PWG1 Summary

PWG1 conveners:

Petr Parfenov (JINR, NRNU MEPhI), Grigory Feofilov (SPbSU)

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

XV MPD Collaboration Meeting, Dubna, Russia, 15-17 April 2025

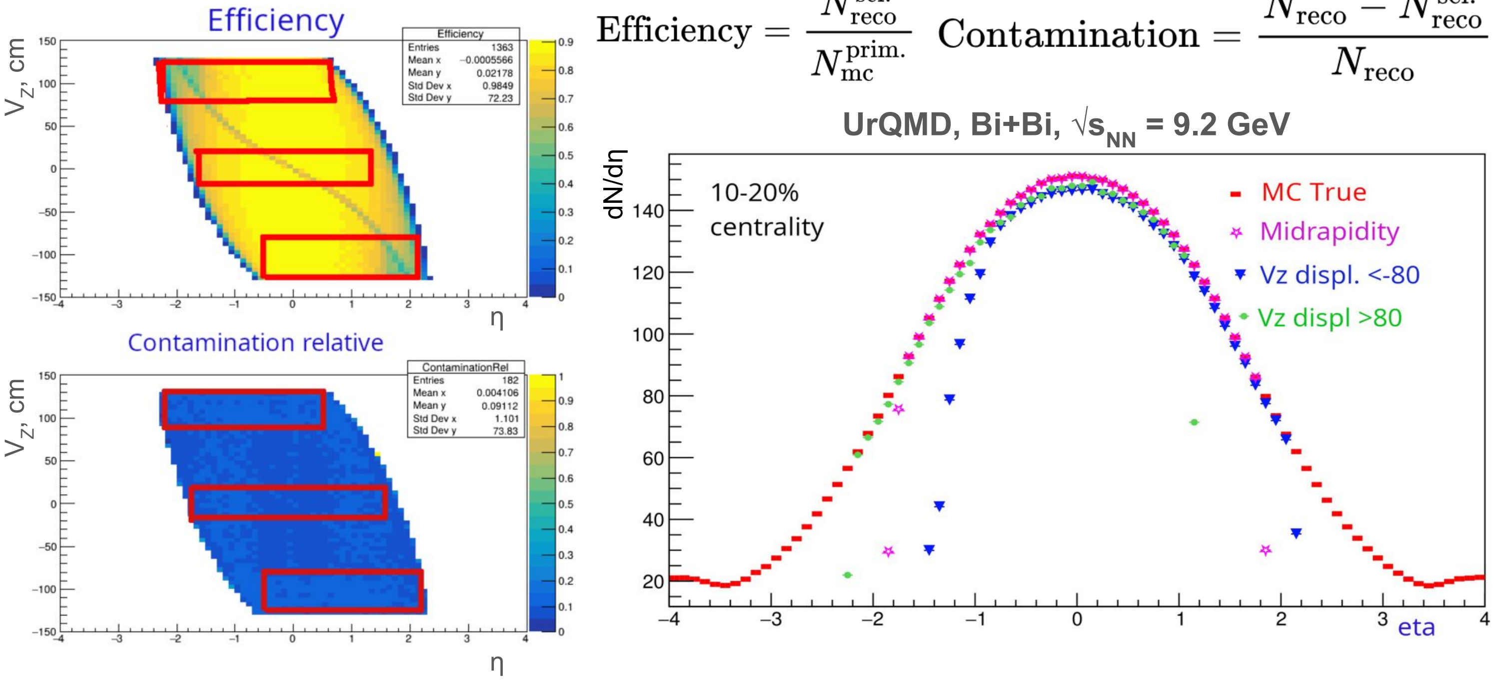
PWG1 activity

There were 5 reports at MPD Cross-PWG since the previous meeting:

1. V. Kovalenko, *Global observables in simulated data for BiBi@9.2 GeV*, **12 Nov 2024**
2. V. Riabov, *Centrality and PID wagons for the MPD-FXT (Req35) productions*, **21 Jan 2025**
3. V. Uzhinsky, *Approbation of DCM and AGT Models,* **4 Feb 2025**
4. P. Parfenov, *An issue with mean-field mode of UrQMD at the lab frame and how to generate UrQMD data for the MPD-FXT,* **4 Feb 2025**
5. D. Idrisov, *Bayesian approach for centrality in MPD-FXT,* **8 Apr 2025**

Global observables (MPD-CLD): η vs V_Z

See V. Kovalenko's talk



$$\text{Efficiency} = \frac{N^{\text{sel.}}_{\text{reco}}}{N^{\text{prim.}}_{\text{mc}}} \quad \text{Contamination} = \frac{N_{\text{reco}} - N^{\text{sel.}}_{\text{reco}}}{N_{\text{reco}}}$$

$N^{\text{sel.}}_{\text{reco}}$ - reco tracks with matched primary mc track

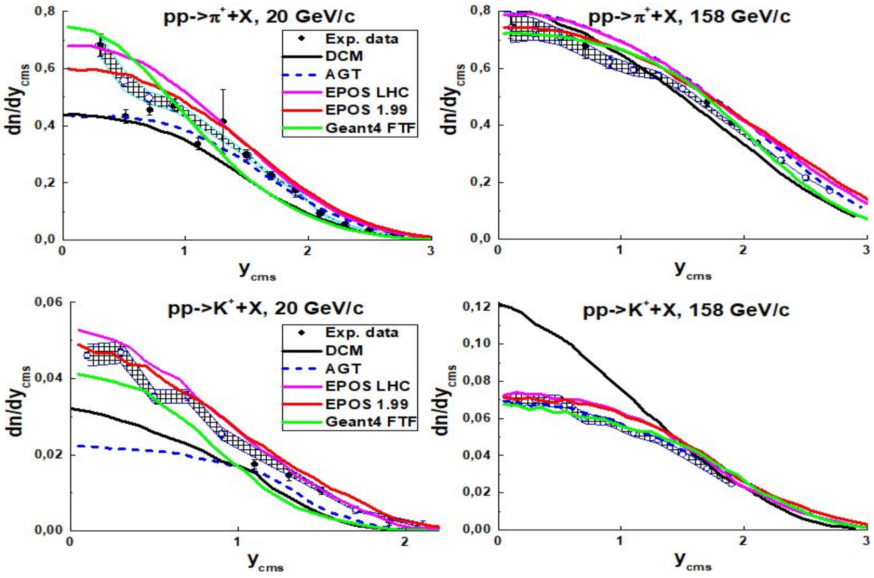
N_{reco} - all reco tracks

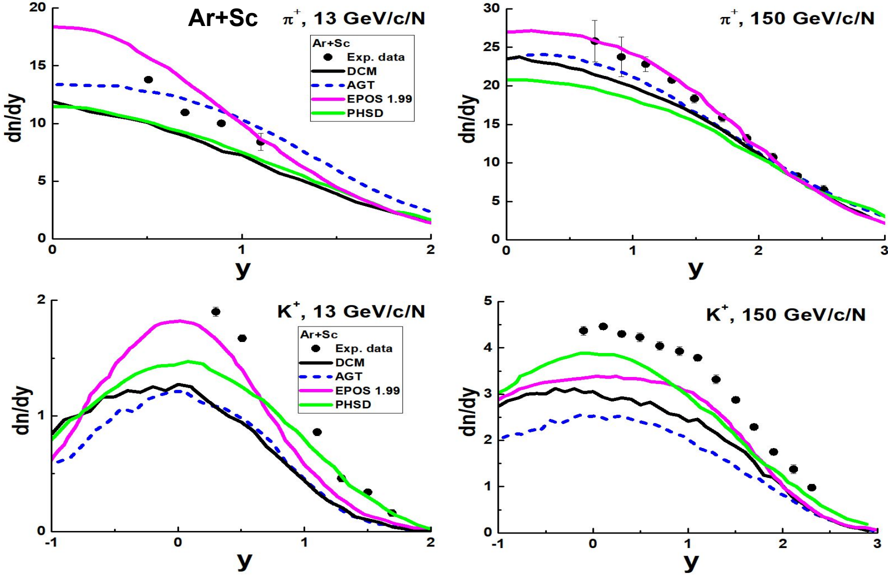
$N^{\text{prim.}}_{\text{mc}}$ - primary mc tracks

η distribution can be measured in extended range using events with displaced vertex position (V_z) together with efficiency and contamination maps

Approbation of DCM and AGT models

See V. Uzhinsky's [talk]





<u>In pp collisions:</u>

- Both AGT and DCM are consistent with other models and data for pions
- DCM overestimates kaon spectra at higher energies

<u>In Ar+Sc collisions:</u>

- Both AGT and DCM are overall consistent with other models and data for pions
- All models struggle with kaon spectra

Coupling of UrQMD and AAMCC models

See P. Parfenov's talk

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

https://github.com/Spectator-matter-group-INR-RAS/AAMCC

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

UrQMD (ver. 3.4) configuration:

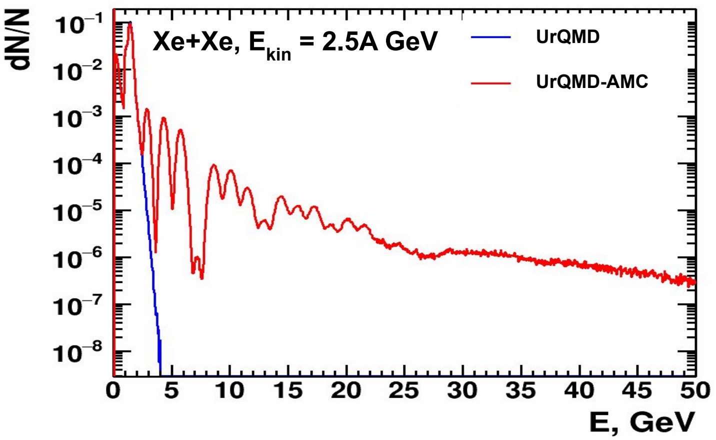
- Xe+Xe, Xe+W (2M events)
- T=2.5A GeV (2.87 GeV)
- mean-field (Skyrme potential)

UrQMD-AMC configuration:

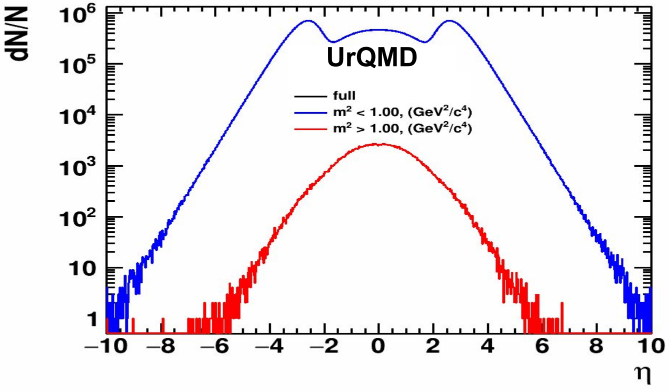
- Same UrQMD setup
- AMC (afterburner mode)
  - Excitation energy of a prefragment: hybrid density function is used based on Ericson formula and ALADIN parametrization

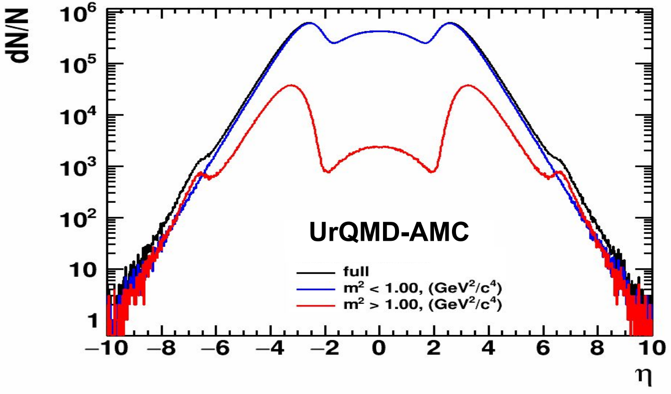
UrQMD-AMC vs UrQMD: main distributions

See P. Parfenov's talk



- Expected differences between UrQMD and UrQMD-AMC due to the presence of the fragments (in the latter model)
- Small overall amount of (light) nuclei in the spectator zone - comparison with different parameterizations of the excitation energy of a prefragment are needed

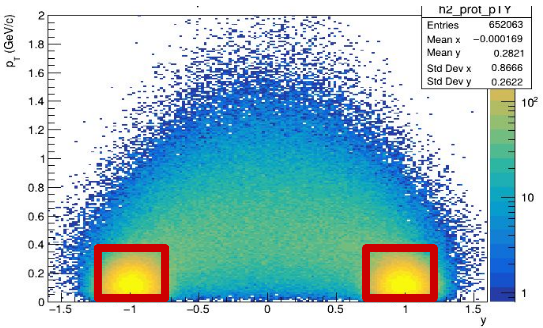


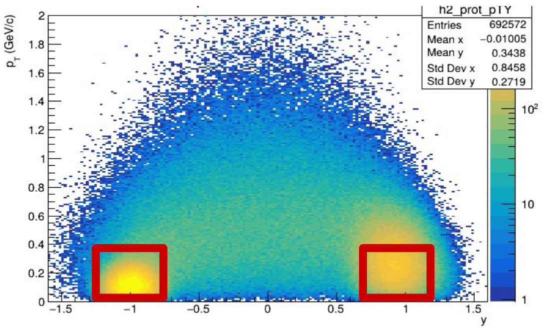


UrQMD-AMC allows us to have an additional mean field model with fragments for feasibility studies

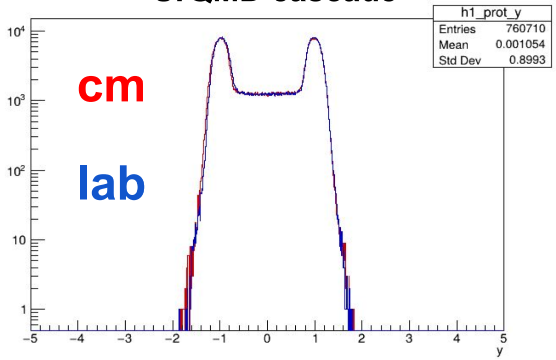
An issue with mean field in the models in MPD-FXT

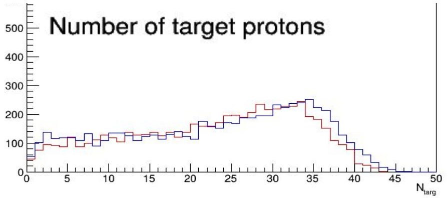
UrQMD mean field (Xe+Xe, Ekin = 2.5A GeV)

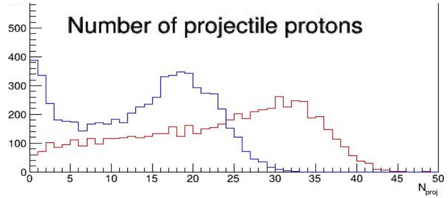




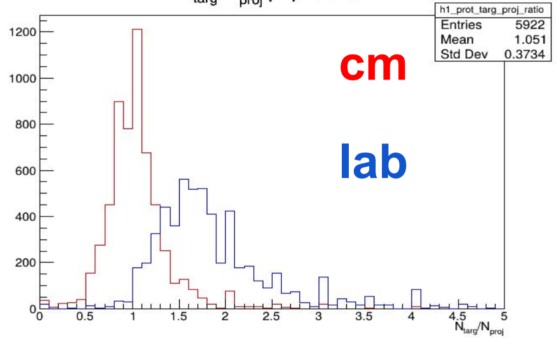
UrQMD cascade







N_{targ}/N_{proj} pf protons



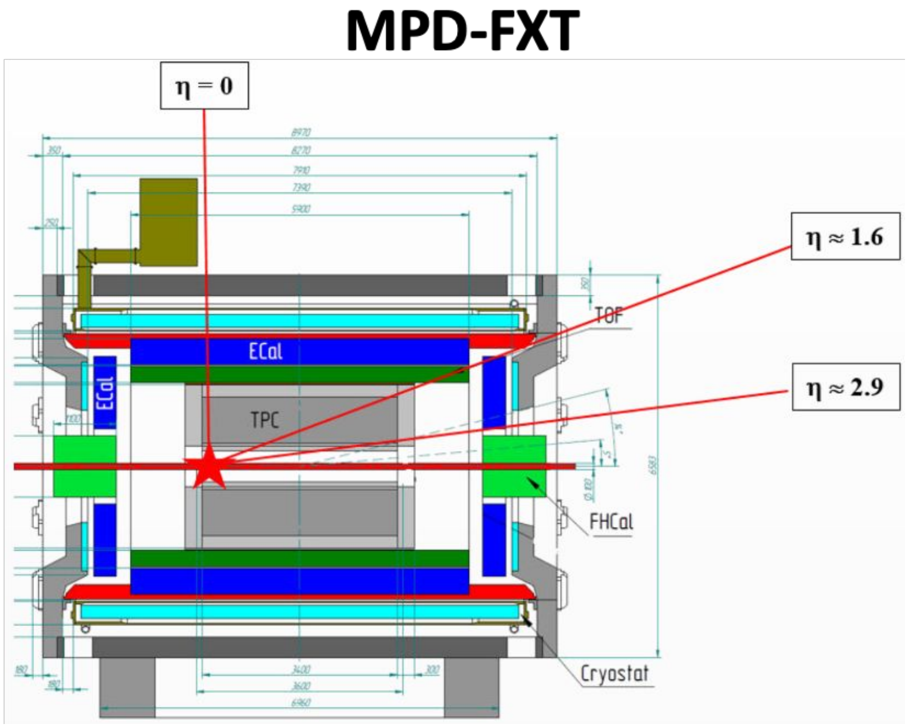
See P. Parfenov's talk

- Difference in the number of projectile and target protons in UrQMD MF
- UrQMD cascade shows consistent results

<u>General recommendation for simulated/reconstructed data preparation:</u>

Generate MF model data in the cms and perform Lorentz boost to lab system when reading model data in the MpdRoot

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

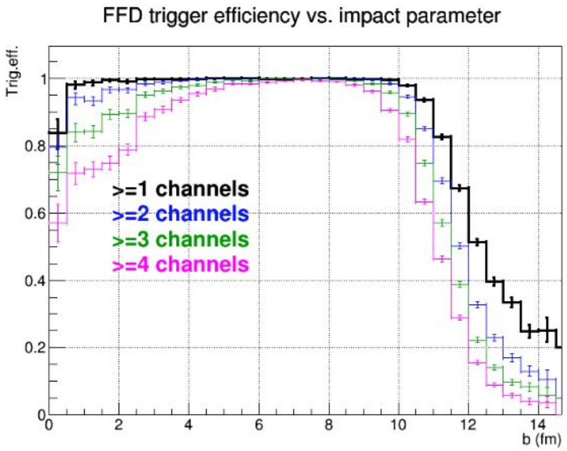
Centrality wagon in MpdRoot framework

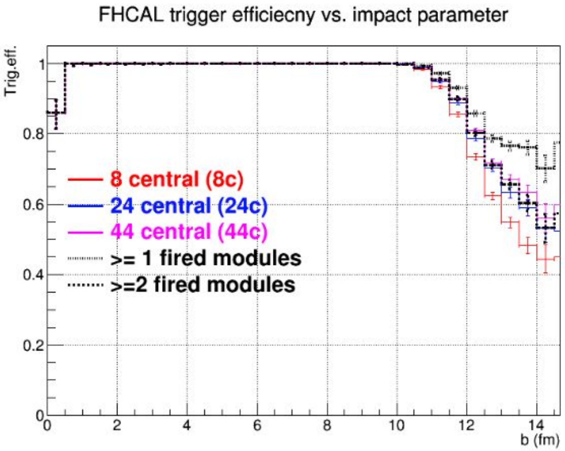
Simplified scripts to get input for the wagon provided by V. Kireyeu

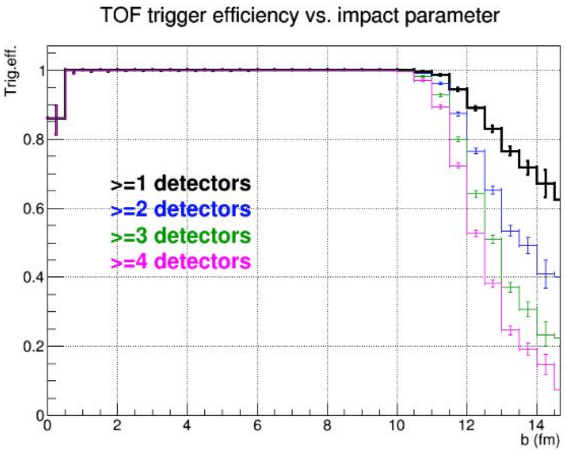
Centrality Framework software

Trigger efficiency for Xe+W at E_{kin} = 2.5A GeV

Xe+W, DCM-QGSM-SMM, 1M events





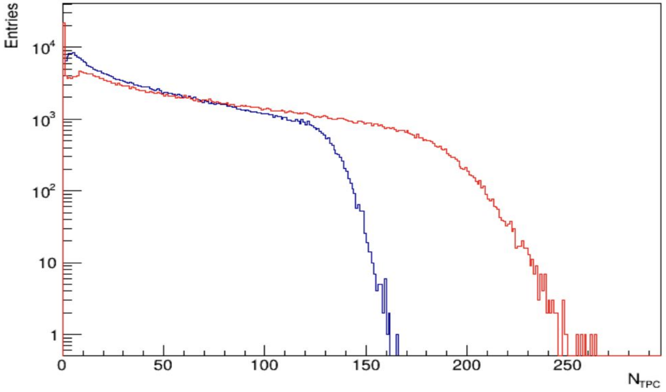


FFD: 88%, 83%, 78%, 73%
FHCAL: 96%, 95%, 94%, 91%
TOF: 97%, 94%, 92%, 89%

- Similar to what we did for BiBi@9.2, select FHCAL (≥1 module) as a reference -> 96%
- Event z-vertex is fixed - no need to worry about vertex dependence of trigger efficiency

See V. Riabov's talk

Centrality determination in MPD-FXT: evCentrality & MC-Glauber



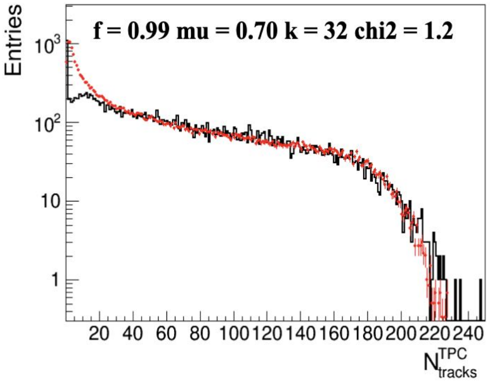
N_{ch}^{reco} - reconstructed tracks

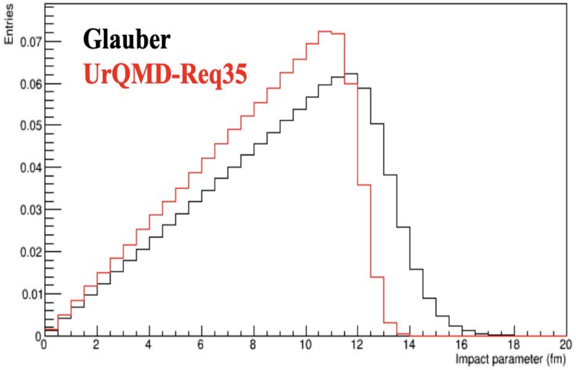
See V. Riabov's talk

$\dfrac{N_{ch}^{\mathrm{reco}}}{\mathrm{eff}\,(\eta, p_T)}$ - reconstructed tracks corrected by the efficiency

Corrected multiplicity was used

Problem: UrQMD MF uses "hard sphere" parameterization





Temporary solution: reweight MC-Glauber data (as a function of *b*)

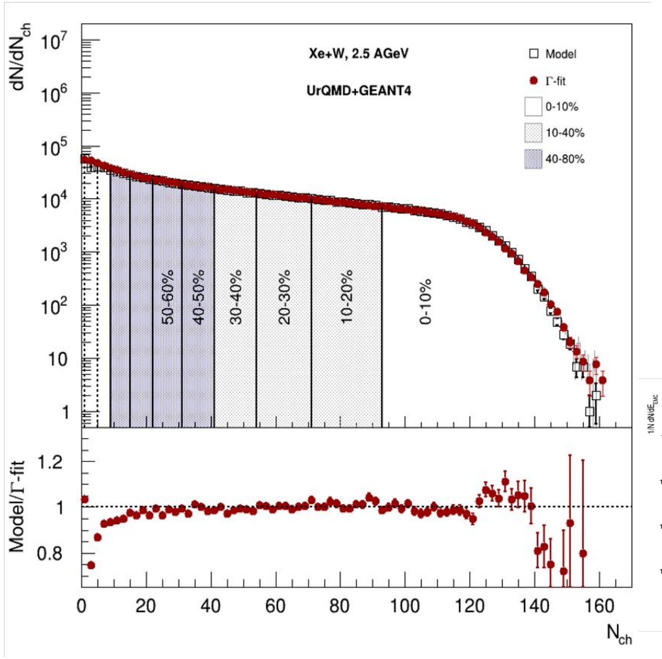
Estimated trig. eff.: ~91%

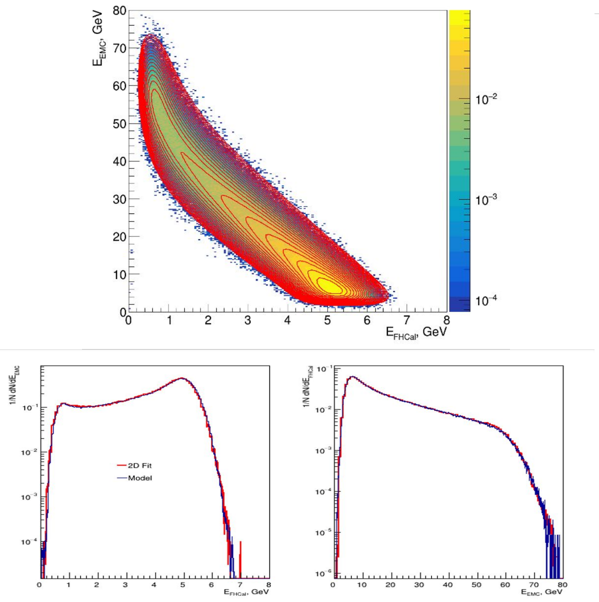
Resulting trig. eff. from MC-Glauber:

Before reweighting: **~80%**, after: **~92%**

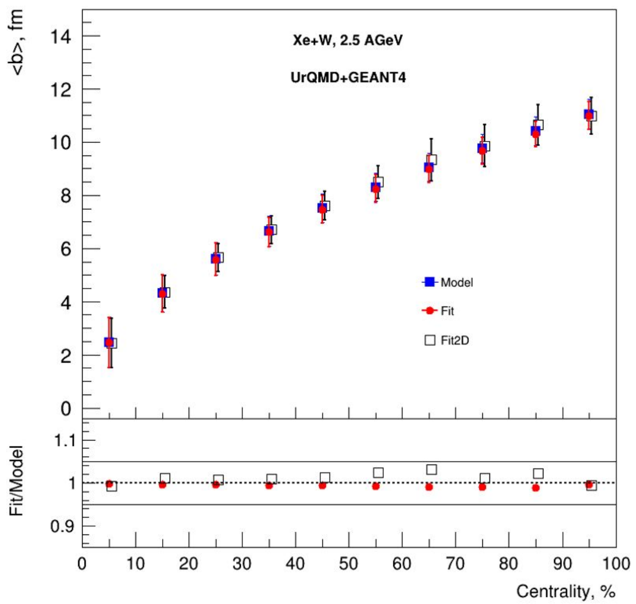
We need to have models with realistic nuclei parameterization (Woods-Saxon): JAM, SMASH, PHSD, PHQMD, etc.

Bayesian approach for centrality in MPD-FXT





See D. Idrisov's talk



Both 1D and 2D bayesian inversion techniques can be employed for centrality determination

We can suppress auto-correlation effects by using energy from EMC (with specific selection) it is important for fluctuation studies (cumulants of net-proton, kaons, etc.)

The BM@N experiment

Simulation:

- DCM-QGSM-SMM, Xe-Cs
- GEANT4 transport

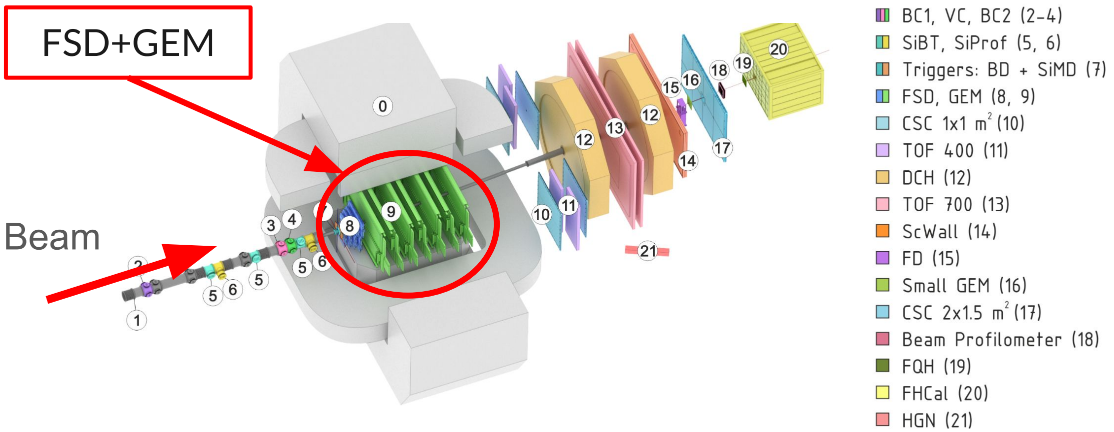
Data:

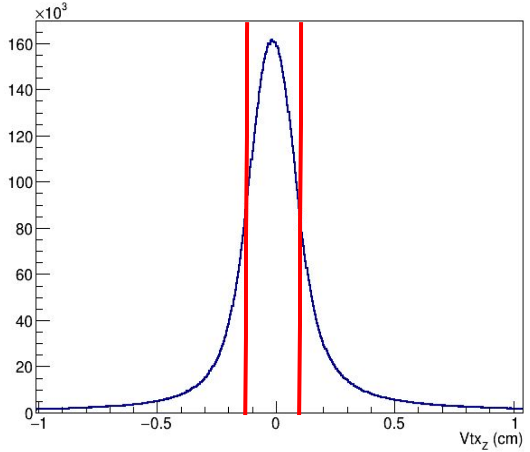
- Run8 Xe-CsI @3.8*A* GeV
- Event selection :
  - Physical runs
  - Centrality trigger (CCT2)
  - More than 1 track in vertex reconstruction
  - $Vtx_R < 1.0$ cm
  - $Vtx_Z < 0.1$ cm

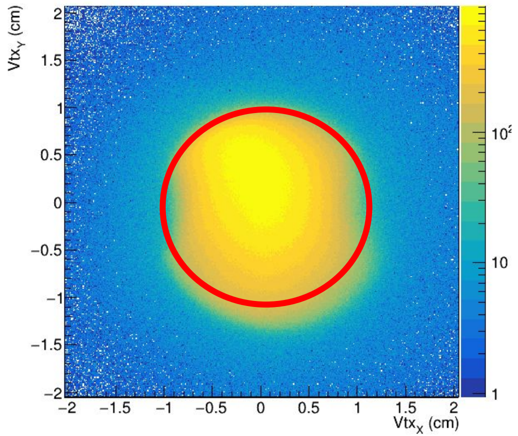
Multiplicity of charged particles from tracking system FSD+GEM

Can be used to test our analysis techniques on the real data

Nucl.Instrum.Meth.A 1065 (2024) 169532



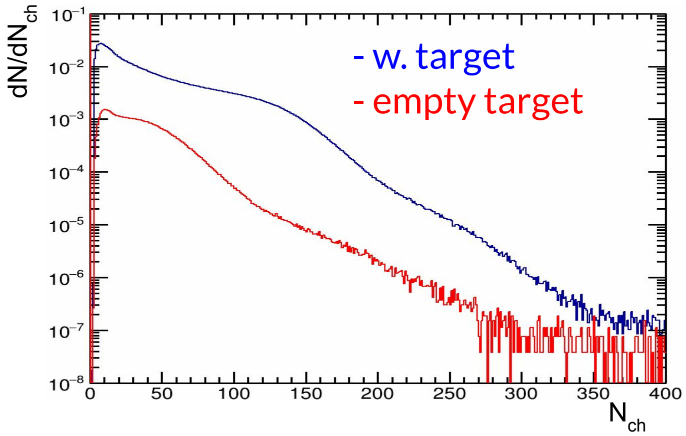




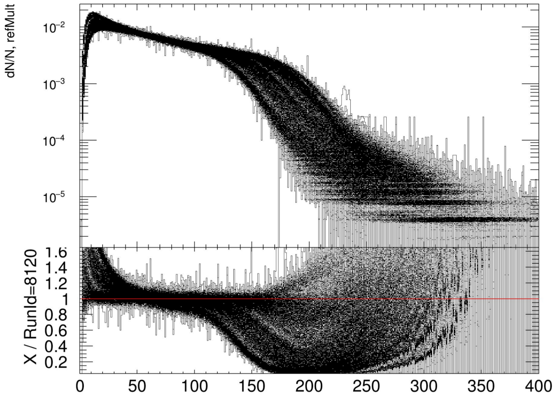
Multiplicity corrections

One of the main corrections to consider:

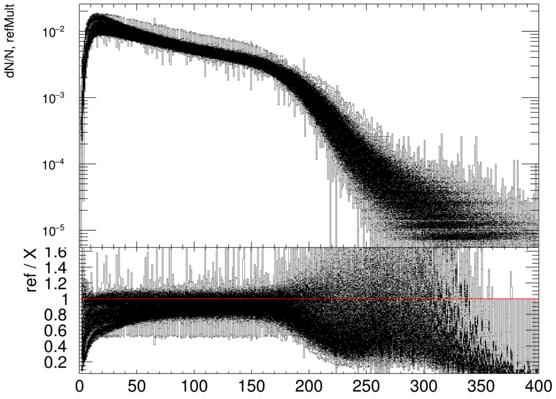
- **<u>Shift correction (run-by-run):</u>**
  f(refMult) = A*Erf(-σ*(refMult-h)) + A
  refMult can then be corrected by:
  refMultCorr = refMult * h_{ref} / f(RunId)
- **<u>Empty target events:</u>**
  Events with collisions outside of the target (Xe+C instead of Xe+Cs(I)) can be subtracted from N_{ch} distribution

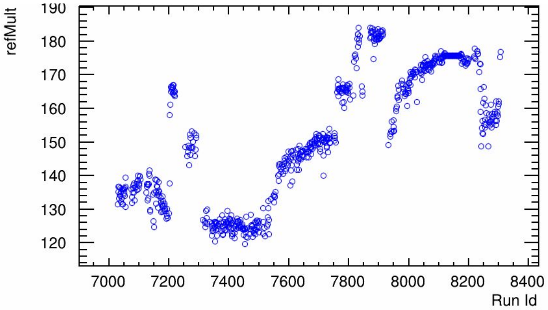


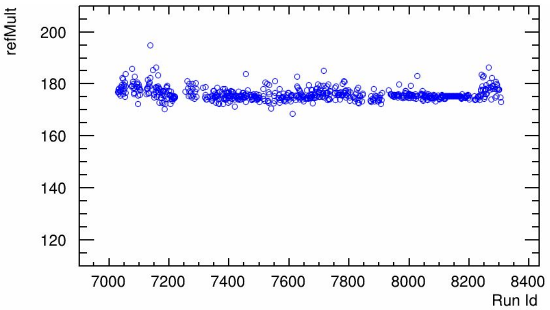
Before correction



After shift

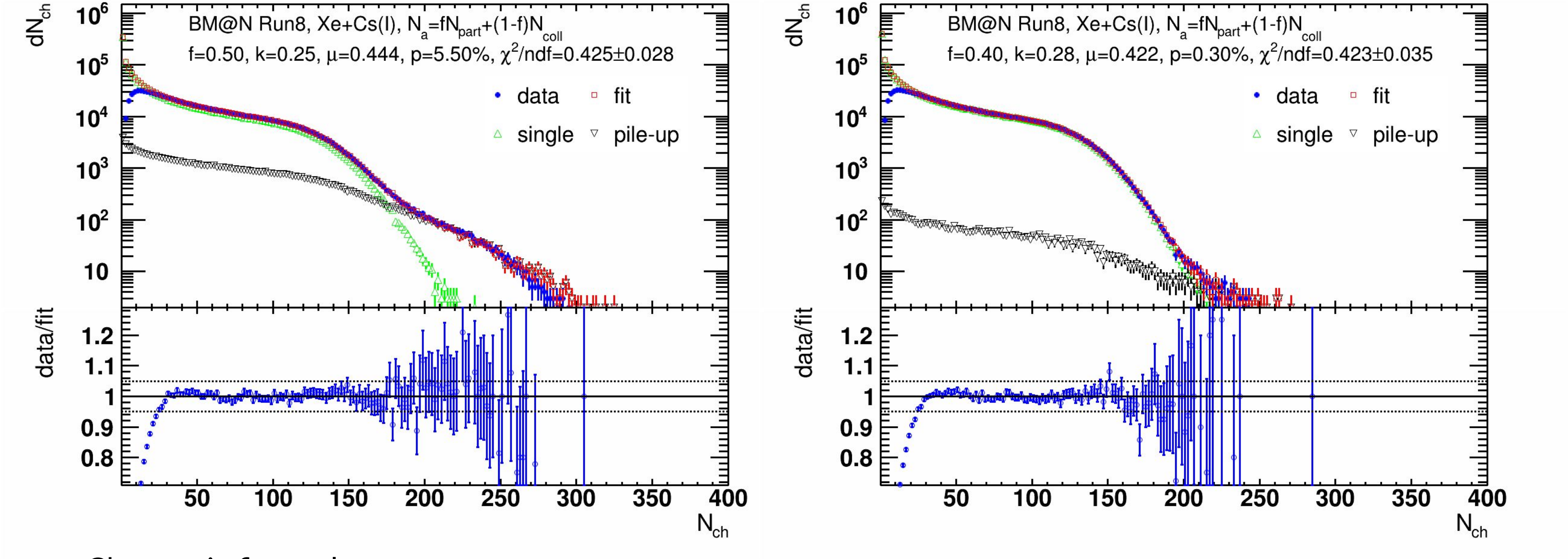






Together with pile-up rejection we can have more robust centrality

Pile-up rejection and centrality determination

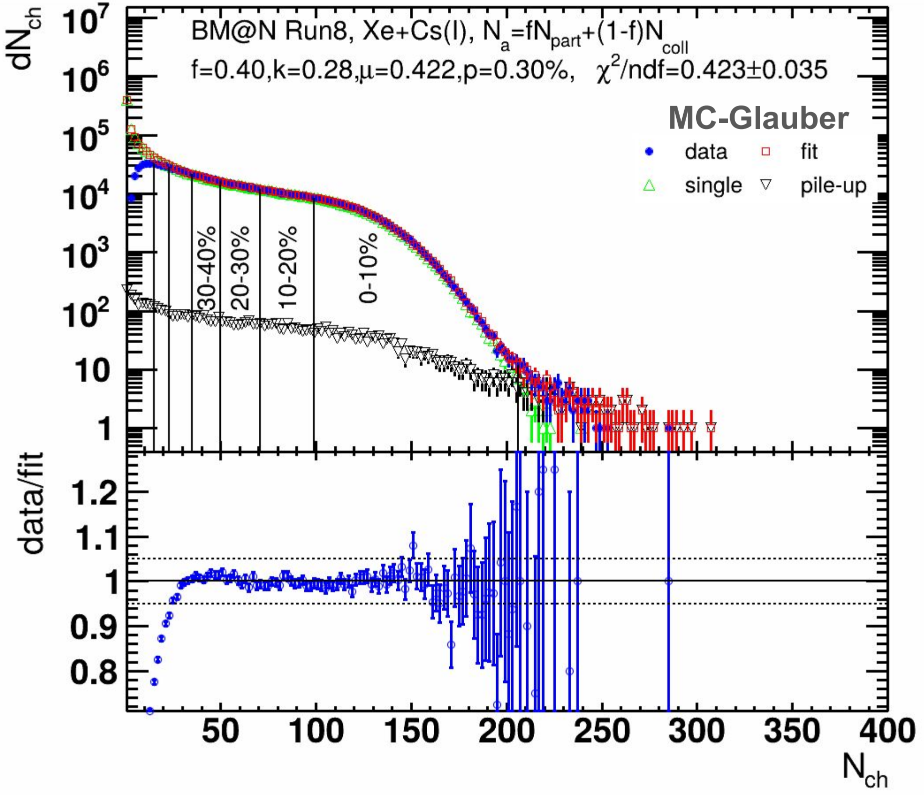


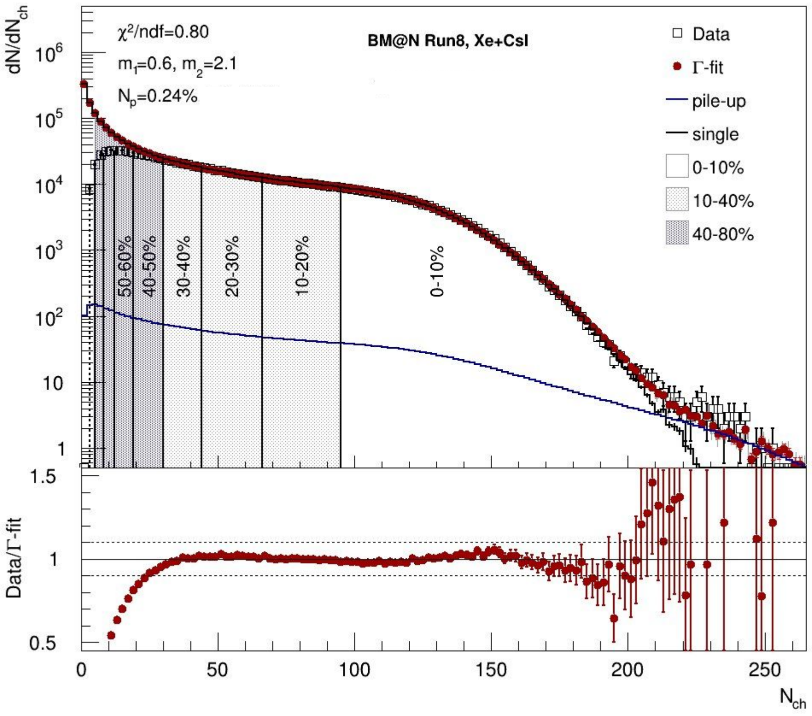
Changes in fit results:

- f: 0.5 -> 0.4
- k: 0.25 -> 0.28
- μ: 0.44 -> 0.42
- pileup: 5.5% -> 0.3%

After pileup rejection the “pileup” events contribution is less than 1%
(f,k,μ) parameters are overall consistent

Centrality determination in the BM@N experiment





Both approaches (based on MC-Glauber and inverse Bayes theorem) reproduce experimental data well

Summary

- **Global observables:** wide spread of V_z can be used to extend rapidity coverage - additional corrections (trigger & tracking efficiencies as a function of V_z, etc.)
- **Model studies:**
  - Study and comparison of different models are important to improve model parameters, chart appropriate models for MPD-FXT and MPD-CLD feasibility studies
  - UrQMD-AMC and UrQMD-SMM give us an additional models with mean field and fragments
  - Provided recommendations for mean field models in the simulation/reconstruction procedures at MPD-FXT
  - We need more mean-field models with realistic nuclei initialization (JAM, SMASH, PHSD, PHQMD, etc.)
- **Feasibility studies at MPD-FXT:**
  - New productions (prod. 35 & 36) are ready for use
  - Trigger efficiencies were estimated using FFD, FHCal, TOF (~90%)
  - Discrepancy in the trigger efficiency estimation from the MC-Glauber-based centrality procedure is due to different nuclei initialization: UrQMD MF uses “hard sphere”, MC-Glauber uses Woods-Saxon
  - E_{EMC} and E_{FHCal} were used for centrality determination using Bayesian inversion method: E_{EMC} is a promising observable that might help to suppress auto-correlation effects - important for some analyses (high-order cumulants of net-protons, kaons, etc.)
- **Latest xenon run at BM@N allows us to test analysis techniques with real experimental data:**
  - Centrality determination procedures based on MC-Glauber and Bayes inversion were tested together with all necessary corrections (shift run-by-run correction, pile-up rejection, empty target subtraction, etc.)

Thank you for your attention!

Backup

UrQMD with mean field mode

24	1	initialization mode
	0	hard sphere (used for EOS$\neq$0)
	1	Woods-Saxon (used for CASCADE mode)
	2	Fast Woods-Saxon (used for CASCADE mode)

*snapshot from the UrQMD User Guide

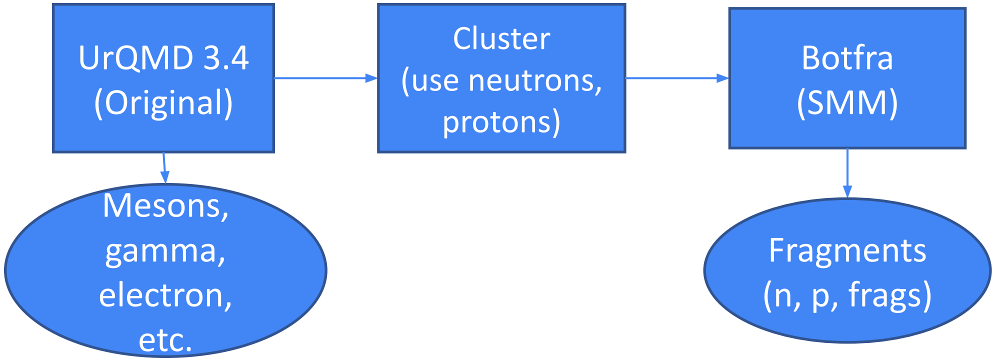
In input.f:

```
      if (eos.ne.0) then
         CTOption(24)=0
      endif
```

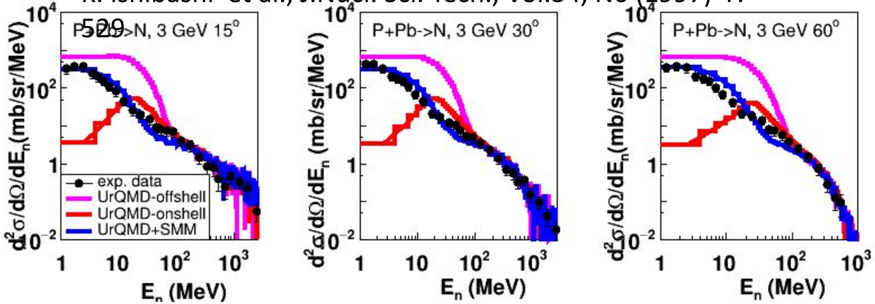
When Skyrme potential is used (EOS = 1), UrQMD essentially locks nuclei initialization to the hard sphere which is not realistic.

In the future studies we need to have MF model with realistic nuclear matter parametrization (based on Woods-Saxon potential): SMASH, PHSD, PHQMD, etc.

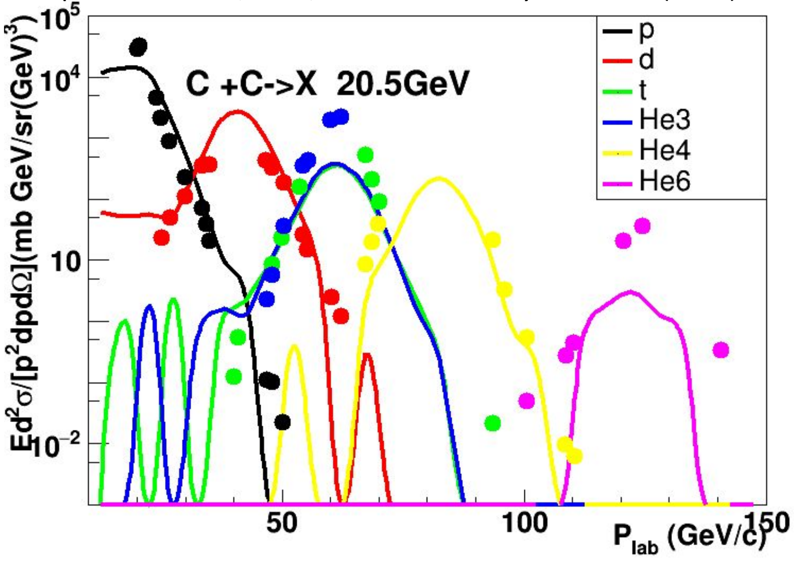
Coupling of UrQMD and SMM models



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



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



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

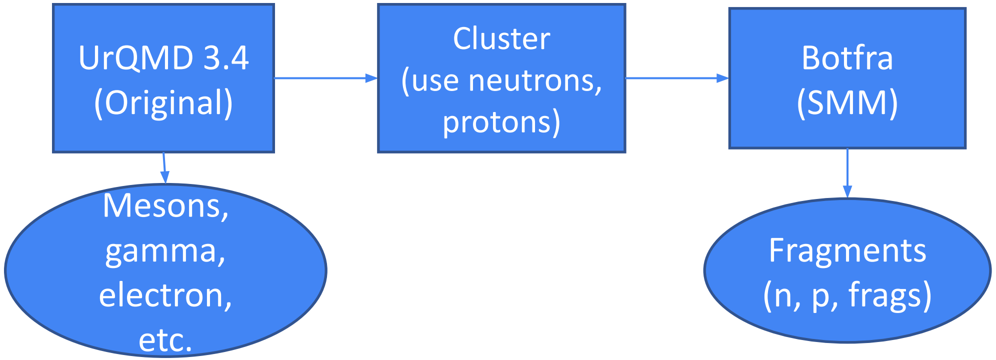
- ➢ Implemented EoS with mean-field approach
- ➢ Fragmentation model for forward/backward spectator region

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)

Coupling of UrQMD and SMM models



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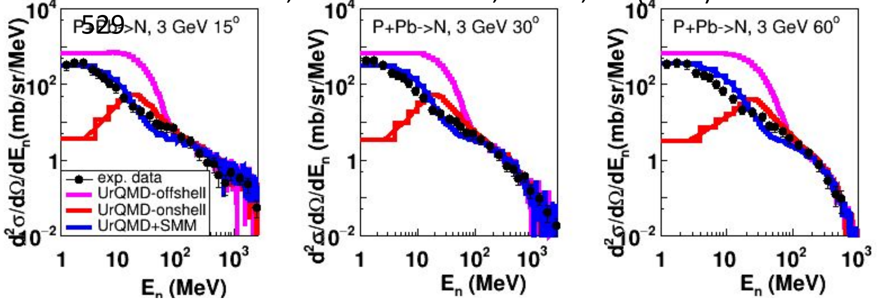

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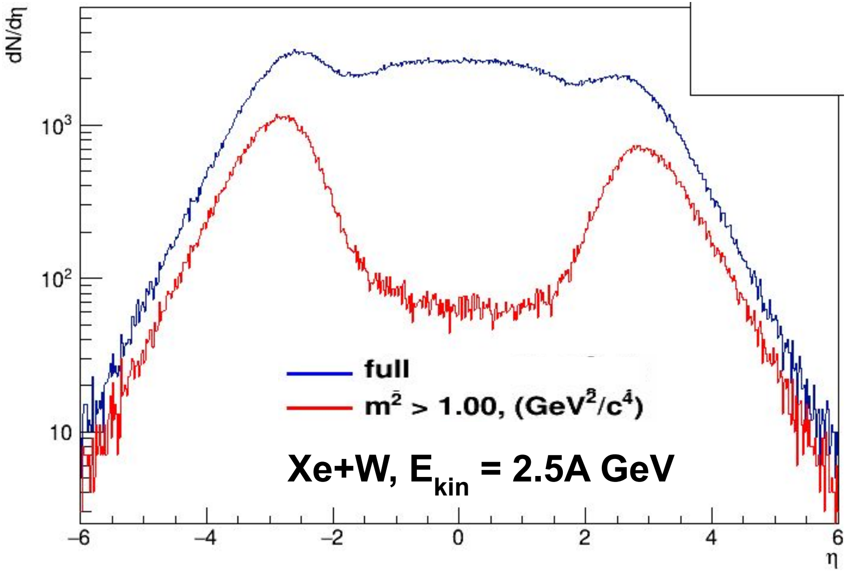
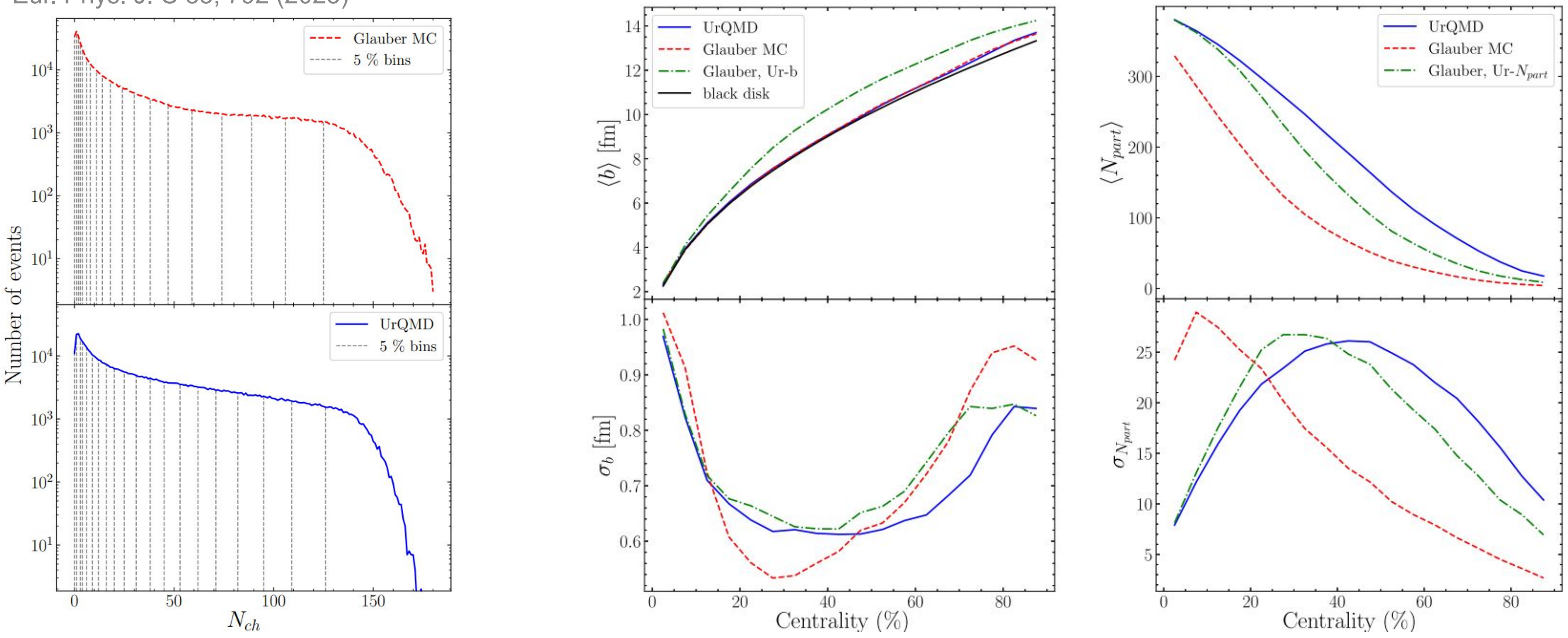


Model dependence of b, N_{part}

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

The Bayesian inversion method (Γ-fit): multiplicity

Relation between multiplicity M and impact parameter b is defined by

the fluctuation kernel:

$$\boxed{P(M \mid c_b) = \frac{1}{\Gamma(k(c_b))\theta^2} M^{k(c_b)-1} e^{-M/\theta}}$$

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

$\langle M \rangle, D(M)$ - mean and variance of multiplicity after reconstruction

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

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

$$\boxed{\begin{gathered}\langle M \rangle = m_1 \cdot \langle M' \rangle \\ D(M) = m_1^2 \cdot D(M') + m_1 \cdot m_2 \langle M' \rangle\end{gathered}}$$

$\langle M'(c_b) \rangle$, $D(M'(c_b))$ - mean and variance of multiplicity from the model

Fit function for N_{ch} distribution:

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

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

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

See D. Idrisov's talk

2 main steps of the method:

Fit experimental (model) distribution with P(M)

↓

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

The Bayesian inversion method (Γ-fit): E_{EMC} & E_{FHCal}

See D. Idrisov's talk

Relation between E_{EMC} & E_{FHCal} and impact parameter b is defined by the fluctuation kernel:

$$P(E,E_F\,|\,c_b)=G_{2D}(E,E_F,\langle E\rangle,\langle E_F\rangle,D(E),D(E_F),R)$$

$$R(E,E_F)=\frac{\varepsilon_1^2 m_1^2}{\varepsilon_2 m_2}R(E',E_F')$$

$\varepsilon_1,\varepsilon_2,m_1,m_2$ - fit parameters

$G_{2D}(\ldots)$ - 2D Gamma function (2 Γ-functions with rotation)

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

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

$\langle E_F\rangle, D(E_F)$ – average value and variance of energy in FHCal

$R(E,E_F)$ – Pirson correlation coefficient

E' - E_{EMC} and/or E_{FHCal} in the model

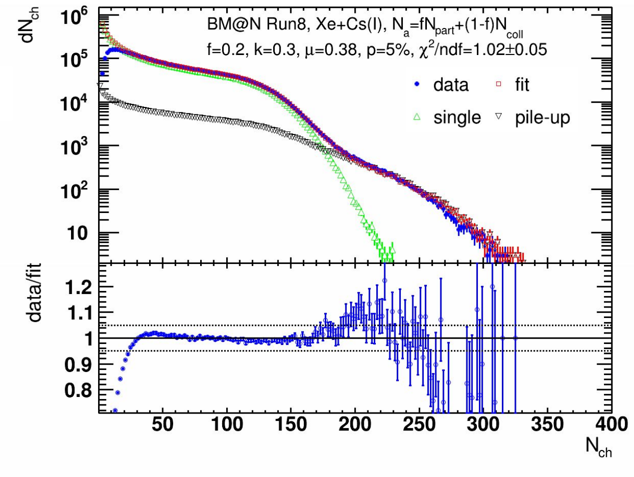
E - E_{EMC} and/or E_{FHCal} after reconstruction

$$\langle E\rangle=\varepsilon_1\langle E'(c_b)\rangle,\quad D(E)=\varepsilon_2 D(E'(c_b))$$
$$\langle E_F\rangle=m_1\langle E_F'(c_b)\rangle,\quad D(E_F)=m_2 D(E_F'(c_b))$$

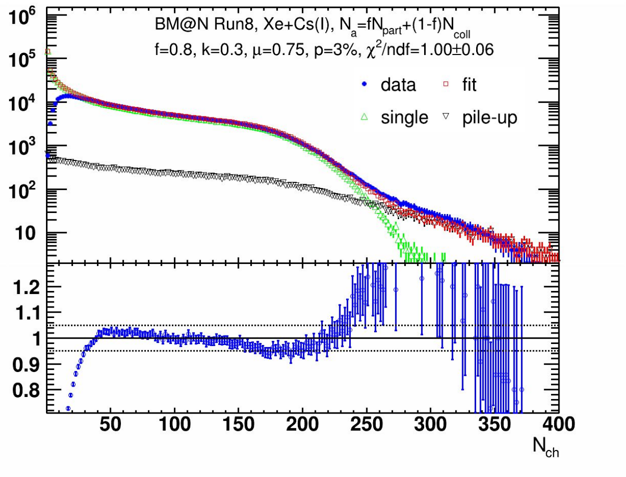
$\langle E'(c_b)\rangle,\quad D(E'(c_b))$ - can be approximated by exponential (or any smooth) function

Centrality determination after refMult correction (7310-7500)

Raw



After shift



		0-10 %	10-20 %	20-30 %	30-40 %	40-50 %	50-60 %
Run 8150-8170		137-236	99-137	71-99	49-71	33-49	21-33
Run 7310-7500	raw	98-177	70-98	49-70	34-49	22-34	14-22
	shift	142-253	103-142	74-103	52-74	35-52	22-35

Example, multiplicity [49;71):

- corresponding 30-40% for Run 8150-8170
- corresponding 20-30% for Run 7310-7500

We suggest using the “shift” correction