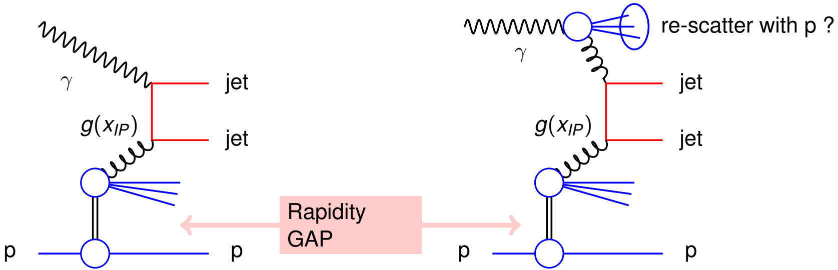
Diffractive Charm Data



- ZEUS DPDF SJ predictions compared to charm diffractive structure function $x_{IP} \cdot F_2^{D(3)c\bar{c}}$
- Fair agreement with data (still statistically limited)

Diffractive Dijet Photoproduction

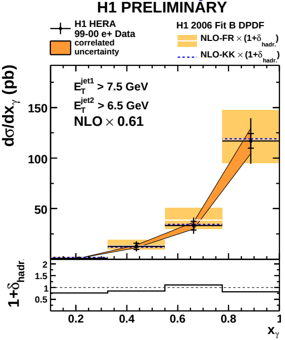
- main mechanism Boson-Gluon Fusion → sensitive to gluon content

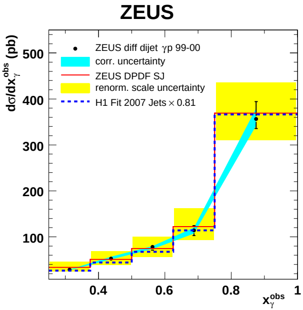


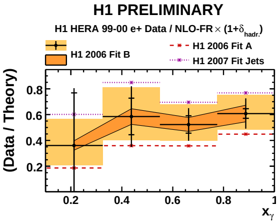
- use Photoproduction at HERA as a hadron-hadron collider
  - "direct photon" ($x_\gamma \to 1$) less hadron-like;
  - "resolved photon" ($x_\gamma < 1$) more hadron-like
- enhance re-scattering with the proton remnant by switching the "photon remnant" ON/OFF.

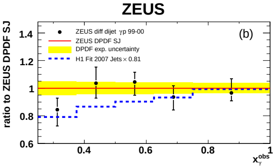
⇒ Expect Resolved to be more suppressed than Direct photon process.

Dijet data in Photoproduction (vs x_γ)



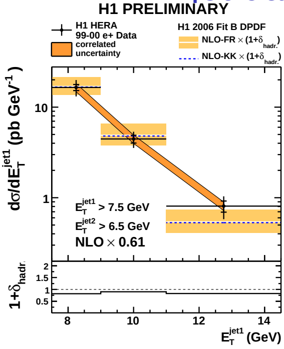


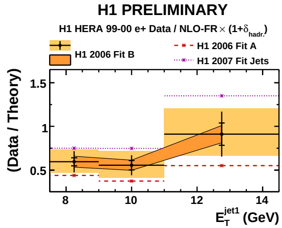


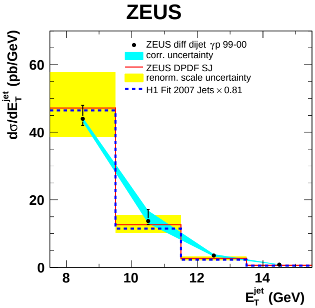


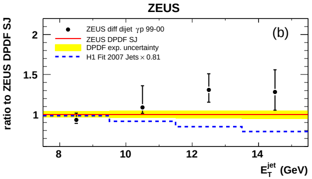
- NLO calculations (Frixione e Ridolfi) with
- H1 2006 Fit B DPDFs (H1);
- H1 Fit 2007 and ZEUS DPDF SJ (ZEUS);
- similar kinematic regions: $E_T^{jet1} > 7.5$ GeV and $E_T^{jet2} > 6.5$ GeV.
- small suppression in H1, compatible with ZEUS
- no evidence for x_γ dependence

Dijet data in Photoproduction (vs E_T)





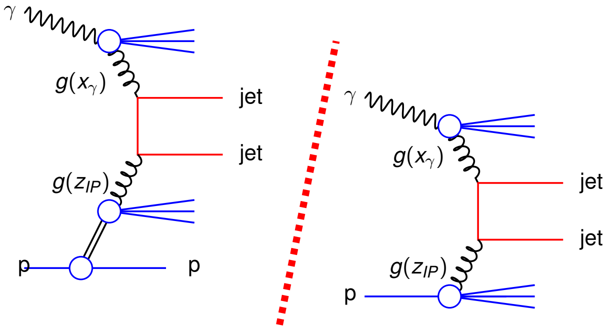




- Test the E_T dependence of absorption
- small suppression in H1 for the low E_T region
- both data still compatible (within errors)

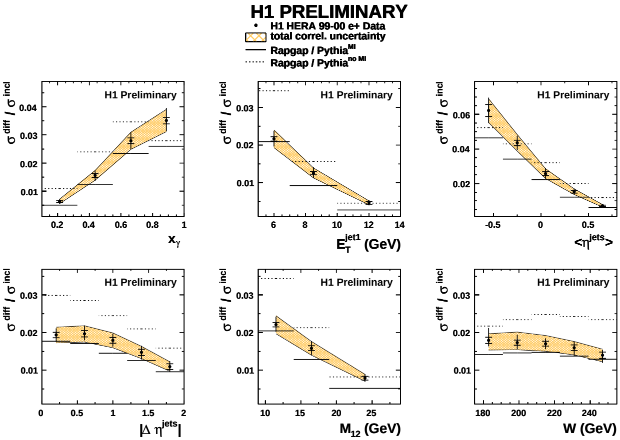
Diffractive to Inclusive dijet ratios

- main idea: measure ratio of diffractive gluon to inclusive gluon



- full or partial cancellation of photon PDFs, scale uncertainties, jet energy scales, ...
- x_γ distribution sensitive to absorption/gap survival
- . . . but also to differences between diffractive and inclusive phase spaces

Diffractive to Inclusive Ratios



- $z_{IP} < 0.8$ cut applied to reduce sensitivity to PDF uncertainties;
- Data compared to RAPGAP/Pythia (w/ and w/o MI), so far;
- MI model gives a fair description of data over a large phase space.

Conclusions

- A wealth of data has been published on Diffraction by the H1 and ZEUS collaborations, using different techniques (LRG, Leading Proton, M_X methods);
- Proton Vertex Factorization works to a good approximation and allows to extract DPDFs from NLO QCD fits to the β and Q^2 dependencies of the inclusive data.
- Diffractive dijet data are able to discriminate between different gluon parametrization.
- Combined fits to inclusive and dijet data constrain both the quark and gluon DPDFs to good and similar precisions.
- Ratio of diffractive to inclusive photoproduction dijets cross sections measured for the first time.
  - trend of the data can be interpreted using multiple interactions