Dijets in DIS and PHP at ZEUS

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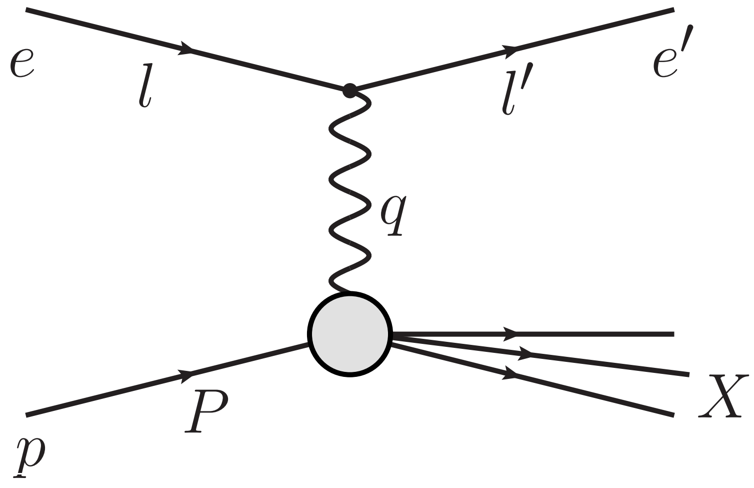
DIS 2011, Newport News

DIS: Eur.Phys.J.C70:965-982,2010
PHP: ZEUS-prel-10-014

On behalf of the ZEUS collaboration

HERA collider

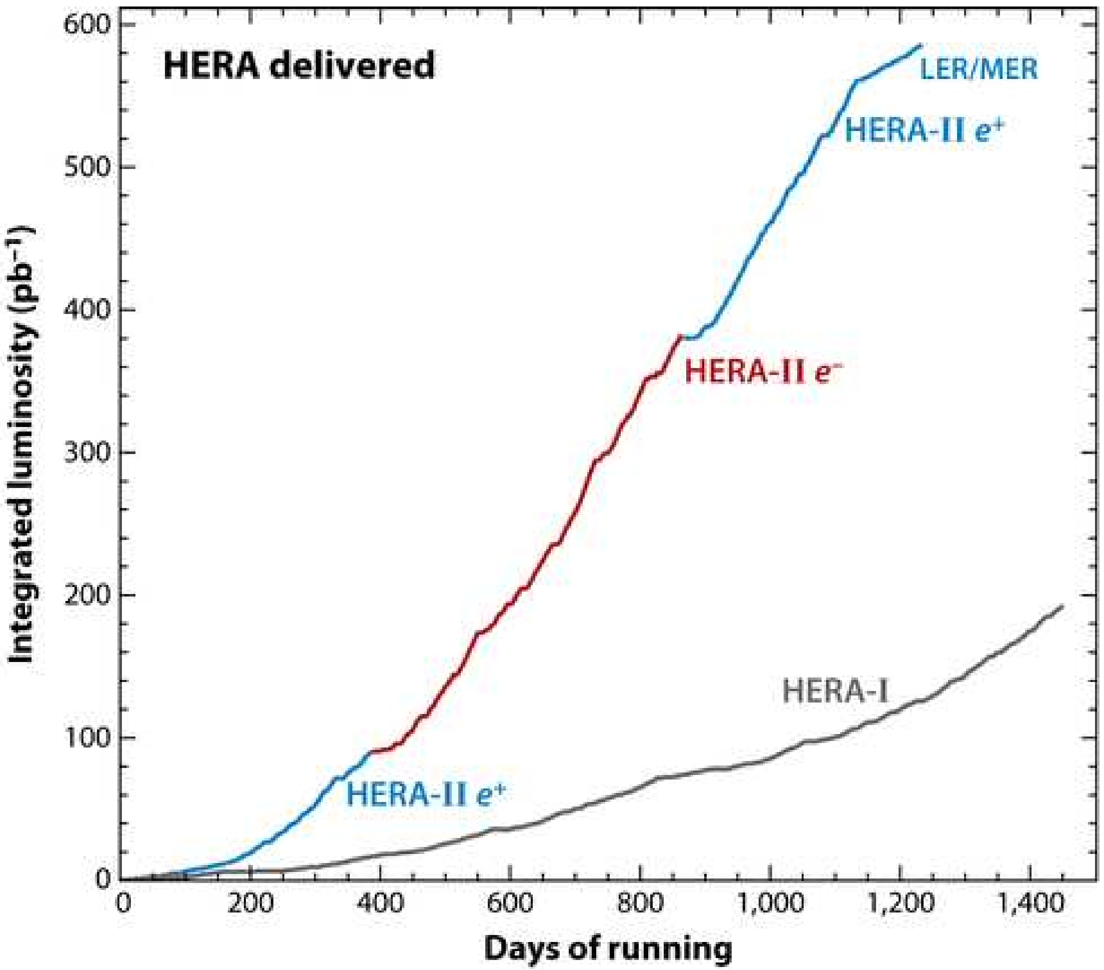


Electrons: 27.5 GeV
Protons: 920 GeV
$\sqrt{s} = 318$ GeV

Kinematics:
$Q^2 = -q^2 = -(l - l')^2$
$y = \frac{Pq}{Pl}$
$x_{Bj} = \frac{Q^2}{2Pq}$
$Q^2 = x_{Bj} y s$

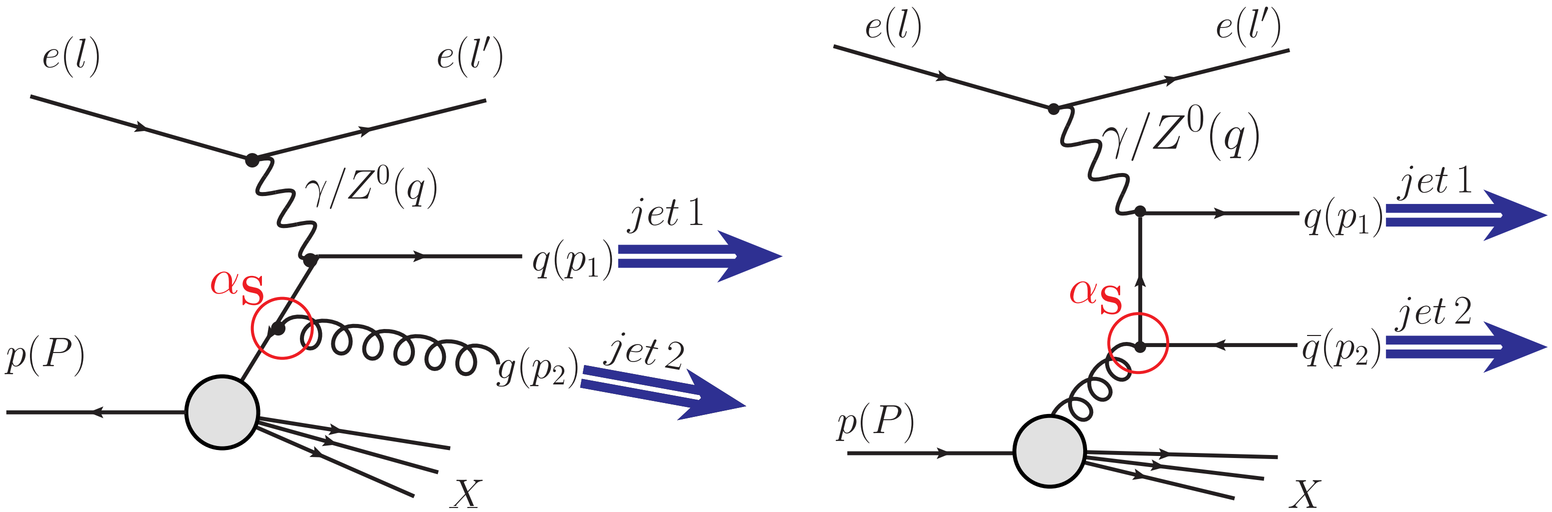
$Q^2 \leq 1$ GeV^2: photoproduction (PHP)

$Q^2 \geq 1$ GeV^2: DIS



Dijets in DIS

Dijet processes in DIS



- Processes of leading order in α_S:
  - QCD Compton scattering (quark-induced)
  - Boson-gluon fusion (gluon-induced)
- Jets in Neutral Current DIS:

- two hard scales: virtuality of the exchanged boson and transverse energy of the jets
- General tests of pQCD (hard matrix element, factorisation, perturbative expansion, PDF universality)
- High-precision measurements of strong coupling α_S
- Sensitive to parton distribution functions in proton

$$\sigma = \sum_n \alpha_S^n \sum_{a=q,\bar{q},g} f_{a/p} \otimes \hat{\sigma}_a^{(n)}$$

Dijet processes in DIS: observables

- Q^2 - virtuality of the exchanged boson
- x_{Bj} - for the parton

model process is the fraction of the proton momentum carried by the struck parton

- $\bar{E}^{jet}_{T,B} = \frac{1}{2}\left(E^1_T + E^2_T\right)$

- mean transverse energy

- $M_{jj} = \sqrt{(p_1 + p_2)^2}$ - invariant dijet mass

(in LO M_{jj} is identical to the centre-of-mass energy of the parton-boson system)

- $\xi = x_{Bj}\left(1 + \frac{M^2_{jj}}{Q^2}\right)$

- in LO is fraction of the proton momentum carried by the initial parton

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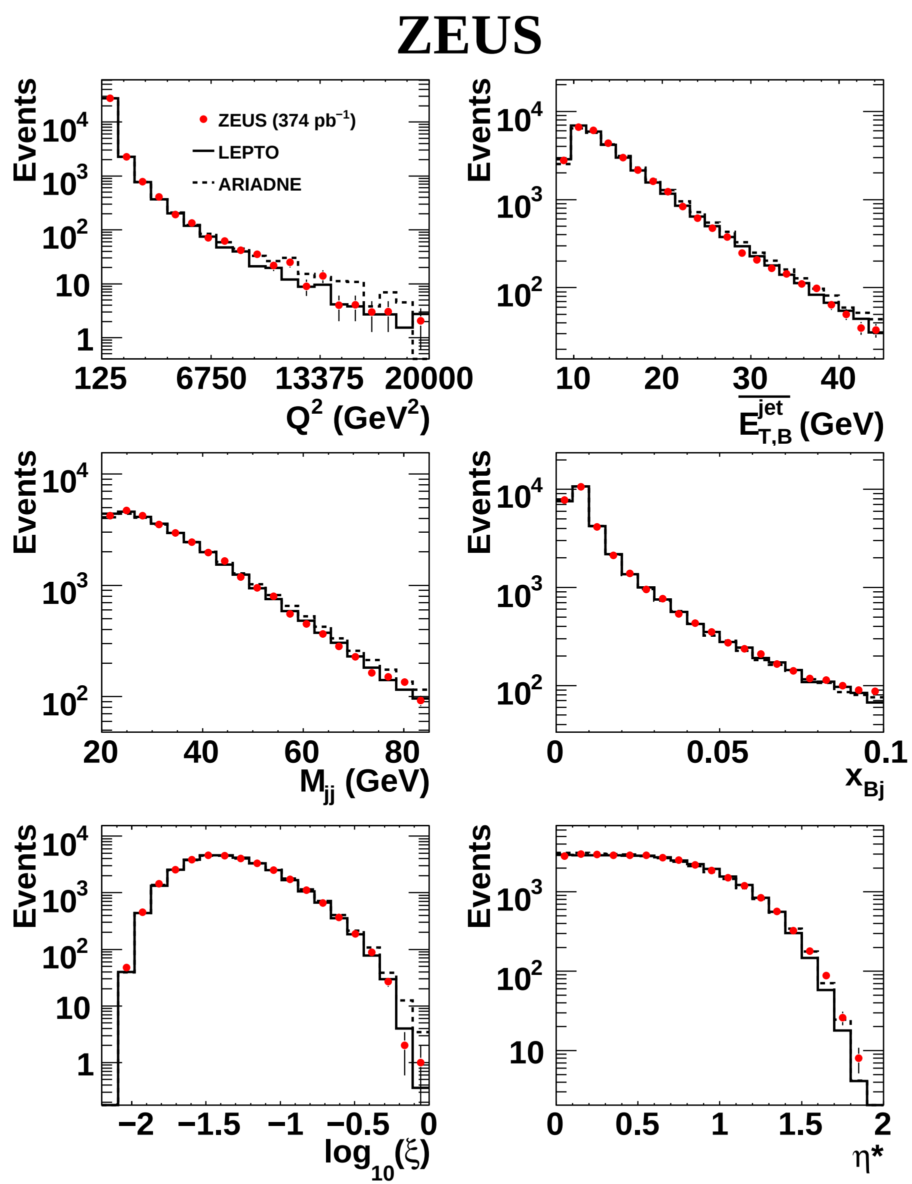
$\eta' = \frac{1}{2}|\eta^1 - \eta^2|$ - difference in pseudorapidity is invariant under longitudinal boosts



Dijets in DIS: samples and selections

- 1998-200 and 2004-2007: $203\ pb^{-1}$ of electron data $+\ 171\ pb^{-1}$ of positron data
- Event phase space:

$125 < Q^2 < 20\,000$ GeV^2
$0.2 < y < 0.6$

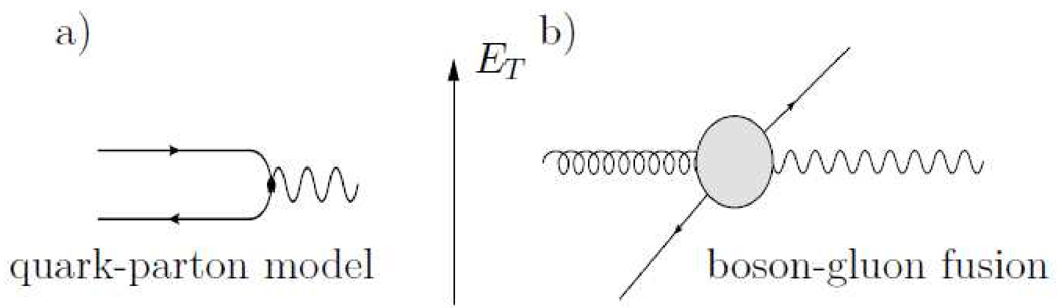
- Jets phase space:

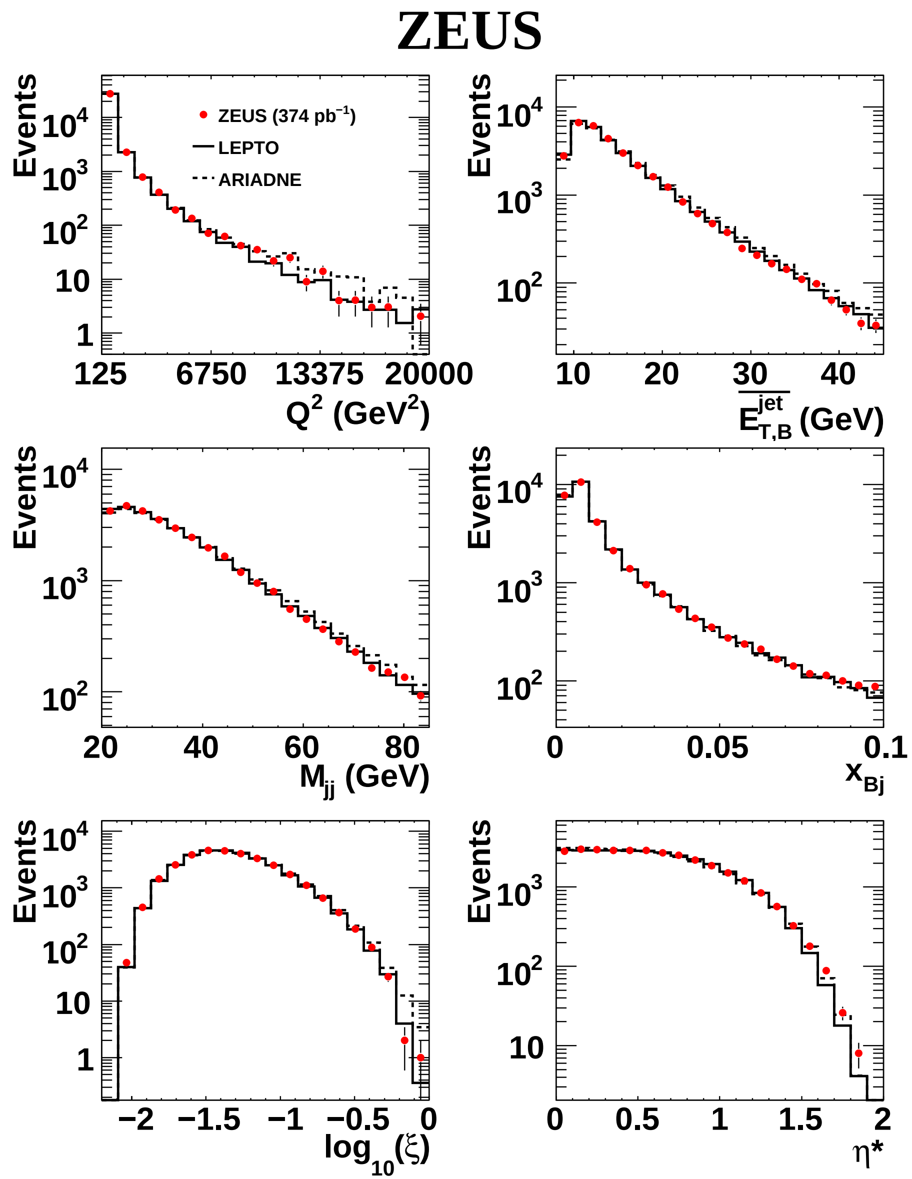
$-1 < \eta^{jet}_{LAB} < 2.5$
$E^{jet}_{T,B(1,2)} > 8$ GeV, $M_{jj} > 20$ GeV

- Jet selections:

\- k_T cluster algorithm in the longitudinally invariant inclusive mode running on calorimeter cells

\- Jet search in the $\eta - \phi$ plane of the Breit frame



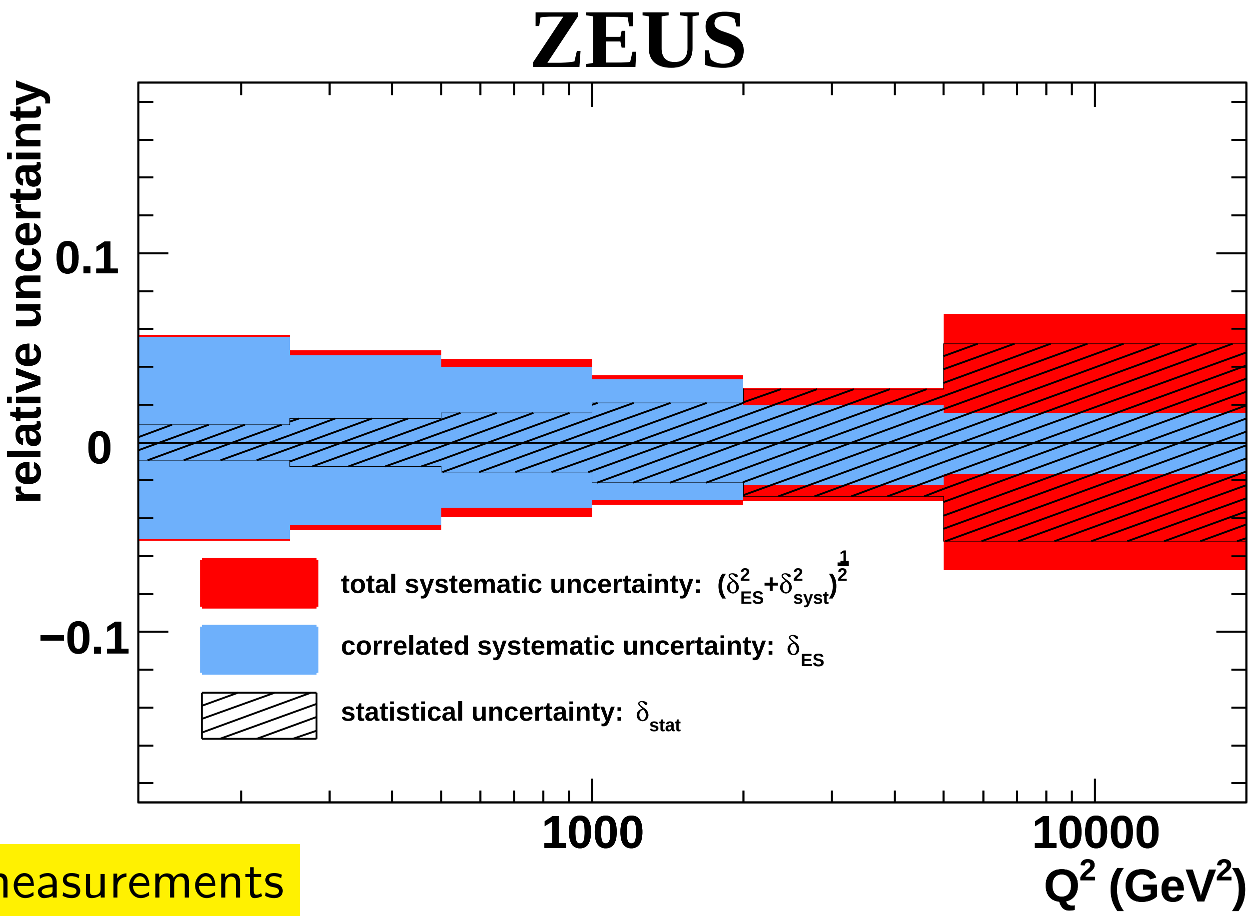


Dijets in DIS: data corrections and uncertainties

- Correction to the hadro
- QED corrections

Uncertainties:

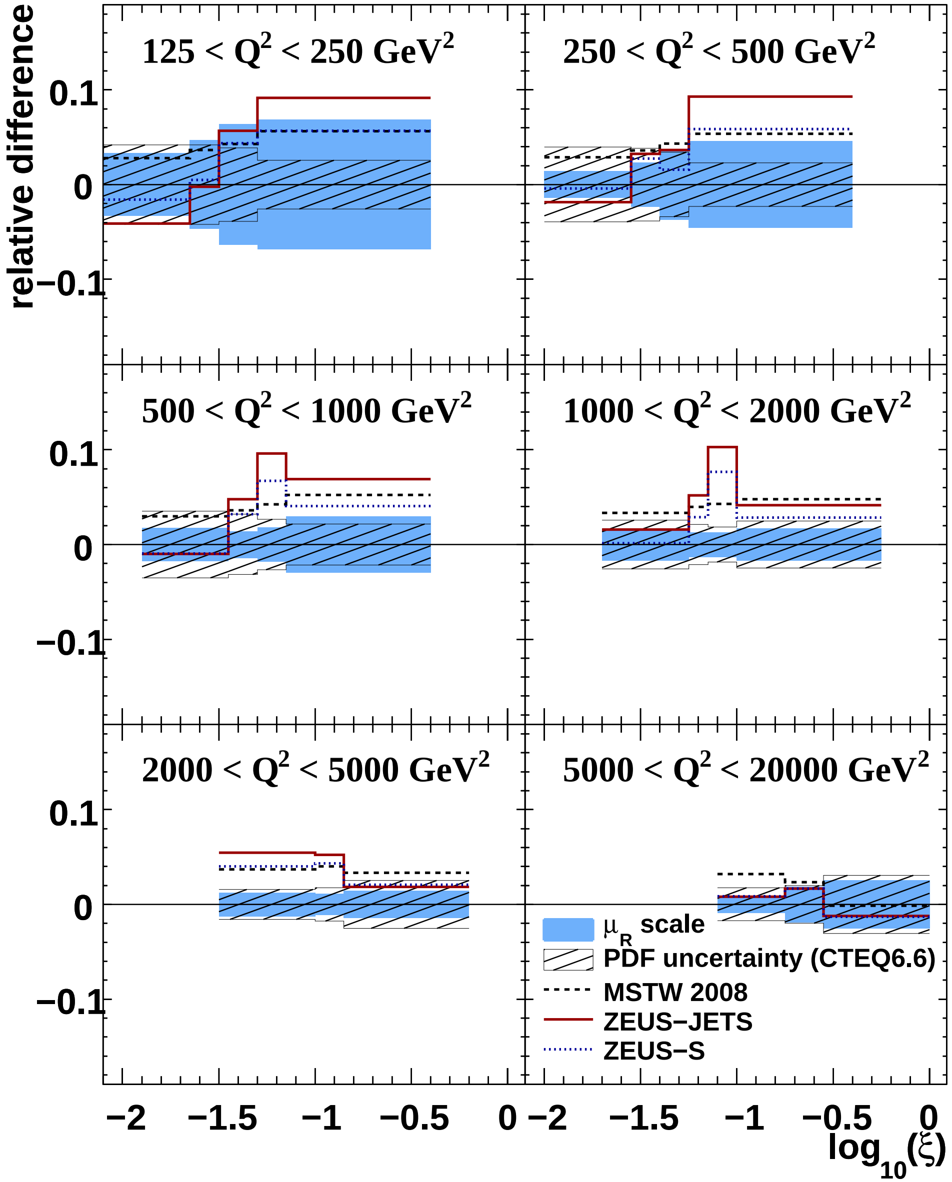
- on the absolute energy scale of the jets: $\pm 1\%$ for $E_{T,LAB}^{jet} > 10$ GeV and $\pm 3\%$ for lower $E_{T,LAB}^{jet}$
- on the absolute energy scale of the electron candidate: $\pm 2\%$
- very high precision of measurements



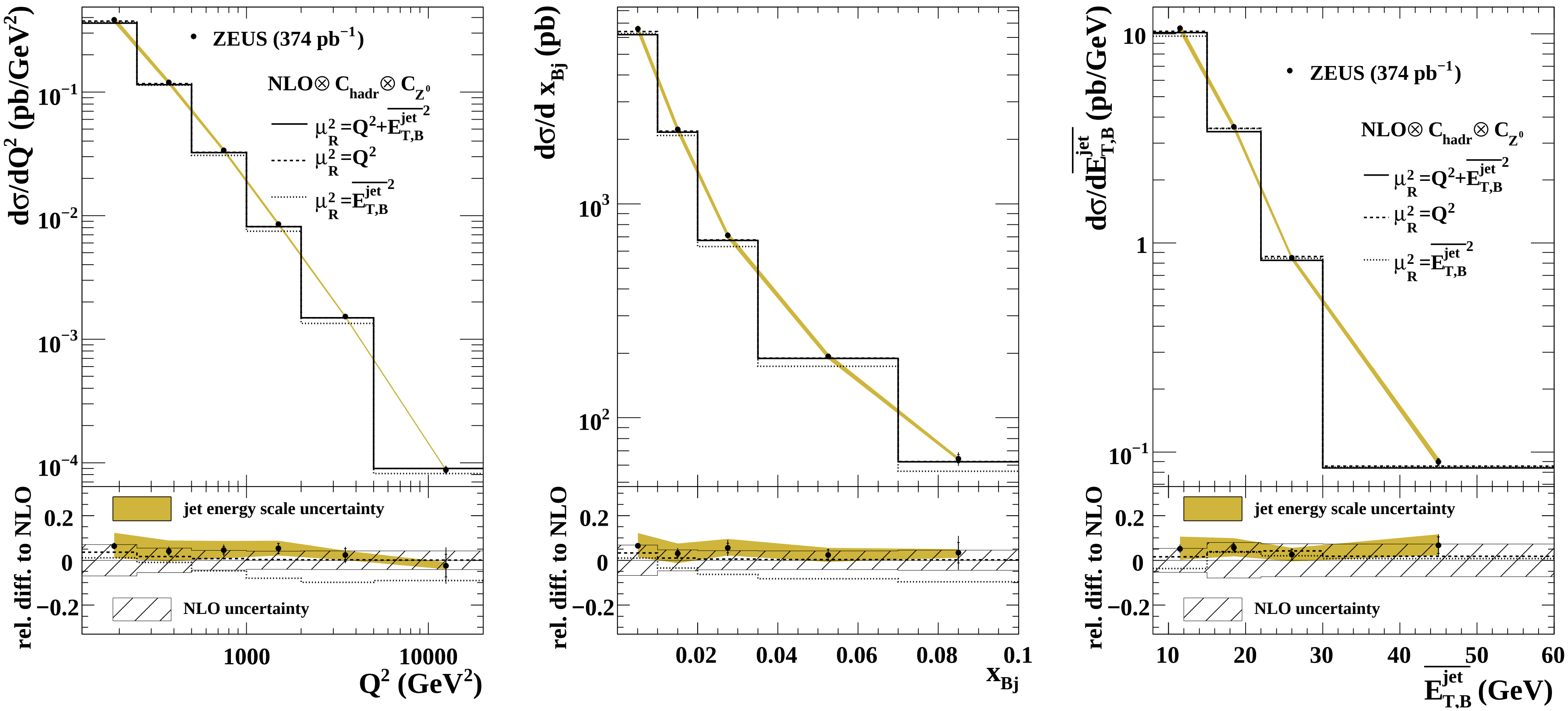
Dijets in DIS: NLO calculations

- NLO ($\mathcal{O}(\alpha_S^2)$) calculations were obtained using NLOJET++ / DISENT
- CTEQ6.6 parameterisations of the proton PDFs
- predictions corrected to the hadron level (corrections differ from unity by 5%)
- **Sources of uncertainty in the theoretical predictions:**

- due to terms beyond NLO: $\pm 6\%$ at low Q^2 and $\pm 3\%$ at high Q^2
- due to uncertainty on α_S: mostly below $\pm 3\%$
- uncertainty of the modelling of the parton shower: less than 2%
- due to proton PDFs: $\pm 4\%$ at low Q^2 and $\pm 2\%$ ath high Q^2



Dijets in DIS: results - Single-differential cross sections

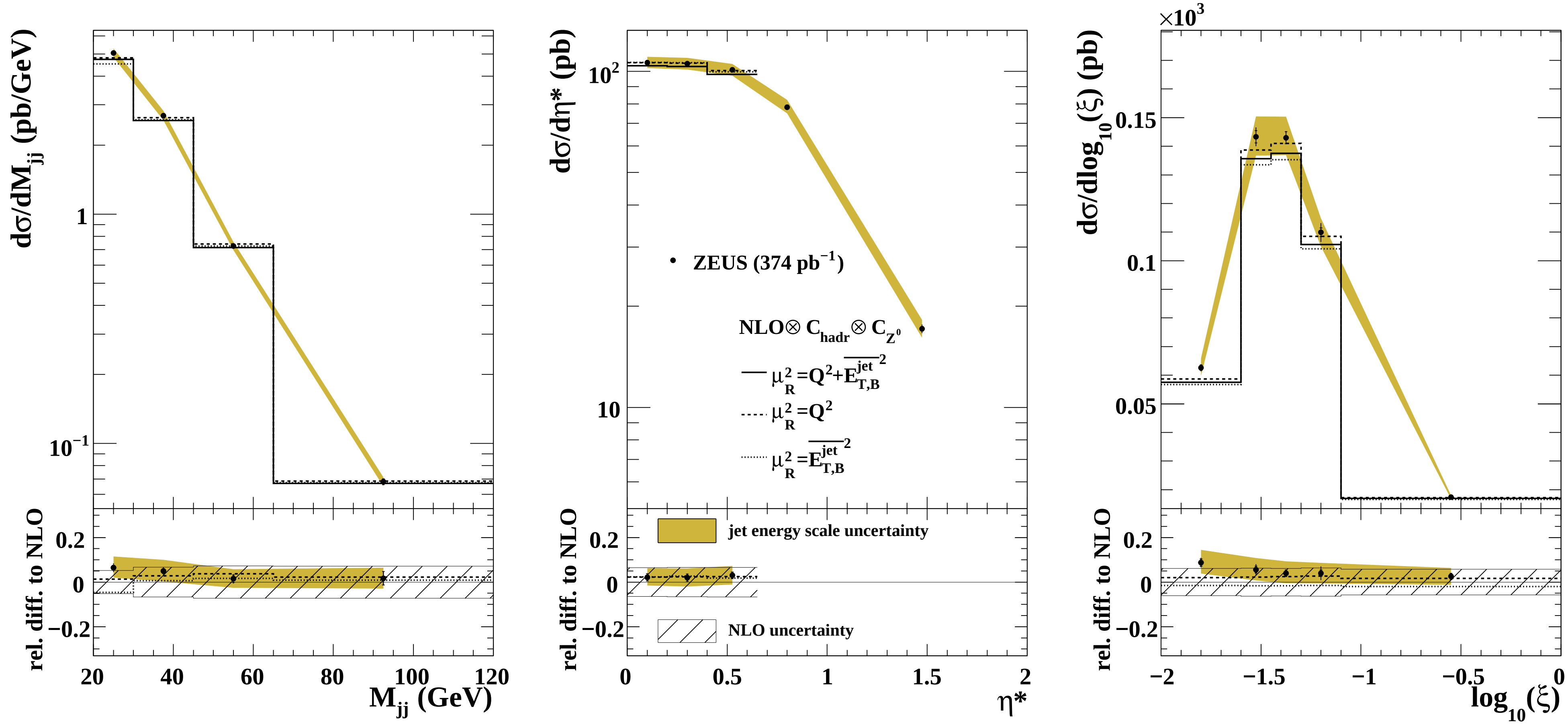


- Kinematic region: - $125 < Q^2 < 20\,000\text{GeV}^2$, $0.2 < y < 0.6$

$-1 < \eta_{LAB}^{jet} < 2.5$, $E_{T,B(1,2)}^{jet} > 8$ GeV, $M_{jj} > 20$ GeV

- Good description of data by NLO QCD in the whole measured range

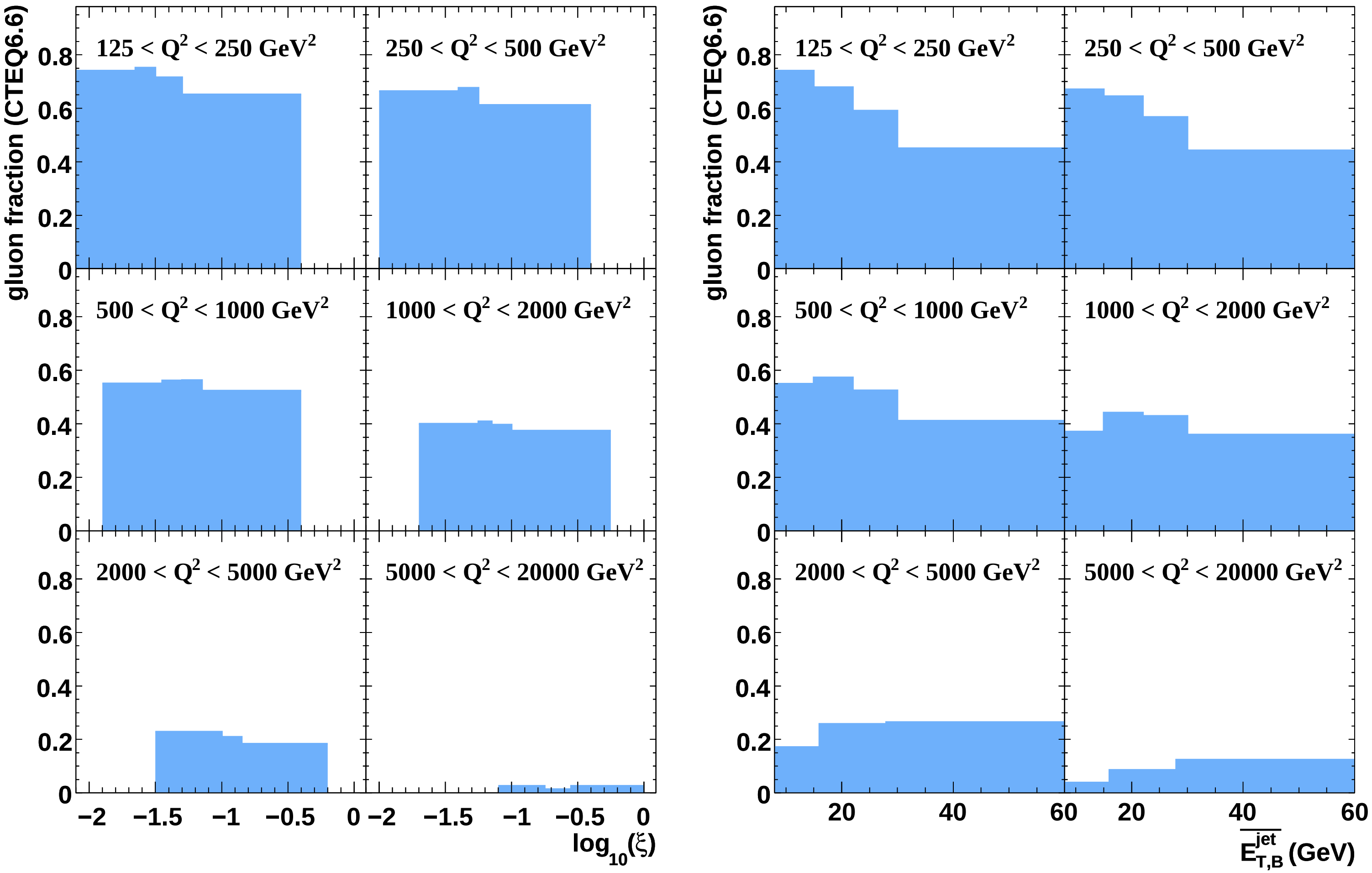
Dijets in DIS: results - Single-differential cross sections



$\eta^* = \frac{1}{2}|\eta^1 - \eta^2|$, $\xi = x_{Bj}\left(1 + \frac{M_{jj}^2}{Q^2}\right)$

- Good description of data by NLO QCD in the whole measured range

Dijets in DIS: gluon induced events

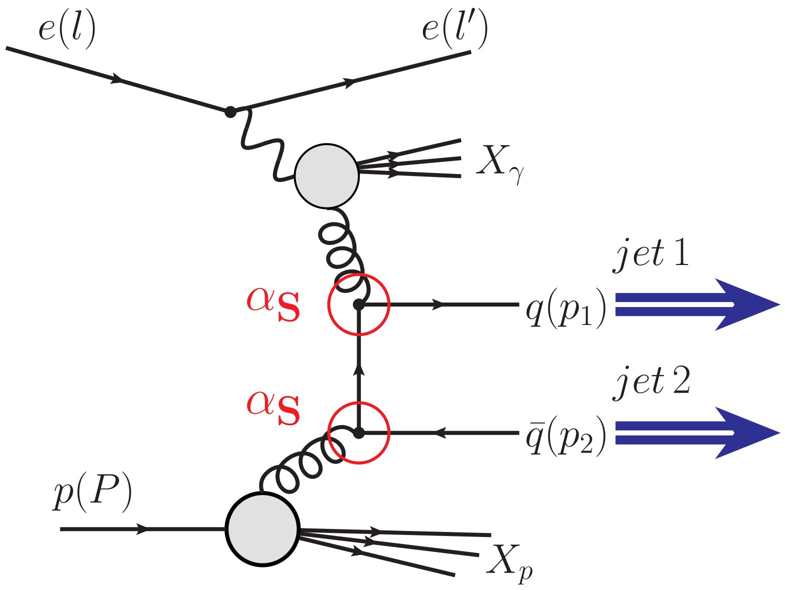


• gluon fraction ranges from about 75% at $125 < Q^2 < 250$ GeV^2 and small ξ to about 5% at the highest Q^2 above 5000 GeV^2

• lower Q^2-region is not statistically limited $\rightarrow$ precise input for the PDF fits can be expected

Dijets in PHP

Dijet processes in PHP



- Processes
of leading order in α_S are the same as in DIS
- Processes of higher orders in α_S:
- direct (point-like exchanged boson, same as in DIS)
- resolved
(represents 'hadronic structure of the photon')
- Jets in PHP:
- one hard scale: jet transverse energy
- General
tests of pQCD (hard matrix element, factorisation, perturbative expansion, PDF universality)
- High-precision measurements of strong coupling α_S
- dijet cross sections sensitive to both proton and photon parton distribution functions

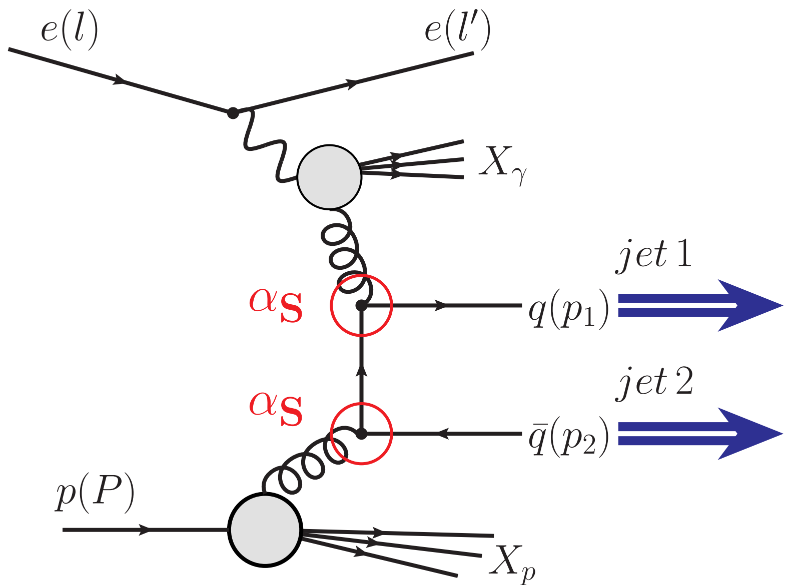
Cross section for resolved photoproduction in LO:

$$d\sigma_{res}^{\gamma p} = \sum_{i,j} \int_{x_\gamma} \int_{x_p} dx_\gamma dx_p f_{i/\gamma} f_{j/p} d\sigma_{ij}$$

$$x_\gamma = \frac{E_T^{jet1} e^{-\eta^{jet1}} + E_T^{jet2} e^{-\eta^{jet2}}}{2yE_e} \qquad x_p = \frac{E_T^{jet1} e^{\eta^{jet1}} + E_T^{jet2} e^{\eta^{jet2}}}{E_p}$$

Dijet processes in PHP: observables

Direct	Resolved
$\gamma q \to qg$	$qg \to qg$
$\gamma q \to q\bar{q}$	$qq \to qq$
	$q\bar{q} \to gg$
	$gg \to q\bar{q}$ (on the figure)
	$gg \to gg$
	$q\bar{q} \to q\bar{q}$
	$q\bar{q} \to q'\bar{q}'$
	$qq' \to qq'$



$\bar{E}_T^{jet}$ - average jet transverse energy
$\bar{\eta}^{jet}$ - average jet pseudorapidity
x_γ^{obs} - fraction of the incoming photon momentum taken by the dijet system
M_{jj} - invariant dijet mass
$|\cos\theta^*|$ - scattering angle in the dijet centre-of-mass system

Dijets in PHP: samples and selections

- data collected during 2005-2006: $189\ pb^{-1}$ of electron data
- Event phase space: - $Q^2 < 1\text{GeV}^2$

  - γp centre-of-mass energy $142 < W_{\gamma p} < 293$ GeV, or equally $0.2 < y < 0.85$
- Jets phase space:

$-1 < \eta^{jet}_{LAB} < 2.5$ $E^{jet}_{T,LAB\,1(2)} > 21\,(17)$ GeV	or	$E^{jet}_{T,LAB\,1,2} > 17$ GeV $M_{jj} > 60$ GeV $\|\cos\theta^*\| < 0.8$

- Jet selections:

- k_T cluster algorythm in the longitudinally invariant inclusive mode running on calorimeter cells
- Jet search was performed in the $\eta - \phi$ plane of the laboratory frame

Data corrections:

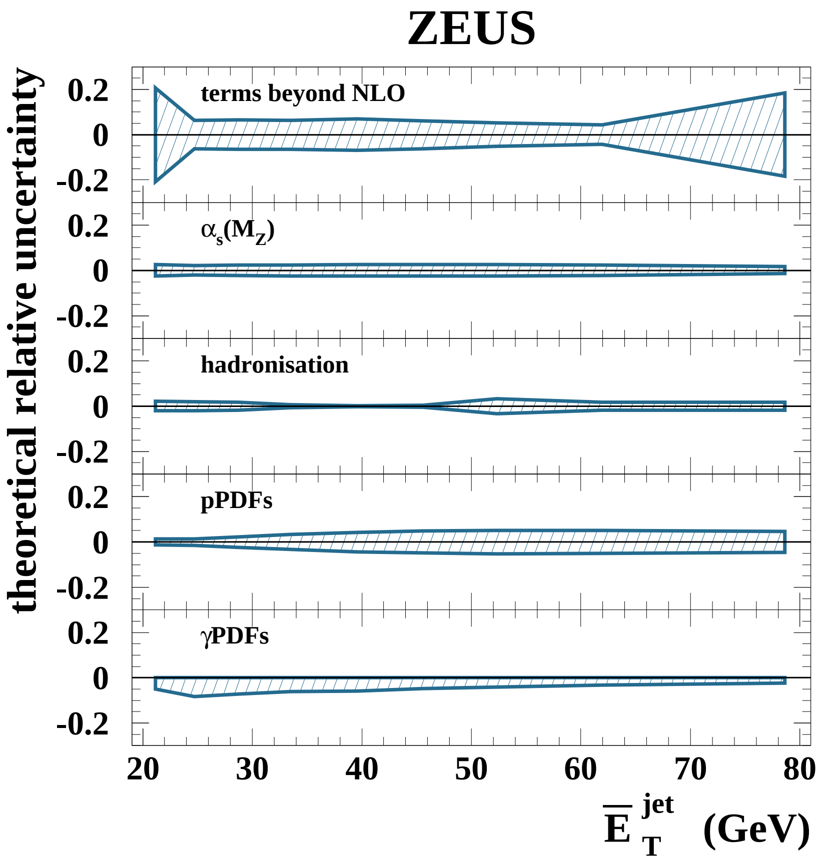
- Correction to the hadronic level
- No need in polarisation corrections

Uncertainties:

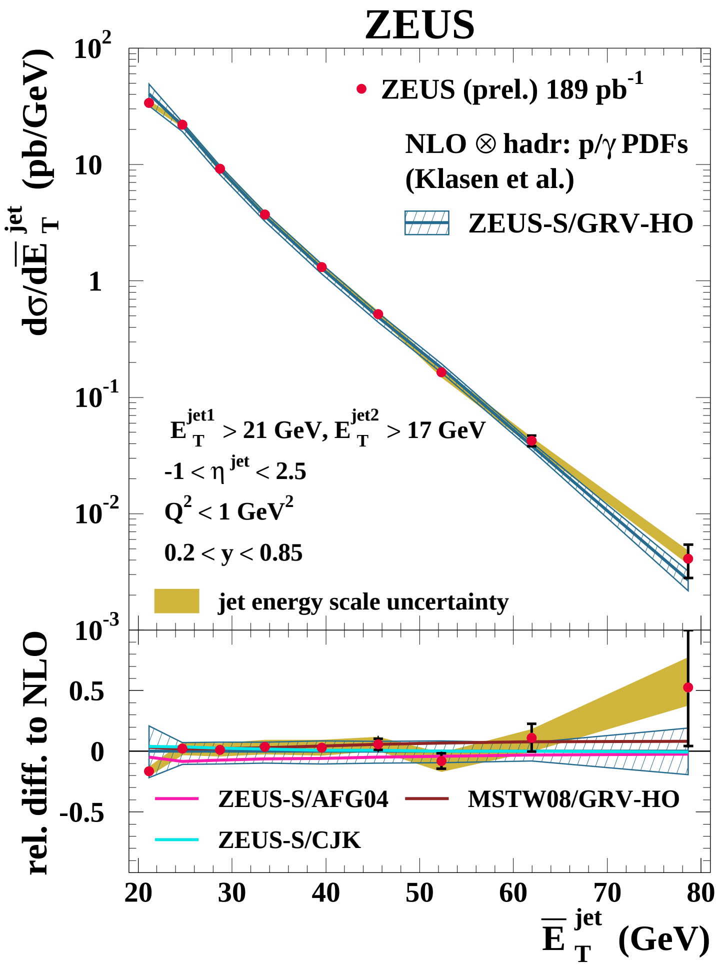
- the absolute energy scale of the calorimetric jets in simulated events was varied by its uncertainty of $\pm 1\%$
- on the CAL energy uncertainty on $W_{\gamma p}$ was estimated by varying y_{JB} by $\pm 1\%$ in simulated events
- total systematic uncertainty in the cross sections was typically below $\pm 5\%$

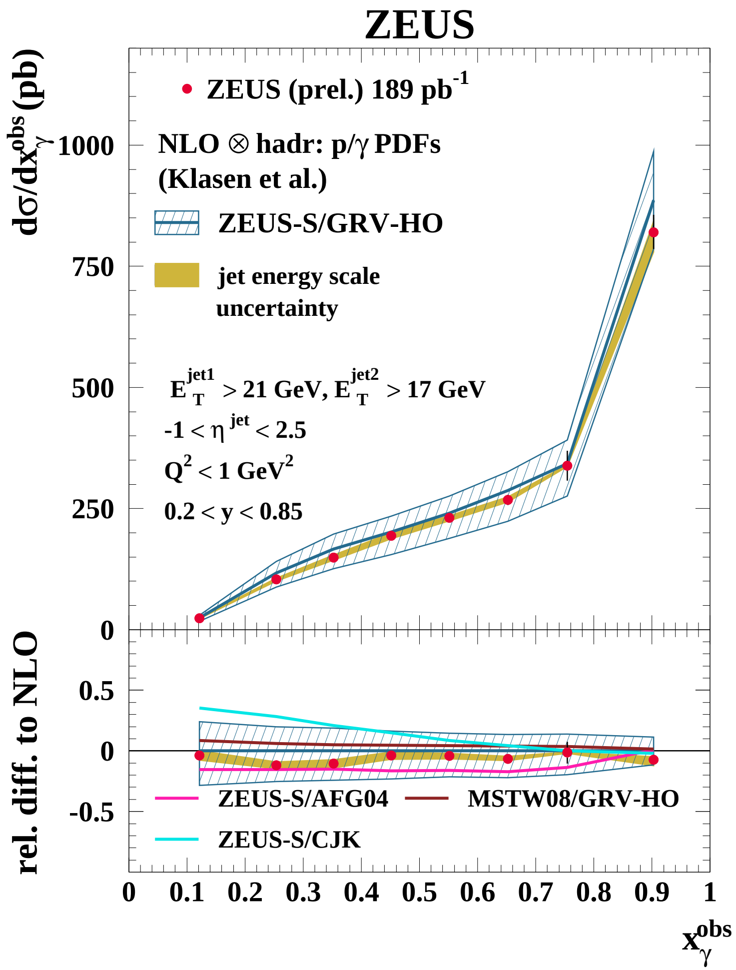
Dijets in PHP: NLO calculations

• NLO ($\mathcal{O}(\alpha_S^2)$) calculations were obtained using the program by Klasen, Kleinwort and Kramer
• $\mu_R = \mu_F = (E_T^{jet})^{max}$
• ZEUS-S parameterisations of the proton PDFs
• GRV-HO parameterisations of the photon PDFs
• predictions corrected to the hadron level (corrections differ from unity by less then 5%)
• **Sources of uncertainty in the theoretical predictions:**
- due to terms beyond NLO: up to 20%
- due to uncertainty on α_S: below $\pm 5\%$
- uncertainty of the modelling of the parton shower: less than 2%
- due to proton PDFs: less than 5%
- due to photon PDFs estimated by using an alternative set of parameterisations, AFG04: less than 5%



Dijets in PHP: results - Single-differential cross sections

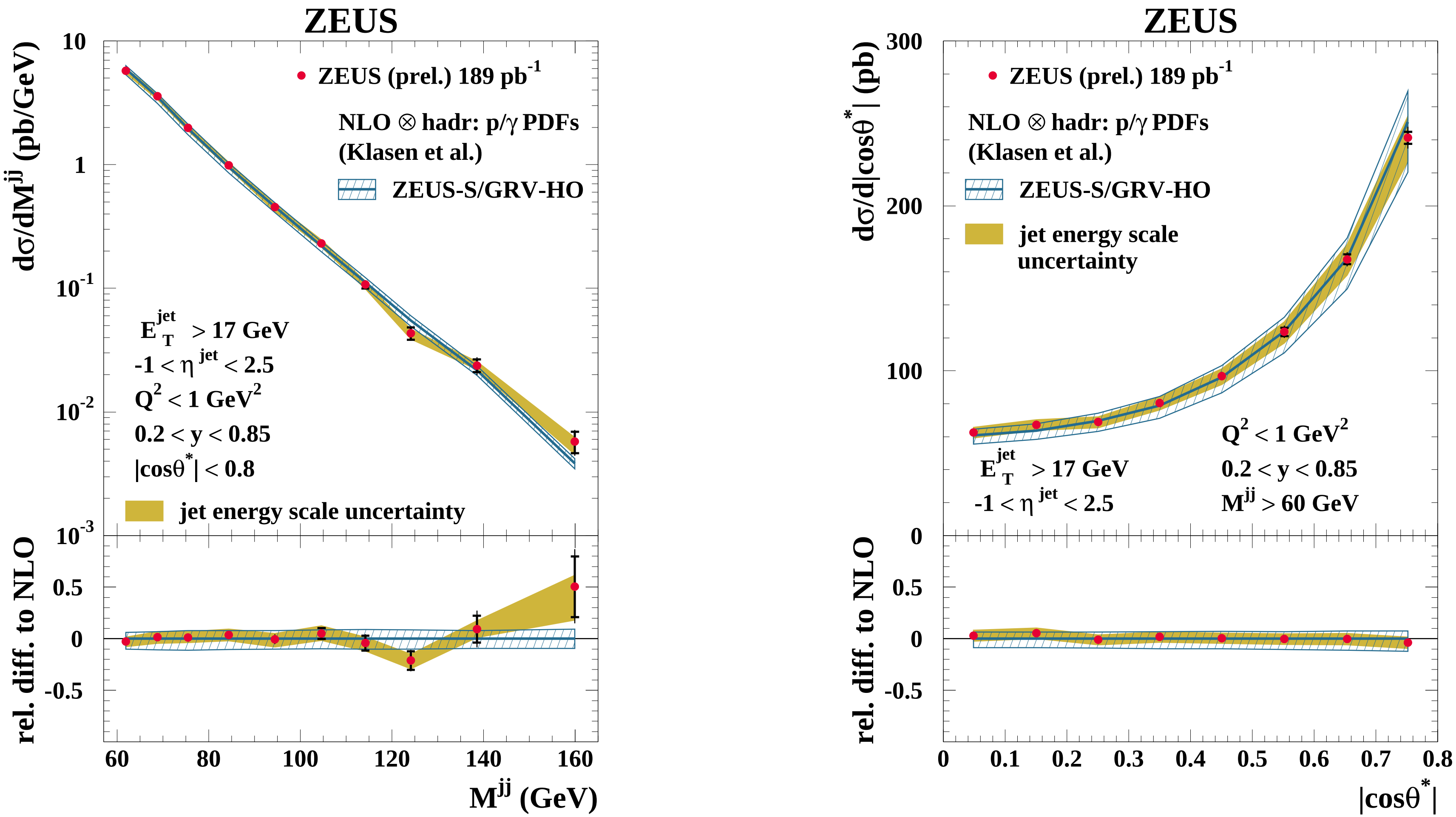




- Kinematic region: $Q^2 < 1\text{GeV}^2$, $0.2 < y < 0.85$
$-1 < \eta^{jet}_{LAB} < 2.5$, $E^{jet}_{T,LAB\,1(2)} > 21\,(17)$ GeV
- Good description in shape and normalisation

$x_\gamma = \frac{E_T^{jet1} e^{-\eta^{jet1}} + E_T^{jet2} e^{-\eta^{jet2}}}{2yE_e}$ cross section is expected to be most sensitive to the photon PDFs, especially at low x_γ, where resolved processes are dominant

Dijets in PHP: results - Single-differential cross sections



- Kinematic region: $Q^2 < 1\text{GeV}^2$, $0.2 < y < 0.85$
$-1 < \eta^{jet}_{LAB} < 2.5$, $E^{jet}_{T,LAB\,1,2} > 17$ GeV, $|\cos\theta^*| < 0.8$, $M_{jj} > 60$ GeV^2
- Good description in shape and normalisation
- Demonstates validity of the description of the dynamics of dijet production by pQCD at $\mathcal{O}(\alpha_S^2)$

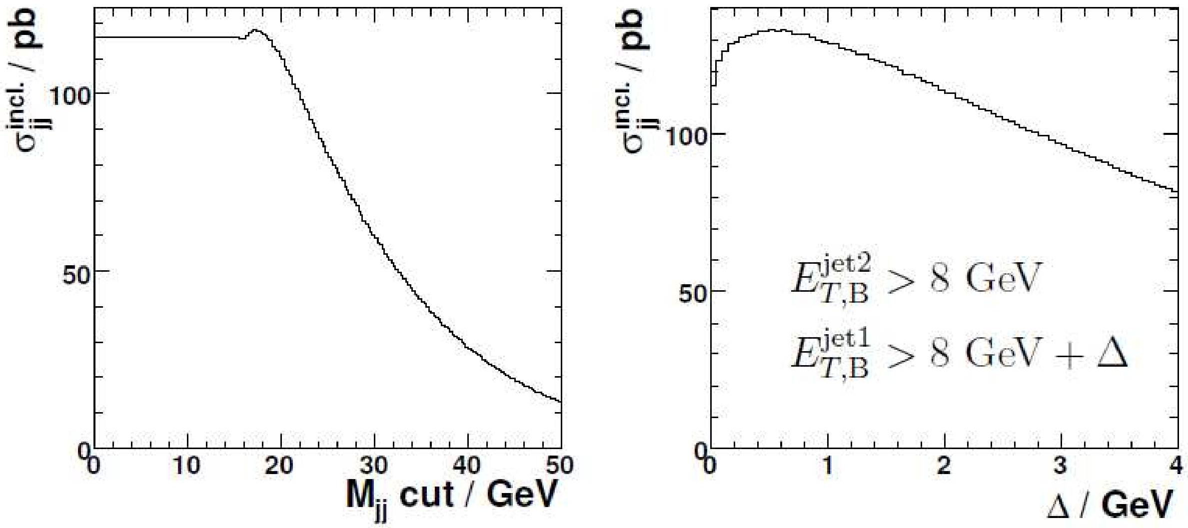
Conclusions

- Dijet measurements in both PHP and DIS were performed at HERA using ZEUS detector
- The measurements of dijets in DIS have very small statistical and systematical uncertainties
- ... and the description of the data by the predictions of NLO QCD is very good
- $\rightarrow$ DIS dijet data will provide useful precision information for the determination of the strong coupling constant and the exctraction of the proton PDFs
- Precise measurements of dijets in PHP was done
- Given cross sections are sensitive to the parton densities in the proton and photon
- ... and the description of the data by the predictions of NLO QCD is very good
- $\rightarrow$ Measurements allow for improving the determination of the photon and proton PDFs in future QCD fits

Backup slides

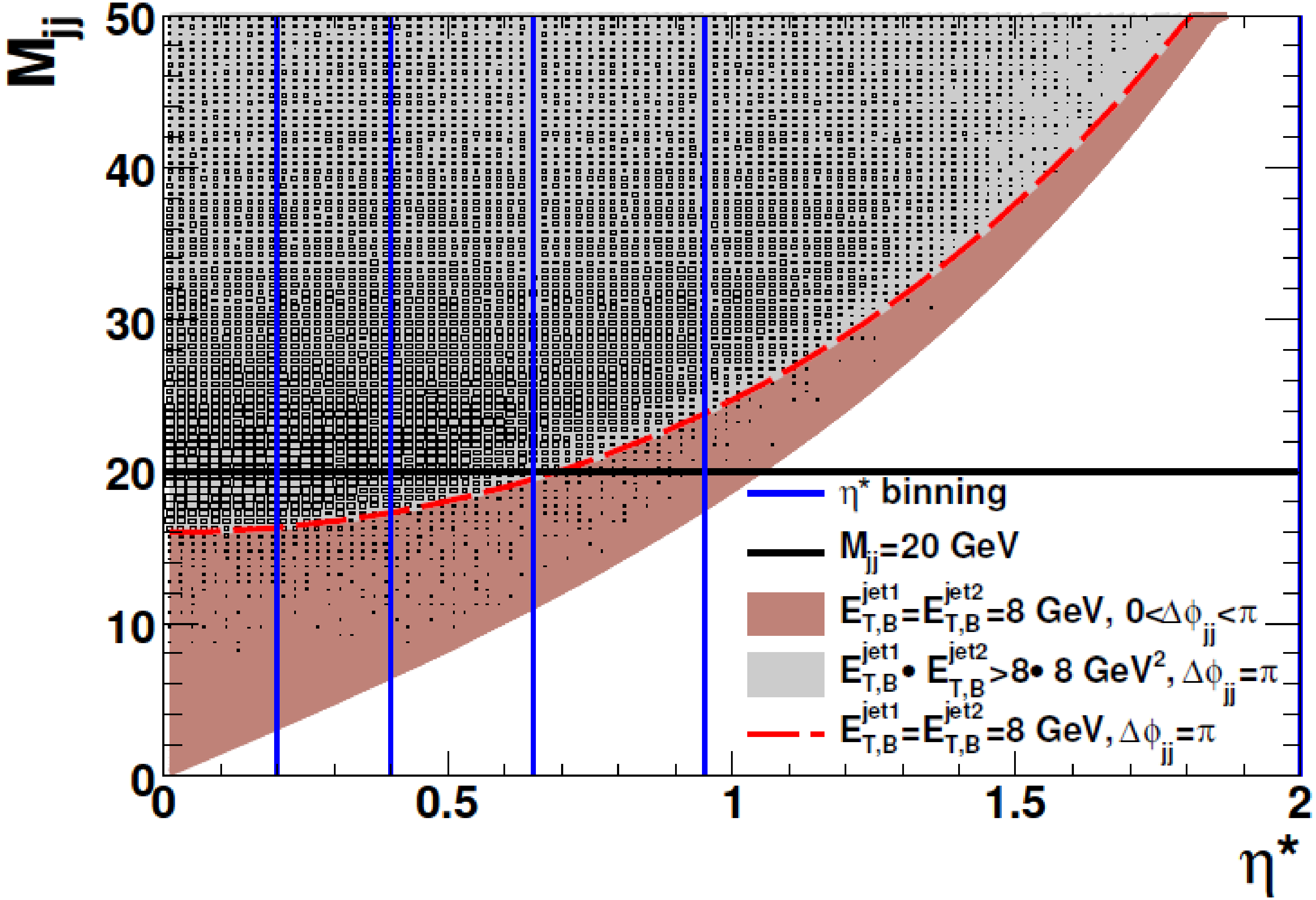
Dijets: Infrared Sensitivity

• In some regions of the dijet phase space the cancellation between soft and collinear singularities in NLO theoretical predictions is incomplete
• Real emissions of hard gluons are suppressed in regions in which the azimuthal difference $\Delta\phi_{jj}$ of the two jets is close to π, where ΔE_T^{jj} and M_{jj} is close to threshold
• But if jets slightly decorrelated, soft gluon emission is allowed but kinematically constrained
• ... some of the virtual divergences are left uncancelled and theory calculations become sensitive to the soft gluon emission
• in order to make theory infrared insensitive asymmetric E_T cut can by applied or cut on M_{jj}
• In DIS dijet analysis cut on $M_{jj} > 20$ GeV has been applied



• In PHP dijet analyses asymmetric cut on $E_{T,LAB}^{jet1(2)} > 21\,(17)$ GeV has been applied for cross sections as functions of $\bar{E}_T^{jet}$, $\bar{\eta}^{jet}$, x_γ^{obs} and cut on $M_{jj} > 60$ GeV for M_{jj} and $|\cos\theta^*|$

Correlation between M_{jj} and η'



$$M_{jj}^2 = 2 \cdot E_T^{jet1} \cdot E_T^{jet2} \cdot [\cosh(\eta_1 - \eta_2) - \cos \Delta\phi_{jj}]$$