Underlying Event, Minimum Bias and Forward Energy Flow Measurements with CMS

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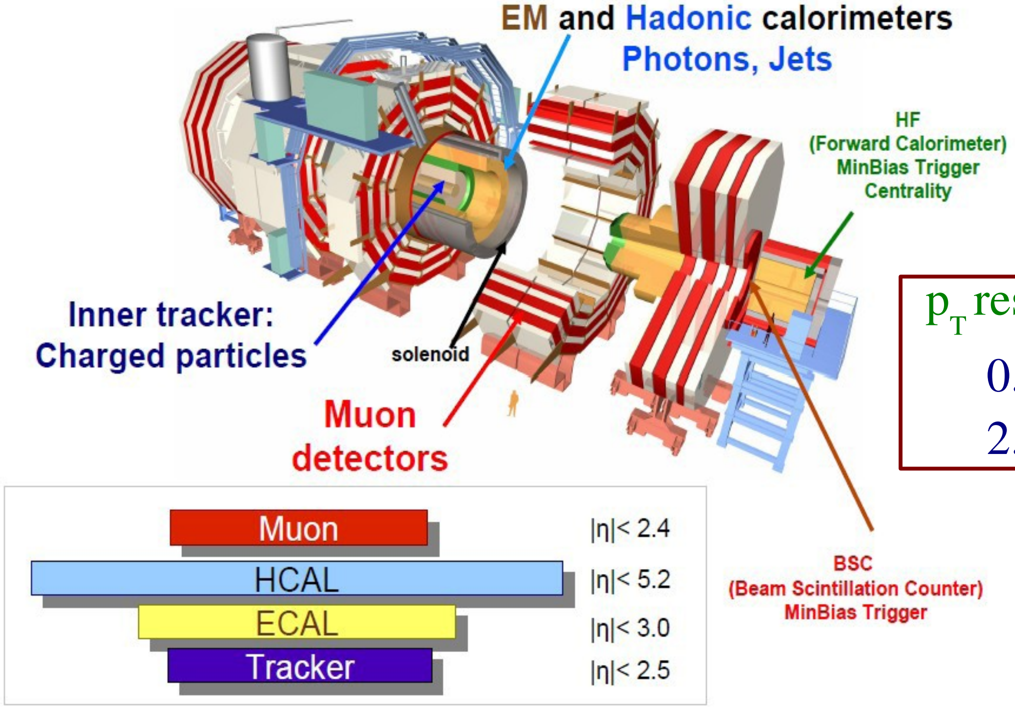
on behalf of CMS Collaboration

3rd workshop on Multi-Parton Interactions at the LHC
Hamburg, 21-25 November 2011

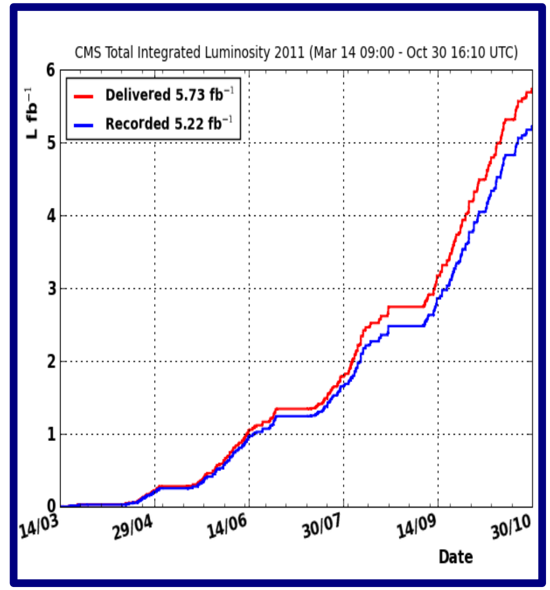
CMS Experiment



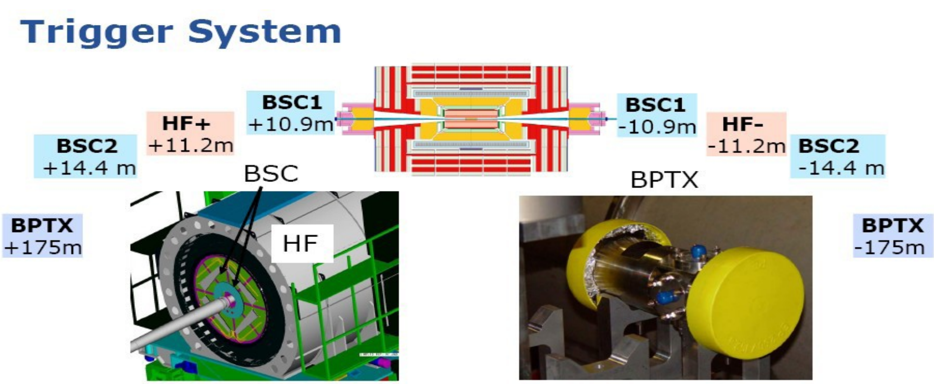
p_T resolution @ 1 GeV/c:

0.7% at $\eta = 0$

2.0% at $|\eta| = 2.5$



Analysis presented are sensitive to pile-up and performed with low lumi



Beam Scintillator Counters
- ± 10.86m from interaction point
- Hit and coincidence rates (beam-halo rejection)

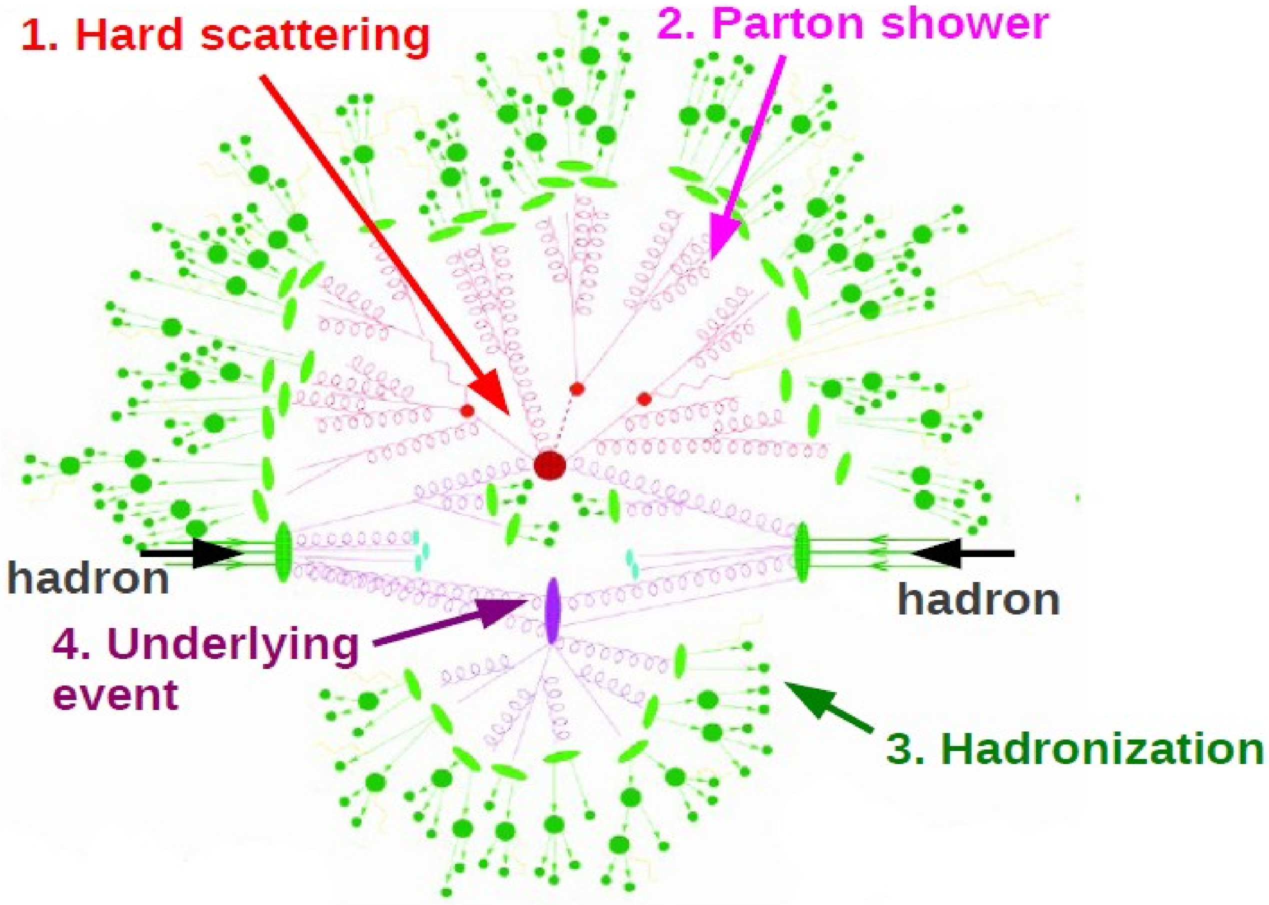
Beam **P**ick-up **T**iming for the e**X**periments
- Bunch structure
- Timing of beam

Time resolution better 2ns!

The Underlying Event

EPJ C70 (2010) 555
JHEP09 (2011) 109
CMS QCD-10-040

Everything except the hard scattering:
UE = MPI +BBR (+ ISR and FSR contamination)



→ Need to “tune” soft interactions MC model(s) to UE: previous and LHC data

The Underlying Event

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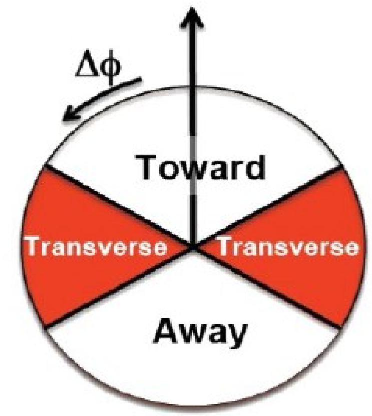
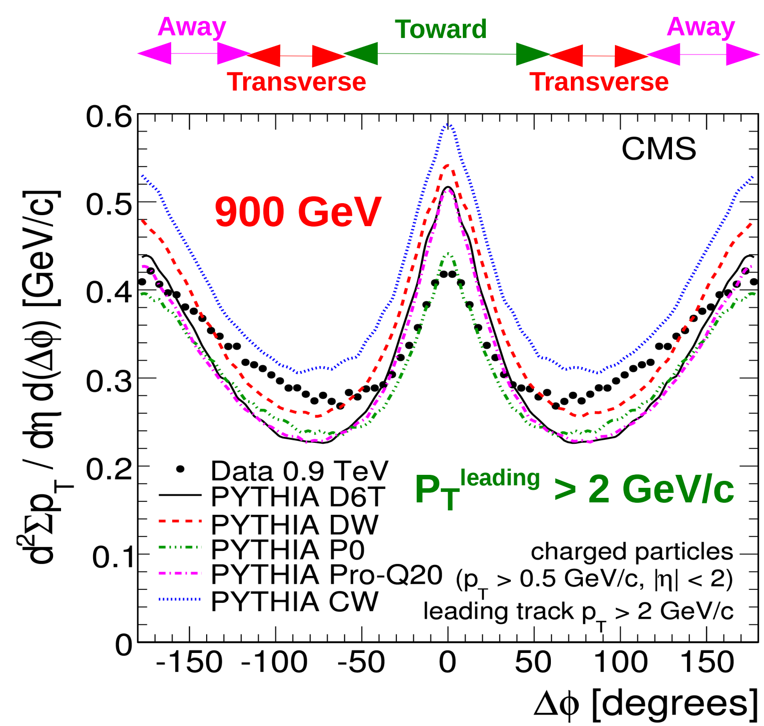


Identify in the event an energy scale (and direction) reflecting the hard scattering:

- → Di-jet events: Leading track-jet (cluster of tracks with highest pT)
- → Drell-Yan: di-muon final state

3 topological regions from the azimuthal difference w.r.t. the leading direction:

- → away ($|\Delta\phi| > 120^o$): hard scattering and radiation
- → transverse ($60^o < |\Delta\phi| < 120^o$): suited for UE studies
- → towards ($|\Delta\phi| < 60^o$): same as "away" for track-jet approach
  suited for UE studies in DY process

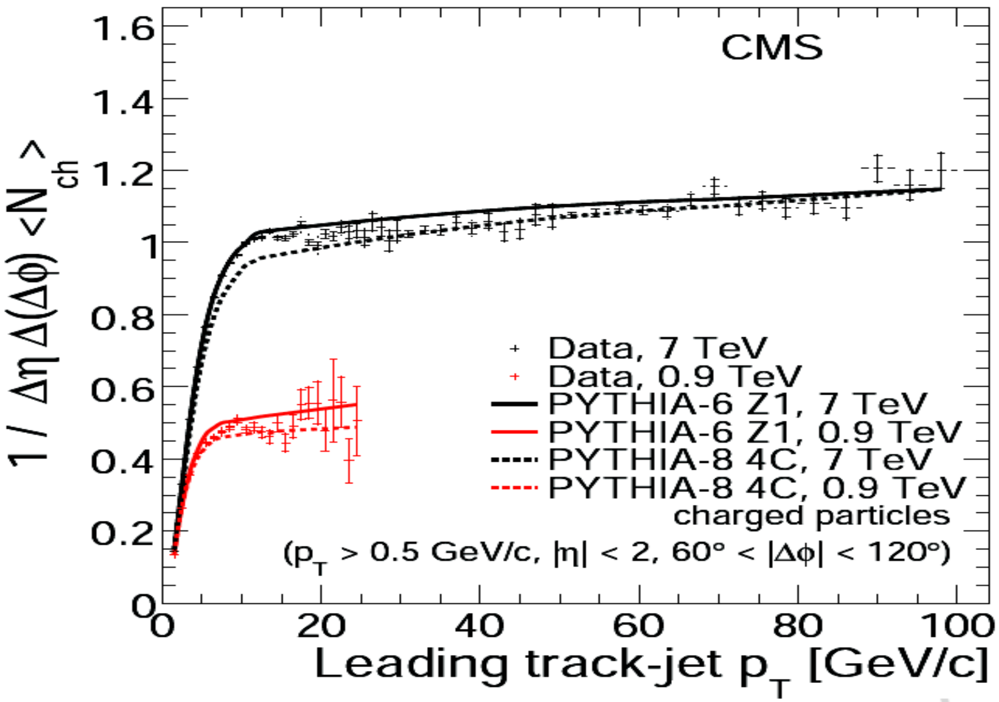


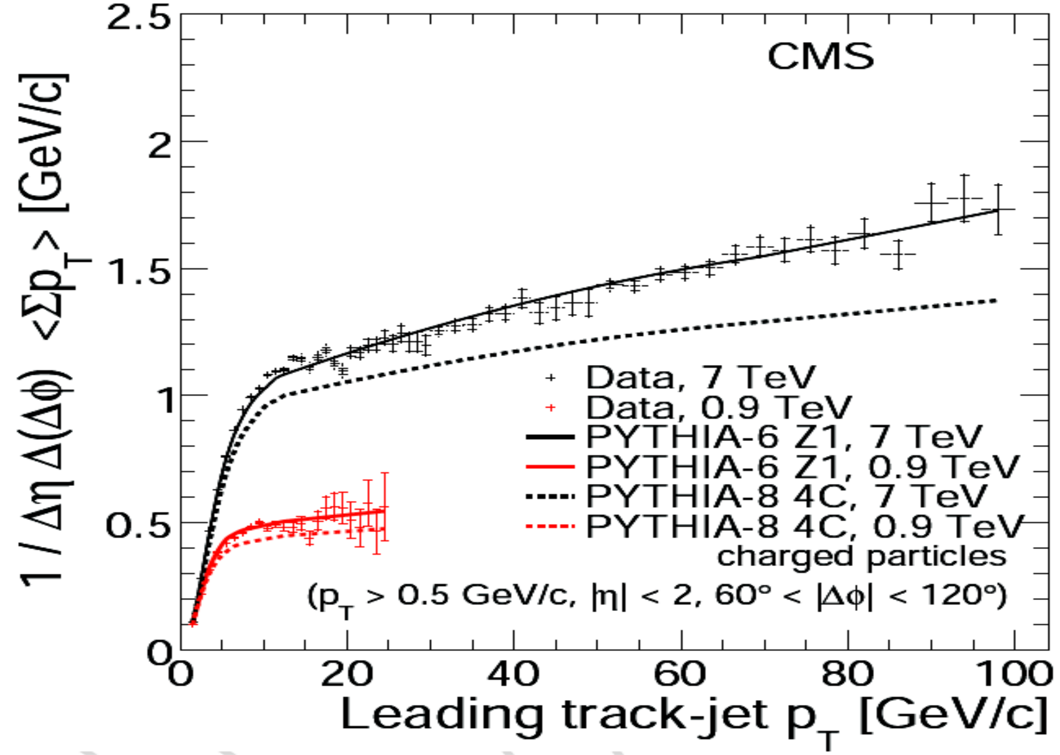
Observables built from charged particles:

- $d^2 N_{chg} /d\eta\, d(\Delta\phi)$: charged multiplicity density
- $d^2\Sigma\, p_T /d\eta d\, (\Delta\phi)$: scalar p_T sum density

UE transverse region: charge and Σp_T density

7 TeV and 900 GeV results for the reference charged multiplicity density and Σp_T density profiles including Z1 (solid) and 4C (dashed) predictions.



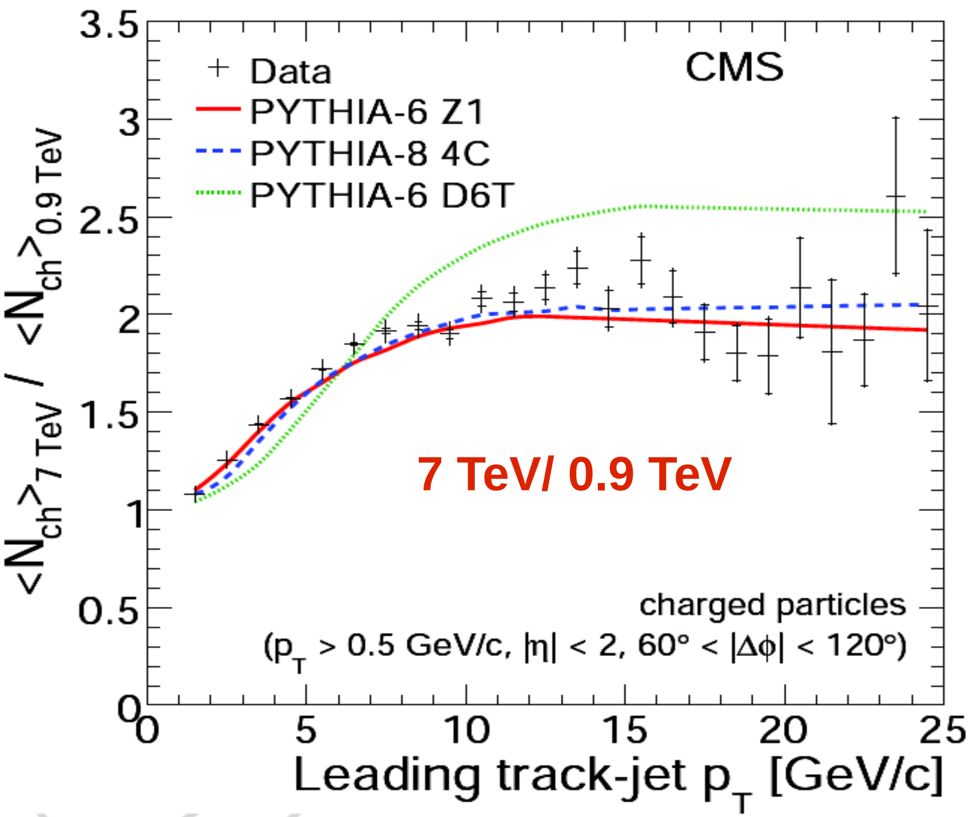


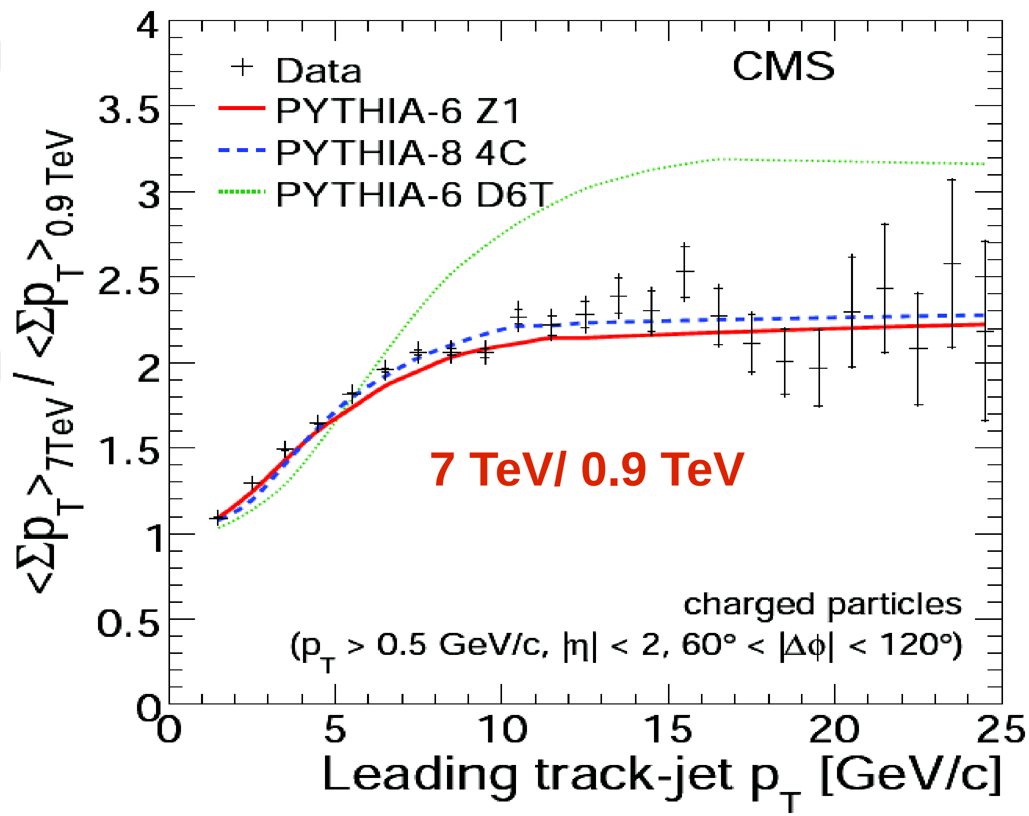
– Fast rise for pT < 8 GeV/c (4 GeV/c), attributed mainly to the increase of MPI activity, followed by a plateau-like region with ≈ constant average number of selected particles and a slow increase of ΣpT, in a saturation regime.

– Increase of the activity with $\sqrt{s}$ also corroborates MPIs (growth with PDFs).

– PYTHIA nicely re-tuned to describe the data, still differences of the order of 5 to 20% for different versions and tunes (even very recent PYTHIA8 tune 4C).

Comparison between 7 TeV and 900 GeV



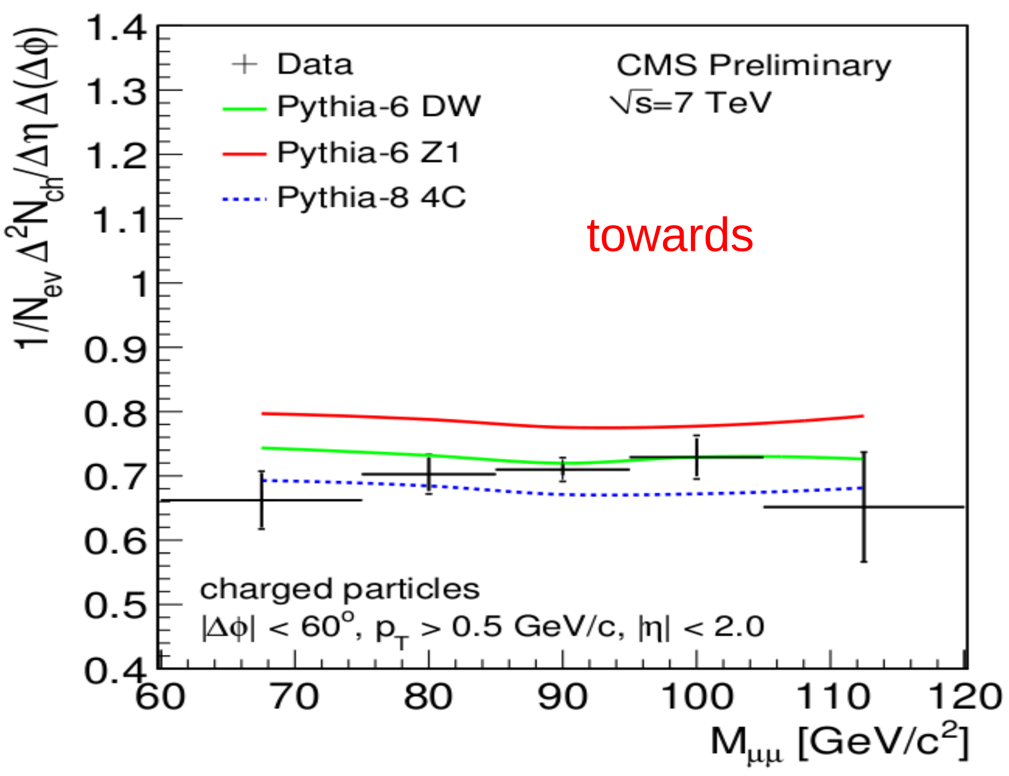


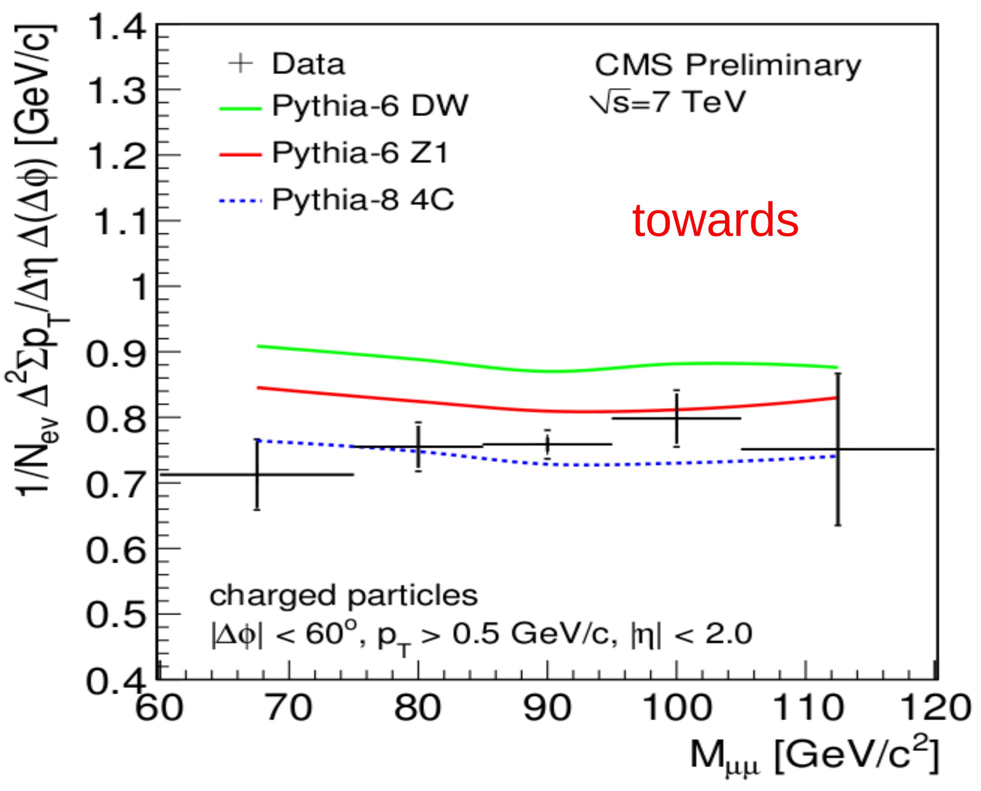
– In the presence of a large energy scale, UE grows significantly with √s
– A factor 2 going from 900 GeV to 7 TeV to be compared with 1.7 for MB.
– MPI growth with √s well described by Z1 and 4C, too pronounced in D6T.

Charge and Σp_T density : Drell-Yan Events

Activity as a function of $M_{\mu\mu}$: for events with small recoil activity by requiring $p_T^{\mu\mu} < 10$ GeV/c

→ close to true UE



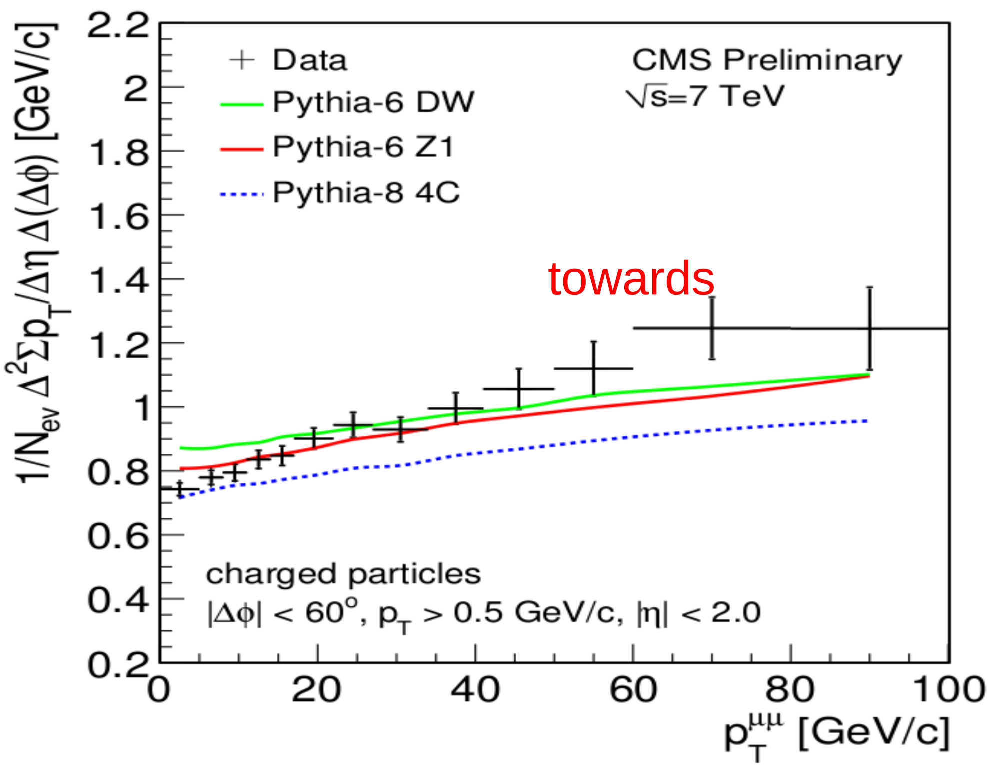


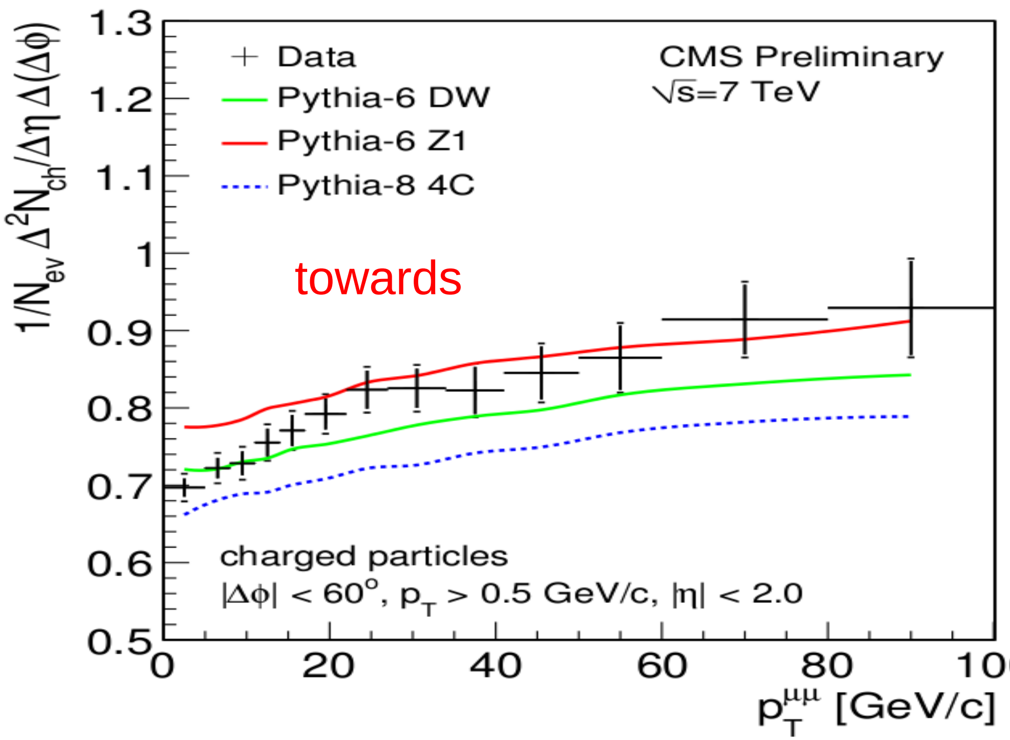
– no dependence on energy scale ($M_{\mu\mu}$), as MPI saturates at these scale (also known from track-jet analysis).

– Pythia-8 4C, Pythia-6 DW and Z1 agrees with the measurements within 10-15%

Charge and Σp_T density : Drell-Yan Events

Activity as a function of $p_T^{\mu\mu}$: for events with $60 < M_{\mu\mu} < 120$ GeV/c^2





– MPI saturates and $p_T^{\mu\mu}$ dependence gives radiation evolution (mainly initial state radiation).

– Transverse region: qualitatively similar as towards but has higher activity due to spill-over contribution from away side hard component.

– Pythia-8 4C underestimate the activity (except at small $p_T^{\mu\mu}$), Pythia-6 tunes agree with the measurements within 10-15%

Single Charged Particle Spectra: dN/dη

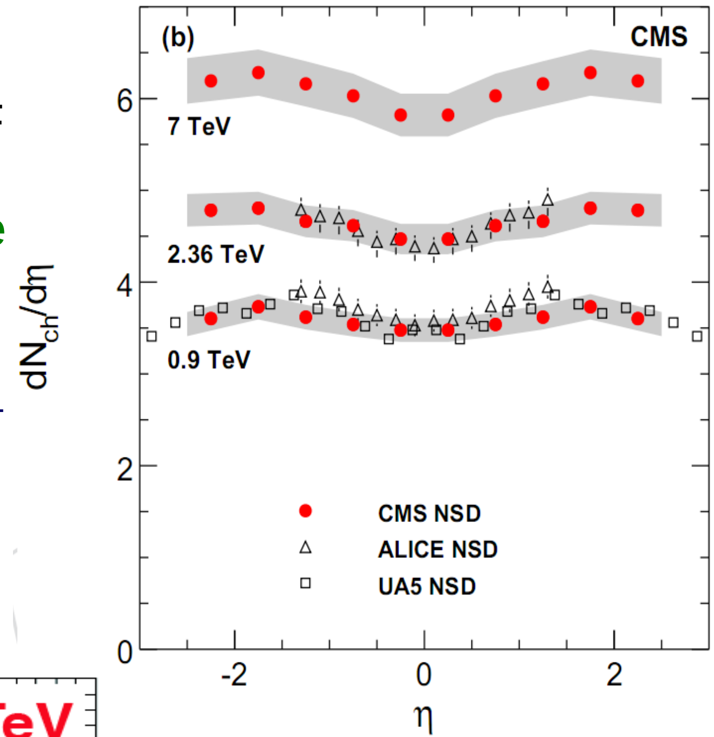
JHEP 02 (2010) 041
PRL 105 (2010) 022002
CMS QCD-10-008

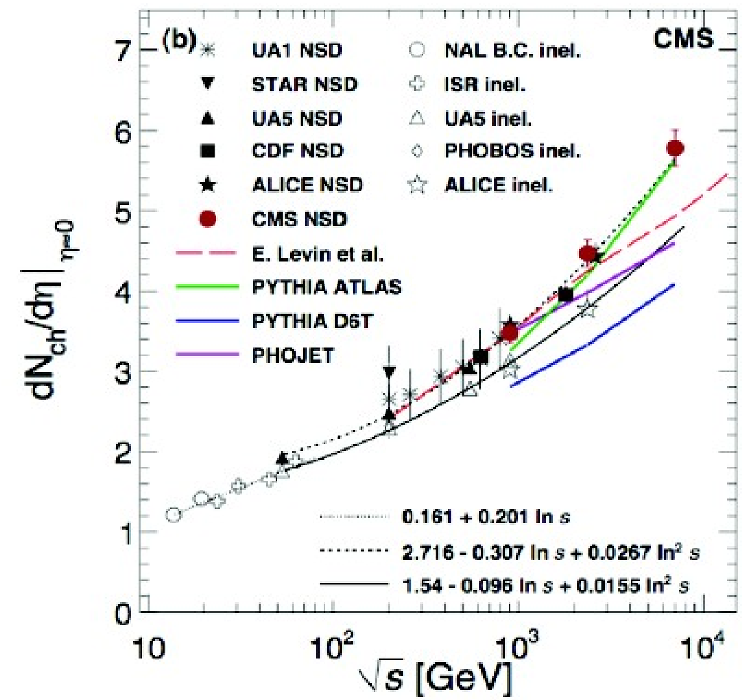
<u>Event Selection:</u>

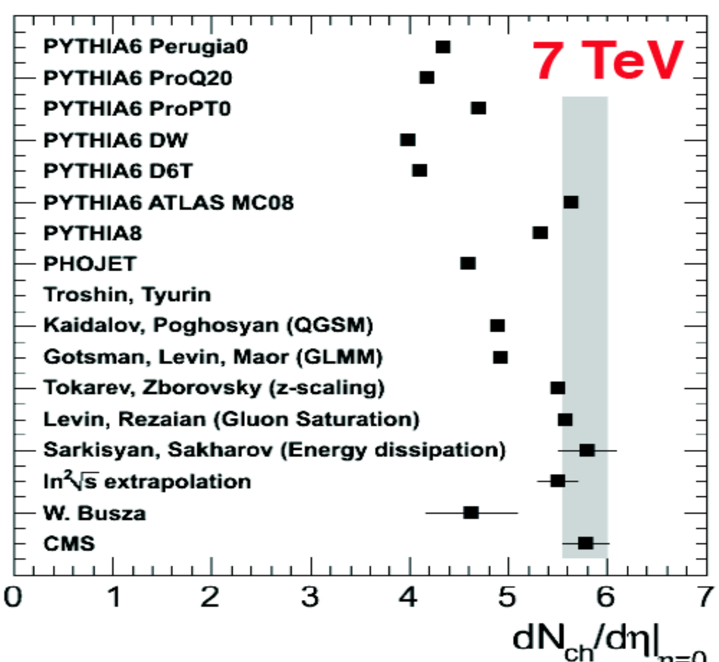
- MinBias trigger (BSC)
- At least 3 GeV in both HF
- primary vertex
  - → Corrected to non single diffraction (NSD)

<u>Charged Particle Selection:</u>

- $|\eta| < 2.5$
- corrected to $p_T > 0$ GeV/c
- 3 different methods







CMS measurements in agreement with other experiments.

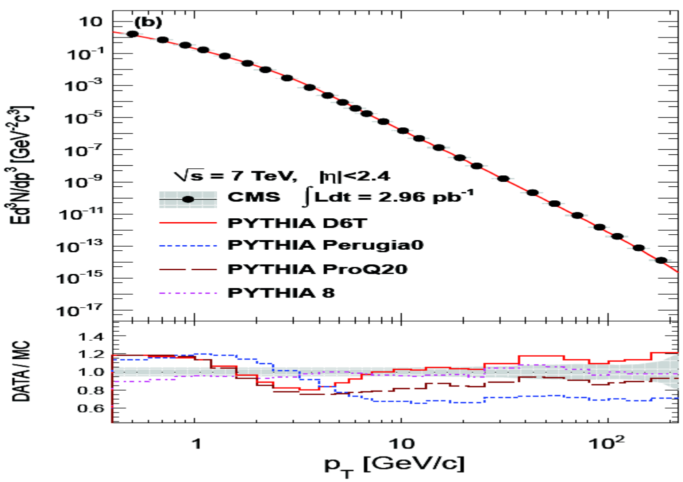
However densities are higher than most models and pre-LHC MC at high energy.

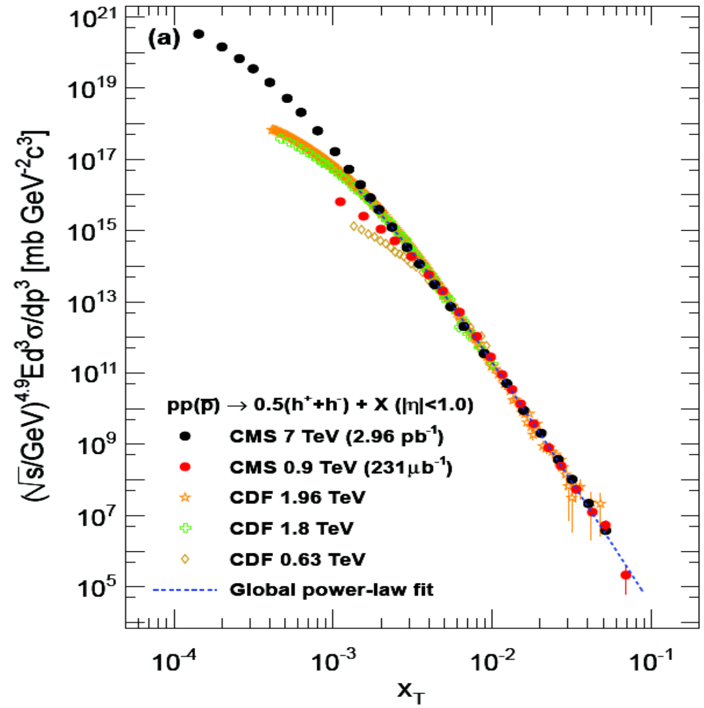
Single Charged Particle Spectra: dN/dp_T

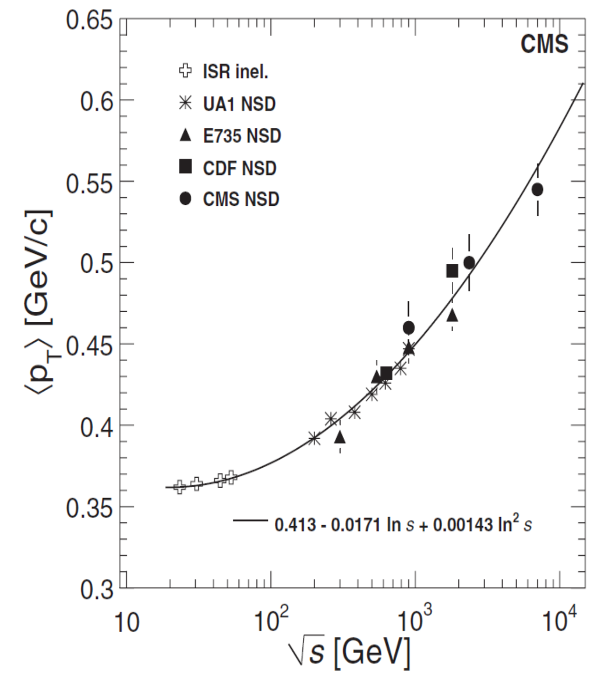
JHEP 02 (2010) 041
PRL 105 (2010) 022002
JHEP 08 (2011) 086

Event Selection:
- MinBias trigger (BSC) + Jet trigger
- At least 3 GeV in both HF
- primary vertex

Charged Particle Selection:
- $|\eta| < 2.4$, $p_T>0.1$ GeV/c

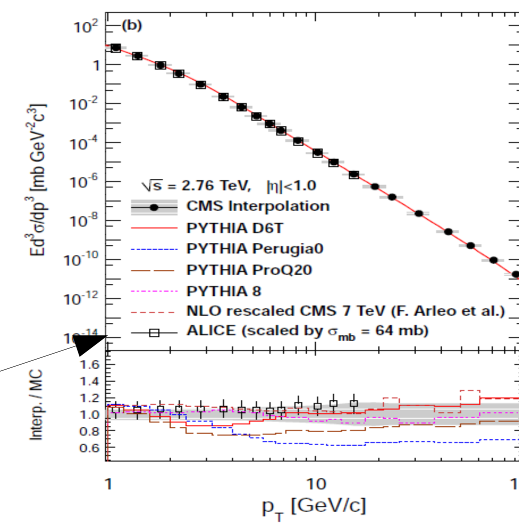






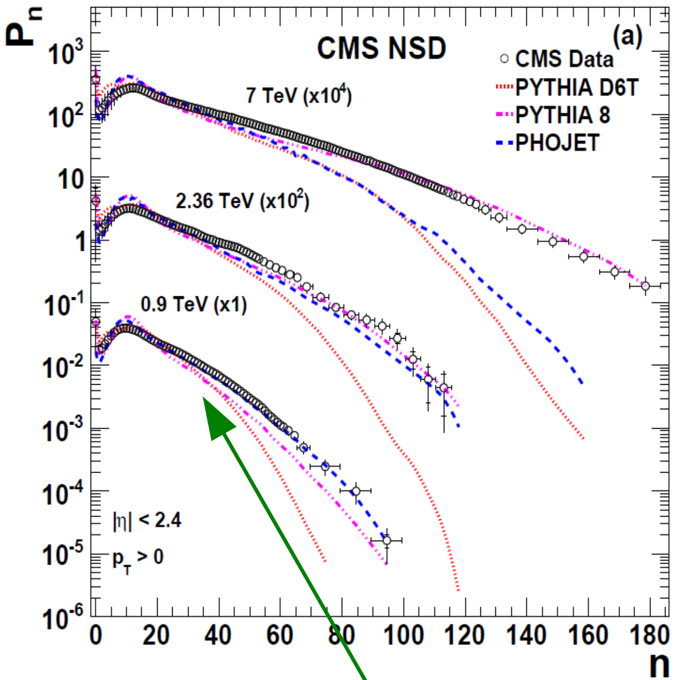
$$E\frac{d^3\sigma}{dp^3} = F(x_T)/p_T^{n(x_T,\sqrt{s})} = F'(x_T)/\sqrt{s}^{\,n(x_T,\sqrt{s})}$$

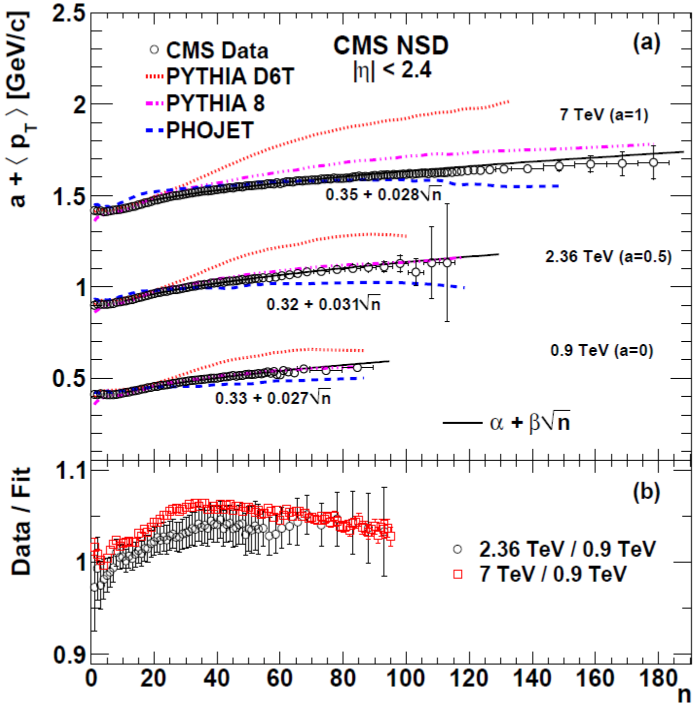
- Empirical $x_T = 2\,p_T/\sqrt{s}$ scaling unifies the differential cross sections from a wide range of collision energies onto a common curve at high x_T
  - → Interpolated (x_T and p_T scaling) data provides a reference for PbPb studies of nuclear modification factors at LHC for $\sqrt{s_{NN}}$=2.76 TeV

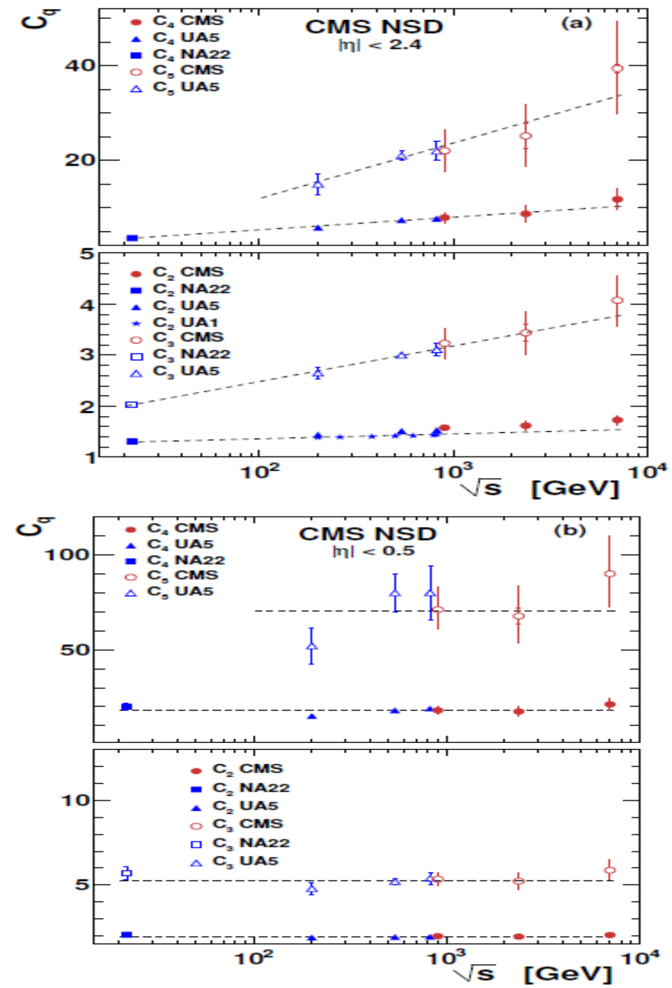


Charged Particle Multiplicities

JHEP 01 (2011) 079







Change in slope: multi-component structure

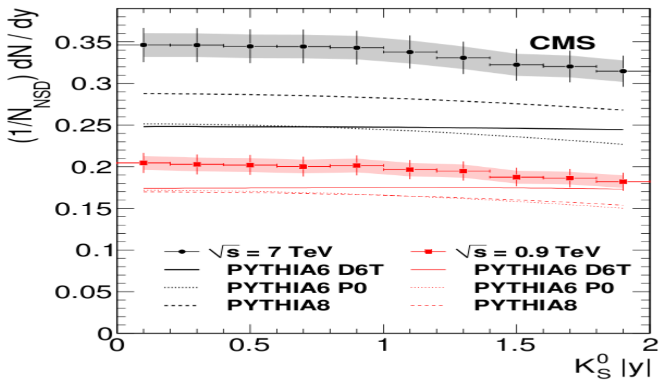
- Large multiplicity tail observed at 7 TeV
- <p$_T$> vs n scale with energy: weekly dependent on √s
- No Monte Carlo is able to describe all multiplicities at all energies (but PYTHIA 8 better)
- Most MC/tunes can not describe simultaneously the multiplicity and the p$_T$ dependence (again PYTHIA 8 better)
- MC produce too few particles with low transverse momentum; PYTHIA 8 compensate for this by producing too many particle with high pT (semi hard MPI modelling)

KNO scaling: violate for |η| < 2.4
hold for |η| < 0.5

Strange Particle Production: K^0_S, Λ , Ξ^-

JHEP 05(2010)064

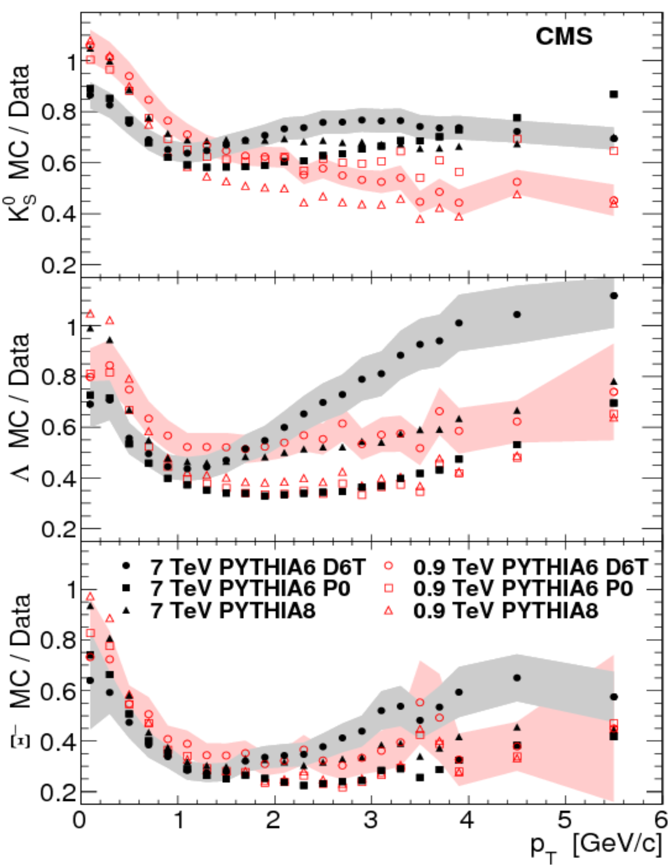
K0 , Λ , Ξ⁻: long-lived particles (cτ > 1 cm) identified from their decay products originating from a displaced vertex.

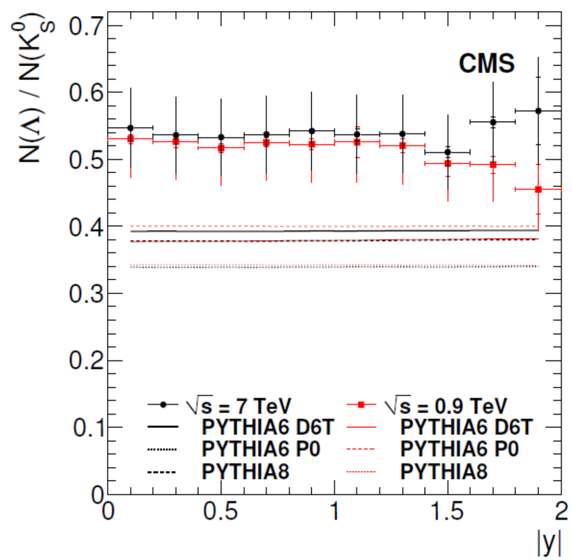


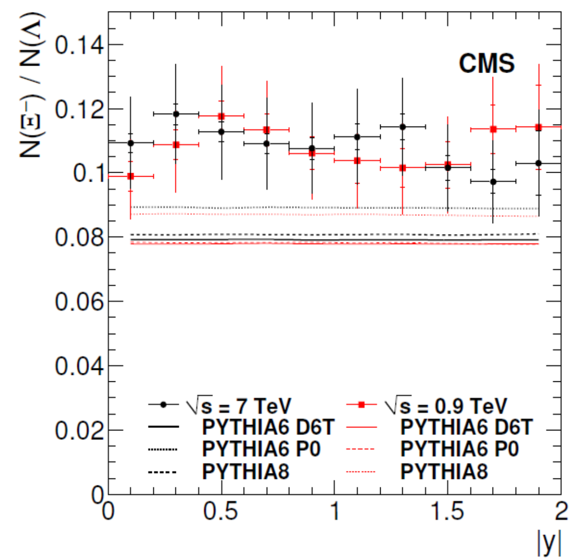
– the amount of strangeness suppression (w.r.t. u and d quarks) is an important component in MC models
– interesting for new physics (e.g. strange enhancement in QGP formation)

Production yields in function of rapidity y and p_T:

- <pT> increasing with particle mass and √s: agreement with predictions
- √s increase in production consistent with inclusive charged particles
- production ratios , Λ / K0 and Ξ⁻ / Λ (versus y and pT) independent of √s:no clear sign of QGP formation





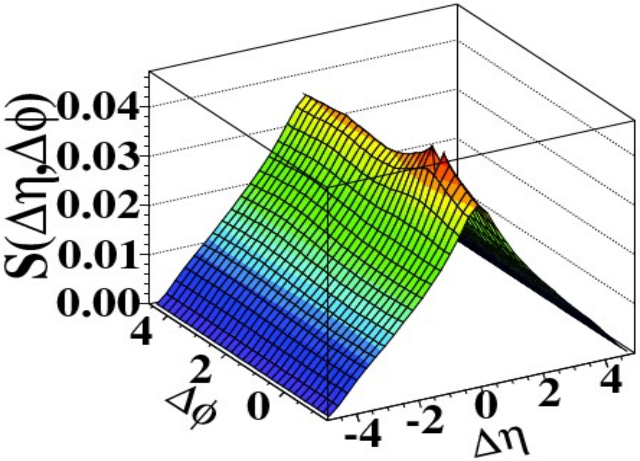


MC underestimating total yield (both √s 0.9 and 7TeV) and √s scaling

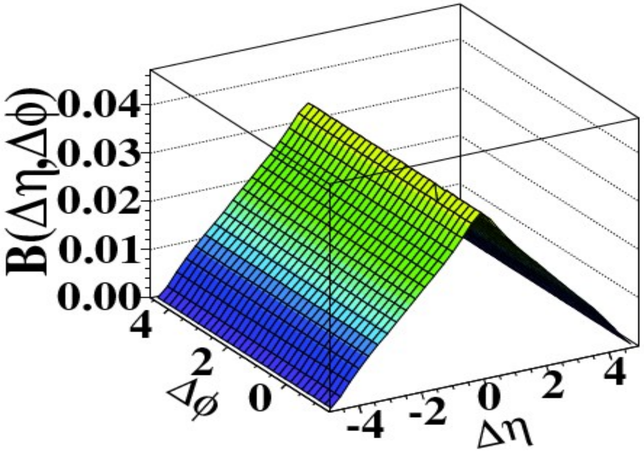
Two-particles correlation in $\Delta\eta$ and $\Delta\phi$

JHEP 09 (2010) 091

Signal distribution
= Correlated and uncorrelated pairs
from same event

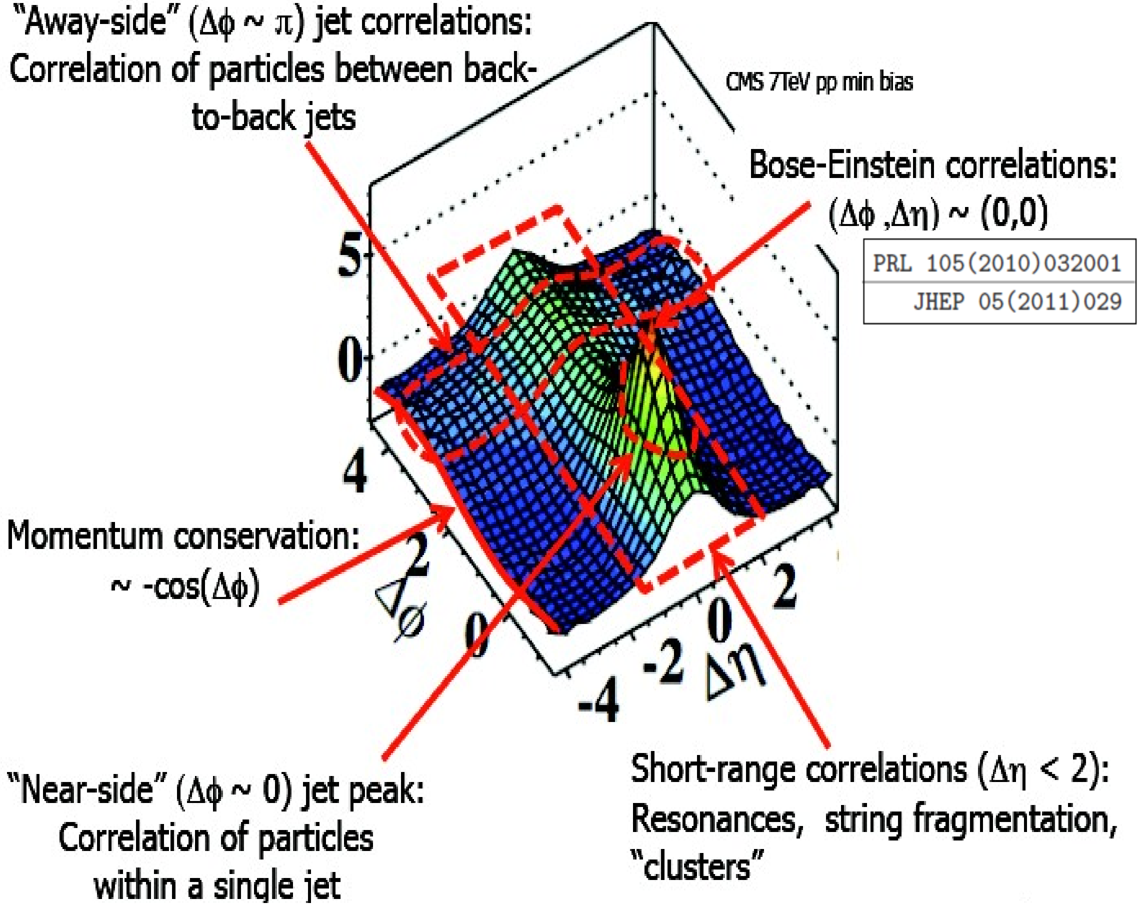


Background distribution
= Uncorrelated pairs
from mixing 2 events

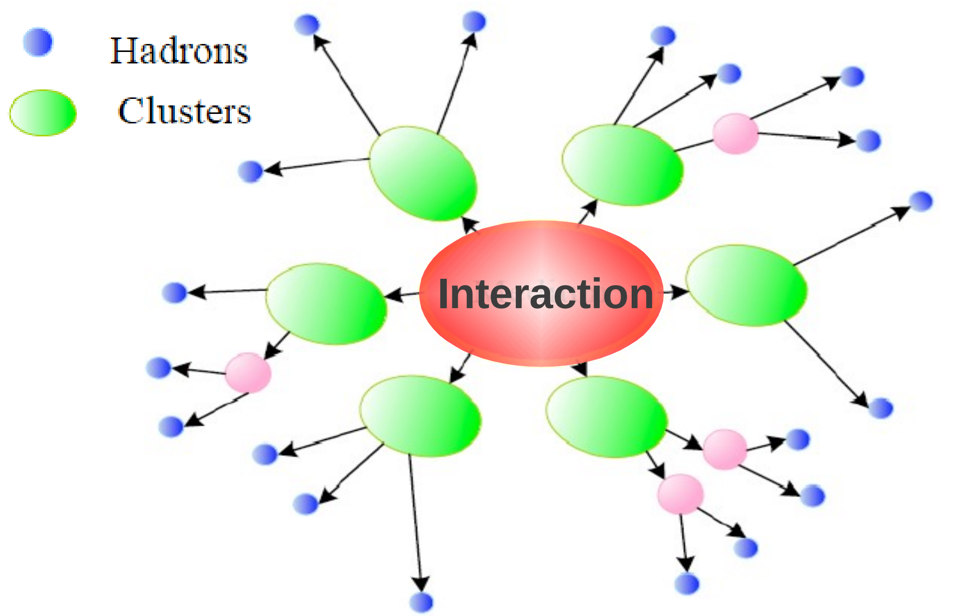


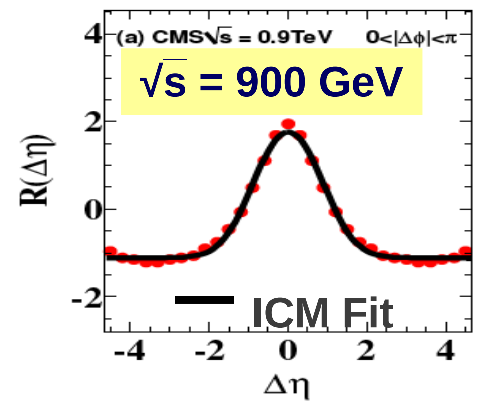
$$R(\Delta\eta,\Delta\phi)=\left\langle (N-1)\left(\frac{S_N(\Delta\eta,\Delta\phi)}{B_N(\Delta\eta,\Delta\phi)}-1\right)\right\rangle_N$$

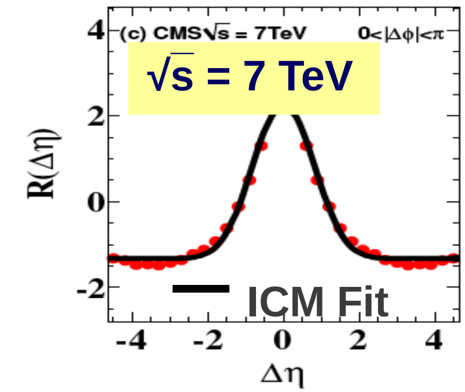
MinBias, $p_T > 0.1$ GeV/c, 7 TeV



MinBias Results: Independent Cluster Model







Independent Cluster Model (ICM)

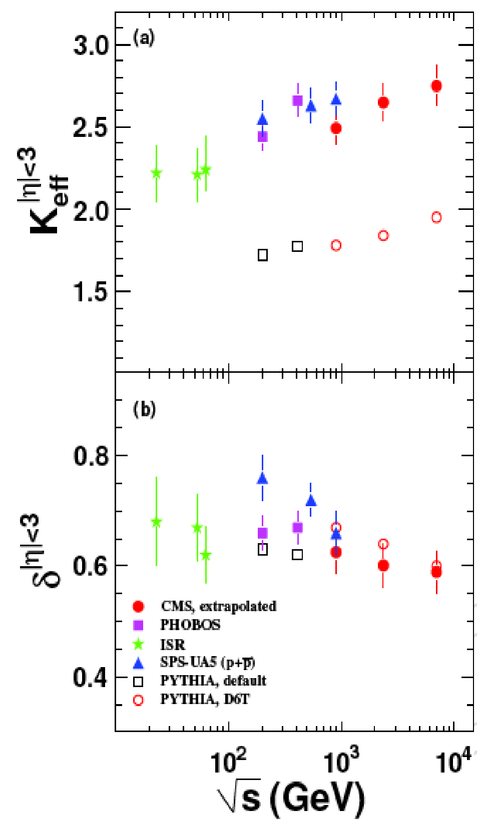
– Clusters are produced independently

– Each cluster decay isotropically into hadrons in its own c.m.s.

– Short range correlations in Δη can be characterized by 2 parameters:

– cluster size K → # correlated particles

– cluster width δ → Δη correlation size

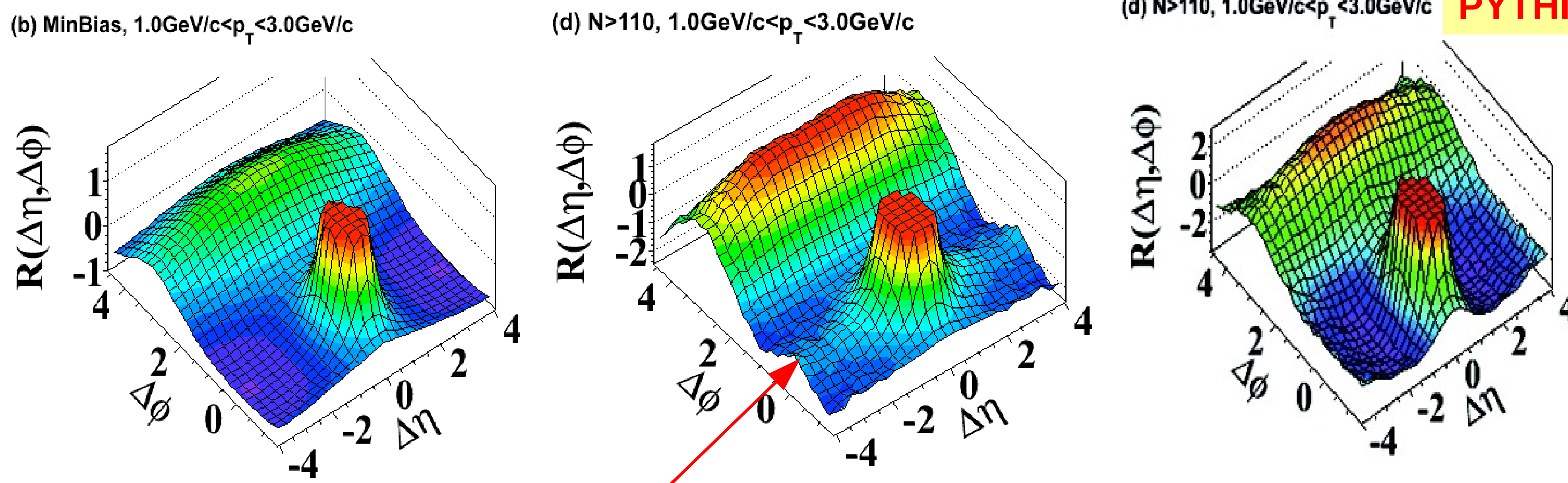


- K_{eff} increase with $\sqrt{s}$
  (more jets at high $\sqrt{s}$?)
- δ constant with $\sqrt{s}$
  (isotropic cluster decay)
- CMS results follow trend from lower $\sqrt{s}$ data
- PYTHIA (D6T) shows similar energy dependencies for K_{eff} and δ as data
- PYTHIA (D6T) predicts too low K_{eff}

High Multiplicity Results at $\sqrt{s}$ = 7 TeV

Intermediate pT : $1 < p_T < 3$ GeV/c

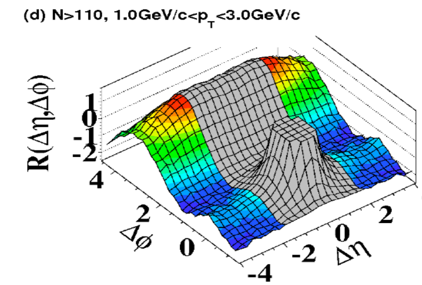
MinBias **High Multiplicity: N>110** **PYTHIA 8**



→ **Observation of a Long-Range, Near-Side angular correlations at high multiplicity in pp events at intermediate p_T (Ridge at Δϕ ~ 0)**

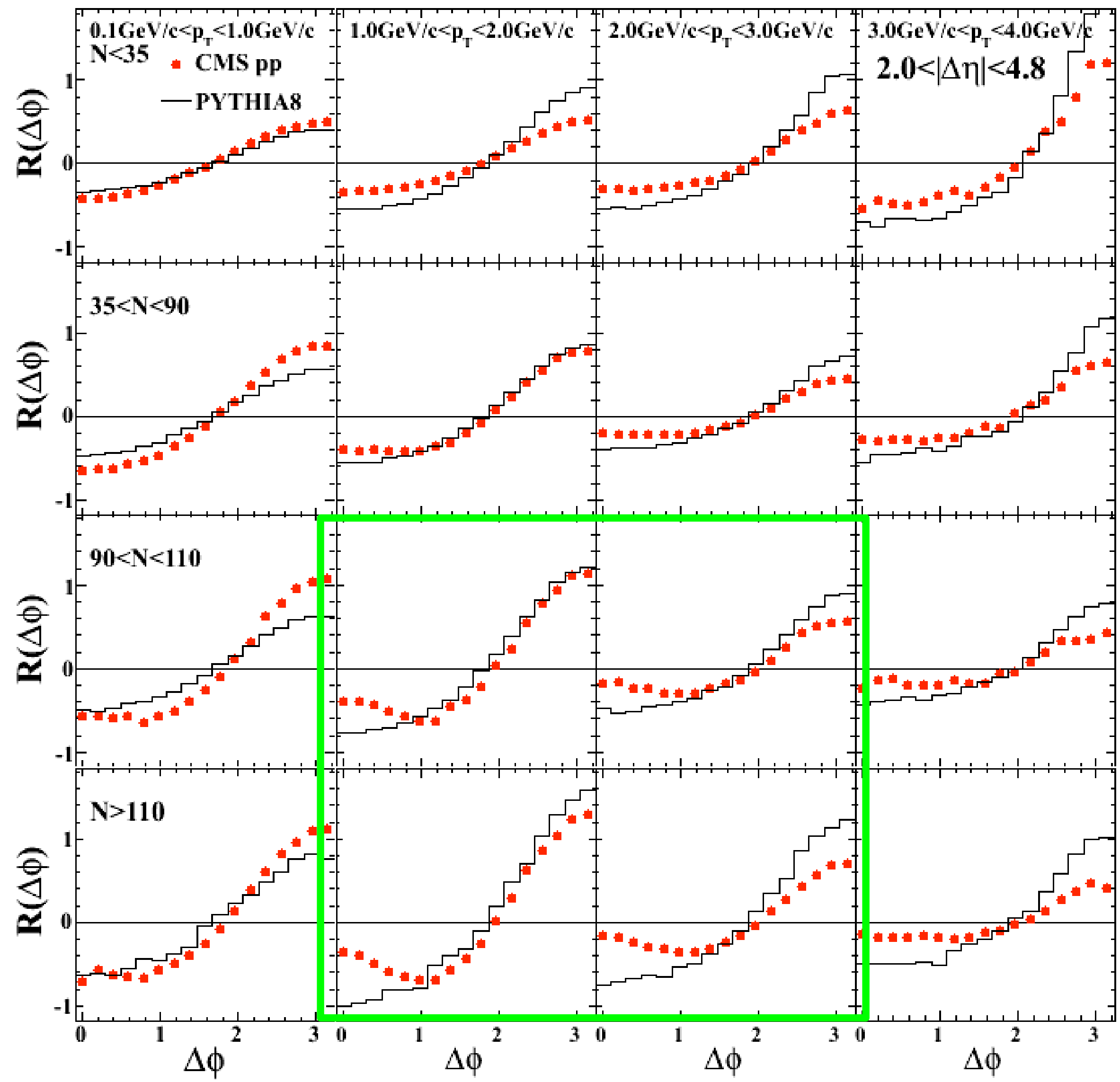
… not reproduced in PYTHIA 8 (and PYTHIA 6, HERWIG++, madgraph)

Multiplicity and p_T dependence



p_T range

Multiplicity



→ **Study dependence on p_T and multiplicity for $2 < |\Delta\eta| < 4.8$ for $R(\Delta\phi)$:**

$$R(\Delta\phi) = \left\langle (N-1)\left(\frac{\int_2^{4.8} S_N(\Delta\eta,\Delta\phi)\, d\Delta\eta}{\int_2^{4.8} B_N(\Delta\eta,\Delta\phi)\, d\Delta\eta} - 1 \right) \right\rangle_N$$

"Ridge" maximal for high multiplicity and intermediate p_T : $1 < p_T < 3$ eV/c

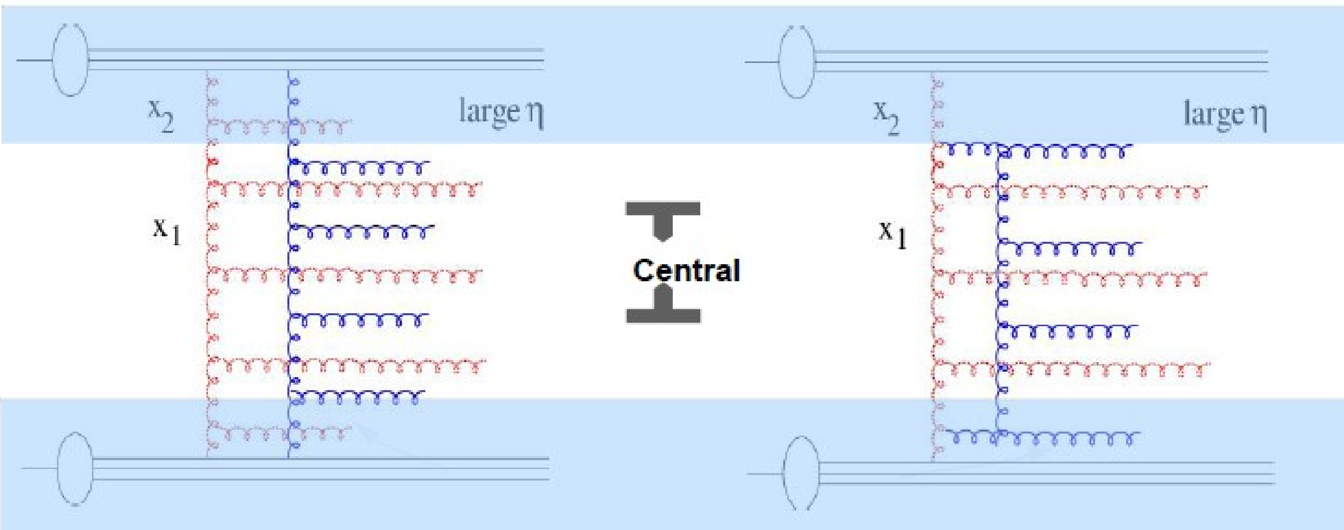
"Ridge" not reproduced by PYTHIA 8

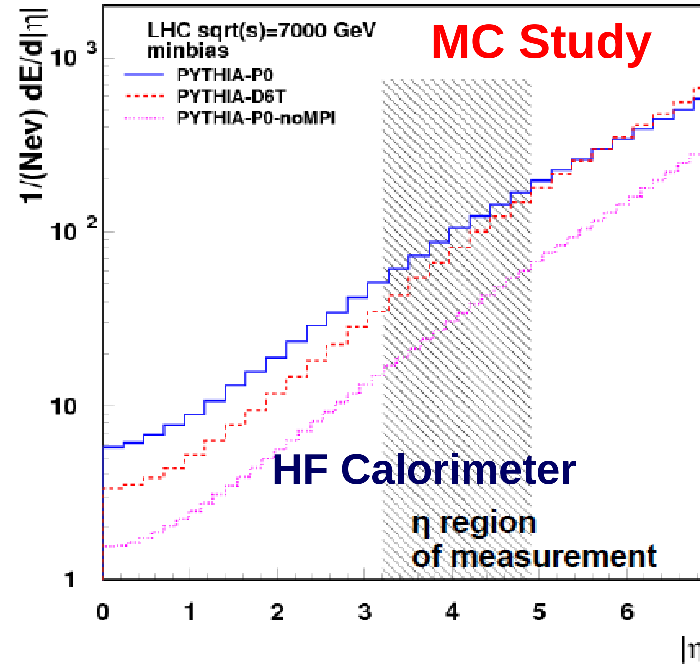
See talk by Sara Alderweireldt

Forward Energy Flow

CMS FWD-10-011 (Submitted to JHEP)

hep-ex: 1110.0181 (submitted EPJC)



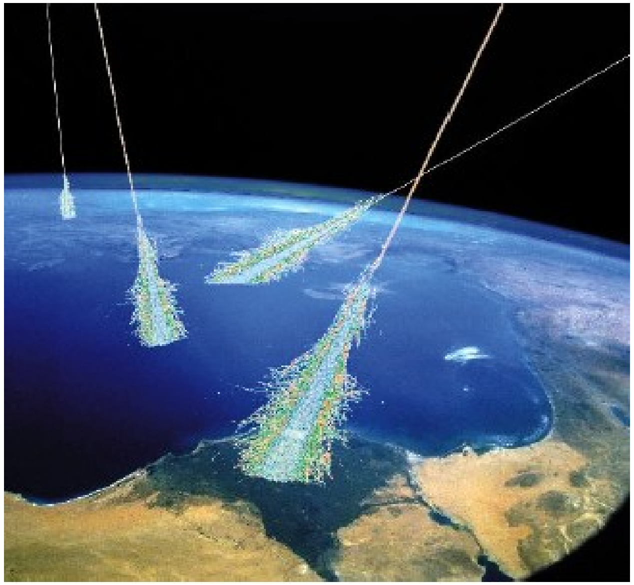


- High energy collisions - large parton densities important:
  → MPI, low x physics and possible saturation effects.

- Energy flow in the forward region
  → Information about color (re)connections to the proton remnant
  → High sensitivity to underlying events and important for the tuning of MC generators

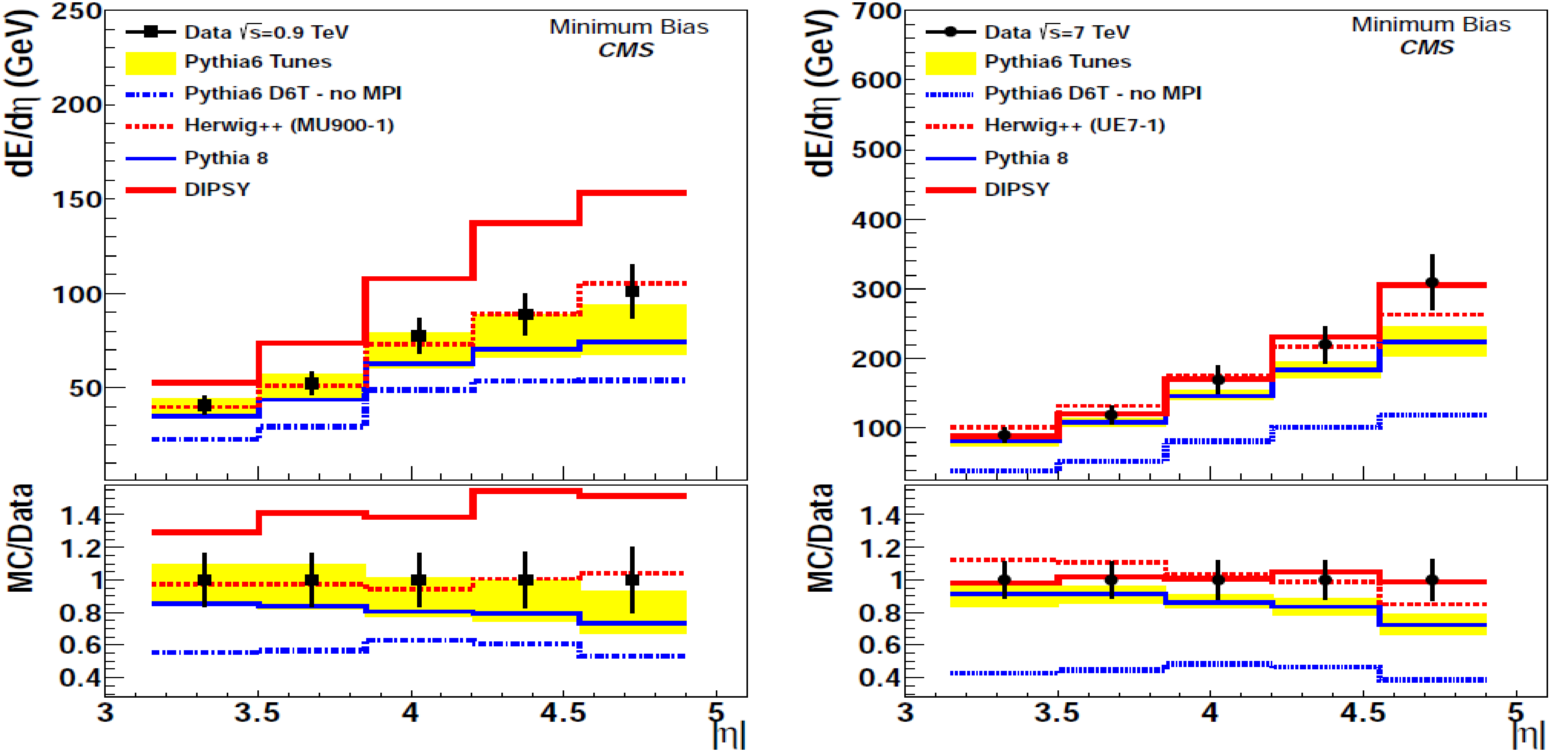
- Forward particle production important in air shower models
  → Majority of the energy carried by the forward particles

→ Test of cosmic ray MC: QGSJET, SIBYLL and EPOS



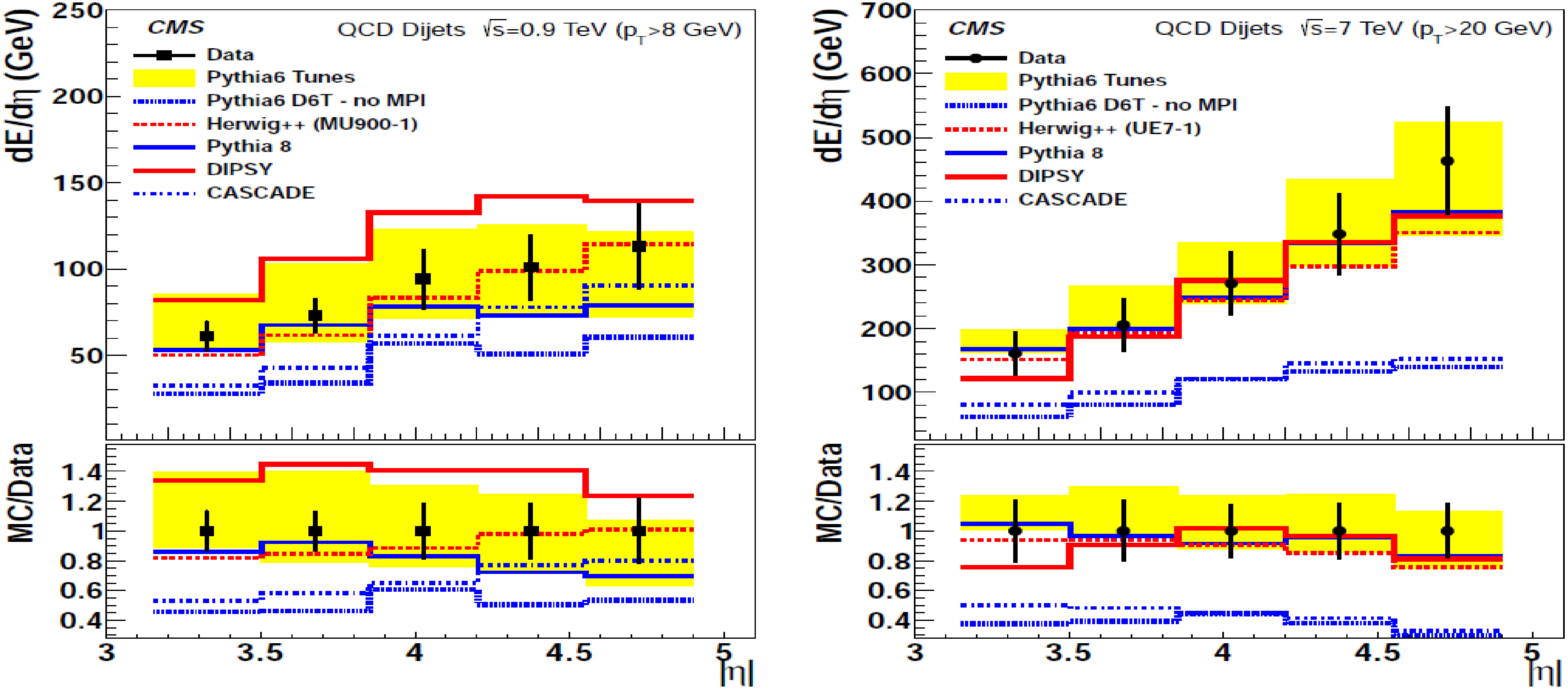
See posters by Niladri Sen and Ann-Karin Sanchez

Forward Energy Flow in Minimum Bias Events



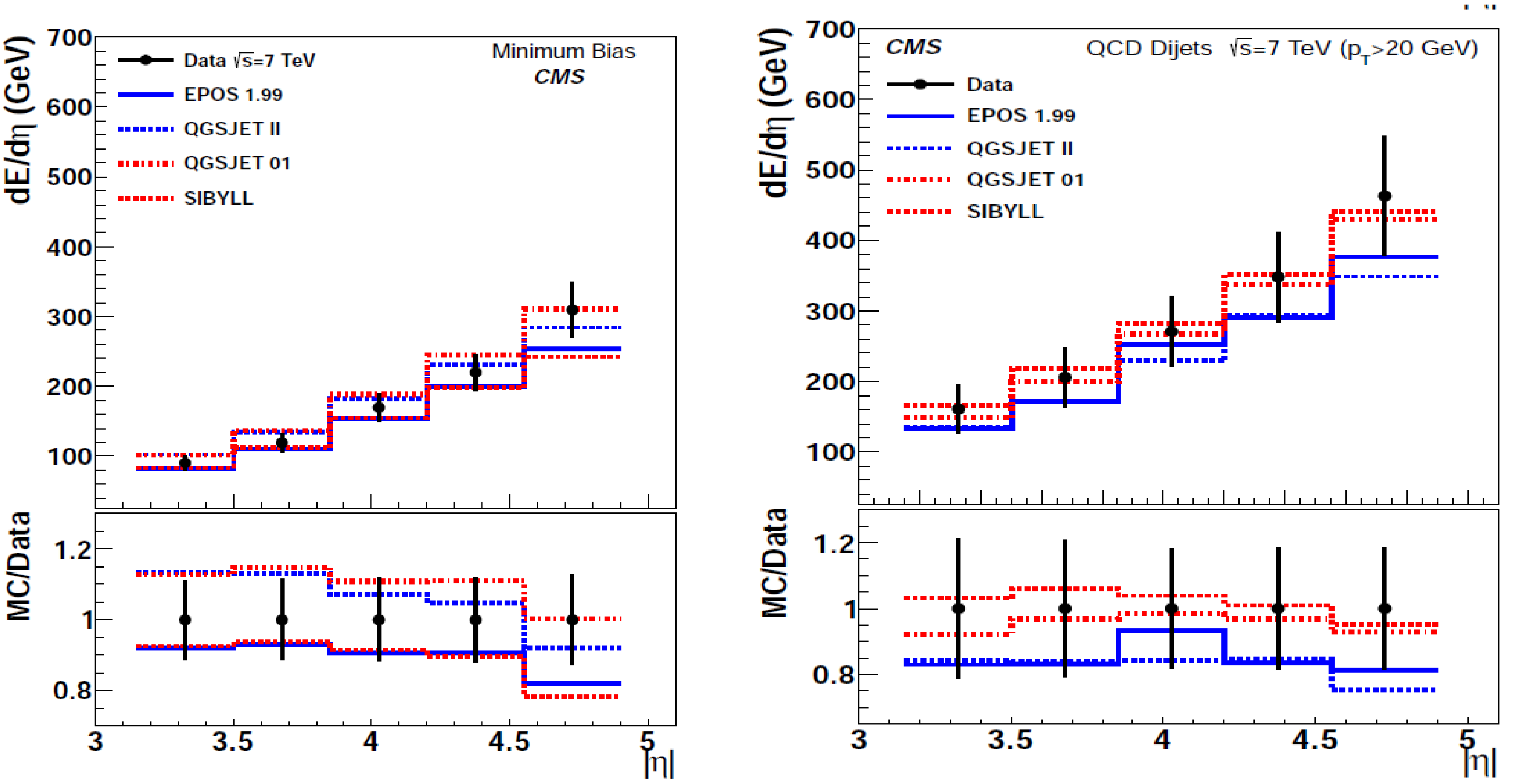
– Strong dependence of forward energy flow with $\sqrt{s}$ reproduced by all MC
– Strong contributions from MPI (PYTHIA6-no MI fails)
– PYTHIA 6 (Z2,CW,D6T,P0,..) and PYTHIA 8 with MPI fails at high η (color reconnection)
– HERWIG++ describes the data (but different tunes for both $\sqrt{s}$)

Forward Energy Flow in di-jet Events



– Significantly higher forward energy flow in dijets events than in MinBias
– Activity increase ~2-3 as collision energy change from 900 GeV to 7 TeV.
– Good description by PYTHIA6 and PYTHIA8
– MPI required: PYTHIA6-no MI & CASCADE failing
– HERWIG++ describes the data (but different tunes for both $\sqrt{s}$)
→ High sensitivity to MC and tunes

Forward Energy Flow: cosmic ray generator



Cosmic ray generators providing a good description of data

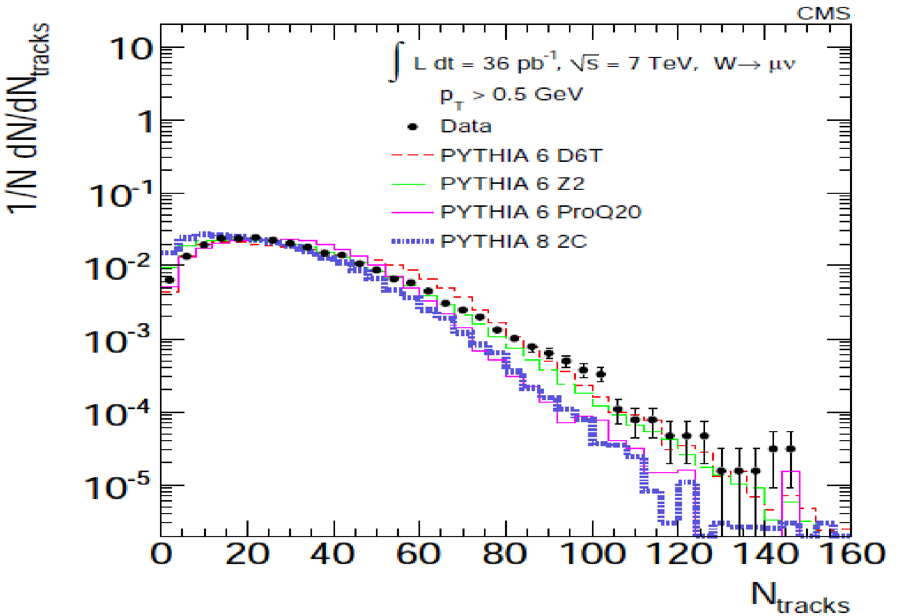
Forward Energy Flow in W/Z Events

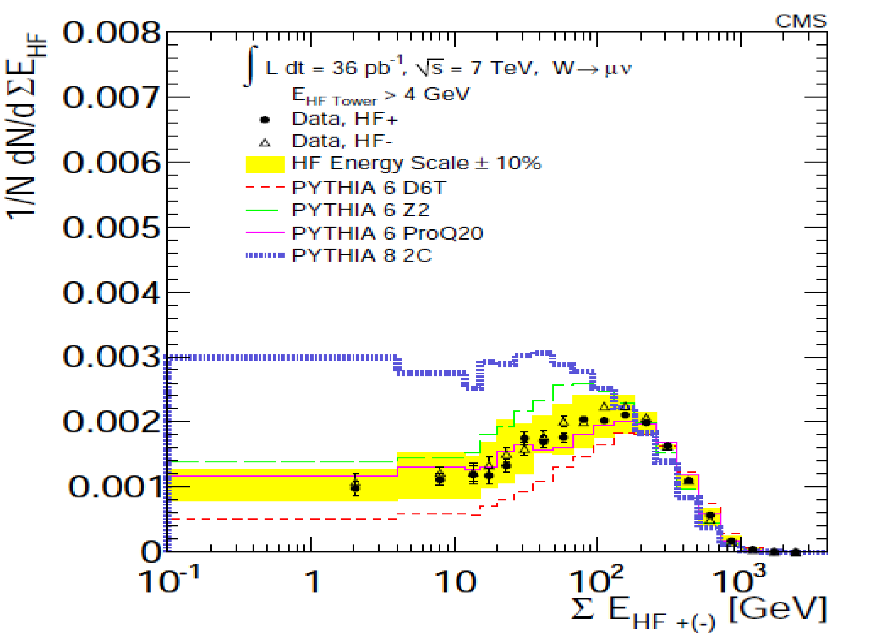
Correlation between central track multiplicity and energy deposit in forward region provide additional information for the understanding of MPI

– Identify the W and Z candidate with leptonic final state

– Central Track Multiplicity:
$p_T > 0.5$ GeV/c, 1 GeV/c
and $|\eta| < 2.5$ (excluding tracks from W/Z)

– Forward Energy: sum of tower deposit in HF with at least 4 GeV energy (to reduce the noise)

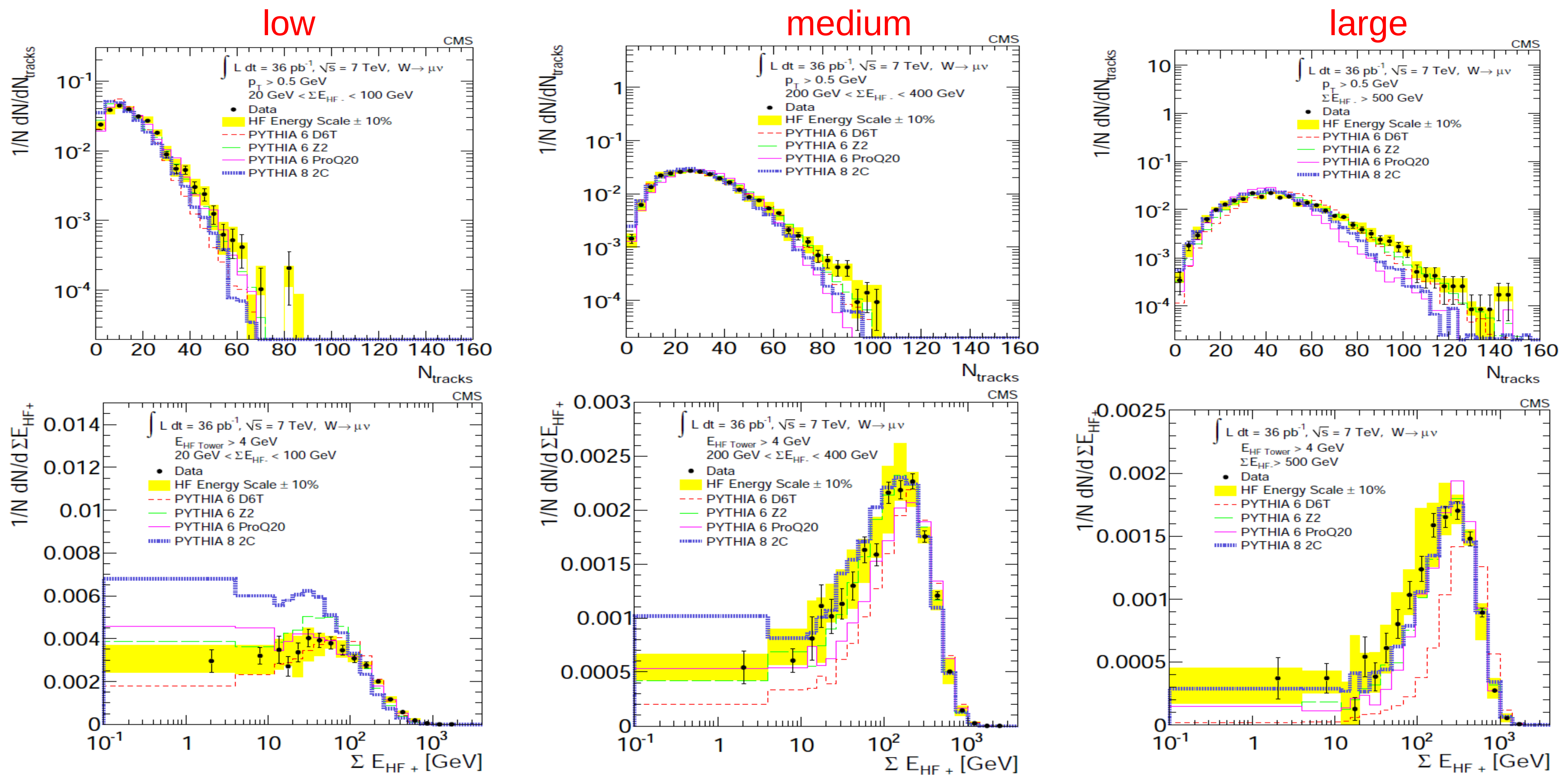




– Track multiplicity and forward energy is Sensitive to underlying event.
– Pythia6 Z2 provide good description of multiplicity
– large differences in small and large energy region

Forward Energy Flow in W/Z Events

Correlation between Forward Flow and Central Track Multiplicity



– track multiplicity, energy distribution in forward and backward region strongly correlated.

– energy spectra and correlations are not well modeled.

Summary

- Charged particle spectra measured at various energies.
- Missing strangeness in MCs.
- Unexpected long range correlation (similar to heavy-ion collisions). MCs don't describe this observation.
- Underlying Event:

  → important to understand the UE modeling for precision measurements and new physics searches.

  → measurement performed at various energies and with different processes.
- Forward Energy Flow: important for understanding of the MPI and low-x physics. Energy flow measured using various processes i.e MinBias, dijet, W/Z.

Many measurements are available and large MC tuning effort going on to describe these measurements