The effect of charged particle multiplicity fluctuations on centrality determination procedure using Bayesian approach at NICA energy range

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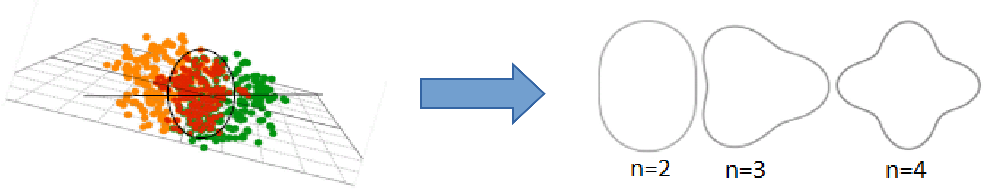
PWG meeting

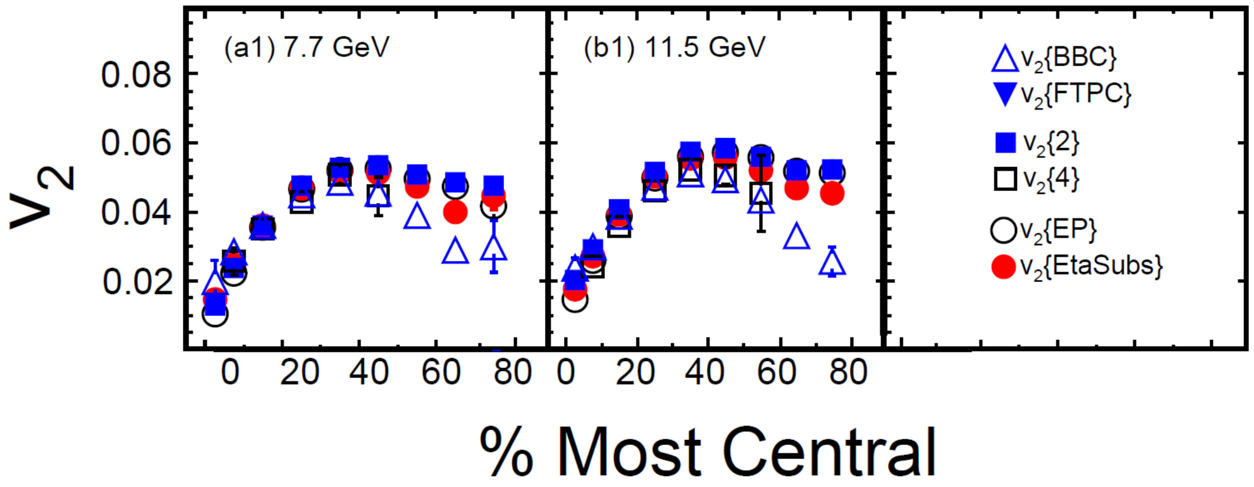
Outline

- **Initial geometry of HIC**
- **The centrality determination methods**
- **Models and results of the multiplicity fits**
- **The fluctuation of impact parameter and multiplicity**
- **Summary and outlook**

Initial geometry of HIC



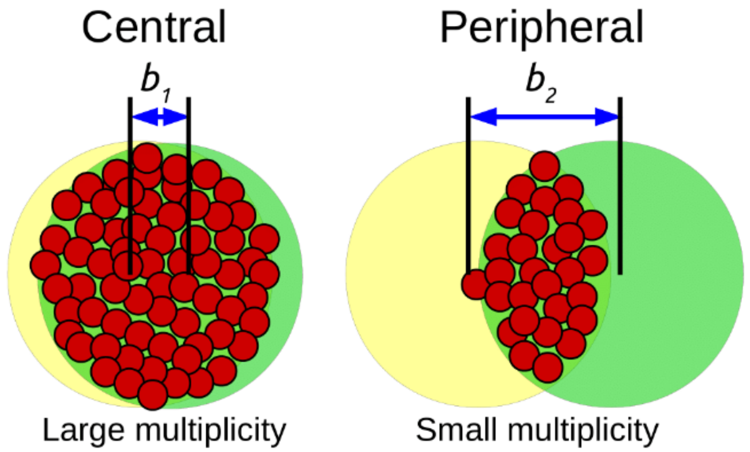
$$\frac{dN}{d\phi} \propto \left(1+2\sum_{n=1} v_n \cos\left[n\left(\phi-\Psi_n\right)\right]\right), \; v_2 = \langle \cos 2(\varphi-\Psi_n)\rangle$$



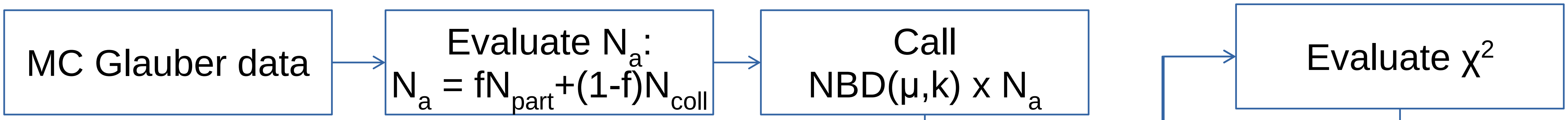
L. Adamczyk, et al., Phys. Rev. C 86, 054908 (2012)

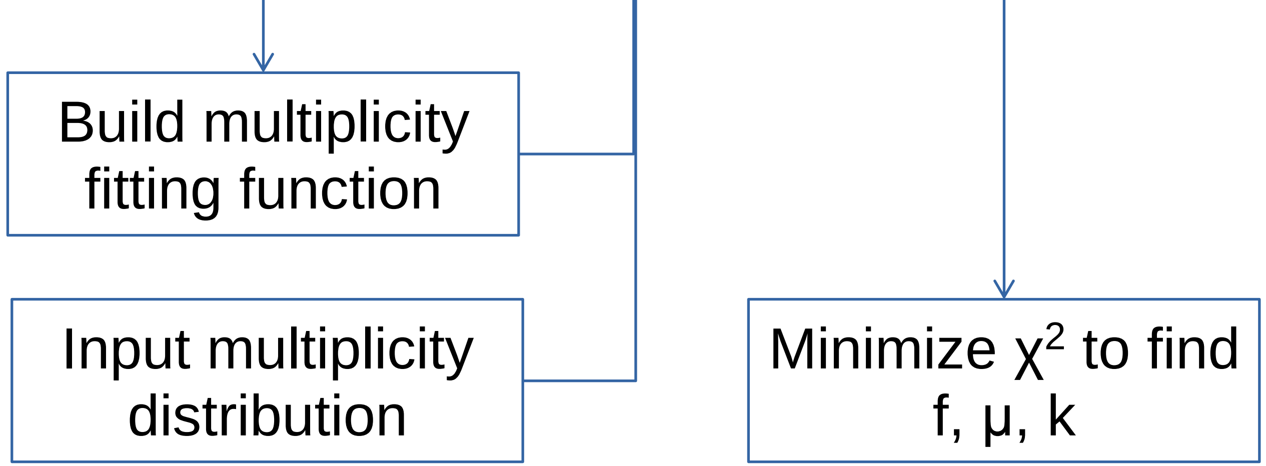
Dependence of elliptic flow on centrality

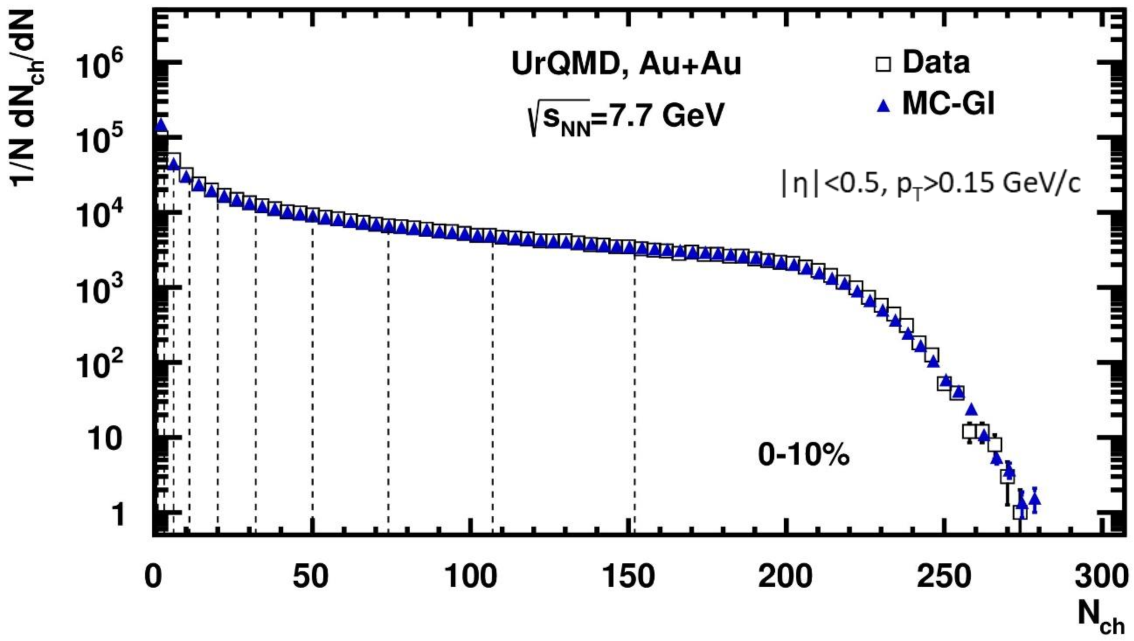
- Evolution of matter produced in heavy-ion collisions depend on its initial geometry
- Centrality procedure maps initial geometry parameters with measurable quantities (multiplicity or transverse energy of the produced particles)
- **This allows comparison of the future MPD results with the data from other experiments (STAR BES, NA49/NA61 scans) and theoretical models**



MC-Glauber based centrality framework







This centrality procedure was used in CBM, NA49, and NA61/SHINE:
I. Segal, et al., J.Phys.Conf.Ser. 1690 (2020) 1, 012107
Implemantation for MPD: https://github.com/FlowNICA/CentralityFramework
P. Parfenov, et al., Particles. 2021; 4(2):275-287

NBD – negative binomial distribution

Parameters of the fit:

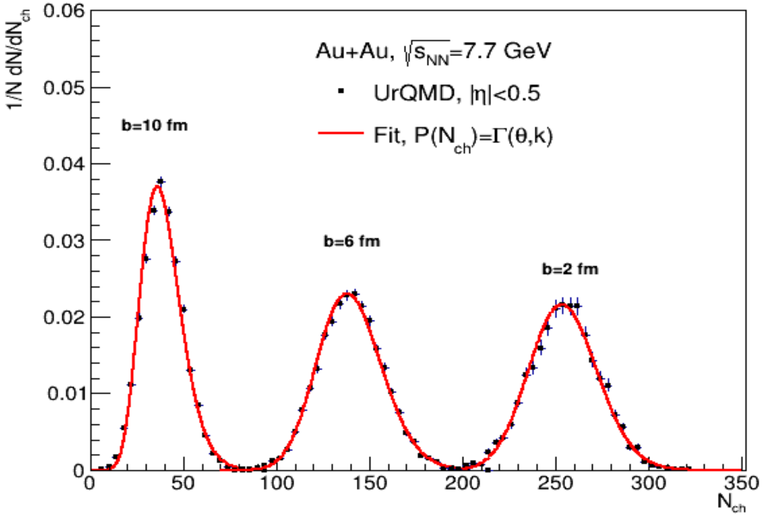
- **f** – fraction of the production from the soft component
- **μ** – mean multiplicity value
- **k** – width of the multiplicity distribution, can be connected to the fluctuations

The Bayesian inversion method (Γ-fit): main assumptions

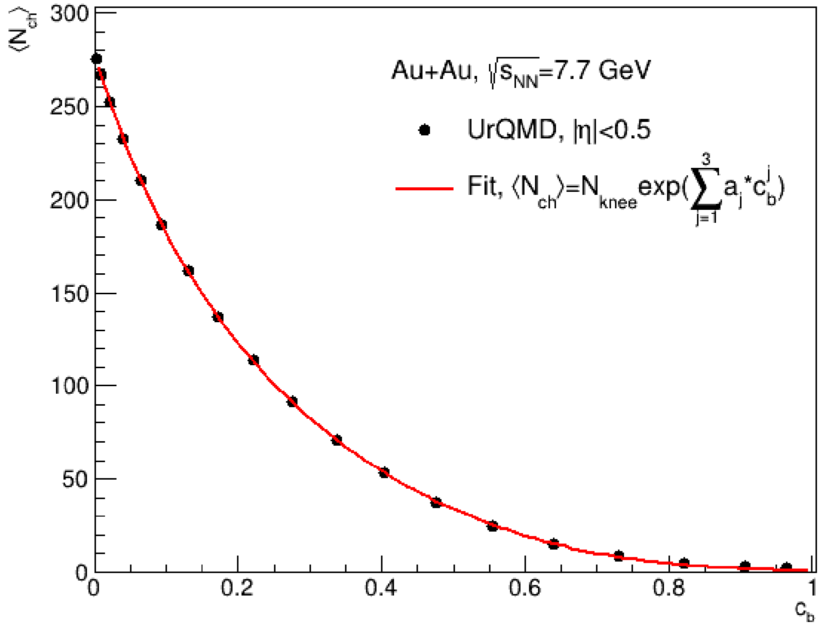
- Relation between multiplicity N_{ch} and impact parameter b is defined by the fluctuation kernel:

$$P(N_{ch}|c_b) = \frac{1}{\Gamma(k(c_b))\theta^k} N_{ch}^{k(c_b)-1} e^{-n/\theta}$$

$$c_b = \int_0^b P(b')db' \simeq \frac{\pi b^2}{\sigma_{inel}}$$ – centrality based on impact parameter



The results of fitting the multiplicity distribution for a fixed impact parameter



The dependence of the average value of multiplicity on centrality and the results of its fit

$$\frac{\sigma^2}{\langle N_{ch}\rangle} = \theta \simeq const$$

$$\langle N_{ch}\rangle = N_{knee} \exp\left(\sum_{j=1}^{3} a_j c_b^j\right), \quad k = \frac{\langle N_{ch}\rangle}{\theta}$$

Five fit parameters N_{knee}, θ, a_j

Reconstruction of *b*

- Normalized multiplicity distribution $P(N_{ch})$

$$P(N_{ch}) = \int_0^1 P(N_{ch}|c_b)dc_b$$

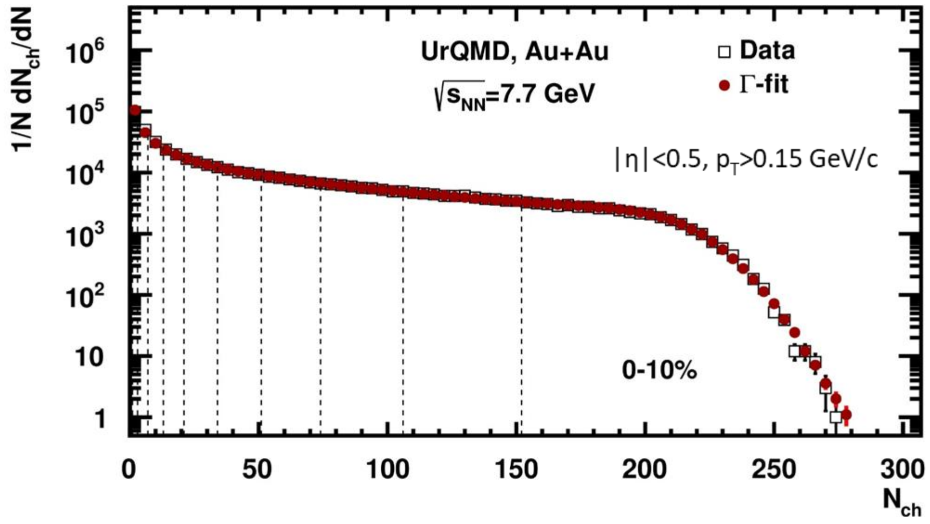
- Find probability of *b* for fixed N_{ch} using Bayes' theorem:

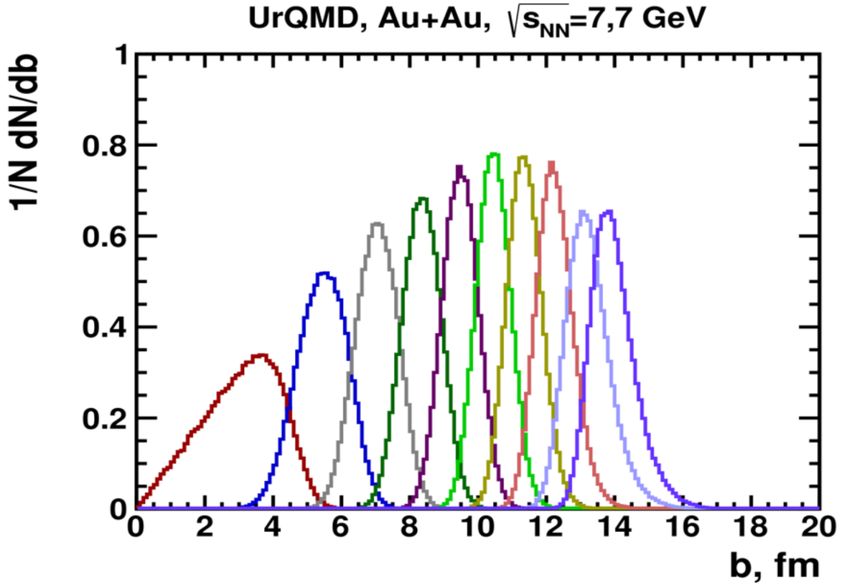
$$P(b|n_1 < N_{ch} < n_2) = P(b)\frac{\int_{n_1}^{n_2} P\,(b|N_{ch})dN_{ch}}{\int_{n_1}^{n_2} P\,(N_{ch})dN_{ch}}$$

- **The Bayesian inversion method consists of 2 steps:**

–Fit normalized multiplicity distribution with $P(N_{ch})$

–Construct $P(b|N_{ch})$ using Bayes' theorem with parameters from the fit

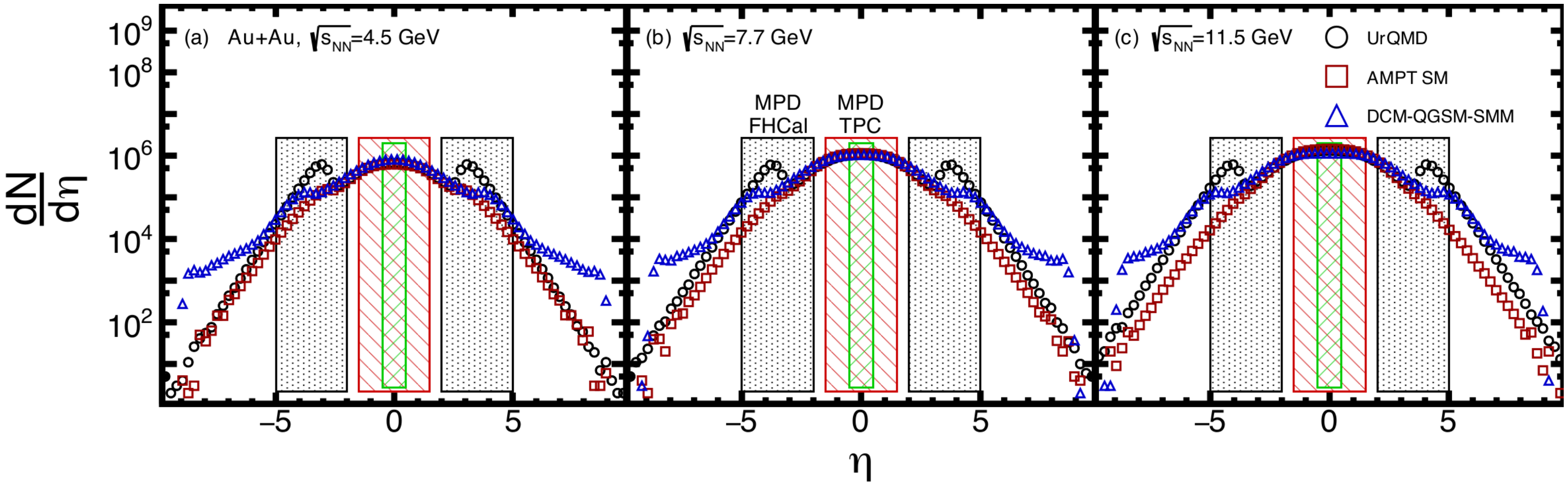




R. Rogly, G. Giacalone and J. Y. Ollitrault, Phys.Rev. C98 (2018) no.2, 024902

Implementation in MPD: https://github.com/Dim23/GammaFit

Models



- UrQMD ver. 3.4 in cascade mode:
  - $\sqrt{s_{NN}}$ = 11.5 GeV
  - $\sqrt{s_{NN}}$ = 7.7 GeV
  - $\sqrt{s_{NN}}$ = 4.5 GeV
- AMPT SM, ver. 1.26 with string melting mode ver. 2.26, σ_{part}=1.5 mb:
  - $\sqrt{s_{NN}}$ = 11.5 GeV
  - $\sqrt{s_{NN}}$ = 7.7 GeV
  - $\sqrt{s_{NN}}$ = 4.5 GeV
- DCM-QGSM-SMM:
  - $\sqrt{s_{NN}}$ = 11.5 GeV
  - $\sqrt{s_{NN}}$ = 7.7 GeV
  - $\sqrt{s_{NN}}$ = 4.5 GeV

Results of the multiplicity fits

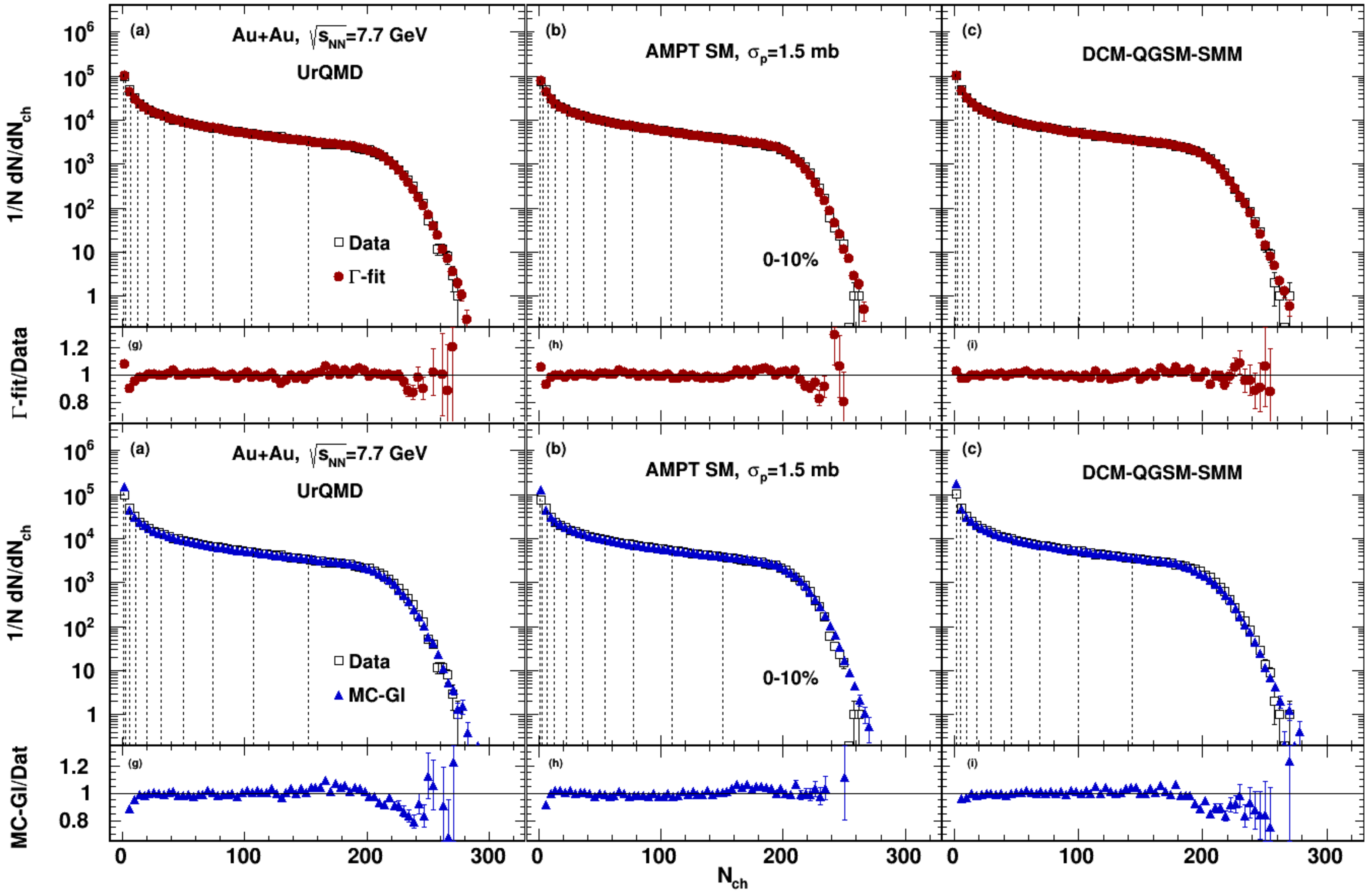
Simulated data sets:

- Au+Au, N_{ev}=500k,

$\sqrt{s_{NN}}$=4.5, 7.7, 11.5 GeV

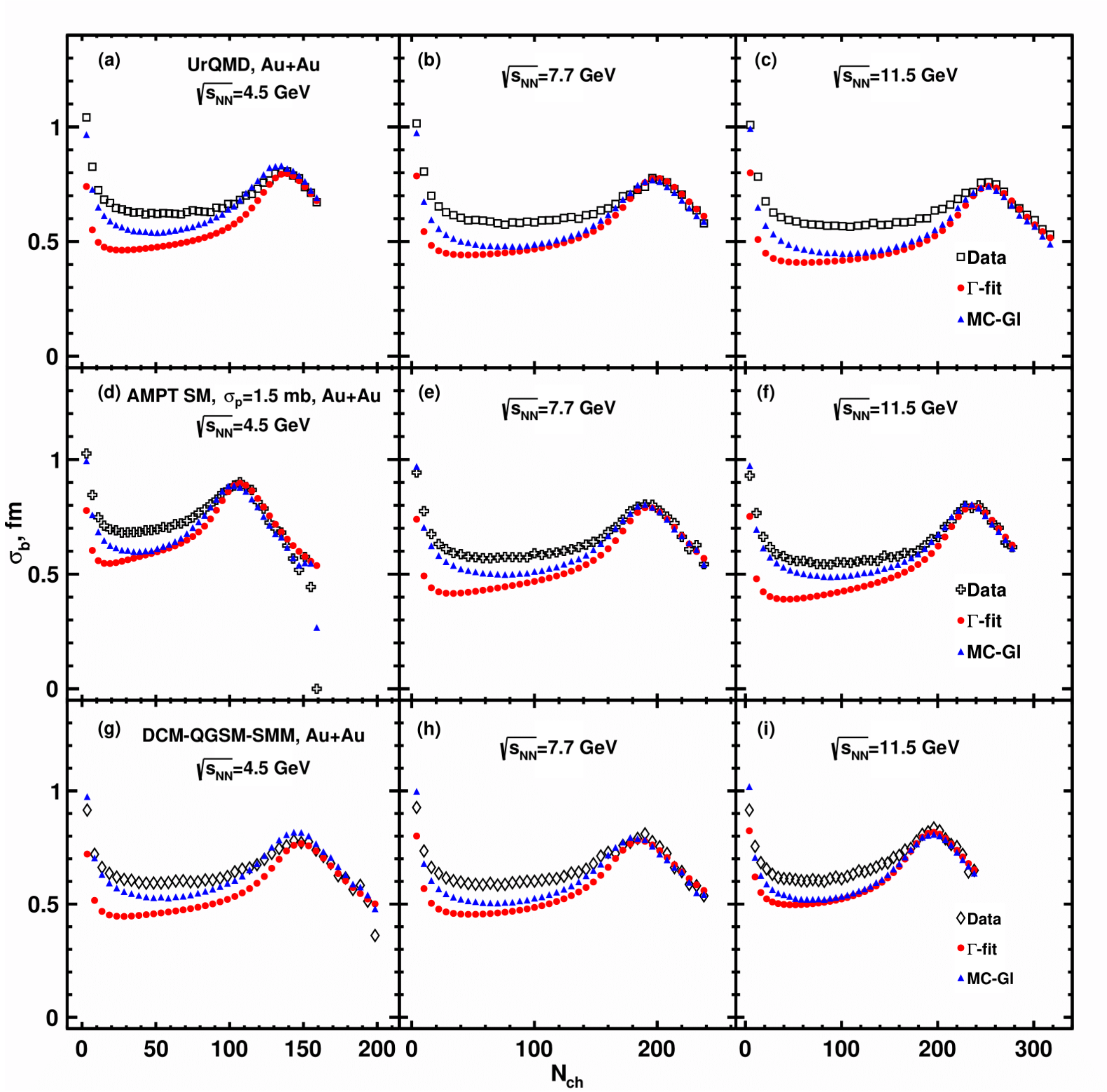
Hadron selection:

- |η|<0.5
- Charged particles only
- p_T>0.15 GeV/c



Good fit quality for both methods

The fluctuation of impact parameter



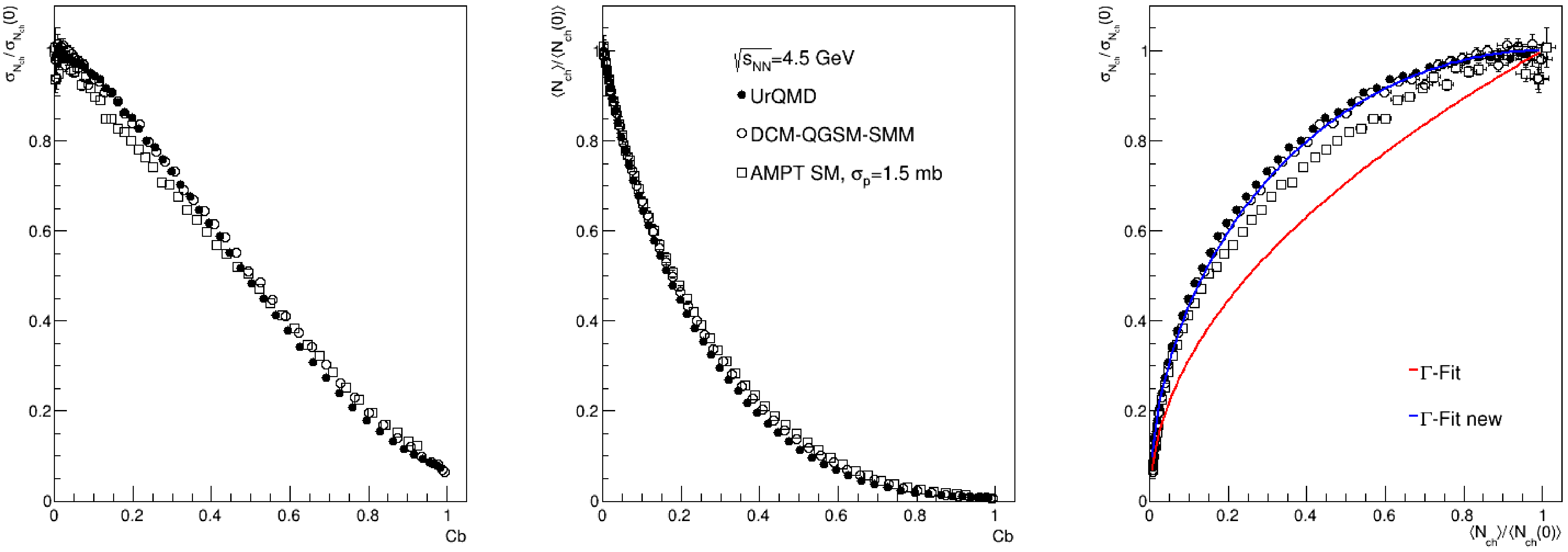
- To estimate impact parameter fluctuations, its variance was calculated for each multiplicity bin with a given width, where M-number of events.

$$\sigma_b^2 = \frac{\sum_{i=1}^{M}(b_i - \langle b \rangle)^2}{M}$$

- The classic Bayesian approach poorly describes impact parameter fluctuations for peripheral collisions
- This phenomenon may be due to the linear dependence of the variance on the multiplicity, and we will show that the new parametrization better describes this relation

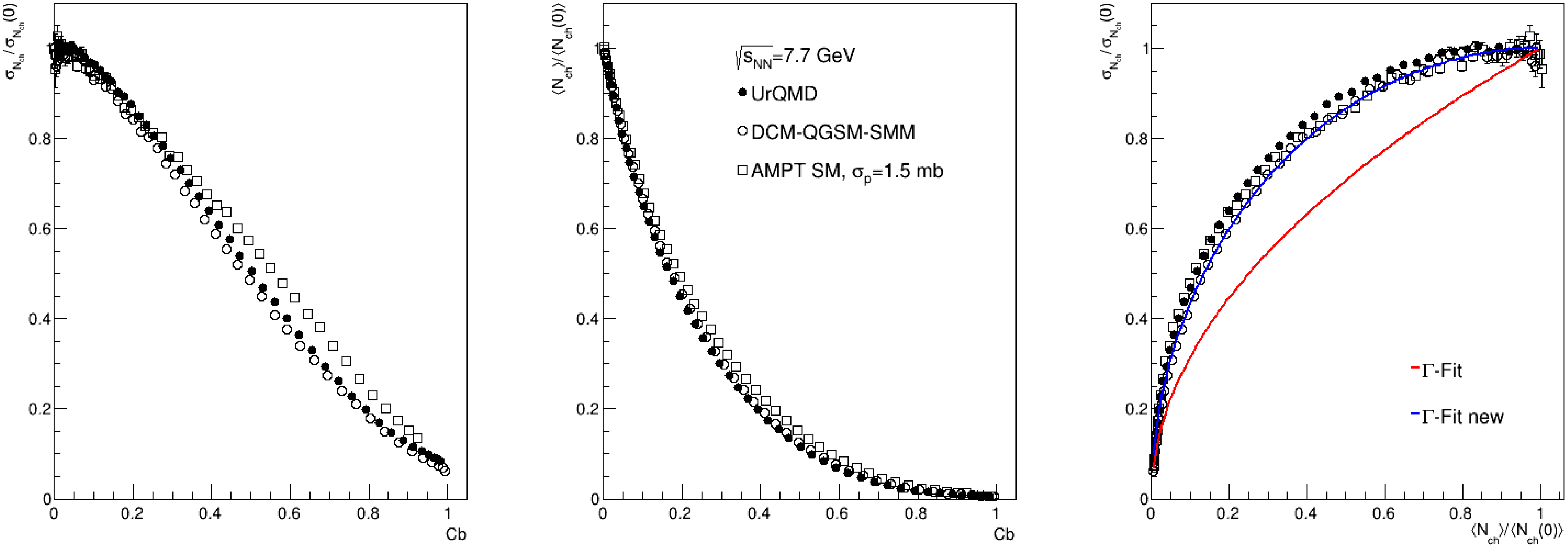
$$\sigma^2_{N_{ch}}(C_b) = \sigma^2_{N_{ch}}(0)\left(1 - \frac{(\langle N_{ch}(C_b)\rangle - \langle N_{ch}(0)\rangle)^2}{\langle N_{ch}(0)\rangle^2}\right)$$

The charged particle multiplicity fluctuations in different model at 4.5 GeV



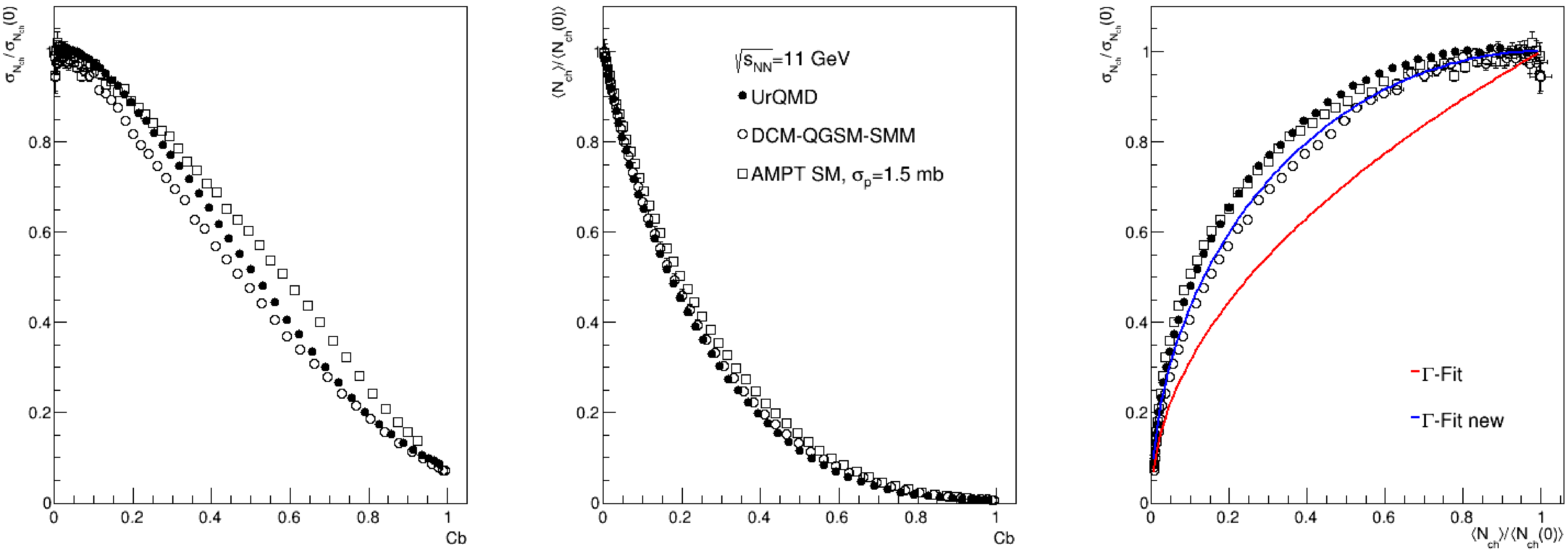
New parameterization(blue line) better describes model data.

The charged particle multiplicity fluctuations in different model at 7.7 GeV



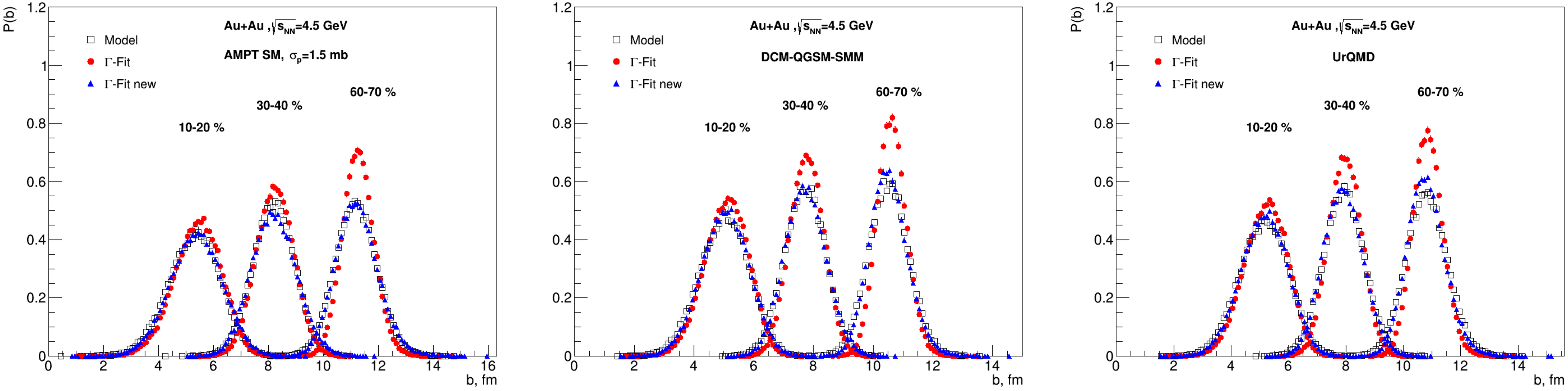
New parameterization(blue line) better describes model data.

The charged particle multiplicity fluctuations in different model at 11 GeV



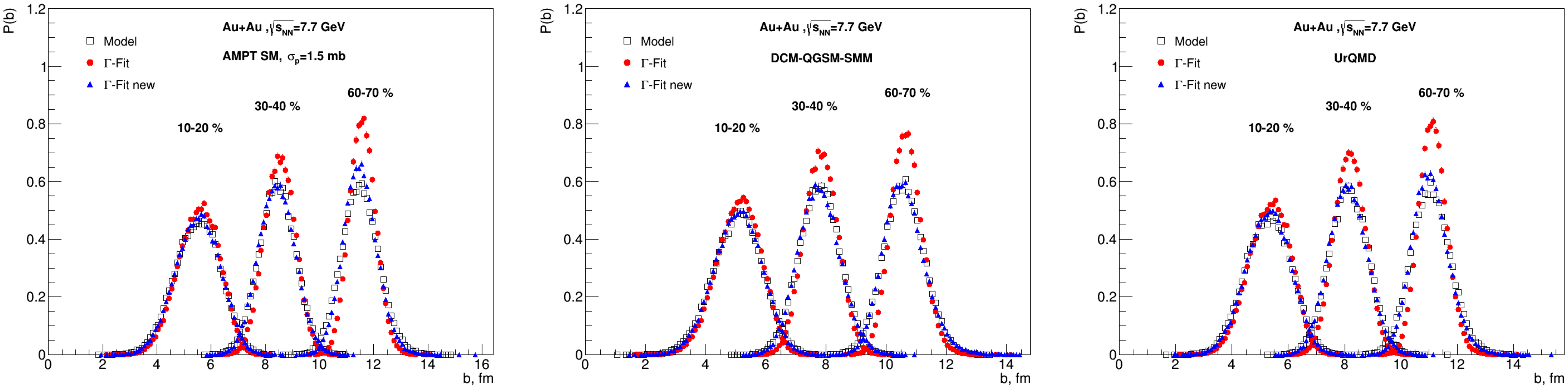
New parameterization(blue line) better describes model data.
The best agreement is observed for all models at 7.7 GeV

Impact parameter distributions for 4.5 GeV



The new parametrization gives better agreement with data from the model.

Impact parameter distributions for 7.7 GeV



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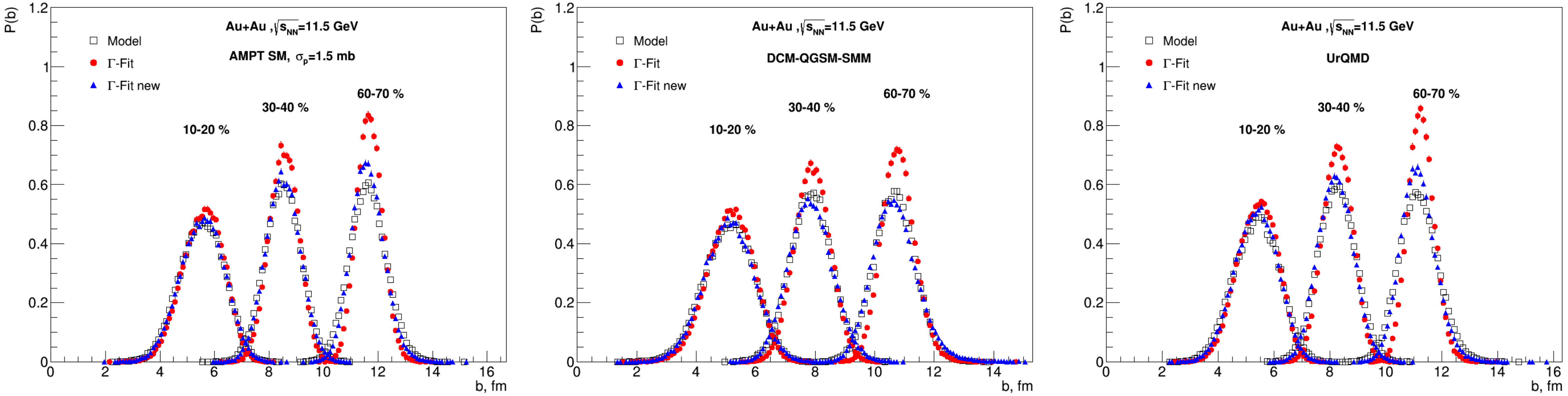
Impact parameter distributions for 11.5 GeV



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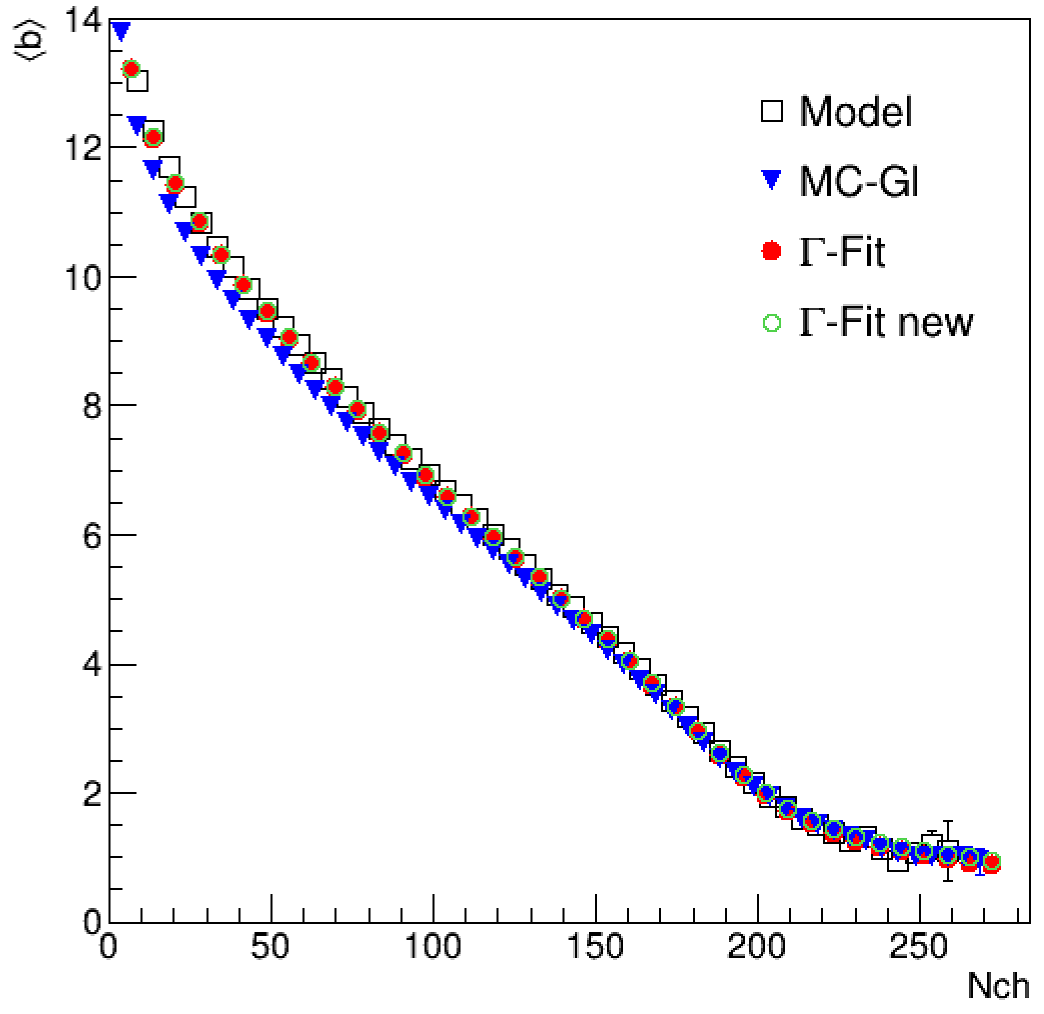
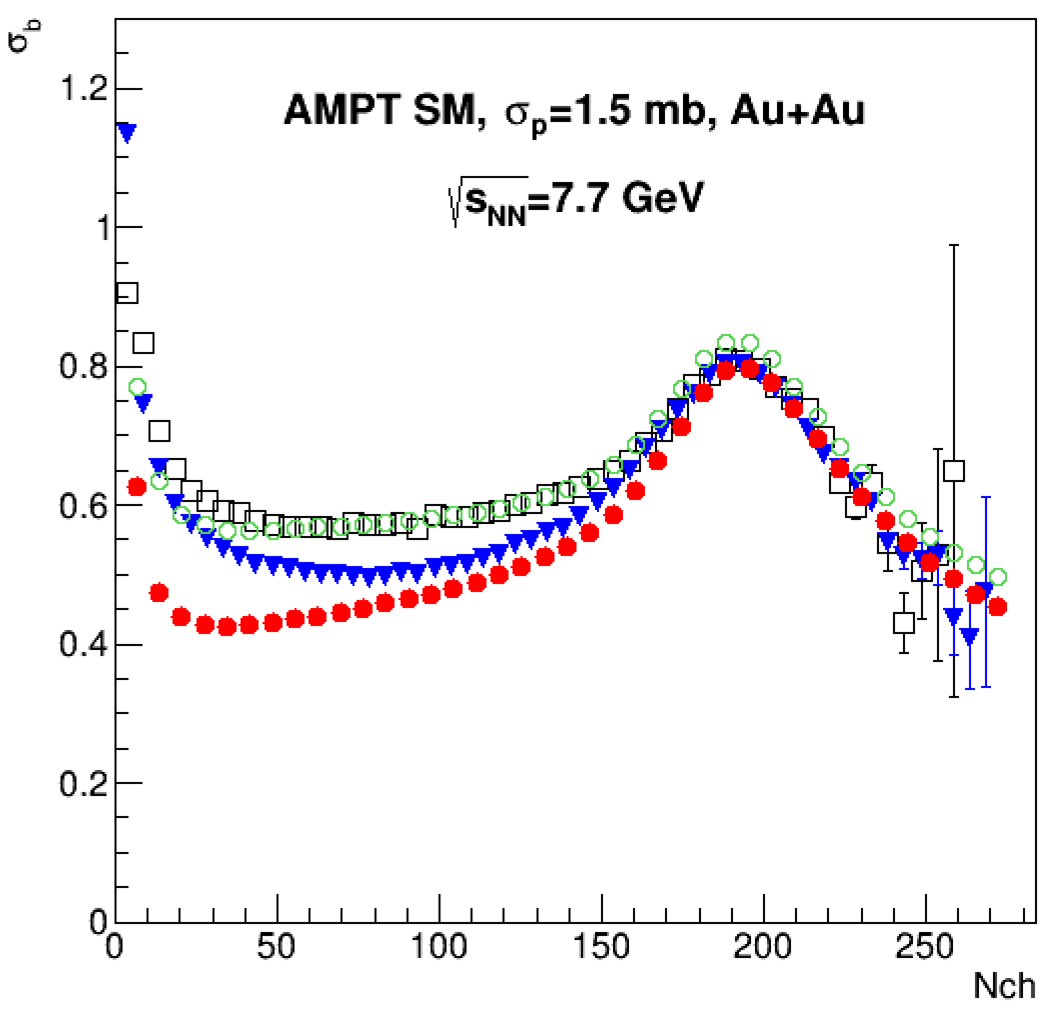
The comparison of impact parameter fluctuation





The new parametrization gives better agreement with data from the model.

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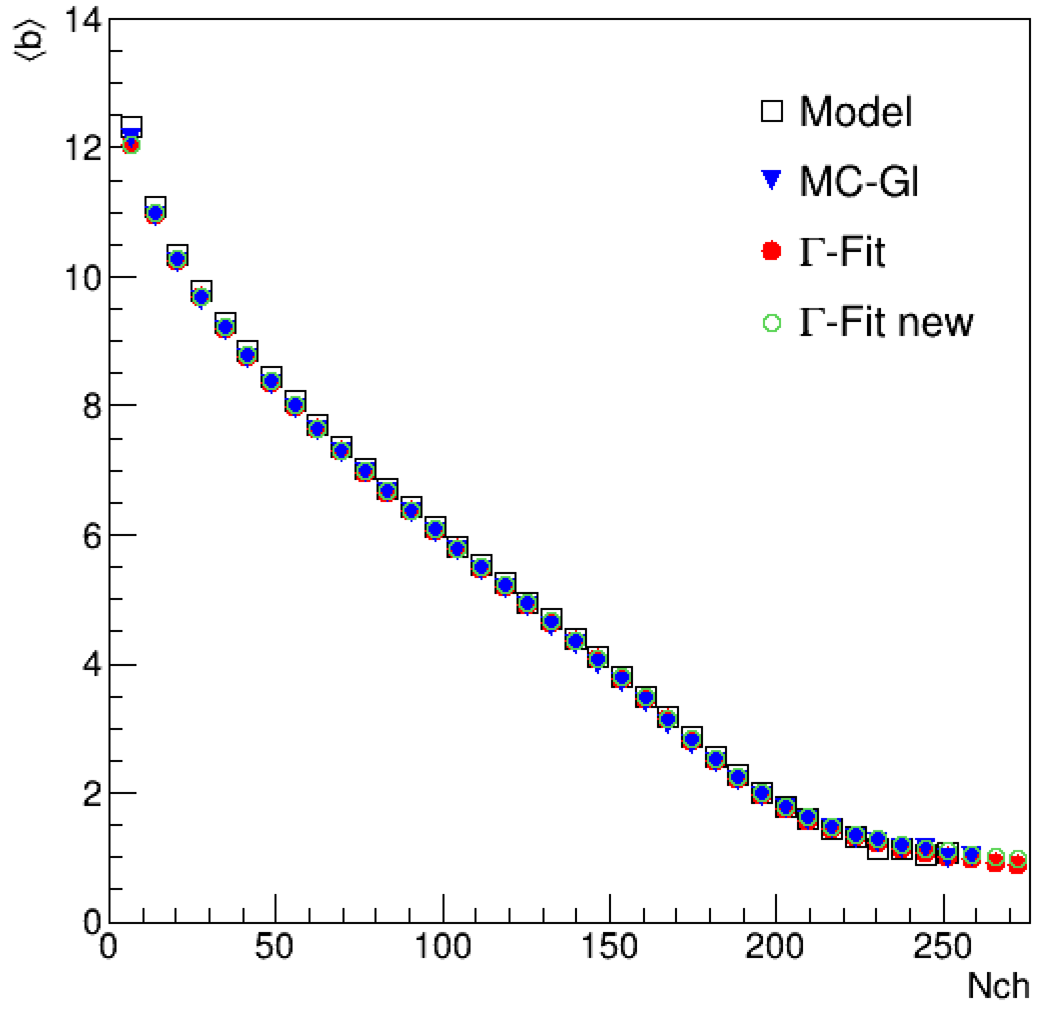

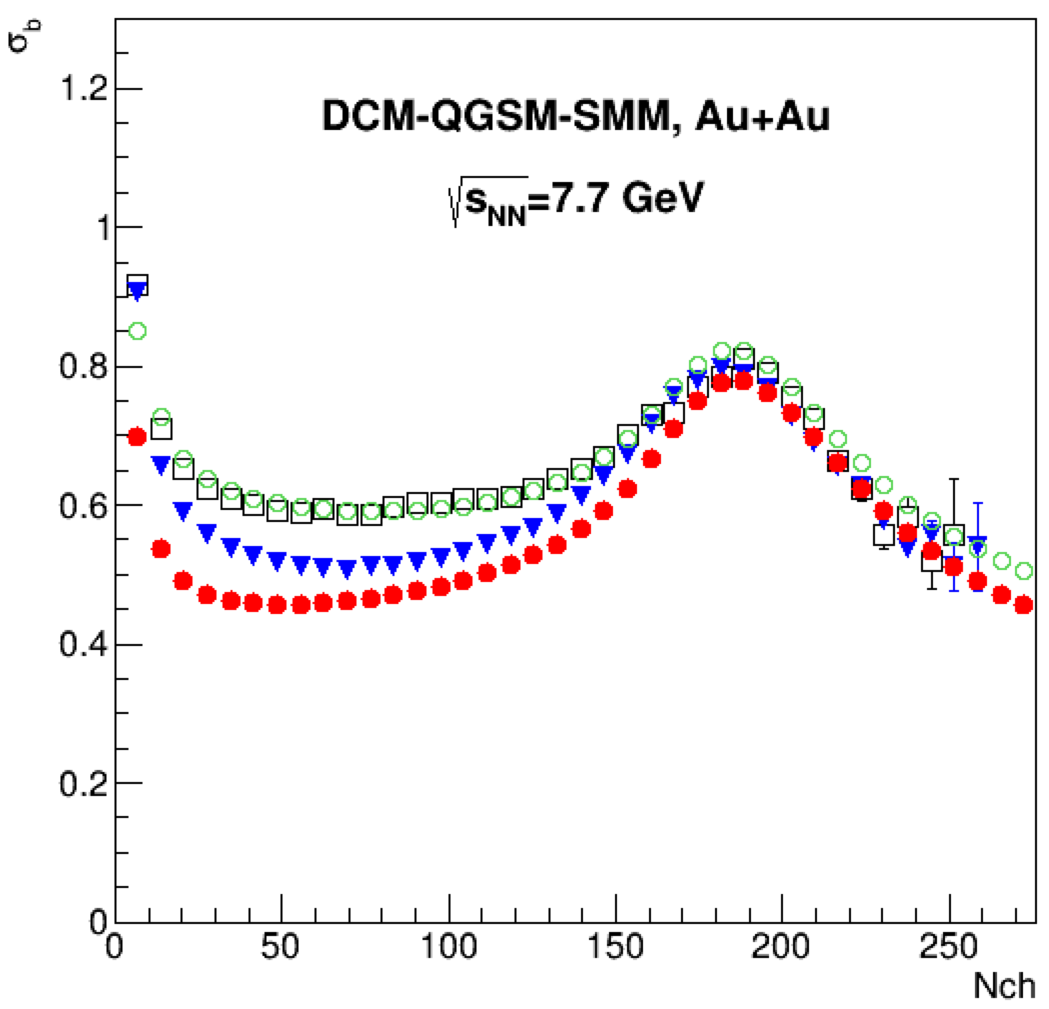

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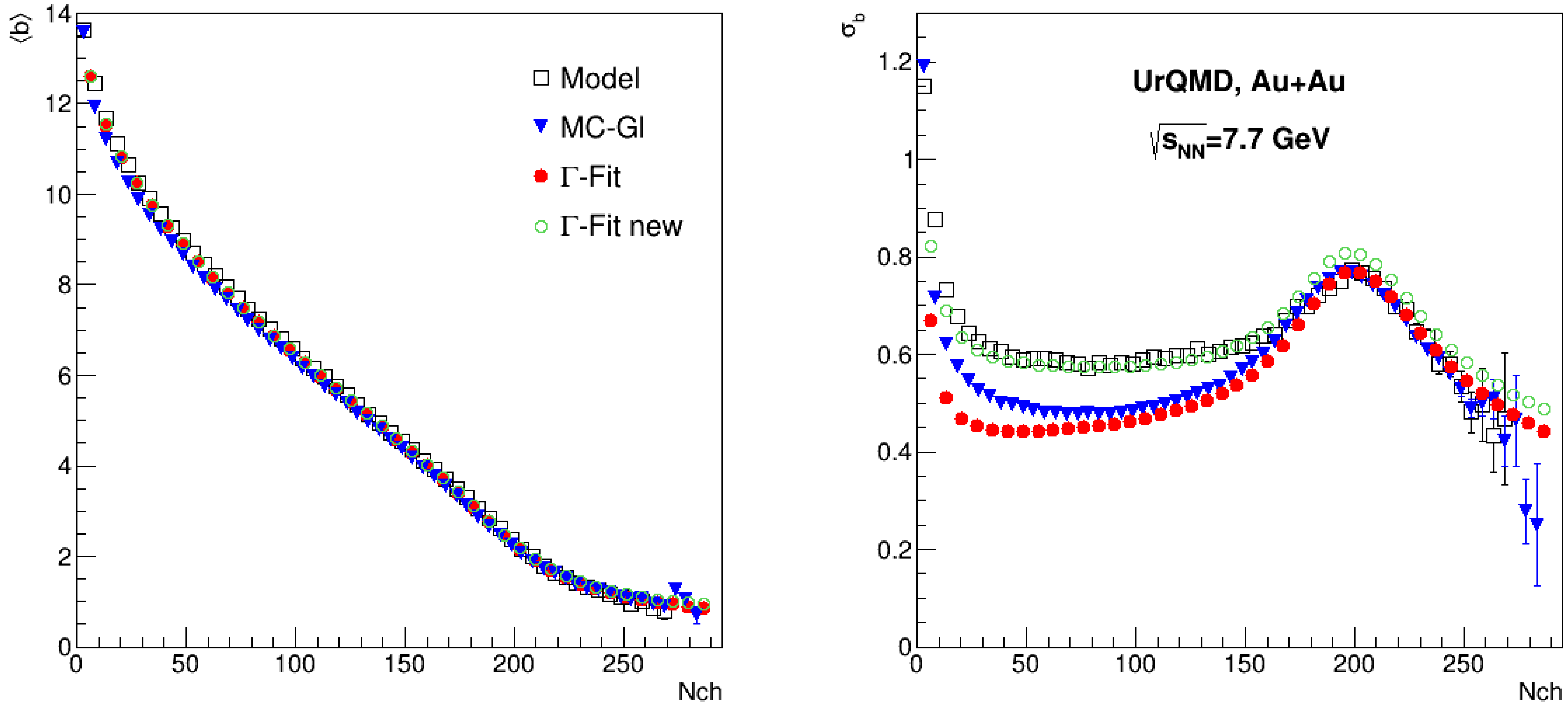


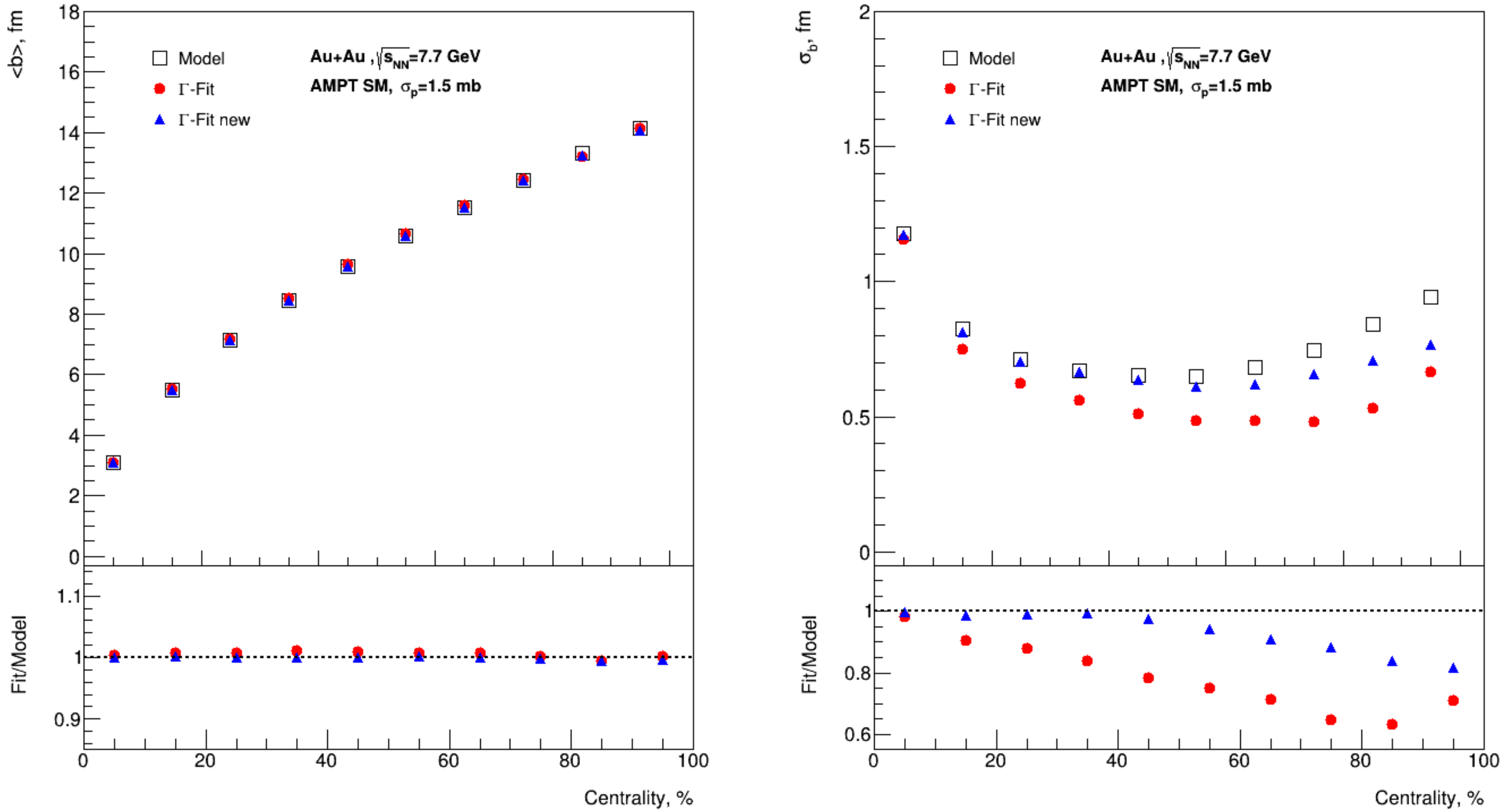
The new parametrization gives better agreement with data from the model.

Summary and outlook

- The new parametrization gives better agreement with data from models for particle multiplicity fluctuations.
- The multiplicity fluctuations are associated with impact parameter fluctuations
- For a better description of impact parameter fluctuations, it is necessary to use the energy-dependent parameterization
- To study of the effect of a new parametrization on the determination of centrality using the transverse energy distribution.

Thank you for your attention

The comparison of impact parameter fluctuation distributions for two methods



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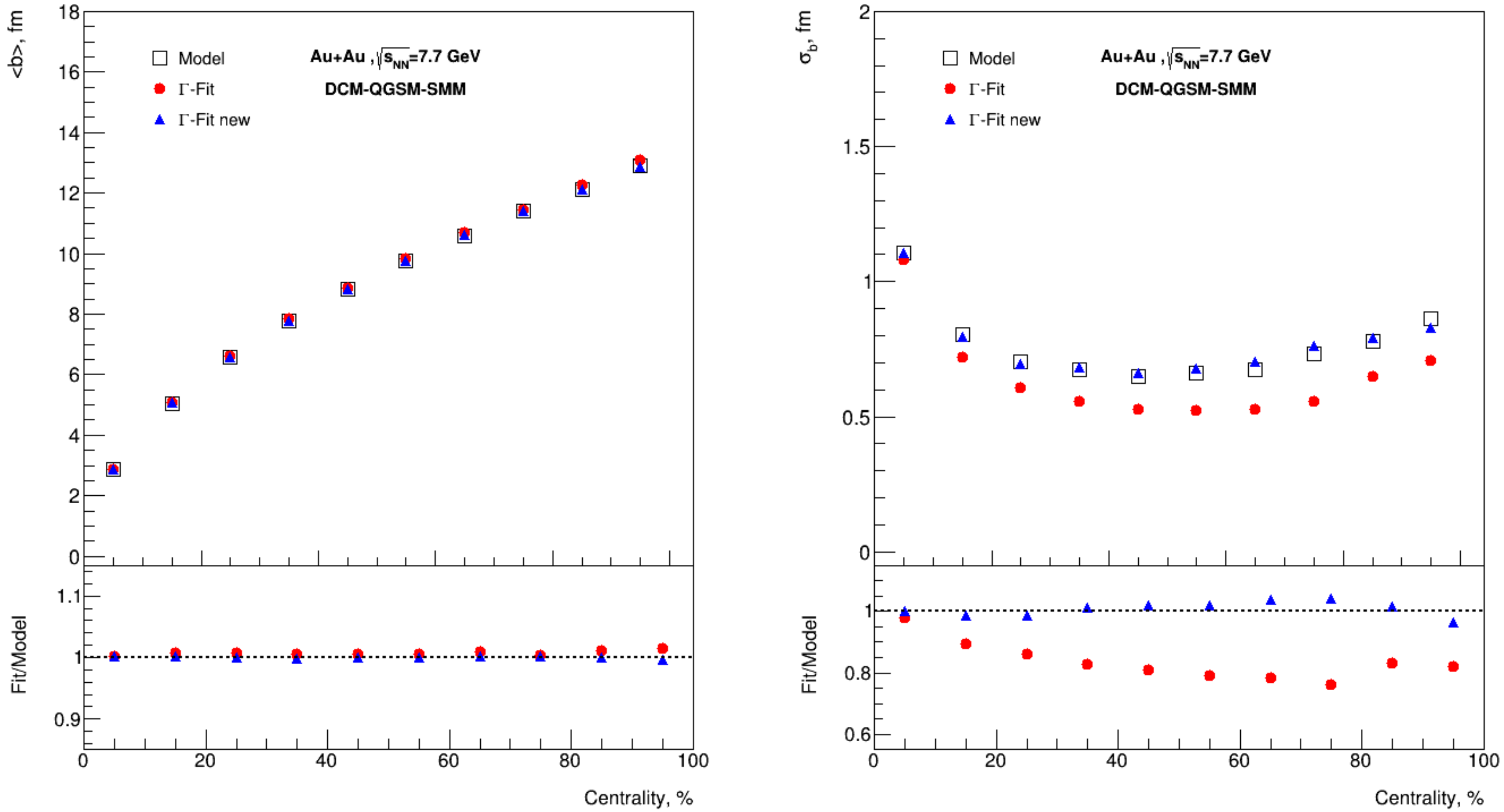

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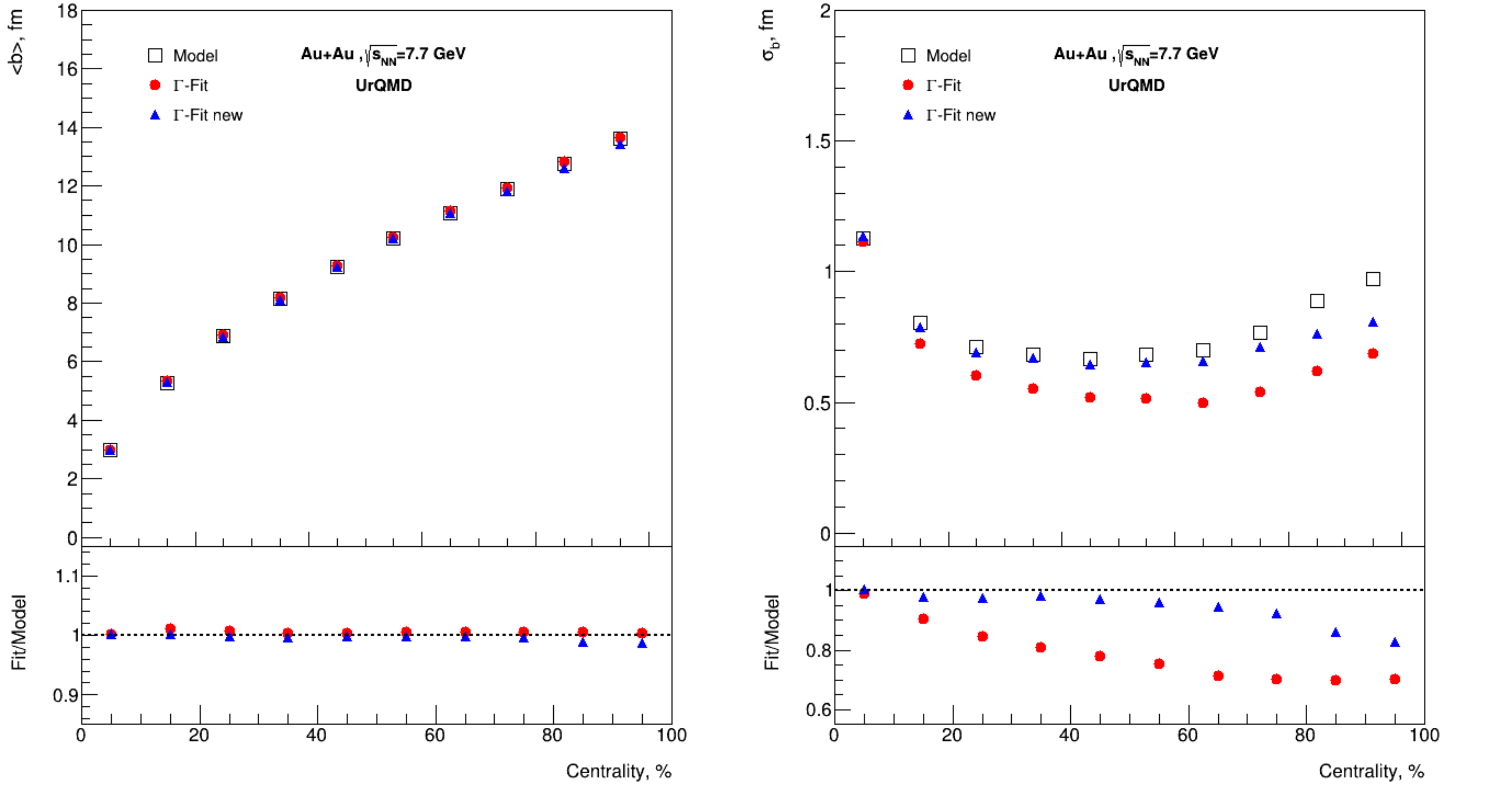
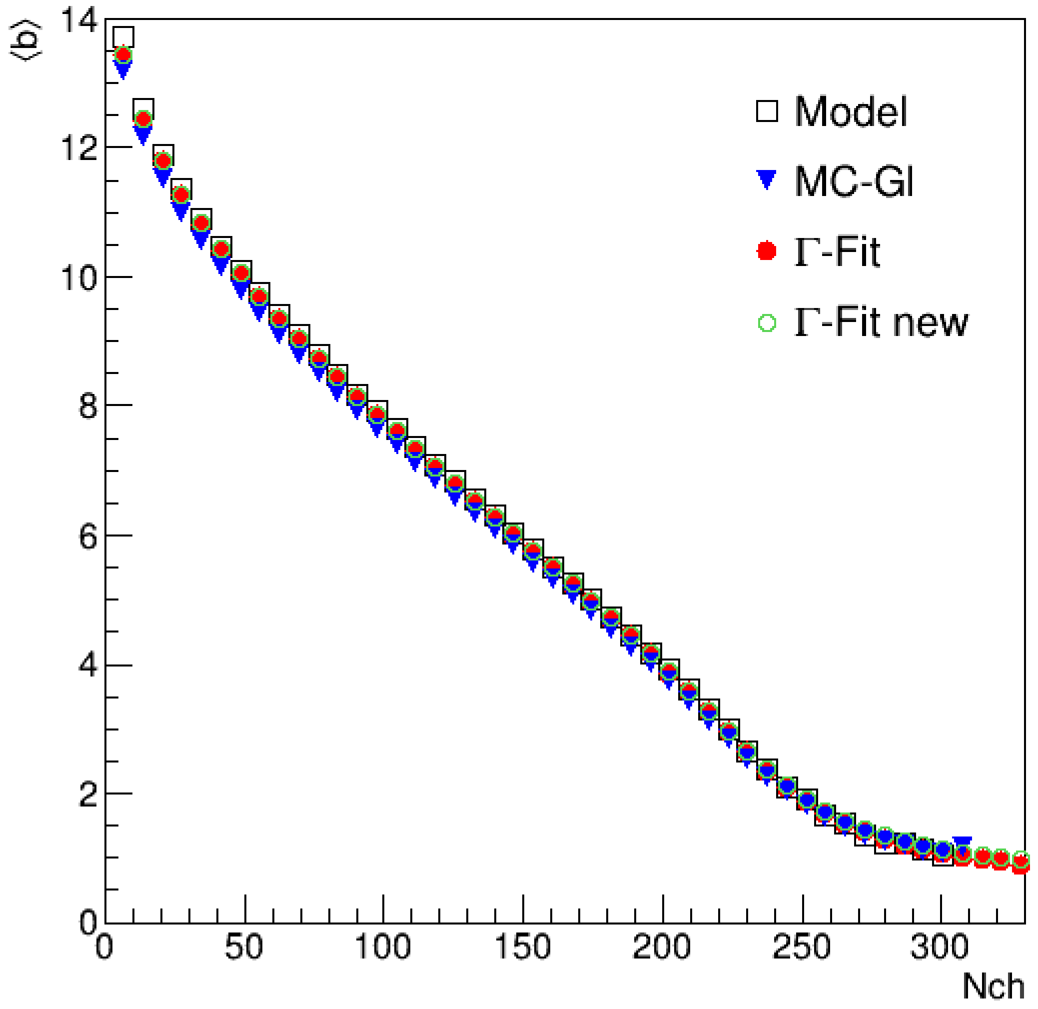
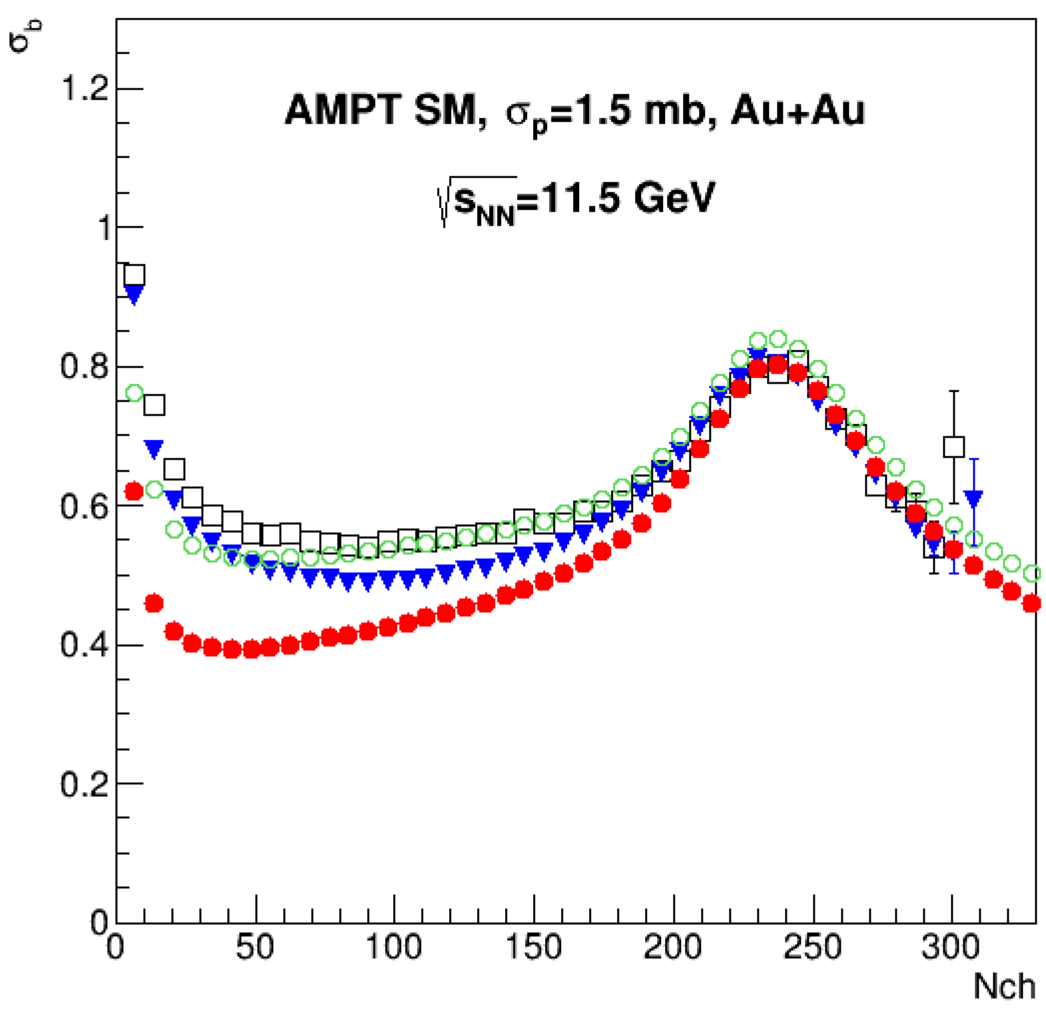


The new parametrization gives better agreement with data from the model.

The comparison of impact parameter fluctuation distributions for different methods





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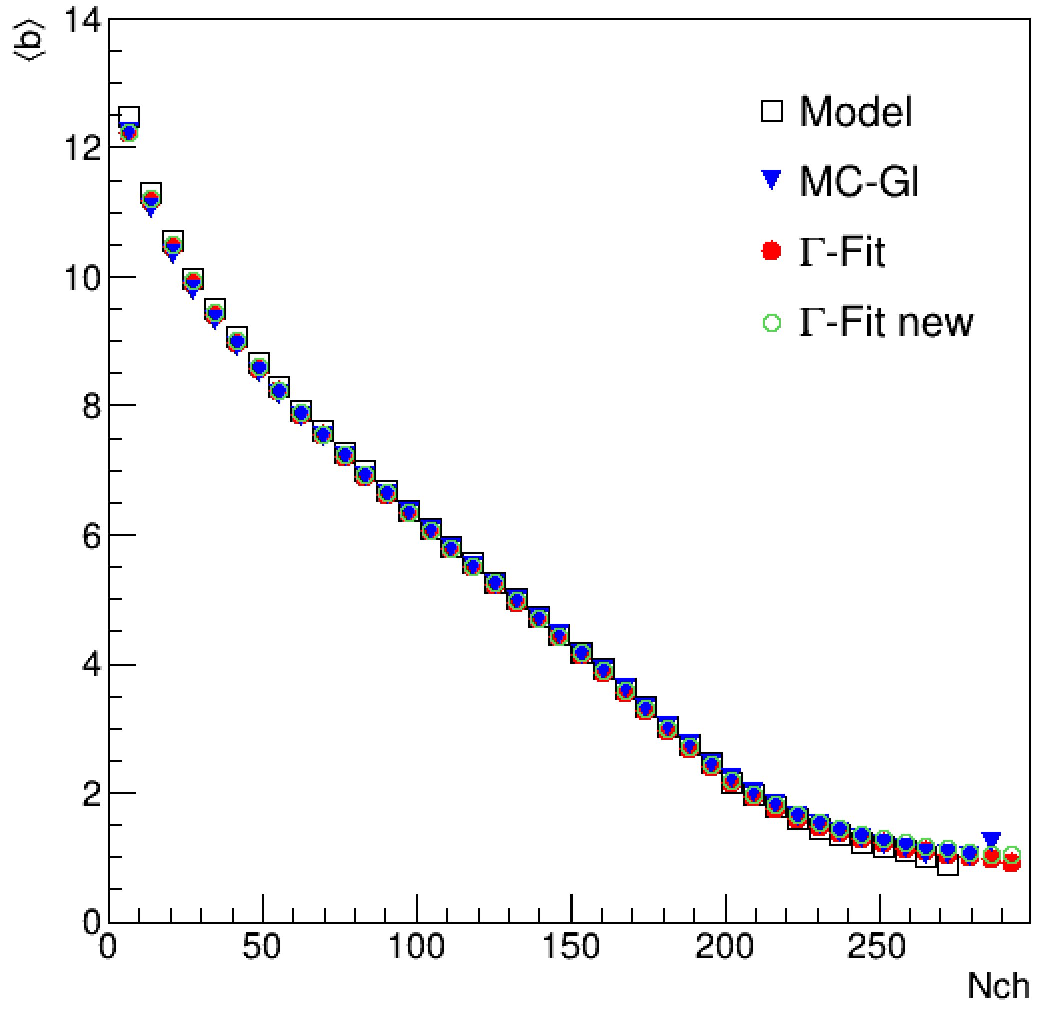

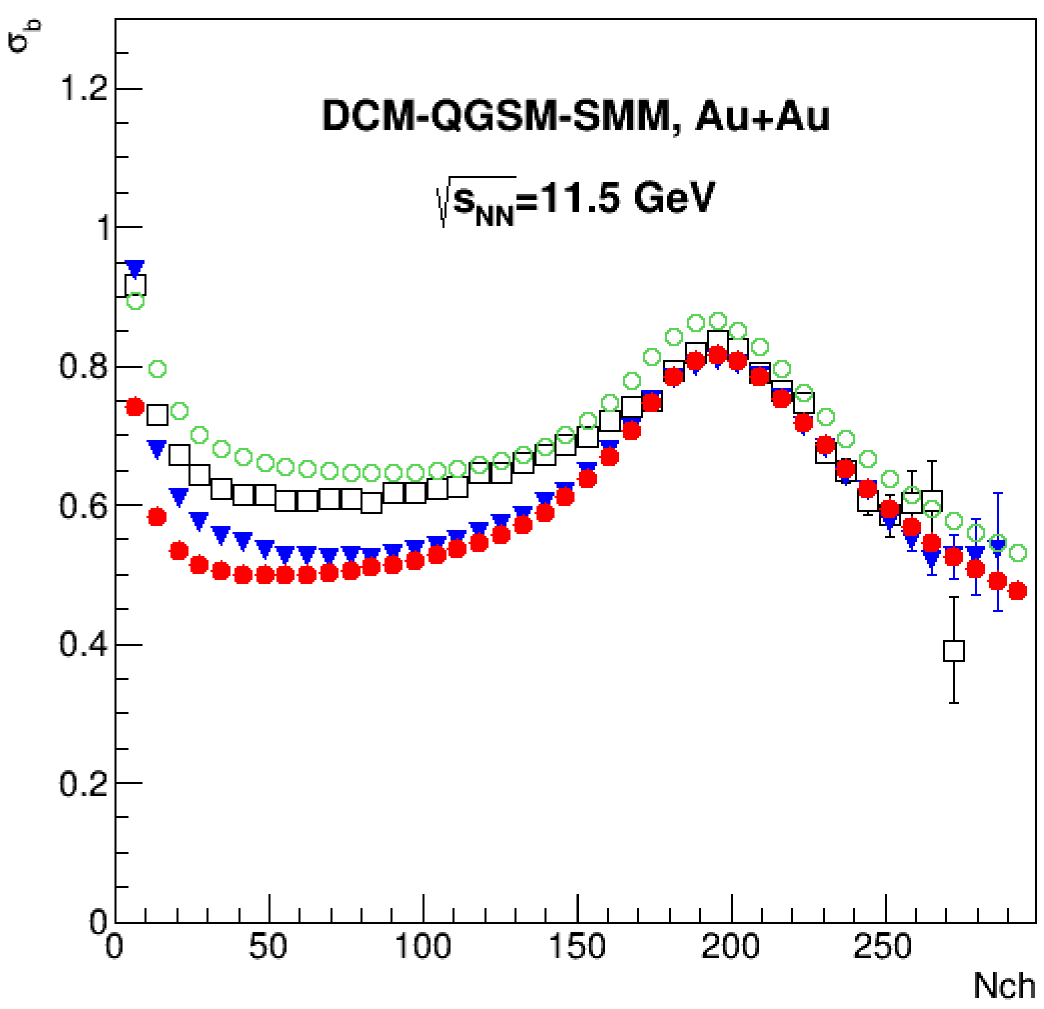

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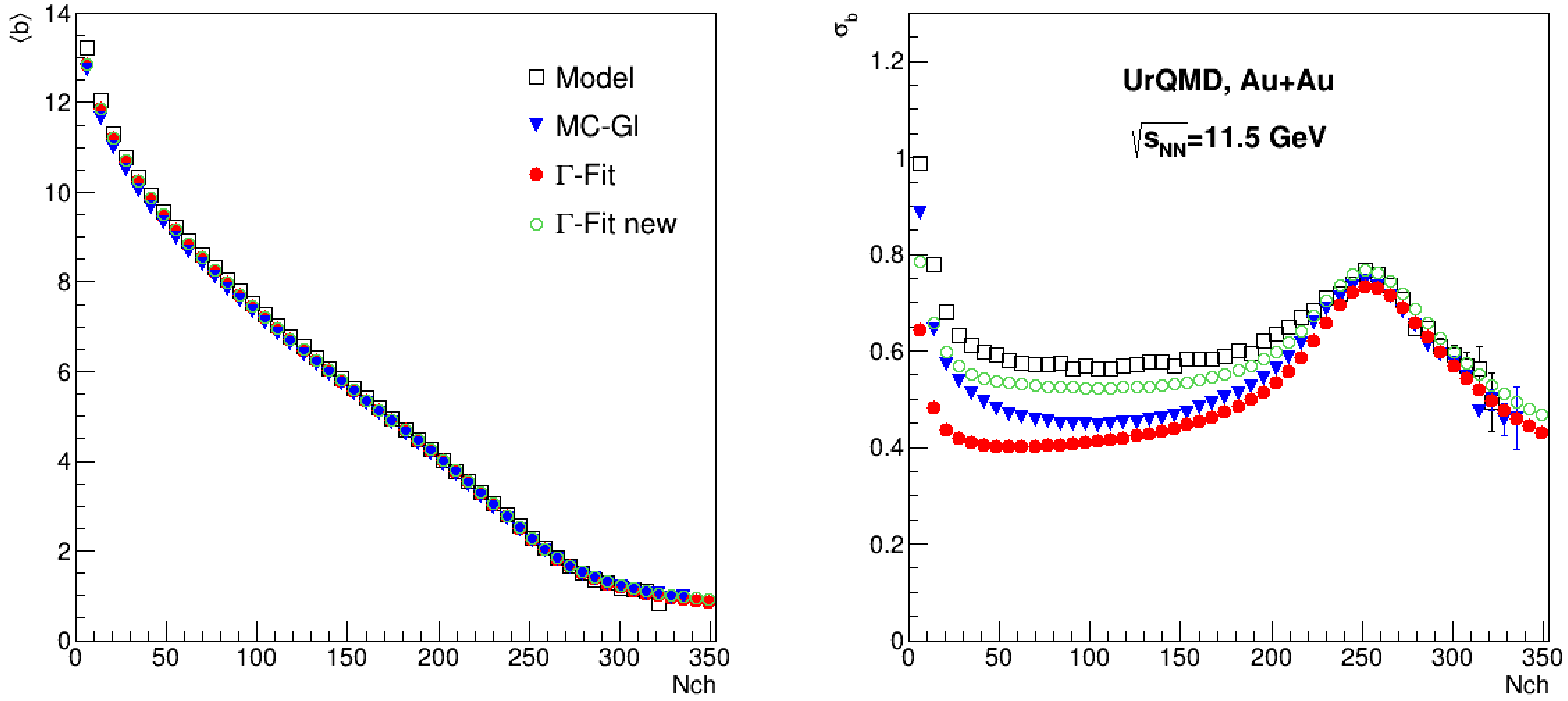

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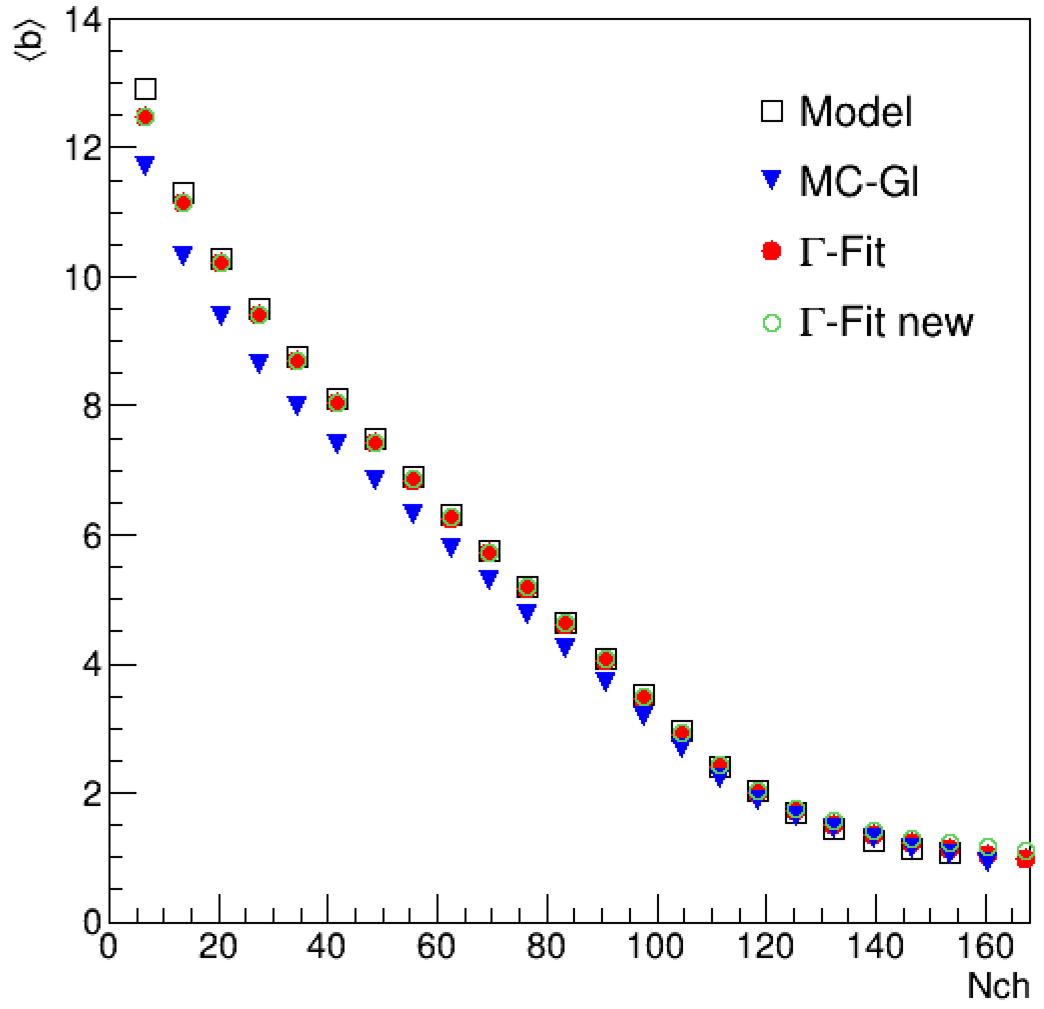

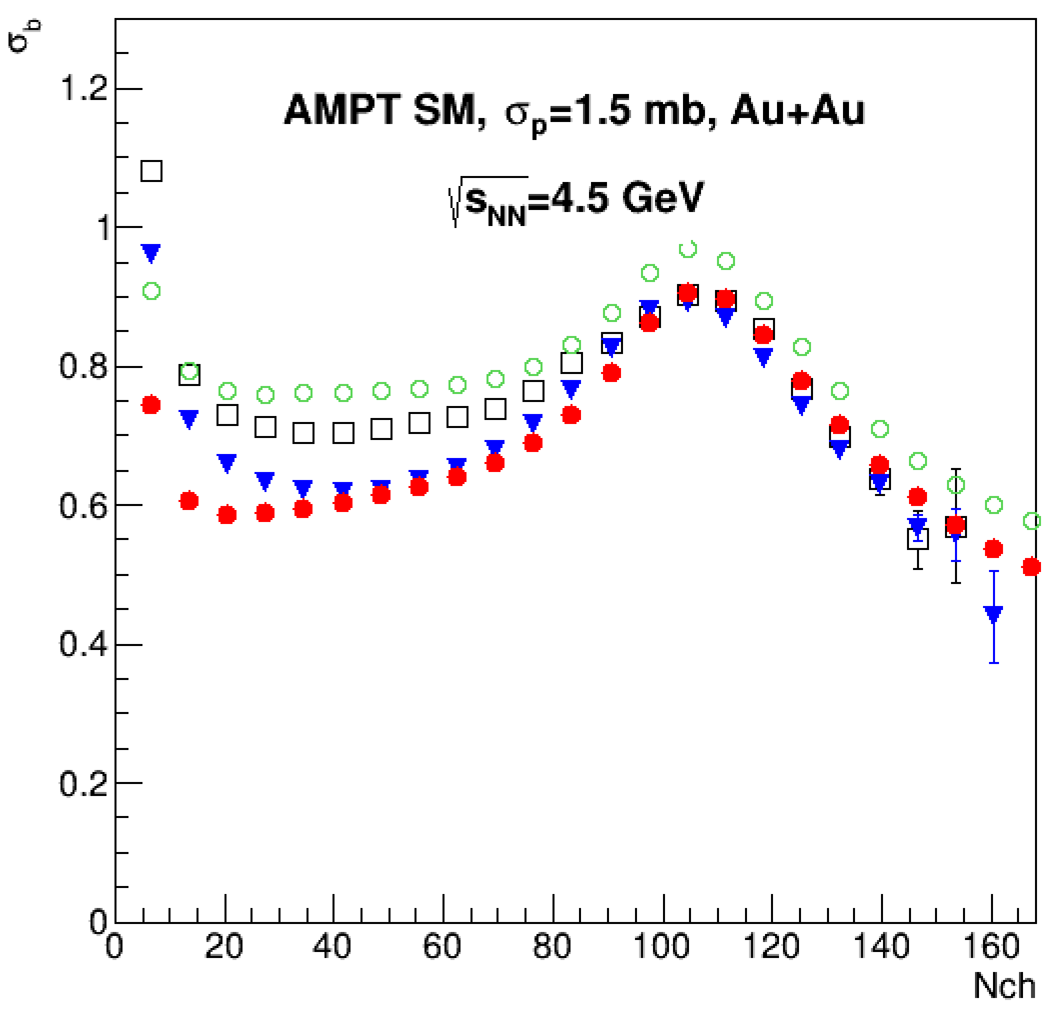

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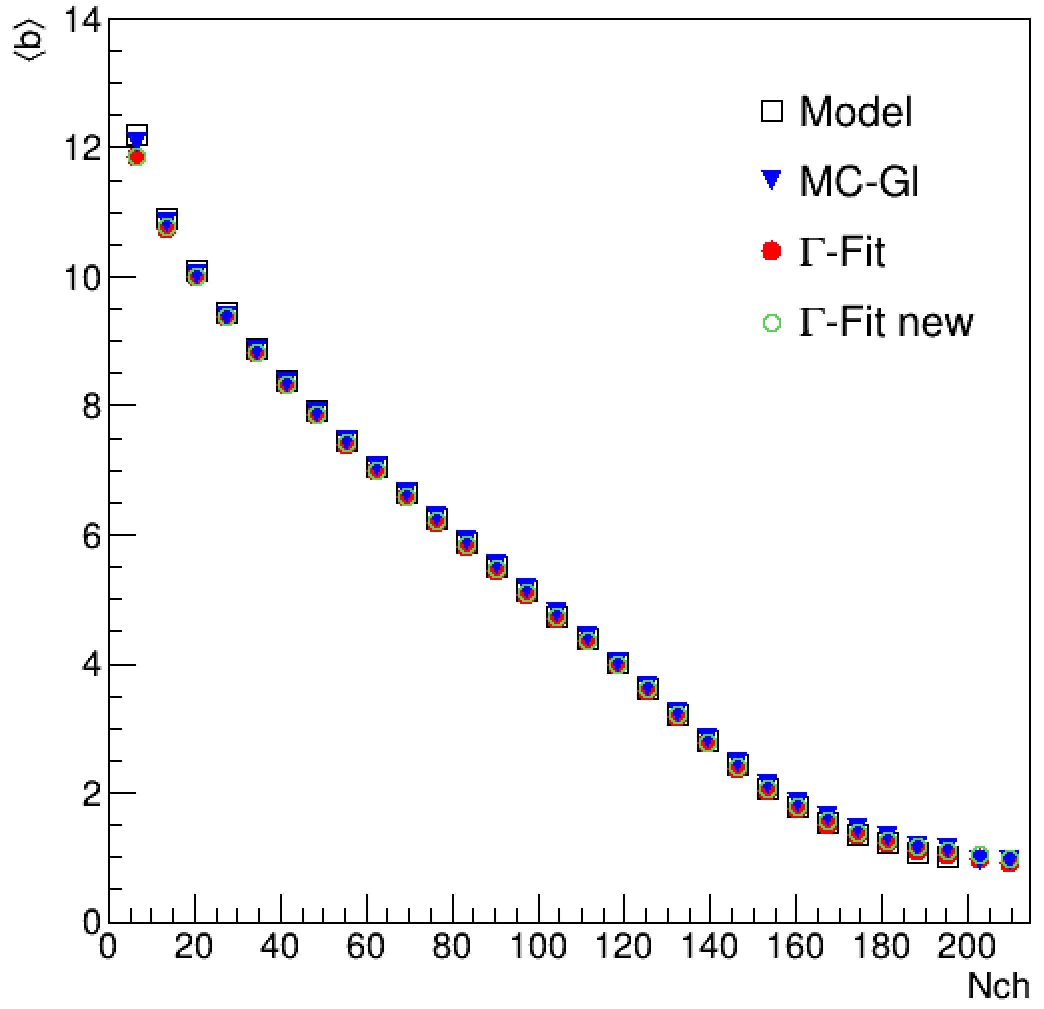
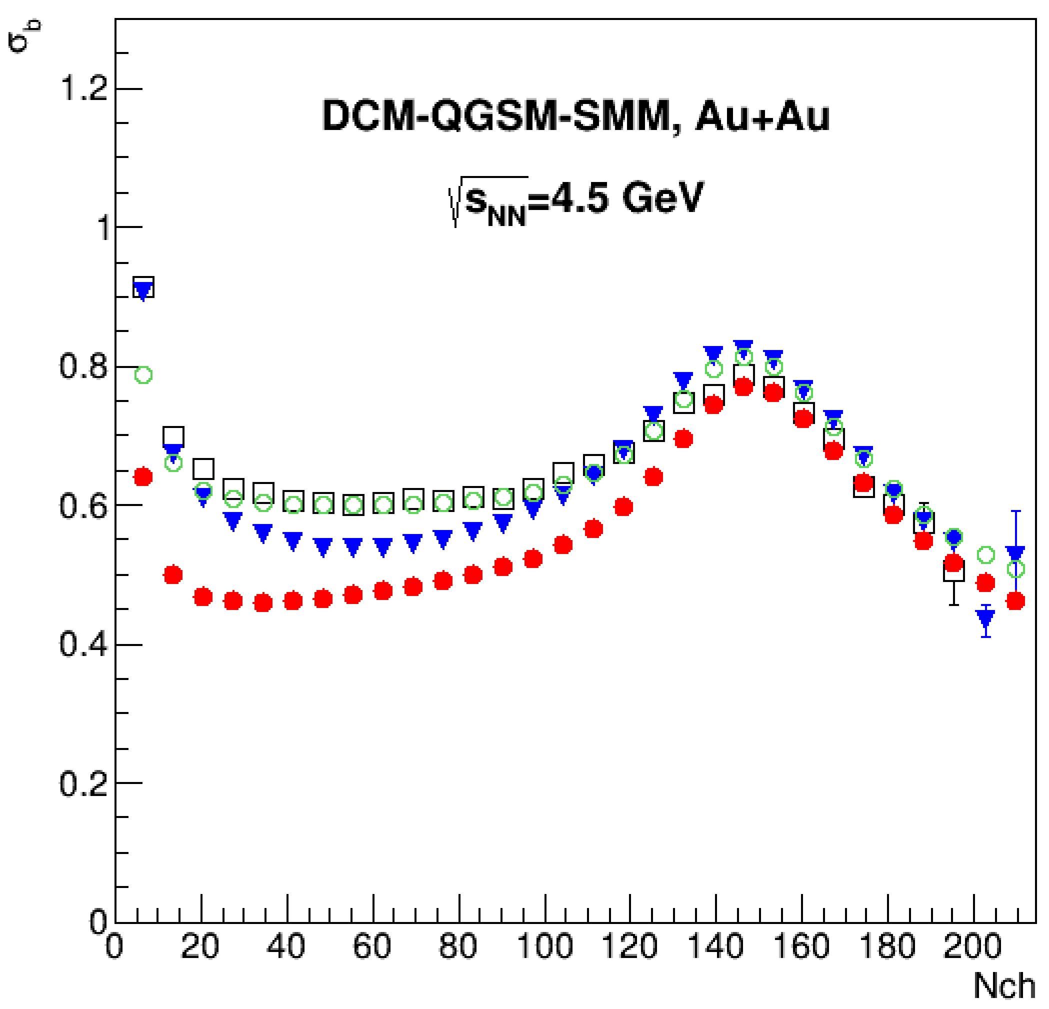
The comparison of impact parameter fluctuation





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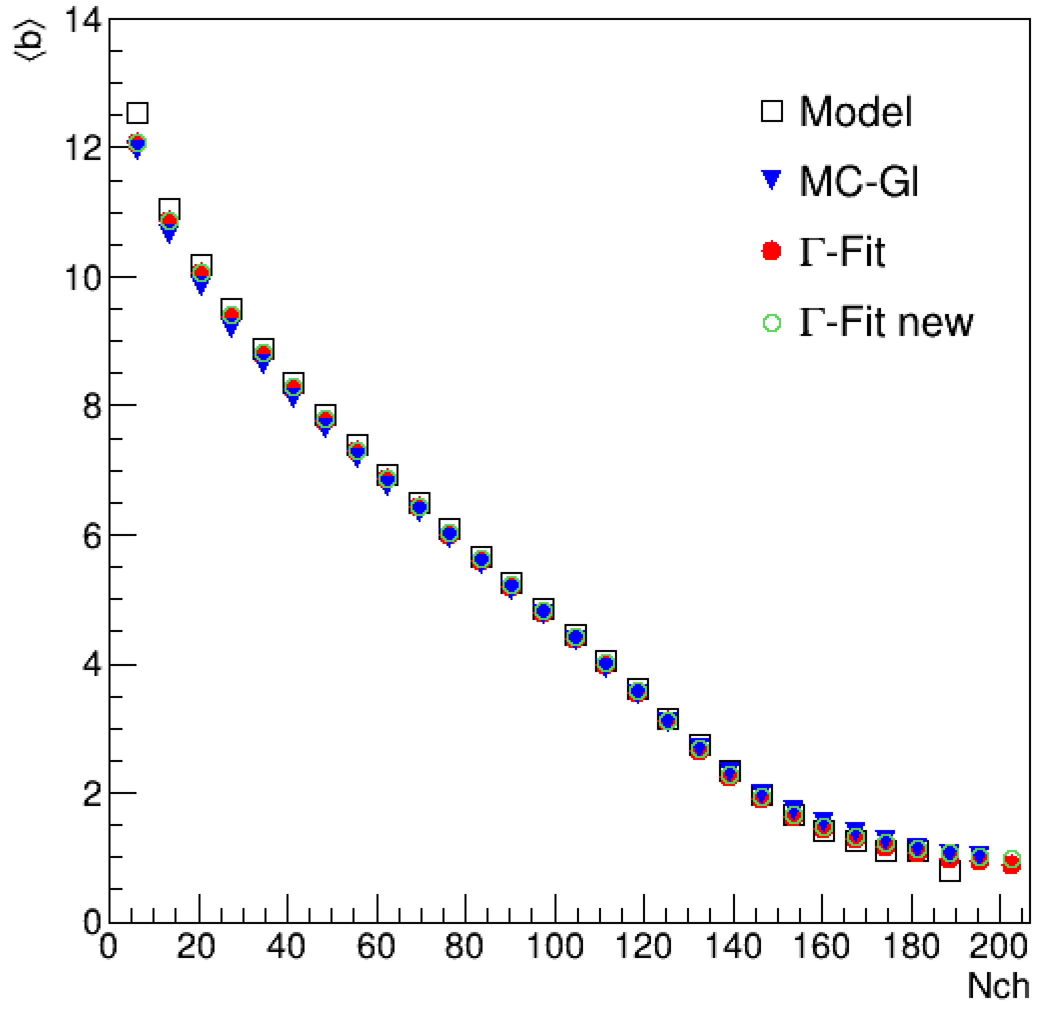
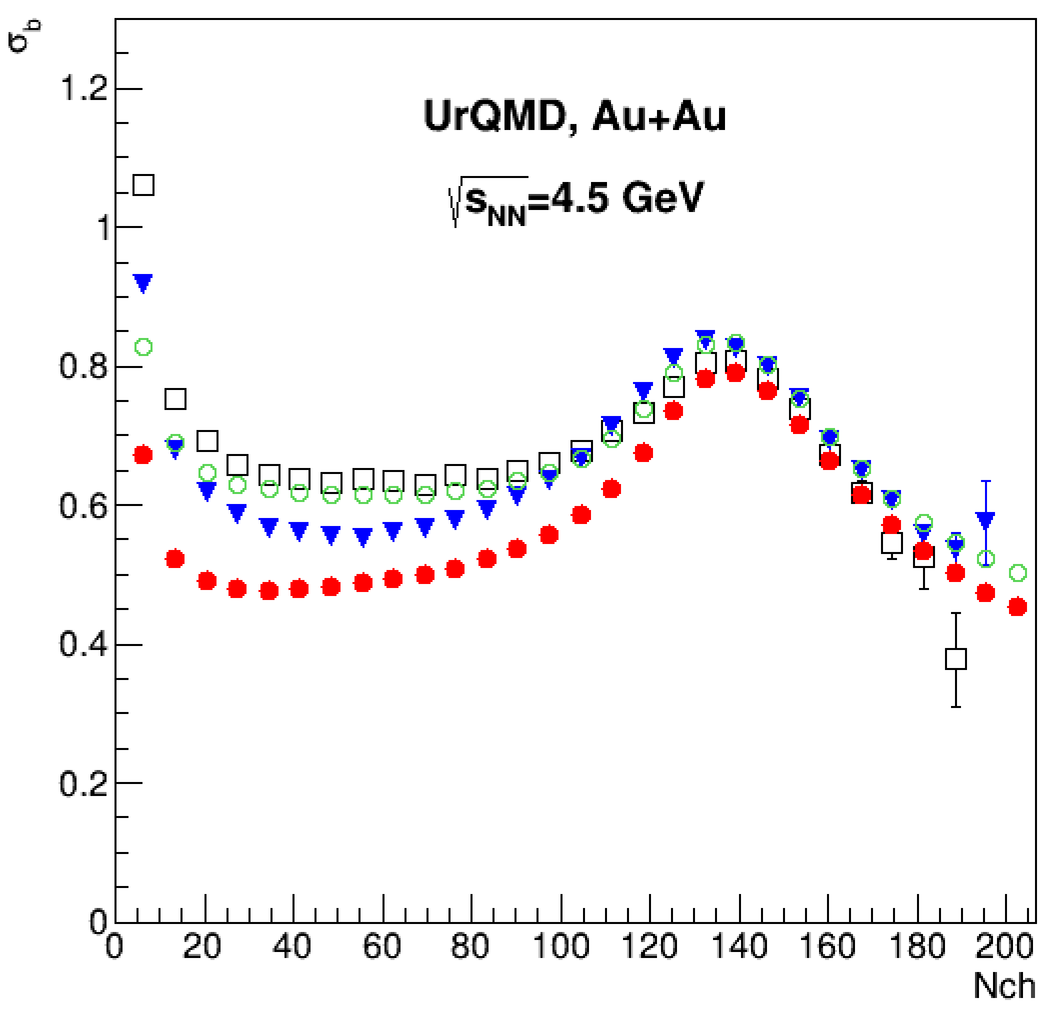
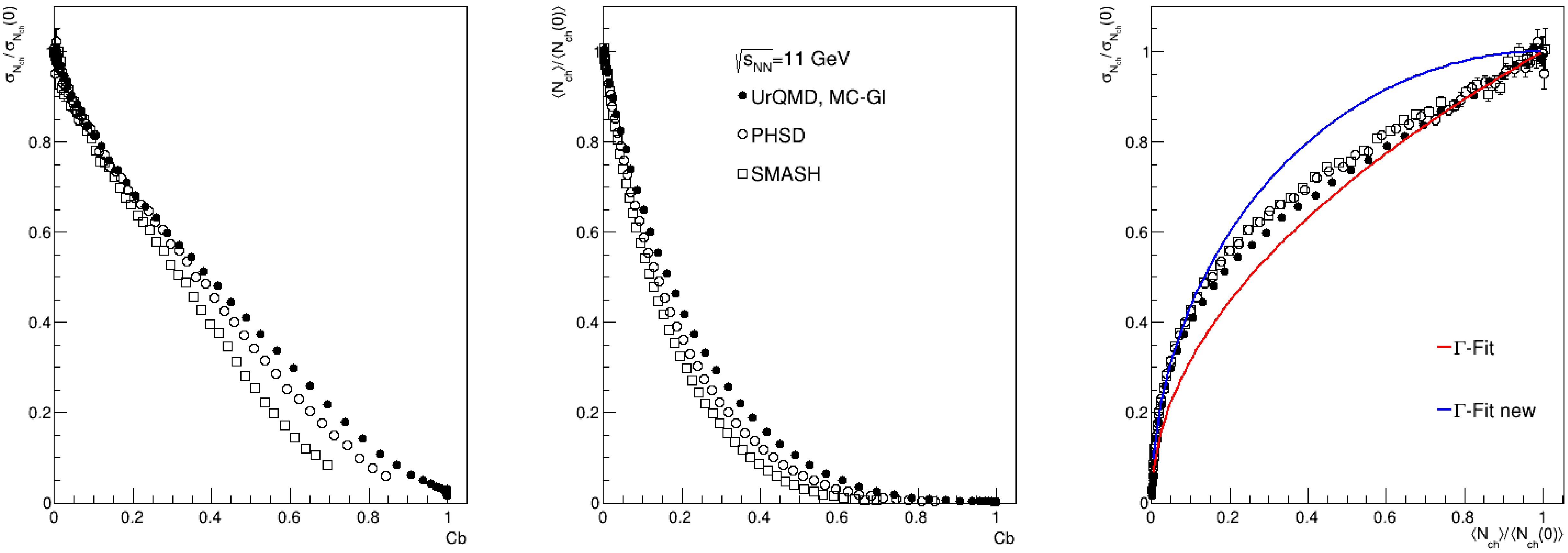




The new parametrization gives better agreement with data from the model.

The charged particle multiplicity fluctuations in deferent model at 11 GeV



New parameterization(blue line) better describes model data in peripheral collisions but worse in central collisions than classic method .