International Symposium on
Multiparticle Dynamics 2008
15-20 September 2008, Hamburg

What can we learn from forward detectors at LHC ?

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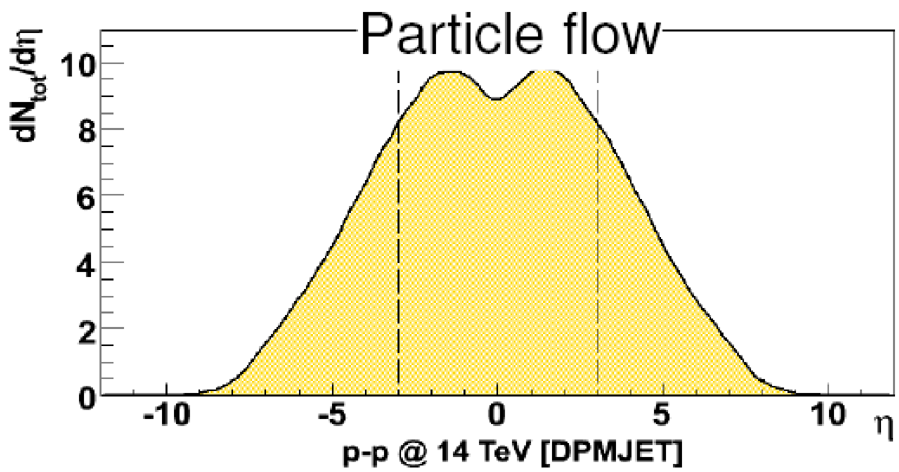
MPI-K, Heidelberg and YerPhI,Yerevan

- forward instrumentations around CMS and ATLAS
- some forward physics studies (low-x QCD dynamics, multi-parton interactions and underlying event, long-range correlations, forward jets..)

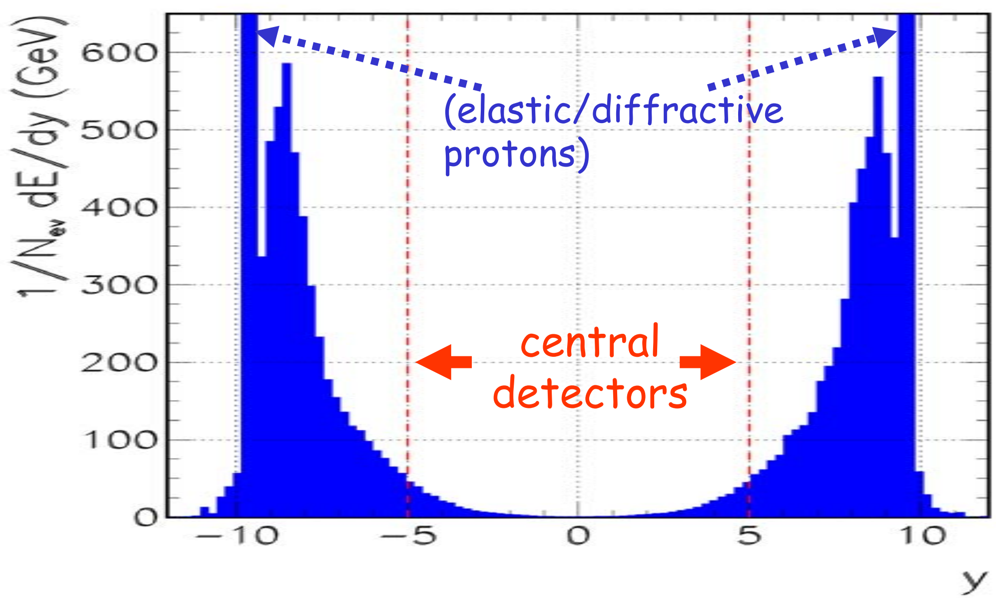
Introduction

The LHC opens up a phase space for particle production up to 20 units of rapidity

While particle production is peaked at central rapidities (-3<y<3), the most of energy is emitted at low angles



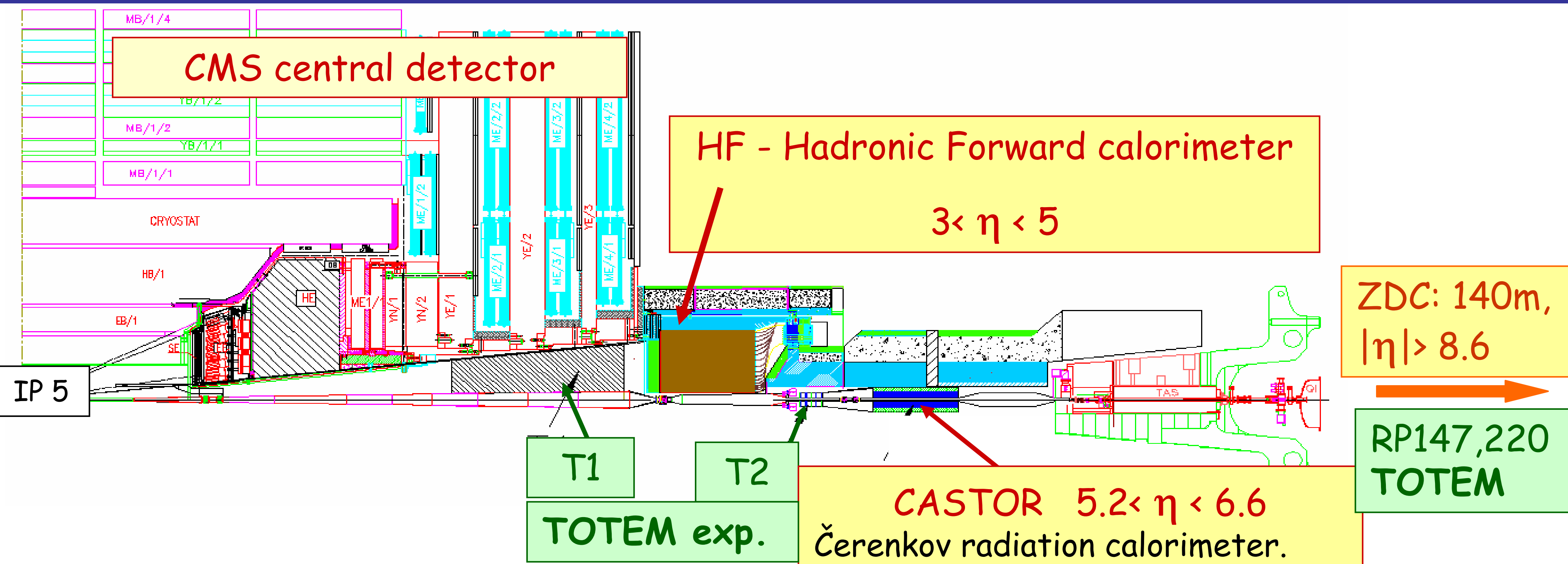
← Particle flow vs rapidity



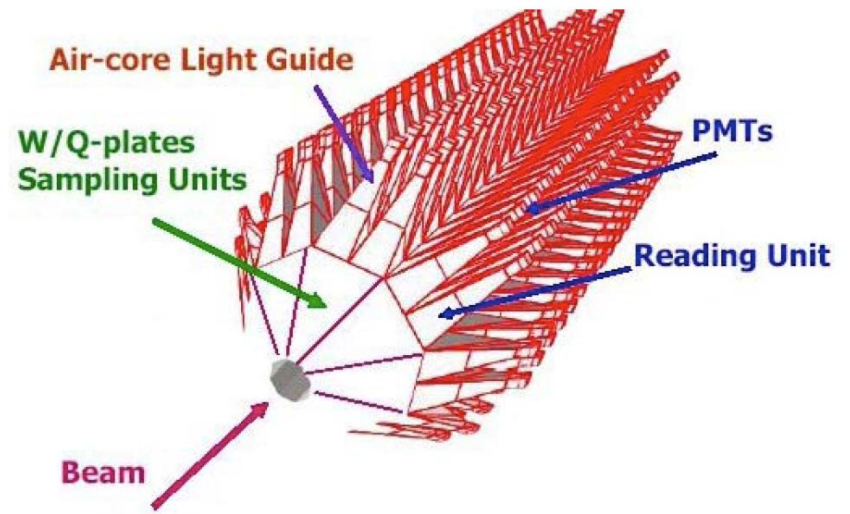
← Energy flow vs rapidity

most energy is deposited in rapidity range between ~ 8 and 9

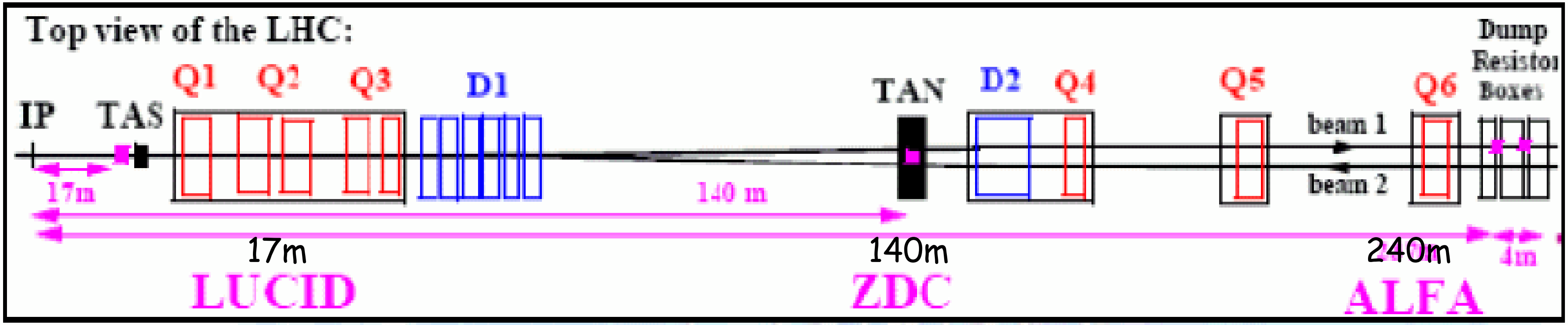
Forward instrumentation around CMS interaction point

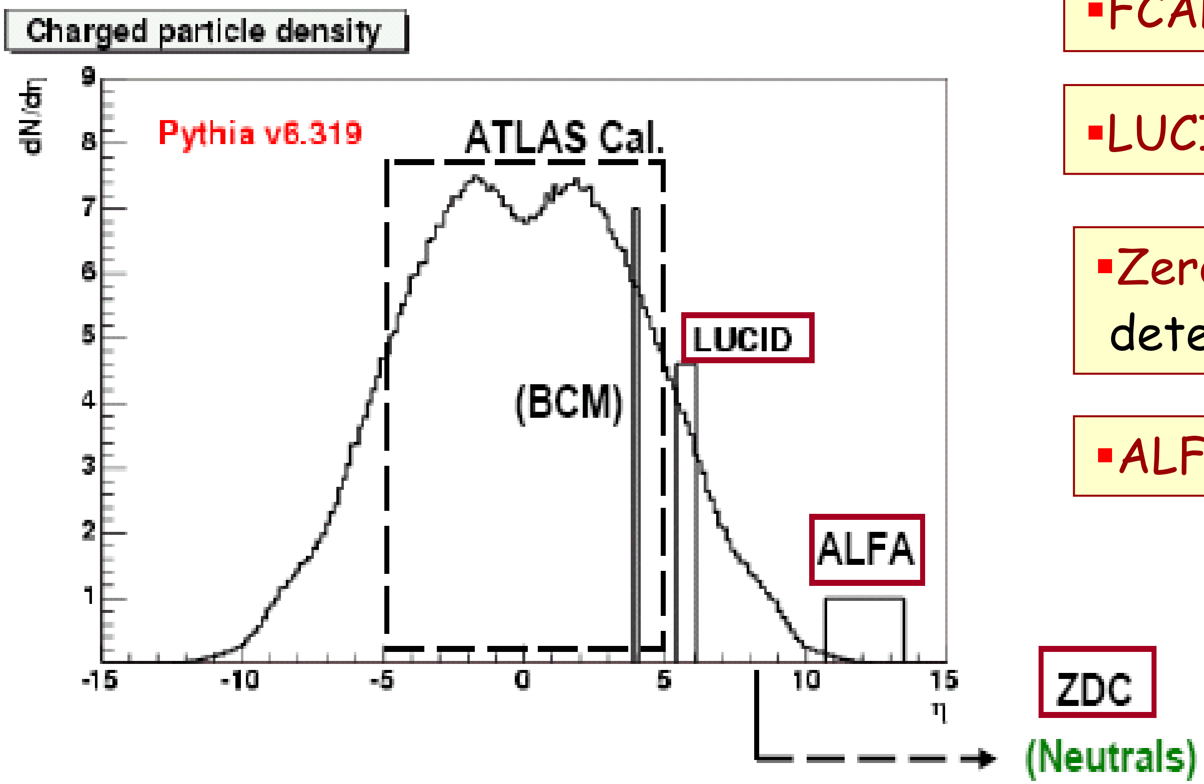


CASTOR 5.2< η < 6.6
Čerenkov radiation calorimeter.
Tungsten absorber+ Quartz plates.
radial: 16φ x long.: 14 sections



Forward instrumentation around ATLAS interaction point





- FCAL $3.2<|\eta|<4.9$
- LUCID (Čerenkov Tubes): $5.4<|\eta|<6.1$
- Zero Degree Calorimeter (ZDC): detects neutrals at $|\eta|>8.3$ at $\sim 0^{o}$
- ALFA: detects leading protons

Physics potential of forward detectors

- **Low-x QCD dynamics**
  - **multi-parton scattering and underlying event**
  - **proton structure, BFKL/CCFM/DGLAP dynamics**
  - **parton saturation**

- **Elastic, diffractive scattering**

- **Measurements for cosmic ray data analysis**
  - **Proton fragmentation, Forward energy and particle flows…**

- **Two-photon interactions and peripheral collisions**

- **QED processes to determine the luminosity to O(1%),**
  e.g. pp → pp+ee , pp+$\mu\mu$

- **Forward physics in pA and AA collisions**

- **New forward physics phenomena**

- …

CMS/TOTEM Note on Prospects for Diffractive and Forward Physics 2006; LHCC-G-124

ATLAS Forward Physics Program; ATL-PHYS-CONF-2008-020

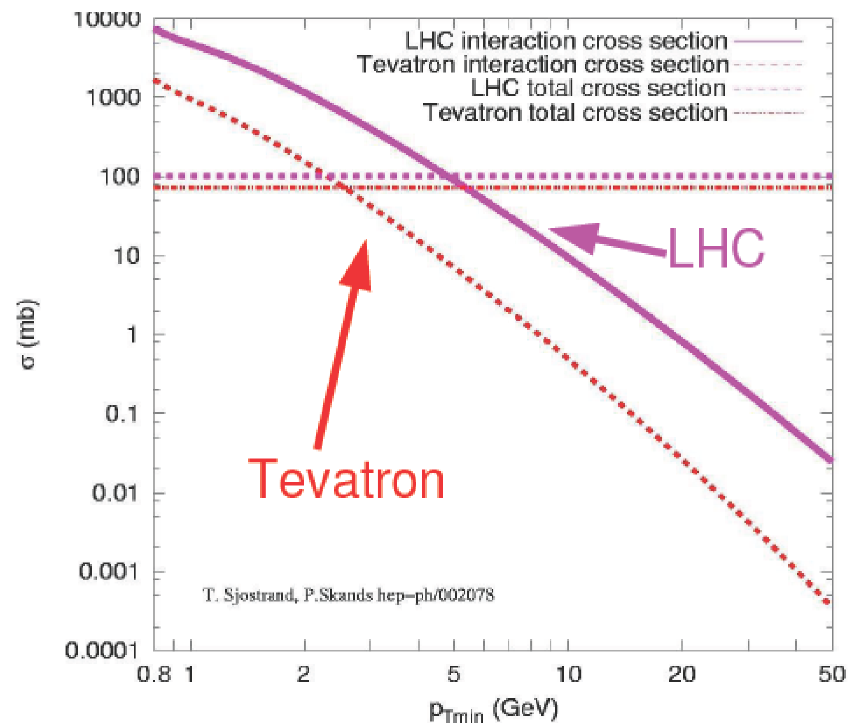
Diffraction physics program in ATLAS experiment; ATL-PHYS-CONF-2008-019

Basic partonic perturbative cross section:

$$\sigma_{hard}(p^2_{\perp min}) = \int_{p^2_{\perp min}} \frac{d\sigma(p^2_\perp)}{dp^2_\perp} dp^2_\perp$$

diverges faster than $1/p^4_{\perp,min}$ as $p_{\perp,min} \to 0$

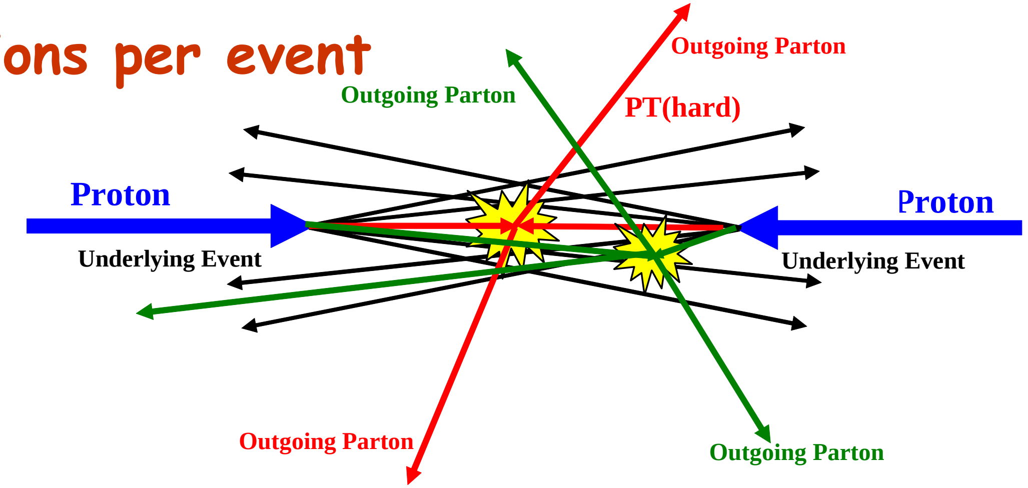
and eventually exceeds σ_{tot}



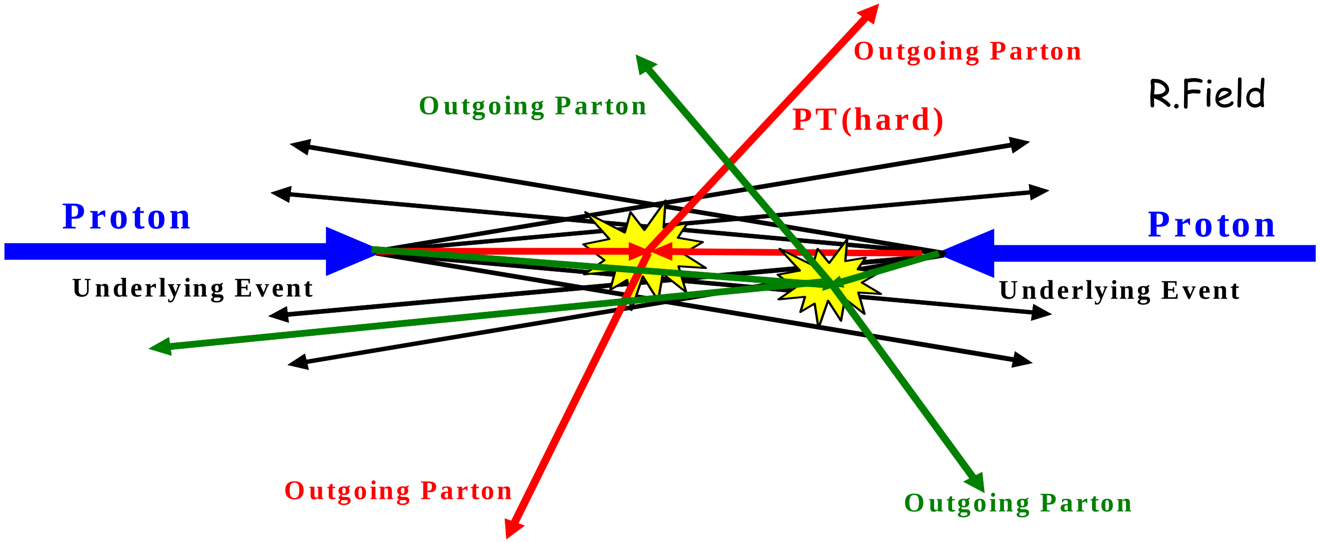
Consequence:

more than one parton interactions per event

$$\langle n \rangle = \frac{\sigma_{hard}(p^2_{\perp \min})}{\sigma_{nd}}$$



Multi-parton Interactions (MI) and Underlying event



In addition to the single hard interaction with large p_T:

- interactions with lower p_T (remnant-remnant interactions and parton shower)
- additional hard parton-parton interactions

➔ higher particle multiplicity, energy offset

→ **important for jet analyses (pedestal under the jet) !**

→ **may fake a discovery signal !**

e.g. $pp \to W+H+X$; $W \to l+\nu$ and $H \to b\bar{b}$ vs $pp \to W+X$, $pp \to b\bar{b}+X$ without any Higgs!)

Del Fabbro, Treleani
Phys.Rev.D66, 074012, 2002

Understanding and modeling of Underlying event and Multi–parton interactions crucial for all precision measurements!

Tuning of Monte Carlo generators

Modeling of multiple interactions depends on how soft interactions are treated, but also on the parton densities and factorisation scheme, parton evolution…

- different models for UE & MI available

color flow, string lengths …

- parameters in the MC generators can be tuned (but not always)

presently reasonable agreement achieved for TeVatron

what does it mean for LHC ?

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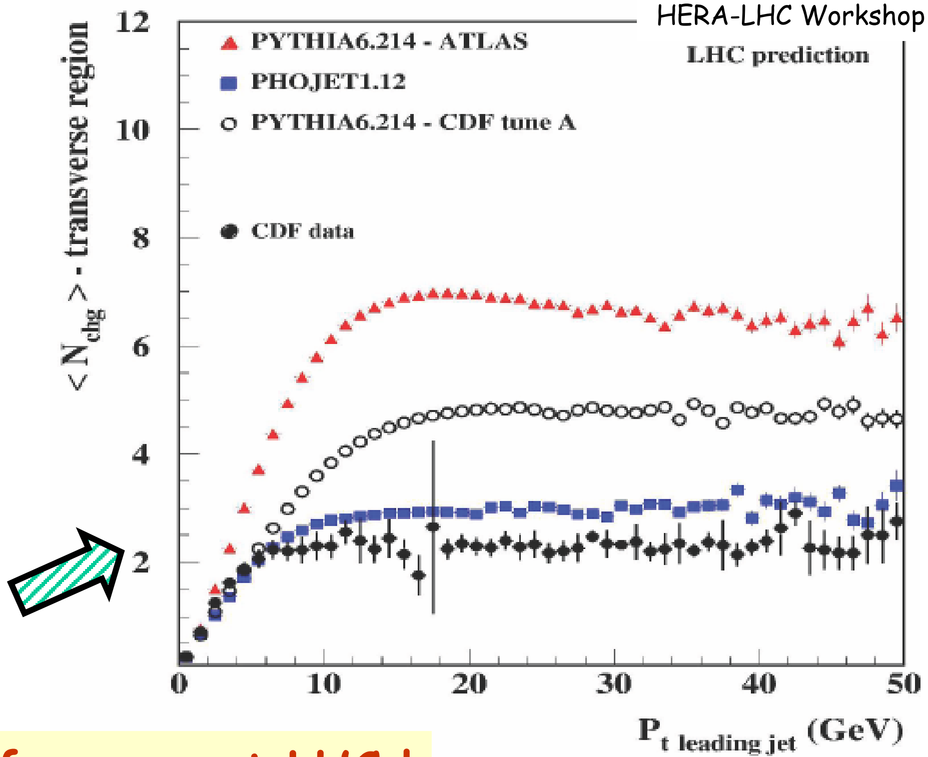
what does it mean for LHC ?

Charged multiplicities in transverse region

C.Buttar et al., HERA-LHC Workshop



Models tuned to TeVatron data give huge differences at LHC !

Tuning the models to the real data needs attention from the first days !

Why need to look forward ?

Central region does not easily distinguish between processes/models

Differences visible in p-fragmentation region, at largest rapidities

Underlying Event: Long Range Correlations

- with forward detectors we can span the energy flow measurement over large rapidity range
- studies made: use energy deposit in $5.2<\eta<6.6$ (CMS-CASTOR) as a trigger to study the **long range correlation**

central forward

no correlation

long range correlation

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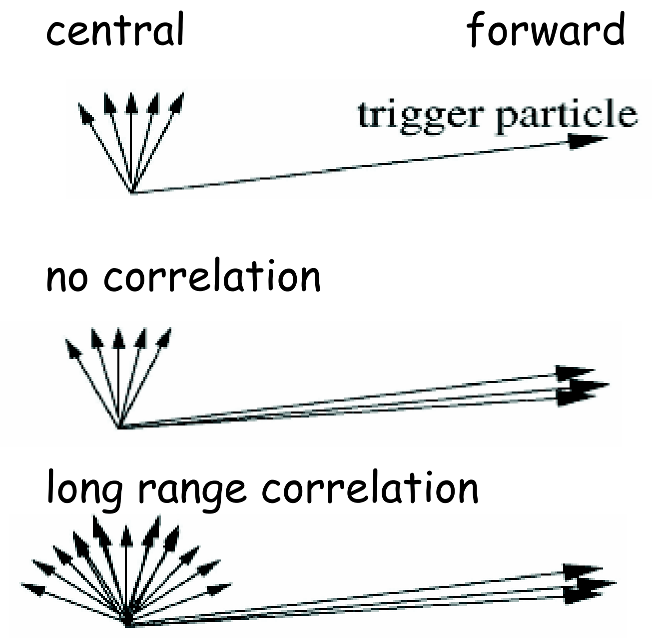
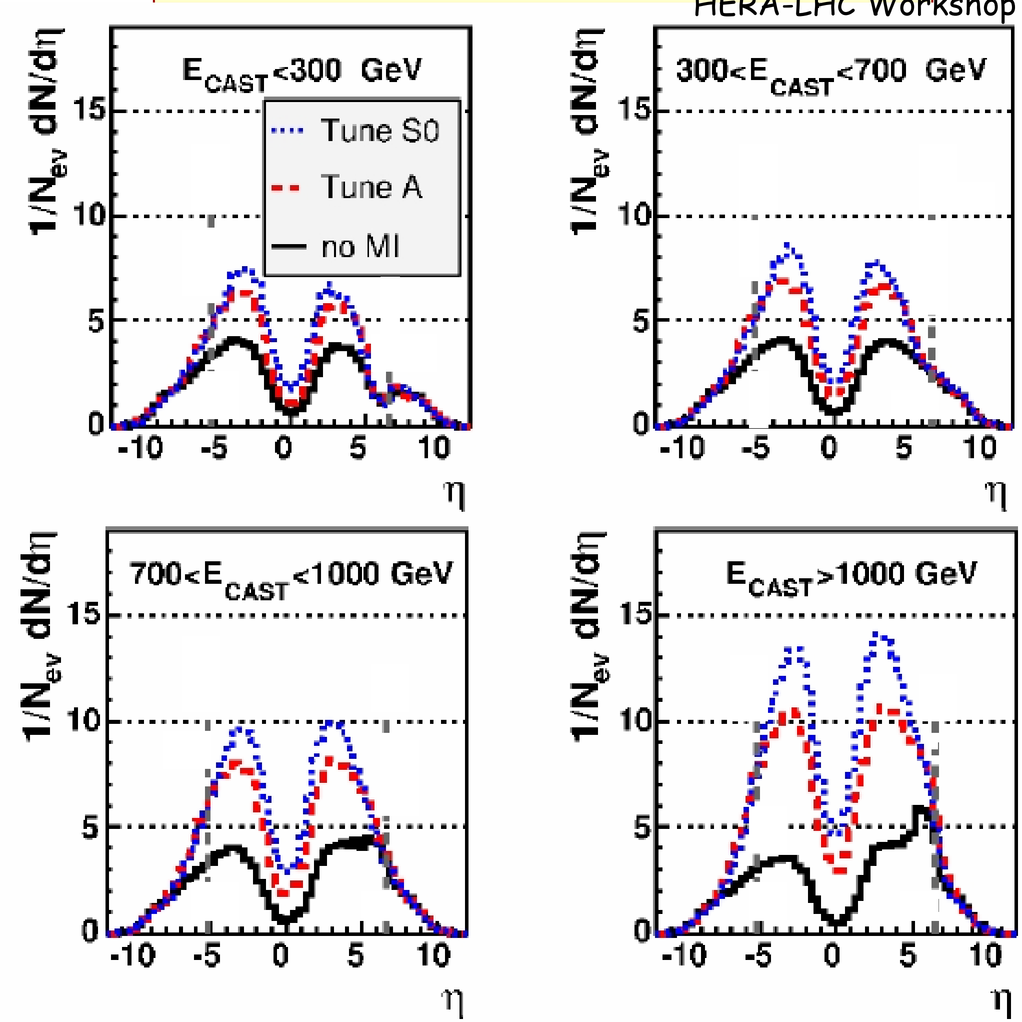
Charged particle (P>1 GeV) multiplicities

$E_{CAST}=\Sigma E_{part}$ $(5.2<\eta<6.6)$ Z.Rurikova, HERA-LHC Workshop





- Pythia without MI ➔ no correlation
- Pythia with MI:

➔ long range correlations, trigger enhancing differences in the central region

➔ *forward measurements are sensitive to the differences between tunes !*

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

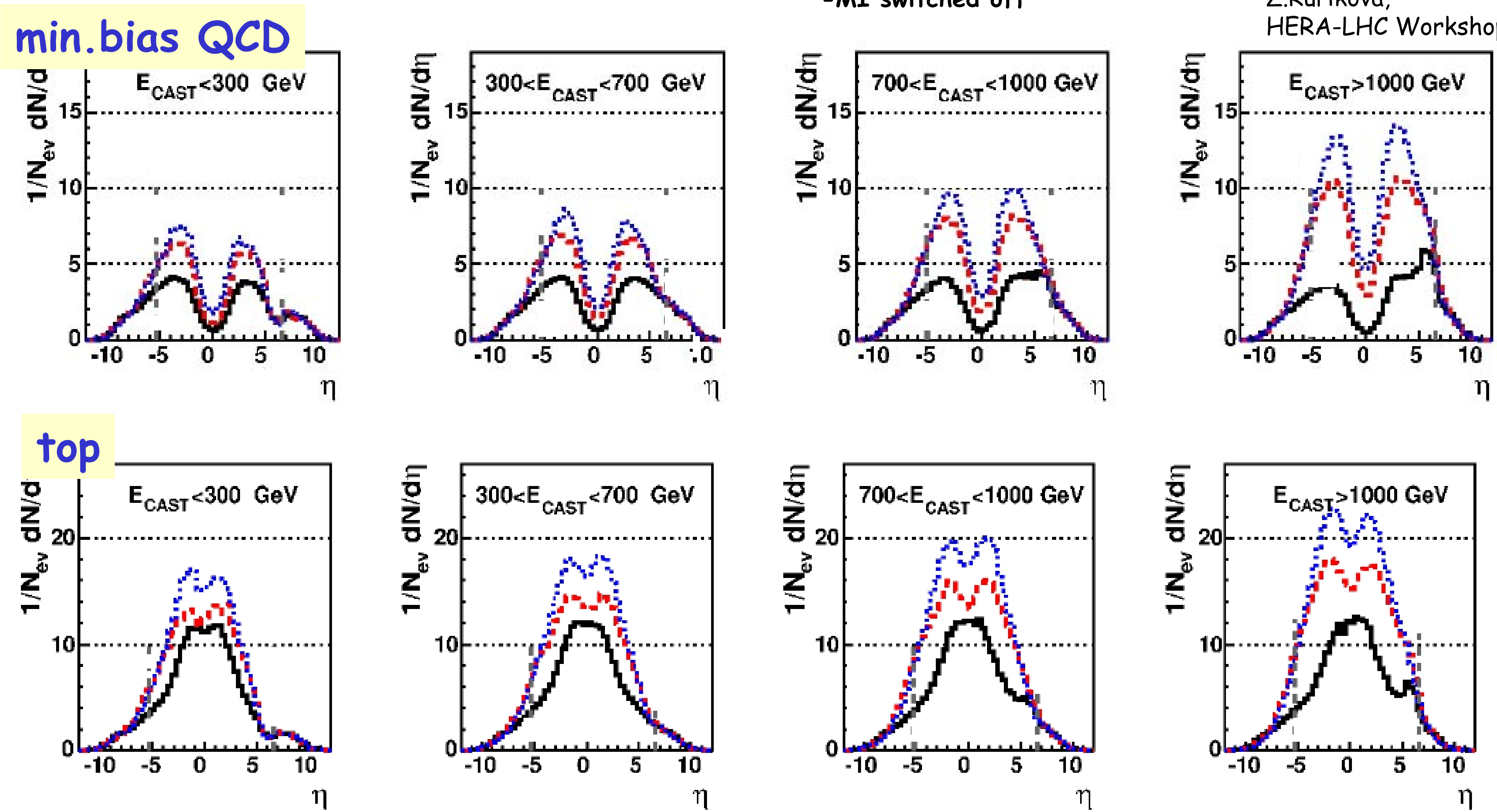
Is Underlying Event the same for all processes ? Compare min.bias vs top

Charged particle (P>1 GeV) multiplicities

$E_{CAST} = \Sigma Epart$ $(5.2 < \eta < 6.6)$

-Rick-Field's CDF tune A (tuneA)
-Sandhoff-Skands tune 0 (tuneS0)
-MI switched off

Z.Rurikova,
HERA-LHC Workshop



In *top* production much more underlying event activity than in *min.bias QCD* processes!
Underlying event extracted from *min.bias QCD* can not be simply applied to *top*.

- **Underlying Event depends on the hardness of collision:**

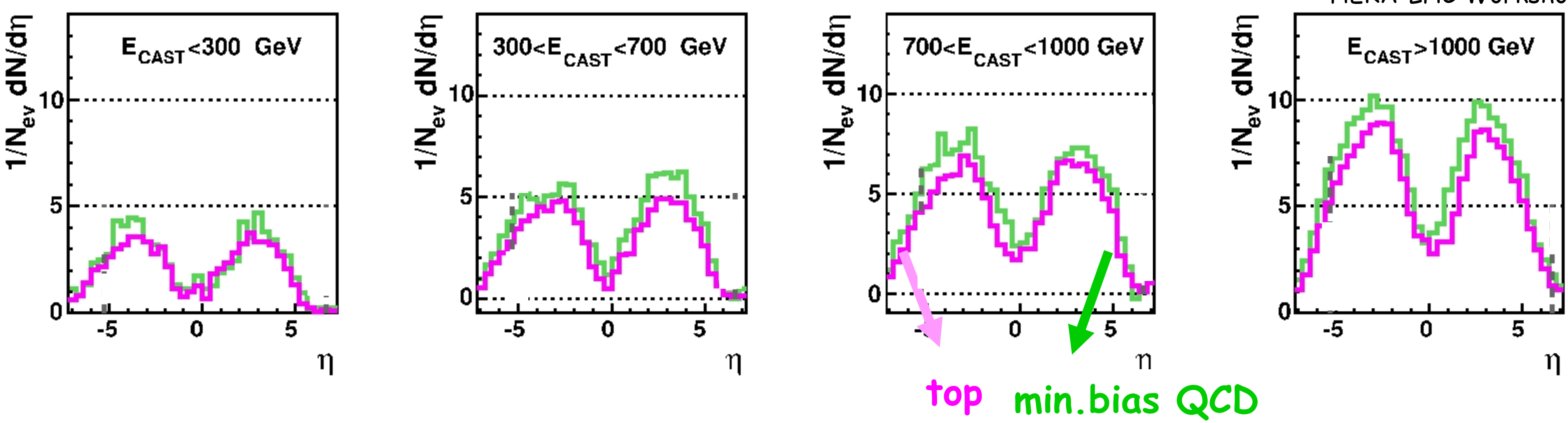
  Softer collisions → less underlying event

  Harder collisions → more underlying event

- **When demanding hard Et(jet)> 40 GeV in central region |η|<2.5, differences between Underlying Events in *QCD* and in *top* processes almost disappear.**

dN/dη(MI)-dN/dη(noMI) vs η: min.bias QCD vs top

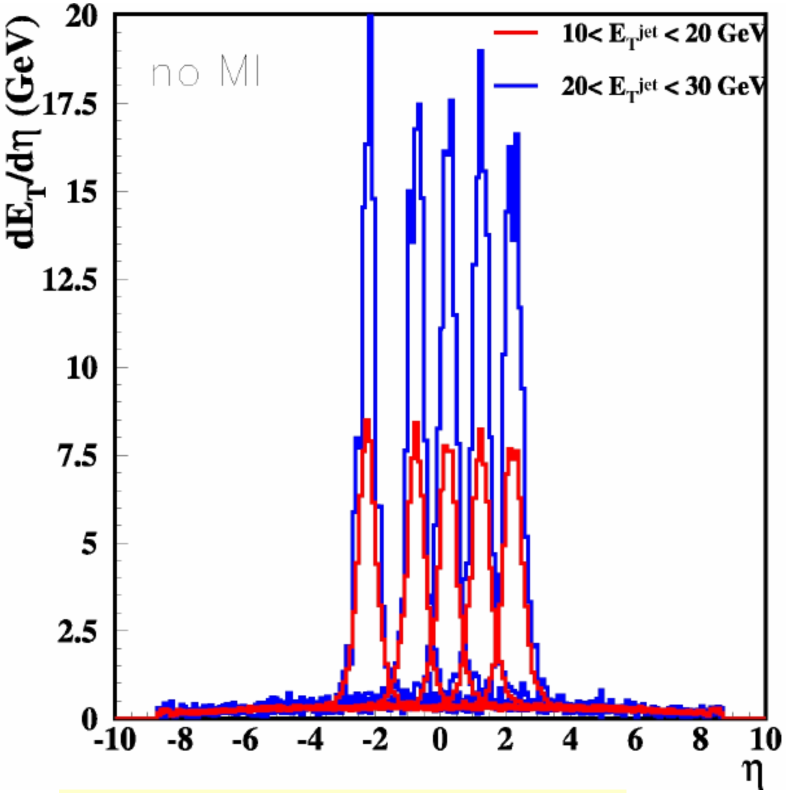
Z.Rurikova,
HERA-LHC Workshop

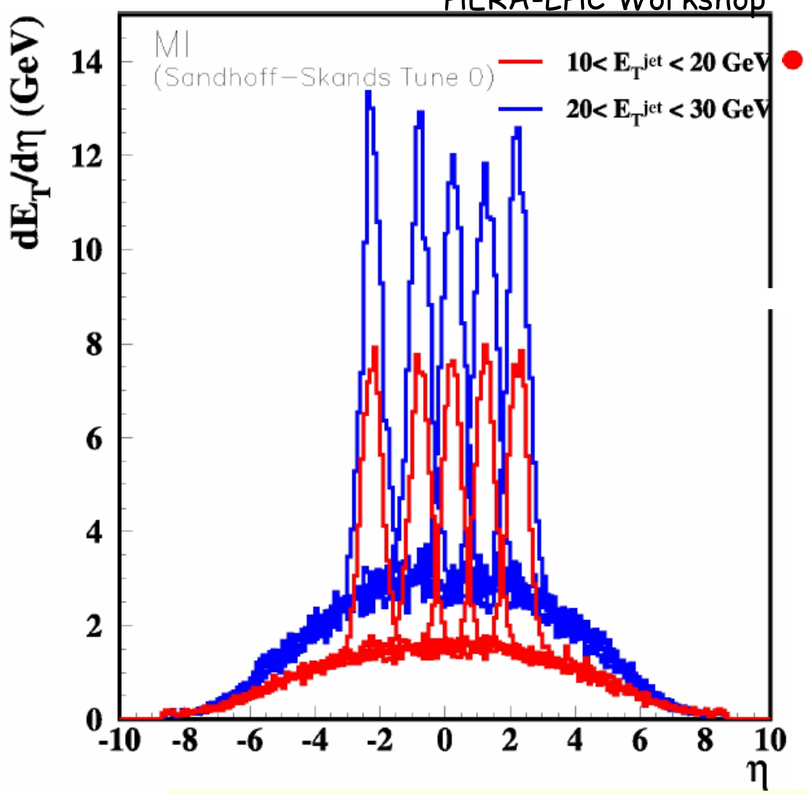


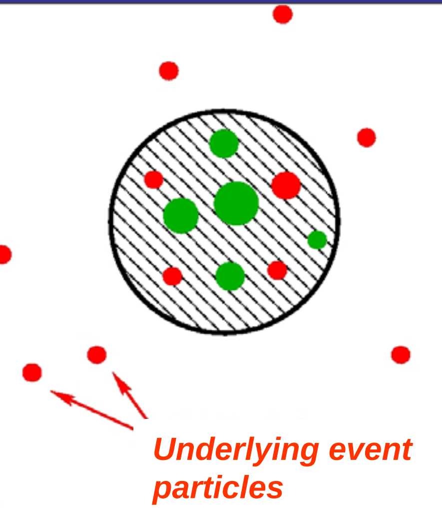
- **This can be useful for *top* analyses !**

- **Particles from Underlying Event contribute to jet energy measurement:** $Et(jet)_{measured} = Et(jet)_{real} + \text{pedestal}$

A.Bunyatyan
HERA-LHC Workshop







No MI → no pedestal

MI → pedestal;

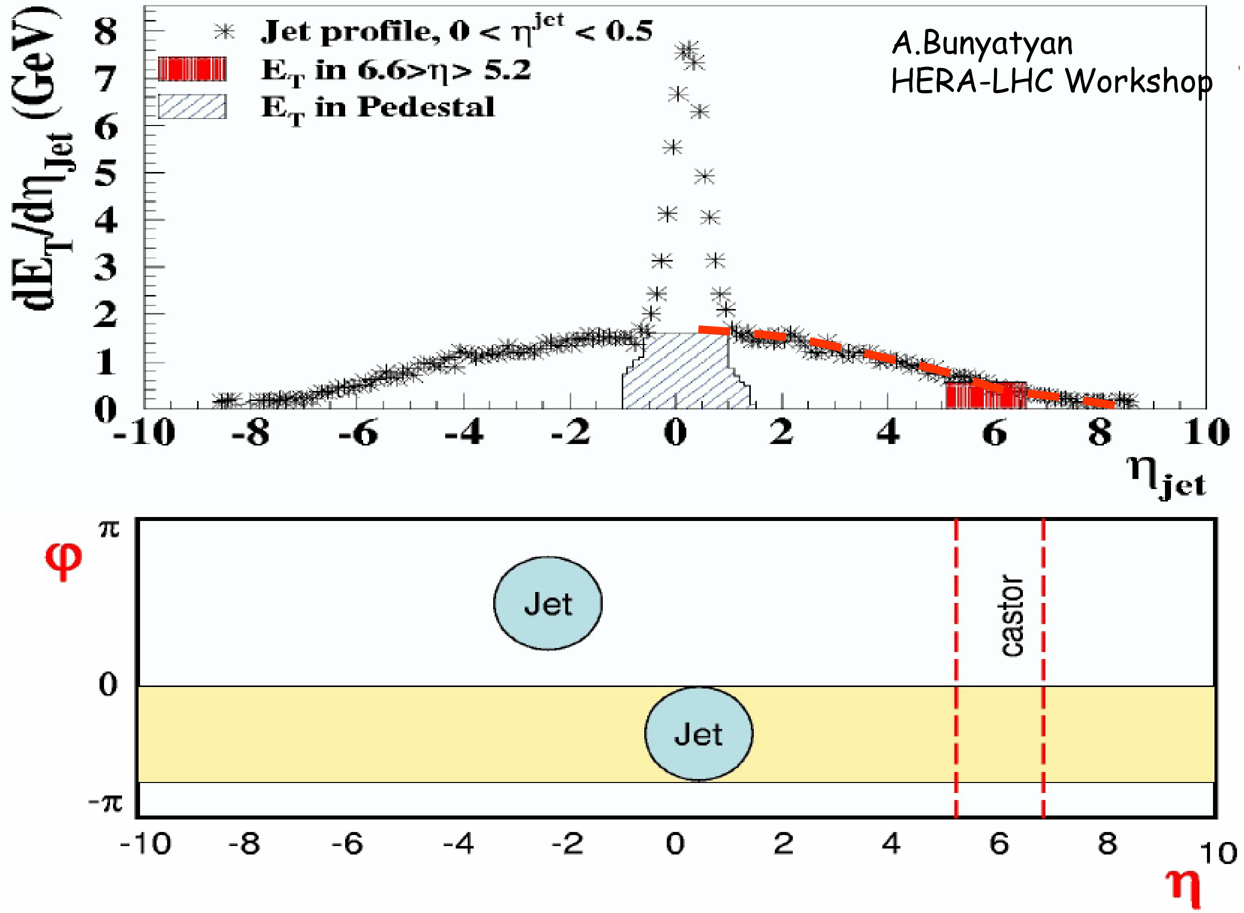
Pedestal independent on η(jet) but depends on collision hardness

E_T(jet) larger → pedestal larger

- **Jet profiles can be used to determine the energy pedestal due to Underlying event**

Determination of true jet E_t

measurements in forward calorimeters may help to determine pedestal shape and so to get "true" E_t(jet)



Fit to jet pedestal:

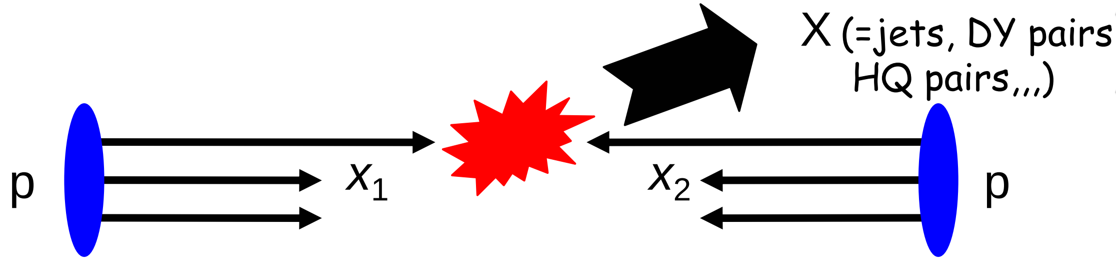
$$f(\eta) = \frac{A}{1 + B \cdot e^{|\eta| - 4}}$$

→ Determine true jet E_T by measuring pedestal in forward η → CASTOR and HF

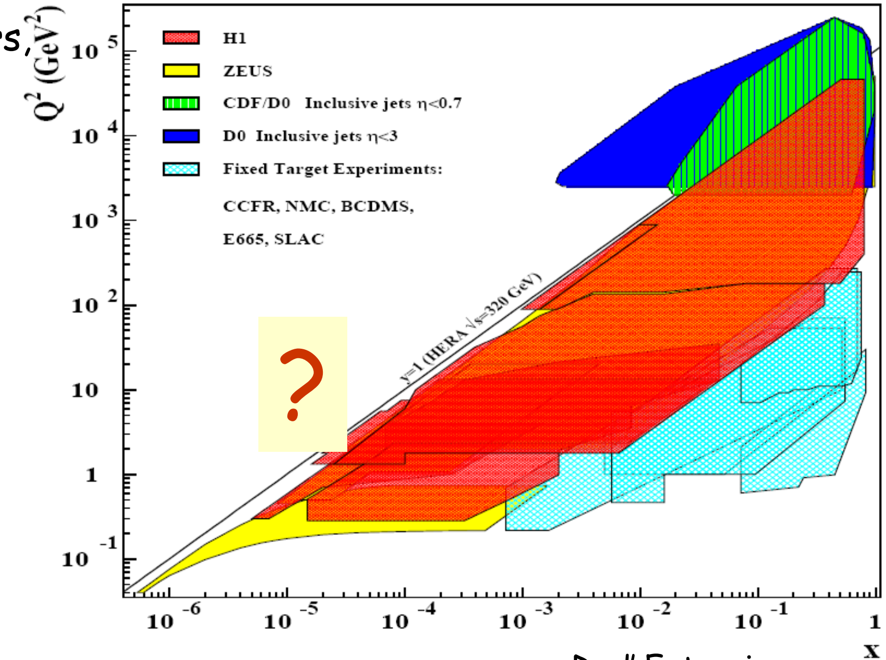
(but may depend on model)

measuring jet profiles up to very forward rapidities allows to determine the jet pedestals and thus obtain "true" E_t(jet)

Low x proton PDF studies



$$x \sim \frac{Q}{\sqrt{s}} e^{-\eta} \qquad Q \equiv p_T, M, \ldots$$



at LHC for Q>10 GeV, y=0, x~10^{-3}
➔ domain probed by HERA and TEVATRON

D. d'Enterria,
hep-ex/0703024

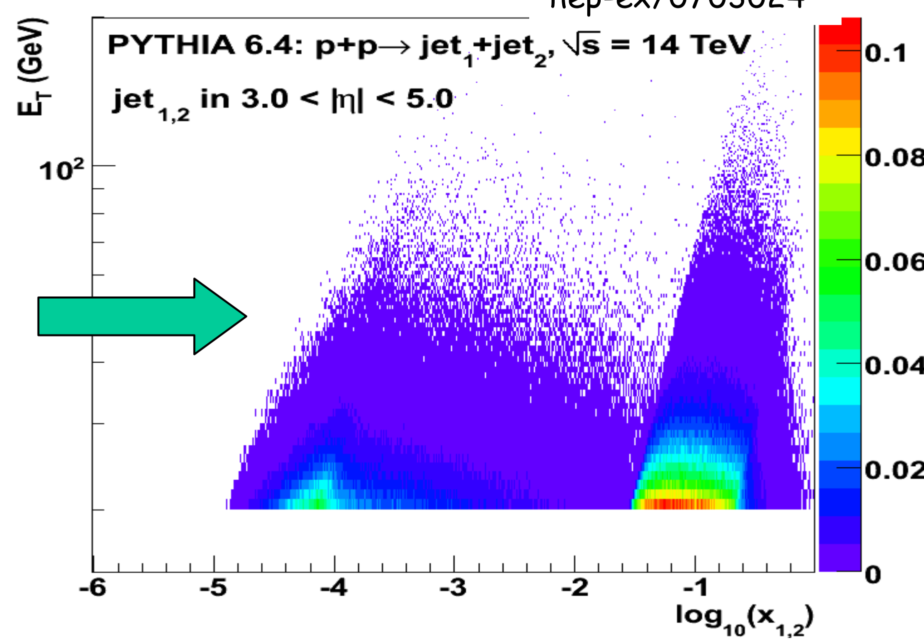
➔need to go to forward rapidities to exploit new low-x domain
(two units in η → one order of magnitude in x)

→ look for jet events with P_T^{jet}~ 20 ÷100 GeV

→ jets in HF/FCal at 3<|η|<5 probe x≈10^{-4} ÷10^{-5}

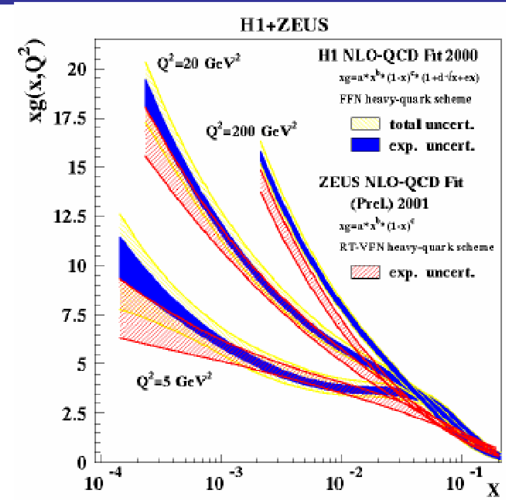
jets at CASTOR (5.2<|η|<6.6) probe x≈10^{-6} !

→ constrain the low-x proton PDF



Low x and Saturation with forward jets

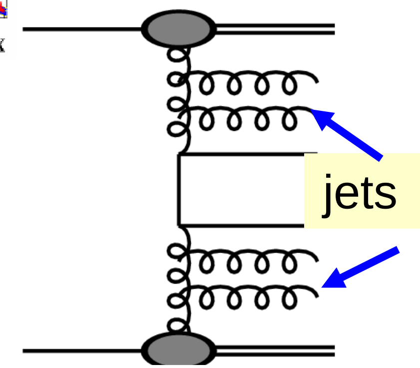
•**Strong rise of gluon density at low-x**



at very low-x linear equations violate unitarity, collinear and k_t factorization invalid

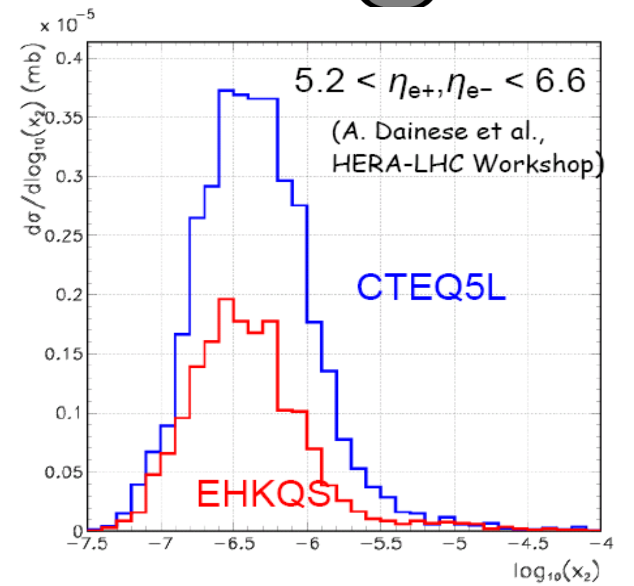
→**saturation**

forward measurements give access to low-x regime and possible saturation effects



▪Mueller-Navelet dijets (separated by large pseudorapidity interval)
-sensitive to non-DGLAP evolution and the saturation effects
→select dijet events with jet in each of the two HF/FCAL/CASTOR (Δy ~ 10 !) and P_T^{jet}~ 30 GeV

Detailed studies of Δy evolution are well feasible



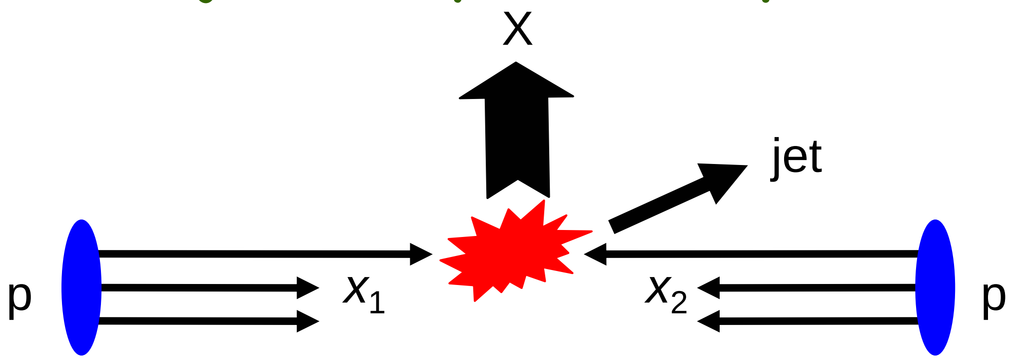
▪Forward Drell-Yan pairs: e+,e- measured at $5.2<\eta<6.6$,

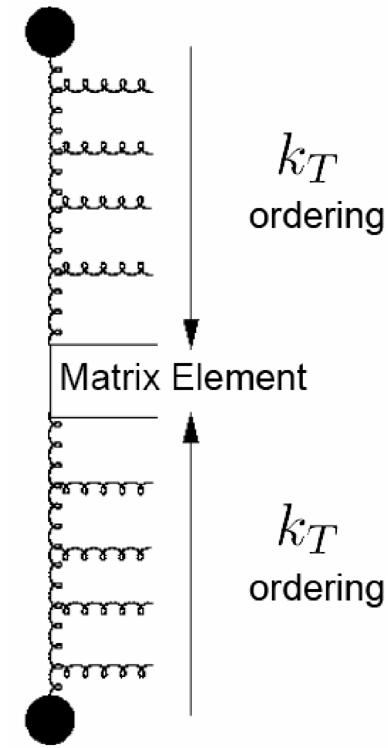
- probes the PDF down to $x \approx 10^{-7}$
- sensitive to saturation effects

cross section is reduced by factor 2 when using saturated PDF EHKQS (with nonlinear term in gluon evolution)

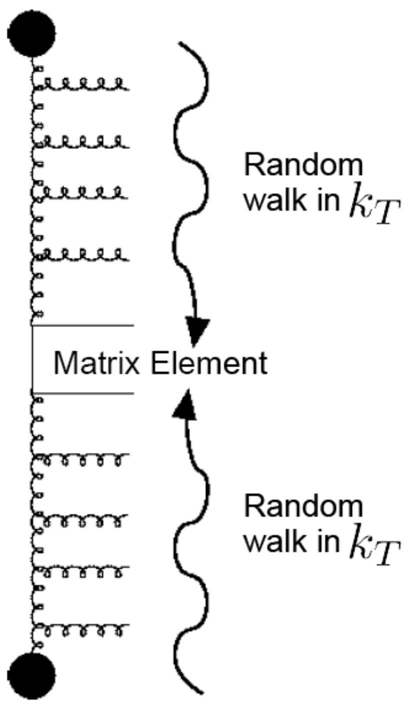
Parton Dynamics with Forward Jets

Forward jets- very sensitive probe of parton dynamics





DGLAP:
Resums terms depending on parton virtuality, resulting in ordering of virtuality of propagators ~kt of emitted partons (implemented in e.g. RAPGAP and PYTHIA MC)



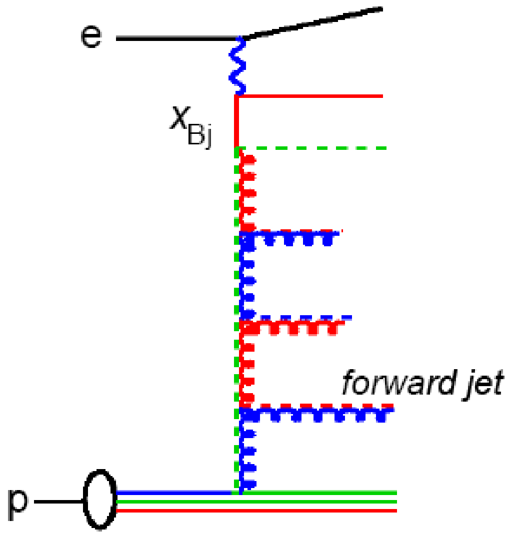
BFKL, CCFM: (no kt ordering)
Resums terms depending on parton propagator fractional momentum

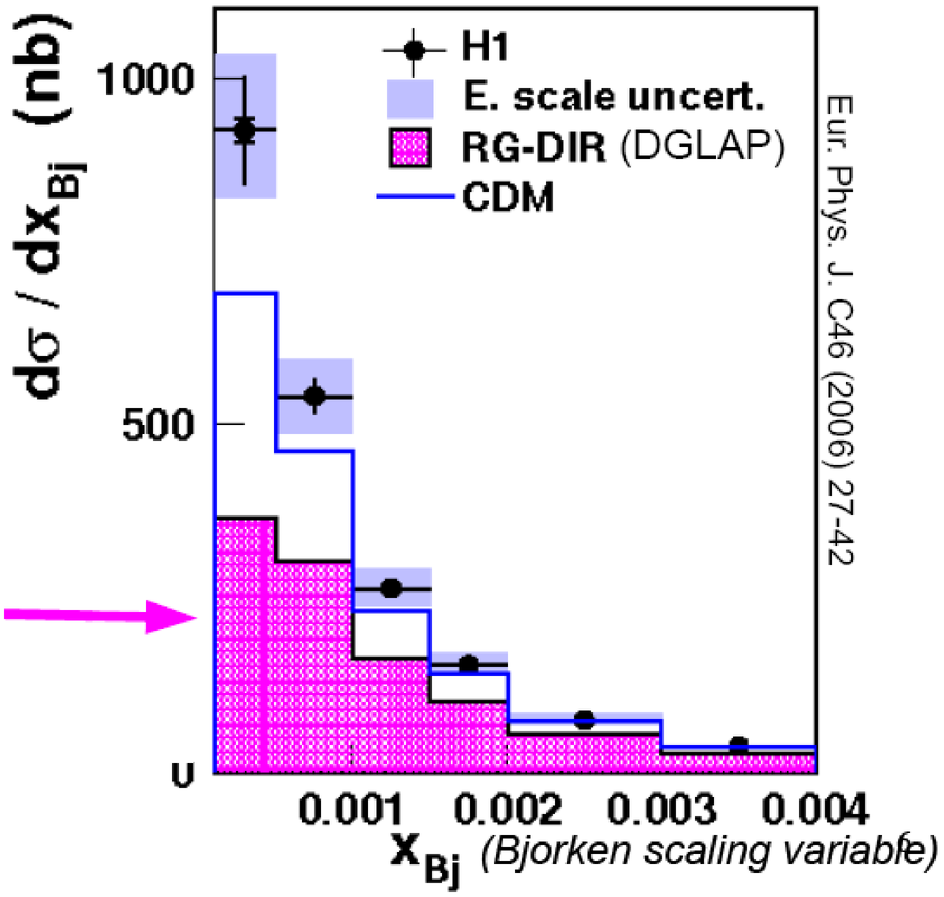
BFKL : Strong ordering of momentum fraction of propagators
CCFM: Angular ordering of gluon emissions (implemented in CASCADE MC)

Non DGLAP like dynamics can be estimate with Colour Dipole Model (*CDM*)

Parton Dynamics with Forward Jets

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





HERA result: ordering of kt of emission in DGLAP is not sufficient!

Need more hard emissions in forward region, as for example in CDM

LHC opens up phase space for emissions, higher order reactions
- small x physics
- gain information of the full evolution

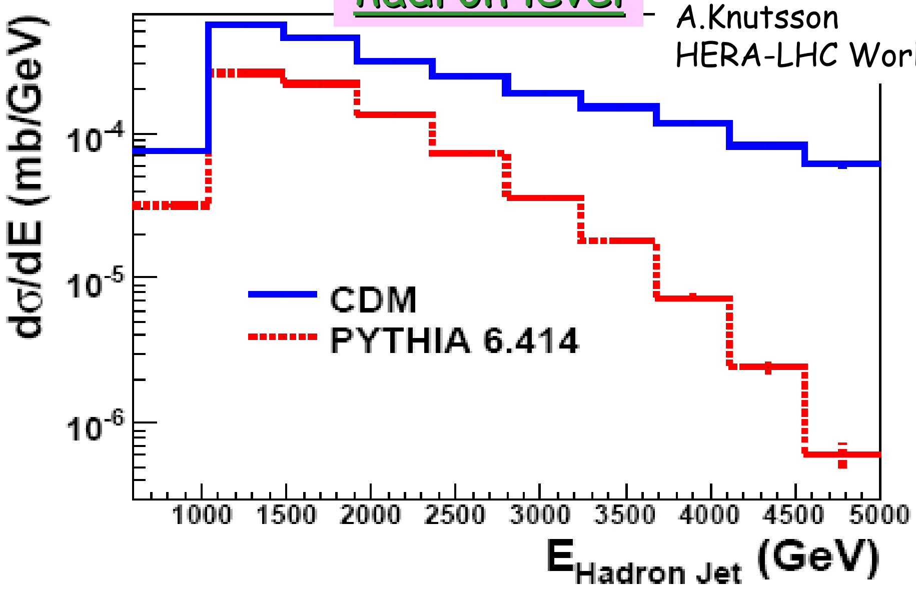
➔ **Tool to learn about higher order QCD reactions**

Parton Dynamics with Forward Jets (studies with CASTOR)

Selection: 2 central jets + 1 jet in CASTOR region ($5.2<\eta<6.6$) region; $E_T^{jet}>$ 10 GeV

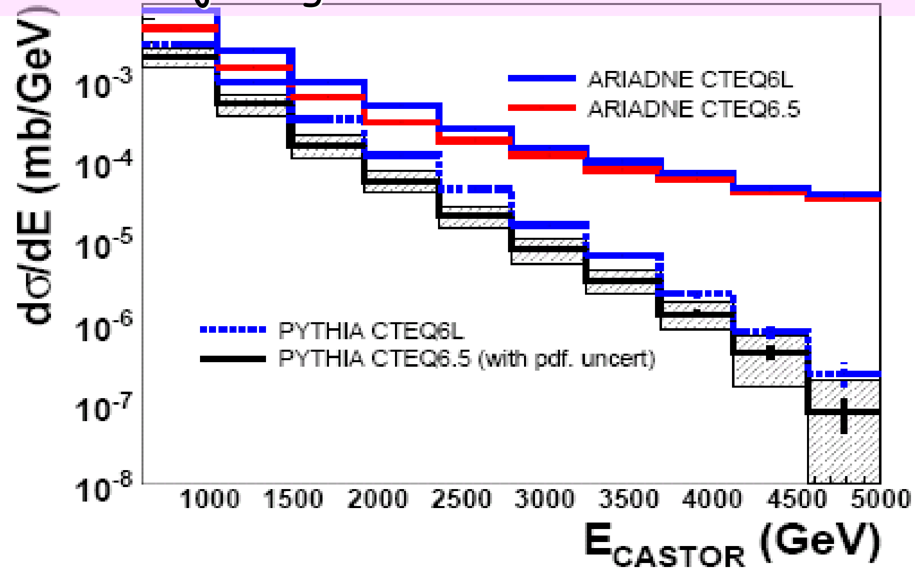
hadron level

A.Knutsson
HERA-LHC Workshop



detector features applied

experimental problem: large particle multiplicity, detector granularity not sufficient to use conventional jet algorithms

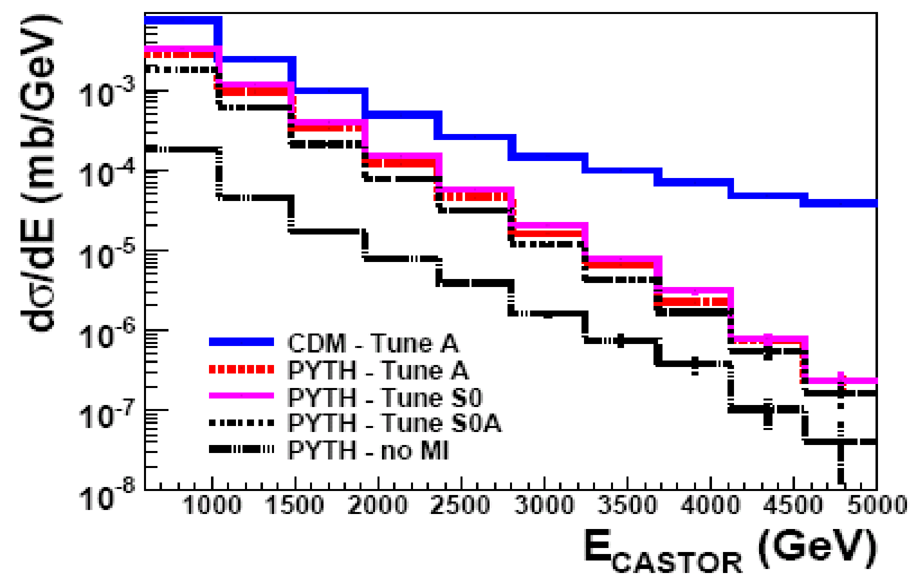


- ARIADNE (Color Dipole Model) with more BFKL like final state, with partons unordered in kt predicts more hard jets in the forward region

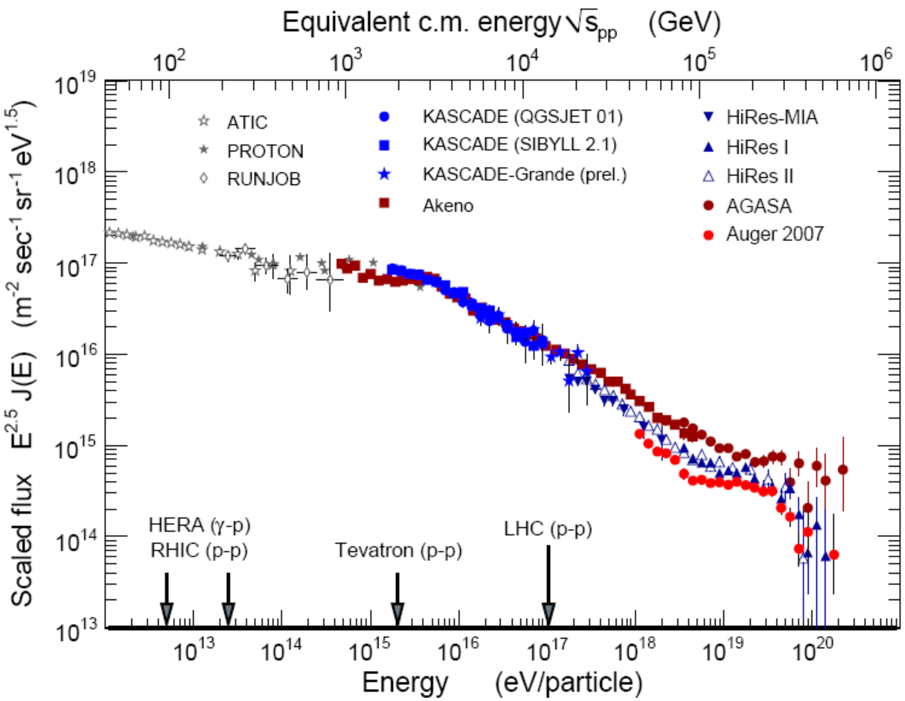
➔ can distinguish between different parton dynamic schemes

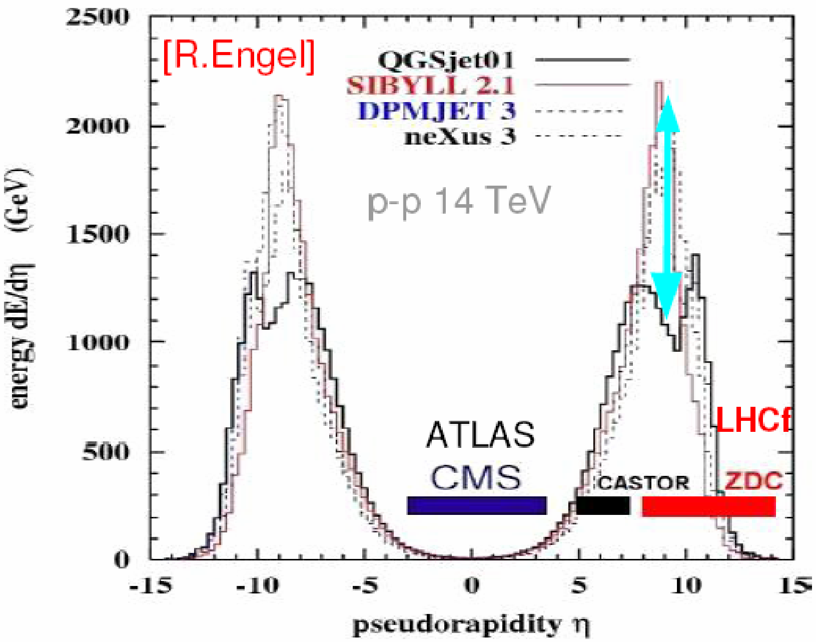
➔ PDF uncertainties are much smaller

- Large effect from switching on/off MI
- At high E difference between CDM and PYTHIA larger than different MI tunes/models



Implication of forward measurements on UHE cosmic ray physics





- Cosmic Ray particle energy and mass are determined via hadronic MC simulations

Significant differences between the model predictions for particle multiplicities, energy flow etc.
Shower development dominated by forward, soft QCD interactions

➔need measurements from accelerator experiments to tune the models

- uncertainties from extrapolations from SpS, HERA, RHIC, Tevatron to GZK limit

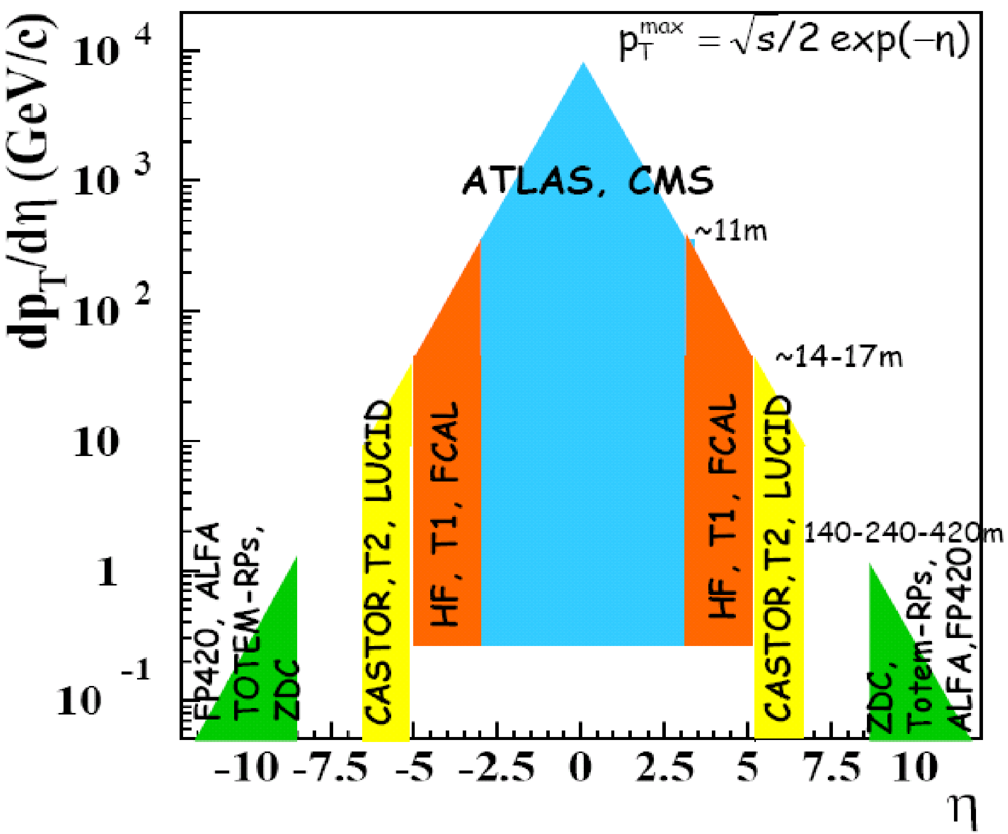
LHC: $\sqrt{s}$=14 TeV → $E_{lab}=10^{17}$ eV

- high momenta are available only in forward region !
- measurement of leading baryon (n), neutral mesons and γ (ZDC, LHCf) and particle flow in pp, pA, AA

➔ strong model constrain

Summary

- The measurements in forward regions give access to a reach physics program
- These measurements can improve our understanding of QCD effects
  - New unexplored region of small-x → Parton evolution and saturation effects
  - Underlying Events and Multi-parton interactions → crucial input for all precision measurements
  - Jet profiles
  - Long range correlations
  - Forward jets



- The forward instrumentations of LHC experiments have capabilities for these measurements !

- Still room for improvement ?

In present configuration of ATLAS and CMS the pseudorapidity region 6.6÷8.3 not covered; ZDC (η>8.3) detects only neutral particles

The possibility to fill this gap with a calorimeter (e.g. at ~130m) has to be investigated