Characteristics of the fragments production in $^{197}Au + ^{197}Au$ reaction at 23 AMeV

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for Breakup Collaboration

Motivation

• extension of an earlier study carried out at a lower energy of 15 AMeV, in which a **new reaction mechanism** of violent collinear breakup of non-fusing colliding systems into 3 and/or 4 massive fragments was discovered *(previous seminar)*

• search for toroidal freeze out configurations predicted to be formed for this heavy system

Search for superheavy nuclei

The theoretical analysis of properties of superheavy nuclei do not predict any long living nuclei with compact shapes beyond the island of stability (N ~ 184, Z ~ 114).

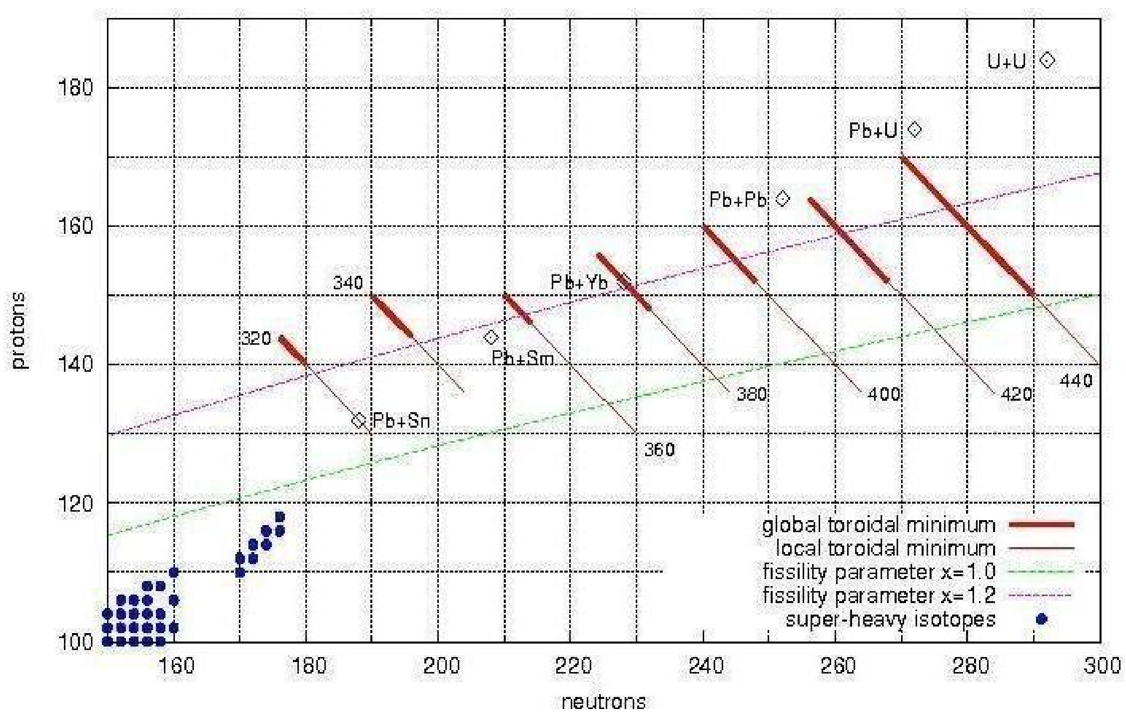
Liquid drop model with shell corrections and Hartree – Fock – Bogoliubov theory with the Gogny D1S force calculations have shown that metastable islands of nuclear bubbles can exist for nuclei in the range A=450-3000

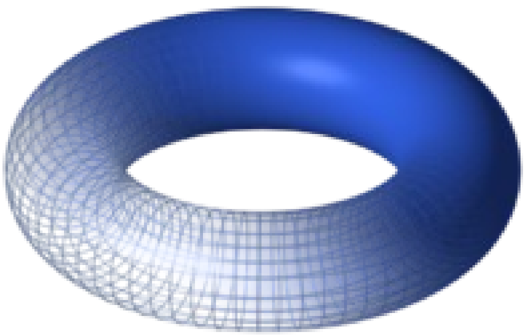
K. Dietrich, K.Pomorski Phys. Rev. Lett. 80, 37 (1998)

J. Decharge et al. Nucl. Phys.A 716, 55 (2003)

Prediction for the toroidal shapes

- The energy of the toroidal minimum decrease relatively to the potential energy of the spherical configuration with increase of the mass of the system
- For Z>140 , the global minimum of potential energy corresponds to the toroidal shape

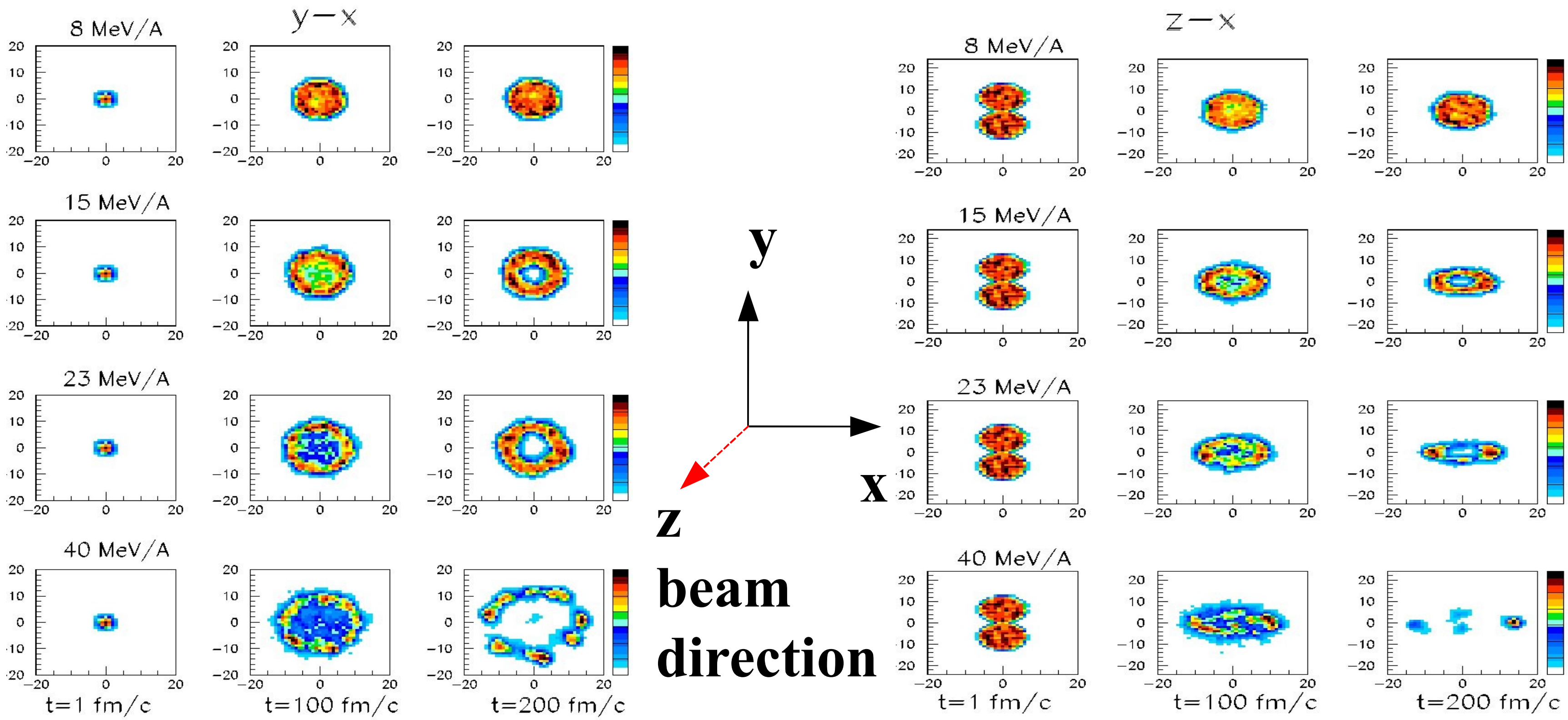




M. Warda,
Int. J. of Mod. Phys. E 16,452 (2007)

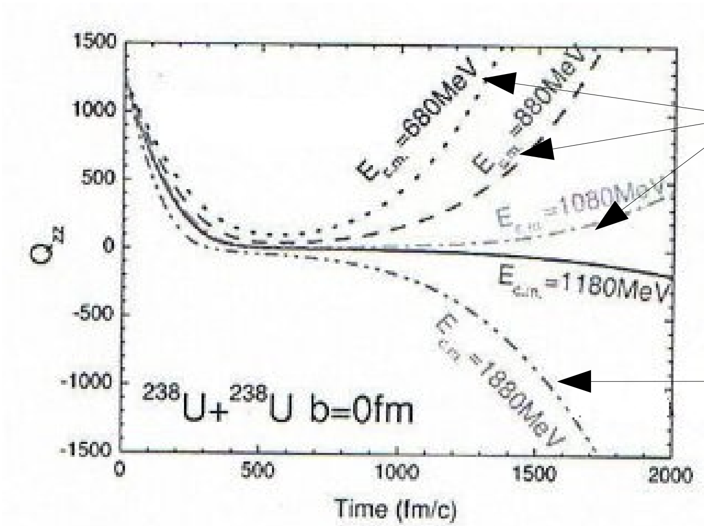
BUU simulations
for central collisions of Au+Au

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



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

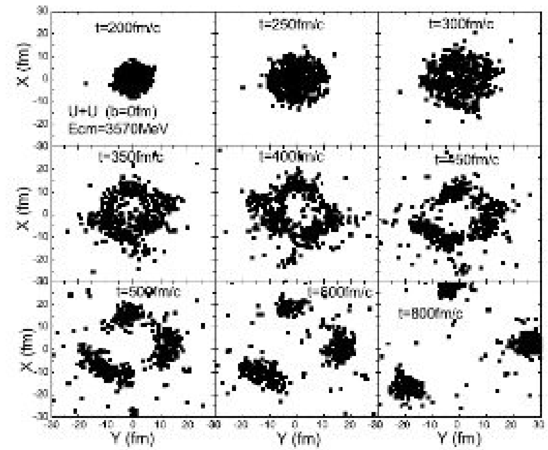
Results of ImQMD simulation



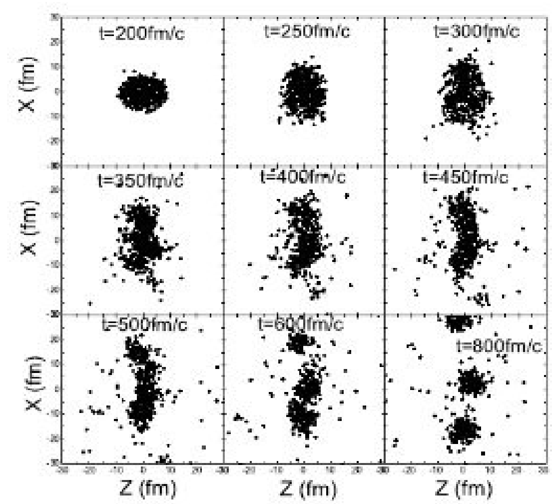
Prolate spheroid

Flat shape

Time evolution of quadrupole moment for $^{238}U + ^{238}U$



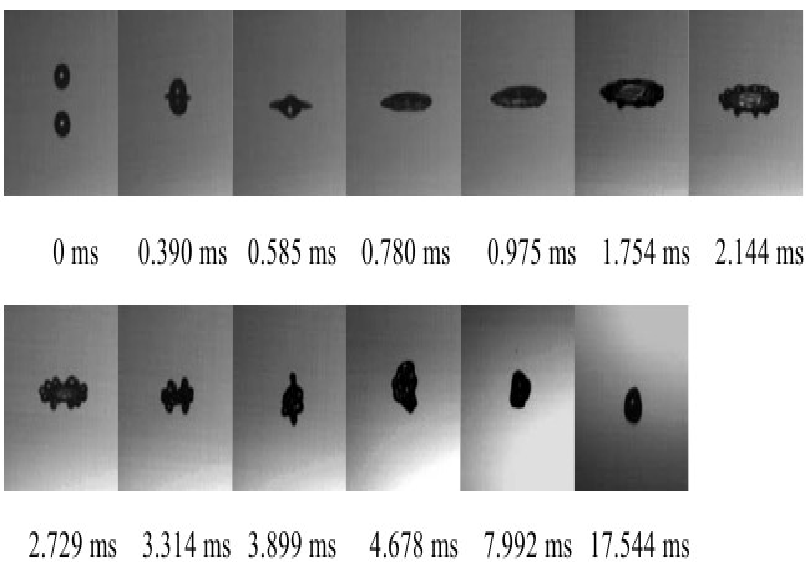
Time evolution of $^{238}U + ^{238}U$ at Ecm=3570 MeV and b=0 fm



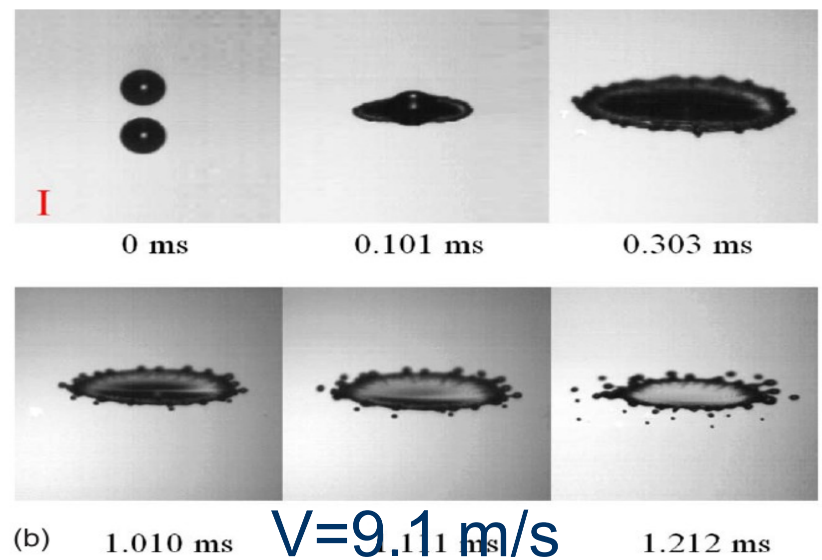
Tian et al., Phys. Rev. C77, 064603 (2008)

Macroscopic droplet collisions

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



V=3.89 m/s



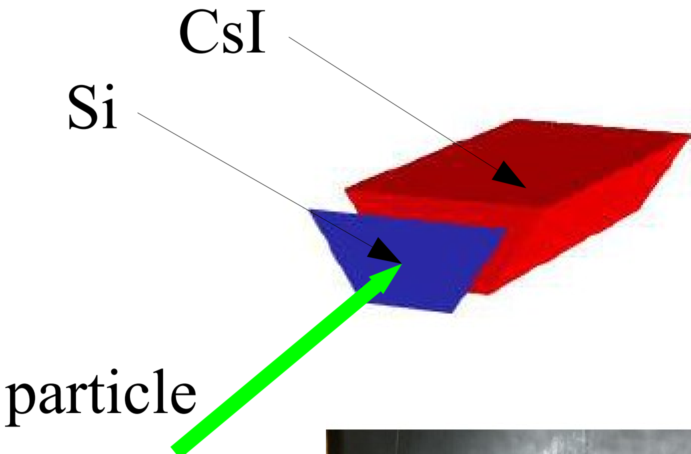
V=9.1 m/s

Phys.Rev.E 80, 036301 2009

Measurements forAu + Au (23 AMeV) at INFN-LNS with CHIMERA detector

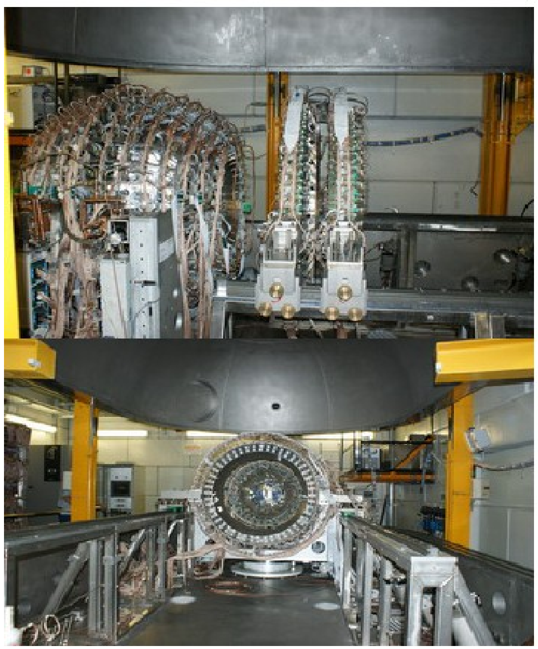
CHIMERA -Charged Heavy Ion Mass and Energy Resolving Array

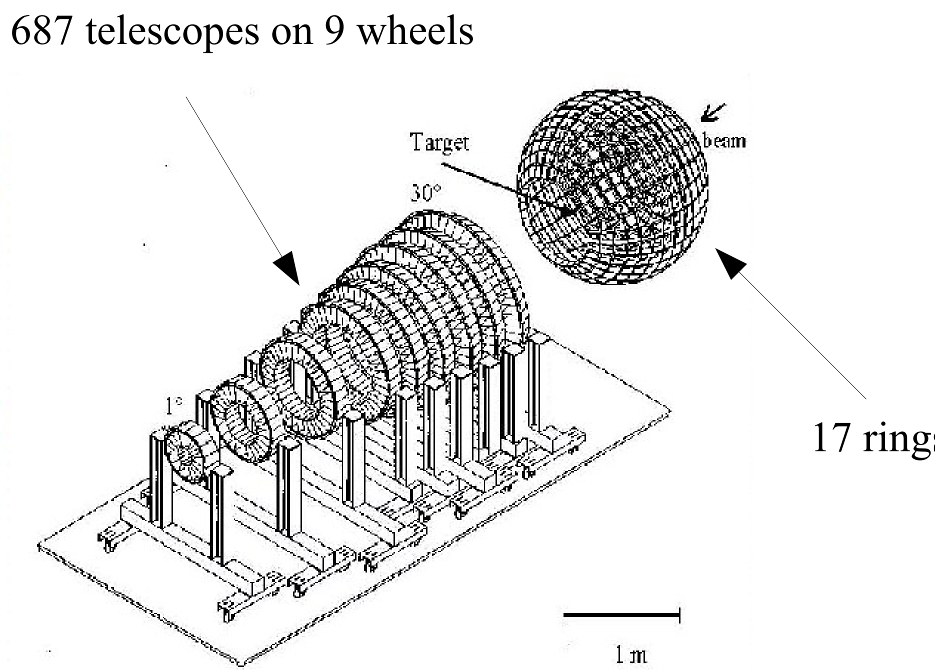
CHIMERA detector



CHIMERAs advantage:

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





Au + Au at 23 AMeV

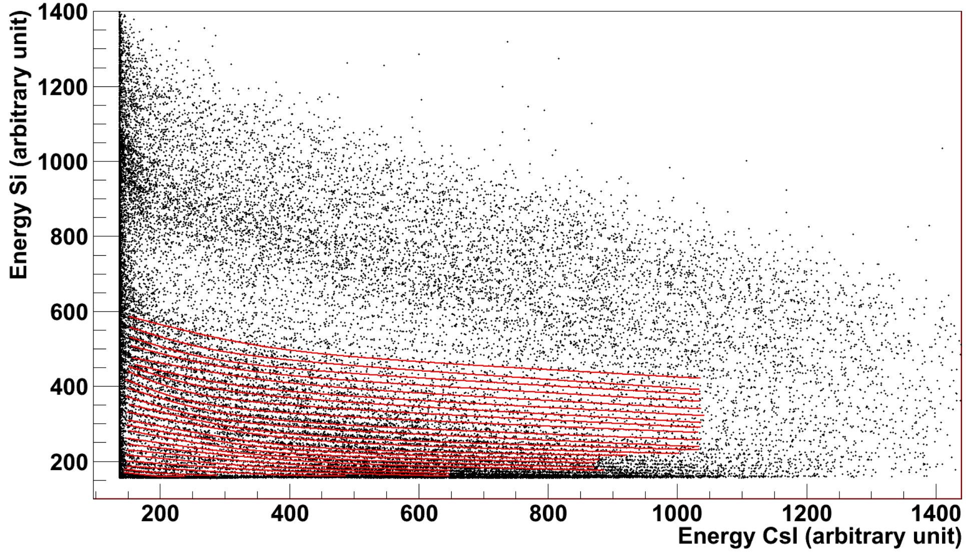
Calibration procedure:

- Energy calibration of Si detectors (done)
- Z identification of fragments, ΔE-E method (done)
- Energy deposited in CsI calculated (done)
- A identification of fragments, TOF method (done)

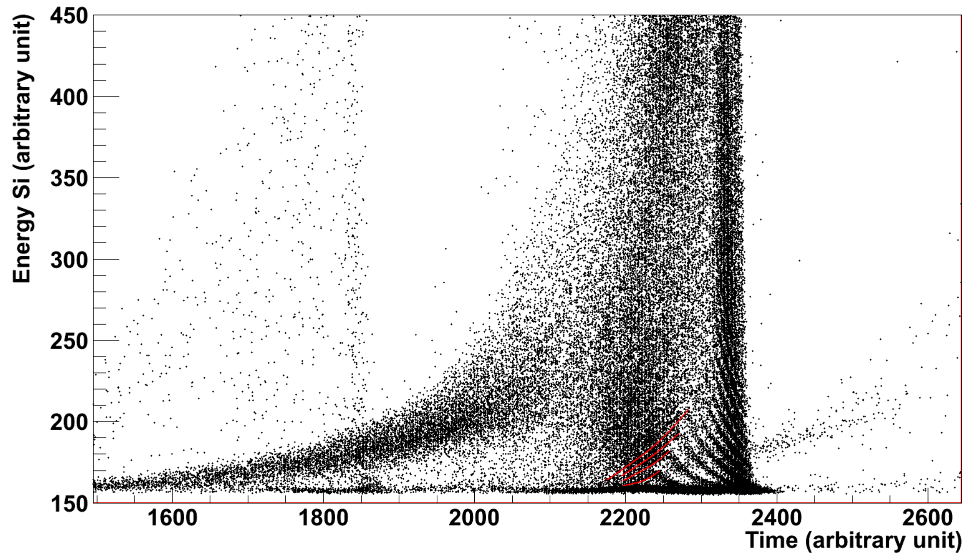
- Light particles identification, PSD method (in future)
- Pulse Shape Analysis, Time90 (in future)

Fragment identifications

telescope 252

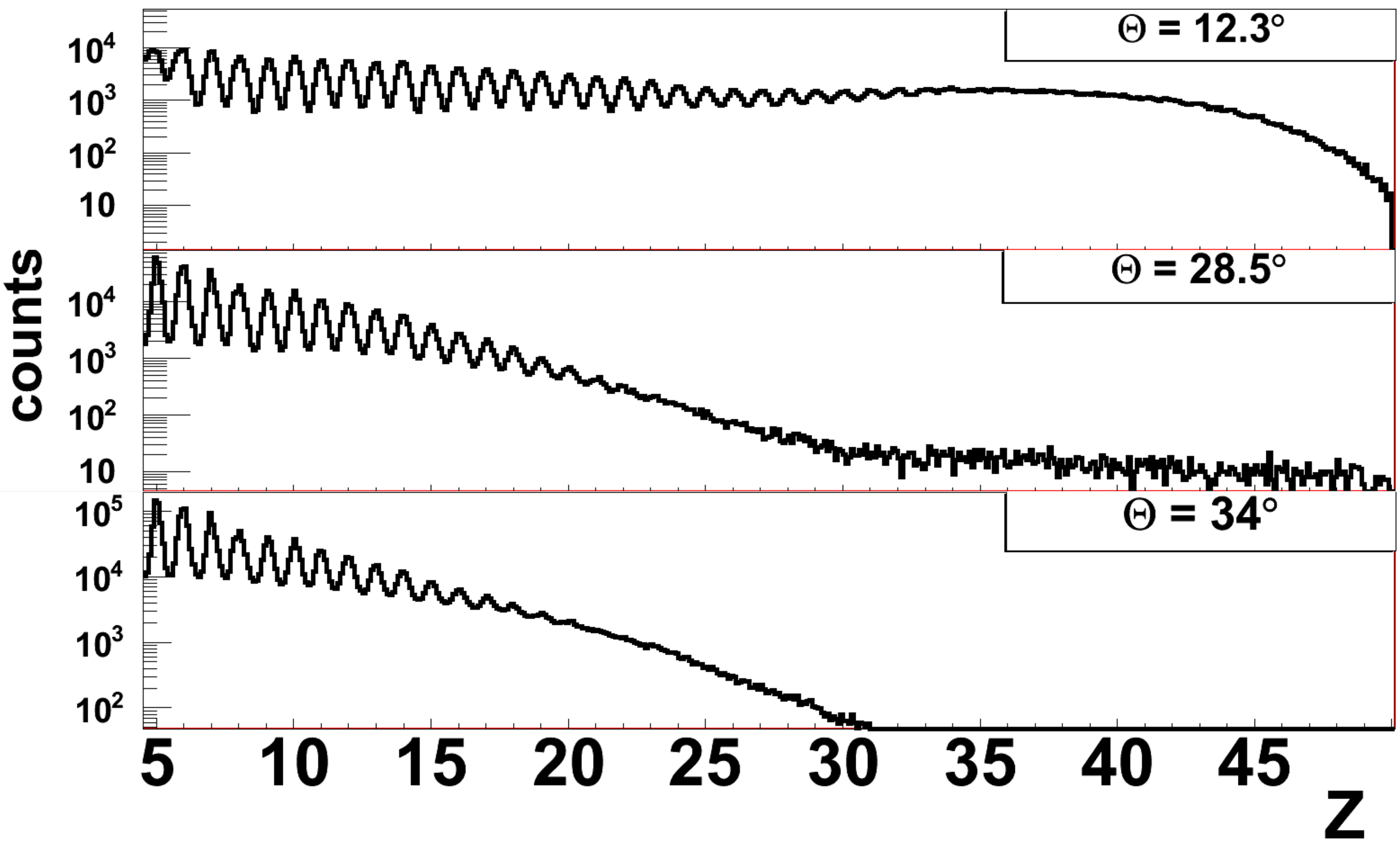


ΔE-E spectrum

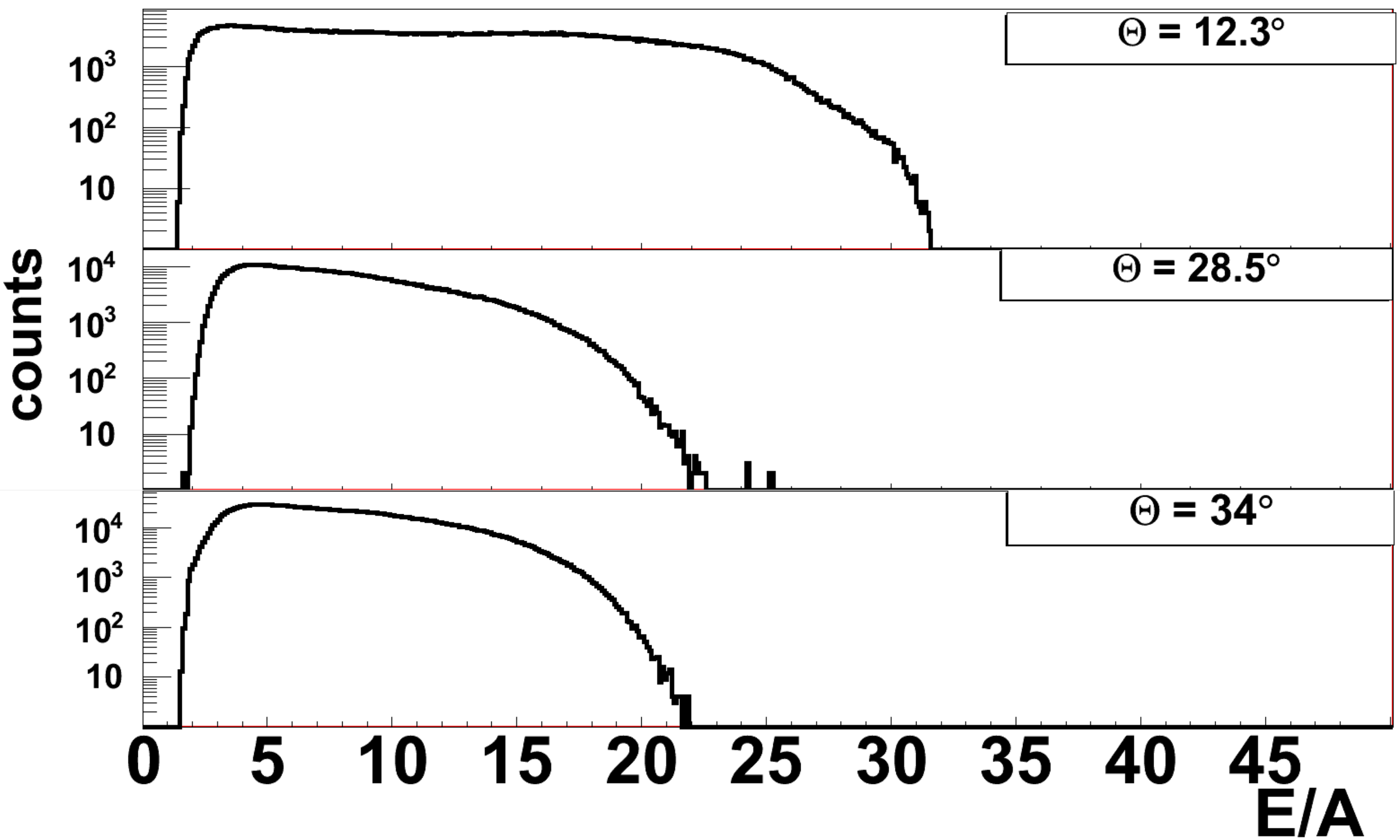


ΔE-Time spectrum

Charge distributions



Energy distributions for fragments with Z=5-50



TOF calibration

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]

$\alpha = 3 \cdot T / d$

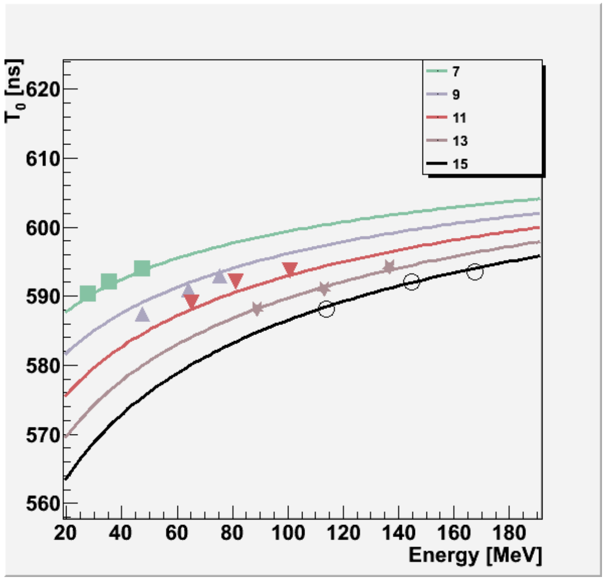
T- cyclotron period [ns]

d- distance between two beam bursts [channels]

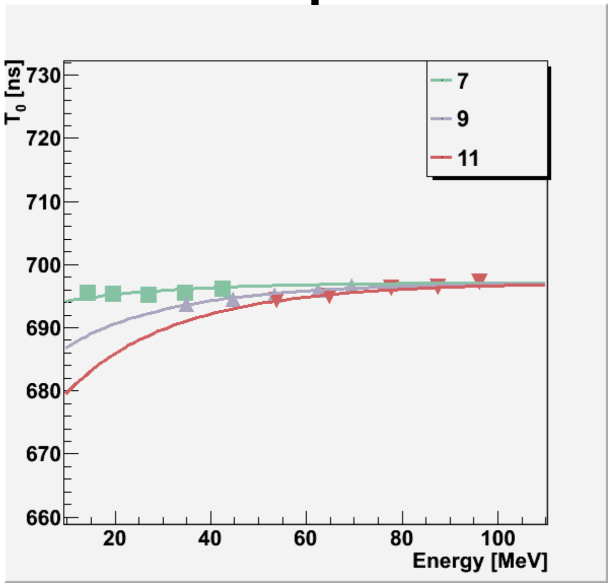
For calibration data the following function is fitted:

TOF calibration

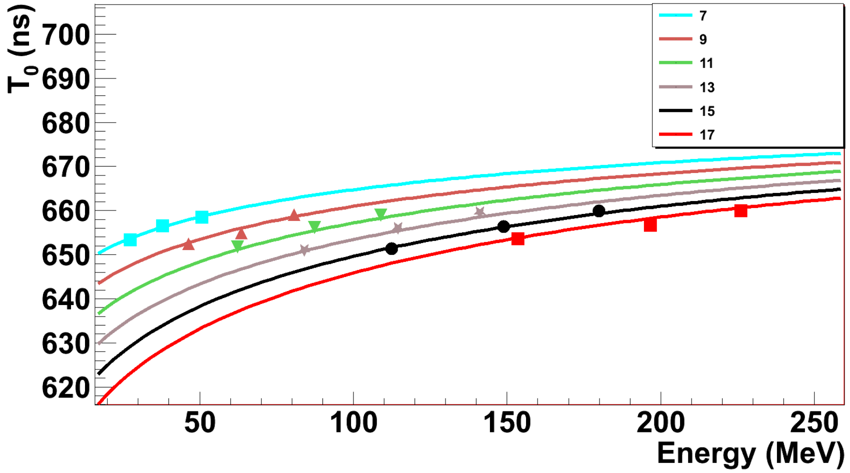
Telescope 430



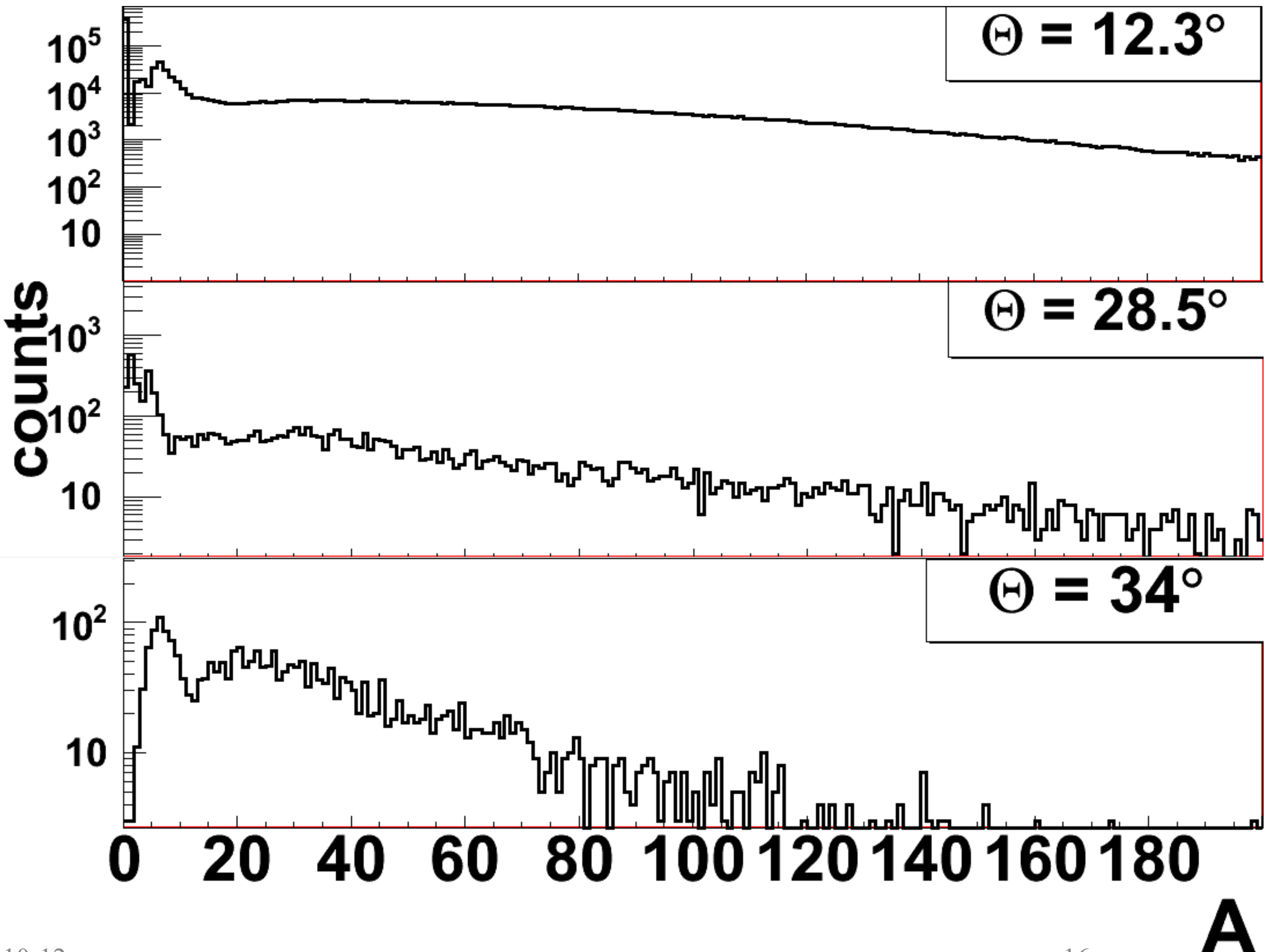
Telescope 858



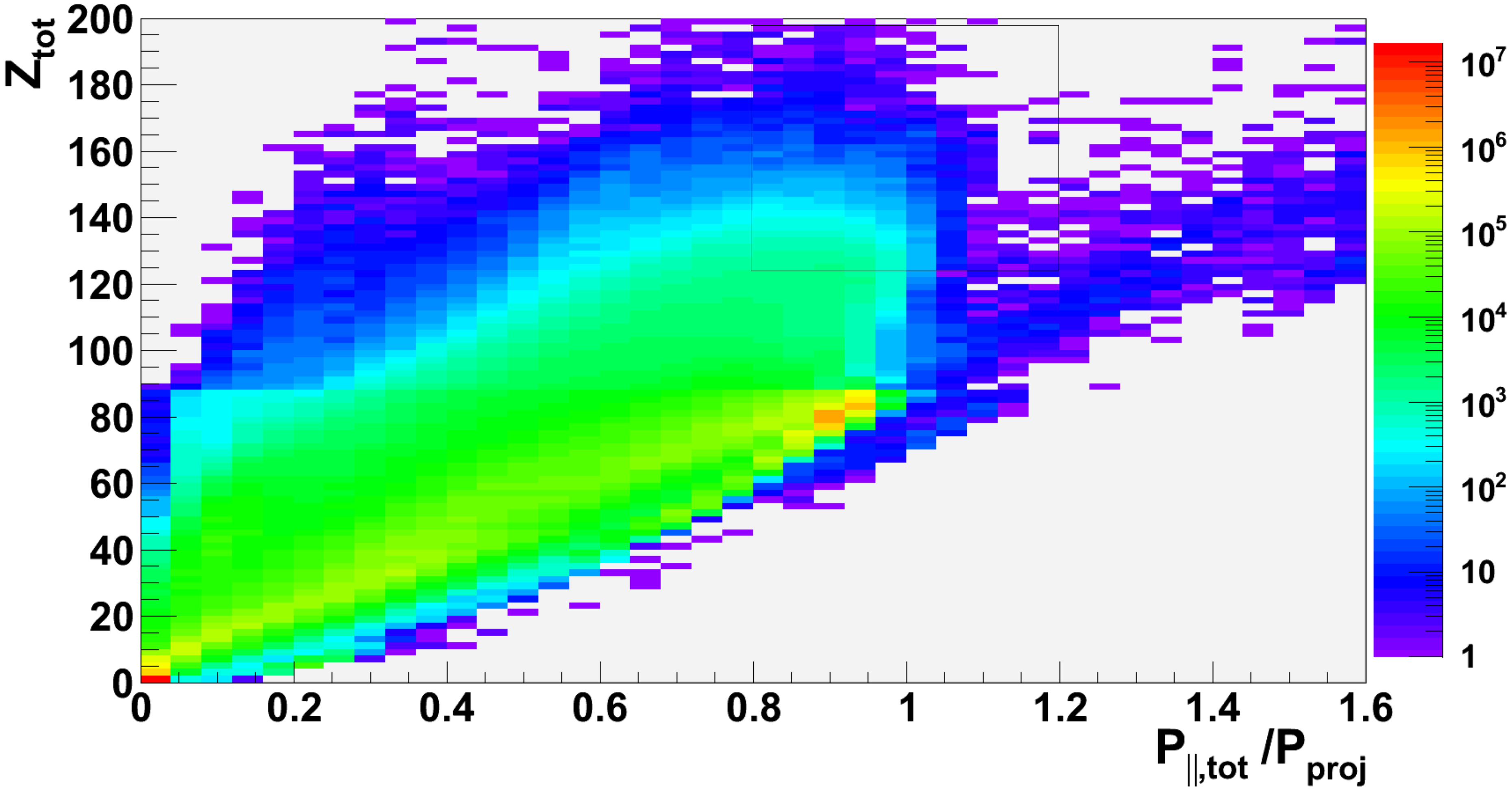
Telescope 632



Mass distributions

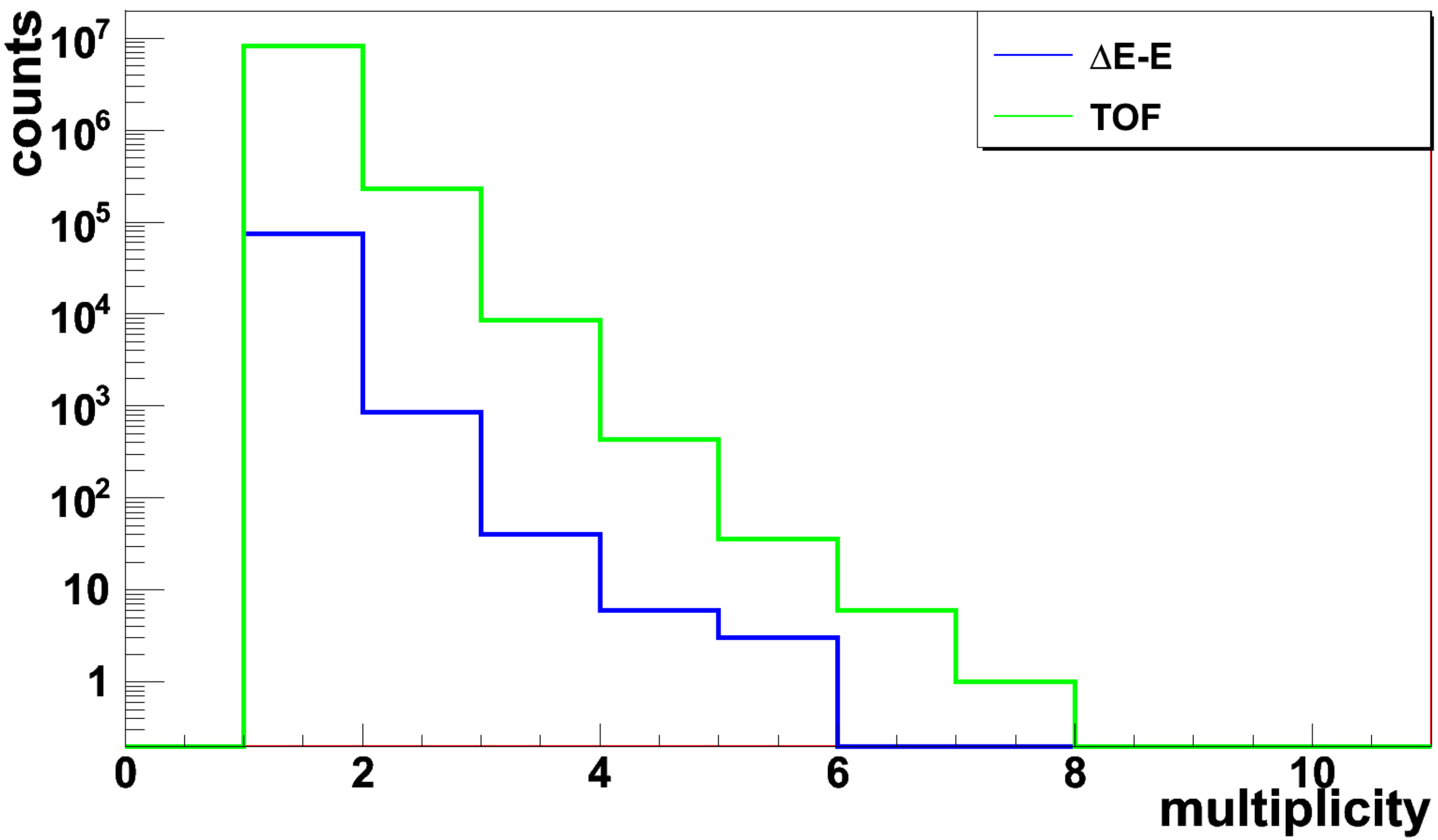


Total momentum vs. Z_{tot} distribution

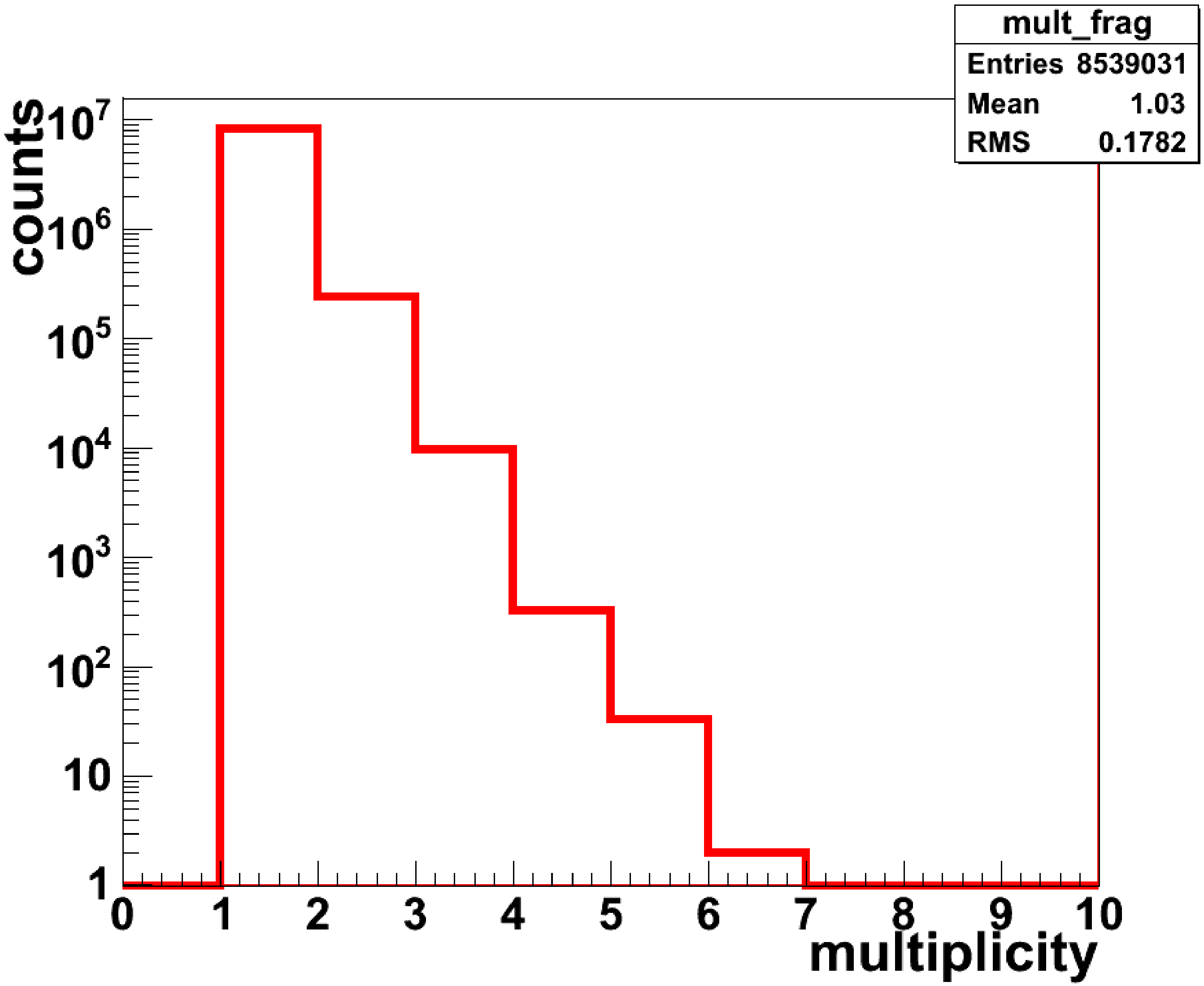


Multiplicity distributions

Multiplicity of identified particles:
$0.8 < P_{\|,tot}/P_{Proj} < 1.1$ & $Z_{tot} > 120$

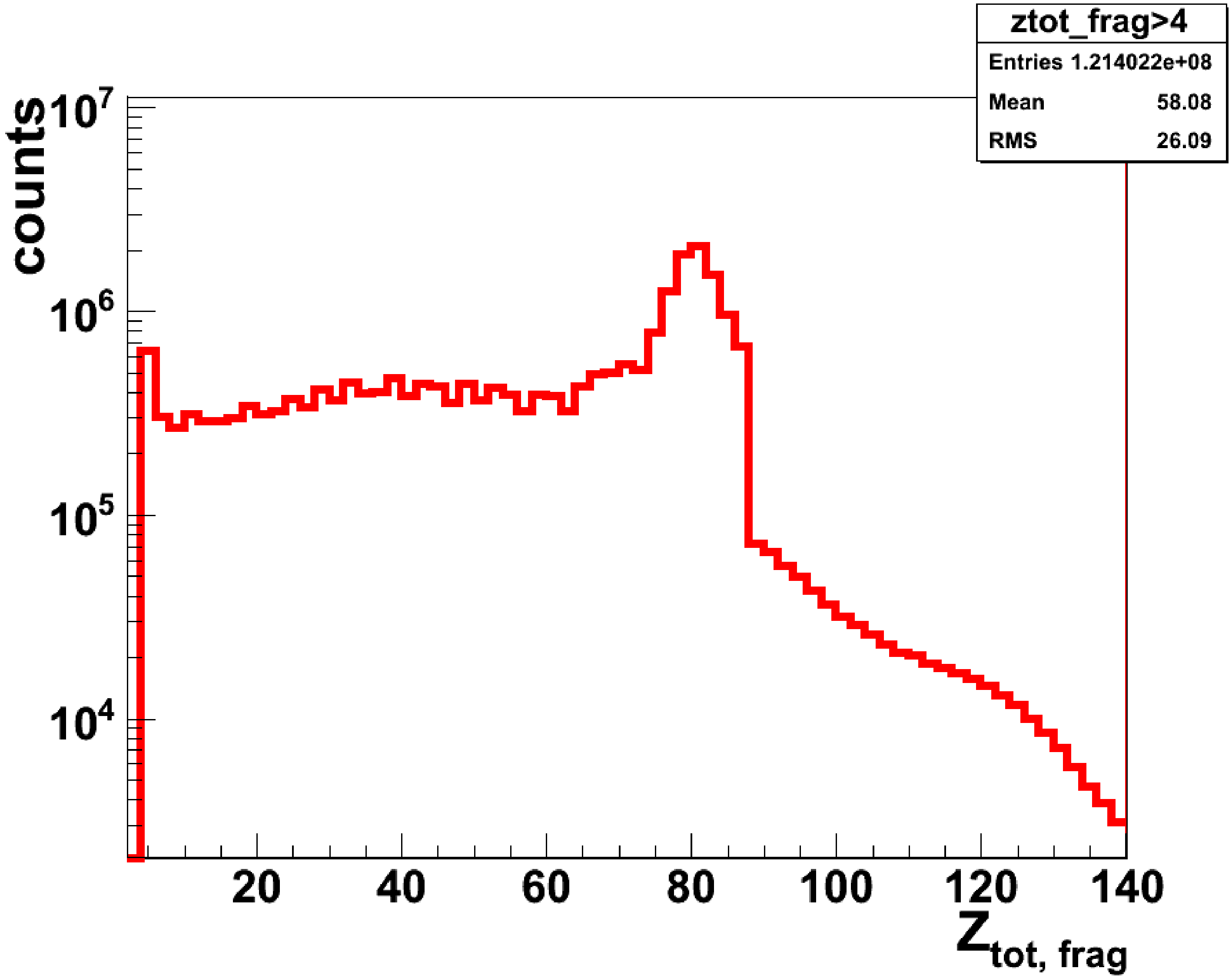


Multiplicity of fragments distributions



$Z_{f\ threshold} = 5$

$Z_{tot,\ fragments}$ distribution



$Z_{f\ threshold} = 5$

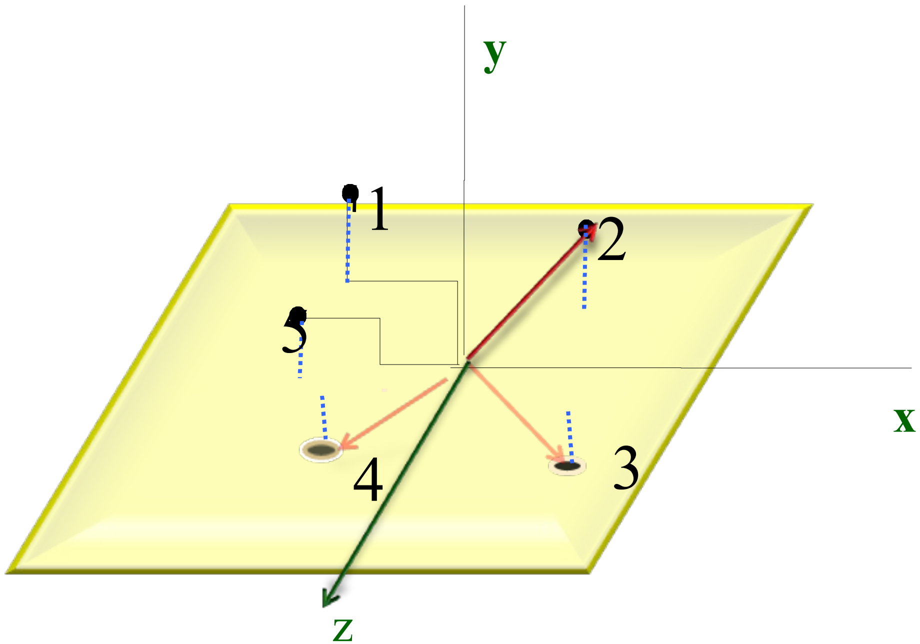
Observables definition

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

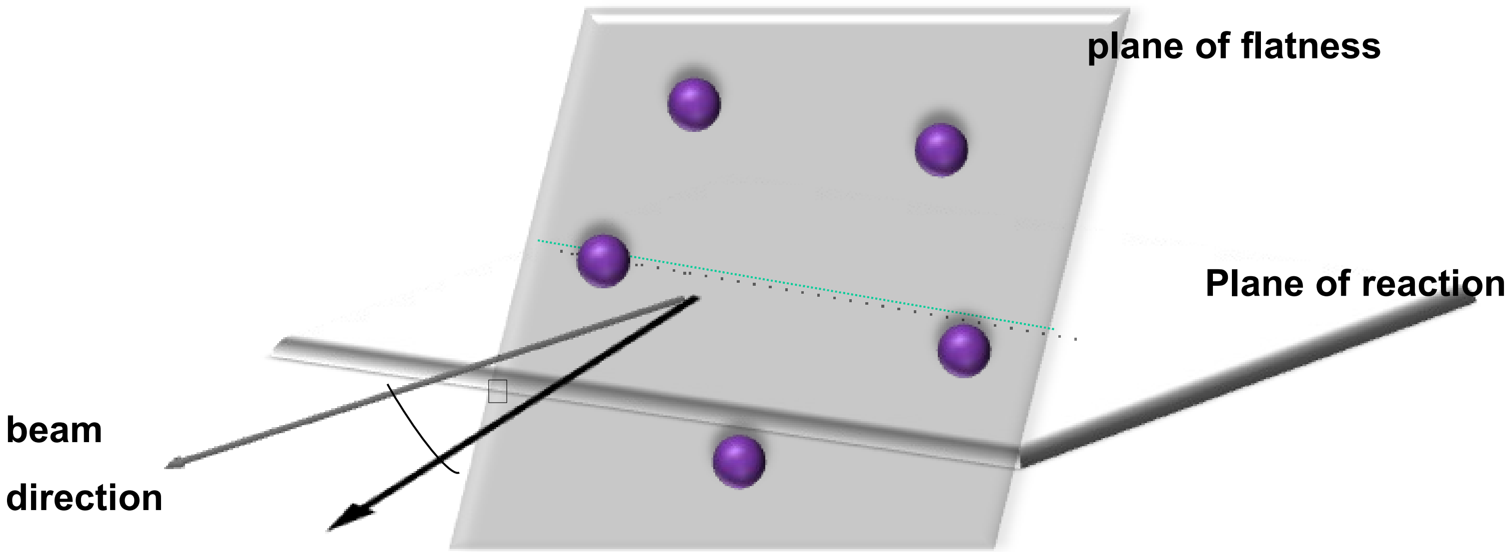
$$d_i = \frac{\left|Av_{x_i} + Bv_{y_i} + Cv_{z_i} + D\right|}{\sqrt{A^2 + B^2 + C^2}}$$

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

A, B, C, D – plane parameters



Observables definition

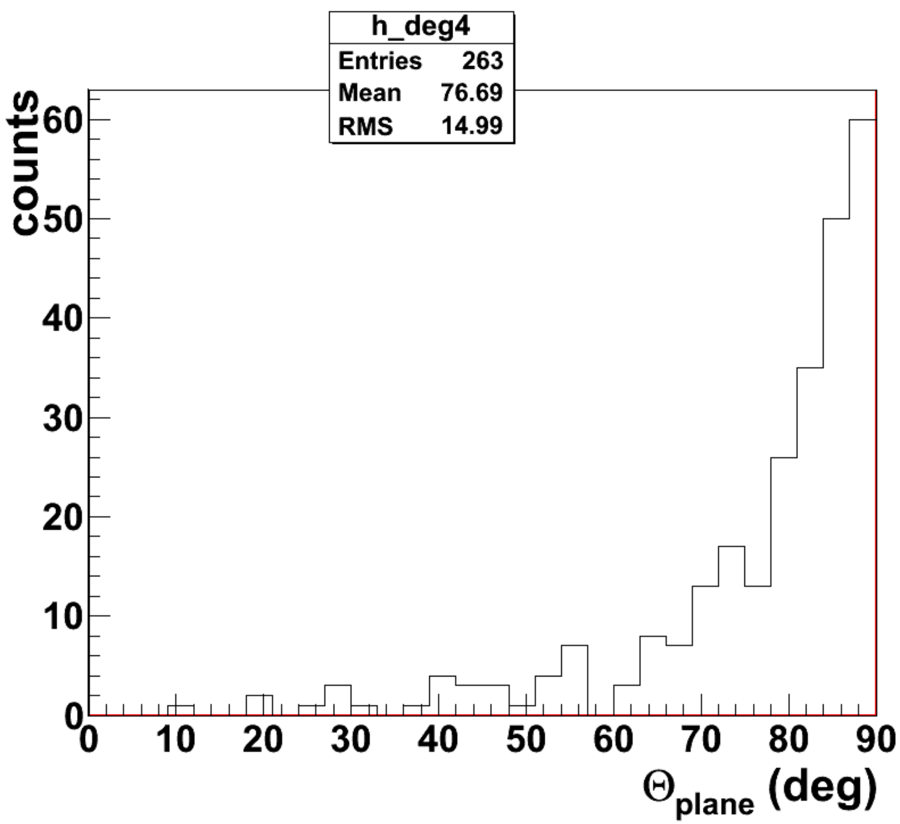


 < 90^0

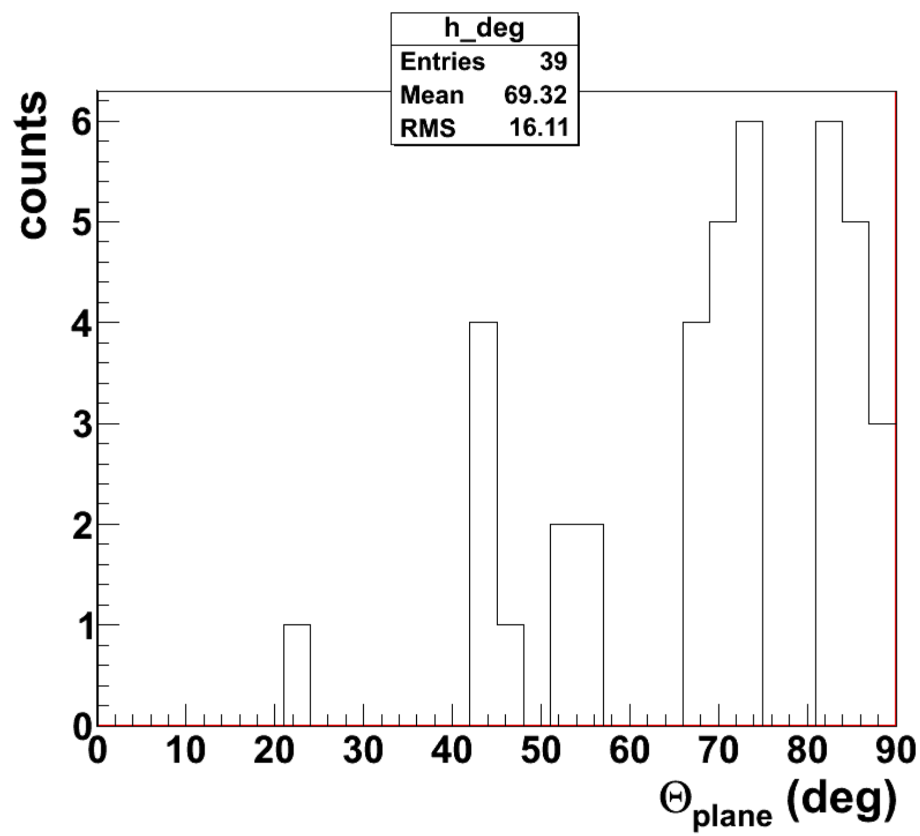
Θ_{Plane} distribution

$Z_{f,\ threshold} = 8$

Number of fragments : 4



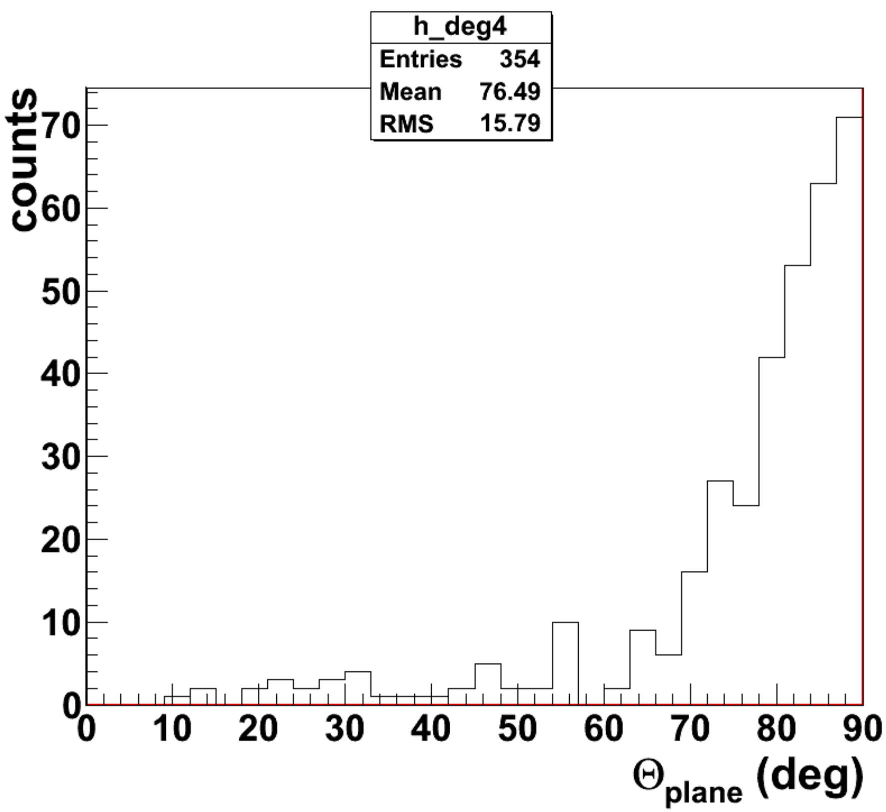
Number of fragments : >=5



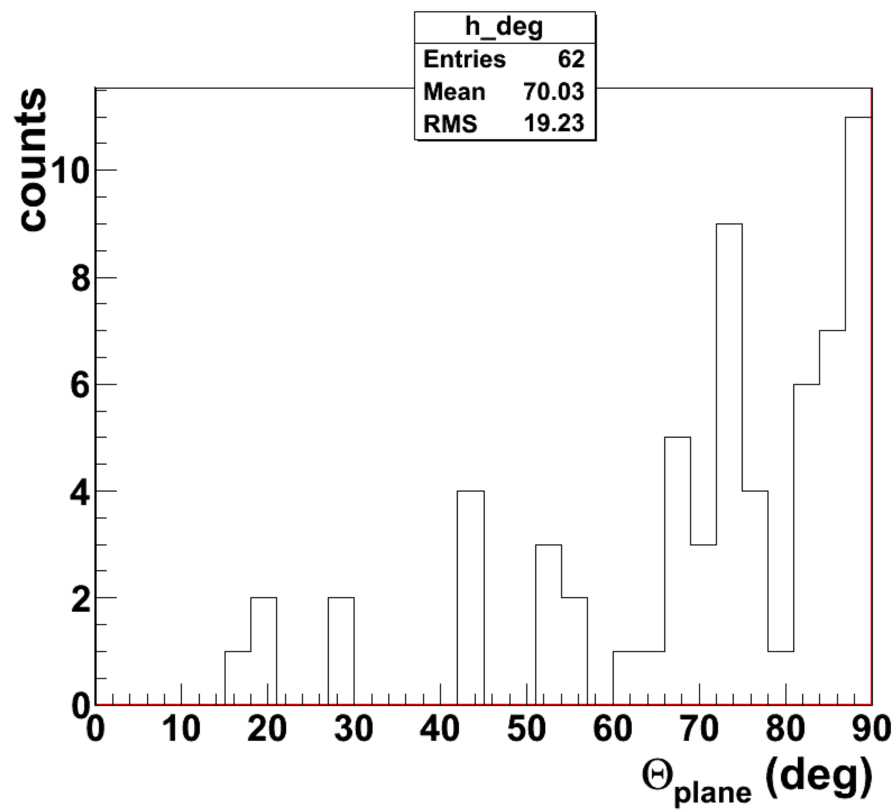
Θ_{Plane} distribution

$Z_{f,\ threshold} = 6$

Number of fragments : 4



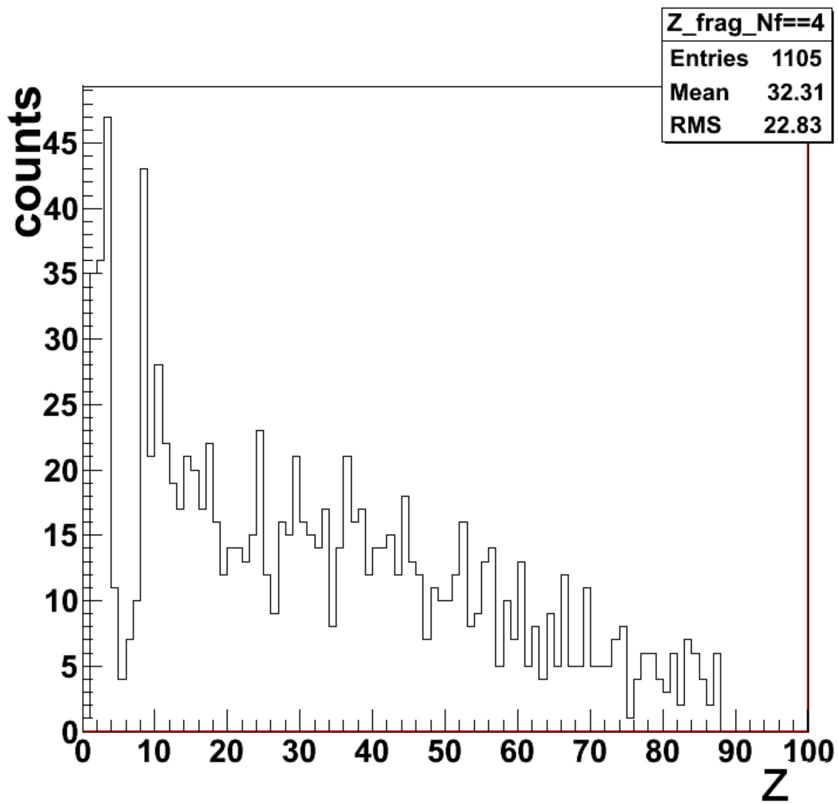
Number of fragments : >=5



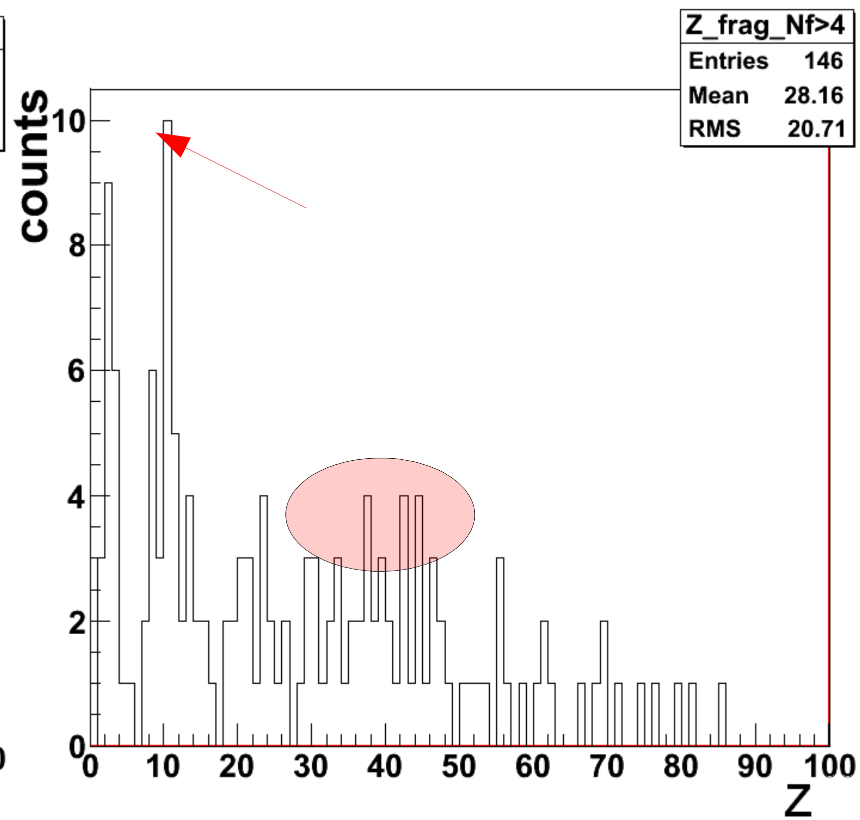
Charge distribution

$Z_{f,\ threshold} = 8$

Number of fragments : 4



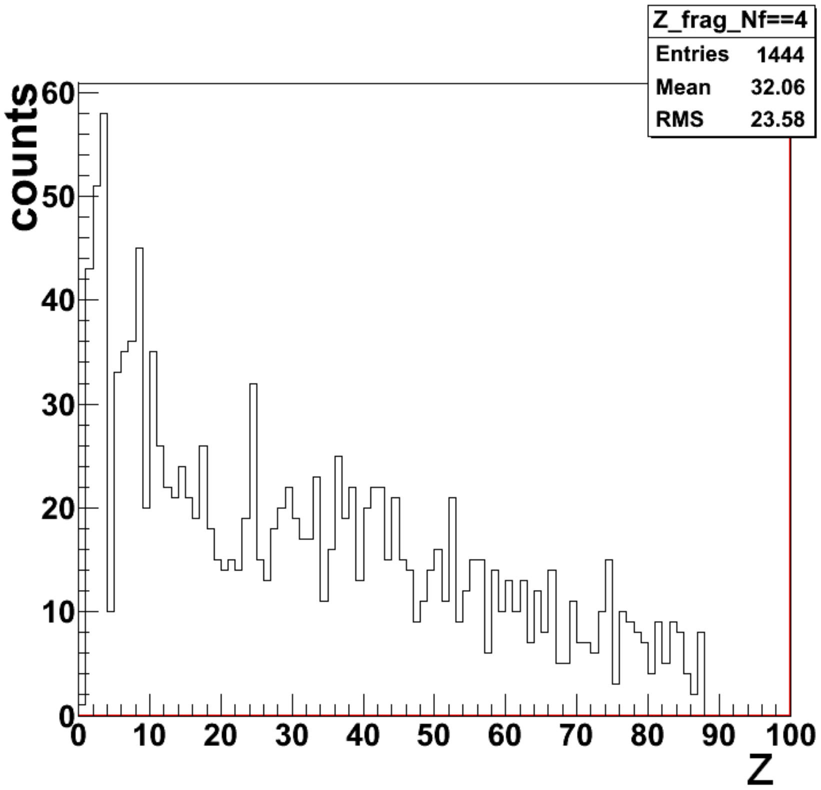
Number of fragments : >=5



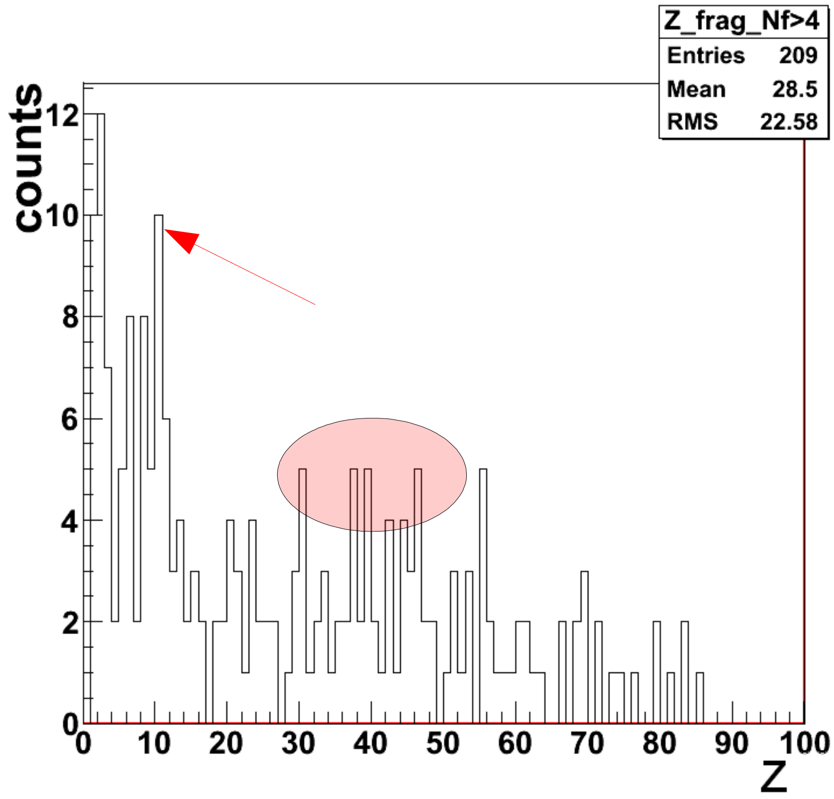
Charge distribution

$Z_{f,\ threshold} = 6$

Number of fragments : 4



Number of fragments : >=5



Summary

•Energy calibration of Si detectors have been completed. Energy loss in CsI detectors was taken into account.

•

•Charge identification of fragments is complete.

•

•Mass identification procedure for fragments stopped in Si detectors is complete.

•

•Selection of events corresponding to central collisions is in progress.

Breakup Collaboration

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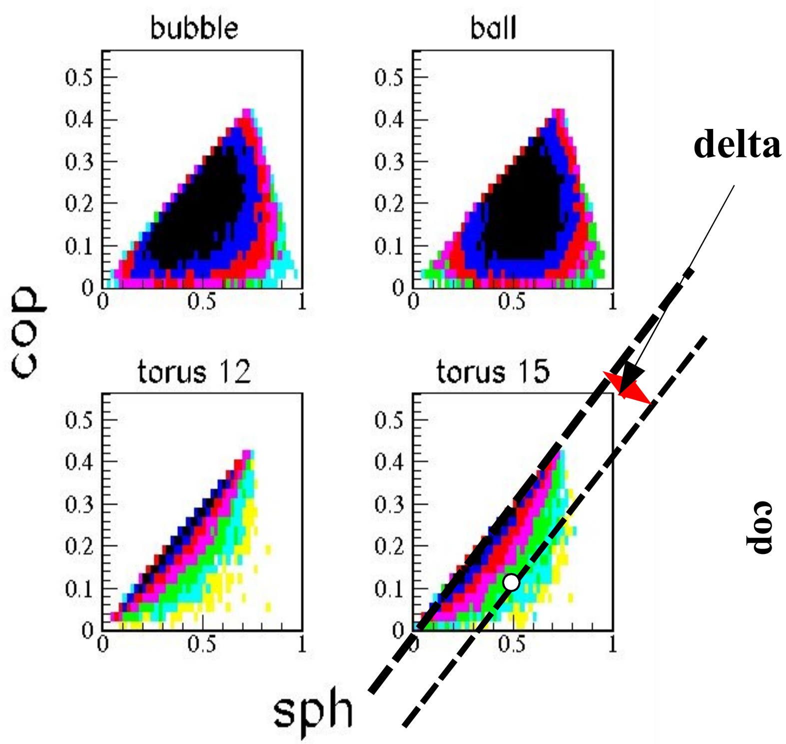
Thank you for your attention

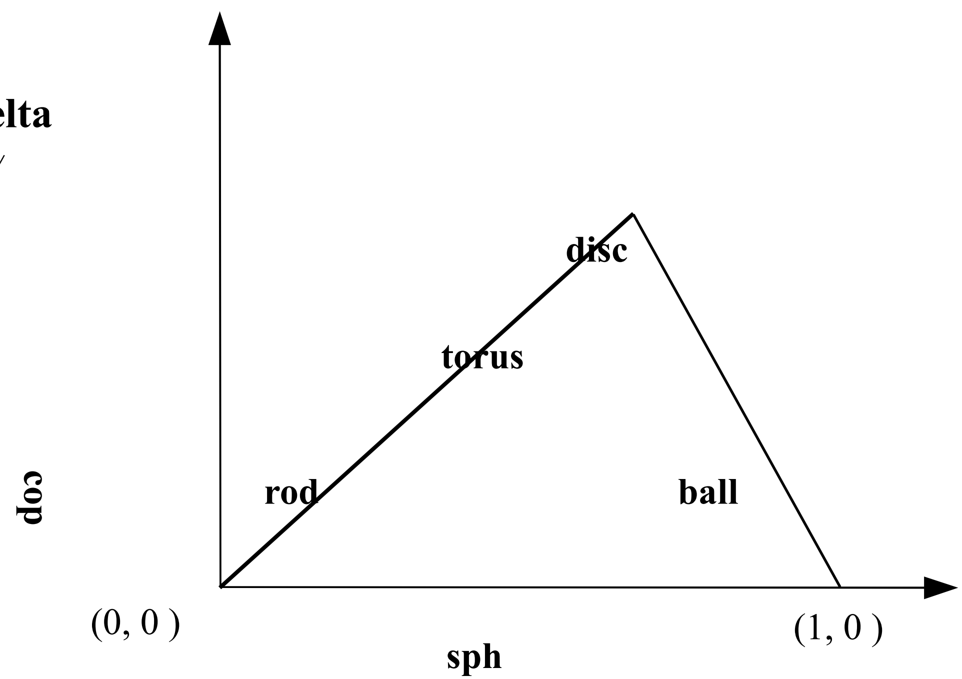
Identification method for toroidal freeze-out configuration

To distinguish between different geometries we plan to use global shape variables proposed in Sochocka PhD thesis:

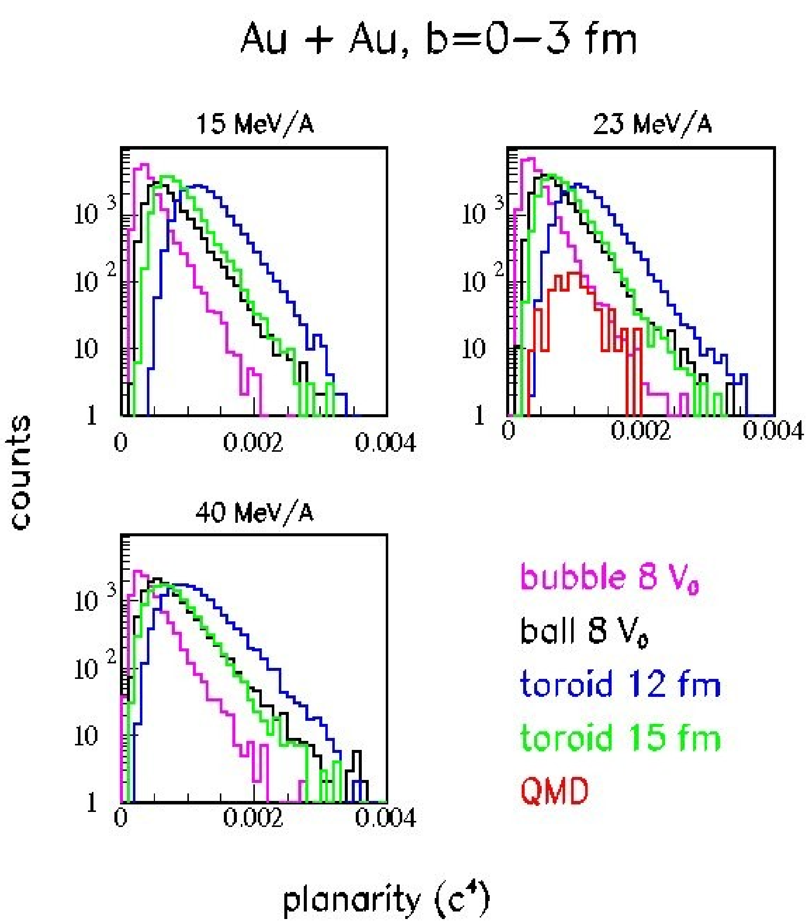
- δ - related to sphericity and coplanarity
- Δ – flatness parameter
- **ETNA model predictions**

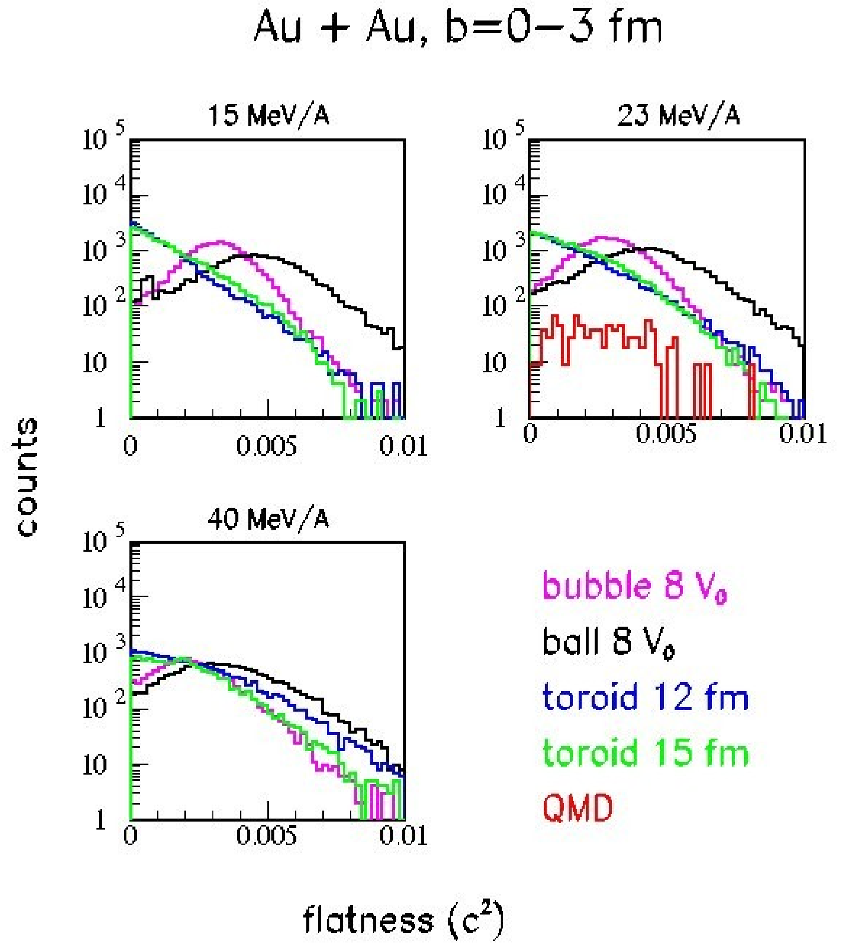
Observables definition





Observables definition





ETNA – Expecting Toroidal Nuclear Agglomeration + GEMINI Code

Flow diagram

$A_{CN} = A_T + A_P$

$Z_{CN} = Z_T + Z_P$

minus preequilibrium nucleons

Drawing of fragments:

•Gaussian distribution

$< Z_{frag} > = Z_{tot} / N$

N – number of fragments

N = 5

All the fragments are placed in ball, bubble and toroidal configuration with additional condition: $R_{ij} > R_i + R_j + 2fm$

Non - central collisions are taken into account up to given impact parameter b

Partition of the available energy:

$E_{ava} = E_{CM} + Q - E_{COULOMB}$

Available energy is distributed between:

$E_{ava} = E^* + E_{th} = NaT^2 + 3/2k(N-1)T$; assuming equal temperatures, N – number of fragments

The dynamical GEMINI code:

- sequential decay of excited fragments
- acceleration in the mutual Coulomb field

Detection of particles in the CHIMERA detector

□, □ □ detector number □ □$_{rand}$,□$_{rand}$

$E_{thr} = 1$ MeV/A

□Z_{FWHM} = 1 ch.u.

A=2.2* Z (GEMINI prediction)