Verification of fragmentation models with NA61 data

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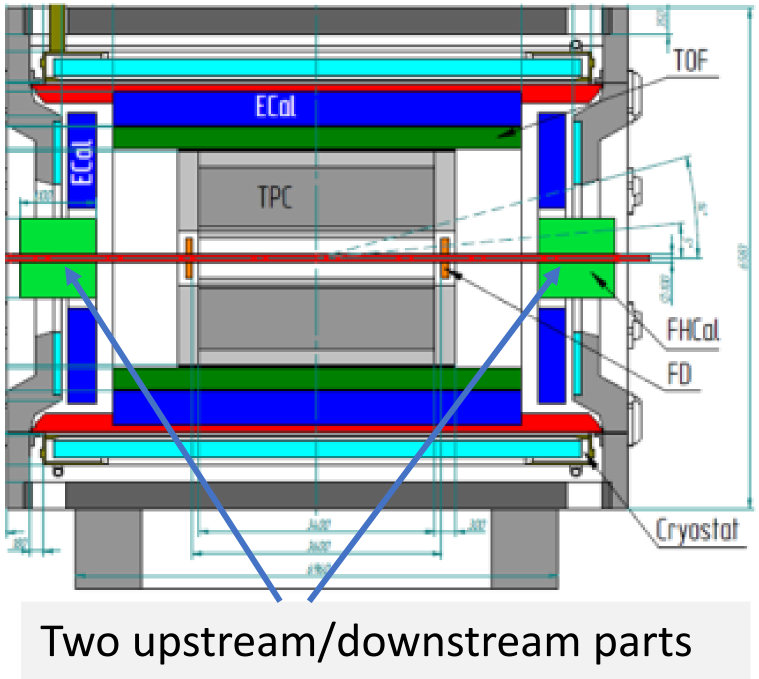
06/09/22

MPD Cross-PWG Meeting

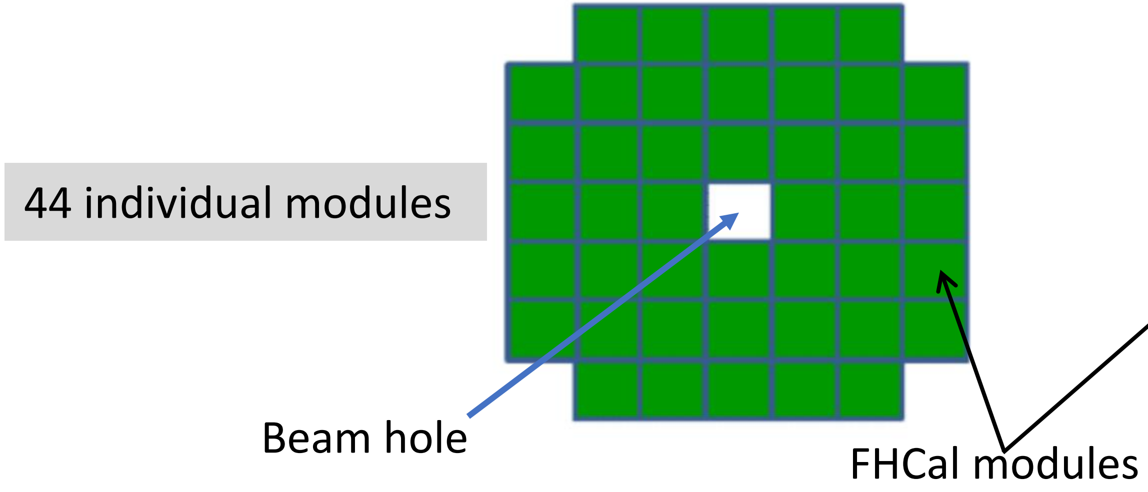
FHCal@MPD

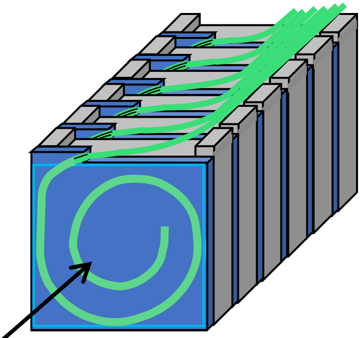


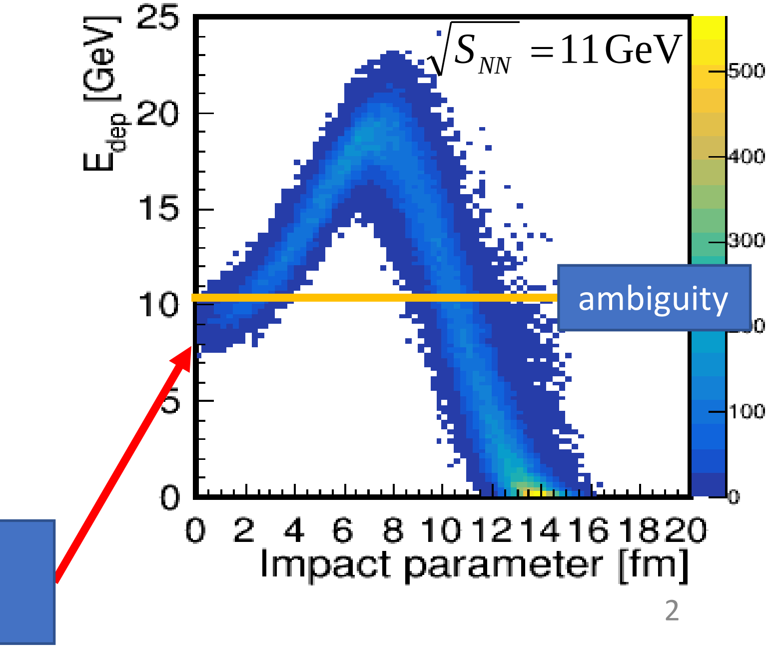
- The main purpose of the FHCal is to detect spectators and to provide an experimental measurement of a heavy-ion collision centrality and orientation of its reaction plane.

- There is an ambiguity in FHCal energy deposition for central/peripheral events due to the fragments (bound spectators) leak into beam hole.

- One of the tasks in preparation for a future experiment is to get an idea of how the calorimeter will work. To do this, it is necessary to choose a Monte Carlo model for the simulation.

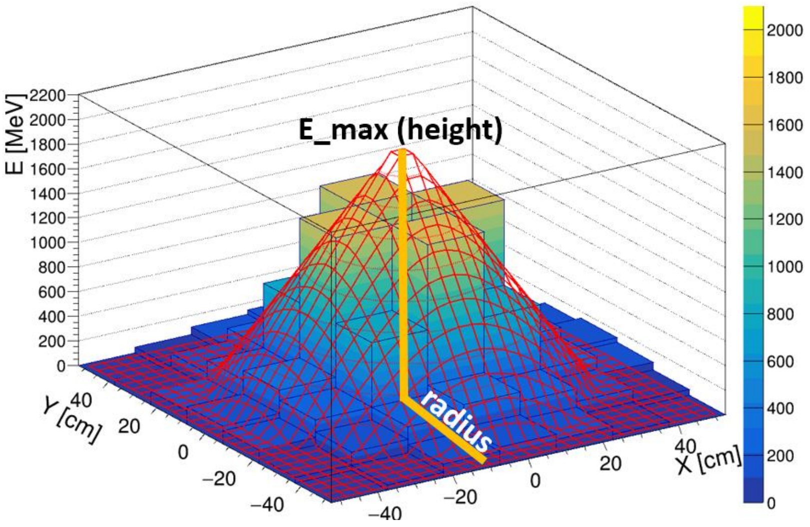




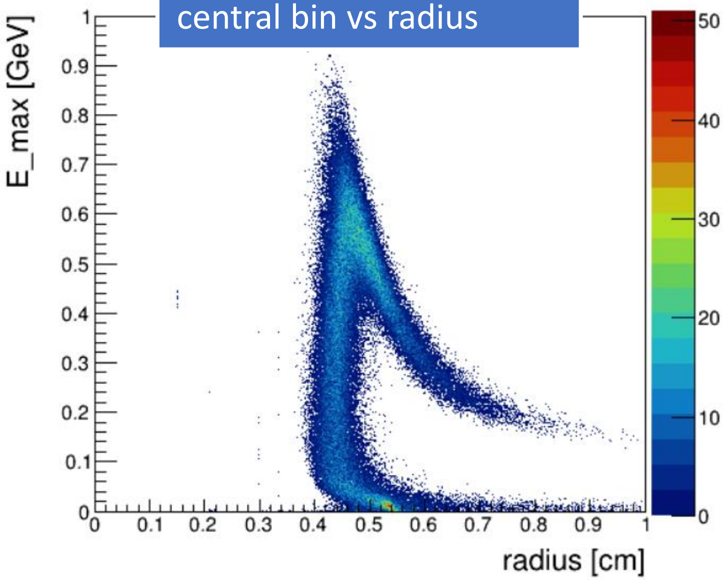


Correlation between obtained fit parameters

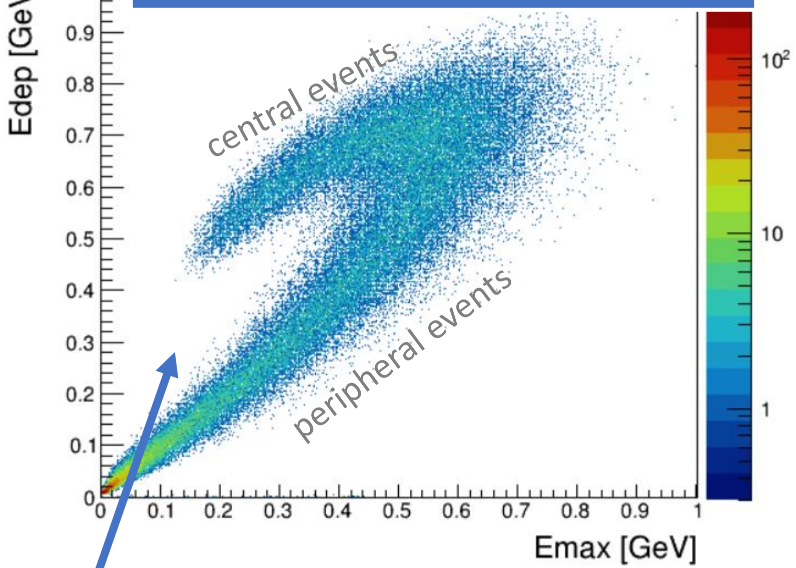
Initially we have experimental energy deposition E_{dep} in FHCal.



Maximum energy in central bin vs radius



Experimental energy deposition vs maximum energy in central bin

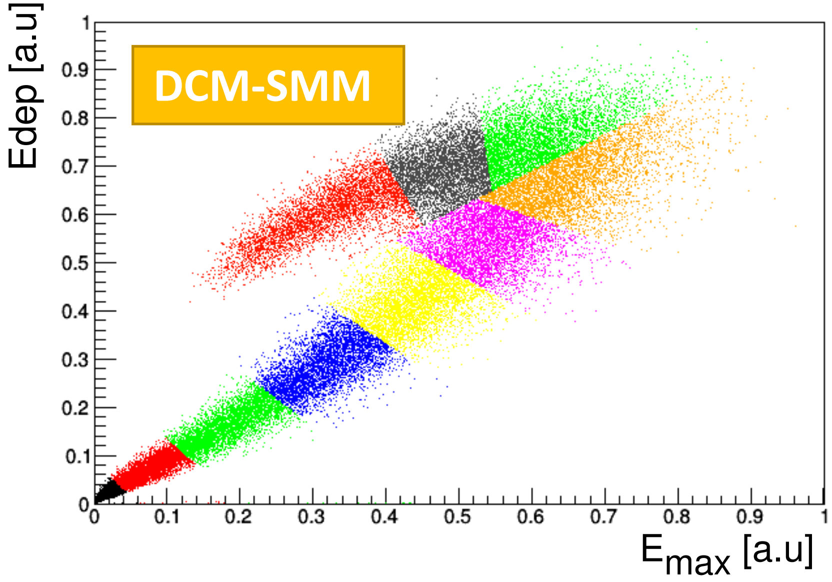


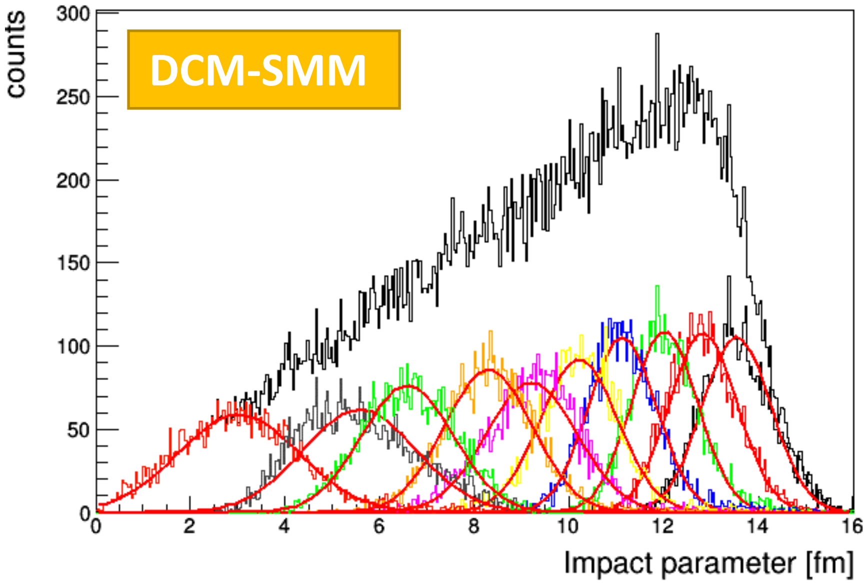
After linear fit we have:

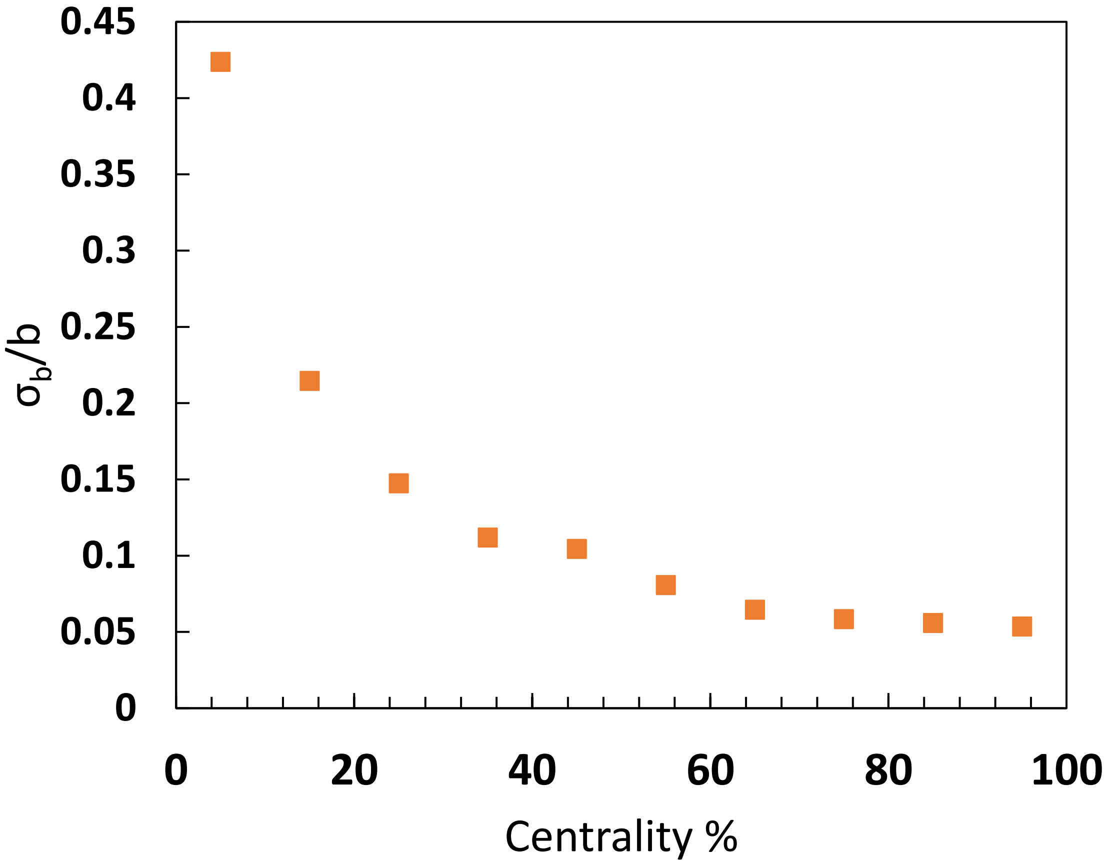
- ***E_{rec}* is reconstructed energy (volume of cone);**
- ***E_{max}* – maximum energy in central bin (in FHCal hole);**
- ***Radius* of spectator spot at FHCal is defined by the scattering spot of spectators.**

This correlation can be used for the centrality determination

Centrality resolution for E_{dep} vs E_{max}







Volkov, V.; Golubeva, M.; Guber, F.; Ivashkin, A.; Karpushkin, N.; Morozov, S.; Musin, S.; Strizhak, A.

Application of FHCal for Heavy-Ion Collision Centrality Determination in MPD/NICA Experiment.

Particles **2021**, *4*, 236-240.
https://doi.org/10.3390/particles4020022

Monte Carlo models

- One of the main requirements for FHCal simulation is a Monte Carlo model that works with fragments. This study provides a comparison of two Monte Carlo models that satisfy the conditions: DCM-SMM and PHQMD (two versions for the clusters identification MST and SACA with $|\eta| < 1$ cut).
- MST identifies clusters only when free nucleons and groups of nucleons, called clusters, are well separated in coordinate space at the end of the reaction.
- SACA allows to study the clusterization pattern early, shortly after the passing time (the time the two nuclei need to pass each other) when the different final clusters still overlap in coordinate space.

Parton-hadron-quantum-molecular dynamics: A novel microscopic n-body transport approach for heavy-ion collisions, dynamical cluster formation, and hypernuclei production

J. Aichelin (SUBATECH, Nantes and Frankfurt U., FIAS), E. Bratkovskaya (Darmstadt, GSI and Frankfurt U.), A. Le Fèvre (Darmstadt, GSI), V. Kireyeu (Dubna, JINR), V. Kolesnikov (Dubna, JINR) et al.

e-Print: 1907.03860 [nucl-th]
DOI: 10.1103/PhysRevC.101.044905
Published in: Phys.Rev.C 101 (2020) 4, 044905

Monte-Carlo Generator of Heavy Ion Collisions DCM-SMM

M. Baznat (IAP, Chisinau), A. Botvina (Moscow, INR and Frankfurt U. and Frankfurt U., FIAS), G. Musulmanbekov (Dubna, JINR), V. Toneev (Dubna, JINR), V. Zhezher (Dubna, JINR)

e-Print: 1912.09277 [nucl-th]
DOI: 10.1134/S1547477120030024
Published in: Phys.Part.Nucl.Lett. 17 (2020) 3, 303-324

Experimental data to compare Pb-Pb 30 GeV/c

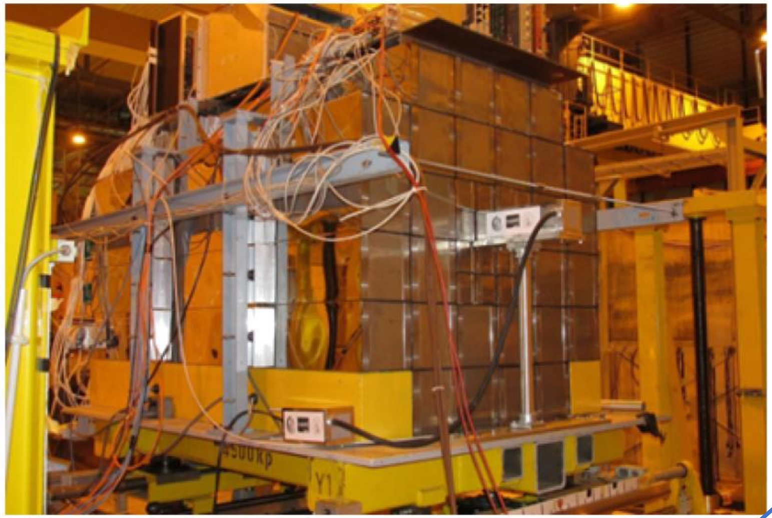
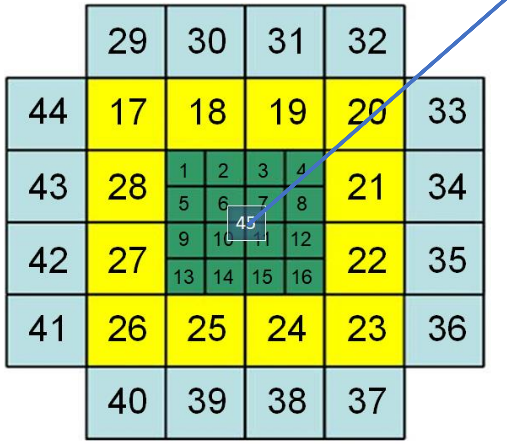
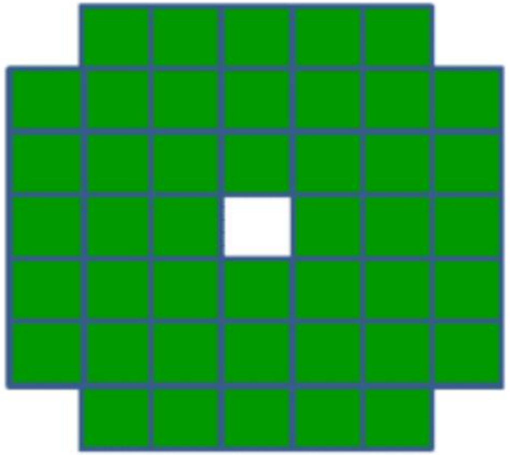


Photo of the PSD placed on the beam line downstream of the NA61/SHINE detector



16 small modules 10x10 cm, 10 sections (dark green)
28 large modules 20x20 cm, 10 sections (yellow and light blue)
Small module 10x10 cm, 2 sections, just before PSD, centered wrt PSD center

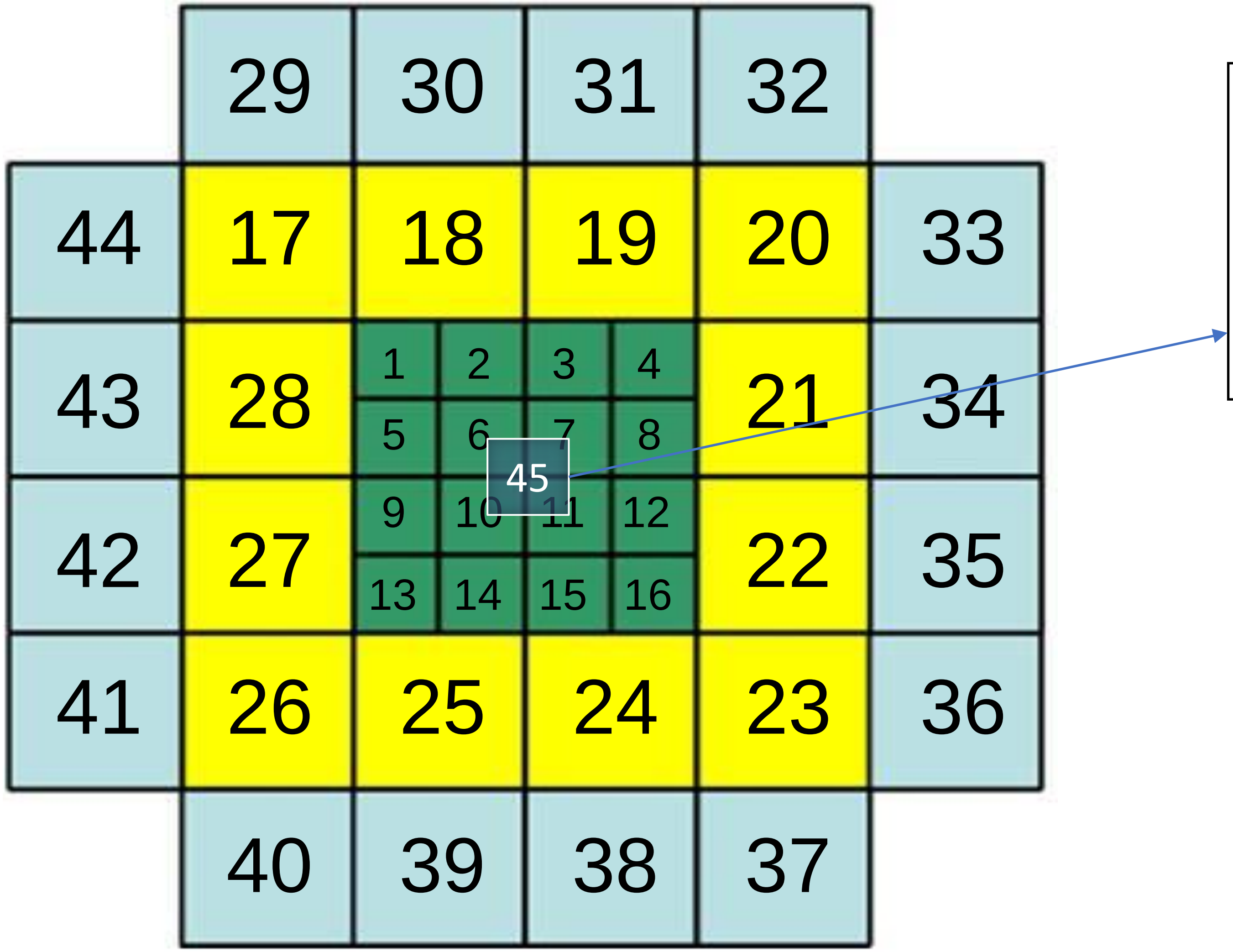


FHCal modules

- Find the most correct Monte Carlo model
- Test dataset from the NA61/CERN experiment was taken as reference data. **Pb-Pb 30 GeV/c, minimum bias, no magnet field**.
- The calorimeter (PSD) in this experiment is similar to the MPD calorimeter.
- PSD does not have a hole in the center, for this reason two comparisons were made:
  - comparing models with "as is" data
  - comparing models with an artificial configuration, with a hole in the center, since such a model most closely matches the FHCal.

Min bias = S4 trigger, threshold E < Pb

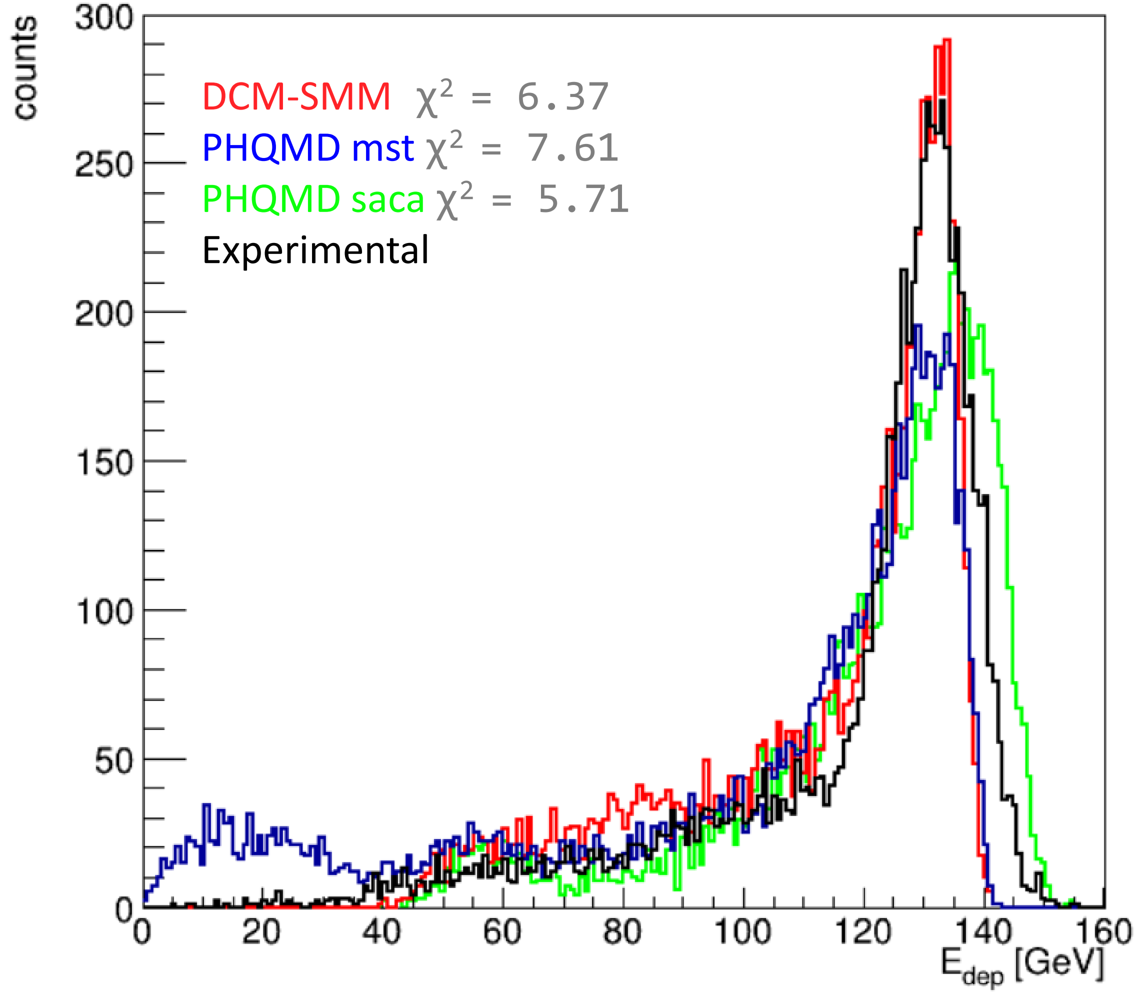
No-hole calorimeter version models comparison note



16 small modules 10x10 cm, 10 sections (dark green)
28 large modules 20x20 cm, 10 sections (yellow and light blue)
Small module 10x10 cm, 2 sections, just before PSD, centered with PSD center

The energy of module 45 is evenly distributed over the 4 central modules (6, 7, 10, 11).

Energy deposition comparison



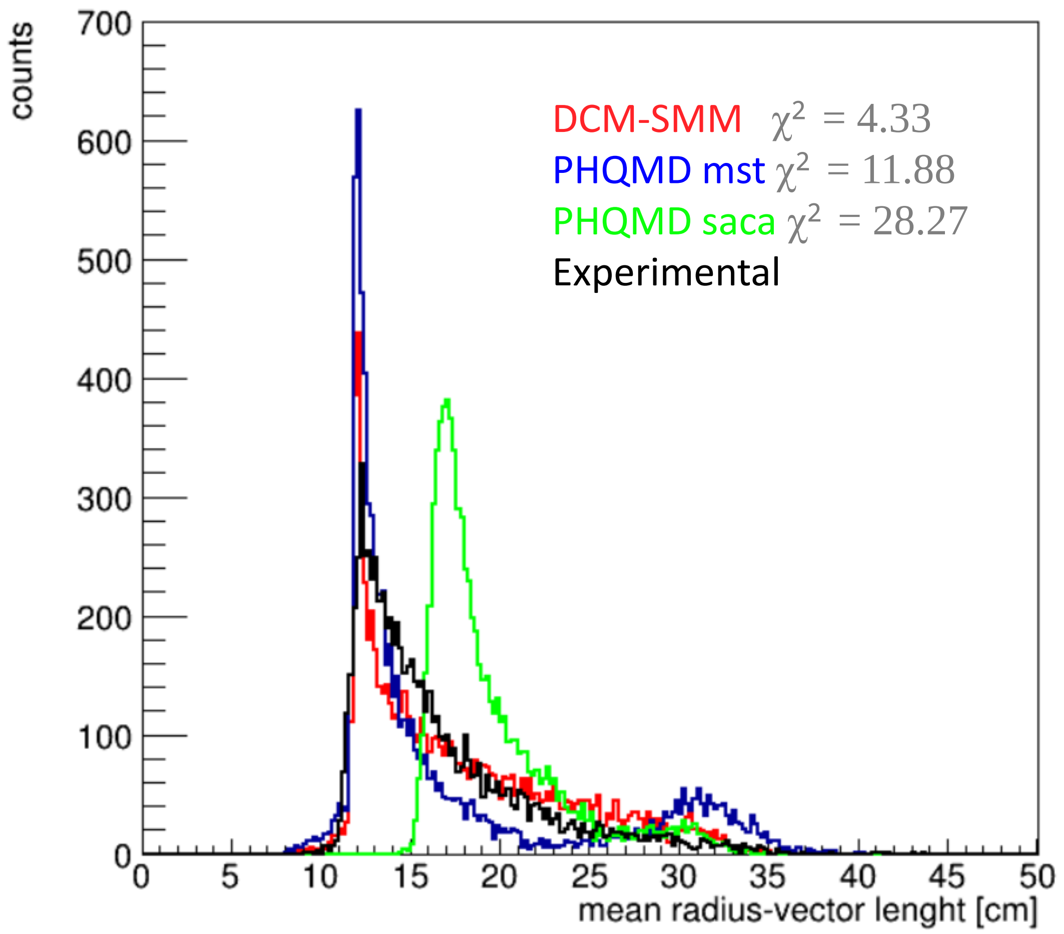
Energy deposition in the calorimeter

- **Pb-Pb 30 GeV/c**
- **NA61 experimental data min. bias trigger (S4, threshold E < Pb).**

$$\chi^2 = \sum_{i=1}^{n} \frac{(MC_i - Exp_i)^2}{\sigma^2_{MC_i} + \sigma^2_{Exp_i}}$$

- Energy deposition is the only observable for which the results are roughly the same
- PQHMD diverges significantly from experiment and DCM-SMM at the peak of the distribution

"Mean" radius-vector length comparison

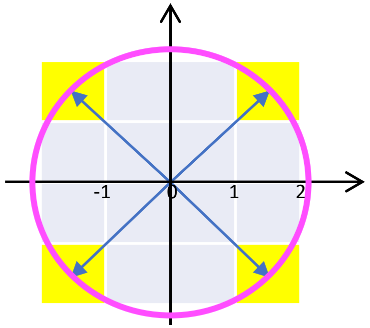


"Mean" radius-vector length (reflects spatial distribution of energy) is calculated as follows:

$$x_{mean} = \frac{\sum_i E_i |x_i|}{\sum_i E_i} \qquad y_{mean} = \frac{\sum_i E_i |y_i|}{\sum_i E_i}$$

$$|\overrightarrow{r_{mean}}| = \sqrt{x_{mean}^2 + y_{mean}^2}$$

Simple example (4×4 calo):



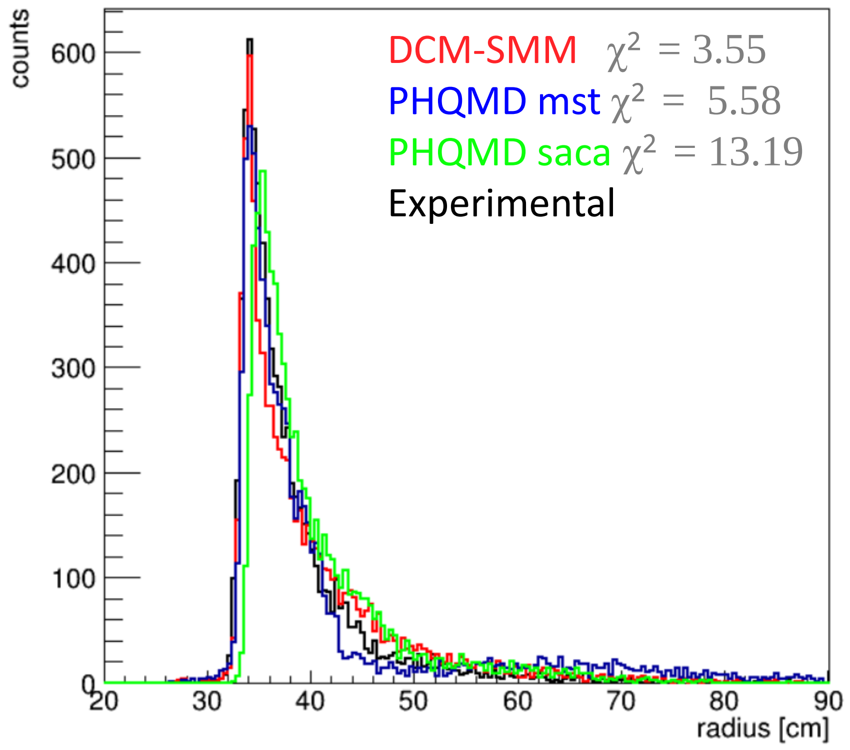
$E_i = 1\ GeV$ *(energy in the i_{th} module)*

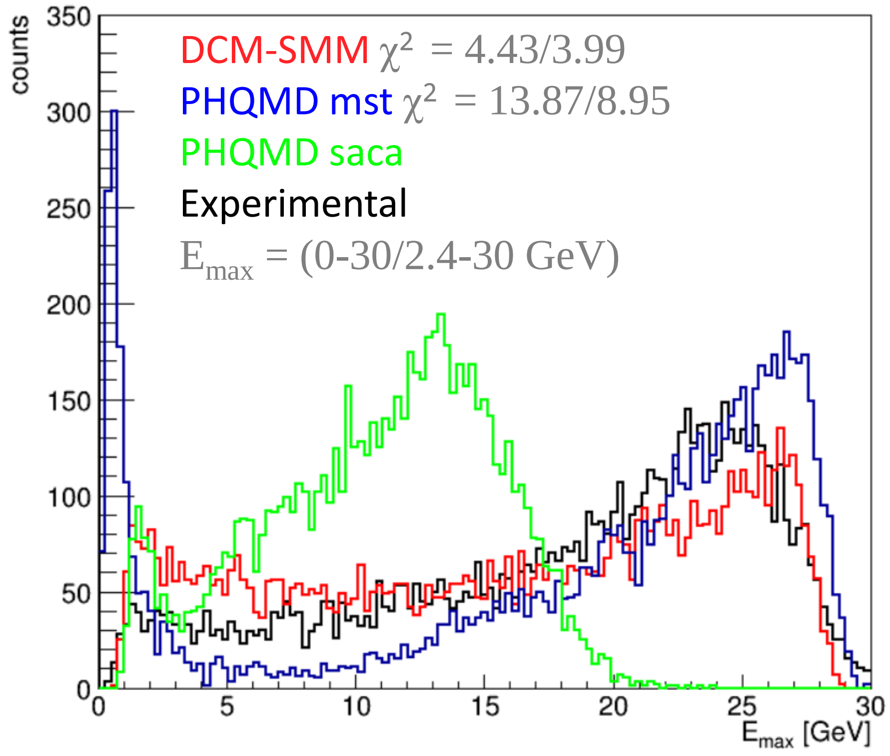
$x_{mean} = y_{mean} = \frac{6}{4}$

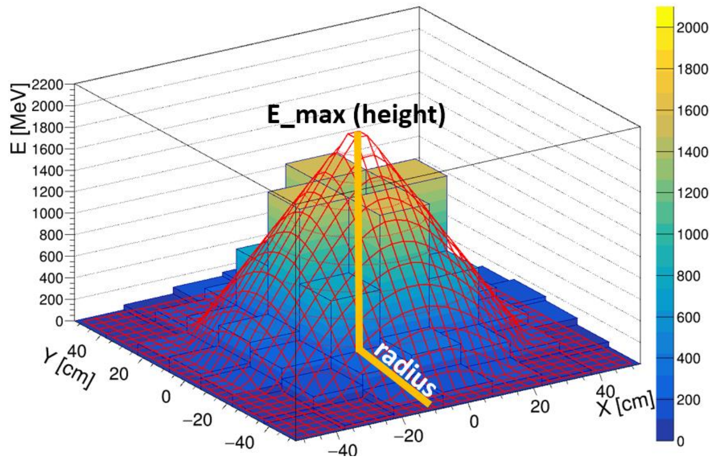
$|\overrightarrow{r_{mean}}| = \sqrt{1.5^2 + 1.5^2} \approx 2.12$

The nominal ring of mean energy deposition with radius $|\overrightarrow{r_{mean}}|$.

Cone radius & E_{max} comparison



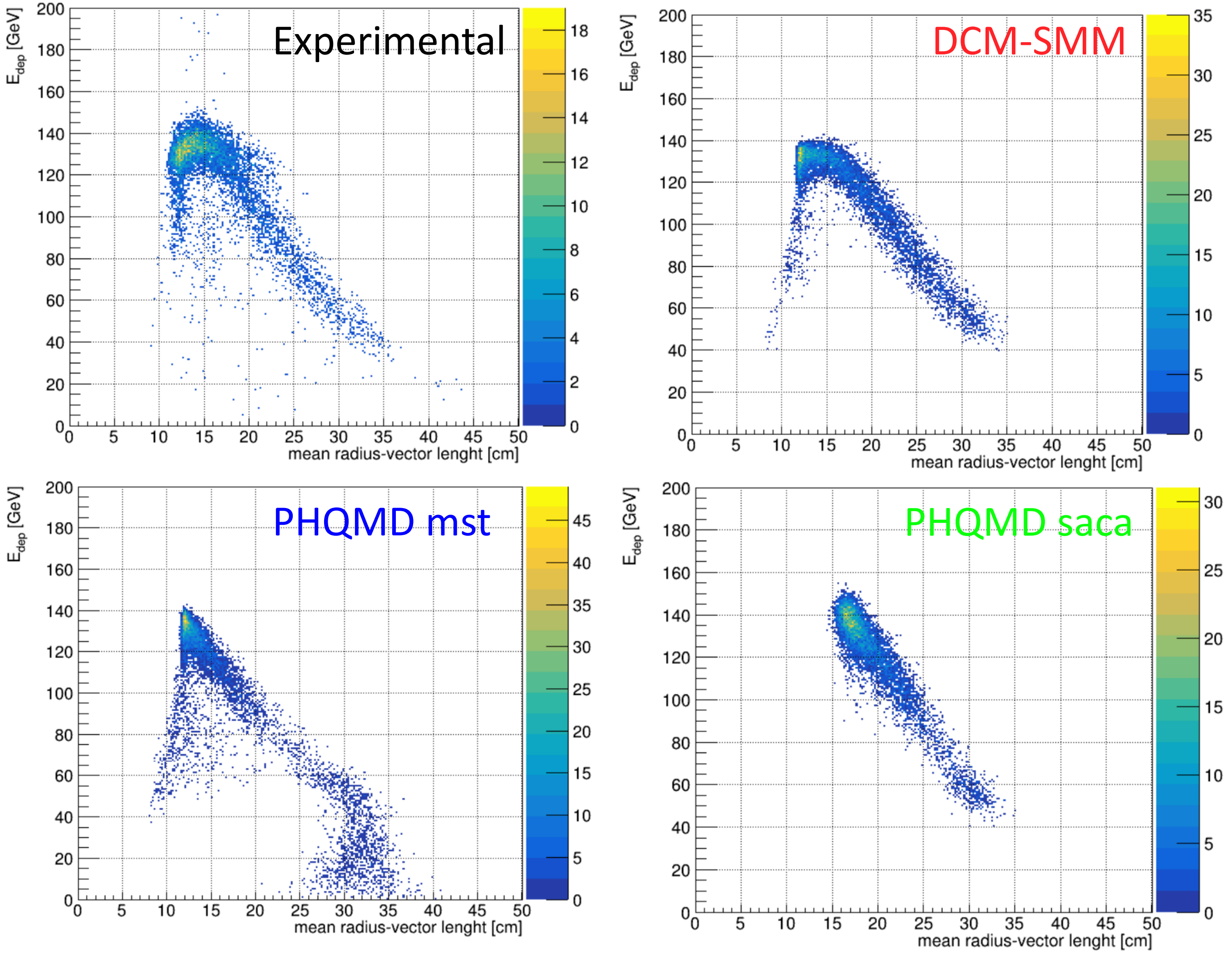




The 3rd and 4th variables (constructed) to compare are radius of the fitting cone and its height (E_{max}).

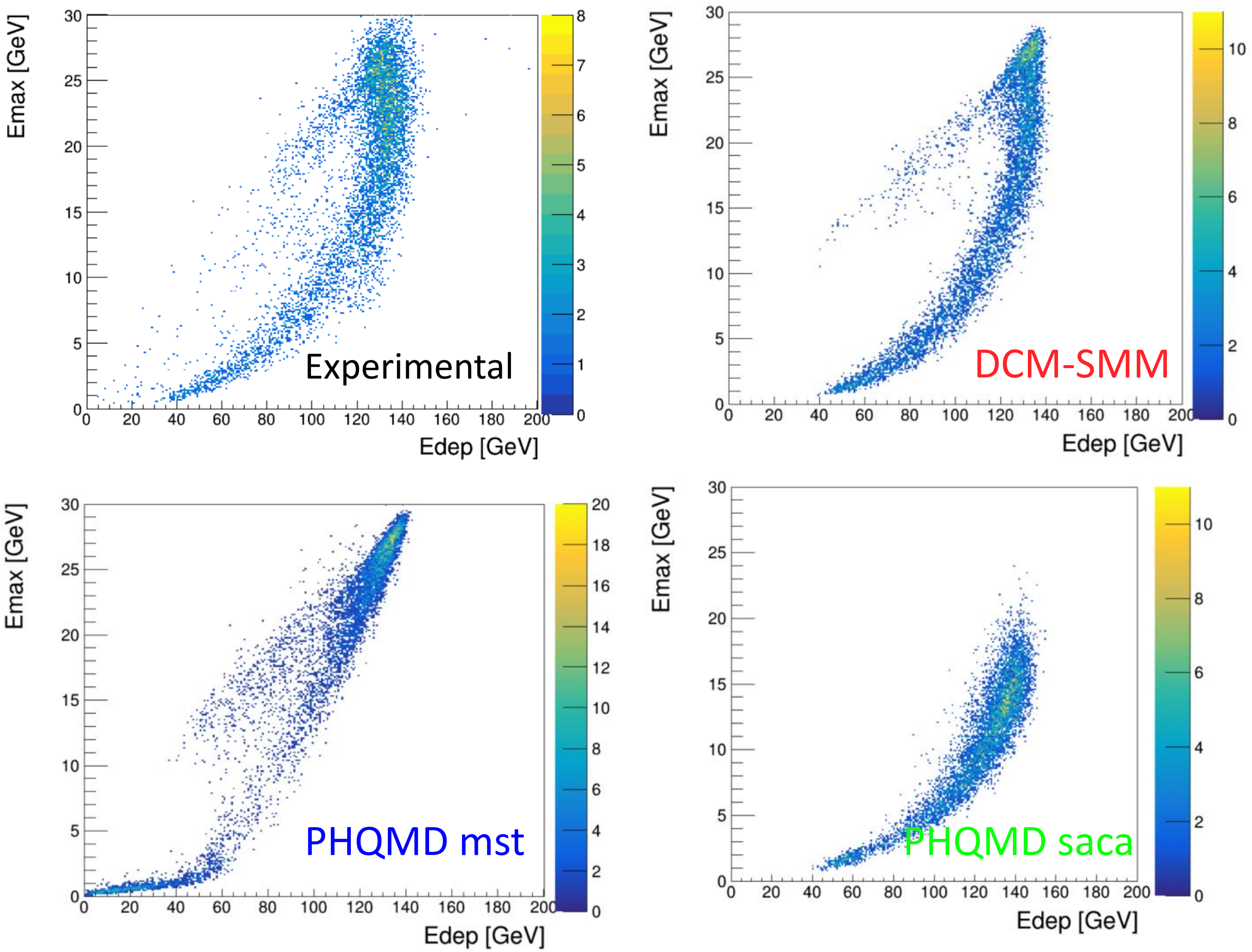
For observables obtained from cone fit DCM-SMM shows greater similarity with experiment

E_{dep} vs mean radius-vector length correlations comparison



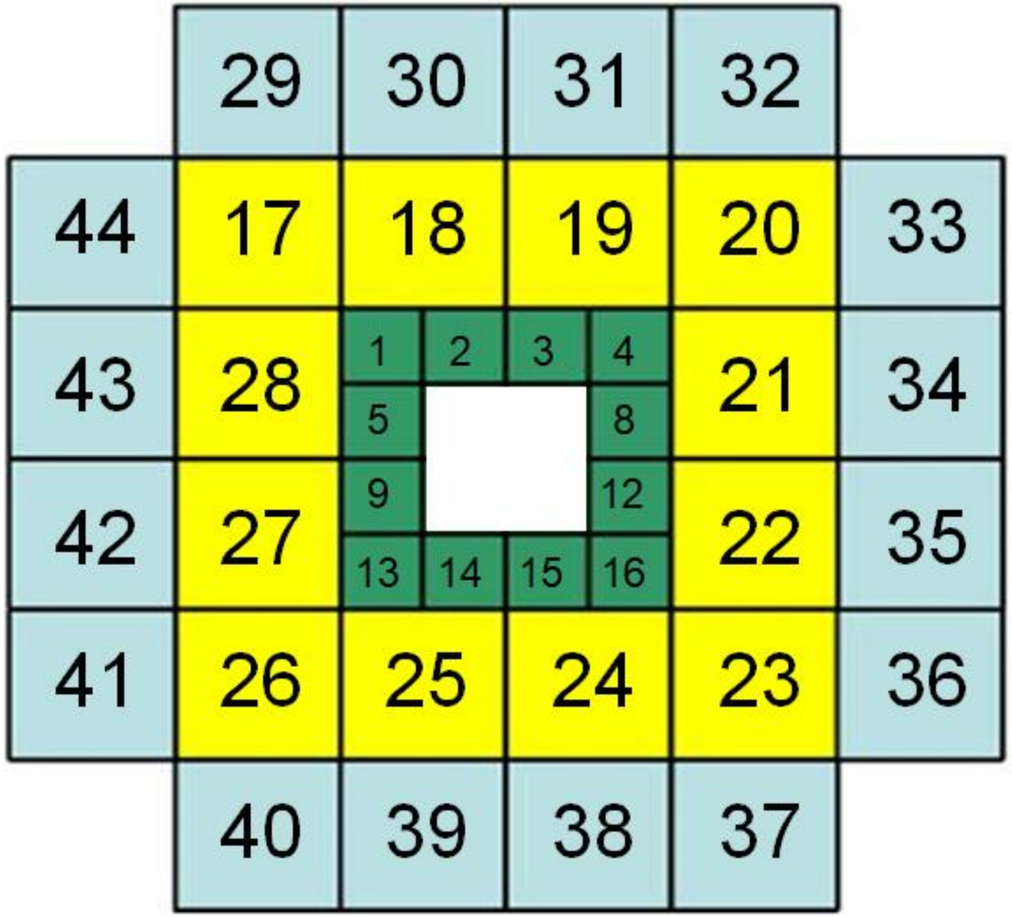
- PHQMD has a clearly different form of distribution
- DCM-SMM is in better agreement with experimental data

E_{dep} vs E_{max} correlations comparison

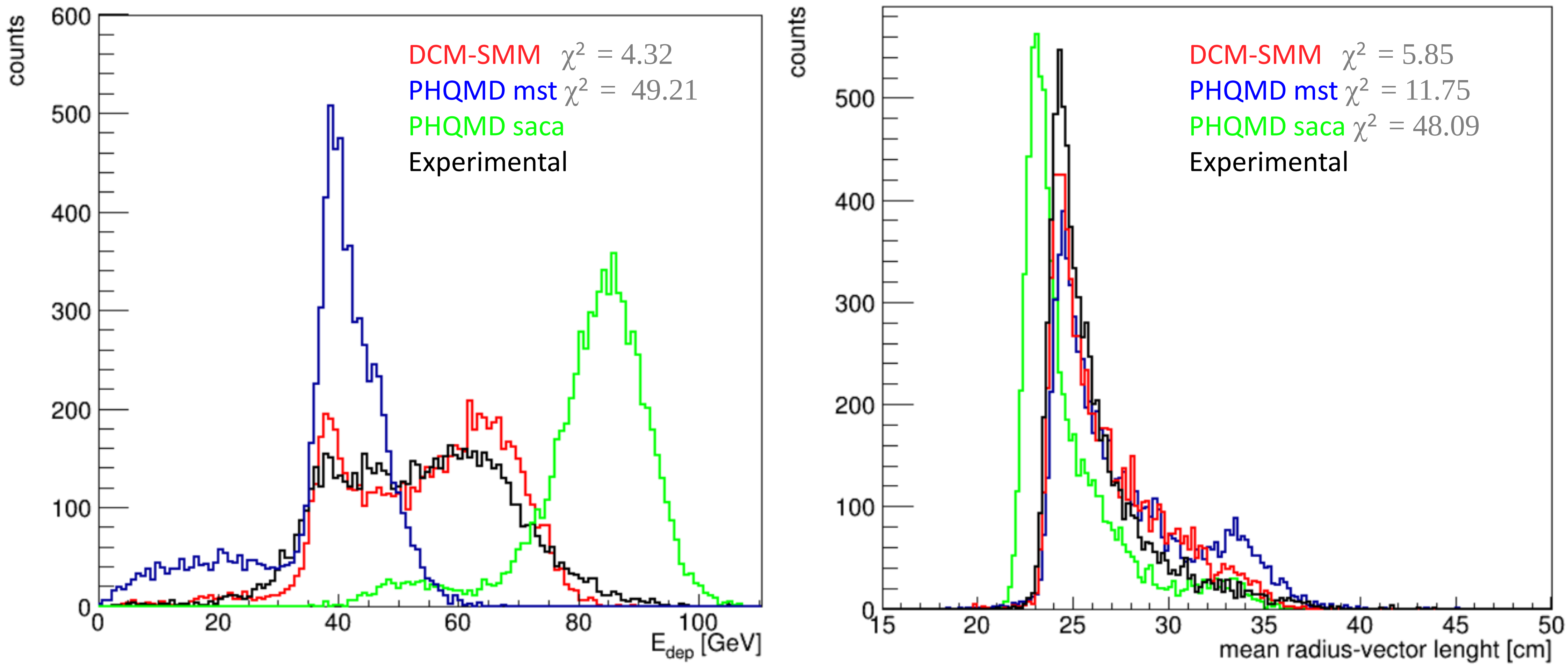


The result of comparing the models with the experimental data for the **no-hole** version of calorimeter is that all variables except E_{dep} show chi-squared comparison results **in favor of the DCM-SMM** model.

Calorimeter with a hole models comparison

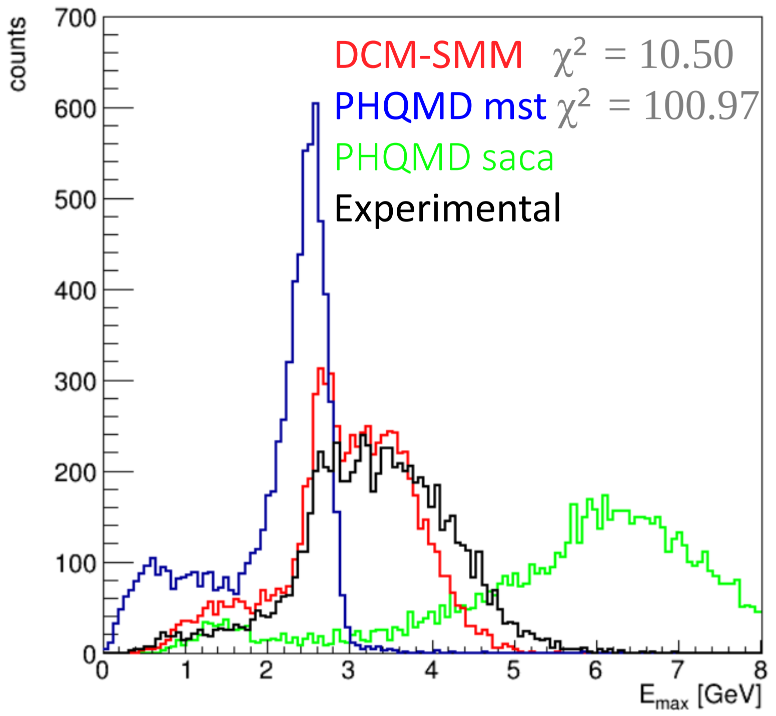


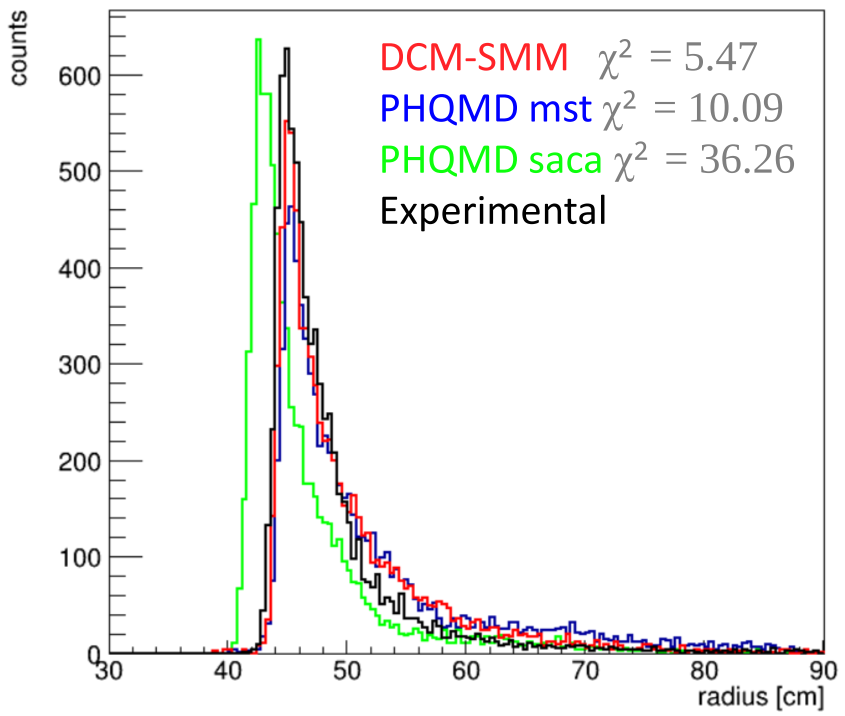
Energy deposition and “mean” radius-vector length comparison

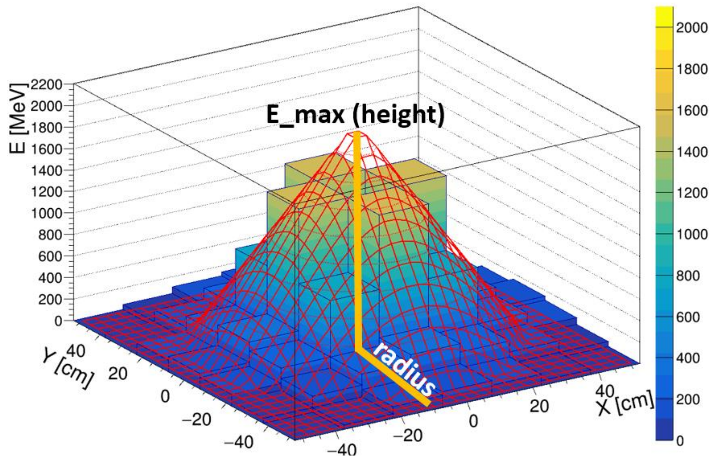


It is clearly seen that both versions of the clustering in the PHQMD model significantly different from experiment for the energy deposition in the case of a calorimeter with a hole.

E_{max} and cone radius comparison



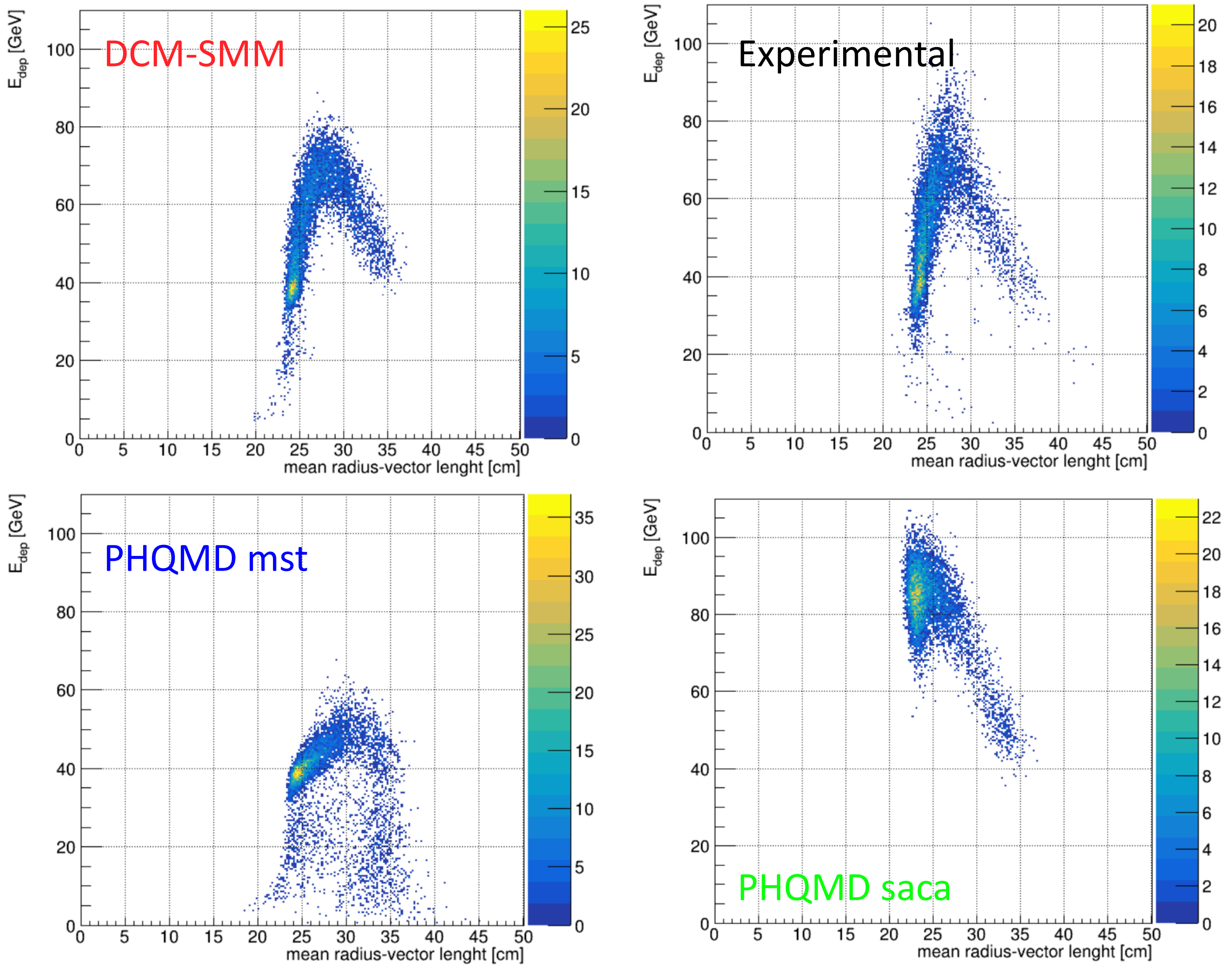




For the reconstructed maximum energy deposition in the center of the calorimeter, it is clear that the **PHQMD SACA distributes the fragments closer to the center of the calorimeter**, but a **large fraction** of **them does not escape into the hole**.

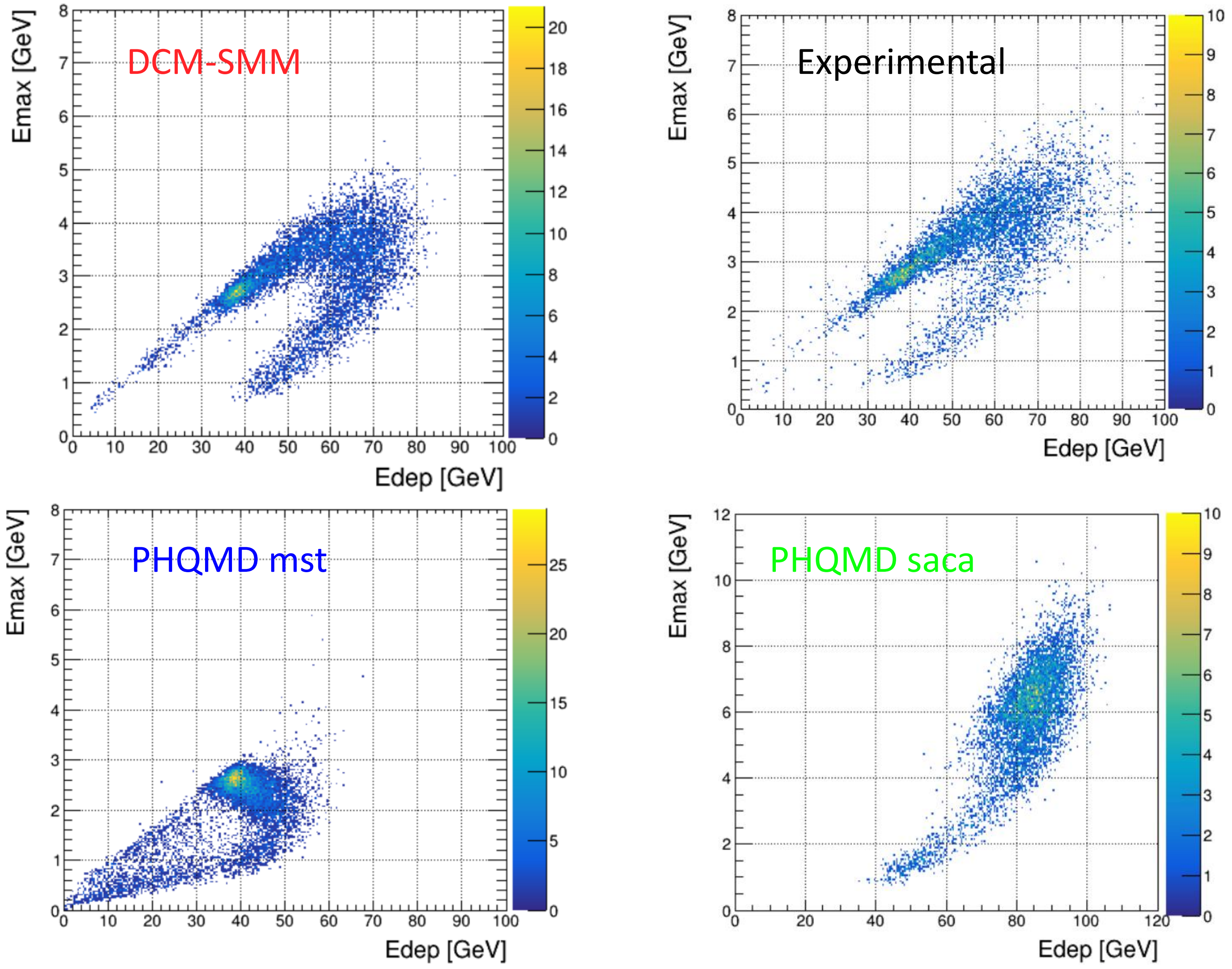
In the case of MST, the energy of the fragments is more evenly distributed over the surface of the calorimeter, producing a peak at the lower energy.

E_{dep} vs mean radius-vector length correlations comparison



- PHQMD has a clearly different form of distribution for both clusterizations
- DCM-SMM is in better agreement with experimental data

E_{dep} vs E_{max} 2D correlations comparison



The result of comparing the models with the experimental data for the **hole** version of calorimeter is that all variables show chi-squared comparison results **strongly in favor of the DCM-SMM** model.

Comparison of χ^2 values

NO HOLE	E_{dep}	**"Mean" r-v**	**Radius**	E_{max}
DCM-SMM	6.37	4.33	3.55	4.43
PHQMD MST	7.61	11.88	5.58	13.87
PHQMD SACA	5.71	28.27	13.19	>100
HOLE	E_{dep}	**"Mean" r-v**	**Radius**	E_{max}
DCM-SMM	4.32	5.85	5.47	10.55
PHQMD MST	49.21	11.75	10.09	>100
PHQMD SACA	>100	48.09	36.26	>100

- It is obvious from the comparison results that the **DCM-SMM model is closer to the experimental data** in the case of a calorimeter without a hole.
- In the case of a hole, the **DCM-SMM model is significantly superior** to both PHQMD versions.

$$\chi^2 = \sum_{i=1}^{n} \frac{(MC_i - Exp_i)^2}{\sigma_{MC_i}^2 + \sigma_{Exp_i}^2}$$

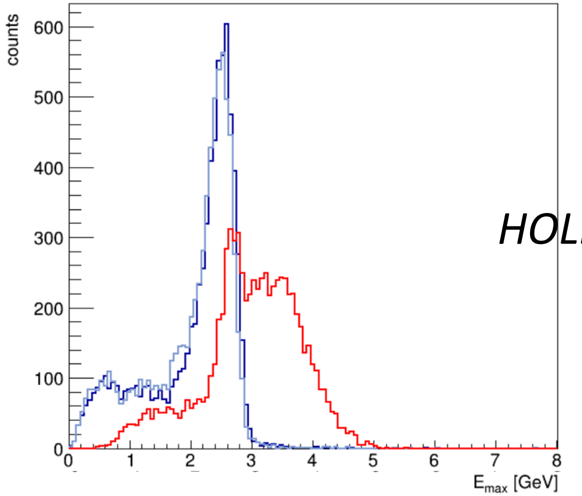
Summary

- Monte Carlo simulations of PSD calorimeter response for DCM-SMM and PHQMD (with two clusterization variants SACA and MST) models are compared with NA61 experimental data for a 30A GeV/c Pb-Pb beam (w/o magnet field).
- The comparison was made in two configurations: in the original one and in the configuration with an artificial beam hole.
- A comparison of several observables (energy deposition in the calorimeter, length of the mean radius vector and maximum energy in the calorimeter and radius of the approximating cone, derived from the 2D approximation) were performed.
- Numerical results of the chi-square comparison were presented. **The DCM-SMM model is shown to fit the experimental data better in both configurations**, in the case of the hole configuration its advantage over PHQMD is quite strong.

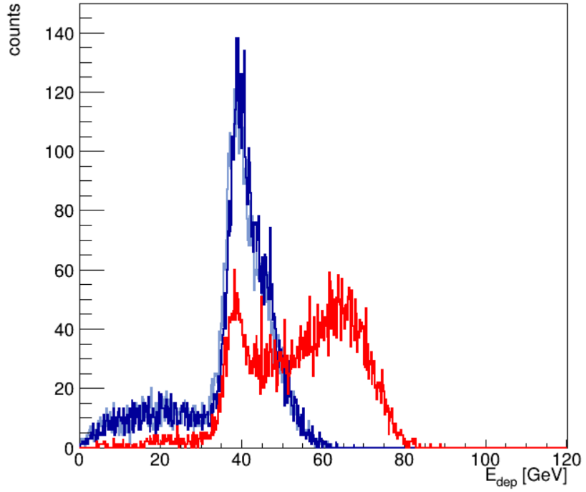
backup

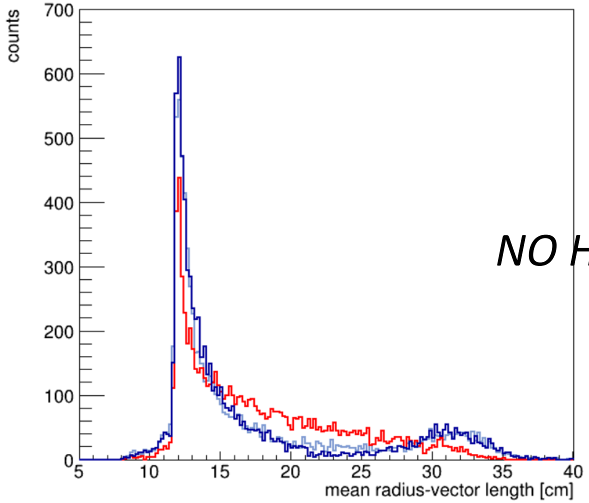
PHQMD MST vs new MST vs DCM-SMM

new MST (less clusterization time)



HOLE





NO HOLE