Multijets at Low-x_{Bj} in *ep* Collisions at HERA

Results from ZEUS

Tom Danielson
University of Wisconsin – Madison

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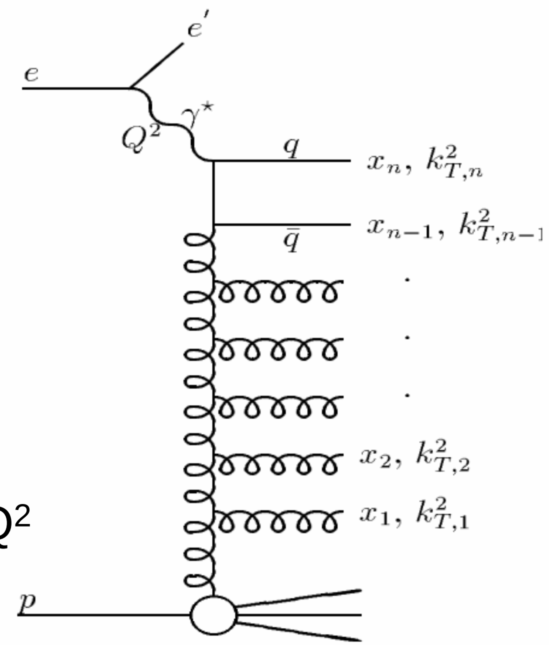
Testing Parton Evolution: Jets at low x_{Bj}

Moving to LHC:

- **Are extracted PDFs usable in the LHC kinematic range ($1 > x > 10^{-6}$) ?**
- **Does DGLAP evolution work sufficiently to extrapolate?**

Study QCD evolution schemes with jets at low x_{Bj} at HERA

- **DGLAP: sums over $\ln(Q^2)$ terms (LEPTO, NLOjet++)**
  - Strong ordering in k_T, ordering in x
  - well tested over large range of Q^2
- **BFKL: sums over $\ln(1/x)$ terms (~ ARIADNE (CDM))**
  - Strong ordering in x, but not ordered in k_T
    - More energetic forward jets
    - Jets less correlated in energies, angles
- **CCFM: k_T factorization (CASCADE)**
  - Evolution in Q^2, x
    - Approaches BFKL for low x_{Bj}, DGLAP for high Q^2
  - angular ordering (instead of k_T ordering)
  - uses unintegrated parton densities



Examine multijet correlations in angles, p_T to search for "non – DGLAP effects"

- **Compare first to DGLAP-based NLO calculations from NLOjet**

Event Selection and Calculations

1998 – 2000 ZEUS $e^{\pm}p$ data, 82 pb^{-1}

Low – x_{Bj} DIS selection

$$10^{-4} < x_{Bj} < 10^{-2}$$

$$10 < Q^2 < 100\,GeV^2$$

$$0.1 < y < 0.6$$

Dijet/trijet selection

$$E_{T,HCM}^{jet1} > 7\,GeV$$

$$E_{T,HCM}^{jet2(,3)} > 5\,GeV$$

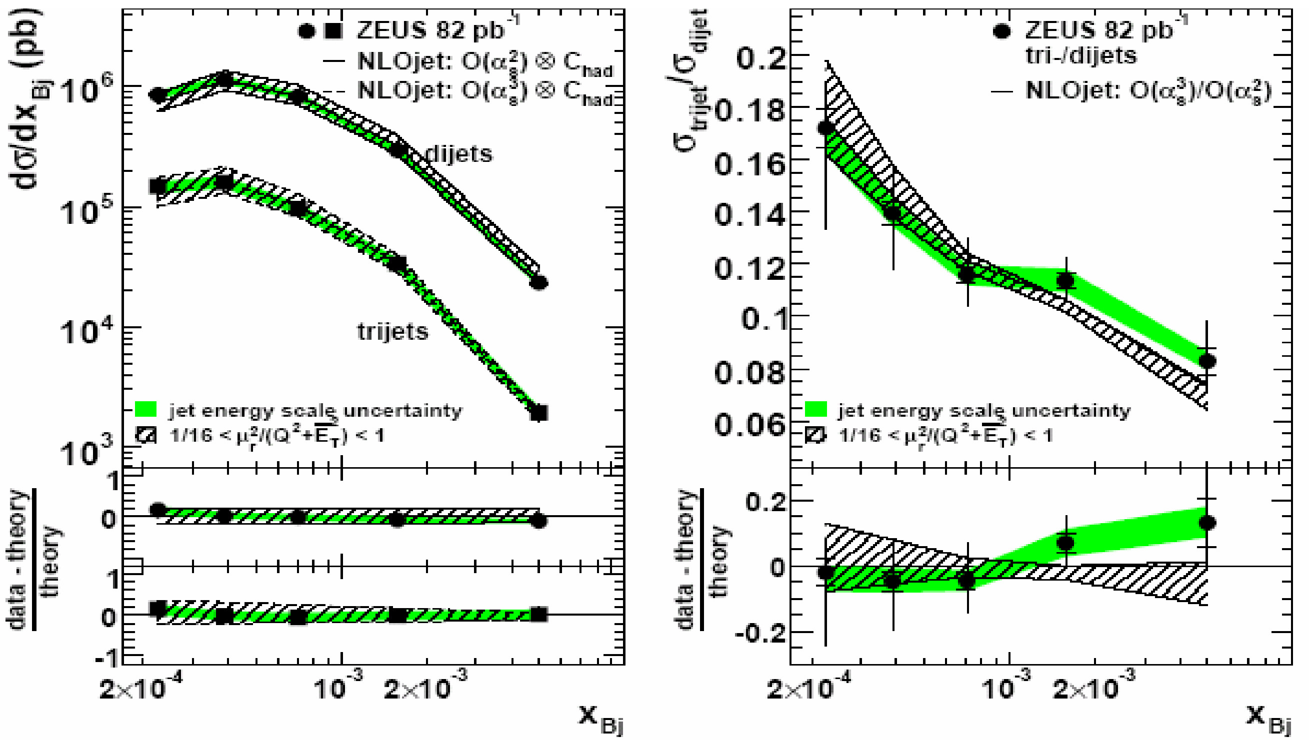
$$-1 < \eta_{LAB}^{jet1,2(,3)} < 2.5$$

Jets found using k_t algorithm in inclusive mode

NLO calculations from NLOjet++

- **Scales:** $$\mu_r^2 = \mu_f^2 = \frac{(\overline{E}_{T,HCM}^{jet})^2 + Q^2}{4}$$
- **Scales varied simult. by factors 2, ½ for theoretical uncertainty**
- **PDF set: CTEQ6M**
- **Hadronization corrections from LEPTO**
- ***For certain jet phase space, $O(\alpha_s^3)$ calculations possible for dijets***

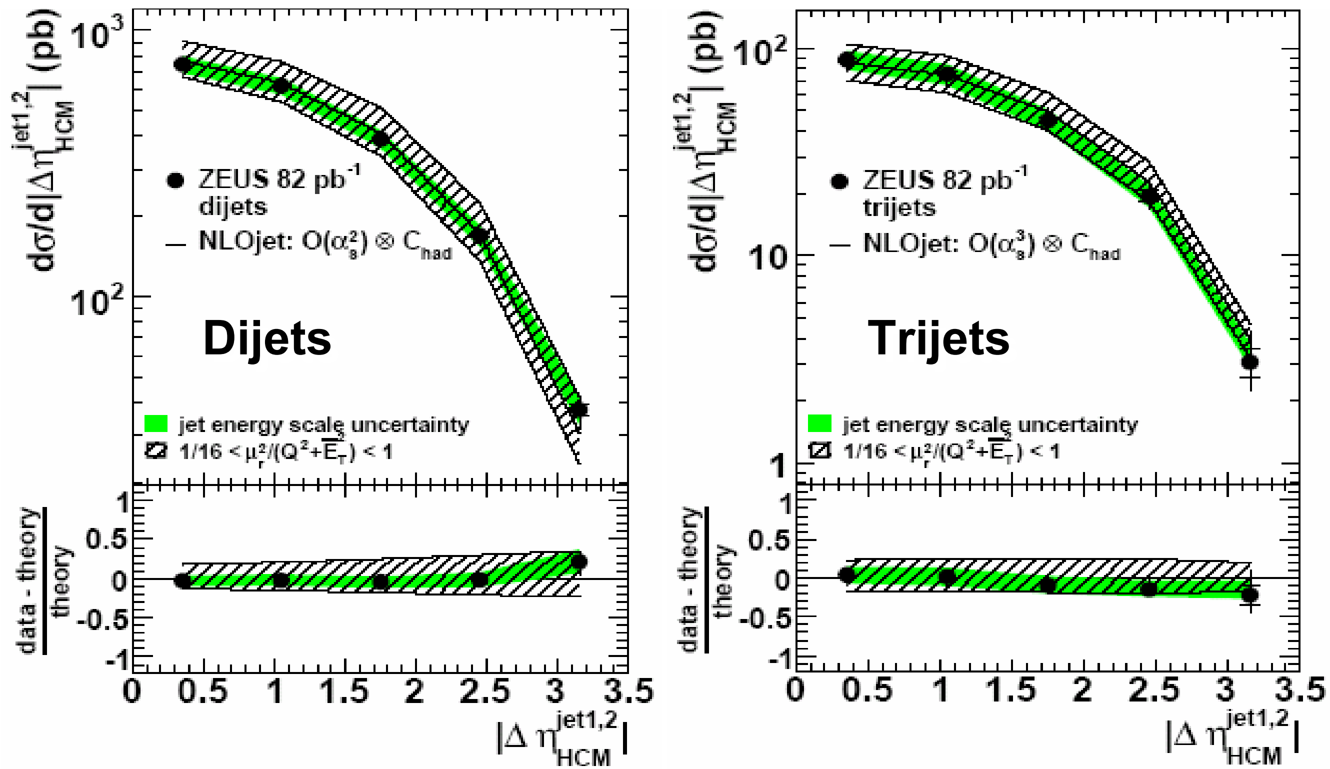
ZEUS Dijet, Trijets vs. x_{Bj}



Test DGLAP-based calculations from NLOjet for inclusive cross sections, ratios

- **Dijet, trijet cross sections both well-described.**
- **Measure cross section ratios → cancel theoretical uncertainties**
  - Ratios also well-described, esp. at low x_{Bj}

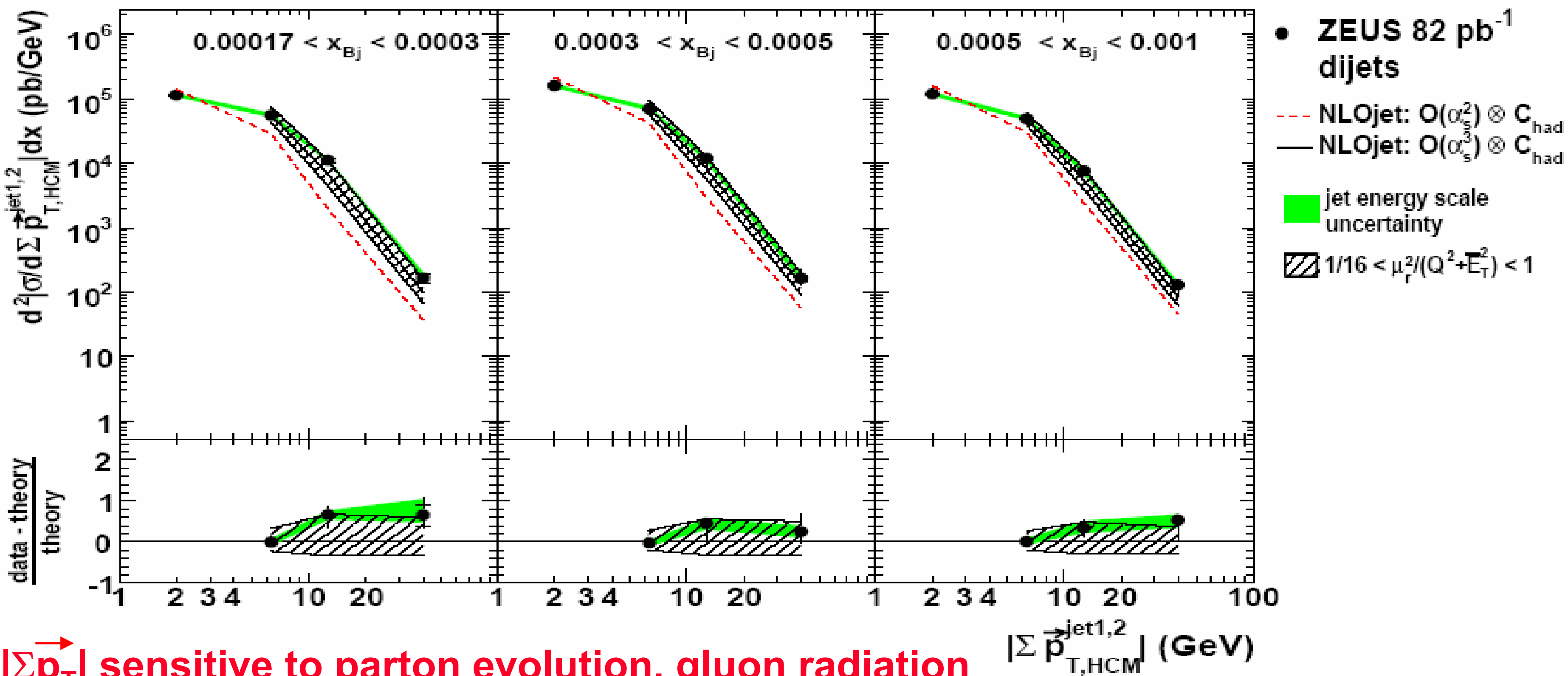
ZEUS Dijets, Trijets vs. $|\Delta\eta|$



NLOjet calculations describe η correlations

- **Description of data independent of x_{Bj}**
- **Higher-order terms not needed to describe dijet η correlations**

ZEUS Dijet p_T Correlations vs. x_{Bj}



$|\Sigma \vec{p}_T|$ sensitive to parton evolution, gluon radiation

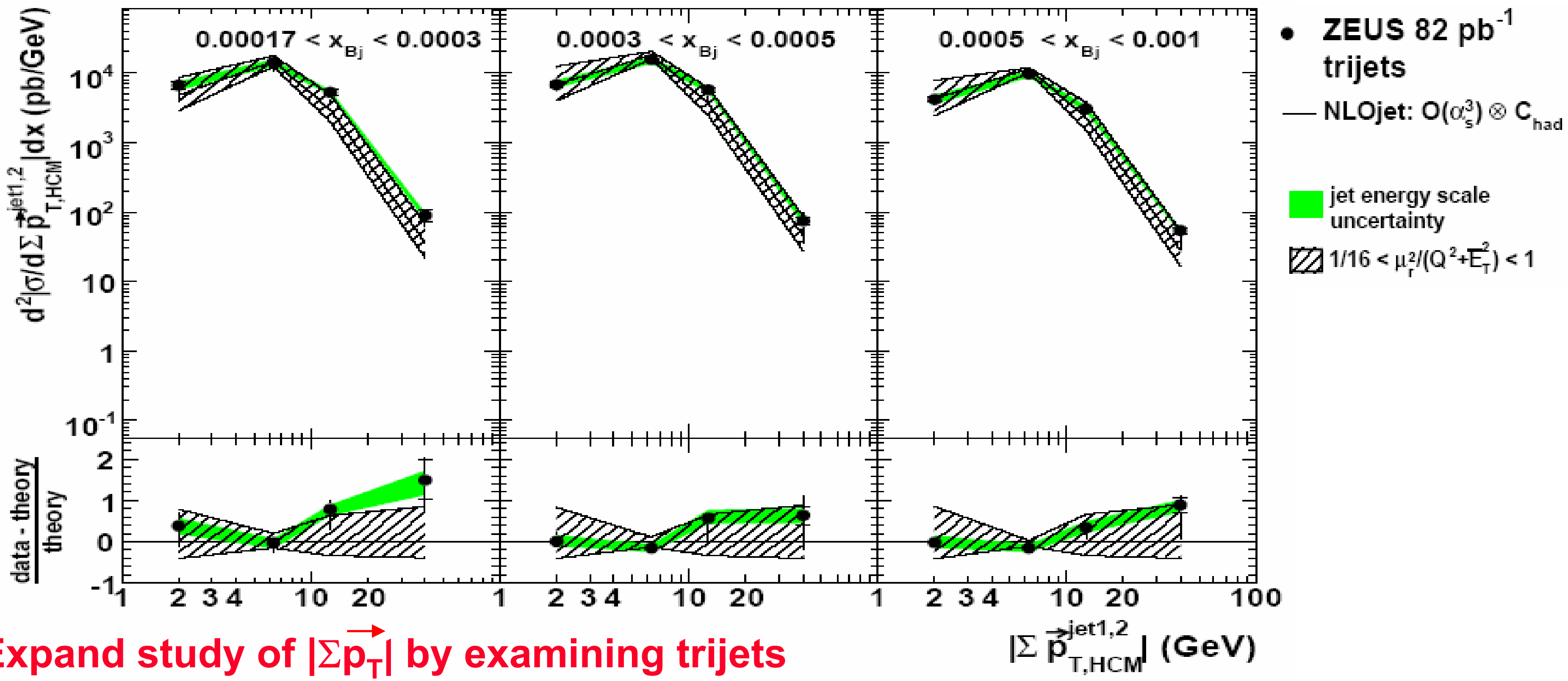
- $|\Sigma \vec{p}_T|$ = 0 without gluon radiation

NLOjet calculations at $O(\alpha_s{}^2)$ do not describe dijet data at low x_{Bj}

NLOjet calculations at $O(\alpha_s{}^3)$ describe data, even at low x_{Bj}

- Higher order terms important at low x_{Bj}
  - Allows for more gluon emission

ZEUS Trijet p_T Correlations vs. x_{Bj}



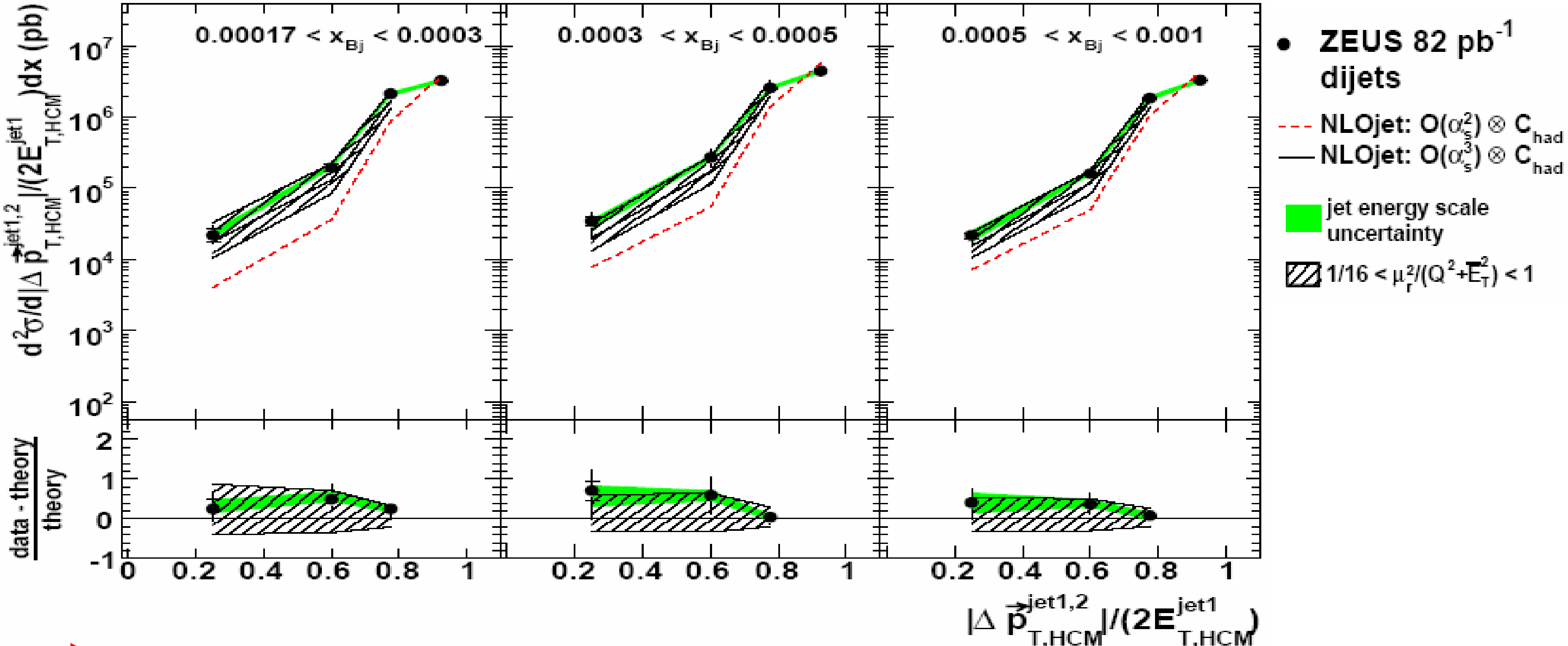
Expand study of $|\Sigma \vec{p}_T|$ by examining trijets

- **Higher order measurement ($O(\alpha_s^2)$ at LO)**

NLOjet calculations at $O(\alpha_s^3)$ describe the data

- **Better description at higher values of x_{Bj}**
  - Higher-order NLO calculations not available
  - Effect much less pronounced than for dijets vs. $O(\alpha_s^2)$ NLOjet calculations

ZEUS Dijet p_T Correlations vs. x_{Bj}



$|\Delta \vec{p}_T|/(2\ E_T^{jet1})$ sensitive to parton evolution, gluon radiation

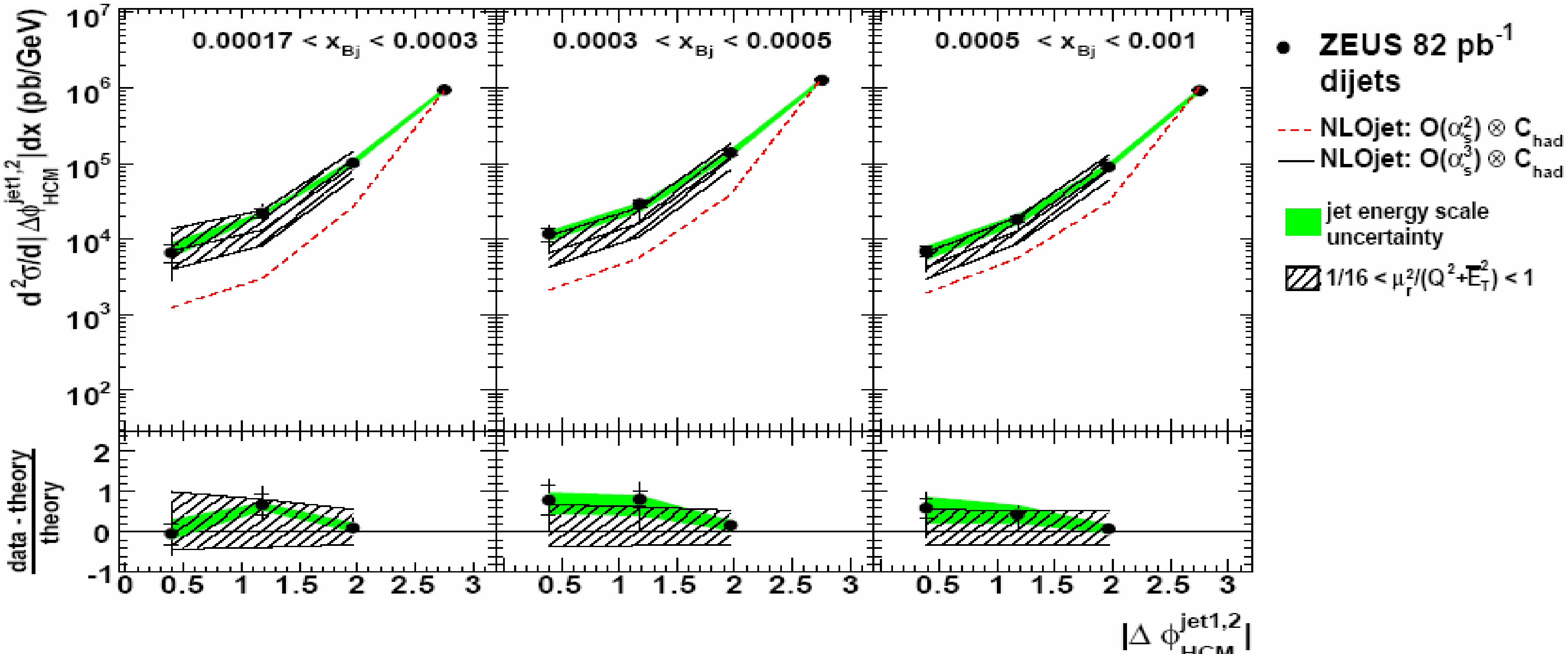
- $|\Delta \vec{p}_T|/(2\ E_T^{jet1}) = 1$ without gluon radiation

NLOjet calculations at $O(\alpha_s{}^2)$ do not describe dijet data at low x_{Bj}

NLOjet calculations at $O(\alpha_s{}^3)$ describe data, even at low x_{Bj}

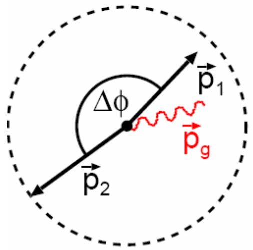
- Higher order terms important at low x_{Bj}
  - Allows for more gluon emission

ZEUS Dijet ϕ Correlations vs. x_{Bj}

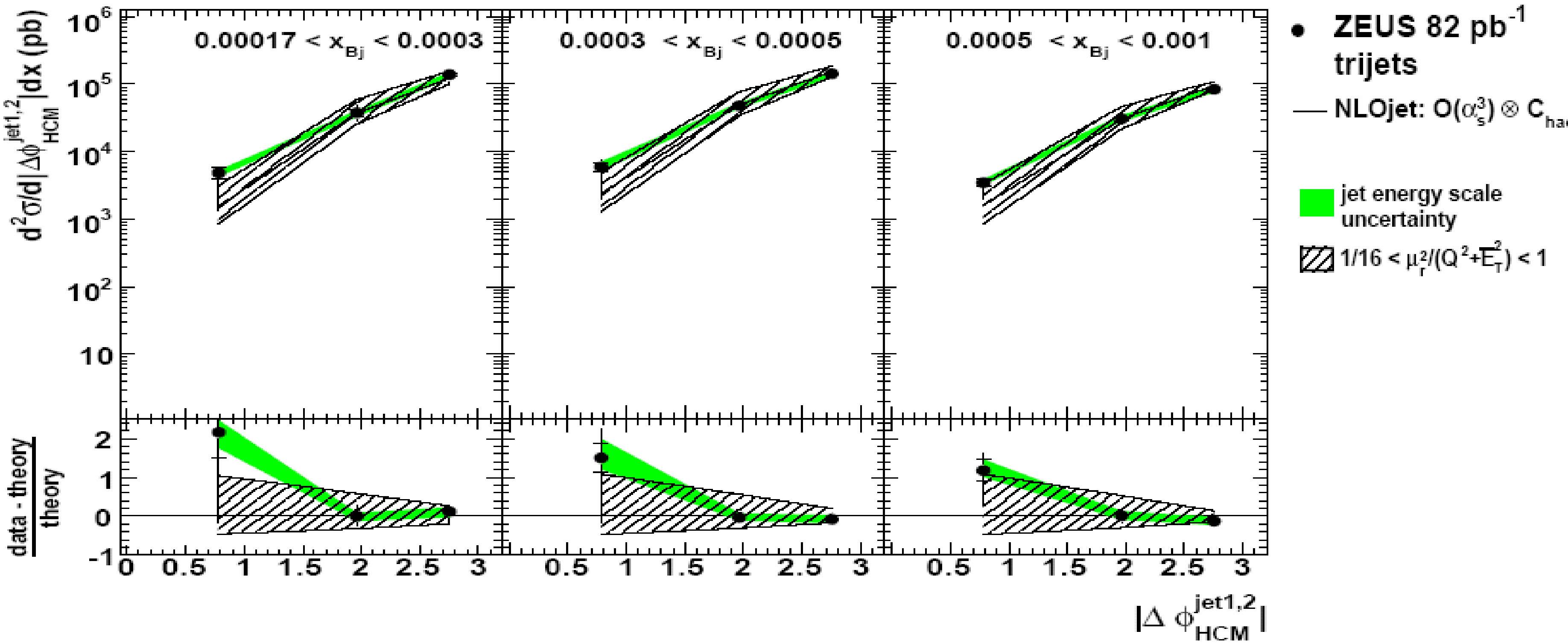


- $|\Delta\phi^*|$ sensitive to parton evolution, gluon radiation
  - $|\Delta\phi^*| = \pi$ without gluon radiation
- NLOjet calculations at $O(\alpha_s^2)$ do not describe dijet data at low x_{Bj}
- NLOjet calculations at $O(\alpha_s^3)$ describe data, even at low x_{Bj}
  - Higher order terms important at low x_{Bj}
    - Allows for more gluon emission

$$\Delta\phi^* = |\phi^{jet1}_{HCM} - \phi^{jet2}_{HCM}|$$



ZEUS Trijet ϕ Correlations vs. x_{Bj}



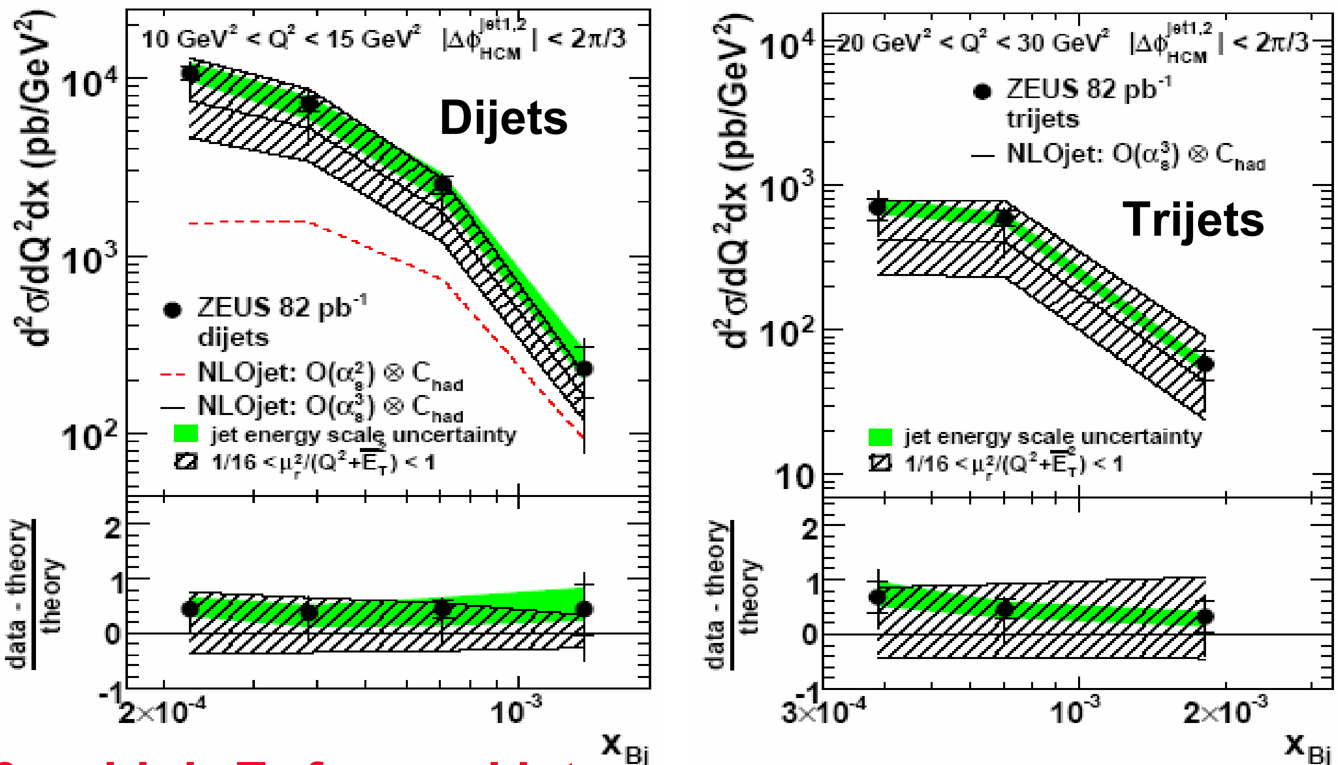
Expand study of $|\Delta\phi^*|$ by examining trijets

- **Combine first two bins in $|\Delta\phi^*|$ to reduce stat., systematic errors**

NLOjet calculations at $O(\alpha_s^3)$ describe the data

- **Slightly better description at higher values of x_{Bj}**
- **Higher-order NLO calculations not available**

ZEUS 2,3-jet Azimuthal Correl. vs. Q^2, x_{Bj}



$|\Delta\phi^*| < 2\pi/3 \rightarrow$ high-E_T forward jet

- Measurements sensitive both to angular correlations, forward jets

NLOjet calculations at $O(\alpha_s{}^3)$ describe dijet, trijet data, even at low x_{Bj}

- Dijets at low x_{Bj}: $O(\alpha_s{}^3)$ calcs for dijets ~ 10 x $O(\alpha_s{}^2)$ calcs

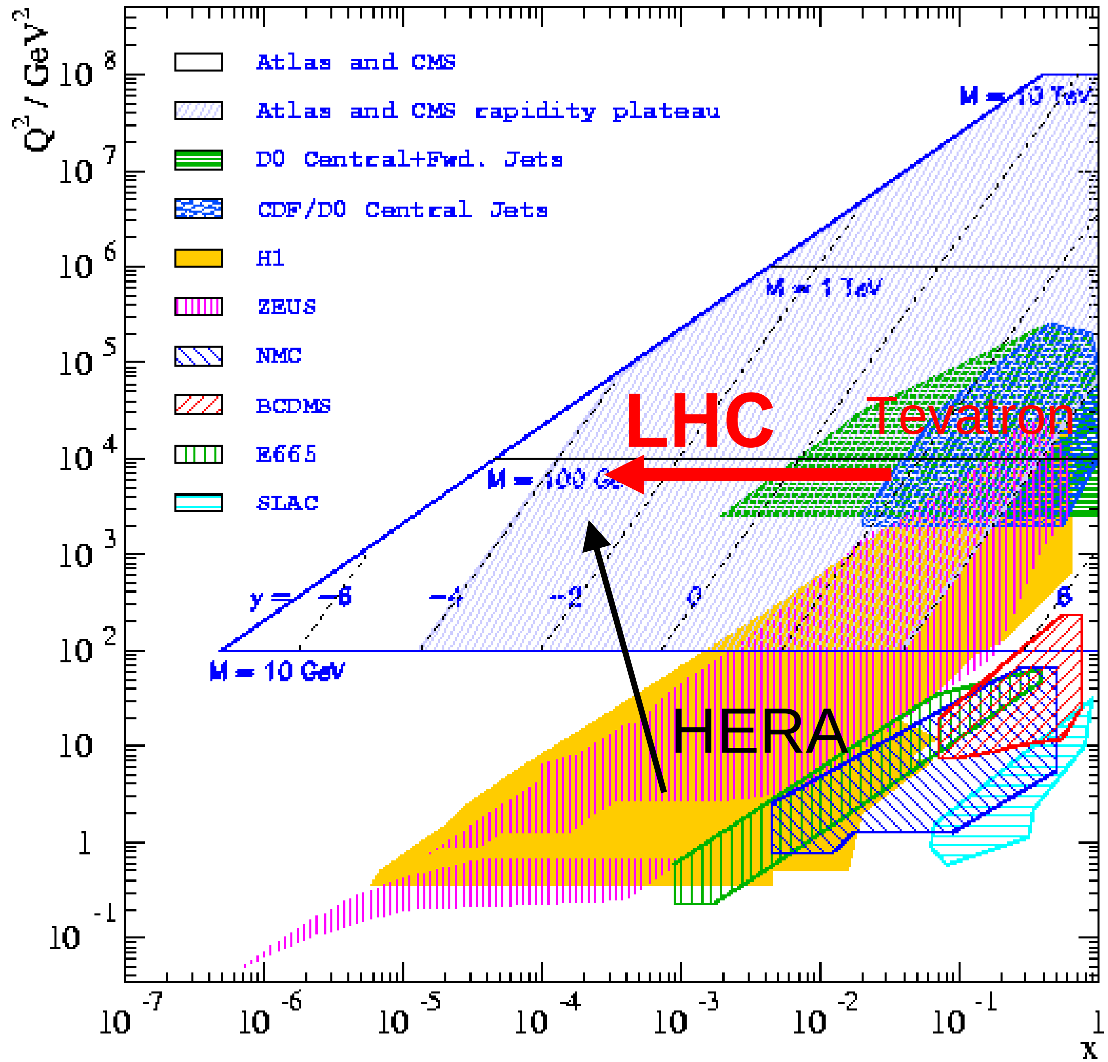
Summary: Low-x_{Bj} Dynamics at HERA

Dijet, trijet correlations at ZEUS measured at small x_{Bj} ($10^{-2} < x_{Bj} < 10^{-4}$)

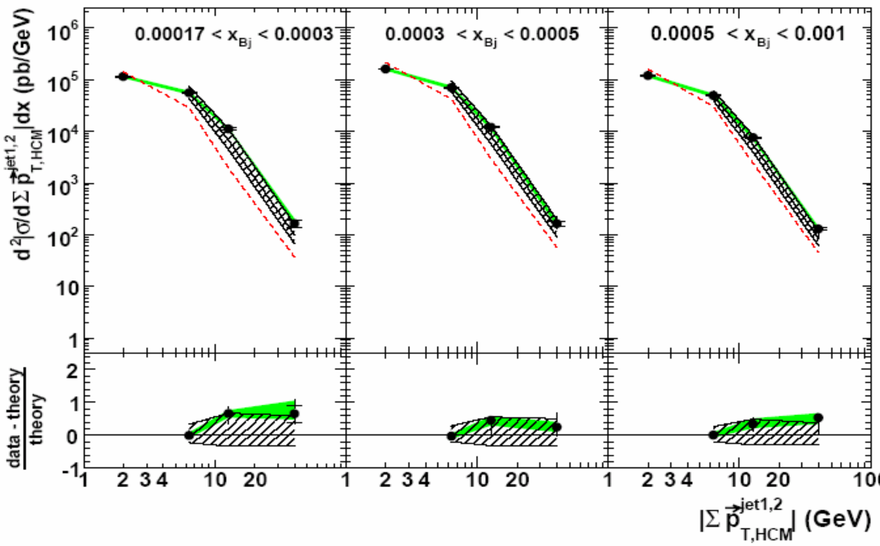
- **Dijet, trijet p_T and azimuthal correlations most senstive to gluon radiation, parton evolution**
  - Higher-order terms important at low Q^2, x_{Bj}
    - **Effects more pronounced for dijets**
      - Higher-order calculations up to 10x larger at very small x_{Bj}
  - Correlations well-described by NLOjet calcs.
- **Cross sections in x_{Bj}, correlations in η well-described by NLOjet calcs.**
  - Less sensitive to parton evolution scheme

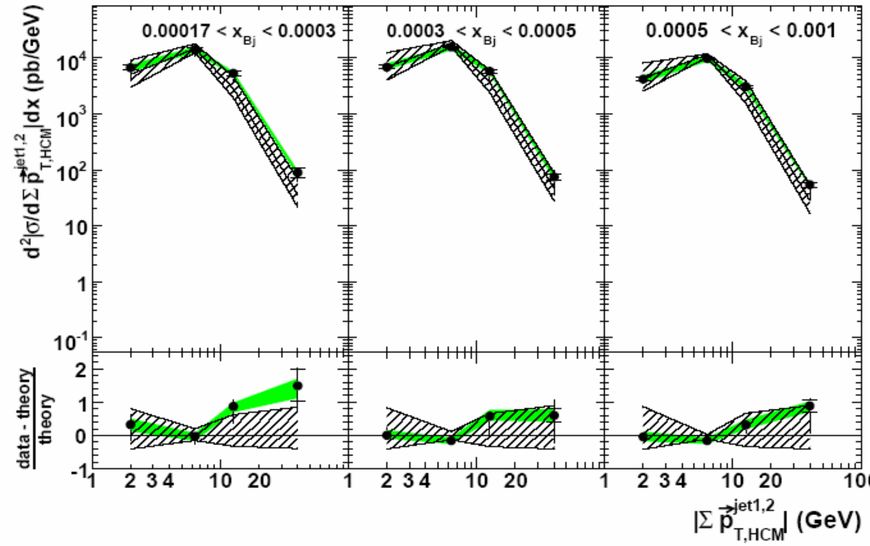
Backup Slides

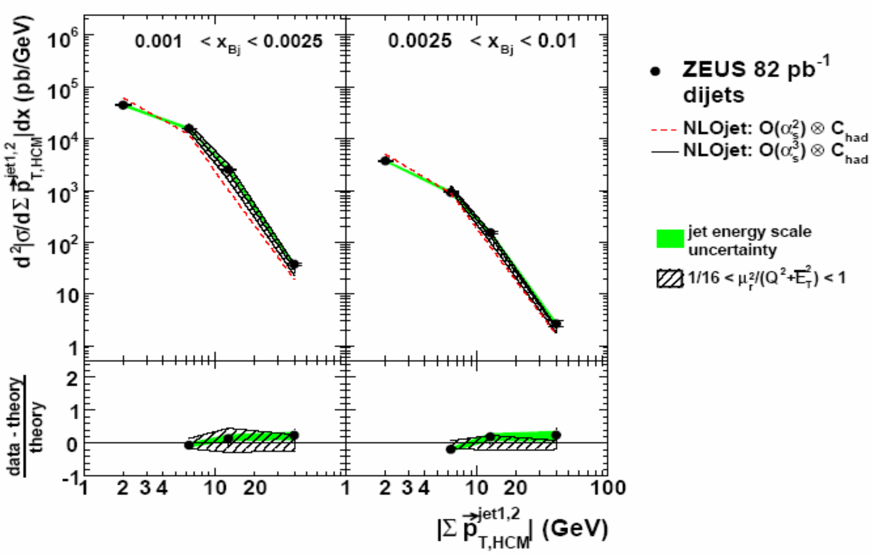
Kinematic Coverage of Colliders

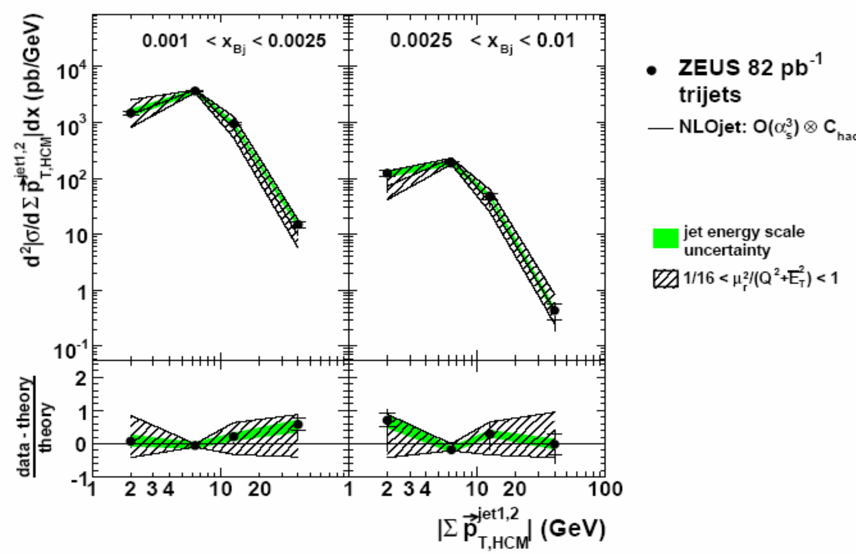


ZEUS Dijet and Trijet p_T Correlations vs. x_{Bj}









ZEUS Dijet and Trijet Azimuthal Correlations vs. x_{Bj}