

# Multiparton Interactions at HERA

*Albert Knutsson*

Ringberg Workshop 5-10/10 2008

*New Trends in HERA physics*

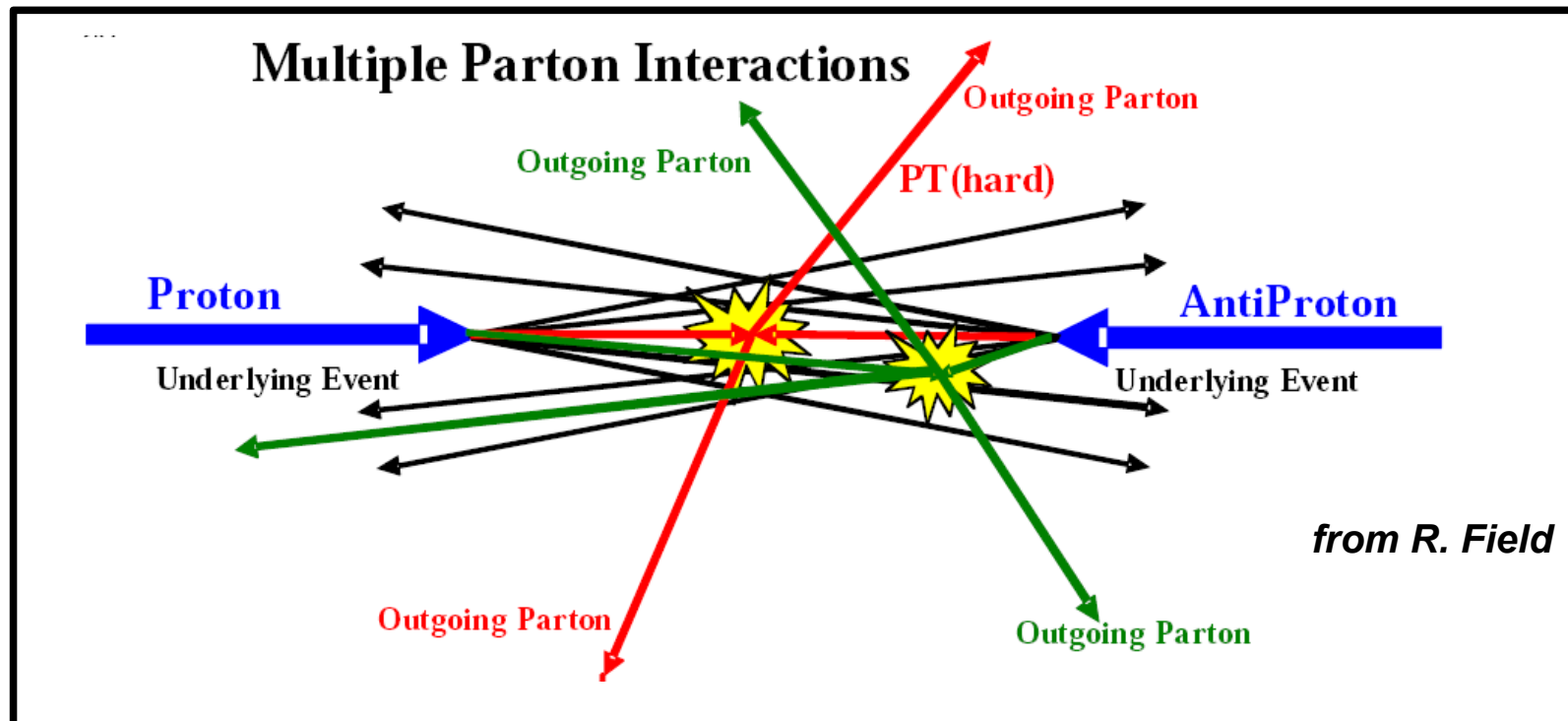
## Outline

- 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:

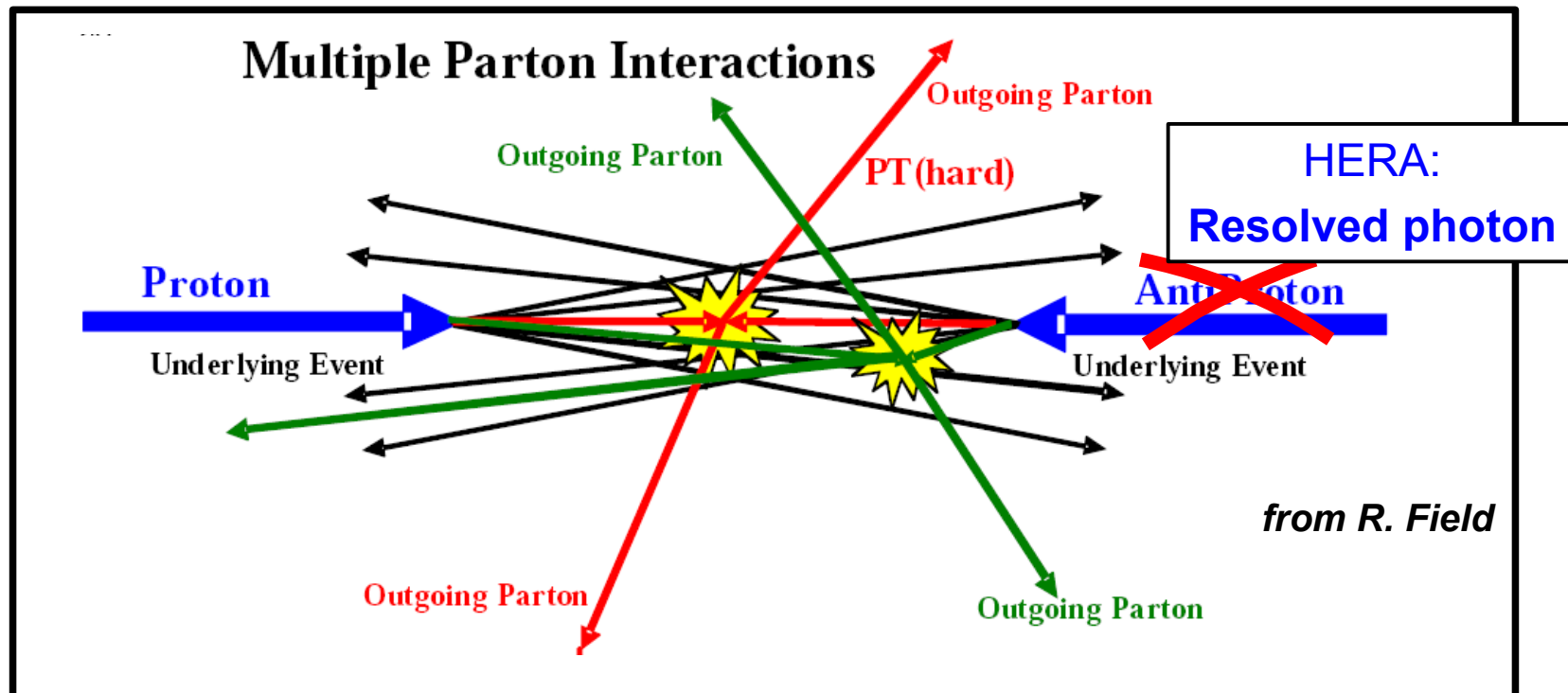
- Parton showers
- Multiple interactions:
  - Additional remnant-remnant, or parton-remnant, interactions – Soft or Hard
- ... but not pile up



# The Underlying Event – not only MI

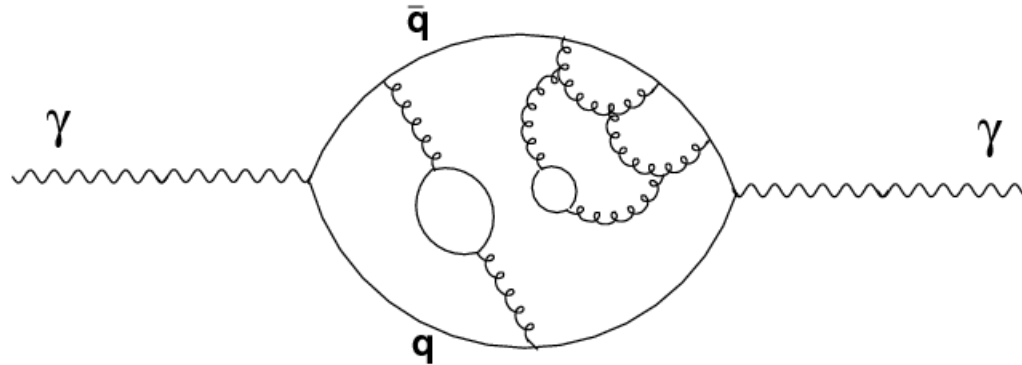
Everything except the studied LO process:

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



# Photon structure

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



Low photon virtuality  $Q^2 \rightarrow$  More long lived photon  $\rightarrow$  Larger resolved component

Photoproduction:  $Q^2 \approx 0 \text{ GeV}^2$  - 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:  $x_\gamma$

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

Handle to separate resolved/direct photon

High  $x_\gamma^{\text{OBS}}$  - Direct photon.

Low  $x_\gamma^{\text{OBS}}$  - Resolved photon.

# Multiparton Interactions

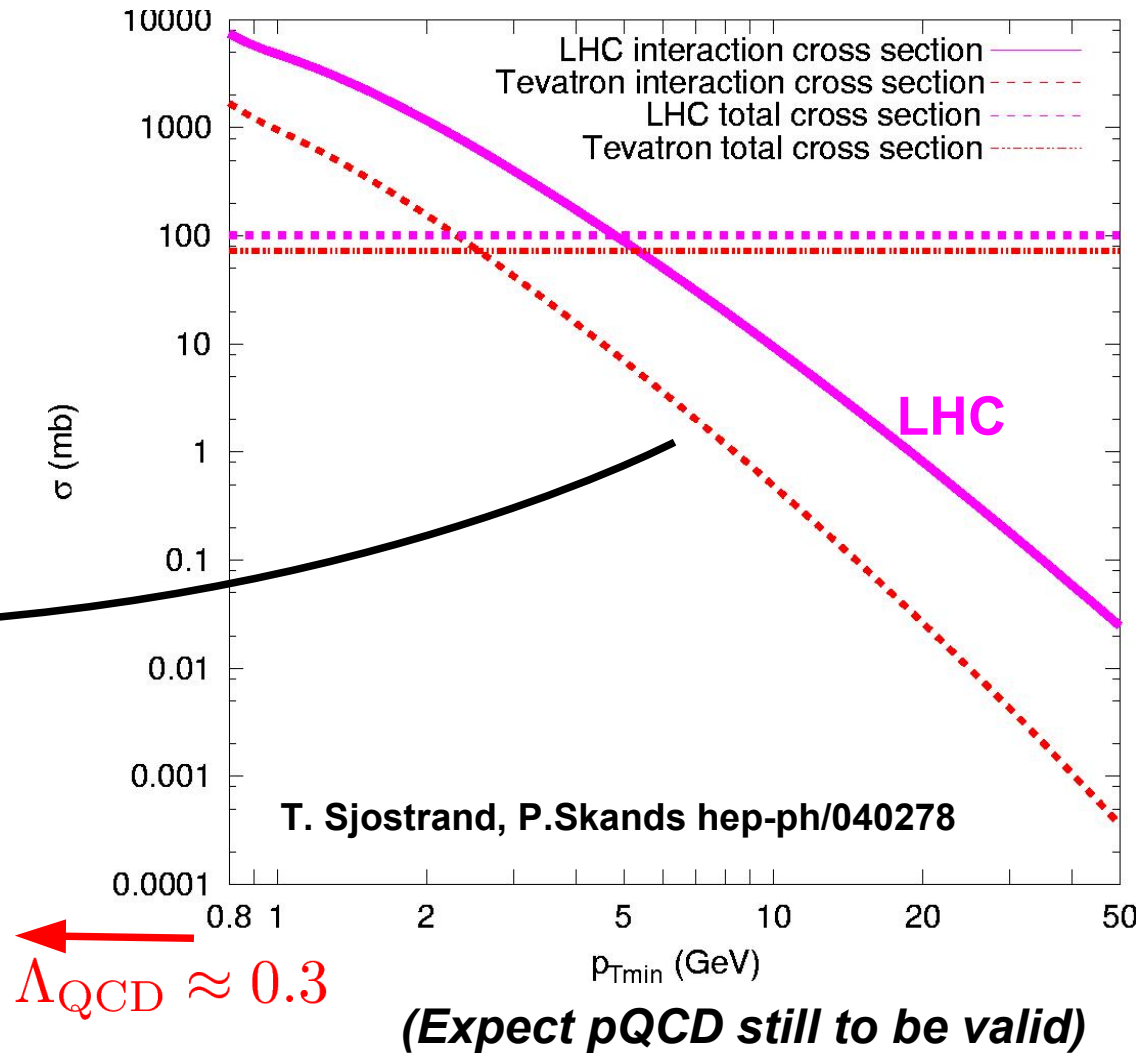
*Theoretical motivation*

**partonic interaction cross-section:**

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

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

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



# Multiparton Interactions

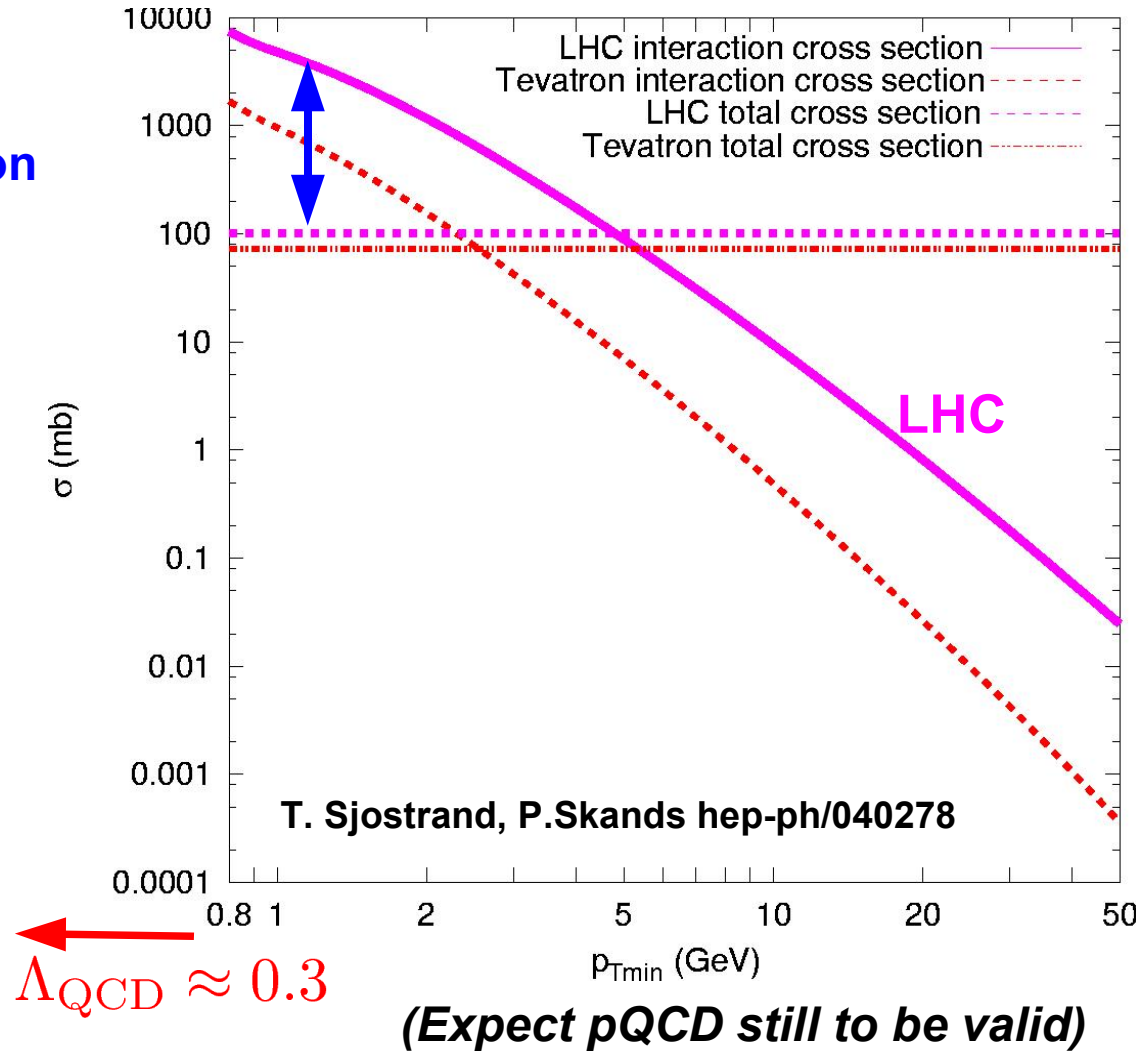
*Theoretical motivation*

Interaction x-section > Total x-section



Suggests *Multiple Interactions*

$$\langle n \rangle = \sigma_{\text{int}} / \sigma_{\text{tot}}$$



# Monte Carlo models with parton showers

(relevant for this presentation )

- *PYTHIA*: LO ME + DGLAP parton showers

MI: • **Average number of interactions/event** =  $\sigma_{\text{hard}}(p_{t, \text{min}}) / \sigma_{\text{non-diff}}$   
• **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.

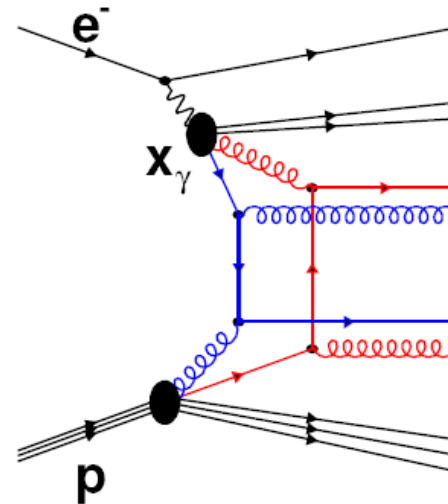
- *CDM*: Parton showers from the Color Dipole Model (No MI).  
QPM and BGF events from LO ME.

# 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.

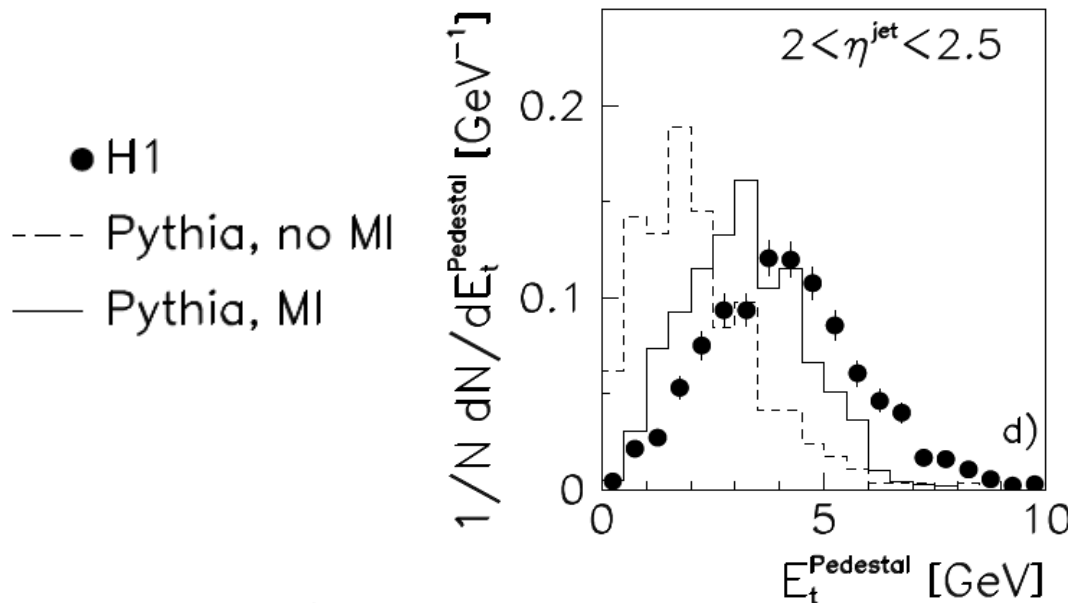


**MI @ HERA > 10 years ago**

# MI studies at HERA > 10 years ago

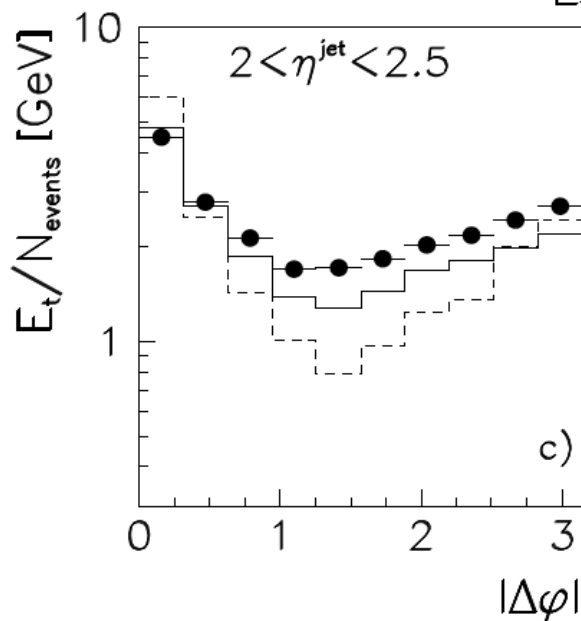
**Trend at HERA may be new, but there is also older measurements:**

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  $E_t$**



**Transverse energy flow.**

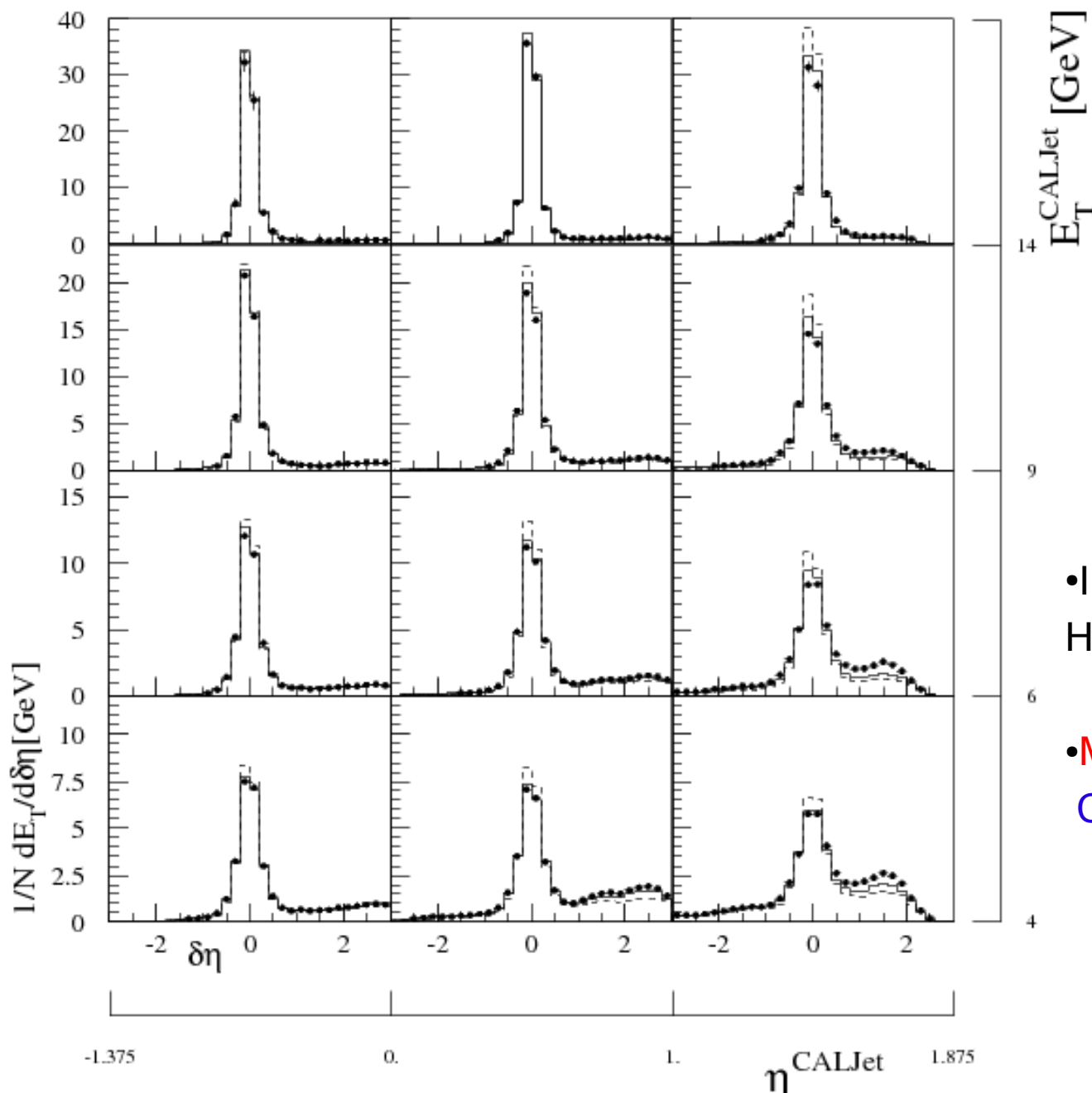
$$|\Delta\phi| = |\phi^{\text{Jet}} - \phi^{\text{Cell}}|$$

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

**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  $E_T$  and jet rapidity

● ZEUS

--- HERWIG no MI

— HERWIG MI

• Insufficient MC model.

HERWIG, no JIMMY: Only pedestal.

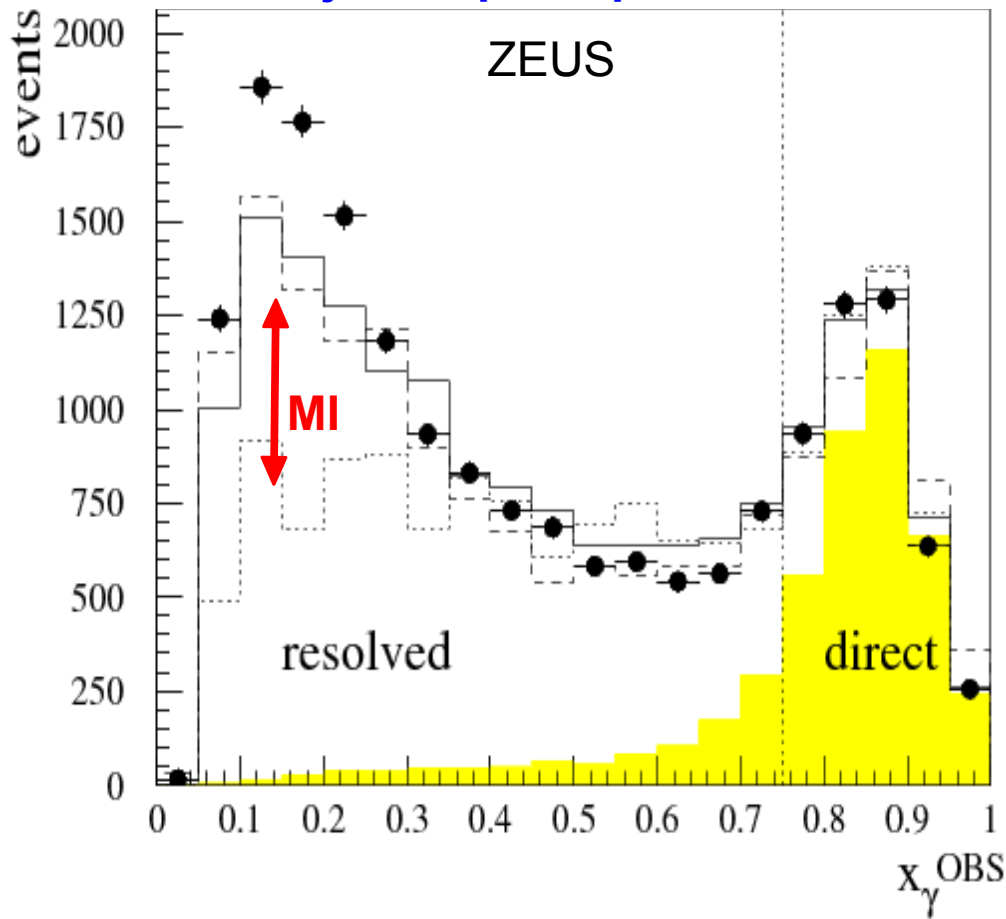
• More UE in forward region.

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

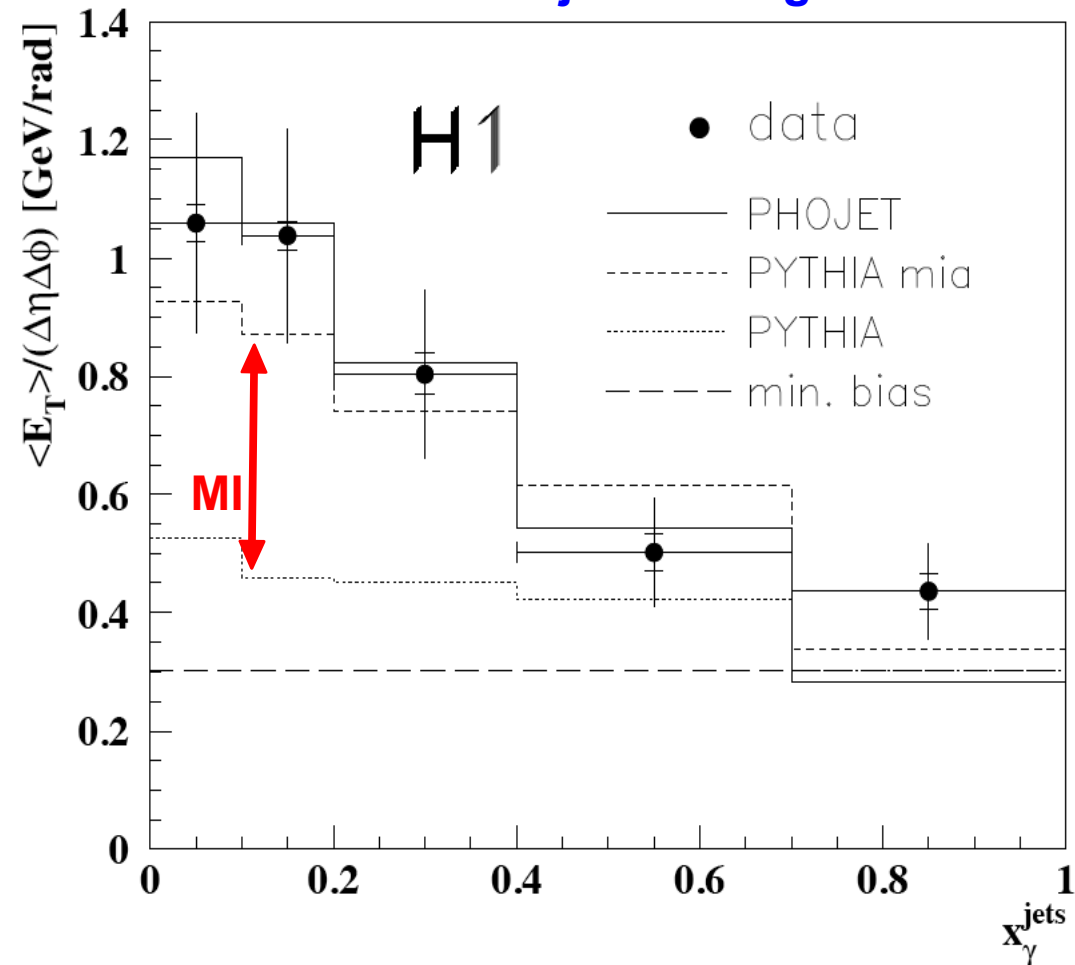


Resolved photon



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

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

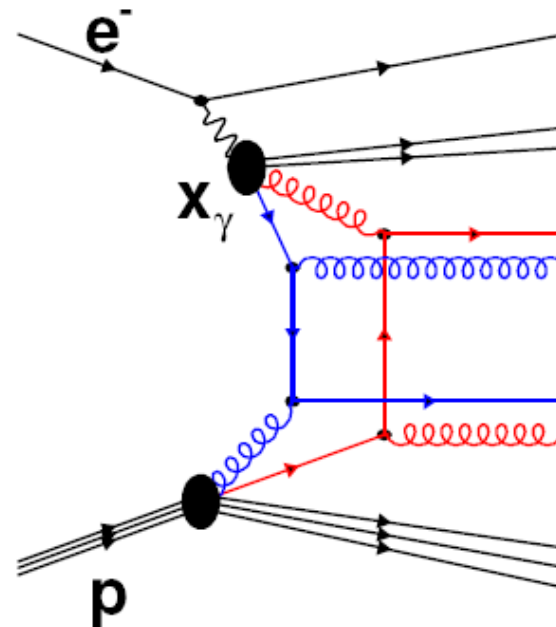
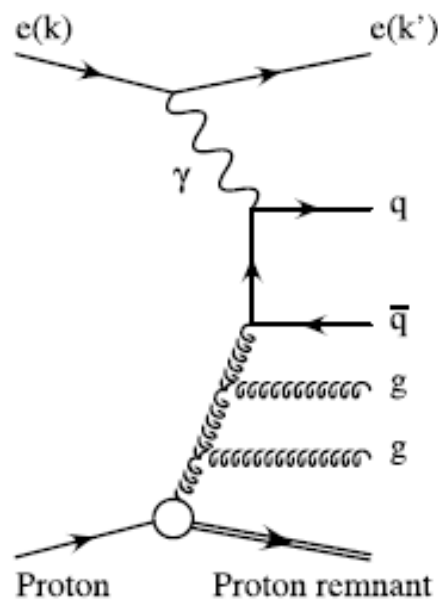


Remnant-remnant interactions

# Multijets in photoproduction

# Multijets in Photoproduction

- Measure 3- and 4-jet final state  $\rightarrow$  Tool to study higher order  $\alpha_s$  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**

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

## **3-, 4-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  $\gamma$ - momentum:  $x_\gamma^{\text{obs}} = \frac{\sum E_{T,i}^{\text{jet}} \exp(-\eta_i^{\text{jet}})}{2yE_e}$

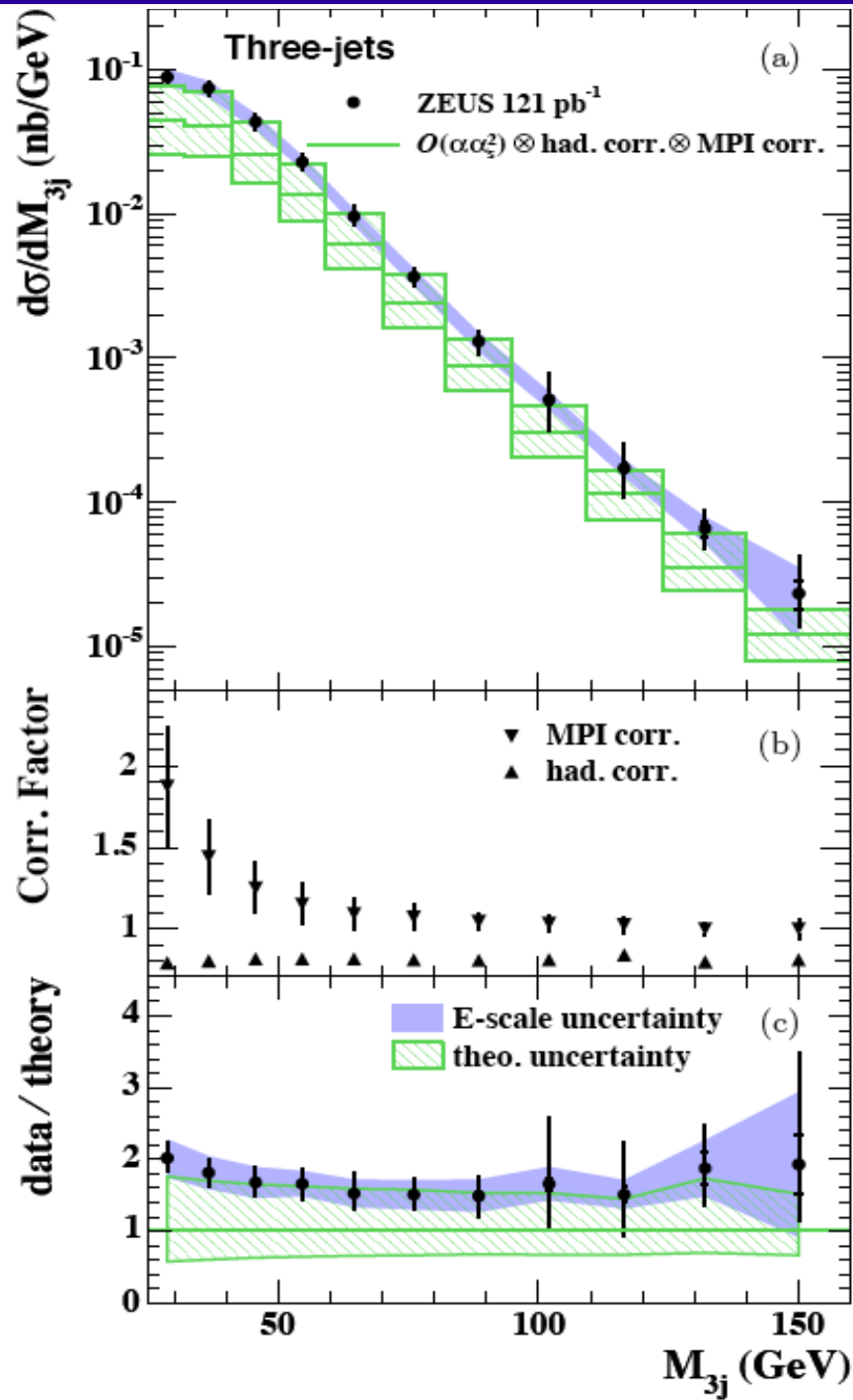
where the sums runs over 3 or 4 jets

## **Measurement**

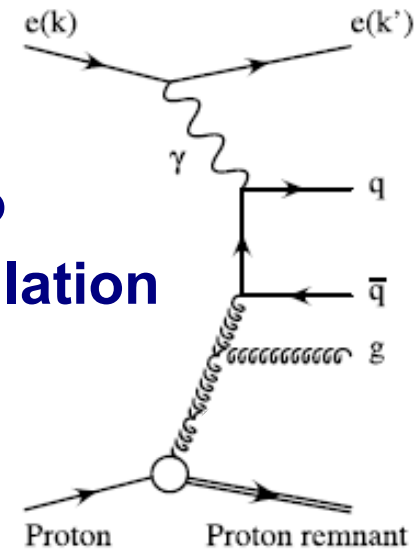
3- and 4-jet cross-sections as a function of several variables and for:

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

# Multijets in Photoproduction



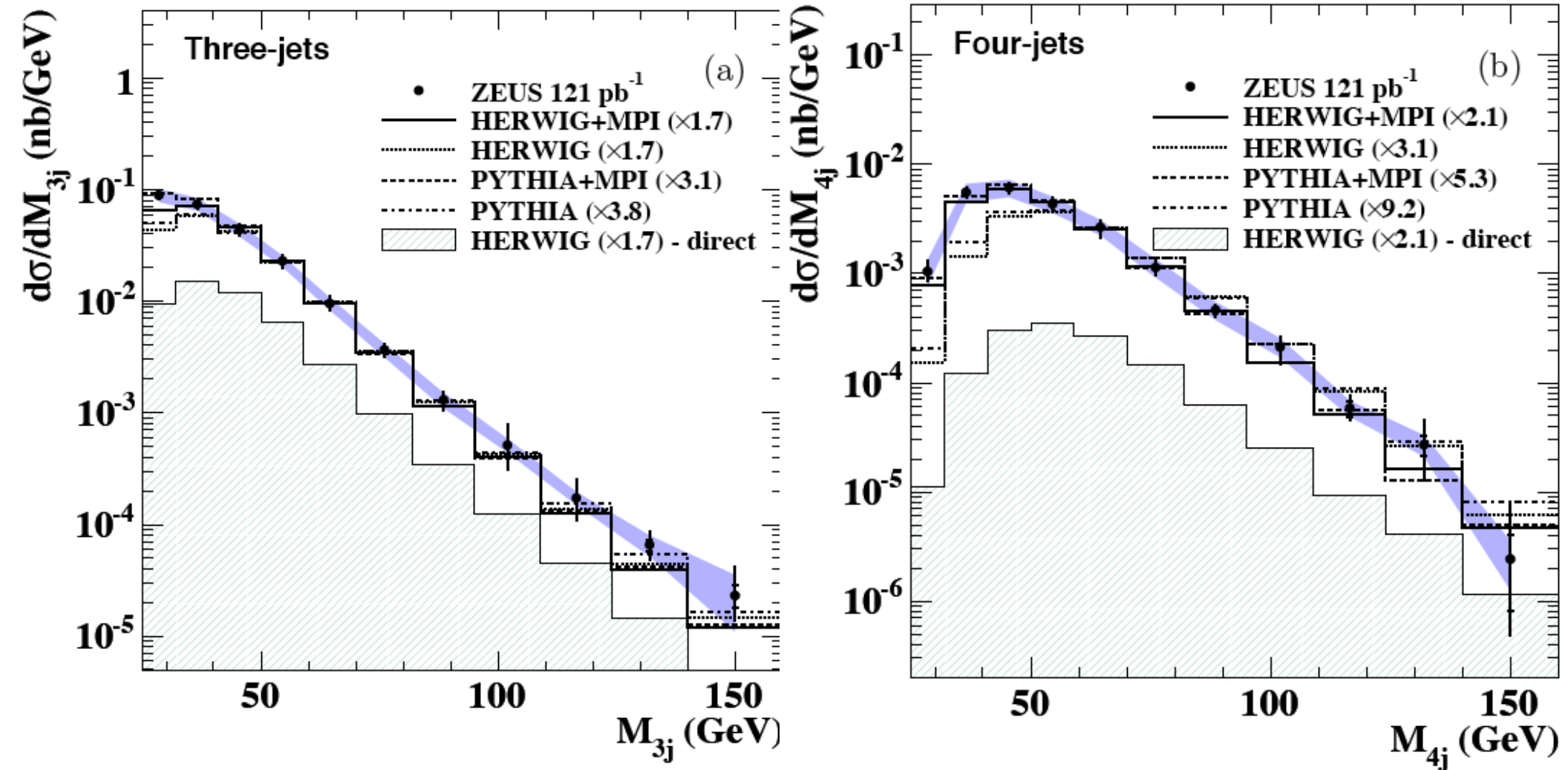
Comparison to  
LO  $O(\alpha\alpha_s^2)$  calculation  
(only for 3 jets)



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

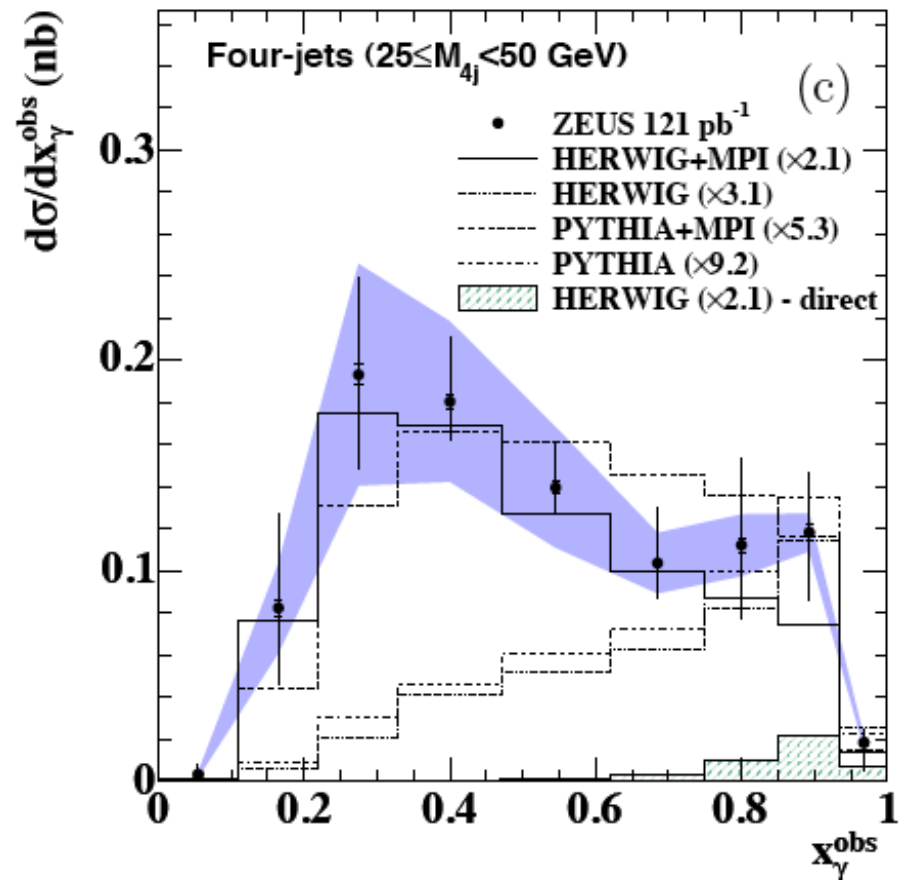
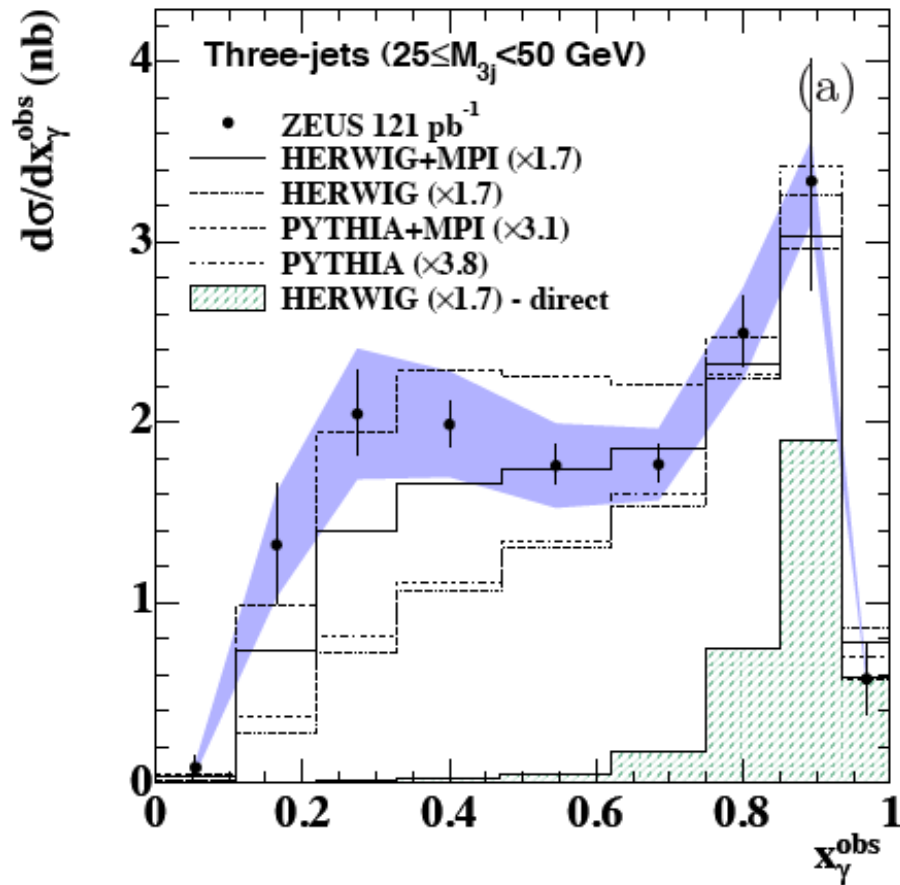


# Multijets in Photoproduction



- 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  $x_\gamma$  (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*

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

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

**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:  $120^\circ < \Delta\phi < 240^\circ$

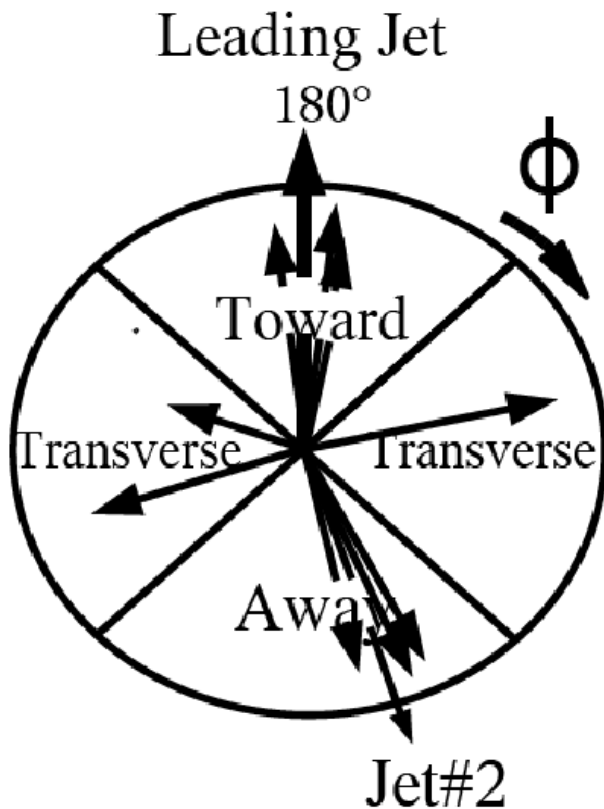
*Defined by the leading jet.*

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

*Often contains the subleading di-jet..*

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

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



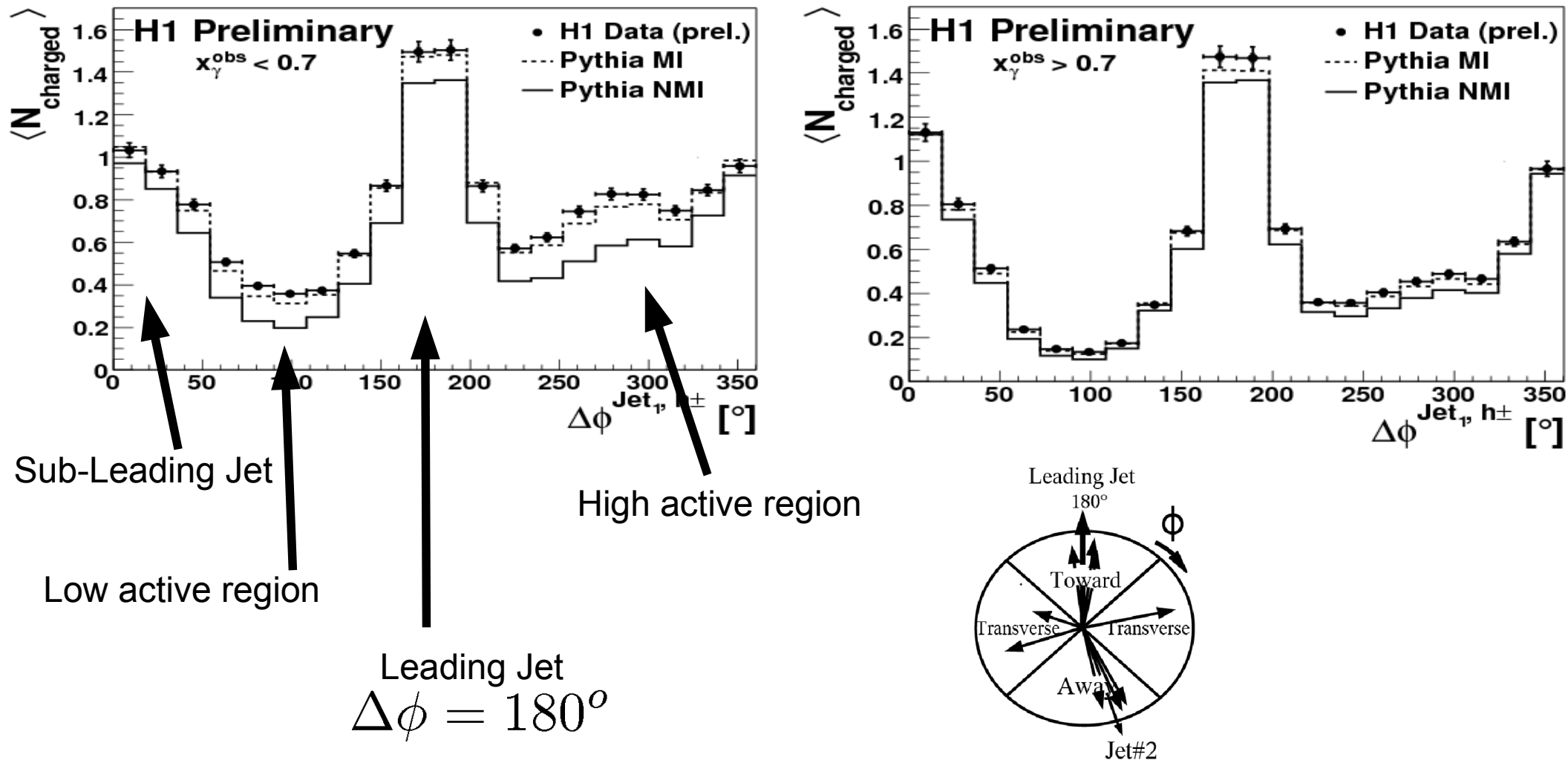
**High active region:  
transverse region with highest**

charged  
particles

$$P_t^{\text{sum}} = \sum_i p_t^i$$

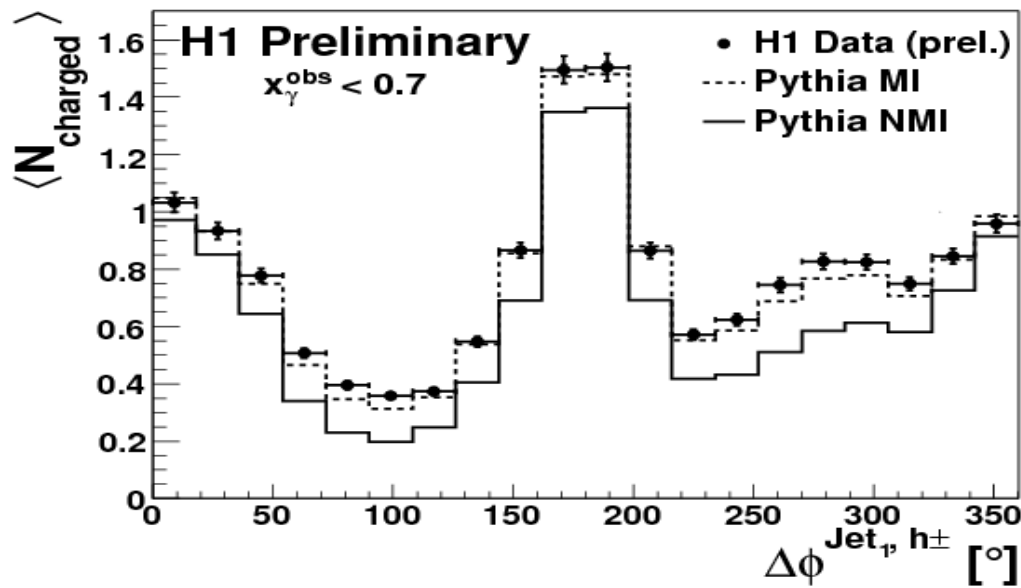
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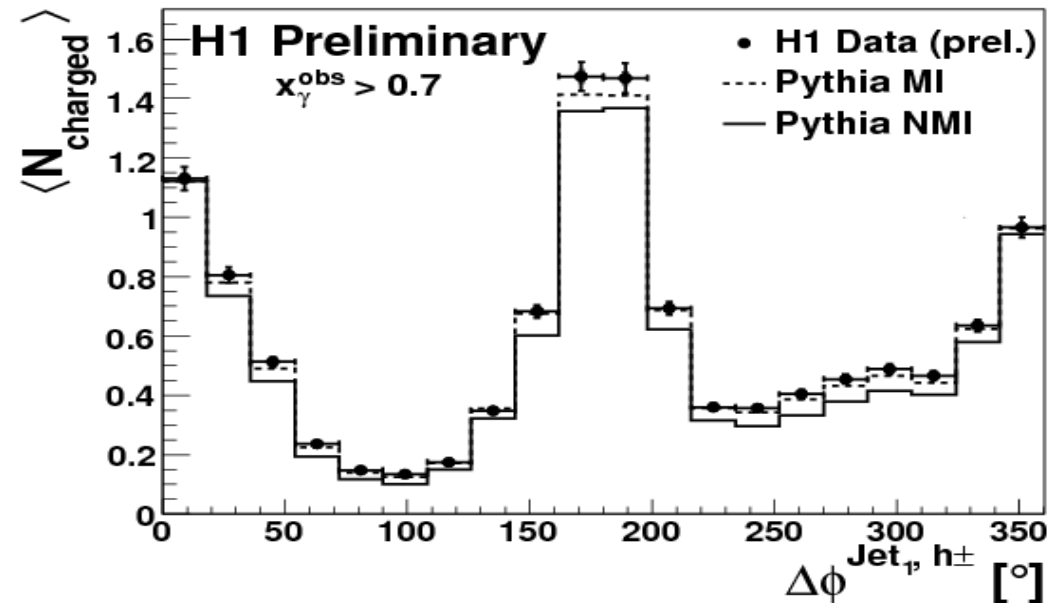


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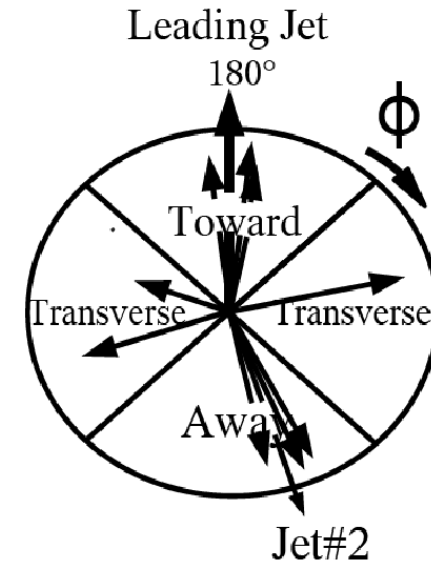
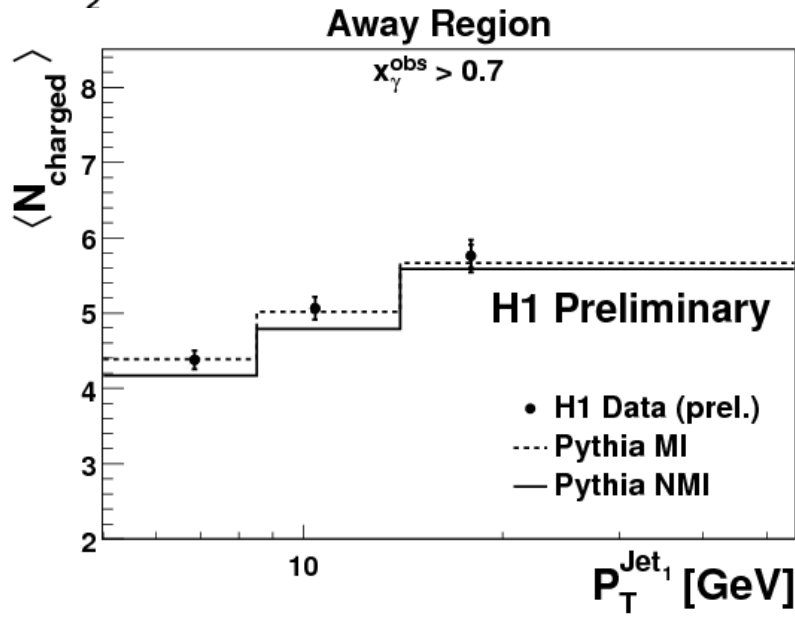
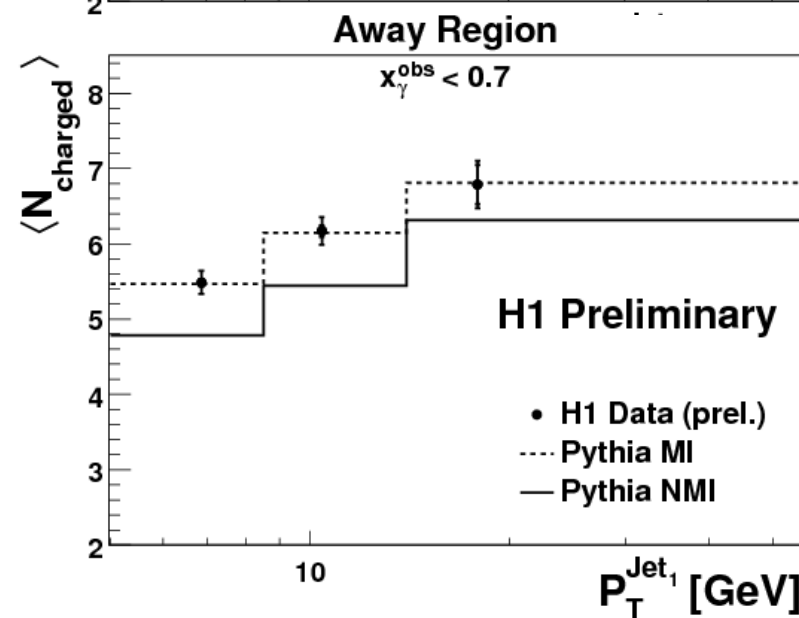
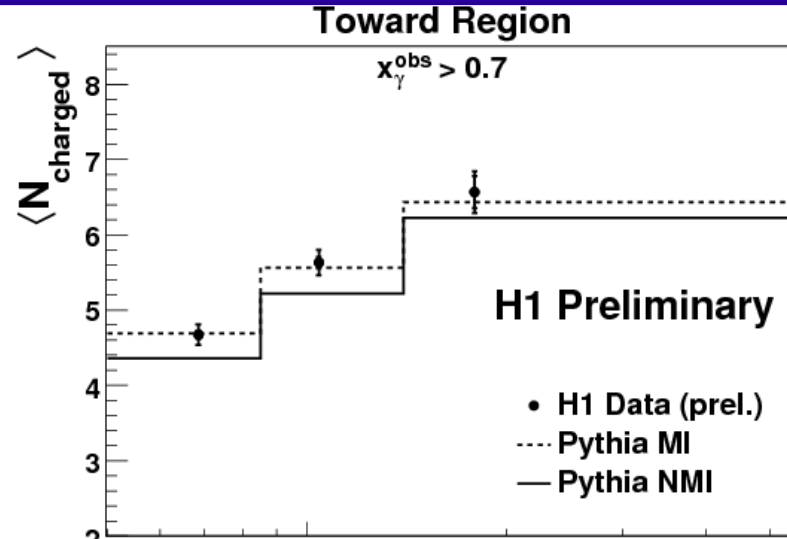
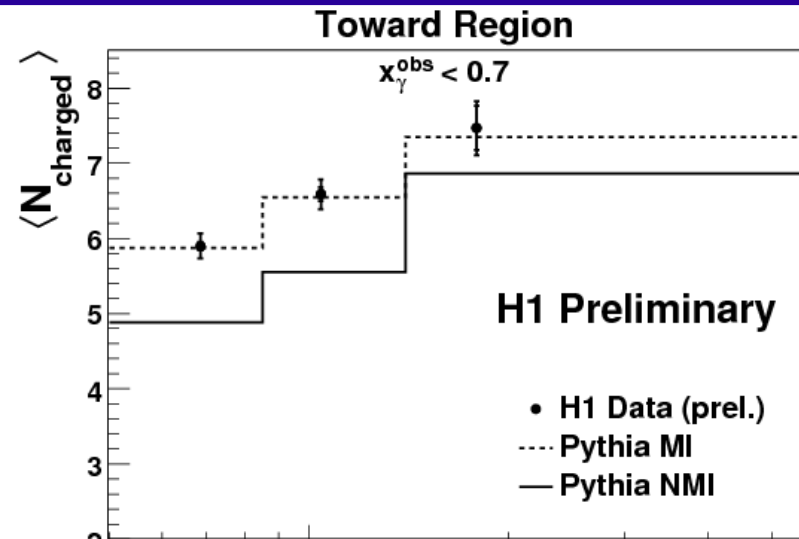
Resolved favoured region



Resolved suppressed region

- Equal amount of charged particles from MI over the full DeltaPhi-range  
    → MI gives pedestal effect ( $\sim 0.1$  particle at low  $x_\gamma$ )

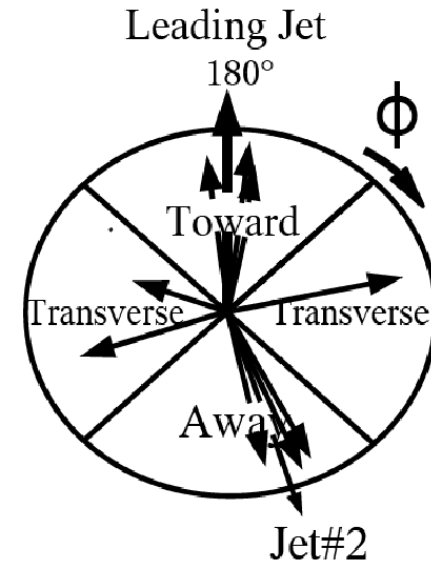
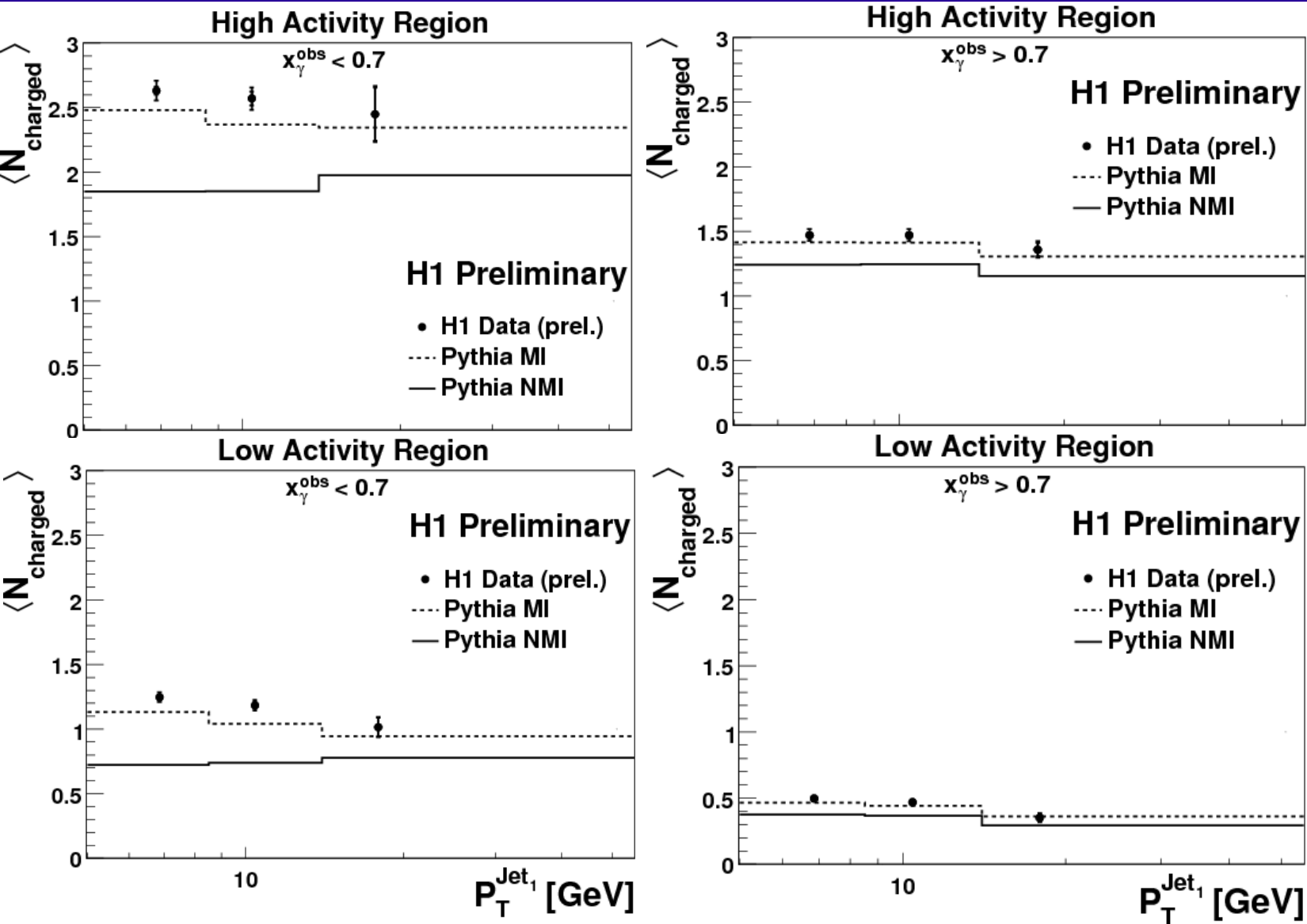
# Charge particle flow in photoproduction



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



# Charge particle flow in photoproduction



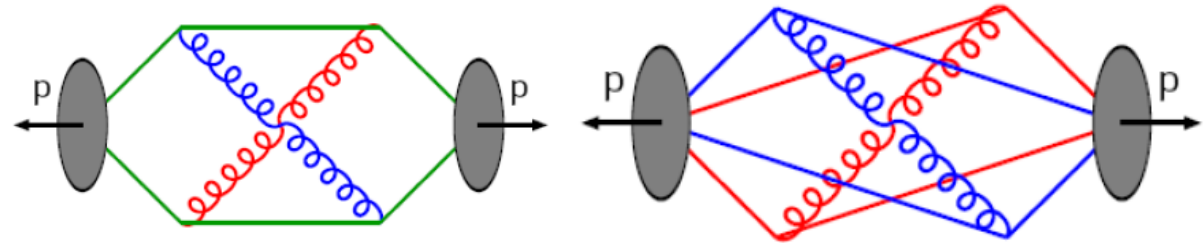
• MI important in transverse regions

• ... but no perfect description of data... but we can tune the MI model...

# Charge particle flow in photoproduction

## Tuning attempt

Different colour correlation scenarios:  
**Long or Short Colour Strings**



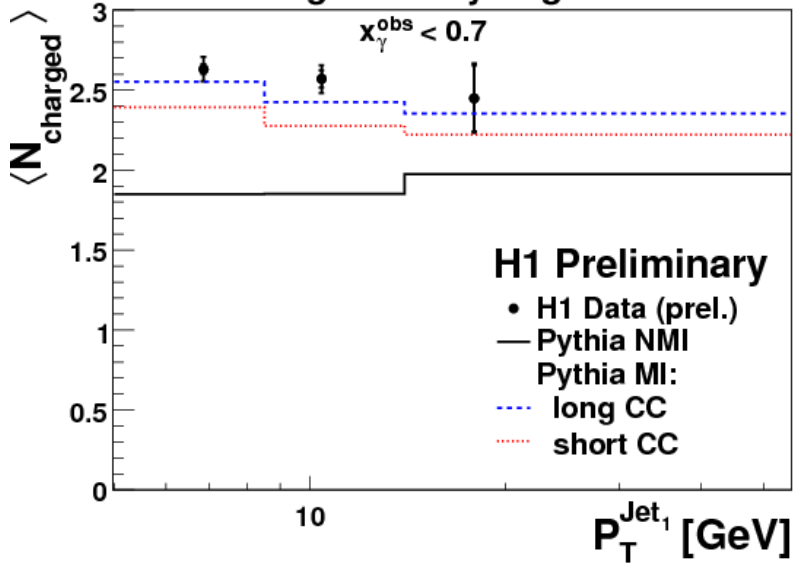
**Data seem to prefer long colour strings.**  
 This is *opposite to the TEVATRON tunes*.

**Now much better description of data.**

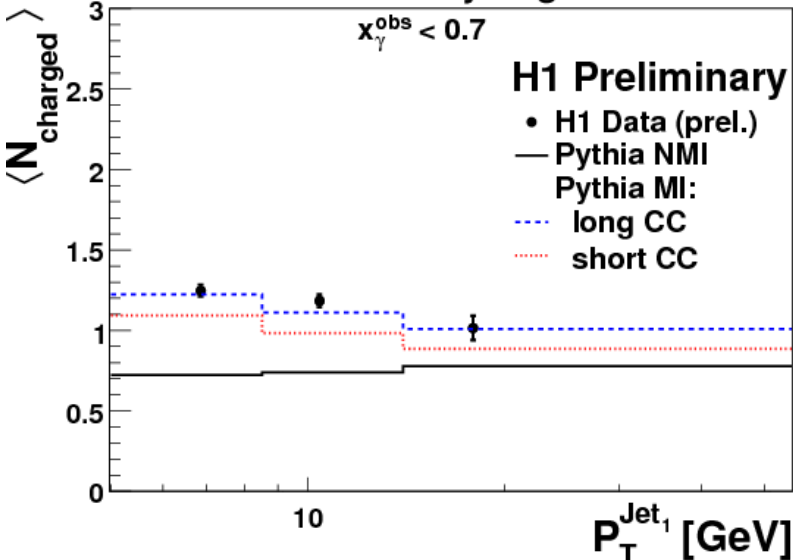
PARP(85) – Probability for MI to produce 2 gluons with colour string to closest neighbour.  
 Default: 0.9 -> Tuned: 0.33

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

### High Activity Region



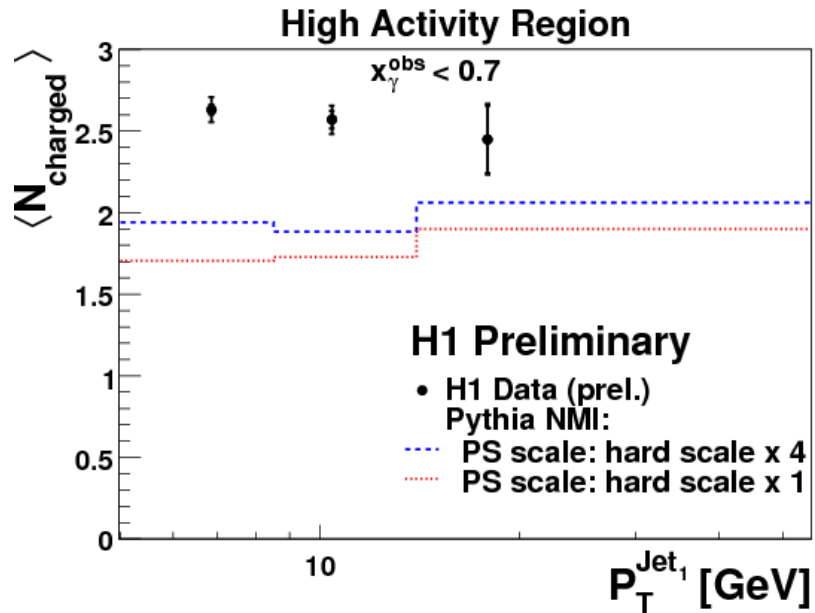
### Low Activity Region



Doesnt change MC at high  $x_\gamma$  (Not shown)

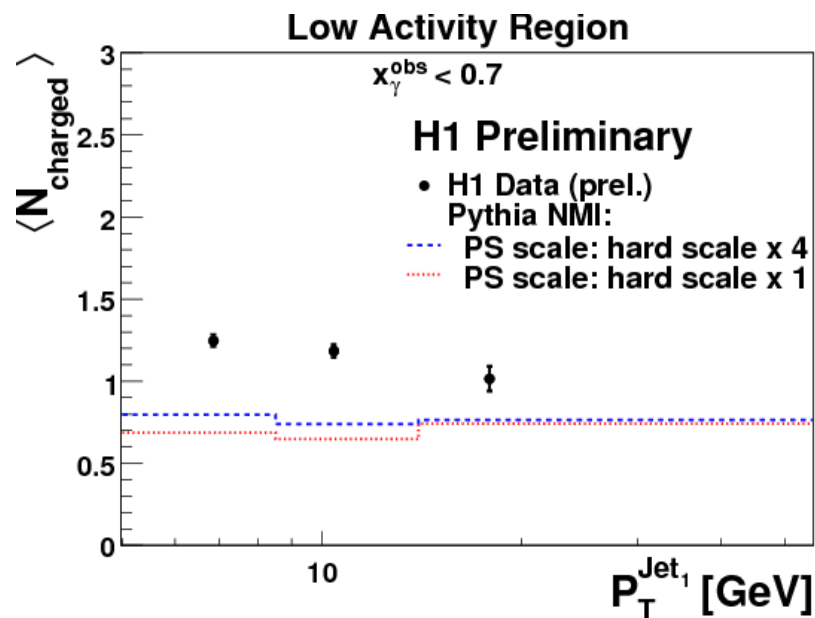
# Charge particle flow in photoproduction

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.

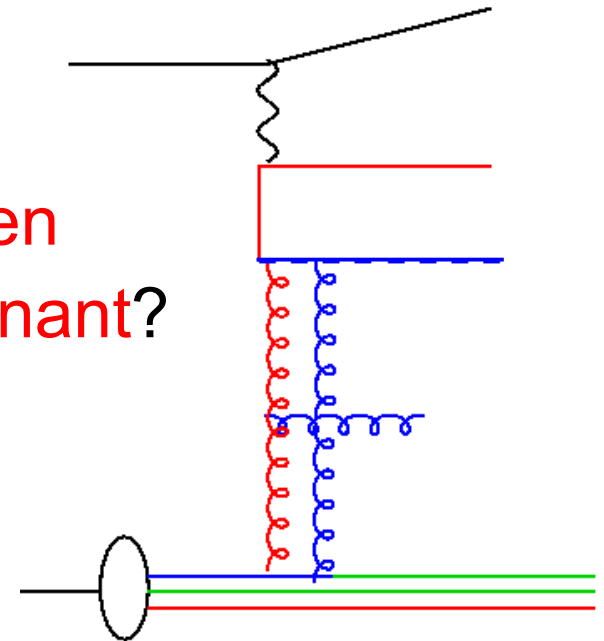
# Minijets in DIS

# Mini jets in DIS

- Photoproduction → large resolved photon component
  - as seen **remnant-remnant interactions** (MI)  
very important

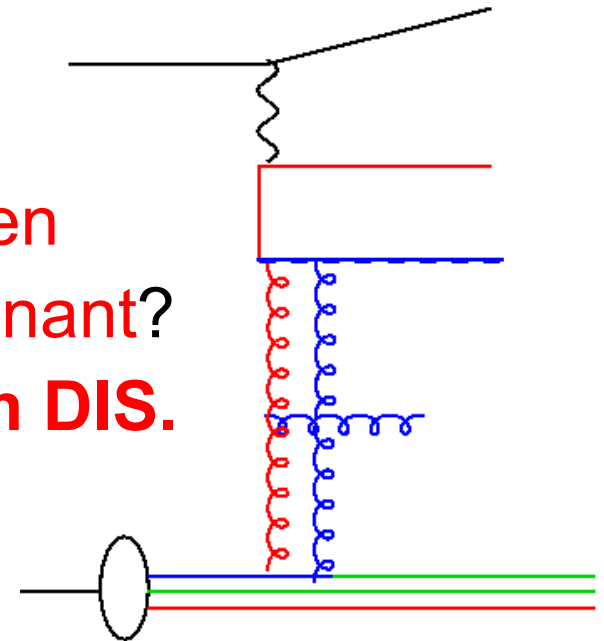
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**very important**
- MI in DIS where the resolved photon component is much smaller?
  - additional **interactions between hard reaction and proton remnant?**



# 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

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

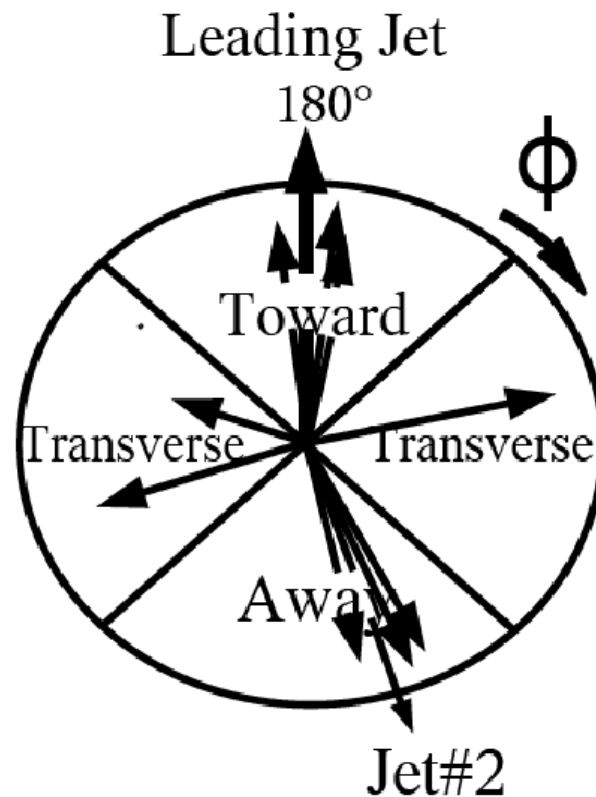
## Jet Selection

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

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

## Mini Jet Selection

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



Measure  $\langle N_{Minijets} \rangle = \frac{\sum^{N_{events}} N_{Minijet}}{N_{events}}$  in bins of

$Q^2$  and  $\eta_1^{jet}$  as a function of  $P_{T,1}^{jet*}$



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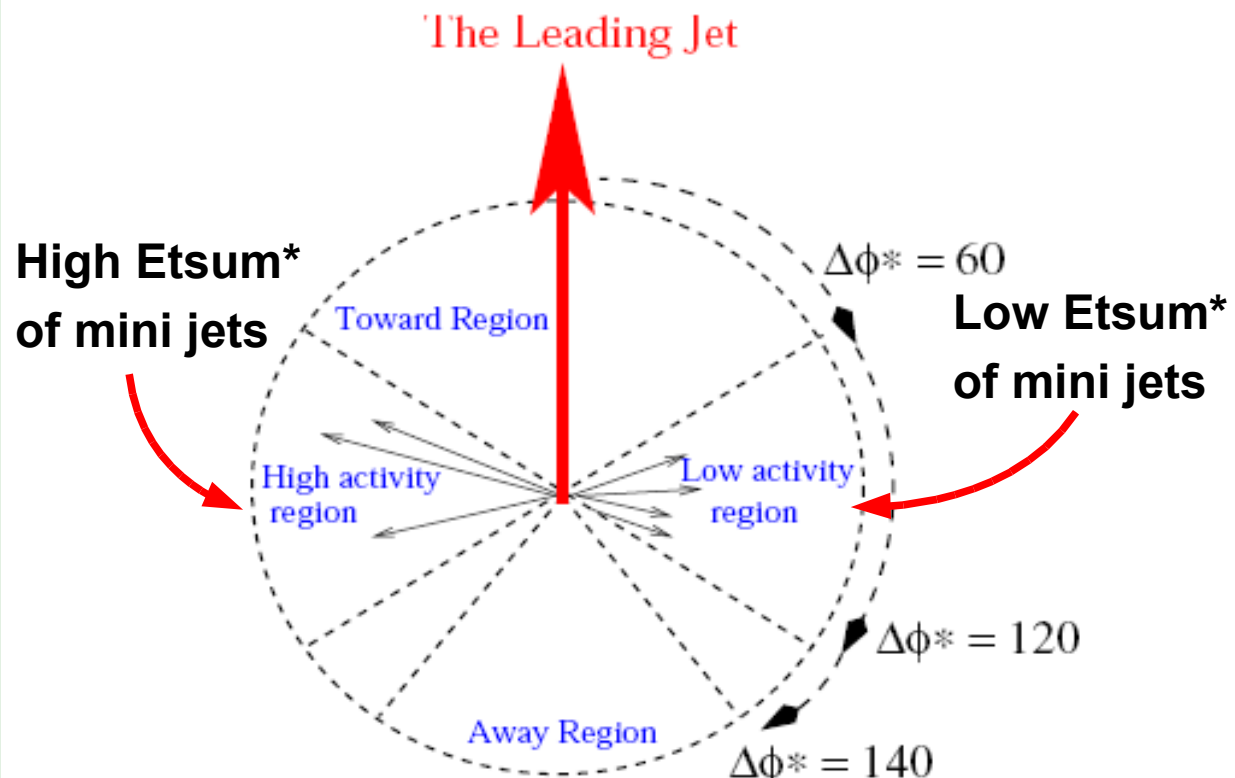
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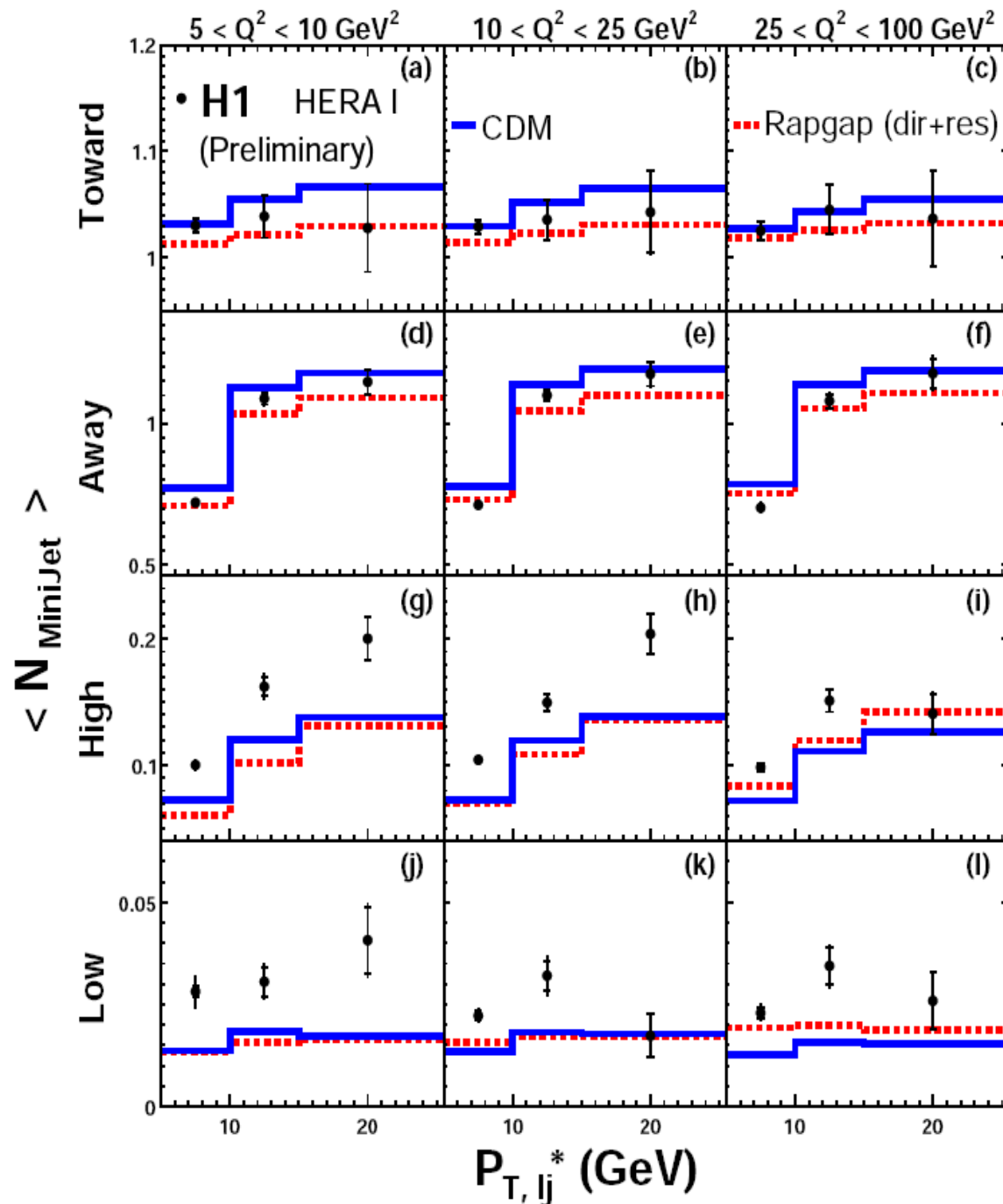
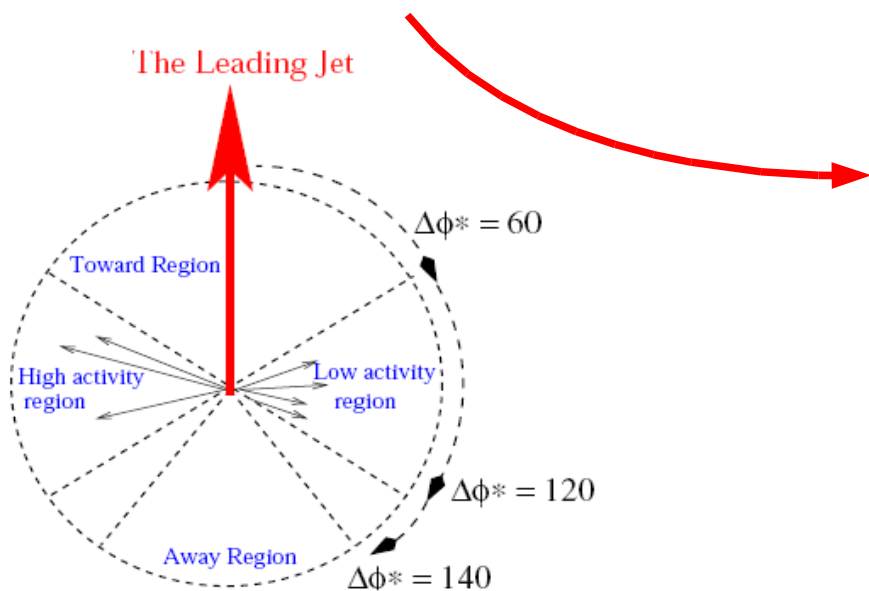
**Inclusive 1 jet sample**

**and**

$$-1.7 < \eta^{jet} < 0.5$$

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

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

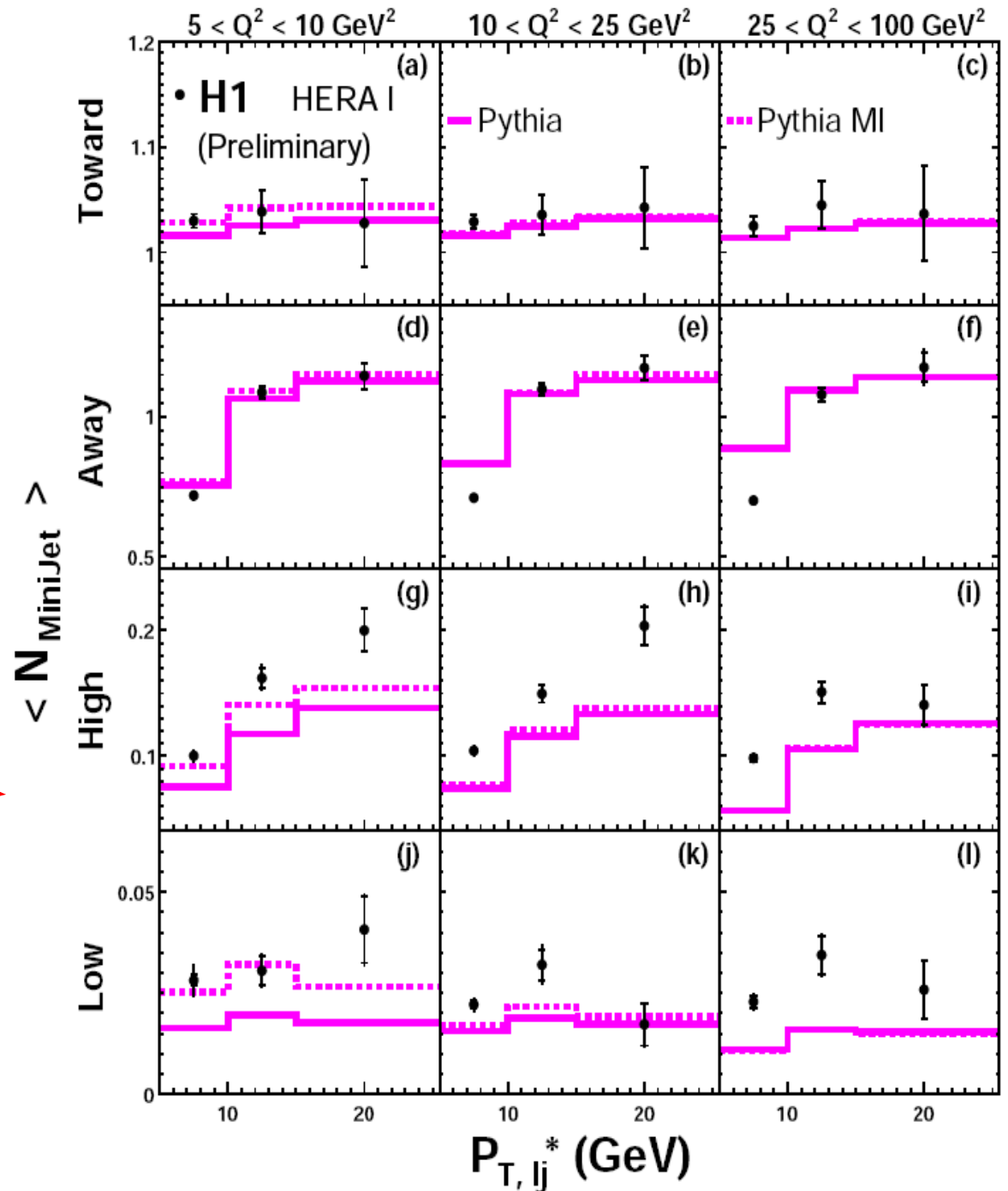


# Mini jets in DIS

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

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



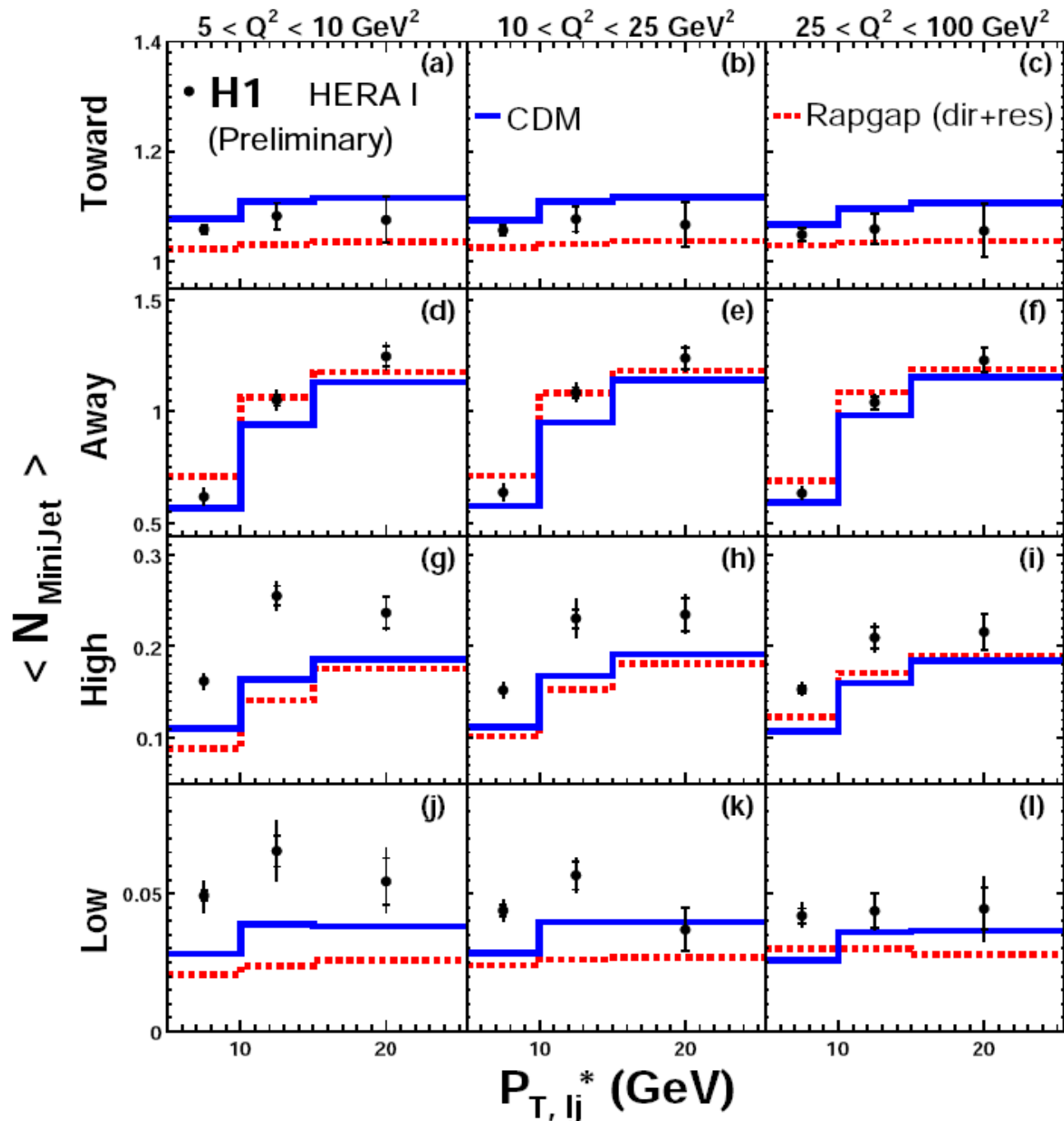
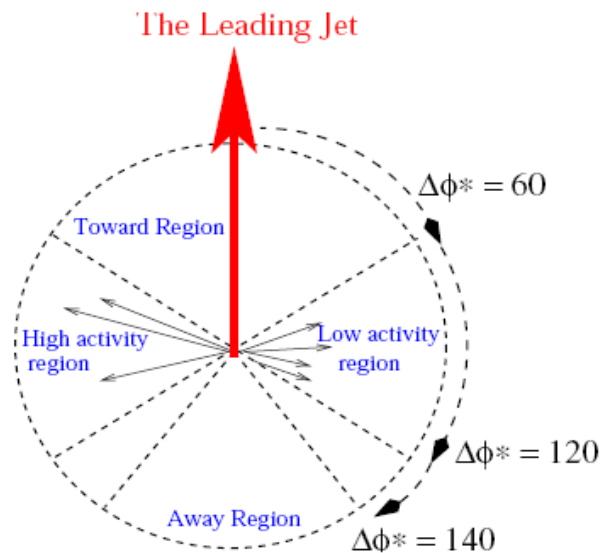
# Mini jets in DIS

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



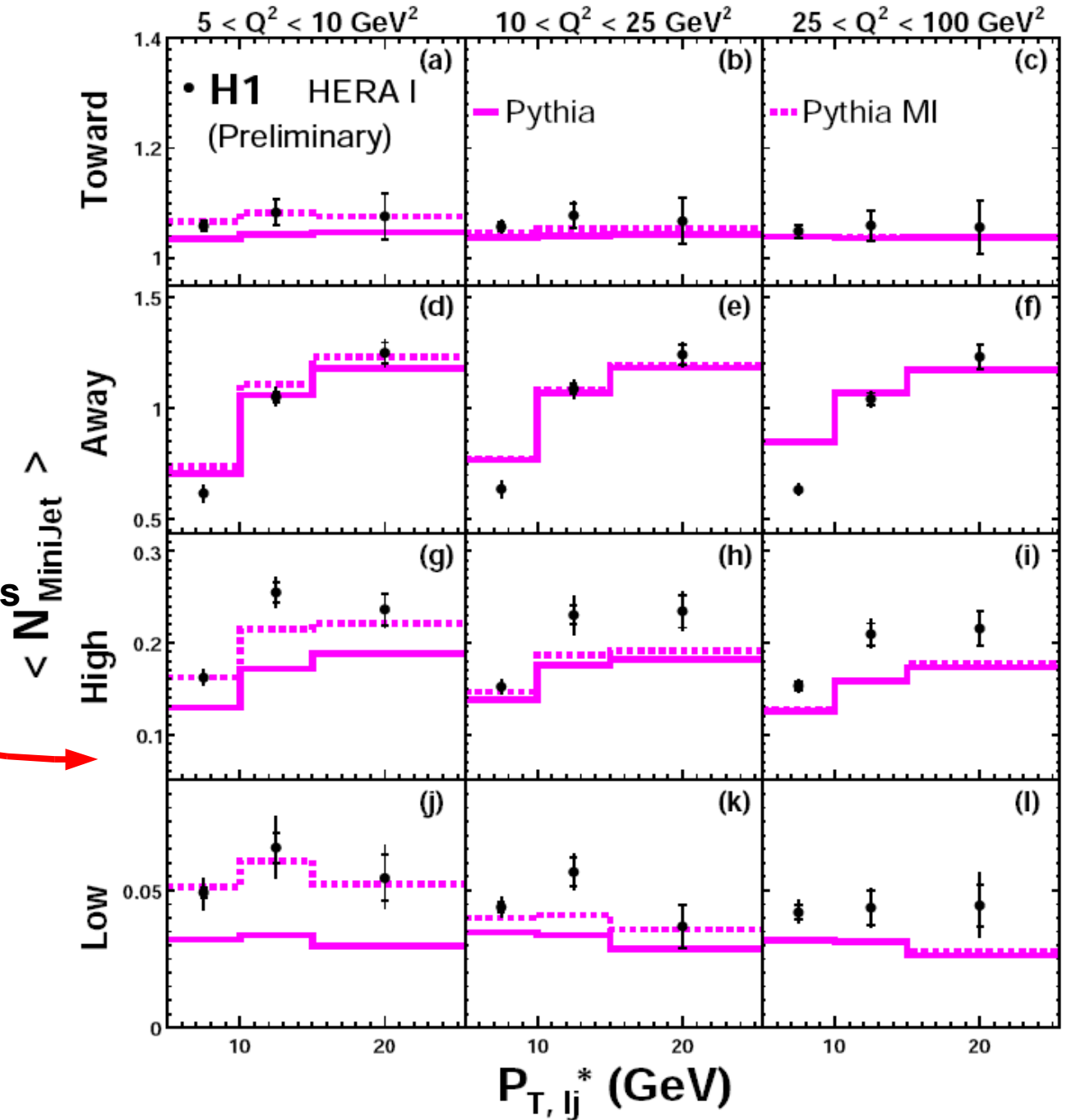
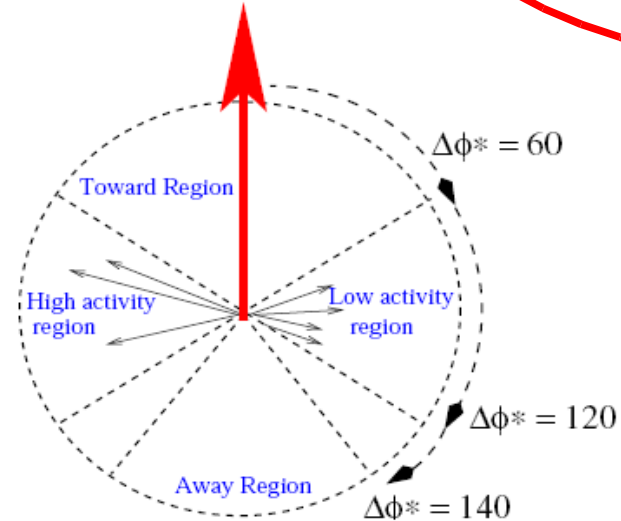
# Mini jets in DIS

Inclusive 1 jet sample  
and

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

• Activity from MI  
improves description of data  
at low  $Q^2$  in transverse regions

The Leading Jet



# 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.  $\gamma$  contribution is large
- More difficult situation. Low resolved photon component

***Insufficient MC model – only remnant-remnant interaction***

***More activity needed in UE***

# Summary

 HERA can help to understand the UE

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***More activity needed in UE***

 Open theoretical issue