Examining the Use of the Glauber Model on Multiplicity Distributions from the Solenoid Tracker at RHIC (STAR) Beam Energy Scan and Fixed-Target Programs

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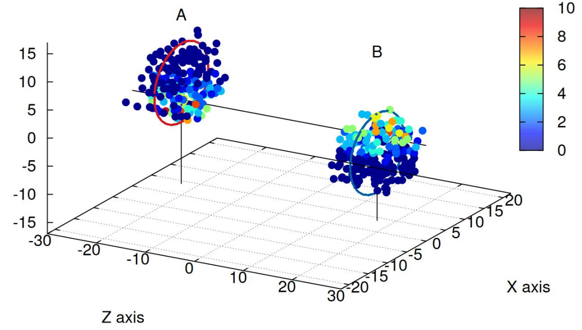
Will traditional particle production simulations represent observed multiplicities for fixed-target events?

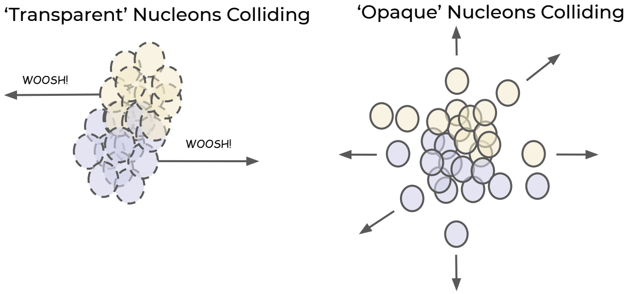
Monte Carlo based Glauber Model (MCGM) has been used at the Large Hadron Collider (CMS, ATLAS, ALICE) and at RHIC (STAR, PHENIX, PHOBOS, BRHAMS). (M.L. Miller et al., Annual Rev. NPS. 57, 205-43 (2007))

- Particles are produced by interactions between nucleons (protons and neutrons) in heavy-ion collisions.
- Glauber Model generates collisions using overlapping 2D nucleons.
- This works to model high energies used by LHC, $\sqrt{s_{NN}}$ ~13 TeV, and RHIC, $\sqrt{s_{NN}}$ 200 GeV, because nucleons pass through each other due to relativistic effects.

At lower energies, nucleons become more opaque and have more classical interactions like billiard balls.



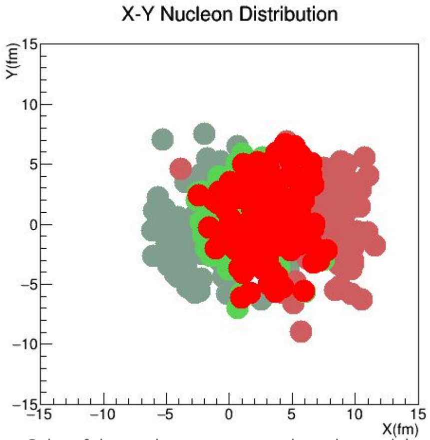
Adamczewski-Musch, J., Arnold, O., Behnke, C.et al.Centrality determination of Au + Au collisions at 1.23A GeV with HADES.Eur. Phys. J. A54,85 (2018).



Methodology

MCGM Generates Au+Au nuclei and simulates binary nucleon-nucleon collisions using 3 geometric parameters.

- Impact parameter b: randomly generated distance between the center of each nucleus.
  - b ≳ 2*(radius of nucleus) is seen as a miss and not recorded
- Number of binary collisions (N_{coll}): total number of each nucleon-nucleon interaction.
- Number of participants (N_{part}): total number of nucleons involved in all interactions



Color of the nucleons corresponds to the nuclei to which they belong. One red nuclei and one green. Brighter colors are nucleons participating in collisions. Dull color are spectators with no interaction.

A Negative Binomial Distribution (NBD) is used to simulate particle production.

Kharzeev, D., Nardi, M., et al., "Hadron production in nuclear collisions at RHIC and high density QCD", Phys. Lett. B507 (2008) 121-128

- Sampled $N = x*N_{coll} + (1-x)*\frac{N_{part}}{2}$ number of times.
  (M.L. Miller et al., Annual Rev. NPS. 57, 205-43 (2007))
- x is the hardness parameter
  - Determines the ratio of hard (transparent) interactions and soft (opaque) interactions.

$$P(n) \propto \binom{n+k-1}{k} \frac{(\mu / k)^n}{(\mu / k + 1)^{n+k}}$$

We have explored varying the hardness parameter, x:

- NBD parameters, μ and k, are scanned over a manually chosen range.
- Multiplicity distributions are generated based on the best fit

History

Collaborations at SIS18, RHIC, and the LHC use the MCGM to fit multiplicity distributions.

HADES collaboration at GSI tried MCGM for $\sqrt{s_{NN}}$ = 2.4 GeV.

Adamczewski-Musch, J., Arnold, O., Behnke, C.et al Phys. J. A54, 85 (2018).

- Used multiplicity dependent efficiency
    - $\varepsilon(\alpha) = 1 - \alpha(\text{Npart})^2$

HADES, PHOBOS, and ALICE use appropriate x for very high and very low $\sqrt{s_{NN}}$.

RHIC traditionally used x ≅ 0.11 for energies lower than $\sqrt{s_{NN}}$ = 200 GeV.

- Our study has considered how fits change as we allow x to float.

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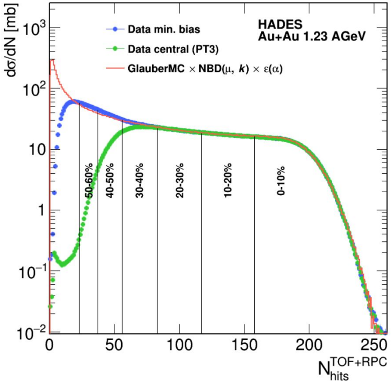

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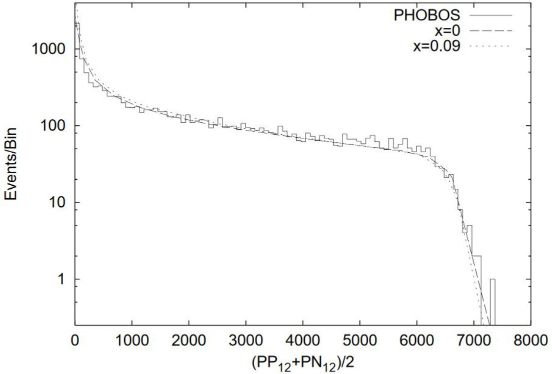
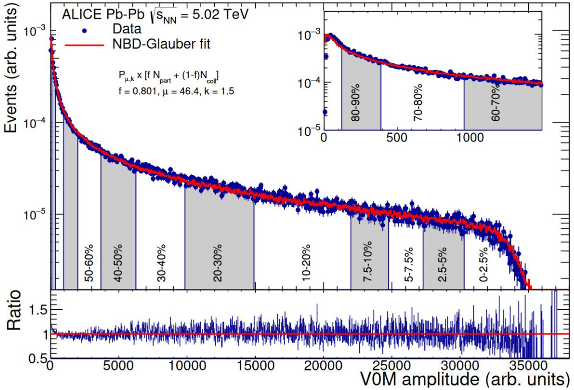


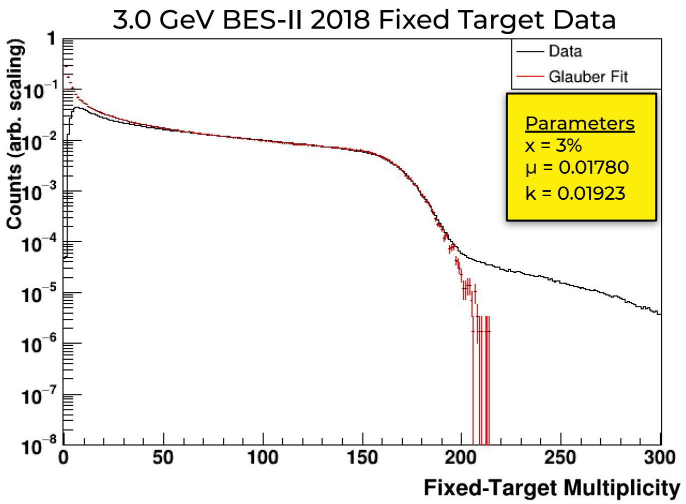
ALICE Collaboration, J. Adam et al., "Centrality dependence of particle production in p-Pbcollisions at√sNN=5.02 TeV,"Phys. Rev.C91no. 6, (2015) 064905

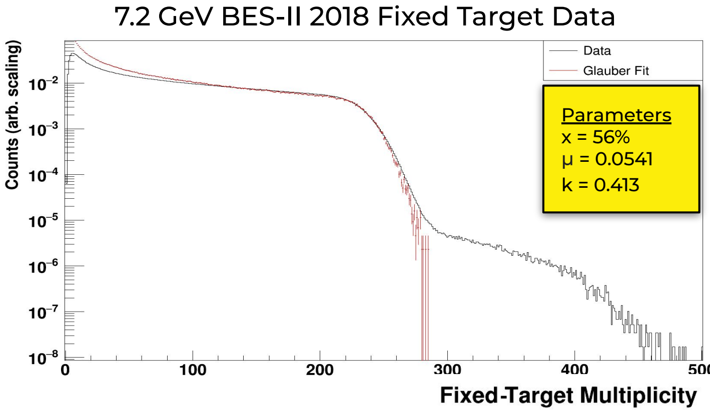


Findings

Comparing model fits for two fixed target multiplicities.

- $\sqrt{s_{NN}}$ = 3.0 GeV:
  - MCGM follows data curve well.
  - Small deviation at most peripheral events.
- $\sqrt{s_{NN}}$ = 7.2 GeV:
  - Still a good fit, but, larger deviation along the multiplicity curve.
  - Varying hardness does not improve the fit.





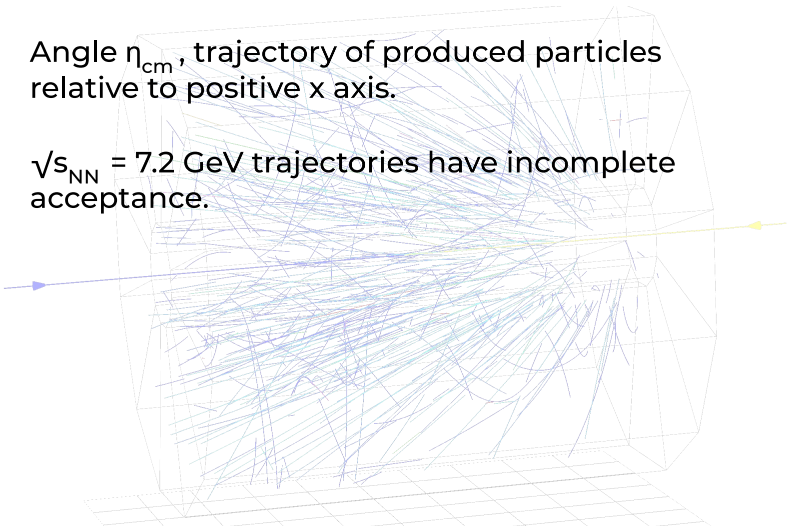
Findings

A closer look at the $\sqrt{s_{NN}}$ = 7.2 GeV Multiplicity best fit deviation.

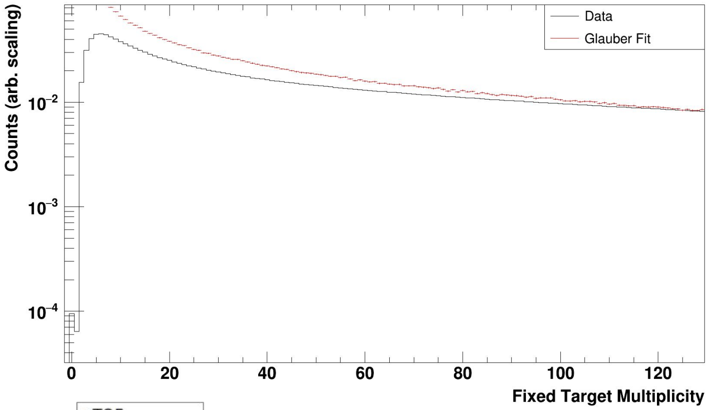
- ❏ Glauber model overshoots at lower peripheral multiplicities.

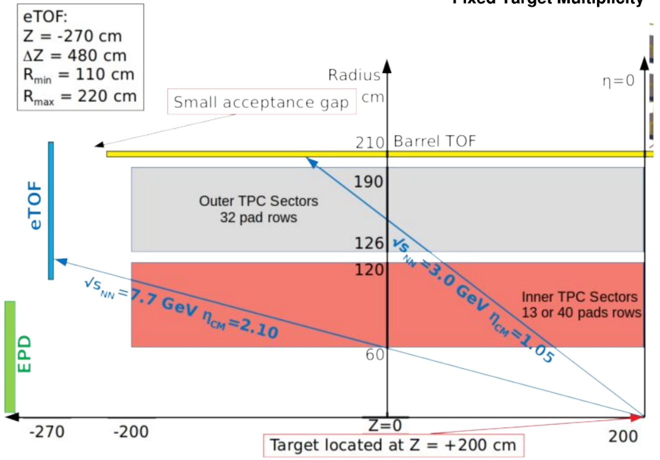
Why the inconsistency?

- ❏ Angle η_{cm}, trajectory of produced particles relative to positive x axis.
- ❏ $\sqrt{s_{NN}}$ = 7.2 GeV trajectories have incomplete acceptance.



7.2 GeV BES-II 2018 Fixed Target Data





Conclusions:

- ❏ The Monte Carlo Glauber Model methodology works well at 3 GeV.
- ❏ There is a larger discrepancy at 7.2 GeV.

Ongoing work:

- ❏ New data sets covering a wide range of collision energies, $\sqrt{s_{NN}}$ = 3.0, 3.2, 3.5, 3.9, 4.5, 5.2, 6.2, 7.2, 7.7 GeV, to fit in fixed-target mode.
- ❏ Test with the multiplicity dependent efficiency parameter.