Centrality determination in MPD at NICA

HADRON 2021

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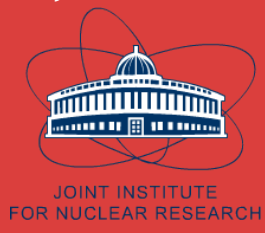
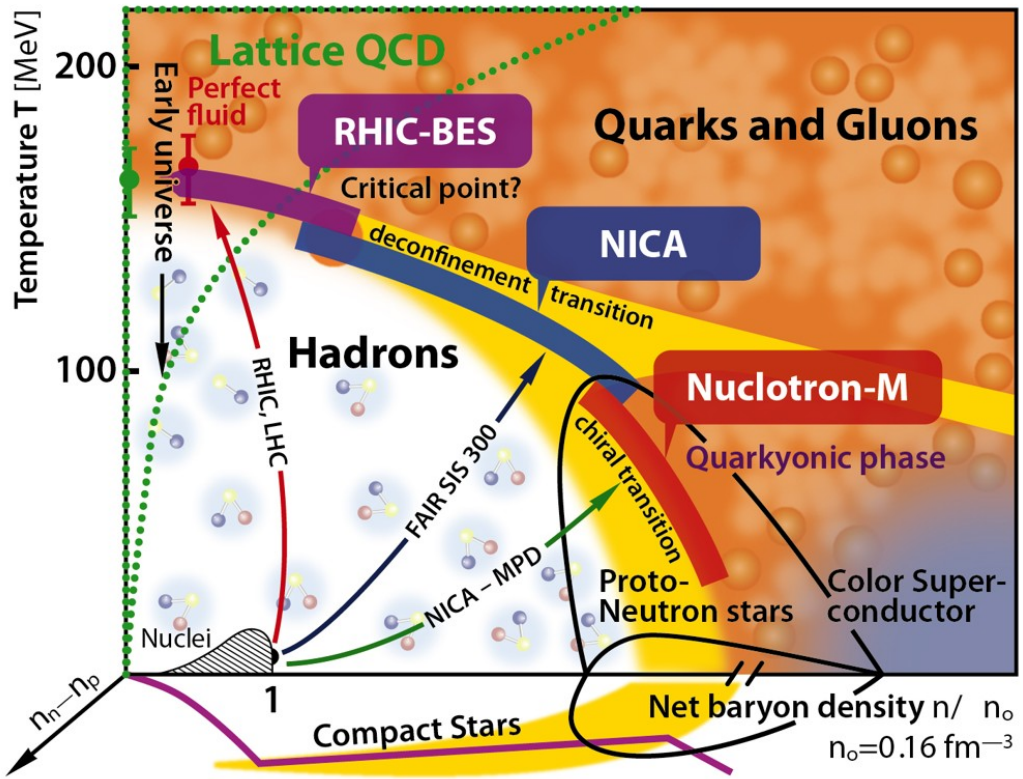
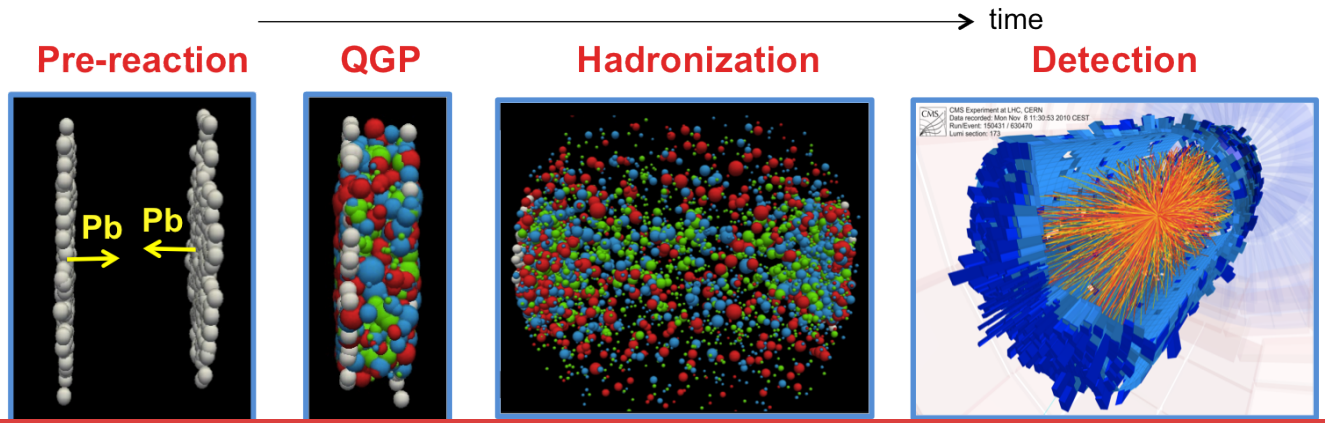


QCD phase diagram (NICA)





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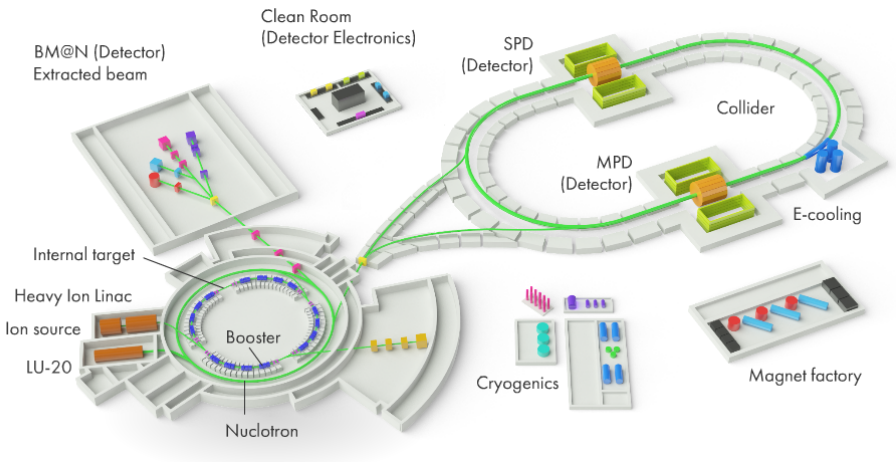
Nuclotron-based Ion Collider fAcility (NICA)



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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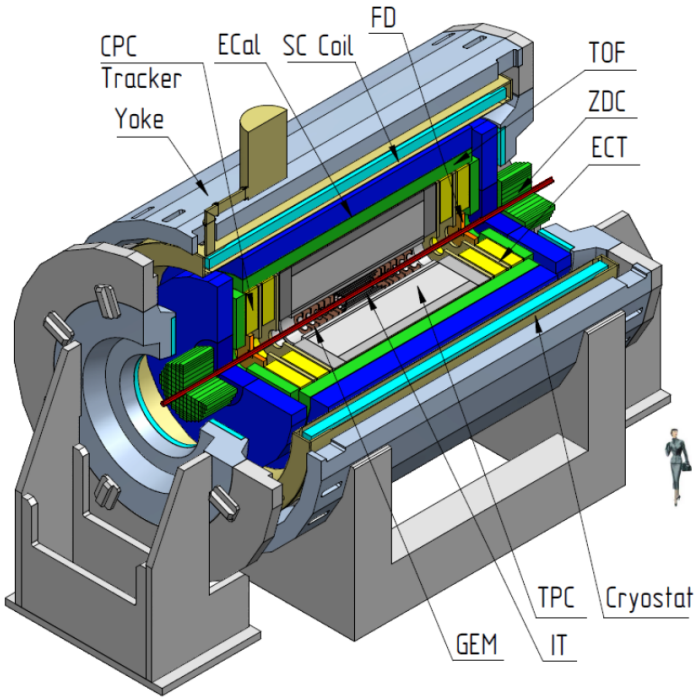
Multi-Purpose Detector (MPD)



- Detect the high multiplicity events and perform particle identification.
  1. 3-D tracking system (TPC).
  2. 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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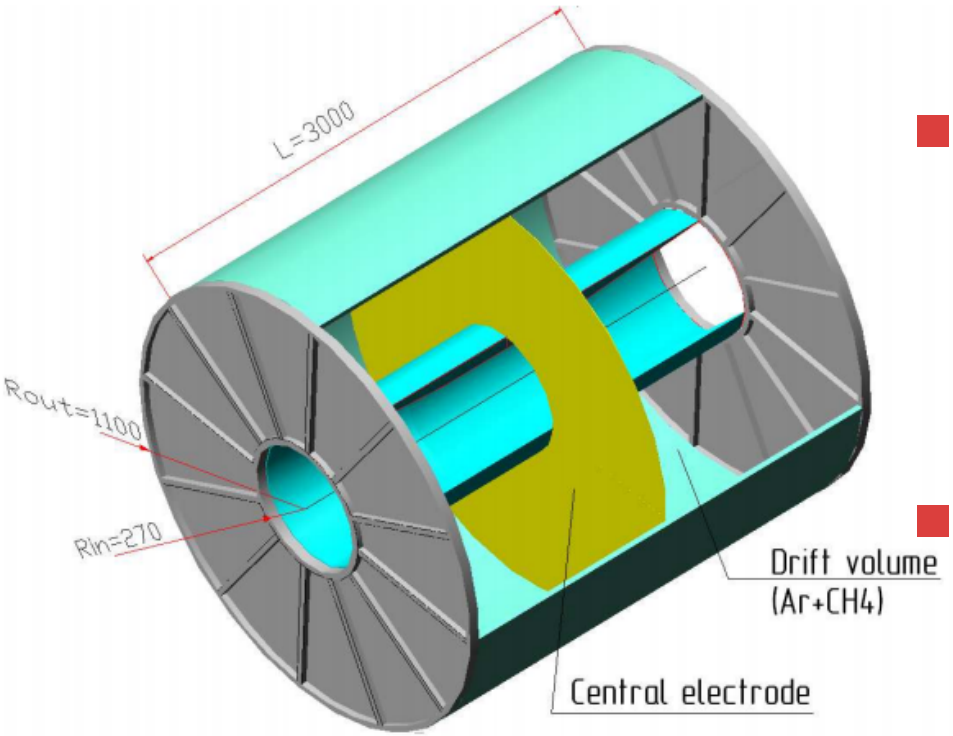
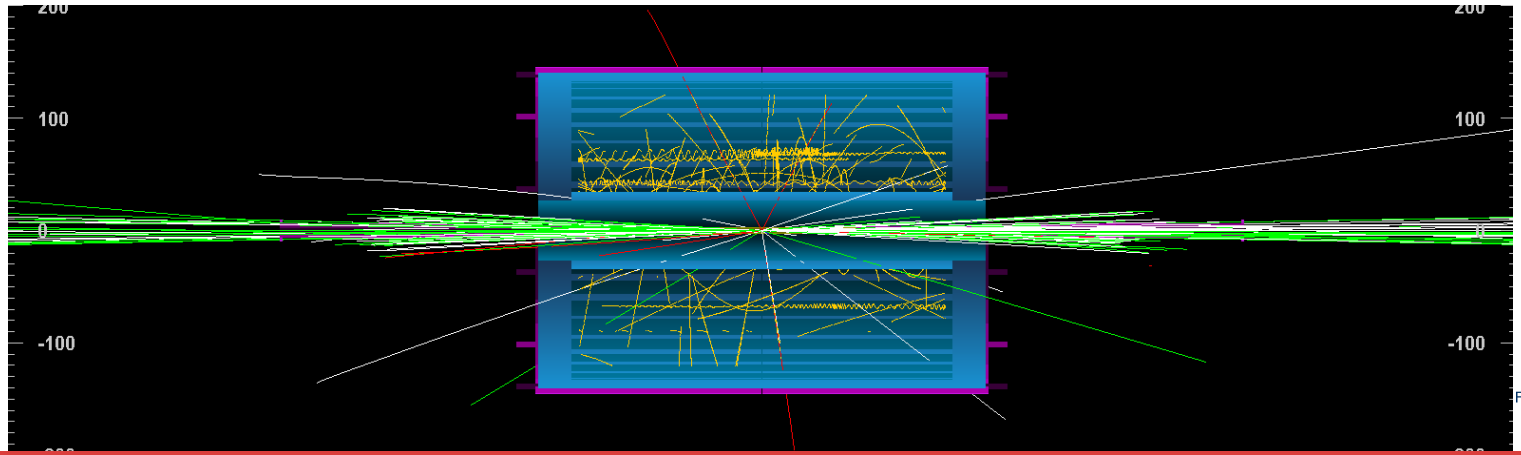
Time Projection Chamber



- 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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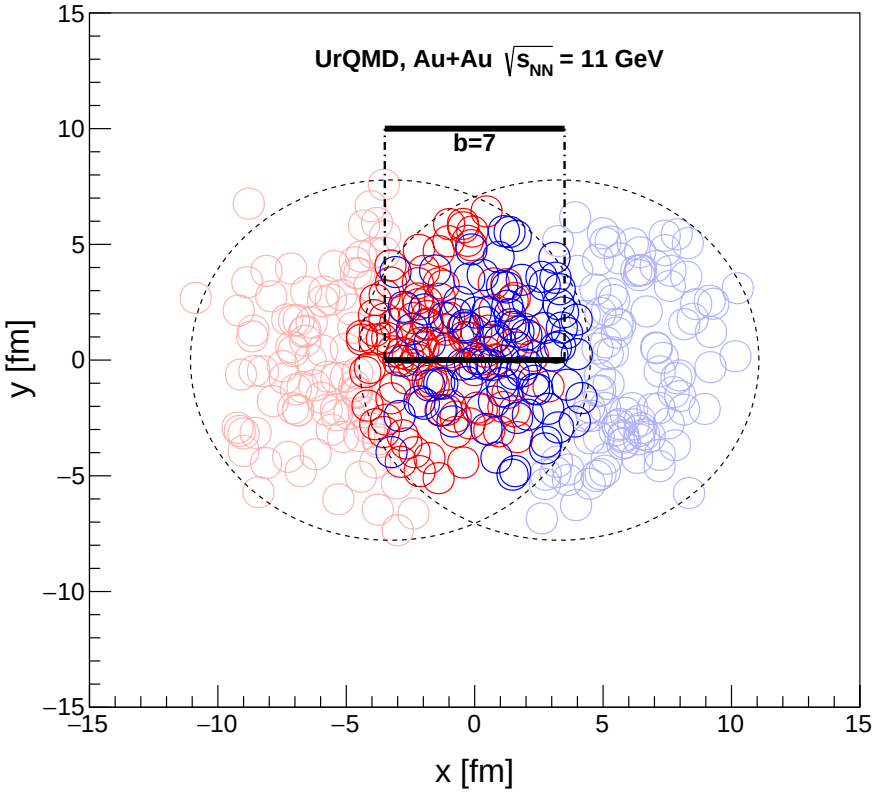
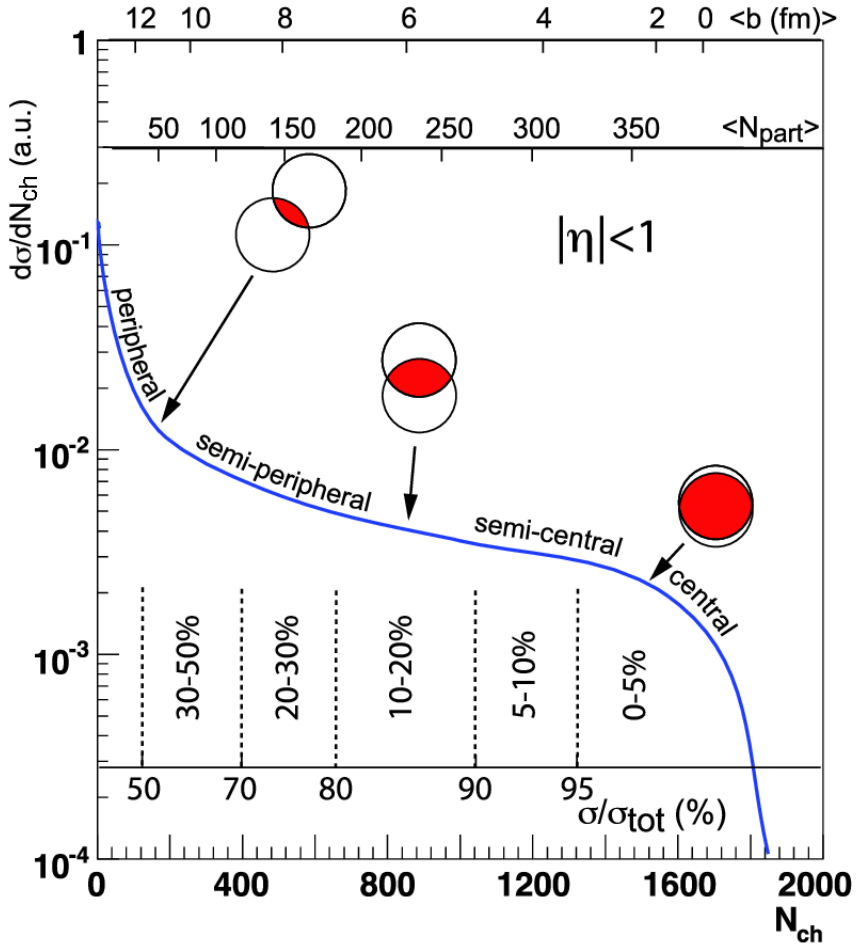
Centrality determination





Au+Au collision at 11 GeV generated in UrQMD at t = 0 fm/c (left). Relation between impact parameter (b), number of participants (N_{part}), multiplicity (N_{ch}) and centrality (right).

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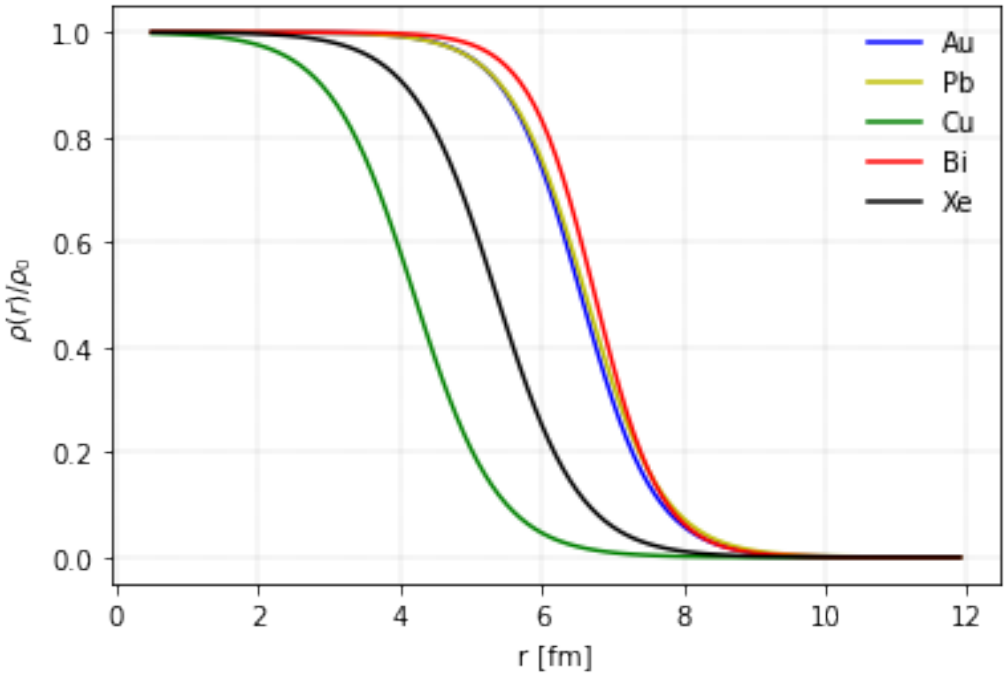
MC-Glauber



Definition

Nuclear density function:

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

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

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

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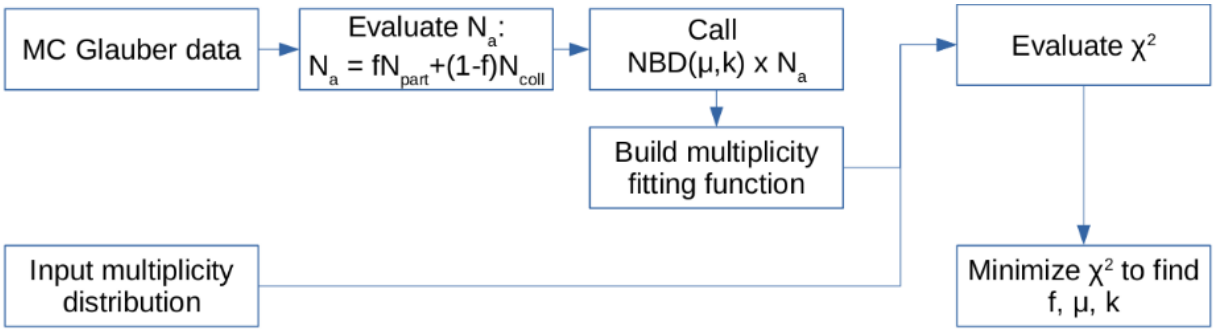
Centrality Determination / MC-Glauber Approach



Definition

Number of ancestors parameterization:

$$N_a(f) = fN_{part} + (1-f)N_{coll} \tag{2}$$

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

$$P(n) = \frac{\Gamma(n+k)}{\Gamma(n+1)\Gamma(k)} \frac{(\mu/k)^n}{(\mu/k+1)^{n+k}} \tag{3}$$

Glauber-based fit function:

$$F_{fit}(f,\mu,k) = \sum^{N_a} N_a \times P(N_{ch}) \tag{4}$$

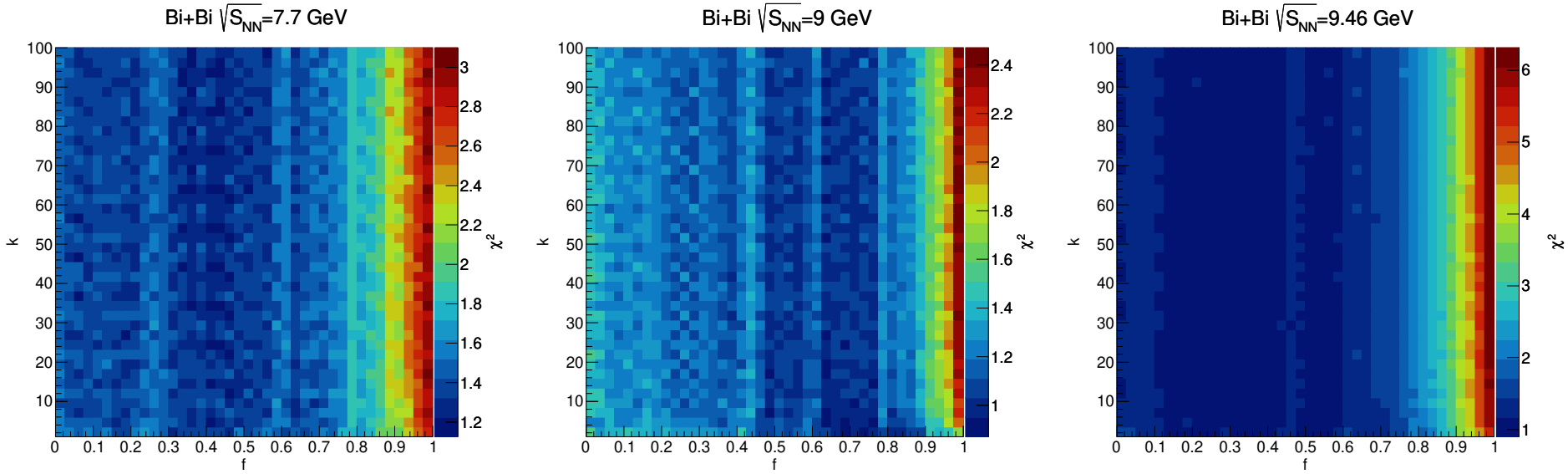


Figure: Relation between the parameters f and k with their corresponding χ^2 with Bi+Bi collisions at 7.7, 9 and 9.46 GeV.

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.

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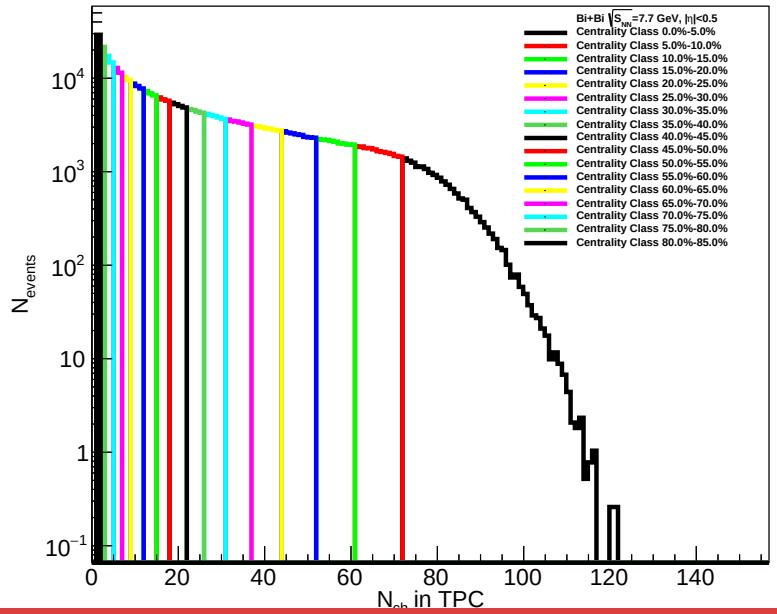
Centrality determination

Definition

Centrality classes based on multiplicity:

$$c[\%] = \frac{\int_{N_{max}}^{N_i} \frac{dN_{ev}}{dN_{ch}} dN_{ch}}{\int_{N_{max}}^{0} \frac{dN_{ev}}{dN_{ch}} dN_{ch}} \quad (5)$$



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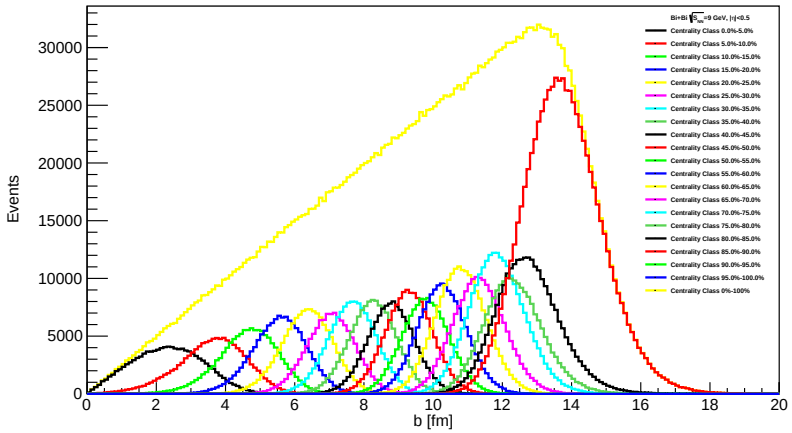
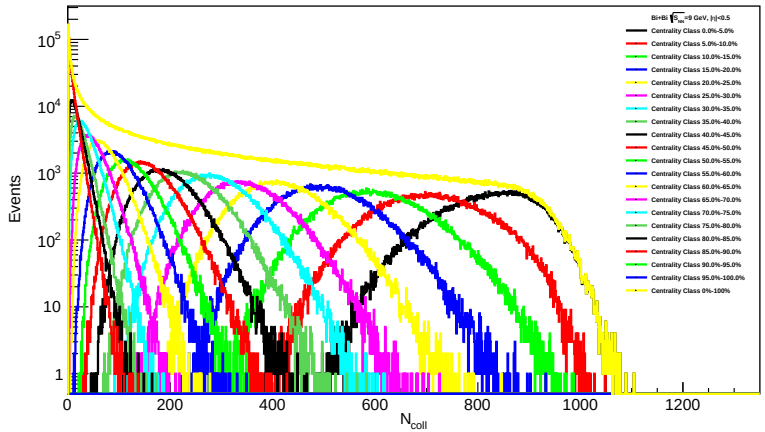
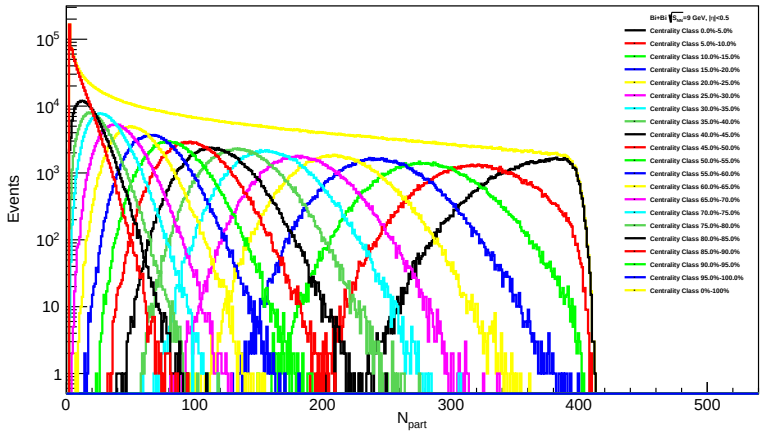
Relation to impact parameter, N_{coll} and N_{part}







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

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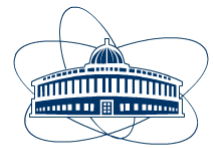
Bi+Bi 9 GeV $|\eta| < 0.5$

Best fit:

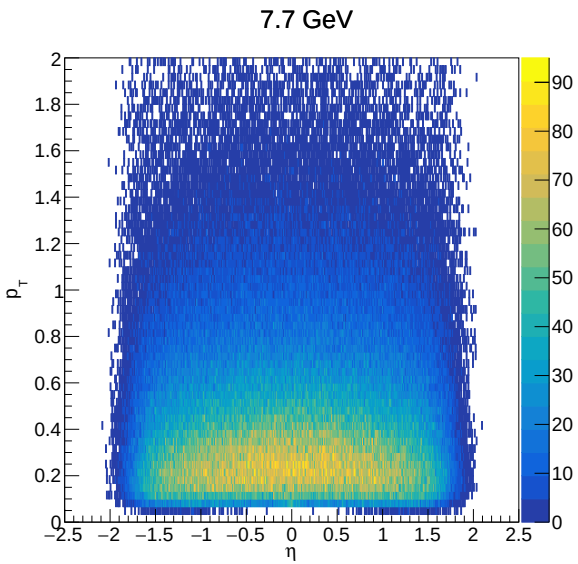
$f = 0.65 \pm 0.104$, $\mu = 0.164202 \pm 0.0730813$, $k = 5 \pm 79.24$,
$\chi^2 = 0.803798 \pm 0.130637$

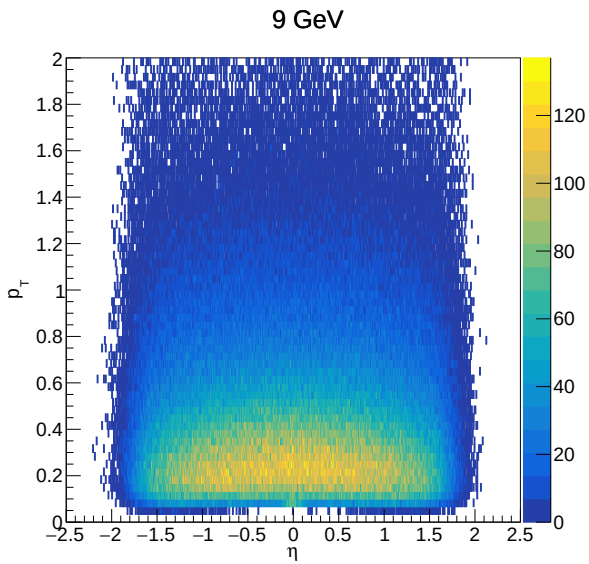
Centrality, %	N_{ch}^{min}	N_{ch}^{max}	$\langle b \rangle$, fm	RMS	$\langle N_{part} \rangle$	RMS	$\langle N_{coll} \rangle$	RMS
0 - 5	81	130	2.34	1.01	359.33	28.11	823.73	86.20
5 - 10	69	81	3.59	0.99	319.98	34.03	705.92	95.03
10 - 15	59	69	4.64	0.88	281.17	33.96	597.94	91.11
15 - 20	50	59	5.54	0.79	245.05	31.97	501.07	82.97
20 - 25	42	50	6.35	0.75	212.09	30.14	415.71	75.63
25 - 30	36	42	7.03	0.71	184.27	27.93	346.16	67.73
30 - 35	30	36	7.66	0.70	159.51	26.41	286.77	61.70
35 - 40	25	30	8.25	0.69	136.70	24.53	234.04	54.94
40 - 45	21	25	8.79	0.68	117.23	22.74	191.25	48.79
45 - 50	17	21	9.30	0.69	99.49	21.40	154.11	43.76
50 - 55	14	17	9.79	0.69	83.79	19.67	122.87	38.33
55 - 60	11	14	10.26	0.71	69.61	18.26	96.23	33.62
60 - 65	8	11	10.81	0.74	54.88	16.78	70.52	28.68
65 - 70	6	8	11.34	0.76	42.36	14.77	50.36	23.24
70 - 75	4	6	11.87	0.82	31.69	13.21	34.78	19.01
75 - 80	3	4	12.34	0.86	23.69	11.28	24.08	14.84
80 - 85	2	3	12.76	0.93	17.92	9.95	17.10	12.16
85 - 90	1	2	13.77	1.13	8.75	7.32	7.36	7.83

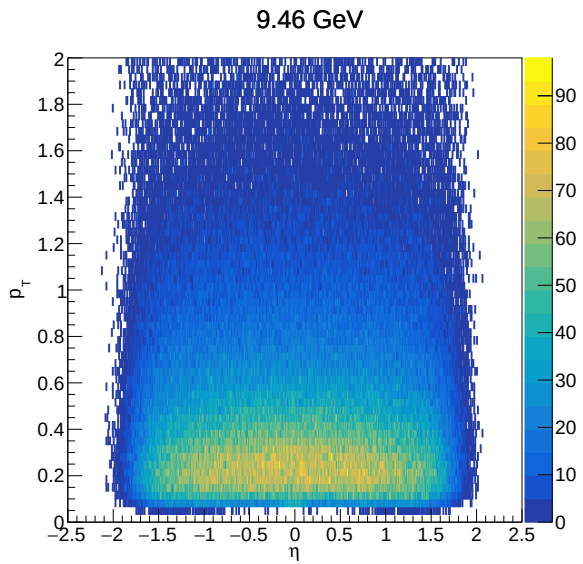


Multiplicity selection

- $p_T > 0.15$ 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

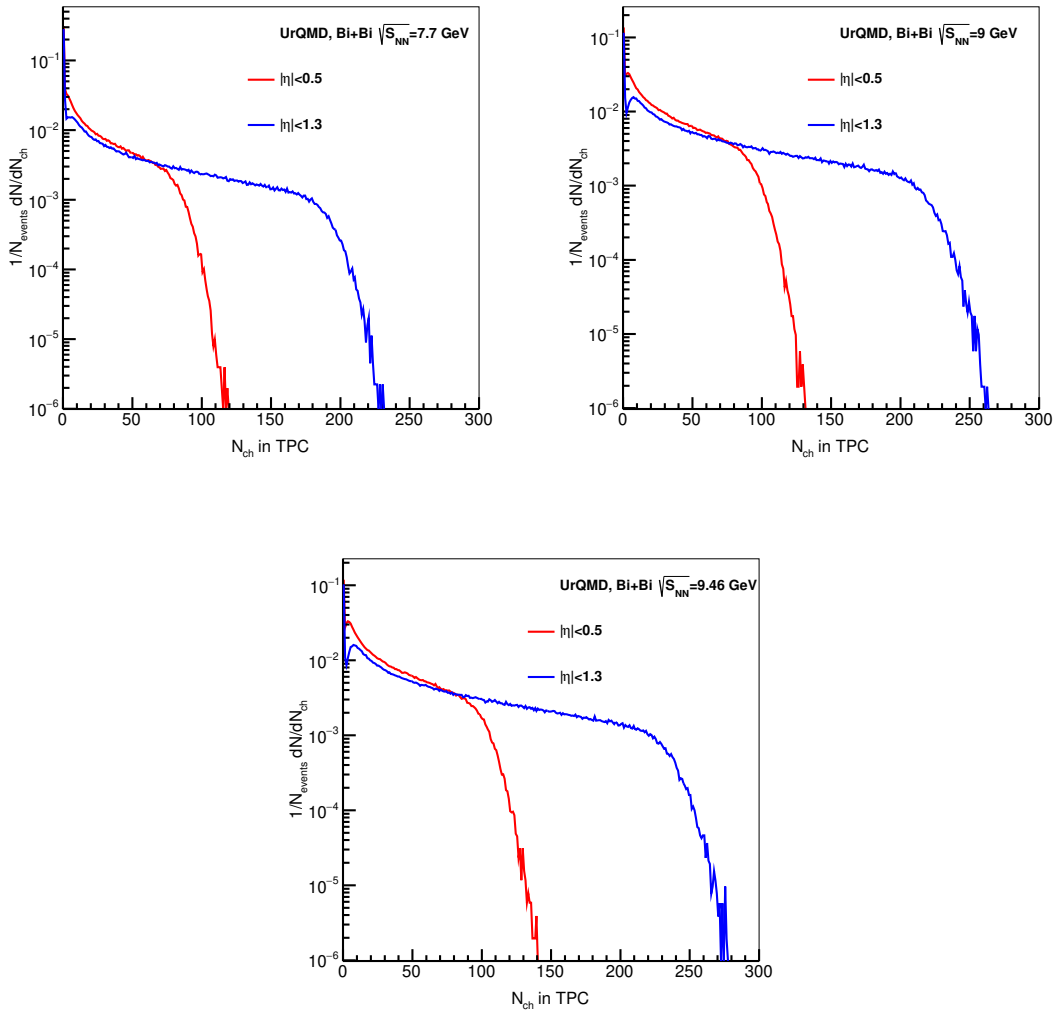


Figure: Comparison of the multiplicity distributions at the two η ranges ($|\eta| < 0.5$ and $|\eta| < 1.3$) at $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV.

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b, N_{coll} and N_{part} vs centrality ($|\eta| < 0.5$)

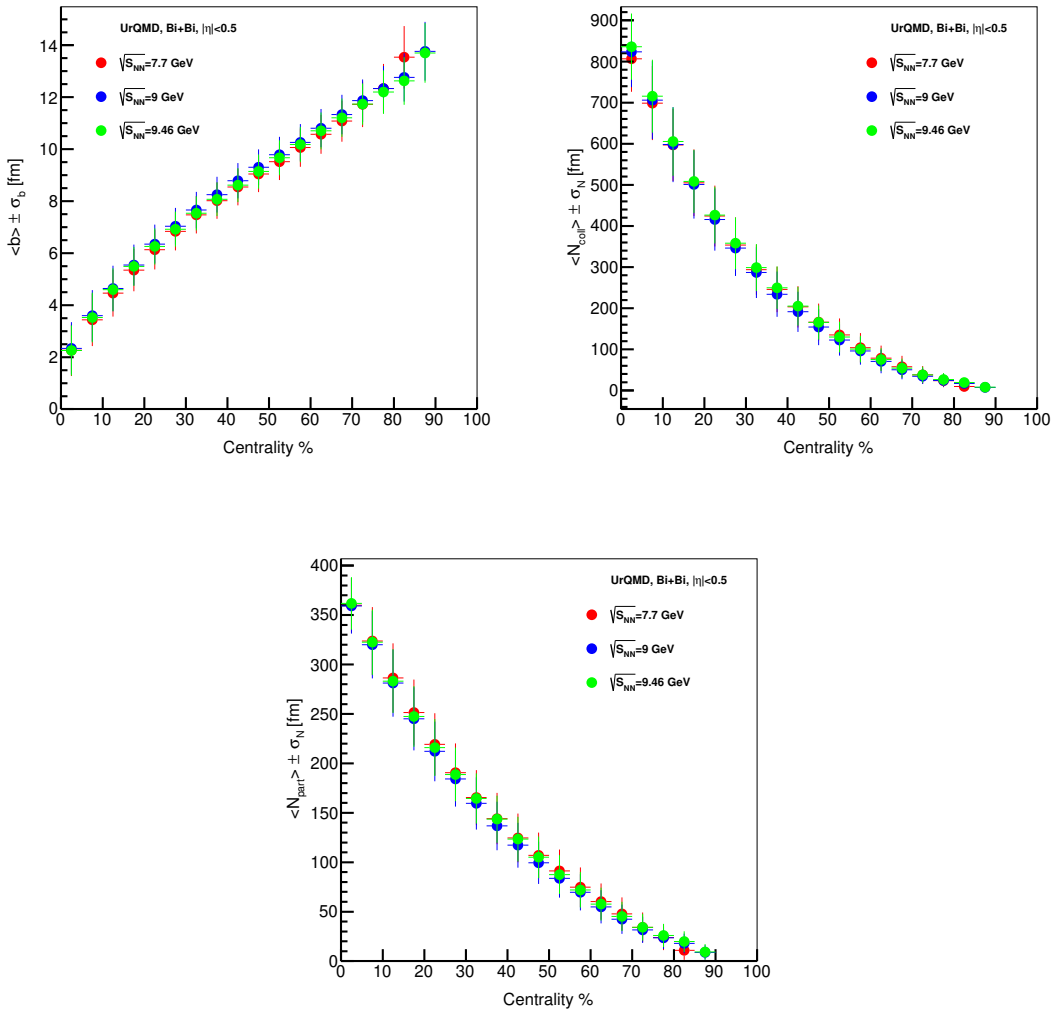

Figure: Comparison of the relation of impact parameter, N_{coll} and N_{part} with centrality of the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV ($|\eta| < 0.5$).

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b, N_{coll} and N_{part} vs centrality ($|\eta| < 1.3$)

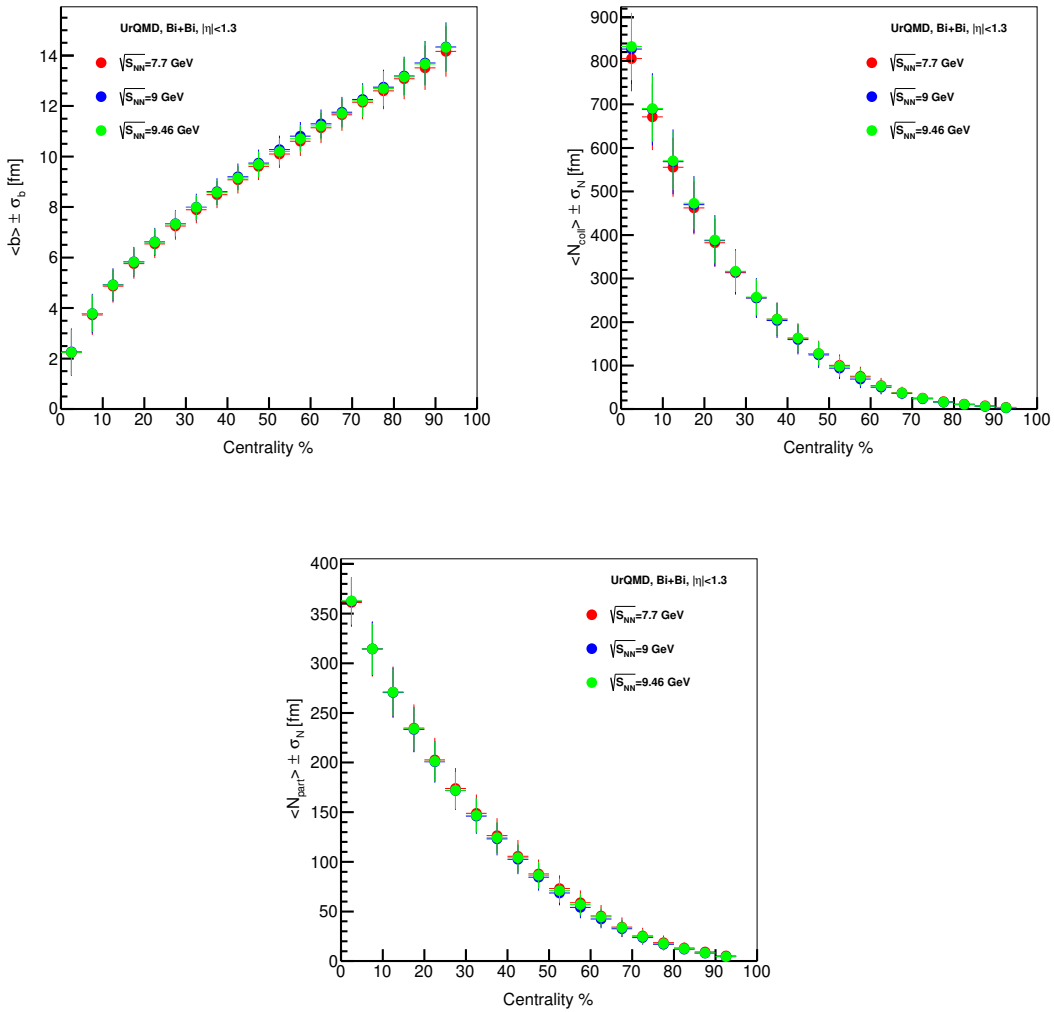

Figure: Comparison of the relation of impact parameter, N_{coll} and N_{part} with centrality of the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV ($|\eta| < 1.3$).

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

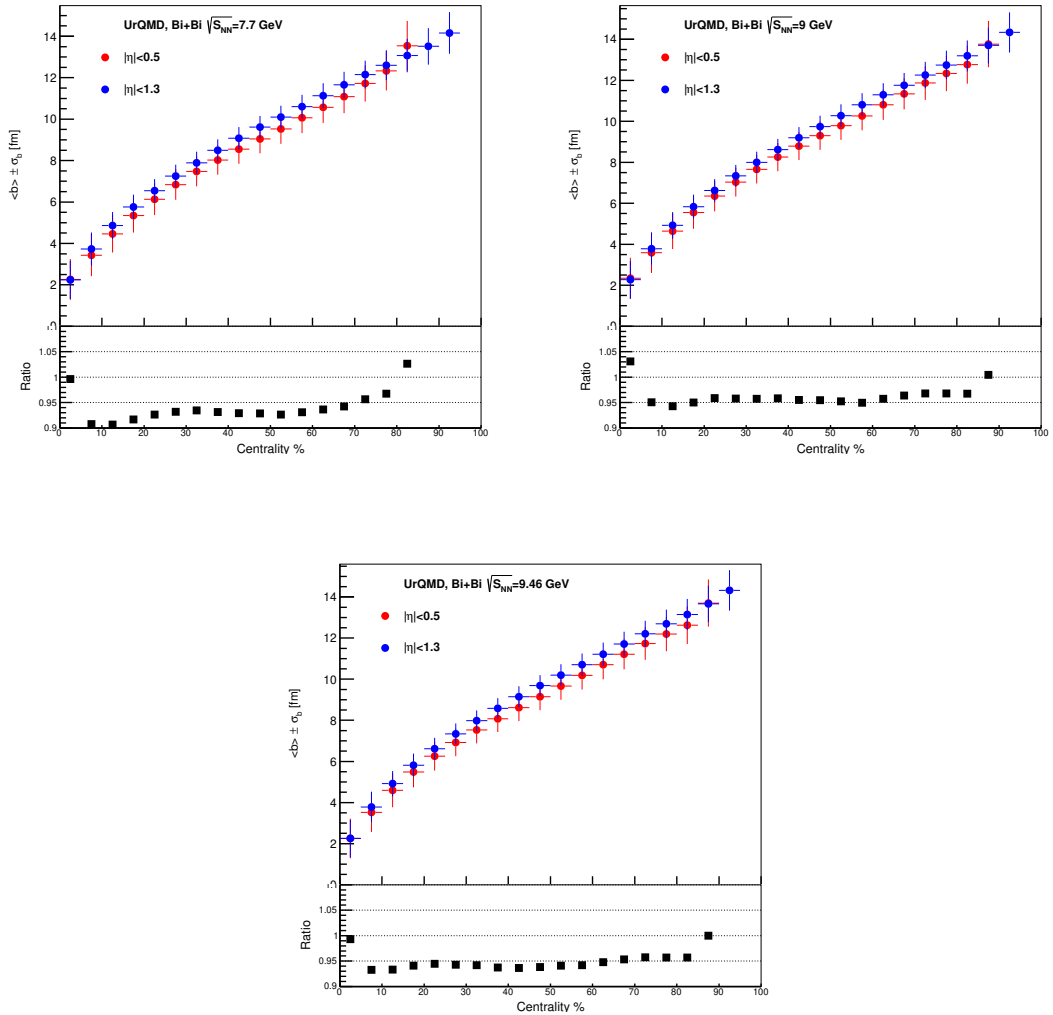

Figure: Pseudorapidity comparison of the relation of impact parameter with centrality at the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV.

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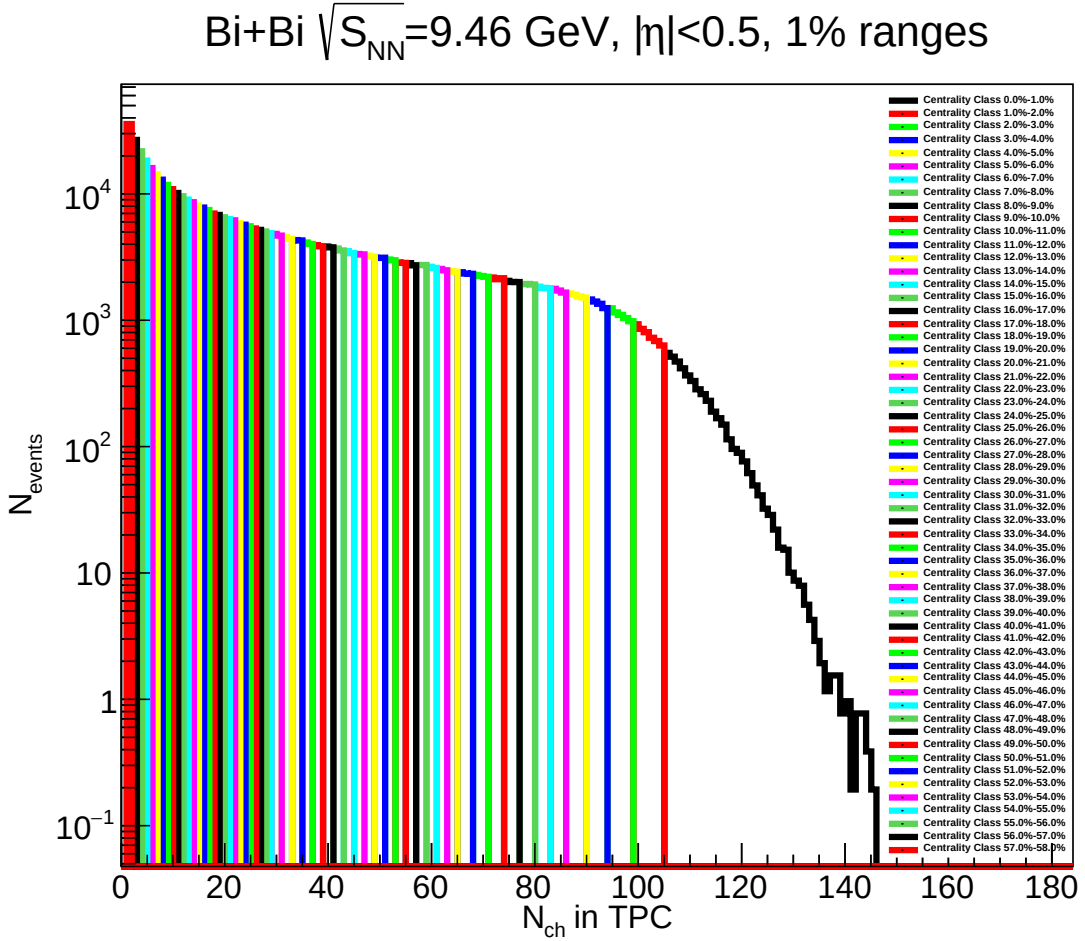
Centrality ranges comparison

- $p_T > 0.15$ GeV/c
- $|\eta| < 0.5$
- 5% centrality range vs 1% centrality range.



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Centrality ranges comparison

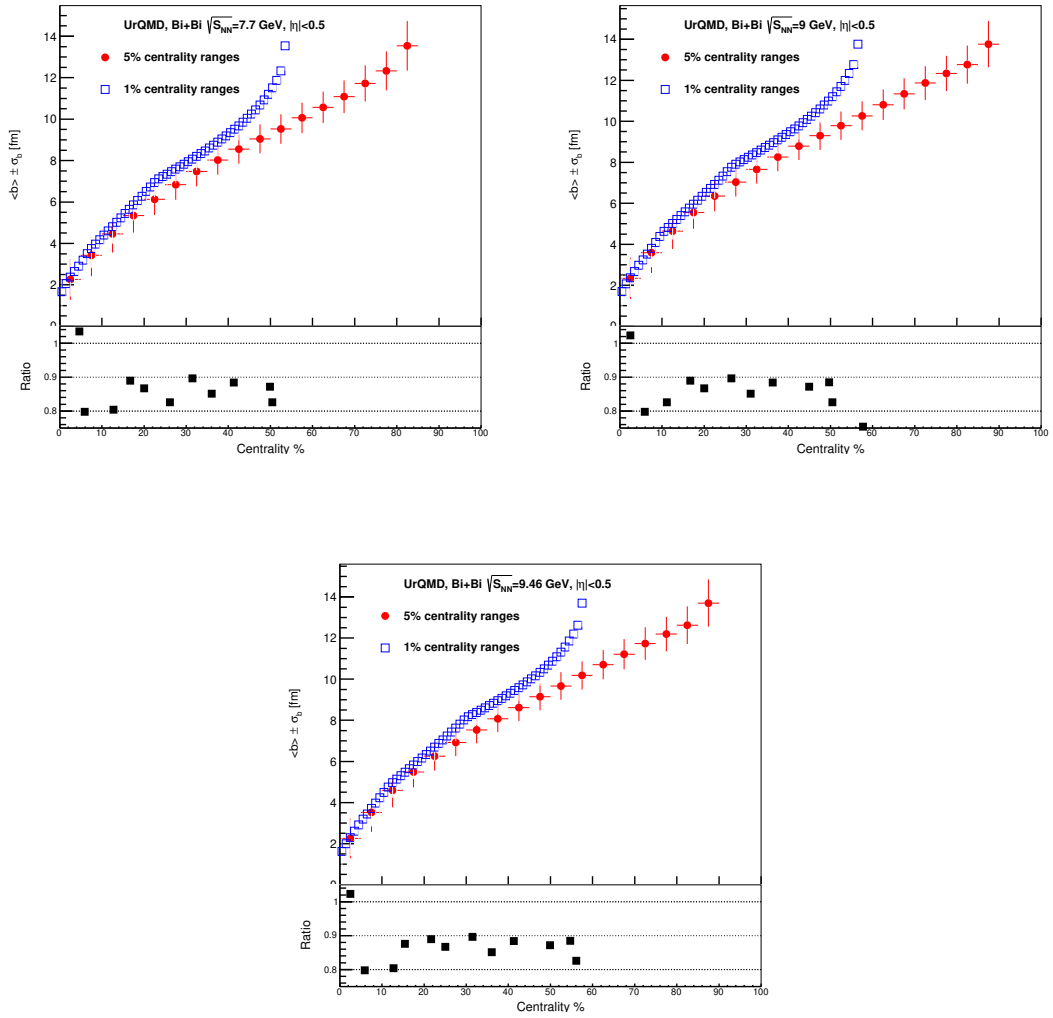

Figure: 5% and 1% centrality ranges comparison of the impact parameter vs centrality at the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV.

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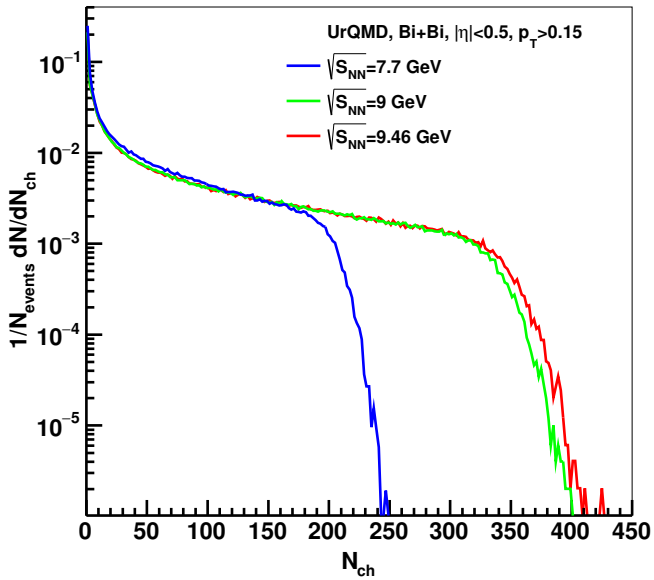
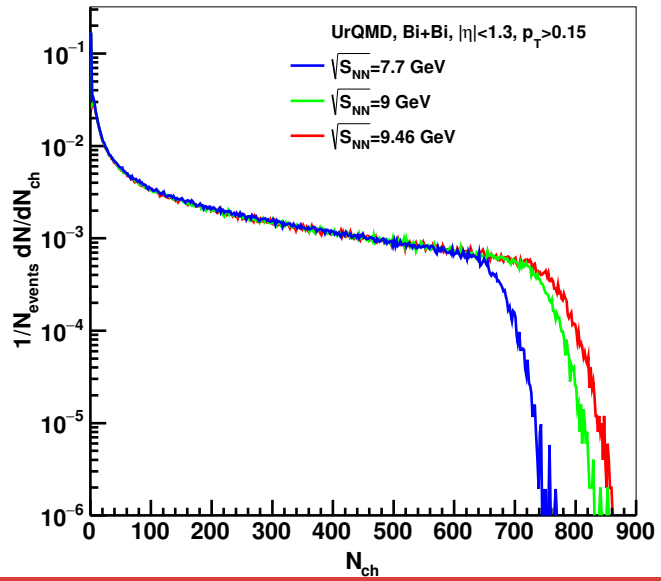
UrQMD model

- $p_T > 0.15$ GeV/c
- $|\eta| < 0.5$
- Only charged particles
- $\sim 600,000$ events.
- Bi+Bi collisions at 7.7, 9 and 9.46 GeV using UrQMD test.f14 output files.





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

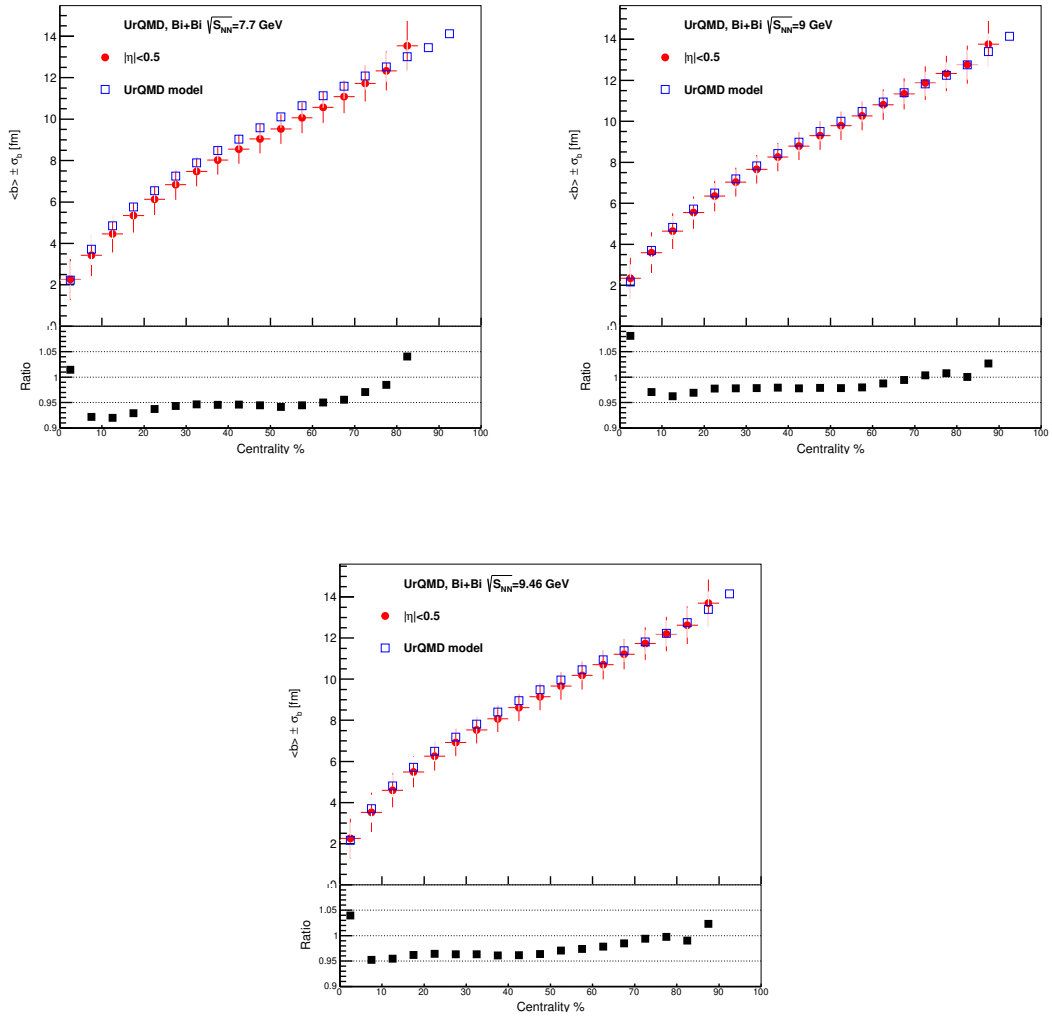


Figure: UrQMD model and TPC results comparison of the impact parameter vs centrality at the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV ($|\eta| < 0.5$).

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

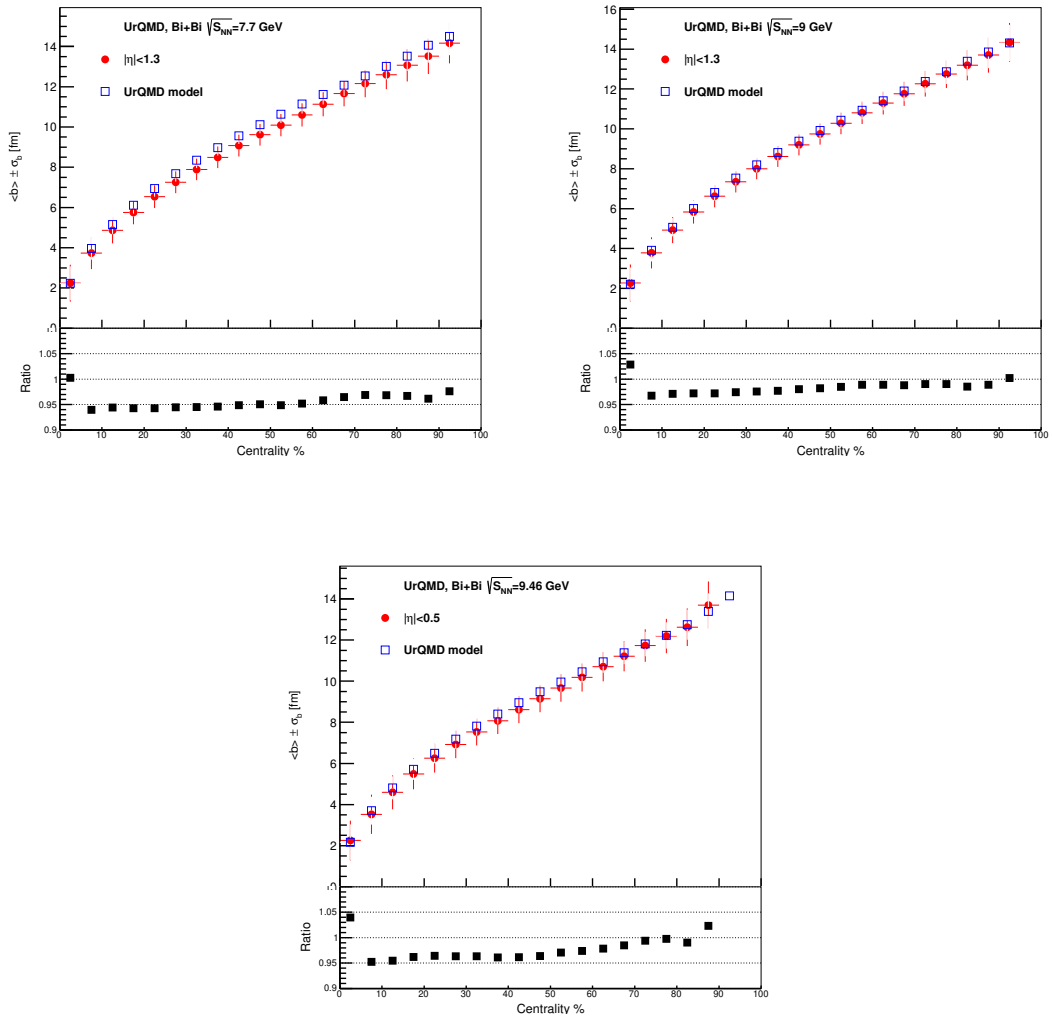

Figure: UrQMD model and TPC results comparison of the impact parameter vs centrality at the three energies $\sqrt{S_{NN}} = 7.7$, 9 and 9.46 GeV ($|\eta| < 1.3$).

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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.
- Compare the FHCal method based on the dE/dx to the centrality determination.
  Volkov, V., Golubeva, M., Guber, F., Ivashkin, A., Karpushkin, N., Morozov, S., Musin, S., Strizhak, A. (2021). Application of FHCal for Heavy-Ion Collision Centrality Determination in MPD/NICA Experiment. Particles, 4(2), 236–240.
- Compare results with other Monte Carlo generators (LAQGSM and PHSD).

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Thank you!