# MC generators
# DCM-QGSM and DCM-SMM

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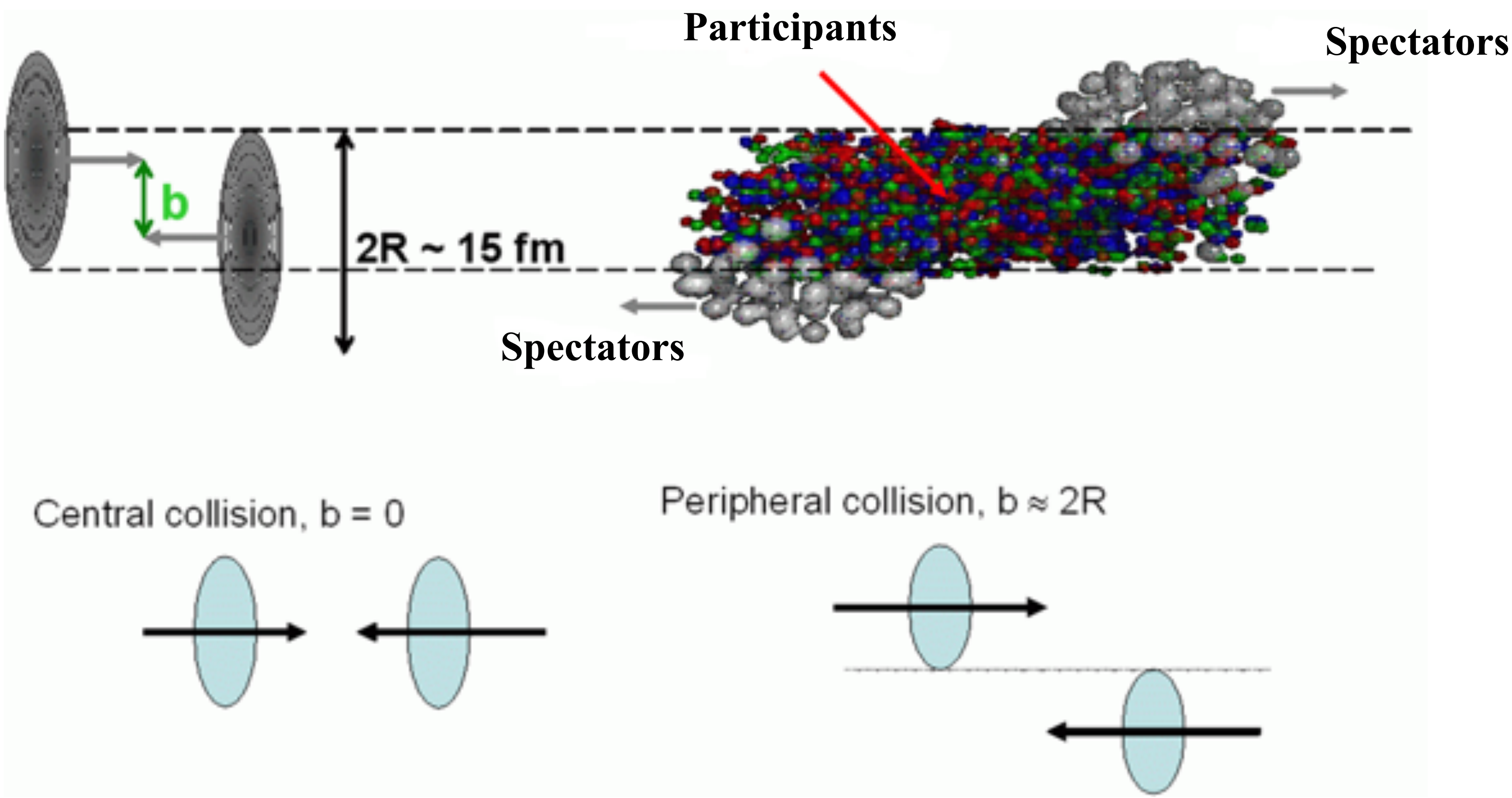
# Contents

# Heavy Ion Collision



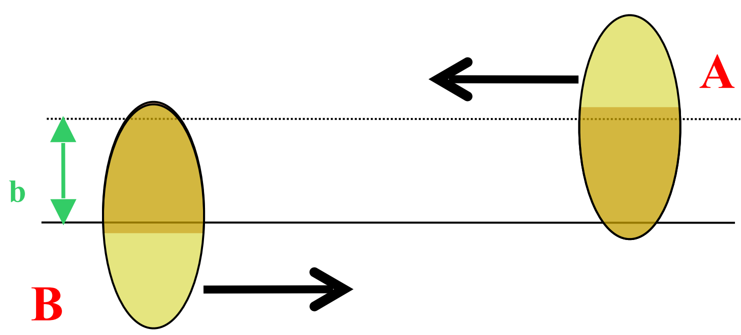

## We need transport generators to

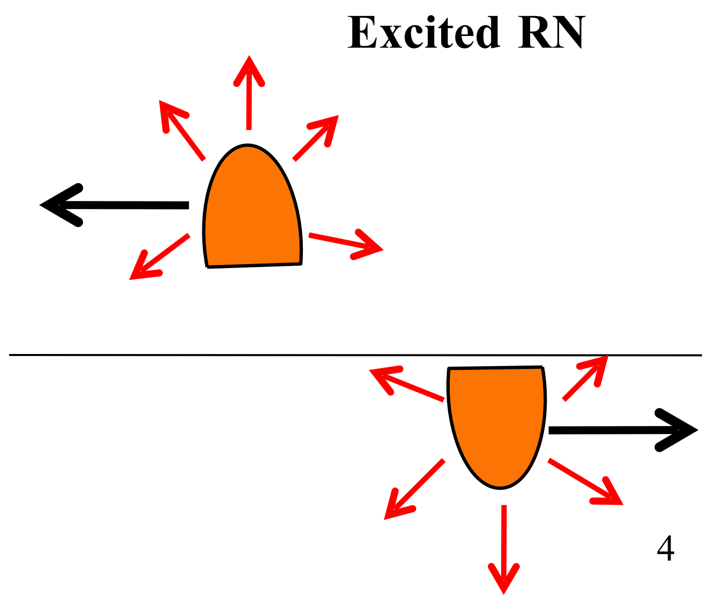
- generate particle production
- calculate the centrality of collision
    - ✓ calculate the number of participants
    - ✓ calculate the number of spectators
- and many other things …

# Heavy ion collisions
in details

- Participant/overlap region – many models
  - ✓ Production of species (mesons, nucleons, resonances, hyperons, …) in binary collisions;
  - ✓ Coalescence of nucleons and hyperons

- Spectator region – a few models: LAQGSM, DCM-QGSM, DCM-SMM
  - ✓ Preequilibrium emission
  - ✓ Multifragmentation
  - ✓ Fermi break-up
  - ✓ Evaporation



# LAQGSM and DCM-QGSM

## Participant/overlap region

✓ Production of species (mesons, nucleons, resonances, hyperons, …) in binary collisions;

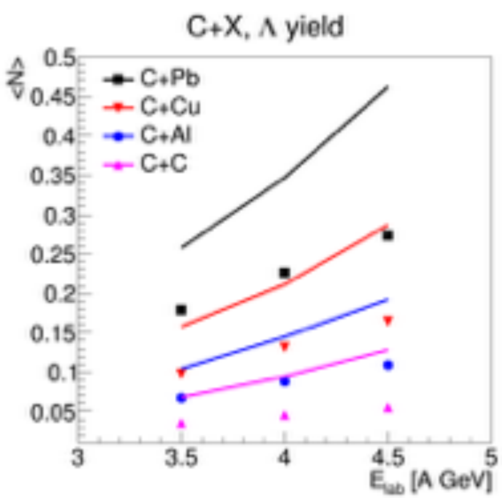
LAQGSM **overestimates** meson production for

- larger colliding nuclei (kaons even at production threshould)
- higher energies
- more centralities

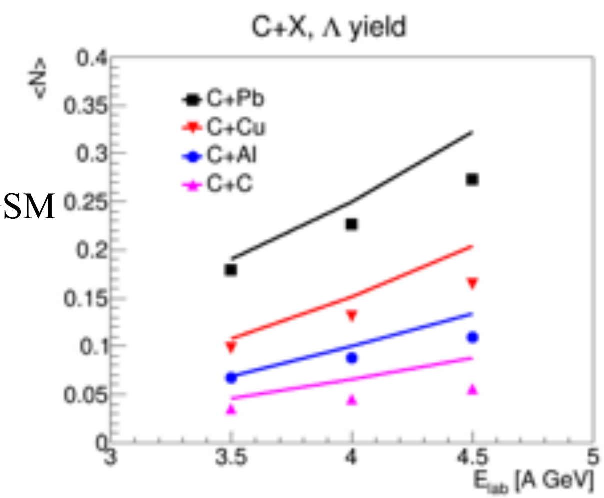
DCM-QGSM is **modified** LAQGSM

- Meson production is suppressed artificially (by formation time) for better agreement with experimental data.
- Corrections of different channels with hyperon production

LAQGSM




DCM-QGSM



# DCM-QGSM and DCM-SMM

## Spectator region - nuclear spallation

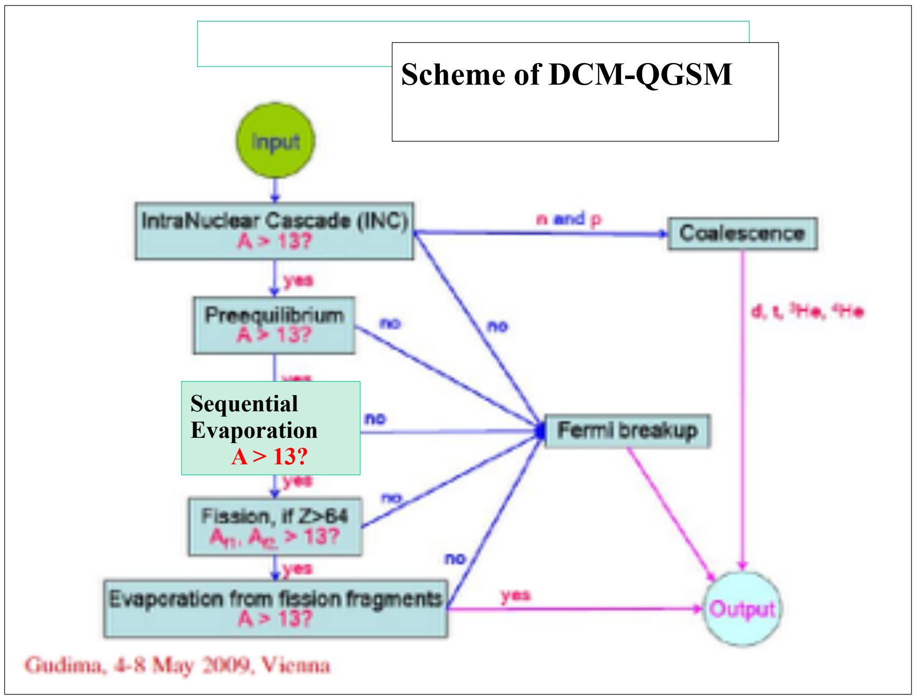
DCM-QGSM,

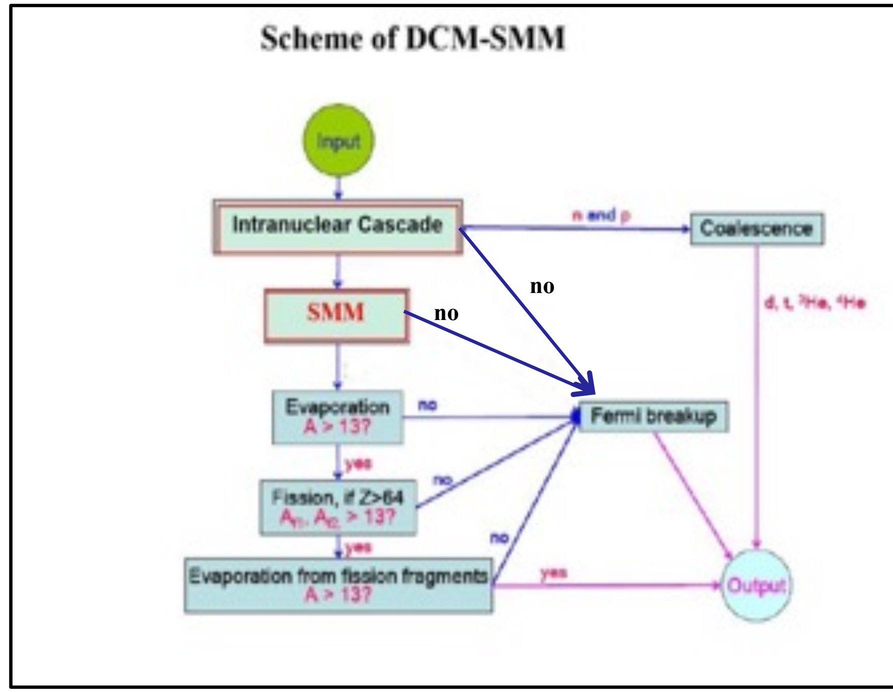
- ✓ Preequilibrium emission
- ✓ Fermi break-up
- ✓ Sequential Evaporation
- ✓ Fission

DCM-SMM

- ✓ Fermi break-up
- ✓ Multifragmentation
- ✓ Evaporation
- ✓ Fission

# Versions of DCM generators:
# DCM-QGSM
# DCM-SMM



# Models: DCM-QGSM vs DCM-SMM

**DCM-QGSM**

**Step 1**

- Intranuclear Cascade

**Step 2**

- Coalescence

**Step 3** Residual Nucleus (**RN**)

- Fermi-break-up if $A_{res} < 13$
- Preequlibrium emission
- Sequential evaporation
- Fission
- Evaportation

**DCM-SMM**

**Step 1**

- Intranuclear Cascade

**Step 2**

- Coalescence

**Step 3** Residual Nucleus (**RN**)

- Fermi break-up if $A_{res} < 13$
- Statistical Multifragmentation
- Evaporation
- Fission
- Evaporation

# Models: DCM-QGSM vs DCM-SMM

**DCM-QGSM**

**Step 2: Coalescence**

- Final state interactions
- Formation of fragments and hyperfragments (d, t, $^3He$, $^4He$, $t_\Lambda$, $^3He_\Lambda$, $^4He_\Lambda$, $^5He_\Lambda$ )
- Coalescence criteria: $(p_i - p_0) < p_c$ and $(r_i - r_0) < r_c$
- $p_c$ = 150, 175, 175, 175 for d, t, $^3He$, $^4He$

**DCM-SMM**

**Step 2: Coalescence**

The same…

# Models: DCM-QGSM vs DCM-SMM

## Step 3 Nuclear Spallation

### Preequilibrium emission

#### Exciton model

**p + A → X**

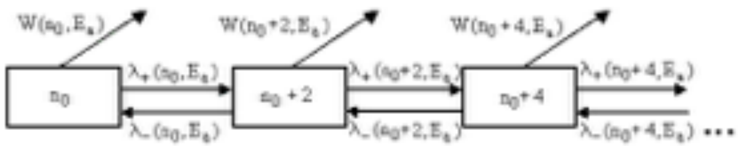
**n = p + h,**

**n –** number of excitons,

**p –** number of particles above Fermi surface,

**h –**

**$n_0$ =**




$\lambda_{+/-}$ – transition probability

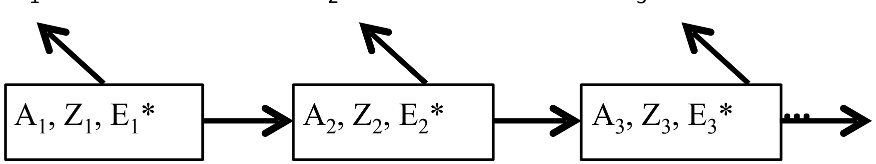
W(n, E) – particle emission probability

**Emission** of **p**, **n**

**Condensation** of protons and neutrons → d, t, $^3$He, $^4$He

### Sequential Evaporation

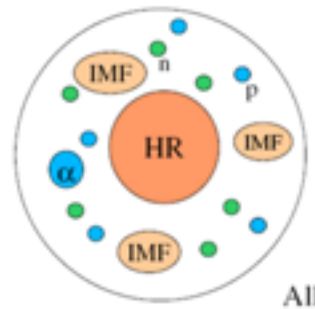
$W_1$(p,n,d, t, $^3$He, $^4$He )  $W_2$(p,n,d, t, $^3$He, $^4$He )  $W_3$(p,n,d, t, $^3$He, $^4$He )




## Step 3 Nuclear Spallation

### Statistical Multifragmentation

J.P.Bondorf, A.S.Botvina, A.S.Iljinov, I.N.Mishustin, K.Sneppen, Phys. Rep. **257** (1995) 133



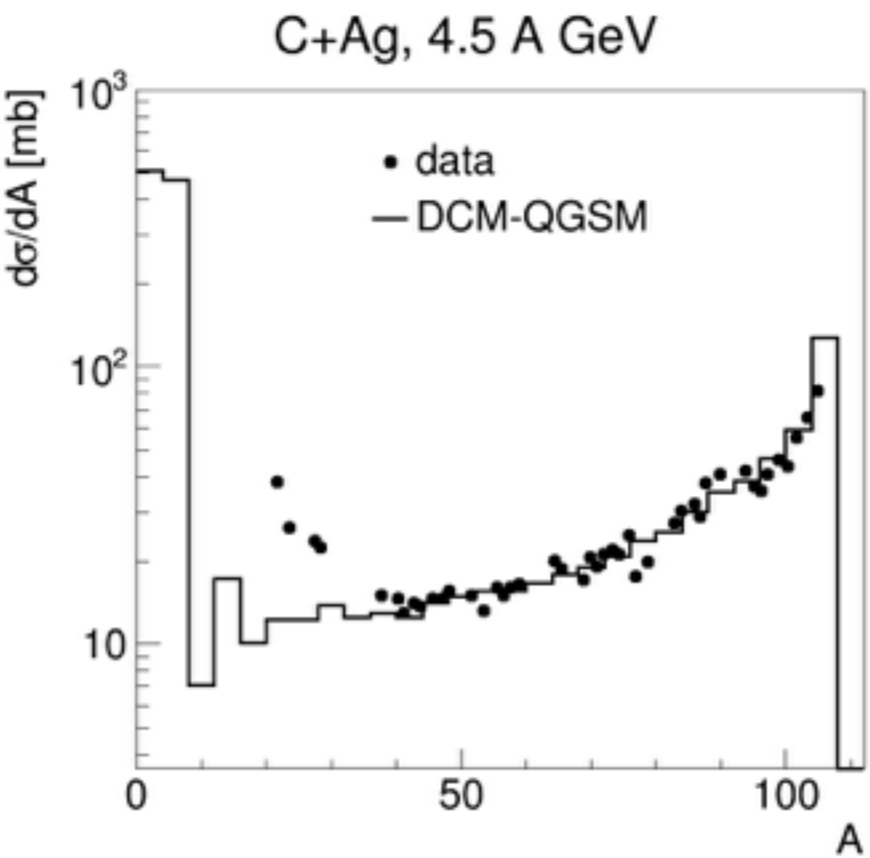

Ensemble of nucleons and fragments in thermal equilibrium characterized by
neutron number $N_0$
proton number $Z_0$, $N_0+Z_0=A_0$
excitation energy $E^*$
break-up volume $V=(1+\kappa)V_0$

All break-up channels are enumerated by the sets of fragment multiplicities or partitions, $f=\{N_{AZ}\}$

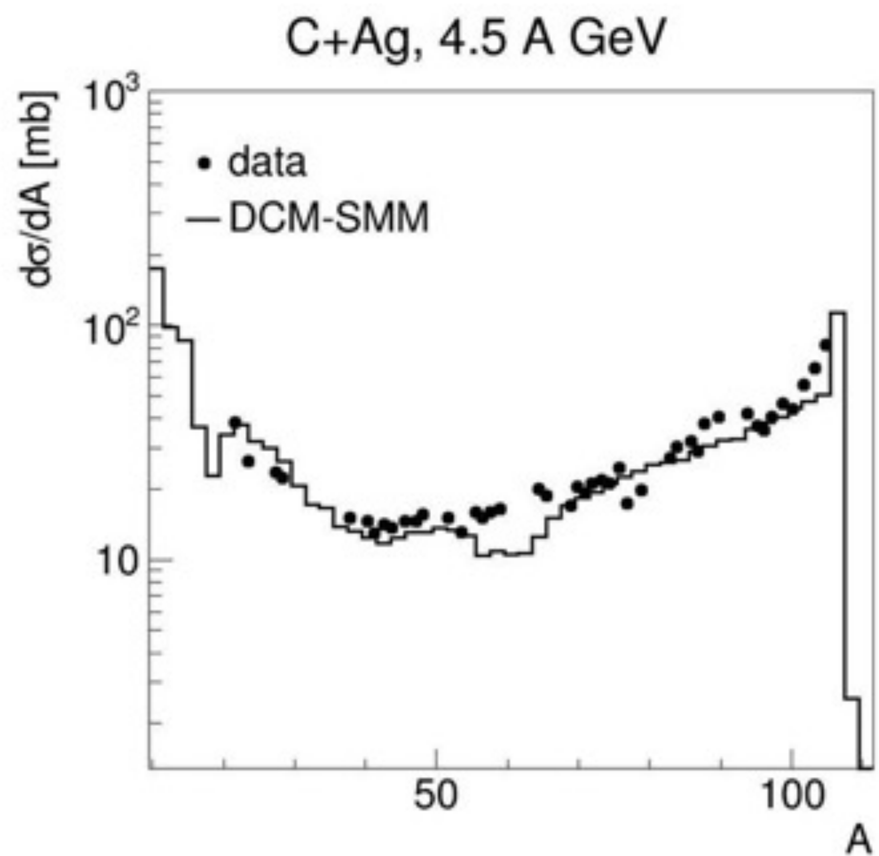
Statistical distribution of probabilities: $W_f \sim \exp\{S_f(A_0, Z_0, E^*, V)\}$
under conditions of baryon number (A), electric charge (Z) and energy ($E^*$) conservation, including compound nucleus.

# Models: DCM-QGSM vs DCM-SMM

DCM-QGSM
Preequilibrium emission
Sequential evaporation

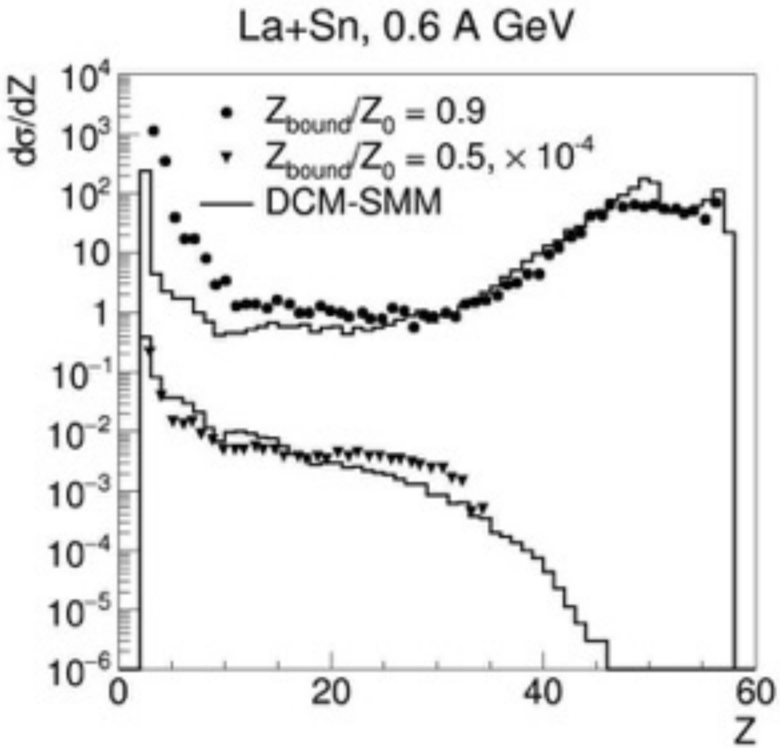


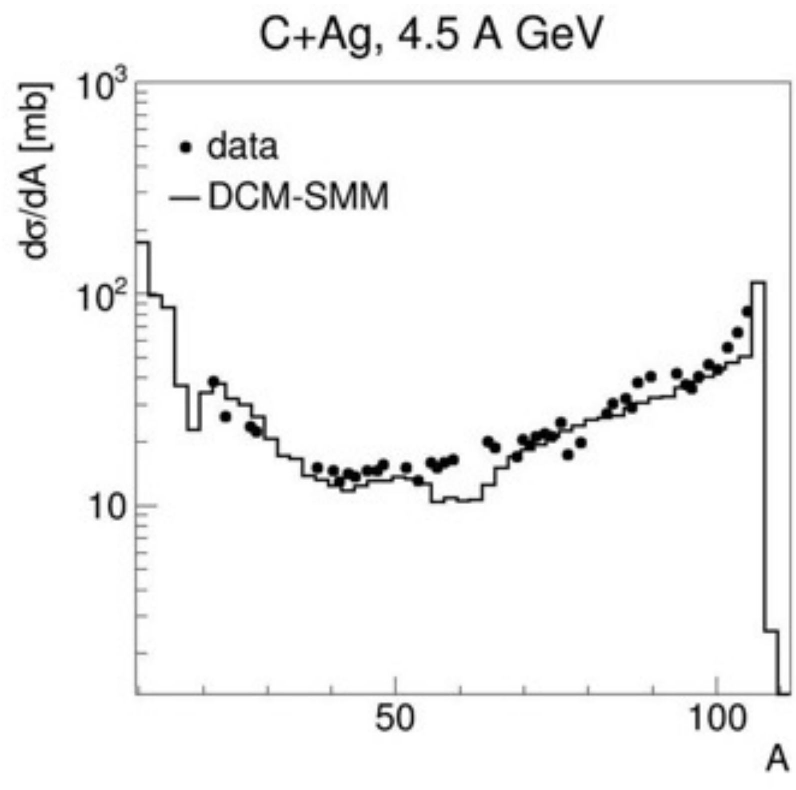

DCM-SMM
Statistical Multifragmentation
Evapotation



# Models: DCM-QGSM vs DCM-SMM

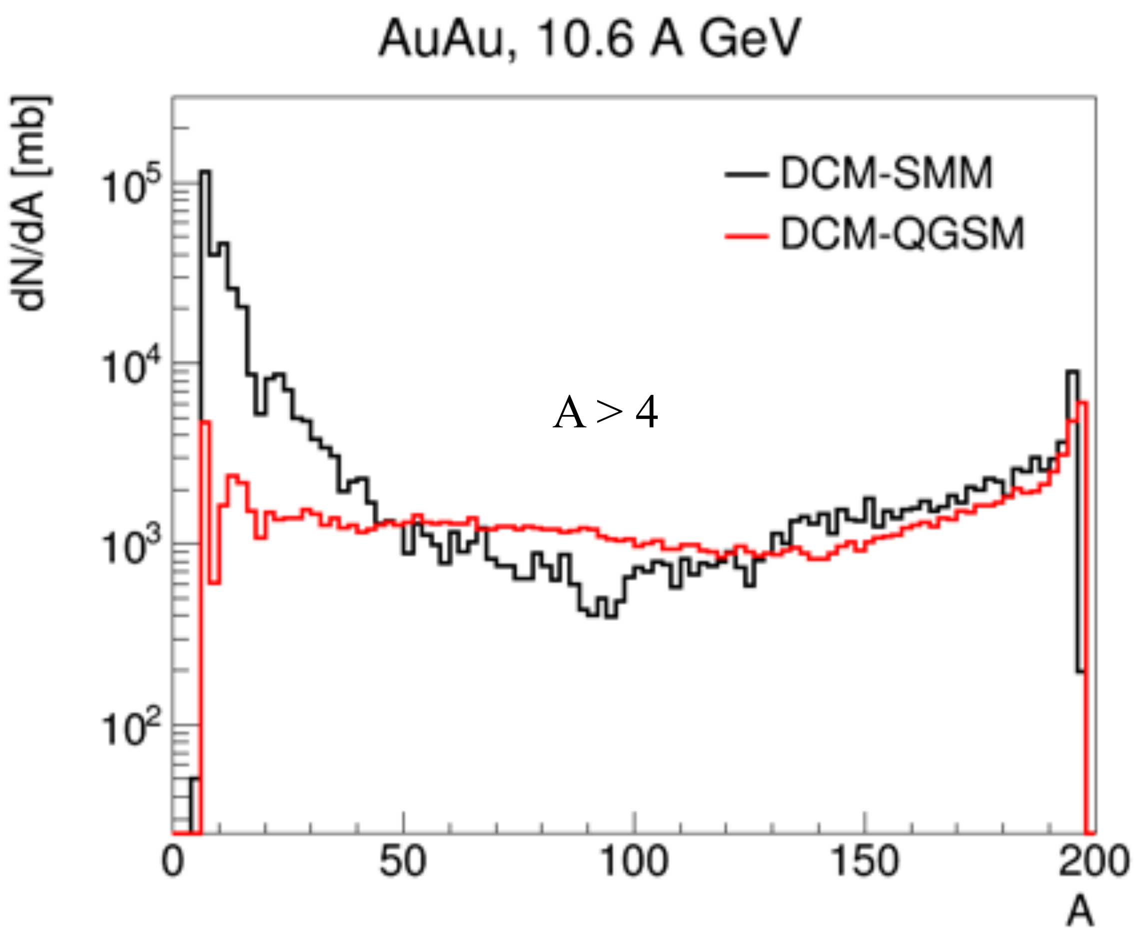
## DCM-SMM
## Statistical Multifragmentation



# Models: DCM-QGSM vs DCM-SMM

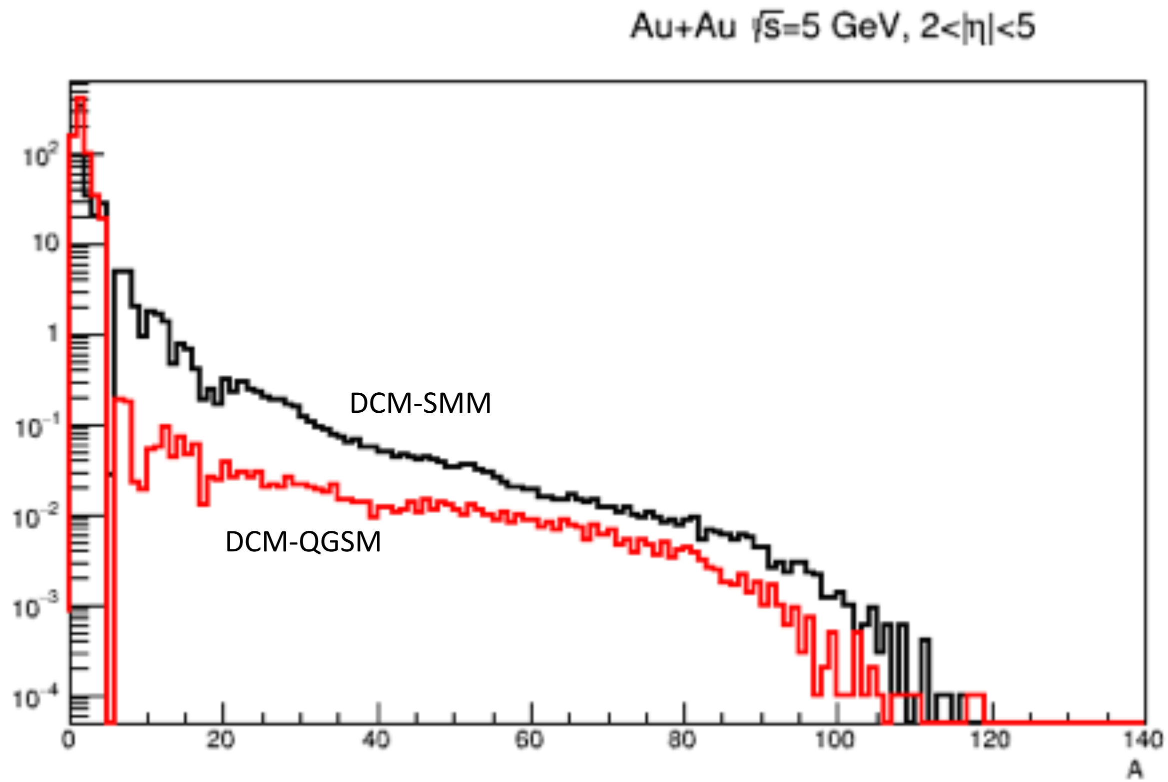
DCM-QGSM contradicts to data for IMF
DCM-SMM is more reliable for the whole spetra



# Models: DCM-QGSM vs DCM-SMM

## Detailed analysis

## Fragment spectra in acceptance of FHCal at MPD



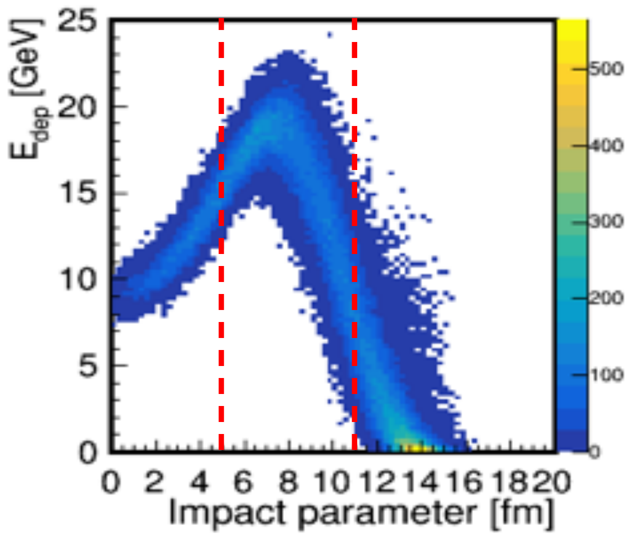

**Much more nucleons and light nuclei are deposited in FHCal by DCM-QGSM**

**They com from preequilibrium emission and sequential evaporation**

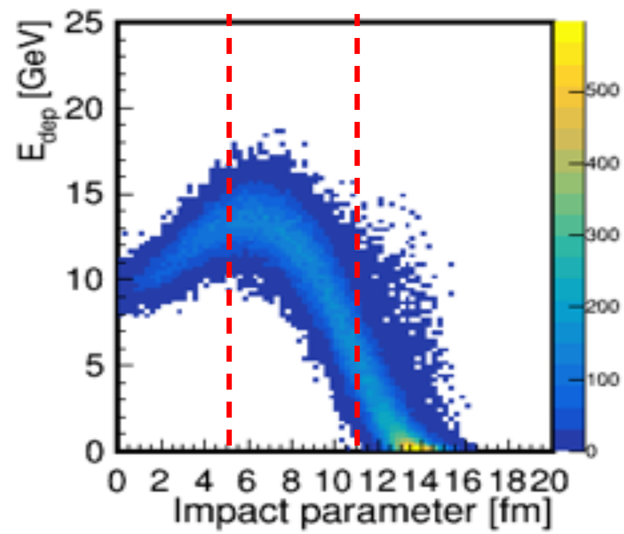
# Resume

Energy deposited in forward calorimeter **FHCal**

**DCM-QGSM**




**DCM-SMM**




Much **more nucleons and light nuclei** are deposited in **FHCal** by **DCM-QGSM** than by **DCM-SMM**

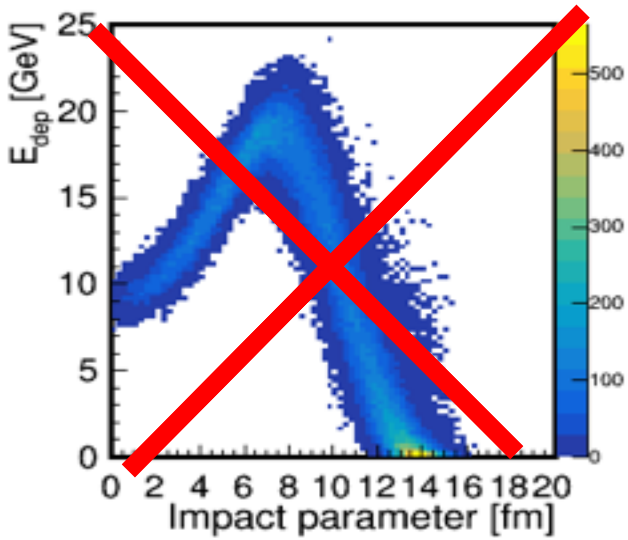
They come from Sequential evaporation

Most of **IMF** icreated at semicentral impact parameters escape through the **hole** that results in decreasing deposition of energy in **FHCal**

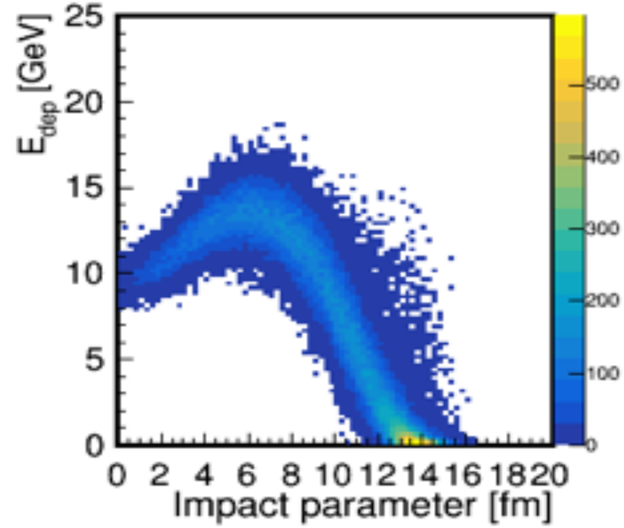
# Resume

Energy deposited in forward calorimeter **FHCal**

**DCM-QGSM**




**DCM-SMM**




**DCM-SMM is more reliable for description of nuclear spallation**

Knowledge of mechanism of **nuclear spallation** is very important for **determination of Centrality by the number of Spectators**

# Centrality by Participants + Spectators

**DCM-QGSM & DCM-SMM**

Taking into account inelastic binary collisions only.

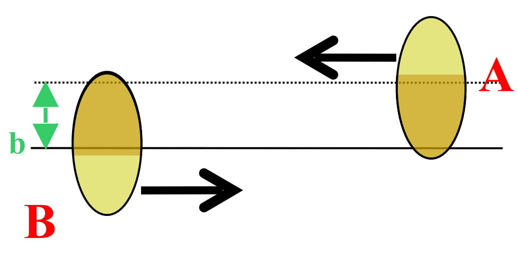
- elastically scattered nucleons are considered as spectators
- closer to Glauber considerations

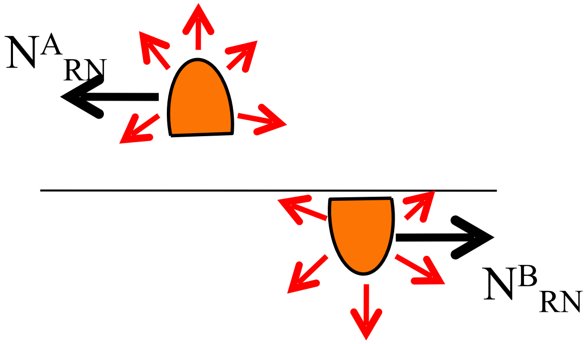
•Number of participants

$$\mathbf{N_{part} = A_0 - N_{spect} = A_0 - A_{RN}}$$

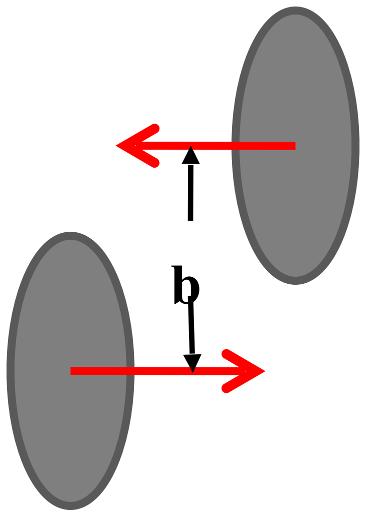
here $\mathbf{A_0}$ – atomic number projectile/target nucleus

•We know $\mathbf{A_{RN}}$ , so we can determine $\mathbf{N_{part}}$



# Centrality definitions




1. Impact parameter interval

2. The Fraction of the Cross Section

3. Number of Participants

$N_{part}$ or $N_{wound}$

4. Number of Spectators

$N_{spect}$

# Motivation

- We need to select events by centrality!
- We can do it by characteristics of **spectators**
  - number
  - mass
  - energy
- **Experimen**t: by energy deposited in forward calorimeter

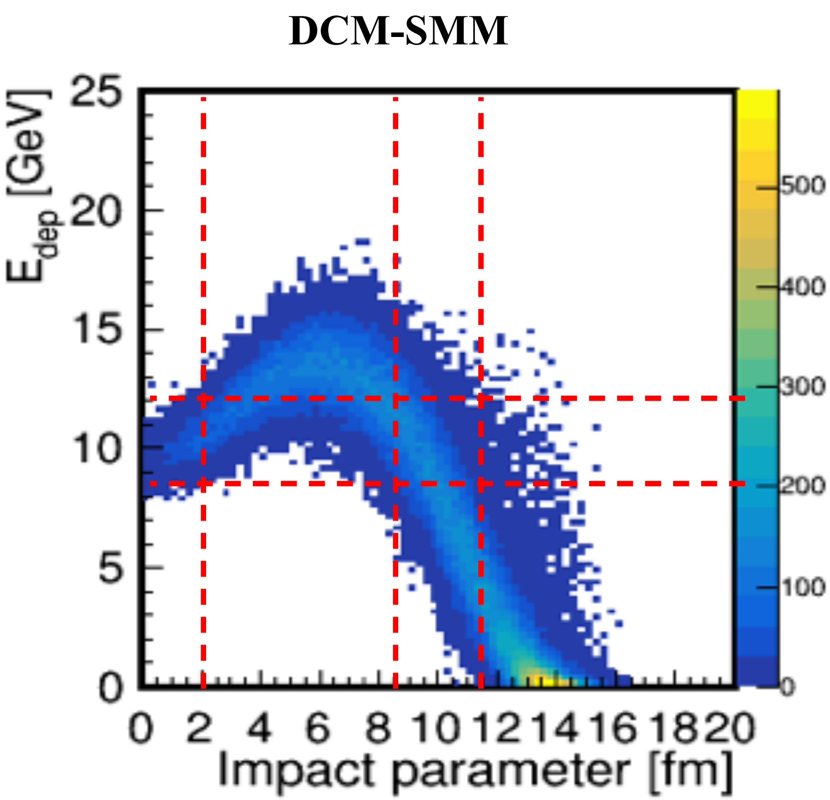
**MPD: FHCal –** under construction

- **Models**

  **DCM-QGSM** **DCM-SMM**

**But**

# Centrality determination by experiment

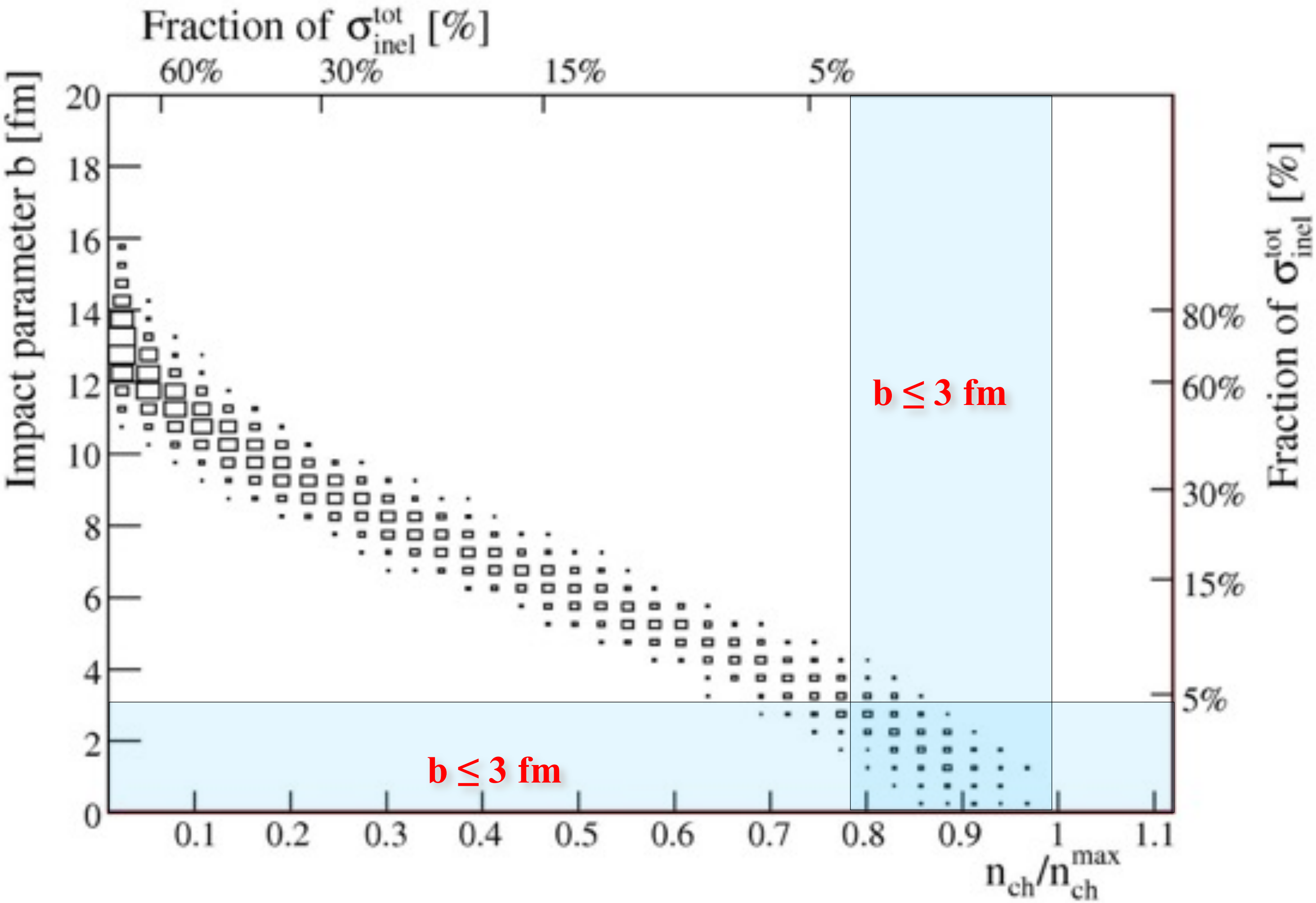



**Energy deposited in FHCal cannot resolve central and peripheral events.**

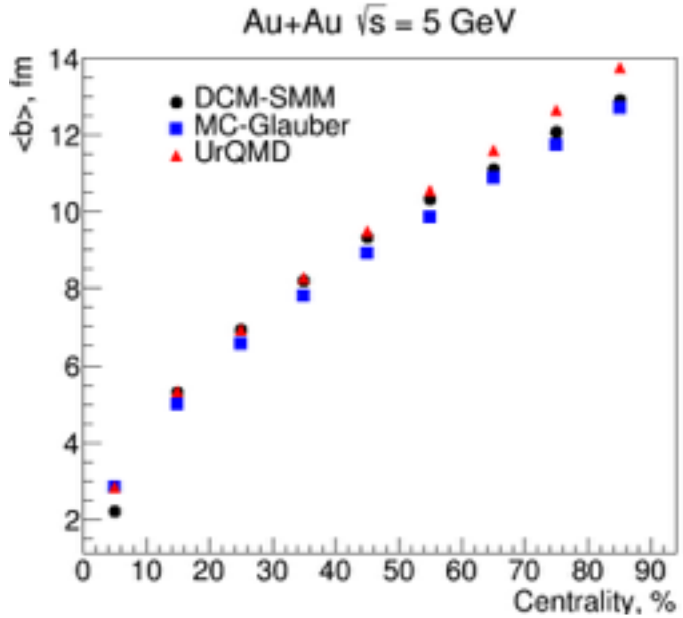
**Additional observalbes are needed to resolve this ambiguity**

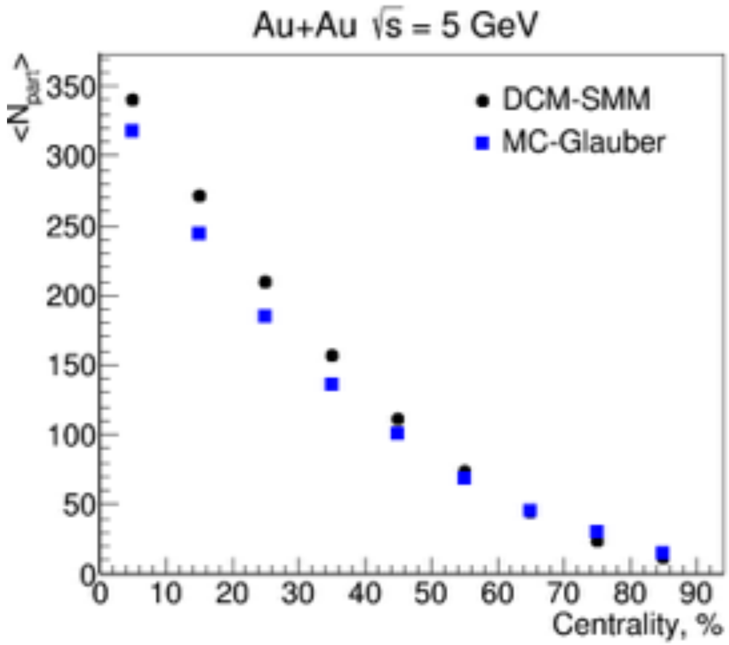
- space information about spectator hit points (INR Team)
- multiplicty of charged particles in an event

# Centrality – impact parameter – charged multiplicity



# Centrality determination
## By **b**, **$N_{part}$**

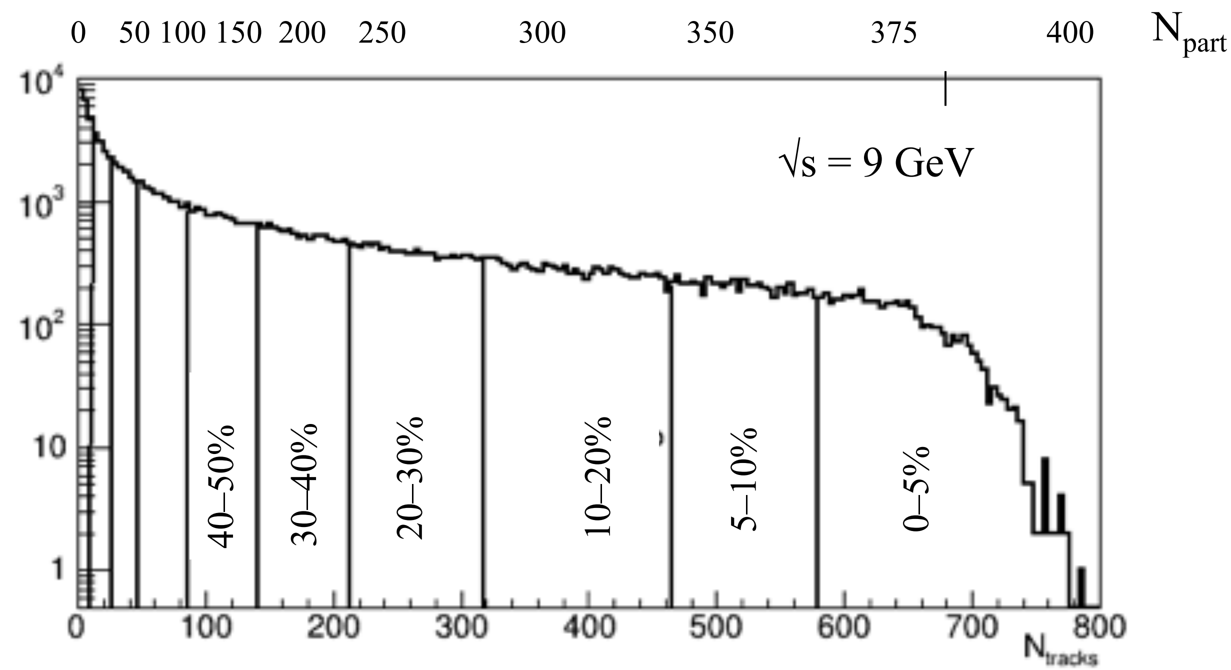


# Centrality determination

by number of tracks, $N_{\mathbf{tracks}}$,

and numper of participants, $N_{\mathbf{part}}$



# Conclusions

- DCM-SMM is more reliable for description of the residual nucleus spallation
- DCM-QGSM with sequential evaporation of the residual nucleus more or less agrees with DCM-SMM for peripheral events
- Plans: to combine both into the generator DCM-QGSM-SMM

# DCM-QGSM-SMM: Plans for Future

**Any transport model with characteristics of binay collisions taken from exp. data overestimates particle production for heavy ion collisions**

1. Modification of nucleon properties in heavy ion collisions
2. Inclusion of heavy resonances in binary collisions
3. Development of the mechanism of strangeness enhancement
4. Development of the mechanism of enhancement of mass spectra dileptons

# Thank You!

# Determination of Centrality by models

- **Number of Participants:** Glauber models, UrQMD, LAQGSM, **DCM-QGSM, DCM-SMM**
  - ✓ protons
  - ✓ neutrons

- **Number of Spectators:** LAQGSM, **DCM-QGSM. DCM-SMM**
  - protons
  - neutrons
  - nuclear fragments (stable and radioactive)

# Models: DCM-QGSM vs DCM-SMM

**DCM-QGSM**

**Step 1:** Intranuclear Cascade

ELab < 4.5AGeV

Binary interactions: **Hadronic model**

hadrons → hadrons (nucleons, hyperons, (non)strange mesons and resonances)

ELab > 4.5AGeV

Binary collisions: **QGSM**

hadrons → quark-gluon strings → hadrons (nucleons, hyperons, (non)strange mesons and resonances)

**DCM-SMM**

**Step 1:** Intranuclear Cascade

ELab < 4.5AGeV

Binary interactions: **Hadronic model**

The same…

ELab > 4.5AGeV

Binary collisions: **QGSM**

The same…

# OverExcitation problem solution

## DCM-QGSM

Before thermalisation **RN** **looses** high excitation energy and mass by

**Preequilibrium emission** of

p, n, d, t, $^{3}$He, $^{4}$He

and

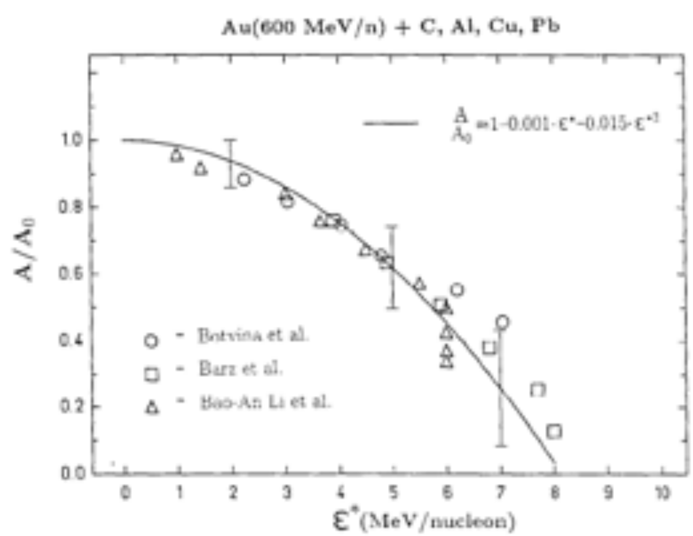
**Sequential Evaporation**

multistep emission of p, n, d, t, 3He, 4He

## DCM-SMM

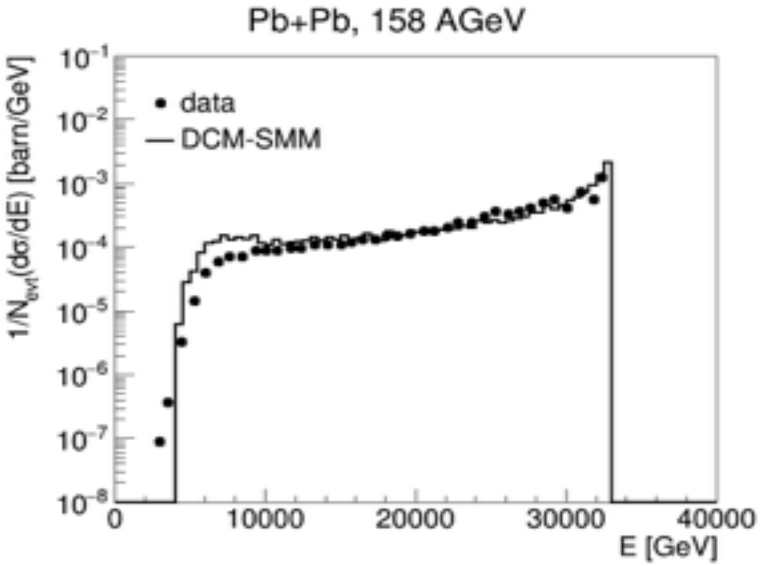
**Recalculation** of excitation energy according to **correlation** between **mass** and **excitation energy** of **RN,** derived from exp. data

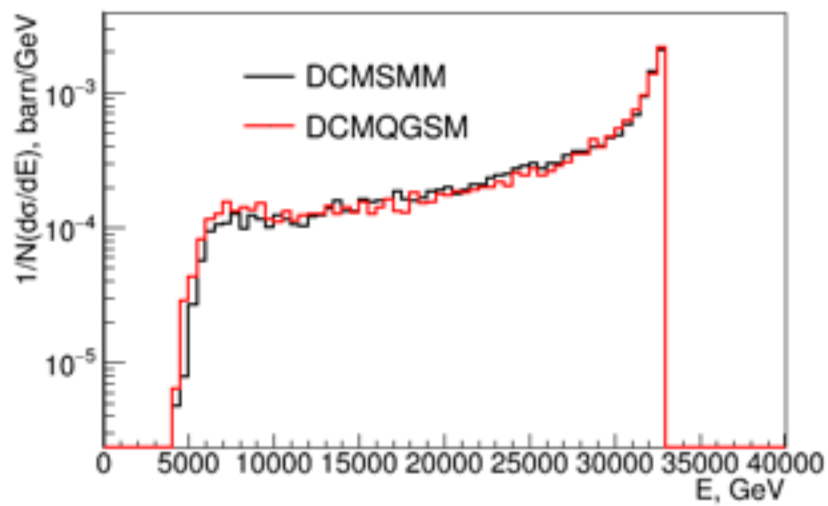
$$A/A_0 = 1- 0.001\varepsilon^* - 0.015\ \varepsilon^{*2}$$



# Models: DCM-QGSM vs DCM-SMM
# Energy Spectra of Fragments

**Comparison with NA49 data**
**Pb+Pb, 158 AGeV**
**Energy deposited in VCal**

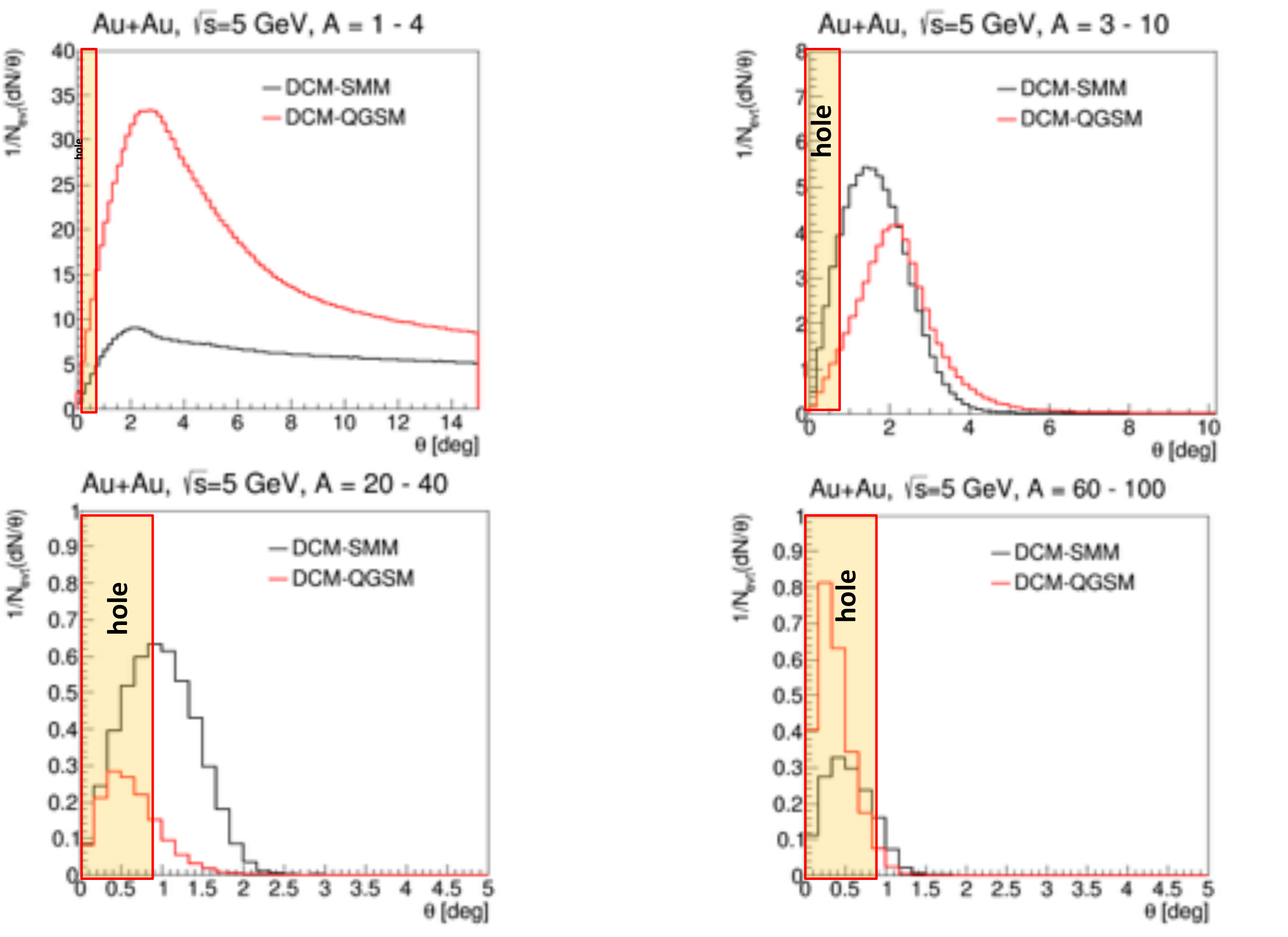



**Agreement with data**

**No difference in energy spectra**

# Models: DCM-QGSM vs DCM-SMM
# Detailed analisys
# Angular distributions of fragments



# Baryonic matter under compression

**At high compression**

nucleons are converted into

- **delta isobars**

↓

- **hyperons and their resonances**

↓

- **higher mass resonances**

Their decay **is suppressed**

# Scenario of nucleon modification

Higher compression

$n, p \rightarrow \Delta$

$u,d \rightarrow s, \ldots$

$n, p \rightarrow \Lambda, \Xi, \Omega, \ldots$

# Hadron modifications in a dense nuclear medium

## 1. Hadronic matter at high density and temperature

**Particle production in a hot and dense fireball**

- $\pi$ - production is suppressed
- vector mesons: $\rho, \omega, \varphi, K^{*}, ...$ - are dominating
- $\rho$, ω – '**melting**': mass dropping and width-broadening;

- Fireball 'cooling' → decay of resonances