Inclusive hadron production in p-p collisions in CMS

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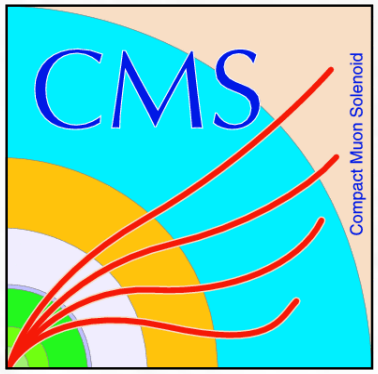
on behalf of the CMS Collaboration



Low-x Workshop 2013,
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Outline

Pseudorapidity and leading-track transverse momentum distributions of charged particles in pp collisions at $\sqrt{s}$ = 8 TeV

- Introduction
- Event selection
- Analysis strategy and corrections
- Results
- Summary and conclusions

Introduction (pseudorapidity distribution) (1)

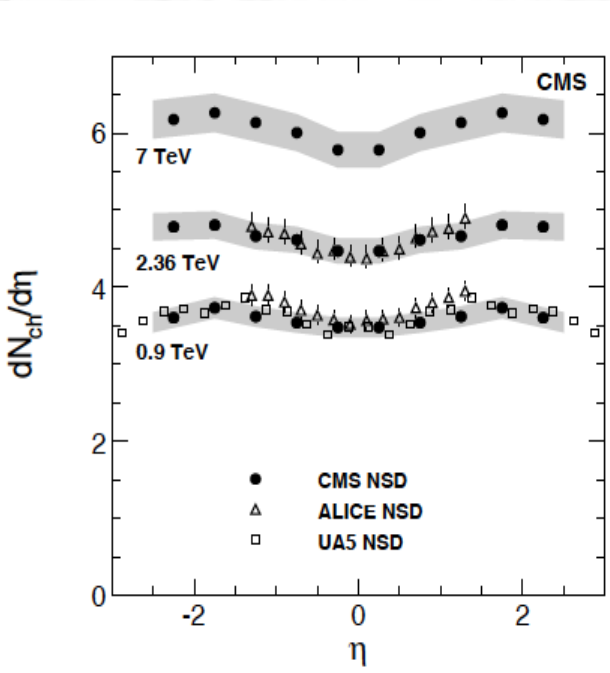
- Measurements of particle yields and kinematic distributions essential in exploring the energy regimes of particle collisions at the LHC → better understanding of the mechanisms of hadron production and the relative roles of soft and hard scattering

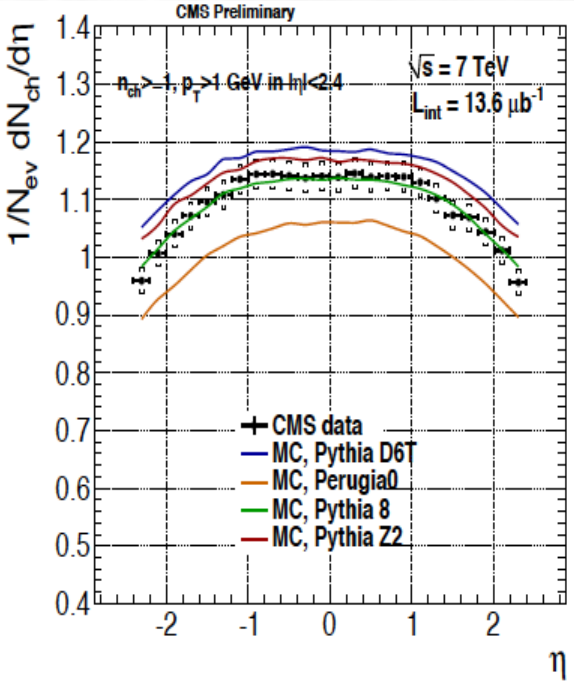
- Most of the particles produced in pp collisions arise from semi-hard (multi)parton scatterings
→ modeled phenomenologically → experimental results provide important input for tuning various models and event generators

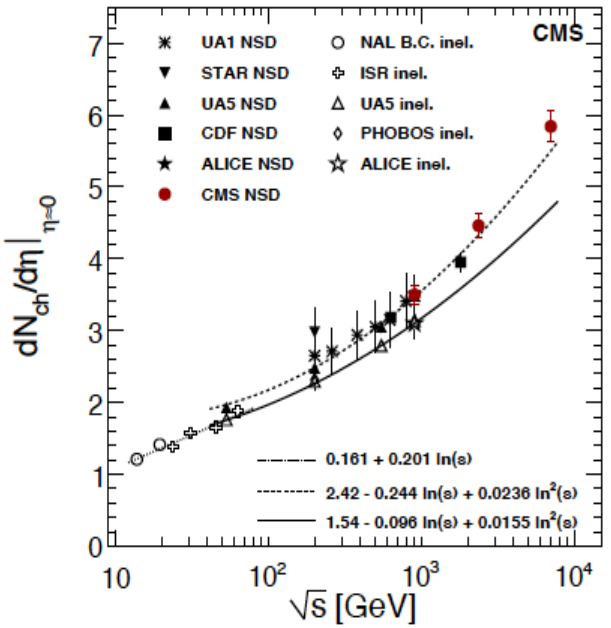
- Both soft and hard scatterings are studied
→ measurement of $dN_{ch}/d\eta$ for $p_T>0.1$ GeV and $p_T>1$ GeV

Introduction (pseudorapidity distribution) (2)

- Central and forward pseudorapities were covered (measurement performed with TOTEM)
- Inclusive measurements of the pseudorapidity and transverse momentum distributions of charged particles previously measured in pp and $p\bar{p}$ collisions for different centre-of-mass energies and phase space regions







Introduction (leading-track transverse momentum distribution)

- Observable $\frac{1}{N}\frac{dN_{ch}}{dp_{T,leading}}$ sensitive to the unitarity bound set

  by inelastic proton-proton cross-section

- The distribution of the integrated leading track transverse momentum $D(p_{T,\,min})$ has been also shown and is defined as:

$$D(p_{T,min}) = \frac{1}{N} \sum_{p_{T,leading} > p_{T,min}} dp_{T,leading} \left(\frac{dN_{ch}}{dp_{T,leading}} \right)$$

- The distribution integrated over the leading track transverse momentum above a $p_{T,\,min}$ value probes the transition from the perturbative to the non-perturbative region → would be interesting to see the saturation in the low p_T region

Event selection

Data

- Common CMS+TOTEM low pile up run (L=17.4 nb^{-1})
- Minimum bias trigger provided by TOTEM (T2 track on either side)
- Trigger events put in two categories:
  - *Inclusive sample:* reconstructed track on either side of T2
  - *Non-single diffractive (NSD) enhanced:* reconstructed tracks on both T2 sides (used only for $dN_{ch}/d\eta$)

  Optimised selection of primary tracks in T2 → reduction of secondary tracks

  → reduction of events migration between the event topologies
- Track selection:
  - Good quality tracks in $|\eta|^{track}<2.4$
  - Track-Vertex association
  - For $dN_{ch}/d\eta$: $p_T>0.1$ GeV or $p_T>1$ GeV
  - For $dN_{ch}/dp_{T,leading}$ analysis: $p_T>0.4$ GeV and $N_{ch}\geq 1$

Stable particle level definition

Defined as primary charged particles (lifetime $c\tau > 1$ cm) and decay products of particles with $c\tau < 1$ cm

Two different event classes defined:

- *Inclusive:* at least one charged particle on either side in the acceptance of T2 with p_T>40 MeV:

$$5.3 < \eta < 6.5 \quad \text{OR} \quad -6.5 < \eta < -5.3$$

- *Non-single diffractive (NSD) enhanced:* at least one charged particle on both sides in the acceptance of T2 with p_T>40 MeV:

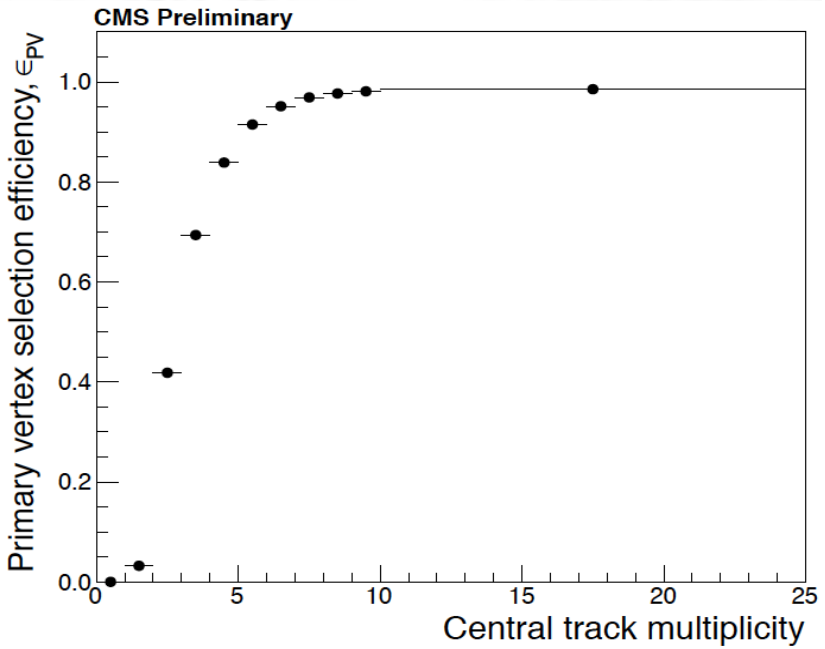
$$5.3 < \eta < 6.5 \quad \text{AND} \quad -6.5 < \eta < -5.3$$

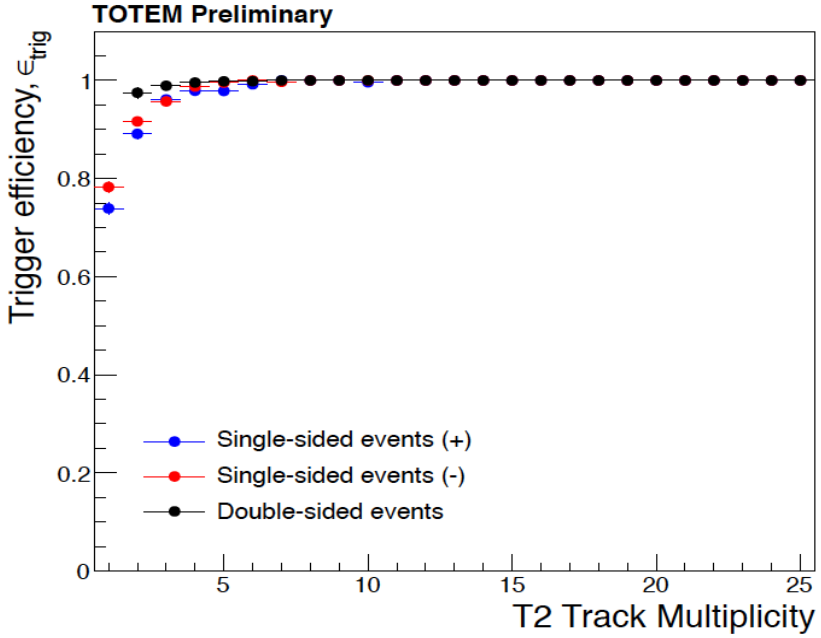
Analysis strategy and corrections (1)

$$\frac{1}{N}\frac{dN_{ch}}{d\eta} \sim \frac{C_{T2}\Delta N_{tracks}(M,p_T,\eta)\ \omega_{track}(M,p_T,\eta)\ \omega_{event}(M,n_{T2})}{\Delta\eta \sum_M N_{evt}(M)\ \omega_{event}(M,n_{T2})}$$

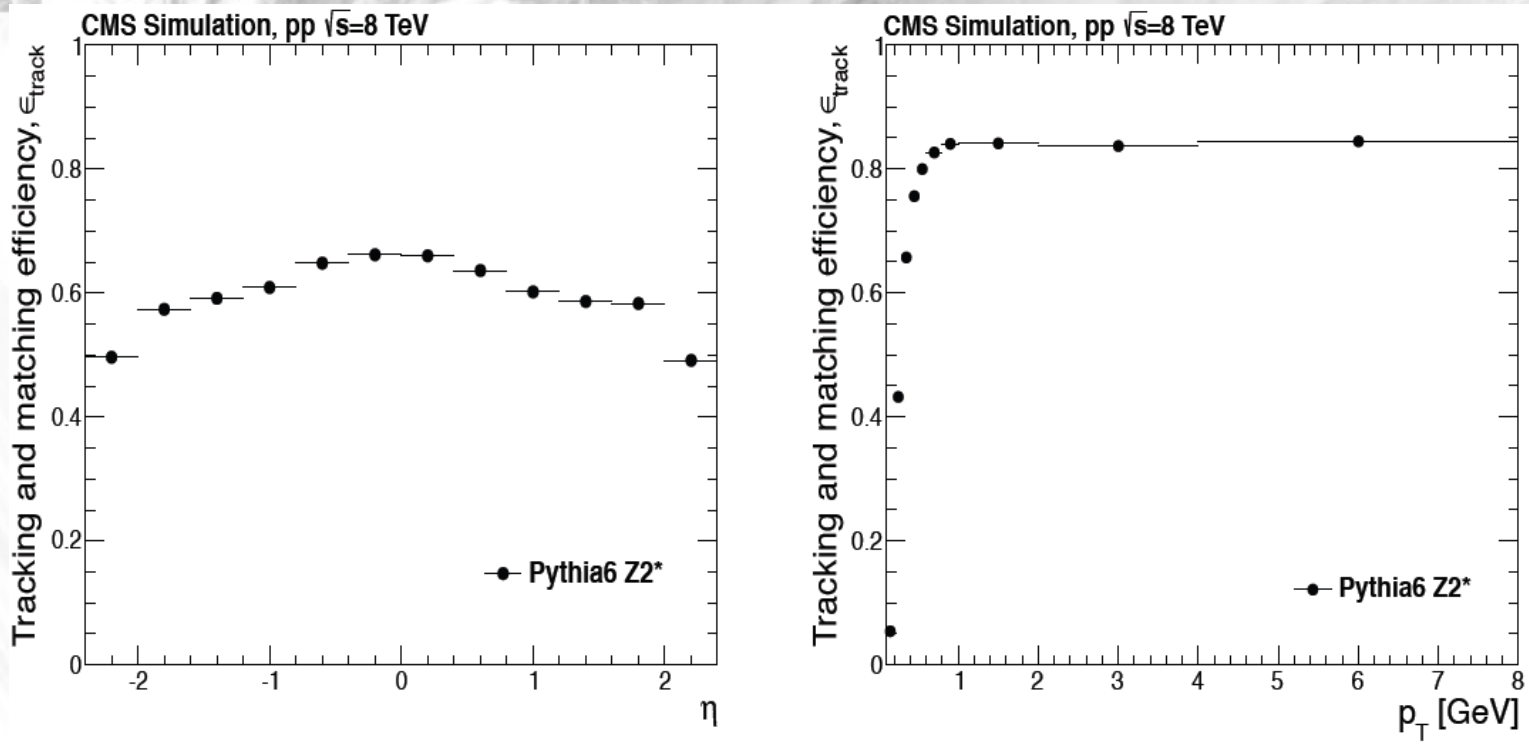
High purity/resolution of track reconstruction → bin-by-bin corrections dependent of multiplicity *M*, pseudorapidity *η*, transverse momentum p_T:

- ω_{event} – trigger and vertex reconstruction efficiency
- ω_{track} – tracking efficiency and non-primary tracks correction
- C_{T2} – T2 efficiency correction factor





Analysis strategy and corrections (2)



- Tracking (and matching) efficiency >60%, dropping <10% at low p_T bins
- Correction for non-primary tracks O(2-3%) up to 15%
- Primary particles giving multiple reconstructed tracks contributes <1%
- Model dependence <1% (estimated from PYTHIA6 Z2* and PYTHIA8 4C)

Analysis strategy and corrections (3)

$$\frac{1}{N_{events}}\frac{dN_{ch}}{dp_{T,leading}} = \frac{\Delta N_{track}\cdot\epsilon_{trig}\cdot\omega_{track}}{N^{sel}_{event}\cdot\epsilon_{trig}\cdot\Delta p_{T,leading}}$$

ϵ_{trig} - the same as in $dN_{ch}/d\eta$ analysis

$$\omega_{track} = C_{T2}\cdot C$$

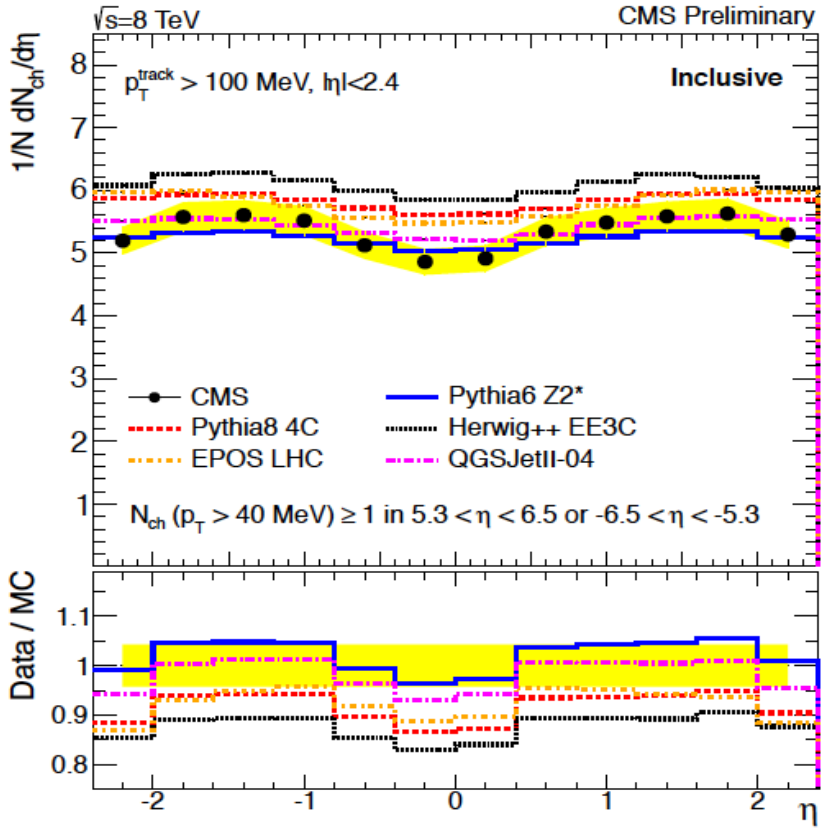
$$C = \frac{\left(\frac{1}{N}\frac{dN_{ch}}{dp_{T,leading}}\right)^{gen}}{\left(\frac{1}{N}\frac{dN_{ch}}{dp_{T,leading}}\right)^{rec}}$$

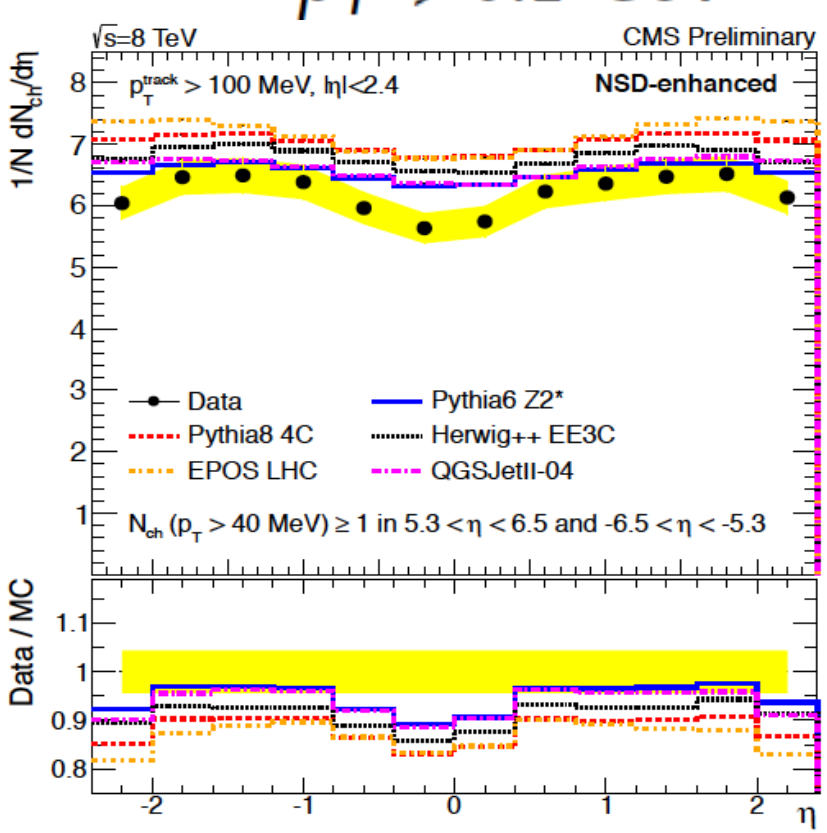
bin-by-bin correction to hadron level

- Average correction factors estimated from different event generators used
- For $p_{T,leading} > 0.8$ GeV corrections <10%;
- Correction factors and associated systematic uncertainties increase for $p_{T,leading} < 0.8$ GeV

Results (1)

p_T >0.1 GeV

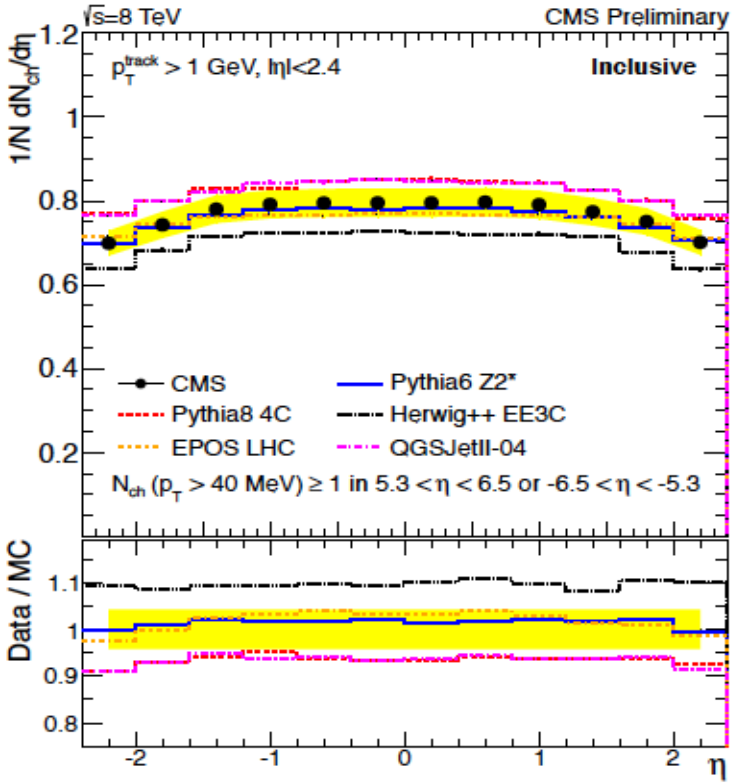


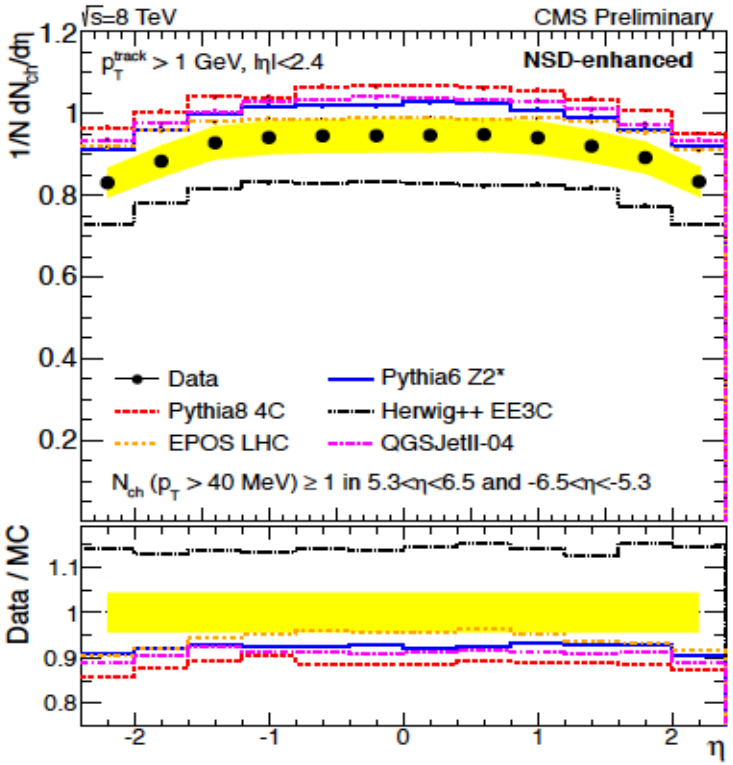


- Inclusive measurement well described by PYTHIA 6 (Z2*) and QGSJETII-04
- Models predictions for the NSD sample overshoot the data (the best description by PYTHIA 6 (Z2*) and QGSJETII-04)

Results (2)

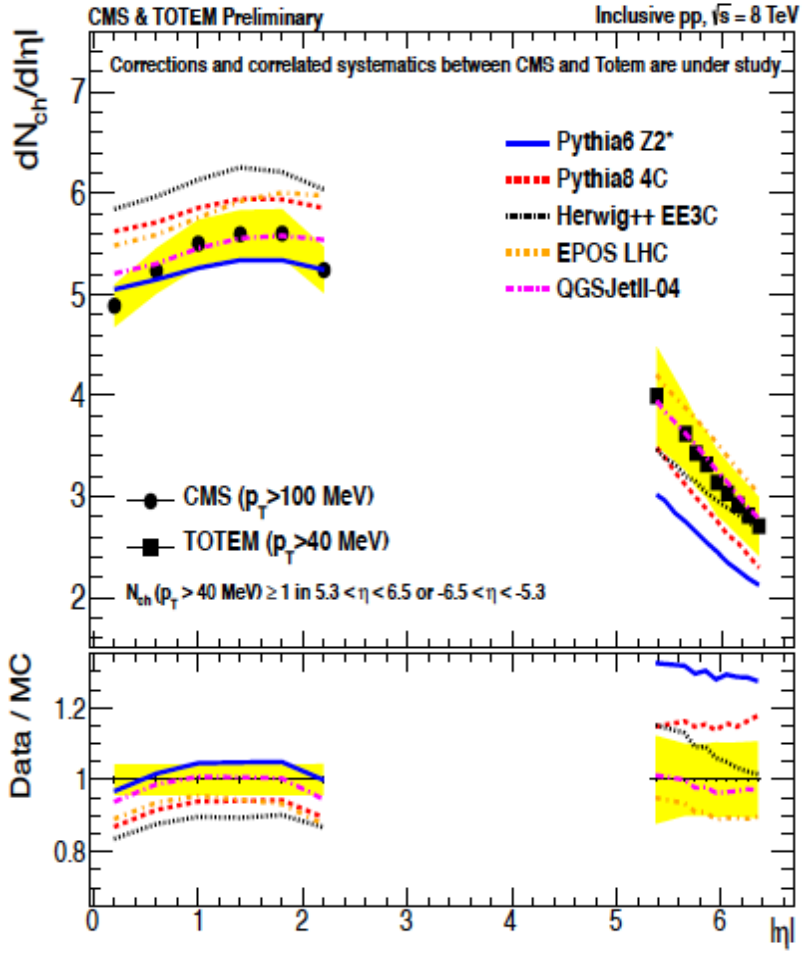
$p_T > 1$ GeV

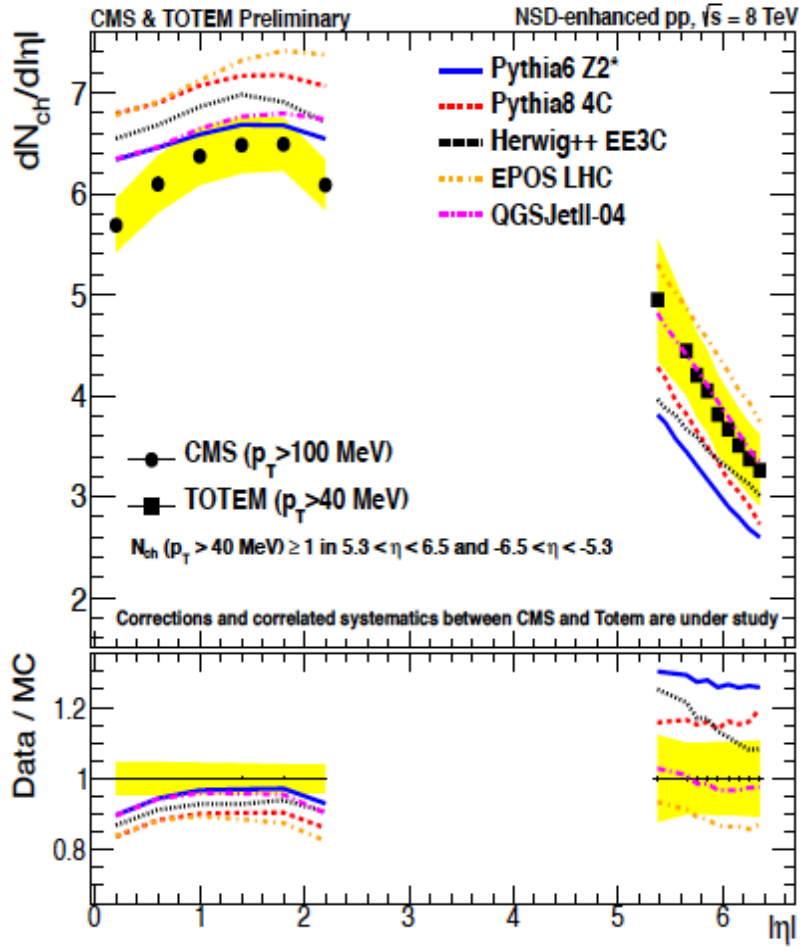




- Inclusive measurement well described by PYTHIA 6 (Z2*) and QGSJETII-04
- Models predictions for the NSD sample do not well describe the data (data points are in between predictions)

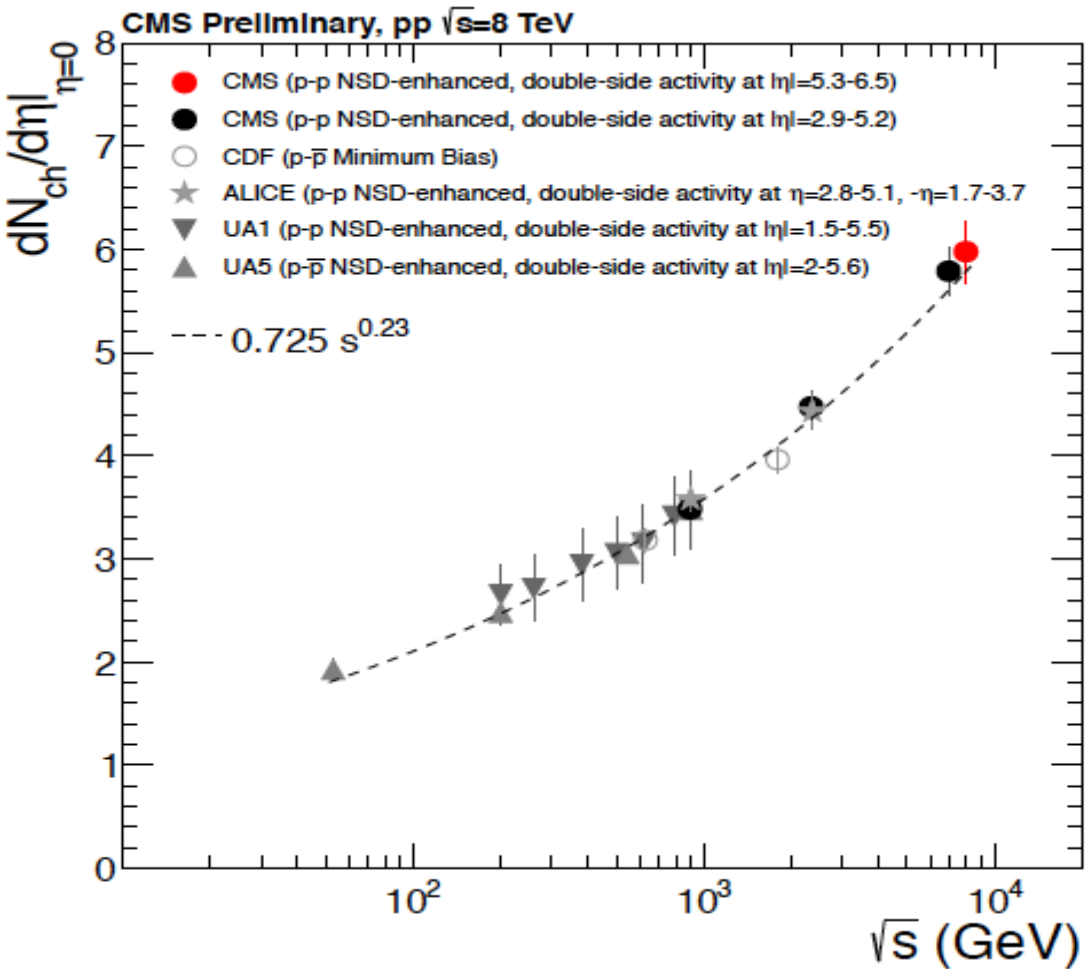
Combined CMS-TOTEM results





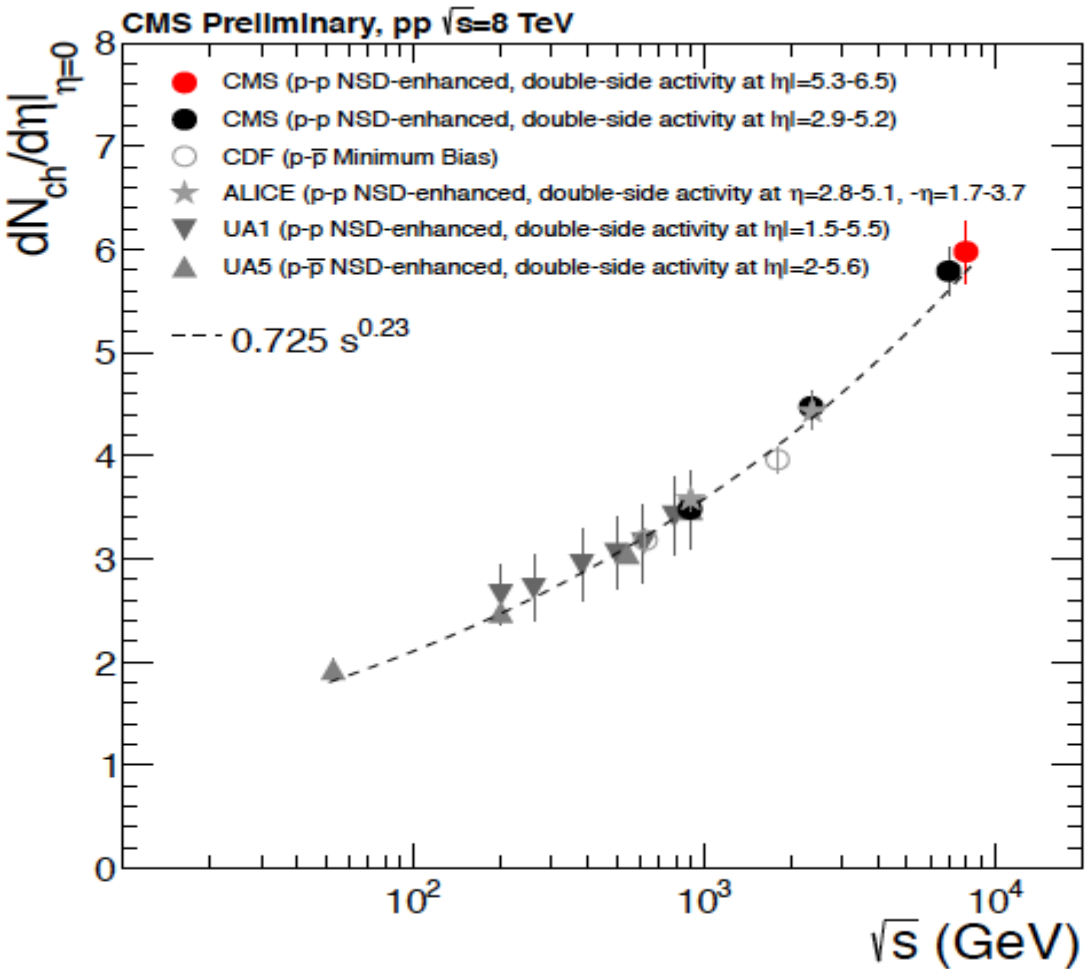
- Data and uncertainties taken from the average of $\pm\eta$ data points

Centre-of-mass energy dependence



- Centre-of-mass energy dependence of $dN_{ch}/d\eta|_{\eta=0}$
- Comparison with previous NSD measurements at $\sqrt{s} = 53 - 8000$ GeV
- Latest (highest $\sqrt{s}$) CMS measurement follows power-law trend ($\sim s^{\epsilon}$) with exponent $\epsilon \sim 0.23$

Centre-of-mass energy dependence



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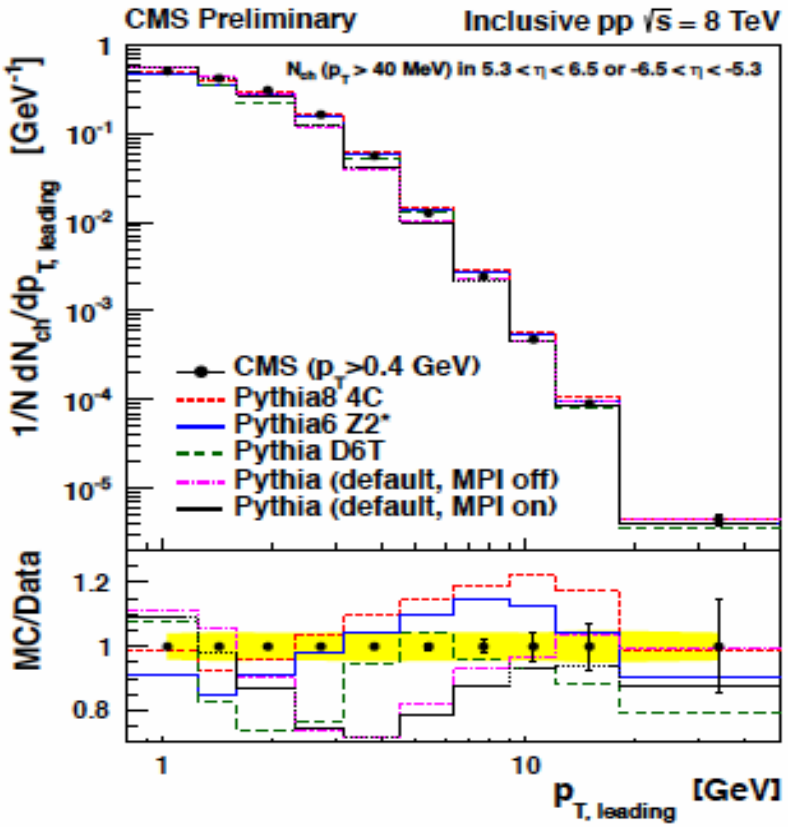
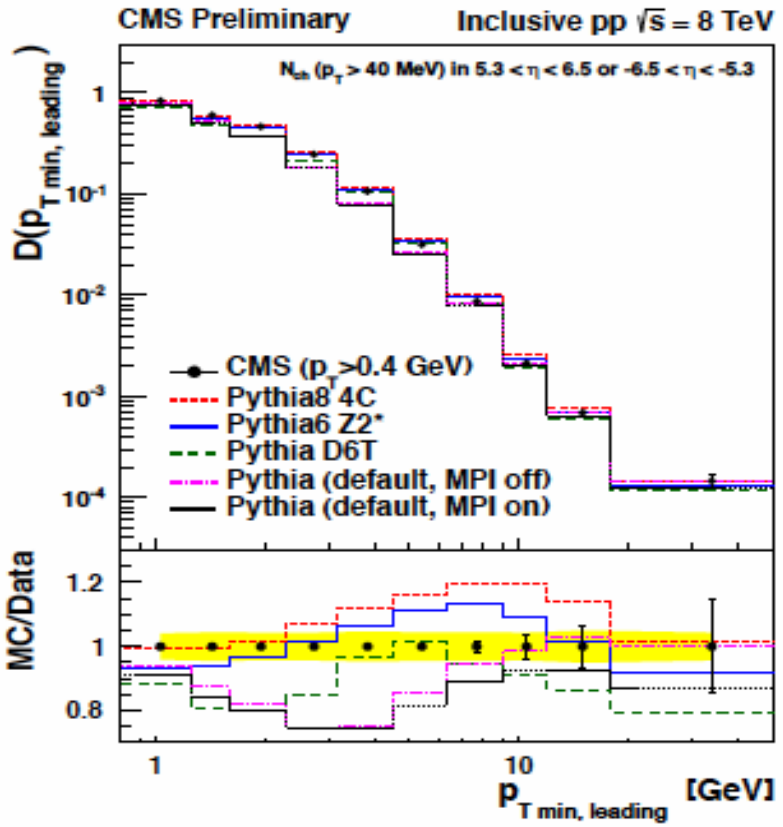
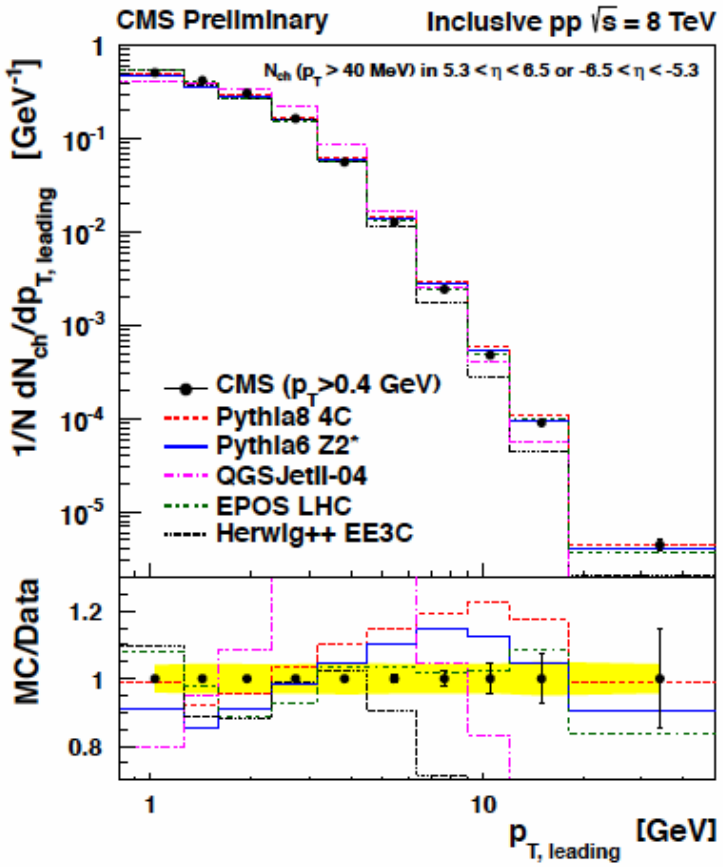
Leading track distributions – results (compared with PYTHIA tunes)

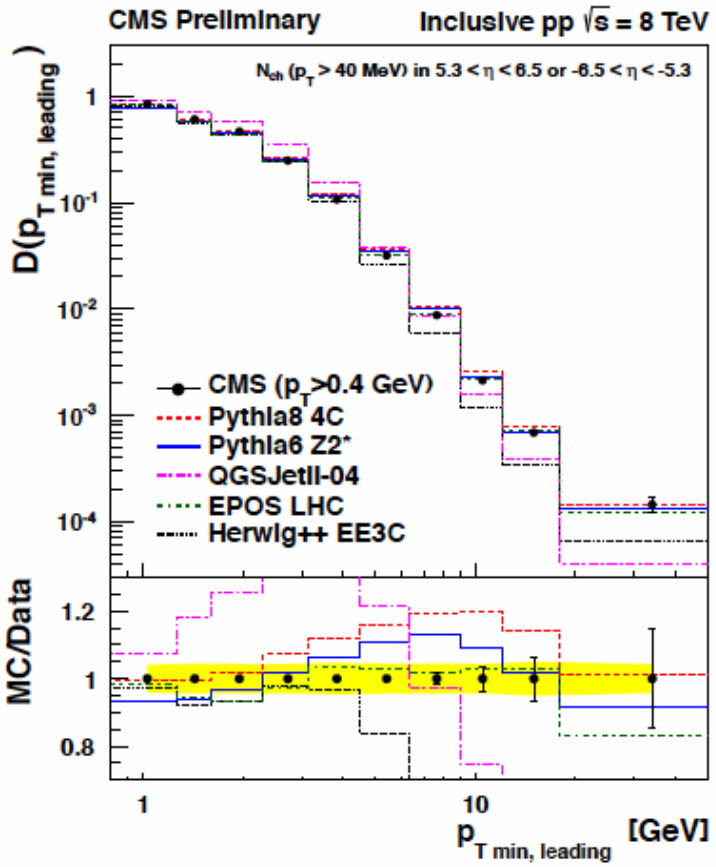




- Shape of the data not well described
- Switching on/off MPI does not seem (strangely) to improve data-MC agreement

Leading track distributions – results (compared with MC generators)





- QGSJETII-04 and Herwig++ fail to describe the measurements
- EPOS LHC in good agreement with the data

Summary and conclusions (1)

Pseudorapidity distributions:

- Fully corrected pdeudorapidity distributions of charged particles with p_T>0.1 GeV and p_T>1 GeV in central region ($|\eta|$<2.4) are presented for the inclusive and NSD-enhanced data samples

- Inclusive measurements better described by existing event generators and tunes

- Data provide an input for further tuning and testing models

Summary and conclusions (2)

Leading track transverse momentum distributions:

- Leading track p_T distribution in central region ($|\eta|<2.4$) presented for tracks with $p_T>0.8$ GeV
- The distribution integrated over the leading track transverse momentum above a $p_{T,\,min}$ value probes the transition from the perturbative to the non-perturbative region
- In the range of $p_{T,\,min}$ of a few GeV the saturation of the normalised distribution is already visible → this region is not well described by theoretical predictions obtained from various Monte Carlo event generators

Thank you for your attention!

Back up material

Systematic uncertainties

Table: Summary of systematic and statistical uncertainties. The values in parentheses apply to the leading-track dN_{ch}/dp_T measurement.

Source	Uncertainty (%)	
	Inclusive	NSD
Primary vertex selection	0.1	0.1
Tracking efficiency	4.0 (4.0)	4.0
Trigger efficiency	0.1	0.1
Model dependence	1.0 (2.3)	1.0
T2 correction	1.5 (0.7)	1.0
Pileup	0.1	0.1
Statistical	0.1 (0.3–14.6)	0.1
Total	4.4 (4.8)	4.2