Centrality determination in MPD using MC Glauber model

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NICA days 2019 and 4th MPD Collaboration Meeting

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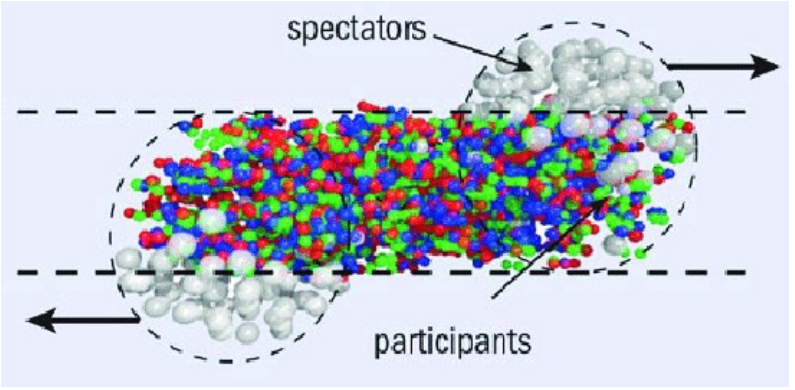
Motivation

Evolution of matter produced in heavy-ion collisions depend on its initial geometry

Goal: map collision geometry to the measurable quantities
Comparison with existing data (RHIC BES, NA49/NA61 scans)

- **Collision geometry:**
  impact parameter, number of participating nucleons, number of binary NN collisions, etc.
- **Measurable quantities:**
  multiplicity of the produced charged particles, energy of the spectators



STAR BES-II program

Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	Run Time	Species	Number Events
9.8	19.6	4.5 weeks	Au+Au	400M MB
7.3	14.5	5.5 weeks	Au+Au	300M MB
5.75	11.5	5 weeks	Au+Au	230M MB
4.6	9.1 [1]	4 weeks	Au+Au	160M MB
9.8	4.5 (FXT)	2 days	Au+Au	100M MB
7.3	3.9 (FXT)	2 days	Au+Au	100M MB
5.75	3.5 (FXT)	2 days	Au+Au	100M MB
31.2	7.7 (FXT)	2 days	Au+Au	100M MB
19.5	6.2 (FXT)	2 days	Au+Au	100M MB
13.5	5.2 (FXT)	2 days	Au+Au	100M MB

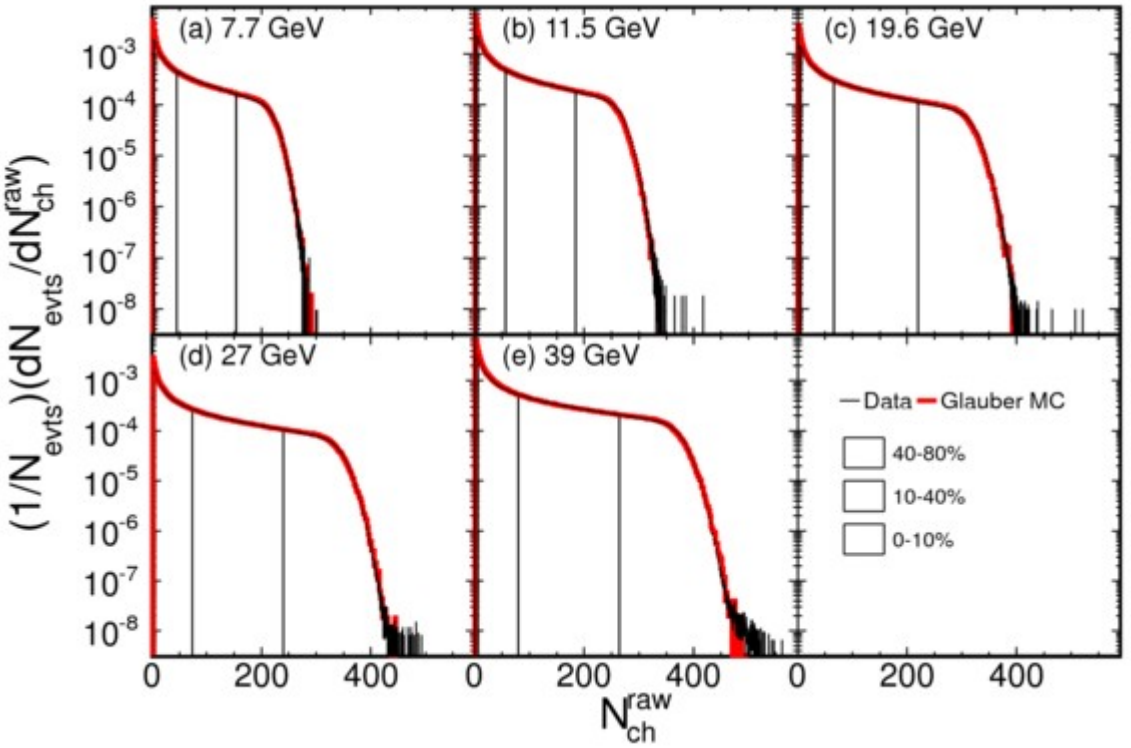
Many measurements at NICA energy range will be done during STAR BES-II

Will require comparison of the future MPD measurements with the RHIC/SPS

Centrality in STAR

- Uncorrected charged particle multiplicity distribution in TPC (|η|<0.5)
- Comparison with MC Glauber simulations
- Fitted using two-component model:

$$\left.\frac{dN_{ch}}{d\eta}\right|_{\eta=0} = n_{pp}\left[(1-x)N_{part}/2 + xN_{coll}\right]$$



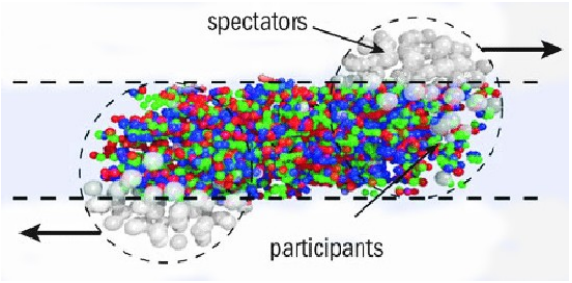
Similar centrality estimator is needed for comparisons with STAR

Phys. Rev. C 86 (2012) 54908

Centrality determination in MPD (NICA)

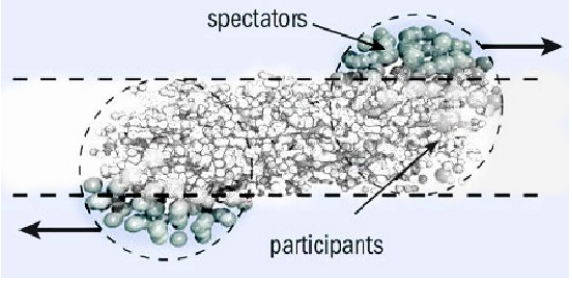
- Time Projection Chamber (TPC)

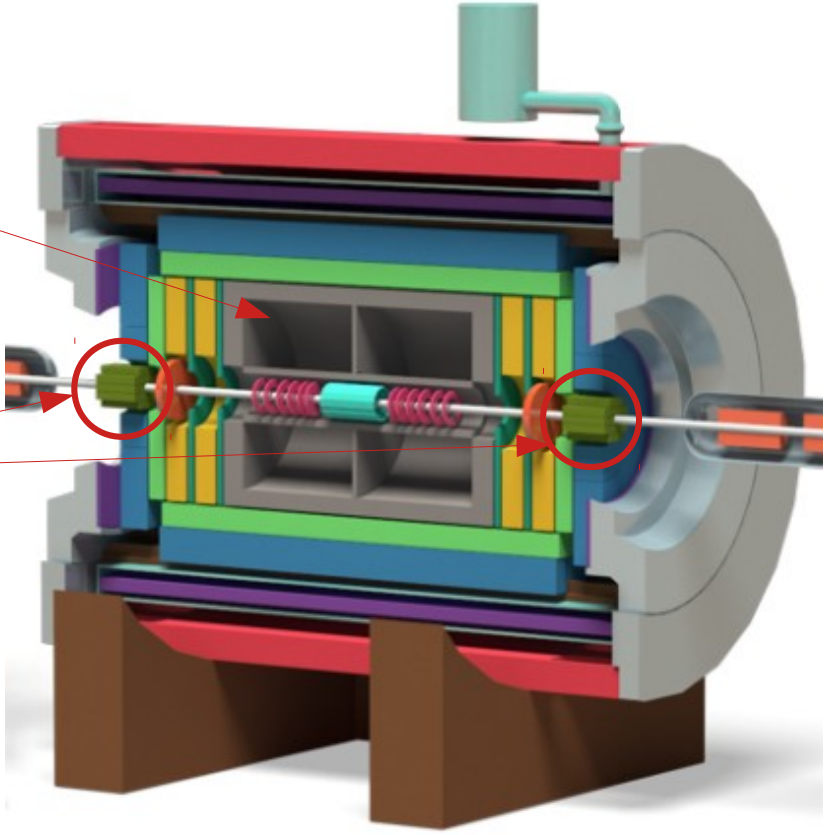
  |η|<1.5



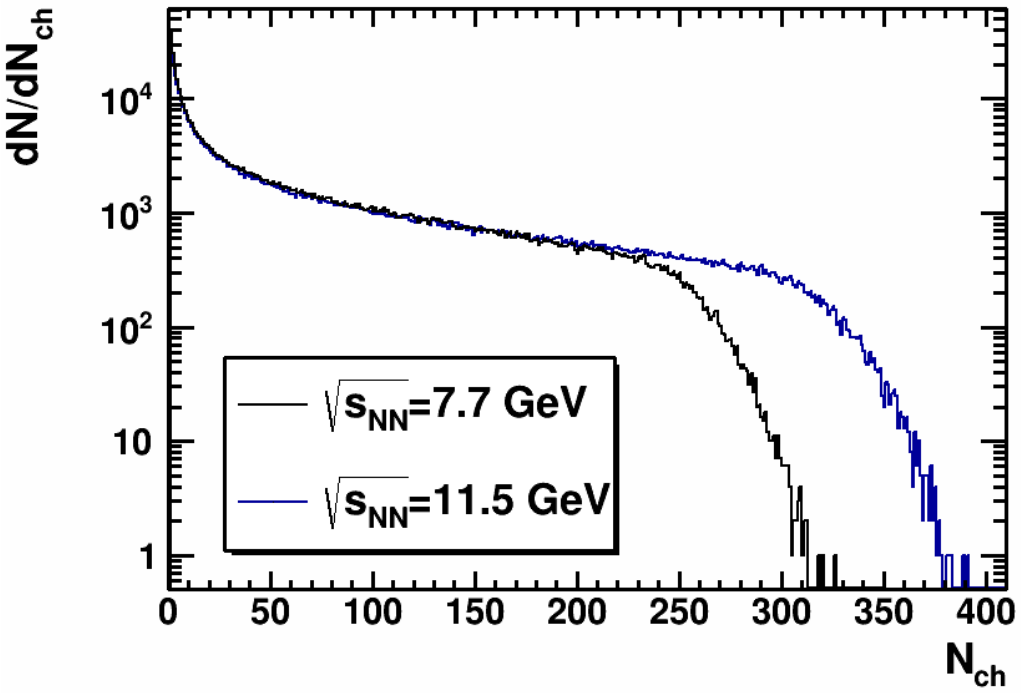
- Forward Hadron Calorimeter (FHCal)

  2<|η|<5





Charged particle multiplicity in MPD



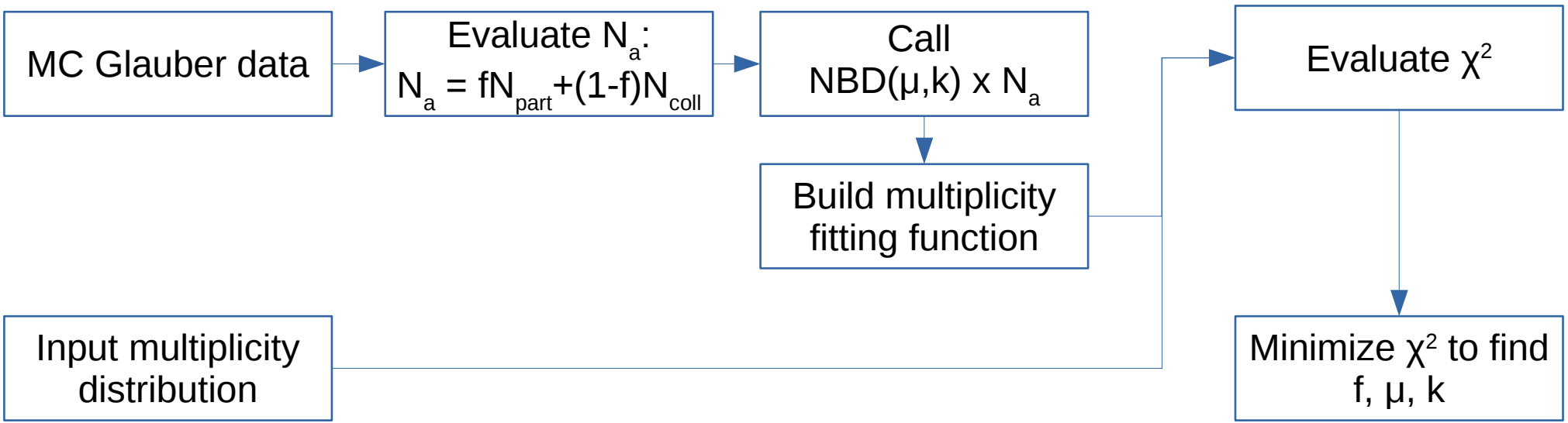
Reconstructed data:

- UrQMD 3.4 simulation
  - Au+Au, N_{ev}=500k, $\sqrt{s_{NN}}$=7.7, 11.5 GeV
- GEANT4 MPD detector simulation
- Reconstruction procedure:
  - Realistic tracking in TPC (Cluster Finder)

Used particle selection:

- $|\eta|<0.5$
- $p_T>0.15$ GeV/c

Integrating the CBM Centrality framework



This centrality procedure was used in CBM, NA49, and NA61/SHINE:
Acta Phys.Polon.Supp. 10 (2017) 919
EPJ Web Conf. 182 (2018) 02132
Implemantation in MPD: https://github.com/IlyaSegal/NICA

Lubynets O., Selyuzhenkov I., Klochkov V. 33-rd CBM CM

Glauber Model configuration

C. Loizides, J. Nagle and P. Steinberg, SoftwareX 1-2 (2015) 13-18
Used TGlauberMC-3.2 version from tglaubermc.hepforge.org

Input to the model

- Inelastic NN cross section
  - σ_{NN}=29.7 mb for $\sqrt{s_{NN}}$=7.7 GeV
  - σ_{NN}=31.2 mb for $\sqrt{s_{NN}}$=11.5 GeV
- Colliding nuclei
  - “Au(197,79)”+”Au(197,79)”

Output from the model

- TNtuple with model parameters:
  - Impact parameter *b*
  - Number of participating in the collision nucleons N_{part}
  - Number of NN collisions N_{coll}
  - Participant eccentricity ε_n
  - etc.

In progress: comparison MC Glauber with GLISSANDO arXiv:1901.04484 [nucl-th]

Centrality framework configuration

NBD Equation:

$$P_{\mu,k}(n)=\frac{\dfrac{\Gamma(n+k)}{\Gamma(n+1)\Gamma(k)}\cdot\left(\mu/k\right)^{n}}{\left(\mu/k+1\right)^{n+k}}$$

Fitting function for charged particle multiplicity:

$$N_{ch}(f,\mu,k)=P_{\mu,k}(n)\cdot\left[f\,N_{part}+(1-f)\,N_{coll}\right]$$

Normalization of the total number of events:

$$\frac{N_{ev}^{reco}}{N_{ev}^{MC\,Glauber}}=\frac{1}{10}$$

Parameter range:

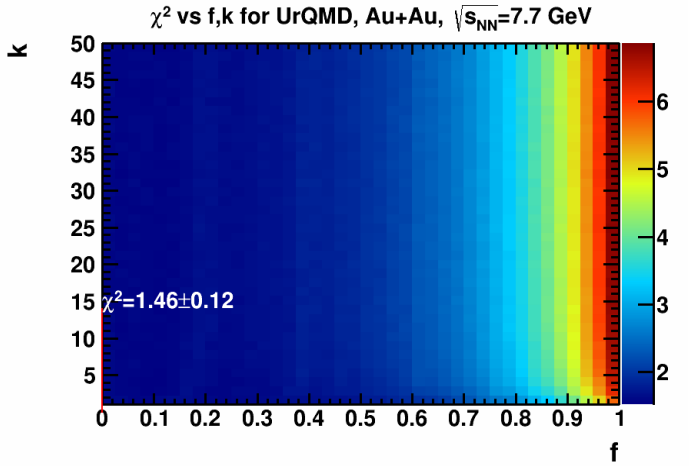
$$f=(0-1),\ f_{step}=0.01$$
$$k=(0-50),\ k_{step}=1$$

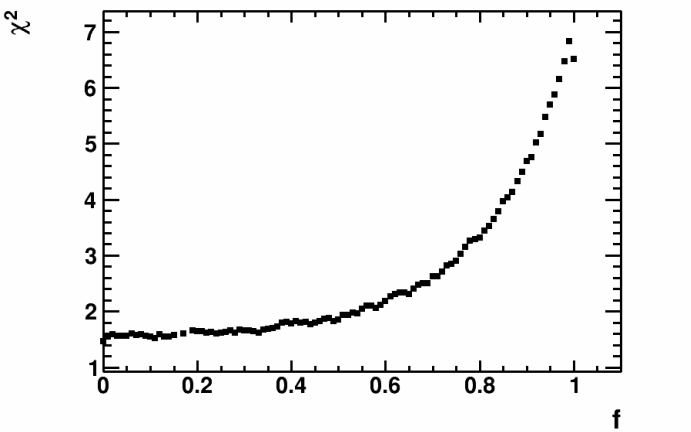
Fitting region:

$$N_{ch}=\begin{cases}(20-310),\ \sqrt{s_{NN}}=7.7\,GeV\\(15-380),\ \sqrt{s_{NN}}=11.5\,GeV\end{cases}$$

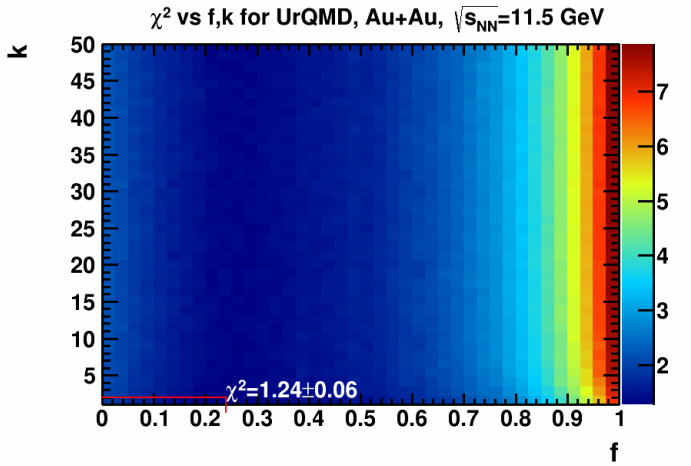
Fit parameters f,k vs χ^2

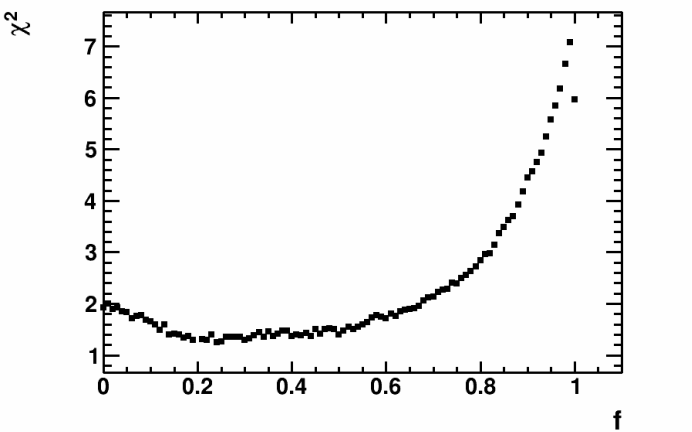
f=0, k=14, μ=0.31, χ^2=1.46±0.12, M=(20,310)





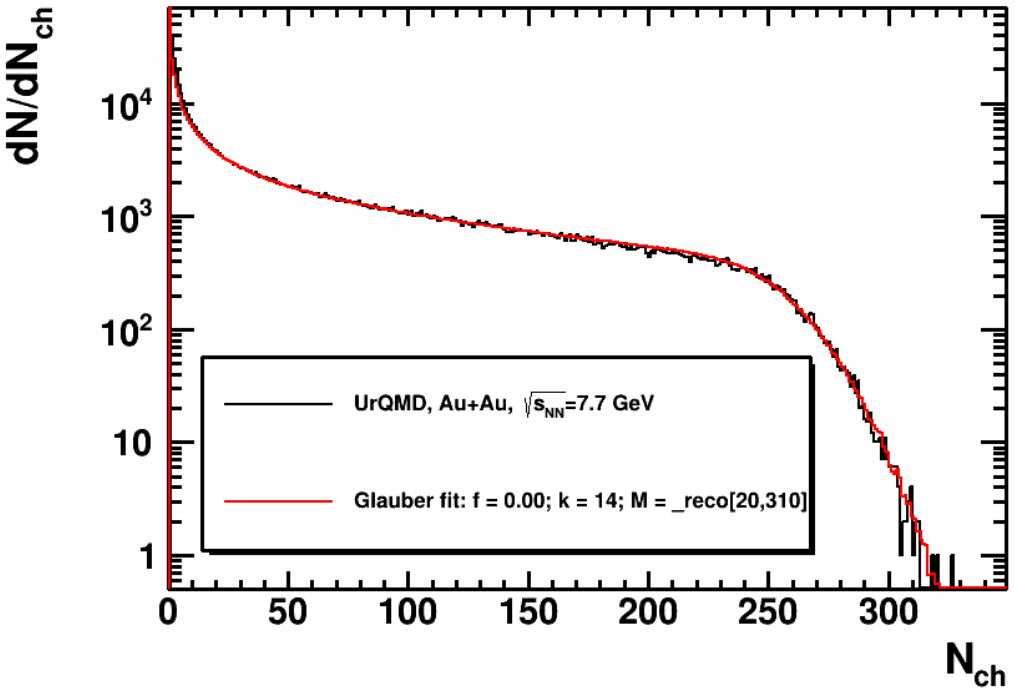
f=0.24, k=2, μ=0.71, χ^2=1.24±0.06, M=(15,380)

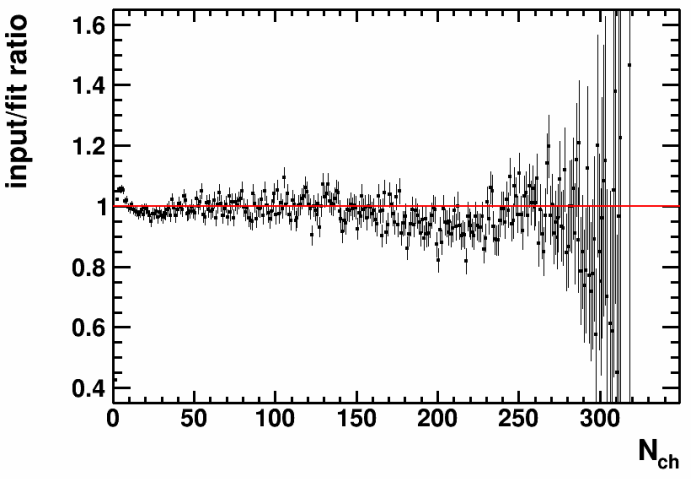




MC Glauber fit: $h^{\pm}$ multiplicity

f=0, k=14, μ=0.31, χ^2=1.46±0.12, M=(20,310)





MC Glauber fit is in the good agreement with simulated input for the large multiplicity region

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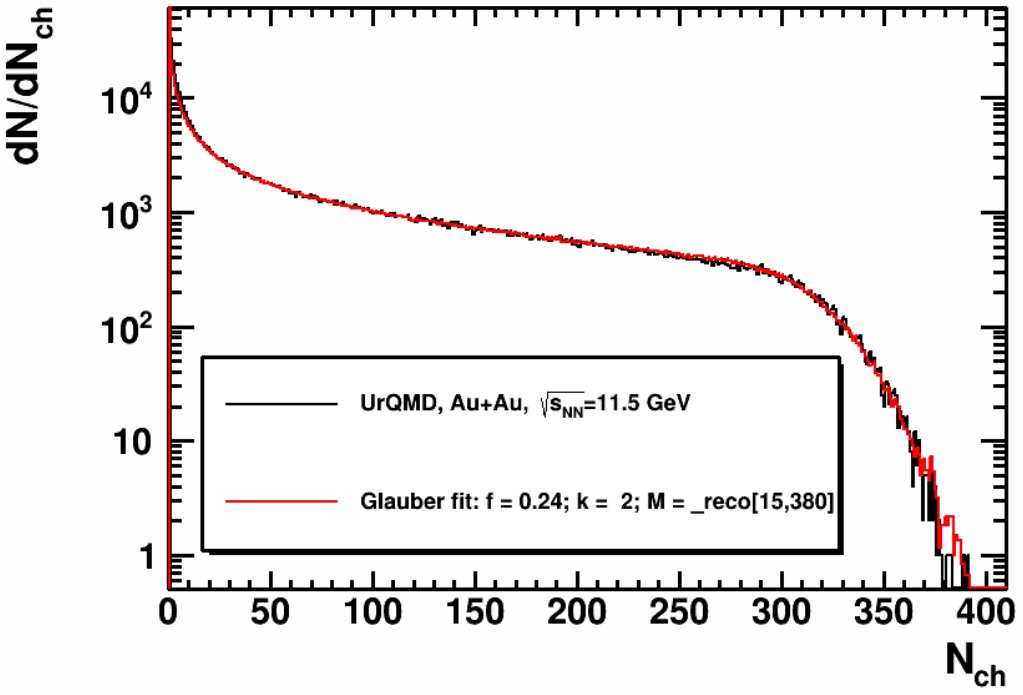
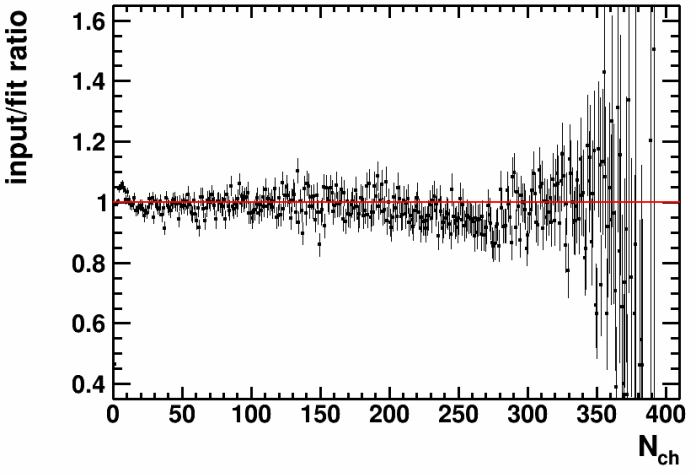
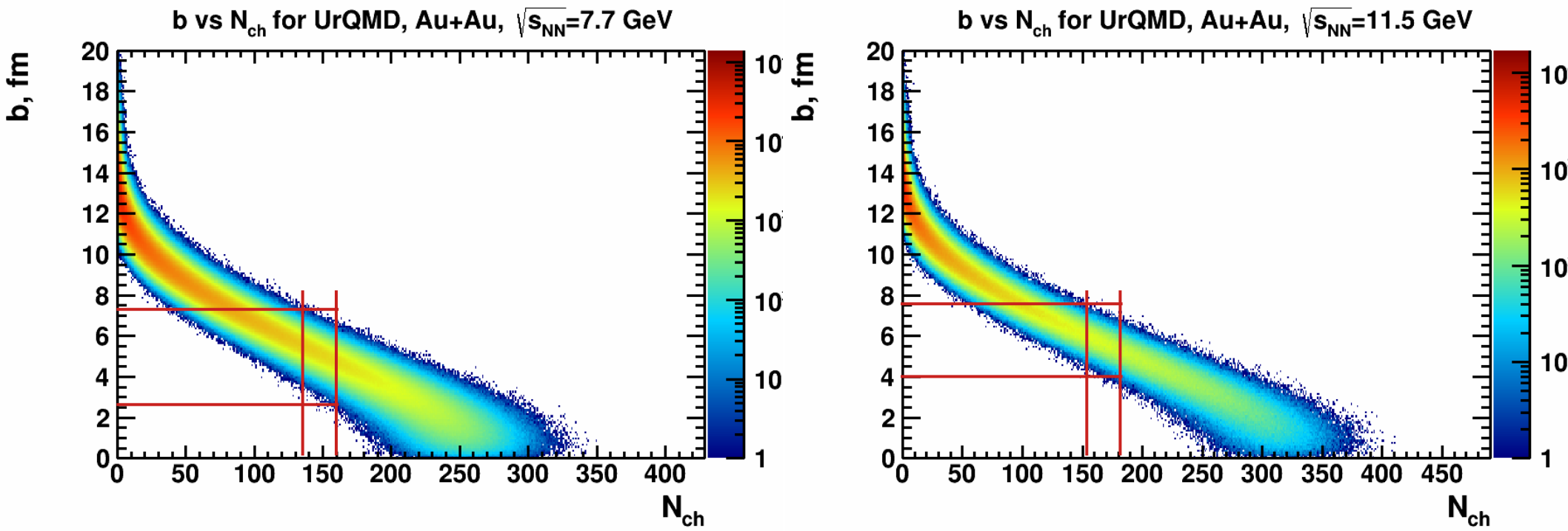




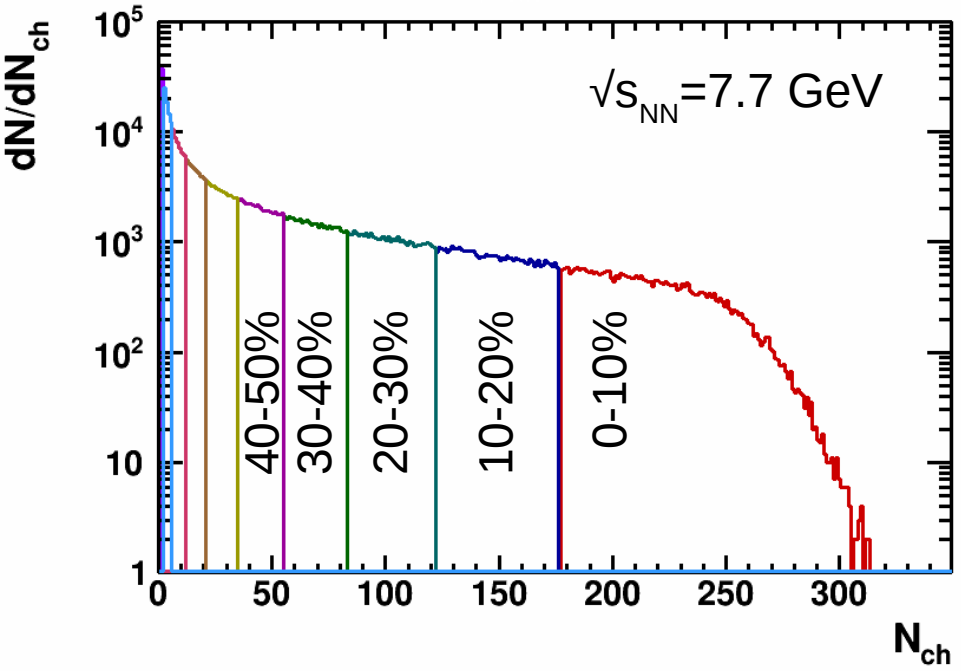
MC Glauber fit is in the good agreement with simulated input for the large multiplicity region

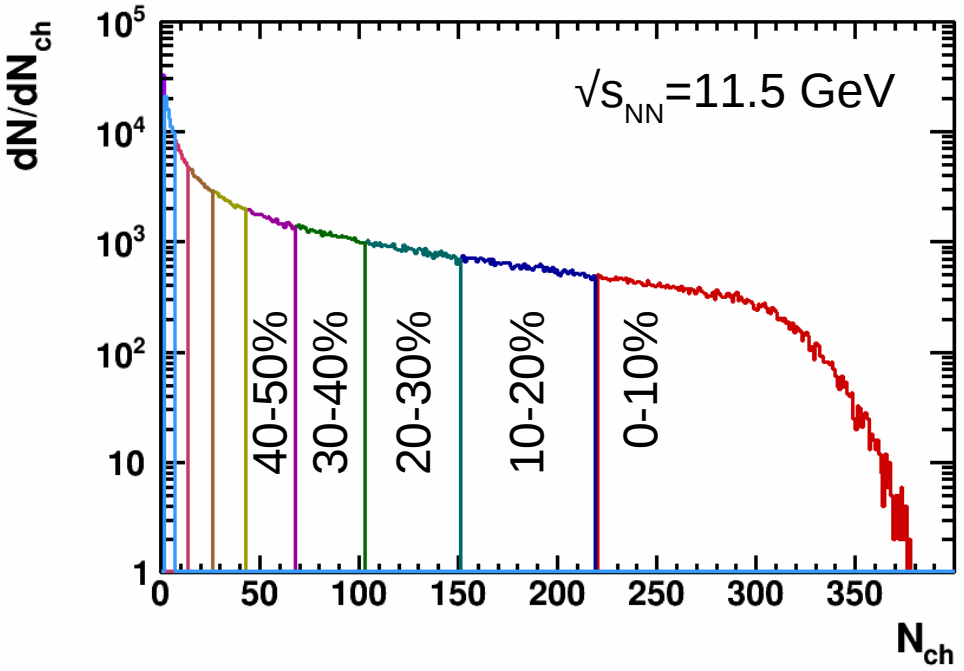
b vs. multiplicity correlation



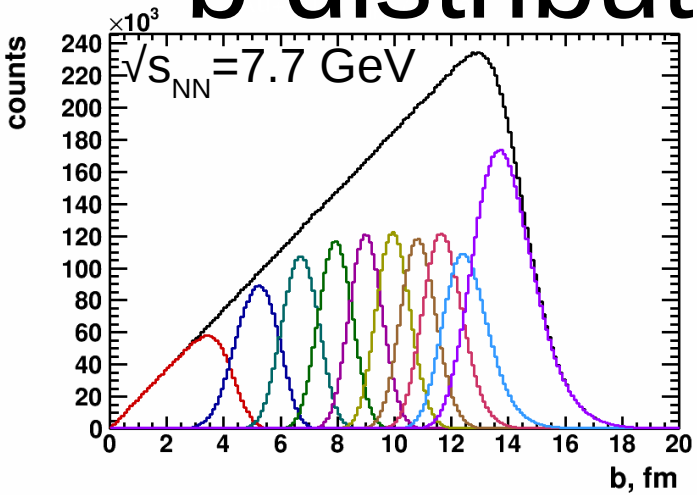
Events in multiplicities M ± ΔM have impact parameter in range b ± σ_b

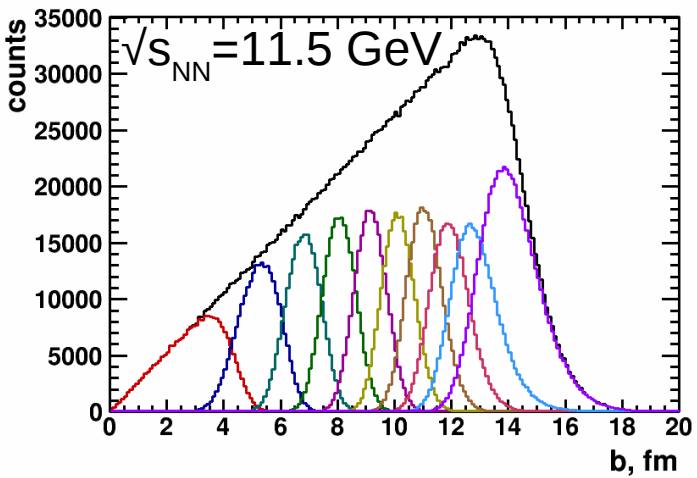
N_{ch} distribution in centrality classes

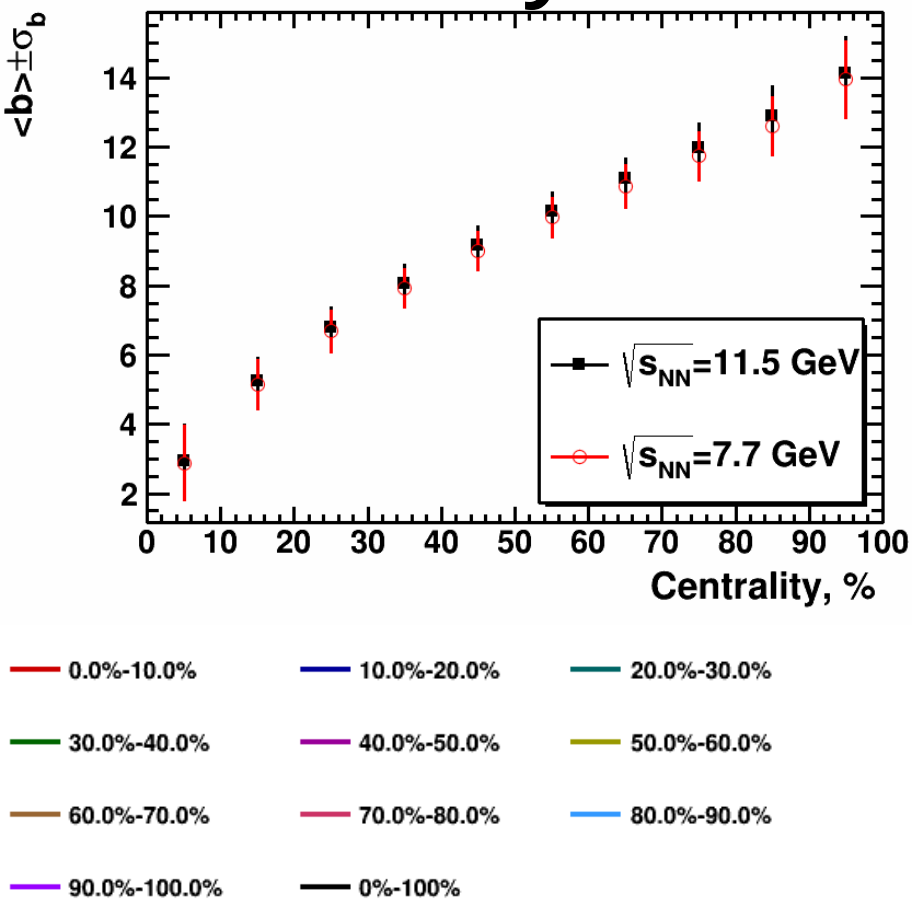




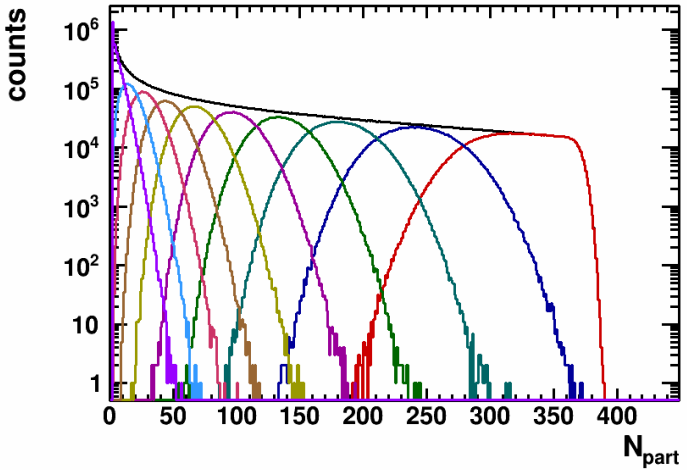
b distribution in centrality classes

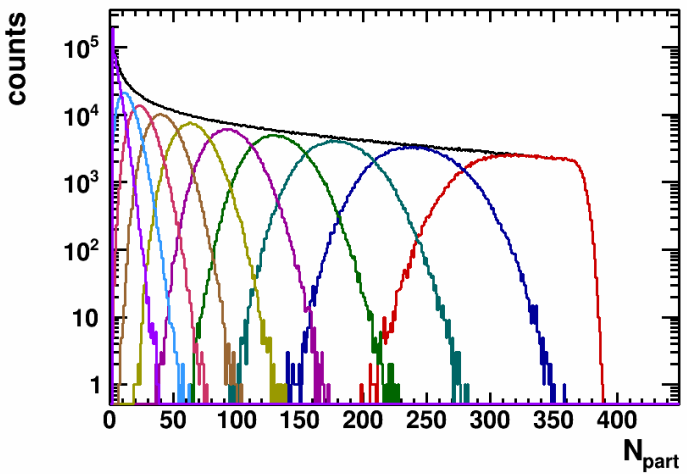


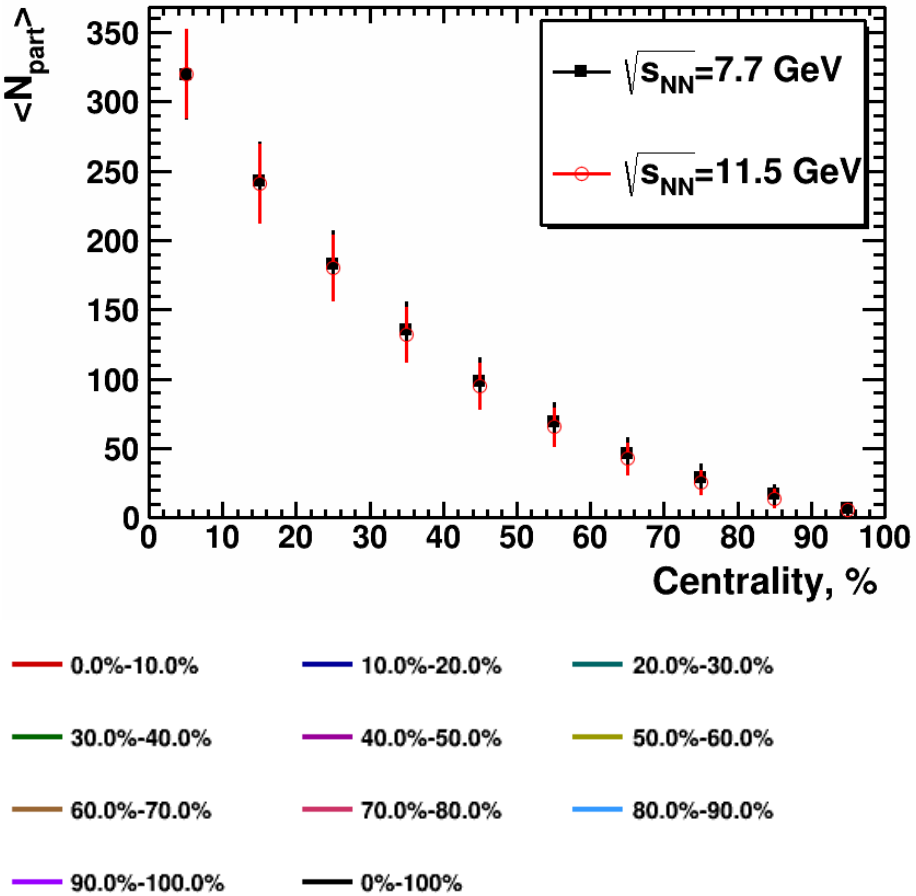




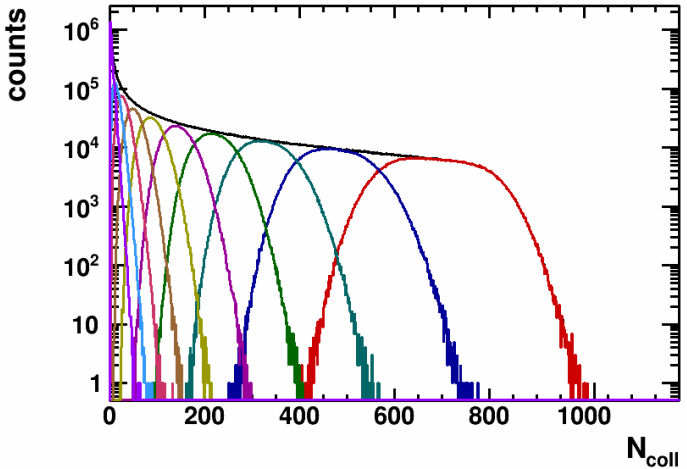
N_{part} distribution in centrality classes

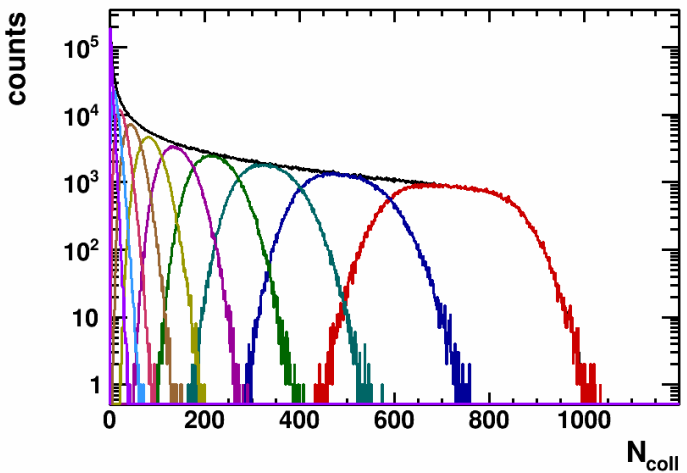


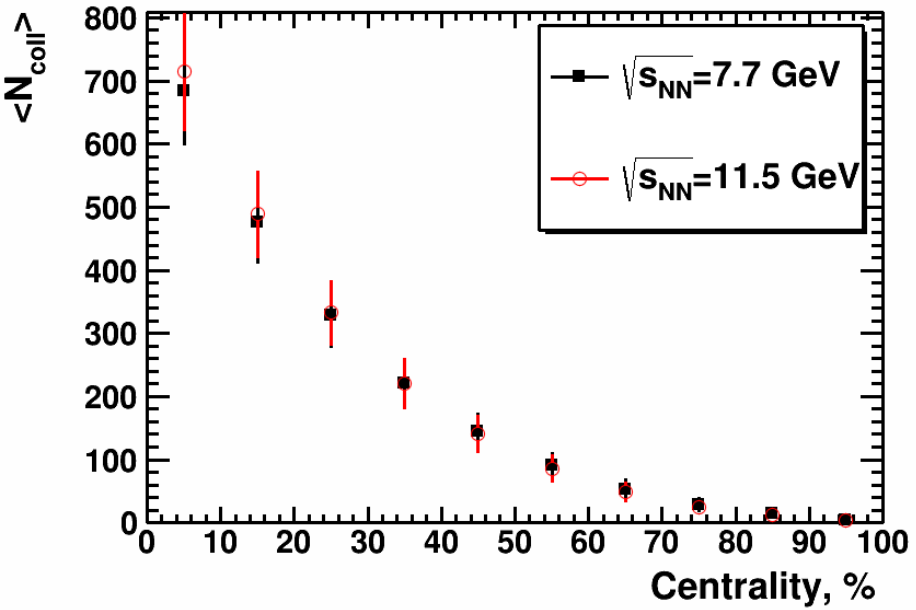


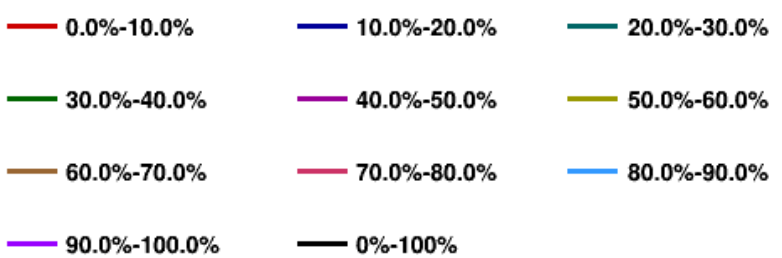


N_{coll} distribution in centrality classes



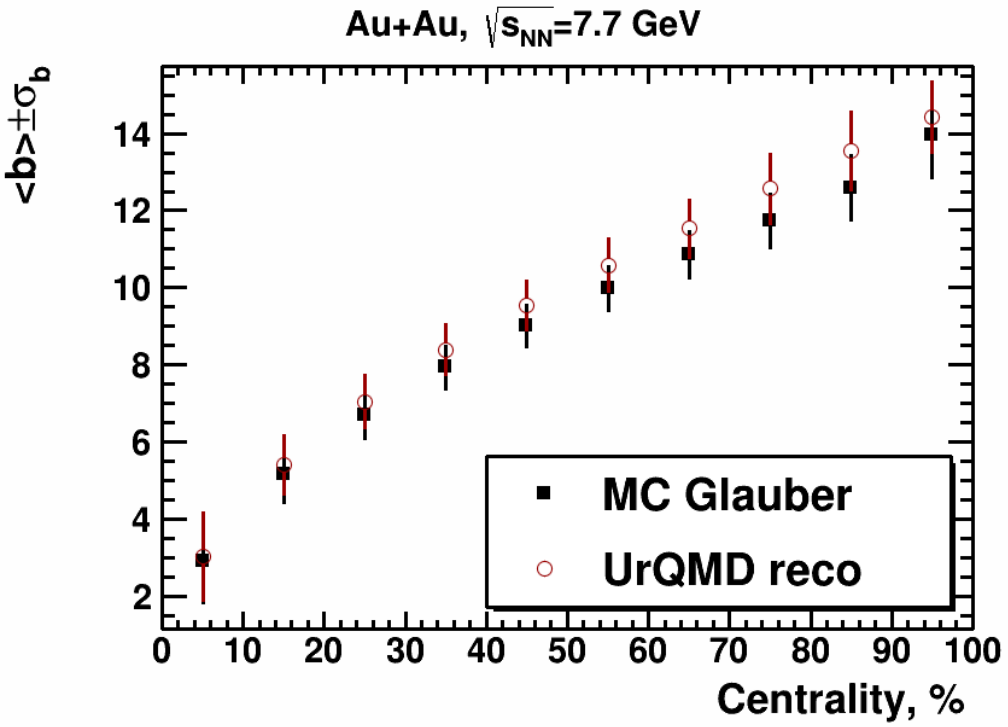


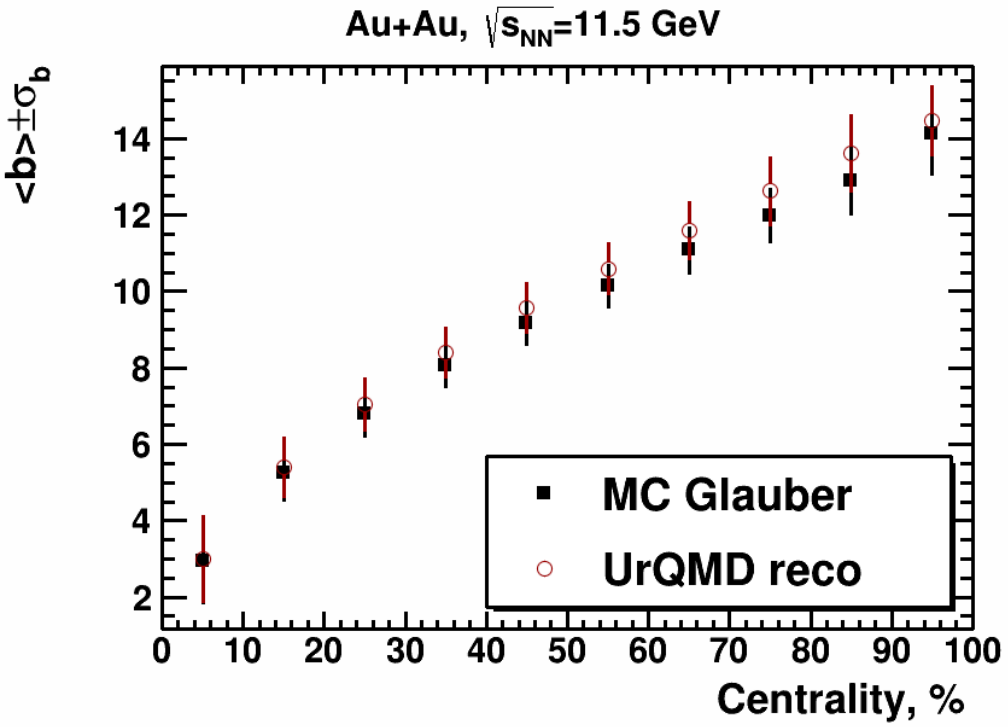




Comparison of the UrQMD, PHSD, SMASH & MC Glauber parameters

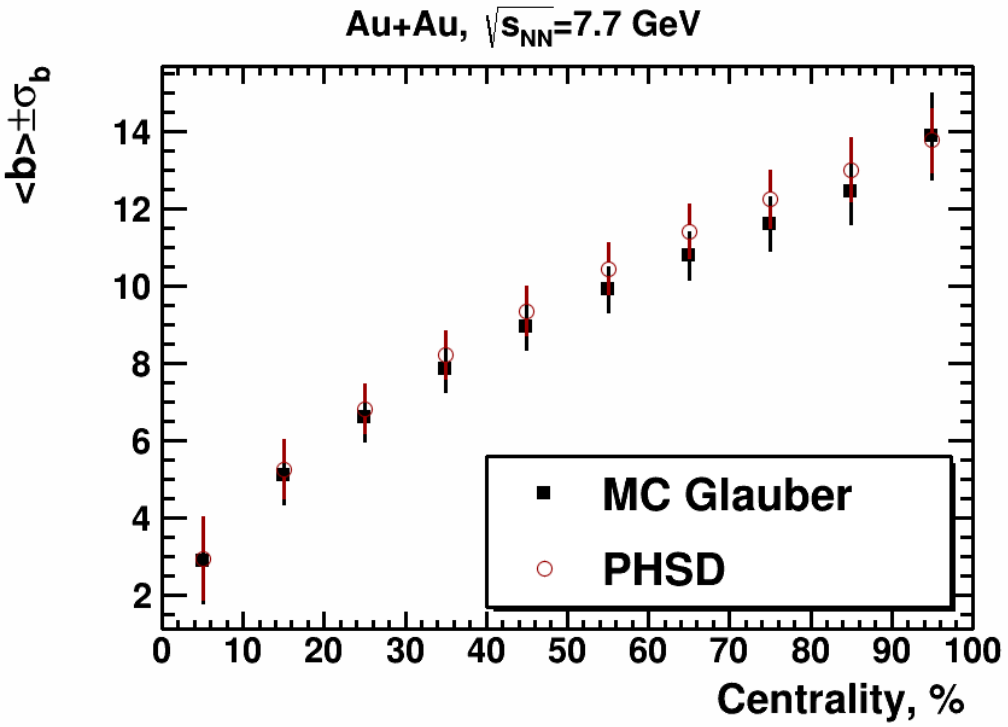
b vs centrality: MC Glauber vs UrQMD

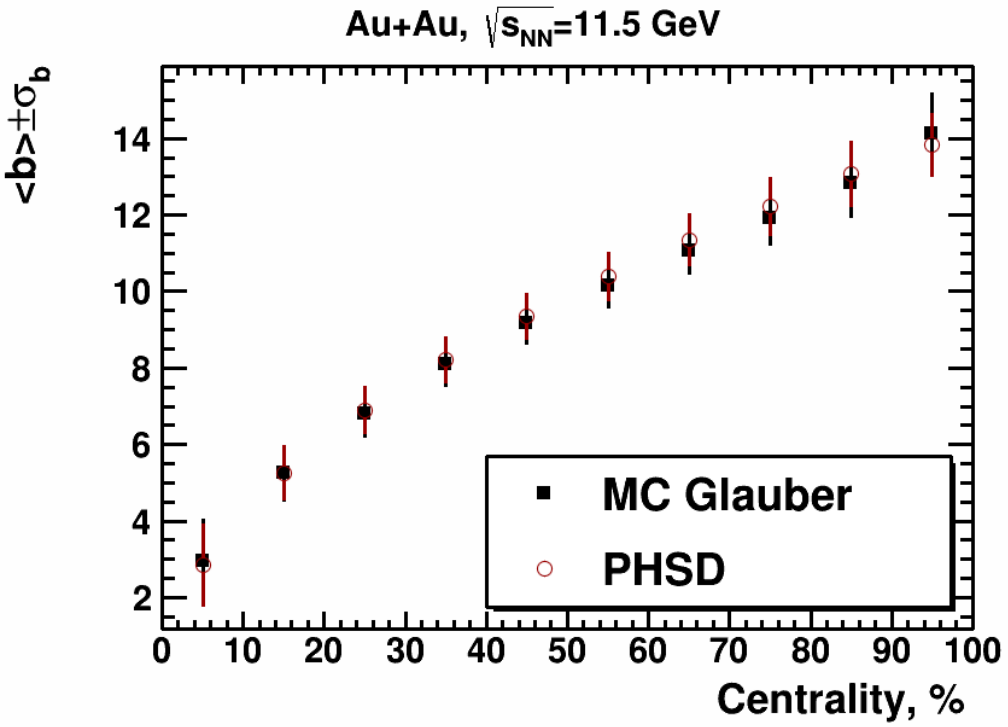




Reasonable agreement between MC Glauber and UrQMD

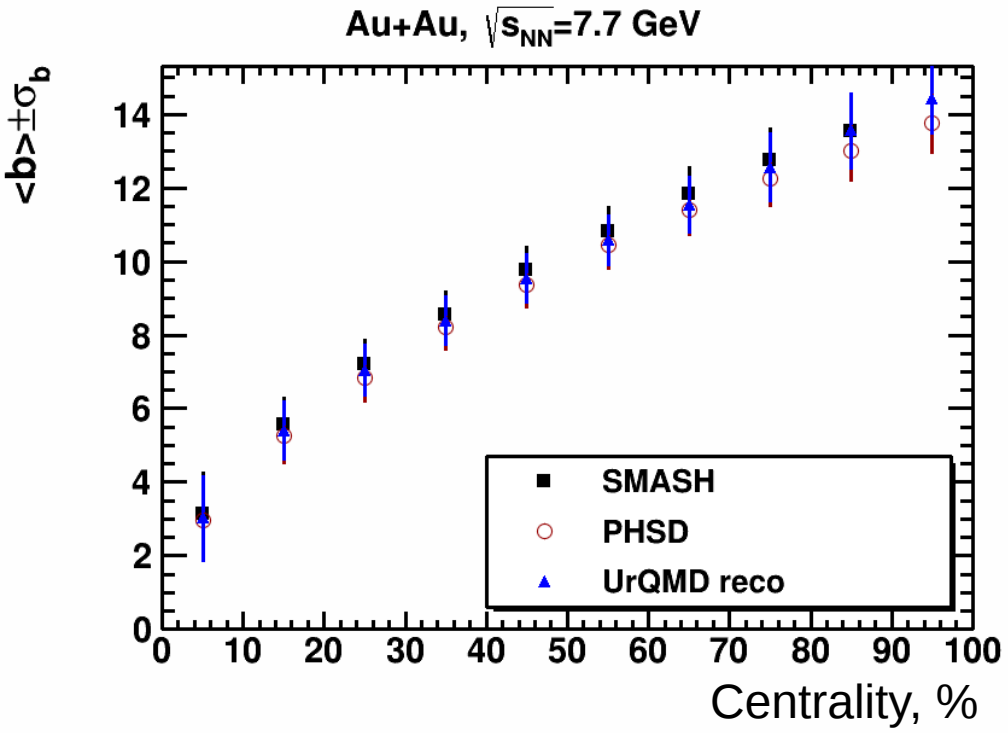
b vs centrality: MC Glauber vs PHSD

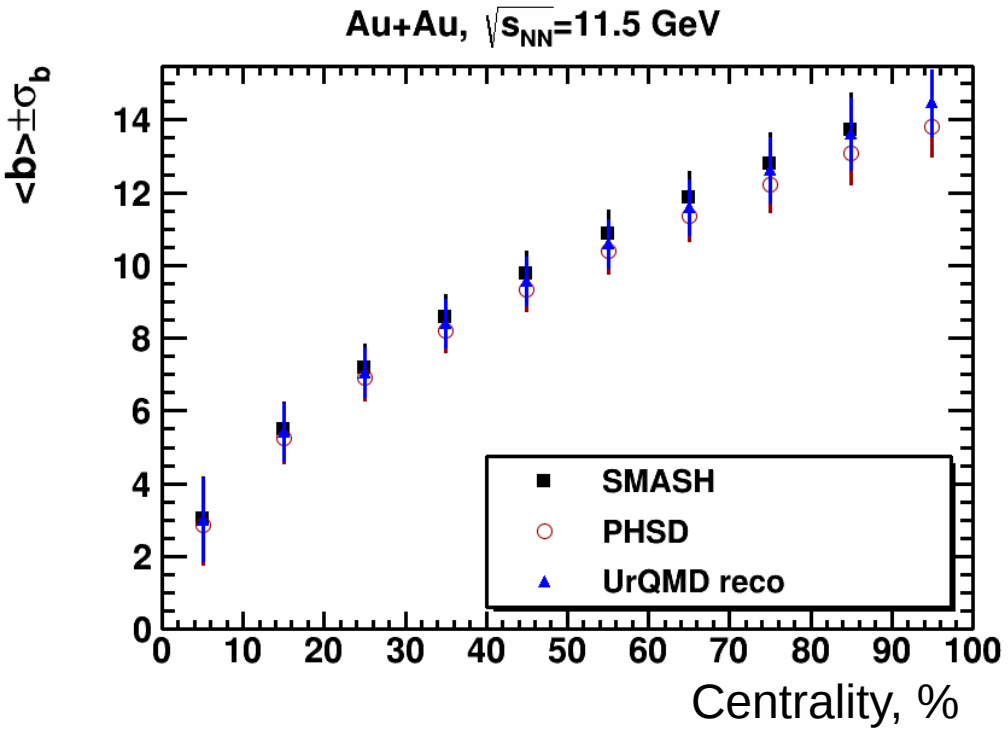




Reasonable agreement between MC Glauber and PHSD

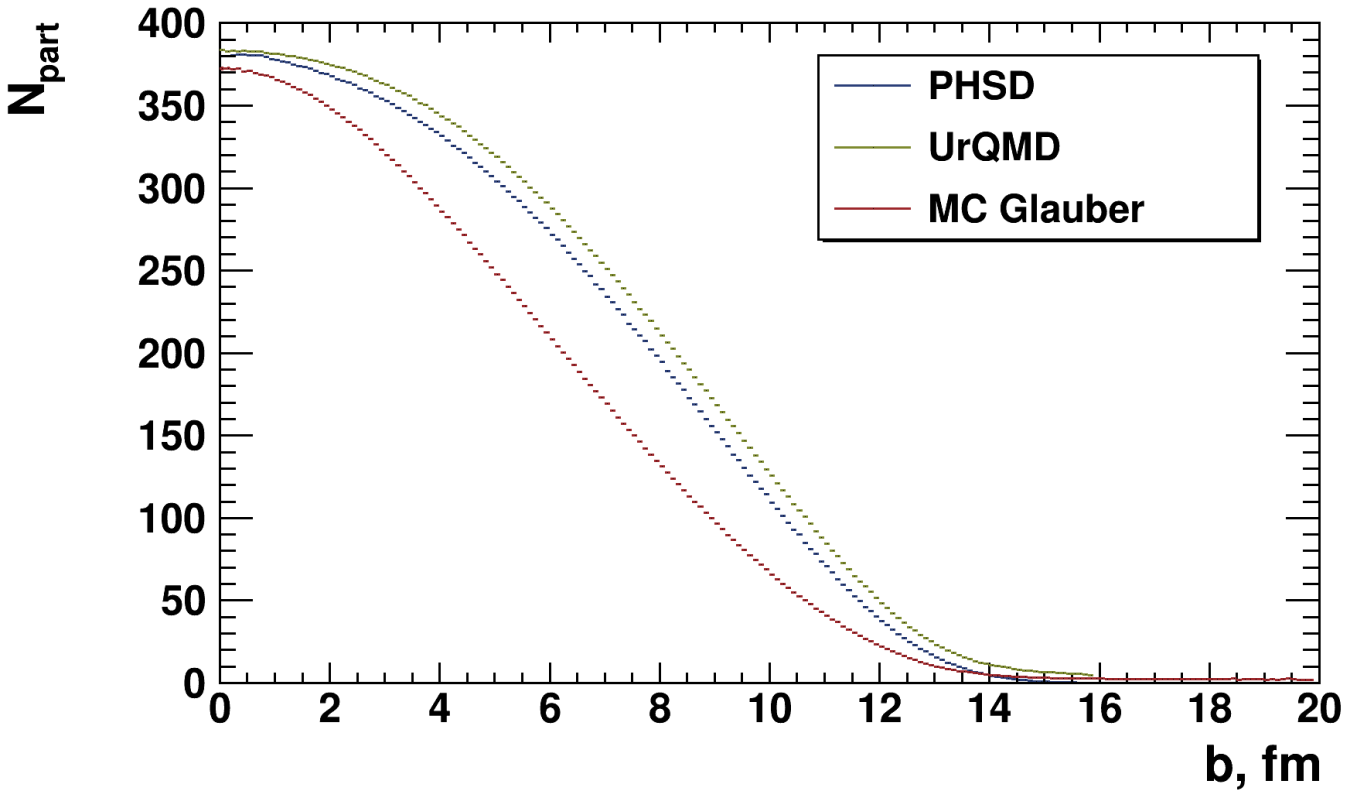
b vs centrality: different models





Reasonable agreement between UrQMD, PHSD and SMASH

N_{part} vs b: all models



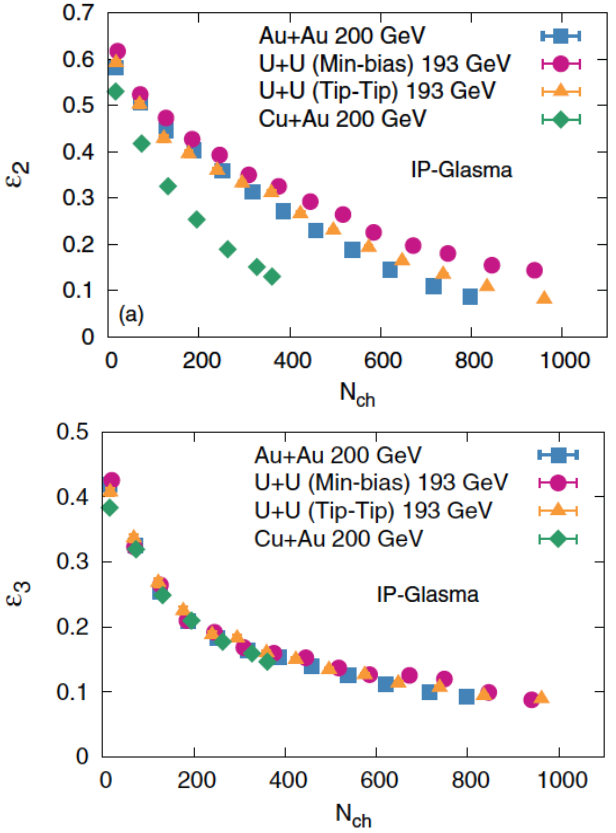
Eccentricity ε_n

- Eccentricity characterizes initial-state spatial anisotropy
- In MC Glauber, ε_n defined as a ε_{part} in the center-of-mass system of the participant nuclei (Phys.Rev. C81 (2010) 054905):

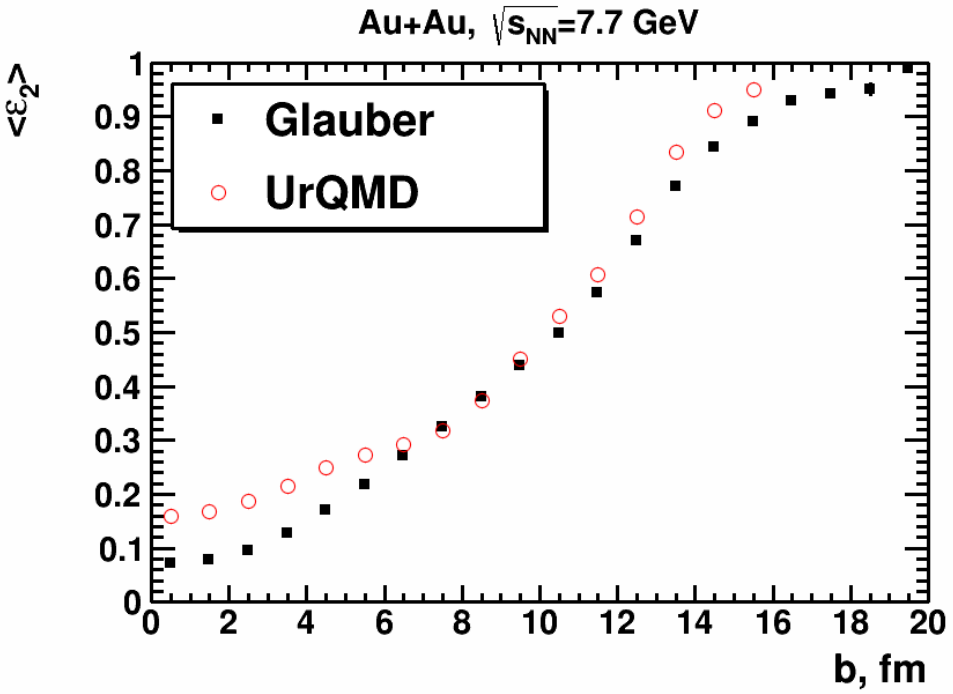
$$\varepsilon_n = \frac{\sqrt{\left\langle r^2 \cos\left(n\varphi\right)\right\rangle^2 + \left\langle r^2 \sin\left(n\varphi\right)\right\rangle^2}}{\left\langle r^2 \right\rangle}$$

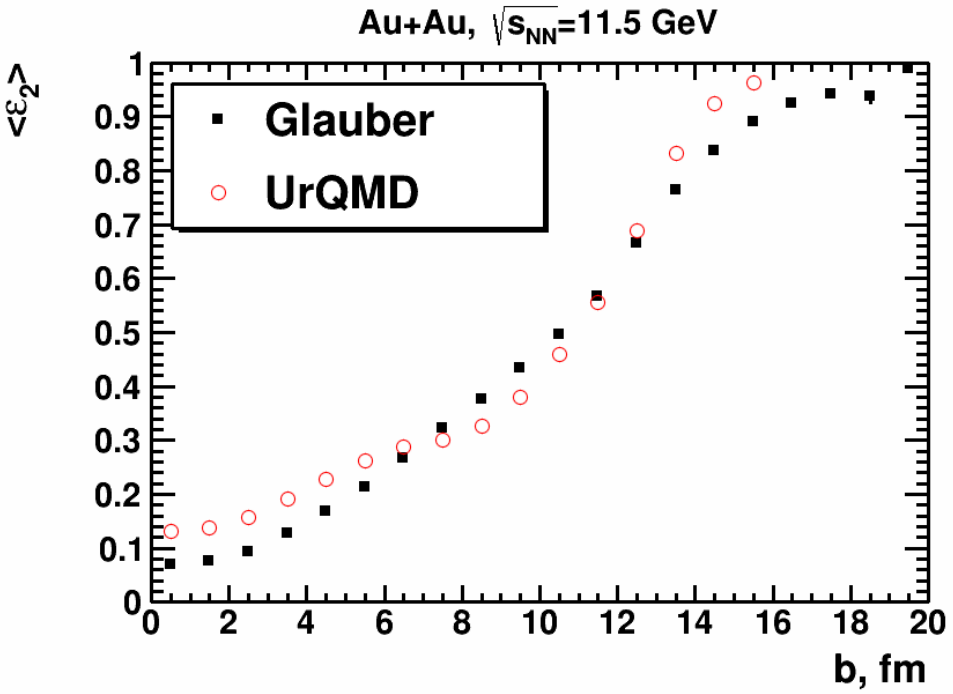
- ε_2 is system dependent
- ε_3 is system independent

B. Schenke, et al.
PRC 89, 064908 (2014)



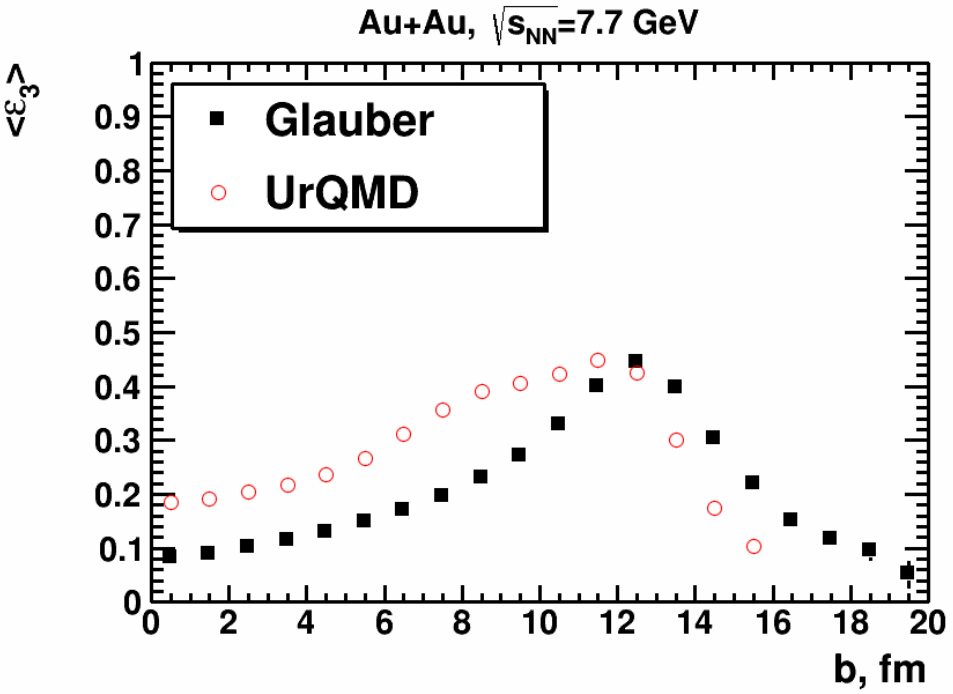
Eccentricity: Comparison w/ UrQMD

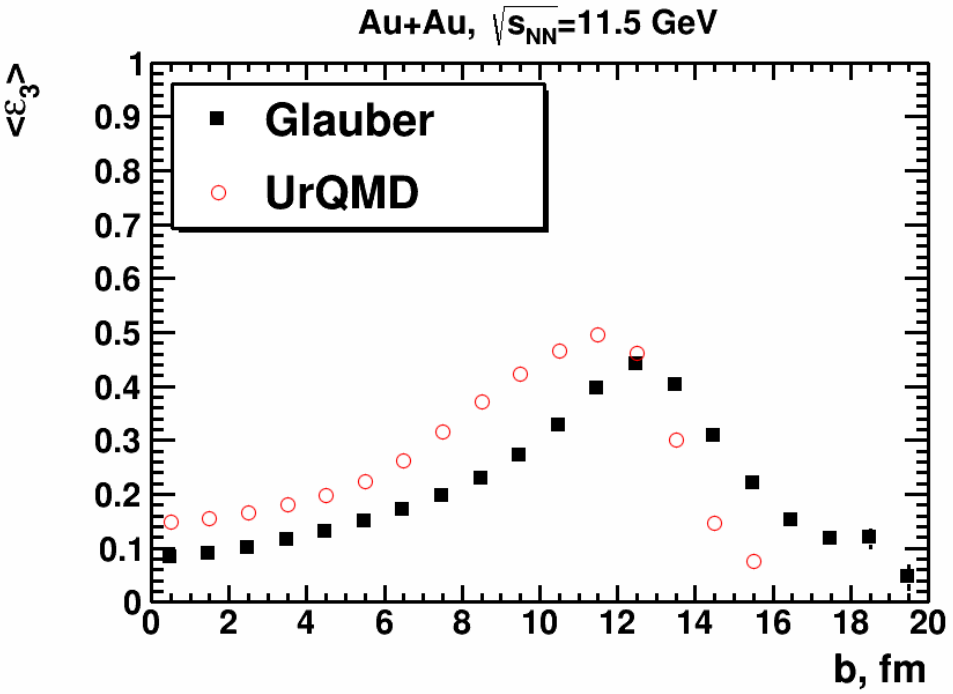




Notable difference between MC Glauber and UrQMD eccentricities

ε_3: Comparison w/ UrQMD





Notable difference between MC Glauber and UrQMD

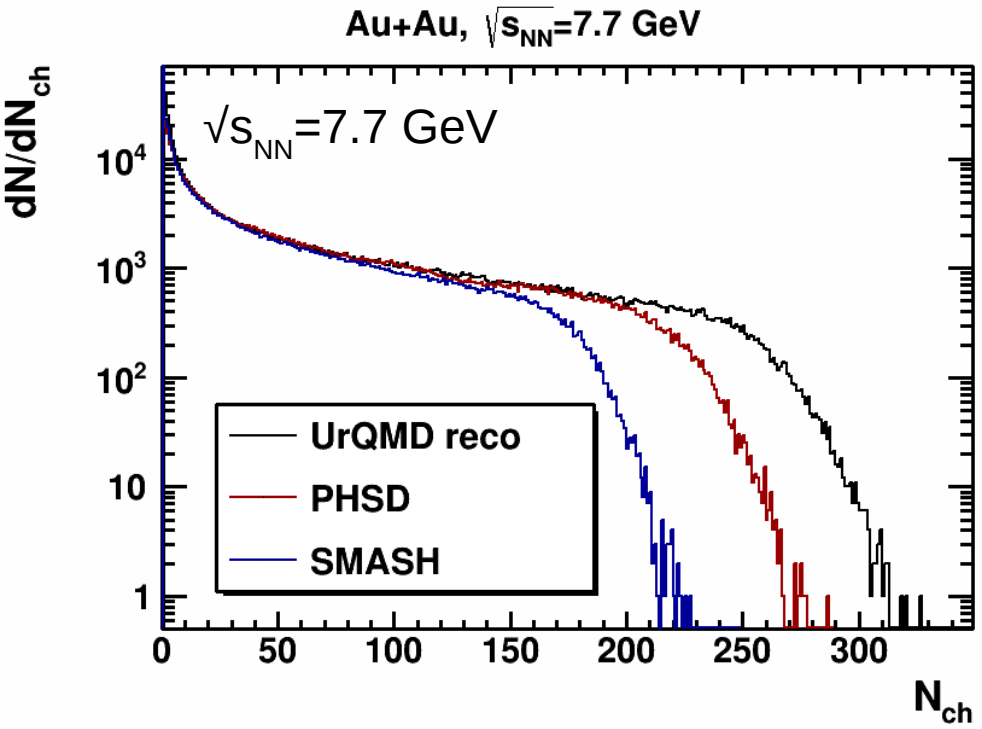
Summary and next steps

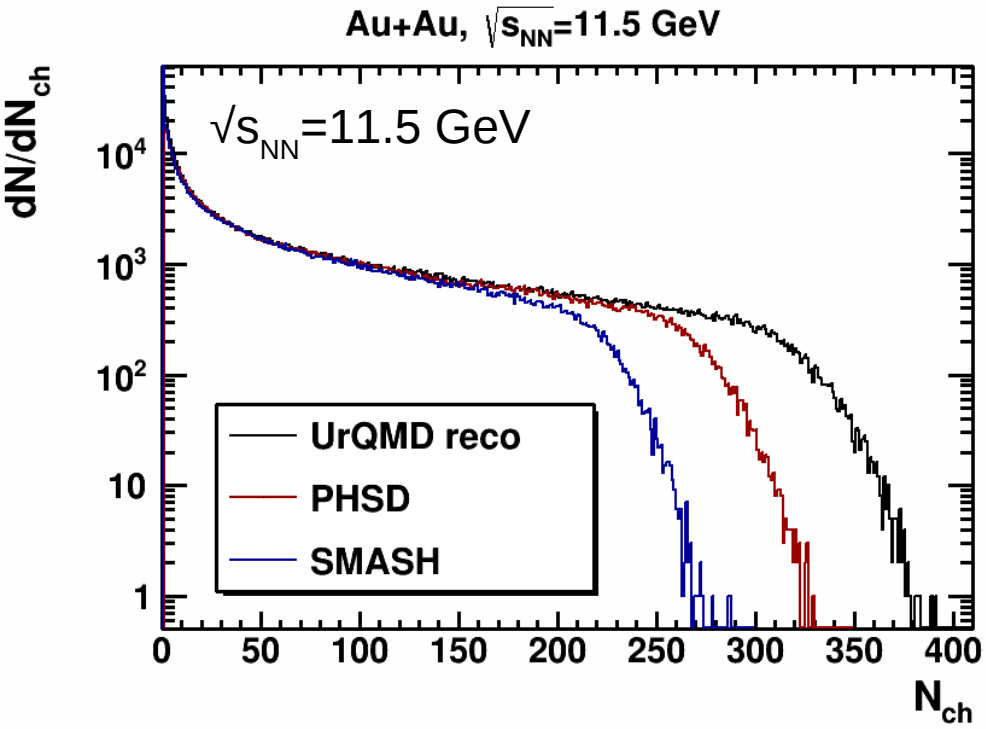
- MC-Glauber based procedure for centrality determination is established
  - UrQMD at two energies ($\sqrt{s_{NN}}$=7.7, 11.5 GeV) are under study
- Fit reproduces charged particle multiplicity with chosen parameters
- Extracted relation between model parameters (b, N_{part}, N_{coll}) and multiplicity centrality classes
  - Impact parameter from MC Glauber and UrQMD in given centrality classes are in reasonable agreement
- Comparison of the ε_n between MC Glauber and UrQMD shows notable difference
- Comparison between MC Glauber and other models: PHSD, PHQMD, SMASH, JAM -work in progress.
- Systematic study and analysis note are under preparation.

Thank you for your attention!

Backup

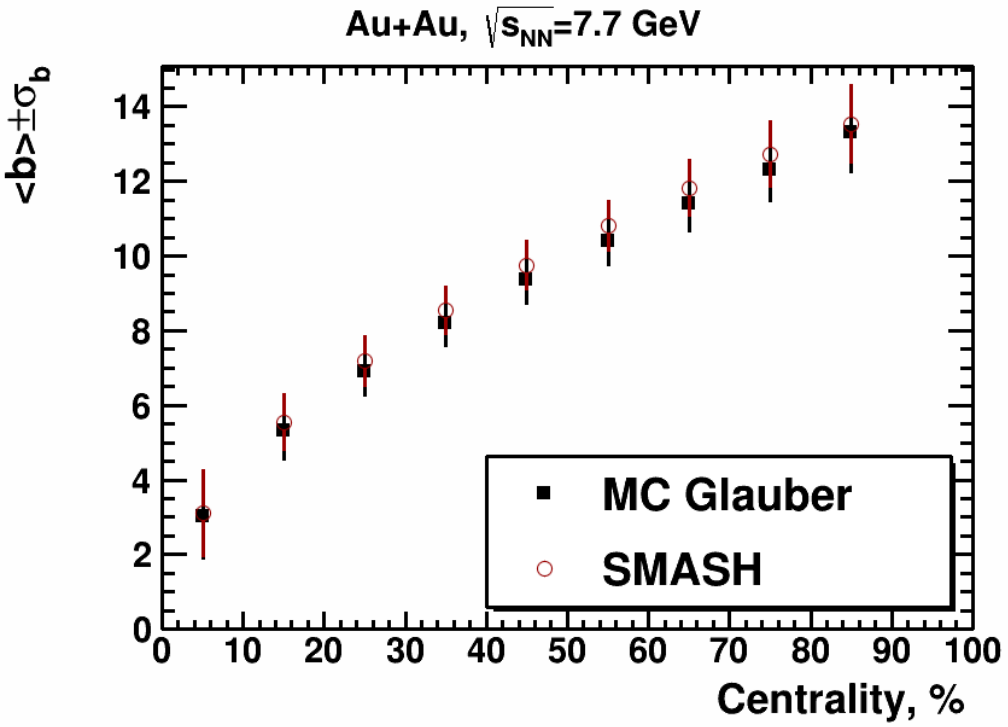
$h^{\pm}$ multiplicity

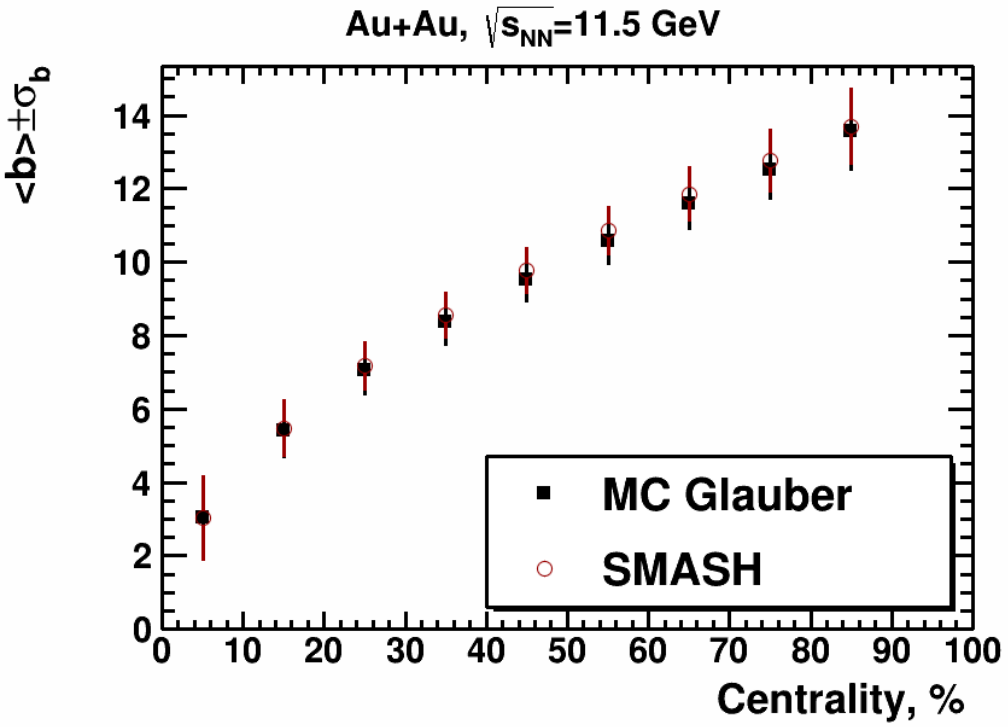




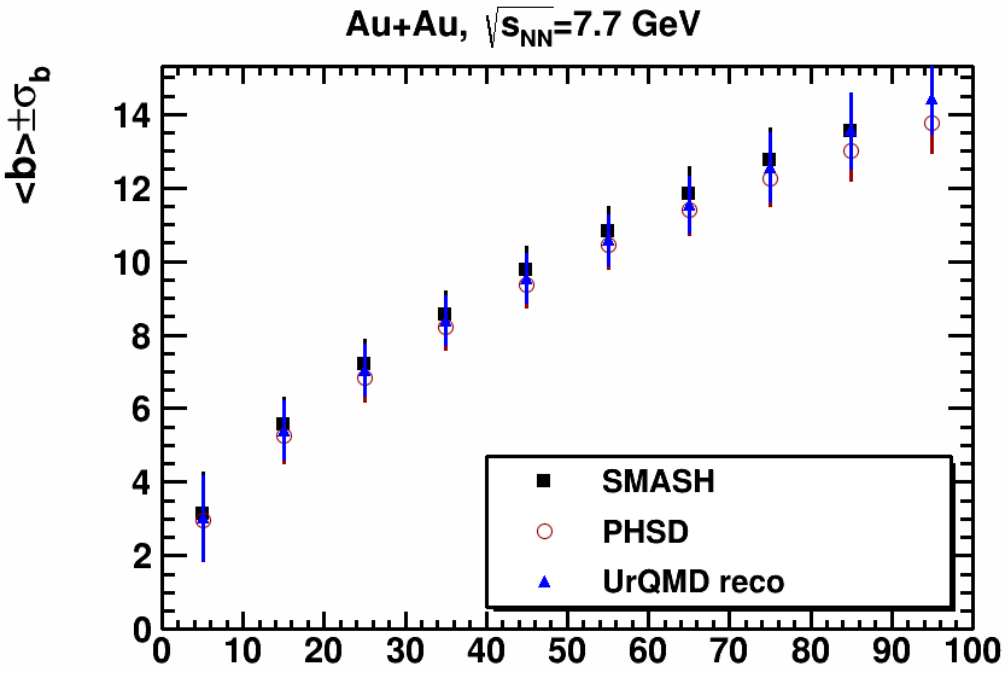
<b> vs centrality: comparison between models

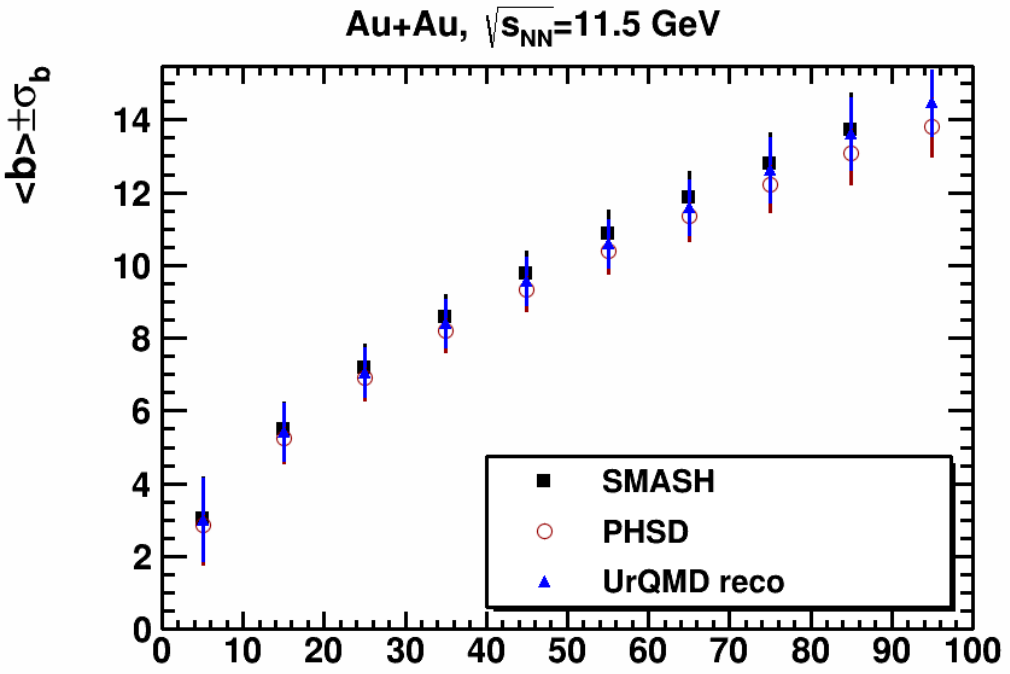
b vs centrality: Glauber vs SMASH



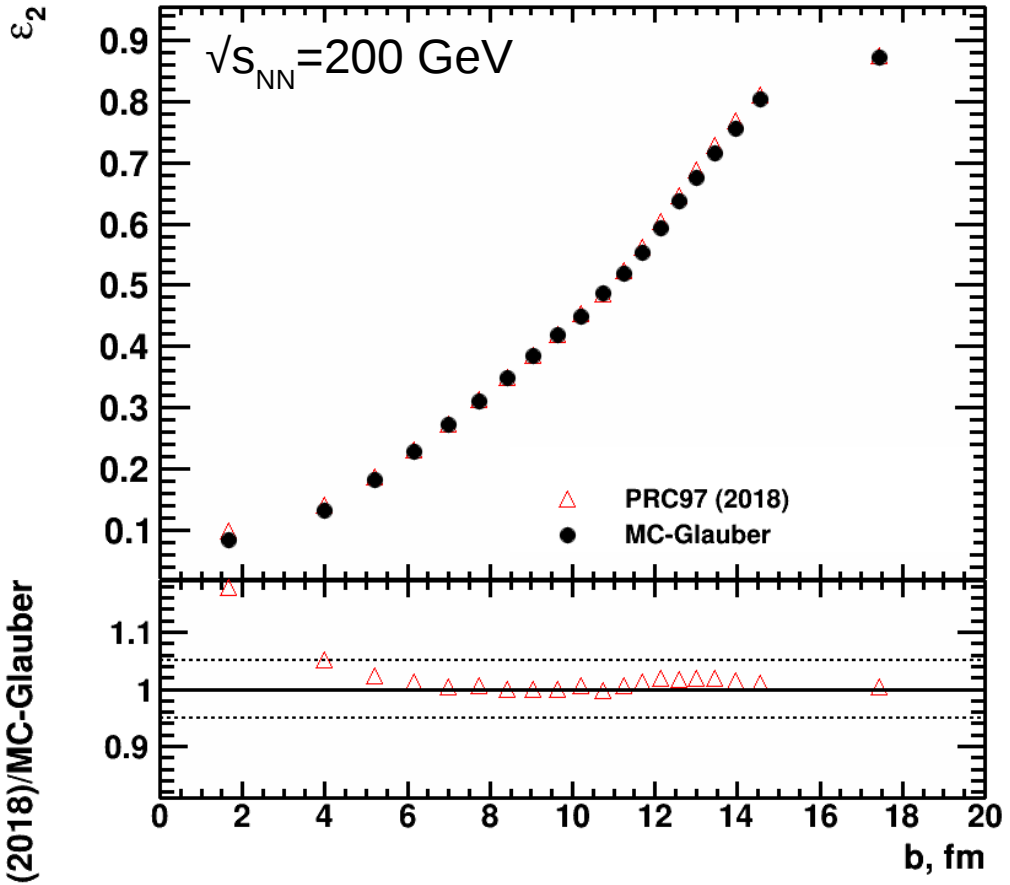


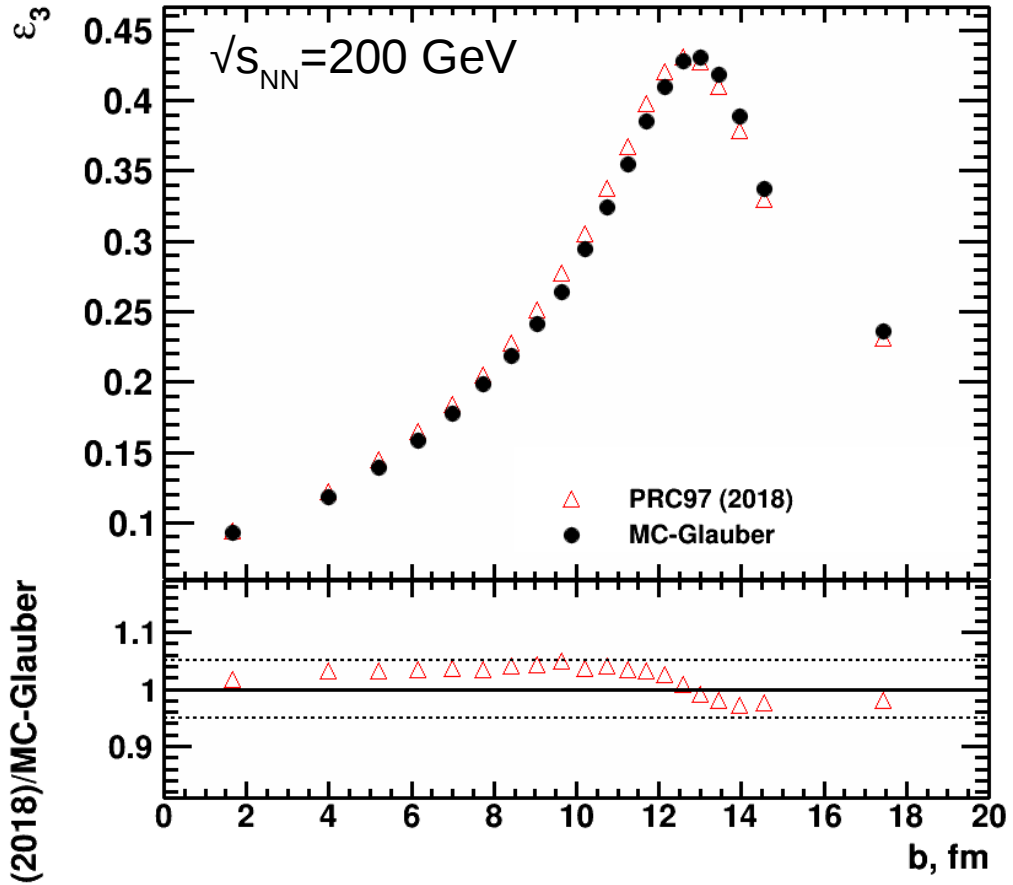
b vs centrality: all models





Eccentricity: comparison with STAR

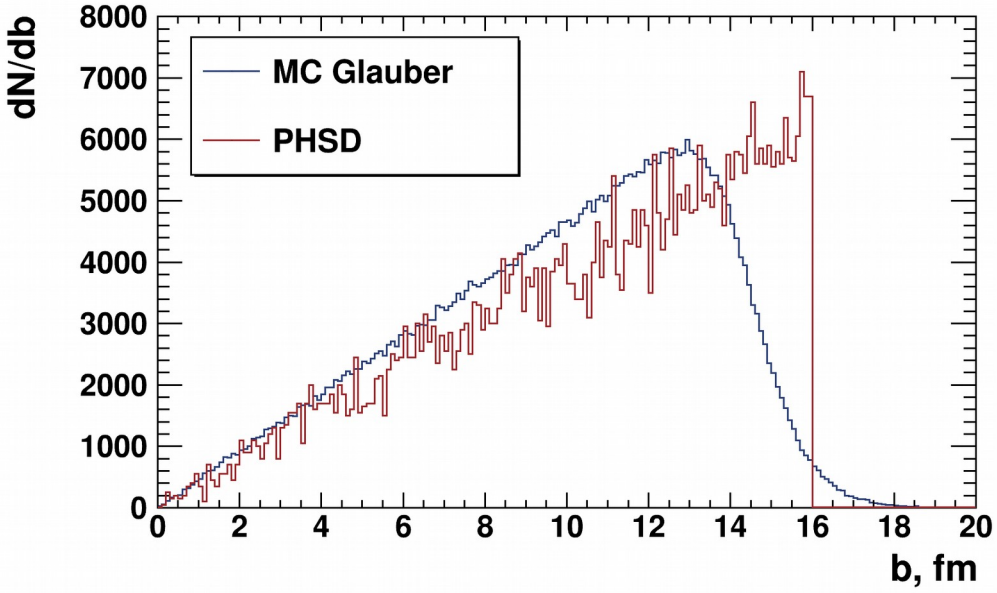


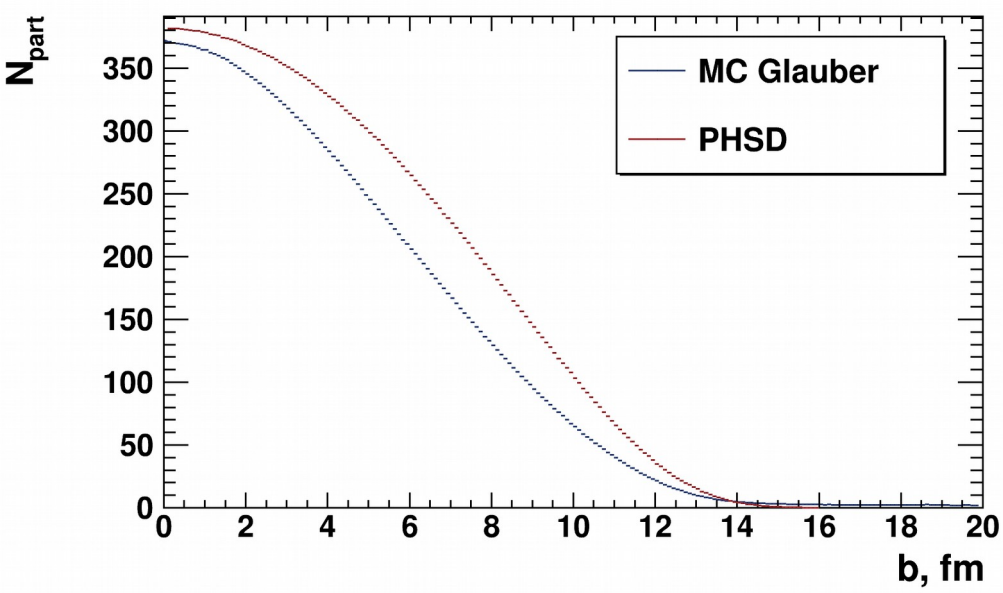


Good agreement with the published data

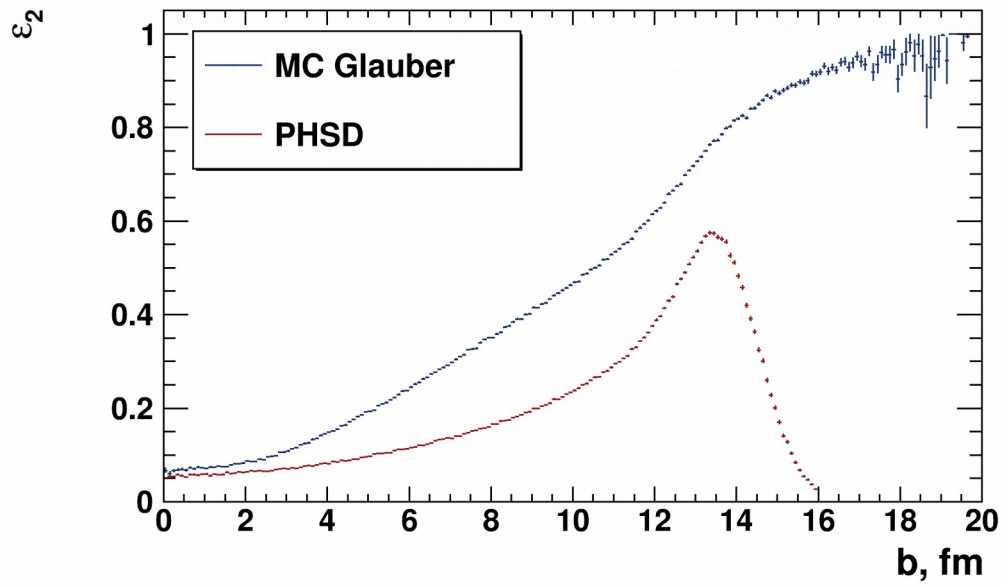
Initial state comparison: $\sqrt{s_{NN}}$=7.7 GeV

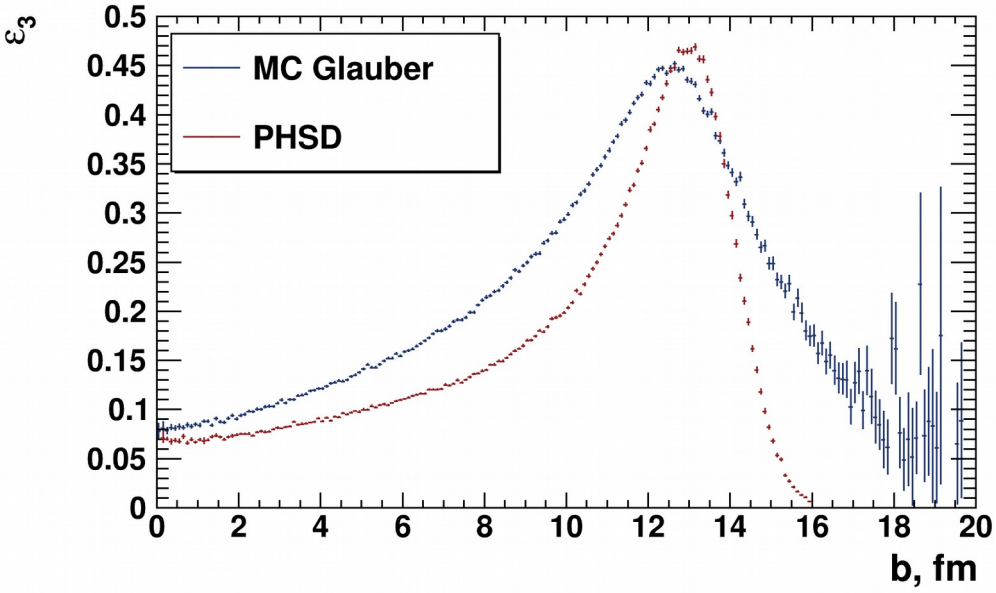
MC Glauber vs PHSD: b, N_{part}





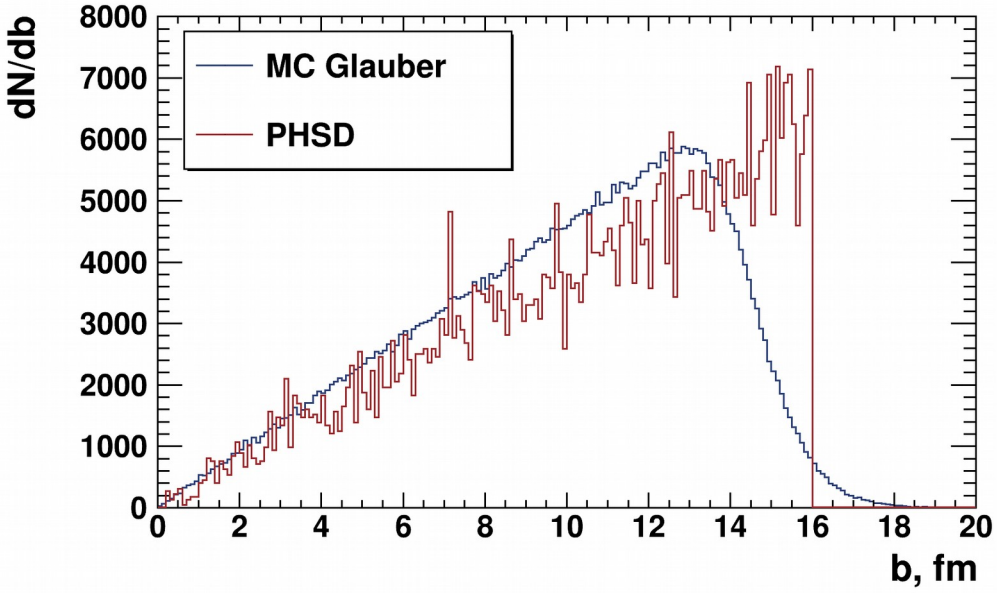
MC Glauber vs PHSD: ε_n

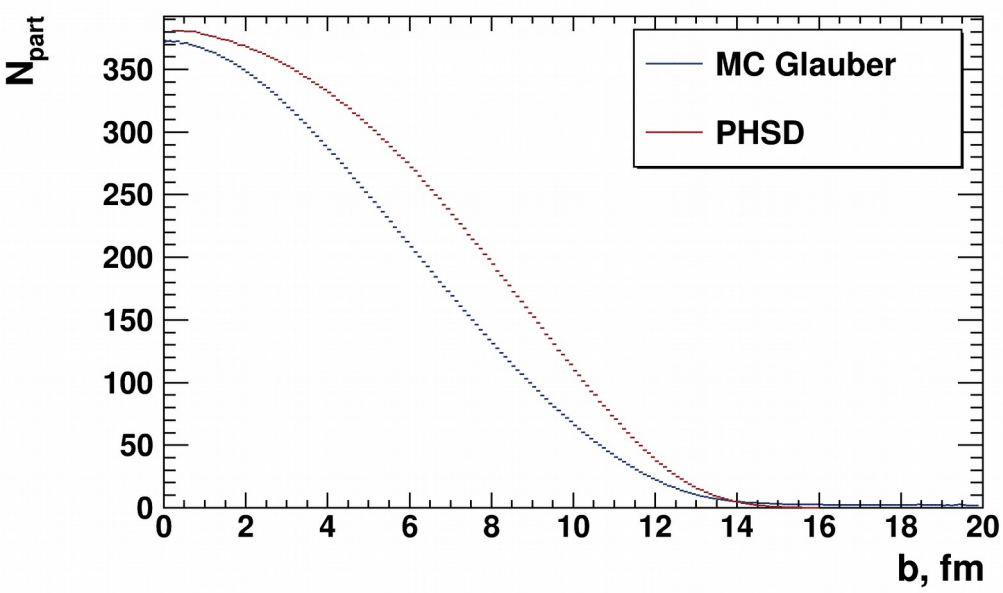




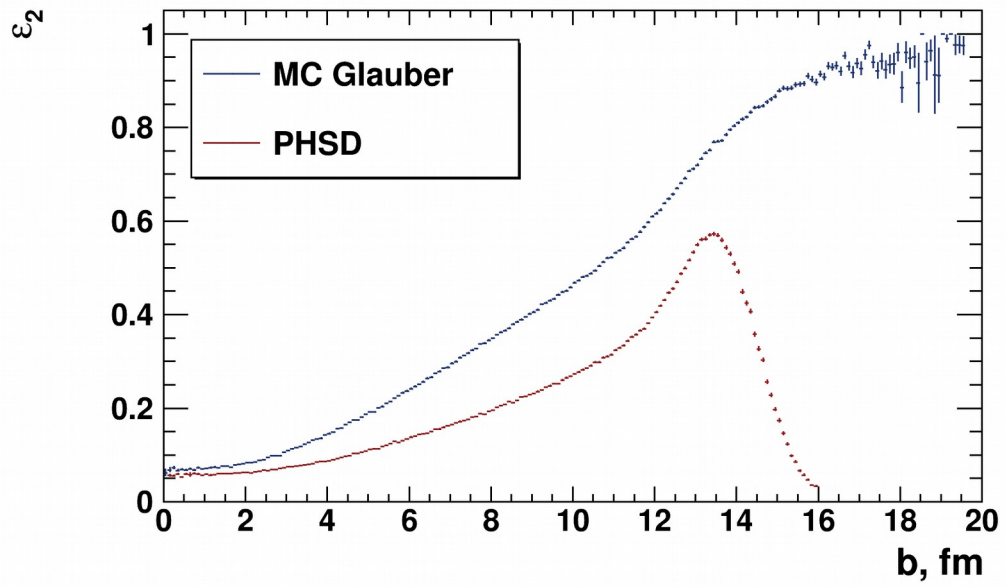
Initial state comparison: $\sqrt{s_{NN}}$=11.5 GeV

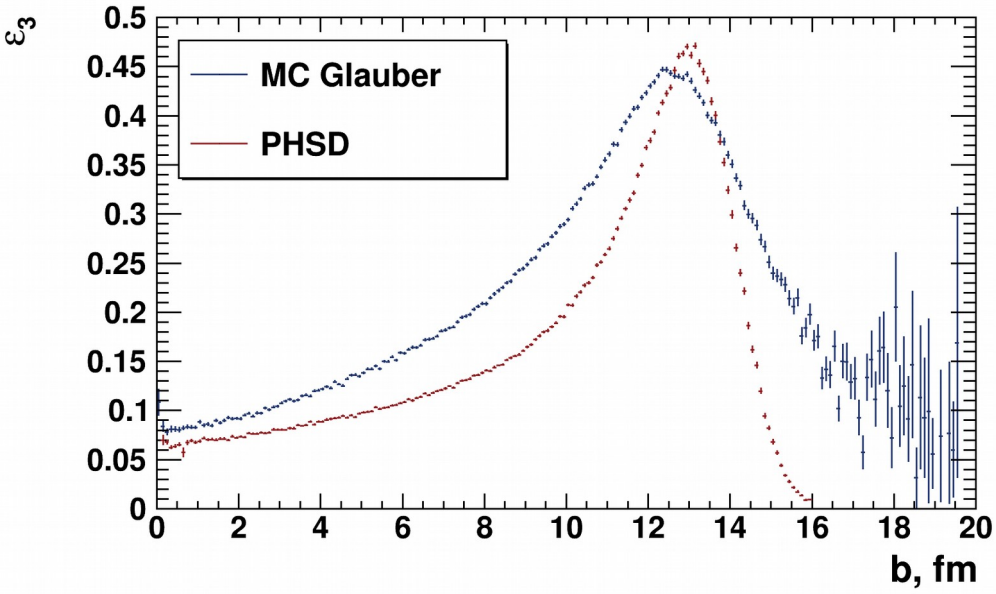
MC Glauber vs PHSD: b, N_{part}



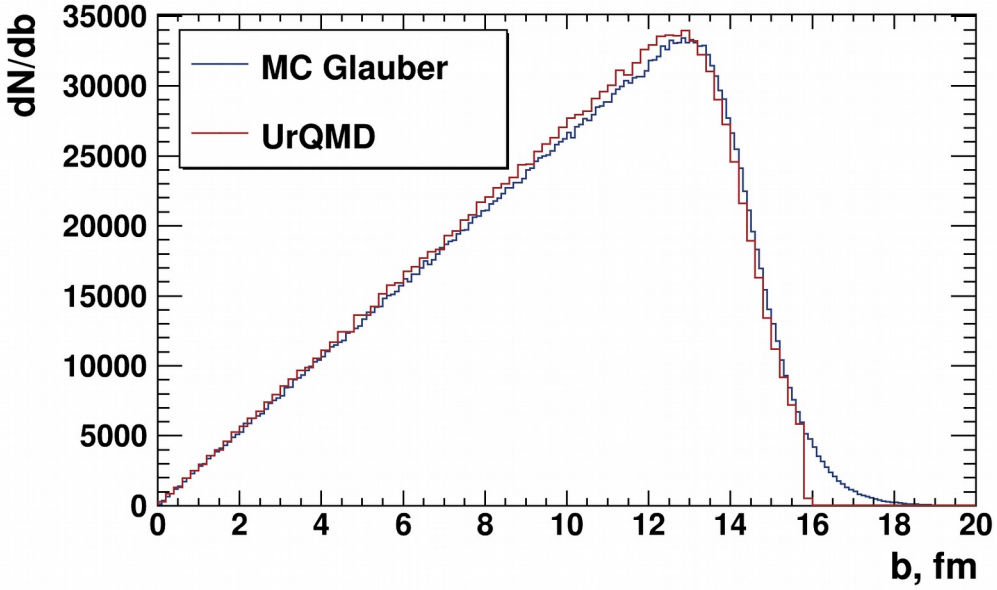


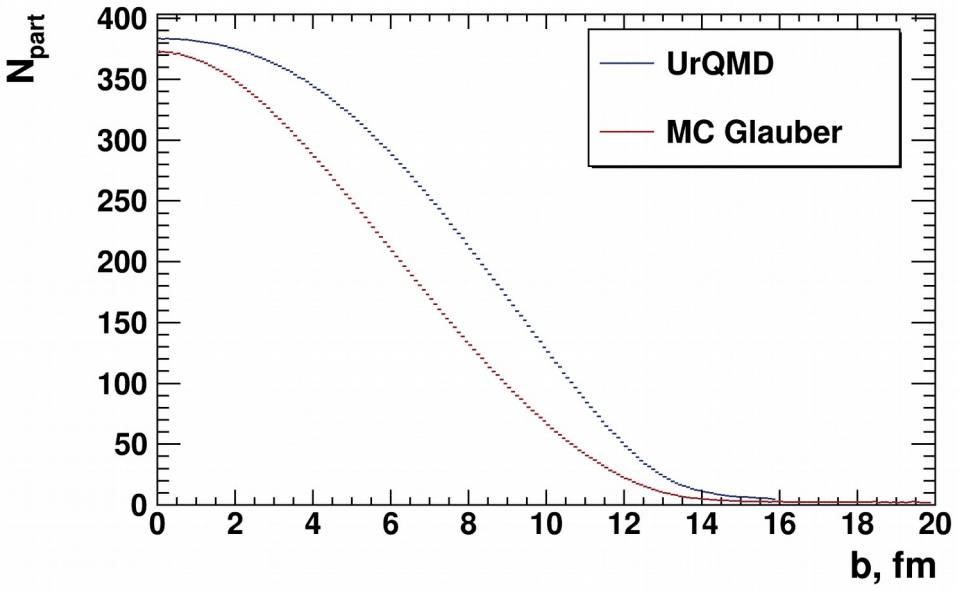
MC Glauber vs PHSD: ε_n



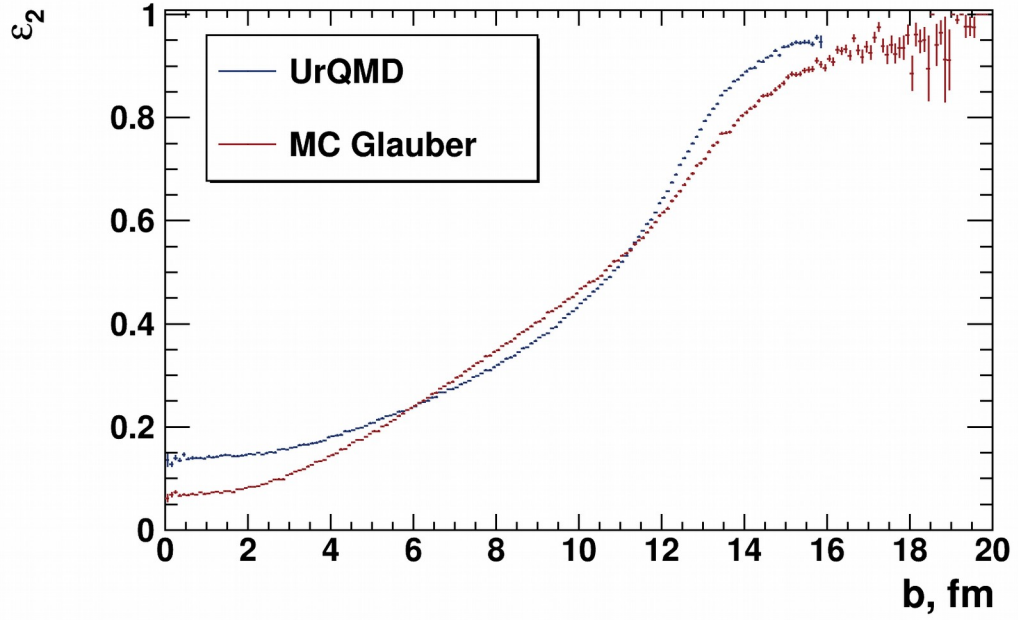


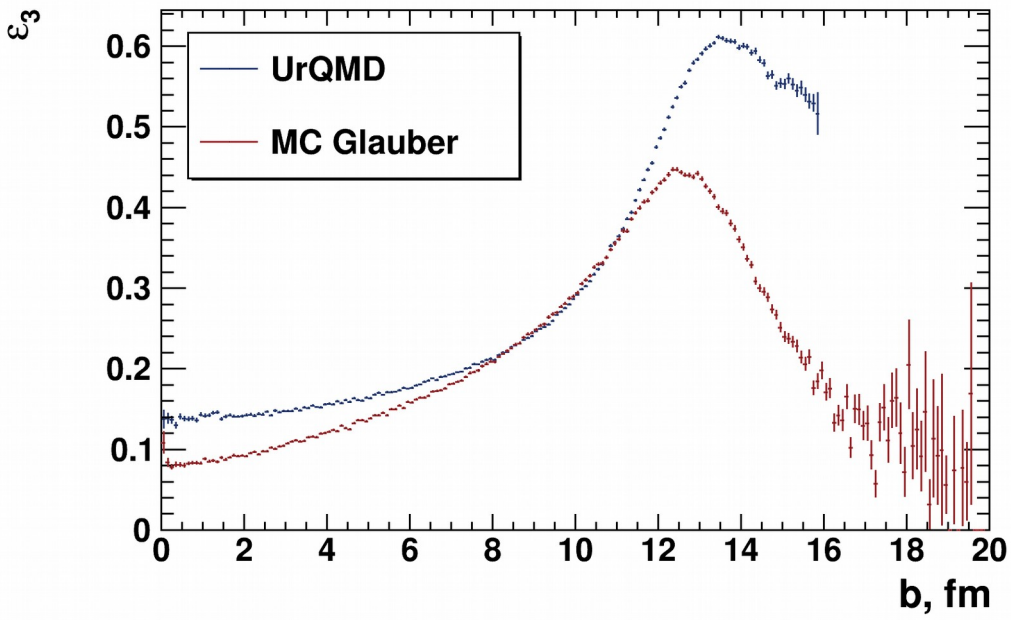
MC Glauber vs UrQMD: b, N_{part}





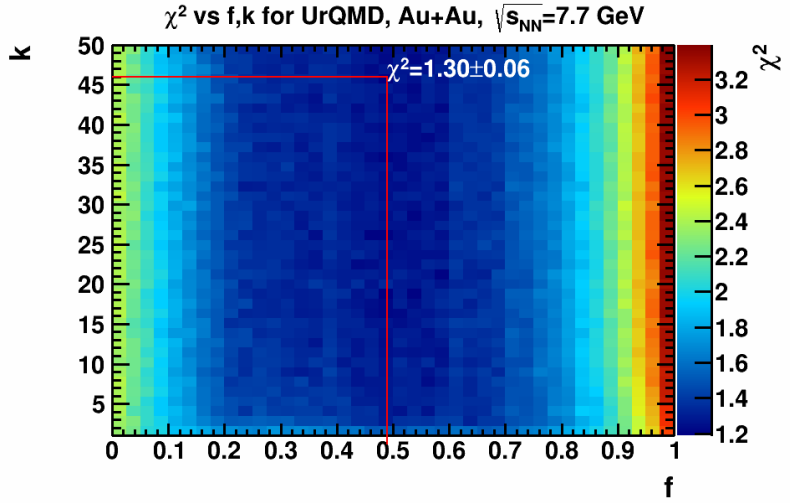
MC Glauber vs UrQMD: ε_n

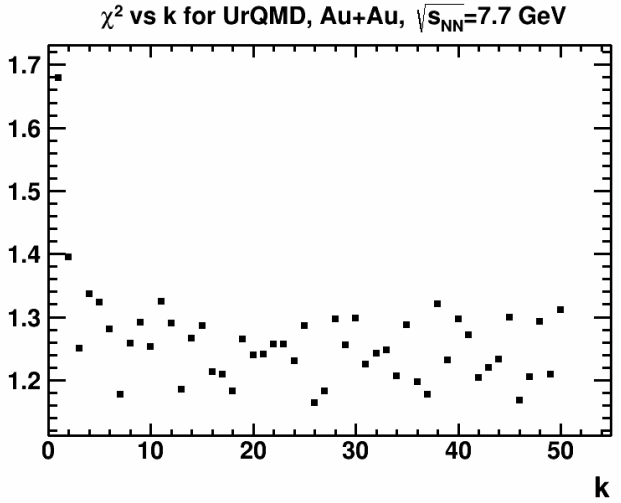


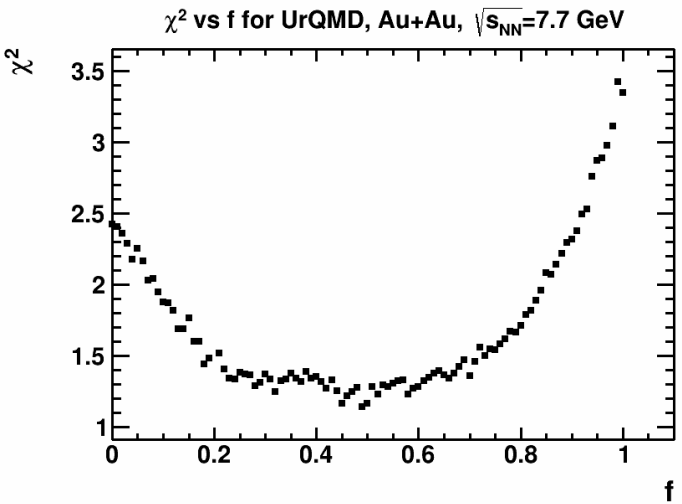


MC Glauber vs pure UrQMD

Fit parameters f,k vs χ^2

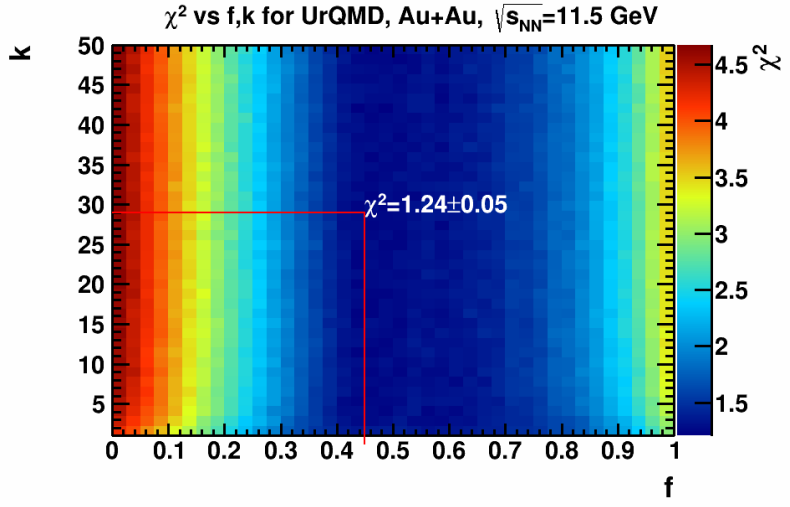


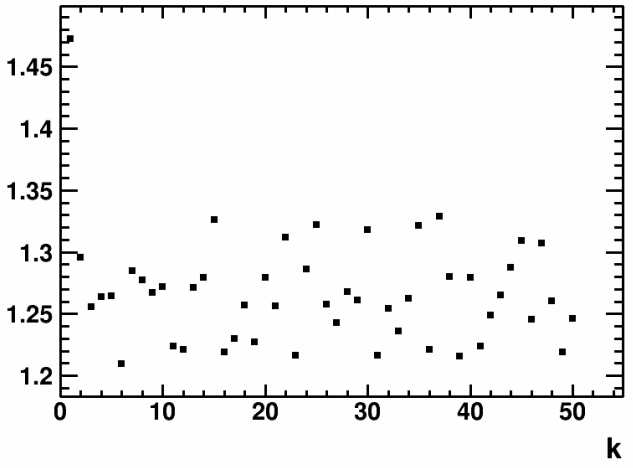


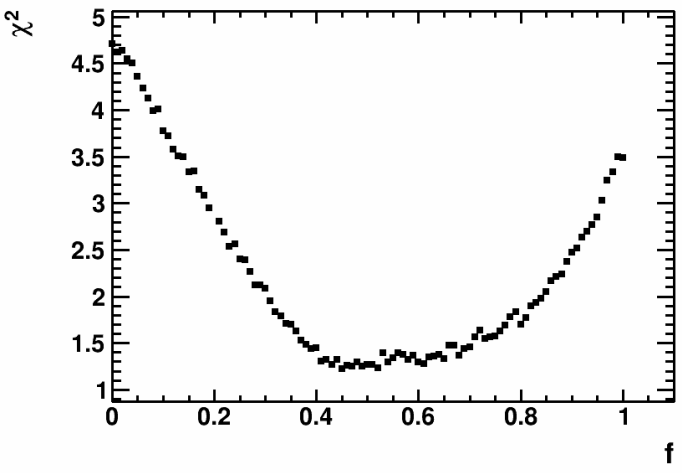


f=0.49, k=46, μ=0.61, χ^2=1.29±0.06, M=(35,445)

Fit parameters f,k vs χ^2

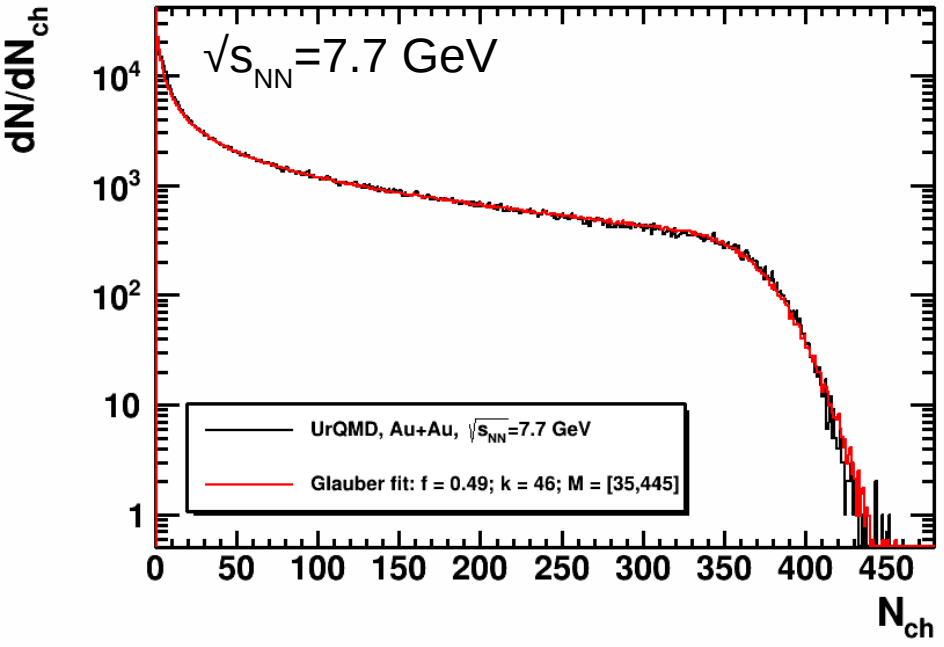


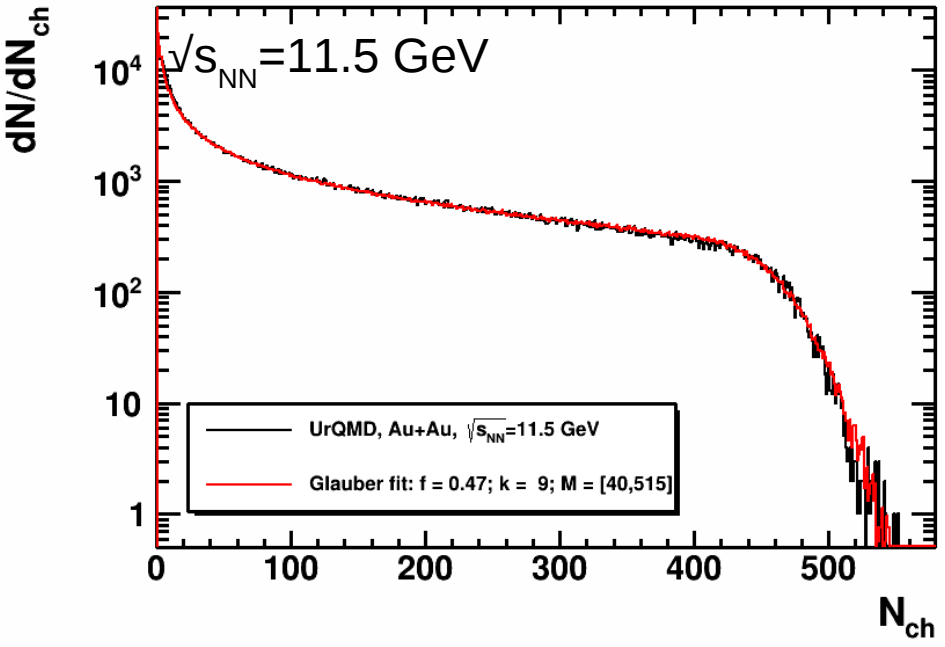




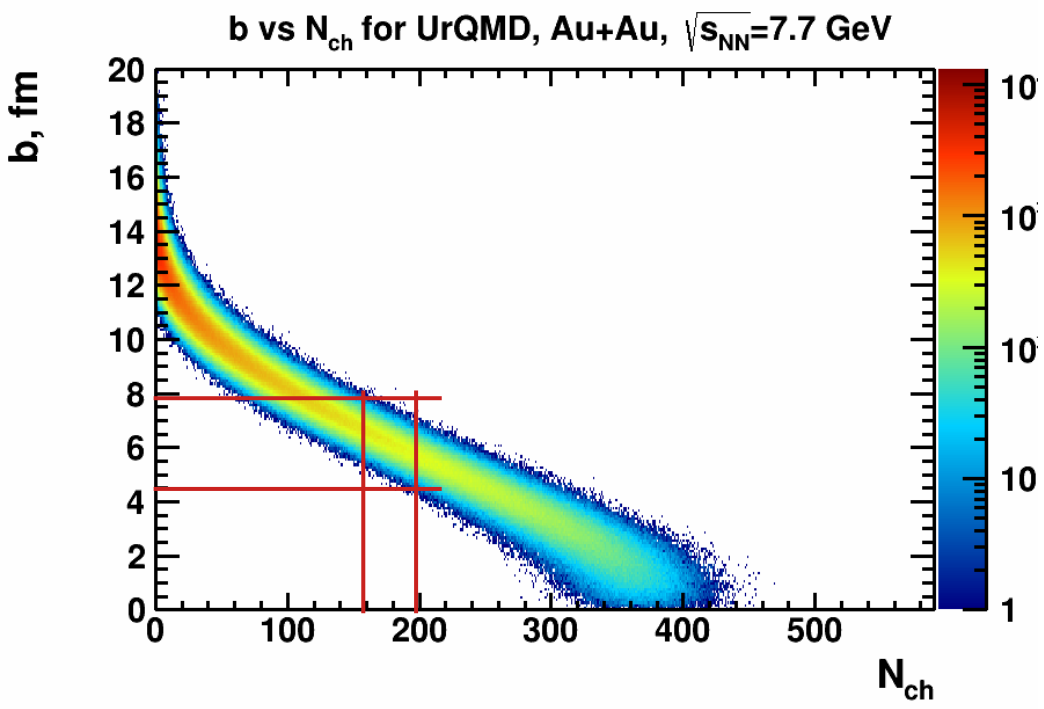
f=0.45, k=29, μ=0.71, χ^2=1.24±0.05, M=(40,540)

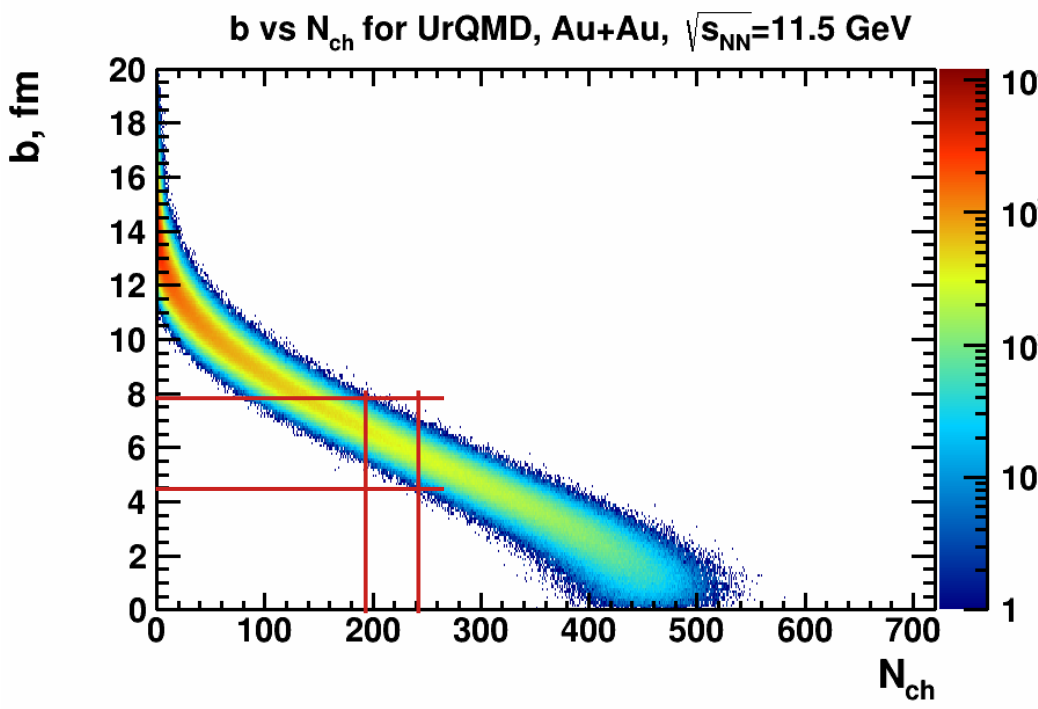
MC Glauber fit: $h^{\pm}$ multiplicity





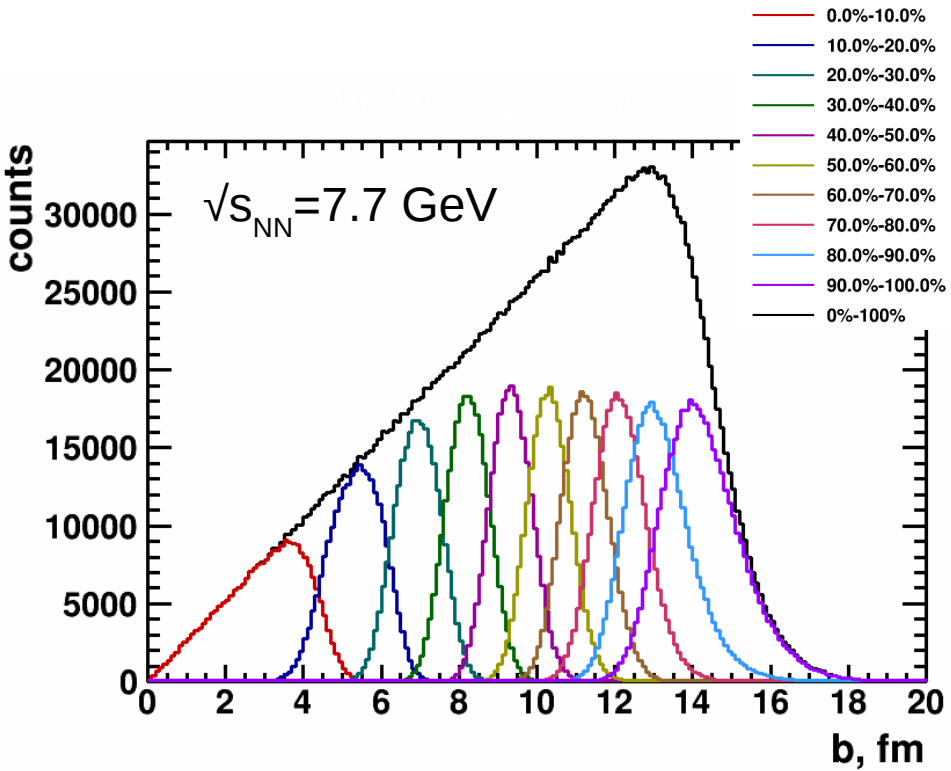
b-multiplicity correlation

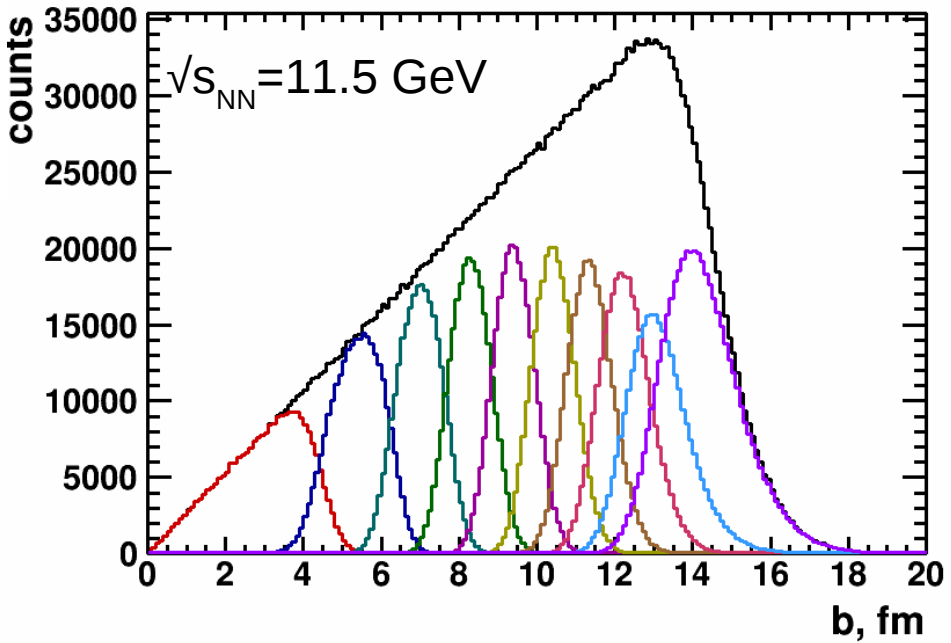




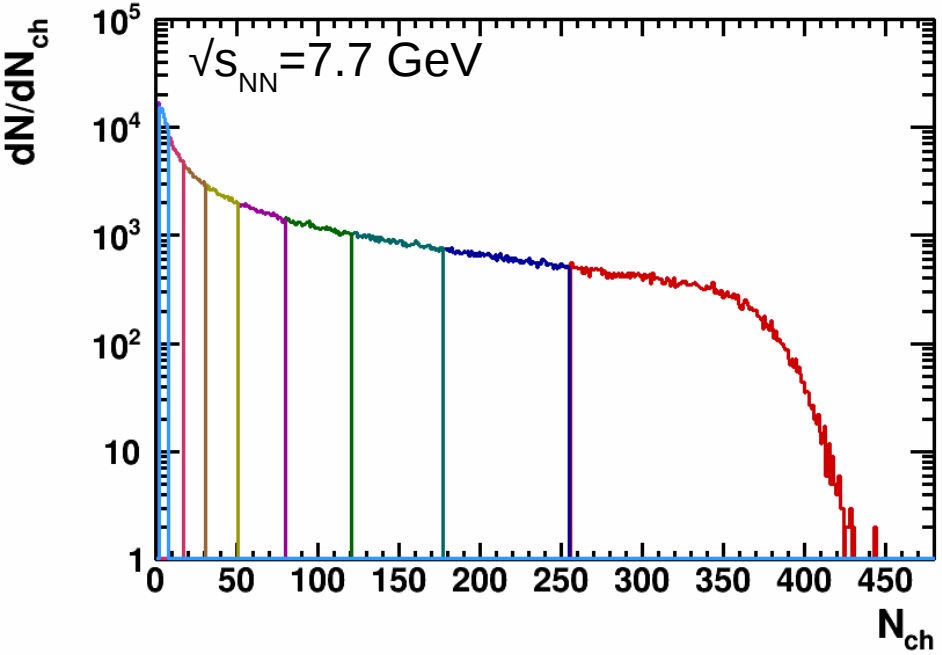
Events in multiplicities M ± ΔM have impact parameter in range b ± σ_b

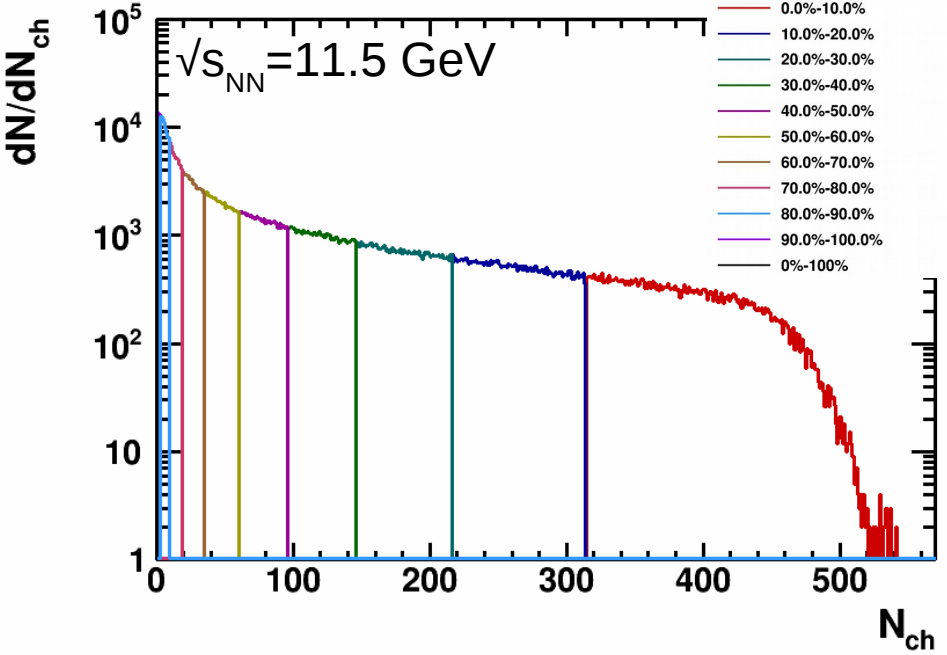
b distribution in centrality classes



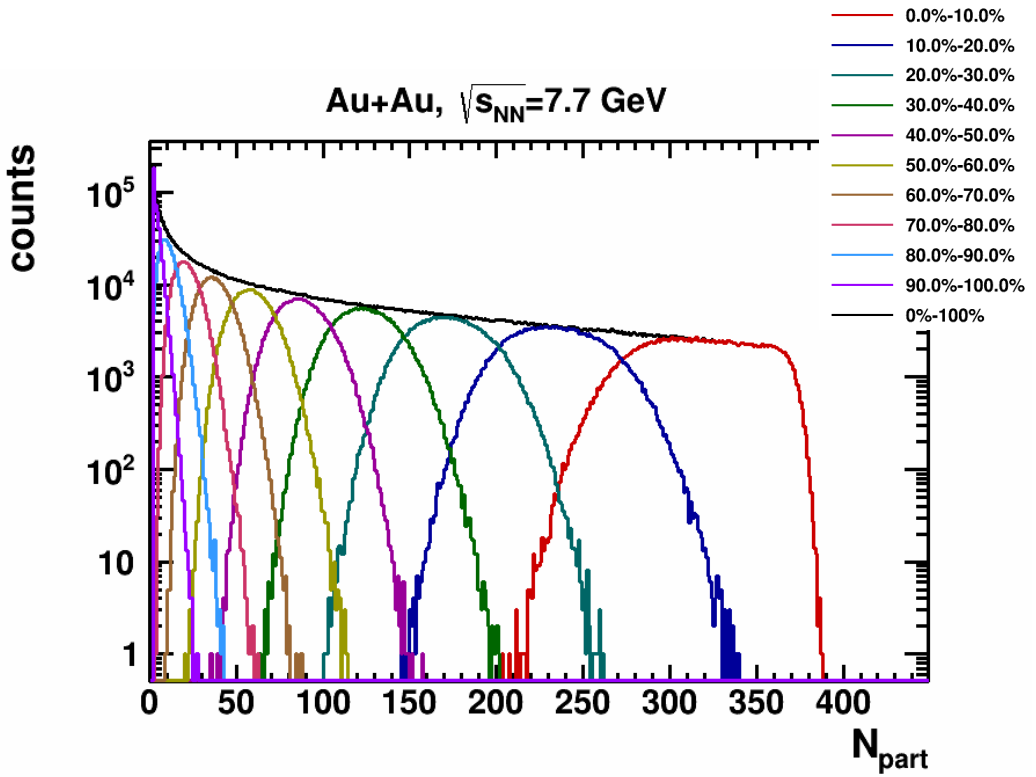


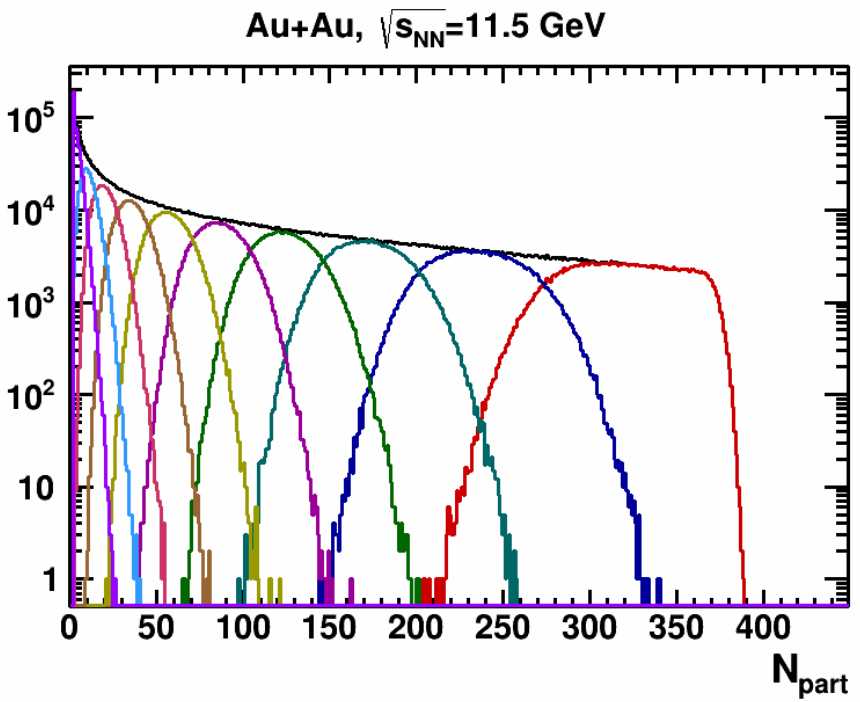
Multiplicity distribution in centrality classes



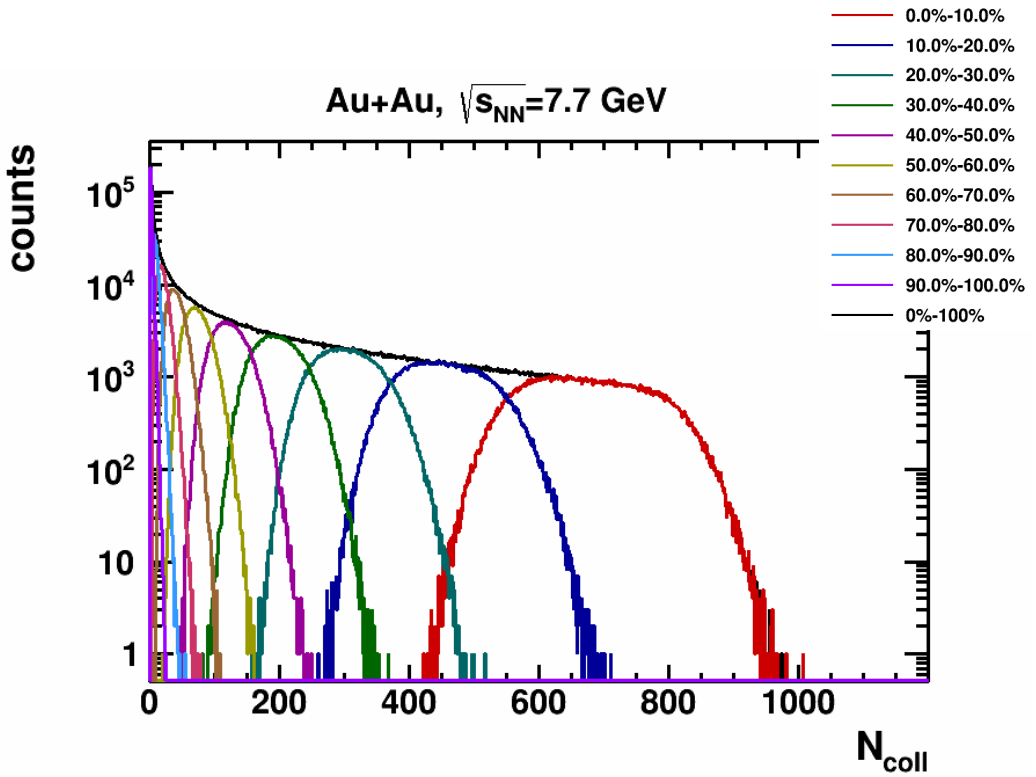


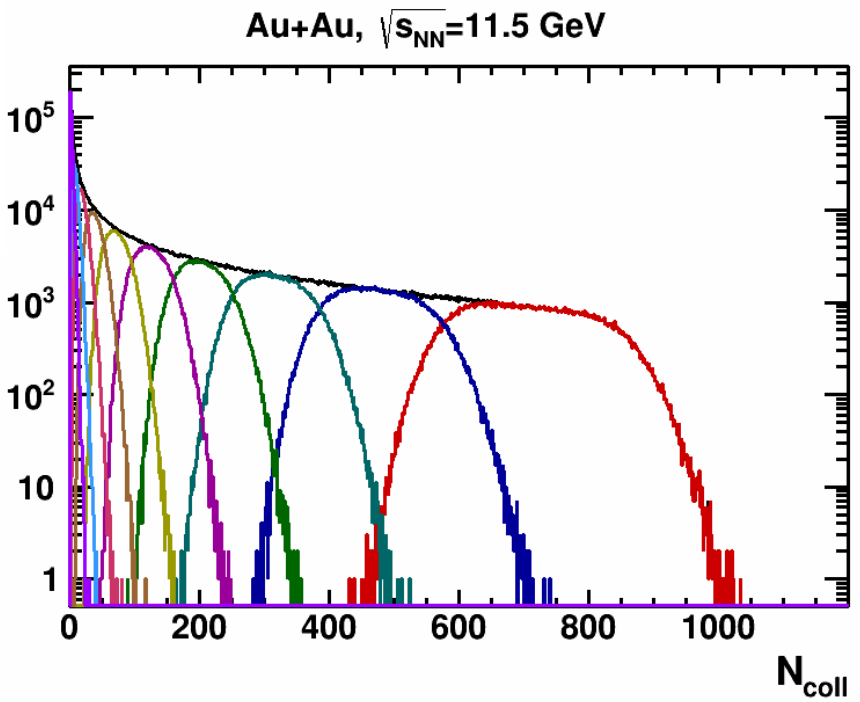
Centrality classes: Npart



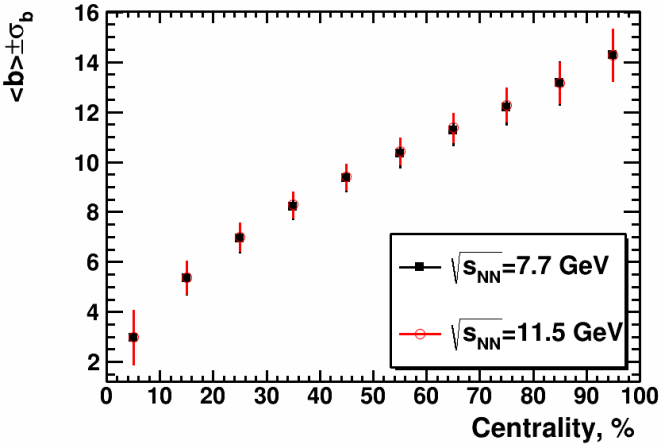


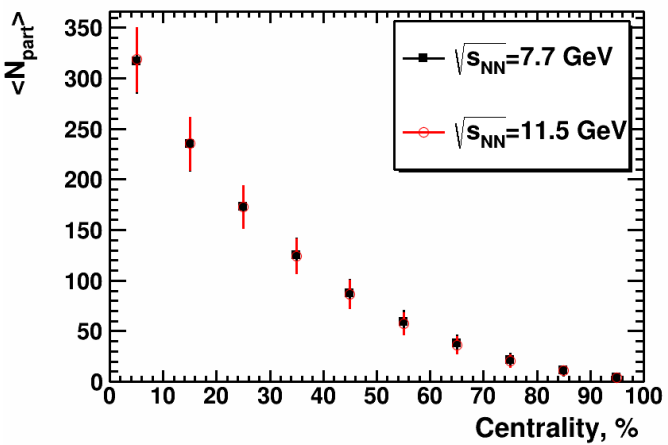
Centrality classes: Ncoll

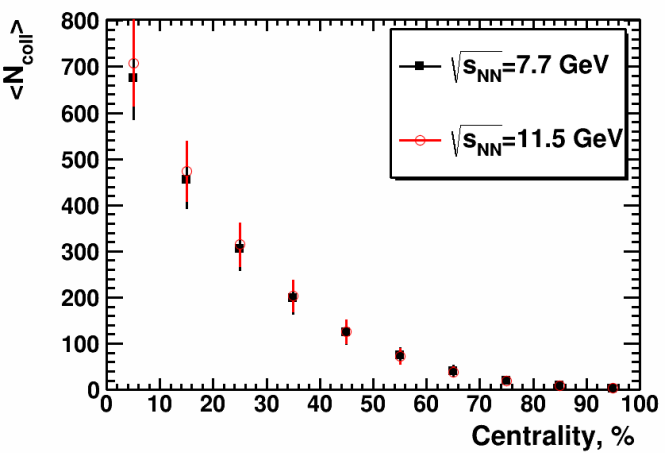




Centrality classes: Ncoll

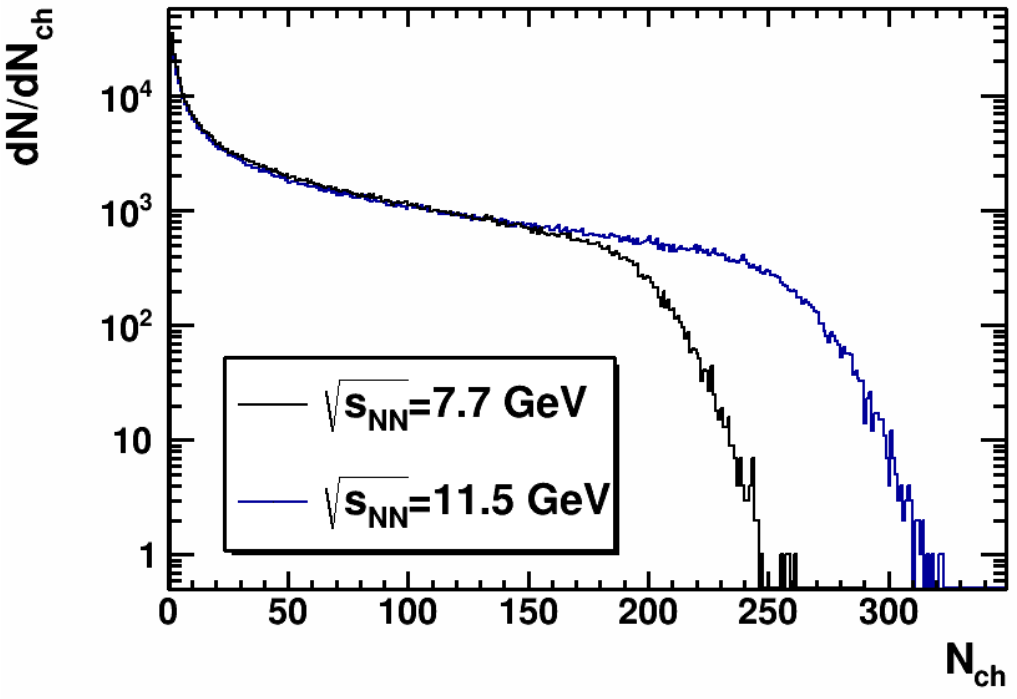






Centrality framework results for UrQMD reco with pion multiplicity

Charged particle multiplicity in MPD



Reconstructed data:

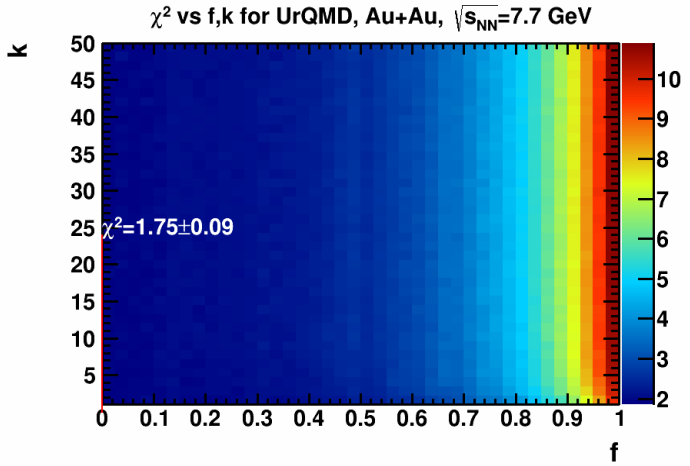
- UrQMD 3.4 simulation
  - Au+Au, N_{ev}=500k, $\sqrt{s_{NN}}$=7.7, 11.5 GeV
- GEANT4 MPD detector simulation
- Reconstruction procedure:
  - Realistic tracking in TPC (Cluster Finder)

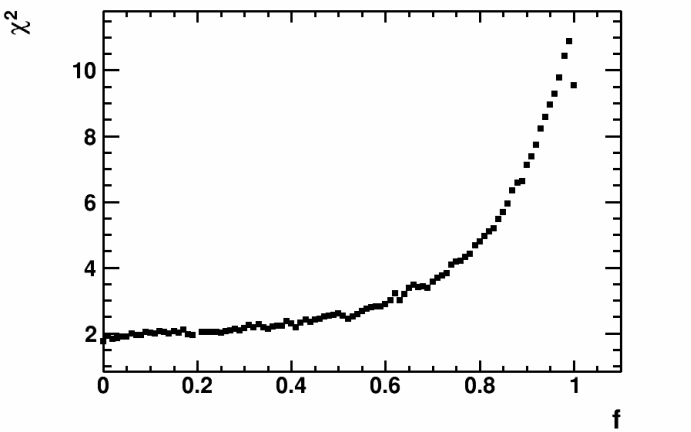
Used particle selection:

- Only charged pions
- $|\eta|<0.5$
- $p_T>0.15$ GeV/c

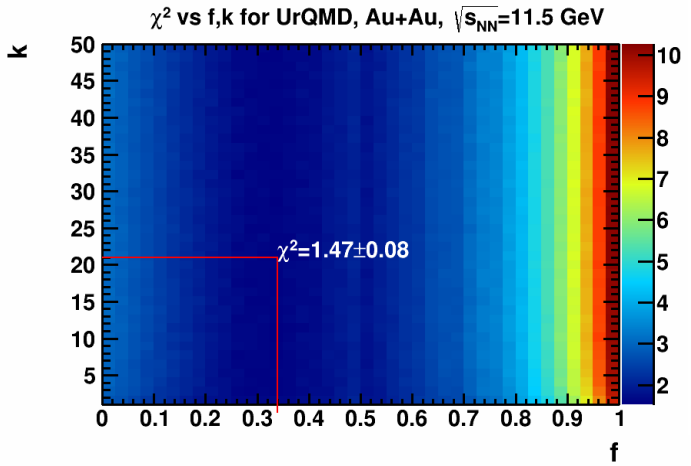
Fit parameters f,k vs χ^2

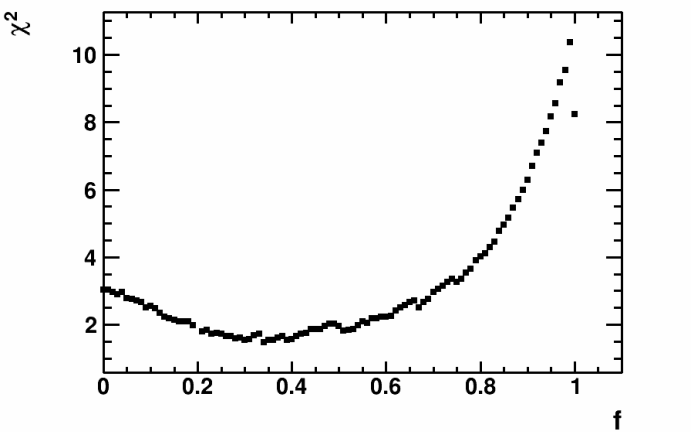
f=0, k=42, μ=0.24, χ^2=1.39±0.1, M=(10,240)





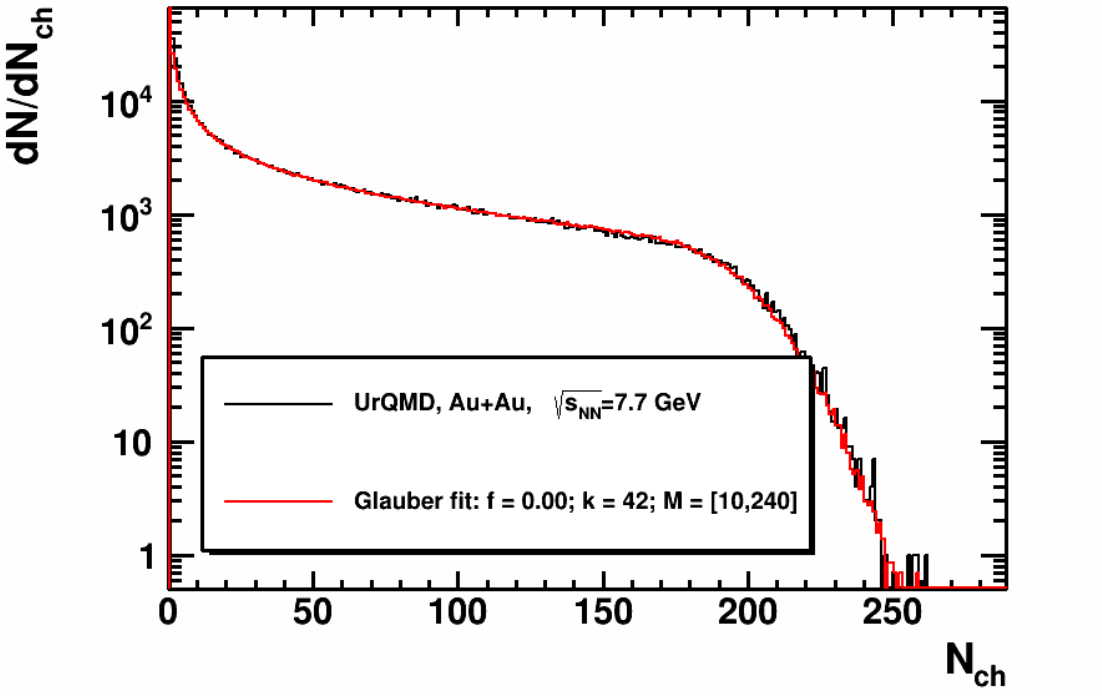
f=0.01, k=43, μ=0.3, χ^2=1.17±0.07, M=(10,320)

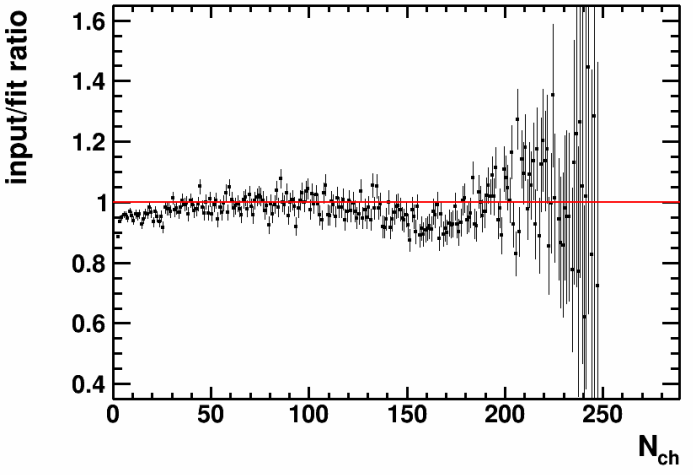




MC Glauber fit: $\pi^{\pm}$ multiplicity

f=0, k=42, μ=0.24, χ^2=1.39±0.1, M=(10,240)





MC Glauber fit is in the good agreement with simulated input for the large multiplicity region

MC Glauber fit: $\pi^{\pm}$ multiplicity

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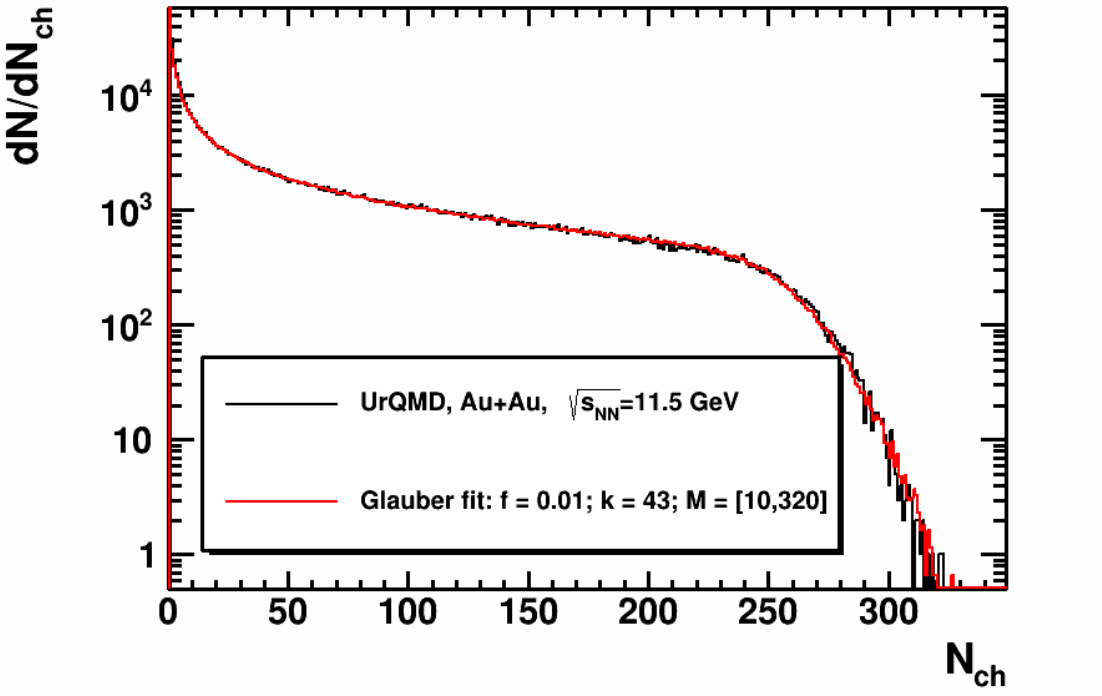
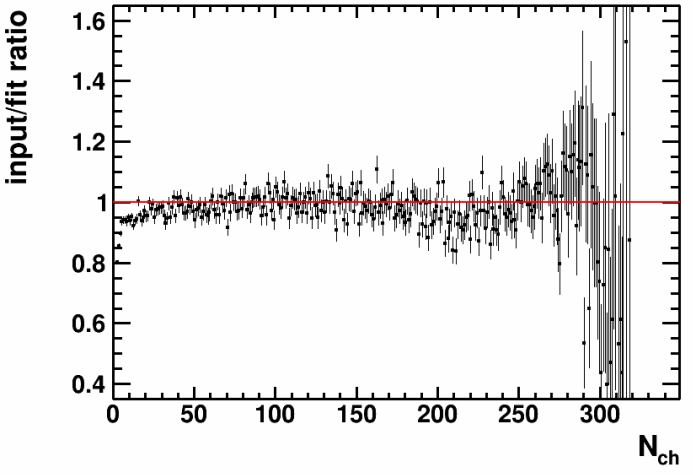
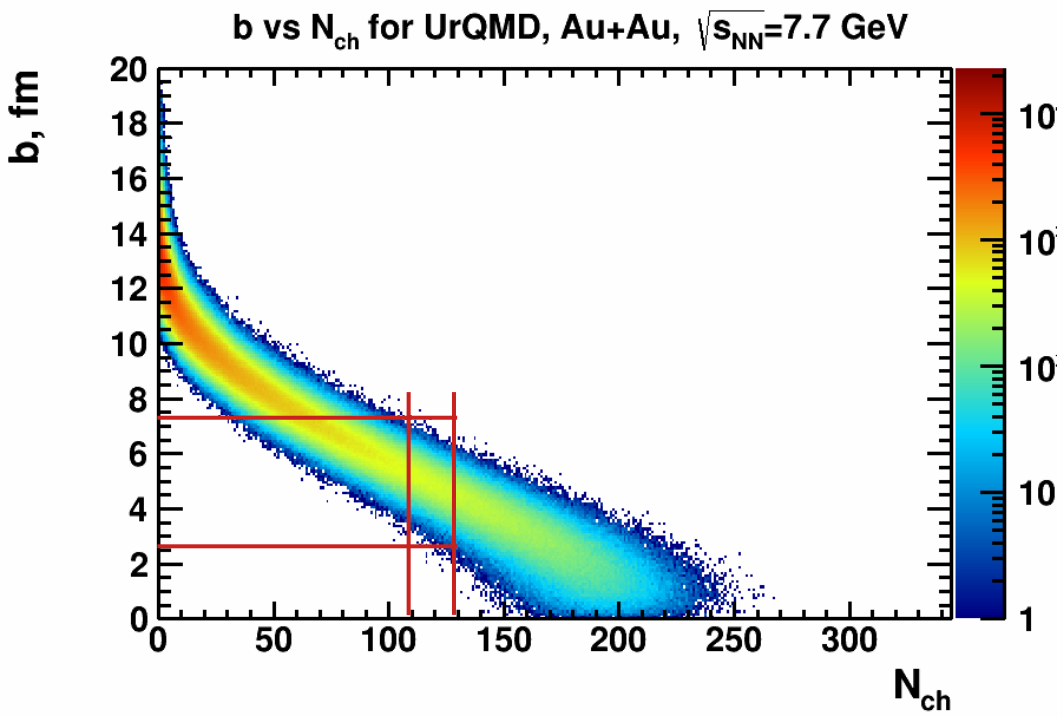
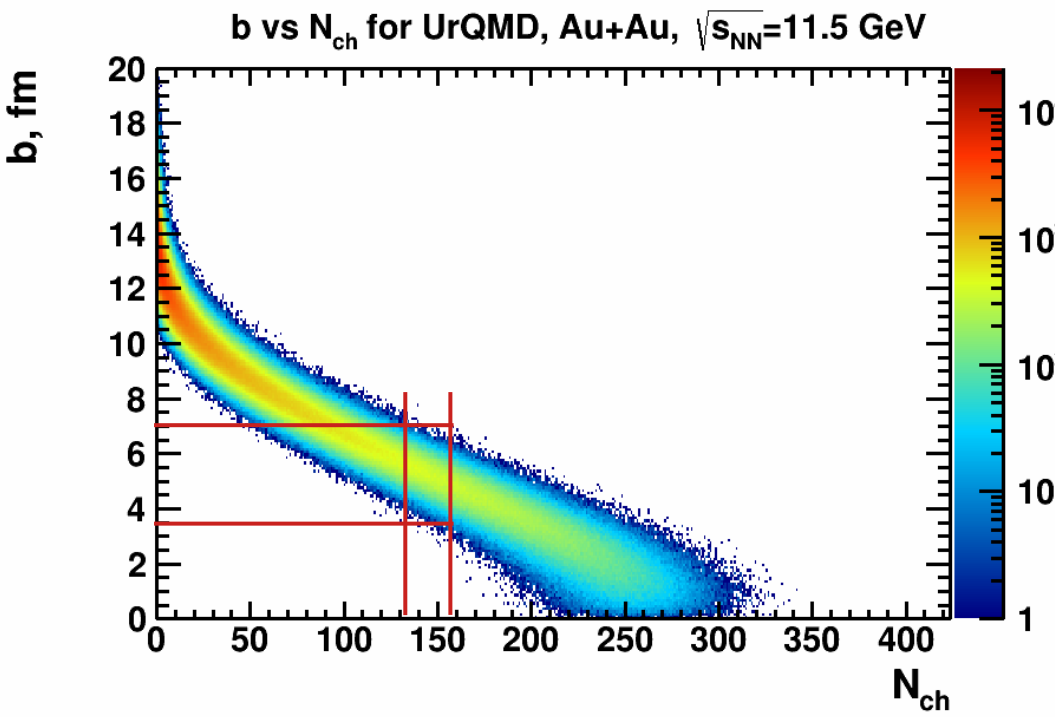




MC Glauber fit is in the good agreement with simulated input for the large multiplicity region

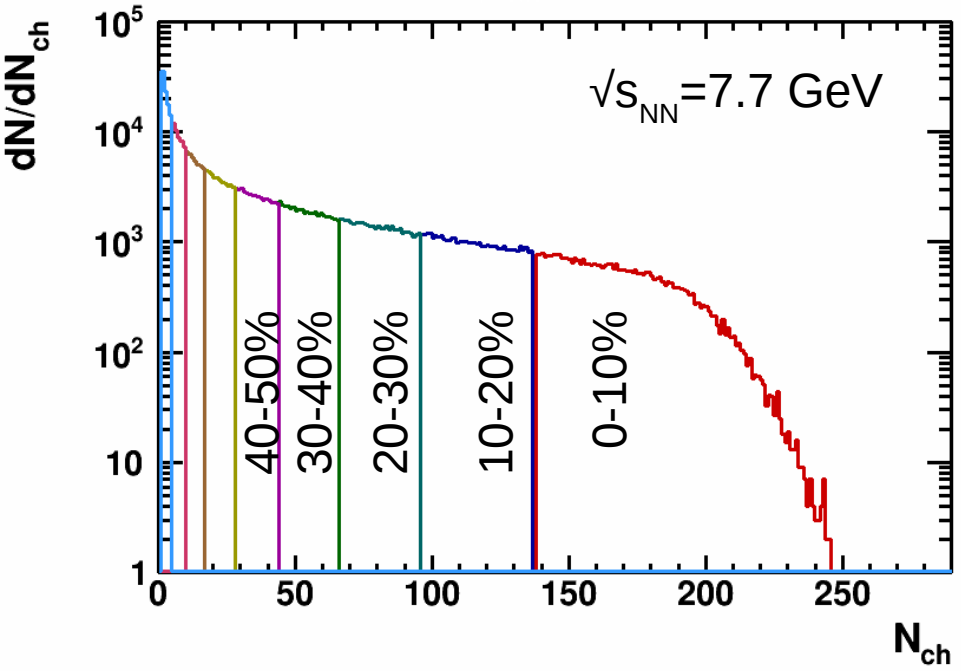
b vs. multiplicity correlation

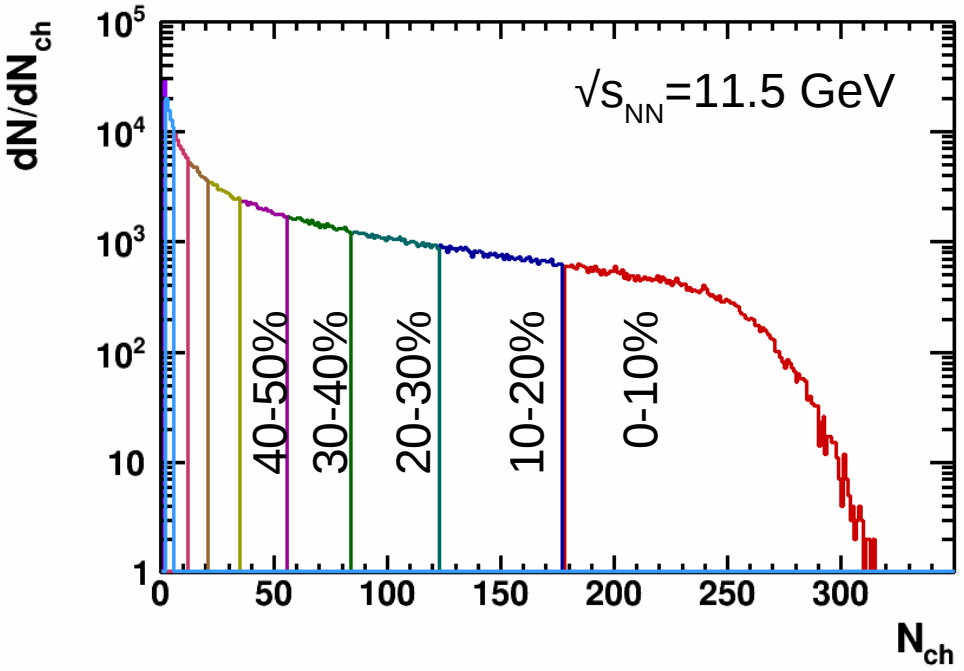




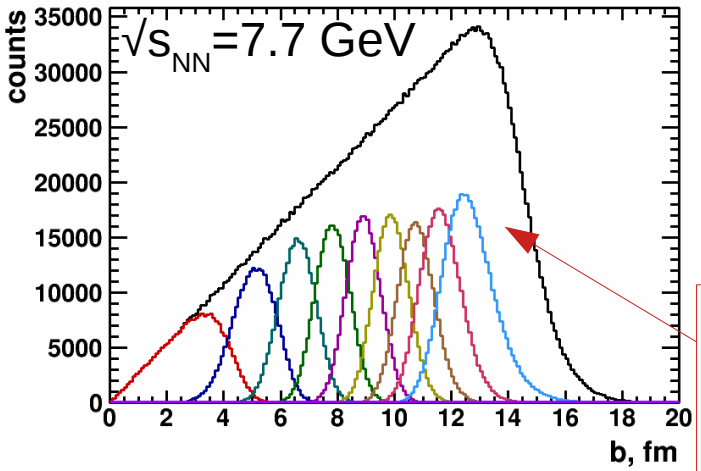
Events in multiplicities M ± ΔM have impact parameter in range b ± σ_b

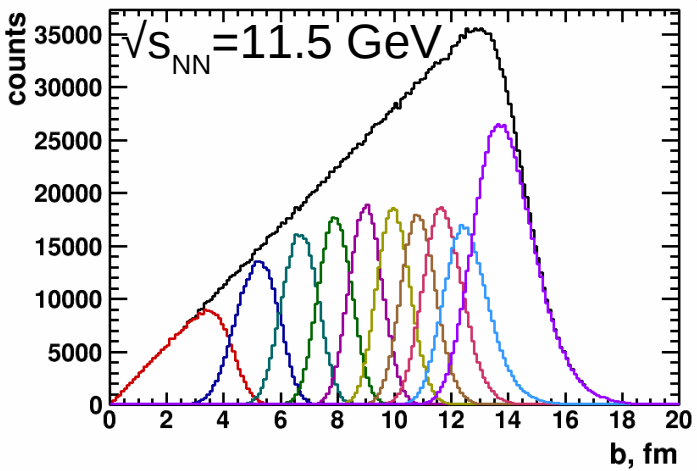
N_{ch} distribution in centrality classes





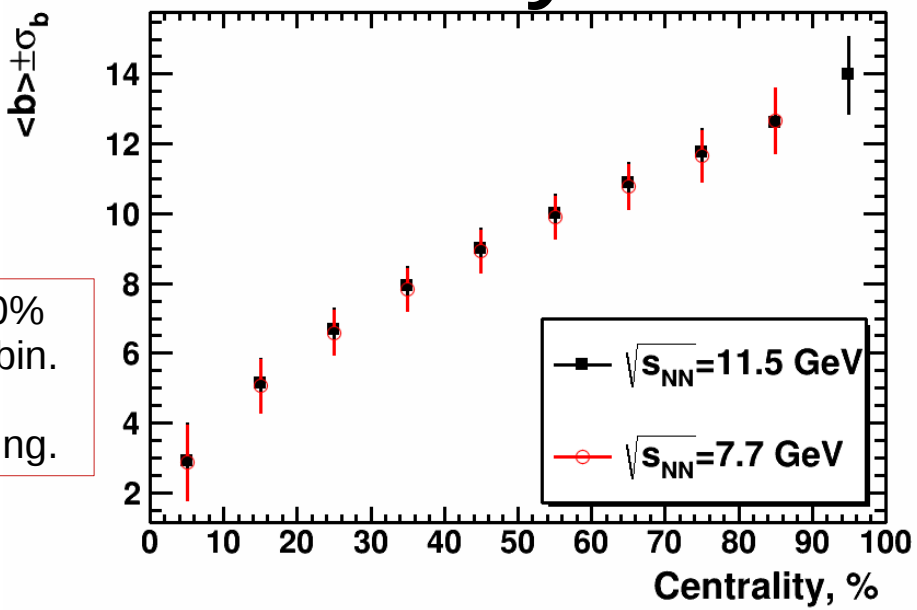
b distribution in centrality classes



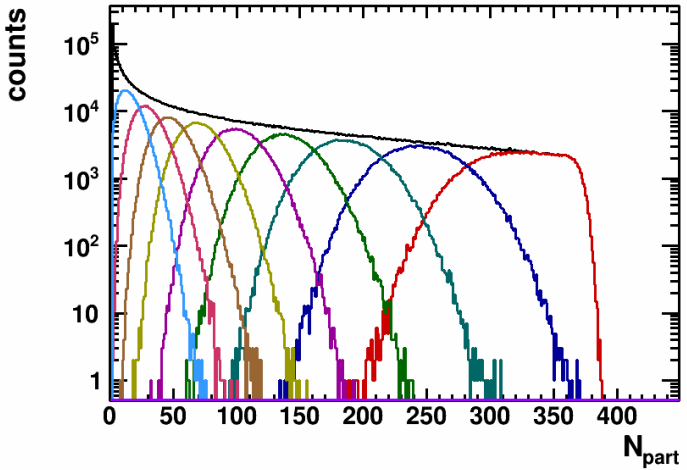


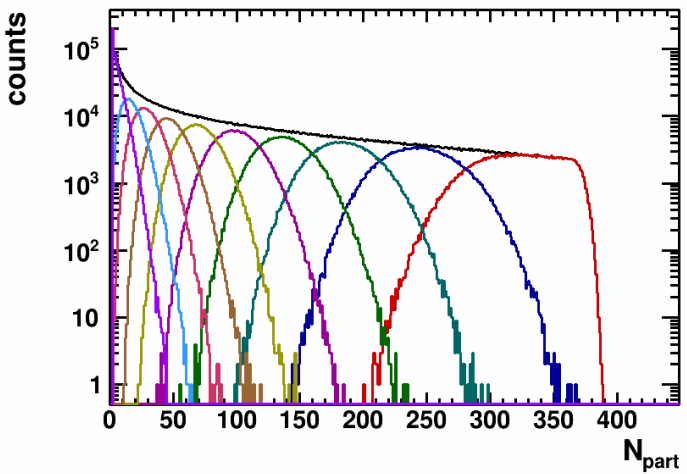
No 90-100% centrality bin.

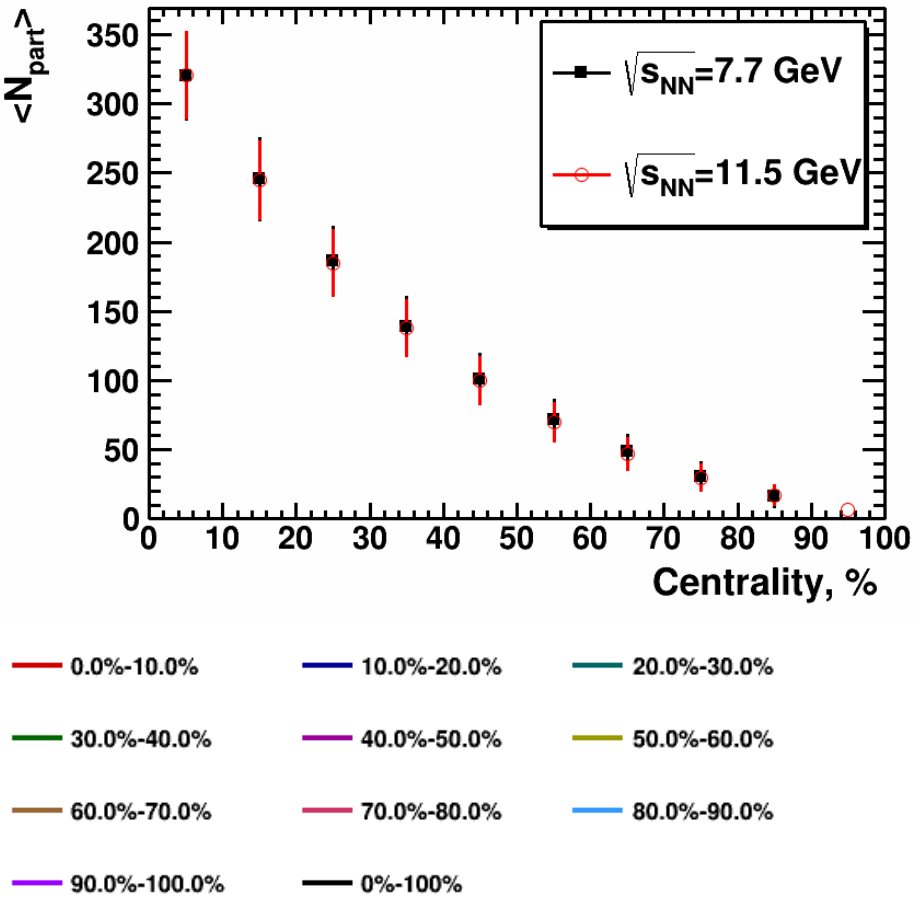
Investigating.



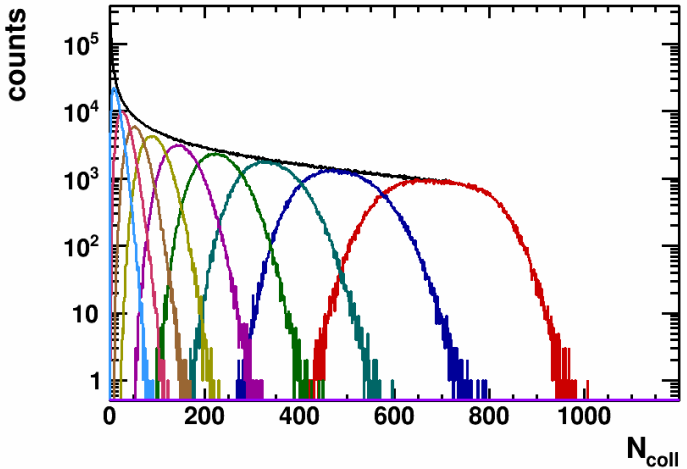
N_{part} distribution in centrality classes

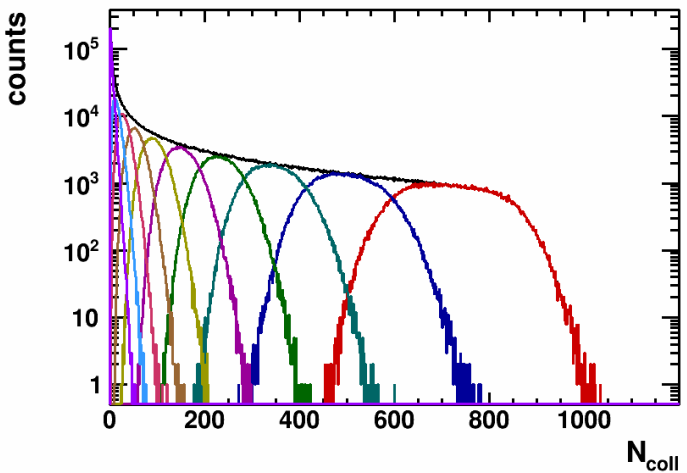


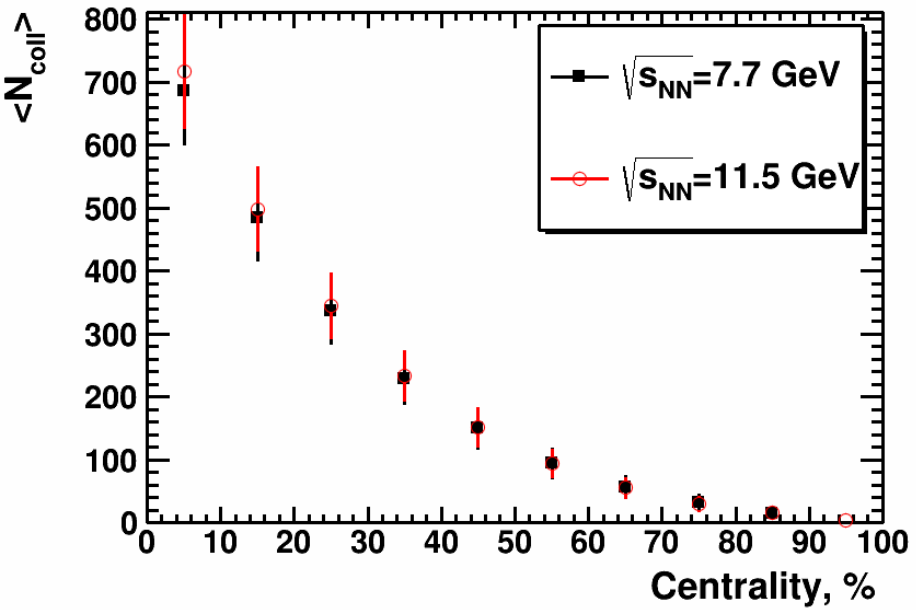


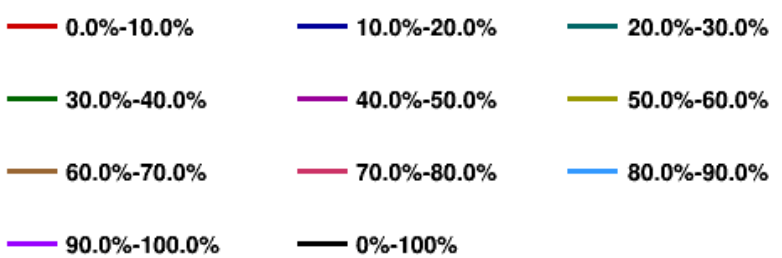


N_{coll} distribution in centrality classes



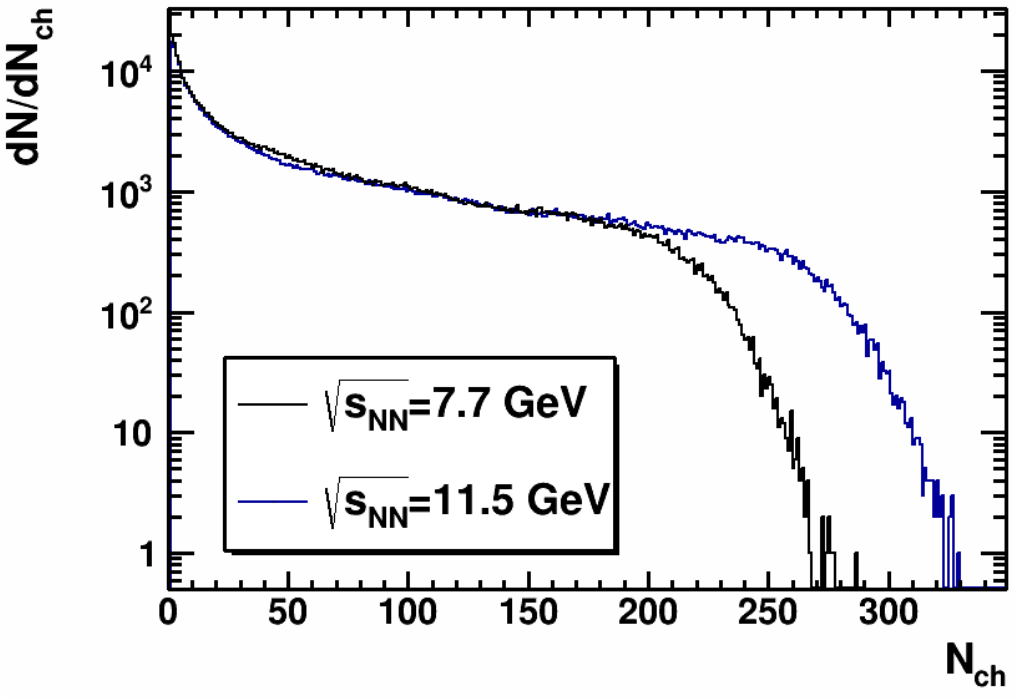






Centrality framework results for PHSD

Charged particle multiplicity in PHSD



Generated data:

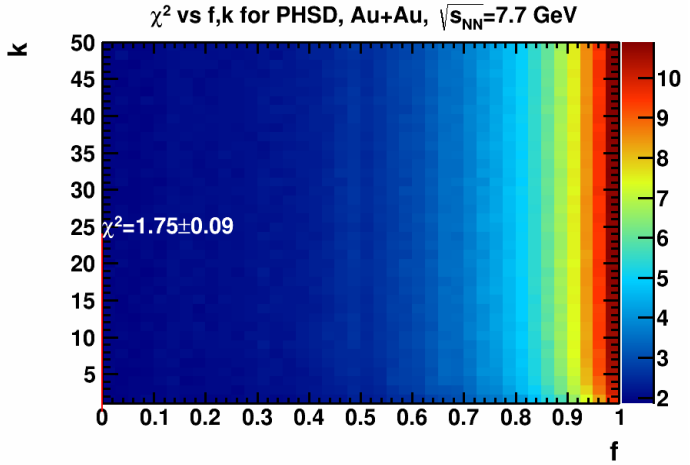
- PHSD v4.0 simulation
  - Au+Au, N_{ev}=500k, $\sqrt{s_{NN}}$=7.7, 11.5 GeV

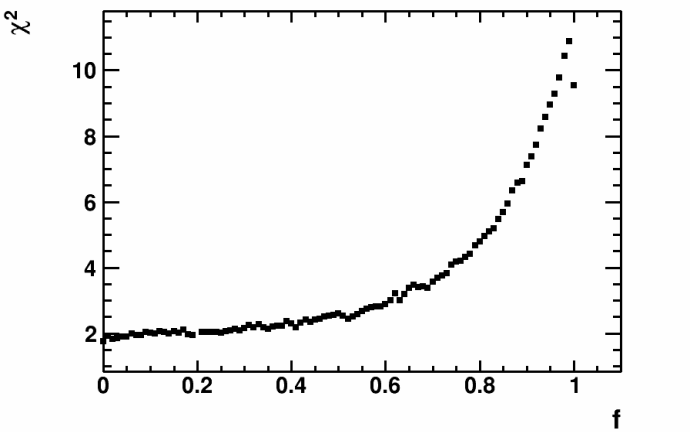
Used particle selection:

- $|\eta|<0.5$
- $p_T>0.15$ GeV/c

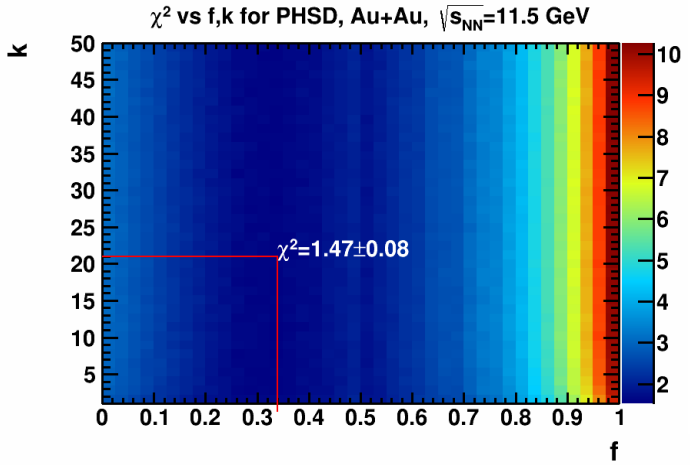
Fit parameters f,k vs χ^2

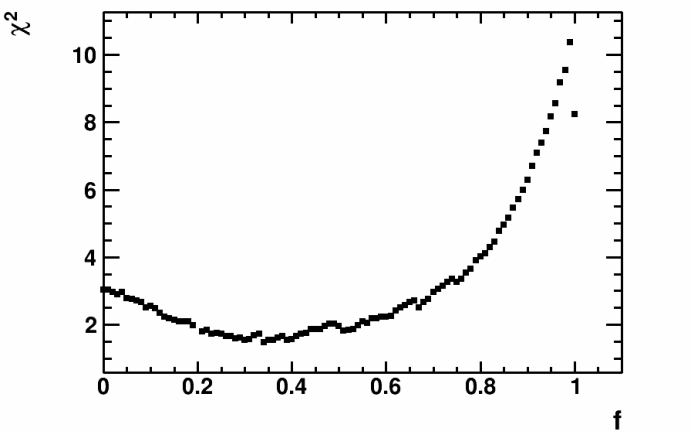
f=0, k=24, μ=0.27, χ^2=1.75±0.09, M=(10,265)





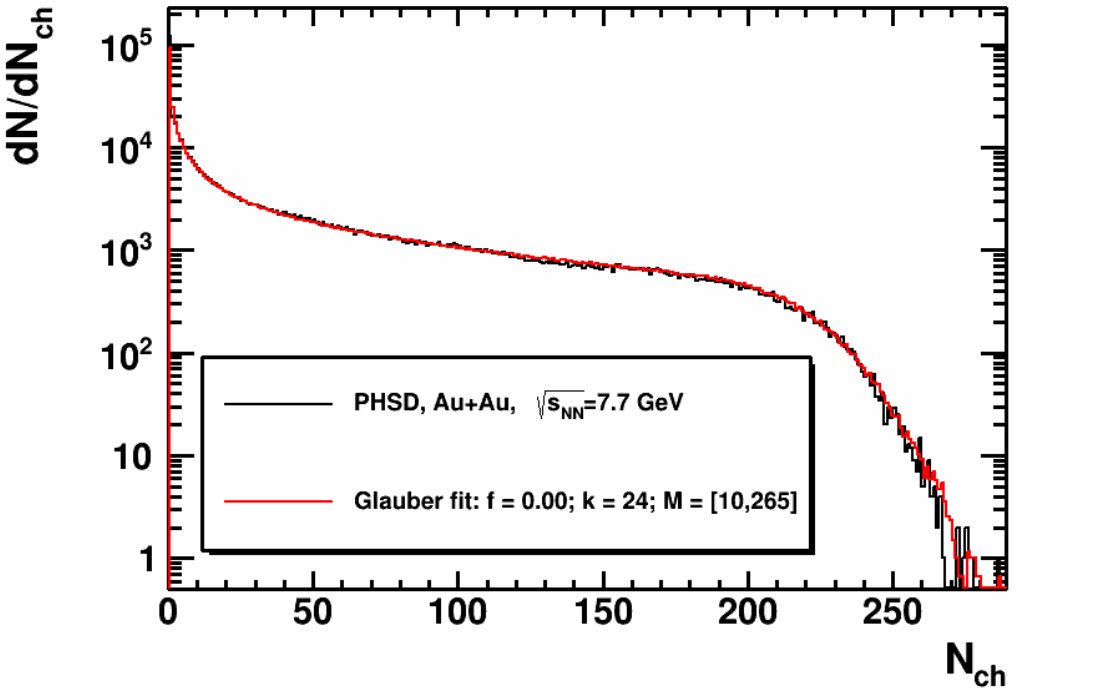
f=0.34, k=21, μ=0.39, χ^2=1.47±0.08, M=(10,320)

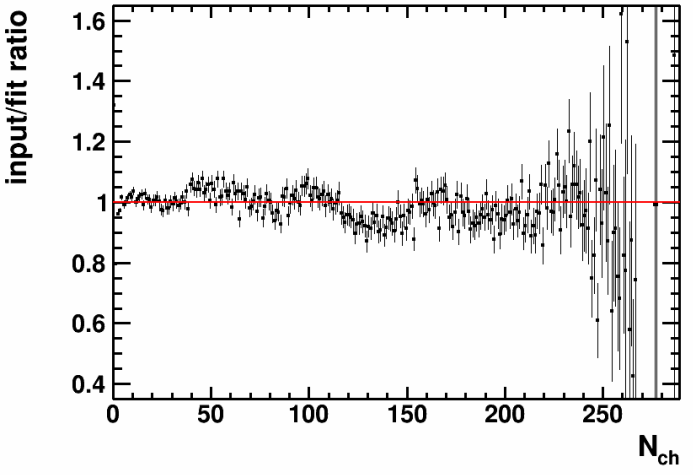




MC Glauber fit: $h^{\pm}$ multiplicity

f=0, k=24, μ=0.27, χ^2=1.75±0.09, M=(10,265)

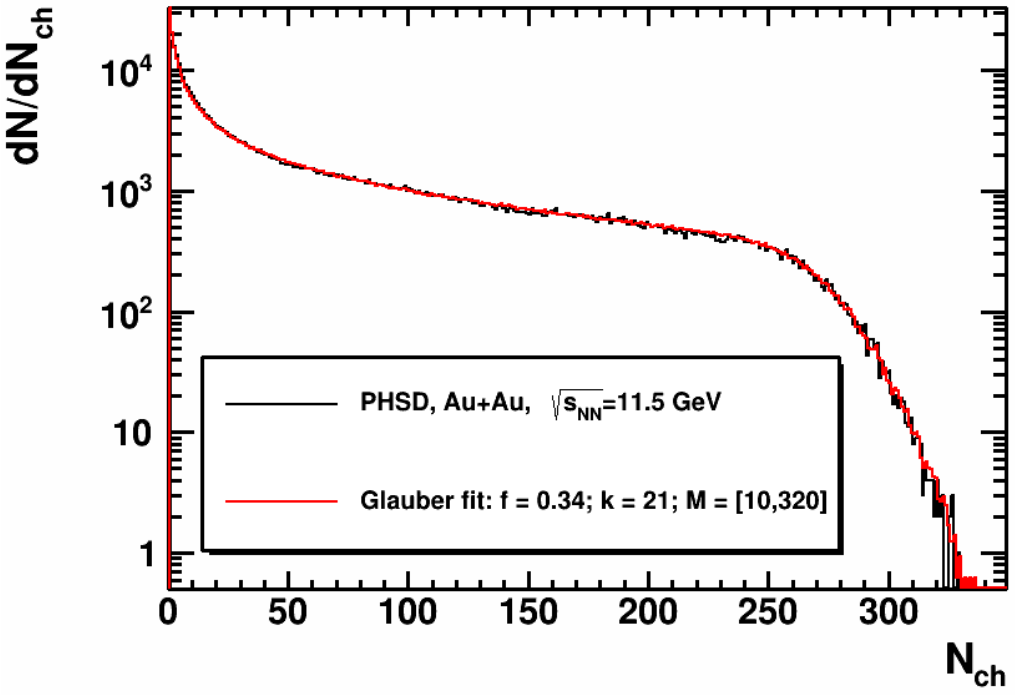


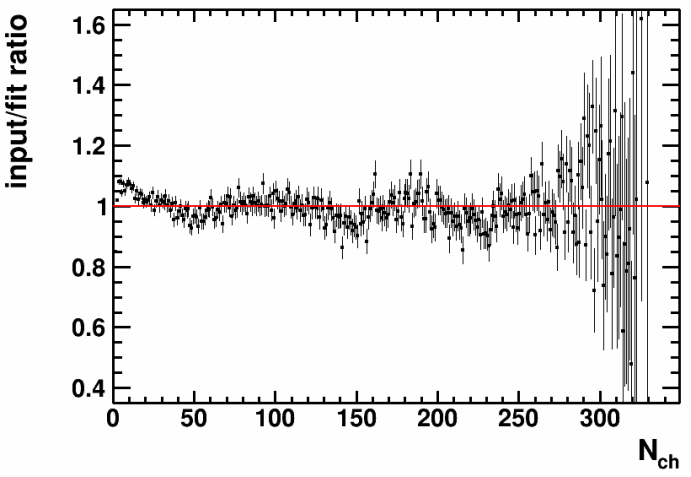


MC Glauber fit is in the good agreement with simulated input for the large multiplicity region

MC Glauber fit: $h^{\pm}$ multiplicity

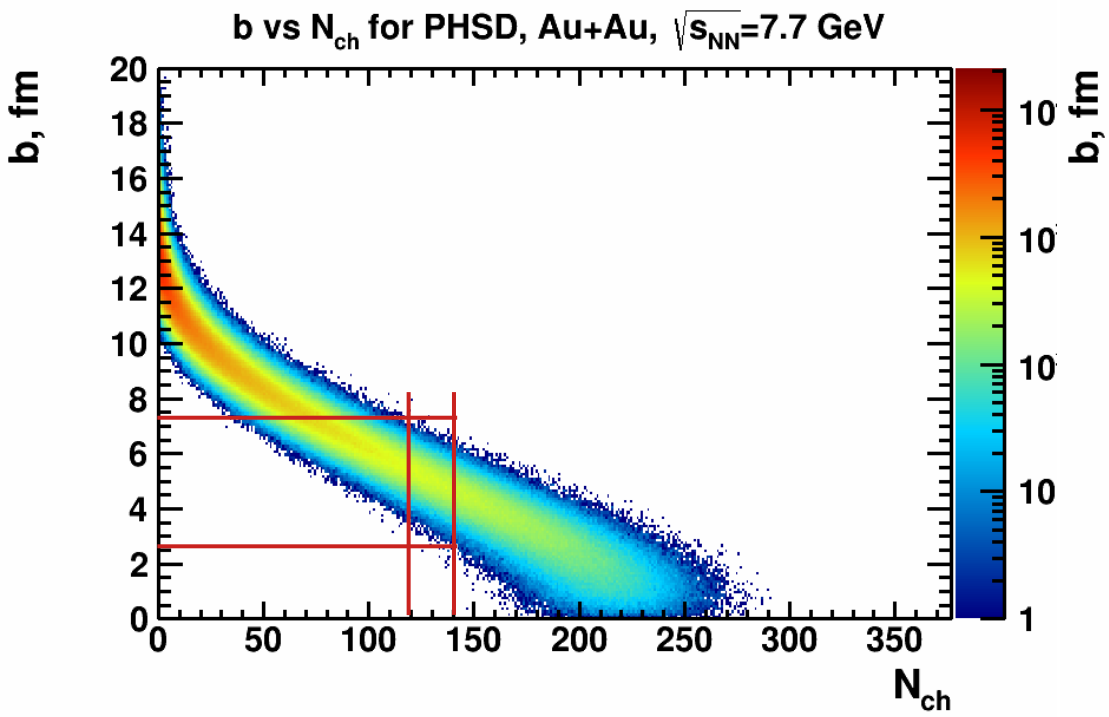
f=0.34, k=21, μ=0.39, χ^2=1.47±0.08, M=(10,320)

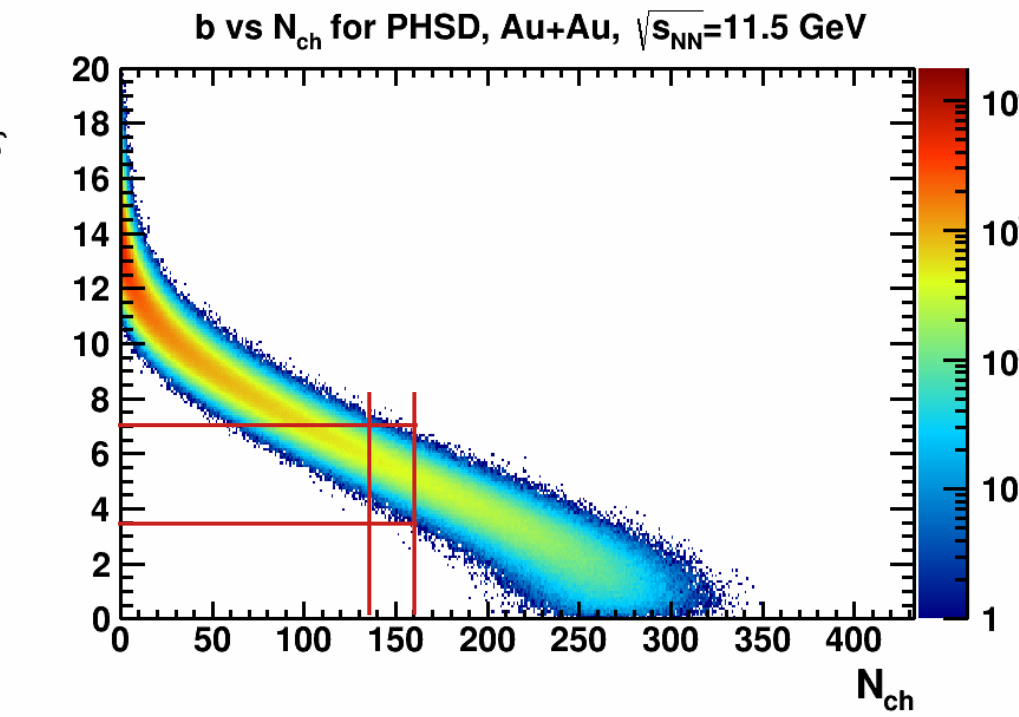




MC Glauber fit is in the good agreement with simulated input for the large multiplicity region

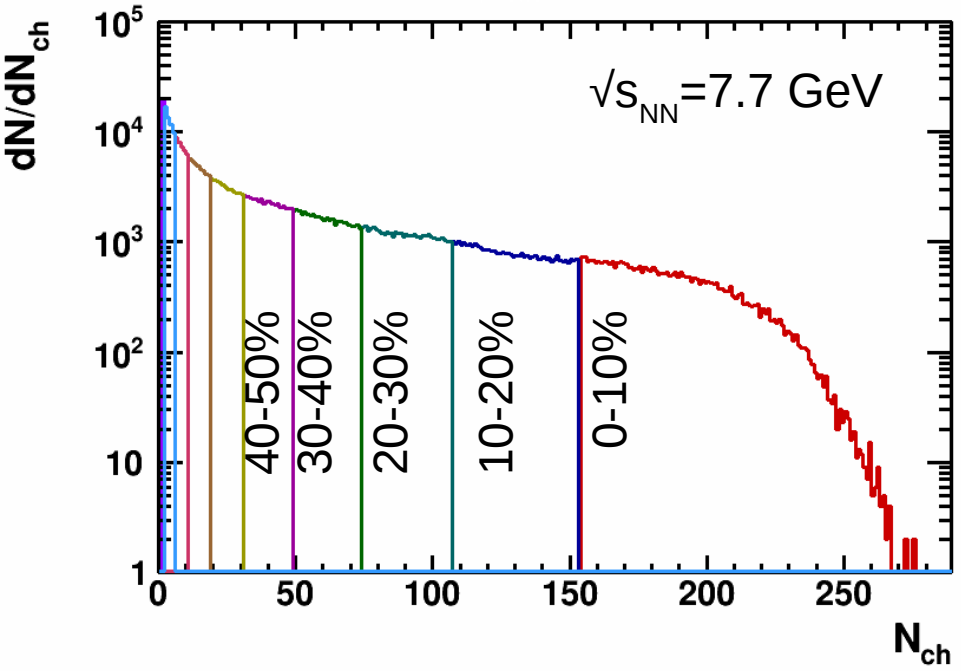
b vs. multiplicity correlation

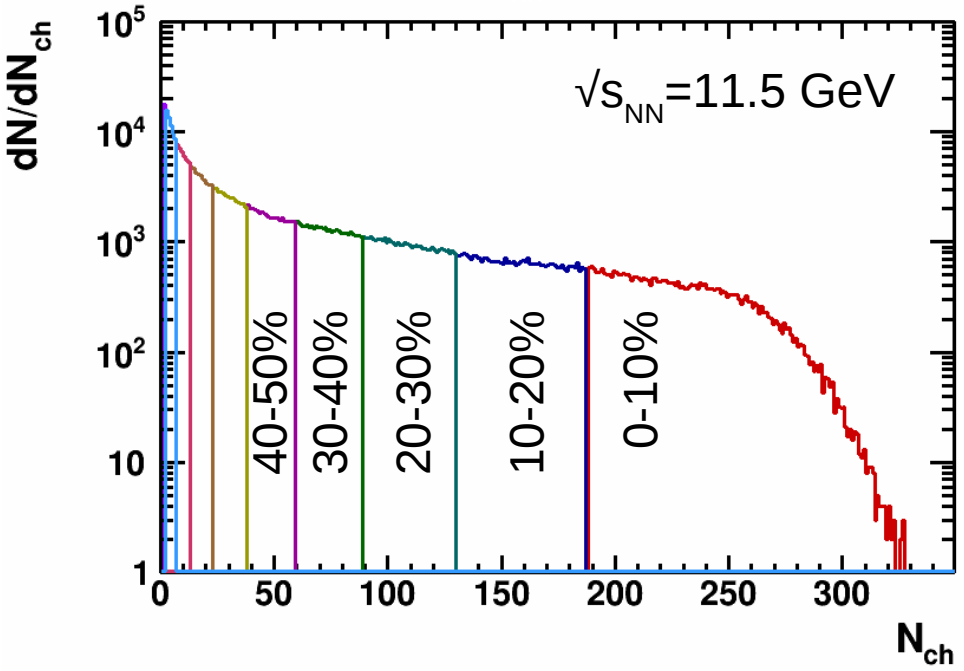




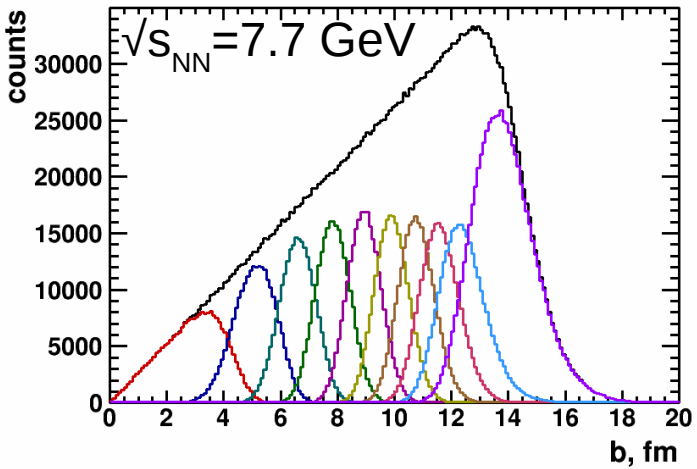
Events in multiplicities M ± ΔM have impact parameter in range b ± σ_b

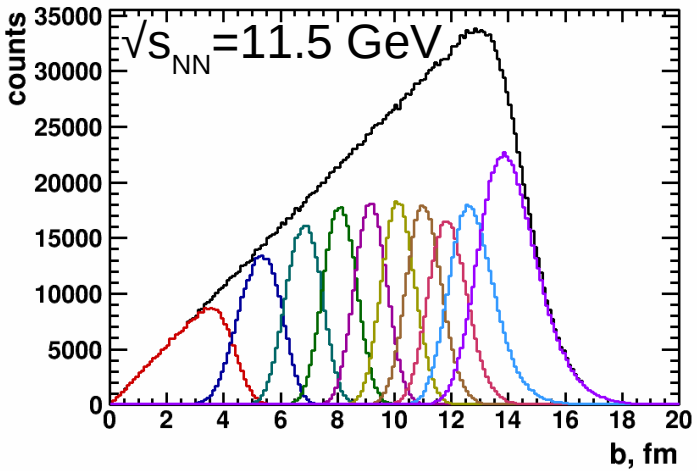
N_{ch} distribution in centrality classes

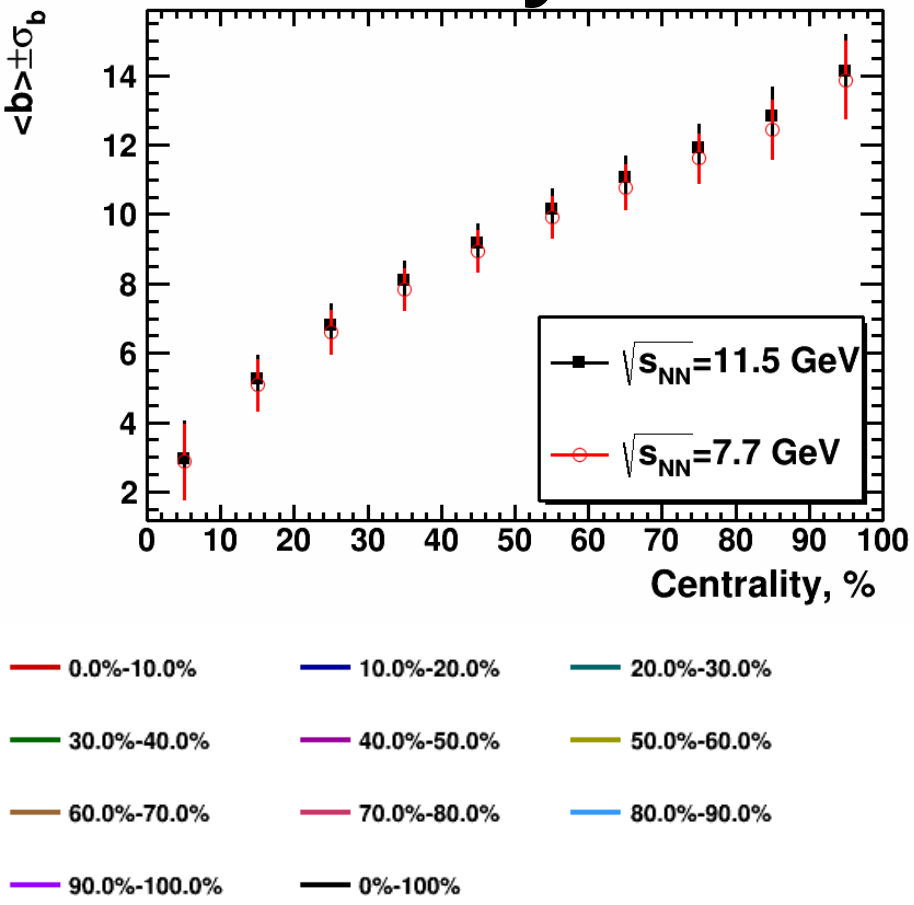




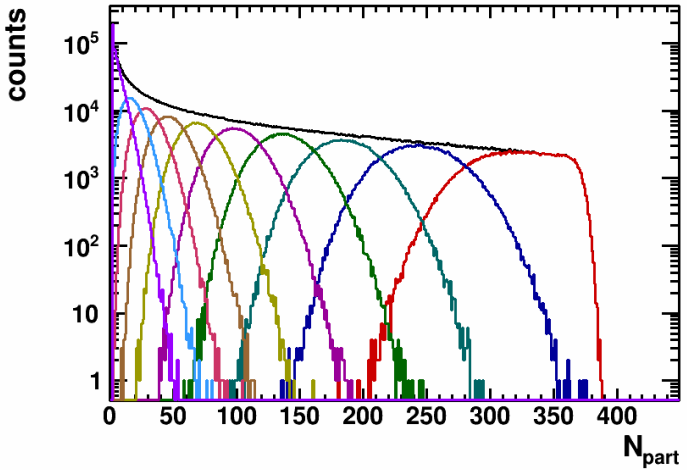
b distribution in centrality classes

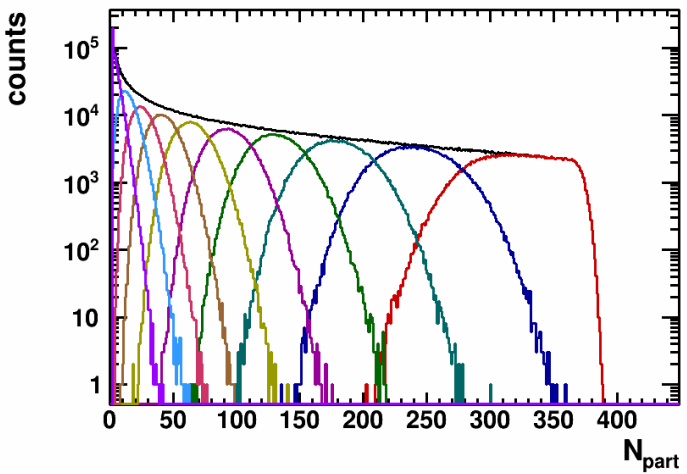


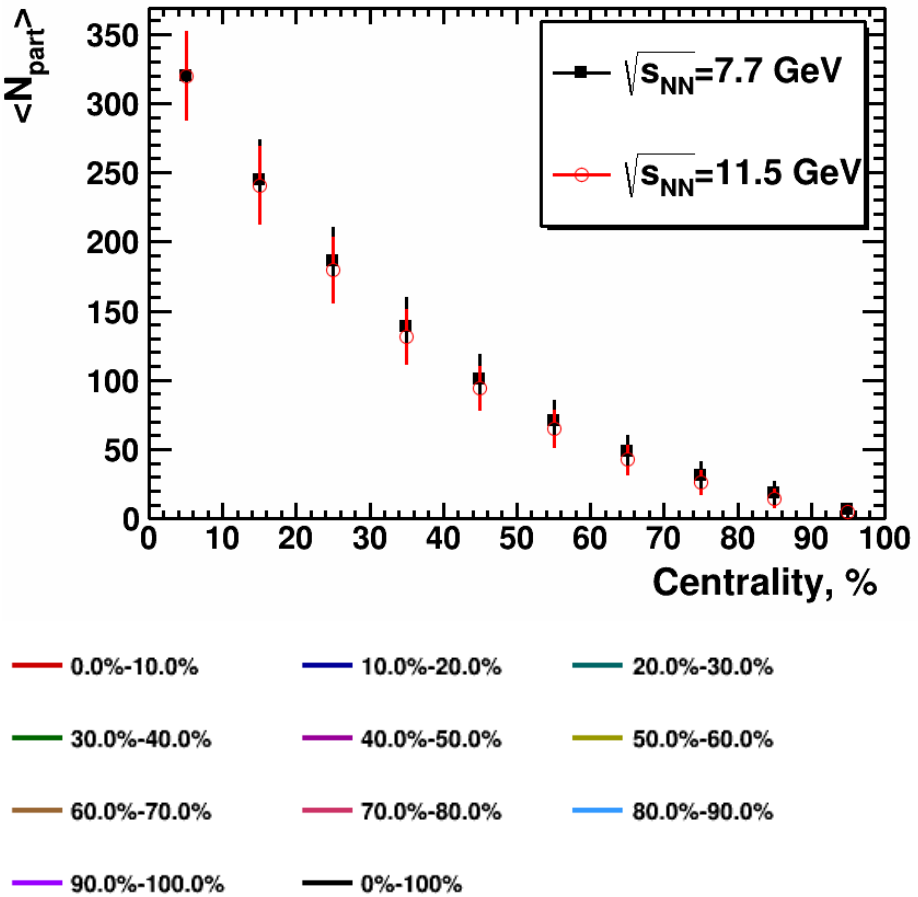




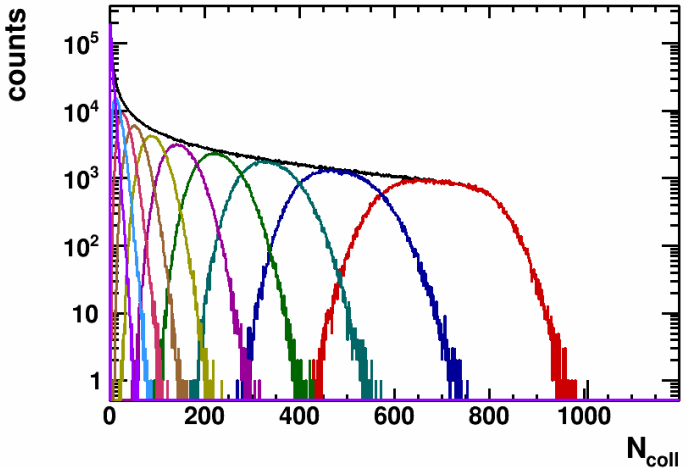
N_{part} distribution in centrality classes

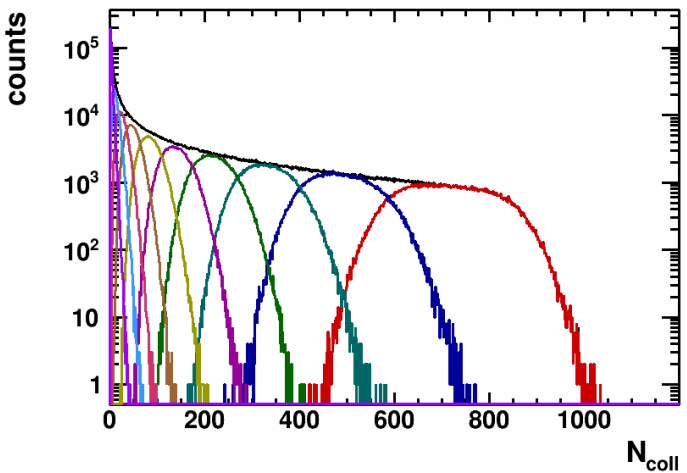


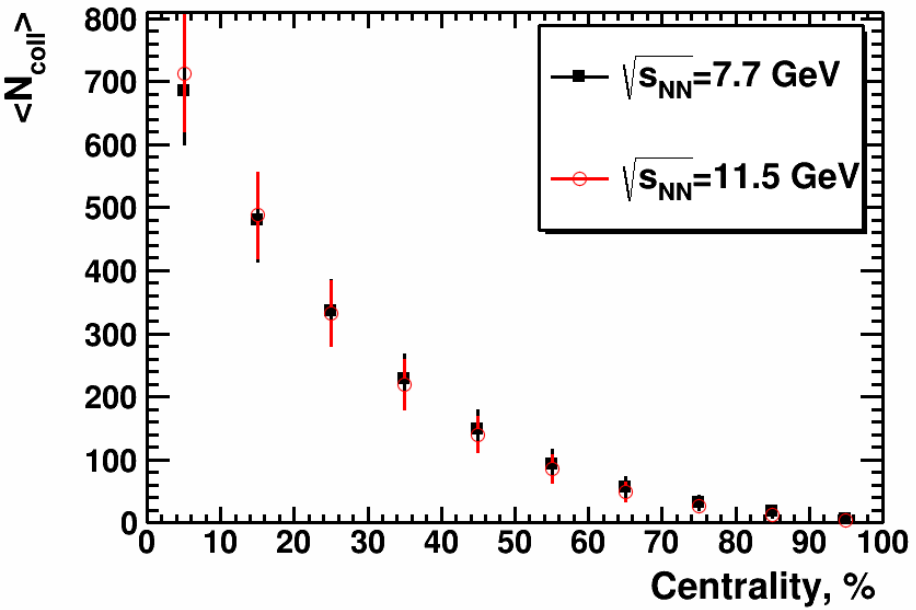




N_{coll} distribution in centrality classes

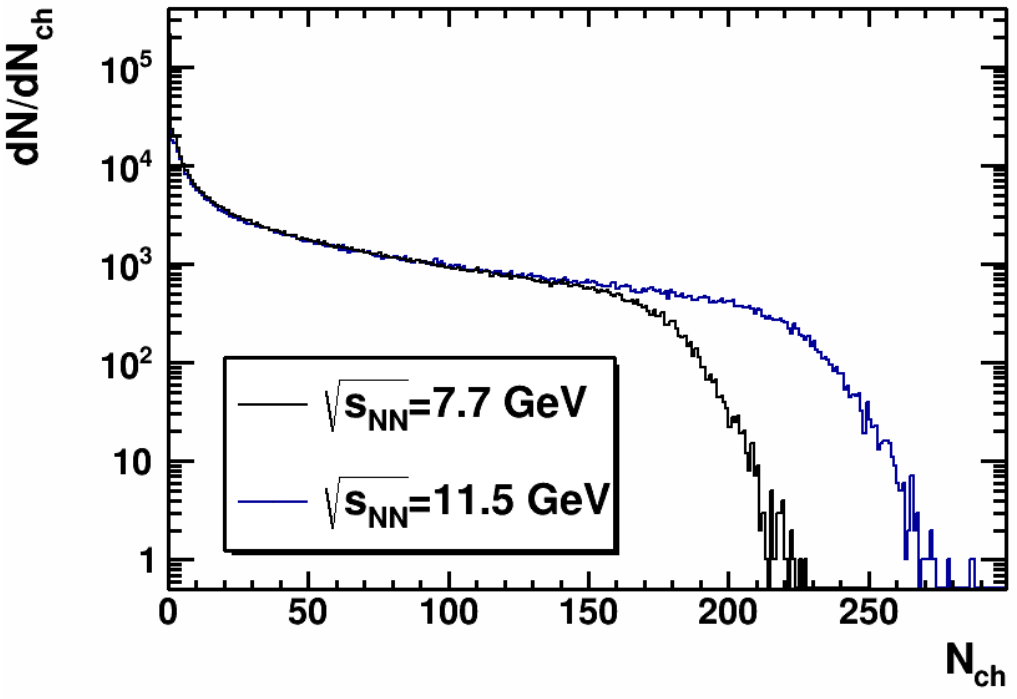






Centrality framework results for SMASH

Charged particle multiplicity in SMASH



Generated data:

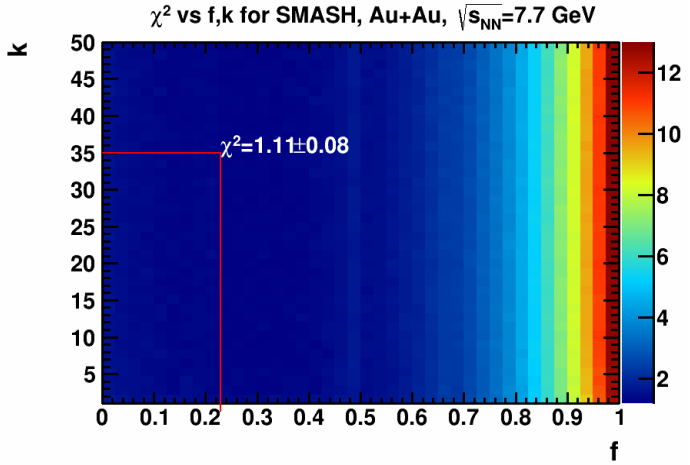
- SMASH v1.6 simulation
  - Au+Au, N_{ev}=500k, $\sqrt{s_{NN}}$=7.7, 11.5 GeV

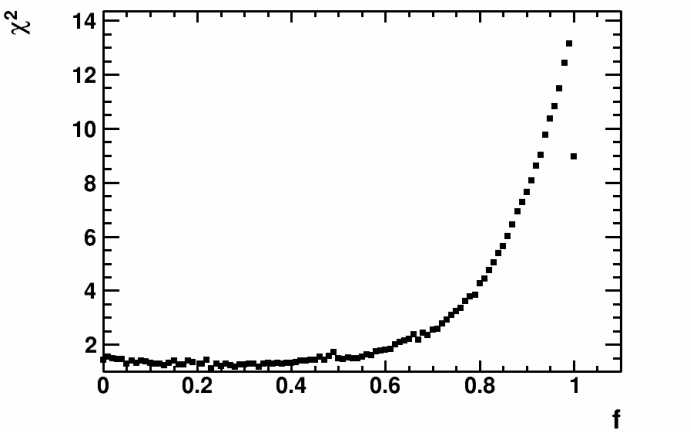
Used particle selection:

- $|\eta|<0.5$
- $p_T>0.15$ GeV/c

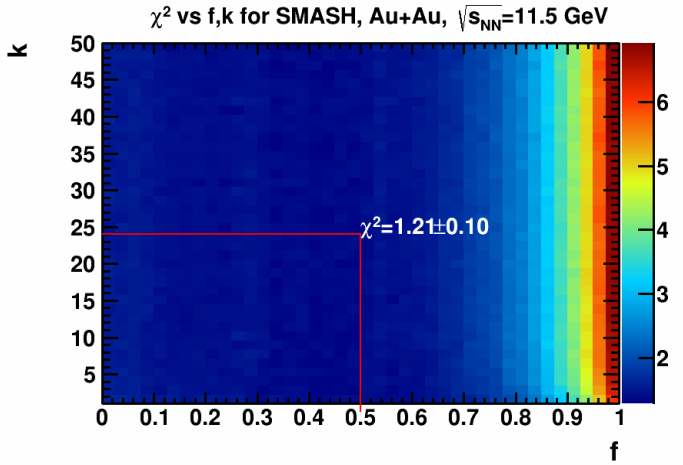
Fit parameters f,k vs χ^2

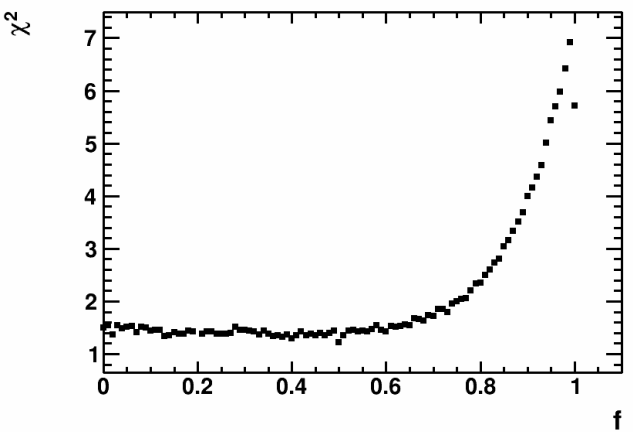
F=0.23, k=35, μ=0.24, χ^2=1.11±0.08, M=(5,225)





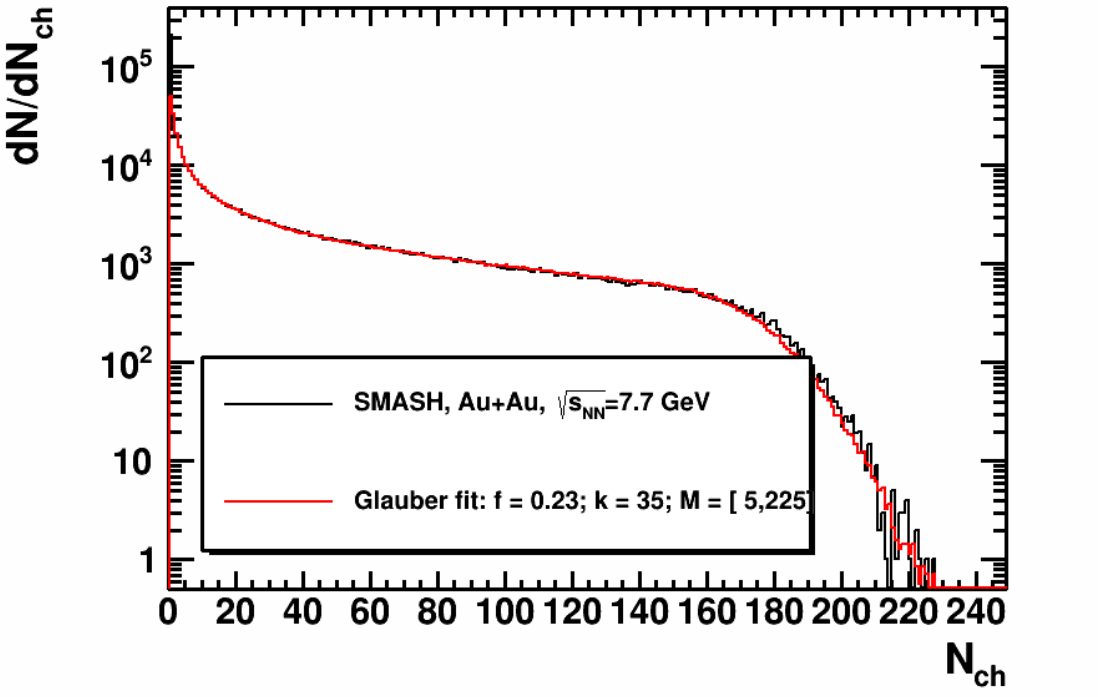
f=0.5, k=24, μ=0.36, χ^2=1.21±0.1, M=(10,265)

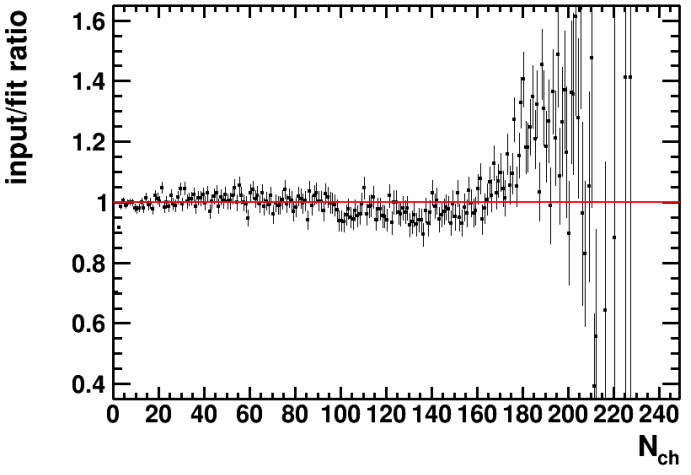




MC Glauber fit: $h^{\pm}$ multiplicity

F=0.23, k=35, μ=0.24, χ^2=1.11±0.08, M=(5,225)

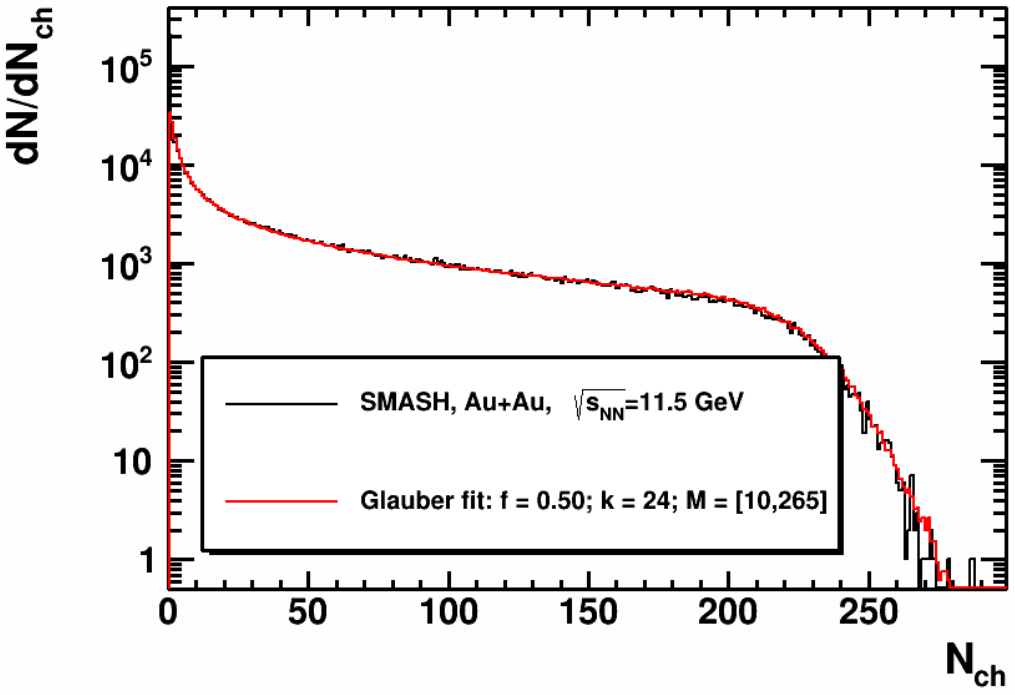


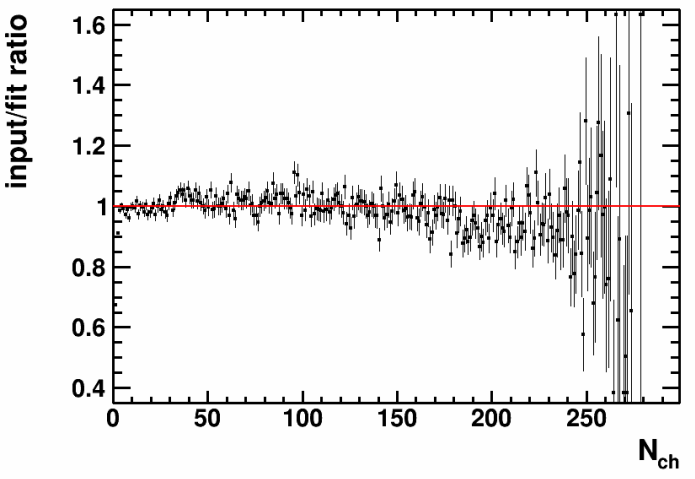


MC Glauber fit is deviate from SMASH data for large multiplicity region

MC Glauber fit: $h^{\pm}$ multiplicity

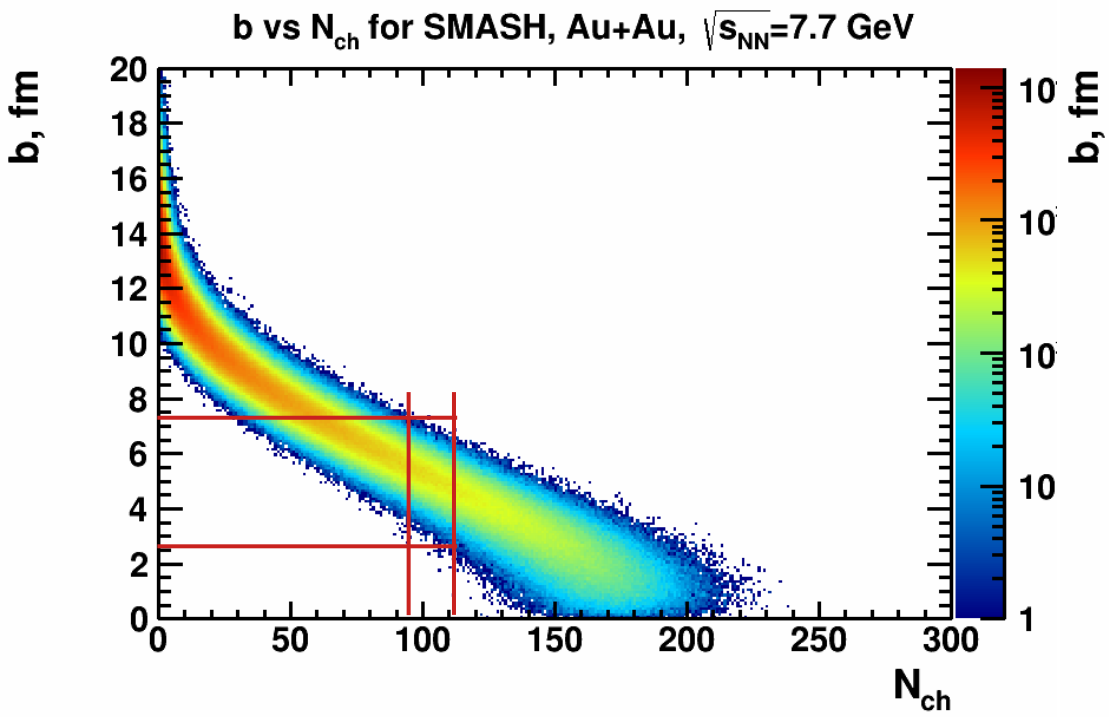
f=0.5, k=24, μ=0.36, χ^2=1.21±0.1, M=(10,265)

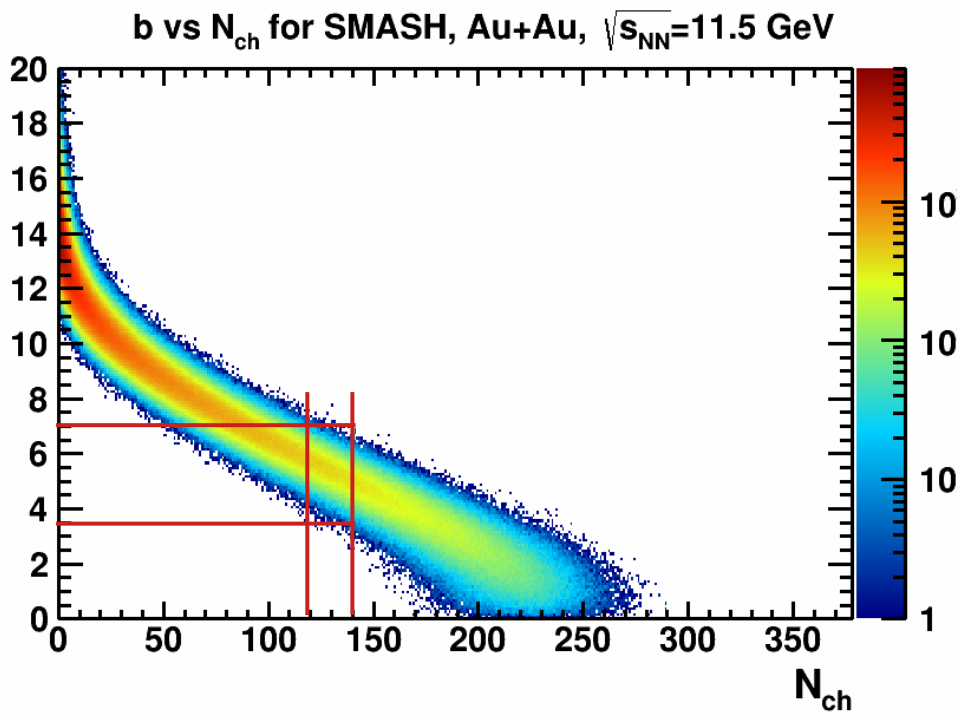




MC Glauber fit is in the good agreement with simulated input for the large multiplicity region

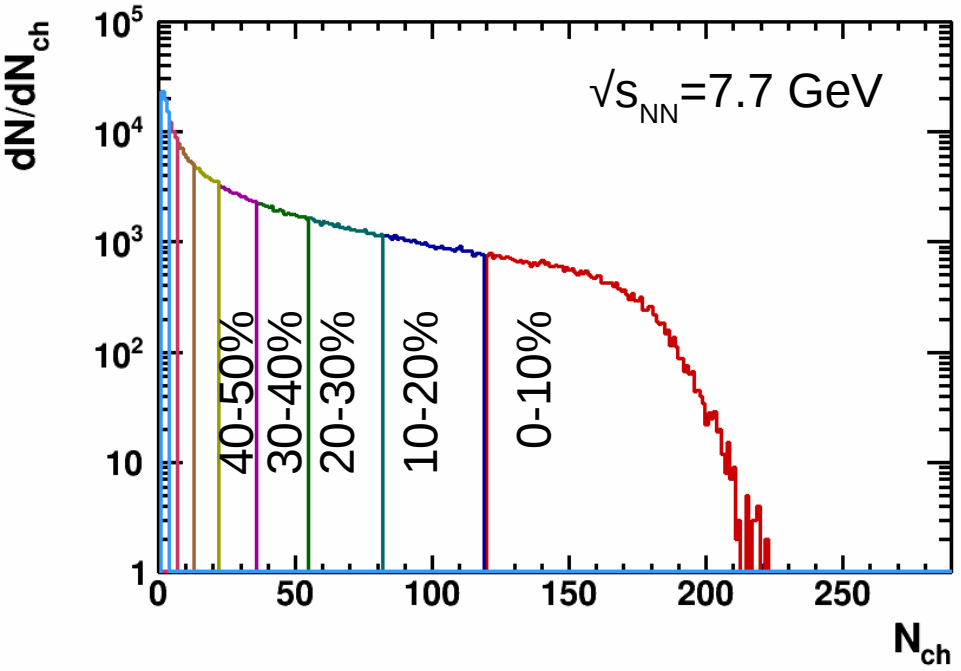
b vs. multiplicity correlation

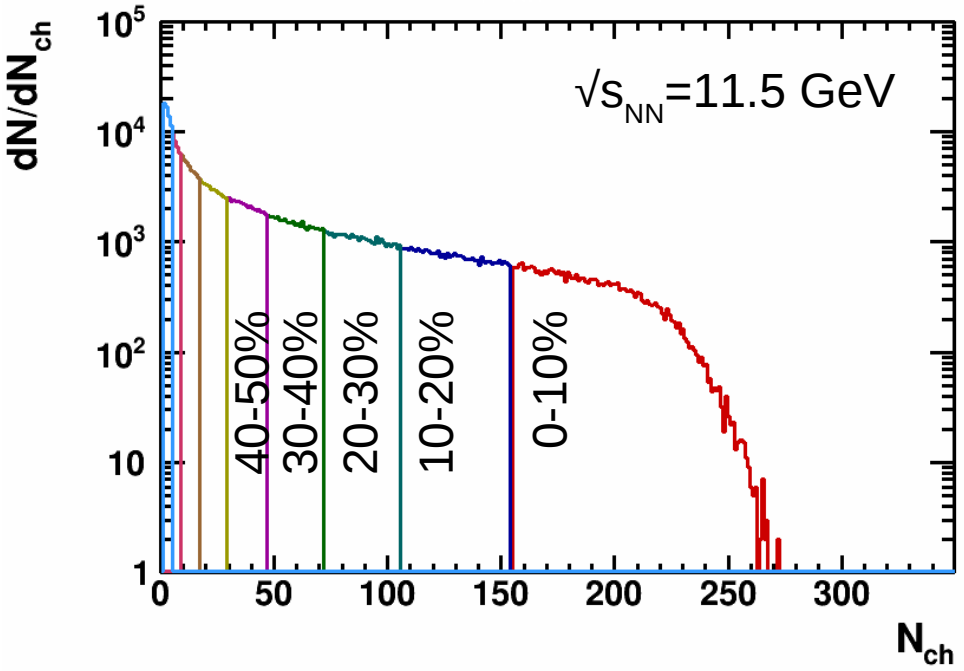




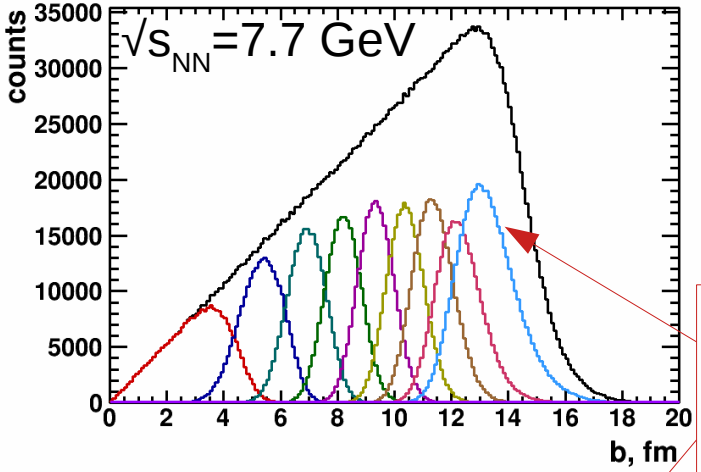
Events in multiplicities M ± ΔM have impact parameter in range b ± σ_b

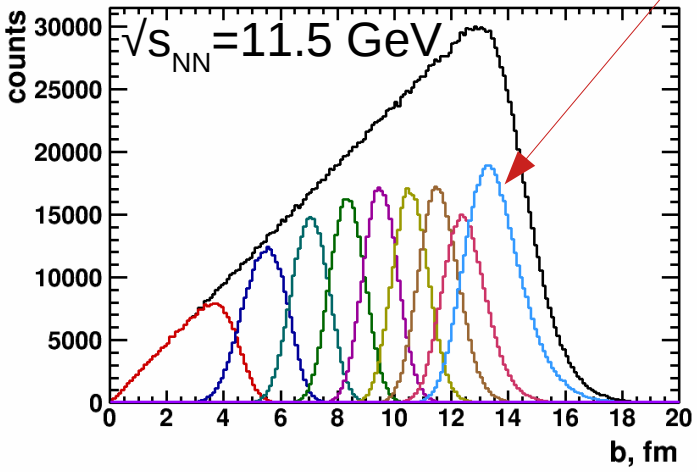
N_{ch} distribution in centrality classes





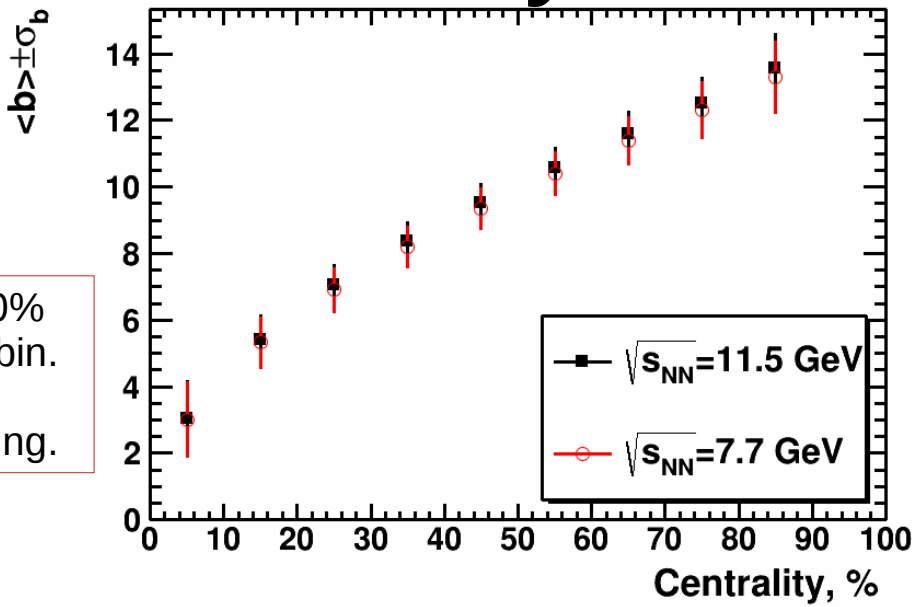
b distribution in centrality classes

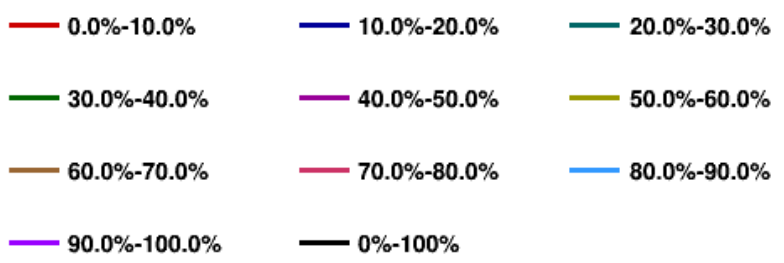




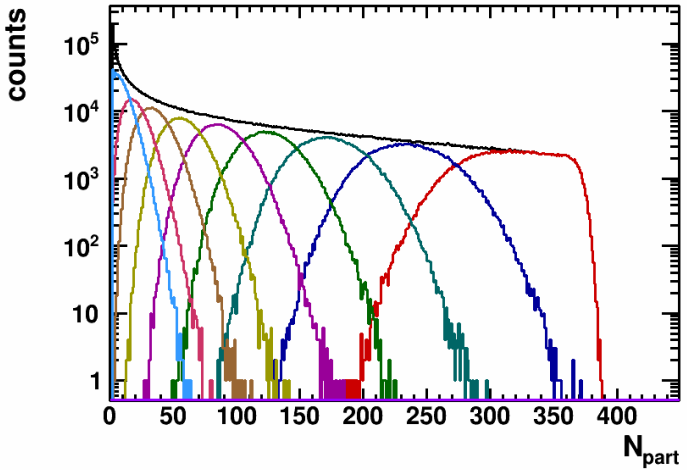
No 90-100% centrality bin.

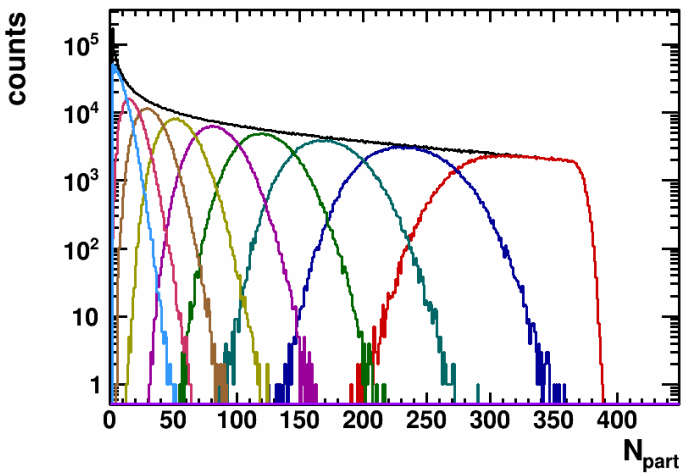
Investigating.

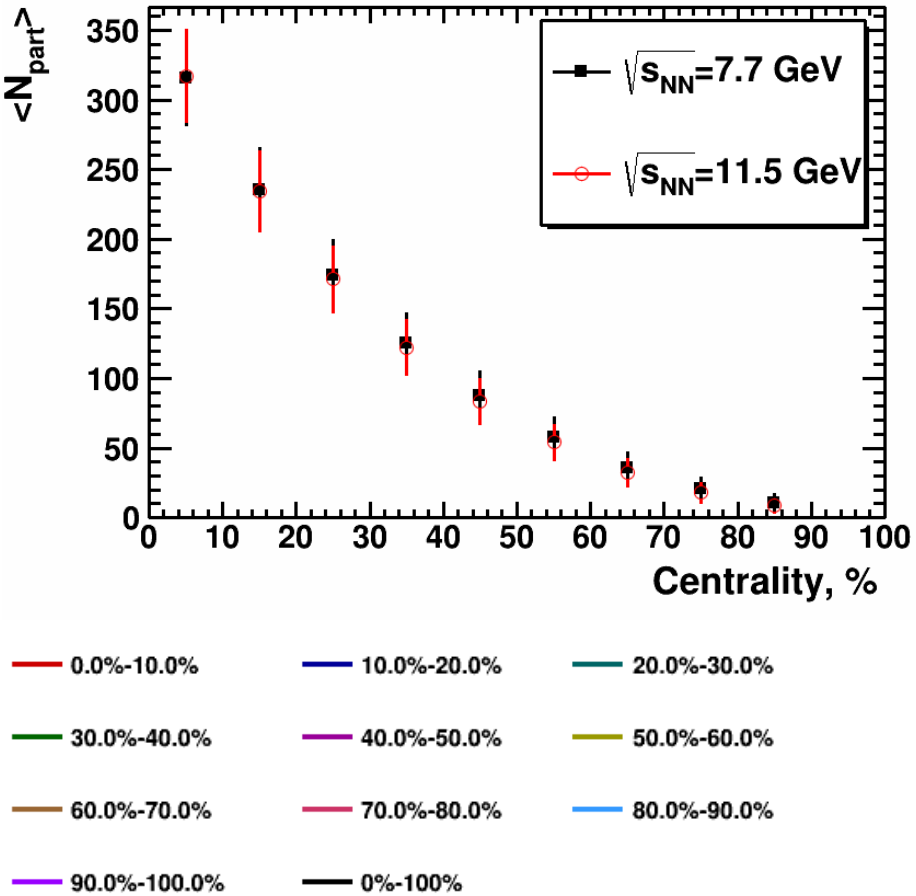




N_{part} distribution in centrality classes







N_{coll} distribution in centrality classes