Multiparton Interactions at HERA

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Ringberg Workshop 5-10/10 2008

New Trends in HERA physics

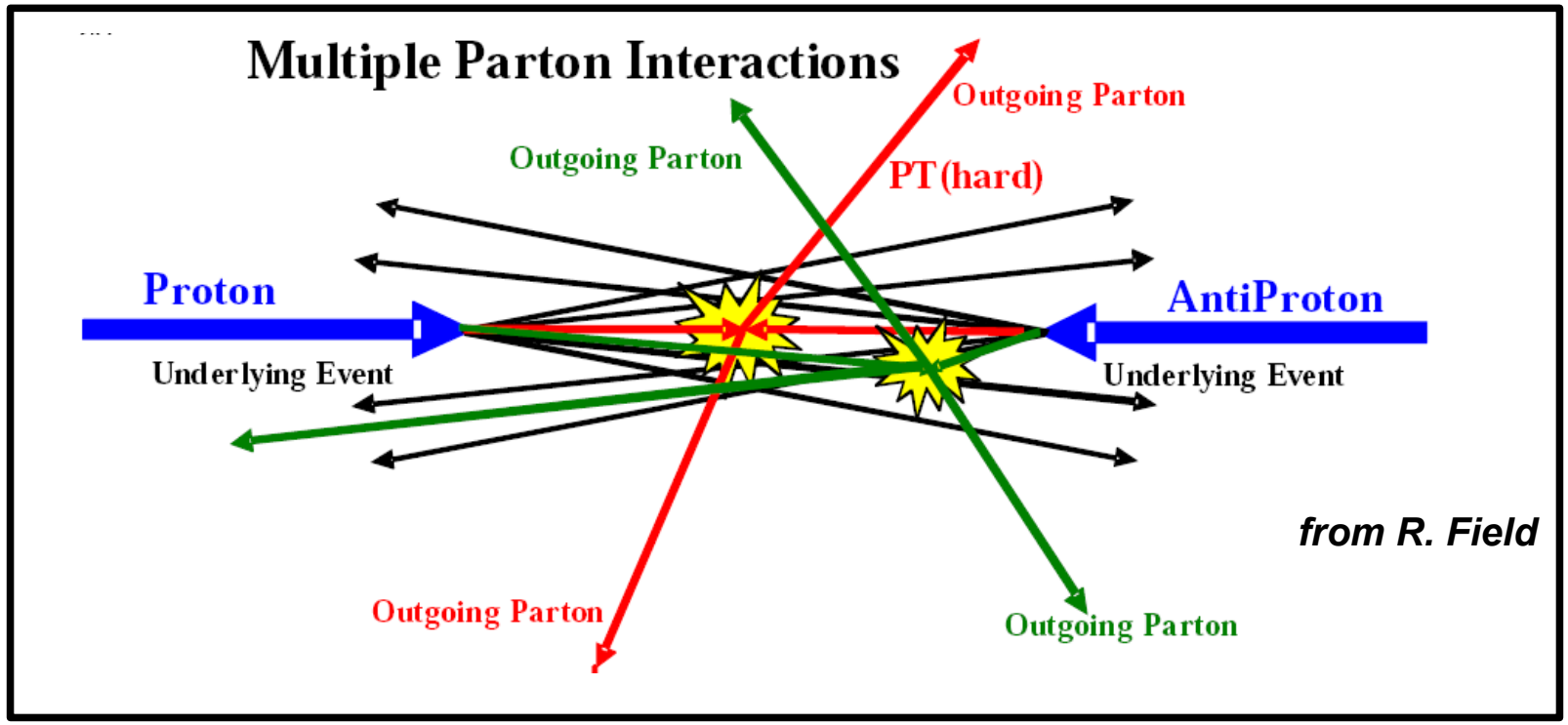
Outline

- Short Intro to Multiparton Interactions
- Short Summary of Monte Carlo generators
- Measurements
  - MI at HERA > 10 years ago
  - Multijets in photoproduction
  - Charge particle multiplicity in photoproduction
  - Mini-jets in DIS
- Summary

The Underlying Event – not only MI

Everything except the studied LO process:

- Parton showers
- Multiple interactions:
  - Additional remnant-remnant, or parton-remnant, interactions – Soft or Hard
- ... but not pile up



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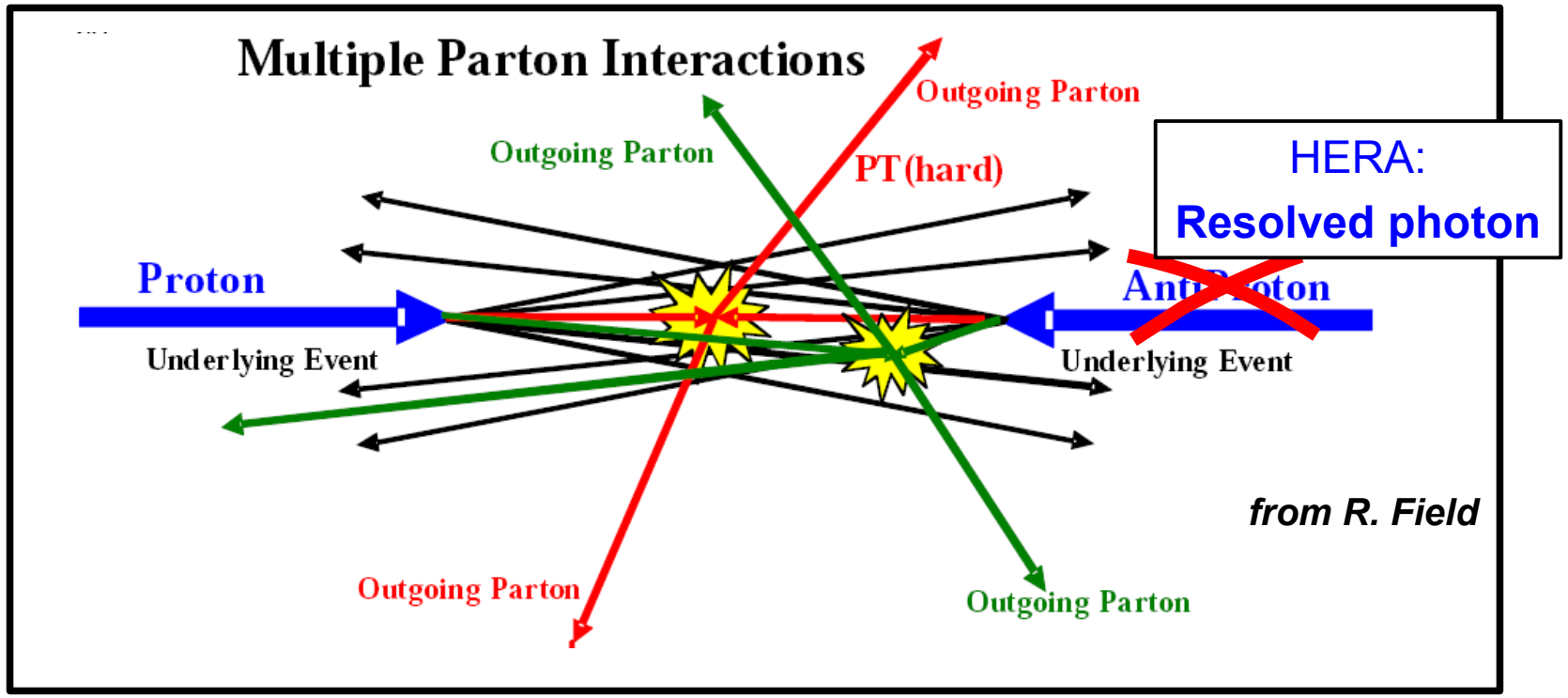
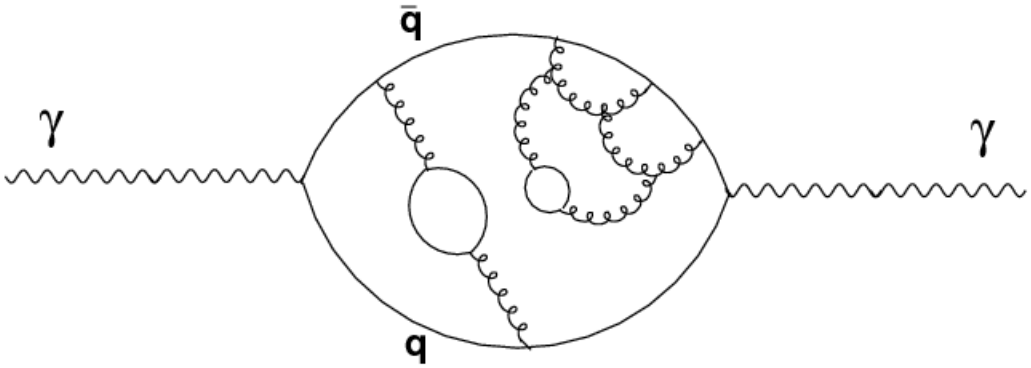


Photon structure

The photon may fluctuate into a quark-anti quark pair, which spans a hadronic-like substructure.



Low photon virtuality Q^2 **→ More long lived photon → Larger resolved component**

Photoproduction: $Q^2 \approx 0\ \mathrm{GeV}^2$ - Almost real photon - High resolved photon component

Can expect remnant-remnant interactions to be favoured in photoproduction.

Fractional momentum of photon carried by the struck parton: x_γ

$$x_\gamma^{\mathrm{OBS}} = \frac{\sum_{i=1}^{N_{jets}} E_{T,i}^{jet} e^{-\eta_i^{jet}}}{2E_\gamma}$$

Handle to separate resolved/direct photon

High x_γ^{OBS} - Direct photon.

Low x_γ^{OBS} - Resolved photon.

Multiparton Interactions

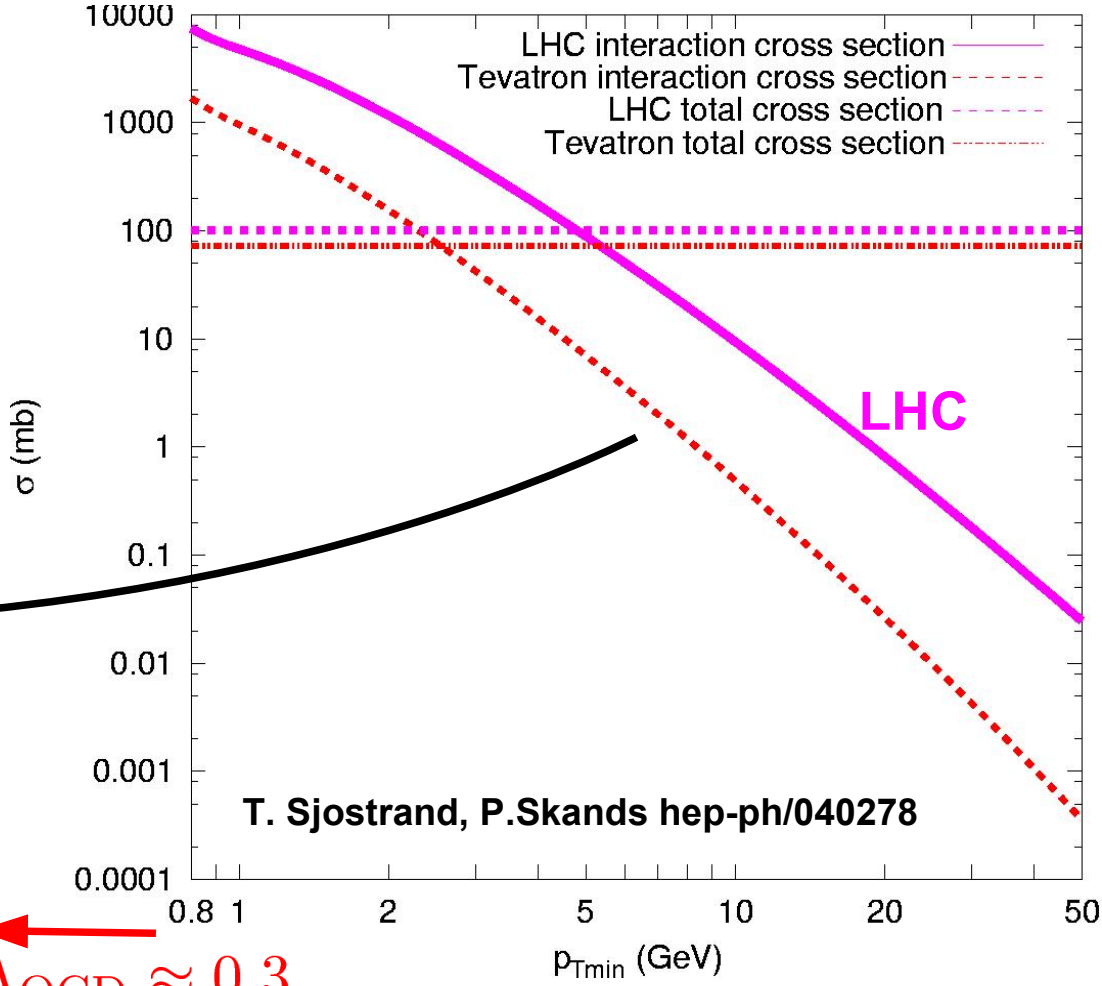
Theoretical motivation

partonic interaction cross-section:

$$\frac{d\sigma_{\rm int}}{dp_T^2} \propto \frac{\alpha_s^2(p_T^2)}{p_T^4}$$

Integrate + cut-off ($p_{T,\rm min}$ ***)***

$$\sigma(p_{T,\rm min}) \propto \frac{1}{p_{T,\rm min}^2}$$



$\Lambda_{\rm QCD} \approx 0.3$

(Expect pQCD still to be valid)

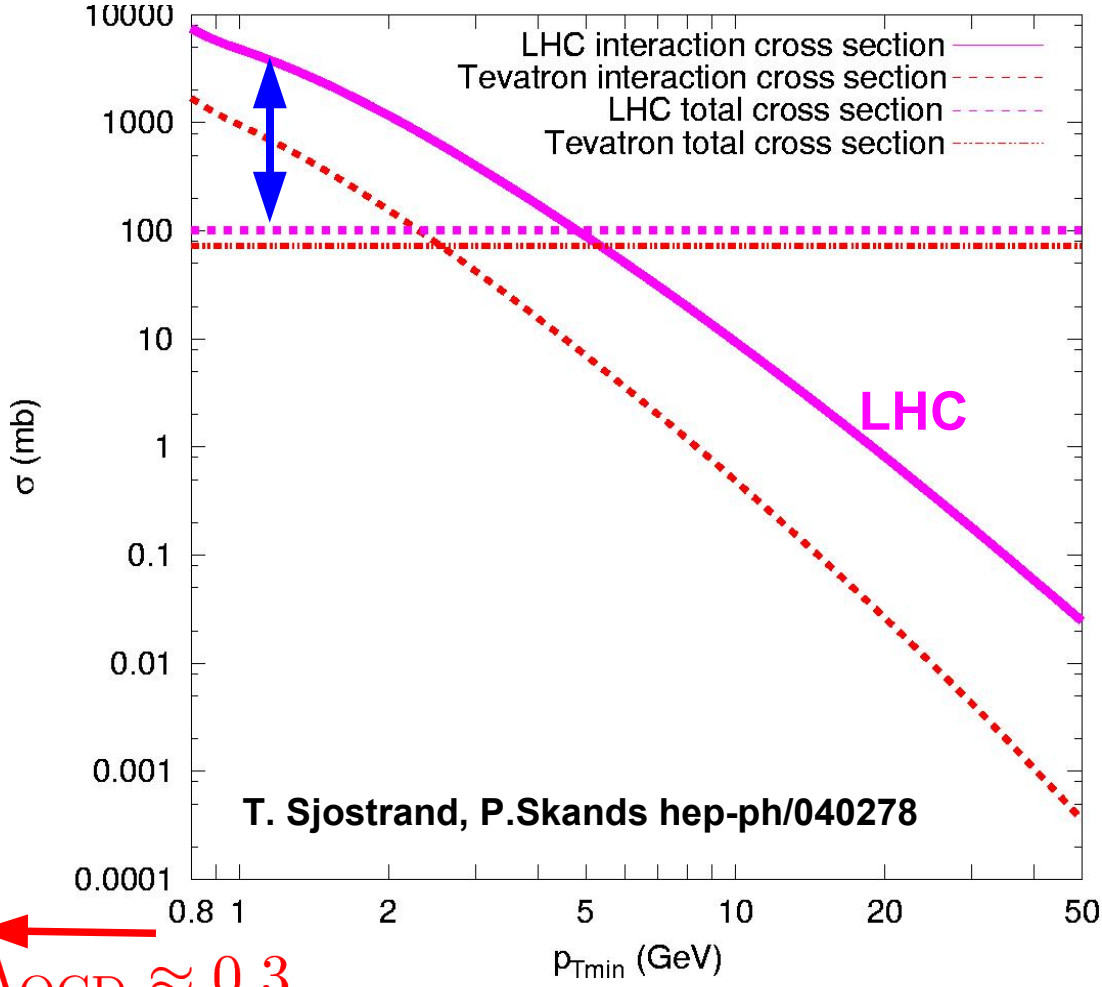
Multiparton Interactions

Theoretical motivation

Interaction x-section > Total x-section

Suggests *Multiple Interactions*

$$< n >= \sigma_{\mathrm{int}} / \sigma_{\mathrm{tot}}$$



$\Lambda_{\mathrm{QCD}} \approx 0.3$

(Expect pQCD still to be valid)

Monte Carlo models with parton showers
(relevant for this presentation)

- *PYTHIA: LO ME + DGLAP parton showers*

  MI:
  - **Average number of interactions/event=** $\sigma_{\mathrm{hard}}(p_{\mathrm{t,\ min}})/\sigma_{\mathrm{non\text{-}diff}}$
  - **Several free parameters:** **Different tunes exist. Here the default parameters are used.**

- *HERWIG*: LO ME + DGLAP parton showers

  MI from JIMMY:
  - **MI add on package used with HERWIG**
  - **Similar to MI in Pythia**
  - **Impact parameter dependence**

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

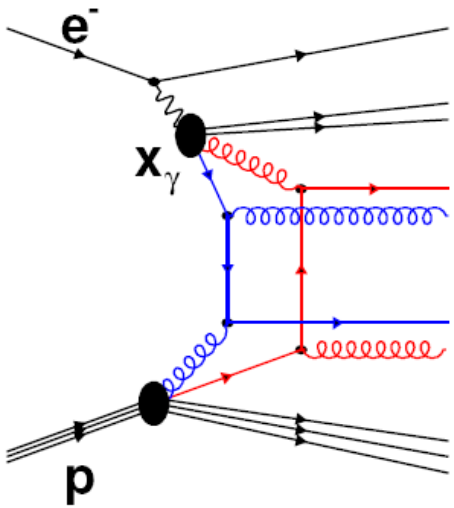
- *CDM*: Parton showers from the Color Dipole Model (No MI).
  QPM and BGF events from LO ME.

Multiple Interactions

Typical experimental signals

- Hard MI

Multi jet events



→ New results in Photoproduction at HERA.

- Soft MI

Additional soft jets or charged particles

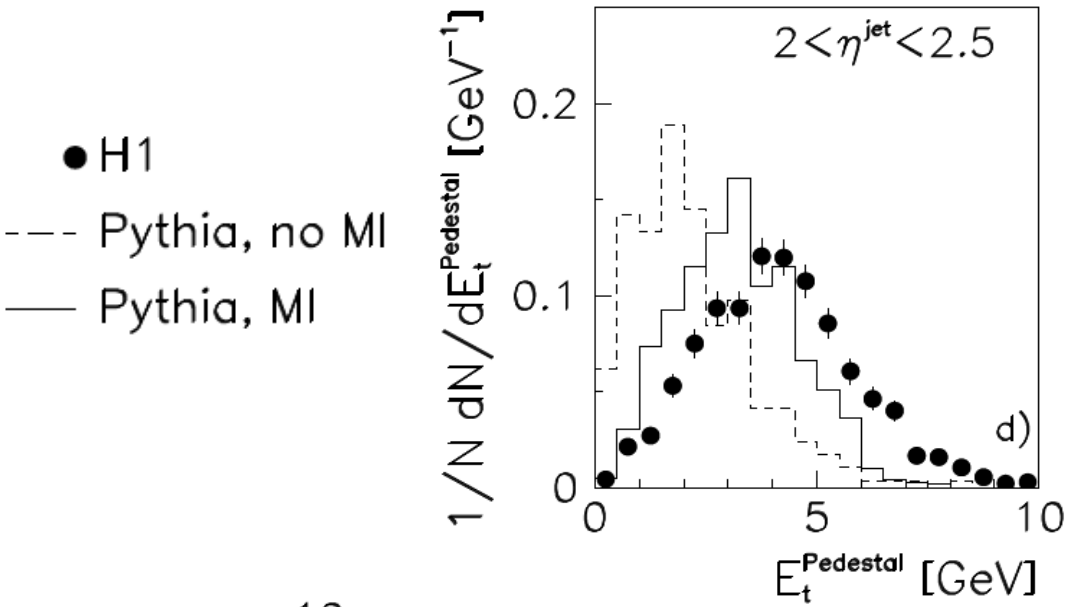
→ New results in Photoproduction and DIS at HERA.

MI @ HERA > 10 years ago

MI studies at HERA > 10 years ago

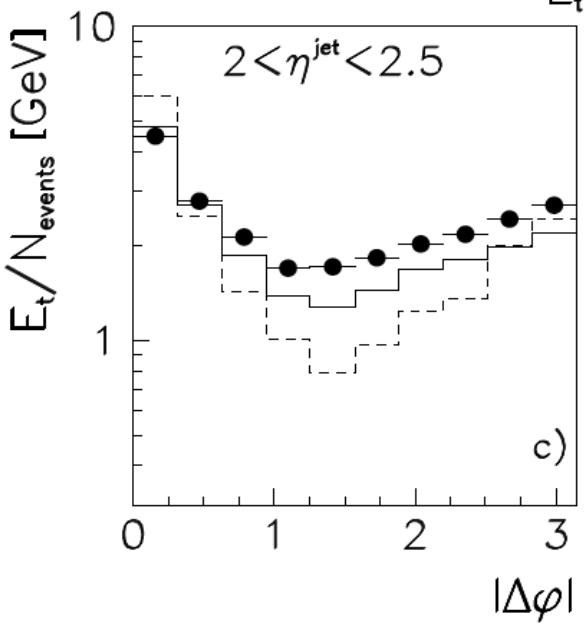
Trend at HERA may be new, but there is also older measurements:

H1 Collaboration (T. Ahmed et al.), Nucl.Phys.B445:195-218,1995
"Inclusive Parton Cross Sections in Photoproduction and Photon Structure"



Particle flow outside the jet cone.

Underlying event pedestal increased Et



Transverse energy flow.

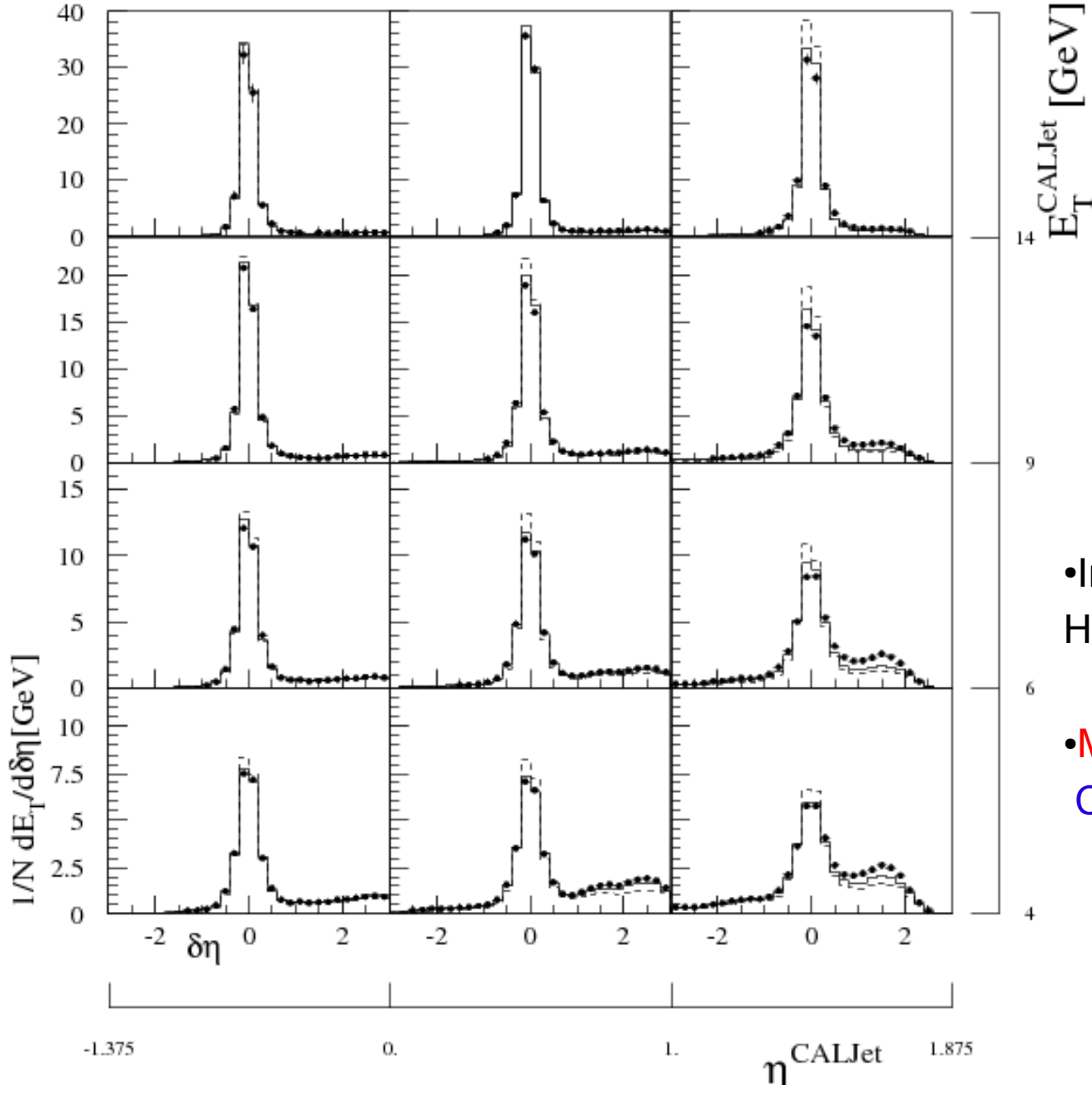
$$|\Delta\phi| = |\phi^{\mathrm{Jet}} - \phi^{\mathrm{Cell}}|$$

$$|\Delta\eta| < 1$$

UE most prominent transverse to the leading jet.

MI studies at HERA > 10 years ago

ZEUS Collaboration (J. Breitweg et al.), Eur.Phys.J.C1:109-122,1998



Transverse energy flow in photoproduction in bins of jet Et and jet rapidity

- ZEUS
- HERWIG no MI
- HERWIG MI

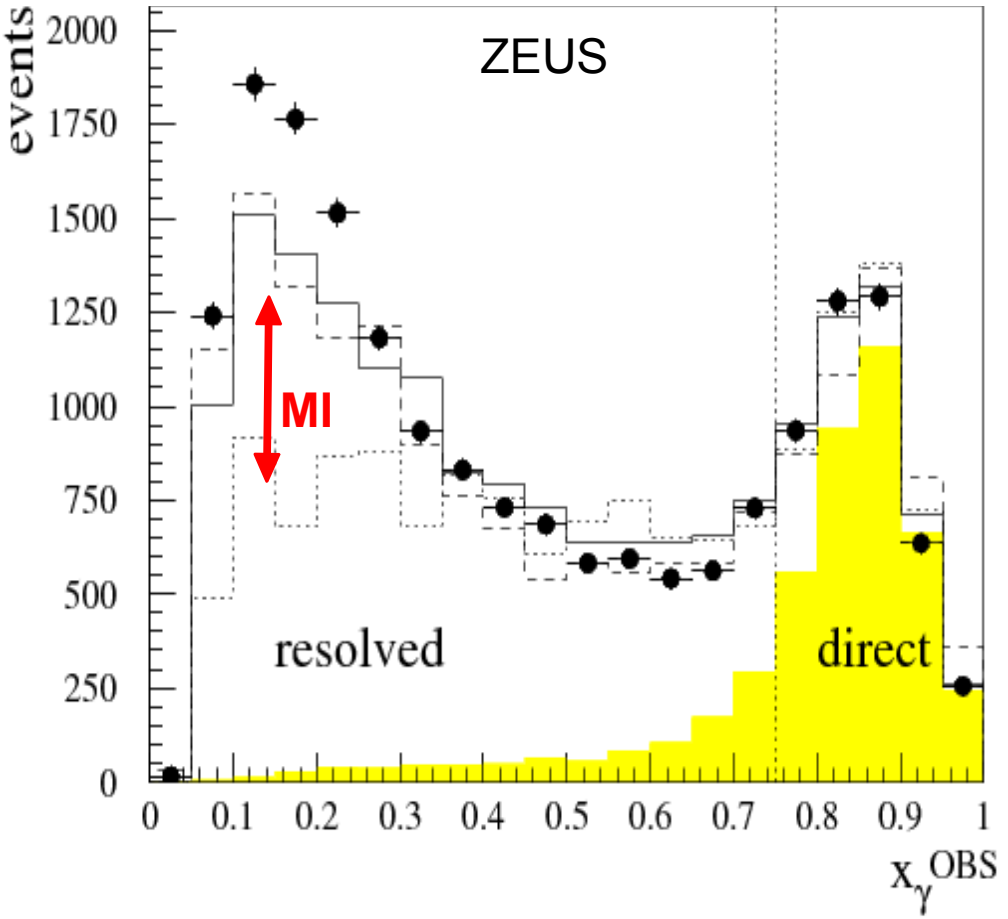
- Insufficient MC model.
  HERWIG, no JIMMY: Only pedestal.

- More UE in forward region.
  Closer to proton remnant.

MI studies at HERA > 10 years ago

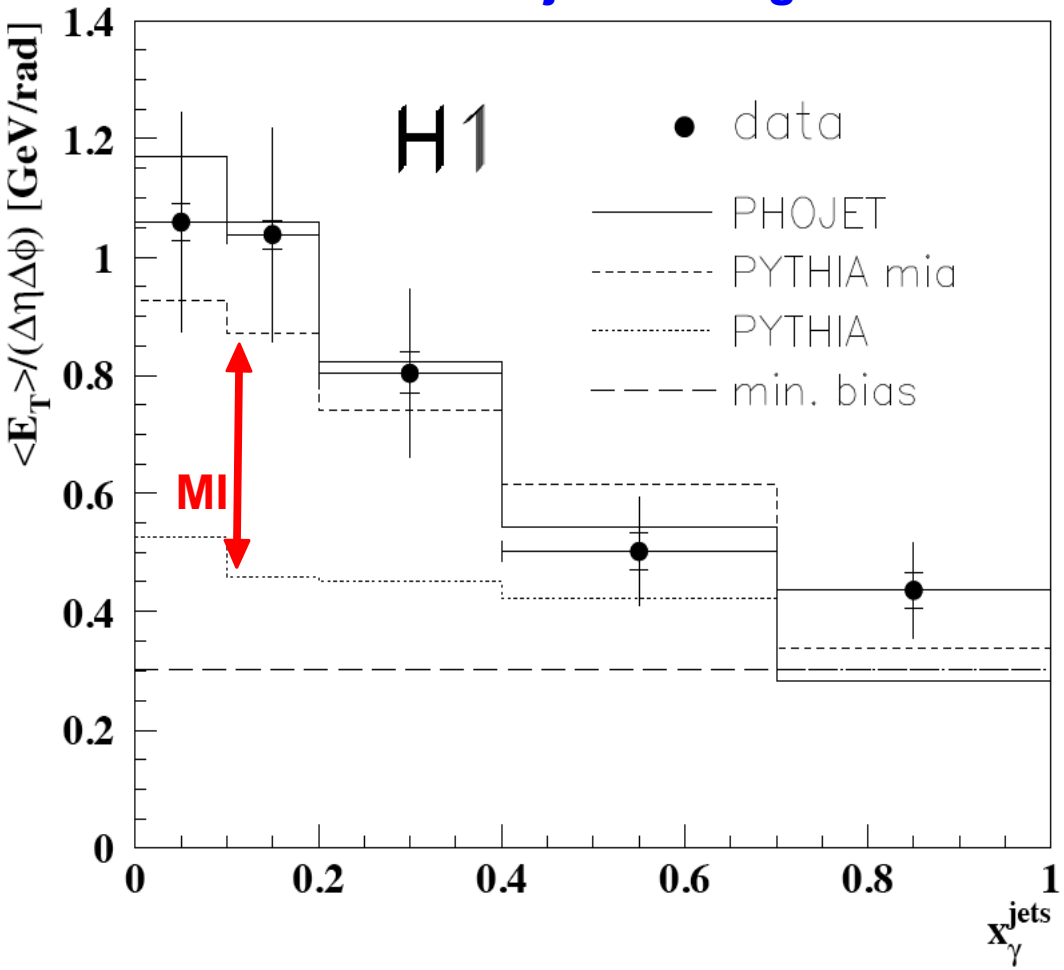
ZEUS Collaboration (J. Breitweg et al.), Eur.Phys.J.C1:109-122,1998

Di-jets in photoproduction



H1 Collaboration (S. Aid et al.), Z.Phys.C70:17-30,1996

Energy flow in photoproduction, outside the two jet with highest Pt.

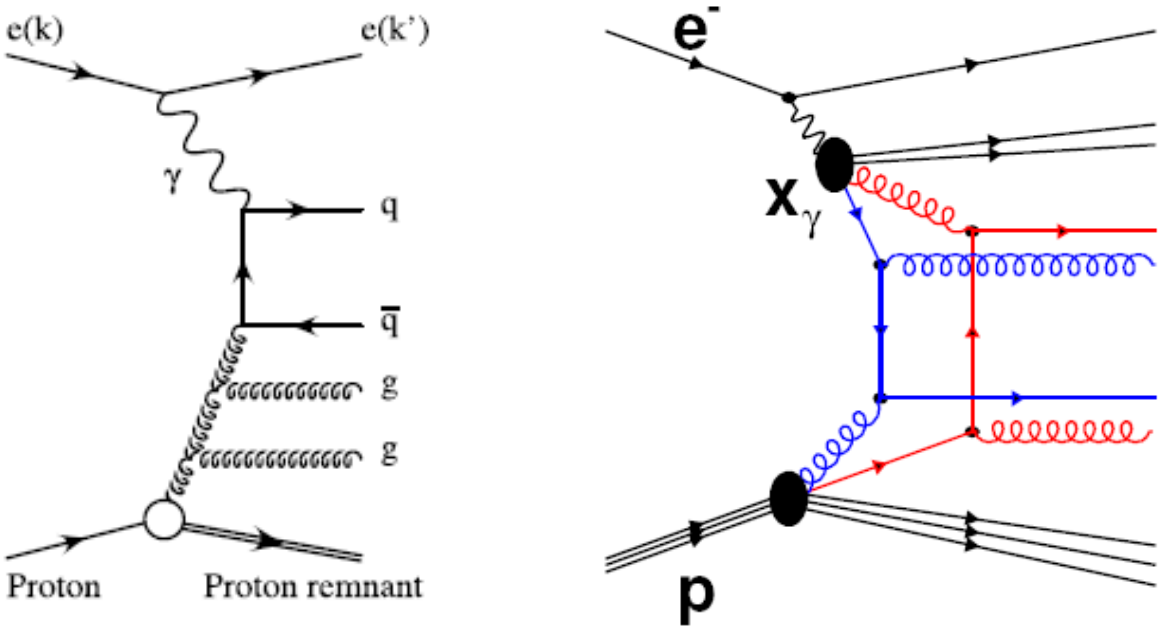


Resolved photon → **Remnant-remnant interactions**

Multijets in photoproduction

Multijets in Photoproduction

- Measure 3- and 4-jet final state ➞ Tool to study higher order α_s reactions in photoproduction:
  - Fixed order calculations
  - QCD models with PS
  - Multiple interactions (Hard)



"Three- and four-jet final states in photoproduction at HERA", *Nucl.Phys.B792:1-47,2008, ZEUS Collaboration*

Multijets in Photoproduction

Kinematic Range

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

3-, 4-Jet Selection

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

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: $x_\gamma^{\mathrm{obs}} = \dfrac{\sum E_{T,i}^{\mathrm{jet}} exp(-\eta_i^{\mathrm{jet}})}{2yE_e}$

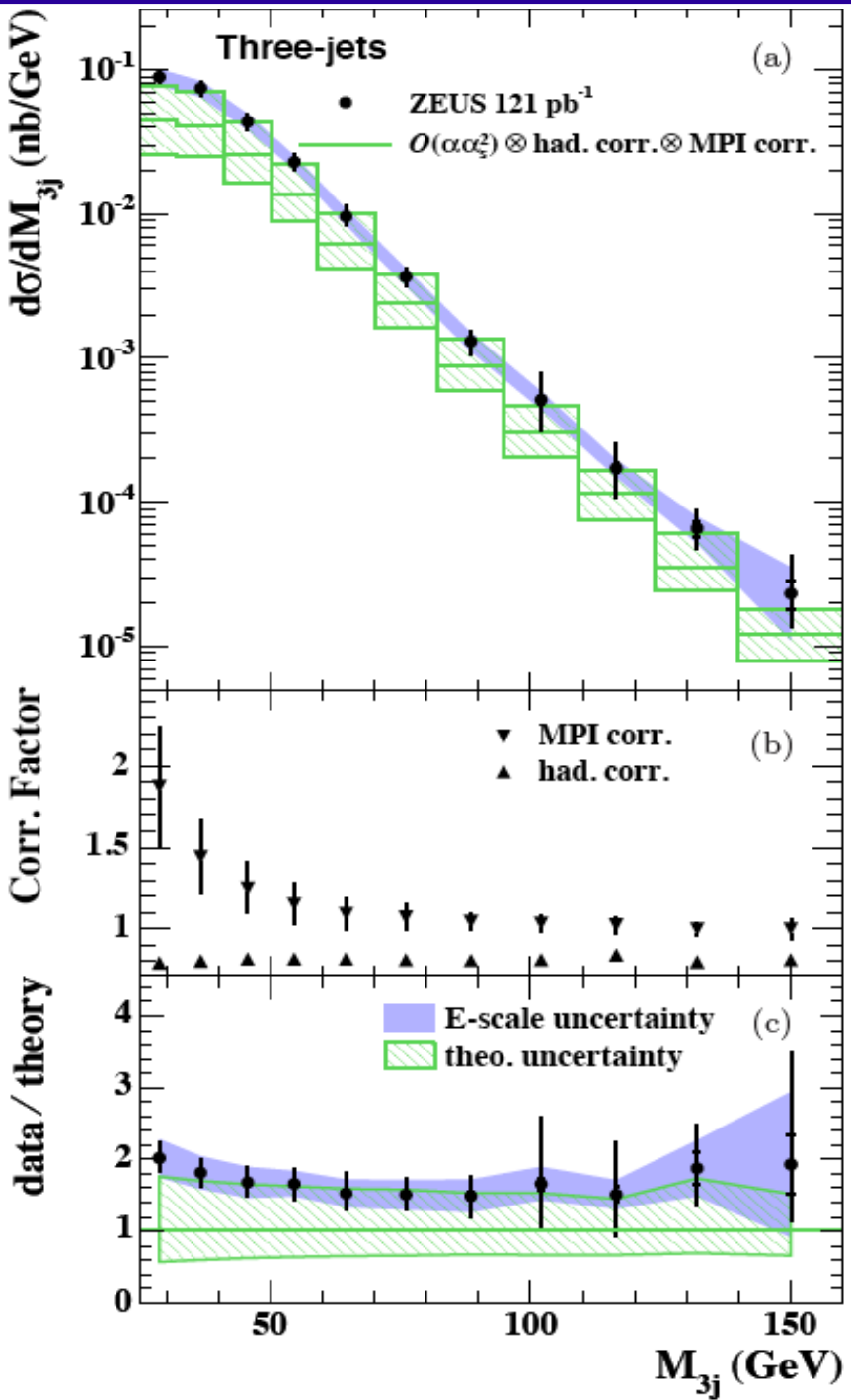
where the sums runs over 3 or 4 jets

Measurement

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

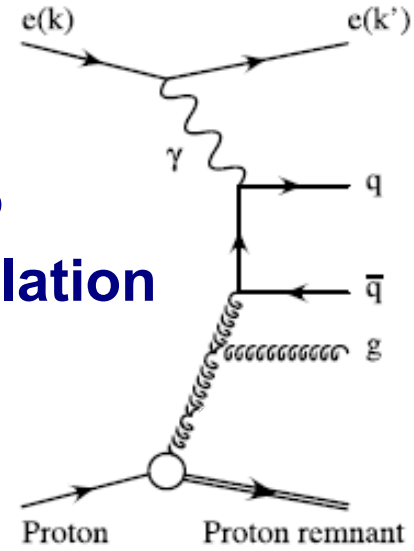
- **Low mass region:** $25 < M_{nj} < 50\ \mathrm{GeV}$
- **High mass region:** $M_{nj} > 50\ \mathrm{GeV}$

Multijets in Photoproduction



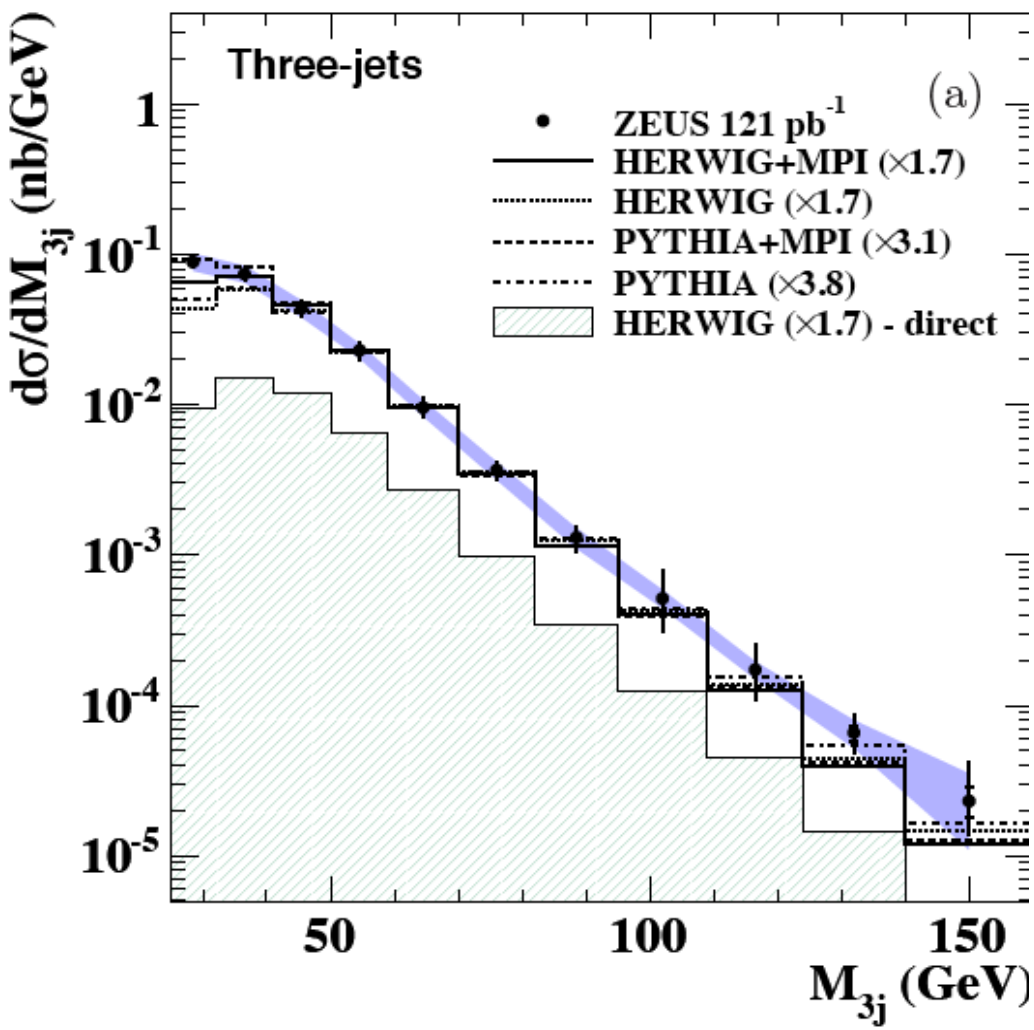
Comparison to LO $O(\alpha\alpha_s^2)$ calculation

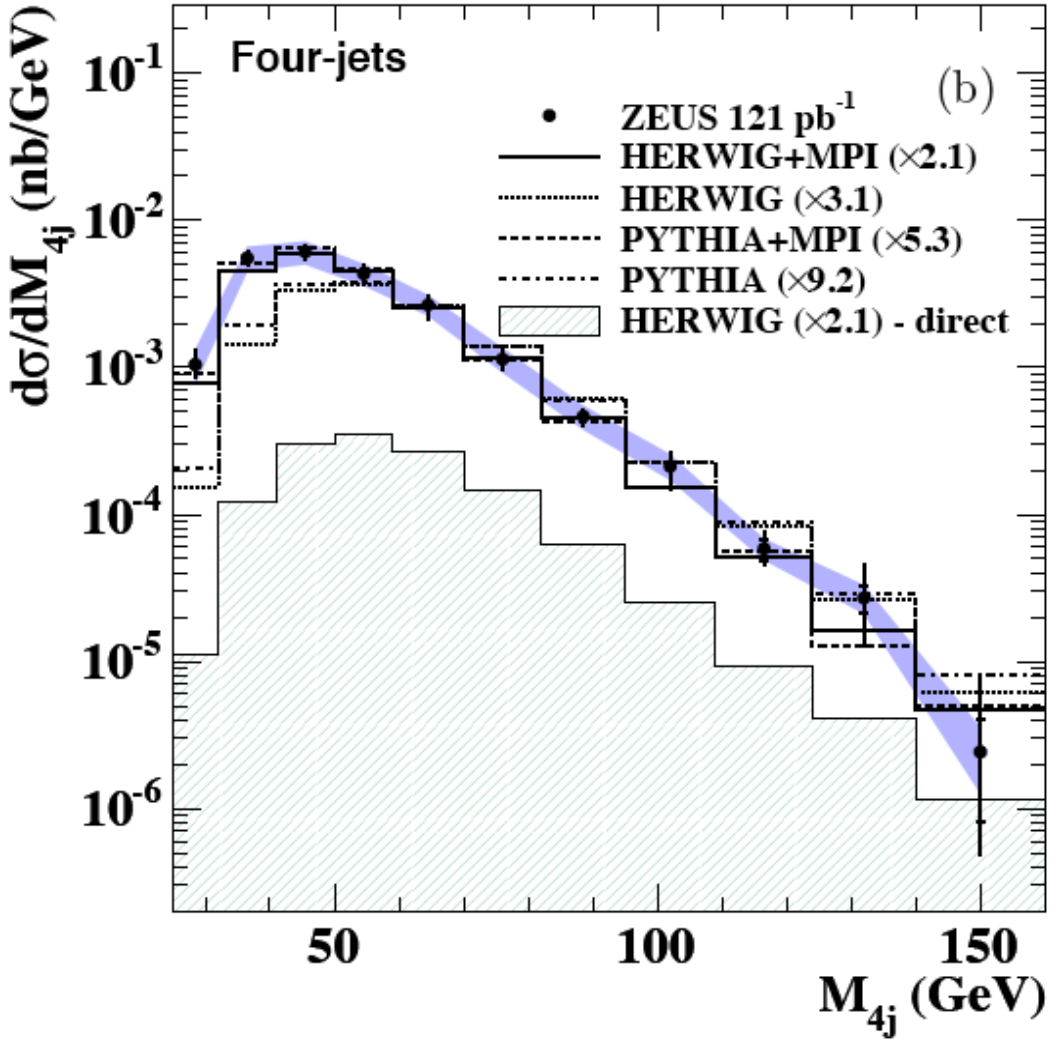
(only for 3 jets)



- **Hadronization corrections**
  - → **Constant**
- **MI corrections**
  - → **Increasing with lower mass**
  - → **Necessary in order to describe data**
- **Data described within the fairly large theoretical uncertainties**

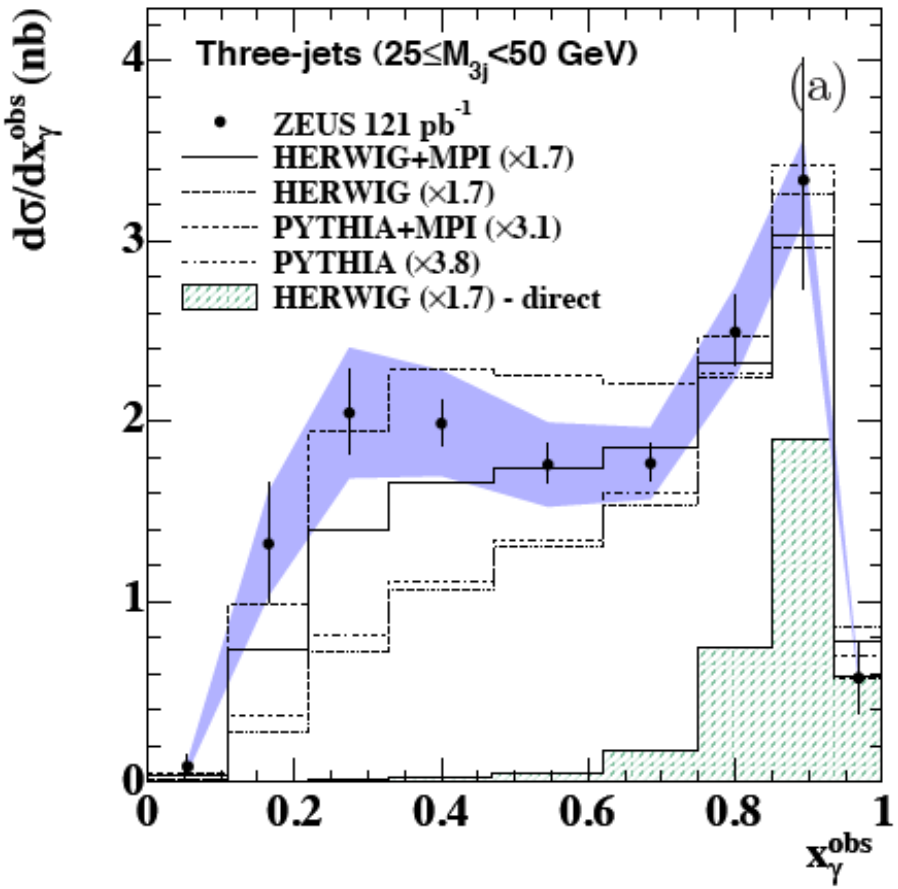
Multijets in Photoproduction

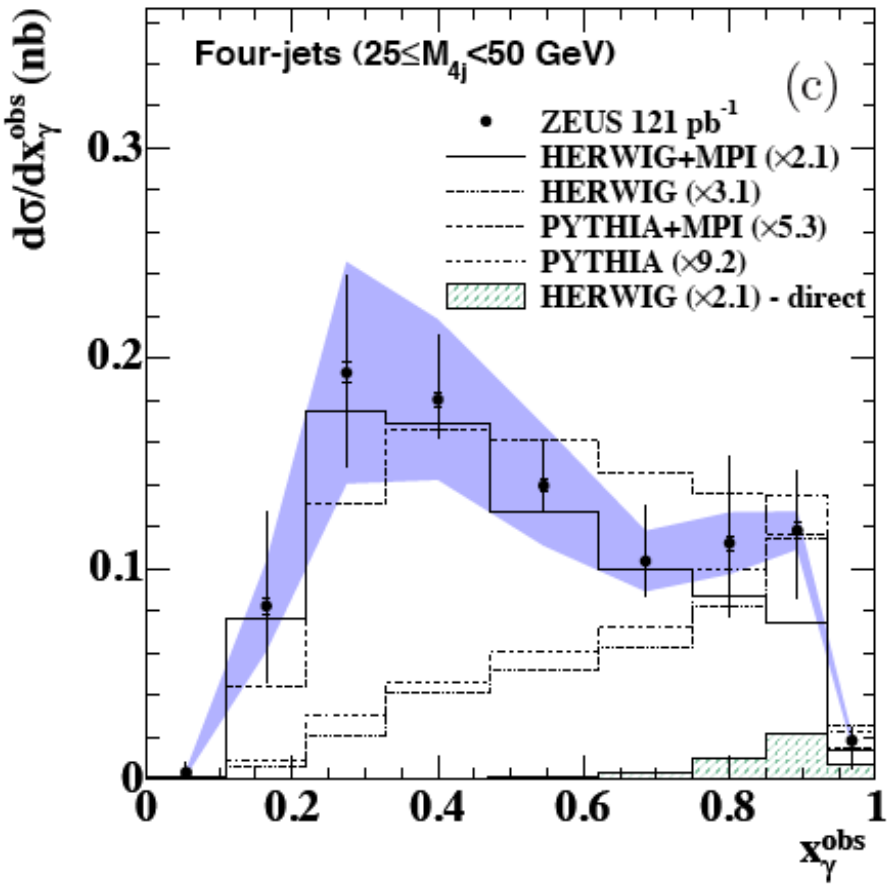




- MC normalized to high mass region (M_nj > 50 GeV)
- Low mass data not described without MI
  - → Most significant for 4-jet scenario
- Inclusion of MI gives satisfactory description of full mass spectrum

Multijets in Photoproduction





- **MI again improves MC description of data**
  - **Although, MC problem with shape in 3-jet scenario**
- **MI most important for the 4-jet final state and at low x_γ (resolved photon)**
- **HERWIG+MI and PYTHIA+MI somewhat different predictions**

Particle flow in photoproduction

Charge particle flow in photoproduction

Photoproduction: $Q^2 < 0.01 \text{ GeV}^2$

Di-jets events: *Jets defined by inclusive kt-algorithm*

$$P_T^{Jets} > 5 \text{ GeV}$$

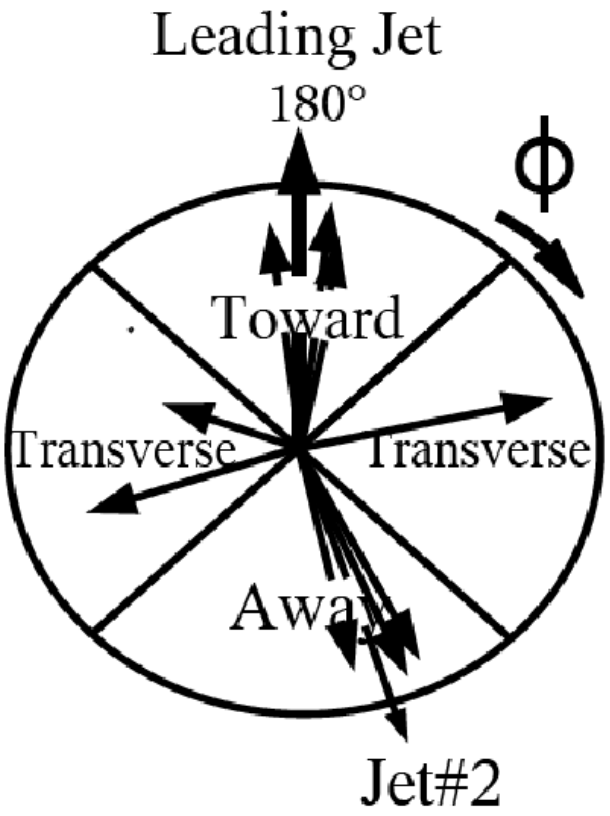
$$|\eta^{\text{Jet}}| < 1.5$$

Charge particle selection: $P_t > 150 \text{ MeV}$

$$|\eta| < 1.5$$

Measure charge particle multiplicity as a function of the azimuthal difference between the leading jet and the particles, $\Delta\phi$

Charge particle flow in photoproduction



Define regions in $\Delta\phi$ for more exclusive measurement:

Toward region: $120^o < \Delta\phi < 240^o$

Defined by the leading jet.

Away region: $300^o < \Delta\phi < 60^o$

Often contains the subleading di-jet..

Transverse Regions: $60^o < \Delta\phi < 120^o$

$240^o < \Delta\phi < 300^o$

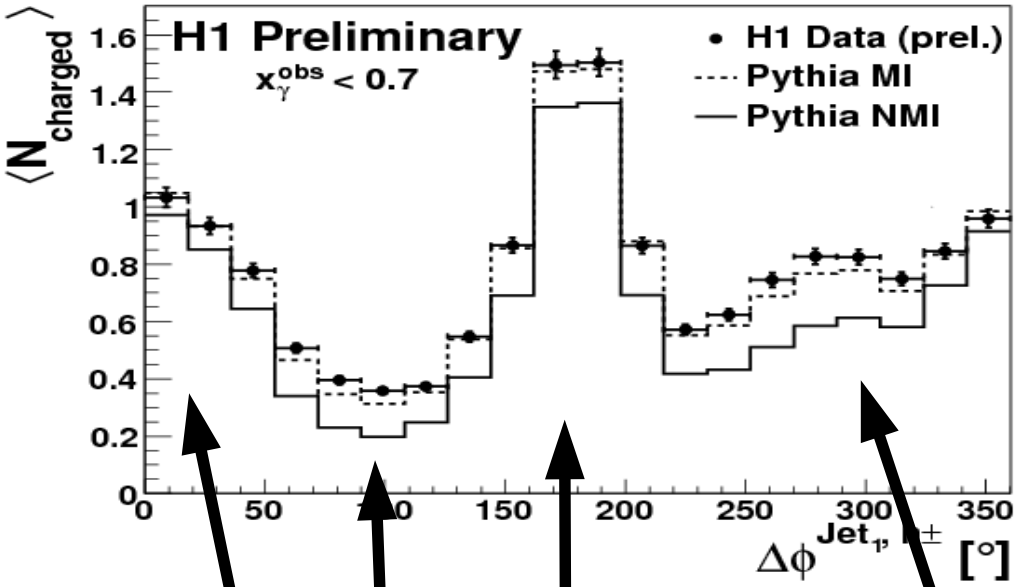
High active region:

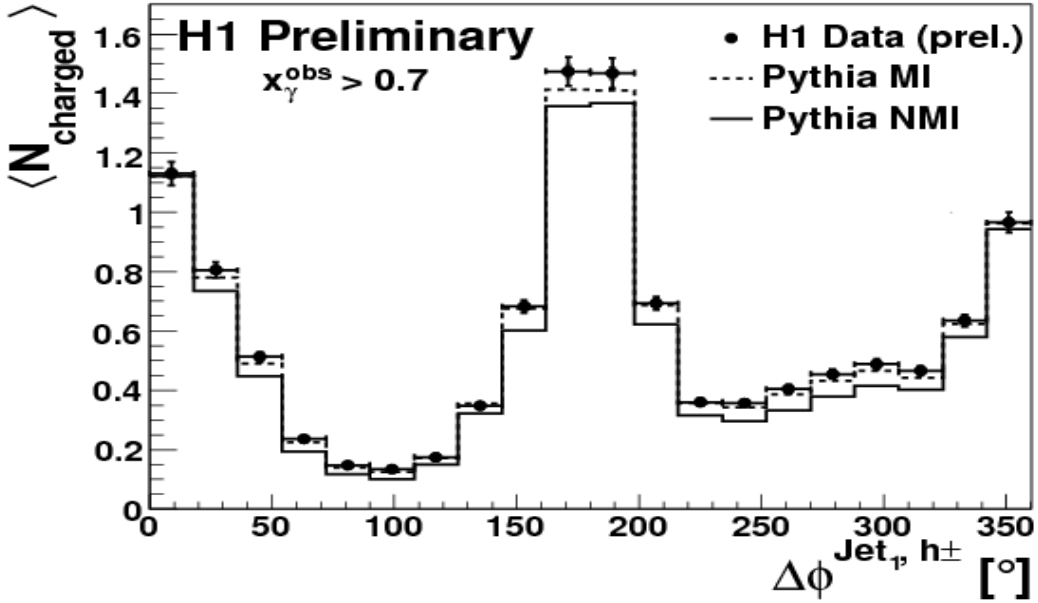
transverse region with highest

$$P_t^{\text{sum}} = \sum_{i}^{\text{charged particles}} p_t^i$$

Charge particle flow in photoproduction

Measure charge particle multiplicity as a function of the azimuthal difference between the leading jet and the particles, $\Delta\phi$





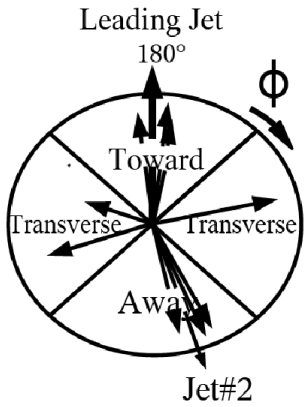
Sub-Leading Jet

Low active region

Leading Jet

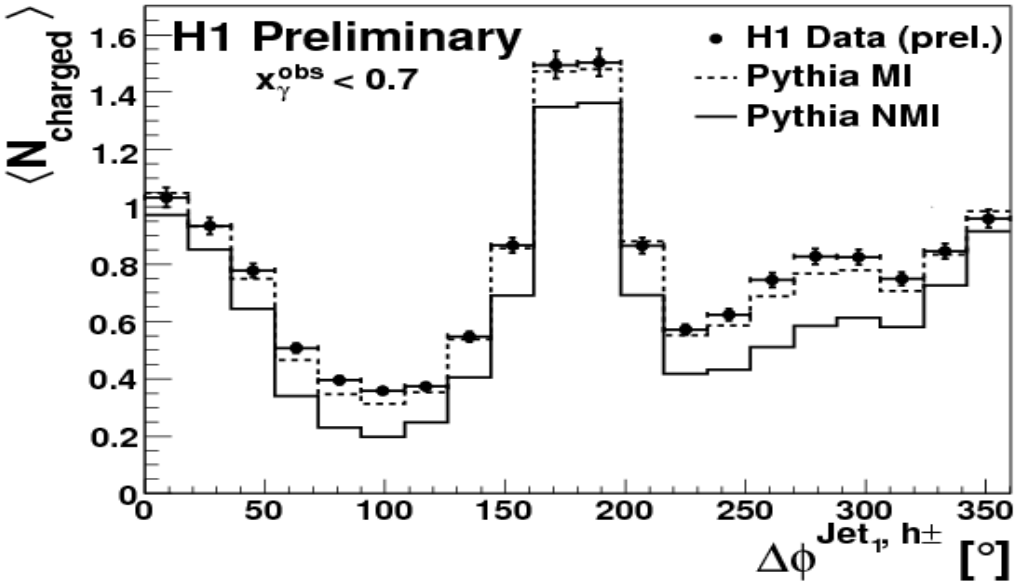
$\Delta\phi = 180^o$

High active region

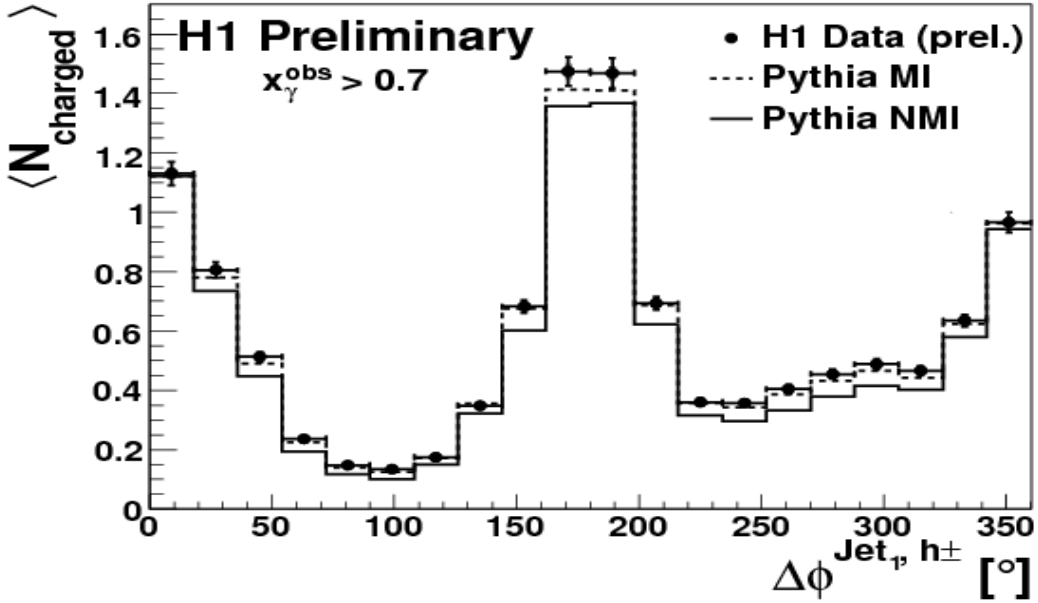


Charge particle flow in photoproduction

Measure charge particle multiplicity as a function of the azimuthal difference between the leading jet and the particles, $\Delta\phi$



Resolved favoured region

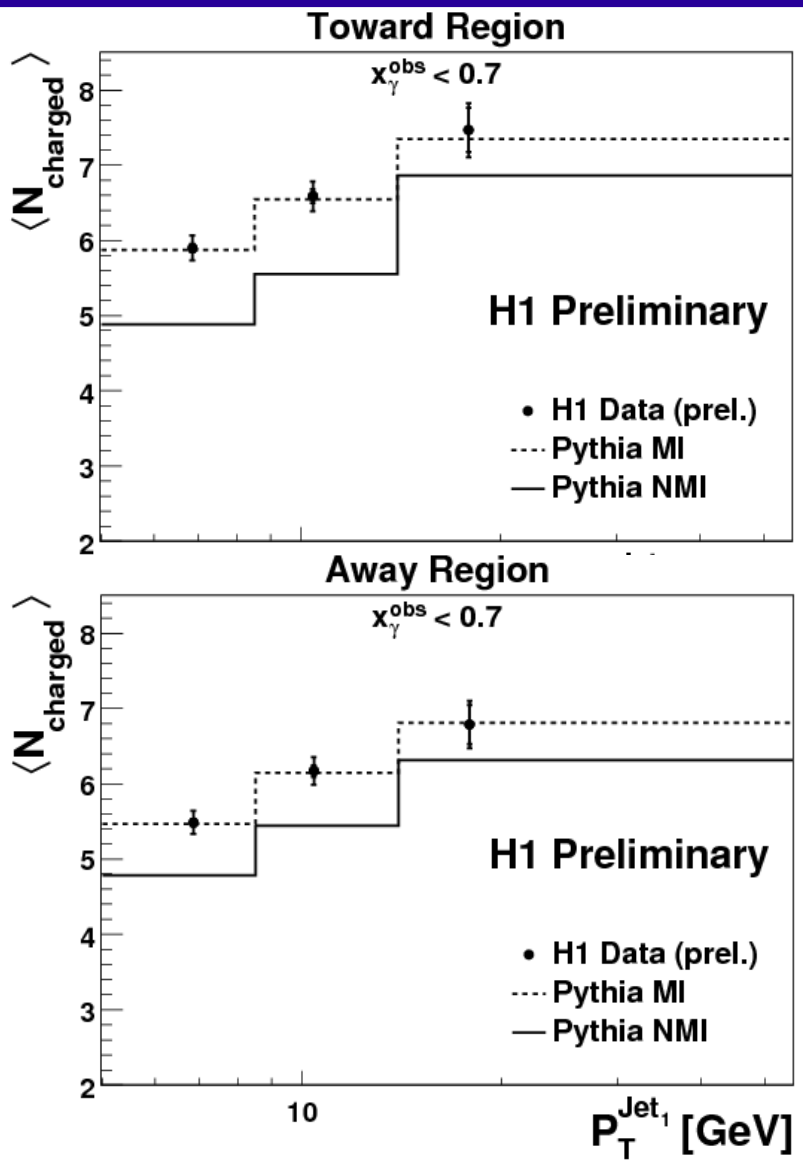


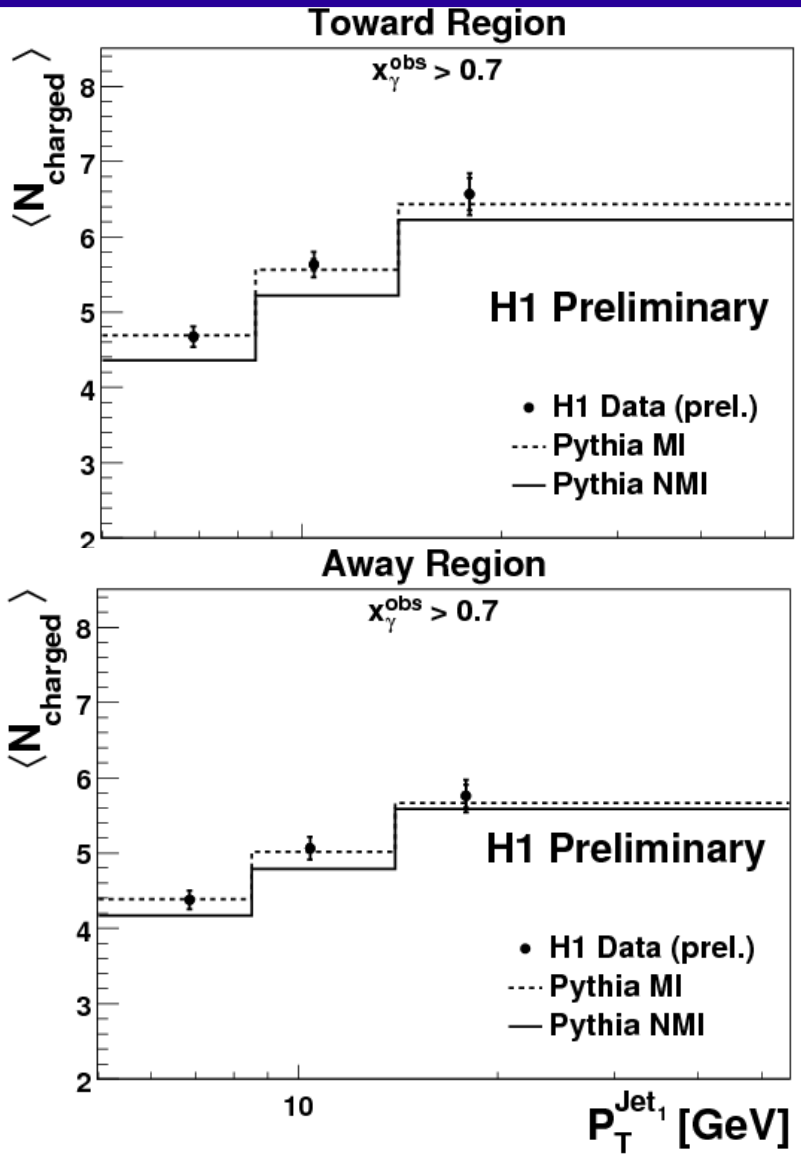
Resolved suppressed region

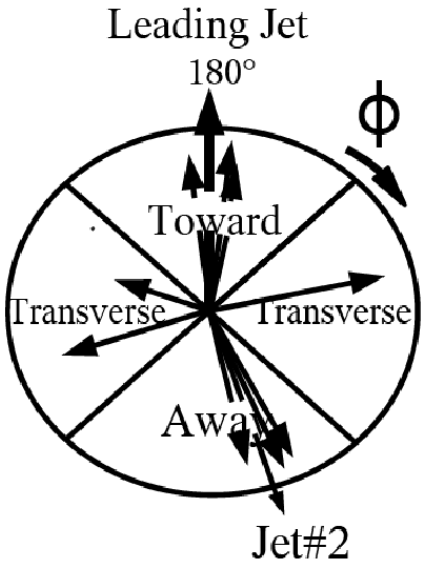
- **Equal amount of charged particles from MI over the full DeltaPhi-range**

→ **MI gives pedestal effect (~ 0.1 particle at low x gamma)**

Charge particle flow in photoproduction

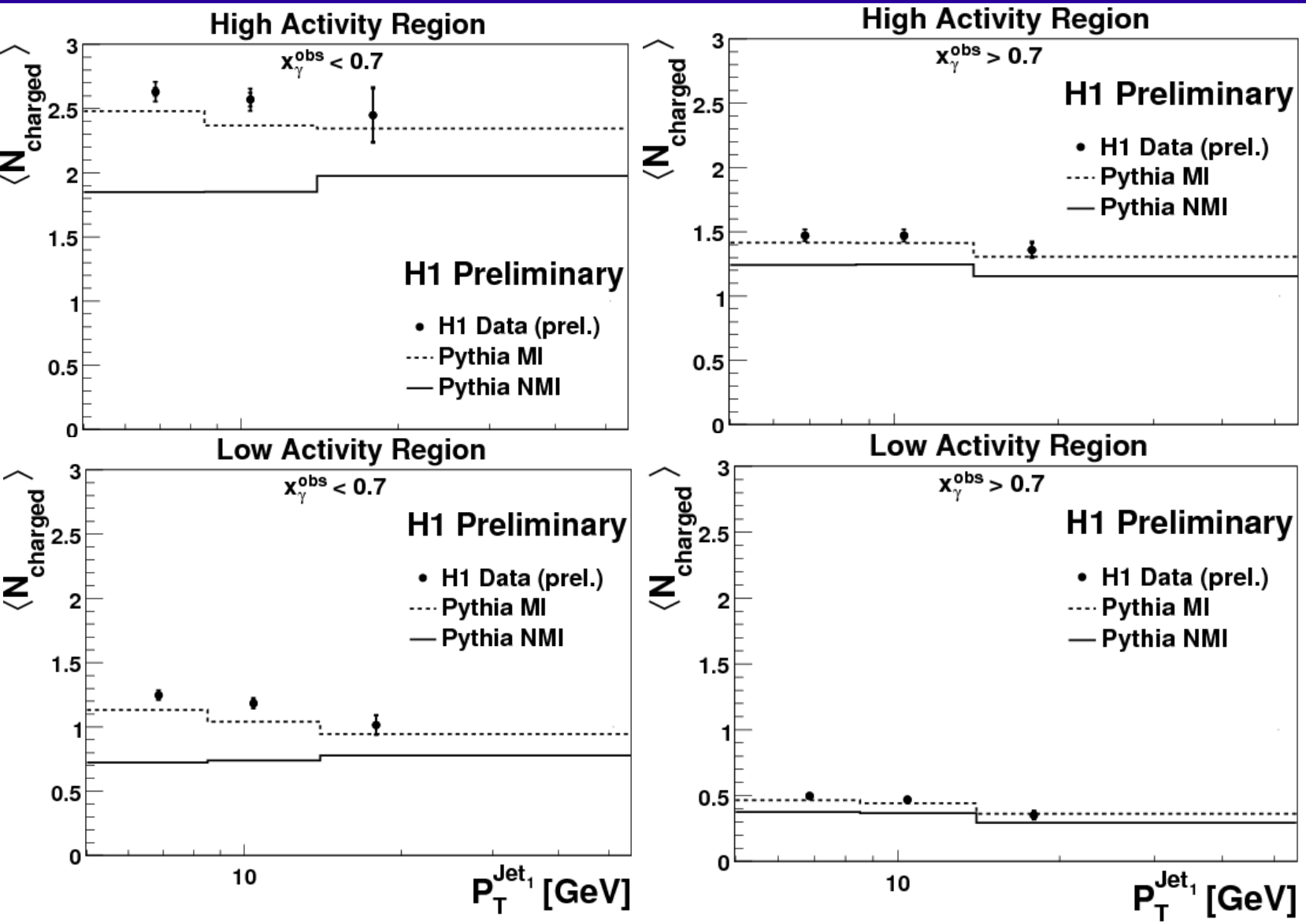


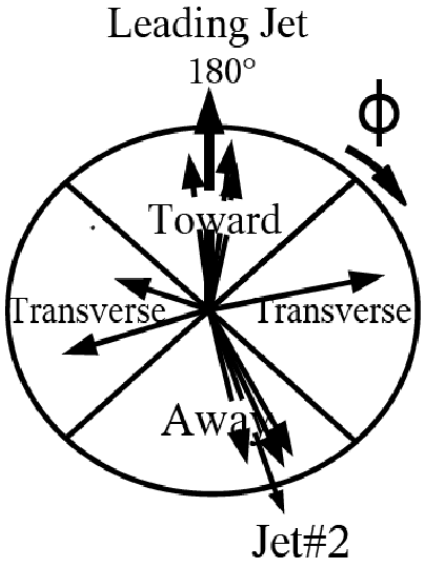




- Charge particle multiplicity in hard region very well described by MI.
- Low P_t jet - MI contributes slightly more → not only pedestal effect

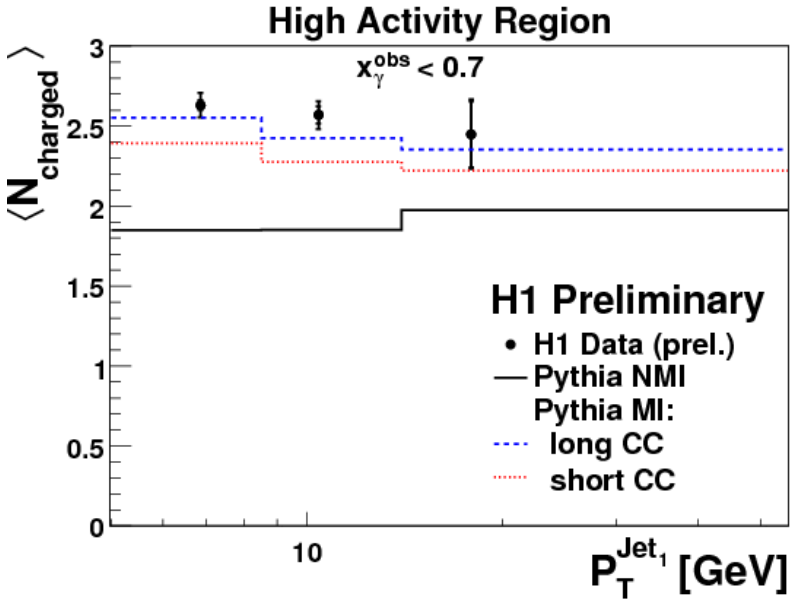
Charge particle flow in photoproduction

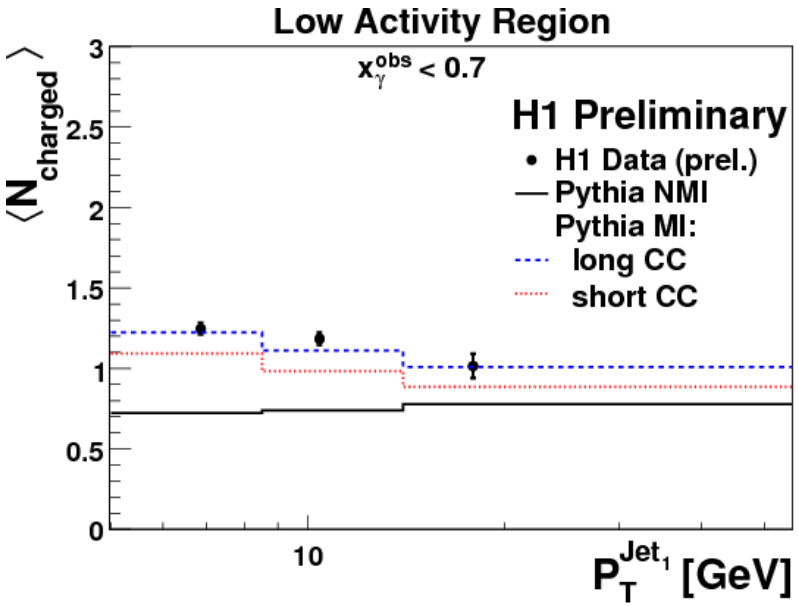




- **MI important in transverse regions**
- **... but no perfect description of data... but we can tune the MI model...**

Charge particle flow in photoproduction



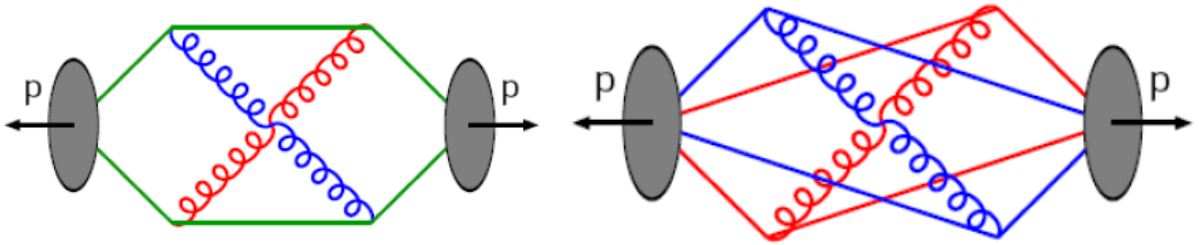


Doesnt change MC at high x_γ (Not shown)

Tuning attempt

Different colour correlation scenarious:

Long or Short Colour Strings



Data seem to prefer long colour strings.

This is *opposite to the TEVATRON tunes*.

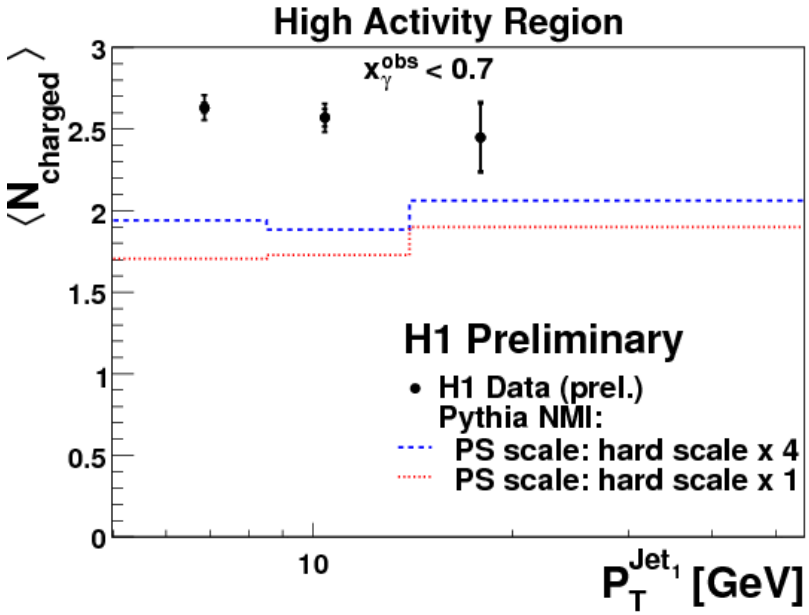
Now much better description of data.

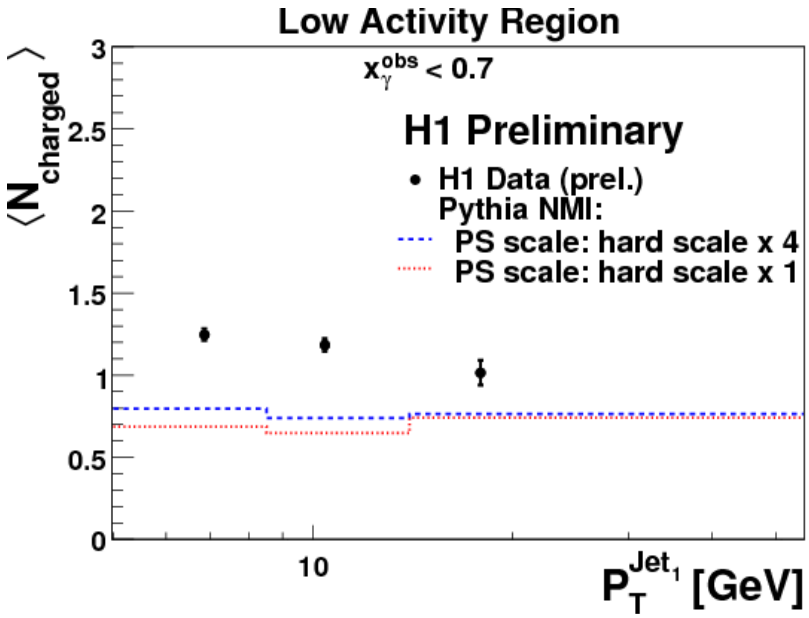
PARP(85) – Probability for MI to produce 2 gluons with colour string to closest neighbour.
Default: 0.9 -> Tuned: 0.33

PARP(86) – Probability for MI to produce 2 gluons as PARP(85) or as a closed gluon loop
Default 0.95: -> Tuned: 0.66

Charge particle flow in photoproduction

Attempt to describe particle multiplicity without MI.





Change the maximum parton virtuality allowed in virtuality ordered parton showers with respect to the scale of the hard scattering *(PARP(67) in PYTHIA)*

Increasing the limit opens up the phase space for more and harder radiation.

Effect not big enough... We need MI.

Minijets in DIS

Mini jets in DIS

- Photoproduction → large resolved photon component

  → as seen remnant-remnant interactions (MI) very important

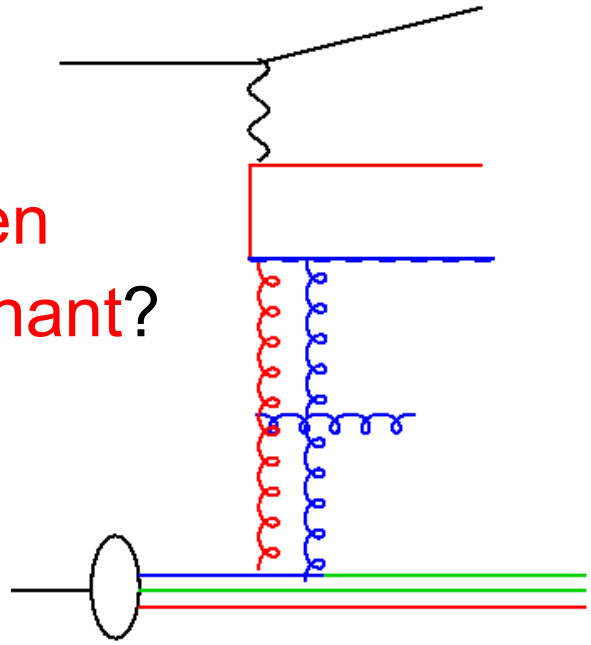
Mini jets in DIS

- Photoproduction → large resolved photon component

  → as seen remnant-remnant interactions (MI) very important

- MI in DIS where the resolved photon component is much smaller?

  → additional interactions between hard reaction and proton remnant?



Mini jets in DIS

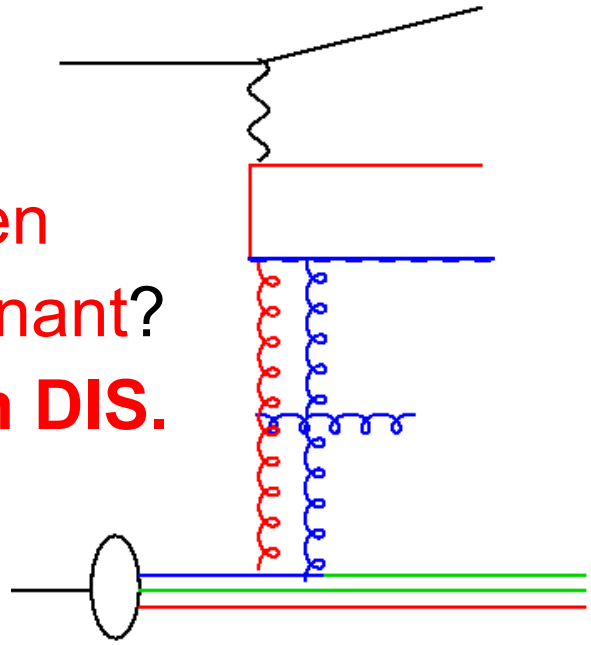
- Photoproduction → large resolved photon component

  → as seen remnant-remnant interactions (MI) very important

- MI in DIS where the resolved photon component is much smaller?

  → additional interactions between hard reaction and proton remnant?

  → **Study mini jet production in DIS.**



Mini jets in DIS

Kinematic Range

- $5 < Q^2 < 100\ \mathrm{GeV}^2$
- $0.1 < y < 0.7$
- $W > 200\ \mathrm{GeV}$

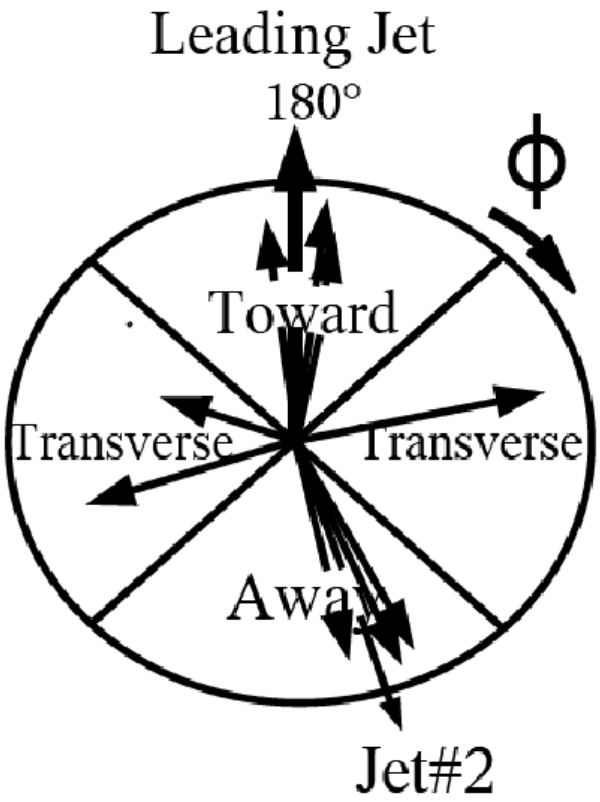
Jet Selection

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

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



Measure $< N_{Minijets} >= \frac{\sum^{N_{events}} N_{Minijet}}{N_{events}}$ **in bins of**

Q^2 **and** η_1^{jet} **as a function of** $P_{T,1}^{jet*}$

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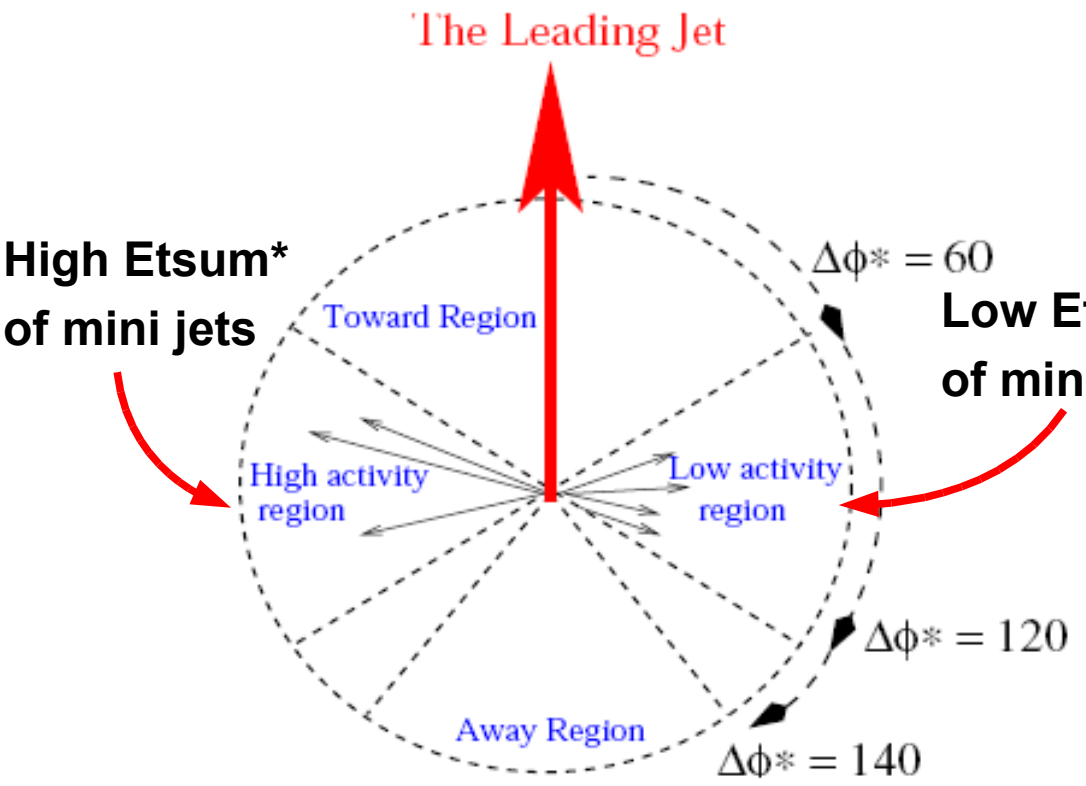
- $P_T^{minijet} > 3\ \mathrm{GeV}$
- $-1.79 < \eta^{minijet} < 2.79$



Measure $< N_{Minijets} >= \frac{\sum^{N_{events}} N_{Minijet}}{N_{events}}$ **in bins of**

Q^2 **and** η_1^{jet} **as a function of** $P_{T,1}^{jet*}$

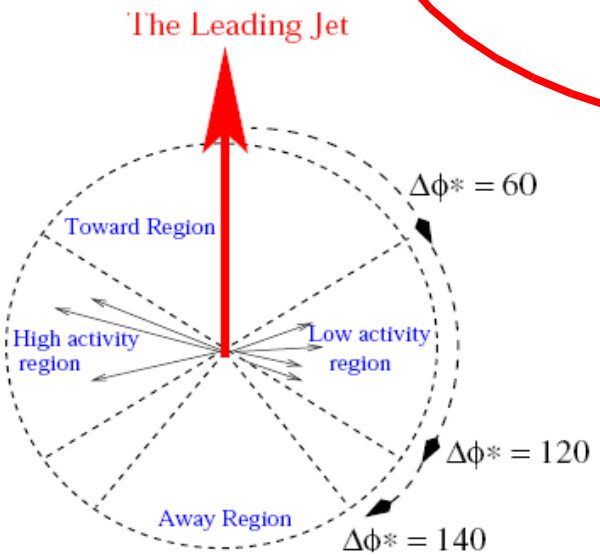
Mini jets in DIS

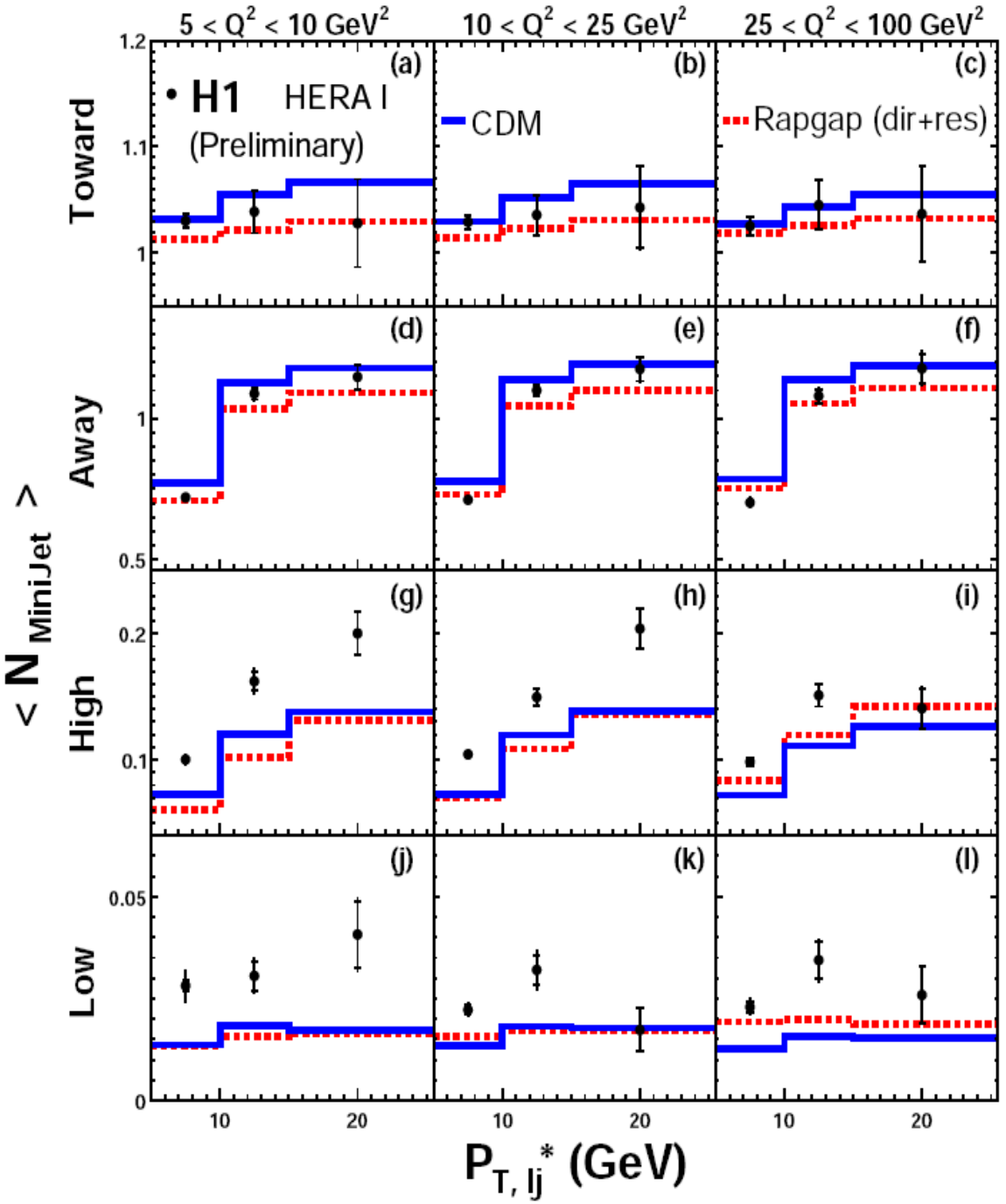
Inclusive 1 jet sample

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

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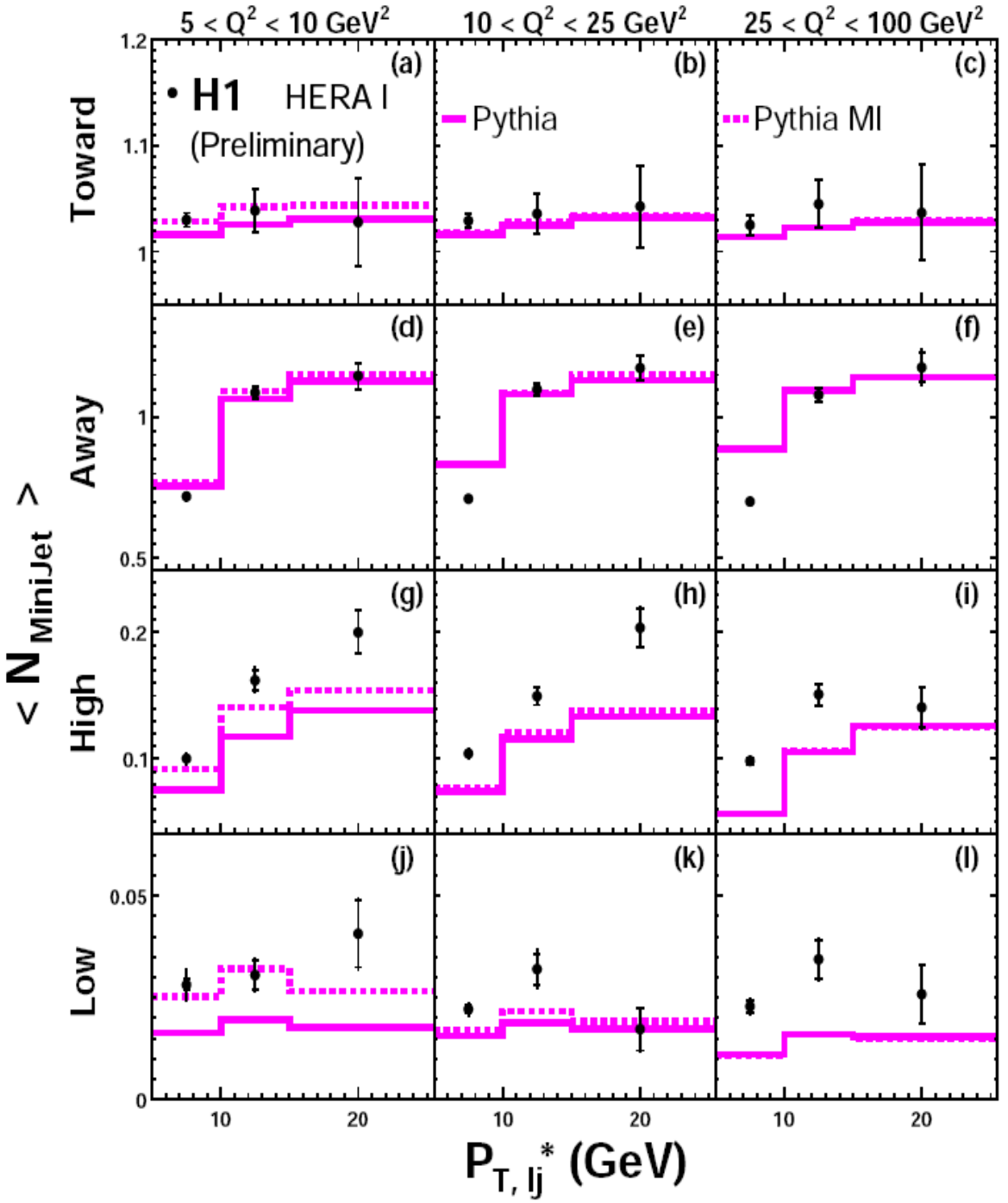
Pythia with MI does slightly better at low Q2

(lower Q2 -> more res. photon)

Without a photon remnant, there is no available MC with MI

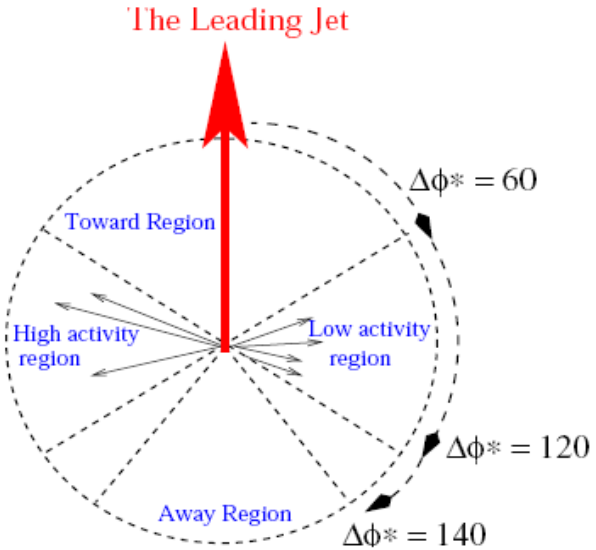


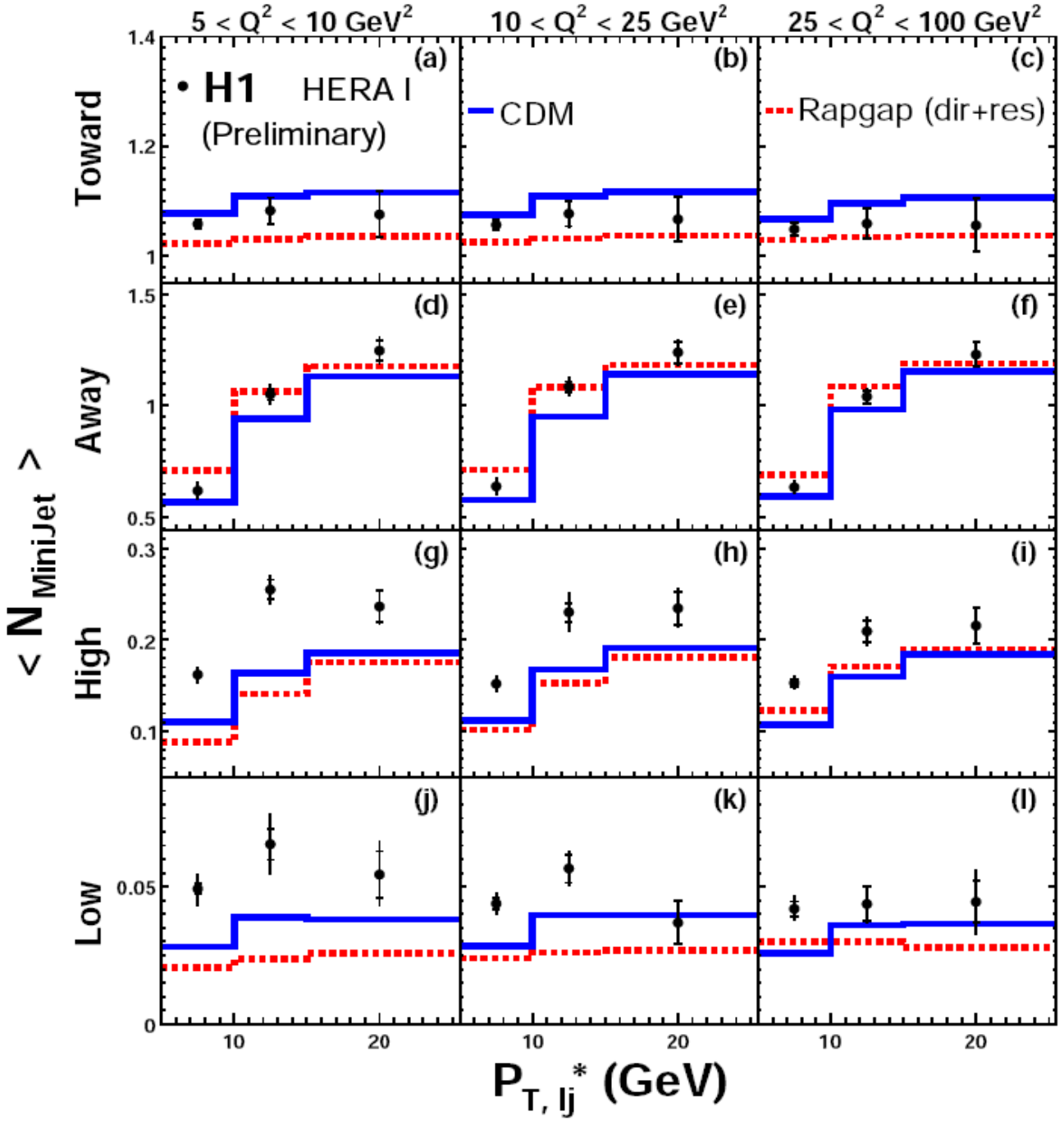
Mini jets in DIS

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

Inclusive 1 jet sample

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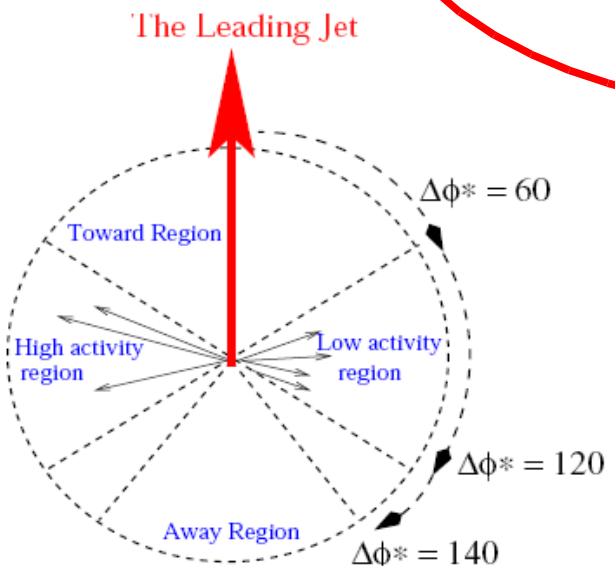
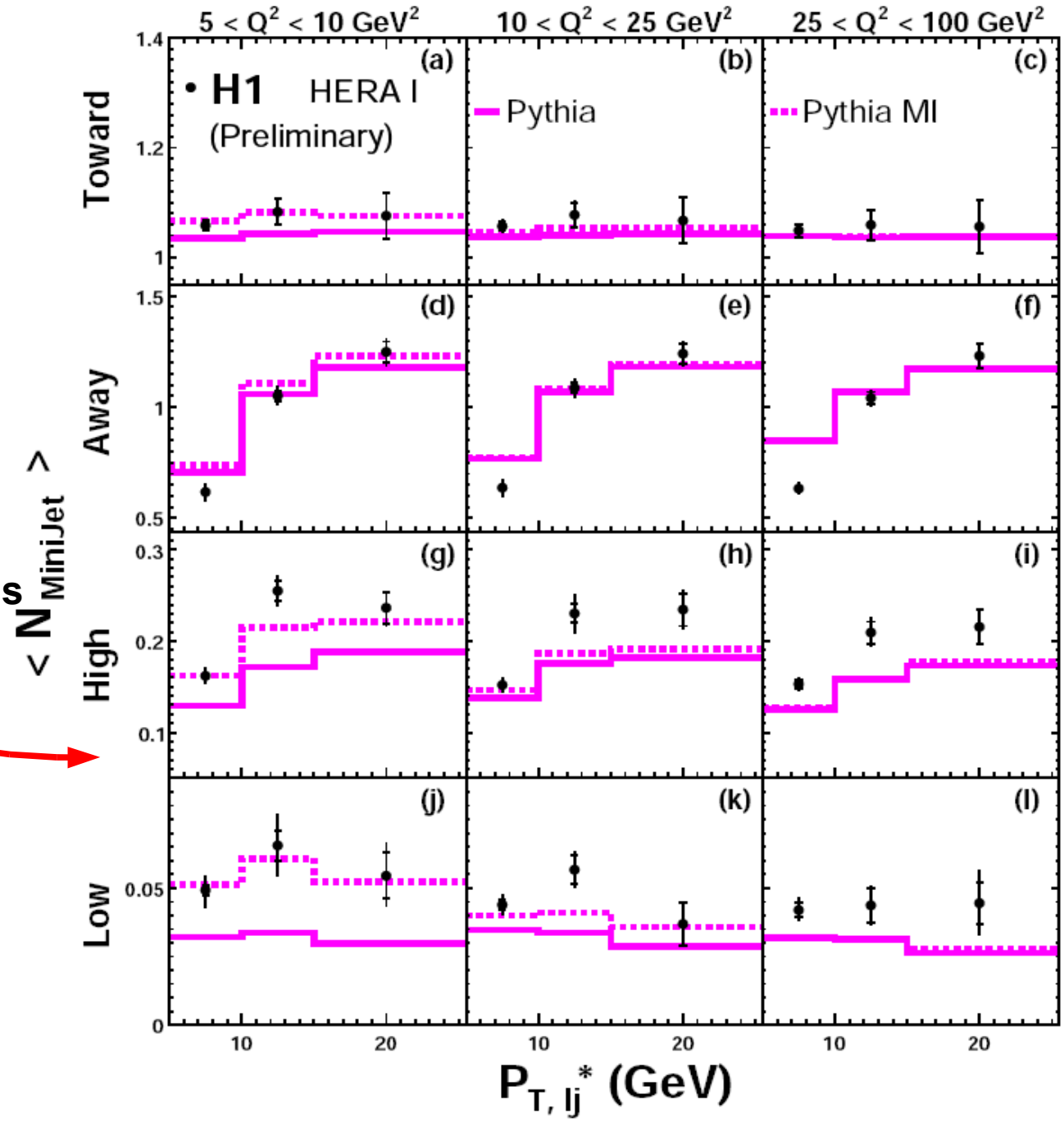
$$0.5 < \eta^{jet} < 2.79$$

•Activity from MI improves description of data at low Q2 in transverse regions





Summary

HERA can help to understand the UE

Hard MI:

Multijet production in photoproduction

- MI Large contribution to multi-jet cross-sections in photoproduction
- Most significant for the 4-jet scenario
- Available fixed order $O(\alpha\alpha_s^2)$ 3-jet calculations not sufficient without MI corrections.

Soft MI:

Particle multiplicity and minijet multiplicity cannot be described without MI

Charge particle production in photoproduction

- Measured already 10 years ago – New measurement more detailed (and higher lumi)
- MI needed in both soft and hard region of reaction

Minijet production in DIS at low Q^2

- MC *without* MI describes hard part of reaction
- Including MI improves description of data where res. γ ontribution is large
- More difficult situation. Low resolved photon component

Insufficient MC model – only remnant-remnant interaction

More activity needed in UE

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Open theoretical issue