Measuring Particle Production Using Tracklets

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Abstract. The purpose of the study was to access the particle production. Tracklets was adopted to measure the relationship between centrality ranged from outermost (70–80%) to central (0–5%) collisions and the primary charged-particle density $\frac{dN_{ch}}{d\eta}$ at $\sqrt{S_{NN}}$ = 2. 76 TeV. It reveals that the dependence of centrality and that measured at lower collision energies ($\sqrt{S_{NN}}$ < 2. 76 TeV) are similar.

1. Introduction

In November 2010, the Large Hadron Collider (LHC) at CERN made a great advance in the field of strong interaction. The first Pb-Pb collisions were generated under extreme conditions. The center-of-mass energy is 2. 76 TeV per nucleon pair ($\sqrt{S_{NN}}$ = 2. 76 TeV). According to Quantum Chromodynamics (QCD), at high temperatures, elementary particles will be unaffected by strong attraction forces from the others because of the extremely high energy density. Quarks and gluons are these particles. There is a transition in the phase between hadronic and deconfined matter. Such interaction can be researched using ultra-relativistic collisions of heavy nuclei in experiments. After the experiments were put forward, the result showed an increase in the magnitude of nuclear collisions with the highest energy.

The key which is observable to describe the properties of the particles and matter created in these collisions is the charged particle diversity. We can describe these collisions by their centrality related to the collision impact parameter as Nuclei are extensible. A previous study has been conducted to measure the centrality of PB-PB collision at low collision energy. However, the problem is that to what extent the centrality will affect particle production is still open. Figuring out the soft processes could be significant because it could reveal the partonic structure of the projectiles and the relative contributions to particle production while hard scattering by studying the relationship between the collision geometry, centre-of-mass energy charged-particle density on the colliding system. The remained problem is what kind of charged baryon or meson is produced during the process and what factors affect the result of the produced charged particles.

2. Setup

2.1. Accelerator
The Large Hadron Collider (LHC) is a particle accelerator, the largest and most powerful one in the world. Two beams of the particle will travel at speed (close to the speed of light) inside the accelerator. The direction of beams is precisely the opposite in separate tubes that are maintained at ultrahigh vacuum. There is a strong magnetic field that controls the acceleration ring to determine the motion of the beams. As shown in Figure1, inside the LHC, particles are guided to four different positions (four particle detectors ATLAS, CMS, ALICE, and LHCb) around the acceleration ring.

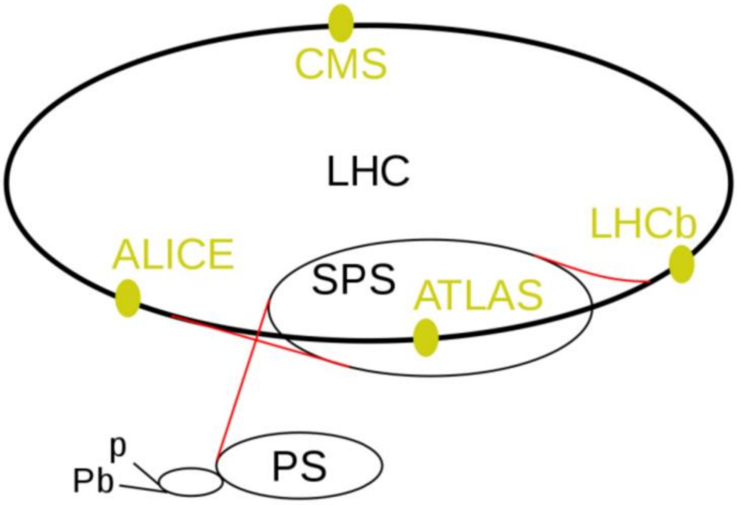

Figure 1. The components of The Large Hadron Collider, showing the position of 4 detectors (ATLAS, CMS, ALICE and LHCb).

2.2. Detector (ALICE)
ALICE is a detector used in LHC. It is designed to investigate strong interactions under the condition of extreme energy densities. In ALICE, pixel hits will be recreated in the pixel detector as the energy deposit adds up. These reformed hits are used in the Tracklists to analyze hits produced by charged particles.

The first three-tracker layers of ALICE are used in this analysis. The first layer is at the position between 3. 6 and 5. 2 cm from the beamline, the second layer is located between 6. 6 and 8. 0cm and the third one is between 9. 4 and 10. 8 cm.

In a homogeneous magnetic field (3. 8 Tesla), charged pions can reach the first or second-pixel layer when its transverse momentum is more excellent than -50(70) MeV/c. It enables Tracklists to reconstruct from the lowest PT particles.

Overall, there are three combinations with three layers, which are 1st and 2nd, 1st and3rd and 2nd and 3rd layers. The first combination of the layer can lead to the lowest PT reached. However, it's much likely to be impacted by the induced background of the beam pipes. The second combination can result in a higher PT, while low PT background will not be easily affected. In summary, all three combinations of layers are complementary to each other, and the results can be helpful to conduct the systematic check.

3. Analysis
The Figure 2 shows the distribution of the total amplitude in the VZERO scintillator tile. The red curve displays the Glauber fit of the Number of Events vs Vzero diagram. Vertical lines separate the

centrality categories used in the Glauber analysis, which collectively correspond to the outermost 80% of hadronic collisions.

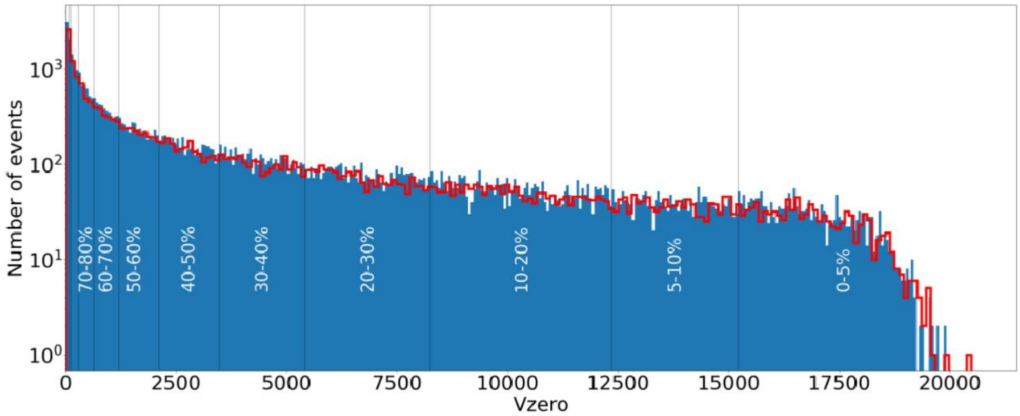

Figure 2. The distribution of the total amplitude in the VZERO scintillator tile.

The selected sample consists of about 20000 events. Figure 2, which displays several events versus VZERO shows the distribution of the total amplitude in the VZERO scintillator tile and the distribution based on the particle production model of nuclear collision described by Glauber. The centrality classes are divided by vertical line, and the Glauber fit is shown as a red line [1].

The Glauber model defines the Apart, the number of participating nucleons, and Nicoll, the number of binary nucleon-nucleon collisions, for events with a given impact parameter and the particle multiplicity of each nucleon-nucleon collision is parameterized by a negative binomial distribution. The model assumes that the number of sources producing particles is given by

$$f \times N_{part} + (1 - f) \times N_{coll}$$

where f quantifies their relative contribution.

To generate the number of particles produced by interaction for each source, negative binomial distribution, a discrete probability distribution representing the probability of random variable, is used for calculation, parameterized by μ and κ, where μ is the average multiplicity of each source, and κ controls the larger multiplicity tail [2]. The Glauber fit is obtained by NBD times the number of sources producing particles.

According to the experimental data of low energy electron-nucleus scattering, the nuclear density of 208Pb is simulated by the Woods-Saxony distribution of a spherical nucleus with a radius of 6. 62fm and an epidermal depth of 0. 546 fm.

The hard-sphere repulsion distance between nucleons is 0. 4fm. Nuclear collisions are simulated by randomly moving two colliding nuclei on the horizontal plane. Assuming that the transverse distance between nucleons from each nucleus is less than the distance corresponding to the inelastic nucleon-nucleon cross-section, it is estimated to be 64 ±5MB based on the interpolation data of different centroid energies at s=2. 76TeV.

For categories of measurement events (Next), the average values of Apart and Ncoll can be extracted through the mapping process. In general, the measured distribution is mapped to the corresponding distribution calculated from the phenomenological Glauber calculation, which is achieved by defining "centrality classes".

Nine classes separate the centrality by dividing the distribution based on the different parts of the total integral. As the graph shows, we covered 80% of the hadronic cross-sections, containing a large proportion of centrality classes.

Figure 3 is made up of two scatter plots, and there are several things we can get from this graph. The scatter plot shown in red color represents the correlation of the Ncoll (the number of collisions) and the impact parameter, it shows that the dot with a smaller impact parameter corresponds to a larger Ncoll(the number of collisions) and vise versa. Also, the red scatter plot density shows that most of the collision events have a large impact parameter, which means the possibility of an impact event with a large impact parameter is higher than with a small impact parameter.

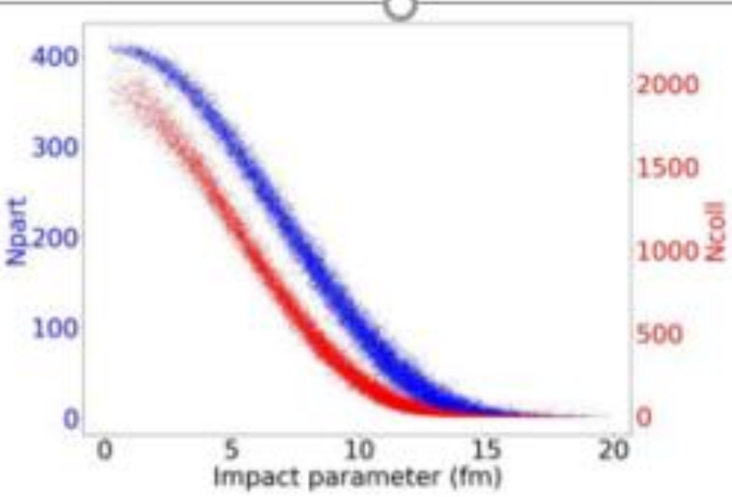

Figure 3. The relationship between several participants and impact parameter and the relationship between several collisions and impact parameters.

On the other hand, the scatter plot shown in blue color is the correlation of the Apart (defined as the number of participants during the collision, the participants have consisted of baryons which are consisted of 3 quarks such as protons and neutrons in our case) and the impact parameter. This scatters plot demonstrates that the dot with a smaller impact parameter usually refers to a larger Apart and vise versa. The density of the dots in the blue scatter plot shows that the possibility of an event with a large impact parameter is also higher than with a small impact parameter.

These two scatter plots look similar and reveal similar patterns of Ncoll and Apart with impact parameters. Considering the density of dots of both scatter plots, we can find that more dots are present when Apart is smaller. Small Apart represents small Vzero, which corresponds precisely with the large density of Vzero distribution when Vzero is small. This is the direct relationship between these two plots.

For each 208Pb nucleus with a radius of 6. 62 fm and a skin depth of 0. 546 fm, the nuclear density of each of them is modelled by a Woods–Saxon distribution. The data used in the Glauber calculation [3] is based on low energy electron–nucleus scattering experiments. The distance of nucleons for hard-sphere exclusion is employed as 0. 4fm. The colliding nuclei is randomly placed in the transverse plane for the model to nuclear collisions.

The distance corresponding to the inelastic nucleon-nucleon cross-section must be estimated to be 64 ± 5 MB at SNN= 2. 76 TeV from interpolating data at different centre-of-mass energies greater than the transverse distance between nucleons since it's a necessary condition for nucleons to collide.

The measurement of the charged-particle multiplicity is based on the tracklets reconstruction. One hit in each layer combined a pair of hits which represents a tracklets candidate. The calculation of differences in azimuthal (Δϕ, bending plane) and polar (Δθ, non-bending direction) angles for pairs of hits [4] is made while the origin is defined as the reconstructed vertex which is defined |zvtx| < 7 cm to minimize edge effects. Tracklets are defined by combinations of hit that satisfy a selection on the sum of the squares (δ2) of each Δϕ and Δθ normalized to its estimated resolution (60 mrad for Δϕ and 25 sin2θ mrad for Δθ). The charged particles with transverse momentum greater than 50MeV/c are distinguished be the tolerance in Δϕ for tracklets reconstruction. If multiple tracklets candidates share only one hit, the smallest δ2 combination will be the only one to be kept.

The measurement of the charged-particle pseudo-rapidity density dNch/dη is from each single centrality class from 0%-80%. The primary vertex position is gained by the two hits correlating in two different SPD layers in the AIICE detector.

The ALICE detector is consisted of 2 different layers as mentioned before. It's necessary to distinguish noises from all data. The noises are shown in the figure 4. The collision point is marked as a blue cross. After the collision, the charged particles hit two layers and leave a hitting point (it's marked as a black circle) in each layer, respectively. It's noticeable that the signals in the same event are not the same, we hypothesis that charged particles may decay during the way between layer 1 and layer 2. The useful signal is shown as the red line below in figure 4. There may also leave a signal between two non-corresponding hitting points in two-layer, defined as noises shown as an orange line. the method used toto distinguish signals and noises is described below.

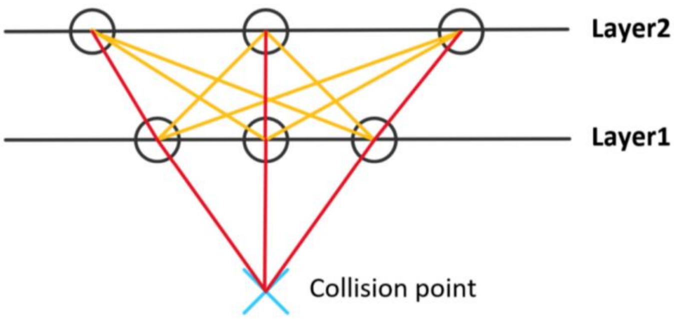

Figure 4. An example of ALICE detector which describes what happened inside the detector, and how such a large number of noises are detected.

As shown in the Figure 4, the blue cross represents the point of the collision. The two black lines represents the inner and outer layer respectively, and the black circle represents the contact point of charged particles and layers.

The charged-particle pseudo-rapidity density $\frac{dN}{d\eta}$ is measured when |η|<0. 5. After selecting the events that meet the conditions, Δη and Δφ is calculated. Since there's a large number of noises which is necessary to be kicked out (all backgrounds are shown below by the yellow line, and all signals are shown below by the red line). In order to distinguish the useful signals and useless backgrounds, a certain region for |Δφ|<0. 035 and 0. 035< |Δφ|<0. 07 is used to plot $\frac{dN}{d\Delta\eta}$ vs Δη to distinguish background and signal, the region for |Δφ|<0. 035| represents signal + background and the region for 0. 035< |Δφ|<0. 07 represents the background, the remained blue region S, which represents several charged particles among -0. 5 < η< 0. 5, is the signal we want.

The plot below (figure 5) reveals that the central part around the origin has the densest density. Almost all points in that region are the signal we want.

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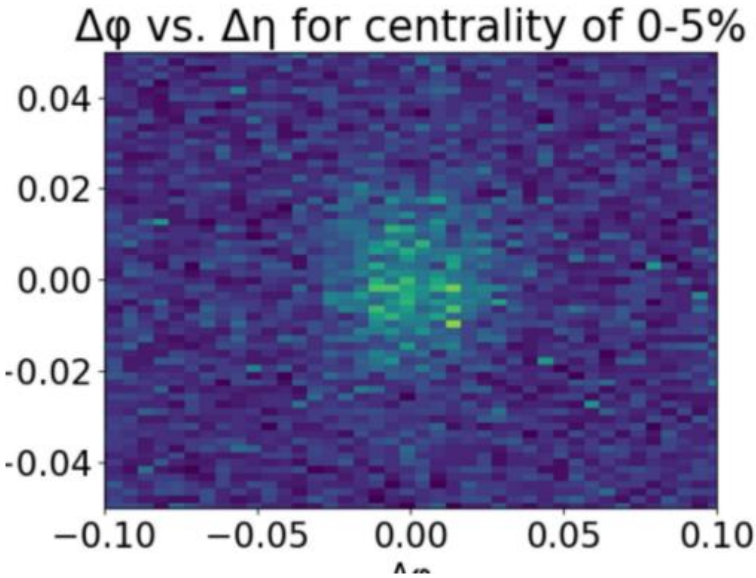

Figure 5. The scatter plot of Δη and Δϕ in the centrality of 0% to 5%.

In the Figure 5, most of the scatters are distributed near the (0,0). The original data used is Pb-Pb collision at $\sqrt{S_{NN}}$ = 2. 76 TeV.

Figure 6 shows almost all region except the top of the blue region is covered by the orange region perfectly. It reveals that the remained blue part is the useful signal without any noises.

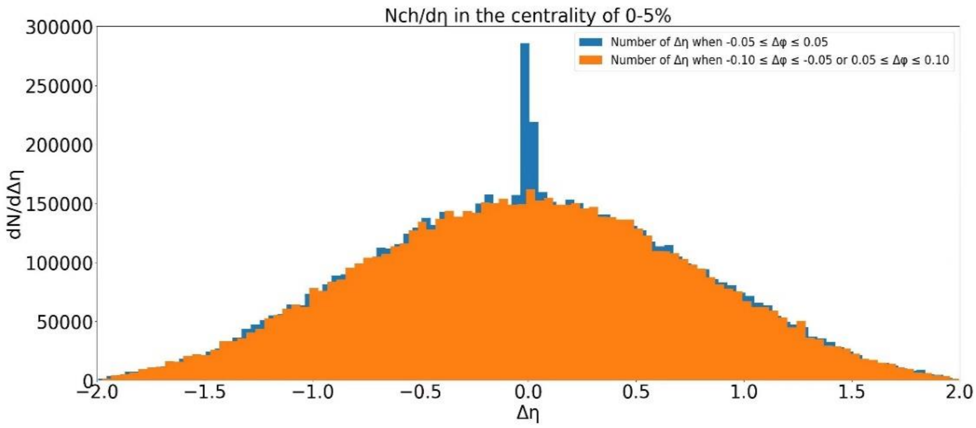

Figure 6. An example describes the method used to distinguish signals and backgrounds.

In the Figure 6, X-axis represents Δη and Y-axis represents the number of times Δη showed up in the centrality of 0-5%. The orange region tells the background, and the blue region tells the background+signal, so the remained blue part represents the signal required.

Apart is defined as the number of participants during the collision, the participants have consisted of baryons which is consisted of 3 quarks such as protons and neutrons in our case. As the collision occurs randomly. As the $\frac{dN}{dN_{part}}$ vs N_{part} graph shown before. It's more likely for several occurrences of N_{part} to be small when N_{part} is large, and it's almost impossible for N_{part} to be 414 in Pb-Pb collision (each Pb element has a relative mass of 207) because the energy required is too much to go against strong interaction.

The total systematic uncertainty on $\frac{dN_{ch}}{d\eta}$ amounts to 7. 0% and 3. 8% from outermost to the most central class [5]. The different centrality classes lead to significant uncertainty about 5. 0% and 2. 5%

into outermost and the most central class. Compared to the values of $\frac{dNch}{d\eta}$ gained by using the VZERO selection alone and our resulting values, there's only 3. 5% difference in the centrality of 70–80%, and only 2% difference in other classes, the differences above are well satisfied within the predicted systematic uncertainty before.

The charged-particle density ($\frac{dNch}{d\eta}$)is divided by the average number of participating nucleon pairs ($\frac{N_{part}}{2}$) in each different centrality class, and the aim is to compare our particle production result with that in different collision systems and that at different energies. The Npart values gained by Glauber calculation are shown before; the Npart value shown in the table is obtained by classifying them into different centrality classes and taking its average in each class. The systematic uncertainty in the Npart values is obtained by varying the impact parameters entering the Glauber calculation. The geometrical Npart values in each centrality class are satisfied with the uncertainties obtained from the Glauber fit and expected to be better than 1% in the 70-80% centrality class which differs 3. 5%.

In the Figure 7, the charged-particle density normalized per participating nucleon pair $\frac{dNch/d\eta}{Npart/2}$ of Pb-Pb collision at $\sqrt{S_{NN}}$= 2. 76 TeV is shown as y-axis, the number of participants (Apart) is shown as x-axis. Error bars and grey band represents the uncorrelated uncertainties and correlated uncertainties, respectively. There is no symbol for statistical errors since they are ignorable.

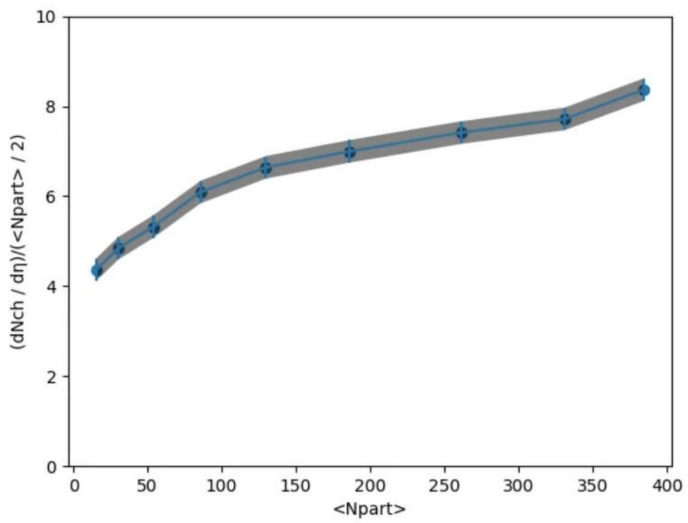

Figure 7. The relationship of the charged-particle density normalized per participating nucleon pair $\frac{dNch/d\eta}{Npart/2}$ of Pb-Pb collision at $\sqrt{S_{NN}}$= 2. 76 TeV and the number of participants (Apart).

4. Conclusion

In conclusion, all following research were conducted on the basis that Pb–Pb collisions at a centre-of-mass energy per nucleon pair $\sqrt{S_{NN}}$=2. 76 TeV. The centrality dependence of the multiplicity density of charged primary particles ($\frac{dNch}{d\eta}$) is measured, showing that $\frac{dNch}{d\eta}$ goes up as centrality goes down. From the centrality of 70-80% to the centrality of 0-5%, the charged-particle density normalized per participating nucleon pair ($\frac{dNch}{d\eta}$)/ ($\frac{N_{part}}{2}$) is doubled during each class of centrality. The results gained squint towards theoretical descriptions, which consisted of a multiplicity evolution moderation with centrality. For further steps, we agree that what kind of charged particle is produced, such as proton or segma+ could be figured out and whether there is any influence on the production of the charged particle during the decay process between layer 1 layer 2. The formation of charged particles is due to the kinetic energy of the two Pb atoms by $E=mc^2$; it's exciting to figure out why this kind of charged particle is produced instead of other kinds of charged particles.

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