Centrality Determination in Xe+Cs(I) based on multiplicity

Demanov Alexander (MEPhi)

Peter Parfenov (JINR)

Arkady Taranenko (MEPhI, JINR)

This work is supported by: Project "Fundamental and applied research at the NICA megascience experimental complex" № FSWU-2024-0024

BM@N analysis meeting, 08/10/2024

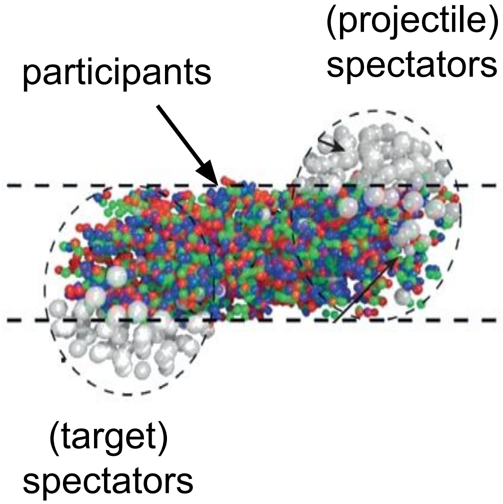
Motivation for centrality determination

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

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

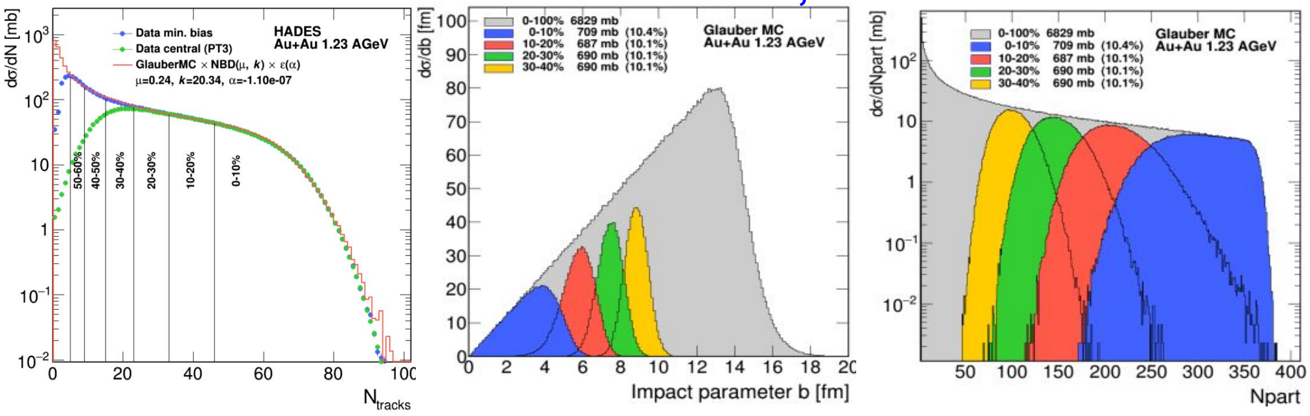
- Centrality class S_1-S_2: group of events corresponding to a given fraction (in %) of the total cross section:

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



Centrality determination

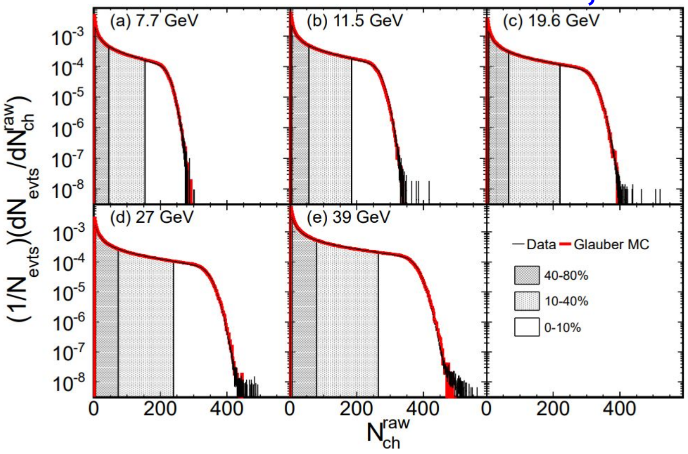
HADES, Au+Au 1.23A GeV



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

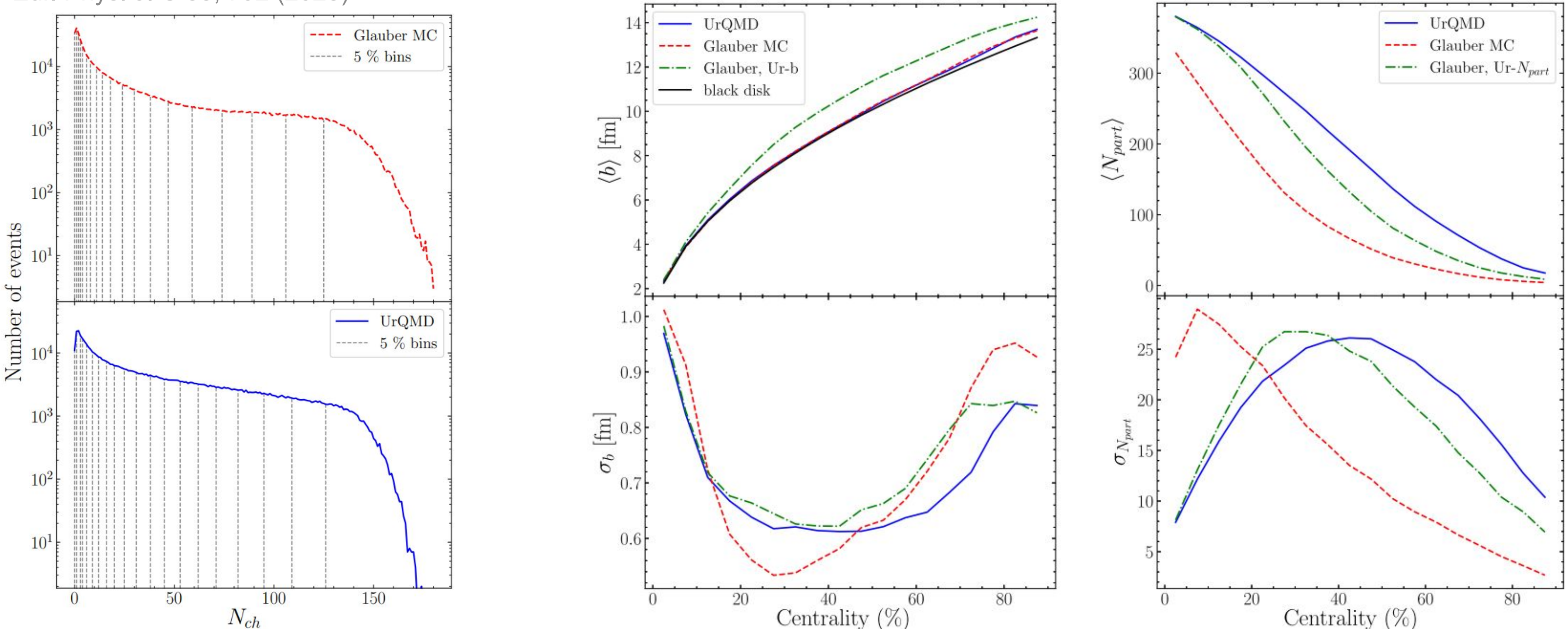
Centrality determination based on multiplicity provides with:

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

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

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

Centrality determination based on Monte-Carlo sampling of produced particles

For **multiplicity of produced particles**
used in HADES, CBM, NA61/SHINE

Get (b, N_{part}, N_{coll}) from MC-Glauber

Evaluate number of ancestors
(sources of produced particles)
$N_a = \mathbf{f} N_{part} + (1-\mathbf{f}) N_{coll}$

Sample multiplicity of produced particles (S_i) N_a times
from NBD(μ, **k**)

Multiplicities from two collision events are randomly superimposed with the probability **p** (pileup events)

Result: total S_{tot}

MC-Glauber distribution

Full Monte-Carlo (real data) distribution

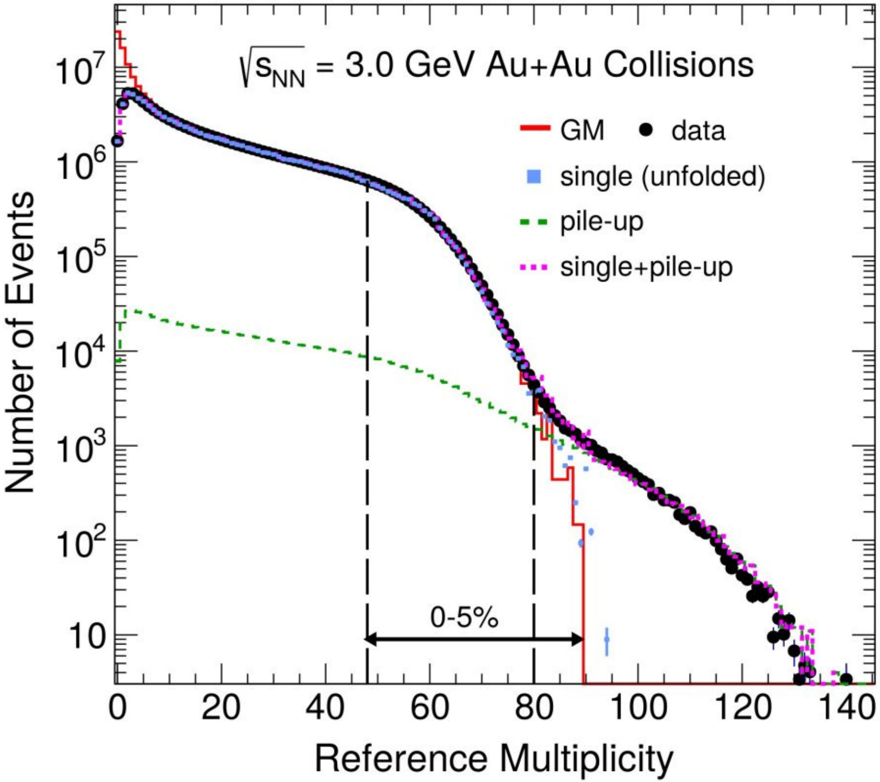
Evaluate χ^2
between $N/dN_{MC/data}$ and N/dN_{Gl}

Scan phase space of parameters
to find their values for minimum of χ^2

Extract relation between geometry parameters and centrality estimator

Implementation of “pileup” in the centrality determination procedure

https://arxiv.org/abs/2112.00240

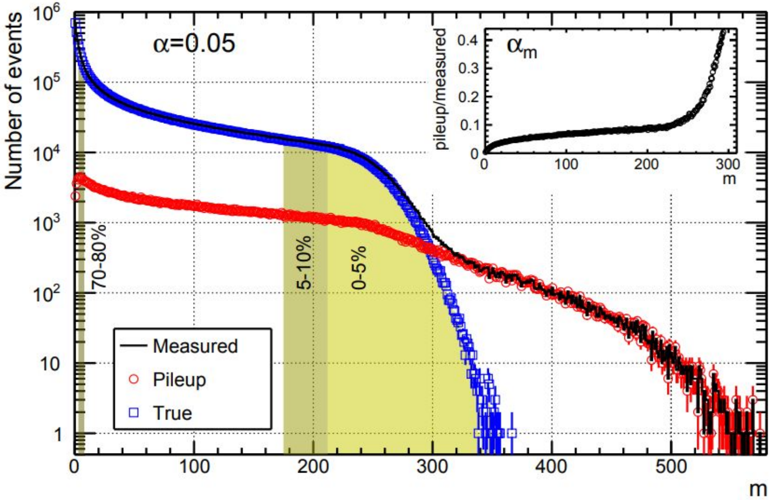


Pileup events occur with the probability $\boldsymbol{\alpha_m}$ at the **m** multiplicity bin.

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

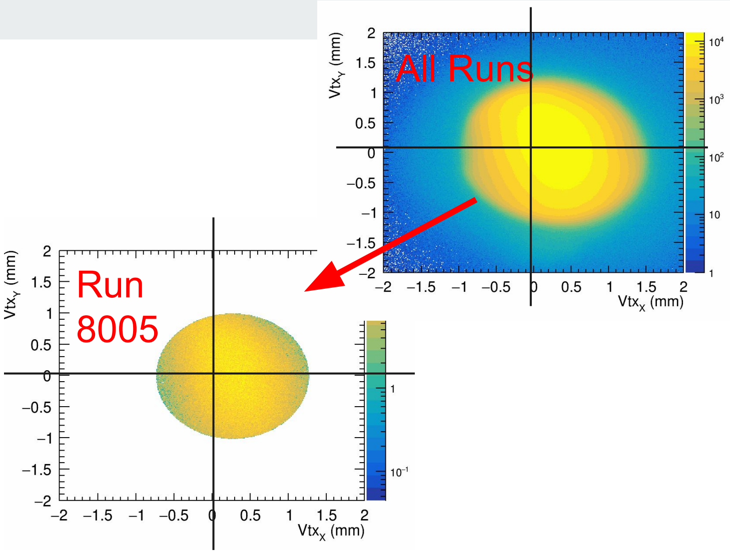
$$P_m(N) = (1 - \alpha_m) P_m^{single}(N) + \alpha_m P_m^{pileup}(N)$$

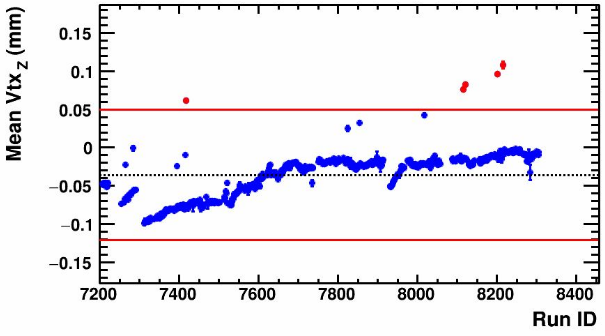
https://arxiv.org/abs/2006.15809

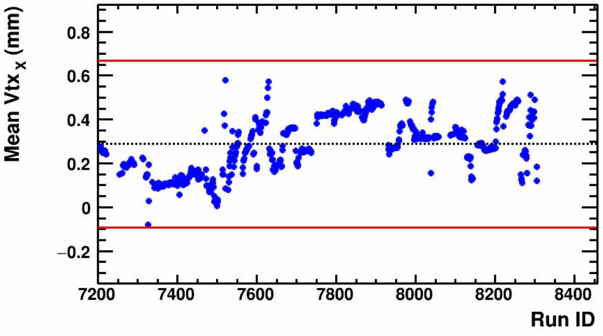


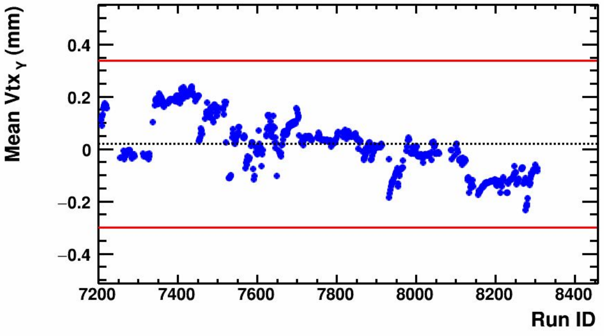
Event selection

- Xe+Cs 3.8 GeV
- Production= last
- Physical runs
- Triggers: CCT2
- Remove BadRuns
- Corrected on <VtxX>, <VtxX>, <VtxZ> for each RunId
- Event selection:
    - More than 1 track in vertex reconstruction
    - VtxR < 1.0 cm ($\mathrm{sqrt}(VtxY_{corr}^2 + VtxX_{corr}^2) < 1$ cm)
    - VtxZ < 0.1 cm
    - Apply graphics cuts
    - Remove pileup (from Oleg Golosov)

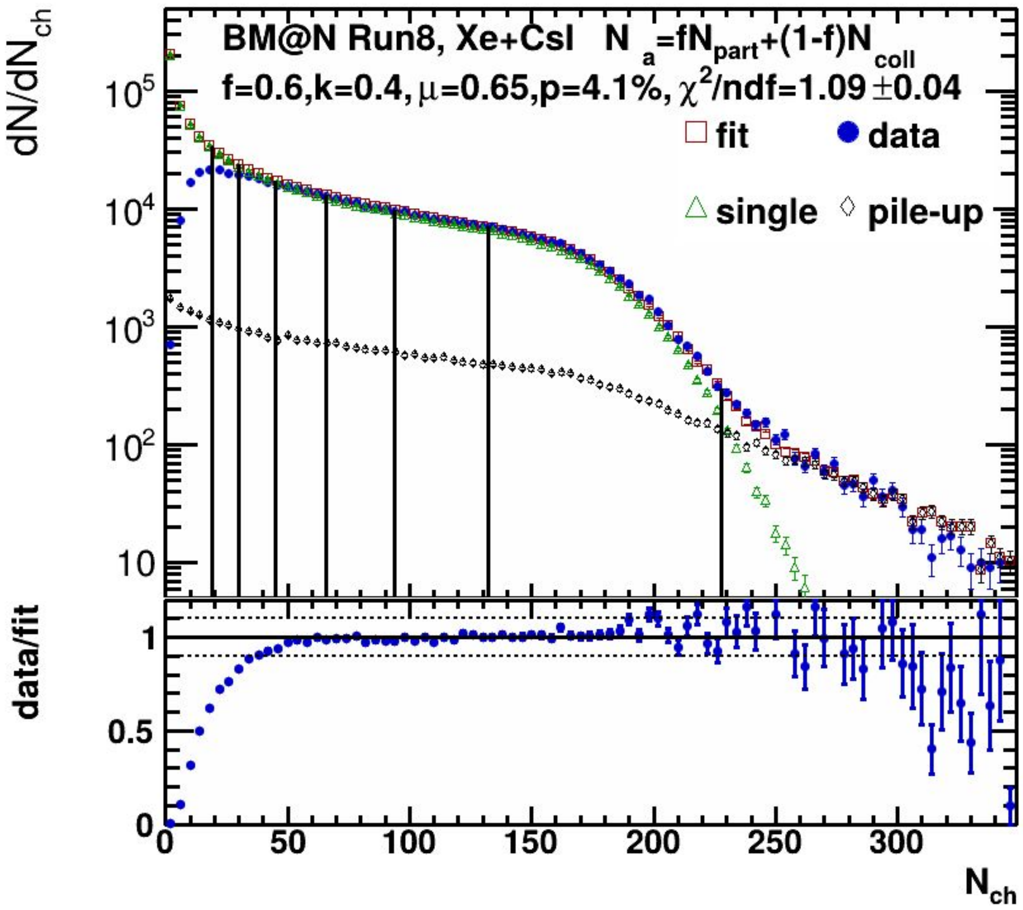








Centrality based on MC-Glauber at low energies



RunId: **8120-8170**

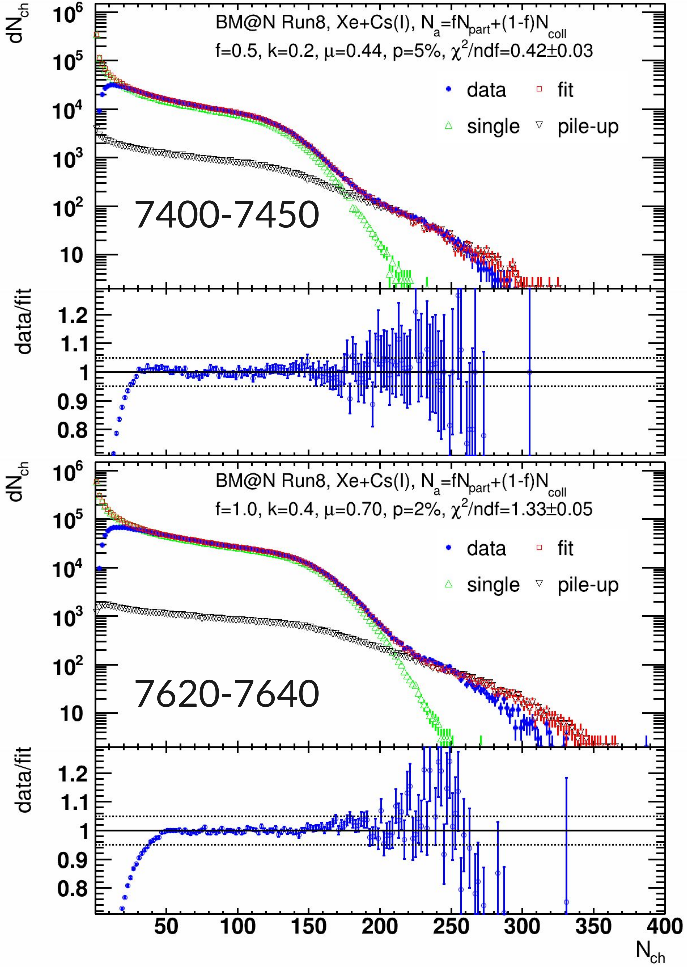
Multiplicity Cuts:

- 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

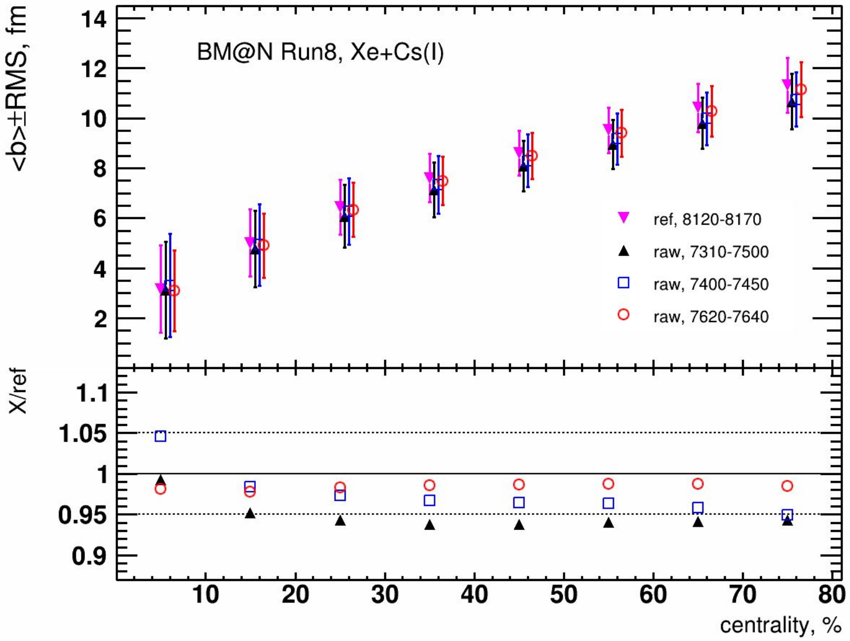
Good agreement with experimental data

Centrality determination: pileup rejection

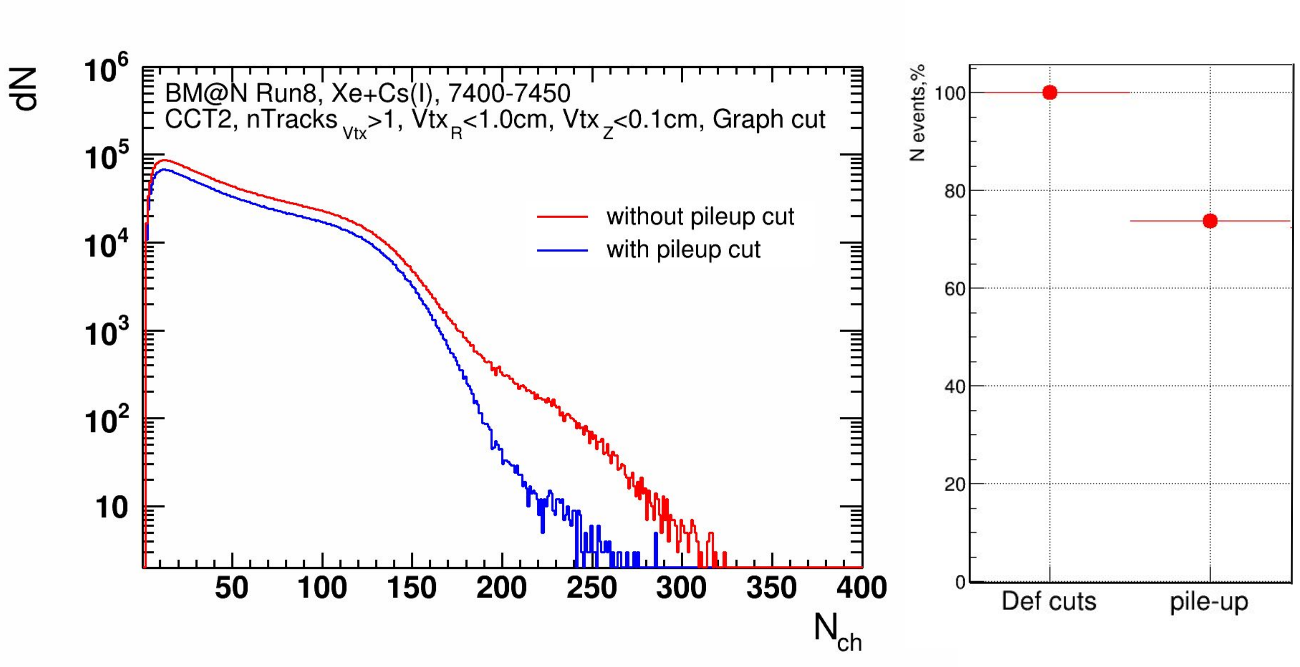


During the run8 the luminosity changes -> different pile-up contribution:

- Fit predicts **6%** pileup events for Run 7400-7450
- Fit predicts **2%** pileup events for Run 7620-7640



Centrality determination: pileup rejection



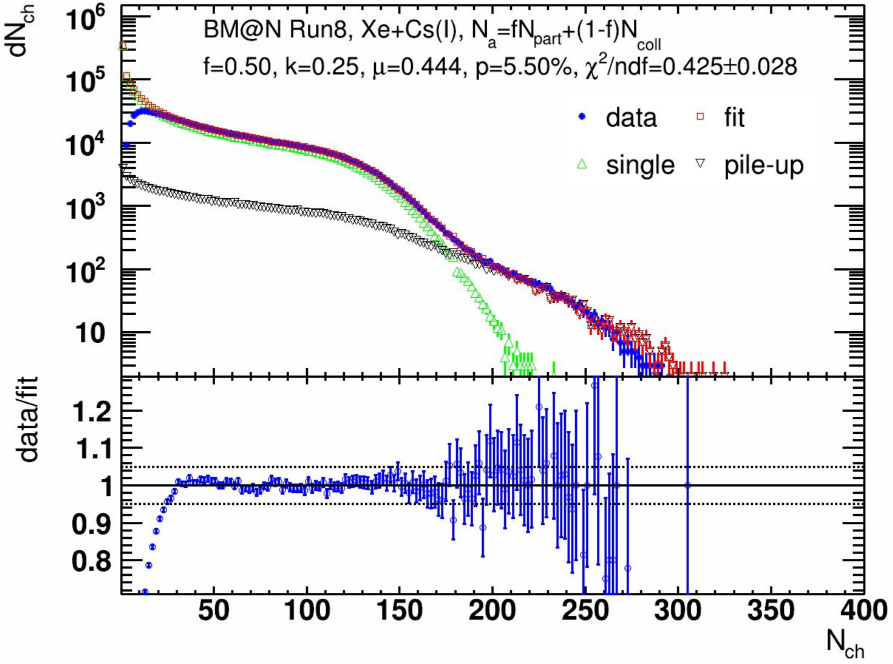
*Def cuts:

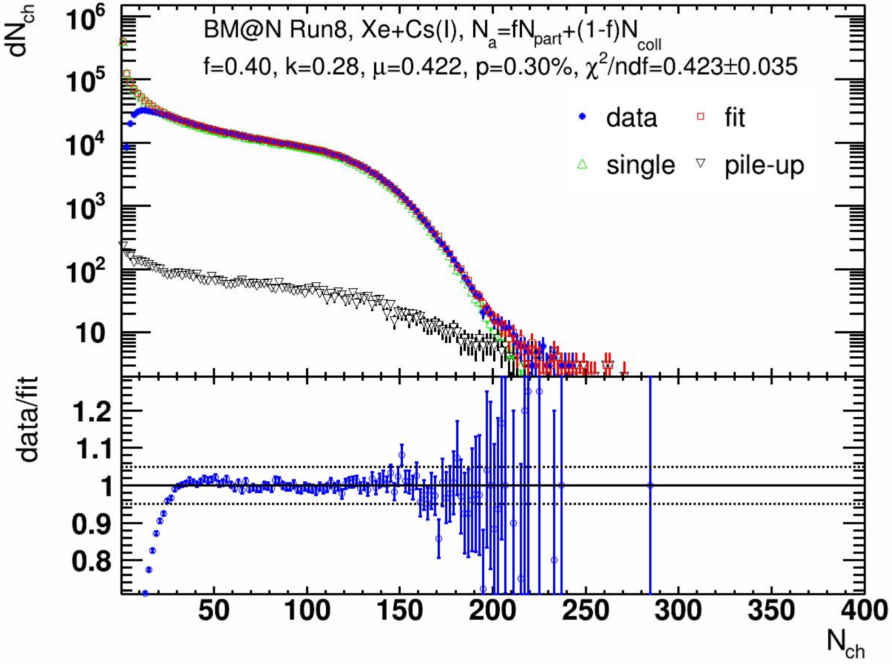
- Rhys runs
- CCT2
- vtxNtracks > 1
- V_R <1 cm
- $|V_Z|$ < 0.1 cm
- Remove BabRuns

*Pileup cuts from Oleg Golosov

- The “pileup” cut was applied with run-by-run corrections
- pileup cuts removes ~25% events
- We use the new multiplicity in our centrality procedure

Centrality determination after remove "pileup"



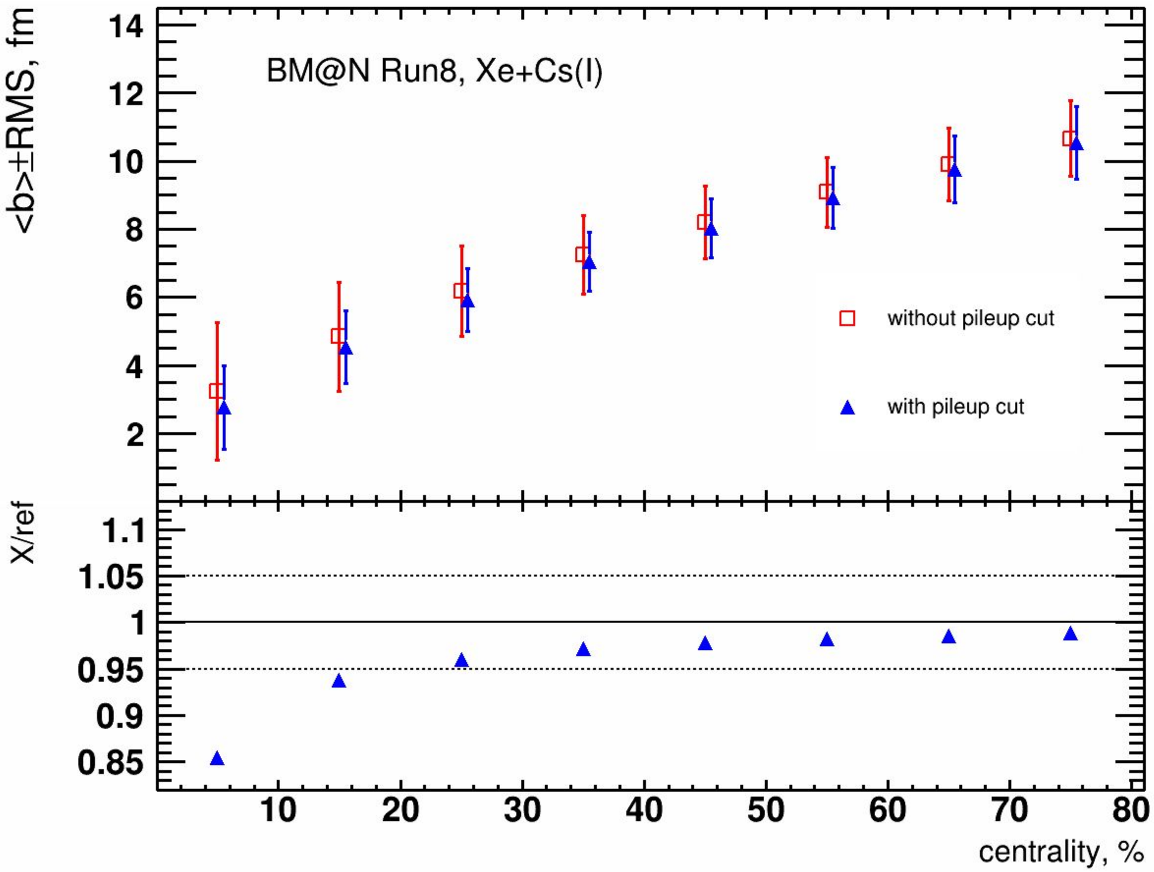


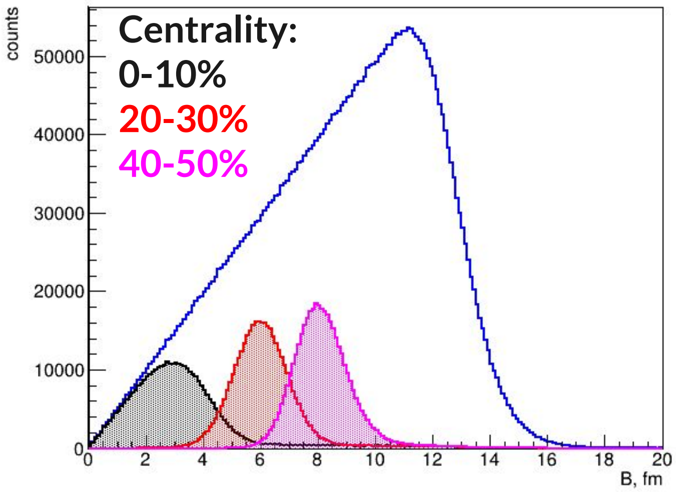
Change fit result

- 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 1%

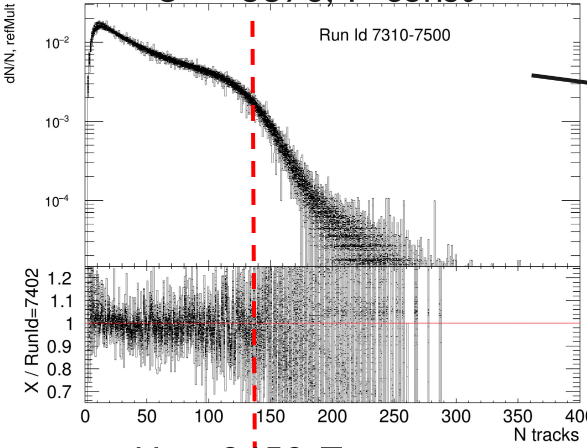
Centrality determination after refMult correction: <b> vs cent



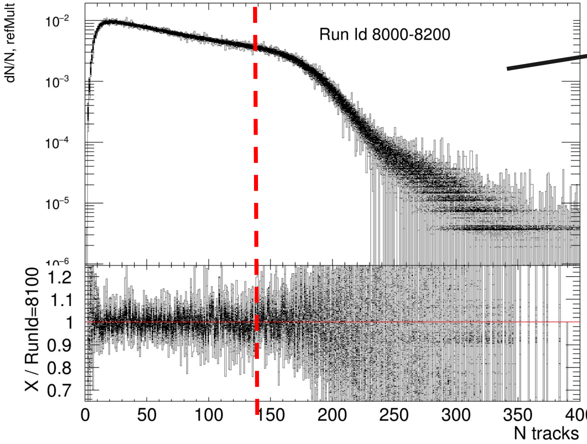


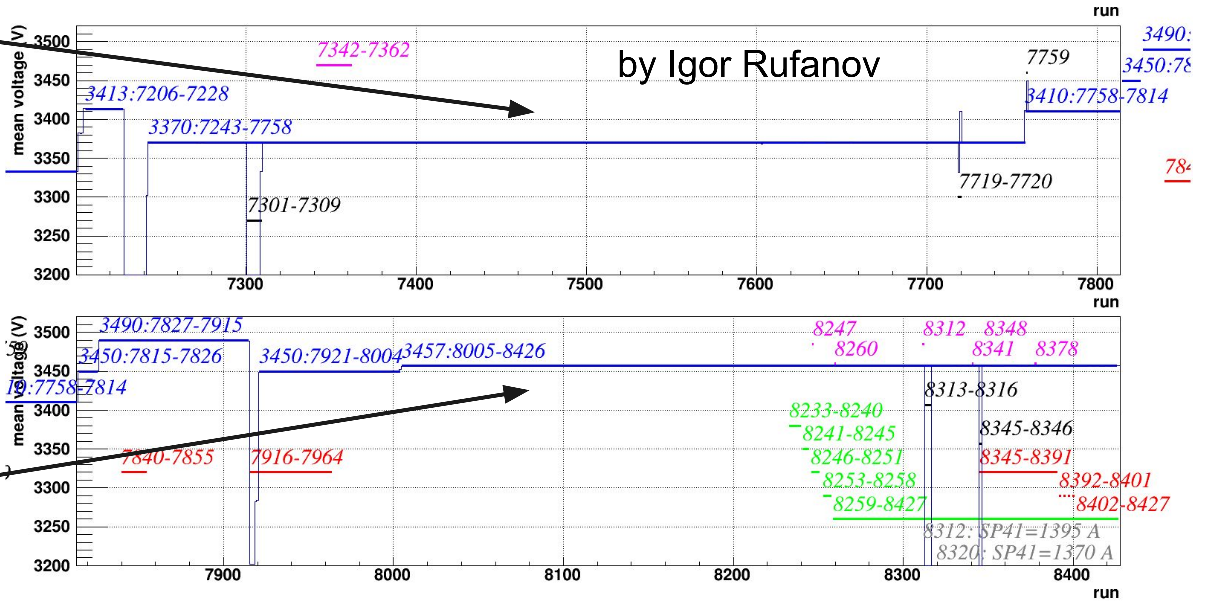
Multiplicity & RunID: Effect of voltage

<U> = 3370, T~const



<U> = 3450, T ~ const

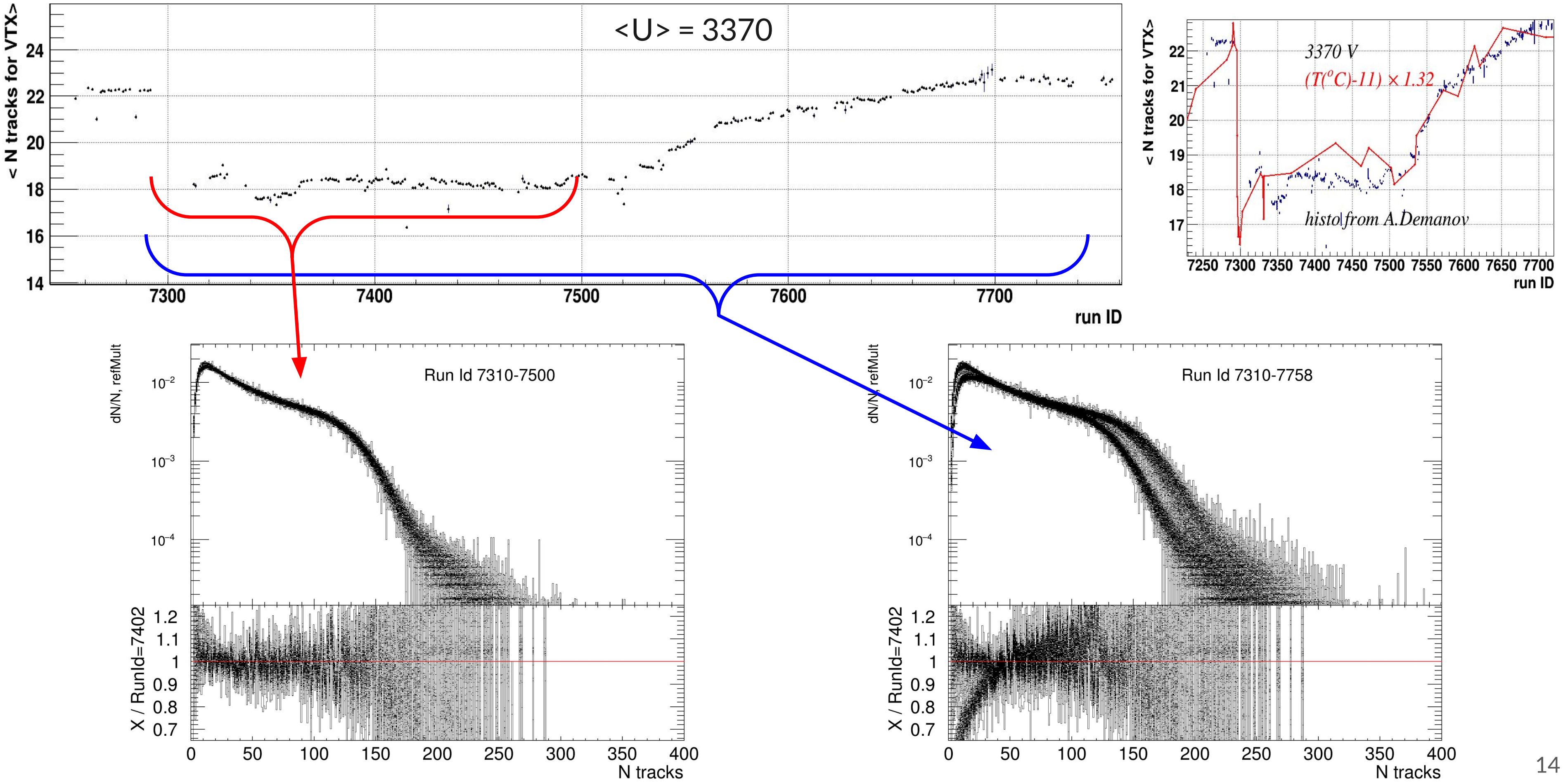




Strong dependence of multiplicity on voltage.

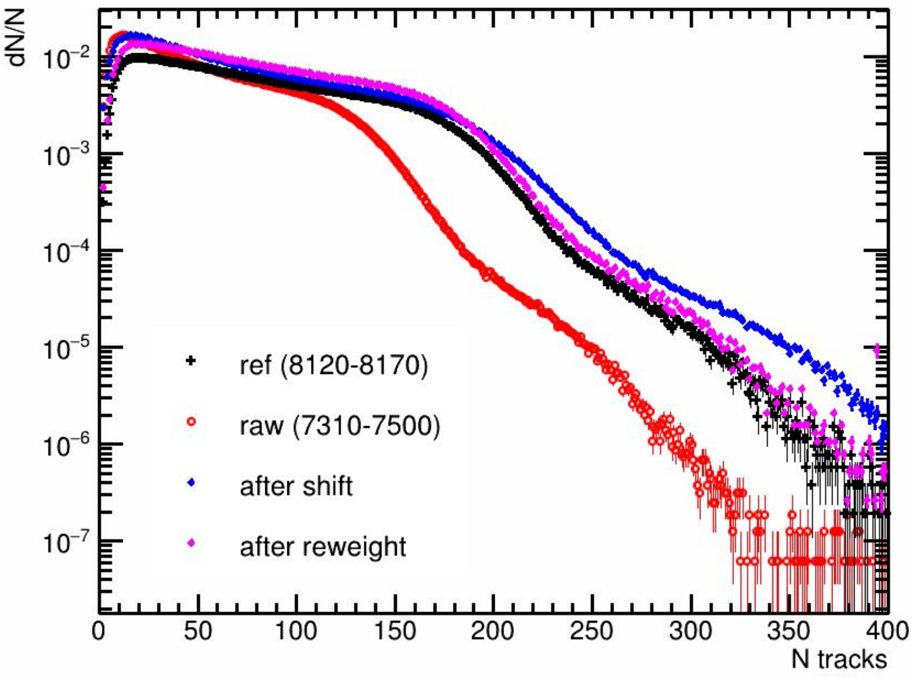
Run-by-run corrections are required!

Multiplicity & RunID: Effect of temperature



Multiplicity correction

For Run 7310-7500 and 8120-8170:
<U> = const, T~const



RunId$_{ref}$: 8120-8170

Shift (or scale):

- Extract the high-end point of refMult distribution in each RunId via fitting the refMult tail by the function:

  f(refMult) = A*Erf(-σ*(refMult-h)) + A

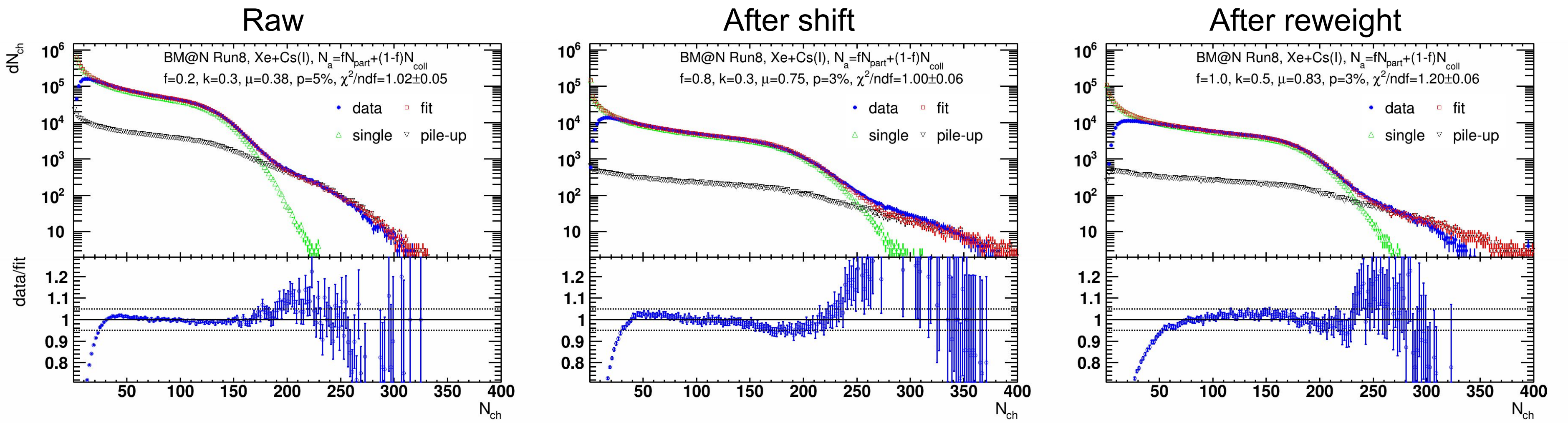
- refMult can then be corrected by:

  refMultCorr = refMult * h$_{ref}$ / h(RunId)

Reweight:

- refMult bin by refMult bin - weight each event by the ratio of normalized refMultCorr for RunId$_{ref}$ to refMultCorr for this RunId
- This gives the refMultCorr distributions at each RunId value the same shape

Centrality determination after refMult correction (7310-7500)



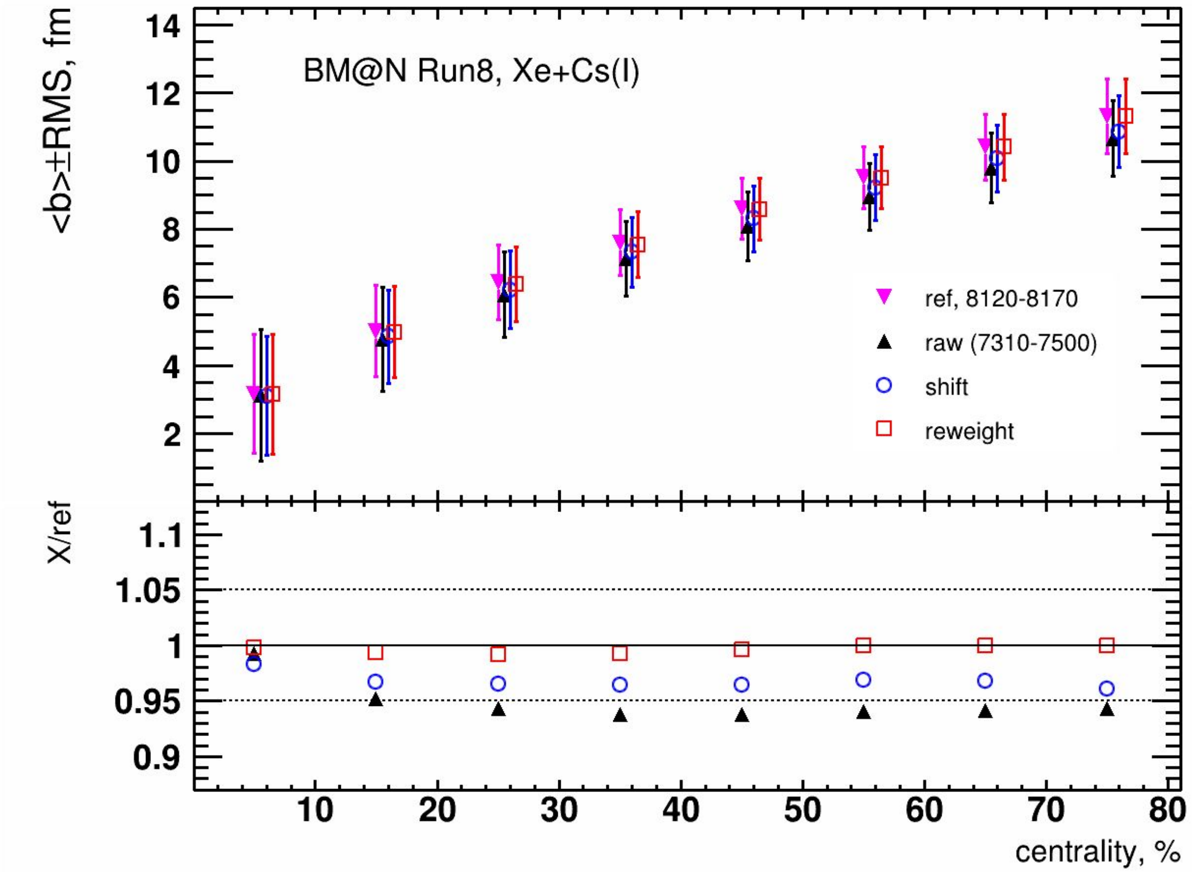
		0-10 %	10-20 %	20-30 %	30-40 %	40-50 %	50-60 %	60-70 %	70-80 %
Run 8150-8170		137-236	99-137	71-99	49-71	33-49	21-33	12-22	6-12
Run 7310-7500	raw	98-177	70-98	49-70	34-49	22-34	14-22	8-14	4-8
	shift	142-253	103-142	74-103	52-74	35-52	22-35	13-22	7-13
	reweight	137-234	100-137	72-100	50-72	33-50	21-33	12-21	6-12

Example, multiplicity [49;71]:

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

We suggest using the “shift” correction

Centrality determination after refMult correction: <b> vs cent



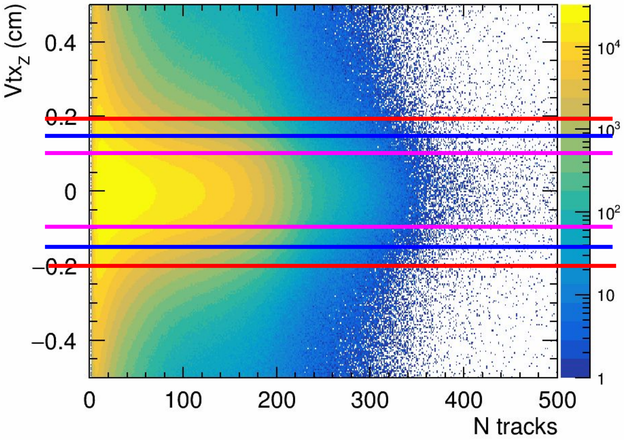
Summary and outlook

- A new approach to accounting for pileup is considered
- The MC-Glauber method reproduce charged particle multiplicity for fixed-target experiment at BM@N
- Corrections for vertex and RunId was proposed
- Optimization of selection criteria:
  - reduction the pileup effect

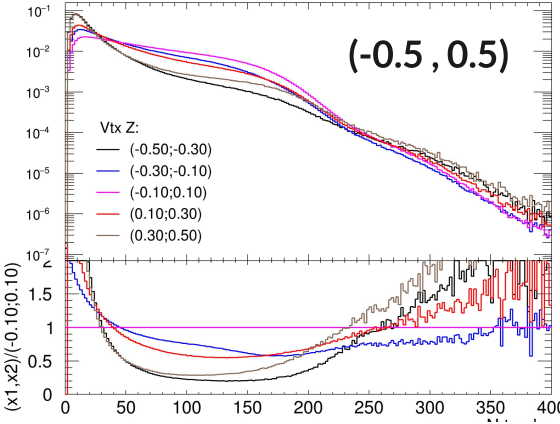
- Consider the multiplicity h^- / π^{+-} to determine centrality
- Adding centrality and refMult in bmnroot

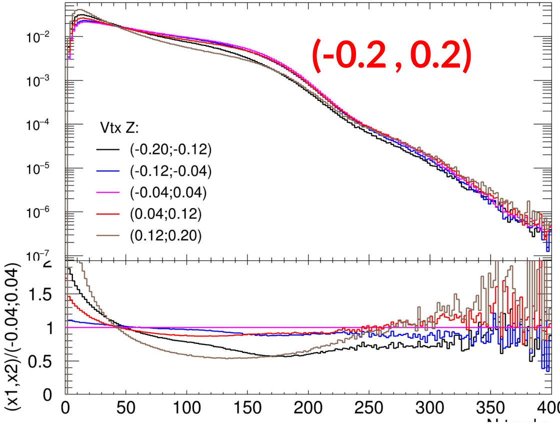
Thank you for your attention!

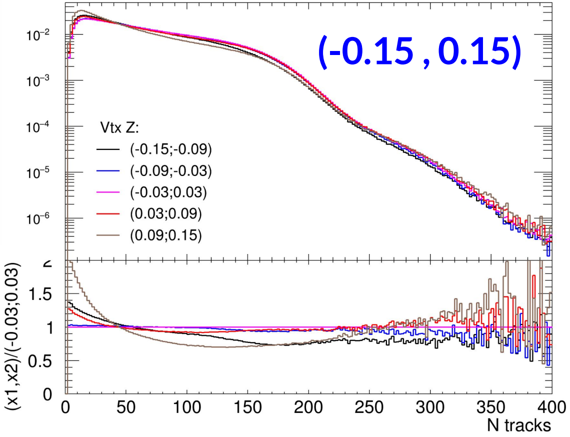
Vertex Z

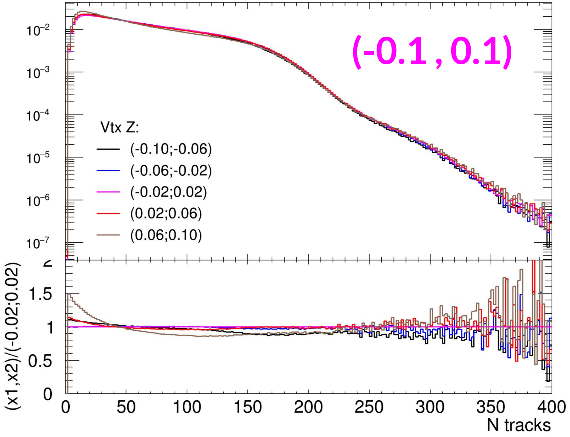


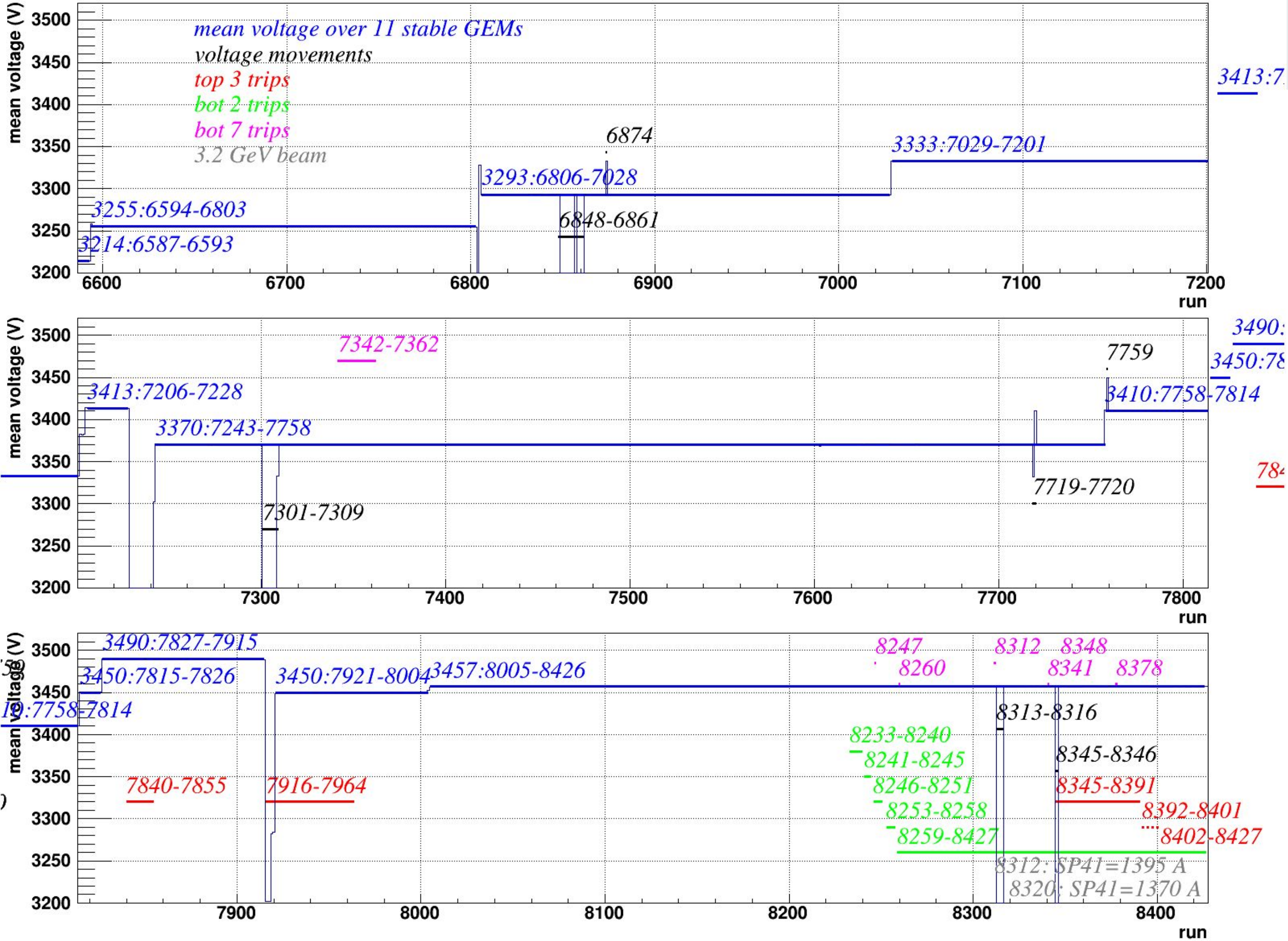
Use VtxZ <0.1



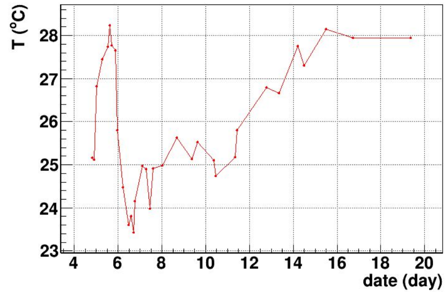


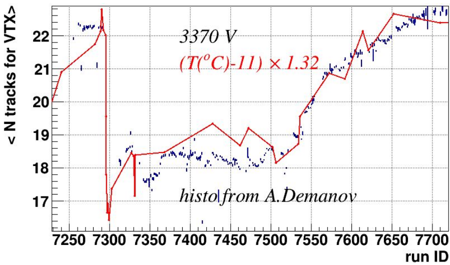






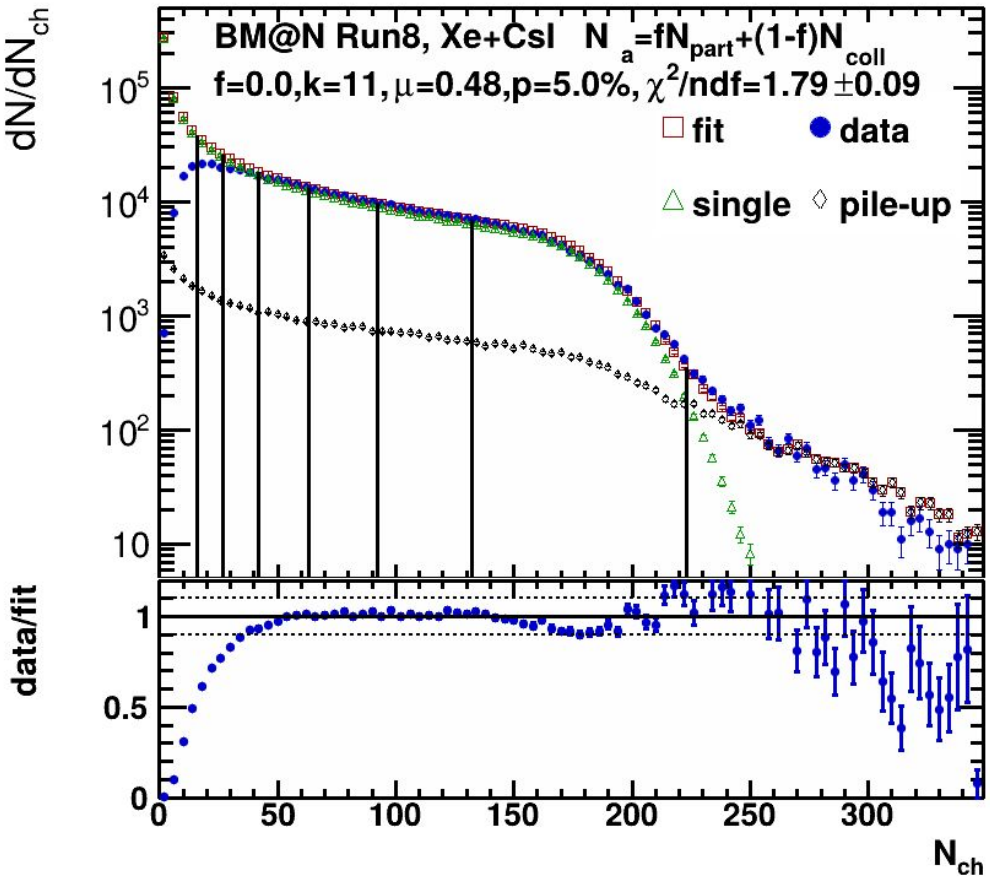
<U> = 3370





10 groups

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



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 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: *μ*

Variance: *μ/k* · *(μ+k)*

It works at high energies where *μ>1, k>1.*

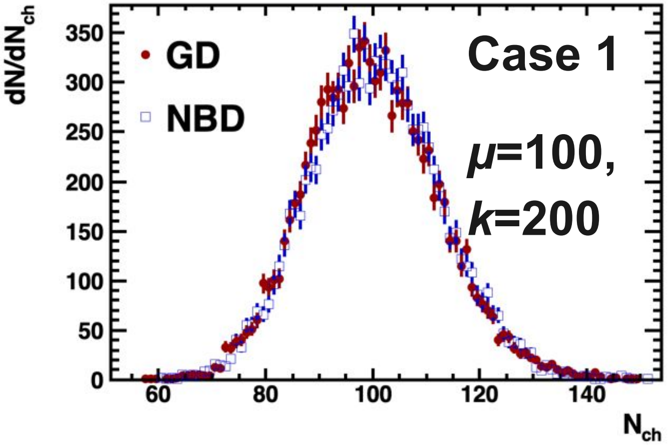
However at lower energies we likely have situation where *μ<1, k<1*. NBD cannot be applicable in that case. We have to use generalized function - gamma distribution (GD):

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

Mean: *μ*

Variance: *μ/k* · *(μ+k)*

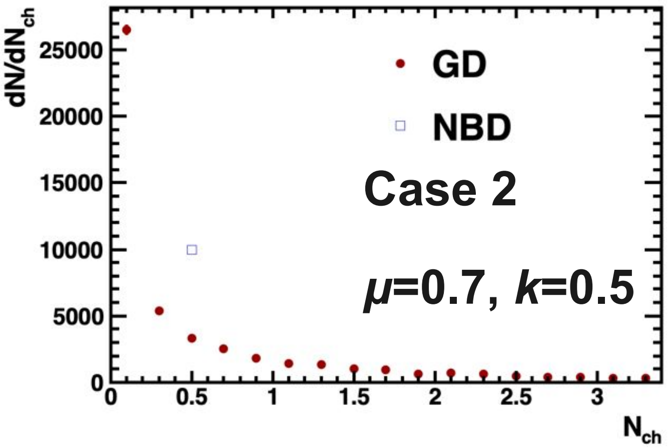
Multiplicity in pp/nn/np collisions



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.

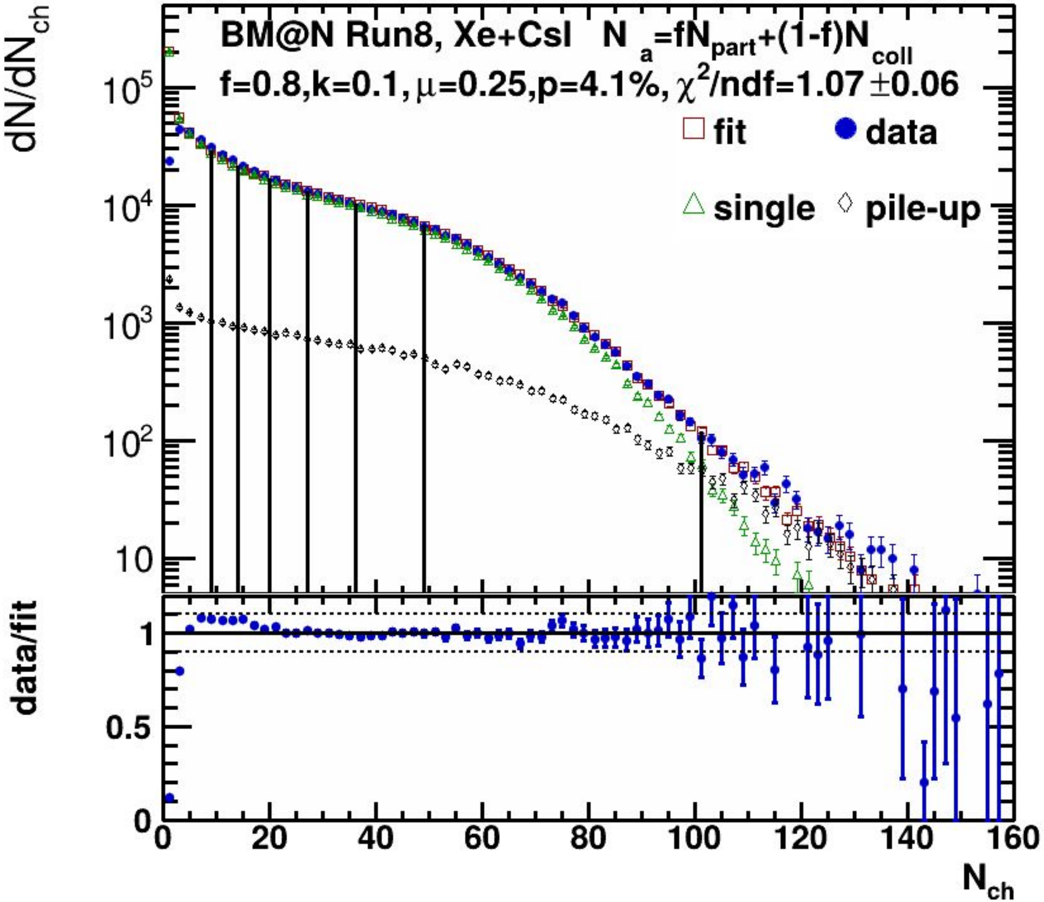
Case 1 can be defined with both NBD and GD.
Case 2 can be defined with GD only!



Case 2 can be more feasible at lower energies, where we have smaller multiplicities and relation between μ and σ^2 might vary greatly

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

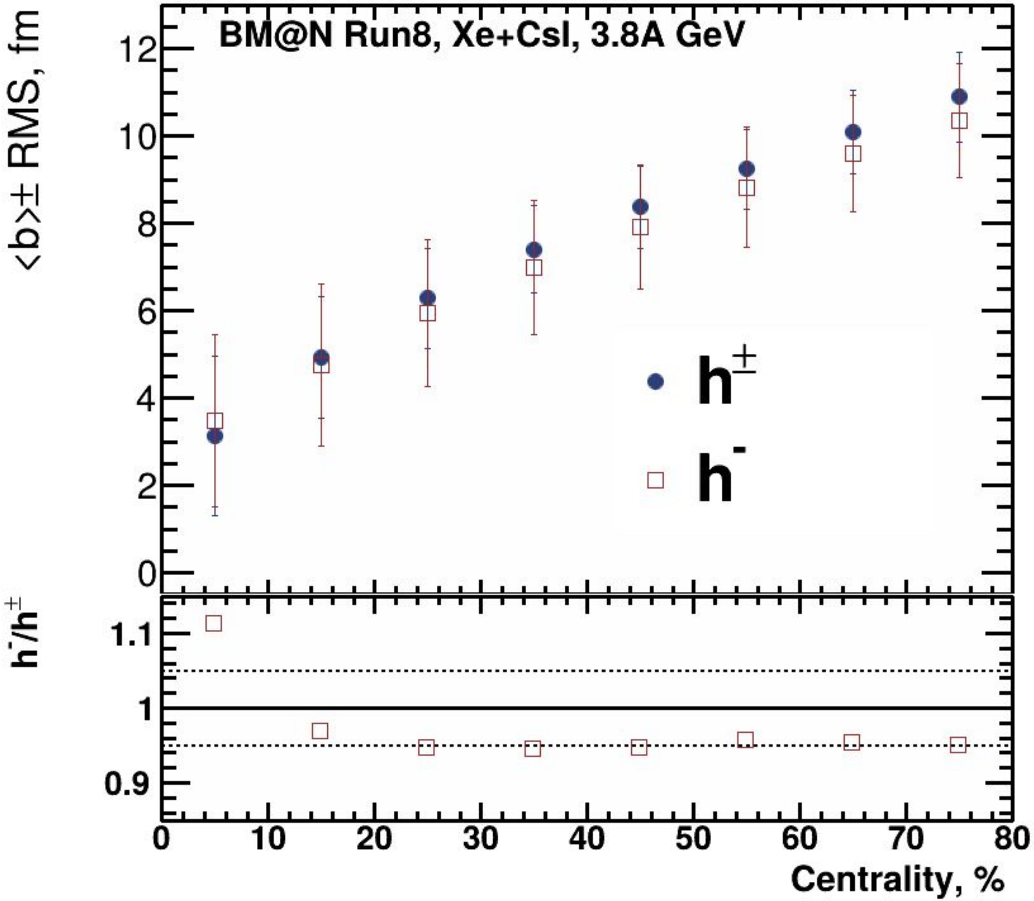
Multiplicity fit & centrality classes: h^-



Multiplicity Cuts:

- CCT2
- N_{vtxTr}>1
- (Sts digi vs N_{tr}) cut
- V_r <1 mm
- V_z < 0.2 mm
- q<1

<b> vs Centrality: comparison



- Difference in the most central class is due to pile-up:
  - Cut on maximum multiplicity differs a little in cases of $h^{\pm}$ and h^{-}
- 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

Multiplicity corrections: shift

Procedure:

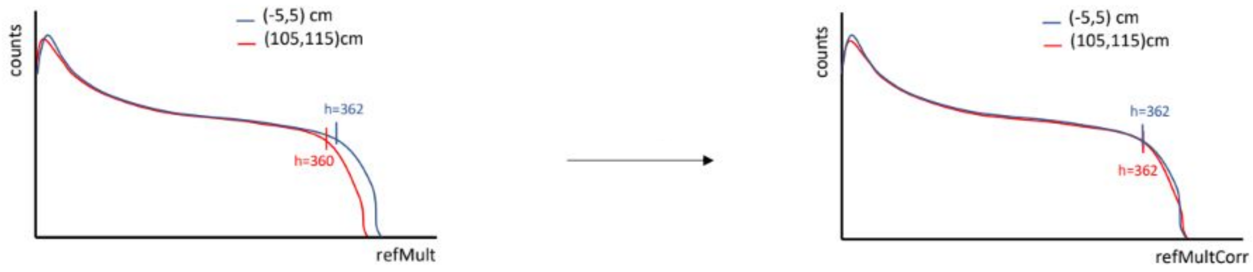
- $RunId_{ref}$: **8120-8170**
- Extract the high-end point of refMult distribution in each RunId via fitting the refMult tail by the function:

$$f(refMult) = A*Erf(-\sigma*(refMult-h)) + A$$

- refMult can then be corrected by:

$$RunId\_CorrFactor(RunId) = h_{ref} / h(RunId)$$
$$refMultCorr = refMult * RunId\_CorrFactor$$

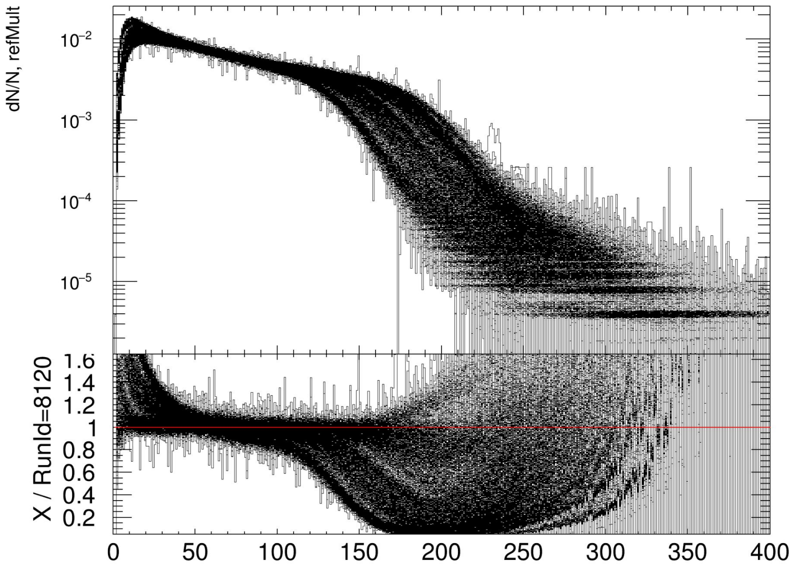
Example



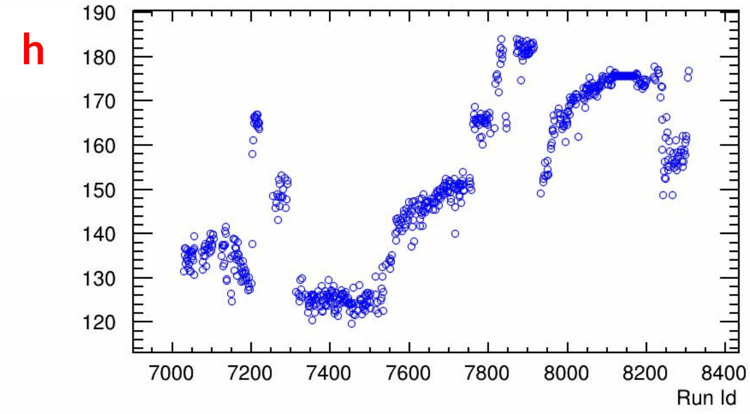
Mult vs RunId: Shift(1)

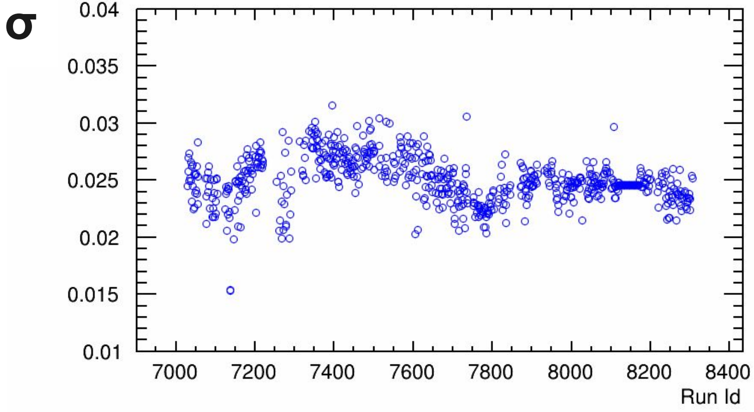
fit: A*Erf(-σ*(refMult-h)) + A

h, σ -> right picture



Reference RunId: 8120-8170

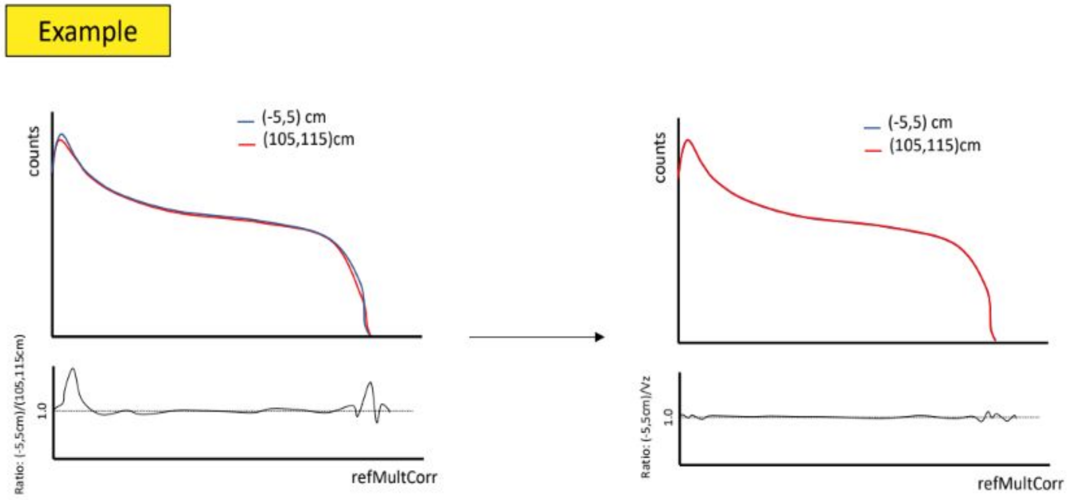




Multiplicity corrections: reweight

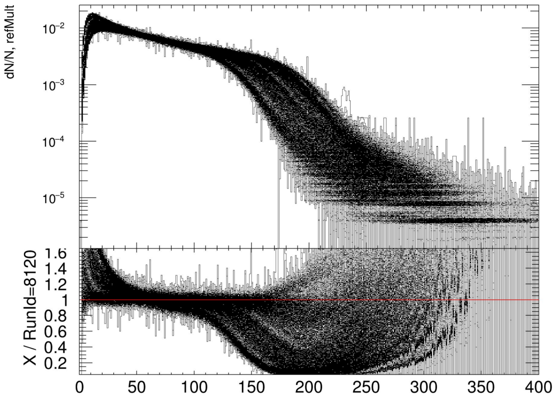
Procedure:

- RunId$_{ref}$: **8120-8170**
- refMult bin by refMult bin - weight each event by the ratio of normalized refMultCorr for RunId$_{ref}$ to refMultCorr for this RunId
- This gives the refMultCorr distributions at each RunId value the same shape

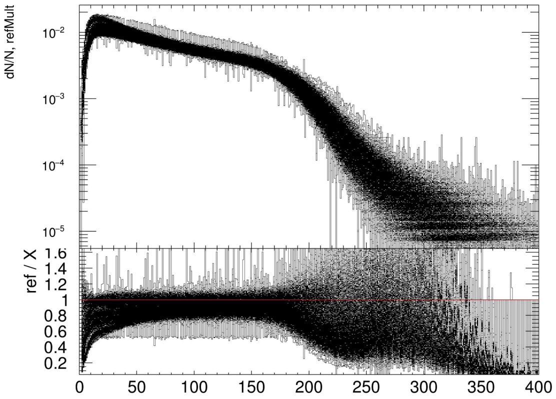


Mult vs RunId: Shift and re-weight

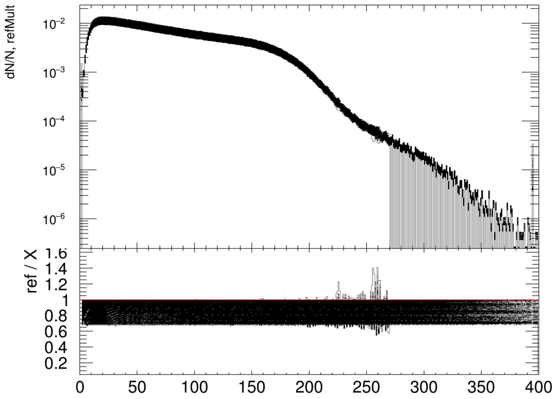
Raw



After shift



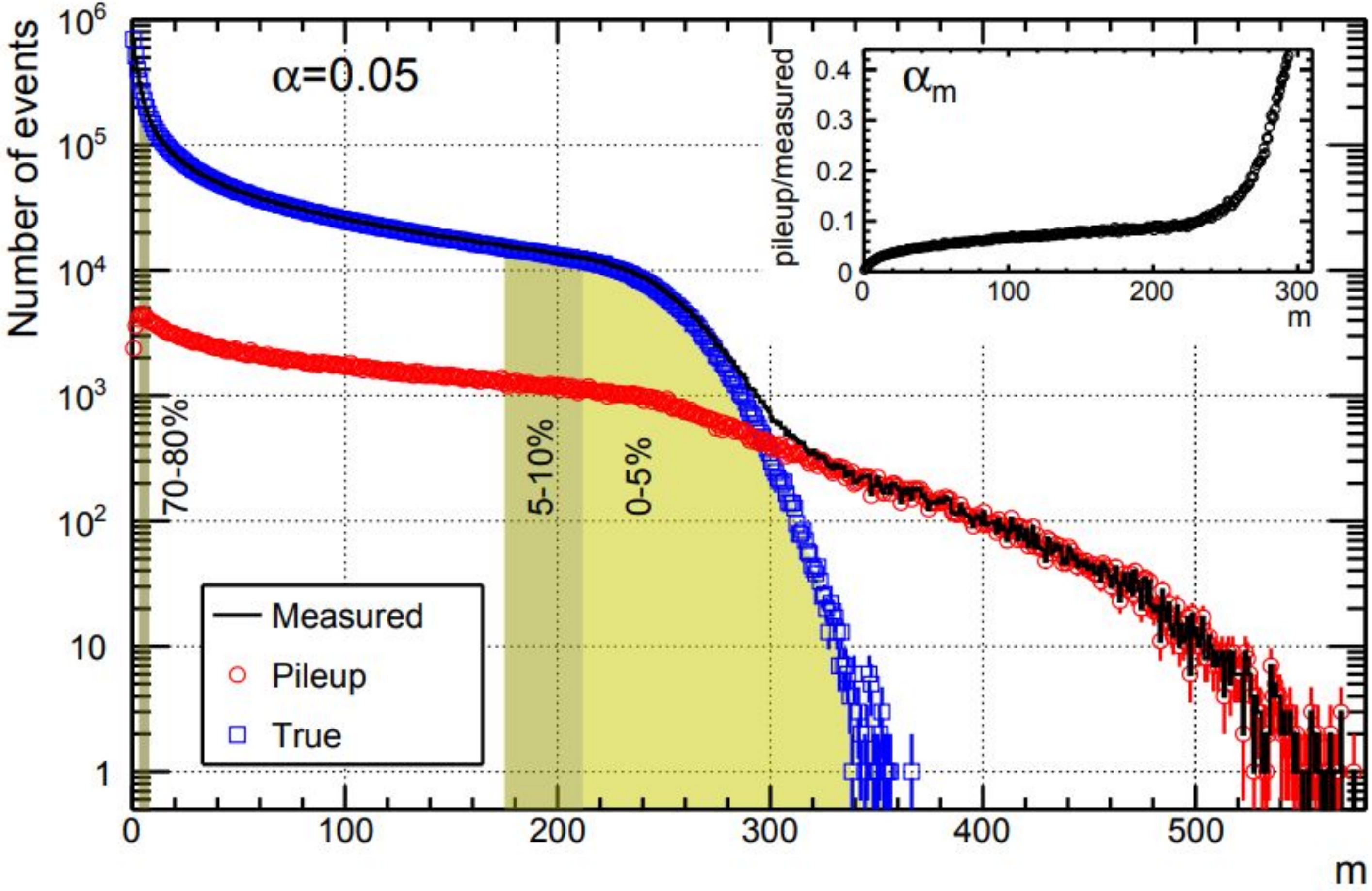
After re-weight



Multiplicity after corrections:

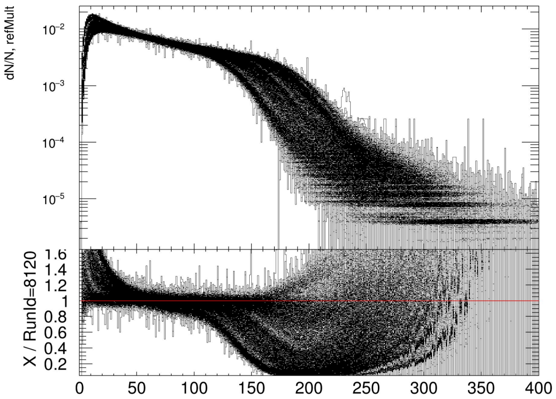
- will be added in bmnroot
- used to centrality determination

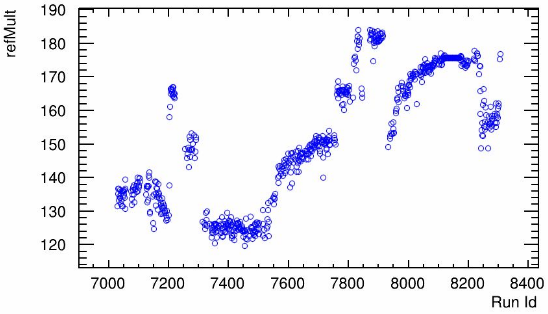
The multiplicity distribution generated from the Glauber



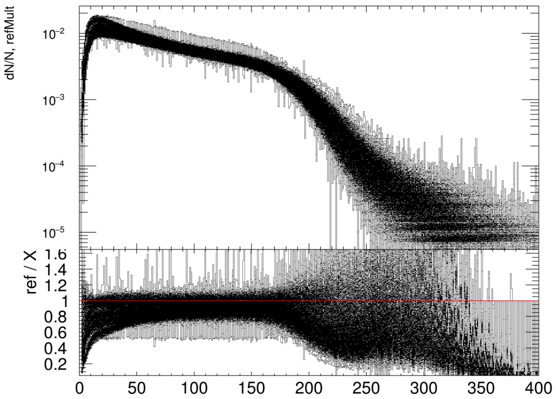
Mult vs RunId: Shift and re-weight (zero bins eval)

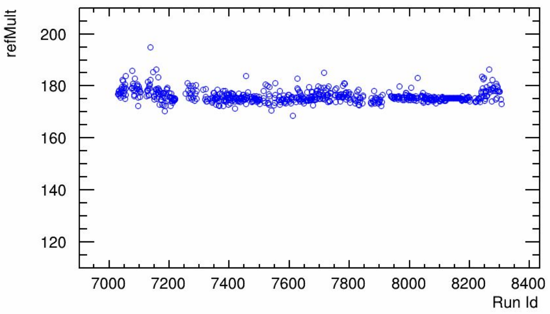
Def



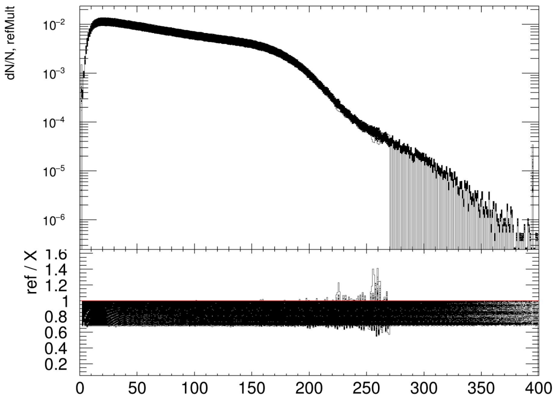


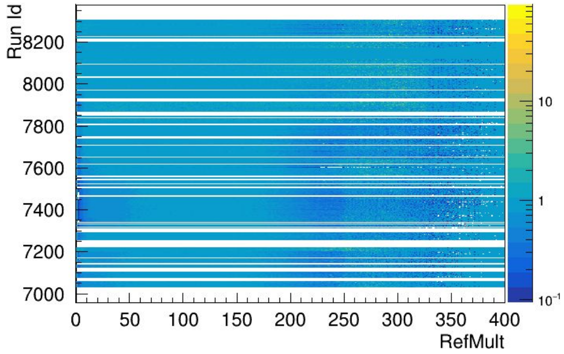
After shift





After re-weight

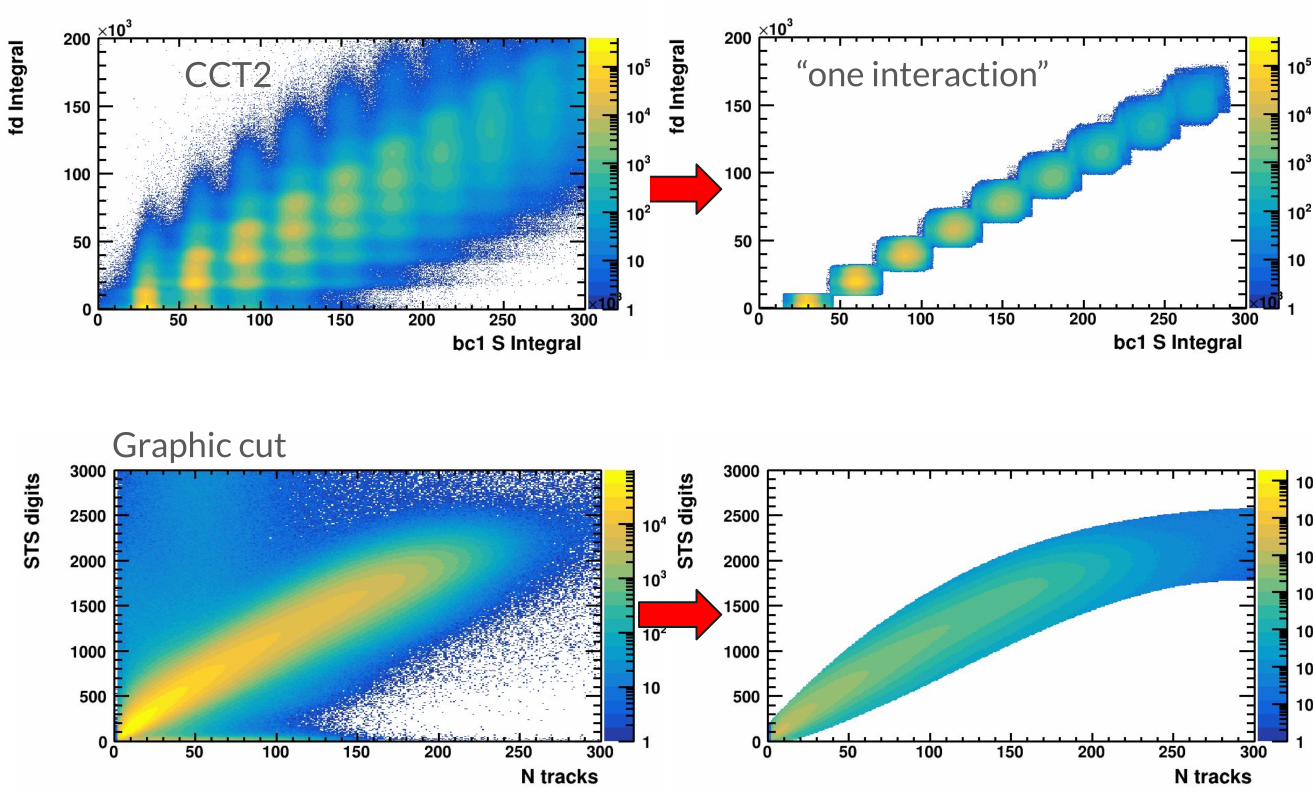




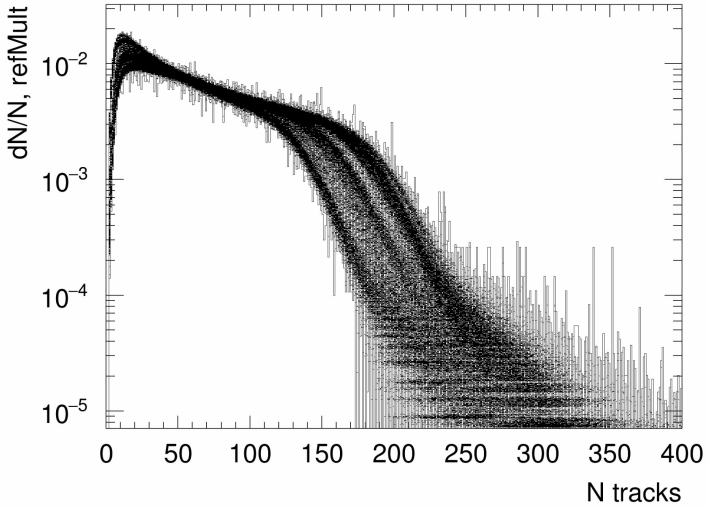
Pileup

Pileup:

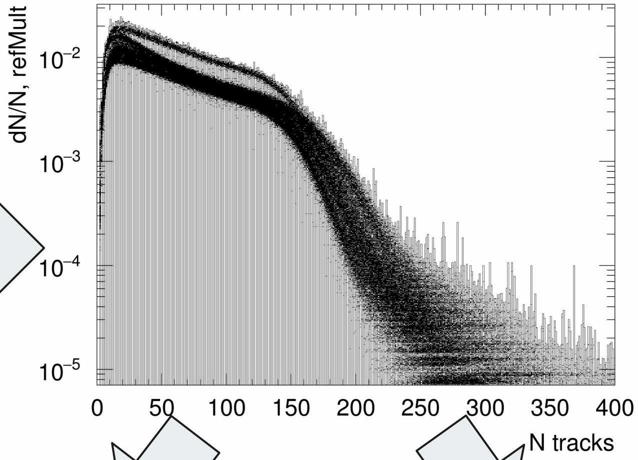
1. Select events with CCT2
2. Select events with “one interaction” (next slide):
   a. Fit of each run ID with Gaus (bc1s,fd)
   b. Scale
   c. Select events with “one interaction”
3. Graphic cut:
   a. Fill StsDigits vs nTracks
   b. Fit of each nTracks bin with Gaus
   c. fun(nTracks,StsDigit)

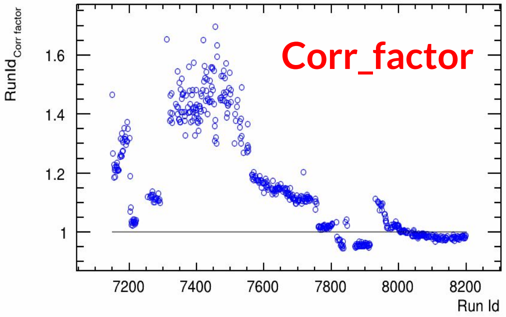


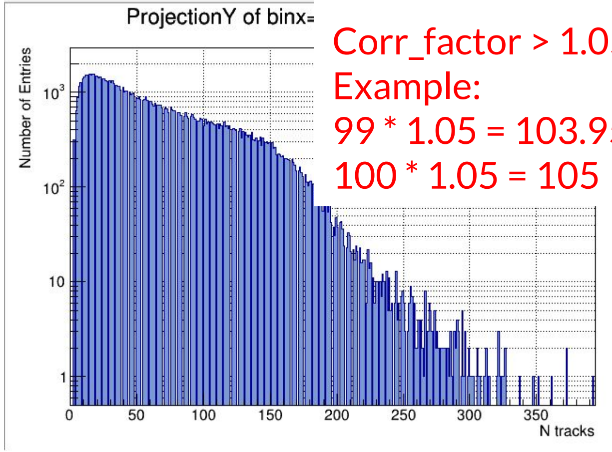
Vtx > 1



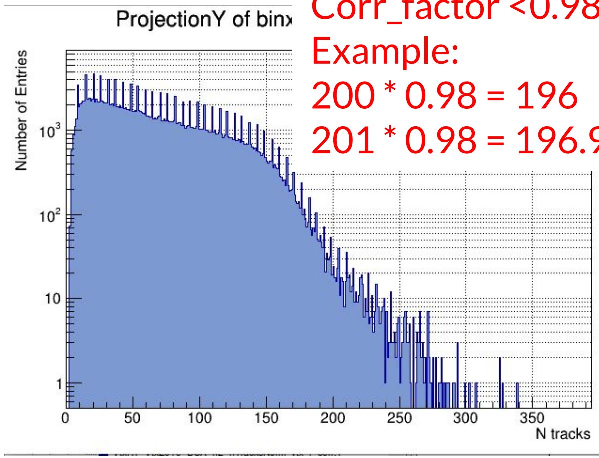
After
“Step 1”







Corr_factor > 1.05
Example:
99 * 1.05 = 103.95
100 * 1.05 = 105

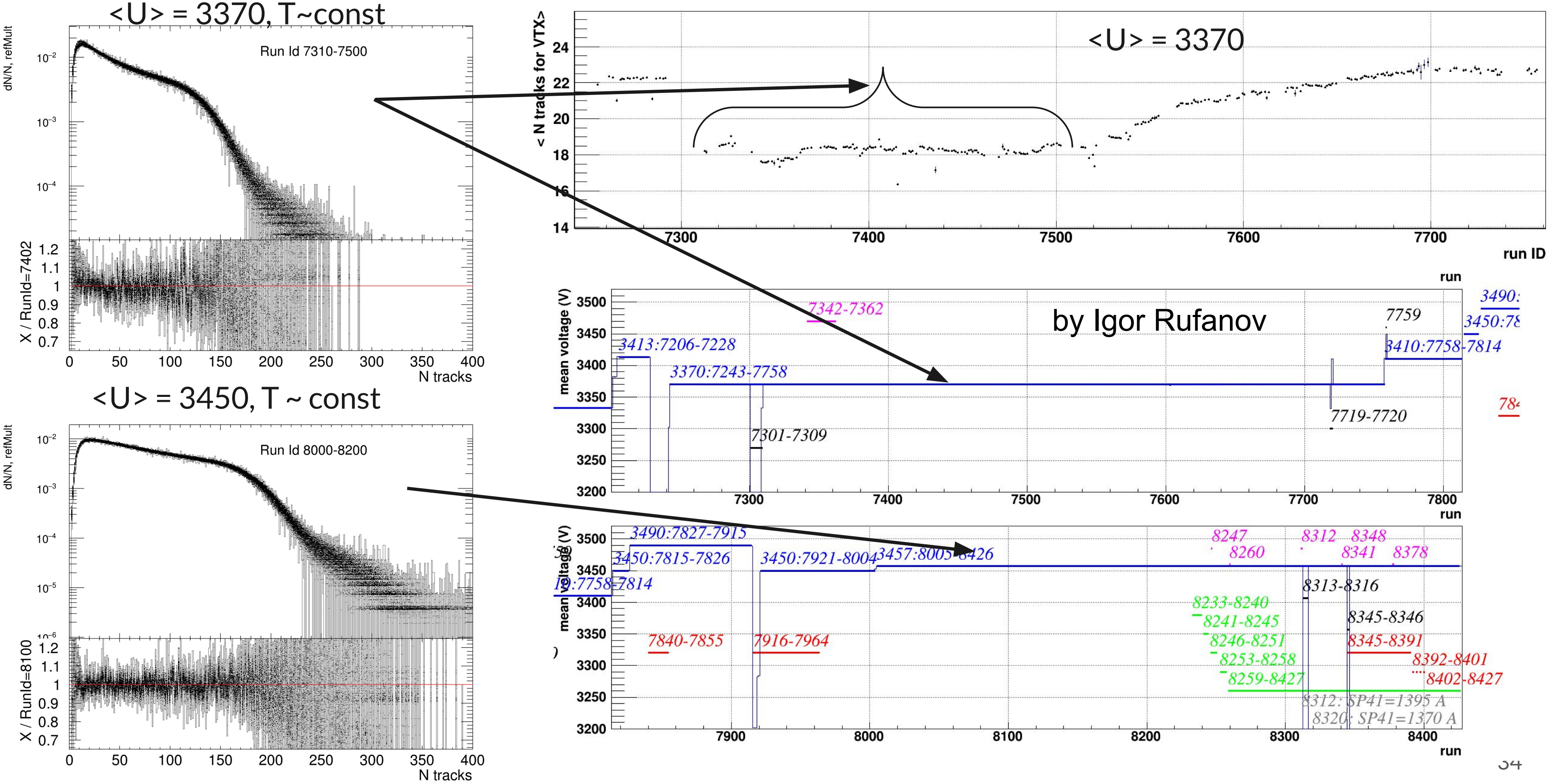


Corr_factor <0.98
Example:
200 * 0.98 = 196
201 * 0.98 = 196.98

For STAR:

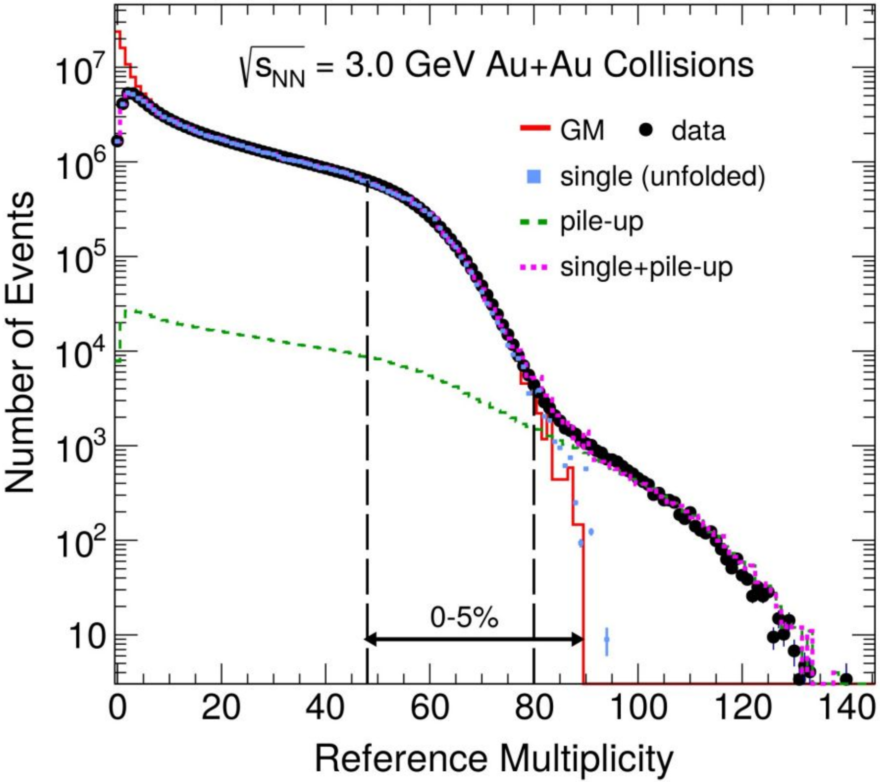
- r_corr < 1.0014…
- r_corr > 0.990…

Multiplicity & RunID: Effect of voltage



Implementation of “pileup” in the centrality determination procedure

https://arxiv.org/abs/2112.00240

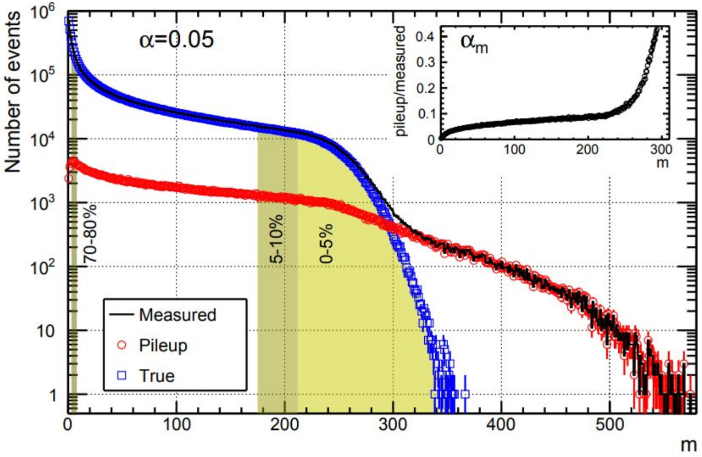


α - the probability to find a pileup event among all collision events.

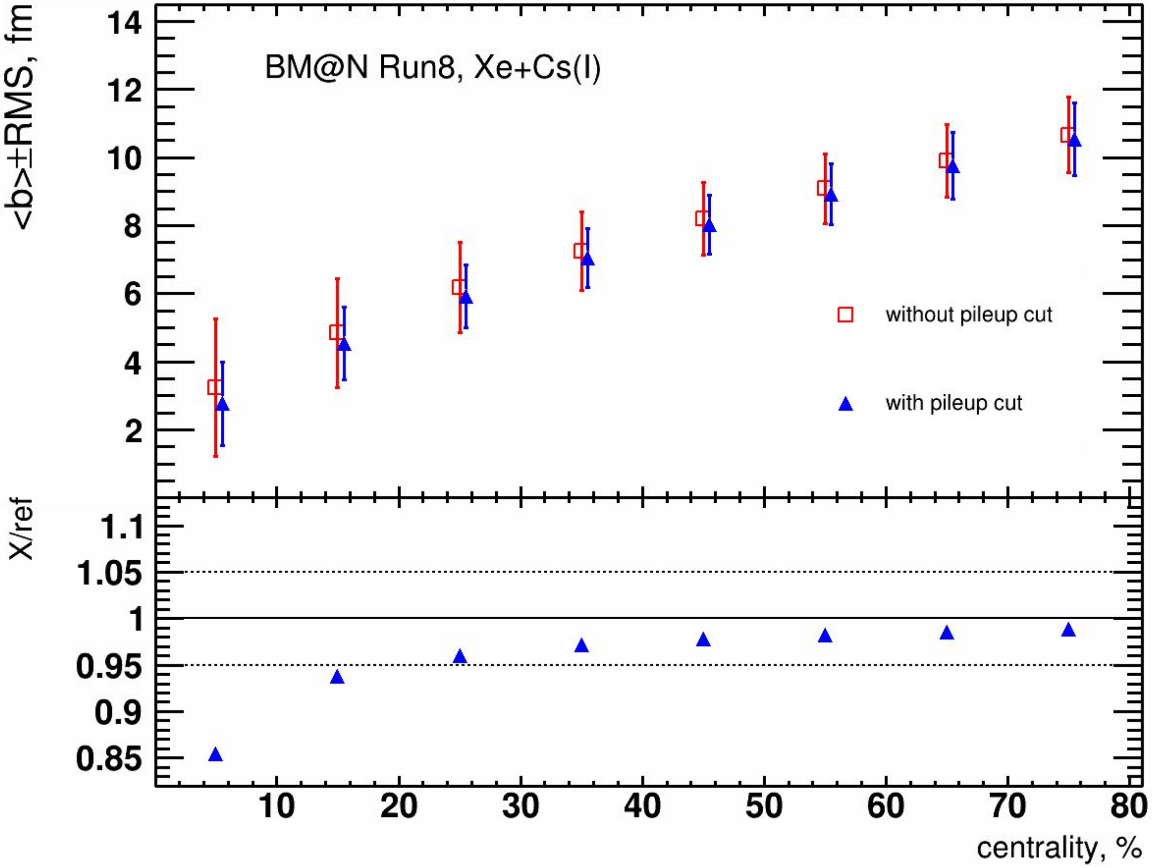
Pileup events occur with the probability $\boldsymbol{\alpha_m}$ at the **m** multiplicity bin, then multiplicity (**m**):

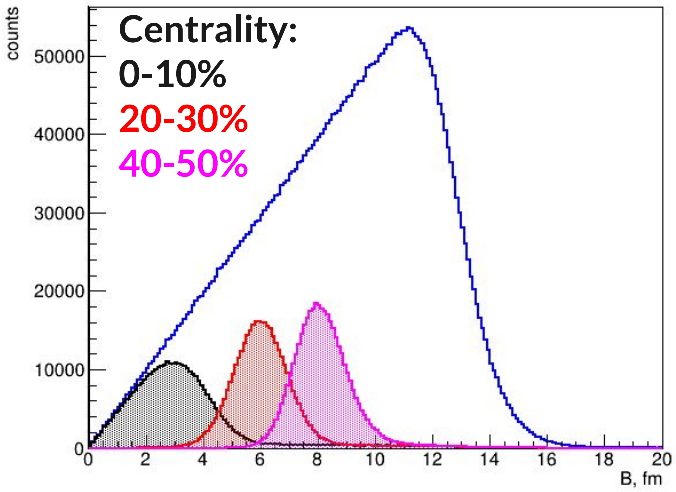
$$P_m(N) = (1 - \alpha_m)P^t_m(N) + \alpha_m P^{pu}_m(N)$$

$P^t_m(N)$ and $P^{pu}_m(N)$ - are the probability distribution functions of N for the true (single-collision) and pileup events.

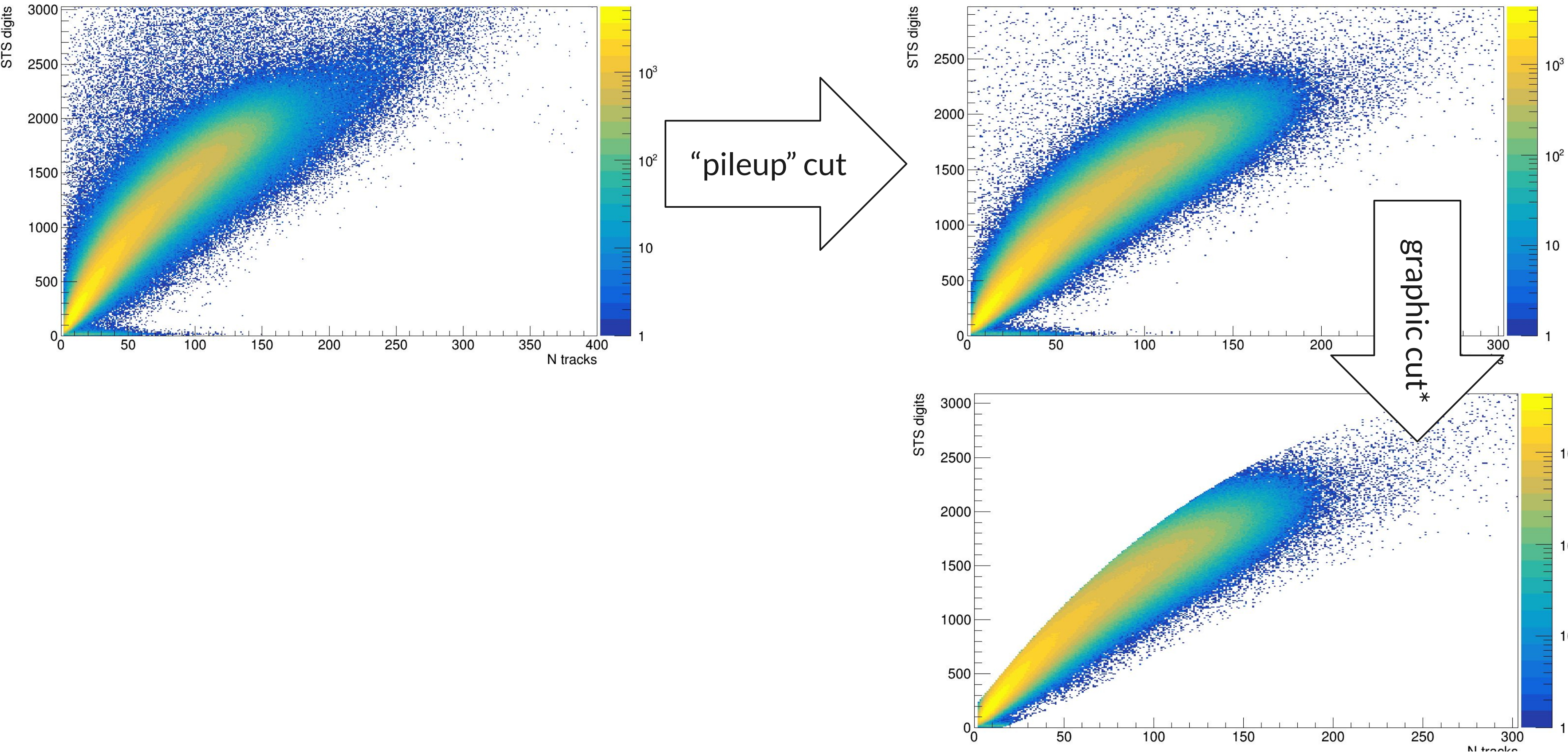


Centrality determination after refMult correction: <b> vs cent





Remove pileup: sts digits vs nTracks (Run7400-7450)



Model dependence of b, N_{part}

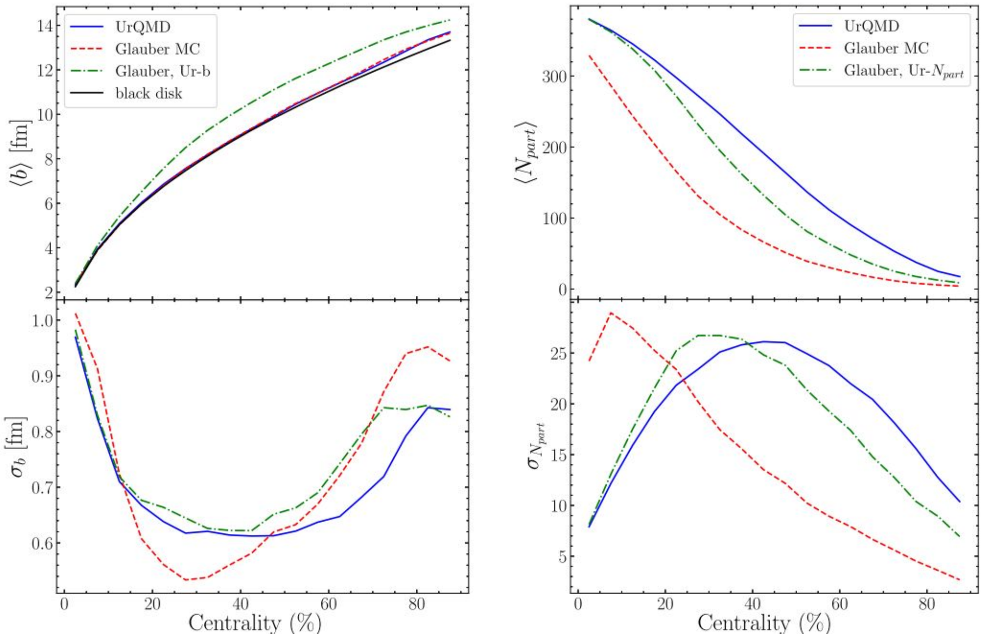
The MC Glauber non-realistic $\mathbf{N_{part}}$ simulations at low energies

Differences in of number of participant nucleons ($\mathbf{N_{part}}$) distributions from UrQMD and MC

The impact parameter (**b**) - model independent centrality estimator

Use MC Glauber for centrality determination

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



Centrality determination after refMult correction: <b> vs cent (check)