Approaches in centrality measurements of heavy ion collisions with forward calorimeters at MPD/NICA facility

Volkov Vadim

INR RAS

17/09/2020

PWG1

Overview

- Can FHCal measure the centrality with spectators?

- FHCal detects not only energies but the space distribution of energies!

- A few methods for centrality determination are discussed:
- a) Correlations of transverse and longitudinal energy components,
- b) 2D-fit of FHCal energy distributions,
- c) Subtraction of pion energy contamination and evaluation of spectator's energy.

Tools:

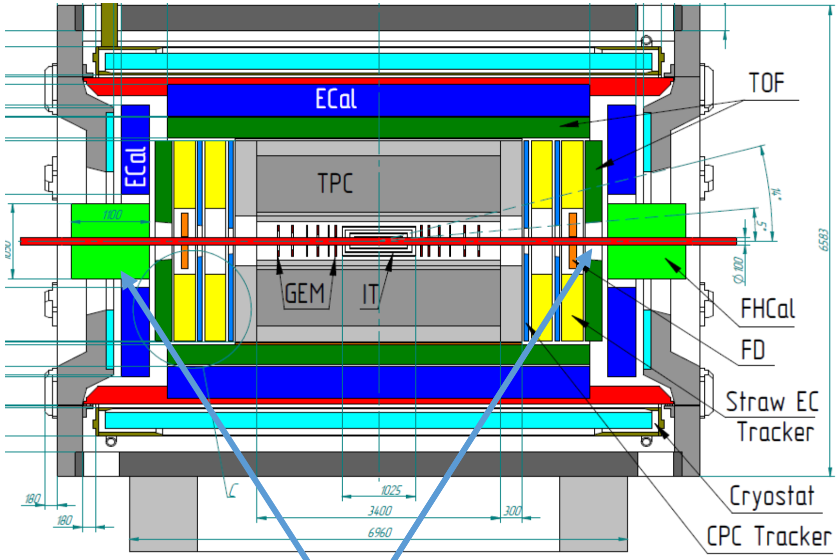
- Simulations in MpdRoot;
- Au-Au at $\sqrt{S_{NN}} = 11\,\mathrm{GeV}$;
- Two, LA-QGSM and DCM-SMM fragmentation models are used and compared.

FHCal@MPD

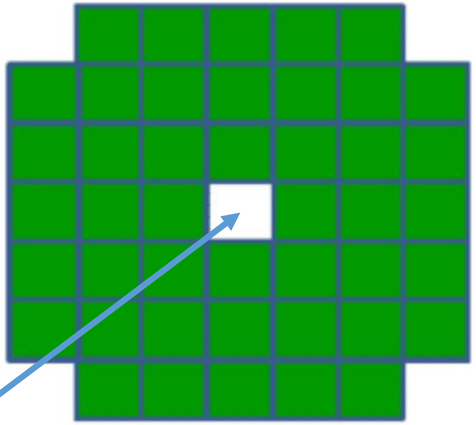
- The main purpose of the FHCal is to detect spectators and to provide an experimental measurement of a heavy-ion collision centrality and orientation of its reaction plane.

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

- FHCal measures not only spectator's but also pion's energies.

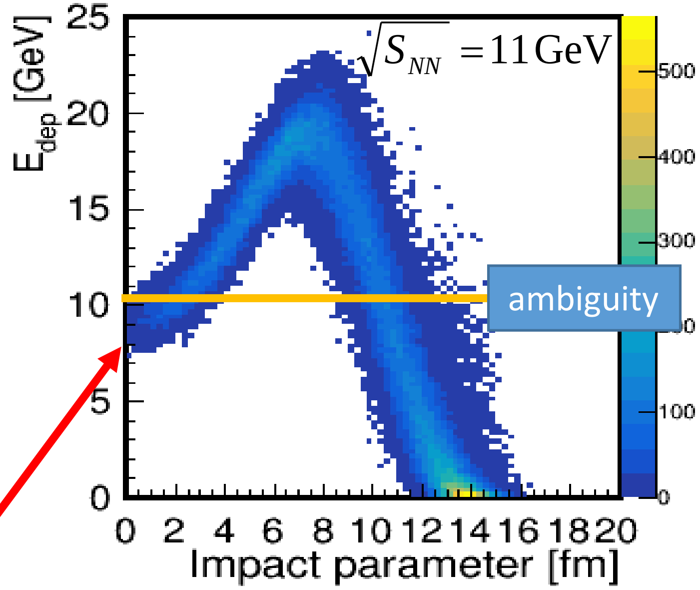


Two upstream/downstream parts



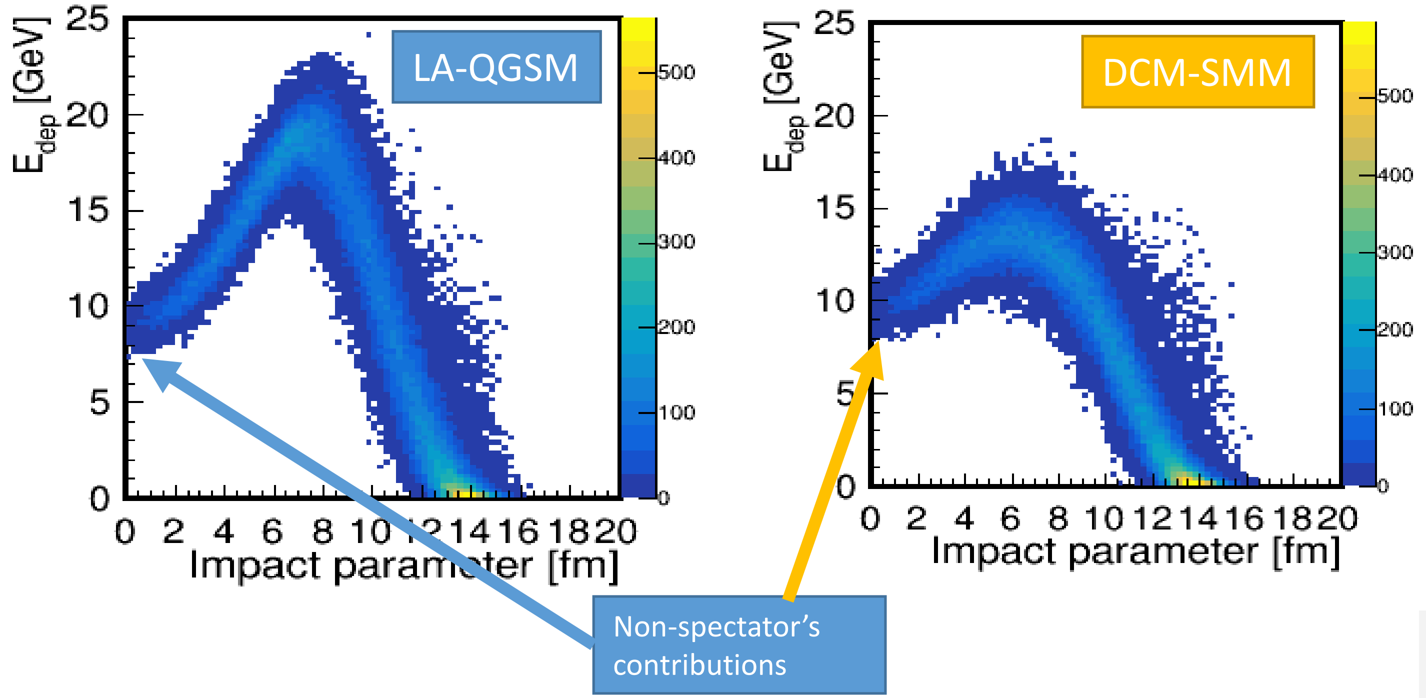
44 individual modules

Beam hole

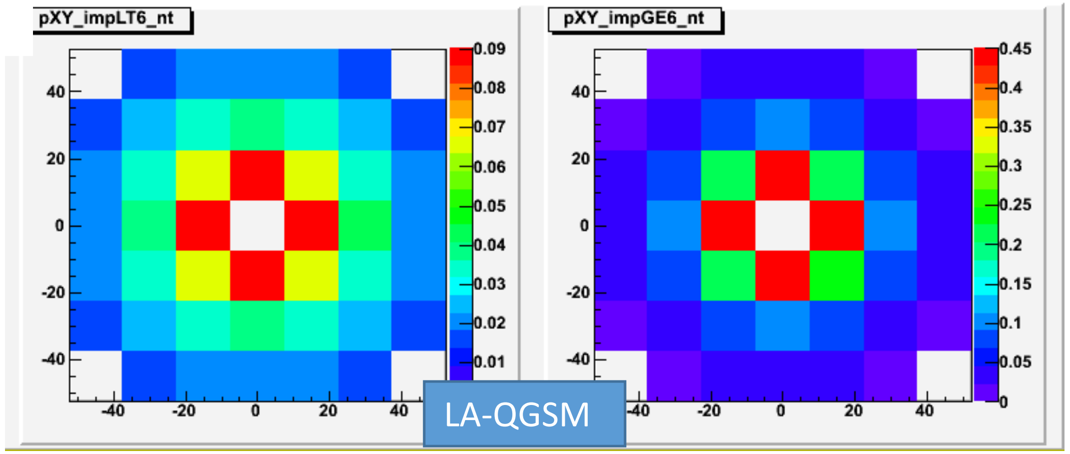


Non-spectator's contributions

Energy depositions in FHCal for different models



Transverse energy distributions are wider for central events and narrower for the peripheral collisions.



Impact parameter b<= 6 **Impact parameter b>6**

This feature can be used for the separation of central/peripheral events.

- Energy depositions are quite different for different fragmentation models.
- Results would depend on the fragmentation model.
- FHCal detects not only the spectators but also the produced particles and wounded nucleons from participant region.

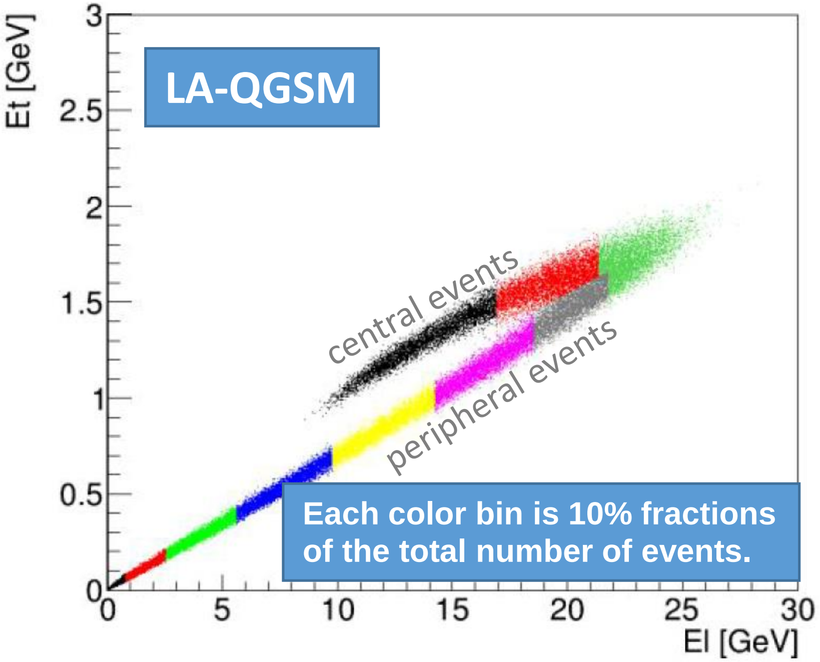
Correlation between transverse and longitudinal energies in FHCal

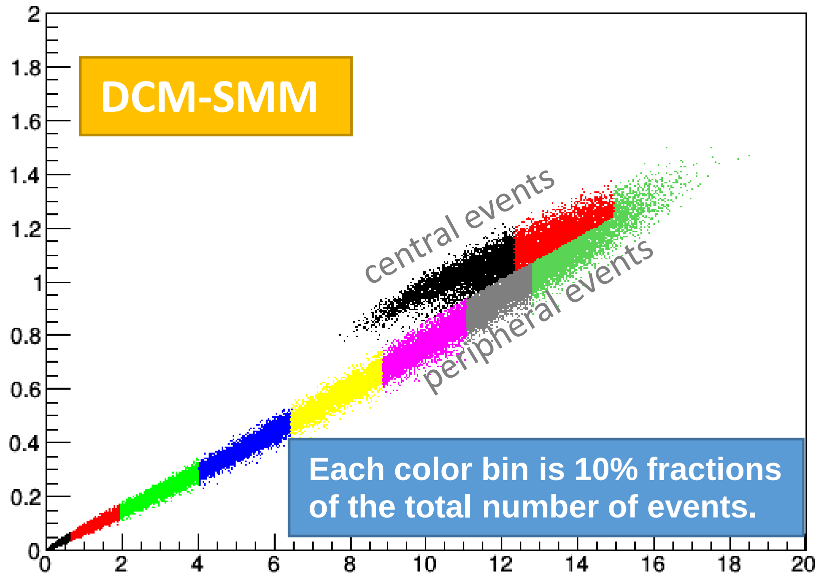
- **LA-QGSM and DCM-SMM models for √S = 11 AGeV are used.**
- The E_T and E_L energies are transverse and longitudinal energies: respectively.

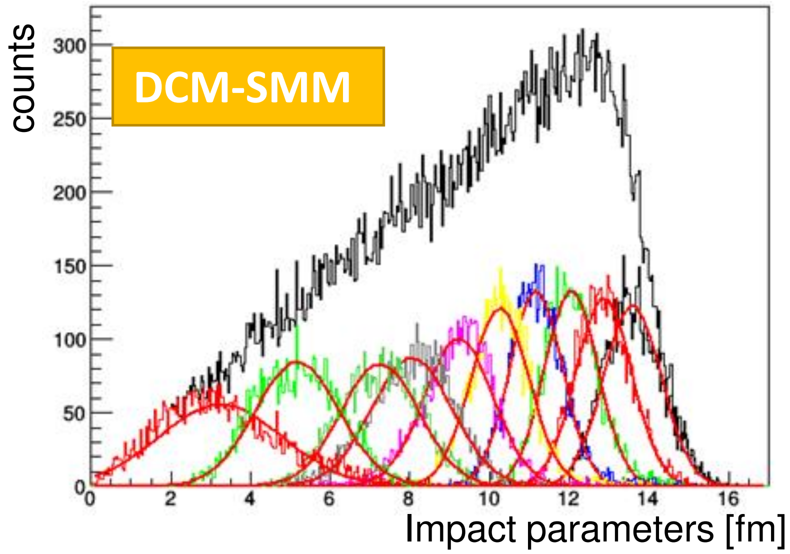
$$E_T = \sum E_i \sin\theta_i, \; E_L = \sum E_i \cos\theta_i$$

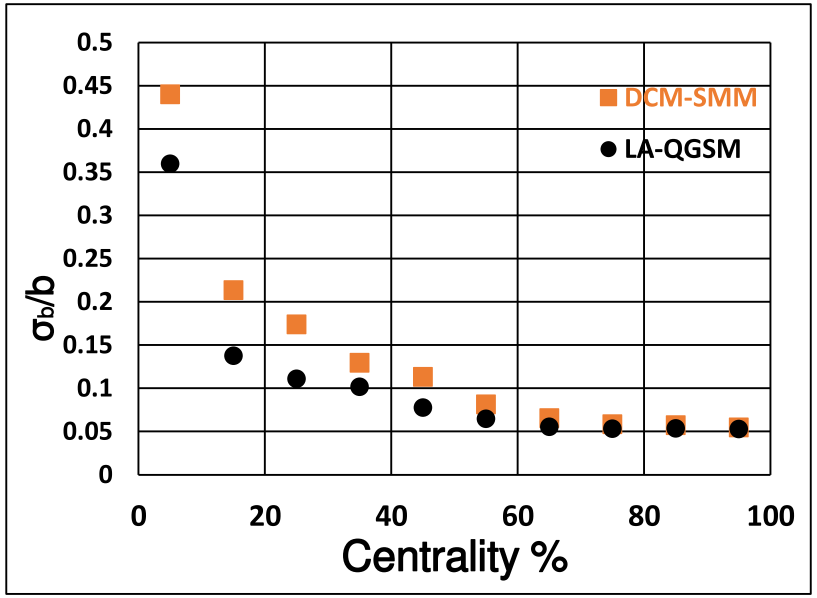
- The (E_T -E_L) histograms are divided into ten parts, 10% of events in each part, 10%-clusters are separated from one another by perpendiculars to the envelope.
- b-distributions for each centrality bin are fitted by Gauss.
- The separation of central and peripheral events with DCM-SMM model is clearly worse.

New approaches are needed







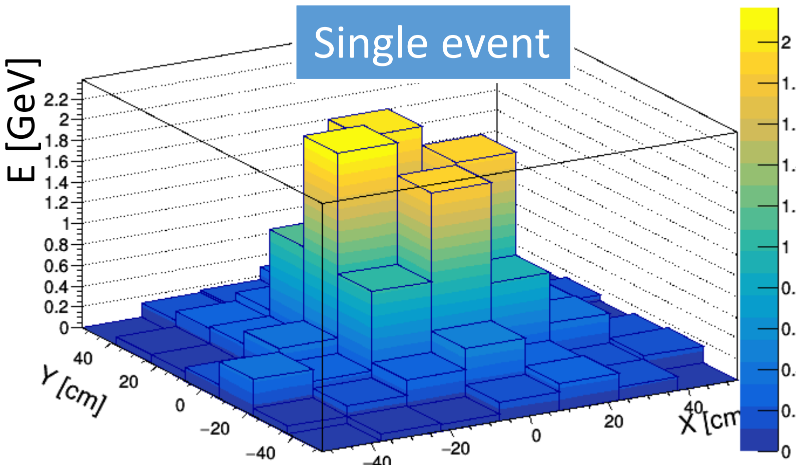


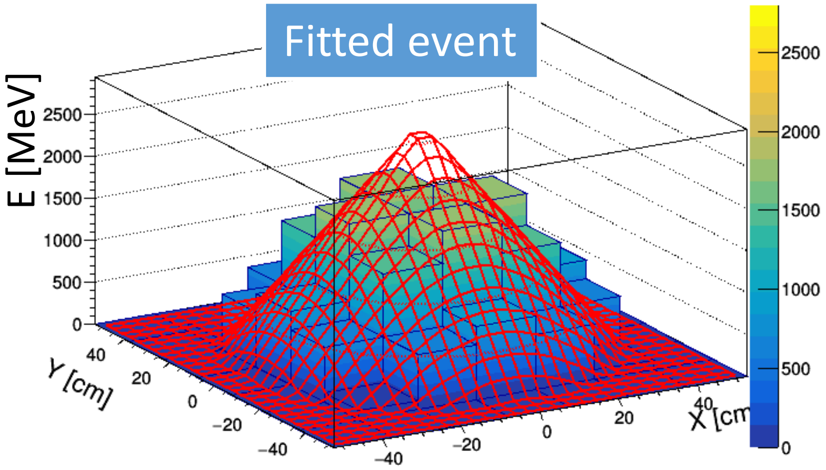
Dependence of resolution of impact parameter on centrality

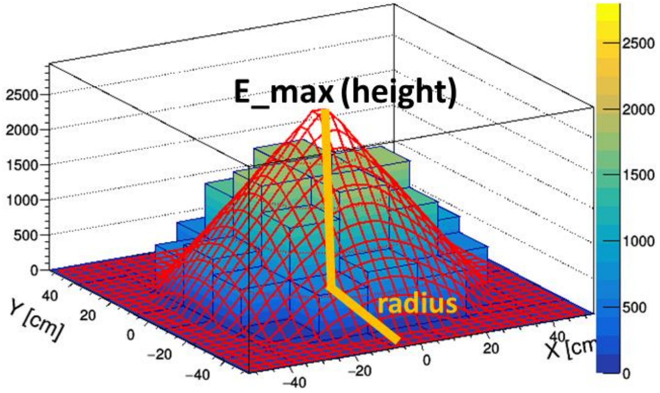
2D-linear fit method

(linear approach)

Energy distribution in FHCal modules



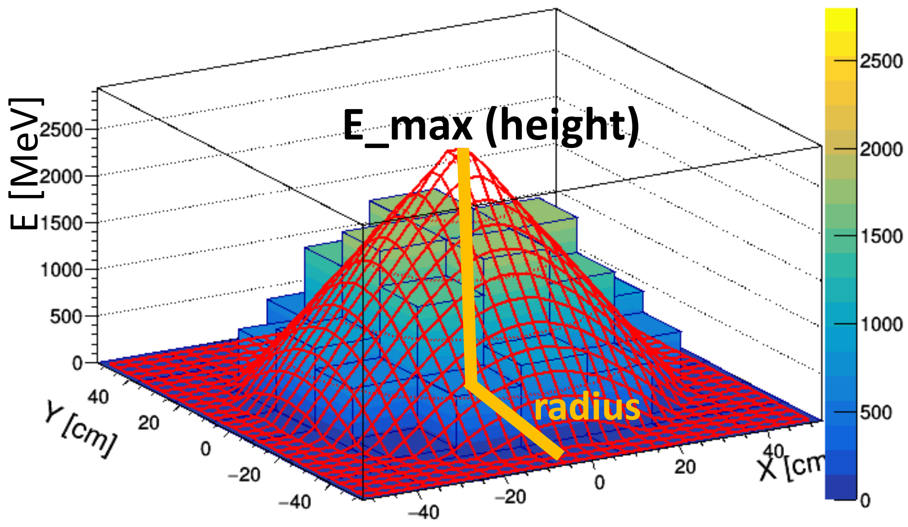


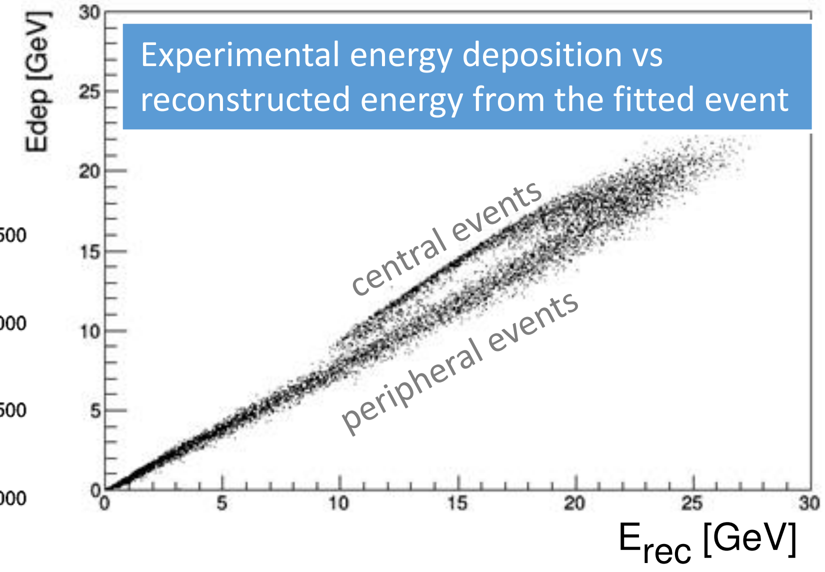


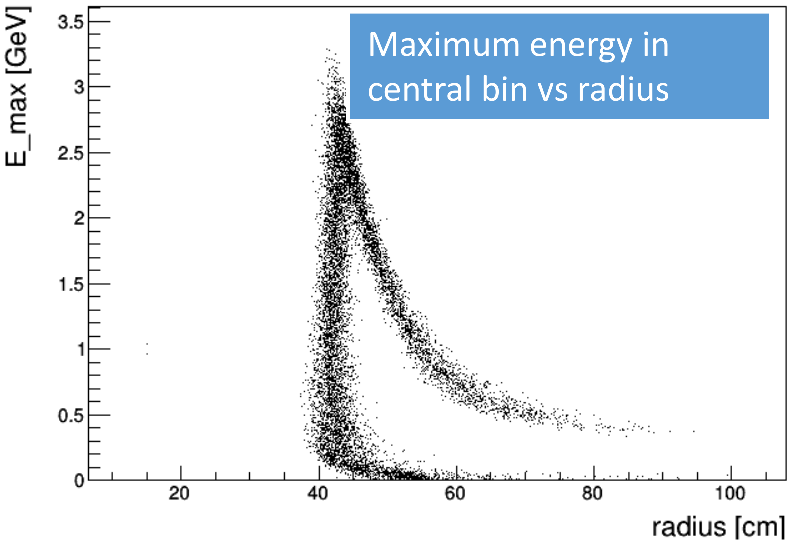
- In this method the space energy distribution in FHCal modules is used.
- The energy in the histogram is uniformly distributed in FHCal modules according to the polar angle.
- The histogram is fitted by a symmetrical cone (linear approximation).
- Weight of each bin is proportional of the energy deposited in corresponding FHCal module.
- This fit provides the new observables: radius, height of the cone. Volume of cone corresponds to the reconstructed energy (E_{rec}).

Correlation between obtained fit parameters. LA-QGSM

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

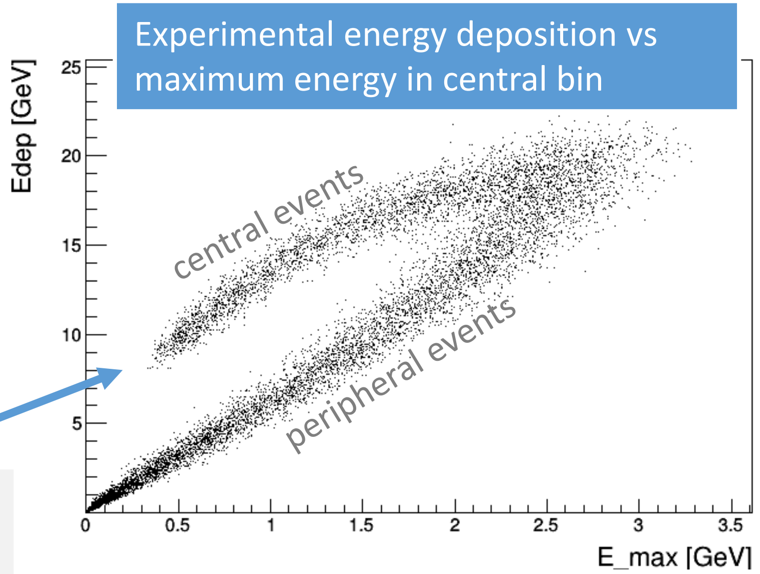






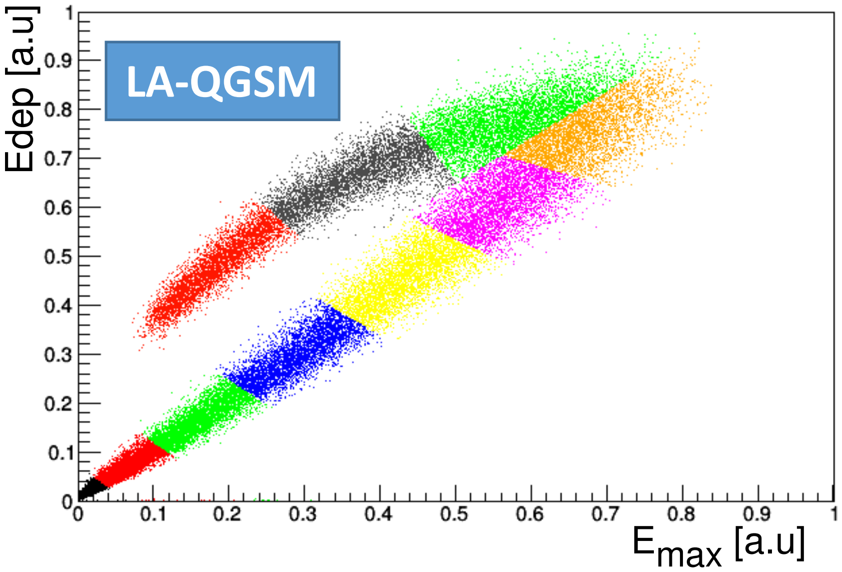
After linear fit we have:

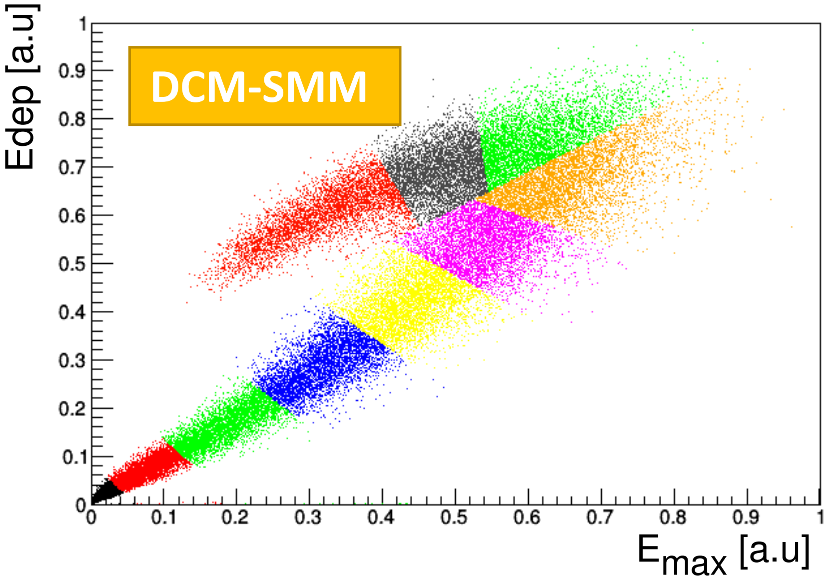
- ***E_{rec}* is reconstructed energy (volume of cone);**
- ***E_{max}* – maximum energy in central bin (in FHCal hole);**
- ***Radius* of spectator spot at FHCal is defined by the scattering spot of spectators.**

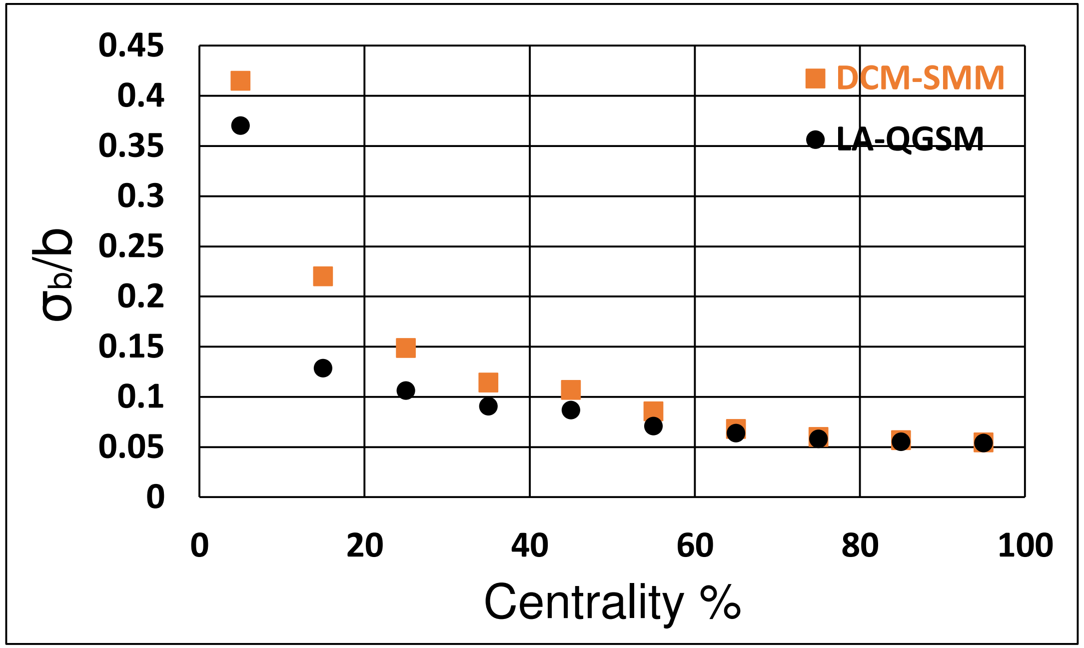


This correlation can be used for the centrality determination

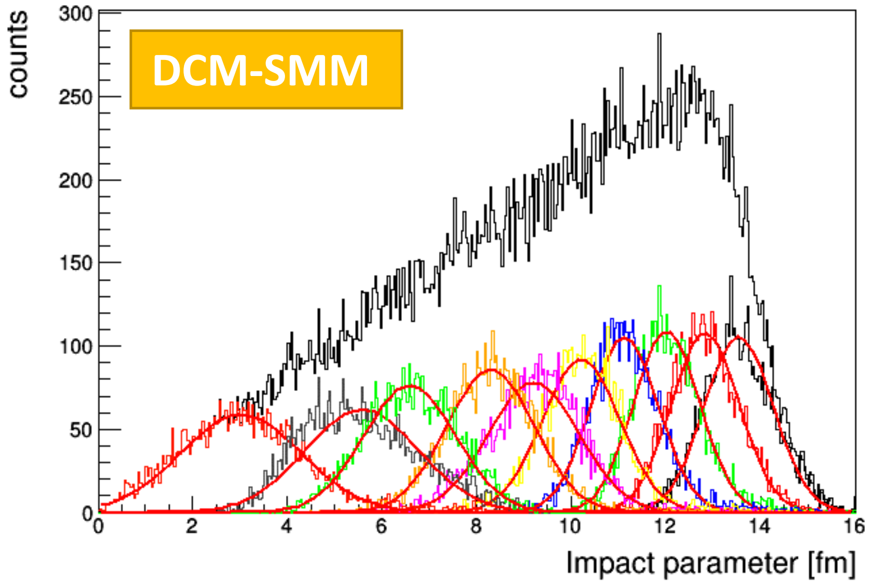
Centrality resolution for E_{dep} vs E_{max}





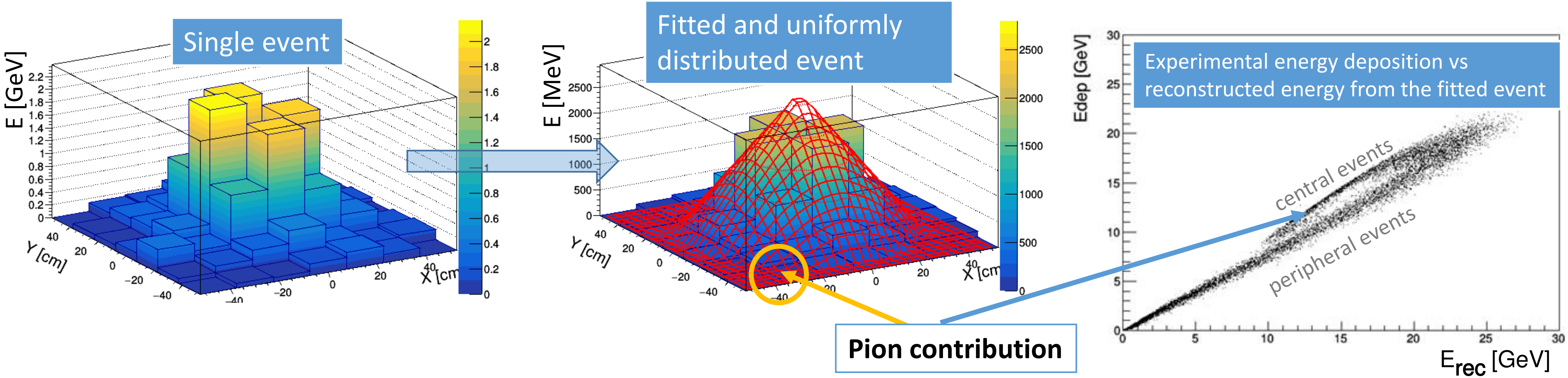


Dependence of resolution of impact parameter on centrality



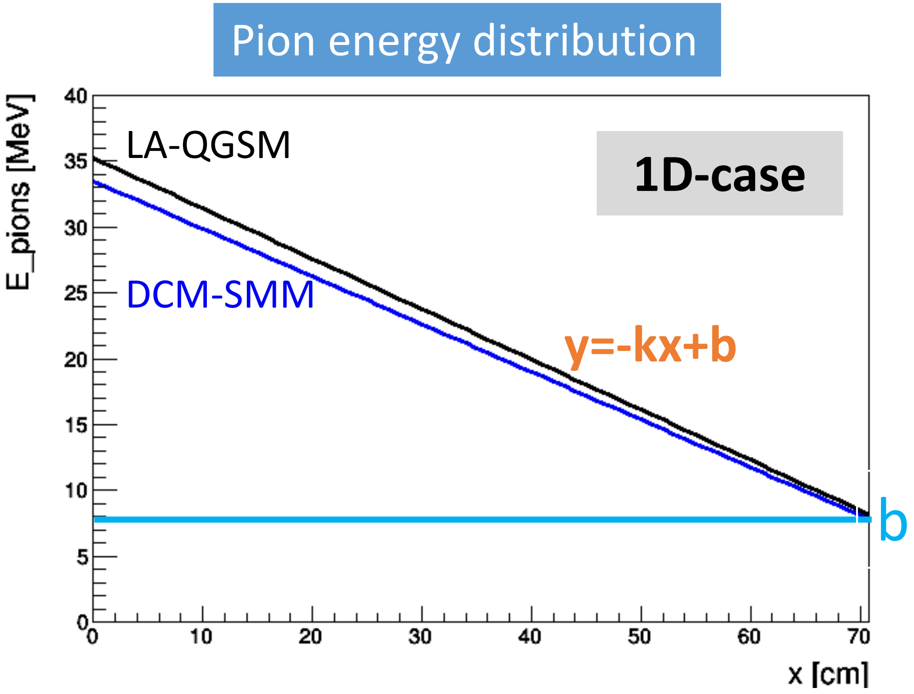
2D linear fit method

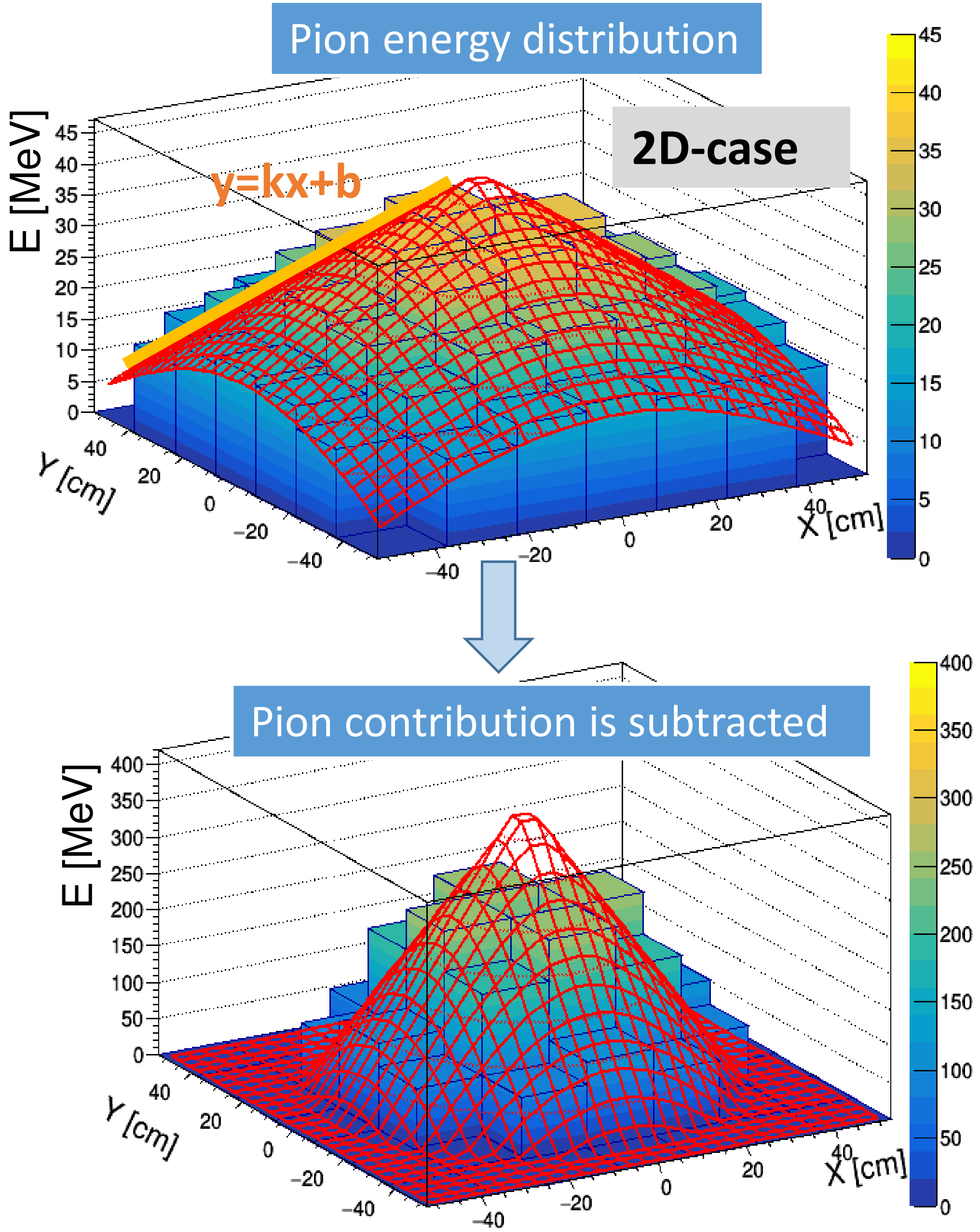
(with subtraction of pion contribution)



- **Narrow cone radius indicates that the outer FHCal modules detect the pions mainly, while the spectators are detected by inner modules.**
- **Energy in outer modules can be regarded as pure non-spectator (pion) contribution.**
- **Let's try to evaluate pion contribution in full FHCal.**

Evaluation of pion energy contribution

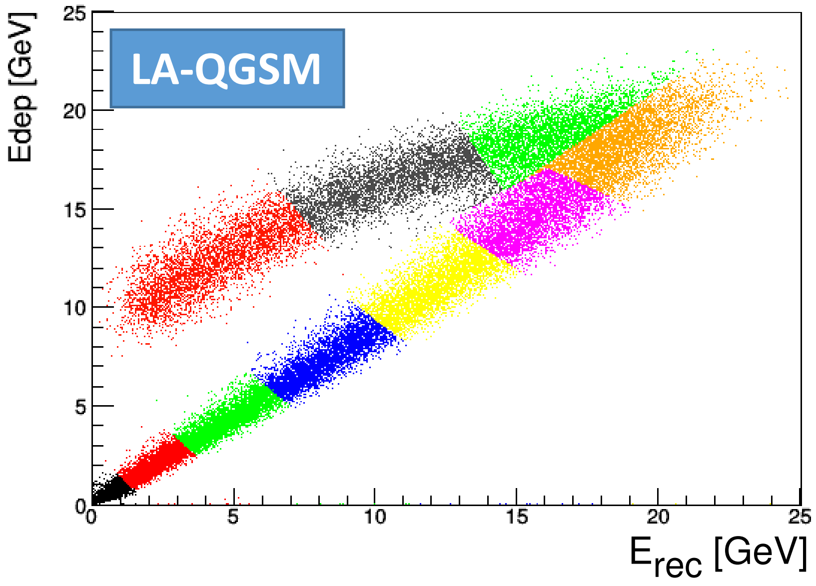


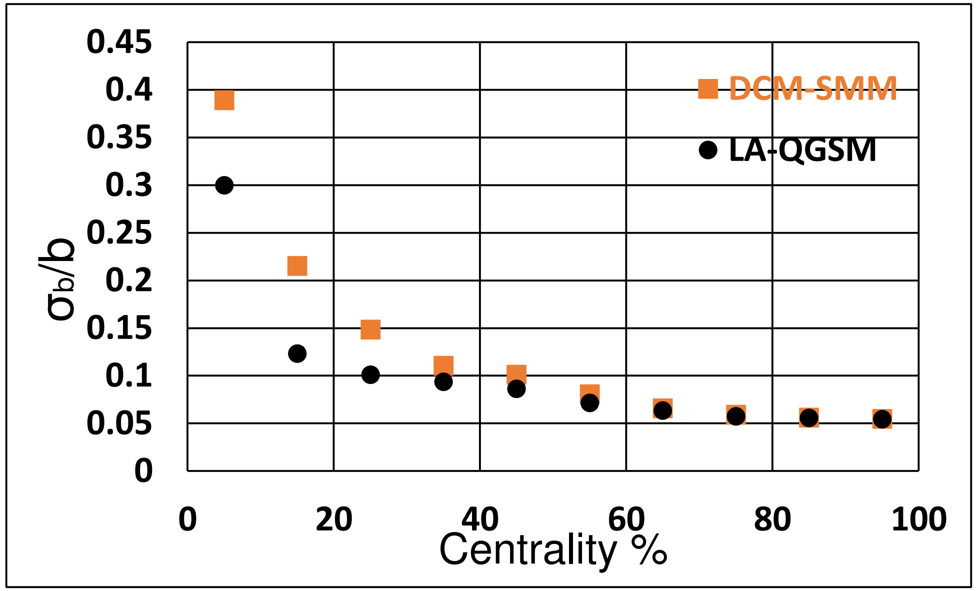


- Linear fit with *y=kx+b* background,
- b is known from outer FHCal modules,
- *k* is taken from simulation and quite similar for LA-QGSM and DCM-SMM models
- The ratio of edge and central energies is almost the same for different models (2.4609 for LA-QGSM, 2.45876 for DCM-SMM)

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

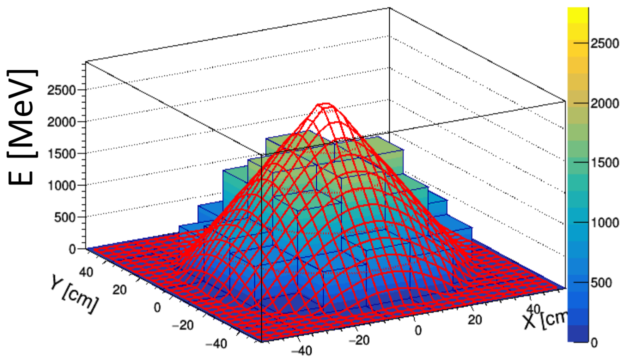
(after subtraction of pion contribution)

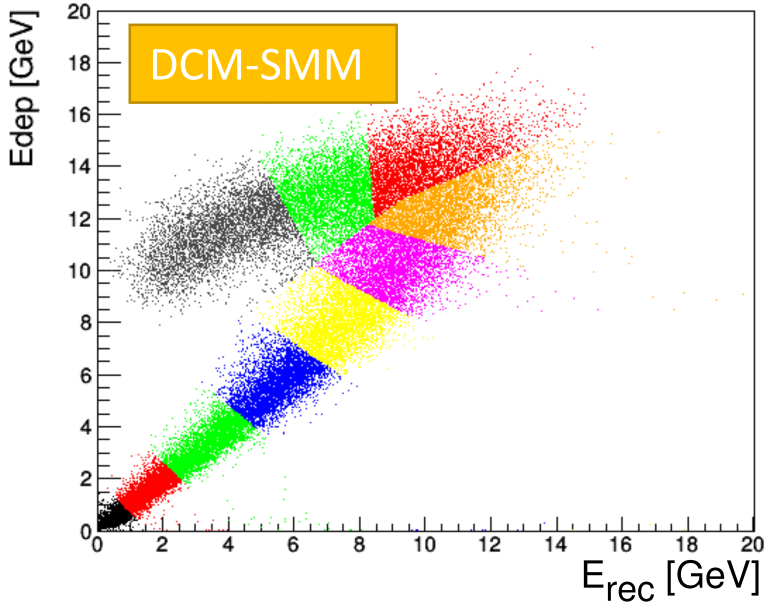


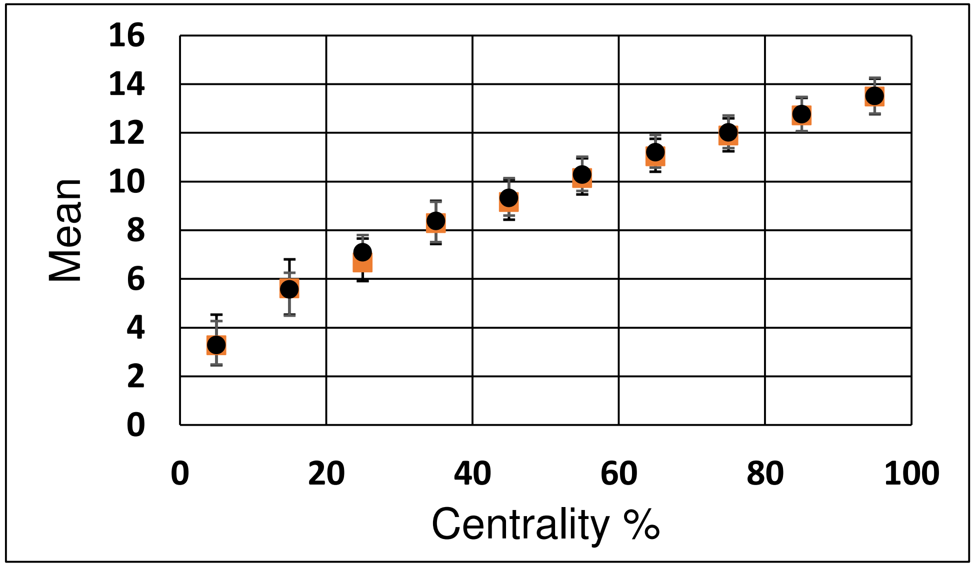


Dependence of resolution of impact parameter on centrality

E_{rec} is a volume of a cone



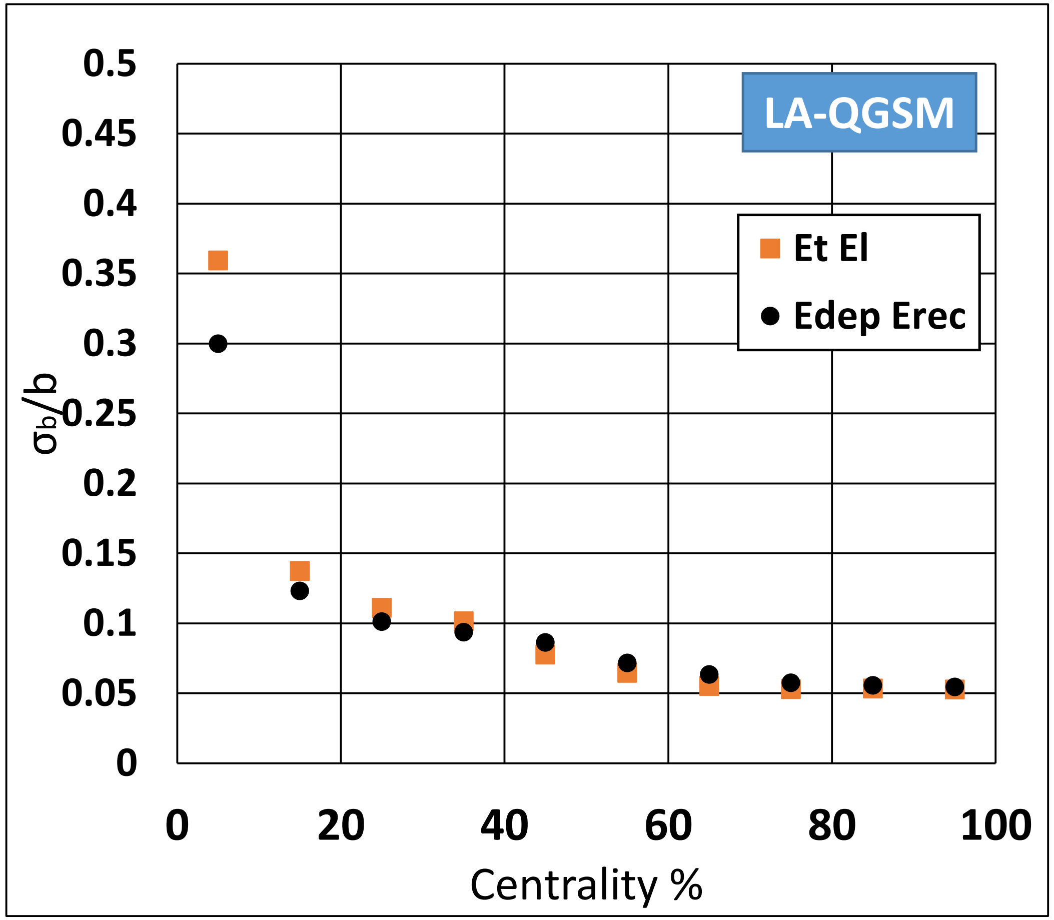


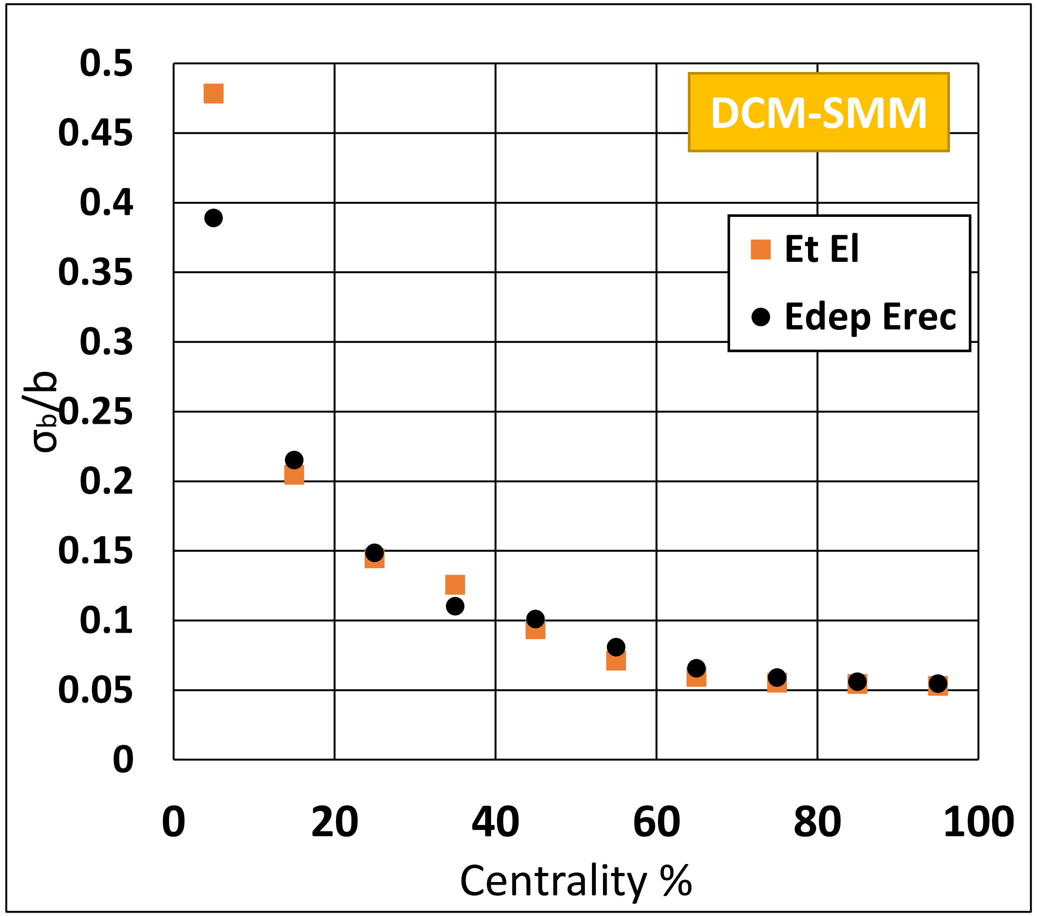


Dependence of impact parameter on centrality

Comparison of results from different methods

Dependence of resolution of impact parameter on centrality





- **Application of linear fit method improves the resolution for the most central events;**
- **DCM-SMM model provides worse results comparing to LA-QGSM one.**

Conclusion

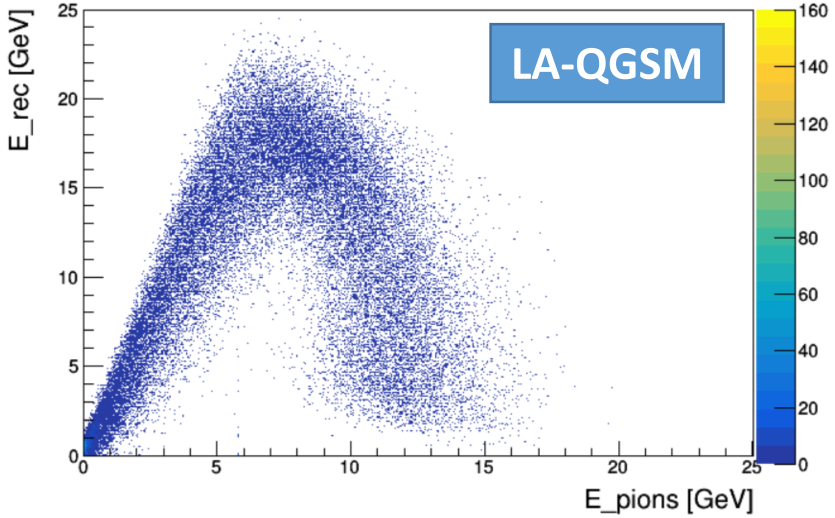
- The ability of FHCal to measure the collision centrality was considered.
- Only the spectators for the centrality reconstruction were used.
- Three methods for the centrality determination have been demonstrated:
  - Transverse-longitudinal energies correlation;
  - 2D-linear fit method;
  - 2D-linear fit with pion contribution subtraction method.
- A few new observables were introduced for the centrality determination.
- The usage of the introduced observables allows to determine the centrality more accurately, especially for the DCM-SMM model.
- DCM-SMM model provides worse centrality resolution because this model has much more heavy fragments which escape in FHCal beam hole.
- The subtraction of the pion contribution makes possible to measure the energy of free (protons/neutrons) spectators.
- Number of free spectators can be estimated more accurately. It can be used for the centrality measurements.

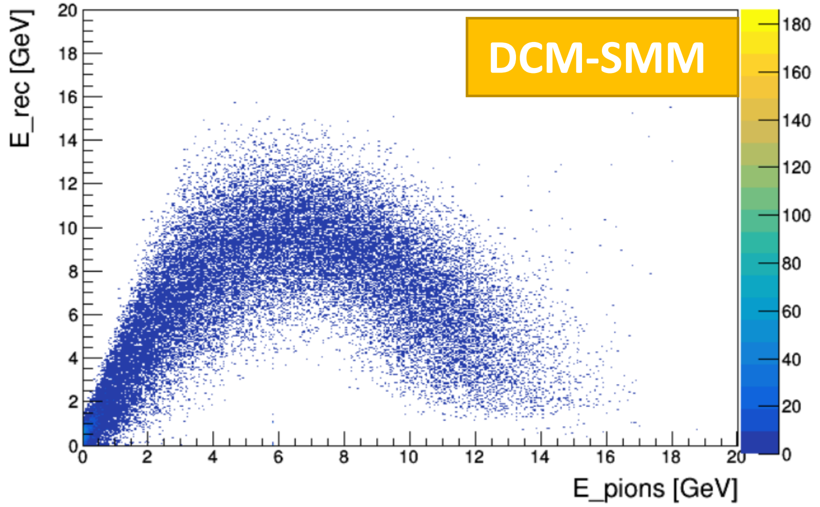
Thank you for your attention!

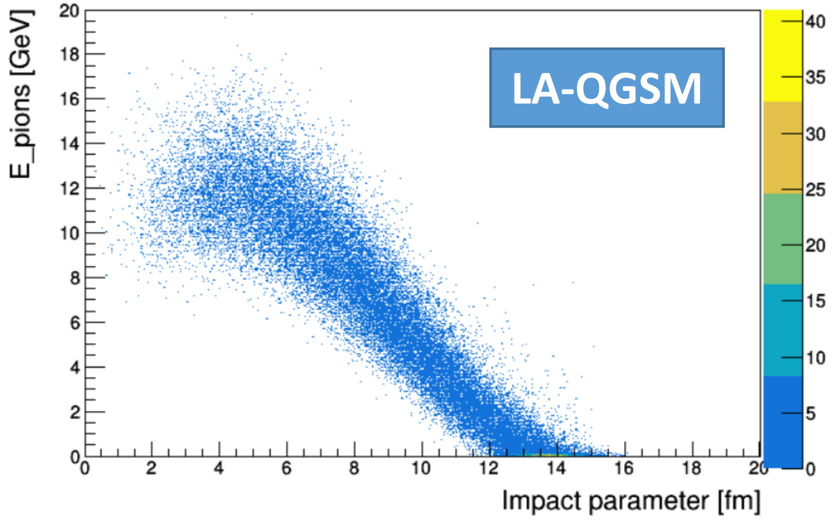
This work was supported by the RFBR 18-02-40065 mega grant

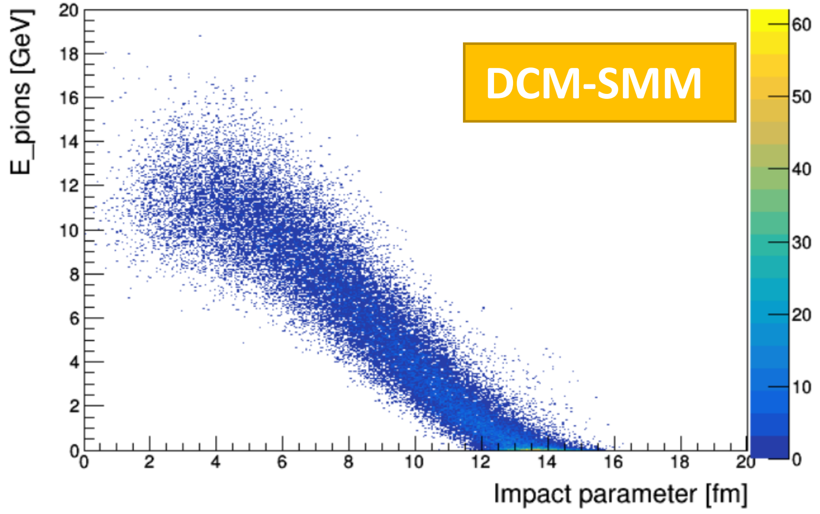
BACKUPS

Energy deposition can be decomposed in two components: energy of free spectators and non-spectators energy









By using the subtraction of the non-spectator's contribution, the energy deposition can be decomposed into two components.

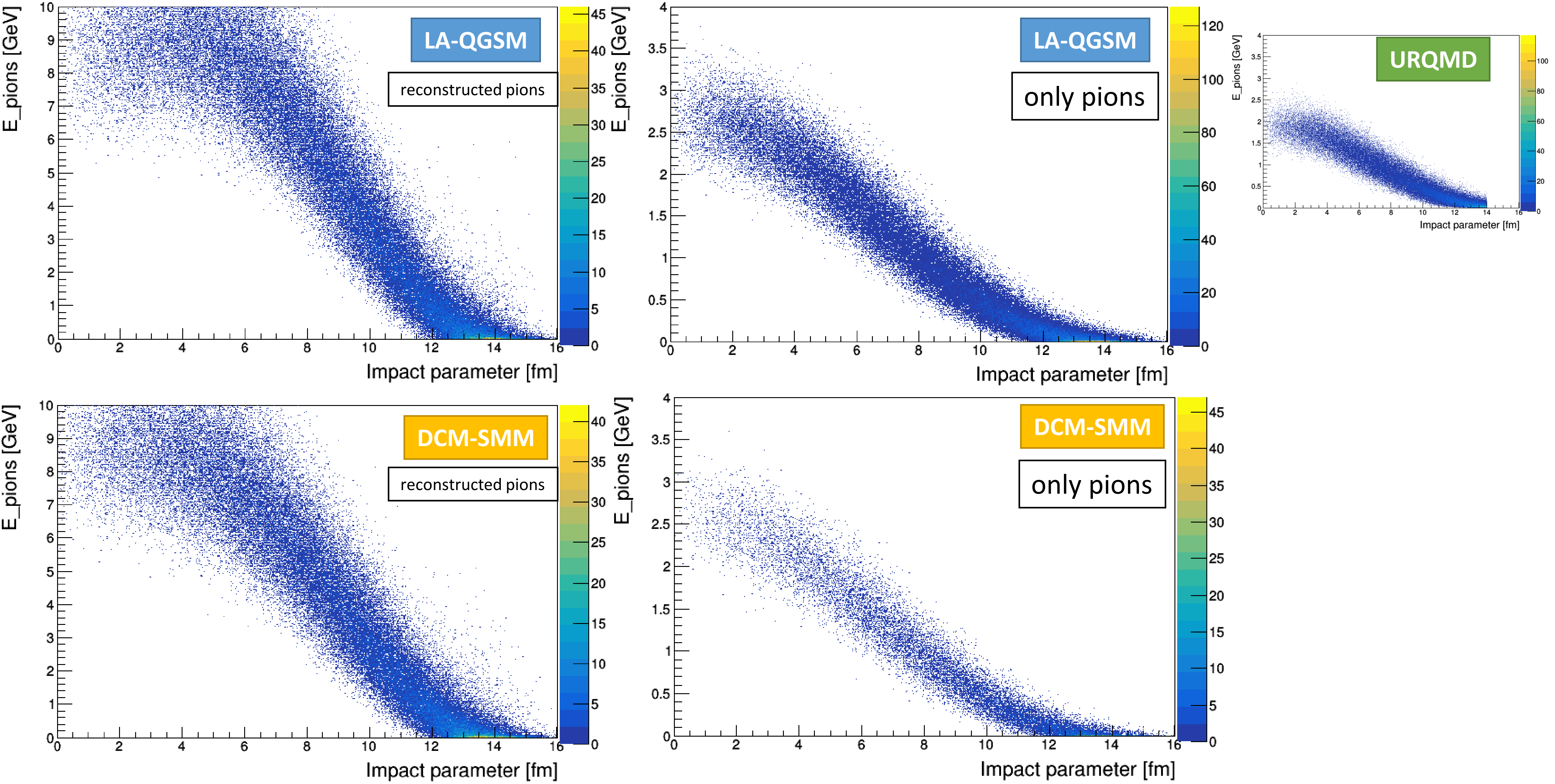
E_dep

Free spectators energy (E_rec)

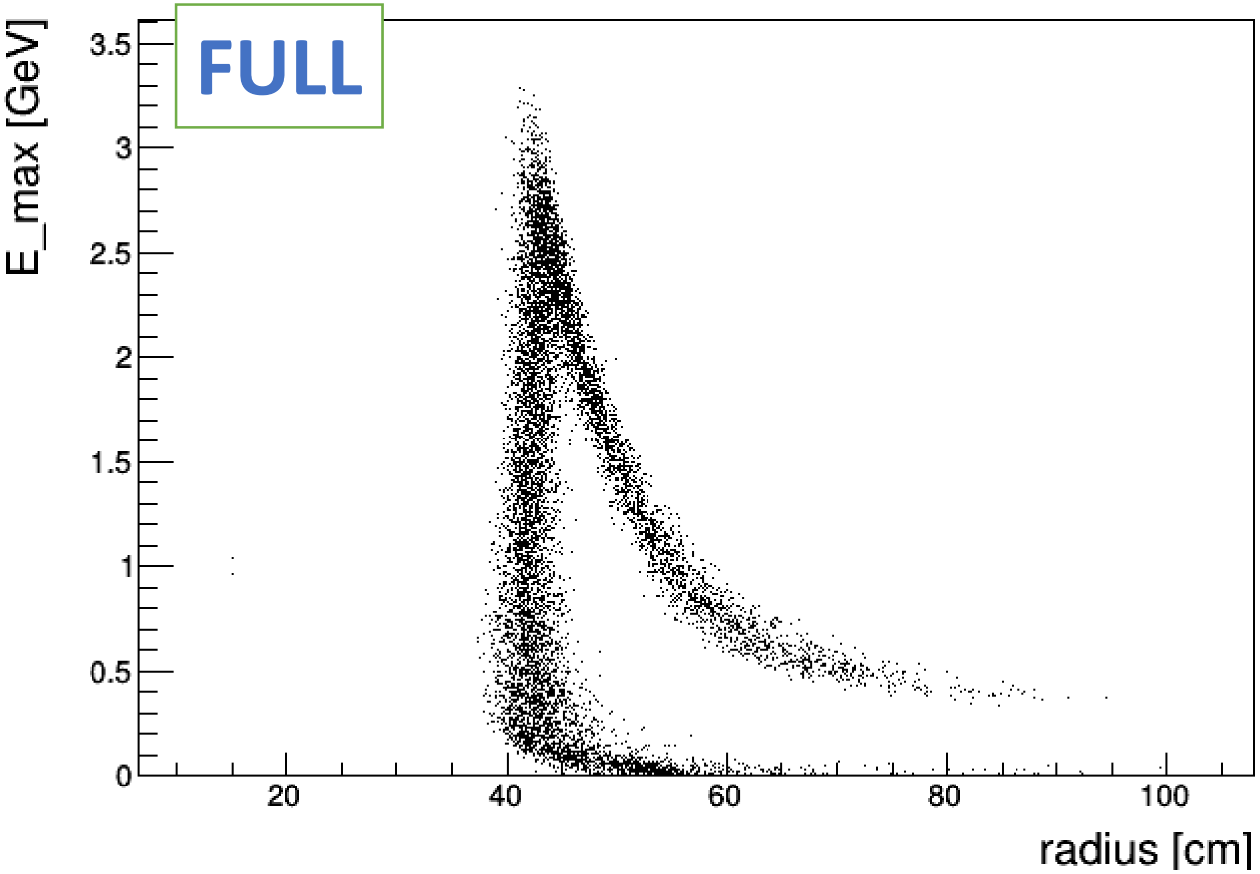
Non-spectators energy (E_pions)

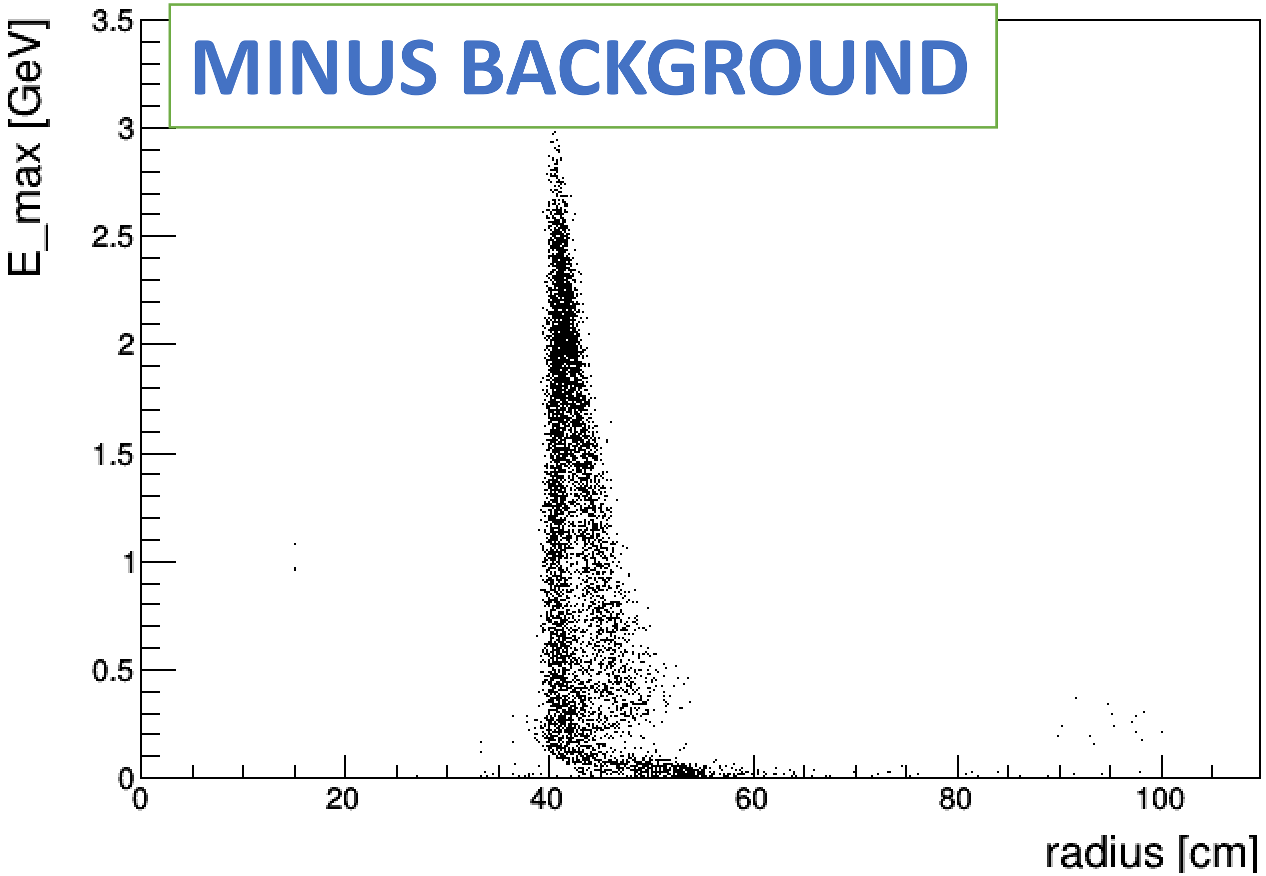
Both energies can be used for centrality determination.

E_pions vs Imp



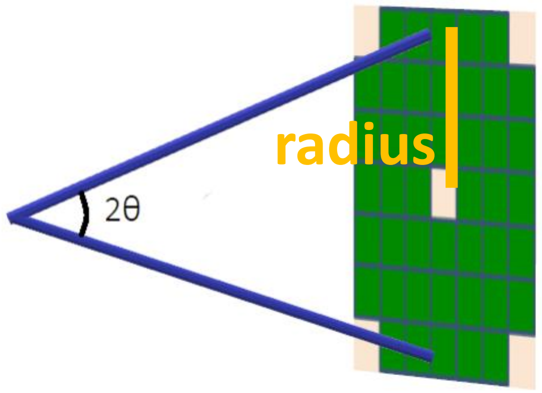
Comparison
LA-QGSM 11 GeV



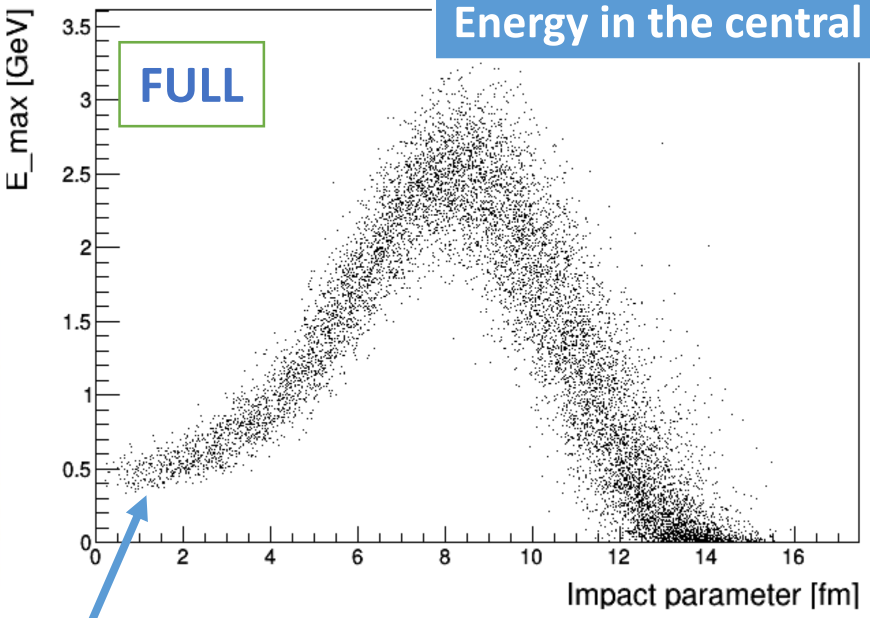


LA-QGSM 11 GeV

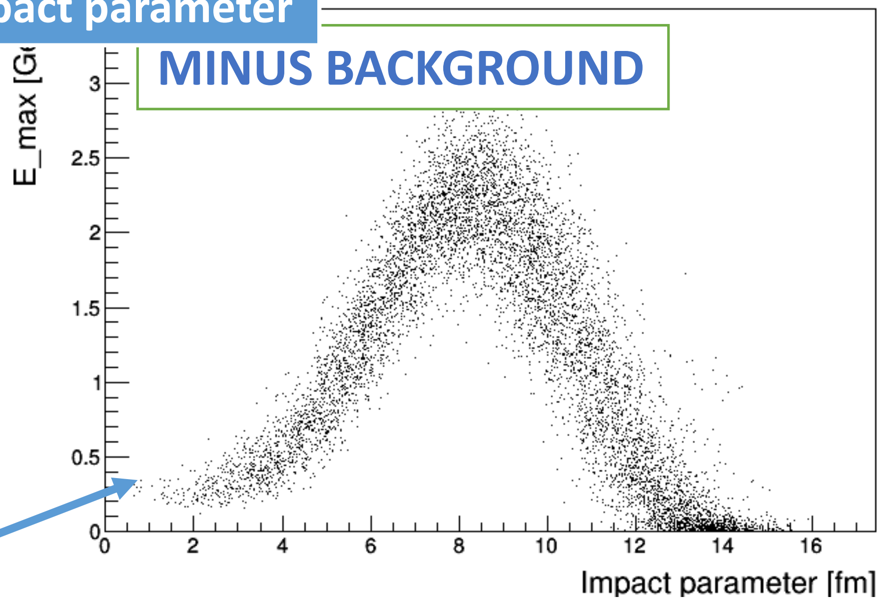
Energy in the central bin vs impact parameter

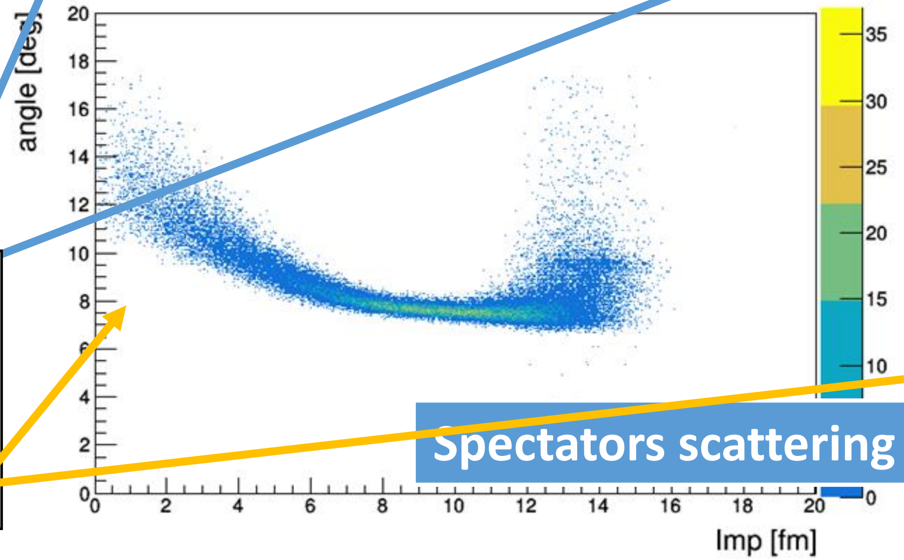


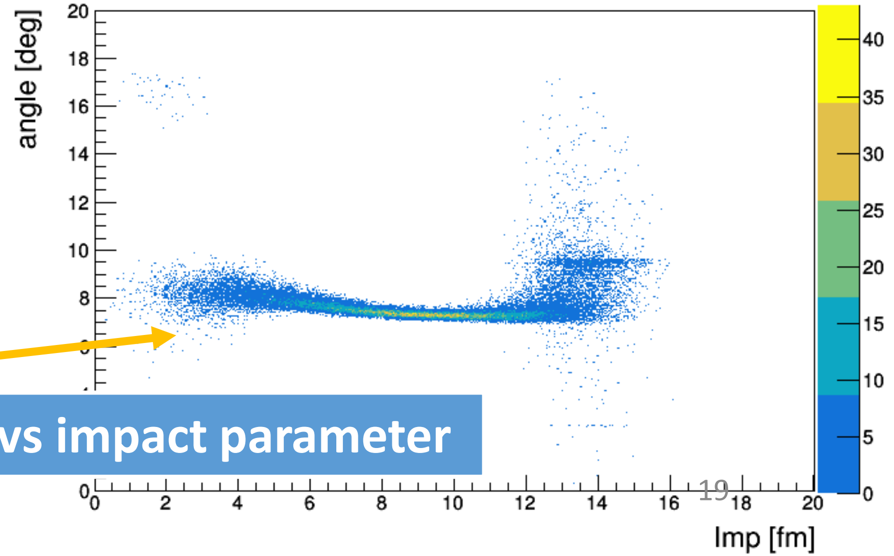
FULL



MINUS BACKGROUND





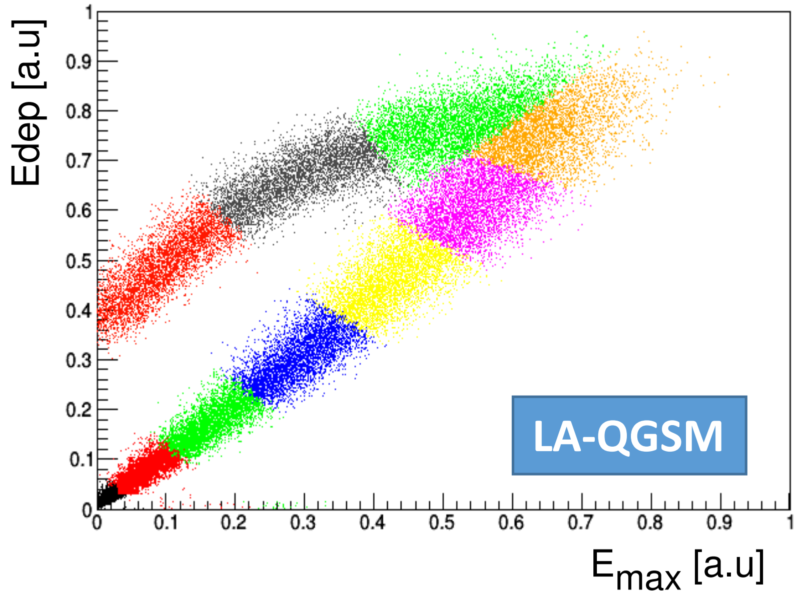


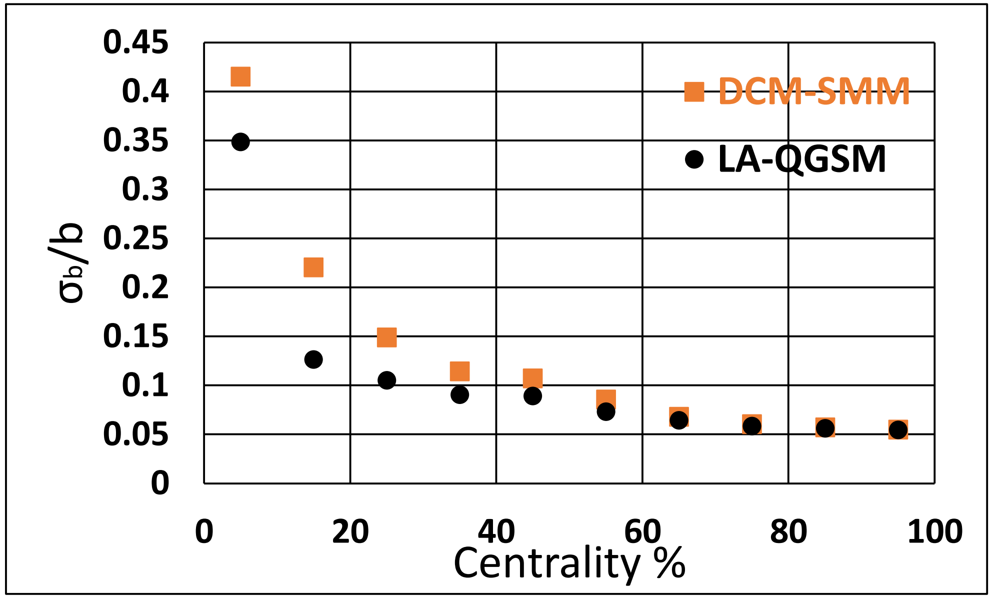
Spectators scattering angle vs impact parameter

After subtracting the pion contribution, the energies for the central events become less

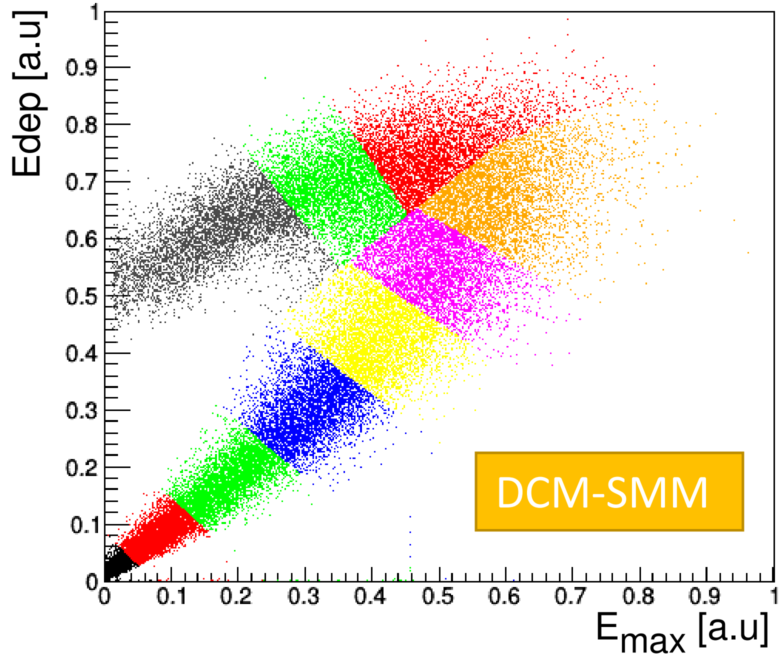
Centrality resolution for E_{dep} vs E_{max}

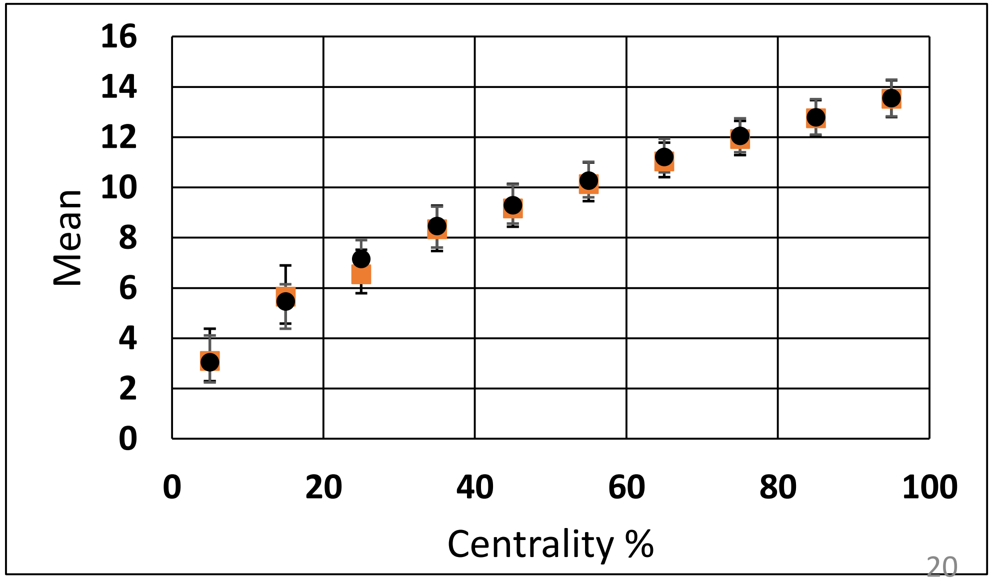
(after subtraction of pion contribution) **backup**





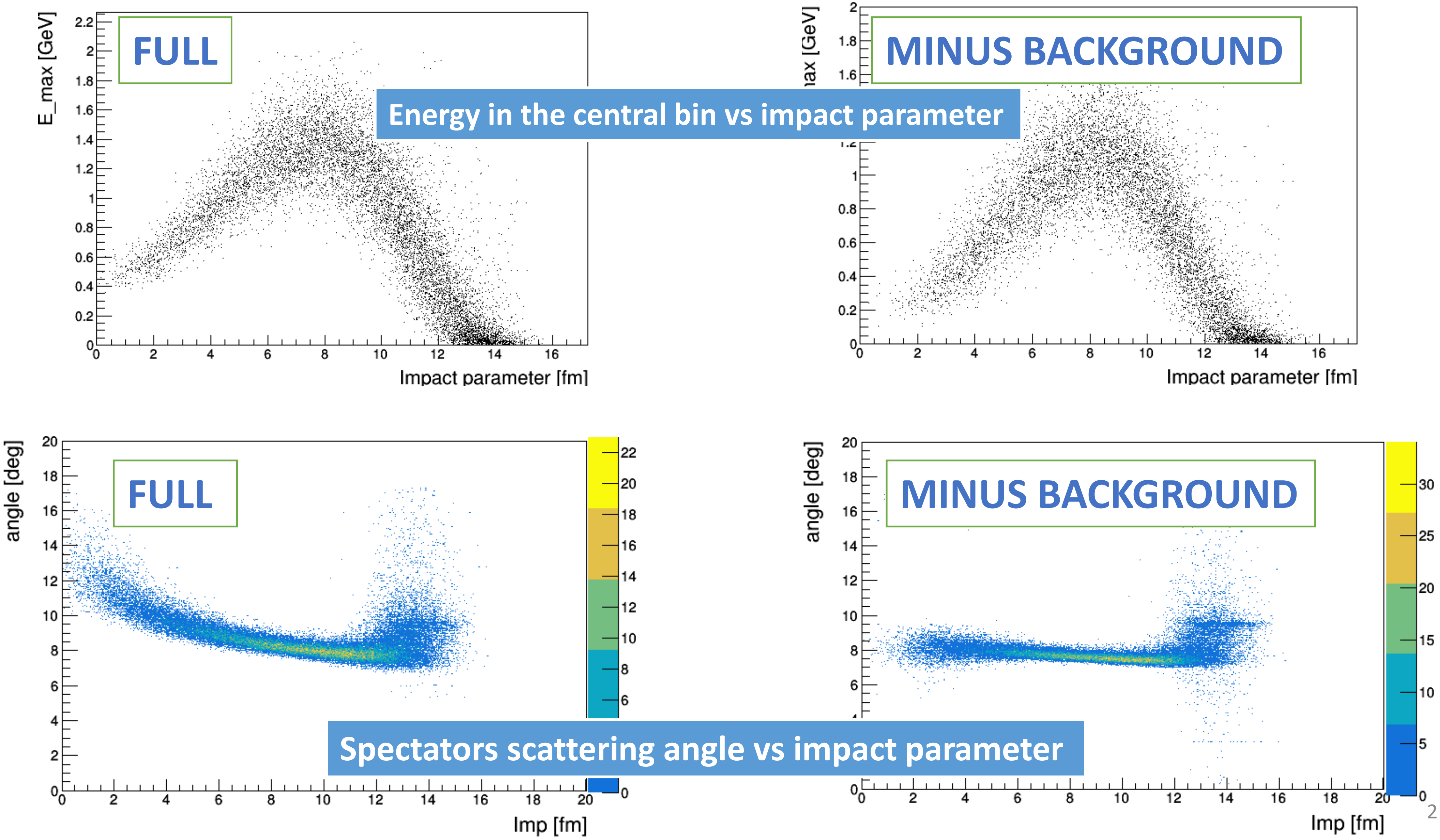
Dependence of resolution of impact parameter on centrality



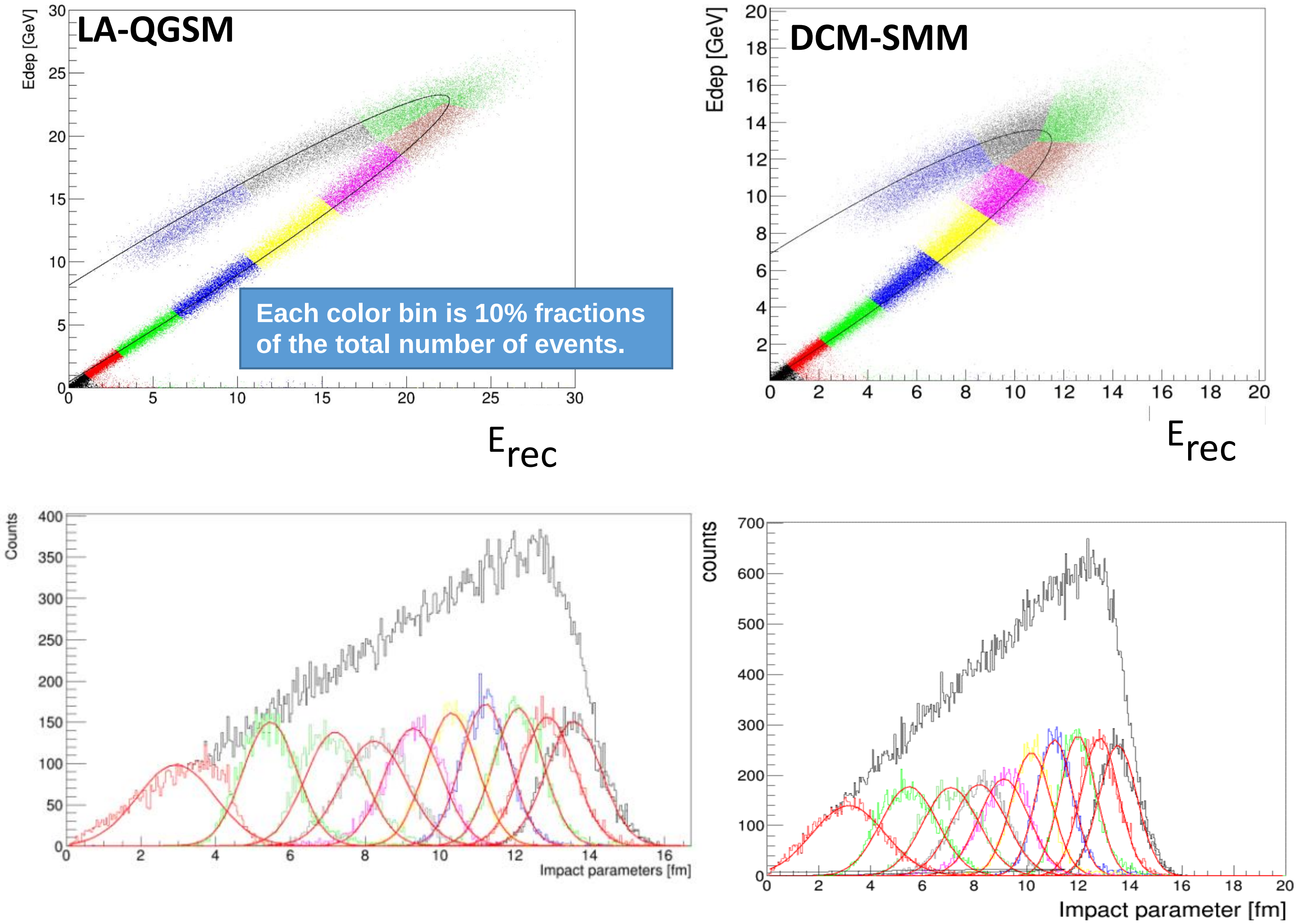


Dependence of impact parameter on centrality

Comparison
DCM-SMM 11 GeV бэкап

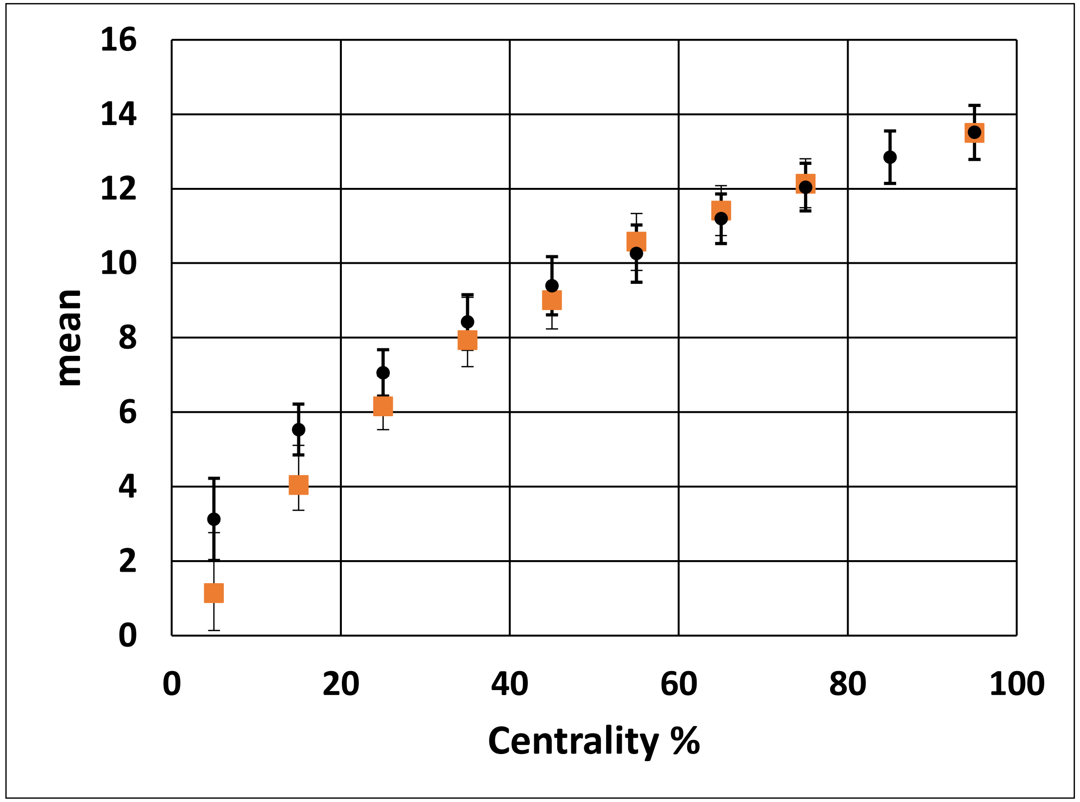


5 GeV example for LA-QGSM and DCM-SMM models

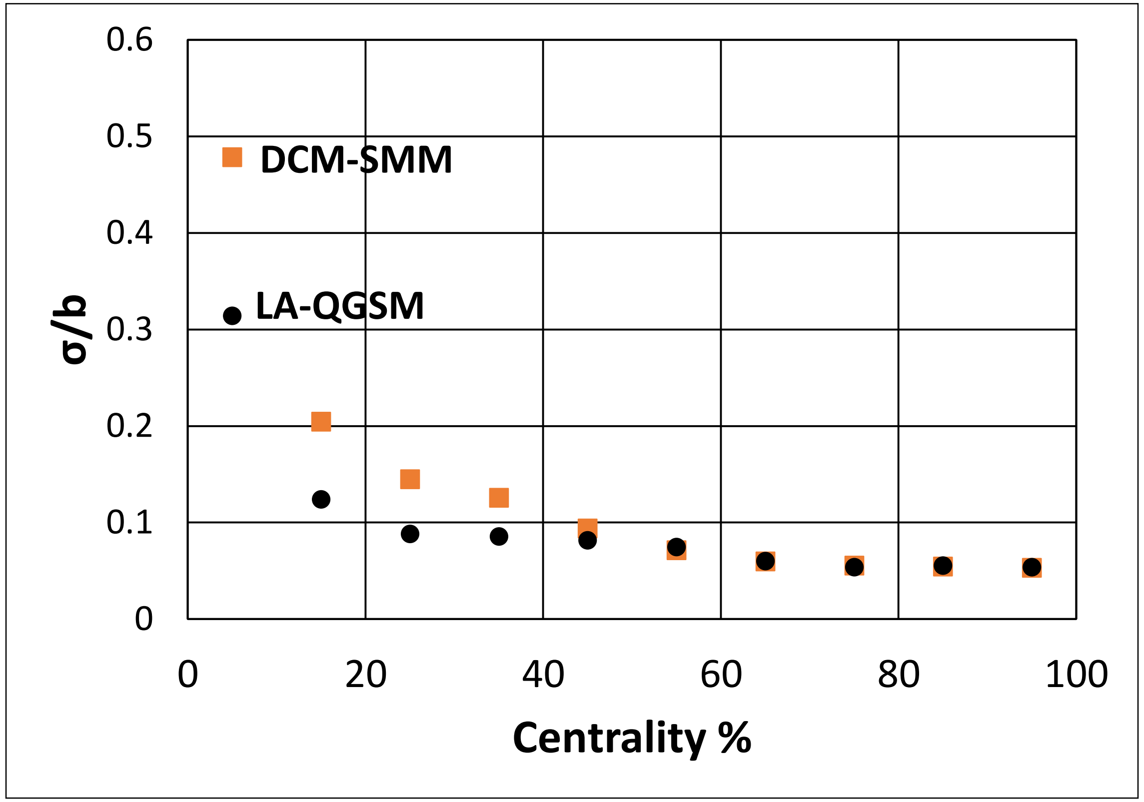


Each color bin is 10% fractions of the total number of events.

LA-QGSM and DCM-SMM models comparison for 5 GeV Erec Edep

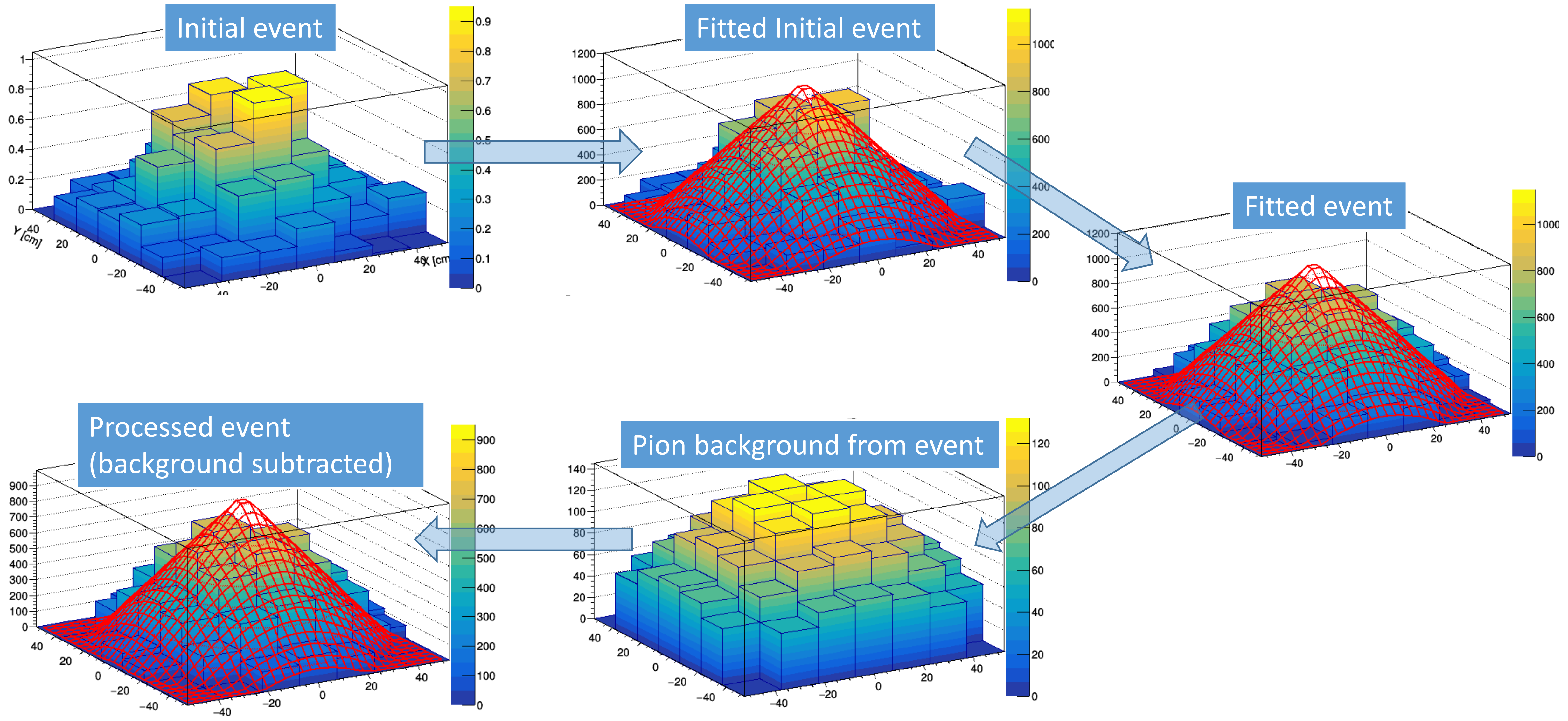


Dependence of impact parameter on centrality

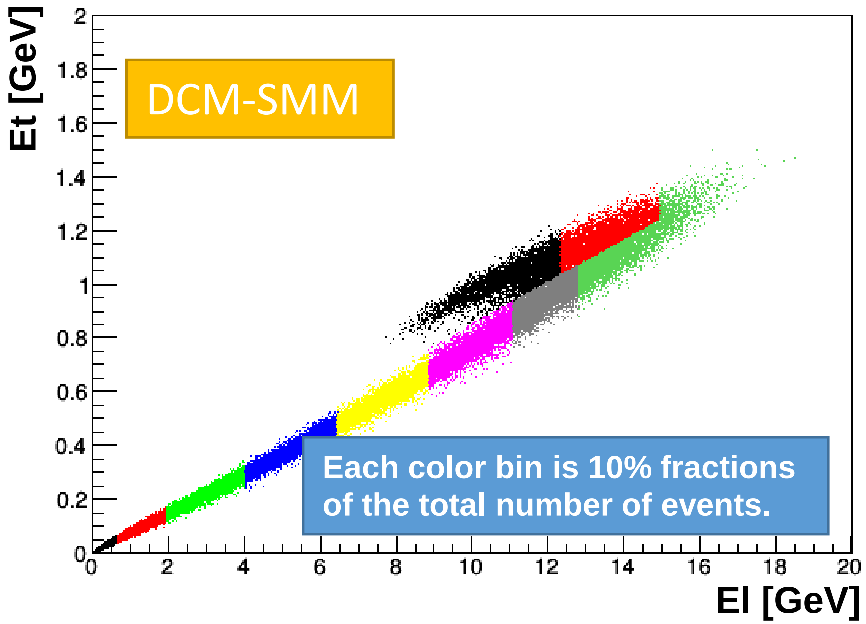


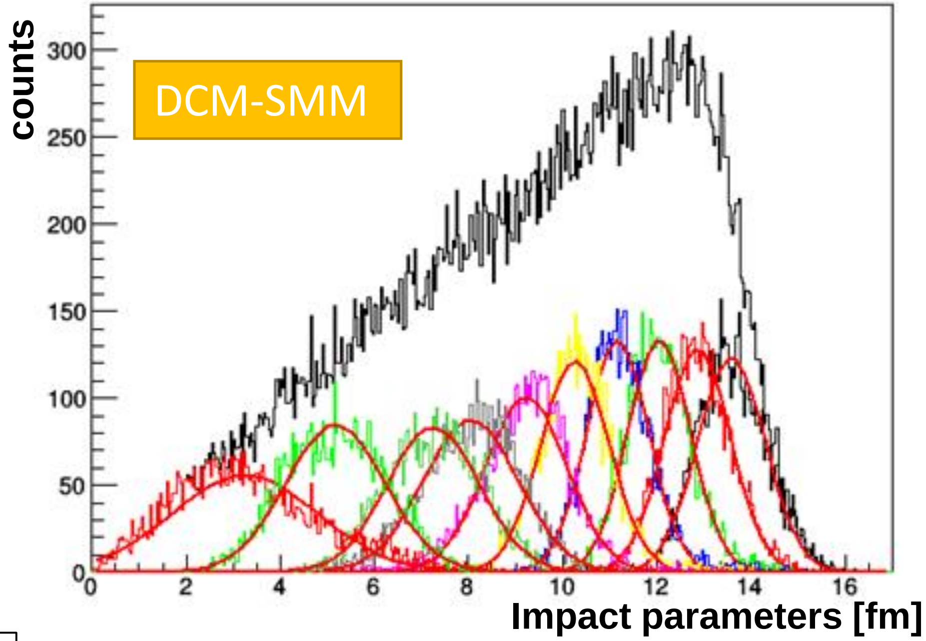
Dependence of resolution of impact parameter on centrality

2D fit method LA-QGSM 11 GeV



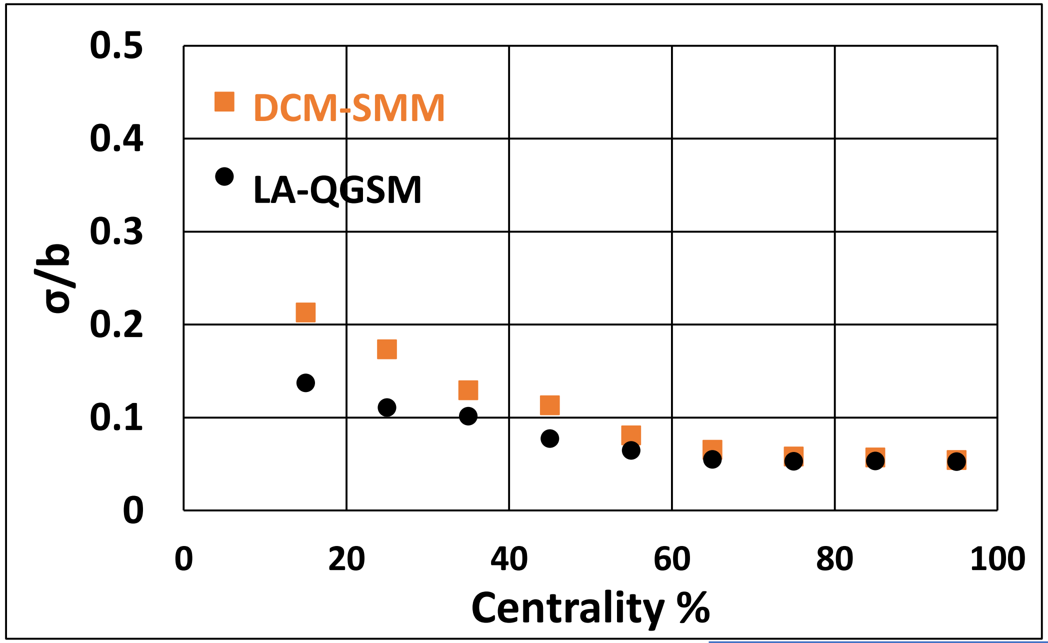
Correlation between transverse and longitudinal energies in FHCal DCM-SMM 11 GeV **backup**

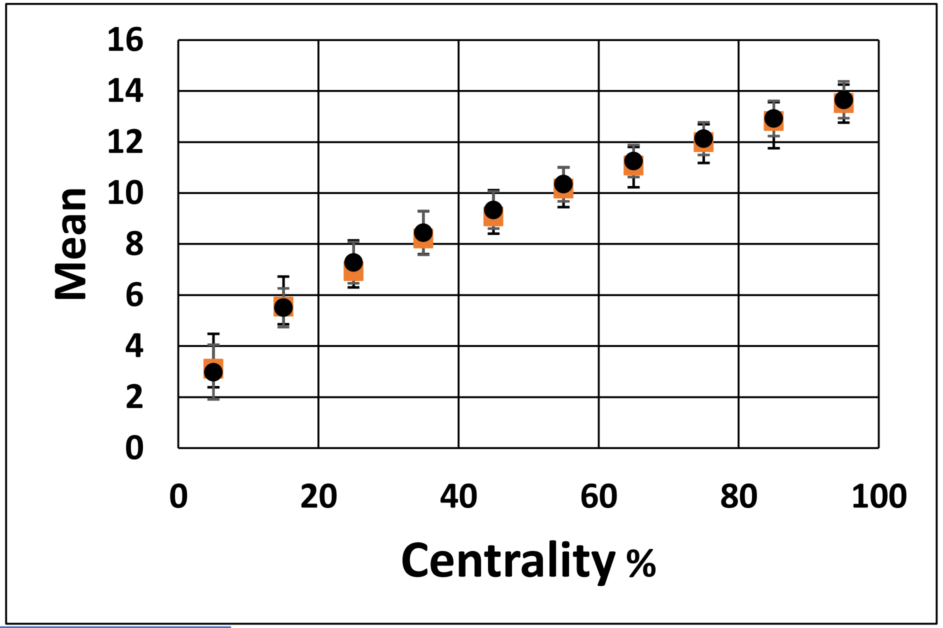




The separation of central and peripheral events with this model is clearly worse.

This approach is not suited for DCM-SMM model





New approaches are needed

2d fit method results LA-QGSM 11 GeV backup