Inclusive hadron production in pp collisions in CMS: pseudorapidity and leading transverse momentum distributions of charged particles at $\sqrt{s}$=8 TeV

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Outline

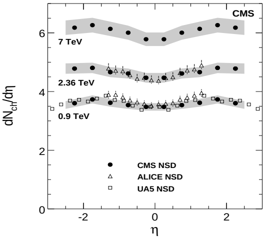
- Introduction
- CMS tracker and track reconstruction
- Event selection
- Analysis methodology and corrections
- Results
- Conclusions

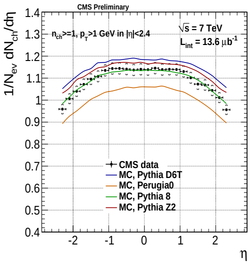
Combined analysis with TOTEM T2
(for more details see also slides from Mirko Berretti: "Cross sections and forward multiplicities measurements with TOTEM" - DIS 2013, 23rd April)

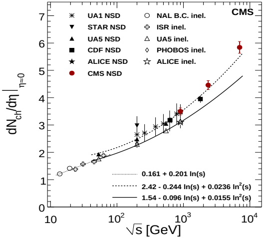
Introduction

Pseudorapidity distribution of charged particles

- Particle yields and kinematic distributions are essential for understanding of the physics of hadron production including the relative roles of soft and hard scattering contributions
- The bulk of particles produced in pp collisions arise from semi-hard (multi)parton interactions → phenomenological models → tuning based on experimental data
- Measurement of $dN_{ch}/d\eta$ in $|\eta| < 2.4$ and for $p_T > 0.1$ GeV and $p_T > 1$ GeV allows the study of both softer and harder scatterings
- Performed in common with TOTEM → test of model predictions from central to forward pseudorapidities in a previously unexplored phase-space region
- Complementing previous measurements at different centre-of-mass energies



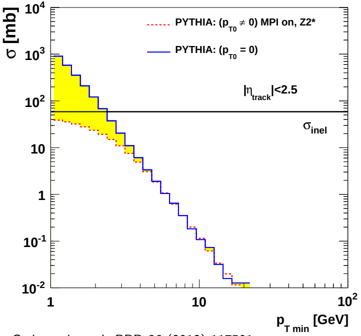




Introduction

Leading track transverse momentum distribution

- Proposed as an observable sensitive to the bound set by the inelastic proton-proton cross section σ_{inel}
- Integrated highest-p_T (leading) track transverse momentum distribution defined as:
  $D(p_{T,min}) = \frac{1}{N} \sum_{p_{T,min}} dp_{T,leading} \left(\frac{dN_{ch}}{dp_{T,leading}} \right)$
- Similar and comparable to low p_T jets inclusive analysis



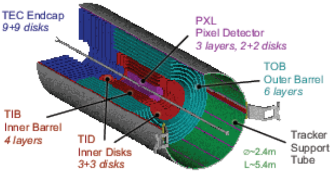
A. Grebenyuk et al. PRD 86 (2012) 117501

- Partonic 2→2 cross section divergent towards very low p_T ($\sim 1/p_T^2$)
- In PYTHIA the rise of $\sigma_{2\rightarrow 2}$ is controled by multi-parton interactions and a regularization factor (PAR(82)∼1 GeV) tuned to data
- Interesting to see the saturation in the low p_T region

for more details see also next talk by A. Grebenyuk

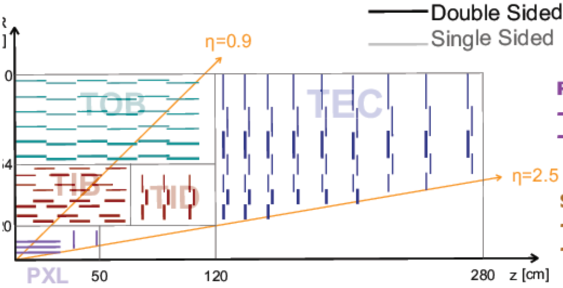
The CMS Tracker

CMS tracker detector



Largest silicon tracker ever built.
Active area: ~200 m²
In operation since July 2008.

Immersed in a 3.8 T magnetic field.
$\sigma(p_T)/p_T \sim 1$-2% (at p_T=100 GeV/c)
IP resolution~10-20 μm (at p_T=10-100 GeV/c)



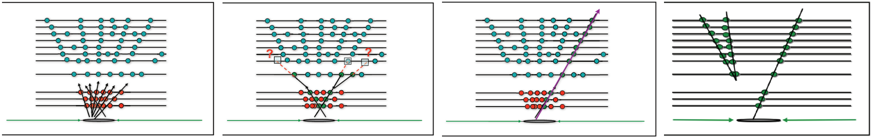
Pixel detector:
- ***66M readout channels***
- ***100x150 μm²***

Strip detector:
- ***~9M readout channels***
- ***80-205 μm pitches***

Track reconstruction

Combinatorial Track Finder: iterative tracking procedure in 4 steps

1. Seeding **2. Track finding** **3. Track fitting** **4. Track selection**



- **Seeding**: Initial track candidates made from hit triplets or pairs with the beamspot (seeds not compatible with the beamspot are discarded). Initial estimate of the trajectory.
- **Track finding**: Each seed is propagated to the successive layers, using a Kalman filter. Search for additional hits that can be assigned to the track candidate.
- **Track fitting**: provide best possible estimate of each trajectory's parameters by means of a Kalman filter and smoother
- **Track selection**: discard tracks not passing certain minimum of criteria (e.g. minimum layers with a hit, goodness of fit, etc.), set quality flags (high purity, tight, loose,...),

Event selection

Data

- Common CMS+TOTEM low pile up run with non-standard β*=90m optics configuration (L=17.4 nb^{-1})
- Minimum bias trigger provided by TOTEM (T2 track in either side)
- Triggered events further categorized in two event samples:
  - *Inclusive sample*: reconstructed track in either hemishpere in T2
  - *Non-single diffractive (NSD) enhanced*: reconstructed tracks in both hemispheres in T2 (double-sided events) [only used for $dN_{ch}/d\eta$]
  - Optimised selection of primary tracks in T2
    - ⋆ Smaller probability of secondary tracks giving event sample migrations
- Track selection:
  - Good quality tracks in $|\eta|^{track}$ <2.4
  - Track-Vertex association
  - for the $dN_{ch}/d\eta$ analysis: $p_T > 0.1$ or 1 GeV;
  - for the $dN_{ch}/dp_{T,leading}$ analysis: $p_T > 0.4$ GeV and $N_{ch} \geq 1$

Stable particle level definition

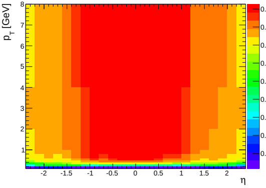
- Defined as primary charged particles or decay products with proper lifetimes $c\tau$ <1 cm
- Two different event samples defined:
  - Inclusive: at least one charged particle in 5.3< η <6.5 OR -6.5< η <-5.3 with p_T >40 MeV
  - NSD-enhanced: at least one charged particle in 5.3< η <6.5 and -6.5< η <-5.3 with p_T >40 MeV (double-sided events)

Methodology and Corrections

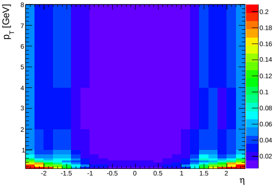
$$\frac{1}{N}\frac{dN_{\rm ch}}{d\eta} \sim \frac{C_{T2}\Delta N_{\rm tracks}(M,p_{\rm T},\eta)\ \omega_{\rm track}(M,p_{\rm T},\eta)\ \omega_{\rm event}(M,n_{T2})}{\Delta\eta\sum_M N_{\rm evt}(M)\ \omega_{\rm event}(M,n_{T2})}$$

High purity/resolution of track reconstruction → Bin-by-bin corrections in multiplicity, η, p_T:

$\omega_{\rm event}$ - accounts for trigger and vertex reconstruction efficiency
ω_{track} - tracking efficiency & non-primary tracks correction
C_{T2} - T2 efficiency correction factor

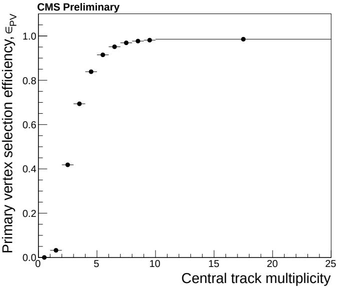


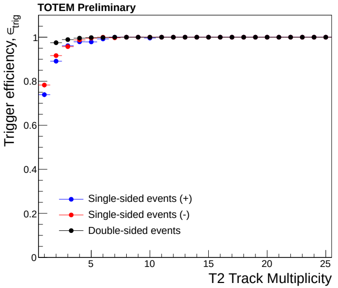
Tracking efficiency



Non-primaries

- 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)
- C_{T2} at the level of 4% (model uncertainty ~1-3% from EPOS LHC and PYTHIA8 4C)





Methodology and Corrections

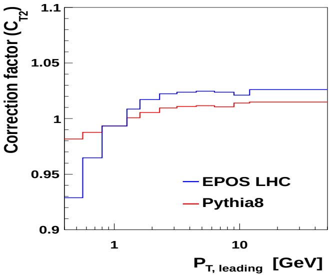
$$\frac{1}{N_{events}} \frac{dN_{ch}}{dp_{T,leading}} = \frac{\Delta N_{track} \cdot \epsilon_{trig} \cdot \omega_{track}}{N^{sel}_{event} \cdot \epsilon_{trig} \cdot \Delta p_{T,leading}}$$

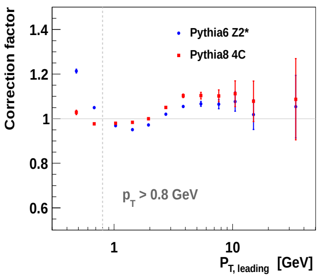
ϵ_{trig} - the same as in $dN_{ch}/d\eta$ analysis

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

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

bin-by-bin correction to hadron level

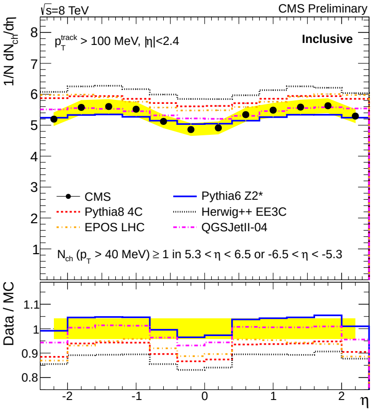


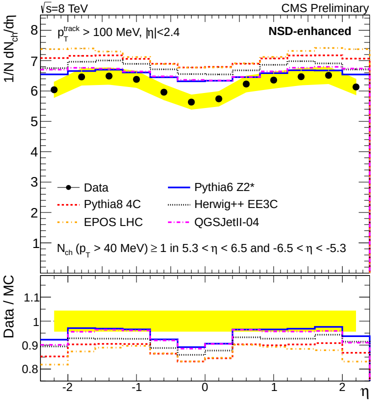


- Average correction factors estimated from different event generators used
- For $p_{T,leading} > 0.8$ corrections <10%;
- Correction factors and associated systematic uncertainties increase for $p_{T,leading} < 0.8$ GeV

Results I

$p_T > 0.1$ GeV

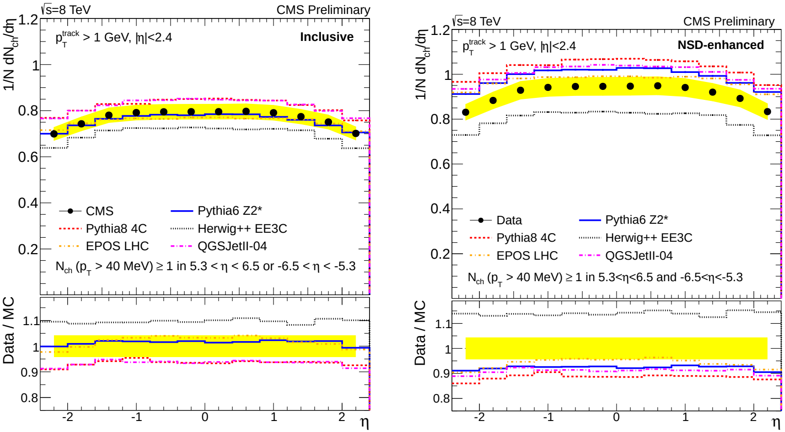




- Predictions vary within 10-20% for the inclusive and NSD-enhanced sample
- Inclusive measurement well described by PYTHIA6 Z2* and QGSJETII-04
- Models oversetimate the data for the NSD sample (better descriptions again by PYTHIA6 Z2* and QGSJETII-04)

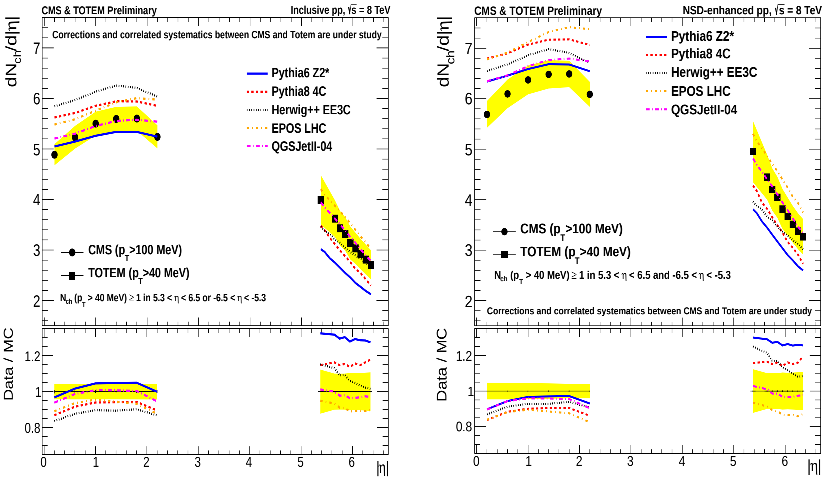
Results II

$p_T > 1$ GeV



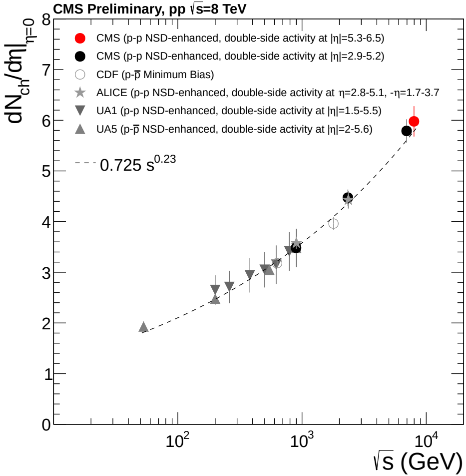
- Predictions vary within 20-30% for the inclusive and NSD-enhanced samples
- Inclusive measurement well described by PYTHIA6 Z2* and EPOS LHC
- NSD measurements not well described; data in between predictions

Combined CMS-TOTEM results



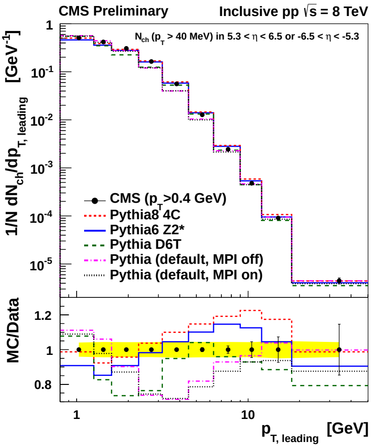
- Data and uncertainties taken from the average of $\pm\eta$ data points
- The central value corrections and uncertainty correlations between CMS & TOTEM need further investigations, especially for the extreme points ($|\eta| = 2.2$ and $|\eta|$=5.4)

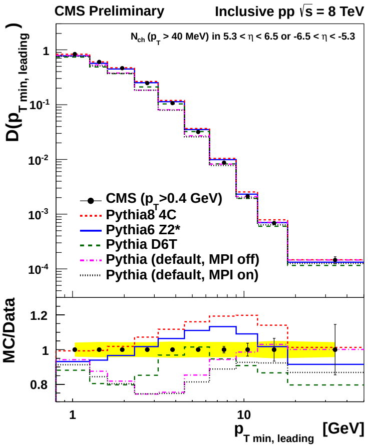
Centre-of-mass energy dependence



- 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 $\epsilon \sim 0.23$

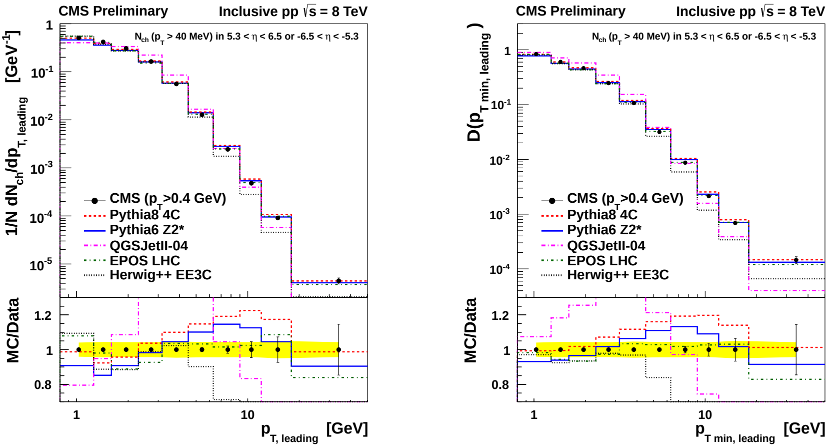
Leading track distributions: Data vs. PYTHIA tunes





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

Leading track distributions: Data vs. MC generators



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

Summary and conclusions

Charged particle pseudorapidity distributions

- Fully corrected pseudorapidity distributions of charged particles with $p_T > 0.1$ and 1 GeV in $|\eta| < 2.4$ are presented for different event samples (inclusive and NSD-enhanced)
- Common measurement with TOTEM T2 applying the same event selection (results to be combined with $dN_{ch}/d\eta$ in T2)
- Inclusive measurements better described by current event generators and tunes
- Data provide useful input for tuning and testing the models from central to forward pseudorapidities

Leading track transverse momentum distributions

- Leading-track p_T distribution presented for tracks with $pT > 0.8$ GeV in $|\eta| < 2.4$.
- Integrated distribution over the leading track transverse momentum above a pT, min value probes the transition from the perturbative to the non-perturbative region
- For $p_{T,min}$ of a few GeV "taming" behavior of the cross section is already visible; this region is not well described by models

Additional material

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

- Tracking efficiency systematic uncertainty dominant for all measurements
- Statistical errors dominant for high p_T tail of the leading track spectrum

Closure tests

- Basic sanity check
- Corrections applied to the simulated sample at detector level $\rightarrow$ correcting back to stable particle level