# PWG1 Summary

PWG1 conveners: Petr Parfenov (JINR), Grigory Feofilov (SPbSU)

With big help from Andrey Moshkin (VBLHEP JINR) and Dmitry Podgainy (MLIT JINR)

XIV MPD Collaboration Meeting, Dubna, Russia, 14-16 October 2024

# Outline

- PWG1 activity
- Selected results since previous meeting
- Summary

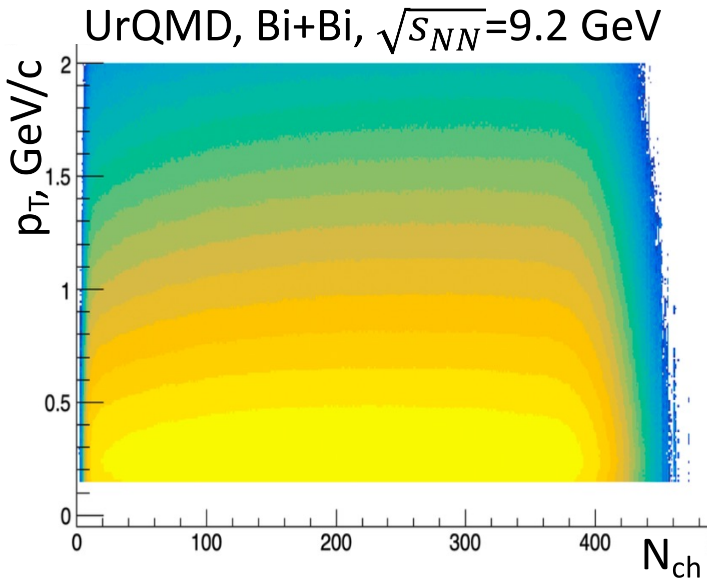
# PWG1 activity

There were 6 reports at MPD Cross-PWG since the previous meeting:

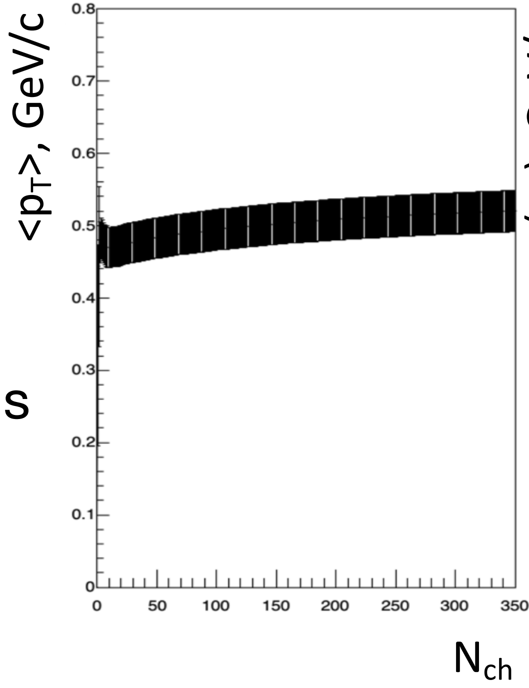
1. T.Q.T. Le, A. Galoyan, V. Uzhinsky, *Coupling of UrQMD 3.4 and SMM models for simulation of neutron and nuclear fragment productions in nucleus-nucleus interactions*, **9 Jul 2024**
2. V. Riabov, *MPD-FXT performance with Xe-beam and W-target*, **9 Jul 2024**
3. V. Riabov, *Beam pipe and luminosity detector at startup,* **20 Aug 2024**
4. D. Flusova, N. Bikmetov, *First results on centrality determination in Xe+W and Xe+Xe collisions at $E_{kin}$= 2.5 AGeV in MPD-FXT,* **8 Oct 2024**
5. E. Andronov, *Status of $p_T$ vs. multiplicity correlations analysis,* **8 Oct 2024**
6. N. Kolomoyets, *Light hadron spectra obtained with MPDRoot,* **8 Oct 2024**

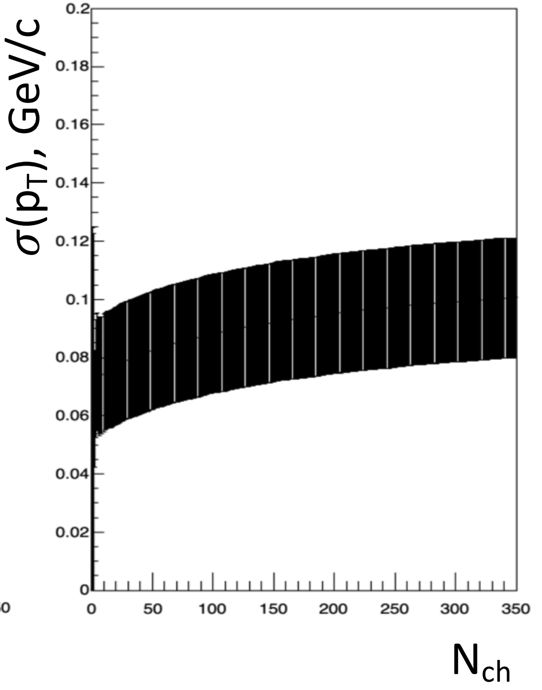
# $p_T$-$N_{ch}$ correlations

Analysis wagon for unidentified $p_T$ spectrum and moments of $p_T$ as a function of multiplicity ($N_{ch}$) is in preparation: **MpdFluctPt**




- Such studies have a long history of measurements for broad energy range and for different colliding systems
- It might help to constrain models
- However only recently HI experiments started to publish full $p_T$ spectrum as a function of multiplicity so one can have a look not only on the mean $p_T$ but on the higher moments as well
- It is used to study collectivity in p-p, p-A and A-A collisions

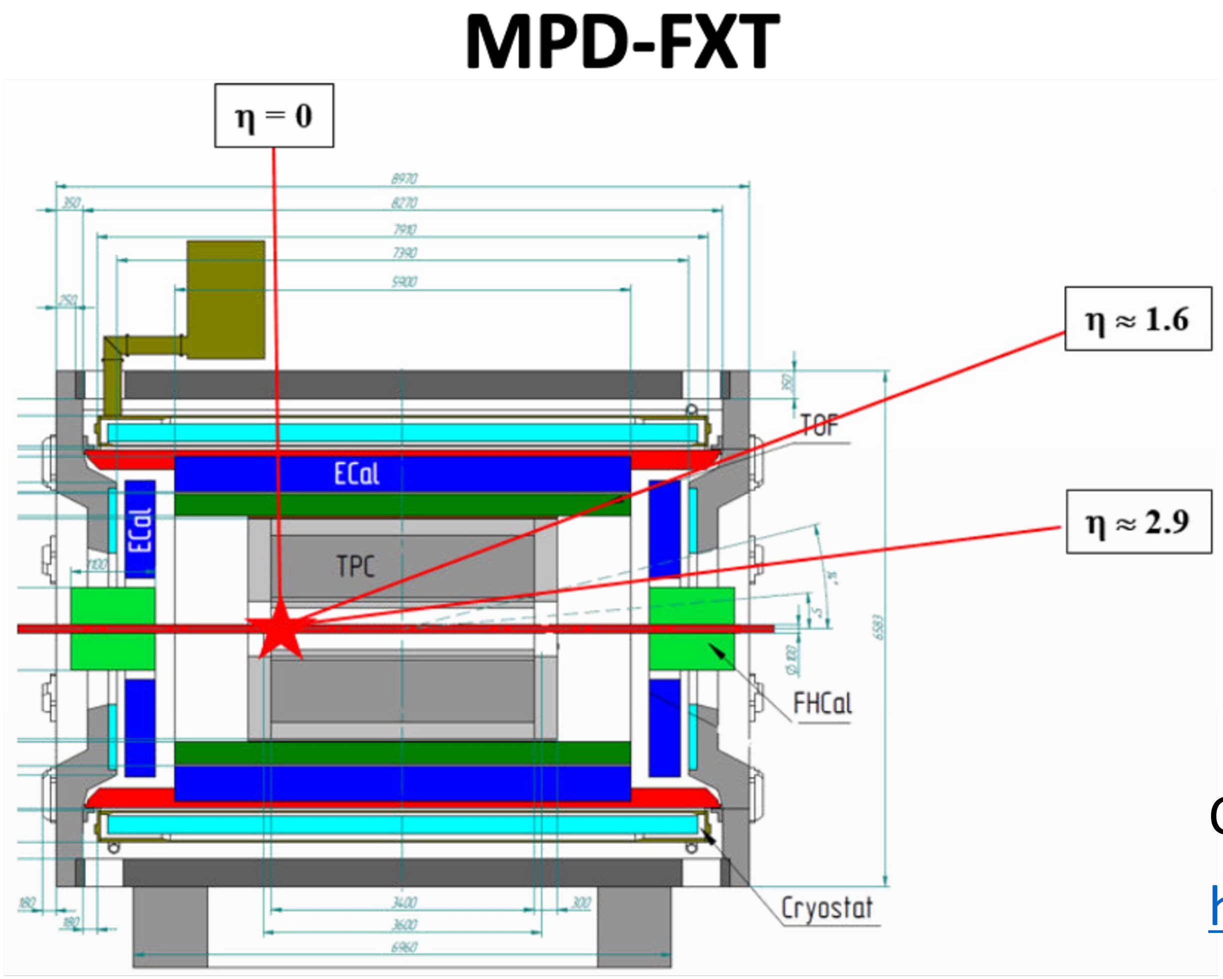



First results for production 25 and 26 (Bi+Bi, $\sqrt{s_{NN}}$=9.2 GeV) are ready

**See E. Andronov talk at the MPD Cross-PWG Meeting (08.10.2024)**

# MPD in Fixed-Target Mode (MPD-FXT)



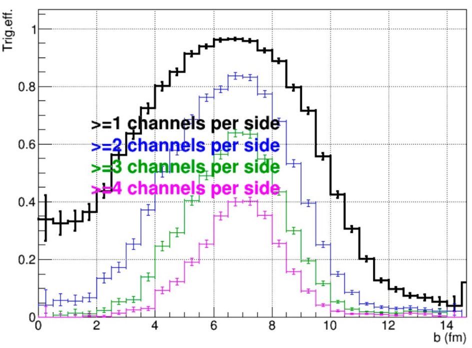

- Model used: UrQMD mean-field
  - Bi+Bi, $E_{kin}$=1.45 AGeV ($\sqrt{s_{NN}}$ =2.5 GeV)
  - Bi+Bi, $E_{kin}$=2.92 AGeV ($\sqrt{s_{NN}}$ =3.0 GeV)
  - Bi+Bi, $E_{kin}$=4.65 AGeV ($\sqrt{s_{NN}}$=3.5 GeV)
  - Xe+W, $E_{kin}$=2.5 AGeV ($\sqrt{s_{NN}}$ =2.87 GeV)
  - Xe+Xe, $E_{kin}$=2.5 AGeV ($\sqrt{s_{NN}}$ =2.87 GeV)
- Point-like target:
  - Bi+Bi: z = -115 cm
  - Xe+W, Xe+Xe: z = -85 cm
- GEANT4 transport
- Multiplicity-based centrality determination

Centrality Framework software:

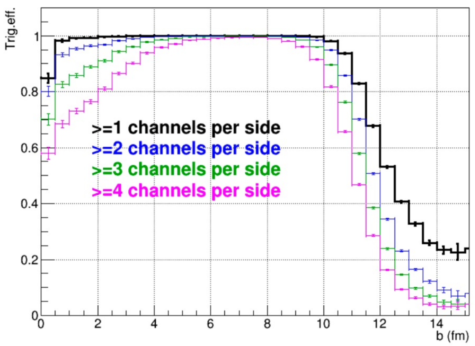
https://github.com/FlowNICA/CentralityFramework/

# FFD, FHCal, TOF: trigger efficiency in Xe+W at MPD-FXT

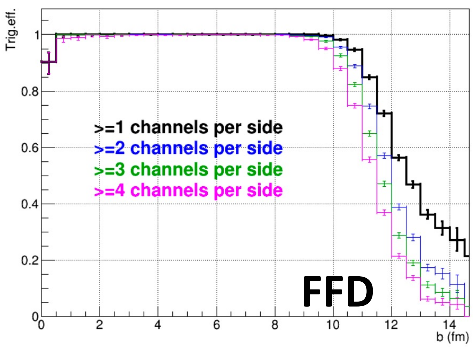
T = 0.5 GeV/n | T = 2.5 GeV/n | T = 4.0 GeV/n



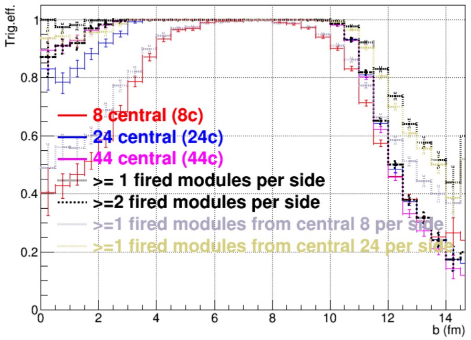

Eff = 12, 22, 35, 55%



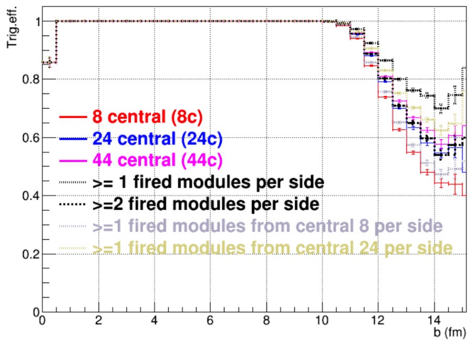

Eff = 73, 78, 83, 88%



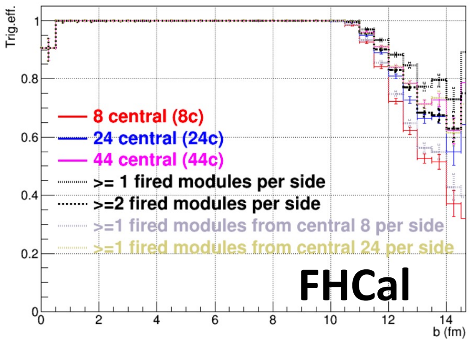

Eff = 78, 82, 85, 89%



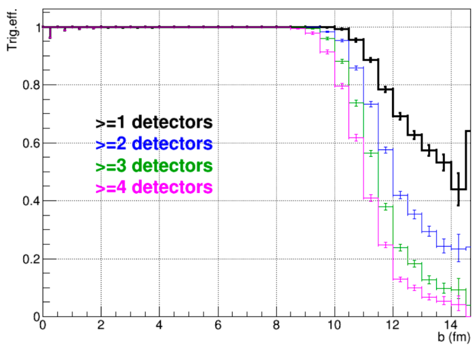

Eff = 82-94%



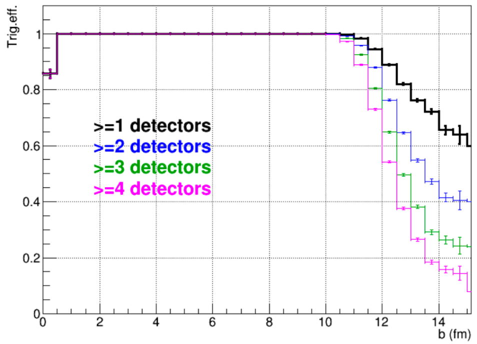

Eff = 93-96%



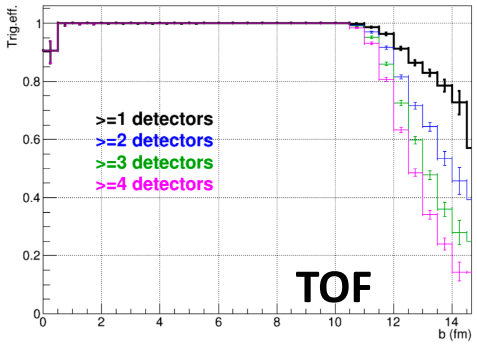

Eff = 93-97%




Eff = 75, 80, 85, 93%




Eff = 89, 91, 94, 97%



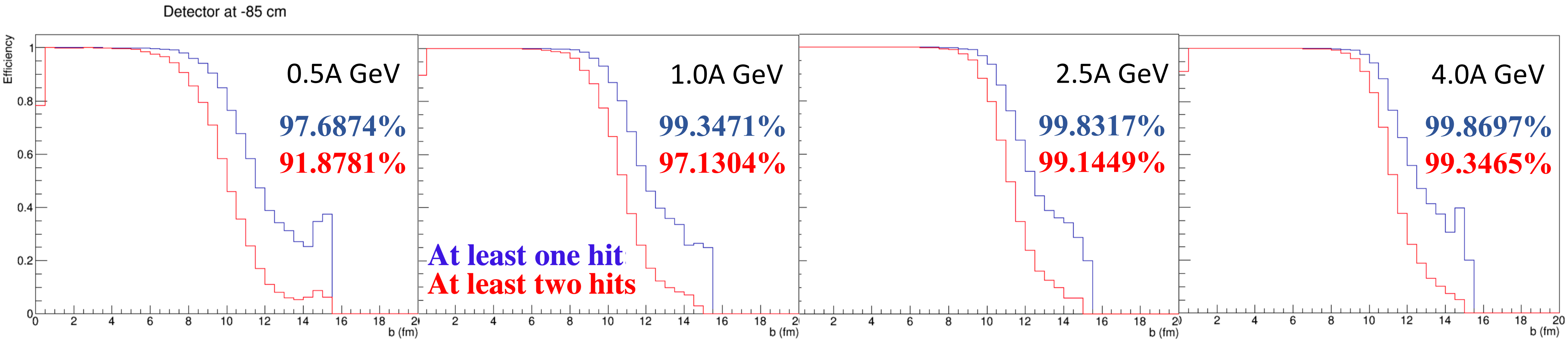

Eff = 91, 93, 95, 98%

- **Most probably FFD will be the main trigger detector**
  - To reject background from the photo-production and EMD, FFD and FHCal trigger decisions should be in coincidence with TOF

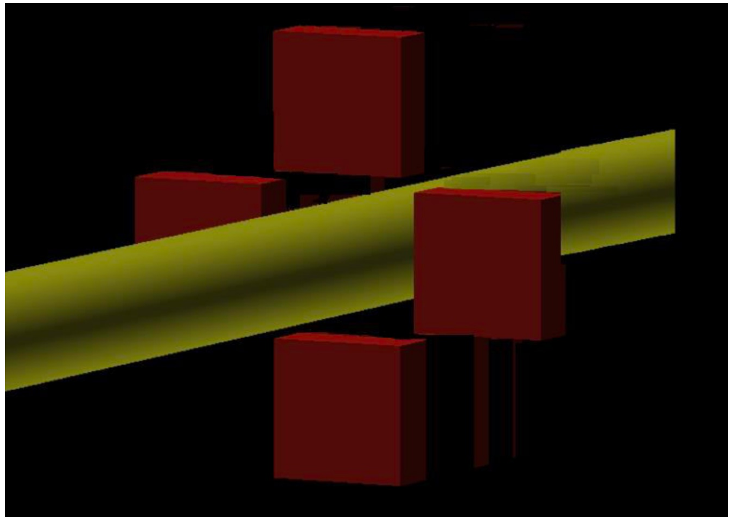
- **Trigger performance:**
  - Both T=2.5 and 4.0 GeV/n can be used in physics runs
  - T=0.5 GeV/n shows bad performance - suitable only for performance study and technical runs

**See V. Riabov talk at the MPD Cross-PWG Meeting (09.07.2024)**

# Luminosity detector: trigger efficiency in Xe+W at MPD-FXT

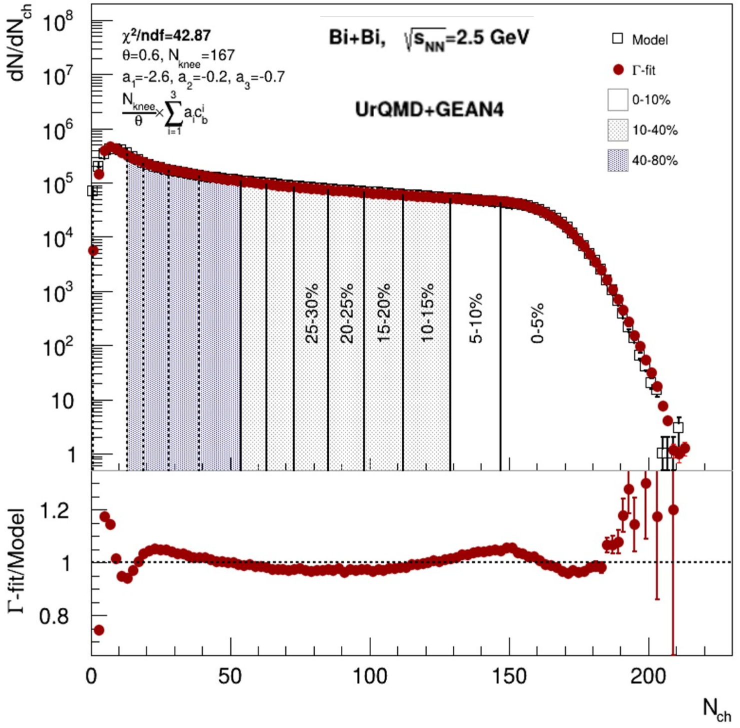


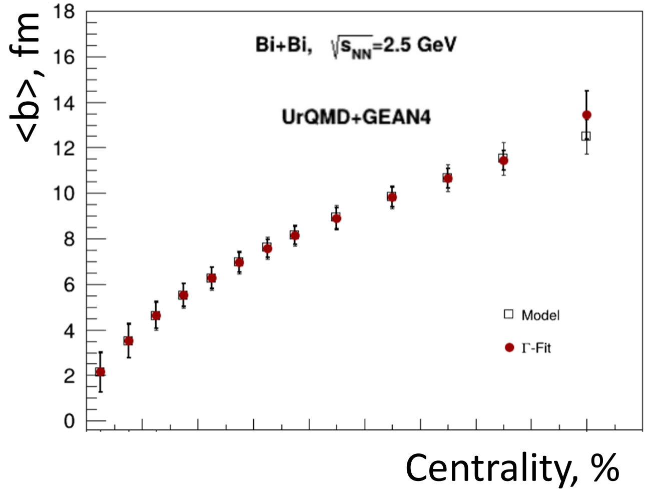

- Setup with simplified geometry was used for GEANT4:
  - stainless steel beam pipe (diameter = 80 mm, width = 1 mm)
  - luminosity detector – 4 scintillator blocks of 10 x 10 cm2 at different locations along z-axis: -85, -40, 60, 160, 260 cm.
  - collision vertex is at -85 cm, $Xe^{124}$+W
  - DCM-QGSM-SMM event generator
- Efficiency is higher for higher beam energies
- It is preferrable for luminosity detector to be placed closer to the target wire

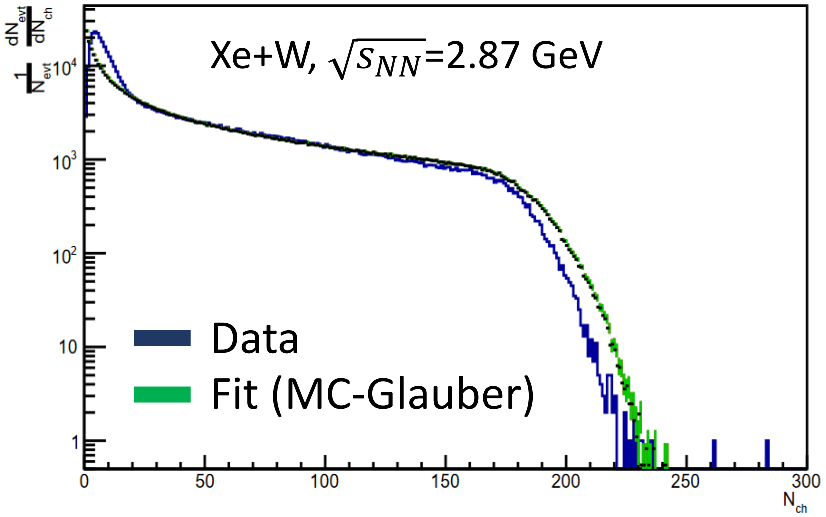


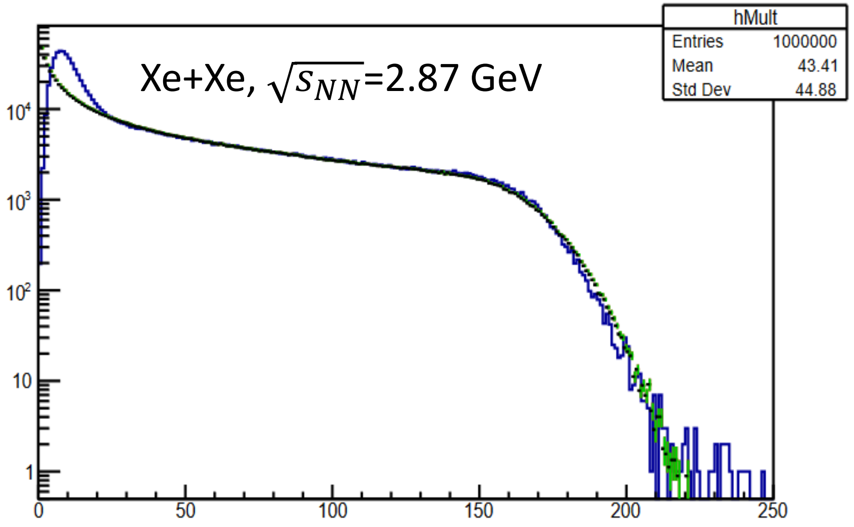
**See V. Riabov talk at the MPD Cross-PWG Meeting (20.08.2024)**

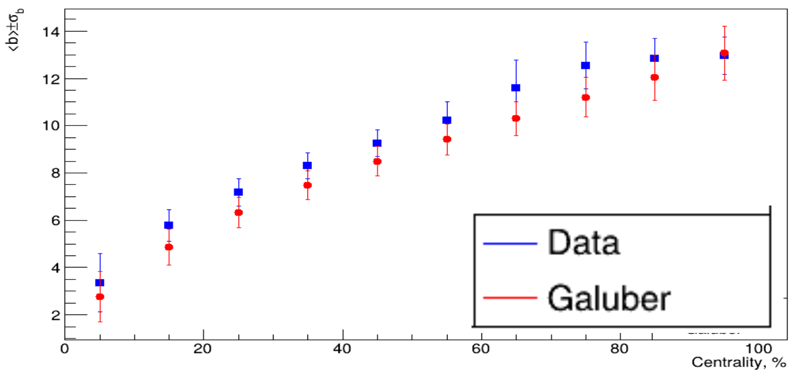
# Centrality determination in MPD-FXT

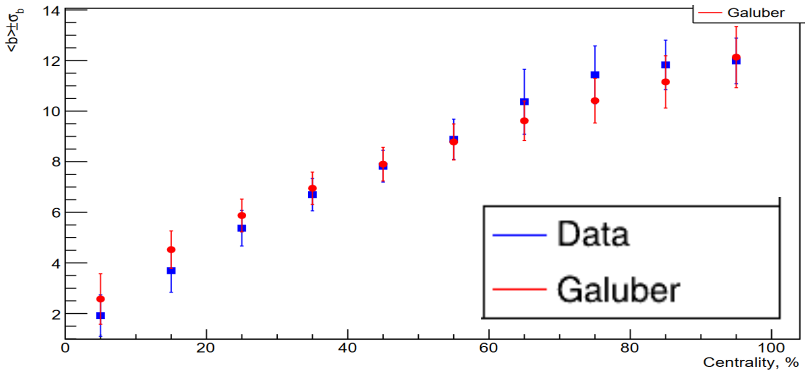


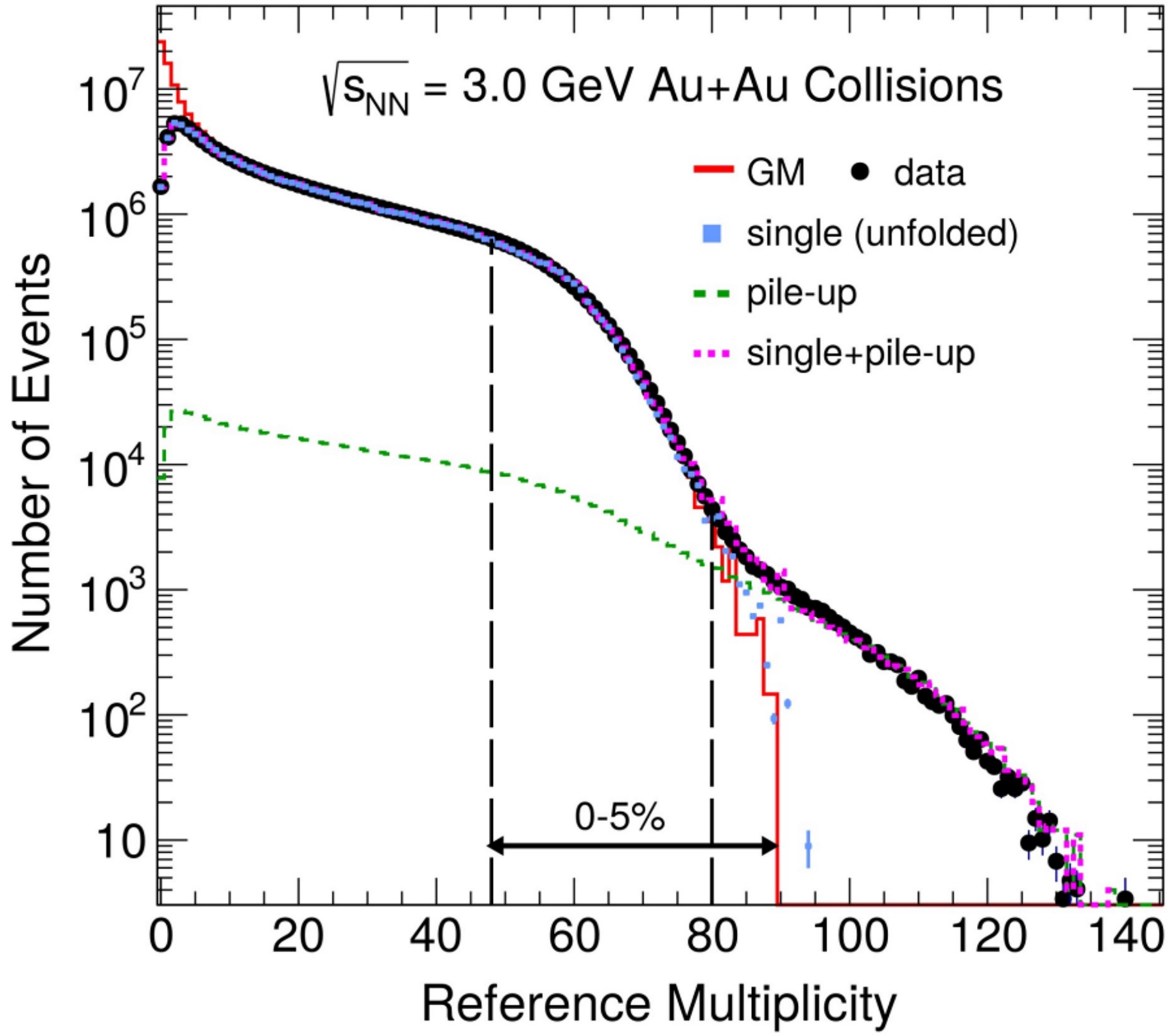




- Both MC-Glauber and $\Gamma$-fit approaches work with MPD-FTX detector configuration
- Centrality provided by $\Gamma$-fit method was used in flow measurements for Bi+Bi, $\sqrt{s_{NN}}$=2.5, 3, 3.5 GeV
- Further study is in progress - **see D. Flusova and N. Bikmetov** **talk** **at CrossPWG 8.10.2024**

# Implementation of “pileup” in the centrality determination procedure

https://arxiv.org/abs/2112.00240

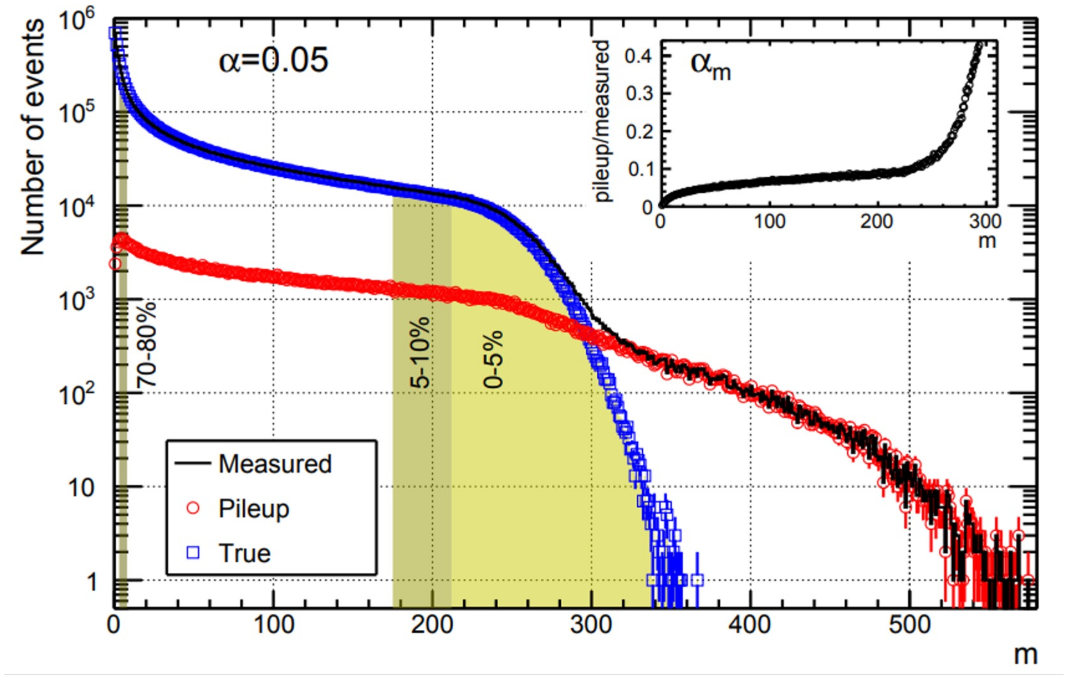



Pileup events occur with the probability $\boldsymbol{\alpha_m}$ at the **m** multiplicity bin.

The probability to find **N** particles of interest at multiplicity **m** with the pileup effects is given by:

$$P_m(N) = (1 - \alpha_m)P_m^{single}(N) + \alpha_m P_m^{pileup}(N)$$

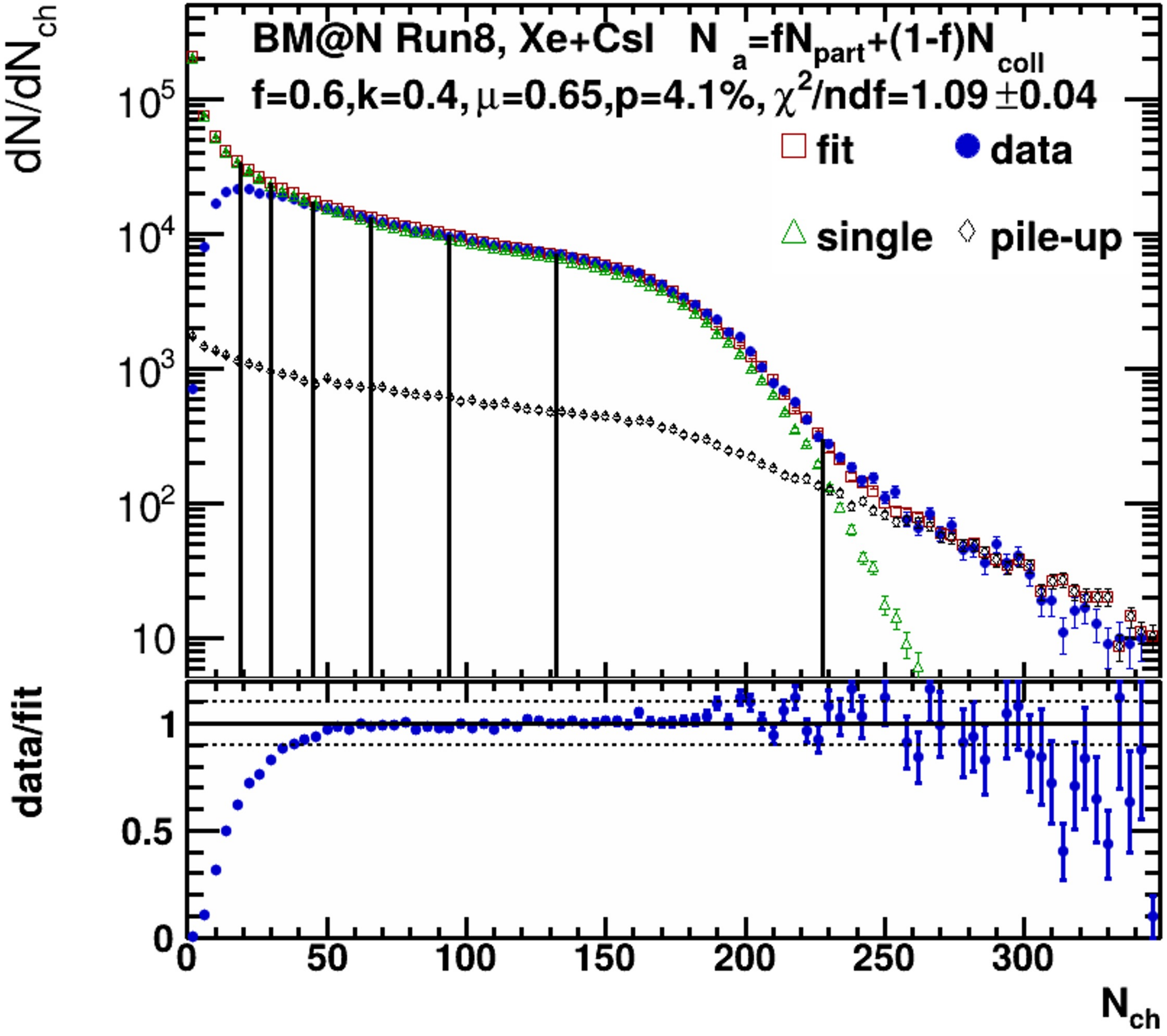
https://arxiv.org/abs/2006.15809




Simple toy model for pileup event generation is available: https://github.com/FlowNICA/McPileUp

Pileup events were implemented in the centrality determination framework: https://github.com/FlowNICA/CentralityFramework

# Testing centrality determination framework in BM@N




RunId: **8120-8170**

Multiplicity Cuts:

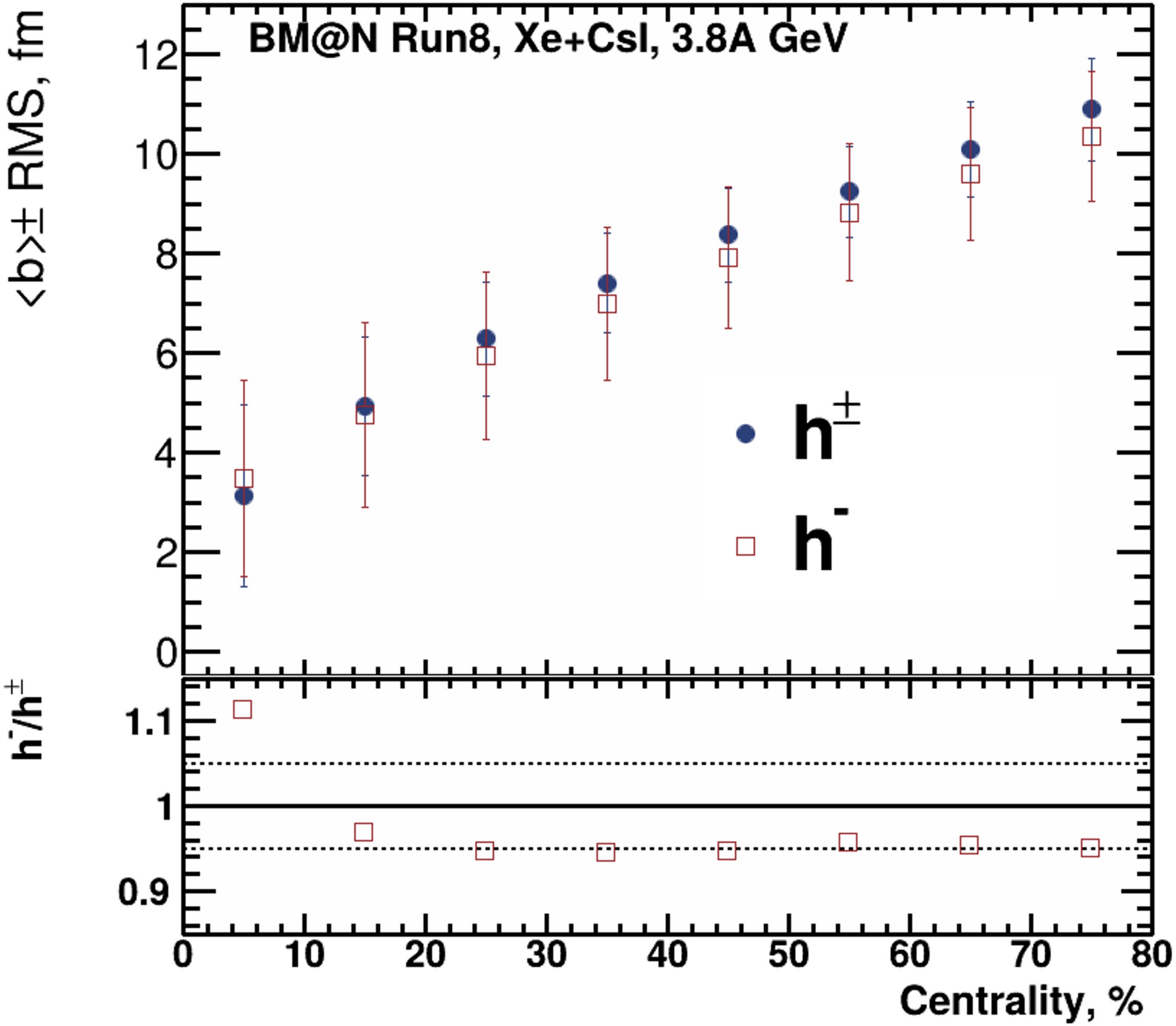
- CCT2
- $N_{vtxTr}>1$
- (Sts digi vs $N_{tr}$) cut
- $V_r$ <1 cm
- $V_z$ < 0.1 cm

- Pileup event sampling is implemented in the framework similar to STAR-like approach[1]
- Generalized NBD parametrization is built in the framework. Fit parameters now are consistent with Kharzeev-Nardi[2] approach

**Good agreement with experimental data**

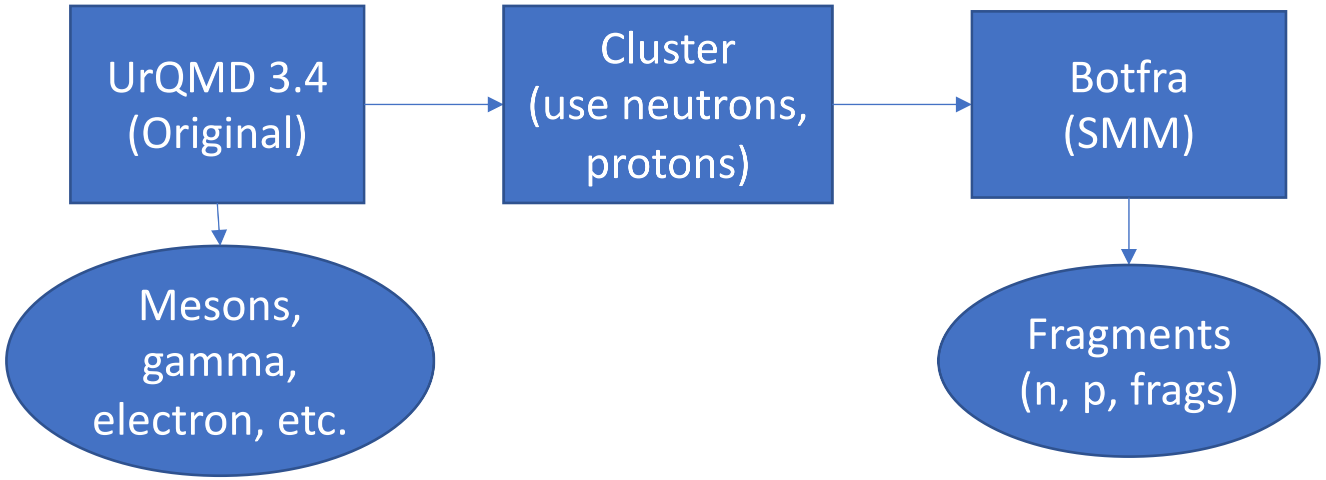
[1] arXiv:2006.15809 (2020)
[2] Phys.Lett. B507 (2001) 121-128

# Testing centrality determination framework in BM@N

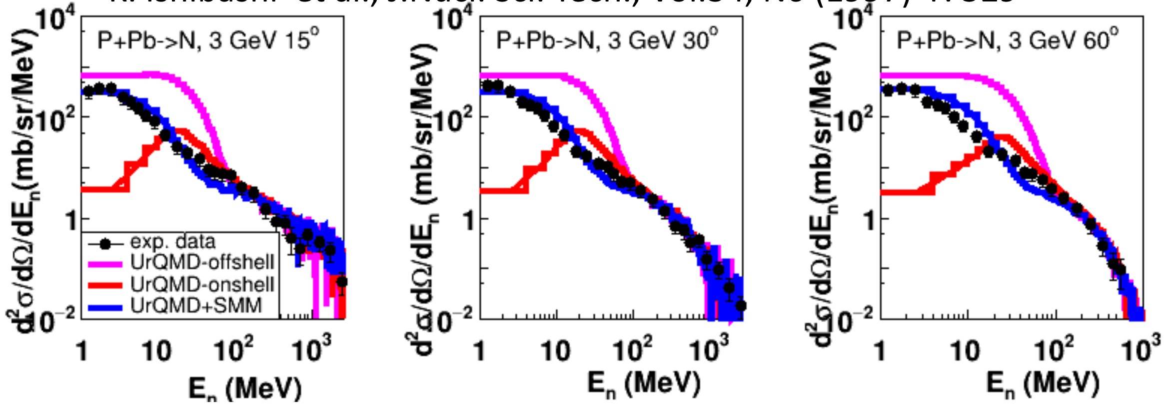



- Difference in the most central class is due to pile-up:
  - Cut on maximum multiplicity differs – expected to improve with optimized pileup rejection
- The difference in the mid-central region is within 5%
  - The possible effect from spectators in the case of $h^{\pm}$ multiplicity seems to be small

# Coupling of UrQMD and SMM models




K. Ishibashi et al., J.Nucl. Sci. Tech., Vol.34, N6 (1997) P. 529




**Realistic heavy-ion model at NICA energies needs to have:**

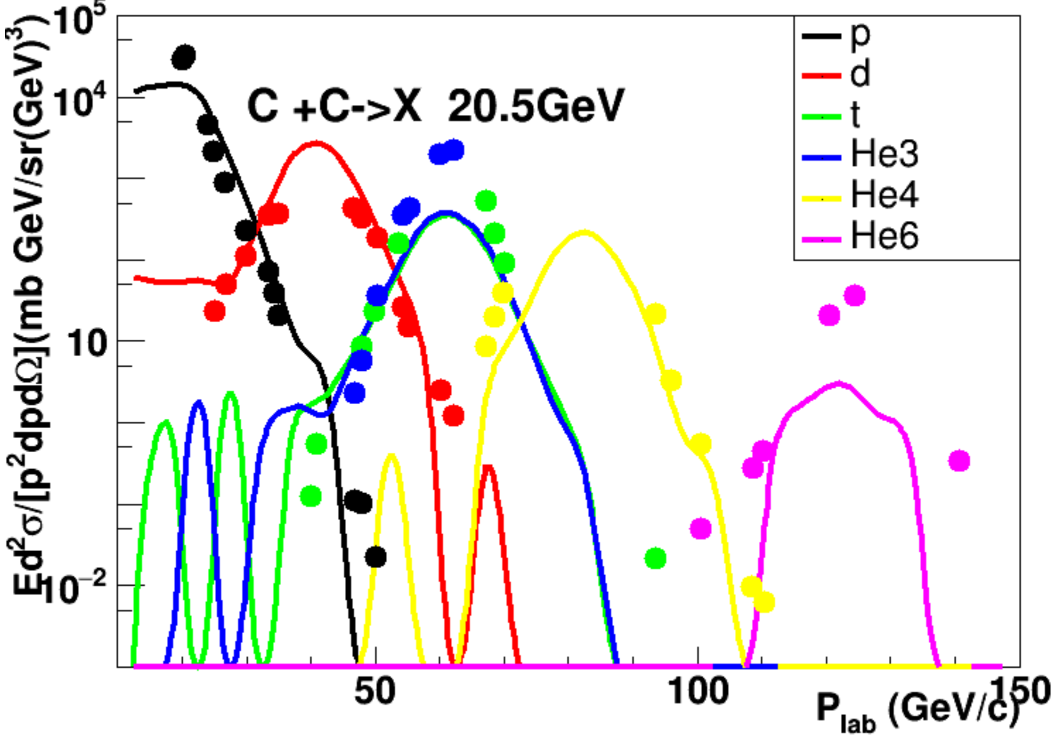
- Implemented EoS with mean-field approach
- Fragmentation model for forward/backward spectator region

**UrQMD+SMM satisfy such requirements:**

- UrQMD describes well spectra of $(\pi^{\pm}, K^{-}, p, \bar{p})$, $v_n$ of protons, etc.
- SMM provides realistic fragmentation

**See T.Q.T. Le talk at the MPD Cross-PWG Meeting (09.07.2024)**

Exp. Data: Afonin, A. G., et al. *Nuclear Physics A* 997 (2020):121718



# Coupling of UrQMD and AAMCC models

**UrQMD:**

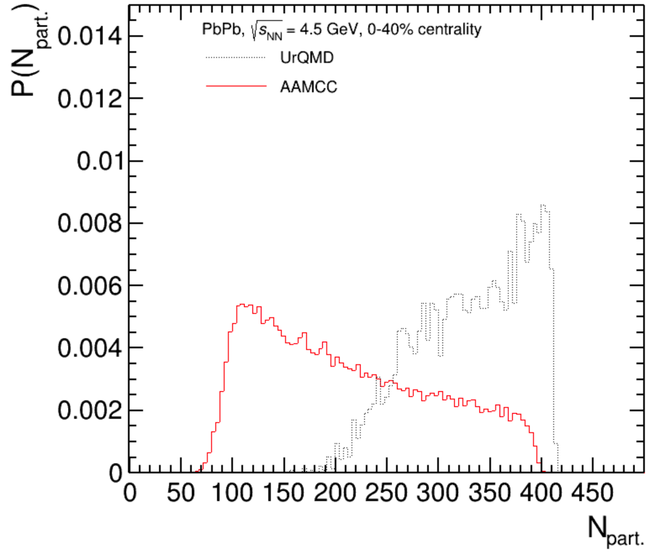
- Version 3.4
- Cascade mode in this work
- Offset radius 5 fm
- Evolution time – 100 fm/c
- Other parameters are set to default values

MCini file

**AMC:**

- Find spectator nucleons
- Define prefragments via MST-clustering
- Constant $d$ = 2.7 fm
- Model prefragments decays
- All the participant data remain intact

MCini file

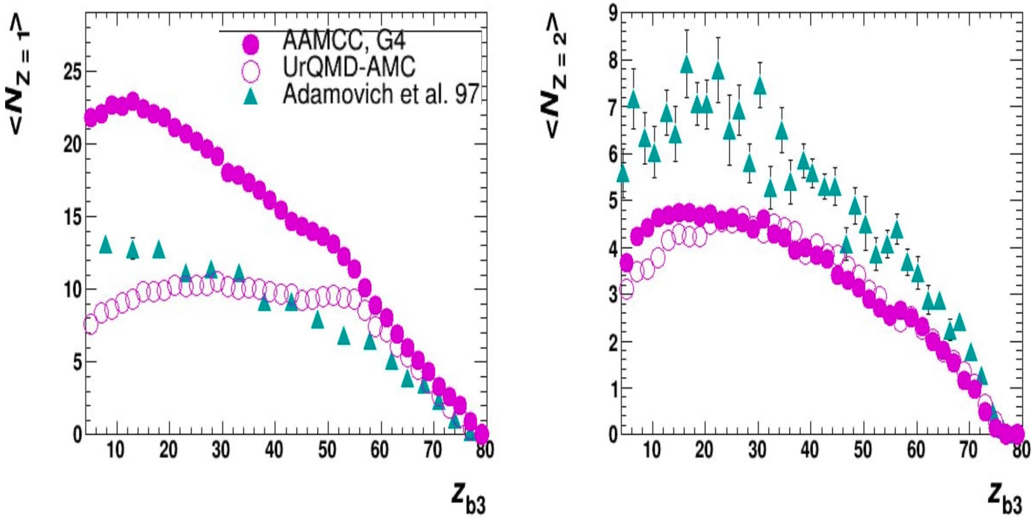



**UrQMD-AMC** allows to have mean-field mode (UrQMD) while having realistic fragmentation with (AAMCC)

**UrQMD-AMC was developed and is ready for use in MPD framework**

- Further work is in progress (participant-spectator separation criteria in UrQMD, calculation of the FHCal response, etc.)

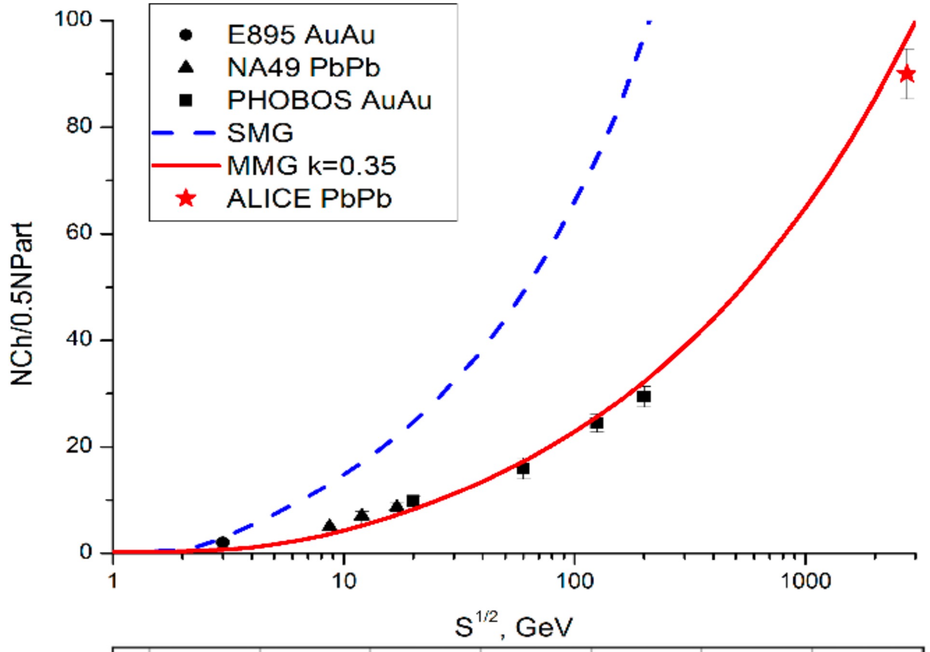
**See A. Svetlichnyi talk at the MPD Cross-PWG Meeting (14.11.2023)**



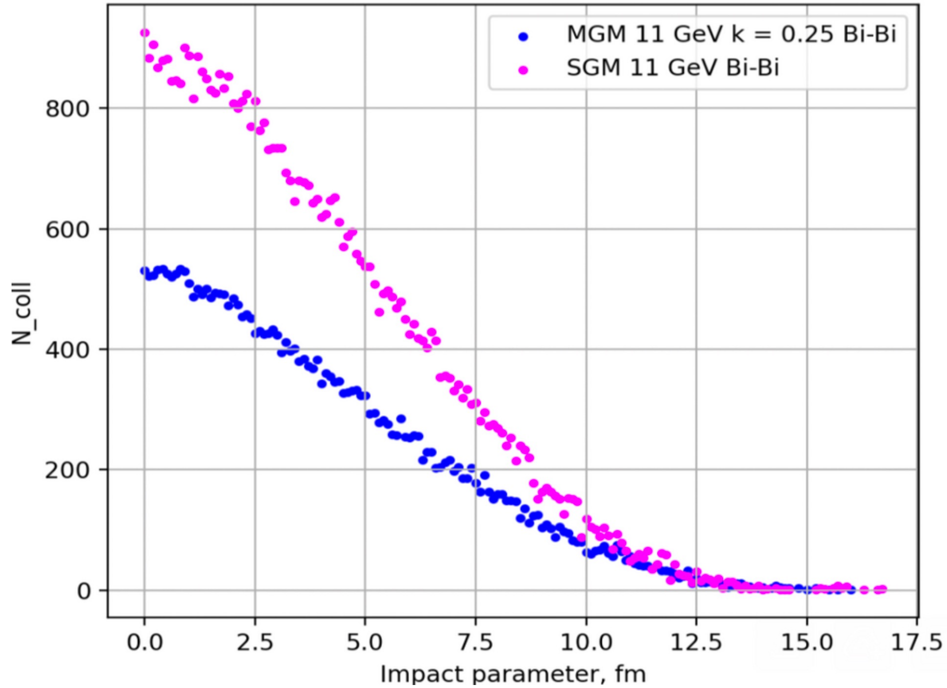
# Modified MC-Glauber

A. Seryakov, G. Feofilov, AIP Conference Proceedings 1701(1):070001

- **Standard MC-Glauber model (SGM):**
  - $\sigma_{NN}^{inel}, d = const;\ E_{tot}, P_{tot} \neq const;$
- **Modified MC-Glauber model (MGM):**
  - $\sigma_{NN}^{inel} = const; d \neq const;\ E_{tot}, P_{tot} = const;$
  - New parameter ***k*** – mean fraction of momentum loss




MGM takes into account NN collisions with energy loss




**Notable difference between SGM and MGM is observed – might be important at NICA energies**

Work is ongoing:

➢ **See S. Simak talk at the MPD Cross-PWG Meeting (20.04.2024)**

# Summary

- **MPD-FXT now the focus of feasibility studies**
  - $Xe^{124}$+W general purpose production was generated with target at z=-85 cm and Xe beam at $E_{kin}$=2.5A GeV
  - Study with simplified beam pipe and luminosity detector shows trigger efficiency $Eff_{trig}$>99% for $E_{kin}$=2.5A GeV

- **Centrality determination in MPD-FXT**
  - Both MC-Glauber and $\Gamma$-fit approaches can be used in the fixed target configuration. $\Gamma$-fit requires further investigation in case of asymmetric collisions

- **BM@N Xe+CsI run provides excellent opportunity to test analysis frameworks on real experimental data**
  - Centrality determination framework can describe multiplicity distribution in Xe+CsI data
    - Pileup event sampling was implemented in the MC-Glauber approach with the additional fit parameter
    - Generalization of NBD was built in the framework. That allows to obtain fit parameter consistant with the Kharzeev-Nardi approach

- **Development of the HI models**
  - UrQMD+SMM and UrQMD-AMC can simultaneously realistically describe particle spectra, flow, etc. (mean-field UrQMD) and spectator fragments
  - Modification for MC-Glauber to take into account NN collisions with energy loss – might be important at NICA energies

# Thank you for your attention!

# Backup

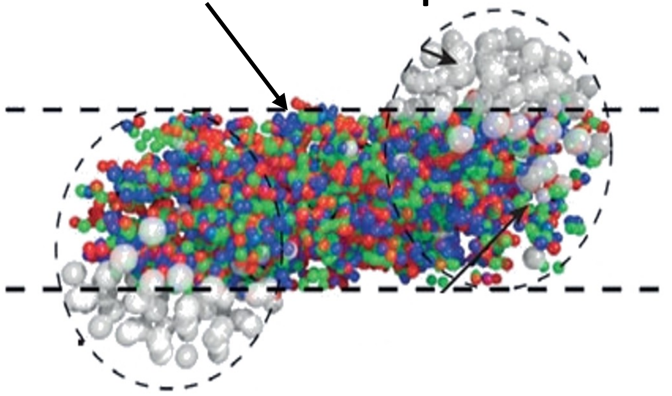
# Motivation for centrality determination

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

- **Goal of centrality determination**:
  <u>map (on average) the collision geometry parameters to experimental observables (centrality estimators)</u>

- Centrality class $S_1$-$S_2$: group of events corresponding to a given fraction (in %) of the total cross section:

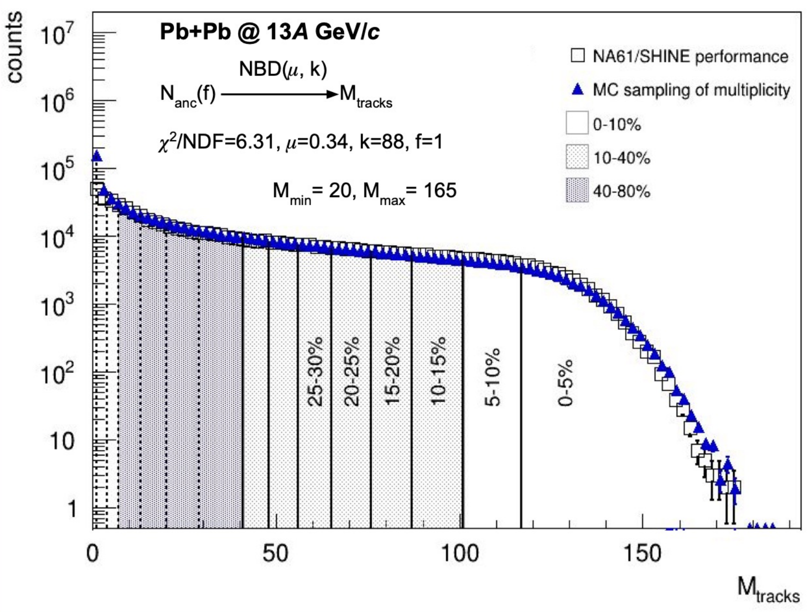
$$C_S = \frac{1}{\sigma_{inel}^{AA}} \int_{S_1}^{S_2} \frac{d\sigma}{dS} dS$$

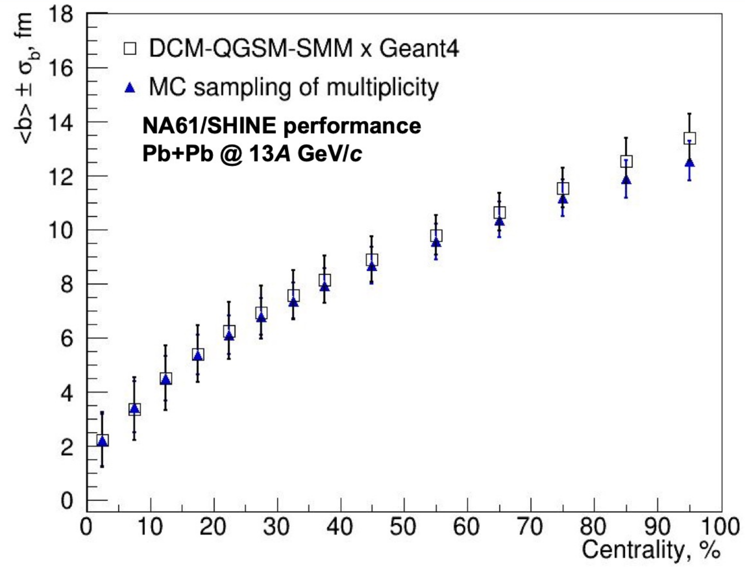


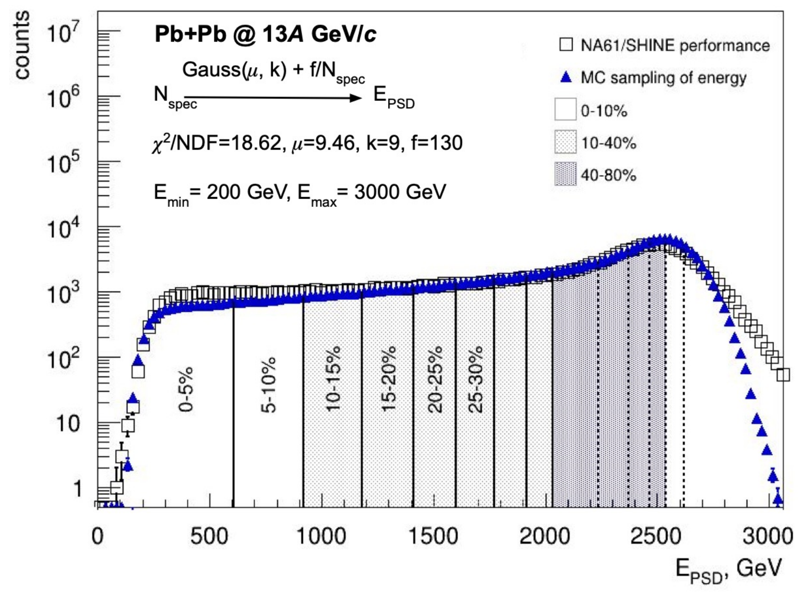
# Overview of centrality determination methods

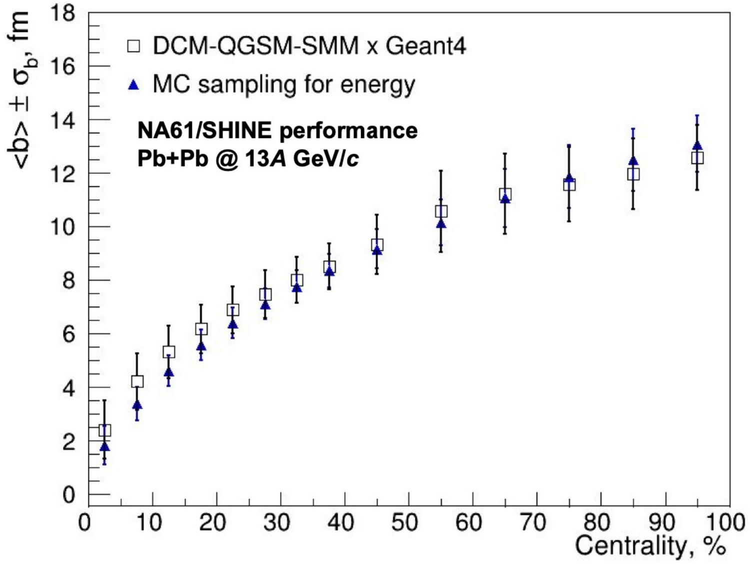
| Method type | MC-Glauber based | Model independent (e.g. Γ-fit method) | Based on ML |
|---|---|---|---|
| Used in | STAR, ALICE, HADES, CBM, MPD, etc. | ALICE, CMS, ATLAS<br>J. Y. Ollitrault et al. Phys.Rev. C 98 (2018) 024902 | Becoming popular<br>Fupeng L. et al. J.Phys.G 47 (2020) 11, 115104 |
| Advantages | Commonly used, well established procedure | Universality due to model independence | The most modern and fast methods |
| Disadvantages | MC-Glauber model provides non-realistic $N_{part}$ simulations at low energies<br>M. O. Kuttan et al. e-Print: 2303.07919 [hep-ph] | In strong connection with $\sigma_{inel}$ which dependence on energy is not well studied at low energies (same problem for MC-Glauber based methods) | There no way to control the physicality of the methods |

# Centrality determination in NA61/SHINE using MC-Glauber

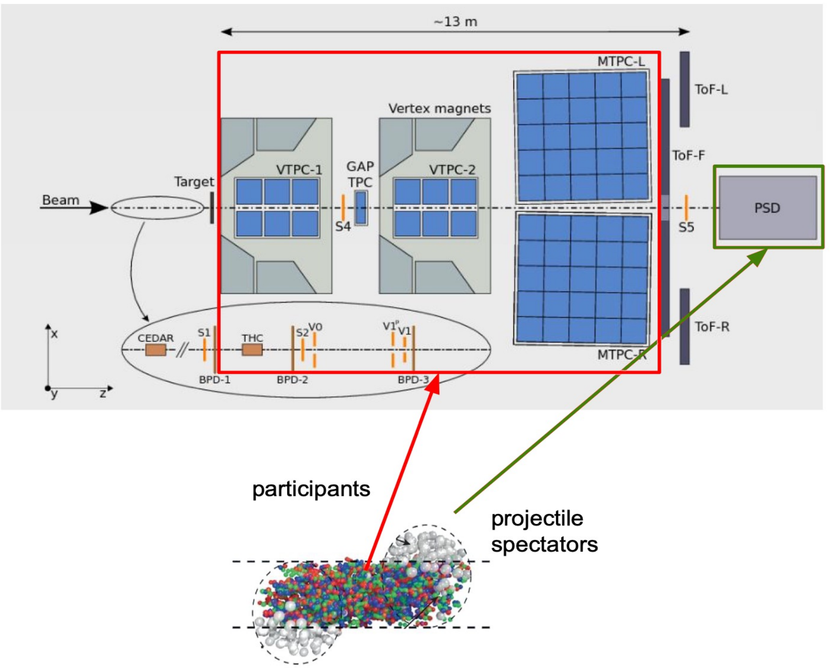


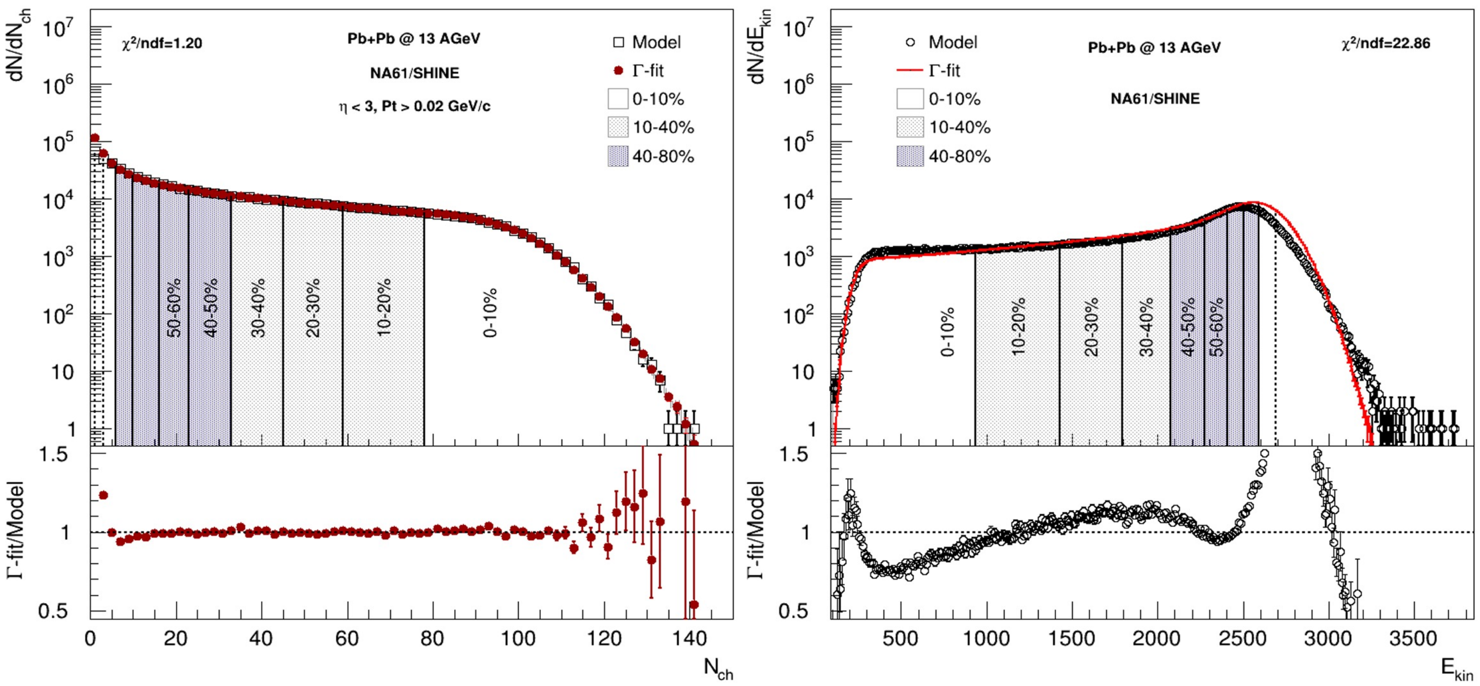



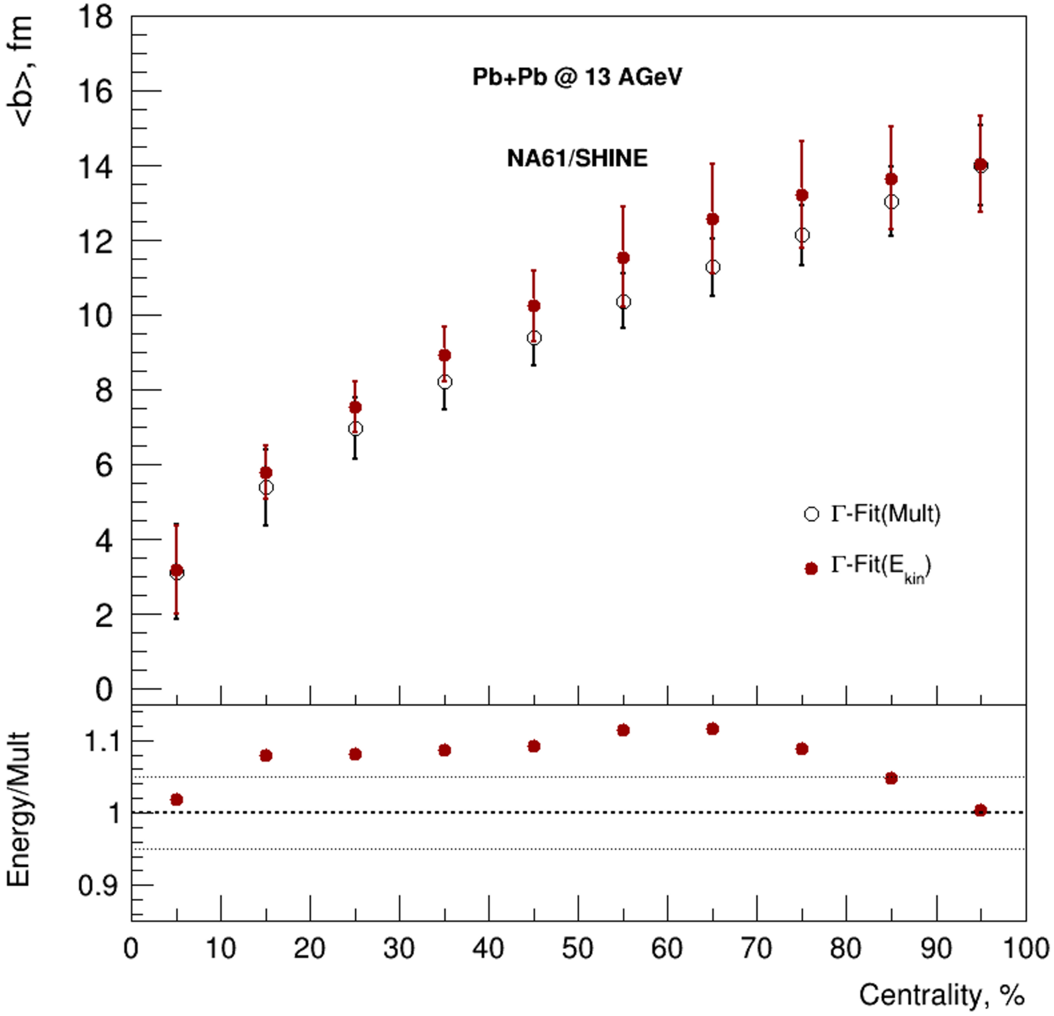

NA61/SHINE setup




- **Simplified procedure for spectator energy is developed and tested on NA61/SHINE data**
- **Possible improvements are under investigation**

# Centrality determination in NA61/SHINE using $\Gamma$-fit

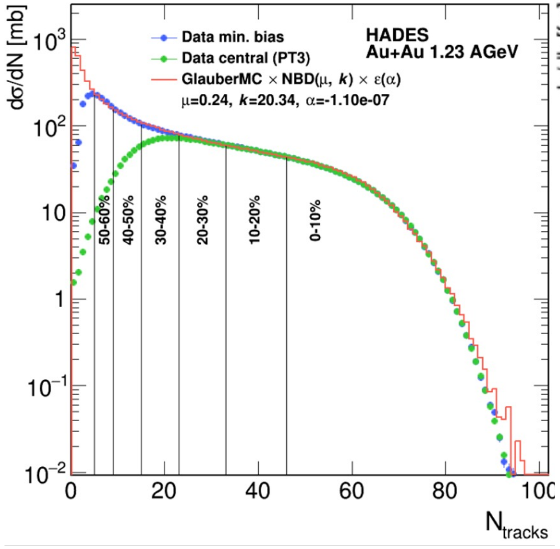


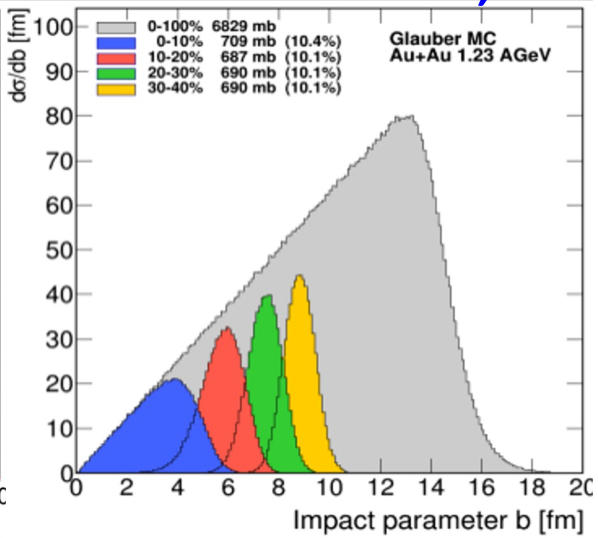



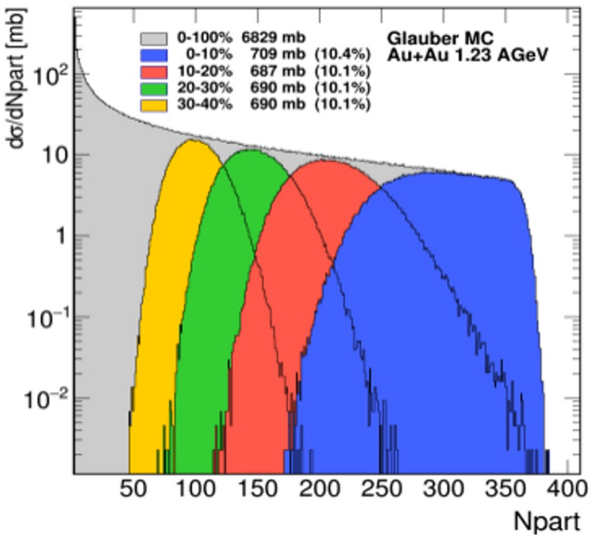

- Centrality determination based on spectator energy using inverse Bayes approach is being developed and tested on model (UrQMD, DCM-QGSM-SMM) and NA61/SHINE data
- Application of centrality determination based on spectator energy using MC-Glauber and inverse Bayes approaches is in progress
- Possible improvements are under investigation

# Centrality determination in HADES, STAR

## HADES, Au+Au 1.23A GeV



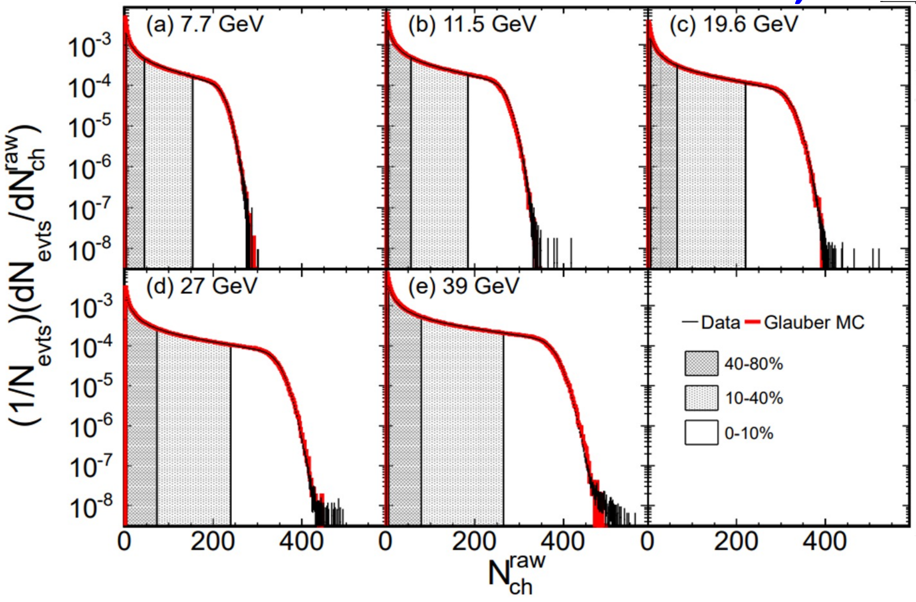




Eur. Phys. J. A (2018) 54: 85

| Centrality Classes | $b_{min}$ | $b_{max}$ | $\langle b \rangle$ |
|---|---|---|---|
| 0 – 5 % | 0.00 | 3.30 | 2.20 |
| 5 – 10 % | 3.30 | 4.70 | 4.04 |
| 10 – 15 % | 4.70 | 5.70 | 5.22 |
| 15 – 20 % | 5.70 | 6.60 | 6.16 |
| 20 – 25 % | 6.60 | 7.40 | 7.01 |
| 25 – 30 % | 7.40 | 8.10 | 7.75 |
| 30 – 35 % | 8.10 | 8.70 | 8.40 |
| 35 – 40 % | 8.70 | 9.30 | 9.00 |
| 40 – 45 % | 9.30 | 9.90 | 9.60 |
| 45 – 50 % | 9.90 | 10.40 | 10.15 |
| 50 – 55 % | 10.40 | 10.90 | 10.65 |
| 55 – 60 % | 10.90 | 11.40 | 11.15 |

## STAR, Au+Au, BES




Phys. Rev. C 86, 054908 (2012)

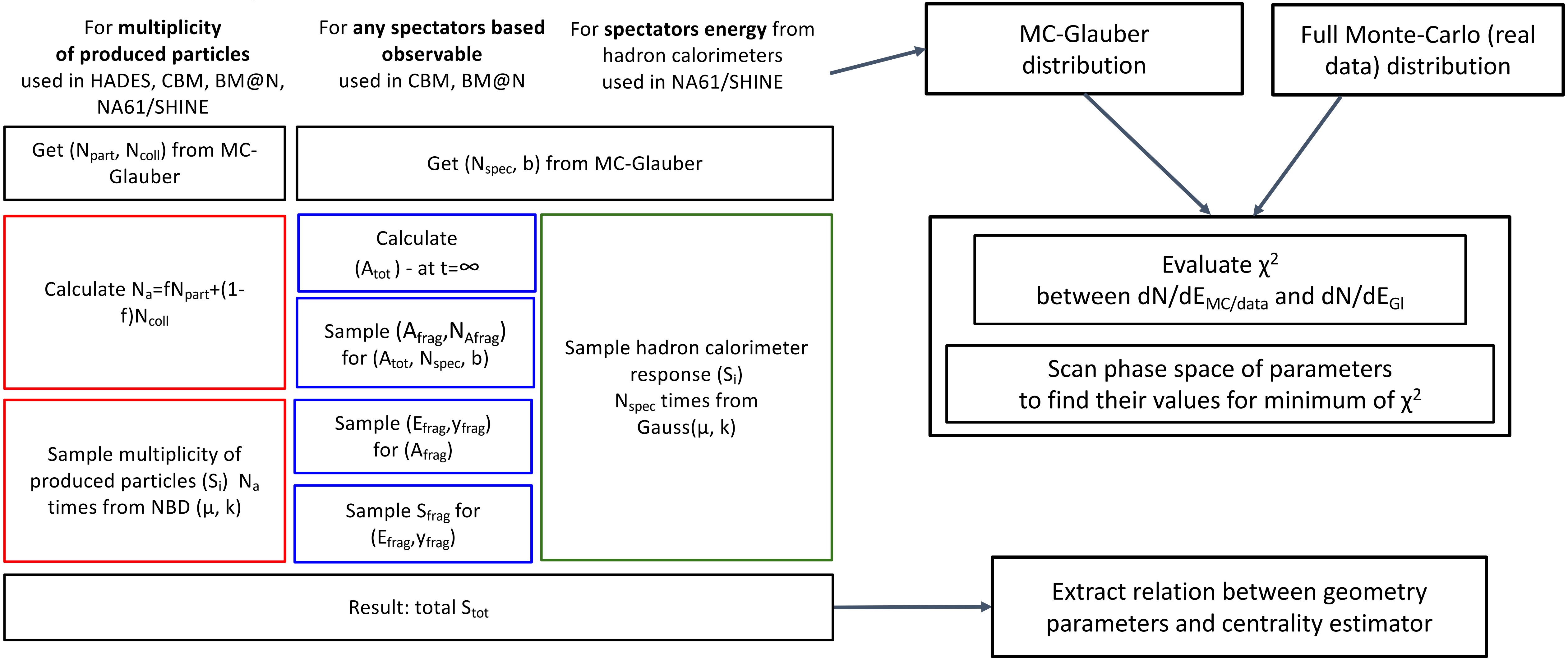
| Centrality (%) | $\langle N_{part} \rangle$ | $\langle N_{coll} \rangle$ |
|---|---|---|
| 0-5% | 337 ± 2 | 774 ± 28 |
| 5-10% | 290 ± 6 | 629 ± 20 |
| 10-20% | 226 ± 8 | 450 ± 22 |
| 20-30% | 160 ± 10 | 283 ± 24 |
| 30-40% | 110 ± 11 | 171 ± 23 |
| 40-50% | 72 ± 10 | 96 ± 19 |
| 50-60% | 45 ± 9 | 52 ± 13 |
| 60-70% | 26 ± 7 | 25 ± 9 |
| 70-80% | 14 ± 4 | 12 ± 5 |

Centrality determination based on multiplicity provides with:

- impact parameter (b)
- number of participating nucleons ($N_{part}$)

Similar centrality estimator is needed for comparisons with STAR, HADES, etc.

# Centrality determination based on Monte-Carlo Glauber sampling




Centrality can be estimated based on multiplicity of produced charged particles or spectator energy

# The Bayesian inversion method (Γ-fit): multiplicity

Relation between multiplicity $N_{ch}$ and impact parameter b is defined by

the fluctuation kernel:

$$P(N_{ch}|c_b) = \frac{1}{\Gamma(k(c_b))\theta^k} N_{ch}^{k(c_b)-1} e^{-n/\theta} \qquad \frac{\sigma^2}{\langle N_{ch}\rangle} = \theta \simeq const,\ k = \frac{\langle N_{ch}\rangle}{\theta}$$

$c_b = \int_0^b P(b')db'$ – centrality based on impact parameter

Mean multiplicity as a function of $c_b$ can be defined as follows:

$$\langle N_{ch}\rangle = N_{knee} \exp\left(\sum_{j=1}^{3} a_j c_b^j\right) \qquad N_{knee}, \theta, a_j$$ - 5 parameters

Fit function for $N_{ch}$ distribution: b-distribution for a given $N_{ch}$ range:

$$P(N_{ch}) = \int_0^1 P(N_{ch}|c_b)dc_b \qquad P(b|n_1 < N_{ch} < n_2) = P(b)\frac{\int_{n_1}^{n_2} P(N_{ch}|b)dN_{ch}}{\int_{n_1}^{n_2} P(N_{ch})dN_{ch}}$$

**2 main steps of the method:**

Fit experimental (model) distribution with P(N)

↓

Construct P(b|E) using Bayes' theorem:
P(b|N) = P(b)P(N|b)/P(N)

# The Bayesian inversion method (Γ-fit): forward energy

Relation between multiplicity $N_{ch}$ and impact parameter b

is defined by the fluctuation kernel:

$$P(E\,|\,c_b) = \frac{1}{\Gamma(k(c_b))\theta^2} E^{k(c_b)-1} e^{-E/\theta}$$

$$\theta = \frac{D(E)}{\langle E \rangle}, \quad k = \frac{\langle E \rangle}{\theta}$$

$c_b = \int_0^b P(b')db'$ – centrality based on impact parameter

$\langle E \rangle$, $D(E)$ – average value and variance of energy

$$\langle E \rangle = \mu_1 \langle E'(c_b) \rangle + \lambda_1, \quad D(E) = \mu_2 D(E'(c_b))$$

Three fit parameters $\mu_1, \mu_2, \lambda_1$

$\langle E'(c_b) \rangle$, $D(E'(c_b))$ – average value and variance of energy from the model

These quantities can be approximated by polynomials

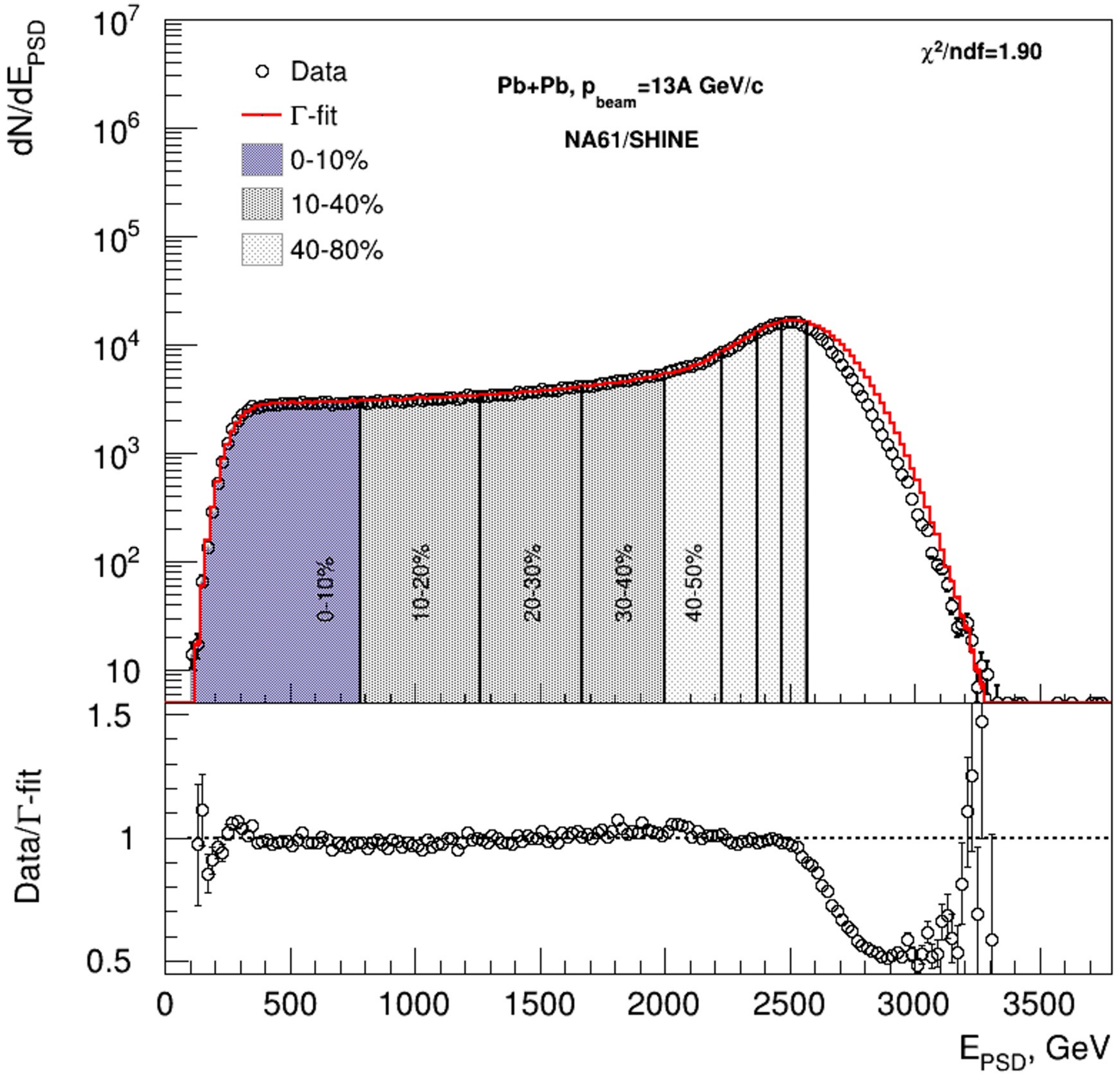
$$\langle E'(c_b) \rangle = \sum_{j=1}^{8} a_j c_b^j, \quad D(E'(c_b)) = \sum_{j=1}^{6} b_j c_b^j$$

**2 main steps of the method:**

Fit experimental (model) distribution with P(E)

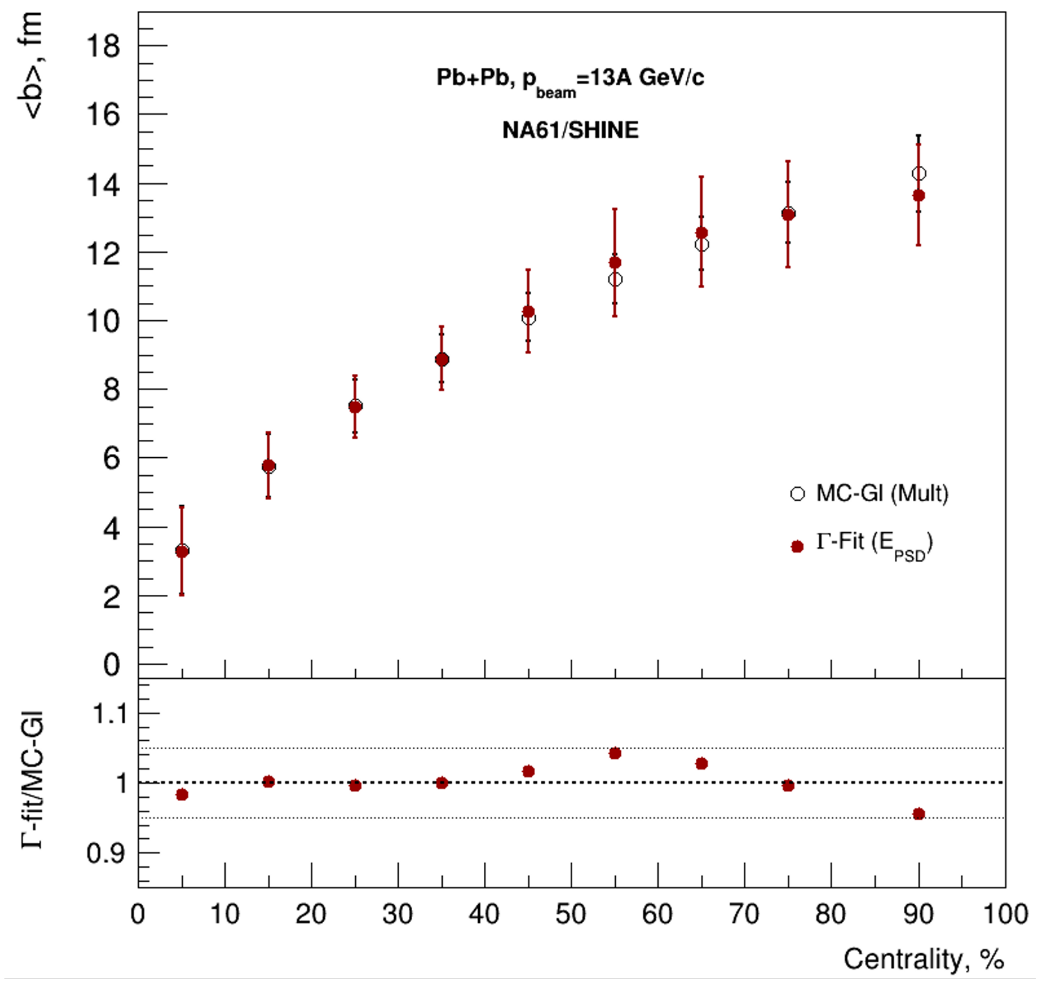
Construct P(b|E) using Bayes' theorem:
P(b|E) = P(b)P(E|b)/P(E)

# Comparison with MC-Glauber fit



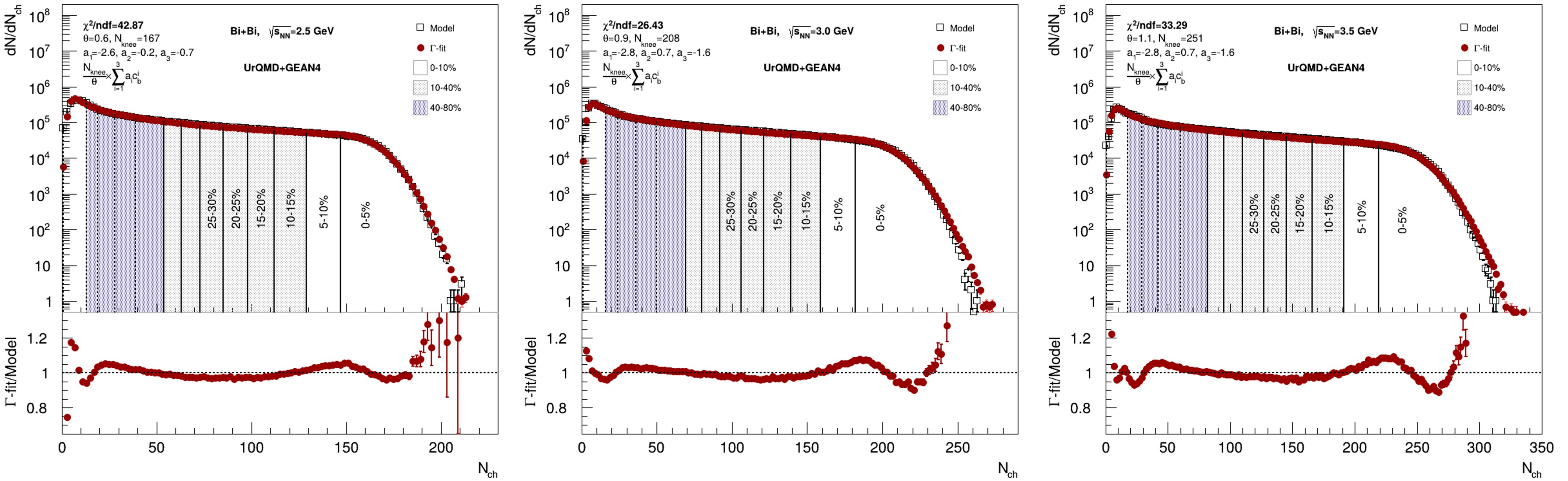

Good agreement between fit and data.

**For more details see D.Idrisov's talk on Cross-PWG 19.09.2023**




There is agreement within 5%.

# Centrality determination in Bi+Bi: multiplicity fit



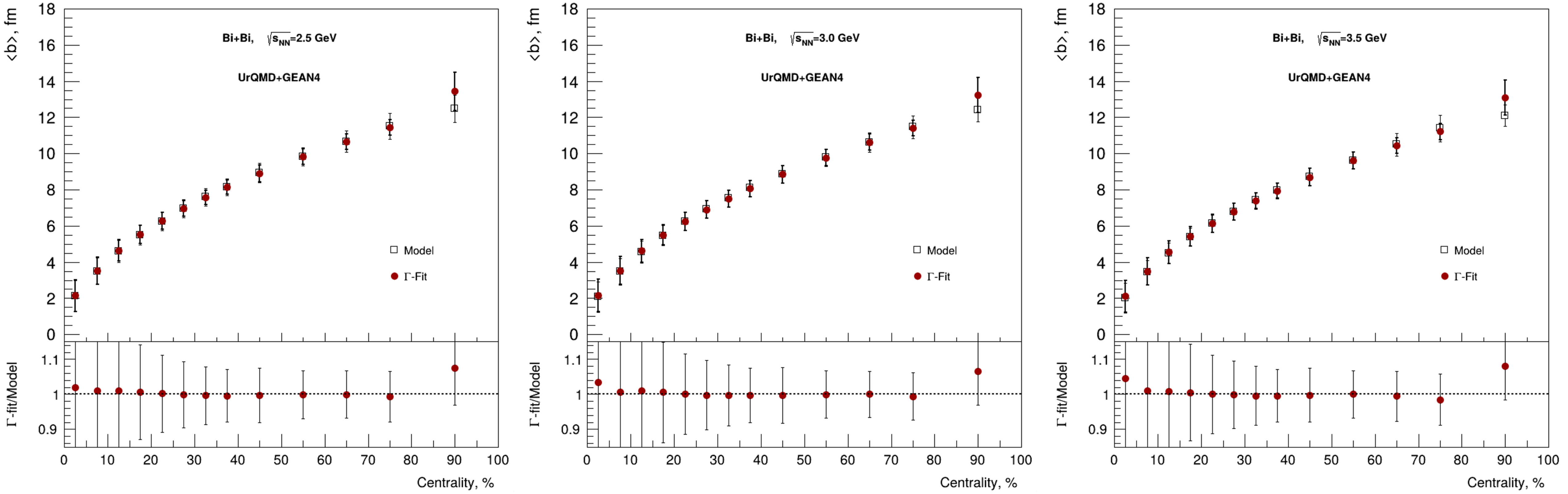

Cuts on tracks:

- Nhits>16
- $0 < \eta < 2$

Good agreement between fit and data

**Multiplicity-based centrality determination using inverse Bayes was used in the flow studies**

# Centrality determination in Bi+Bi : <b> vs Centrality



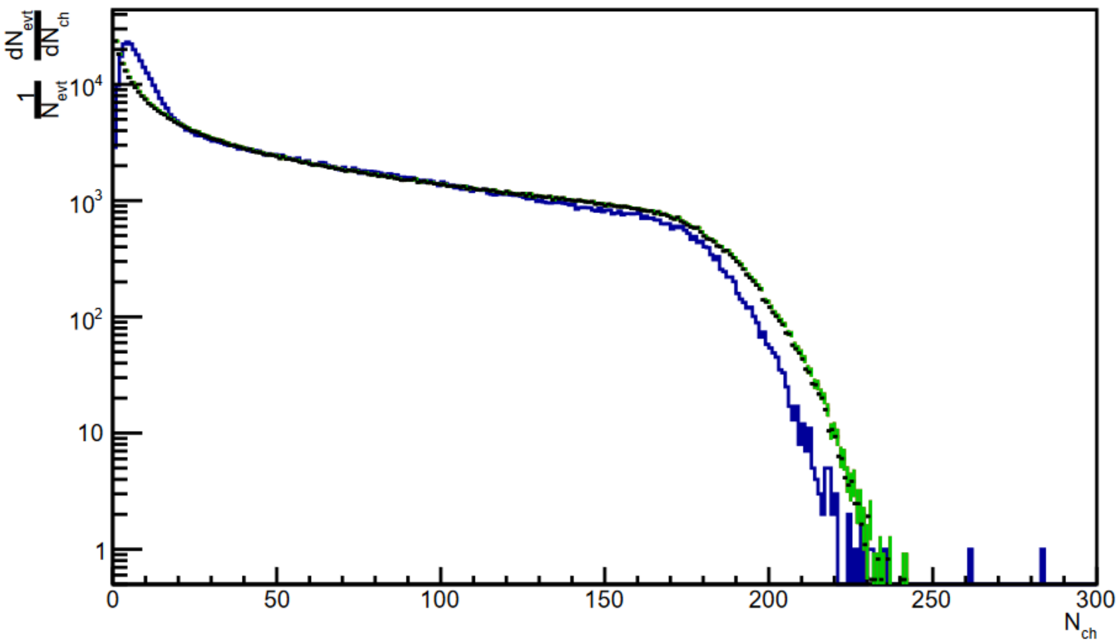

Cuts on tracks:

- Nhits>16
- $0 < \eta < 2$

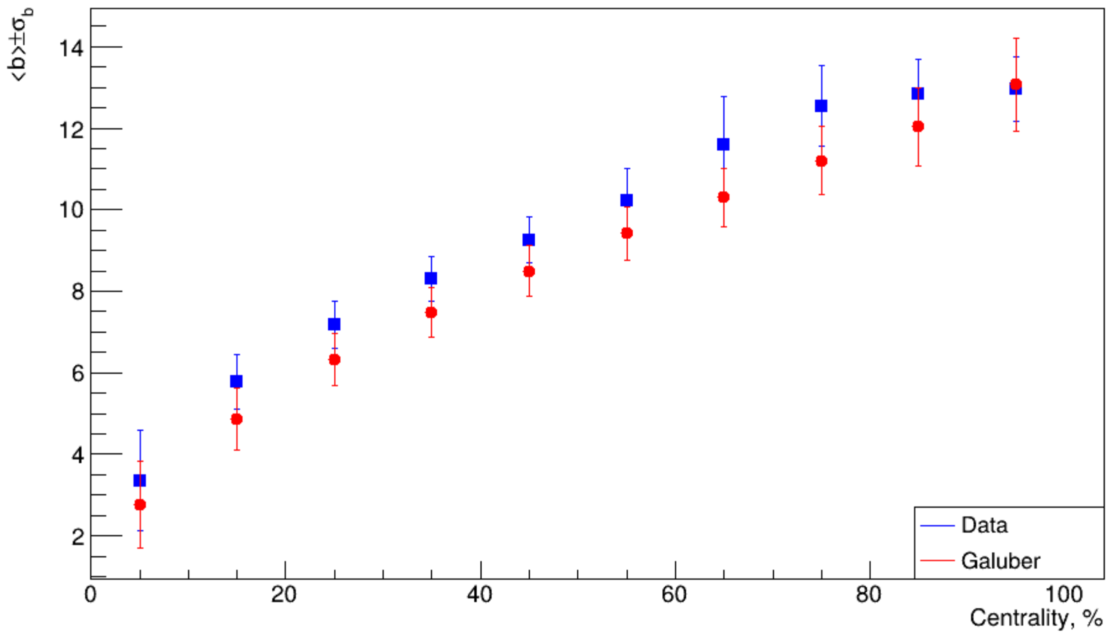
Good agreement between fit and data

**Multiplicity-based centrality determination using inverse Bayes was used in the flow studies**

# Centrality determination in Xe+W: MC-Glauber approach




See D. Flusova and N. Bikmetov talk at CrossPWG 8.10.2024




Fit parameters:

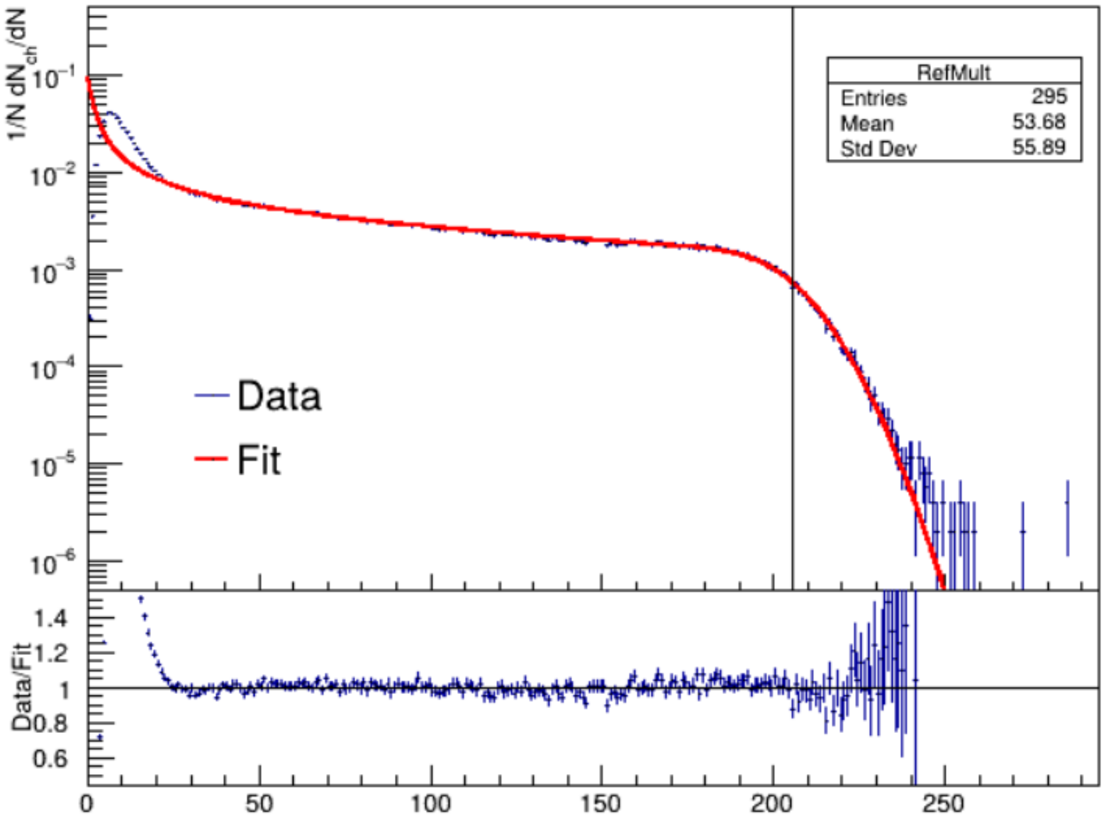
$\mu = 0.62, f = 0.8, k = 53, \chi^2 = 2.815 \pm 0.115$

**Cuts: 0 < η < 2; Charge ≠ 0;**

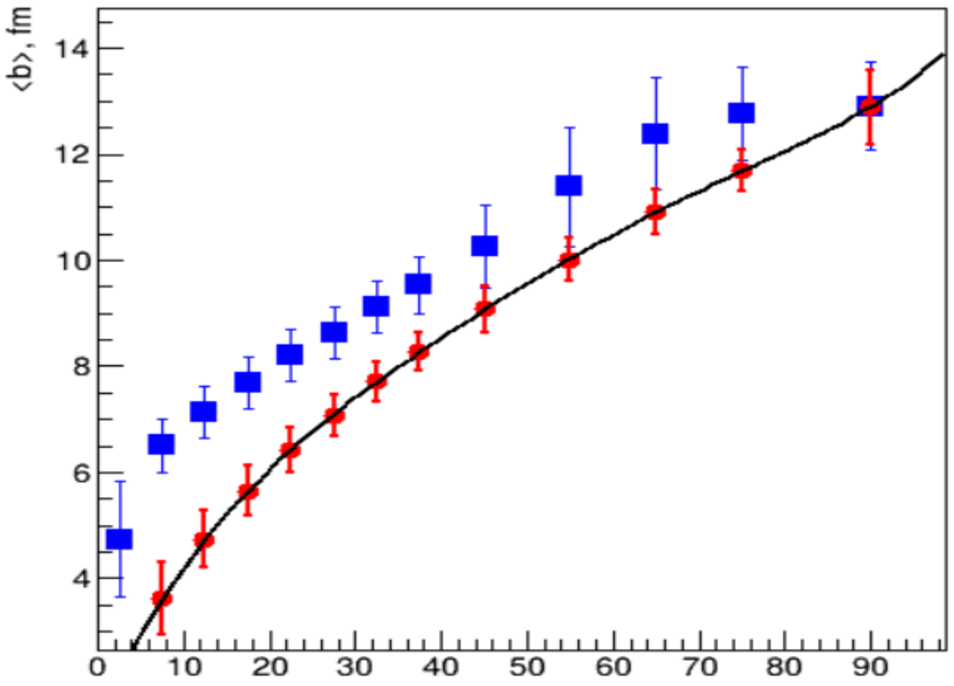
Overall reasonable agreement with model data

**There is still no full agreement with data for most central collisions**

# Centrality determination in Xe+W: $\Gamma$-fit approach




See D. Flusova and N. Bikmetov talk at CrossPWG 8.10.2024




Fit parameters:

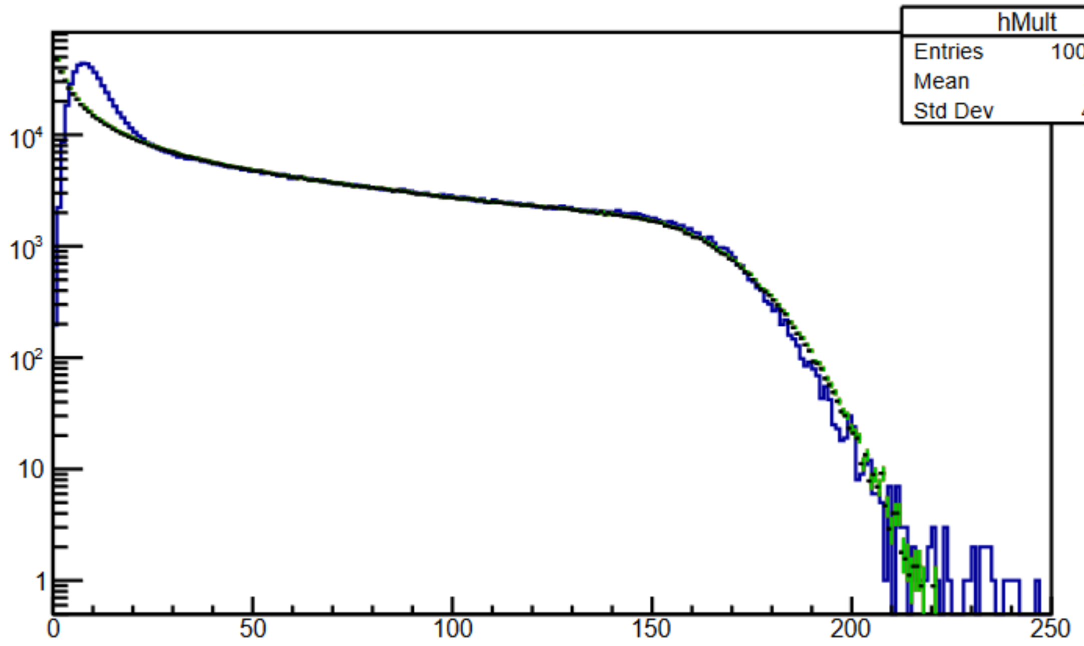
$\theta$ = 0.75; $N_{knee}$ = 205.38; $a_1$ = -3.33; $a_2$ = 0.08; $a_3$ = -2.80; $\chi^2$ = 1.16

**Cuts: 0 < η < 2; Charge ≠ 0;**

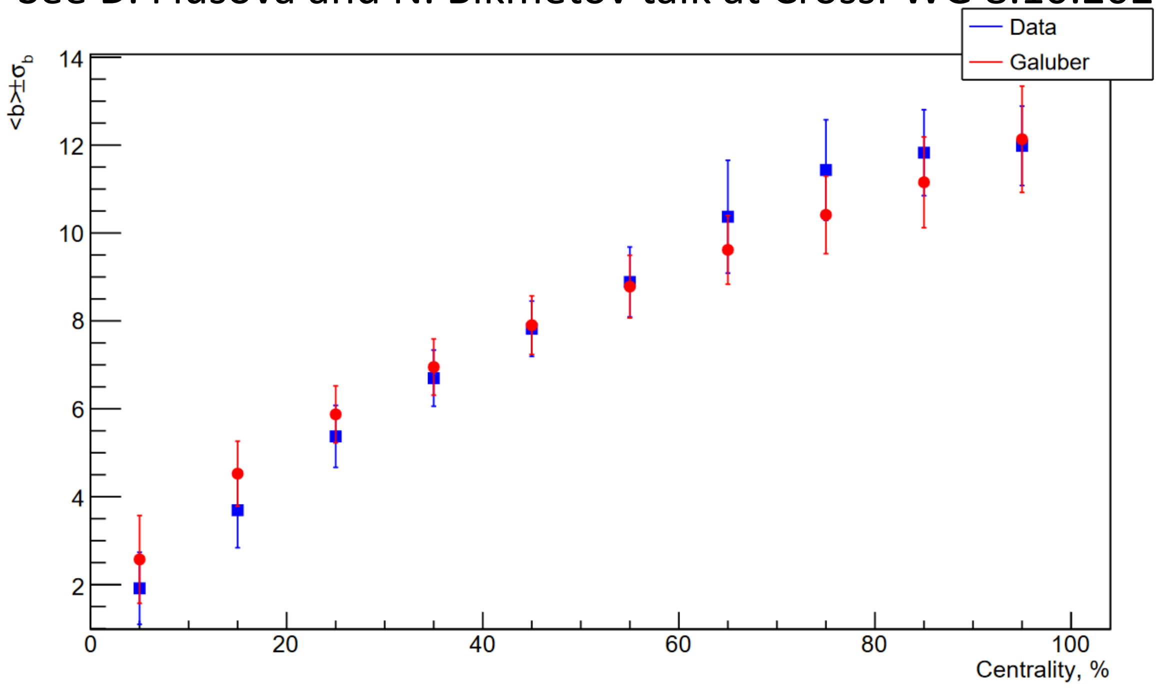
$\Gamma$-fit provides better fit but worse <b> estimation than MC-Glauber approach

**Inverse Bayes approach needs to be modified for asymmetrical collisions**

# Centrality determination in Xe+Xe: MC-Glauber approach




See D. Flusova and N. Bikmetov talk at CrossPWG 8.10.2024




Fit parameters:

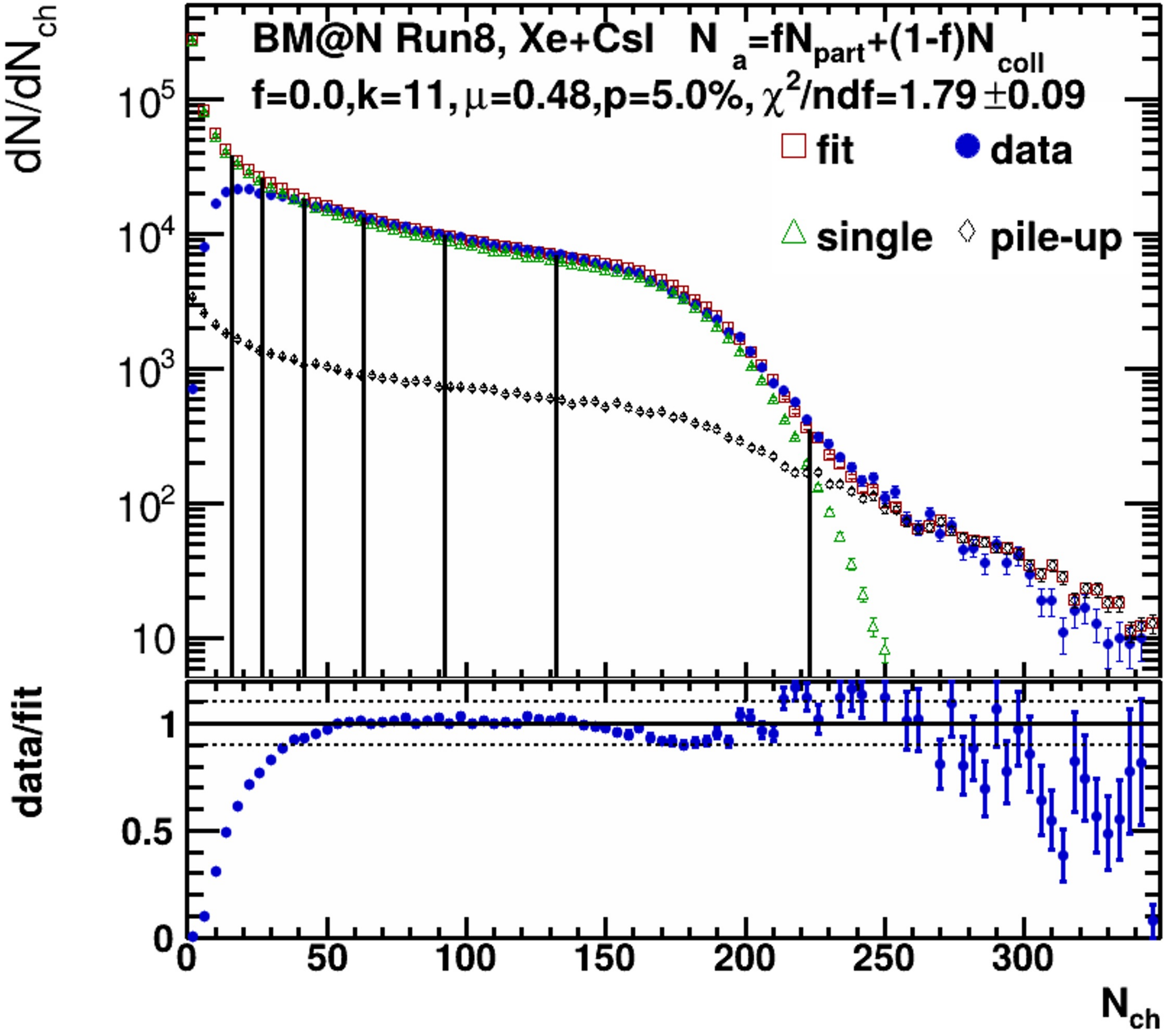
$\mu = 0.73, f = 0.9, k = 60, \chi^2 = 3.212 \pm 0.115$

**Cuts: 0 < η < 2; Charge ≠ 0;**

Overall good agreement with model data for both multiplicity fit and <b> estimation

**Good agreement: further optimizations are in progress**

# Main problem with centrality based on MC-Glauber at low energies




Fit suggests unphysical results

- **f=0** - means that hard processes are dominating
- hard to fit pion multiplicity (or small systems)

**Maybe our parametrization of multiplicity is not working at low energies?**

# Multiplicity in pp/nn/np collisions

Generally **NBD** is used to define multiplicity $N_{ch}$ in such collisions:

$$P(n;\mu,k) = \frac{\Gamma(n+k)}{\Gamma(n+1)\Gamma(k)} \frac{\left(\frac{\mu}{k}\right)^n}{\left(\frac{\mu}{k}+1\right)^{n+k}}$$

Mean: $\mu$

Variance: $\mu/k\cdot(\mu+k)$

It works at high energies where $\mu>1$, $k>1$.

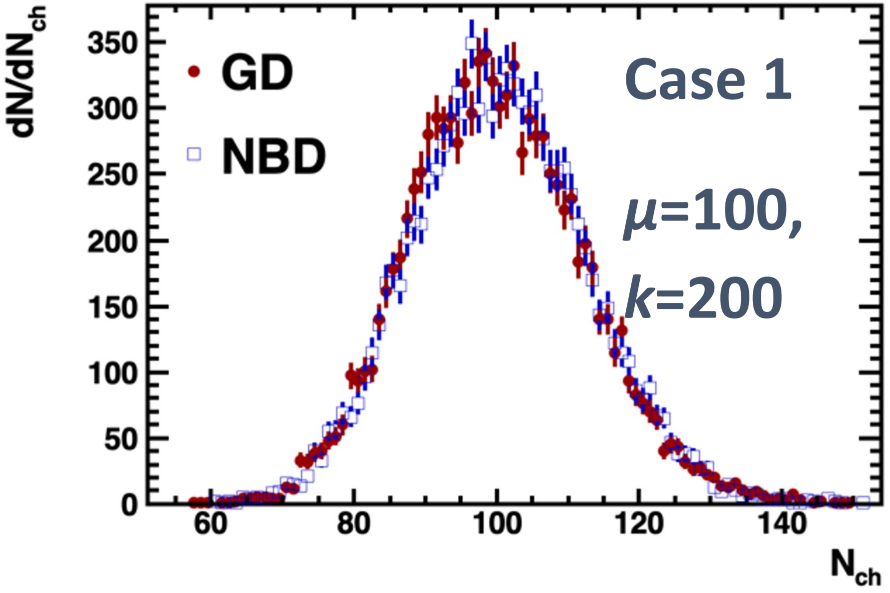
However at lower energies we likely have situation where $\mu<1$, $k<1$. NBD cannot be applicable in that case. We have to use generalized function - gamma distribution (**GD**):

$$P(x;\mu,k) = \frac{e^{-\frac{x}{\beta}} x^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)}, \alpha = \frac{\mu k}{\mu+k}, \beta = \frac{\mu}{k}+1$$

Mean: $\mu$

Variance: $\mu/k\cdot(\mu+k)$

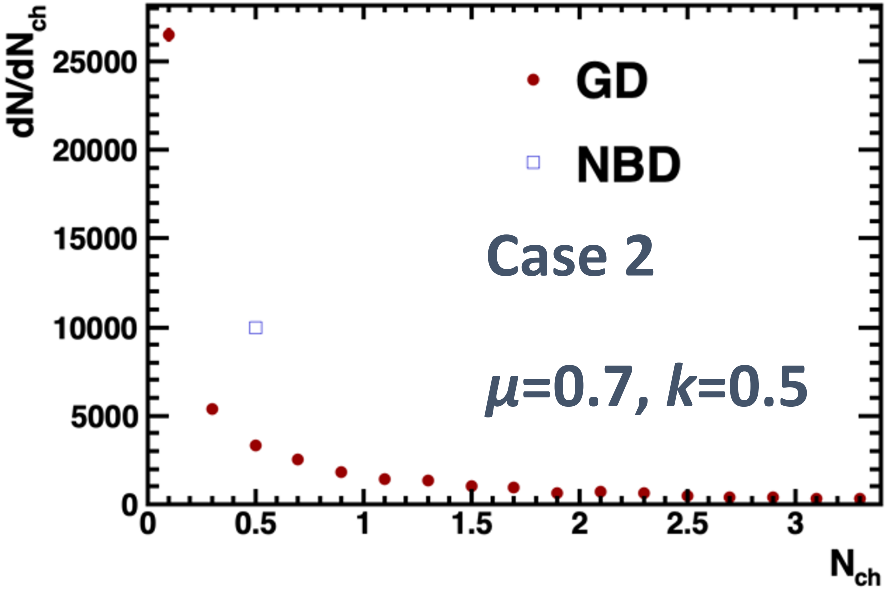
# Multiplicity in pp/nn/np collisions




**Case 1:** $k>1$, $\mu \sim \sigma^2 = \mu/k \cdot (\mu + k)$. The mean multiplicity is generally on the same level as its variation.

**Case 2:** $k<1$, $\mu < \sigma^2 = \mu/k \cdot (\mu + k)$. The mean multiplicity might be smaller than its variation.

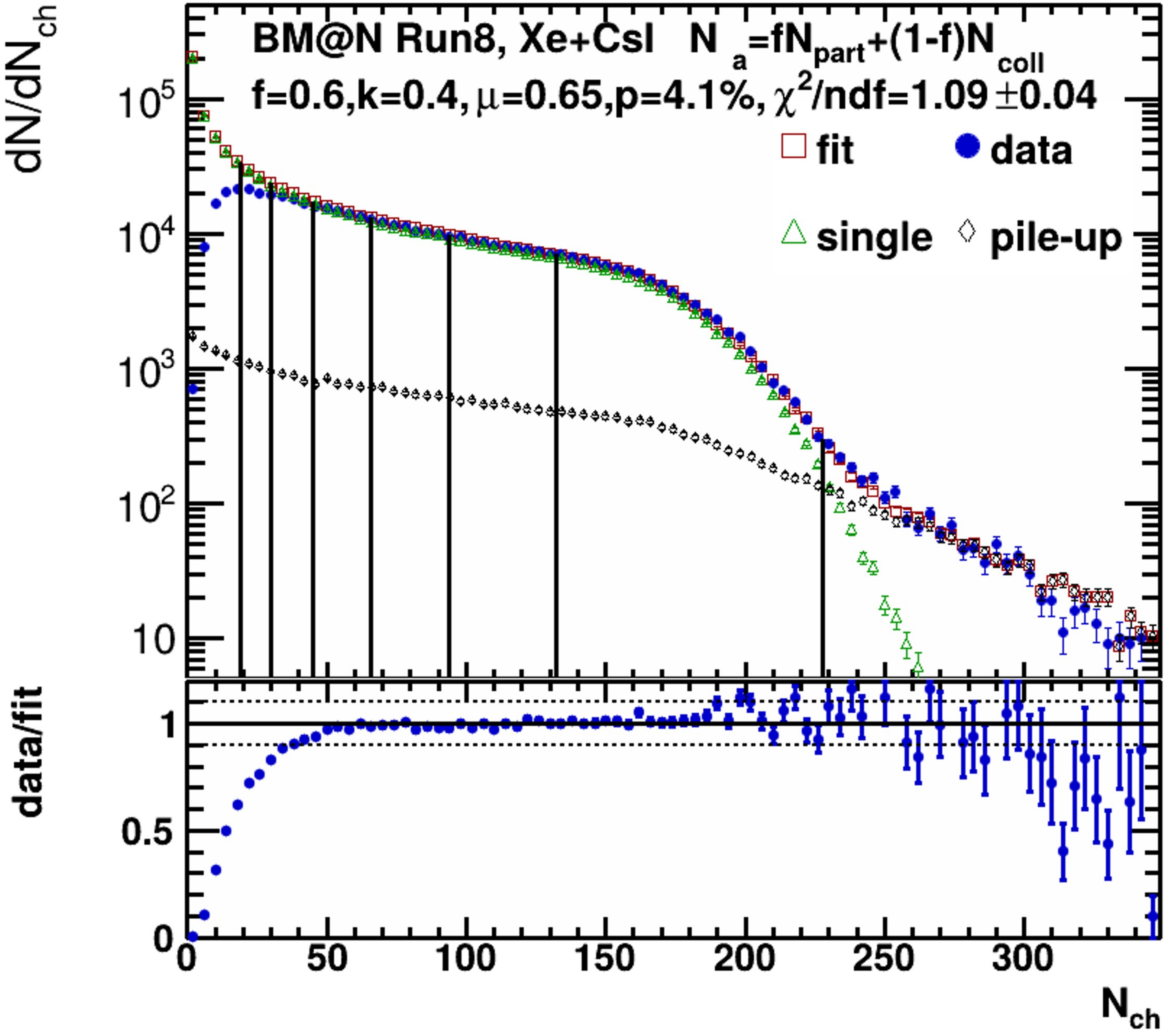
**Case 1 can be defined with both NBD and GD.**
**Case 2 can be defined with GD only!**




Case 2 can be more feasible at lower energies, where we have smaller multiplicities and relation between $\mu$ and $\sigma^2$ might vary greatly

**What do we get if we implement it into our centrality procedure?**

# Multiplicity fit & centrality classes: $h^{\pm}$




RunId: **8120-8170**

Multiplicity Cuts:

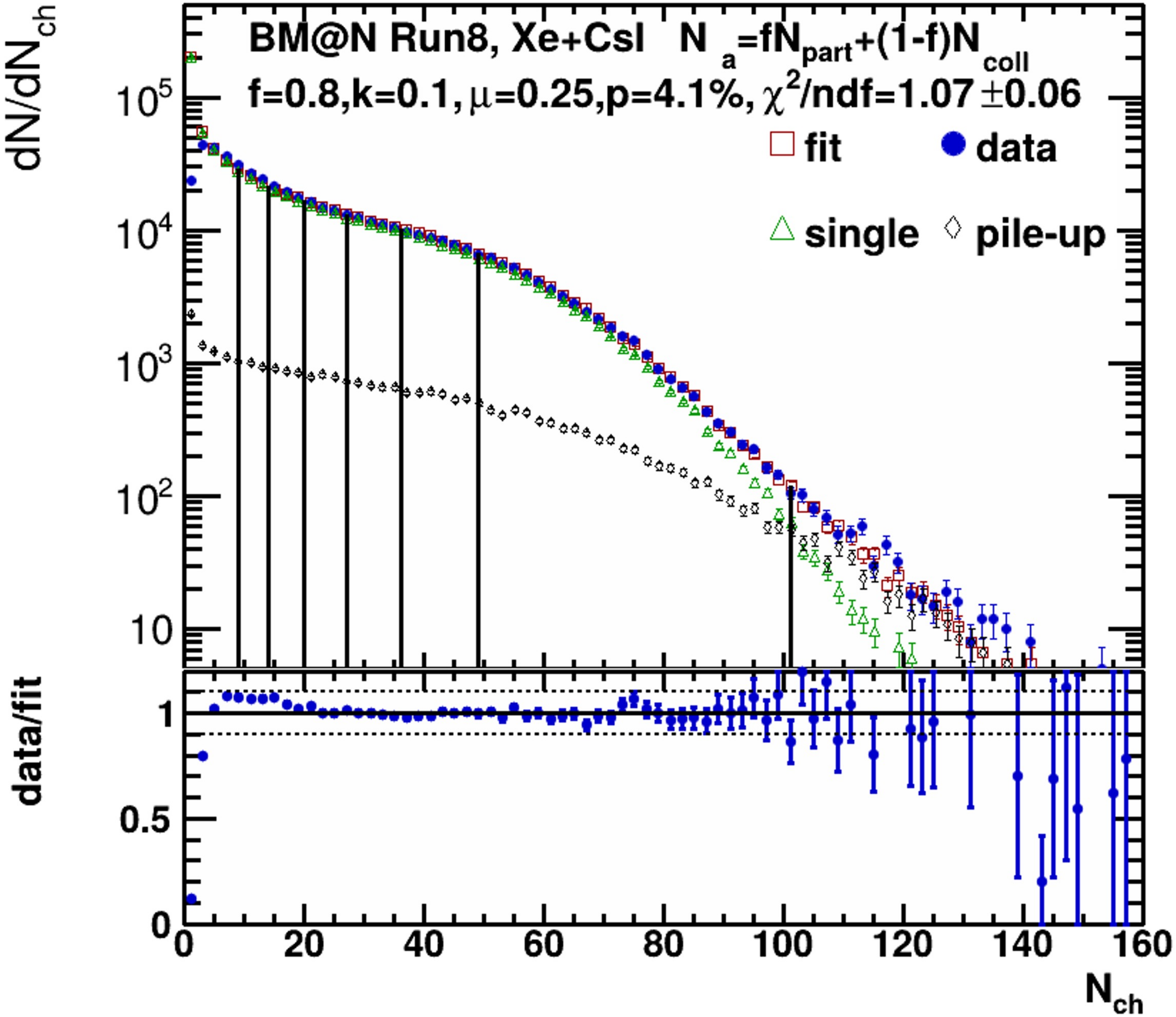
- CCT2
- $N_{vtxTr}$>1
- (Sts digi vs $N_{tr}$) cut
- $V_r$ <1 cm
- $V_z$ < 0.1 cm

Fit suggests **f=0.6** - means that soft processes are dominating at $E_{kin}$=3.8A GeV
In agreement with Kharzeev-Nardi approach

Phys.Lett. B507 (2001) 121-128

**Good agreement with experimental data**

# Multiplicity fit & centrality classes: $h^-$




RunId: **8120-8170**

Multiplicity Cuts:

- CCT2
- $N_{vtxTr}$>1
- (Sts digi vs $N_{tr}$) cut
- $V_r$ <1 cm
- $V_z$ < 0.1 cm
- Negative charge only

New parametrization (GB) can describe multiplicity of negatively charged tracks (mostly $\pi^-$)

**Good agreement with experimental data**

# MC Glauber model

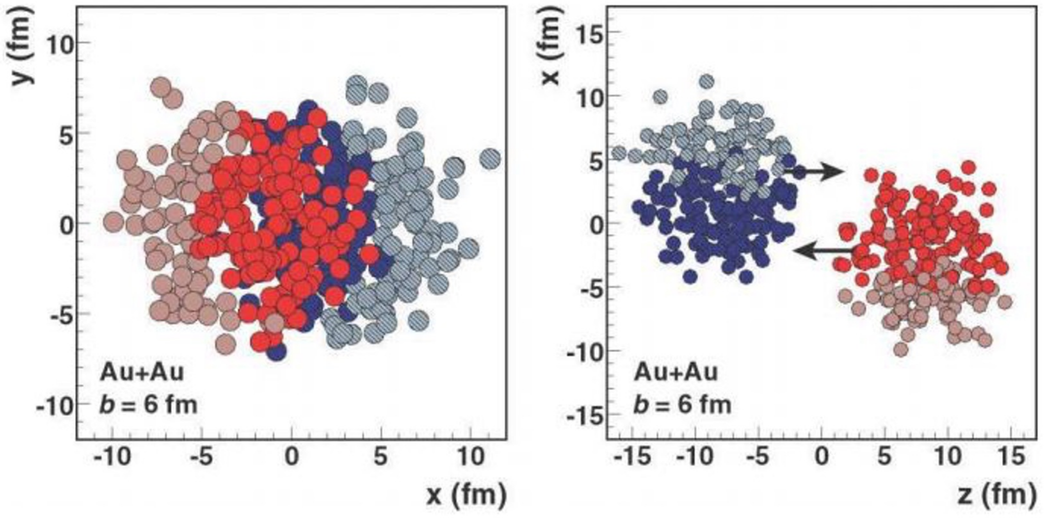
MC Glauber model provides a description of the initial state of a heavy-ion collision

- Independent straight line trajectories of the nucleons
- A-A collision is treated as a sequence of independent binary NN collisions
- Monte-Carlo sampling of nucleons position for individual collisions

Main model parameters
- Colliding nuclei
- Inelastic nucleon-nucleon cross section ( $\sigma^{NN}_{inel}$ ) (depends on collision energy)
- Nuclear charge densities (Wood-Saxon distribution)

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

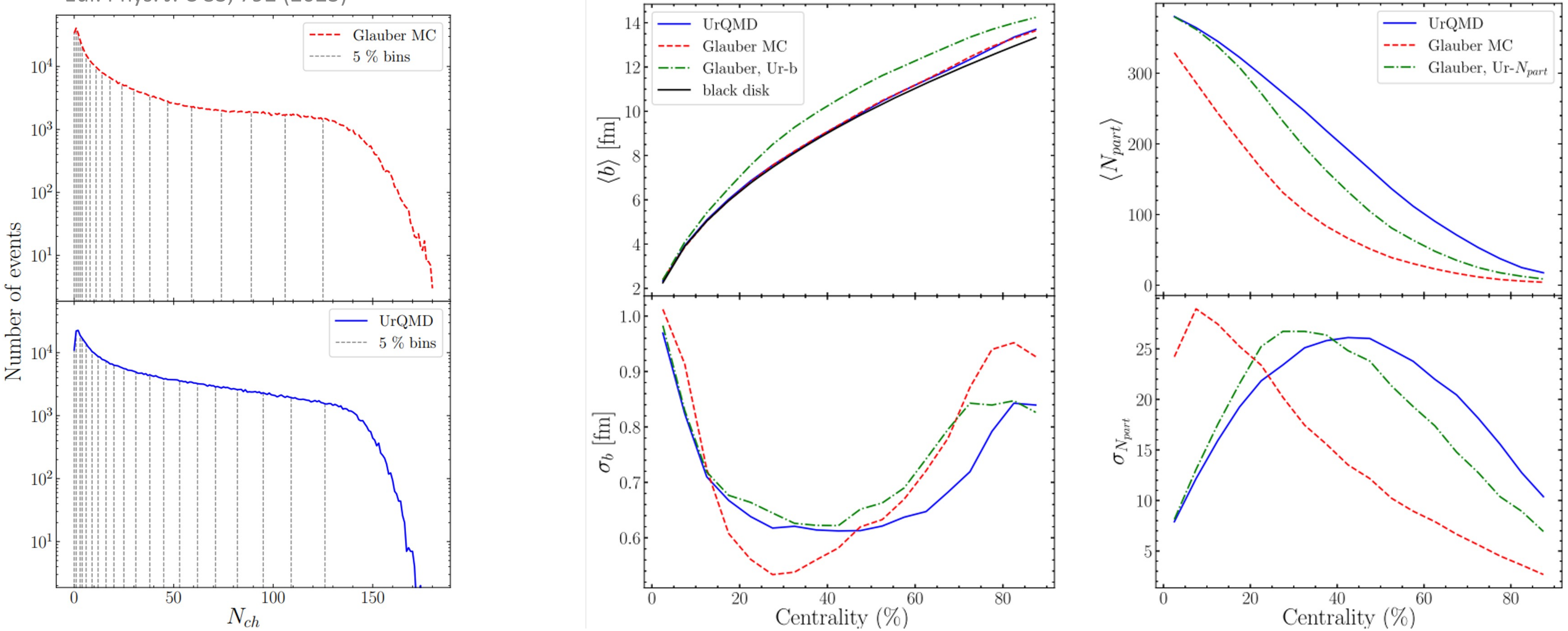
Glauber Modeling in High Energy Nuclear Collisions: ARNPS57:205-243,2007




Geometry parameters
- $b$ – impact parameter
- $N_{part}$ – number of nucleons participating in the collision
- $N_{spec}$ – number of spectator nucleons in the collision
- $N_{coll}$ – number of binary NN collisions

# Model dependence of b, $N_{part}$

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




- Use MC Glauber for centrality determination
- The MC Glauber non-realistic $\mathbf{N_{part}}$ simulations at low energies
- Differences in of number of participant nucleons ($\mathbf{N_{part}}$) distributions from UrQMD and MC
- The impact parameter (**b**) - model independent centrality estimator