

Multiple Parton Interactions in PhotoProduction at HERA



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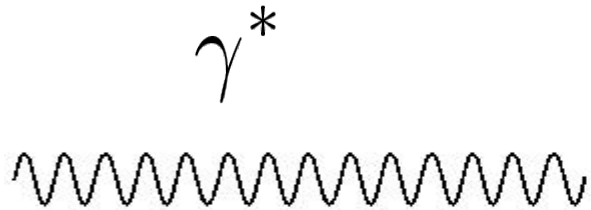
Lluís Martí Magro

1st MPI@LHC, Perugia. 27th of October, 2008.

Introduction & Motivation

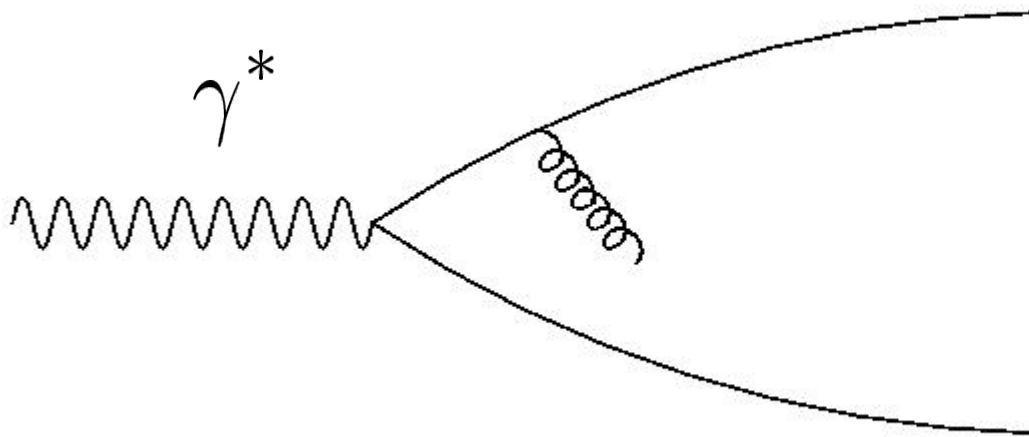
Introduction & motivation

x At high virtualities, Q^2 , the photon is a **point-like** particle



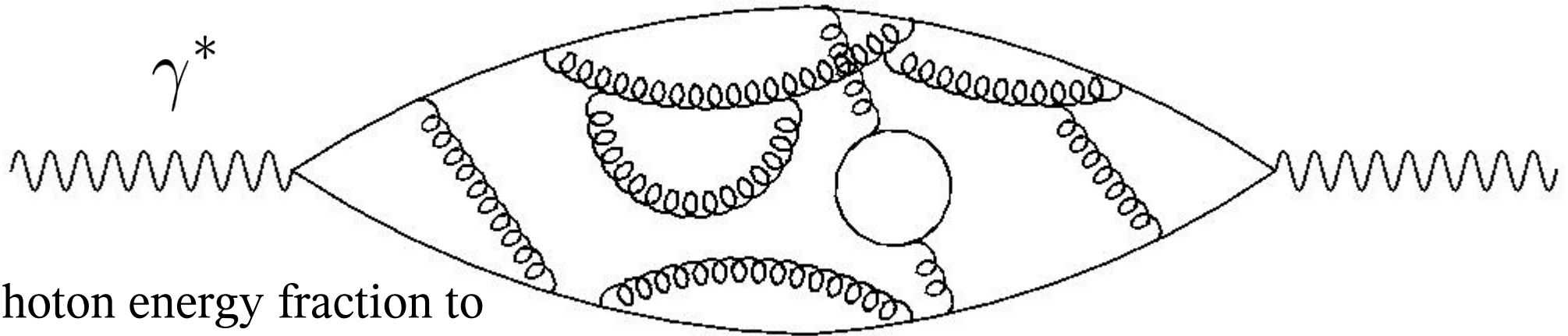
Introduction & motivation

✗ while going to **lower virtualities** the photon lives longer and may fluctuate into a quark-anti quark pair



Introduction & motivation

x in photoproduction the photon lives enough to develop a complicated hadronic structure.



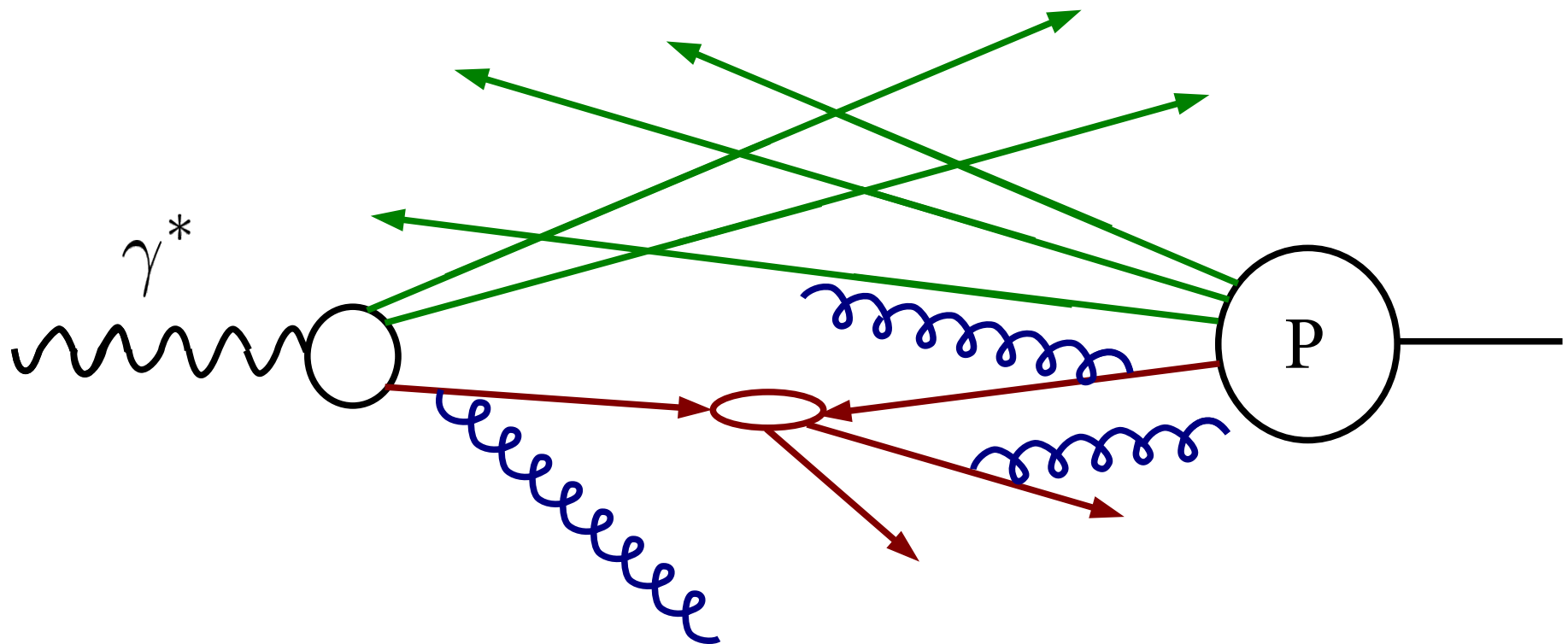
photon energy fraction to enter in the hard interaction

$$X_{\gamma}^{\text{obs}} = \frac{\sum_{i=1}^{N_{\text{jets}}} E_{\text{T}}^{\text{jet}_i} e^{-\eta^{\text{jet}_i}}}{2 E_{\gamma}}$$

- high values correspond to point-like photons
- low values correspond to resolved photons

Introduction & motivation

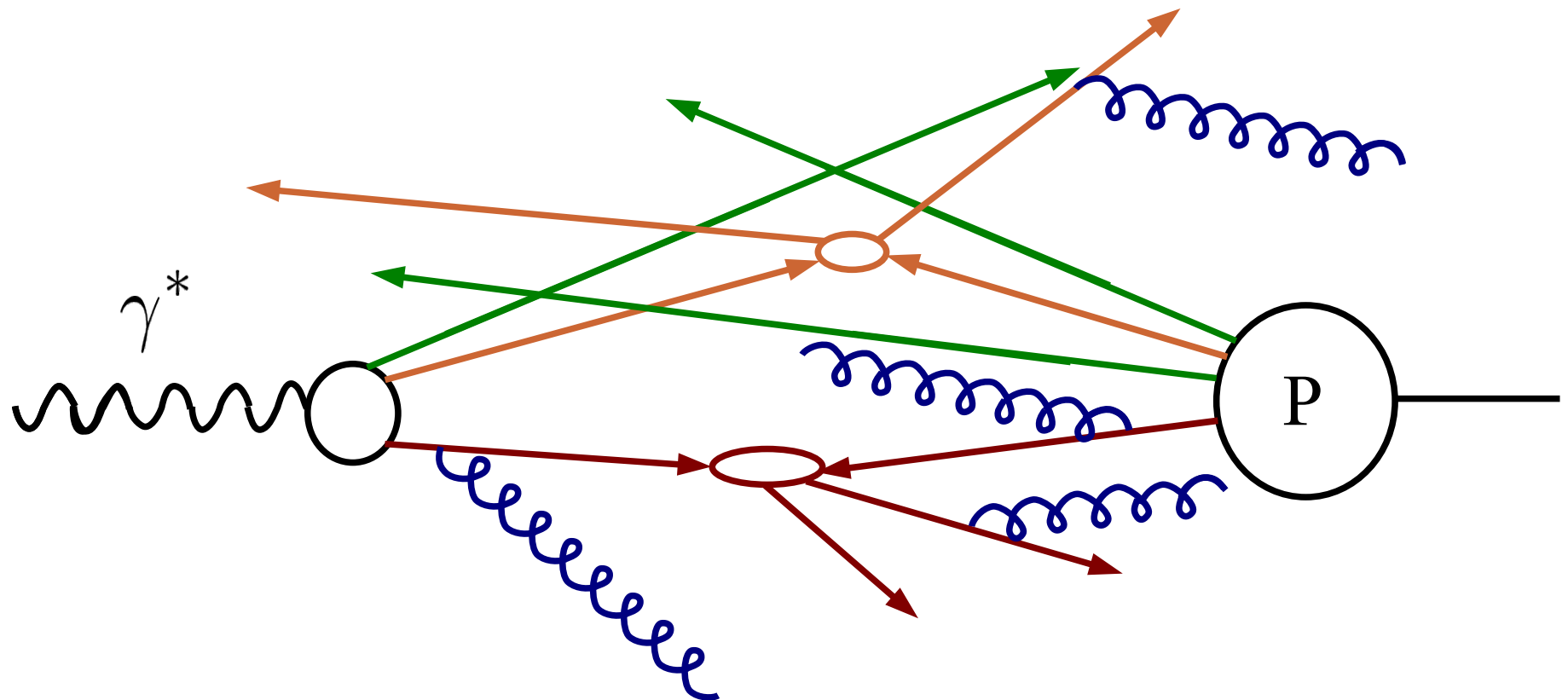
In ep we have a similar situation to the hadron-hadron collisions



there are remnants from the photon and the proton side

Introduction & motivation

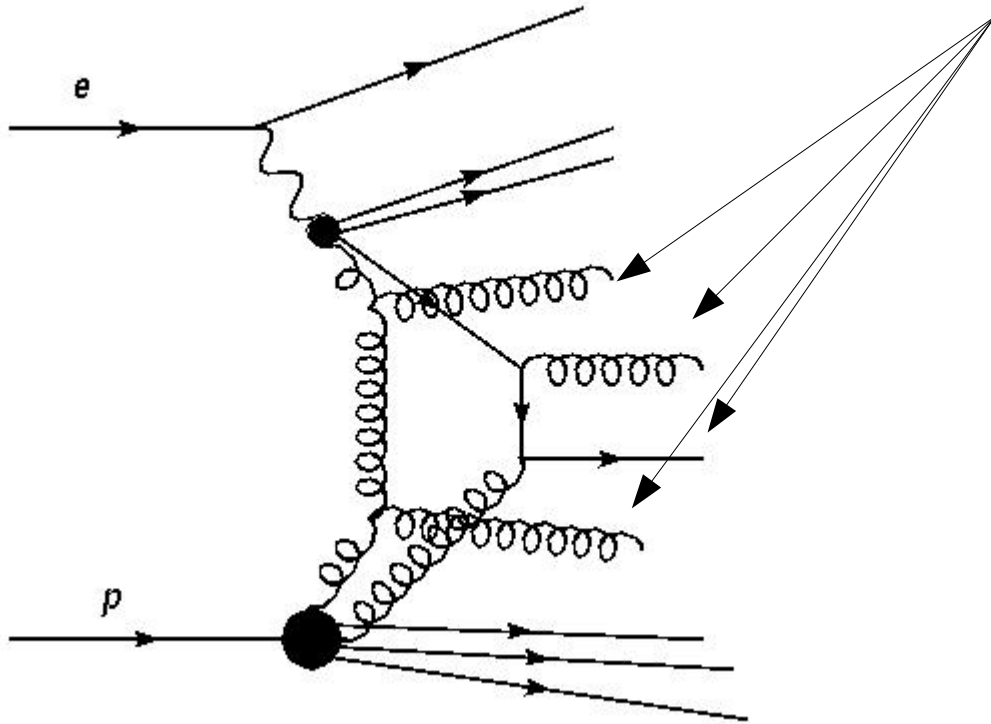
x and partons from the remnants can interact



Multiple parton interactions

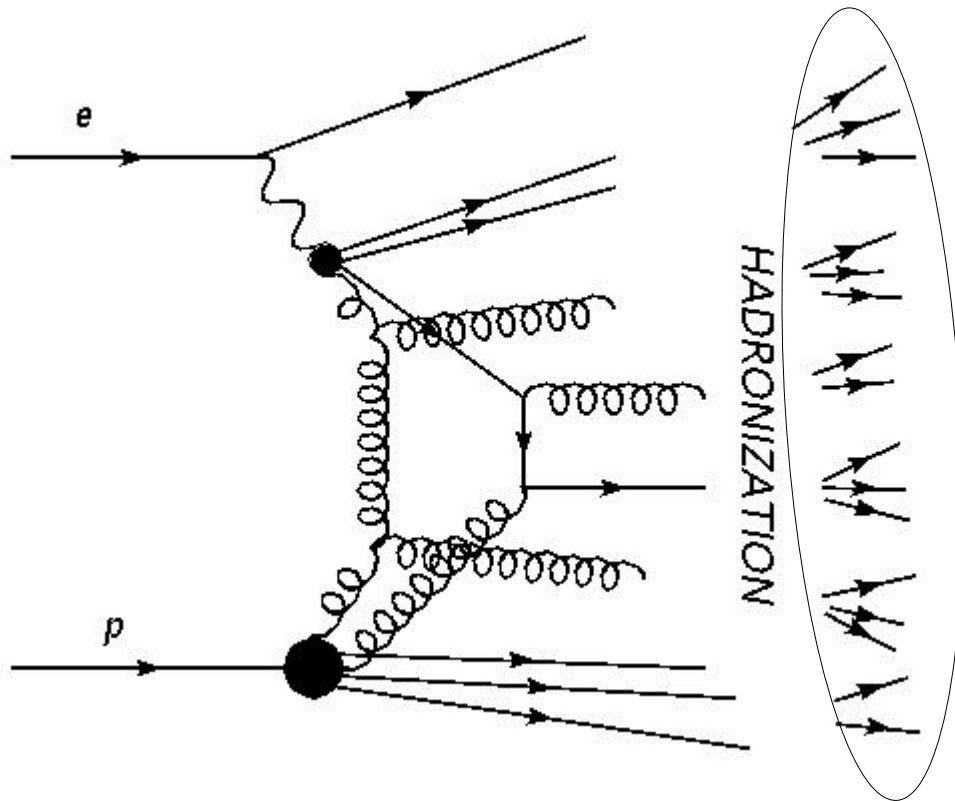
Observables:

- **Hard MPI** in multi jet events: three or more jets with high P_T



Multiple parton interactions

Observables:



- **Hard MPI** in multi jet events: three or more jets with high P_T

- **Soft MPI**: charged particles, low P_T jets, energy flow....

Monte Carlo

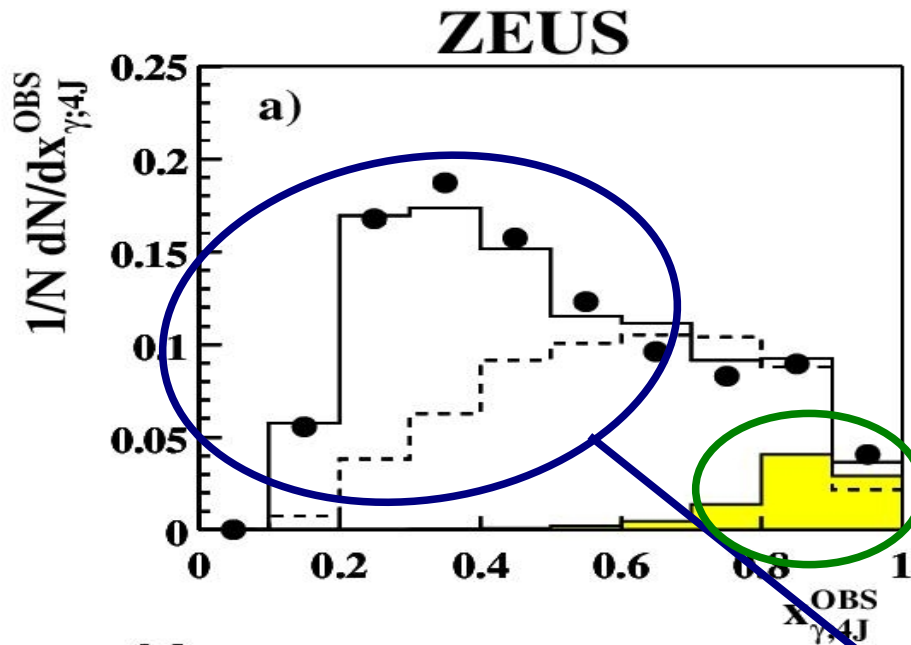
- ✓ **PYTHIA:** LO ME + DGLAP PS
(semi-)hard MPI + different string scenarios for hadronization
- ✓ **HERWIG:** LO ME + DGLAP PS
MPI from JIMMY. With impact parameter dependence. Similar to PYTHIA
- ✓ **CASCADE:** off shell LO ME + CCFM PS (no resolved photon, no MPI model implemented)
- ✓ **CDM:** LO ME + PS from the Color Dipole Model(no MPI impl.)
- ✓ **RAPGAP:** LO ME + DGLAP PS (no MPI implemented)

HERA

Past

HERA present

4 jets events at ZEUS

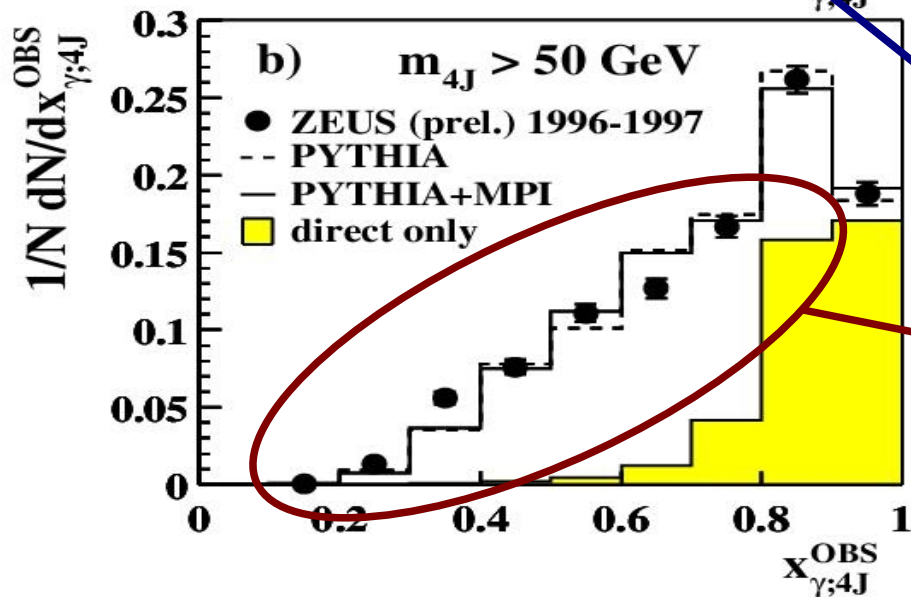


Photoproduction $Q^2 < 1 \text{ GeV}^2$

4-jet events: $E_T^{\text{jet}1,2} > 6 \text{ GeV}$ $E_T^{\text{jet}3,4} > 5 \text{ GeV}$

$$|\eta^{\text{jets}}| < 2.4$$

The direct photon component contributes only at high X_γ values



At low X_γ data can be described when including **MPI**

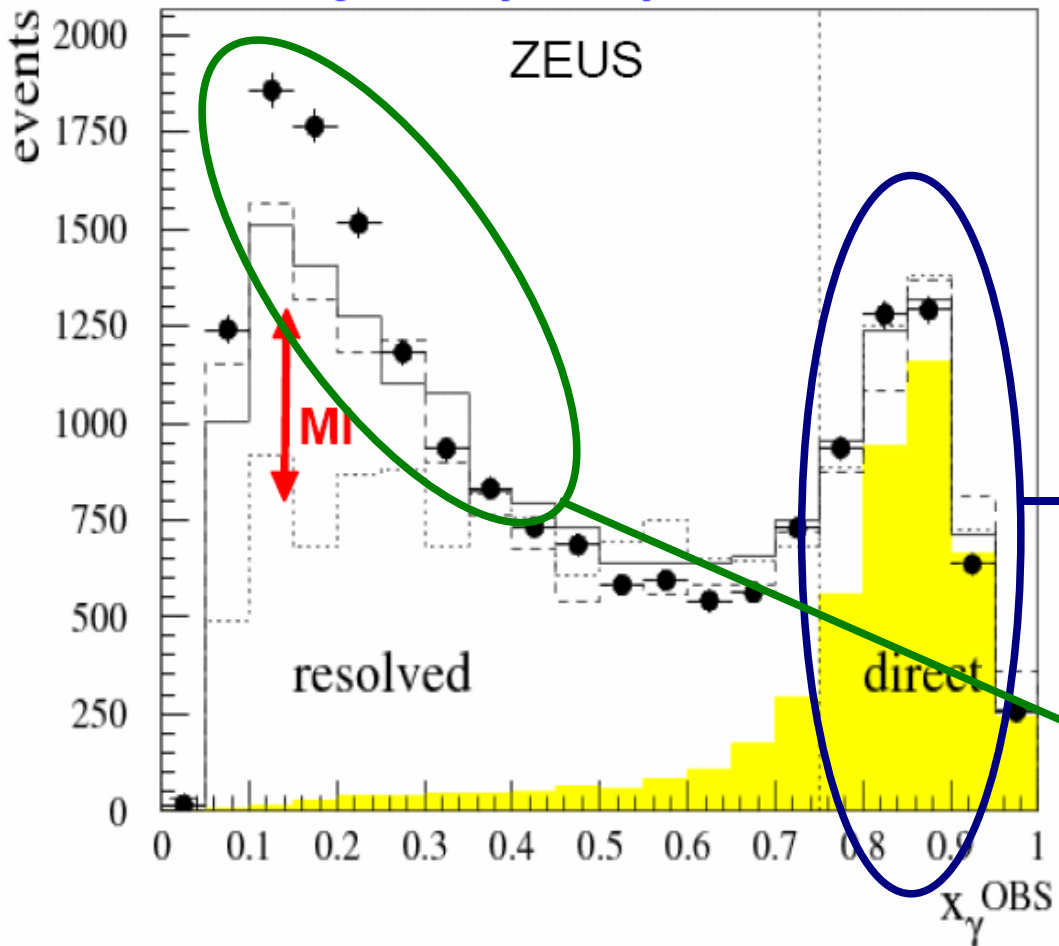
For an invariant mass of $M_{4J} > 50 \text{ GeV}$ the MPI contribution vanishes

“Multijets in photoproduction at HERA” XXXI International Conference of High Energy Physics, abstract 849

HERA present

dijets events at ZEUS

Di-jets in photoproduction



Photoproduction $Q^2 < 4 \text{ GeV}^2$

2-jet events: $E_T^{\text{jet}1,2} > 6 \text{ GeV}$

$-1.375 < \eta^{\text{jets}} < 1.875$

direct component – no large differences between MCs

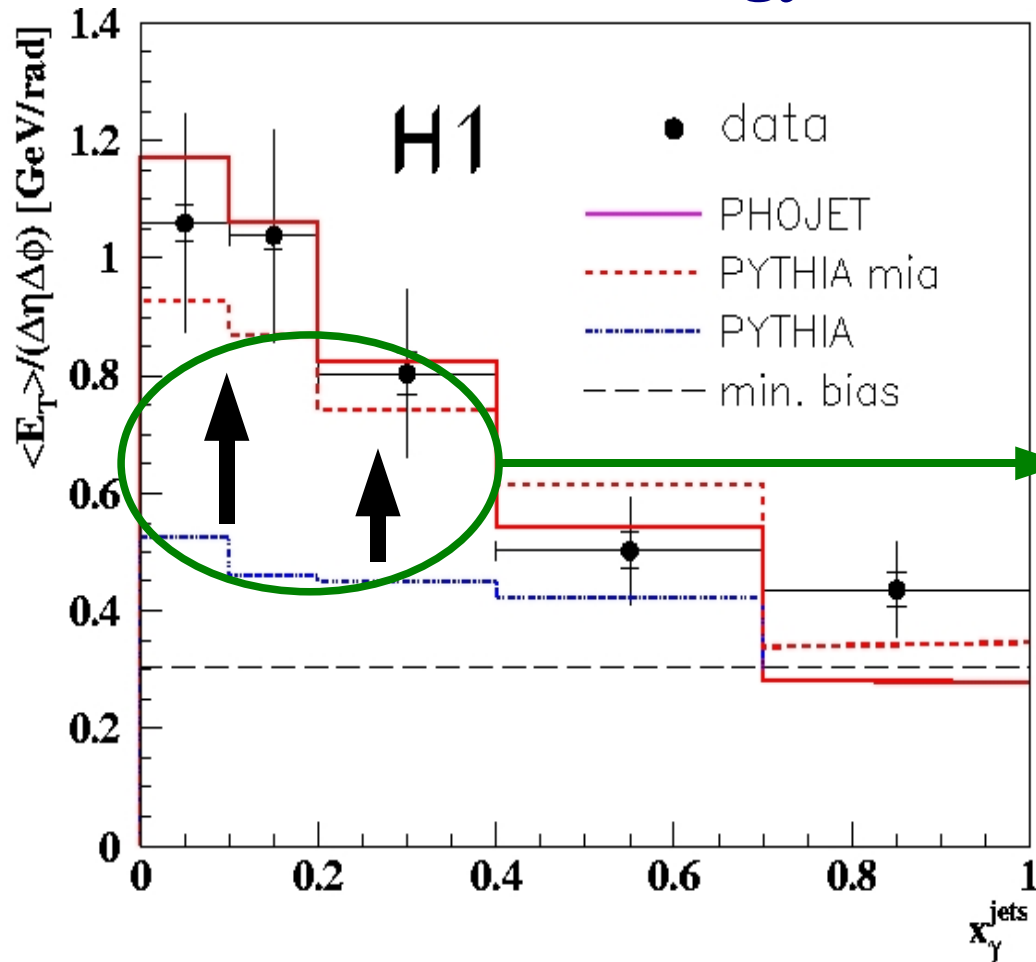
including MPI we get a much better data description

“Dijet Cross Sections in Photoproduction at HERA”

Eur.Phys.J.C1:109-122,1998

HERA present

Energy flow outside jets at H1



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

At least one jet ($E_T^{\text{jet}} > 5 \text{ GeV}$

$-1 < \eta^{\text{jet}} < 2.5$)

The transverse energy density outside the jets can be described when MPI are simulated.

“Jets and Energy Flow in Photon-Proton Collisions at HERA” hep-ex/9511012

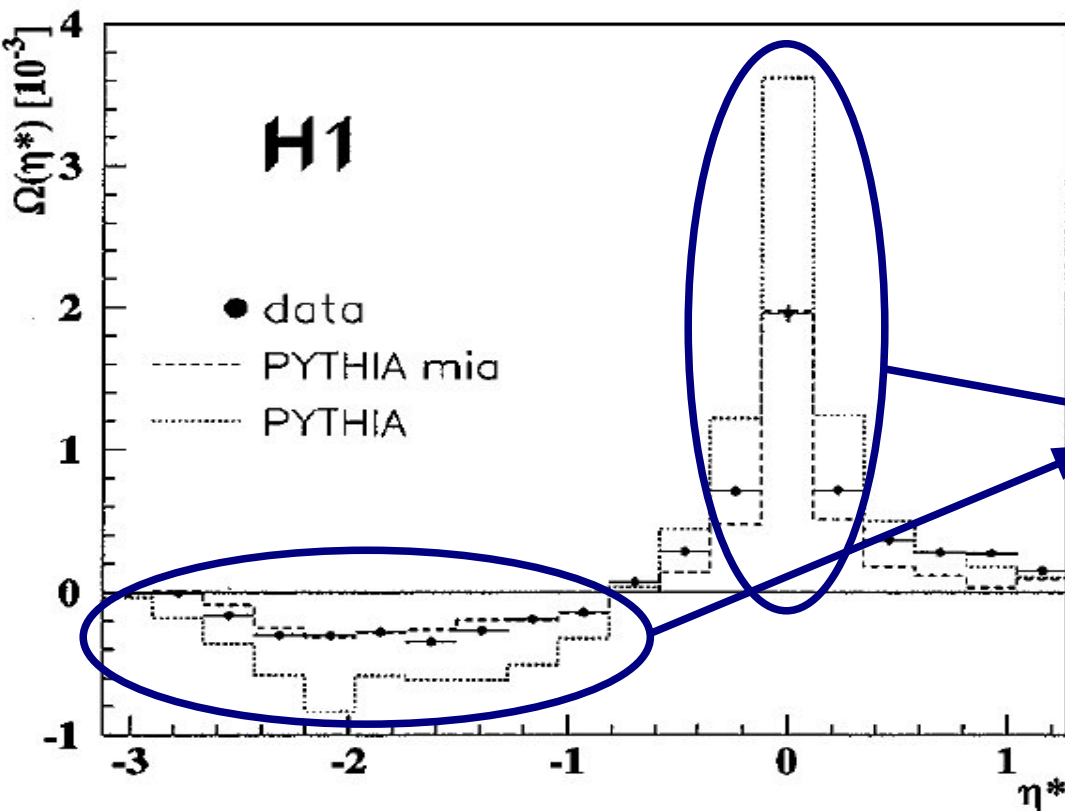
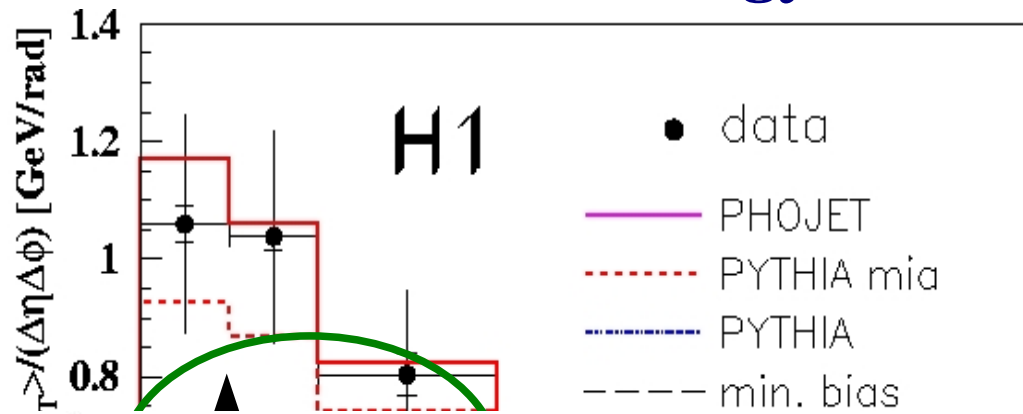
HERA present

Energy flow outside jets at H1

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

High E_T sample ($E_T > 20 \text{ GeV}$

$-0.8 < \eta < 3.3$)



$$\Omega = \frac{1}{N_{ev}} \sum_{i=1}^{N_{ev}} \frac{(\langle E_{T,\eta=0} \rangle - E_{T,\eta=0}^i)(\langle E_{T,\eta} \rangle - E_{T,\eta}^i)}{(E_T^2)_i}$$

Only with MPI you can describe the Ω rapidity correlations

HERA
Present

HERA present: Multi jet events

Three and four jets events

Photoproduction: $Q^2 < 1 \text{ GeV}^2$

Variable: n-jet invariant mass $M_{nj} = \sqrt{\left(\sum_{i=1}^n p_i\right)^2}$
with n number of jets n=3,4

Three and four jets events: $E_T^{\text{jets}} > 6 \text{ GeV}$

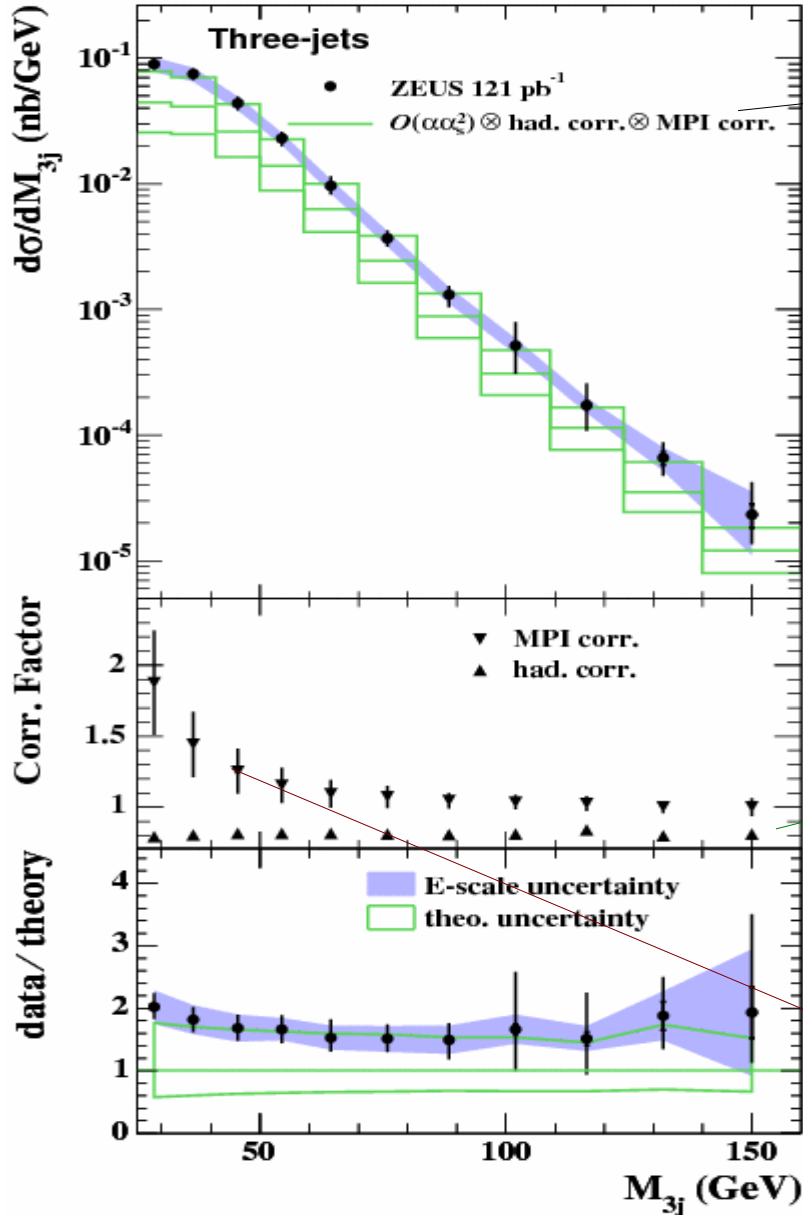
$$|\eta^{\text{jets}}| < 2.4$$

“Three- and four-jet final states in photoproduction at HERA”

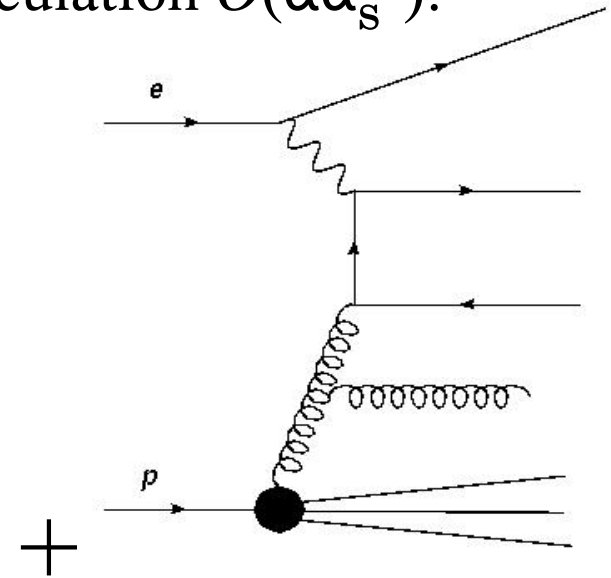
Nucl.Phys.B792:1-47, 2008, ZEUS Collaboration.

HERA present: Multi jet events

Three jets events



measured 3-jet cross section compared to the LO calculation $O(\alpha_s^2)$:

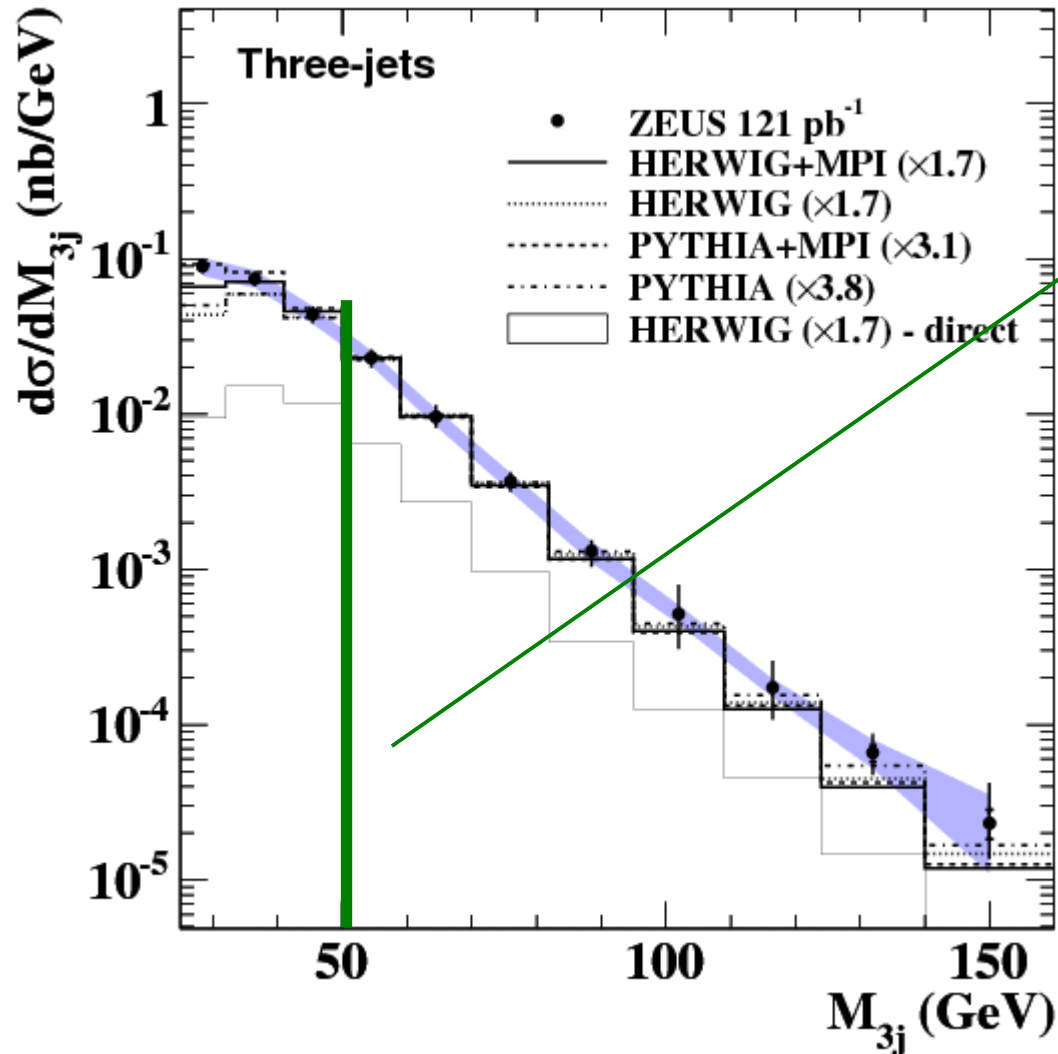


Hadronization corrections (small and constant)

MPI corrections (larger and increasing with decreasing 3-jet invariant mass)

HERA present: Multi jet events

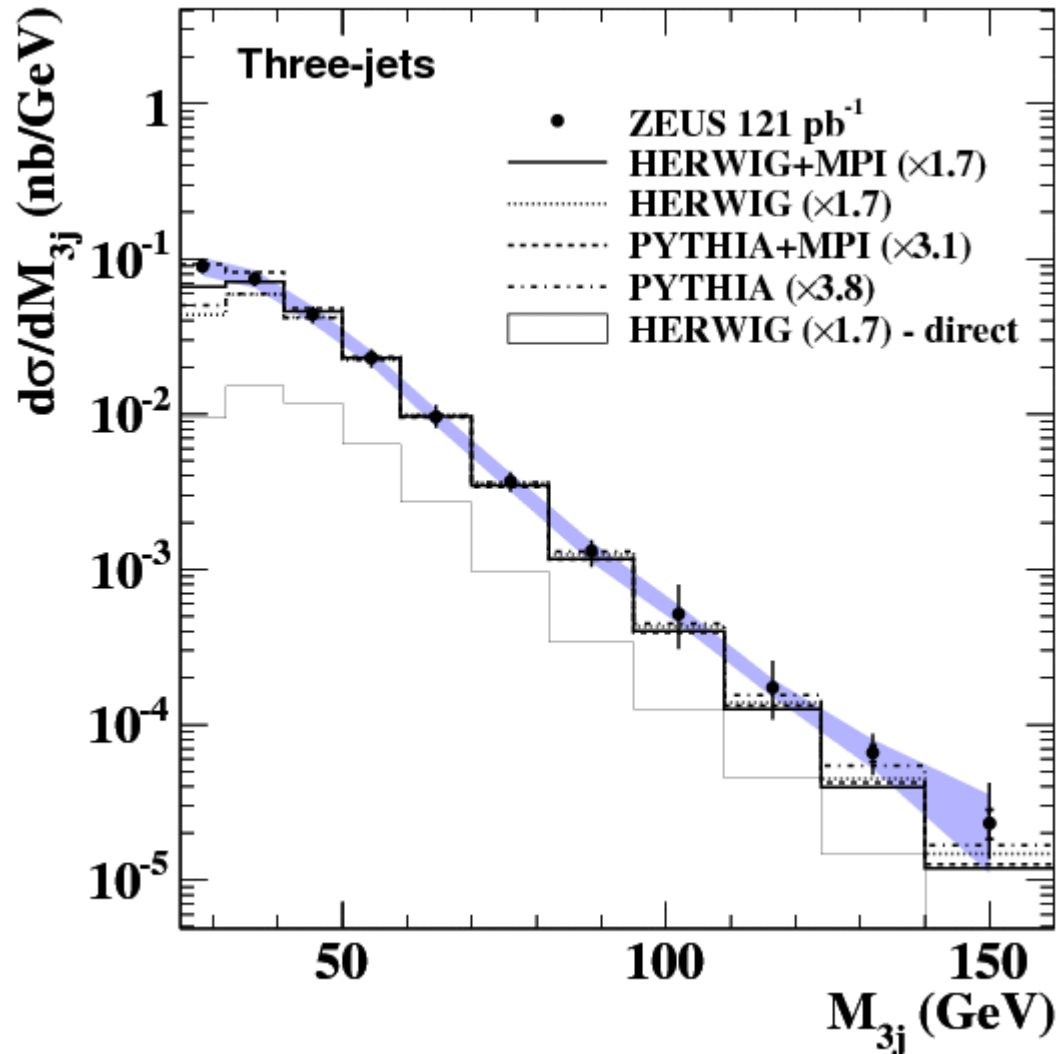
Three jets events



The Monte Carlos were normalized to the high 3-jet invariant mass ($M_{3j} > 50$ GeV)

HERA present: Multi jet events

Three jets events



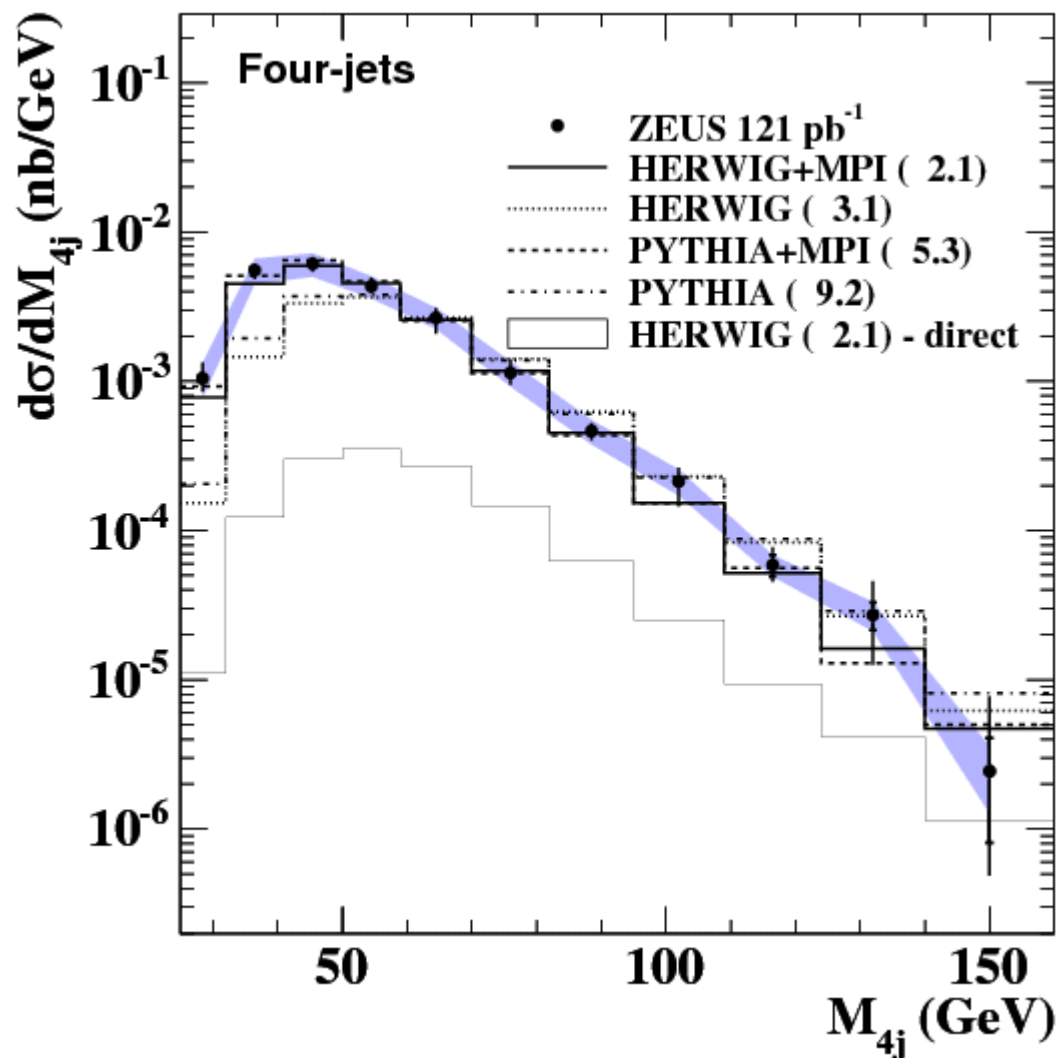
The $O(\alpha\alpha_s)$ + PS Monte Carlos cannot describe the total normalization

BUT

only if **MPI** are included they can describe the shape (specially the low mass region)

HERA present: Multi jet events

Four jets events



Again, the $O(\alpha\alpha_s)$ + PS Monte Carlos cannot describe the total normalization

BUT

only if **MPI** are included they can describe the shape.

HERA present: Multi jet events

Charged particle multiplicity

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

$$\text{Dijet events: } P_T^{\text{jets}} > 5 \text{ GeV}$$

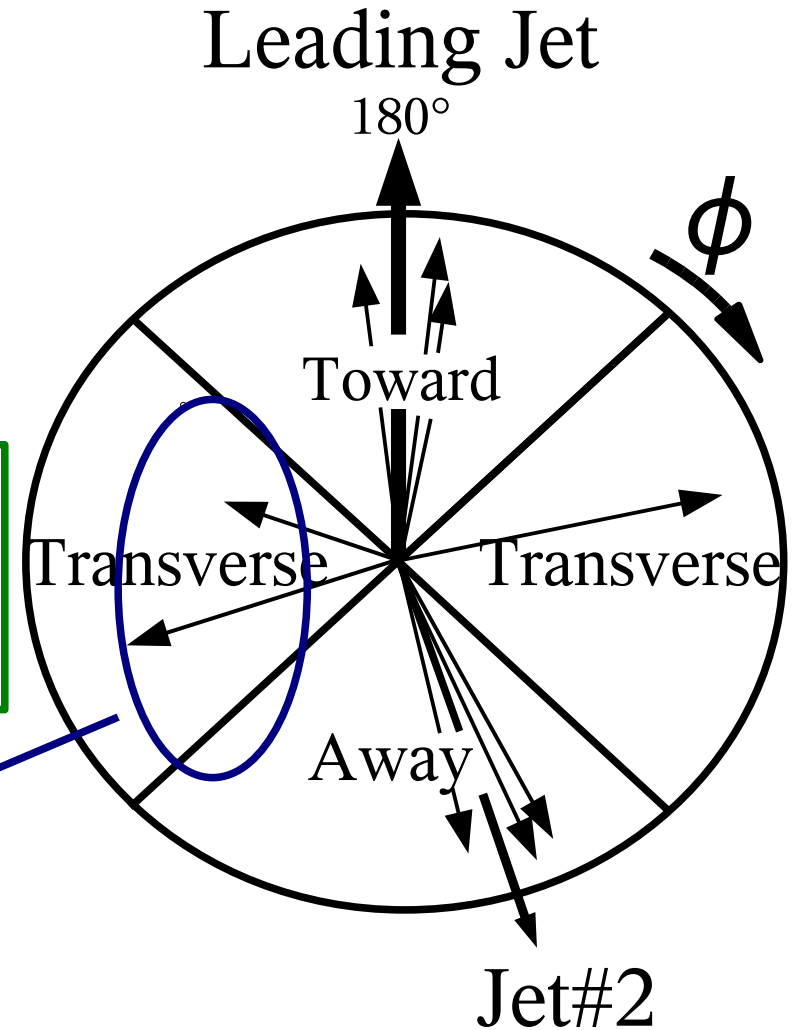
$$|\eta^{\text{jets}}| < 1.5$$

$$\text{Charged particles: } P_T > 150 \text{ MeV}$$

$$|\eta| < 1.5$$

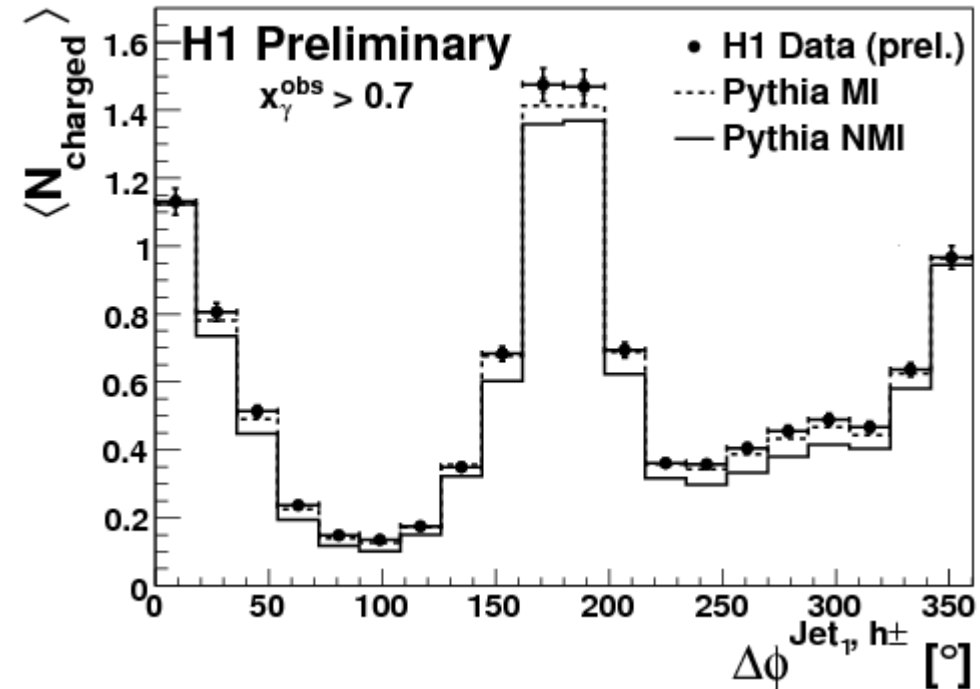
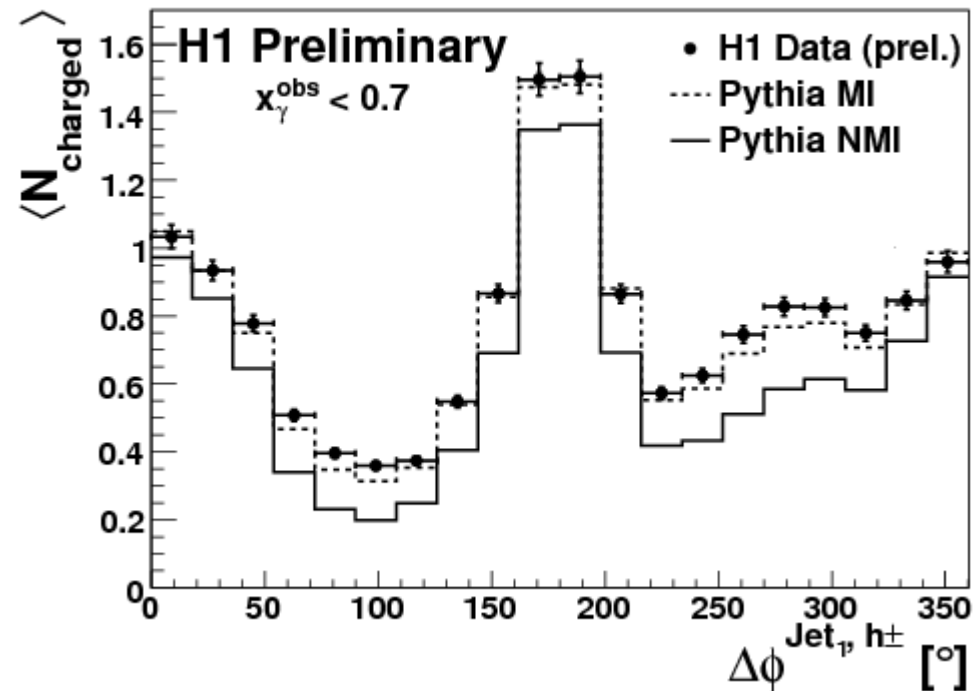
The high activity region is the transverse region hemisphere

$$\text{with higher } P_T^{\text{sum}} = \sum_i^{\text{tracks}} p_T^i$$



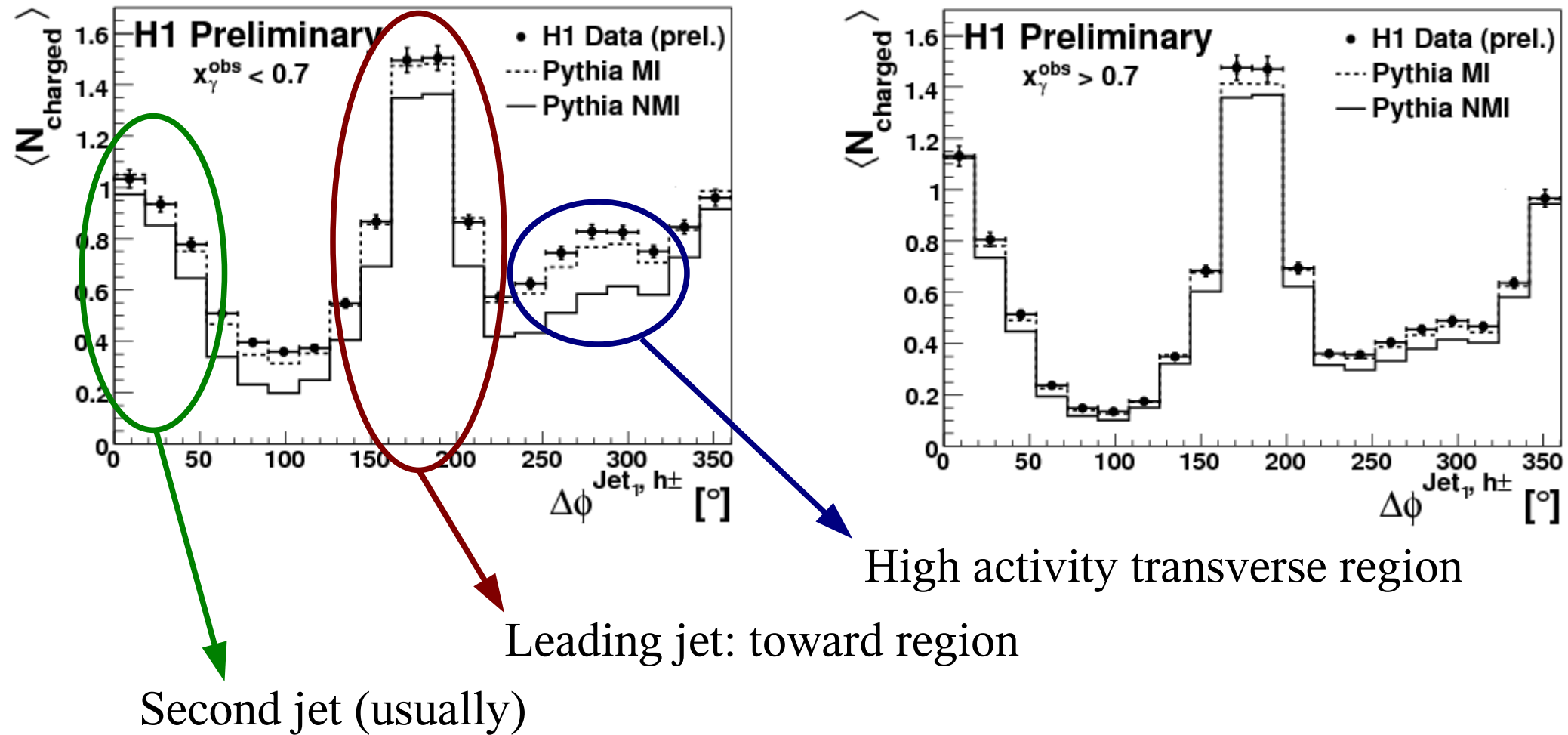
HERA present: Charged particle multiplicity

x Charge particle multiplicity as a function of the $\Delta\phi$ between the leading jet and the charged particles



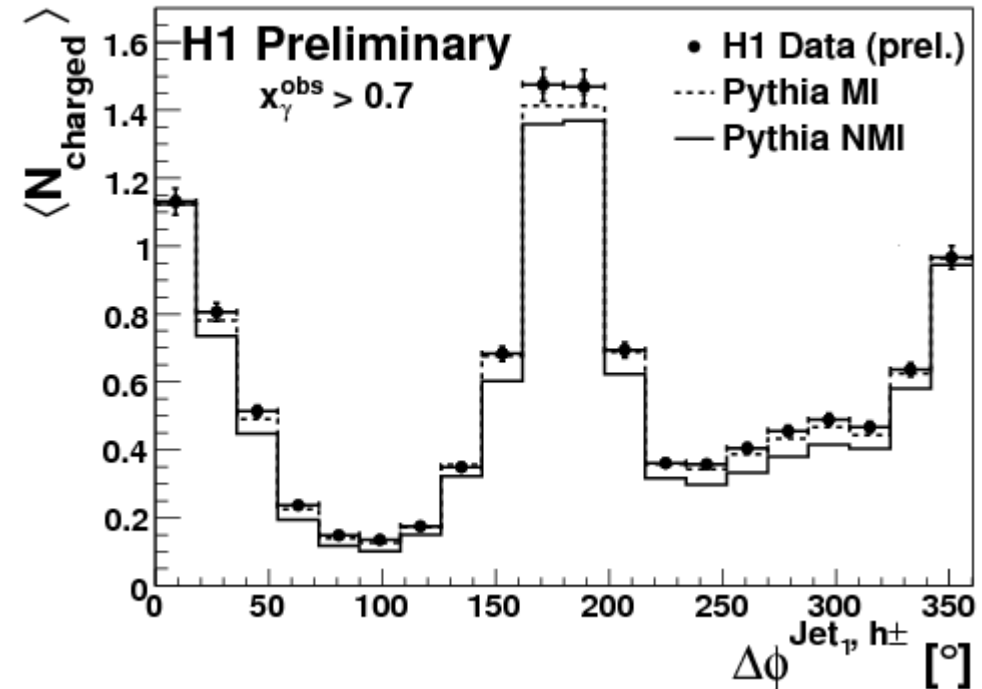
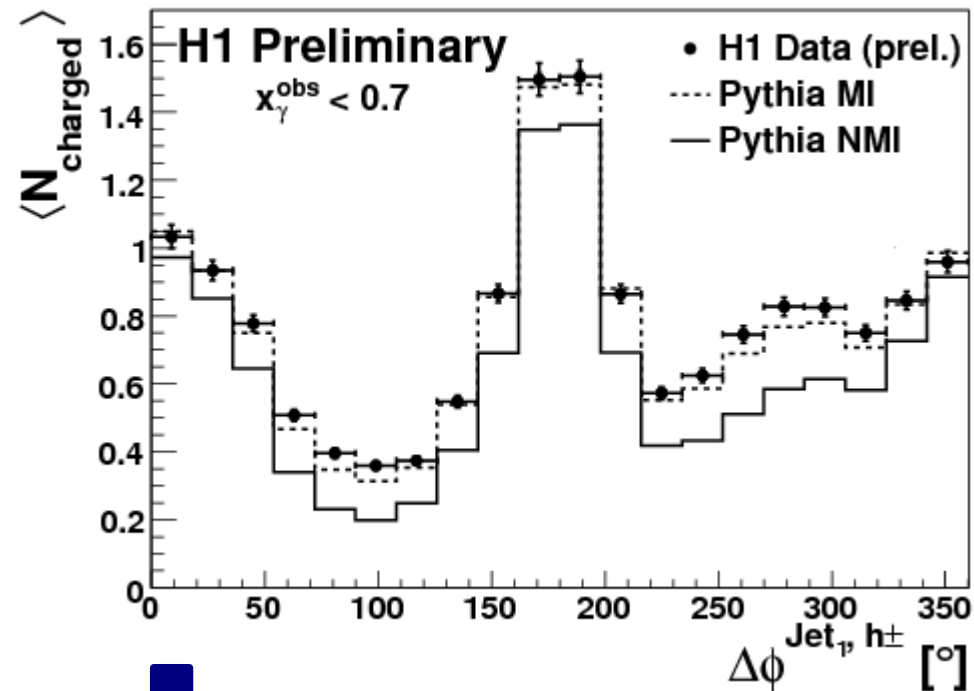
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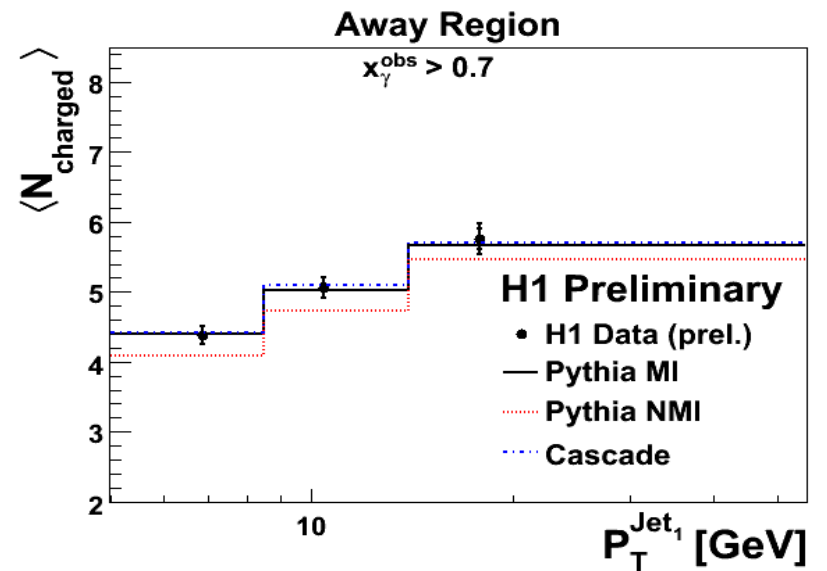
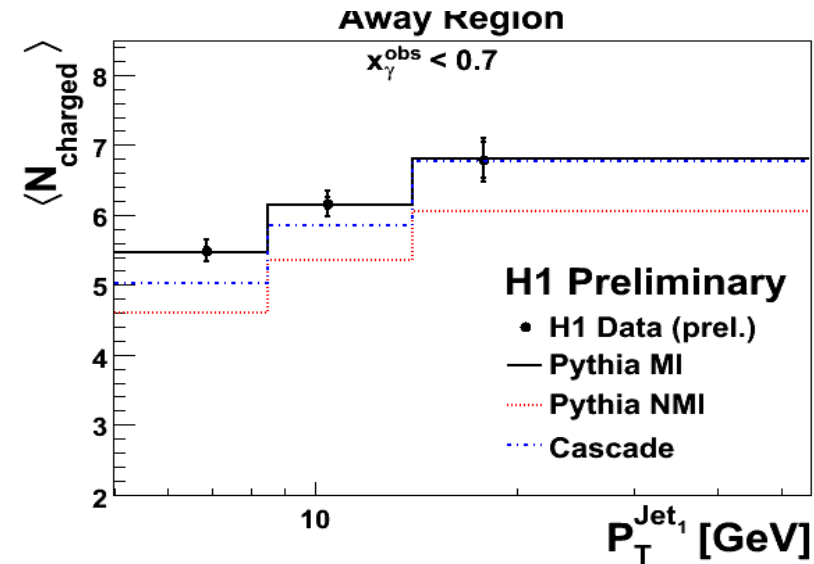
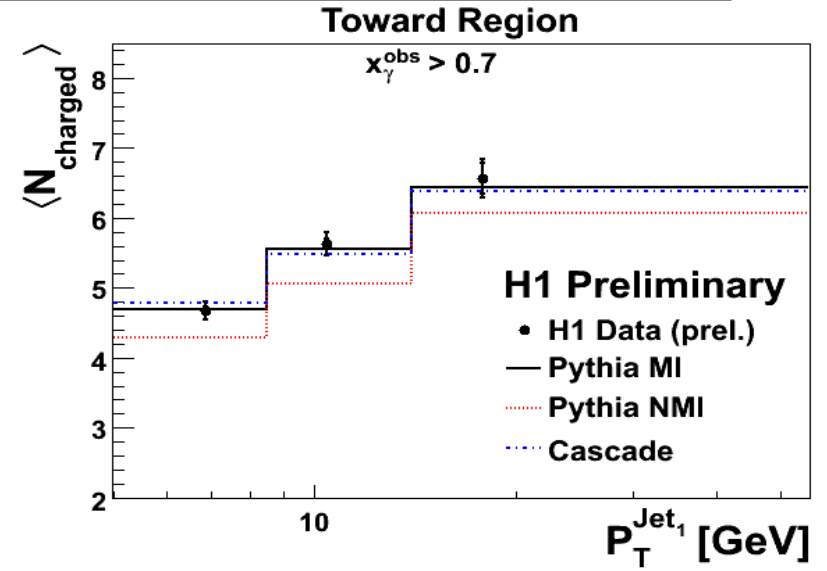
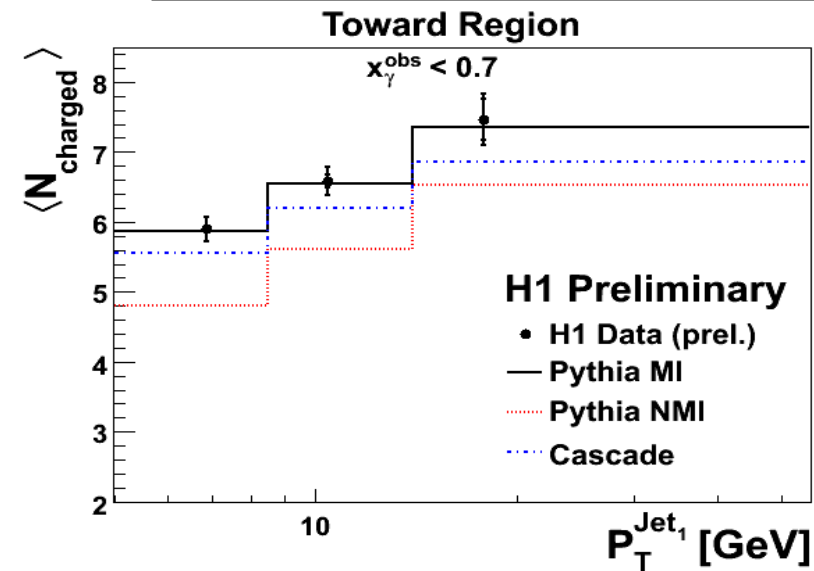
HERA present: Charged particle multiplicity

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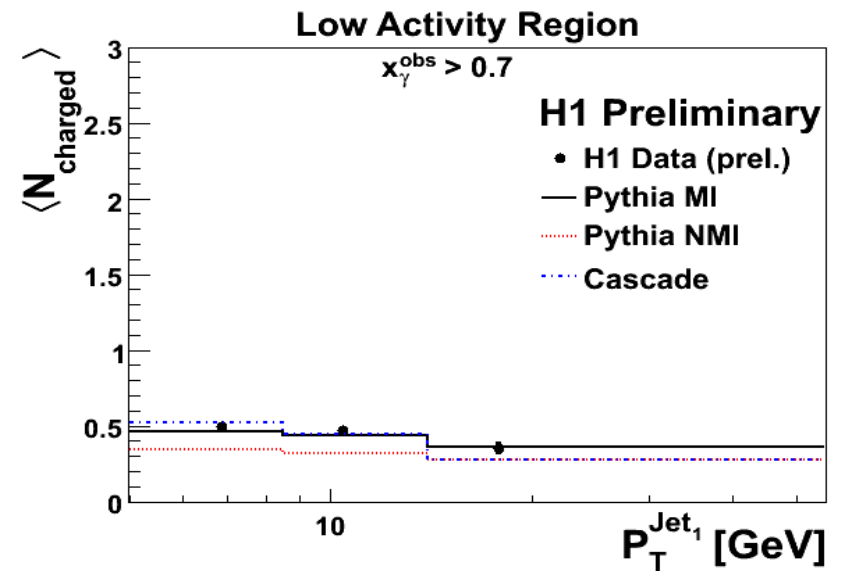
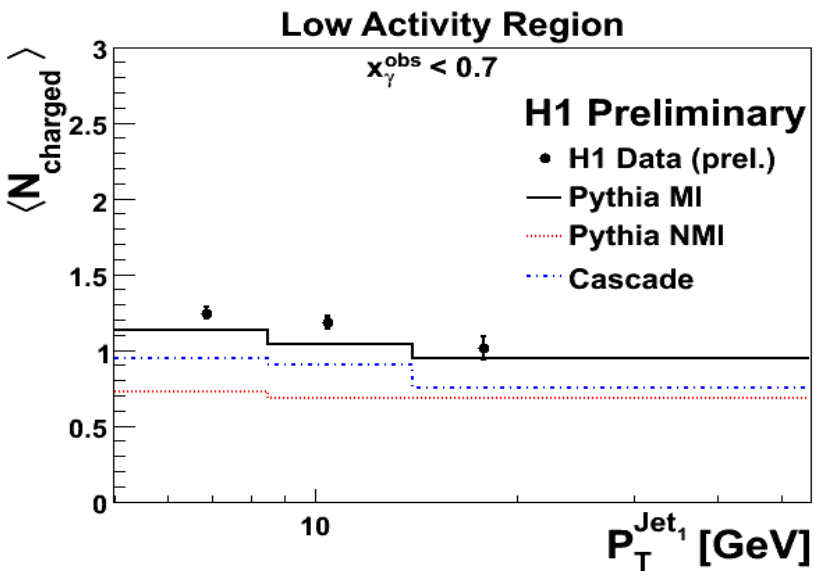
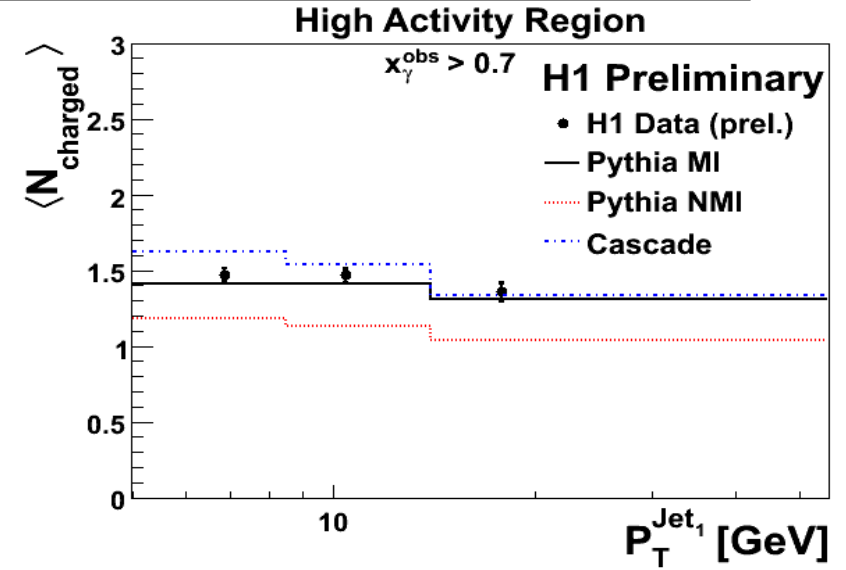
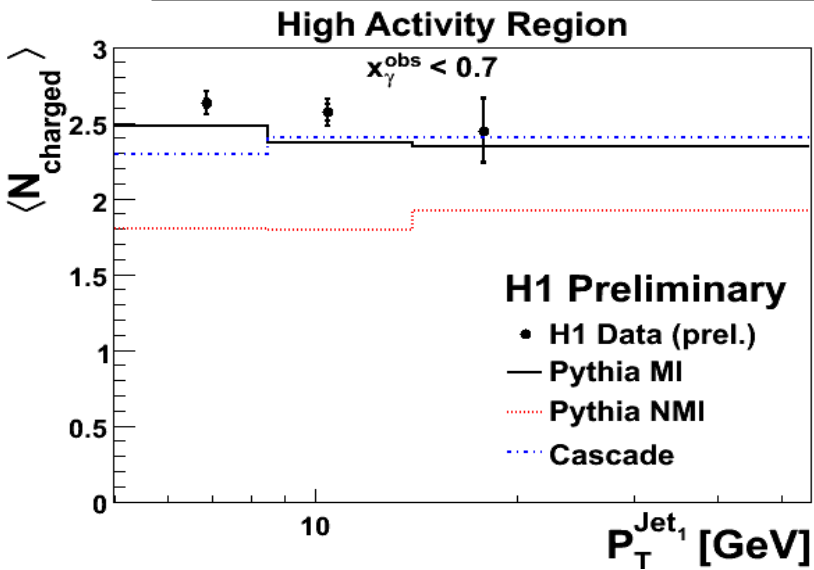
It look as a pedestal over the $\Delta\phi$ but...it is not so simple...

HERA present: Charged particle multiplicity



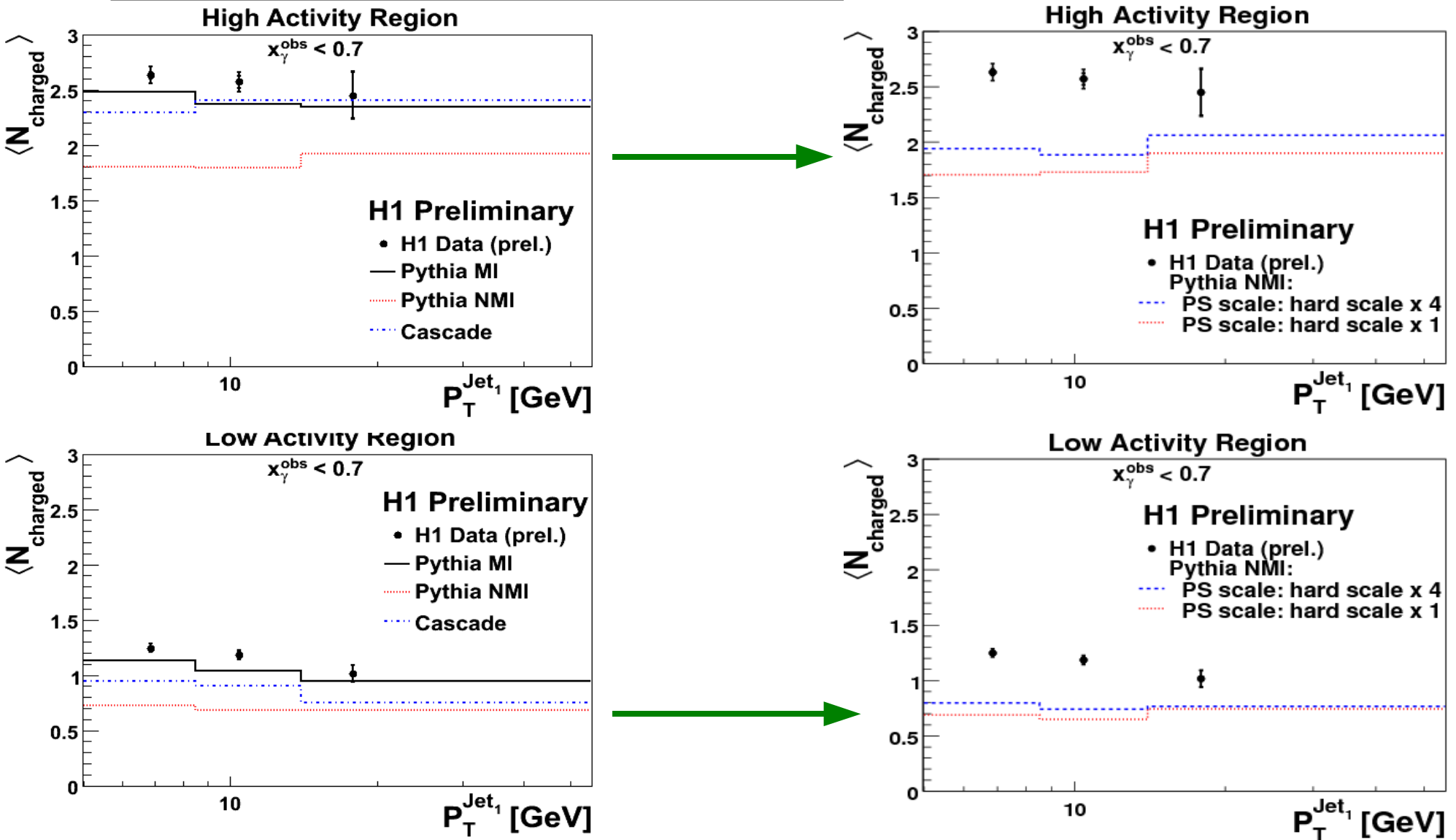
✘ MPI contributes more at low $P_T^{\text{Jet}1}$ BUT not as just a pedestal since it decreases with increasing $P_T^{\text{Jet}1}$

HERA present: Charged particle multiplicity



✘ MPI contributes more at low $P_T^{\text{Jet}1}$ BUT not as just a pedestal since it decreases with increasing $P_T^{\text{Jet}1}$

HERA present: Charged particle multiplicity



\times MPI contributes more at low $P_T^{\text{Jet}_1}$ BUT not as just a pedestal since it decreases with increasing $P_T^{\text{Jet}_1}$

HERA present: Multi jet events

Low E_T jets multiplicity

$$5 < Q^2 < 100 \text{ GeV}^2$$

One jet events: $E_T^{\text{jet}} > 5 \text{ GeV}$

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

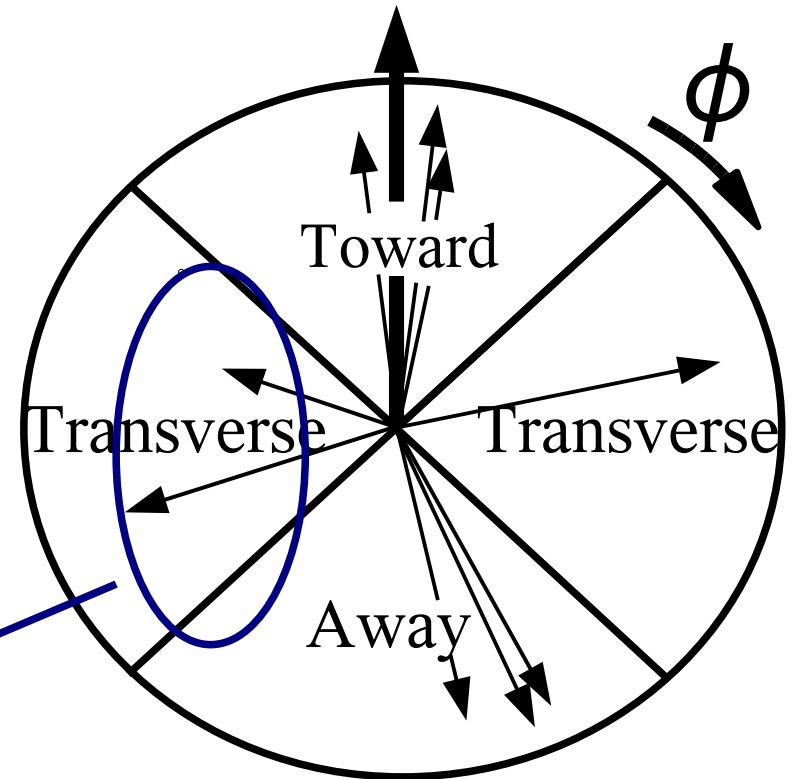
Mini-jets: $E_T > 3 \text{ GeV}$

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

The high activity region is the transverse region hemisphere

with higher $E_T^{\text{sum}} = \sum_i^{\text{jets}} E_T^i$

Leading Jet



HERA present: Multi jet events

Low E_T jets multiplicity

$$5 < Q^2 < 100 \text{ GeV}^2$$

One jet events: $E_T^{\text{jet}} > 5 \text{ GeV}$

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

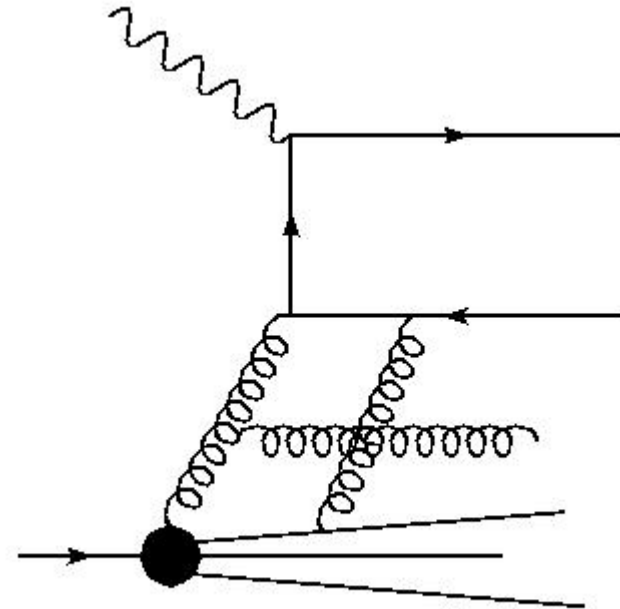
Mini-jets: $E_T > 3 \text{ GeV}$

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

WHY?

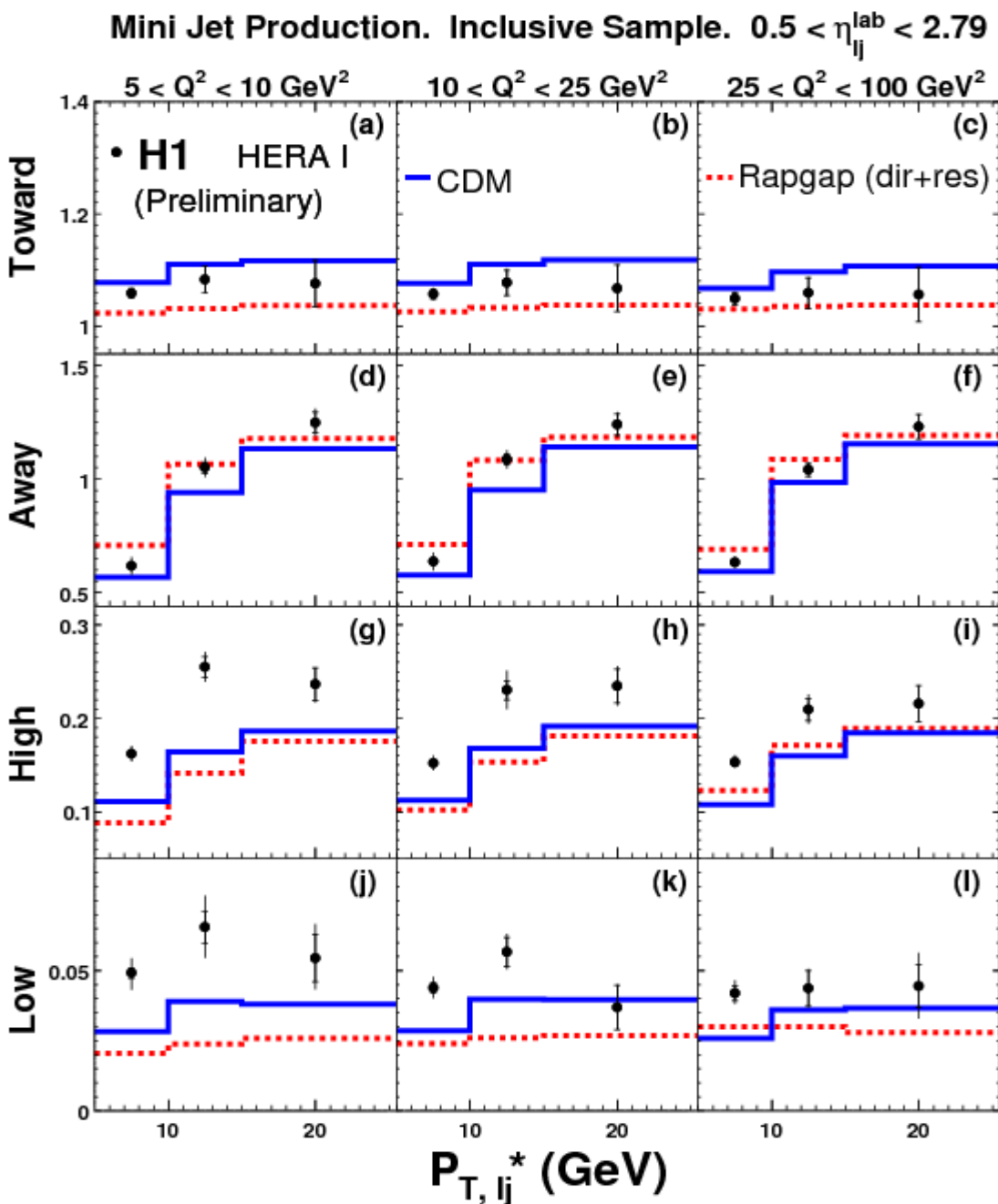
Study the effect of MPI as $Q^2 \nearrow$

AND



interactions between the hard scattering and the proton remnant

HERA present: Multi jet events

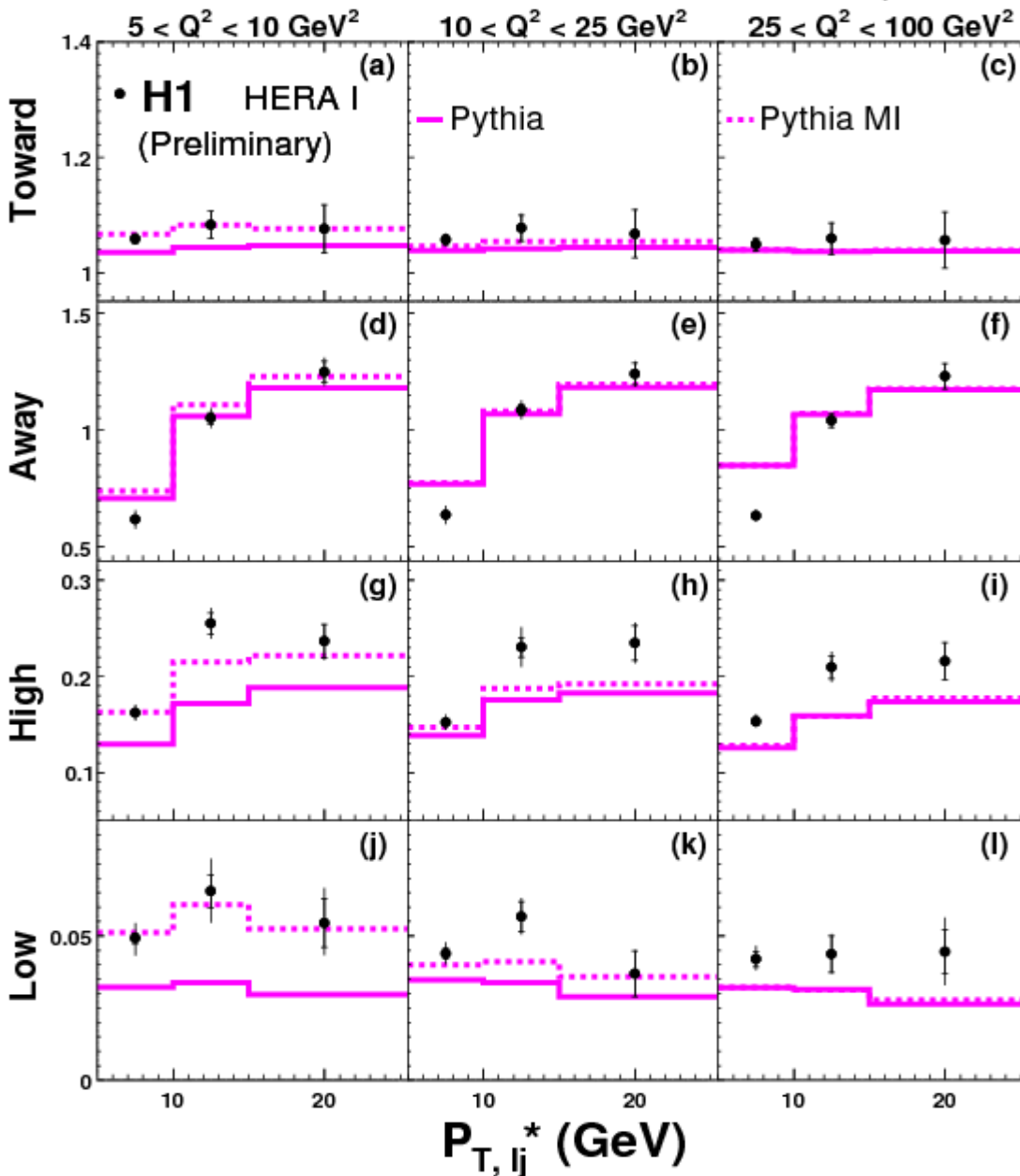


Toward and away regions are described by MC without MPI

MC underestimate the number of mini jets in the transverse regions

HERA present: Multi jet events

Mini Jet Production. Inclusive Sample. $0.5 < \eta_{ij}^{\text{lab}} < 2.79$



Including MPI we describe better the low Q^2 regions but without resolved photons there is no MPI in MC

Summary and outlook

✓ Hard MPI:

✓ Multijet photoproduction

3-jet cross section not described alone with $O(\alpha\alpha_s^2)$. MPI are needed

In 4-jet events the contribution from MPI is even larger

✓ Soft MPI:

✓ Charged particle multiplicity in photoproduction

Charged particle multiplicity outside the hard interaction not described without MPI (although CASCADE...)

Minijets in photoproduction can provide supplementary information

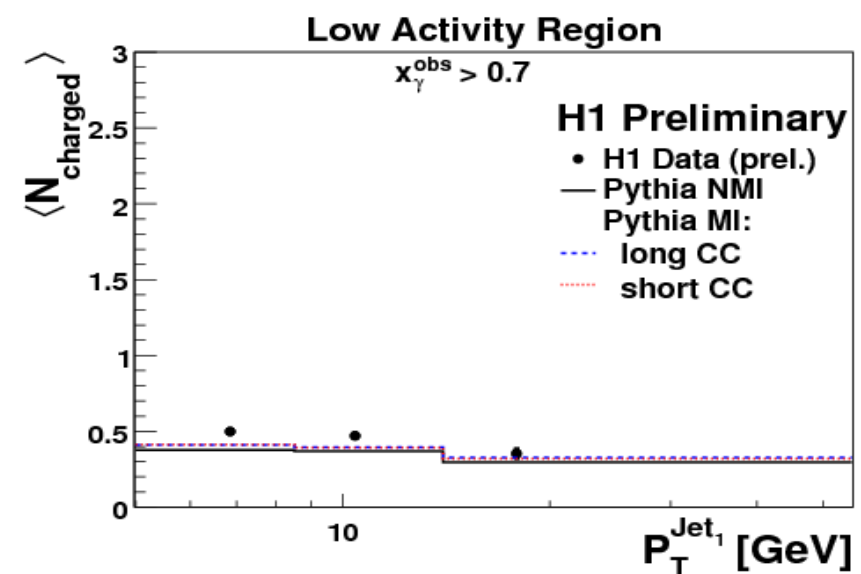
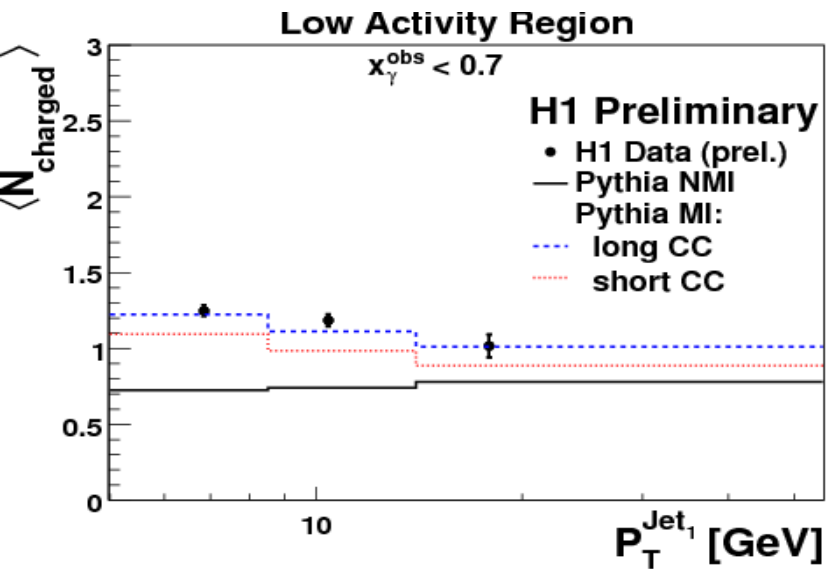
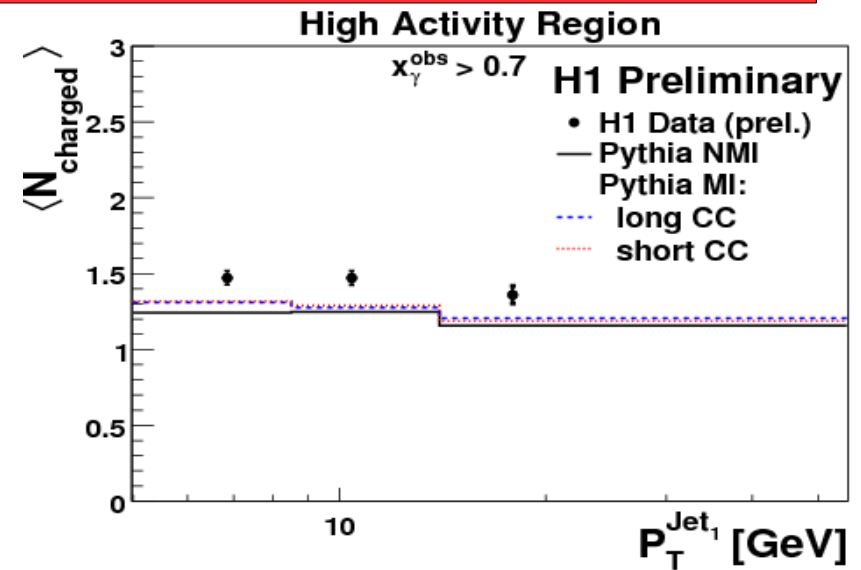
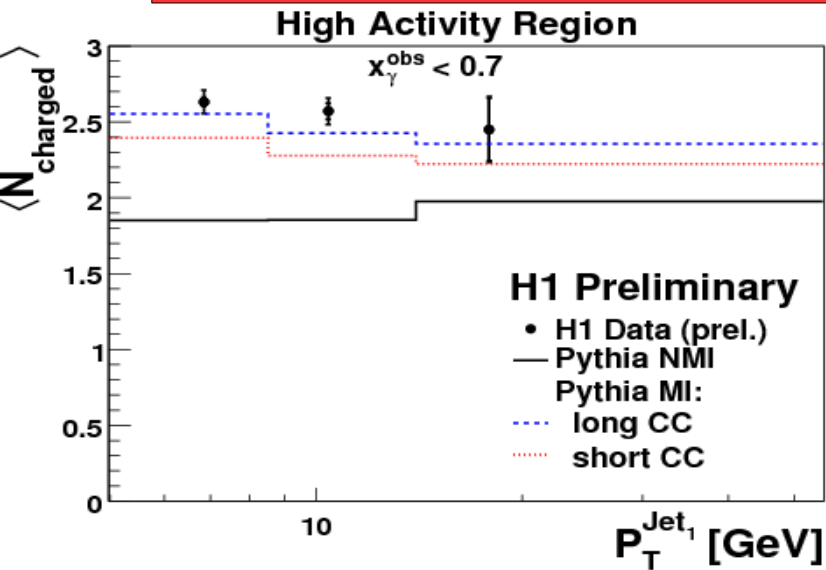
✓ Minijet production in at low Q^2

Including MPI improves the description where the resolved photon still contributes

Need to improve MC: improve PS (CASCADE) and MPI?

Thanks for your attention

HERA present: Charged particle multiplicity



✘ MPI contributes more at low $P_T^{\text{Jet}1}$ BUT not as just a pedestal since it decreases with increasing $P_T^{\text{Jet}1}$