Multijets in Photoproduction and Multiparton Interactions at HERA

Albert Knutsson

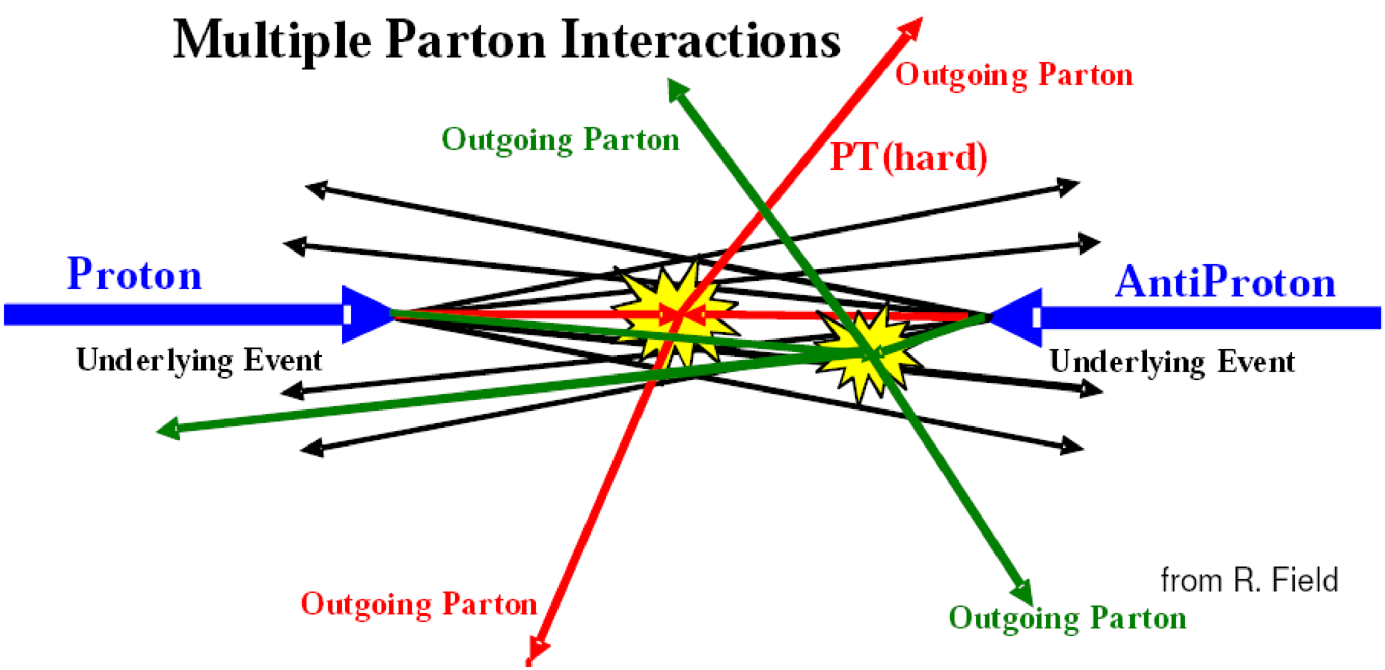
on behalf of H1 and ZEUS

PHOTON07, Paris, 9-13/7 2007

Outline

- Multiparton Interactions
- Short Summary of Monte Carlo generators
- Multijets in photoproduction (ZEUS)
- Mini jets in DIS (H1)
- Summary

Multiparton Interactions (MPI)



- Underlying event: Everything except the lowest order process
  - Additional parton-remnant interactions, MPI (soft or hard)
  - Partonshowers
  - ...but not pile up

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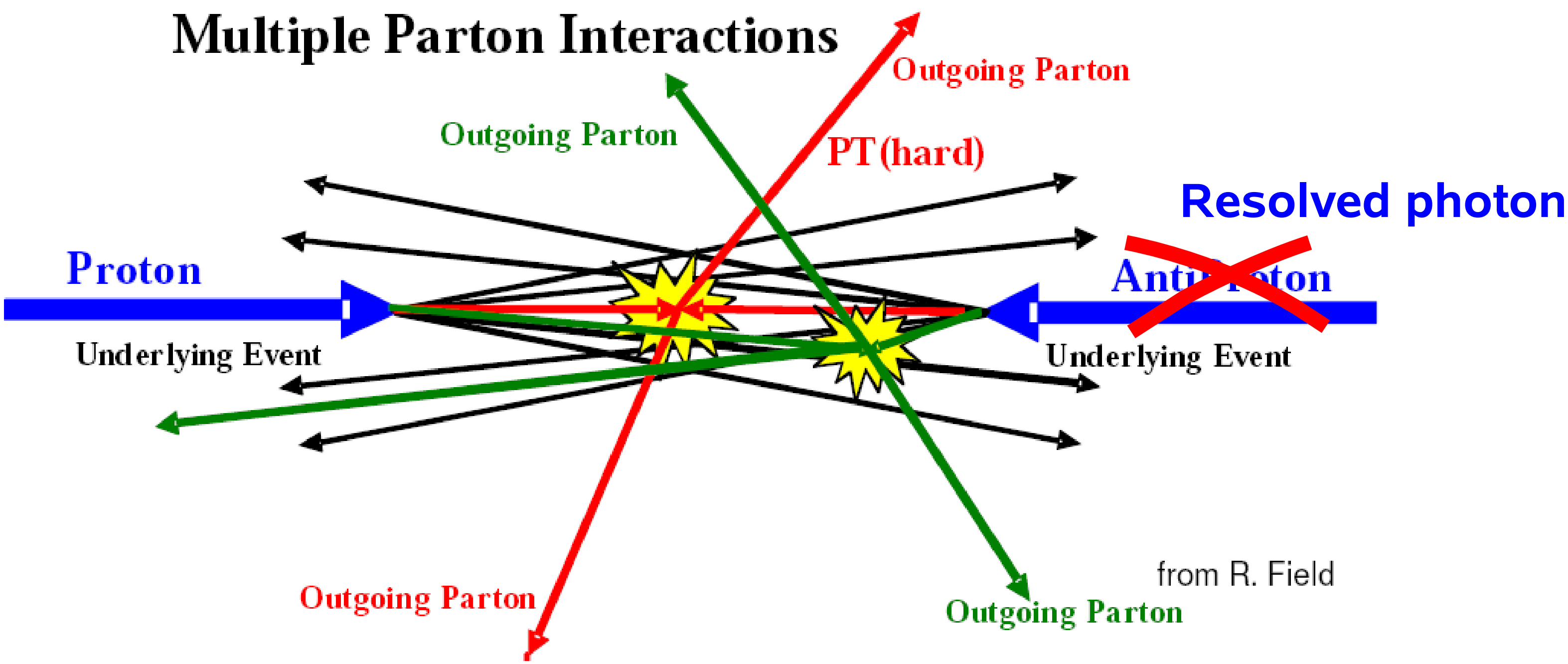

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Monte Carlo models with parton showers

(relevant for this presentation)

- *RAPGAP*: LO ME + DGLAP parton showers (No MPI)
  Resolved photon component can be included.

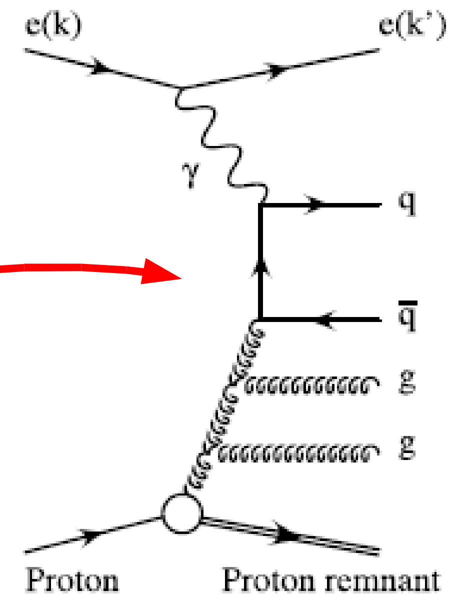
- *CDM*: Parton showers from the Color Dipole Model (No MPI).
  QPM and BGF events from LO ME.

- *PYTHIA*: LO ME + DGLAP parton showers
  MPI:
  - **Average number of interactions/event=** $\sigma_{\text{hard}}(p_{\text{t, min}})/\sigma_{\text{non-diff}}$
  - **Several free parameters: Different tunes exist. Here the default parameters are used.**

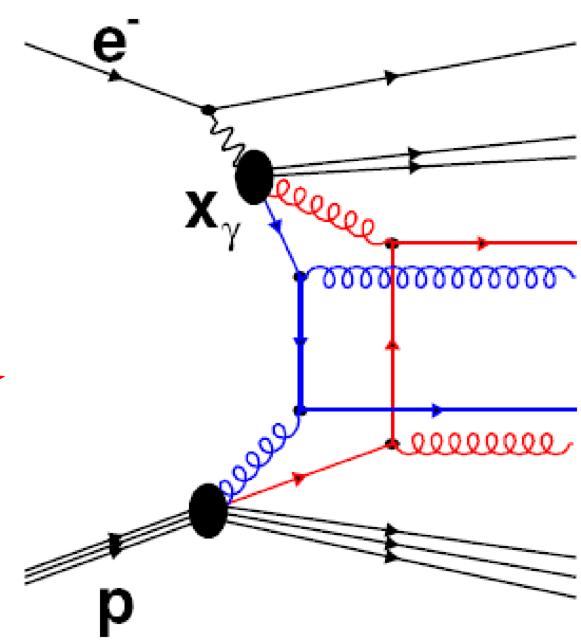
- *HERWIG*: LO ME + DGLAP parton showers
  MPI from JIMMY:
  - **MPI add on package used with HERWIG**
  - **Similar to MPI in Pythia**
  - **Impact parameter dependence**

Multijets in Photoproduction (ZEUS)

- Measure 3- and 4-jet final state ➔ higher order reaction
- Tool to study higher order α_s reactions in photoproduction
  - test fixed order calculation $O(\alpha, \alpha_s^2)$ (i.e. for 3-jet, for 4-jet one needs $O(\alpha, \alpha_s^3)$)
  - test QCD models with PS



- Higher order reaction ➔ sensitive to MPI?



Multijets in Photoproduction (ZEUS)

Kinematic Range

- $0.2 < y < 0.85$
- $Q^2 < 1.0 \text{ GeV}^2$

Jet Selection

- $E_T^{jet_{1,2,3,4}} > 6 \text{ GeV}$
- $|\eta^{jet}| < 2.4$

Jets defined by the inclusive kt-algorithm

Variable Definitions

Inv. mass of n-jet system: $M_{nj} = \sqrt{(\sum p_i)^2}$

Fraction of γ – momentum: $x_\gamma^{\text{obs}} = \dfrac{\sum E_{T,i}^{\text{jet}} exp(-\eta_i^{\text{jet}})}{2yE_e}$

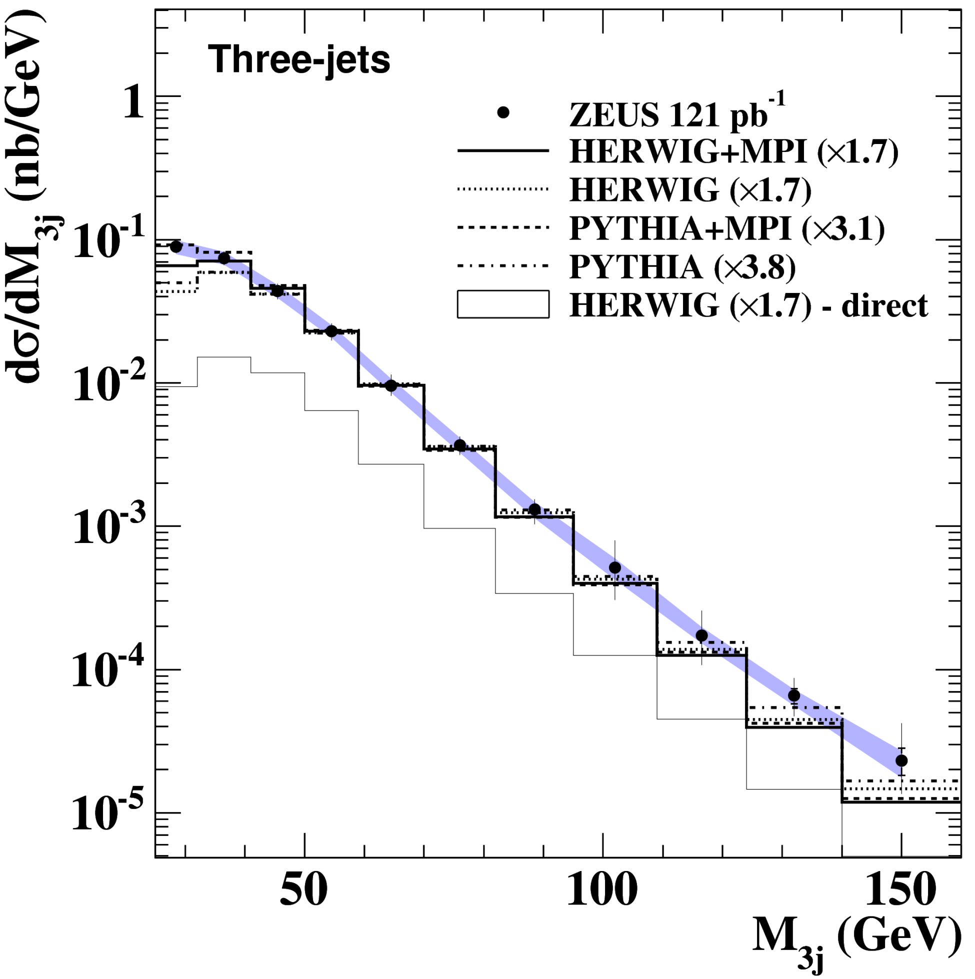
where the sums runs over 3 or 4 jets

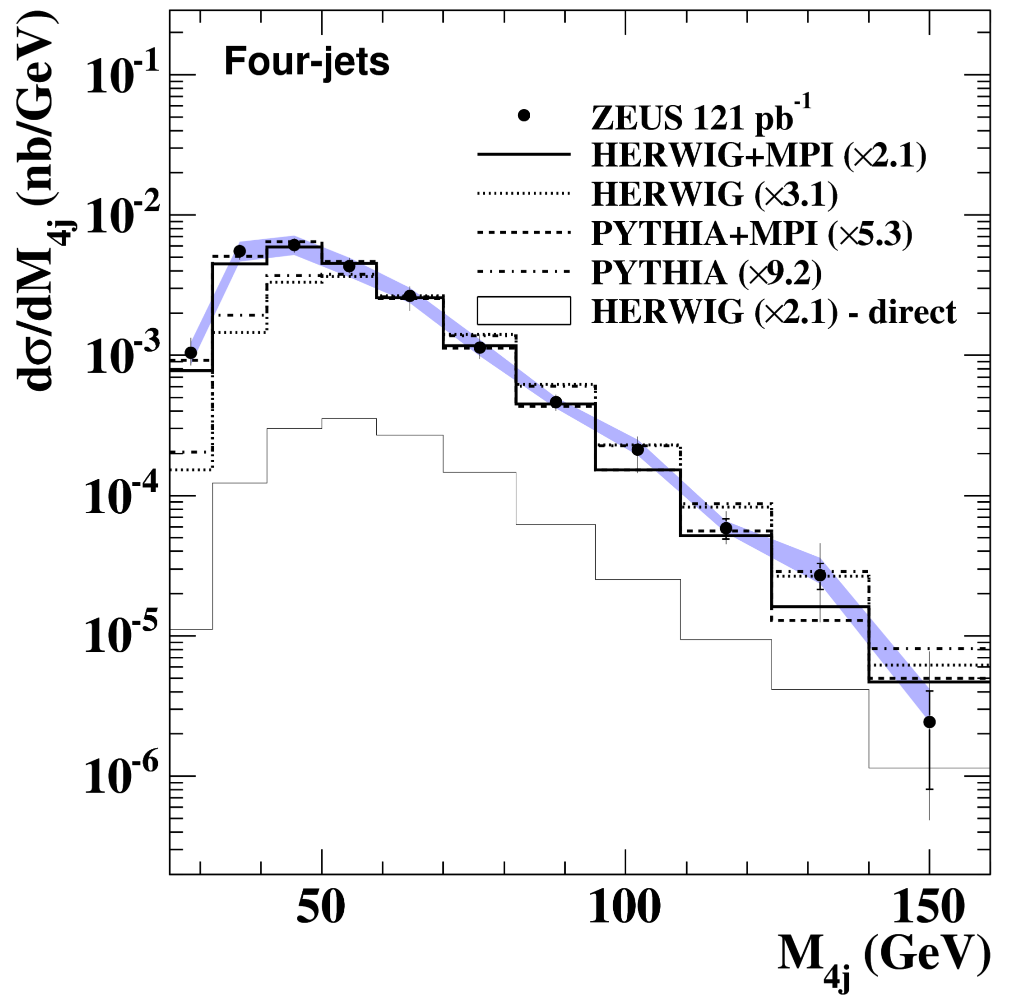
Measurement

3- and 4-jet cross-sections as a function of several variables and for:

- **Low mass region:** $25 < M_{nj} < 50 \text{ GeV}$
- **High mass region:** $M_{nj} > 50 \text{ GeV}$

Multijets in Photoproduction (ZEUS)

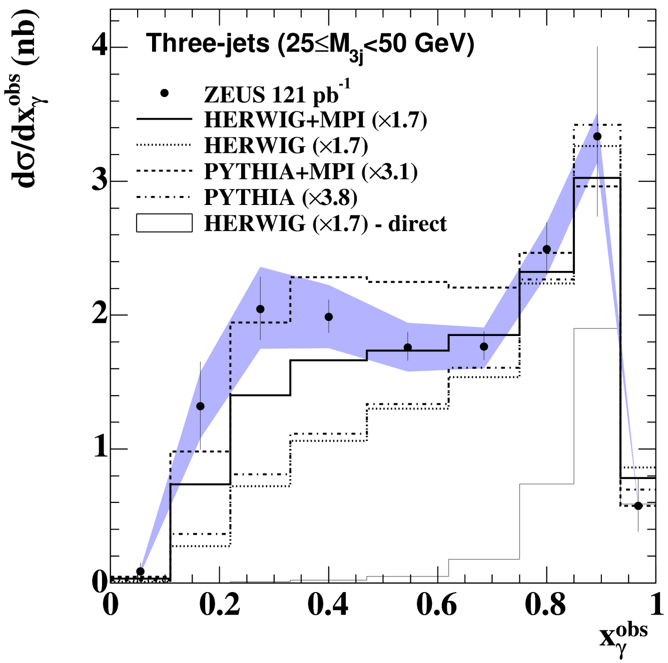


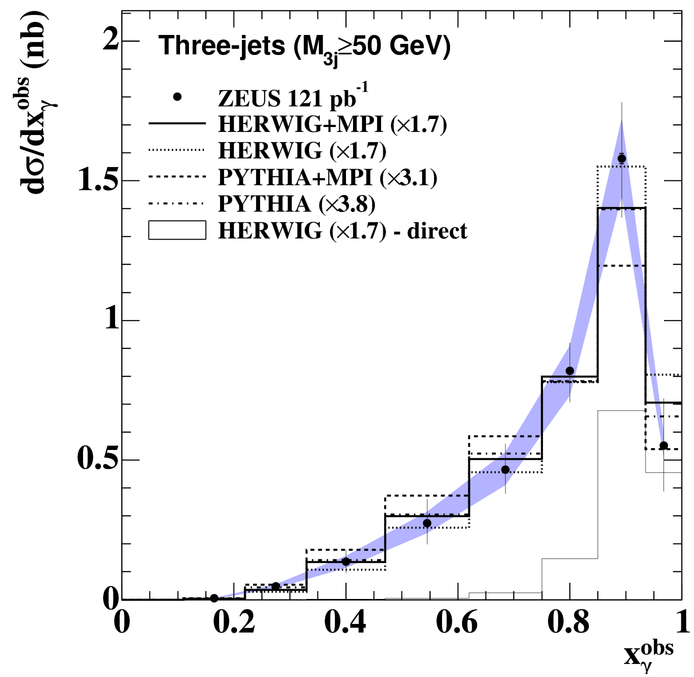


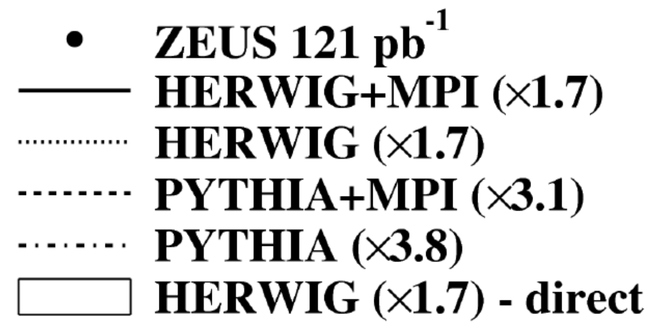
MC w/o MPI is normalized to high mass region (M_nj > 50 GeV)

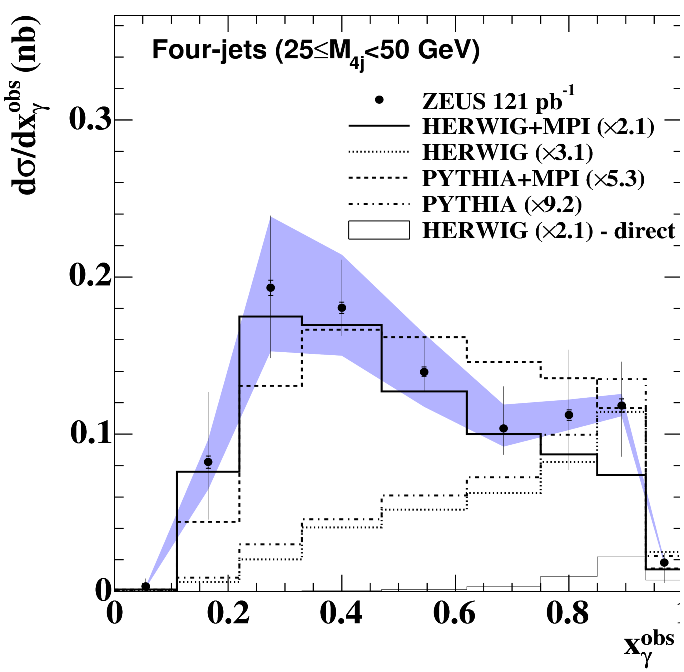
- Low mass data not described without MPI's
  - → Most significant for 4-jet scenario
- Inclusion of MPI gives satisfactory description of full mass spectrum

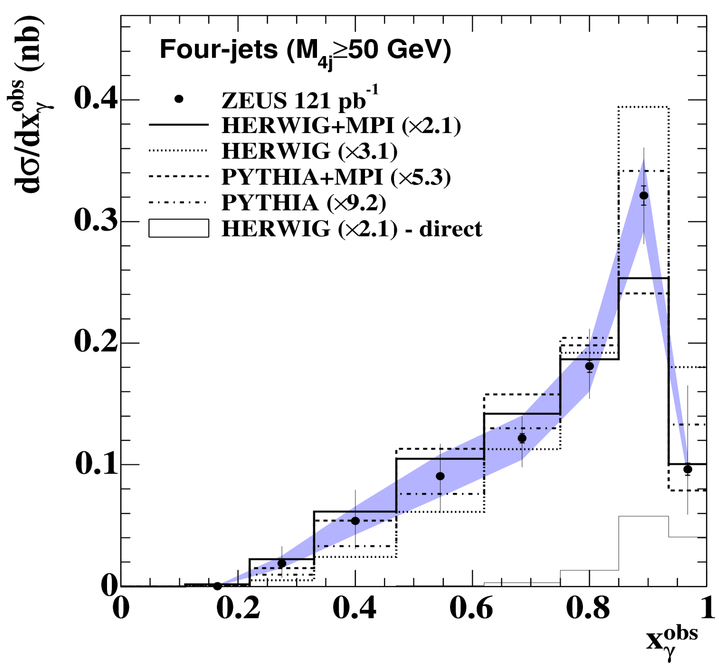
Multijets in Photoproduction (ZEUS)











- MPI again improves MC description of data in low mass region significantly
- High contribution from resolved gamma over the full x_γ range
- Most significant for the 4-jet final state
- PYTHIA+MPI overshoots data at medium x_γ

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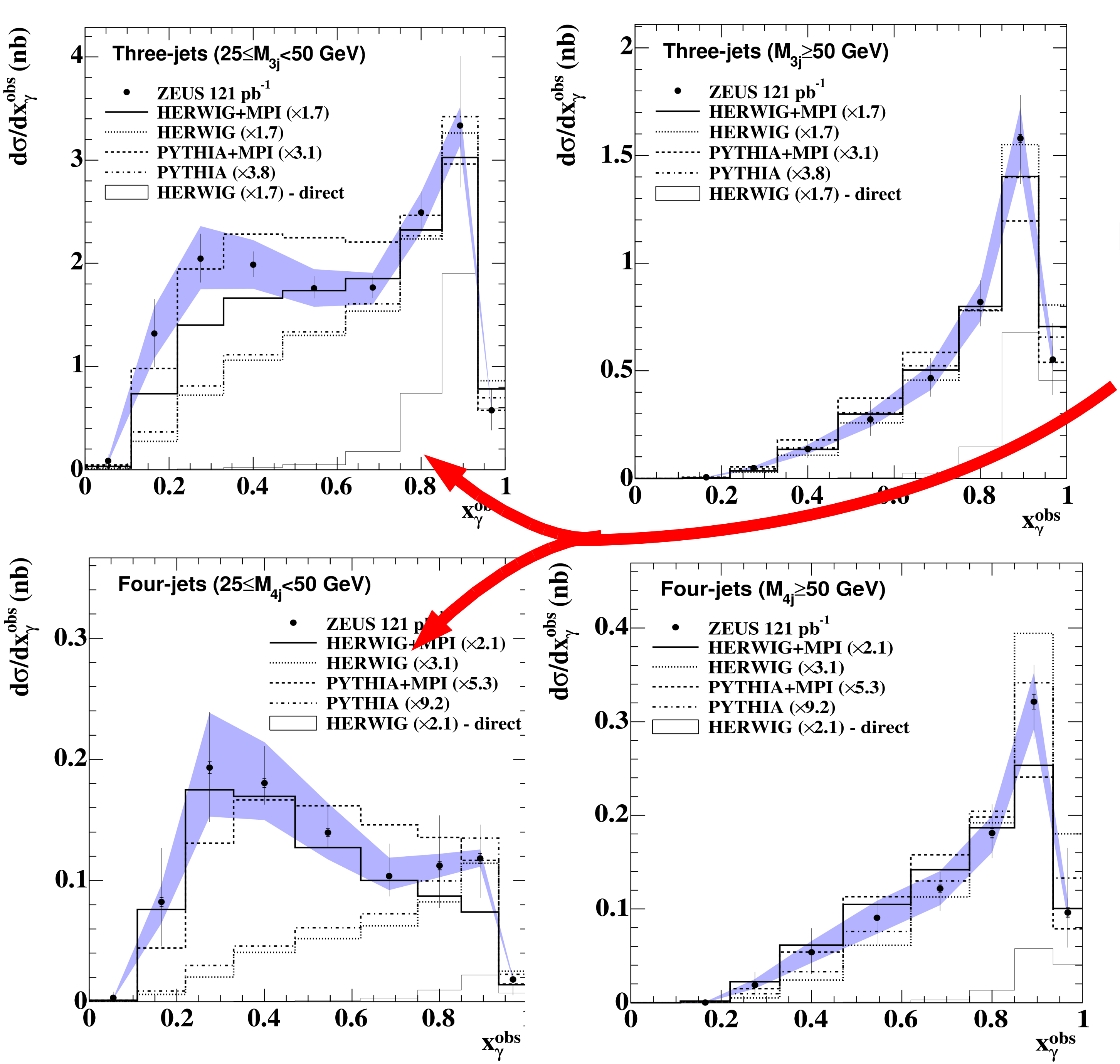

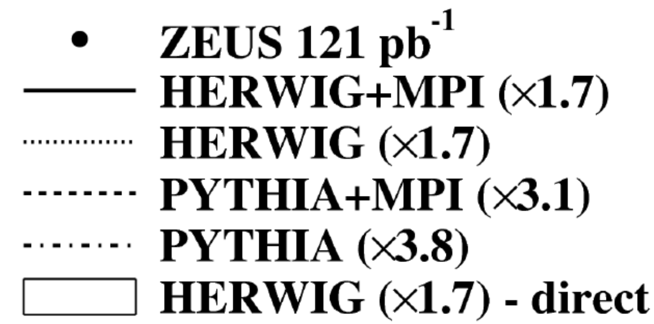

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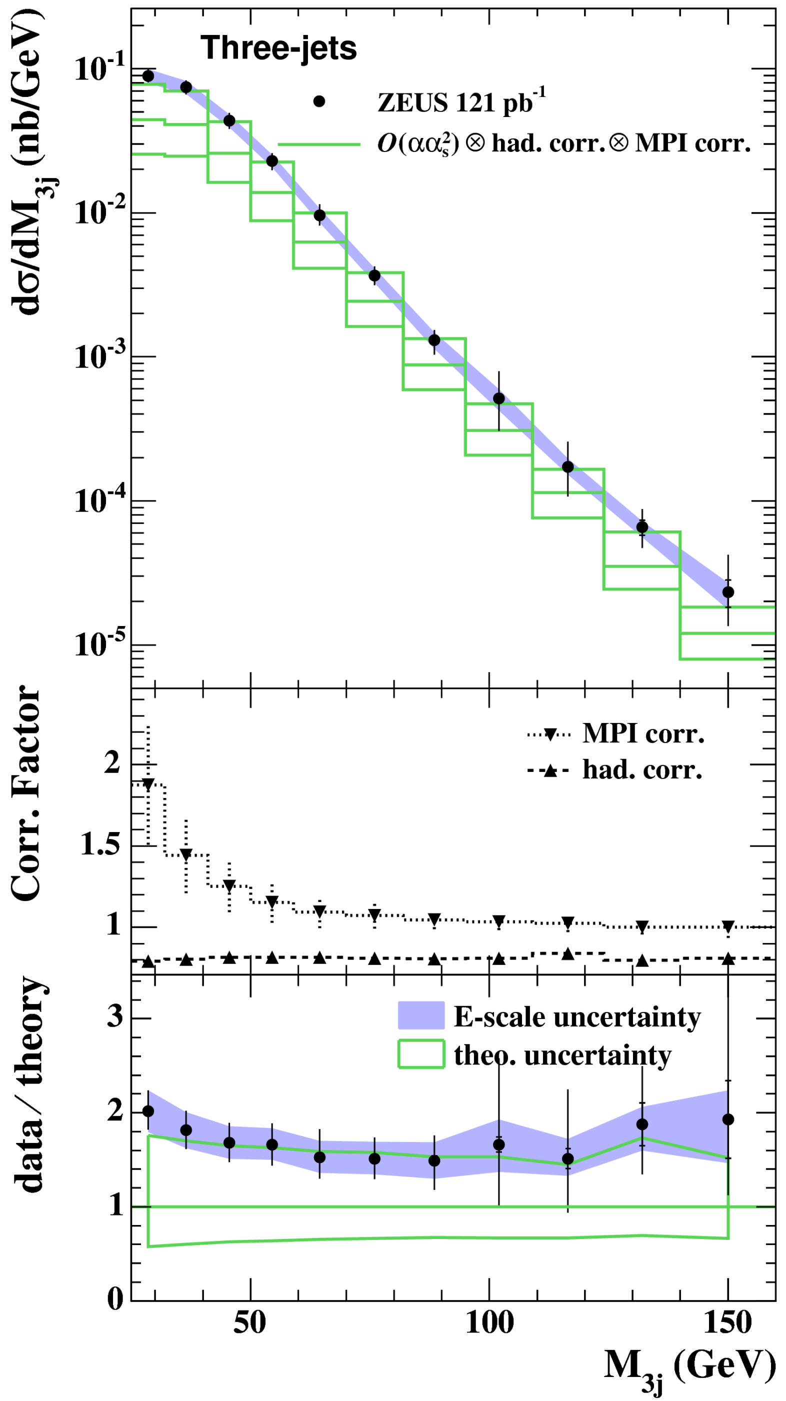
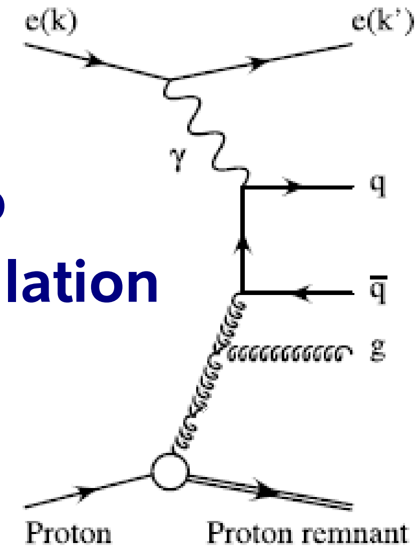


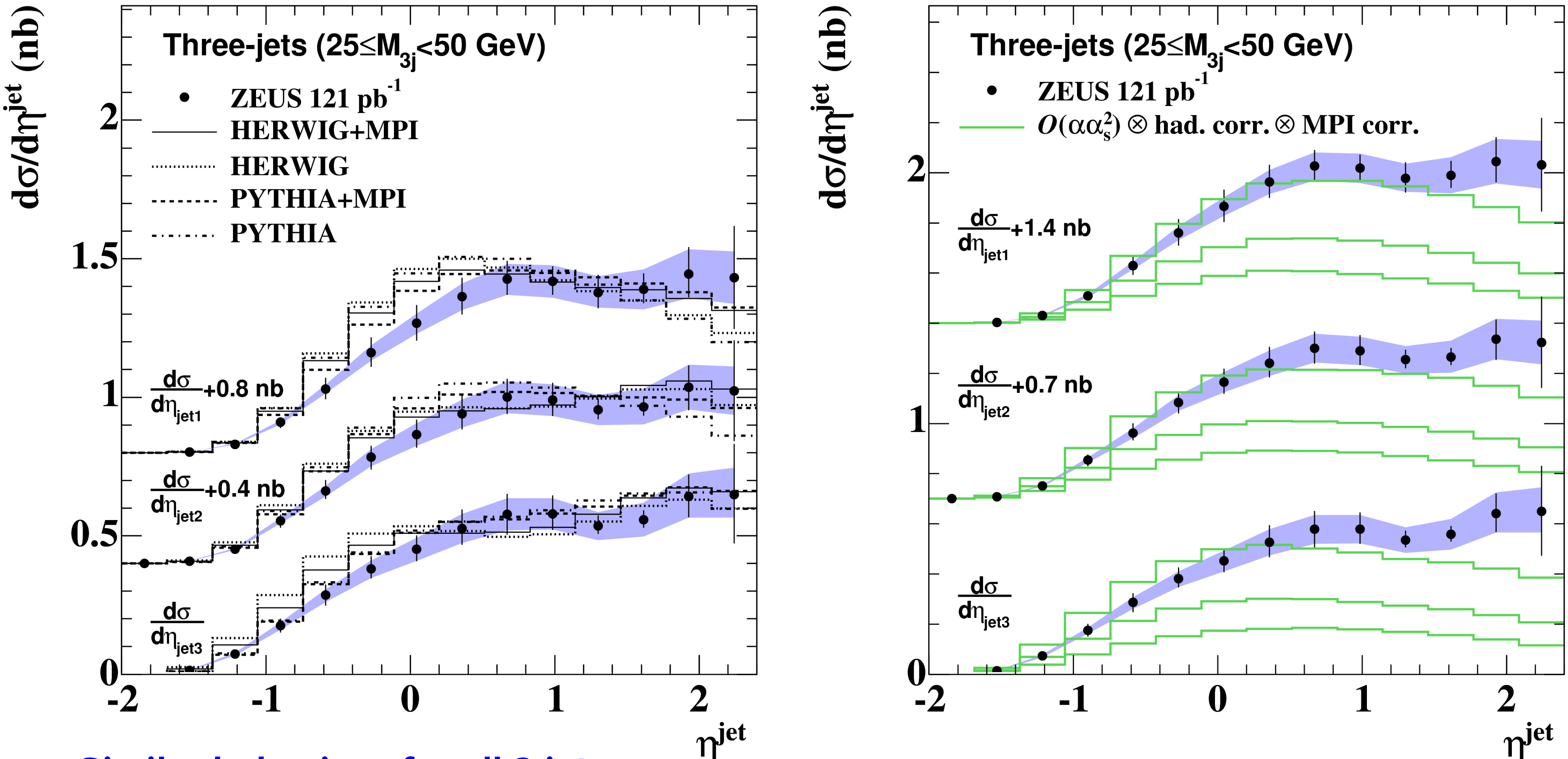
Comparison to
LO $O(\alpha\alpha_s^2)$ calculation



- Hadronization corrections
  - Constant
- MPI corrections
  - Increasing with lower mass
  - Necessary in order to describe data
- Data covered by the large theoretical uncertainties

Multijets in Photoproduction (ZEUS)

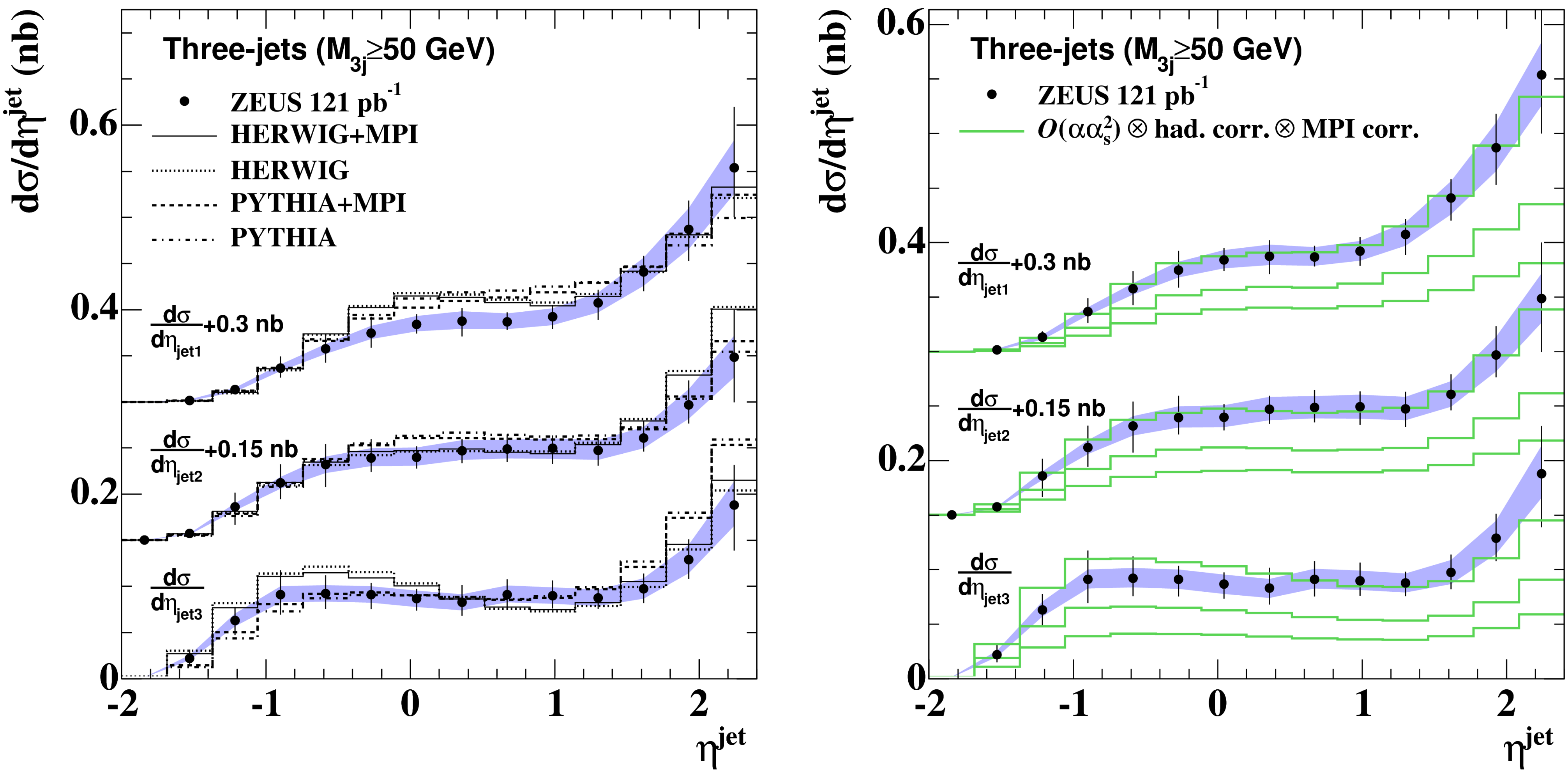
Cross-sections as a function of rapidity for each of the jets (ordered in E_T)



- Similar behaviour for all 3 jets
- No perfect description of data by MC
- Fixed order calculation fails in forward region where higher order reactions are expected to be most prominent

Multijets in Photoproduction (ZEUS)

Cross-sections as a function of rapidity for each of the jets (ordered in E_T)



- Higher mass ⟶ higher order reactions kinematically suppressed:
  - ➔Slightly better description by Monte Carlo with ME+PS compared to low M_nj region
  - ➔Much better description of data by $O(\alpha\alpha_s^2)$ -calculations compared to low M_nj region

Mini jets in DIS (H1)

- Photoproduction → large resolved photon component

  → remnant-remnant interactions (MPI) very important (as seen from the ZEUS results)

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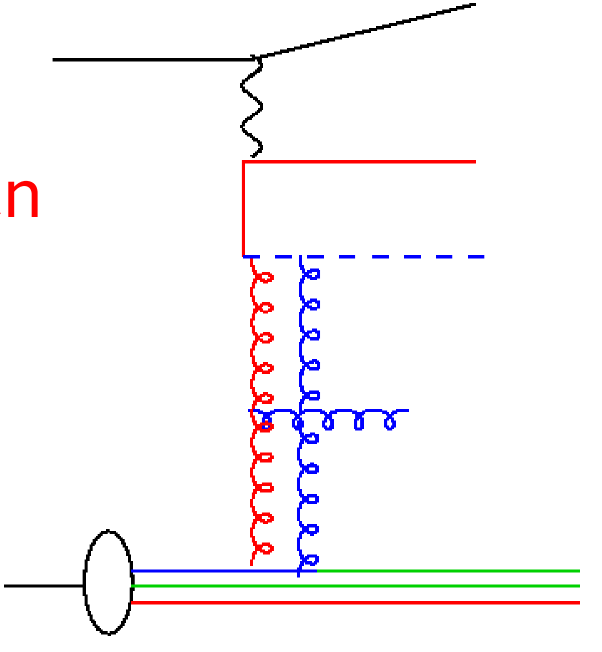
- MPI in DIS where the resolved photon component is much smaller?
  → additional interactions between ME and proton remnant?



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- Photoproduction → large resolved photon component
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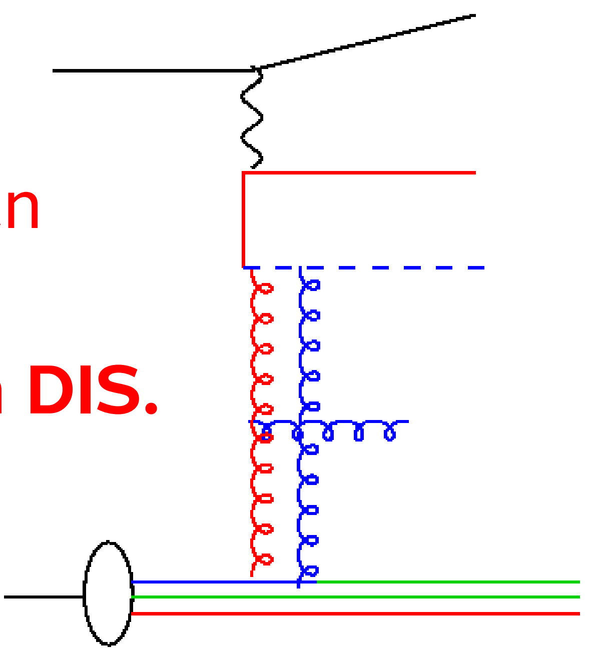
- MPI in DIS where the resolved photon component is much smaller?
  → additional interactions between ME and proton remnant?
  → **Study mini jet production in DIS.**



Mini jets in DIS (H1)

Kinematic Range

- $5 < Q^2 < 100.0\ \mathrm{GeV}^2$
- $0.1 < y < 0.7$
- $W > 200\ \mathrm{GeV}$

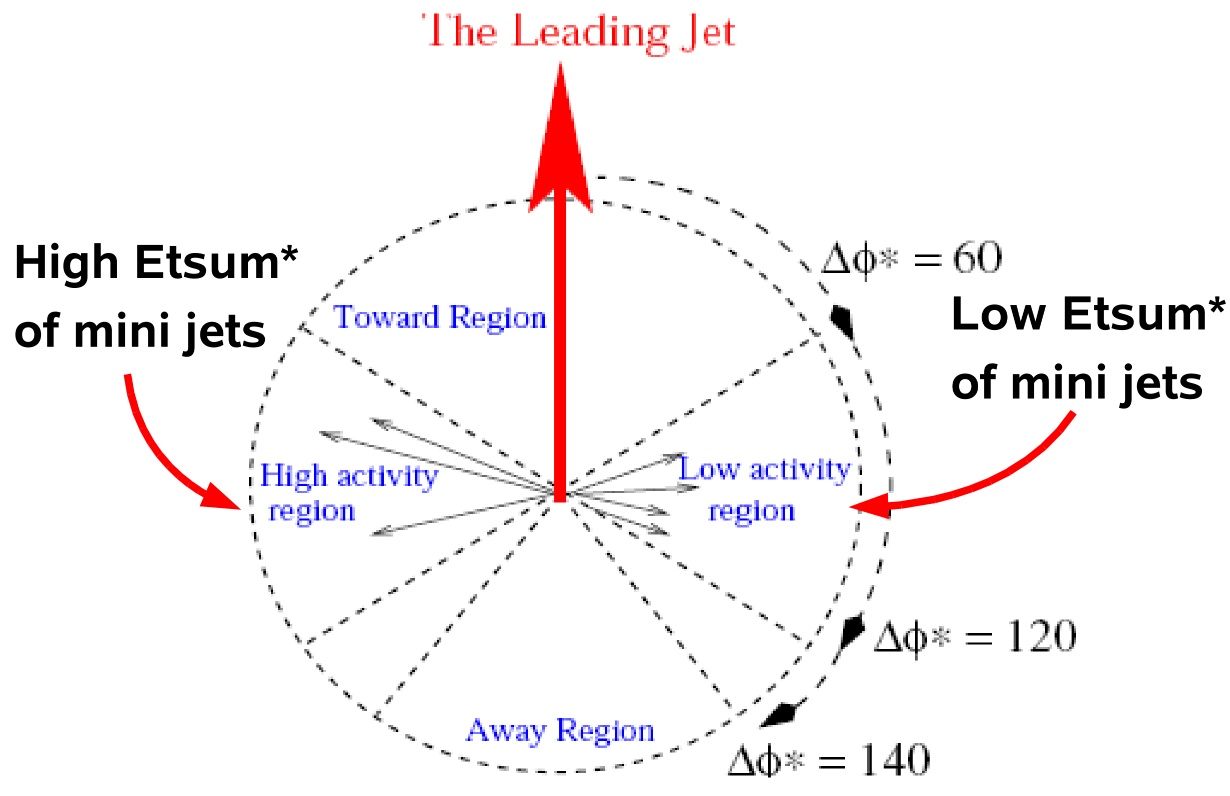
Jet Selection

2 samples: Inclusive 1-jet sample and di-jet sample:

- $P_{T,1(2)}^{jet} > 5\ \mathrm{GeV}$
- $-1.79 < \eta_{1(2)}^{jet} < 2.79$
- $|\phi_1^* - \phi_2^*| > 140$

Mini Jet Selection

- $-1.79 < \eta^{minijet} < 2.79$
- $P_T^{minijet} > 3\ \mathrm{GeV}$



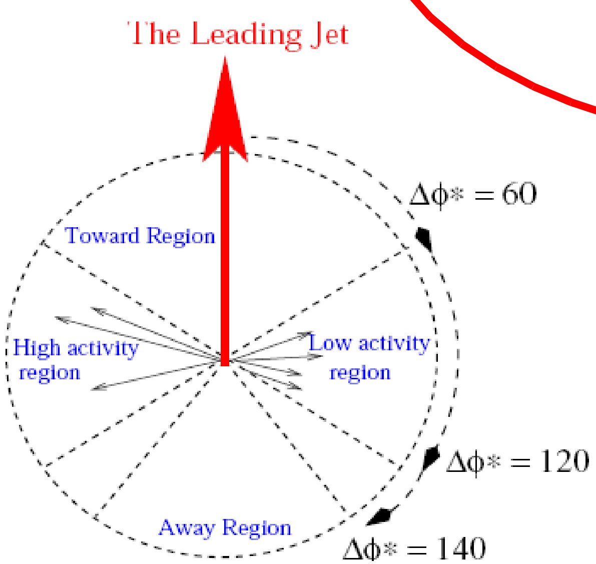
Measure $< N_{Minijets} > = \frac{\sum^{N_{events}} N_{Minijet}}{N_{events}}$ **in bins of** Q^2 **and** η_1^{jet} **as a function of** $P_{T,1}^{jet*}$

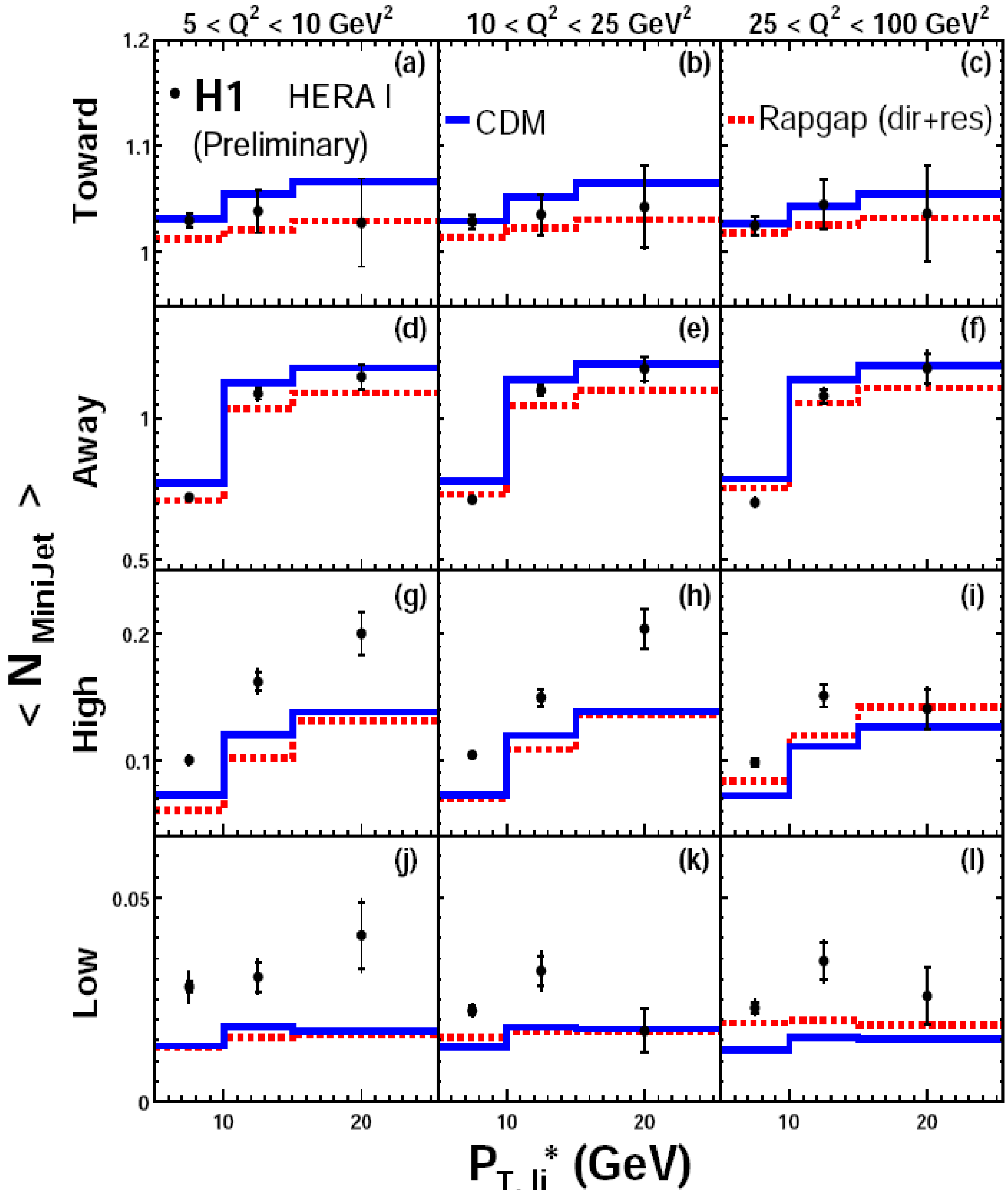
Mini jets in DIS (H1)

Inclusive 1 jet sample
and
$$-1.7 < \eta^{jet} < 0.5$$

•**Hard regions (toward and away) described by MC without MI**

•**Models without MI fails in transverse regions**





Mini jets in DIS (H1)

Inclusive 1 jet sample

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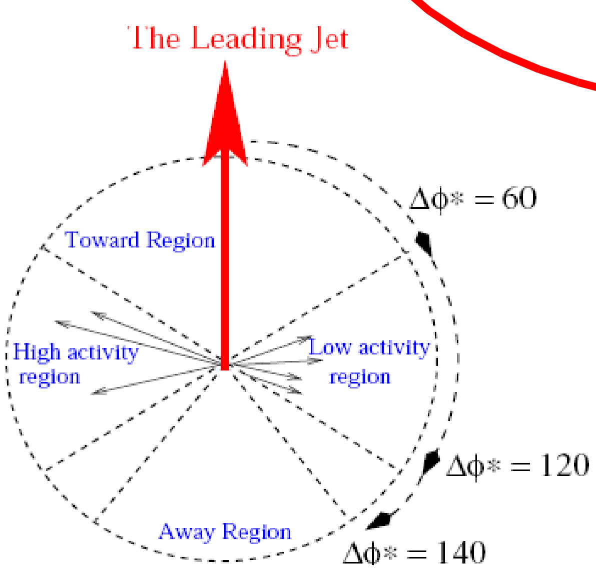
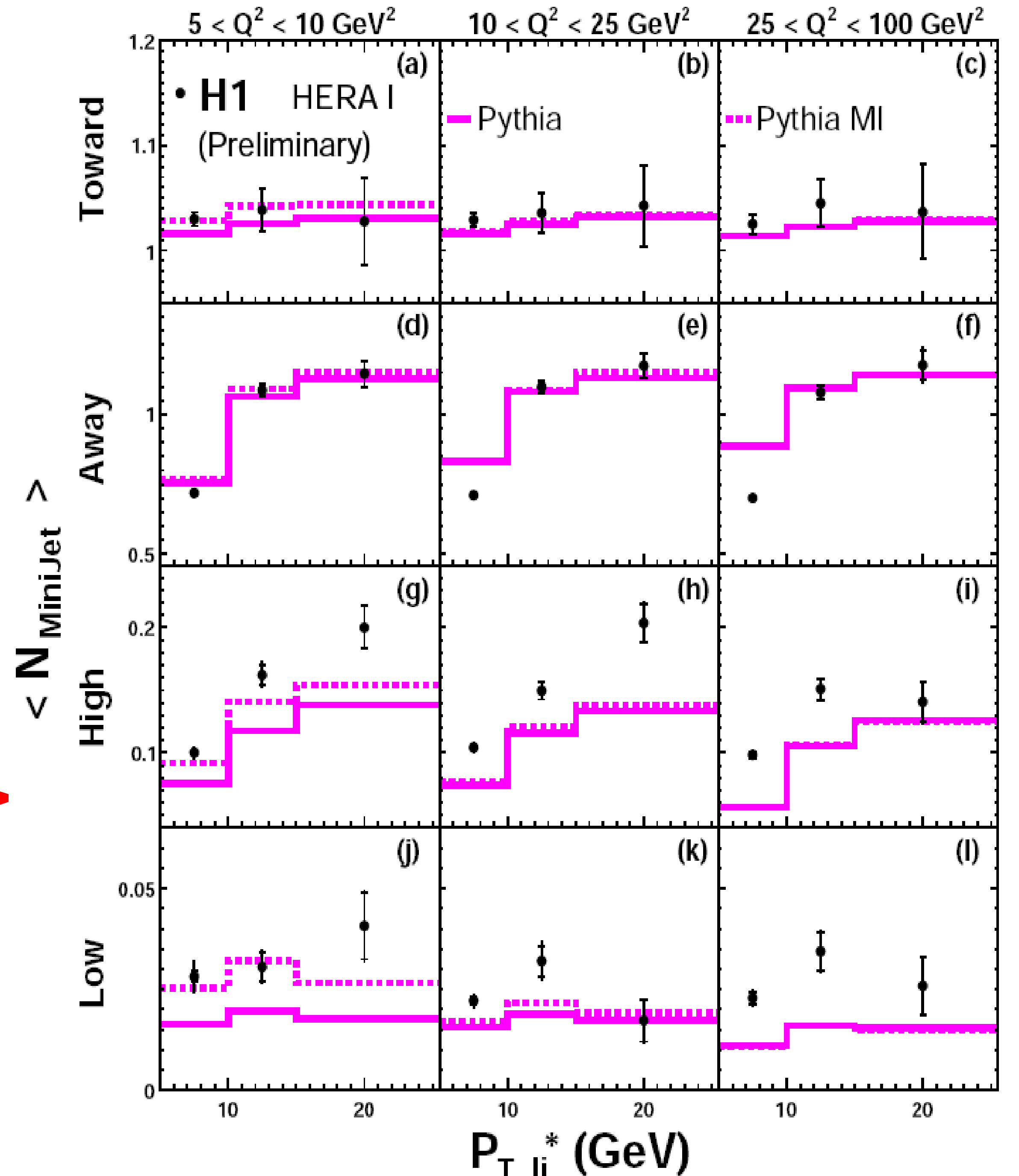
Pythia with MPI does slightly better at low Q2
(lower Q2 -> more res. photon)





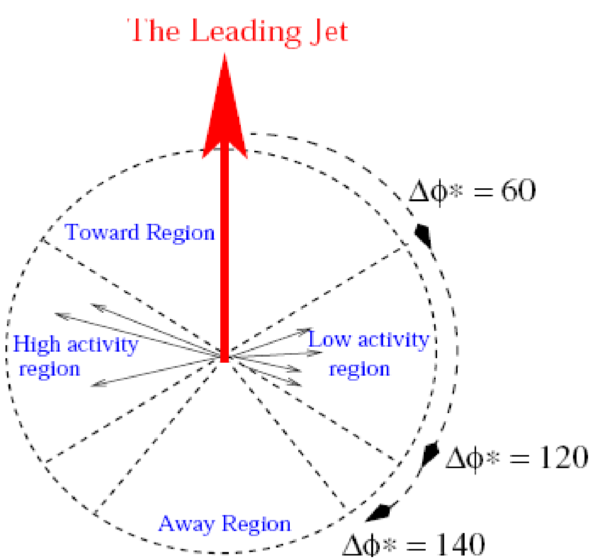
Mini jets in DIS (H1)

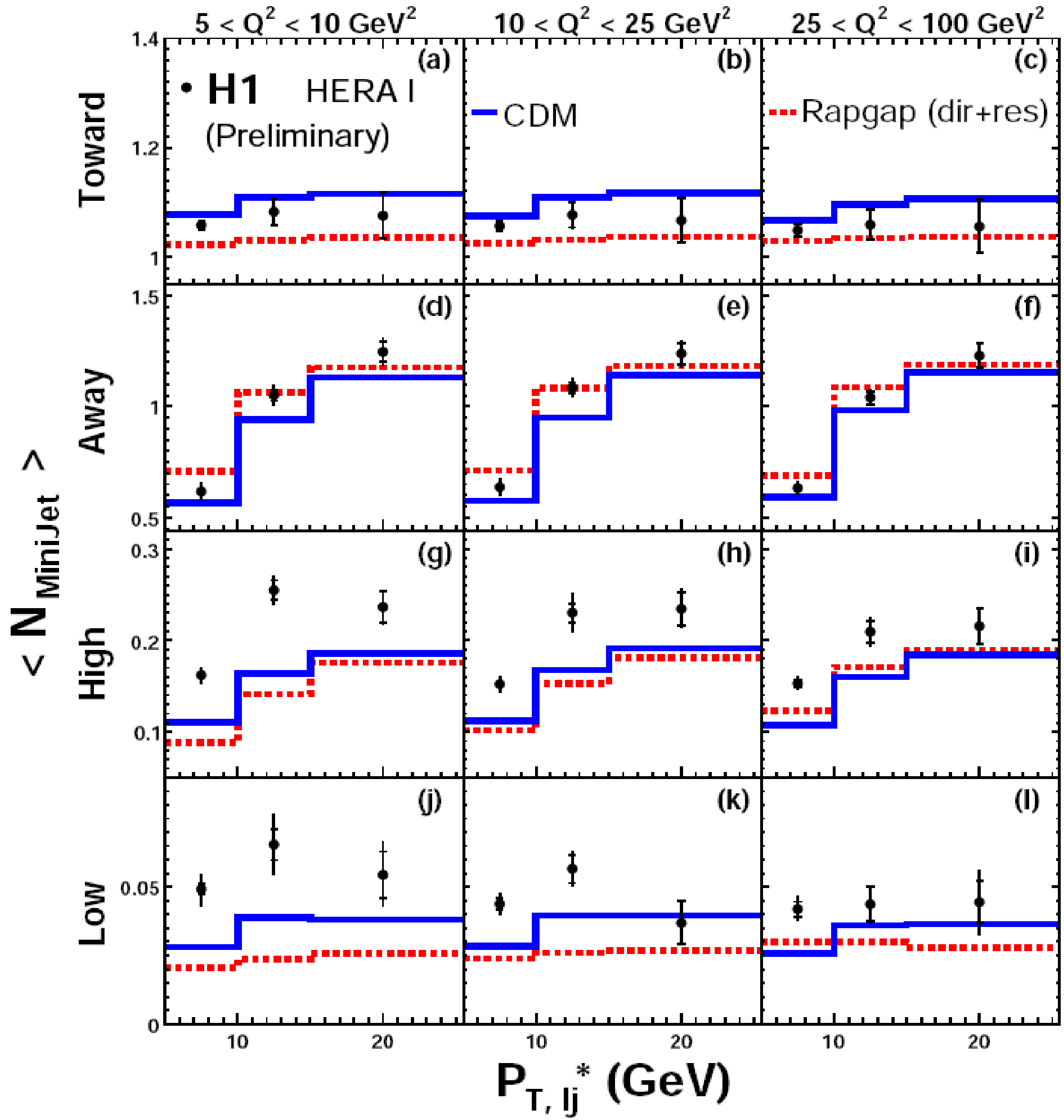
Inclusive 1 jet sample

and

$$0.5 < \eta^{jet} < 2.79$$

- **More activity in transverse regions compared to event sample with leading jet in central region**
- **Again, more transverse activity in data compared to MC**





Mini jets in DIS (H1)

Inclusive 1 jet sample

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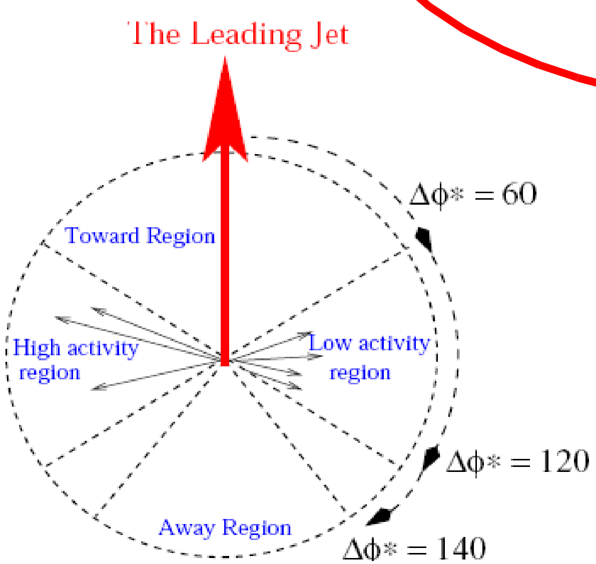
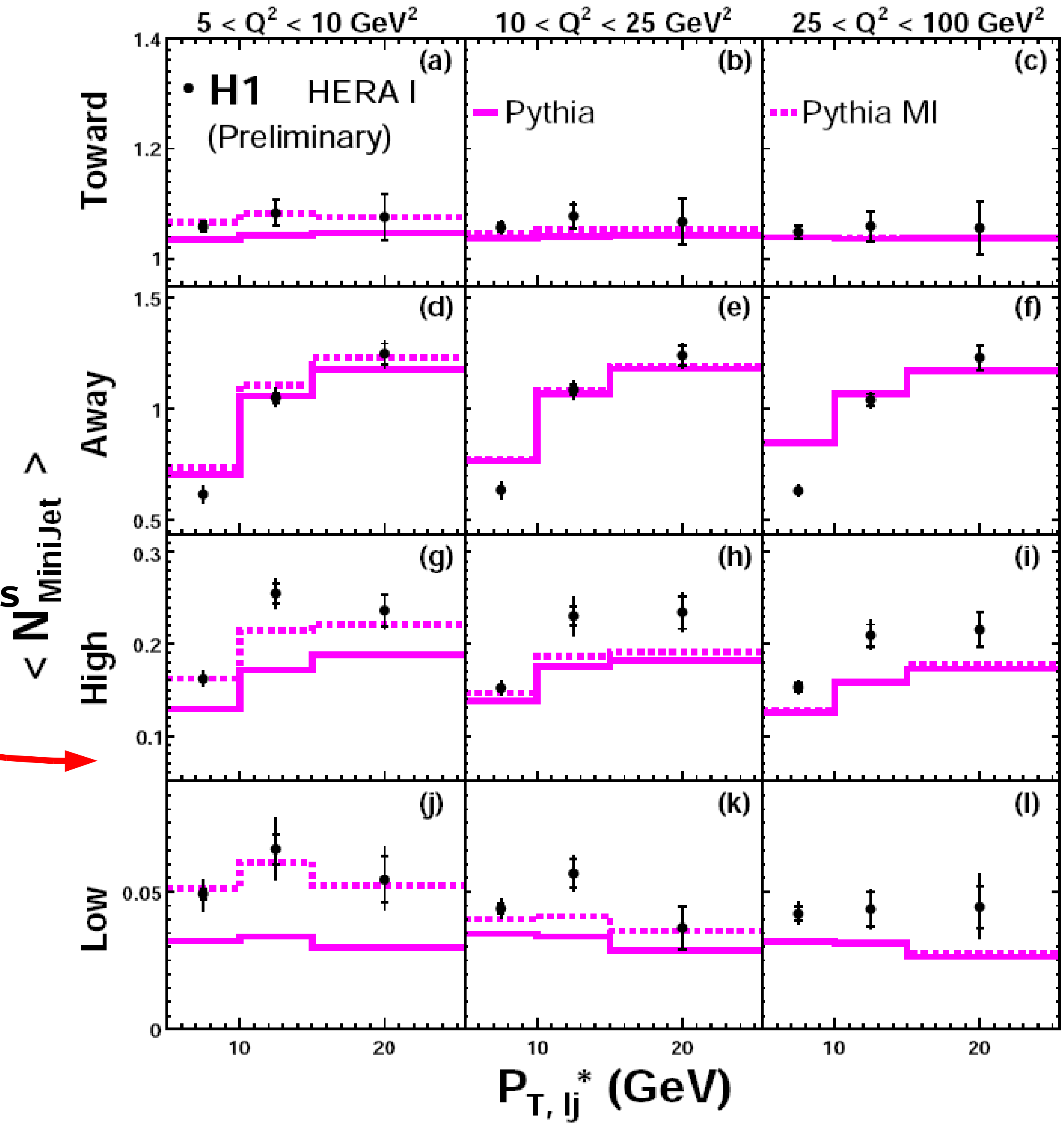
- **Again, activity from MPI improves description of data at low Q2 in transverse regions**





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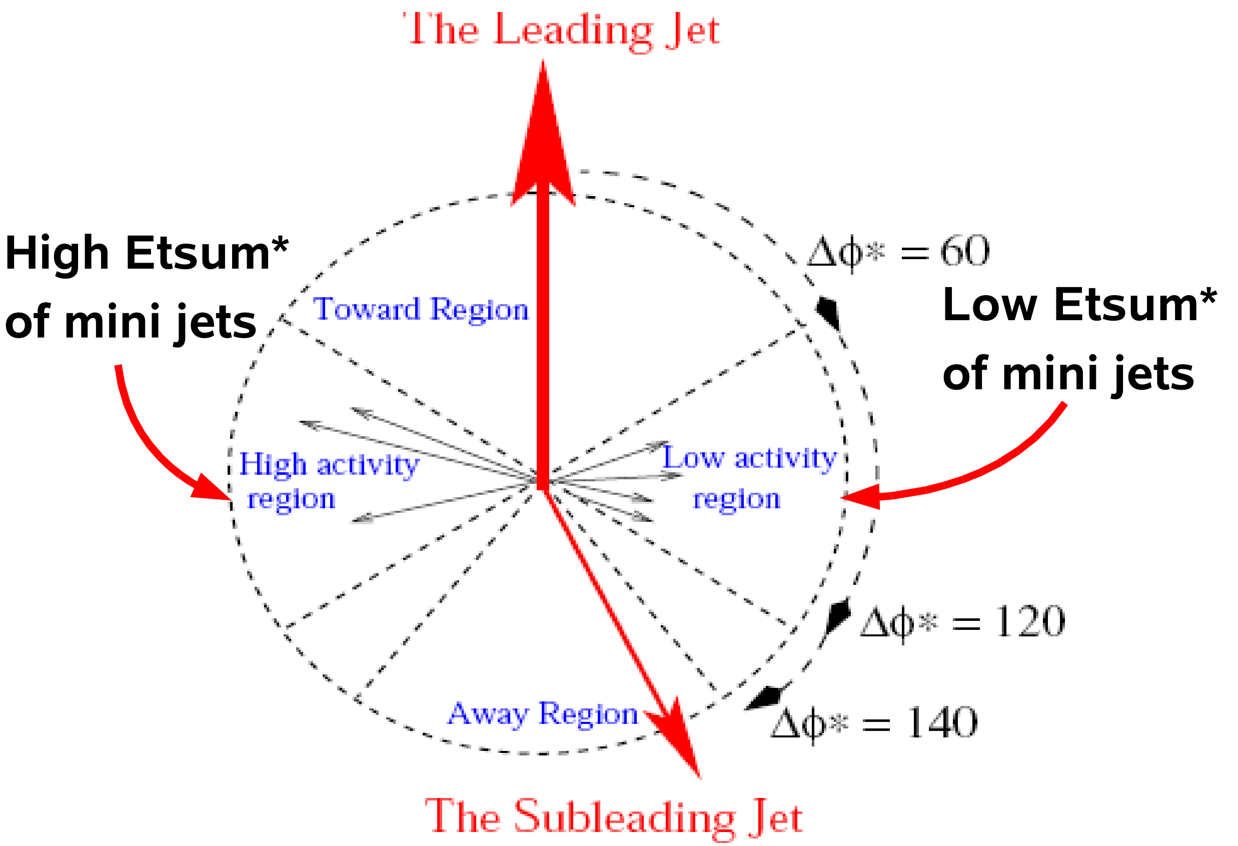

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x_γ **and as a function of** $P_{T,1}^{jet*}$

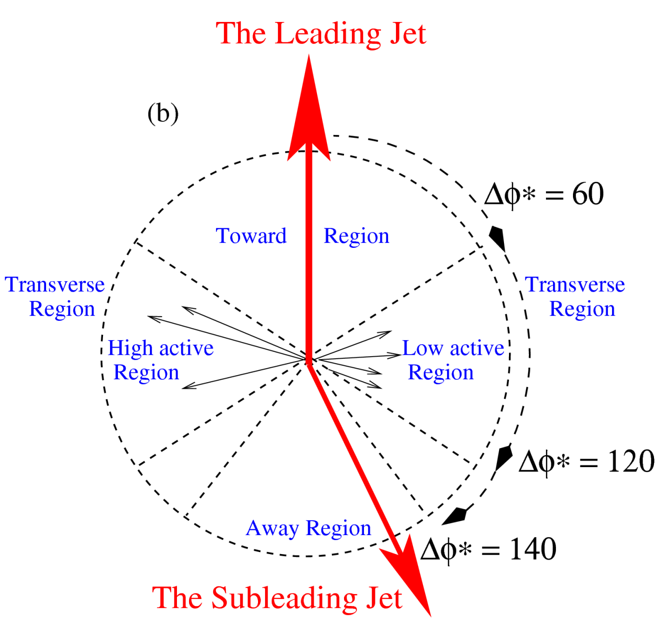
Mini jets in DIS (H1)

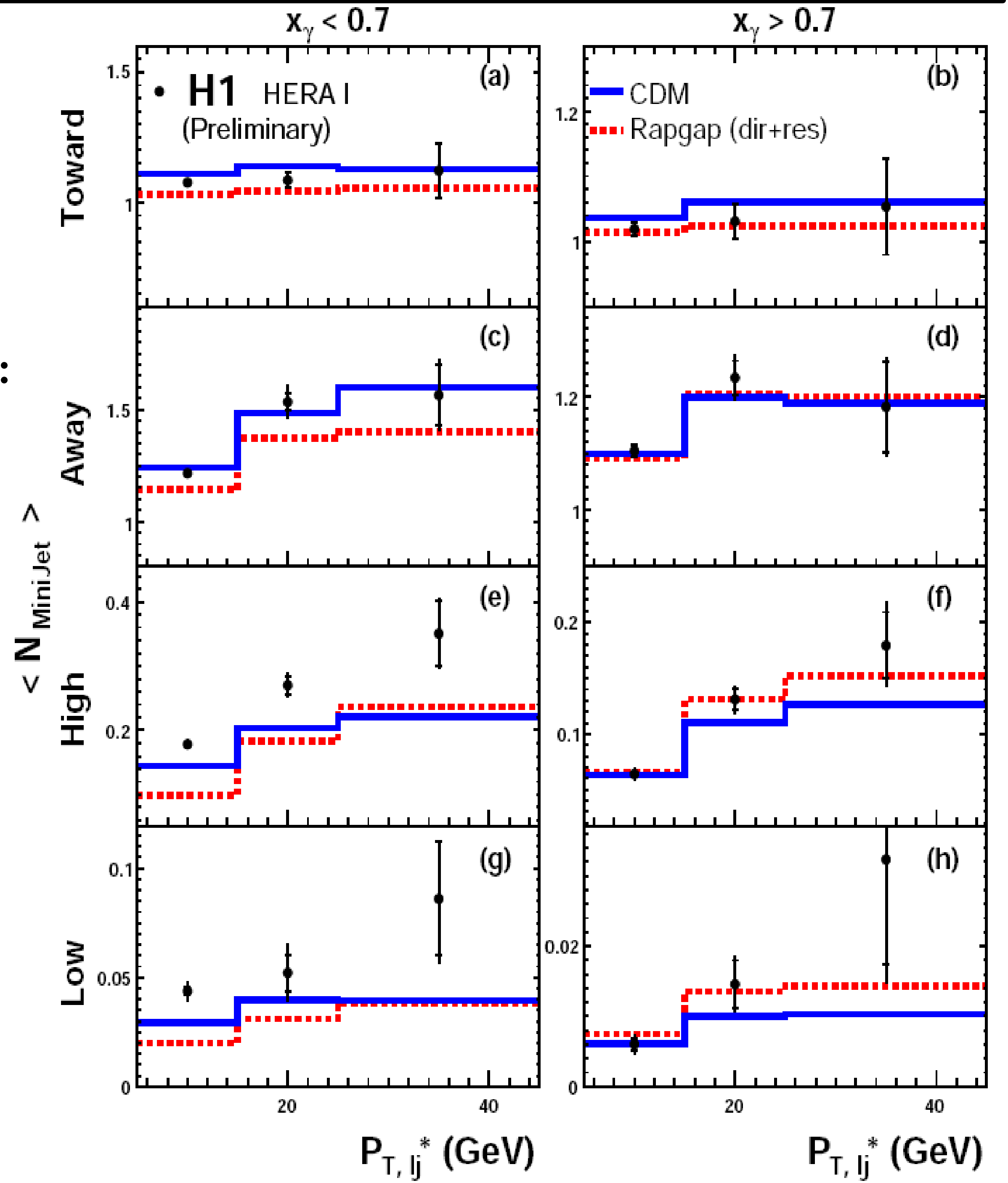
Di-jet sample

$$-1.7 < \eta^{jet} < 2.79$$

- **Same behaviour again:**
  - **Hard regions OK**
  - **More resolved photon (low x_γ):**

    → CDM or RAPGAP not enough activity in transverse regions



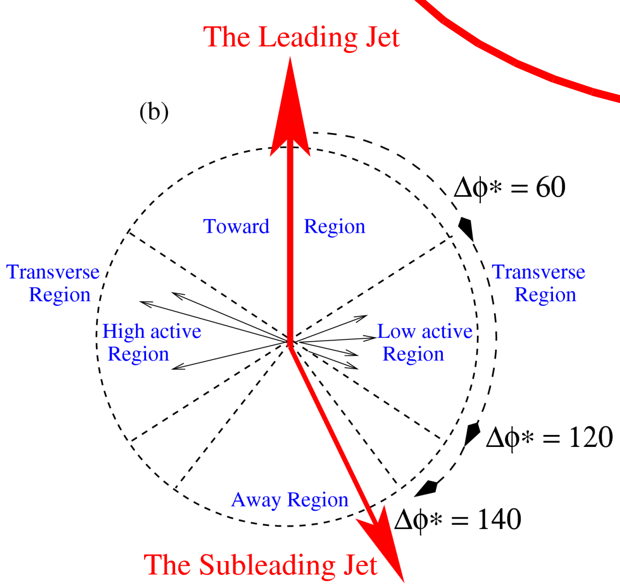


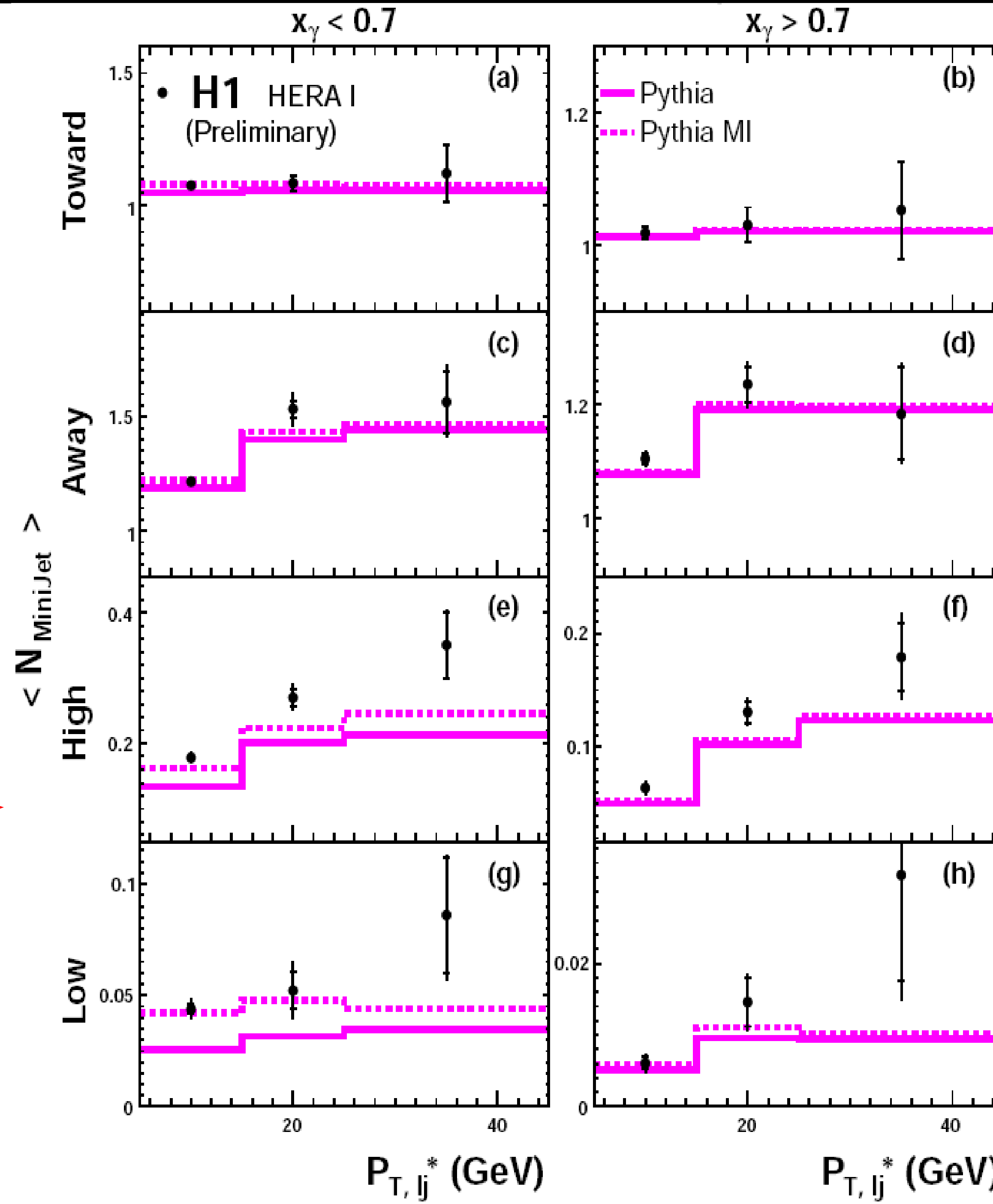
Mini jets in DIS (H1)

Di-jet sample

$$-1.7 < \eta^{jet} < 2.79$$

And again… MI improves, but not satisfactory





Summary

ZEUS - 3- and 4-jet cross-sections in photoproduction:

- $O(\alpha\alpha_s^2)$ calculation:
    - ***Describes 3-jet mass spectrum***
    - ***Describes 3-jet rapidity distributions in high mass region, but fails at low mass***
    - ***Large theoretical uncertainty***
    - ***MPI corrections large and needed to describe data***
- LO ME+PS Monte Carlo:
    - ***MPI needed to describe data. Most relevant for low M_nj and the 4-jet final state***
    - ***No perfect description of jet rapidity distributions***

H1 - Mini jet production in DIS:

- LO ME+PS Monte Carlo *without* MPI:
    - ***Describes mini jet multiplicity in hard regions***
    - ***Not enough activity in transverse regions***
- LO ME+PS Monte Carlo *with* MPI:
    - ***Including MPI improves description of data where res. γ contribution is large***
    - ***Remaining regions still need more activity to describe data***