Centrality determination method in nuclear collisions by using hadron calorimeter

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NA61/SHINE experimental setup

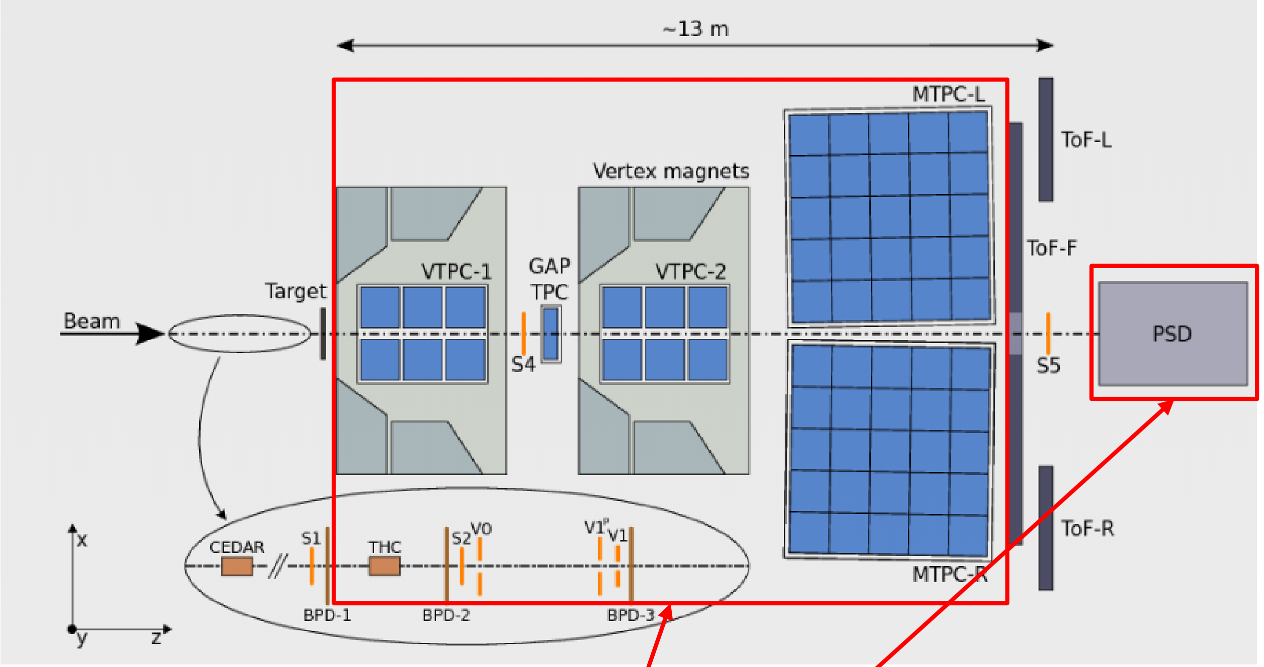
Data samples:

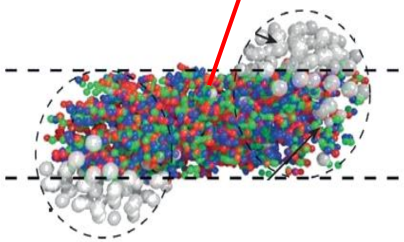
- Pb-Pb @ p_{beam} = 13A GeV/c
- data from 2016 physics run
- DCM-QGSM-SMM x Geant4

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

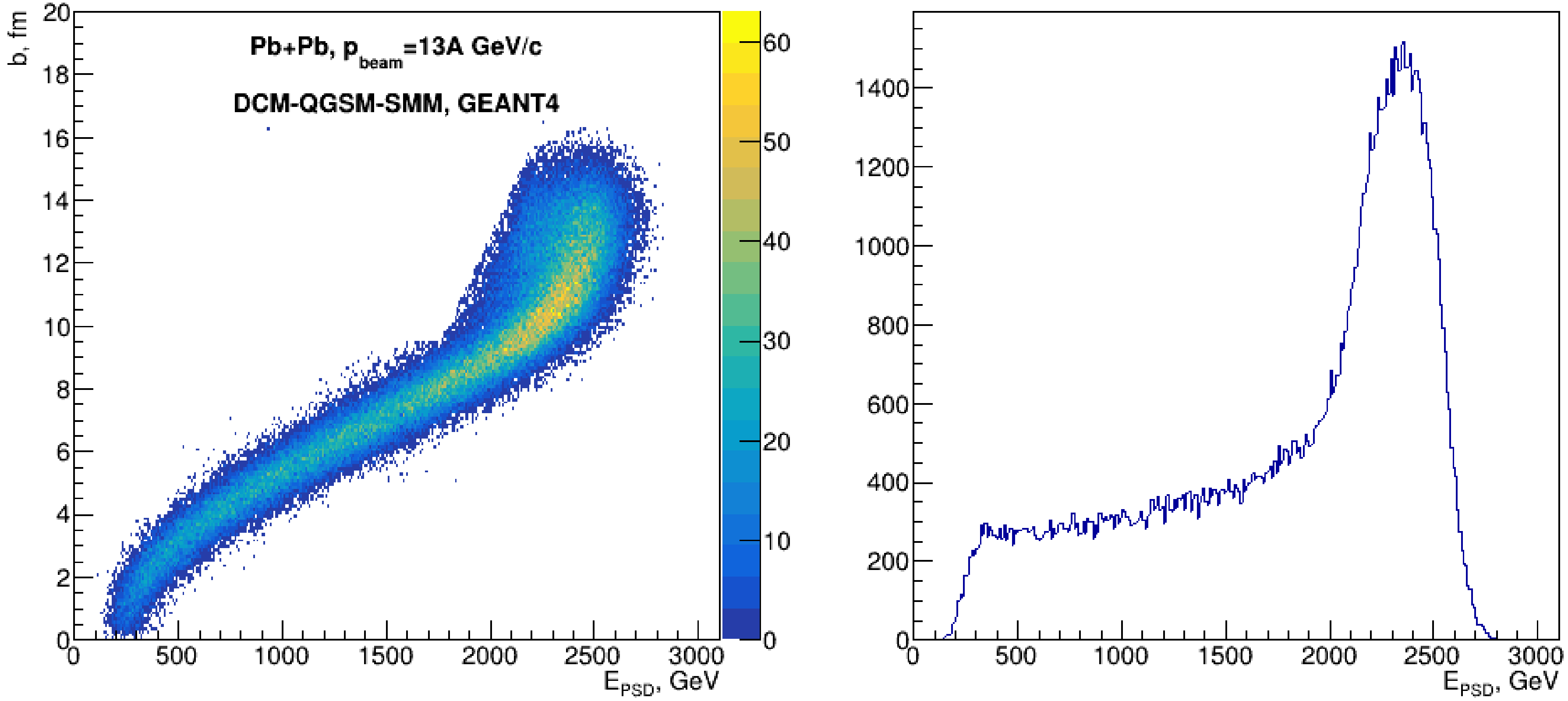
Subsystems

- Multiplicity: TPCs
- Spectators energy: PSD





Correlation between energy and impact parameter



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

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

- Relation between energy E and impact parameter b is defined by the fluctuation kernel:

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

$$c_b = \int_0^b P(b')db'$$ – 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

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

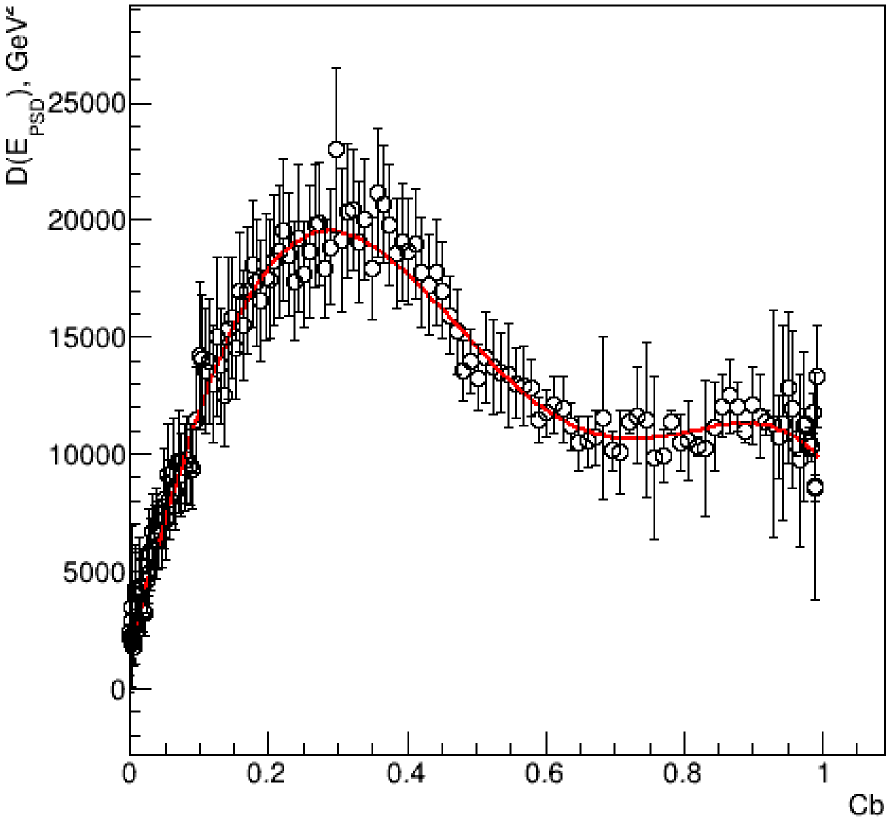
$\langle E'(c_b) \rangle, \quad D(E'(c_b))$ – average value and variance of energy from the rec. model data

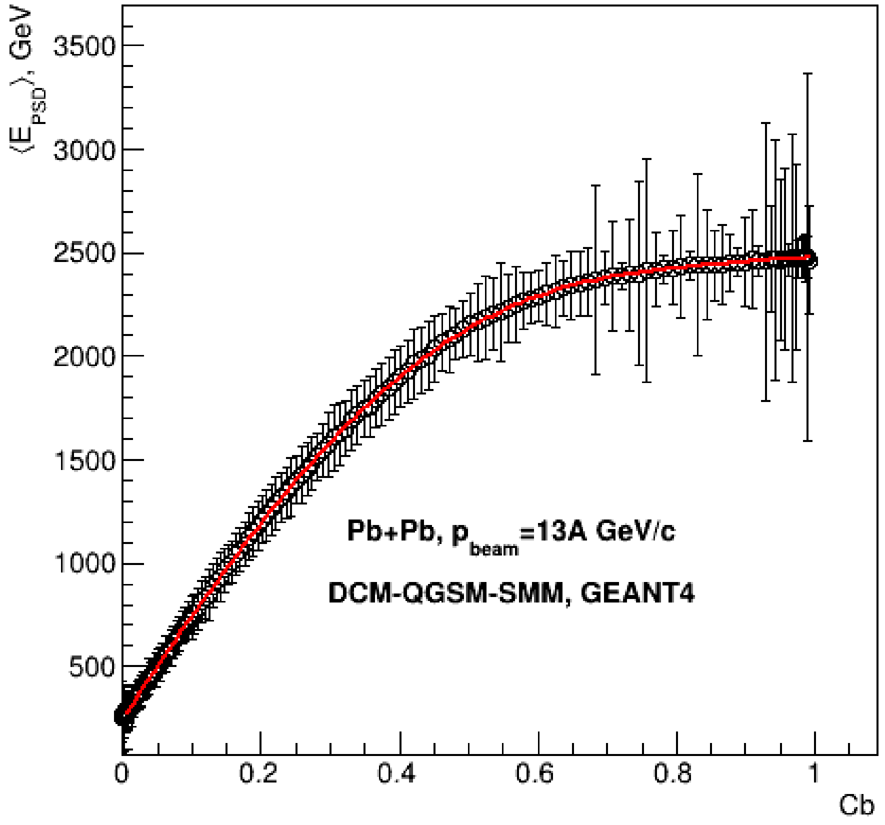
Three fit parameters μ_1, μ_2, λ_1

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

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

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)

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

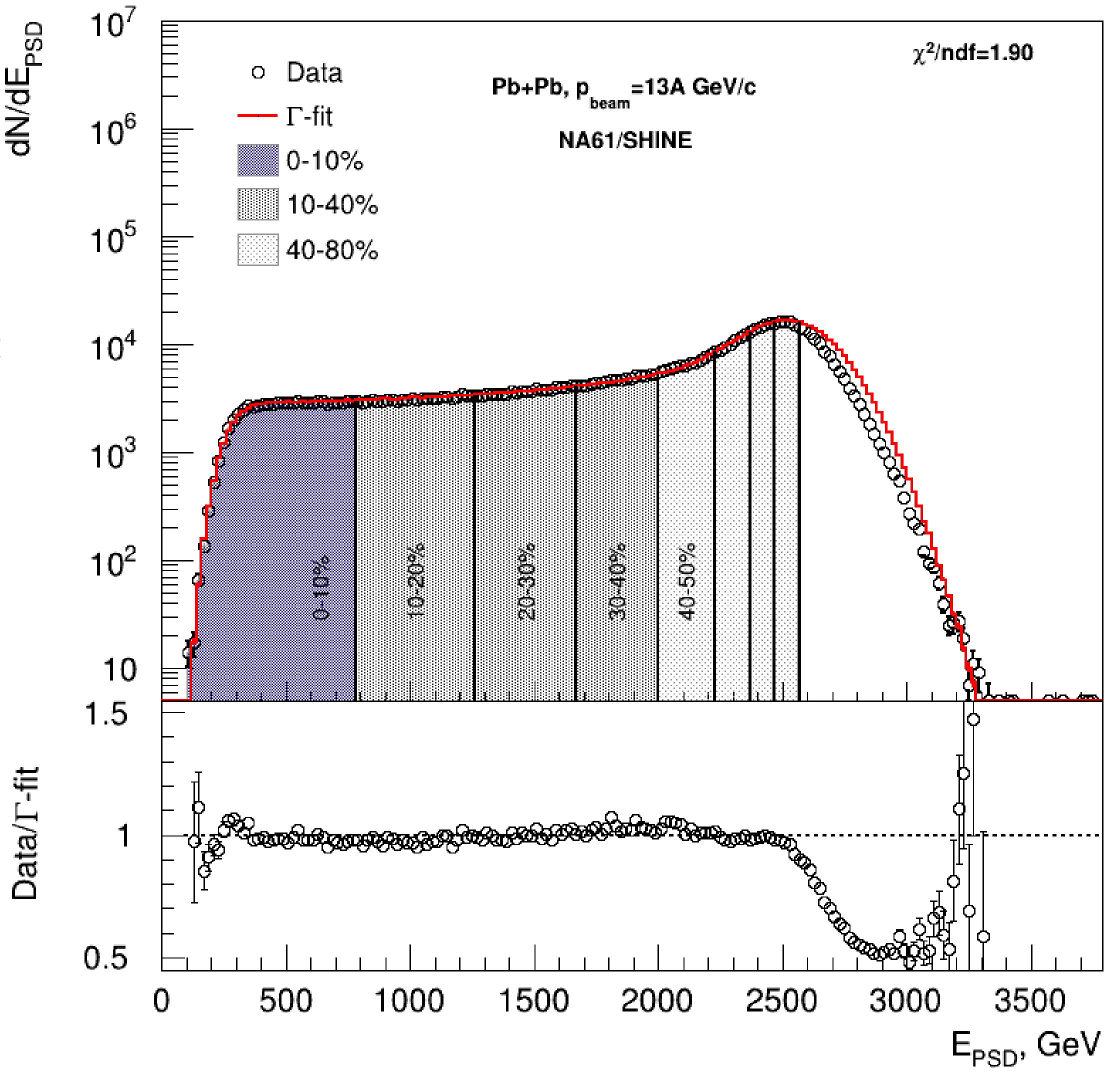
- Find probability of *b* for fixed range of E using Bayes' theorem:

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

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

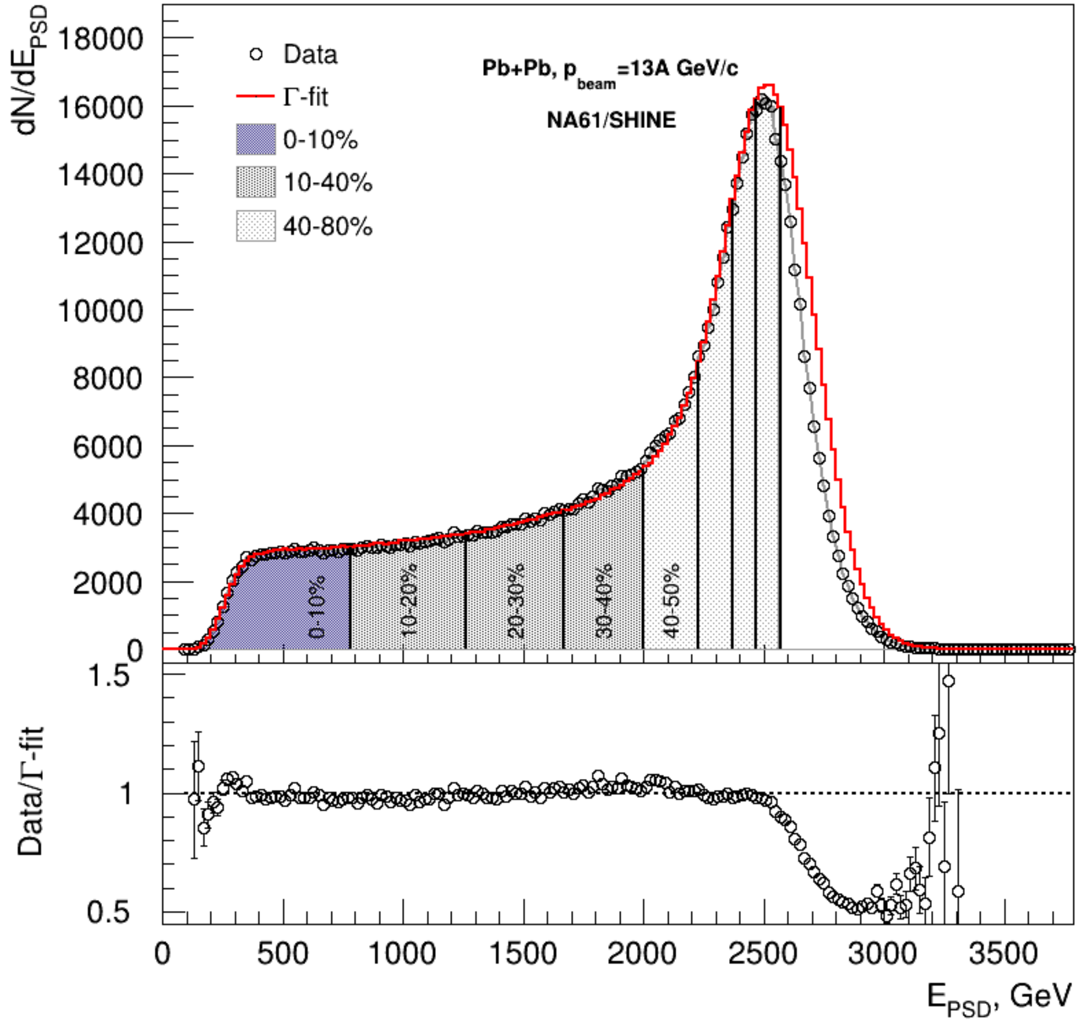
–Fit normalized energy distribution with P(E)

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

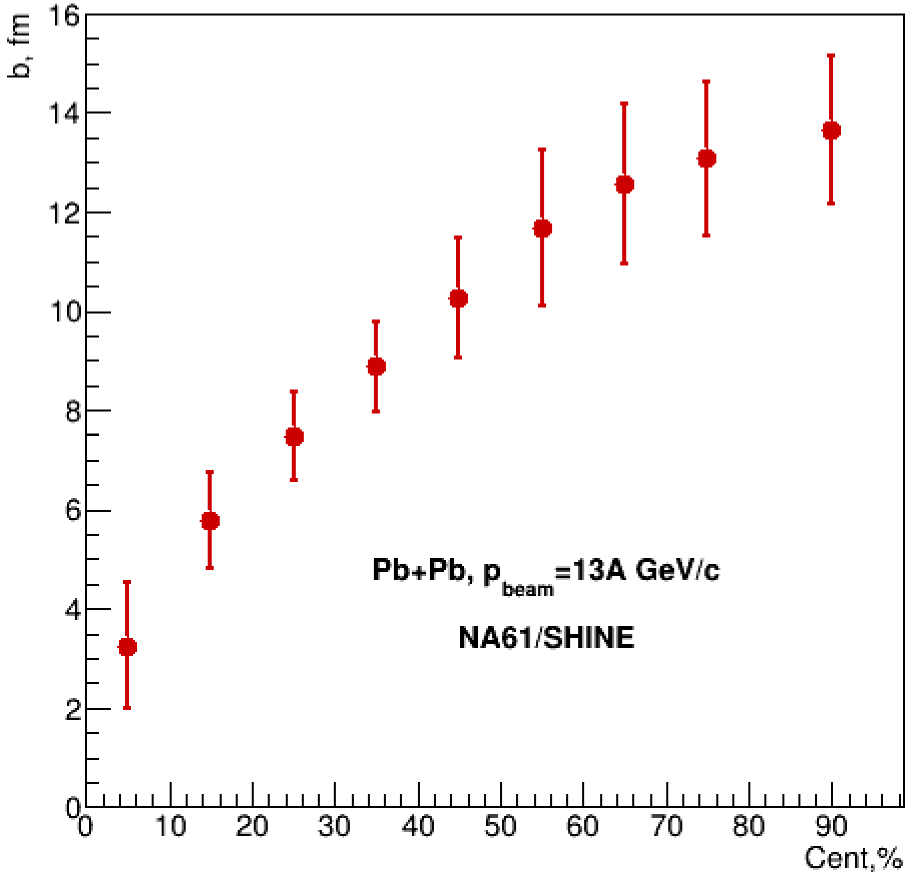


Good agreement between fit and data in wide energy range

Fit results for NA61

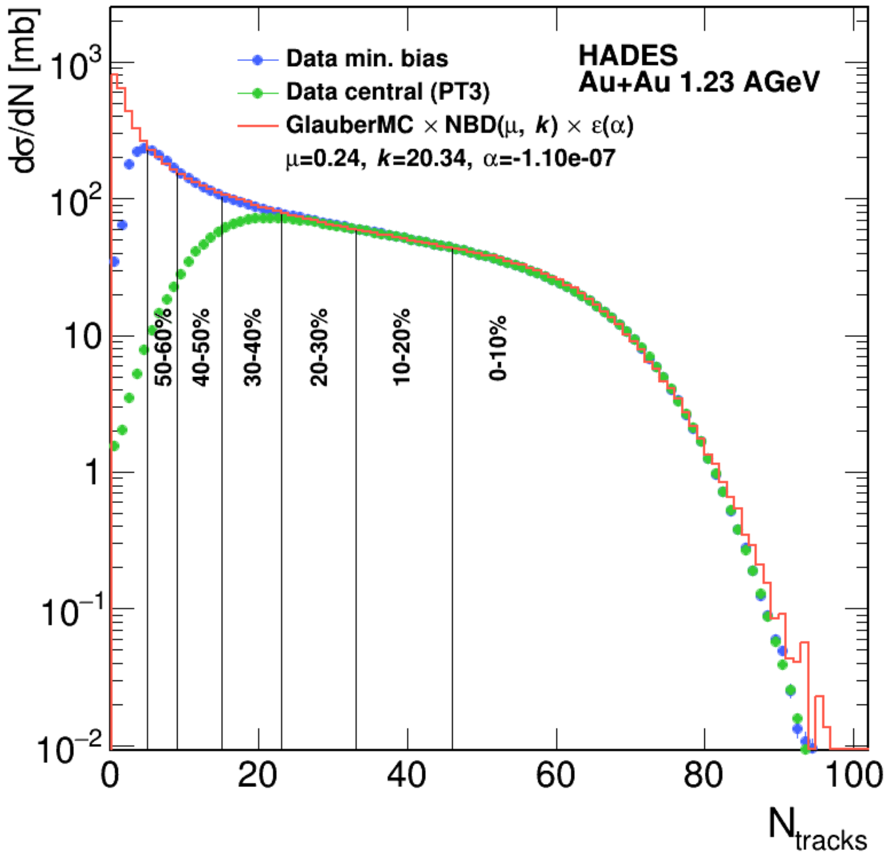


The method reproduces the energy distribution well.
The difference in the peripheral region is due to the trigger efficiency



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: $N_a = N_{part}$

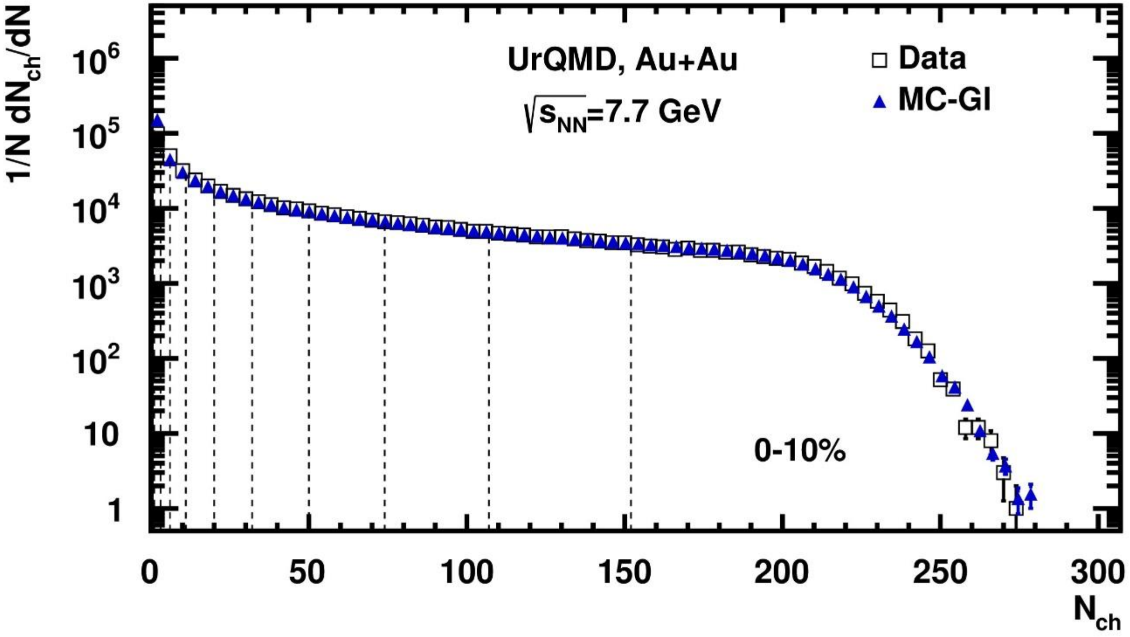
Call NBD(μ,k) x N_ax ε(α)

Build multiplicity fitting function

Input multiplicity distribution

Evaluate χ^2

Minimize χ^2 to find α, μ, k



NBD – negative binomial distribution

Parameters of the fit:

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

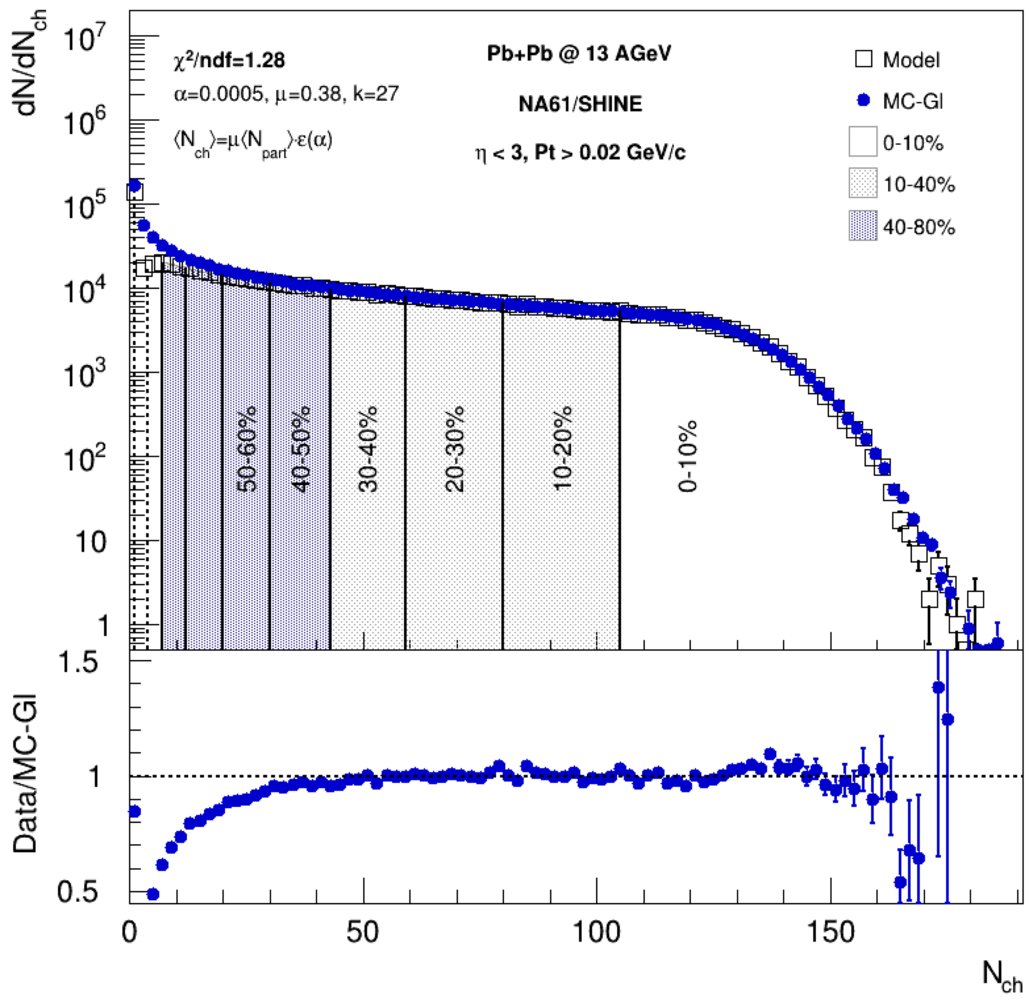
This centrality procedure was used in CBM, NA49, and NA61/SHINE:

I. Segal, et al., J.Phys.Conf.Ser. 1690 (2020) 1, 012107

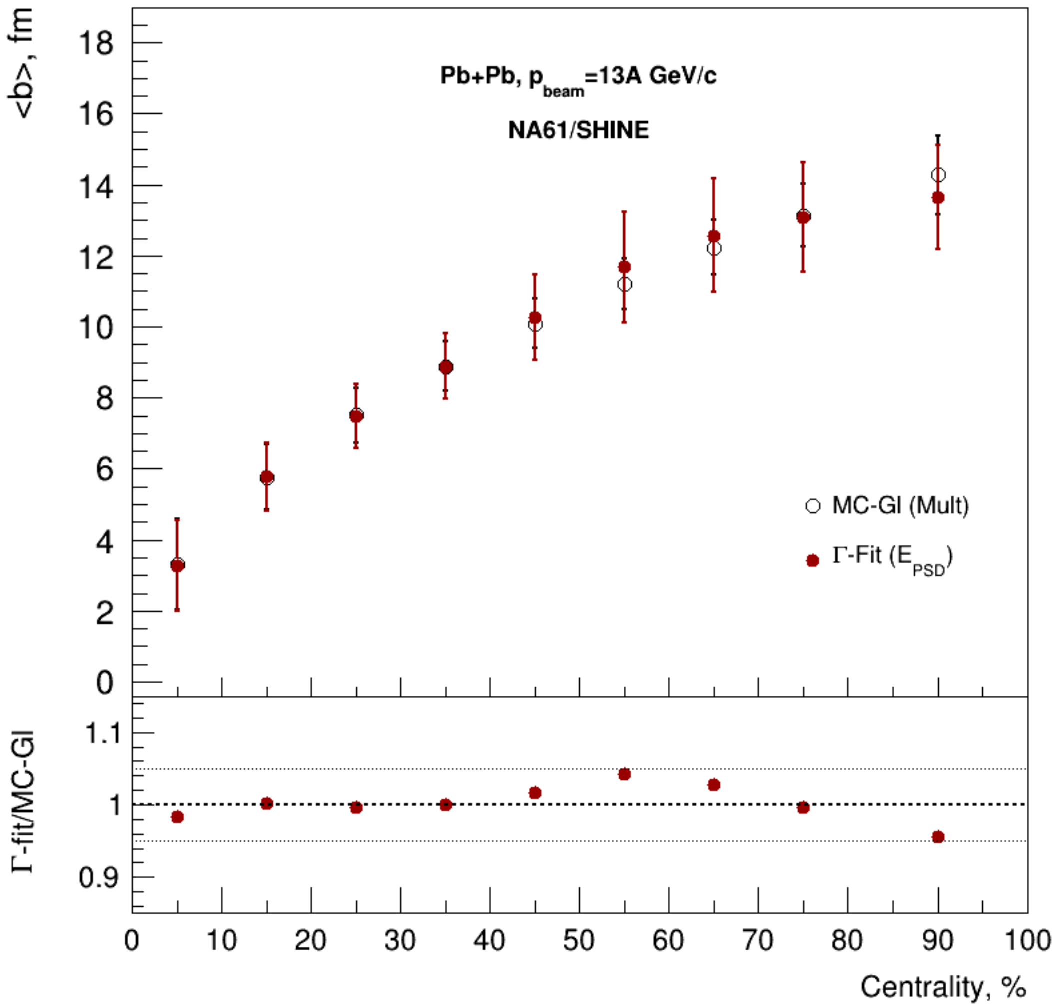
Implemantation for MPD: https://github.com/FlowNICA/CentralityFramework

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

Comparison with MC-Glauber fit

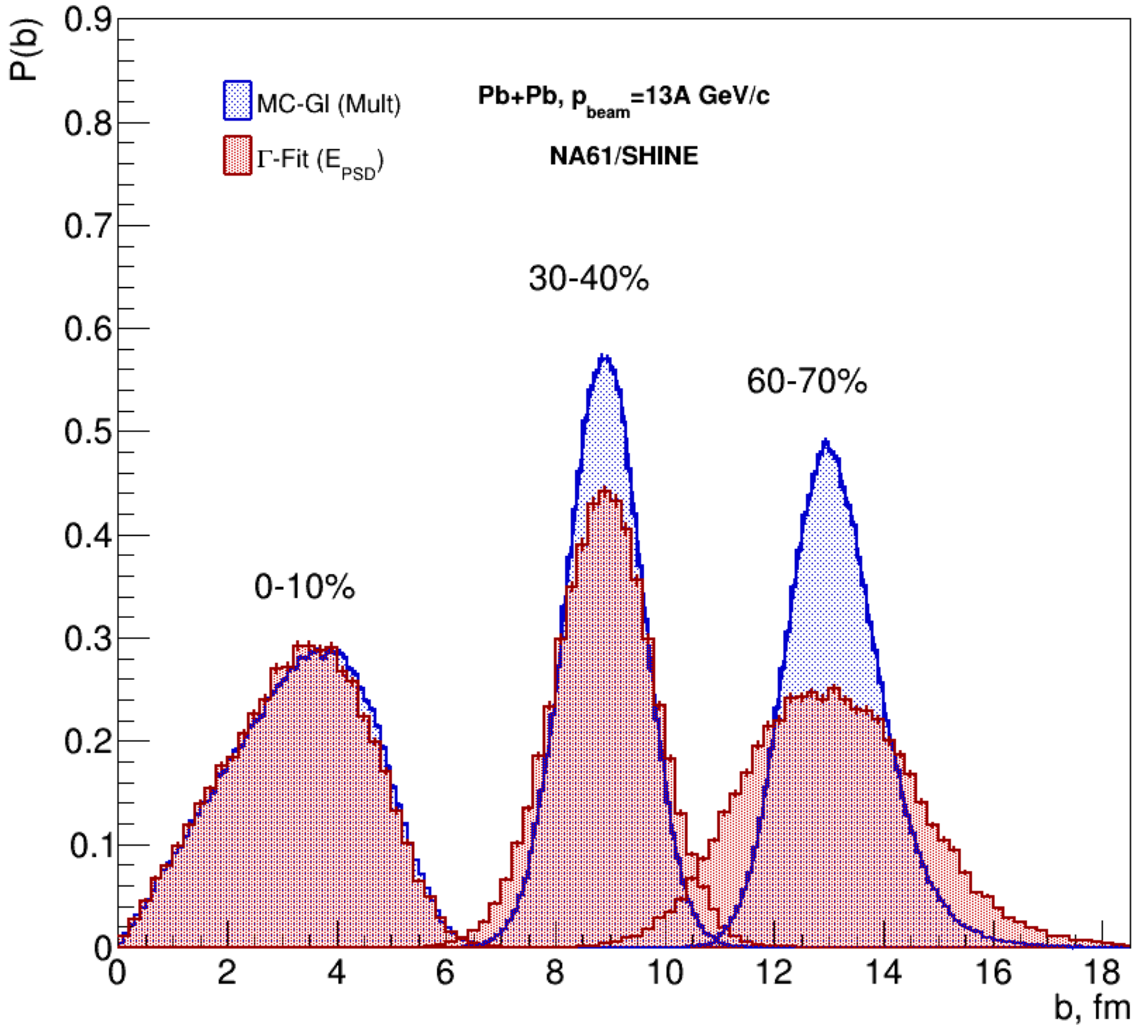


Good agreement between fit and data.



There is agreement within 5%.

Impact parameter distribution in centrality classes



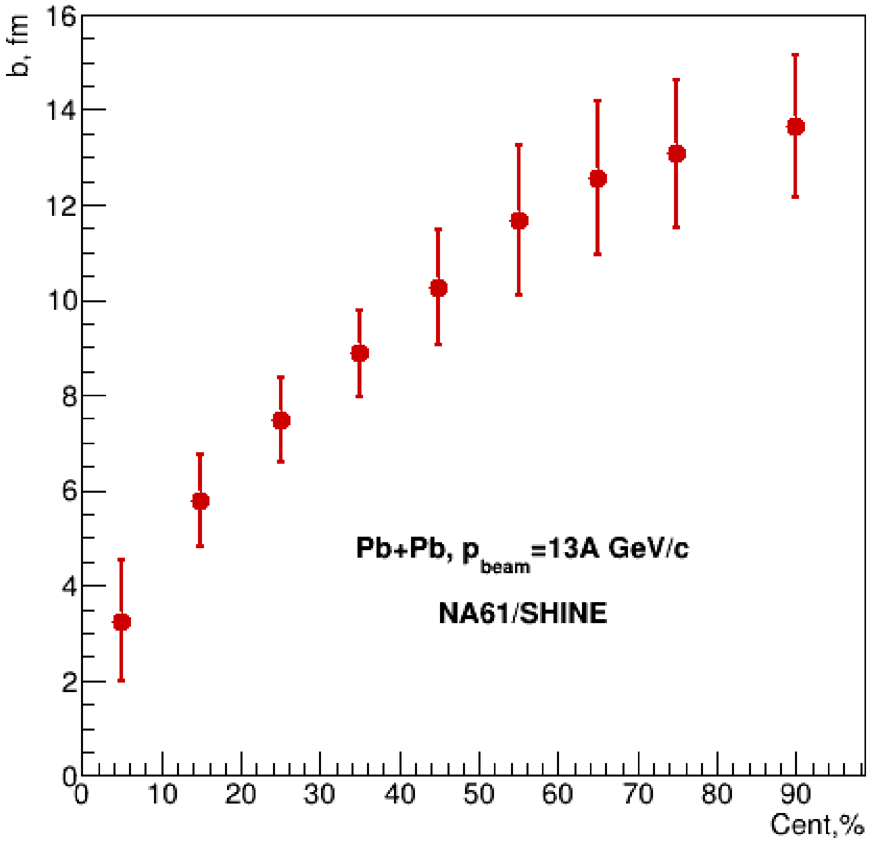
The difference in the width of distributions increases in the peripheral region

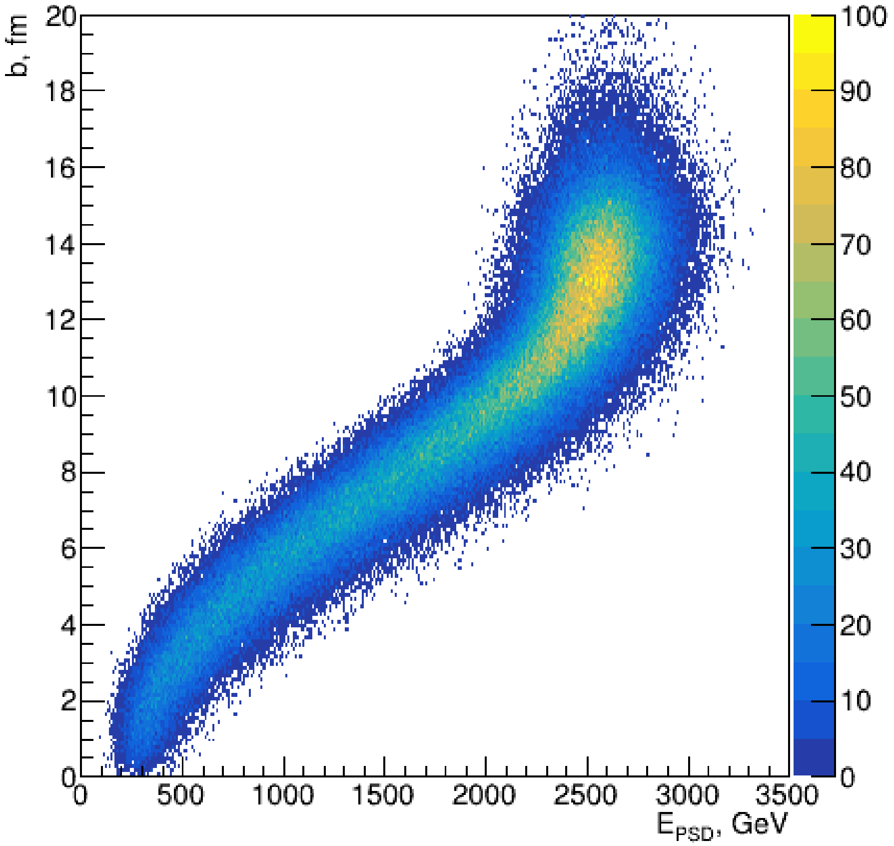
Summary

- 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

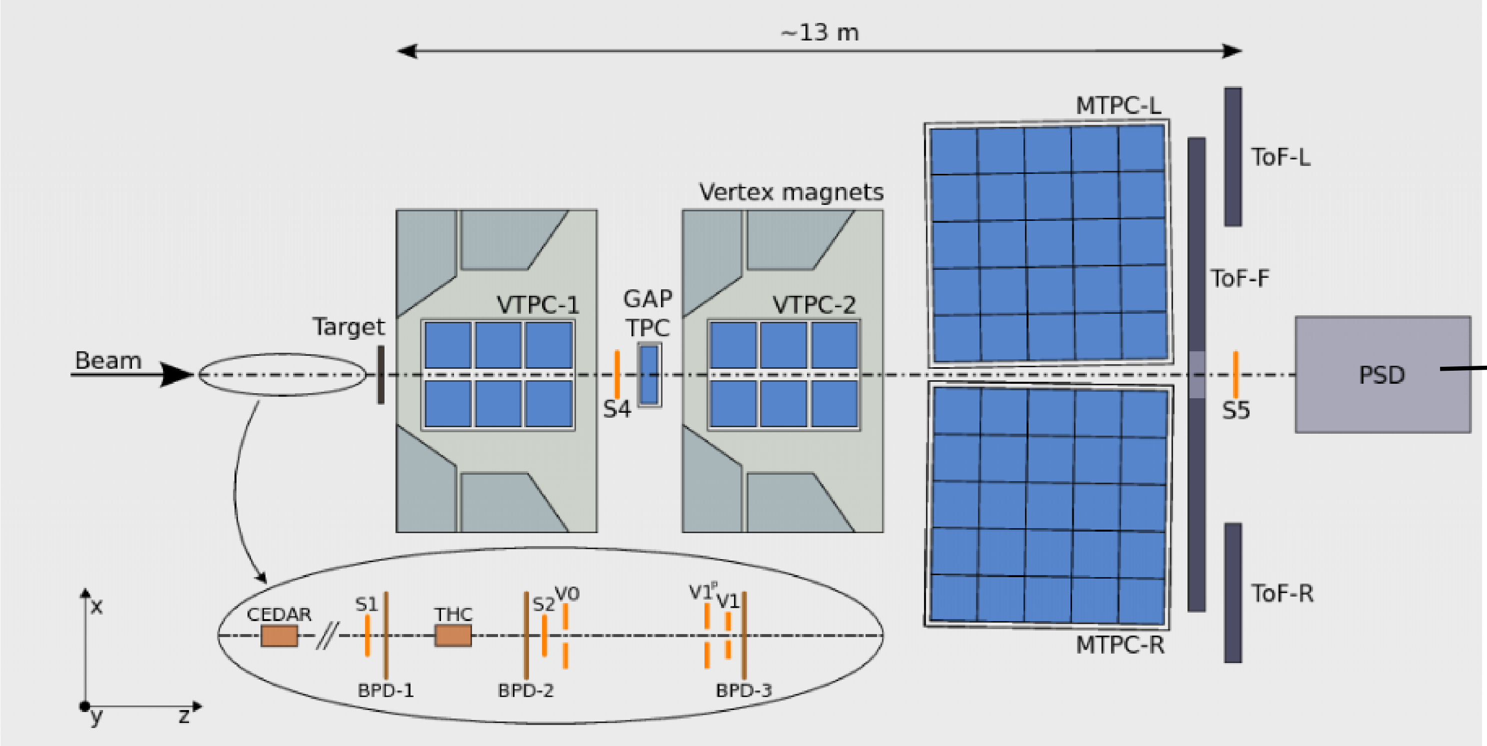
Thank you for your attention!

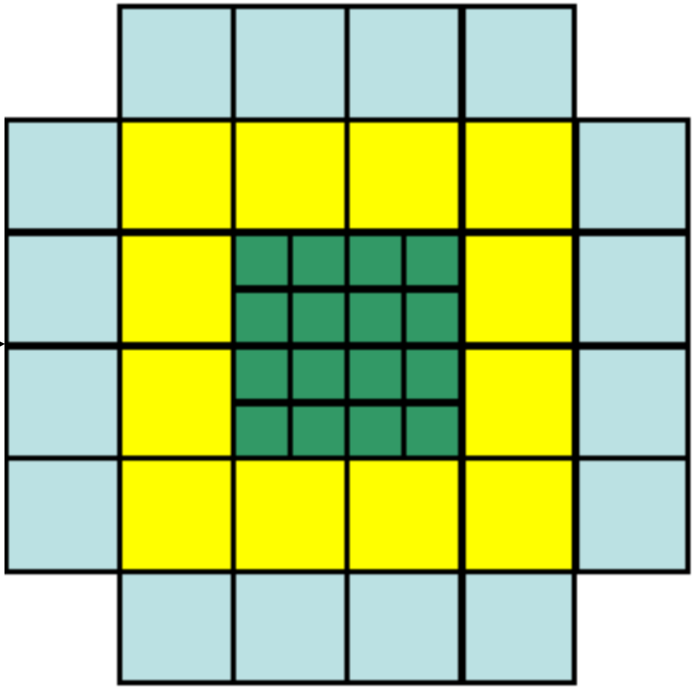
Correlation between energy and impact parameter(Fit)





NA61/SHINE experimental setup





PSD detector layout