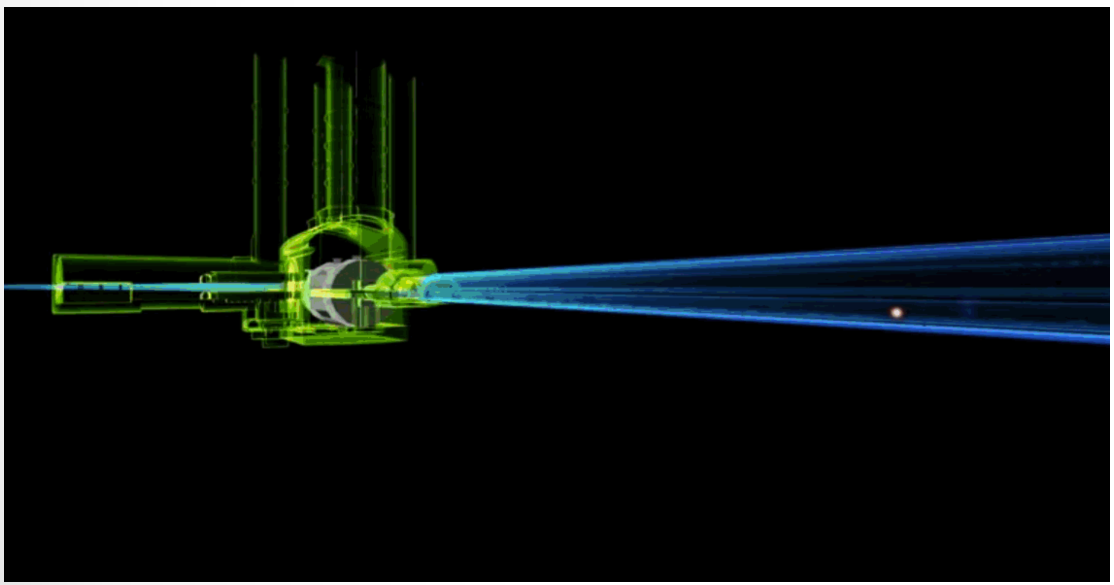
Glauber modelling in high energy nuclear collisions



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Introduction

- The Glauber model is a set of theoretical techniques used to model high energy heavy ion collisions inside particle colliders.

- **High energy Nuclear Physics** studies the behaviour of nuclear matter in energy regimes, a few GeV to a few TeV

- **Heavy ion** in nuclear physics is any particle with one or more units of electric charge and a mass exceeding that of the helium-4 nucleus (alpha particle).

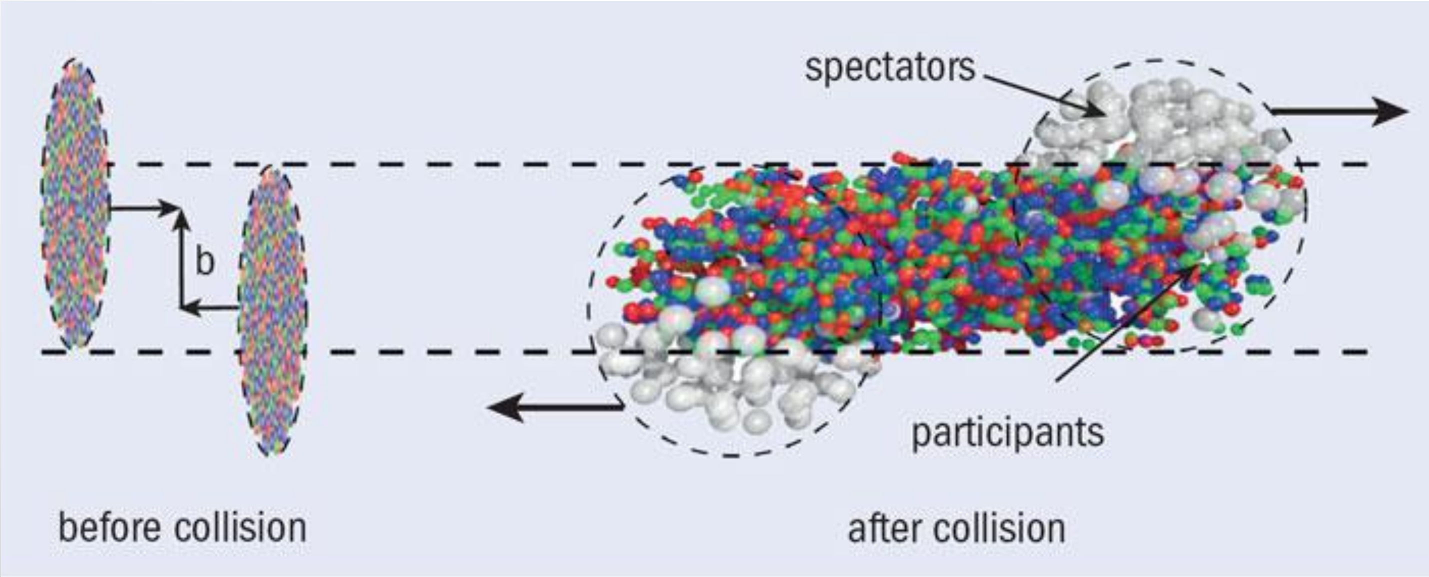
- A **particle accelerator** is a machine that uses electromagnetic fields to propel charged particles to nearly light speed (99.995 % the speed of light)and to contain them in well-defined beams.

[Miller M L et al. Rev. Nucl. Part. Sci. 57 205 (2007)]

In this project we simulate **Au-Au Collisions** at $\sqrt{s_{NN}}$ **= 200Gev** with σ^{NN}_{inel} = 42mb this using the **Glauber Model** and compare with results from the experiment (STAR Experiment at RHIC) . [Miller M L et al. Rev. Nucl. Part. Sci. 57 205 (2007)]

We study the following quantities

1. **Impact parameter (b)**
2. **Number of collisions (N_{part})**
3. **Number of participants (N_{coll})**



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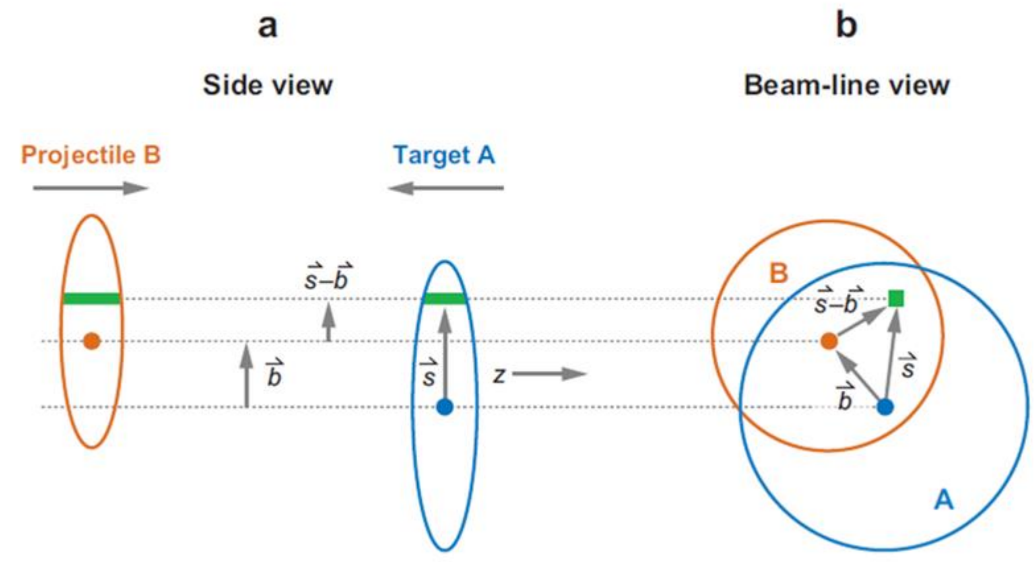
Optical Glauber Model



A = number of nucleons in projectile A
B = number of nucleons in projectile B
b = impact parameter
s = displacement of flux tube from centre of target A

σ_{inel}^{NN} = inelastic nucleon-nucleon cross sectional area

$\hat{T}_{AB}$ = Effective overlap area for which a specific nucleon in A can interact with a given nucleon in B

$\hat{T}_{A}$ = Probability per unit transverse area of a given nucleon being located in the target flux tube A

$\hat{T}_{B}$ = Probability per unit transverse area of a given nucleon being located in the target flux tube B

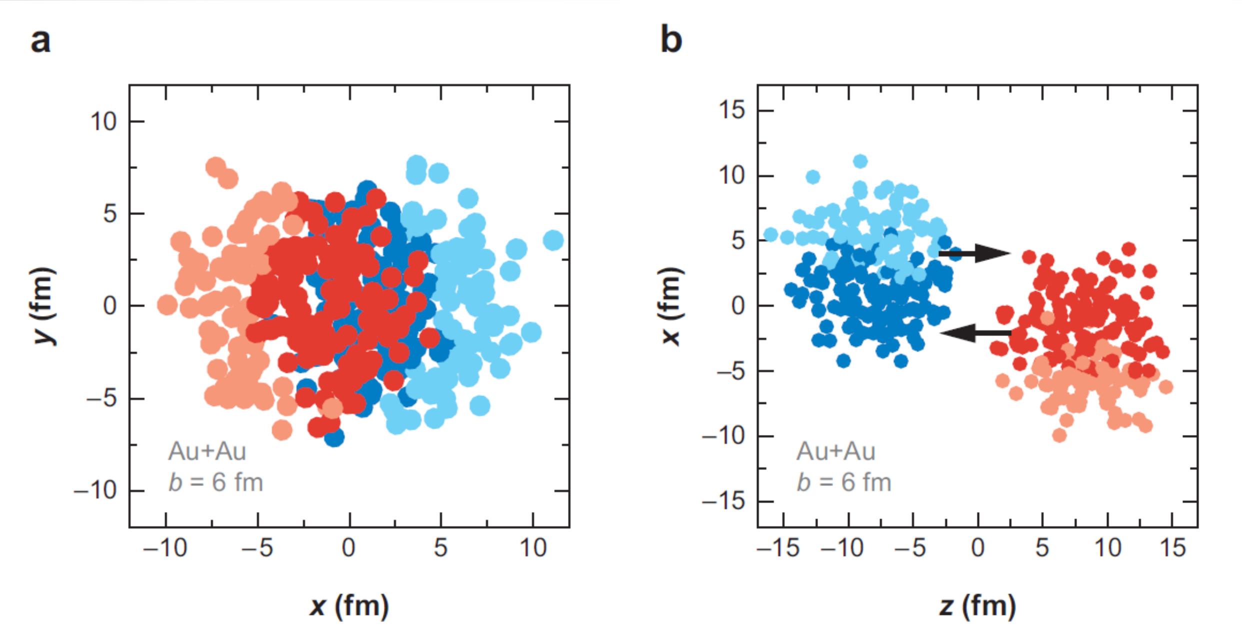
$$P(n,b) = \binom{AB}{n}[\hat{T}_{AB}(b)\sigma_{inel}^{NN}]^n[1-\hat{T}_{AB}(b)\sigma_{inel}^{NN}]^{AB-n}$$

$$N_{coll}(b) = \sum_{n=1}^{AB} nP(n,b) = AB\hat{T}_{AB}(b)\sigma_{inel}^{NN}$$

$$N_{part}(b) = A\int \hat{T}_A(s)\left\{1-\left[1-\hat{T}_B(s-b)\sigma_{inel}^{NN}\right]^B\right\}d^2s + B\int \hat{T}_B(s-b)\left\{1-\left[1-\hat{T}_A(s)\sigma_{inel}^{NN}\right]^A\right\}d^2s$$

[Miller M L et al. Rev. Nucl. Part. Sci. 57 205 (2007)]

Monte Carlo Glauber Model



Au_Au Collisions

$\sqrt{s_{NN}}$ = 200GeV

σ_{inel}^{NN} = 42mb

n_p = 79

n_n = 118

A=197

Dmin = 0.4 fm

$$\rho(r) = \rho_0 \frac{1}{1+\exp\left(\frac{r-R}{a}\right)}$$

$$D = \sqrt{\frac{\sigma_{NN}}{\pi}}$$

$\sqrt{s_{NN}}$ = 200GeV

σ_{inel}^{NN} = 42mb.

ρ = nuclear charge density

ρ_0 = nuclear charge density at centre of nucleus (2.3×10^{17} kg/m^3.)

r = distance from centre of nucleus

R = radius of nucleus (6.380 fm)

a = skin depth (0.5350 fm)

σ_{inel}^{NN} =Inelastic nucleon-nucleon cross section

D = ball diameter

[Miller M L et al. Rev. Nucl. Part. Sci. 57 205 (2007)]

Monte Carlo Glauber Model

1. Distributing the nucleons around the centre of the each nucleus by means of a radial distribution

2. Moving the centres of the two nuclei to positions b/2 above and below the beam axis.

3. Assuming a collision is said to have occurred if the transverse distance between two nucleons is less than the ball diameter(D)

$$D = \sqrt{\frac{\sigma_{NN}}{\pi}}$$

4. Running this algorithm for every nucleon in each nucleus for a million cycles (total number of events) and store values of Impact parameter(b), N_{part} and N_{coll} for each event.

Root

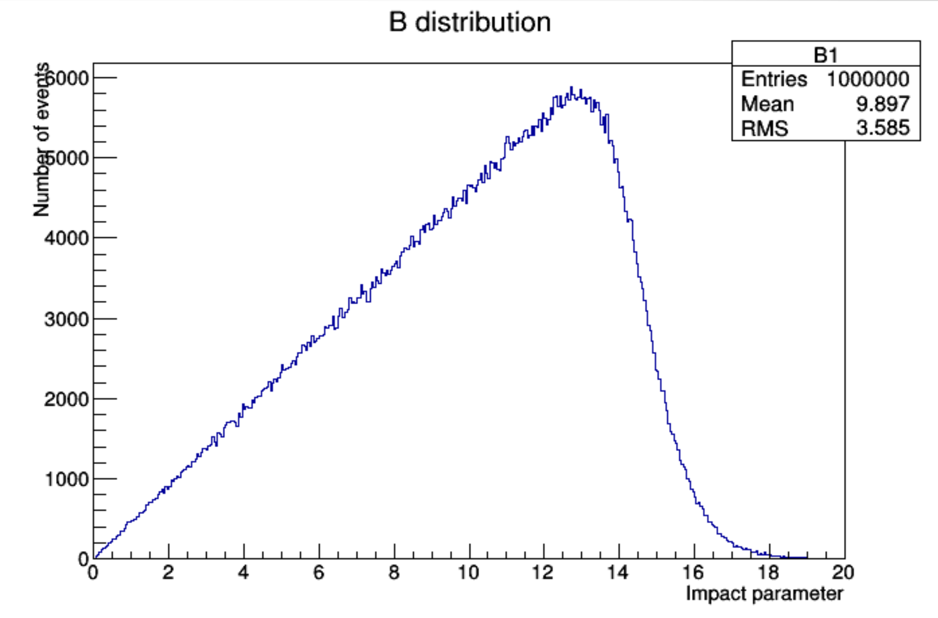
- Root is an open source scientific data framework used to statistical analysis, big data processing and creating visualizations. It is used extensively in the field of high energy physics.

- It has been used in this project to

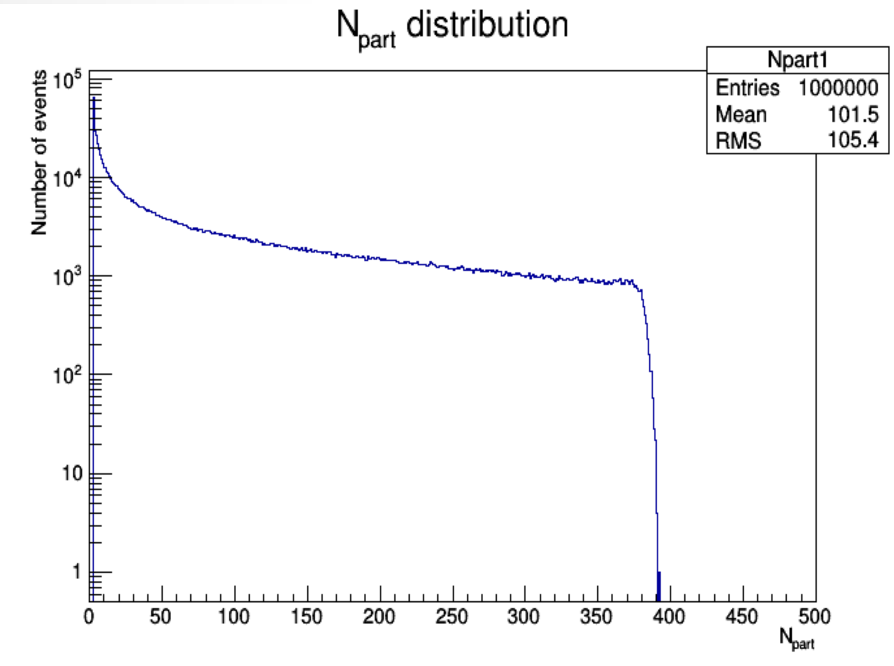
1. Run the Glauber Model simulation
2. Store data in files
3. Run C++ programs
4. Draw graphs, histograms, labels and formulae
5. Calculate centrality bins, mean values of distribution and errors

[B Alver *et al.* arXiv:0805.4411 [nucl-ex](2008)]

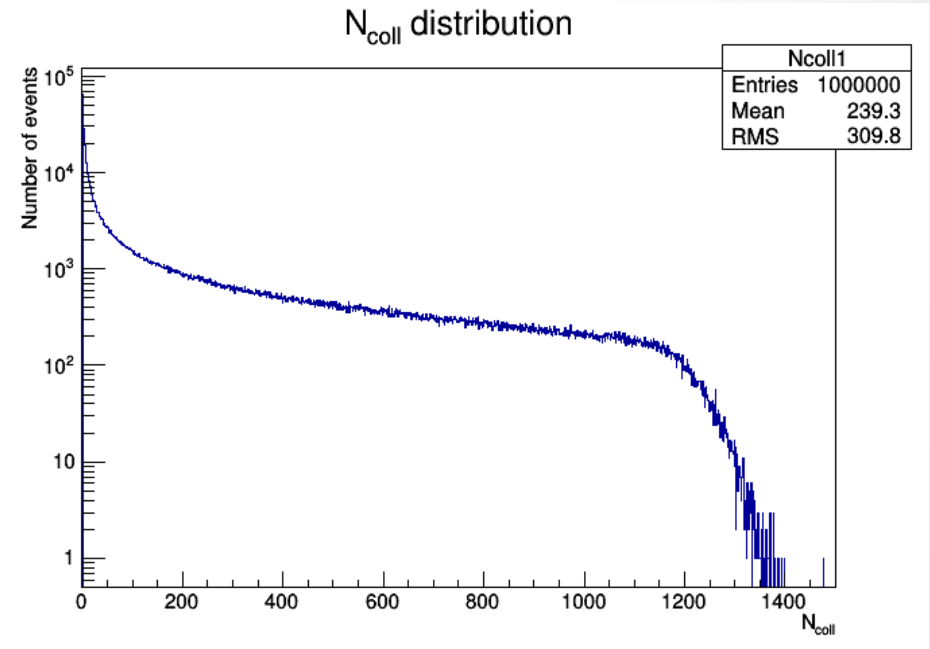
Results



B distribution
B1
Entries 1000000
Mean 9.897
RMS 3.585
Number of events
Impact parameter



N_{part} distribution
Npart1
Entries 1000000
Mean 101.5
RMS 105.4
Number of events
N_{part}



N_{coll} distribution
Ncoll1
Entries 1000000
Mean 239.3
RMS 309.8
Number of events
N_{coll}

The charged particle multiplicity

- Number of charged particles produced in the collisions.

- It is a function of N_{part} and N_{coll}

$$\frac{dn}{d\eta} = (1-x)n_{pp}\frac{\langle N_{part}\rangle}{2} + xn_{pp}\langle N_{coll}\rangle$$

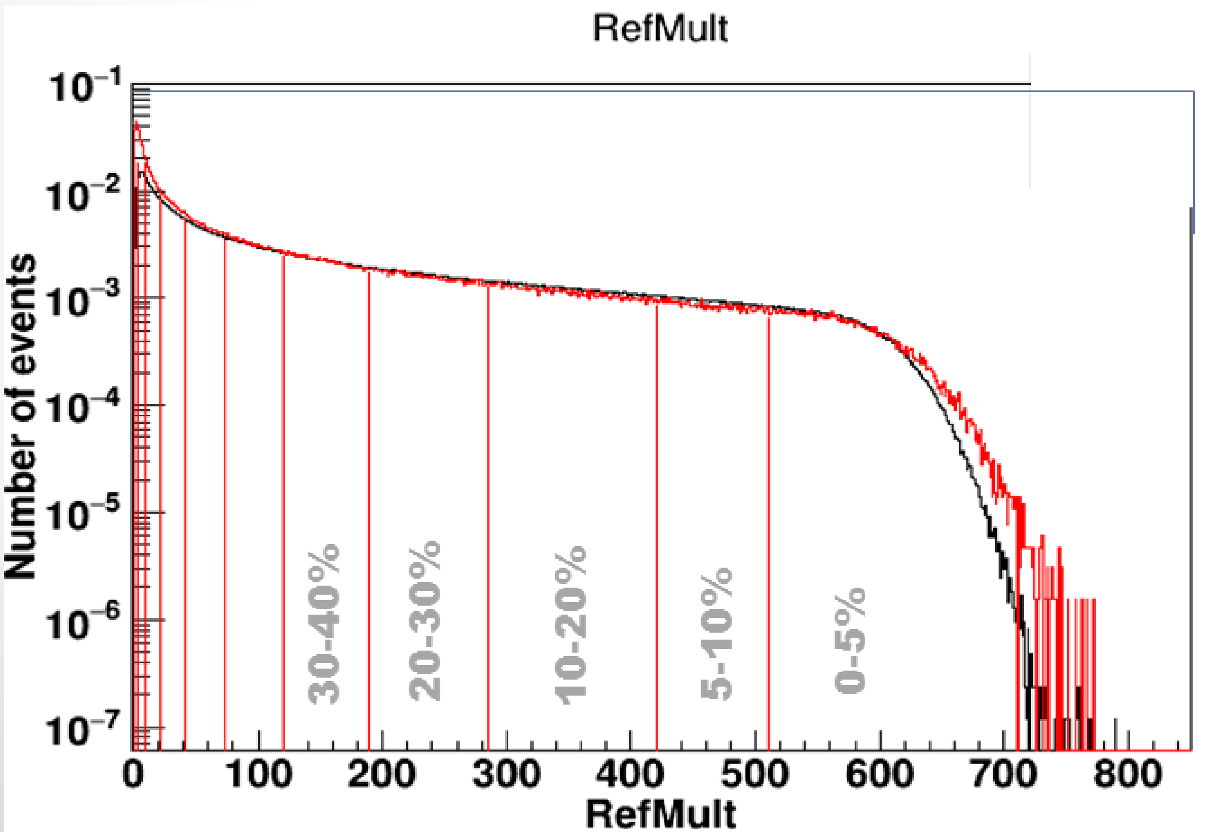
x = fraction of hard component (0.13)
n = number of charged particles produced
η = Pseudorapidity
n_{pp} = multiplicity measured in pp collisions per unit of pseudorapidity

- Charged particle multiplicity (CPM) distribution was constructed with random values of N_{part} and N_{coll} taken from the simulated data.

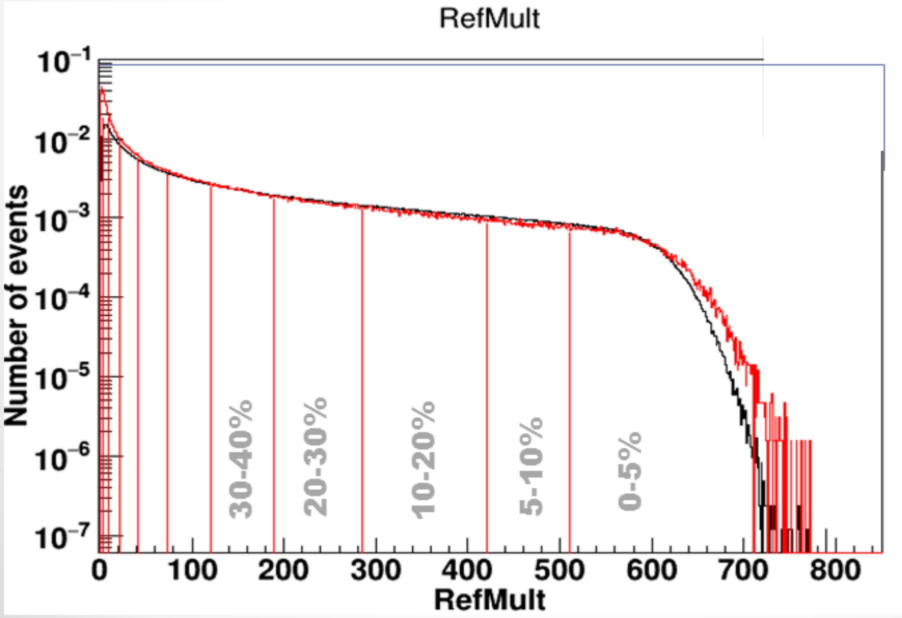
- The simulated CPM with the CPM from the experimental data were plotted together.

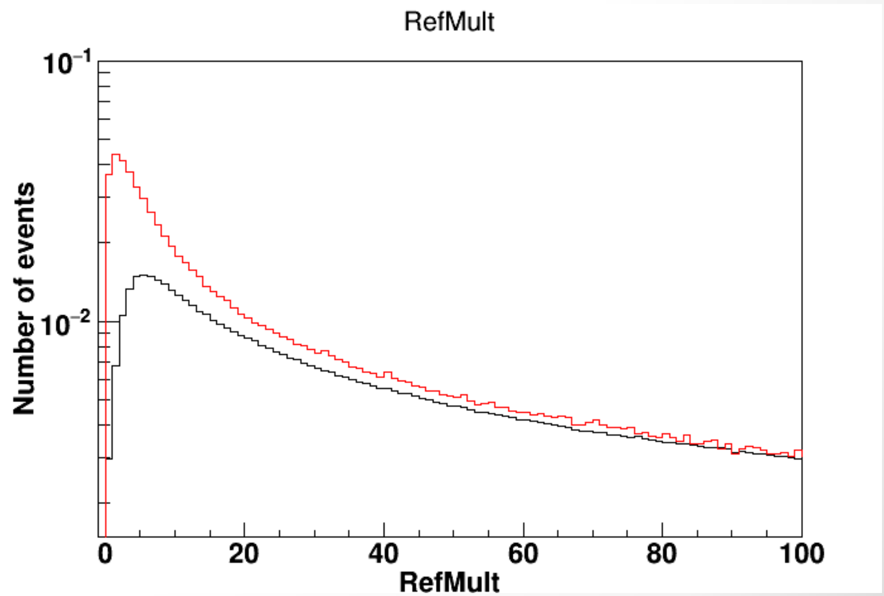
- The 10 centrality were created based of fraction of total integral.

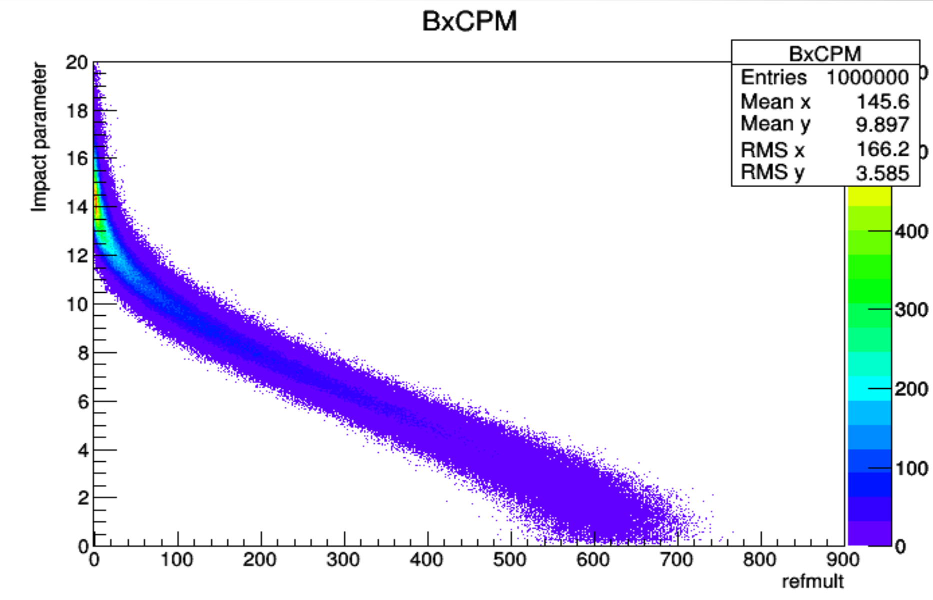
- Lines were drawn in the histogram at these cuts to separate different centrality bins.

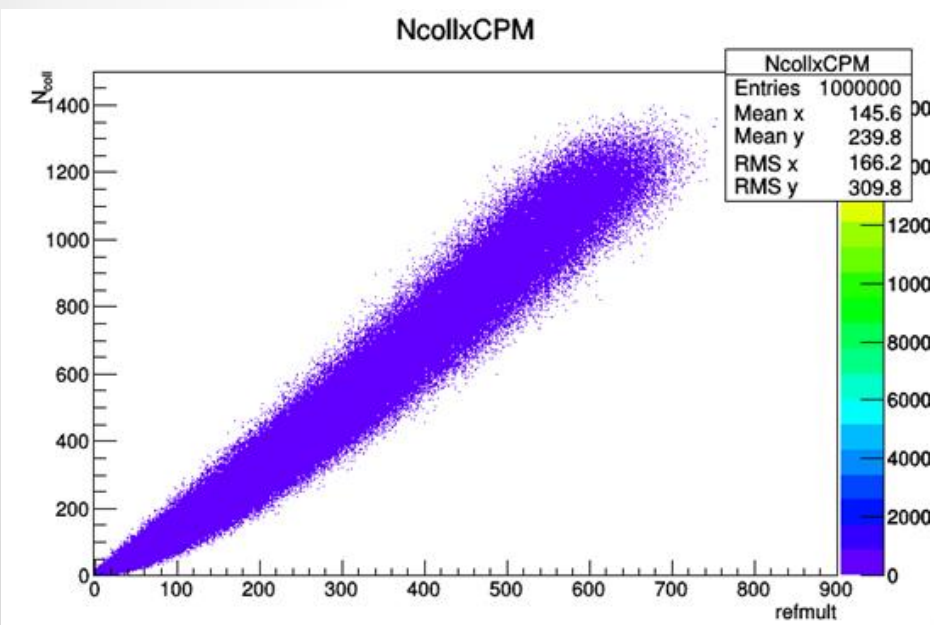


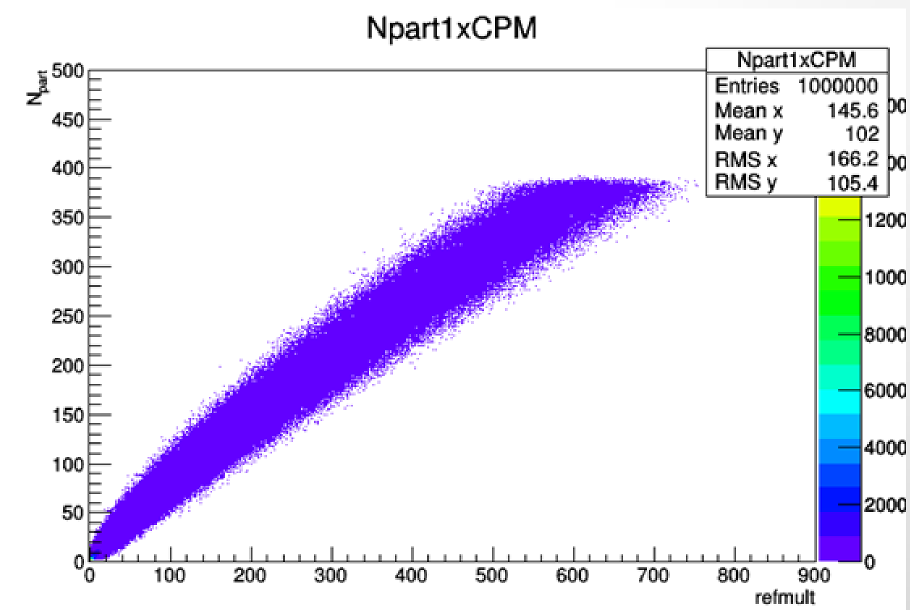
Centrality	Mean multiplicity	Mean multiplicity (published)[3]	% Error
10-20%	347.95	348.77	0.235666
20-30%	233.94	234.09	0.064119
30-40%	152.05	152.74	0.453798
40-50%	94.91	95.08	0.179117
50-60%	55.28	55.36	0.144718
60-70%	29.58	29.67	0.30426
70-80%	13.64	13.94	2.199413
80-90%	5.07	5.63	11.04536
90-100%	1.53	1.87	22.22222






BxCPM
Impact parameter
refmult
BxCPM
Entries 1000000
Mean x 145.6
Mean y 9.897
RMS x 166.2
RMS y 3.585


NcollxCPM
N_{coll}
refmult
NcollxCPM
Entries 1000000
Mean x 145.6
Mean y 239.8
RMS x 166.2
RMS y 309.8


Npart1xCPM
N_{part}
refmult
Npart1xCPM
Entries 1000000
Mean x 145.6
Mean y 102
RMS x 166.2
RMS y 105.4

Centrality	Multiplicity cut	Multiplicity cut (used in experiment)[3]	Mean Impact Parameter (b)	Mean Impact Parameter (b) (published)[3]
90-100%	3	-	14.54 ± 1.05	-
80-90%	9	-	14.03 ± 1.04	-
70-80%	21	>14	13.01 ± 0.86	12.3-13.2
60-70%	41	>30	11.97 ± 0.68	11.4-12.3
50-60%	73	>56	10.96 ± 0.59	10.5-11.4
40-50%	121	>94	9.89 ± 0.57	9.33-10.5
30-40%	189	>146	8.72 ± 0.56	8.10-9.33
20-30%	285	>217	7.36 ± 0.59	6.61-8.10
10-20%	421	>312	5.69 ± 0.7	4.66-6.61
5-10%	511	>431	4.10 ± 0.65	3.31-4.66
0-5%	>511	>510	2.31 ± 0.96	0-3.31

Centrality	$\langle N_{part} \rangle$	$\langle N_{part} \rangle$ (published)[3]	$\langle N_{coll} \rangle$	$\langle N_{coll} \rangle$ (published)[3]
90-100%	3.47 ± 1.51	-	2.34 ± 1.34	-
80-90%	5.81 ± 3.19	-	4.43 ± 3.04	-
70-80%	13.26 ± 5.75	15.7 ± 2.6	12.05 6.71	15.0 ± 3.2
60-70%	26.96 ± 8.26	28.8 ± 3.7	29.65 ± 12.5	312.4 ± 5.5
50-60%	47.54 ± 11.18	49.3 ± 4.7	63.73 ± 21.52	66.8 ± 9.0
40-50%	76.79 ± 4.51	78.3 ± 5.3	124.4 ± 34.19	127 ± 13
30-40%	115.8 ± 18.13	117.1 ± 5.2	222.4 ± 50.23	221 ± 17
20-30%	167.4 ± 22.75	167.6 ± 4.4	373.8 ± 71.98	365 ± 24
10-20%	235.2 ± 28.39	234.3 ± 4.6	603.2 ± 101.6	577 ± 36
5-10%	299.7 ± 23.29	298.6 ± 4.1	847.3 ± 92.39	805 ± 50
0-5%	350 ± 21.44	350.6 ± 2.4	1066 ± 102.4	1012 ± 59

Conclusion

1. Impact parameter(b), N_{part} and N_{coll} distributions were simulated for Au-Au collisions at 200 GeV using the Monte Glauber Model.

2. Charged particle multiplicity distribution was constructed and compared with Experimental data centrality bins were found.

3. $< b >$,$< N_{part} >$ and $< N_{coll} >$ was calculated and for each centrality bins was found to be consistent with results

4. The simulated CPM is comparable with the experimental data at high multiplicity region whereas it **deviates at low multiplicity**. This occurs due to the inefficiency of the detector.

5. Therefore to correctly estimate the multiplicity at low centralities we use the simulated multiplicity.

References

1. Miller M L, Reygers K, Sanders S J, and Steinberg P Annu. Rev. Nucl. Part. Sci. 57 205 (2007)
2. B Alver *et al.* arXiv:0805.4411 [nucl-ex](2008)
3. B. I. Abelev *et al. Phys. Rev. C* **79**, 034909 (2009)
4. Kharzeev D, Nardi M. *Phys. Lett. B* 507:121 (2001)
5. R L Ray and M S Daugherity J.Phys.G35:125106(2008)
6. H Masui, B Mohanty, N Xu Phys.Lett.B679:440-444 (2009)