Precise QCD measurements at HERA

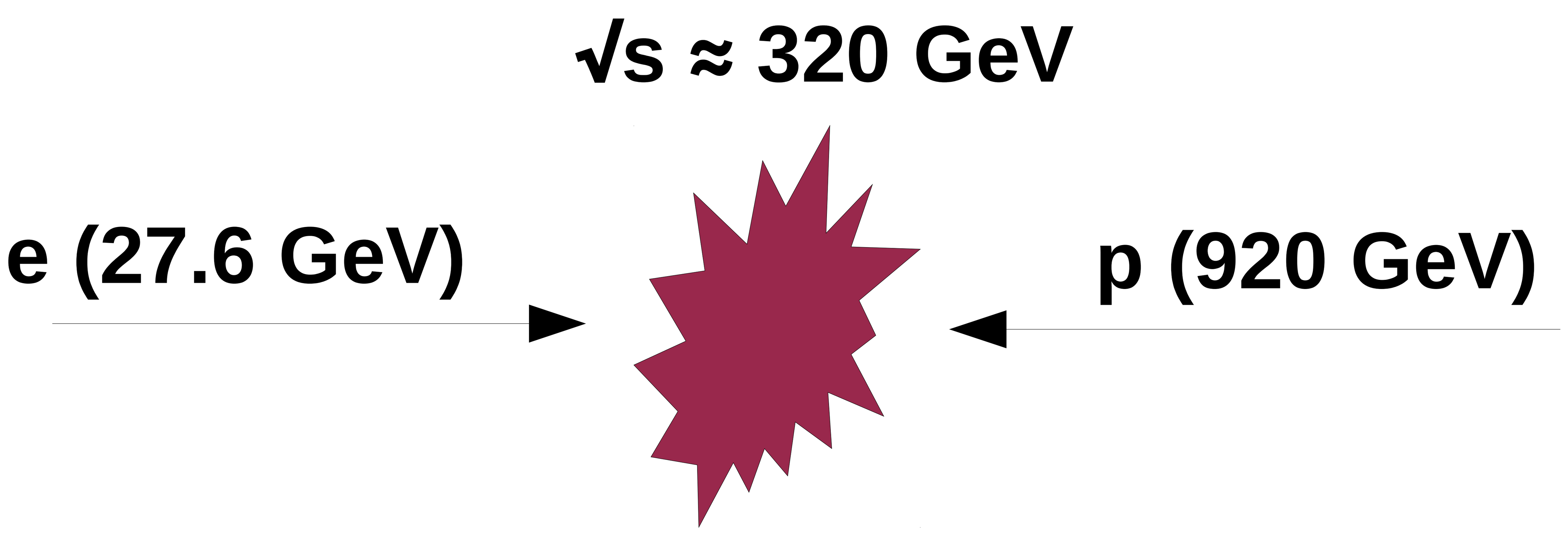
Krzysztof Nowak
on behalf of
H1 and **ZEUS**
collaborations

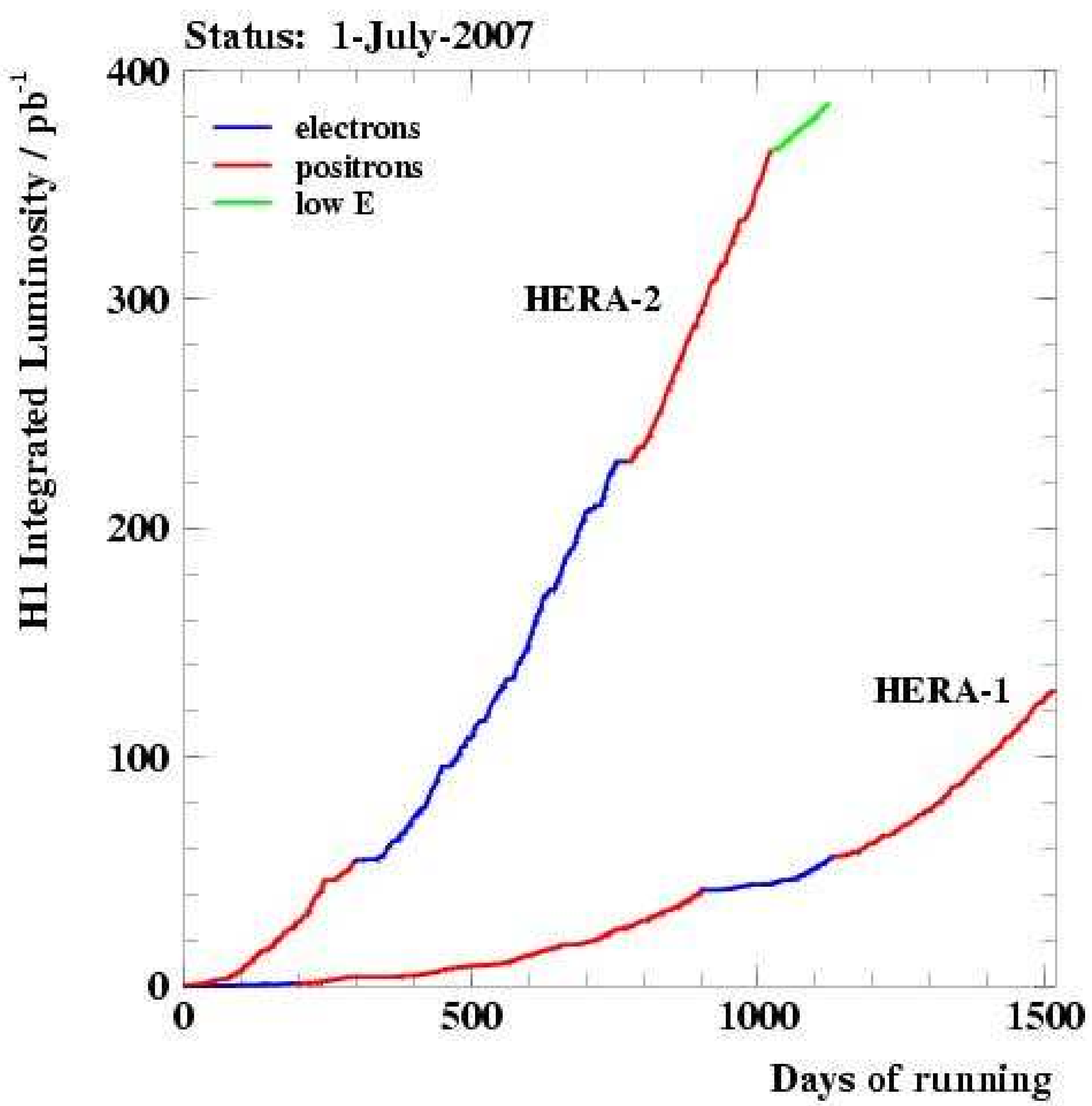
- Introduction to jets at HERA
- H1 and ZEUS jet measurements
- Strong coupling constant α_s determination

QCD at HERA

HERA ep collisions great for precise QCD studies

- ✔ *Interacting hadron (as opposed to ee)*
- ✔ *Relatively clean environment (as opposed to pp)*
- ✔ *Lasting legacy in understanding of the proton dynamics*





Collected ~0.5 fb^{-1} of luminosity per experiment

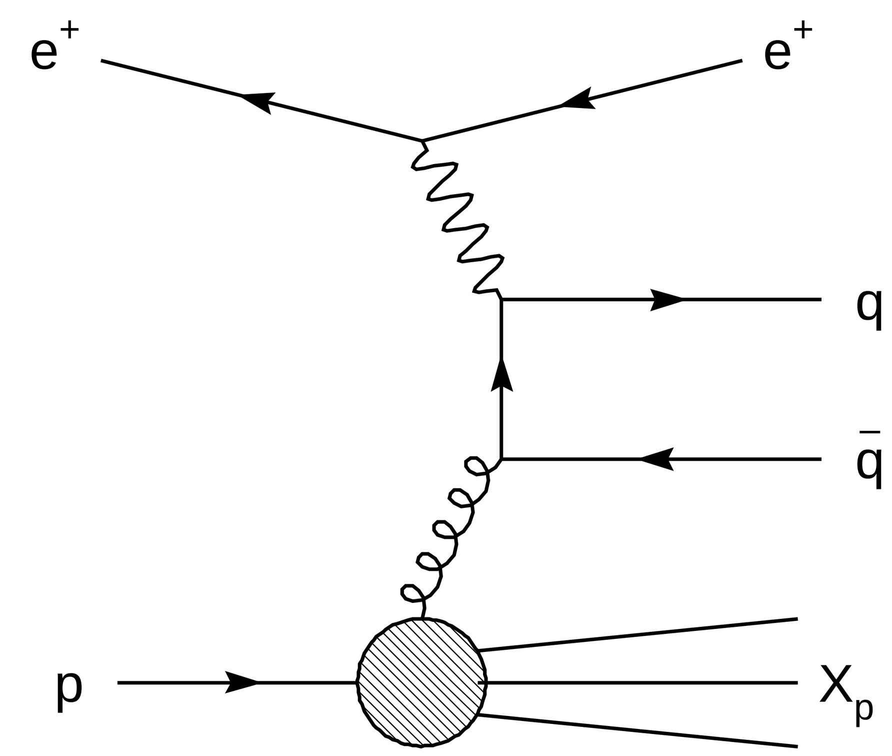
Work ongoing to provide final measurements using all available data

Electron – proton collisions

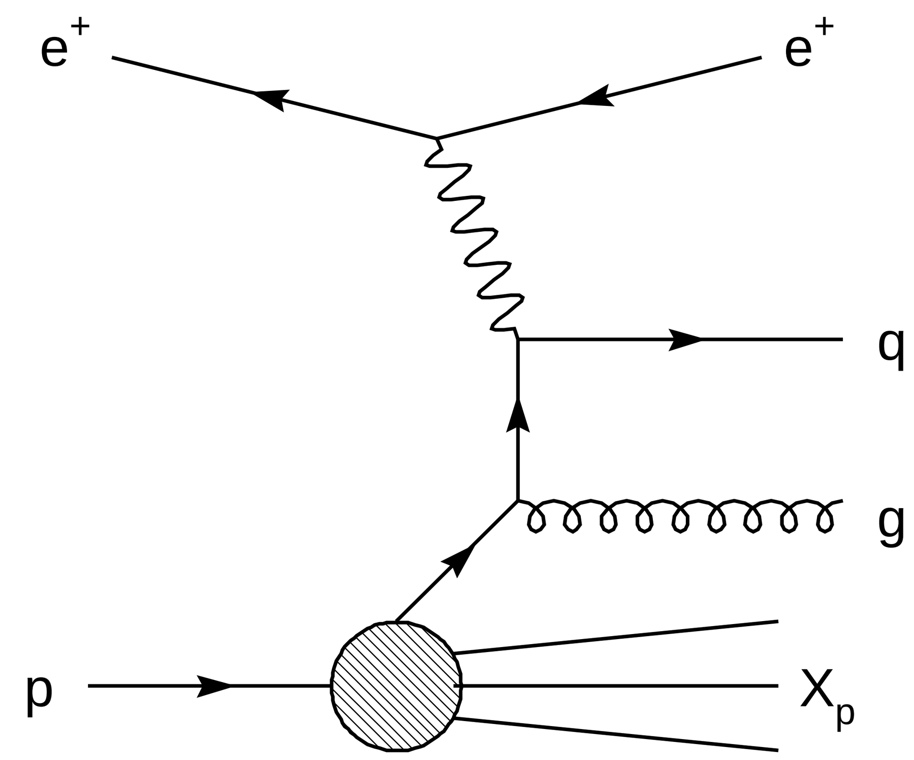
Two kinematic regions depending the virtuality of the mediating boson Q^2:

1. *Deep Inelastic Scattering (DIS)*

- $Q^2 \gg \Lambda_{QCD}$
- *Hard scale always present*



Boson-gluon fusion



QCD Compton

Electron – proton collisions

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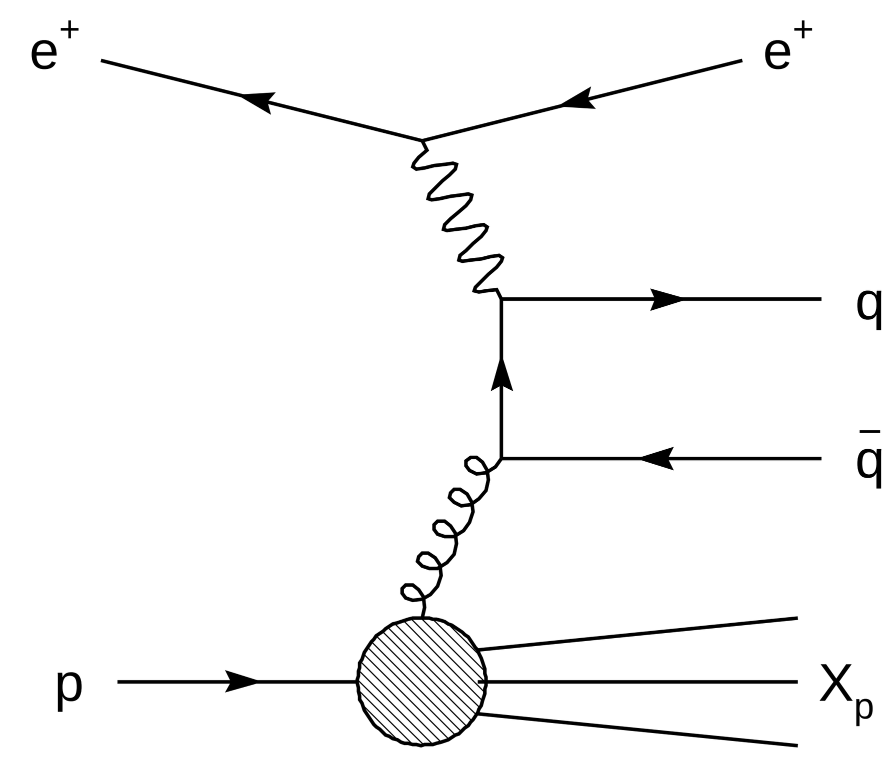

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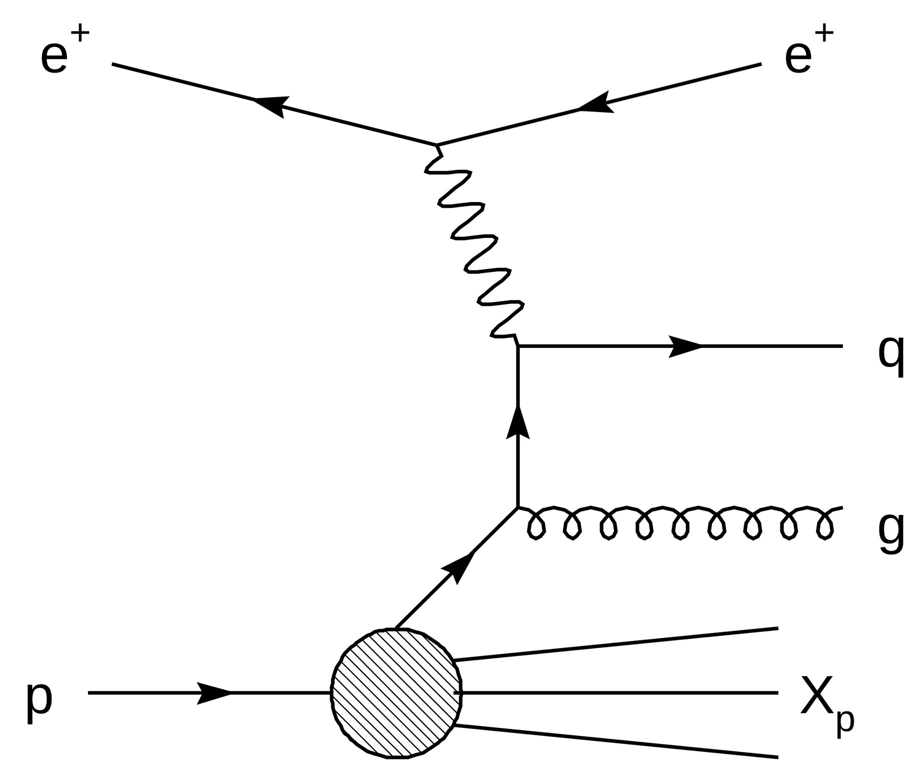
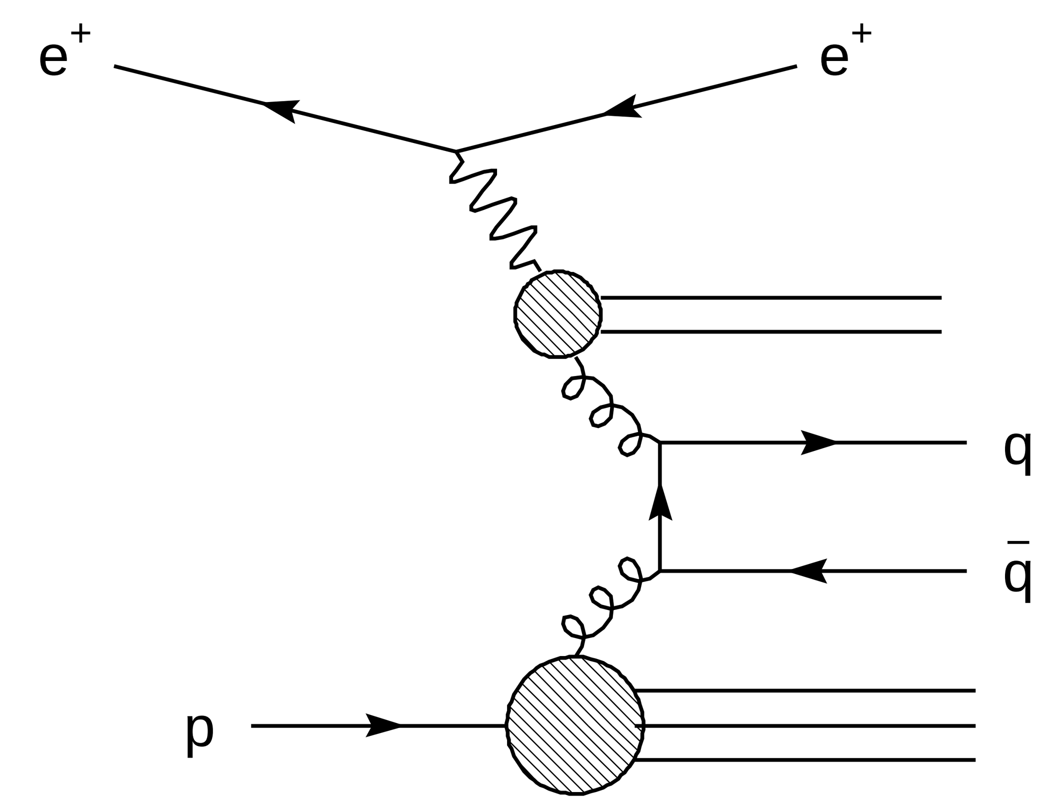


QCD Compton

2. Photoproduction (PHP)

- $Q^2 \approx 0\, GeV$
- *Mediating photon may fluctuate into partons (resolved events) – similarity to hadron-hadron collisions*



Resolved photoproduction

Jet physics at HERA

Jet cross section:

$$d\sigma_{jet} \sim \sum_{j=q,\bar{q},g} \int dx\, f_{j/p}(x,\mu_F)\, d\hat{\sigma}_j(x,\alpha_s(\mu_R),\mu_R,\mu_F)$$

proton content **pQCD matrix element**

x - **Bjorken x**
f - **PDFs**
μ_R - **renormalization scale**
μ_F - **factorization scale**
α_s - **strong coupling const.**

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proton content — pQCD matrix element

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In the resolved case:

$$d\sigma_{jet} \sim \sum_{i,j=q,\bar{q},g} \int dx_p \int dx_\gamma\, f_{j/p}(x_p,\mu_{Fp})\, f_{i/\gamma}(x_\gamma,\mu_{F\gamma})\, d\hat{\sigma}_{ij}(x_p,x_\gamma,\alpha_s,\mu_R,\mu_F)$$

proton content — photon content — pQCD matrix element

Jet physics at HERA

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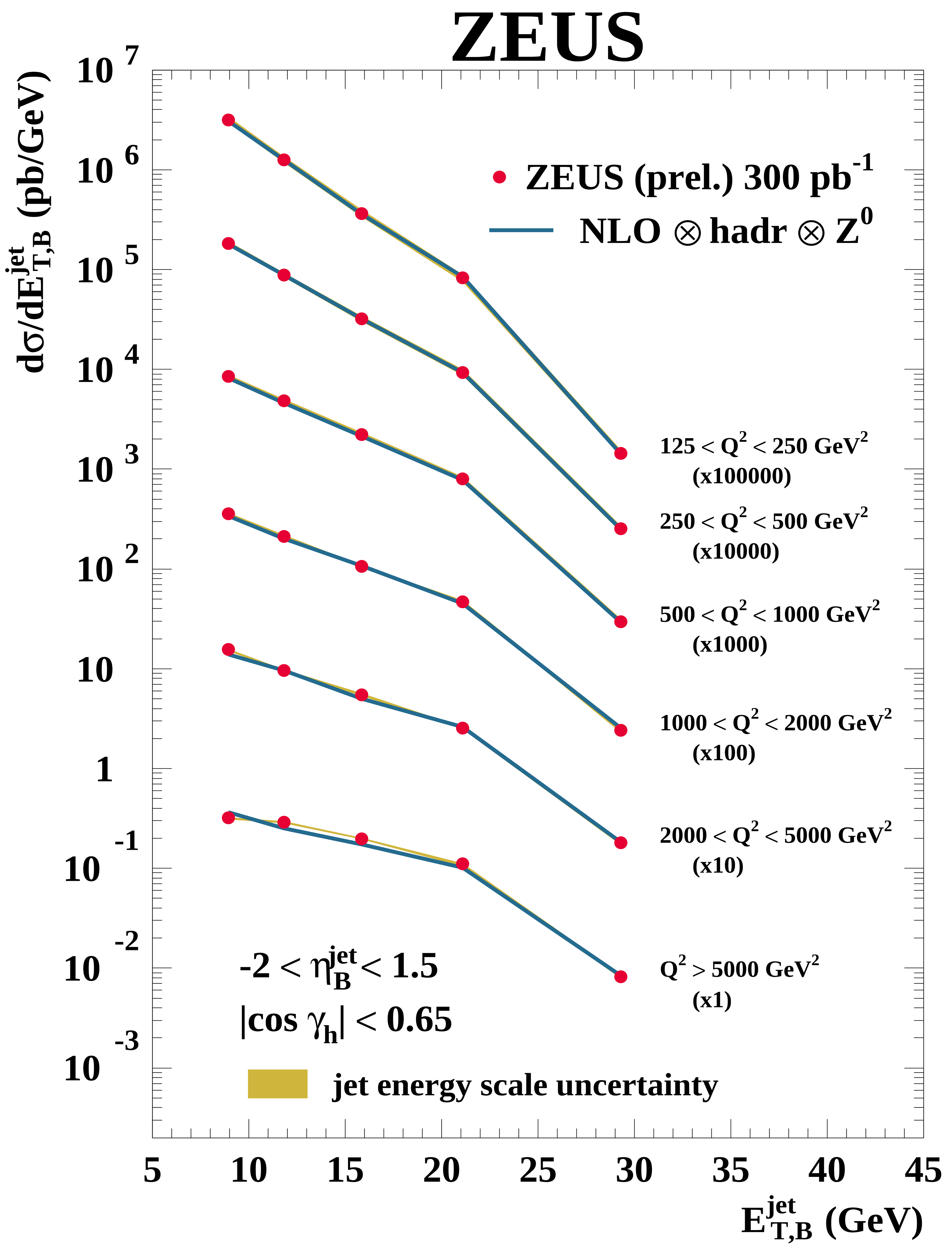
proton content **photon content** **pQCD matrix element**

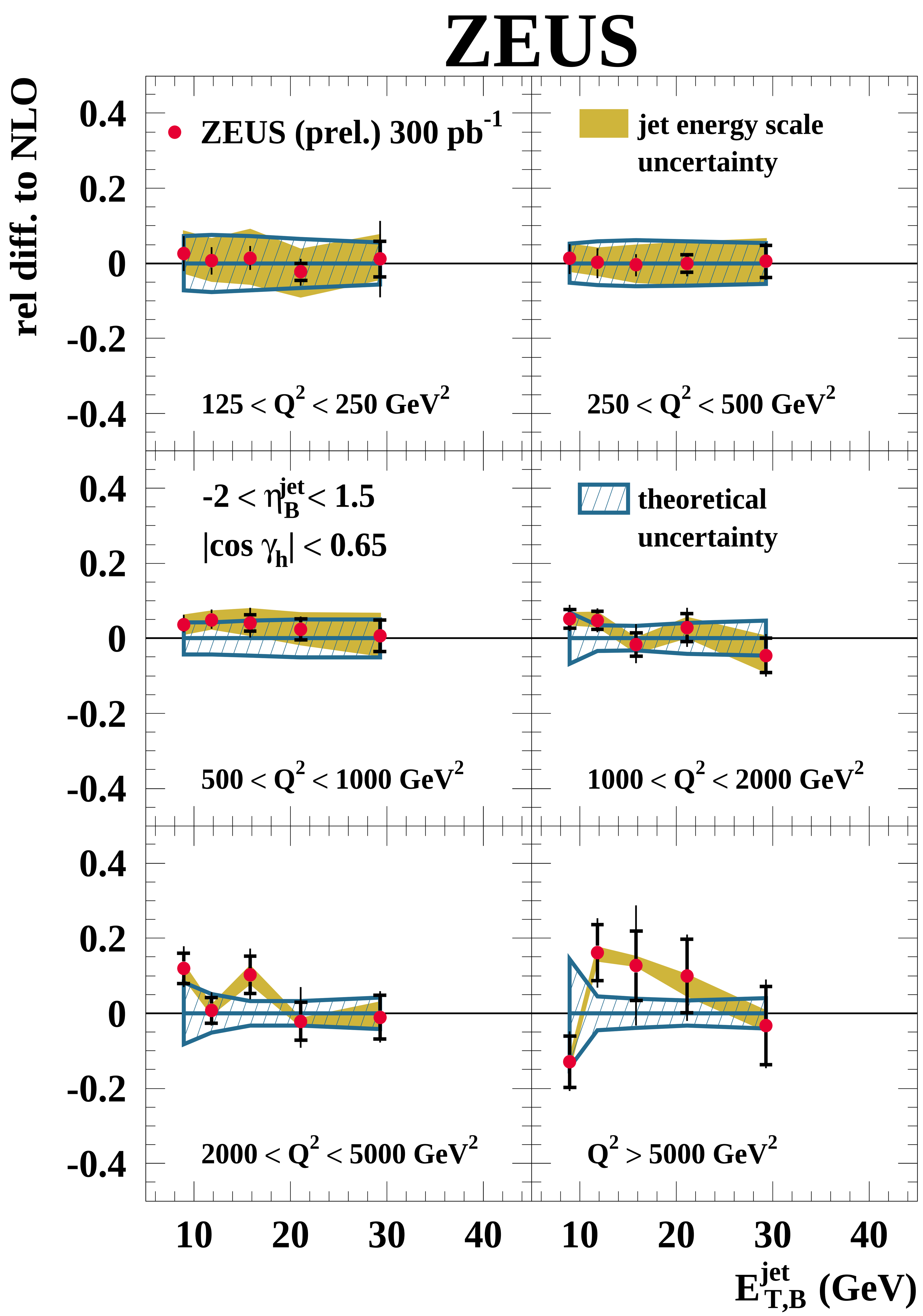
Use of jets:

- ✓ *sensitivity to the structure of both proton and photon*
- ✓ *extensive pQCD tests*
- ✓ *determination of* α_s

High Q^2 DIS inclusive jets

$\mathcal{L} = 300\,\mathrm{pb}^{-1}$
$Q^2 > 125\,GeV^2$
$|\cos\gamma_h| < 0.65$
$P_{T,B}^{JET} > 8\,GeV$
$-2.0 < \eta_B^{JET} < 1.5$





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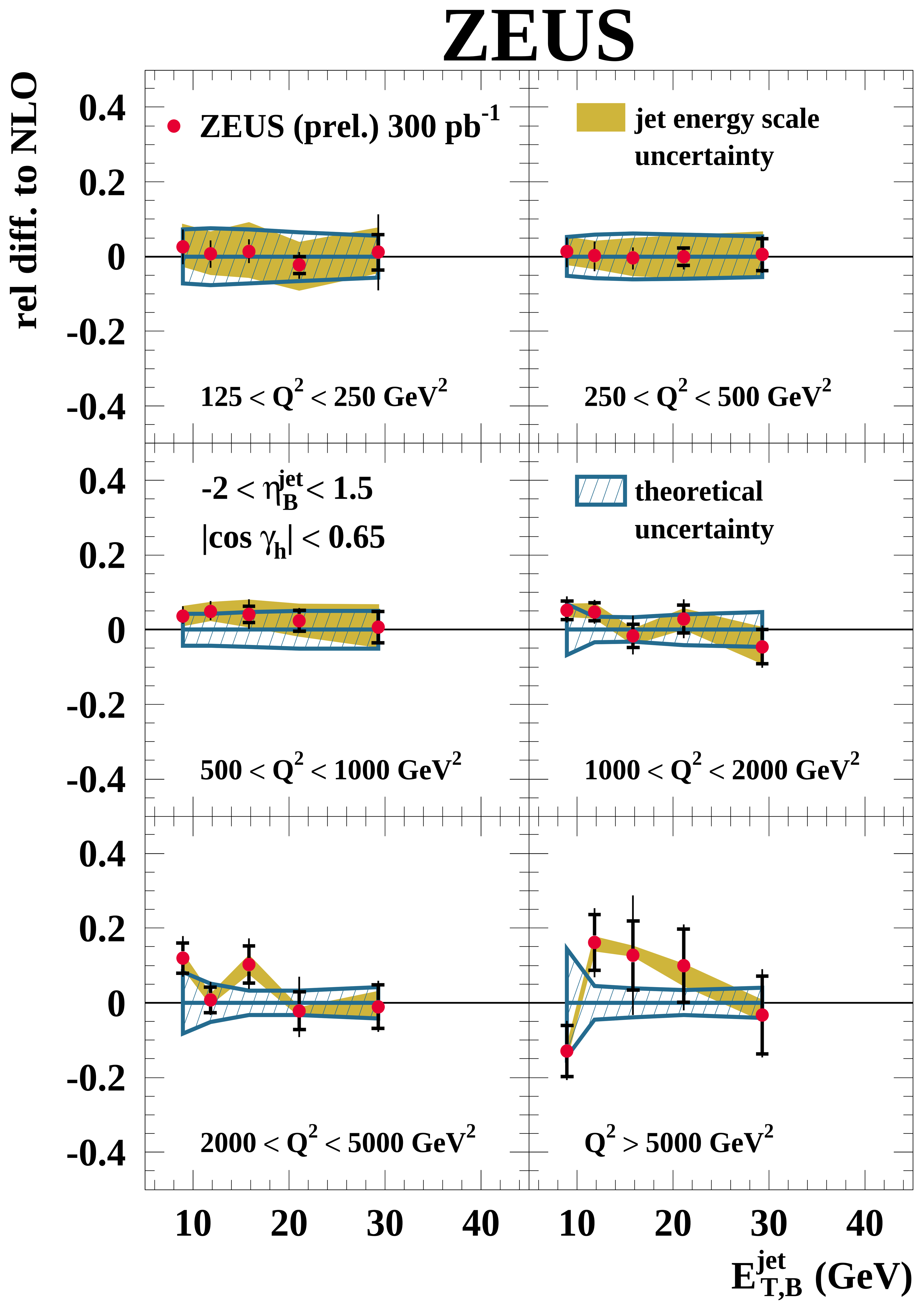
Dominant experimental error – jet energy scale

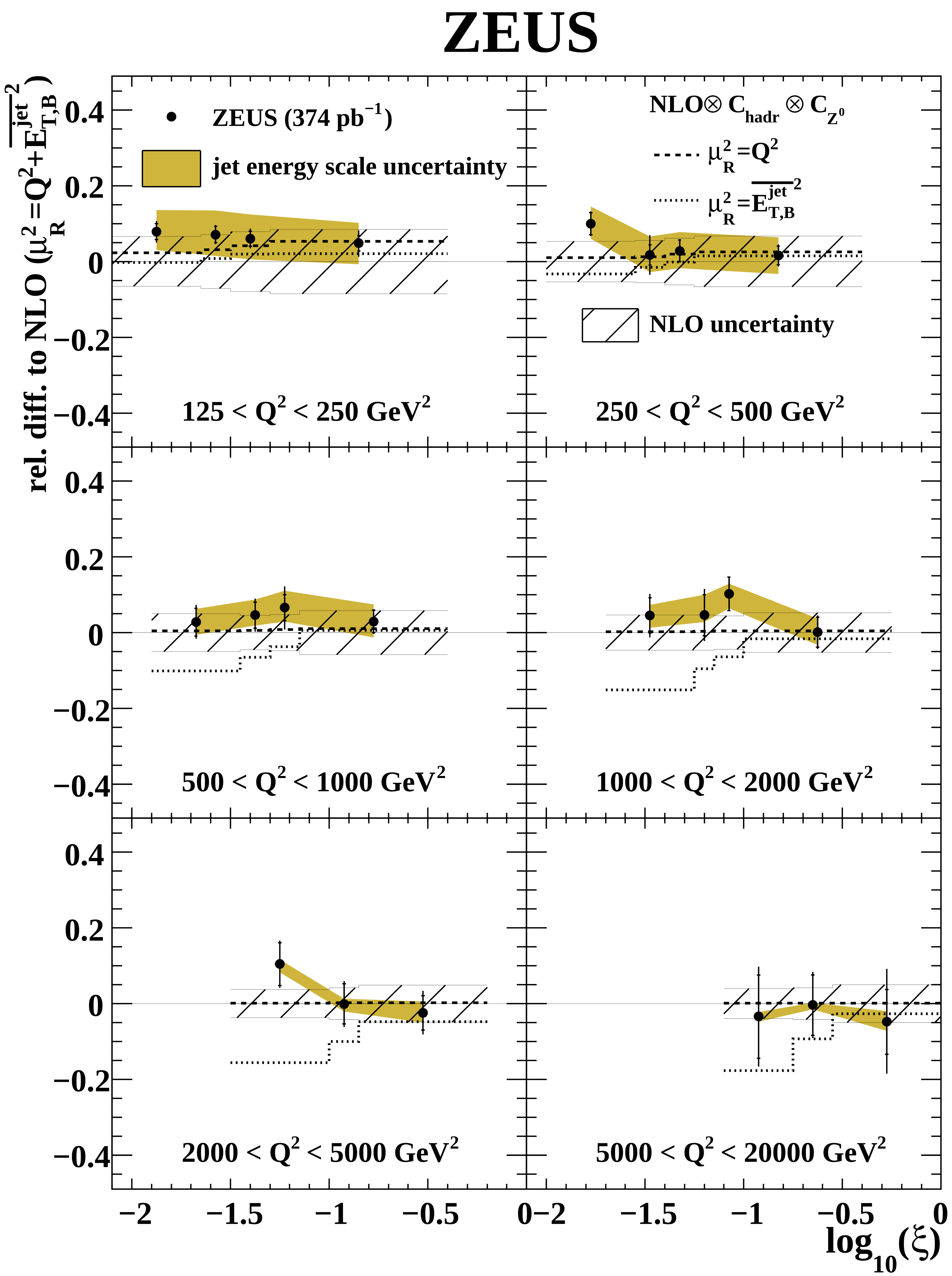
Comparably high theoretical uncertainty (estimated terms beyond NLO)



Measurement well described by NLO prediction

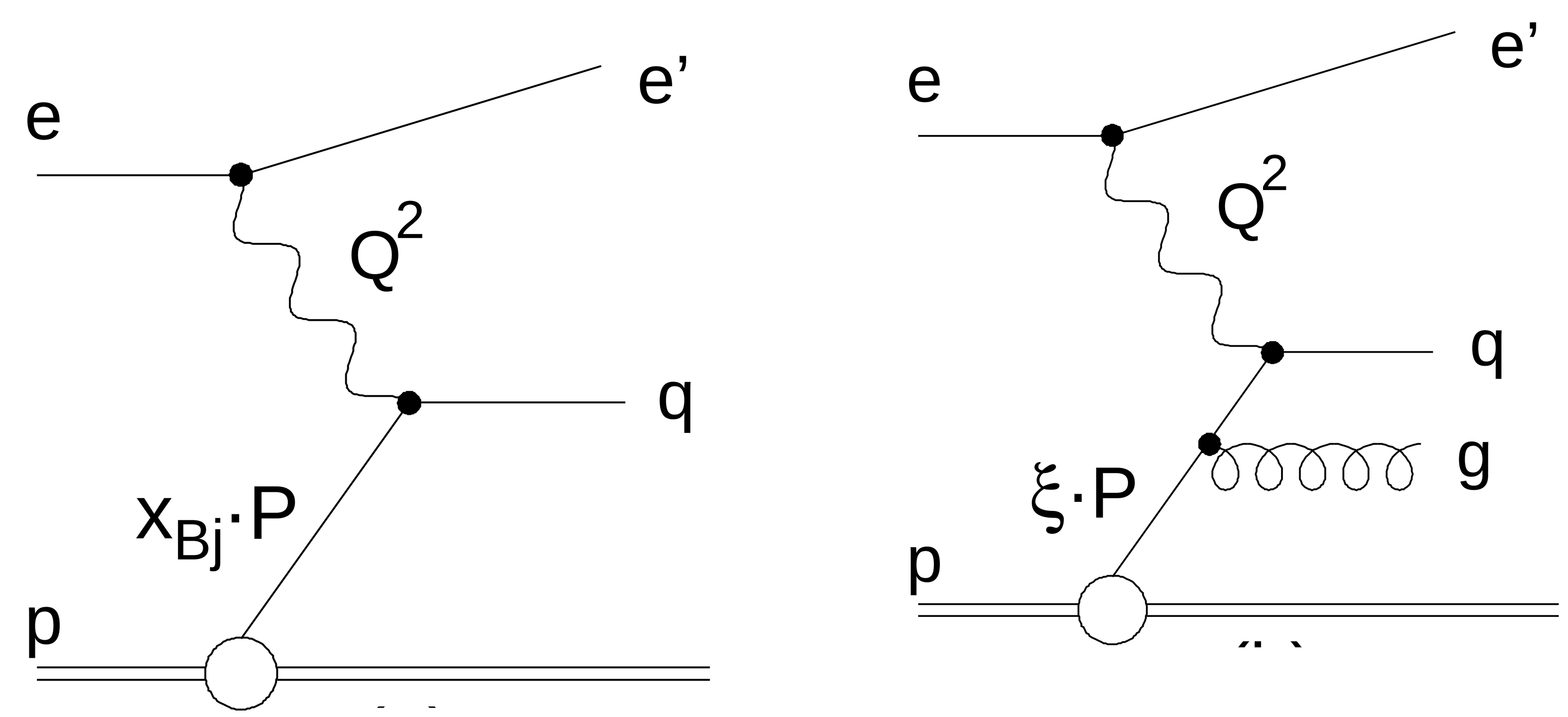
High Q^2 DIS dijets

$\mathscr{L} = 374\,pb^{-1}$
$125 < Q^2 < 20000\,GeV^2$
$0.2 < y < 0.6$
$P_{T,B}^{JET} > 8\,GeV$
$-1.0 < \eta_{lab}^{JET} < 2.5$



Estimator of the fraction of the proton momentum taken by the interacting parton (ξ) possible

$$\xi = x_{Bj}(1 + M_{jj}^2 / Q^2)$$



Measurement sensitive to proton PDF

Measurement well described by the NLO calculation

Low Q^2 DIS jets

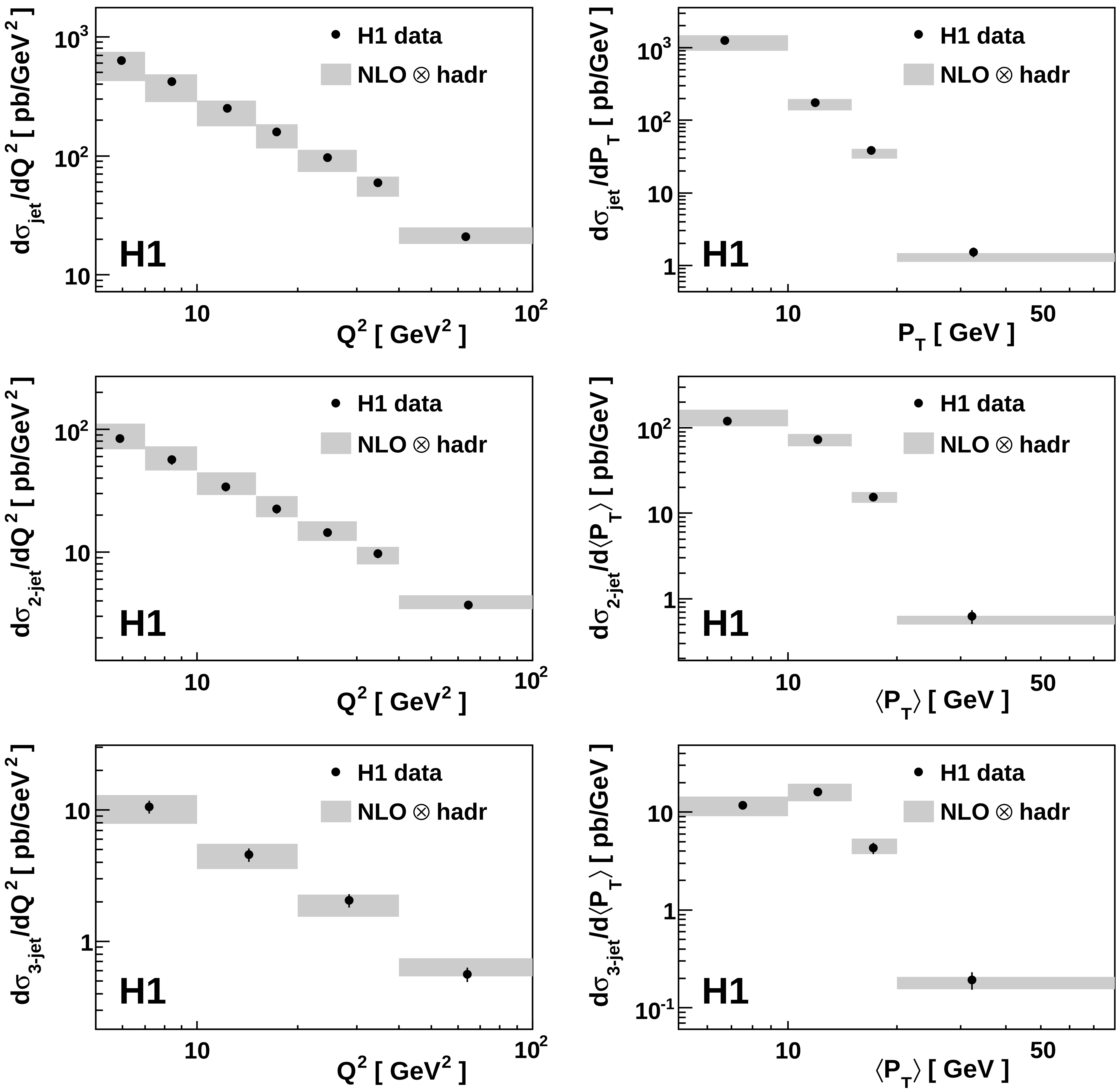
$\mathcal{L} = 43.5 pb^{-1}$
$5 < Q^2 < 100\, GeV^2$
$0.2 < y < 0.7$
$P_{T,B}^{JET} > 5\, GeV$
$-1.0 < \eta_{lab}^{JET} < 2.5$

Inclusive Jet, 2-Jet and 3-Jet Cross Sections

Inclusive

Dijet

Trijet



Inclusive and multijet cross section measured

Large theoretical uncertainty (10-30%) especially at lower Q^2

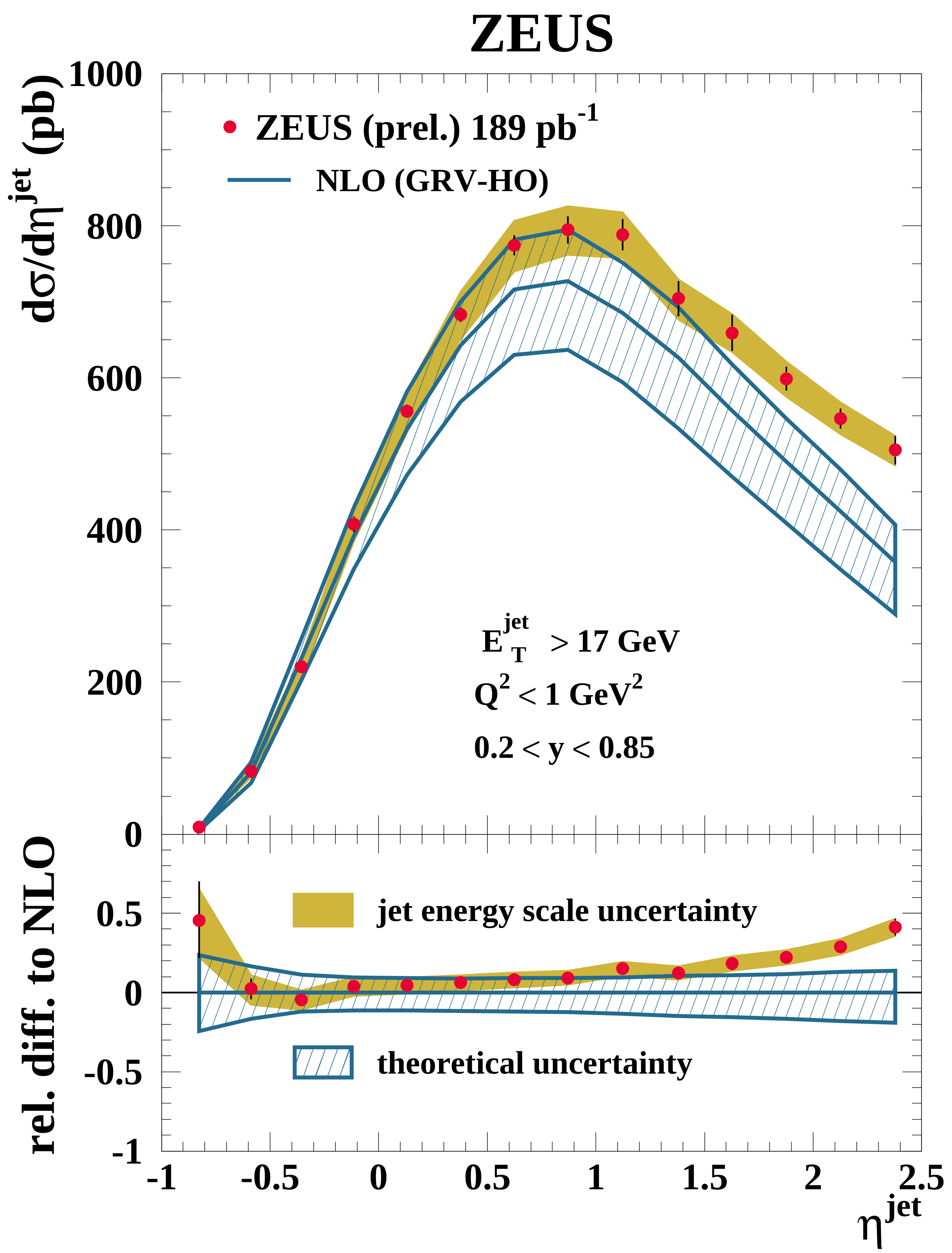
Mostly due to missing higher orders in the calculations

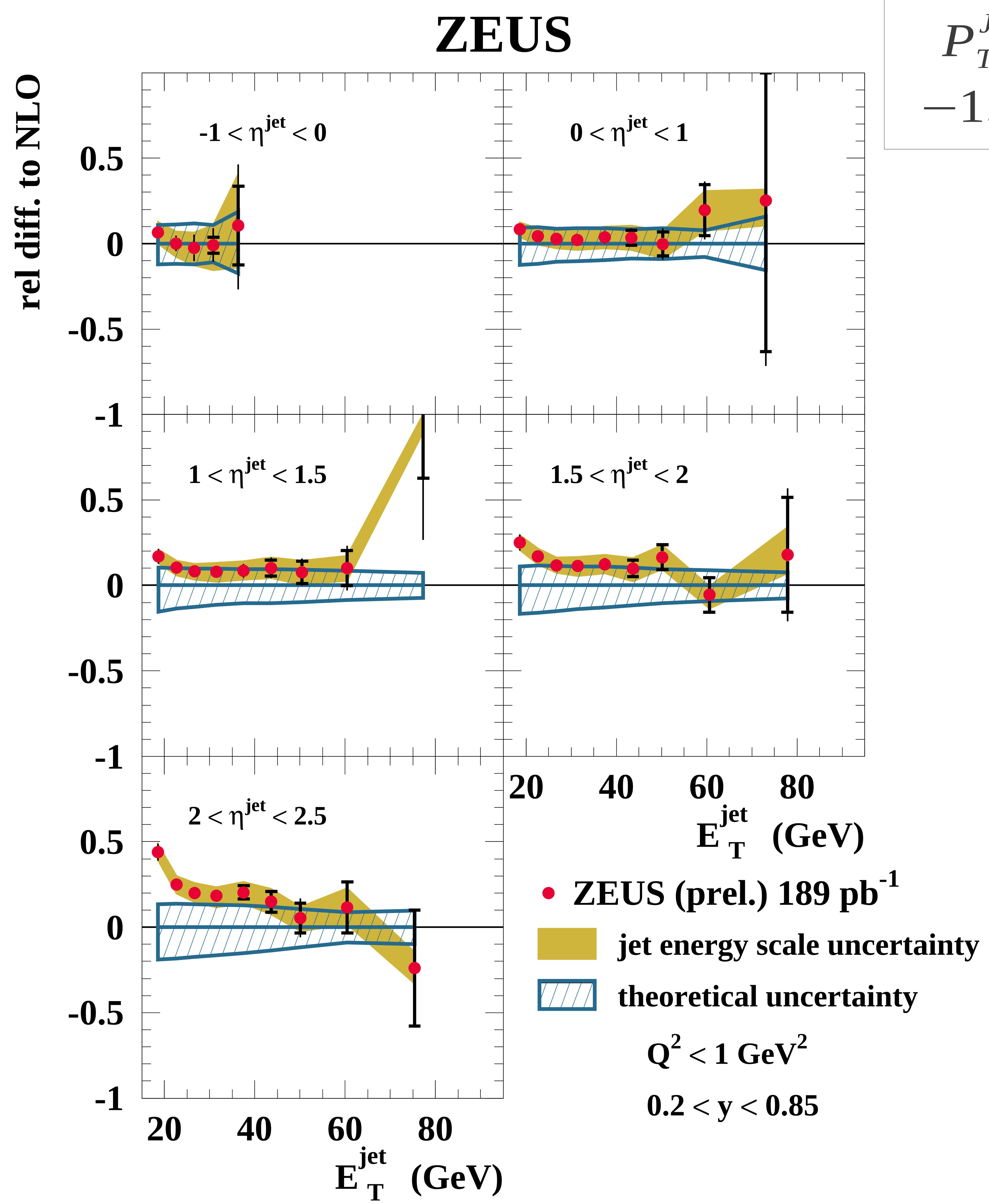
Measurement well described by the NLO calculation

NNLO calculation needed to take full advantage of the precise data

Jets in photoproduction

$\mathscr{L} = 189 pb^{-1}$
$Q^2 < 1\,GeV^2$
$0.2 < y < 0.85$
$P_T^{JET} > 17\,GeV$
$-1.0 < \eta_{lab}^{JET} < 2.5$





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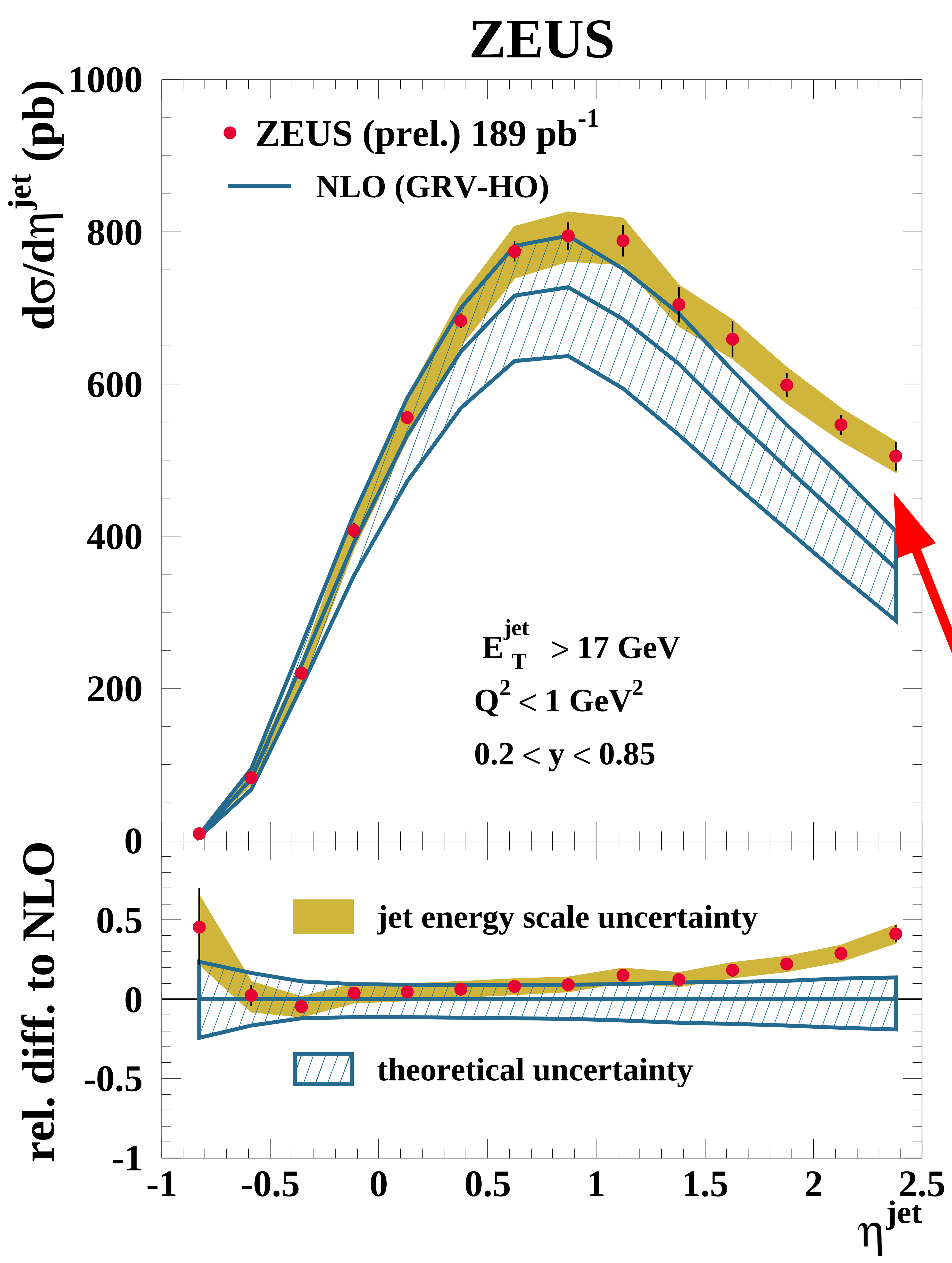

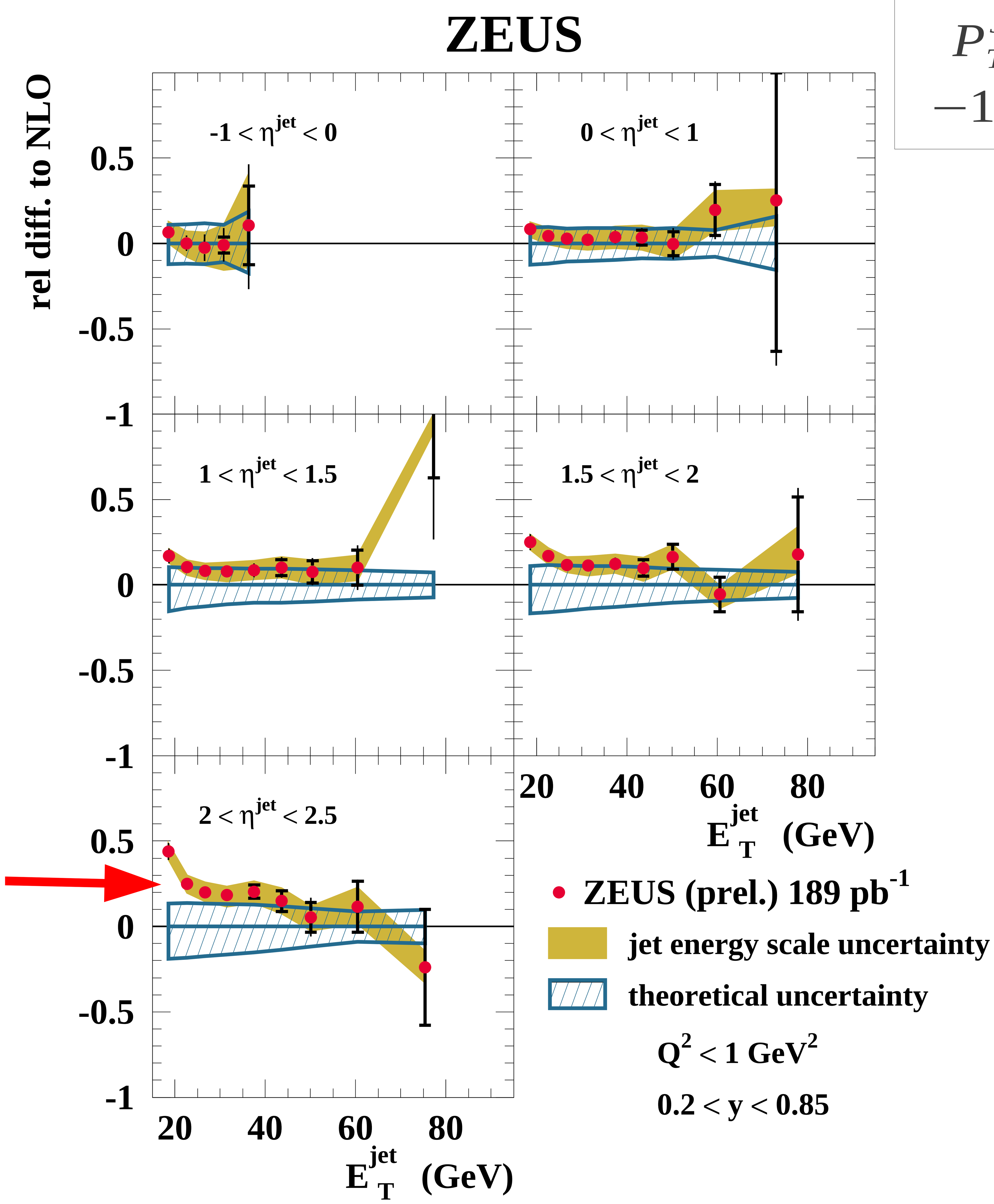

Everything well described except of forward region (low P_T)

Jets in photoproduction

$\mathcal{L} = 189\,pb^{-1}$
$Q^2 < 1\,GeV^2$
$0.2 < y < 0.85$
$P_T^{JET} > 17\,GeV$
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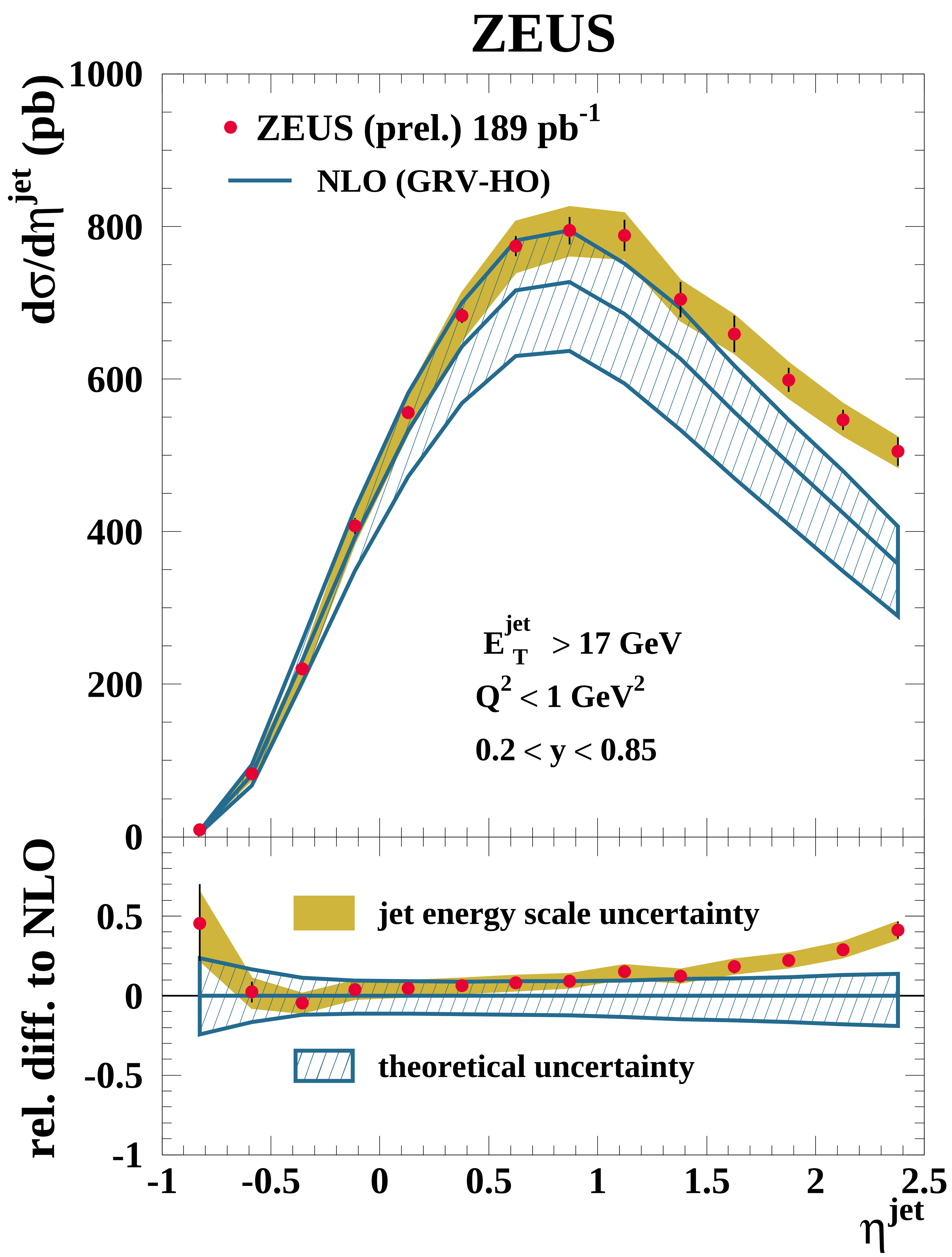
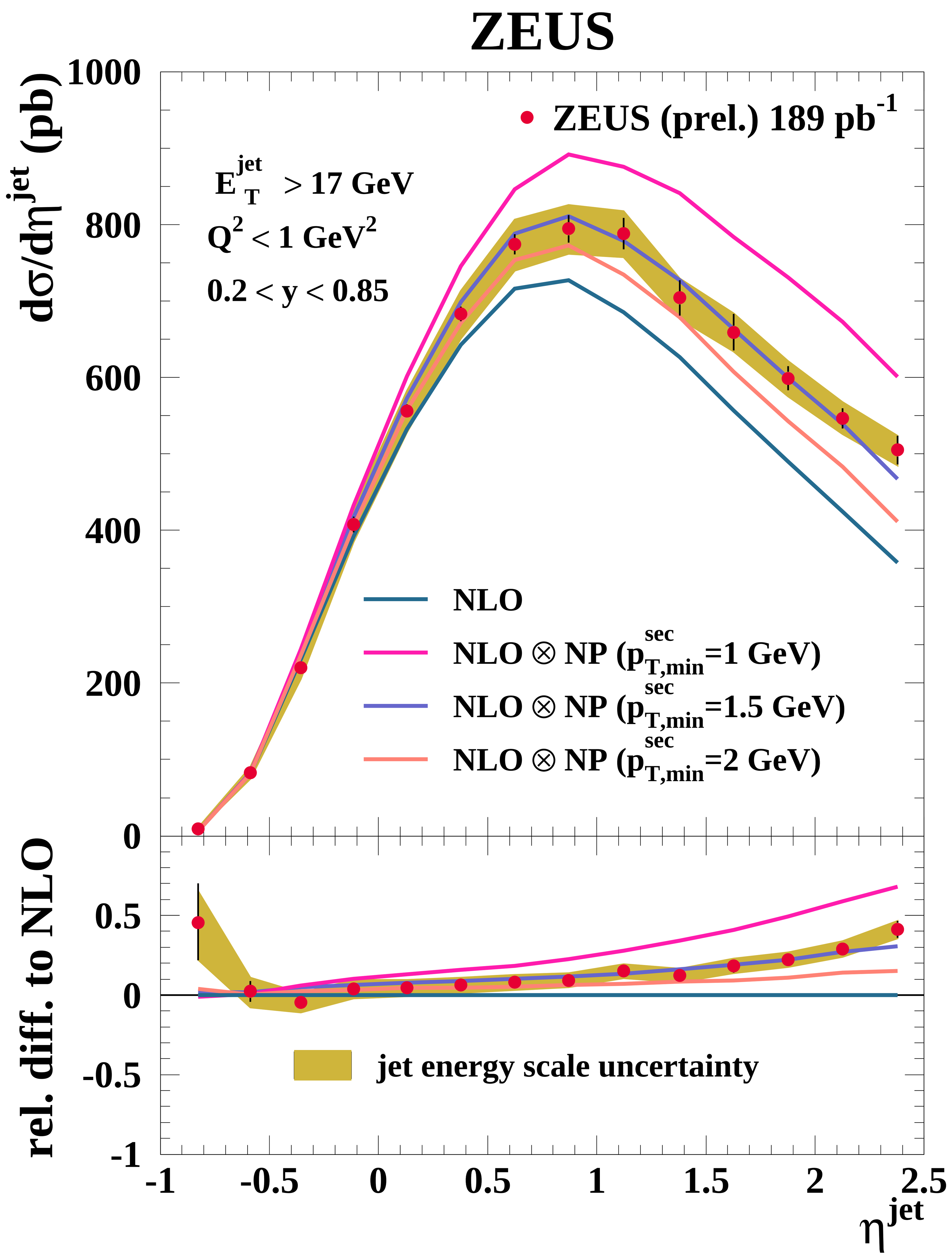
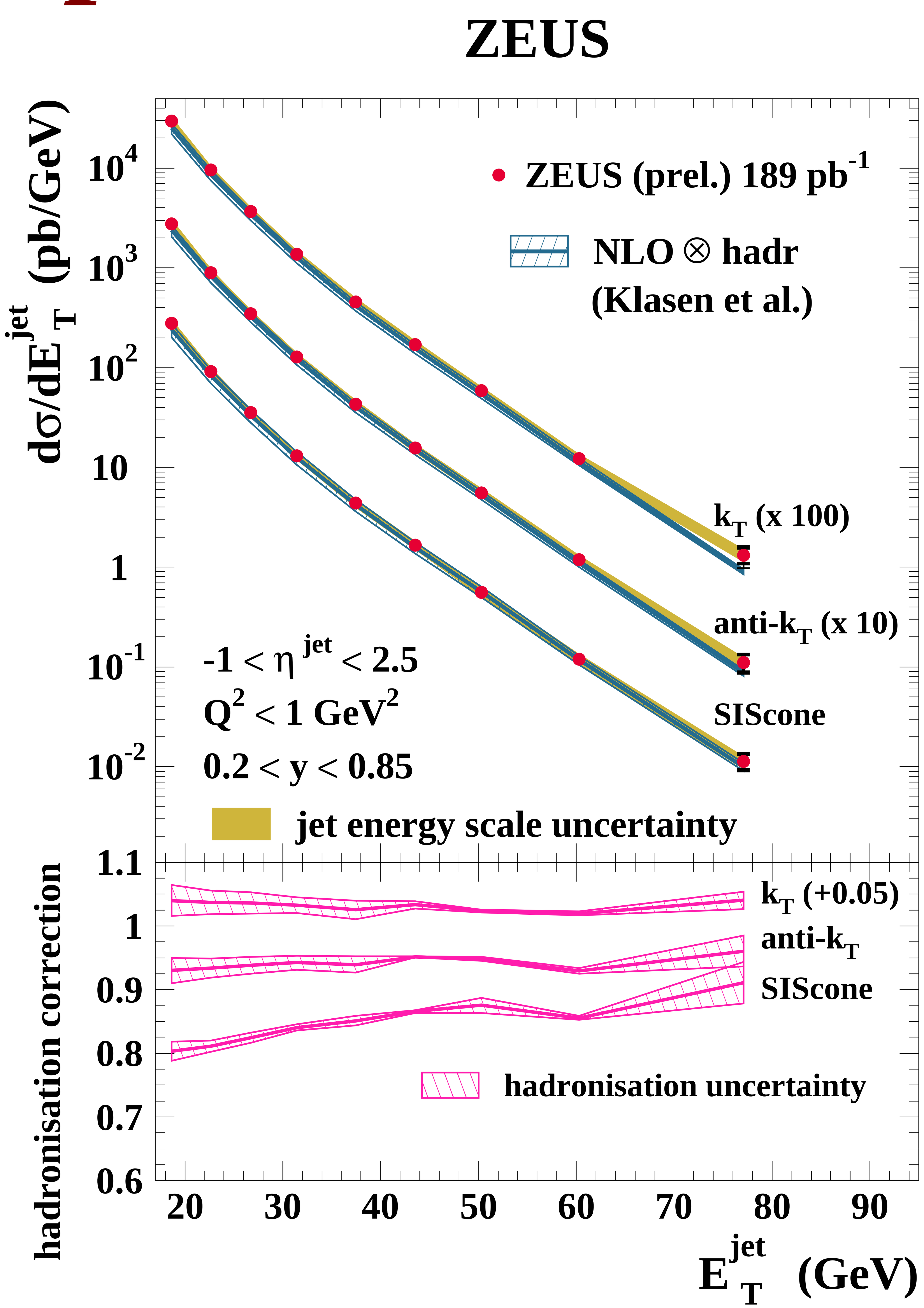




One of possible explanations: Multiparton Interactions

Jet algorithms comparison

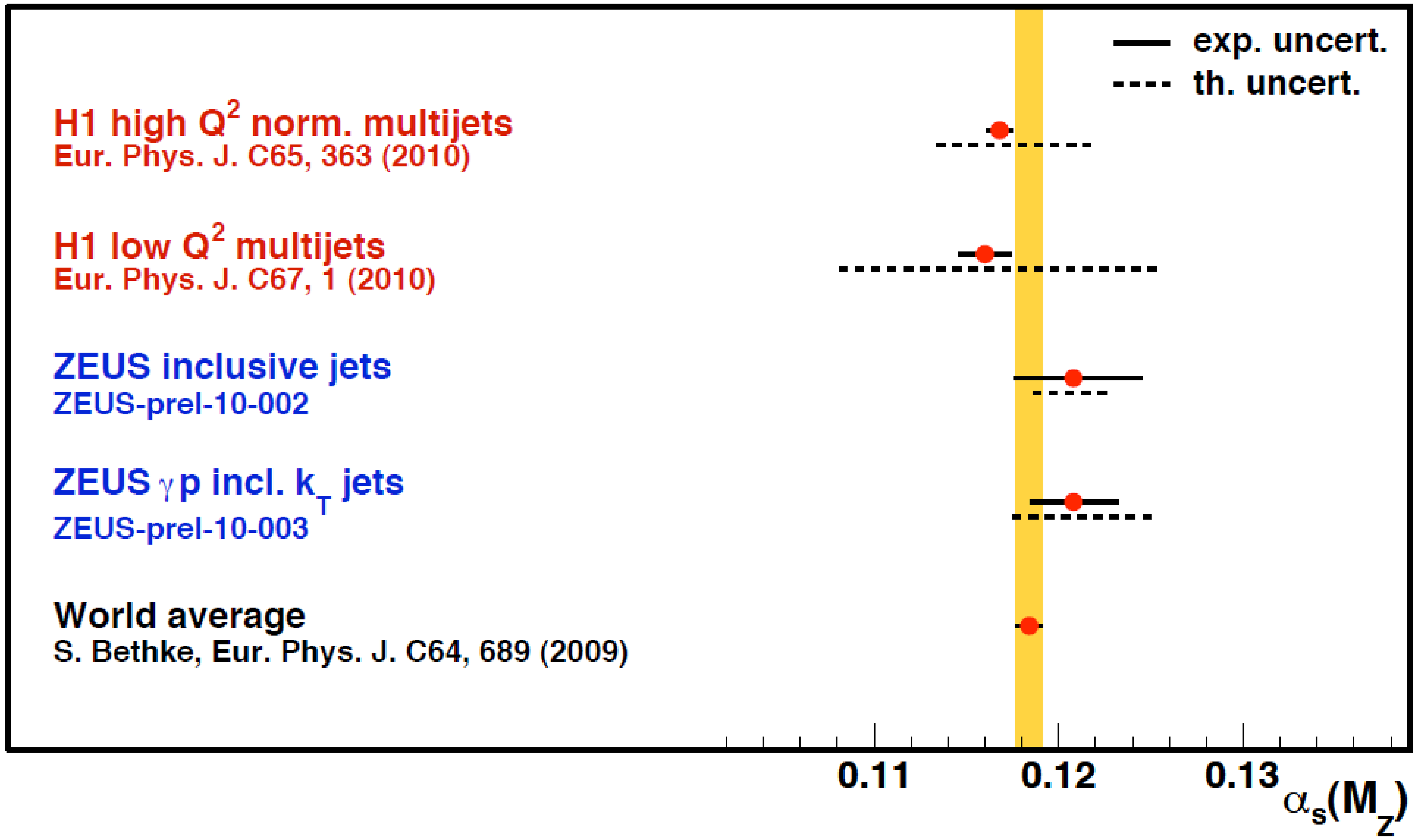
Performance test for new algorithms developed for LHC (anti-k_T, SIScone) using DIS and PHP data



- *k_T and anti-k_T exhibit similar performance*
- *SIScone hadronization correction somewhat higher*
- *SIScone slightly higher missing terms uncertainty*

Determination of α_s

Both experiments use their data to determine the strong coupling constant $\alpha_s(M_Z)$



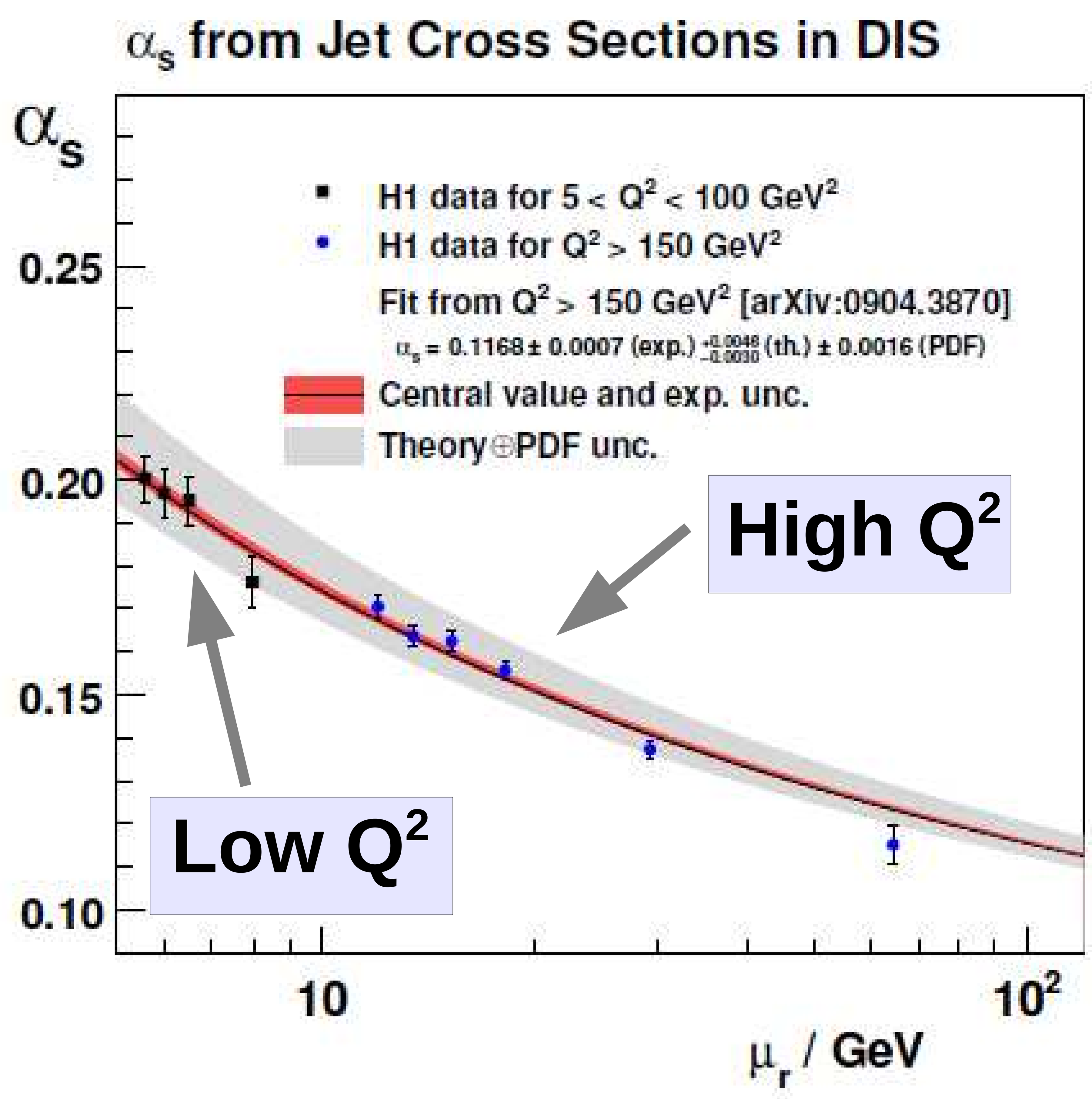
All determined couplings consistent with the world average

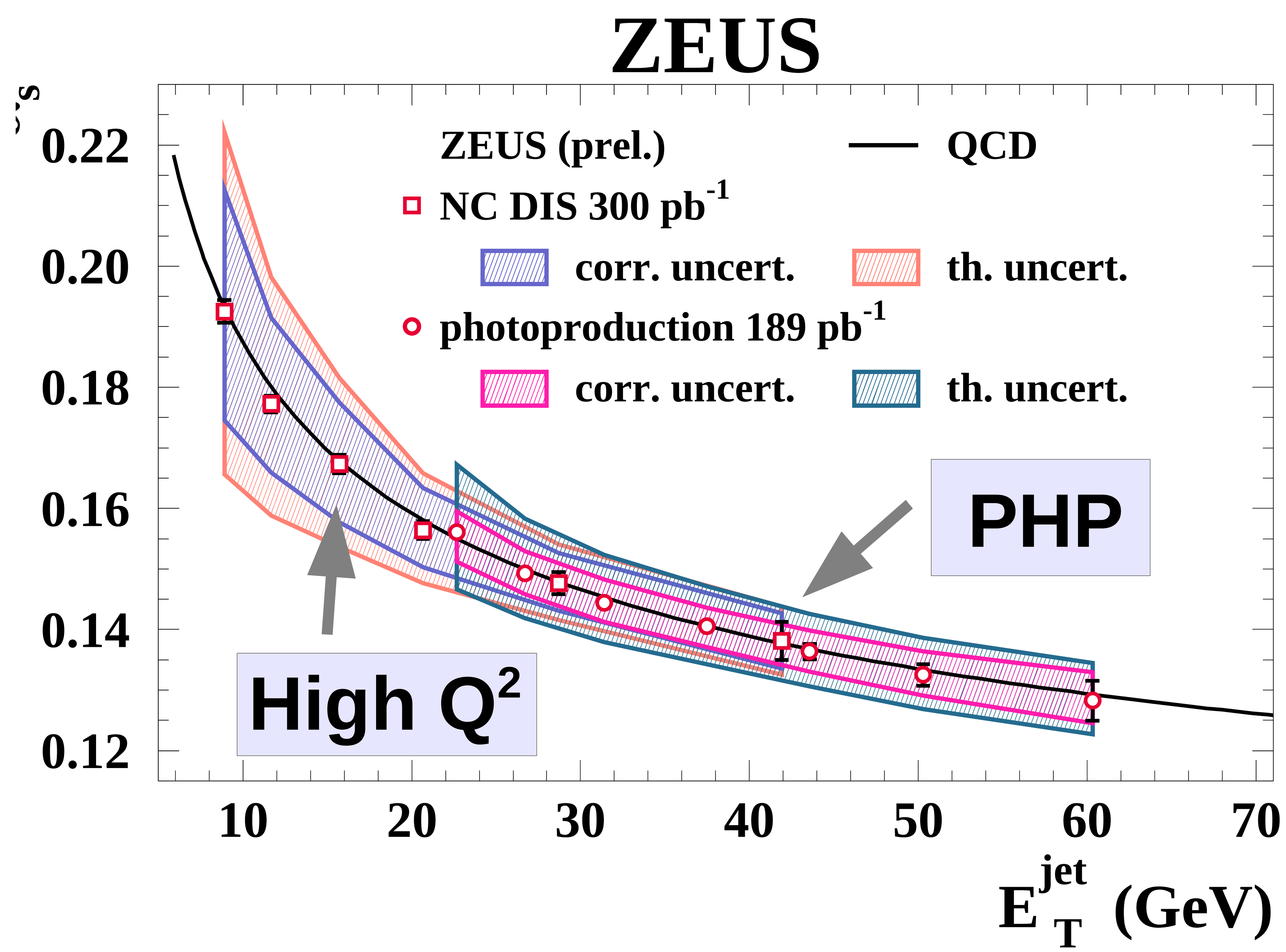
Couplings extracted from simultaneous fit to inclusive, dijet and trijet has reduced experimental uncertainty

Precision limited by the NLO calculation

Running of α_s test

Both experiments perform tests of the running α_s





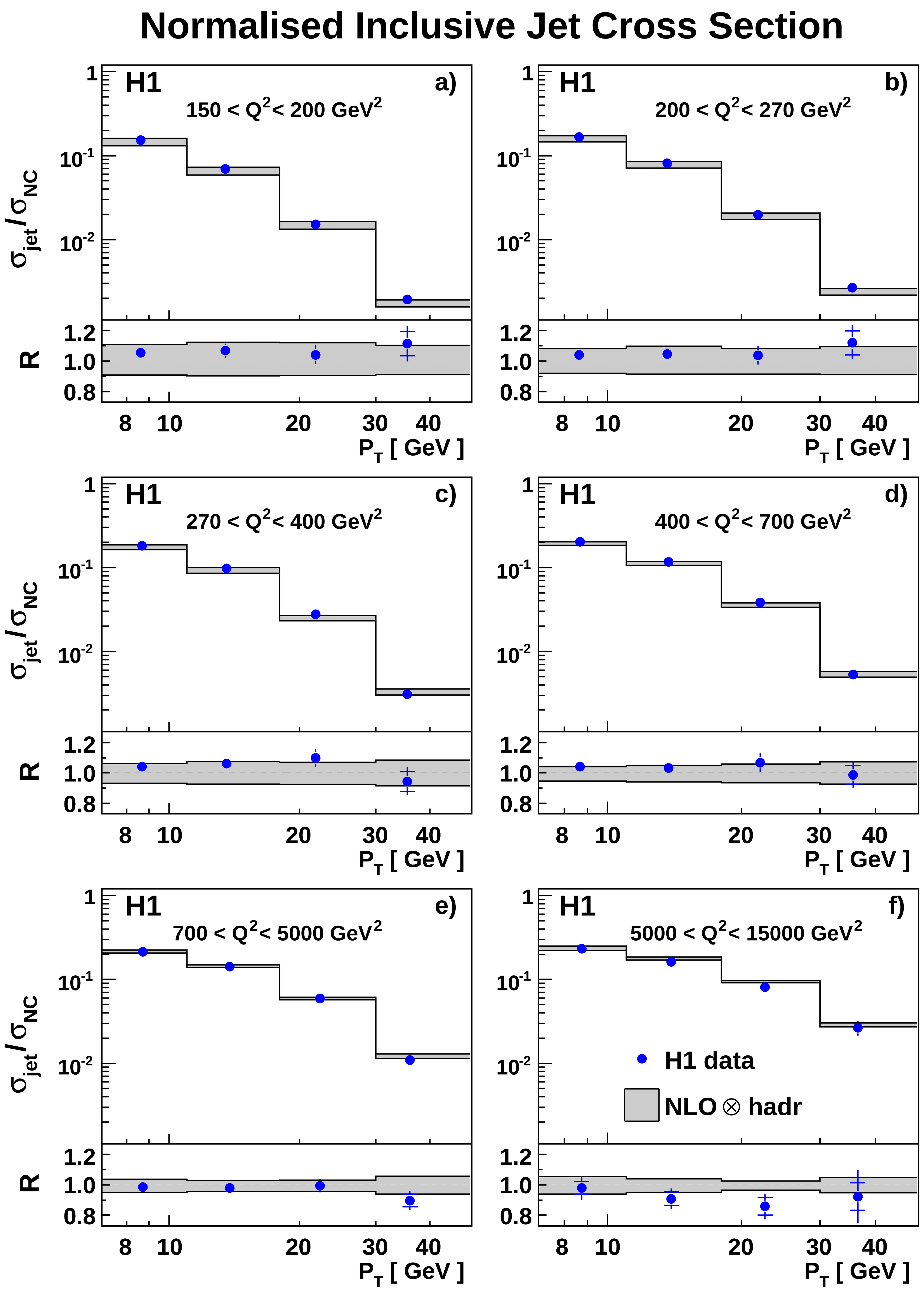
Tests show high level of consistency in our understanding of QCD

Conclusions

- *Jet measurements from HERA as important tool for*
  - *understanding of QCD*
  - *precise determination of strong coupling constant $\alpha_s(M_Z)$*
  - *test of the running of α_s over wide range of the scale*

High Q^2 DIS normalized jets

$\mathscr{L} = 395\,\mathrm{pb}^{-1}$
$150 < Q^2 < 15000\,GeV^2$
$0.2 < y < 0.7$
$7(5) < P_T^{JET} < 50\,GeV$
$-0.8 < \eta^{JET} < 2.0$



Inclusive, dijets and trijets cross sections normalized to inclusive DIS cross sections

Normalization allows to decrease experimental error

Theory error dominating, mostly renormalization scale uncertainty (up to 30%) - NNLO needed

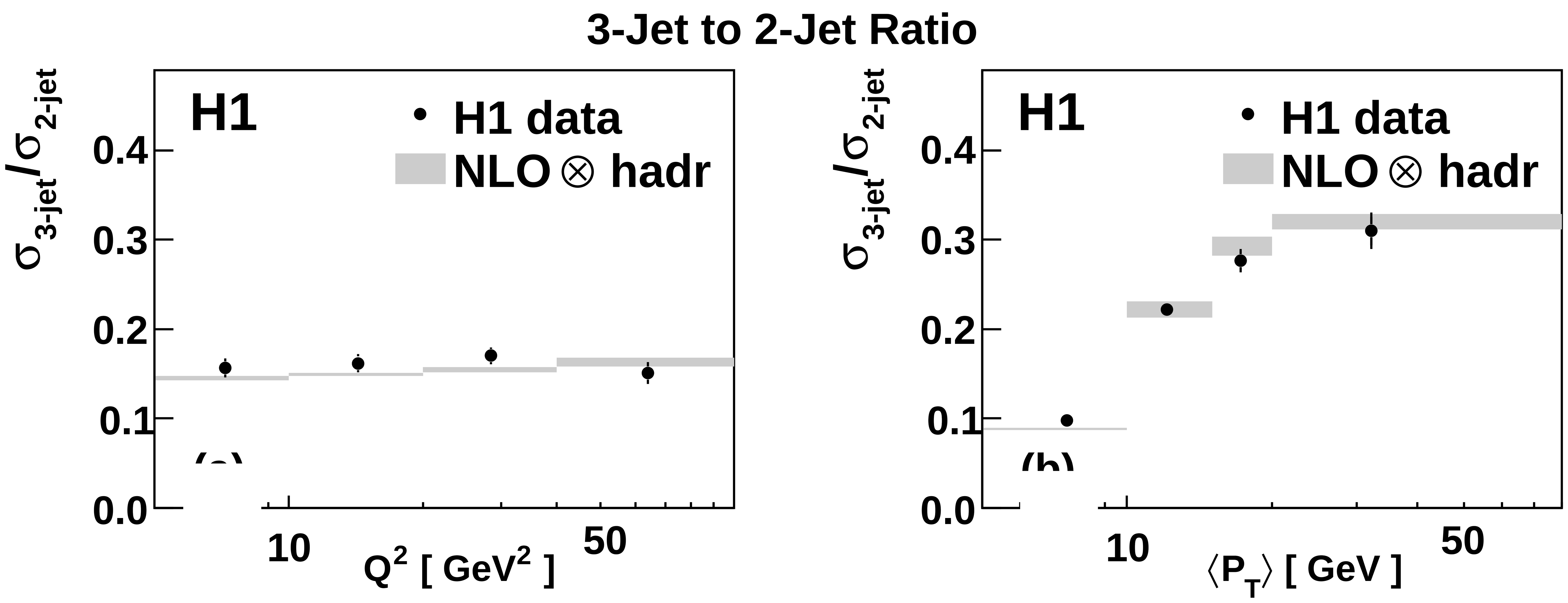
Data well described by NLO calculations (DISENT, NLOJET++, FastNLO)

Low Q^2 DIS jets

$\mathcal{L} = 43.5 \text{pb}^{-1}$
$5 < Q^2 < 100\, GeV^2$
$0.2 < y < 0.7$
$P_{T,B}^{JET} > 5\, GeV$
$-1.0 < \eta_{lab}^{JET} < 2.5$

Improvement on the uncertainty can be achieved by measuring trijet to dijet ratio:

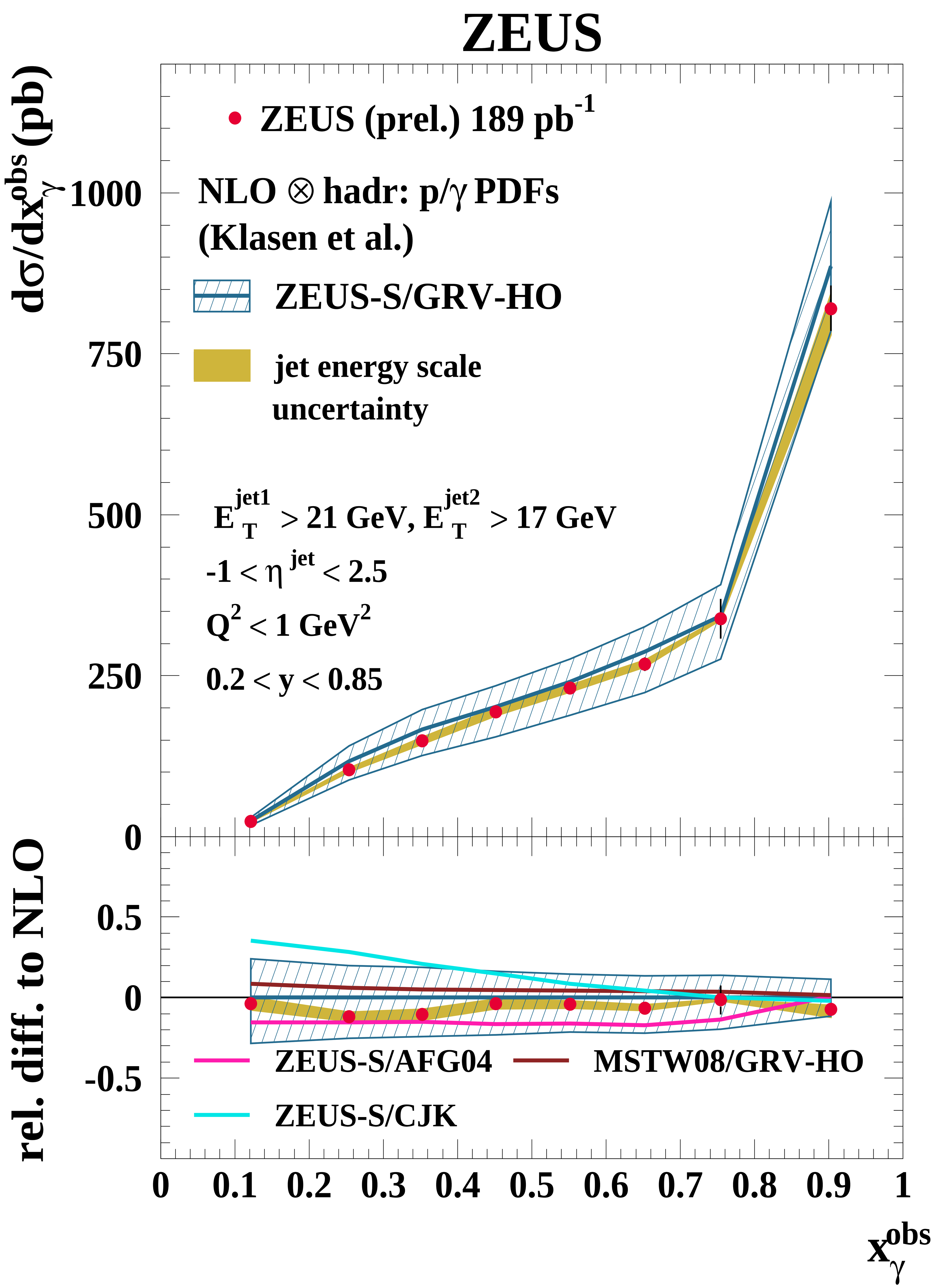
- *Cancellation of some systematic uncertainties (by 50%)*
- *Strong reduction of missing higher orders influence*



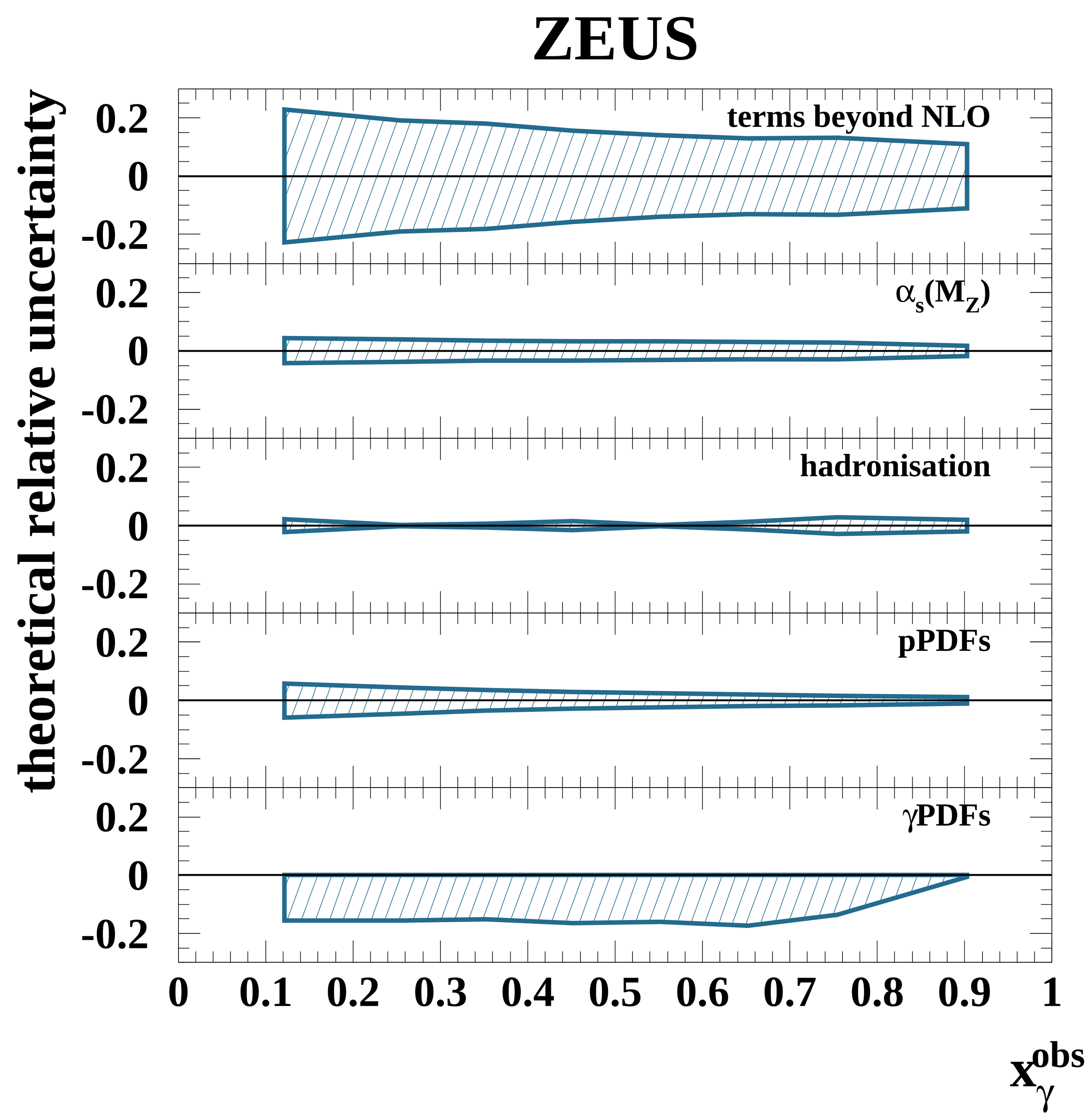
No discrepancy between theory and data observed

Dijets in photoproduction

$\mathscr{L} = 189 \mathrm{pb}^{-1}$
$Q^2 < 1 GeV^2$
$0.2 < y < 0.85$
$P_{T,B}^{JET} > 21(17) GeV$
$-1.0 < \eta_{lab}^{JET} < 2.5$



Large theoretical uncertainty (missing higher orders)



- *Sensitivity to photon PDF at low x_γ^{obs}*
- *High x_γ^{obs} better known, more suitable to be used in fits*

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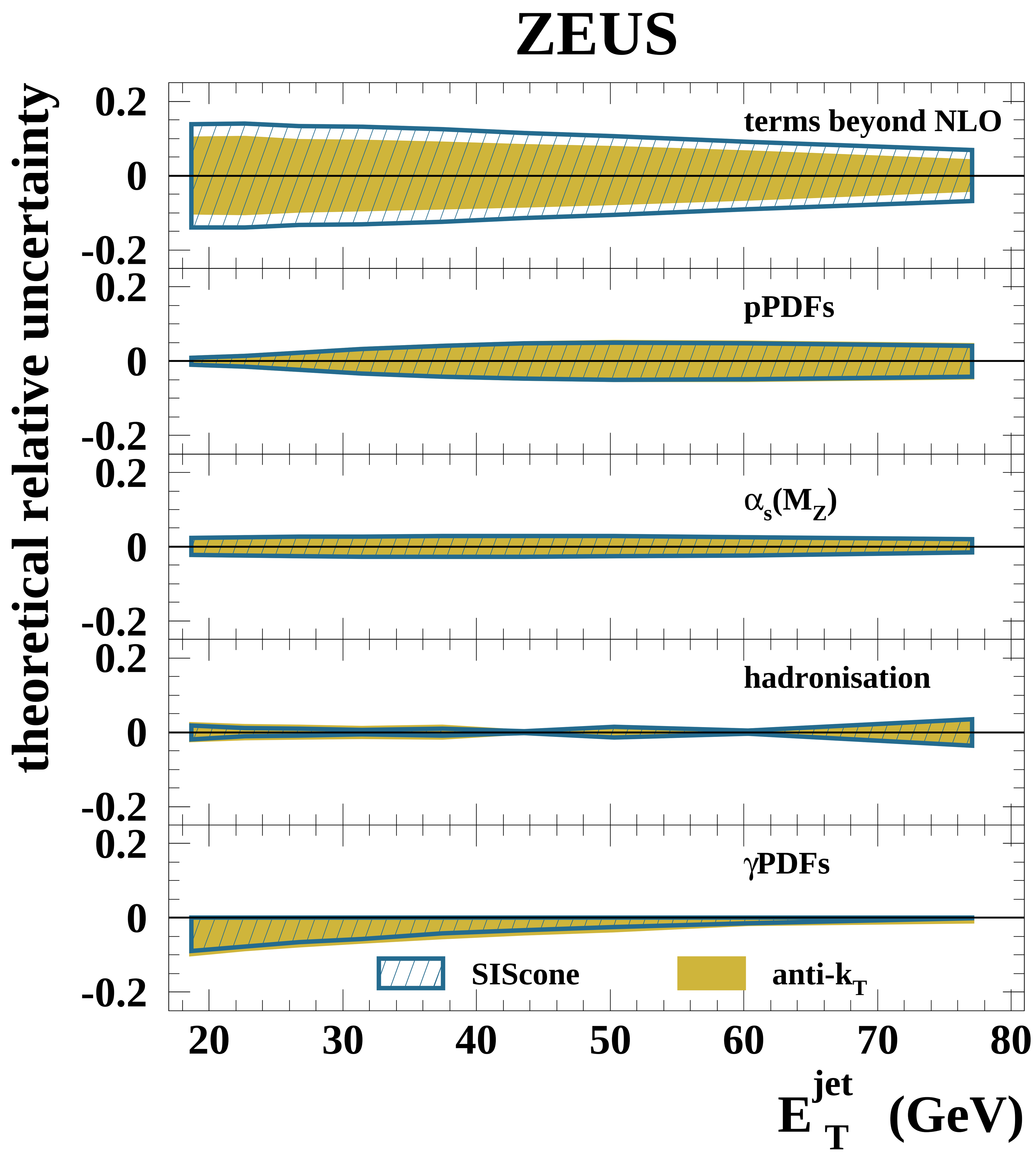
Performance test for new algorithms developed for LHC (anti-k_T, SIScone) using DIS and PHP data



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