Particle spectra in Minimum Bias events at 13TeV

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Motivation

Probe the different components of hadron production

- The transition from the perturbative to the non-perturbative region
- Behaviour of QCD at small-\(x\)
- Multiple parton interactions
- Saturation of parton densities
- Soft diffractive components

Tune the modeling of these contributions

- Center-of-mass energy dependence
- Taming of the cross section in the low \(p_T\) region
Multiple Parton Interactions

- Soft to semi-hard interactions
- Phenomenological models
- Tuning of the model parameters based on experimental data

Comparison to the new CMS tunes

- Simultaneous fits to CDF UE data at 0.9 and 1.96 TeV, and CMS UE at 7 TeV
- Energy dependence of the MPI parameters
- Different parton densities
- **Theoretical uncertainties** from allowed parameter space
Pseudorapidity at 0T

- Measurement of pseudorapidity distribution of charged hadrons in proton-proton collisions at $\sqrt{s} = 13$ TeV

- Presented for inelastic events
- No minimum transverse momentum requirement (measurement done at 0T)
- Corrected to primary long-lived charged hadrons (no leptons)
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Measurement of pseudorapidity distribution of charged particles in proton-proton collisions at $\sqrt{s} = 8$ TeV

Presented for different diffractive event selections (TOTEM event selection)
Corrected down to zero transverse momentum
Corrected to all charged particles

TOTEM acceptance: $5.3 < |\eta| < 6.4$

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**TOTEM acceptance**: $5.3 < |\eta| < 6.4$

Results after tuning

Pseudorapidity Predictions

Event selection

We can implement a similar event selection but instead of TOTEM we use particles in the range $3 < |\eta| < 5$ (HF calorimeter) in the following way:

- **Non-Single Diffractive enhanced**: at least one particle with $E > 5 \text{GeV}$ on each side.

- **Single Diffractive enhanced**: at least one particle with $E > 5 \text{GeV}$ on one side. Other side no particle with $E > 5 \text{GeV}$.

- **Inelastic enhanced**: at least one particle on either side with $E > 5 \text{GeV}$.

Particle selection

- $-2.4 < |\eta| < 2.4$ (Tracker acceptance)
- $p_T > 500 \text{MeV}$
- Final State Charged particles
The shape of all the predictions for the inclusive and inelastic selections is very similar, only changing the predicted value by ~0.5 particles per η unit.

For the NSD selection: **PYTHIA8 Tunes** predict the same shape with different values, while **EPOS-LHC** has a valley in the central region.

For the SD selection: **PYTHIA8 Tunes** predict significantly different behaviour than **EPOS-LHC**.
Measuring on different diffractive event topologies

- Will provide further constrains for the models
- Show where each model does a good/bad description

Integrated pT spectrum

- Total 2 $\rightarrow$ 2 partonic cross section:
  \[
  \sigma(p_T) \propto \frac{1}{p_T^2}
  \]

- Divergent towards low pT

\[\sigma(p_T) > \sigma_{inel}\]

$\rightarrow$ phenomenological factor

\[
\left[\alpha_s^2(p_{T,0}^2 + p_T^2)/\alpha_s^2(p_T^2)\right] [p_T^4/(p_{T,0}^2 + p_T^2)^2]
\]

Integrated pT spectrum

- At $\sqrt{s} = 8$ TeV the turn over happens at $p_T\text{-min} \sim 5$ GeV

Integrated-pT at 8 TeV

Data
- Pythia 6 Z2*
- Pythia 6 CUET
- Pythia 6 (default, MPI on)
- Pythia 6 (default, MPI off)
- Pythia 6 (default, MPI off, no sat)

MC scaled to data at $p_T\text{-min} = 9$ GeV

CMS

$pp \sqrt{s} = 8$ TeV

$N_{ch}$ ($p_T > 40$ MeV) $> 0$ in $5.3 < \eta |< 6.5$
Leading charged particles, $\eta |< 2.4$

arXiv:1507.00233
Integrated-pT at 8 TeV

Integrated pT spectrum

- At $\sqrt{s} = 8$ TeV the turn over happens at $p_T$-min $\sim 5$ GeV

How does it look at different center of mass energies??

How does it look for different diffractive topologies??

$N_{ch} (p_T > 40$ MeV$) > 0 \text{ in } 5.3 < |\eta| < 6.5$

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Data
Pythia 8 4C
Pythia 8 CUET
Pythia 8 MONASH
QGSJetII-04
EPOS LHC
Herwig++ UE-EE-5C

arXiv:1507.00233
**Integrated-pT at 13 TeV. Predictions**

Selection: inclusive $pp$ \[ \sqrt{s} = 13 \text{ TeV} \]

- $p_T_{\text{min}}$ distribution
  - CMS $p_T > 40 \text{ MeV} > 0$ in $5.3 < \eta < 6.5$
  - Leading charged particles, $|\eta| < 2.4$

**MC scaled to data at $p_T_{\text{min}} = 9 \text{ GeV}$**

- Similar turn over value

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[arXiv:1507.00233]
Integrated $p_T$ leading distribution. Predictions

For inclusive, inelastic enhanced and NSD samples the turn over happens at the same $p_T$-min value.
Integrated $p_T$ leading distribution. Predictions

SD enhanced

- Sensitive to smaller effective CM energy — $M_x < s$
- Turn over happens at smaller values of $p_T$-min
- Measuring the $r(p_{T \text{ min}})$ as a function of $M_x$ one can access the energy dependence of saturation scale
Integrated $p_T$ leading distribution. Predictions

NSD enhanced: $E_{part} > 5$ GeV in $-5 < \eta < -3$ and $3 < \eta < 5$

SD enhanced: $E_{part} > 5$ GeV in either $-5 < \eta < -3$ or $3 < \eta < 5$

NSD extends to higher $p_T$-min values

Turn over shifted to small $p_T$-min
Summary

- Pseudorapidity distribution at $\sqrt{s} = 13$ TeV for inclusive events

- Predictions for the pseudorapidity density at $\sqrt{s} = 13$ TeV for different event selections

- New proposal for extracting information about the energy dependence of the saturation scale

- Experimental results to be released soon