Centrality determination in the BM@N experiment

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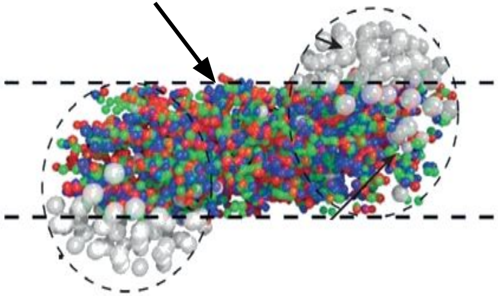
Motivation for centrality determination

- 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)

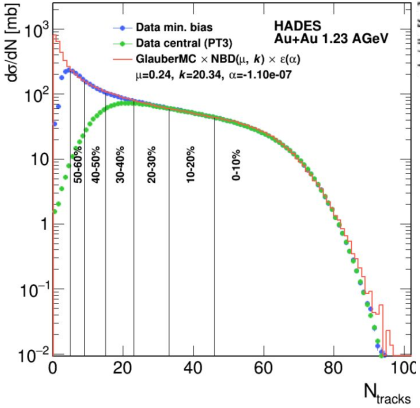
- Centrality class S_1-S_2: group of events corresponding to a given fraction (in %) of the total cross section:

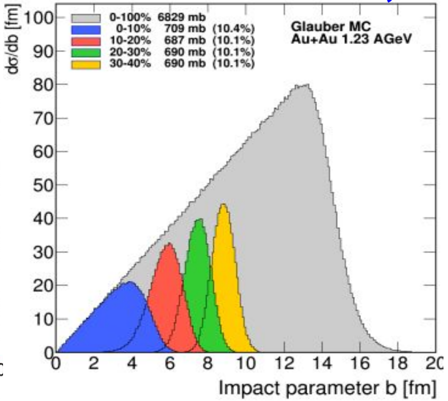
$$C_S = \frac{1}{\sigma_{inel}^{AA}} \int_{S_1}^{S_2} \frac{d\sigma}{dS} dS$$

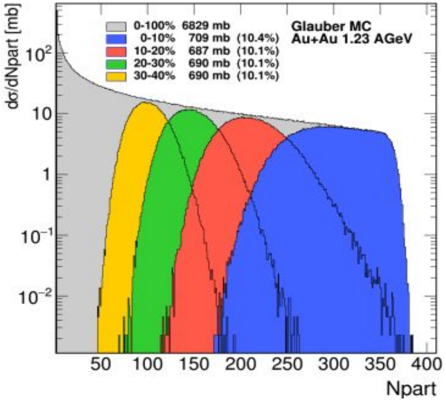


Centrality determination

HADES, Au+Au 1.23A GeV







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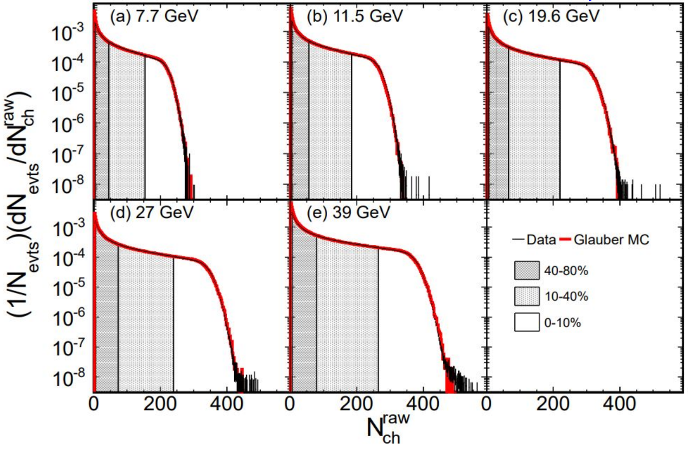
Centrality Classes	$b_{\min}$	$b_{\max}$	$\langle b \rangle$
0 – 5 %	0.00	3.30	2.20
5 – 10 %	3.30	4.70	4.04
10 – 15 %	4.70	5.70	5.22
15 – 20 %	5.70	6.60	6.16
20 – 25 %	6.60	7.40	7.01
25 – 30 %	7.40	8.10	7.75
30 – 35 %	8.10	8.70	8.40
35 – 40 %	8.70	9.30	9.00
40 – 45 %	9.30	9.90	9.60
45 – 50 %	9.90	10.40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

STAR, Au+Au, BES



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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 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

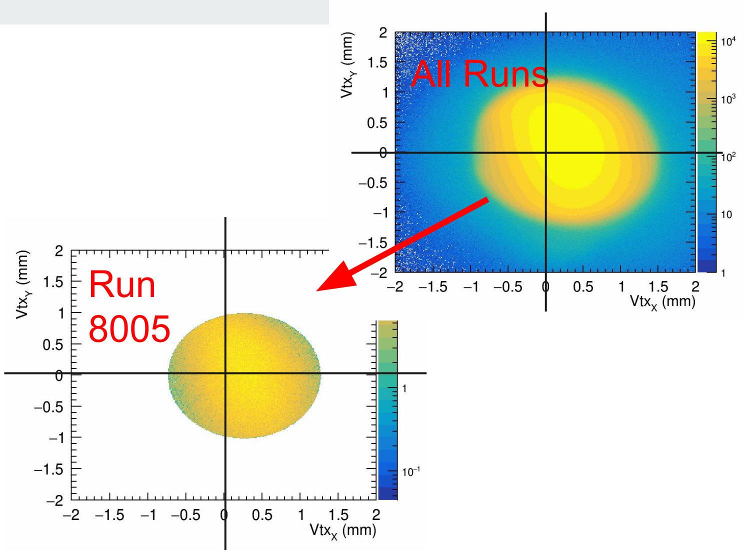
Evaluate χ^2 between $N/dN_{MC/data}$ and N/dN_{Gl}

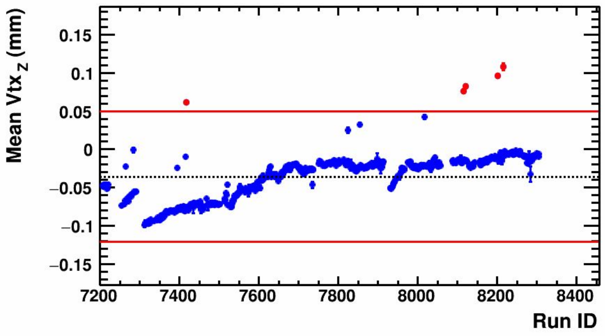
Scan phase space of parameters to find their values for minimum of χ^2

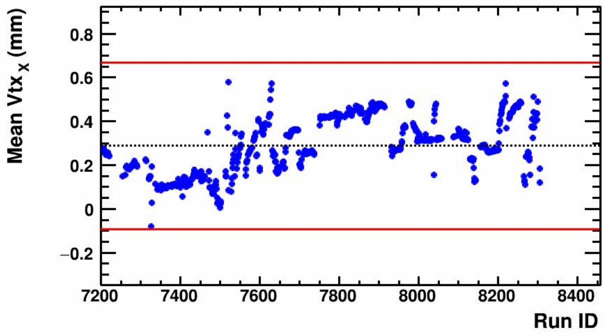
Extract relation between geometry parameters and centrality estimator

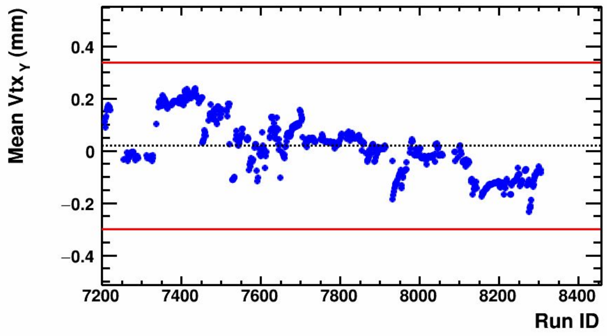
Event selection

- Xe+Cs 3.8 GeV
- Production= last
- Triggers: CCT2
- Remove BadRuns
- Corrected on <VtxX>, <VtxX>, <VtxZ> for each RunId
- Event selection:
  - Physical runs
  - More than 1 track in vertex reconstruction
  - VtxR < 1.0 cm ($sqrt(VtxY_{corr}^2 + VtxX_{corr}^2) < 1$ cm)
  - VtxZ < 0.2 cm (<0.2 cm, <0.5 cm, <1.0 cm)
  - Apply graphics cuts to remove pileup

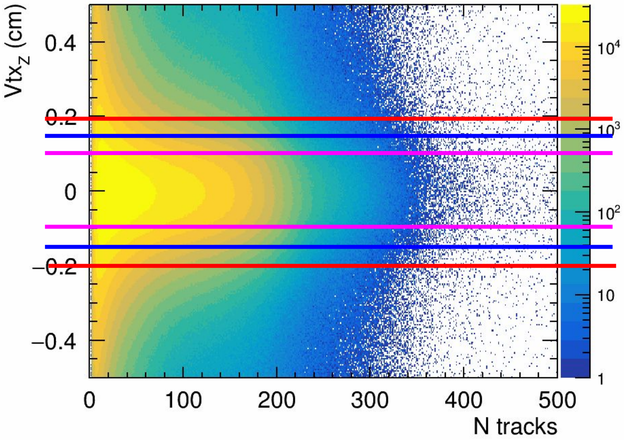




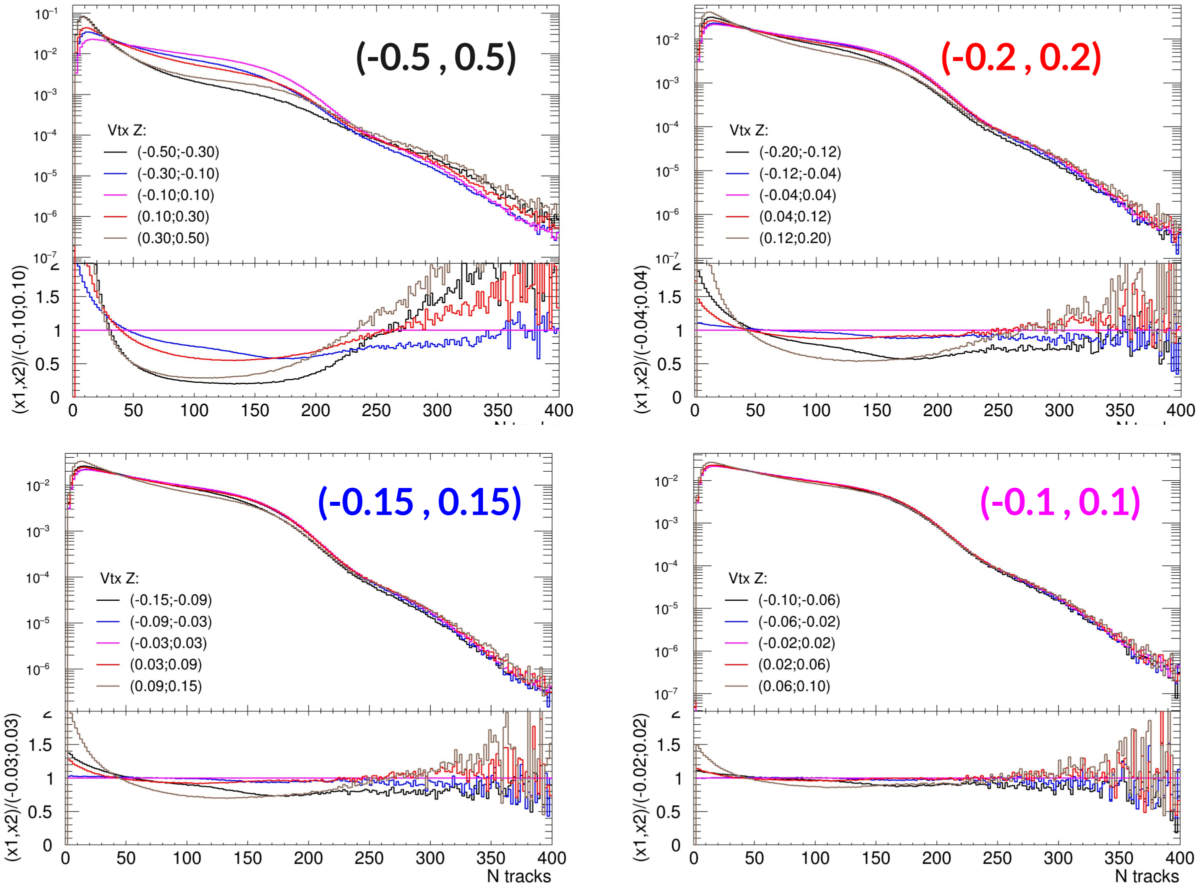




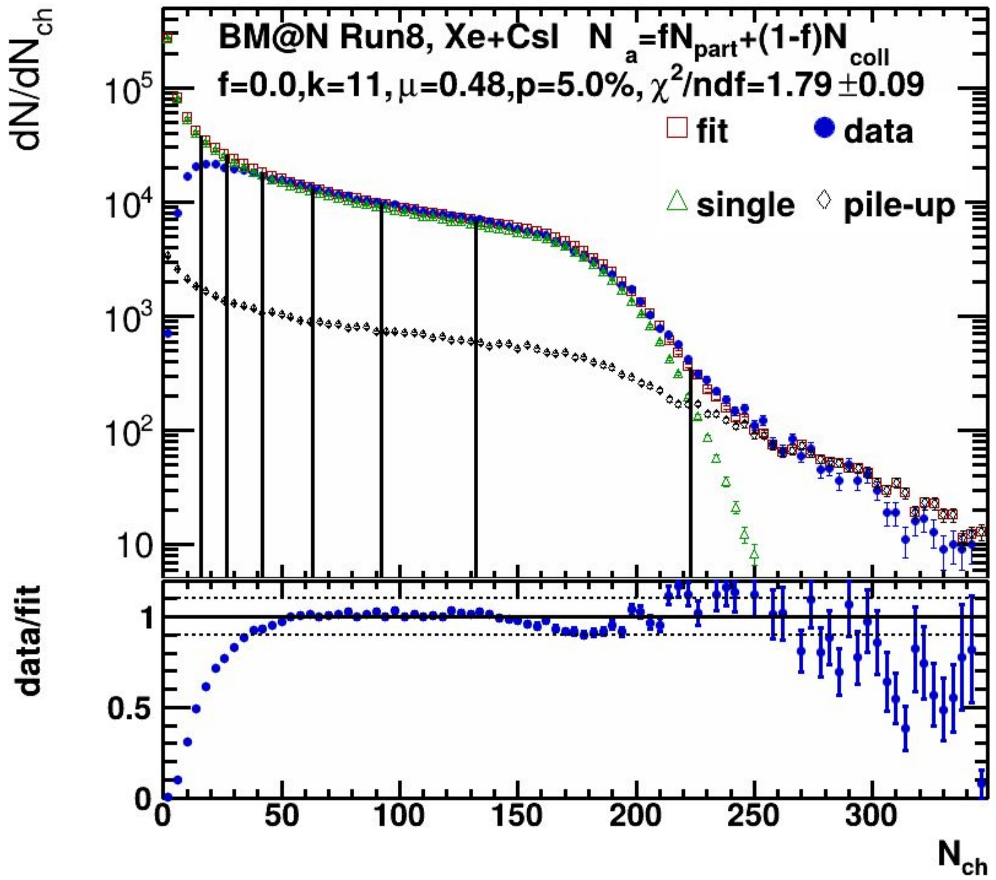
Vertex Z



Use VtxZ <0.2



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 mm
- V_z < 0.2 mm

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

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

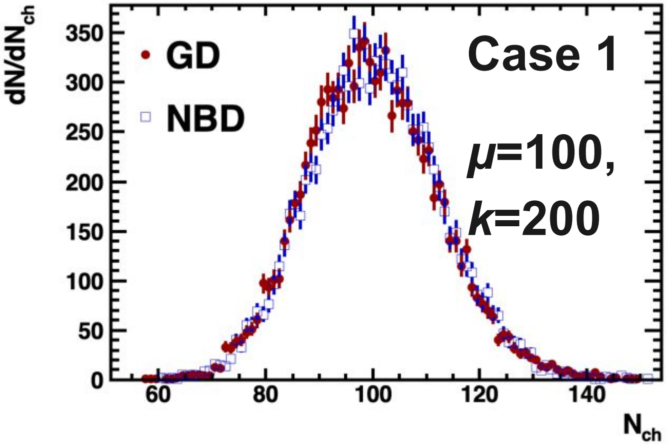
However at lower energies we likely have situation where $\mu<1$, $k<1$. NBD cannot be applicable in that case. We have to use generalized function - gamma distribution (GD):

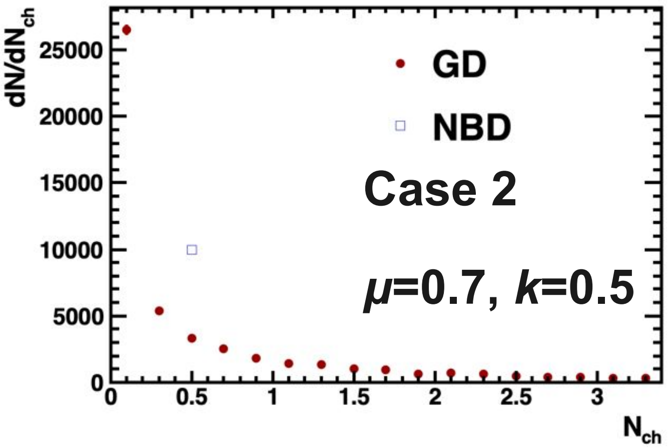
$$P(x;\mu,k) = \frac{e^{-\frac{x}{\beta}} x^{\alpha-1}}{\beta^\alpha \Gamma(\alpha)}, \alpha = \frac{\mu k}{\mu+k}, \beta = \frac{\mu}{k}+1$$

Mean: μ

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.

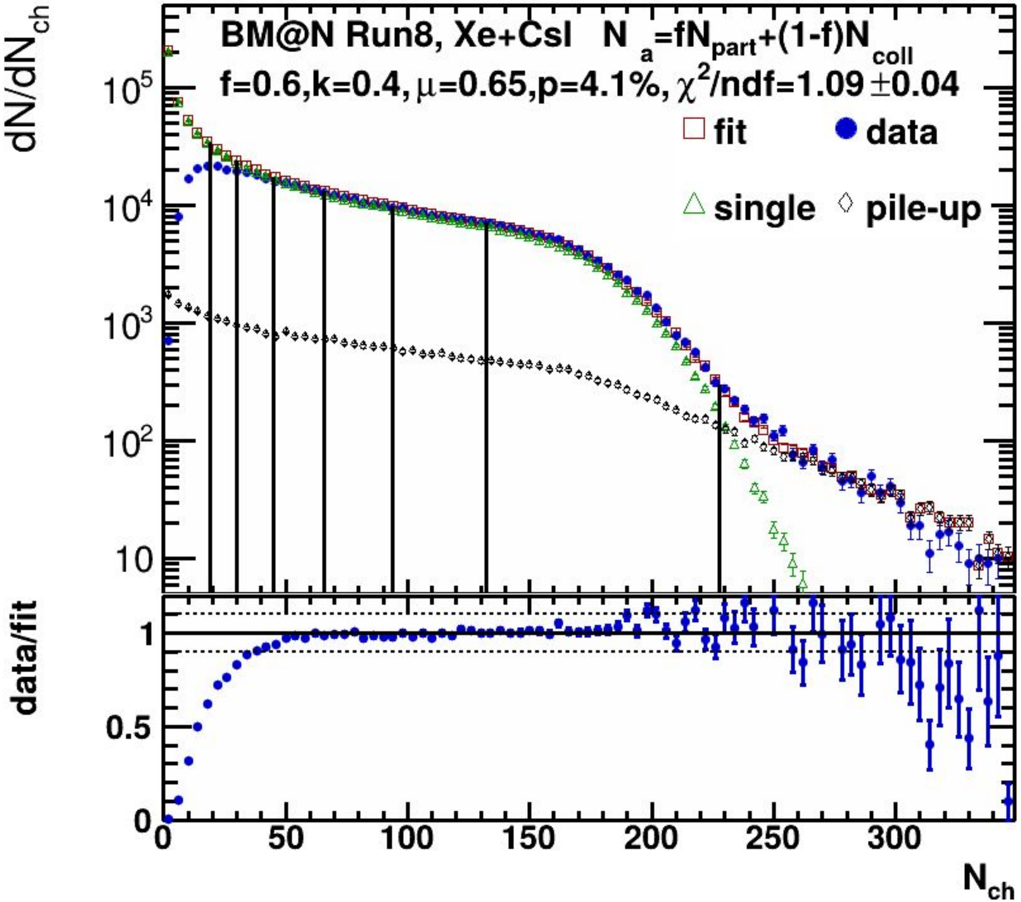
Case 2: $k<1$, $\mu < \sigma^2 = \mu/k \cdot (\mu+k)$. The mean multiplicity might be smaller than its variation.

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 μ and σ^2 might vary greatly

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

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

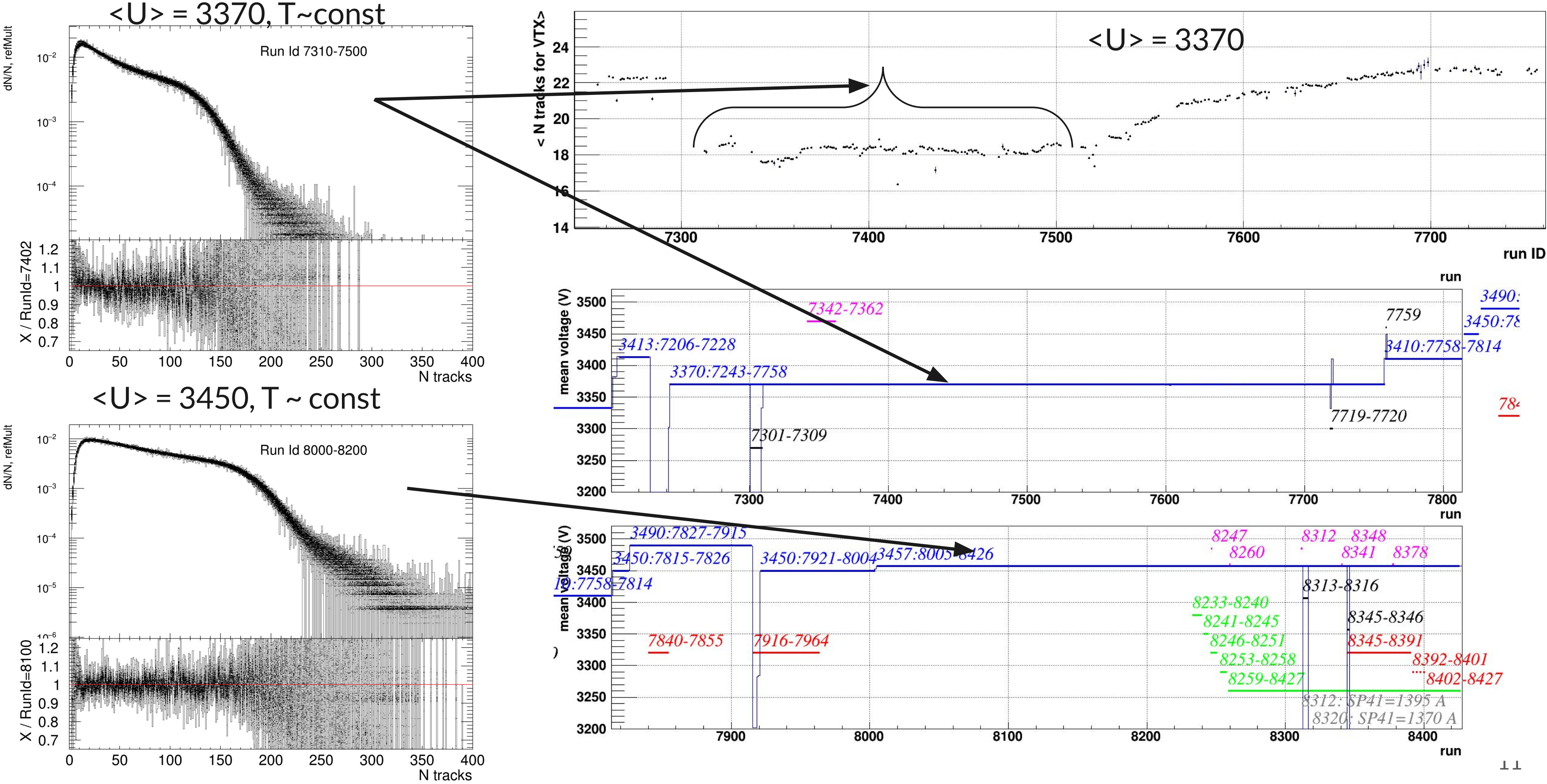


RunId: **8120-8170**

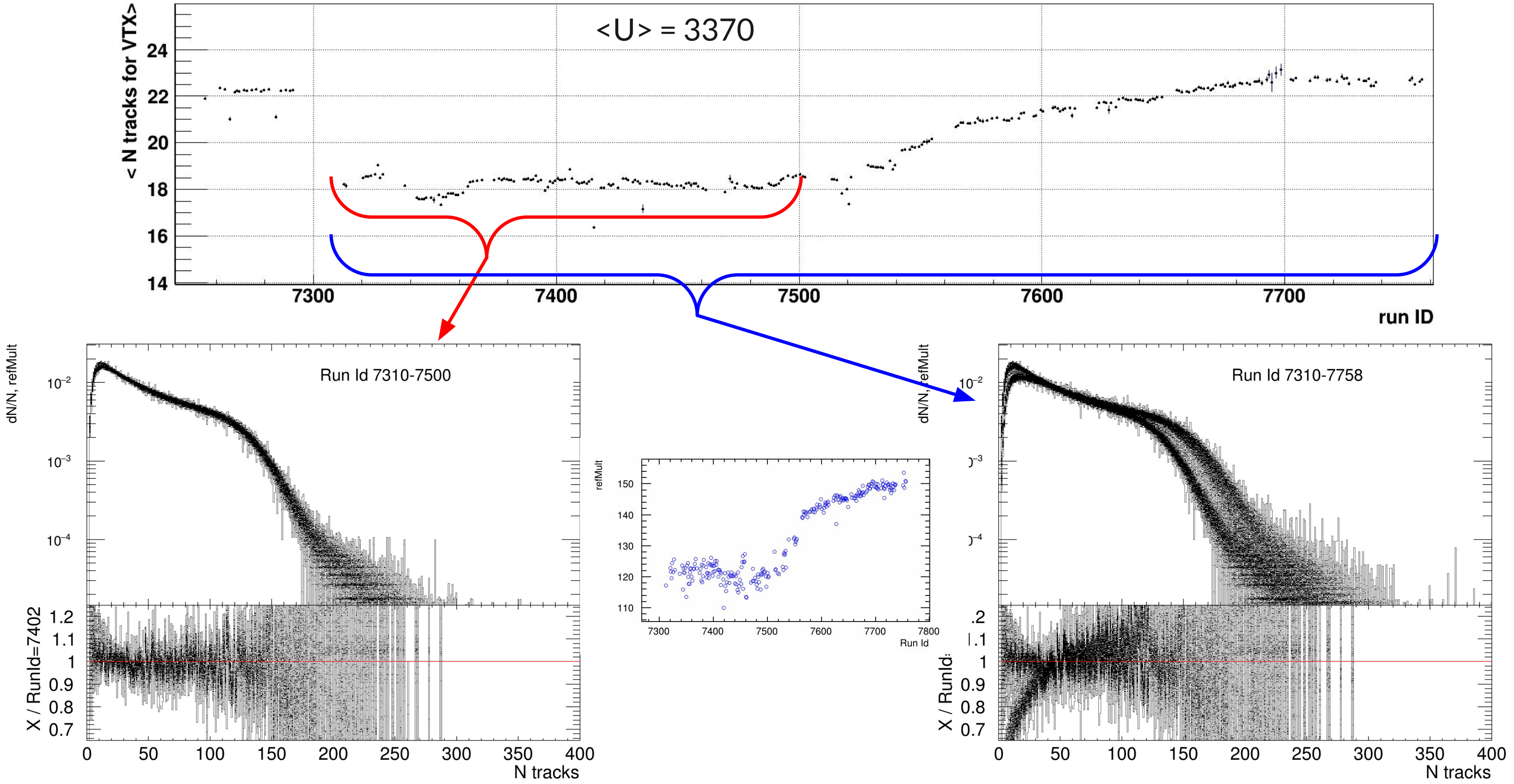
Multiplicity Cuts:

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

Multiplicity & RunID: Effect of voltage



Multiplicity & RunID: Effect of temperature



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:

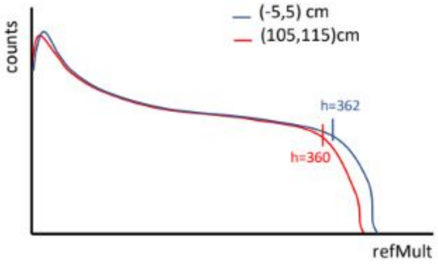
f(refMult) = A*Erf(-σ*(refMult-h)) + A

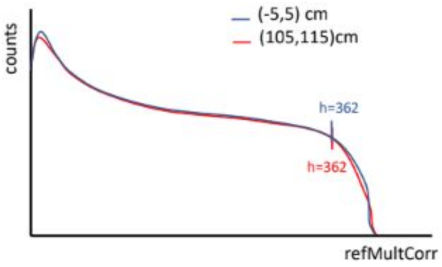
- refMult can then be corrected by:

RunId_CorrFactor(RunId) = h_{ref} / h(RunId)

refMultCorr = refMult * RunId_CorrFactor

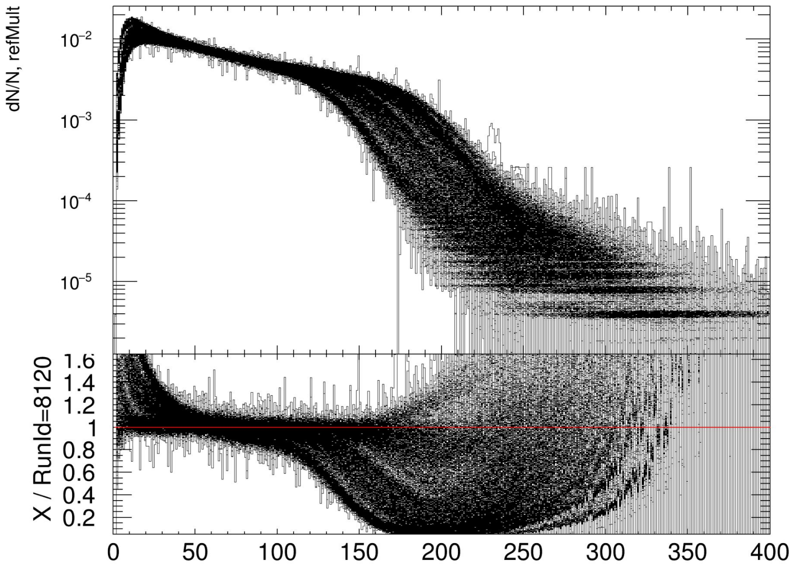
Example



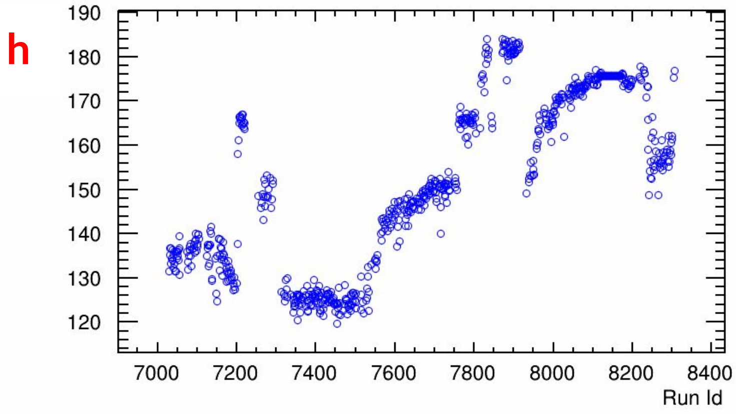


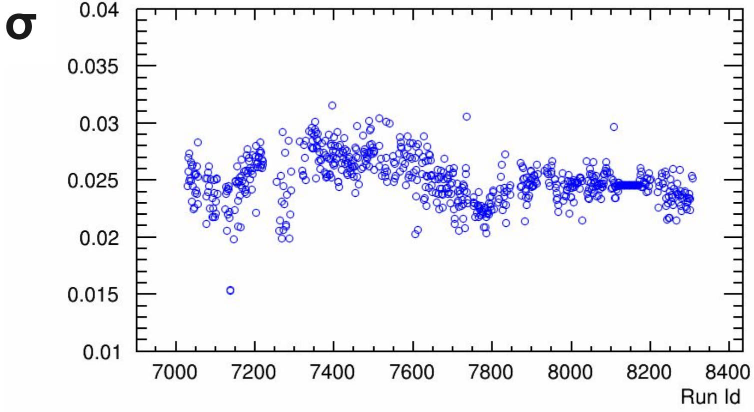
Mult vs RunId: Shift(1)

fit: A*Erf(-σ*(refMult-h)) + A
h, σ -> right picture



Reference RunId: 8120-8170

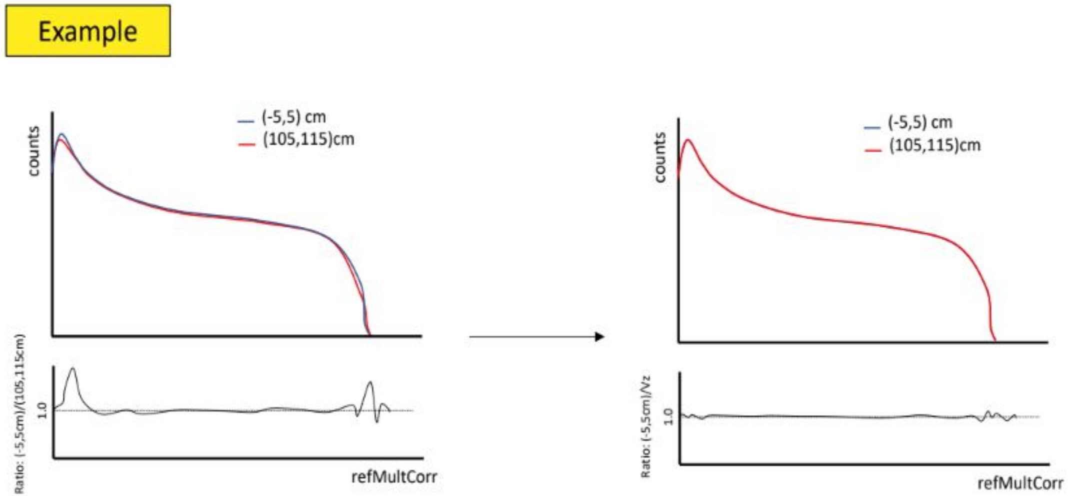




Multiplicity corrections: reweight

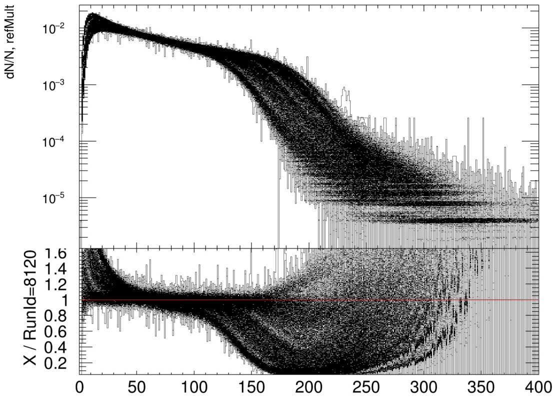
Procedure:

- $RunId_{ref}$: **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

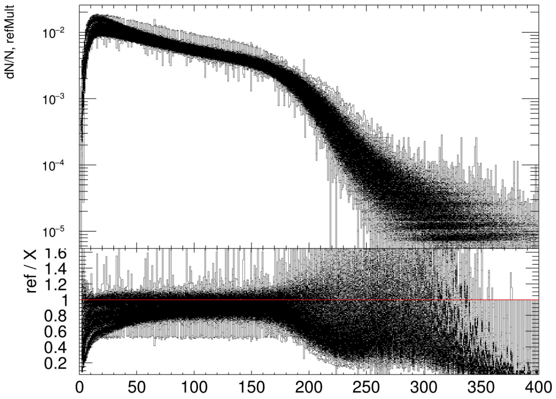


Mult vs RunId: Shift and re-weight

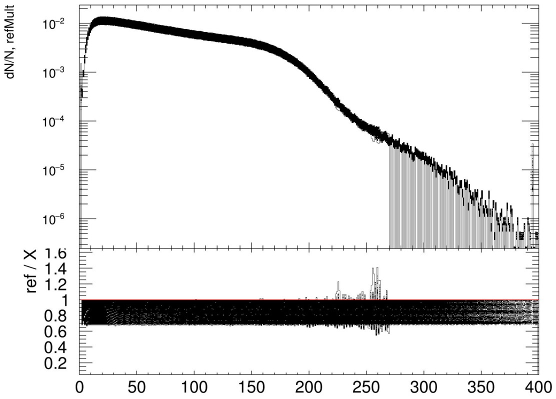
Raw



After shift



After re-weight



Multiplicity after corrections:

- will be added in bmnroot
- used to centrality determination

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
- Adding centrality and refMult in bmnroot

Model dependence of b, N_{part}

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

- elastic scatterings

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

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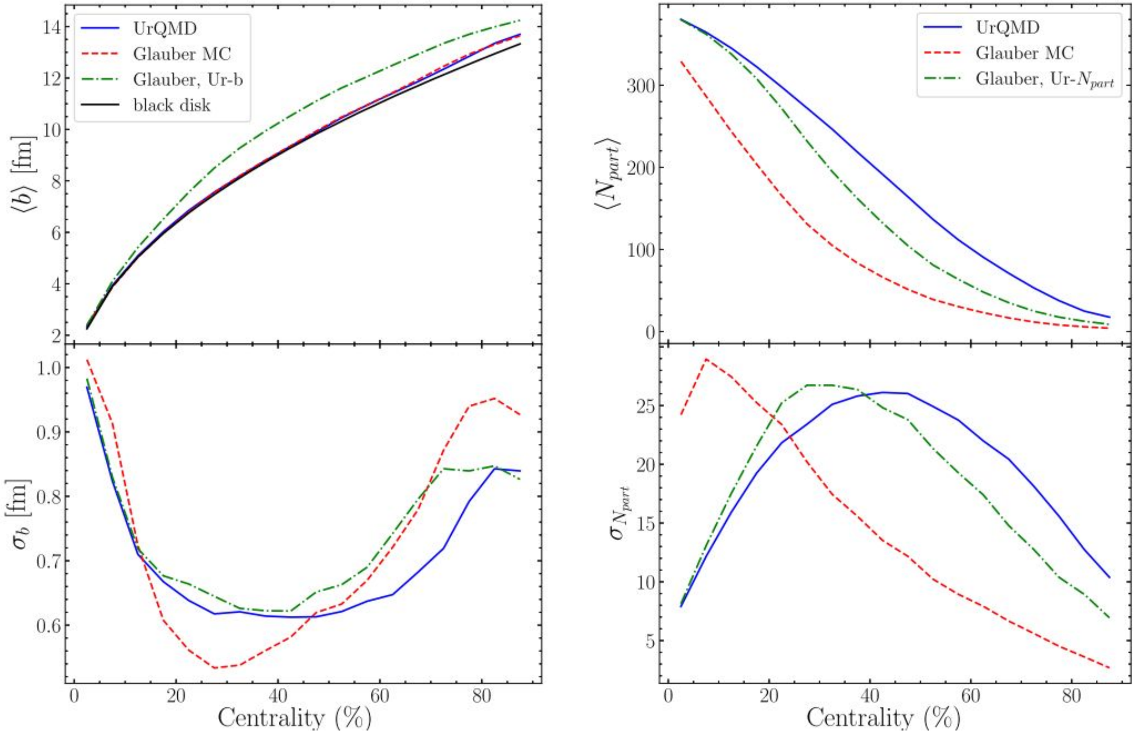
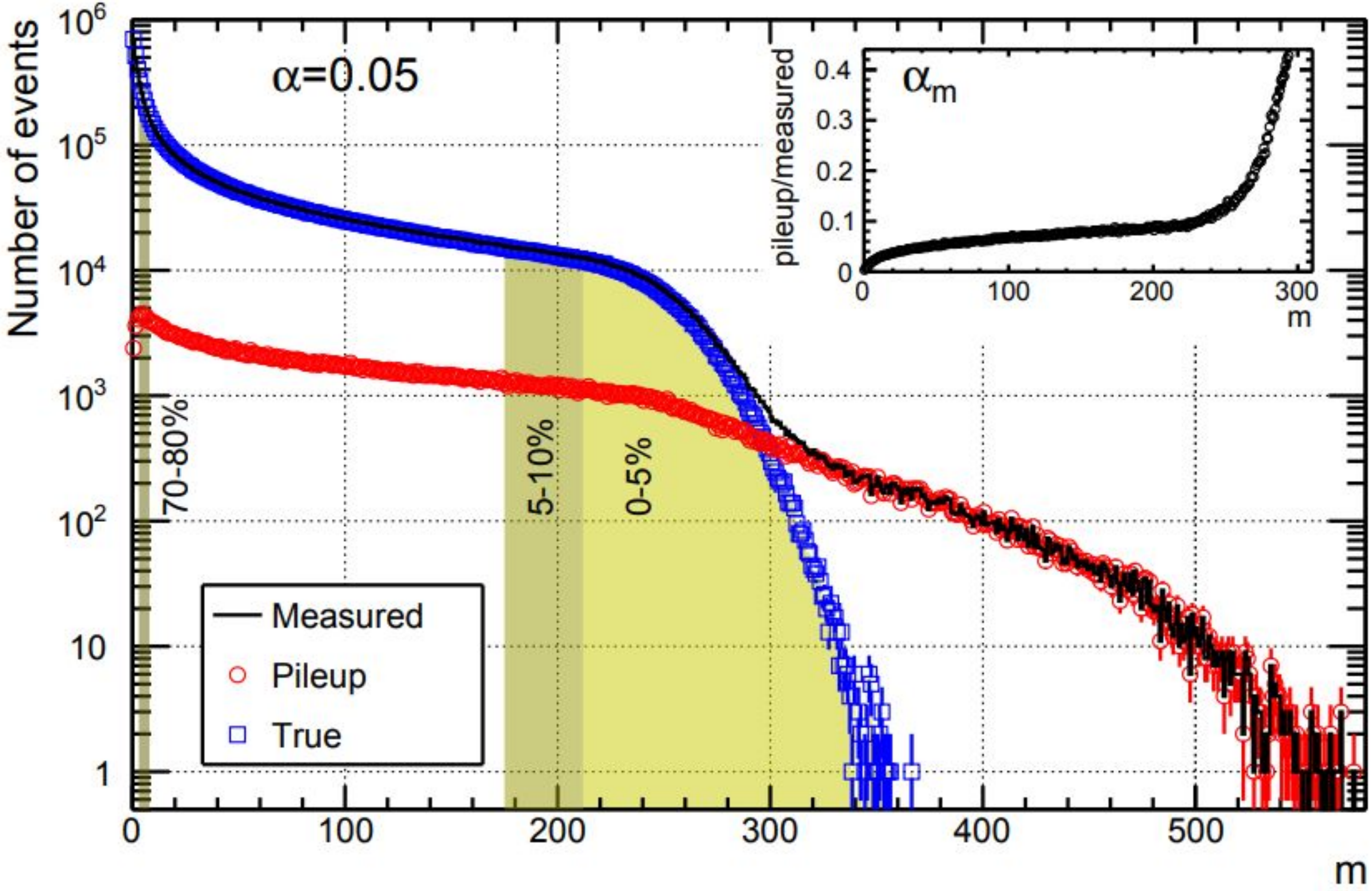
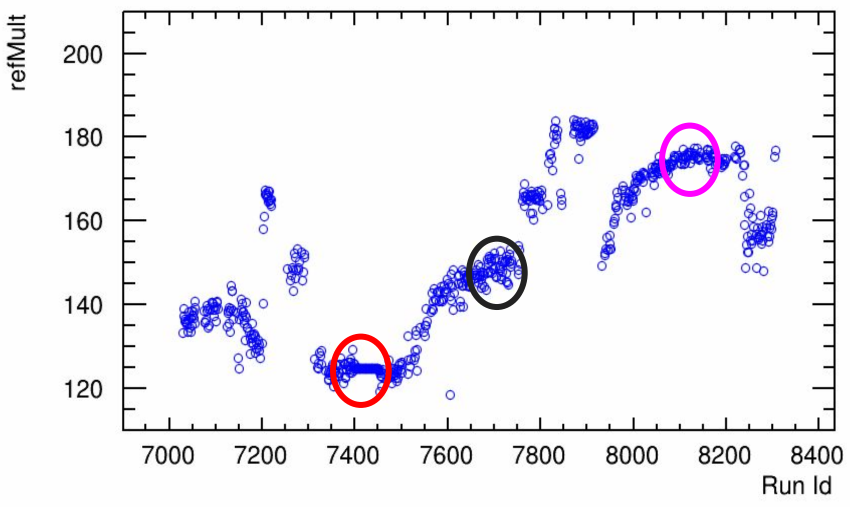
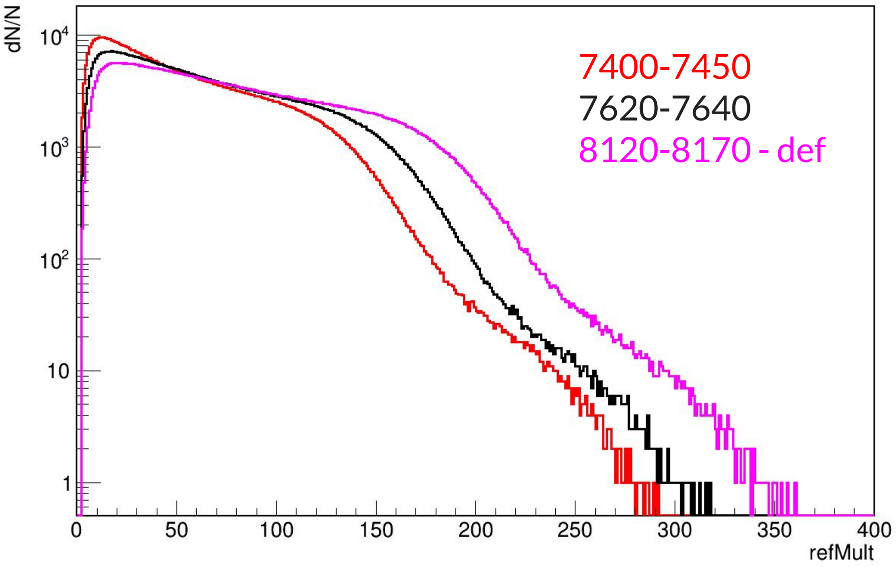


The multiplicity distribution generated from the Glauber

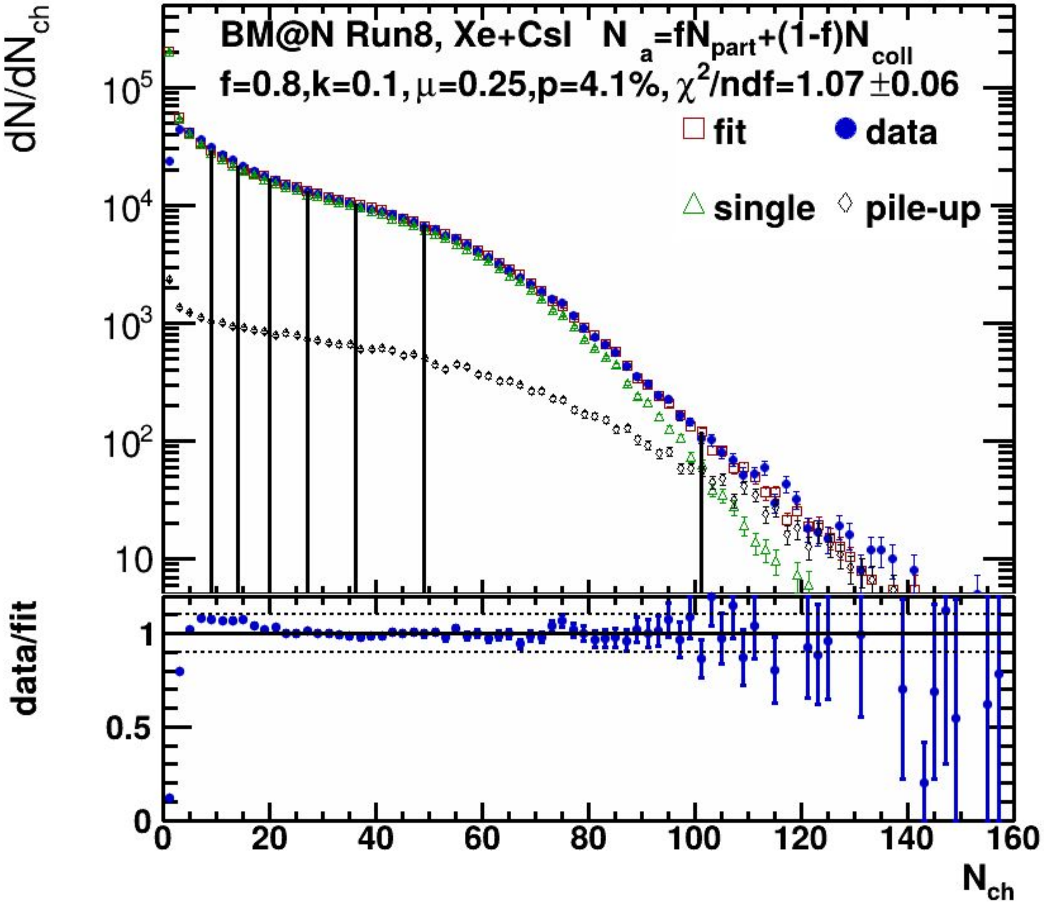


Mult vs RunId: different reference ranges





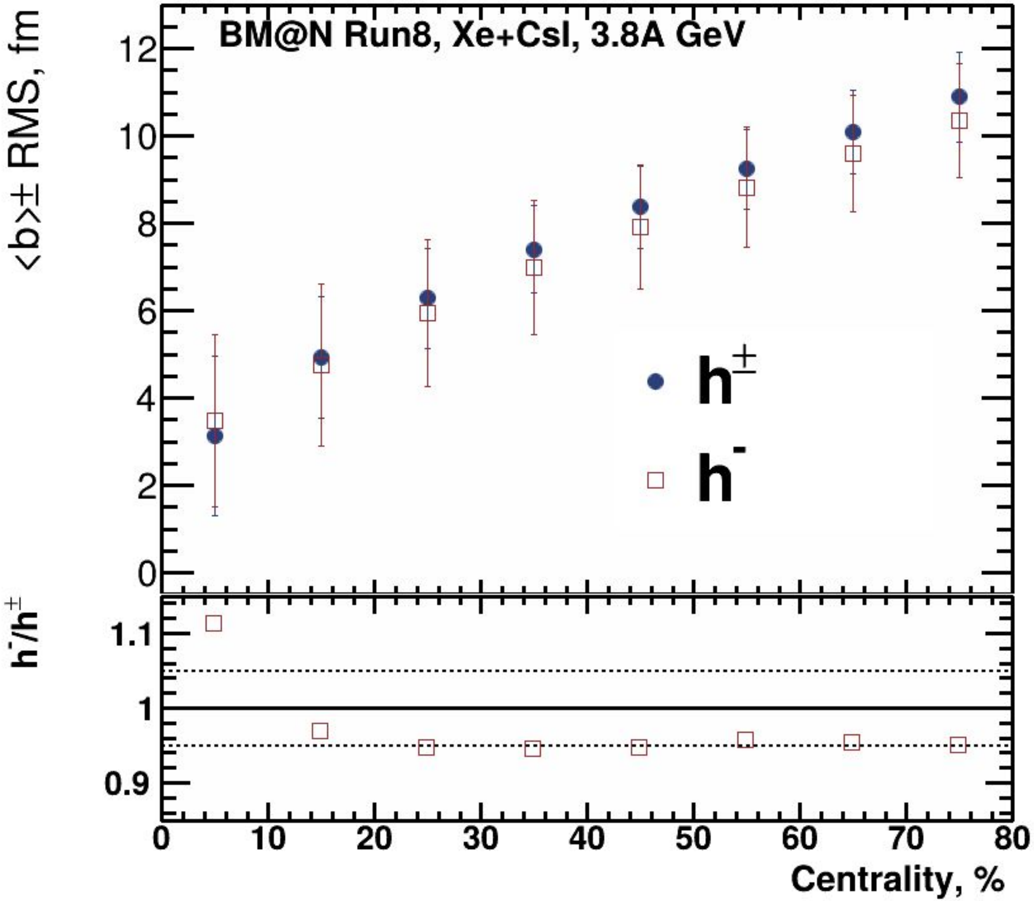
Multiplicity fit & centrality classes: h^-



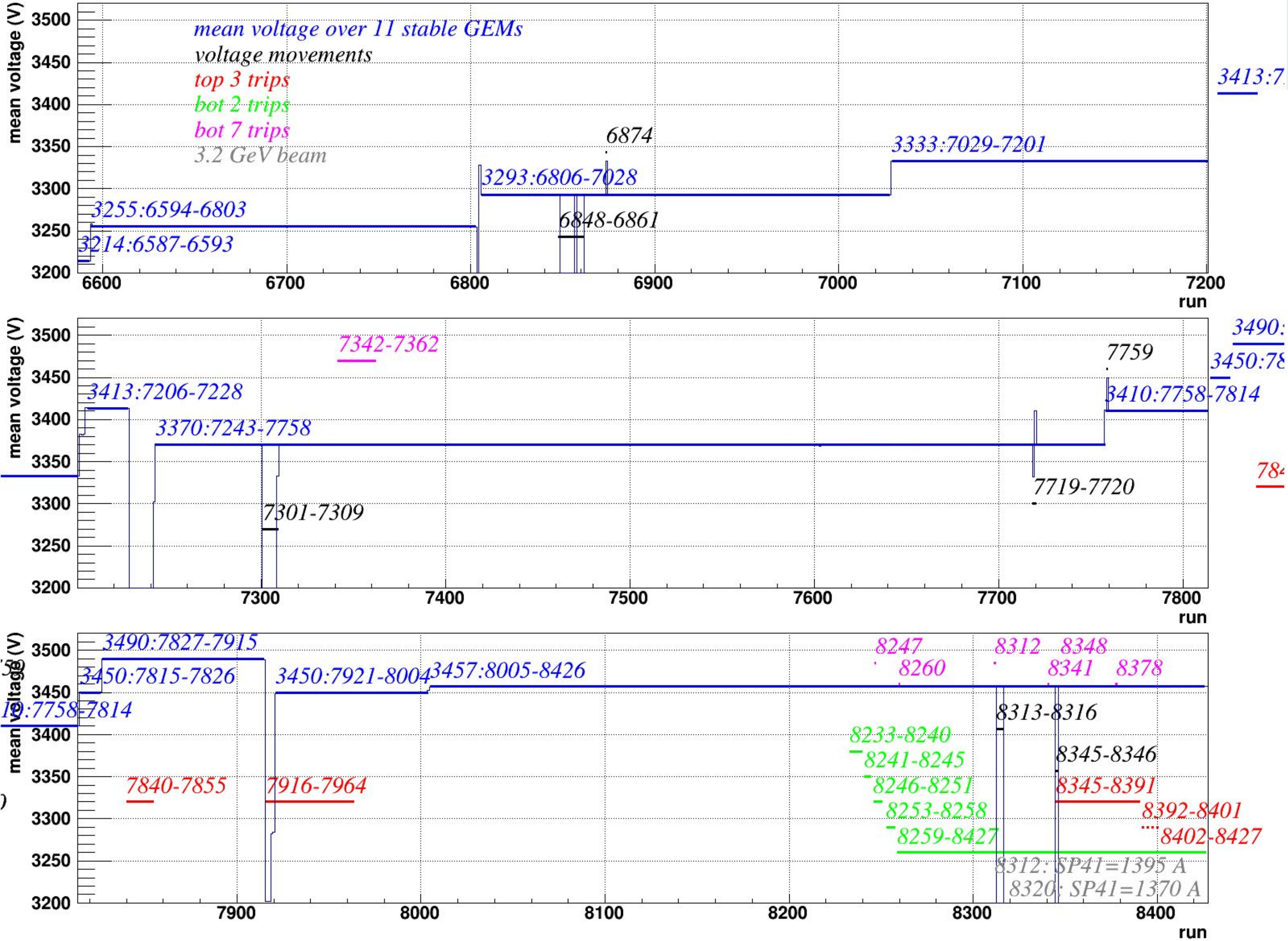
Multiplicity Cuts:

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

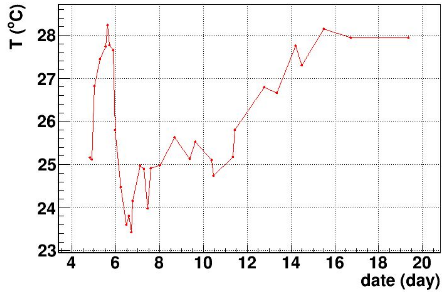
<b> vs Centrality: comparison

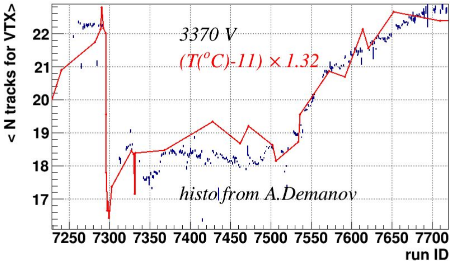


- Difference in the most central class is due to pile-up:
  - Cut on maximum multiplicity differs a little in cases of $h^{\pm}$ and h^{-}
- The difference in the mid-central region is within 5%
  - The possible effect from spectators in the case of $h^{\pm}$ multiplicity seems to be small



<U> = 3370

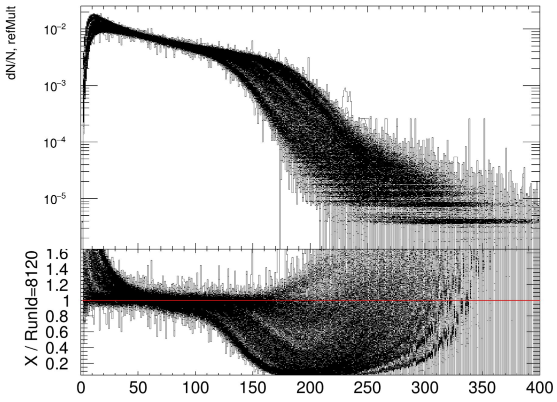


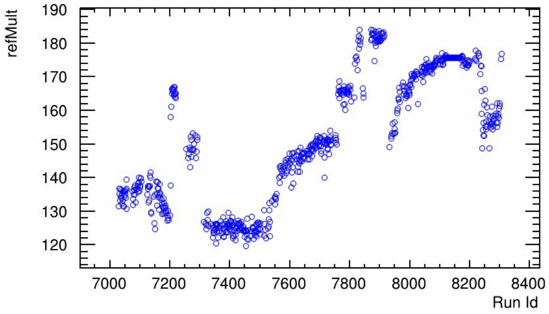


10 groups

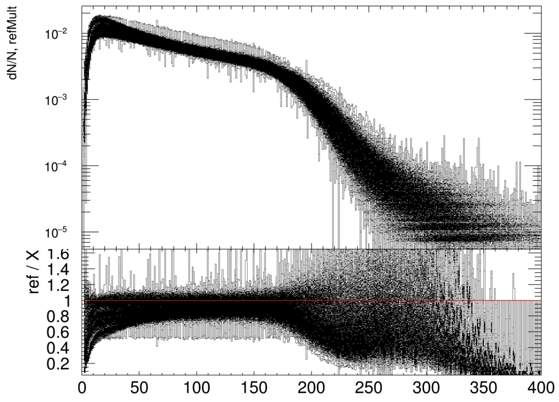
Mult vs RunId: Shift and re-weight (zero bins eval)

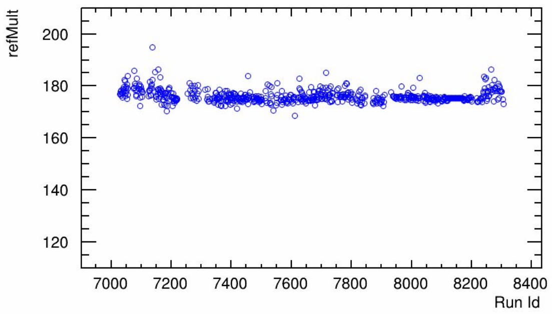
Def



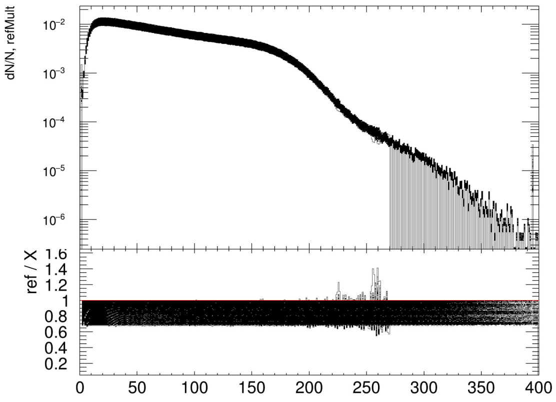


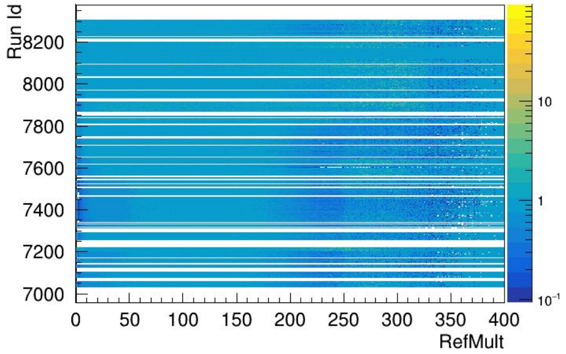
After shift





After re-weight

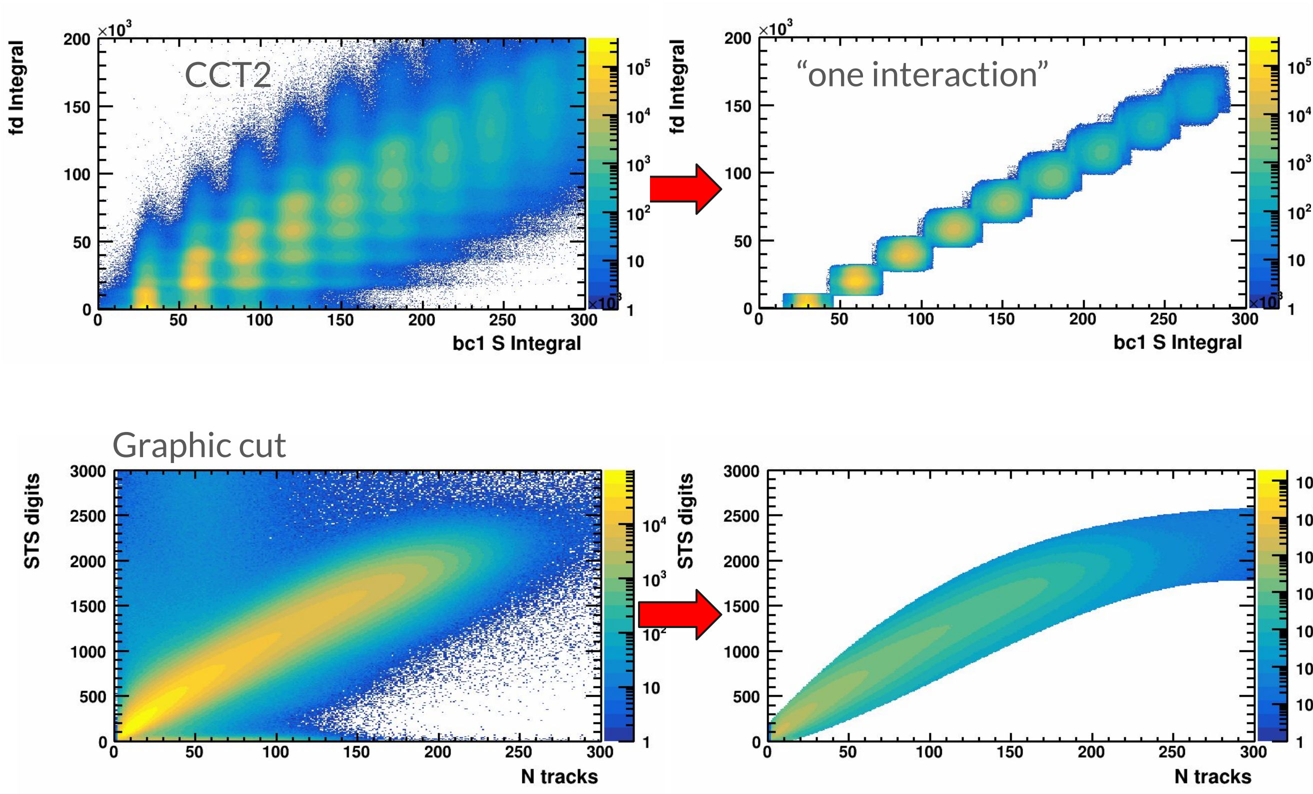




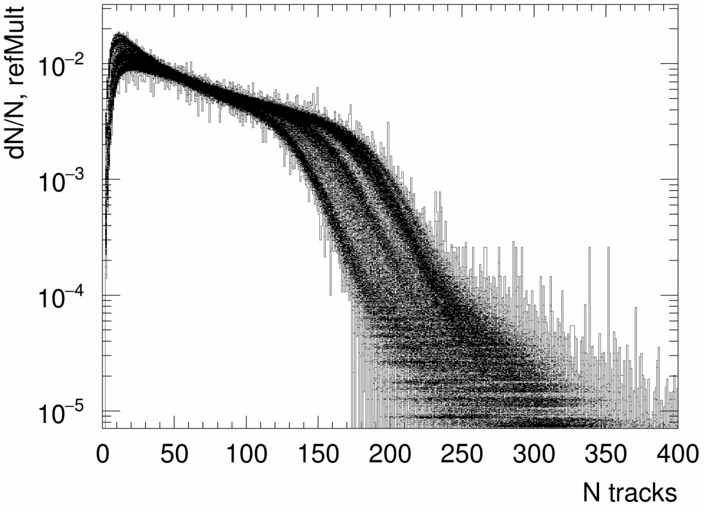
Pileup

Pileup:

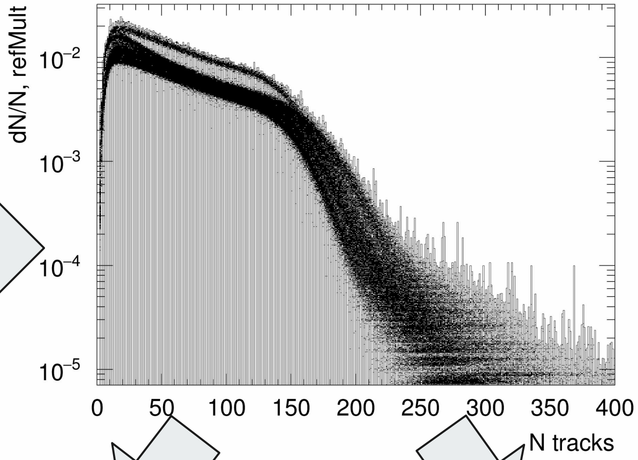
1. Select events with CCT2
2. Select events with “one interaction” (next slide):
   a. Fit of each run ID with Gaus (bc1s,fd)
   b. Scale
   c. Select events with “one interaction”
3. Graphic cut:
   a. Fill StsDigits vs nTracks
   b. Fit of each nTracks bin with Gaus
   c. fun(nTracks,StsDigit)

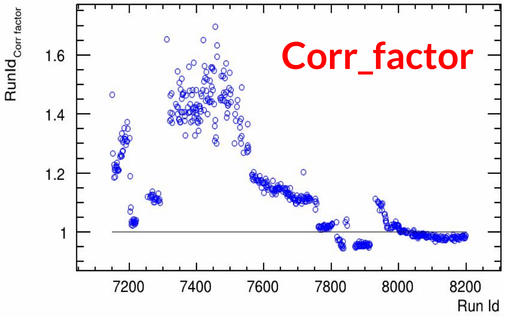


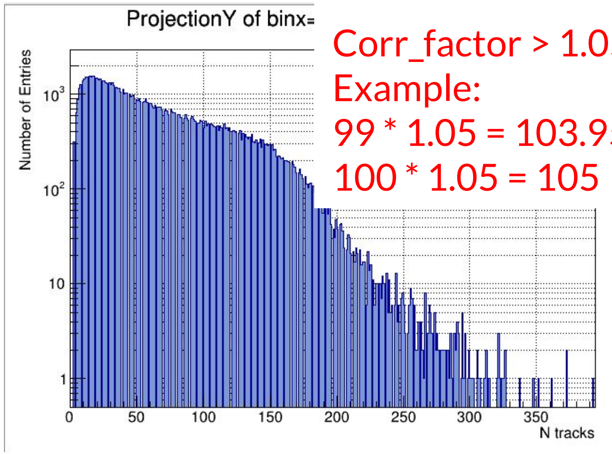
Vtx > 1



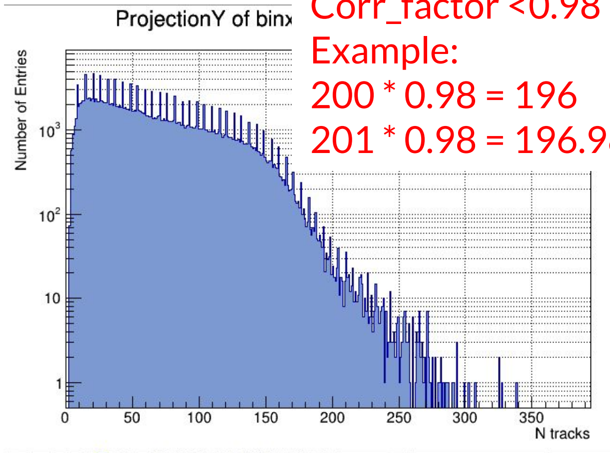
After "Step 1"







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...