First experiment with a ^{208}Pb at NSCL

Oleg B. Tarasov

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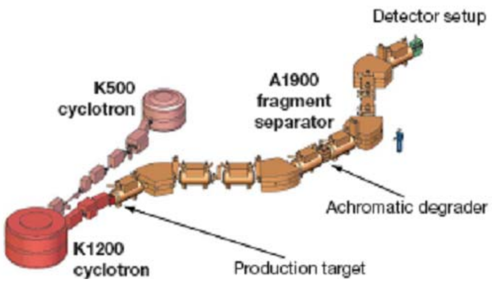
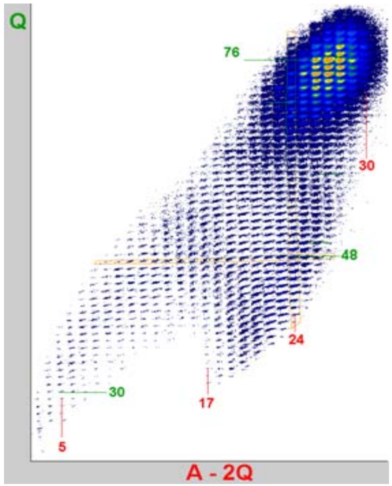


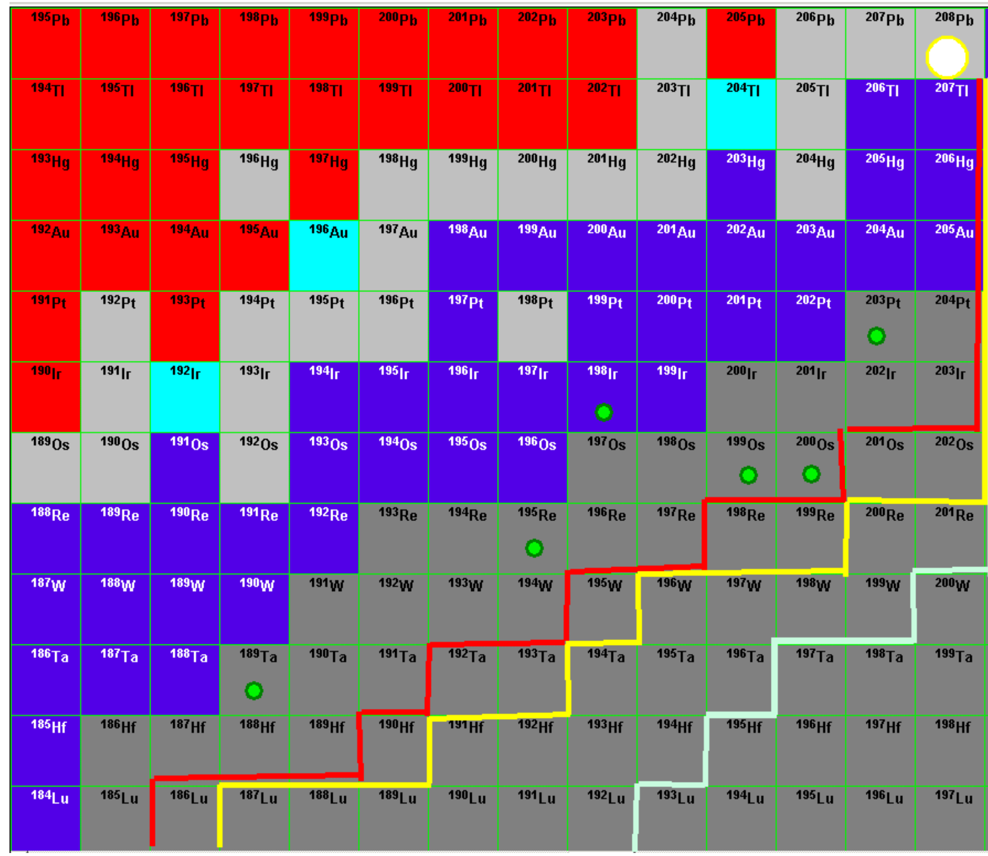


1a. Goals of the #05120 experiment

proposal: Achieving isotopic identification of A~200 amu would be an important technological development for the Coupled Cyclotron Facility. It would allow for the possibility to expand experiments to elements heavier than Xenon and would open a new, wide area of neutron-rich isotopes.

- ***Can we distinguish isotopic separation in the Z=82 region using the dE-E-ToF-Bρ measurement technique at intermediate energies?***

- ***Study of the production mechanism. First observation of isotopes?***



Beam: ^{208}**Pb (1pnA)**
27+ 08.10 MeV/nuc (K500)
63+ 85.00 MeV/nuc (K1200)
RF: **23.86532 MHz**

48hours

The yellow solid line shows the limit for the neutron-rich side which has reached in the GSI experiment*.
The red line shows the boundary of nuclei implanted in detectors to study their properties*.
Green circles show nucleus the time of lives whose were measured.
The white line shows the limit of 1 event per day statistics calculated by LISE++ with EPAX2 in the ^{208}Pb (80MeV/u, 1pna)+ Be(140mg/cm^2) reaction using A1900 separator (dp/p=1%).

** T.Kurtukian-Nieto et al., Contribution in the International Symposium on Exotic Nuclear System, Atomki, Debrecen, Hungary, 20-24 June 2005.*

1a. Goals of the #05120 experiment

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Can we distinguish isotopic separation (A,Z,Q) in the Z=82 region using the dE-E-ToF-Bρ measurement technique at intermediate energies?

The atomic number is determined from the combination of energy loss (ΔE) and time of flights (TOF) values according to the Bethe formula:

$$Z \approx \sqrt{\Delta E \Big/ \left(\frac{1}{\beta^2} \ln\left(\frac{5930}{1/\beta^2 - 1} \right) - 1 \right)} . \qquad /1/$$

The fragment mass can be extracted in atomic units from the relativistic formula:

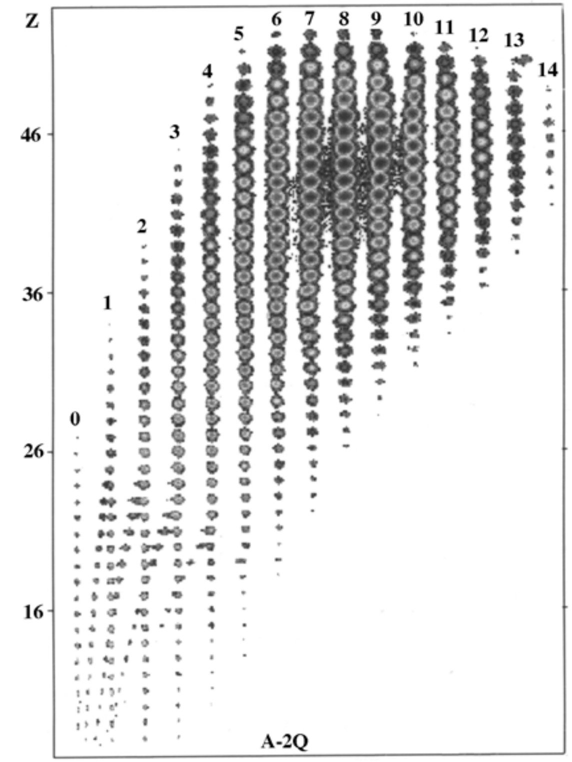
$$A = \frac{TKE}{931.5 \times (\gamma - 1)} , \qquad /2/$$

where TKE is calculated as a sum of the energy loss values in each of the detectors in a multilayer telescope stopping the products. The charge state (Q) of the ion evaluated from a relation based on the TKE, velocity and magnetic rigidity values:

$$Q = 3.33 \times 10^{-3} \frac{TKE \times \beta\gamma}{B\rho(\gamma - 1)} . \qquad /3/$$

Equations 1-3 can be used to determine the experimental resolution in ΔE, Bρ, TKE, and TOF necessary to successfully identify heavy fragments . These conditions are as follows:

1. The time resolution (RMS) should be better than 0.2%.
2. The TKE resolution should be better than 0.8%.
3. The energy loss resolution should be better than 1.0%
4. The Bρ-resolution should be better than 0.2%.



Identification plot of fully stripped fragments in the reaction ^{112}Sn(63MeV/u)+Ni.

M.Lewitowicz et al., Nucl.Phys. A583 (1995) 857.

But…

1b. Energy loss resolution due to charge state fluctuations

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Nuclear Instruments and Methods in Physics Research B 193 (2002) 1–7

NIM B Beam Interactions with Materials & Atoms

www.elsevier.com/locate/nimb

Energy-loss straggling of (200–1000) MeV/u uranium ions

H. Weick [a,*], A.H. Sørensen [b], H. Geissel [a,c], C. Scheidenberger [a], F. Attallah [a], V. Chichkine [a,c], S. Elisseev [c], M. Hausmann [a], H. Irnich [c], Y. Litvinov [a,c], B. Lommel [a], M. Maier [a,c], M. Matoš [a], G. Münzenberg [a], N. Nankov [a,c], F. Nickel [a], W. Schwab [a], Th. Stöhlker [a], K. Sümmerer [a], B. Voss [a]

[a] *Gesellschaft für Schwerionenforschung GSI, 64291 Darmstadt, Germany*

[b] *Institute of Physics and Astronomy, University of Aarhus, 8000 Aarhus C, Denmark*

[c] *II. Physikalisches Institut, University of Giessen, 35392 Giessen, Germany*

The energy-loss straggling of partially ionized heavy ions is determined by both the stochastic fluctuations of the energy loss in atomic collisions with fixed charge states, the **collisional straggling** and by the influence of charge-state fluctuations, the **charge-exchange straggling**.

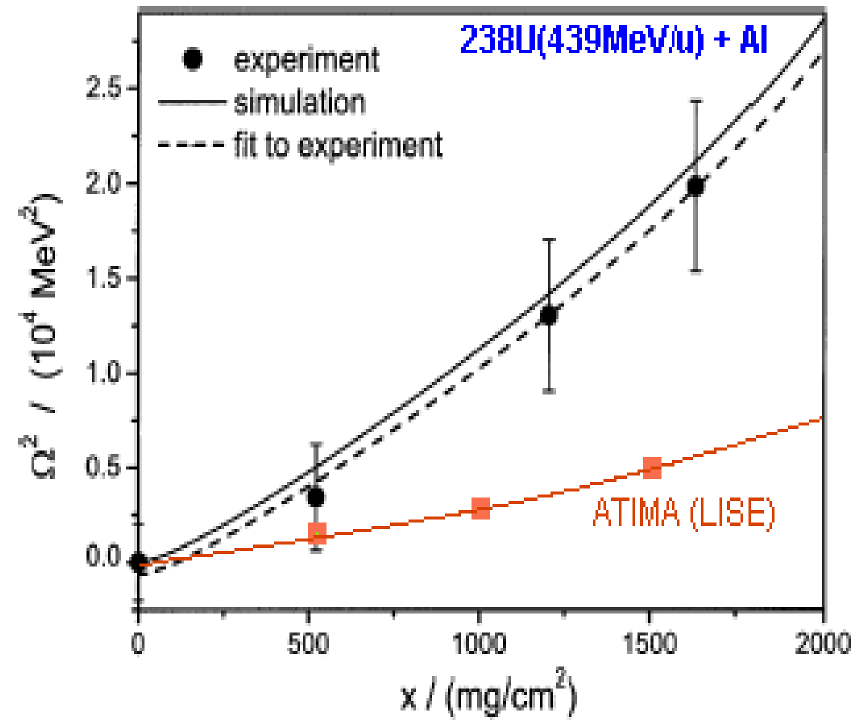


Fig. 2. Measured and simulated energy-loss straggling for uranium ions impinging with 439 MeV/u on different aluminum targets. Incident and exit charge state are both 91^+.

1b. Energy loss resolution due to charge state fluctuations

Charge state fluctuations may limit the energy loss resolution. The measurement will determine how important it is. " **(Proposal #5120)**

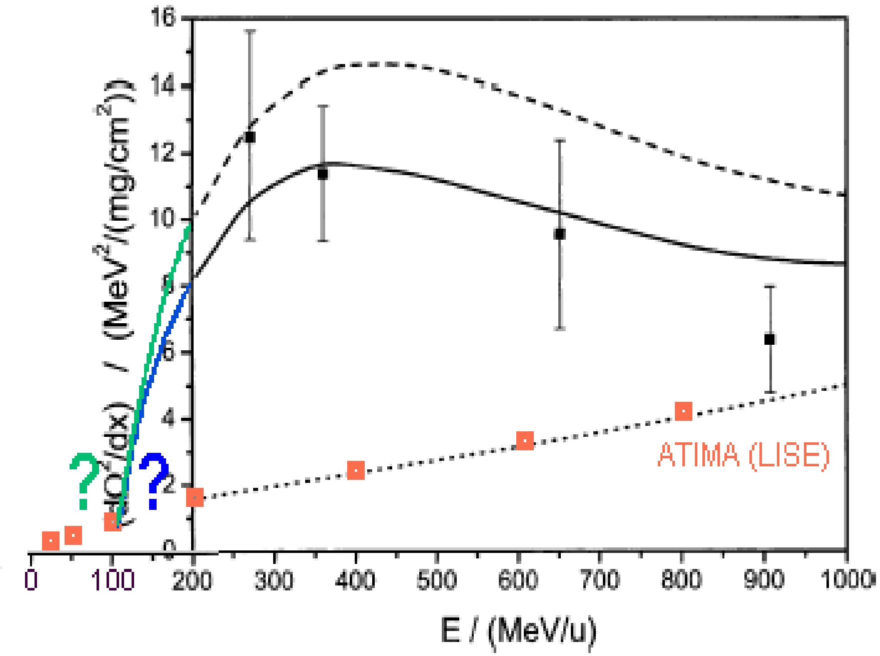


Fig. 3. Differential energy-loss straggling including charge exchange of uranium ions in aluminum: experimental values (points), theory with stopping power calculated for realistic charge distribution (—), theory with stopping power of point-like charges (– – –), and the contribution from collisional straggling only (···).

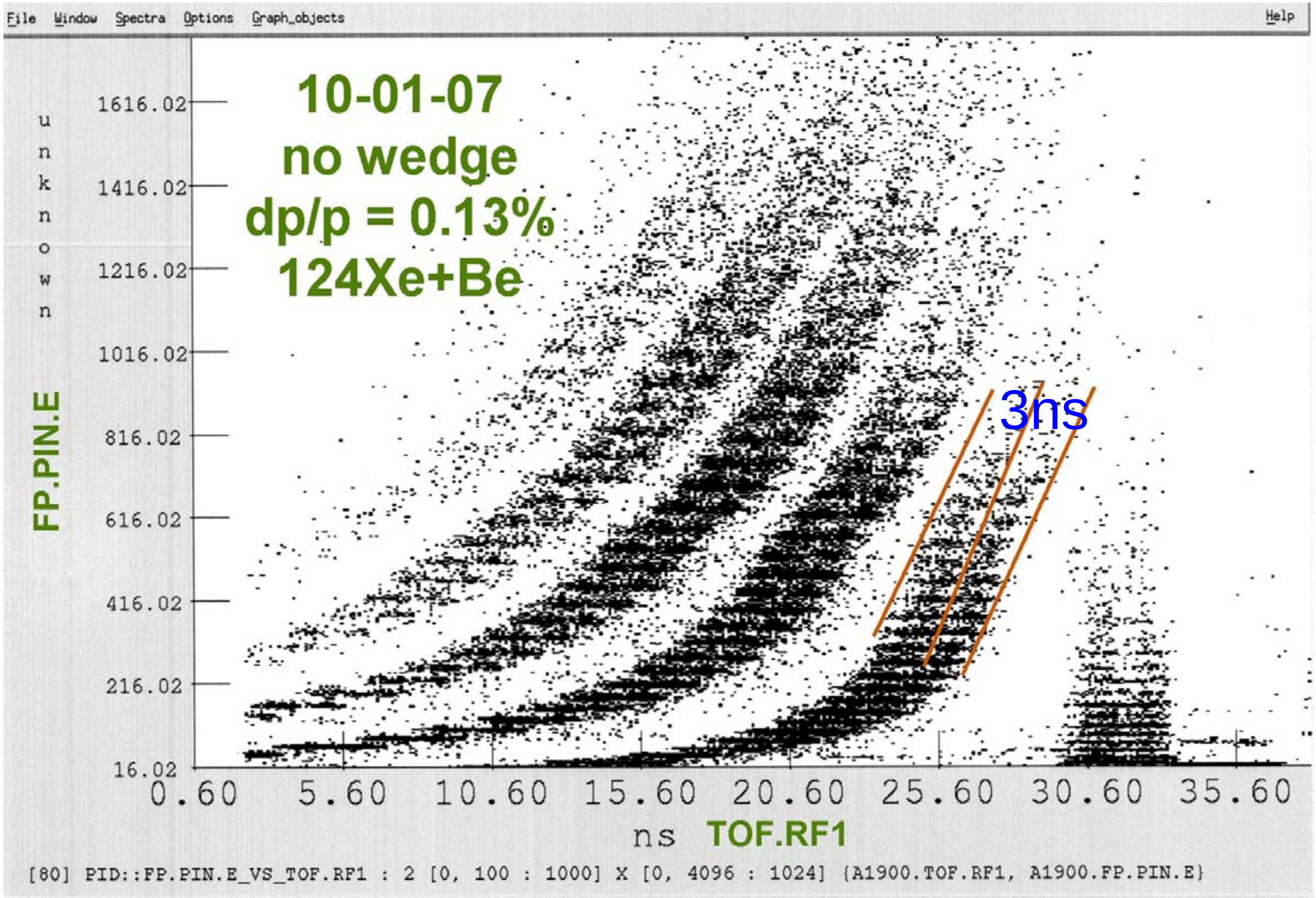
The theoretical investigation indicates a maximum in the charge-exchange contribution in the case of uranium projectiles in aluminum near ***400*** *MeV/u.*

NIMB193(2002)1

More experimental data at lower energies *are needed to be conclusive in this statement.*

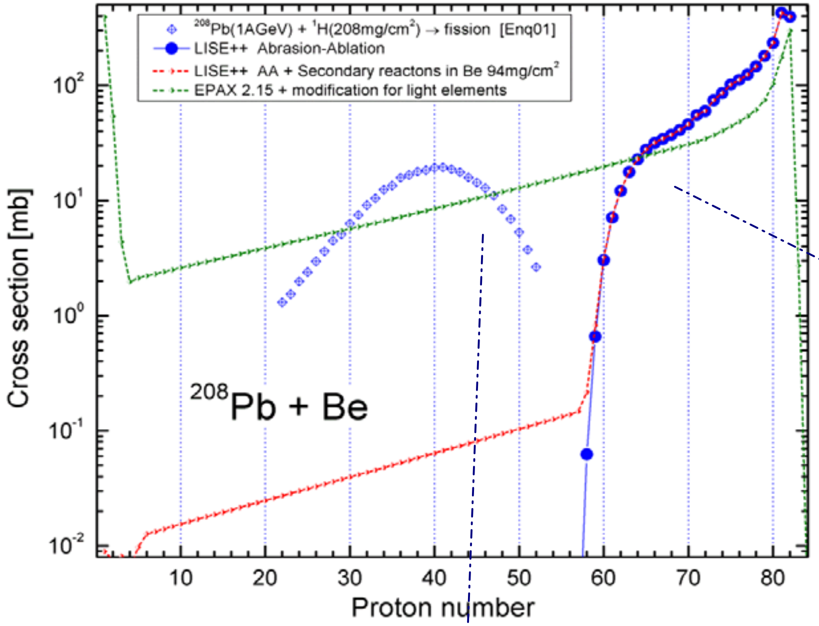
NIMB193(2002)1

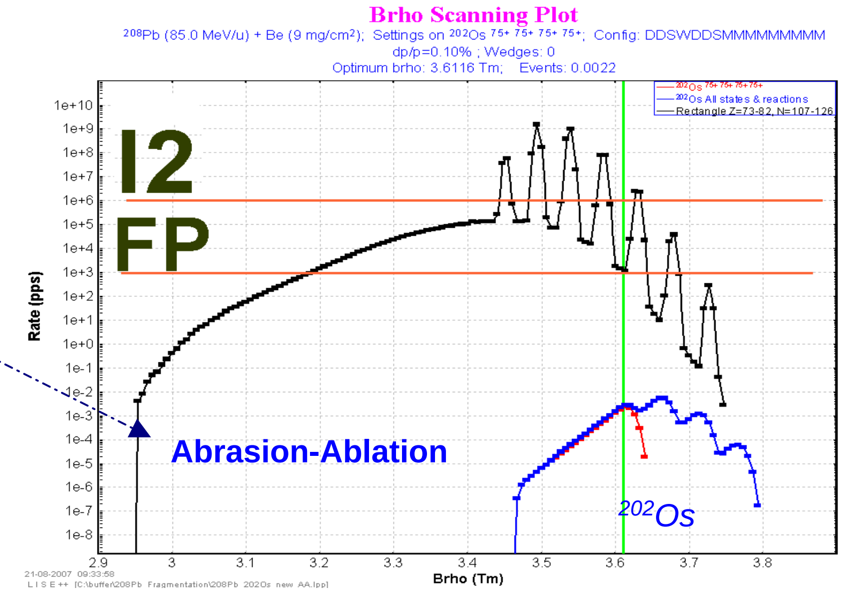
1b. Expected difficulties: TOF



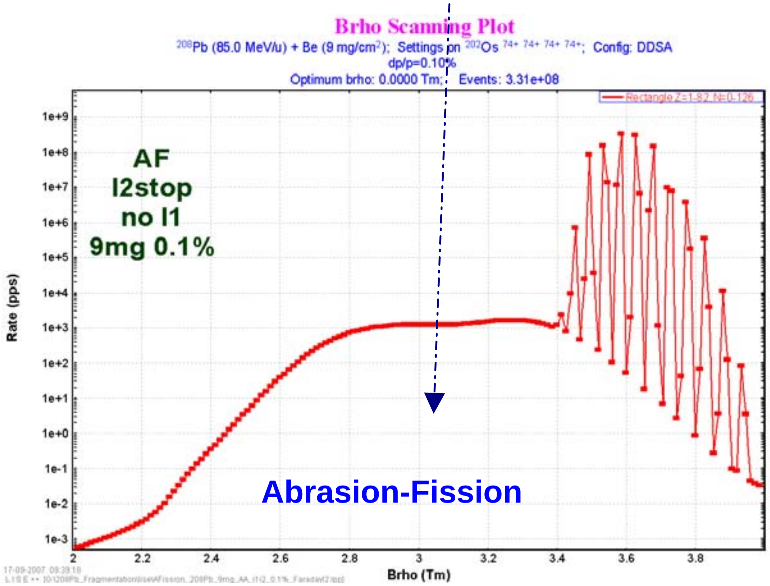
- **Phase slits in K500 requested**
- **Additional tuning requested with 'feedback', intensity loss**
- **I2-timing (only 18m, thick wedge)**

1b. Primary beam charge states. Thin target





dp/p=0.1%

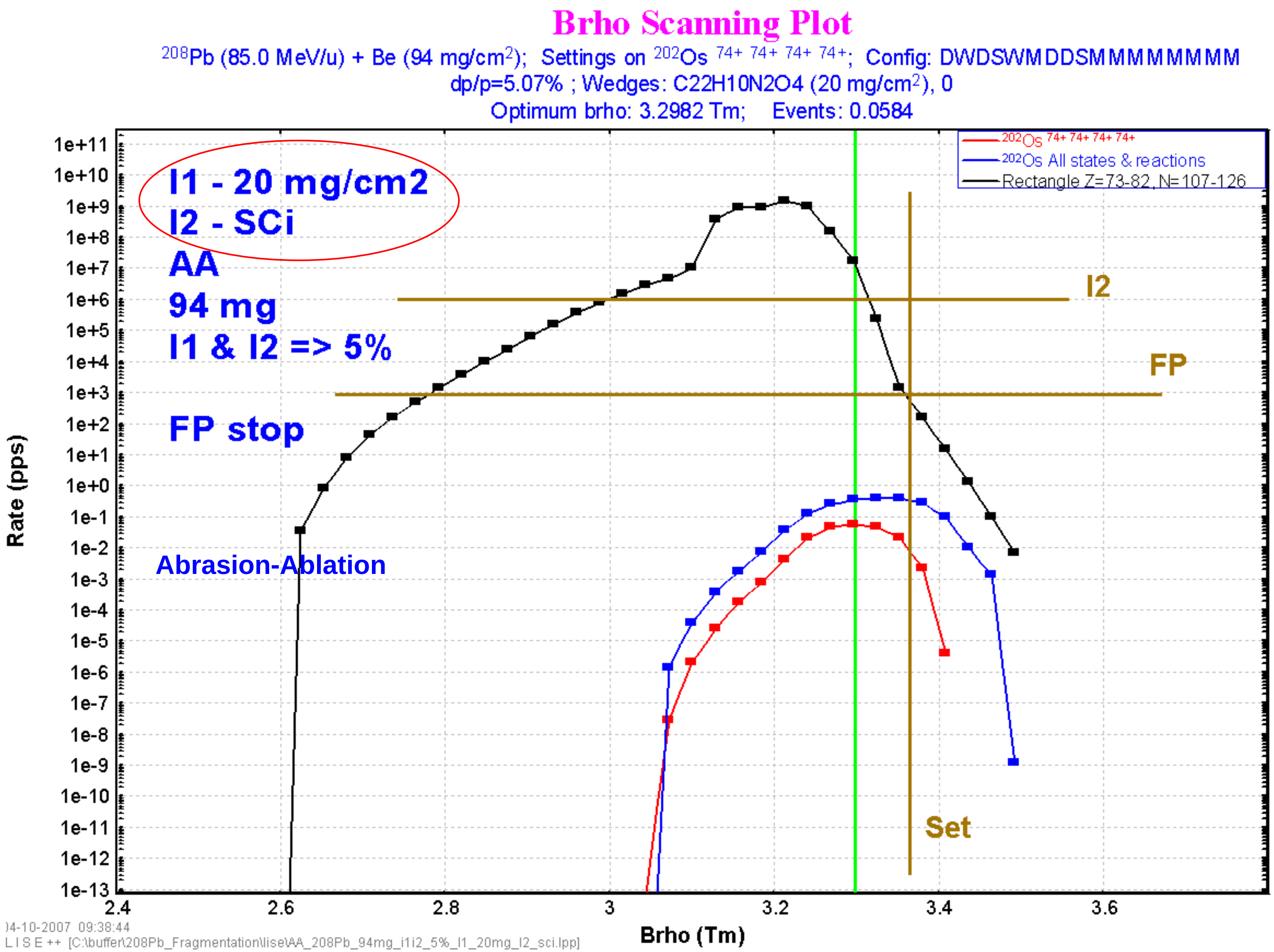


^{202}Os - setting fragment

Limits

- I2-Sci < 1e6 cps
- DAQ (FP) < 1e3 cps

1b. Primary beam charge states. Thick target



1c. Experiments at GSI (Pb+Be)

No huge charge state issue in the case of projectile fragmentation reactions at relativistic energies with heavy beams at GSI

^{208}Pb(1AGeV)+Be :

M. Pfutzner et al., PRC 65 65, 064604 (2002)
M. Caamano et al., Eur. Phys. J. A 23, 201 (2005)
T. Kurtukian-Nieto, arXiv:0711.0101v1 [nucl-ex] (Dated: February 2, 2008)

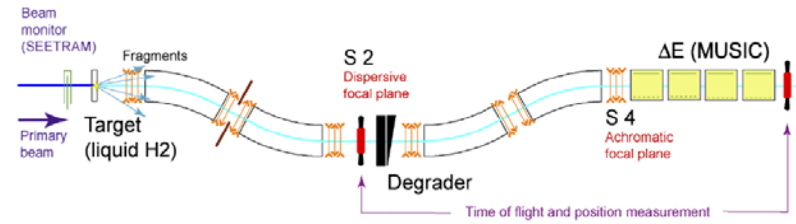
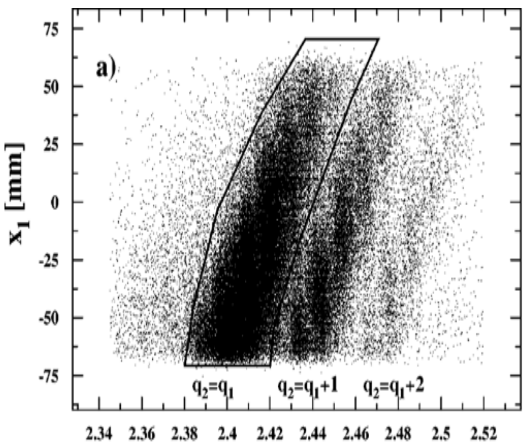


Fig. 1. Schematic view of the FRagment Separator. Each magnetic section between focal planes (the target location, S_2 and S_4) consists of two dipoles plus several quadrupoles and sextupoles (the latter are not represented here as they were not used during this experiment). L. Audouin et al. / Nuclear Physics A 768 (2006) 1–21

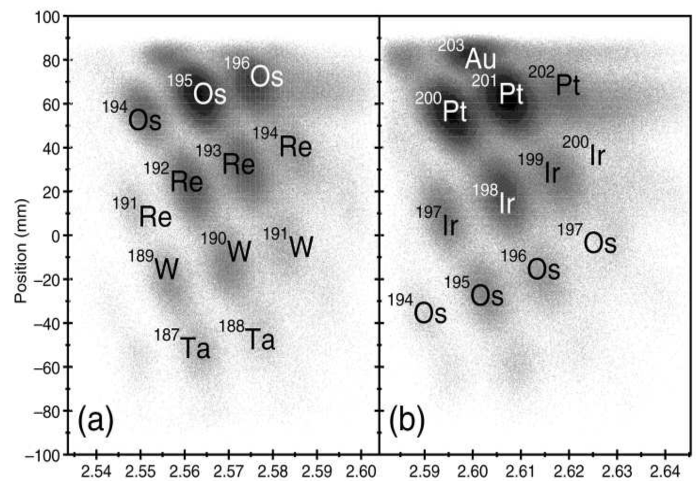
dE from MUSIC (two ionization chambers with a niobium stripper placed in between); no TKE measurements



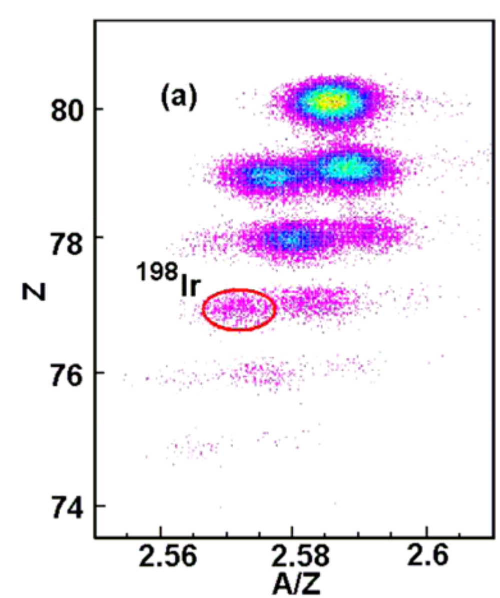
Steps in the heavy-ion identification procedure. Only a sample of the full statistics is shown.

Position at the intermediate focus vs *A*/*q* ratio measured in the second stage of the FRS. A contour line shows the selection of events with the same ionic charge in both FRS stages.

M. Pfutzner et al.

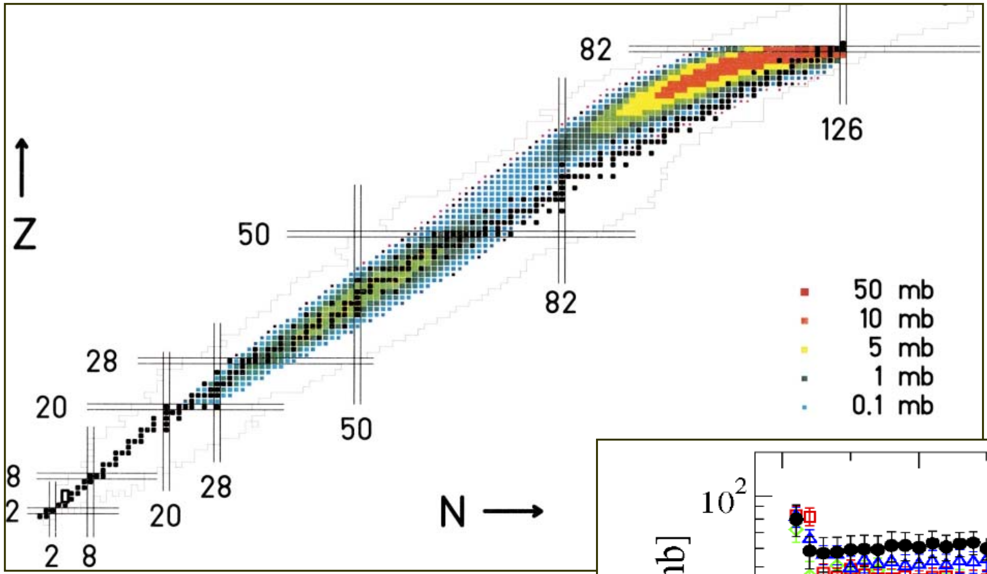


M. Caamano et al.



T. Kurtukian-Nieto,

1c. Experiments at GSI (Pb+p)



[208]Pb(1AGeV)+p; T.Enqvist et al., Nuclear Physics A 686, 481 (2001)

^{208}Pb(1AGeV)+p : T.Enqvist et al., NPA 686, 481 (2001)

^{208}Pb(500AMeV)+p : L. Audouin et al., NPA 768,1 (2006)

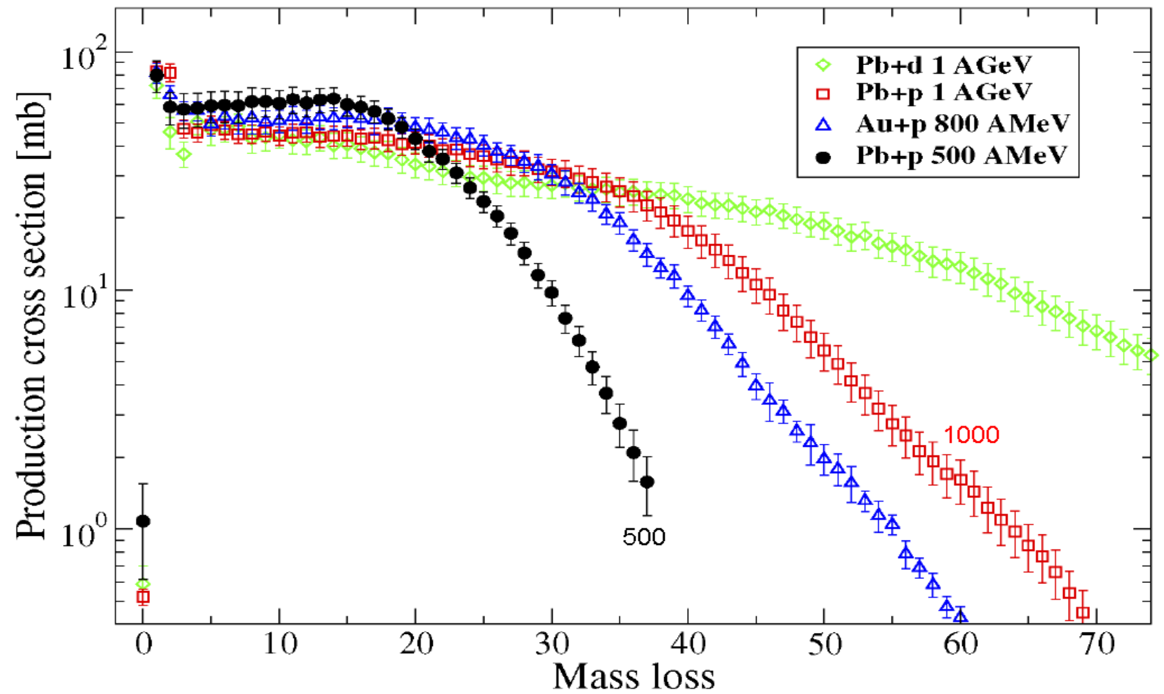
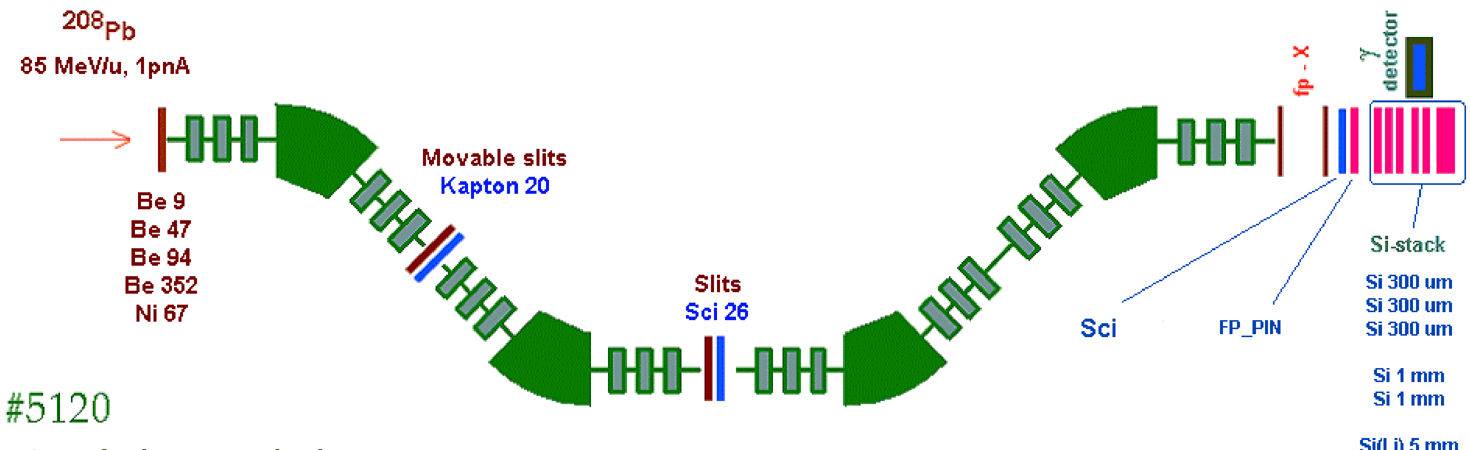


Fig. 7. Production cross sections of the residues of the reaction Pb + p at 500 *A* MeV as a function of the mass loss with respect to the projectile (full circles). Data obtained in previously mentioned experiments are also represented: Au + p at 800 *A* MeV (triangles), Pb + p (squares) and Pb + d (diamonds) at 1 *A* GeV. The isolated points at $\Delta A = 0$ correspond to a single nuclide, ^{208}Bi.

L. Audouin et al. / Nuclear Physics A 768 (2006) 1–21

2a. Experiment # 5120 : set-up



BaF + 2 NaI for beam monitoring

TOF[a]	between I2_Sci & FP_PIN (18m)
TOF[b]	between RF & FP_PIN (36m)
dE	Energy loss in the 1st PIN
TKE	Σ (dEi)

a	if I2_Sci inserted ("wedge" mode)
b	in "wedge" mode should be done special analysis because β1 != β2

β	Bρ, TOF
Bρ	I2_Sci (X)
Bρ*	Bρ + FP_PPAC (X)

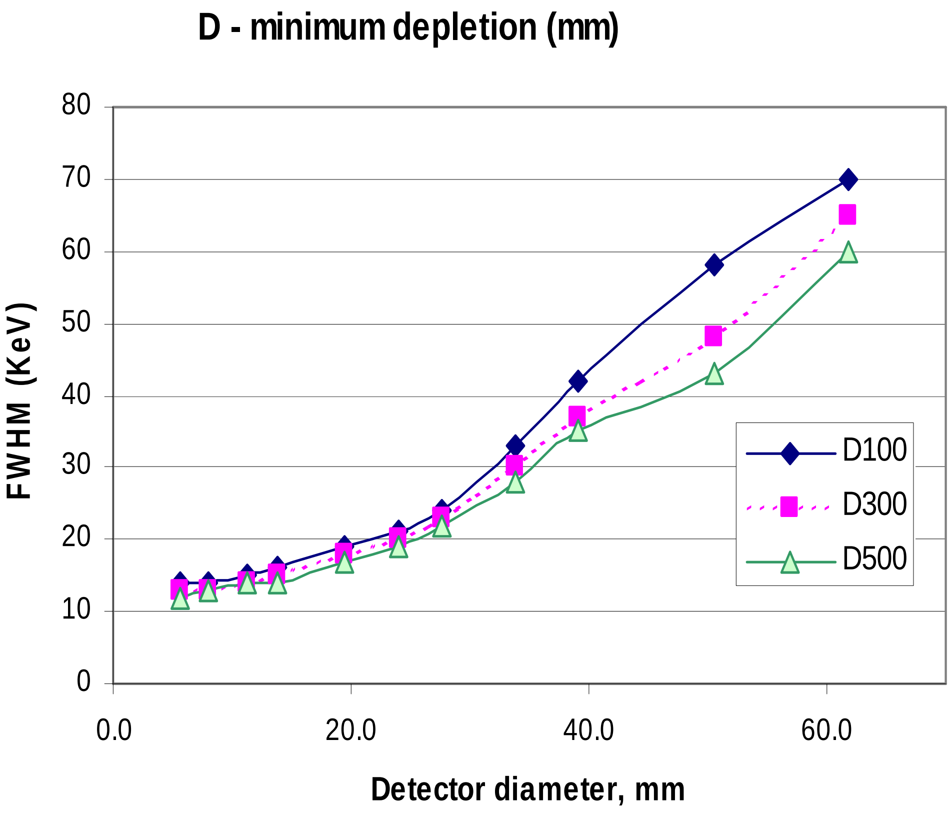
Z	dE, β
A	TKE, β
Q	TKE, β, Bρ

2b. dE - detectors

Guaranteed Maximum Resolution (ORTEC)

For 5.486-MeV alphas

(FWHM/E are equal to 1.06%, 0.87%, 0.78% for diameter=50mm)



http://www.ortec-online.com/detectors/chargedparticle/ultra.htm

2b. dE - detectors

Factor	Thickness		Size		Comments
Energy Detector Resolution	Increasing	👍👍			Increasing Energy loss value
Energy Resolution noise	Increasing	👍	Decreasing	👍👍	Increasing Energy loss value
Energy Straggling, Charge state fluctuations	Increasing	👍👍👍👍			
A,Z,Q identification formulas validity	Increasing	👍			100-500 microns
Time Resolution	Increasing	👍	Decreasing	👍👍	
Thickness “defect”	Increasing	👍	Decreasing	👍	
Spectra Cleaning	Decreasing	👍			should be 2-4 dE detectors
Detector cost	Increasing	👍	Decreasing	👍👍	
Detector size (horizontal)			25-30 mm for fragmentation		circle or rectangle shapes.
			40-60 mm for fission		we do not need large vertical size

Proposed configuration: 3 X 300 * 3 X 1000 Scintillator

* Fission H.Size = 50 mm (30?)
* Fragmentation H.Size = 30 mm

2b. Experiment # 5120 : set-up

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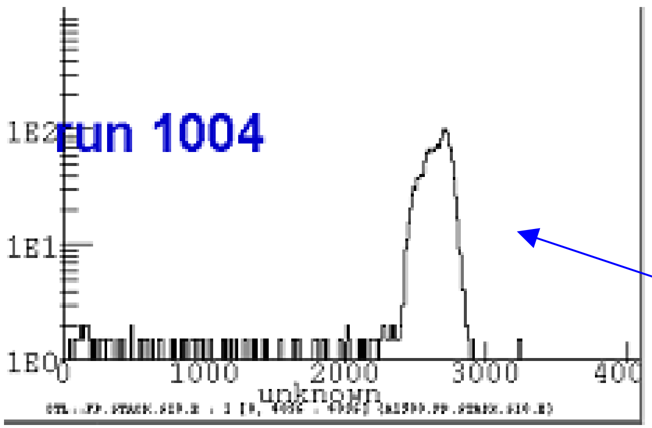
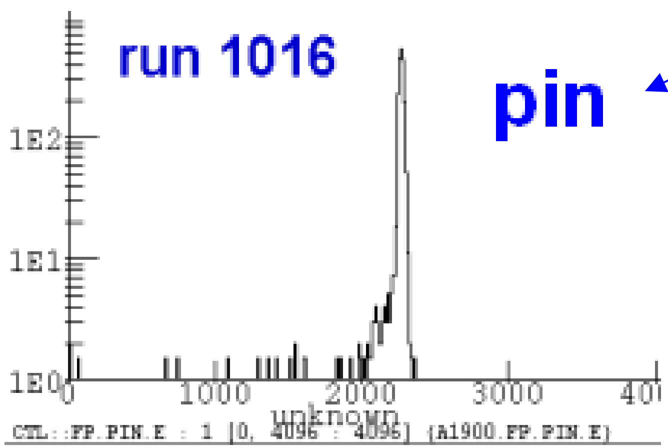




New ORTEC SBD detectors* (D~20mm) have been substituted during the experiment for PIN diodes 500 um (50x50mm),

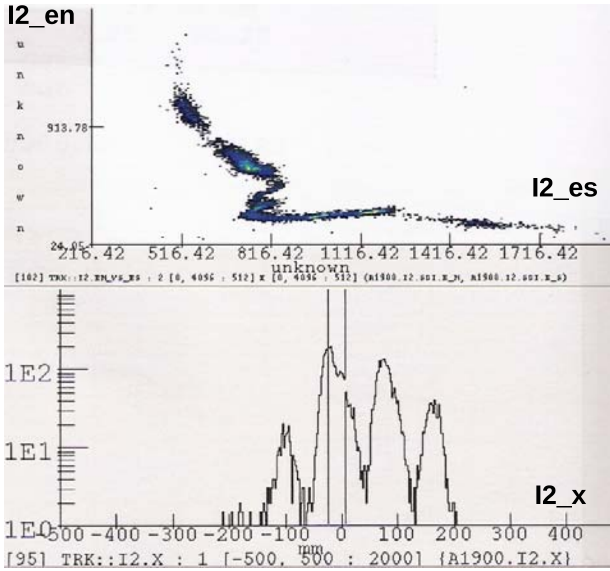
**** - though measured own resolution before and after the experiment for α-particles was about 20-22 KeV***

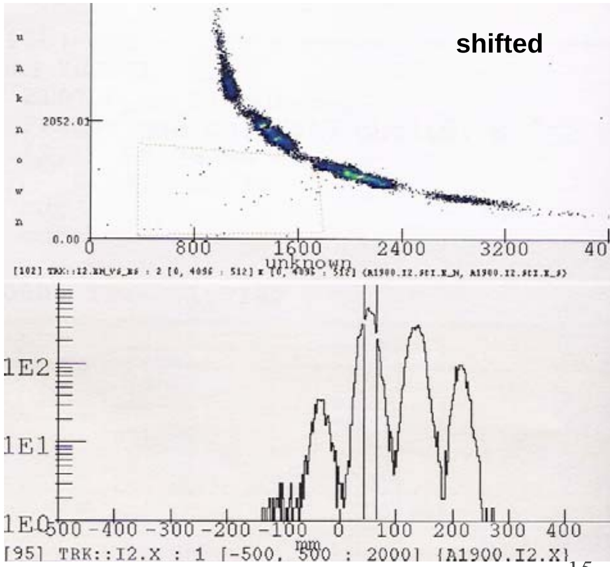
- **No explanation.**
  Double peak structure.
  Position dependance.
  Channeling?
- **Similar effect has been observed at the GANIL experiment with the U-beam**
- **It is necessary to test them with other beams (Kr,Xe)**

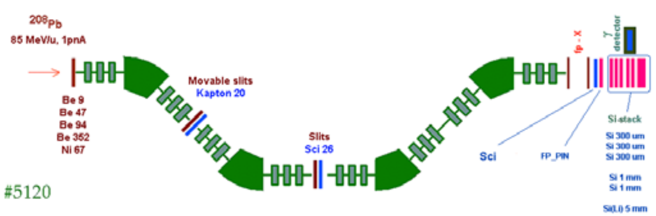
2c. Runs

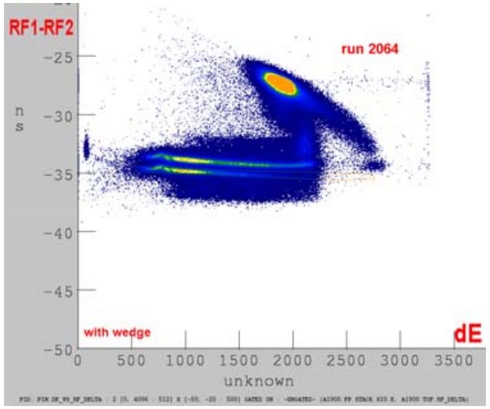
- I2-Sci X-position problem during the experiment ☹
- No Kapton in I1 (no reference lines, difficult analysis : set of charge states, different velocities) ☹
- I2-wedge 26 mg/cm^2 (Sci) is too thick for heavy ions Z~70-80 ☹
- TOF I2&FP resolution is not good enough (short path) ☹
- TOF RF-Pin - unstable ☹
- It is possible to work at dp/p =0.5% with NI-target (67mg/cm^2) between beam charge states ☺

I2_SCI damage









3a. Identification

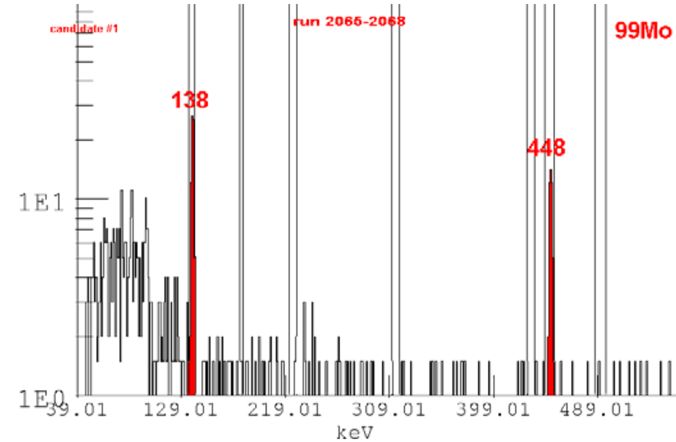
Identification and calibration

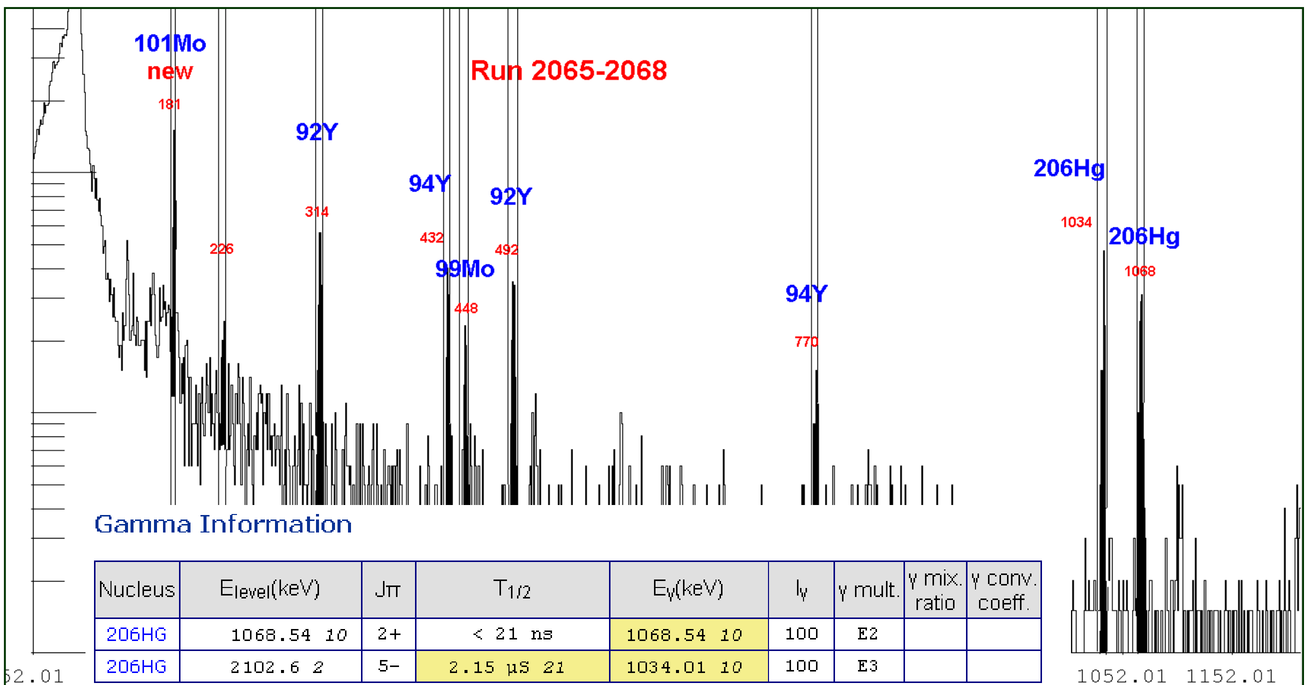
a. **primary beam** *(preliminary)*

b. **nuclei with identified isomeric states**

   ^{120}Sn, ^{206}Hg, ^{92,94}Y, ^{99}Mo *(A,Z – ok, Q-?)*

c. **Z-Q=0 line for light nuclei**

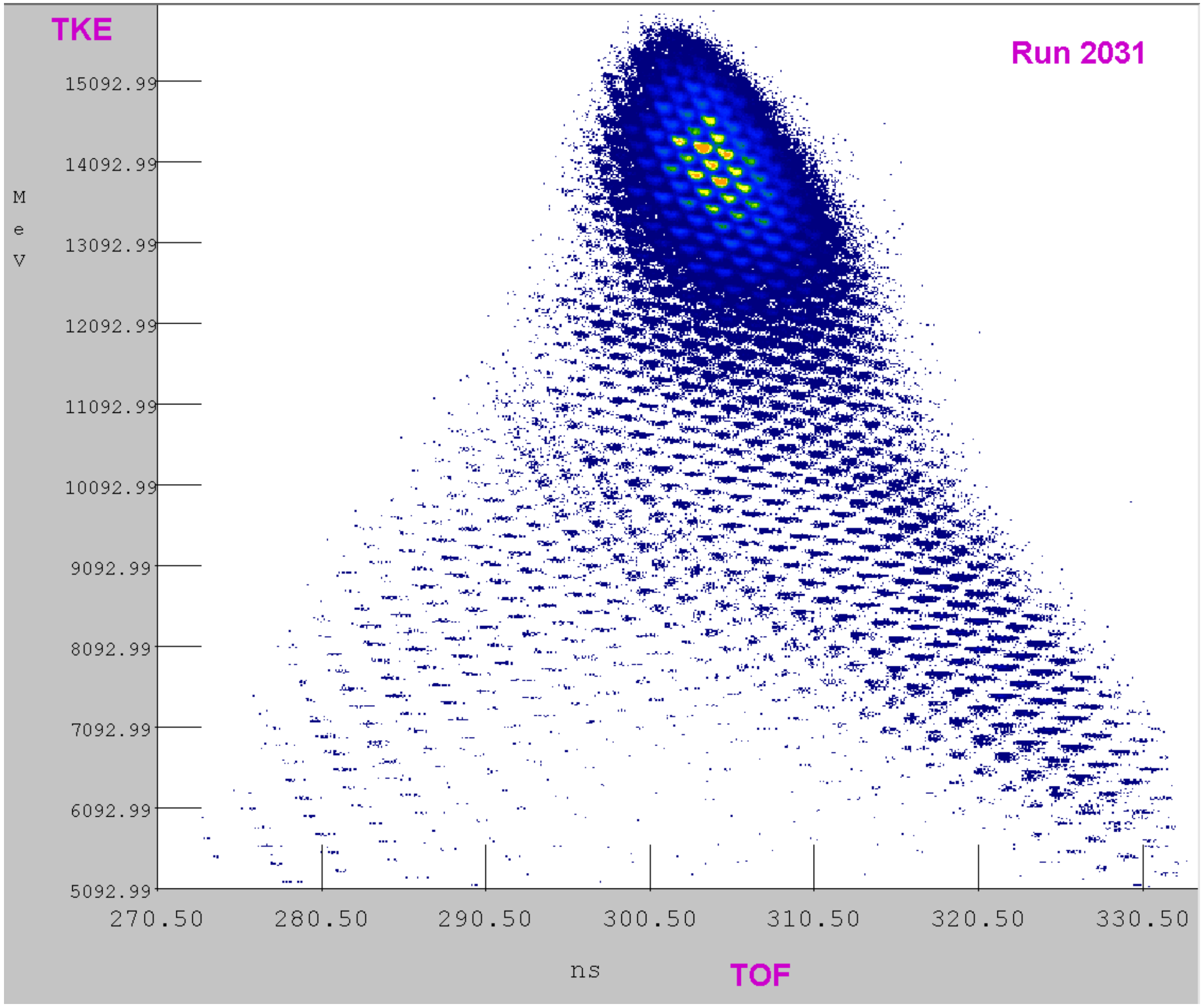




Gamma Information

Nucleus	E$_{level}$(keV)	Jπ	T$_{1/2}$	E$_{\gamma}$(keV)	I$_{\gamma}$	γ mult.	γ mix. ratio	γ conv. coeff.
206HG	1068.54 *10*	2+	< 21 ns	1068.54 *10*	100	E2		
206HG	2102.6 *2*	5−	2.15 μs *21*	1034.01 *10*	100	E3		

3a. Calibration, Separation



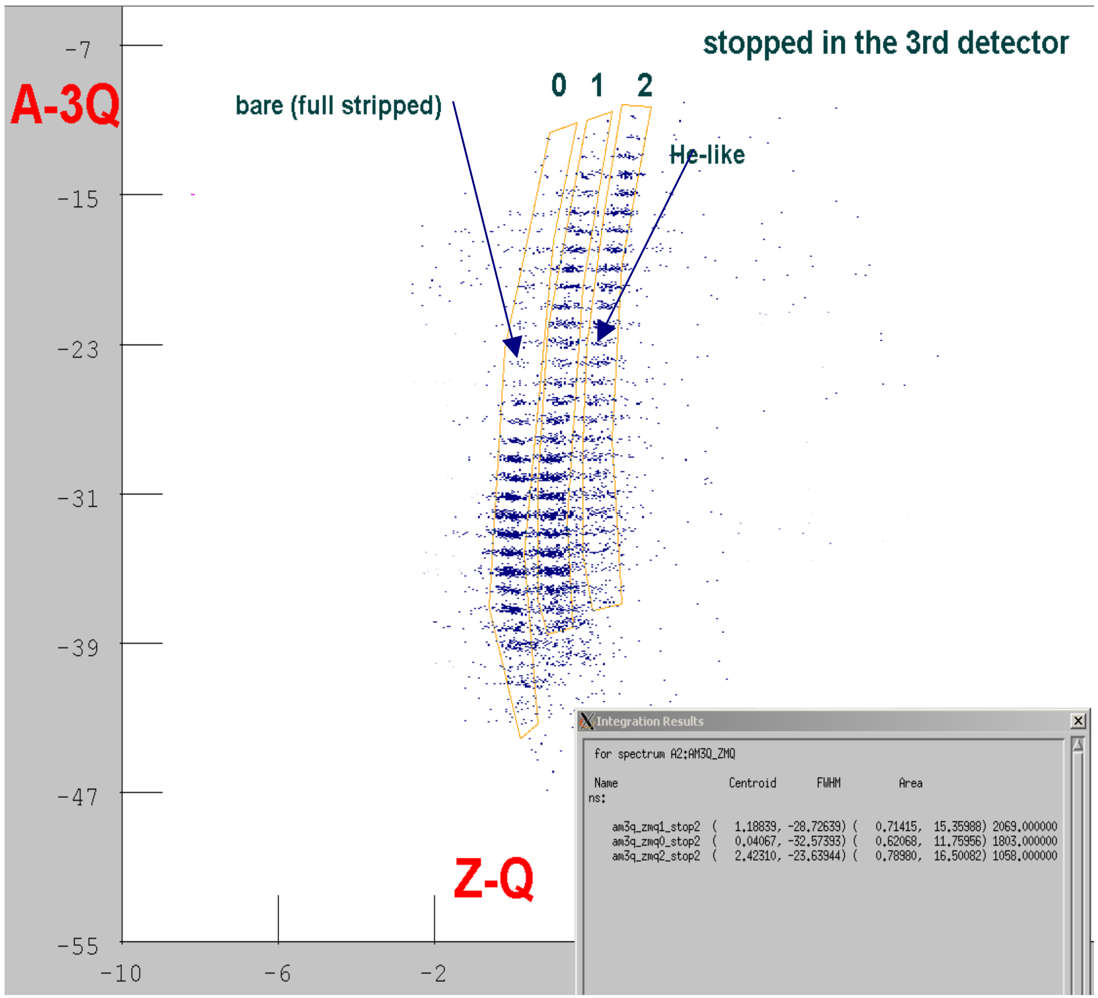
Energy Loss method: TKE = $E_0c + E_1c + E_2c + E_3c$, where $E_ic = e_i\,(ch) * e_i\_slope + e_i\_offset$

TKE Global method : TKE = $\sum e_i\,(ch) * TKE_i\_slope + TKE\_offset$

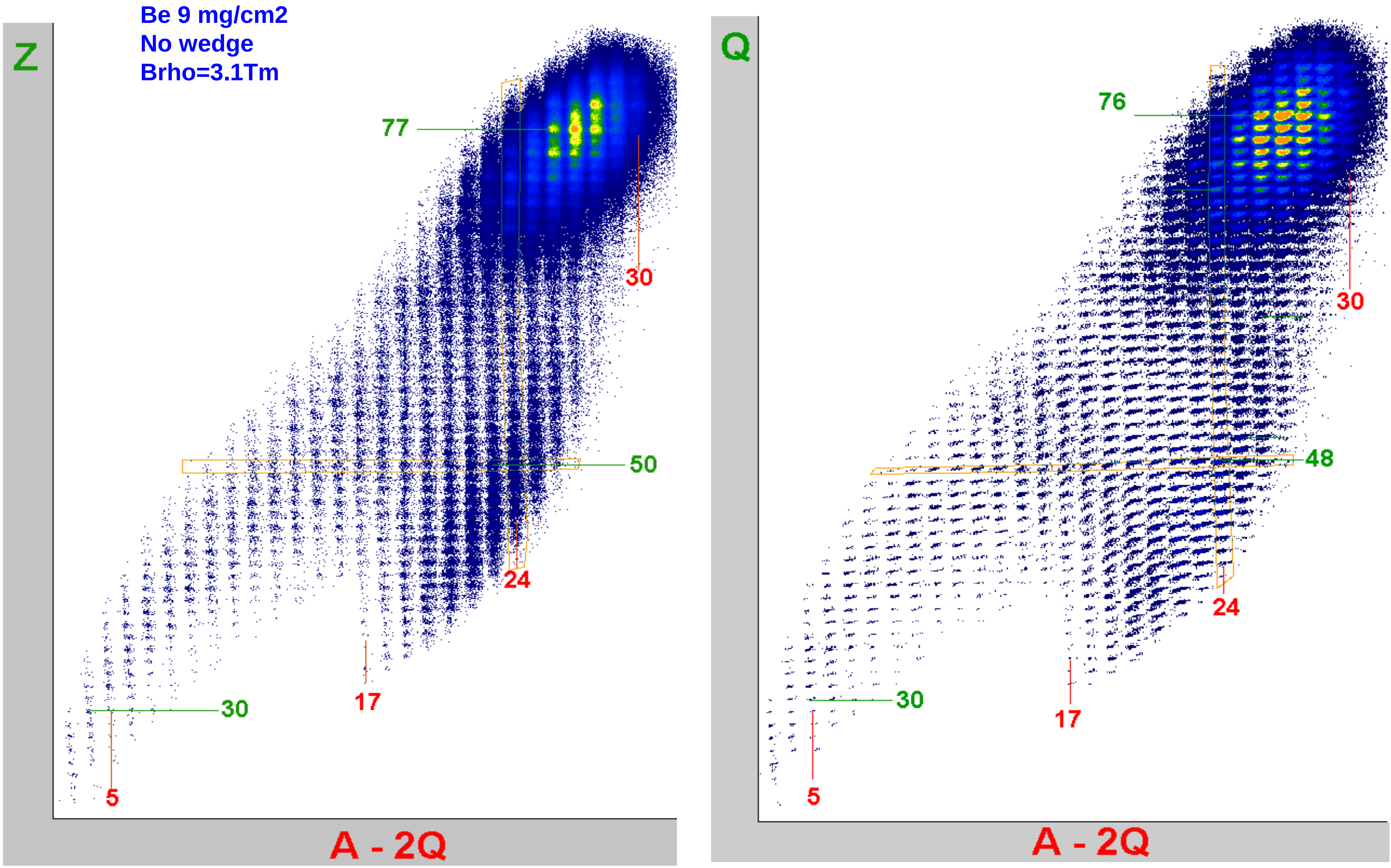
3c. Charge state separation

Be 9 mg/cm2
No wedge
Brho=3.1Tm

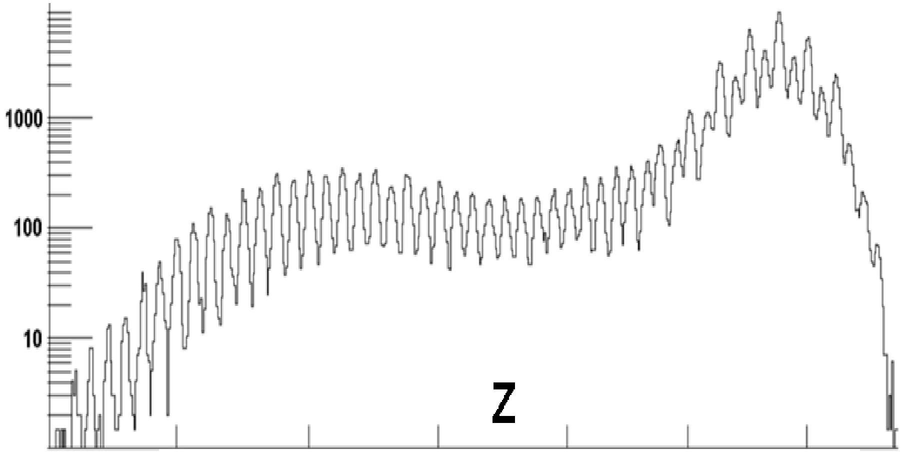
$$Q = 3.33 \times 10^{-3} \frac{TKE \times \beta\gamma}{B\rho(\gamma - 1)}$$

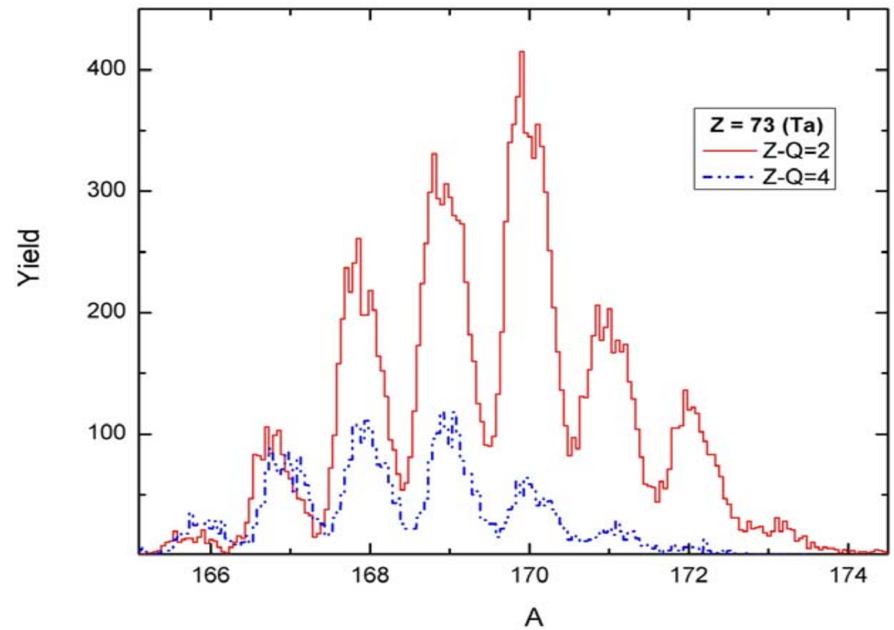


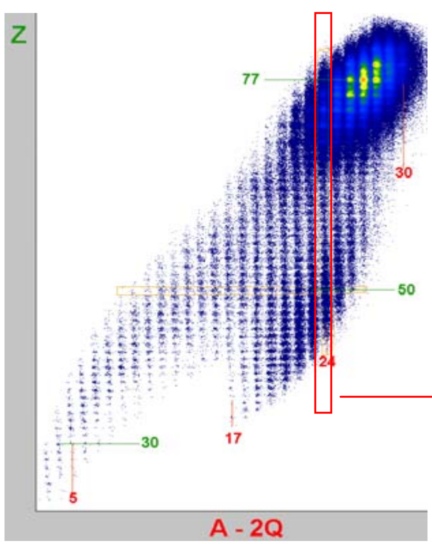
3d. PID plot

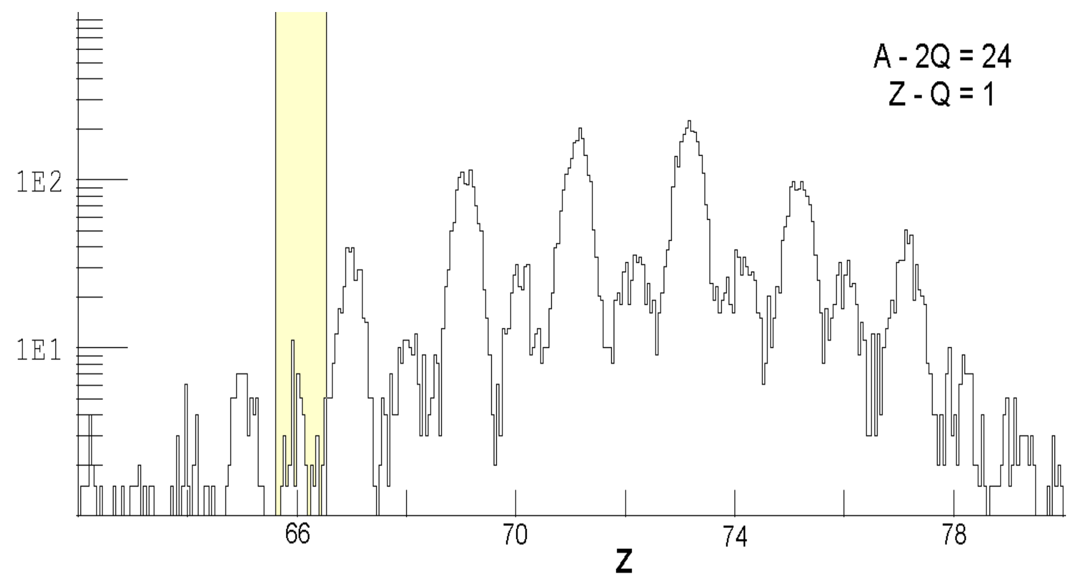


It is not limit! There are some ways to improve separation in future (dE & ToF resolution).


1000
100
10
Z


Yield
400
300
200
100
166
168
170
172
174
A
Z = 73 (Ta)
Z-Q=2
Z-Q=4


Z
77
30
50
24
30
17
5
A - 2Q


A - 2Q = 24
Z - Q = 1
1E2
1E1
66
70
74
78
Z

4a. Focus (run 2031, no I2SCI)

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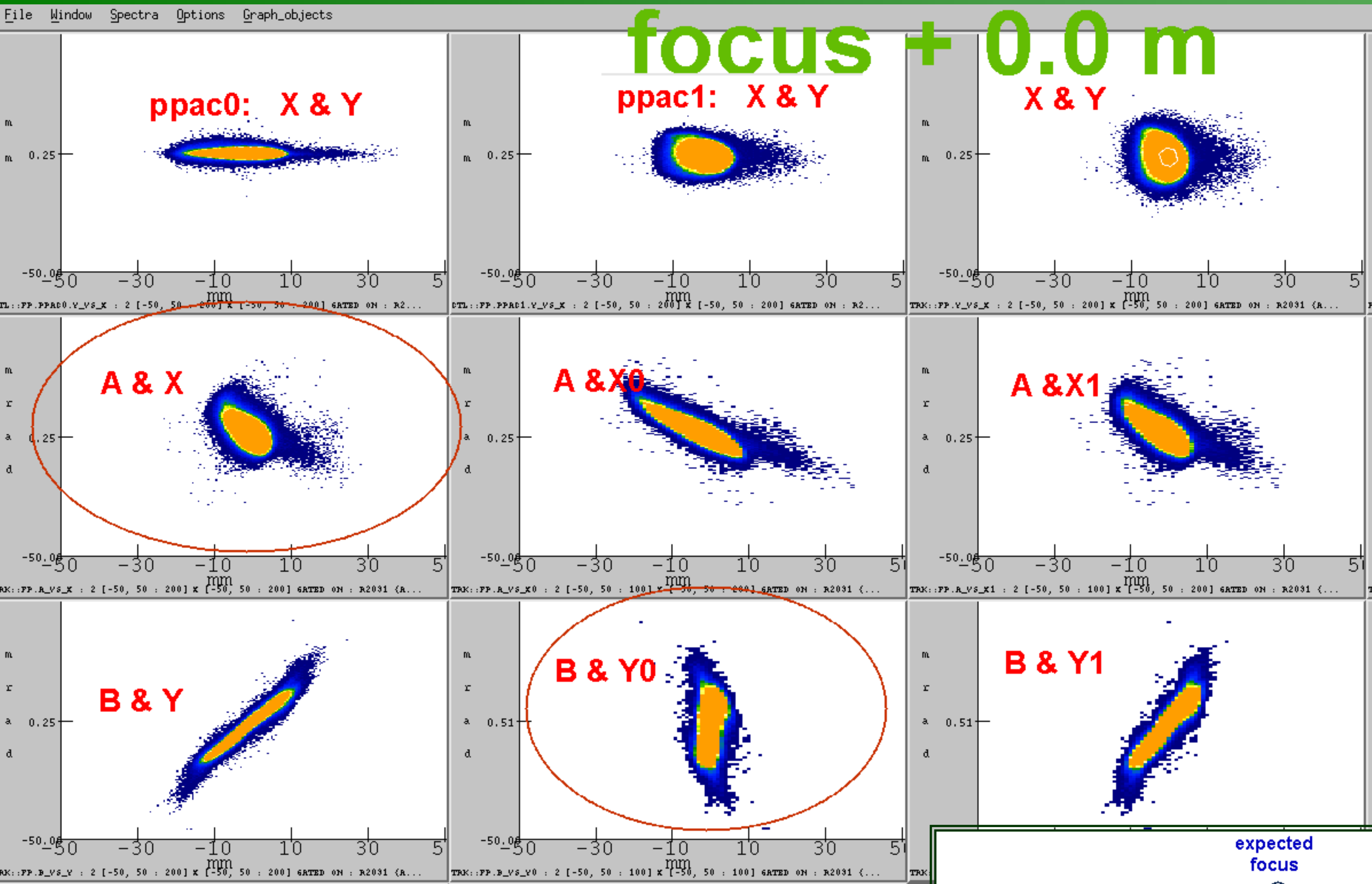
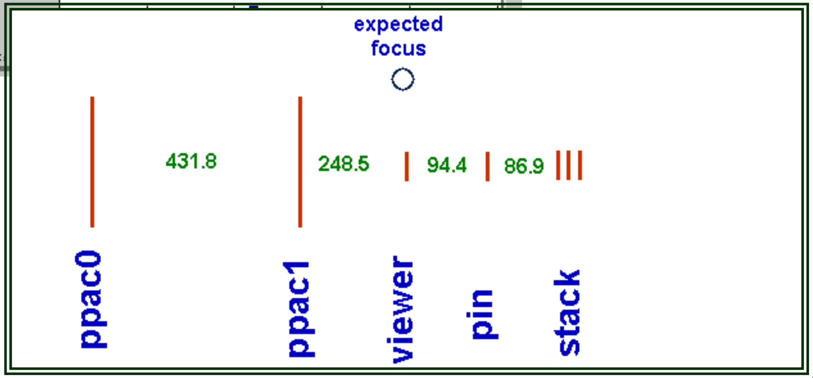
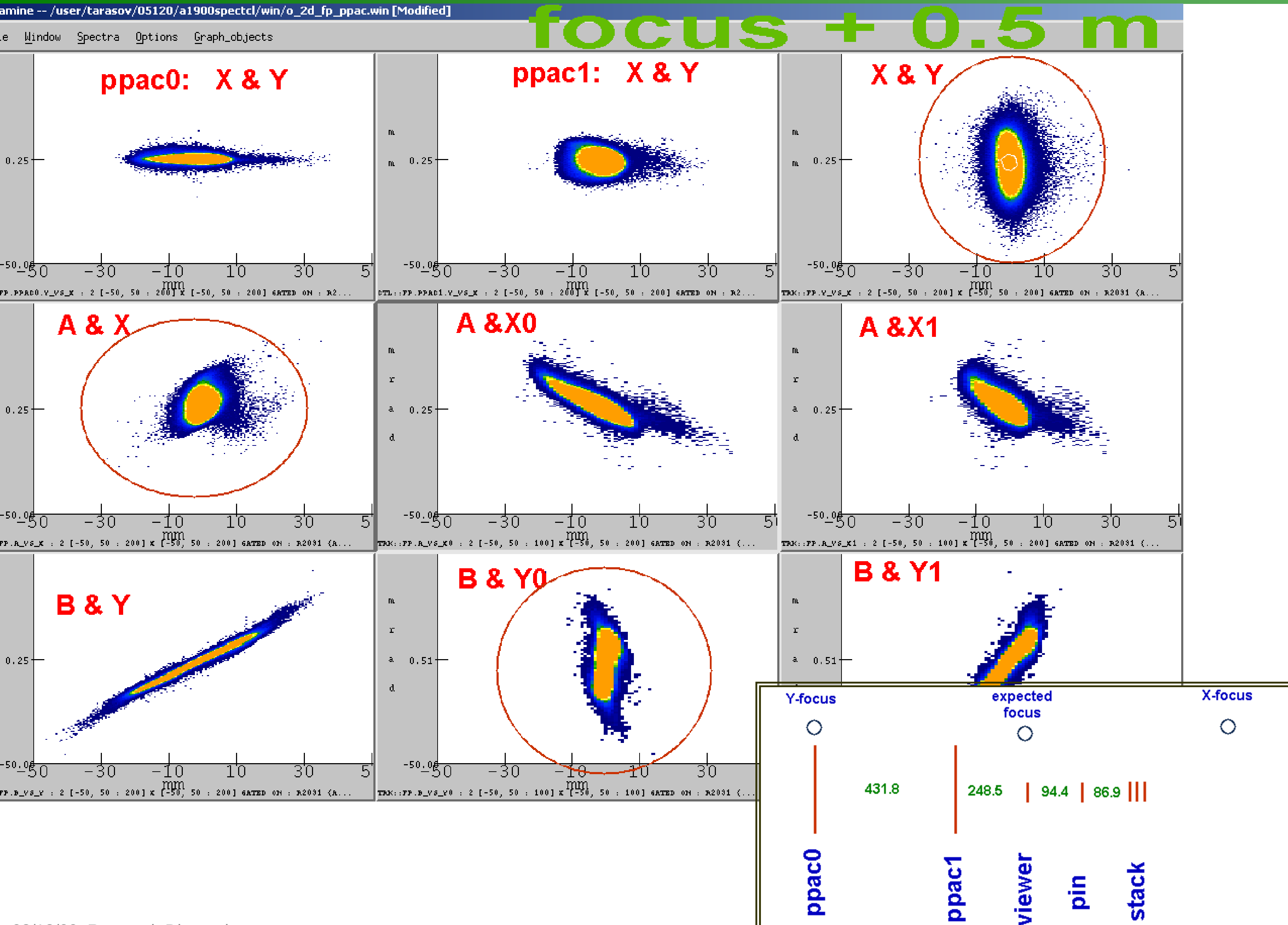
focus + 0.0 m

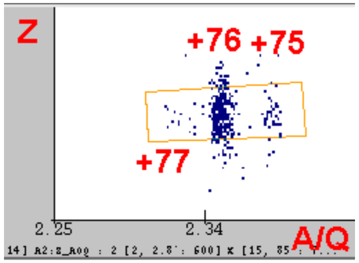




4a. Focus (run 2031, no I2SCI)



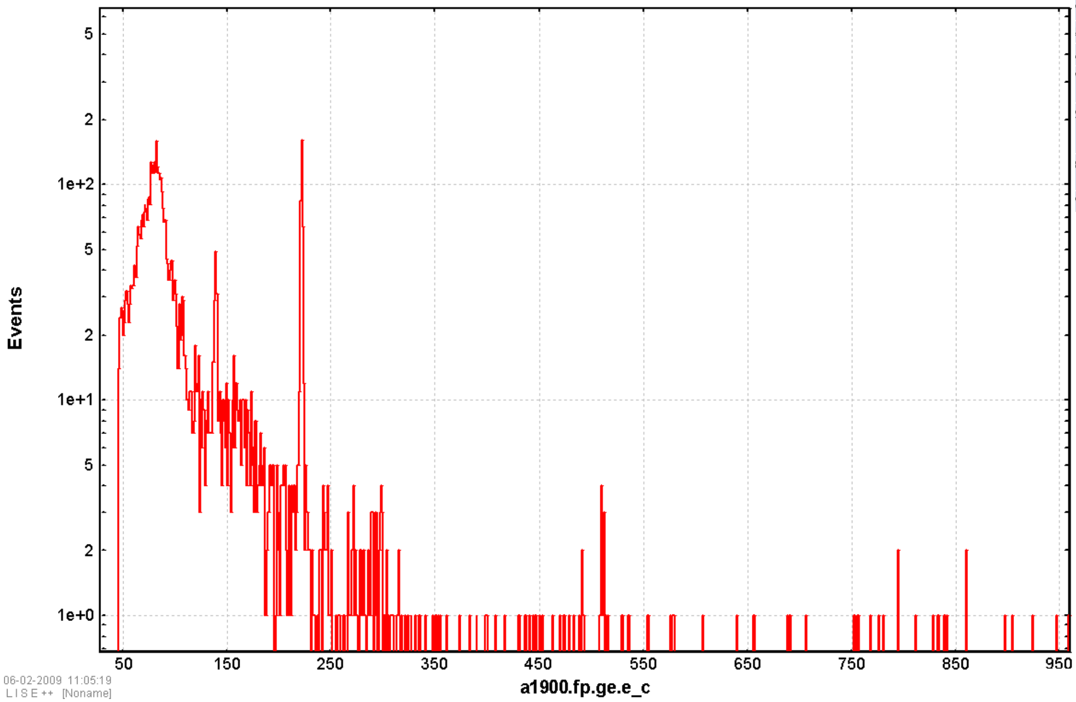
4b. New isomers (^{177}Ir)



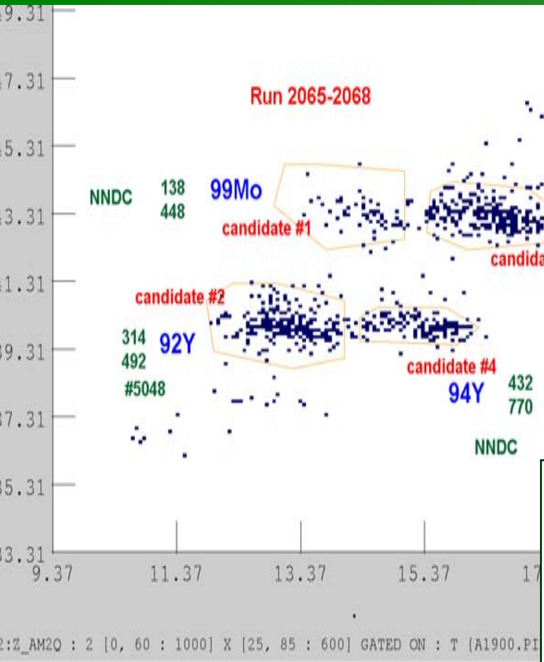
g222
stop in Si1
run 2031
177Ir

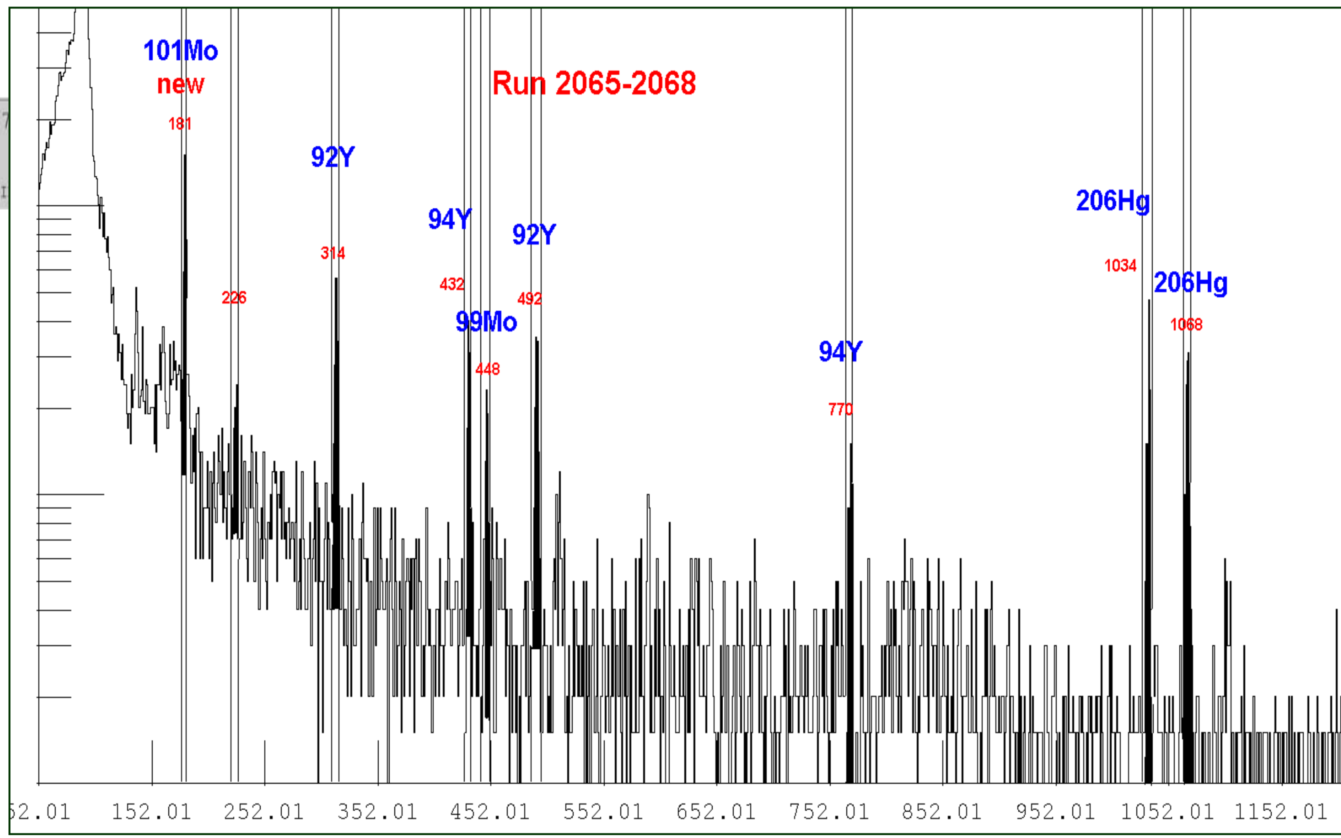
ADOPTED LEVELS, GAMMAS for ^{177}Ir

E_{level} (keV)	XREF	Jπ	$T_{1/2}$	E_γ (keV)	I_γ	γ mult.	Final level	
0.0	ABC	5/2−	30 s 2 % α = 0.06 1 % ε = 99.94 1, %A=0.06 1					
0.0+X	C	(9/2−)						
44.51 21	BC	9/2−		44.1?	100	[E2]	0.0	5/2−
51.2	B			52.1			0.0	5/2−
85.6	AB	(1/2−)		85.6			0.0	5/2−
105.3	B			54.9			51.2	
118.70+X 24	C	(11/2−)		118.6	100	M1+E2	0.0+X	(9/2−)
148.00 20	AB	(3/2−)		62.4 96.8 148.0		 M1+E2	85.6 51.2 0.0	(1/2−) 5/2−
157.20 20	A	(3/2+)		71.8 2 157.2 2			85.6 0.0	(1/2−) 5/2−
180.8 5	C	5/2+						
222.97 14	ABC	7/2−	?	75.1 117.8 177.8 223.0		 M1(+E2)	148.00 105.3 44.51 0.0	(3/2−) 9/2− 5/2−
258.5 3	C	13/2−		214.2	100	E2	44.51	9/2−
265.9 7	B	(3/2,5/2)		42.8 180.2 265.9			222.97 85.6 0.0	7/2− (1/2−) 5/2−
278.80+X 24	C	(13/2−)		160.1 278.9	100 8 42 3	M1+E2 E2	118.70+X 0.0+X	(11/2−) (9/2−)
[illegible] 4	C	7/2+		100.8	100	M1+E2	180.8	5/2+
[illegible] 3	AB			183.4 2	100		148.00	(3/2−)
[illegible] 11	B							
[illegible] 4	C	9/2+		122.9 223.9	100 8 44 6	M1+E2 [E2]	281.7 180.8	7/2+ 5/2+
[illegible]0 25	BC	11/2−		174.9 210.0 388.7	17 3 47 10 100 13	[M1(+E2)] E2 M1(+E2)	258.5 222.97 44.51	13/2− 7/2− 9/2−
[illegible]+X 3	C	(15/2−)		175.4 335.5	100 8 63 8	M1+E2 (E2)	278.80+X 118.70+X	(13/2−) (11/2−)
[illegible] 4	C	11/2+		145.4	100 5	M1+E2	404.7	9/2+



4b. New isomers (^{101}Mo)





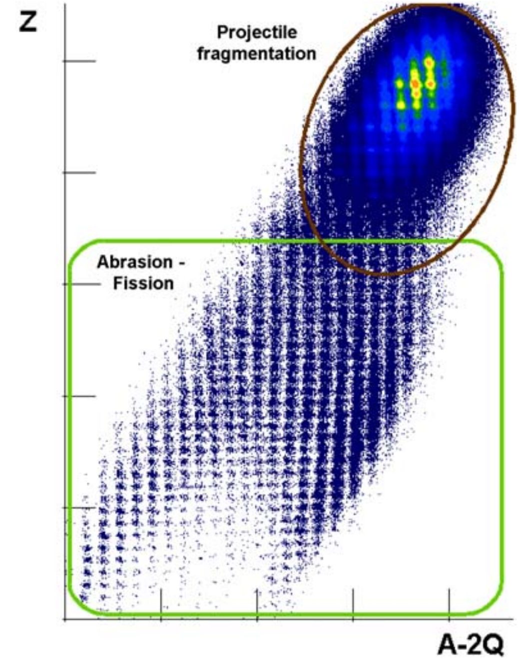
Two main contributions

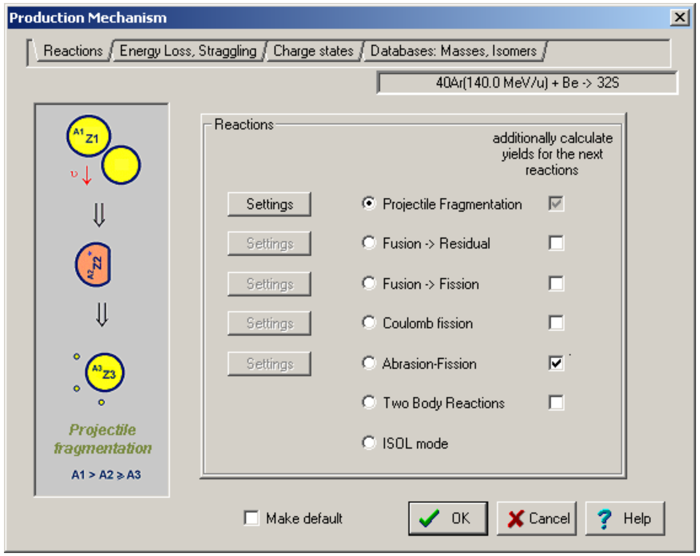
Abrasion-Evaporation /Projectile fragmentation/

Abrasion-fission

$A3^* + A4^* < 238$

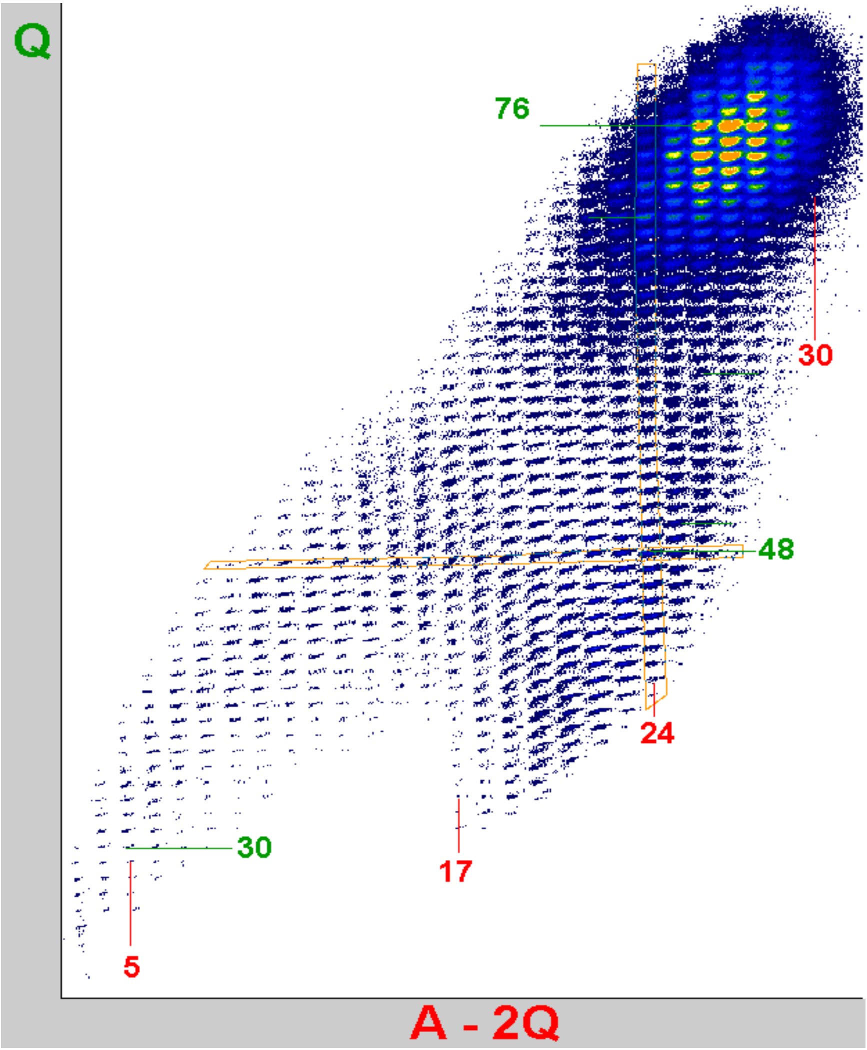
+ abrasion-breakup, pickup, etc.

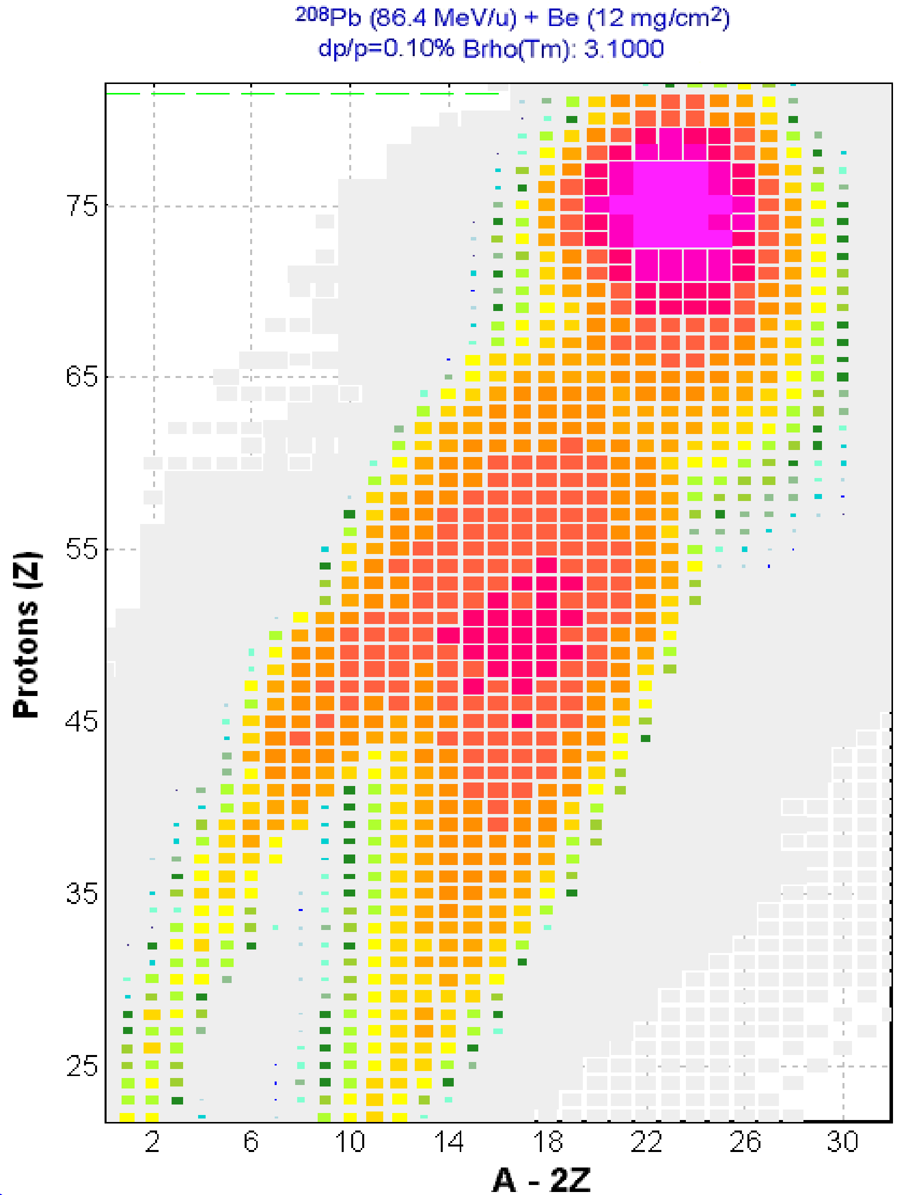




Tech. Rep. MSUCL1300, NSCL, Michigan St.Univ. 2005; www.nscl.msu.edu/lise

4c. Data vs. LISE++

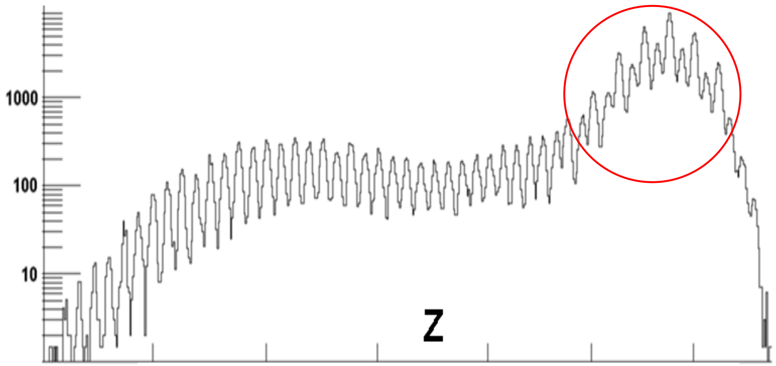


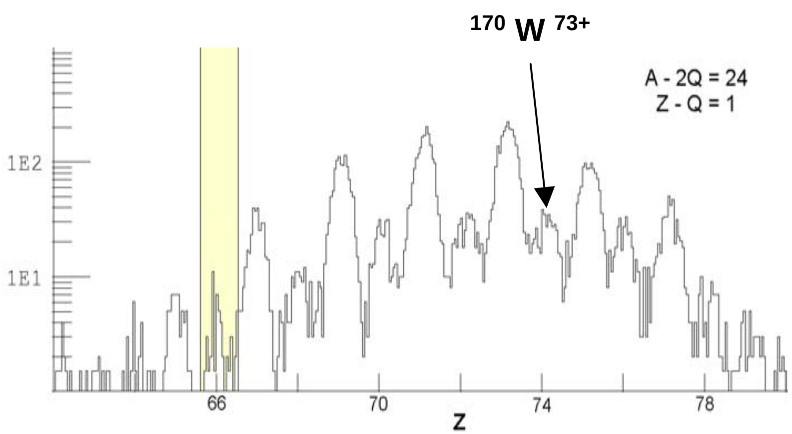


Good qualitative agreement between experimental data & LISE++ AA & AF

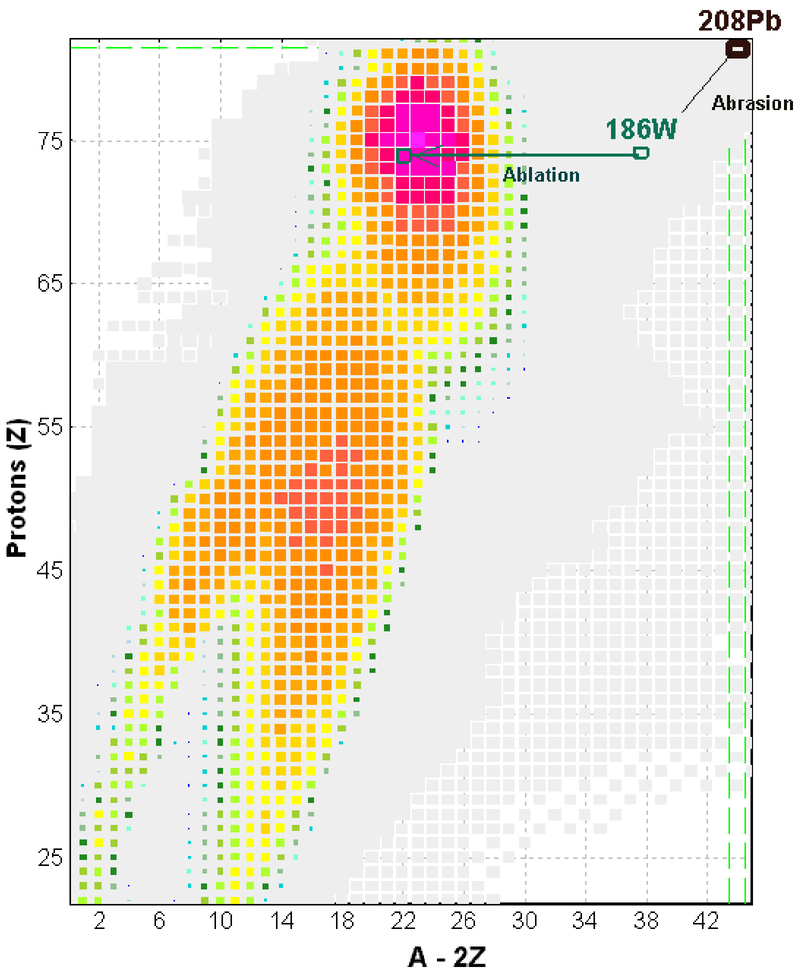
www.nscl.msu.edu/lise

4d. Elemental Odd-Even Effect





More probable prefragment is ^{186}W according to the LISE++ evaporation calculator

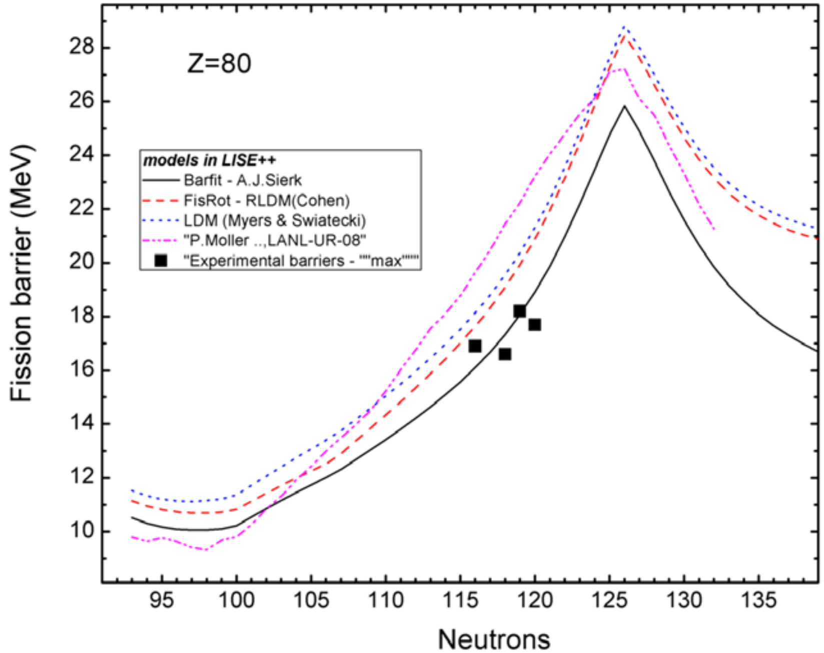


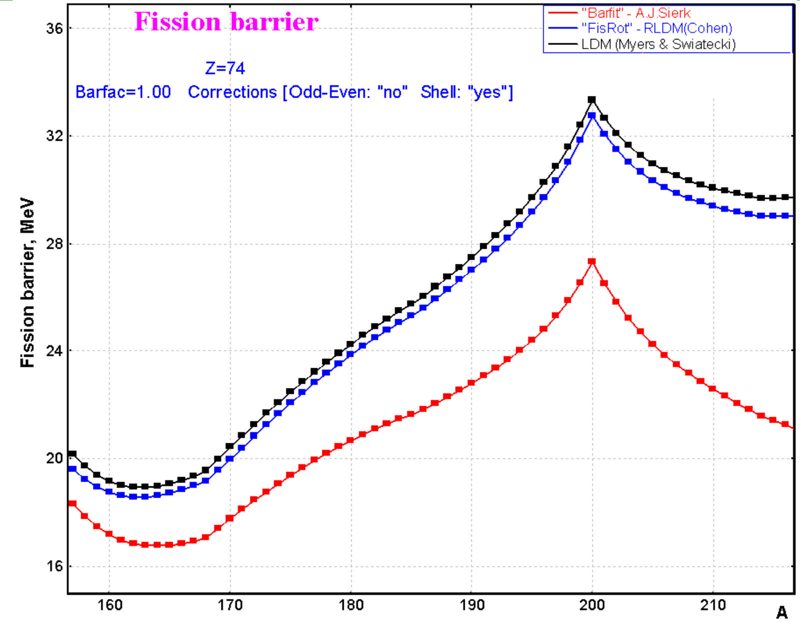
E* (^{186}W) ~ 200 MeV
assuming E =27 MeV per abraded nucleon

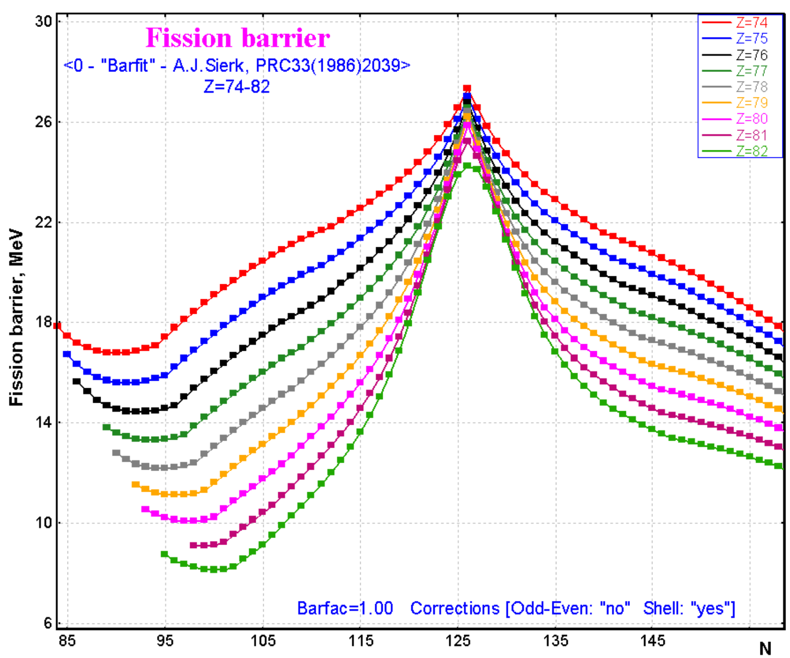
Why???

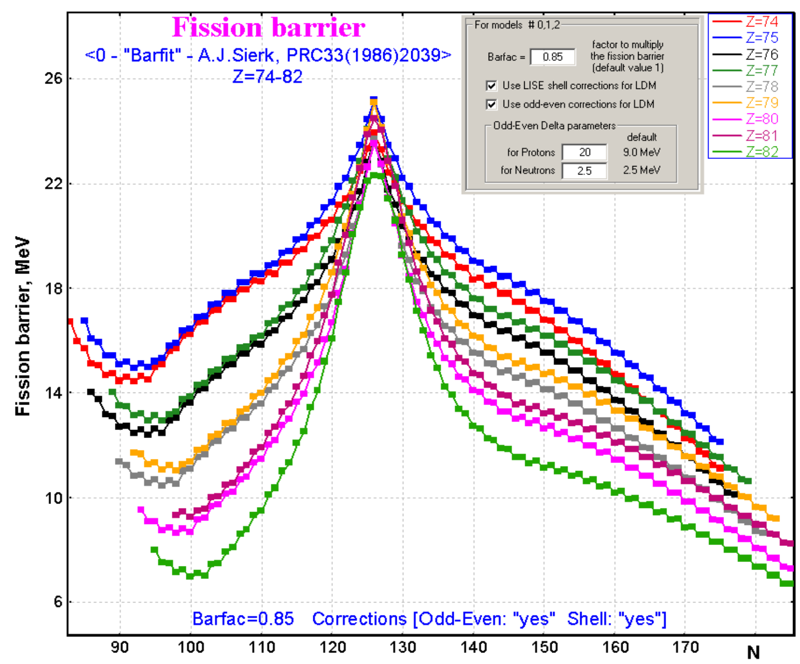
1. Level density difference for odd-even elements (GSI)?
2. Accumulation effect. Odd elements are “washed out” ?

4d. Elemental Odd-Even Effect

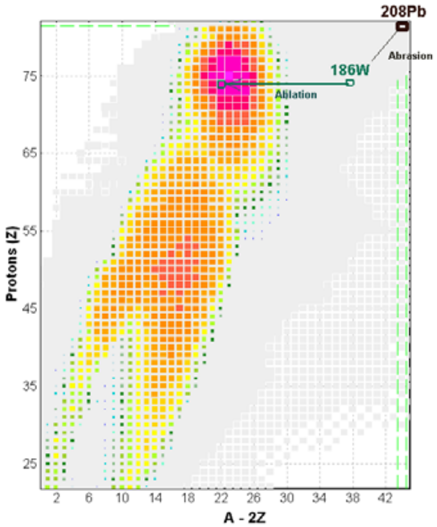








4d. Elemental Odd-Even Effect



$^{186}W^*_{(200MeV)} \rightarrow {}^{170}W$

16 times competition between fission and n-evaporation

Accumulation effect?

Even element are depleted by fission? Odd-Even effect in Fission barrier?

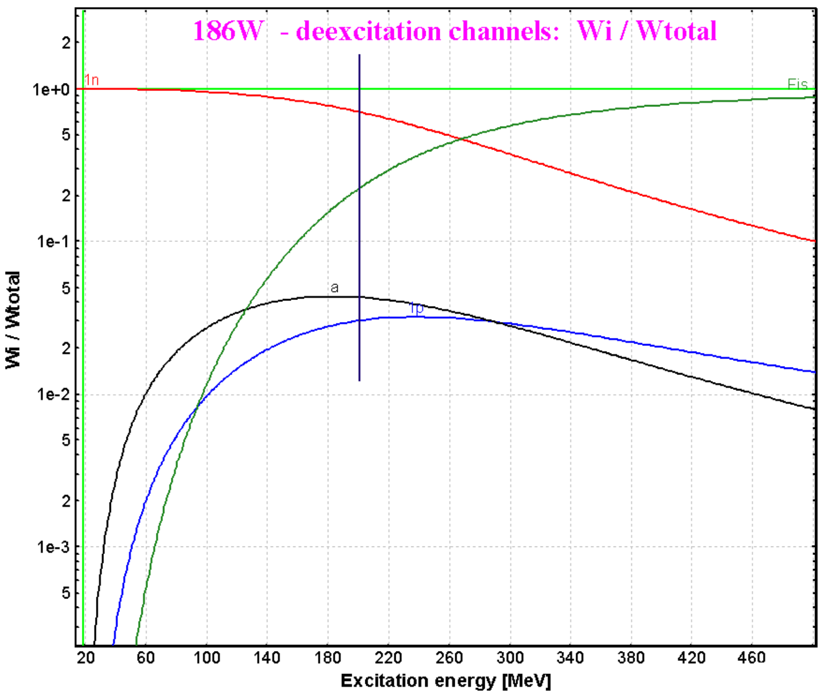
But fission channel is suppressed….

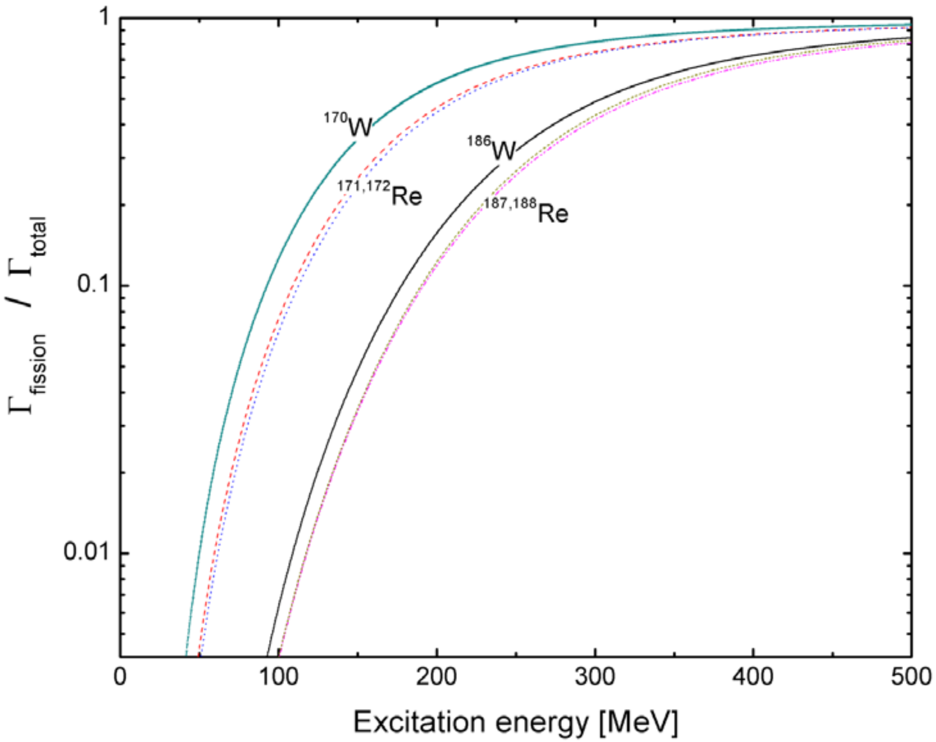
For example 30 years mortgage:

APR 5.3% finally you pay double price (+100%).

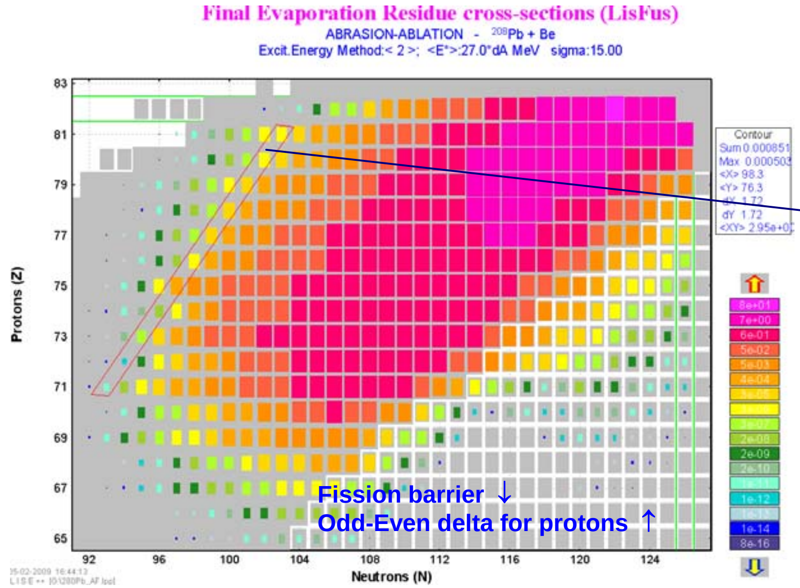
APR 9.4% finally you pay triple price (+200%).

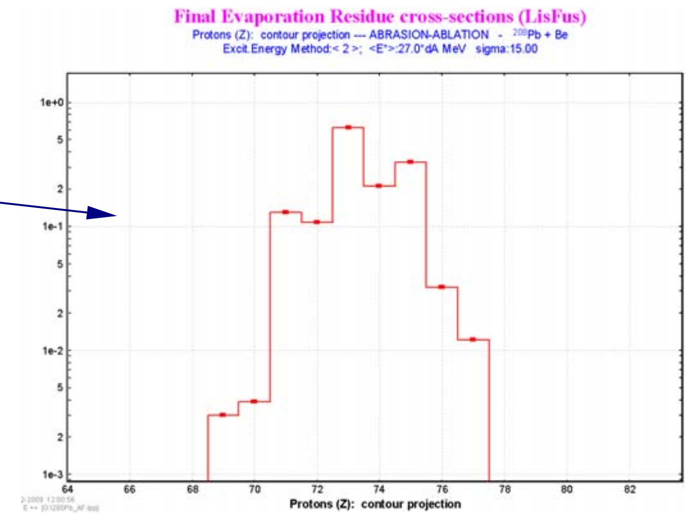
More data should help to answer



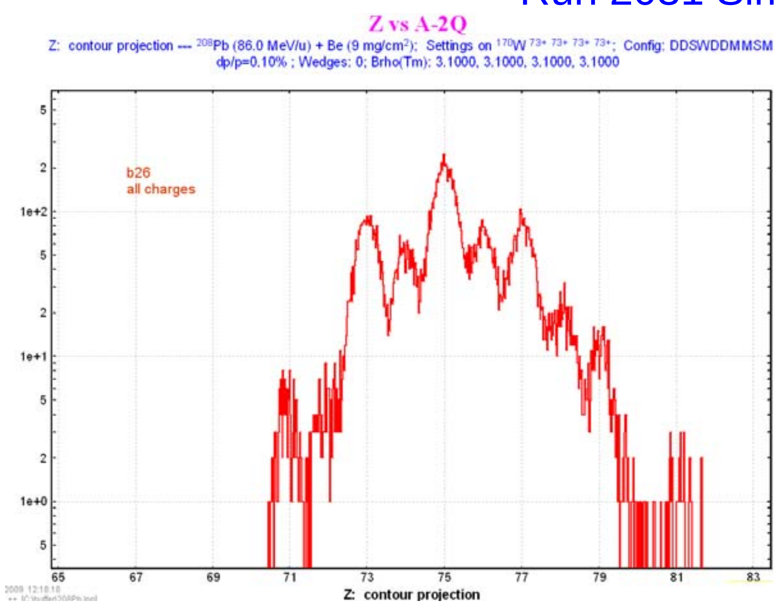


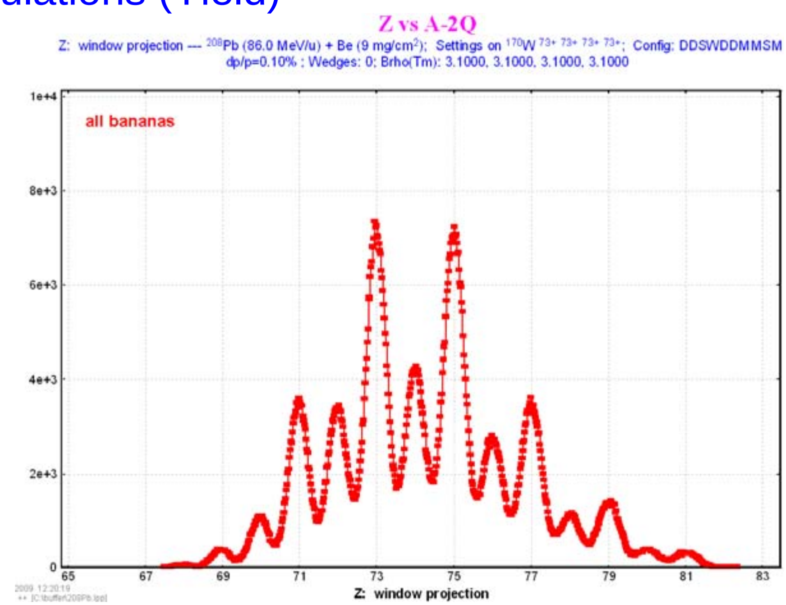
4d. Elemental Odd-Even Effect (LISE++)



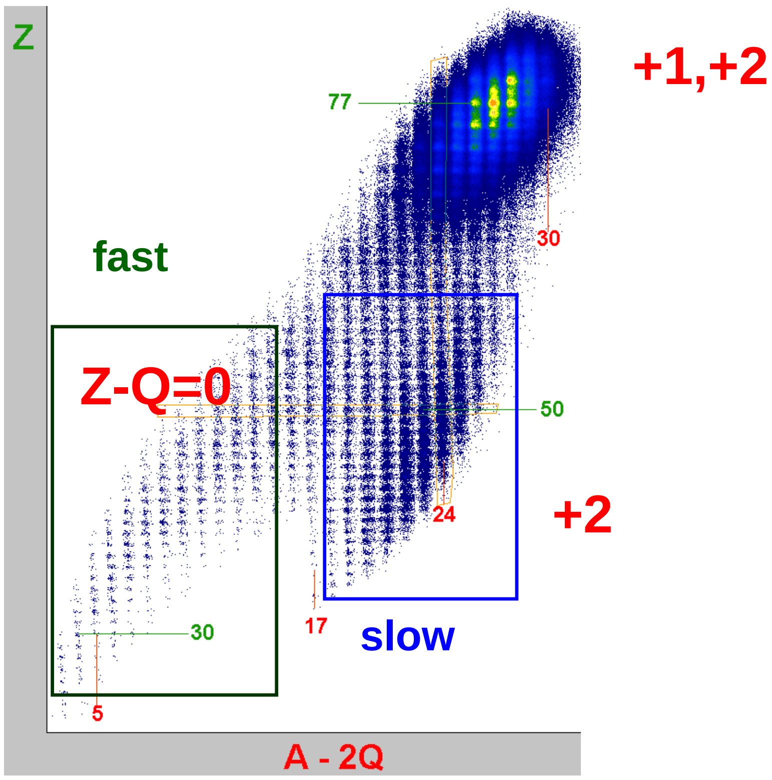


Run 2031 Simulations (Yield)

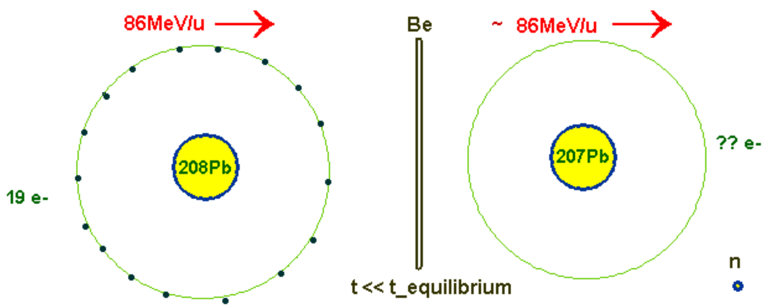


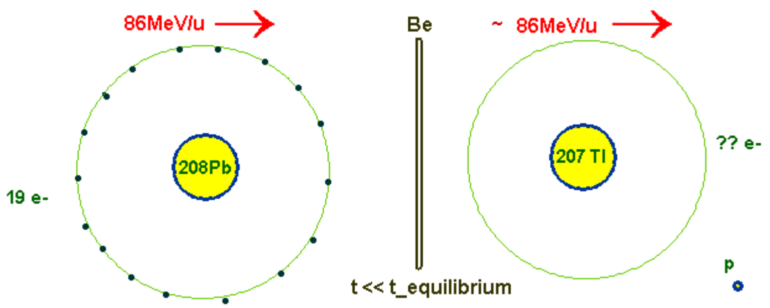


4e. Initial charge state



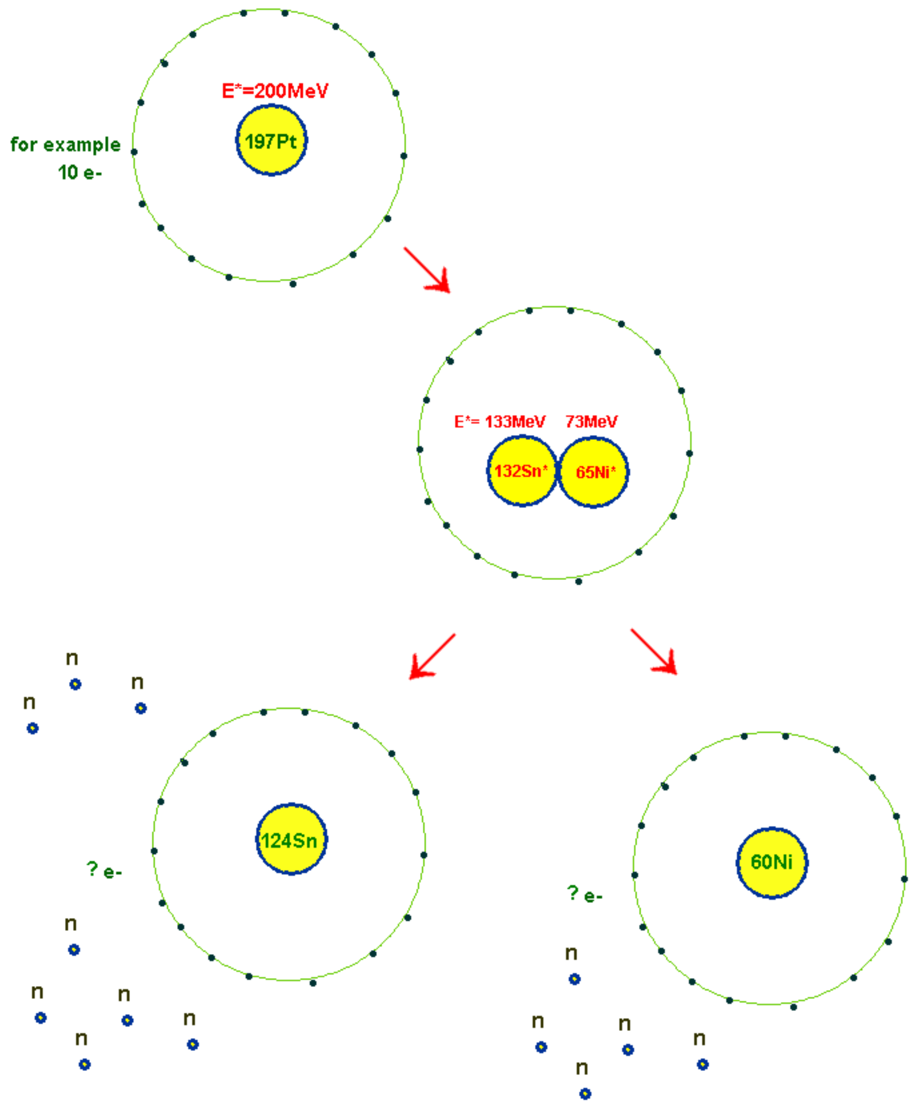
- Beam: $^{208}Pb^{63+}$ (86 Mev/u), $19e^-$
  Target : Be 9 mg/cm^2
- Equilibrium Be-thickness is equal to:
  150 mg/cm^2 for Pb-isotopes
  90 mg/cm^2 for Sn-isotopes
- We assumed in LISE++ that fragments after reaction are full-stripped





Knowing an initial charge state is important for prediction of secondary beam intensities and contaminants.

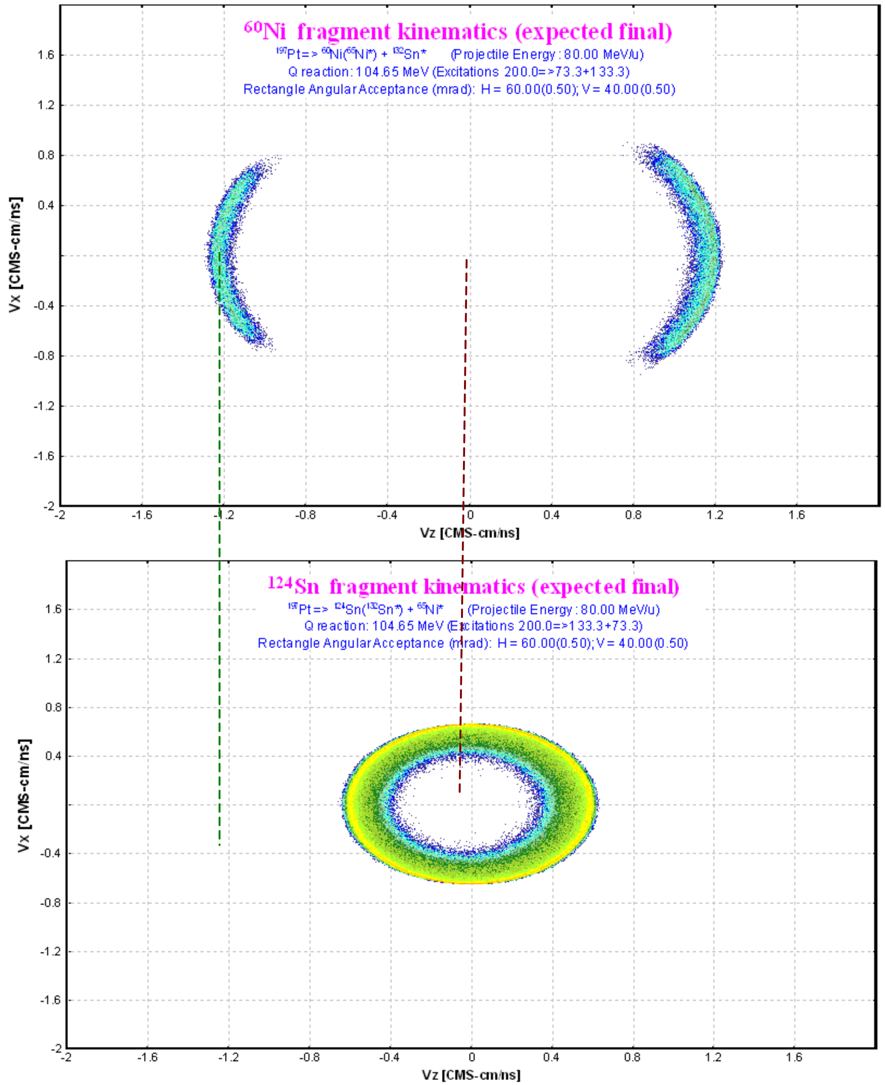
4e. Initial charge state (fission case)



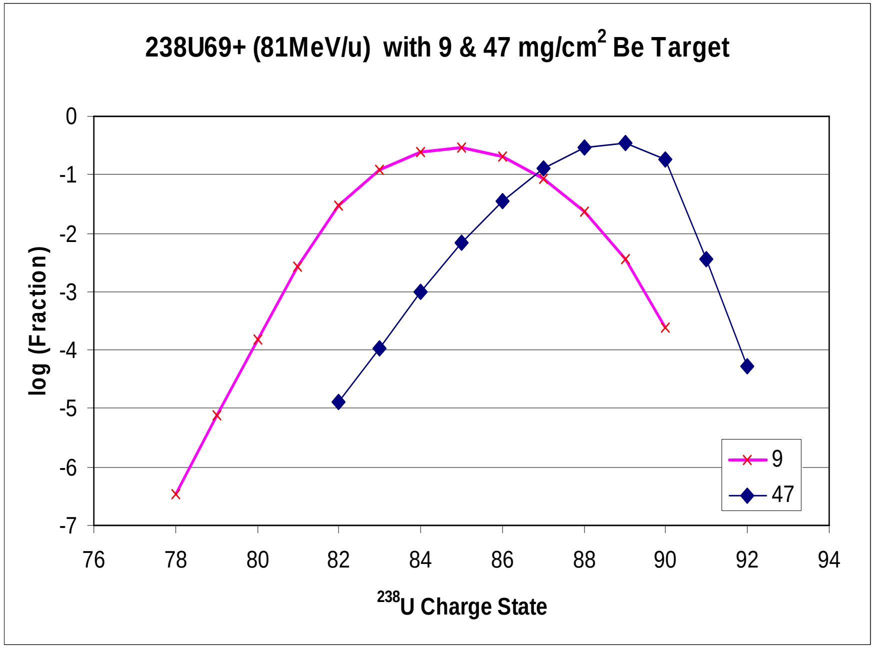
β_{max} (CM) = 0.02c

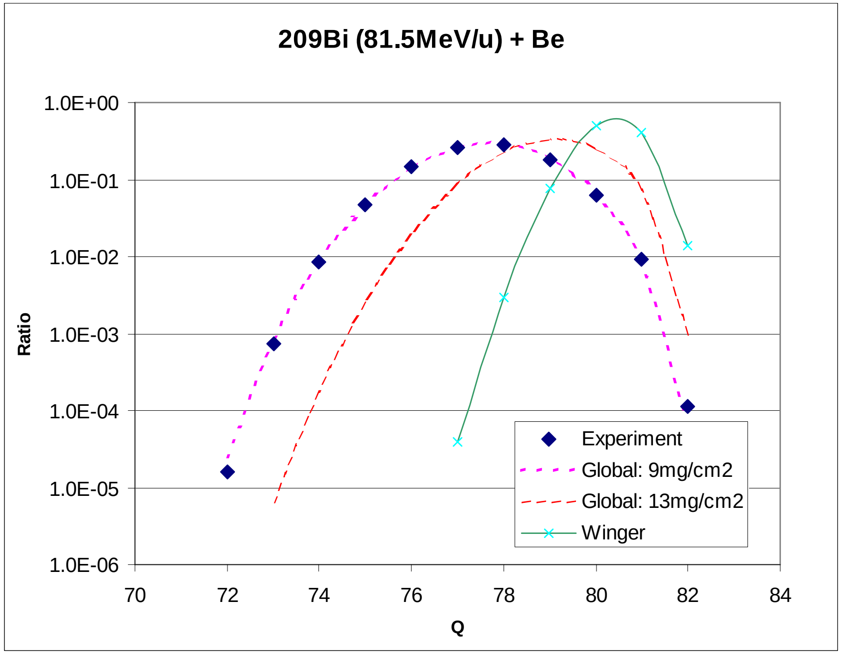
β (CM) = 0.043c

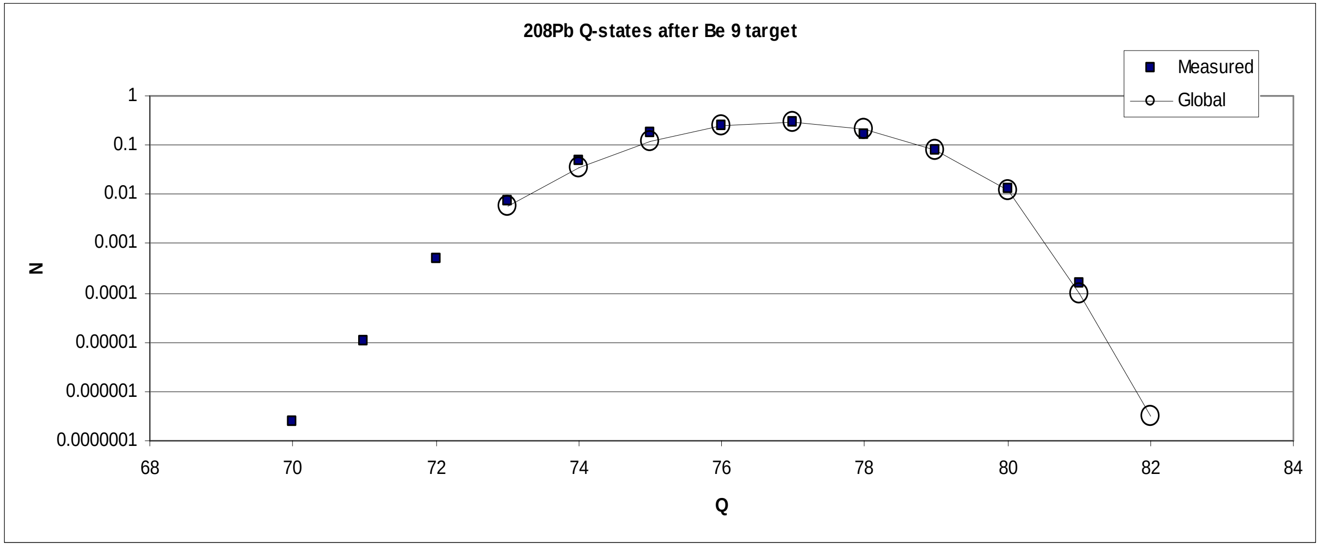
β (e-) = 0.008c



4f. Charge state distribution







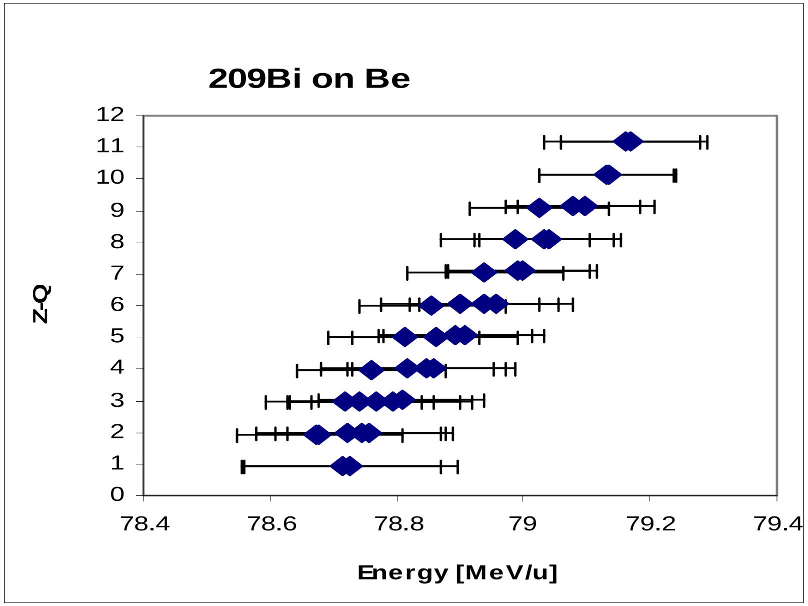
& Ni target

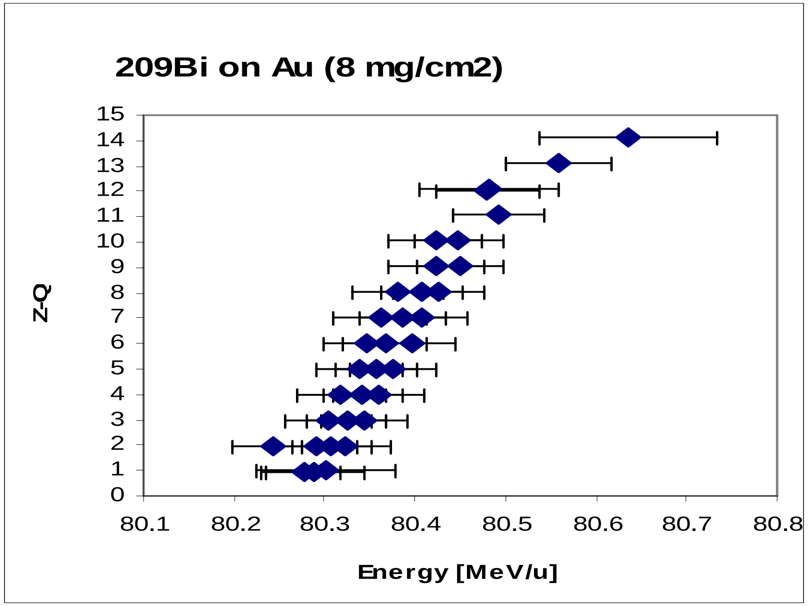
4f. Charge state. Energy loss as f(Q)

It has been seen (A1900 group),
that the Calculated "effective" thickness
depends from beam charge state.
$B\rho 0 \rightarrow B\rho 1$

$Q\uparrow \quad \rightarrow \quad \delta E\uparrow$

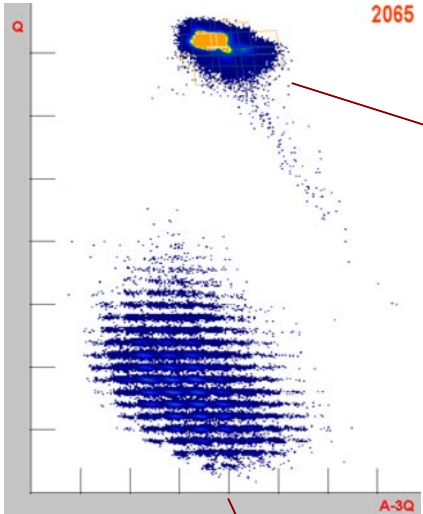
It is correlated with charge state fluctuations for energy straggling

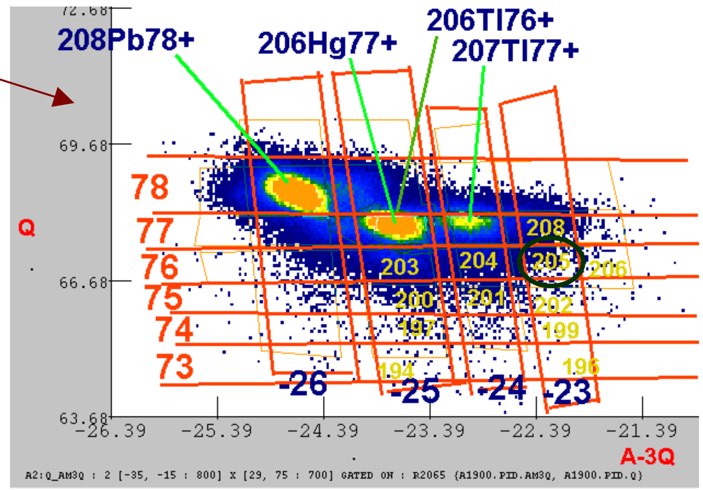


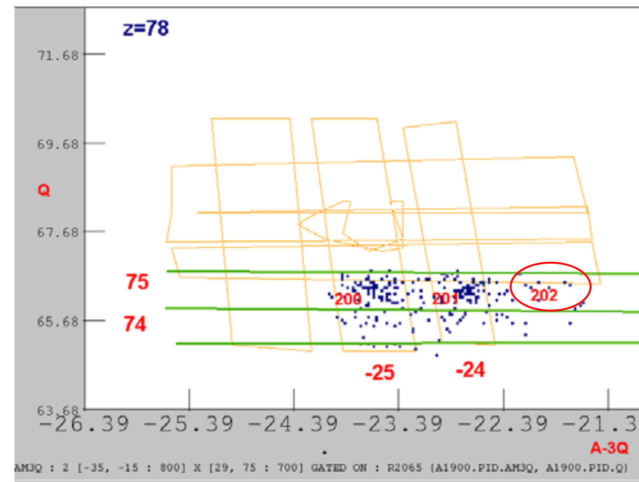


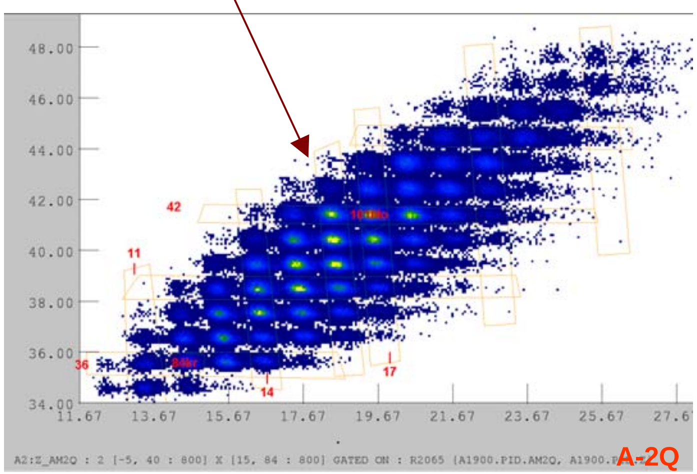
4g. New Isotopes

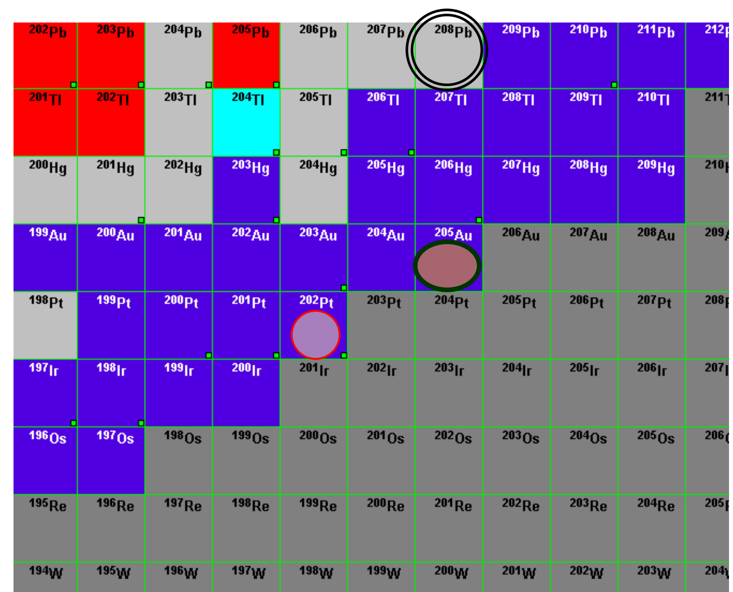
MICHIGAN STATE UNIVERSITY











- Runs contains ^{206}Hg isomer
- Thick wedge
- “blind” during the experiment
- TOF-resolution is not enough

5a. Outlook

- Two-stage separator

  cleaning

  no limitations with I2-detector

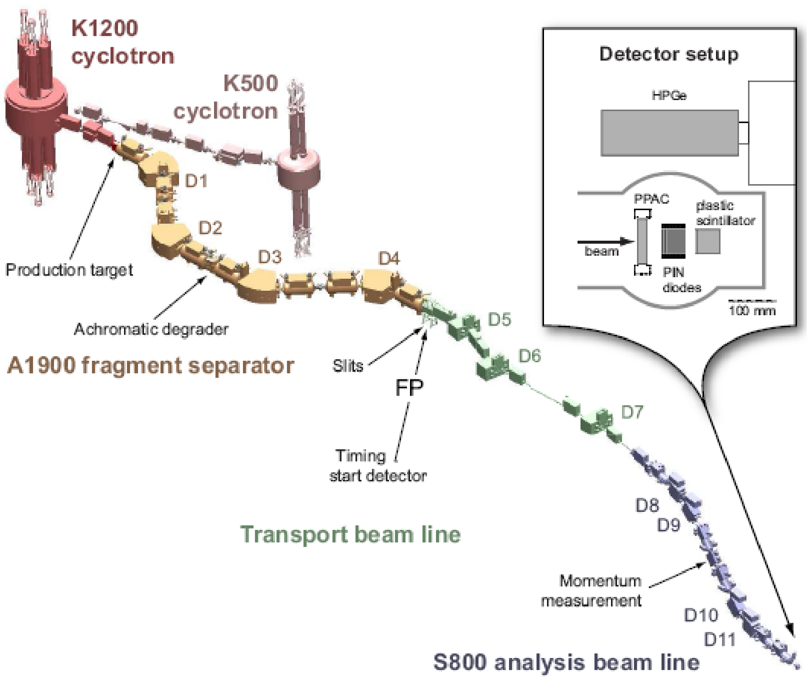
  MCP(x,t) at FP A1900

  TOF 46 m

- Methodical experience from ^{208}Pb and two-separator experiments

  New set of detectors, thin wedge etc

  Analysis; new "Z"-approach in the recent ^{76}Ge experiment is a good tool against charge state fluctuations $\sigma(Z)_{Z=30} < 0.1$



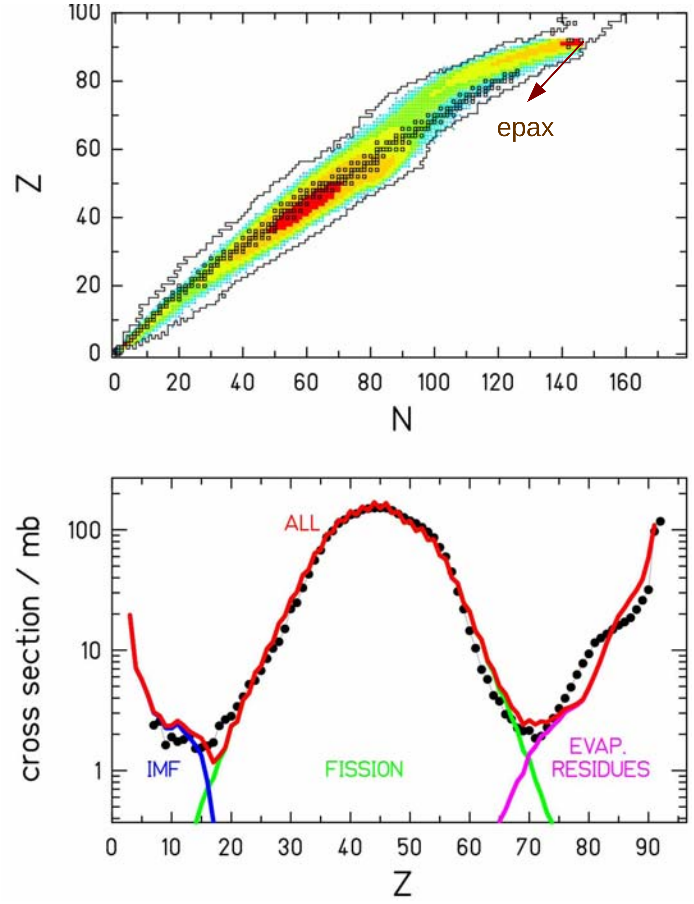
5a. Outlook (U-beam fragmentation)

- Can we identify isotopes of elements $80 \le Z \le 90$ by dE-E-ToF-Bρ method using Si-detectors?

- FRIB.
  U-fragmentation
  EPAX cross section??

- How are we going to make secondary beams the U-primary beam (identification?)

- Recent seminar at the NSCL.
  Non-observed level 400KeV of ^{215}Ac.
  Fragmentation instead fusion-fission?



Cross sections for the nuclei produced in ^{238}U (1 *A* GeV) + p. Up: Prediction of ABRABLA presented on the chart of the nuclides. Down: Experimental data (full dots) [this work, 11, 12, 13] are compared with the results of ABRABLA (solid line). The solid line is obtained by the sum of the three components: the evaporated IMF, the fission fragments and the heavy evaporation residues (dashed lines). *M.V.Ricciardi et al., PRC 73, 014607 (2006)*

5b. Conclusion

- **Isotopic identification of nuclides having A~200 has been achieved with Bρ–ToF–ΔE–E measurement techniques, demonstrating that adequate A,Z,Q resolution at this energy region is possible when using silicon detectors.**

- **The results demonstrate that experiments with heavy nuclei are possible at the NSCL using beams of A>200. There are some ways to improve separation to produce secondary beams in future using heavy primary beams at 80-100 MeV/u energy domain**

- **The data has shown the existence of previously unreported isomeric transitions and further analysis is ongoing that may also lead to the observation of new isotopes.**

- **Preliminary results show good agreement with the LISE++ code. Production cross-sections have been extracted from the data that can help improve the accuracy of production models such as Abrasion-Ablation and Abrasion-Fission used in the LISE++ code.**

a. Methodical approaches (RB production, straggling, identification etc)
b. Odd-Even effect in elemental production (fission barrier)
c. Search for New isotopes
d. Search for New isomers
e. Reaction mechanism: Production cross sections.
f. Initial charge state after reaction
g. Charge state distributions; Energy loss as f(Q)

5c. Participants of the #05120 experiment

A.M.Amthor

M. Portillo

T.N.Ginter

T.Baumann

B.M.Sherrill

M.Hausmann

D.Bazin

O.B.Tarasov

D.J.Morrissey

C.M.Folden III

M.Thoennessen

J.Pereira

This work was supported by NSF #PHY-06-06007 grant.