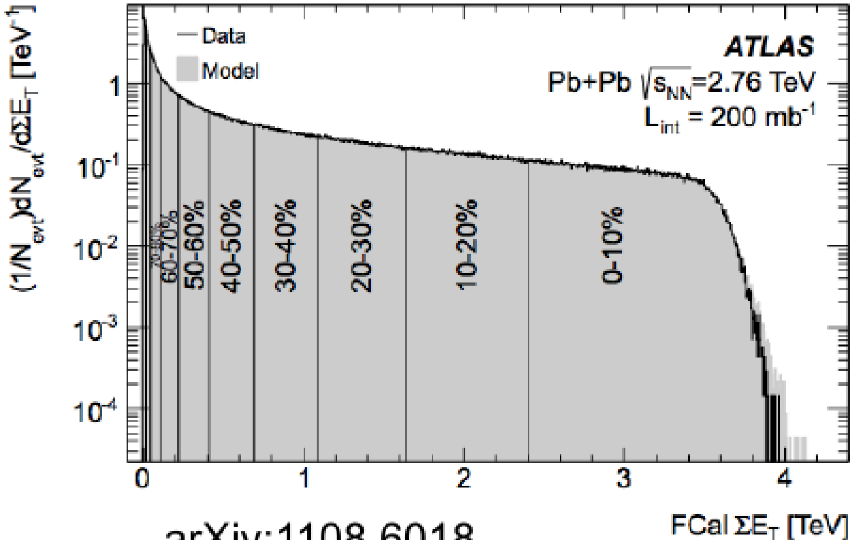
Centrality determination in HEP experiments¶

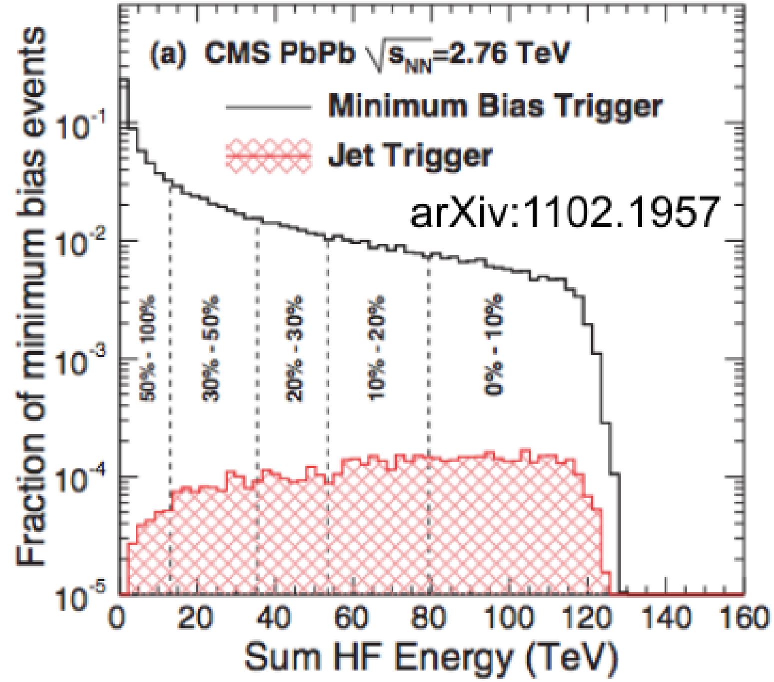
Arkadiy Taranenko

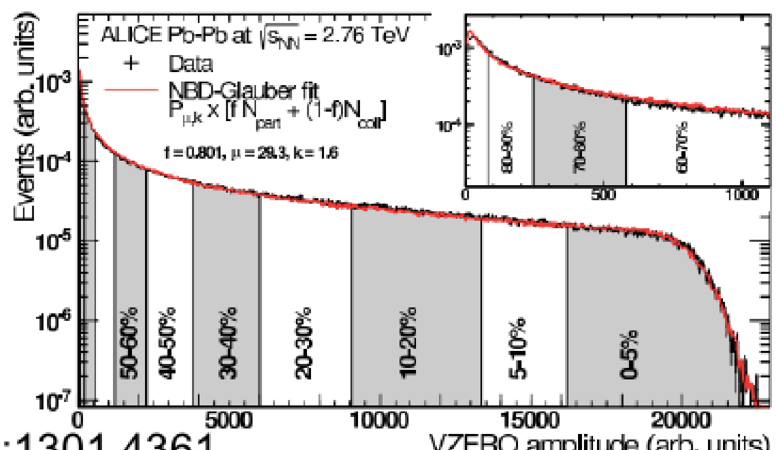
Centrality determinations



arXiv:1108.6018

Figure 1: Measured FCal ΣE_T distribution divided into 10% centrality intervals (black).





arXiv:1301.4361

Fig. 10: (Color online) Distribution of the sum of amplitudes in the VZERO scintillators. The distribution is fitted with the NBD-Glauber fit (explained in the text) shown as a line. The centrality classes used in the analysis are indicated in the figure. The inset shows a zoom of the most peripheral region.

Slice the measured variables (forward usually) to determine the centrality of each event

Centrality in ALICE

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-PH-EP-2012-368
18 Dec 2012

Centrality determination of Pb–Pb collisions at $\sqrt{s_{NN}}$= 2.76 TeV with ALICE

ALICE Collaboration*

The total Pb–Pb cross section is calculated as $\sigma_{PbPb} = N_{evt}(N_{coll} \geq 1)/N_{evt}(N_{coll} \geq 0) \times \pi b^2_{max}$, i.e. the geometrical value corrected by the fraction of events with at least one nucleon-nucleon collision. We obtain $\sigma_{PbPb} = (7.64 \pm 0.22(syst.))$ b, in agreement with the ALICE measurement $\sigma_{PbPb} = (7.7 \pm 0.1(stat.)^{+0.6}_{-0.5}(syst.))$ b [9].

4 Determination of the hadronic cross section

In order to classify the collisions in percentiles of the hadronic cross section using the charged particle multiplicity, it is necessary to know the particle multiplicity at which the purity of the event sample and the efficiency of the event selection becomes 100%. We define the *Anchor Point* (AP) as the amplitude of the VZERO detector equivalent to 90% of the hadronic cross section, which determines the absolute scale of the centrality. The determination of the AP requires the knowledge of the trigger efficiency and the remaining background contamination in nuclear collision events. Two methods have been used to study this. The difference in the

Centrality in ALICE

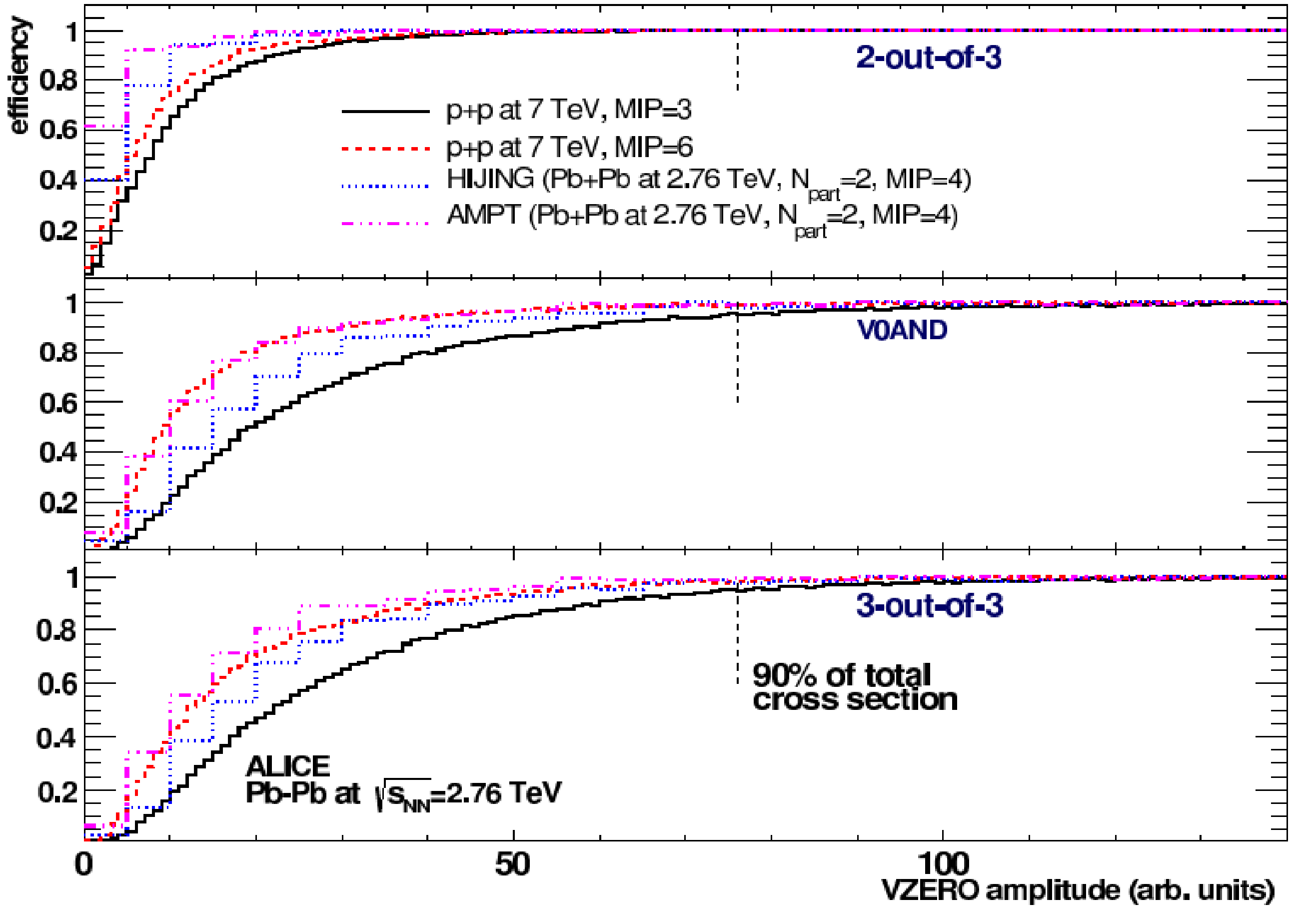


Fig. 7: (Color online) Efficiency of the three online triggers (2−out − of−3, *V0AND*, 3−out − of−3) used for Pb–Pb collisions as a function of the VZERO amplitude calculated with HIJING and AMPT, and measured in dedicated pp runs. The efficiency in the simulation has been calculated for events with $N_{\mathrm{part}} = 2$.

Centrality in ALICE

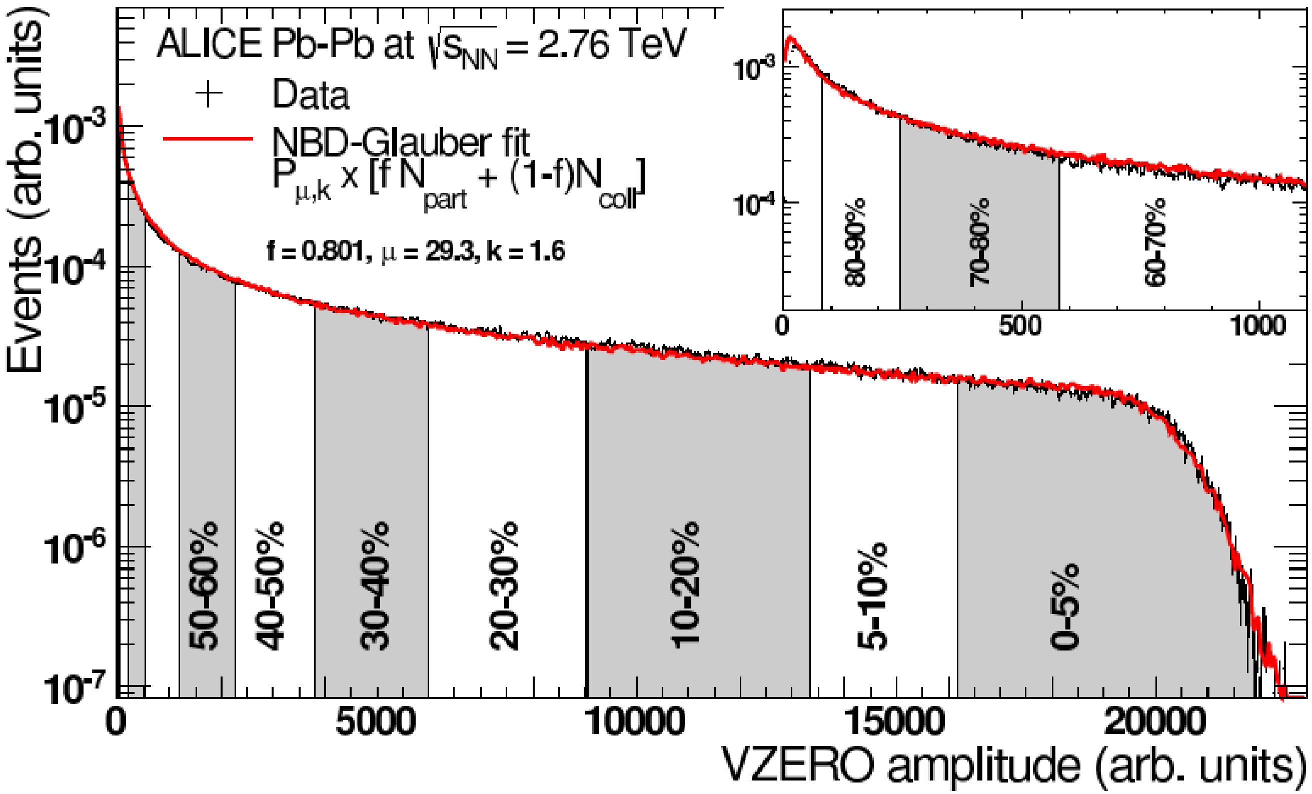
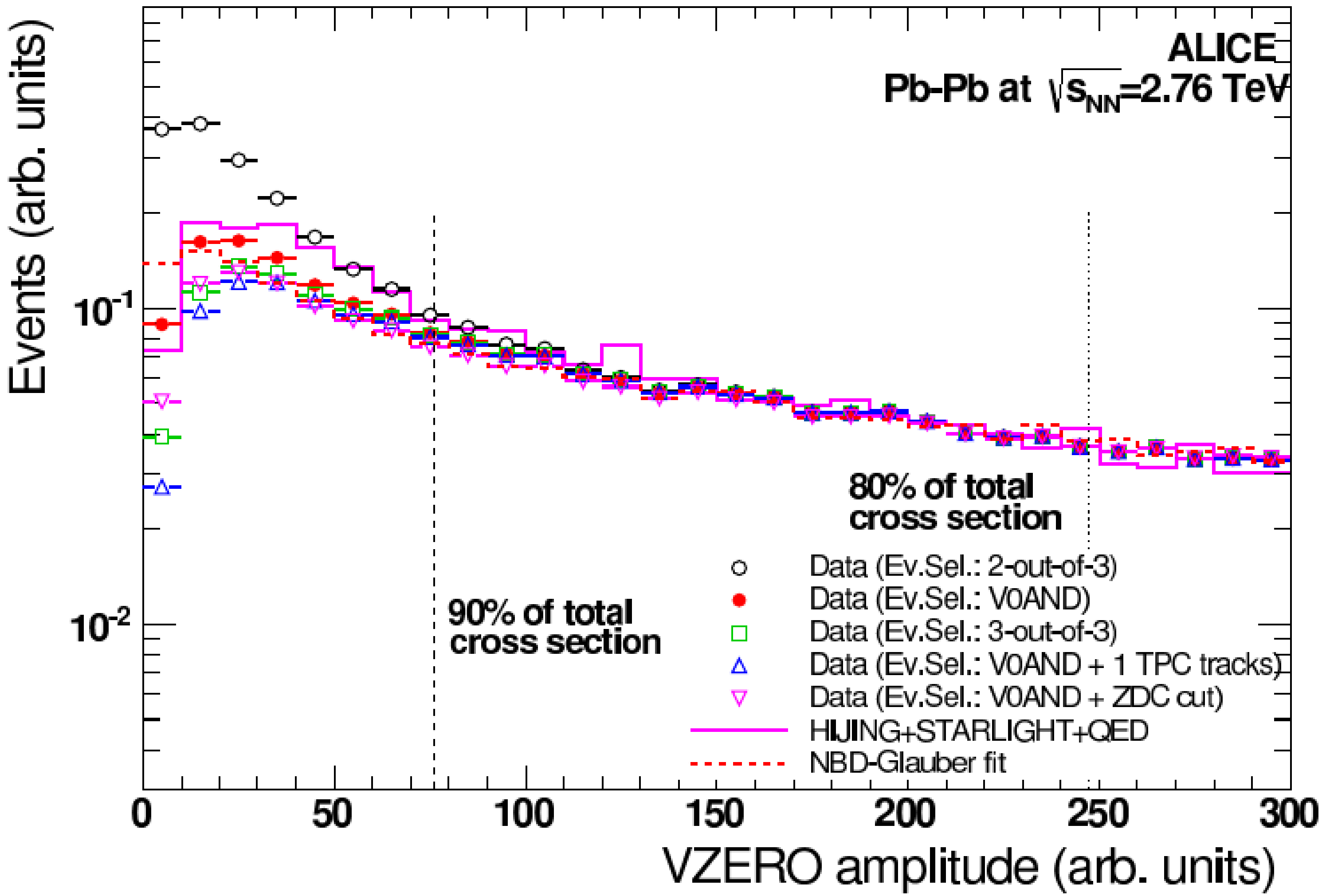


Fig. 10: (Color online) Distribution of the sum of amplitudes in the VZERO scintillators. The distribution is fitted with the NBD-Glauber fit (explained in the text) shown as a line. The centrality classes used in the analysis are indicated in the figure. The inset shows a zoom of the most peripheral region.

Centrality in ALICE



Centrality in ALICE

Table 3: Comparison of the percentage of the hadronic cross section above the VZERO amplitude chosen as AP ($V0_{AP}$) for various cases considered in the systematic studies of the Glauber fits and with HIJING and AMPT simulations.

Method	% of total cross section above the $V0_{AP}$
Glauber Fits	
Baseline	90.00
(i) fit TPC tracks	89.88
(ii) fit SPD clusters	89.87
(iii) fit only 50% of cross sec	90.11
(iv) different ancestor dependence	90.66
(v) different Wood-Saxons par	90.43
HIJING simulations	
2−out−of−3	92.50
V0AND	89.05
3−out−of−3	90.15
V0AND + TPC	91.12
V0AND + ZDC	89.52
AMPT simulations	
2−out−of−3	92.49
V0AND	89.49
3−out−of−3	90.59
V0AND + TPC	91.36
V0AND + ZDC	89.00

Centrality in ALICE

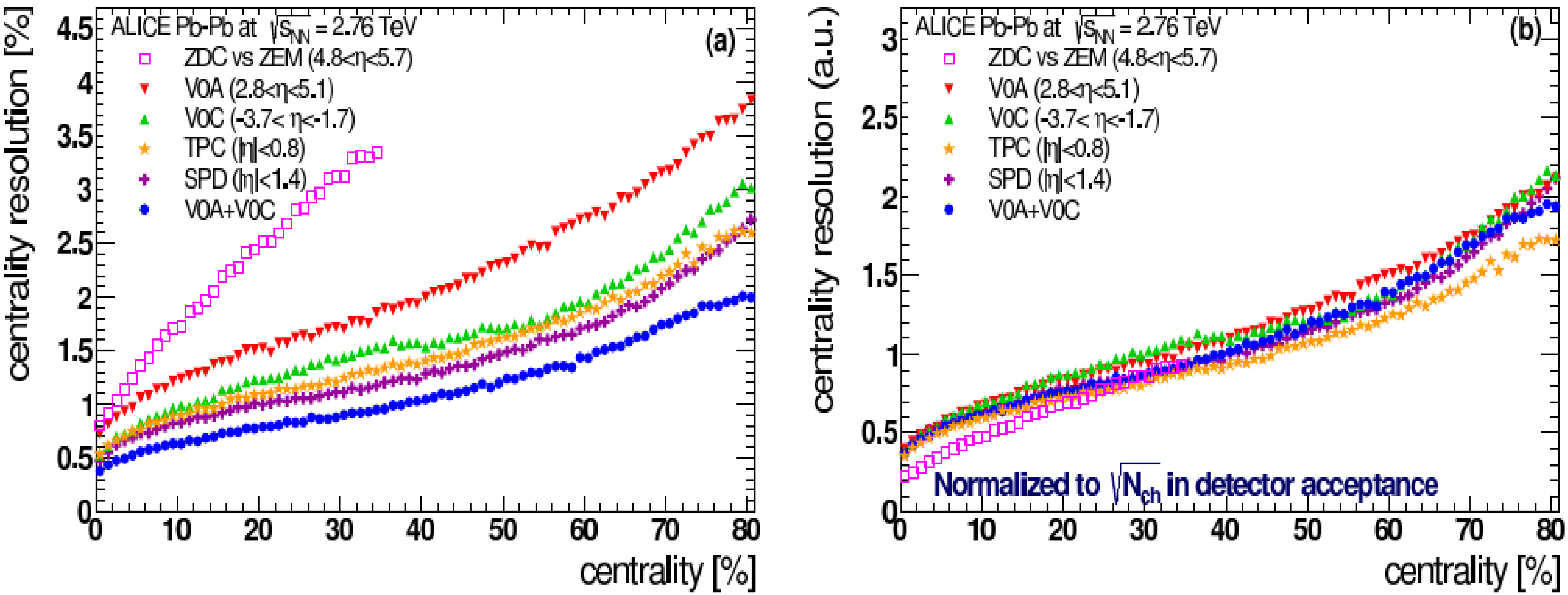


Fig. 16: (Color online) Left: Centrality resolution Δ_i for all the estimators evaluated in the analysis. Right: Resolution, in arbitrary units, scaled by $\sqrt{N_{\mathrm{ch}}}$ measured in each detector.

Centrality in PHENIX

In Analysis note 103 [1], Kensuke Homma have used HIJING simulation at 200 GeV Au+Au to estimate the trigger efficiency, where the simulated HIJING events were run through a GEANT simulation of the BBC response. The vertex distribution for these events was chosen to approximate what was seen during real data taking. From these events, Kensuke Homma has estimated a efficiency of $92.3 \pm 0.4(stat) \pm 1.6(sys)$. As far as we know, the BBC response

3. Fitting

Use of the Negative Binomial Distribution (NBD) weighted with probabilities for a given N_{part} from the Monte-Carlo Glauber model (MCG) to fit the number of hits in the BBCs is explained in the analysis note 210 and used later e.g. in the analysis note 219. Briefly this approach is based on the following assumptions:

- The shape of the N_{part} distribution is assumed to be the same as in the MCG model.
- Each participant produces hits in the BBC independently from any other participant.
- N_{hit} produced by a single participant obey NBD statistics.

Using the fact that the convolution of N-times Negative Binomial Distributions, $NBD(\mu, k)$, where μ is the mean and k is responsible for the width, is again the NBD with N-times μ and N-times k, one can write that the probability to observe N_{hit} in BBC in the event with number of participants equal to N_{part} is $NBD(N_{part} \times \mu, N_{part} \times k)$. Using the probability to have N_{part} given by the Monte-Carlo Glauber model $MCG(N_{part})$ one can write.

$$\frac{1}{\varepsilon(N_{hit})} P(N_{hit}) = \sum_{N_{part}} NBD(\mu N_{part}, k N_{part}) \times MCG(N_{part}) \quad (1)$$

Centrality in PHENIX

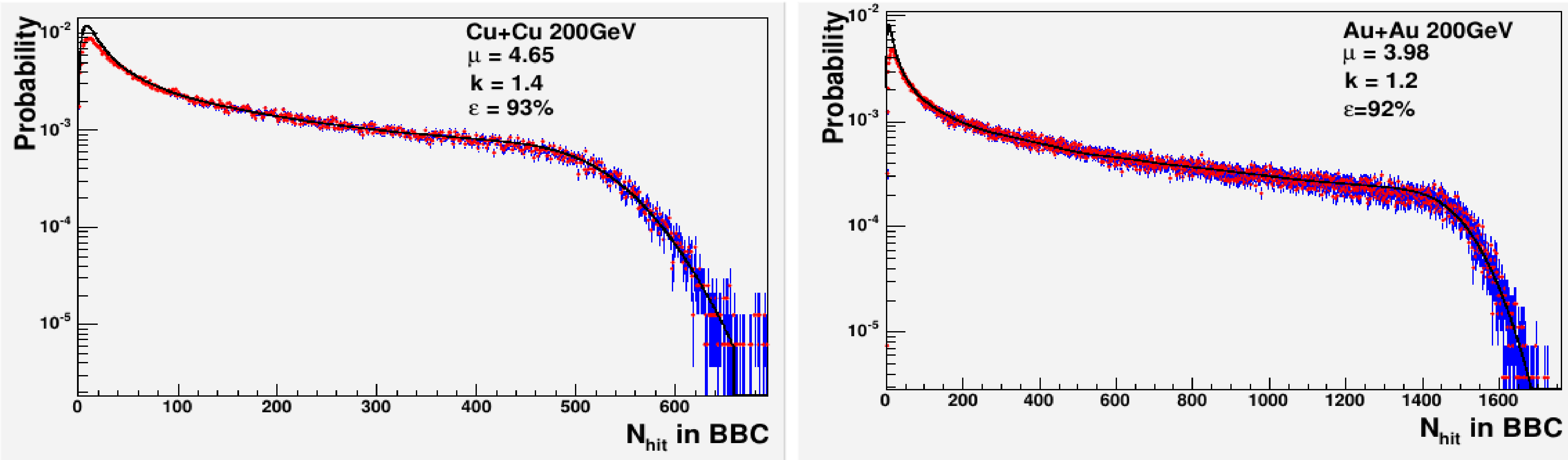
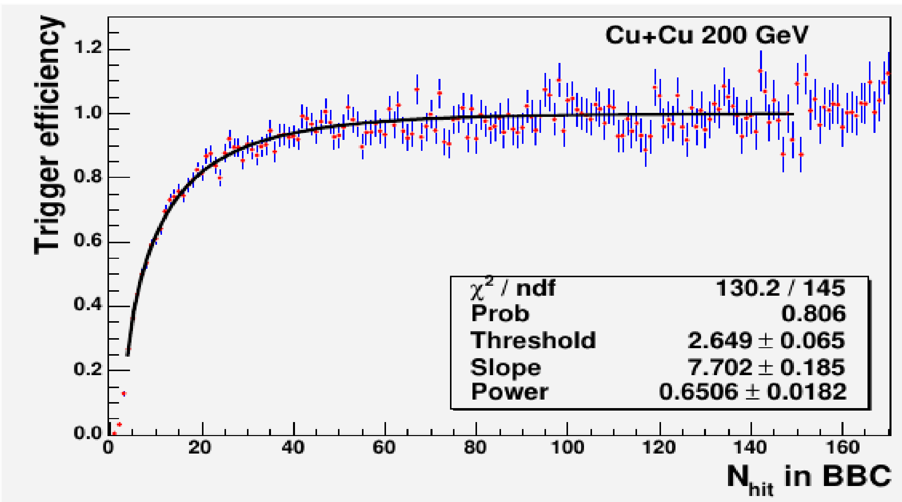
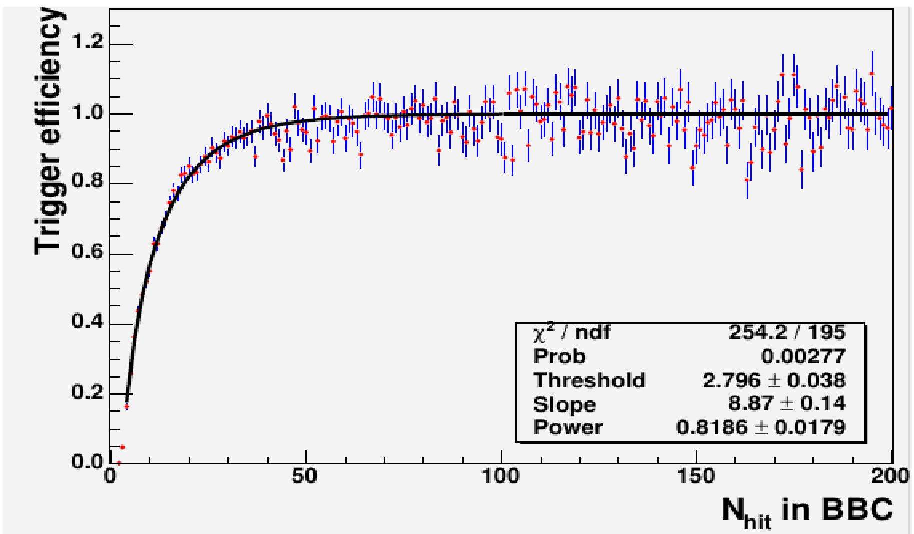


Figure 3. Distribution of the number of hits in both BBC (blue) fitted by the MCG-NBD function (red) for $Cu + Cu$ and (left) and $Au + Au$ (right).





Centrality in PHENIX

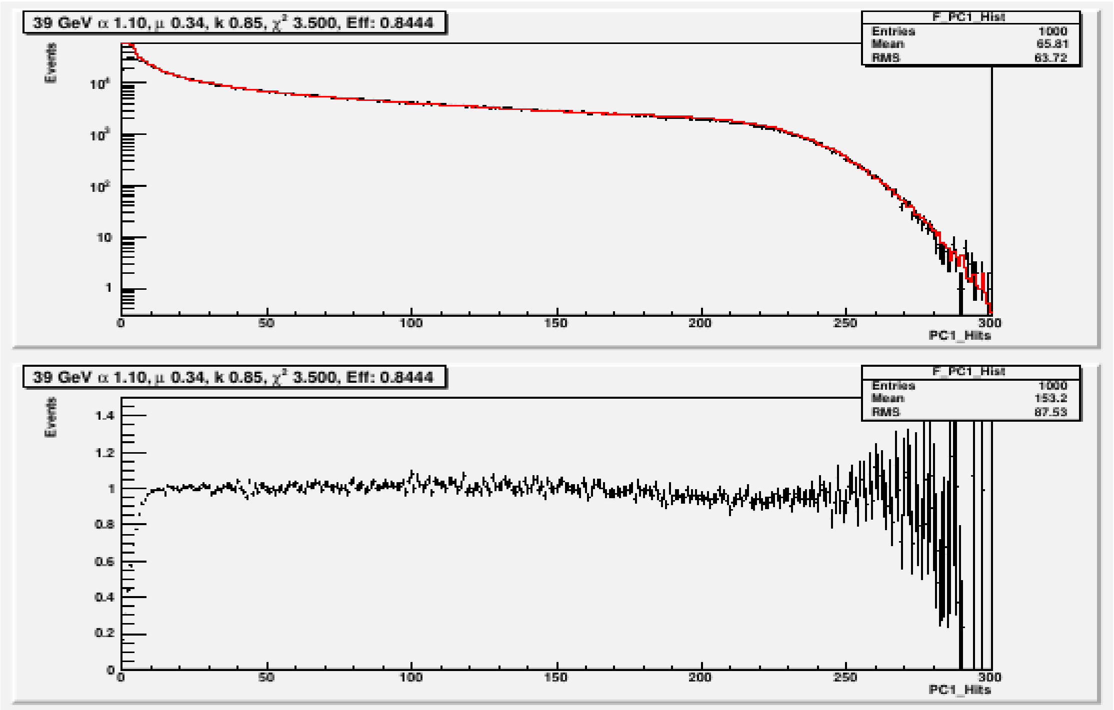


Figure 13: Upper panel: Example of NBD-fit of PC1 hit distirubtion for BBC-Z vertex cut $|z| < 20$ cm and BBCLL1(>1 tubes). Lower panel: The resulting efficiency function plotted vs number of PC1 hits.

- **PC1 hits:** α **= 1.1,** μ**=0.34 , k=0.55 ,** χ^2/ndf**=1.648, trig_eff=0.835**
- **PC3 hits:** α **= 1.1,** μ**=0.32 , k=0.45 ,** χ^2/ndf**=1.201, trig_eff=0.848**
- **RXN**$_{Out}$ **Q:** α **= 1.1,** μ**=0.84 , k=0.50 ,** χ^2/ndf**=1.316, trig_eff=0.856**
- **RXN**$_{In}$ **Q:** α **= 1.02,** μ**=1.27 , k=1.45 ,** χ^2/ndf**=1.306, trig_eff=0.869**

Centrality in PHENIX

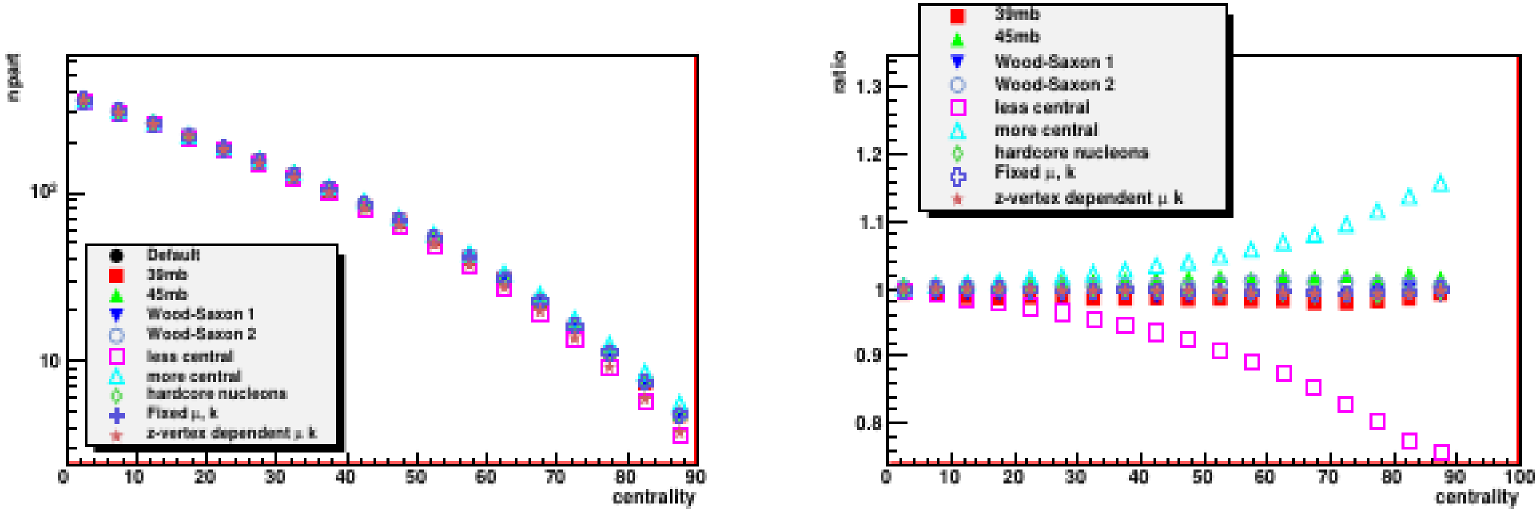
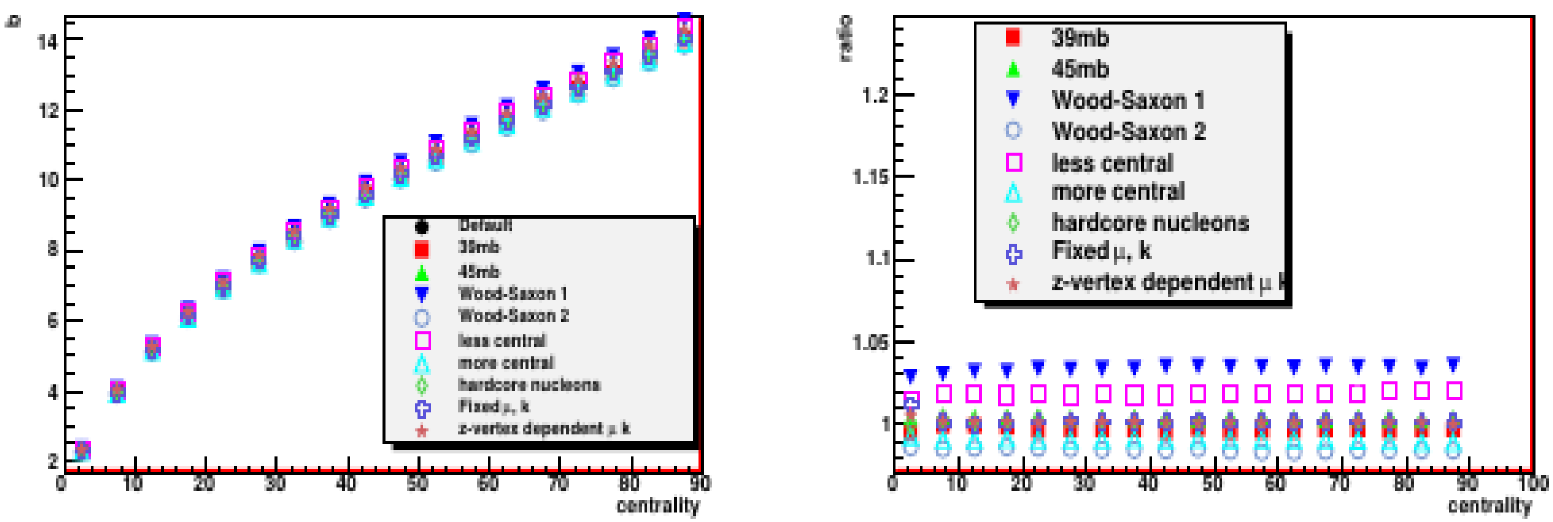


Figure 5: Comparison of $\langle N_{\mathrm{part}} \rangle$ values. The right panel shows the ratio to the default.



Centrality in STAR

Glauber Fit Procedure

Inputs: Simulated Ncoll, Npart distributions and experimental refMultCorr distribution
Fit parameters: μ, k, x, d
Glauber Procedure:
For each simulated isobar collision

- Define m = $xN_{coll} + (1\text{-}x)\frac{N_{part}}{2}$
- Sample m times from negative binomial distribution to get ideal multiplicity

$$\mathrm{NBD}(n) = \frac{\Gamma(n+k)}{\Gamma(n+1)\Gamma(k)}\left(\frac{\mu/k}{1+\mu/k}\right)^n(1+\mu/k)^{-k}$$

- Reduce the ideal multiplicity by a factor of 1-efficiency where efficiency is

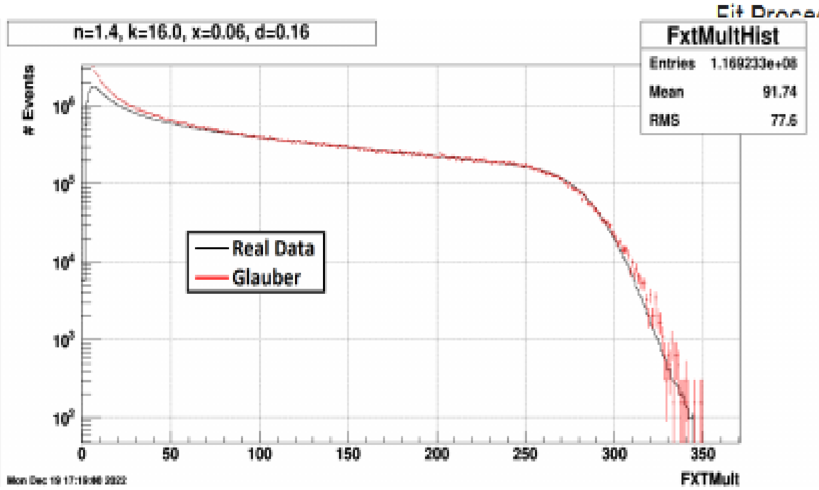
$$\epsilon = 0.98 * (1.0 - (\text{ideal mult}) * d/540.0)$$

Parameter meanings:

- μ: NBD parameter representing mean particle production per nn collision
- k: NBD "shape" parameter to tune sharpness of upper edge of Glauber multiplicity
- x: Hardness parameter which determines Ncoll/Npart contributions to multiplicity
- d: Efficiency parameter representing maximum *inefficiency* at high multiplicities

Fit Procedure:

- Scan parameter space (n_{pp}, k,
per iteration within the range
until local minimum in $\chi^2/n.d.$
  - i.e. adjust parameter space
on the boundary.
  - $\Delta n_{pp} = 0.1$, $\Delta k = 1$, $\Delta x =$



Final parameters

- nMCevents = 1m
- Fit range = [100,500]
- $n_{pp} = 1.4$
- k = 16
- x = 0.06
- eff = 0.16
- $\chi^2/n.d.f. = 1.450$

Npart in PHENIX/STAR 200 GeV

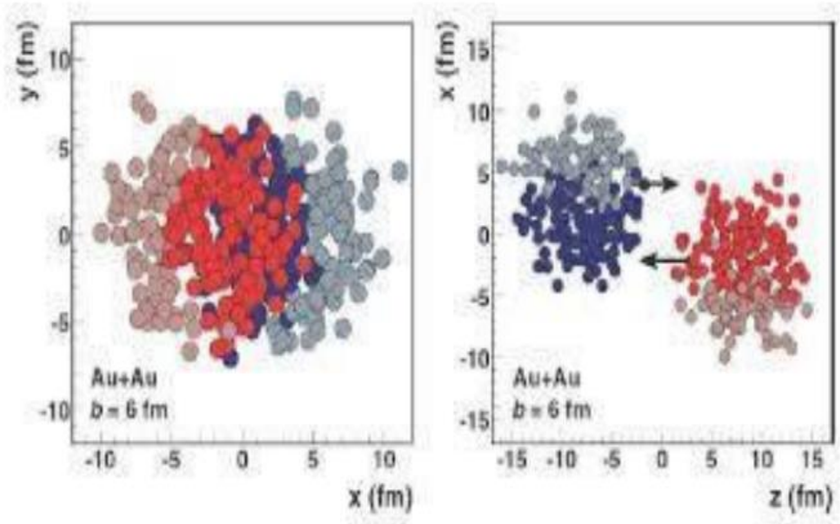
Table 1: The average values and
tities with default setting. NB
DEFULAT)

Bin %	$\langle N_{\rm part}\rangle$ $\sigma_{N_{\rm part}}$	$\langle N_{\rm coll}\rangle$ $\sigma_{N_{\rm coll}}$
0-5	350.8	1067
	(20.38	109
5-10	301.7	857.8
	(22.32	108.1
10-20	236.1	609.5
	(5.517	59.81
20-30	167.6	377.6
	(5.811	36.39
30-40	115.5	223.9
	(5.841	23.2
40-50	76.15	124.6
	(5.502	14.94
50-60	47.07	63.9
	(4.726	9.359
60-70	26.72	29.75
	(3.669	5.41
70-80	13.67	12.55
	(2.492	2.822
80-90	6.153	4.688
	(1.359	1.252

TABLE III: E_T and E_T^{em} as
the header of the table. All u

Centrality (%)	N_{part}
$70-80$	14 ± 4
$60-70$	27 ± 5
$50-60$	47 ± 8
$40-50$	76 ± 8
$30-40$	115 ± 9
$20-30$	166 ± 9
$10-20$	234 ± 8
$5-10$	299 ± 7
$0-5$	352 ± 3

Centrality Beam Energy Scan



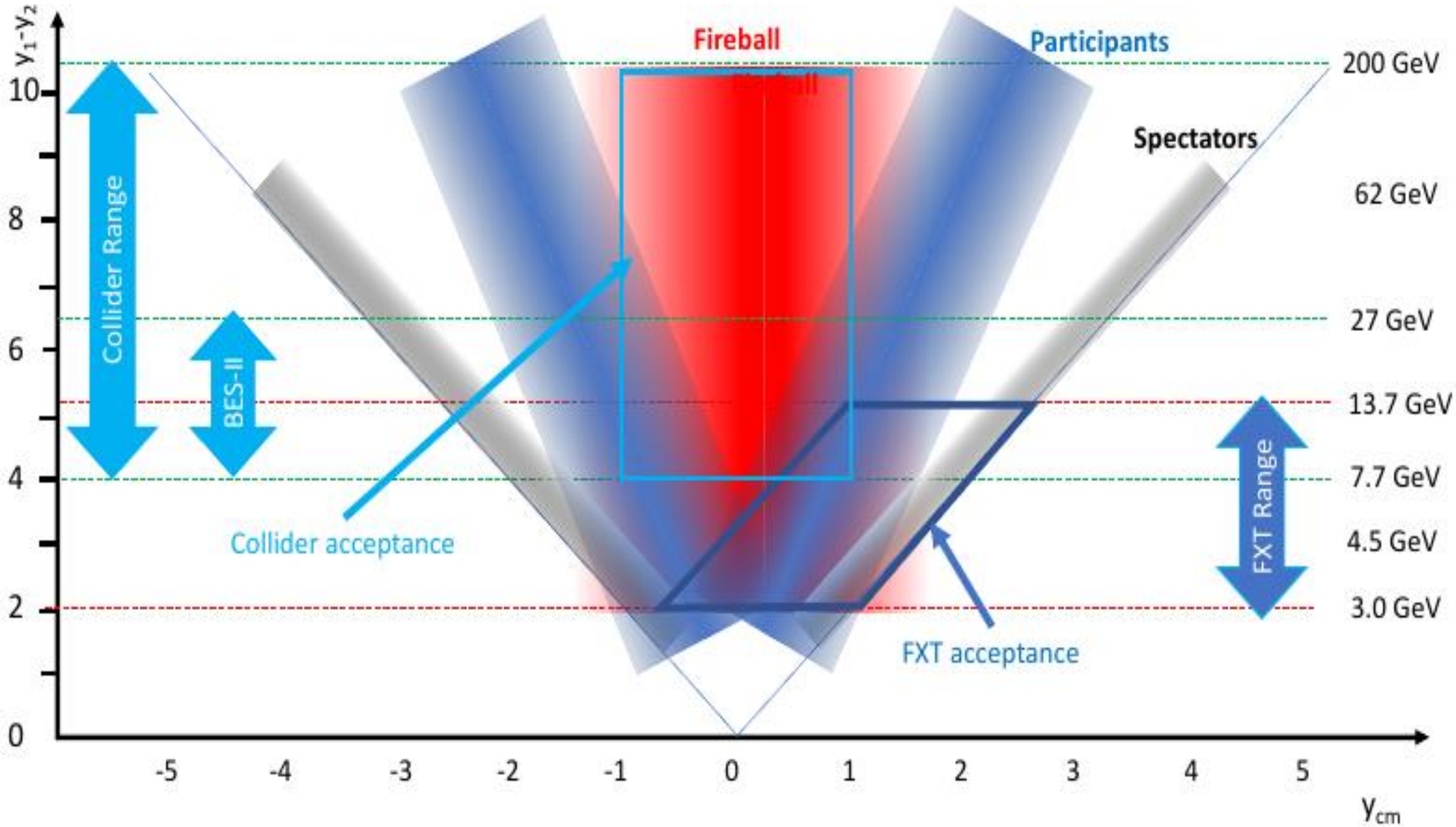
Glauber Model:

- Nucleons distributed with Woods-Saxon
- Nucleons do not scatter during collisions
- Collisions are determined by the inelastic σ_{pp}
- Particle production with negative binomial
- Crude hardness parameter (x)
  - ➔ N = x Ncoll + (1-x) (Npart/2)

Basics:

- The Glauber model has been used to determine centrality by RHIC and LHC experiments since 2001
- The Glauber model considers particle production, not stopping of participant nucleons
- Hadron production in centered at the center-of-mass rapidity
- Closer to target rapidity, most charged hadrons of "stopped protons"
- Center-of-mass rapidity shifts through the FXT energy range ➔ Can not use RefMult

Centrality Beam Energy Scan



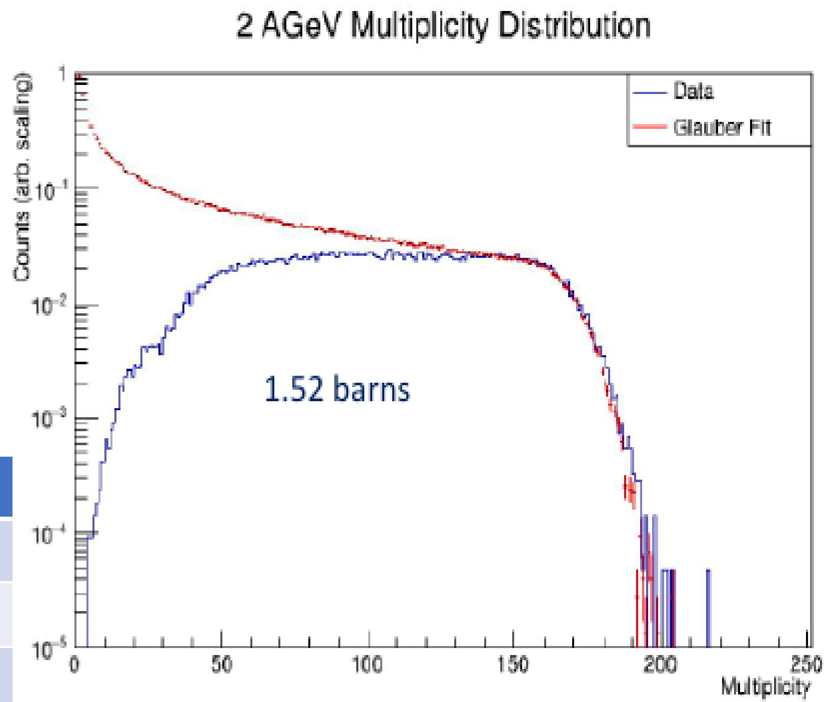
The FXT part of the program is dominated by participant baryons, while the collider part sees mostly the fireball

Centrality Beam Energy Scan

Comparison to E895

E895 2.0 AGeV

<u>Settings</u>
Lower cutoff: 130
Upper cutoff: 192
events data: 7.1E4
events MC: 1E6
μ range:[0.08,0.18]
k range: [2.7, 7.0]
x range: [0%, 10%]



Total Au+Au cross section is 6.78 barns

<u>Parameters</u>
x = 9%
μ = 0.107473
k = 6.22456

χ^2 = 132
Trigger Efficiency: 24%

E895 measured 23%

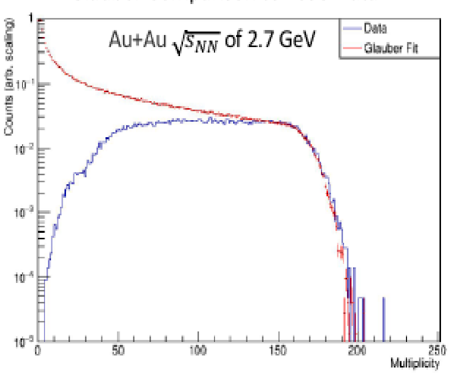
Energy	E895 est.	Glaub. Est.
2 AGeV	23%	24%
4 AGeV	27%	25%
6 AGeV	68%	60%
8 AGeV	42%	40%

Centrality Beam Energy Scan

Application of Glauber to AGS Data

- E895 experiment at the AGS at BNL collided gold nuclei at $\sqrt{s_{NN}}$ values of 2.7, 3.3, 3.8, 4.3 GeV
- Triggering ion chamber allowed for direct measurement of every incident gold ion, making Glauber approach unnecessary
- We tested out Glauber approach on these data

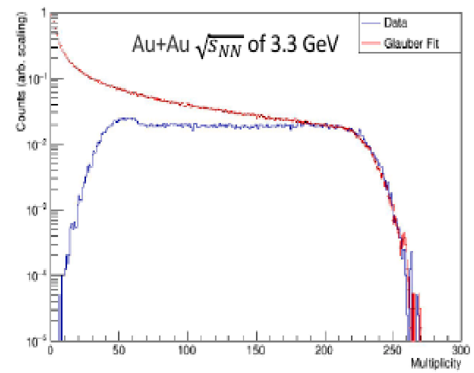
Glauber Comparison to E895 Data



Efficiency predicted by Glauber: 24%

E895 determination of efficiency: 23%

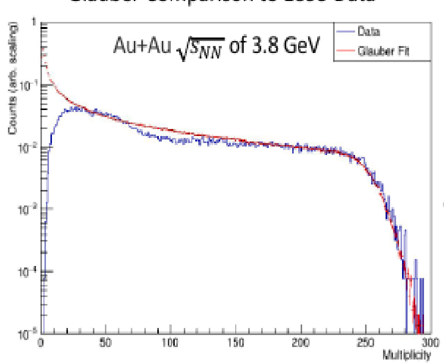
Glauber Comparison to E895 Data



Efficiency predicted by Glauber: 25%

E895 determination of efficiency: 27%

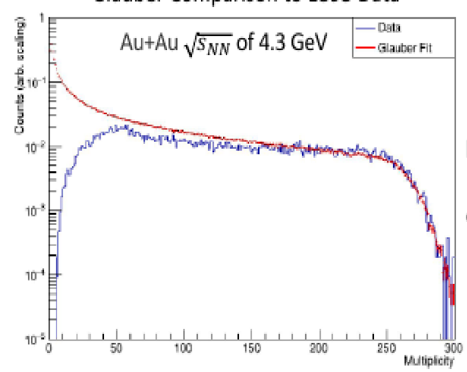
Glauber Comparison to E895 Data



Efficiency predicted by Glauber: 60%

E895 determination of efficiency: 68%

Glauber Comparison to E895 Data



Efficiency predicted by Glauber: 40%

E895 determination of efficiency: 42%

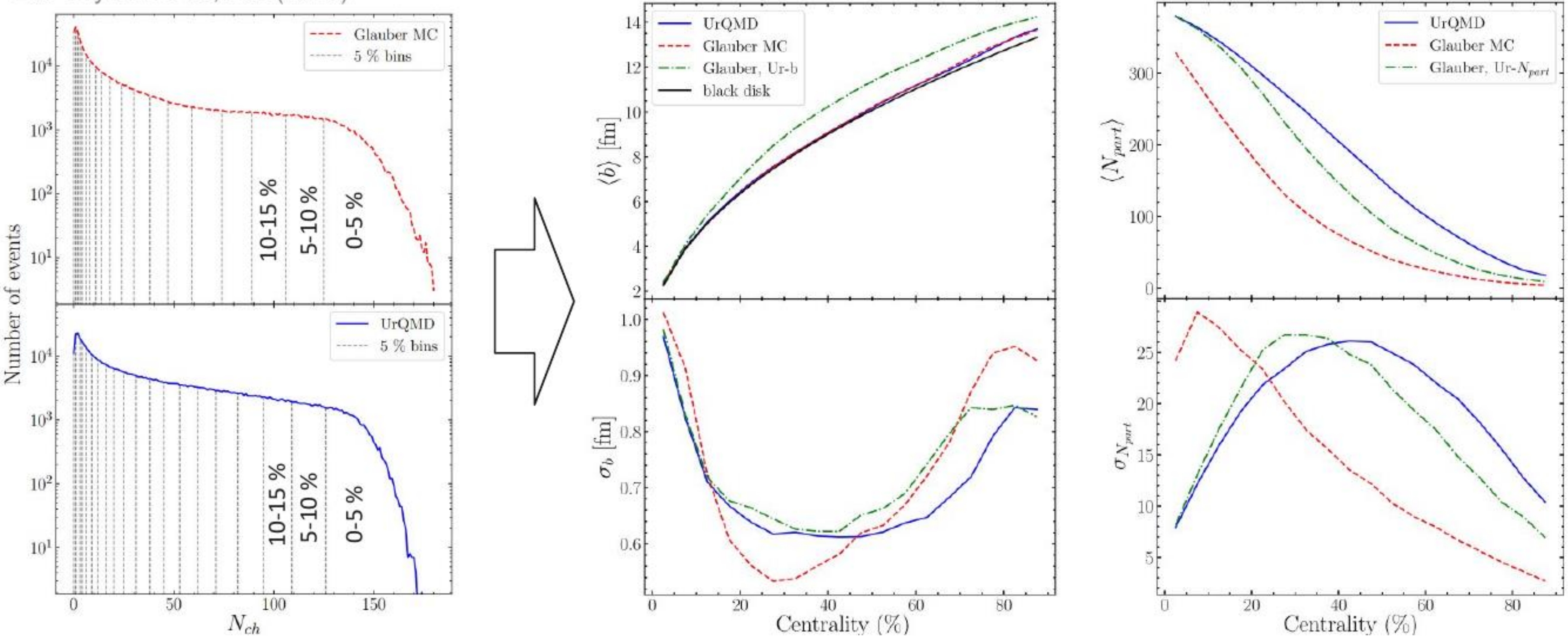
Centrality in STAR BES

$\langle N_{\mathrm{part}} \rangle$

Cent.	3 (FXT)	3.2 (FXT)	3.5 (FXT)	3.9 (FXT 2020)	3.9 (FXT 2019)	4.5 (FXT)	5.2 (FXT 2020)	7.7 (FXT 2020)	7.7 (BES-I)	7.7 (BES-II)	11.5 (BES-I)	14.6 (BES-II)	19.6 (BES-II)	27 (BES-I)	27 (BES-II)	39 (BES-I)
0–5	333	332	333	333	332	334	336	336	337	336	338	339	340	343	340	342
5–10	286	285	285	284	282	286	286	287	290	288	291	289	289	299	291	294
10–15	241	240	240	240	238	241	241	242	246	243	245	245	245	252	246	249

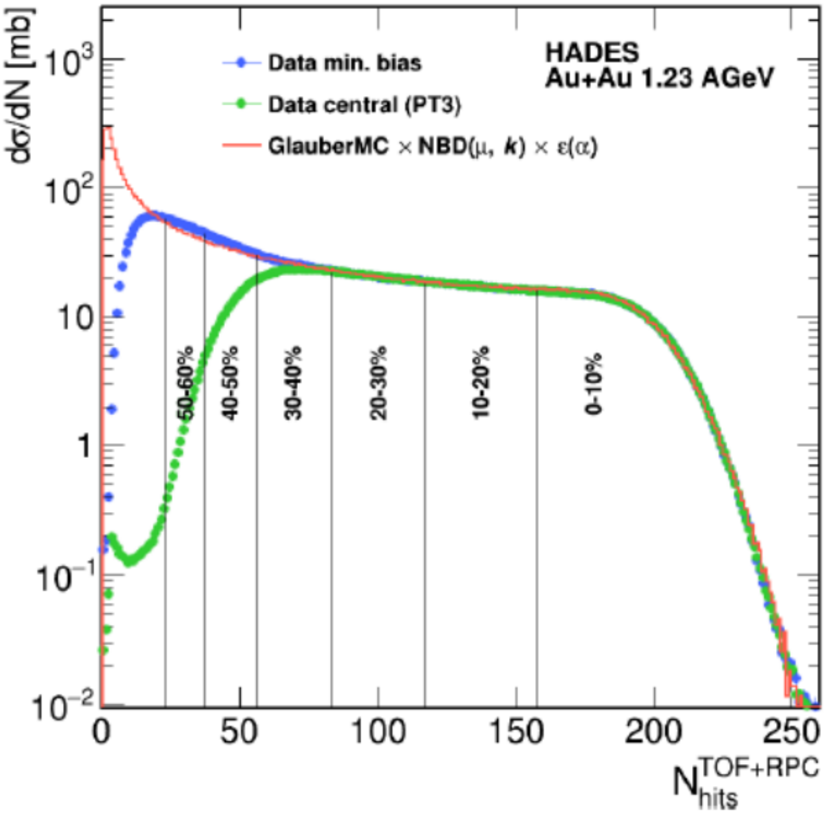
Model dependence of b, N_{part}

Eur. Phys. J. C 83, 792 (2023)



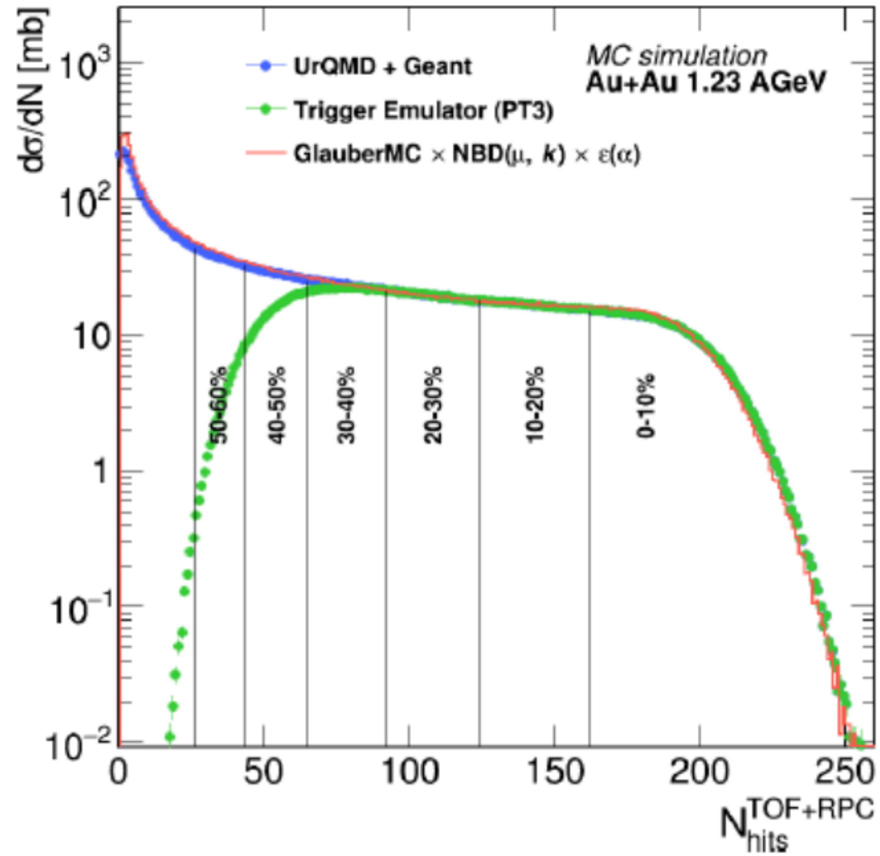
Centrality in HADES

HADES uses 0% hardness

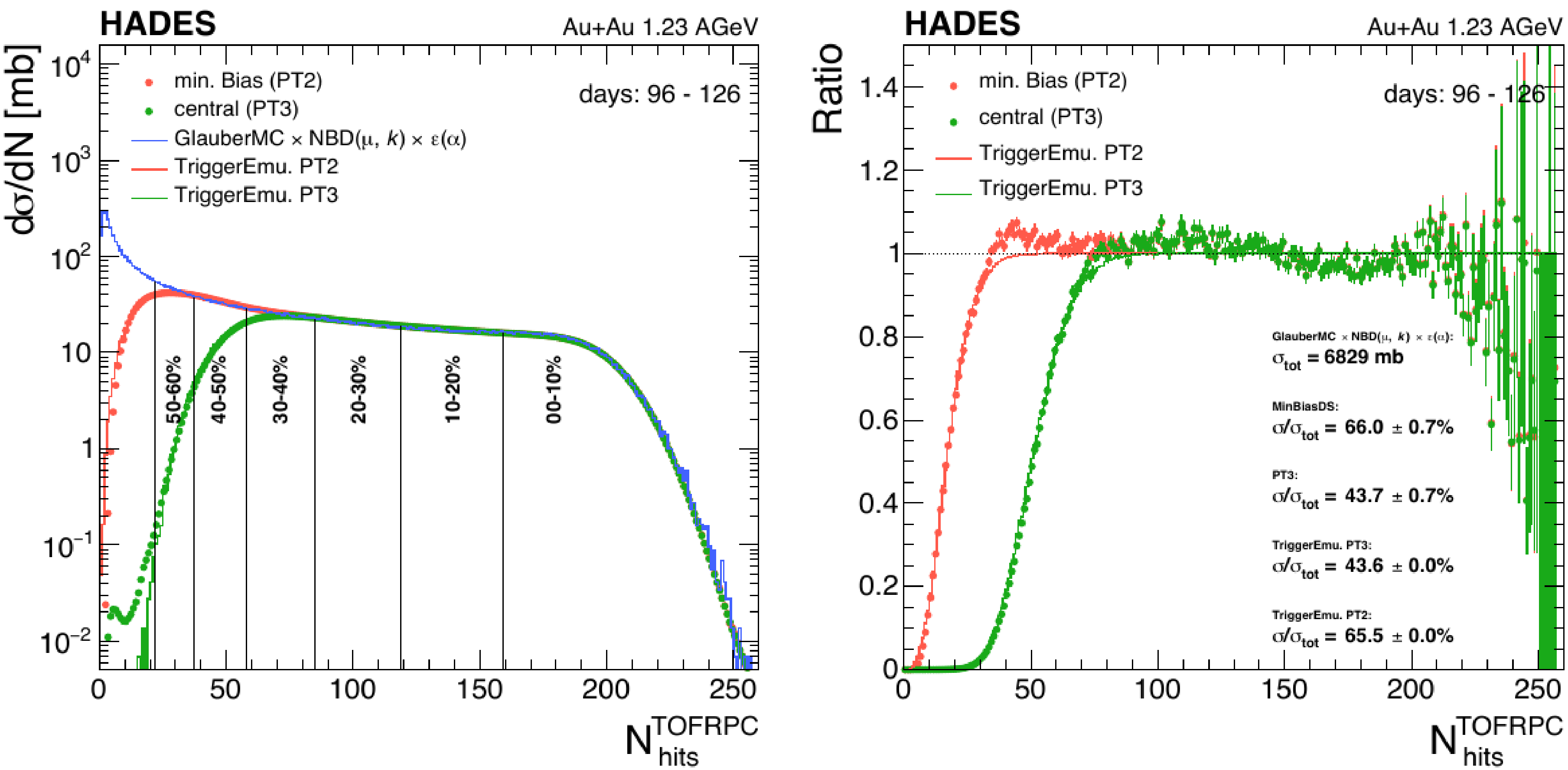


arXiv:1712.07993v2

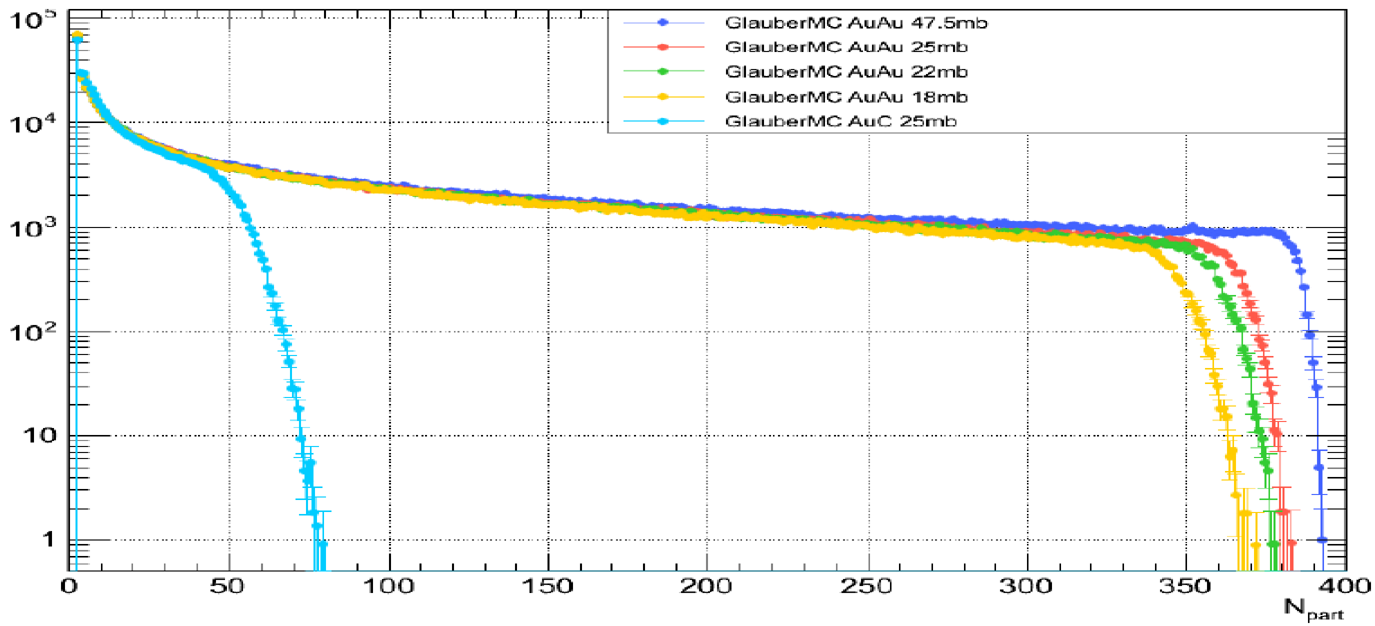
UrQMD matches, except at lowest Multiplicity

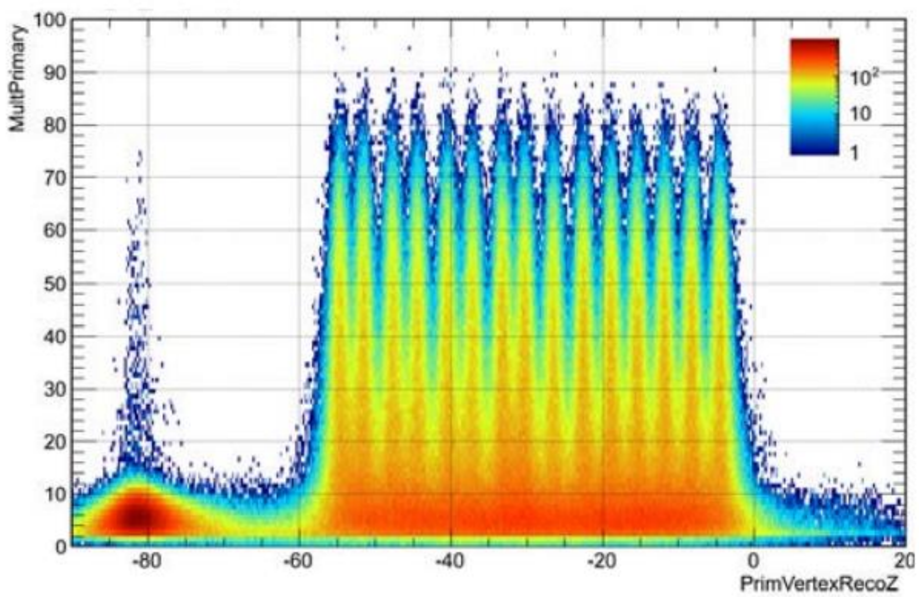


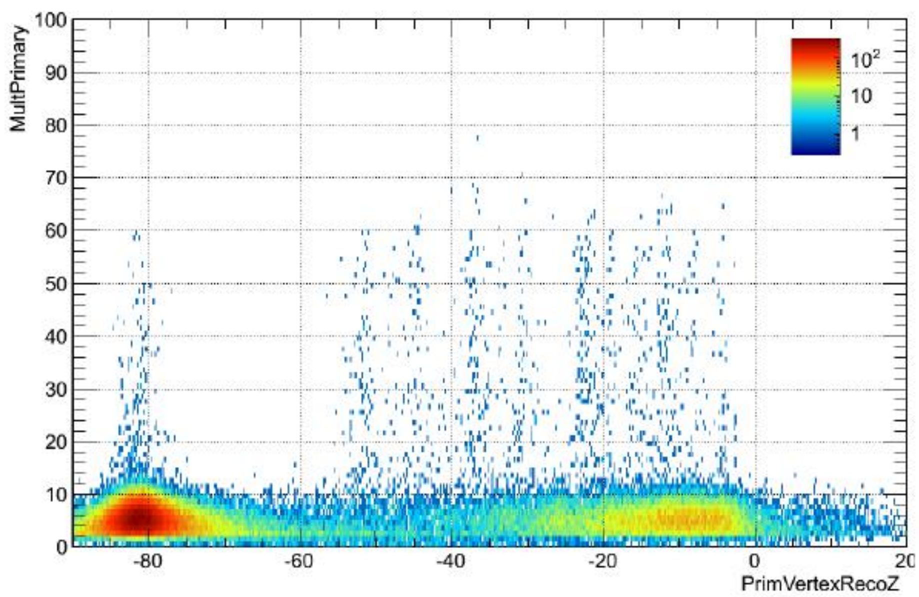
Centrality in HADES



Centrality in HADES







Centrality at NICA

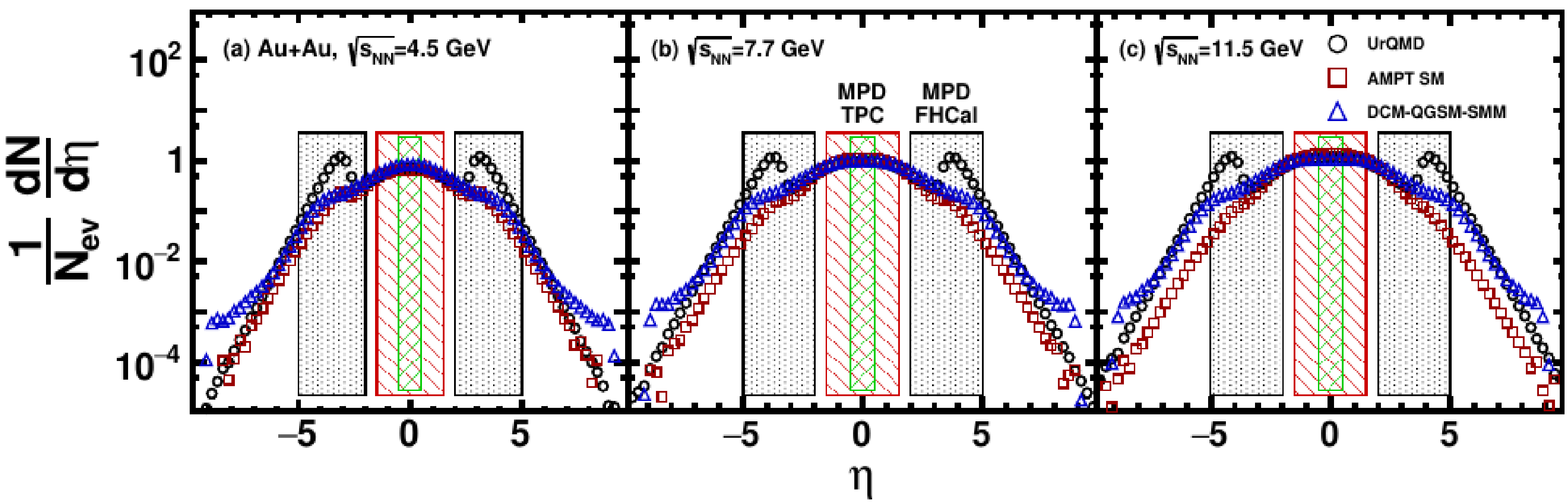
particles

MDPI

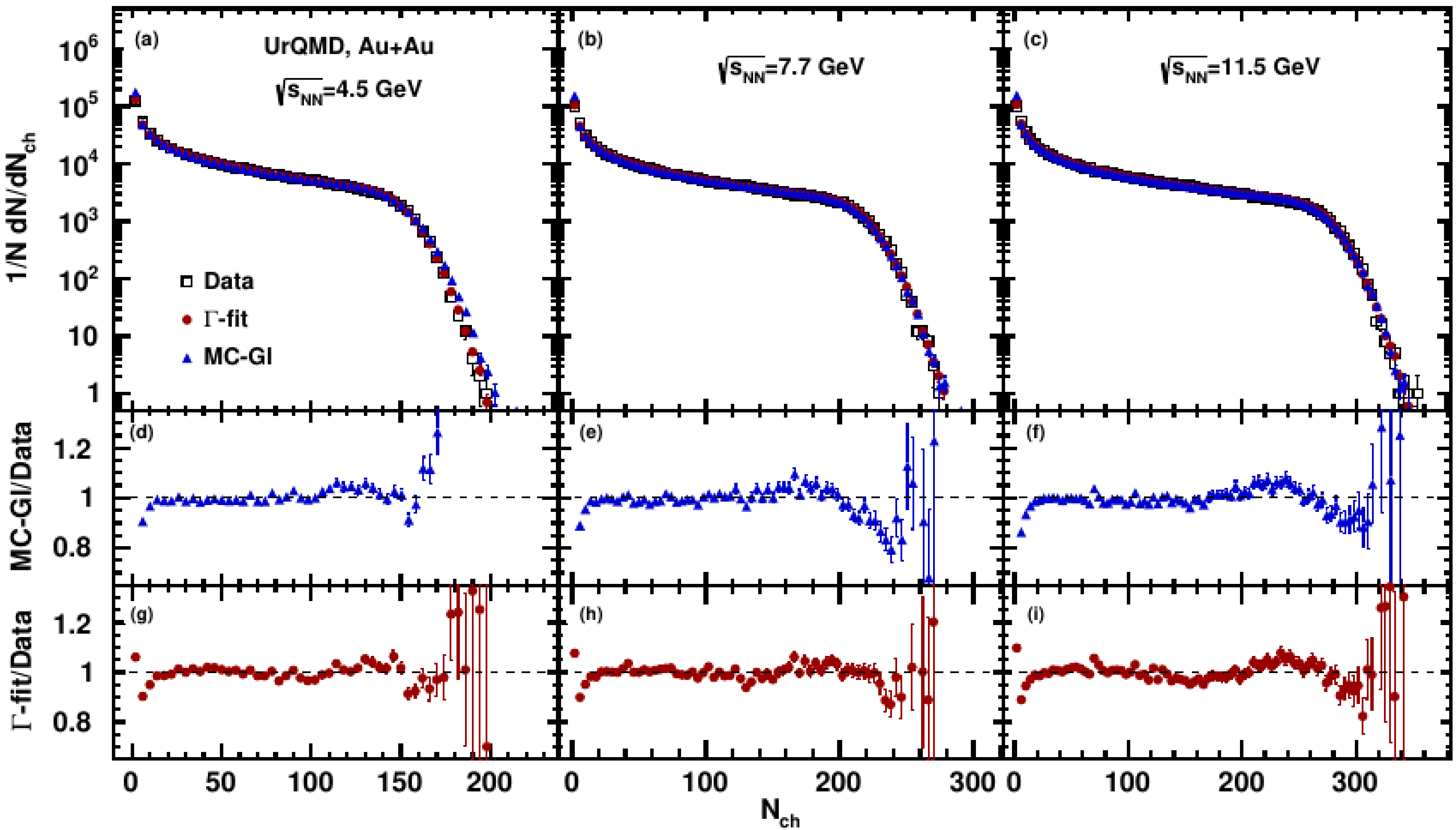
Article

Relating Charged Particle Multiplicity to Impact Parameter in Heavy-Ion Collisions at NICA Energies

Petr Parfenov *, Dim Idrisov, Vinh Ba Luong and Arkadiy Taranenko



Centrality at NICA



Centrality at NICA

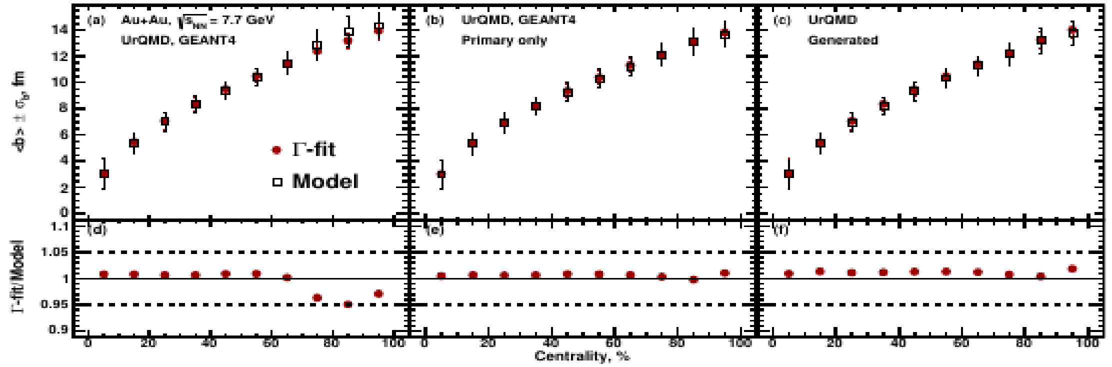


Figure 16. Centrality dependence of the average impact parameter $\langle b \rangle$ for Au + Au collisions at $\sqrt{s_{NN}} = 7.7$ GeV for Γ-fit approach. Multiplicity of charged particles were gathered for (**a**) all charged tracks and (**b**) only primary tracks from the model itself. Additional track quality cut $N_{hits} > 16$ was applied. The resulting values were compared with generated UrQMD data without any reconstruction (**c**). Lower plots shows fit-to-model ratio.

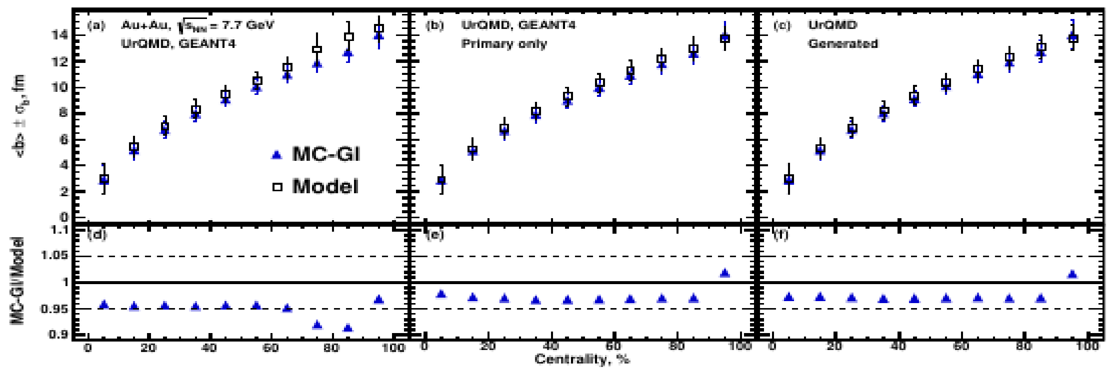
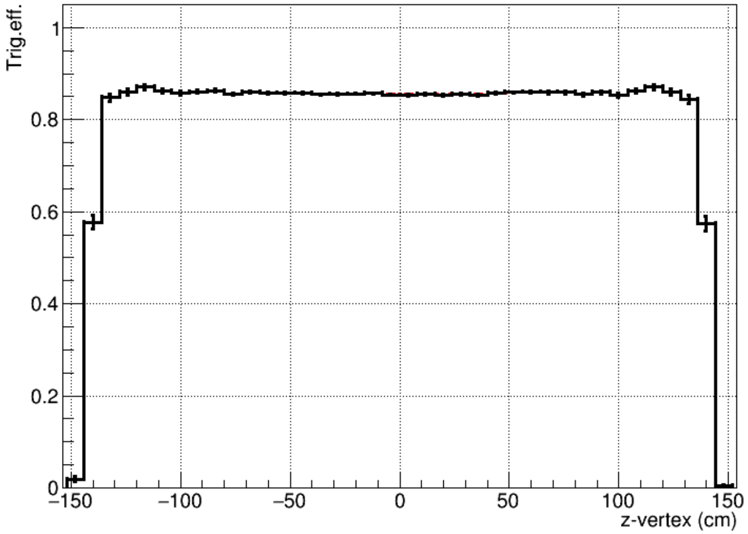


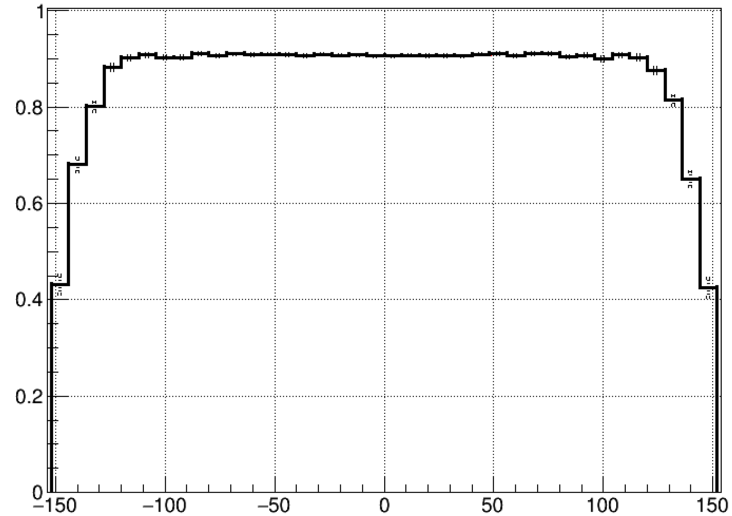
Figure 17. Centrality dependence of the average impact parameter $\langle b \rangle$ for Au + Au collisions at $\sqrt{s_{NN}} = 7.7$ GeV for MC-Glauber approach. Multiplicity of charged particles were gathered for (**a**) all charged tracks and (**b**) only primary tracks from the model itself. Additional track quality cut $N_{hits} > 16$ was applied. The resulting values were compared with generated UrQMD data without any reconstruction (**c**). Lower plots shows fit-to-model ratio.

Trigger efficiency: events with z_{vrtx} != 0 and N_{TPC} > 0

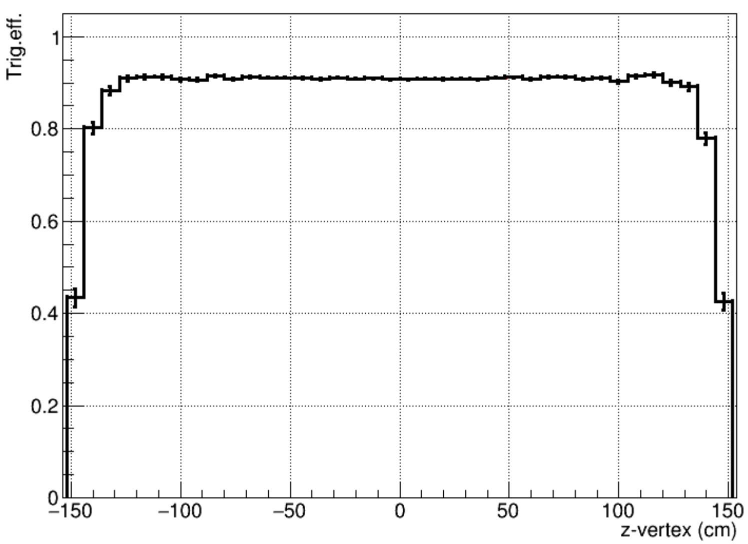
FFD + vertex + Ntr >0



FHCAL+ vertex + Ntr >0



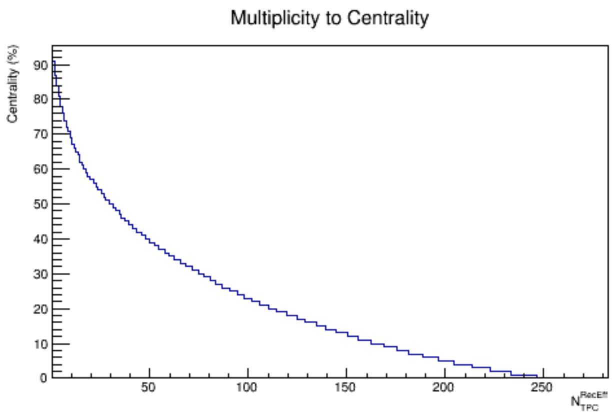
FFD||FHCAL+ vertex + Ntr >0

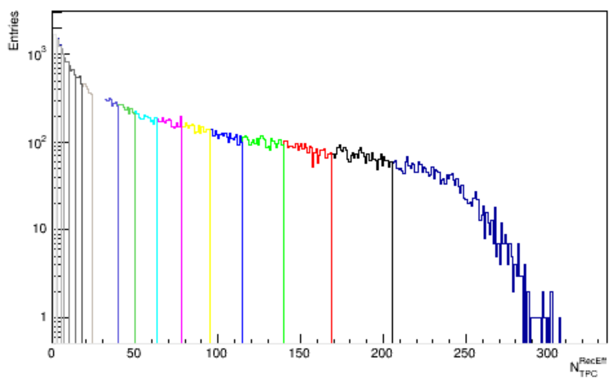


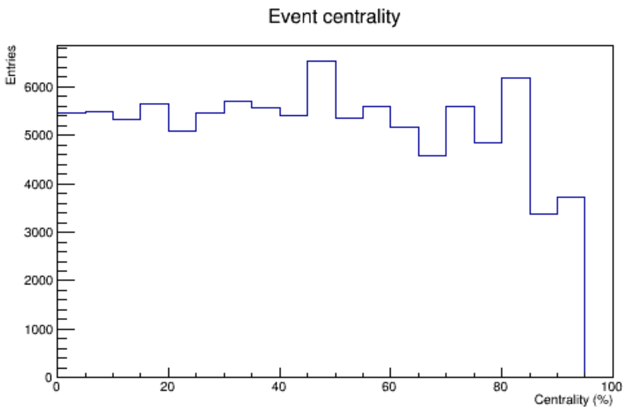
- Request 26 production, 1M DCM-QGSM-SMM
- Trigger efficiency is flat vs. z-vertex
- Trigger efficiency dropped by ~ 5% due extra req-s
- Proposal is to use FFD||FHCAL trigger selection for the large productions and ignore the fact that T_0 measurements are not available for !FFD events
- The resulting trigger efficiency is ~ 91%

Centrality by TPC multiplicity, DCM-QGSM-SMM

- Only for good events:
  - ✓ reconstructed vertex: z-vertex !=0
  - ✓ reconstructed vertex is outside of the FFD: |z-vertex| < 130 cm
  - ✓ number of tracks: $N_{TPC} > 0$, track selections: nhits > 10; $p_T > 0.1$ GeV/c; DCA < 2.0 cm; $|\eta| < 0.5$
  - ✓ Rndm() > TrigEff[N_{TPC}]
- Resulting multiplicity distribution samples ~91% of the total cross section
- Event multiplicity is calculated using weight for each track ~ 1/RecEff(z-vertex, η)
- Centrality is defined as percentile of the total multiplicity with maximum of 91%

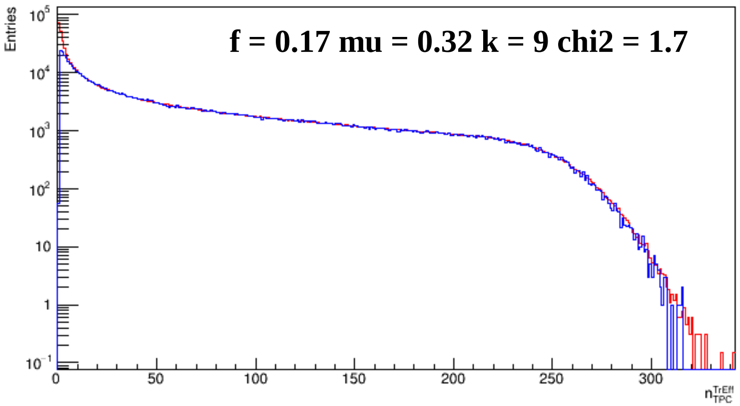


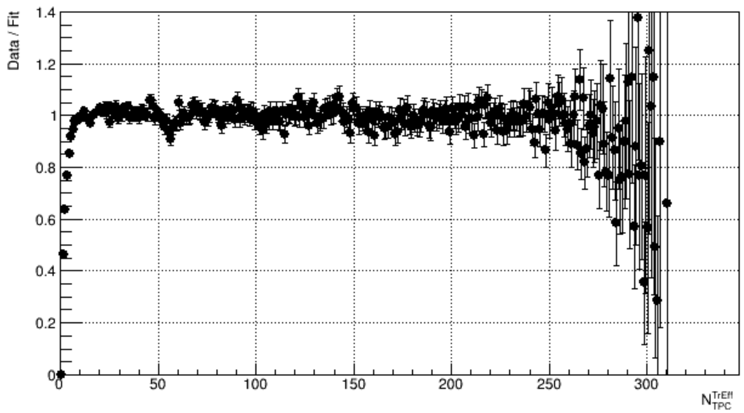




Glauber fit to N_{TPC}^{TrEff} distribution, DCM-QGSM-SMM

- Only for good events, isEventOk:
  - ✓ reconstructed vertex: z-vertex !=0
  - ✓ reconstructed vertex is outside of the FFD: |z-vertex| < 130 cm
  - ✓ number of tracks: $N_{TPC} > 0$, track selections: nhits > 10; $p_T > 0.1$ GeV/c; DCA < 2.0 cm; $|\eta| < 0.5$
  - ✓ Rndm() > TrigEff[N_{TPC}]
- Event multiplicity is calculated using weight for each track ~ 1/RecEff(z-vertex, η)
- Fit range: 9-308

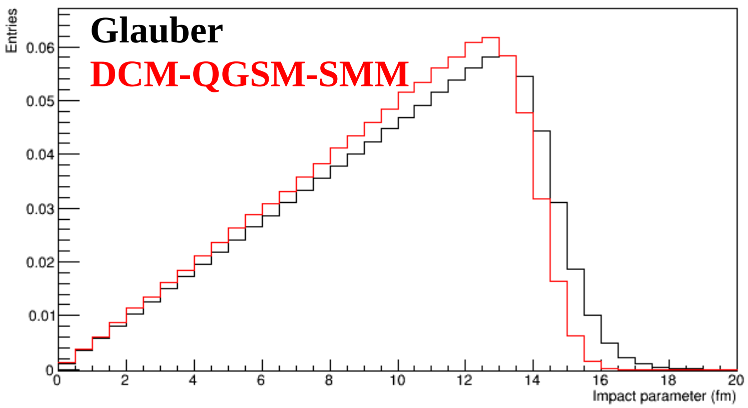


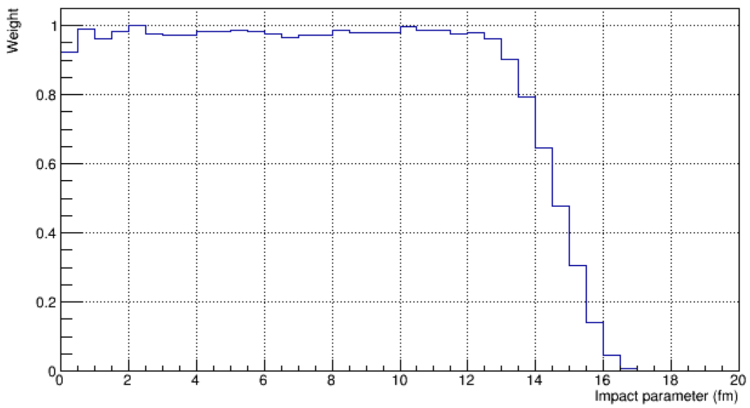


- Predicted trigger efficiency: Integral(data) / Integral (fit) = 83%
- Close but not quite the simulated 91% → why?

Impact parameter distributions, DCM-QGSM-SMM

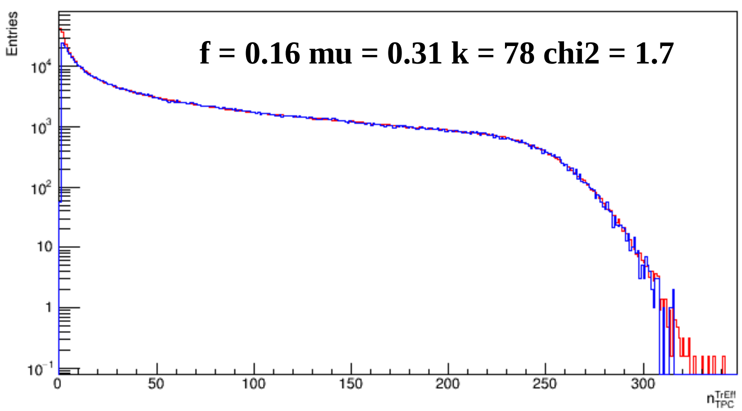
- Lets compare impact parameter distributions in Glauber and DCM-QGSM-SMM
- Distributions are different at b > 12 fm → different radii, definition of inelastic collisions ???
- Glauber can be reweighted to have the same b-distribution as in DCM-QGSM-SMM

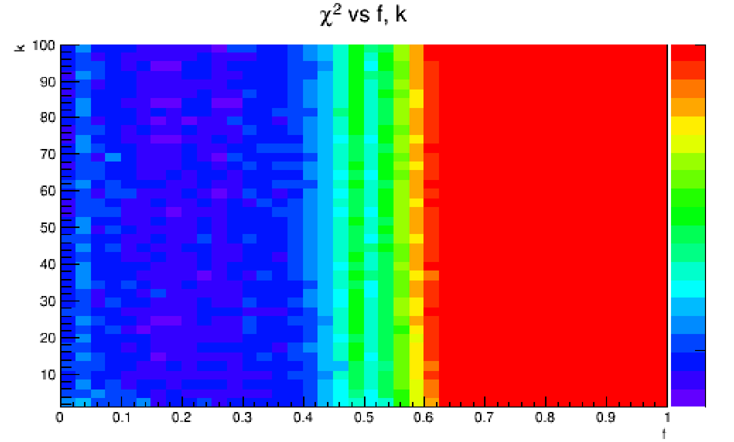


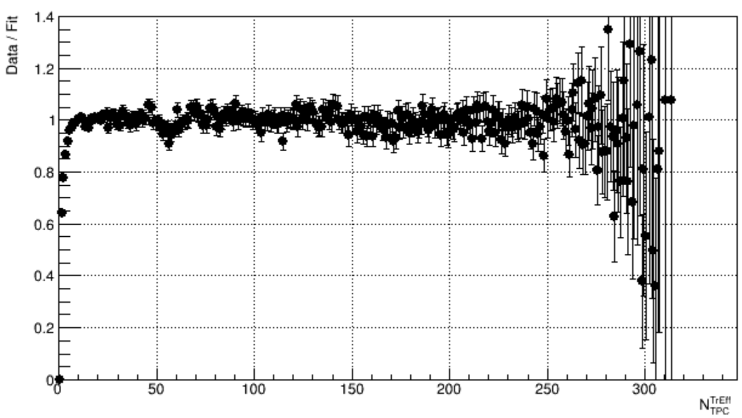


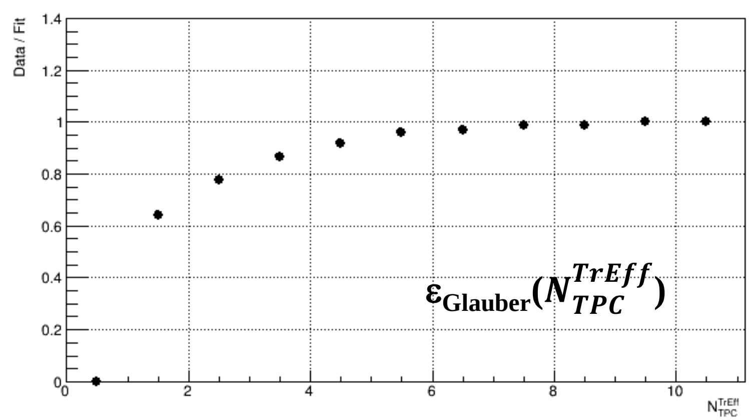
Weighted Glauber fit to N_{TPC}^{TrEff} distribution, DCM-QGSM-SMM

- Same conditions as in slide 7, but with weights for Glauber events by b-value









- Predicted trigger efficiency: Integral(data) / Integral (fit) = 90% ≅ simulated 91%
- Turn on curve is very similar to the simulated one (it should not be identical)