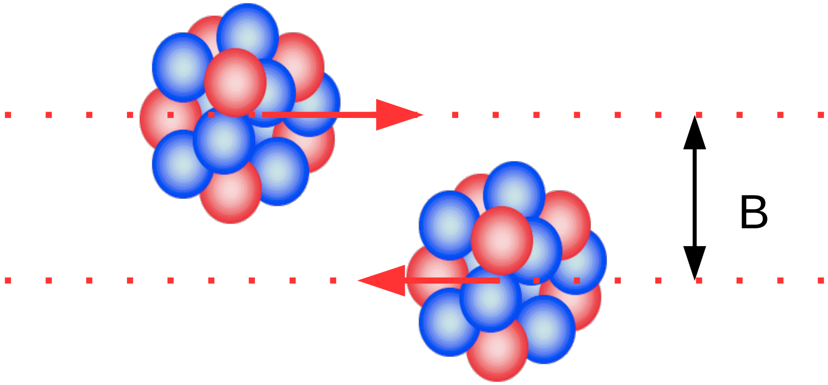
HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

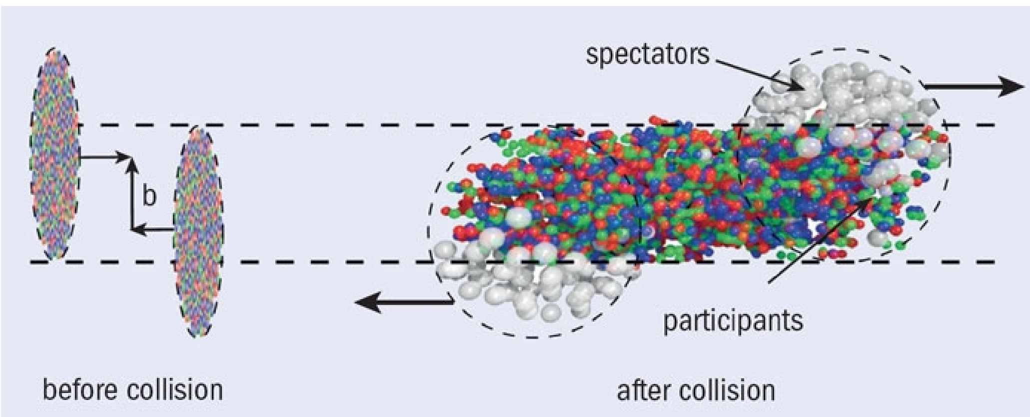
Performance of centrality determination in heavy-ion collisions with CBM experiment

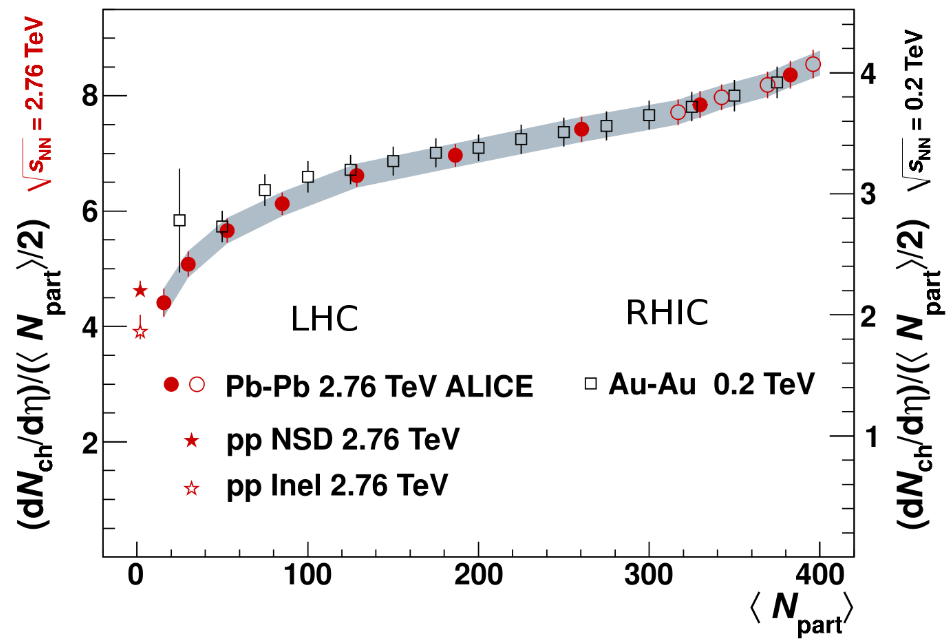


Viktor Klochkov (GSI)
Ilya Selyuzhenkov (GSI)
for the CBM collaboration

Collision geometry and event centrality

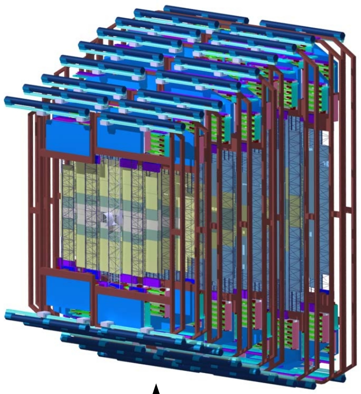
Heavy-ion collision geometry: impact parameter, number of participants, binary collisions → cannot be measured directly.



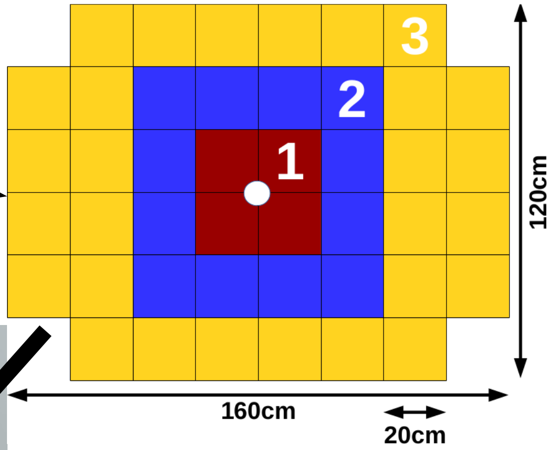


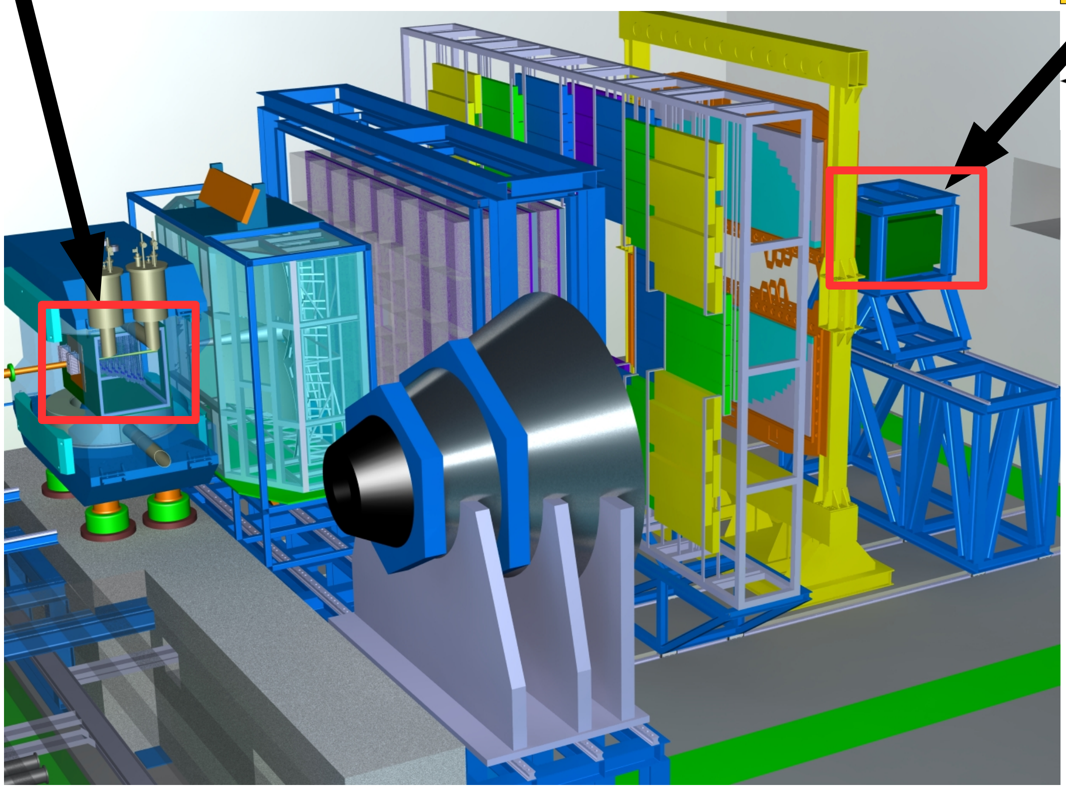
Collisions are grouped into centrality classes with the most central class defined by events with the highest multiplicity (smallest forward rapidity region energy) which corresponds to small values of the impact parameter.

CBM experiment performance for centrality determination



The central part of the PSD is sensitive mostly to spectator fragments





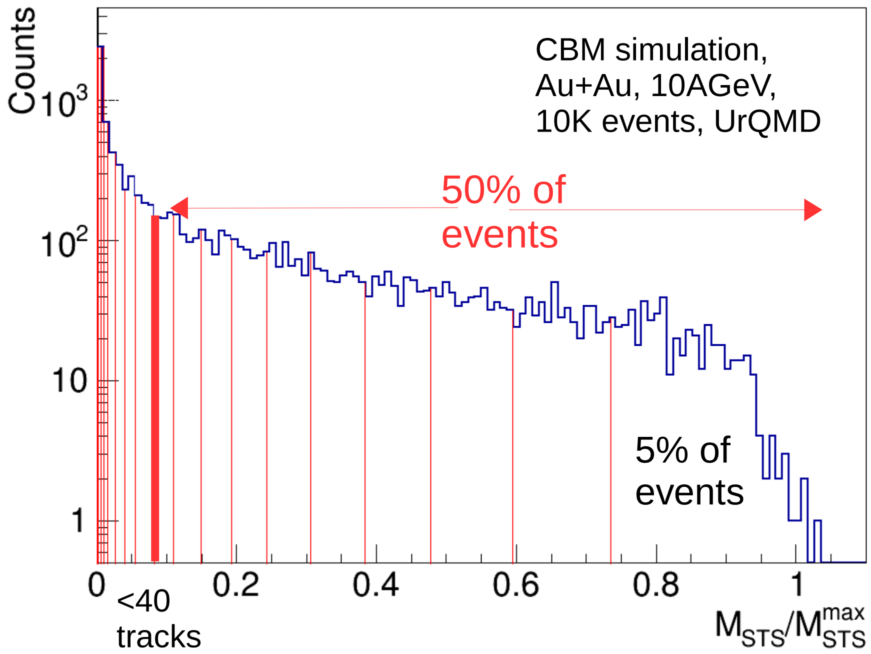
In CBM the multiplicity of produced particles is measured with the STS

Transverse to the beam layout of the PSD modules.

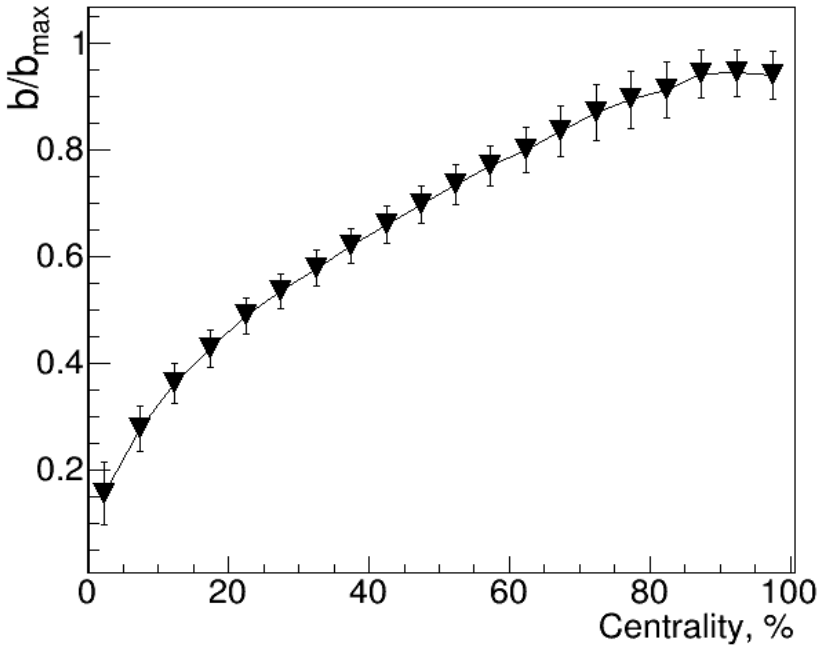
Hole is needed because of high beam intensities

Study of PSD performance was done for PSD TDR (https://repository.gsi.de/record/109059)

Centrality determination with STS multiplicity



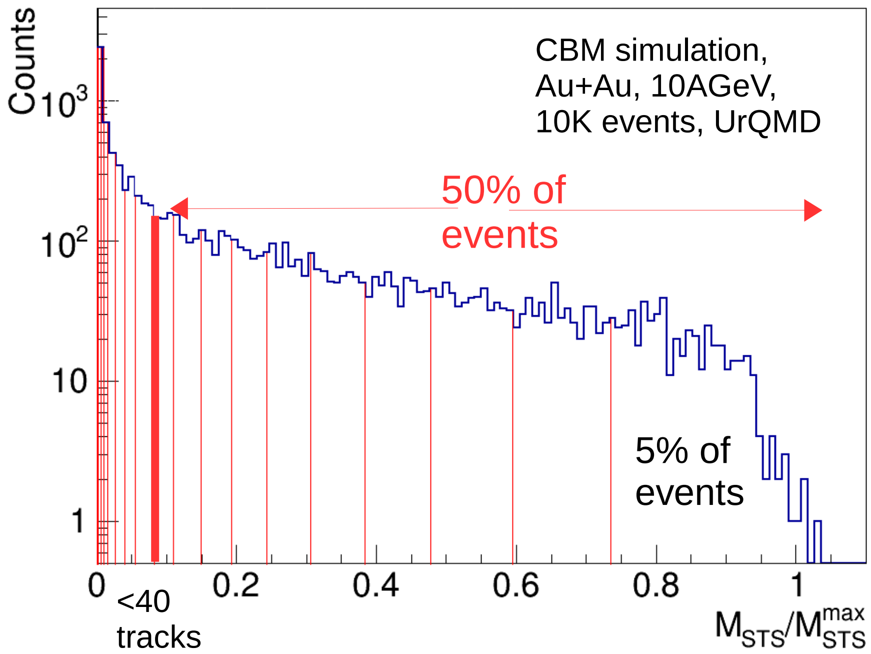
Total number of reconstructed tracks with at least 3 hits in 8 STS stations was used



The magnitude of impact parameter over its maximal value

Centrality selection for peripheral events (50-100%) is difficult due to low multiplicity.

Centrality determination with STS multiplicity



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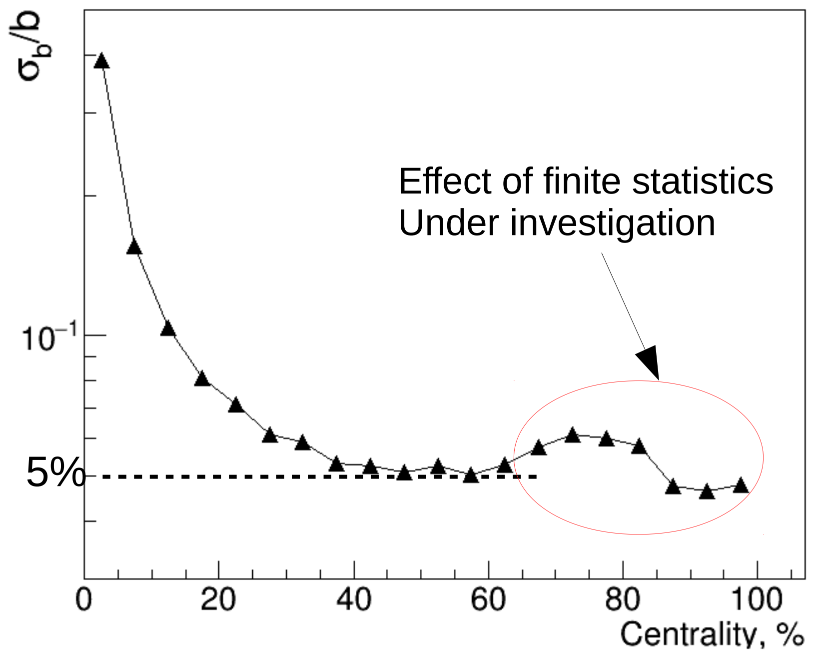
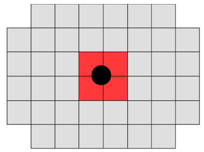
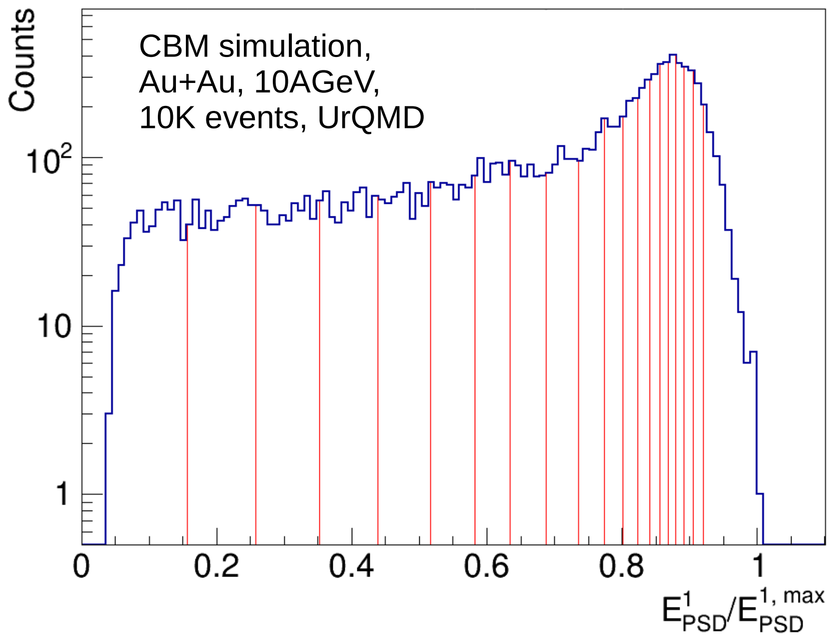


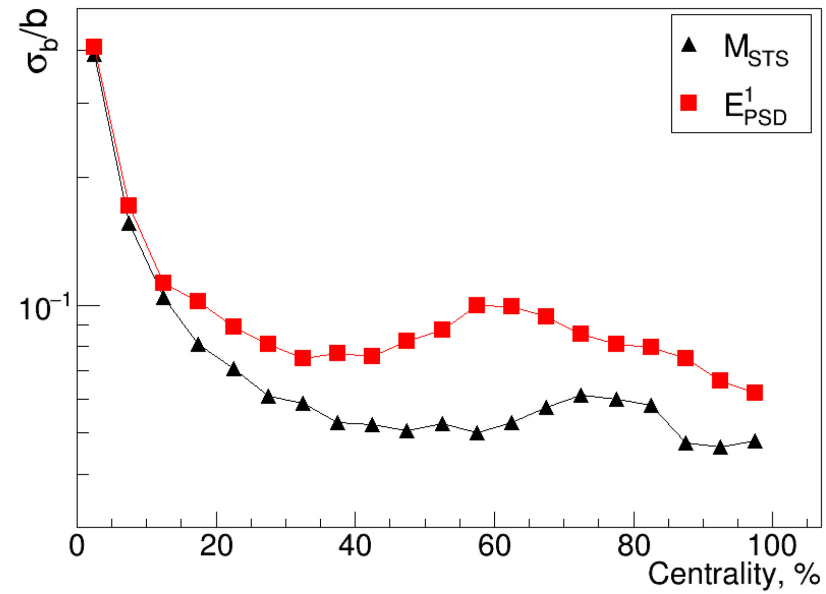
Standard deviation of the impact parameter over its mean value in each slice

Centrality selection with slice size 5% of total number of collisions shows impact parameter resolution ~5% for midcentral events

Centrality determination with PSD energy



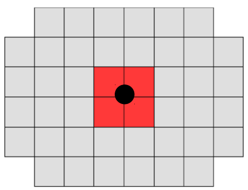




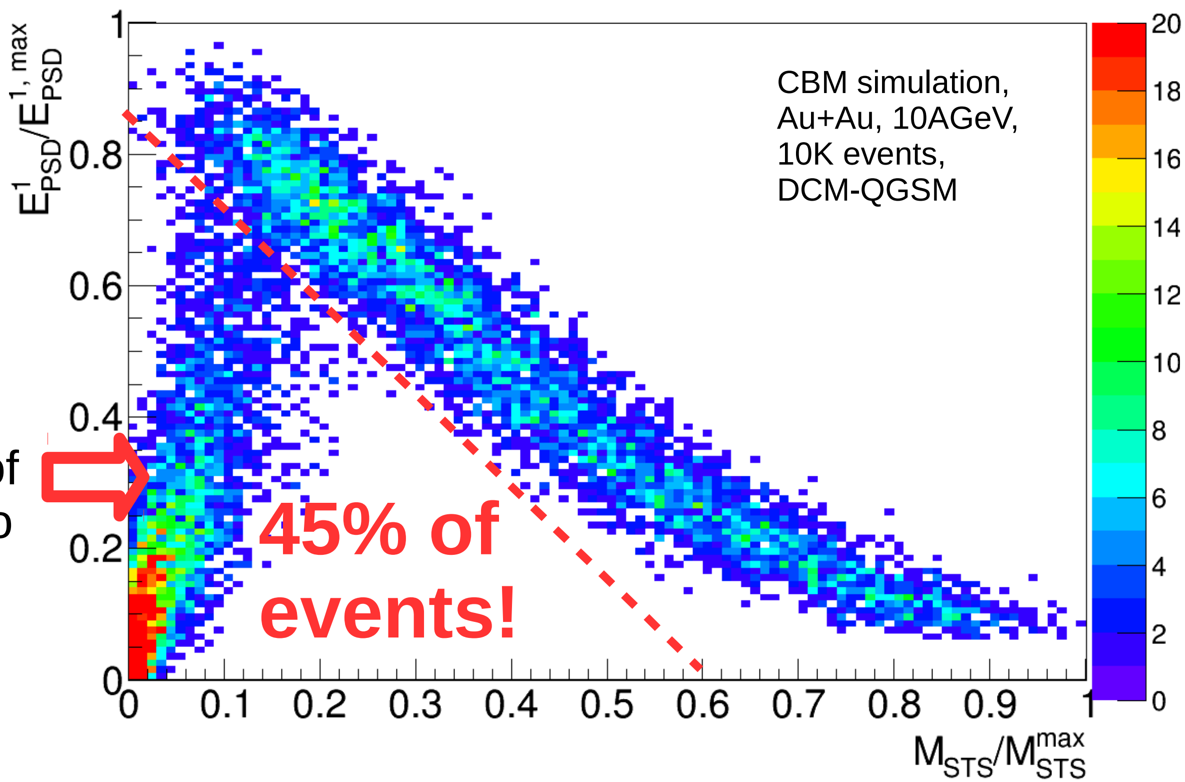
Impact parameter resolution with different centrality estimators

PSD detector can be used as independent centrality estimator. Impact parameter resolution obtained with PSD1 is comparable to that of the STS for central events, 40% worse for midcentral

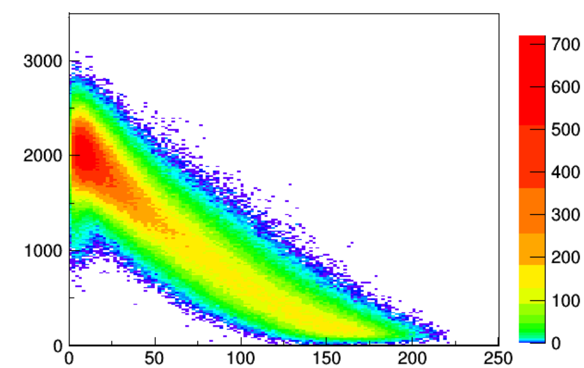
Correlation between multiplicity in STS and energy in PSD for simulation with fragments



CBM: PSD vs STS



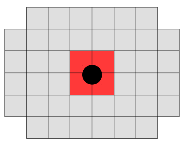
NA61/SHINE:
PSD (without hole) vs TPC

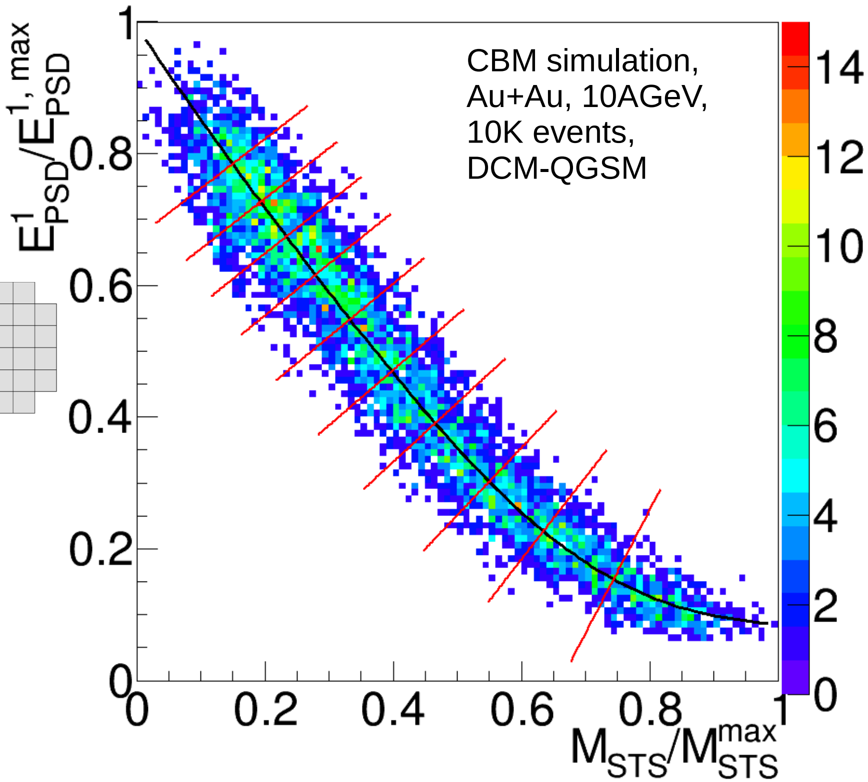


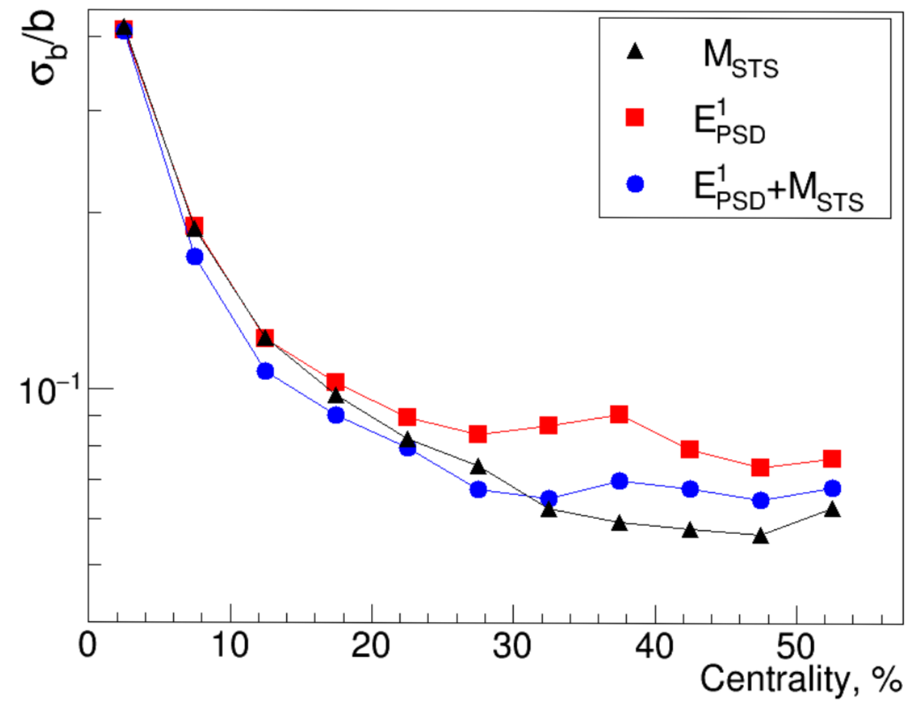
Fragments region, loss of energy due to the hole

Apply cuts on correlation to remove events with fragments.
It introduces bias for centrality determination
with PSD in very peripheral collisions

2D centrality selection with PSD1 and STS







Centrality determination procedure for 2D correlation:

- Iterative fitting (profiling, fitting, profile perp. to the fit, refit)
- Slicing perpendicular to refit

Using correlation between STS and PSD improves
the impact parameter resolution in central (0-30%) collisions

Using Glauber Monte-Carlo to set normalization and for determination of the “anchor” point

(similar to the approach used by ALICE at the LHC)

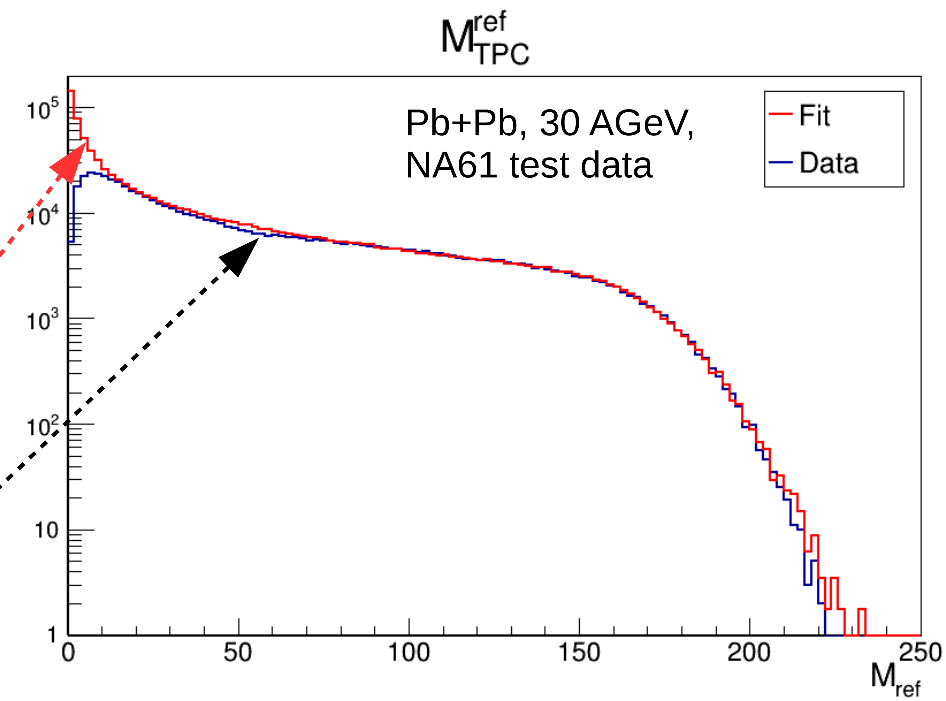
1. Fitting data with Glauber model based function:

$$F_{fit}(f,\mu,\sigma)=P_{\mu,\sigma}\circ[f\,N_{part}+(1-f)\,N_{coll}]$$

where $P_{\mu,\sigma}$ is negative binomial distribution, N_{part} and N_{coll} are simulated with Glauber Monte-Carlo.

2. Total cross-section estimation

3. Determine the “anchor” point (deviation from the Glauber fit)



M_{ref} – selected multiplicity in midrapidity region

Procedure for centrality determination

1. Use total cross-section for normalization and determine the “anchor” point (centrality value below which determination is not reliable): → rely on fits with Glauber model

2. Make all variables dimensionless

3. Parameterise the 2D correlation between multiplicity and/or PSD subgroup energies (in case of 2D analysis)

4. Slice the 2D correlation or 1D distribution

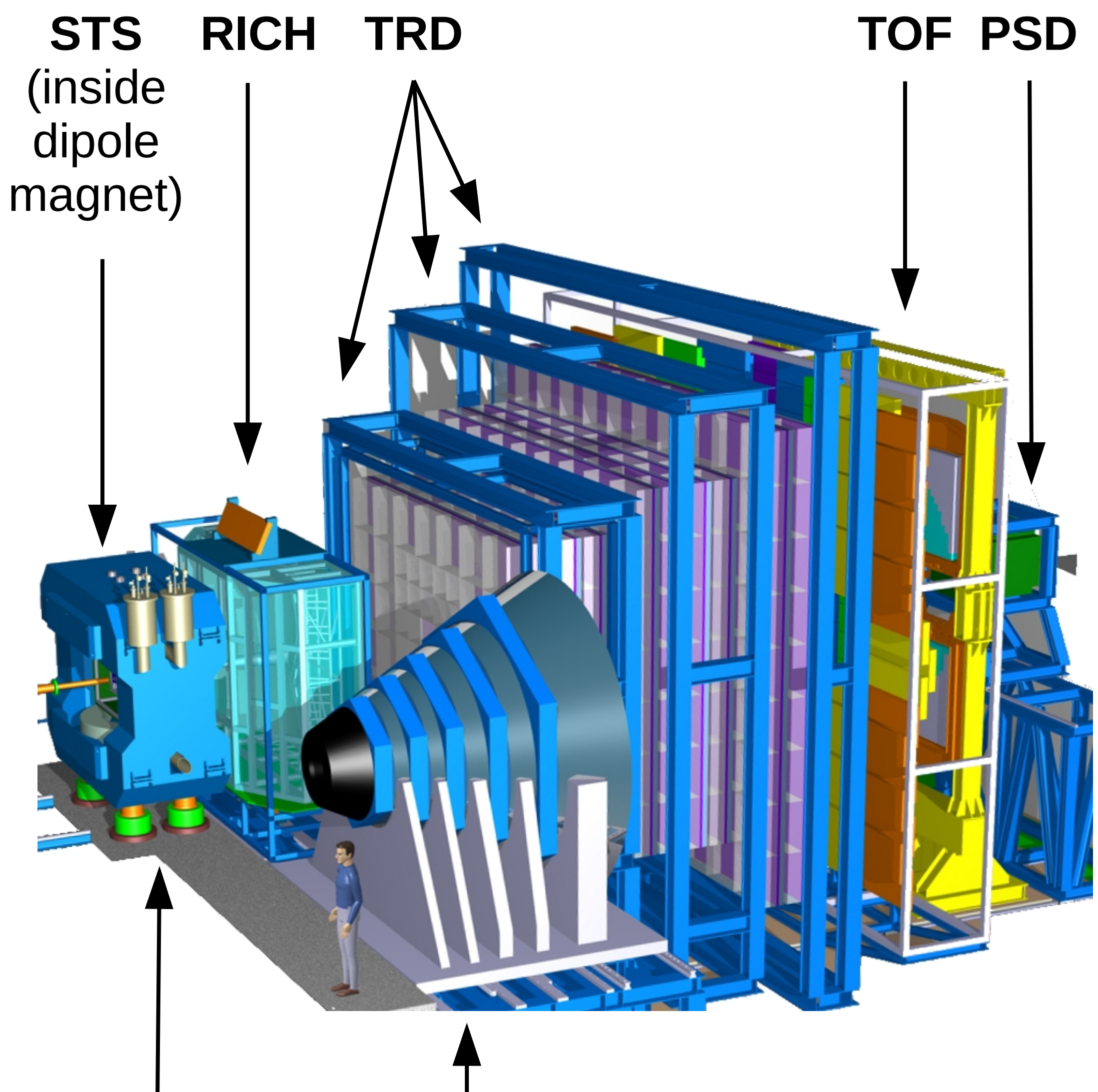
5. Save the output (CentralitySlice objects) into root-file

6. Using CentralitySlice objects to get centrality for a given event via user interface

Summary

- The size and evolution of the medium created in a heavy-ion collision depends on collision centrality
- PSD and STS detectors can be used for centrality selection in the CBM experiment
  → PSD is limited to 0-50% due to loss of fragments in a beam hole
- Centrality Framework was developed and tested with CBM simulated data and NA61 Pb+Pb test data

CBM detector subsystems



Dipole Magnet
bends particle's trajectories
for momentum measurement

STS (Silicon Tracking System)
charged particle tracking

RICH (Ring Imaging CHerenkov)
TRD (Transition Radiation Detector)
electron identification

TOF (Time of Flight detector)
hadron identification

PSD (Projectile Spectator Detector)
collision centrality and
reaction plane determination

MVD (Micro-Vertex Detector)
secondary vertex reconstruction

MUCH (MUon CHambers)
muon identification

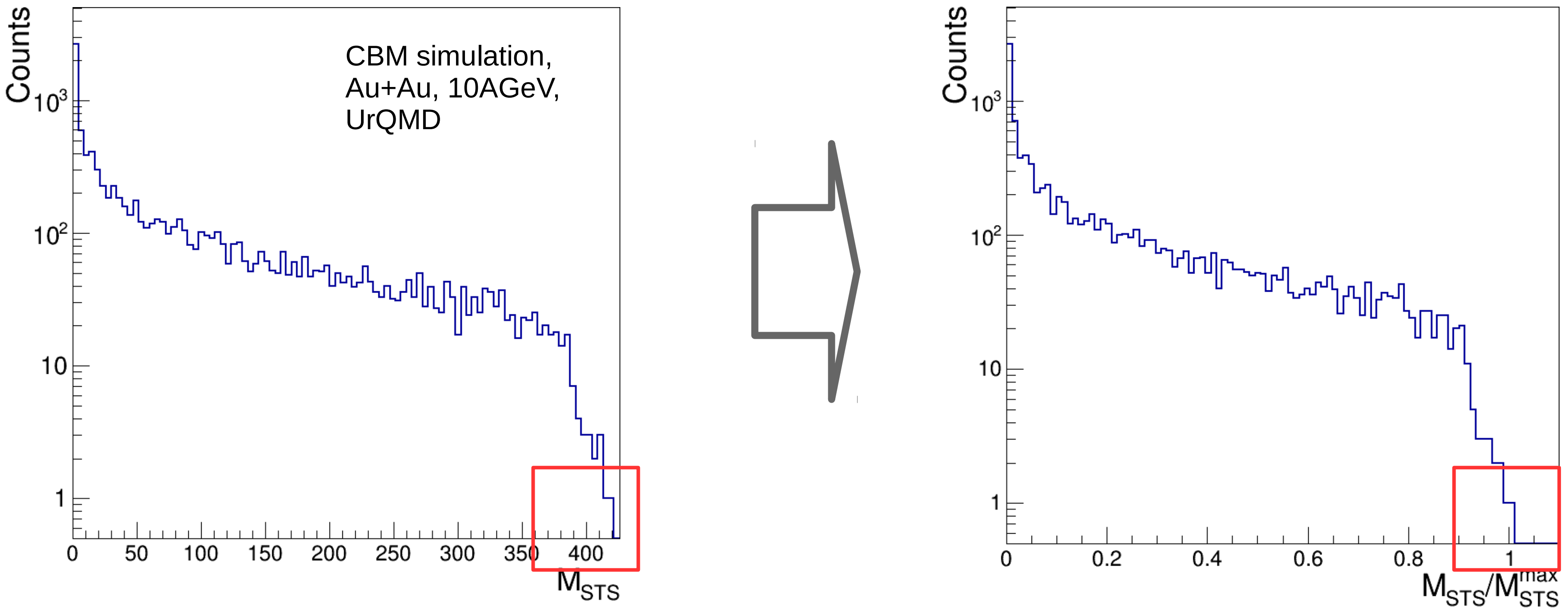
DAQ/FLES (First-level Event Selector)
online reconstruction / event selection,
High Performance Computing

Make all centrality variables dimensionless

Data from different running periods requires run-by-run normalization

Before

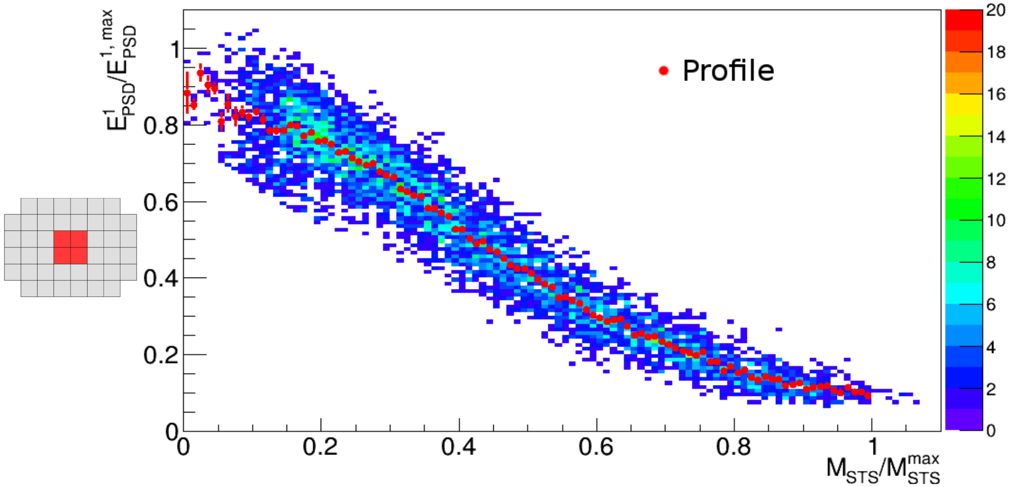
After



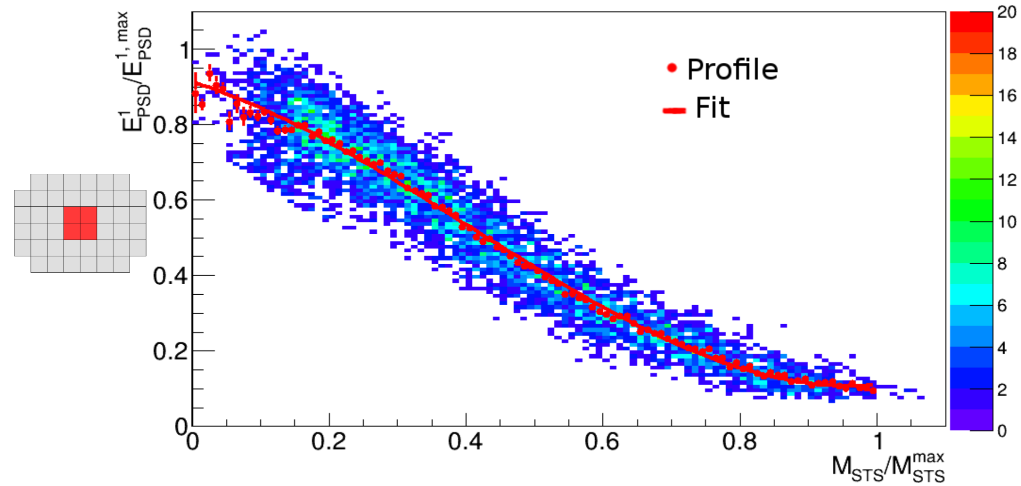
Algorithm for fitting the 2D correlation

CBM simulation,
Au+Au, 10 AGeV,
SHIELD

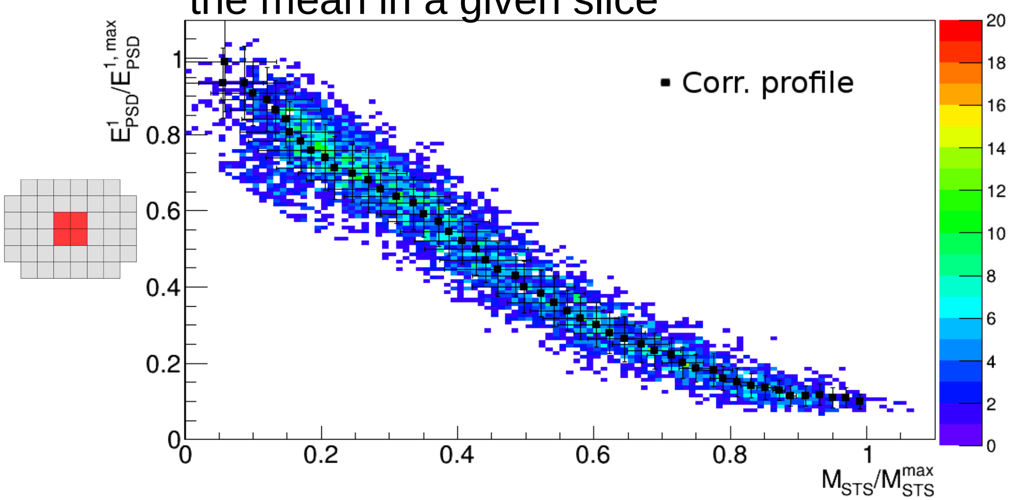
1. Profiling correlation



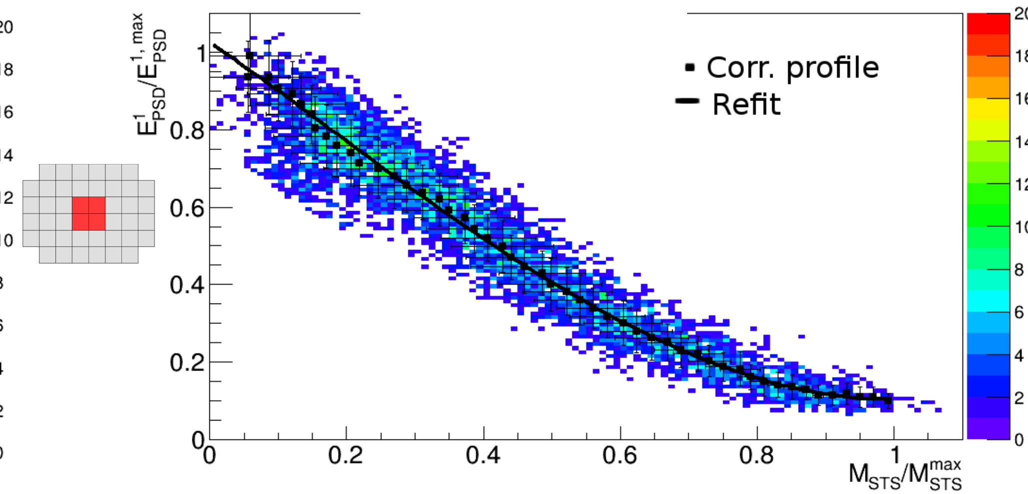
2. Fitting profile



3. Moving along profile fit and recalculate the mean in a given slice

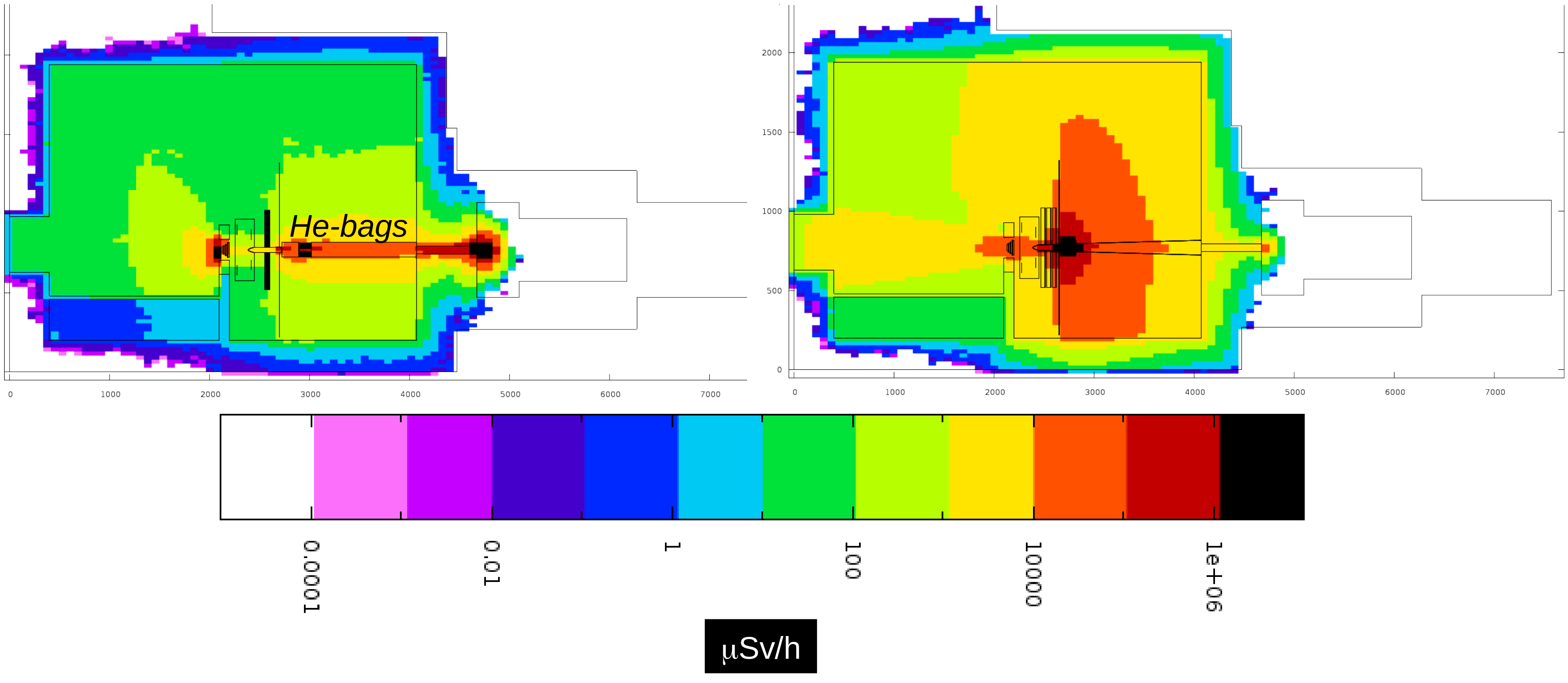


4.Refit the new mean values

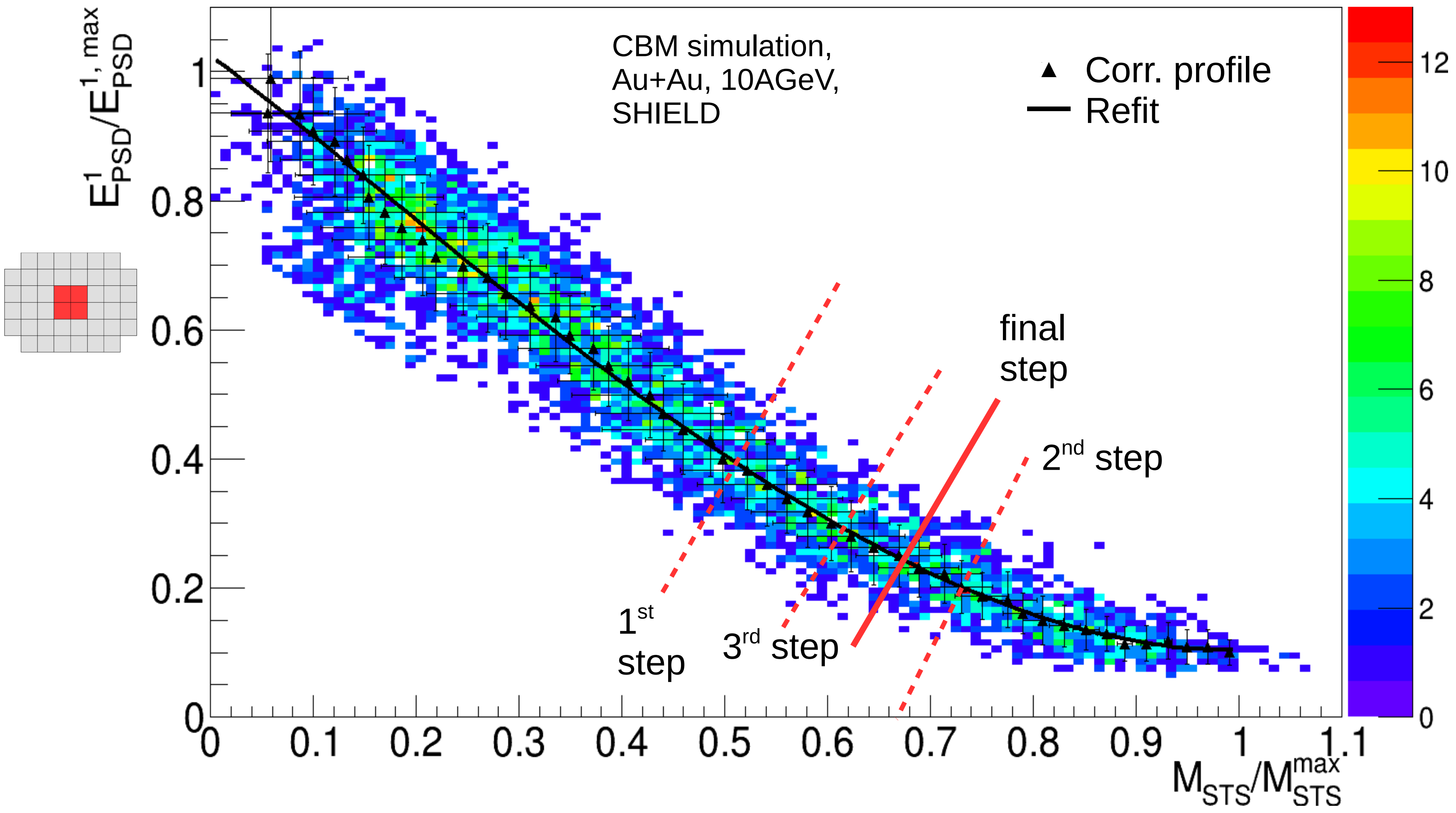


Dose rate in the cave during run

PSD with 20×20 cm² hole
10^7 Au/s
SIS100 – Au @ 10 AGeV
250 μm Au target
1 months run

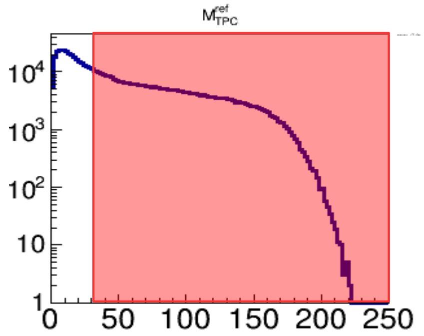


Algorithm for centrality slice determination (bisection method)

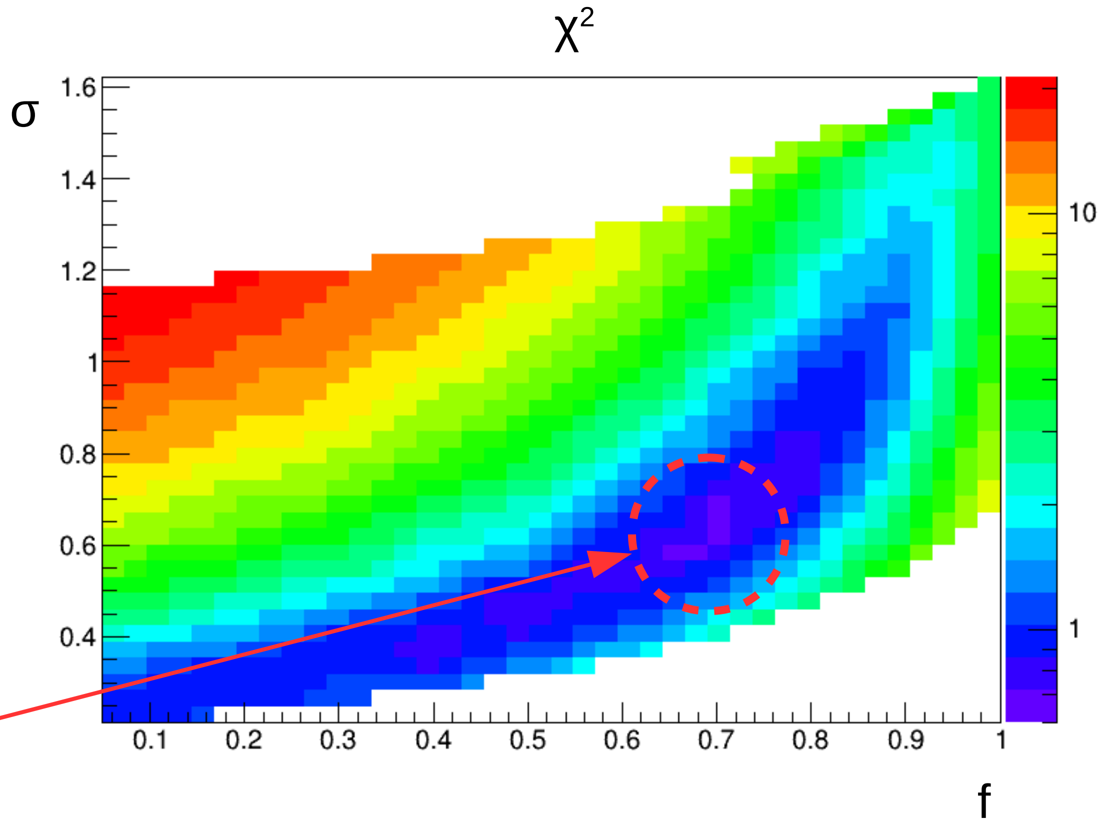


Self-consistency check of the fitting algorithm

1. Generate function with a fixed (input) parameters ***f, σ*** and ***μ***
2. Fit generated function in some range (for example M>30)



3. Compare fit parameters with input values



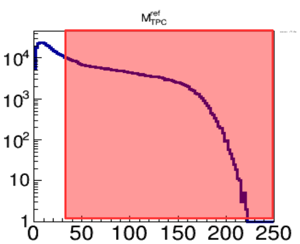
Minimal value for χ^2 corresponds to ***f ≈ 0.7, σ ≈ 0.6*** and ***μ ≈ 0.26*** which is close to real values ***f = 0.7, σ = 0.67*** and ***μ = 0.27***

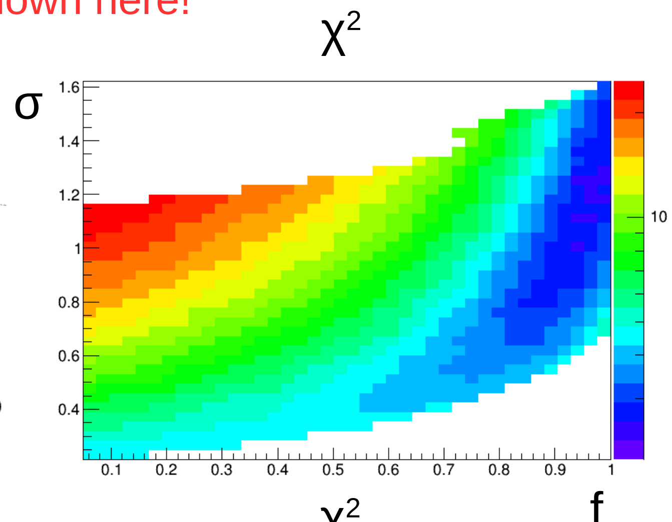
Extracted values are sensitive to the fit range!

Fitting NA61 test data with Glauber model in different ranges

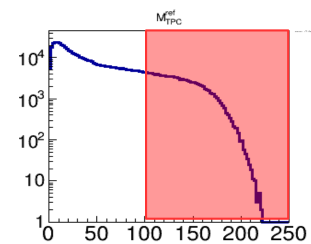
All points plot for best μ fit, which is not shown here!

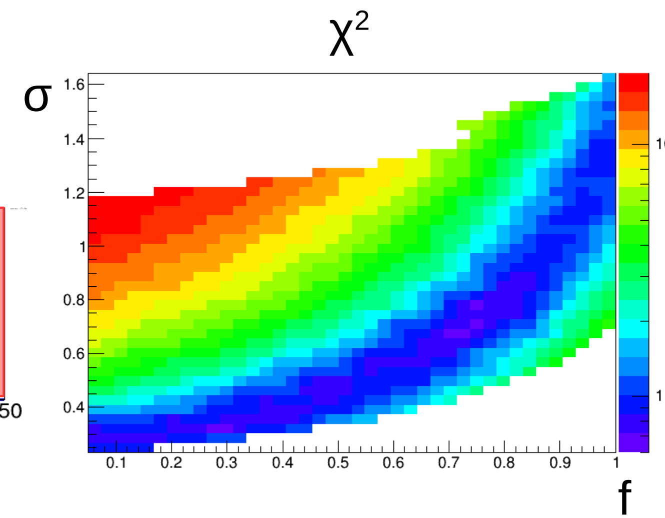
M>30



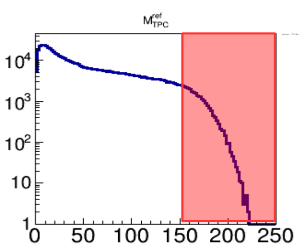


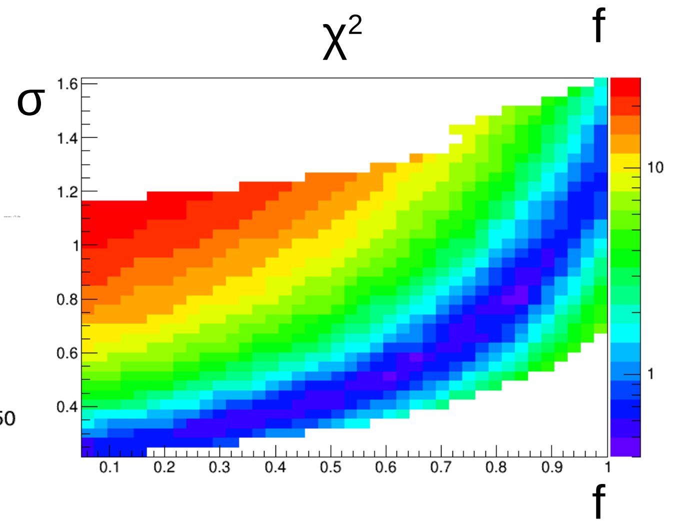
M>100





M>150





No minimal value for fit with “M>30”
→ probably due to the trigger bias.

Few local minima for M>150 due to small amount of fit points or low statistics.

Minimal value for M>100 could be used for determination of the parameters.
Todo: check fit errors.

σ_b/b for different models