Centrality determination method in nuclear collisions by using hadron calorimeter

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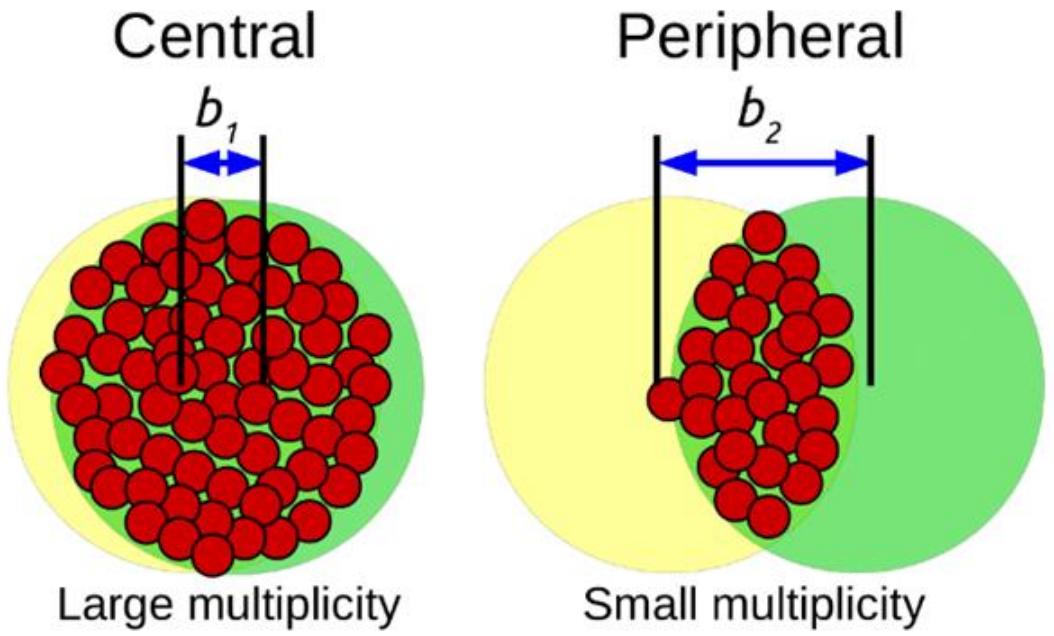
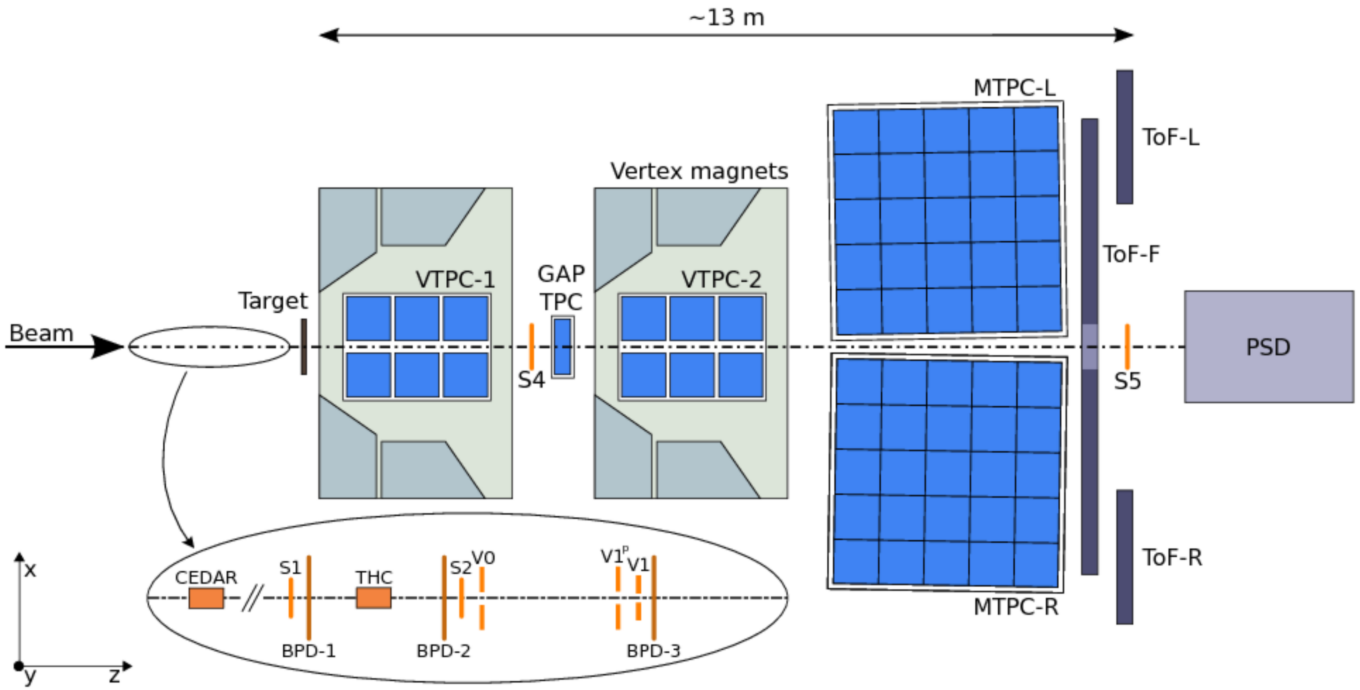
Initial geometry of HIC

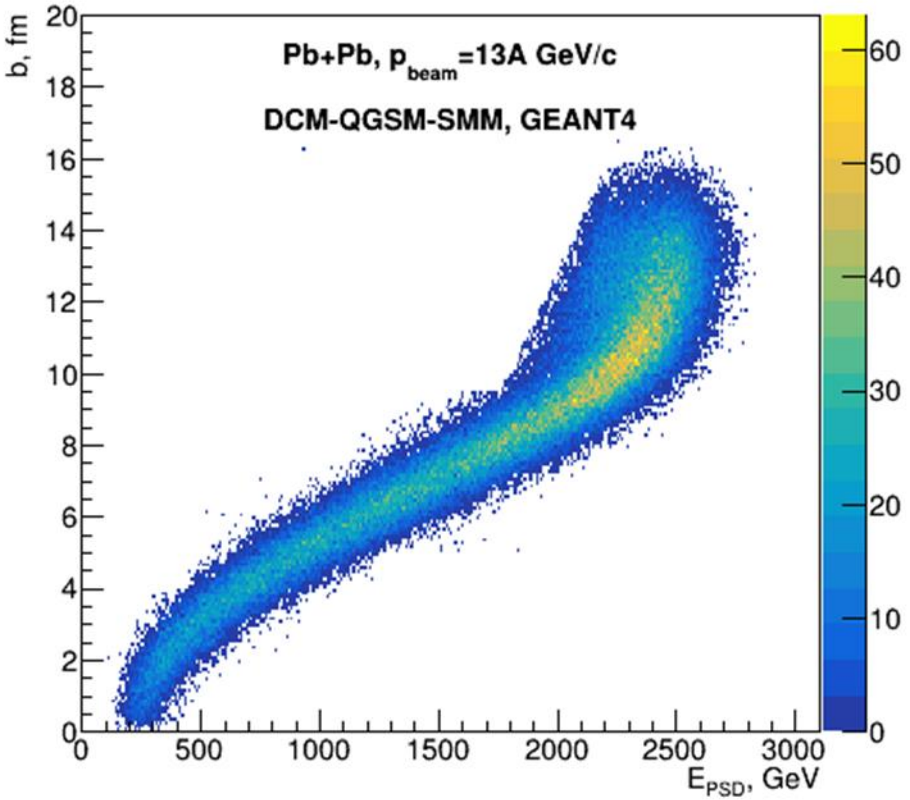
- Evolution of matter produced in heavy-ion collisions depends on its initial geometry
- Centrality procedure maps initial geometry parameters with measurable quantities
- **This allows comparison of the future MPD results with the data from other experiments (STAR BES, NA49/NA61) and theoretical models**

- **Collision geometry**
- **Models:**
  Impact parameter *b*
- **Measurable quantities (Experiment):**
  - Multiplicity or transverse energy of the produced particles
  - Energy of the spectators



NA61/SHINE experimental setup





Subsystems

- Multiplicity: TPCs
- Spectators energy: PSD

Data samples:

- Pb-Pb @ p_{beam} = 13A GeV/c, (2016 physics run)
- DCM-QGSM-SMM x Geant4 (rec. data)

M.Baznat et al. PPNL 17 (2020) 3, 303

The Bayesian inversion method (Γ-fit): main assumptions

- Relation between energy E and impact parameter b is

defined by the fluctuation kernel:

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

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

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

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

$$\langle E \rangle = \mu_1 \langle E'(c_b) \rangle + \lambda_1, \quad D(E) = \mu_2 D(E'(c_b))$$

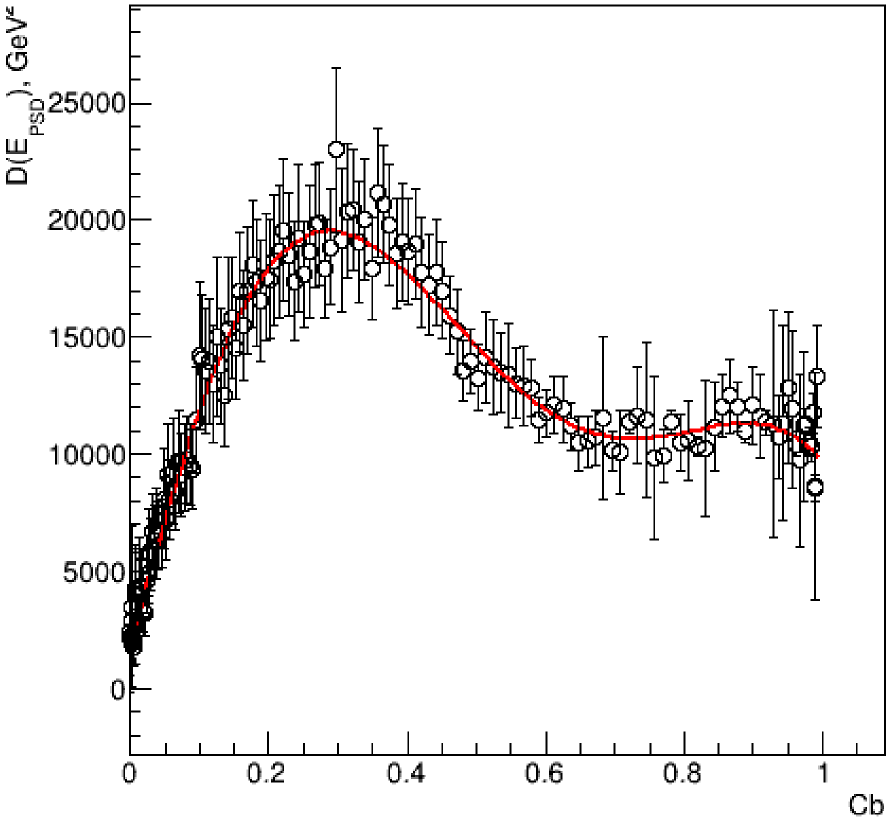
$\langle E'(c_b) \rangle, \quad D(E'(c_b))$ – average value and variance of energy from the rec. model data

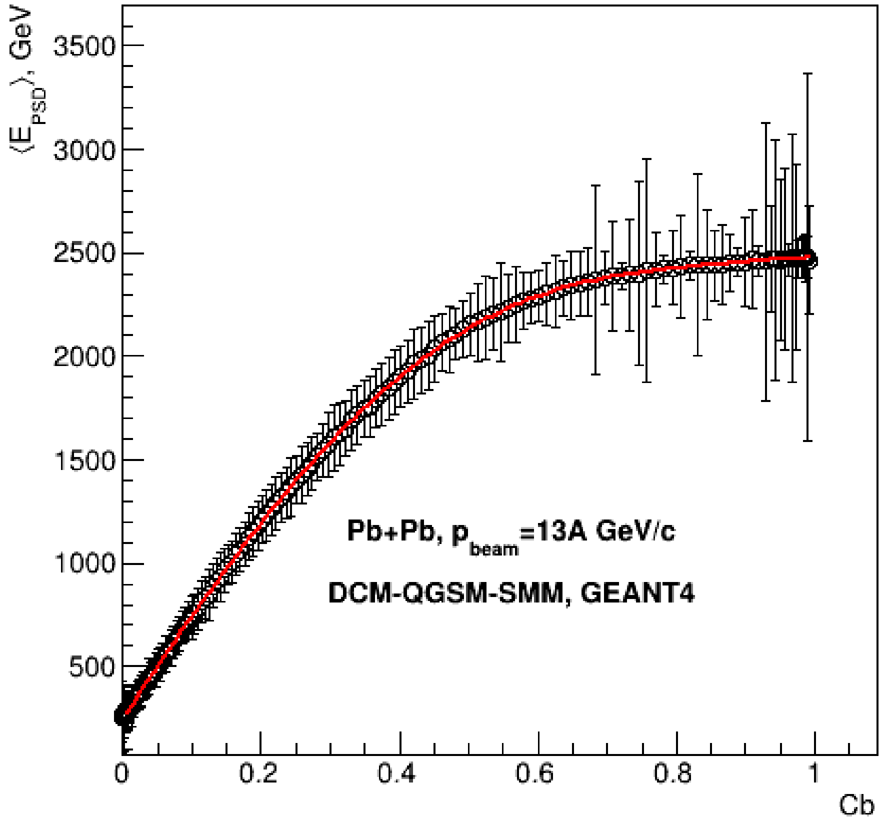
Three fit parameters μ_1, μ_2, λ_1

$\langle E'(c_b) \rangle, \quad D(E'(c_b))$ - can be approximated by polynomial

$$\langle E'(c_b) \rangle = \sum_{j=1}^{8} a_j c_b^j, \quad D(E'(c_b)) = \sum_{j=1}^{6} b_j c_b^j$$

Dependence of the average value and variance of energy on centrality





The average value and dispersion of energy from the DCM-QGSM-SMM model are well described by polynomials

Reconstruction of *b*

- Normalized energy distribution P(E)

$$P(E) = \int_0^1 P(E \mid c_b)\, dc_b$$

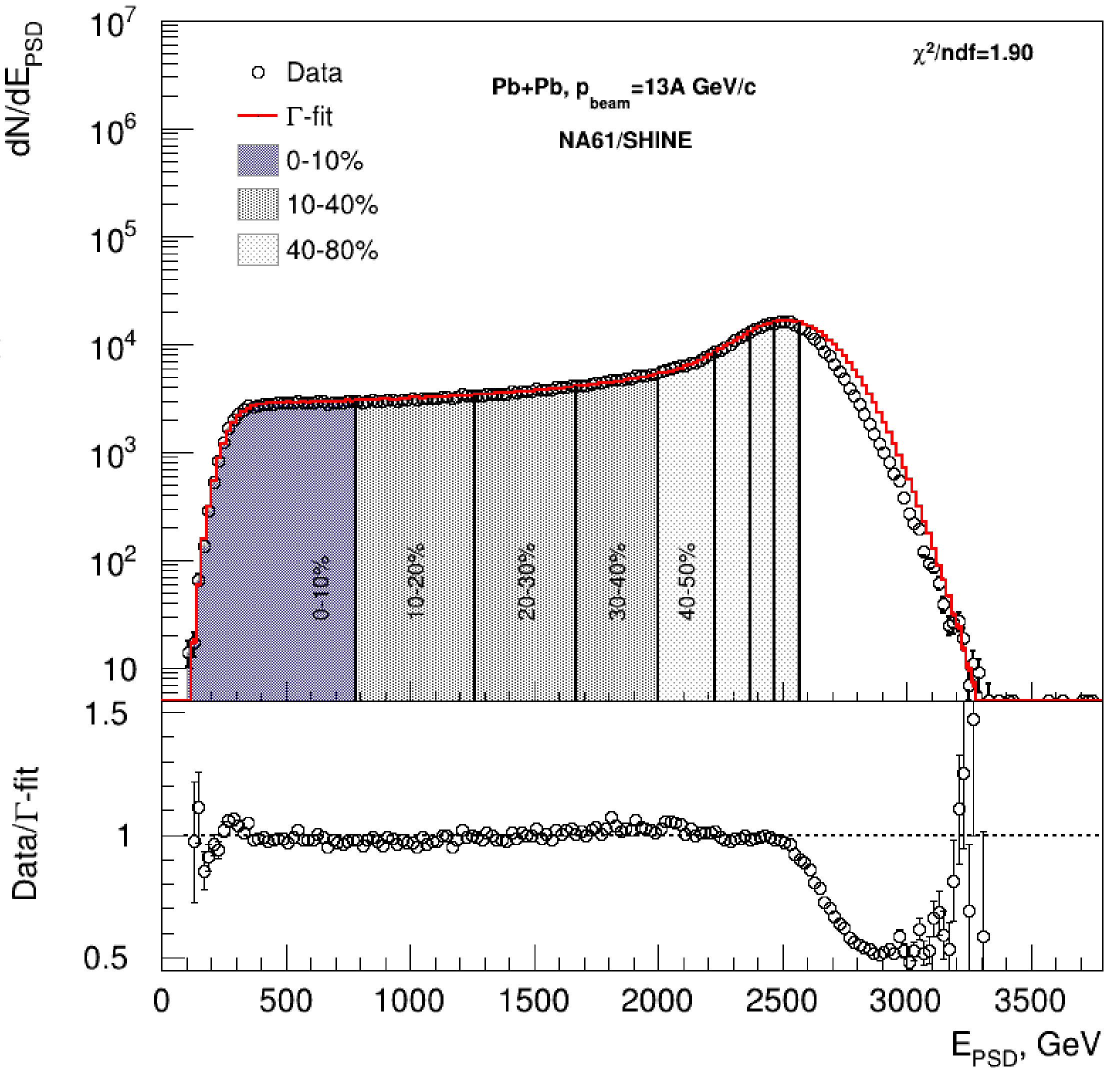
- Find probability of *b* for fixed range of E using Bayes' theorem:

$$P(b \mid E_1 < E < E_2) = P(b) \frac{\int_{E_1}^{E_2} P(b \mid E)\, dE}{\int_{E_1}^{E_2} P(E)\, dE}$$

- **The Bayesian inversion method consists of 2 steps:**

–Fit normalized energy distribution with P(E)

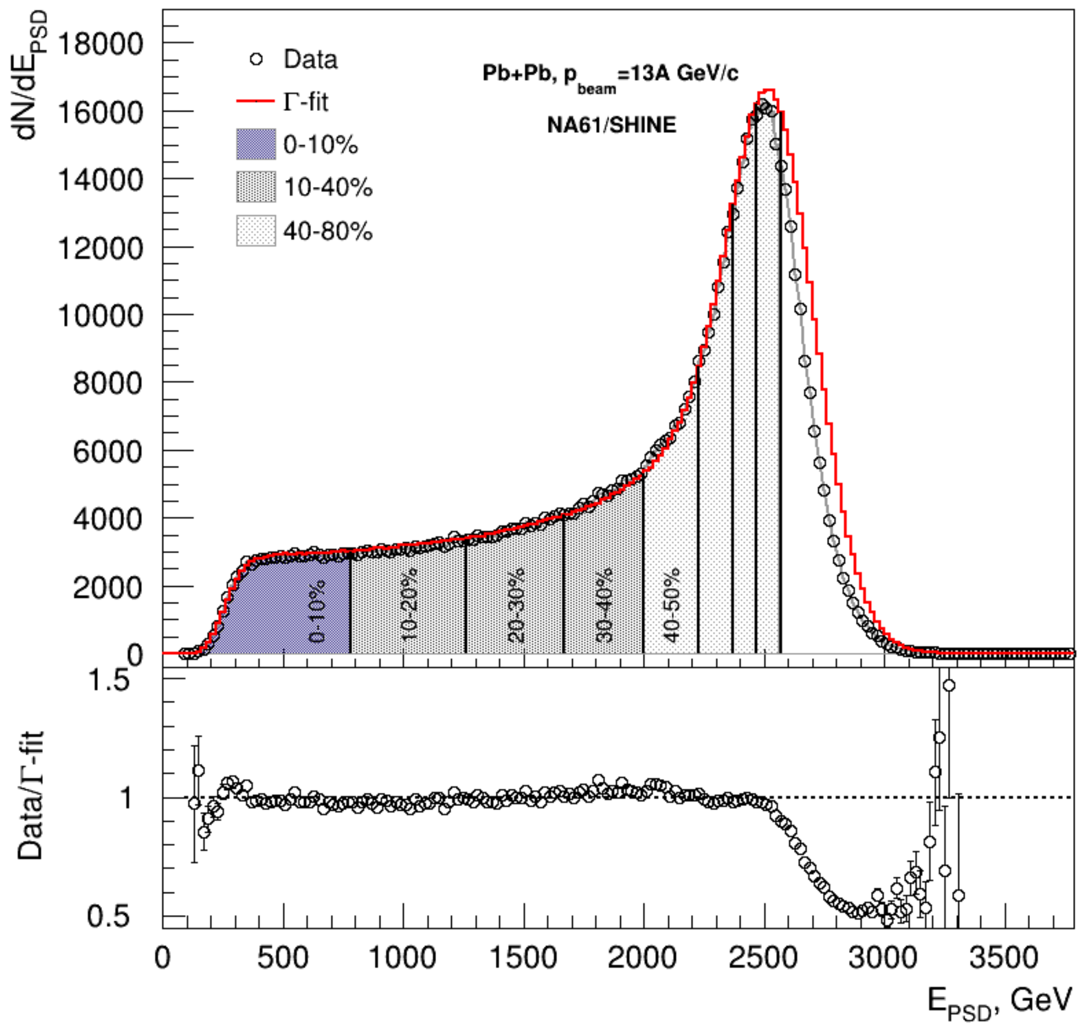
–Construct P(*b*|E) using Bayes' theorem with parameters from the fit



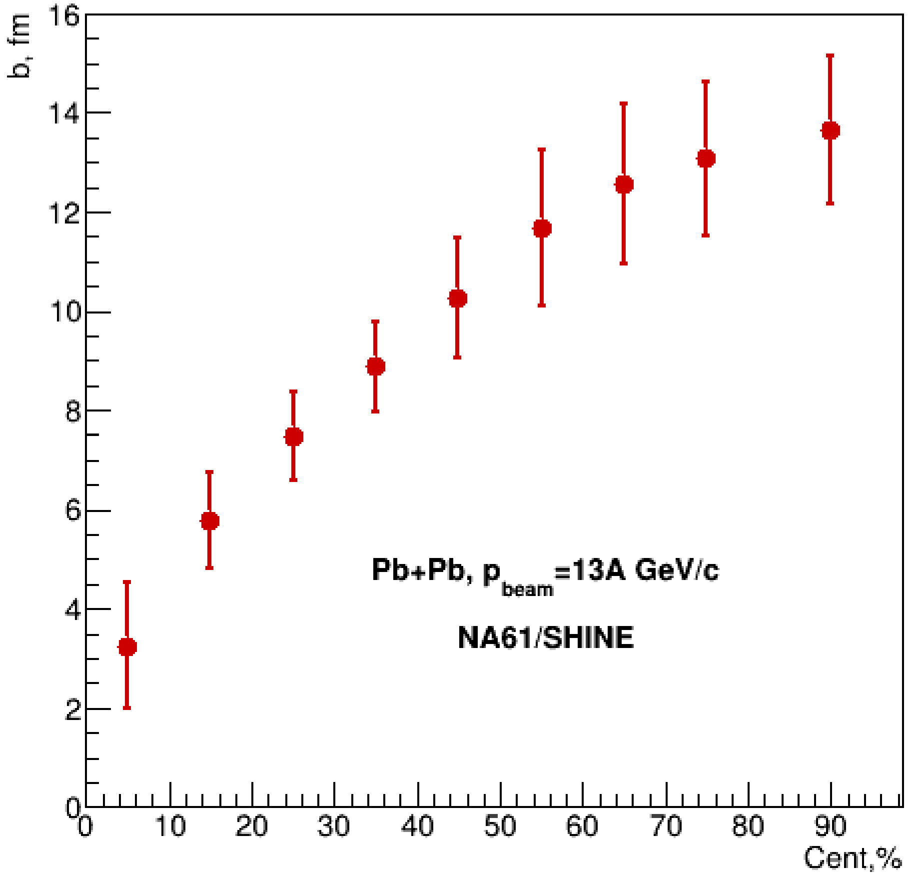
Good agreement between fit and data in wide energy range

Rudolph Rogly, et al., Phys. Rev. C 98, 024902

Fit results for NA61

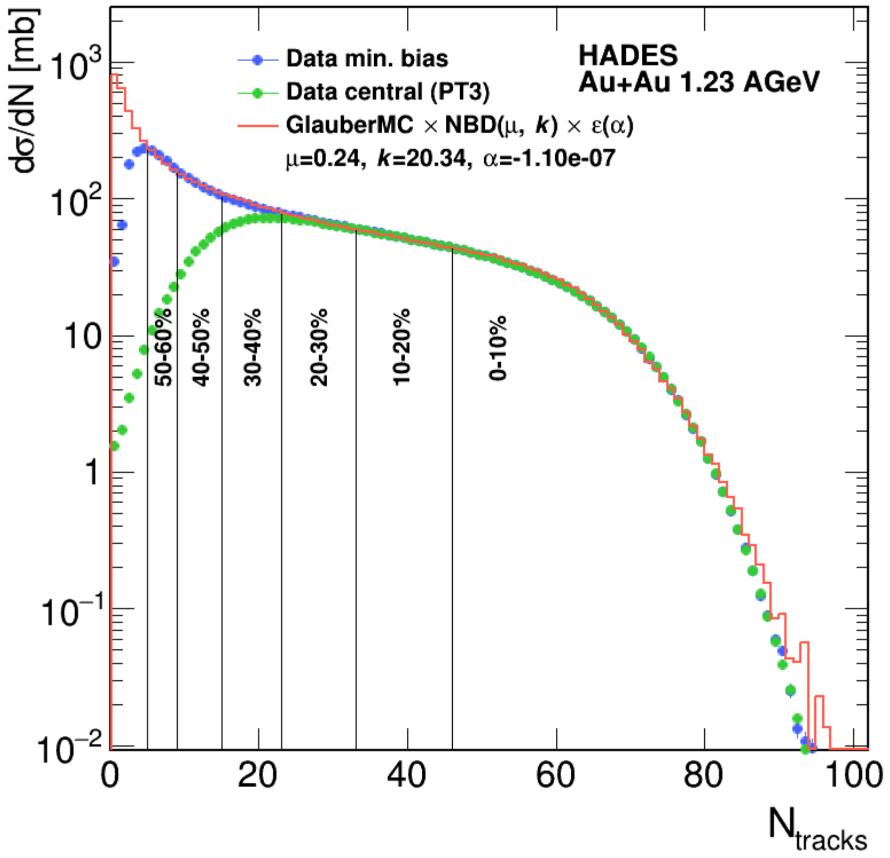


The method reproduces the energy distribution well.
The difference in the peripheral region is due to the trigger efficiency



The distribution width of the impact parameter increases in the peripheral region

Centrality determination in the FIX-target experiments



The cross section as a function of Ntracks for minimum bias (blue symbols) and central (PT3 trigger, green symbols) data in comparison with a fit using the Glauber MC model (red histogram).

In order to take additional, non-linear multiplicity dependent inefficiencies into account, a phenomenological efficiency function **$\varepsilon(\alpha) = 1-\alpha \cdot Npart^2$** was used.

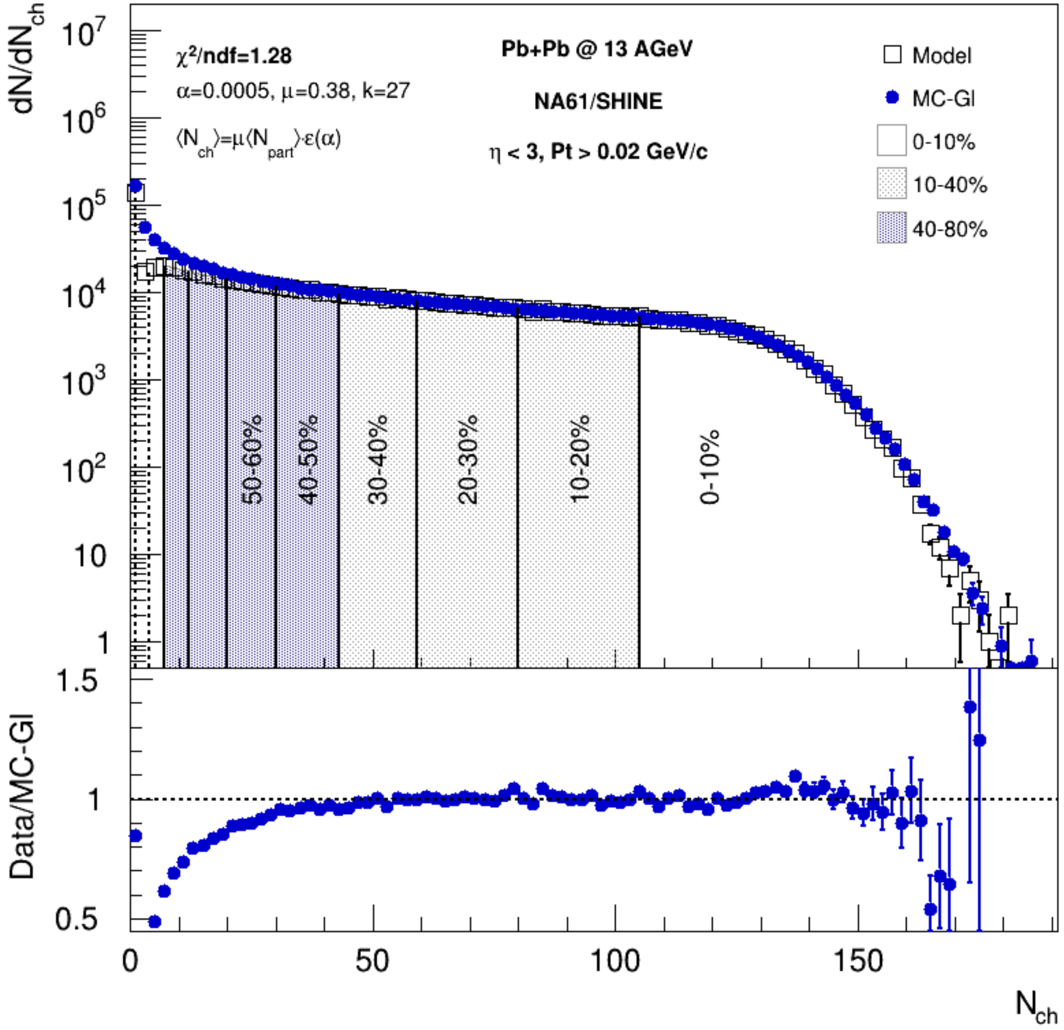
This function models the efficiency for charged tracks obtained from simulated data with the transport model UrQMD and GEANT3.3 for detailed simulation of the detector response

https://arxiv.org/abs/1712.07993

MC-Glauber based centrality framework

MC Glauber data → Evaluate N_a: $N_a = N_{part}$ → Call $NBD(\mu,k) \times N_a \times \varepsilon(\alpha)$ → Build multiplicity fitting function

Input multiplicity distribution → Evaluate χ^2 → Minimize χ^2 to find α, μ, k



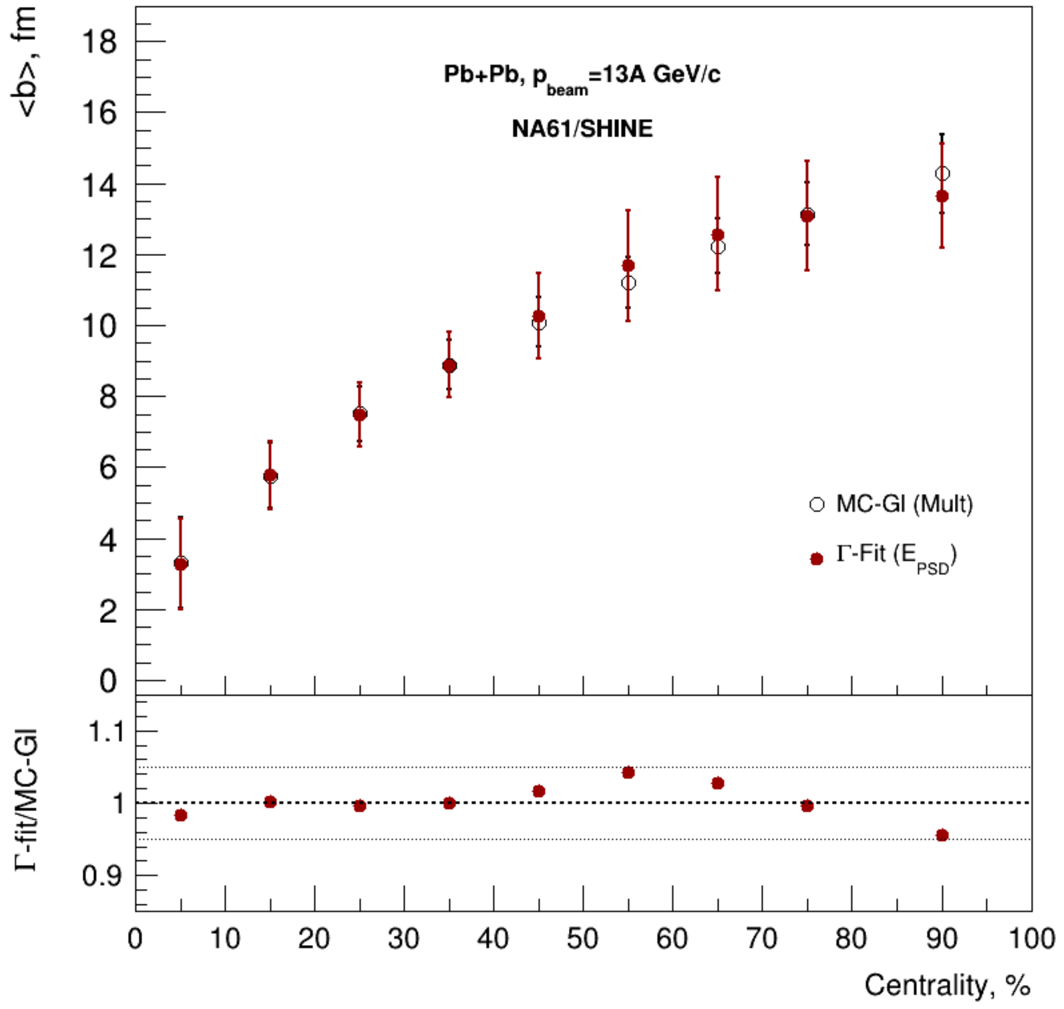
NBD – negative binomial distribution

- **α** – coefficient in efficiency function
- **μ** – mean multiplicity value
- **k** – width of the multiplicity distribution, can be connected to the fluctuations

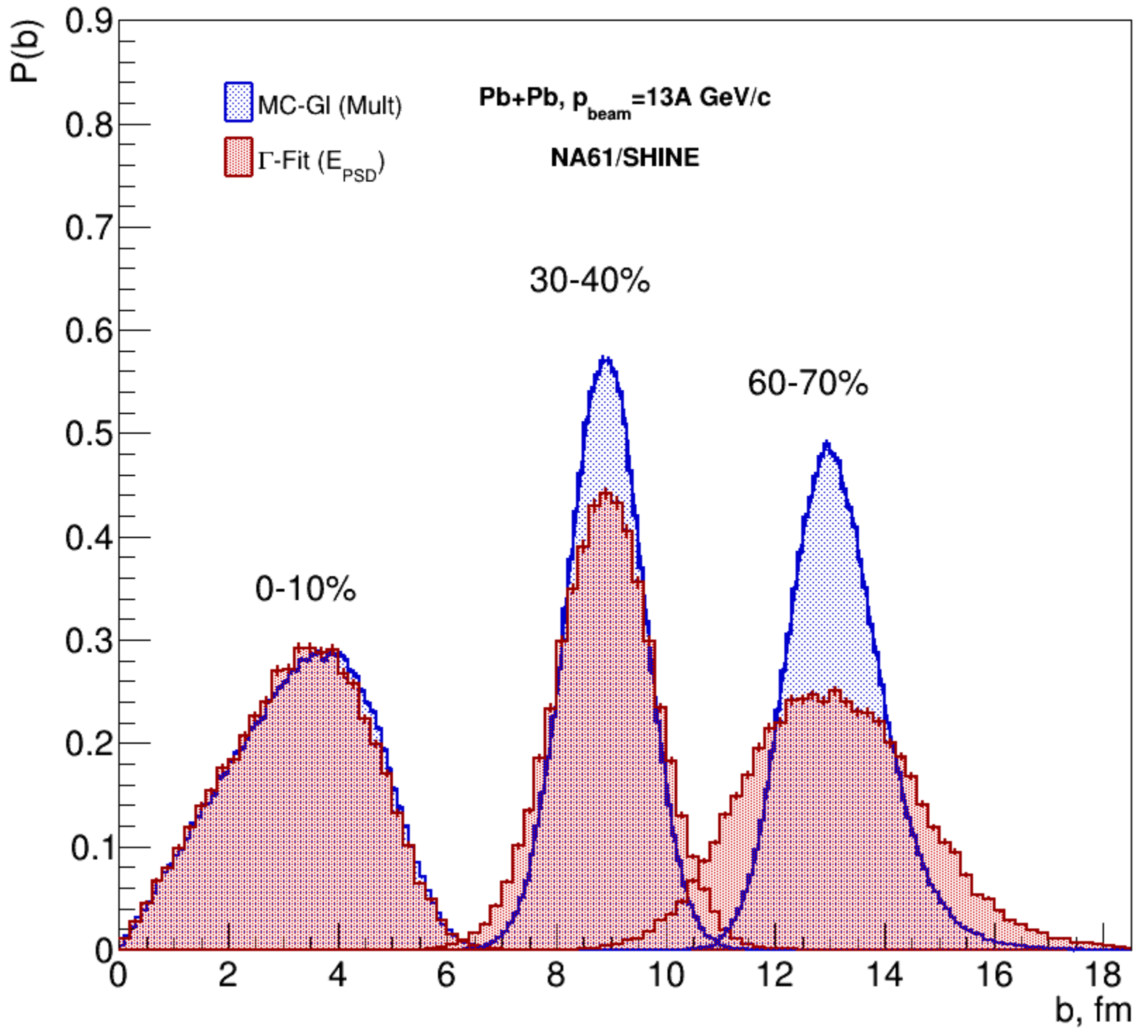
Implemantation for MPD: https://github.com/FlowNICA/CentralityFramework

P. Parfenov, et al., Particles. 2021; 4(2):275-287

Comparison with MC-Glauber fit



There is agreement within 5%.



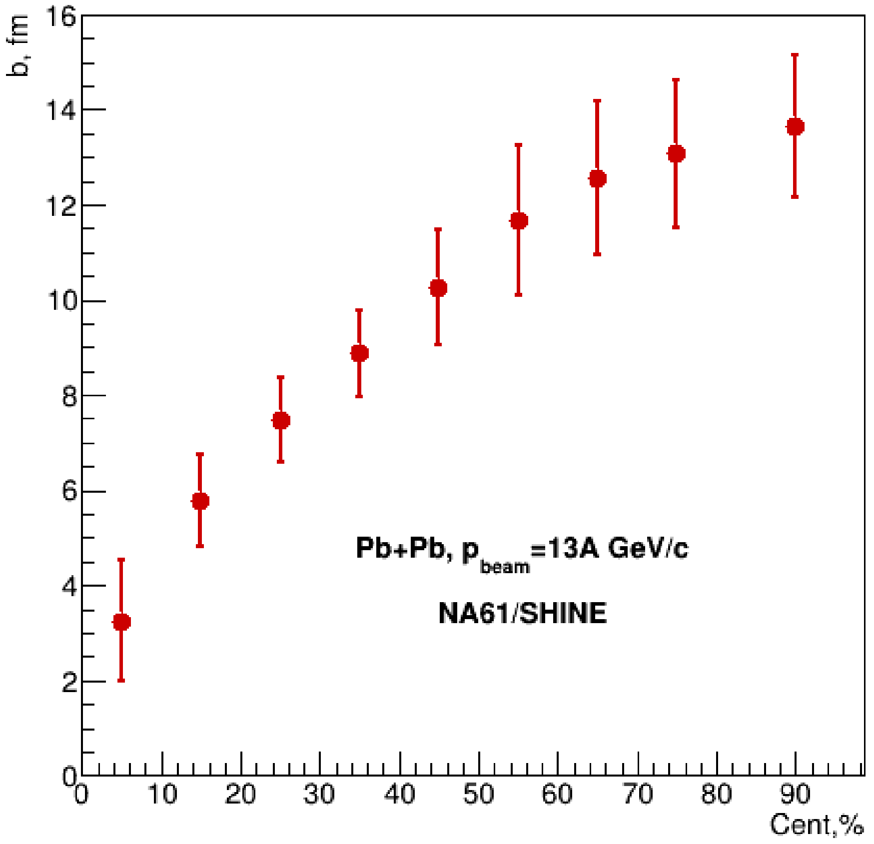
The difference in the width of distributions increases in the peripheral region

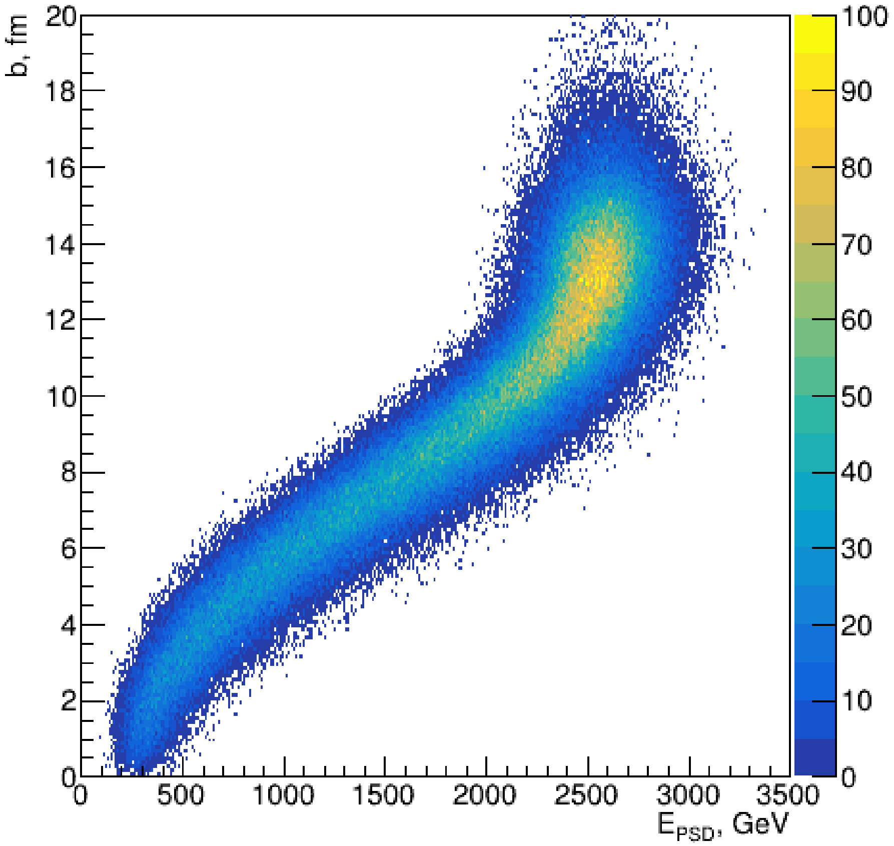
Summary and outlook

- A new approach was proposed for centrality determination with energy of spectators
- Centrality determination procedure was tested on NA61/SHINE data
- The results are in good agreement with the classical approach based on the MC-Glauber method
- Investigate the effectiveness of the method at higher energies
- Modification of the proposed method for use at BM@N and MPD experiments
- Comparison with other methods for determining centrality

Thank you for your attention!

Correlation between energy and impact parameter(Fit)





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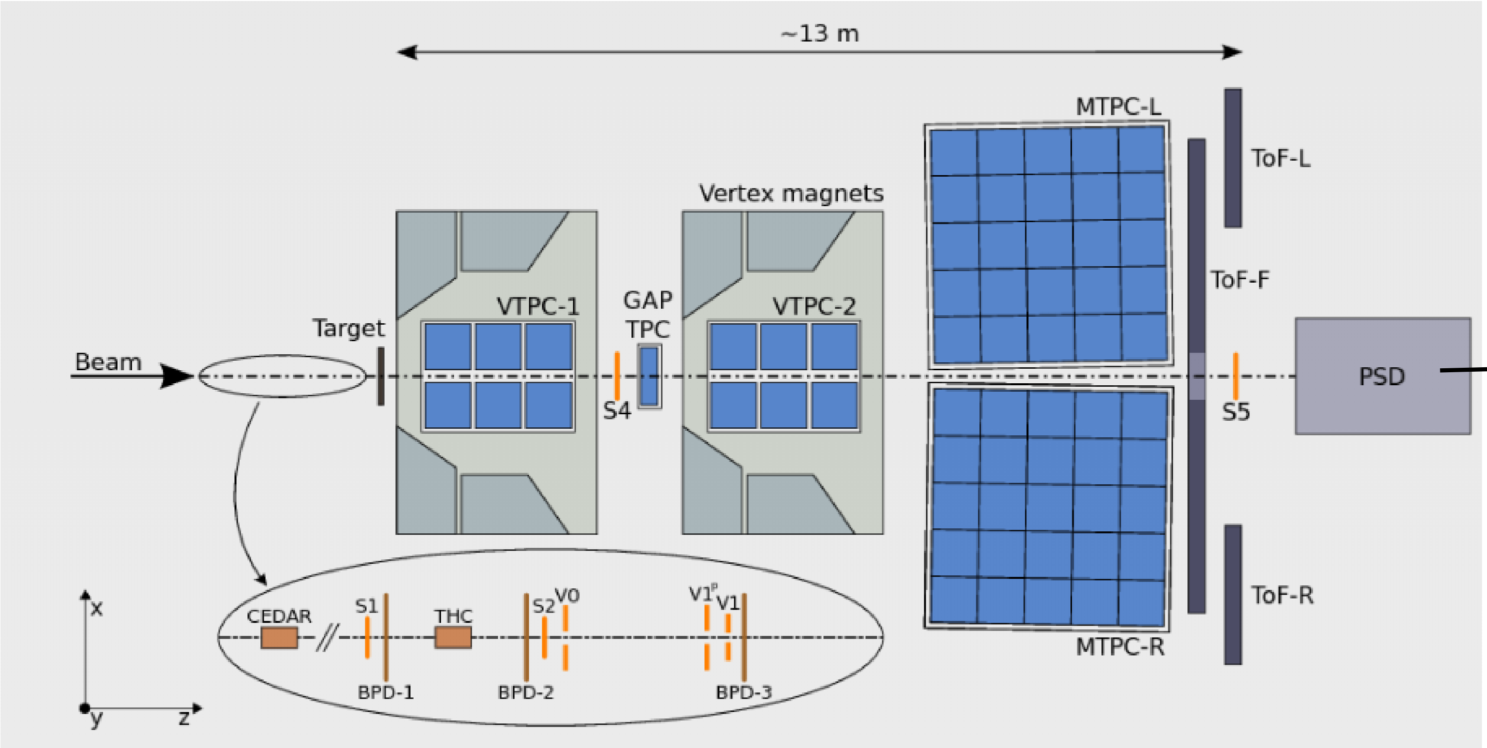

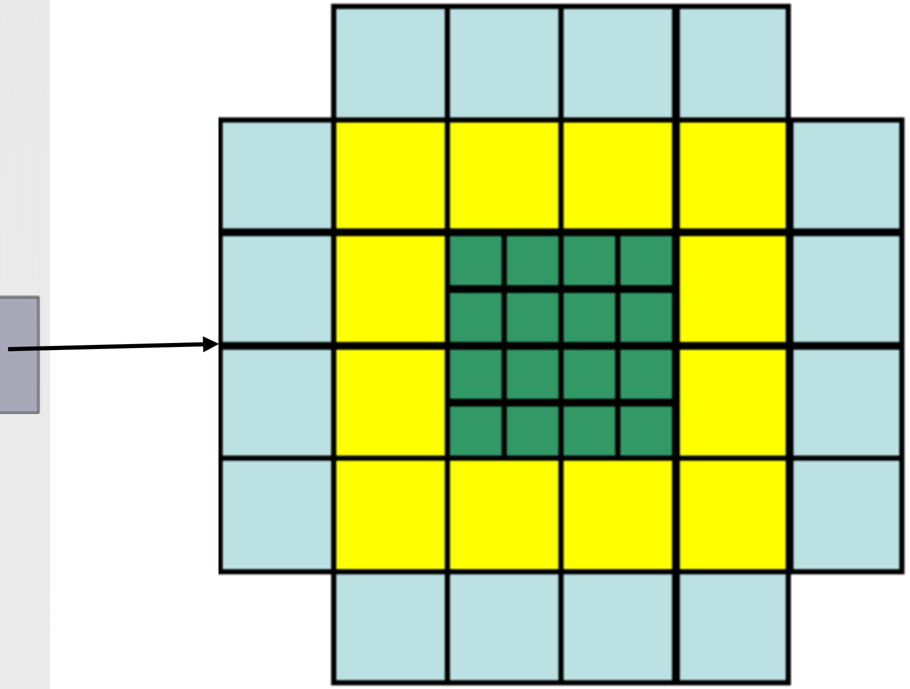

PSD detector layout

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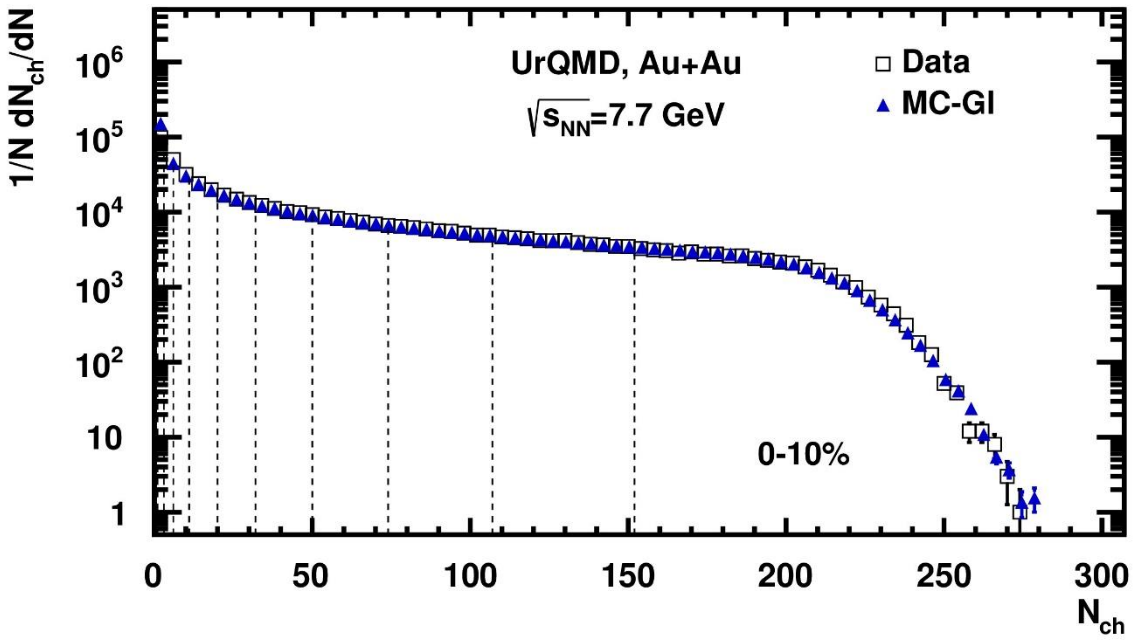

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This centrality procedure was used in CBM, NA49, and NA61/SHINE:
I. Segal, et al., J.Phys.Conf.Ser. 1690 (2020) 1, 012107
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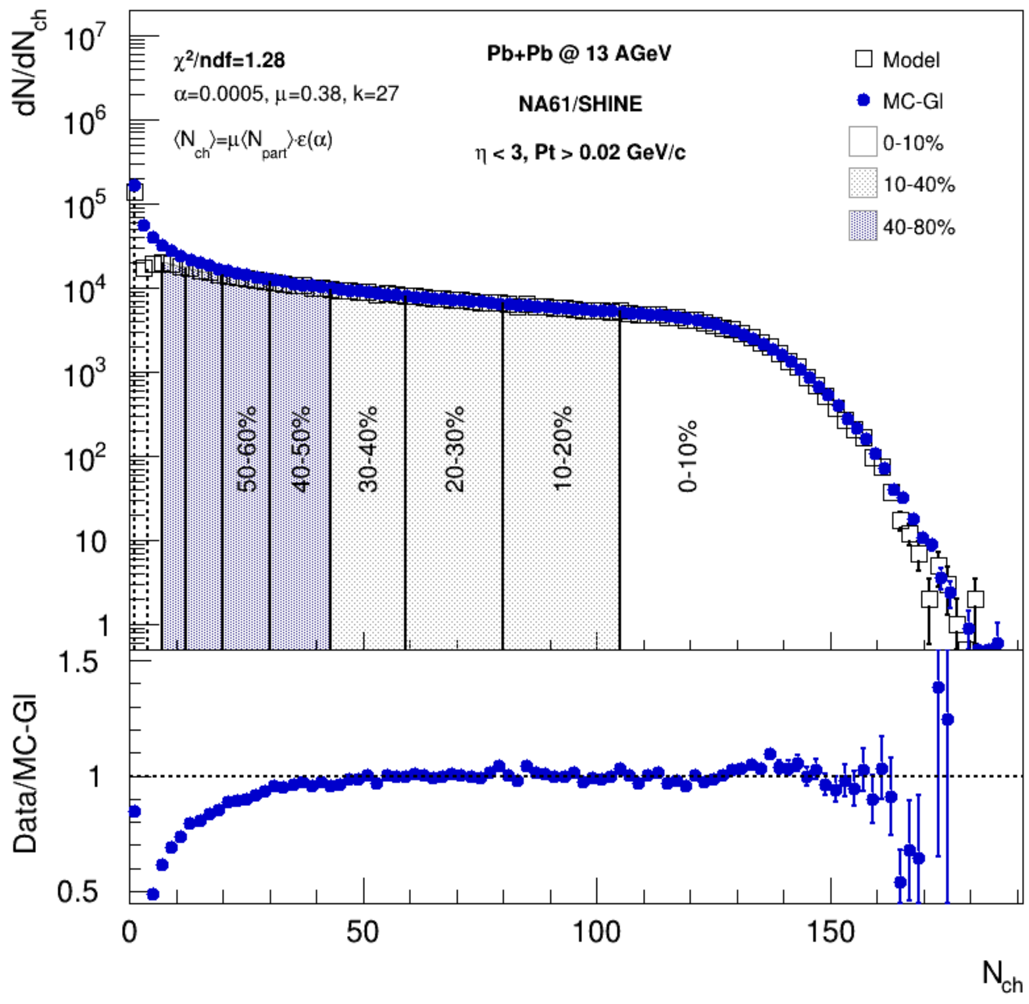

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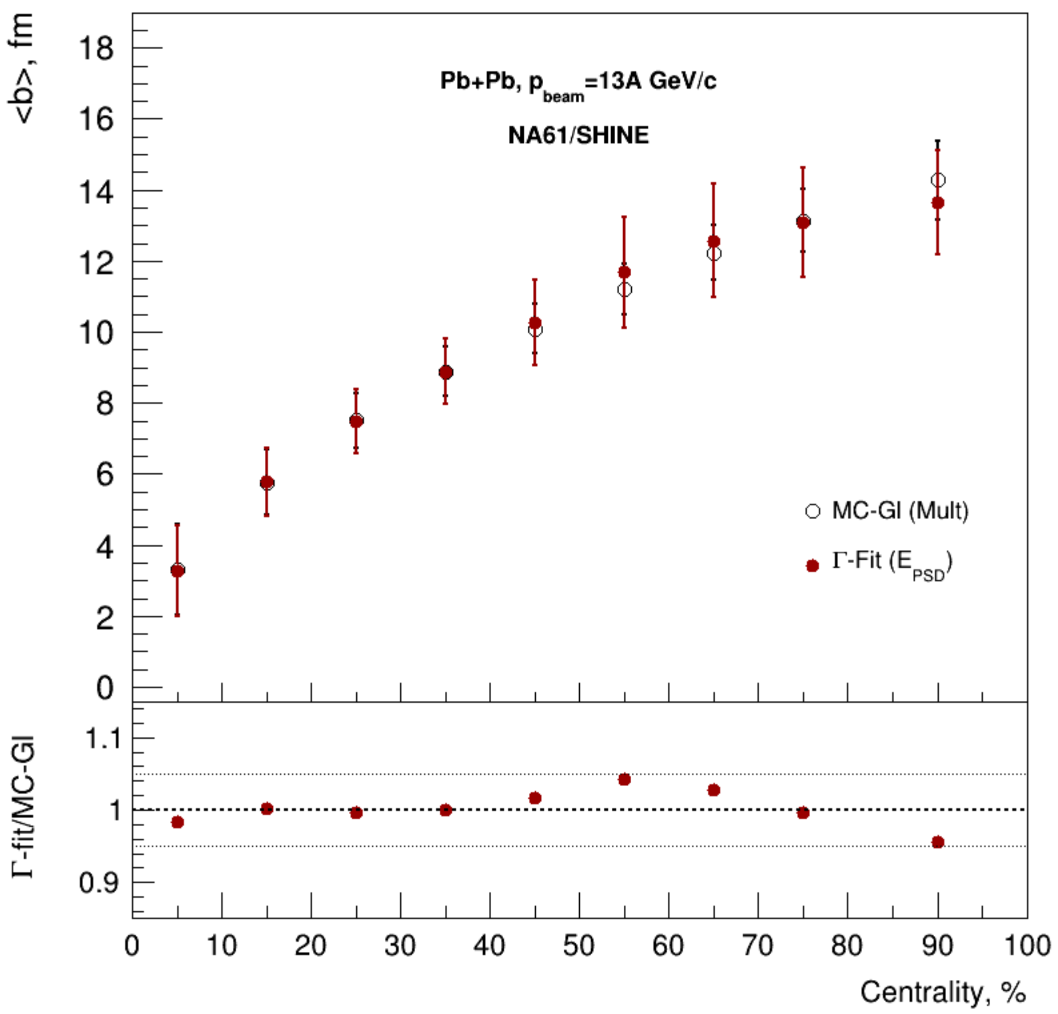

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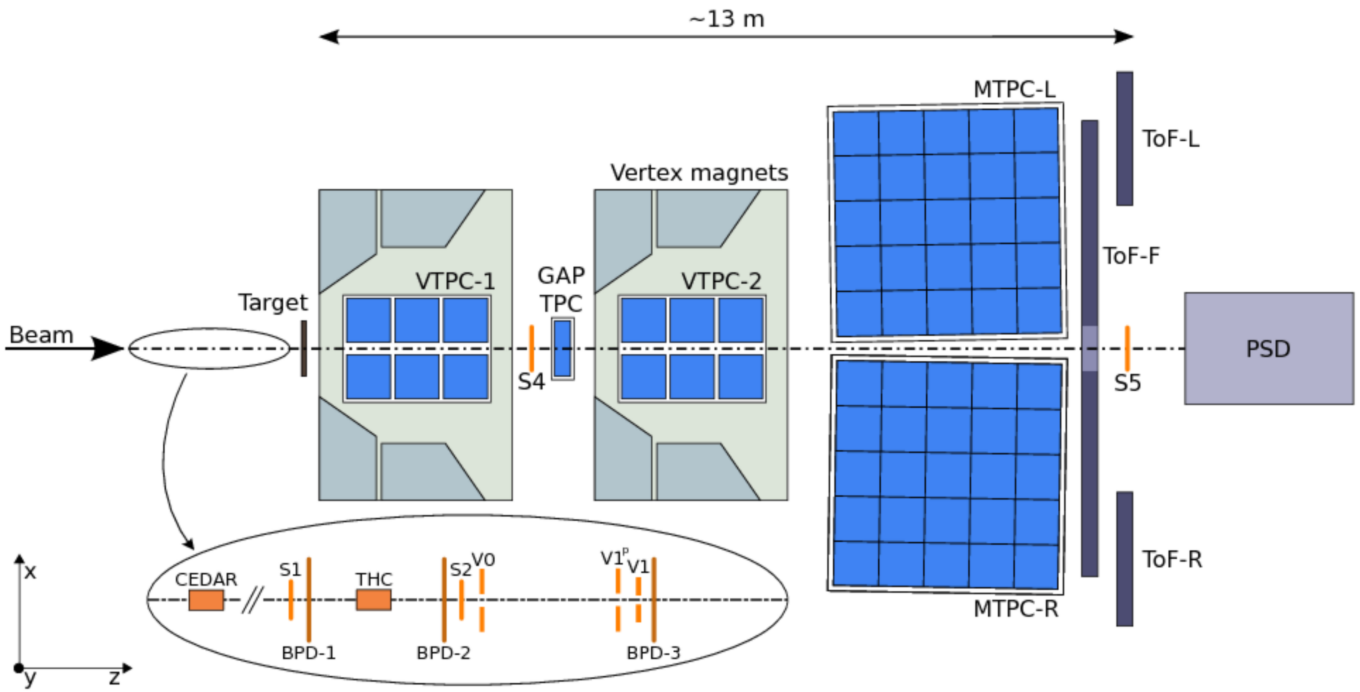
The layout of the NA61/SHINE experimental setup



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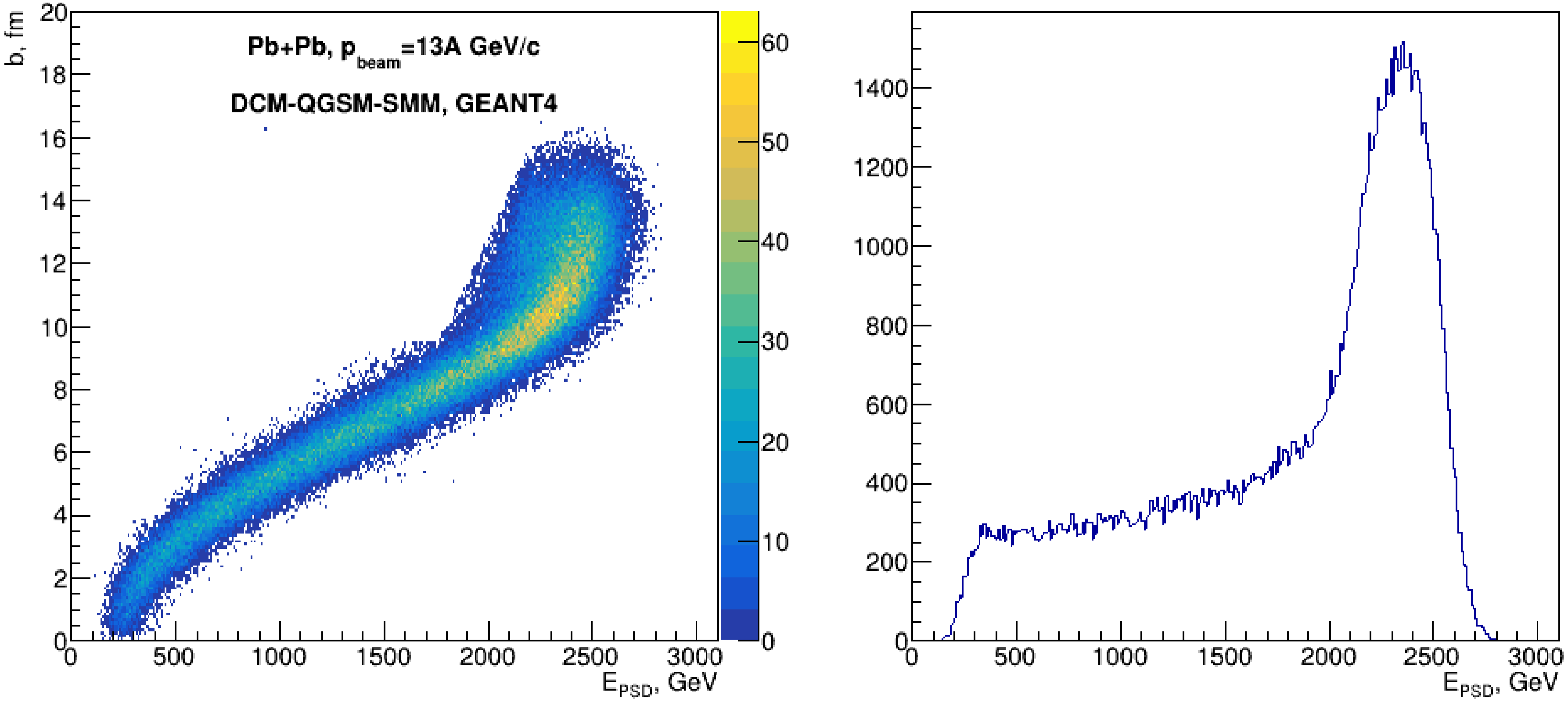
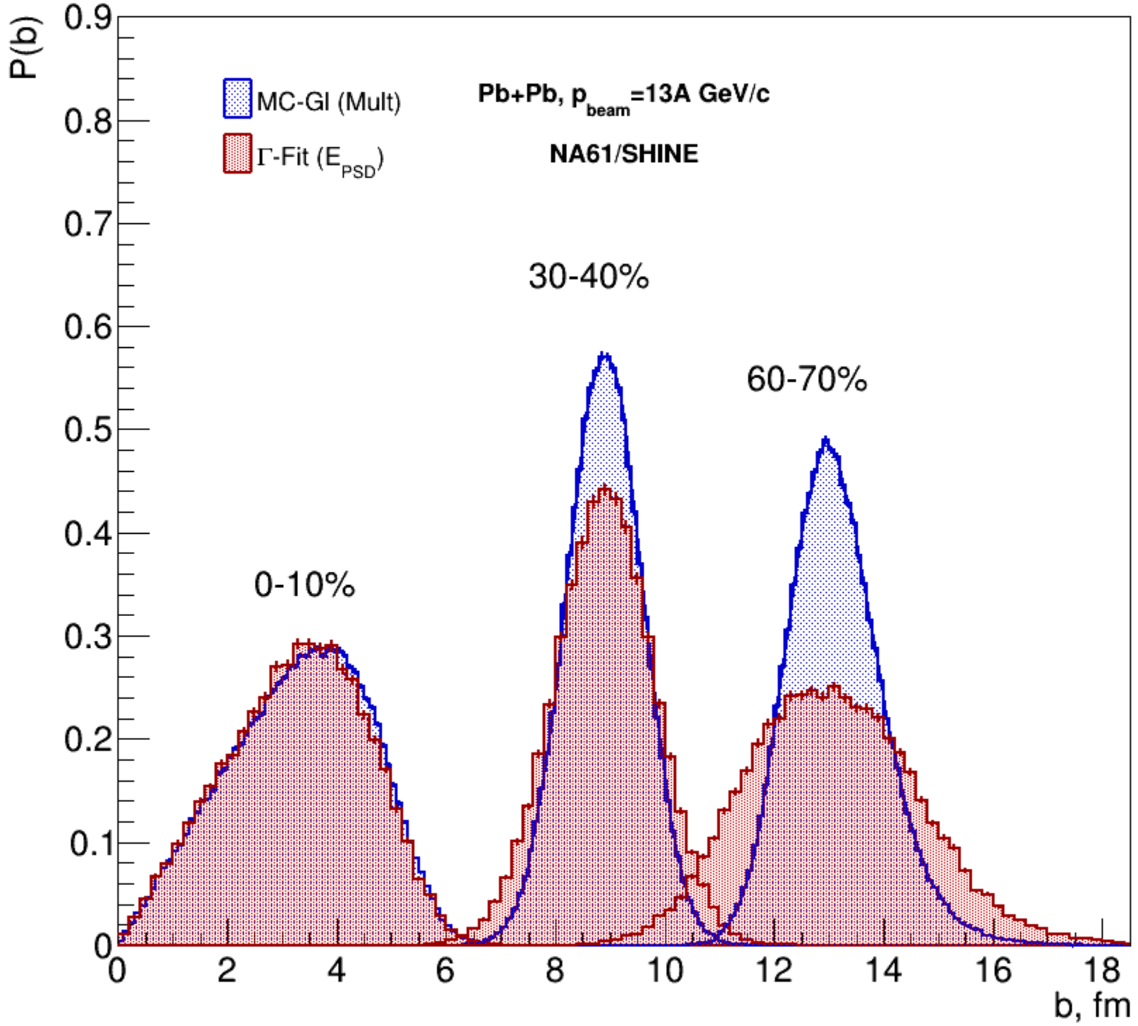


The results of simulations of fully reconstructed data show a strong correlation between the energy deposed in the PSD detector and the impact parameter

Impact parameter distribution in centrality classes



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Ann.Rev.Nucl.Part.Sci. 57 (2007) 205-243

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