Centrality Determination in Heavy Ion Collisions for the PHENIX experiment at RHIC

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Abstract

In the physics of Relativistic Heavy Ions (RHI), the centrality related parameters (such as the number of participating nucleons or number of binary collisions between nucleons) are the essential characteristics of the collisions. The majority of publications from all four RHIC experiments related to RHI physics present their results as functions of one or more centrality-related parameters. Centrality's precise determination is therefore critical to understand most of the RHI results. The distribution of the number of participating nucleons can be obtained with the commonly used Glauber model. In the PHENIX experiment, this distribution is related to the number of particle hits in the Beam-Beam Counters via statistics of the Negative Binomial Distribution (NBD). These properties allow us to achieve two principle goals: to validate the commonly used theoretical model and to establish an accurate relationship between the observable quantity (number of hits) and the number of participating nucleons. Using the data collected during full energy (200 GeV) Au+Au Run4 of the PHENIX experiment we studied the parameters of the NBD, their systematic dependencies and accuracy to which they can be determined. The work is done by using the MINUIT minimization tool in the ROOT environment. This work will contribute to future analysis by many members of the PHENIX collaboration, yielding better measurements of the centrality-related parameters.

Objectives

To determine centrality to greater accuracy than before

- Centrality is a fundamental characterization of a collision event
- Most PHENIX results are presented as functions of centrality
- Improves on previous method of calculation

To generate lookup tables for all parameters, starting from measured BBC hits

- Tables will be used to find all MCG variables from BBC hits
- Using lookup tables is a concise and fast path to eliminate repetitive and time-consuming calculation which otherwise must be done analytically

Methods

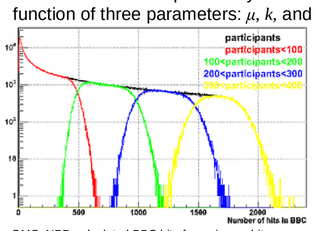
1. Using Glauber/Monte-Carlo (GMC) simulations we can:
   - Create relationships between participants in a collision and other parameters
   - Construct Beam-Beam Counter (BBC) hits using the Negative Binomial Distribution (NBD)
2. Fitting data using the NBD allows us to construct relationship between BBC hits and participants, and thus the rest of the GMC variables, especially centrality

Beam-Beam Counter (BBC) Hit Distributions and the Negative Binomial Distribution (NBD)

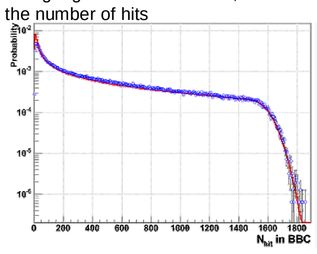
- Measured hits in the BBC follow the negative binomial distribution:

$$NBD(n_{hits},\mu,k)=\frac{\Gamma(n+k)}{\Gamma(k)n!}\left(\frac{\mu}{k}\right)^{n}\frac{1}{(1+\mu/k)^{n+k}} \qquad \lim_{k\to\infty} NBD = \text{Poisson Distribution}$$

- The NBD returns the probability of measuring a given number of hits, and is a function of three parameters: μ, k, and the number of hits



GMC+NBD-calculated BBC hits for various arbitrary number of participants

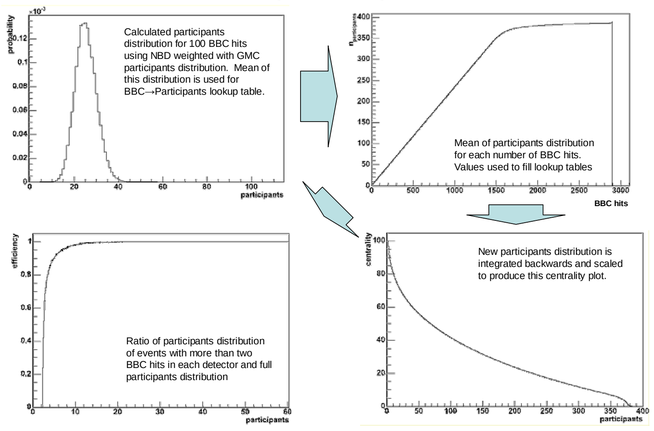


Actual BBC data distribution, fit with the NBD distribution, $\chi^2/ndf \approx 330/320$

- By fitting a measured BBC distribution for μ and k, we can create a relationship between BBC hits and participants
- We also fit trigger efficiency

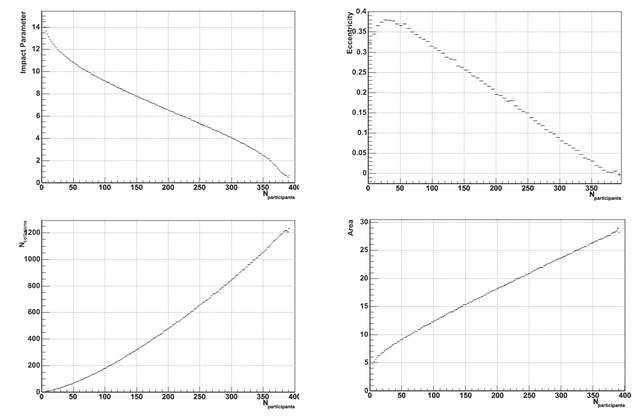
Lookup Tables – μ, k Dependent

Using Glauber/Monte-Carlo+NBD, relationships between number of participants and BBC hits, efficiency, and centrality are constructed

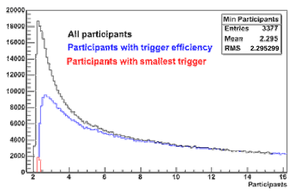


Lookup Tables – μ, k Independent

Using Glauber/Monte-Carlo, relationships between a four parameters and number of participants are constructed

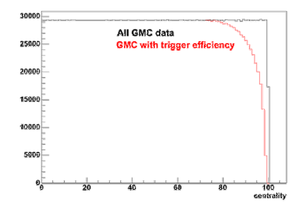


Minimum Reconstructed Participants



- Plot shows three participants distributions
- As low as 2.3 participants (RMS of red distribution) can be reconstructed

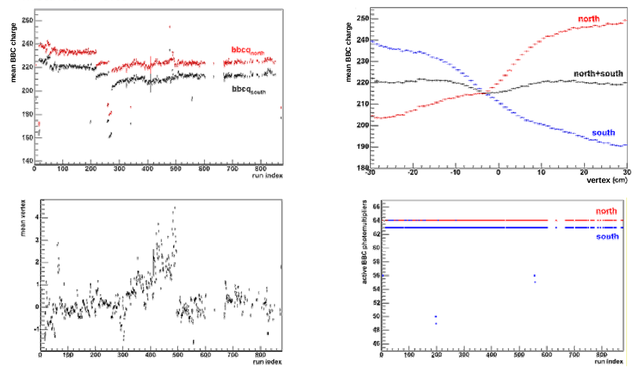
Reconstructed Centrality



- Plot shows centrality in 1% bins
- Centralities up to 98% can be determined, because of trigger efficiency

Data QA

- We used data collected during full energy (200 GeV) Au+Au Run4
- BBC data varied over the course of Run4
- BBC data varied in the north and south BBC
- BBC data varied over different vertices
- Mean run vertex varied



Data Recalibration

Goals of Recalibration

- Standardize entire Run4
- Fit entire Run4 with one single set of μ, k
- Create one set of lookup tables for participants, centrality, and efficiency
- Greatly simplify lookup procedure for Run4 data
- Method can easily be used for future analysis of other heavy ion runs

Recalibration Steps

1. Vertex recalibration
2. Mean sum of BBC charge scaled as a function of vertex
3. Mean sum of BBC charge scaled as a function of run index

Recalibration Steps

Step #1: Vertex recalibration

Step #2: BBC sum recalibration

Final Recalibration Results

Summary / Outlook

1. BBC data can be fit with the NBD weighted with GMC participants distribution to extract values for μ, k and efficiency
2. GMC data is used to create lookup tables for eccentricity, area, impact parameter and number of collisions as functions of number of participants
3. GMC+NBD yield lookup tables for number of participants as a function of BBC hits, and centrality and efficiency as functions of number of participants
4. We attempted bulk recalibration of Run4 data to fit μ, k and efficiency, but discovered problems with our recalibration methods
5. In order to use this method, Run4 data must be fit with the NBD in smaller chunks, with different vertex conditions, to accurately reconstruct number of participants, and thus centrality from measured BBC data

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