Charged Particle Multiplicity in pp Collisions at $\sqrt{s} = 13$ TeV

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The Workshop of the APS Topical Group on Hadronic Physics
Charged Particle Multiplicity IN PP COLLISIONS AT $\sqrt{S} = 13$ TEV OUTLINES

- Standard model
- THE SCHEMA of ATLAS DETECTOR
- Jet definition
- Minimum bias and underlying event

- Event generator monte carlo simulation Pythia 8 and Herwig++
- Study charged particle multiplicity distribution
- Jet particle multiplicity
Standard Model

is the theory of the electromagnetic, weak and strong interactions

There are six quarks (up u, down d, charm c, strange s, top t, bottom b), and six leptons (electron, electron neutrino, muon, muon neutrino, tau, tau neutrino)

Gauge bosons are the force carriers that conciliate strong, weak, and electromagnetic interaction between the fermions

The Higgs is needed to understand and the properties of the other particles, such as mass
$gg \rightarrow q \bar{q}$, where $q$ by default is a light quark ($u, d, s$)

<table>
<thead>
<tr>
<th>Generation</th>
<th>Flavour</th>
<th>Electric charge</th>
<th>Mass</th>
<th>Flavour</th>
<th>Electric charge</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>1\textsuperscript{st}</td>
<td>$u$</td>
<td>$+2/3e$</td>
<td>$2.3^{+0.7}_{-0.5}$ MeV</td>
<td>$\nu_e$</td>
<td>0</td>
<td>$&lt; 2$ eV</td>
</tr>
<tr>
<td></td>
<td>$d$</td>
<td>$-1/3e$</td>
<td>$4.8^{+0.5}_{-0.3}$ MeV</td>
<td>$e$</td>
<td>$-1e$</td>
<td>511.0 keV</td>
</tr>
<tr>
<td>2\textsuperscript{nd}</td>
<td>$c$</td>
<td>$+2/3e$</td>
<td>$1.28 \pm 0.03$ GeV</td>
<td>$\nu_\mu$</td>
<td>0</td>
<td>$&lt; 2$ eV</td>
</tr>
<tr>
<td></td>
<td>$s$</td>
<td>$-1/3e$</td>
<td>$95 \pm 5$ GeV</td>
<td>$\mu$</td>
<td>$-1e$</td>
<td>105.7 MeV</td>
</tr>
<tr>
<td>3\textsuperscript{rd}</td>
<td>$t$</td>
<td>$+2/3e$</td>
<td>$173.2 \pm 1.2$ GeV</td>
<td>$\nu_\tau$</td>
<td>0</td>
<td>$&lt; 2$ eV</td>
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<tr>
<td></td>
<td>$b$</td>
<td>$-1/3e$</td>
<td>$4.18 \pm 0.03$ GeV</td>
<td>$\tau$</td>
<td>$-1e$</td>
<td>1776.8 $\pm$ 0.2 MeV</td>
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</tbody>
</table>

Top quark mass study $qq\bar{q}/gg \rightarrow t\bar{t}$

**Bosons**

<table>
<thead>
<tr>
<th>Spin 1</th>
<th>Mass</th>
<th>Interaction</th>
<th>Spin 0</th>
<th>Mass</th>
<th>couples to</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$</td>
<td>0</td>
<td>electromagnetic</td>
<td>$H^0$</td>
<td>$125.7 \pm 0.4$ GeV</td>
<td>mass</td>
</tr>
</tbody>
</table>
THE PYTHIA 8 program is used to generate events in high-energy physics between elementary particles.

HERWIG++ is an event generator for the simulation of high-energy physics events with different decays of hadron-hadron, lepton-lepton, and lepton-hadron collisions.

<table>
<thead>
<tr>
<th>Generator</th>
<th>Version</th>
<th>Tunes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pythia 8</td>
<td>8.186</td>
<td>2C (CTEQ6L1)</td>
</tr>
<tr>
<td>Pythia 8</td>
<td>8.186</td>
<td>2M (MRST LO**)</td>
</tr>
<tr>
<td>Herwig+++</td>
<td>2.7.1</td>
<td>UE-EE-5-CTEQ6L1 (CTEQ6L1)</td>
</tr>
<tr>
<td>Herwig+++</td>
<td>2.7.1</td>
<td>UE-EE-5 (MRST LO**)</td>
</tr>
</tbody>
</table>

RIVET is a C++ class library, which supports simulation-level analyses by using calculation tools to validate different event generator models with least effort and accurate results.
Some subatomic particles can be observed in the detector; such as electrons, protons, neutrons, muons and charged poins because of their long life-time and electric charge; which cause signals in the detector.

**The ATLAS detector** is used as a model to define acceptances in this study.

**Inner detector**: to measure the momentum of each charged particle

**Calorimeter**: to measure the energies that carried by the particles

**Muon spectrometer**: to identifies and to measures the momenta of the muons

**Magnet system**: bending the charged particles to measure their momentum
Jets

**DETECTOR-LEVEL JETS** are formed from the observable quantities in a detector

**PARTICLE JETS** form from the final state hadrons and their stable decay products.

**PARTONS JETS** are produced during the scattering process.

As the scattered quarks and gluons move from the initial collision, this process of hadron formation repeats, creating collimated spray of particles called a “JET”
Standard Model and beyond the Standard Model processes predictions need Parton Distribution Functions (PDFs). of the proton, where the parton density function $f_i(x, Q^2)$ provides the possibility of finding a parton of flavour $i$ (quarks or gluon) in the proton. A parton is carrying a fraction $x$ of the proton momentum where $Q$ is the energy scale of the hard

**A TUNE** is a particular configuration or set of values of the parameters of the particular Monte Carlo model that control multi-parton interaction (MPI)

The 2C and 2M tunes are used with the parton density functions CTEQ 6L1 and the MRST LO** PDF sets
PDF and Tunes
Pythia 8

Parton Distribution Functions (PDFs)

\[ t1 = \text{MultipartonInteractions:pT0Ref} \]
\[ t2 = \text{MultipartonInteractions:ecmPow} \]
\[ t3 = \text{MultipartonInteractions:a1} \]
\[ t4 = \text{BeamRemnants:reconnectRange} \]

<table>
<thead>
<tr>
<th>name-PDF</th>
<th>t1</th>
<th>t2</th>
<th>t3</th>
<th>t4</th>
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<tbody>
<tr>
<td>MB tune A2-CTEQ6L1</td>
<td>2.18</td>
<td>0.22</td>
<td>0.06</td>
<td>1.55</td>
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<tr>
<td>MB tune A2-MSTW2008LO</td>
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<td>0.30</td>
<td>0.03</td>
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<td>UE tune AU2-CTEQ6L1</td>
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<td>0.01</td>
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<tr>
<td>Parameter</td>
<td>2C</td>
<td>2M</td>
<td>4C</td>
<td>4Cx</td>
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<tr>
<td>-----------------------------------------------</td>
<td>-----</td>
<td>-----</td>
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<td>on</td>
<td>on</td>
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<tr>
<td>SpaceShower:pTORef</td>
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<td>2.0</td>
<td>2.0</td>
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<tr>
<td>SigmaDiffractive:maxXB</td>
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<tr>
<td>SigmaDiffractive:maxAX</td>
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<td>N/A</td>
<td>65</td>
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<td>SigmaDiffractive:maxXX</td>
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<td>N/A</td>
<td>65</td>
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</table>
PDF AND TUNES
PREPACKAGED SET OF PARAMETER

<table>
<thead>
<tr>
<th></th>
<th>original values before any tunes</th>
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</thead>
<tbody>
<tr>
<td>2</td>
<td>Tune 1</td>
</tr>
<tr>
<td>3</td>
<td>Tune 2C (CTEQ 6L1)</td>
</tr>
<tr>
<td>4</td>
<td>Tune 2M (MRST LO**)</td>
</tr>
<tr>
<td>5</td>
<td>Tune 4C</td>
</tr>
<tr>
<td>6</td>
<td>Tune 4Cx</td>
</tr>
<tr>
<td>7</td>
<td>ATLAS MB tune A2-CTEQ6L1</td>
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<tr>
<td>8</td>
<td>ATLAS MB tune A2-MSTW2008LO</td>
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<tr>
<td>9</td>
<td>ATLAS UE tune AU2-CTEQ6L1</td>
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<td>10</td>
<td>ATLAS UE tune AU2-MSTW2008LO</td>
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<tr>
<td>11</td>
<td>ATLAS UE tune AU2-CT10</td>
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<tr>
<td>12</td>
<td>ATLAS UE tune AU2-MRST2007LO*</td>
</tr>
<tr>
<td>13</td>
<td>ATLAS UE tune AU2-MRST2007LO**</td>
</tr>
</tbody>
</table>

6: m0 = 172.5
23: m0 = 91.1876
24: m0 = 80.399

#CTau lifetime cut
ParticleDecays:limitTau0 = on
ParticleDecays:tau0Max = 10.0

# Tune A2 settings
Tune:pp = 5
PDF:useLHAPDF = on
PDF:LHAPDFset = MSTW2008lo68cl.LHgrid
MultipartonInteractions:bProfile = 4
MultipartonInteractions:a1 = 0.03
MultipartonInteractions:pT0Ref = 1.90
MultipartonInteractions:ecmPow = 0.30
BeamRemnants:reconnectRange = 2.28
SpaceShower:rapidityOrder=off
# Technical parameters for this run

cd /Herwig/Generators
set LHCGenerator:NumberOfEvents 10000000
set LHCGenerator:RandomNumberGenerator:Seed 31122001
set LHCGenerator:PrintEvent 10
set LHCGenerator:MaxErrors 1000000
set LHCGenerator:DebugLevel 0
set LHCGenerator:DumpPeriod -1
set LHCGenerator:DebugEvent 0

# LHC physics parameters (override defaults here)
set LHCGenerator:EventHandler:LuminosityFunction:Energy 13000.0
set /Herwig/Shower/Evolver:IntrinsicPtGaussian 2.2*GeV

# Matrix Elements for hadron-hadron collisions

cd /Herwig/MatrixElements/
insert SimpleQCD:MatrixElements[0] MEMinBias

# Need this cut only for min bias
set JetKtCut:MinKT 0.0*GeV
set QCDCuts:MHatMin 0.0*GeV
set QCDCuts:X1Min 0.055
set QCDCuts:X2Min 0.055

# MPI model settings
set /Herwig/UnderlyingEvent/MPIHandler:IdenticalToUE 0

cd /Herwig/Generators

#insert LHCGenerator:AnalysisHandlers 0

# Save run for later usage with 'Herwig++ run'
saverun LHC-MB LHCGenerator

http://projects.hepforge.org/herwig/trac/wiki/MB_UE_tunes
Charged particle multiplicity in $tt^\pm$ production in Herwig++ and Pythia 8

The Phase space of charged-particle multiplicity distributions defined as follow:
$n_{ch} \geq 1, n_{ch} \geq 6, P_T > 500$ MeV and $|\eta| < 3$ at $\sqrt{s} = 13$ TeV

The distribution at low number of charged particles

The distribution when the number of charged particles increases

Systematic uncertainty

Comparisons between Herwig++ and Pythia 8:
Pythia 8 8.186 Top:qqbar2ttbar && Herwig++ 2.7.1 LHC-TTBA
Pythia 8 8.186 Top:qqbar2ttbar && Herwig++ 2.7.1 LHC.in included MEHeavyQuark (qqbar/gg → ttbar)
Variations (Distribution) are very high and wide

The uncertainty is up to +40 %

The uncertainty varies from +50 % to +20 %

Variations are very high

Variations are very high

The uncertainty varies from -10 % to +15 %

Variations are very high

Variations are very high

The uncertainty varies from -10 % to +40 %

Pythia 8 Top:qqbar2ttbar
Herwig++ LHC-TTBA

the variations decreased

Pythia 8 Top:qqbar2ttbar
Herwig++ MEHeavyQuark

Pythia 8 Top:qqbar2ttbar
Herwig++ LHC-TTBA

The uncertainty varies from +50 % to -20 %
The mean particle density varies from 8 to 10.

uncertainty for the highest inclusive phase-space region is 0.3 %.

uncertainty for the highest inclusive phase-space region is 10.15 %.

**Less variation**
Pythia 8 Top:qqbar2ttbar
Herwig++ LHC-TTBA

**More variation**
Pythia 8 Top:qqbar2ttbar
Herwig++ MEHeavyQuark

The mean particle density decreases at higher values of $|\eta|$.
CHARGED-PARTICLE MULTIPLICITIES AS A FUNCTION OF THE TRANSVERSE MOMENTUM

The charge density is very high at low $pt$ region and decreases at high $pt$

Models tend to under-predict the number of low $P_T$ particles

The uncertainty is measured for the range -0.02% for $p_T = 1$ GeV to -0.3% for $p_T = 2$
AVERAGE TRANSVERSE MOMENTUM AS A FUNCTION OF THE NUMBER OF CHARGED PARTICLES IN THE EVENT

the models vary widely

Distribution well agree between most of the models

Systematic Uncertainties is very high in the range from 20% to 40%

bin (20 < n_{ch} < 80)
Comparison between two different PDF in Herwig++ (ttbar Jet)

Jet charged particle multiplicity in Herwig++ with two different PDF UE-EE-5-CTEQ6l1, and UE-EE-5

In Herwig++ the number of the jets is less than Pythia 8 where there are more minimum bias events and less number of the tracks.
Comparison between two different PDF in Herwig++(ttbar Jet)

The mean particle density is getting low in the central region and decreases at high pt region where the statistical is getting low.

The entire uncertainty on Nev at \( \sqrt{s} = 13 \text{ TeV} \) for the highest inclusive phase-space region is (+1.5 % to -1.5 %)

Both of PDF models tend to over-predict the number of low PT particles, while at higher PT the PDF do not vary widely.

The uncertainty is measured for the bin range \( 1 < p_T < 13 \text{ GeV} \) (10 % to 20 %)

At low \( p_T \) region the charge density is very high and decreases at high pt region where the statistical is getting low.

"Herwig++ LHC-UE-EE-5-CTEQ6L1 Jet
"Herwig++ LHC-UE-EE-5 UE-EE-5 (MRST LO**) Jet"
Comparison between two different PDF (ttbar Jet)

Number of the jets almost the same for both PDFs. Both of PDFs predicted more jets in events at $n_{\text{Jet}} \geq 35$, and the variations between the PDFs are big. Systematic uncertainty is decreases for both $n_{\text{Jet}} \geq 35$ (- 0.4%).

"Herwig++ LHC-UE-EE-5-CTEQ6L1 Jet
"Herwig++ LHC-UE-EE-5 (MRST LO**) Jet"
The distribution of particle multiplicity in high energy inelastic processes provides essential information on the dynamics of strong interactions.

The principal features of multiplicity predicted by QCD are observed qualitatively both in pp and hadron-initiated processes.

The multiplicity is used to select or to describe events, e.g. as a trigger for specific processes, as an input for kinematic variables’ spectra. The distribution of multiplicity, its mean value and multiplicity fluctuations are the essential characteristics of the collision dynamics. However, the multiplicity distribution tells us just about the averaged, integrated numbers, while deeper information comes from the moments of the distribution, which measure particle correlations.