Measurement of charged particle spectra in pp collisions at CMS

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Outline

- Motivation of interest
- State of knowledge
- The CMS Silicon Tracker: layout and performances
- Minimum Bias trigger performances
- CMS proposed analysis
- Conclusions
Motivation

Minimum Bias (mostly non-single diffractive inelastic interactions)
~65% of the total LHC scattering process: \( \sigma_{NSD} = \sigma_{tot} - \sigma_{elas} - \sigma_{SD} \)

- analyse global properties of hadron production:
  higher energies \( \rightarrow \) new opportunity for comprehension, sensitivity to fragmentation models

- predict background levels associated to many physics processes:
  at design luminosity of \( \mathcal{L}=1.0 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1} \) and for the final expected beam bunch pattern of 2808\( \times \)2808 there will be on average 20 collisions per recorded event: 1 signal + \( \sim \)19 min-bias pile-up

- understand the complex nature of the radiation environment in which LHC's detector systems will operate (particular attention for Si tracker)
History

- asymptotic scaling of multiplicity distribution in hadron-hadron collisions (KNO scaling) predicted in 1972;
- early confirmation at 10-30-60 GeV;
- first observations of violation at higher energies from the UA5 collaboration (c.m. energies of 200-546-900 GeV) → notion of multiple parton interaction [T. Sjöstrand prd 36 (1987) 2019] ;

- CDF at Tevatron:
  - minimum bias trigger events at 1800 and 630 GeV
  - novel approach dividing dataset into “soft” and “hard” subsamples (based on presence of calorimetric activity in the transverse region)
Evidence of energy invariance in "soft" sample:

- a) KNO scaling
- b) energy invariant $p_T$ distributions at fixed multiplicities
  → in purely "soft" interactions the number of produced charged particles is the only global event variable changing with $\sqrt{s}$
  ← consequence/confirmation: mean $p_T(N)$ invariance
- c) $\langle p_T \rangle_{\text{event}}$ dispersion scaling and compatibility with no dynamical fluctuations
The Pixel Tracker

- ~1 m total length
- 3 barrel layers at radii of 4, 7 and 11 cm
- 2 disks on each side at 34 and 46 cm
- about 60 million of pixels with shape of $100 \times 150 \, \mu m^2$
- design resolution of about 10 $\mu m$
  for the $r-\phi$ measurement and
  about 20 $\mu m$ for the $z$
  measurement

High resolution three dimensional space points:

\[
\rightarrow \text{primary vertex reconstruction} \\
\rightarrow \text{track seeding} \\
\rightarrow \text{fast HLT track reconstruction}
\]
Performances

**Tracker:**
November cosmic ray data acquisition with magnetic field (CRAFT)

- **Operational Fraction:**
  - Barrel pixels: 99.1%
  - Forward pixels: 94.0%
  (readout chips without bias voltage, reparation in course)

- **Cosmic Track Finding Efficiency:**
  - Tag&Probe technique:
    - tag = cosmic tracks in muon systems
    - probe = tracker tracks CKF track algorithm
  - Combinatorial Track Finder, standard for collision
  (Kalman filter)

<table>
<thead>
<tr>
<th>Efficiency (%)</th>
<th>Data</th>
<th>MC</th>
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<tbody>
<tr>
<td>CKF</td>
<td>99.5 ±0.1</td>
<td>99.9 ±0.1</td>
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**MB trigger:** hadronic forward based

- **Backgrounds:**
  - **Beam-gas** collisions: at start up (43×43 bunch pattern) expected rate of 5 mHz; for the full luminosity (2808×2808 bunch pattern) expected rate of 35 kHz. Comparing to the beam bunch crossing-clock collision rate (32 MHz): 1 collision per 1000 would be a beam gas interaction;
  - **Beam-halo** collisions: no events triggered out of 10^4 MC events;
  - **Cosmics**: measured negligible during cosmic data acquisition with magnetic field;

Charged particle spectra at CMS
CMS proposed analysis

- Charged spectra with reconstructed particle and low-$p_T$ adapted algorithm
- Pseudorapidity distribution with hit-counting
- {Tracklets: work in progress}
Low $p_T$ tracks reconstruction (I)

Pixel subdetector permits:
- specific low $p_T$ algorithm
- same analysis for pp and PbPb interaction (thanks to low occupancy)

Basic logic (both standard and low $p_T$ tracks): make hit pairs then predict range of possible coordinates of the third hit

Criteria specific for low $p_T$:
- tracks coming from a cylinder of origin;
- minimum $p_T$ requirement (0.075GeV/c);
- the track must be able to reach the third hit layer candidate; helix propagation;

Triplet cleaning:
- fake rejection checking compatibility between predicted incidence angle and cluster shape

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Charged particle spectra at CMS
Low $p_T$ tracks reconstruction (II)

Essentially flat acceptance above $p_T$ of 0.1, 0.2 and 0.3 GeV/$c$ for pions, kaons and protons.

Flat efficiency in the range $|\eta|<1.5$, except for protons.
Low $p_T$ tracks reconstruction (III)

Multiple counting (essentially looper) below 1% around $\eta = 0$, quickly to zero for $|\eta| > 0.5$

Clean up imposing vertexing + cluster-shape/incident-angle relation:

- low fake rate at 0.5%(2%) for $\eta = 0$ ($|\eta| = 2$), below 1%
- for $p_T > 0.16\text{GeV}/c$

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Charged particle spectra at CMS
Charged hadron spectra with low $p_T$ tracks

Binning measured tracks in $\Delta N_{\text{measured}}(\eta, p_T)$ and correcting for all the considered effects:

$$\Delta N_{\text{corrected}} = \frac{(1 - \text{fakeRate})(1 - \text{feedDown})}{\text{geomAccep} \cdot \text{algoEffic} \cdot (1 - \text{multiCount})} \cdot \Delta N_{\text{measured}}$$

→ Triple differential invariant yield:

$$E \frac{d^3 N}{dp^3} = \frac{d^3 N}{d \phi dy dp_T} = \frac{1}{2 \pi p_T} \frac{d^2 N}{dy dp_T} = \frac{1}{2 \pi p_T} E \frac{d^2 N}{p d \eta dp_T}$$

Fitted by a reparametrization of a Tsallis function:

$$E \frac{d^3 N}{dp^3} = \frac{dN}{dy} \frac{(n-1)(n-2)}{2 \pi nT [nT + (n-2) m]} \left[1 + \frac{E_T(p_T)}{nT}\right]^{-n}$$

→ thermal low $p_T$:

$$E \frac{d^3 N}{dp^3} = A \exp\left[-\frac{E(p_T)}{T}\right]$$

→ high $p_T$ empirical power-law tail:

$$E \frac{d^3 N}{dp^3} = \frac{A}{(1 + p_T/p_0)^n}$$

Combining both quantities obtaining the $p_T$ integrated $dN/dy$ distribution from fit!
Charged hadron spectra with low $p_T$ tracks

Good high $p_T$ description from the fit

Bad low $p_T$ description for unidentified hadrons

$\rightarrow$ sum the measured differential yields for $0.2 < p_T < 2 \text{GeV/c}$

$\rightarrow$ thermal fit extrapolation down to 0 GeV/c

Better situation for identified hadrons:

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Charged particle spectra at CMS
Charged hadron spectra with low $p_T$ tracks

- Differential cross-section:

$$d \sigma_{\text{inelastic}} = \frac{dN}{\Delta N_{\text{events}}} \cdot \sigma_{\text{inelastic}} = \frac{dN}{\Delta N_{\text{events}}} \cdot \frac{\Delta N_{\text{events}}}{\text{Lumi} \Delta t} = \frac{dN}{\text{Lumi} \Delta t}$$

(measuring time $\Delta t$ and luminosity $\text{Lumi}$ known and independently measured)
Hit counting method

• Early startup:
  low luminosity scenario → no pile-up
  (needed only $10^4$ events here for the analysis)

• Method:
  (as PHOBOS@RHIC)
  counting hits on one pixel barrel layer
  → correcting for:
    • Looper particle
    • Decays from primary
    • Particles from beam-pipe interaction

• Small minimum $p_T$ requirement:
  ~30 MeV/c to leave hit in the first layer
  (to be compared with 75 MeV/c request from full tracking)
Hit counting method

Hit selection criteria: release of energy $dE/dx$ in the Silicon

**Primary**: average energy deposit proportional to $\cosh(\eta)$ and Landau-distributed around the mean

**Background**: no strict relation crossing-angle/pseudorapidity
Hit counting method

Ingredients for calculating the pseudorapidity distribution of charge hadrons:

\[
\frac{dN}{d\eta} = \frac{\sum_M E_t^{\text{real}} \cdot \frac{1}{\epsilon(M)} \cdot \frac{dN}{d\eta}(M)}{\sum_M E_t^{\text{real}} \cdot \frac{1}{\epsilon(M)}}
\]

(* more in backup)

Systematics:

- **MODEL DEPENDENCES from corrections**
  
  the analysis uses 2 MC dataset: one giving the correction, one acting as the “real” measure
  
  → need to evaluate the response in case of momentum and multiplicity distribution extreme differences
  
  between MC and “real” data;

  simulated scenarios:
  
  a) multiplicity-distribution*0.5 (random removal), multiplicity-distribution*2 (merging dataset), unchanged pT-distribution;
  
  b) p-distribution*0.5, p-distribution*1.5, unchanged multiplicity

- **VERTEXING**
  
  estimated effect of uncertainty on actual vertexing efficiency \((\text{eff}_\nu)\):

  analysis without vertex reconstruction → calculated the vertex bias → \(\text{sys}_\nu=(1-\text{eff}_\nu)*\text{vertex-bias}\)
Hit counting method

8% of systematics

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Charged particle spectra at CMS
Conclusion

- CMS is ready for first collisions analysis
- Results feed through to detector + physics community
- Interesting results available after 1 month of collisions (1\textsuperscript{st} analysis) or even few days (2\textsuperscript{nd} analysis)
Bibliography

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• Soft and hard interactions in ppbar collisions at sqrt(s)=1800 and 630 GeV, Physical Review D, Volume 65 072005
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• Measurement of charged hadron spectra in proton-proton collisions at sqrt(s)=14TeV, F. Sikler, K.Krajczar, CMS AN-2007/021
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Start of Back up slides
The CMS Silicon Tracker

- Total area: \( \approx 1 \text{ m}^2 \) (Pixel) + 200 m\(^2\) (Strip)
- Coverage up to \( |\eta| < 2.4 \)
- Active elements:
  66 million pixels + 9.6 million silicon strips

Pixel subdetector close to the interaction point
Track cleaning from shape

Low $p_T$ track reconstruction

Barrel (last sim)

Endcap (last sim)

Barrel (p+p Geant4)

Endcap (p+p Geant4)
Charged hadron spectra with low pT track

Particle ID: truncated mean estimator
Hit counting method

**Corrections**

- **Event selection:**
ratio between MC events passing selection cut and total events with M pixel hits:

\[ \epsilon(M) = \frac{E^{MC}_I(M)}{E^{MC}(M)} \]

dependent on the number of hits on the layer ("multiplicity" \( M \)).

→ to correct the \( M \)-dependent measured multiplicity
distribution of charged particle \( \frac{dN}{d\eta}(M) \)

- **hit/tracks:**
convert the measured number of hits \( H(\eta, M) \)
into number of charged tracks \( T(\eta, M) \)
through simulation prediction

\[ \chi(\eta, M) = \frac{H^{MC}(\eta, M)}{T^{MC}(\eta, M)} \]

\[ \leftarrow \text{small model-dependence} \]

(only detector geometry)

and finally measure the \( M \)-dependent
multiplicity distribution of charged hadrons:

\[ \frac{dN}{d\eta}(\eta, M) = \frac{1}{\chi(\eta, M)} \frac{H^{\text{real}}(\eta, M)}{E_I(M)} \]
Hit counting method

Corrections

• **Looper:**
  particle with $p_T < 800\text{MeV/c}$ not reaching calorimeters apparatus;
  both primary and secondary;
  properly rejected for high eta ($|\eta| > 2$) with the $dE/dx$ hit selection

→ estimate the hits from looper passing $dE/dx$ cut from high-eta rejected hits:

$$\text{looperHit}_{\text{passing}}^{\text{real}} = \left( \frac{\text{looperHit}_{\text{passing}}^{\text{MC}}}{\text{totalHit}_{\text{notpassing}}^{\text{MC}}} \right) \cdot \text{totalHit}_{\text{notpassing}}^{\text{real}}$$