Forward Jets with the CASTOR calorimeter at the CMS experiment

Albert Knutsson

Mini workshop on small x physics
DESY, 30/1 - 2009

Outline

- CASTOR – the calorimeter
- Physics motivation
- MC studies
- Summary

Some other CASTORs...

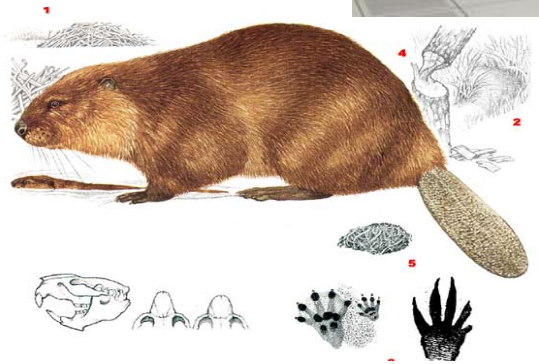
Please don't confuse the calorimeter with other CASTORs!

- **CA**sk for **S**torage and **T**ransportation **O**f **R**adioactive materia

"Castor-Behälter mit Atommüll"

- **C**ern **A**dvanced **STOR**age manager (~17000TB)

- ***Castor*** – latin genus for beaver



European Beaver (Castor Fiber)

CASTOR

Centauro **A**nd **ST**range **O**bject **R**esearch

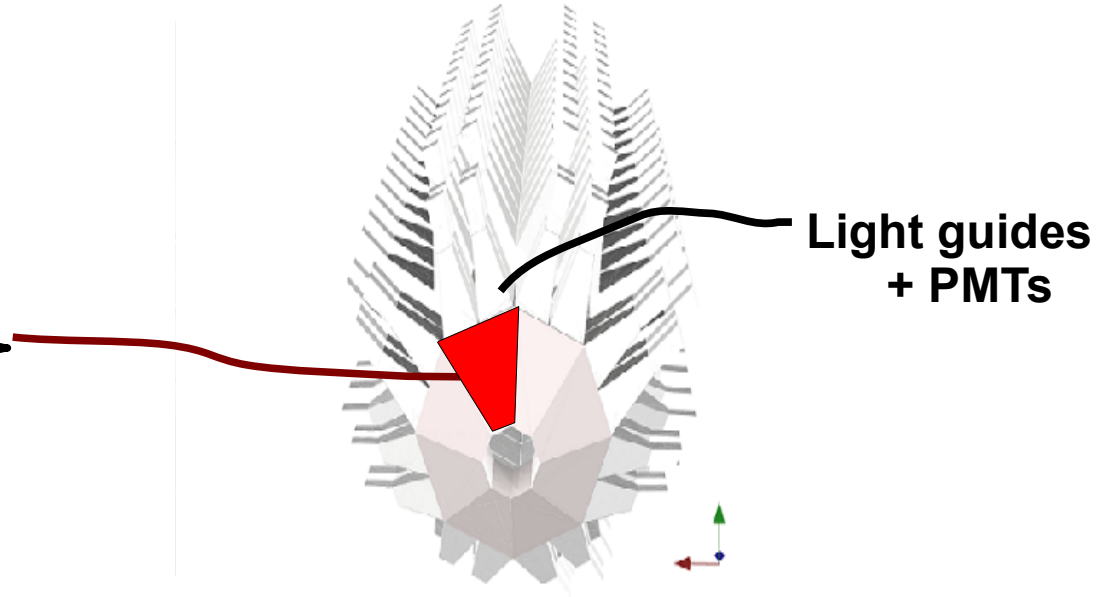
A Cherenkov radiation calorimeter.

Tungsten absorber plates

and

Quartz plates as active medium

sandwiched in



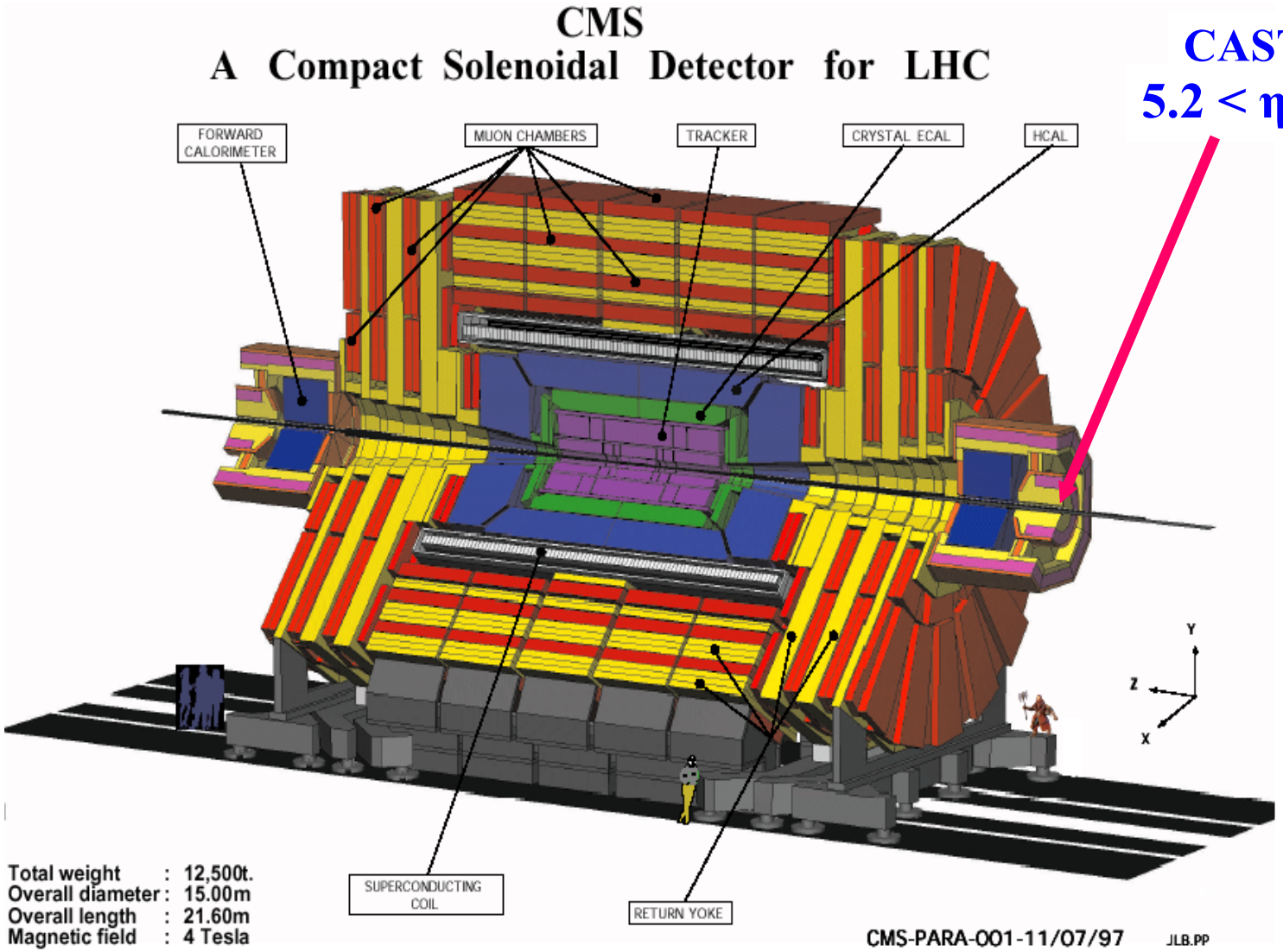
Octants in *Phi* with 2 columns of light guides and PMTs on top.

16 azimuthal * (2 EM + 12 HAD) longitudinal channels = 224 channels
Length: 1.6m, Diameter: 0.6m

$5.2 < \eta < 6.6$

Good segmentation in *Phi*, large depth, *no segmentation in rapidity*.

Position of CASTOR in CMS



More Forward - Lower x

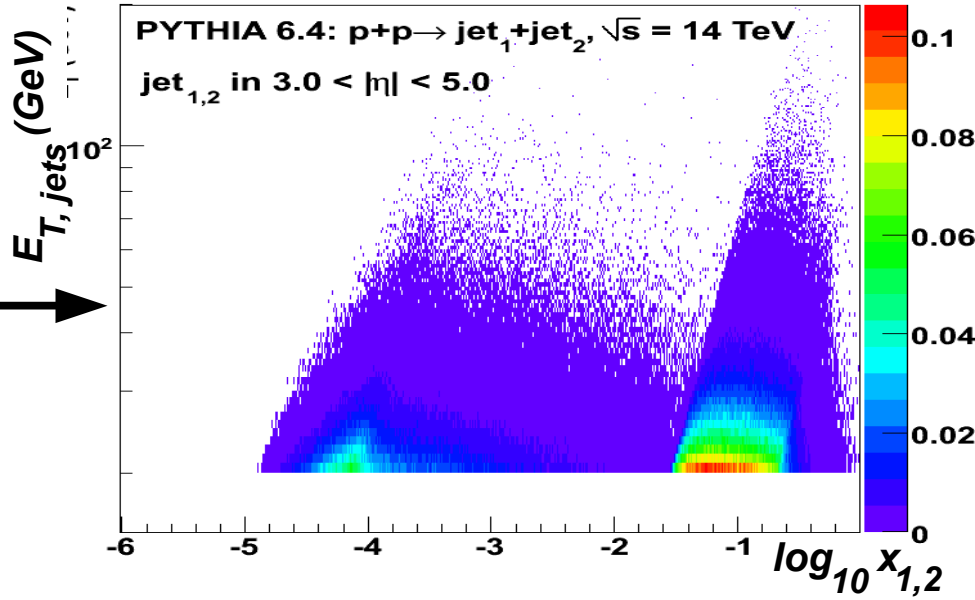
Jets in CMS Hadronic Forward Calorimeter

$(3 < \eta < 5)$

$x \sim 10^{-5}$

Dijets with at least one jet in HF

CMS note PAS-FWD-08-001



2 units in rapidity

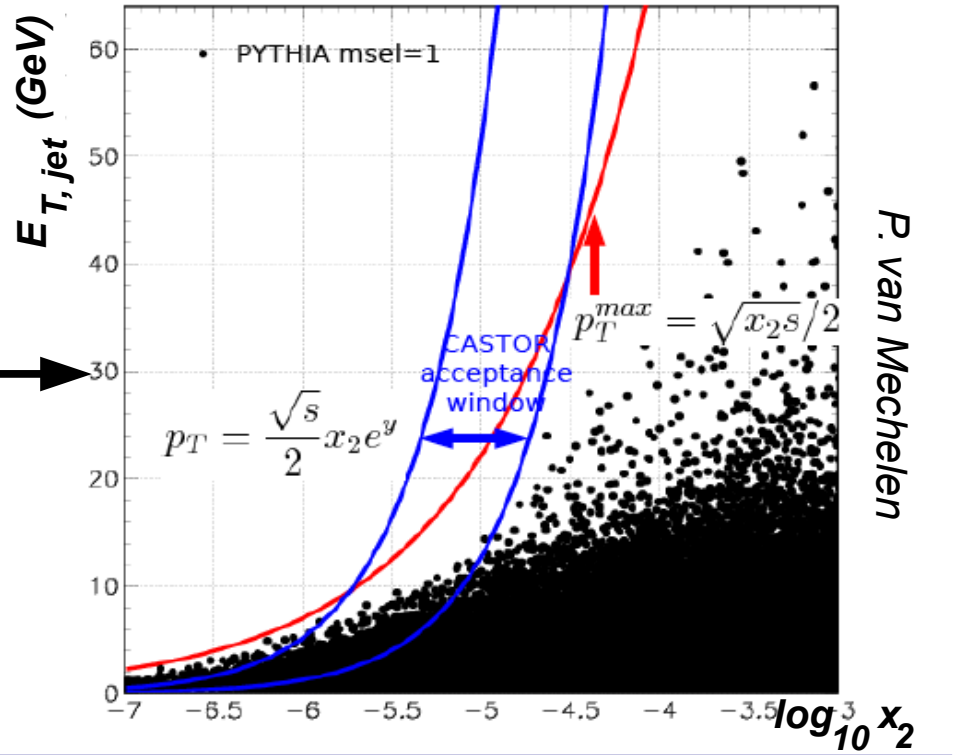
→

Roughly 1 magnitude in *x*

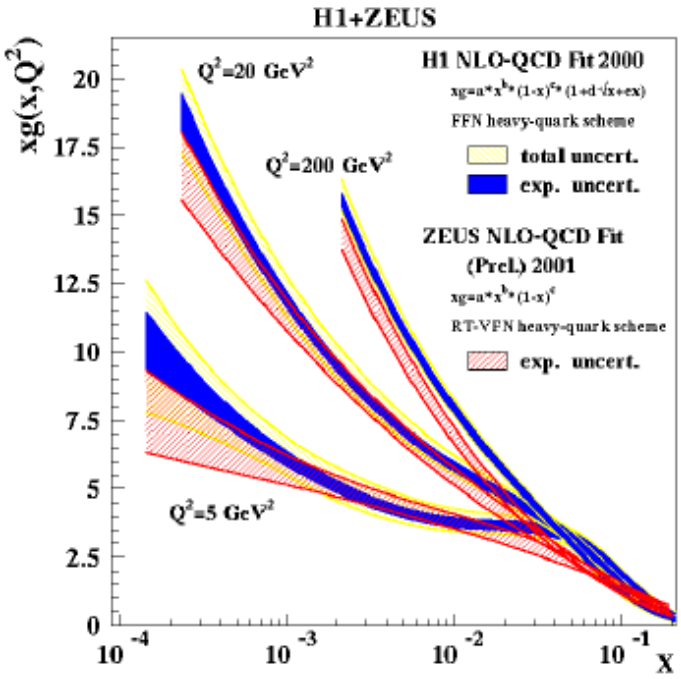
Dijets with at least one jet in CASTOR

$(5.2 < \eta < 6.6)$

$x \sim 10^{-6}$



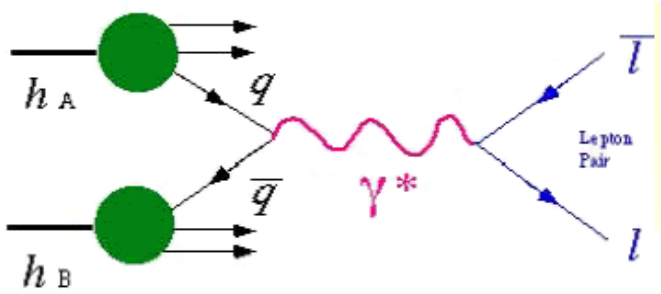
PDFs at Low x



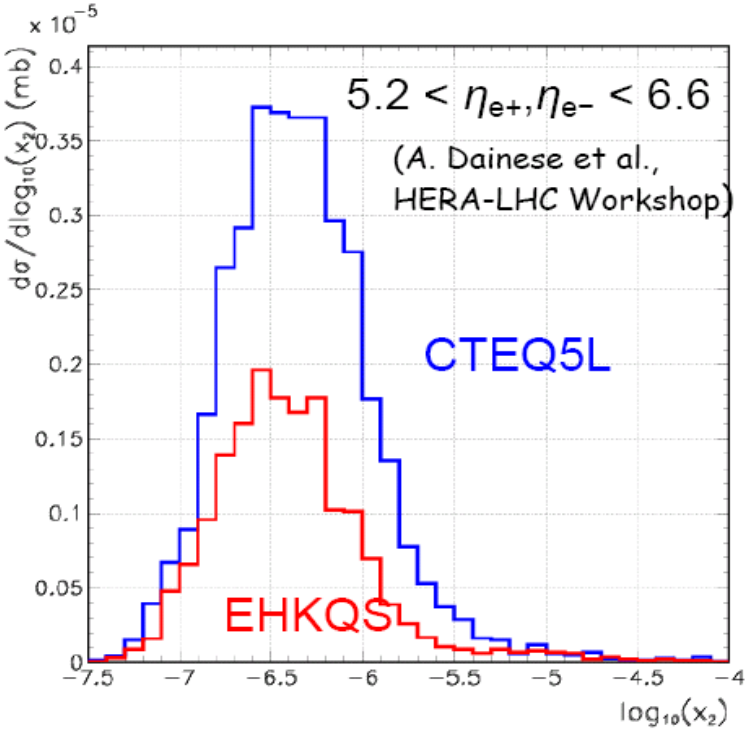
-5

HERA experiments have measured PDFs down to x ~ 10^{-4}
Strong rise of the gluon

Measure Drell-Yang pairs in CASTOR



→ Target low x (10^{-6}) region and possible sensitivity to saturation



Saturated PDF suppress DY production by a factor of 2

Parton Dynamics

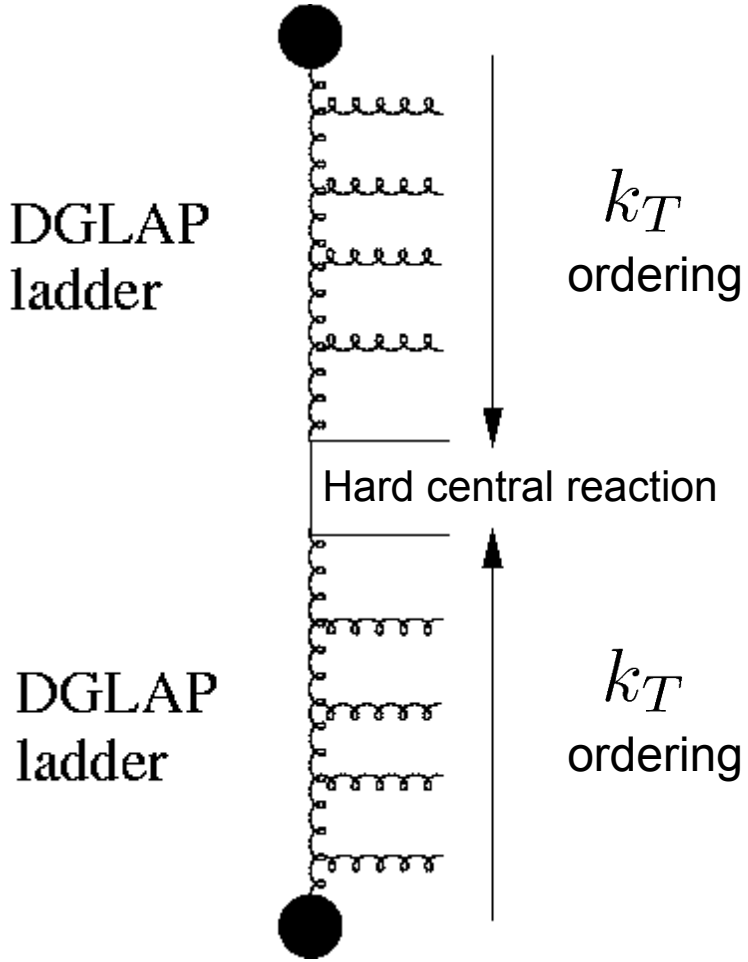
Matrix element QCD calculations exist only for up to Next-to-Leading-Order O(α_s^3).

Higher order reactions estimated by using approximate calculations,
so called evolution equations.
Different evolution equations resum different terms
in the pertubative expansion.

DGLAP
(*Dokshitzer-Gribov-Lipatov-Altarelli-Parisi*)

Resums terms depending on parton
virtuality, resulting in ordering
of virtuality of propagators ~ kt of emitted partons.

Implemented in e.g. the Monte Carlo
generators **RAPGAP (ep)** and **PYTHIA (pp)**

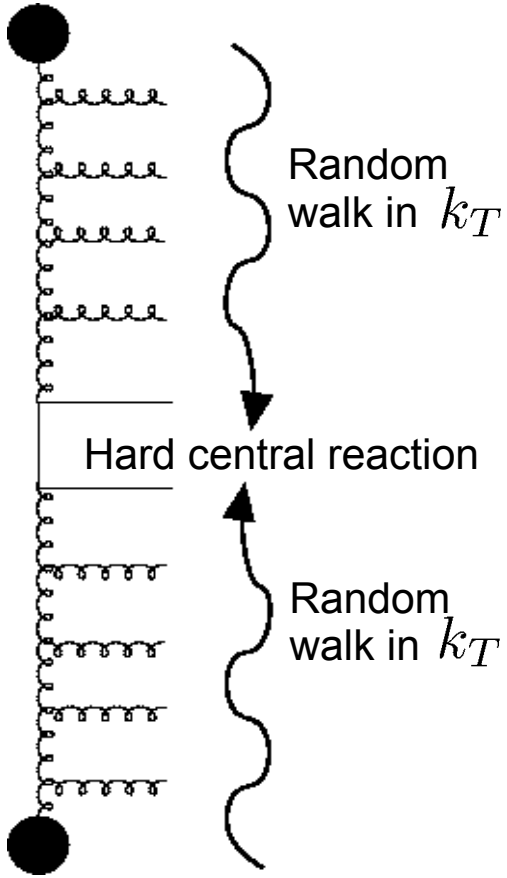


Parton Dynamics

Non DGLAP calculations

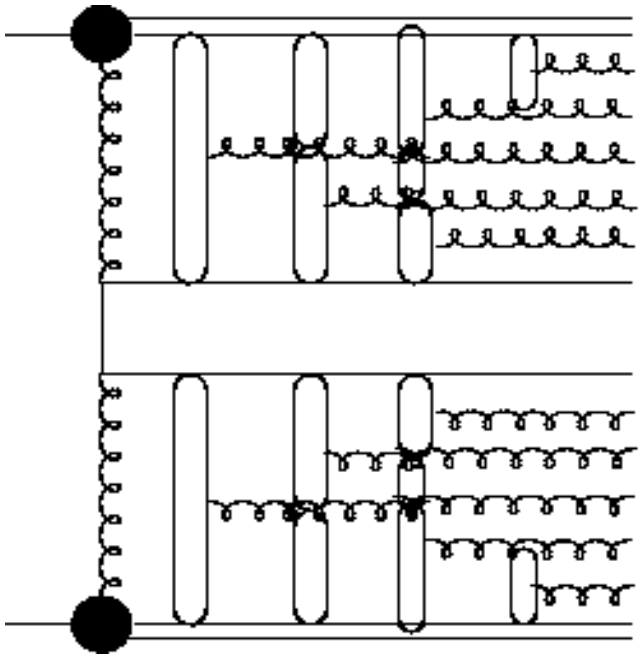
No ordering in k_t of emitted partons

BFKL/CCFM
(Balitski-Fadin-Kripov-Lipatov)/
(Ciafaloni,Catani,Fiorani,Marchesini)



Color Dipole Model (CDM)

Colored objects span color dipoles in between.
Dipoles decays into gluons...
....which in turn spans new color dipoles, and so on...

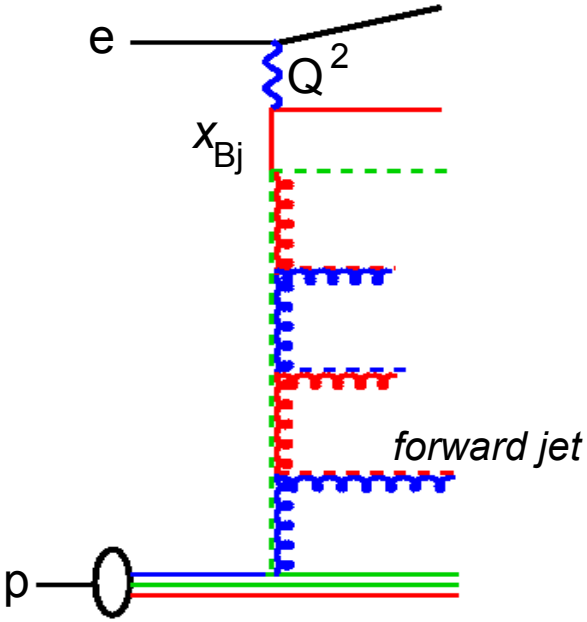


Radiation emitted randomly in k_T

No ordering in k_T: *Can expect more harder radiation close to proton remnant (the forward region).*

Parton Dynamics

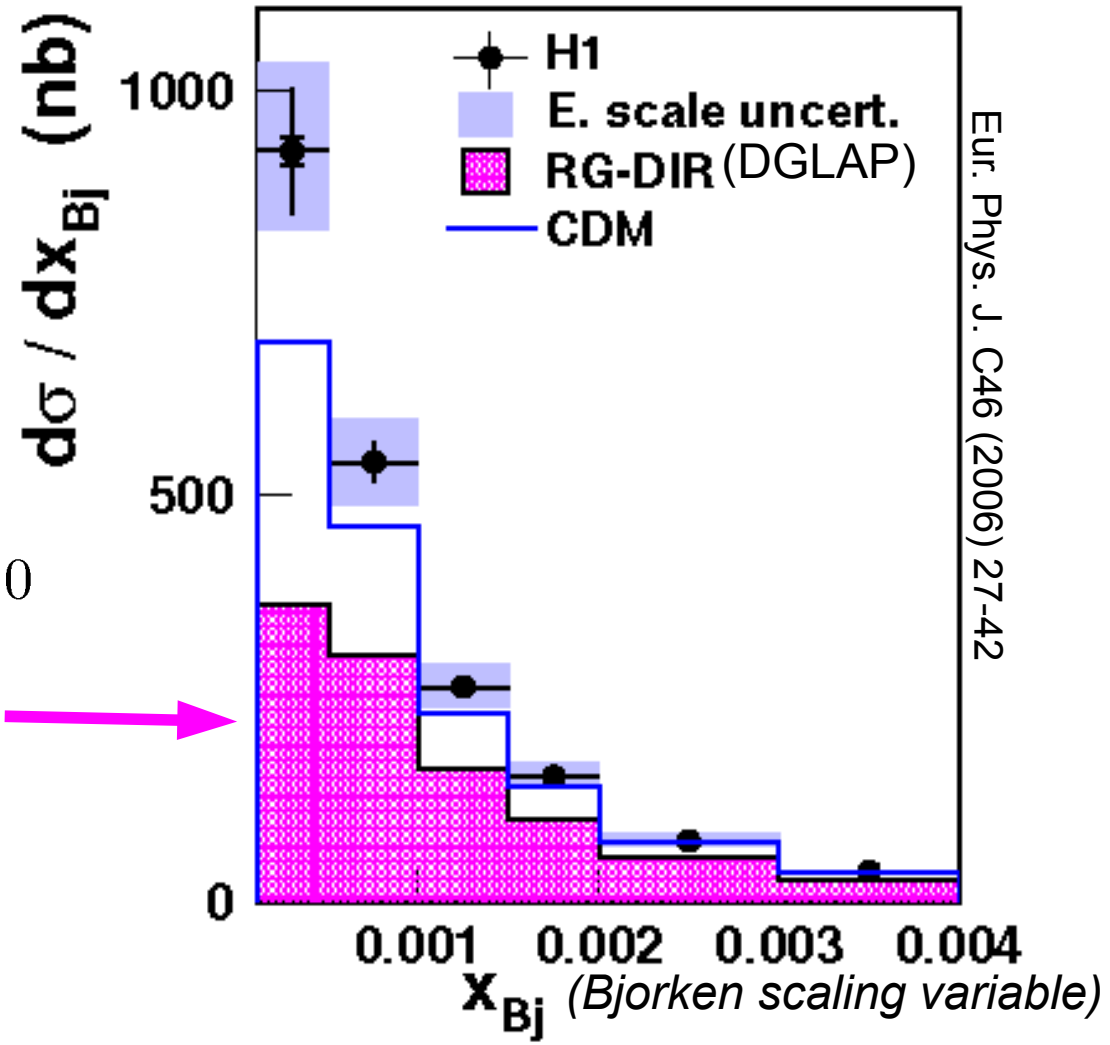
In **ep physics at HERA DGLAP describes inclusive measurements** (e.g. F_2) **successfully**. but **fails for** more exclusive final states, for example **forward jet production**:



DGLAP suppressed: $0.5 < \frac{E_{T,jet}^2}{Q^2} < 5.0$

Ordering of kt of emissions (DGLAP) are not sufficient.

Need more hard emissions in forward region.



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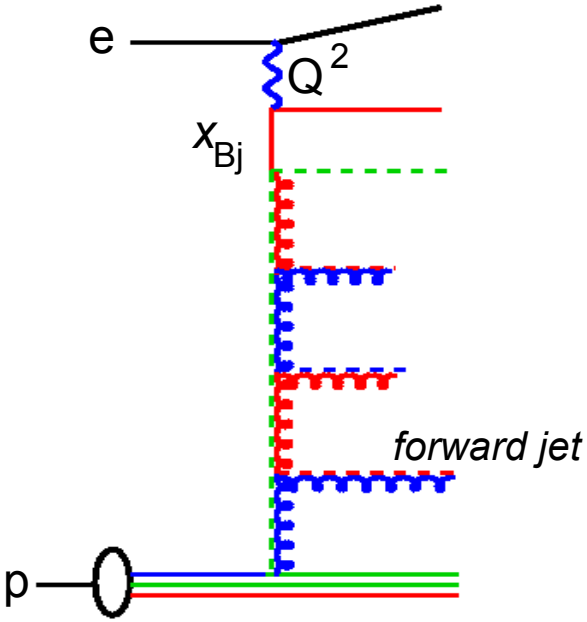

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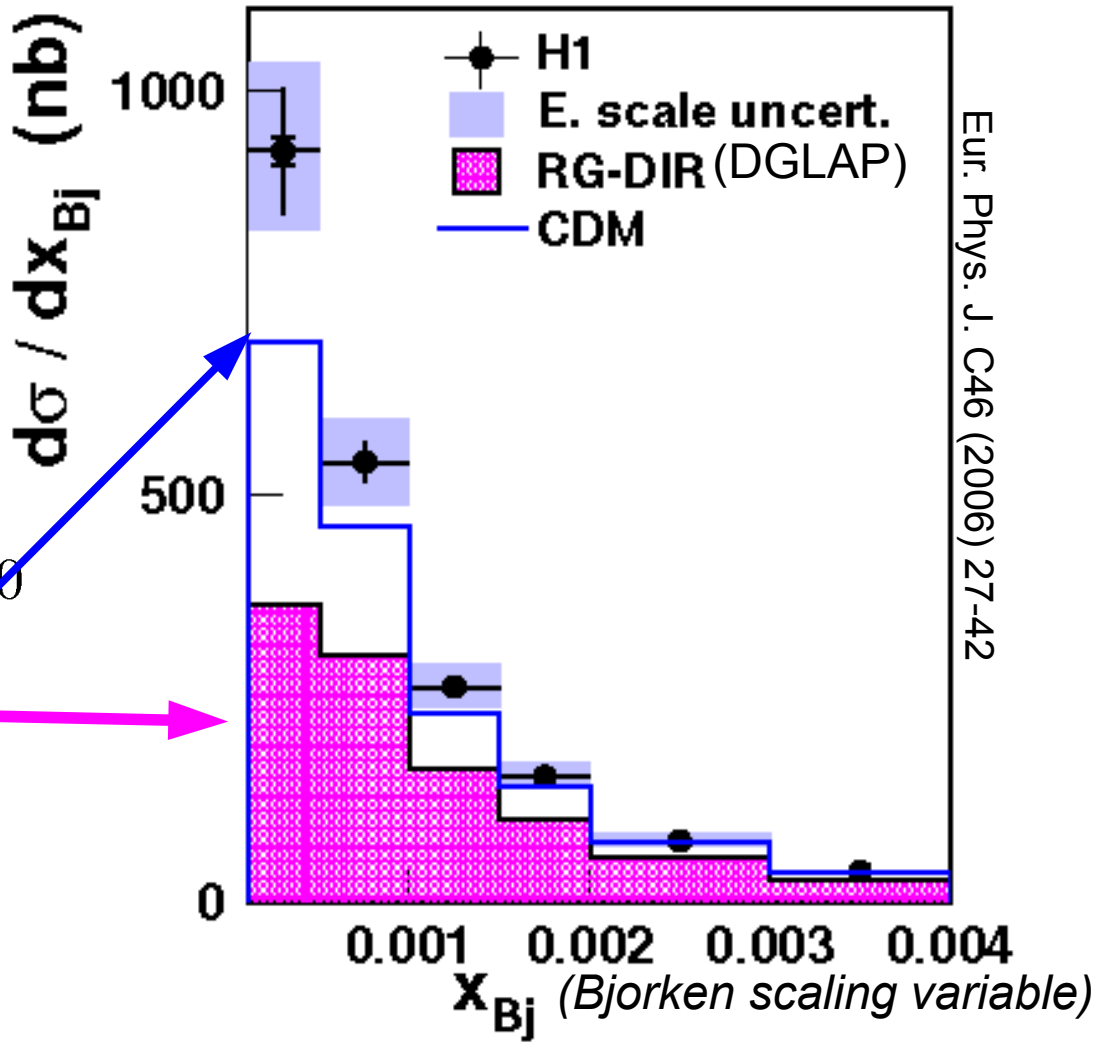


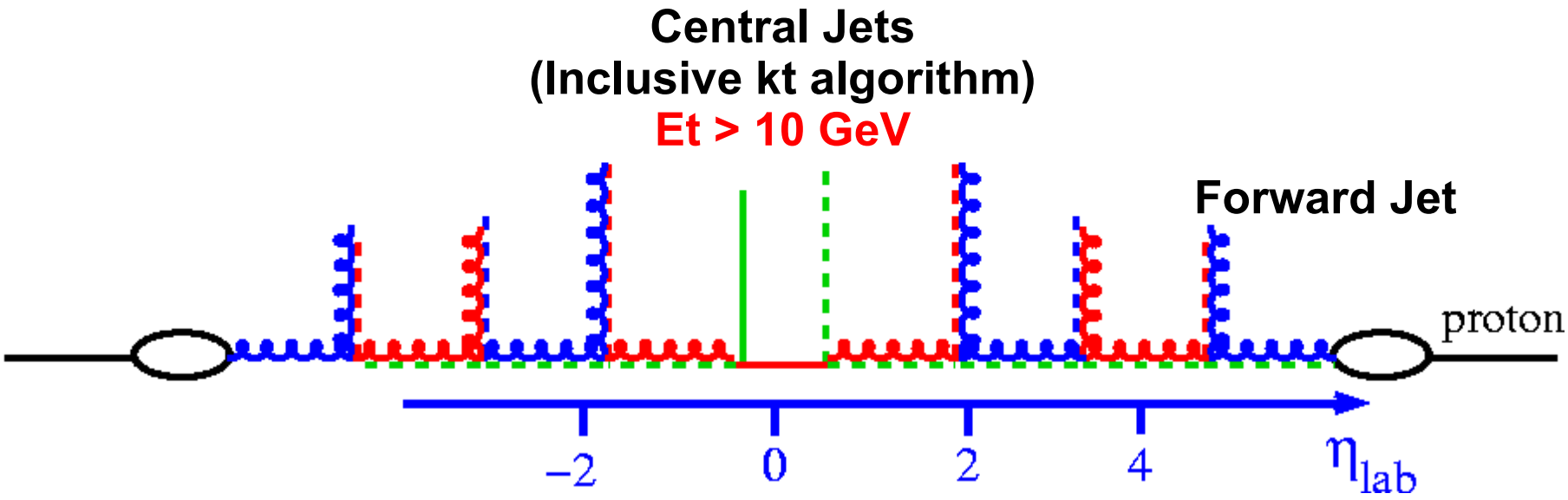
Ordering of kt of emissions (DGLAP) are not sufficient.

Need more hard emissions in forward region.

As for example in the Color Dipole Model (BFKL like scenario).

Event selection / Physics motivation

2 central jets + 1 CASTOR jet



Hard jet or particle in forward region,
large rapidity range between central and and forward region

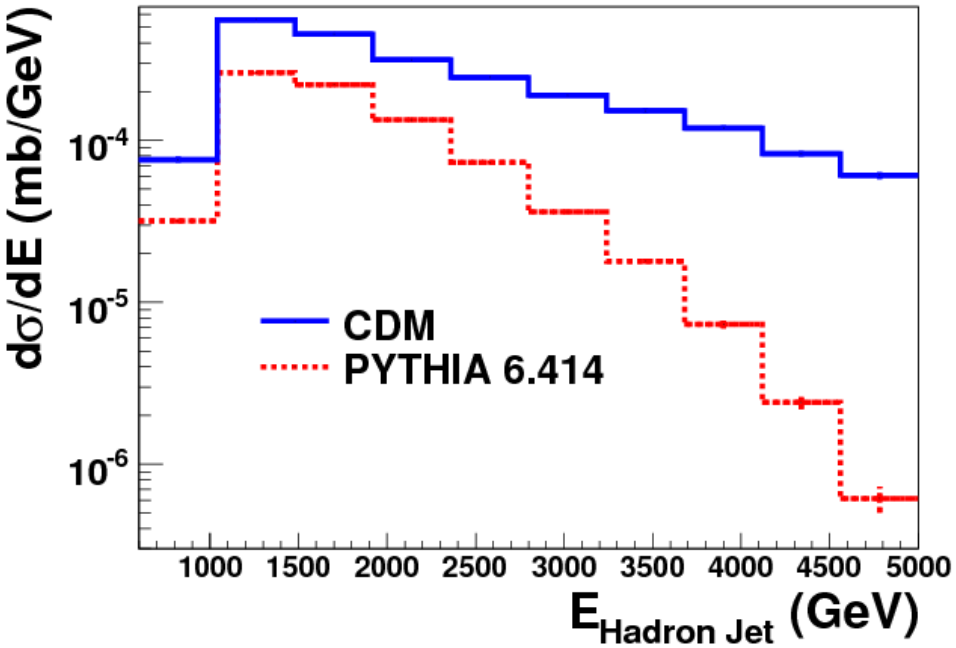
- •Opens up phase space for emissions, higher order reactions
- •Small x physics
- •Possible to apply constraints on parton ladder
- •Gain information of the full evolution

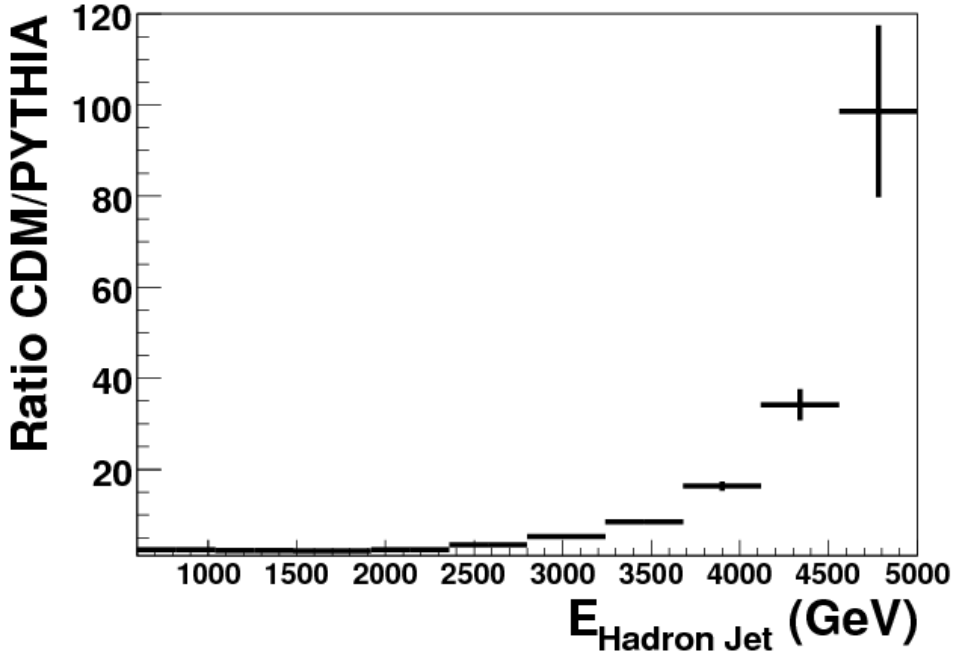
→ Tool to study higher order QCD reactions

Forward Jets in CASTOR

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

Hadron level – Generator studies





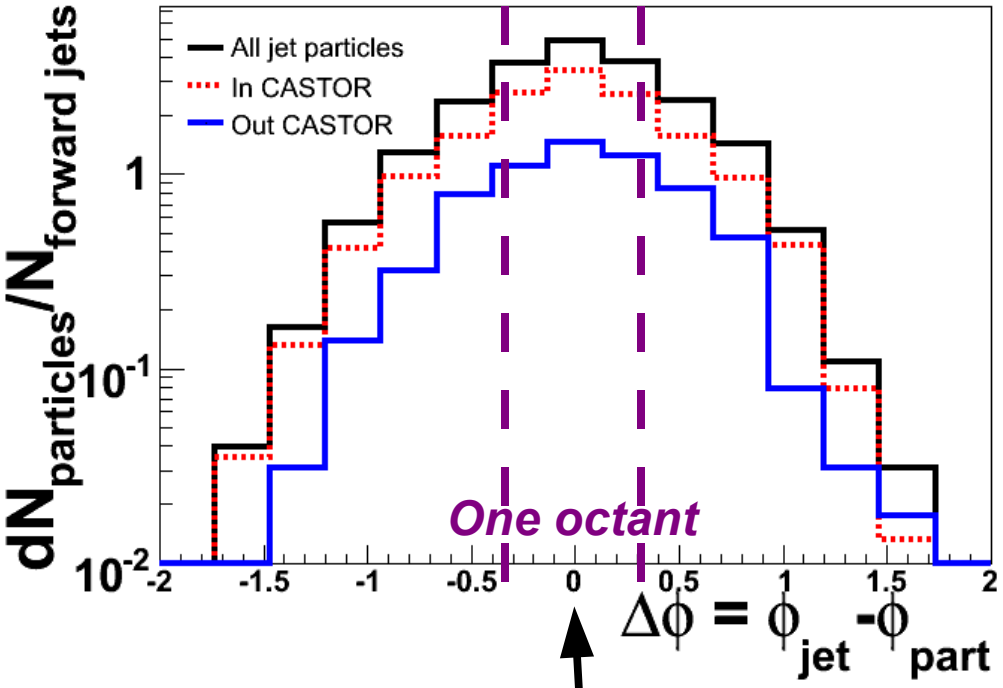
**The Color Dipole Model – giving a more BFKL like final state –
with partons unordered in kt (with respect to rapidity) –
predicts more hard jets in the CASTOR region.**

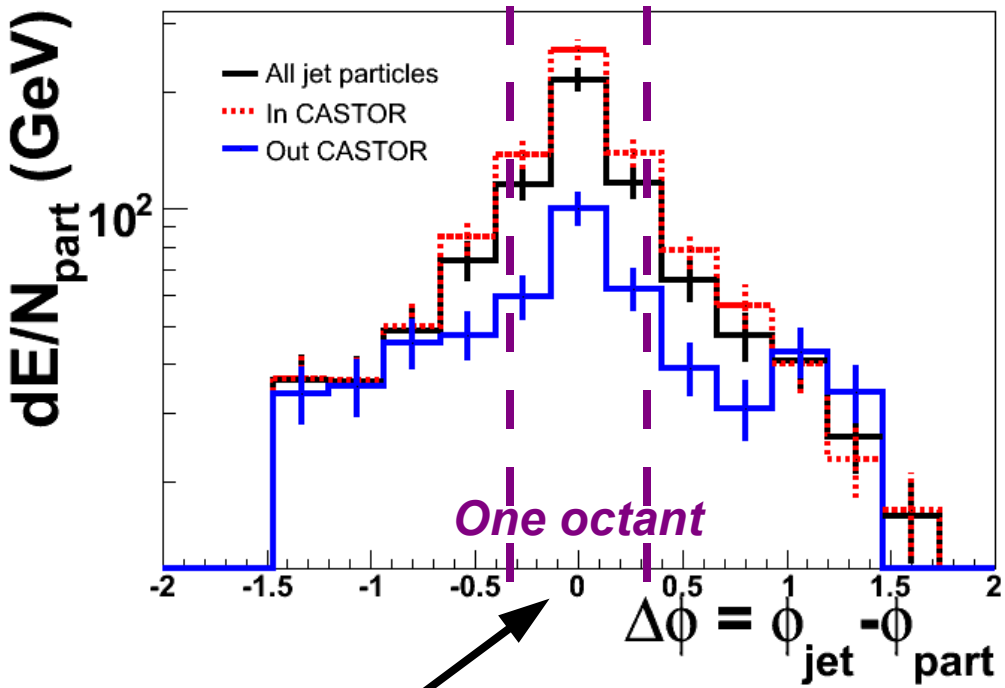
**Both PYTHIA and ARIADNE are run together with Multipartoninteractions Tune A.
(Tune A = One of the R. Field tunes to TEVATRON data.)**

Forward Jets in CASTOR

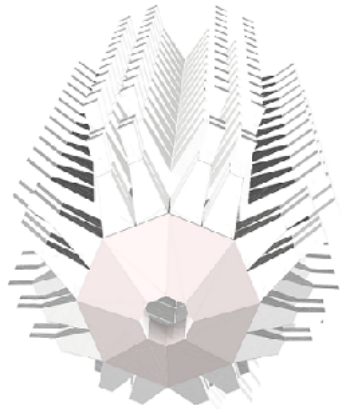
Forward jet events: How much activity can we expect in CASTOR?

"JET PROFILES"





- On event average ~ 10 particles/most active octant
- On average 100 GeV/particle in octant around jet axis



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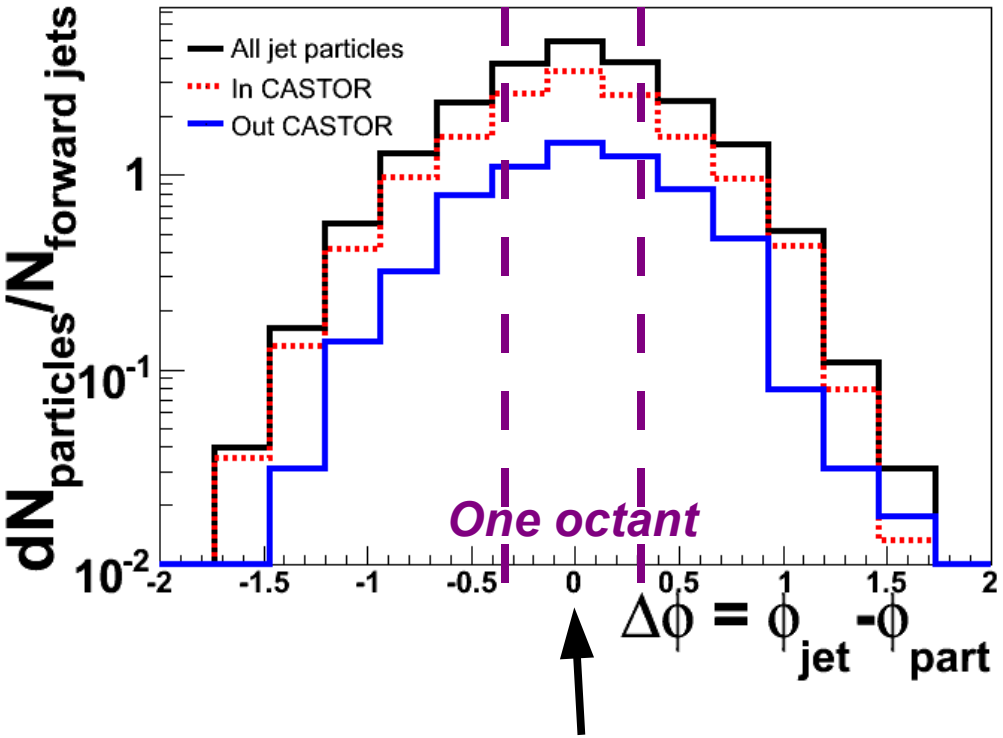
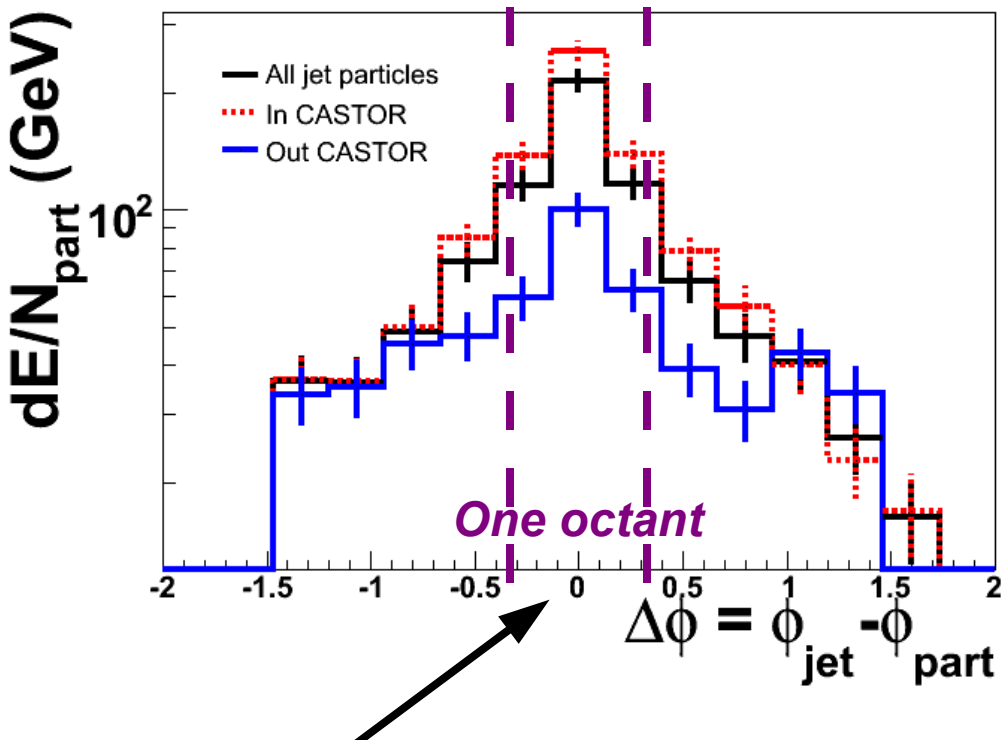
Forward jet events: How much activity can we expect in CASTOR?

"JET PROFILES"





- On event average ~ 10 particles/most active octant
- On average 100 GeV/particle in octant around jet axis

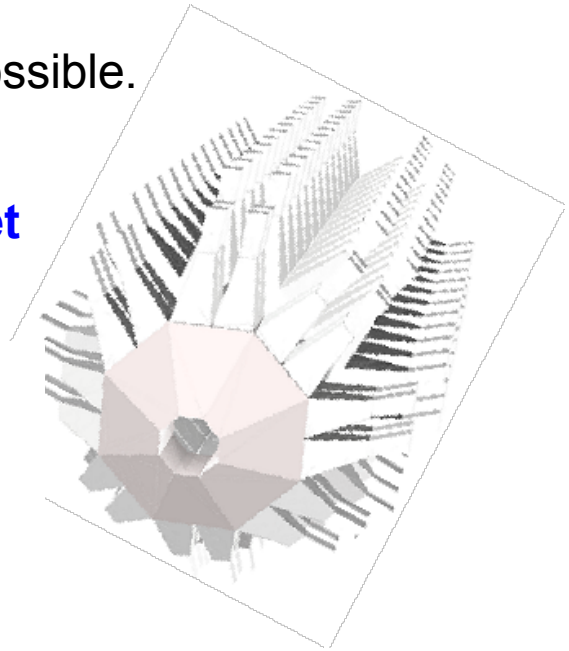
In addition *no rapidity segmentaion* in CASTOR.

Too much activity to separate particles and run a conventional jet algorithm

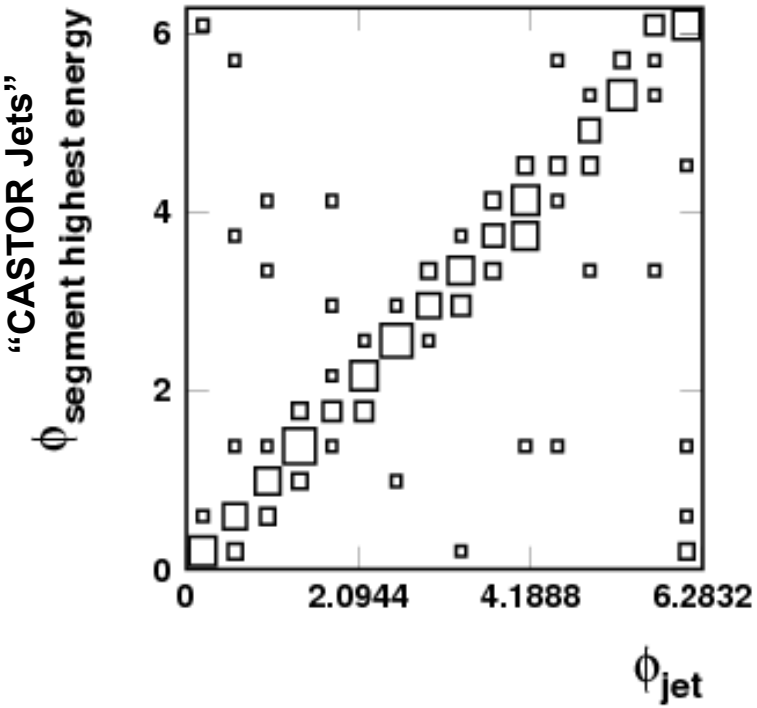
CASTOR Jet reconstruction

No eta segmentation in CASTOR. Conventional jet algorithm is not possible.

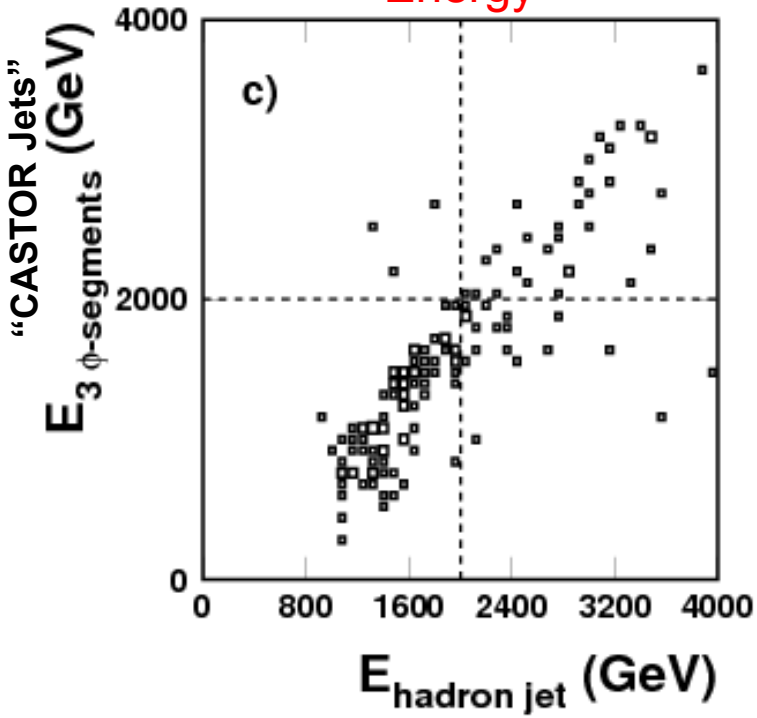
Reconstruct jets by summing energy in most active phi segment (= 2*pi/16) with neighboring segments = CASTOR Jet



Phi



Energy

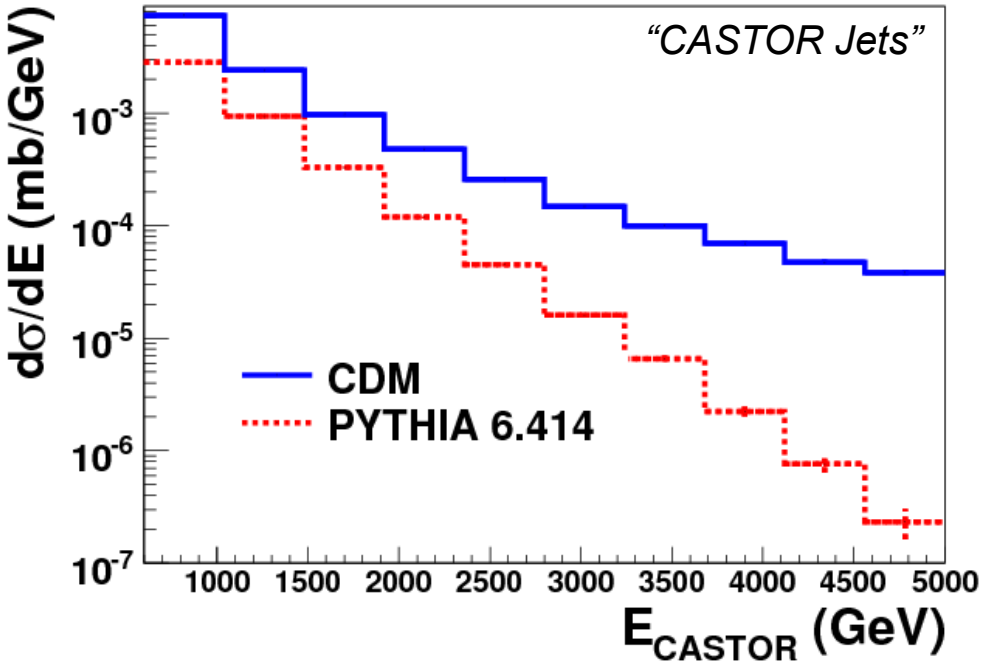


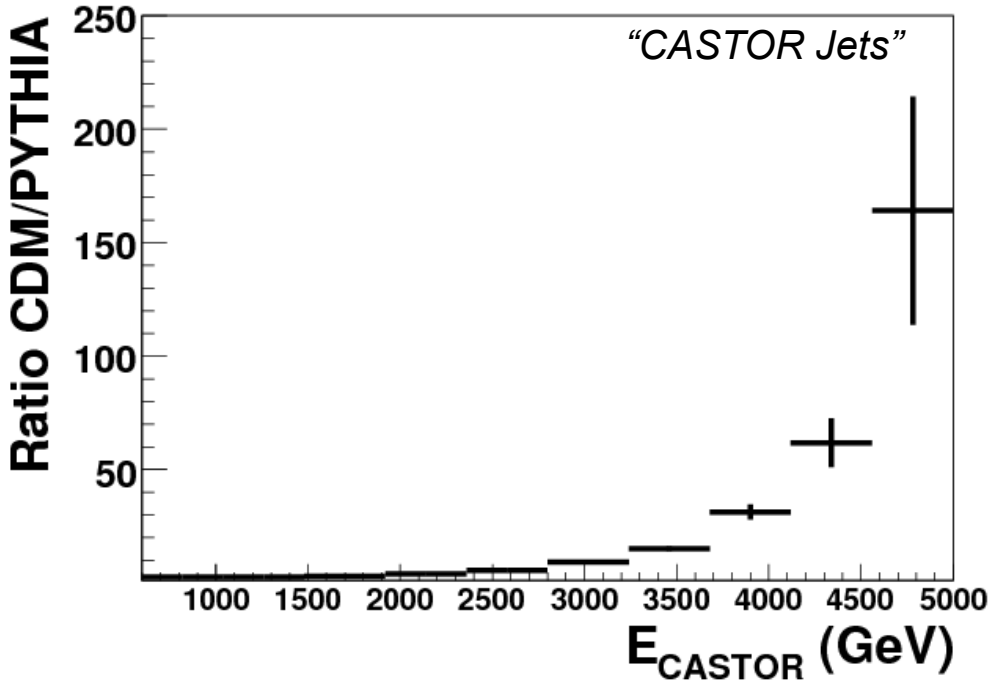
(MC studies – no detector simulation applied)

In these slides: Everything is "CASTOR jets", if not else stated.
A more sophisticated jet algorithm for CASTOR exist and is implemented in the Fast Simulation by the Antwerpen group.

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)

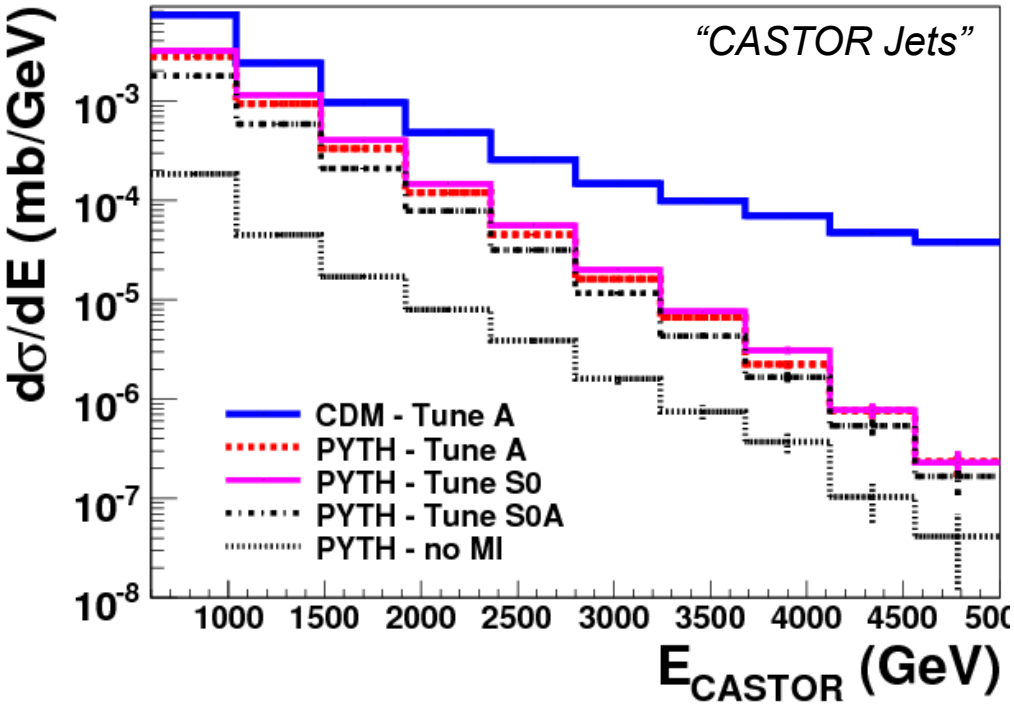


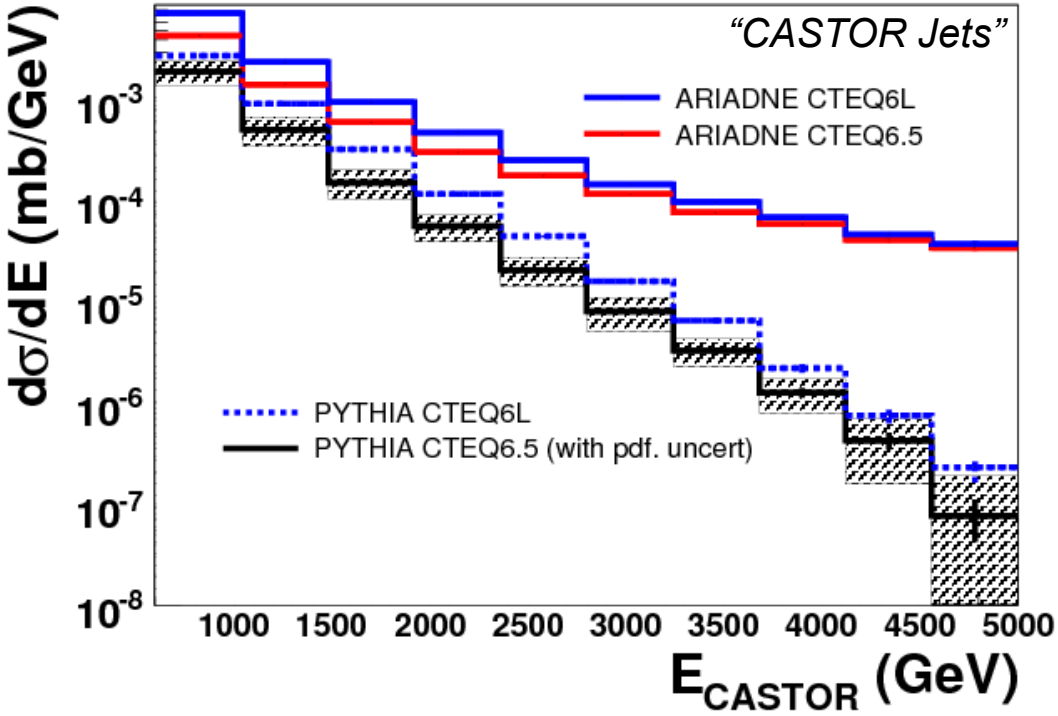


→ With "CASTOR Jets" we can make measurements that distinguish between the different QCD models (DGLAP/non-DGLAP).

→ Study made at < 1pb^{-1} . One of the first topics to be analysis by using CASTOR

MI and PDF uncertainty





→ **At high energy: DGLAP/non-DGLAP separation >> Difference between MI tunes**

→ **At high energy: DGLAP/non-DGLAP separation >> PDF uncertainty/sensitivity**

Mueller-Navelet Jets

• 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

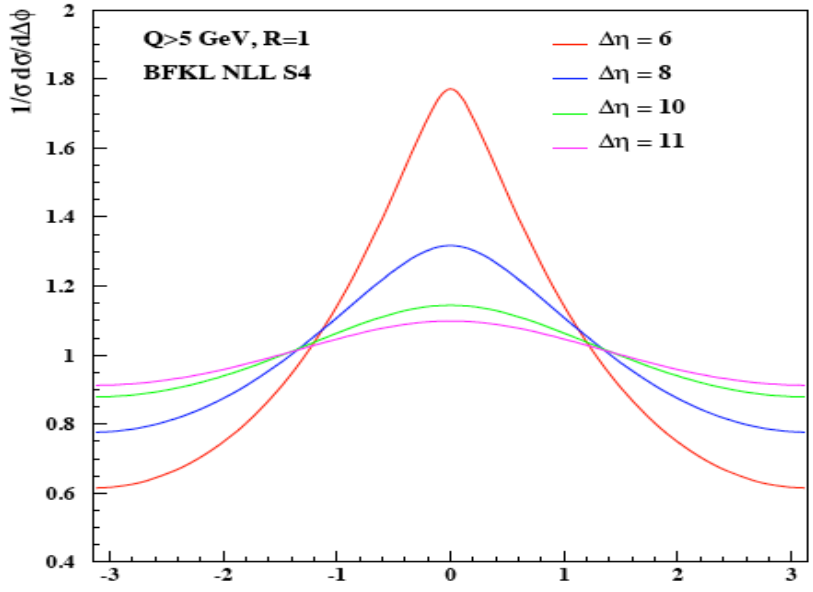
For H.O. DGLAP the momentum conservation between the two jets are expected to be more conserved, while H.O BFKL emissions expects to give a flatter Delta Phi distribution.

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

Large rapidity range between jets 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).

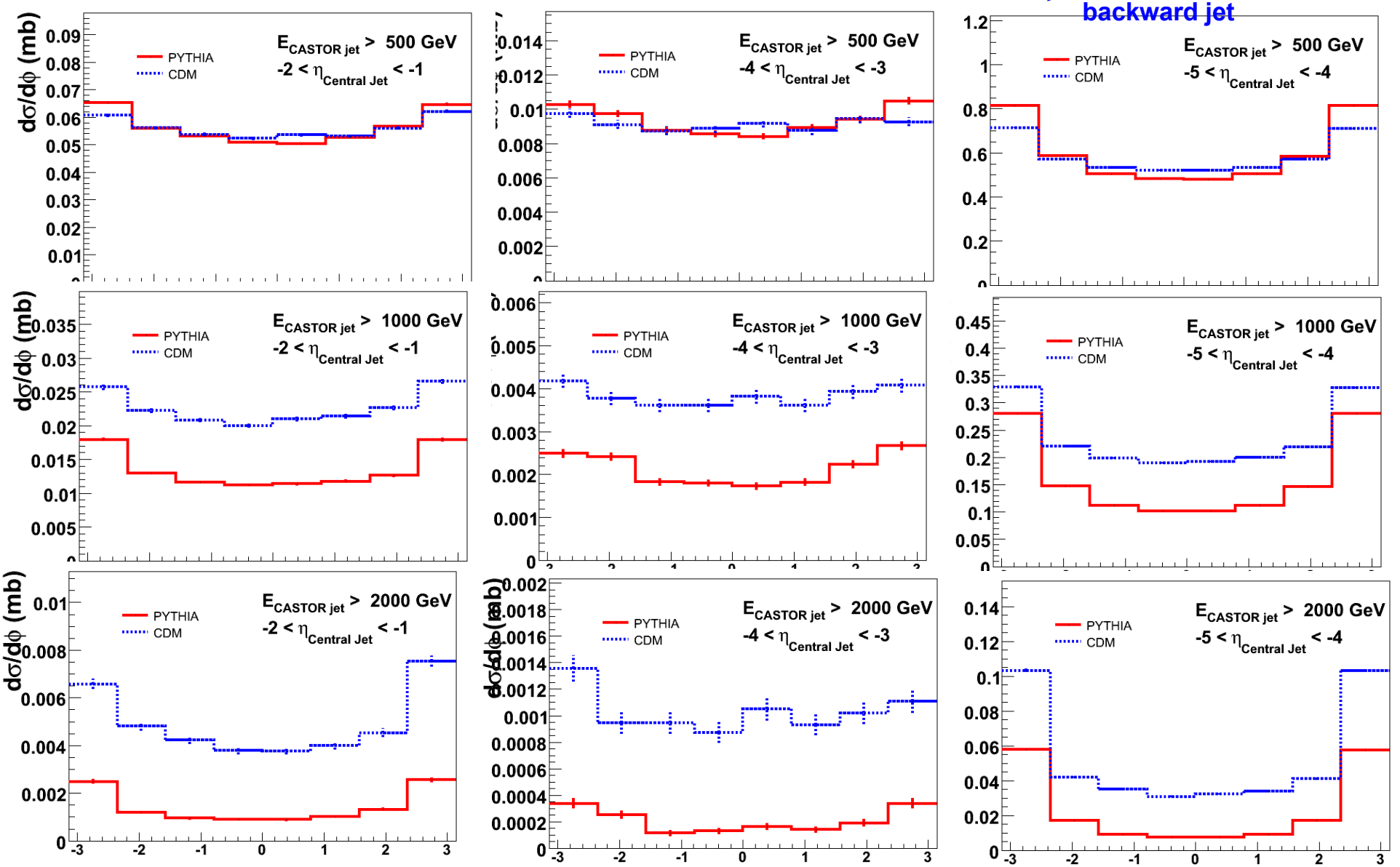
Larger eta separation - > Flatter distribution.



Mueller-Navelet Jets

Selection: Central Jet with Et > 25 GeV + "CASTOR Jet".
5.2 < Eta(CASTOR) < 6.4
("CASTOR Jet" defined as most active azimuthal segment (2*pi/16) + Neighbours.)

Larger Rapidity Separation between "CASTOR jet" and backward jet



Larger CASTOR jet energy

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

Mueller-Navelet Jets

Selection: Central Jet with Et > 25 GeV + "CASTOR Jet".
5.2 < Eta(CASTOR) < 6.4
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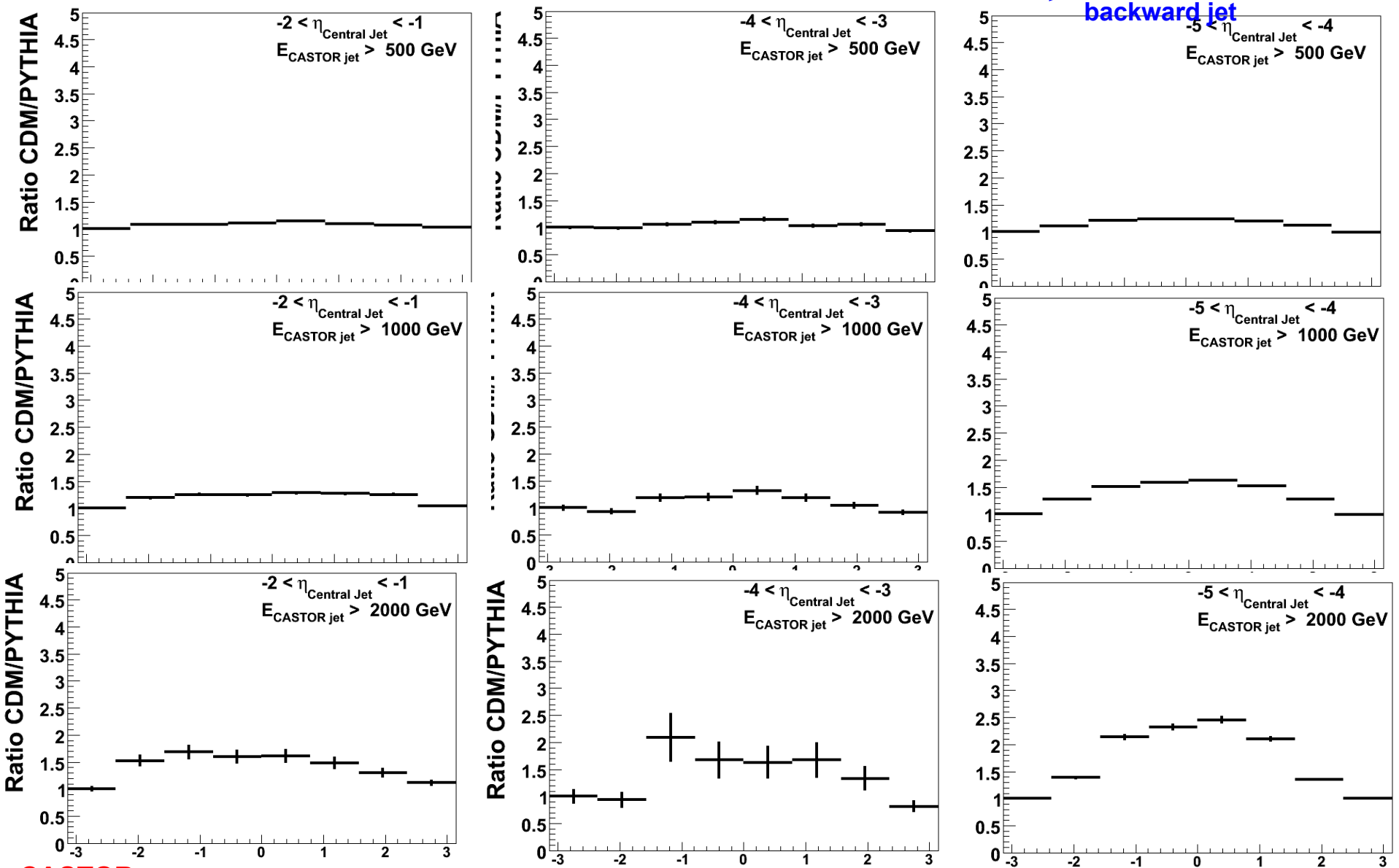
Larger Rapidity Separation between "CASTOR jet" and backward jet

Ratio CDM / PYTHIA



Larger CASTOR jet energy

First bin normalized to 1.0

Summary

- **CASTOR is forward a Cherenkov radiation calorimeter in the CMS experiment.**

- **CASTOR is a calorimeter without segmentation in rapidity and the particle multiplicity within a detector segment can be high. Good correlation between energy deposit in CASTOR azimuthal segments and the jet energy. Possible way to reconstruct jet energies and azimuthal angle.**

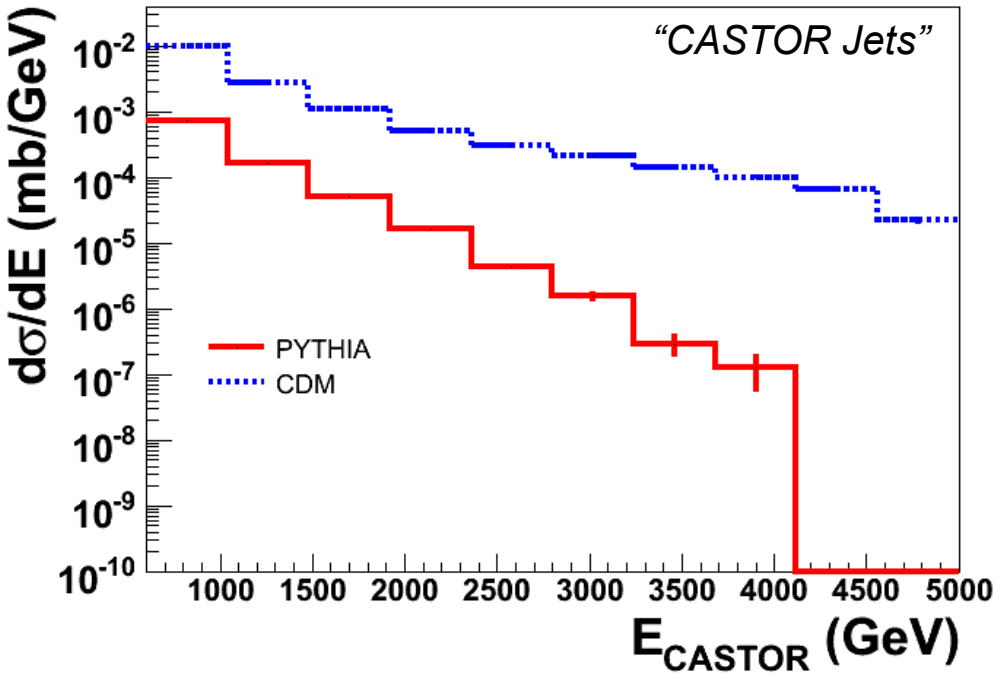
- **2+foward jet or Mueller-Navelet jet events with with one jet in CASTOR, gives sensitivity to parton dynamics beyond DGLAP.**

Back up slides

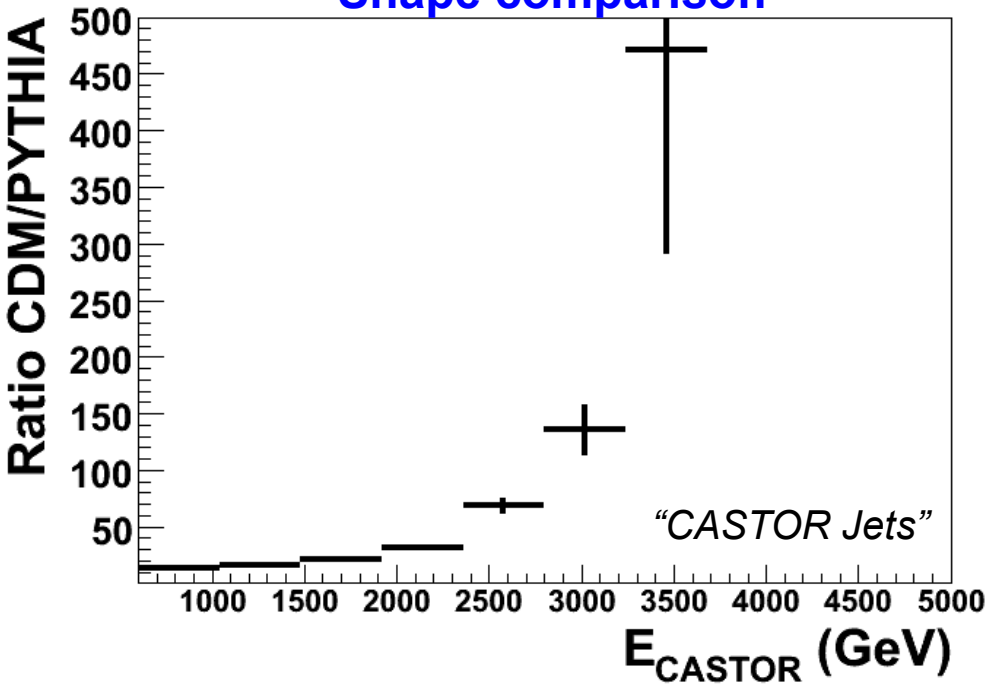
5 TeV beams

Hadron level MC studies – (No detector simulation applied)

Cross-section



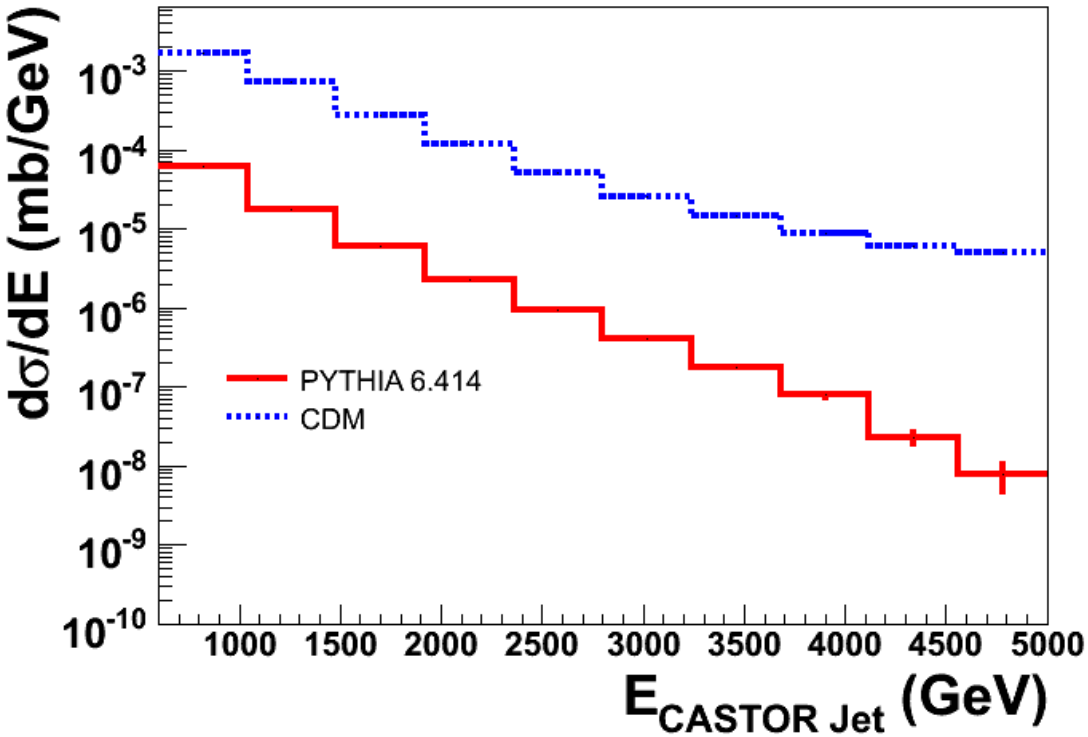
Shape comparison

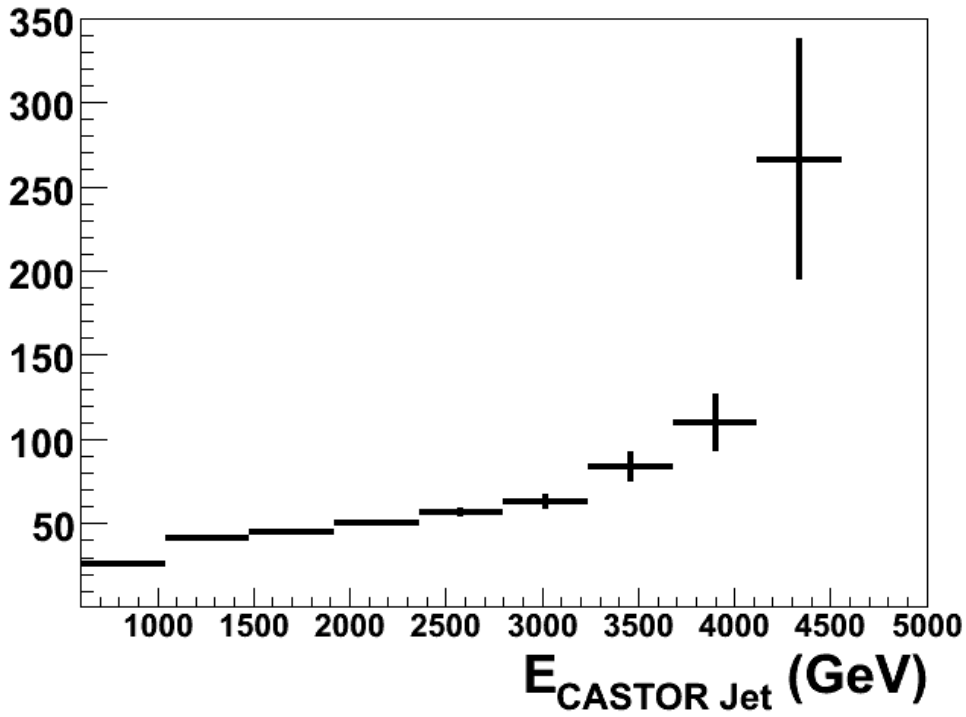


→ Ok! Can expect physics signal for 5 TeV beams
→ This study: 250000 events, sigma_tot=5mb => Lumi<<1 pb^-1

Harder central jets. P_t > 25 GeV

Pt (central jets) > 25 GeV

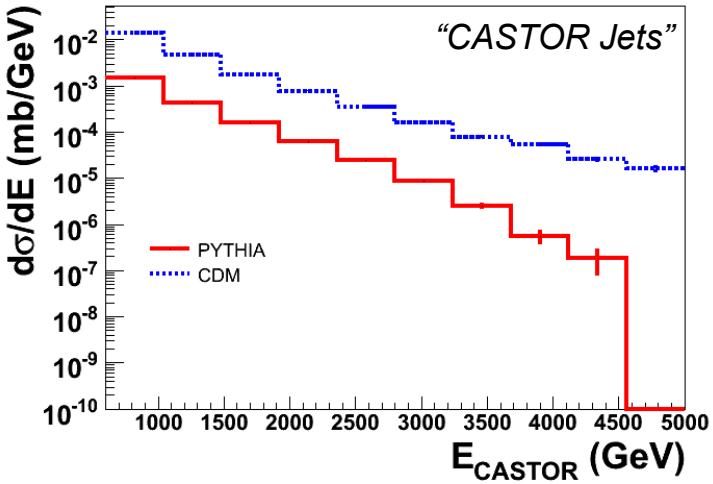


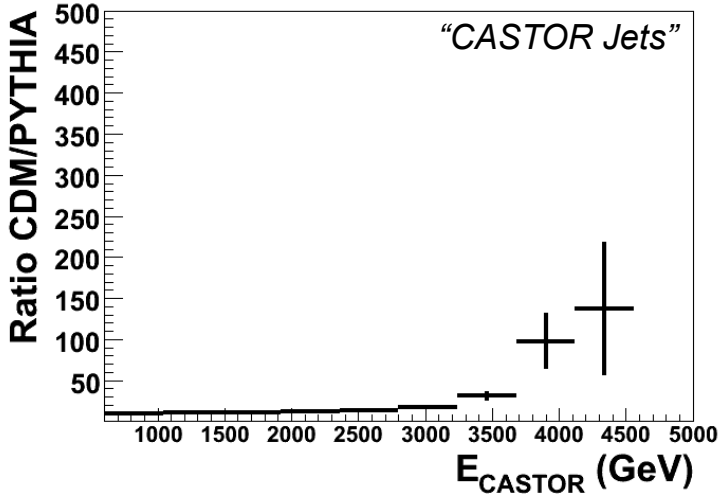


Upper limit on particle energy

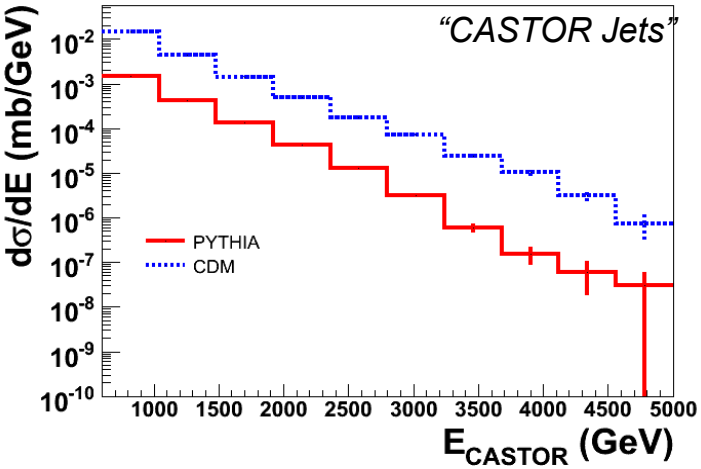
Test beam data only < 350 GeV. Assume really bad limitations:

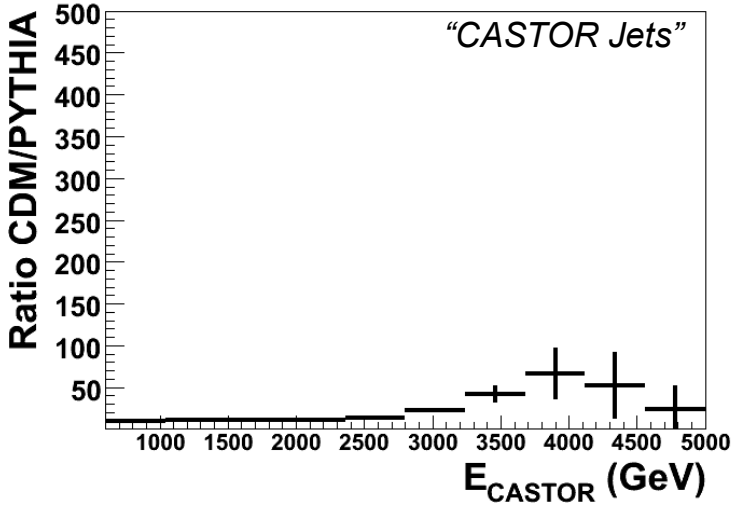
All particle energies above 1000 GeV → 1000 GeV





All particle energies above 500 GeV → 500 GeV



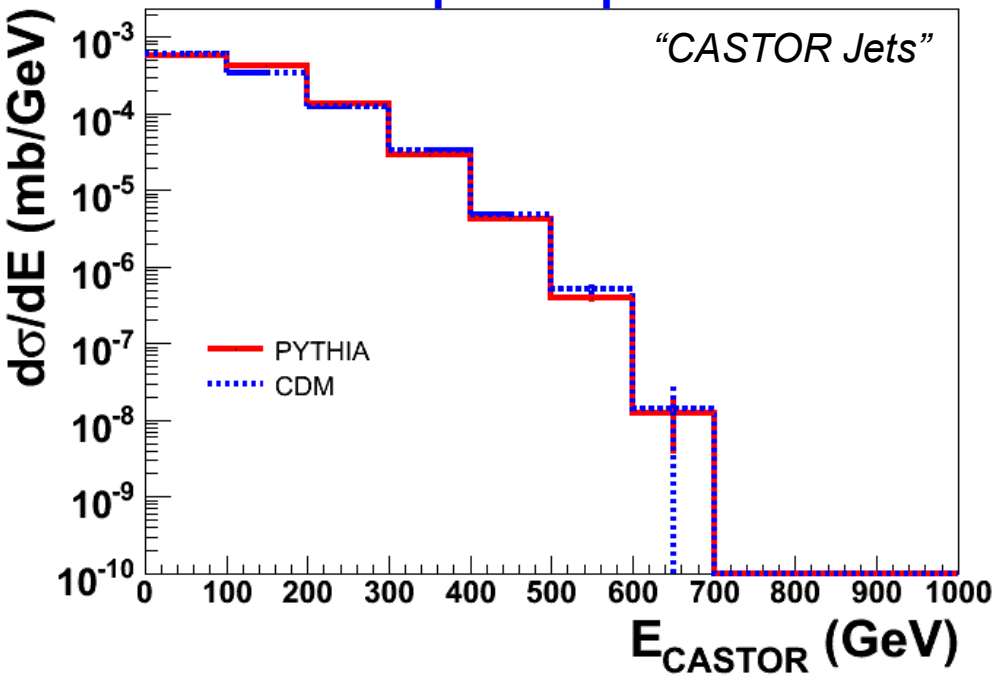


- The assumption is too pessimistic, but even if it would true we can still do the measurement.

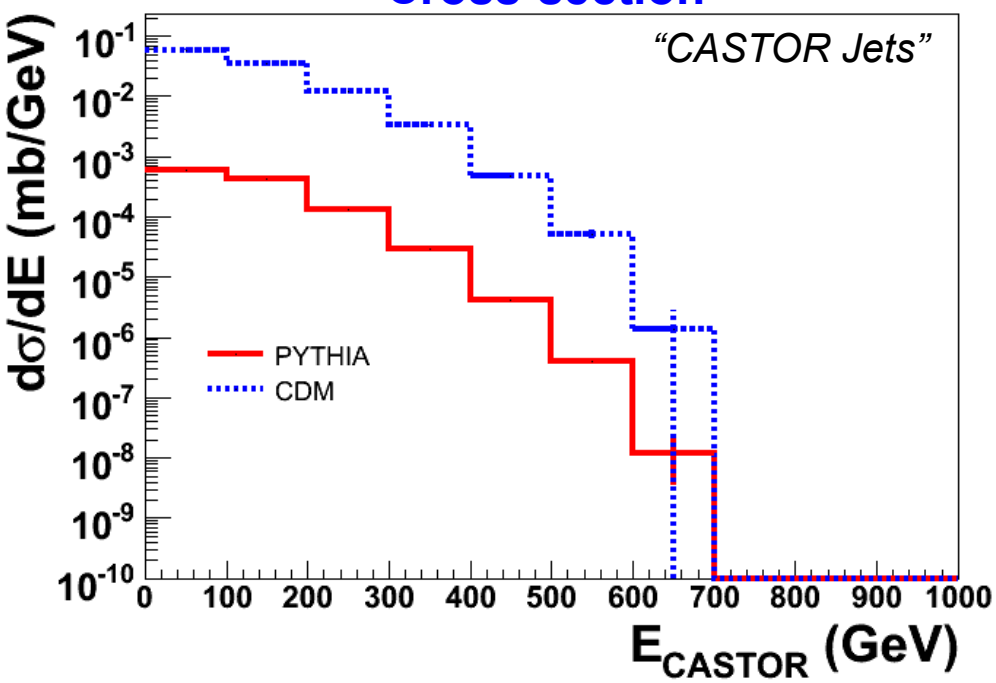
450 GeV beams

Hadron level MC studies – (No detector simulation applied)

Shape comparison



Cross-section

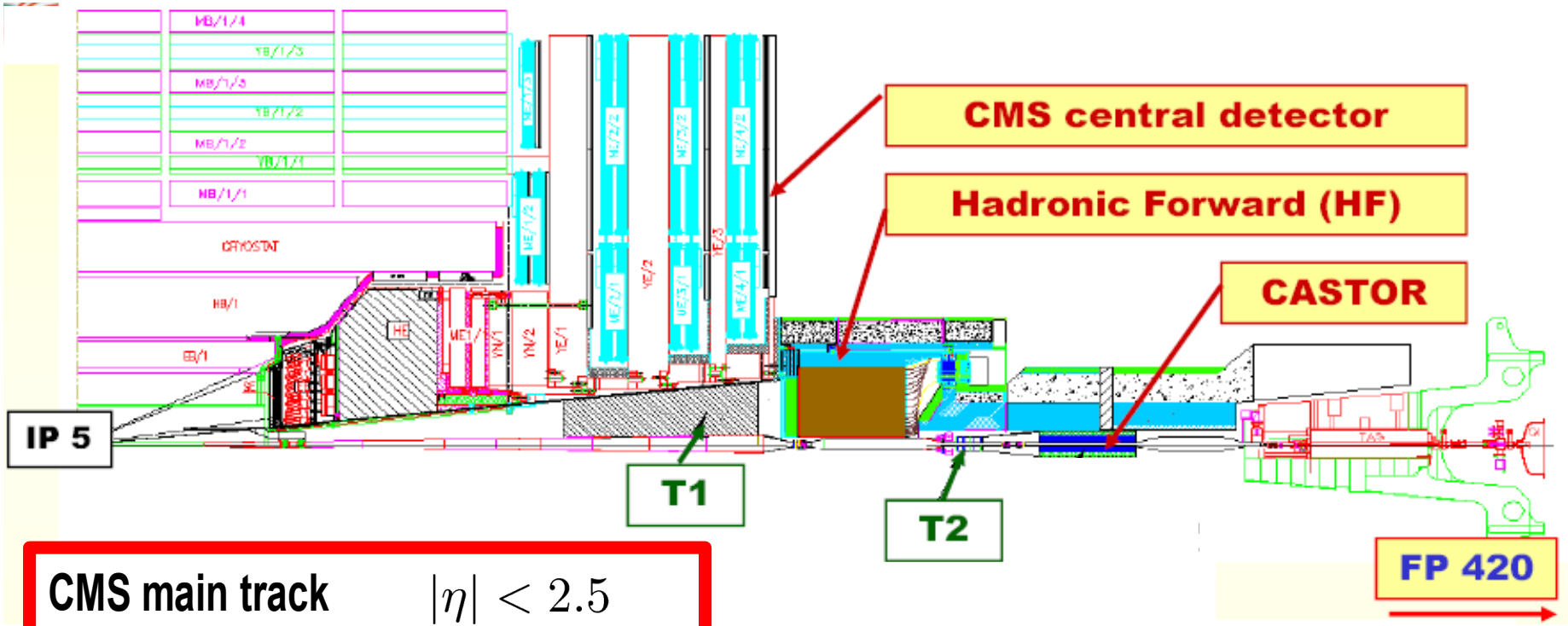


→ No difference in shape.

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

→ Possibly interesting measurement.

Forward detectors around IP 5



CMS main track	$\|\eta\| < 2.5$
CMS main calo	$\|\eta\| < 3.0$
TOTEM 1	$3.1 < \|\eta\| < 4.7$
HF cal	$3.0 < \|\eta\| < 5.0$
TOTEM 2	$5.2 < \|\eta\| < 6.5$
CASTOR	$5.2 < \eta < 6.6$
Zero Deg Calo	$\eta > 8.0$
FP420	$420m$
TOTEM-RP	$147/220m$

Few gaps, good coverage!