Diffractive Dijets in Photoproduction and DIS (H1 Results)

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HERA-LHC Workshop Midterm Meeting

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- Introduction
- Experimental Aspects; Rapidity Gaps
- NLO Calculations
- Results for DIS and Photoproduction
  (+ excursion to charm production)
- Conclusions

Introduction

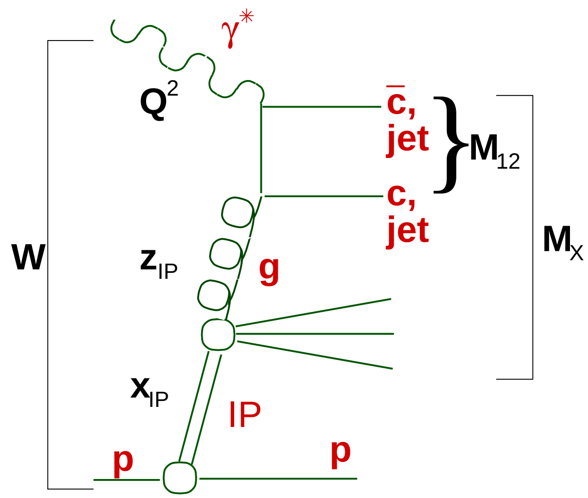
- Collins: Proof of QCD factorization in diffractive DIS
  $\sigma^{\gamma^* p \to p' X} \sim \sum_i p_i^D \otimes \hat{\sigma}^{\gamma^* i}$

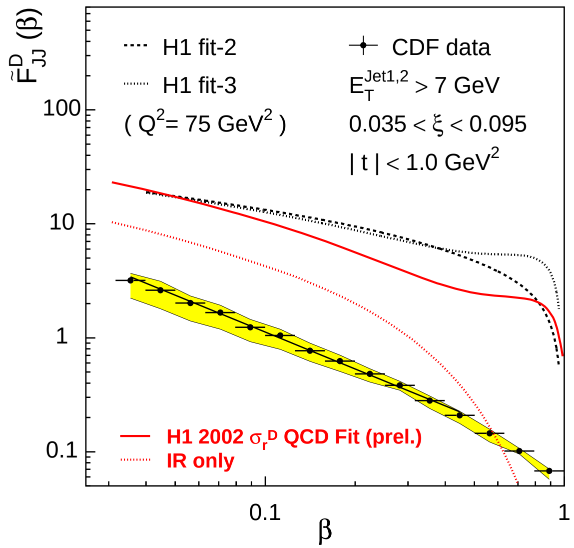
- Use pdf's from F_2^D to predict final state cross sections e.g. jets

- Should (?) be valid for direct photoproduction, but NOT for hadron-hadron (TEVATRON, LHC)

  (non-cancellation of soft gluon singularities)

- Factor $7 \ldots 10$ difference between CDF diffractive dijet data and HERA extrapolation





Introduction (cont.)

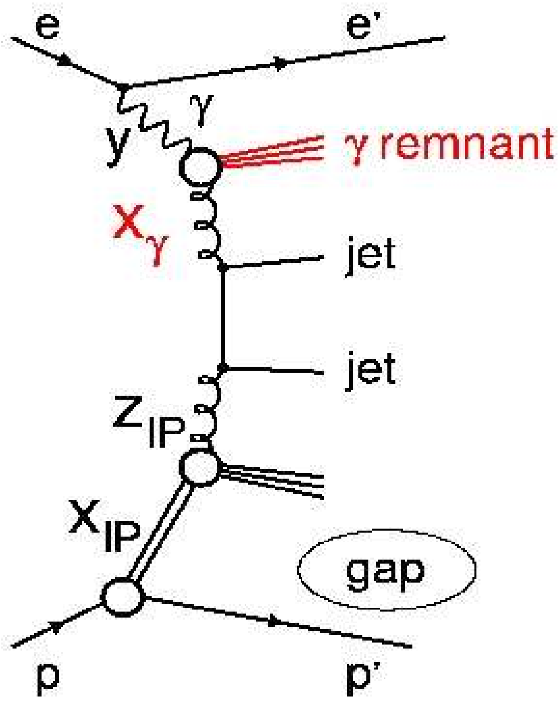
- **Goal:**
  Use similarity between resolved photoproduction and hadron-hadron to understand factorization breakdown in single expt.

- Analyze diffractive dijets at HERA in DIS and photoproduction in **THE SAME KINEMATIC RANGE** (except Q^2) and compare with NLO QCD

- NLO QCD using latest H1 NLO diffractive pdf's

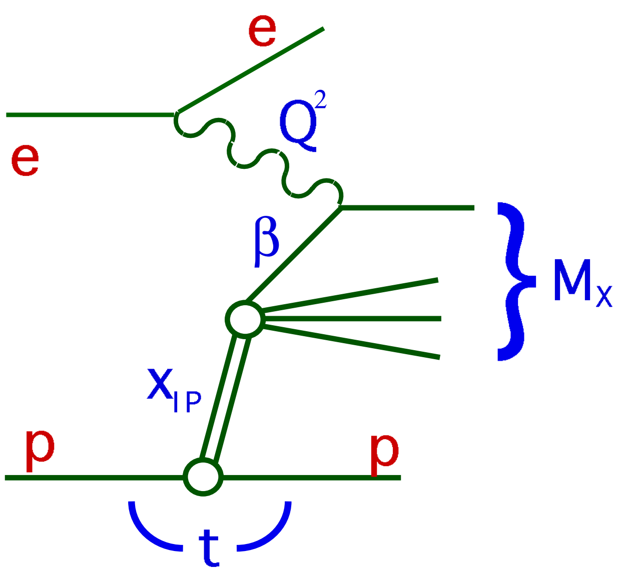
- If factorization breaks down in HERA photoproduction:

  (a) dependence on photon remnant x_γ?
  OR
  (b) dependence on size of photon: Q^2?



Diffractive Cross section and Structure Functions

In a frame where the proton is moving fast:



$x_{I\!P} = \xi = \frac{Q^2+M_X^2}{Q^2+W^2} = x_{I\!P/p}$
(momentum fraction of colour singlet exchange)

$\beta = \frac{Q^2}{Q^2+M_X^2} = x_{q/I\!P}$
(fraction of exchange momentum of
q coupling to γ^*, $x = x_{I\!P}\beta$)

$t = (p-p')^2$
(4-momentum transfer squared)

Diffractive reduced cross section σ_r^D:

$$\frac{d^4\sigma}{dx_{I\!P}\ dt\ d\beta\ dQ^2} = \frac{4\pi\alpha^2}{\beta Q^4}\left(1-y+\frac{y^2}{2}\right)\sigma_r^{D(4)}(x_{I\!P},t,\beta,Q^2)$$

Structure functions F_2^D and F_L^D:

$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{2(1-y+y^2/2)}F_L^{D(4)}$$

Integrated over t: $F_2^{D(3)} = \int dt\ F_2^{D(4)}$

– Longitudinal F_L^D: affects σ_r^D at high y

[γ inelasticity $y = Q^2/sx$]

– If $F_L^D = 0$: $\sigma_r^D = F_2^D$

Factorization in Diffraction

Diffractive pdf's / proof of QCD Factorization for diffractive DIS:

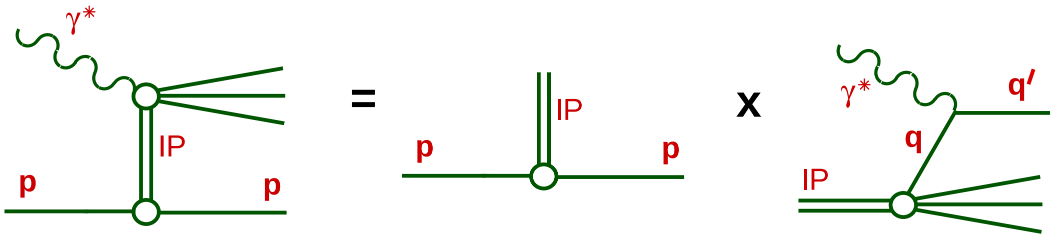
- Diffractive parton distributions (Trentadue, Veneziano, Berera, Soper, Col lins, ...):

$$\frac{d^2\sigma(x,Q^2,x_{I\!P},t)^{\gamma^* p\to p' X}}{dx_{I\!P}\;dt} = \sum_i \int_x^{x_{I\!P}} d\xi \hat{\sigma}^{\gamma^* i}(x,Q^2,\xi)\; p_i^D(\xi,Q^2,x_{I\!P},t) \quad (+\text{higher twist})$$

- $\hat{\sigma}^{\gamma^* i}$ hard scattering coeff. functions, as in incl. DIS
- p_i^D diffractive PDF's in proton, conditional probabilities, valid at fixed $x_{I\!P}$, t, obey (NLO) DGLAP

Ingelman-Schlein Model ('Resolved Pomeron' model):

$x_{I\!P}, t$ dependence factorizes out (Donnachie, Landshoff, Ingelman, Sc hlein, ...):



- additional assumption, no proof !
- consistent with present data if sub-leading $I\!R$ included

$$F_2^D(x_{I\!P},t,\beta,Q^2) = f_{I\!P/p}(x_{I\!P},t)\; F_2^{I\!P}(\beta,Q^2)$$

Shape of diffr. PDF's indep. of $x_{I\!P}$, t, normalization controlled by Regge flux $f_{I\!P/p}$

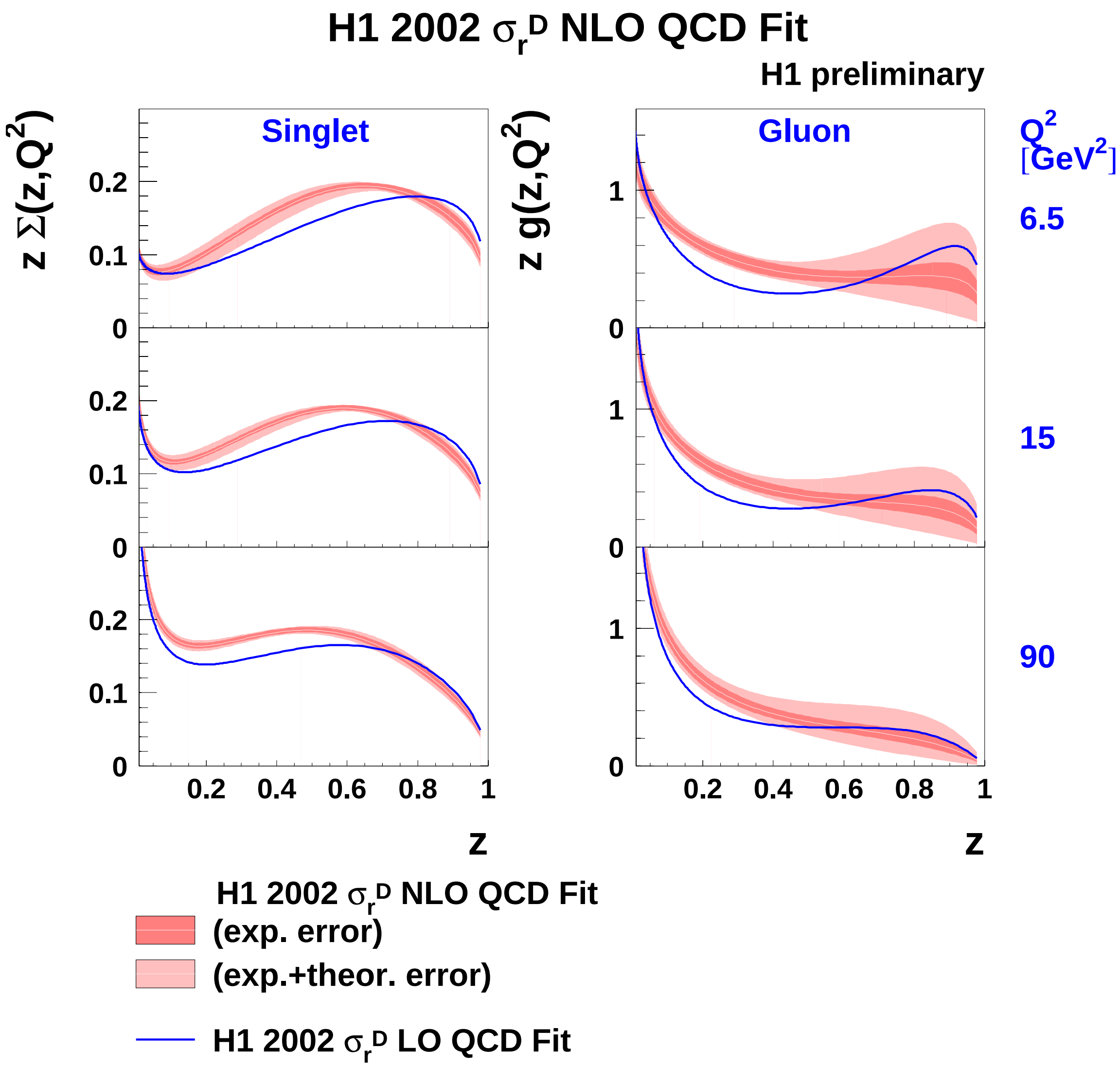
Diffractive NLO pdf's from F_2^D QCD Fit

QCD Fit Technique:

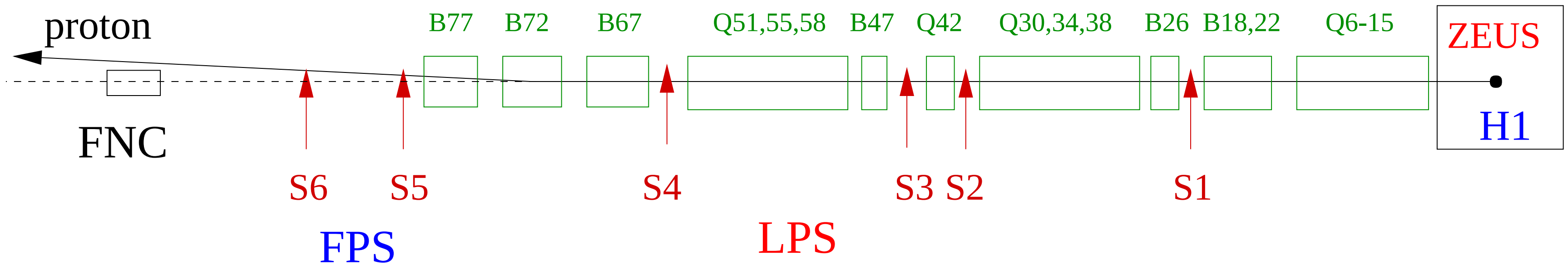
- factorize $f(x_{I\!P})f(z,Q^2)$
- Singlet Σ and gluon g parameterized at $Q_0^2 = 3\ \mathrm{GeV}^2$
- NLO DGLAP evolution
- Fit data for $Q^2 > 6.5\ \mathrm{GeV}^2$, $M_X > 2\ \mathrm{GeV}$
- For first time propagate exp. and theor. uncertainties !

PDF's of diffractive exchange:

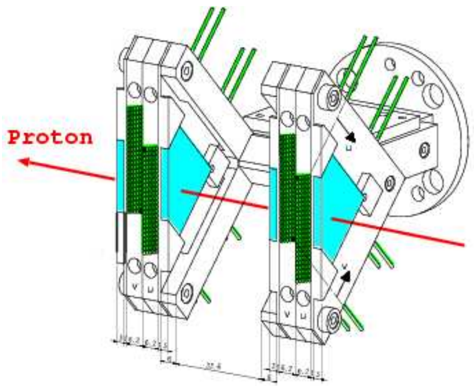
- Extending to large fractional momenta z
- Gluon dominated
- Σ well constrained
- substantial uncertainty for gluon at highest z
- Similar to previous fits



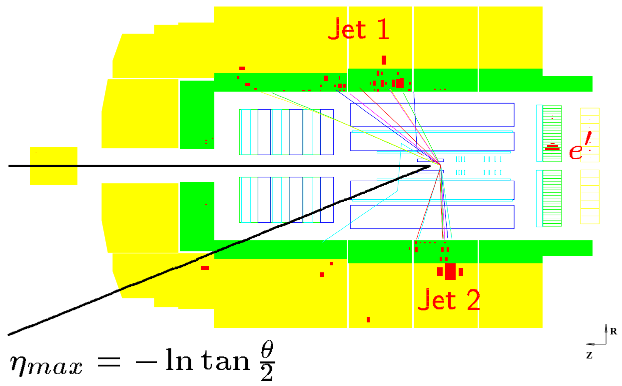
Diffractive Selection Techniques



Forward Proton Spectrometers at $z = 24 \ldots 90$ m



Rapidity Gap Selection in central detector



Measure leading proton

- Free of dissociation bkgd.
- Measure p 4-momentum
- low statistics (acceptance)

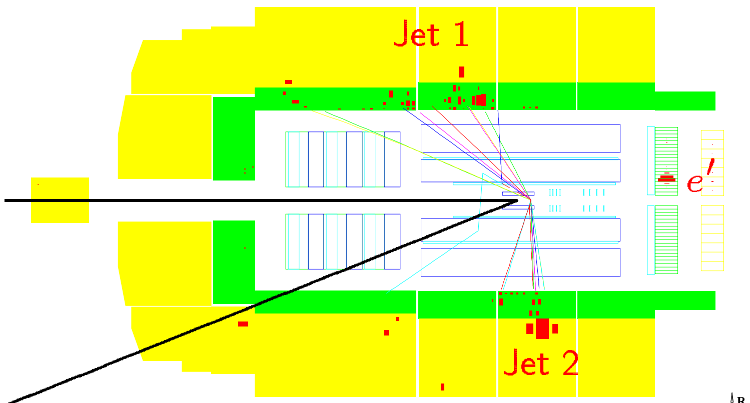
Require large rapidity gap

- $\Delta\eta$ large when $M_{\mathrm{central}} \ll W_{\gamma p}$
- integrate over outgoing p system
- high statistics (similar: M_X method)

Rapidity Gaps at Detector and Hadron Level

Detector Level:

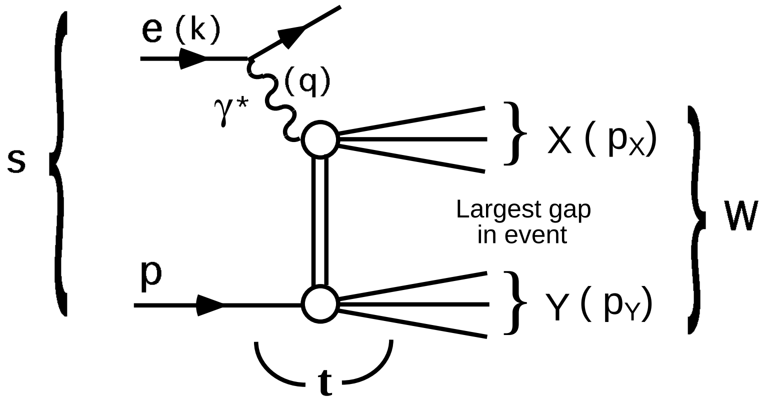
- No activity above noise in LAr calorimeter for $\eta > 3.2$
- Veto on activity in forward PLUG, FMD, PRT detectors



$\Rightarrow$ Gap spanning at least $3.2 < \eta < 7.5$

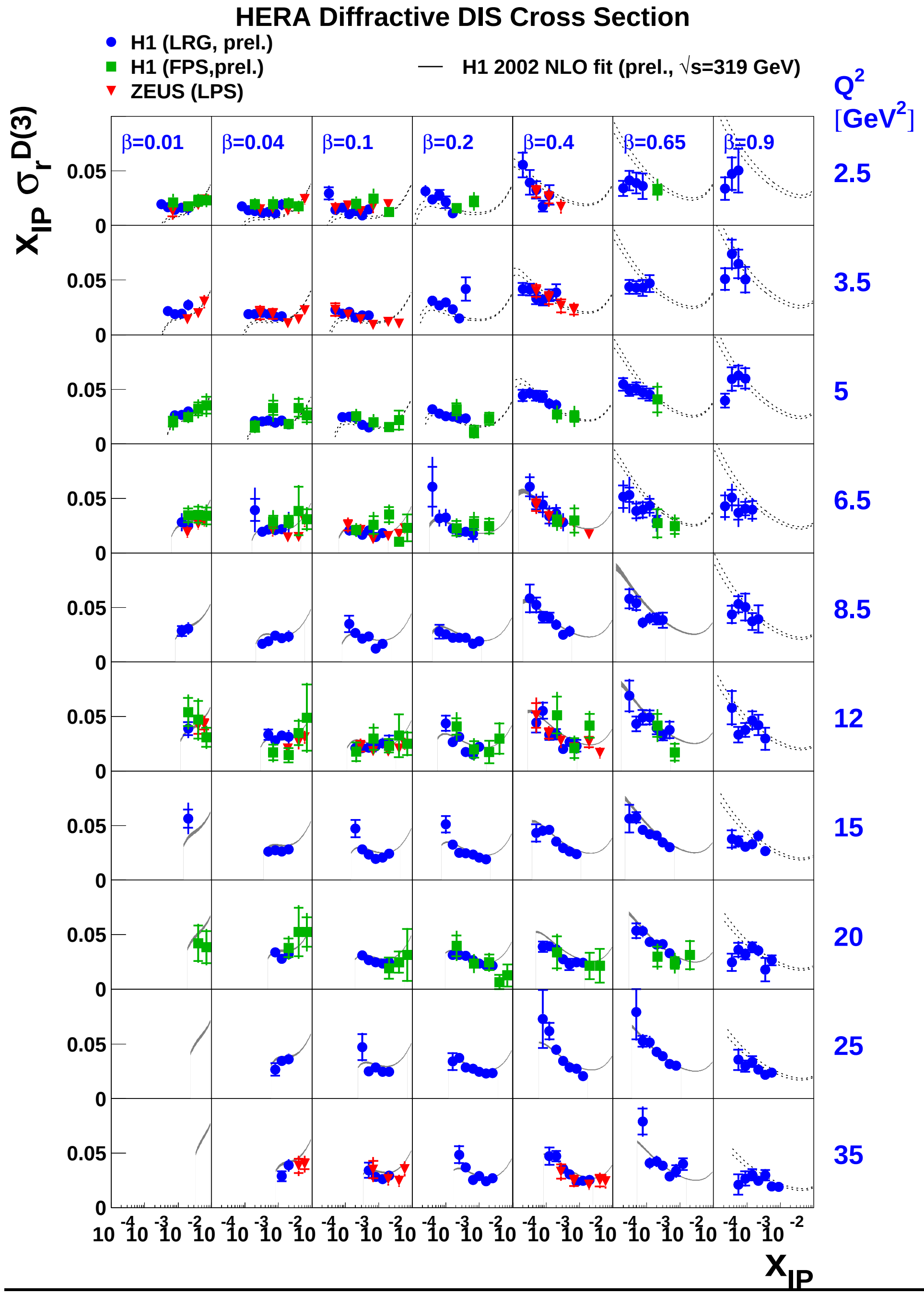
Level of stable Hadrons:

- Define systems X and Y on basis of largest gap in rapidity distribution of final state hadrons
- calculate $x_{I\!P}$, M_Y, t from X and Y



- Model independent
- Can be defined for any Monte Carlo etc.

$\Rightarrow$ Correction from Detector to Hadron Level using MC; Uncertainties included in errors!



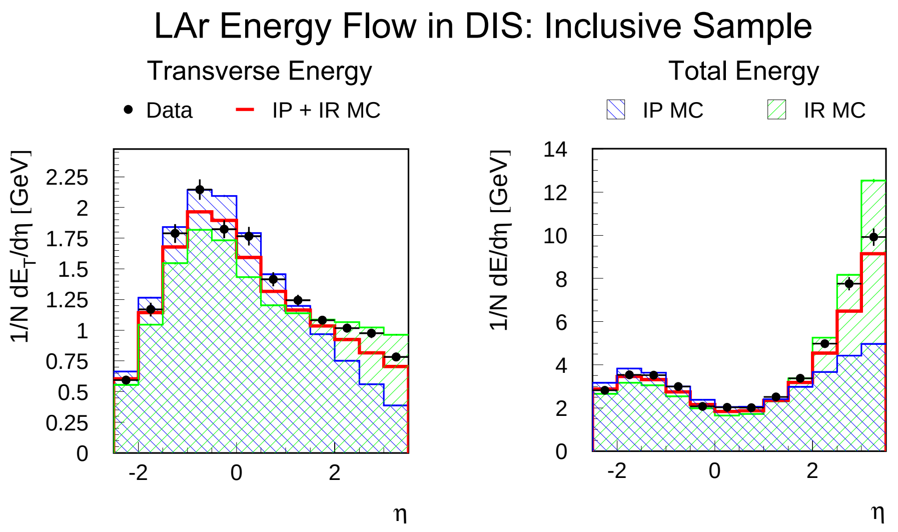
Cross Check: Comparison of Rapidity Gap and Leading Proton Data

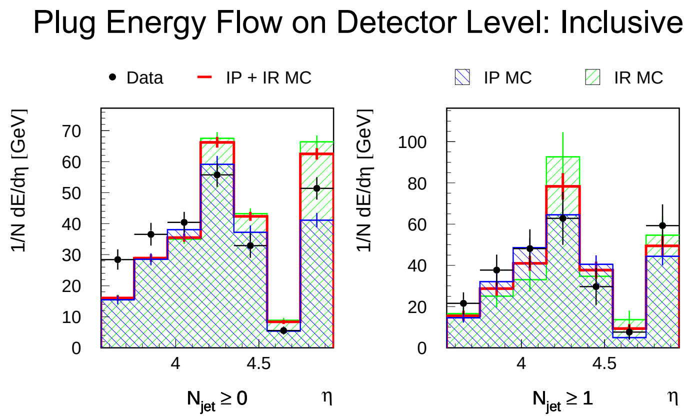
- Good agreement of FPS/LPS and Rapidity gap data!
- Correction for $M_Y > m_P$ applied

Cross Check: Forward Energy Flow for FPS tagged data

(Diploma thesis by S. Schenk, Heidelberg, 2003)

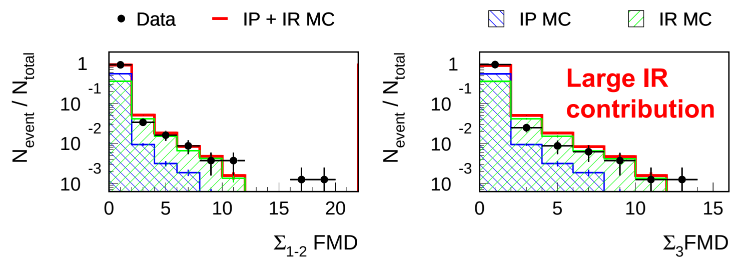
Compare measured forward energy flow for FPS tagged events (leading p identified) with diffractive MC (RAPGAP) without applying rapidity gap selection





- Calibration checks with DIS events
- Noise cut: $E_{bin} > 20$ GeV

Forward Muon Detector Hits



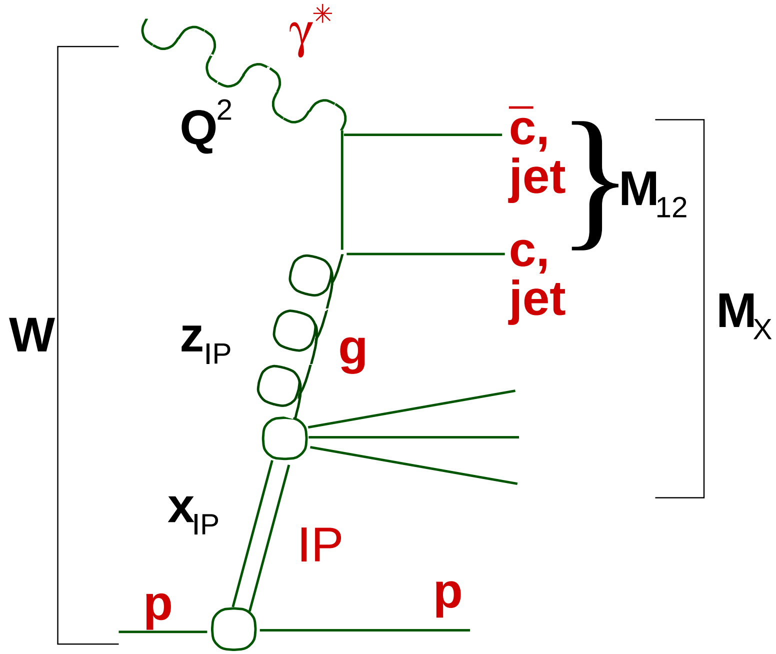
Inclusive Sample

Good agreement!

Important cross check of validity of rapidity gap selection and use of Monte Carlos as e.g. RAPGAP!

Jet Production in Diffractive ep Interactions

Test QCD factorization by applying dpdf's to final state cross sections .. .



Q^2: Photon virtuality
W: $\gamma^* p$ CMS energy

M_X: mass of diffractively produced system

$M_{12} = \sqrt{\hat{s}}$: mass of two jets

$$x_{I\!P} = \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

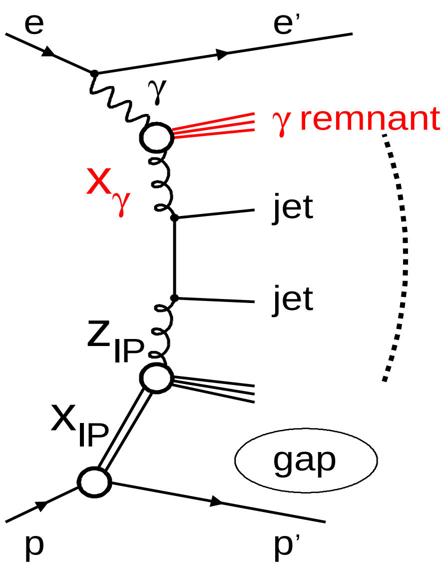
momentum fraction of diffractive exchange w.r.t. proton

$$z_{I\!P} = \frac{Q^2 + M_{12}^2}{Q^2 + M_X^2}$$

momentum fraction of diffractive exchange entering hard process

H1 Diffractive Dijet Data in DIS and Photoproduction

Data Selection / Cross Section Definition:



Photoproduction

- tagged electron:
  - $0.3 < y < 0.65 \Rightarrow 165 < W < 242$ GeV
  - $Q2 < 0.01$ GeV2
- jets:
  - inclusive k_T algorithm, distance parameter 1.0
  - $E_T^{jet1} > 5$ GeV, $E_T^{jet2} > 4$ GeV
  - $-1 < \eta_{jet(1,2)} < 2$ (lab frame)
- diffraction:

  $x_{IP} < 0.03$; $M_Y < 1.6$ GeV; $-t < 1$ GeV^2

DIS

- $4 < Q^2 < 80$ GeV^2
- $165 < W < 242$ GeV
- same jets and diffractive cuts as in γp

- Use **same phasespace for DIS and photoproduction** for direct comparison
- asym. jet cuts for NLO comparison

NLO Calculations for DIS and Photoproduction

- $\longrightarrow$ use standard NLO programs for jets in DIS and photoproduction:
  DISENT (DIS) and Frixione/Ridolfi (Photoproduction)

- Calculate NLO cross section at fixed $x_{I\!P}$ by running program with reduced E_p:
  $E_p = x_{I\!P} E_{p,nom.}$

- Use diffractive pdf $p_{i/I\!P}(z, \mu^2)$ instead of proton pdf

- Multiply with flux factor:
  $f_{I\!P}(x_{I\!P}) = \int \mathrm{d}t f_{I\!P}(x_{I\!P}, t)$

- Data integrated over $x_{I\!P}$:
  "$x_{I\!P}$ slicing"

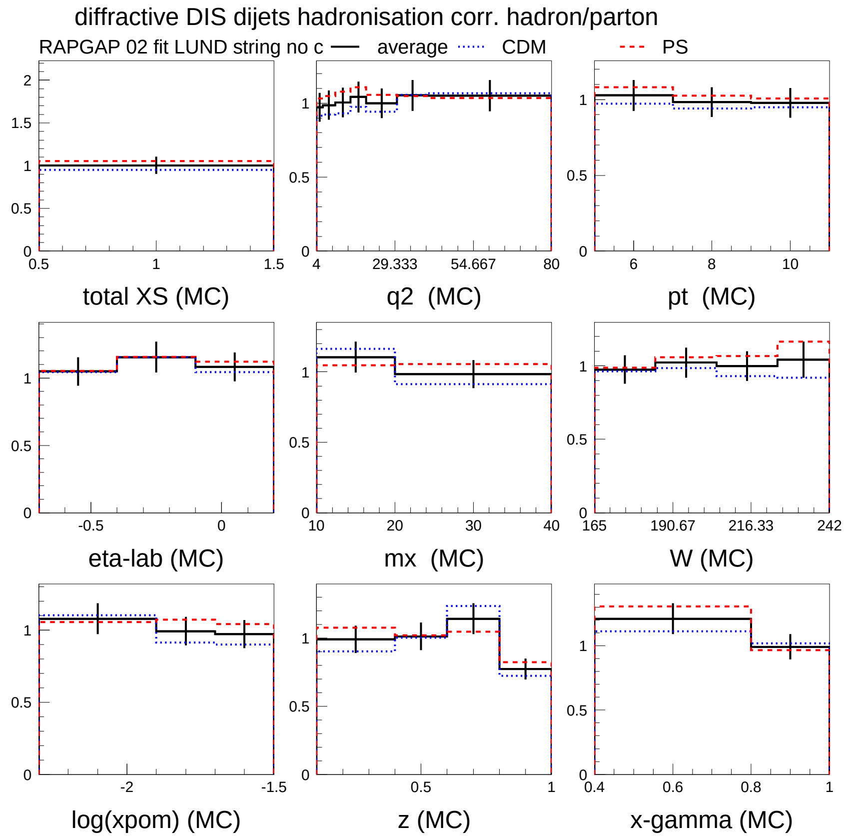
Stability of calculations w.r.t. number of $x_{I\!P}$ slices and other parameters checked!

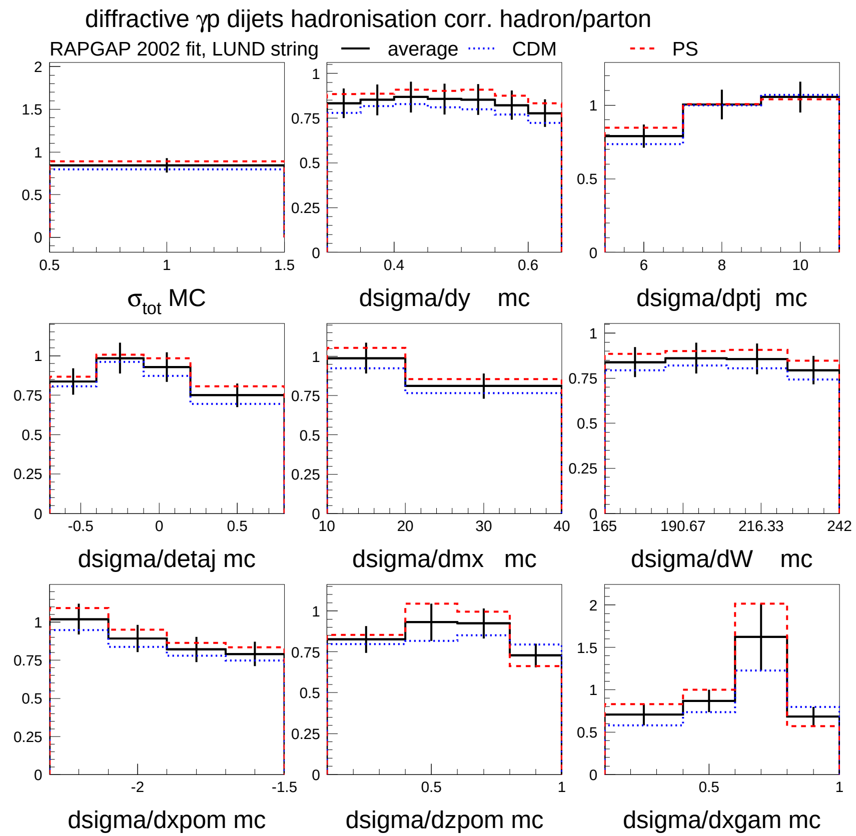
Hadronization Corrections

NLO Calculations refer to partons, measurements are corrected to stable hadron level!

$$(1 + \delta_{had}) = \sigma^{hadron} / \sigma^{parton}$$

(Hadron level includes gap definition)

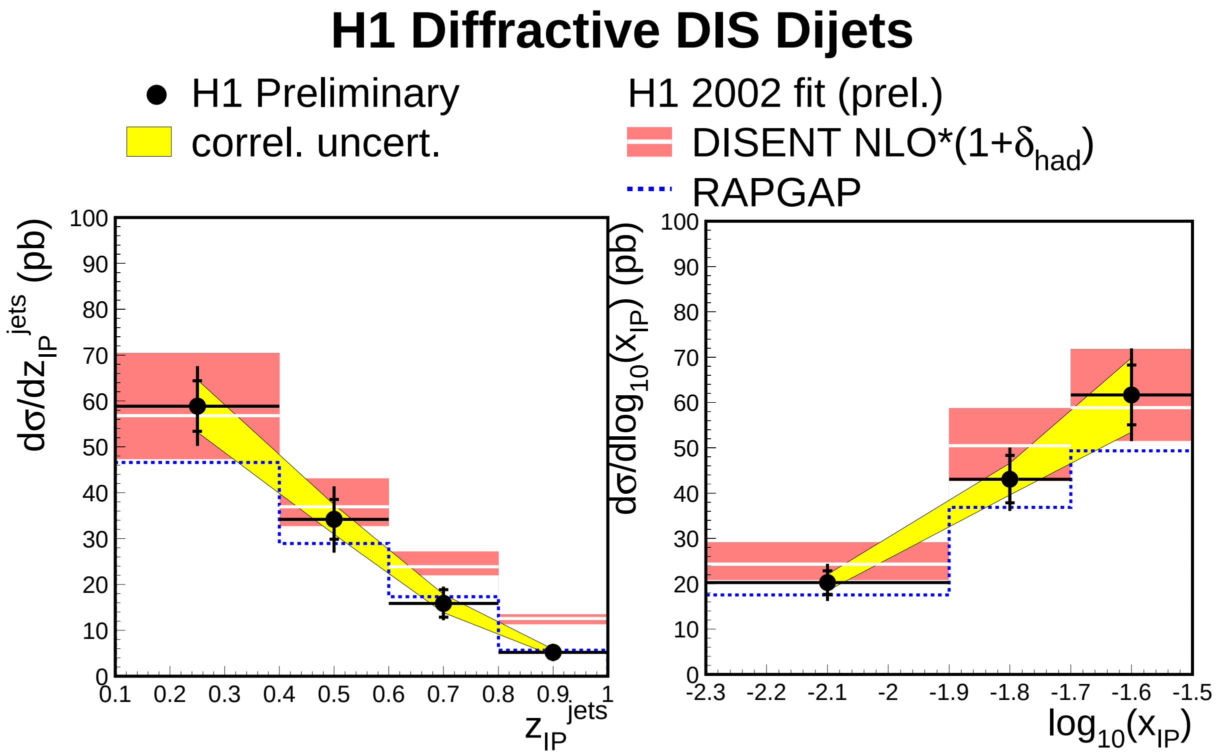




Corrections at low p_T, high x_γ important in photoproduction, also non-negligible in DIS

Uncertainty yet to be evaluated (e.g. using POMWIG)

Results: DIS



(a) (b)

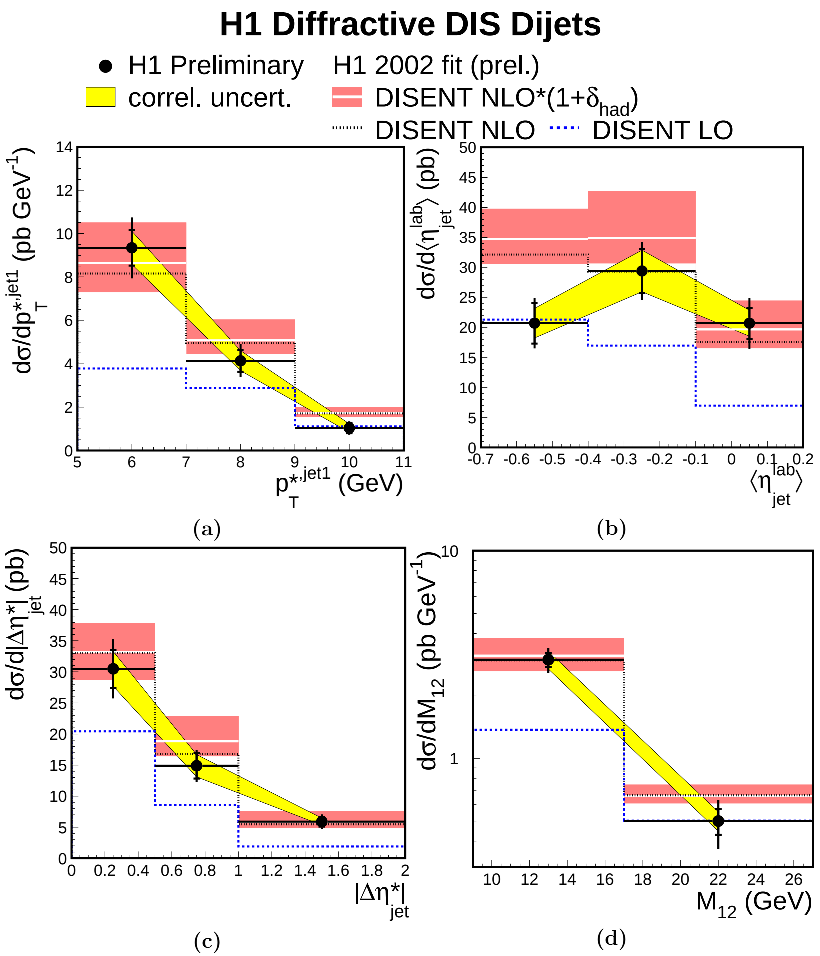
NLO error band:
renormalization scale unc.

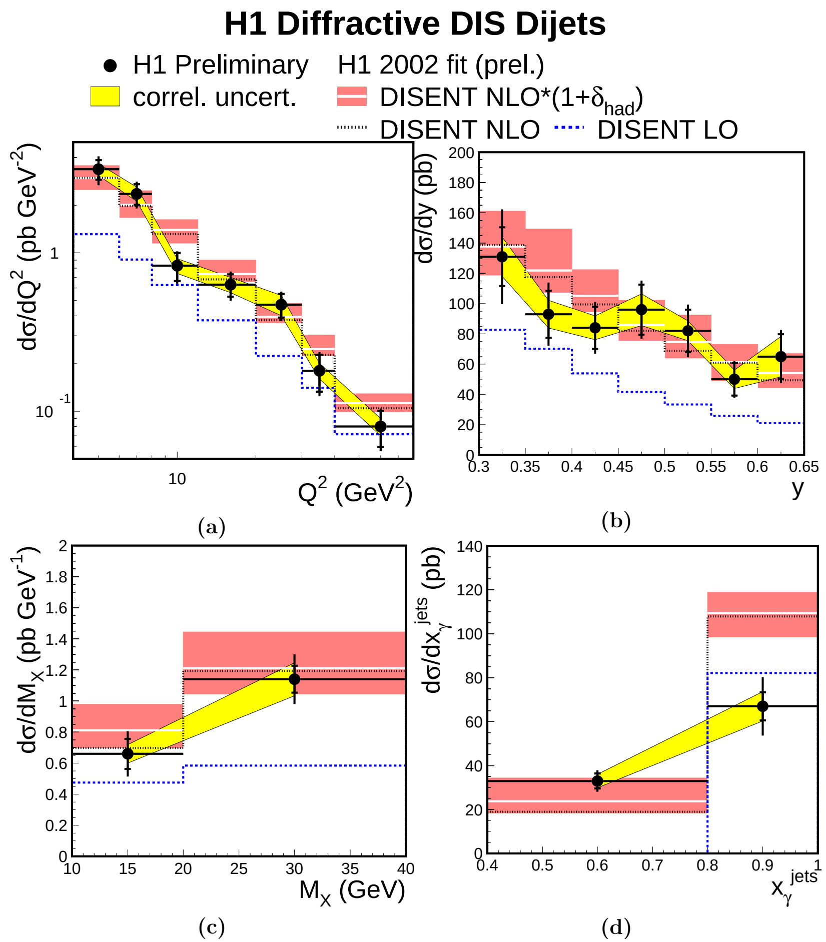
(hadr.cor. and pdf unc.
not yet included)

Data well described by NLO
(except at high $z_{I\!P}$ where pdf uncertainties are biggest)

RAPGAP LO + PS + resolved γ^* similar to NLO

Results: DIS (cont.)



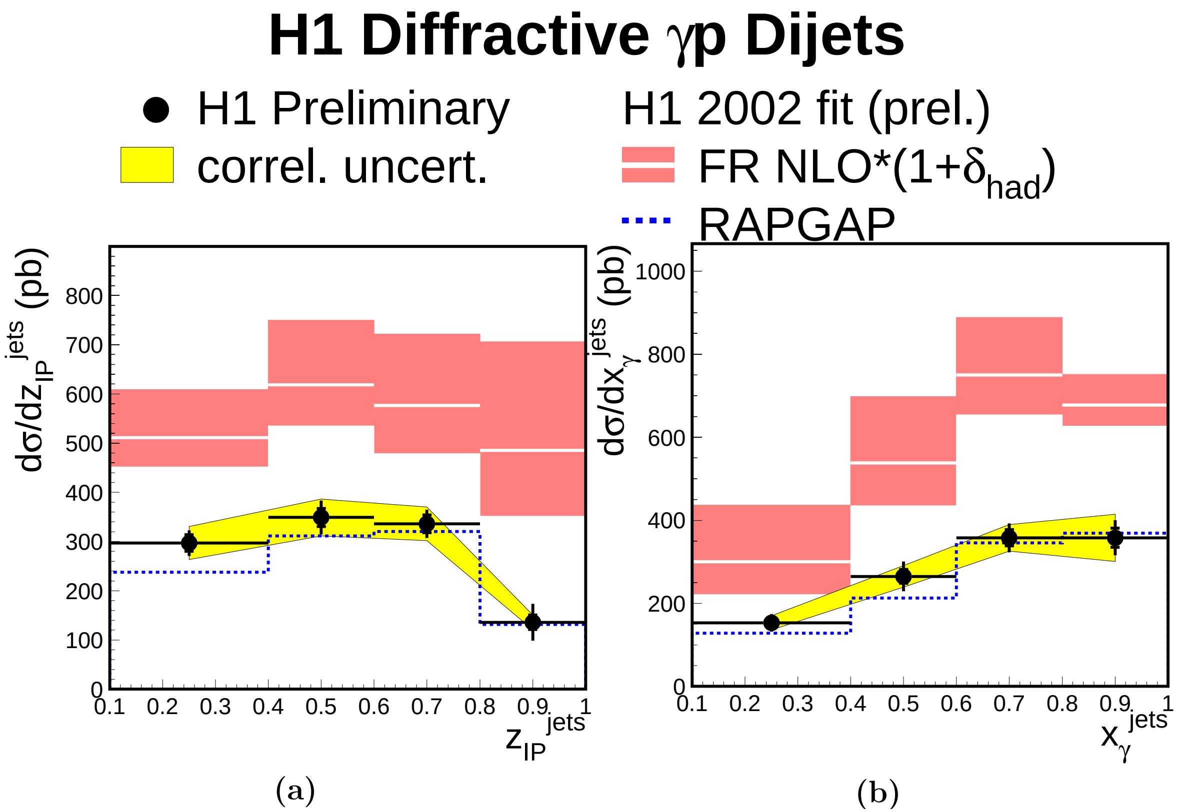


K-Factor (NLO/LO) of ~ 1.9 in DISENT

Good description by NLO except small η_{jet} region

$\Rightarrow$ Overall compatibility with QCD factorization in DIS!

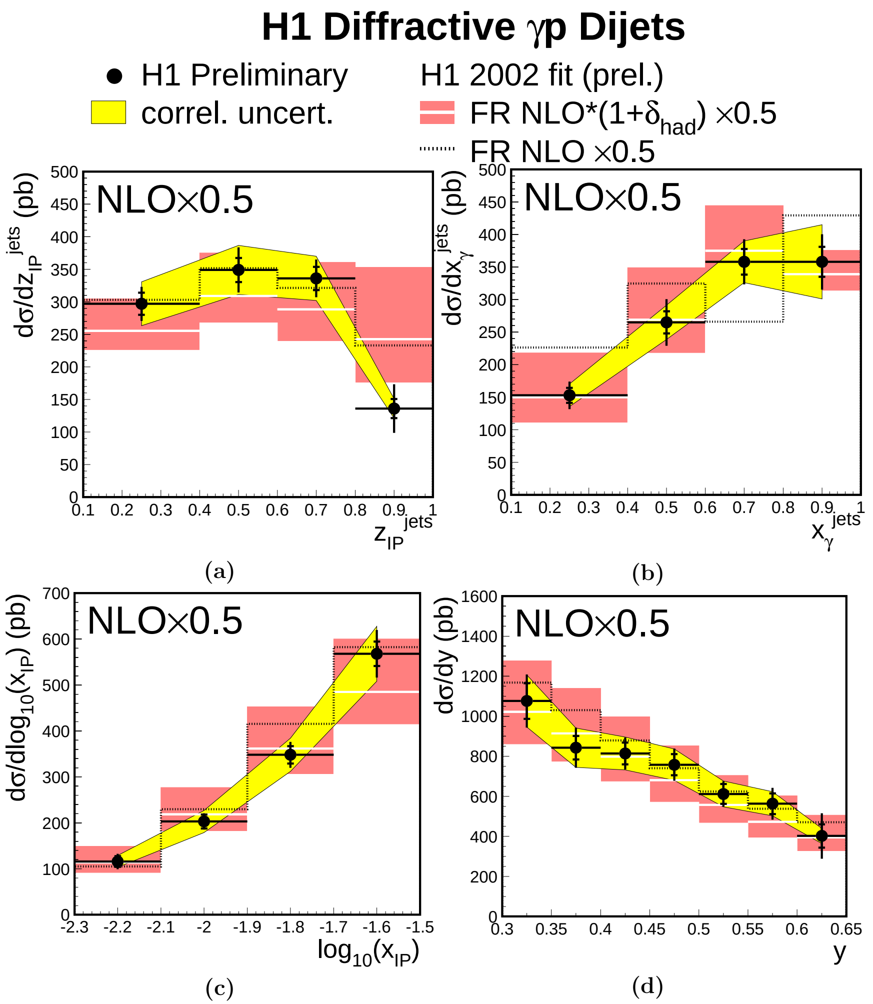
Results: Photoproduction

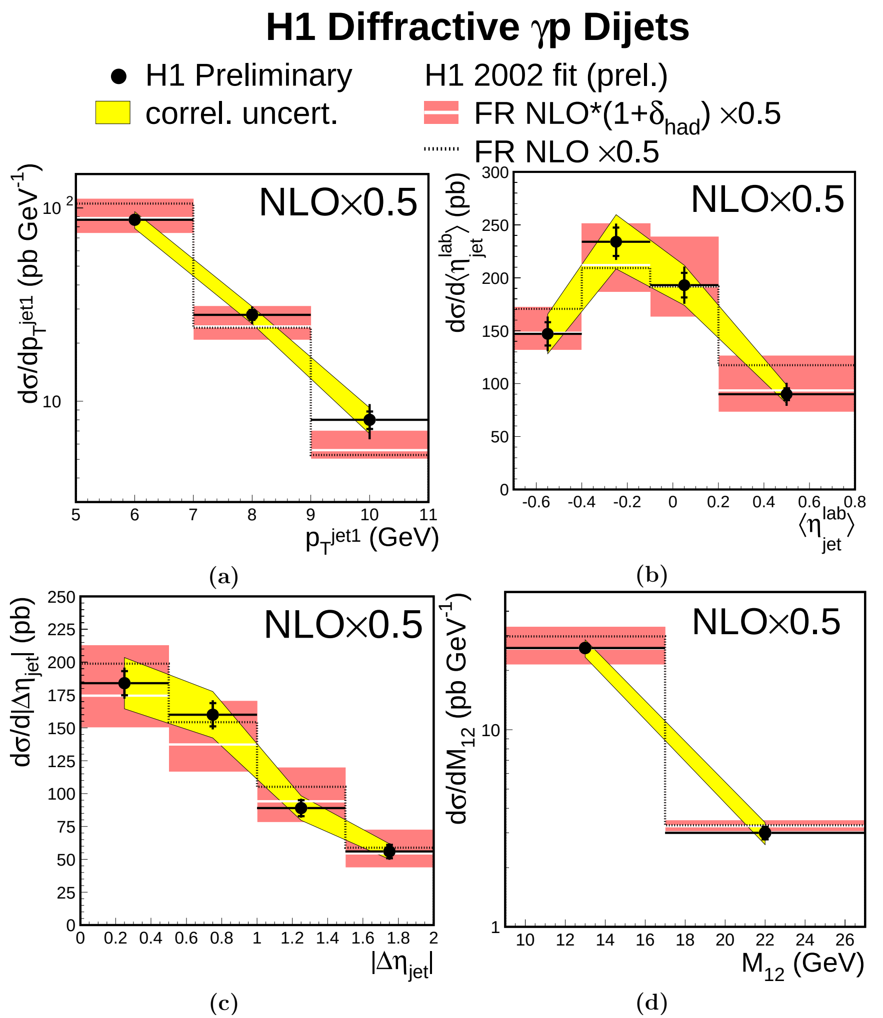


Data well described by LO+PS MC RAPGAP (direct+resolved)

NLO Calculation above the data
Approx. factor 0.5 needed (Beyond exp. and theor. uncertainties)!

Results: Photoproduction (cont.)





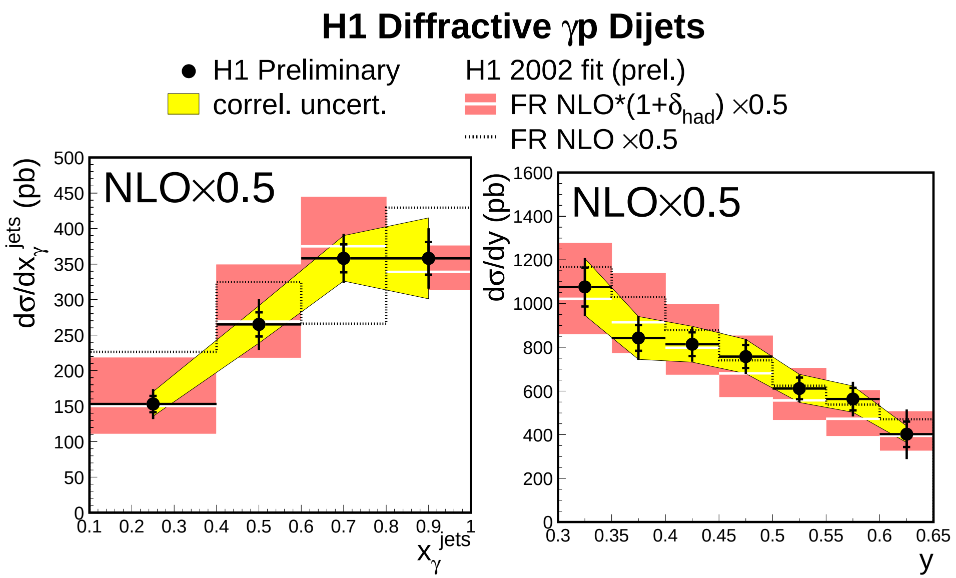
Global suppression by factor 0.5 describes differential distributions well

Importance of hadronization corrections for x_γ distrib.!

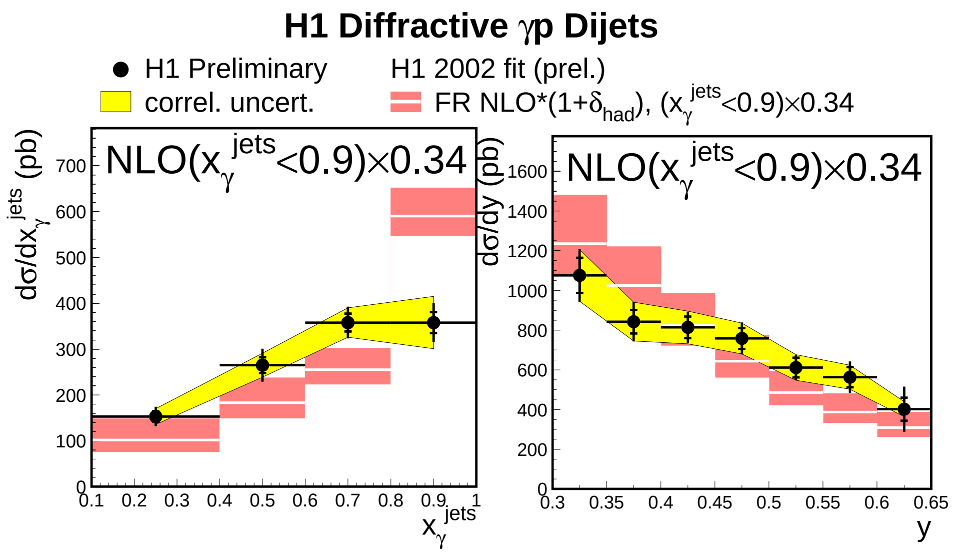
Results: Photoproduction (cont.)

Comparison global suppression vs resolved-only:

Global suppression by factor 0.5:



Suppression of resolved by factor 0.34:
(direct-resolved separation using $x_\gamma^{jets} = 0.9$)

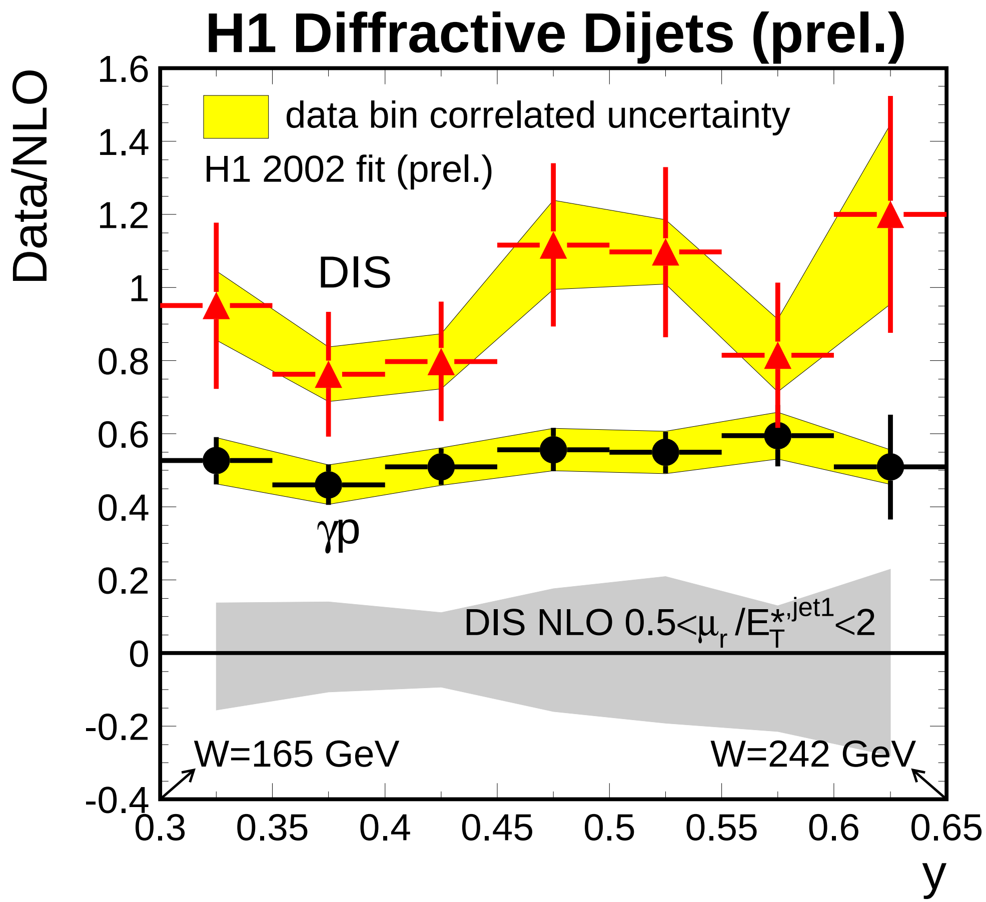


(a) (b)

Better description of data when using global suppression!
(stable vs variation of $_{\gamma}^{jets} = 0.9$ cut)
Importance of hadronization corrections!

$\Rightarrow$ Data favour Q^2-dependent suppression over one depending on x_γ!

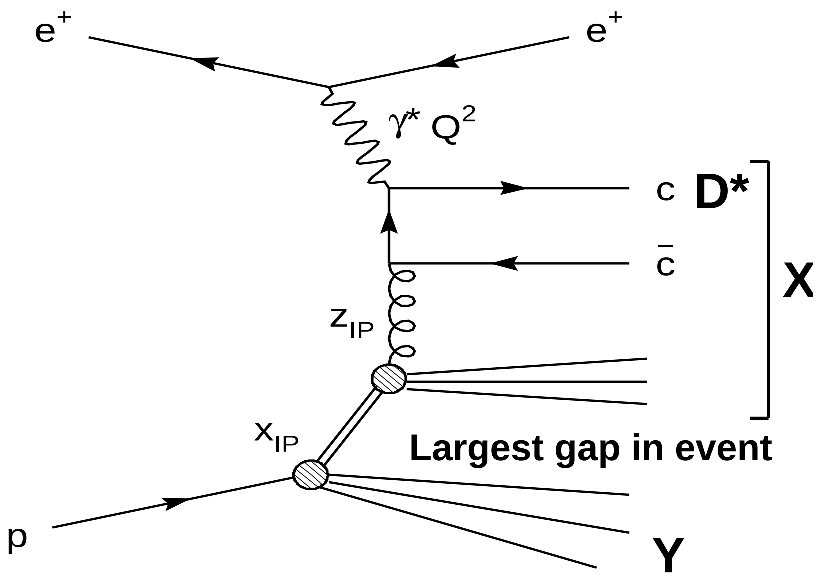
Comparison of DIS and Photoproduction

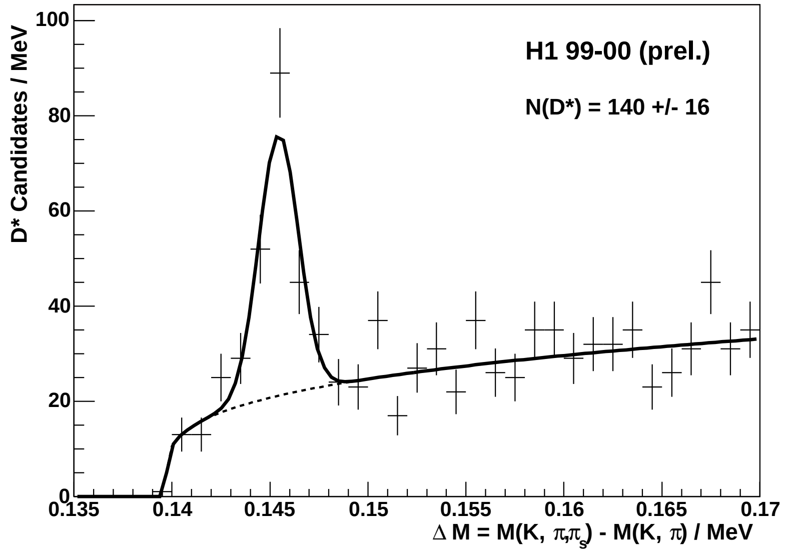


- Ratio Data/NLO for **DIS** compatible with **one**!
- Ratio Data/NLO for **photoproduction** around **0.5**
- **No significant** $W^2 = ys$ **dependence** observed!

Excursion: Diffractive Charm Production in DIS

Test QCD factorization in DIS using heavy quark production

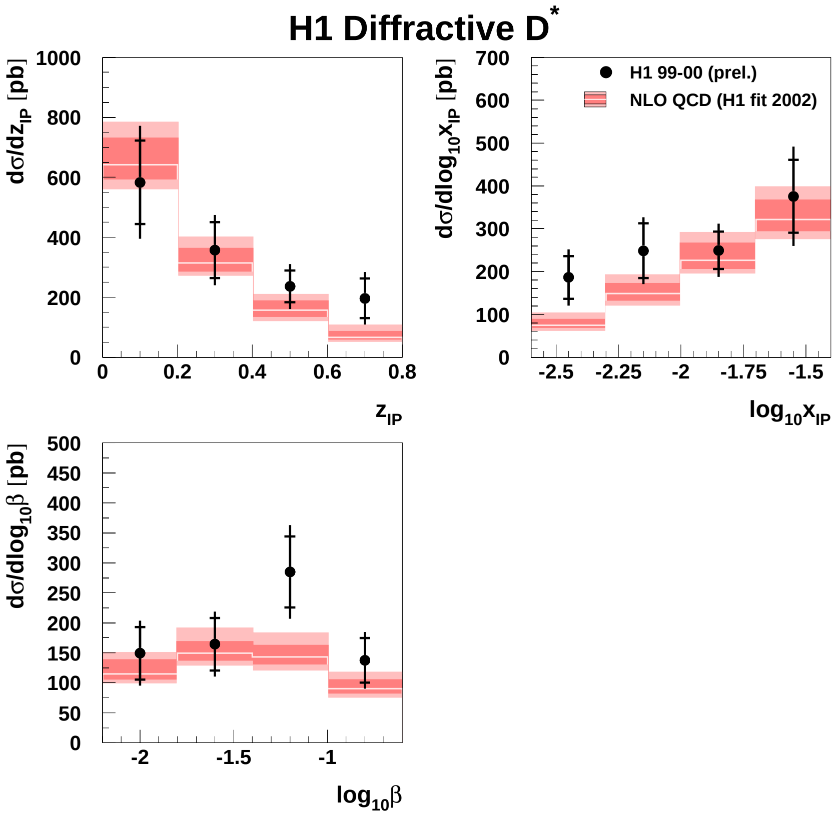


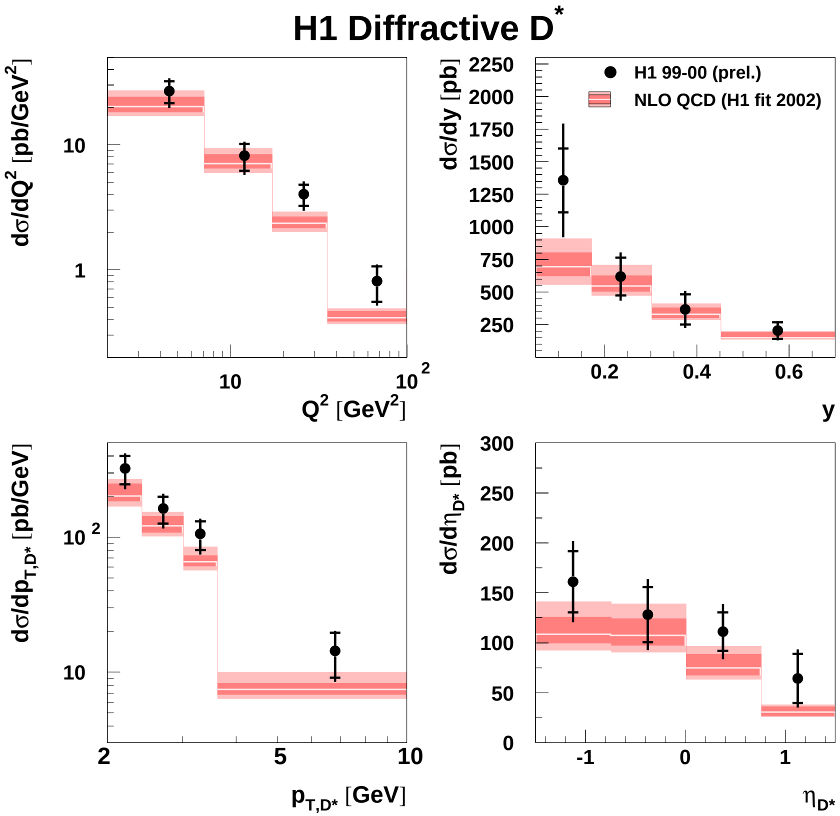


Charm tagging using D^* mesons

$$2 < Q^2 < 100 \text{ GeV}^2$$
$$x_{I\!P} < 0.04$$
$$p_T(D^*) > 2 \text{ GeV}$$
$$|\eta(D^*)| < 1.5$$

Excursion: Diffractive Charm Production in DIS (cont.)





NLO Calculation based on diffractive version of
HVQDIS (Smith, Harris) by Alvero, Collins et al., using H1 2002 pdf's

Diffractive D^* data well described by NLO!

$\Rightarrow$ Further support of validity of QCD factorization in diffractive DIS!

Conclusions

- Understand breakdown of QCD factorization in diffraction in single experiment by comparing HERA DIS and photoproduction dijets
- NLO calculations using standard programs extended for diffraction; latest H1 diffractive pdf's used

Summary:

- Dijets in **diffractive DIS overall consistent with QCD factorization** Ratio Data/NLO compatible with one
- **Supported by diffractive charm** data

- **In Photoproduction Ratio Data / NLO QCD smaller by factor $\mathbf{0.5 \pm 0.1}$ than in DIS**
- Beyond exp. and theor. uncceratinties
- Comparison Data-NLO favours **suppresion of both direct and resolved contributions** over models where only resolved is suppressed

- **Suppression only dependent on size of photon?**