Centrality determination in heavy-ion collisions with CBM experiment

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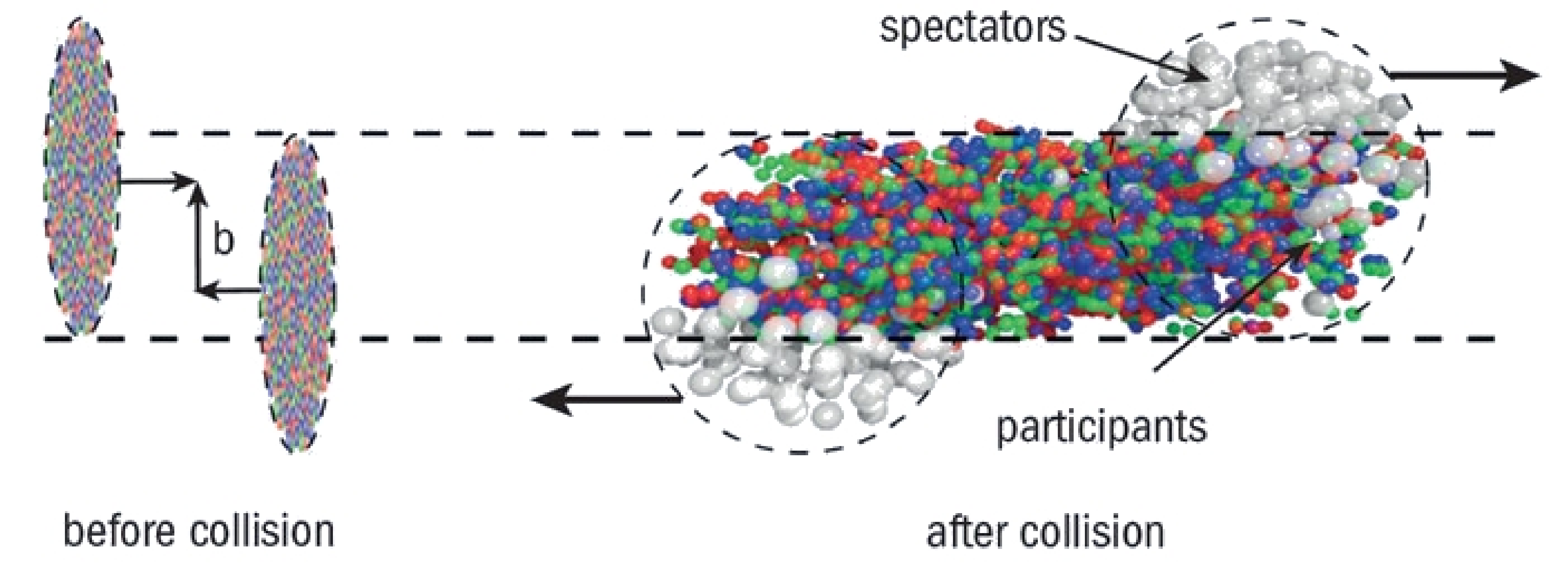
for the CBM Collaboration

Collision geometry

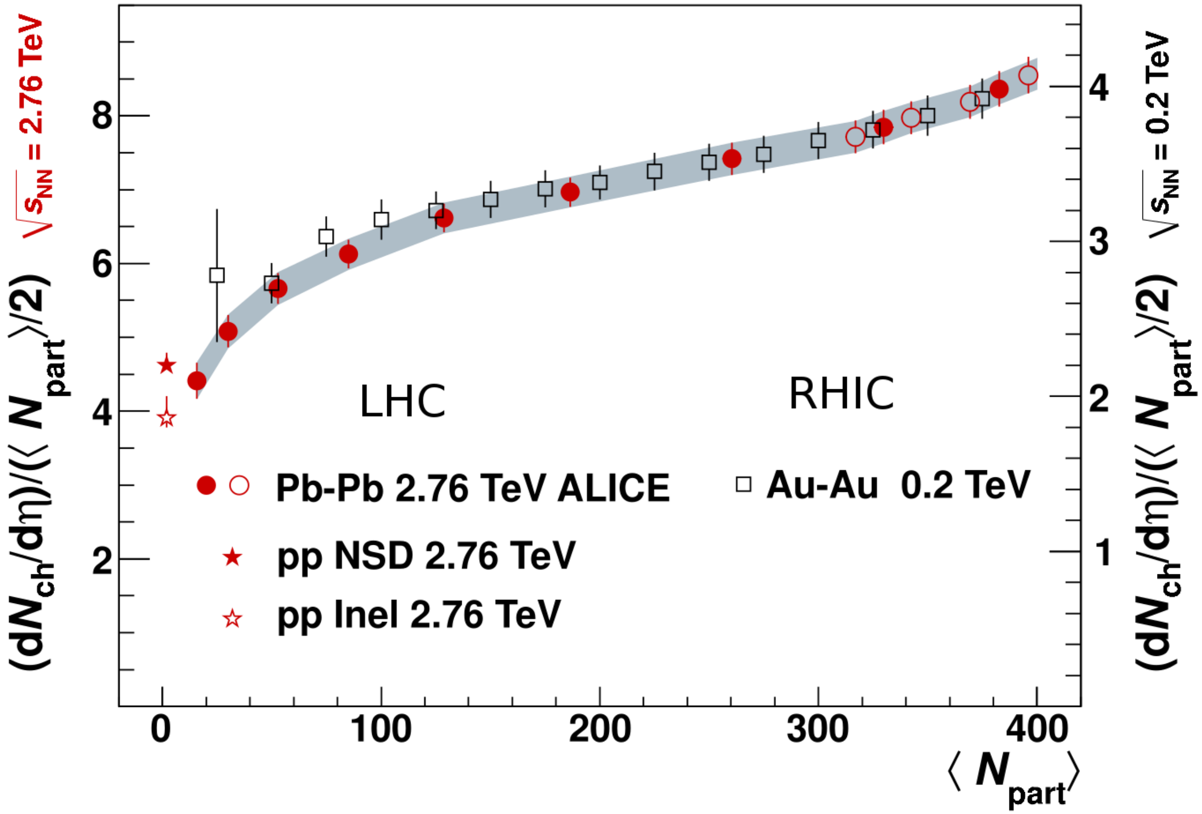
Heavy-ion collision geometry: impact parameter, number of participants, binary collisions.



Cannot be measured directly!

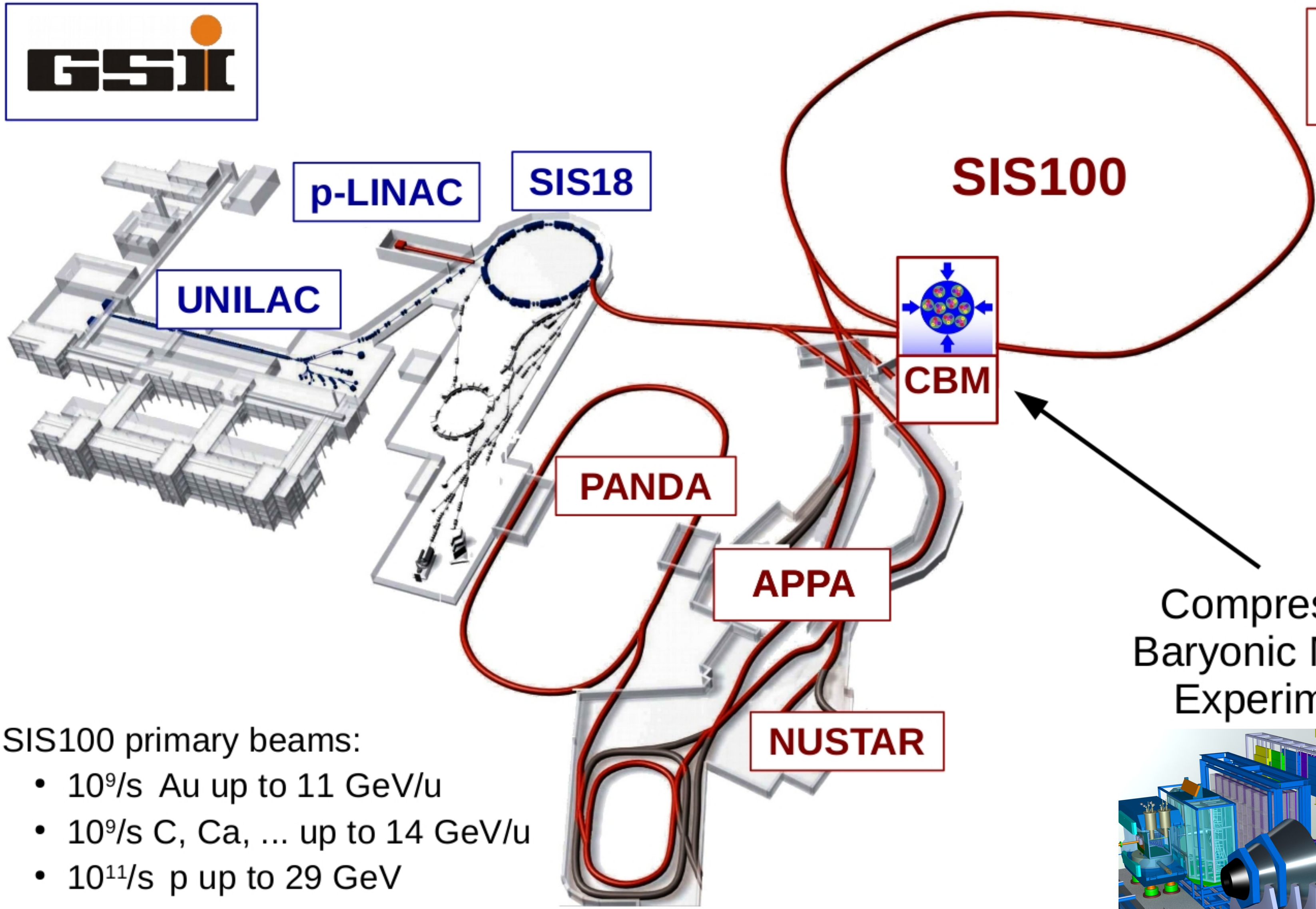
Centrality: estimating geometry in experiment

Collisions are grouped into event (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.

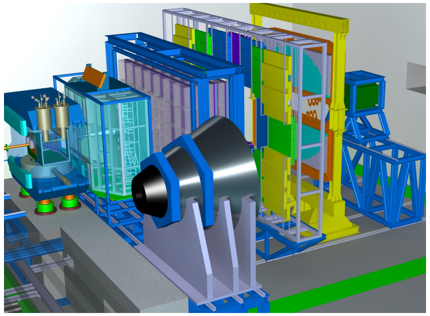


A procedure to convert between average model quantities (<b>, <N_{part}>, etc) and measurable multiplicities / energies is needed.

Facility for **A**ntiproton and **I**on **R**esearch (FAIR)



Compressed Baryonic Matter Experiment

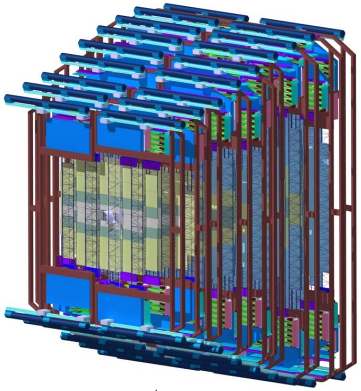


SIS100 primary beams:

- 10^9/s Au up to 11 GeV/u
- 10^9/s C, Ca, ... up to 14 GeV/u
- 10^{11}/s p up to 29 GeV

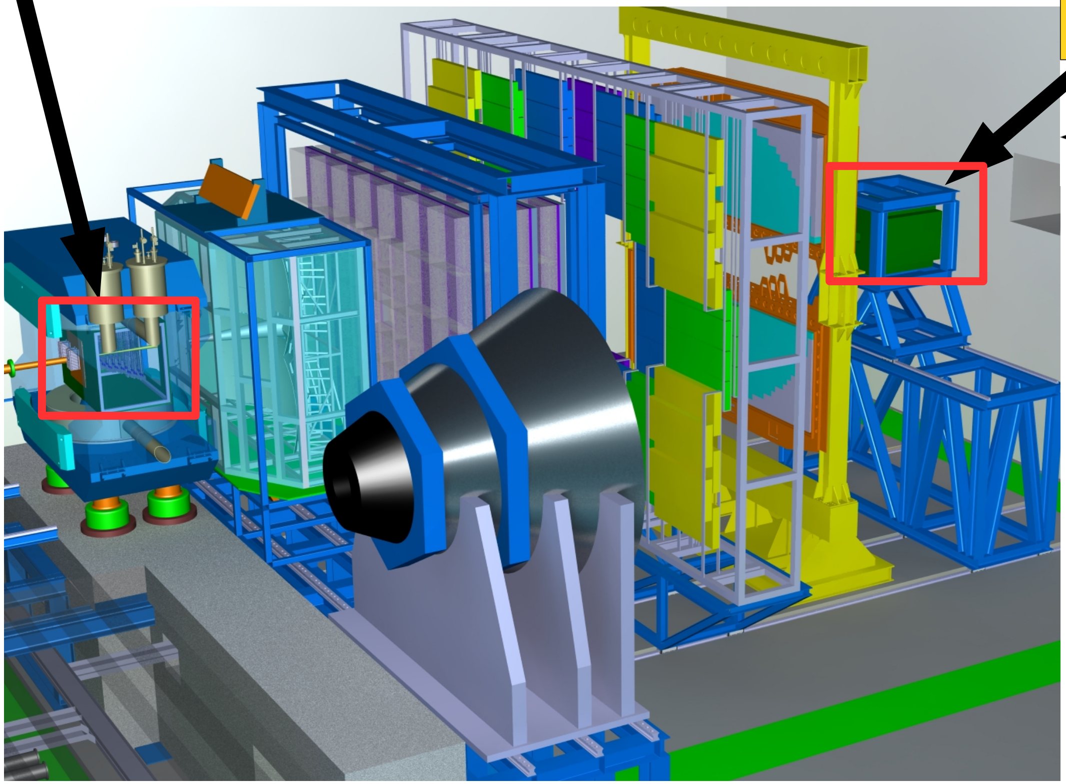
CBM experiment subsystems used in centrality determination

Silicon Tracking System (STS)

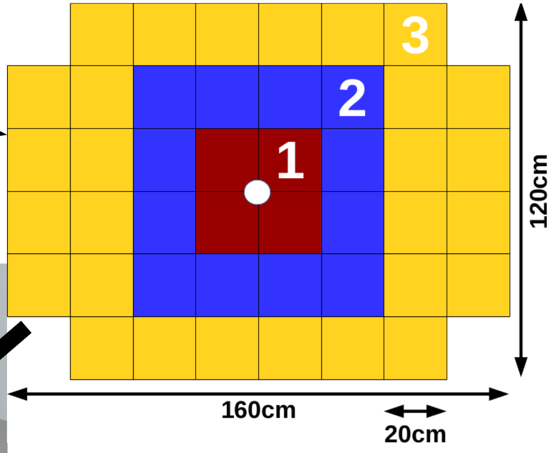


STS+MVD allows to measure the multiplicity of produced particles

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



Projectile Spectator Detector (PSD)



Transverse to the beam layout of the PSD modules.

Hole is needed because of high beam intensities

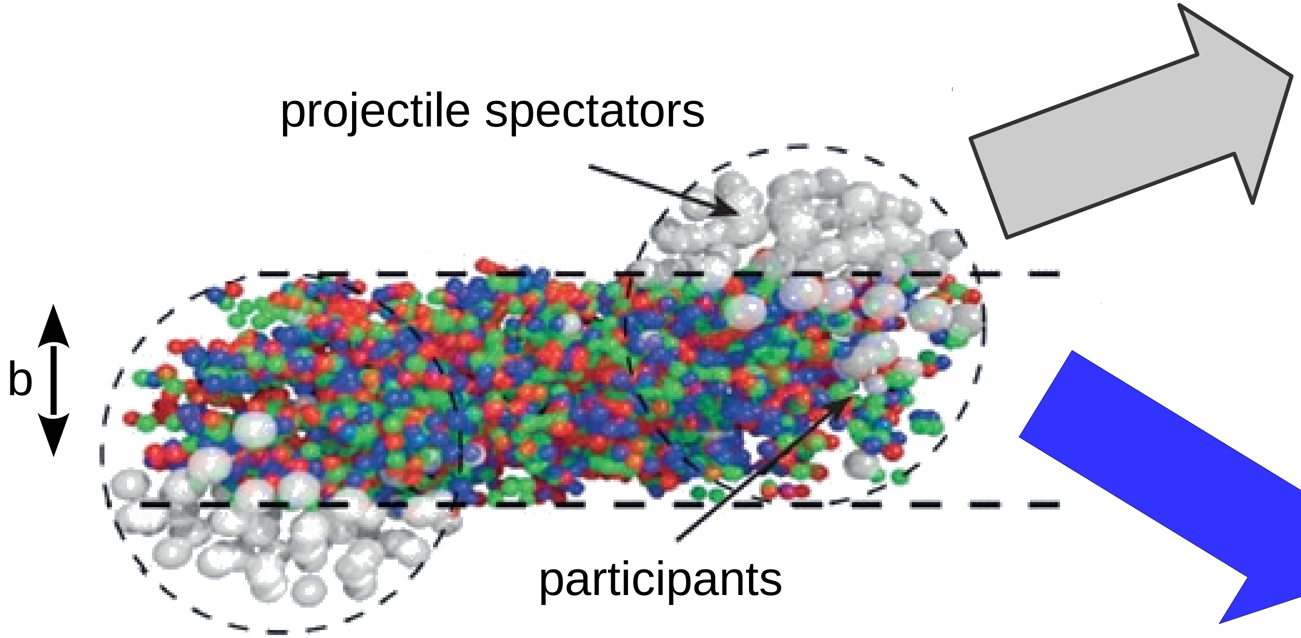
STS TDR https://repository.gsi.de/record/54798

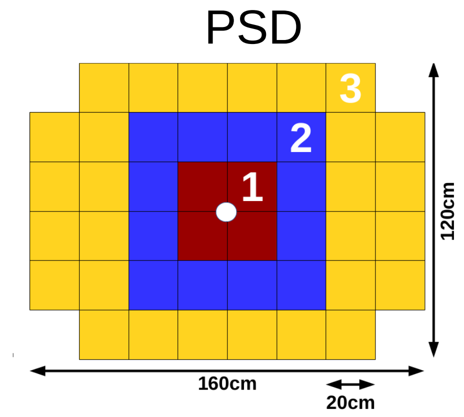
PSD TDR https://repository.gsi.de/record/109059

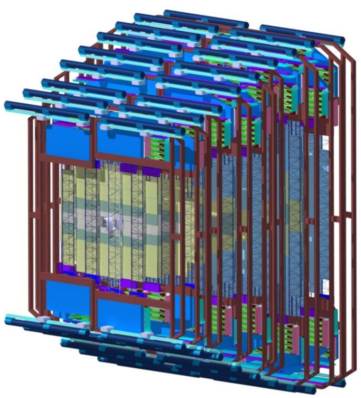
Simulation setup

Models	UrQMD (no fragments), DCM-QGSM (with fragments)
System	Au-Au
Energy	10 AGeV
Statistics	~0.5M events
CBM geometry	MVD, STS, RICH, TDR, TOF, PSD
PSD geometry	44 modules, 4 central, 6 cm hole, elongated in x
Transport code	GEANT4
Detector response	CBMRoot

Centrality estimators in CBM





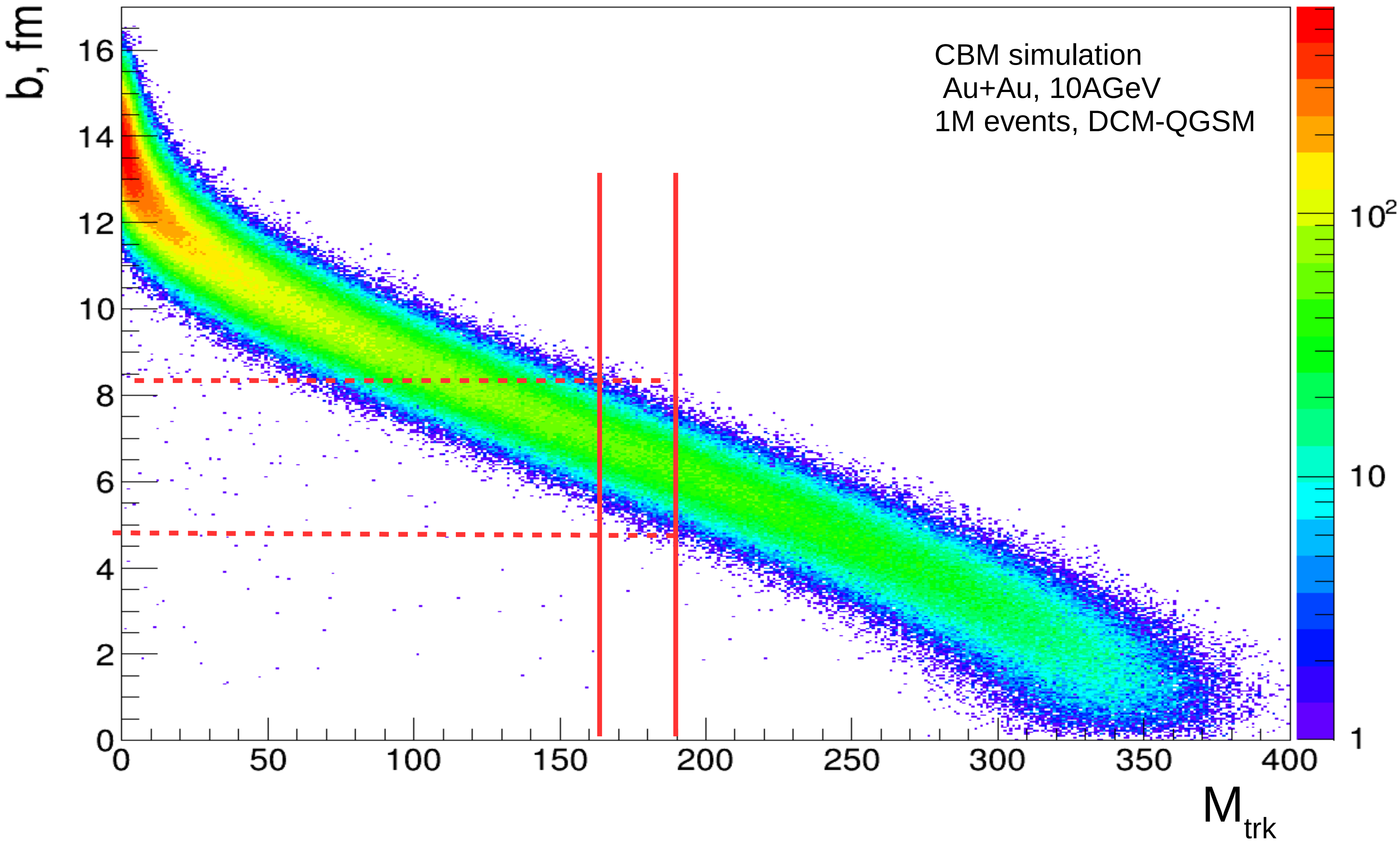


target spectators
are not measured

PSD is sensitive mostly to spectator fragments.

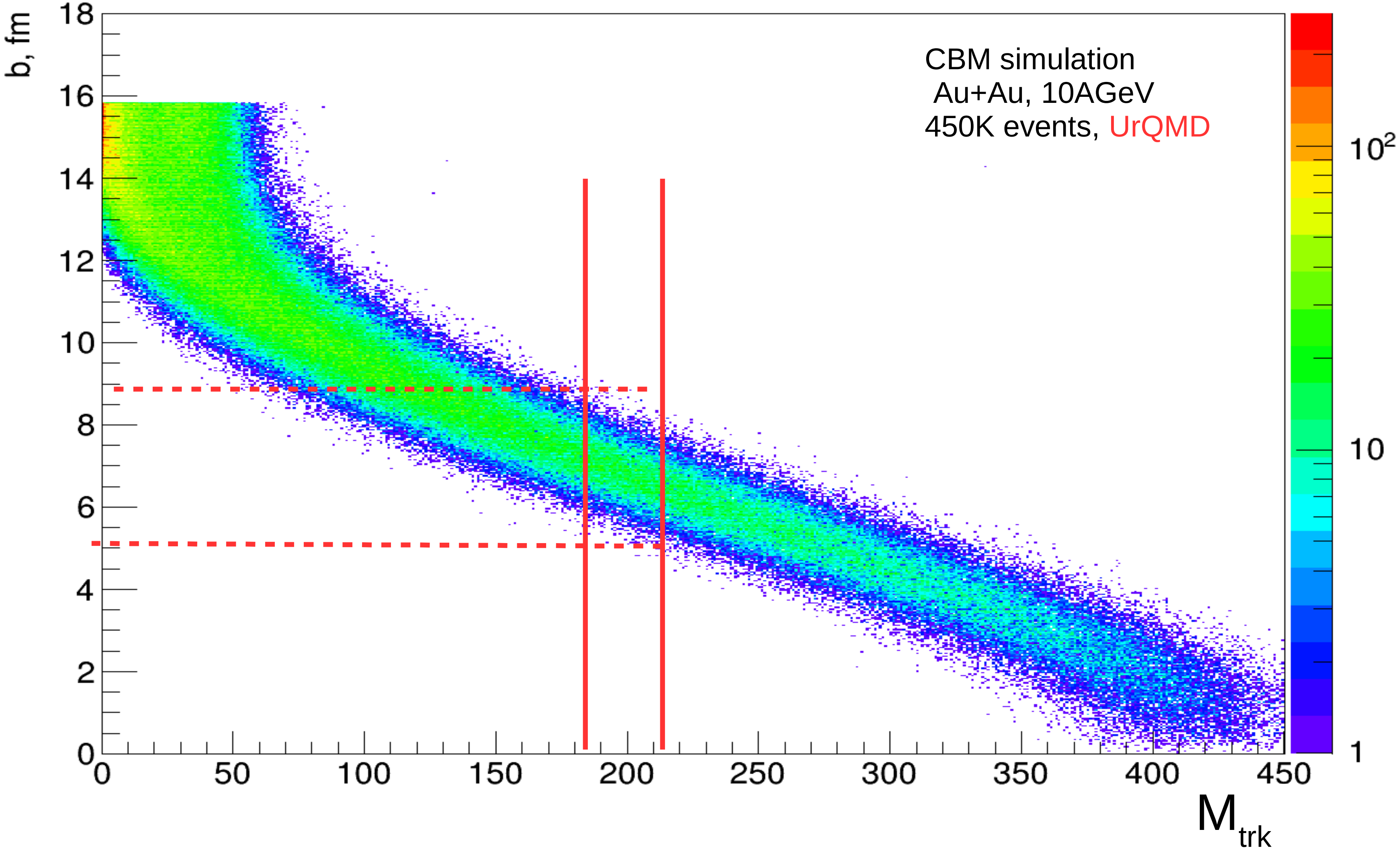
STS+MVD provide the multiplicity of produced particles.

Estimating model parameters with measured quantities



Events with multiplicities M±ΔM have impact parameter in range B±σ

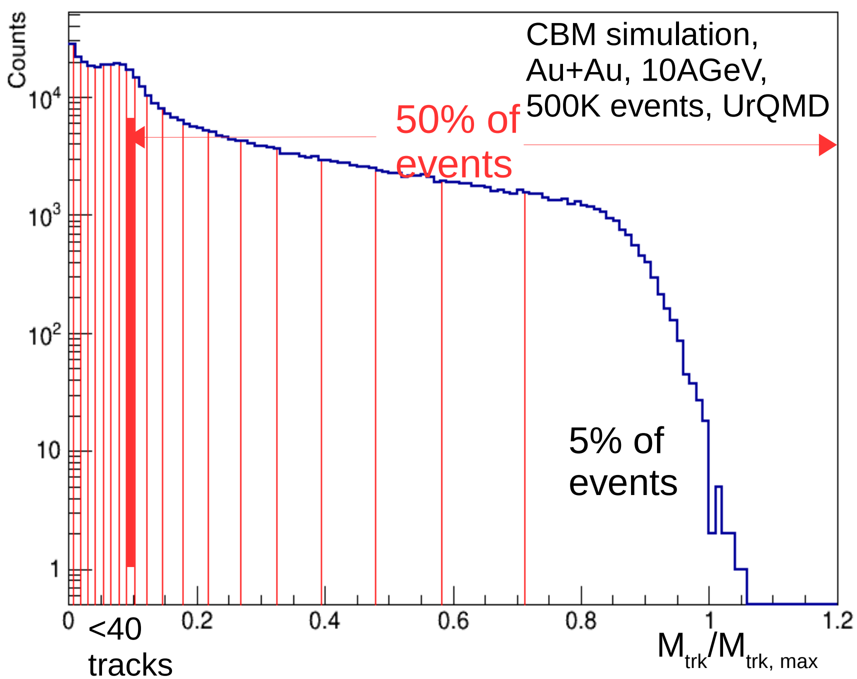
Estimating model parameters with measured quantities



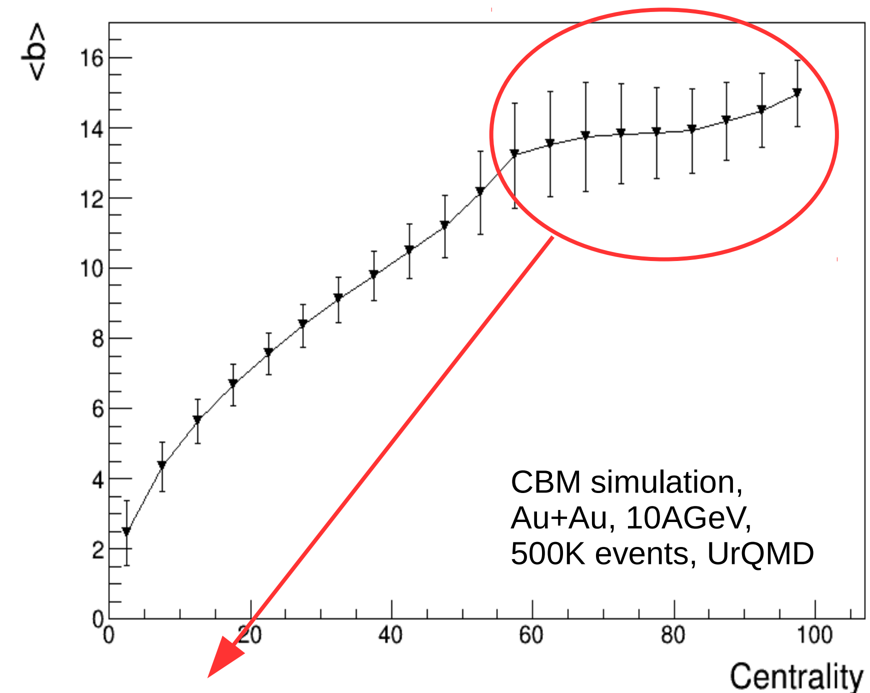
Events with multiplicities M±ΔM have impact parameter in range B±σ

Centrality determination with track multiplicity

Track multiplicity classes



Average impact parameter versus centrality



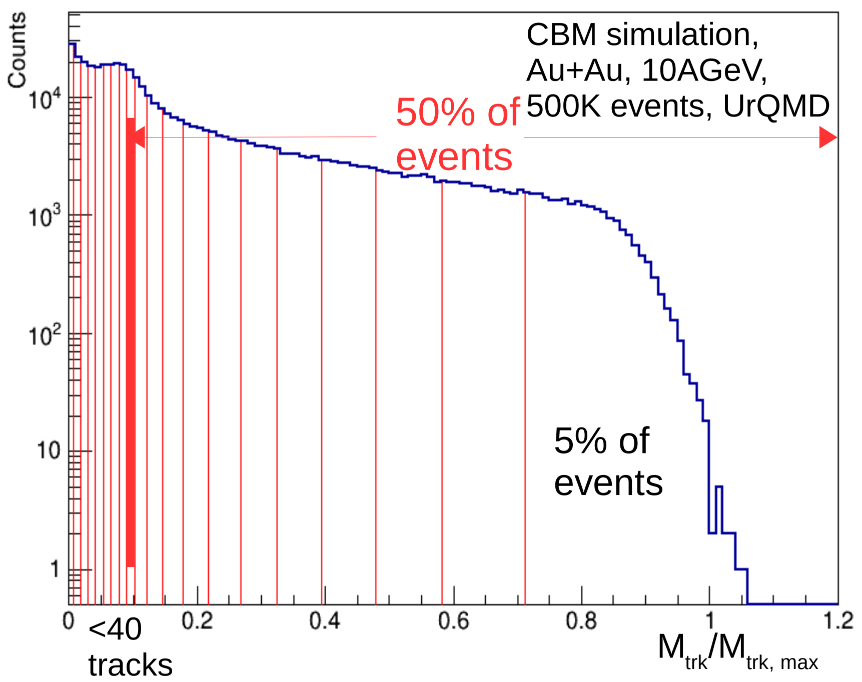
N_{trk} - number of STS+MVD tracks with at least 3 hits

Impact of b<15.8 fm cut in UrQMD

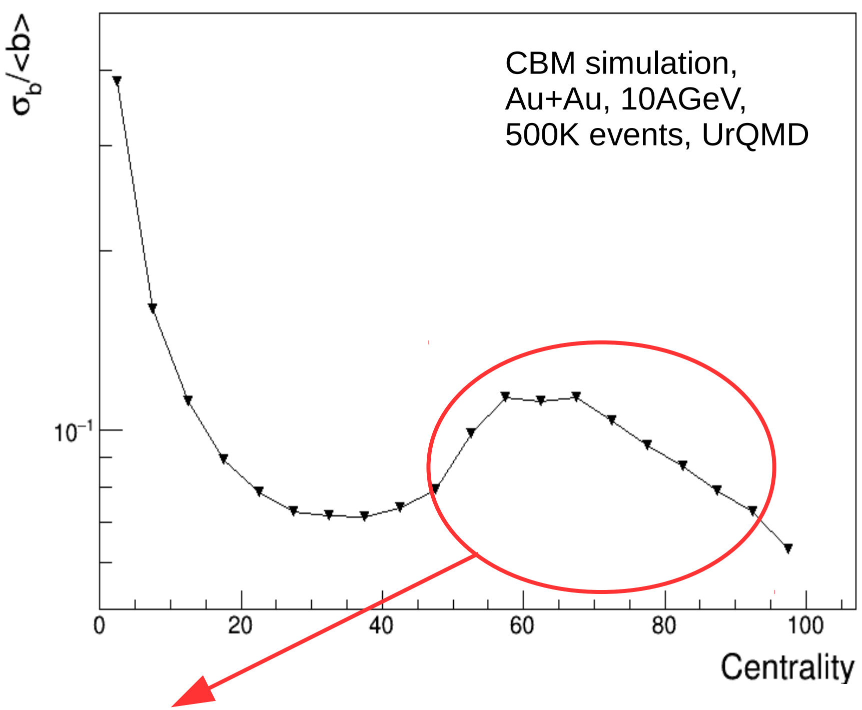
Centrality selection for peripheral events (50-100%) is difficult due to low multiplicity.

Centrality determination with track multiplicity

Track multiplicity classes



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

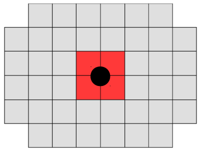


Impact of b<15.8 fm cut in UrQMD

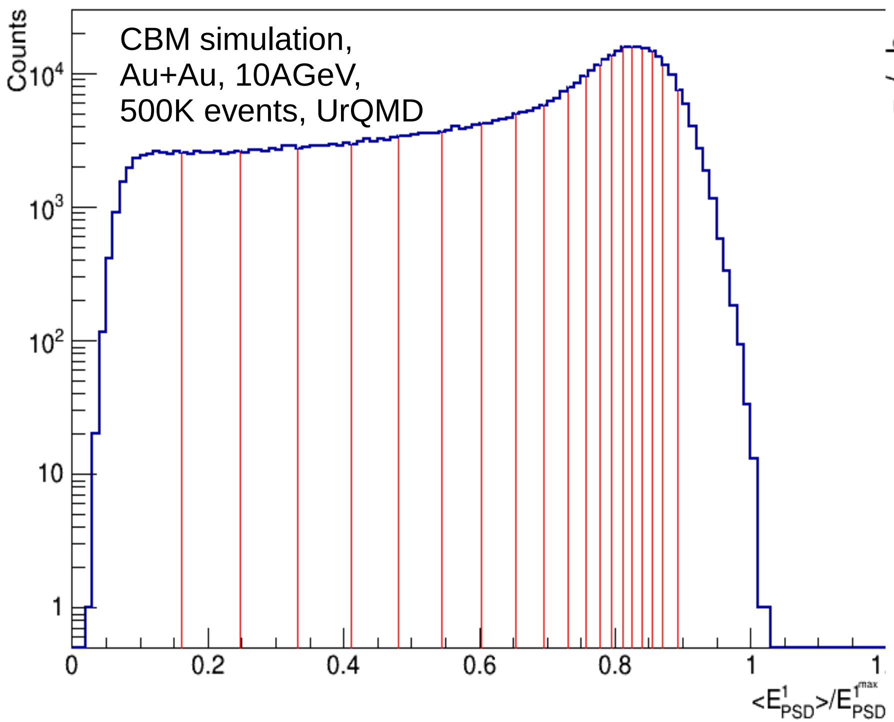
With 5% wide centrality classes the impact parameter resolution is below 7% for midcentral events

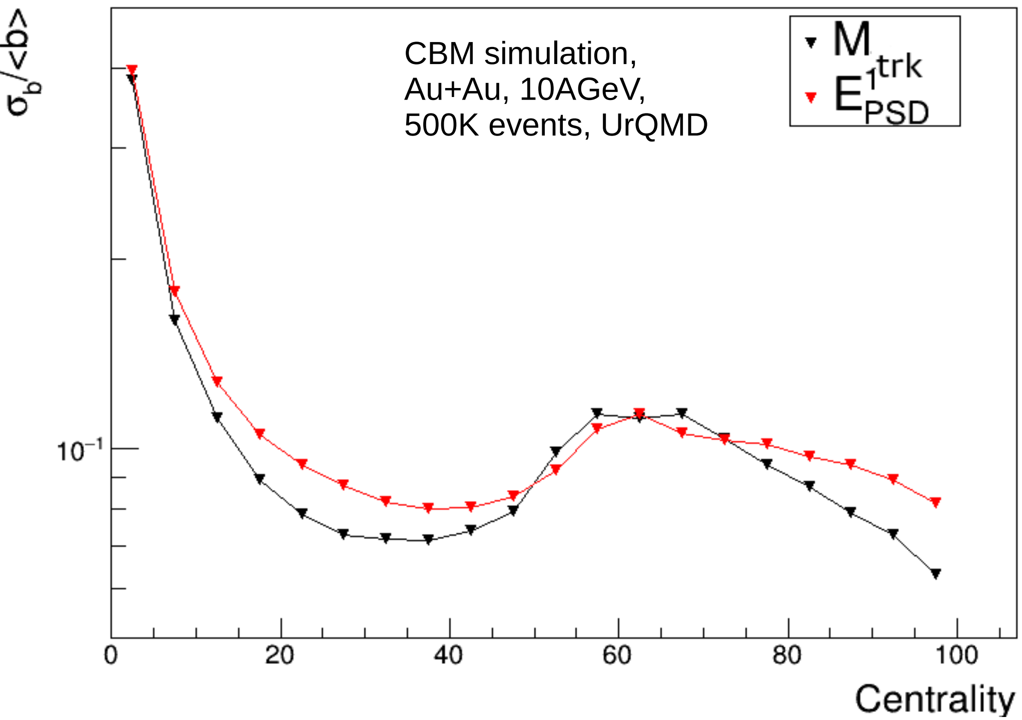
Centrality determination with PSD energy

Energy in central modules



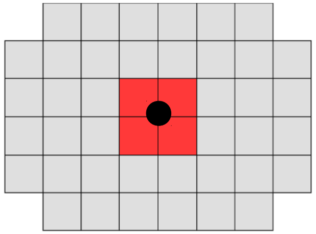
Impact parameter resolution with different centrality estimators



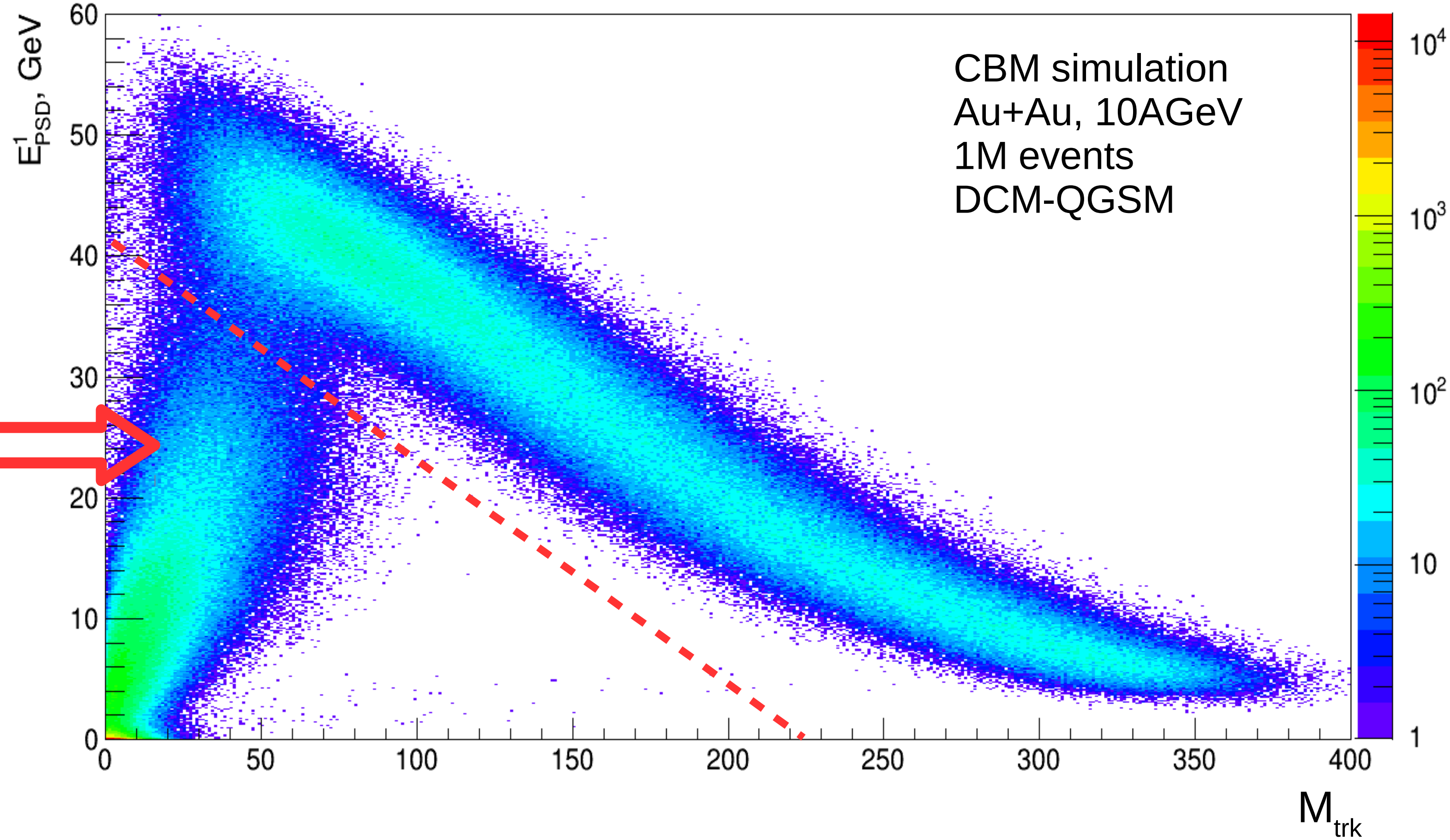


PSD is an independent centrality estimator.
Impact parameter resolution obtained with PSD1 is comparable to that of the STS for central events and by ~20% worse than for midcentral

Simulation with fragments

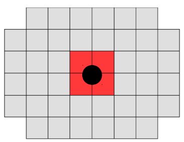


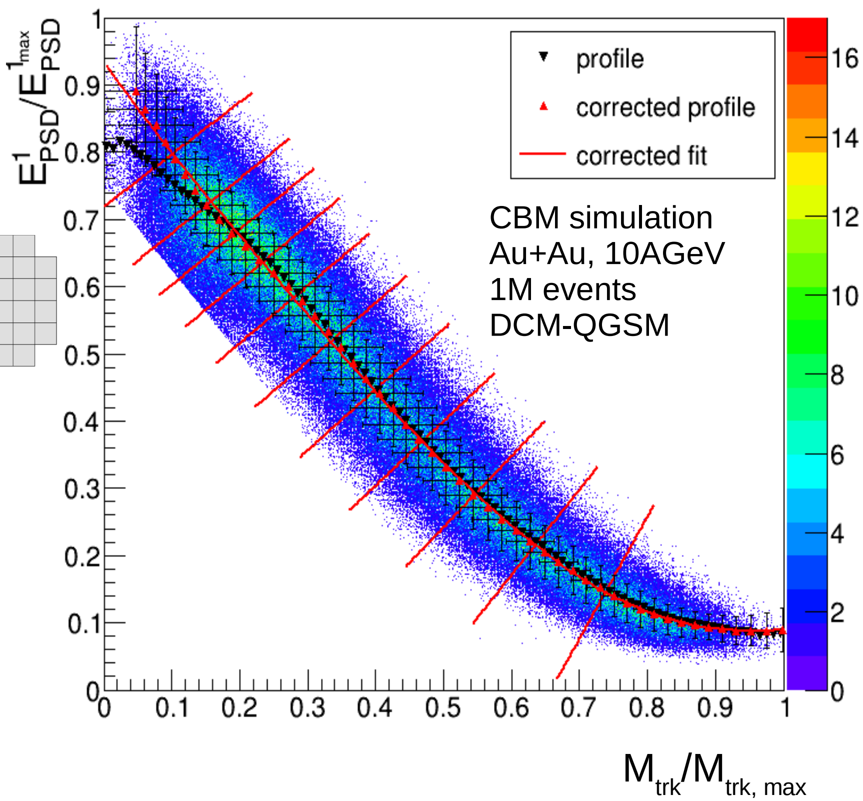
Correlation between energy in PSD and multiplicity in STS

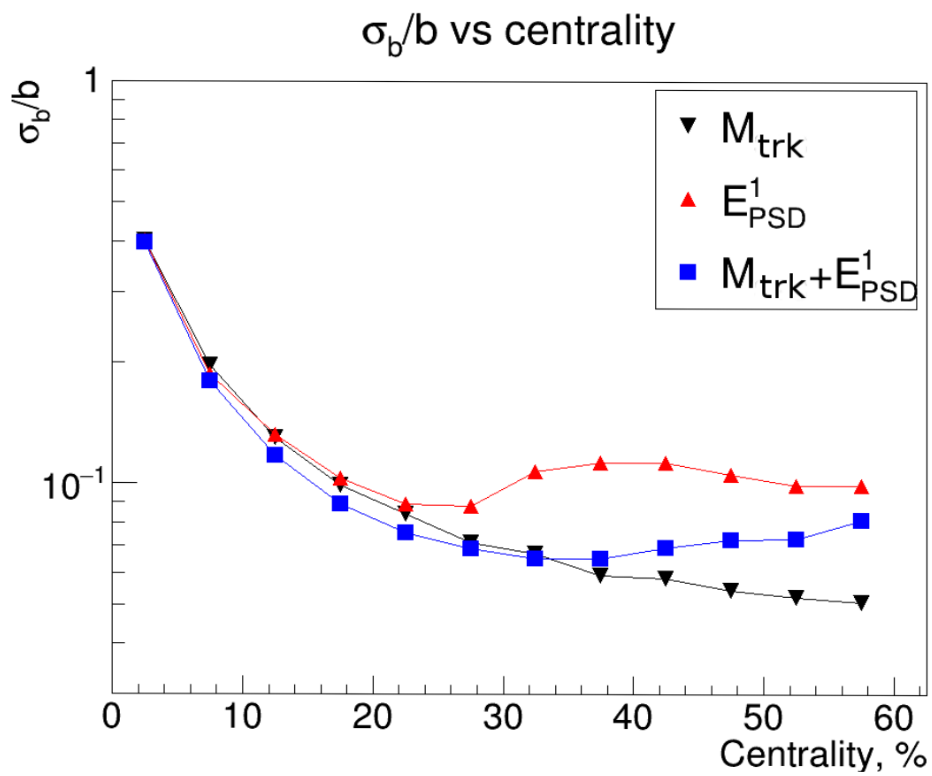


Apply cuts on correlation to remove events with fragments.
It introduces bias for centrality determination with PSD in very peripheral collisions

Combined centrality selection with PSD1 and STS







Centrality determinatıon procedure for 2D correlation:

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

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

Glauber Monte-Carlo fit

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

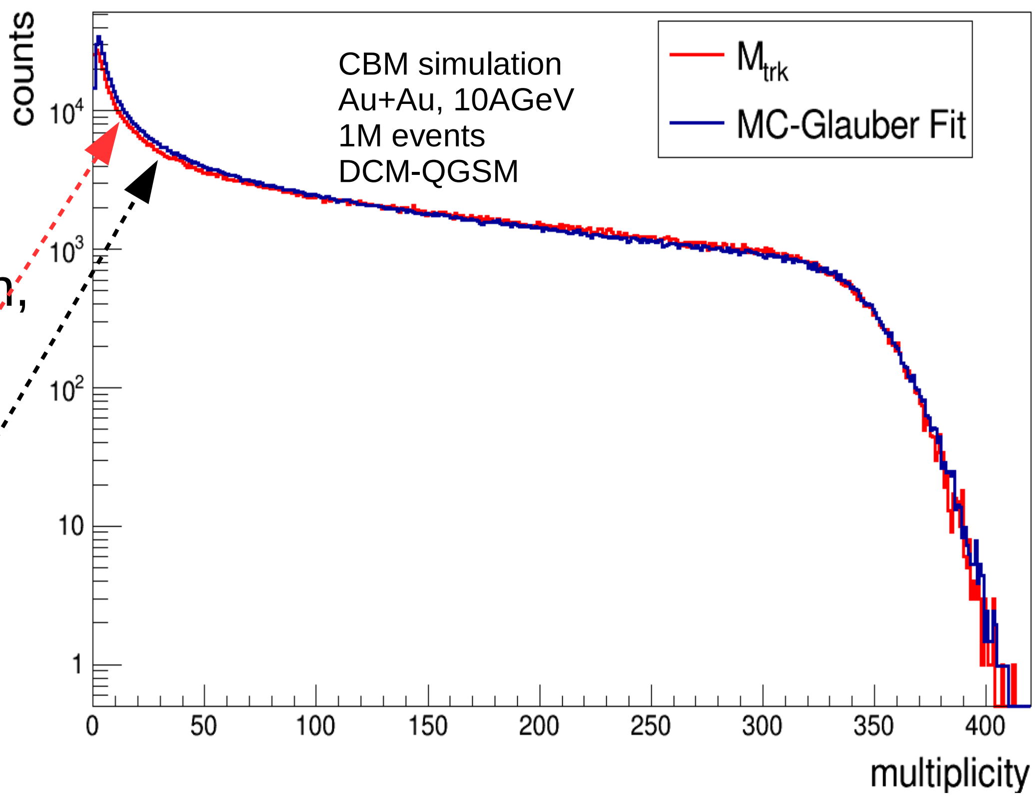
1. Fitting data with Glauber model based function:

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

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

2. Total cross-section estimation

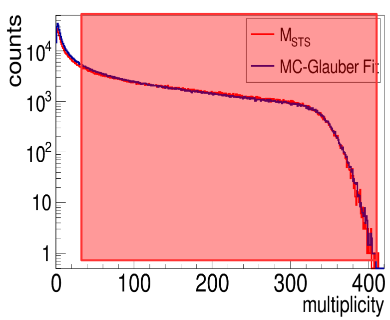
3. Determine the “anchor” point (deviation from the Glauber fit)



*ALICE IJMPA 29 (2014) 1430044

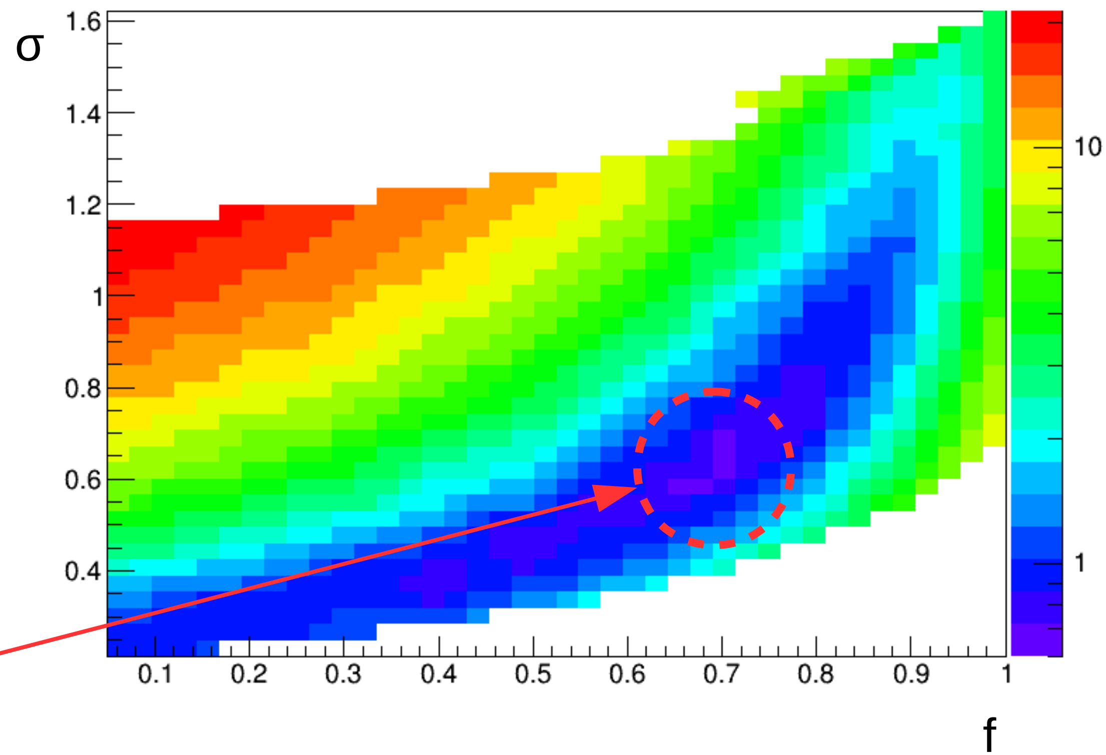
Self-consistency of the fitting algorithm

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

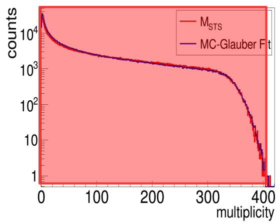
Ploted for best μ fit χ^2



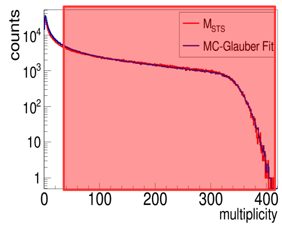
Minimal value for χ^2 corresponds to ***f ≈ 0.7, σ ≈ 0.6*** and ***μ ≈ 0.26*** which is close to real values ***f = 0.7, σ = 0.67*** and ***μ = 0.27***

Extracted values are sensitive to the fit range!

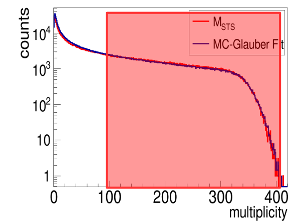
Glauber Monte-Carlo fit for different multiplicity ranges



M_{trk}>0



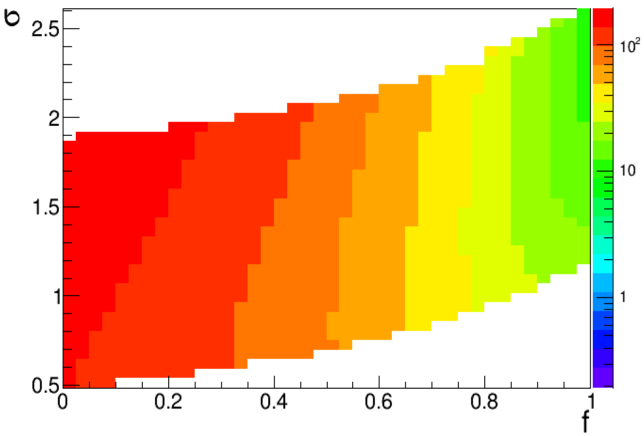
M_{trk}>20



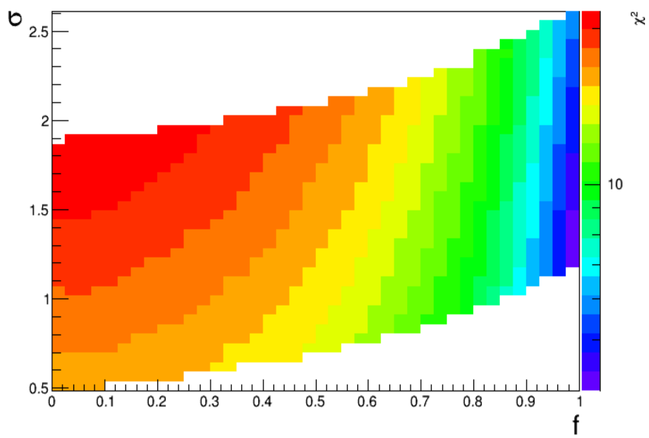
M_{trk}>60

χ^2

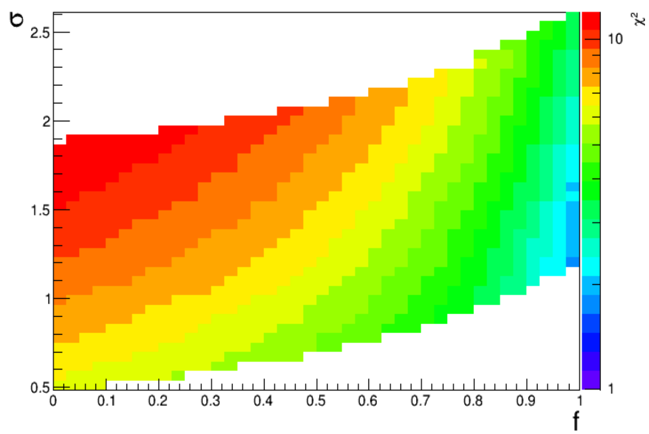
Ploted for best μ fit



χ^2



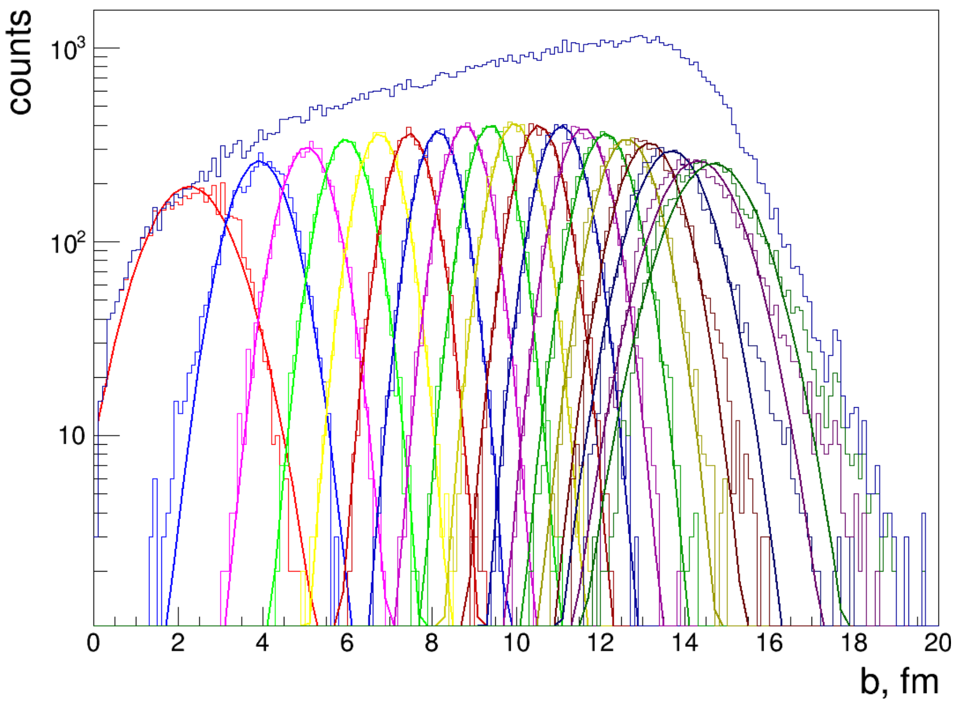
χ^2



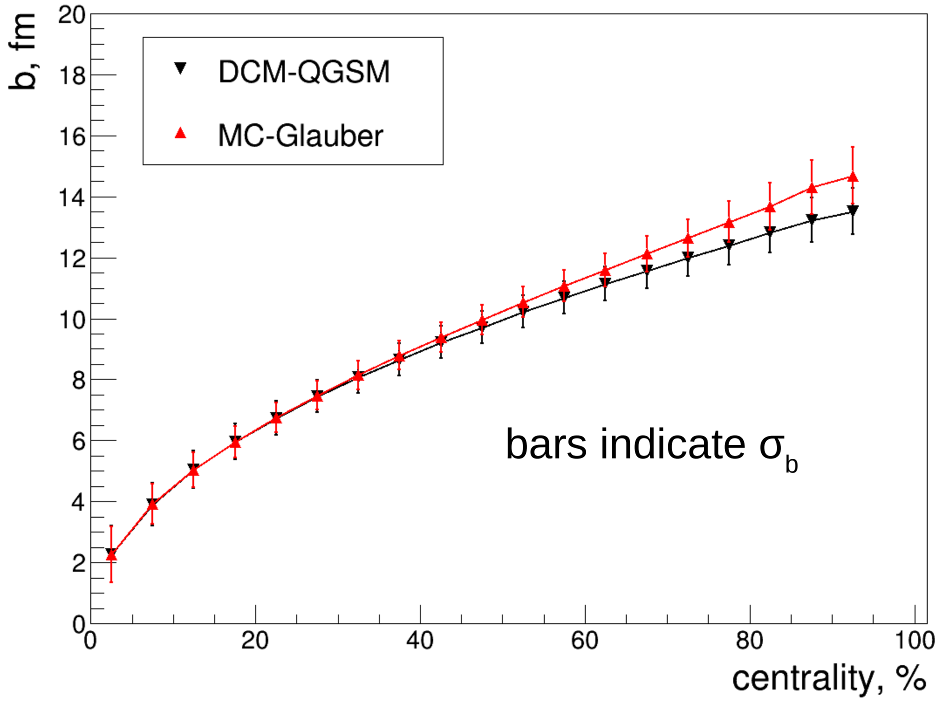
Best fit parameters are similar for different fit ranges.
The best fit corresponds to small contribution of N_{coll} (f=1).

Extract model parameters with MC-Glauber

Impact parameter distribution
in different centrality classes



Average impact parameter vs centrality



Extracted model parameters with MC-Glauber (both width and mean) are consistent with simulated DCM-QGSM values using multiplicity for centrality classes determination.
For peripheral (>50%) collisions small difference for mean is observed.

Procedure for centrality determination

1. Determine the total cross-section and the ”anchor” point (a value below which determination is not reliable) based on a fit with a Glauber model based function

2. Make all variables dimensionless

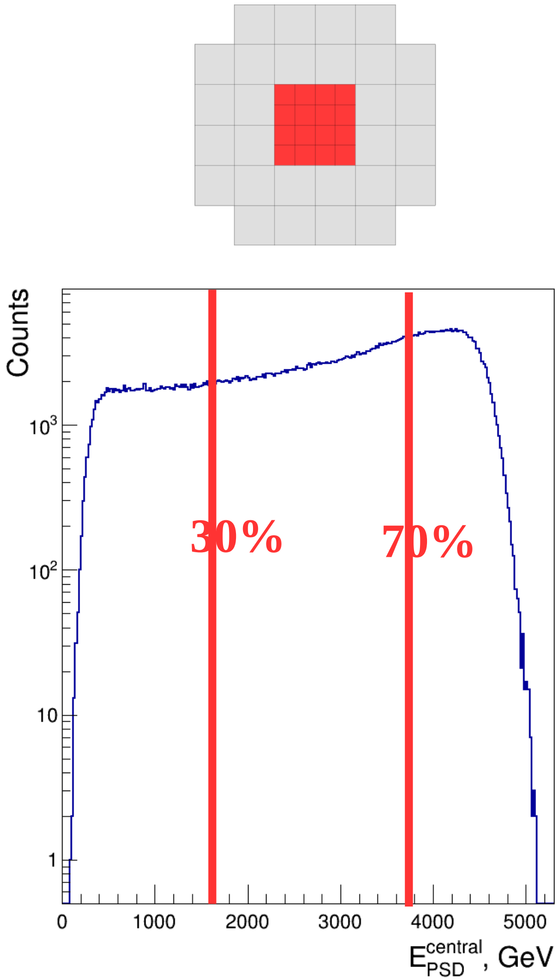
3. Parameterise the 2D correlation between multiplicity and/or PSD subgroup energies (in case of 2D analysis)

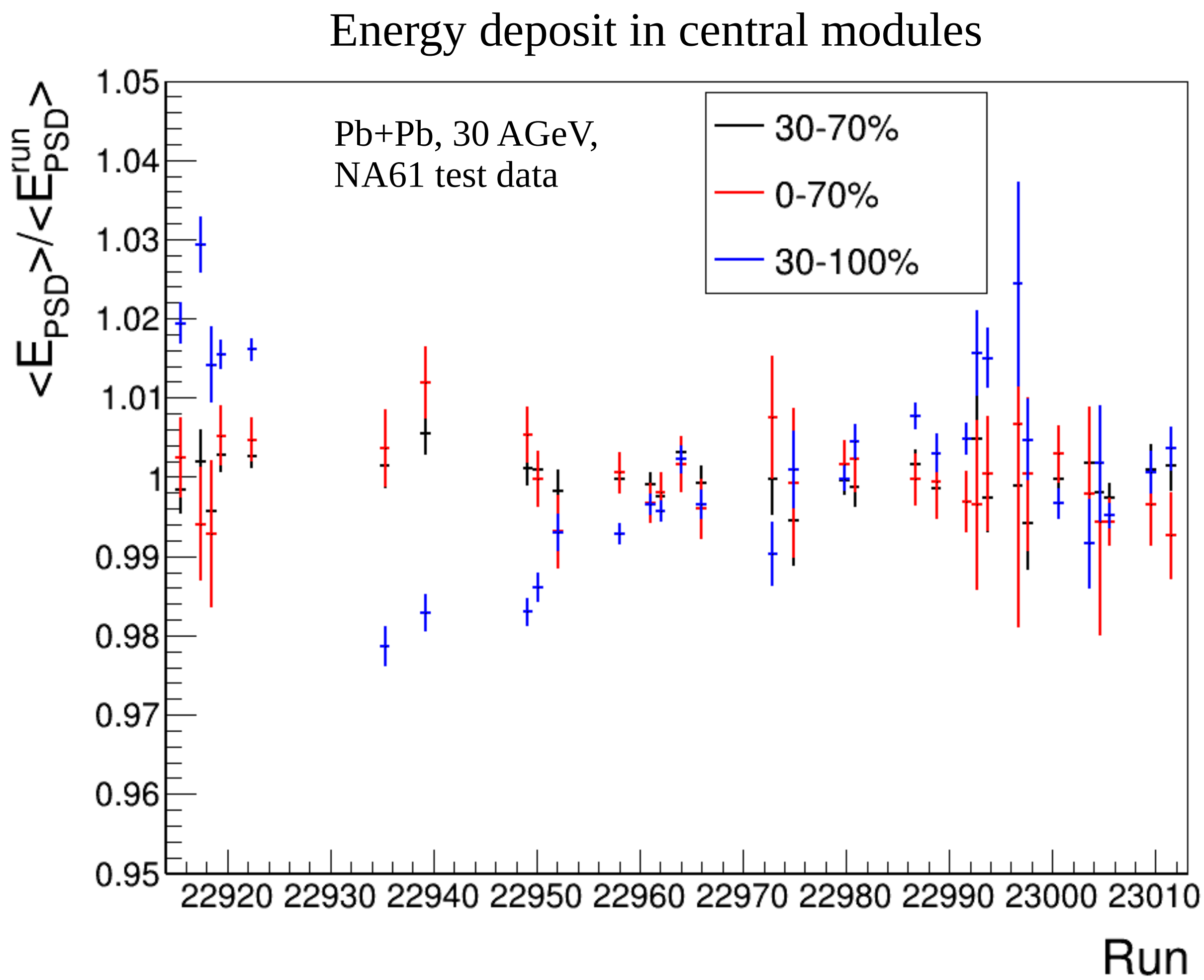
4. Slice the 2D correlation or 1D distribution

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

Testing the procedure with real data
(NA61/SHINE)

In reality performance of the detectors changes with time (detector gain variations, beam parameters variations, etc)





Run-by-run correction procedure was implemented for CBM

Summary

- Centrality Framework was developed for CBM. It includes the following components:
  - Centrality determination based on energy in PSD and track multiplicity
  - MC-Glauber fitting procedure to determine the total cross-section and the ”anchor” point
  - Run-by-run equalization of centrality estimators
- Centrality Framework was tested with CBM simulations and NA61/SHINE Pb+Pb test data
  - The impact parameter resolution obtained with the PSD centrality estimation is comparable to that of the STS
  - PSD usage is limited due to loss of fragments in a beam hole

Next steps:

- Expand model parameters estimation for selection with PSD and correlation