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MonteCarlo Study of pT distributions of pp collisions at 13 TeV

Andrea Aguirre Polo
Supervised by: Antonio Ortiz and Guy Paic
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Summary

In this work, a study of the transverse momentum distributions, with different kinematic cuts in the amount of particles coming from multiparton interactions and multiplicity, was carried. The regions of the maximum transverse moment per event for very high multiplicity events were described, noticing that there are certain exclusion zones.

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1 Introduction

The study of high multiplicity pp collisions offer a very important reference to study high-energy density features of quantum chromodynamics (QCD). In non-diffractive proton–proton (pp) collisions at high energies, there are a set of particles that arise from the proton break-up (beam remnants), and from other semi-hard scatterings. The partonic scatterings with large momentum transfer generates jets accompanied by particles produced by initial- and final-state radiation (ISR and FSR, respectively). For a single pp collision there may be several semi-hard parton-parton scatterings in a scenario incorporating multi-parton interactions (MPI) [1].

The measurements performed at RHIC and LHC in small systems (pp, p–A, and d–A collisions) have shown for high particle multiplicities similar phenomena as were originally observed only in A–A collisions and have been attributed there to the formation of the strongly interacting quark gluon plasma [2, 3], namely, long range angular correlations and collectivity [4]. The origin of these effects in small systems is still an open question; mechanisms implemented in the Monte Carlo event generators can produce collective-like effects [5]. The interpretation of the results from the analysis of high-multiplicity pp collisions is challenging due to the selection biases of the sample towards events in which partonic scatterings with large momentum transfer (hard scatterings) occurred.

1.1 PYTHIA

PYTHIA is a Monte Carlo event generator that generates high-energy particle collision event records using all the Standard Model physics we know. It includes QCD processes, such as soft and hard QCD sub-processes, as well as total and partial cross sections, parton shower, multiple parton–parton interactions, hadronization, decays, etc. The current version is PYTHIA 8.307, version adopted in this work.

2 Reproduction of results

The first part of this work consisted on generating events to obtain the transverse momentum and pseudorapidity distributions for *pp* collisions at 13 TeV, in order to compare with ALICE results [6].

2.1 Pseudorapidity and transverse-momentum distributions

The pseudorapidity (η) and transverse-momentum (p_T) are event observables that characterize the main properties of the collision. We simulate pp collisions at 13 TeV to compute the average multiplicity density of charged particles as a function of η and the invariant charged-particle yield as a function of p_T.

In Pythia 8, we have to set the simulation conditions for the processes we need, in Listing 1 we show Pythia8 setting we use for our work, that includes only primary particles from soft QCD processes.

Listing 1: Pythia 8 settings

```
pythia.readString("SoftQCD:inelastic = on");
pythia.readString("ParticleDecays:limitTau0 = on"); //when on, only
    particles with tau0 < tau0Max are decayed
pythia.readString("ParticleDecays:tau0Max = 10"); //then, tau0 <10, so we
    are only choosing primary particles
```

We also adopt the kinematic cuts used in [6], as described following:

- The pseudorapidity distribution is measured at central rapidity in $|\eta| < 1.8$
- The measurements have been obtained for inelastic events (INEL) and events having at least one charged particle produced with $p_T > 0$ in the pseudorapidity interval $|\eta| < 1$ (INEL$>$ 0).
- The transverse-momentum distribution of charged particles is measured in the range $0.15 < p_T < 20$ GeV/c and $|\eta| < 0.8$ for INEL$>$ 0 events.

Having this, we can plot the average charged-particle density distribution $\langle dN_{ch}/d\eta \rangle$ measured in INEL and INEL>0 events in the pseudorapidity range $|\eta| < 1.8$, with the INEL$>$ 0 cut implemented in Listing 1, obtaining a good reproduction of the results reported in [6], as shown in Figure 1.

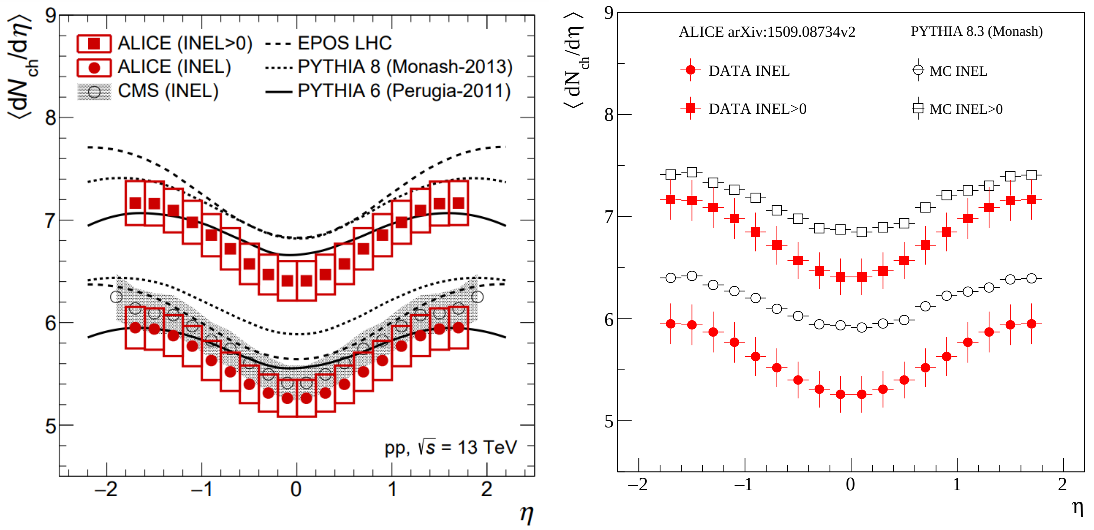

Figure 1: Average pseudorapidity density of charged particles as a function of η produced in pp collisions at $\sqrt{s} = 13$ TeV. The ALICE results are shown in the normalisation classes INEL and INEL$>$ 0 and compared to Monte Carlo calculations. The left panel shows results from original article [6] and left shows our reproduced results using MC Pythia 8.3.

Listing 2: Kinematic INEL>0 cut

```
1  for (int iEvent = 0; iEvent < nEv; ++iEvent) {
2      if (!pythia.next()) continue;
3      inel=0;
4      for (int i = 0; i < pythia.event.size(); ++i)
5        if (pythia.event[i].isFinal() && pythia.event[i].isCharged())
6          {
7          if( pythia.event[i].pT() < 0 || pythia.event[i].pT() > 15.0 )
8          continue;
9          if( TMath::Abs(pythia.event[i].eta()) > 1 )
10         continue;
11         inel = 1;
12         }
13
14         int nCh = 0;
15     for (int i = 0; i < pythia.event.size(); ++i)
16         if ( inel == 1 && pythia.event[i].isFinal() &&
               pythia.event[i].isCharged() )
17     {
18         if( TMath::Abs(pythia.event[i].eta()) > 1.8 )
19         continue;
20         ++nCh;
21         Heta->Fill(pythia.event[i].eta());
22
23         if( pythia.event[i].pT() < 0.15 || pythia.event[i].pT() > 20.0 )
24         continue;
25         if( TMath::Abs(pythia.event[i].eta()) > 0.8 )
26         continue;
27         HpT->Fill(pythia.event[i].pT());
28     }
29     if ( inel == 1 ){ nCharge->Fill( nCh ); }
30 }
```

For the pT invariant yield of charged particles we use the kinematic cuts 0.15 GeV/c $\leq p_T \leq$ 20 GeV/c and $|\eta| < 0.8$ as implemented in lines 23-26 of Listing 2, the reproduction of Fig.3 results in [6], are shown in Figure 2.

3 pT leading

With the knowledge acquired in the first part of this work, we can now develop a code that subtracts the information of the particle with the highest momentum in each event, as we show in Listing 3, in order to study the phenomena associated with anisotropy in the transverse momentum space for high multiplicity events.

For $|\eta| < 4$, $pT > 0.15$ GeV/c and $|\eta| < 0.8$, $pT > 0.15$ GeV/c cuts, we graph p_T leading spectra of charged particles as present in Figure 3.

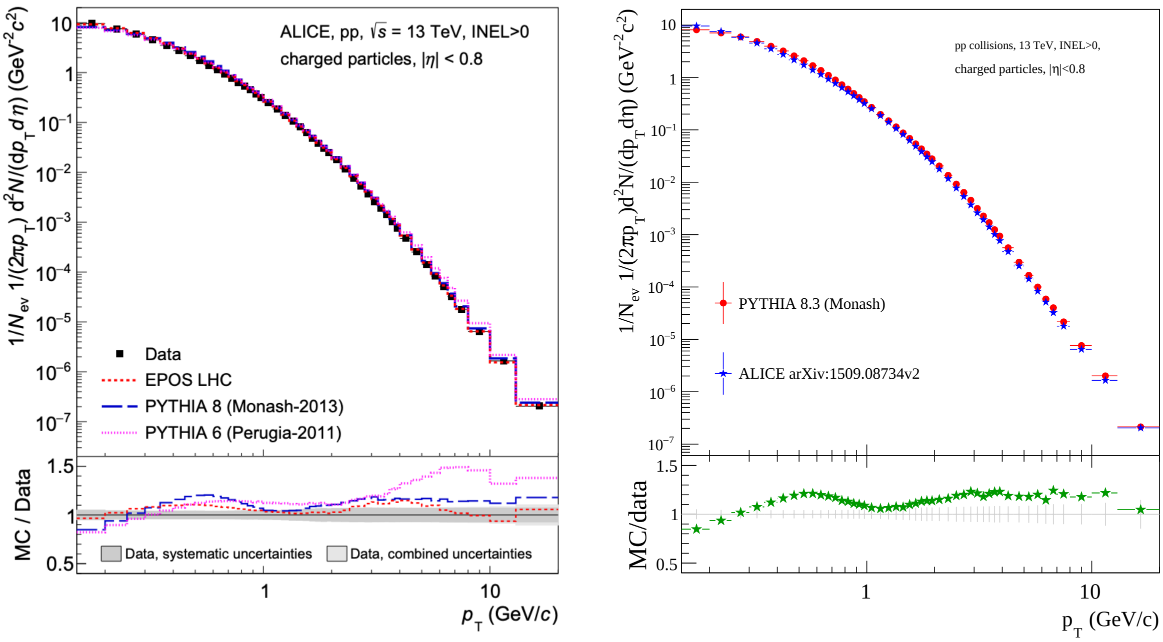

Figure 2: Invariant charged-particle yield as a function of p_T normalised to INEL> 0 events. The data are compared to Monte Carlo calculations. Original article (left) our simulation (right): the red circle marks corresponds to PYTHIA 8.3 simulations of pp collisions at 13 TeV with INEL>0, $|\eta| < 0.8$ and 0.15 GeV/c $< p_T <$ 20 GeV/c kinematic cuts. The green stars are the comparison of Monte Carlo over data from [6], the combined uncertainties are included in the gray line.

Listing 3: pT leading selection

```
   int nCh = 0;
   double pTlead = 0;
  for (int i = 0; i < pythia.event.size(); ++i)
  if ( pythia.event[i].isFinal() && pythia.event[i].isCharged() )
  {
      if( pythia.event[i].pT() < 0.15 )
      continue;
      if( TMath::Abs(pythia.event[i].eta()) > 4 ) // and also for
          TMath::Abs(pythia.event[i].eta()) > 0.8
      continue;
      HpT->Fill(pythia.event[i].pT());
      ++nCh;
      if( pTlead < pythia.event[i].pT() ){
          pTlead = pythia.event[i].pT();
      }
  }
  LpT0->Fill( pTlead );
```

In Figure 3 we can see a shift on maximum value, unlike the spectrum p_T from Figure 2, this corresponds to the p_T leading behaviour, as an event shape observable. Given that p_T leading only the p_T maximum value for each event.

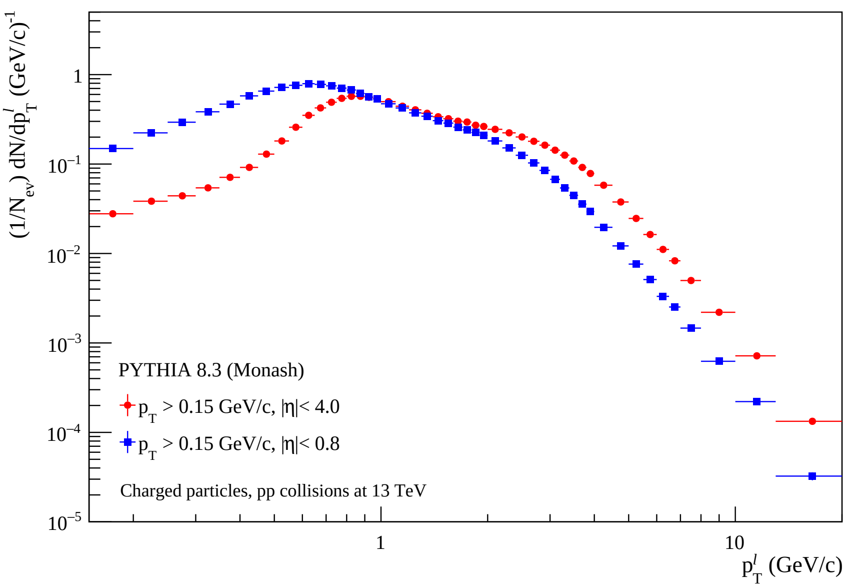

Figure 3: p_T leading spectra of charged particles produced using PYTHIA 8.3 simulation of pp collisions at 13 TeV. Illustrating $p_T > 0.15$ GeV/c, $|\eta| < 4$ (red circles) and $|\eta| < 0.8$ (blue squares) kinematic cuts.

3.1 MPI biases on p_T leading

To study the effects of considering a certain number of MPI particles produced on p_T leading distributions, it was proposed to obtain p_T leading spectra for various MPI values (1, 5, 15, 20, 25) as we plotted in figure 4

To determine how the p_T depends on different MPI values and pseudorapidity cuts ($|\eta| > 0.8$ and $|\eta| > 4$), we plot p_T leading spectra for each MPI value selected previously.

We also generate TH2 histograms where we stored the information from p_T leading and multiplicity from each event, with the purpose of visualizing the dependency of p_T leading as a function of the multiplicity. In figure 5 we graph the behaviour of average p_T leading as a function of multiplicity and also the standard deviation.

Aditionally, we calculated the average multiplicity values for our MPI selection, the results are presented in Table 1.

3.2 Multiplicity classes

The different average multiplicities for the MPI values calculated in the previous section are used for a new approach of study. For that we generated PYTHIA events with kinematic cuts in the multiplicity classes, using the intervals: $0 < N_{ch} \leq \langle N_{ch} \rangle$, $\langle N_{ch} \rangle <$

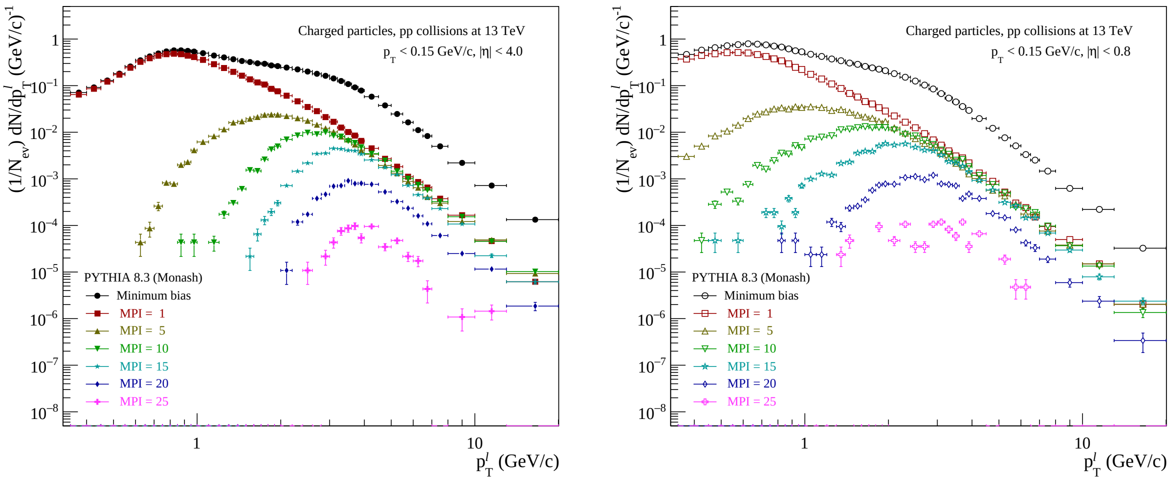

Figure 4: p_T leading spectra of charged particles produced with MPI = 1, 5, 10, 15, 20, 25. Illustrating $p_T > 0.15$ GeV/c, $|\eta| < 4$ (left) and $|\eta| < 0.8$ (right) kinematic cuts.

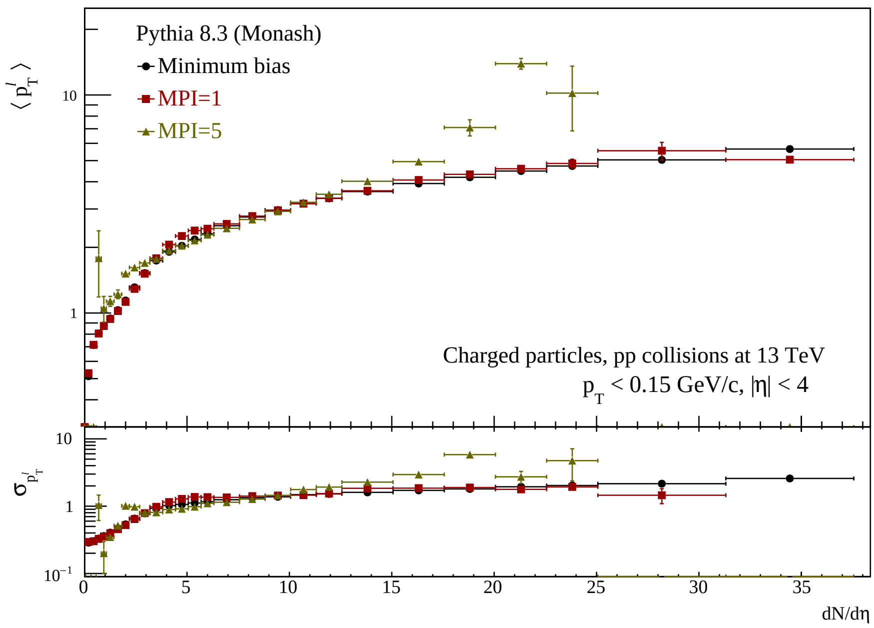

Figure 5: The upper plot shows the average p_T leading as a function of multiplicity, for pp collisions at 13 TeV, with $|\eta| < 4$ and $p_T > 0.15$ GeV/c for minimum biases and MPI values of 1 and 5. Bottom plot shows the standard deviation.

$N_{ch} \leq 2\langle N_{ch}\rangle, \ldots, 5\langle N_{ch}\rangle < N_{ch} \leq 6\langle N_{ch}\rangle, 6\langle N_{ch}\rangle < N_{ch}$. The p_T leading spectra is shown in figure 6.

In this way, it was possible to make a comparison between the invariant yields as a function of p_T leading for different cuts in multiplicity, as shown in Figure 6.

MPI	$\|\eta\| < 0.8$	$\|\eta\| < 4$
	$\langle N_{ch} \rangle$	
1	4.007095	14.684509
5	10.934136	55.275934
10	19.862934	98.334788
15	28.391156	141.688566
20	36.248123	171.873527
25	43.727425	204.044776

Table 1: Average charged particles produced by event for different MPI values with $|\eta| < 0.8$ and $|\eta| < 4$ cuts.

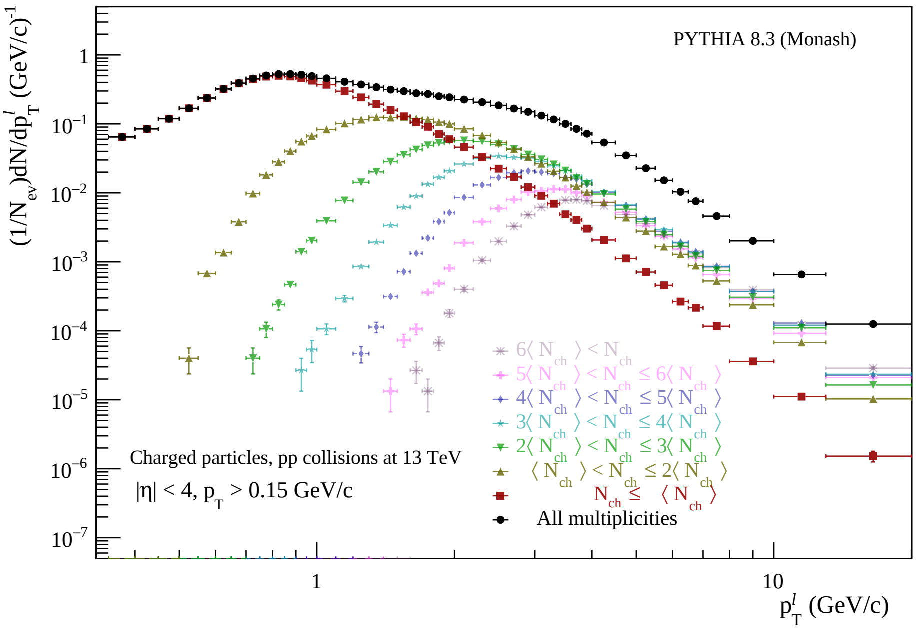

Figure 6: p_T leading spectra of charged particles produced for different multiplicity classes with $p_T > 0.15$ GeV/c, $|\eta| < 4$ kinematic cuts.

4 Conclusions

During this work, the techniques for the Monte Carlo study of distributions concerning the transverse moment were learned, in addition to applying the appropriate kinematic cuts for the study of said observable.

We were able to notice how the natural bound $N_{MPI} \leq N_{ch}$ imposes a restriction on the values of p_T leading that can be obtained in events of very high multiplicity. For values of MPI=5, the leading p_T is above 0.4 GeV/c, while for MPI=20, the leading p_T is above 1.5 GeV/c.

This is the basis of the analysis of the topology of the event and event shape variables, such as the Flatenicity [7], among other observables that can be measured experimentally.

5 Acknowledgements

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