Multifragmentation experiments to simulate neutrino sphere

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IFJ PAN, Kraków, Poland

- SN1987A
- Fragments from Au+Au, INDRA@GSI
- Fragmentation of exotic beams, ALADIN@GSI
- Simulations for setups@RIKEN
- GEANT4
- Primary generator: UrQMD + Clustering, ^{132}Sn+^{124}Sn @ 300 AMeV
- 0.5 T magnetic field

RIKEN, June 5-6, 2015

NATIONAL SCIENCE CENTRE
POLAND

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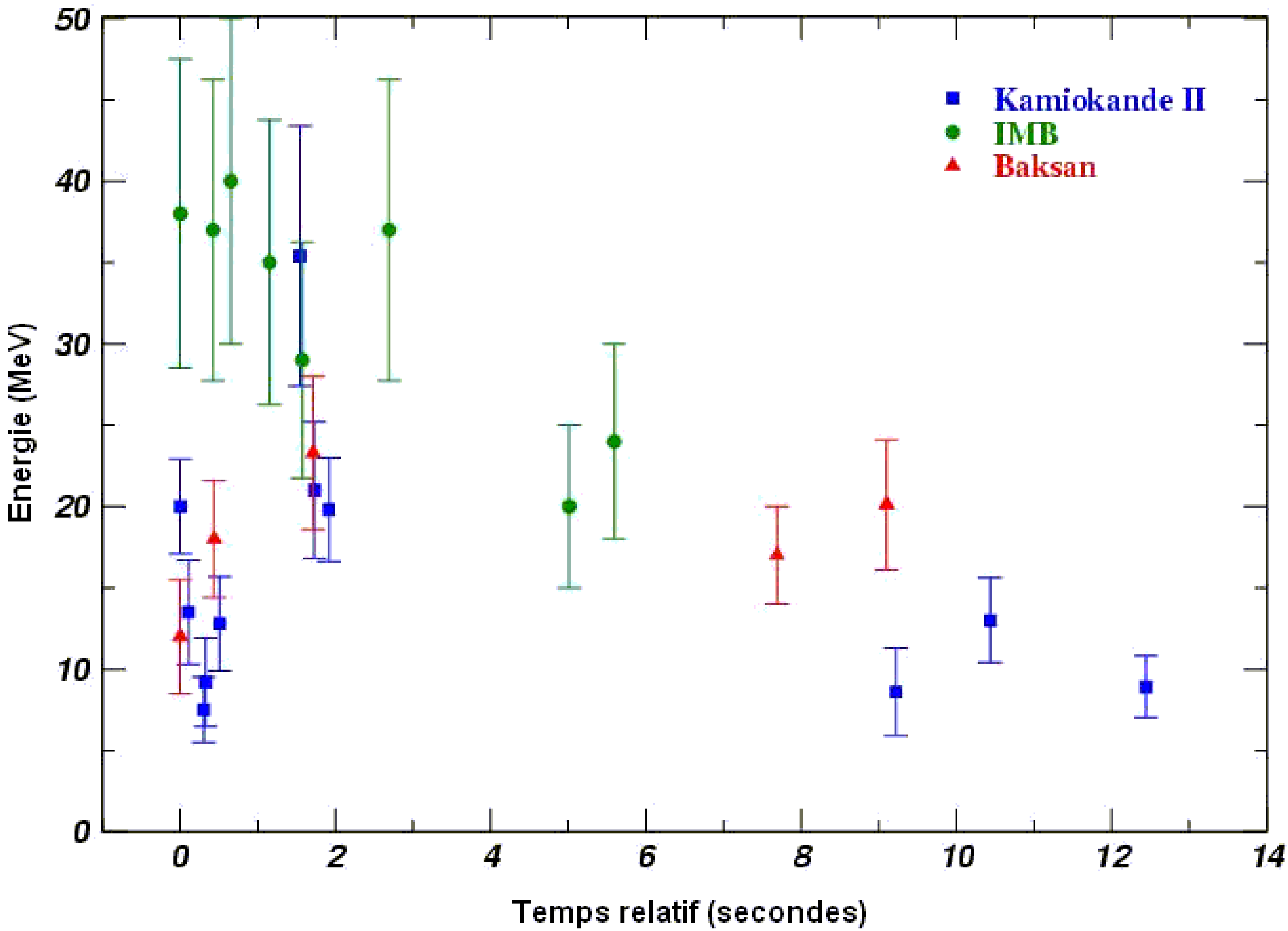
Neutrino detection from SN1987A

spectrum ?
flux ?

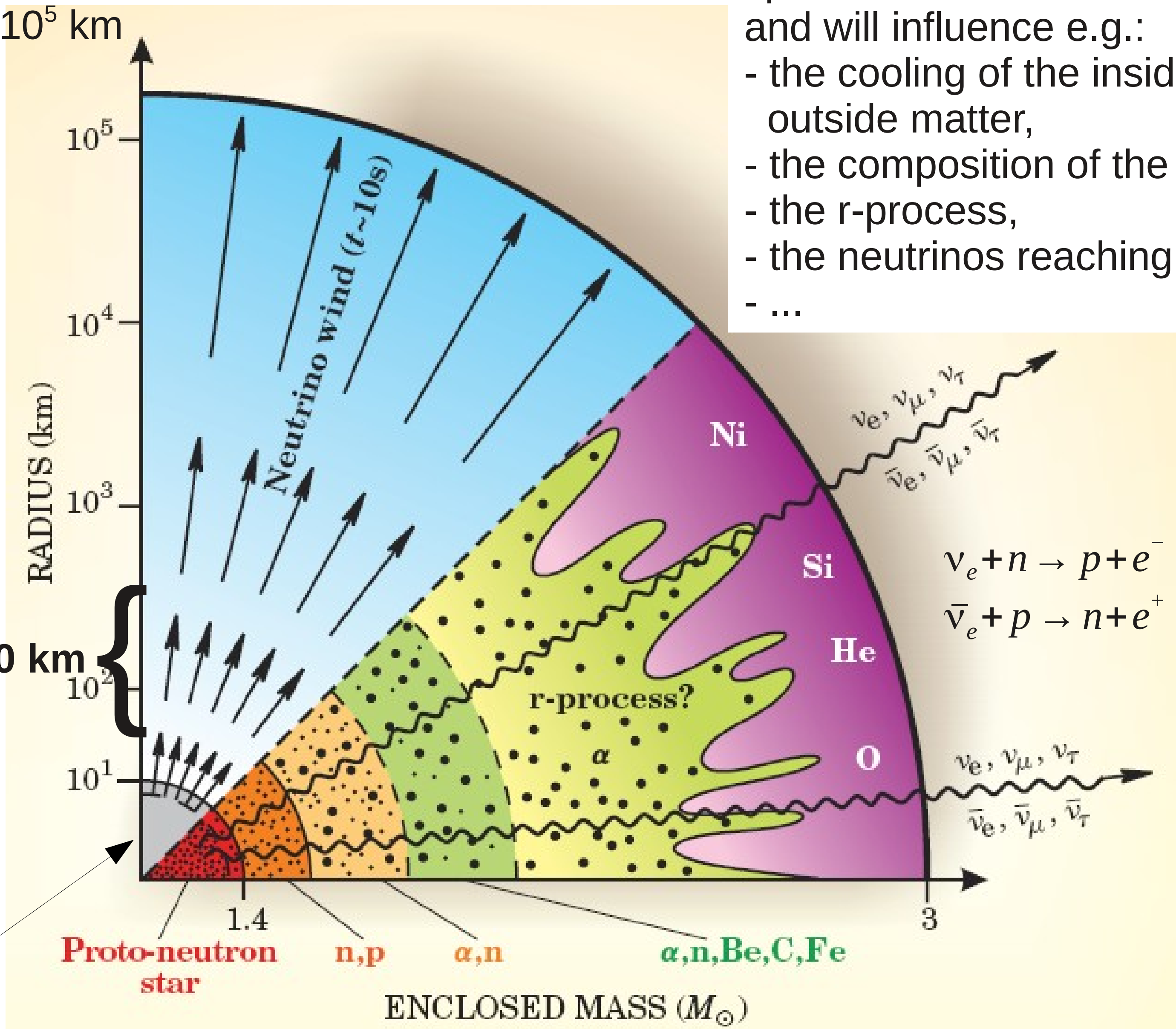


http://cerncourier.com/cws/article/cern/29812

What are the properties of matter where the neutrinos are freed?

The structure and properties of the neutrino sphere matter will be influenced by neutrinos and will influence e.g.:
- the cooling of the inside and heating of the outside matter,
- the composition of the neutrino driven winds,
- the r-process,
- the neutrinos reaching the Earth
- ...

$R_\odot \approx 7\times10^5$ km



$R_\nu \approx$ **30-150 km**

~ $1 \div 3\rho_0$

$$\nu_e + n \rightarrow p + e^-$$
$$\bar{\nu}_e + p \rightarrow n + e^+$$

neutrino sphere:

$\rho \sim 10^{-3}$-$10^{-1}\rho_0$
T ~ 4-5 MeV
$Y_e \sim 0.2$ (N/Z~4)

http://sparkie.net.au/2013/06/23/nucleosynthesis-of-gold/

Different scenarios of fragment formation in HIC

is clustering indeed a low density phenomenon?

Statistical

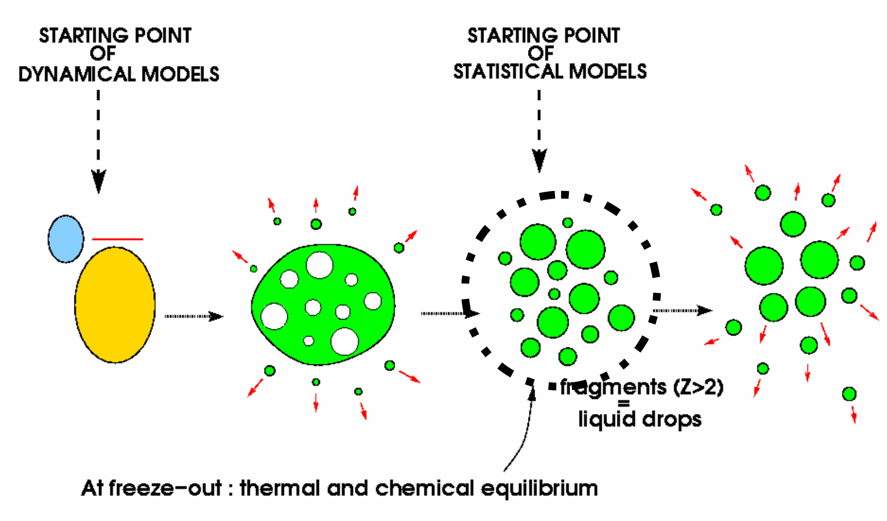
(SMM: J.P. Bonforf, A.S. Botvina et al.)

Fragments „freezing out" during the system expansion at **$\rho \approx 1/8\text{-}1/3\ \rho_o$**.

Thermal and chemical **equilibrium** is assumed.

Primary fragments: **hot, spherical** non-overlapping, **non-interacting** (except Coulomb)

Problem: too small kinetic energies (extra expansion energy put "by hand")



„Little Big Bang"

(CMD: X. Campi, H. Krivine, E. Plagnol et al.)

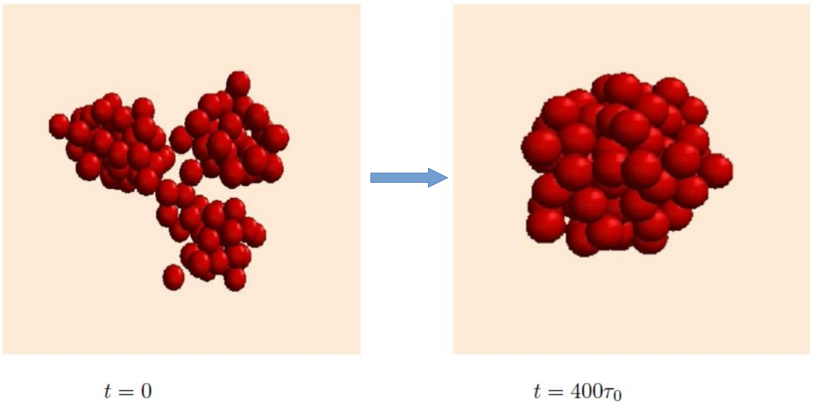
Excited, compressed system attains a partial equilibrium.

The self-bound pre-fragments are formed in a hot and **dense** phase.

Pre-fragments are **cooler** than the system.

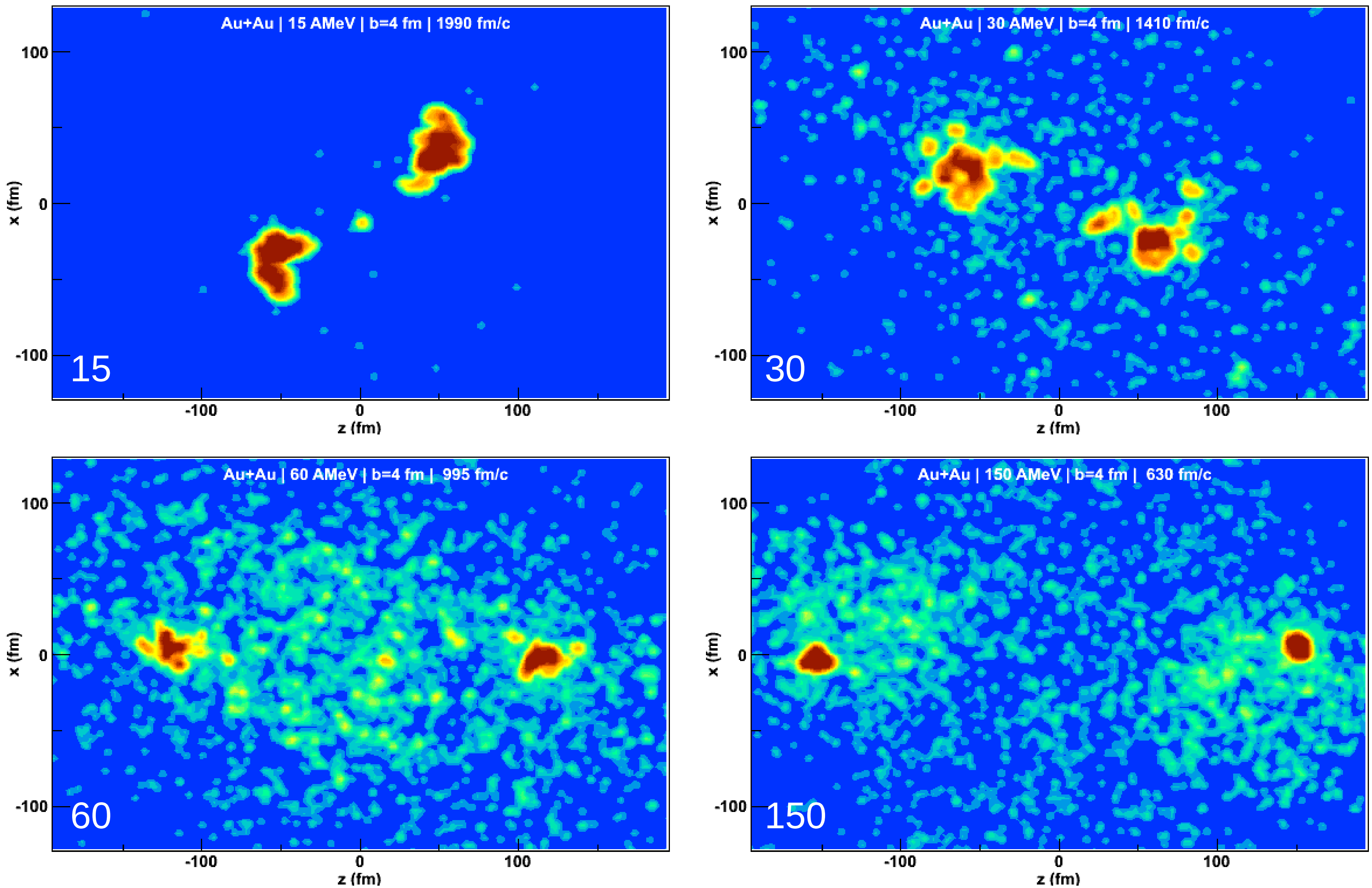
The system of **interacting** clusters of **arbitrary shapes** expands.

The asymptotic distribution of spherical fragments reveals the primordial distribution.



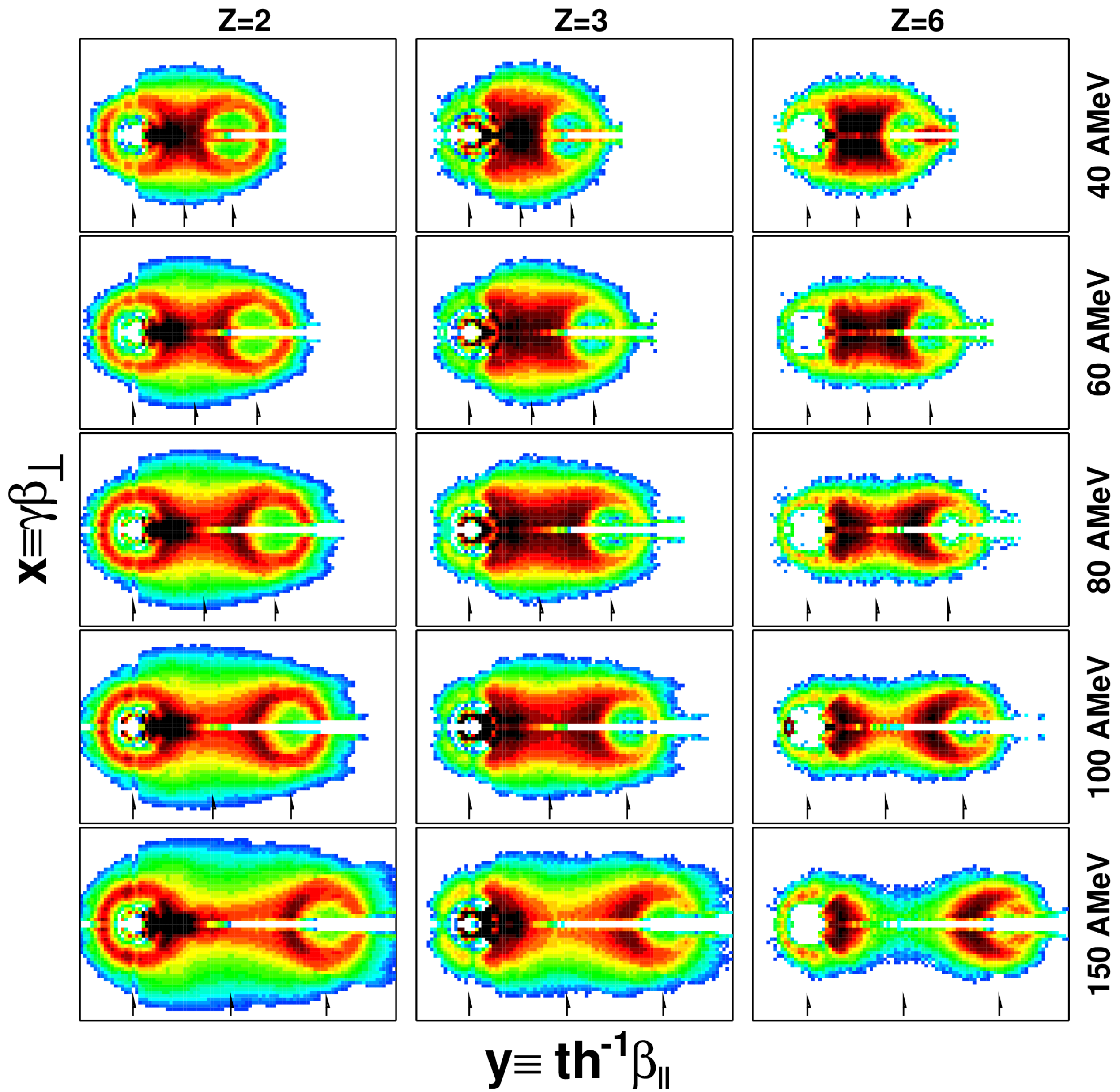
$\rho > \rho_o$ $\rho \approx \rho_o$

superposition of 20 events
Au+Au @ 15, 30, 60, 150 AMeV, b=4 fm



J. Łukasik, CHIMERA

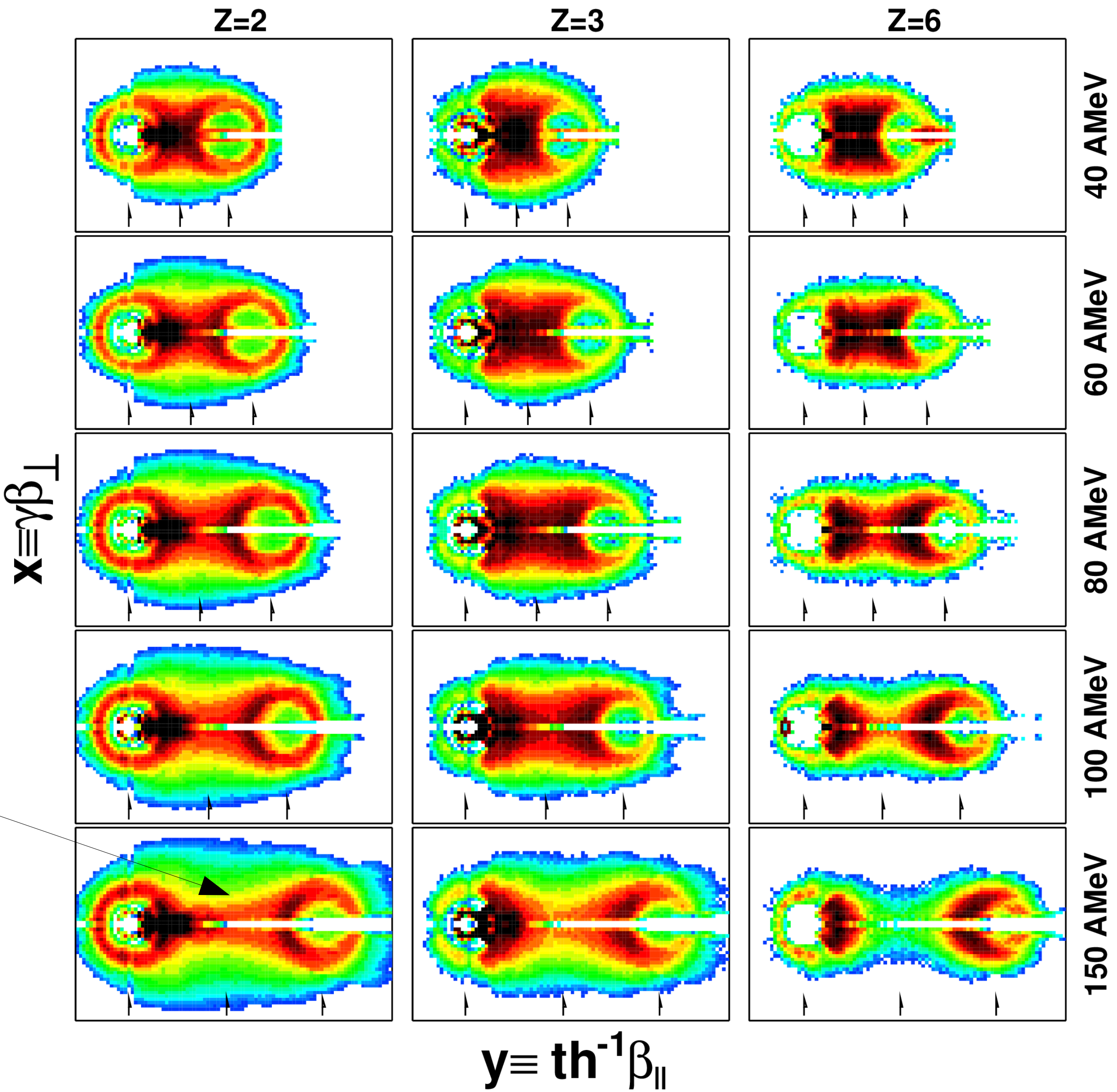
Peripheral Au+Au @ 40-150 MeV/nucleon (INDRA@GSI)
Invariant cross sections:



J. Łukasik et al., PLB 566 (03) 76

Peripheral Au+Au @ 40-150 MeV/nucleon (INDRA@GSI)
Invariant cross sections:

Low density,
Neutron rich environment



J. Łukasik et al., PLB 566 (03) 76

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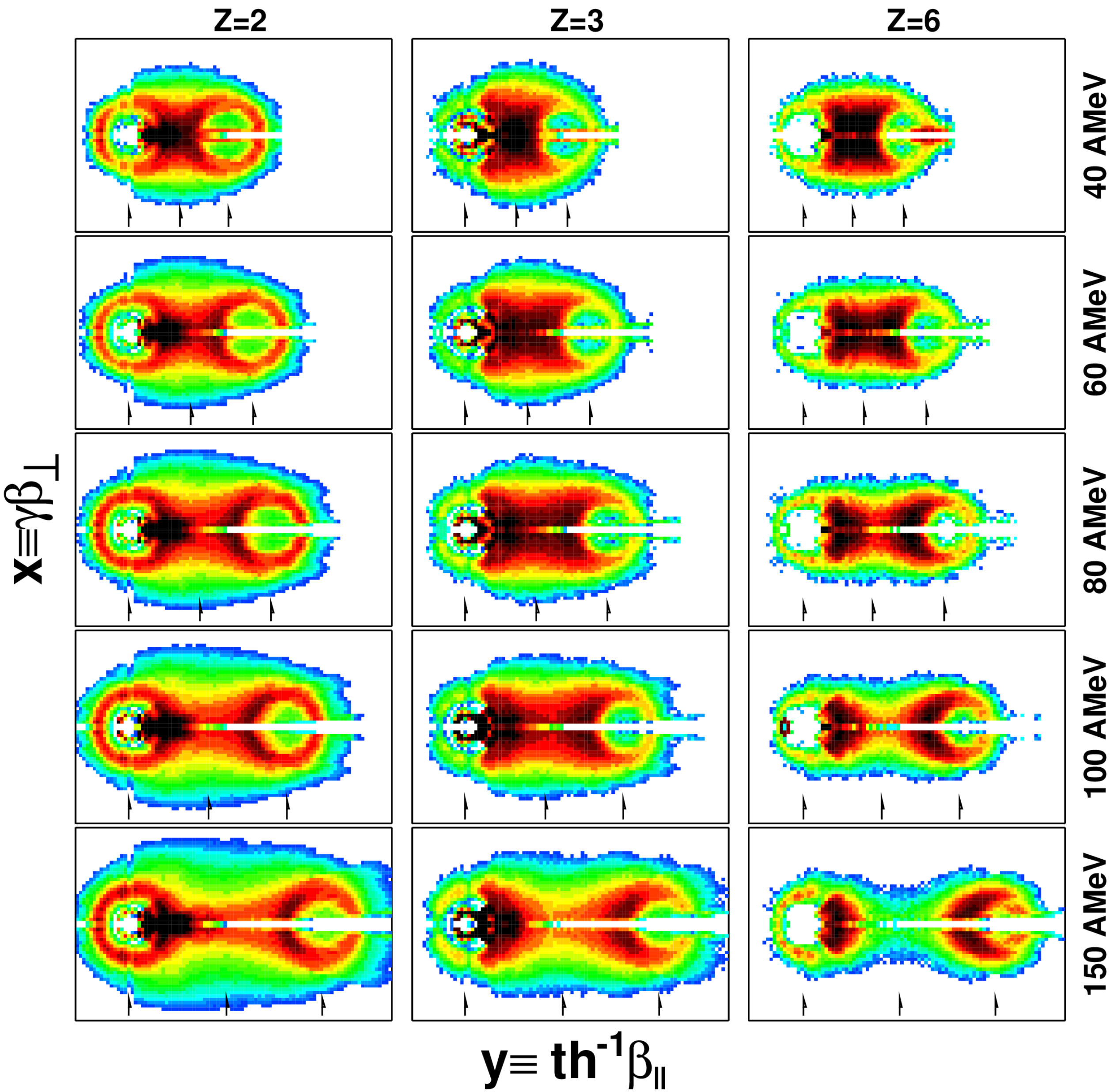
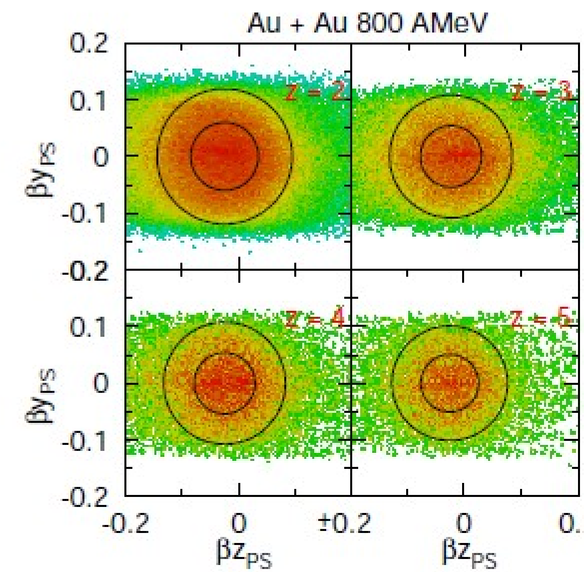
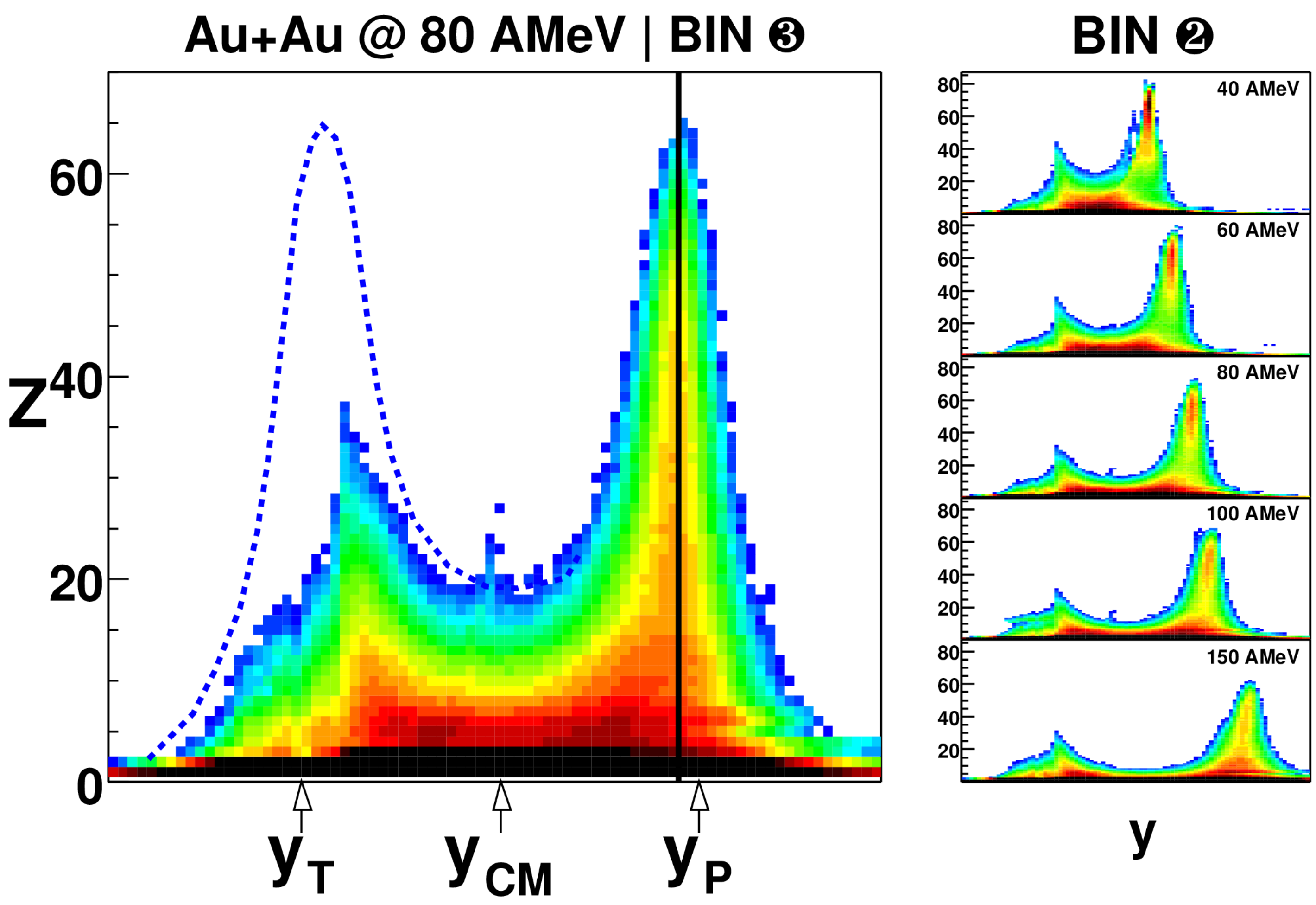


equilibrated source?



A. Schuettauf PHD thesis (1996)

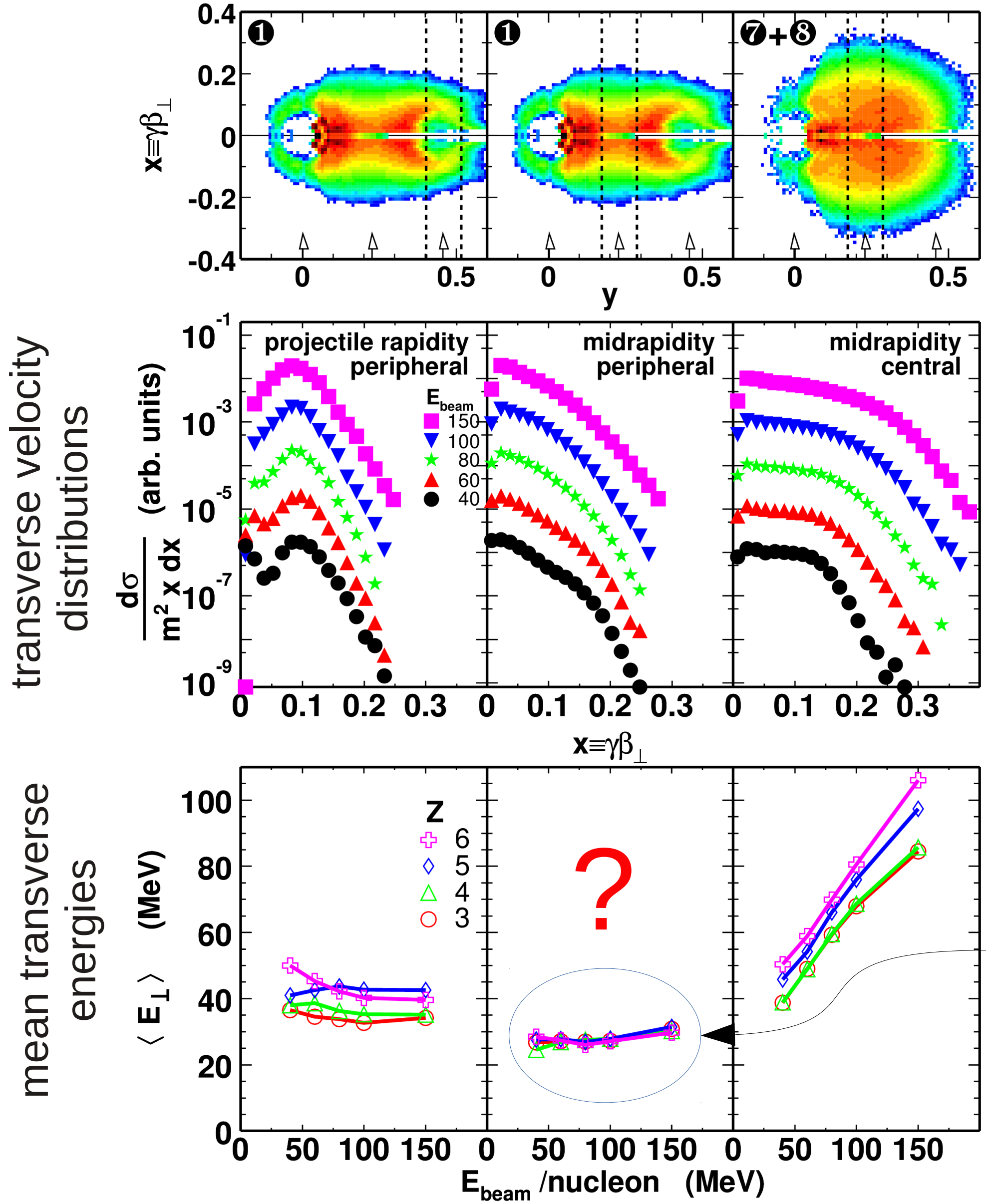
Rapidity of fragments with atomic number Z
(peripheral collisions)



J. Łukasik et al., PRC 66 (02) 064606

Au+Au

transverse velocity distributions and mean transverse energies



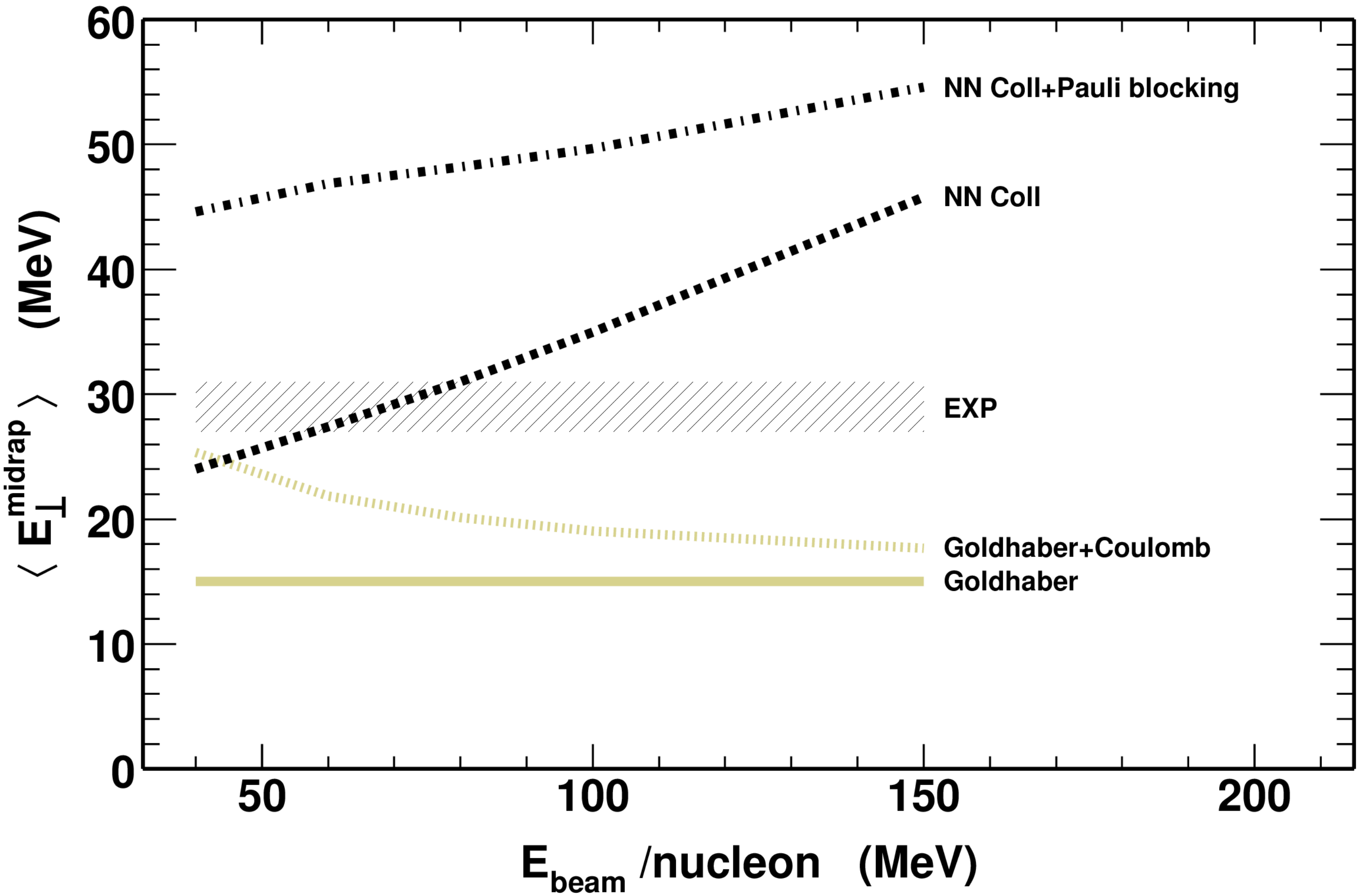
No dependence of mean transverse energies of fragments of $3 \leq Z \leq 6$ on the bean energy and their mass.
Surprisingly large value (~30 MeV)

Can it be “statistical” emission from the source of T=30 MeV ?

J. Łukasik et al., PRC 66 (02) 064606

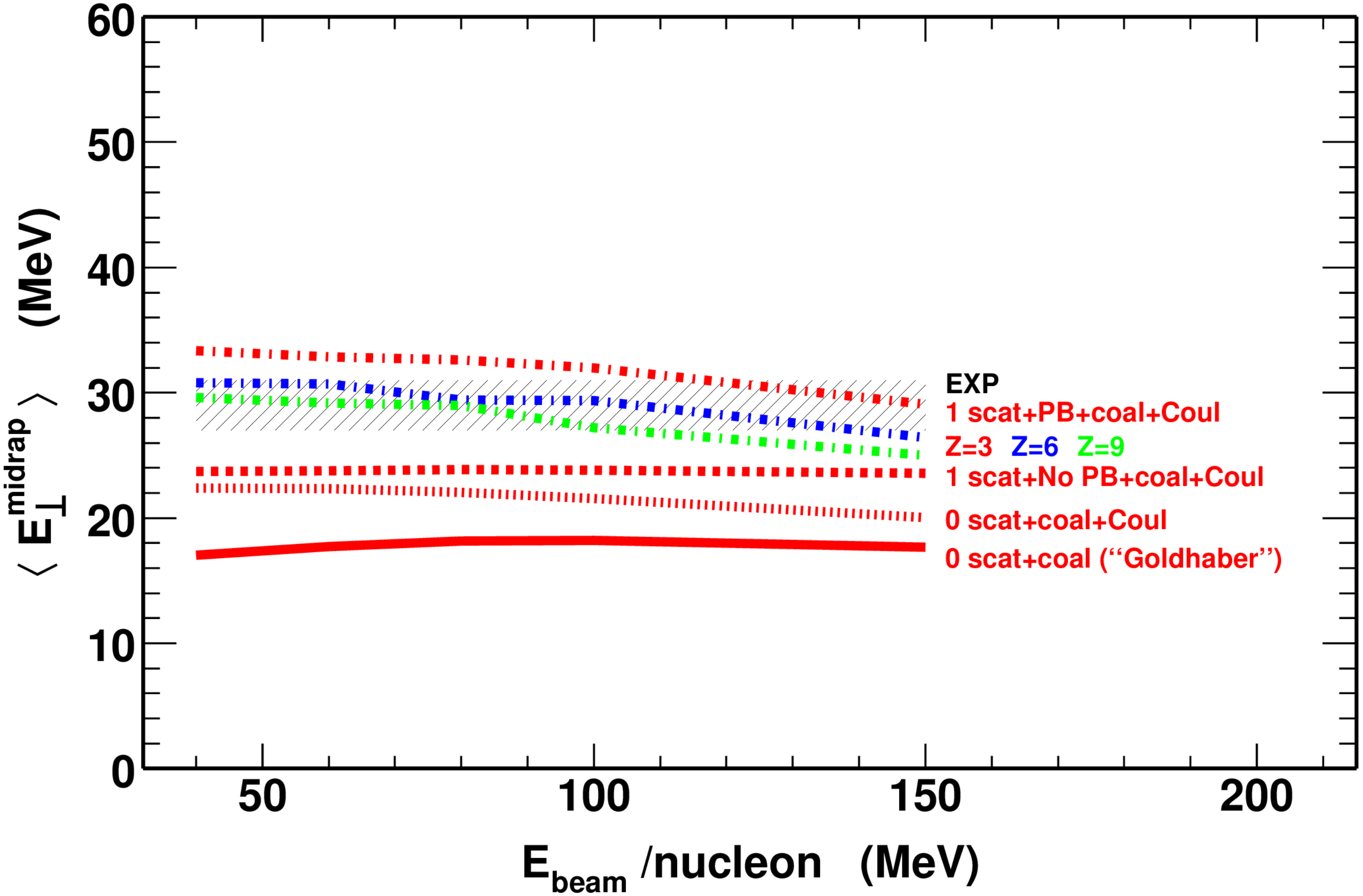
Au+Au

mean transverse energies of “mid-rapidity” fragments in peripheral collisions



J. Łukasik et al., PRC 66 (02) 064606

Mean transverse energies of "mid-rapidity" fragments in peripheral collisions:
experiment + Monte-Carlo



J. Łukasik et al., PRC 66 (02) 064606

Important role of the N-N collisions in fragment formation – possibly they trigger the fragment emission. On average one scattered nucleon in the fragment is enough to explain the high and constant value of the mean transverse energies of the fragments.

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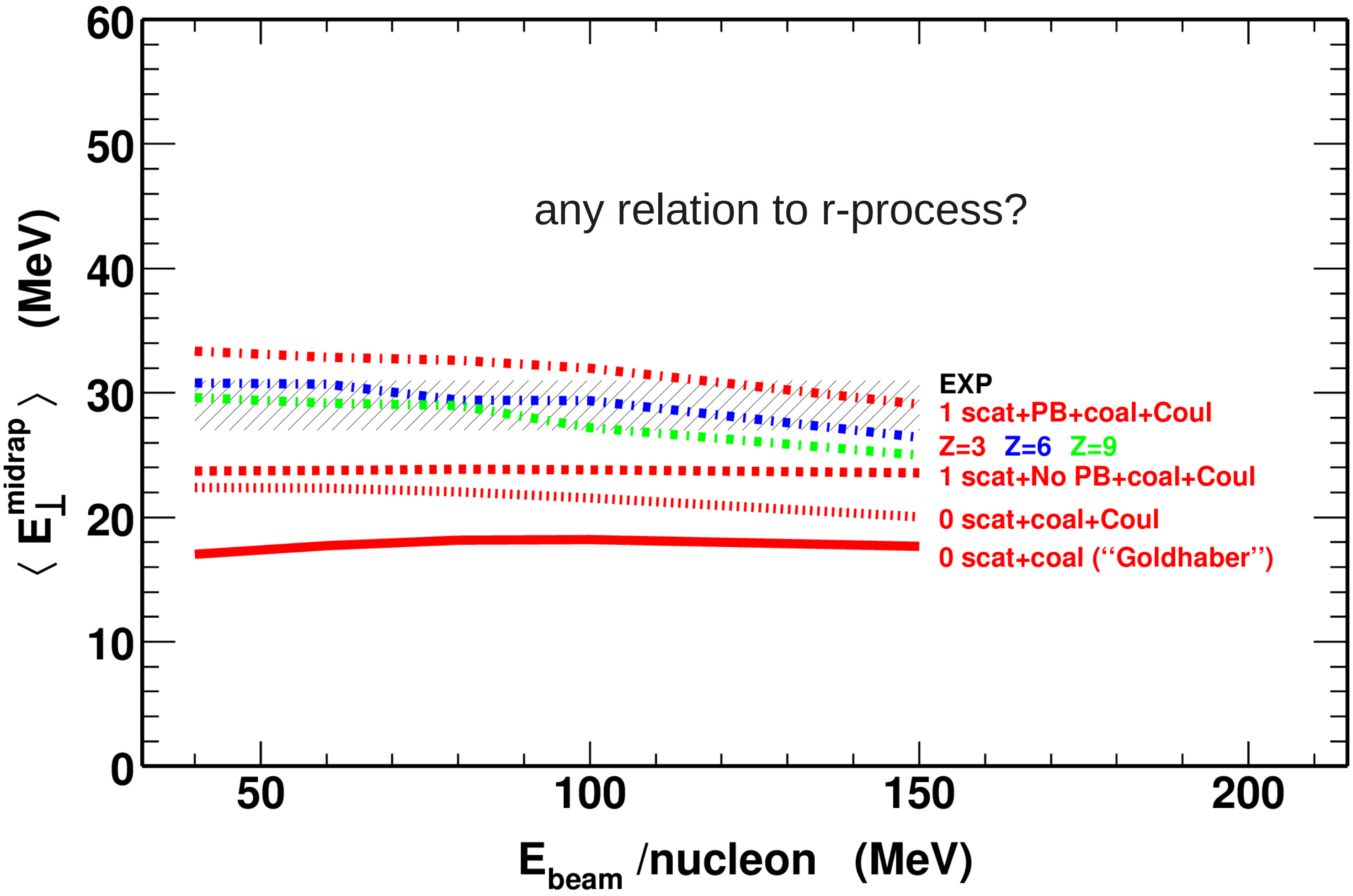
experiment + Monte-Carlo

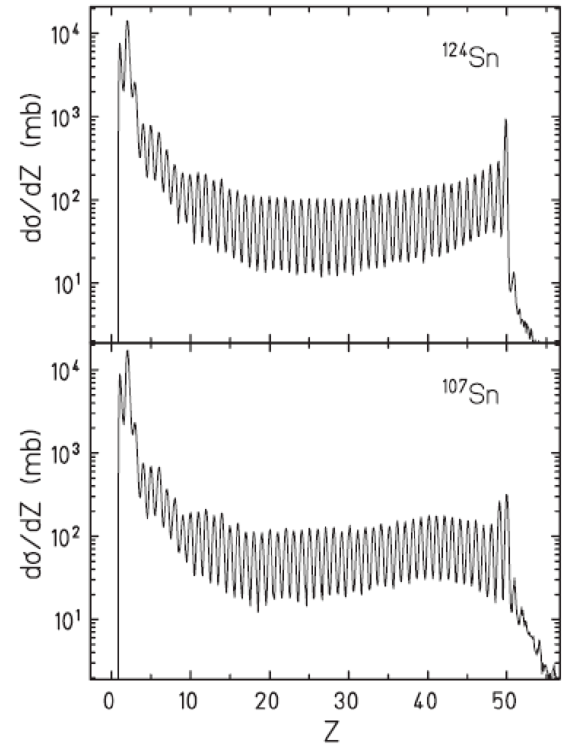


J. Łukasik et al., PRC 66 (02) 064606

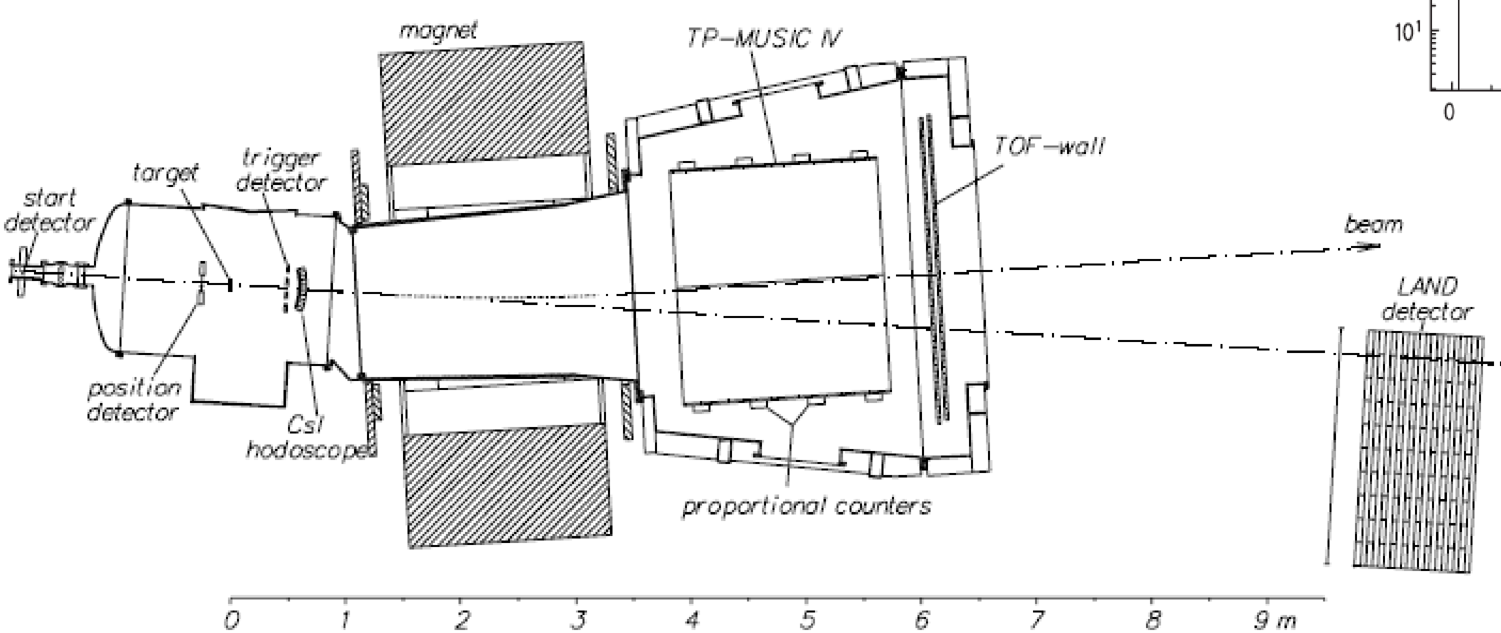
Important role of the N-N collisions in fragment formation – possibly they trigger the fragment emission. On average one scattered nucleon in the fragment is enough to explain the high and constant value of the mean transverse energies of the fragments.

Fragmentation of ^{107}Sn, ^{124}La and ^{124}Sn @ 600 AMeV ALADIN@GSI

N/Z ≥ 1.14



88c C. Sfienti et al. / Nuclear Physics A 749 (2005) 83c–92c



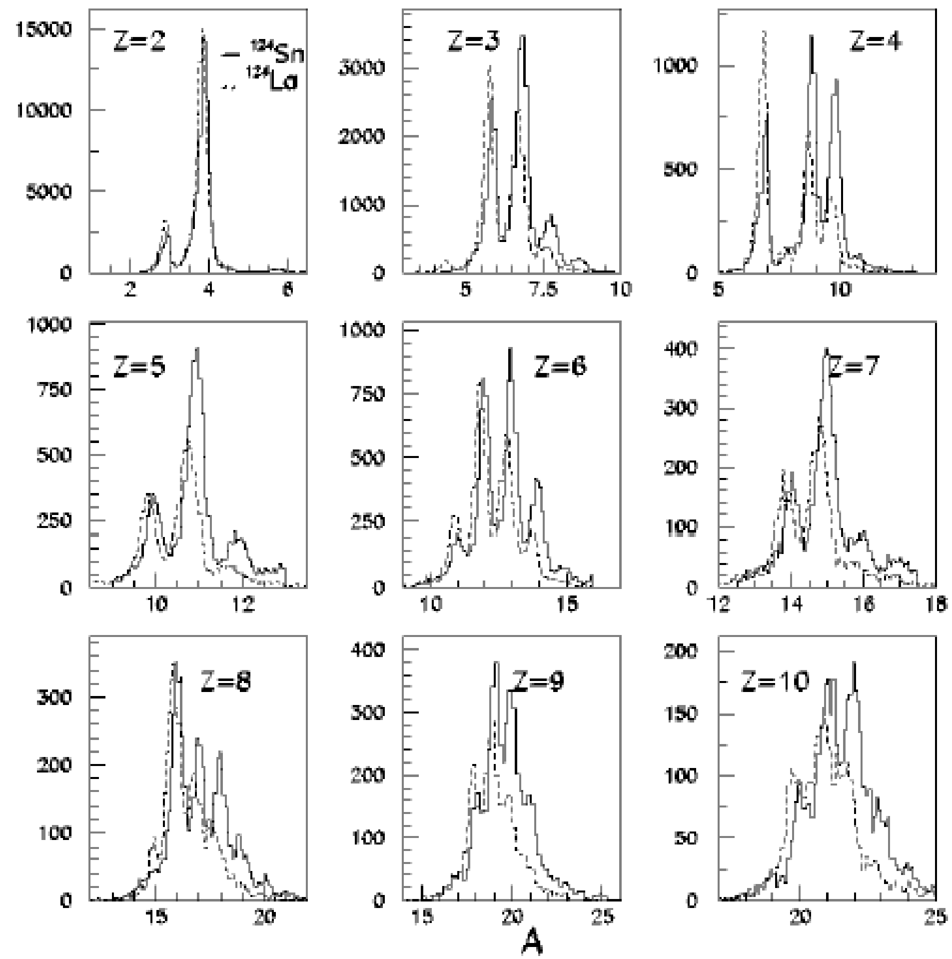
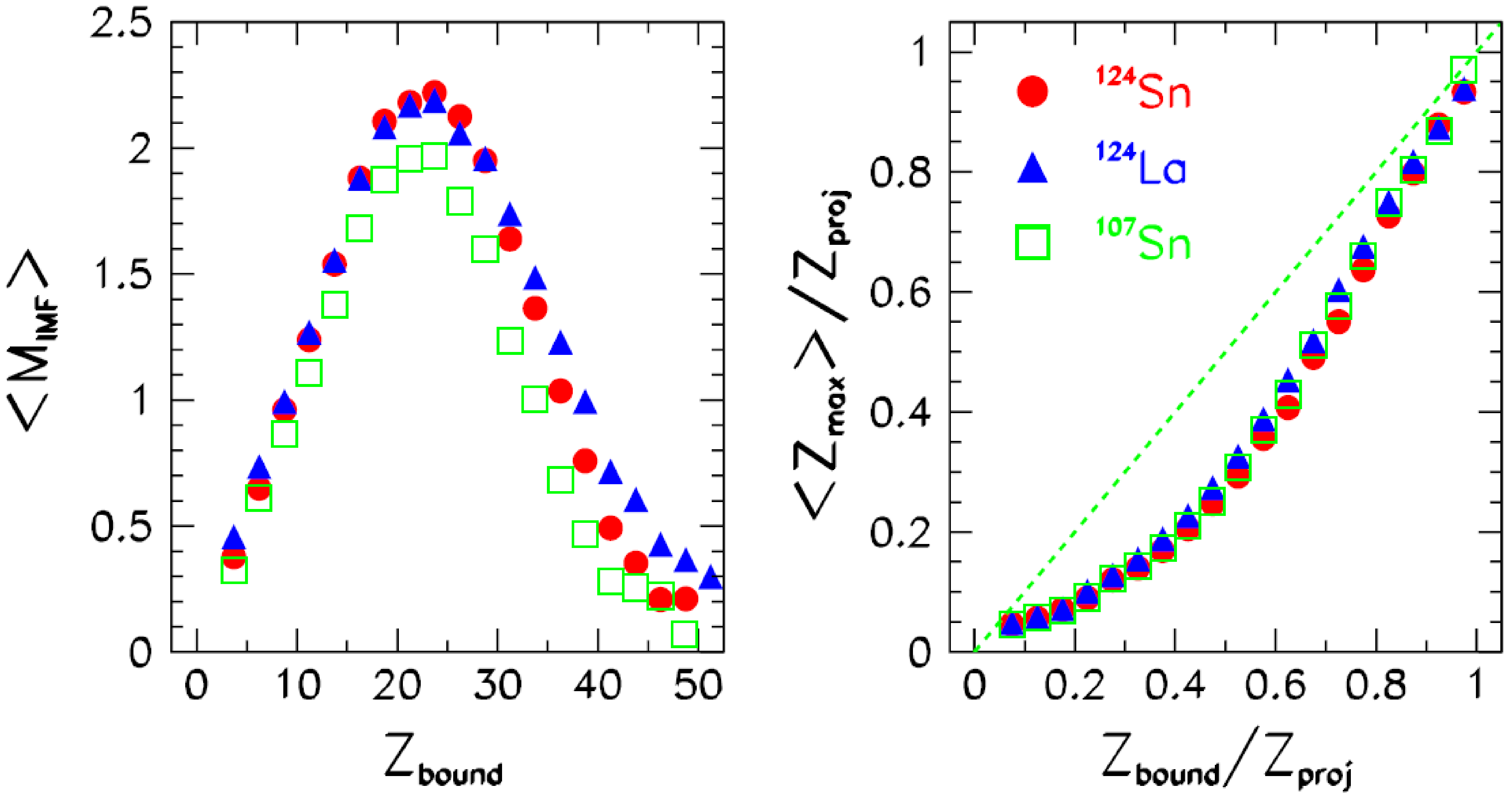


Figure 5. *Mass spectra for light fragments with* $Z \leq 10$ *from the fragmentation of* ^{124}La *(dashed line) and* ^{124}Sn *(full line).*

~ 4% FWHM mass resolution

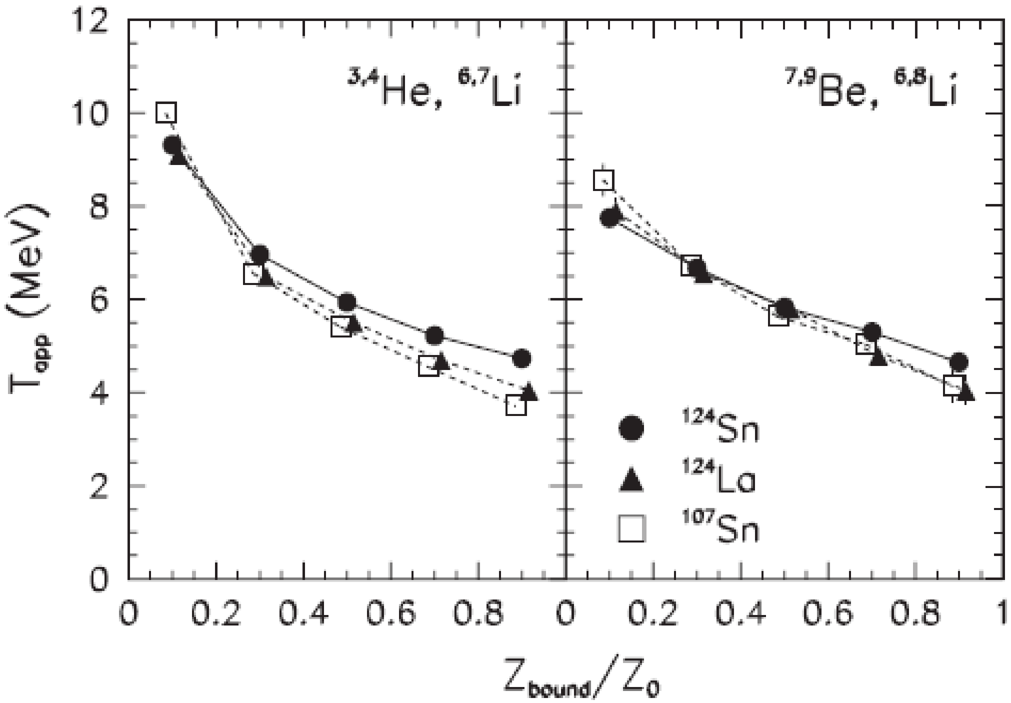
“rise and fall” in projectile fragmentation



Breakup temperatures and the symmetry energy

Albergo temperatures

$$R \equiv \frac{Y_1/Y_2}{Y_3/Y_4} = c\exp(((B_1-B_2)-(B_3-B_4))/T) \quad e.g. \begin{array}{ll} 1\rightarrow {}^6Li & 2\rightarrow {}^7Li \\ 3\rightarrow {}^3He & 4\rightarrow {}^4He \end{array}$$

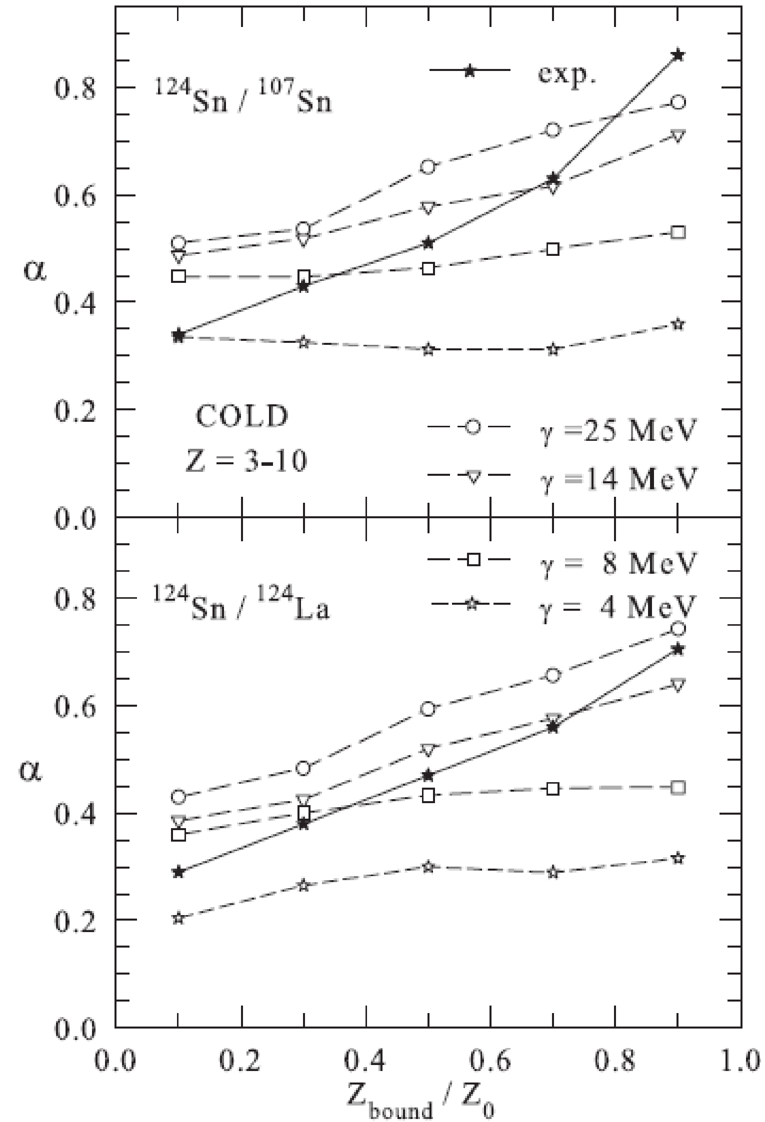


Symmetry energy drops down with temperature

Isoscaling coefficients α

$$R_{21}(N,Z) \equiv \frac{Y_2(N,Z)}{Y_1(N,Z)} \propto \exp(N\alpha + Z\beta) \quad e.g. \begin{array}{l} 1\rightarrow {}^{107}Sn \\ 2\rightarrow {}^{124}Sn \end{array}$$

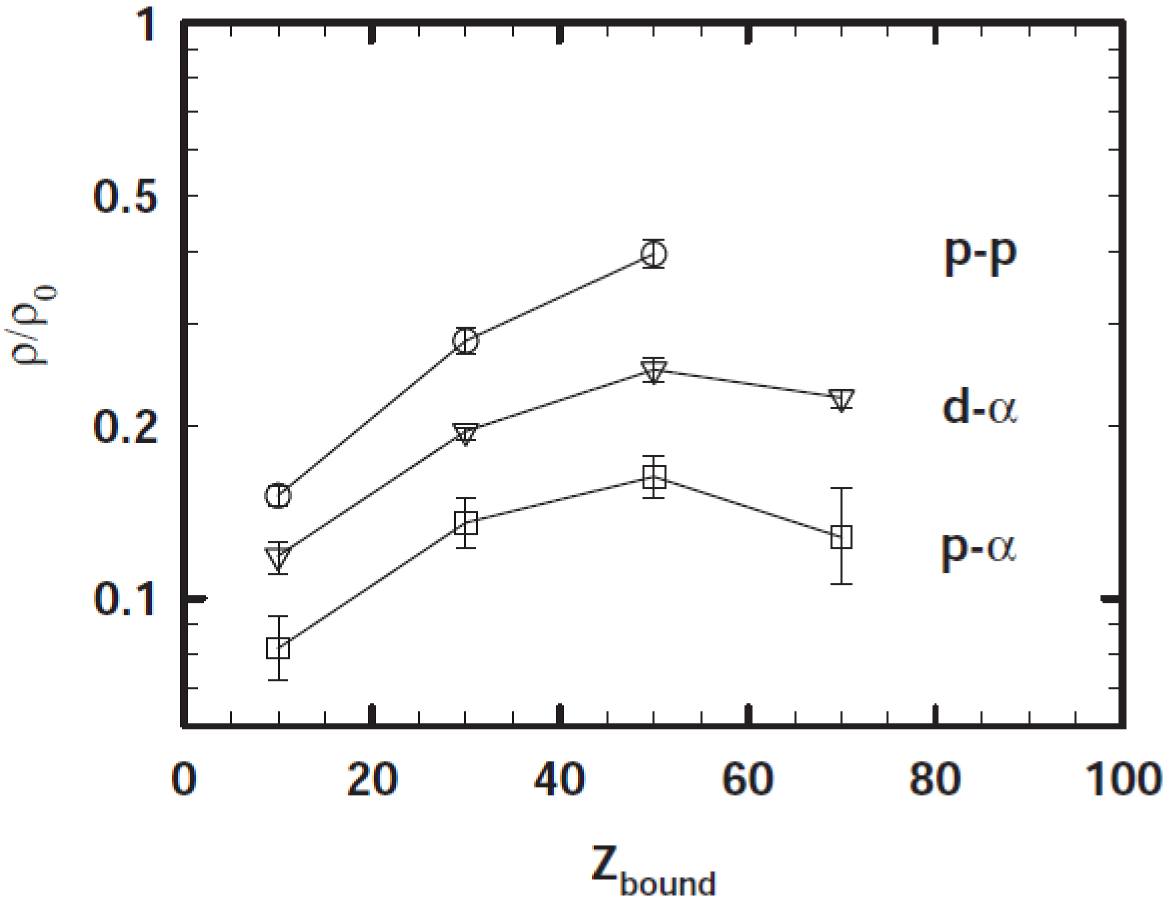
$$\alpha \approx \frac{4\gamma}{T}\left(\frac{Z_1^2}{A_1^2} - \frac{Z_2^2}{A_2^2}\right) \quad \text{where } \gamma \rightarrow E_{sym} \text{ coeff.}$$



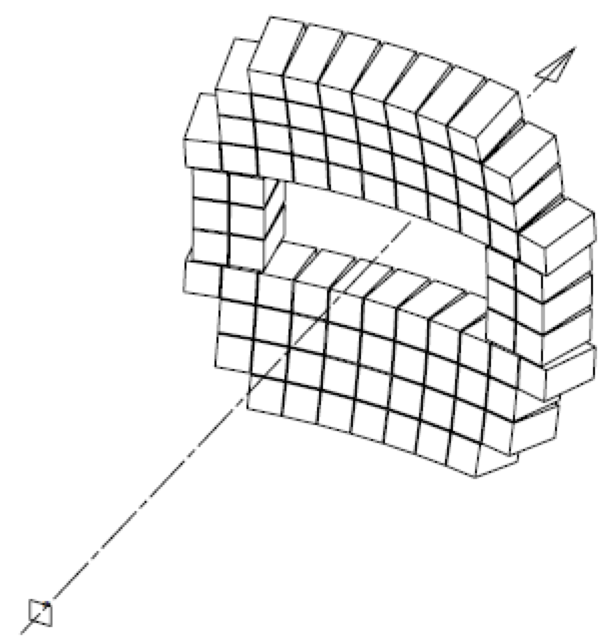
Ogul et al. PRC 83(11)024608

Breakup densities from 2-particle correlation (Au+Au @ 1AGeV)

S. Fritz et al., Phys. Lett. B461(1999)315



ALADIN + HODOSCOPE



A. Schuettauf PHD thesis (1996)

Start, Active coll, KYOTO Trigger,
KATANA, NEBULA+Veto, HOD(s), Lanzhou TOF.

(Why) do we need those?

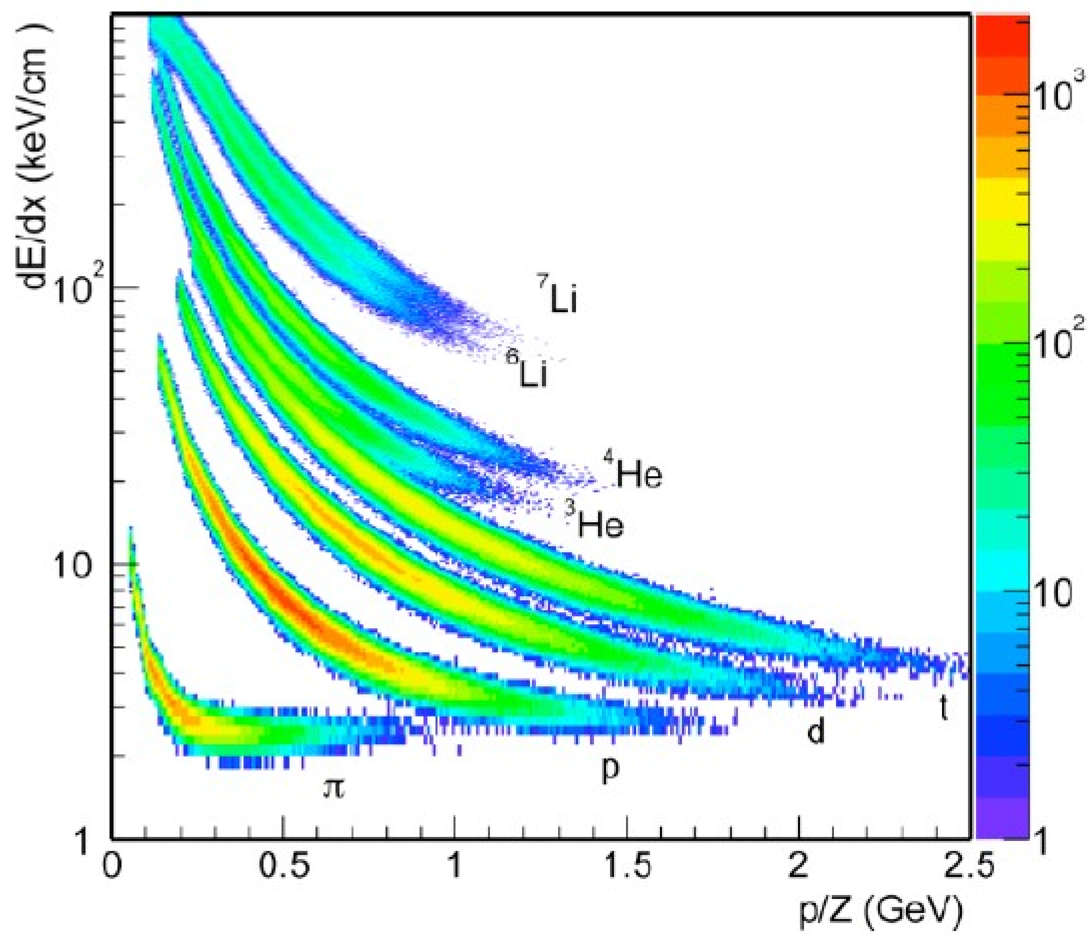


Fig. 11 Simulated PID of the TPC based on the performance of the STAR TPC. Comparable performance was achieved in the EOS detector and would be achieved with the SAMURAI TPC.

From Betty's proposal

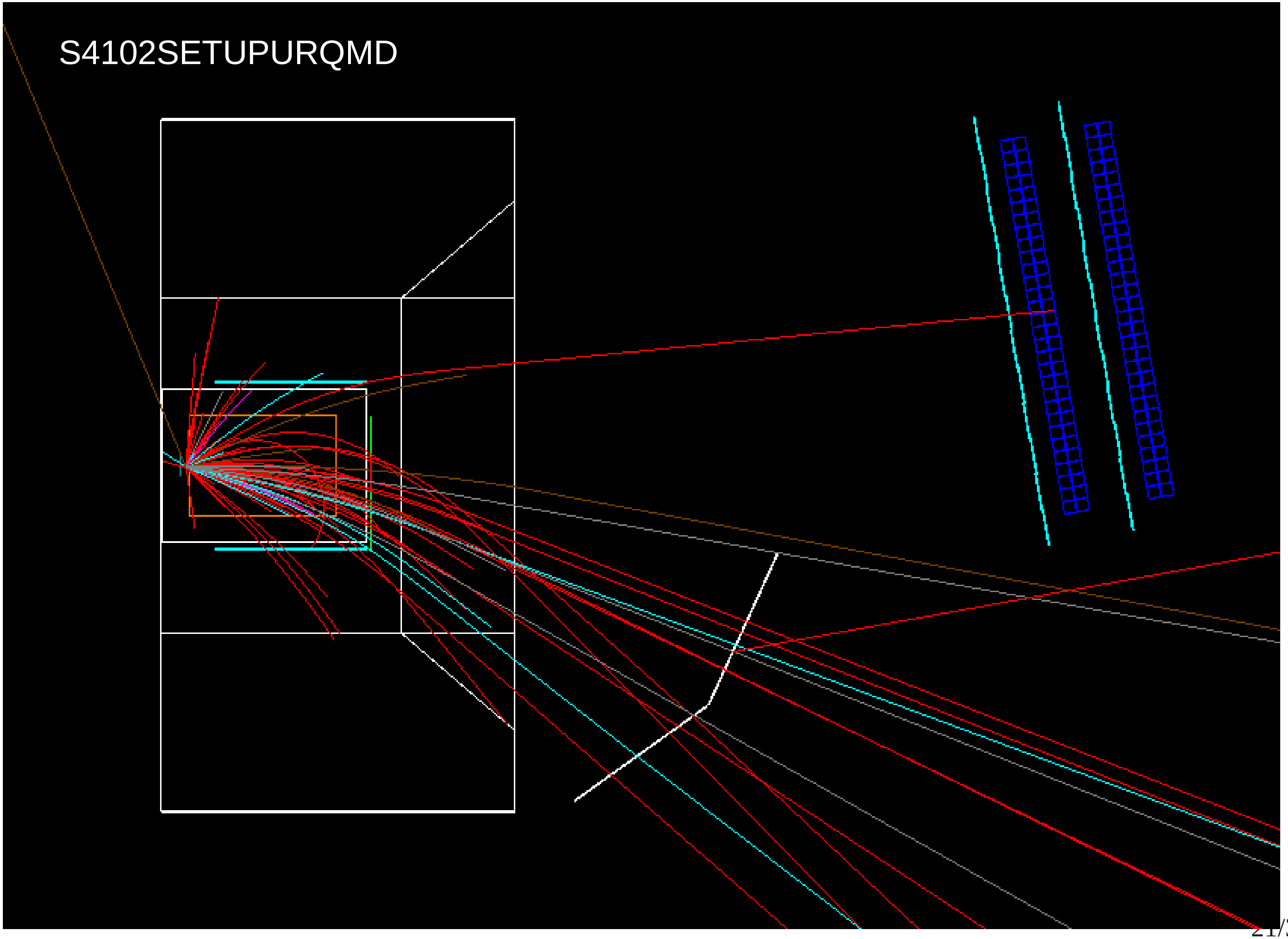
Why do we need those?

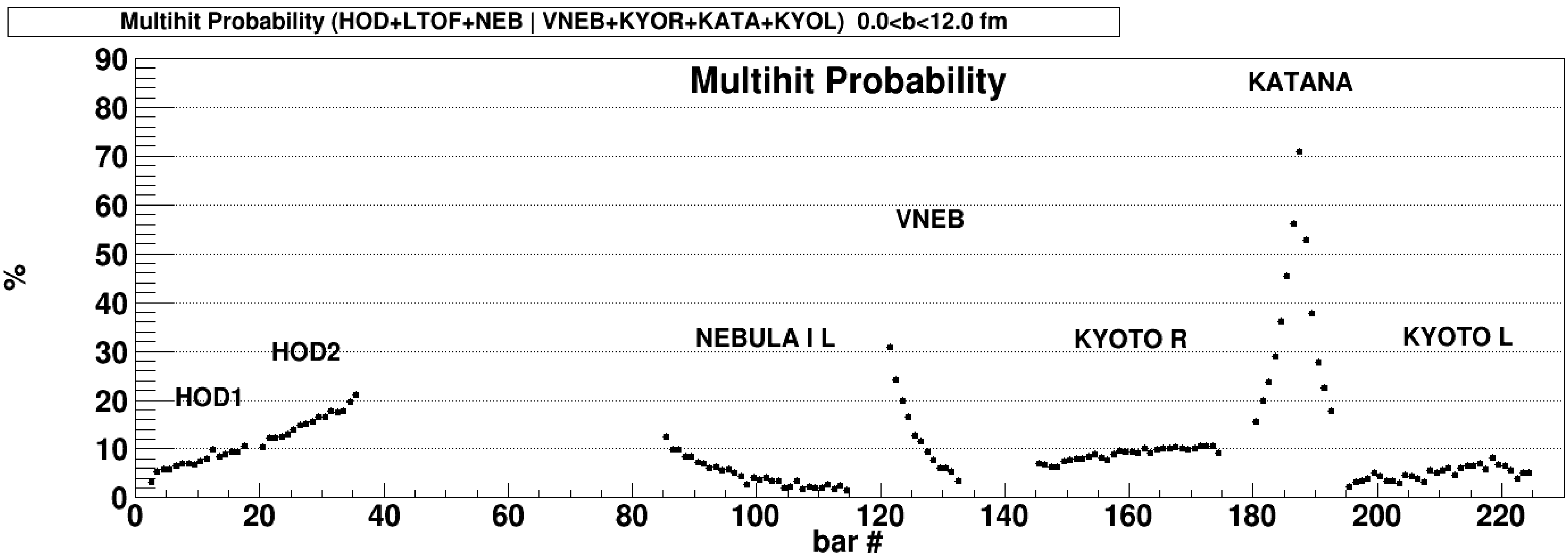
Start	→ for TOF, trigger, good evt selection
Active coll	→ reject non-target coll., beampipe hits, ...
KYOTO	→ multiplicity trigger, TOF (?)
KATANA	→ trigger for evts with Z<20, veto for GG
NEBULA+Veto	→ TOF for LCP, masses (imp. for central)
HOD(s)	→ TOF for LCP, masses (for mid-central)
Lanzhou TOF	→ TOF for LCP, masses (for mid-central)

Do wee need “beam trigger” ? (...yes) → not obvious how to do it with GG

2 x HOD (16 bars x 10 cm)

NEBULA (30 bars x 12 cm)




Multihit Probability (HOD+LTOF+NEB | VNEB+KYOR+KATA+KYOL) 0.0<b<12.0 fm
Multihit Probability
KATANA
VNEB
HOD1
HOD2
NEBULA I L
KYOTO R
KYOTO L
%
bar #

Impact Parameter:

0<b<4 fm

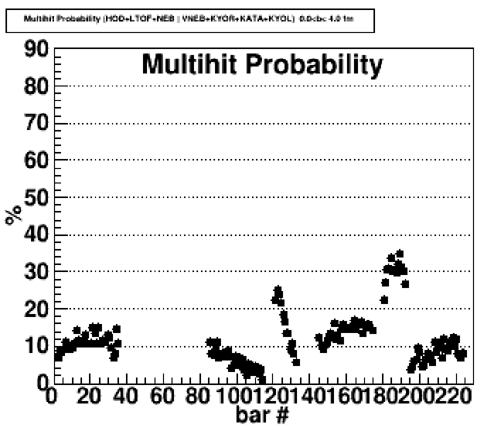
Geom. Efficiency

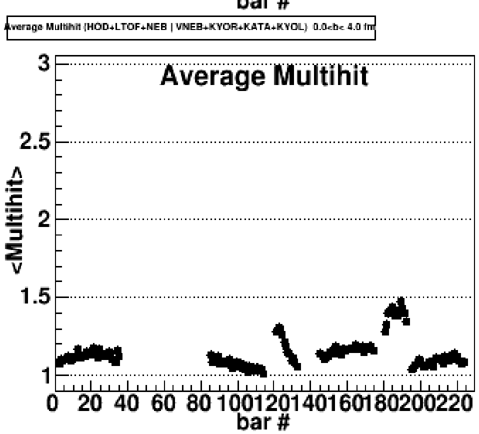
$\frac{\text{Hits1}}{\text{TPC tracks}}$ | $\frac{\text{Hits2}}{\text{Forw. Exit}}$

25.3 % | 75.4 %

Hits1=HOD+HOD+NEBULA+KYOTO

Hits2=HOD+HOD+NEBULA





Impact Parameter:

4<b<8 fm

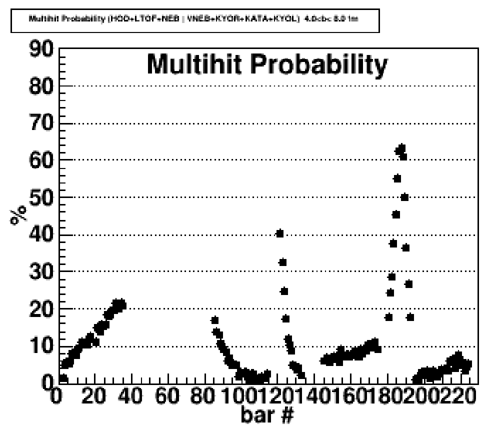
Geom. Efficiency

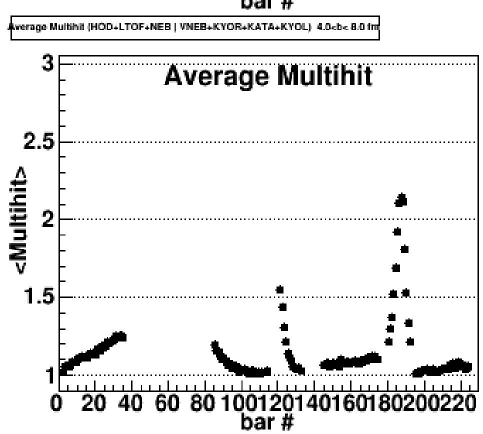
$\frac{\text{Hits1}}{\text{TPC tracks}}$ | $\frac{\text{Hits2}}{\text{Forw. Exit}}$

27.9 % | 70.7 %

Hits1=HOD+HOD+NEBULA+KYOTO

Hits2=HOD+HOD+NEBULA





Impact Parameter:

8<b<12 fm

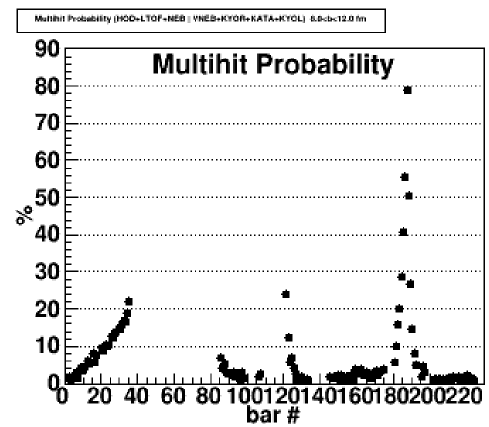
Geom. Efficiency

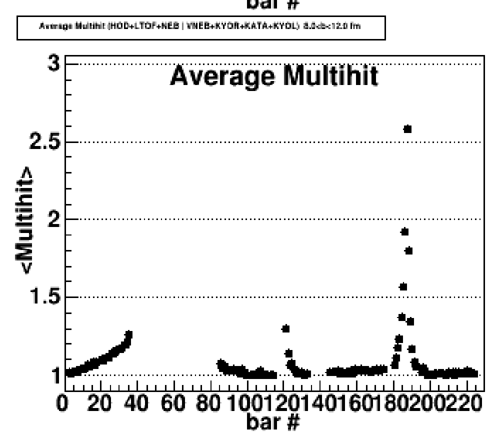
$\frac{\text{Hits1}}{\text{TPC tracks}}$ | $\frac{\text{Hits2}}{\text{Forw. Exit}}$

31.0 % | 61.6 %

Hits1=HOD+HOD+NEBULA+KYOTO

Hits2=HOD+HOD+NEBULA





Impact Parameter:

0<b<12 fm

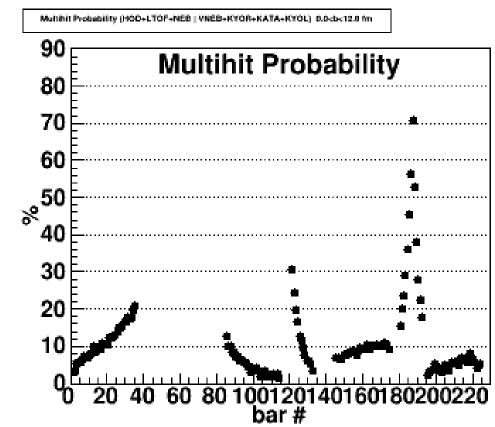
Geom. Efficiency

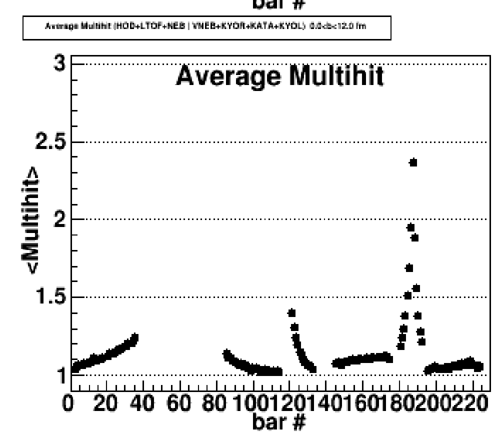
$\frac{\text{Hits1}}{\text{TPC tracks}}$ | $\frac{\text{Hits2}}{\text{Forw. Exit}}$

28.3 % | 67.2 %

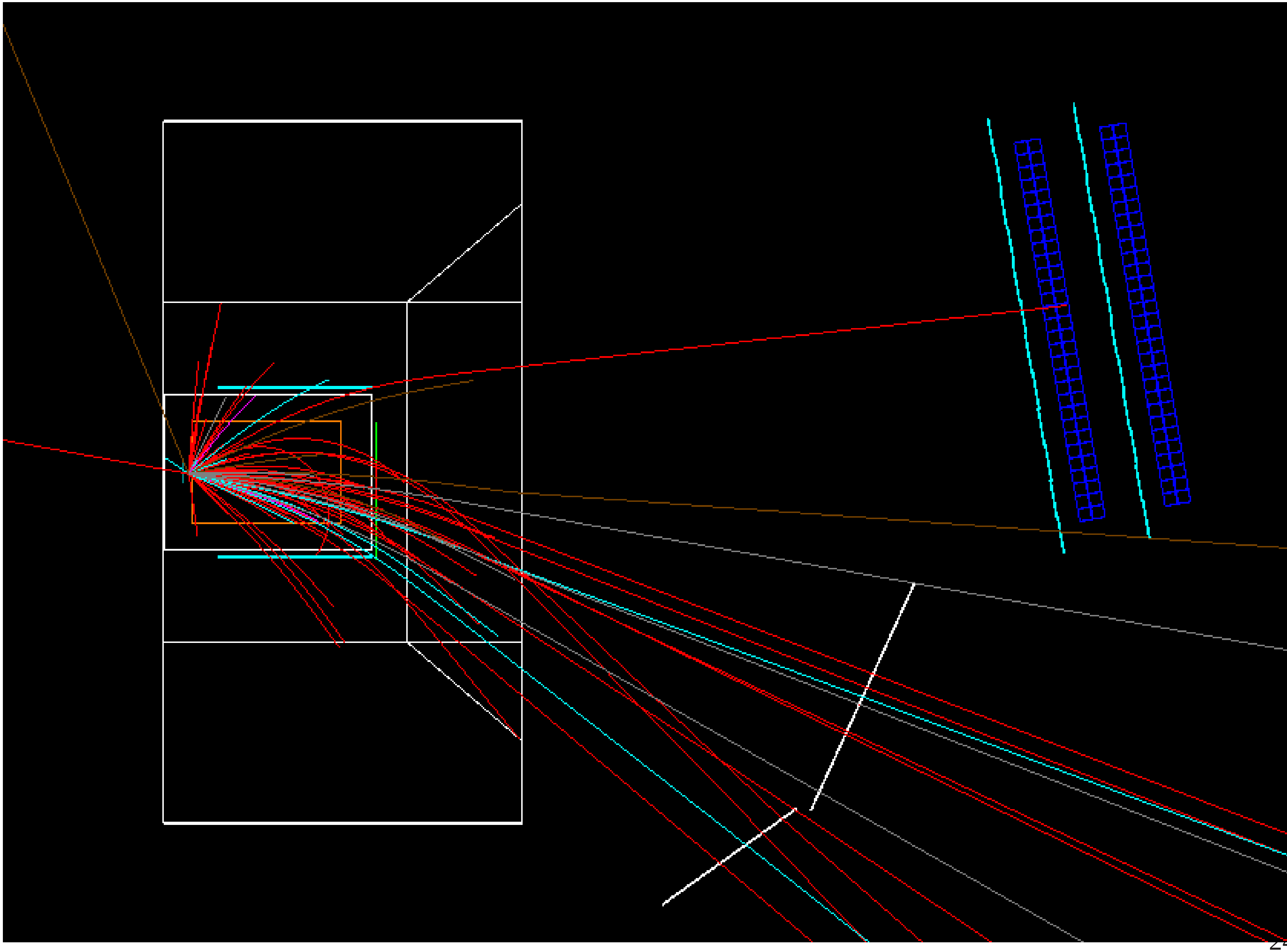
Hits1=HOD+HOD+NEBULA+KYOTO

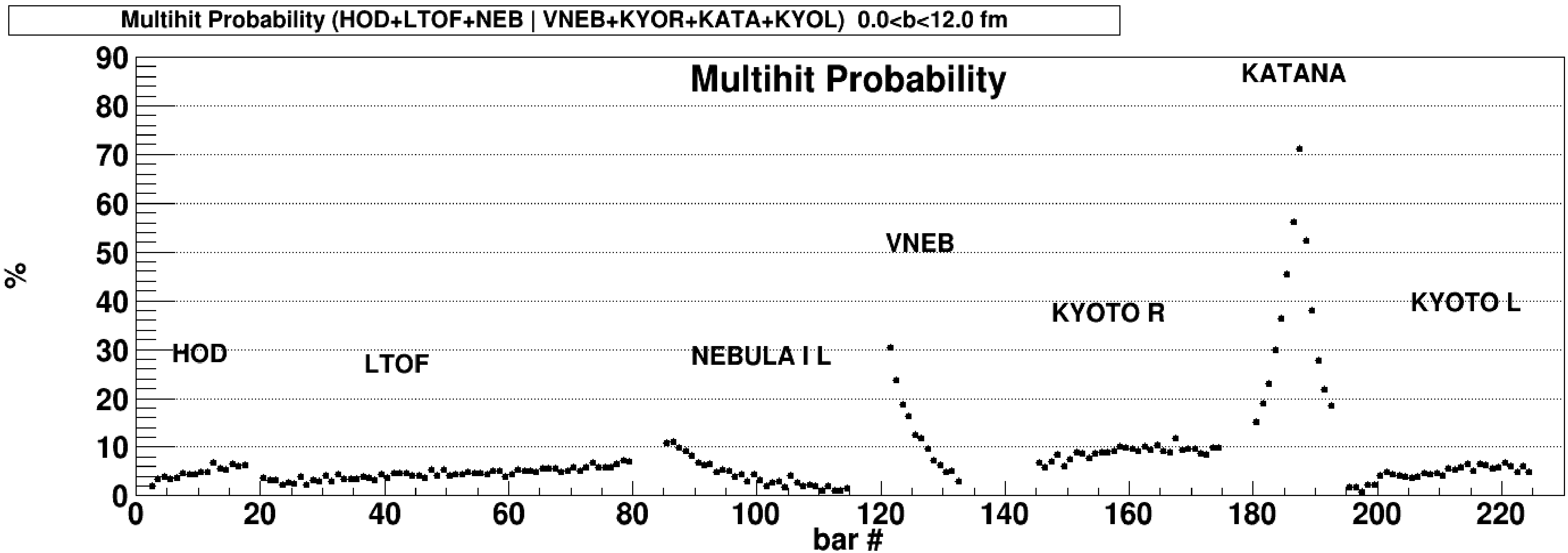
Hits2=HOD+HOD+NEBULA





HOD (16 bars x 10 cm) LANZHOU TOF (60 bars x 4 cm) NEBULA (30 bars x 12 cm)




Multihit Probability (HOD+LTOF+NEB | VNEB+KYOR+KATA+KYOL) 0.0<b<12.0 fm
Multihit Probability
%
bar #
HOD
LTOF
NEBULA I L
VNEB
KYOTO R
KATANA
KYOTO L
0
10
20
30
40
50
60
70
80
90
0
20
40
60
80
100
120
140
160
180
200
220

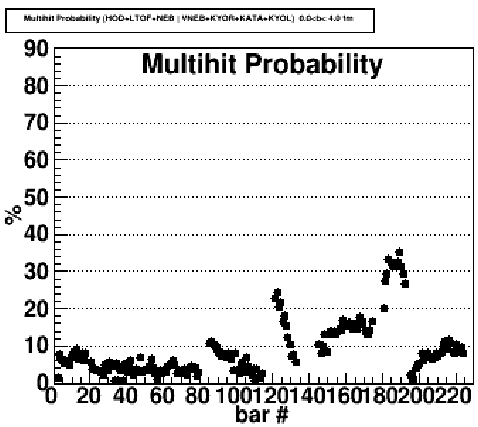
Impact Parameter:
0<b<4 fm

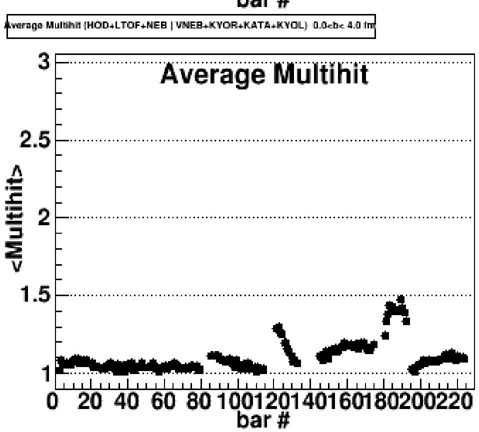
Geom. Efficiency
Hits1 / TPC tracks | Hits2 / Forw. Exit

24.1 % | 68.0 %

Hits1=HOD+LTOF+NEBULA+KYOTO

Hits2=HOD+LTOF+NEBULA





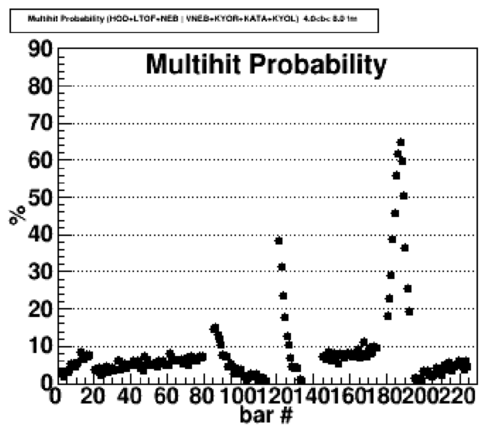
Impact Parameter:
4<b<8 fm

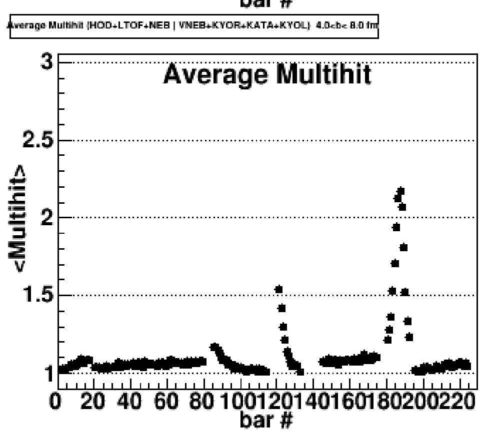
Geom. Efficiency
Hits1 / TPC tracks | Hits2 / Forw. Exit

26.0 % | 63.6 %

Hits1=HOD+LTOF+NEBULA+KYOTO

Hits2=HOD+LTOF+NEBULA





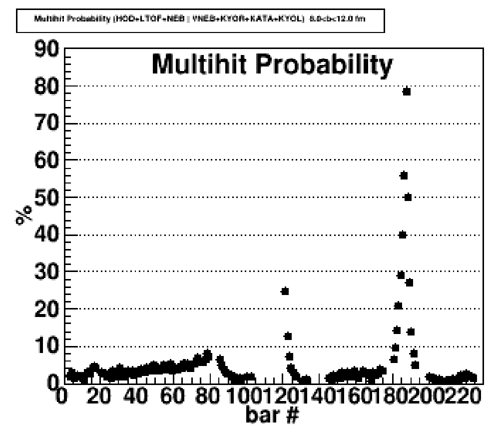
Impact Parameter:
8<b<12 fm

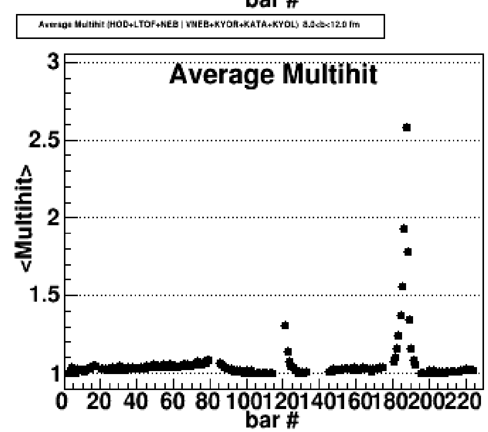
Geom. Efficiency
Hits1 / TPC tracks | Hits2 / Forw. Exit

28.9 % | 56.8 %

Hits1=HOD+LTOF+NEBULA+KYOTO

Hits2=HOD+LTOF+NEBULA





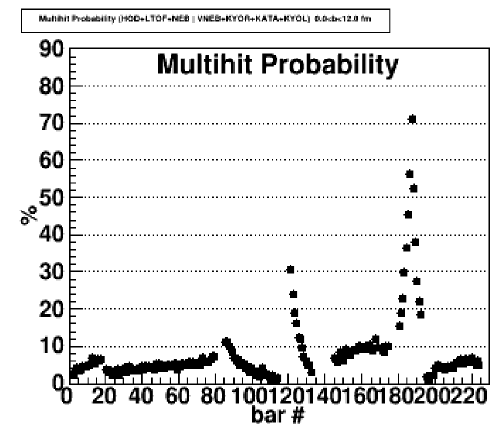
Impact Parameter:
0<b<12 fm

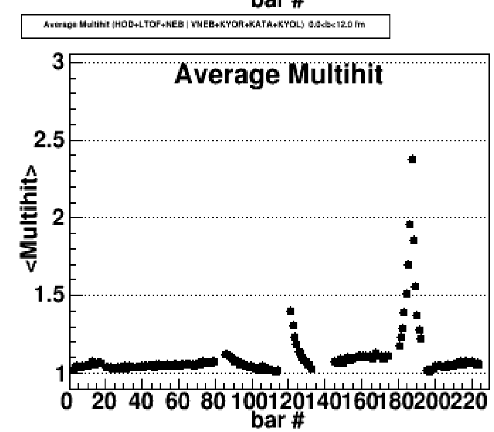
Geom. Efficiency
Hits1 / TPC tracks | Hits2 / Forw. Exit

26.5 % | 61.1 %

Hits1=HOD+LTOF+NEBULA+KYOTO

Hits2=HOD+LTOF+NEBULA





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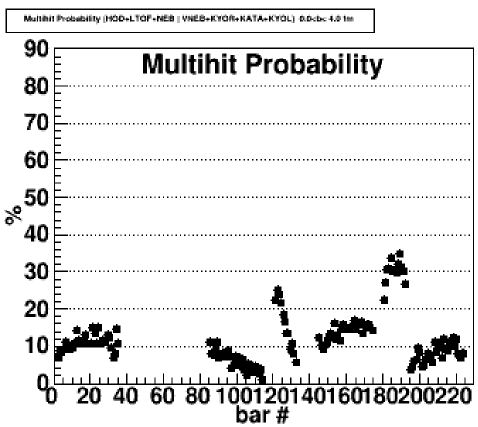

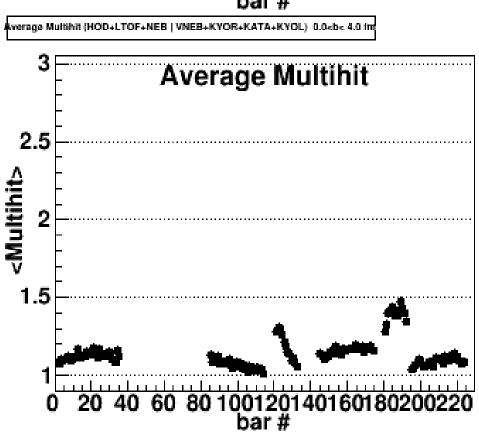

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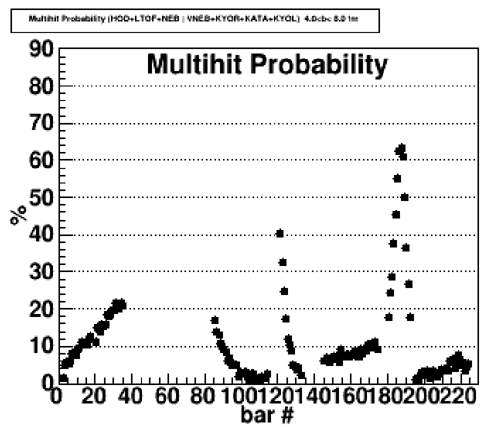

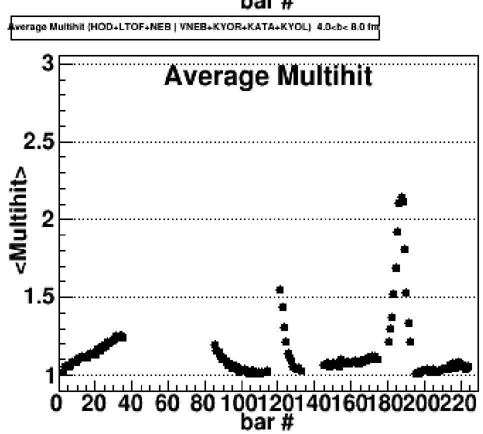

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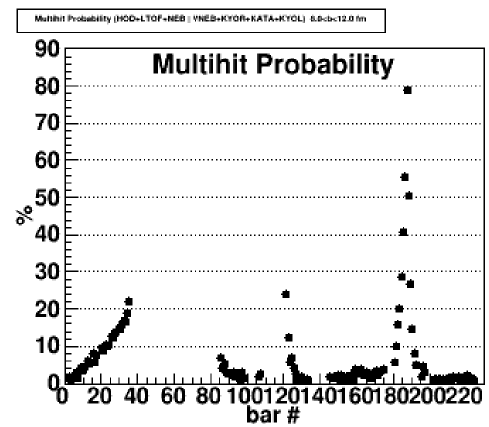
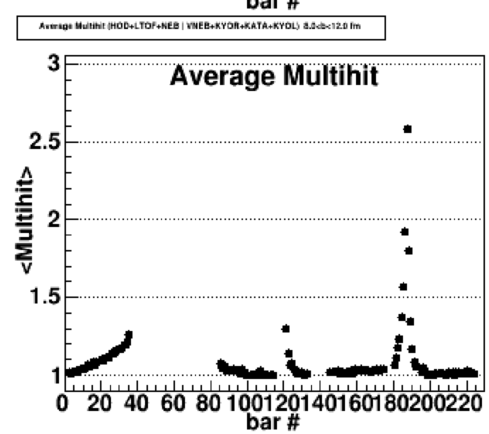
Geom. Efficiency
Hits1 / TPC tracks | Hits2 / Forw. Exit

31.0 % | 61.6 %

Hits1=HOD+HOD+NEBULA+KYOTO

Hits2=HOD+HOD+NEBULA





Impact Parameter:

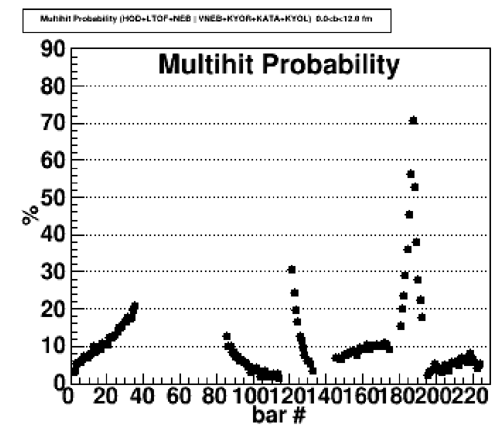
0<b<12 fm

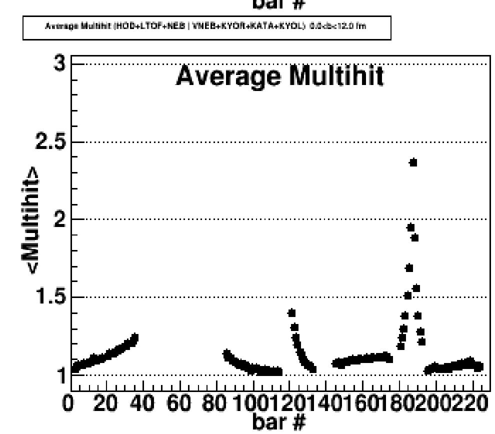
Geom. Efficiency
Hits1 / TPC tracks | Hits2 / Forw. Exit

28.3 % | 67.2 %

Hits1=HOD+HOD+NEBULA+KYOTO

Hits2=HOD+HOD+NEBULA





Rough mass resolution

$$(*\quad B\varrho = \frac{A\, u\, \beta\, \gamma}{Z\, e} \quad *)$$

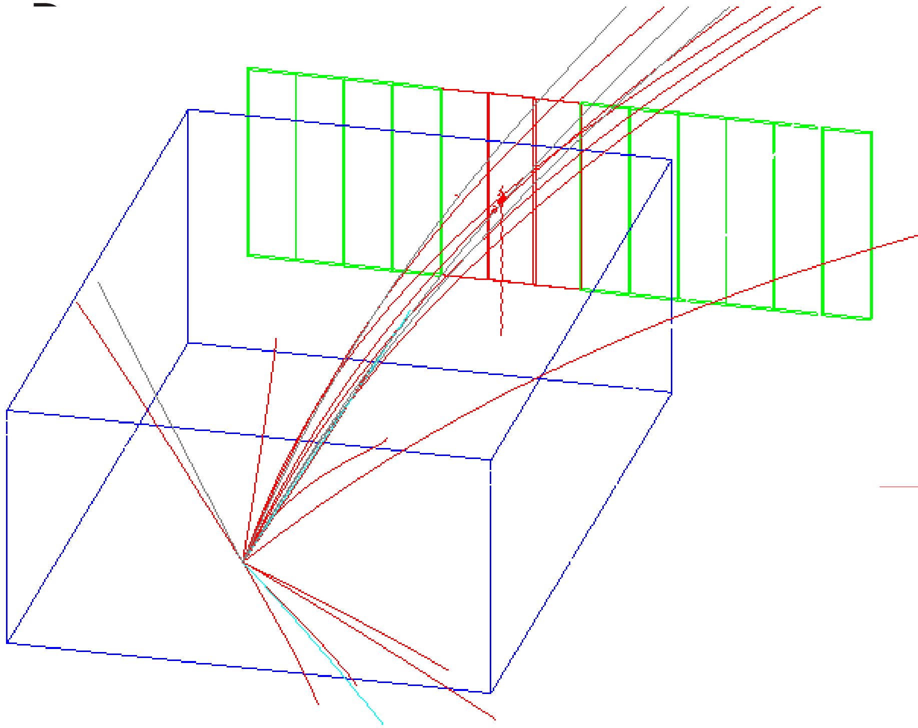
```
In[280]:= u = 931.49432 (*MeV*);
mp = 1.007276470 * u;
Zp = 1;
Ek = 300 (*MeV*);
Etot = Ek + mp;
p = Sqrt[Ek^2 + 2 Ek mp];
gamma = 1 + Ek / mp;
b = p / Etot;
gam = 1 / Sqrt[1 - b * b];
R = p / 1000 / Zp (*GeV/c*);
dR = 0.02 * R (*  → 2% from Aki GeV/c*);
c = 0.000299792458 (* m/ps *);
s = 4 (* m *);
ds = 0.0;
dt = 100 (* ps *);
```

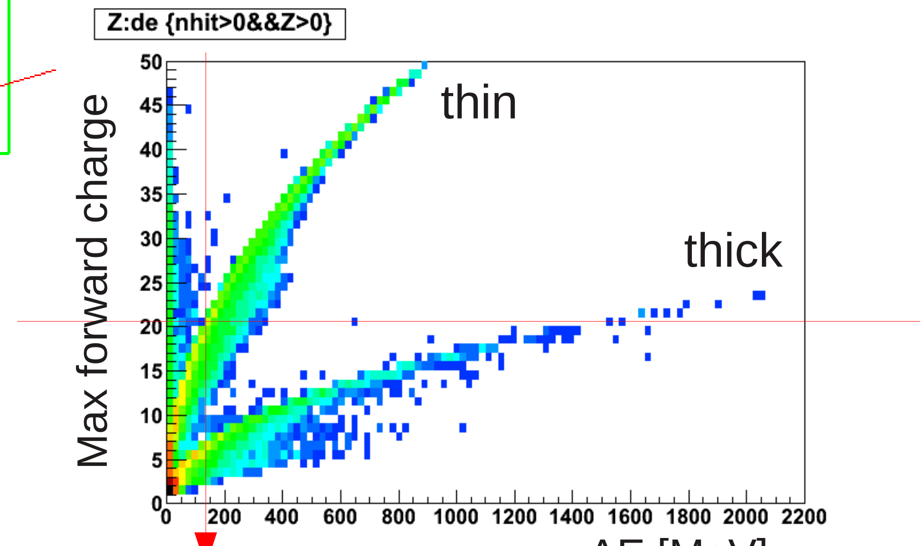
$$\mathrm{dAoverA} = \frac{\sqrt{ds^2\, gam^4\, R^2 + b^2\, c^2\, dt^2\, gam^4\, R^2 + dR^2\, s^2}}{R\, s} * 235.5 \quad (*\ \%\ \mathrm{FWHM}\ *)$$

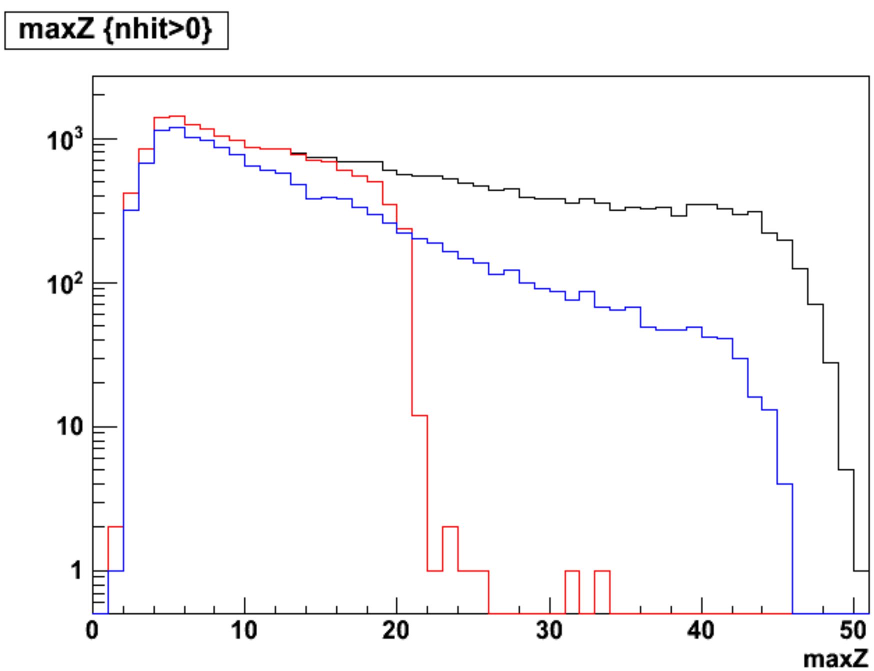
Out[295]= 5.11943 → up to $Z \approx 10$

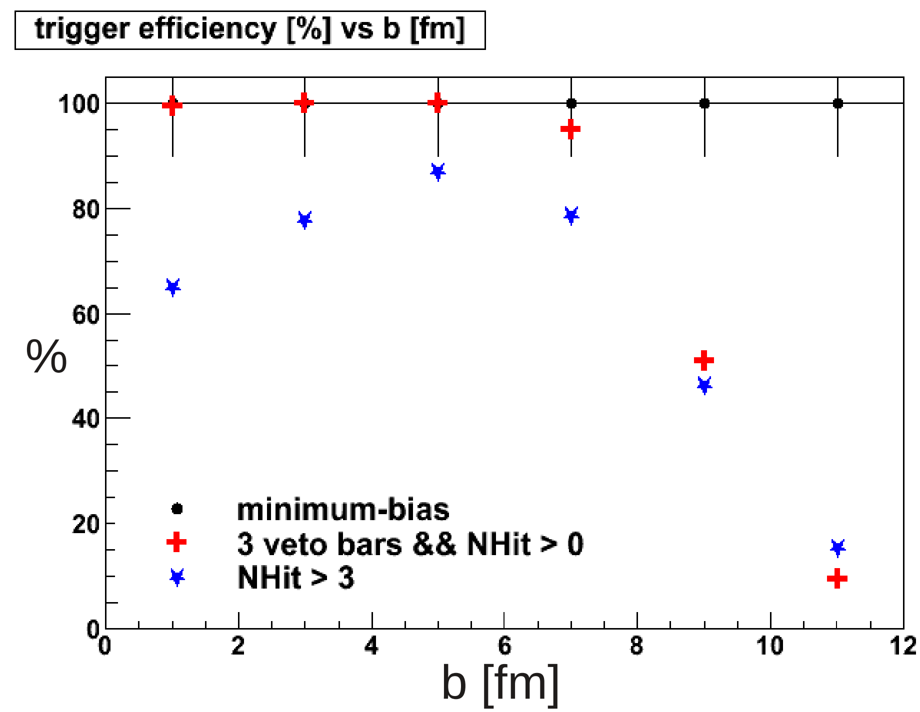
S87310URQM

3 veto bars 10x40x0.1 cm3 with 5mm overlap +
10 multiplicity bars 10x40x1 cm3
veto bars read out from both sides
multiplicity bars read out from one side → 16 channels



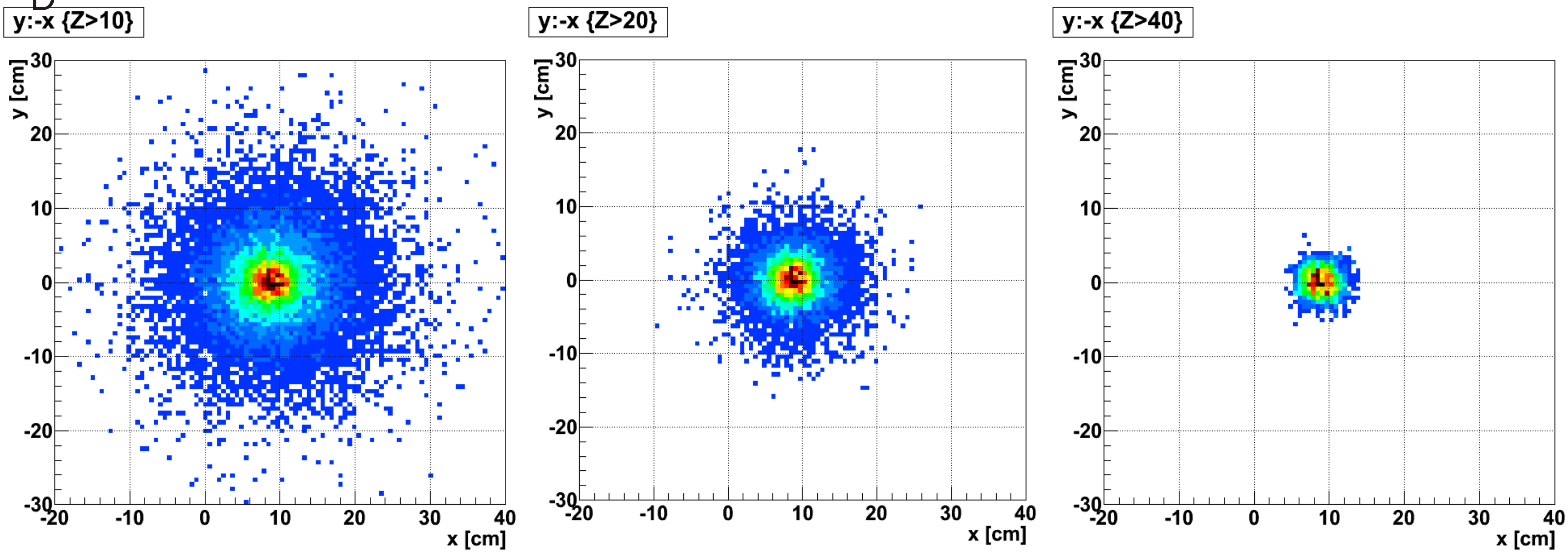






Z>10, Z>20 and Z>40 spots 5 cm behind the exit TPC window, B=0.5 T, 4x4cm2 target
Sn+Sn @ 300 AMeV, UrQMD+clustering

S41URQM
D



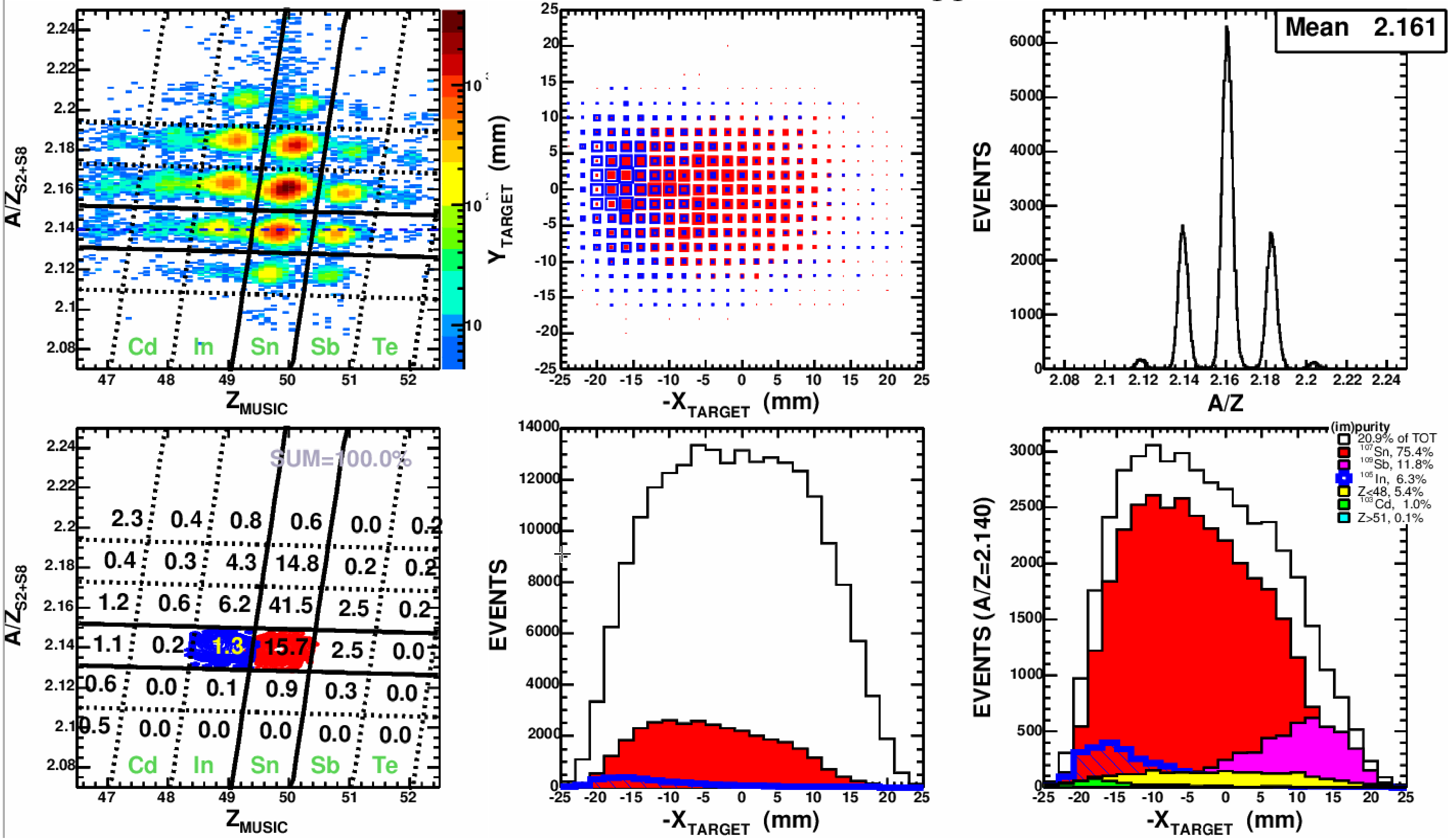
problems

- Beam hole – should be reduced
- Area around the beam – requires more segmented detectors
- “Cracks” between plastic bars (use double walls...?)
- Tracking in air – less accurate, precise field maps needed
- Can we adapt the TPC for more peripheral collisions (T~4-5 MeV)?
- ...

summary

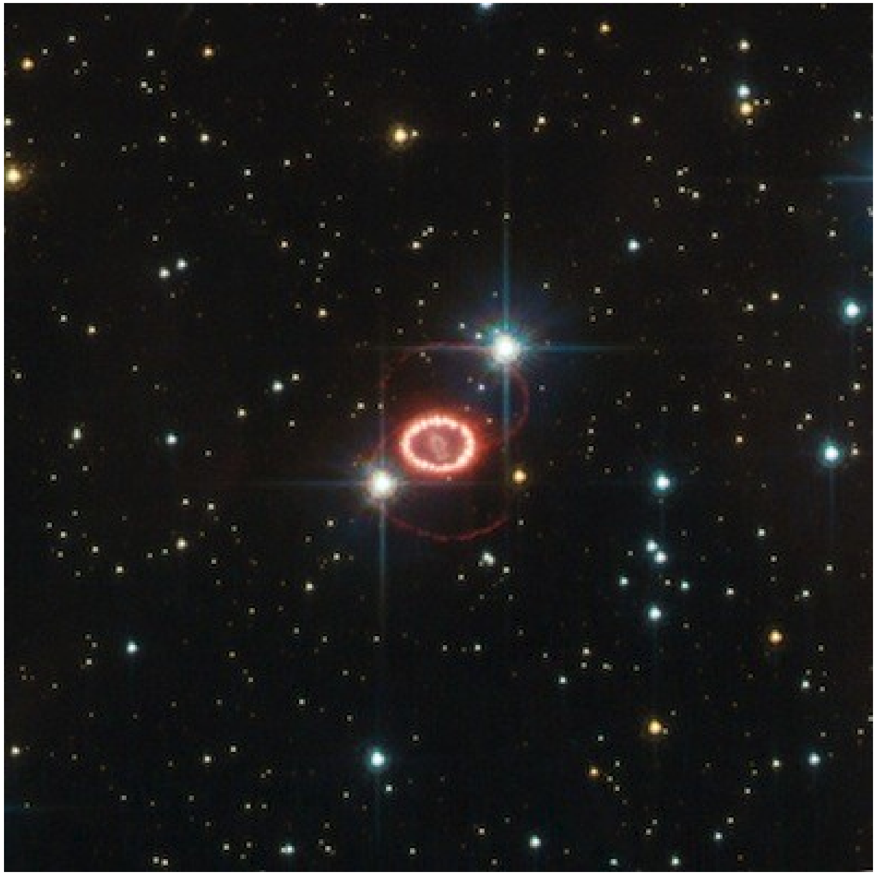
- relativistic neutron rich exotic beams needed
- various projectiles for isoscaling and Esym
- high efficiency and mass resolution for temperature extraction
- projectile fragmentation @ non-central collisions to reduce radial flow, to obtain the right temperature range (4-5 MeV) and to get the neutron rich environment
- or spallation-like inverse kinematics reactions
- better coverage around the beam needed, high position resolution for corr. funct.
- neutron measurement for T and Esym

^{107}Sn runs 1952-1996, beam trigger



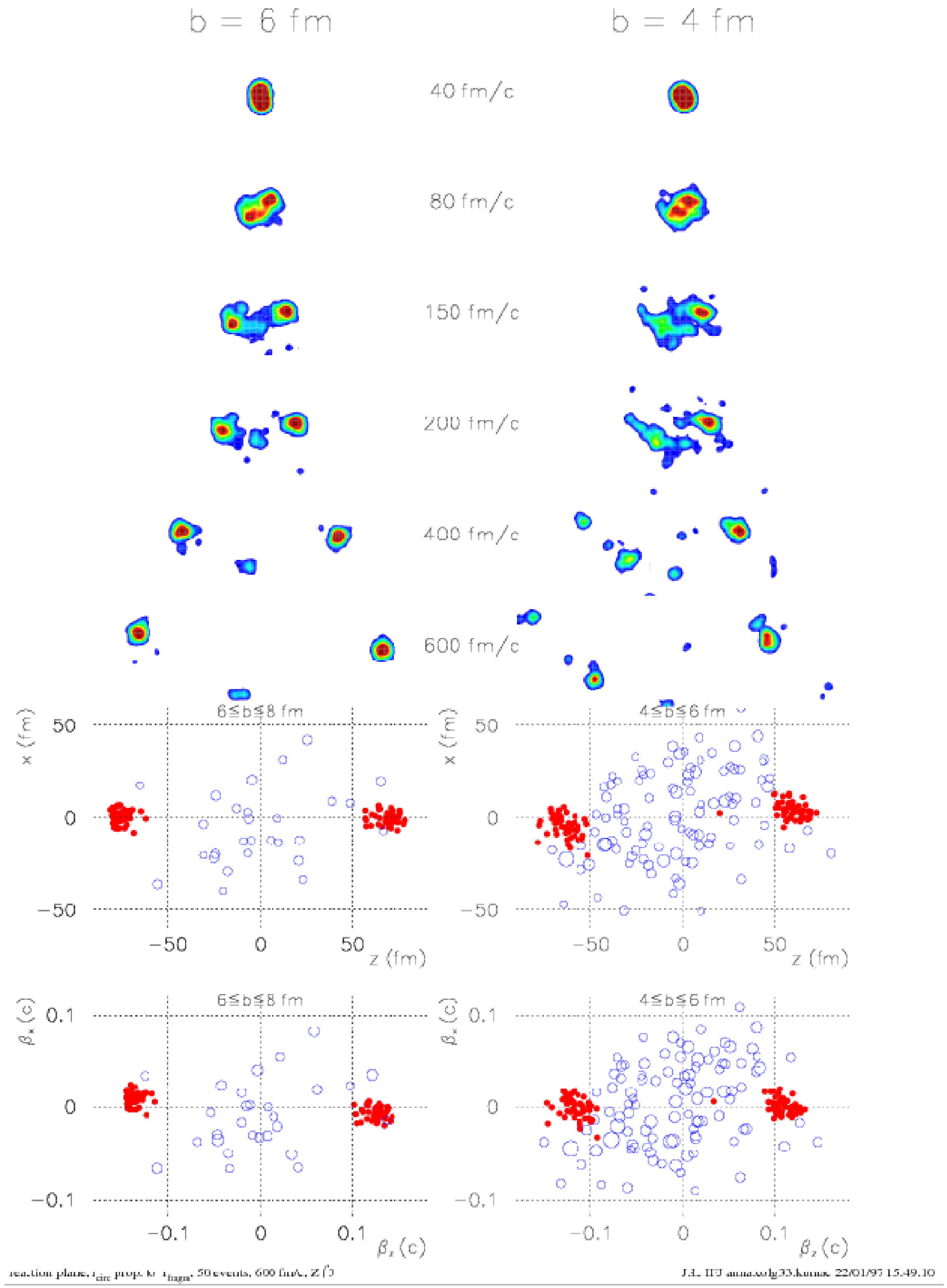
Twenty-five years after supernova 1987A

The string of pearls clumps of matter in an older ring of debris around SN 1987A that are being heated as shock waves and debris from the supernova crash into them. Image: NSA/P Challis and R Kirshner (Harvard Smithsonian CfA)/B Sugerman (STScI).



A wider view of the region around SN 1987A, showing the inner ring and two outer rings. Image: ESA/Hubble and NASA.

http://www.astronomynow.com/news/n1202/23sn/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b = 4 fm
40 fm/c
80 fm/c
150 fm/c
200 fm/c
400 fm/c
600 fm/c
6≦b≦8 fm
4≦b≦6 fm
x (fm)
z (fm)
6≦b≦8 fm
4≦b≦6 fm
β_x (c)
β_z (c)