CMS results on soft QCD and multi-parton interactions

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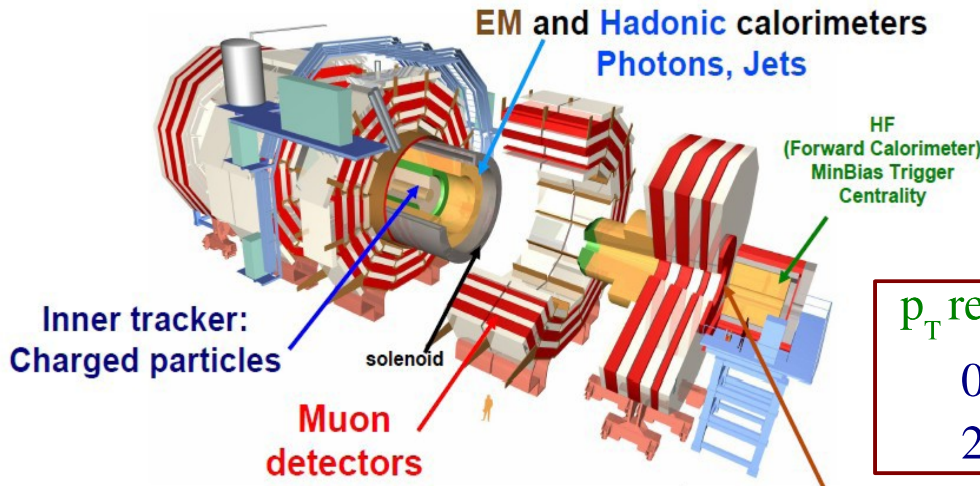
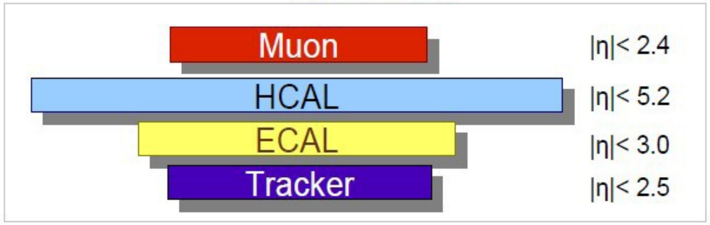
on behalf of CMS Collaboration

Low X Meeting
Cyprus, June 27- July 1, 2012

CMS Experiment

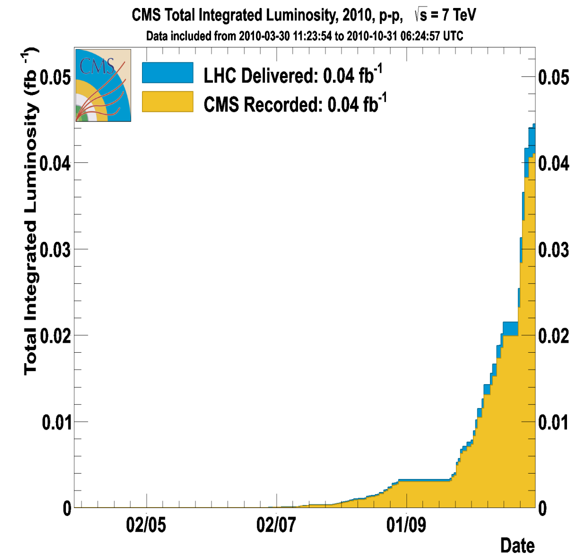




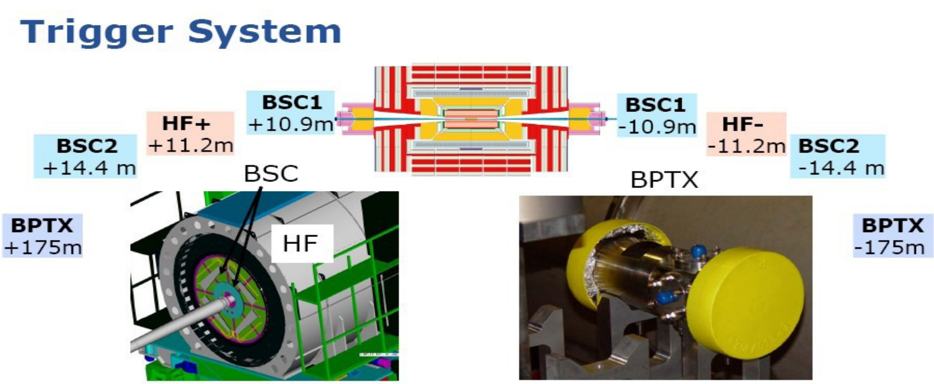
p_T resolution @ 1 GeV/c:

0.7% at $\eta = 0$

2.0% at $|\eta| = 2.5$



Most of the 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!

Measurement of inelastic pp cross-section

CMS PAS-FWD-11-001
CMS PAS-QCD-11-002

→ Important for luminosity estimate, cosmic ray physics, characterization of centrality in heavy ion collisions.

→ Precise phenomenological description for low energy cross-section but large uncertainty in extrapolation.

→ Using forward calorimetry (HF), measurement is performed for limited $\xi \equiv M_x^2/s > 5E\text{-}06$.

$$\sigma_{\text{inel}}(\xi > 5 \times 10^{-6}) = \frac{N_{\text{inel}}(1 - f_\xi)F_{\text{pileup}}}{\mathcal{L}\epsilon_\xi}$$

→ Model dependent extrapolation to full ξ range.

→ An alternative approach based on assumption that pile-up events are distributed according to Poisson probability.

$$P(n) = \frac{(L \cdot \sigma)^n}{n!} e^{-L \cdot \sigma}$$

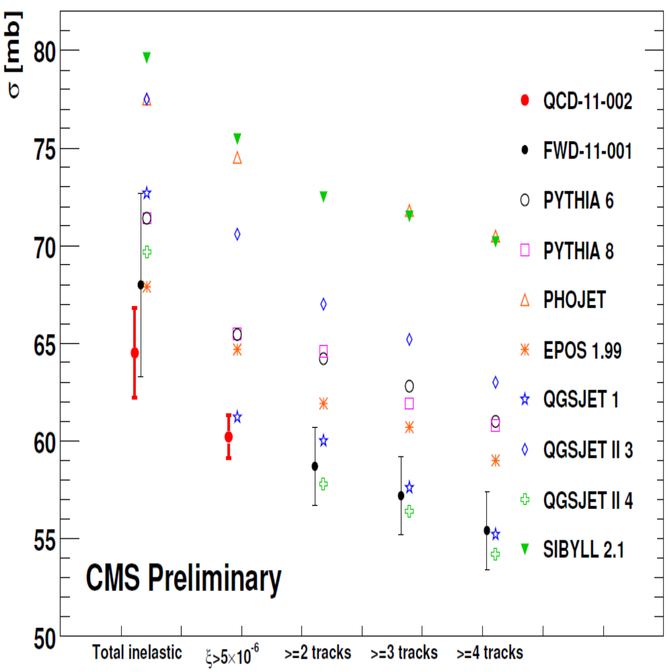
→ Number of Inelastic pile-up events measured at different lumi. and fitted to evaluate σ.

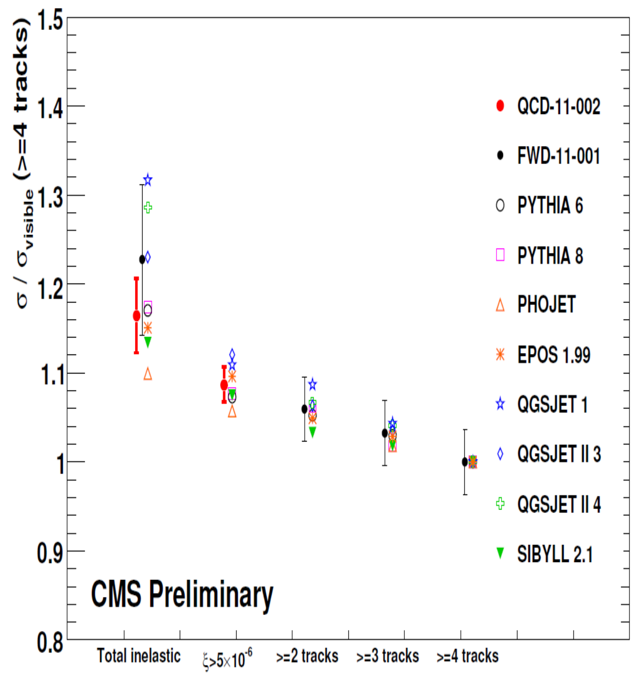
Measurement of inelastic pp cross-section

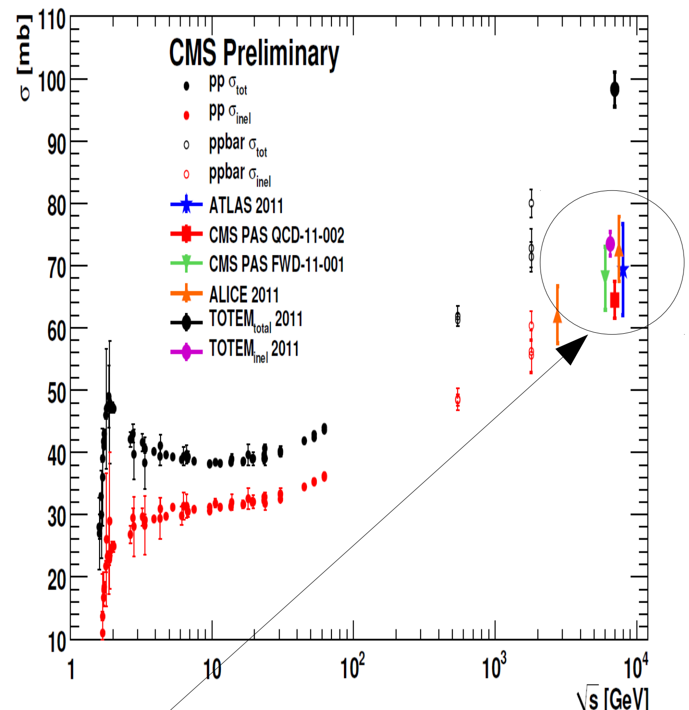
$$\sigma_{\mathrm{inel}}(\xi > 5\times10^{-6}) = 60.2 \pm 0.2(\mathrm{stat.}) \pm 1.1(\mathrm{syst.}) \pm 2.4(\mathrm{lumi.})\ \mathrm{mb}$$

Extrapolated cross-section:

$$\sigma_{\mathrm{inel}} = 64.5 \pm 0.2(\mathrm{stat.}) \pm 1.1(\mathrm{syst.}) \pm 2.6(\mathrm{lumi.}) \pm 1.5(\mathrm{extr.})\ \mathrm{mb}$$







→ Normalization vary widely for different models, but trend is similar for all models.

→ Measured cross-section follow the increasing trend established by previous measurement.

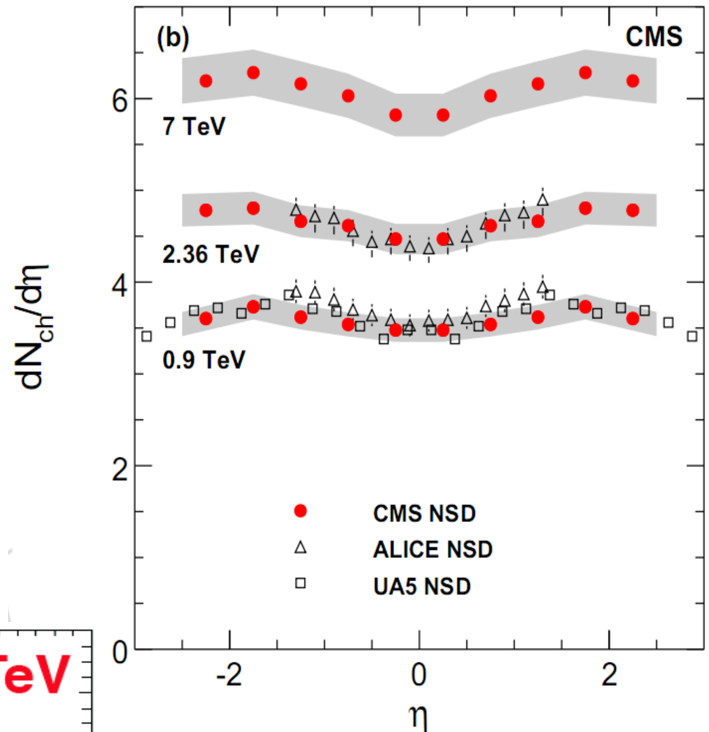
→ Results are in good agreement between different approach and experiments.

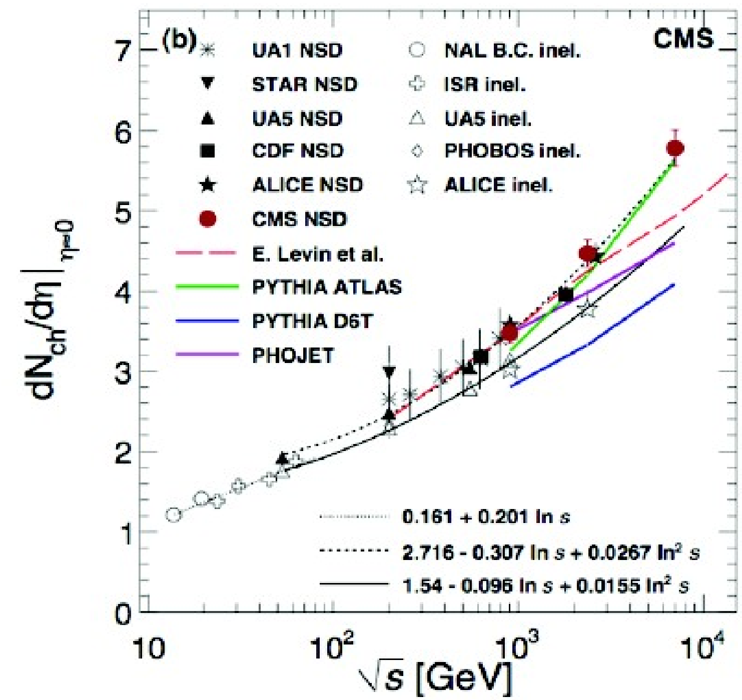
Single Charged Particle Spectra: dN/dη

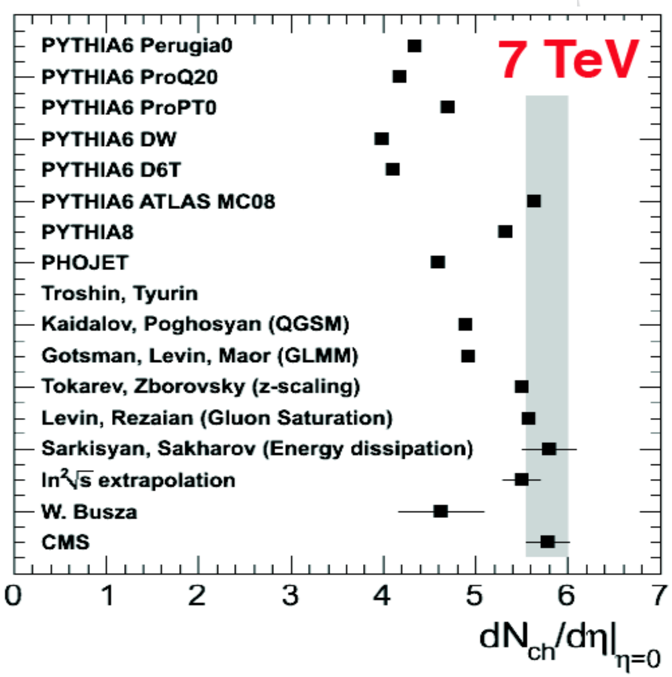
JHEP 02 (2010) 041
PRL 105 (2010) 022002
CMS QCD-10-008

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

Charged Particle Selection:
- |η| < 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

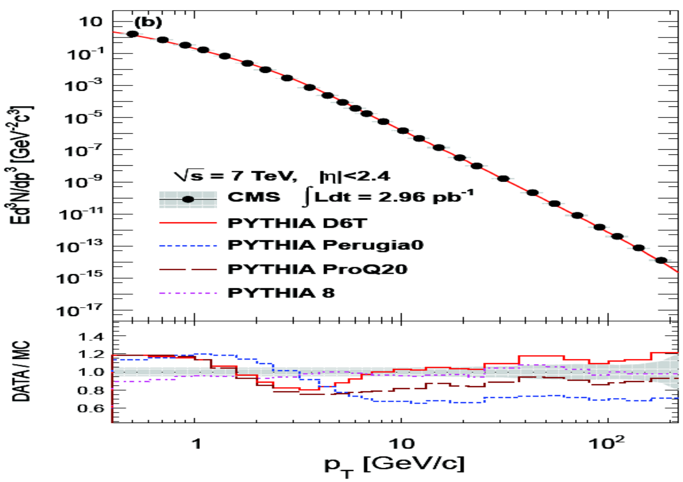
JHEP 02 (2010) 041
PRL 105 (2010) 022002
JHEP 08 (2011) 086

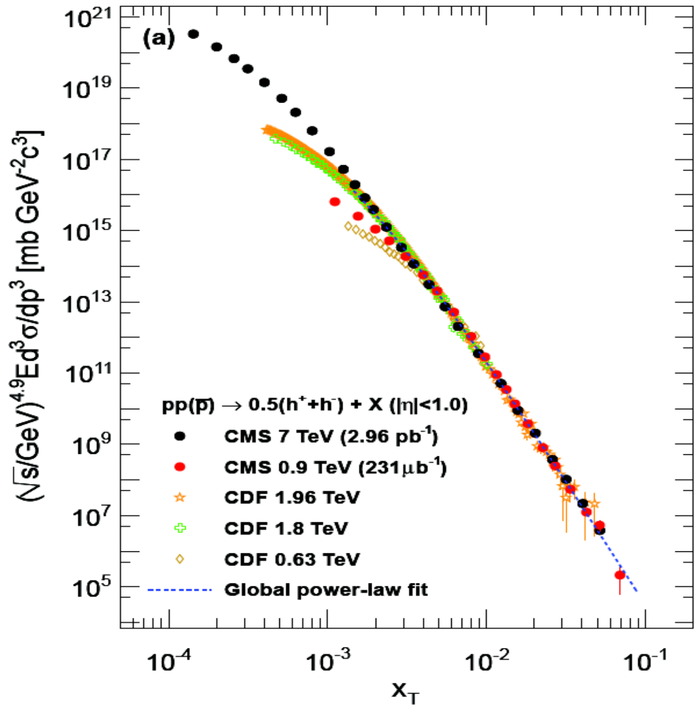
Event Selection:

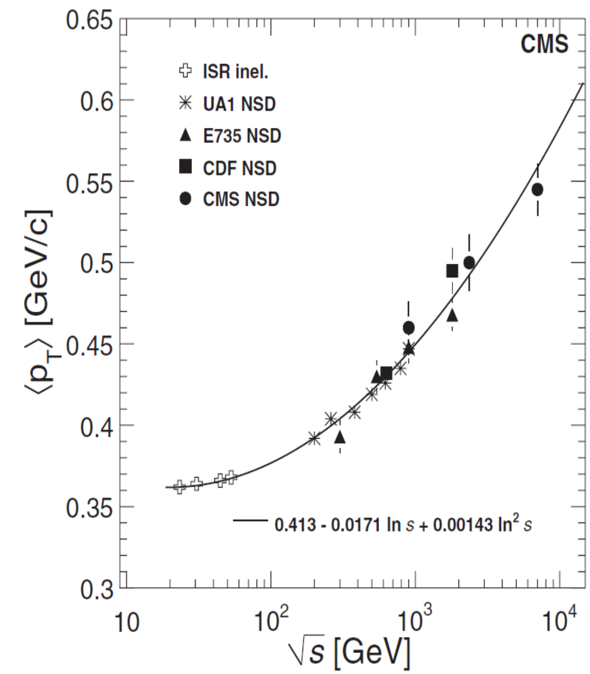
- MinBias trigger (BSC) + Jet trigger
- At least 3 GeV in both HF
- primary vertex

Charged Particle Selection:

- $|\eta| < 2.4$, $p_T > 0.1$ GeV/c

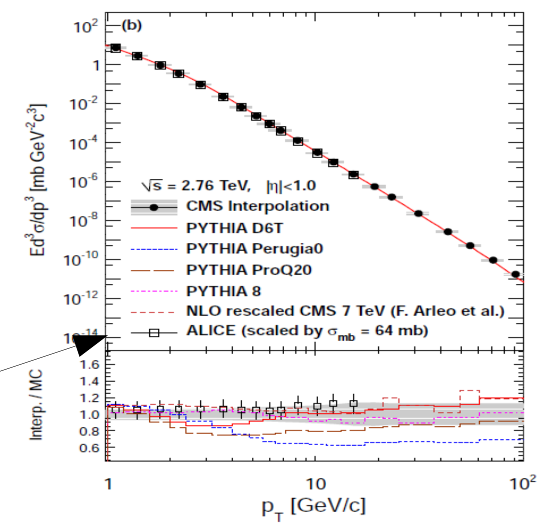






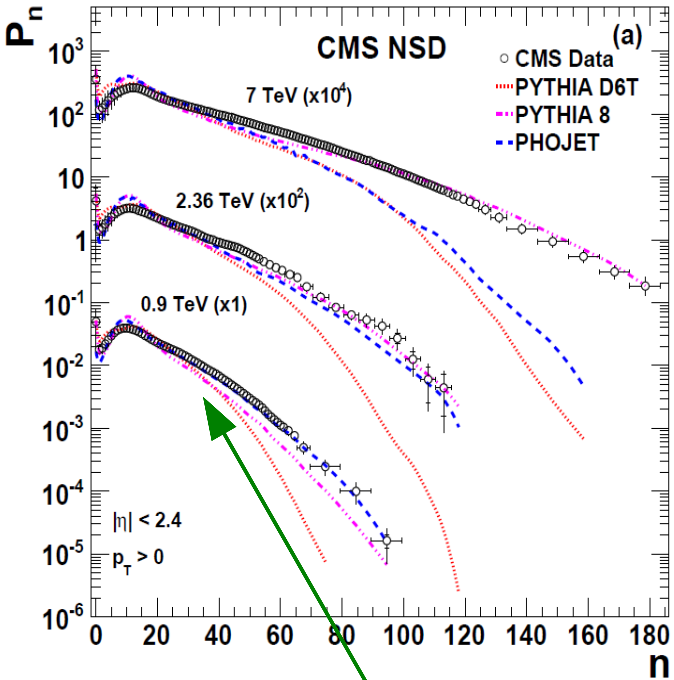
$$E\frac{d^3\sigma}{dp^3} = F(x_T)/p_T^{n(x_T,\sqrt{s})} = F'(x_T)/\sqrt{s}^{n(x_T,\sqrt{s})}$$

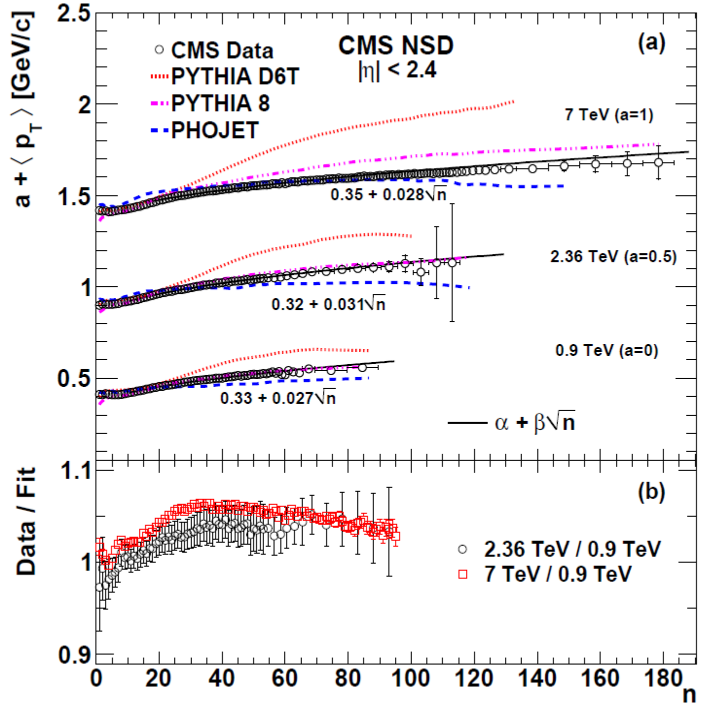
- Empirical $x_T = 2\,p_T/\sqrt{s}$ scaling unifies the differential cross sections from a wide range of collision energies onto a common curve at high x_T
  - → Interpolated (x_T and p_T scaling) data provides a reference for PbPb studies of nuclear modification factors at LHC for $\sqrt{s_{NN}}$=2.76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

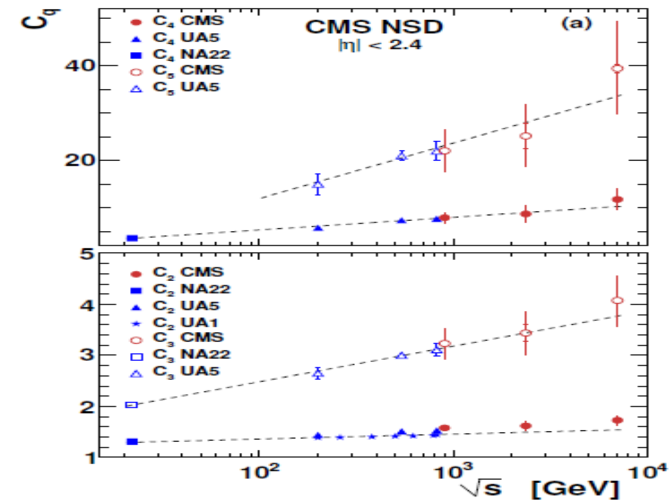


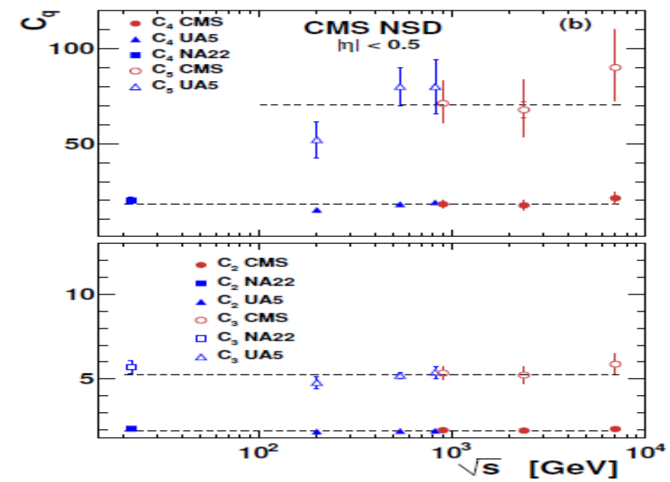
Charged Particle Multiplicities

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)

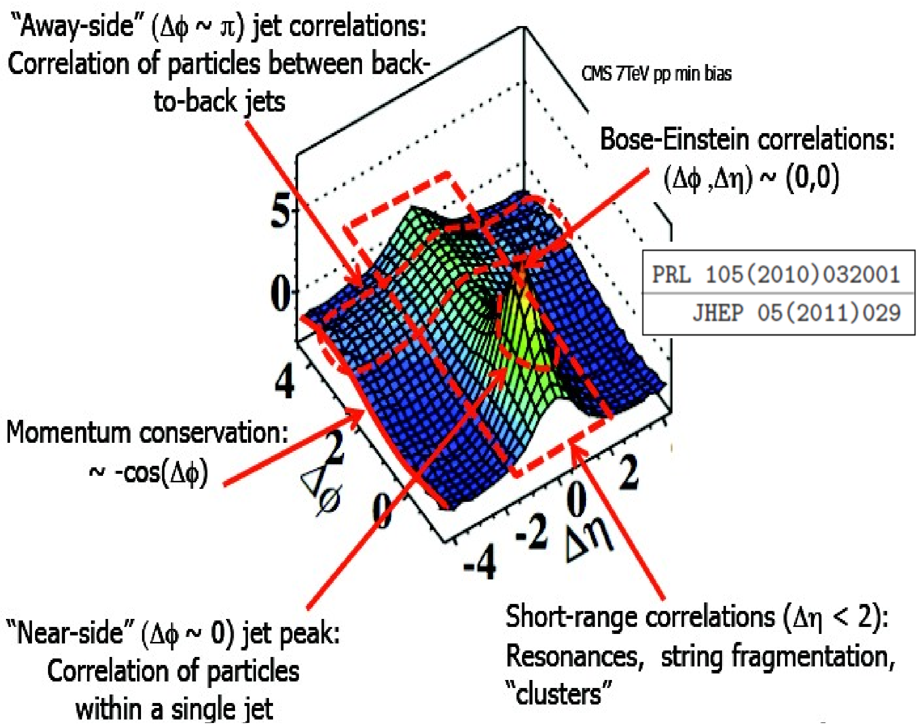
KNO scaling: violate for |η| < 2.4
hold for |η| < 0.5

Two-particles correlation in Δη and Δφ

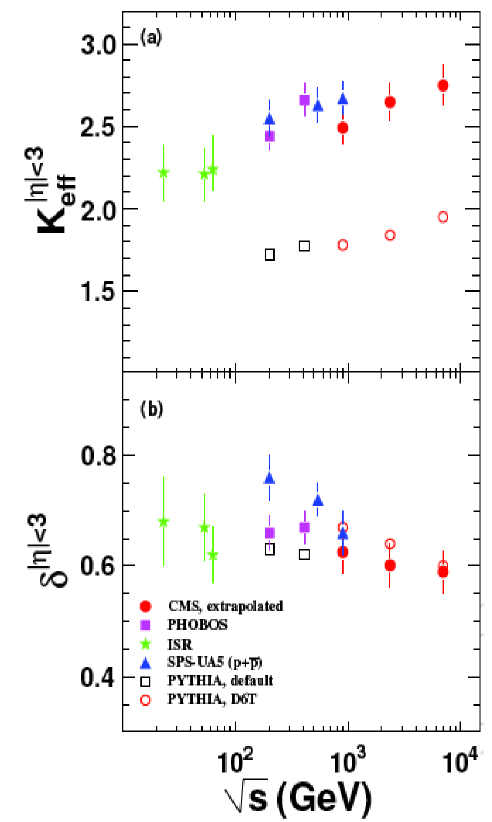
JHEP 09 (2010) 091

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

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



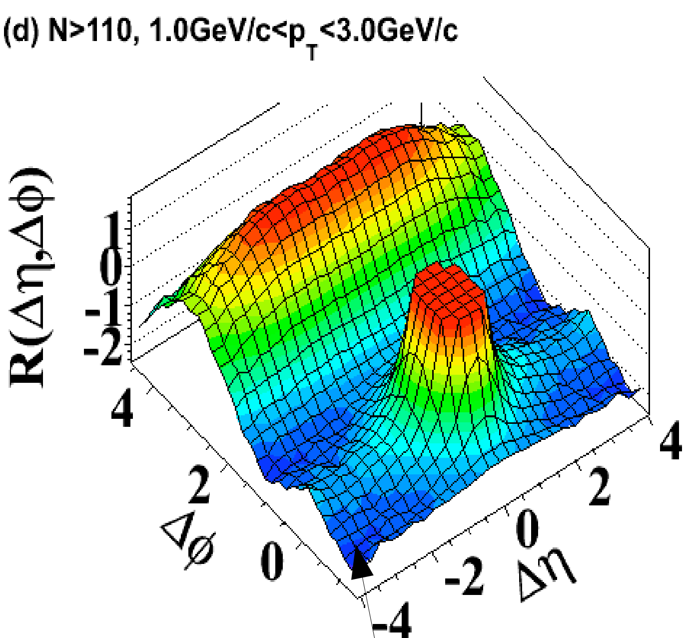
- K_{eff} increase with $\sqrt{s}$ (more jets at high $\sqrt{s}$?)
- δ constant with $\sqrt{s}$ (isotropic cluster decay)
- CMS results follow trend from lower $\sqrt{s}$ data
- PYTHIA (D6T) shows similar energy dependencies for K_{eff} and δ as data
- PYTHIA (D6T) predicts too low K_{eff}

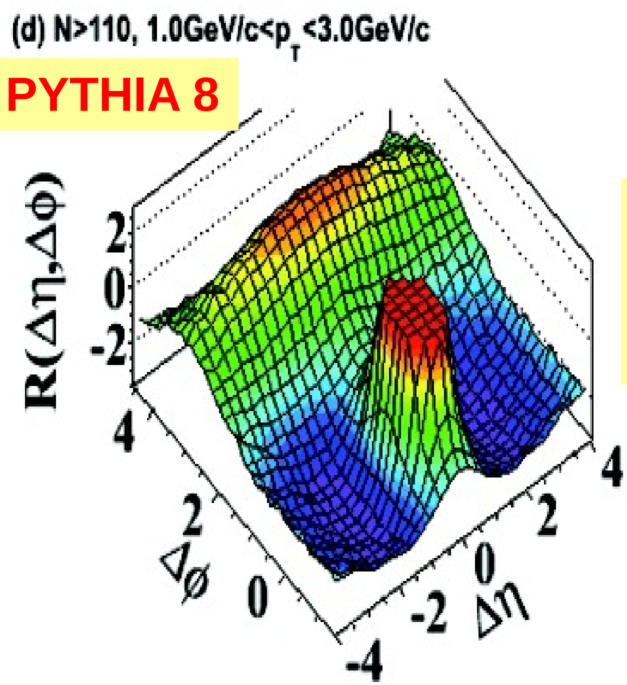


– Clusters are produced independently and decay isotropically into hadrons in its own c.m.s.
– Short range correlations in Δη can be characterized by 2 parameters:
– cluster size K → # correlated particles
– cluster width δ → Δη correlation size

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

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





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

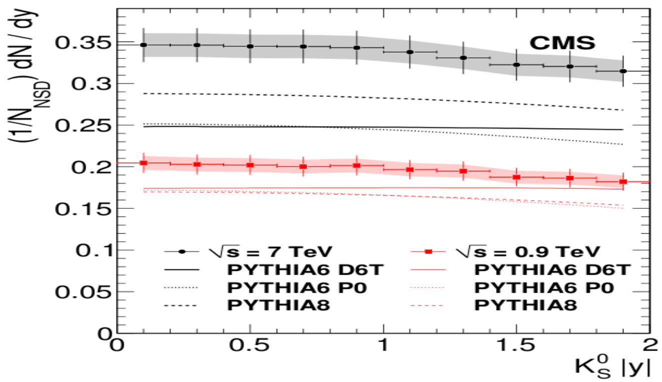
→ **Observation of a Long-Range, Near-Side angular correlations at high multiplicity in pp events at intermediate p_T (Ridge at $\Delta\phi \sim 0$)**

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

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

JHEP 05(2010)064

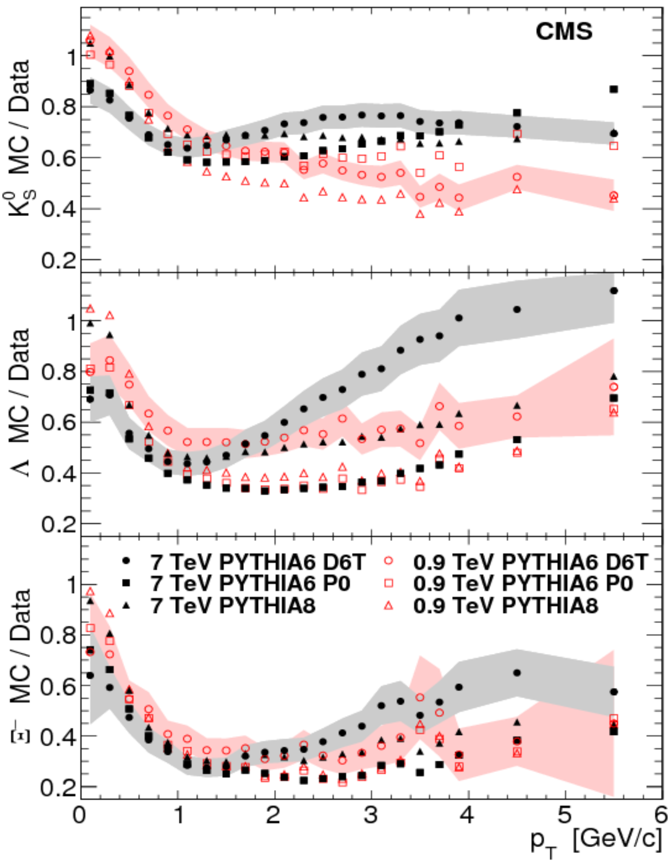
K0 , Λ , Ξ⁻: long-lived particles (cτ > 1 cm) identified from their decay products originating from a displaced vertex.

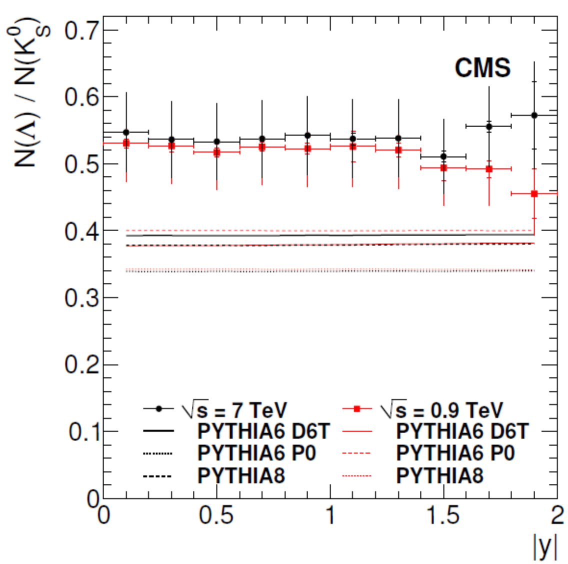


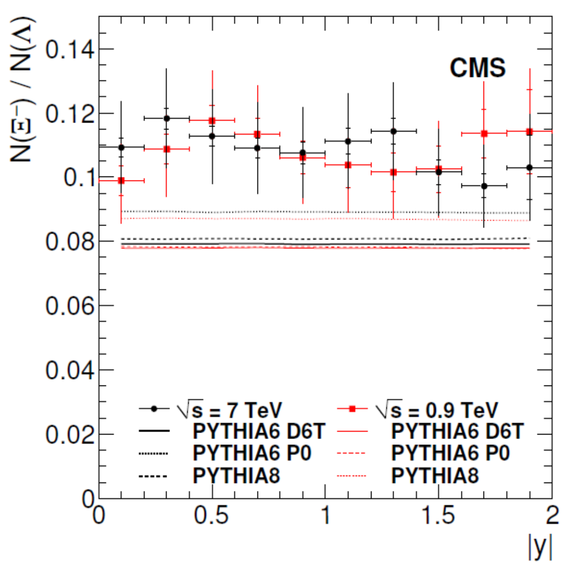
- the amount of strangeness suppression (w.r.t. u and d quarks) is an important component in MC models
- interesting for new physics (e.g. strange enhancement in QGP formation)

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





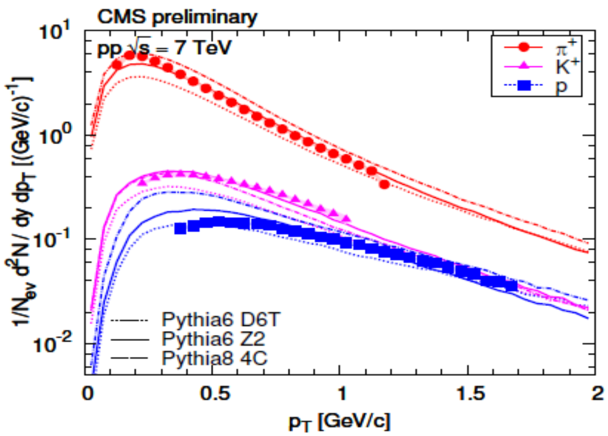


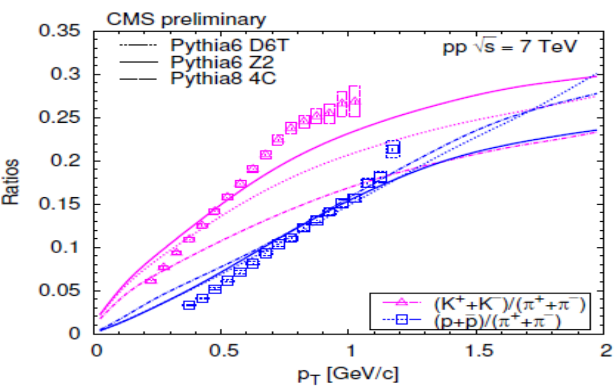
MC underestimating total yield (both √s 0.9 and 7TeV) and √s scaling

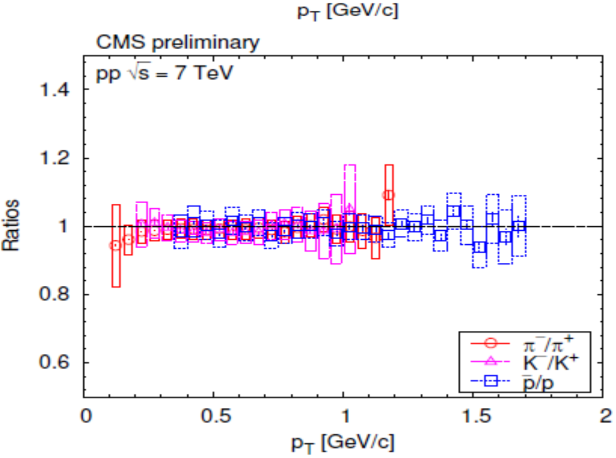
Spectra of charged pions, kaons and protons

CMS PAS-FSQ-12-014

→ charged pions, kaons and protons are identified by measuring energy loss in tracker







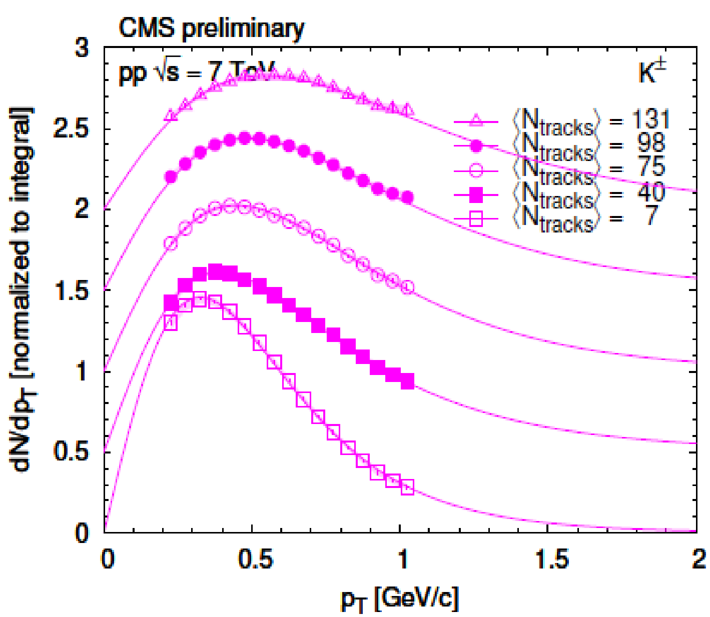
→ Z2 tune describe the measurement (except at low p_T), D6T and 4C systematically undershoot and overshoot the spectra.

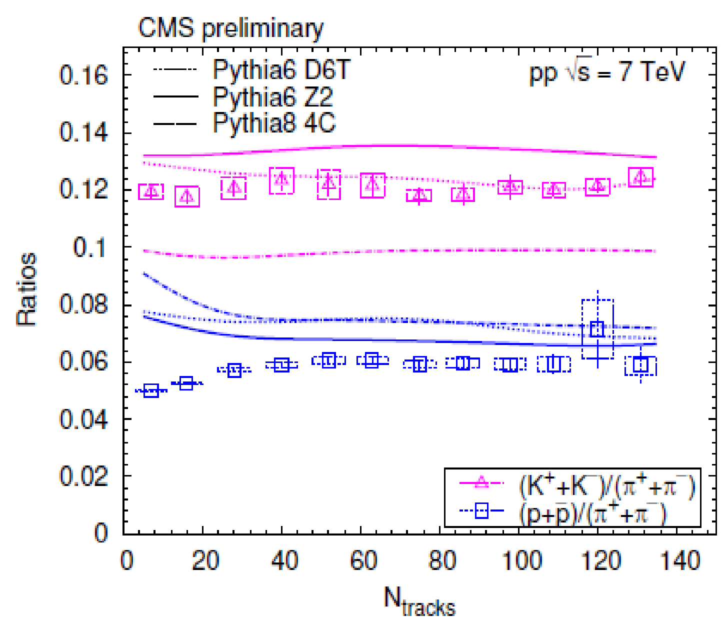
→ p/π described by all tunes but there is substantial deviation for K/π. Ratio of +ve and -ve particles is around one as expected.

→ p_T spectra for pions is similar for different multiplicity and √s, whereas for kaons and proton there is clear evolution with track multiplicity.

→ K/π and p/π ratios are flat as a function track multiplicity and well described by D6T and Z2 tune.

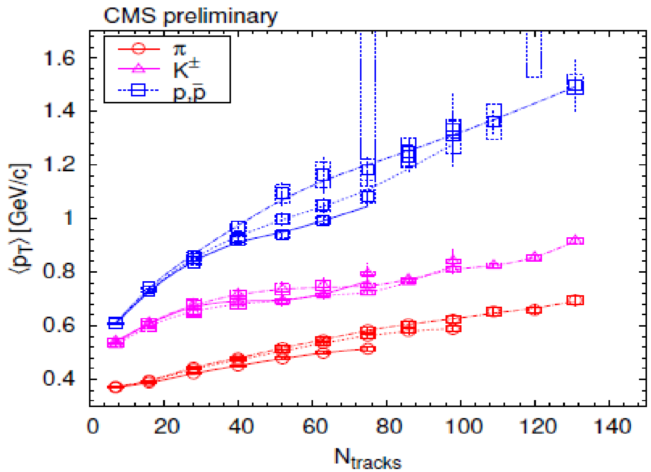
→ Ratios of +ve and -ve charged particle as a function of track multiplicity is also flat and is ~1.



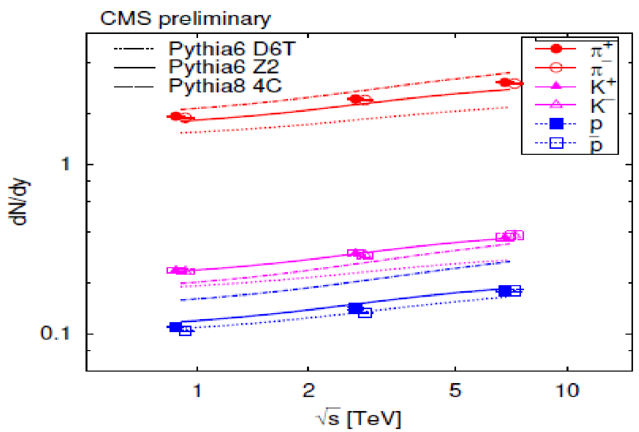


Spectra of charged pions, kaons and protons

CMS PAS-FSQ-12-014

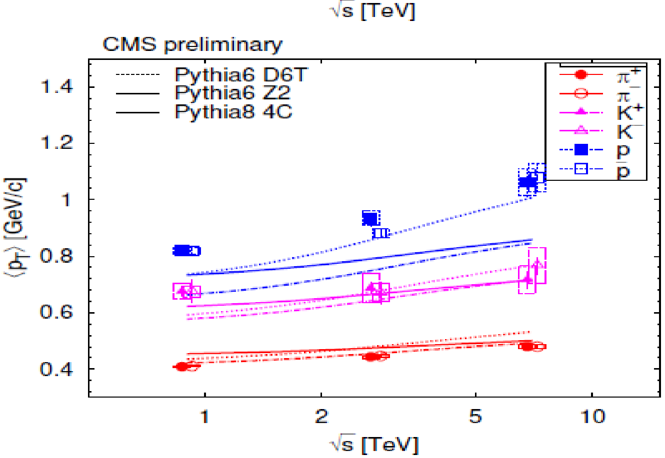


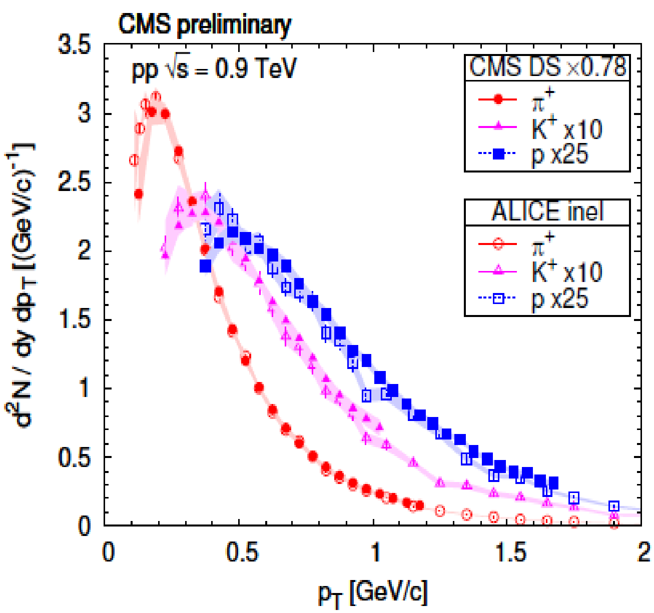
→ $\langle p_T \rangle$ and particle ratios as a function of track multiplicity is independent of $\sqrt{s}$.

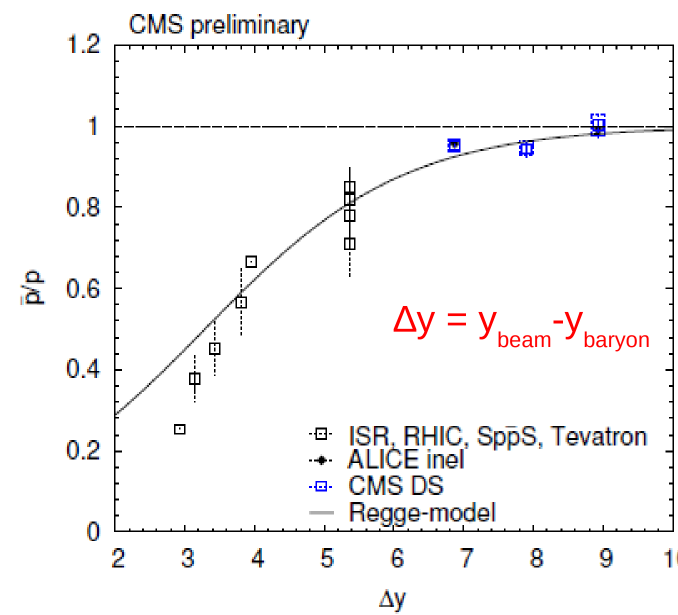


→ $\sqrt{s}$ dependence of dN/dy is well described by Z2 tune whereas $\langle p_T \rangle$ evolution with $\sqrt{s}$ is not described by any of the tune for all particles simultaneously.

→ There is nice agreement with ALICE measurement at 0.9 TeV but small difference for protons.





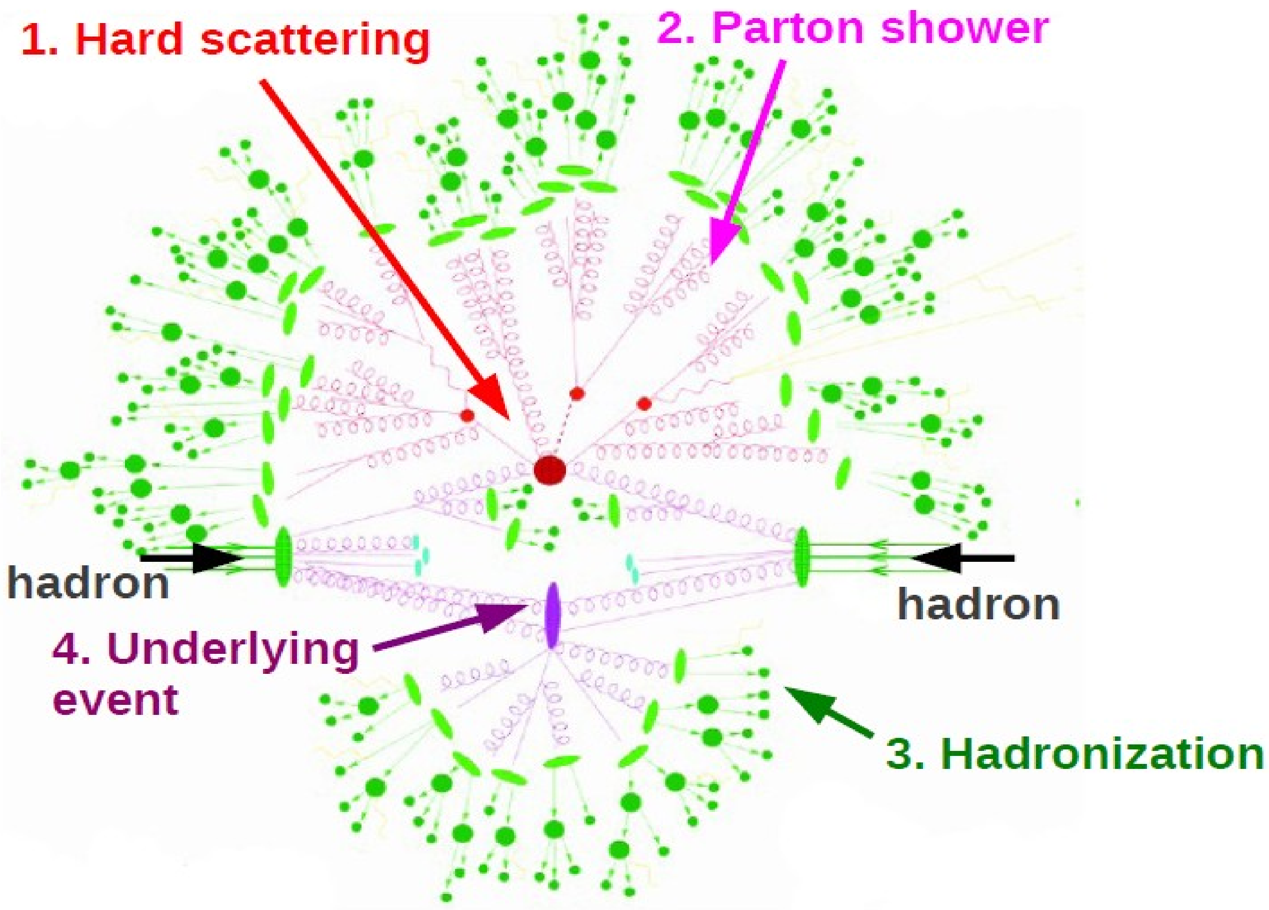


→ pbar/p ratio as a function of Δy follows the previous measurements and is described by Regge-Model.

The Underlying Event

EPJ C70 (2010) 555
JHEP09 (2011) 109
arXiv:1204.1411
CMS PAS-FWD-11-003

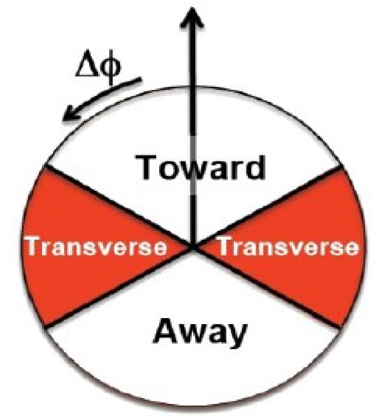
Everything except the hard scattering:
UE = MPI +BBR (+ ISR and FSR contamination)



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

The Underlying Event

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

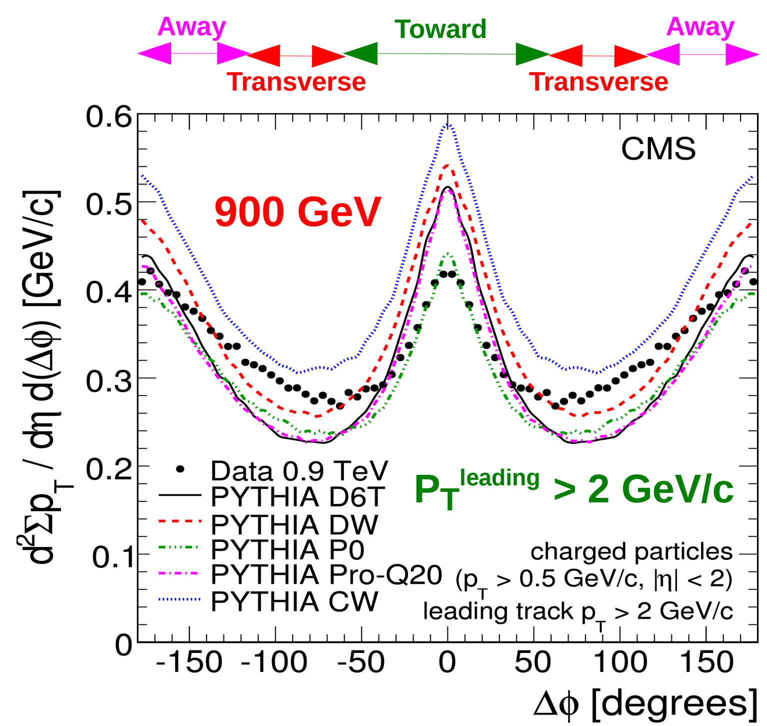


Identify in the event an energy scale (and direction) reflecting the hard scattering:

- → 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



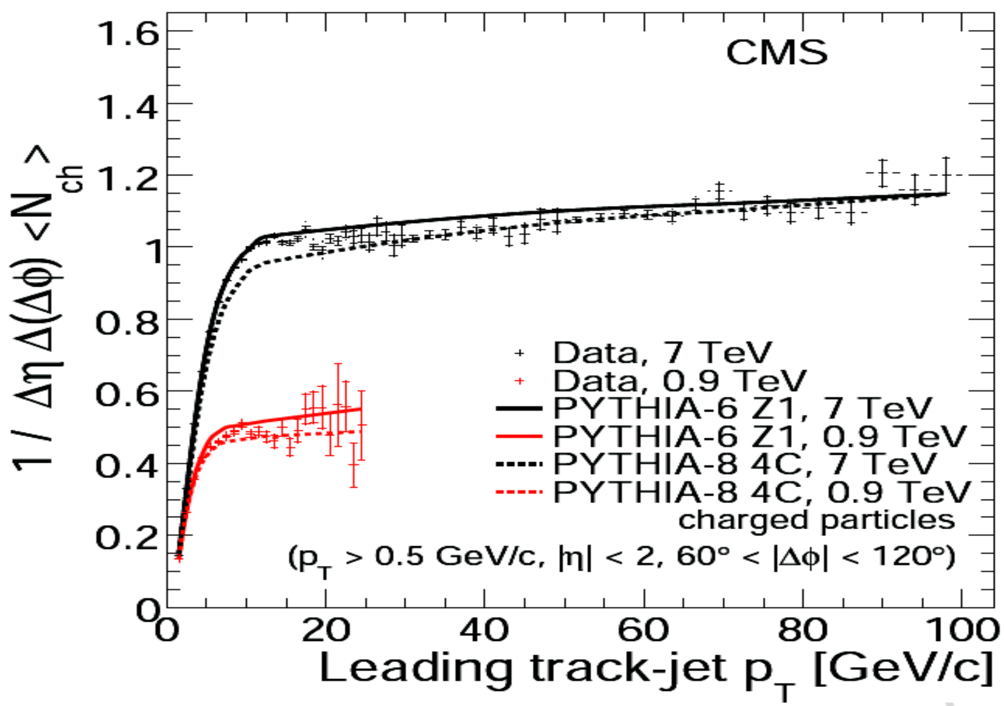
Observables built from charged particles:

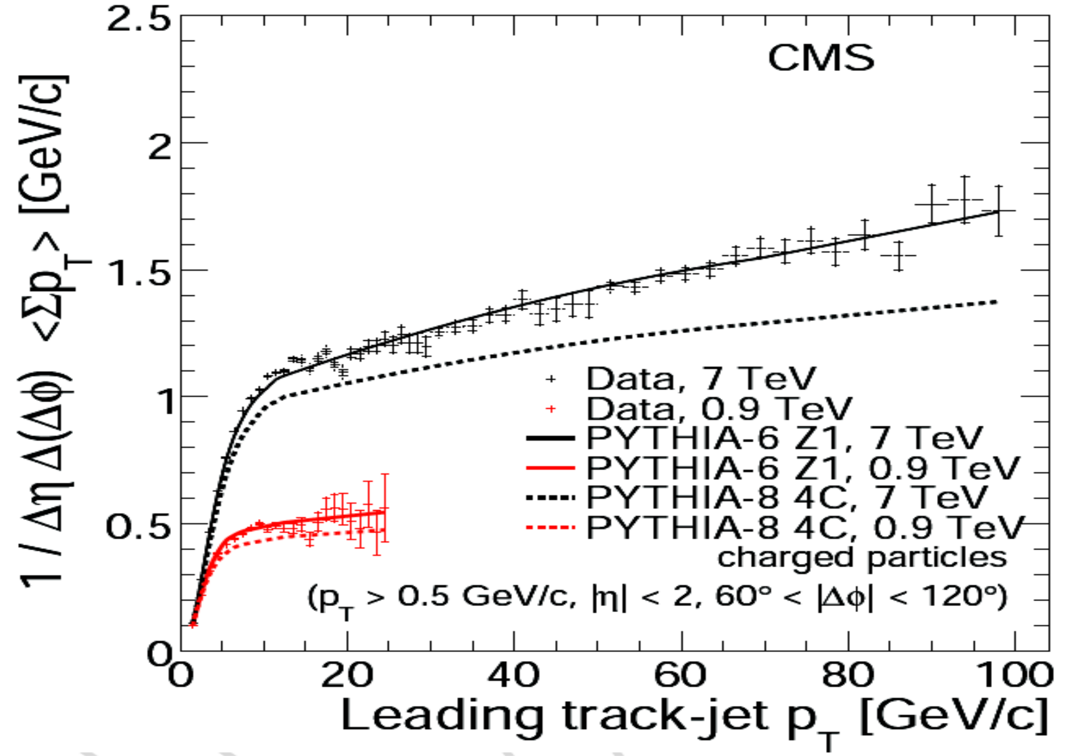
$d^2 N_{chg} /d\eta\, d(\Delta\phi)$: charged multiplicity density

$d^2\Sigma\, p_T /d\eta d (\Delta\phi)$: 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.



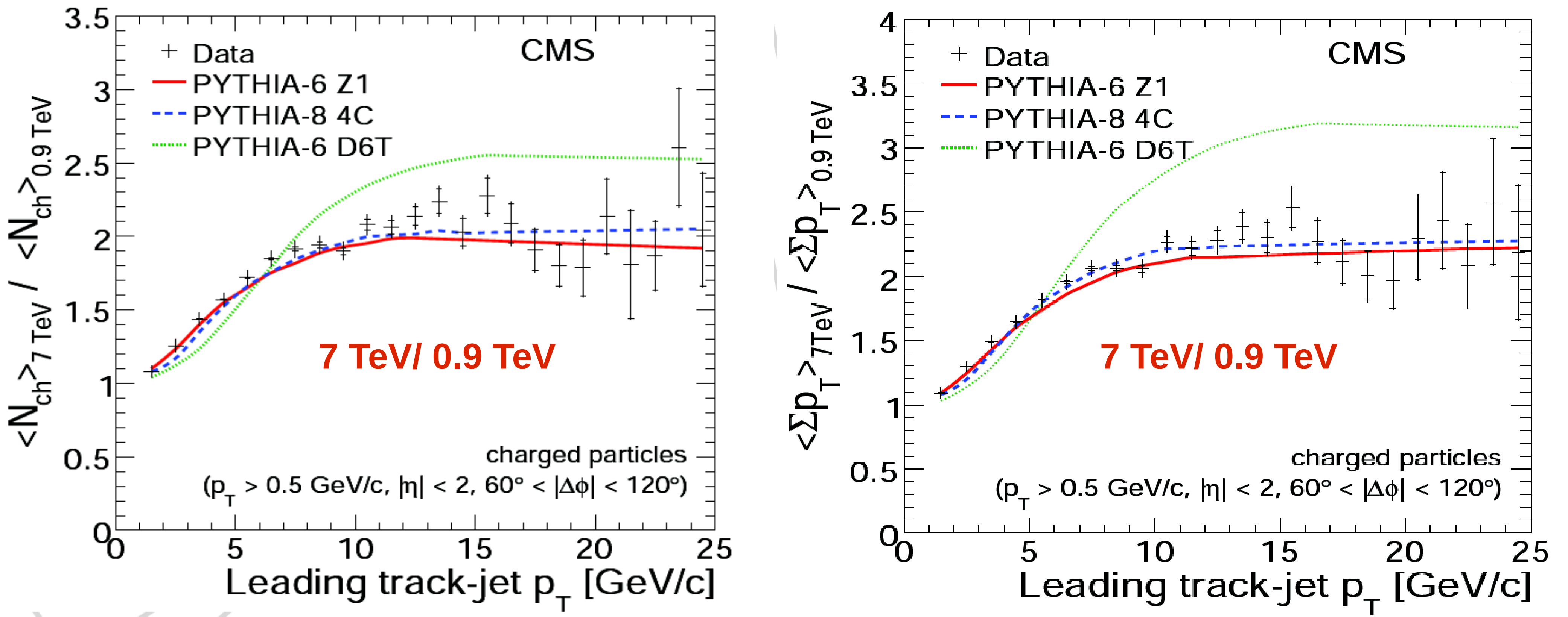


– Fast rise for pT < 8 GeV/c (4 GeV/c), attributed mainly to the increase of MPI activity, followed by a plateau-like region with ≈ constant average number of selected particles and a slow increase of ΣpT, in a saturation regime.

– Increase of the activity with √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

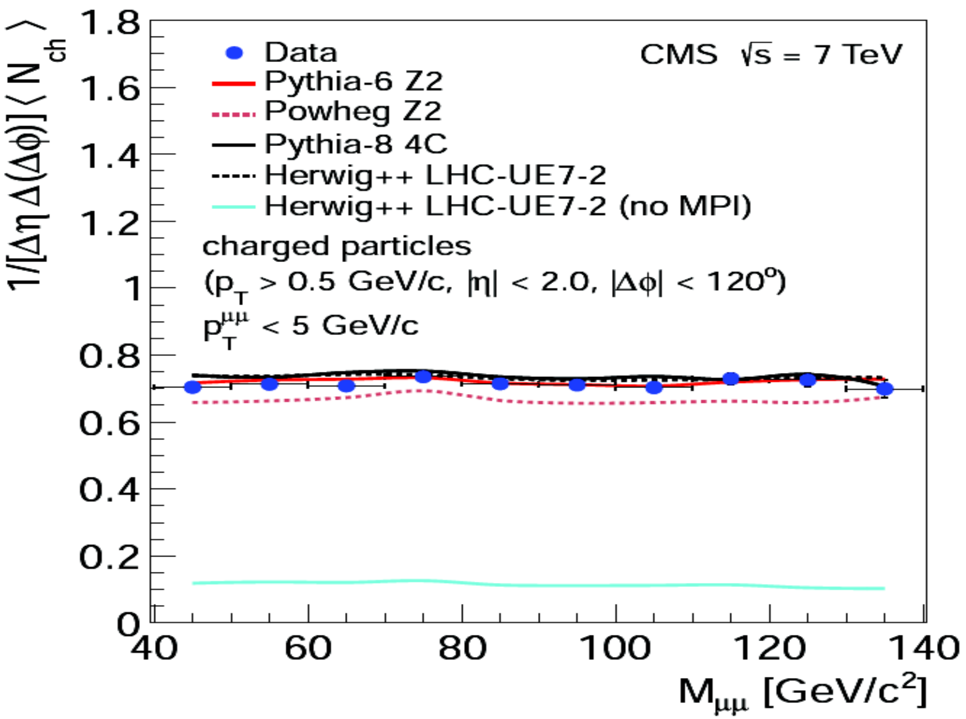
– A factor 2 going from 900 GeV to 7 TeV to be compared with 1.7 for MB.

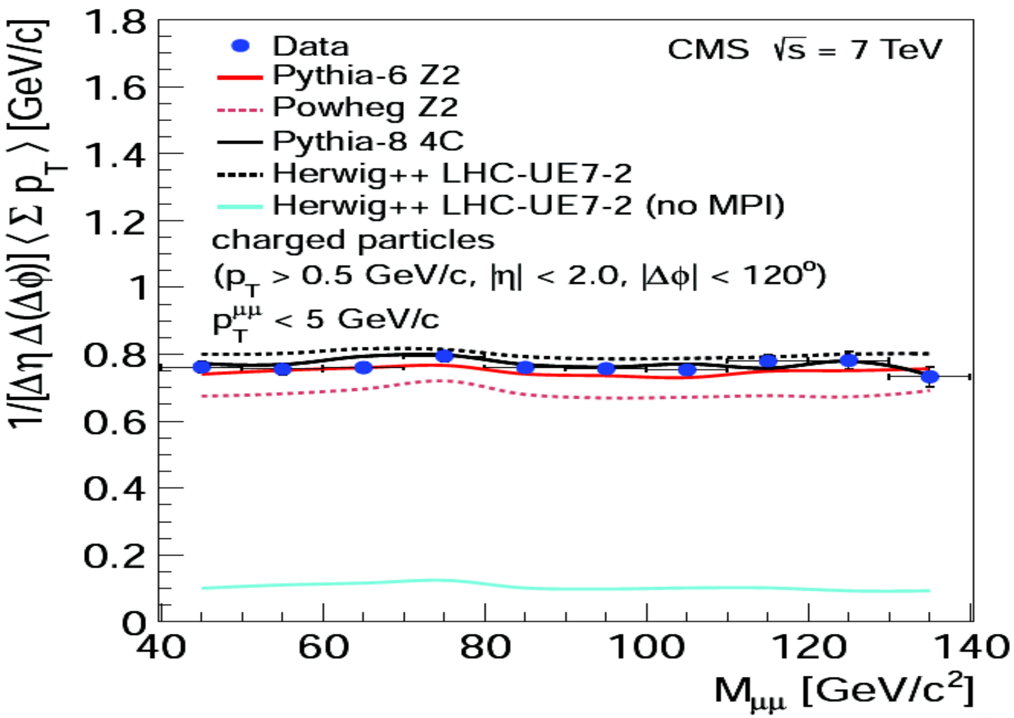
– MPI growth with √s well described by Z1 and 4C, too pronounced in D6T.

Charge and Σp_T density : Drell-Yan Events

Activity as a function of $M_{\mu\mu}$: for events with small recoil activity by requiring $p_T^{\mu\mu} < 5$ GeV/c

→ close to true UE

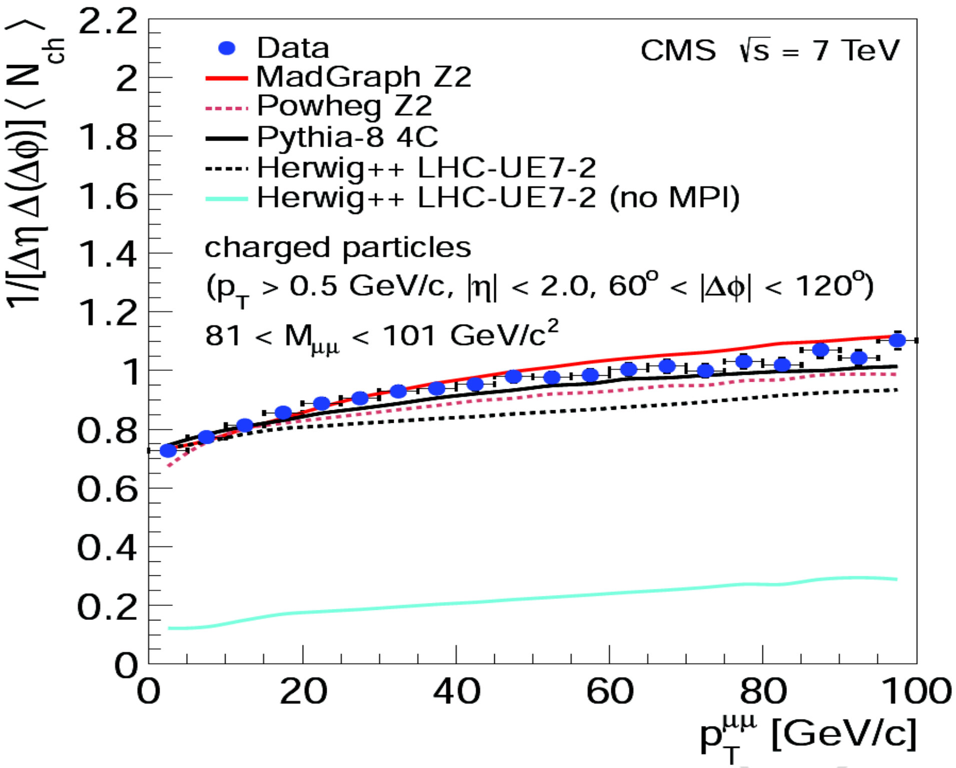


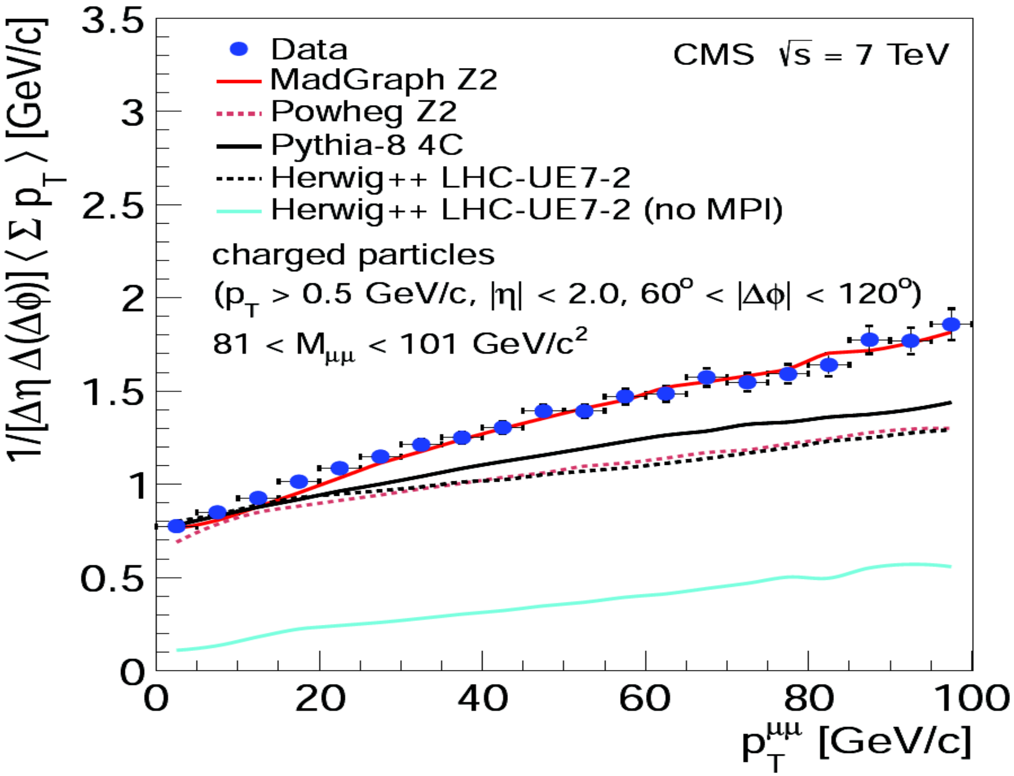


- Monte-Carlo without MPIs fails to describe measurement.
- No dependence on energy scale ($M_{\mu\mu}$), as MPI saturates at these scale (also known from track-jet analysis).
- Pythia and Herwig tunes derived from leading track/track-jet topology describe measurement in DY well → certain universality of the UE activity

Charge and Σp_T density : Drell-Yan Events

Activity as a function of $p_T^{\mu\mu}$: for events with $81 < M_{\mu\mu} < 101$ GeV/c^2



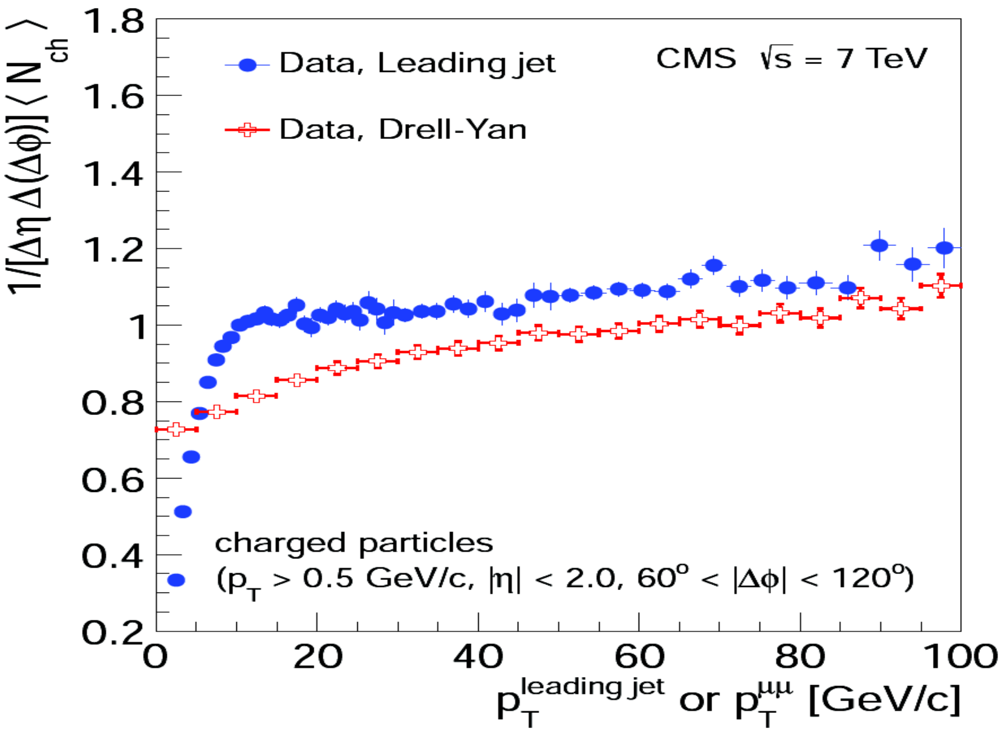


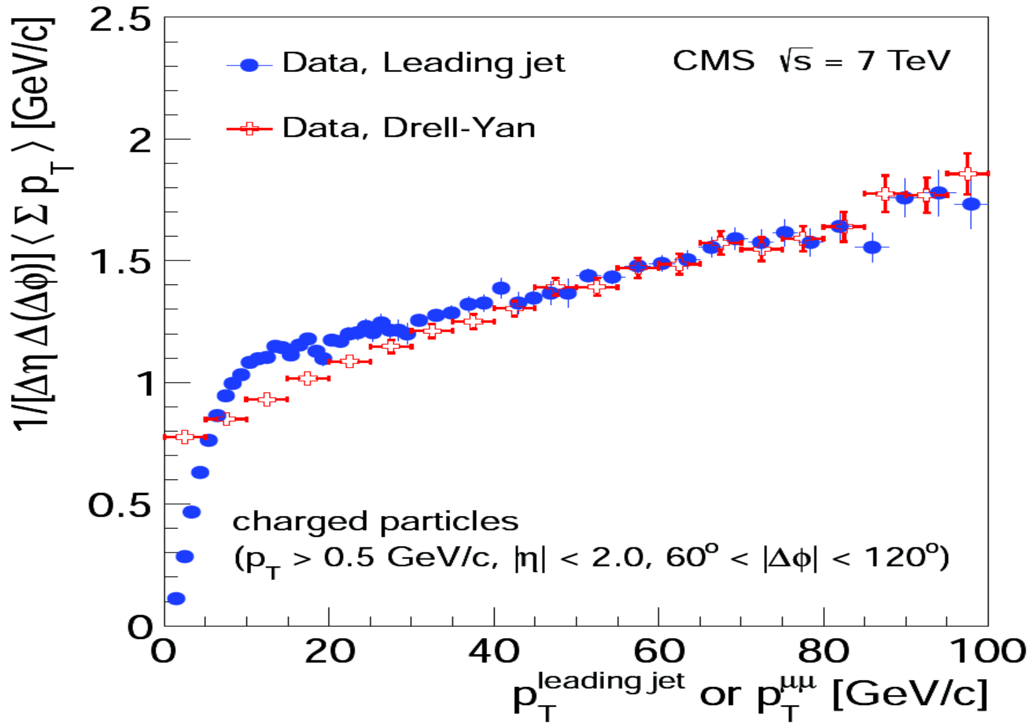
– MPI saturates and $p_T^{\mu\mu}$ dependence gives radiation evolution (mainly initial state radiation).

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

– Pythia and Herwig prediction describe the particle density well but underestimate the energy density.

Comparison with UE activity using Track-jet





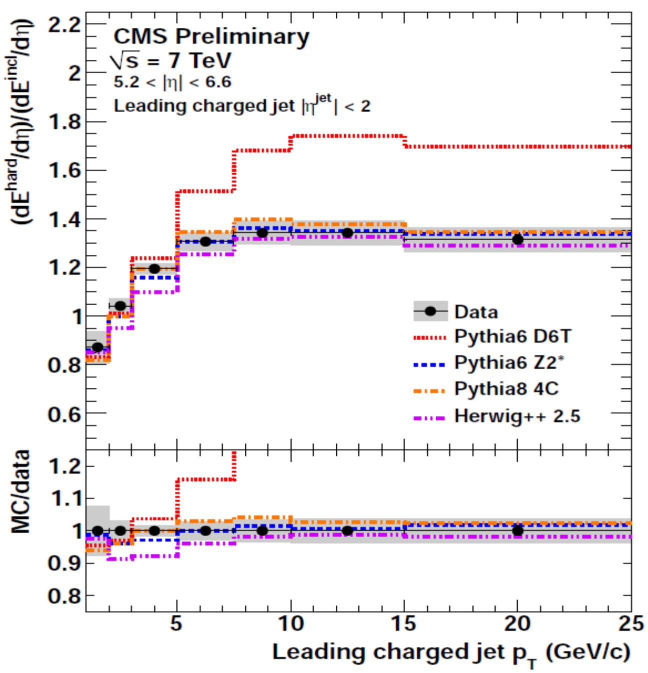
→ For $p_T^{\mu\mu}$ and $p_T^{leading\ jet}$ > 10 GeV/c DY events have a smaller particle density with a harder pT spectrum as compared to that in hadronic events.

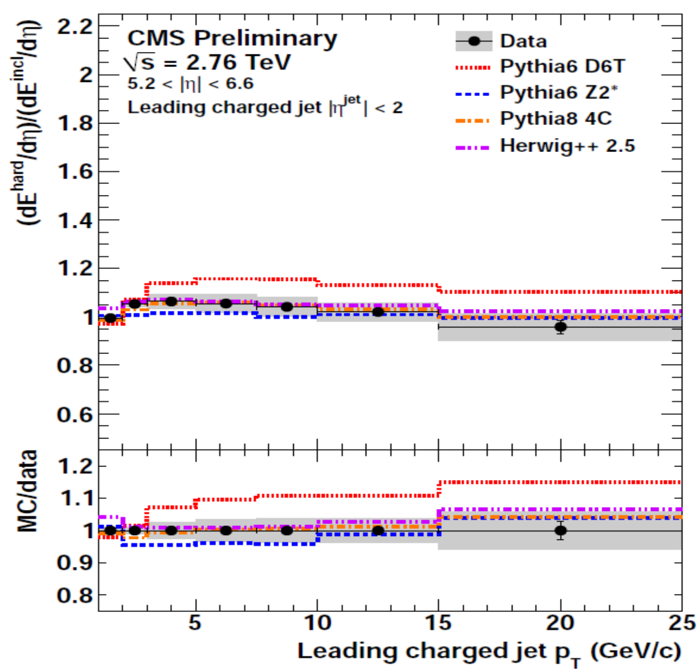
→ This is due to the nature of radiation in hadronic and Drell-Yan events. Drell-Yan events only have initial state QCD radiation initiated by quarks, whereas hadronic events have both initial and final state QCD radiation predominantly initiated by gluons.

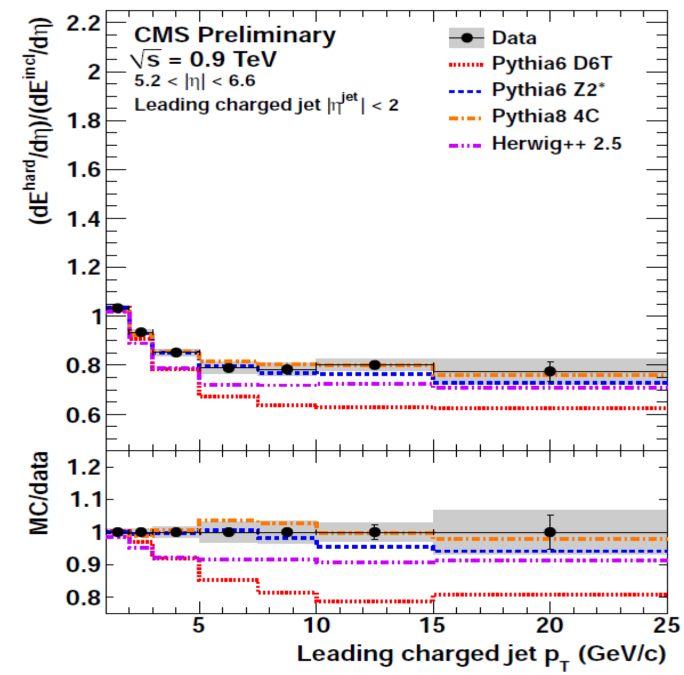
Underlying Event at Forward Rapidity

→ UE measured in forward rapidity (5.2 < η < 6.6) using CASTOR located ~ z = 14.3 m from IP.

→ Energy density (dE/dη) is measured inclusively and in presence of jet in central region for different centre-of-mass energies 0.9, 2.76 and 7 TeV.





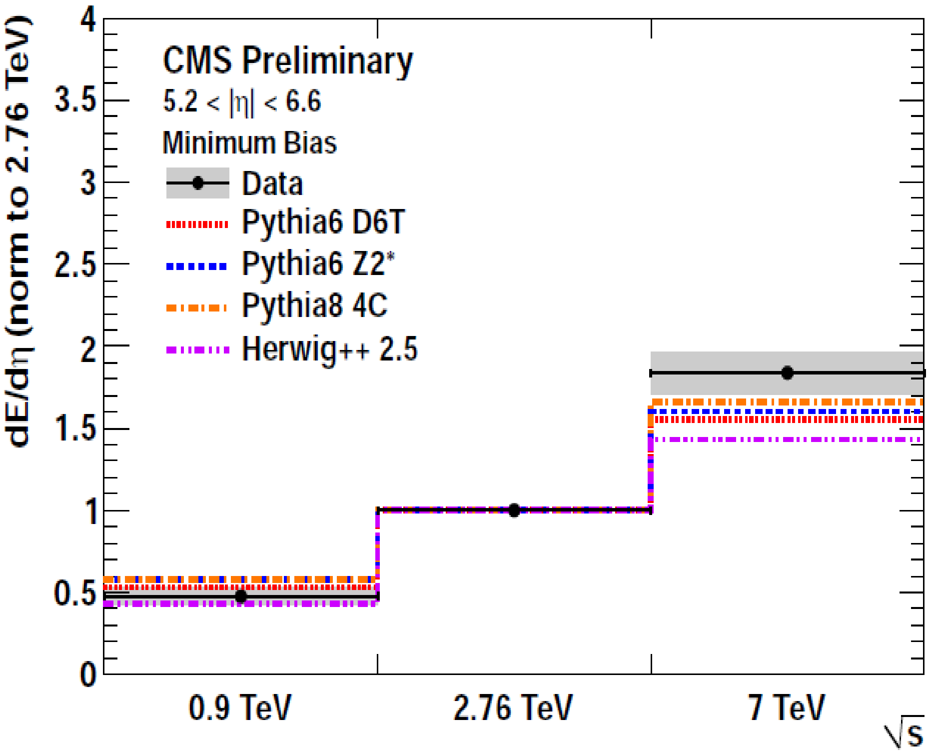


→ At 7 TeV, UE shows similar feature as in case of measurement in central region.

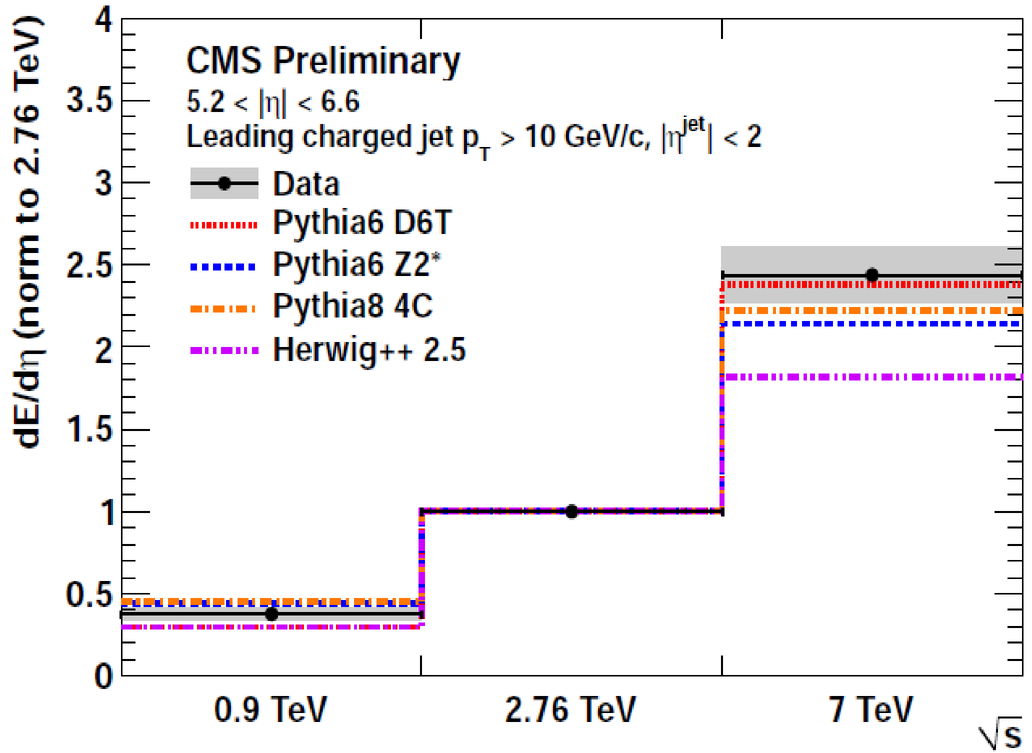
→ For 2.76 and 0.9 TeV rising effect is not visible: kinematic effect where central jet with high UE depletes the energy of proton remnant which fragment into CASTOR for low COM energies.

→ Pythia6 Z2* and Pythia8 4C gives overall good agreement with measurement.

Underlying Event at Forward Rapidity ($\sqrt{s}$ dependence)



Inclusive



Central jet p_T > 10 GeV/c

None of the Pythia and Herwig++ tune describe perfectly the energy dependence with Pythia6 D6T and Pythia8 4C being the closest.

Underlying Event using jet area approach

→ Alternative measurement based on jet area using variable which is not sensitive to hard outlier

G. Salam et. al JHEP 04 (2010) 065

$$\rho' = \underset{j \in physical\ jets}{\text{median}} \left[\left\{ \frac{p_{T,j}}{A_j} \right\} \right] * C$$

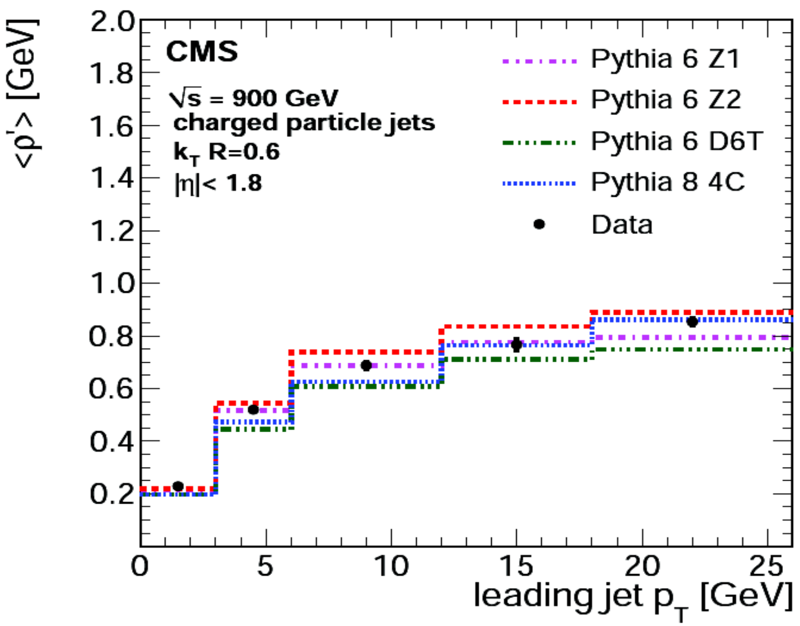
$$\text{with} \quad C = \frac{\Sigma_j A_j}{A_{tot}} \qquad A_j = \frac{N_j^{ghosts}}{N_{total}^{ghosts}} A_{tot}$$

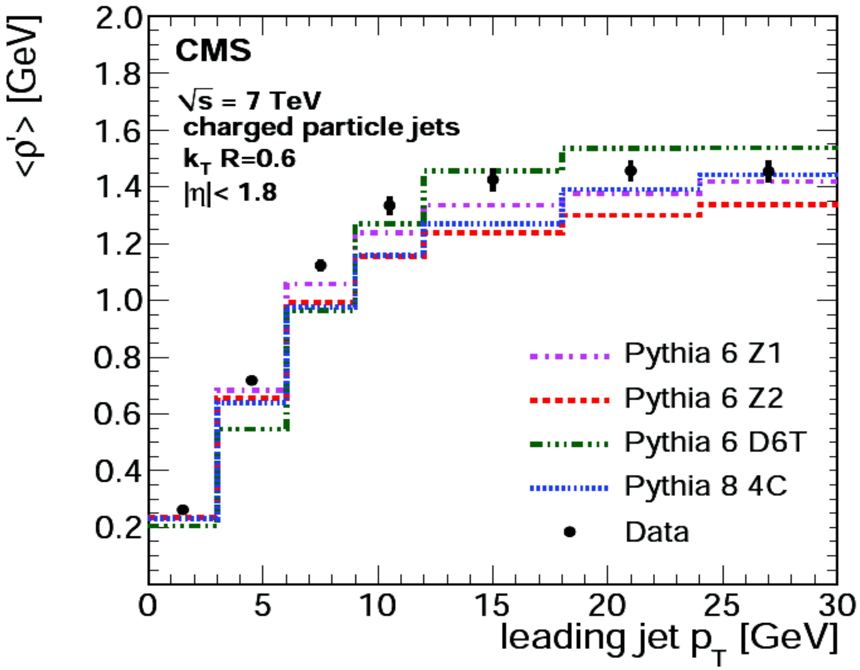
→ Require exact shape and size of jet area and should be sensitive to soft hadronic activity; K_T algorithm is suitable.

→ Same behavior as in conventional approach for UE measurement.

→ Activity increase by factor of ~2 as √s increase from 0.9 to 7 TeV.

→ None of the tune describe √s and scale dependence completely.





Summary

- Extensive program on soft QCD and MPI measurements in CMS
- Identified and and unidentified charged particle spectra are studied at different energies.
- Strangeness is observed to be underestimated by MCs.
- Unexpected long range correlation (similar to heavy-ion collisions). MCs don't describe this observation.
- Underlying event is measured at various energies and with different processes in central and forward rapidity region.
- Different MCs describe one or another measurement but none of the model describe measurements all together.