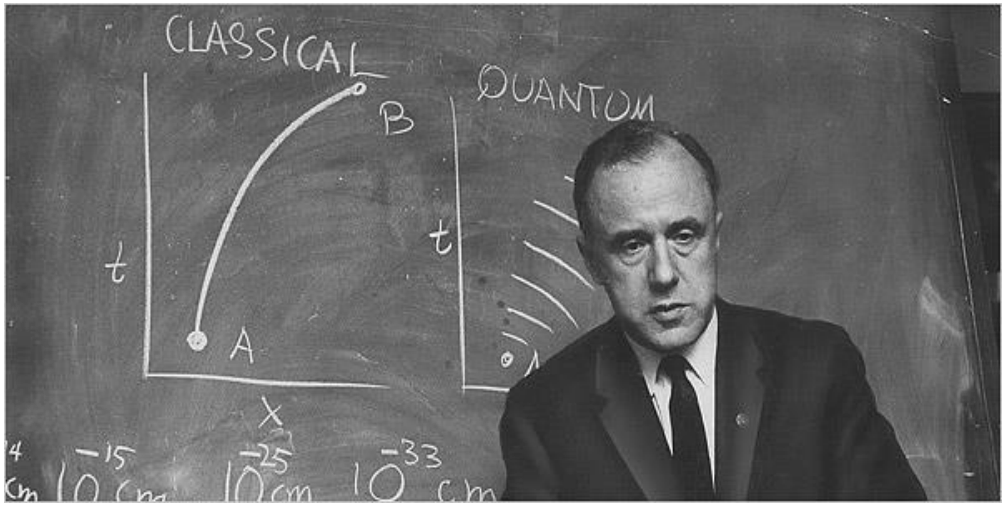
Search for hyperheavy toroidal nuclear systems formed in heavy ion collision

Roman Płaneta
Jagiellonian University
for CHIMERA collaboration



The existence of nuclei with non-spherical shapes was first suggested by J.A. Wheeler in 1950

HIB@LNS 2015

Search for superheavy nuclei

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Liquid drop model with shell corrections and Hartree – Fock – Bogoliubov theory with the Gogny D1S force calculations have shown that metastable islands of nuclear bubbles can exist for nuclei in the range A=450-3000

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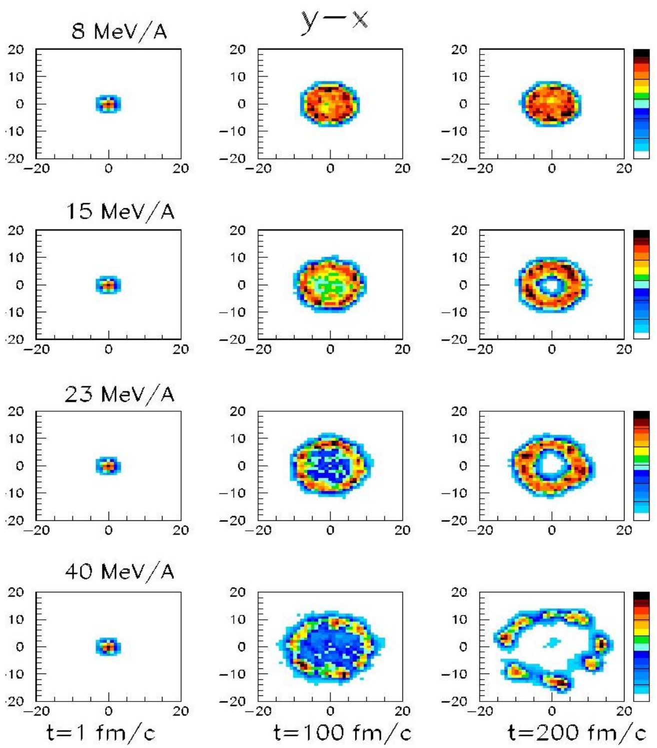
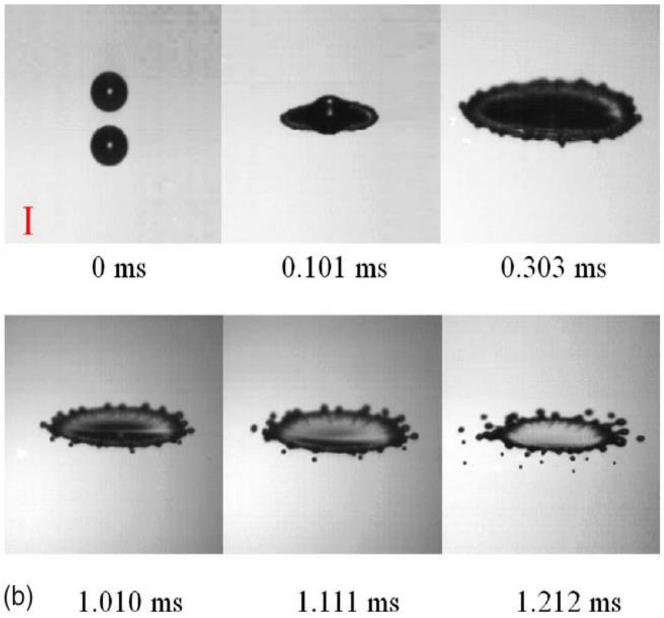
BUU simulations for central collisions of Au+Au

Threshold energy for toroidal freeze-out configuration is at about 23 AMeV



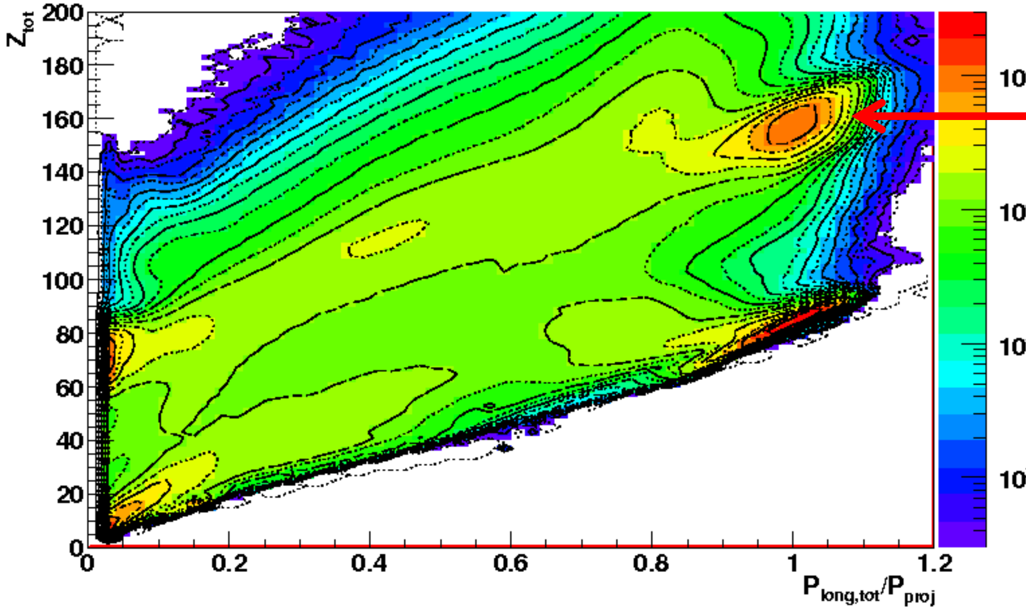
A.Sochocka et al., Int. J. Mod. Phys. E17, 190 (2008)

Formation the toroidal-shapes configurations can be observed in binary droplet collision at high velocity.



Phys. Rev. E 80, 036301 (2009)

Global properties of experimental data for Au + Au reaction at 23 AMeV



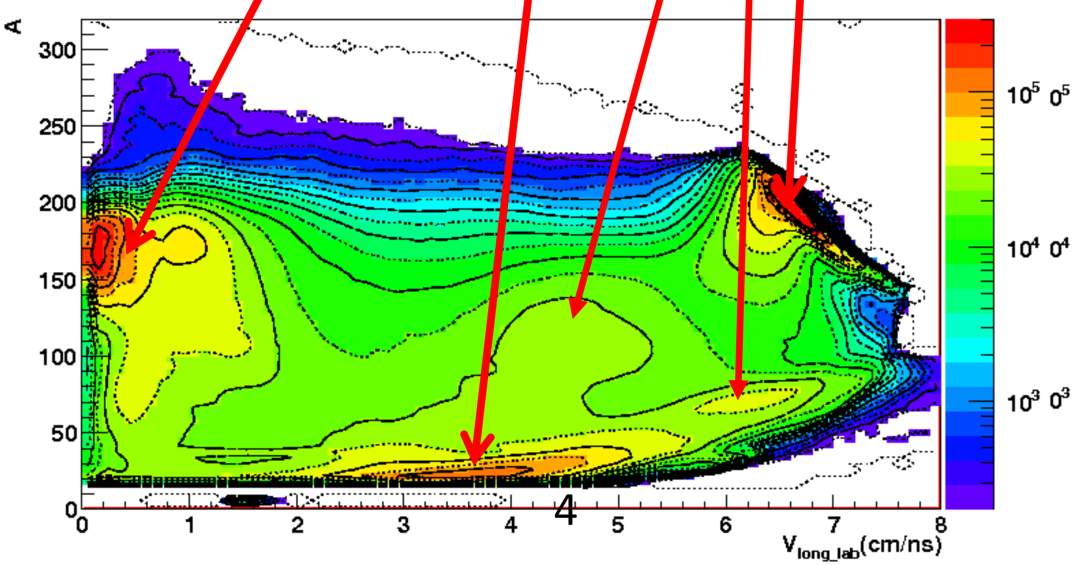
well defined events

Fission fragments from PLF decay

TLF

IVS

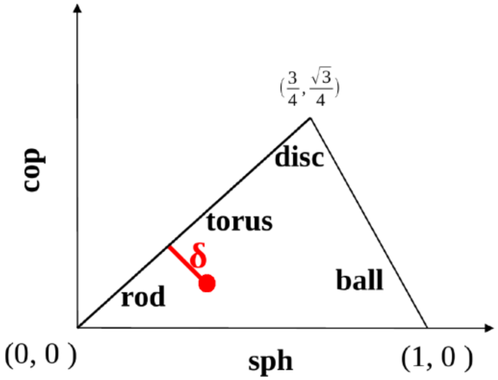
PLF

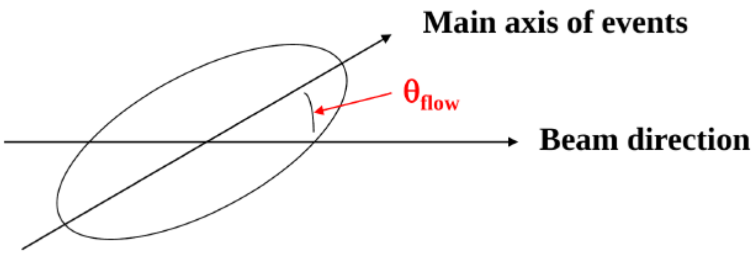


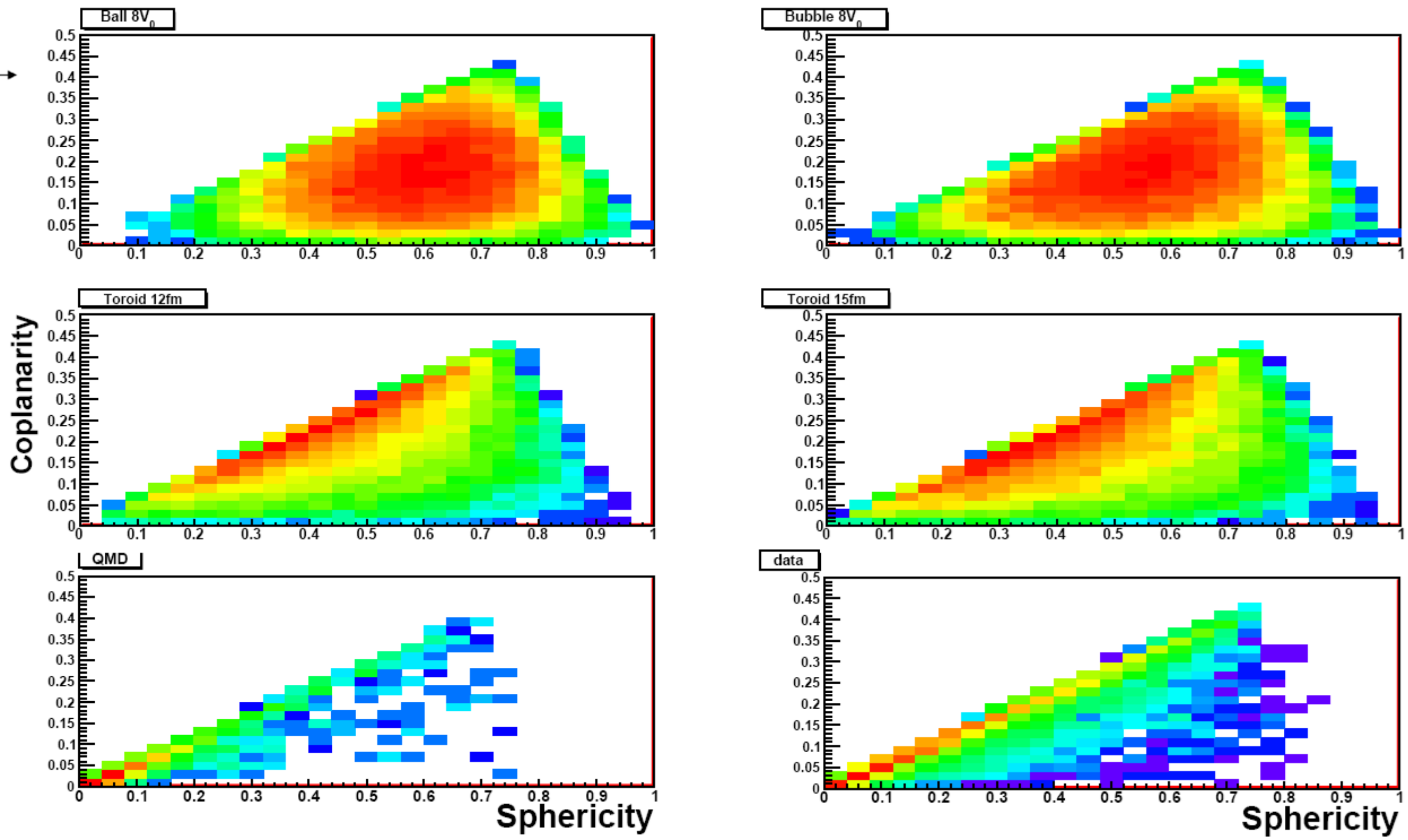
R.Najman et al.,
Phys. Rev. C,
accepted for publication

Shape analysis

δ parameter measures the shape of the events in momenta space.

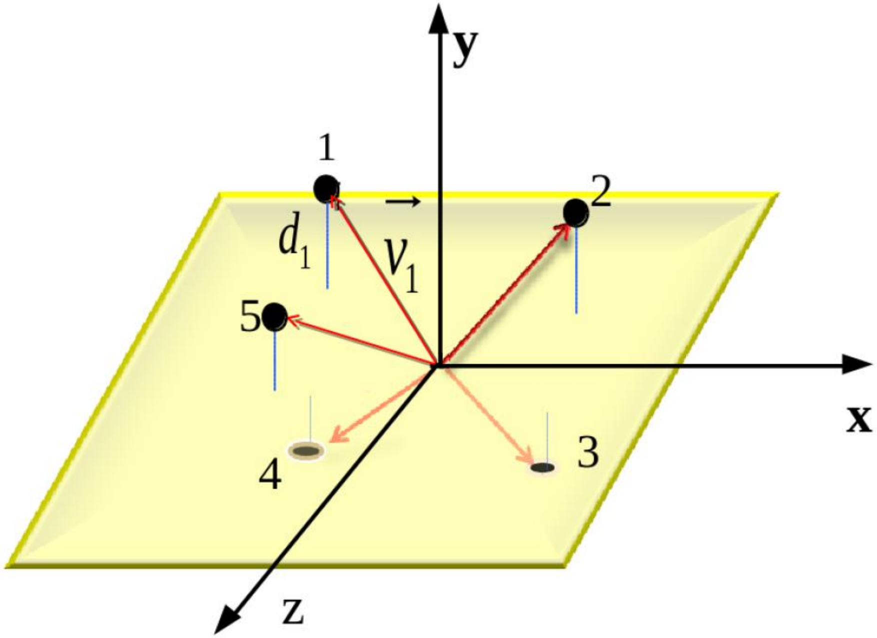






Shape analysis

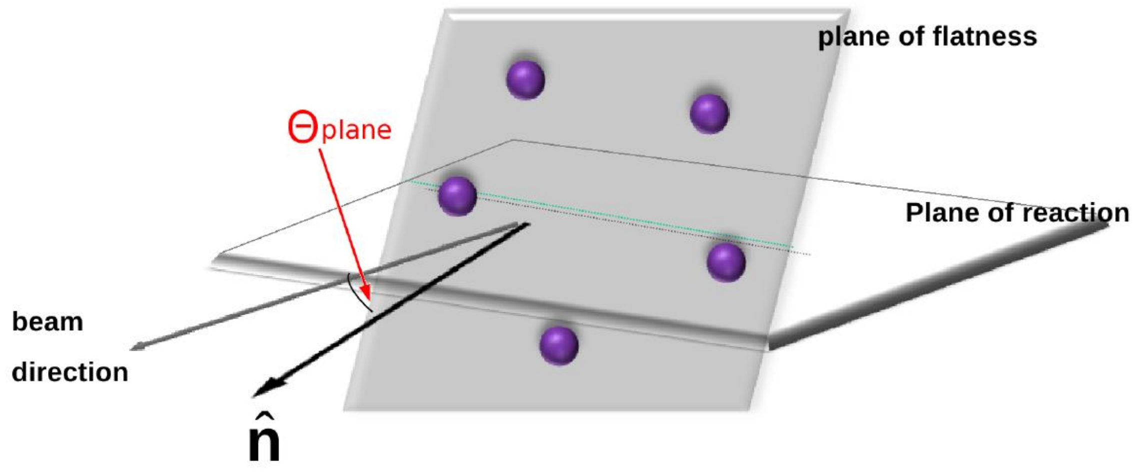
Δ^2 parameter measures the flatness of the events in velocity space. For toroids it is much smaller than for sphere or bubble.



$$\Delta^2 = min[\sum_{i=1}^{5} d_i^2(A, B, C, D)],$$

$$d_i = \frac{A \cdot v_{x,i} + B \cdot v_{y,i} + C \cdot v_{z,i} + D}{\sqrt{A^2 + B^2 + C^2}}.$$

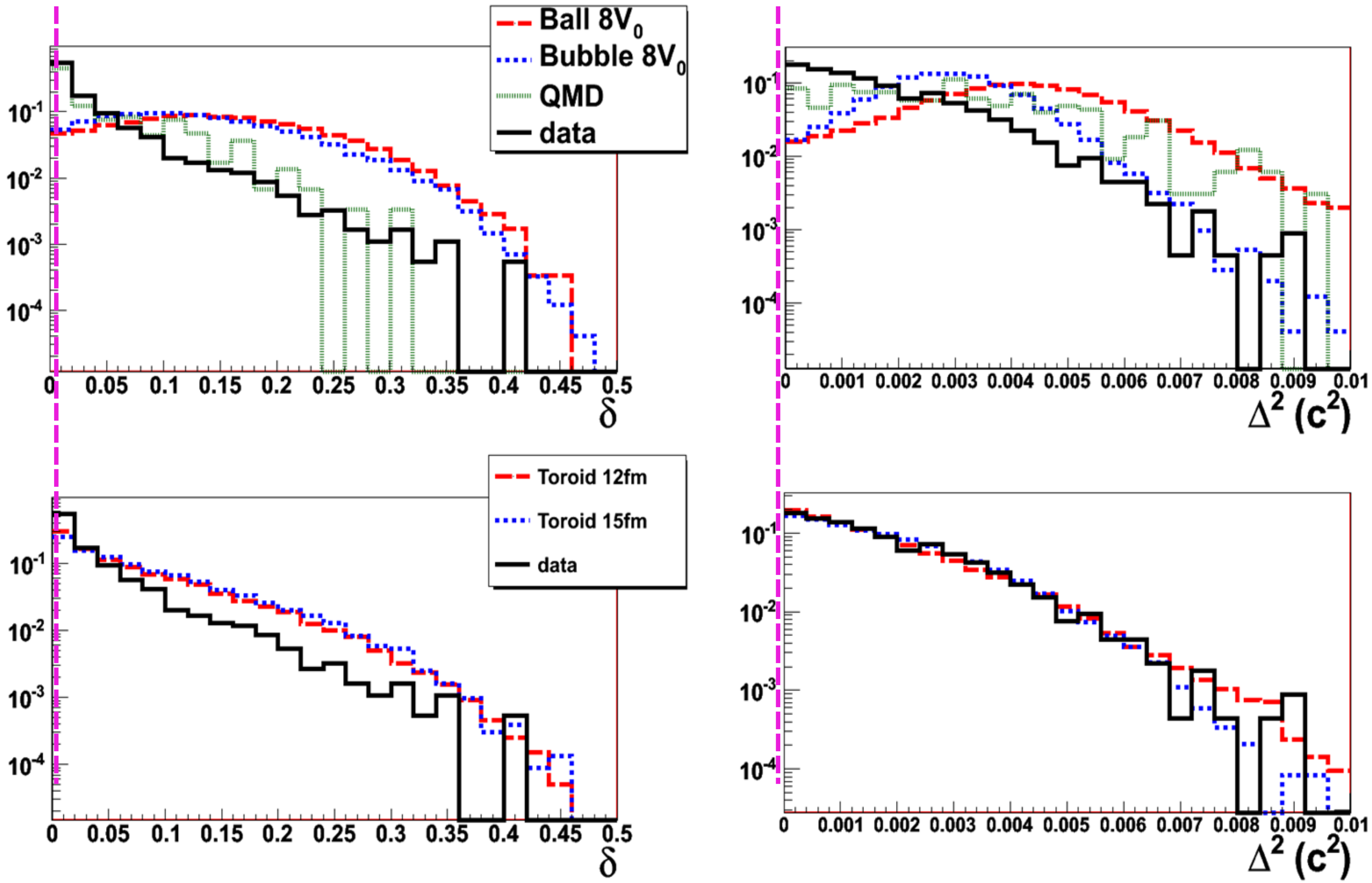
A, B, C, D - plane parameters



Observables distributions

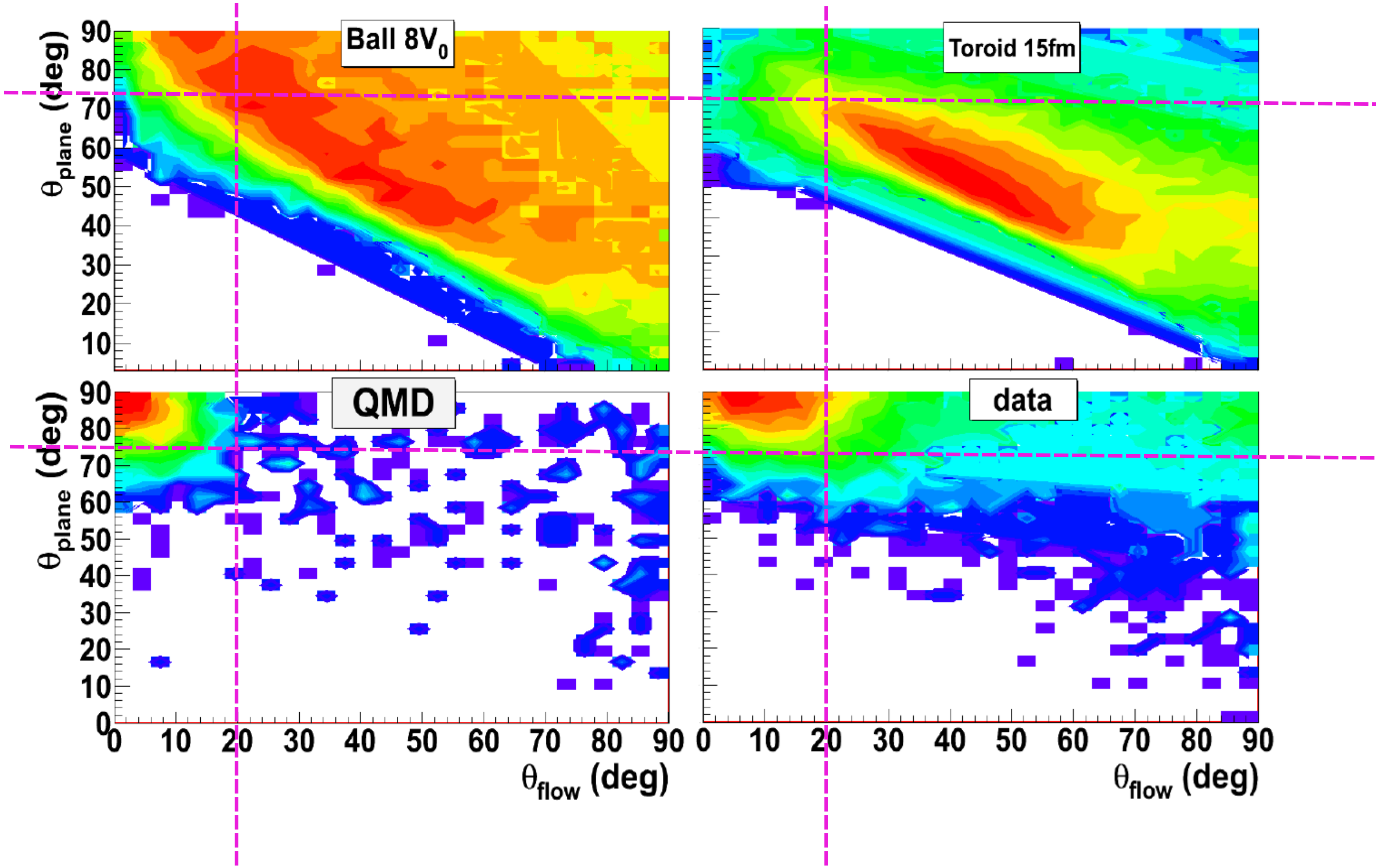
Flat events conditions: $\Delta^2 < 0.001\ c^2$

$\delta < 0.05$

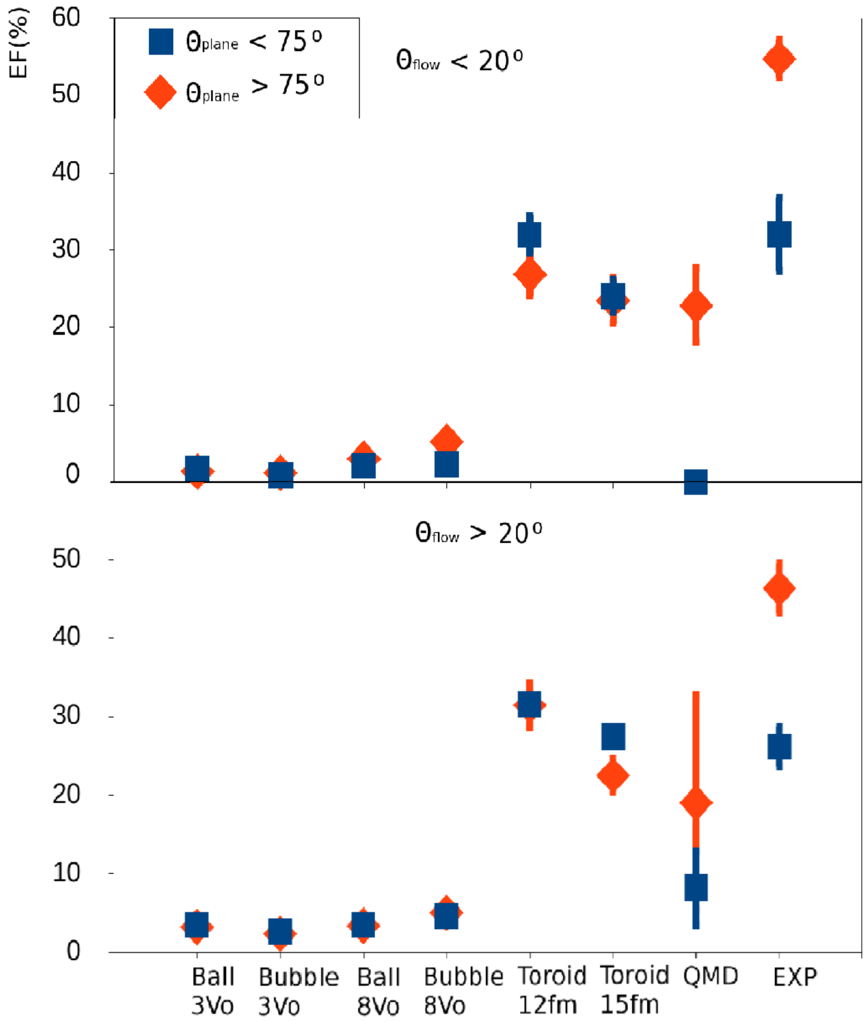


One can see that for both observables the biggest difference between experimental distribution and model predictions is observed for the Ball $8V_0$, and Bubble $8V_0$ configurations. In contrast to that, the experimental data seem to be more consistent with the simulations assuming toroidal freeze-out configurations.

Location of toroidal events on the Θ_{plane} vs Θ_{flow} plane



Efficiency factor:

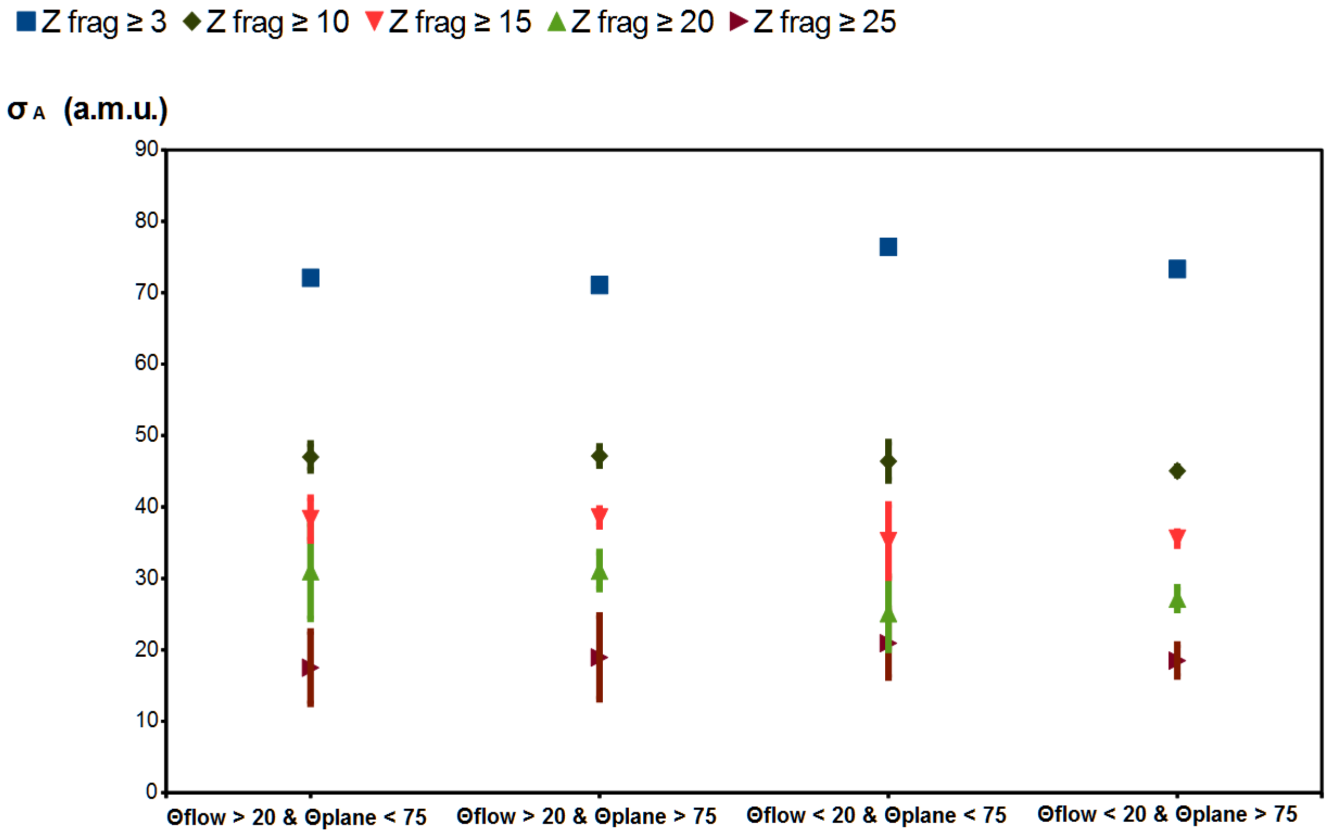


Efficiency factor – ratio of number of events fulfilling the selection conditions to the total number of events with 5 heavy fragments

$$\delta < 0.05 \qquad \Delta^2 < 0.001\, c^2$$

- **EF values for experimental data are very close to the model predictions for toroidal configurations.**
- **This observation may indicate the formation of toroidal/flat freeze-out configuration created in the Au + Au collisions at 23 MeV/nucleon.**

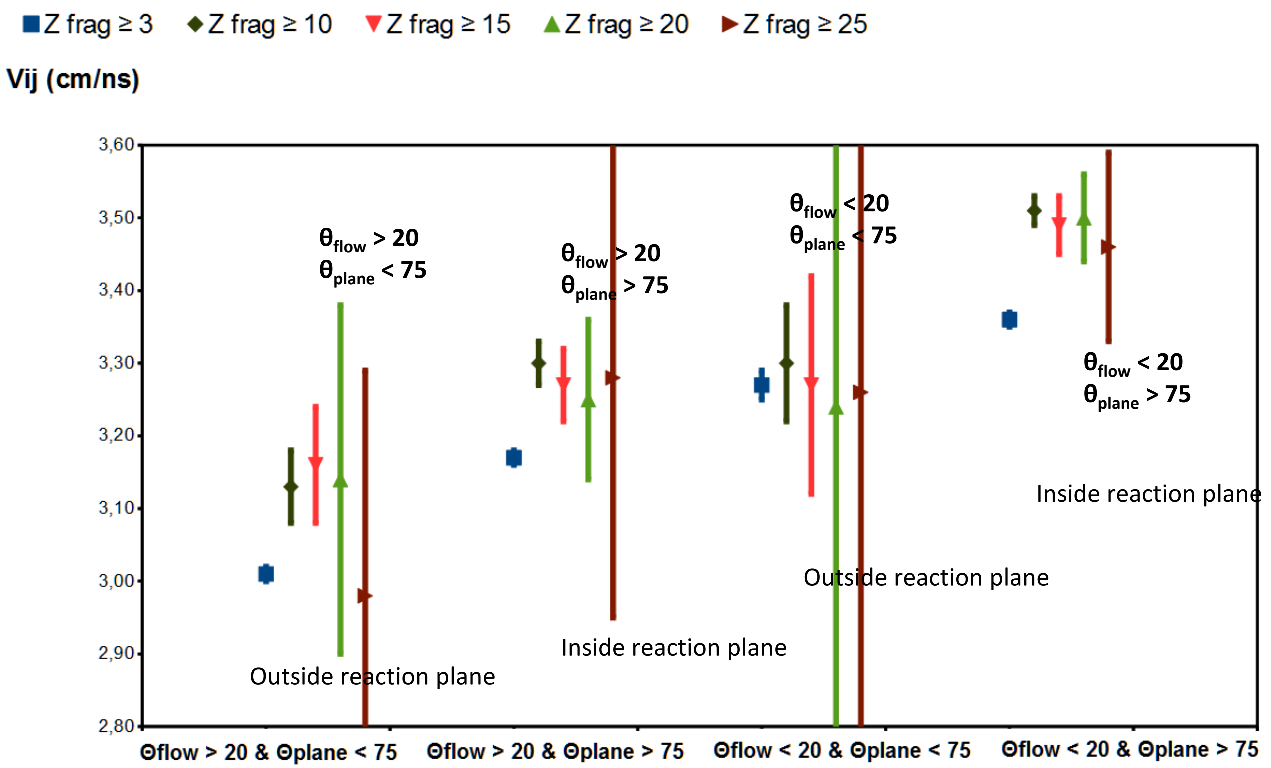
Other observables



σ_A - standard deviation of masses for flat events with 5 fragments

σ_A can not be used as indication of toroidal objects formation in Au +Au reaction

Other observables



region where observation of toroidal freeze-out configuration is expected

region dominated noncentral collisions

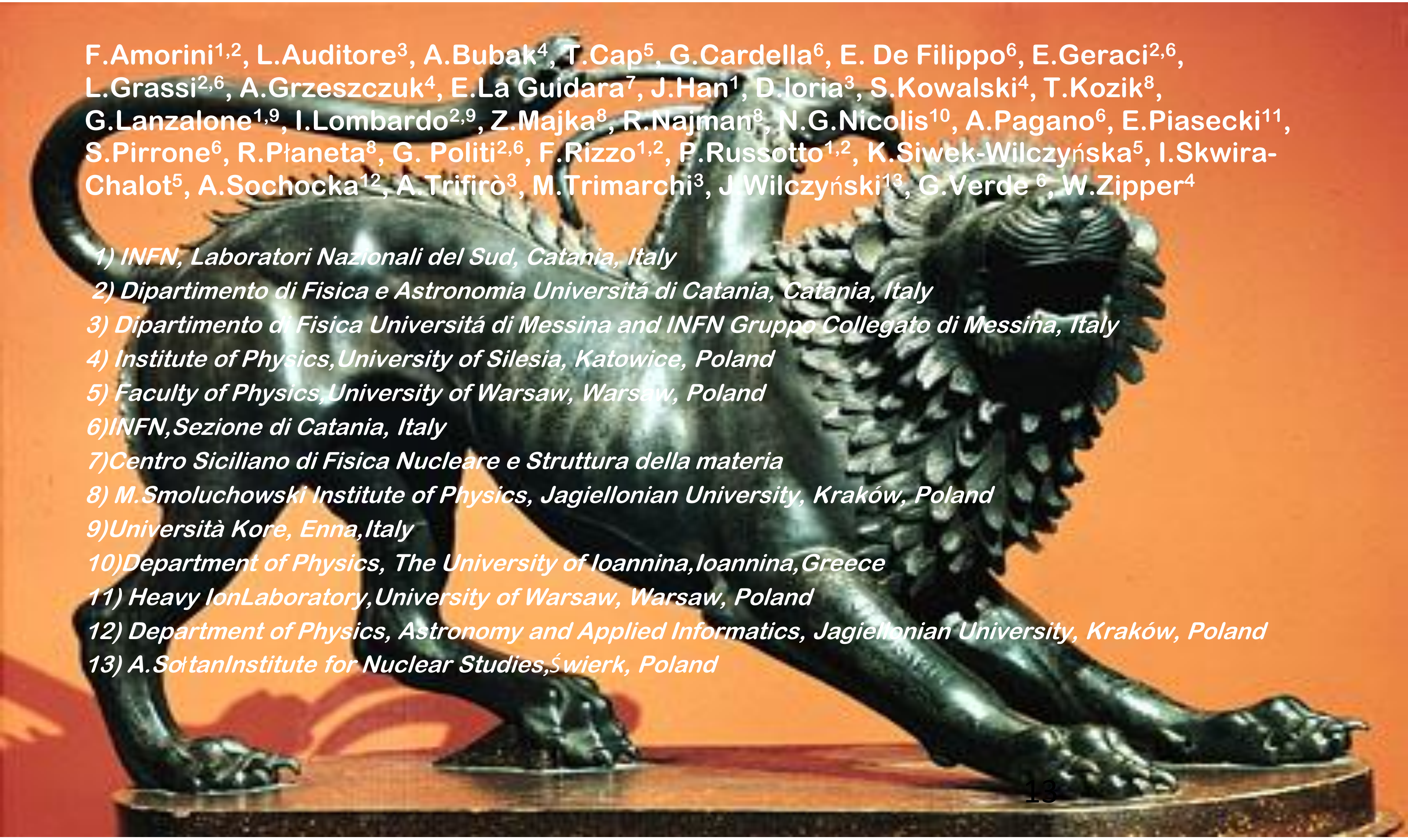
V_{ij} -is mean value of relative velocities for flat events with 5 fragments

The mean values of v_{ij} are smallest for the region where observation toroidal freeze-out configuration is expected.

Summary and outlook

- The experimental data are compared with ETNA and QMD model predictions.
- Efficiency factor is used as indication of formation of exotic freeze-out configuration.
- Distributions of v_{ij} indicate that freeze-out configuration for events located outside reaction plane are more extended
- Comparison between experimental data and model predictions may be used as an indication of the formation of toroidal nuclear systems

Breakup Collaboration



F.Amorini[1,2], L.Auditore[3], A.Bubak[4], T.Cap[5], G.Cardella[6], E. De Filippo[6], E.Geraci[2,6], L.Grassi[2,6], A.Grzeszczuk[4], E.La Guidara[7], J.Han[1], D.Ioria[3], S.Kowalski[4], T.Kozik[8], G.Lanzalone[1,9], I.Lombardo[2,9], Z.Majka[8], R.Najman[8], N.G.Nicolis[10], A.Pagano[6], E.Piasecki[11], S.Pirrone[6], R.Płaneta[8], G. Politi[2,6], F.Rizzo[1,2], P.Russotto[1,2], K.Siwek-Wilczyńska[5], I.Skwira-Chalot[5], A.Sochocka[12], A.Trifirò[3], M.Trimarchi[3], J.Wilczyński[13], G.Verde [6], W.Zipper[4]

1) INFN, Laboratori Nazionali del Sud, Catania, Italy
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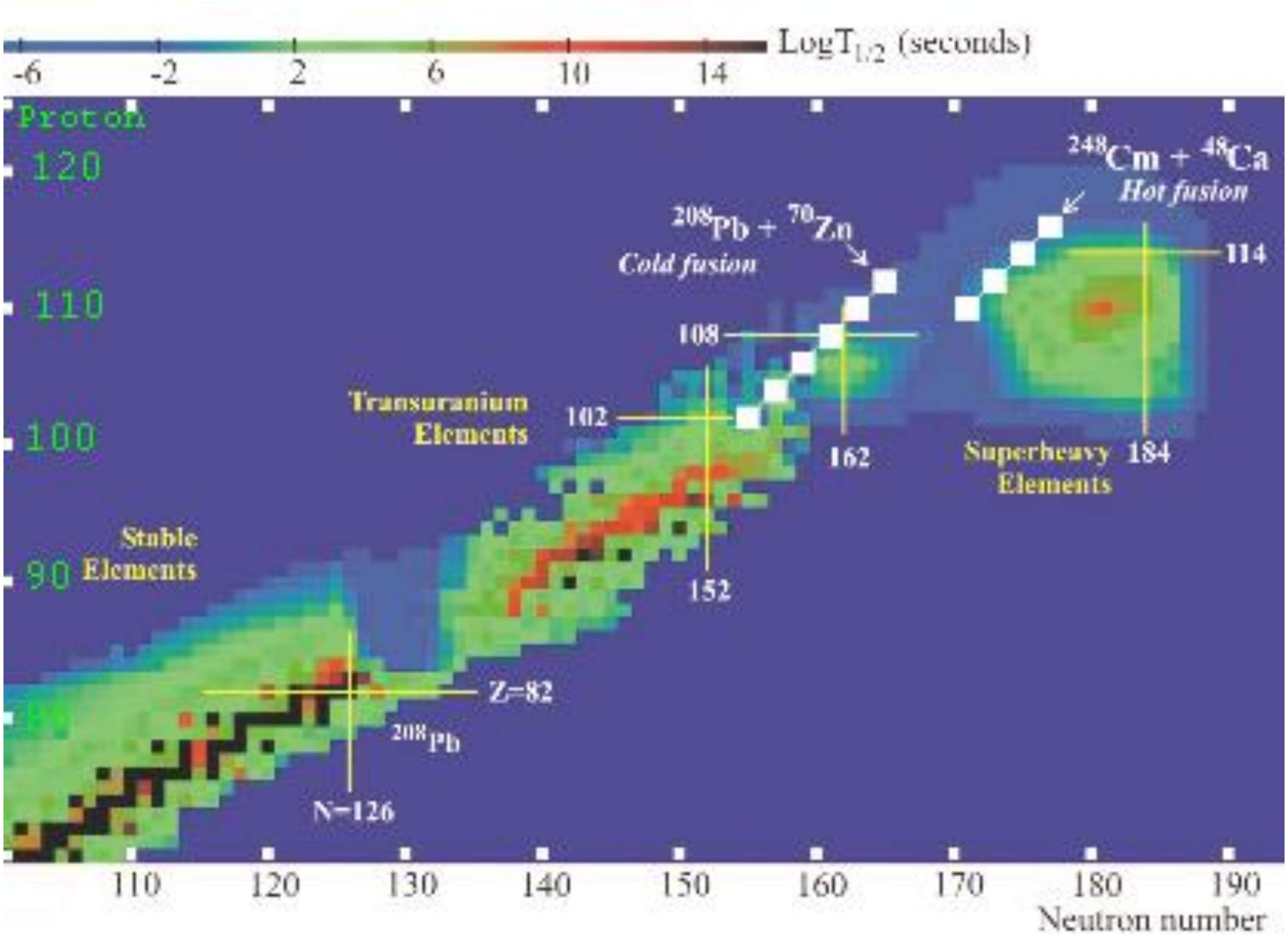
3) Dipartimento di Fisica Universitá di Messina and INFN Gruppo Collegato di Messina, Italy
4) Institute of Physics,University of Silesia, Katowice, Poland
5) Faculty of Physics,University of Warsaw, Warsaw, Poland
6)INFN,Sezione di Catania, Italy
7)Centro Siciliano di Fisica Nucleare e Struttura della materia
8) M.Smoluchowski Institute of Physics, Jagiellonian University, Kraków, Poland
9)Università Kore, Enna,Italy
10)Department of Physics, The University of Ioannina,Ioannina,Greece
11) Heavy IonLaboratory,University of Warsaw, Warsaw, Poland
12) Department of Physics, Astronomy and Applied Informatics, Jagiellonian University, Kraków, Poland
13) A.SołtanInstitute for Nuclear Studies,Świerk, Poland

Search for superheavy nuclei



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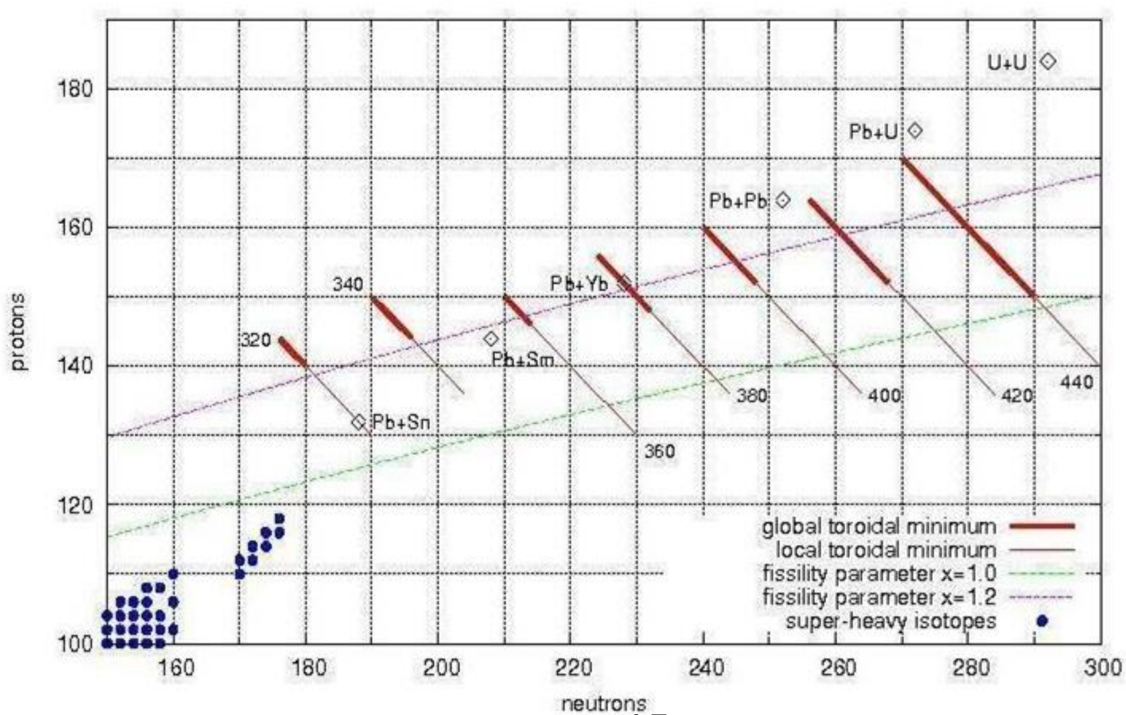
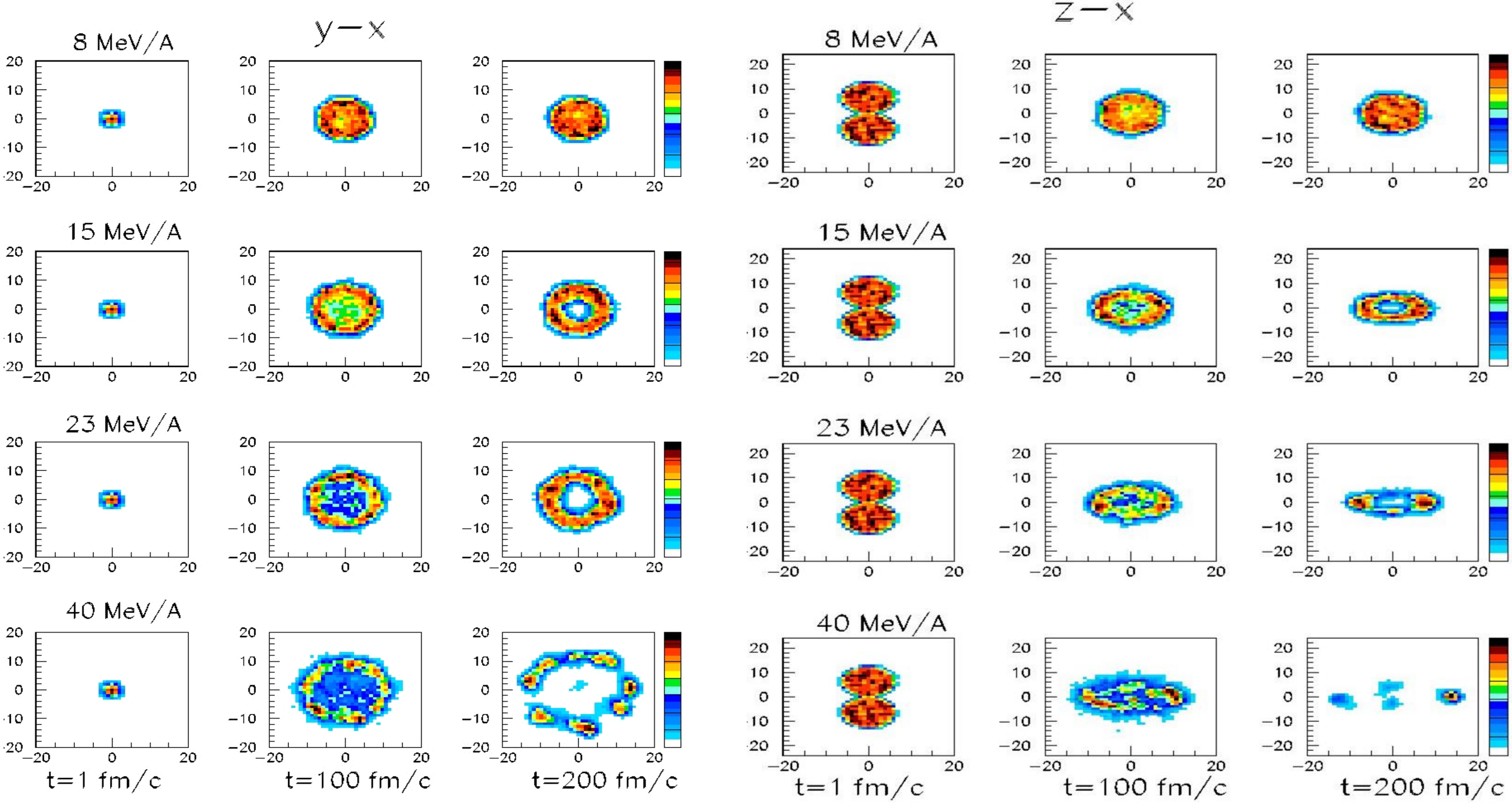


BUU simulations for central collisions of Au+Au

Calculations predict that a threshold energy for toroidal freeze-out configuration is at about 23 MeV / nucleon



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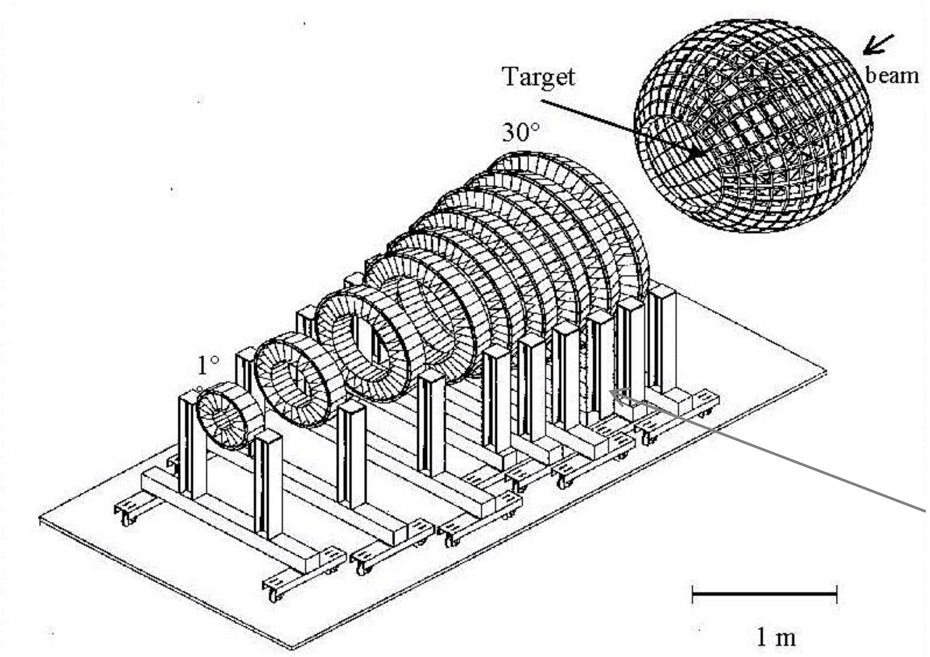
CHIMERA – Charged Heavy Ion Mass and Energy Resolving Array



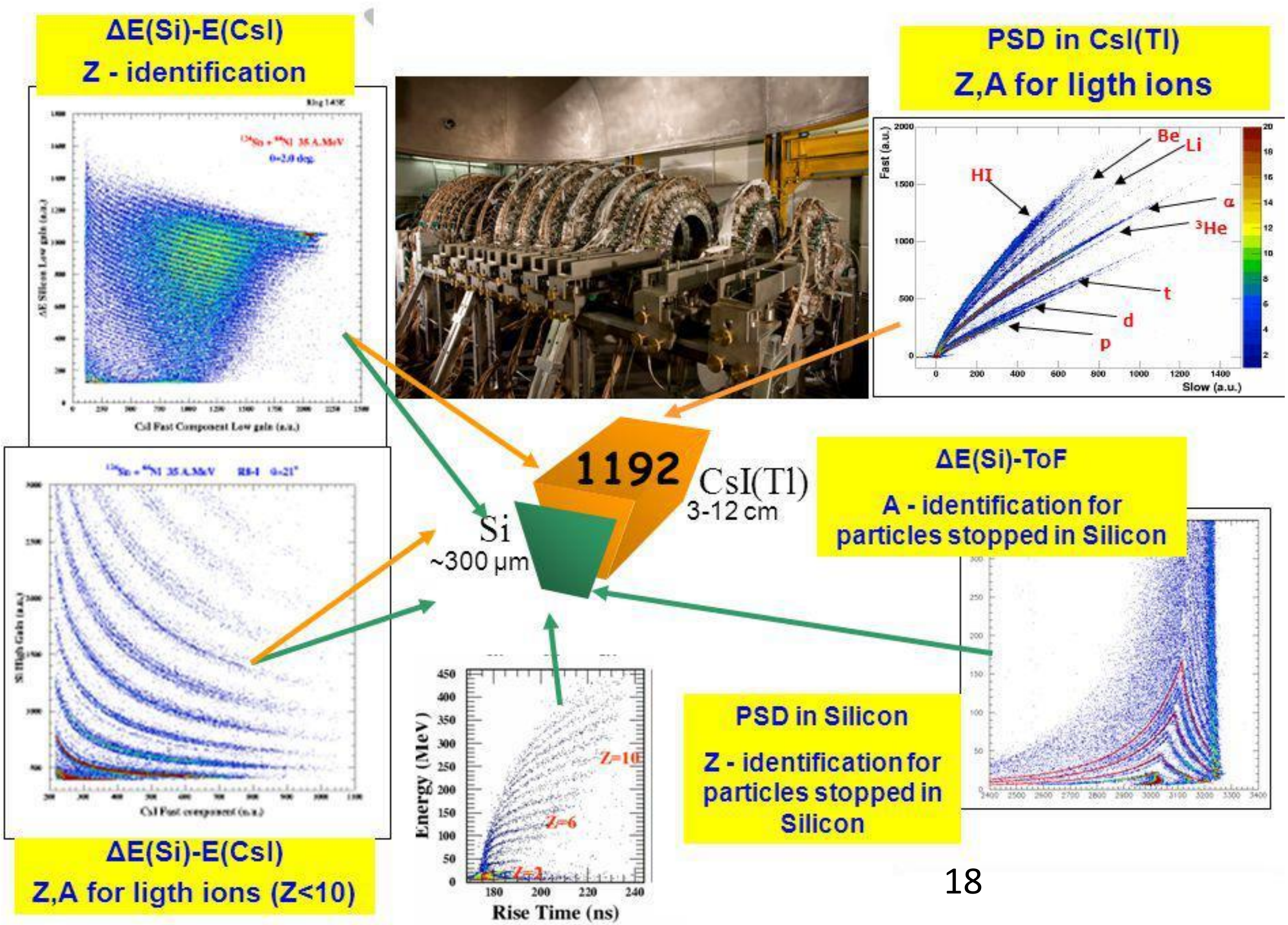
17 rings

687 telescopes on 9 wheels

CHIMERAs advantage:

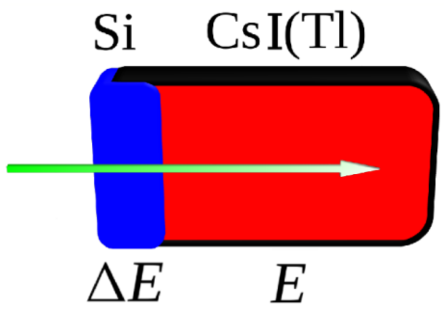
•1192 telescopes: Si and CsI
• Low detection threshold - 1MeV/A
• Covering almost 94% of 4π
• Z and A identification

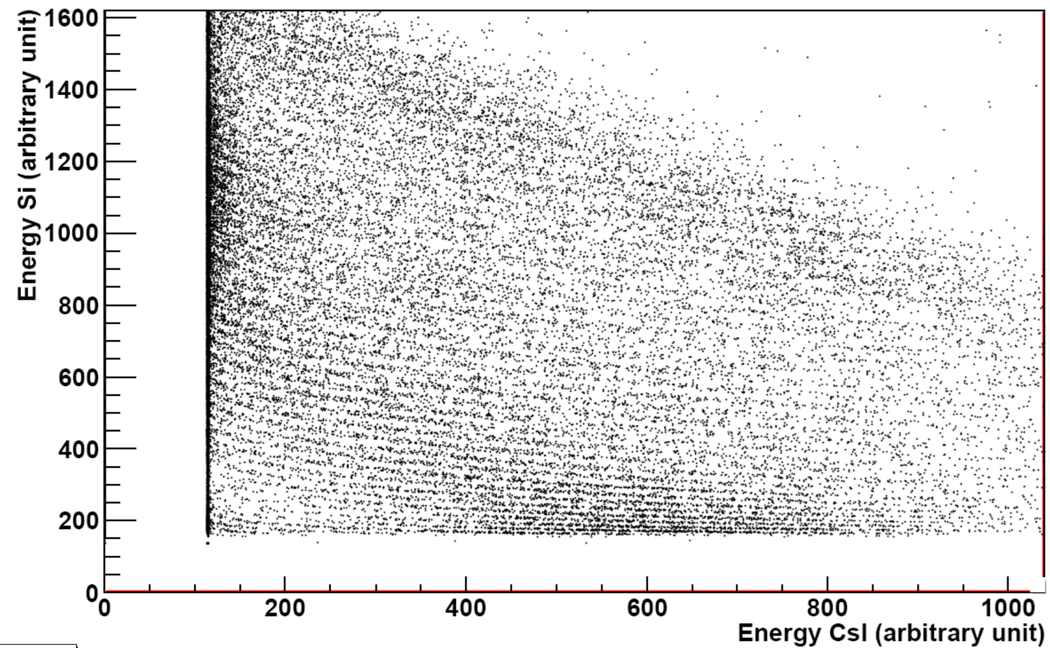
CHIMERA – Charged Heavy Ion Mass and Energy Resolving Array

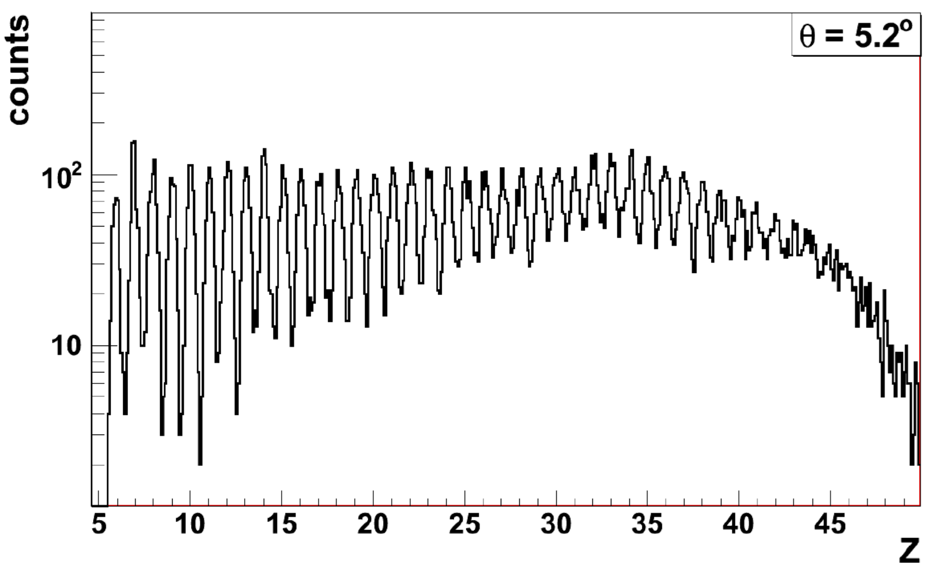


DE-E Techinique

$$E = \Delta E_{Si} + E_{R,CsI}.$$

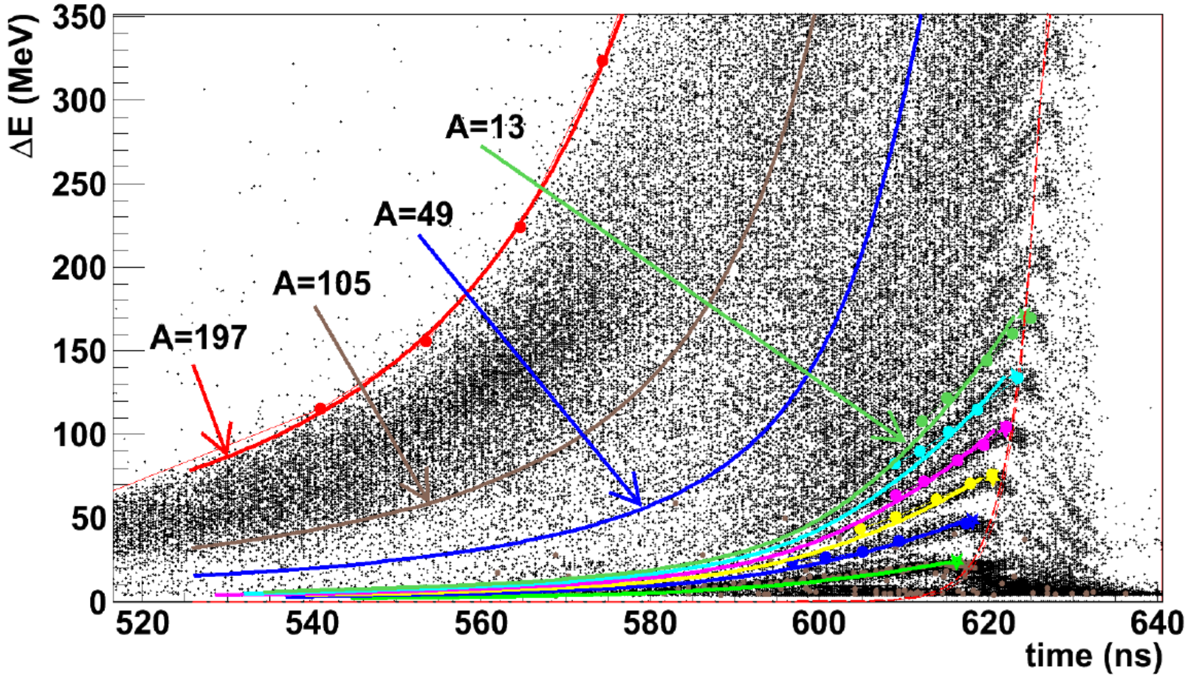






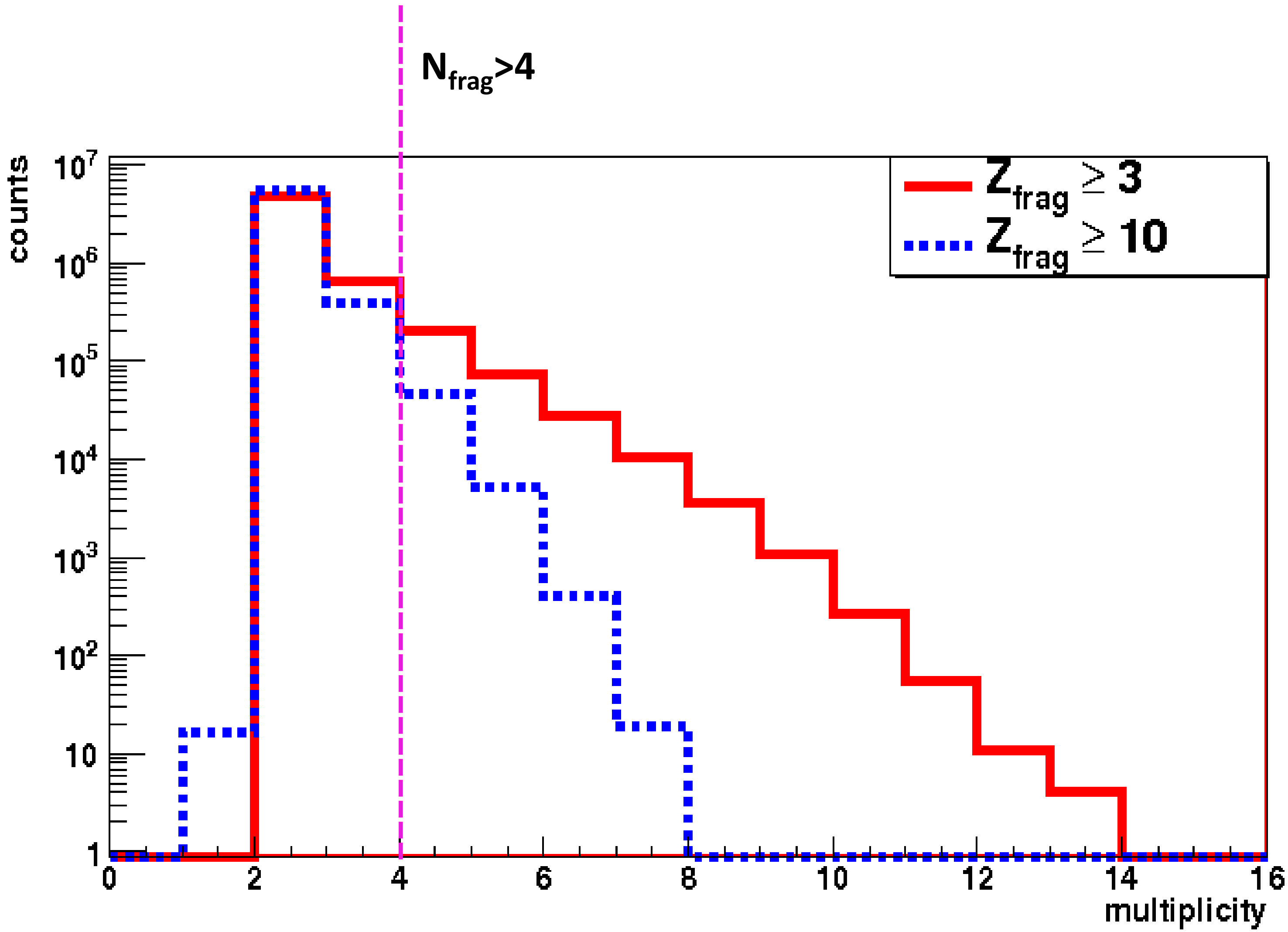
ToF Techinique

Detector 641
ϴ=28.5^0



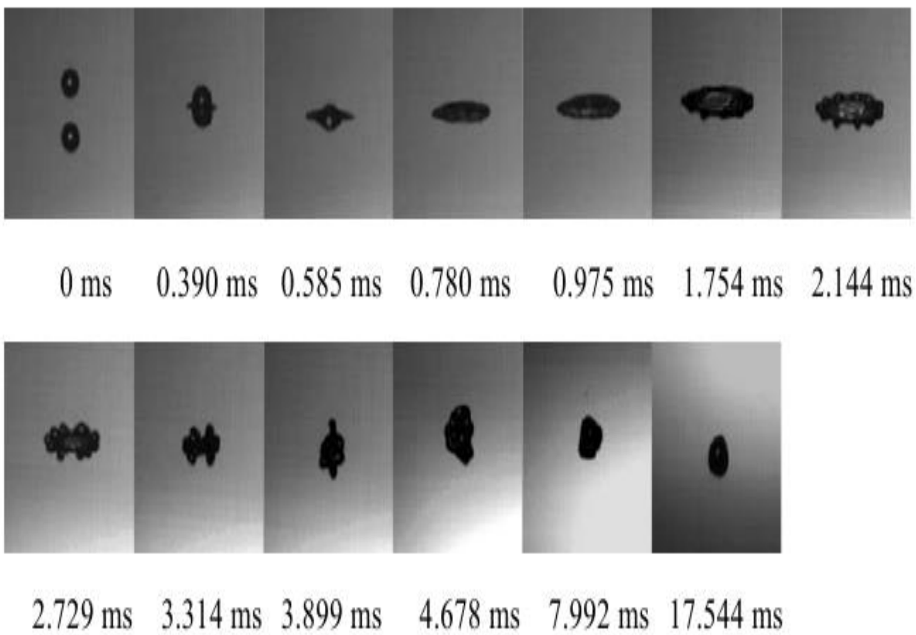
The external line corresponds to Au like nuclei.
You can also see isolated lines corresponding to fragments with mass from 4 up to 15.

Multiplicity distribution for well defined events

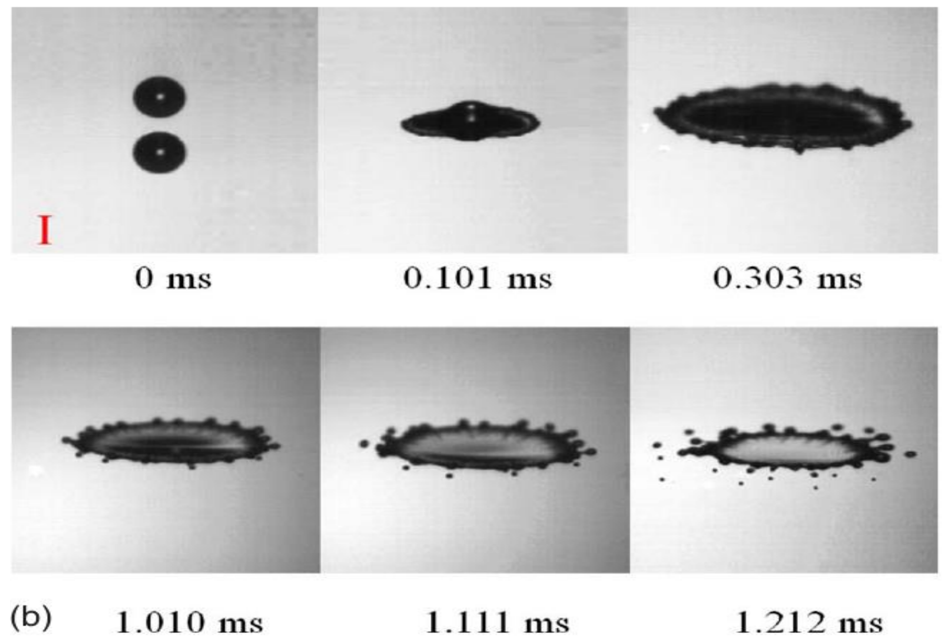


Macroscopic droplet collisions

Formation the toroidal-shapes configurations can be observed in binary droplet collision at high velocity



V=3.89 m/s

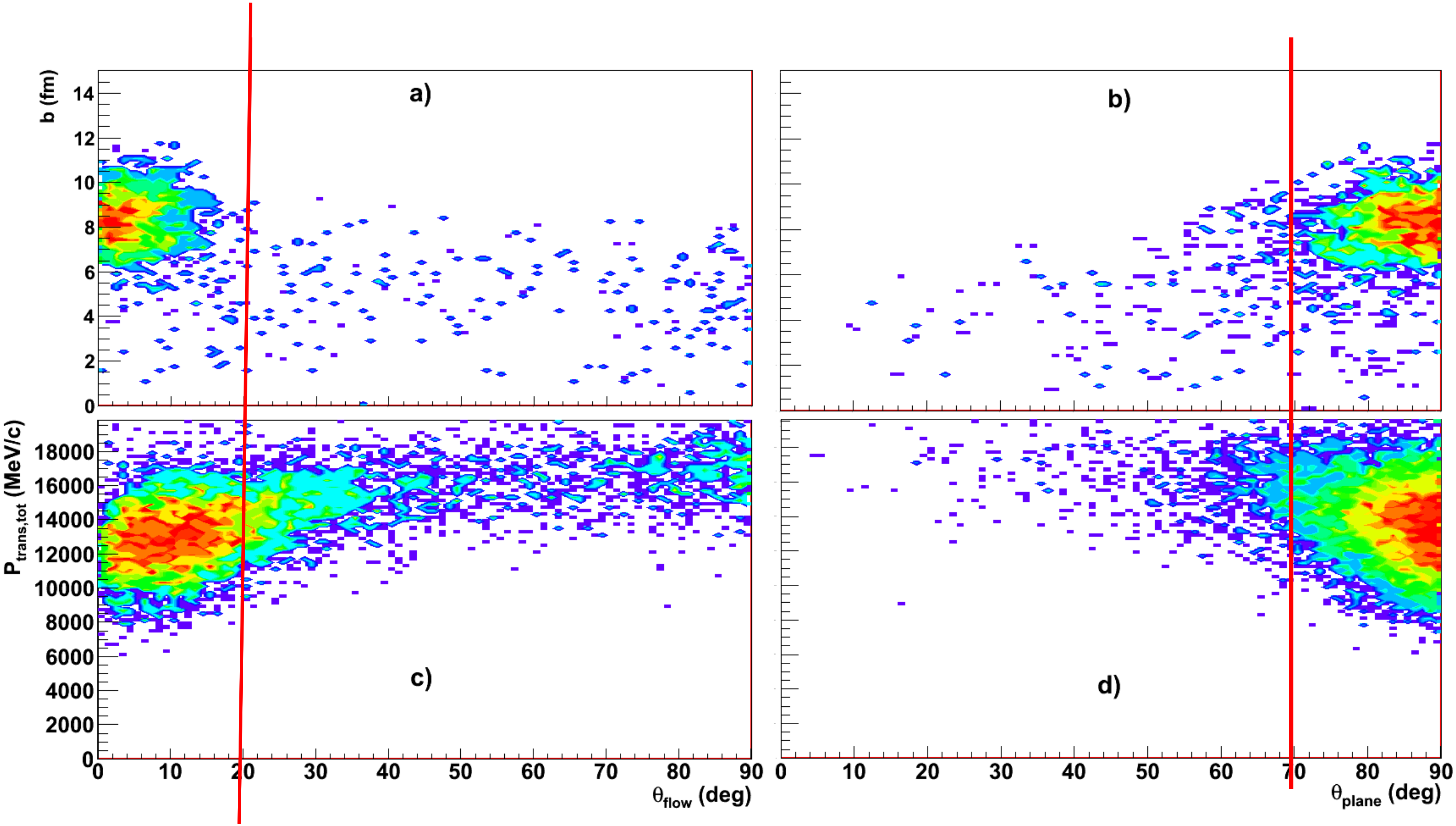


V=9.1 m/s

22

Phys.Rev.E 80, 036301 2009

Estimation of collision centrality



One can see on this plot that noncentral events are located at small θ_{flow} **angles (> 20 degree**) and big θ_{plane} **angles (< 75 degree**).

As an impact parameter estimator for experimental data we used total transverse momentum

ToF Techinique

$$E = \frac{1}{2} \cdot m \cdot \frac{R^2}{(t_0 - t)^2} \longrightarrow t_0 = \alpha \cdot ch_{time} + 1.01734 \cdot \sqrt{\frac{m \cdot R^2}{2E}}$$

E- particle energy [MeV] calculated from:

$E = a_L \cdot Channel_{desilpg} + b_L$

m- ion mass [u]

R – distance from target to detector [cm]

t_0 – time offset calculated for each detector [ns]

$\alpha = 3 \cdot T / d$

T- cyclotron period [ns]

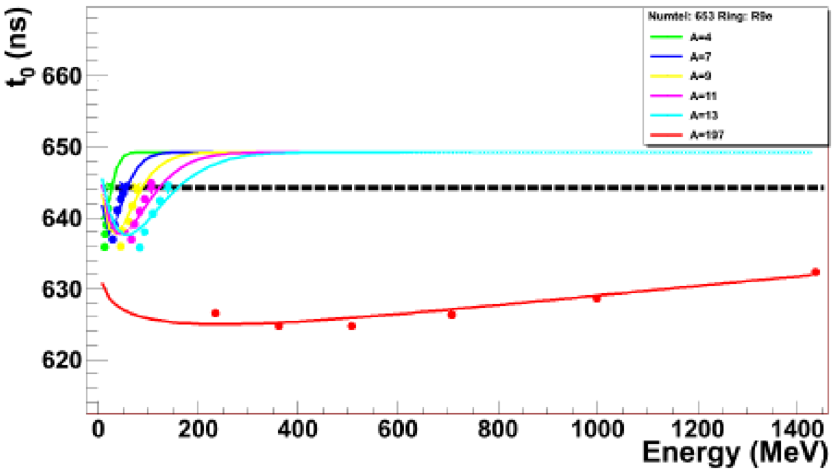
d- distance between two beam bursts [channels]

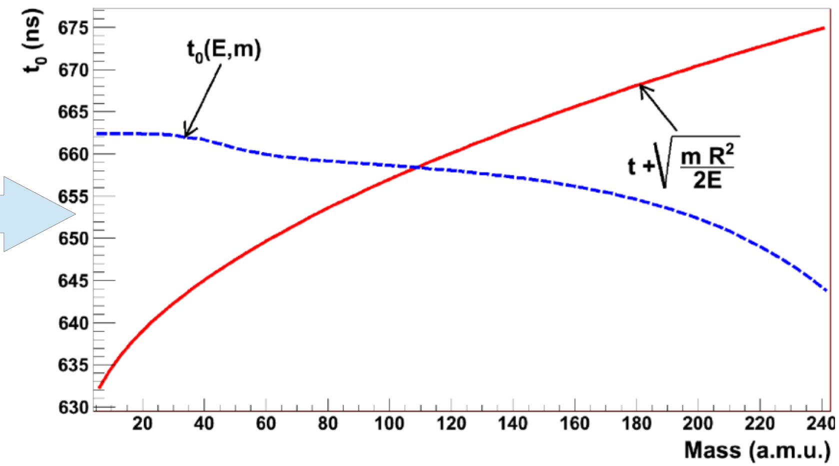
For calibration data the following 8-parametres function is fitted:

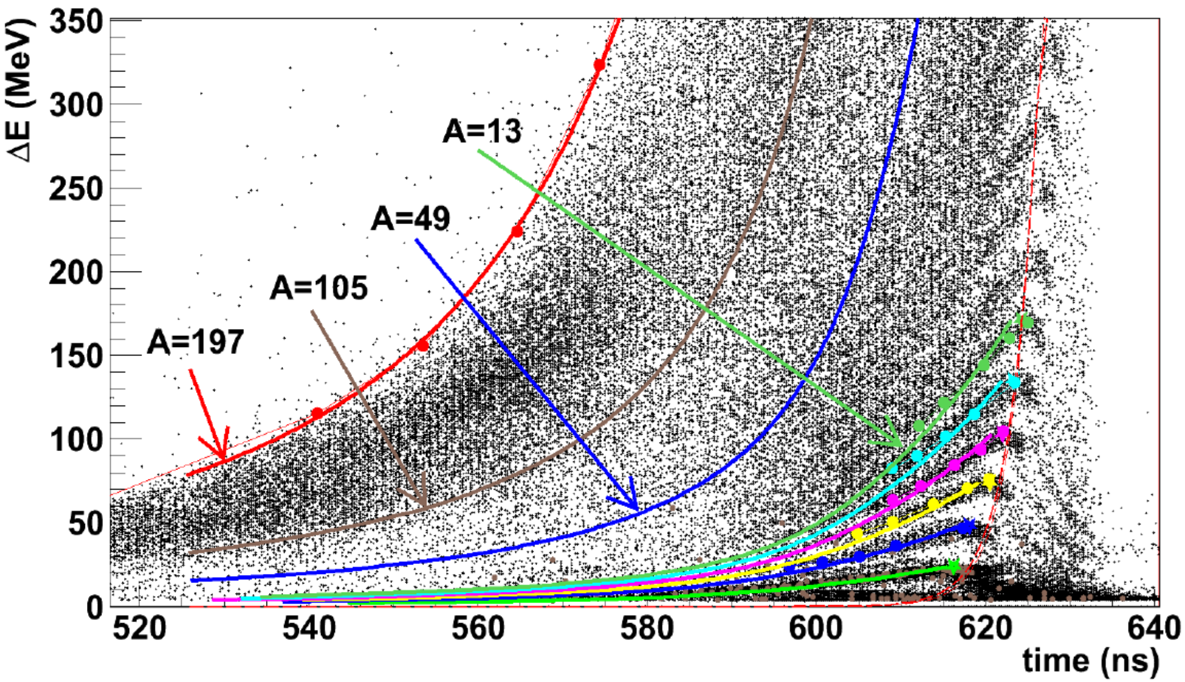
$$t_0 = \begin{cases} t_{0,sat} & t_{0,sat} < \Delta t \\ t_{0,sat} - \Delta t & t_{0,sat} > \Delta t, \end{cases}$$

$$\Delta t = B - A(1 - exp(\gamma m)) \cdot (\frac{E}{E_{PT}})^{(\alpha - \delta m)} \cdot exp(-(\frac{E + (\beta + \mu m) E_{PT}}{E_{PT}})^{\epsilon})$$

ToF Techinique







Reconstruction results