Universiteit Antwerpen

Measurements of Hadron Production and Correlations at CMS

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(On Behalf of the CMS Collaboration)

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Outline

The CMS detector

The theoretical framework of soft QCD

Results :

- Single charged particle Spectra:
  dn/dη (NSD , with 1 central track, MBUEWG)
  dn/dpt

- Multiplicities

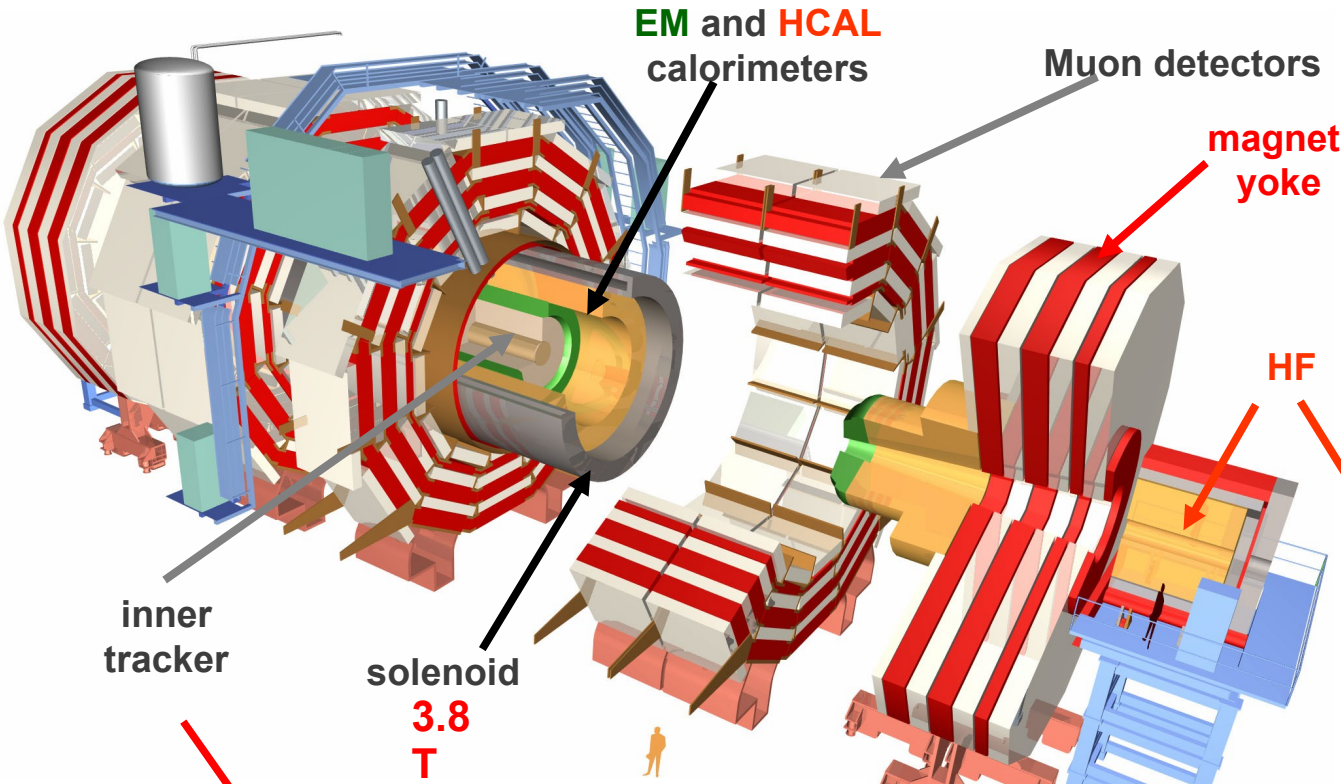
- Strange particle production

Rivet

Analysis Summary

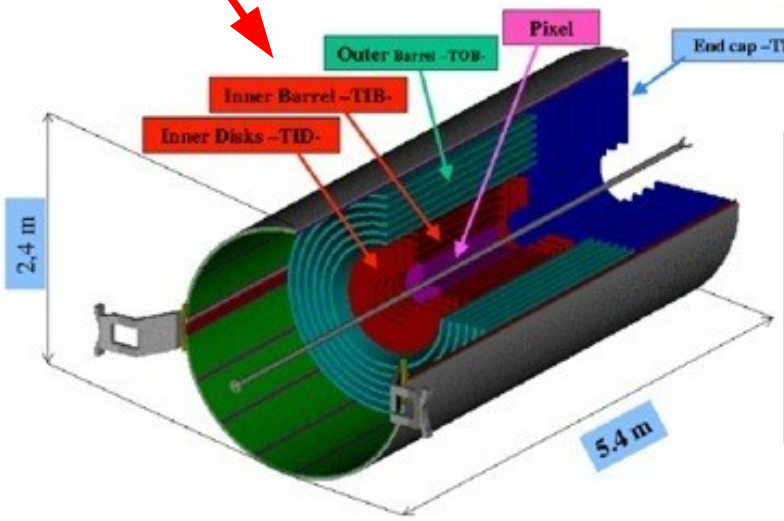
Conclusions

The CMS Detector



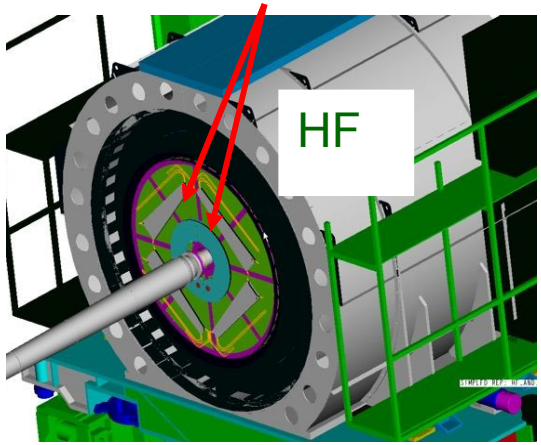
Total weight	12500 t
Overall diameter	15 m
Overall length	21.6 m

Inclusive Trigger: Scintillators around Beam Pipe (BSC)



CMS η coverage:

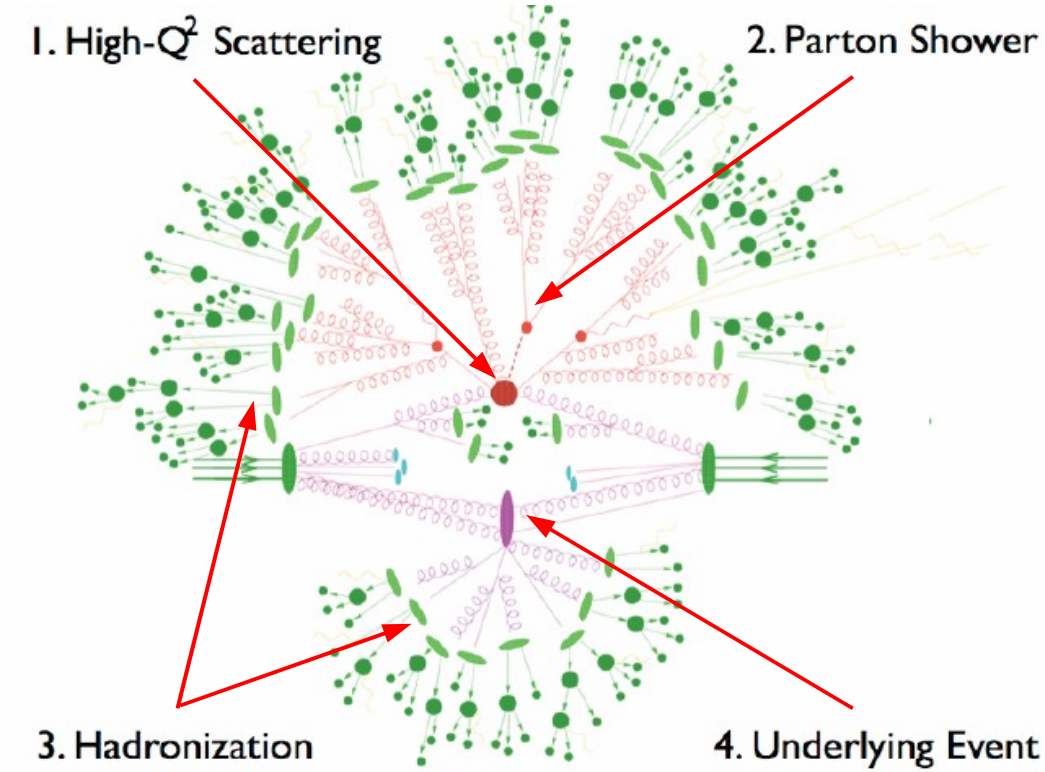
Tracker (Pixel + Strip)	$\|\eta\| < 2.4$
Calorimeters (EM+HCAL)	$\|\eta\| < 3.0$
HF Calorimeter	$3 < \|\eta\| < 5$
Muon Detectors	$\|\eta\| < 2.4$



Soft Interactions and Underlying Event

The majority of the pp collisions are soft
→ no "perturbative" predictions
→ need to model them phenomenologically

==> Use Monte-Carlo (MC) description to correct data:



- PS, UE and hadronization models tuned on previous (low energy) data
- Different models available diverging at high energy prior to LHC

→ Early LHC data give us a unique chance to fill gaps in our knowledge on soft QCD

→ Reference for high energy pp collisions and heavy ions run

Single Charged Particle Spectra: dN/dη

JHEP 02 (2010) 041

PRL 105 (2010) 022002

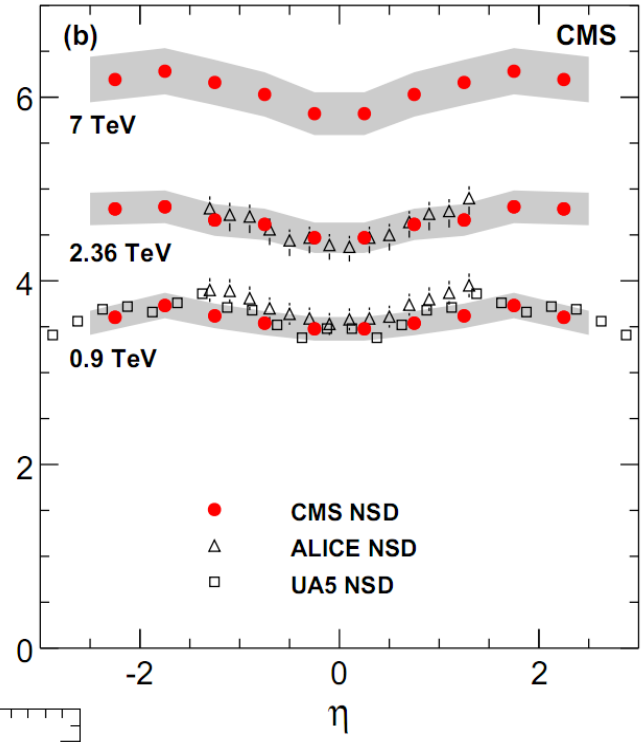
Event Selection

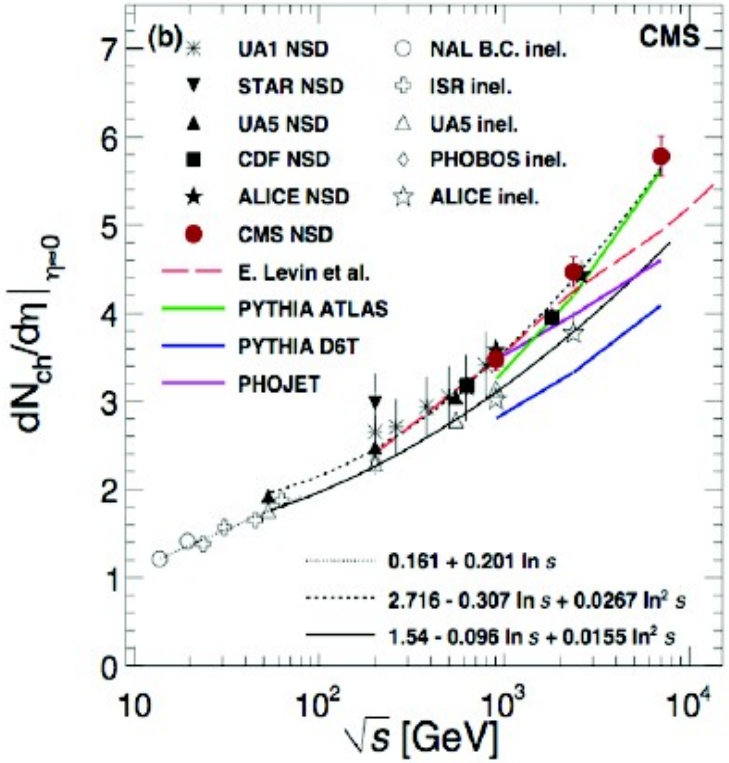
– MinBias trigger (BSC)
– At least 3 GeV in both HF
– primary vertex

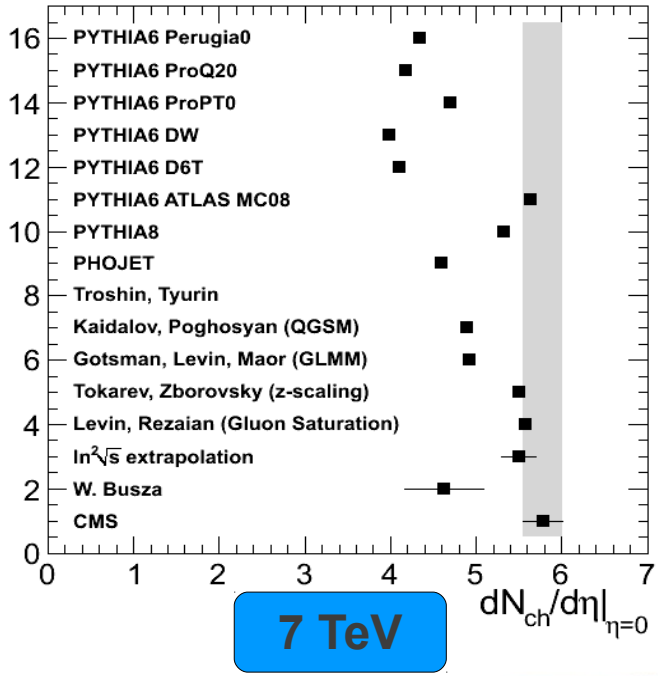
=> *Corrected to non single diffraction (NSD)*

Charged Particle Selection

– $|\eta| < 2.5$
– 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.

=> MC tuning effort on LHC data ongoing (see http://lpcc.web.cern.ch/LPCC/)

dN/dη with 1 track in central region

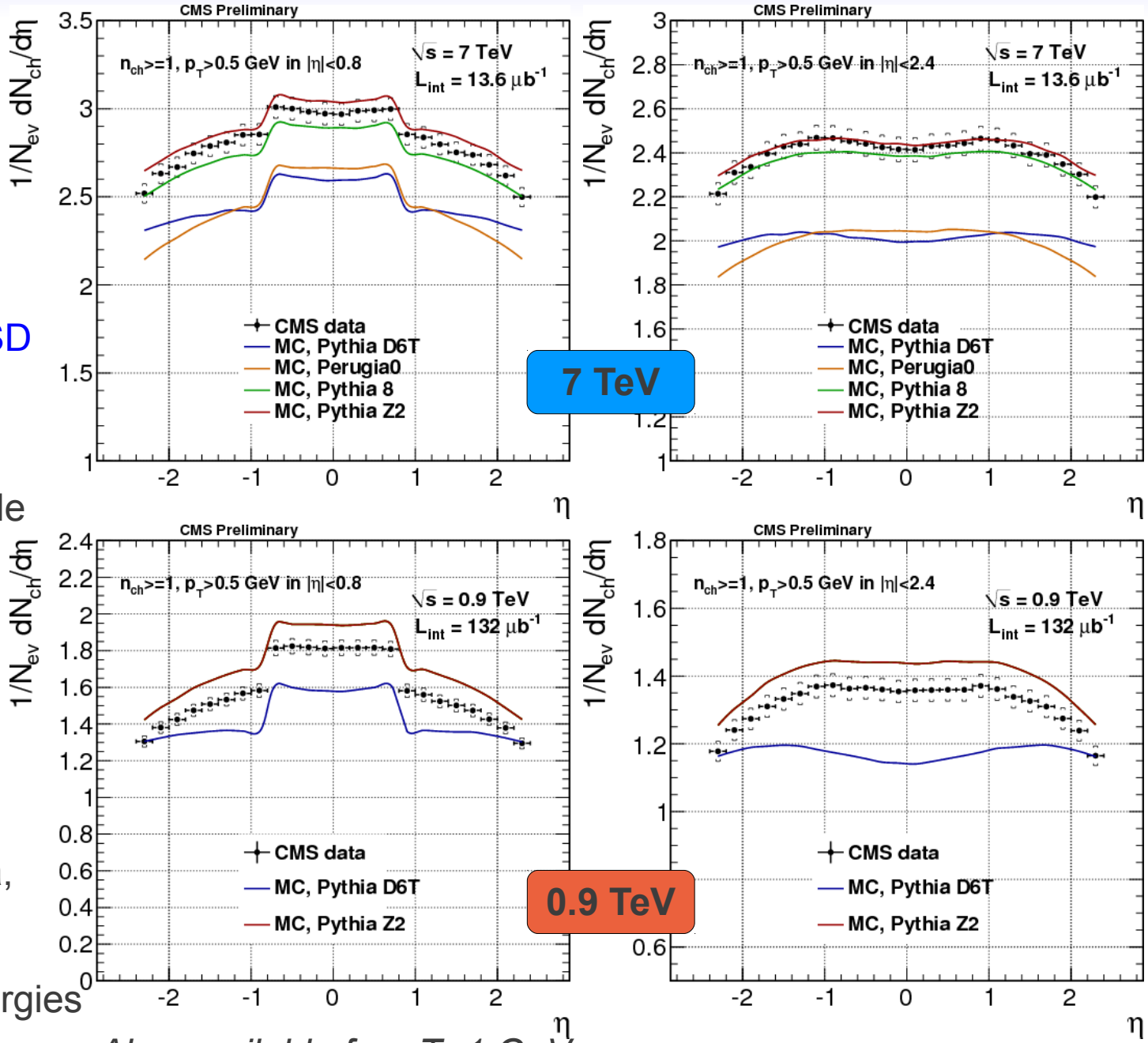
CMS Paper QCD-10-024

Why ?

- Minimize dependence on MC modeling of diffraction
  ==> No correction to NSD

- Provide distributions in acceptance regions reachable by all 4 LHC experiments
  ==> *easy cross-check of results*

PYTHIA 8, and PYTHIA 6 Z2 (tuned on UE @ 7 TeV) describe quite well 7TeV data, but fail for 0.9 TeV.
Pre-LHC tunes can't predict enough particles for both energies

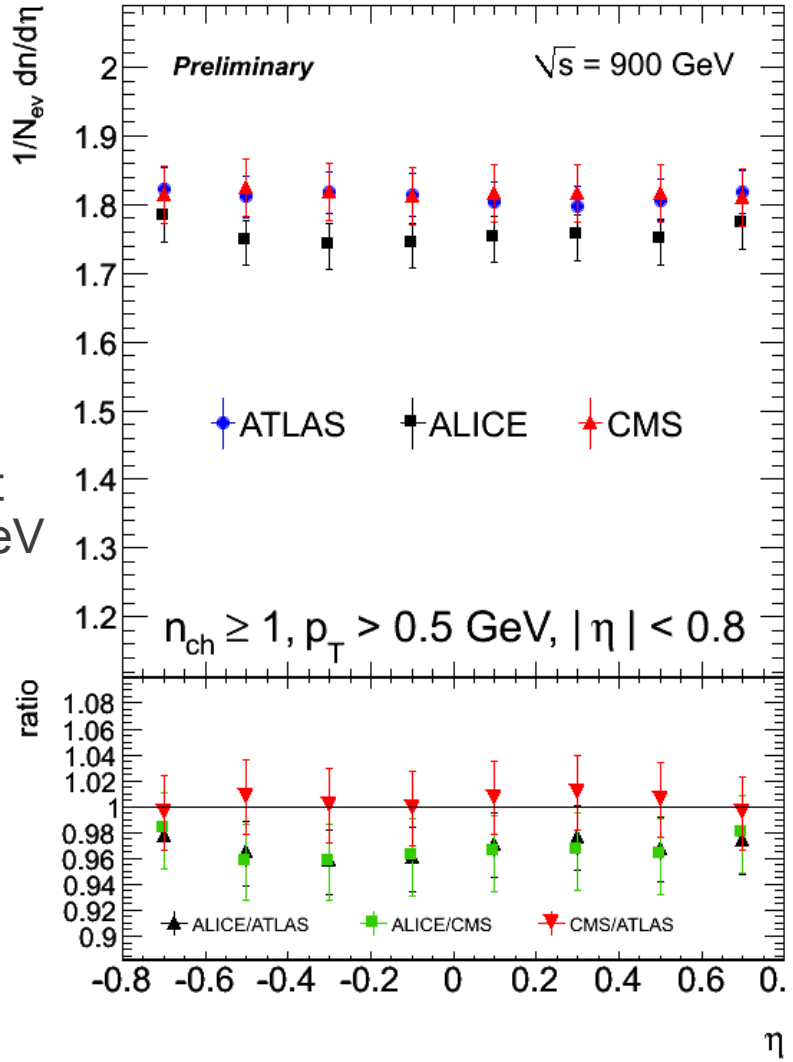


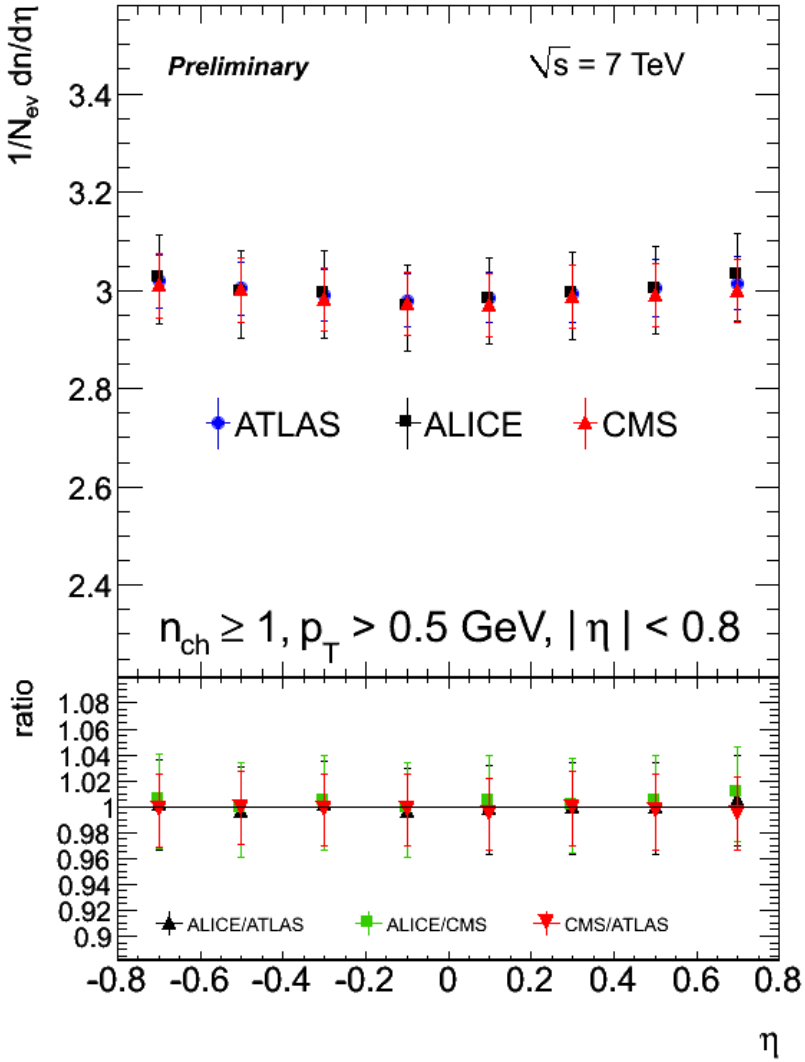
Also available for pT>1 GeV

Combined results from ATLAS , ALICE & CMS thanks to the **Minimum-Bias/Underlying Event Working Group**

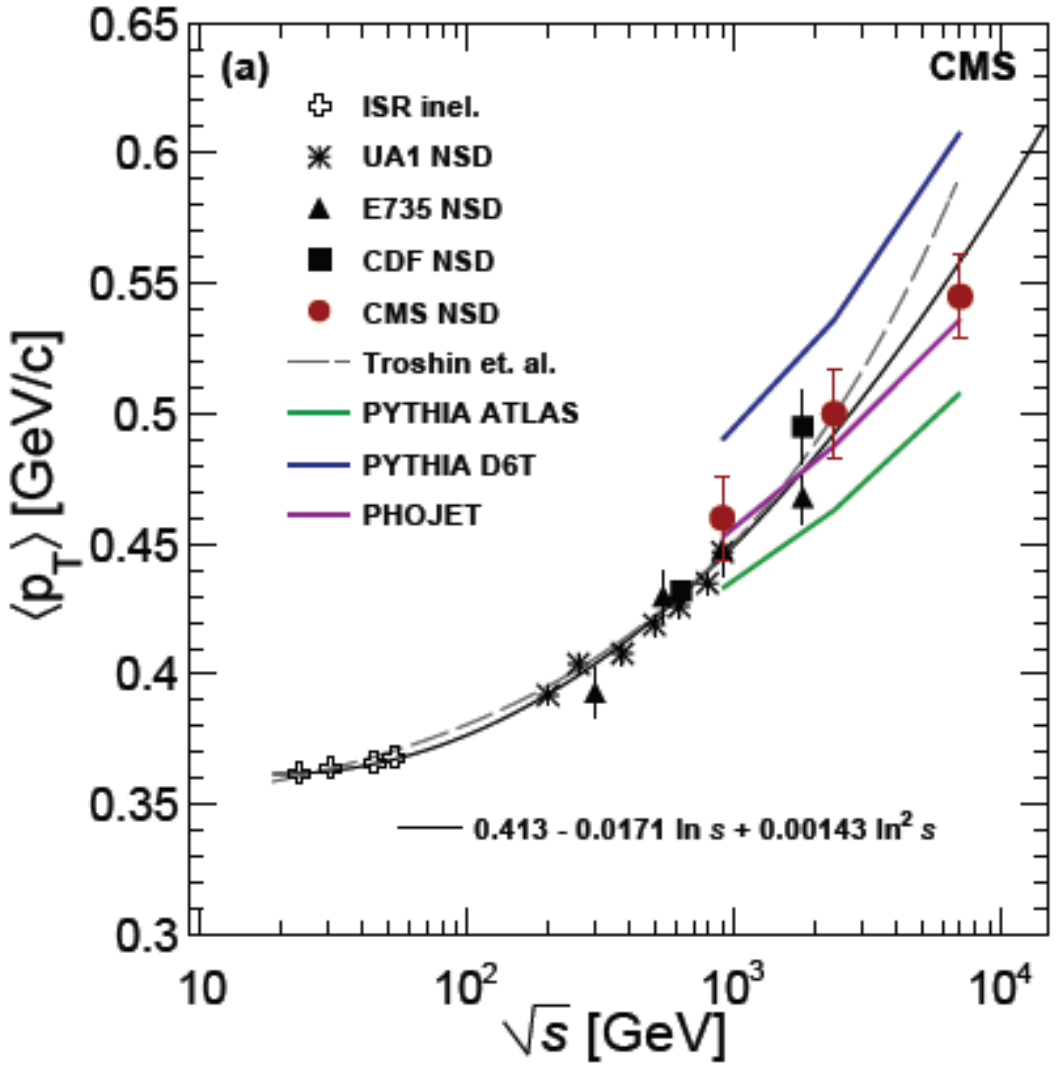
ALICE is a bit lower than CMS & ATLAS at 900GeV, but well within errors

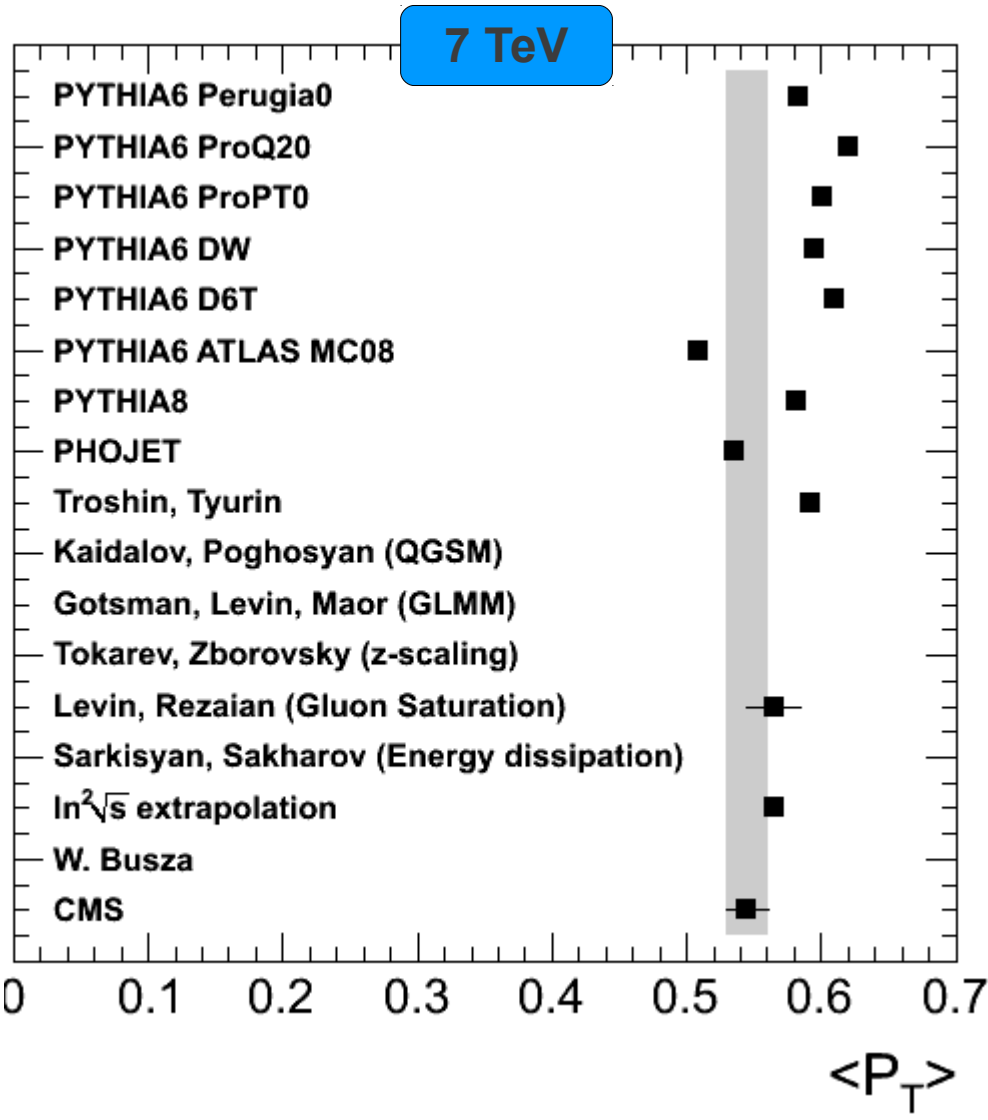
Excellent agreement from all 3 exp. at 7TeV





Pt and evolution





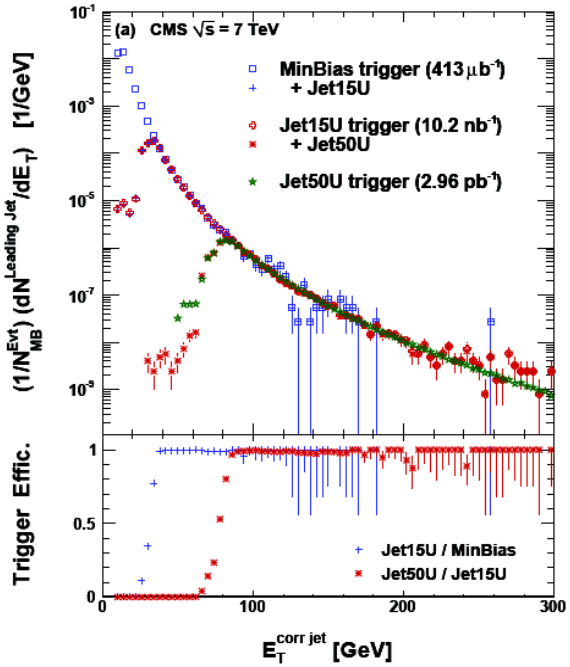
Overall, pre-LHC tunes predict to strong events
Theoretical predictions show as well higher <pT> than observed

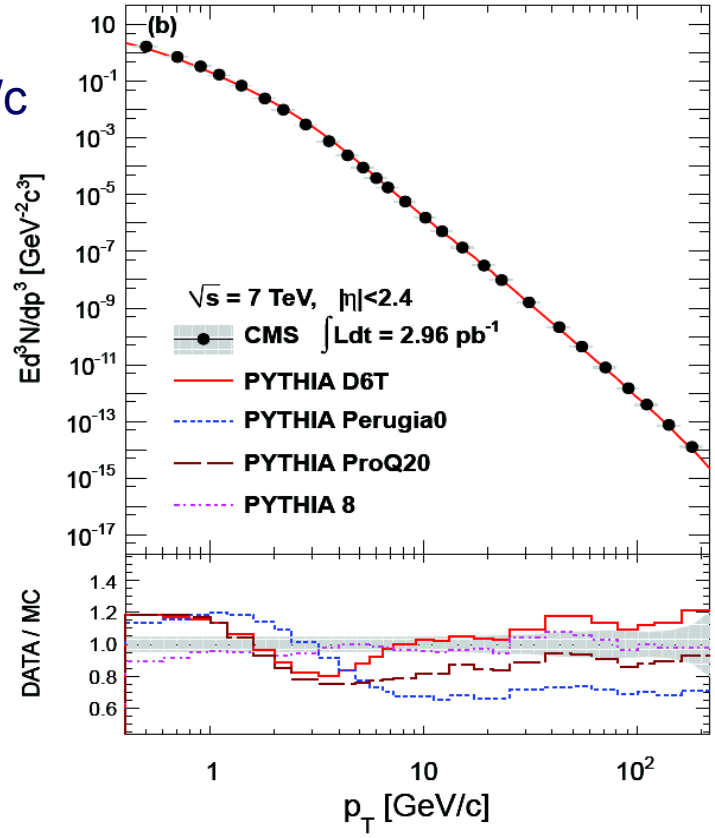
Single Charged Particle Spectra: dN/dp_T

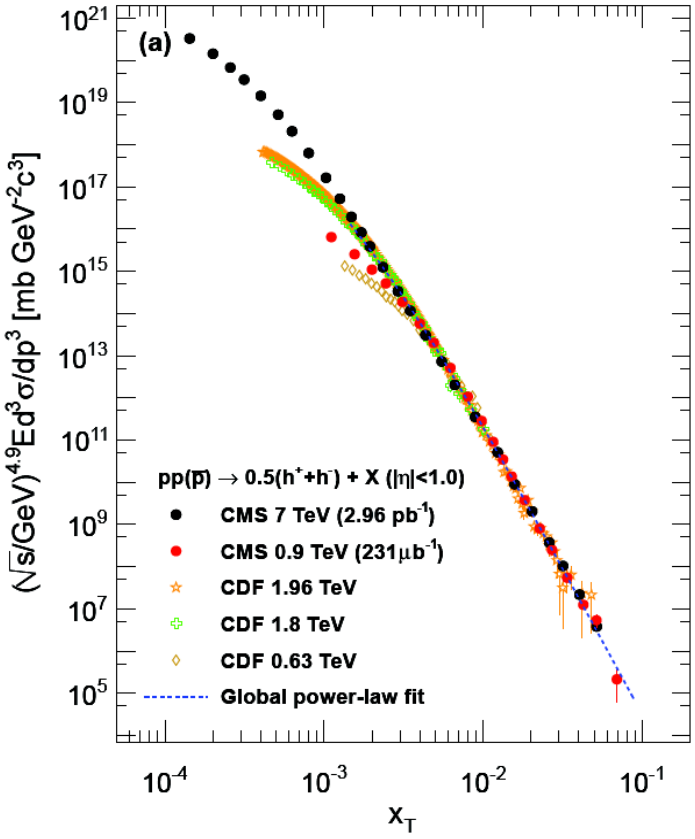
CMS Paper QCD-10-008

PRL 105 (2010) 022002

MinBias p_T reach extended by jet triggers to ~100 GeV/c





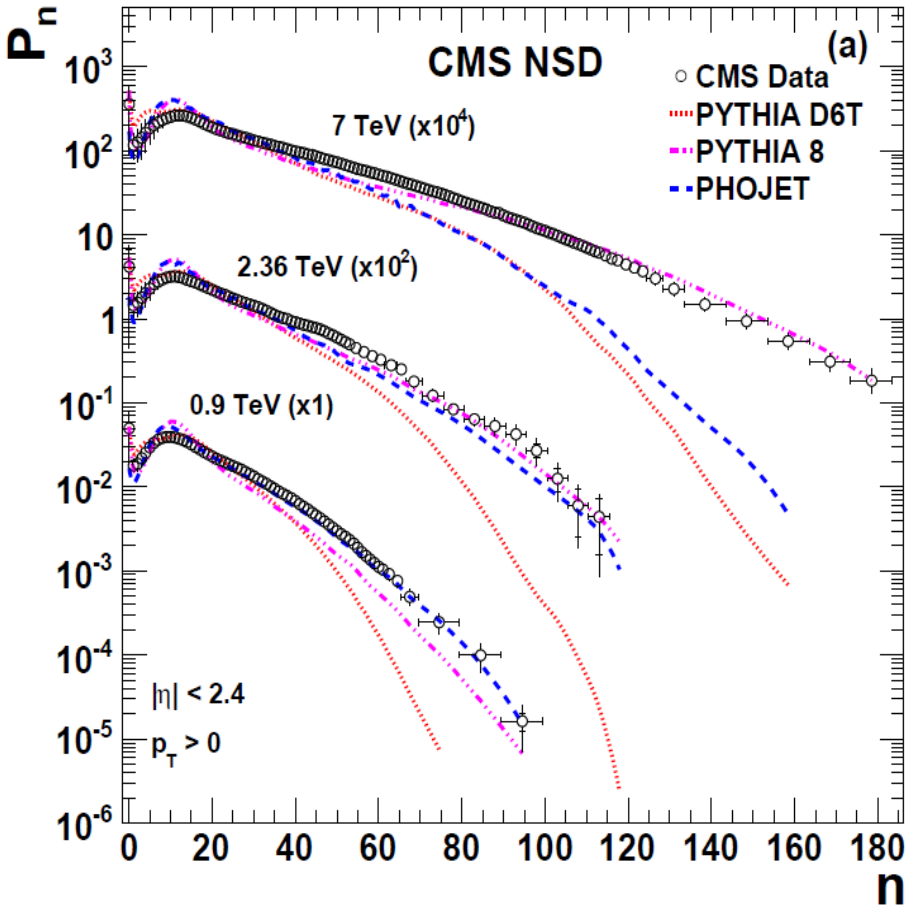


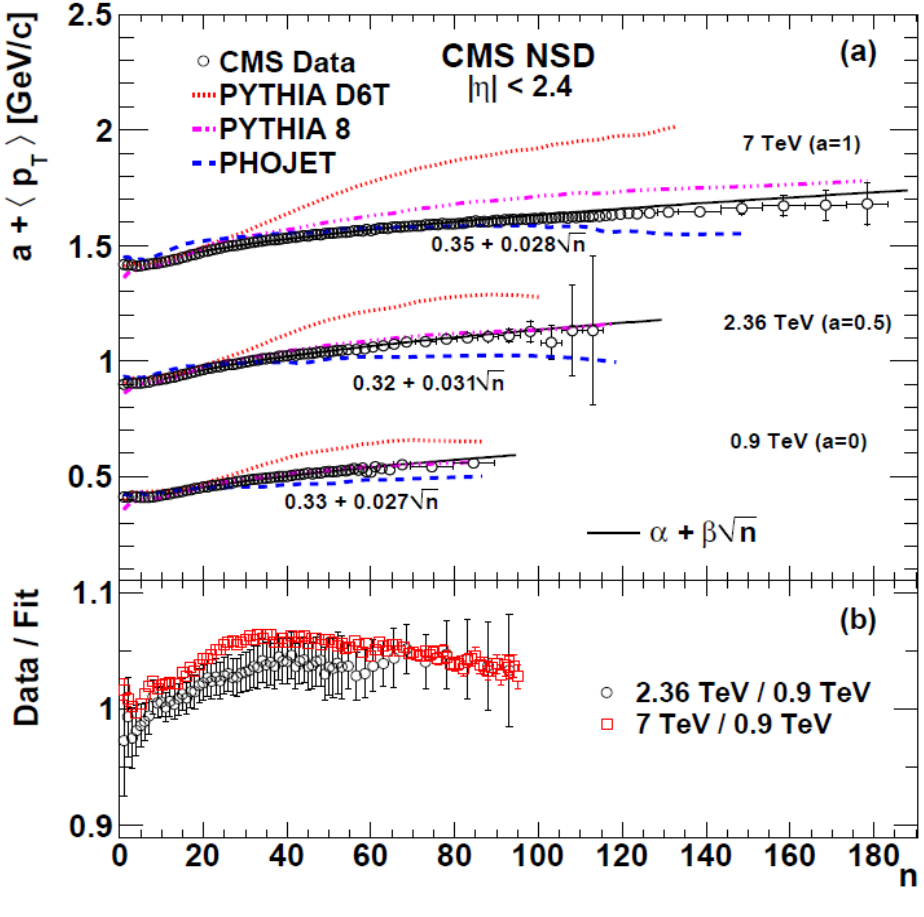
$$E\frac{d^3\sigma}{dp^3} = F(x_T)/p_T^{n(x_T,\sqrt{s})} = F'(x_T)/\sqrt{s}^{n(x_T,\sqrt{s})}$$

- Results at 7 TeV most compatible with PYTHIA 8 while PYTHIA 6 is worse
- Empirical $x_T = 2\ p_T / \sqrt{s}$ 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

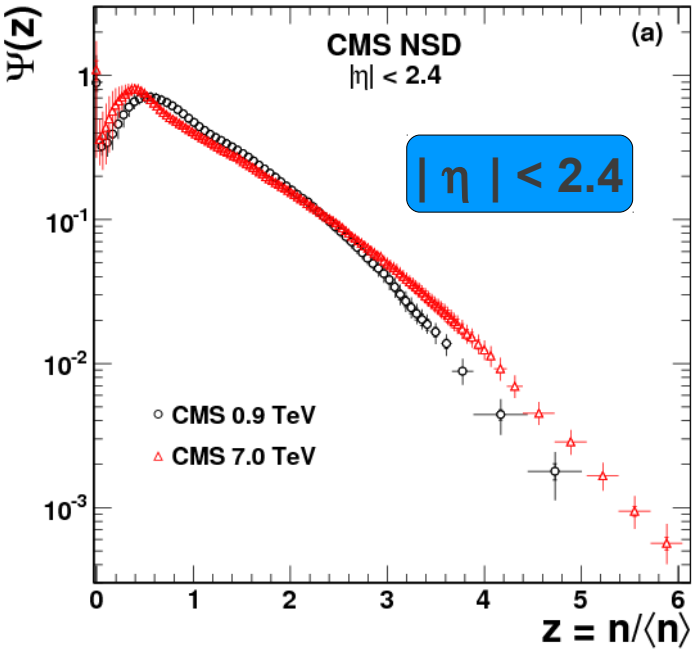
JHEP 01 (2011) 079

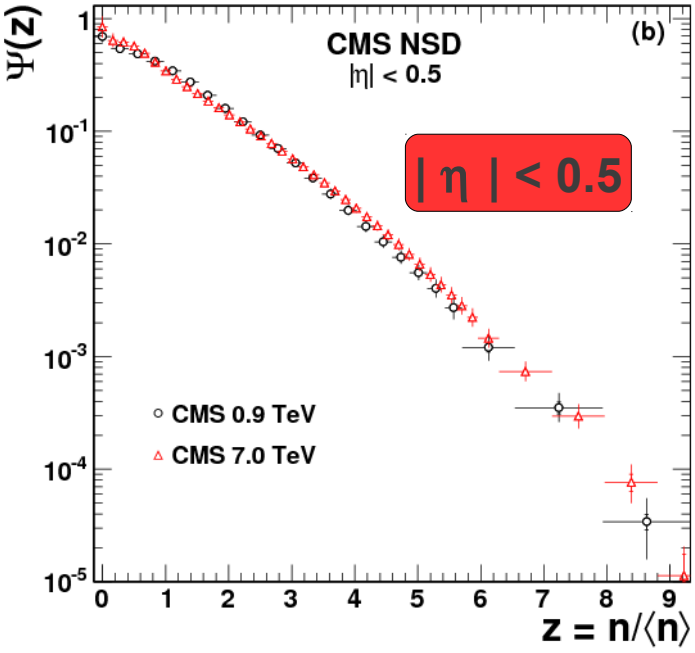


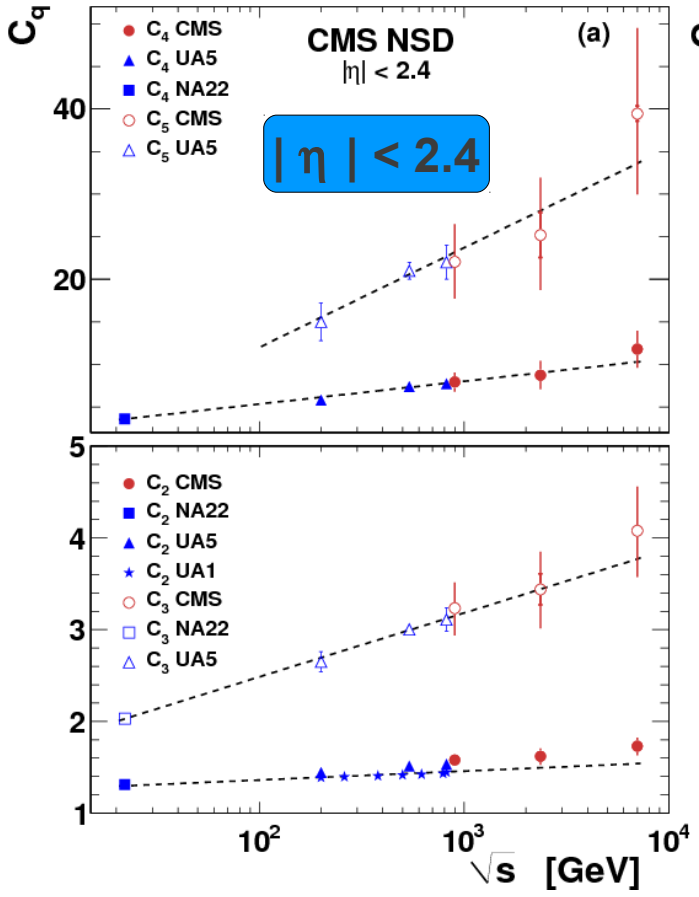


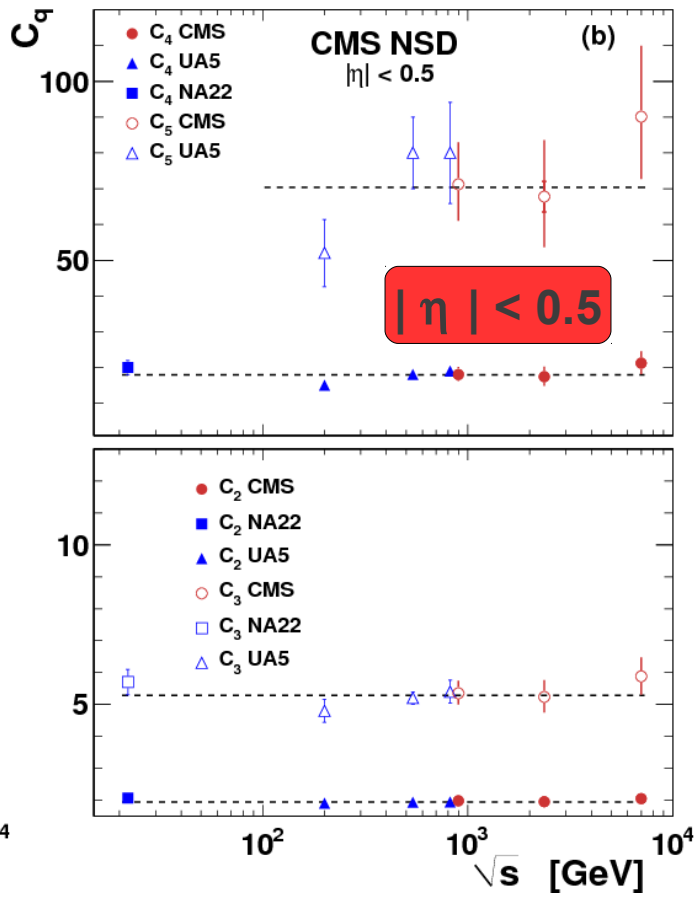
- Large multiplicity tail observed at 7 TeV (cf. dN/dη)
- Presence of second NBD, sign of MPI ?
- $\langle p_T \rangle$ vs n scales with energy
- No Monte Carlo is able to describe all multiplicities at all energies (but PYTHIA 8 better)
- Most MC/tunes can not describe simultaneously the multiplicity and the p_T dependence (again PYTHIA 8 better)

KNO / Moments









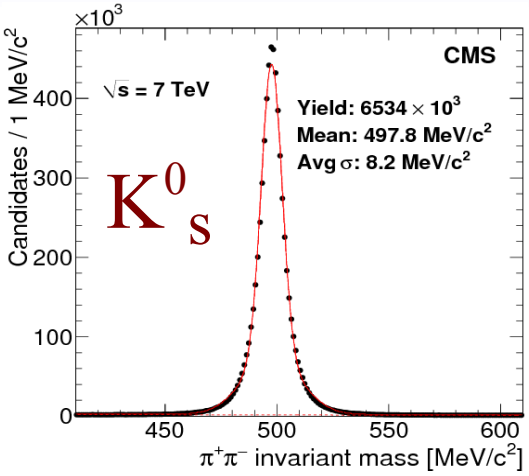
For large acceptance, KNO is violated, which is confirmed by the rise of the C-moments with energy

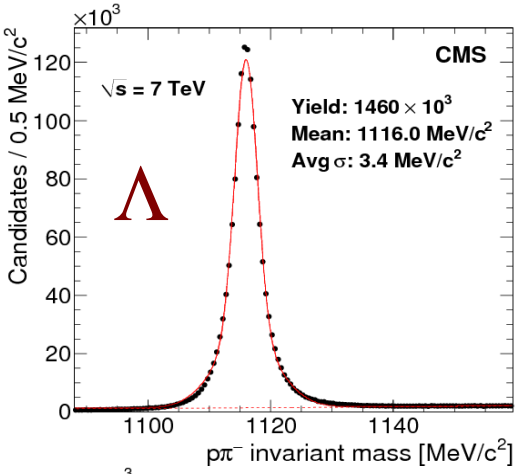
For central rapidity, KNO holds, and fits of moments VS energy are compatible with a constant

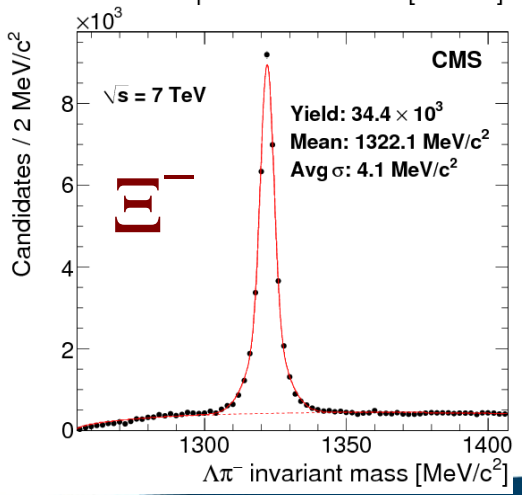
Strange Particle Production: K^0_S, Λ , Ξ^-

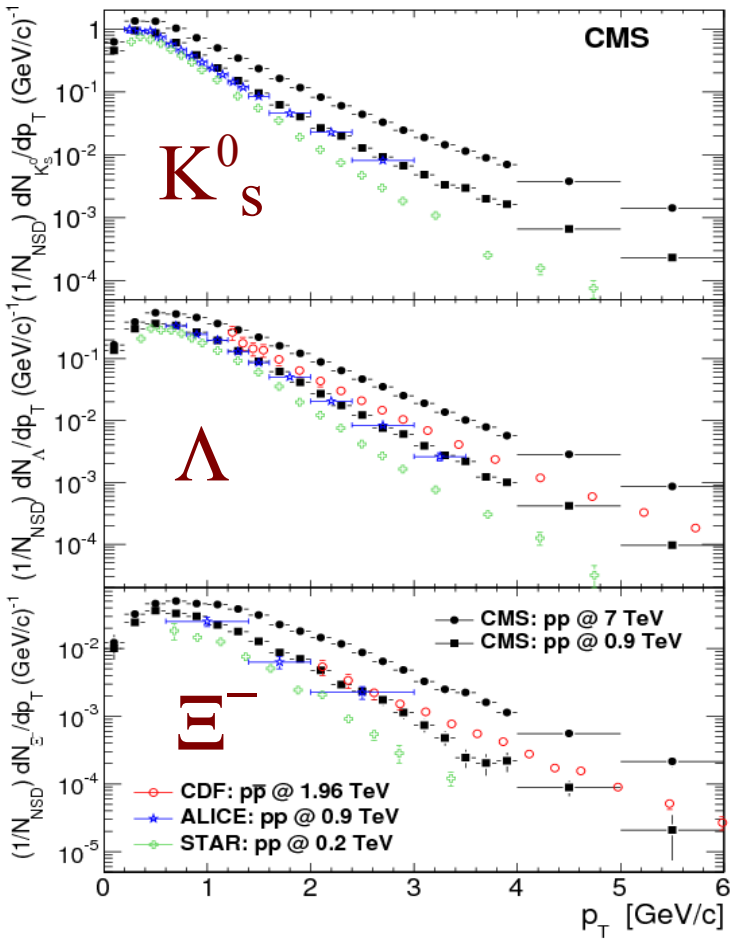
CMS Paper QCD-10-007

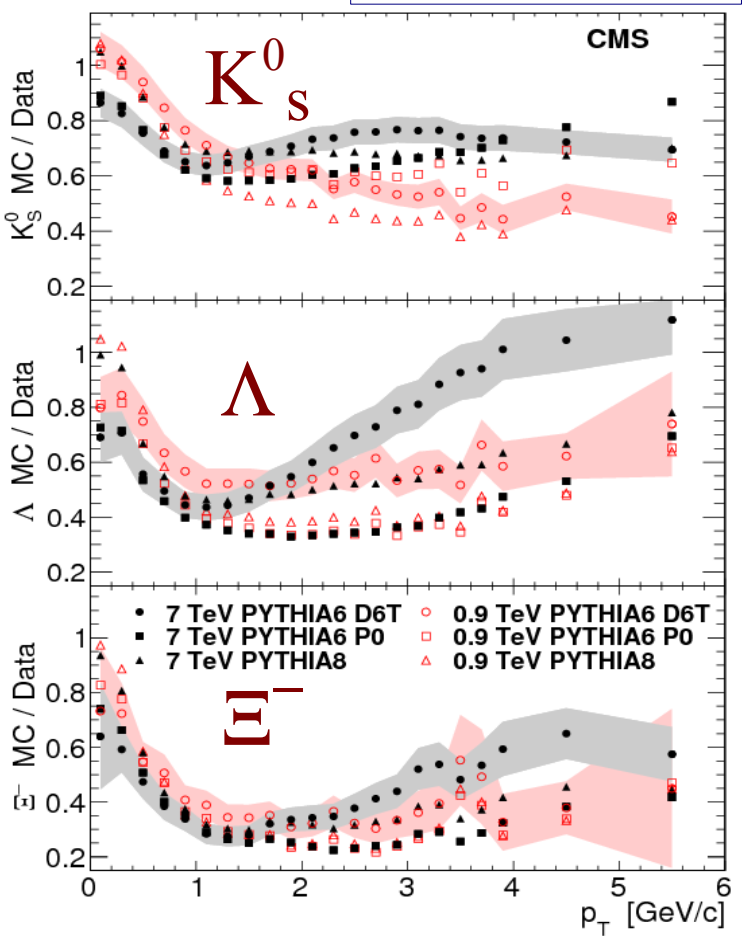
JHEP 05 (2011) 064









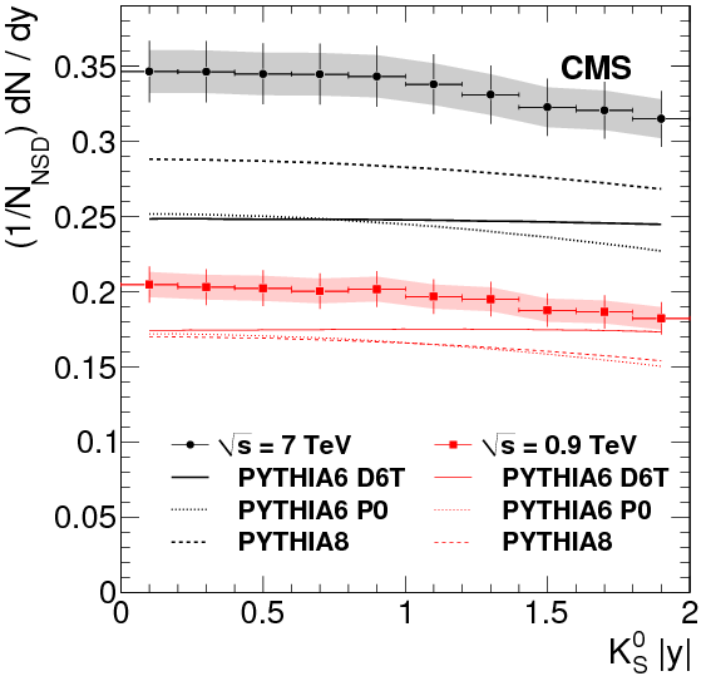


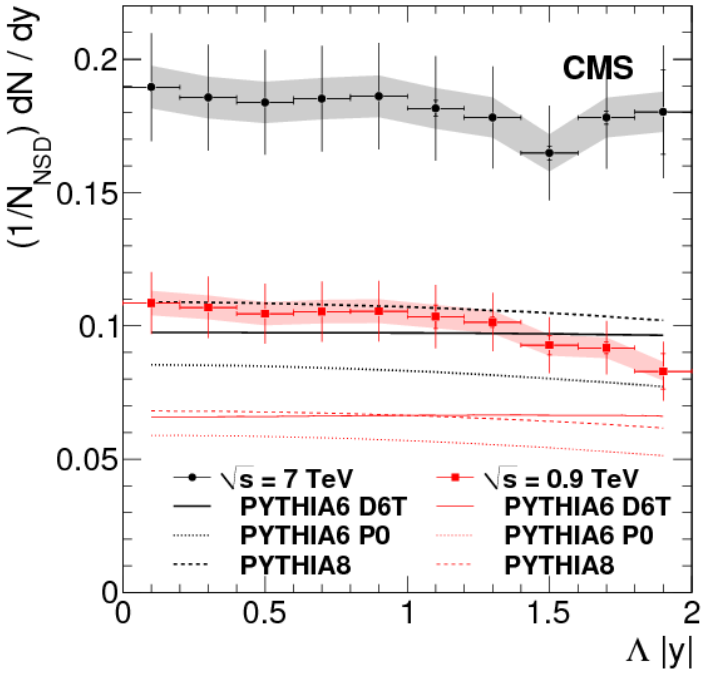
Similar increase for strange as for charged particle with energy

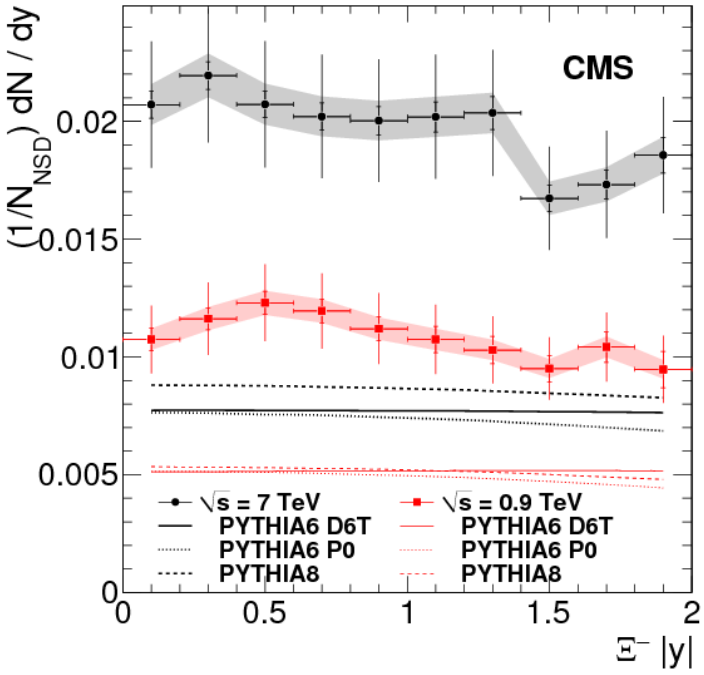
=> PYTHIA fails again to match this increase !

Discrepancy larger for Ξ^- at both energy and up to factor 3 at 7 TeV.

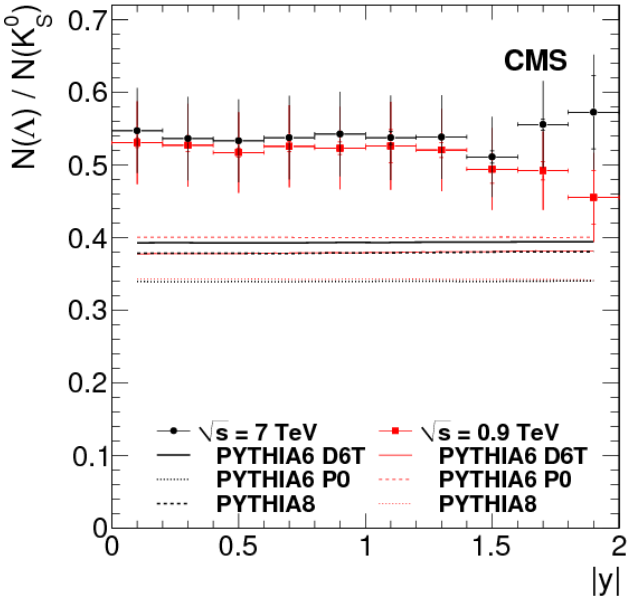
Strange Particle Production: K^0_S, Λ , Ξ^-

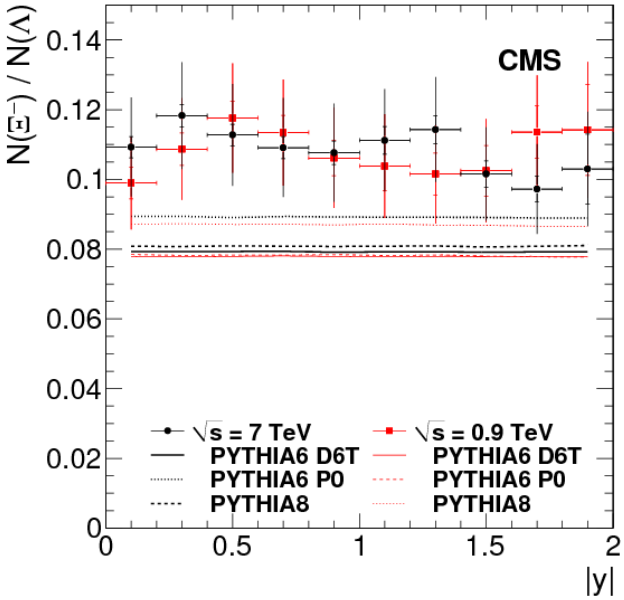






==> Again, increase similar with energy, and pre-LHC tunes produce too few strange particles





Production ratios seem to be energy-independent

==> No clear sign of QGP formation

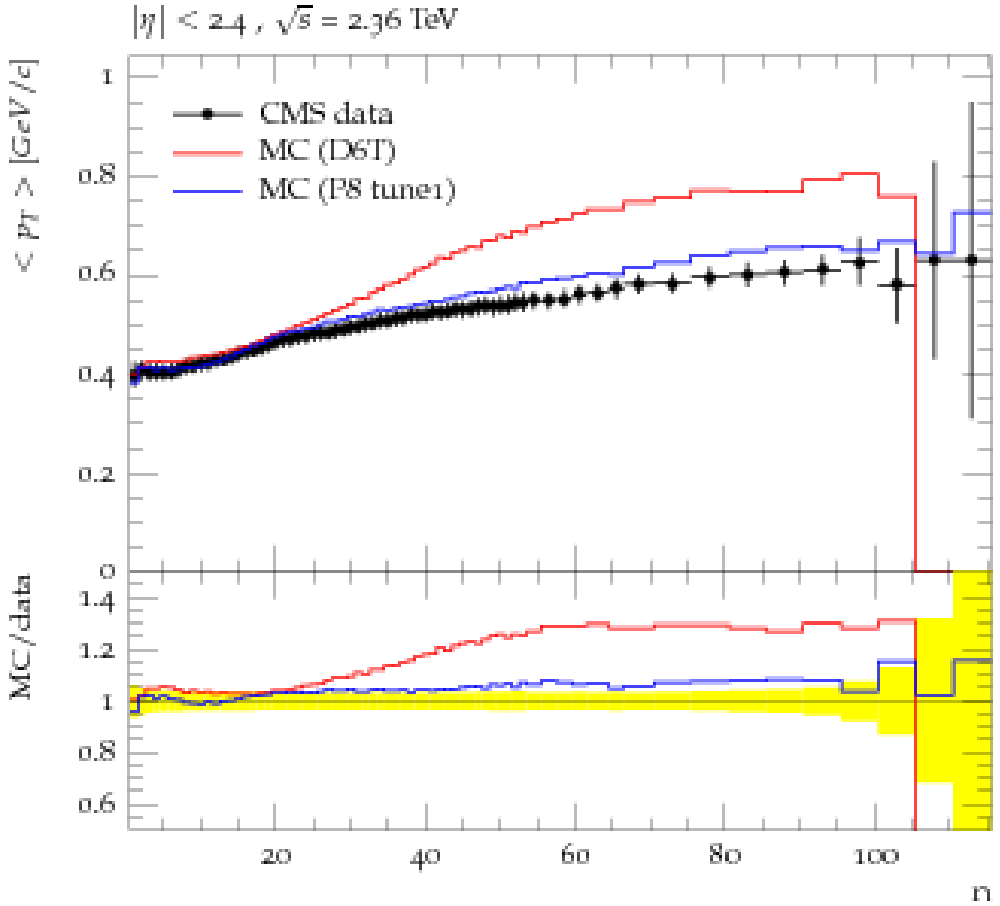
Rivet

Some analysis are ported to RIVET, which enables easy tuning/cross-check of Monte-Carlos: See http://projects.hepforge.org/rivet/

(all analysis should soon have a RIVET implementation)

For now, we have 4 analysis:

CMS_2010_S8547297
CMS_2010_S8656010
CMS_2011_S8884919
CMS_2011_S8978280



Analysis Summary

Summary page of all CMS QCD analysis:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsQCD#Results

Plots (pdf + png) , arxiv + cern preprint + paper + durham DB links

Transverse momentum and pseudorapidity distributions of charged hadrons in pp collisions at sqrt(s) = 0.9 and 2.36 TeV	***arXiv:1002.0621***
Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at sqrt(s) = 7 TeV	***arXiv:1005.3299***
Charged particle transverse momentum spectra in pp collisions at sqrt(s) = 0.9 and 7 TeV	***arXiv:1104.3547***
Charged particle multiplicities in pp interactions at sqrt(s) = 0.9, 2.36, and 7.0 TeV	***arXiv:1011.5531***
Pseudorapidity distributions of charged particles in pp collisions at sqrt(s) = 7 TeV with at least one central charged particle	***CMS-PAS-QCD-10-024***
Strange particle production in pp collisions at sqrt(s) = 0.9 and 7 TeV	***arXiv:1102.4282***

Underlying events	CHAO, Yuan (Monday)
Bose-Einstein correlations	PADULA, Sandra (Wednesday)
2-particle correlations / Ridge	KIM, Ji Hyun (Wednesday)

CONCLUSIONS

- Understanding of soft QCD contributions is crucial for new physics searches and precision measurements of Standard Model processes
- Pre-LHC Monte Carlo tunes do not describe the data well in all aspects
  → Monte Carlo tuning effort ongoing
- Strangeness production has been investigated showing similar discrepancy
- Common efforts between the LHC experiments to provide well-defined plots is starting to show results
- RIVET implementations of all analysis to help tunning MC

ARIGATO !