Centrality determination in MPD at NICA

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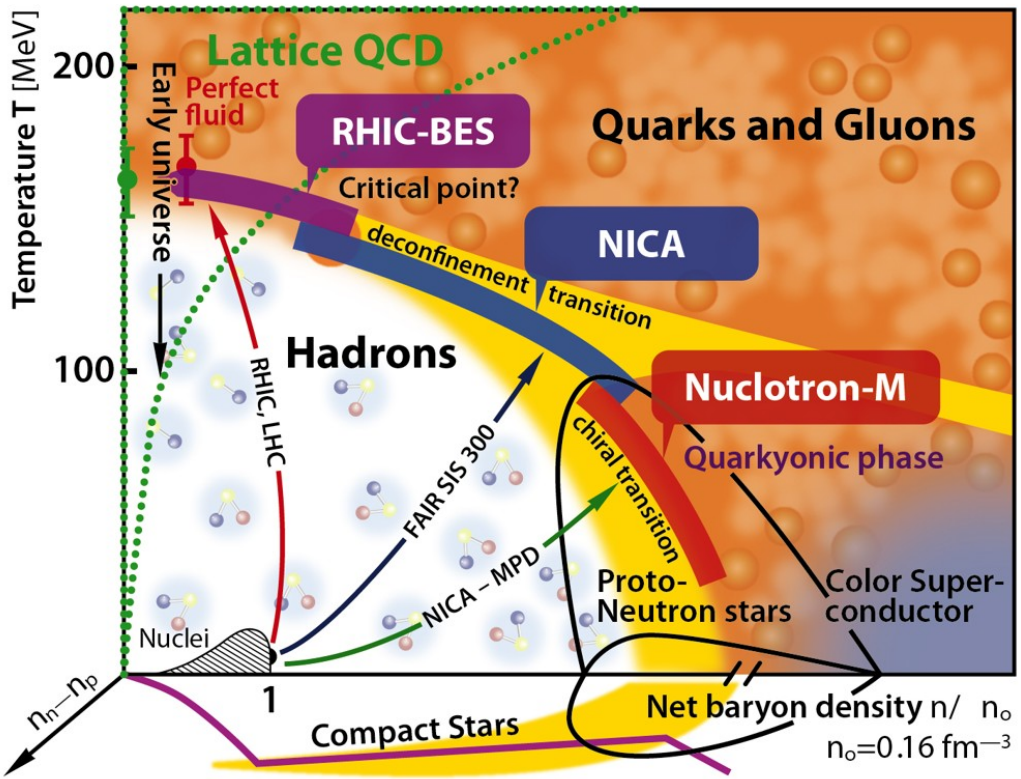
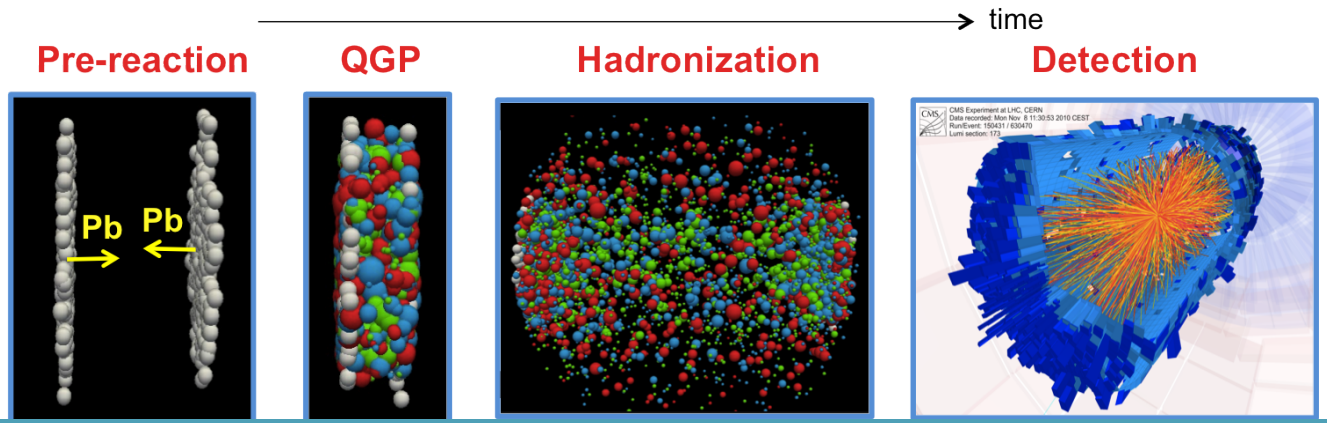
MexNICA

QCD phase diagram (NICA)





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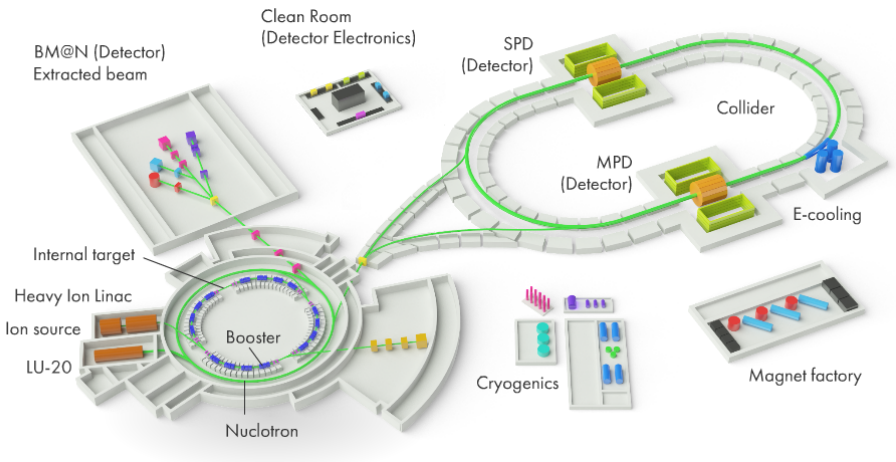
Nuclotron-based Ion Collider fAcility (NICA)



First events with Bi+Bi at $\sqrt{S_{NN}} = 9.2$ GeV.

- Study of in-medium properties of hadrons and nuclear matter and the equation of state.
- Search for location of the phase transition between hadronic matter and QGP; search for new phases of baryonic matter and the Critical Point.

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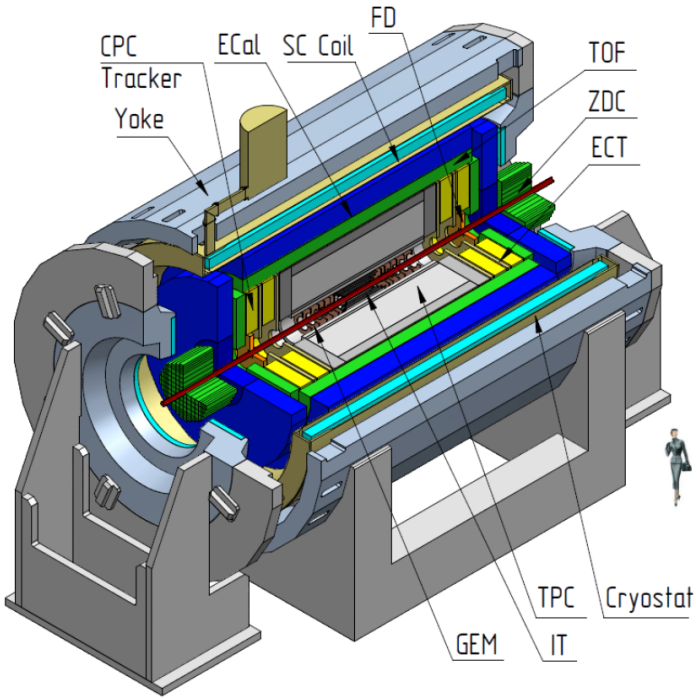
Multi-Purpose Detector (MPD)



- Detect the high multiplicity events and perform particle identification.

  3-D tracking system (TPC). Particle identification (PID) system based on the time-of-flight measurements and calorimetry.

- Event rate in the MPD interaction region $\sim$ 6 kHz.
- Total charged particle multiplicity would be 1000+ in the most central Au+Au collisions at $\sqrt{S_{NN}} = 11$ GeV.
- $\langle p_T \rangle \leq 500$ MeV/c

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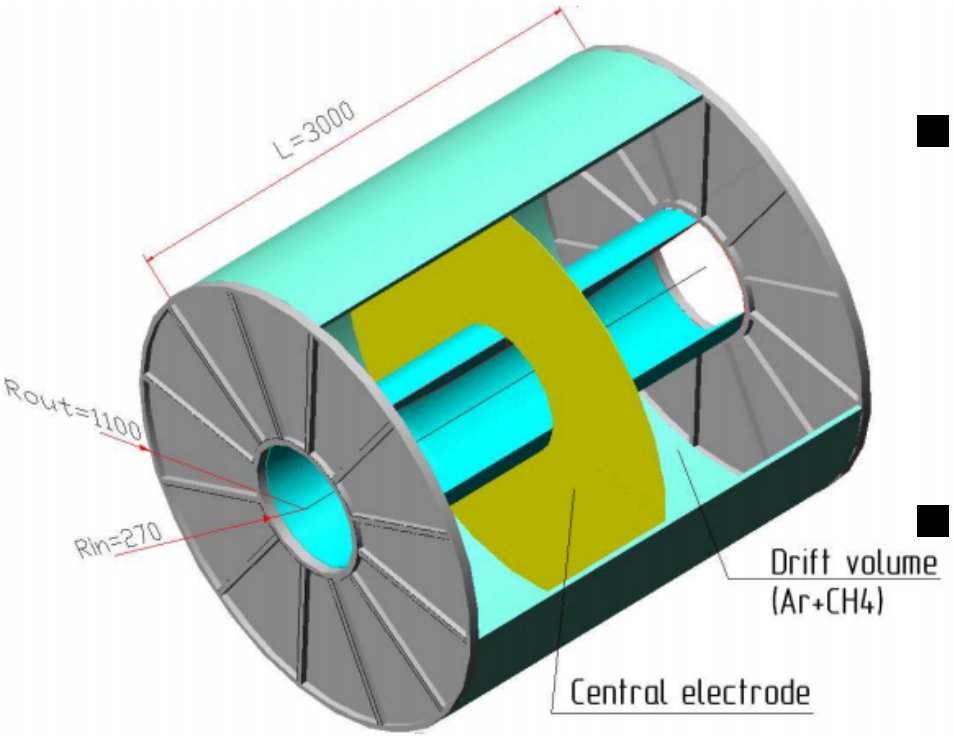
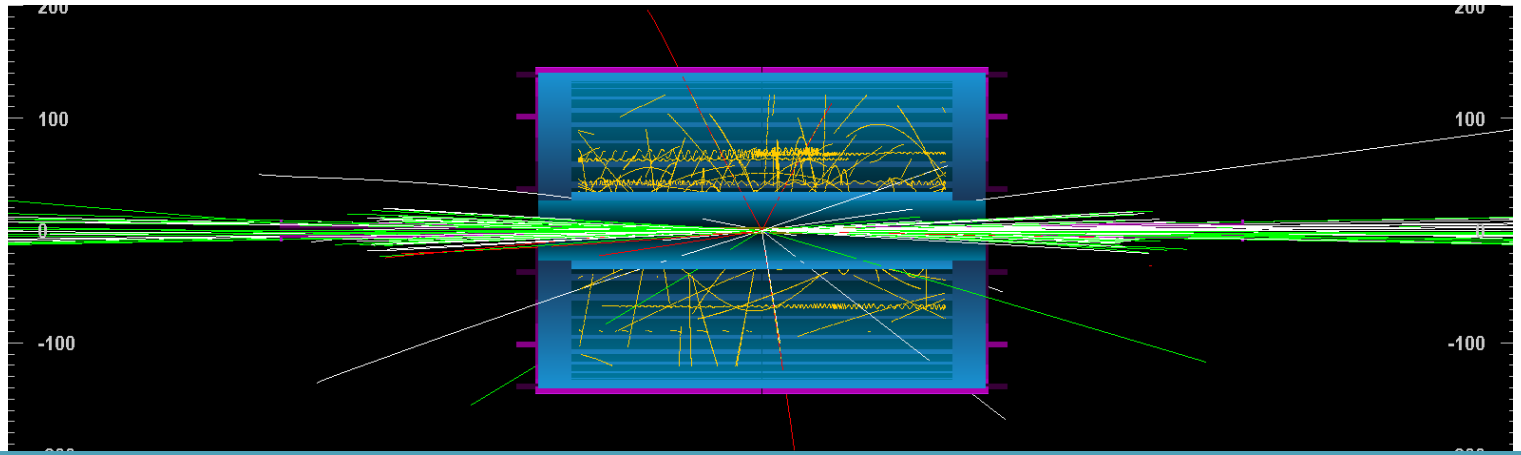
Time Projection Chamber



- Provide charged particles momentum measurement with sufficient resolution, particle identification and vertex determination.
- Provide efficient tracking up to pseudorapidity region $|\eta| \leq 1.5$ and $p_T \geq 100$ MeV/c.



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Centrality determination

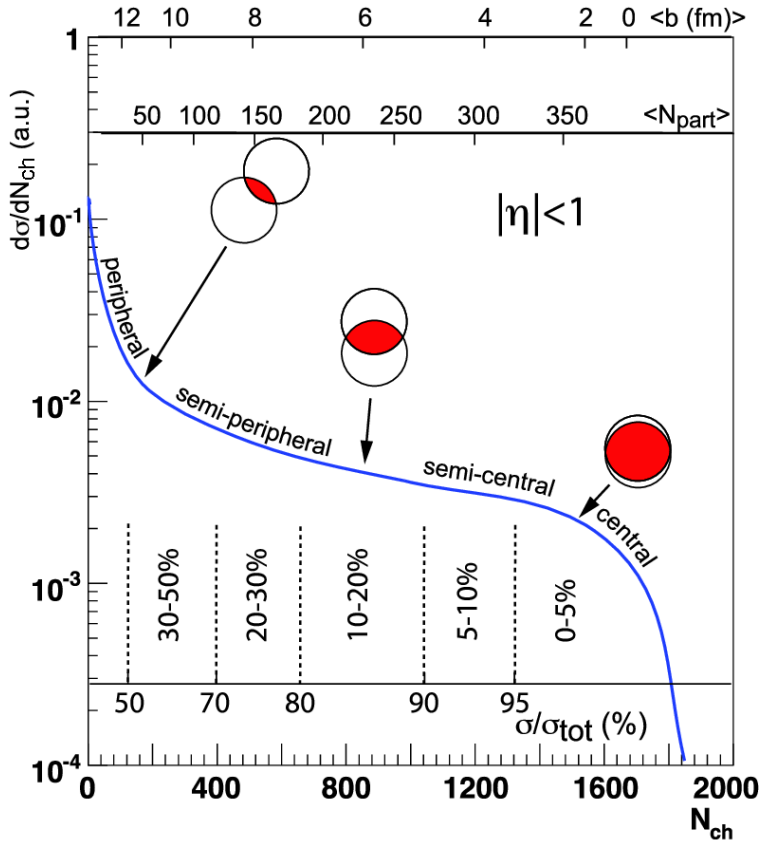
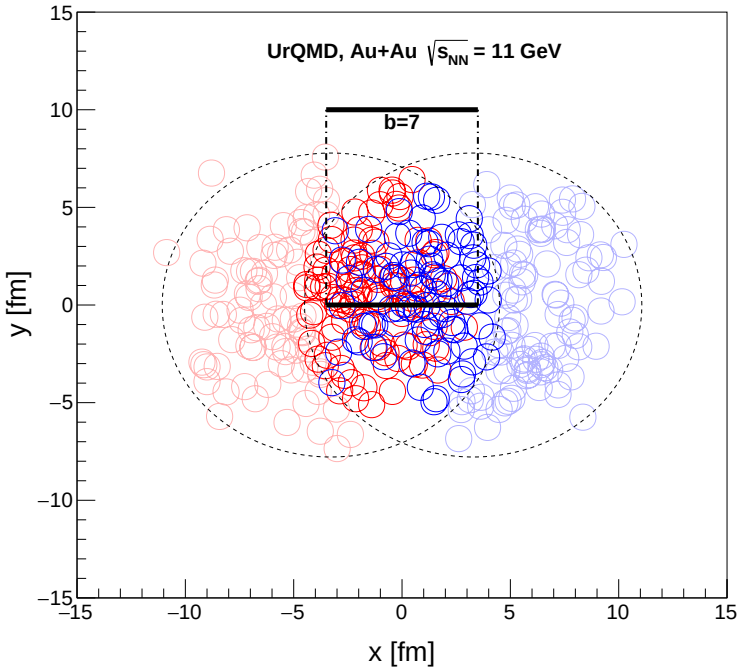


Figure: Relation between impact parameter (b), number of participants (N_{part}), multiplicity (N_{ch}) and centrality.



Definition

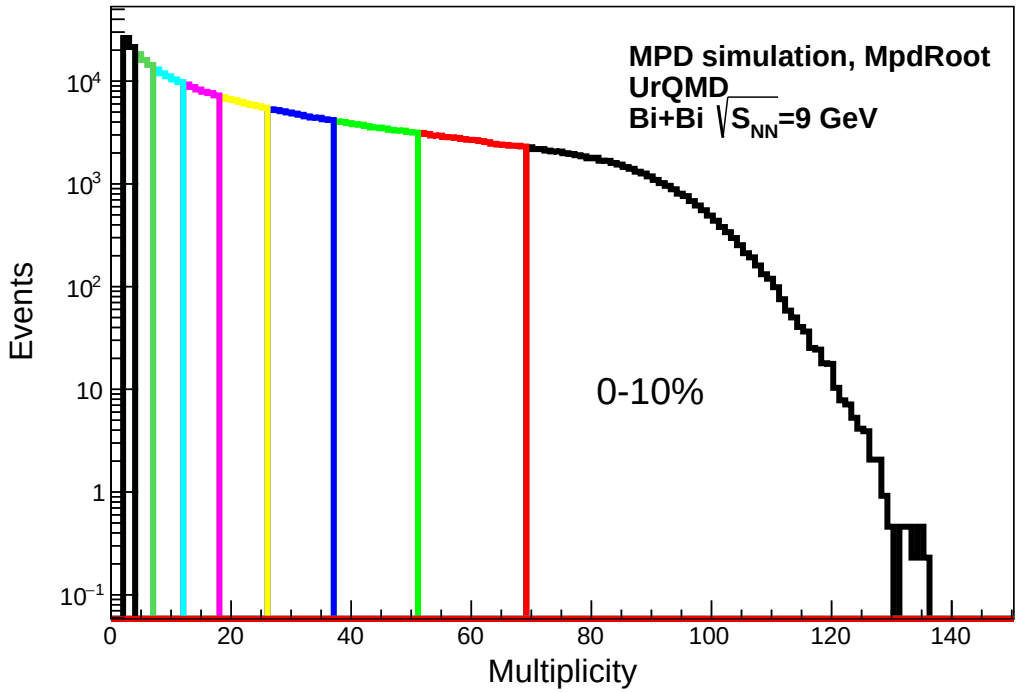
Centrality: Percentage of the total nuclear interaction cross section σ_{AA}

$$c_b = \frac{\int_0^b \frac{d\sigma}{db'} db'}{\int_0^\infty \frac{d\sigma}{db'} db'} = \frac{1}{\sigma_{AA}} \int_0^b \frac{d\sigma}{db'} db' \quad (1)$$

Definition

Centrality classes based on the **multiplicity distribution**:

$$c_m[\%] = \frac{\int_{N_{max}}^{N_i} \frac{dN_{ev}}{dN_{ch}} dN_{ch}}{\int_{N_{max}}^{0} \frac{dN_{ev}}{dN_{ch}} dN_{ch}} \quad (2)$$



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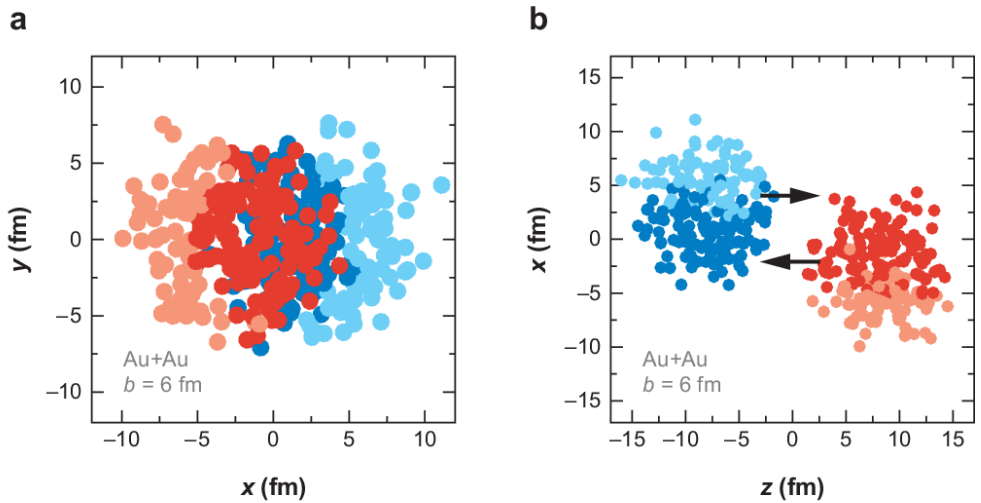
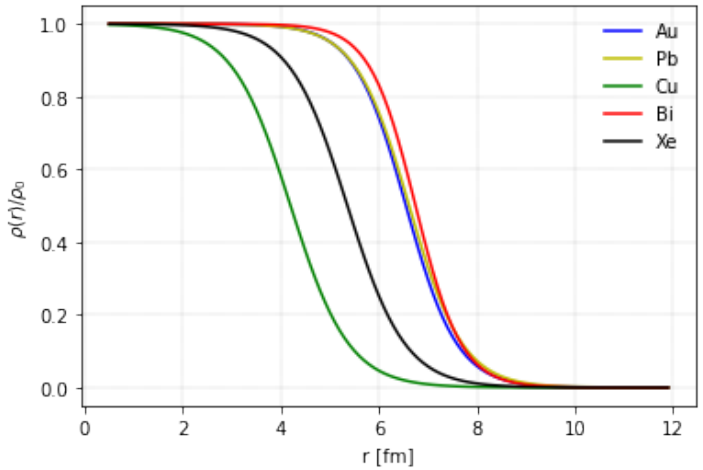
MC-Glauber





Nuclear density function for five different nucleus (Au, Pb, Cu, Bi and Xe).

- Describe the dependence of N_{part} and N_{coll} on b in p–A and A–A collisions.
- Compose two nuclei out of nucleons and simulate their collision process event by-event.
- **Geometrical quantities:** Impact parameter b, N_{part}, N_{spec} and N_{coll}.

Definition

Nuclear density function:

$$\rho(r) = \rho_0 \frac{1 + w(r/R)^2}{1 + exp(\frac{r-R}{a})} \qquad (3)$$

Loizides, C.; Nagle, J.; Steinberg, P. Improved version of the PHOBOS Glauber Monte Carlo. SoftwareX 2015, 1–2, 13.

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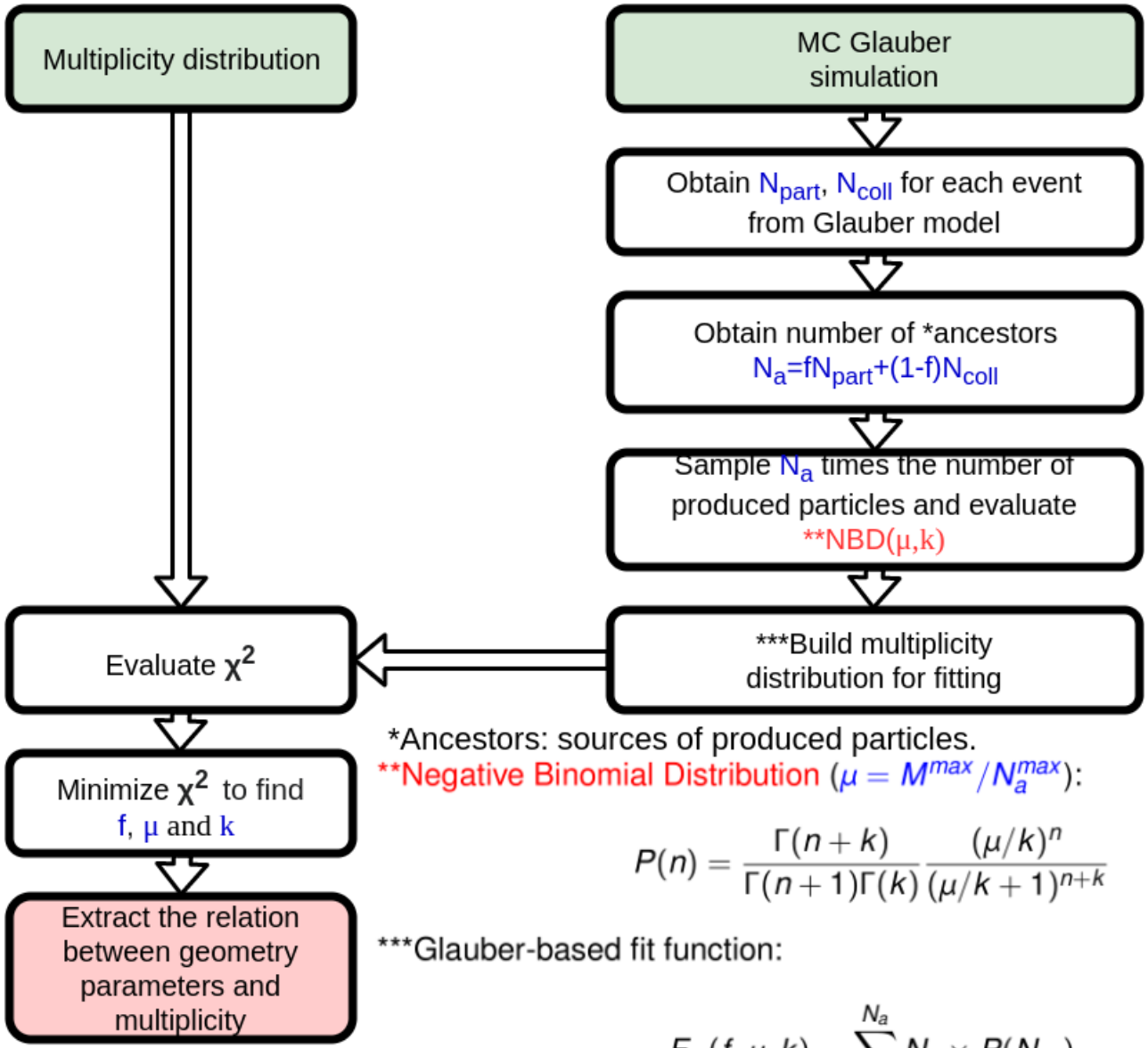
Centrality Determination / MC-Glauber Approach



*Ancestors: sources of produced particles.

**Negative Binomial Distribution ($\mu = M^{max}/N_a^{max}$):

$$P(n) = \frac{\Gamma(n+k)}{\Gamma(n+1)\Gamma(k)} \frac{(\mu/k)^n}{(\mu/k+1)^{n+k}}$$

***Glauber-based fit function:

$$F_{fit}(f,\mu,k) = \sum_{1}^{N_a} N_a \times P(N_{ch})$$

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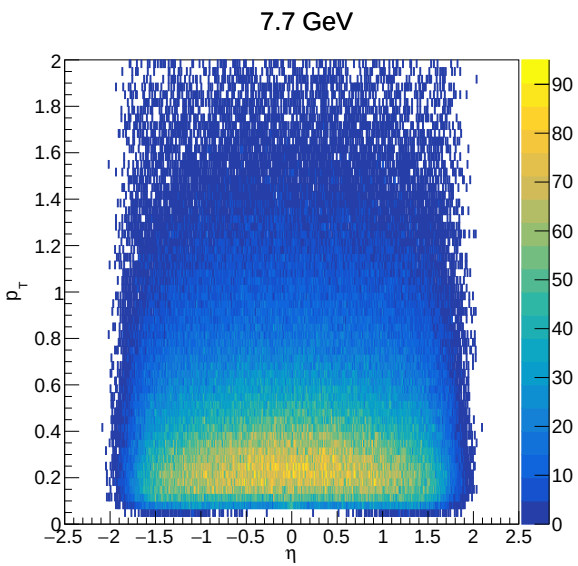
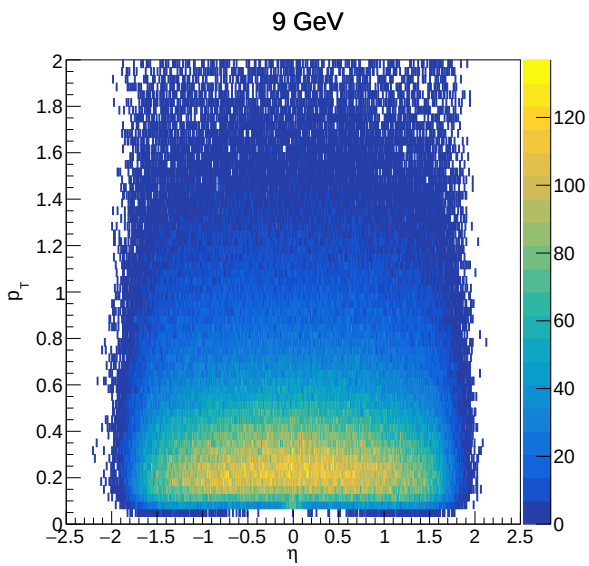
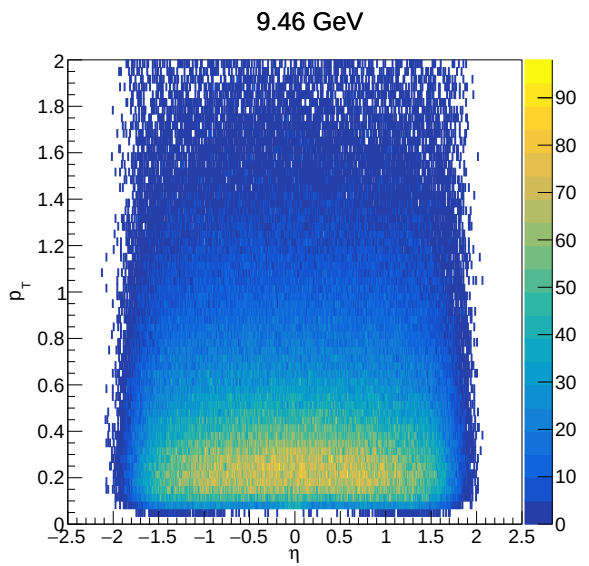
Multiplicity selection

- $p_T > 0.15$ GeV/c
- $|\eta| < 0.5$ and $|\eta| < 1.3$
- Only charged particles
- $N_{hits} > 16$
- Primary particles.
- $\sim 600,000$ reconstructed events in MpdRoot Framework.
- Bi+Bi collisions at 7.7, 9 and 9.46 GeV using UrQMD.







Multiplicity distribution

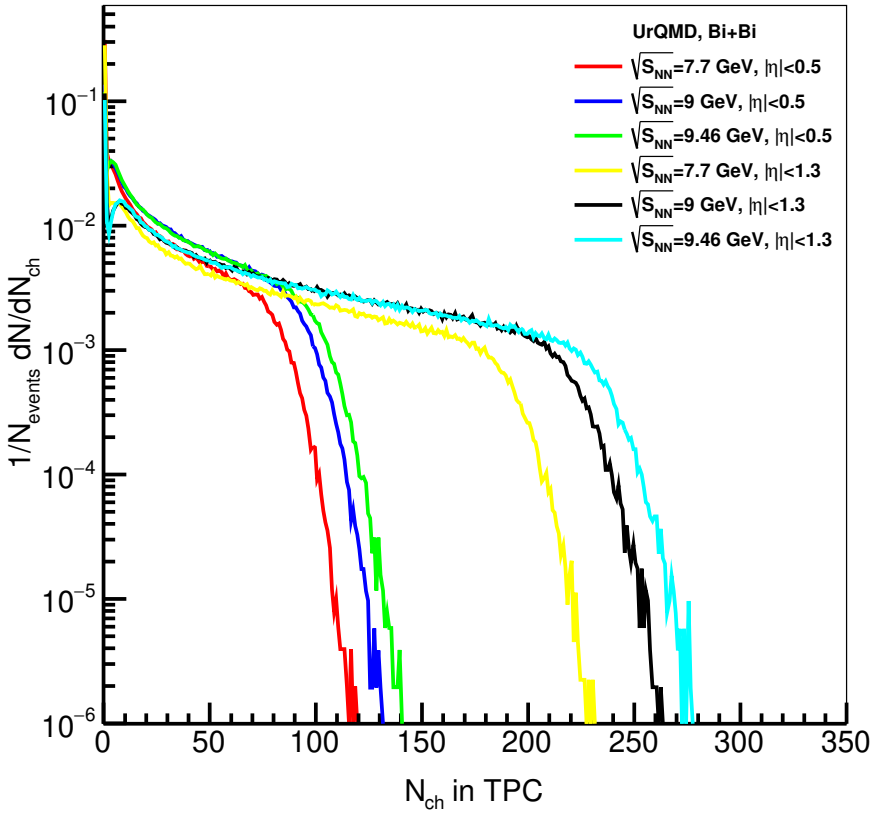


Figure: Comparison of the multiplicity distributions at the two η ranges ($|\eta| < 0.5$ and $|\eta| < 1.3$) at $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV.

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b vs centrality

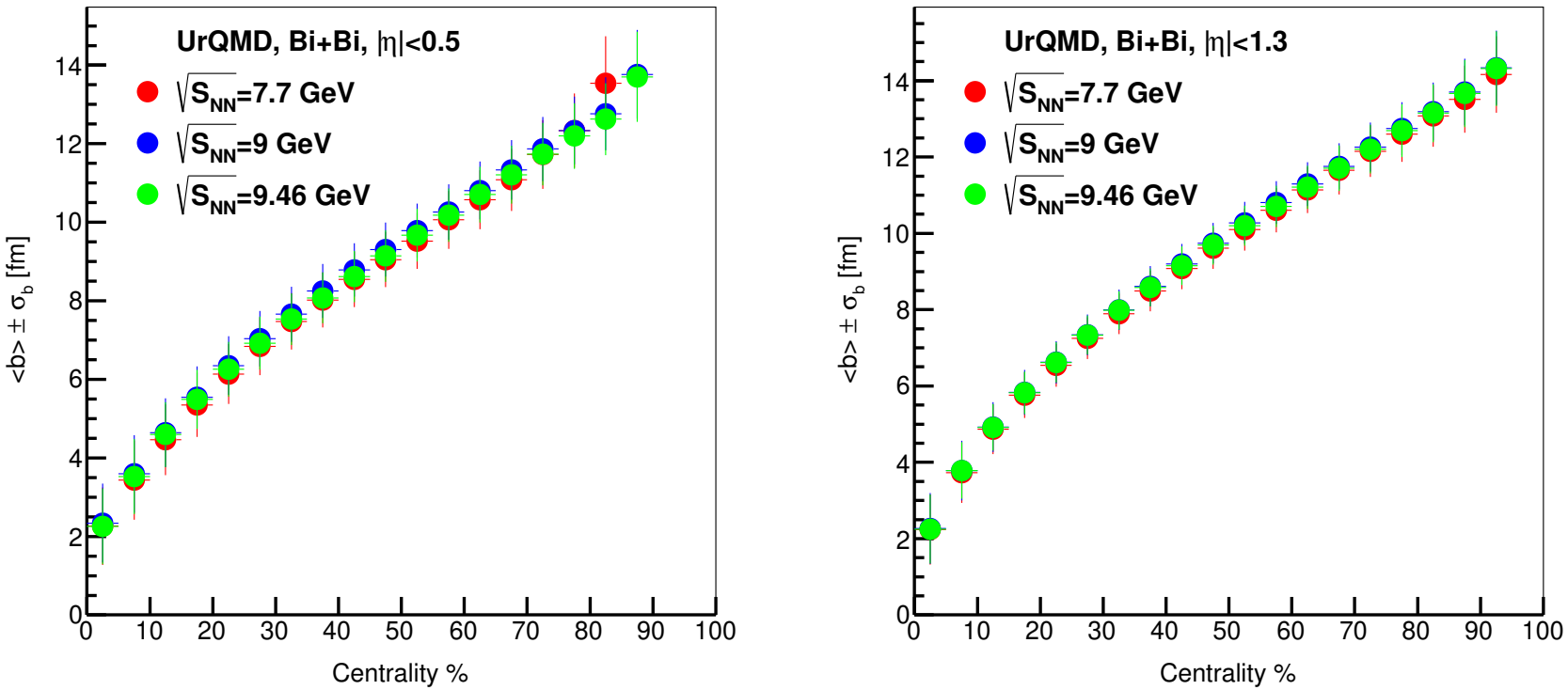

Figure: Comparison of the relation of impact parameter *b* with centrality of the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV for $|\eta| < 0.5$ (left) and $|\eta| < 1.3$ (right).

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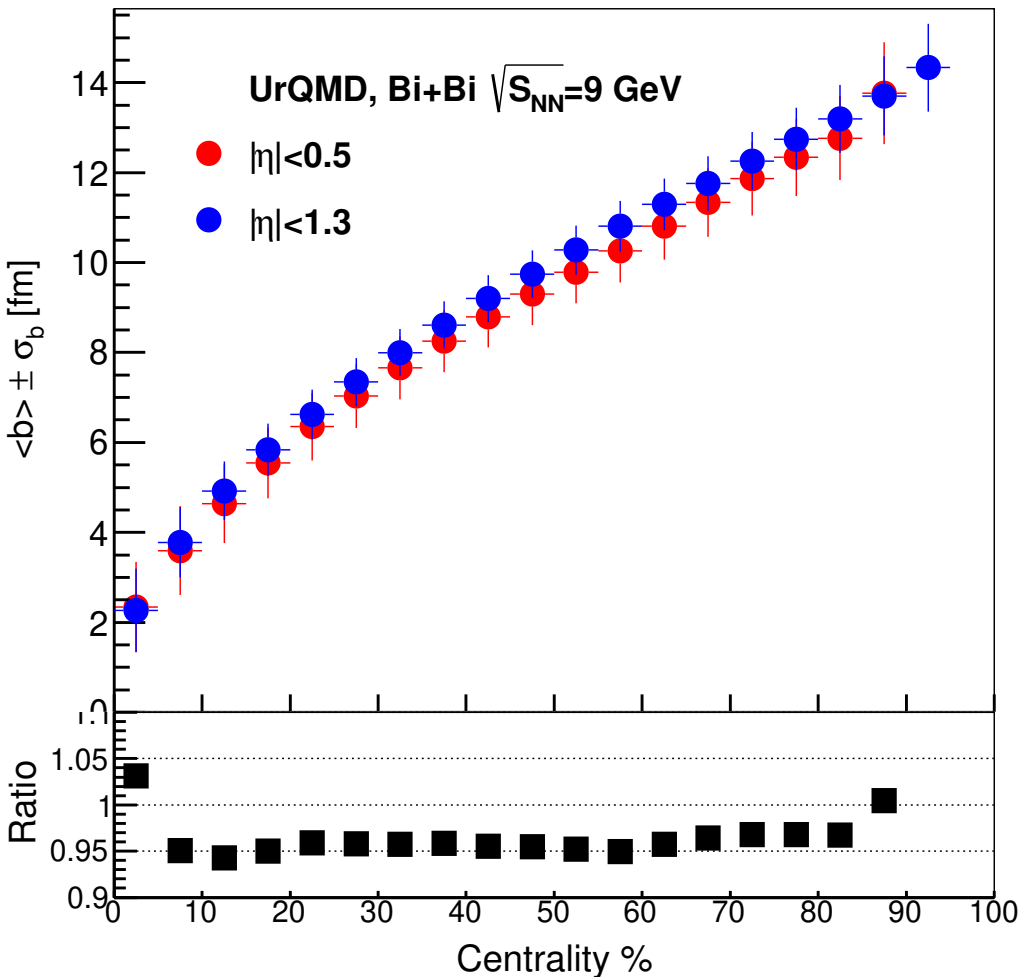
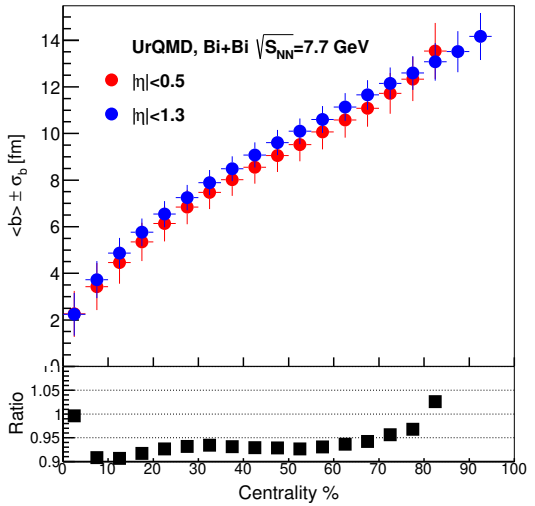
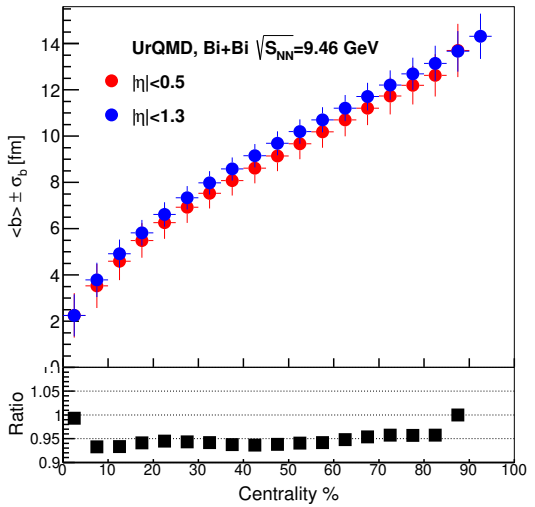
$|\eta| < 0.5$ and $|\eta| < 1.3$ comparison

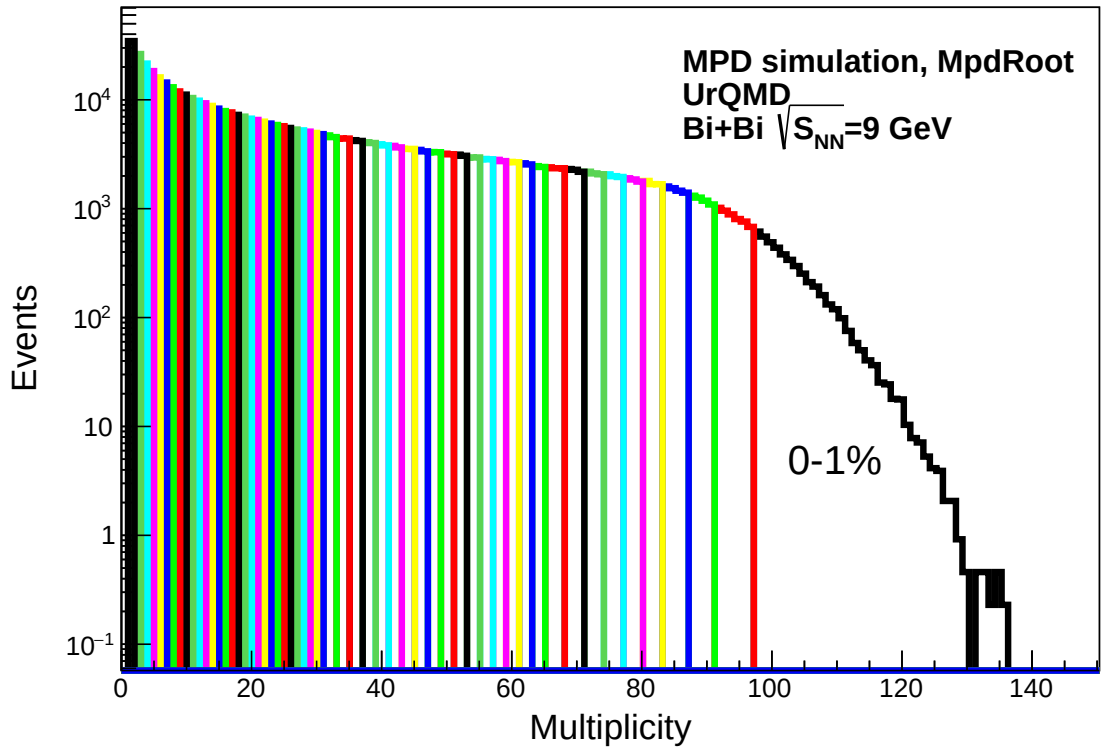






Pseudorapidity comparison of the relation of impact parameter with centrality at the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV.

Centrality ranges comparison



- Reduce the range of the centrality classes to 1% to compare it with the previous results obtained of 5%.
- $p_T > 0.15$ GeV/c
- $|\eta| < 0.5$

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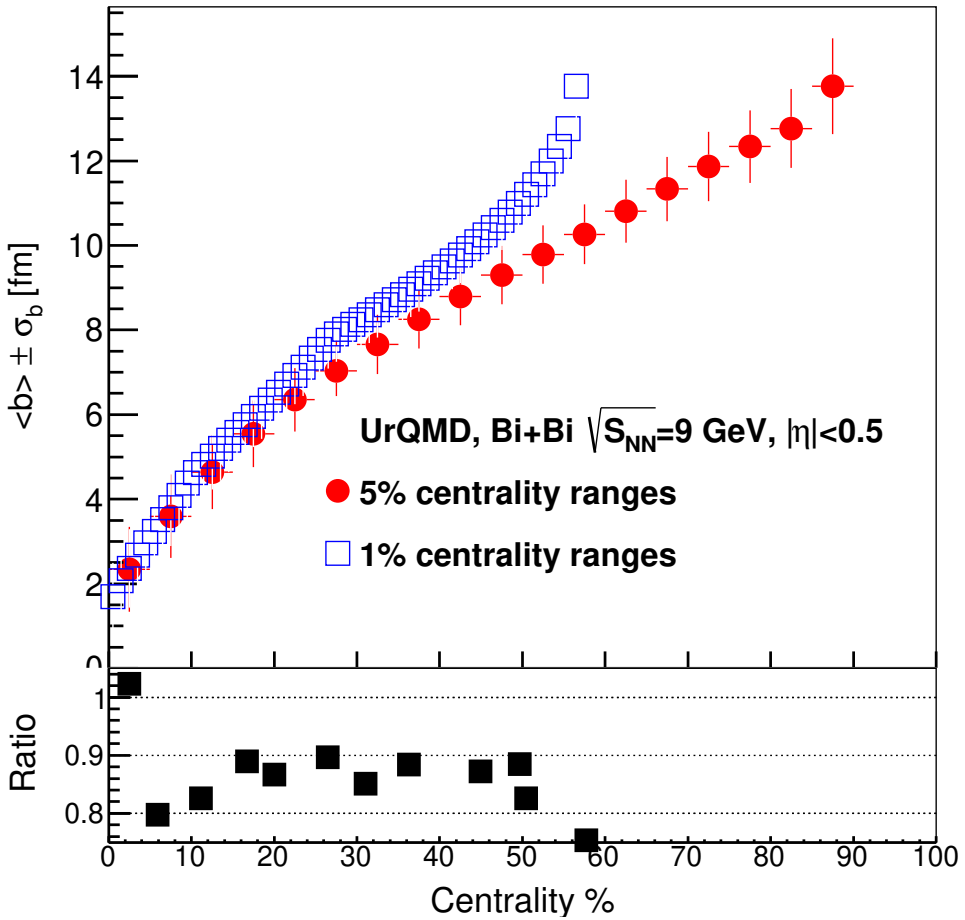
Centrality ranges comparison



5% and 1% centrality ranges comparison of the impact parameter vs centrality at the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV.

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UrQMD model

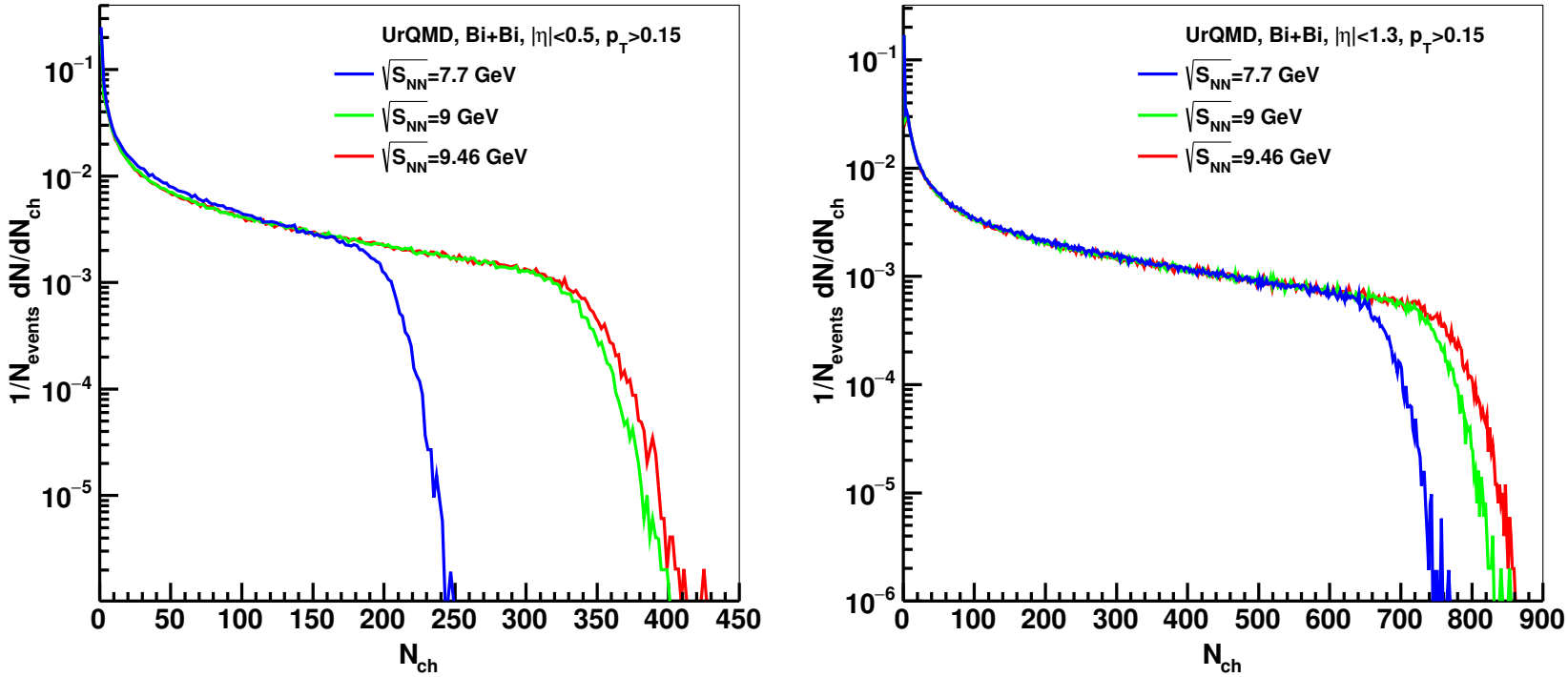

Figure: Multiplicity distributions based on the UrQMD generator for Bi+Bi collisions at the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV in the pseudorapidity ranges of $eta < 0.5$ (left) and $eta < 1.3$ (right).

- Only charged particles
- $\sim 600,000$ events.
- Bi+Bi collisions at 7.7, 9 and 9.46 GeV using UrQMD output files (test.f14).

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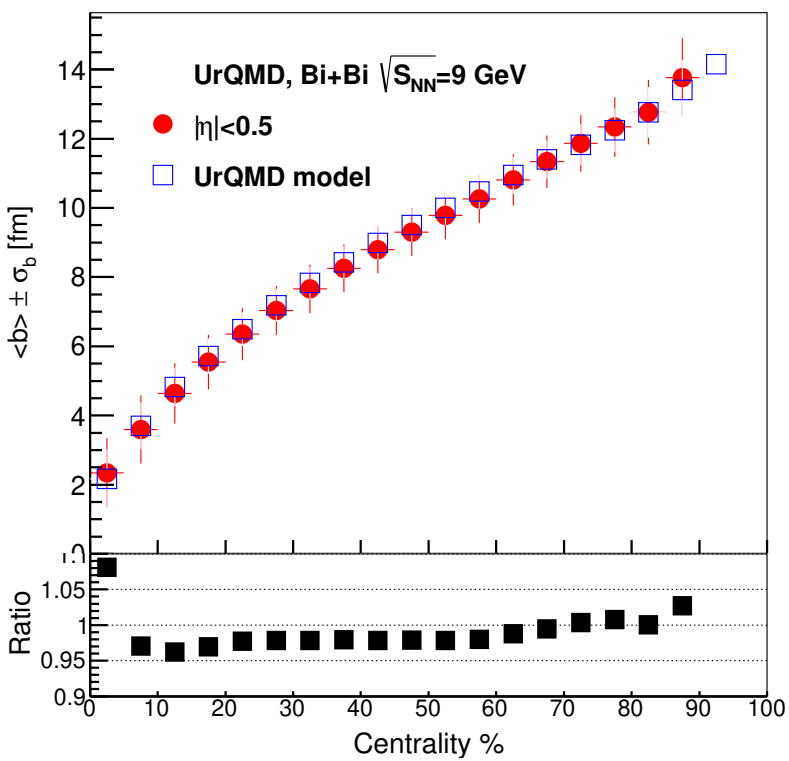
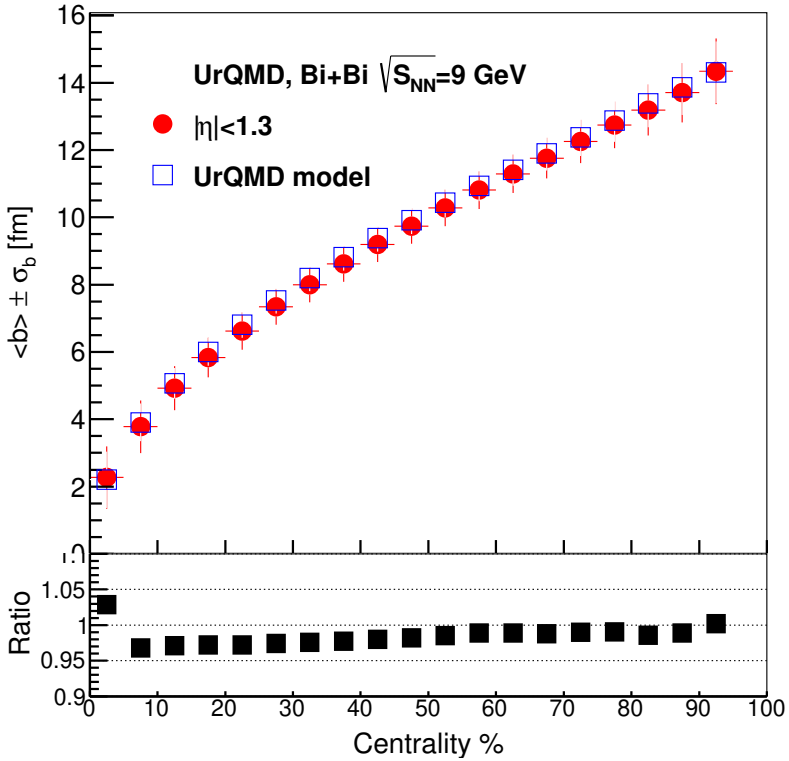
UrQMD model ($|\eta| < 0.5$ and $|\eta| < 1.3$)





UrQMD model and TPC results comparison of the impact parameter vs centrality at the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV with $|\eta| < 0.5$ (left) and $|\eta| < 1.3$ (right).

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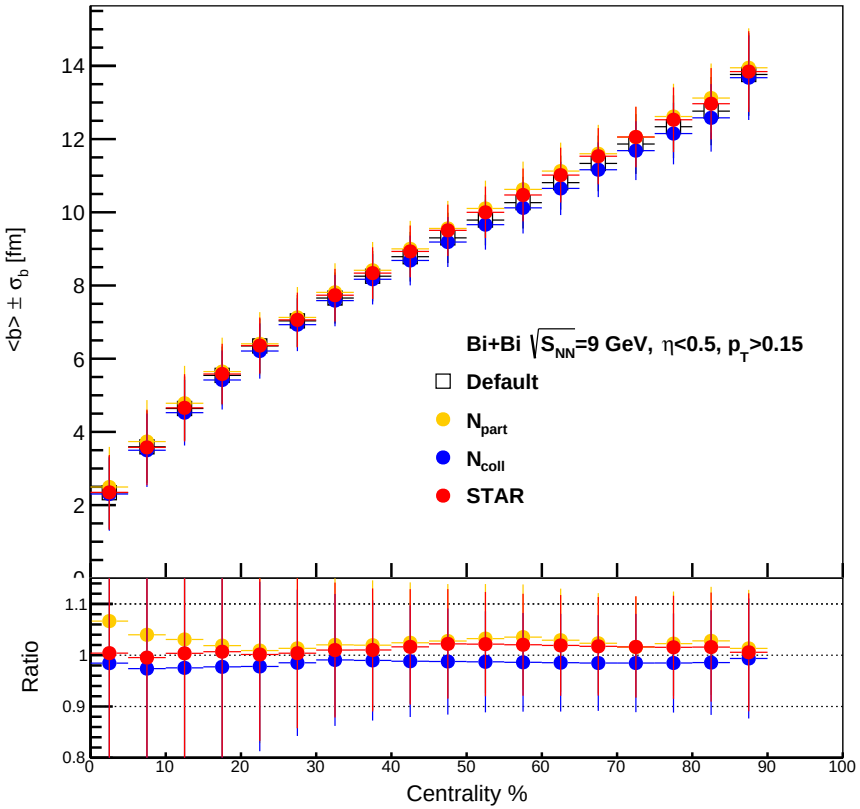
Parameterization comparision

- "Default"
  $N_a(f) = fN_{part} + (1-f)N_{coll}$
  $f = 0.65 \pm 0.104$

- "Npart"
  $N_a(f) = (N_{part})^f$
  $f = 1 \pm 0.008$

- "Ncoll"
  $N_{coll}(f) = (N_{coll})^f$
  $f = 0.91 \pm 0.002$

- "STAR"
  $N_a(f) = \frac{(1-f)}{2} N_{part} + fN_{coll}$
  $f = 0.1 \pm 0.032$



- Better agreement with STAR and Default (0-40%).

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Different generators comparision

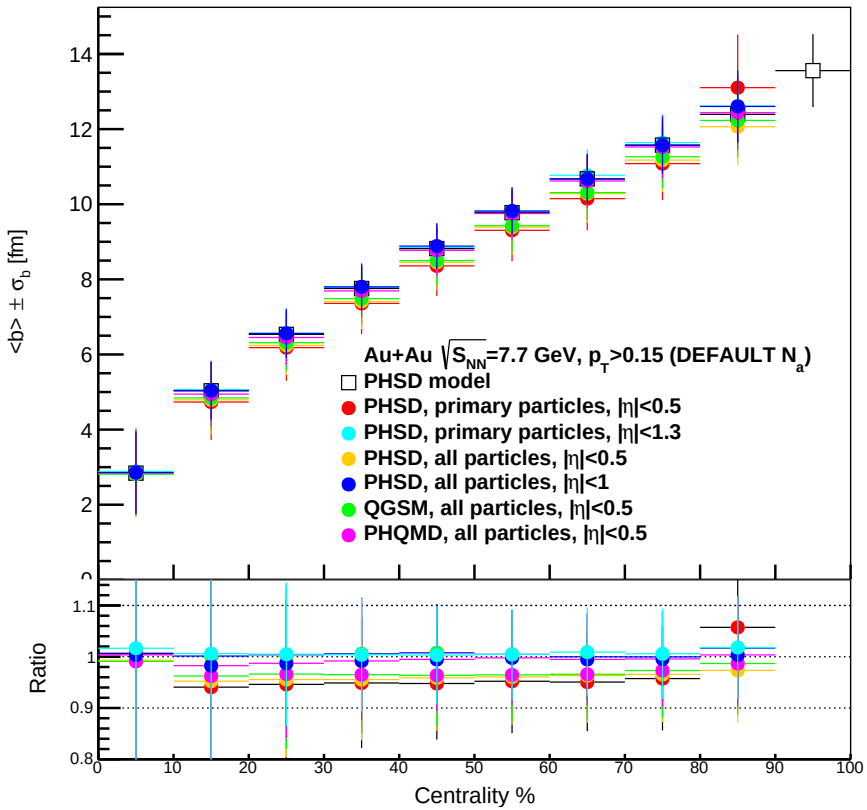

Figure: Comparison of the different generators of the relation of the impact parameter and the centrality for Au+Au collisions at 7.7 GeV.

- Better agreement with **PHSD, primary particles,** $|\eta| < 1.3$.

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Future work

- Compare and explore Γ – *Fit* method.
  Rogly, R., Giacalone, G., Ollitrault, J.Y. (2018). Reconstructing the impact parameter of proton-nucleus and nucleus-nucleus collisions. Phys. Rev. C, 98, 024902.
- Finish analysis of new obtained reconstructed data from Bi+Bi collisions at 9.2 GeV.
- Compare results with other Monte Carlo generators (LAQGSM, PHSD and PHQMD) for Bi+Bi collisions at the four different energies (7.7, 9, 9.2 and 9.5 GeV).

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Thank you!

Backup slides

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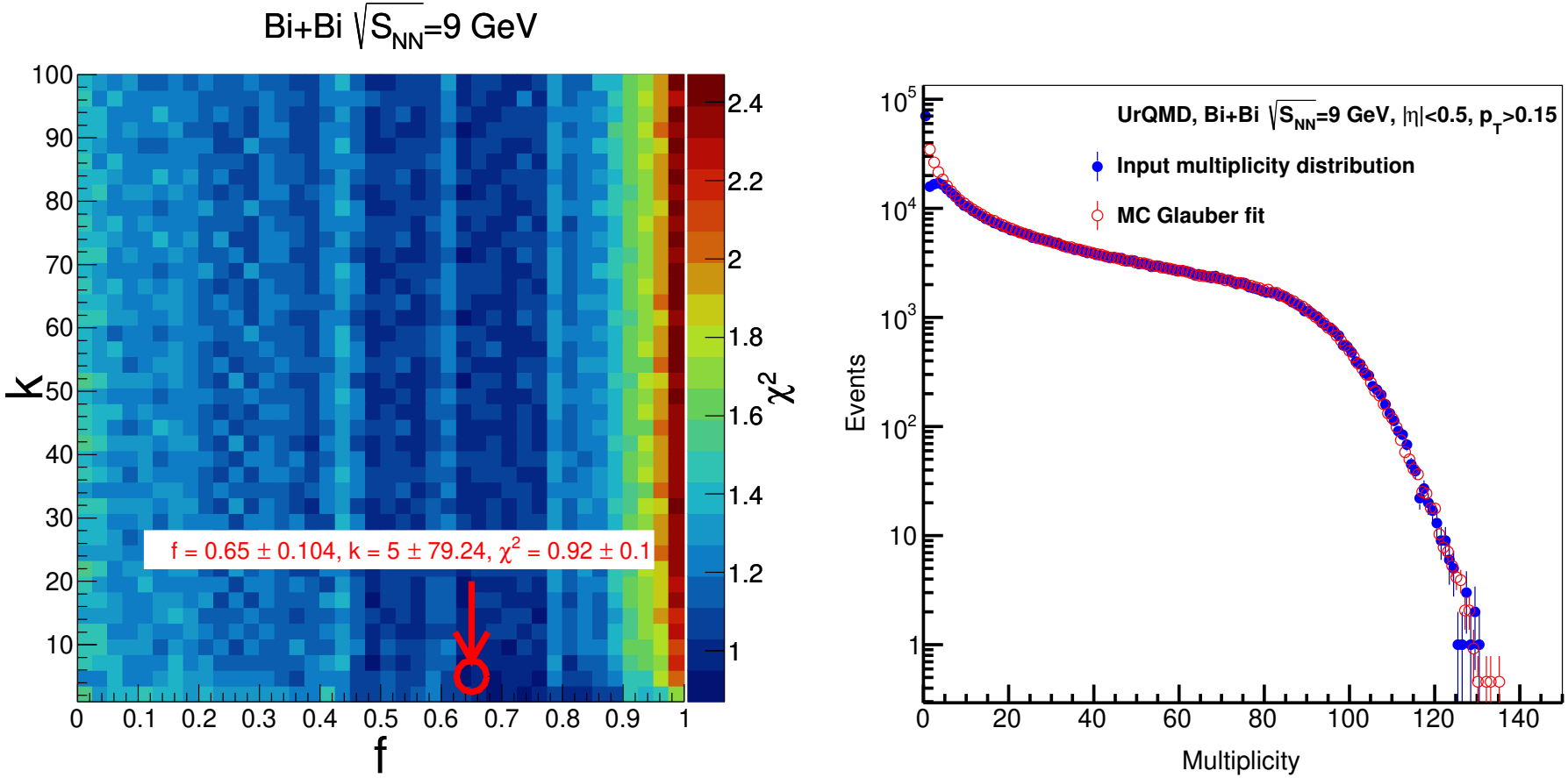

Figure: Relation between the parameters f and k with their corresponding χ^2 with Bi+Bi collisions at 9 GeV (left). Comparison between the input multiplicity distribution and the MC Glauber fit corresponding to the parameters $f = 0.65$, $k = 5$ and $\mu = 0.16$ (right).

Parfenov, P., Idrisov, D., Luong, V., Taranenko, A. (2021). Relating Charged Particle Multiplicity to Impact Parameter in Heavy-Ion Collisions at NICA Energies. Particles, 4(2), 275–287. DOI: https://doi.org/10.3390/particles4020024

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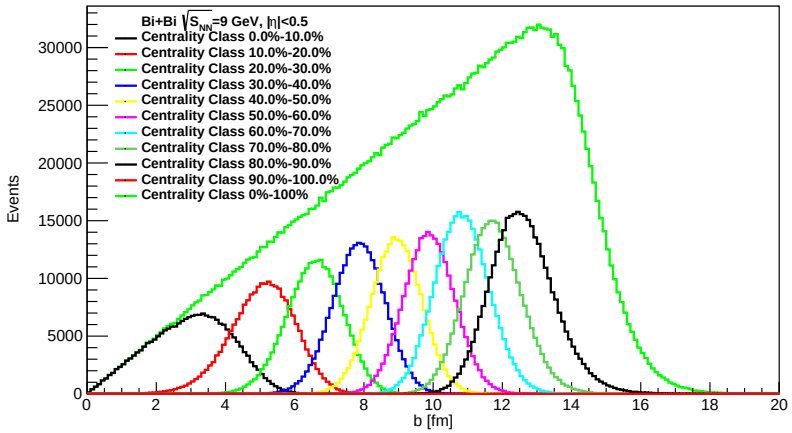
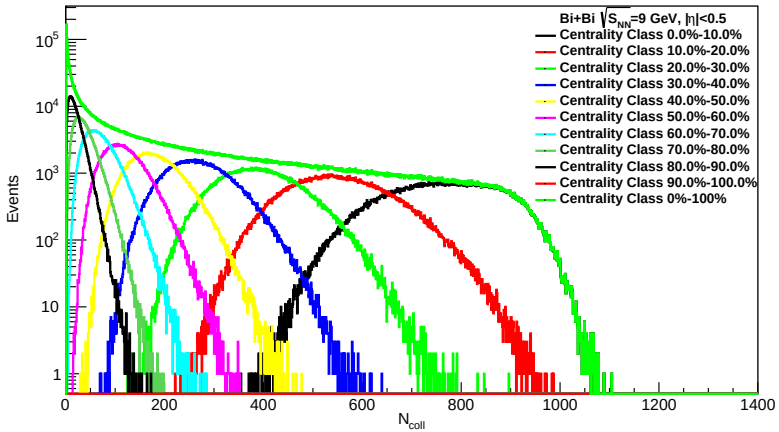
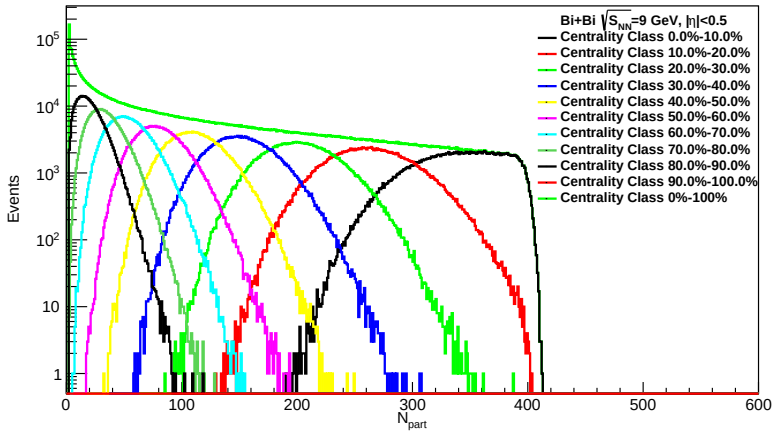
Relation to impact parameter, N_{coll} and N_{part}







Impact parameter, number of collisions and number of participants distributions with multiplicity cuts.

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N_{coll} vs centrality

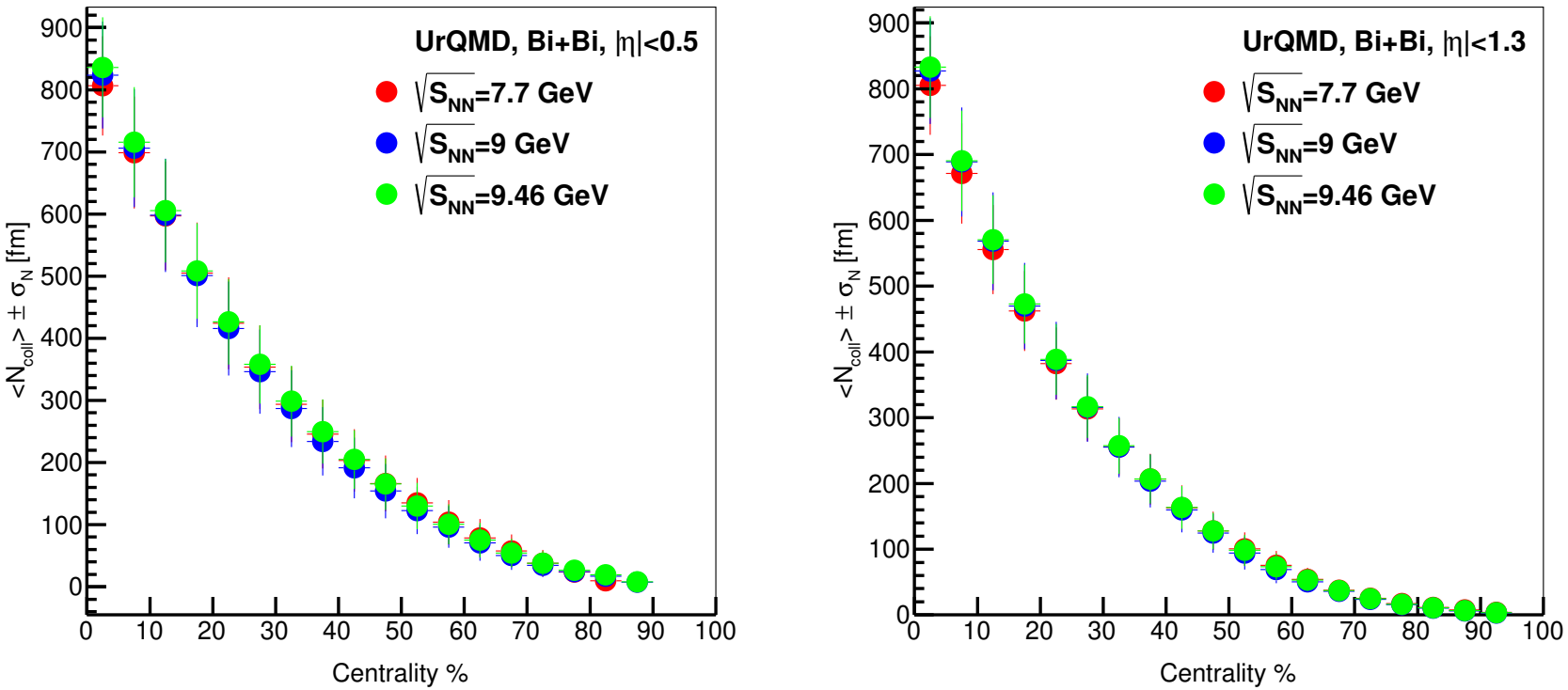

Figure: Comparison of the N_{coll} with centrality of the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV for $|\eta| < 0.5$ (left) and $|\eta| < 1.3$ (right).

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N_{part} vs centrality

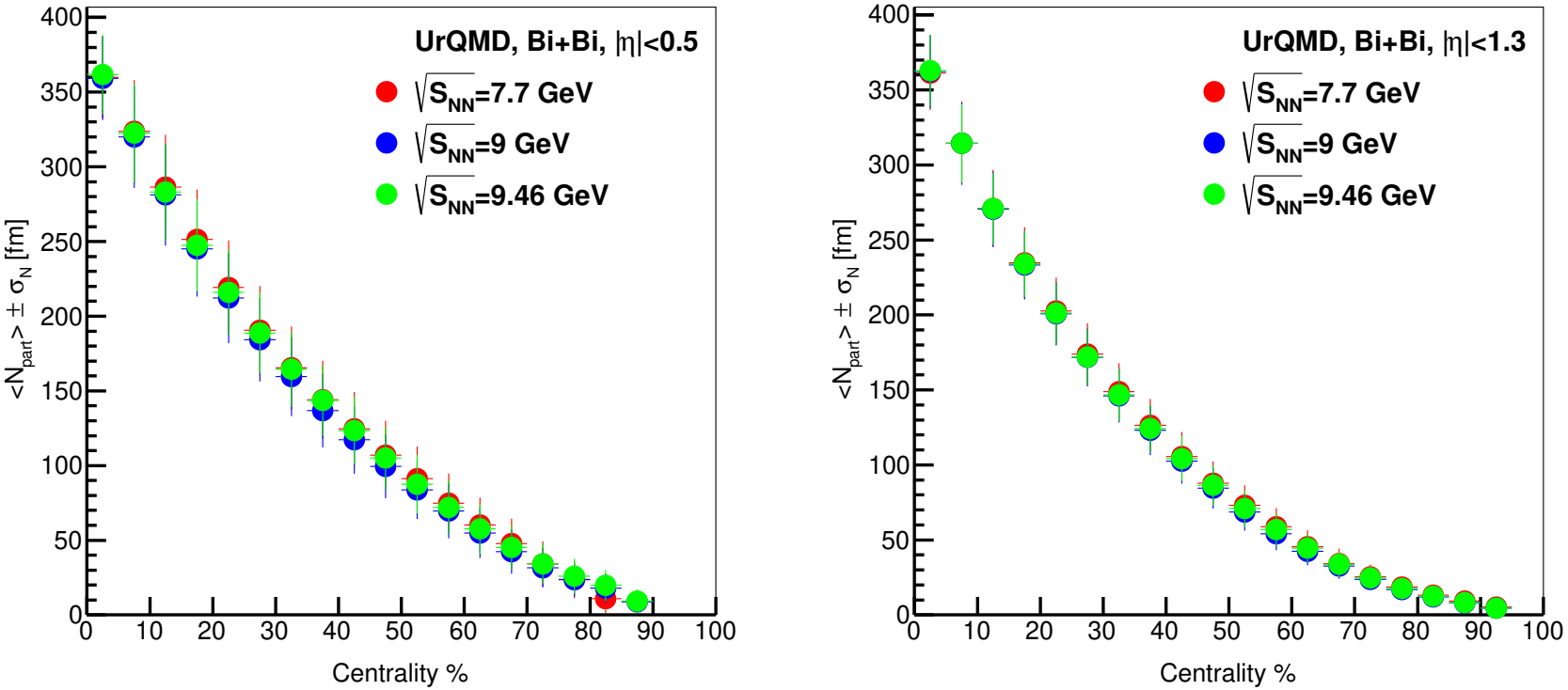

Figure: Comparison of the N_{part} with centrality of the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV for $|\eta| < 0.5$ (left) and $|\eta| < 1.3$ (right).

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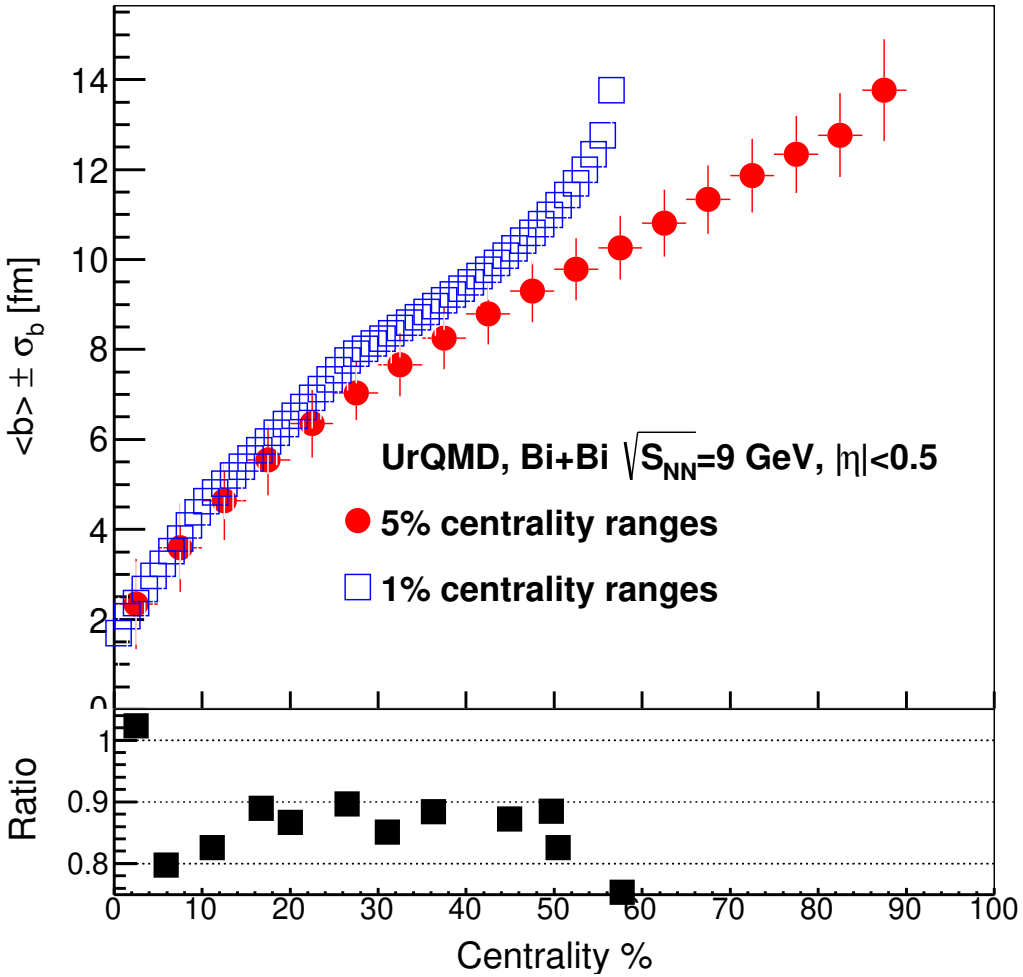
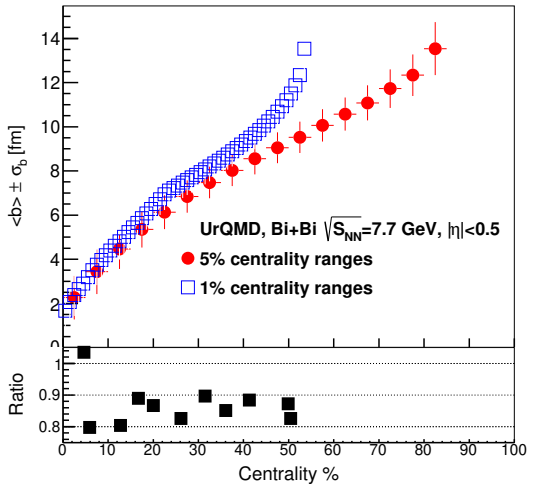
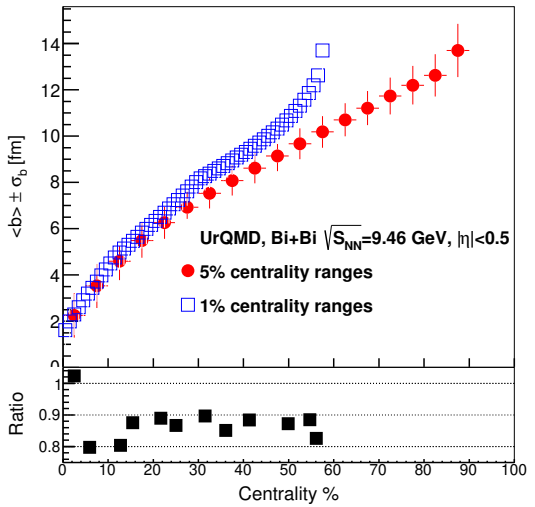
Centrality ranges comparison







5% and 1% centrality ranges comparison of the impact parameter vs centrality at the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV.

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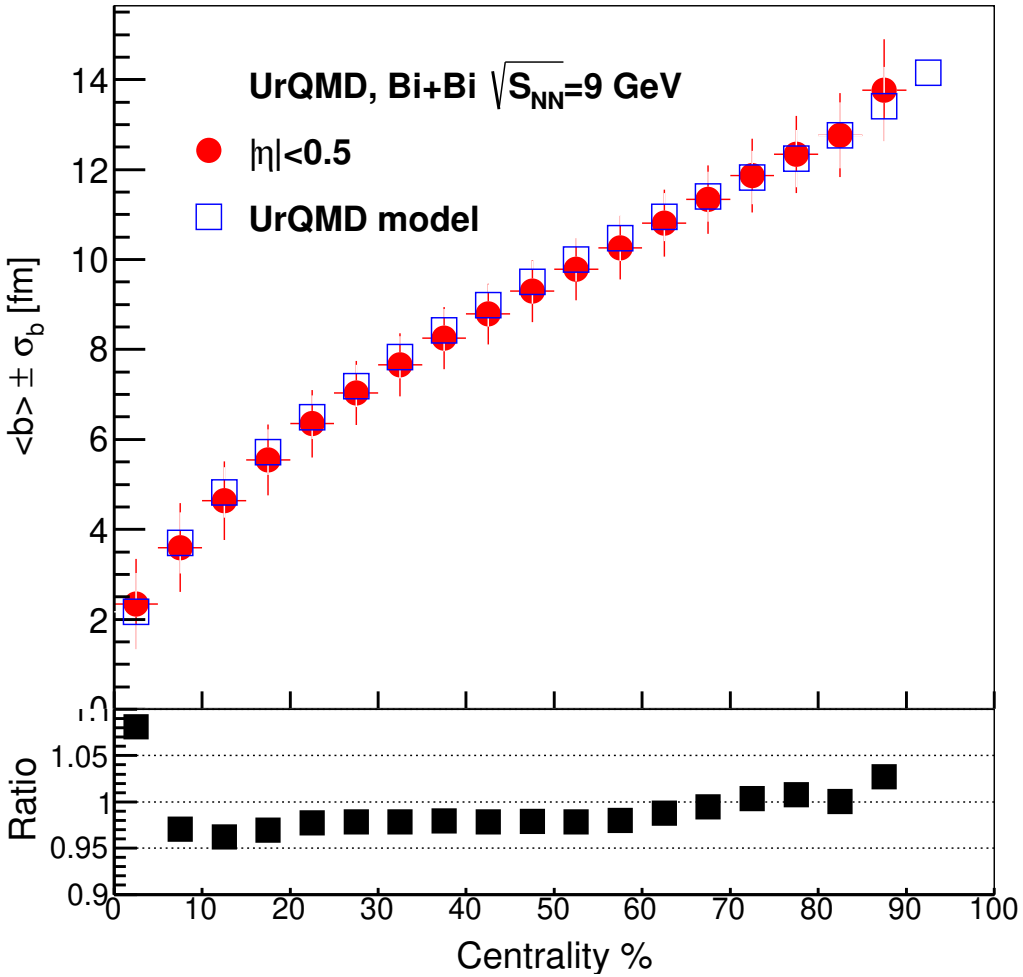
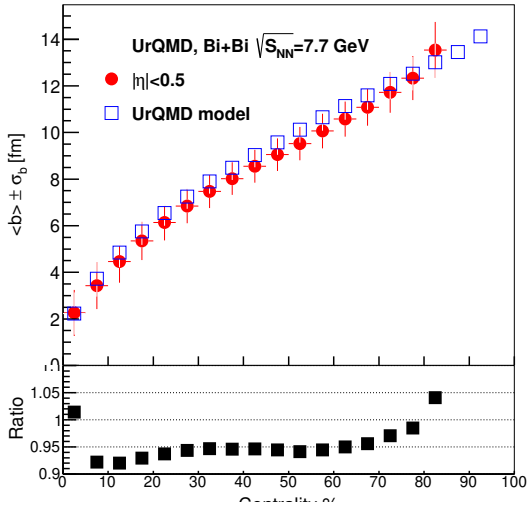
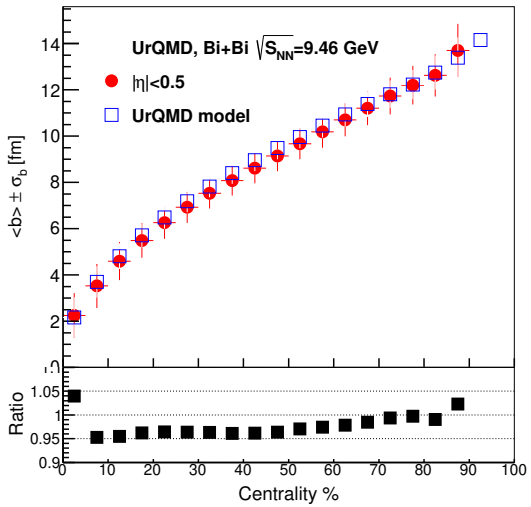
UrQMD model ($|\eta| < 0.5$)







UrQMD model and TPC results comparison of the impact parameter vs centrality at the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV ($|\eta| < 0.5$).

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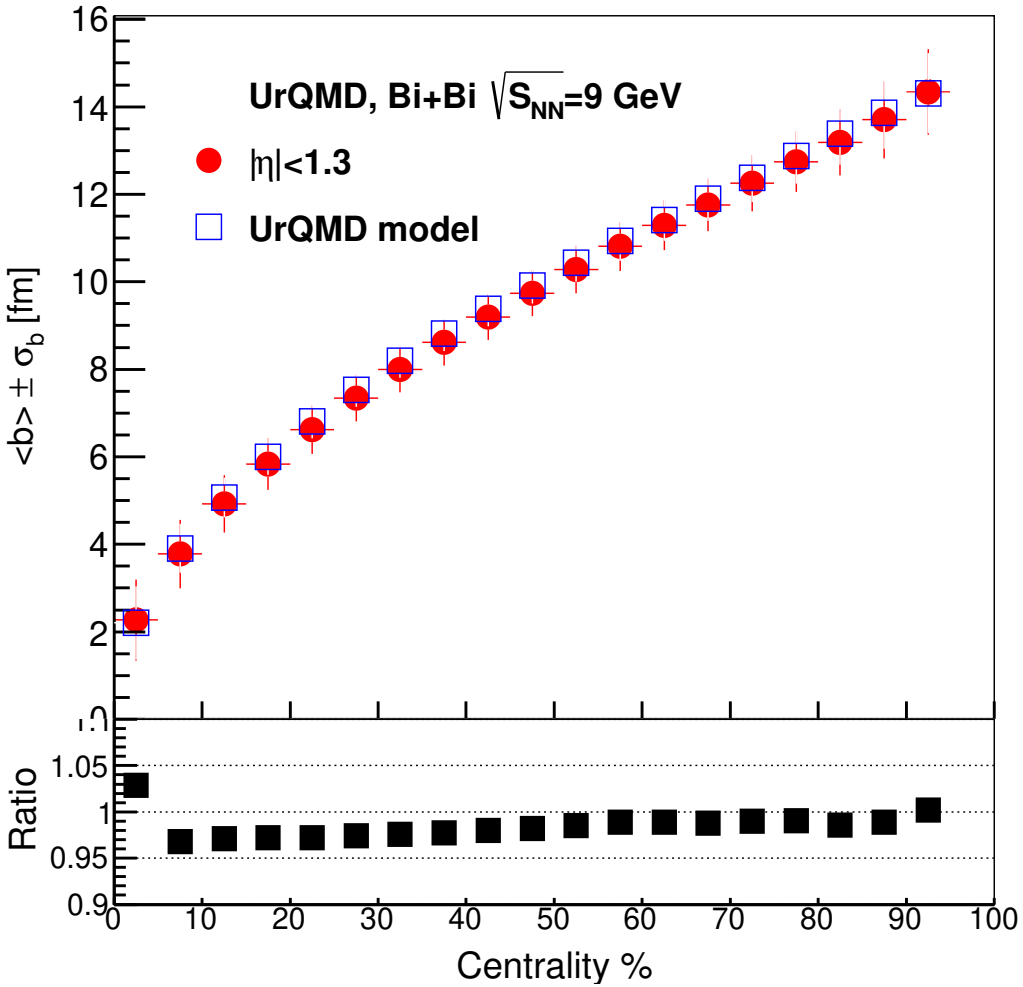
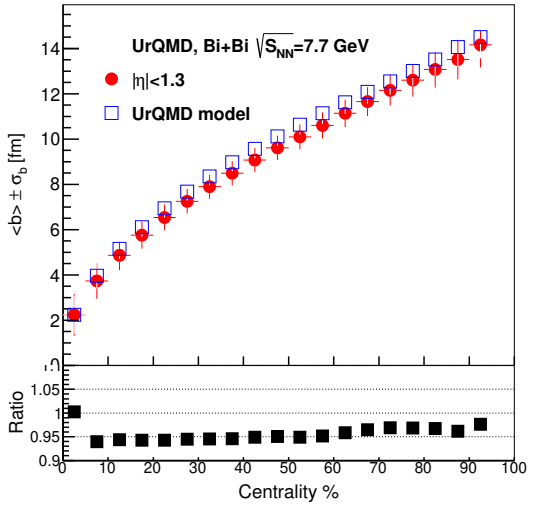
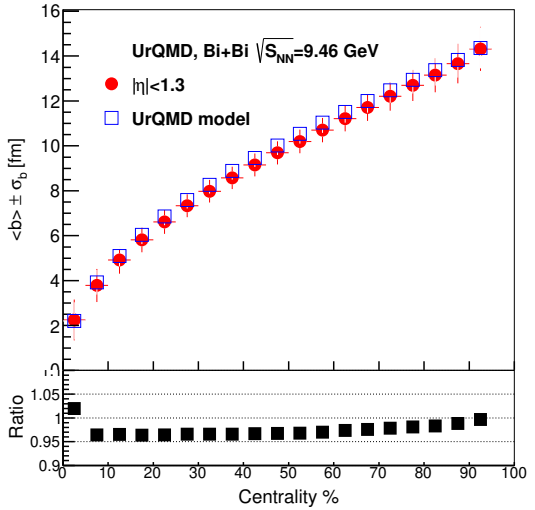
UrQMD model ($|\eta| < 1.3$)







UrQMD model and TPC results comparison of the impact parameter vs centrality at the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV ($|\eta| < 1.3$).

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