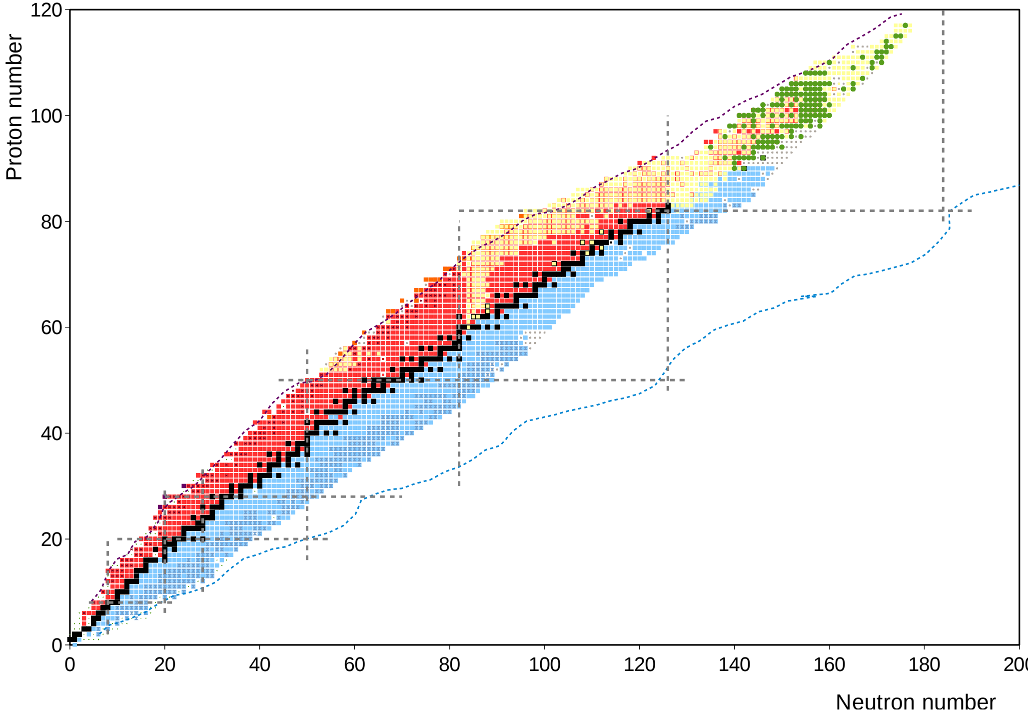
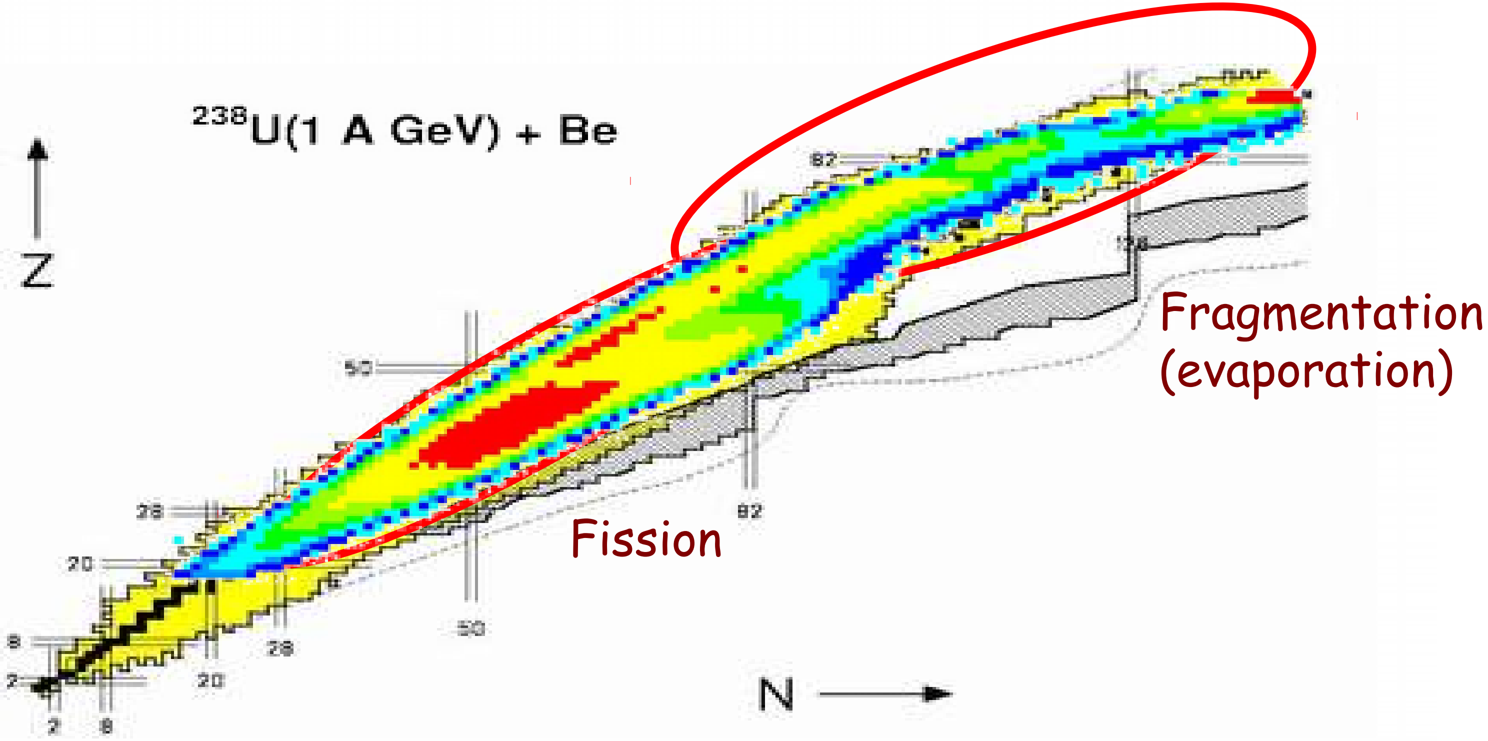
How to measure most exotic isotopes ?

- In-flight methods
  (fragmentation, fusion-evaporation)
- ISOL
  (spallation, fusion, DIC)



What if in one reaction one could produce all particle bound isotops and therefore provide us the means to see a clear separations between bound and unbound nuclei.



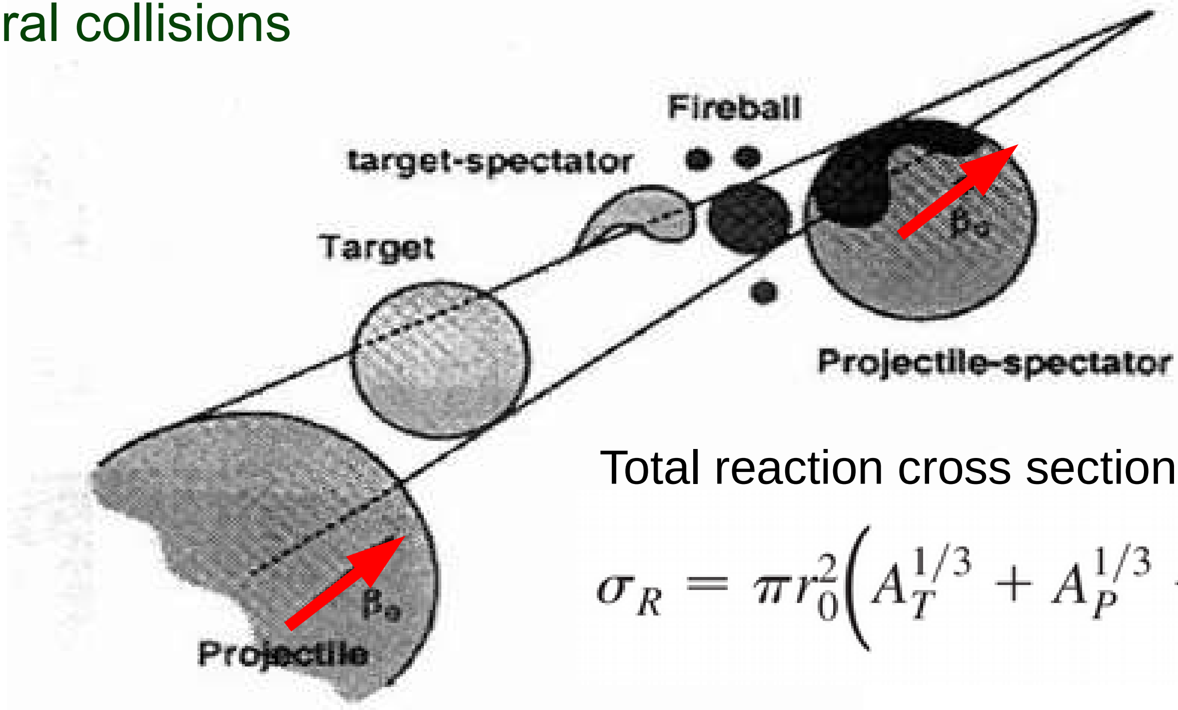
J. Benlliure

Surrey, June'05

NUSTAR minischool

Projectile fragmmentation with high energy heavy ion beams !

Random removal of protons and neutrons from heavy projectile in peripheral collisions



Total reaction cross section

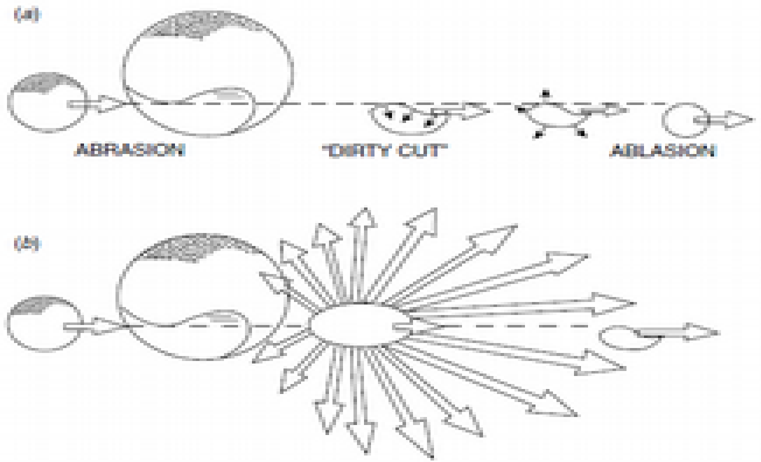
$$\sigma_R = \pi r_0^2 \left(A_T^{1/3} + A_P^{1/3} + a \frac{A_T^{1/3} A_P^{1/3}}{A_T^{1/3} + A_P^{1/3}} - c \right)^2$$

Geometric model of the fragmentation

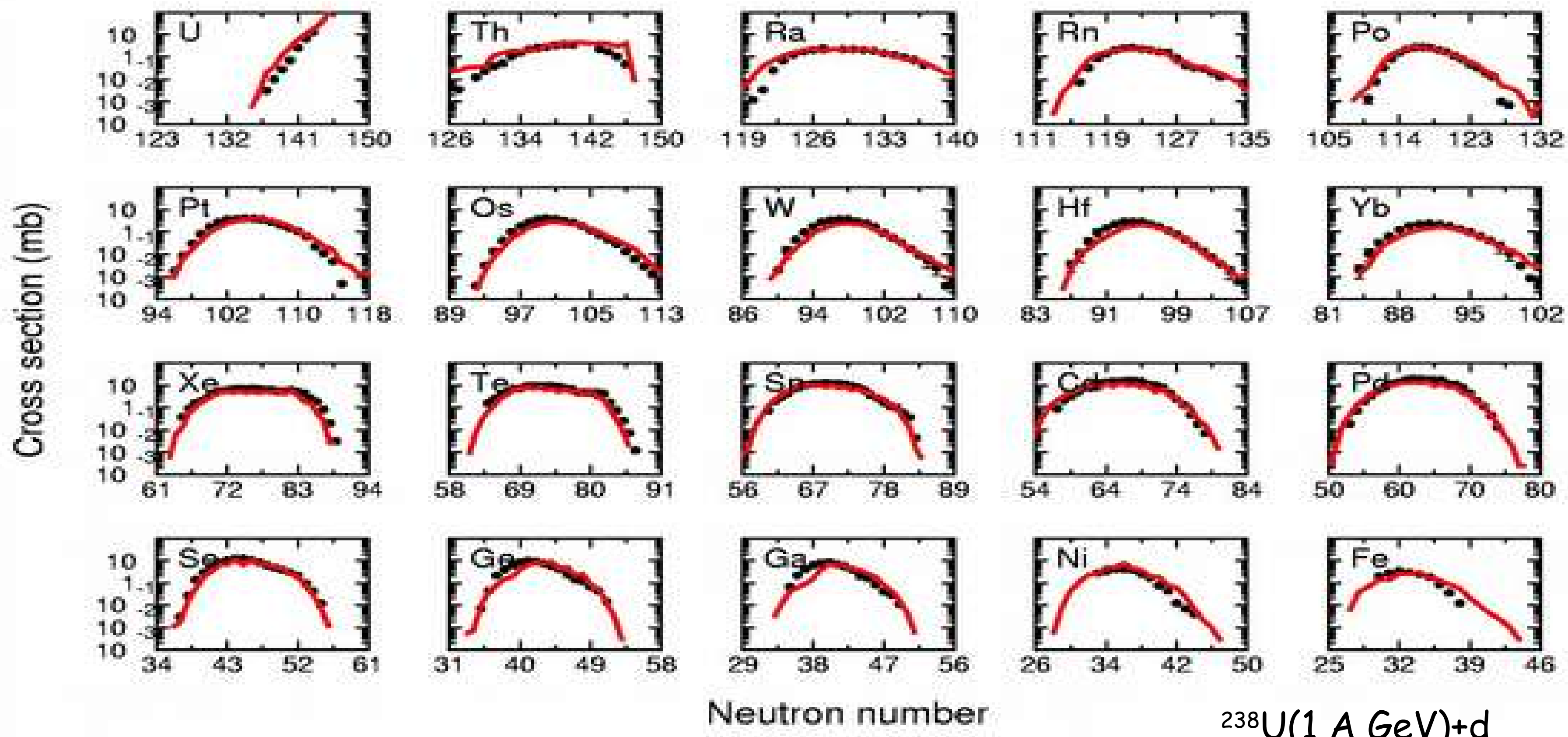
Abrasion
Incomming projectile shears off a sector of the target
The non-overlapping regions of the target and projectile nuclei are
assumed to be undisturbed and unheated. They are so called "spectators".
The hot overlap region forms a "fireball" that decays with release of nucleons and fragments.

Ablasion
The target nucleus have a region of extra surface area, where the projectile cut.
Energy associated with the excess of surface is of about 1 MeV per excess fm^2 of surface area.
The excess of energy becomes available as excitation energy and results
in emission of nucleons and fragments.

(Fission)
Extra excitation energy is released through fission.



Cross sections are smooth functions which can be approximated by gaussian or exponentials in A-A$_{projectile}$



^{238}U(1 A GeV)+d

Model of projectile fragmentation

Momentum width of projectile fragments in the center
Of mass is isotropic and is derived from intrinsic momentum
(removal of the Fermi momentum from equilibrated system).

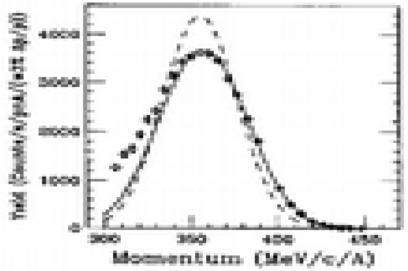


Fig. 2. Momentum distribution for ^{8}Li observed in the fragmentation of ^{16}O at 90 MeV/A in a 790 mg/cm^2 ^{9}Be target. The solid line comes from fitting the data, see caption fig. 1, over the range p/A = 300 to 500 MeV/c. The dashed line is the corresponding Gaussian curve from fragmentation only, while the dotted line was obtained by adding this fitted σ_f in quadrature with the approximate target effect width σ_t from eq. (5). The low momentum tail is easily observed in this figure.

$$\sigma^2 = \sigma_0^2 \frac{A_f (A_p - A_f)}{A_p - 1}$$

$$\sigma_0^2 = \frac{p_F^2}{5}$$

A.S. Goldhaber Phys.Lett. B 53 (1974)

Longitudinal momentum width:

$$\sigma_\parallel^2 = \frac{0.83\, p_F}{\sqrt{5}} \sqrt{\frac{A_f (A_p - A_f)}{A_p - 1}}$$

Transversal momentum width:
(includes corrections due to e.g.
Coulomb deflection).

$$\sigma_\perp^2 = \sigma_\parallel^2 + \frac{A_f (A_f - 1)}{A_p (A_p - 1)} \sigma_2^2$$

$$\sigma_2 = 195 \frac{MeV}{c}$$

ROLE OF ELECTROMAGNETIC SEPARATORS – “IN-FLIGHT” METHODS

primary beam

10^{10} pps

TARGET

primary beam

reaction products

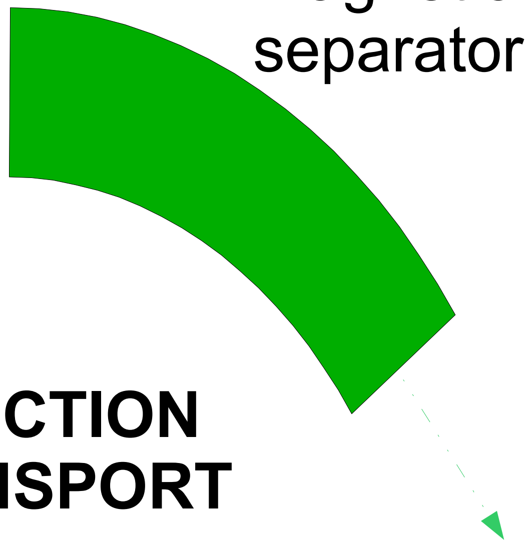
interesting reaction products

10^{10} pps

10^{3} pps

10^{-1} -10^{-3} pps

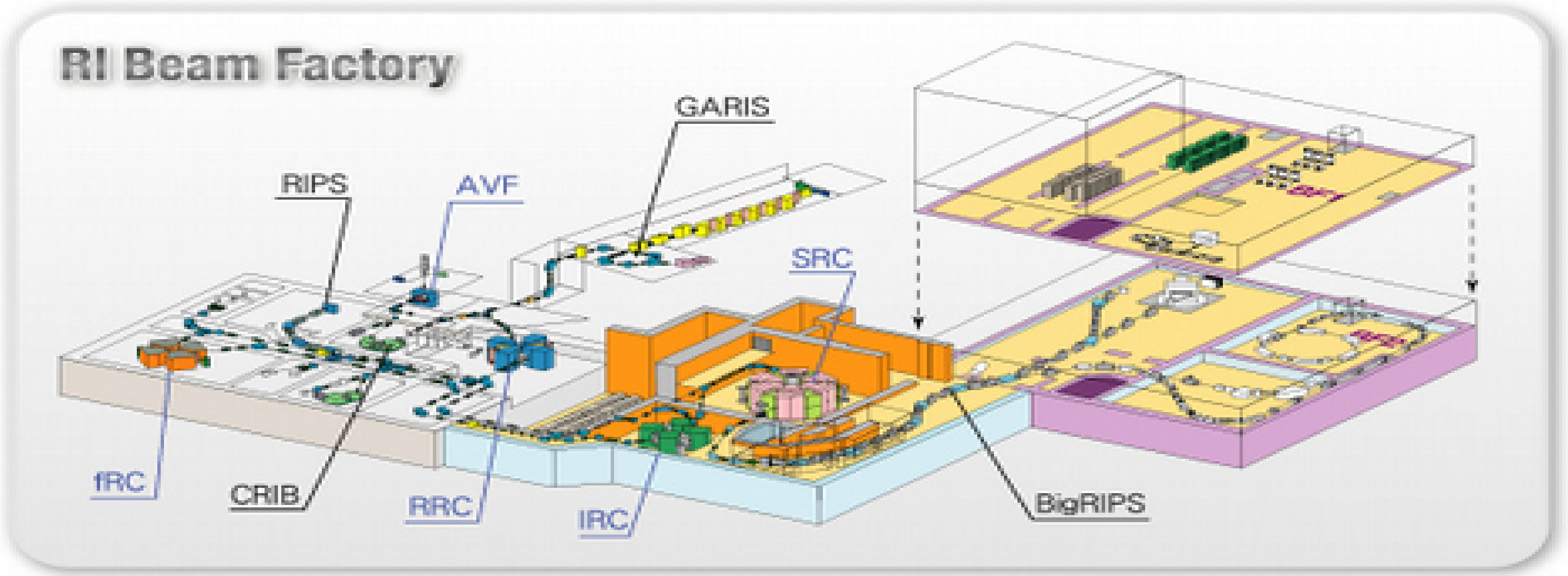
magnetic separator



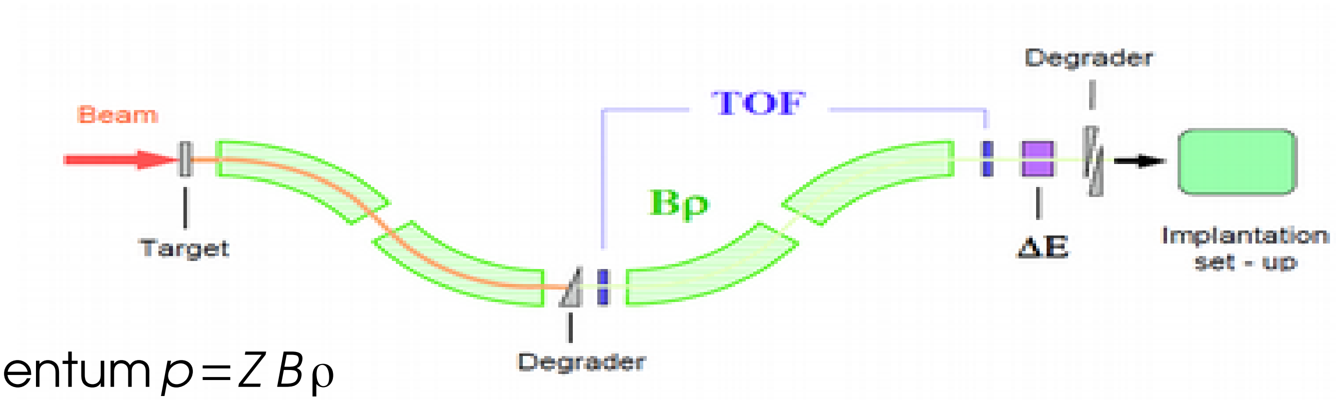
SELECTION
TRANSPORT

interesting reaction products

RIBF at RIKEN (JAPAN)
Primary beams of 350 MeV/nucl.



Large acceptance separators !
Ion identification.



$A\gamma v =$ momentum $p = Z B\rho$

$B\rho$ - magnetic rigidity (magnetic field times bending radius)

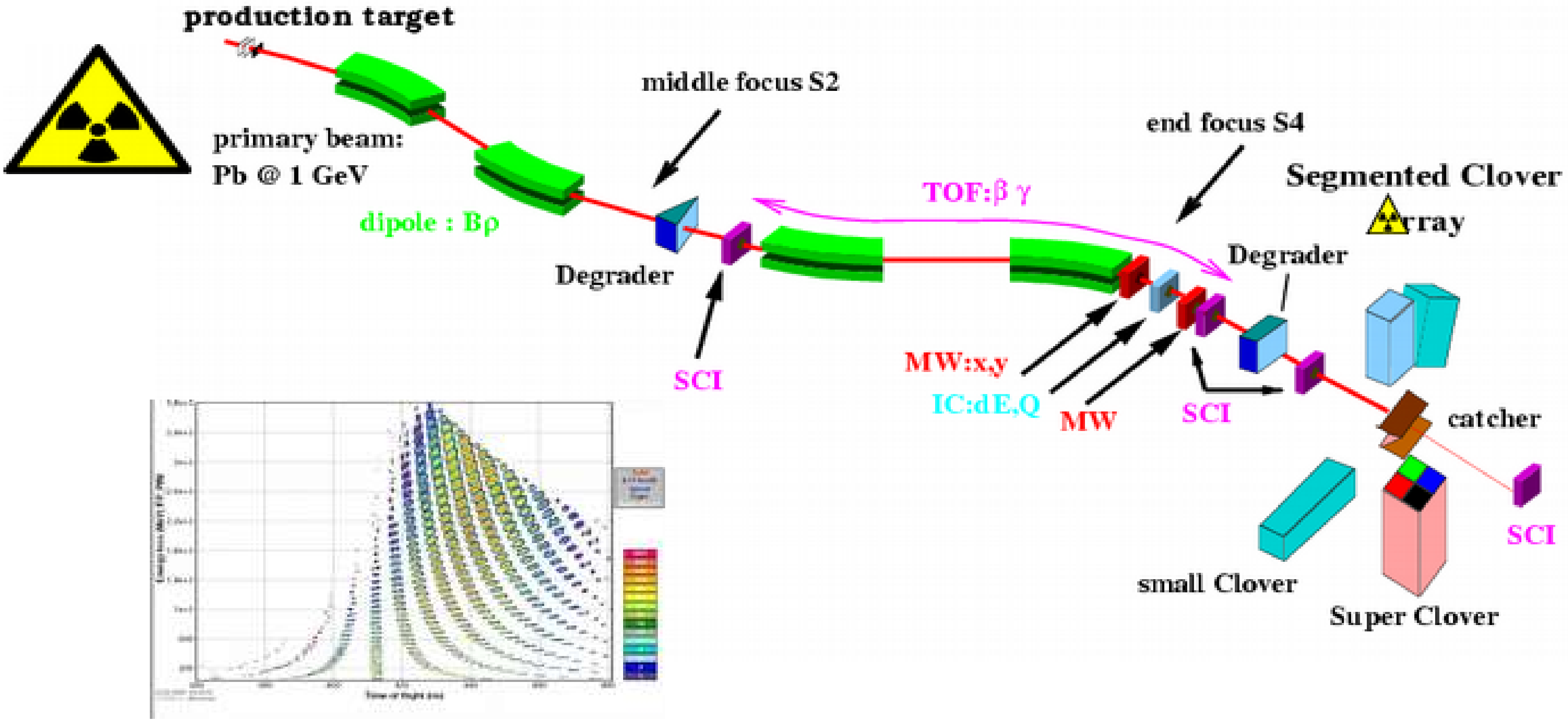
$$\frac{A}{Z} = \frac{B\rho}{v\gamma}$$

Measure: $B, \rho, velocity\,(\text{or } time\ of\ flight)$

$$\Delta E \simeq Z^2$$

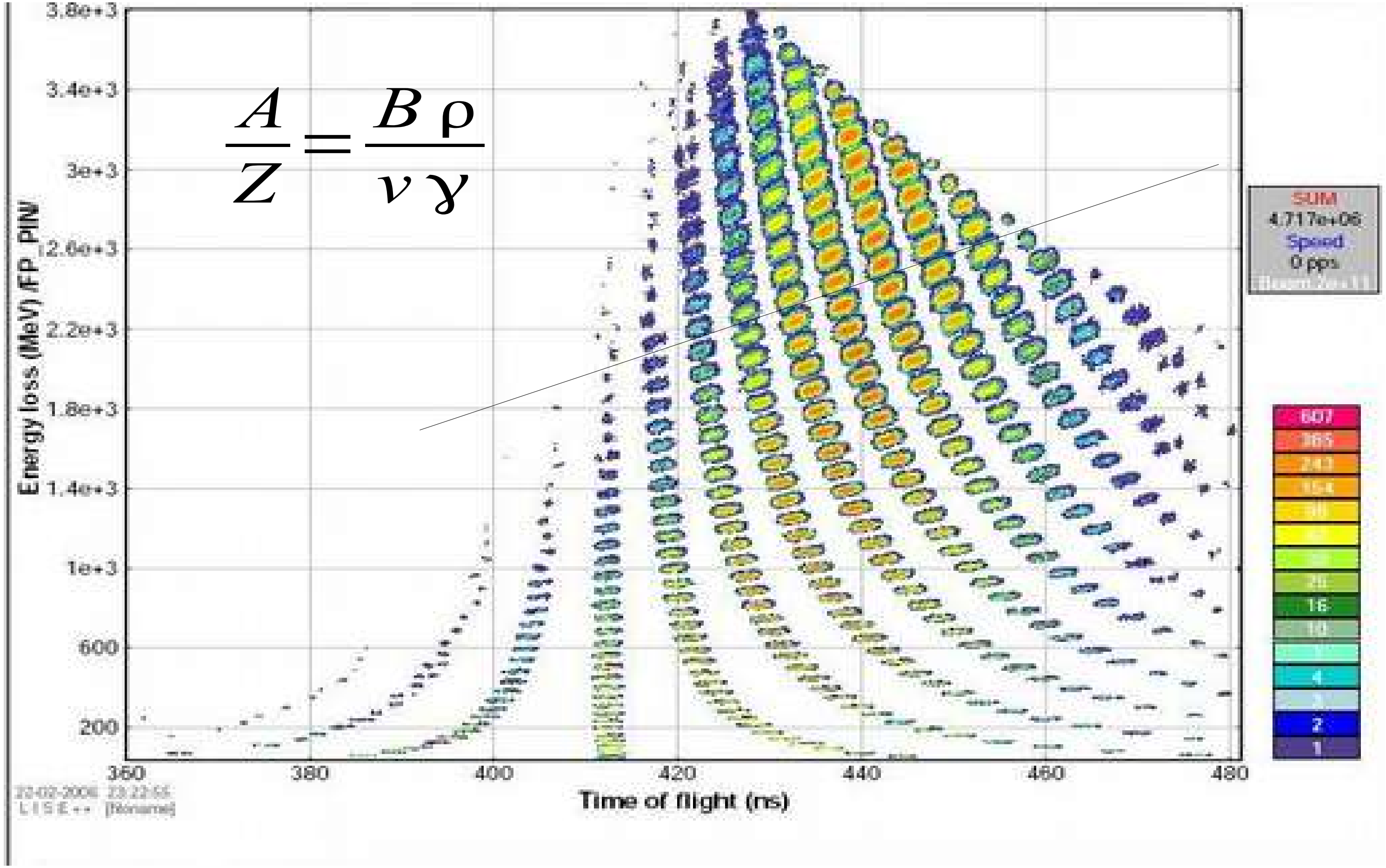
$(Bethe-Bloch\ formula)$

Relativistic heavy ion fragmentation

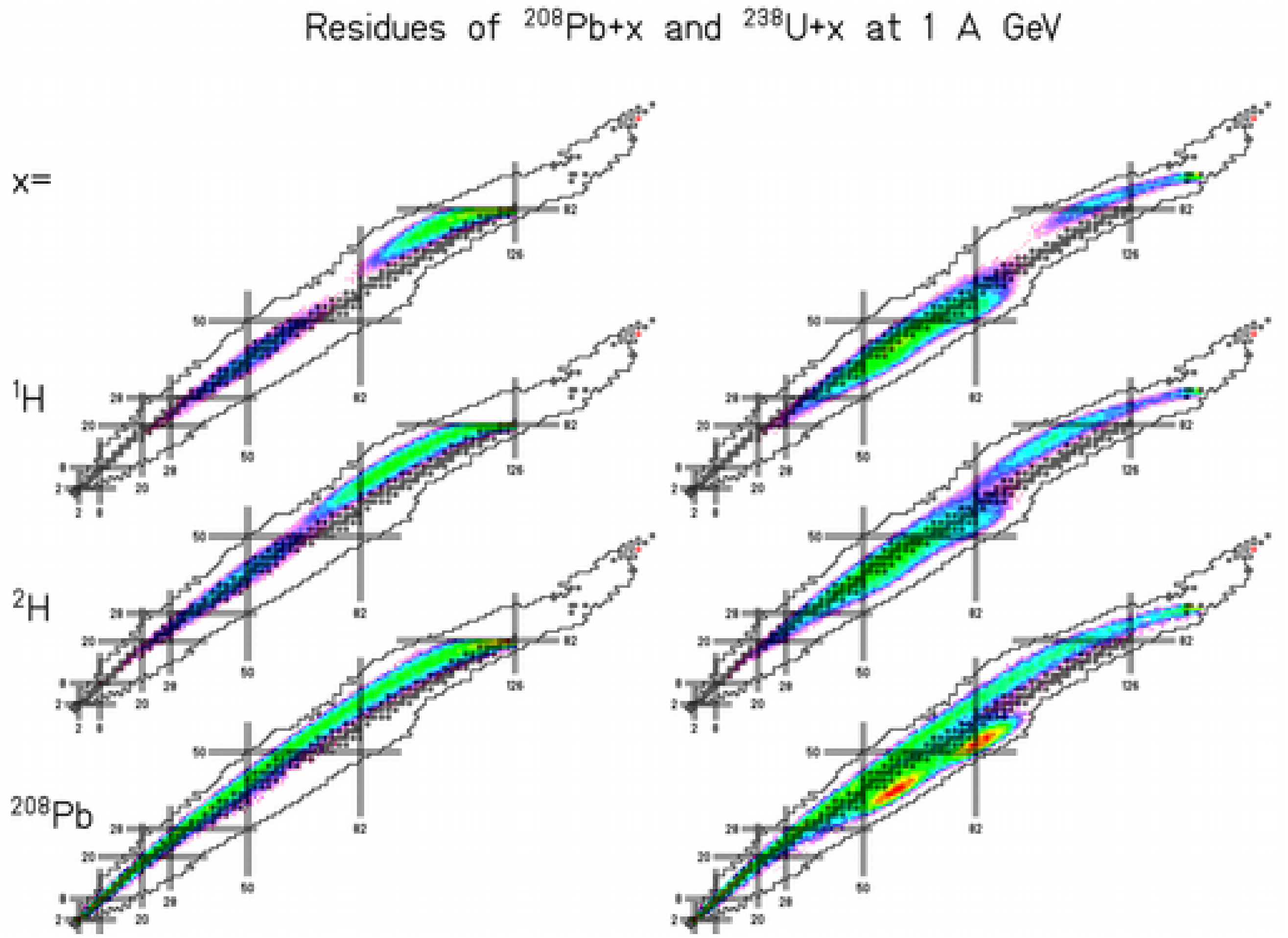


Ion identification plot

$$\frac{A}{Z} = \frac{B\rho}{v\gamma}$$

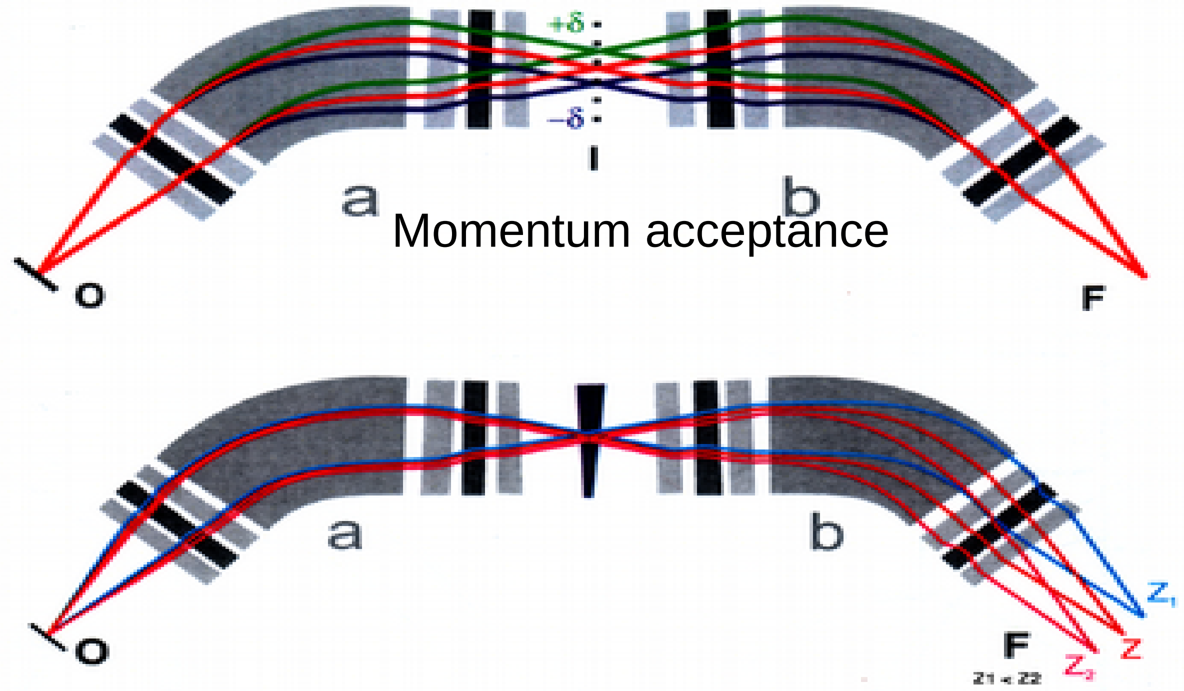


Fragmentation vs. fission



Fragment separator - doubly achromatic device

Focussing of ions independent of their velocity and angular spread

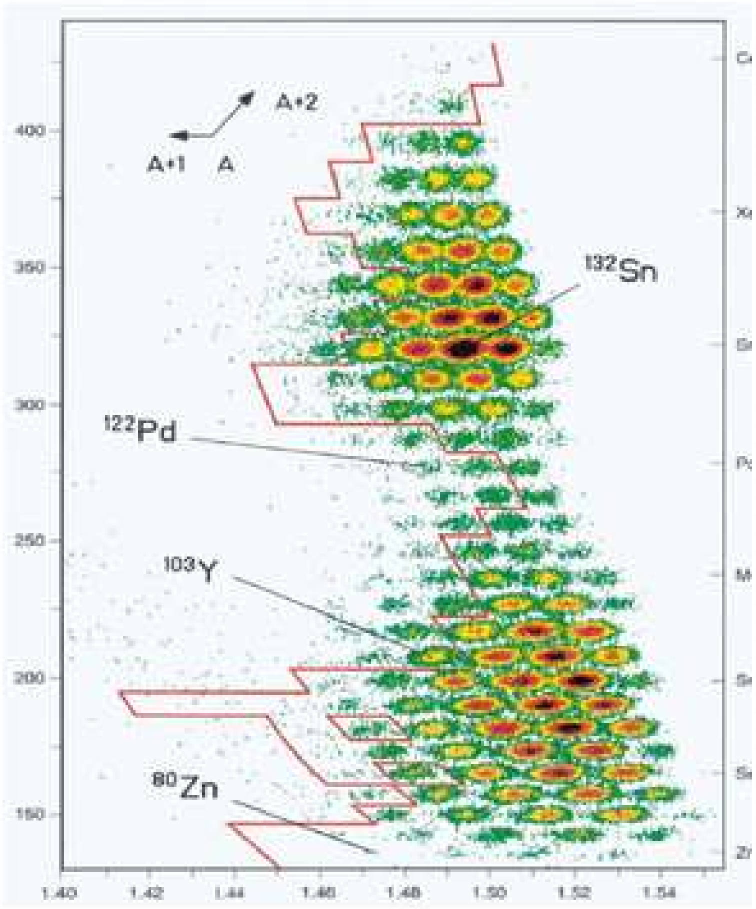


Momentum acceptance

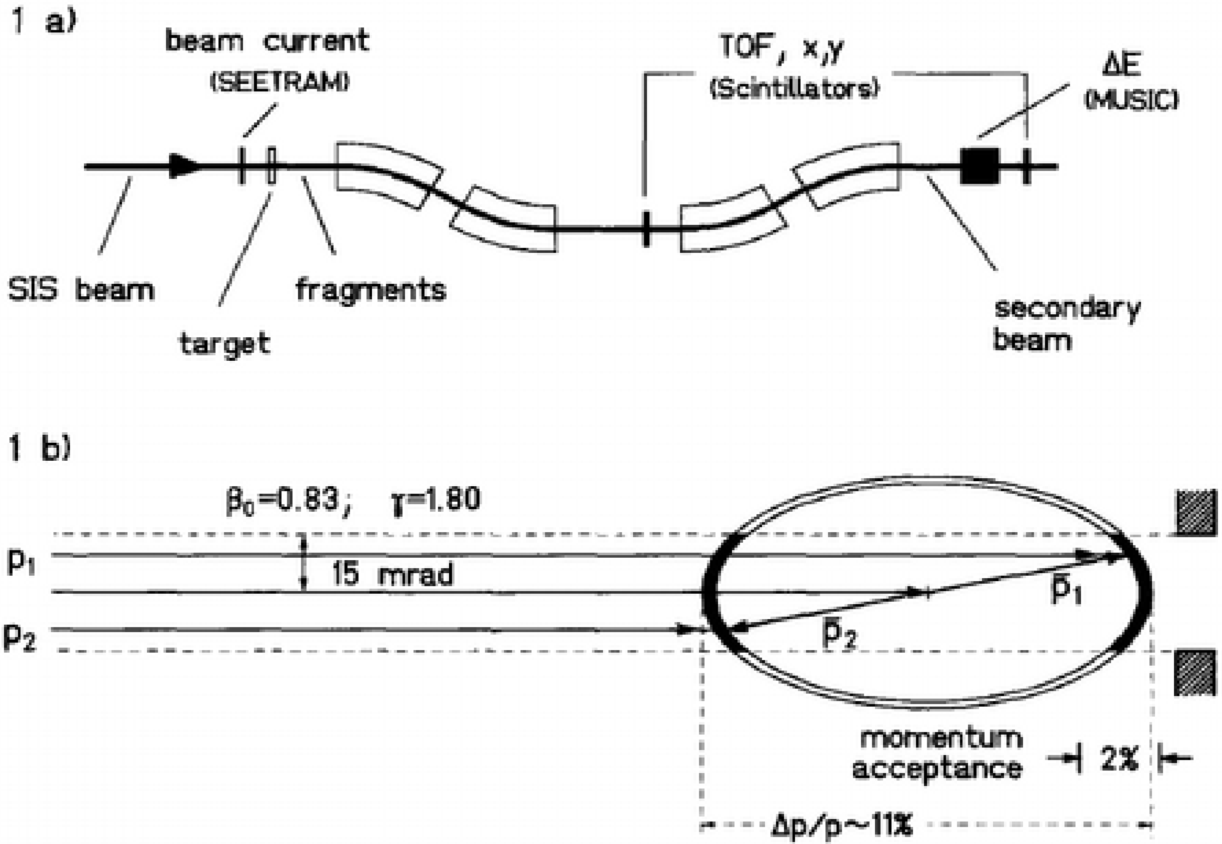
Currently operational:
FRS (GSI, Germany), LiSE (Ganil, France), A1900 (USA),
BIG RIPS (RIKEN,JAPAN)RIBLL (Lanzhou, China)

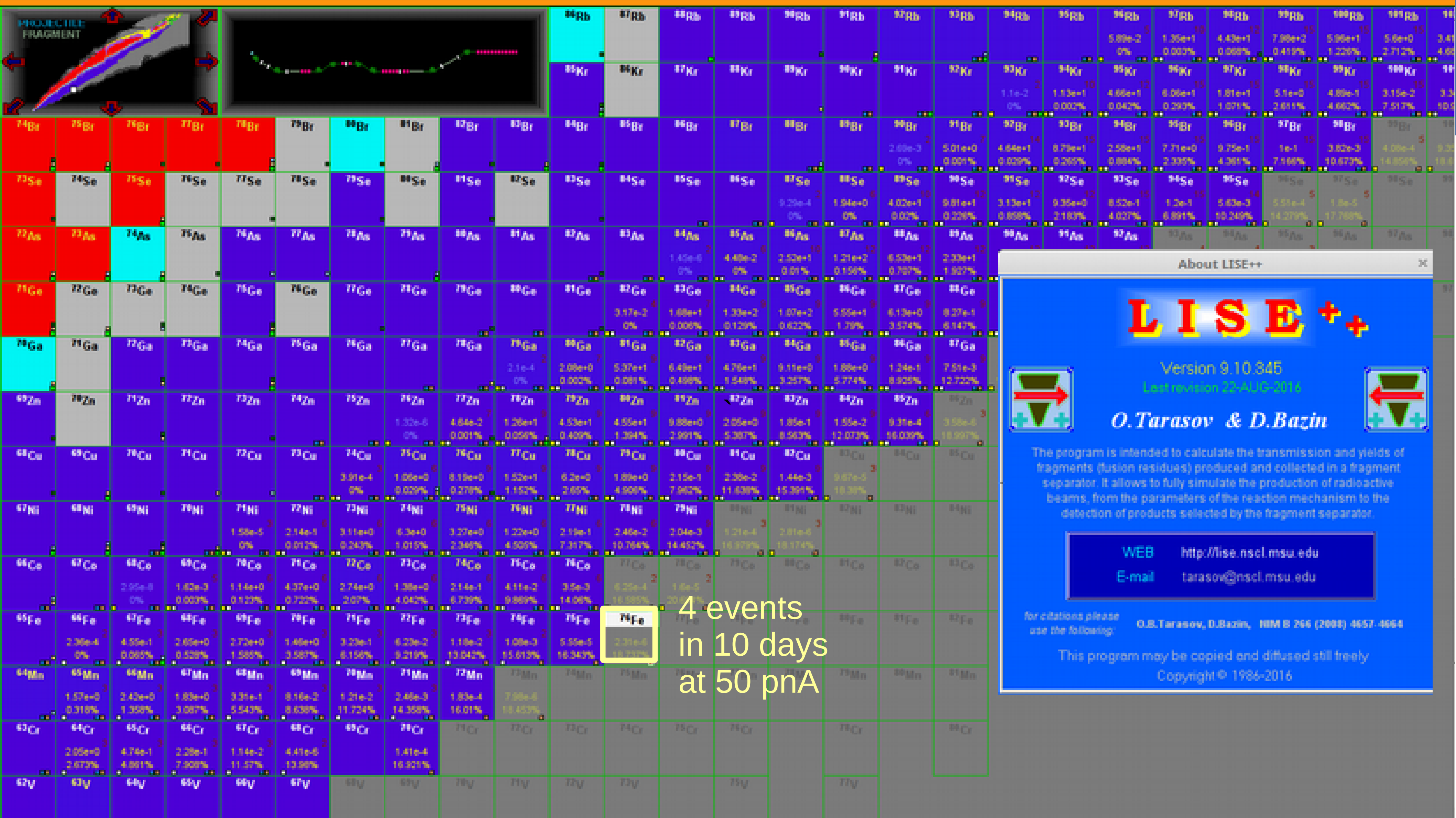
Fission kinematics

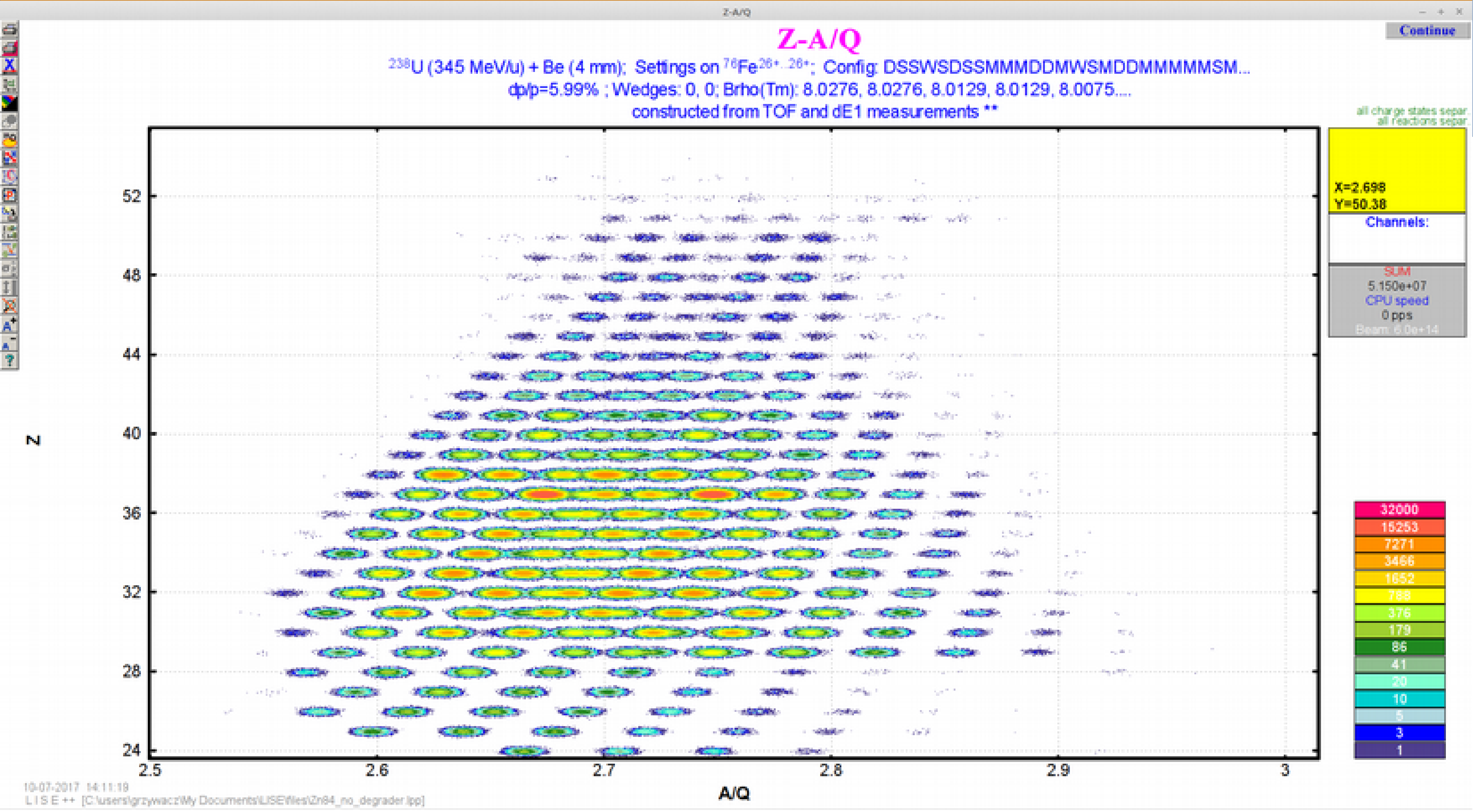
M. Bernas et al. / Physics Letters B 331 (1994) 19-24

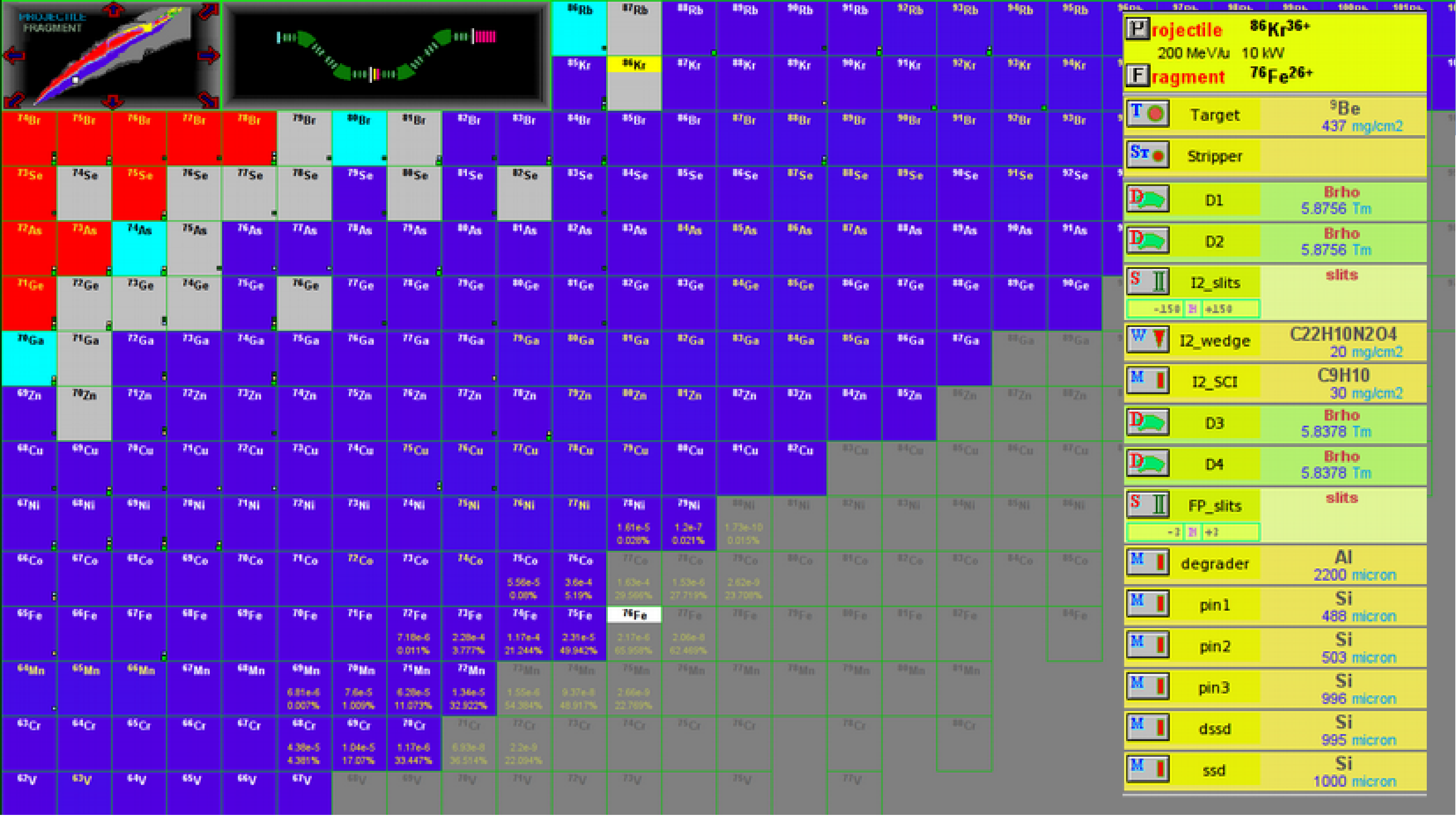


M. Bernas et al. / Physics Letters B 331 (1994) 19–24

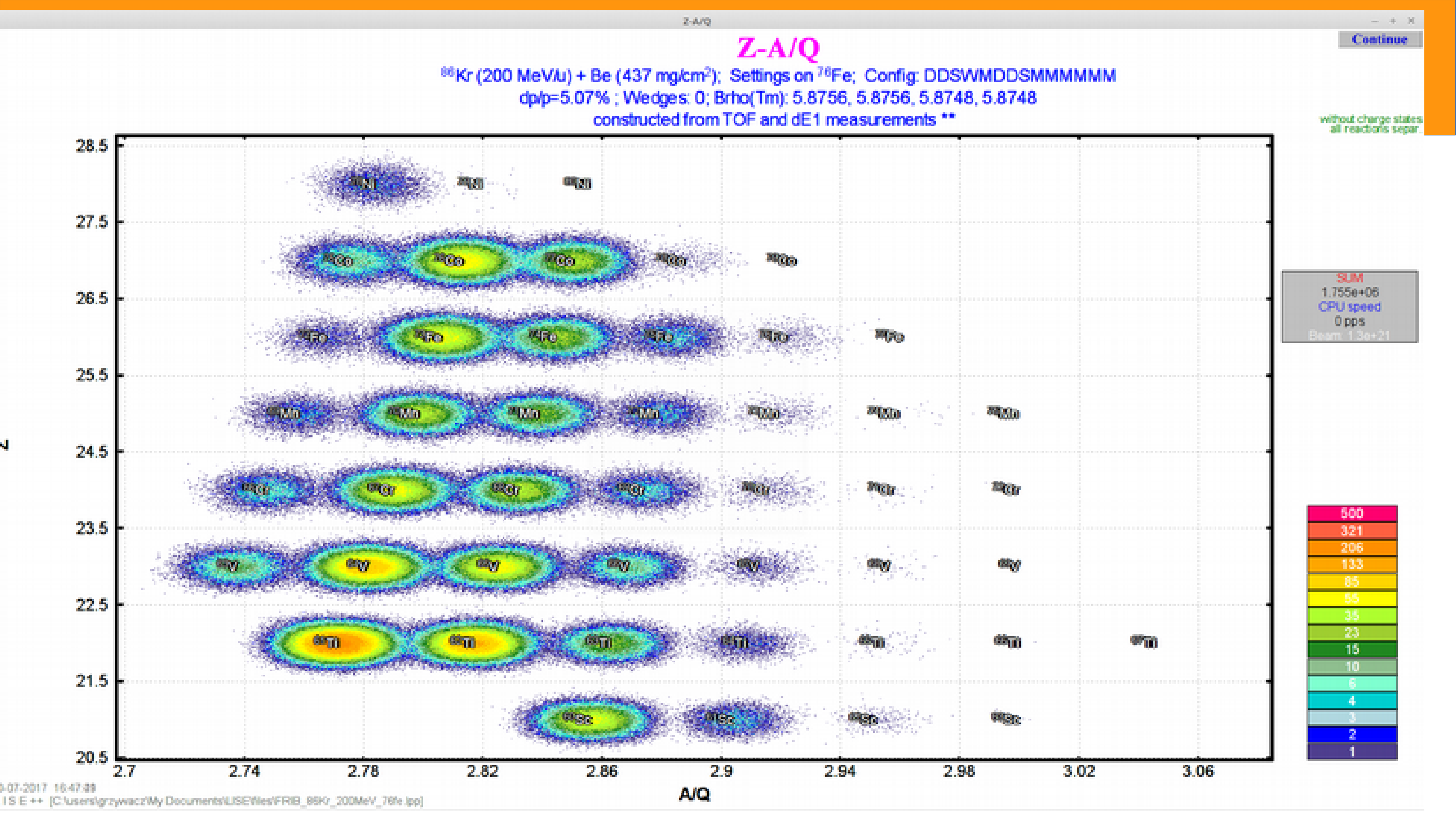



PROJECTILE FRAGMENT
About LISE++
LISE++
Version 9.10.345
Last revision 22-AUG-2016
O.Tarasov & D.Bazin
The program is intended to calculate the transmission and yields of fragments (fusion residues) produced and collected in a fragment separator. It allows to fully simulate the production of radioactive beams, from the parameters of the reaction mechanism to the detection of products selected by the fragment separator.
WEB http://lise.nscl.msu.edu
E-mail tarasov@nscl.msu.edu
for citations please use the following:
O.B.Tarasov, D.Bazin, NIM B 266 (2008) 4657-4664
This program may be copied and diffused still freely
Copyright © 1986-2016
76Fe
4 events
in 10 days
at 50 pnA


Z-A/Q
Continue
Z-A/Q
238U (345 MeV/u) + Be (4 mm); Settings on 76Fe26+, 26+; Config: DSSWSDSSMMMDDMWSMDDMMMMMSM...
dp/p=5.99% ; Wedges: 0, 0; Brho(Tm): 8.0276, 8.0276, 8.0129, 8.0129, 8.0075....
constructed from TOF and dE1 measurements **
all charge states separ
all reactions separ
X=2.698
Y=50.38
Channels:
SUM
5.150e+07
CPU speed
0 pps
Z
52
48
44
40
36
32
28
24
2.5
2.6
2.7
2.8
2.9
3
A/Q
32000
15253
7271
3466
1652
788
376
179
86
41
20
10
5
3
1
10-07-2017 14:11:18
L I S E ++ [C:\users\grzywacz\My Documents\LISE\files\Zn84_no_degrader.lpp]



PROJECTILE
FRAGMENT
Projectile 86Kr36+
200 MeV/u 10 kW
Fragment 76Fe26+
Target
9Be
437 mg/cm2
Stripper
D1
Brho
5.8756 Tm
D2
Brho
5.8756 Tm
I2_slits
slits
-150 +150
I2_wedge
C22H10N2O4
20 mg/cm2
I2_SCI
C9H10
30 mg/cm2
D3
Brho
5.8378 Tm
D4
Brho
5.8378 Tm
FP_slits
slits
-3 +3
degrader
Al
2200 micron
pin1
Si
488 micron
pin2
Si
503 micron
pin3
Si
996 micron
dssd
Si
995 micron
ssd
Si
1000 micron


Z-A/Q
Continue
Z-A/Q
^{86}Kr (200 MeV/u) + Be (437 mg/cm^2); Settings on ^{76}Fe; Config: DDSWMDDSMMMMMM
dp/p=5.07% ; Wedges: 0; Brho(Tm): 5.8756, 5.8756, 5.8748, 5.8748
constructed from TOF and dE1 measurements **
without charge states
all reactions separ.
SUM
1.755e+06
CPU speed
0 pps
Z
A/Q
500
321
206
133
85
55
35
23
15
10
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4
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2
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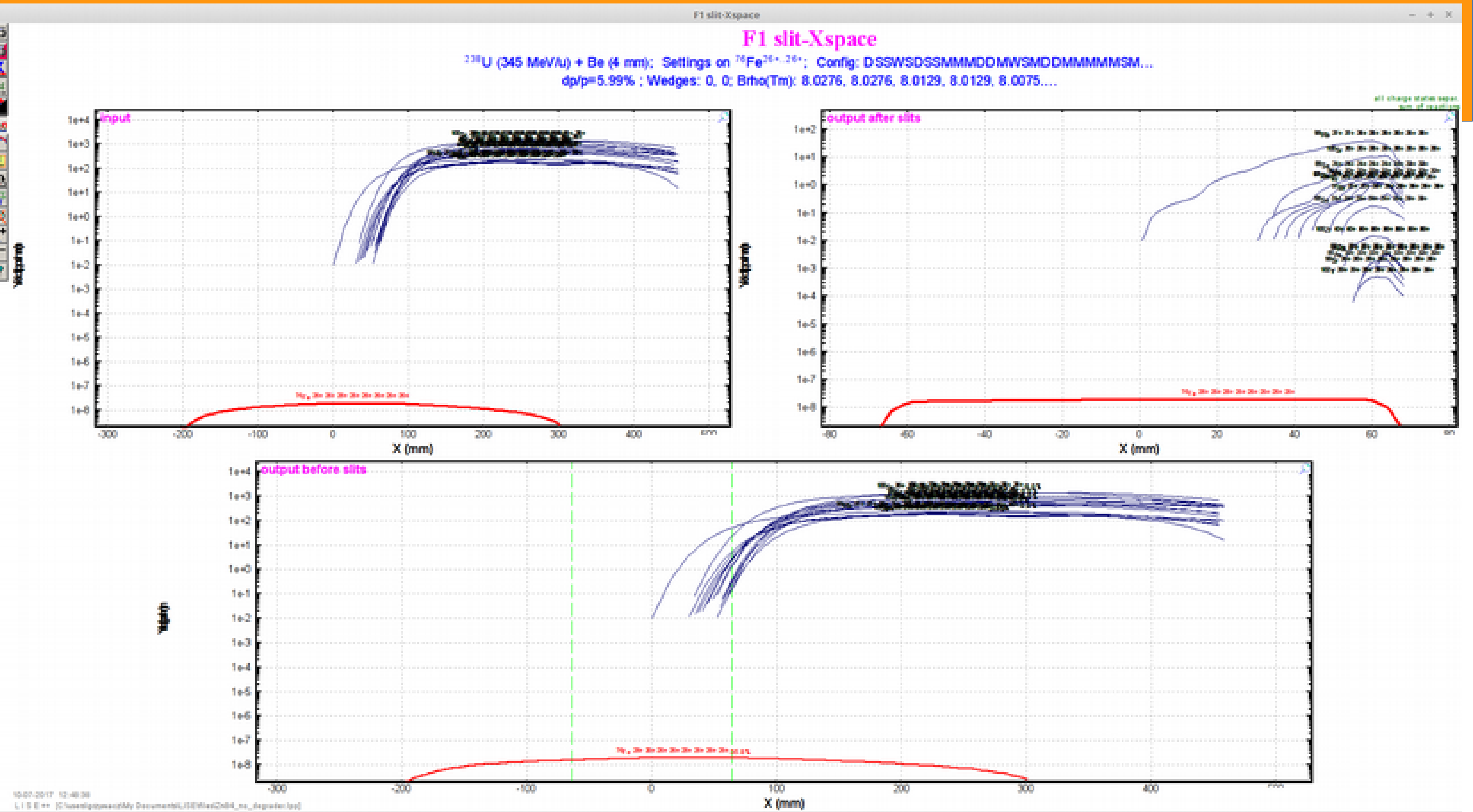
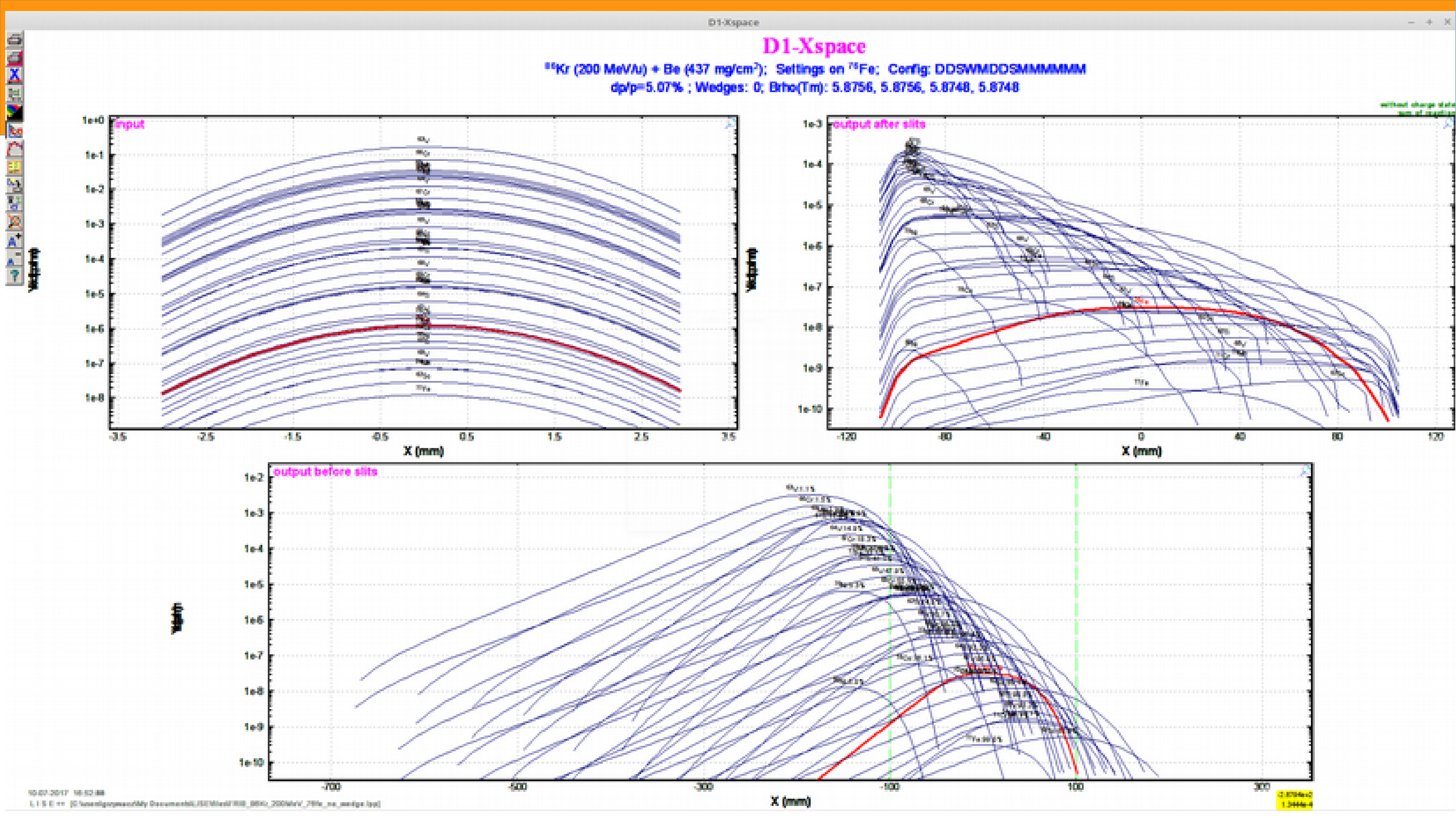
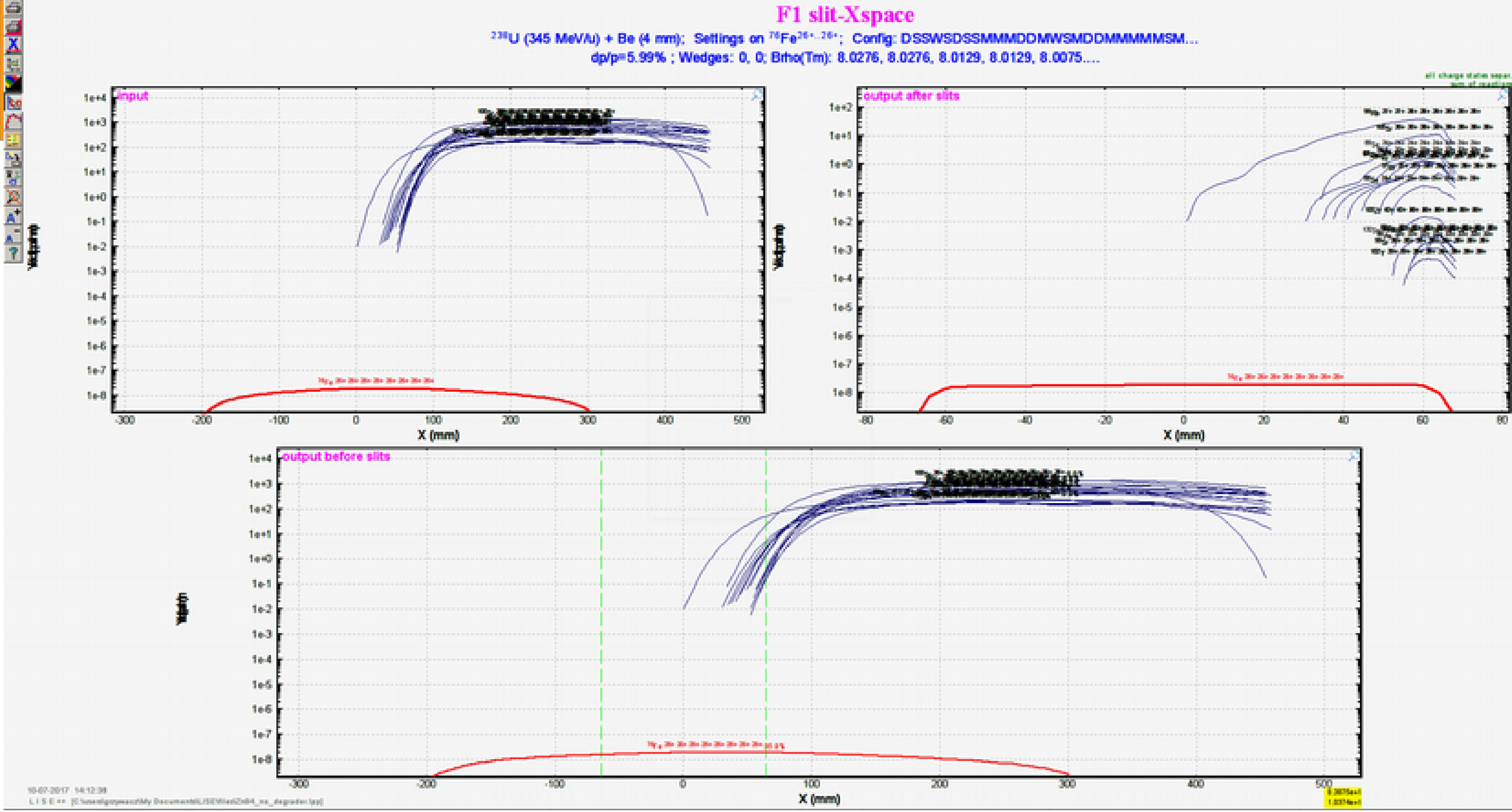
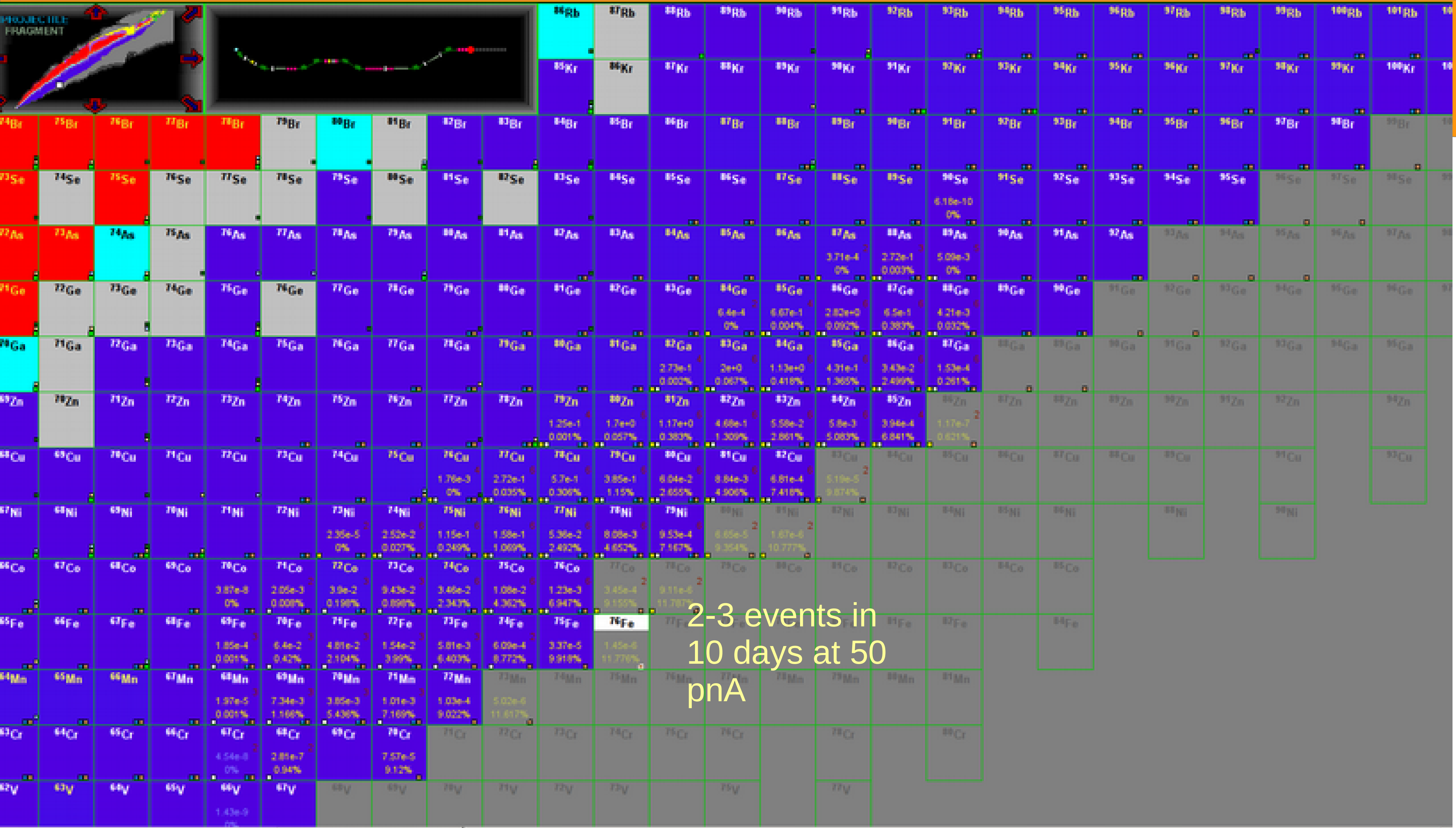
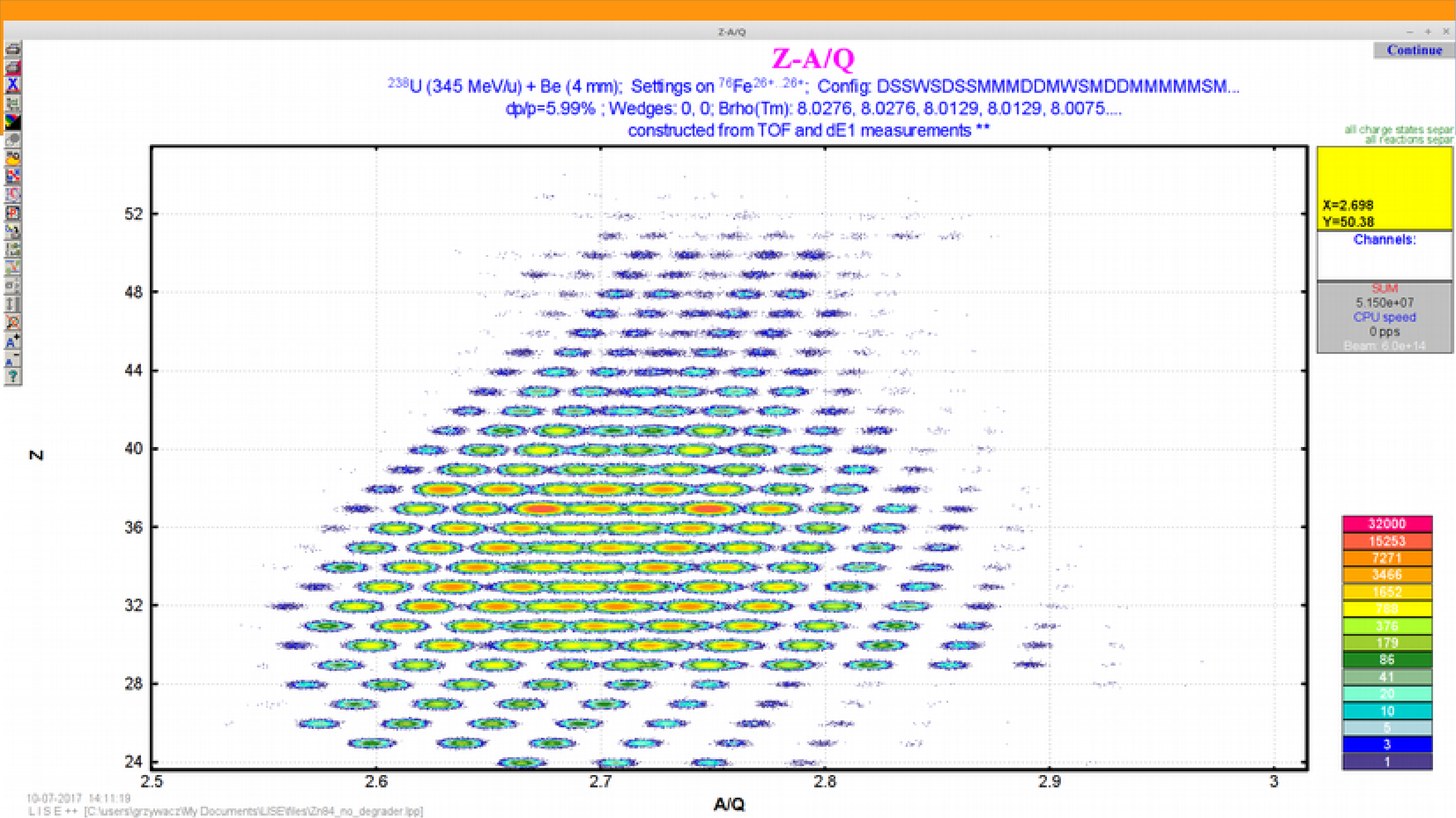
L I S E ++ [C:\users\grzywacz\My Documents\LISE\files\FRIB_86Kr_200MeV_76fe.lpp]


F1 slit-Xspace
F1 slit-Xspace
238U (345 MeV/u) + Be (4 mm); Settings on 76Fe26+..26+; Config: DSSWSDSSMMMDDMWSMDDMMMMMSM...
dp/p=5.99% ; Wedges: 0, 0; Brho(Tm): 8.0276, 8.0276, 8.0129, 8.0129, 8.0075....
input
output after slits
output before slits
X (mm)
X (mm)
X (mm)


D1-Xspace
D1-Xspace
dp/p=5.07% ; Wedges: 0; Brho(Tm): 5.8756, 5.8756, 5.8748, 5.8748
input
output after slits
output before slits
X (mm)
X (mm)
X (mm)


F1 slit-Xspace
238U (345 MeV/u) + Be (4 mm); Settings on 76Fe26+..26+; Config: DSSWSDSSMMMDDMWSMDDMMMMMSM...
dp/p=5.99% ; Wedges: 0, 0; Brho(Tm): 8.0276, 8.0276, 8.0129, 8.0129, 8.0075....
input
X (mm)
output after slits
X (mm)
output before slits
X (mm)


2-3 events in
10 days at 50
pnA


Z-A/Q
Continue
Z-A/Q
^{238}U (345 MeV/u) + Be (4 mm); Settings on ^{78}Fe$^{26+..26+}$; Config: DSSWSDSSMMMDDMWSMDDMMMMMSM...
dp/p=5.99% ; Wedges: 0, 0; Brho(Tm): 8.0276, 8.0276, 8.0129, 8.0129, 8.0075....
constructed from TOF and dE1 measurements **
all charge states separ
all reactions separ
X=2.698
Y=50.38
Channels:
SUM
5.150e+07
CPU speed
0 pps
Beam: 6.0e+14
Z
52
48
44
40
36
32
28
24
2.5
2.6
2.7
2.8
2.9
3
A/Q
32000
15253
7271
3466
1652
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376
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20
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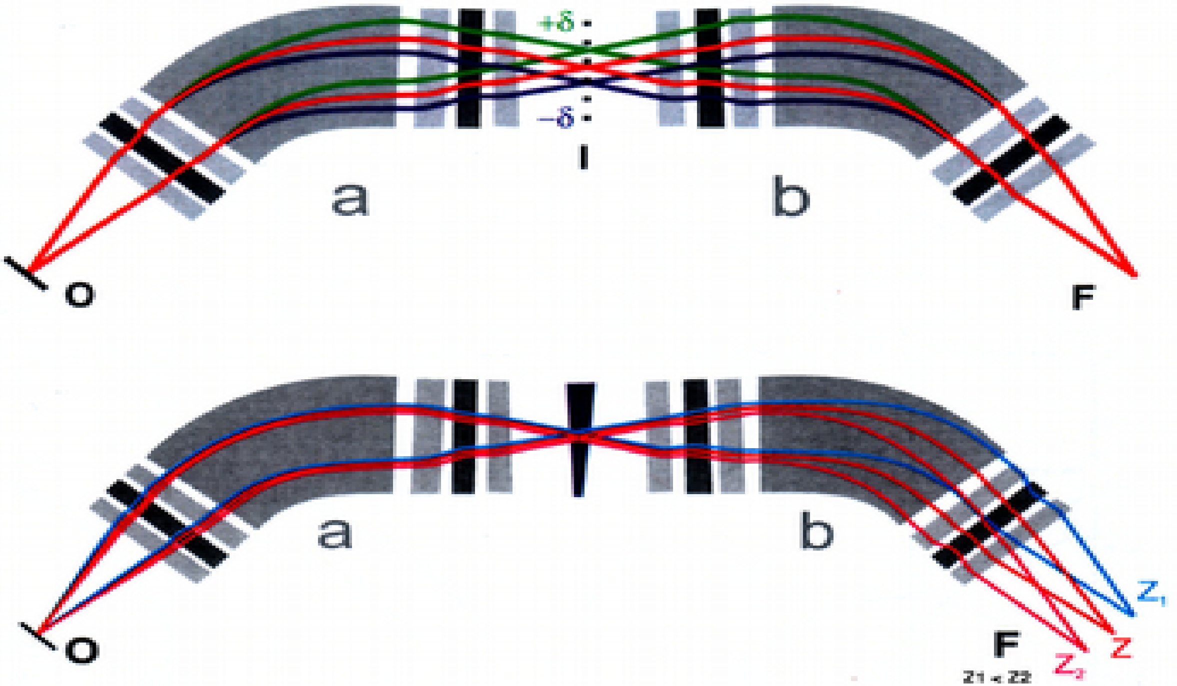
1
10-07-2017 14:11:19
L I S E ++ [C:\users\grzywacz\My Documents\LISE\files\Zn84_no_degrader.lpp]

Fragment separator - doubly achromatic device

Focussing of ions independent of their velocity and angular spread



Currently operational:
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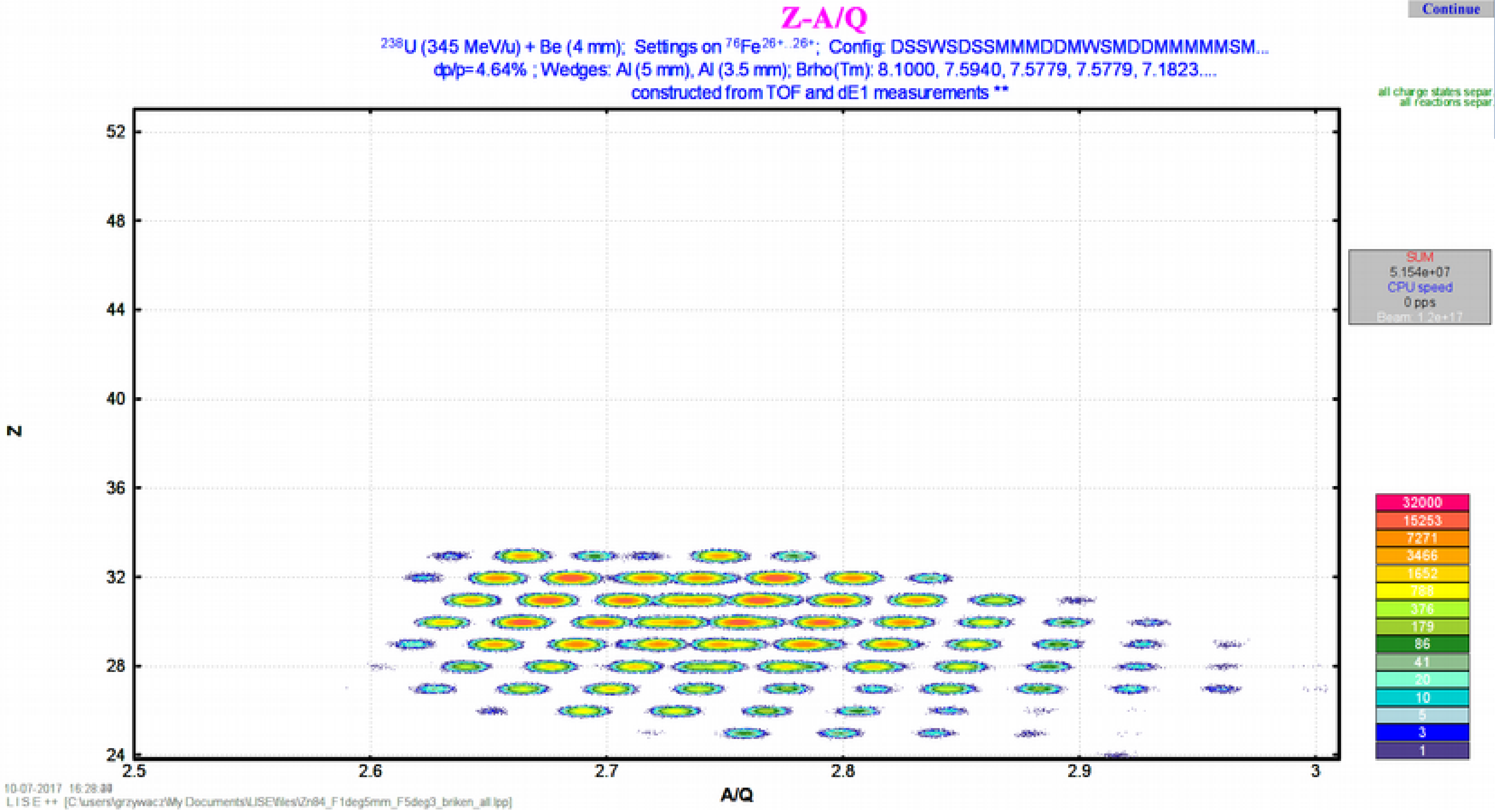
BIG RIPS (RIKEN,JAPAN)RIBLL (Lanzhou, China)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dp/p=4.64% ; Wedges: Al (5 mm), Al (3.5 mm); Brho(Tm): 8.1000, 7.5940, 7.5779, 7.5779, 7.1823....
constructed from TOF and dE1 measurements **
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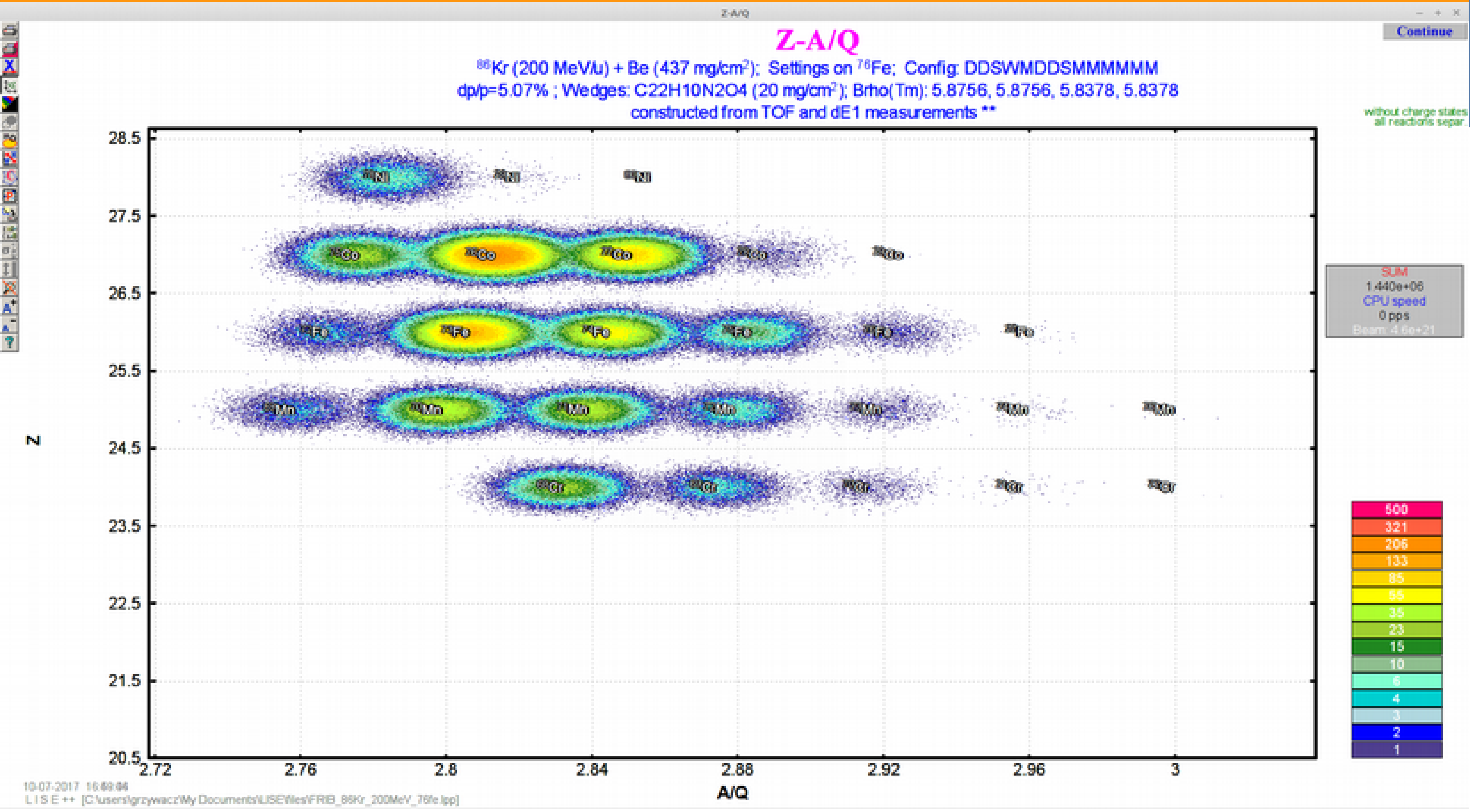
Z-A/Q
Continue
Z-A/Q
86Kr (200 MeV/u) + Be (437 mg/cm2); Settings on 76Fe; Config: DDSWMDDSMMMMMM
dp/p=5.07% ; Wedges: C22H10N2O4 (20 mg/cm2); Brho(Tm): 5.8756, 5.8756, 5.8378, 5.8378
constructed from TOF and dE1 measurements **
without charge states
all reactions separ.
SUM
1.440e+06
CPU speed
0 pps
28.5
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26.5
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24.5
23.5
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21.5
20.5
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2.84
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