Minimum Bias at 13 TeV

Outline of Talk

- **C2CR07:** My Min-Bias talk at Lake Tahoe in 2007.
- **MB-UE-DPS:** Relationships between Min-Bias (MB), the underlying event (UE), and double parton scattering (DPS).
- **CMS UE Tunes:** Two PYTHIA 6 tunes, three PYTHIA 8 tunes, and one HERWIG++ tune from the CMS “Physics Comparisons & Generator Tunes” subgroup.
- **MB@13TeV:** Some MB measurements from the LHC and comparisons.
- **Simultaneous UE-MB-DPS Tunes:** Can we fit UE data, MB data, and DPS sensitive with one universal tune?
There is a lot of nice MB data at 13 TeV with a variety of trigger and selection criteria. I apologize for not being able to show everything!
**Outline of Talk**

- What is Min-Bias? Does it really exist?
- "Jets" in Min-Bias Collisions. Clear Jet structure as low as 1 GeV/c!
- Extrapolating Tevatron Min-Bias to the LHC.
- Using Pile-Up collisions to Study Min-Bias. Is Pile-Up Unbiased?
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Rick Field
University of Florida
(for the CDF Collaboration)

Min-Bias at the Tevatron

Outline of Talk

► What is Min-Bias? Does it really exist?

► “Jets” in Min-Bias Collisions. Clear Jet structure as low as 1 GeV/c!

► Extrapolating Tevatron Min-Bias to the LHC.

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Proton-AntiProton Collisions at the Tevatron

Elastic Scattering

Single Diffraction

Double Diffraction

\[ \sigma_{\text{tot}} = \sigma_{EL} + \sigma_{SD} + \sigma_{DD} + \sigma_{HC} \]

1.8 TeV: 78mb = 18mb + 9mb + (4-7)mb + (47-44)mb

The “hard core” component contains both “hard” and “soft” collisions.

“Soft” Hard Core (no hard scattering)
Proton-AntiProton Collisions at the Tevatron

\[ \sigma_{\text{tot}} = \sigma_{\text{EL}} + \sigma_{\text{SD}} + \sigma_{\text{DD}} + \sigma_{\text{ND}} \]

1.8 TeV: \(78 \text{mb} = 18 \text{mb} + 9 \text{mb} + (4-7) \text{mb} + (47-44) \text{mb}\)

The “hard core” component contains both “hard” and “soft” collisions.

“Soft” Hard Core (no hard scattering)
Elastic Scattering

Single Diffraction

Double Diffraction

$\sigma_{\text{tot}} = \sigma_{\text{EL}} + \sigma_{\text{SD}} + \sigma_{\text{DD}} + \sigma_{\text{ND}}$

1.8 TeV: 78mb = 18mb + 9mb + (4-7)mb + (47-44)mb

The “hard core” component contains both “hard” and “soft” collisions.

“Soft” Hard Core (no hard scattering)

Hard Core

Beam-Beam Counters

3.2 < |\(\eta|\) < 5.9

“Hard” Hard Core (hard scattering)

CDF “Min-Bias” trigger
1 charged particle in forward BBC
AND
1 charged particle in backward BBC

The CDF “Min-Bias” trigger picks up most of the “hard core” cross-section plus a small amount of single & double diffraction.

Proton AntiProton

"Soft" Hard Core (no hard scattering)

Proton AntiProton

PT(hard)

Final-State Radiation

Outgoing Parton

Underlying Event

Underlying Event
Inelastic Collisions

Today’s terminology courtesy of Juan M. G. Luyando, Benoit Roland, and Paolo Gunnellini.
The Inelastic Non-Diffractive Cross-Section

“Semi-hard” parton-parton collision ($p_T < \approx 2 \text{ GeV/c}$)

Majority of “min-bias” events!

Multiple-parton interactions (MPI)!

“Semi-hard” parton-parton collision ($p_T < \approx 2 \text{ GeV/c}$)
The Inelastic Non-Diffractive Cross-Section

Occasionally one of the parton-parton collisions is hard ($p_T > \approx 2\text{ GeV/c}$)

Majority of “min-bias” events!

“Semi-hard” parton-parton collision ($p_T < \approx 2\text{ GeV/c}$)

Multiple-parton interactions (MPI)!
Select inelastic non-diffractive events that contain a hard scattering.

Hard parton-parton collisions is hard ($p_T > \approx 2 \text{ GeV/c}$)

The “underlying-event” (UE)!

Given that you have one hard scattering it is more probable to have MPI! Hence, the UE has more activity than “min-bias”. 

Multiple-parton interactions (MPI)!

"Semi-hard" parton-parton collision ($p_T < \approx 2 \text{ GeV/c}$)

$1/(p_T)^4 \rightarrow 1/(p_T^2 + p_{T0}^2)^2$
Fit the “underlying event” in a hard scattering process.

“Underlying Event”

Allow primary hard-scattering to go to \( p_T = 0 \) with same cut-off!

1/(\( p_T \)) \( ^4 \rightarrow \) 1/(\( p_T^2 + p_{T0}^2 \))^2

“Min-Bias” (ND)

Predict MB (ND)!

+ …
Fit the “underlying event” in a hard scattering process.

Allow primary hard-scattering to go to $p_T = 0$ with same cut-off!

$1/(p_T)^4 \rightarrow 1/(p_T^2 + p_T^2)^2$

“Min-Bias” (add single & double diffraction)

Predict MB (IN)!

SM@LHC 2016
University of Pittsburgh May 4, 2016
Most of the time MPI are much “softer” than the primary “hard” scattering, however, occasionally two “hard” 2-to-2 parton scatterings can occur within the same hadron-hadron. This is referred to as double parton scattering (DPS).
Two correlation observables that are sensitive to DPS are $\Delta S$ and $\Delta^{rel} p_T$ defined as follows:

$$\Delta S = \arccos \left( \frac{\vec{p}_T^{\text{object#1}} \cdot \vec{p}_T^{\text{object#2}}}{|\vec{p}_T^{\text{object#1}}| \times |\vec{p}_T^{\text{object#2}}|} \right)$$

$$\Delta^{rel} p_T = \frac{|\vec{p}_T^{\text{jet#1}} + \vec{p}_T^{\text{jet#2}}|}{|\vec{p}_T^{\text{jet#1}}| + |\vec{p}_T^{\text{jet#2}}|}$$

For $\gamma + 3\text{jets}$ object#1 is the photon and the leading jet (jet1) and object#2 is jet2 and jet3. For $W + \text{dijet}$ production object#1 is the $W$-boson and object#2 dijet. For 4-jet production object#1 is hard-jet pair and object#2 is the soft-jet pair. For $\Delta^{rel} p_T$ in $W + \text{dijet}$ production jet#1 and jet#2 are the two dijets, while in 4-jet production jet#1 and jet#2 are the softer two jets.
Universal UE-MB-DPS Tune

"Underlying Event"  One hard scattering plus BBR & MPI

DPS
Two hard scatterings plus BBR & MPI

"Min-Bias" (ND)  No hard scatterings plus BBR & MPI

My dream!
Universal UE-MB-DPS Tune

"Underlying Event"

One hard scattering plus BBR & MPI

DPS

Two hard scatterings plus BBR & MPI

Alternatively one can produce separate MB tunes (like ATLAS Tune A2), and separate UE tunes (like ATLAS Tune A14), and separate DPS tunes (like CMS Tune CDPSTP8S2-4j).

The experimental side of me thinks this is fine. The theoretical side of me dreams of a universal tune.
Charged particle (all $p_T$) pseudo-rapidity distribution, $dN_{\text{chg}}/d\eta$, at 1.96 TeV with no trigger (i.e. no-bias) from PYTHIA Tune DW.

Charged particle ($p_T > 0.5$ GeV/c) pseudo-rapidity distribution, $dN_{\text{chg}}/d\eta$, at 1.96 TeV with the CDF Min-Bias trigger from PYTHIA Tune DW.

About 2.5 charged particles per unit $\eta$ at $\eta = 0$.

About 0.9 charged particles ($p_T > 0.5$ GeV/c) per unit $\eta$ at $\eta = 0$.

About 1.5 charged particles ($p_T > 0.5$ GeV/c) per unit $\eta$ at $\eta = 0$ with CDF min-bias trigger.
Charged particle (all pT) pseudo-rapidity distribution, $dN_{\text{chg}}/d\eta$, at 1.96 TeV with no trigger (i.e. no-bias) from PYTHIA Tune DW.

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Charged particle (pT > 0.5 GeV/c) pseudo-rapidity distribution, $dN_{\text{chg}}/d\eta$, at 1.96 TeV with the CDF Min-Bias trigger from PYTHIA Tune DW.

About 1.5 charged particles ($p_T > 0.5$ GeV/c) per unit $\eta$ at $\eta = 0$ with CDF min-bias trigger.

What you see for “Min-Bias” depends on your trigger!
Using $c_\tau = 10\text{ mm}$ reduces the charged particle density by almost 10%! Mostly from $K_S^+ \rightarrow \pi^+\pi^-$ (68.6%) and $\Lambda \rightarrow p\pi^-$ (64.2%).
Corrected MB Observables

- Option 1: Use the Monte-Carlo to correct for the trigger bias and for the detector effects. MB observables corrected to the no trigger particle level.

- Option 2: Define the trigger at the particle level. Use the Monte-Carlo to correct for the detector effects. MB observables corrected to the triggered particle level.

\[(A) \text{ At least 1 charged particle}\left\{\begin{array}{l}
p_T > 0.5 \text{ GeV} \\
|\eta| < 2.4
\end{array}\right.\]

- **Activity**: at least 1 particle with $E > 5$ GeV
- **Veto**: no particle with $E > 5$ GeV

- Inclusive: (A)

- Inelastic enhanced: (A) + **Activity** on at least one Forward Region

- NSD enhanced: (A) + **Activity** on both Forward Regions

- SD enhanced: (A) + **Activity** on one Forward Region and **Veto** on the other side
Shows the predictions of PYTHIA Tune A, Tune DW, Tune DWT, and the ATLAS tune for the charged particle density $dN/d\eta$ and $dN/dY$ at 14 TeV (all $p_T$).

PYTHIA Tune A and Tune DW predict about 6 charged particles per unit $\eta$ at $\eta = 0$, while the ATLAS tune predicts around 9.

PYTHIA Tune DWT is identical to Tune DW at 1.96 TeV, but extrapolates to the LHC using the ATLAS energy dependence.
Shows the predictions of **PYTHIA Tune A**, Tune DW predict about 6 charged particles per unit $\eta$ at $\eta = 0$, while the ATLAS tune predicts around 9.

**PYTHIA Tune DWT** is identical to Tune DW at 1.96 TeV, but extrapolates to the LHC using the ATLAS energy dependence.
Physics Comparisons & Generator Tunes

CMS at the LHC
PC&GT

Hannes Jung, Paolo Gunnellini, Rick Field


Abstract

Using the "Rivet" and "Professor" framework, we construct a new PYTHIA 6 tune using the CTEQ6L1 PDF and two new PYTHIA 8 UE tunes (one using CTEQ6L1 and one using the HERAPDF1.5LD). By simultaneously fitting CDF data from pp collisions at 300 GeV, 900 GeV, and 1.96 TeV together with CMS data for pp collisions at 7 TeV, we test the Underlying Event (UE) models and constrain their parameters, allowing for more precise predictions at 13 TeV and 14 TeV. The consistency of these new tunes with measurements of double-parton scattering (DPS) is also investigated.
PYTHIA 6.4 Tune CUETP6S1-CTEQ6L: Start with Tune Z2*-lep and tune to the CDF PTmax “transMAX” and “transMIN” UE data at 300 GeV, 900 GeV, and 1.96 TeV and the CMS PTmax “transMAX” and “transMIN” UE data at 7 TeV.

PYTHIA 6.4 Tune CUETP6S1-HERAPDF1.5LO: Start with Tune Z2*-lep and tune to the CDF PTmax “transMAX” and “transMIN” UE data at 300 GeV, 900 GeV, and 1.96 TeV and the CMS PTmax “transMAX” and “transMIN” UE data at 7 TeV.

PYTHIA 8 Tune CUETP8S1-CTEQ6L: Start with Corke & Sjöstrand Tune 4C and tune to the CDF PTmax “transMAX” and “transMIN” UE data at 900 GeV, and 1.96 TeV and the CMS PTmax “transMAX” and “transMIN” UE data at 7 TeV. Exclude 300 GeV data.

PYTHIA 8 Tune CUETP8S1-HERAPDF1.5LO: Start with Corke & Sjöstrand Tune 4C and tune to the CDF PTmax “transMAX” and “transMIN” UE data at 900 GeV, and 1.96 TeV and the CMS PTmax “transMAX” and “transMIN” UE data at 7 TeV. Exclude 300 GeV data.

PYTHIA 8 Tune CUETP8M1-NNPDF2.3LO: Start with the Skands Monash-NNPDF2.3LO tune and tune to the CDF PTmax “transMAX” and “transMIN” UE data at 900 GeV, and 1.96 TeV and the CMS PTmax “transMAX” and “transMIN” UE data at 7 TeV. Exclude 300 GeV data.

HERWIG++ Tune CUETHS1-CTEQ6L: Start with the Seymour & Siódmok UE-EE-5C tune and tune to the CDF PTmax “transMAX” and “transMIN” UE data at 900 GeV, and 1.96 TeV and the CMS PTmax “transMAX” and “transMIN” UE data at 7 TeV.
CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transAVE” region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |\eta| < 0.8. The data are compared with PYTHIA 6.4 Tune Z2*.

CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transAVE” region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |\eta| < 0.8. The data are compared with PYTHIA 8 Tune CUETP8S1-CTEQ6L (excludes 300 GeV in fit).

"TransAVE" Charged Particle Density

Charged Particles (|\eta|<0.8, PT>0.5 GeV/c)

PTmax (GeV/c)

Charged Particle Density

300 GeV

900 GeV

1.96 TeV

7 TeV

CMS Tune CUETP8S1-CTEQ6L

Exclude 300 GeV data!
CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transAVE” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are compared with the PYTHIA 8 Tune Monash-NNPDF2.3LO.

CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transAVE” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are compared with the PYTHIA 8 Tune CUETP8M1-NNPDF2.3LO (excludes 300 GeV in fit).
CMS MB Trigger Selections

CMS PAS FSQ-15-008

(A) At least 1 charged particle
\[ p_T > 0.5 \text{ GeV} \]
\[ |\eta| < 2.4 \]

- **Activity**: at least 1 particle with \( E > 5 \text{ GeV} \)
- **Veto**: no particle with \( E > 5 \text{ GeV} \)

- **Inclusive**: (A)
- **Inelastic enhanced**: (A) + **Activity** on at least one Forward Region
- **NSD enhanced**: (A) + **Activity** on both Forward Regions
- **SD enhanced**: (A) + **Activity** on one Forward Region and **Veto** on the other side

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Measurement of pseudorapidity distributions of charged particles in proton-proton collisions at \( \sqrt{s} = 13 \text{ TeV} \) by the CMS experiment.

The CMS Collaboration

**Abstract**

Pseudorapidity distributions of charged particles, \( \mathrm{d}N_{\text{ch}}/\mathrm{d}\eta \), produced in proton-proton collisions at a center-of-mass energy \( \sqrt{s} = 13 \text{ TeV} \) are measured in the pseudorapidity range \( |\eta| < 2.4 \) for charged particles with a transverse momentum \( p_T > 0.4 \text{ GeV} \). Measurements are presented for four event categories. The first two categories correspond to inclusive and inelastic-enhanced event samples. The other two categories are distinct subsets of the inelastic-enhanced event sample that are either enhanced or depleted in single-diffractive dissociation events. The measurements are compared to predictions from Monte Carlo event generators which were tuned to describe the underlying event properties at lower center-of-mass energy.
Charged-particle distributions in $\sqrt{s} = 13$ TeV $pp$ interactions measured with the ATLAS detector at the LHC

The ATLAS Collaboration

Abstract

Charged-particle distributions are measured in proton-proton collisions at a centre-of-mass energy of 13 TeV, using a data sample of nearly 9 million events, corresponding to an integrated luminosity of 170 fb$^{-1}$, recorded by the ATLAS detector during a special Large Hadron Collider fill. The charged-particle multiplicity, its dependence on transverse momentum and pseudorapidity and the dependence of the mean transverse momentum on the charged-particle multiplicity are presented. The measurements are performed with charged particles with transverse momentum greater than 500 MeV and absolute pseudorapidity less than 2.5, in events with at least one charged particle satisfying these kinematic requirements. Additional measurements in a reduced phase space with absolute pseudorapidity less than 0.8 are also presented, in order to compare with other experiments. The results are corrected for detector effects, presented as particle level distributions and are compared to the predictions of various Monte Carlo event generators.
CMS “inclusive” data at 13 TeV on the charged particle density, $dN/d\eta$, with $p_T > 0.5$ GeV/c and $|\eta| < 2.4$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 2.4$. The data are corrected to the particle level and compared with several MC models at generator level.

- **Inclusive:** (A)
  
  (A) At least 1 charged particle $\begin{cases} p_T > 0.5 \text{ GeV} \\ |\eta| < 2.4 \end{cases}$.
CMS “inclusive” data at 13 TeV on the charged particle density, dN/dη, with p_T > 0.5 GeV/c and |η| < 2.4 for events with at least one charged particle with p_T > 0.5 GeV/c and |η| < 2.4. The data are corrected to the particle level and compared with several MC models at generator level.

- **Inclusive**: (A)
  
  (A) At least 1 charged particle \( \{ p_T > 0.5 \text{ GeV}, |\eta| < 2.4 \} \)
CMS “inelastic enhanced” data at 13 TeV on the charged particle density, dN/d\(\eta\), with p\(_T\) > 0.5 GeV/c and |\(\eta\)| < 2.4 for events with at least one charged particle with p\(_T\) > 0.5 GeV/c and |\(\eta\)| < 2.4. The data are corrected to the particle level and compared with several MC models at generator level.

- Inelastic enhanced: (A) + Activity on at least one Forward Region
CMS “NSD enhanced” data at 13 TeV on the charged particle density, dN/dη, with p_T > 0.5 GeV/c and |η| < 2.4 for events with at least one charged particle with p_T > 0.5 GeV/c and |η| < 2.4. The data are corrected to the particle level and compared with several MC models at generator level.

- **NSD enhanced**: (A) + Activity on both Forward Regions
CMS “SD enhanced” data at 13 TeV on the charged particle density, $dN/d\eta$, with $p_T > 0.5$ GeV/c and $|\eta| < 2.4$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 2.4$. The data are corrected to the particle level and compared with several MC models at generator level.

- SD enhanced: (A) + Activity on one Forward Region and Veto on the other side
13 TeV “SD Enhanced” dN/dη

CMS PAS FSQ-15-008

CMS Preliminary
SD selection
- data
- PYTHIA8 CUETM1
- PYTHIA8 CUETS1
- PYTHIA8 CUETM1 MBR
- PYTHIA8 4C MBR

CMS PAS FSQ-15-008

CMS Preliminary
SD selection
- data
- PYTHIA8 CUETM1
- PYTHIA8 MONASH
- EPOS LHC
- HERWIG++ UE-EE-4C
MB at 13 TeV: dN/dη

CMS Preliminary

Inclusive selection

- data
- PYTHIA8 CUETM1
- PYTHIA8 MONASH
- EPOS LHC
- HERWIG++ UE-EE-4C

CMS PAS FSQ-15-008

arXiv:1602.01633

ATLAS $\sqrt{s} = 13$ TeV

$\eta_{ch} \geq 1$, $p_T > 500$ MeV, $|\eta| < 2.5$

$\tau > 300$ ps

Data
- PYTHIA 8 A2
- PYTHIA 8 Monash
- EPOS LHC
- QGSJET II-04
MB at 13 TeV: $dN/d\eta$

- CMS Preliminary
- Inclusive selection
- $N_{ch} \geq 1$, $|\eta| < 2.4$
- $p_T > 0.5$ GeV

CMS PAS FSQ-15-008

$\sqrt{s} = 13$ TeV

$\tau > 300$ ps

$N_{ch} \geq 1$, $p_T > 500$ MeV, $|\eta| < 2.5$

ATLAS

arXiv:1602.01633
Not exactly the same observable! CMS requires $N_{\text{ch}} \geq 1$ in $|\eta| < 2.4$ while ATLAS requires $N_{\text{ch}} \geq 1$ in $|\eta| < 2.5$. The smaller $\eta$ range biases in favor of larger $dN/d\eta$!
The smaller $\eta$ range biases in favor of larger dN/d$\eta$!

$\eta < 0.8$

$\tau > 300$ ps

ATLAS $\sqrt{s} = 13$ TeV

$\eta < 2.5$

ATLAS $\sqrt{s} = 13$ TeV

$\frac{1}{N_{ev}} \cdot \frac{dN_{ch}}{d\eta}$

$rac{MC}{Data}$

$\frac{N_{ev} \cdot dN_{ch}}{d\eta}$

$\frac{MC}{Data}$

$|\eta| < 2.5$

$|\eta| < 0.8$

$n_{ch} \geq 1$, $p_T > 500$ MeV

arXiv:1602.01633

arXiv:1602.01633
MB Distributions at 13 TeV

\[ n_{ch} \geq 1, \ p_{T} > 500 \text{ MeV}, \ |\eta| < 2.5 \]
\[ \tau > 300 \text{ ps} \]

ATLAS \ \sqrt{s} = 13 \text{ TeV}

1/\mathcal{N}_{ev} \cdot d\mathcal{N}_{ev} / d\eta_{ch}

MC / Data

1
0.5

1/\mathcal{N}_{ev} \cdot d\mathcal{N}_{ev} / d\eta_{ch}

MC / Data

1
0.5

\[ p_{T} [\text{GeV}] \]

1
10

\[ \eta_{ch} \]

20
40
60
80
100
120
140

Data
PYTHIA 8 A2
PYTHIA 8 Monash
EPOS LHC
QGSJET II-04

Data
PYTHIA 8 A2
PYTHIA 8 Monash
EPOS LHC
QGSJET II-04

arXiv:1602.01633

arXiv:1602.01633
MB Distributions at 13 TeV

Difficult for the models to produce the exact shape of these distributions!
8 TeV versus 13 TeV

\[ n_{ch} \geq 1, \quad p_T > 500 \text{ MeV}, \quad |\eta| < 2.5 \]
\[ \tau > 300 \text{ ps} \]

**ATLAS** \( \sqrt{s} = 8 \text{ TeV} \)

\[ 1/N_{ev} \cdot dN_{ch}/d\eta \]

Data 2012
- PYTHIA 8 A2
- PYTHIA 8 Monash
- EPOS LHC
- QGSJET II-04

**ATLAS** \( \sqrt{s} = 13 \text{ TeV} \)

\[ 1/N_{ev} \cdot dN_{ch}/d\eta \]

Data
- PYTHIA 8 A2
- PYTHIA 8 Monash
- EPOS LHC
- QGSJET II-04
8 TeV versus 13 TeV

arXiv:1603.02439

\[ n_{ch} \geq 1, p_T > 500 \text{ MeV}, |\eta| < 2.5 \]
\[ \tau > 300 \text{ ps} \]

ATLAS \( s = 8 \text{ TeV} \)

arXiv:1602.01633

\[ n_{ch} \geq 1, p_T > 500 \text{ MeV}, |\eta| < 2.5 \]
\[ \tau > 300 \text{ ps} \]

ATLAS \( s = 13 \text{ TeV} \)
$8 \text{ TeV versus 13 TeV}$

$\tau > 300 \text{ ps}$

$8 \text{ TeV}$

$\tau > 300 \text{ ps}$

$13 \text{ TeV}$

$\frac{1}{N_{\text{ev}}} \frac{1}{(2\pi p_{T})} \frac{d^2 N_{\text{ch}}}{d p_{T} d \eta}$ [GeV$^2$]

$\frac{MC}{Data}$

$p_{T} [\text{GeV}]$

$\frac{1}{N_{\text{ev}}} \frac{1}{(2\pi p_{T})} \frac{d^2 N_{\text{ch}}}{d p_{T} d \eta}$ [GeV$^2$]

$\frac{MC}{Data}$

$p_{T} [\text{GeV}]$
Dependence on N_{ch}g Cut

$$\frac{1}{N_{\text{ev}}} \cdot \frac{dN_{\text{ch}}}{d\eta}$$

- ATLAS \( \sqrt{s} = 8 \text{ TeV} \)
- $n_{\text{ch}} \geq 1$ \( p_T > 500 \text{ MeV}, |\eta| < 2.5 \)
- $\tau > 300 \text{ ps}$

- Data 2012
- PYTHIA 8 A2
- PYTHIA 8 Monash
- EPOS LHC
- QGSJET II-04

$$\frac{1}{N_{\text{ev}}} \cdot \frac{dN_{\text{ch}}}{d\eta}$$

- ATLAS \( \sqrt{s} = 8 \text{ TeV} \)
- $n_{\text{ch}} \geq 20$ \( p_T > 500 \text{ MeV}, |\eta| < 2.5 \)
- $\tau > 300 \text{ ps}$

- Data 2012
- PYTHIA 8 A2
- PYTHIA 8 Monash
- EPOS LHC
- QGSJET II-04
Changing the $N_{\text{ch}}$ cut is similar to changing the MB trigger!
Each cut (trigger) selects a different mixture of ND, SD, DD, CD.
Dependence on $N_{\text{chg}}$ Cut

$N_{\text{chg}} \geq 1$, $p_T > 500$ MeV, $|\eta| < 2.5$

$\tau > 300$ ps

$\sqrt{s} = 8$ TeV

ATLAS

$1/N_{\text{ev}} \cdot d^2N_{\text{ch}} / dr d\phi_T$

Data 2012
PYTHIA 8 A2
PYTHIA 8 Monash
EPOS LHC
QGSJET II-04

$1/N_{\text{ev}} \cdot d^2N_{\text{ch}} / dr d\phi_T$

Data 2012
PYTHIA 8 A2
PYTHIA 8 Monash
EPOS LHC
QGSJET II-04

MC / Data
Compares the CMS CUEP8M1-NNPDF2.3LO tune with the CMS+TOTEM dN/d\eta data at 8 TeV.

The CMS UE tunes do a fairly good job (although not perfect) describing the MB data! No need for a separate MB tune.

The CMS UE tune CUEP8M1-NNPDF2.3LO (Mstar) does a better job in the forward region due to the PDF!

From CMS GEN-14-001
Measurement of the pseudorapidity dependence of the energy and transverse energy density in pp collisions at $\sqrt{s} = 13$ TeV with CMS

The CMS Collaboration

Abstract

The measurement of the energy flow is presented in the pseudorapidity range $3.15 < |\eta| < 6.6$ in proton-proton collisions at the LHC for the centre-of-mass energy of $\sqrt{s} = 13$ TeV. The data have been obtained during several periods of low luminosity operation in 2015. The energy flow, $dE/d\eta$, as well as the transverse energy density, $dE_T/d\eta$, are studied as a function of pseudorapidity for soft-inclusive-inelastic and non-single-diffractive-enhanced events. The results are compared to models tuned to describe high-energy hadronic interactions and to earlier pp data at $\sqrt{s} = 900$ GeV and 7 TeV. Comparison to the earlier data allows to test the hypothesis of the limiting fragmentation.
Energy Flow

CMS PAS FSQ-15-006

CMS Physics Analysis Summary

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Measurement of the pseudorapidity dependence of the energy and transverse energy density in pp collisions at $\sqrt{s} = 13$ TeV with CMS

The CMS Collaboration

The measurement of the energy flow is presented in the pseudorapidity range $3.15 < |\eta| < 4.6$ in proton-proton collisions at the LHC for the centre-of-mass energy of $\sqrt{s} = 13$ TeV. The data have been obtained during several periods of low luminosity operation in 2015. The energy flow, $dE/d\eta$, as well as the transverse energy density, $dE_T/d\eta$, are studied as a function of pseudorapidity for soft-inclusive-inelastic and non-single-diffractive-enhanced events. The results are compared to models tuned to describe high-energy hadronic interactions and to earlier pp data at $\sqrt{s} = 900$ GeV and 7 TeV. Comparison to the earlier data allows to test the hypothesis of the limiting fragmentation.

CUETP8M1 does a fairly good job!
Measurement of the energy distribution in the very forward direction at 13 TeV with CMS

The CMS Collaboration

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The event-by-event energy deposition into the very forward acceptance, $-6.6 < \eta < -5.2$, of CMS is measured and characterized in proton-proton collisions at 13 TeV. Data from the electromagnetic and hadronic sections of the CASTOR calorimeter are used for this purpose. The results are corrected to stable particle level and presented independently for the electromagnetic as well as the hadronic component of the hadronic multiparticle production. The data are sensitive to the production of neutral and charged mesons, which is a key ingredient for the modelling of cosmic ray induced extensive air showers at ultra-high energies. The presented data are relevant for the fraction of primary energy converted into secondary muons. Furthermore, the data are sensitive to the characteristics of multi-parton interactions.
CUETP8M1 does a fairly good job, but overestimates the soft energy!

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MB at 13 TeV: $dN/d\eta$

CMS UE Tune CUETP8S1-HERAPDF1.5LO.


CMS PAS FSQ-15-008

(13 TeV)

CMS Preliminary

- Inelastic selection

- $N_{ch} \geq 1$ in $|\eta| < 2.4$

- $p_T > 0.5$ GeV

- PYTHIA8 CUETM1

- PYTHIA8 CUETS1

- PYTHIA8 CUETM1 MBR

- PYTHIA8 4C MBR

$\eta$
The UE tunes do a fairly good job predicting the MB data.

Do not need separate MB tunes!

But may need to tune diffraction!
Simultaneous UE-MB-DPS Tune at 7 TeV: Simultaneously fit the CMS PTmax UE data, the ALICE dN/dη data, and the CMS pp→4j DPS data starting with PYTHIA 8 tune CUETP8M1-NNPDF2.3LO and vary three parameters (MultipartonInteractions:pT0Ref, MultipartonInteractions:expPow, ColourReconnection:range). Weight all data equally.
Simultaneous UE-MB-DPS Tune

Paolo Gunnellini and the CMS PC&GT Team

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UE and MB are good, but DPS is bad!
Simultaneous UE-MB-DPS Tune at 7 TeV: Simultaneously fit the CMS PTmax UE data, the ALICE dN/dη data, and the CMS pp→4j DPS data starting with PYTHIA 8 tune CUETP8M1-NNPDF2.3LO and vary three parameters (MultipartonInteractions:pT0Ref, MultipartonInteractions:expPow, ColourReconnection:range). High weight for DPS data.
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DPS is good, but UE and MB are bad!
Using Pile-Up to Study Min-Bias

![Diagram of Charged Particle Density: \(dN/d\eta\)]

- Shows the charged particle density, \(dN_{\text{chg}}/d\eta\), for charged particles \((p_T > 0.5 \text{ GeV/c})\) pointing to the **primary vertex** for “Min-Bias” collisions at 1.96 TeV.

- Shows the charged particle density, \(dN_{\text{chg}}/d\eta\), for charged particles \((p_T > 0.5 \text{ GeV/c})\) pointing to the **pile-up vertices** for “Min-Bias” collisions at 1.96 TeV.

- Clearly the pile-up “min-bias” is biased because there must be some particles in the central region to form a vertex (e.g. elastic scattering does not contribute).

- About 2.6 charged particles per unit \(\eta\) at \(\eta = 0\).

- About 1.6 charged particles per unit \(\eta\) at \(\eta = 0\).
Is the Pile-Up Biased?

Shows the charged particle multiplicity distribution for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) pointing to the pile-up vertices for “Min-Bias” collisions at 1.96 TeV.

Shows the charged particle density, $dN_{\text{chg}}/d\eta$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) pointing to the pile-up vertices for high $p_T$ jet production ($PT(\text{jet#1}) > 150$ GeV/c) at 1.96 TeV.

The pile-up is different for Min-bias collisions and high $p_T$ jet production! Amasing!
Is the Pile-Up Biased?

Jet#1 Direction

The pile-up knows the direction of the leading high p_T jet! Amasing!

Shows the data on the $\Delta \phi$ dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) pointing to the primary vertex relative to the leading jet (rotated to 270°) for $PT(jet#1) > 150$ GeV/c $|\eta(jet#1)| < 2$.

Shows the data on the $\Delta \phi$ dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) pointing to the pile-up vertices relative to the leading jet (rotated to 270°) for $PT(jet#1) > 150$ GeV/c $|\eta(jet#1)| < 2$.
Is the Pile-Up Biased?

The pile-up knows the direction of the leading high $p_T$ jet! Amasing!

The pile-up conspires to help give you what you ask for (i.e. satisfy your “trigger” or your event selection)!

- Shows the data on the $\Delta \phi$ dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) pointing to the primary vertex relative to the leading jet (rotated to 270°) for $p_T(jet#1) > 150$ GeV/c $|\eta(jet#1)| < 2$.

- Shows the data on the $\Delta \phi$ dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) pointing to the pile-up vertices relative to the leading jet (rotated to 270°) for $p_T(jet#1) > 150$ GeV/c $|\eta(jet#1)| < 2$. 
We now have a lot of MB data at several energies and with a variety of trigger and selection criteria. Fantastic!

No one QCD Monte-Carlo model describes everything perfectly.

The PYTHIA 8 tunes such as CUETP8S1, CUETP8M1, and Monash, describe fairly well both the underlying event and the non-diffractive contribution to MB observables. We need to work on tuning the diffractive models!

Tunes that use NPDF2.3LO PDF do a better job in the forward region due to the low-x gluon distribution.

I do not understand why we cannot simultaneously fit both the UE and the DPS sensitive observables with the same tune. We will continue to work on this.

Pile-up is interesting. We need to measure a variety of pile-up observables and compare the QCD Monte-Carlo models. I am sure this is being done.