Forward- and 3-jet production at HERA

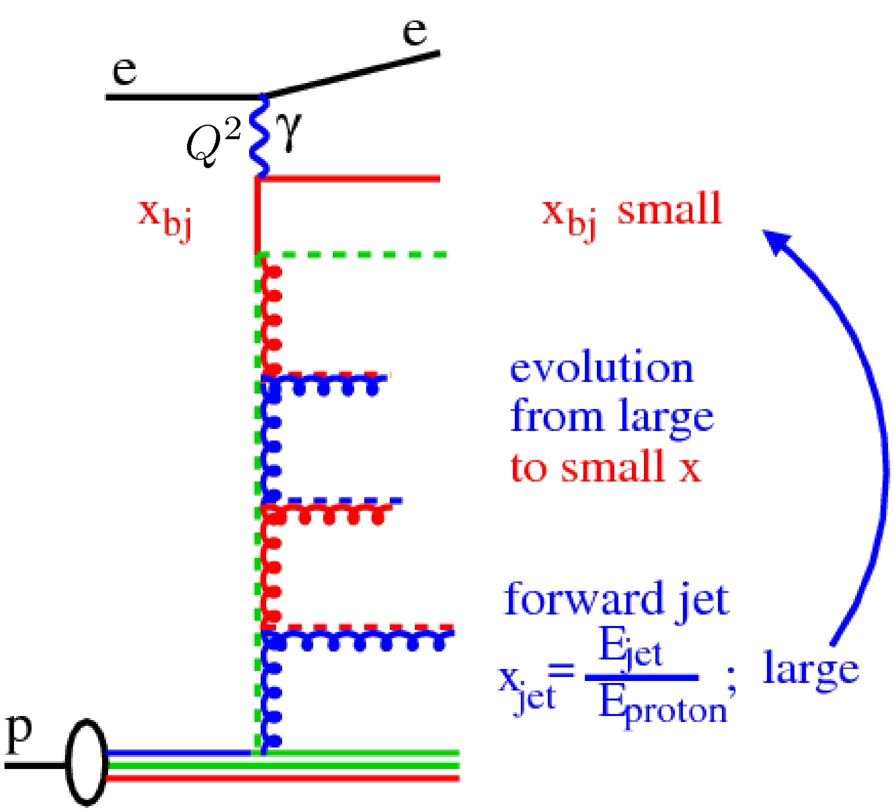
DESY-Lund Small-x meeting

Hamburg 12/10-2009

Albert Knutsson

Forward Jets in DIS (DESY 05-135)

- **Test QCD at small x.** $(5 < Q^2 < 100 \text{ GeV}^2 \quad 10^{-4} < x_{Bj} < 4 \cdot 10^{-3})$



H1 data with a jet close to the proton remnant were analysed.

$$1.75 < \eta_{jet} < 2.79$$
$$p_{t,jet} > 3.5 \text{ GeV}$$

Target phase space for evolution in x (BFKL)

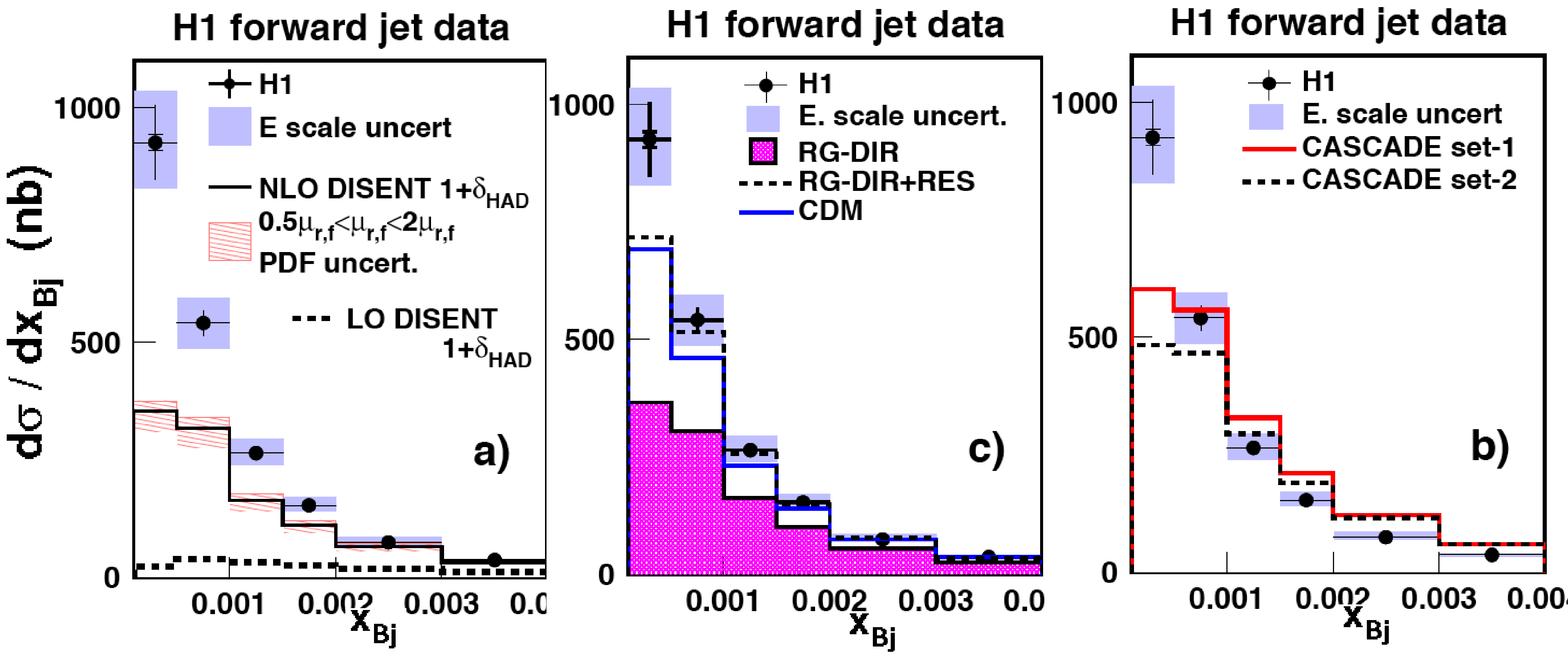
$$x_{jet} >> x_{Bj}$$

Suppress phase space for evolution in Q^2 (Suppress DGLAP)

$$p^2_{t,jet} \sim Q^2$$

Eur.Phys.J.C46:27-42,2006

Forward Jets in DIS (DESY 05-135)



- Available fixed order calculations "NLO di-jets" (corrected for had. effects) not enough.
- RAPGAP (DGLAP) direct factor of 2 below data
- RAPGAP with contributions from resolved photons, and CDM are quite good.
- CASCADE (CCFM) fails in shape. Total forward jet cross-section roughly described.

Eur.Phys.J.C46:27-42,2006

3-jet events in DIS (DESY 07-200)

$$5\mathrm{GeV}^2 < Q^2 < 80\mathrm{GeV}^2$$
$$0.0001 < x < 0.01$$

(Essentially the same kinematic range as for the forward jets.)

Jet selection:

$$N_{jet} > 3$$
$$p^*_{T,1} > 4 \text{ GeV}$$
$$p^*_{T,1} + p^*_{T,2} > 9 \text{ GeV}$$
$$-1 < \eta_i < 2.5 \;,\; i = 1,2,3$$
$$\eta_i < 1.3 \;,\; \text{for one } i \in \{1,2,3\}$$

3-jet events in DIS (DESY 07-200)

MC studies by summer student, **Christoph Straeter**, 2009

(For the first time we code hztool in C++, and for the first time CASCADE is compare to these data)

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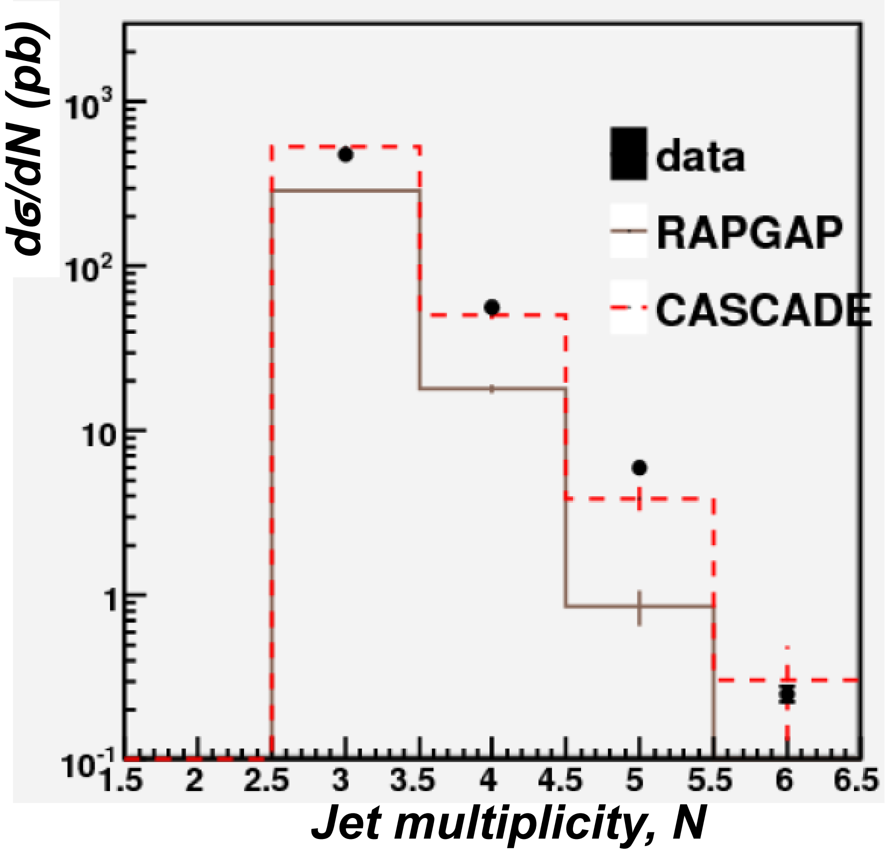

Multiplicity and total jet-cross section described by CASCADE.

MC studies by summer student, Christoph Straeter, 2009

(For the first time we code hztool in C++, and for the first time CASCADE is compare to these data)

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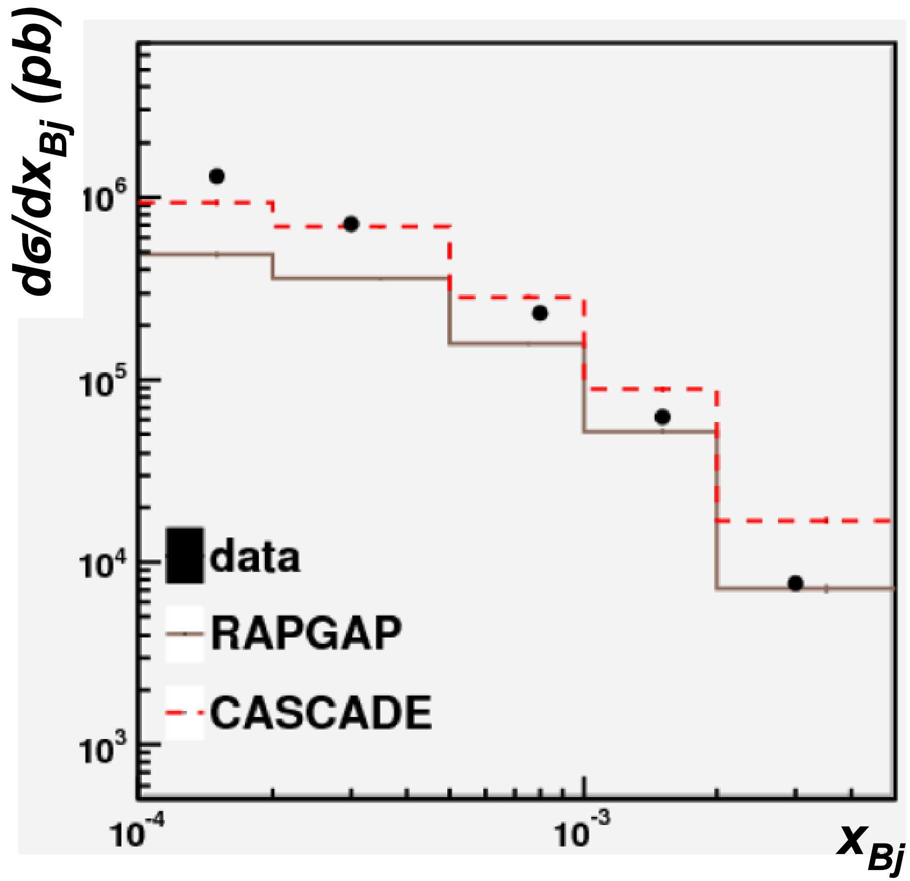
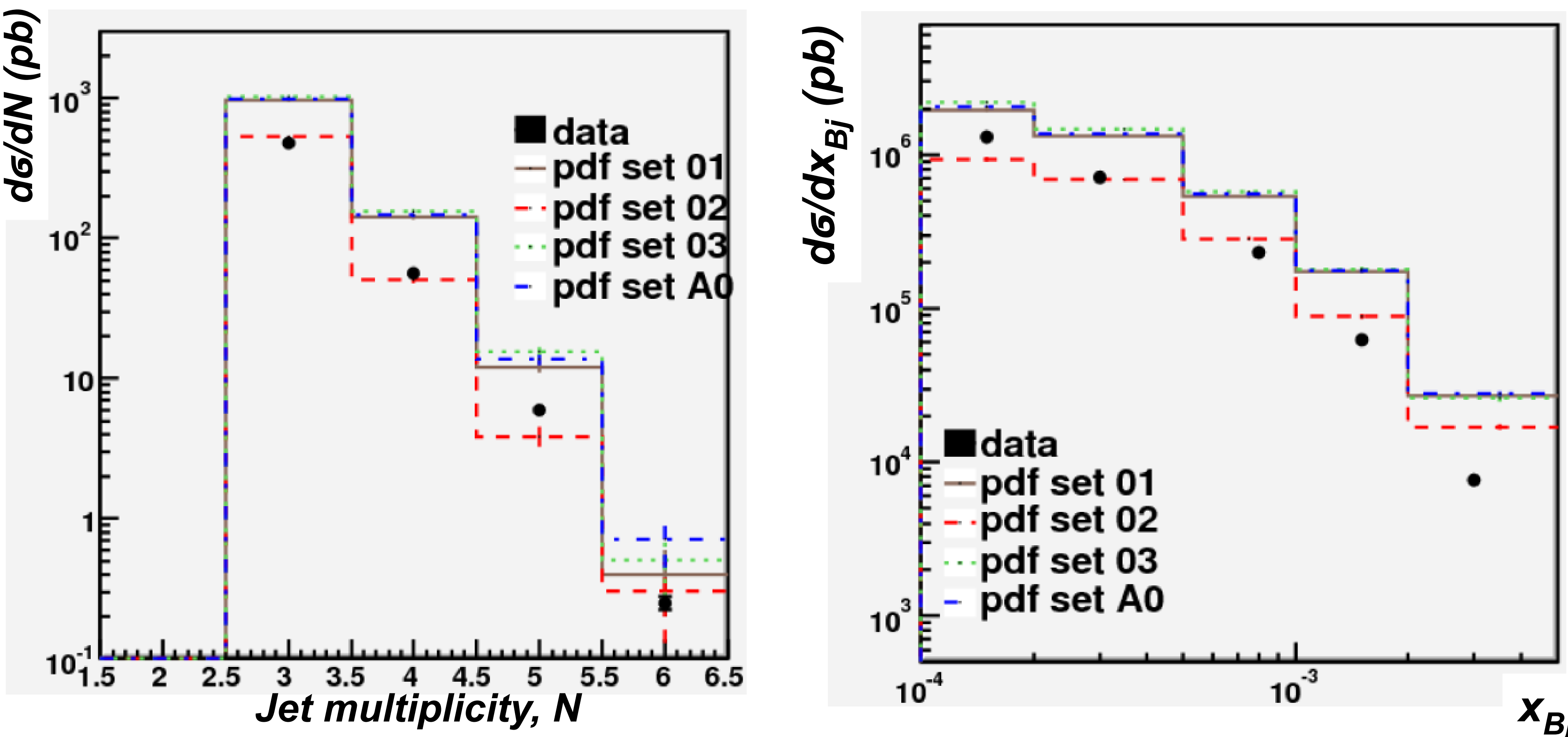


Same as for the forward jets:

CASCADE do not describe the shape: too low at low x, to high at high x.

3-jet events in DIS (DESY 07-200)

High sensitivity to the choice of uPDF.



Data compared to predictions with uPDF using different fits and different splitting functions.

Only the uPDF with the **full CCFM splitting function** (both singular and non sing. terms) describes the data.

2+Forward jet (DESY 07-200)

Same as before

$$N_{jet} > 3$$

$$p^*_{T,1} > 4 \text{ GeV}$$

$$p^*_{T,1} + p^*_{T,2} > 9 \text{ GeV}$$

$$-1 < \eta_i < 2.5 \ , \ i = 1,2,3$$

$$\eta_i < 1.3 \ , \text{ for one } i \in \{1,2,3\}$$

But with the additional requirement
that one of the jets are in the forward region.

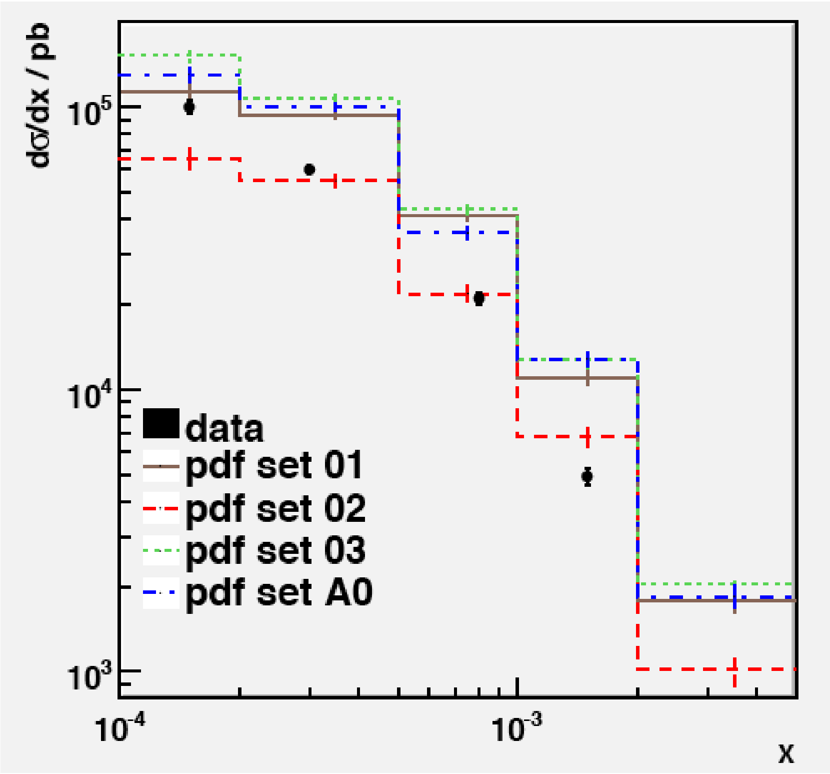
$$\eta_j > 1.73$$

$$\frac{E_j}{p_0} > 0.035$$

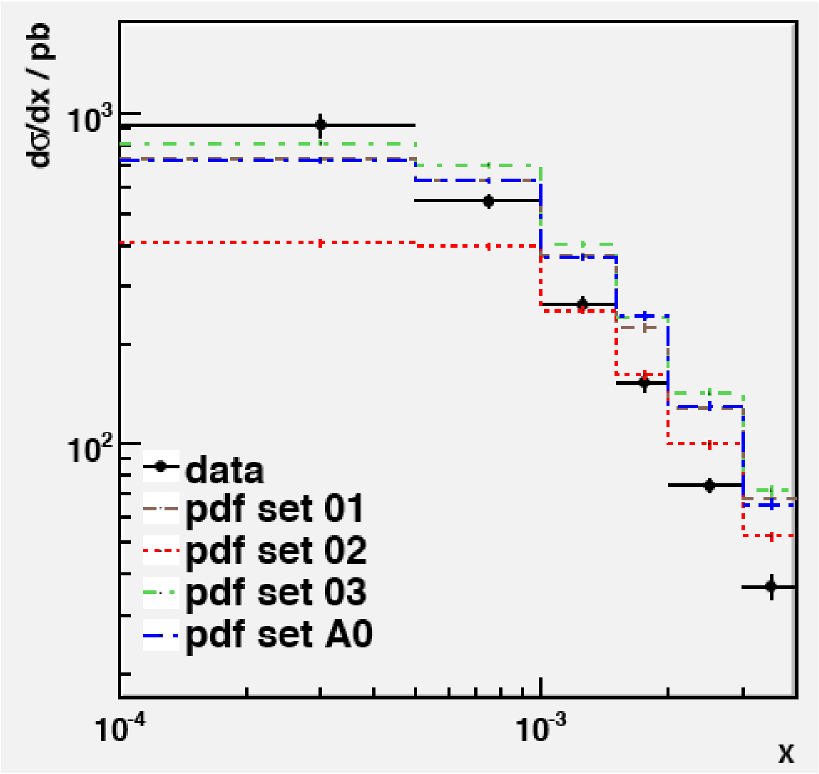
The same forward jet selection as for the inclusive forward jets, **except no pt2/Q2 requirement**.

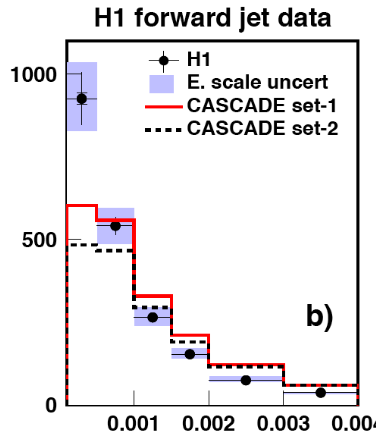
Comparison 2+forward and inclusive forward

2+forward jet events (desy 07-200)



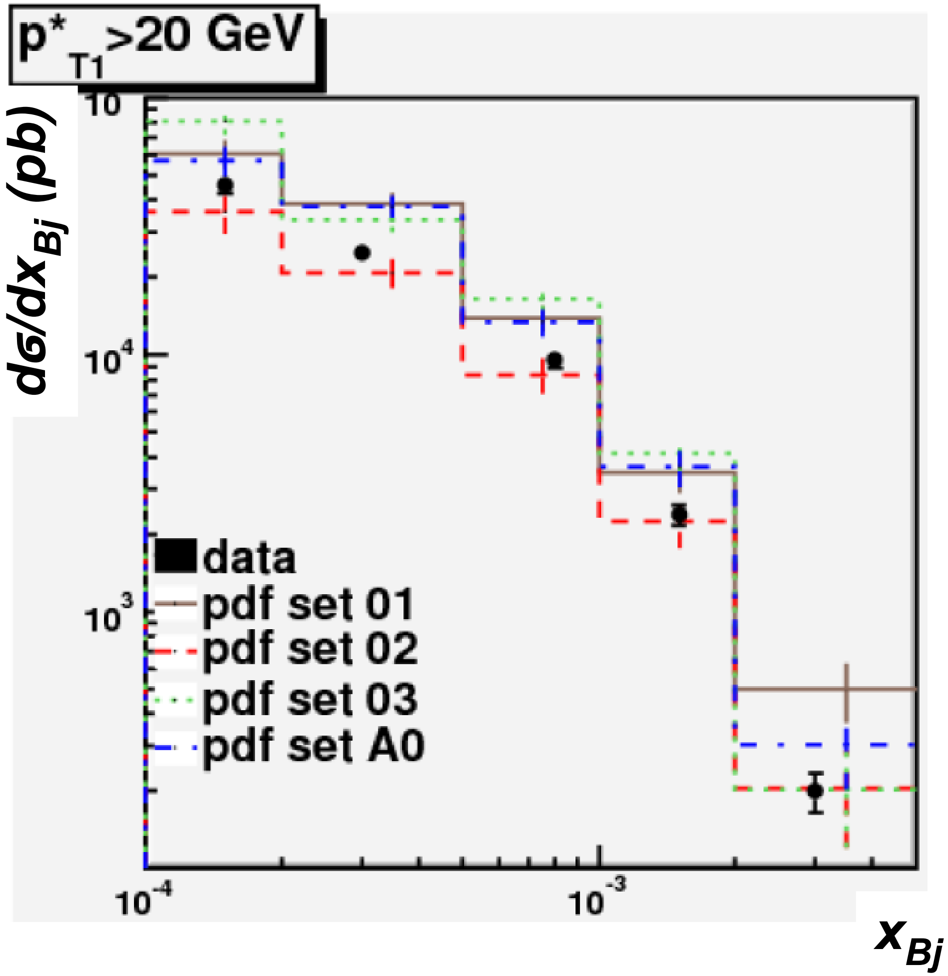
Inclusive jet events (desy 05-135)



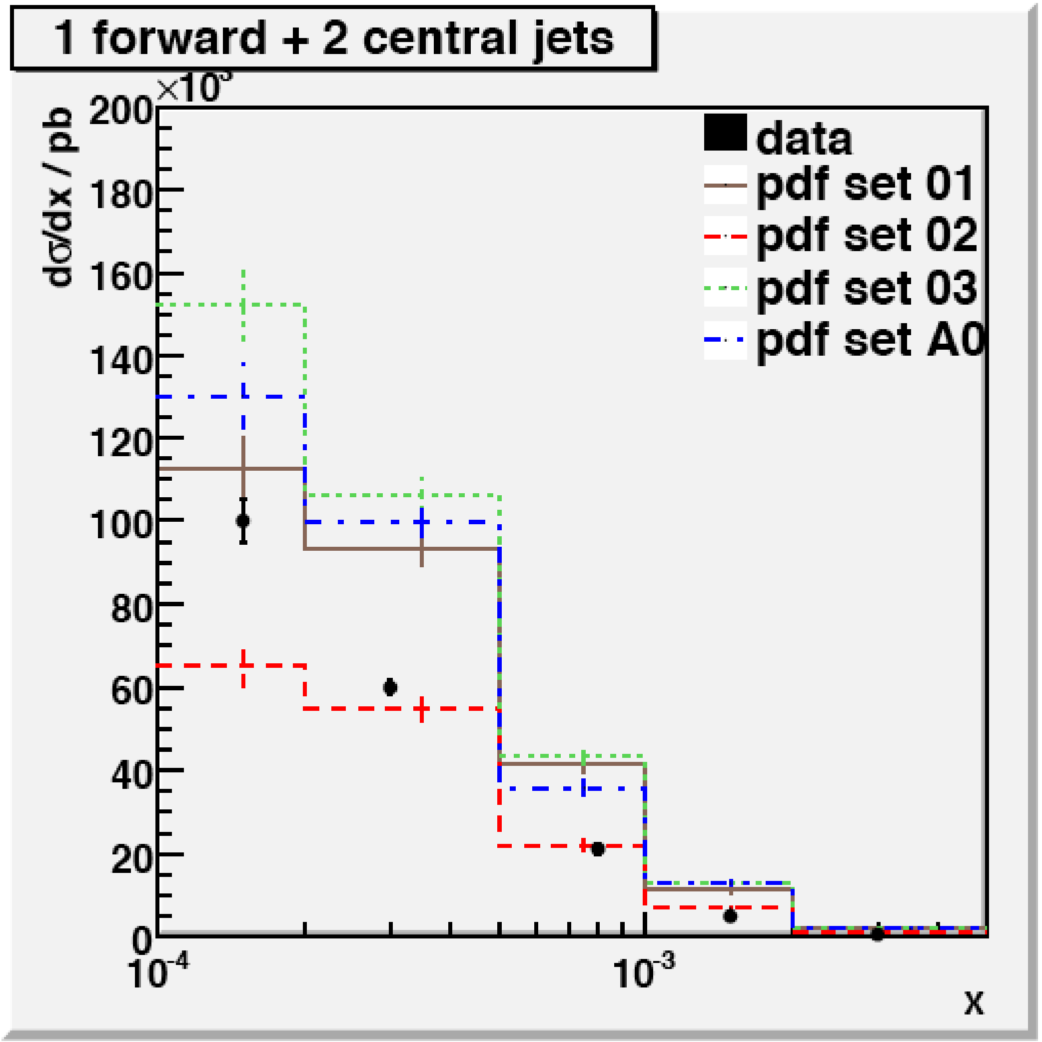


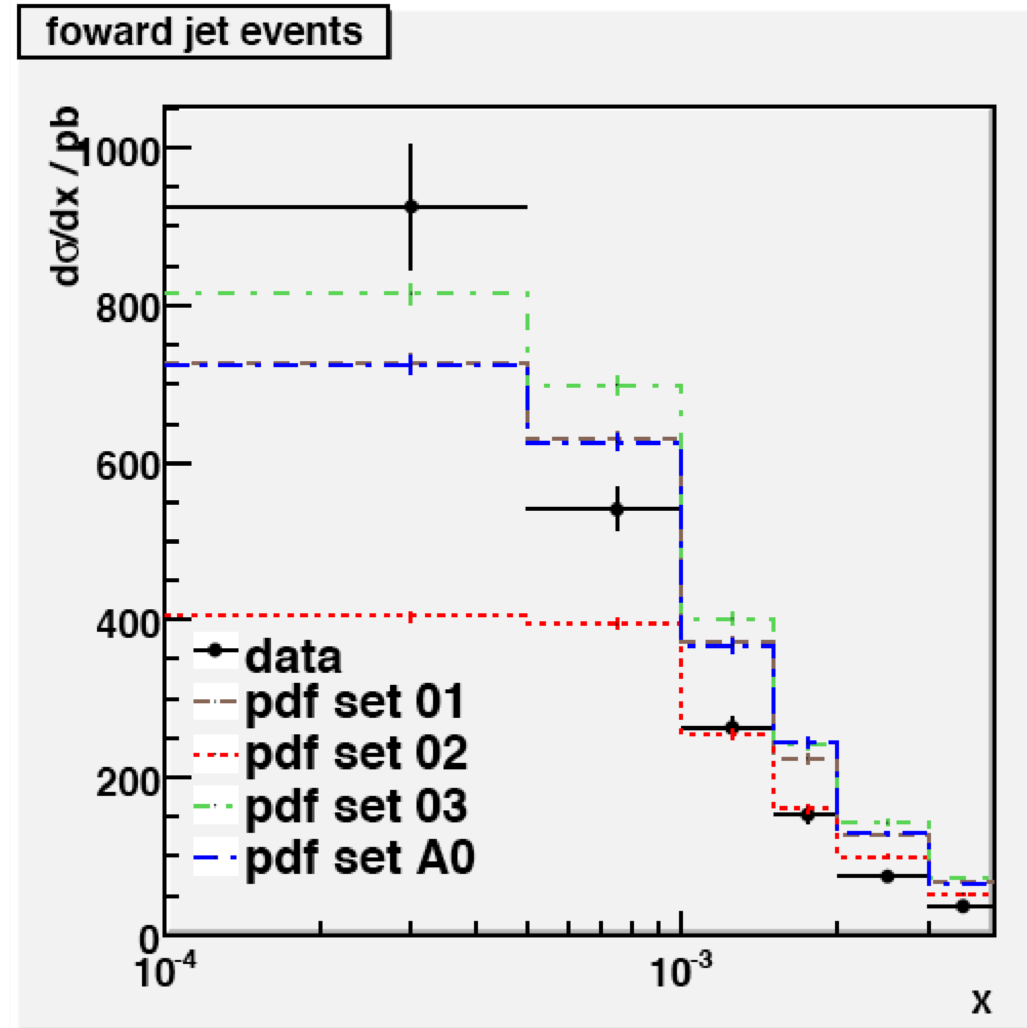
- Possibly improvement of shape for the 2+foward jets events. But still no ok.

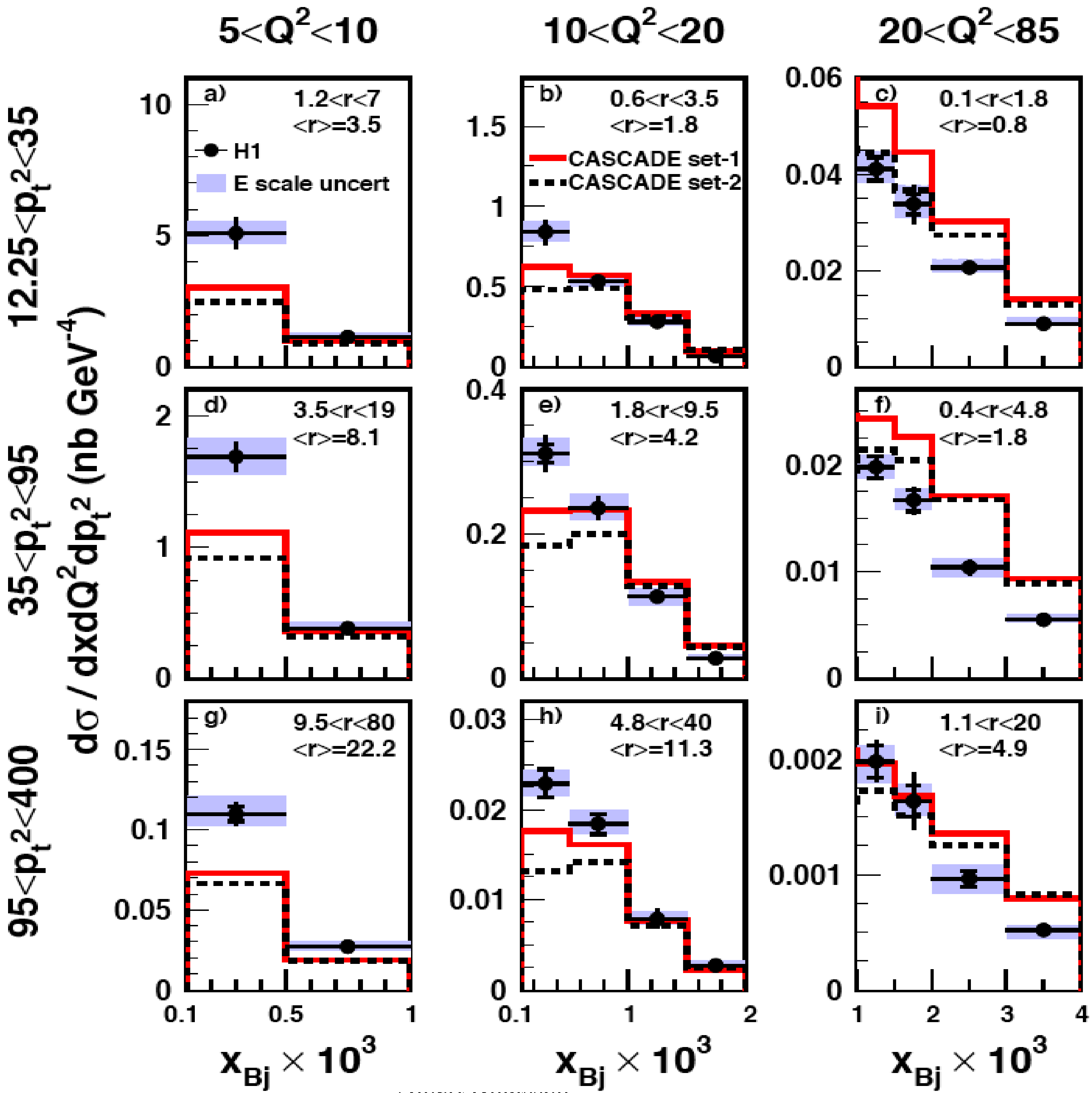
BACK UP



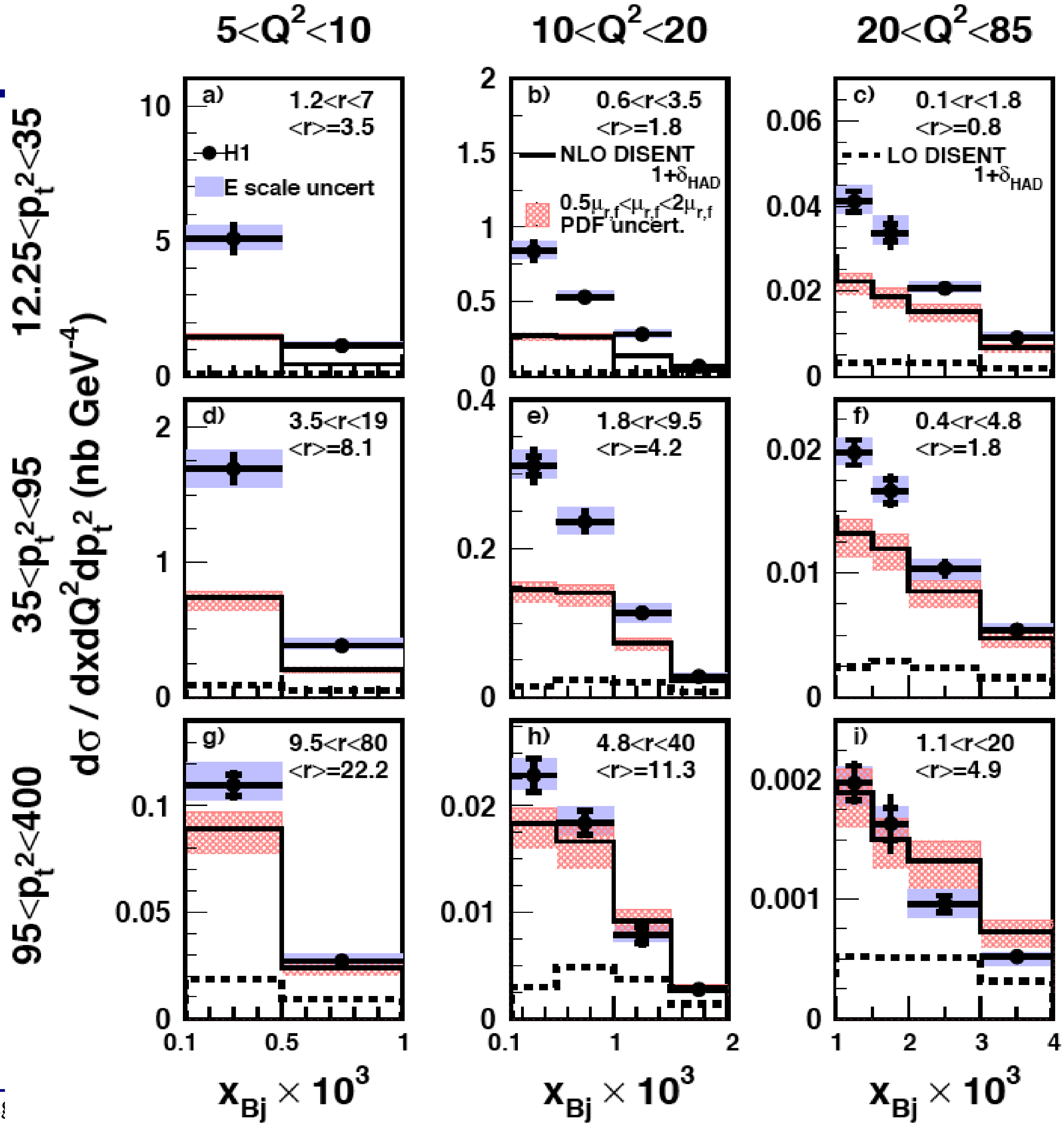
•Increasing the pt of jet1 improves the desciption.

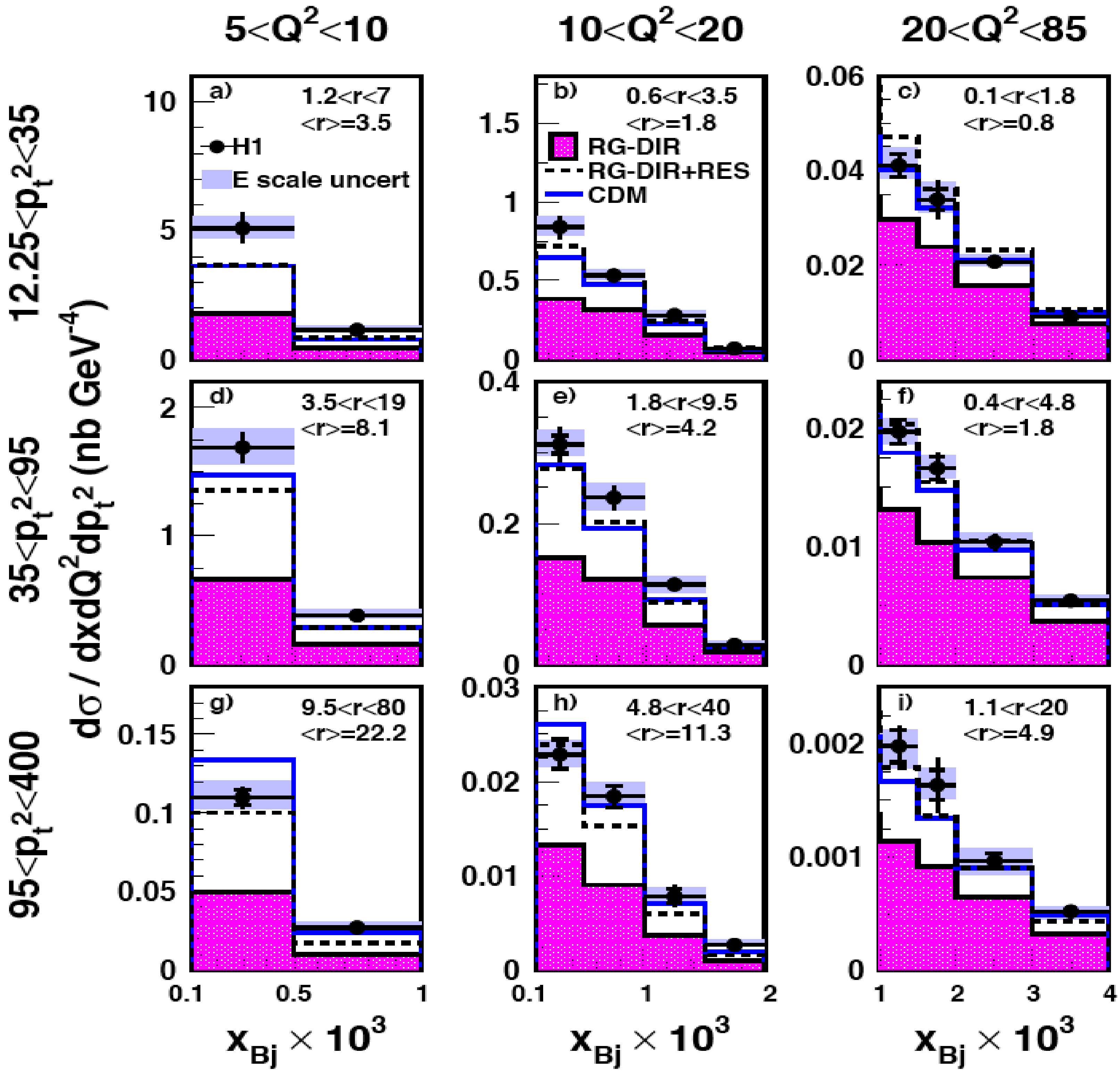

1 forward + 2 central jets
$\times 10^3$
200
180
160
140
120
100
80
60
40
20
0
10^{-4}
10^{-3}
x
dσ/dx / pb
data
pdf set 01
pdf set 02
pdf set 03
pdf set A0

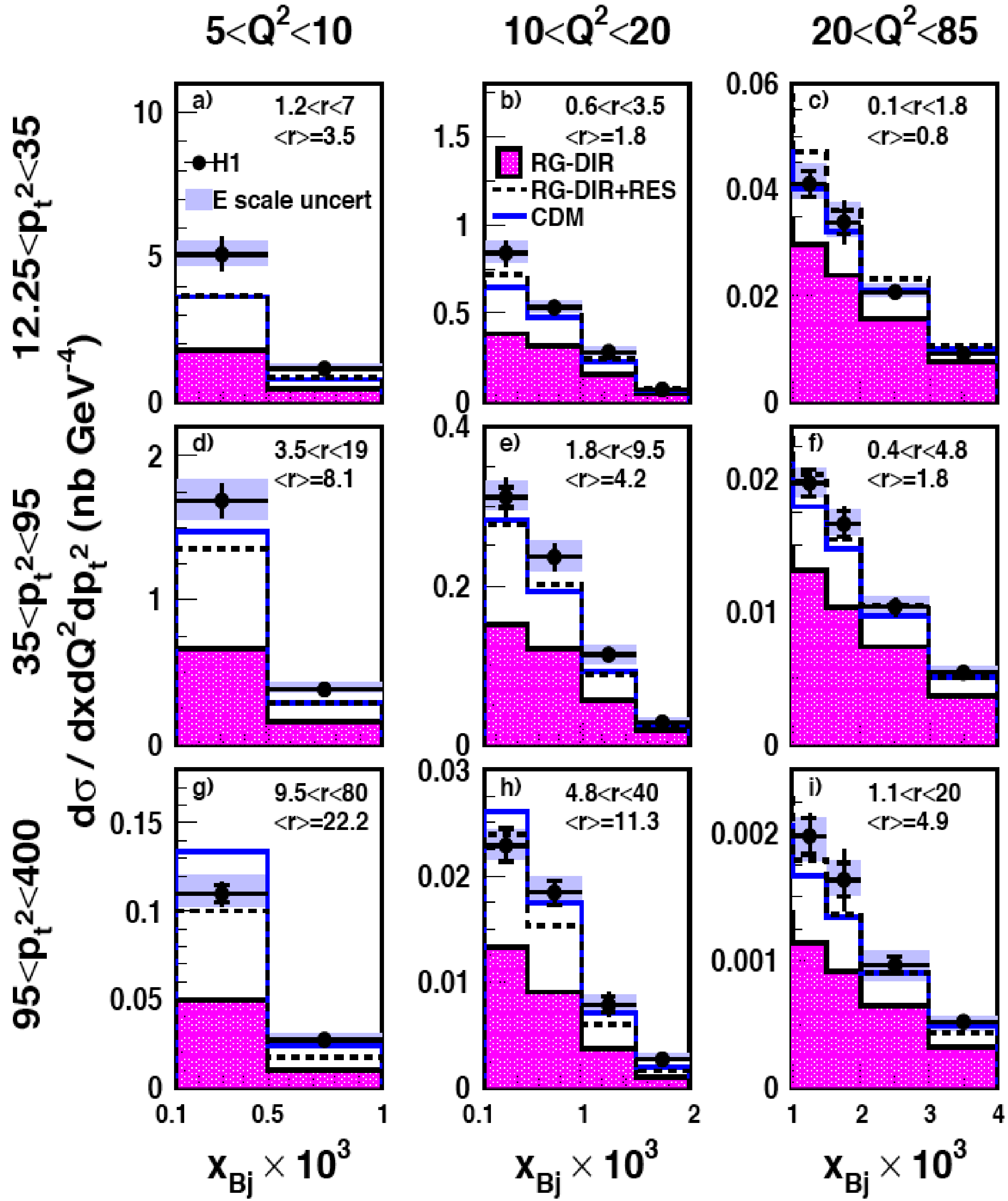

foward jet events
1000
800
600
400
200
0
10^{-4}
10^{-3}
x
dσ/dx / pb
data
pdf set 01
pdf set 02
pdf set 03
pdf set A0



$5<Q^2<10$
$10<Q^2<20$
$20<Q^2<85$
$12.25<p_t^2<35$
$35<p_t^2<95$
$95<p_t^2<400$
$d\sigma / dxdQ^2dp_t^2$ (nb GeV^{-4})
a) $1.2<r<7$ $\langle r\rangle=3.5$
H1
E scale uncert
b) $0.6<r<3.5$ $\langle r\rangle=1.8$
CASCADE set-1
CASCADE set-2
c) $0.1<r<1.8$ $\langle r\rangle=0.8$
d) $3.5<r<19$ $\langle r\rangle=8.1$
e) $1.8<r<9.5$ $\langle r\rangle=4.2$
f) $0.4<r<4.8$ $\langle r\rangle=1.8$
g) $9.5<r<80$ $\langle r\rangle=22.2$
h) $4.8<r<40$ $\langle r\rangle=11.3$
i) $1.1<r<20$ $\langle r\rangle=4.9$
$x_{Bj} \times 10^3$
$x_{Bj} \times 10^3$
$x_{Bj} \times 10^3$


5<Q²<10
10<Q²<20
20<Q²<85
12.25<p_t²<35
35<p_t²<95
95<p_t²<400
dσ / dxdQ²dp_t² (nb GeV⁻⁴)
a) 1.2<r<7 <r>=3.5
H1
E scale uncert
b) 0.6<r<3.5 <r>=1.8
NLO DISENT 1+δ_HAD
0.5μ_r,f<μ_r,f<2μ_r,f PDF uncert.
c) 0.1<r<1.8 <r>=0.8
LO DISENT 1+δ_HAD
d) 3.5<r<19 <r>=8.1
e) 1.8<r<9.5 <r>=4.2
f) 0.4<r<4.8 <r>=1.8
g) 9.5<r<80 <r>=22.2
h) 4.8<r<40 <r>=11.3
i) 1.1<r<20 <r>=4.9
x_Bj × 10³
x_Bj × 10³
x_Bj × 10³


5<Q²<10
10<Q²<20
20<Q²<85
12.25<pt²<35
35<pt²<95
95<pt²<400
dσ / dxdQ²dpt² (nb GeV⁻⁴)
a) 1.2<r<7 <r>=3.5
H1
E scale uncert
b) 0.6<r<3.5 <r>=1.8
RG-DIR
RG-DIR+RES
CDM
c) 0.1<r<1.8 <r>=0.8
d) 3.5<r<19 <r>=8.1
e) 1.8<r<9.5 <r>=4.2
f) 0.4<r<4.8 <r>=1.8
g) 9.5<r<80 <r>=22.2
h) 4.8<r<40 <r>=11.3
i) 1.1<r<20 <r>=4.9
xBj × 10³
xBj × 10³
xBj × 10³



5<Q²<10
10<Q²<20
20<Q²<85
12.25<pt²<35
35<pt²<95
95<pt²<400
dσ / dxdQ²dpt² (nb GeV⁻⁴)
a) 1.2<r<7 <r>=3.5
H1
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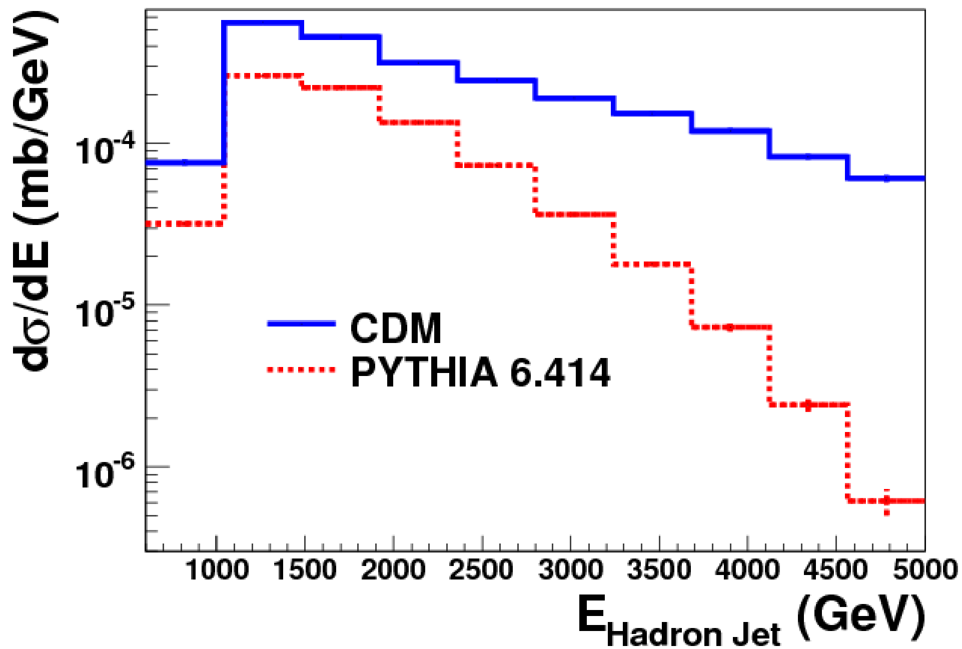
i) 1.1<r<20 <r>=4.9
x_Bj × 10³
x_Bj × 10³
x_Bj × 10³

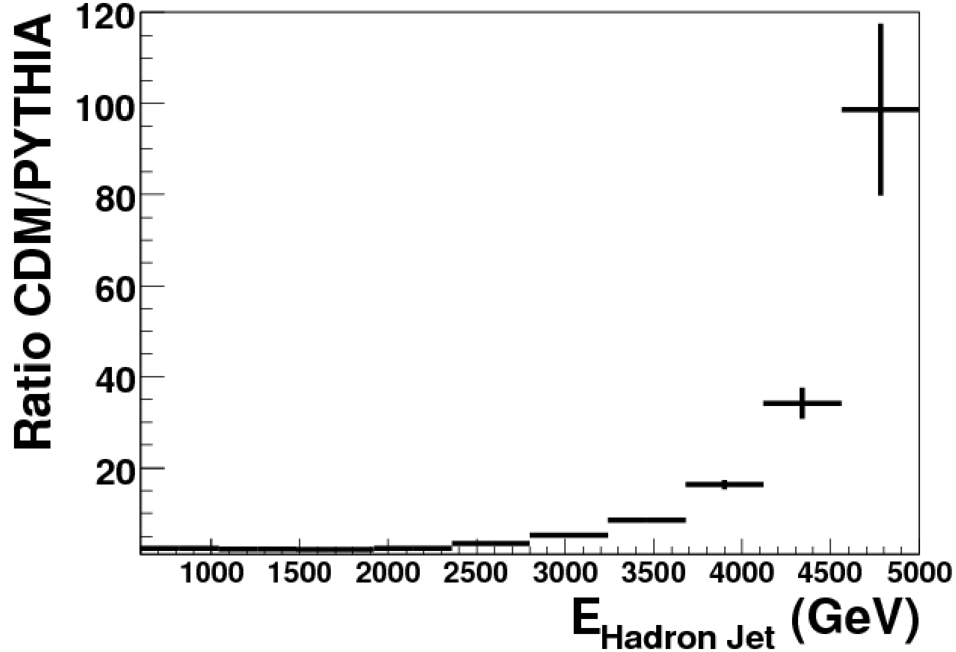
LHC FORWARD JETS

Forward Jets in CASTOR

Selection: 2 central jets, 1 jet in CASTOR region $(5.2 < \eta < 6.6)$
with $E_t > 10\ \mathrm{GeV}$

Hadron level – Generator studies



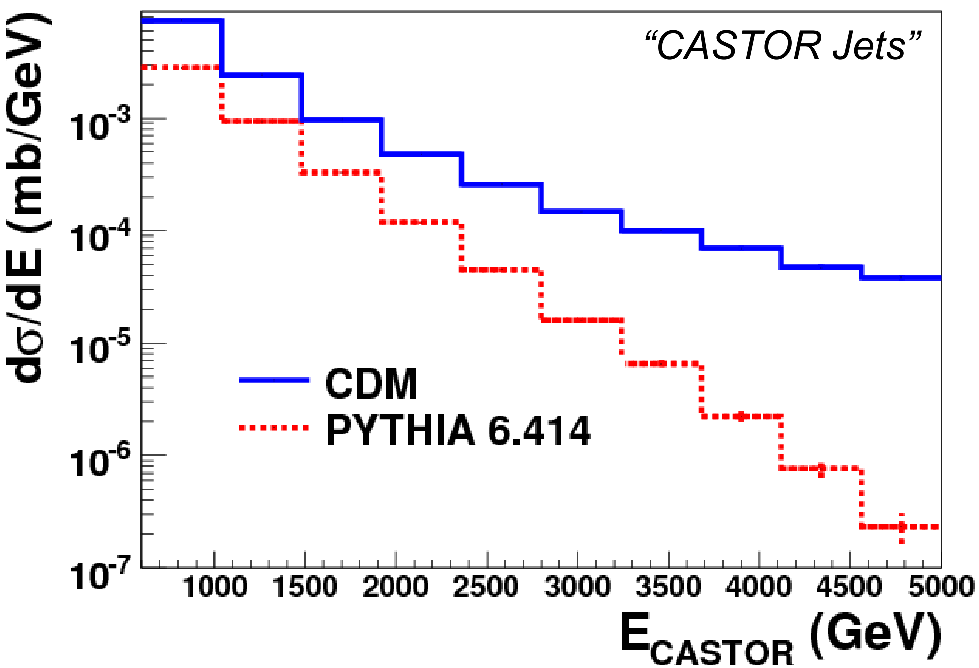


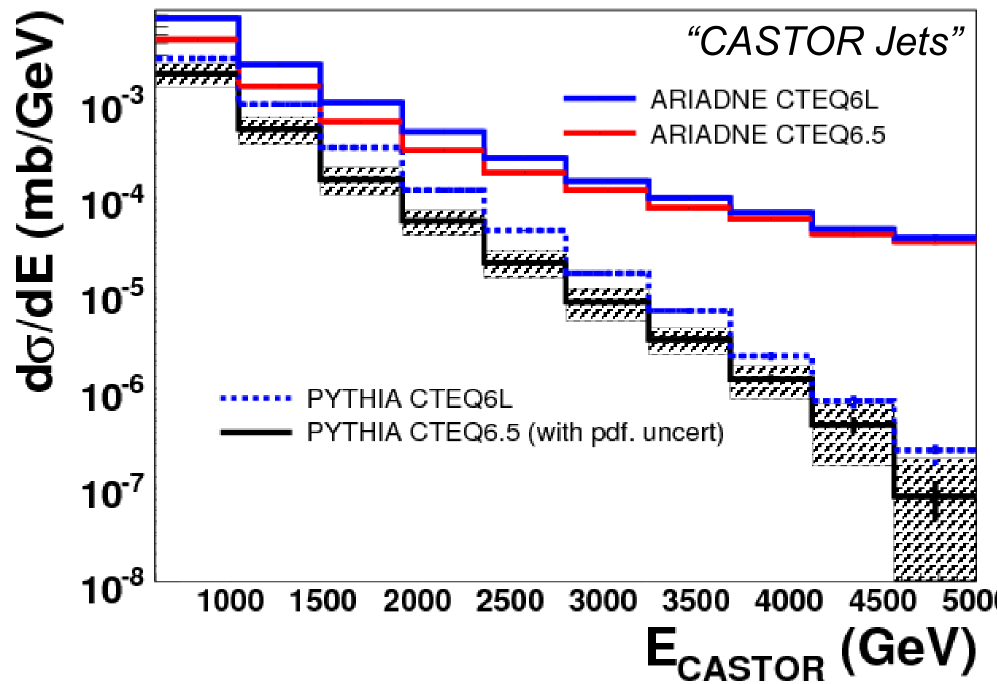
The Color Dipole Model – giving a more BFKL like final state – with partons unordered in kt (with respect to rapidity) – predicts more hard jets in the CASTOR region.

Both PYTHIA and ARIADNE are run together with Multipartoninteractions Tune A. (Tune A = One of the R. Field tunes to TEVATRON data.)

CASTOR Jets

-Instead of conventional jet algorithm:
"CASTOR Jets": Jet reconstruction as described earlier
(most active segment+neighbors)
-Particle energy smeared according to test beam data
-Noise cut of particles (E_particles > 1 GeV)

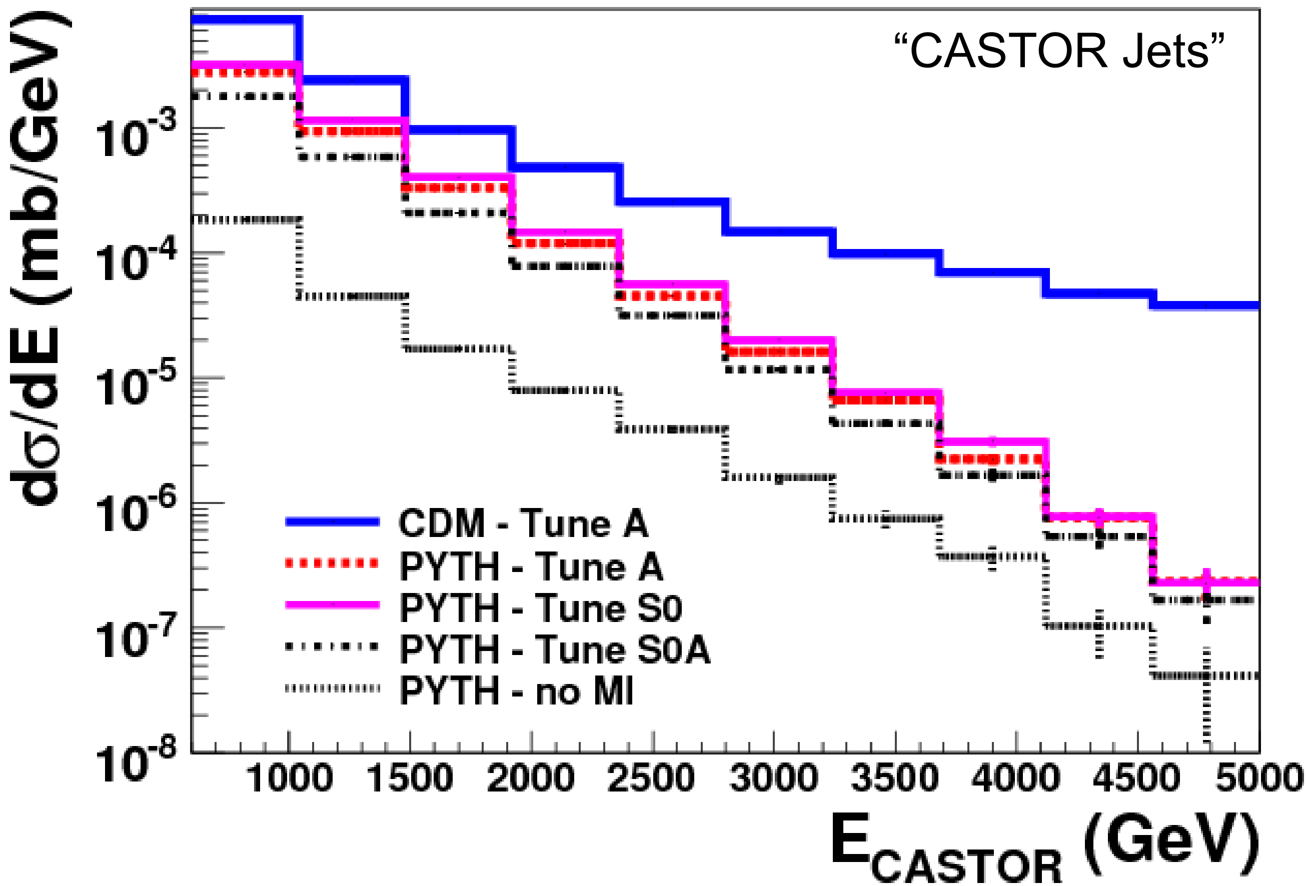




- With "CASTOR Jets" we can make measurements that distinguish between the different QCD models (DGLAP/non-DGLAP).
- At high energy DGLAP/non-DGLAP separation >> PDF uncertainty/sensitivity
- Study made at < 1pb^{-1} . One of the first topics to be analysis by using CASTOR

Effects from MI on forward jet analysis

Selection: 2 central jets, 1 jet in CASTOR region $(5.2 < \eta < 6.6)$
with $E_t > 10$ GeV

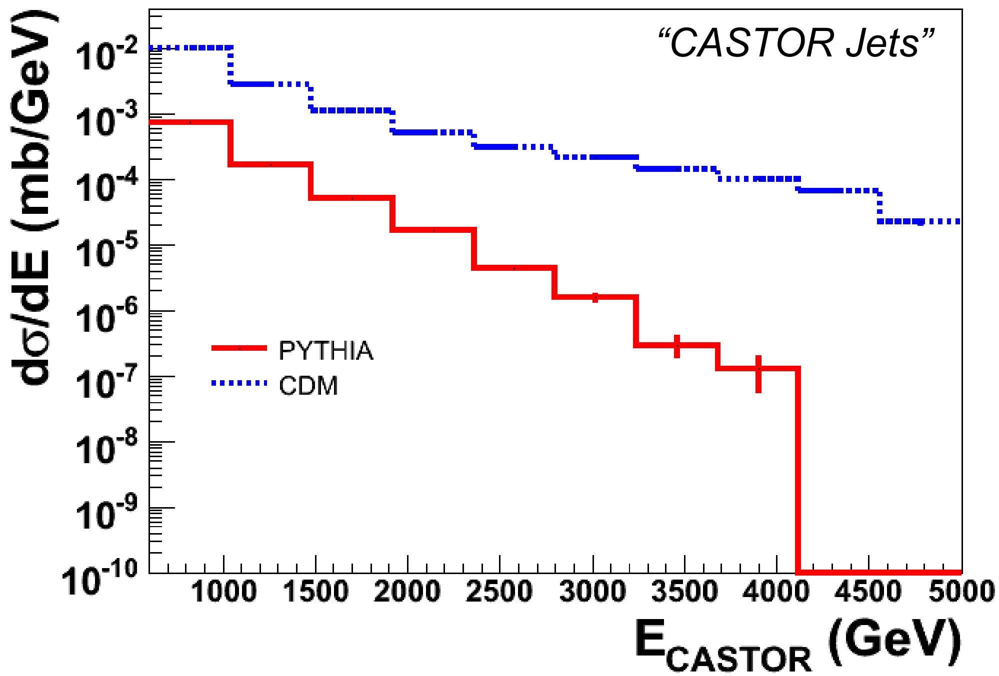


- **Large effect from switching MI off in MC.**
- **At high E difference between CDM and PYTHIA still larger than different MI tunes/models**

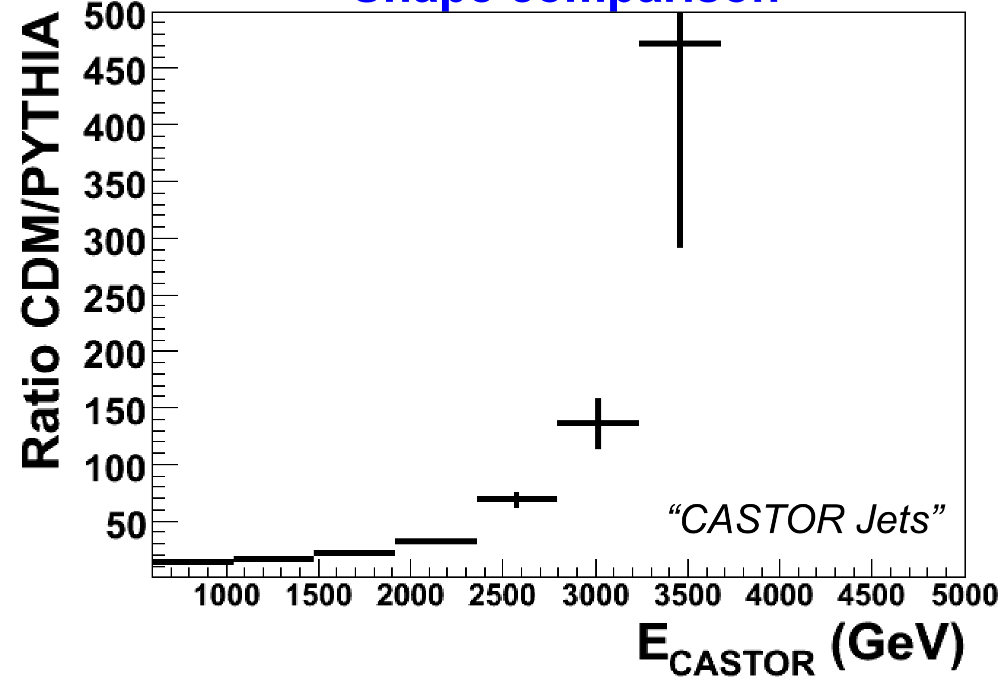
5 TeV beams

Hadron level MC studies – (No detector simulation applied)

Cross-section



Shape comparison

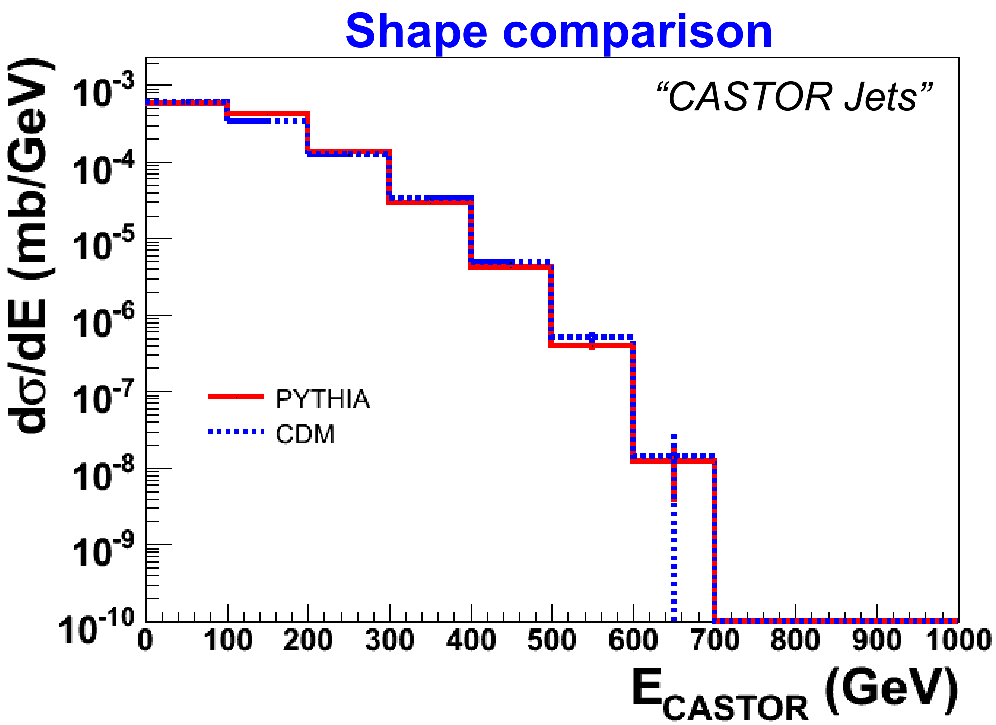


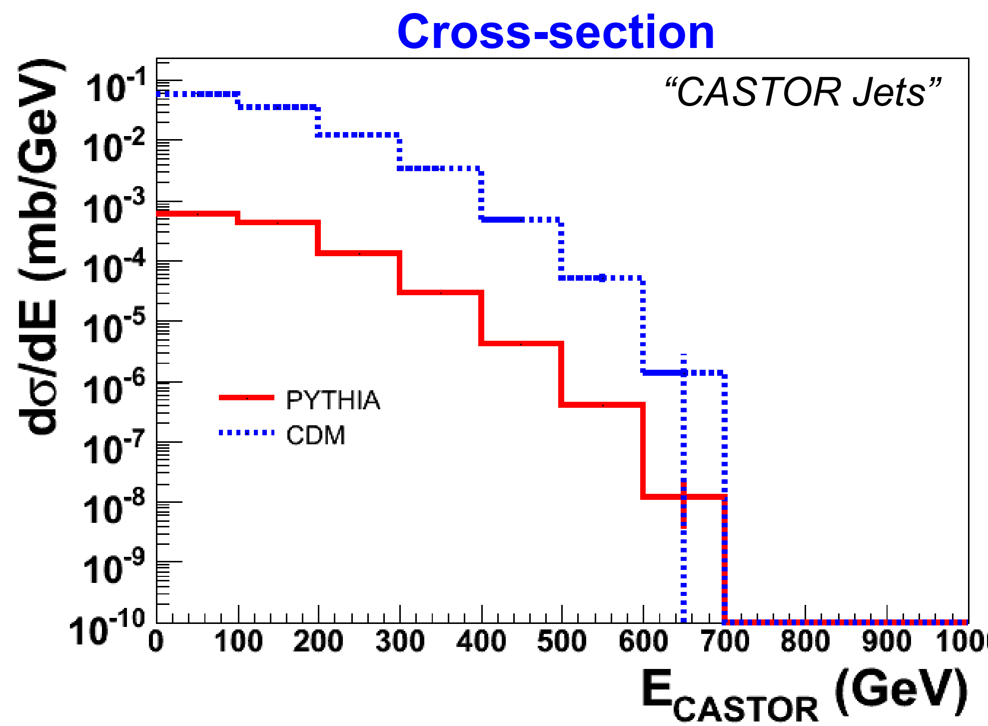
→ Ok! Can expect physics signal for 5 TeV beams

→ This study: 250000 events, sigma_tot=5mb => Lumi<<1 pb^-1

450 GeV beams

Hadron level MC studies – (No detector simulation applied)





→ No difference in shape.

→ Total forward jet cross-section ~2 orders of magnitude lower for PYTHIA .

→ Possibly interesting measurement.

Motivation

• Search for higher order QCD effects. Parton dynamics beyond DGLAP. BFKL effects.

CASTOR has good segmentation in Phi. Make use of it!

Azimuthal decorrelations for Mueller-Navelet jets

At LO: Delta Phi =180

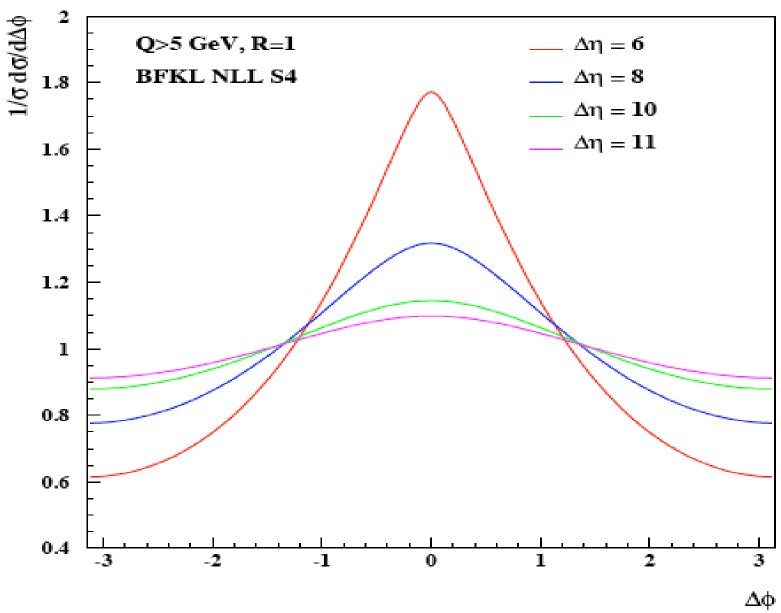
For H.O. DGLAP the momentum conservation between the two jets are expected to be more conserved, while H.O BFKL emissions expects to give a flatter Delta Phi distribution.

Effect from using unintegrated gluon densities.
Input k_t from gluon PDF > 0. => Delta Phi < 180 already at LO

Large rapidity range between jets (use CASTOR) to open up phase space for more emissions

Azimuthal decorrelation between Mueller-Navelet jets at the TEVATRON as predicted by BFKL NLL (C. Royon - DIS2007 proceeding).

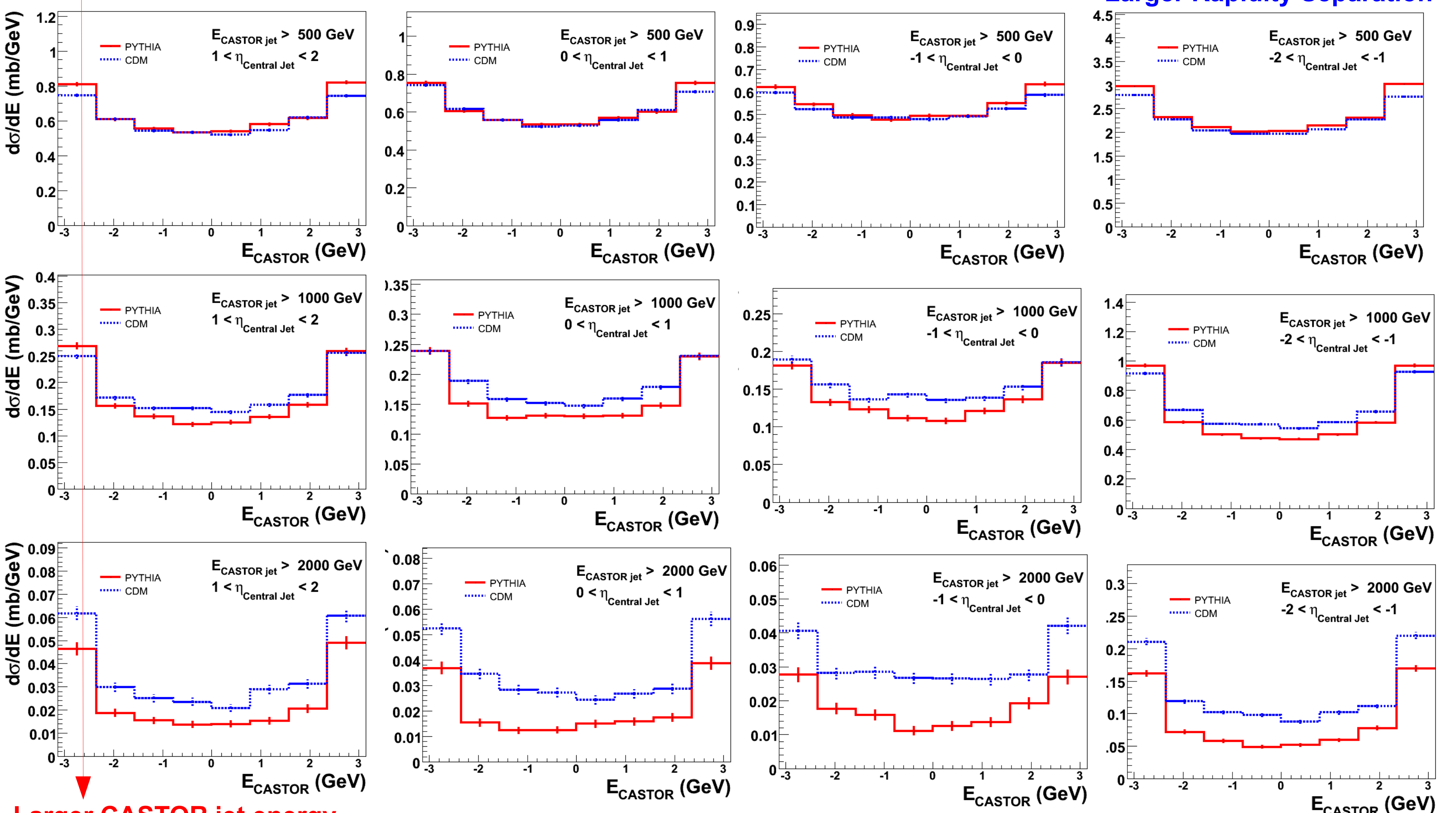
Larger eta separation - > Flatter distribution.



CDM-PYTHIA comparison

Selection: Central Jet with Et > 10 GeV + “CASTOR Jet”.
5.2 < Eta(CASTOR) < 6.4
(“CASTOR Jet” defined as most active azimuthal segment (2*pi/16) + Neighbours.)

Larger Rapidity Separation

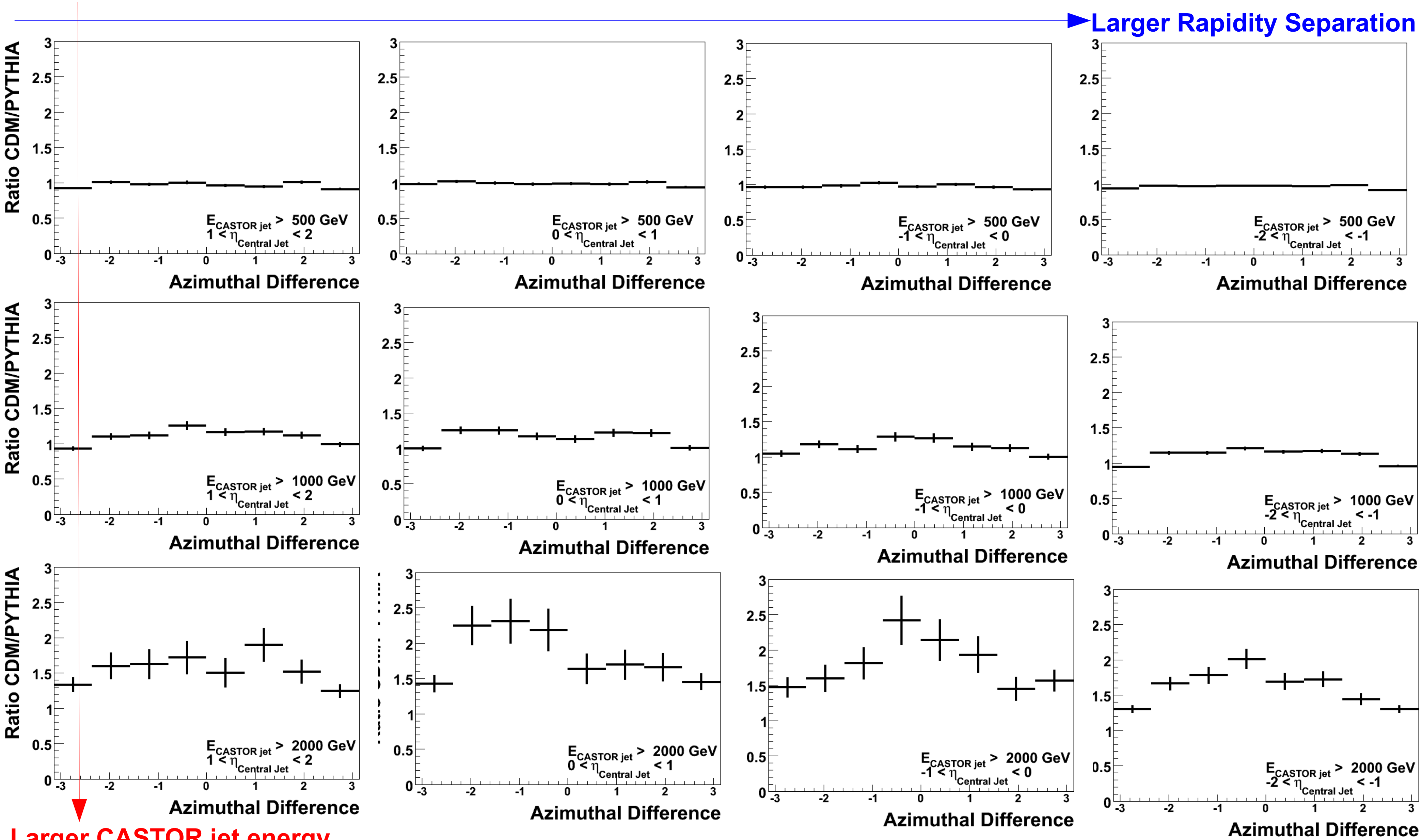


Larger CASTOR jet energy

PYHTIA multiplied with 10 for visualisation. (Shape difference best seen on next slide.)

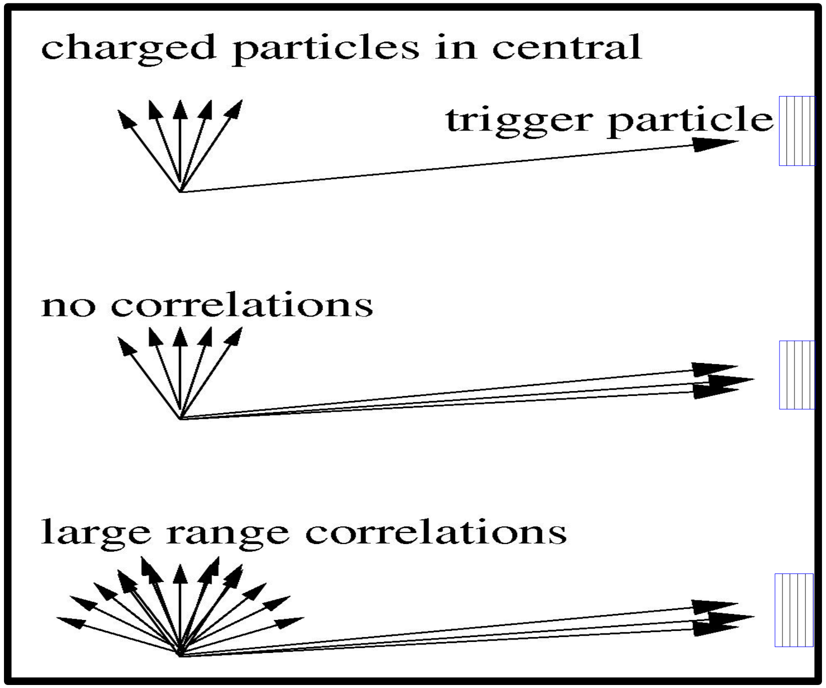
CDM-PYTHIA Comparison

Selection: Central Jet with Et > 10 GeV + “CASTOR Jet”.
5.2 < Eta(CASTOR) < 6.4
(“CASTOR Jet” defined as most active azimuthal segment (2*pi/16) + Neighbours.)



- **Larger shape difference for higher CASTOR Jet energies**

Long range correlations and MI

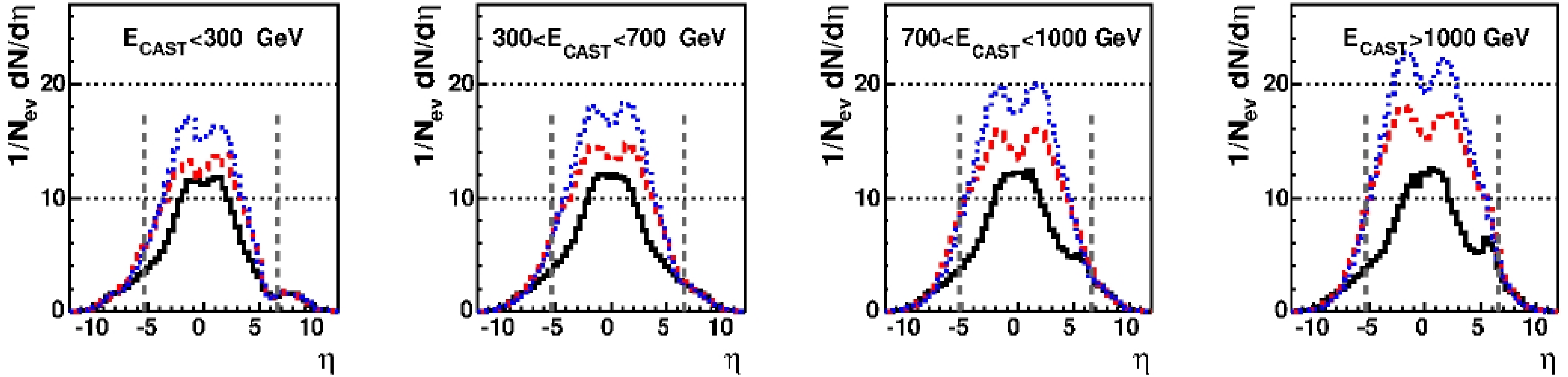


•**With MPI**:
Large energy of trigger in CASTOR,
→
Higher particle multiplicity in central region

•**Without MPI:**
No, or very small, correlation

PYTHIA:
-Rick-Field's CDF tune A (tune A)
-Sandhoff-Skands tune 0 (tune S0)
-MI switched off

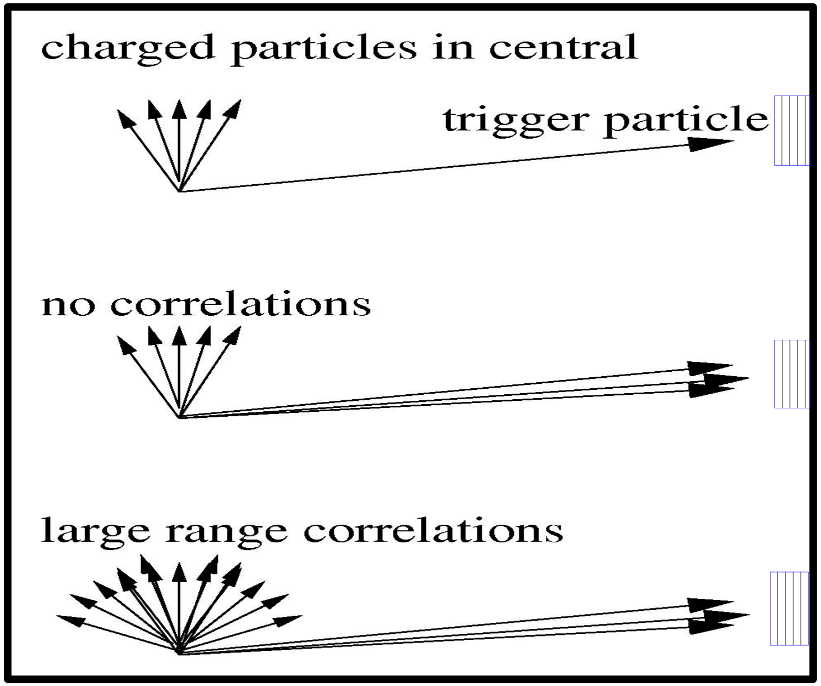
Top events



→ **Top events much higher activity in the UE**

(CASTOR particles smeared according to beam test data + 1 GeV noise cut applied.)

Long range correlations and MI



•**With MPI**:
Large energy of trigger in CASTOR,
→
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•**Without MPI:**
No, or very small, correlation

PYTHIA:
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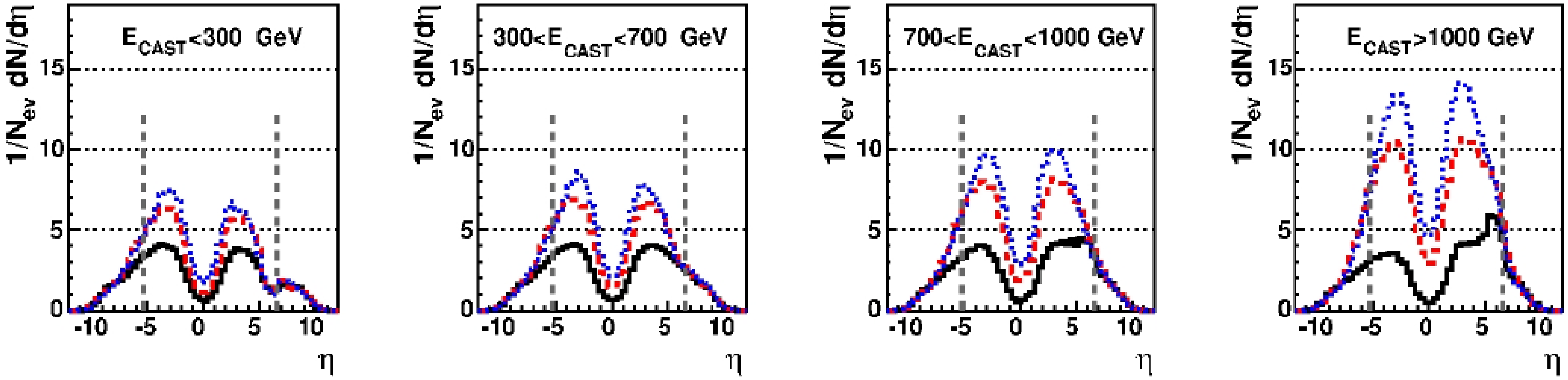
-Sandhoff-Skands tune 0 (tune S0)
-MI switched off

QCD events



(CASTOR particles smeared according to beam test data + 1 GeV noise cut applied.)