Studies of Superheavy Elements at GANIL

- Motivations
- Set-up
- Experiments
- Perspectives

Motivation

Scientific case

- Production, detection and identification of new isotopes or elements.
- Study of their α-decay or spontaneous fission (= identification).
- Spectroscopy of transfermium nuclei
- Where is located the « island » of stability ? New magic Z, N

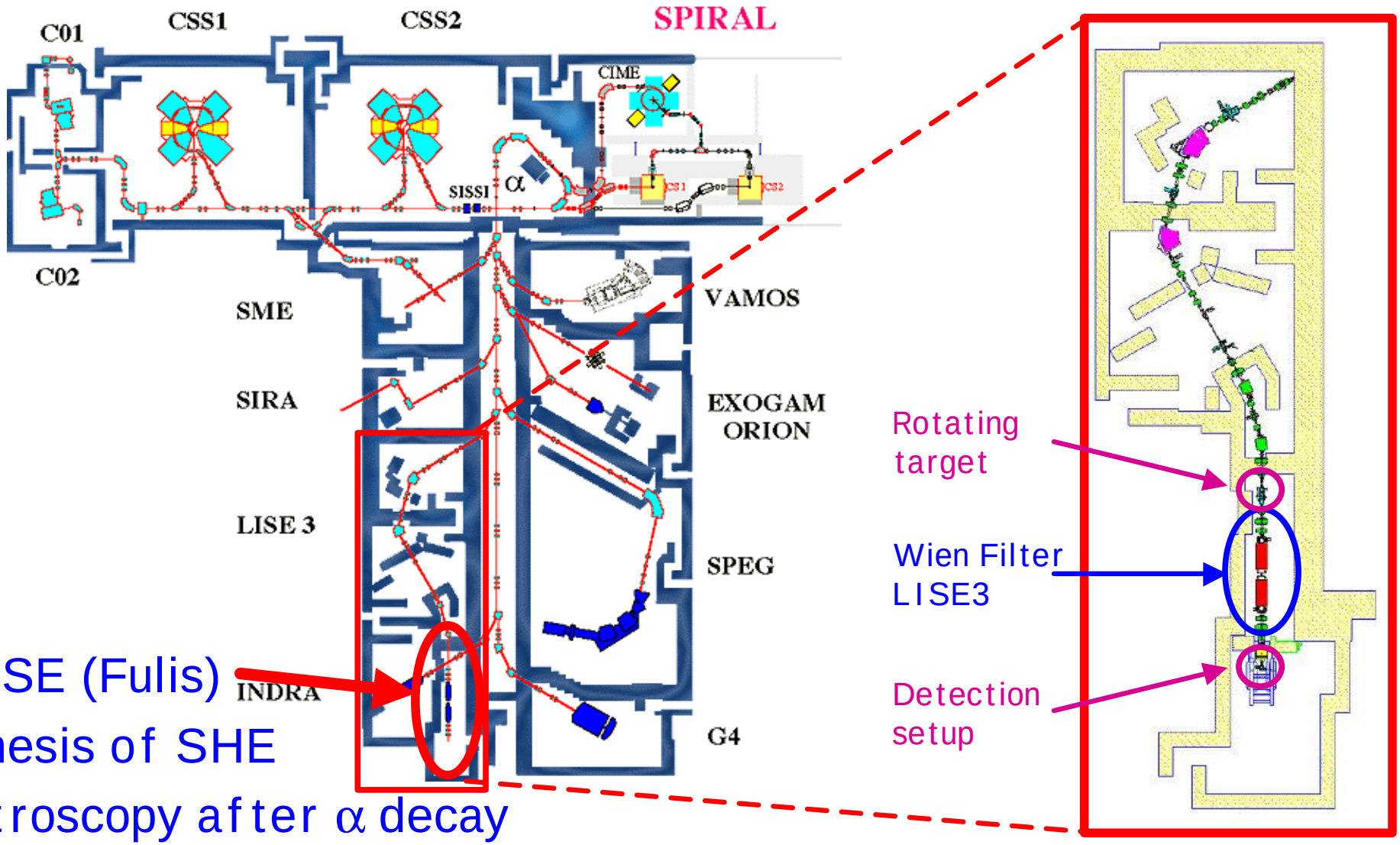
Means

- Intense Primary beams (Kr, Ge)
- Powerful Wien Filter

+

- Rotating targets
- Detection set-up

GANIL experimental areas



D6 : LISE (Fulis)

- Synthesis of SHE
- Spectroscopy after α decay

Rotating Targets

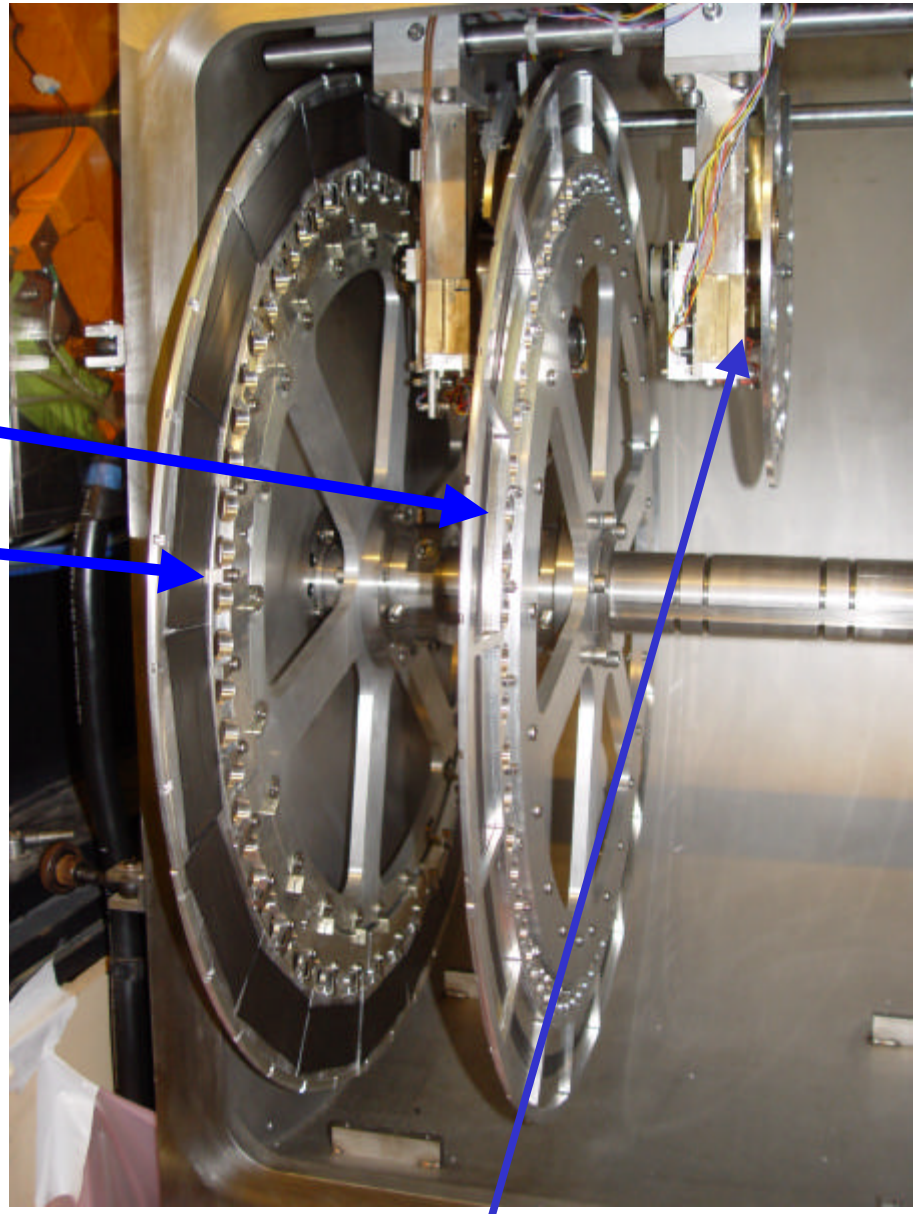
18 ^{208}Pb/^{209}Bi targets

18 C stippers

Rotation : up to 2000 rpm

Beam synchronised with wheel rotation

On-line monitoring of target quality



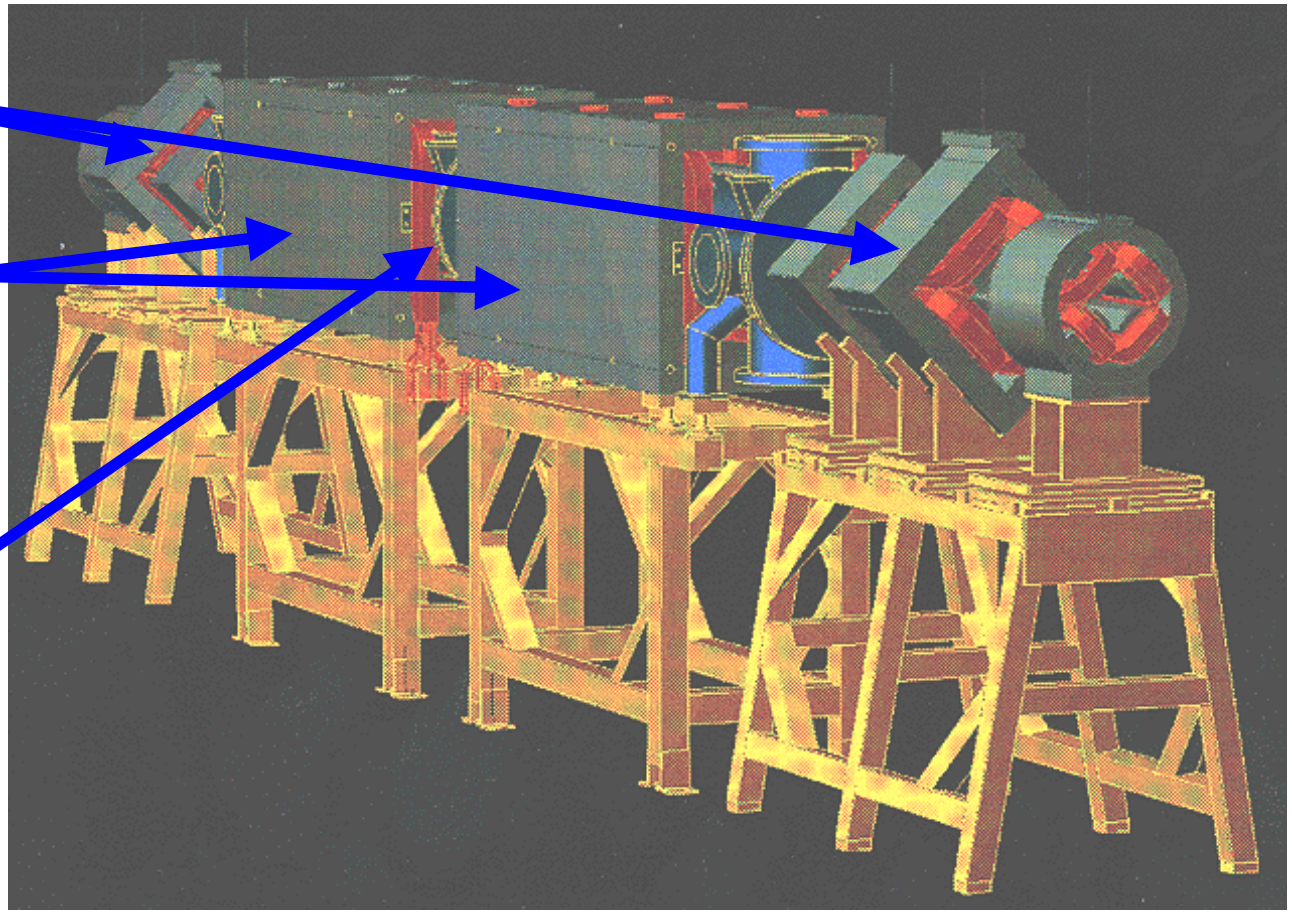
Auxiliary fixed targets: ^{152}Sm, ^{160}Gd

Wien Filter

Two Q triplets

Two E⊥B sections

Shield (beam dump) at mid-filter



Wien Filter

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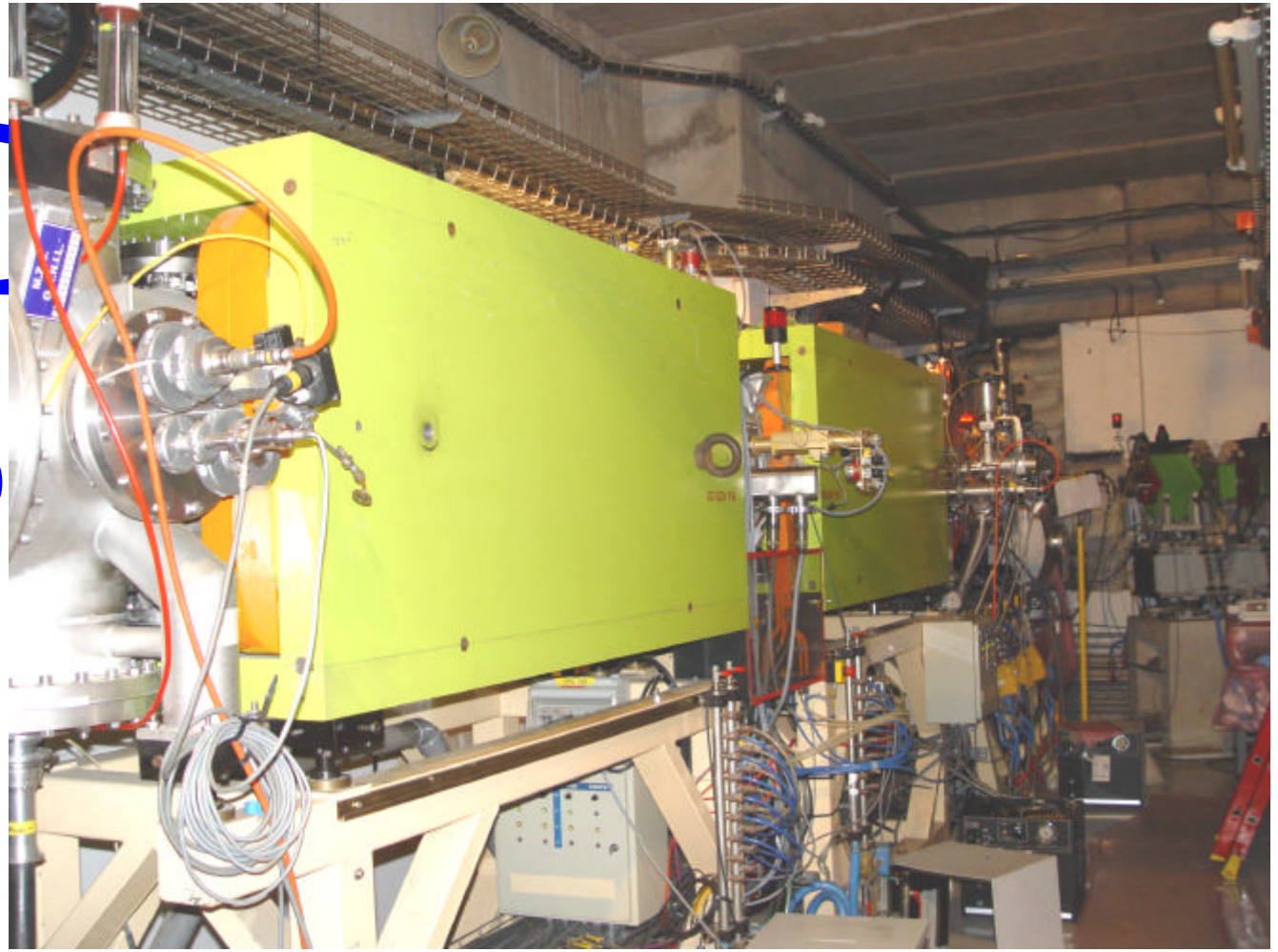


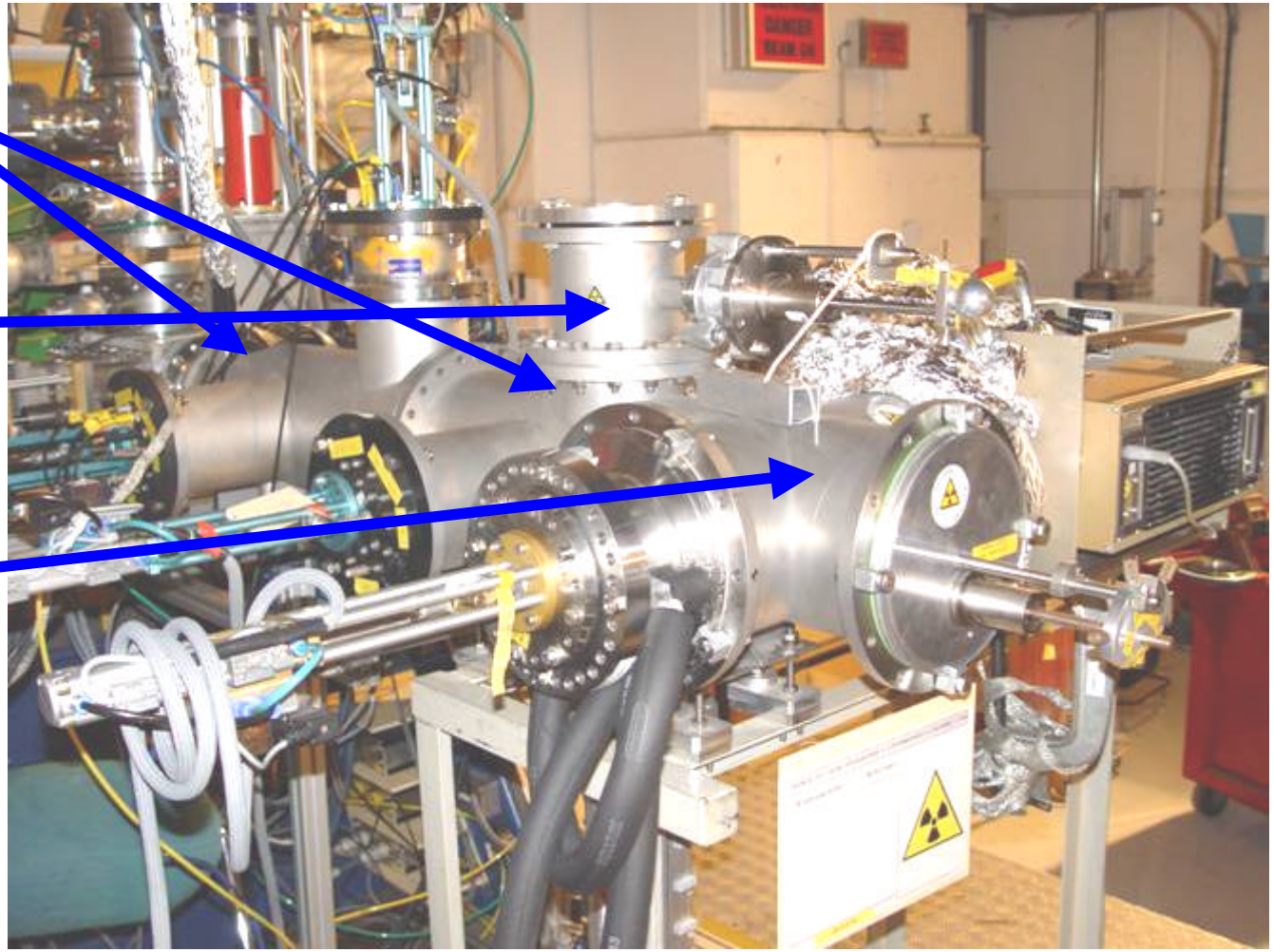
Beam stop

Focal plane detectors

ToF detectors (galottes)

Degraders

Implantation + Tunnel

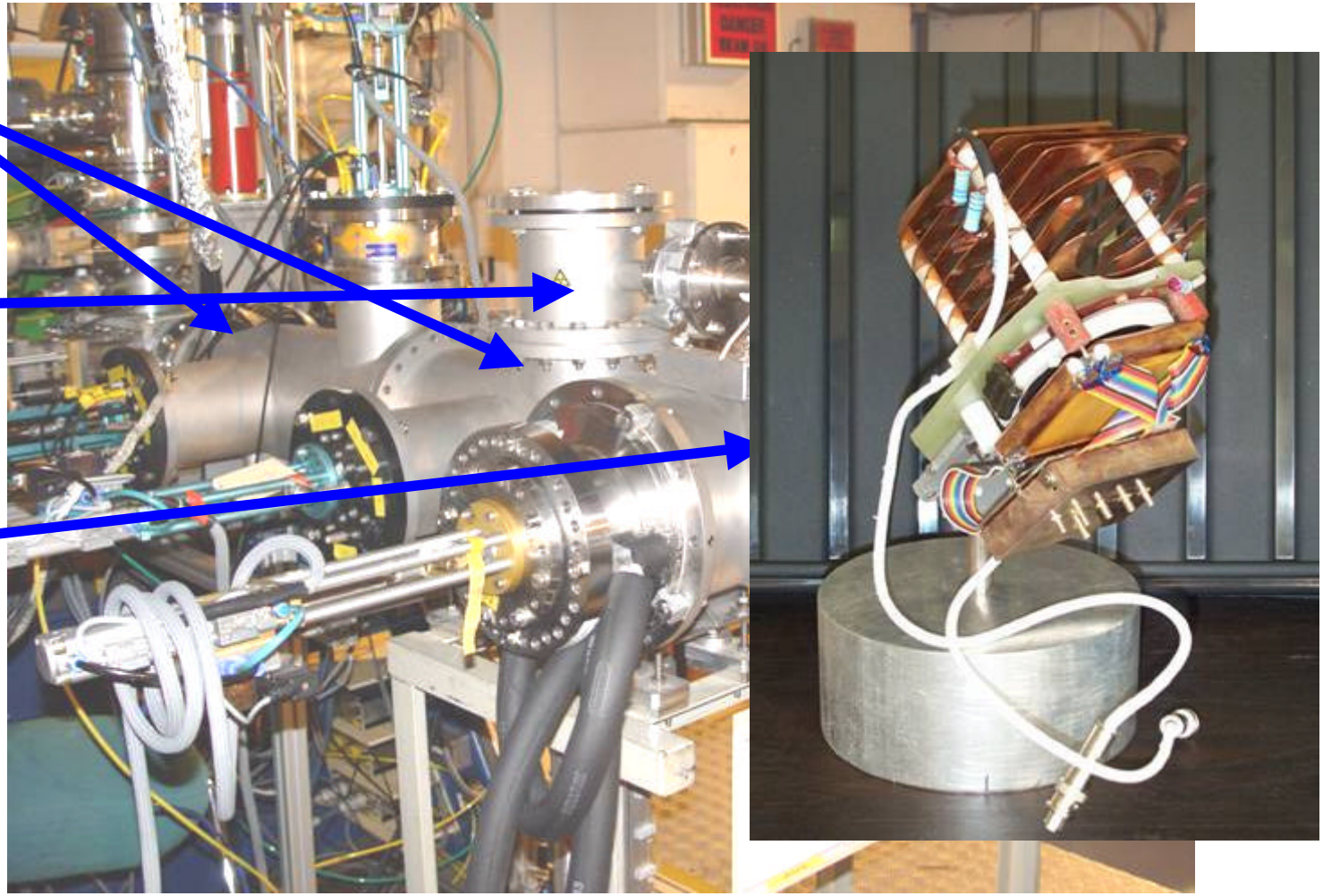


Focal plane detectors

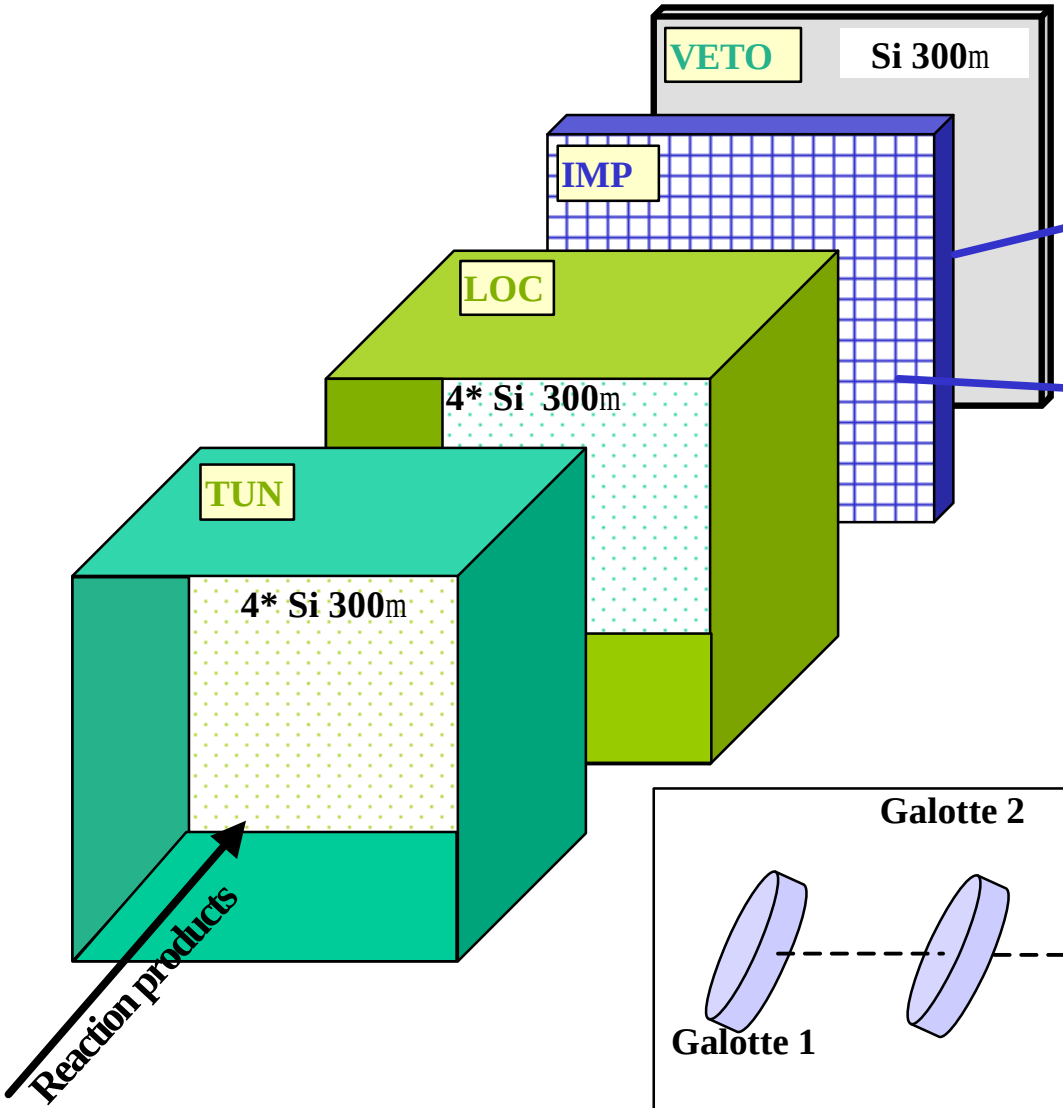
ToF detectors (galottes)

Degraders

Implantation + Tunnel



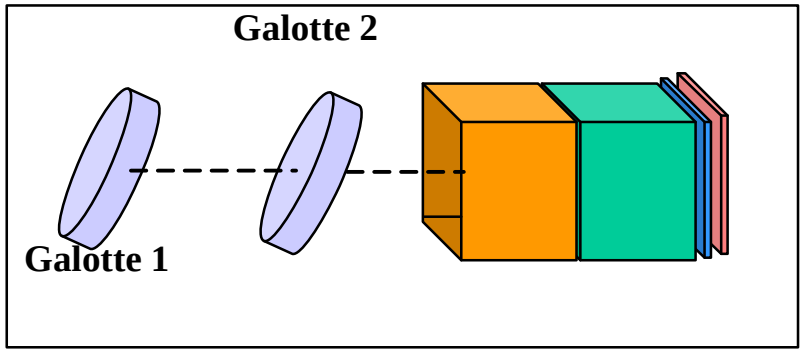
Implantation and tunnel detectors



Backward:
32 vertical strips
(8*2mm+16*1mm+8*2mm)

Front face:
16 horizontal strips (3mm)

Cooled to –10°C
Résolution =
20 keV for implantation
40 keV for tunnel



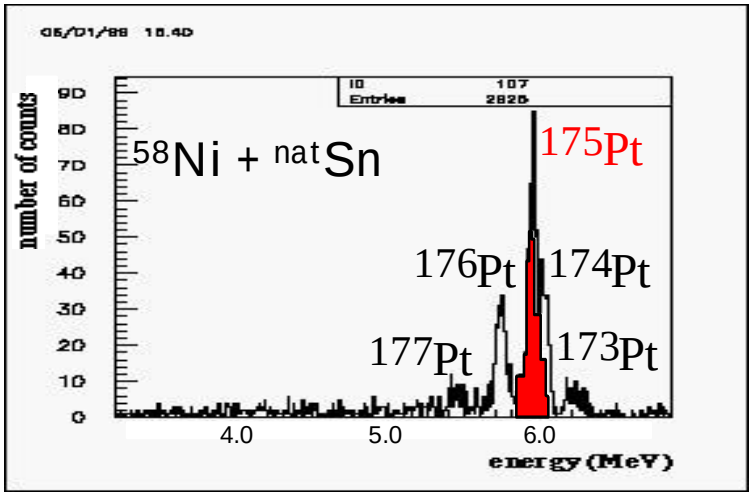
Chronology up to 1999…

oct. 97 first test (SL00)

july 98 test of noise suppression (SL01)

rejection ≈ 10^8

nov. 98 first fusion detected by α decay at GANIL (FULIS)



rejection ≈ 10^8-10^{10}

july 99 E339 experiment – test of inverse kinematics

rejection ≈ 10^9-10^{10}

Chronology from 1999 to 2001... (1)

july 99 Observation of 3 events of Z=118 at Berkeley

nov. 99 Experiment $^{86}Kr + ^{208}Pb$ at GANIL

- Intense primary beam of ^{86}Kr
- New rotating target
- Modifications of the Wien Filter LISE3
- Improvements of the detection setup

-estimations for **^{86}Kr(THI)**:

If σ = 1pb + N_i = 1μAp = 6.25 10^{12} pps

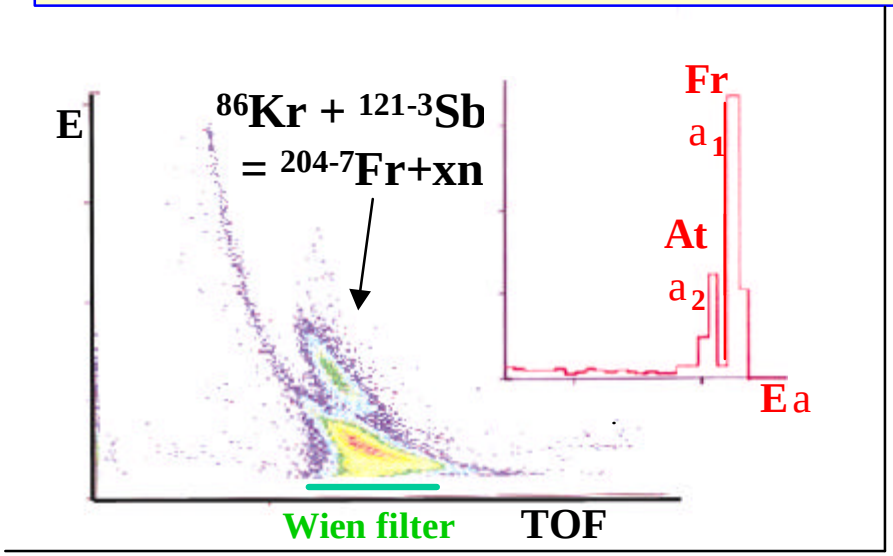
→ Number of Z=118 → 0.5 day^{-1}

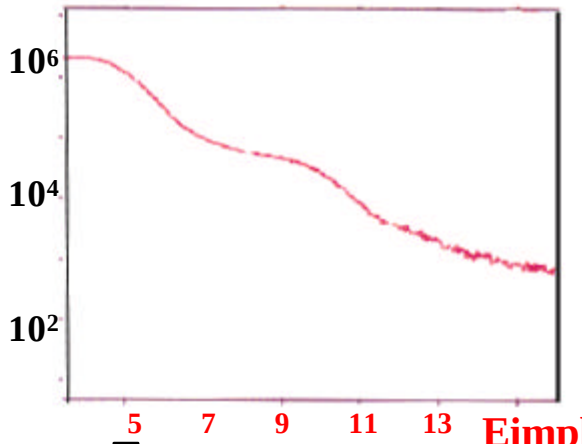
- GANIL Intensity:

N_i ~ 2μAp

→ 7 times Berkeley's intensity

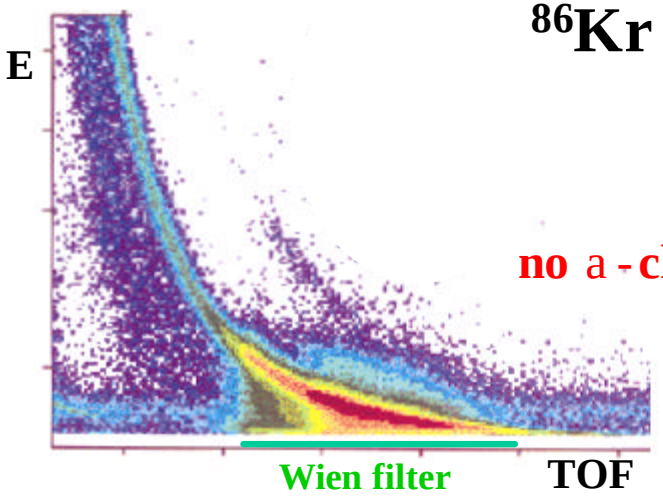
Detection ExTOF - Identification via a-chain



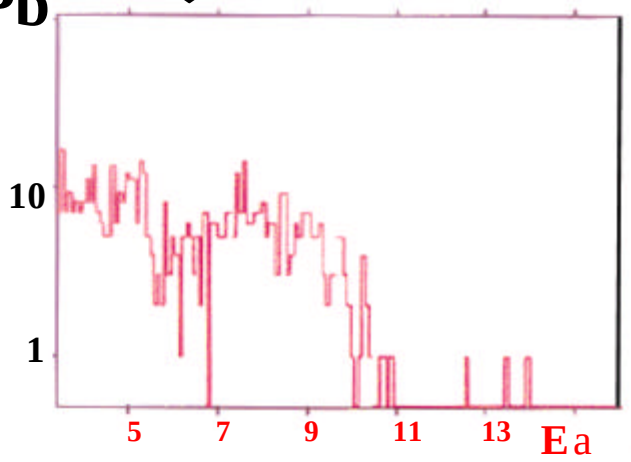


anti-coincidence MCP 's

^{86}Kr + ^{208}Pb

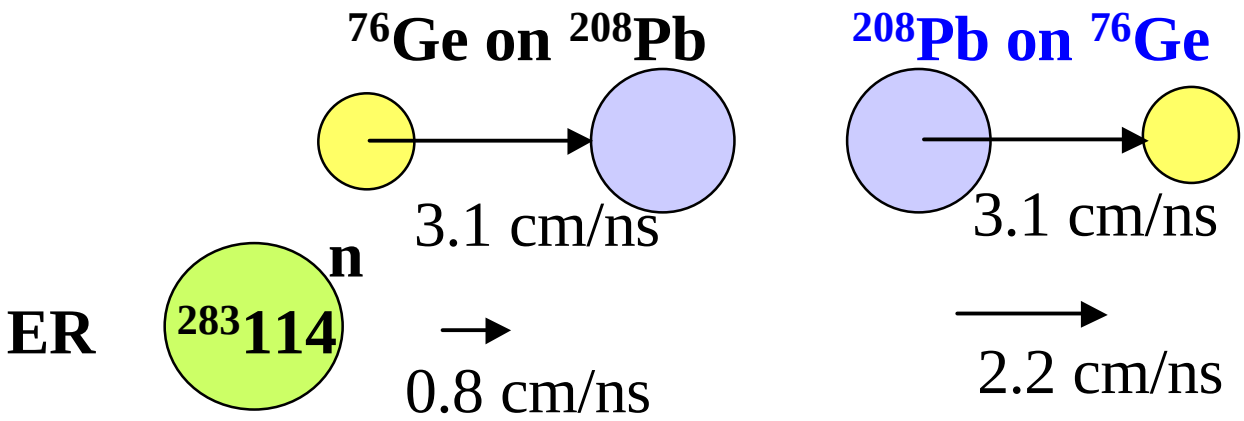


no a-chain



Assets of Inverse kinematics

May 2002



- **One accelerator setting for a large E* range = gain in time**
- Forward focalisation ideal for secondary beam production (COULEX), LISE well suited
- Better "quality" of data (α and FF energy)

Drawbacks :

- High Electric and Magnetic fields in Wien Filter
- Low intensity Pb beam (presently)

Inverse Kinematics: ^{208}Pb beam

First test. June 1999: E339

⇒ - need to lift up the first upper plate of the Wien filter.

^{208}Pb +^{51}V,… May 2002 E339b

Experimental improvements

- additional devices in the reaction chamber:
  - fast rotating target wheel
  - oscillating stripper foils
  - remote controlled collimator

- additional devices in the detection chamber:
  - **ionization chamber : ΔE (NIM)**
  - cooling of the Si detectors

Results:

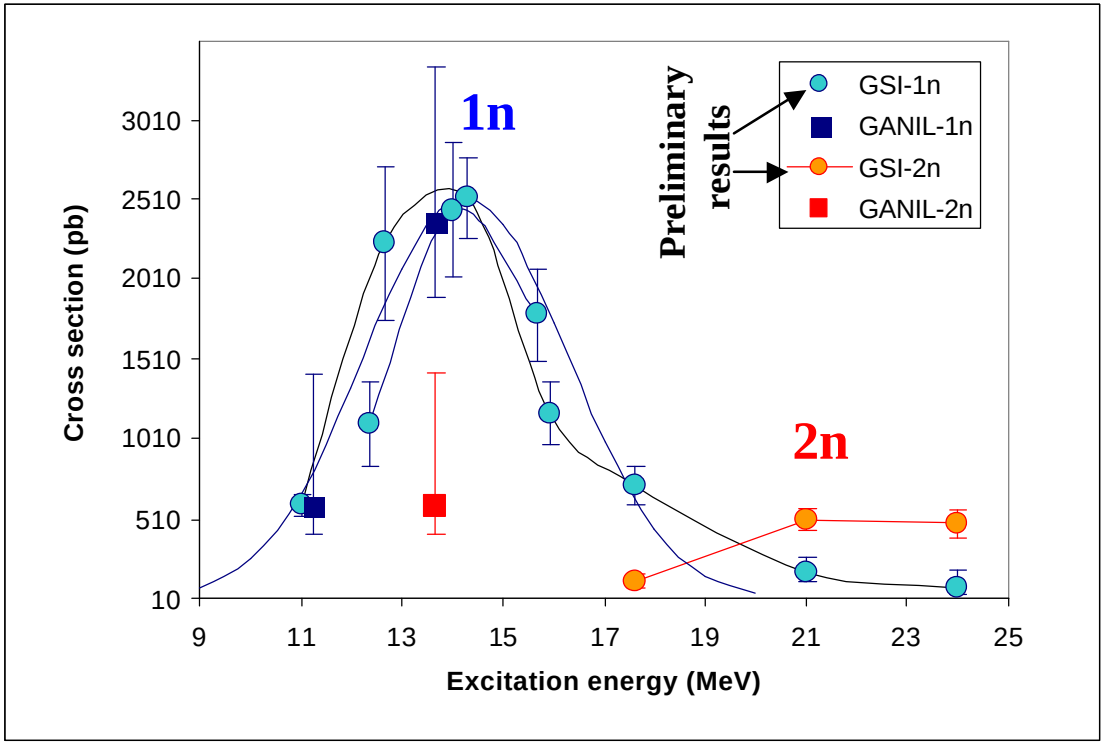
- Method for **measuring the velocity selected by the filter**
- **40 keV resolution** on α-energy in decay chains of transfer products.
- Direct information on **Z of implanted product** (Δ**E.E)**
- Test of fusion in inverse kinematics (at the entrance of LISE)

for **experiments on Coulomb excitation** (after the velocity filter): E387.

Tests of small cross sections in cold fusion reactions

dec. 00

Experiment E369: $^{54}Cr + ^{208}Pb$ ® $^{261,260}Sg(106)$ + 1n, 2n



Rejection $=1.7\ 10^{10}$

- 10(1) events corresponding to the 1n(2n) channel

(known with decay chains)

$\varepsilon_{det} = 0.85$

➔ ε_{trans}(LISE) ~ 15%

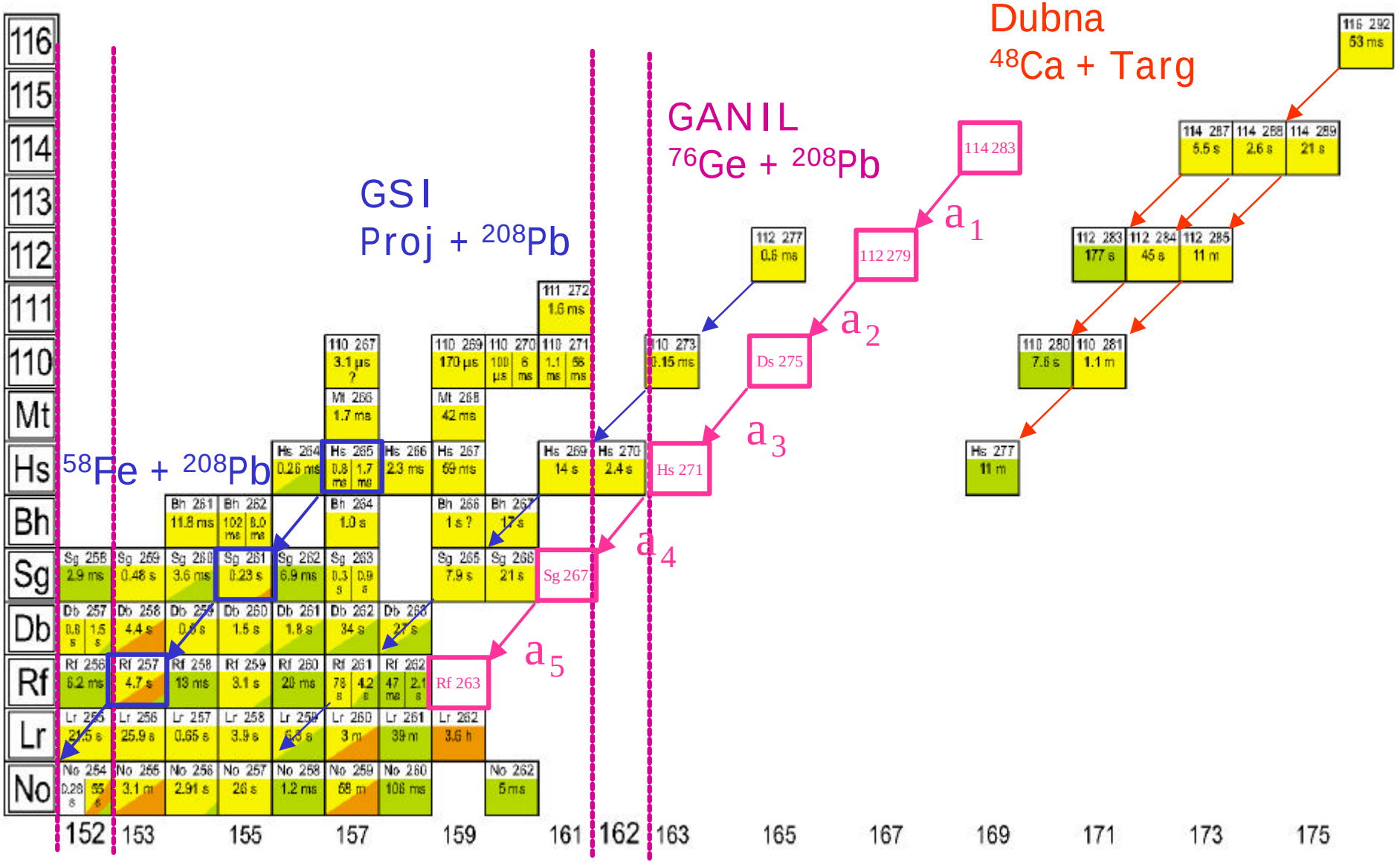
E440
Synthesis of Z=114 via the reaction
$^{76}Ge + ^{208}Pb \rightarrow ^{283}114 + 1n$

Autumn 2003

Program: 1st part : feasibility with **^{40}Ar, ^{58}Fe and ^{208}Pb beams**
2nd part: **^{76}Ge for Z=114**

$^{208}Pb + ^{208}Pb$

- 208Pb beam from CO at 114 velocity: transmission 17% due to multiple Coulomb scattering.
- target position closer to q-poles ↦ transmission 27 %, in agreement with calculated value.


Dubna
48Ca + Targ
GANIL
76Ge + 208Pb
GSI
Proj + 208Pb
58Fe + 208Pb
a1
a2
a3
a4
a5
114 283
112 279
Ds 275
Hs 271
Sg 267
Rf 263
116 292 53 ms
114 287 5.5 s
114 288 2.6 s
114 289 21 s
112 283 177 s
112 284 45 s
112 285 11 m
110 280 7.6 s
110 281 1.1 m
Hs 277 11 m
112 277 0.6 ms
110 273 0.15 ms
111 272 1.6 ms
110 267 3.1 µs ?
110 269 170 µs
110 270 100 µs 6 ms
110 271 1.1 ms 55 ms
Mt 266 1.7 ms
Mt 268 42 ms
Hs 264 0.26 ms
Hs 265 0.8 ms 1.7 ms
Hs 266 2.3 ms
Hs 267 69 ms
Hs 269 14 s
Hs 270 2.4 s
Bh 261 11.8 ms
Bh 262 102 ms 8.0 ms
Bh 264 1.0 s
Bh 266 1 s ?
Bh 267 17 s
Sg 256 2.9 ms
Sg 259 0.48 s
Sg 260 3.6 ms
Sg 261 0.23 s
Sg 262 6.9 ms
Sg 263 0.3 s 0.9 s
Sg 265 7.9 s
Sg 266 21 s
Db 257 0.8 s 1.5 s
Db 258 4.4 s
Db 259 0.5 s
Db 260 1.5 s
Db 261 1.8 s
Db 262 34 s
Db 263 27 s
Rf 256 6.2 ms
Rf 257 4.7 s
Rf 258 13 ms
Rf 259 3.1 s
Rf 260 20 ms
Rf 261 78 s 4.2 s
Rf 262 47 ms 2.1 s
Lr 255 21.5 s
Lr 256 25.9 s
Lr 257 0.65 s
Lr 258 3.9 s
Lr 259 6.3 s
Lr 260 3 m
Lr 261 39 m
Lr 262 3.6 h
No 254 0.28 s 55 s
No 255 3.1 m
No 256 2.91 s
No 257 26 s
No 258 1.2 ms
No 259 58 m
No 260 106 ms
No 262 5 ms
116
115
114
113
112
111
110
Mt
Hs
Bh
Sg
Db
Rf
Lr
No
152
153
155
157
159
161
162
163
165
167
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171
173
175

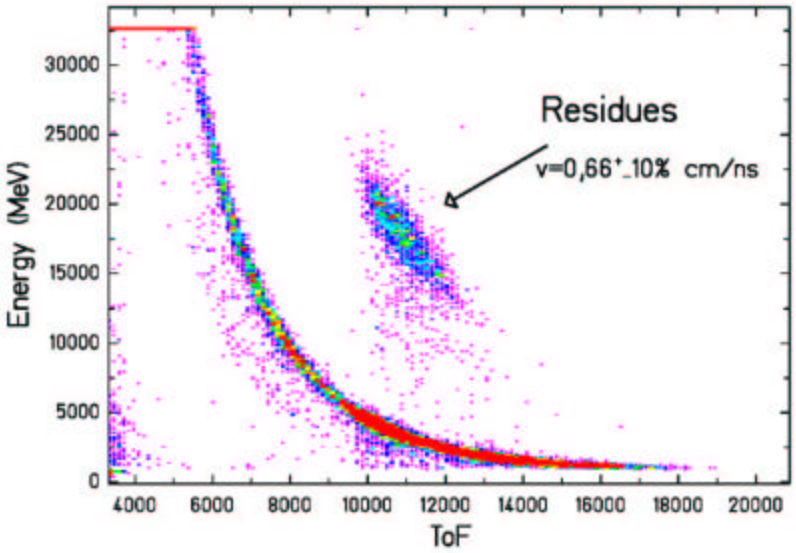
E440 1st part - Sep./Oct 2003

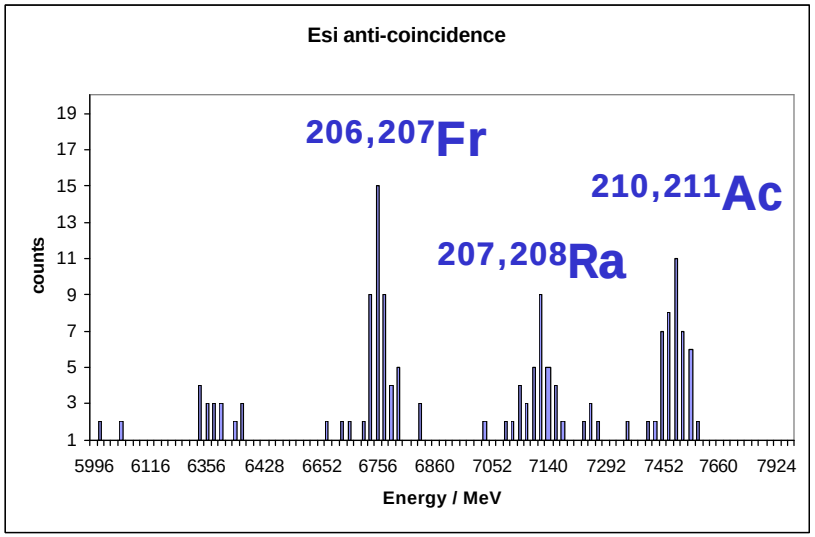
$^{40}Ar + ^{208}Pb \rightarrow ^{245}Fm(100) + 3n$

Beam from CIME
Good behaviour of targets (irradiation + mechanic)

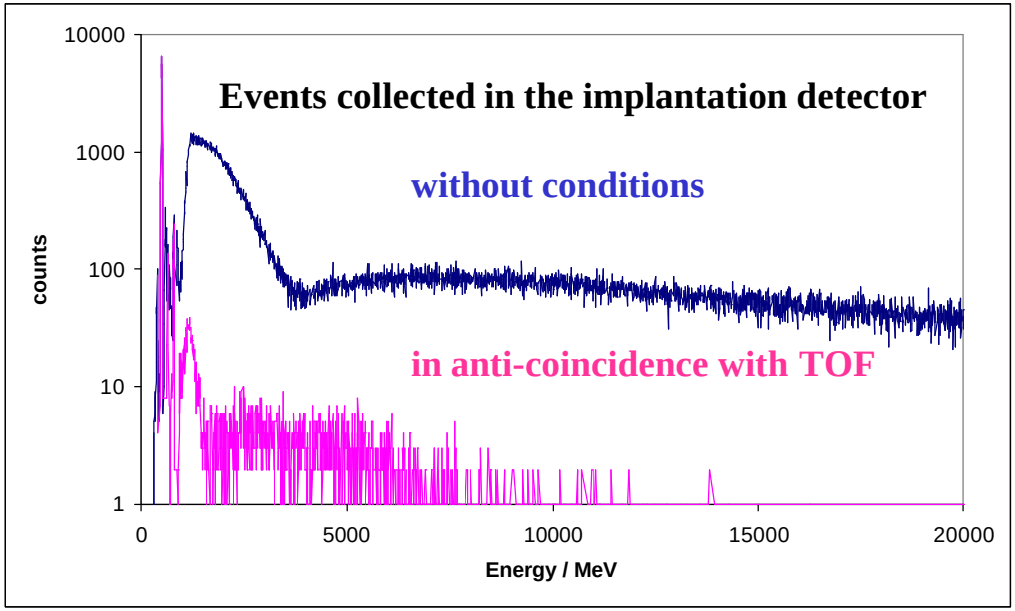
^{58}Fe beam

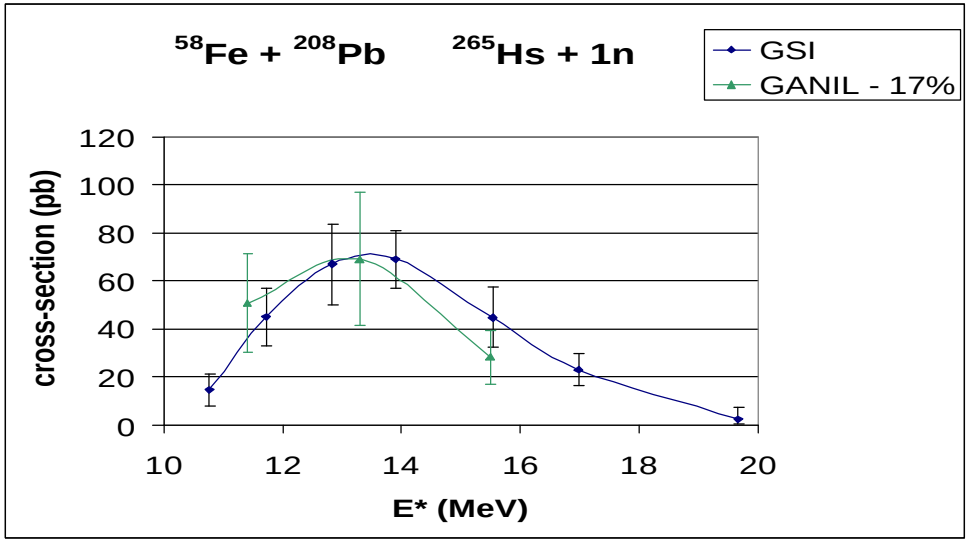
$^{58}Fe + ^{152}Sm \rightarrow ^{210}Ra(88)^* - ^{58}Fe + ^{160}Gd \rightarrow ^{218}Th(90)^*$





$^{58}Fe + {}^{208}Pb \rightarrow {}^{265}Hs(108) + 1n$





Réf // GANIL

^{265}Hs

10.31-10.58 // 10.68 MeV
1.55 ms // 1.5 ms

^{261}Sg

9.56 // 9,64 MeV
230// 70 ms

^{257}Rf

α 82%
β^+ 18%

8.715 // 8,63 MeV
4.3 // 0,45 s

^{253}No

8.01 // 8,14 MeV
1.7 mn // 15,7 s

3 incident beam energies (equal to GSI)
500 pnA
Beam suppression > $2*10^{10}$
Transmission = 15-20 %

Search for $^{283}114$

E440 2nd part - Nov 2003

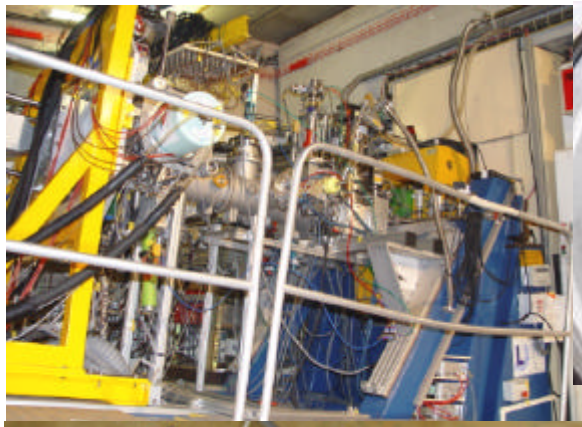
$^{76}Ge + ^{208}Pb \rightarrow ^{283}114 + 1n$

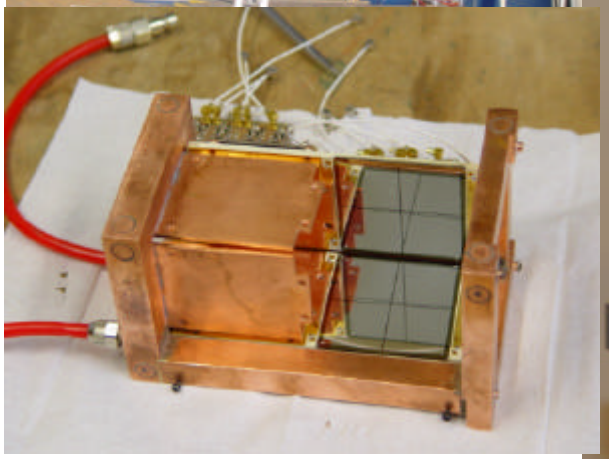
- 1 beam energy, E = 5.02 MeV/A
- large intensity: new method developed by Ion Source Group > 1pμA
- very good rejection factor (low background) > 10^{11}
- good behavior of targets (420 μg/cm^2)
- 3 α and 4 α chains of actinides (transfer products).
- sensitivity : **1 event = 0.6 pb** - beam dose =$5*10^{18}$ **^{76}Ge**

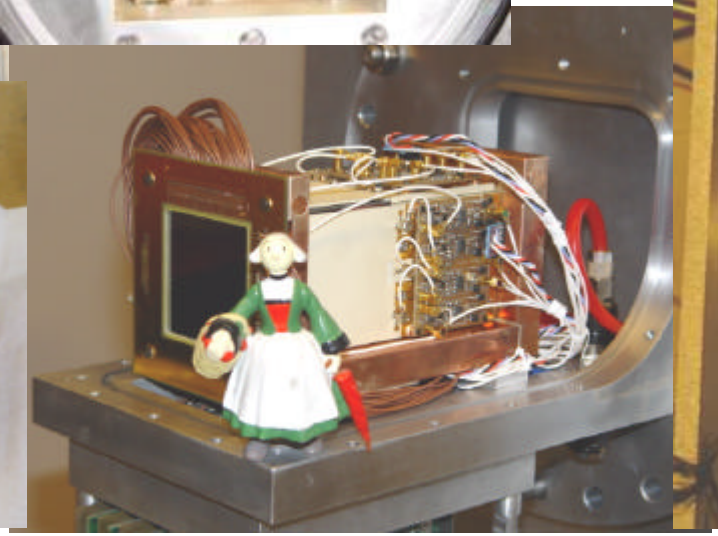
- no event attributed to 283-114
  - ↦ **cross section < 1.2 pb in energy range 274.5-278.5 MeV c.m. unless decays (α or spontaneous fission) within 3 μs**

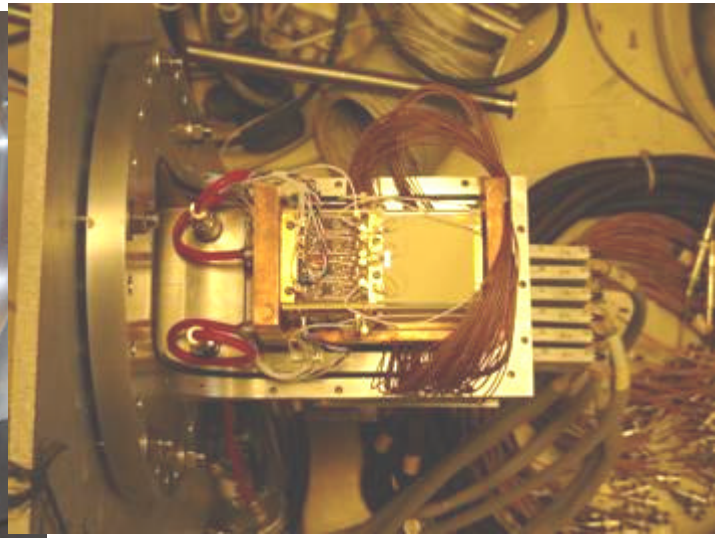
E375 – Spectroscopy of transfermium nuclei

- 2003 : $^{48}Ca + ^{209}Bi \rightarrow ^{255}Lr + 2n$
- Modified Setup at the focal plane :



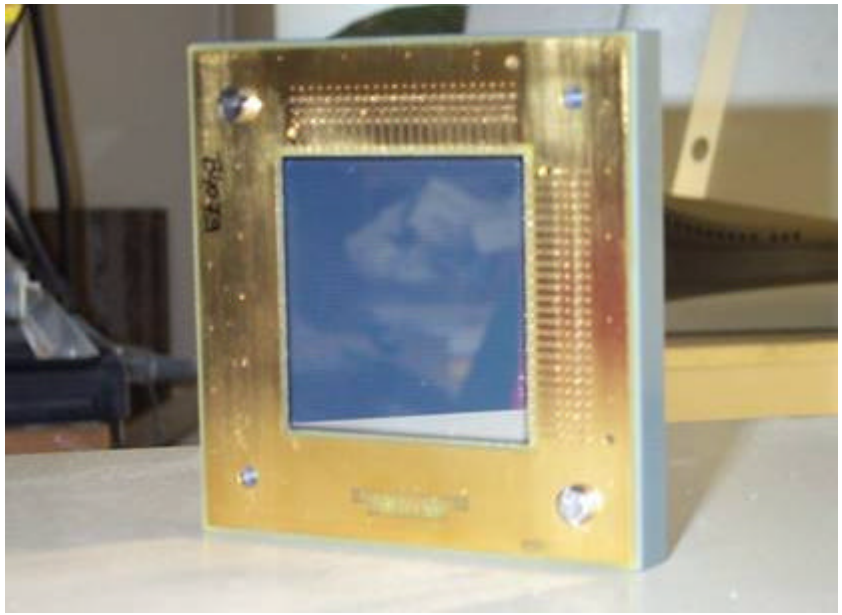


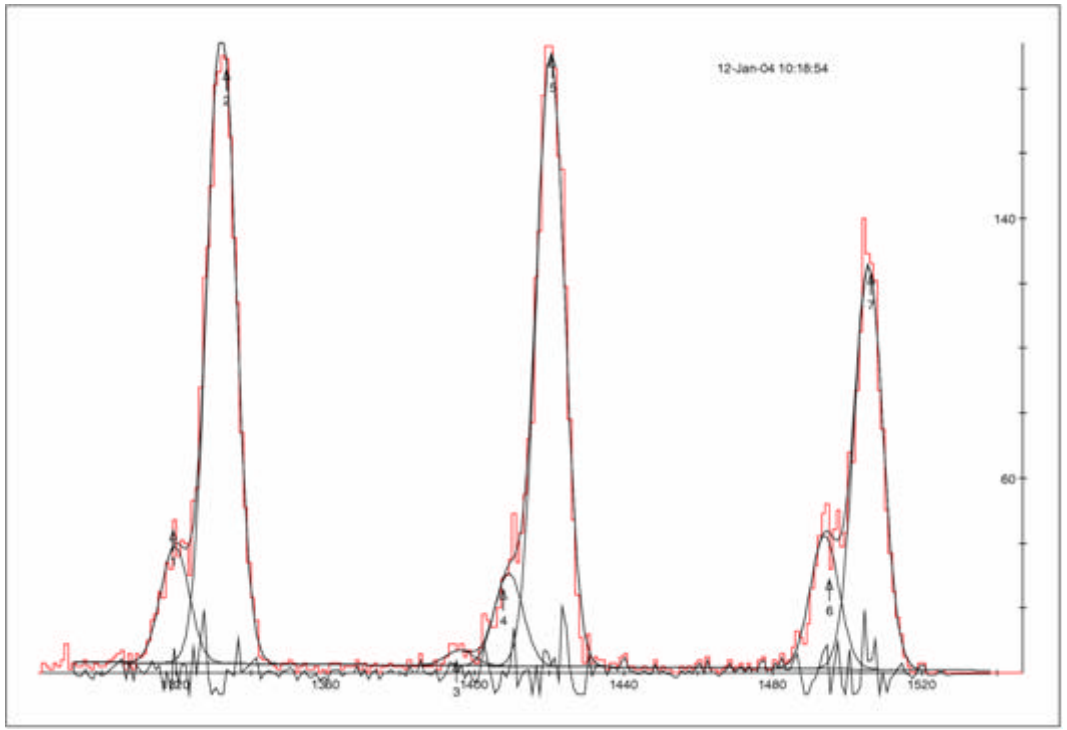




Box for Electron Spectroscopy after Tagging

BEST (I): Implantation





Double side stripped detector

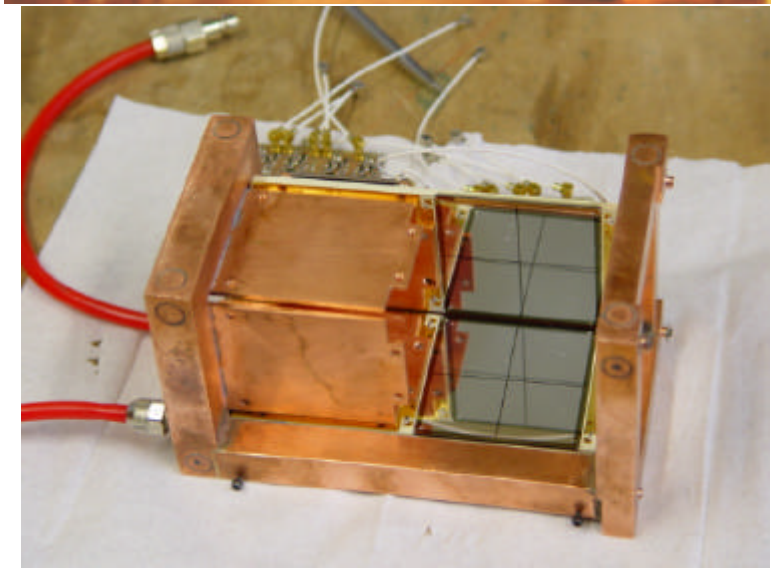
48x48 strips

5x5 cm

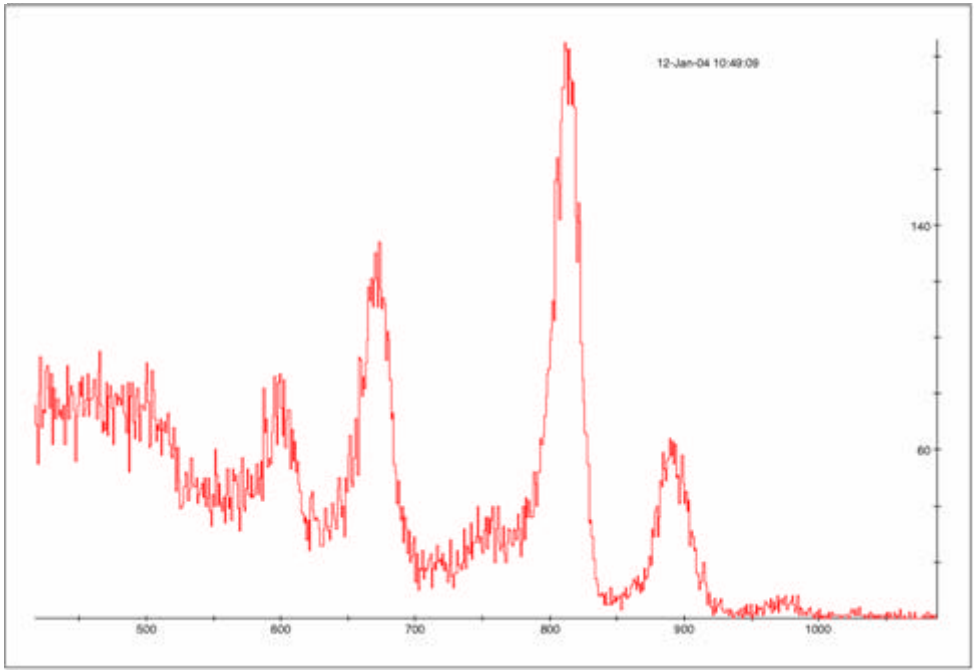
Cooled to -15°

Resolution ~ 35 keV

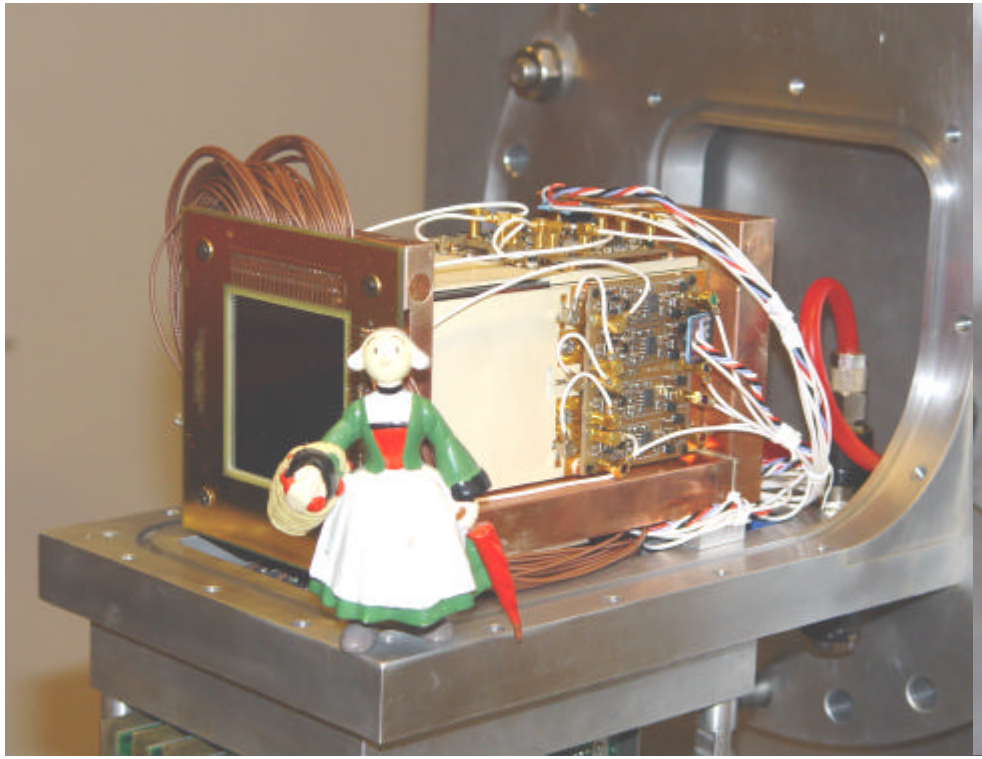
BEST (II): Tunnel

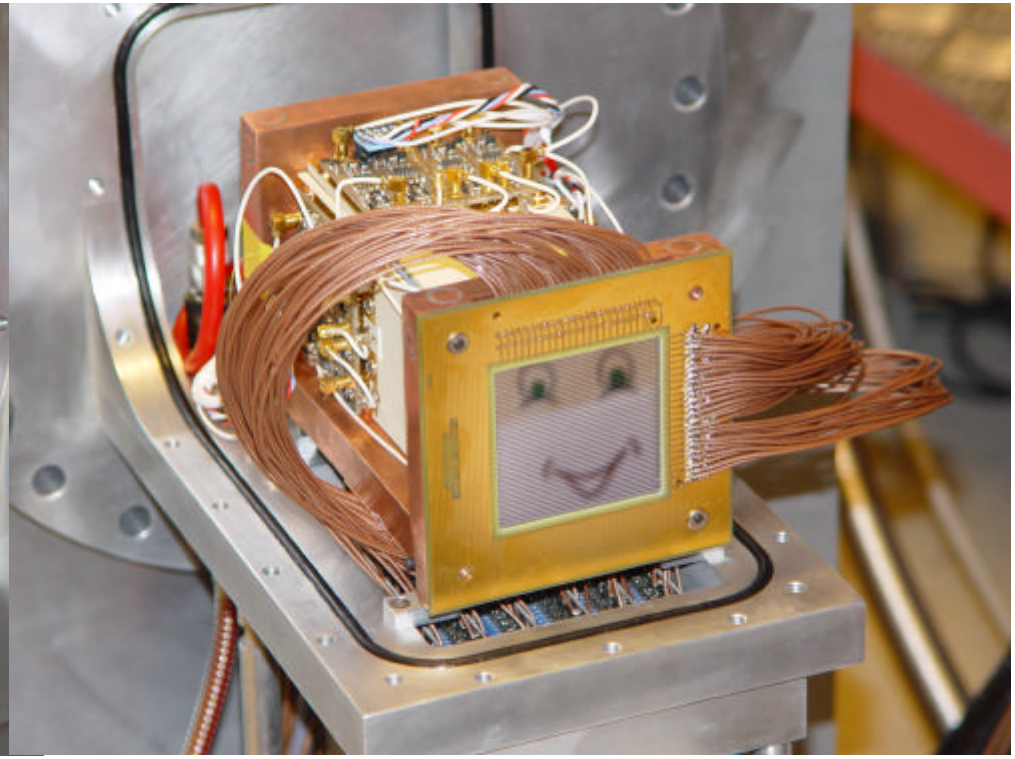


- 4-fold segmented Si
- 1 mm thick
- a veto; resolution < 20 keV
- Electron spectroscopy;
  resolution 7-8 keV (cold)

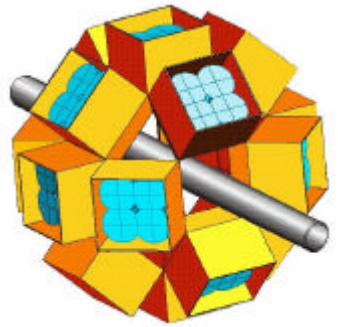


BEST (IV)



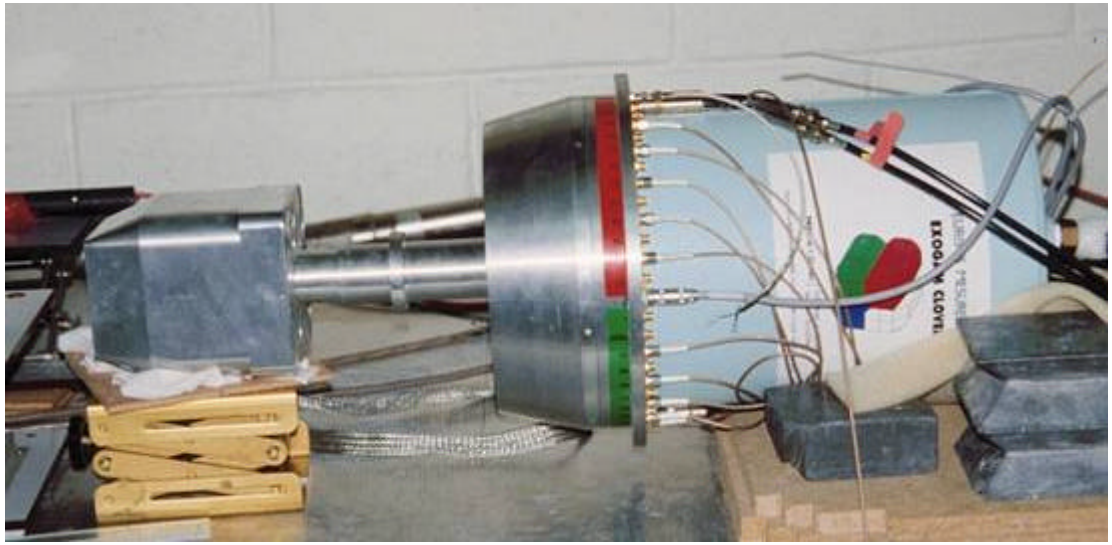


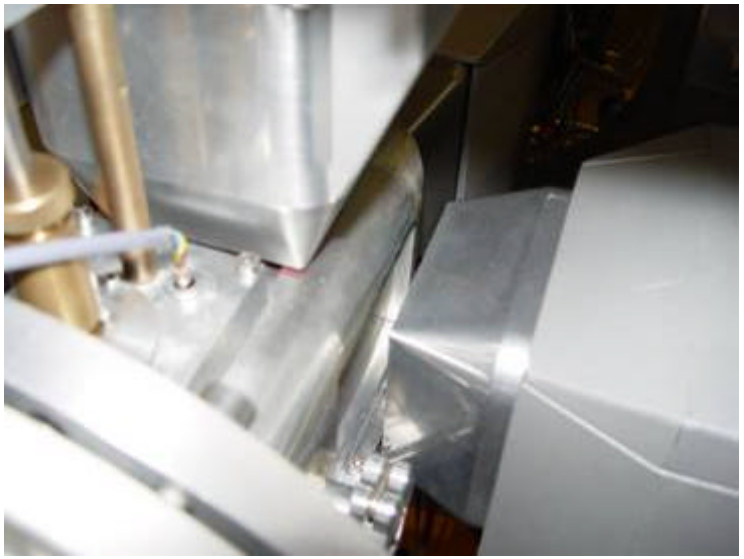
BEST (V): Ge clovers



4 segmented clovers from Exogam with passive shields

Efficiency : ~ 10% for Eγ < 500 keV





E375 experiment

- Targets : ^{209}Bi ~420 µg / cm^2
- Beam : $^{48}Ca^{8+}$ @ 4.57 MeV/A; average intensity : 1eµA
- Beam rejection ~2 10^{10}
- ^{255}Lr a-decay rate : ~1/min
- Analysis in progress : results coming soon…

Conclusions

Large cross sections : present set-up OK (LISE, EXOGAM)

- Coulex of transactinides and transfermium produced in inverse kinematics
- Spectroscopy after α-decay of transfermium (a,b,g).

(Sub)picobarn range needs large transmission and very highly Intense stable beams
(Linear superconducting accelerator)

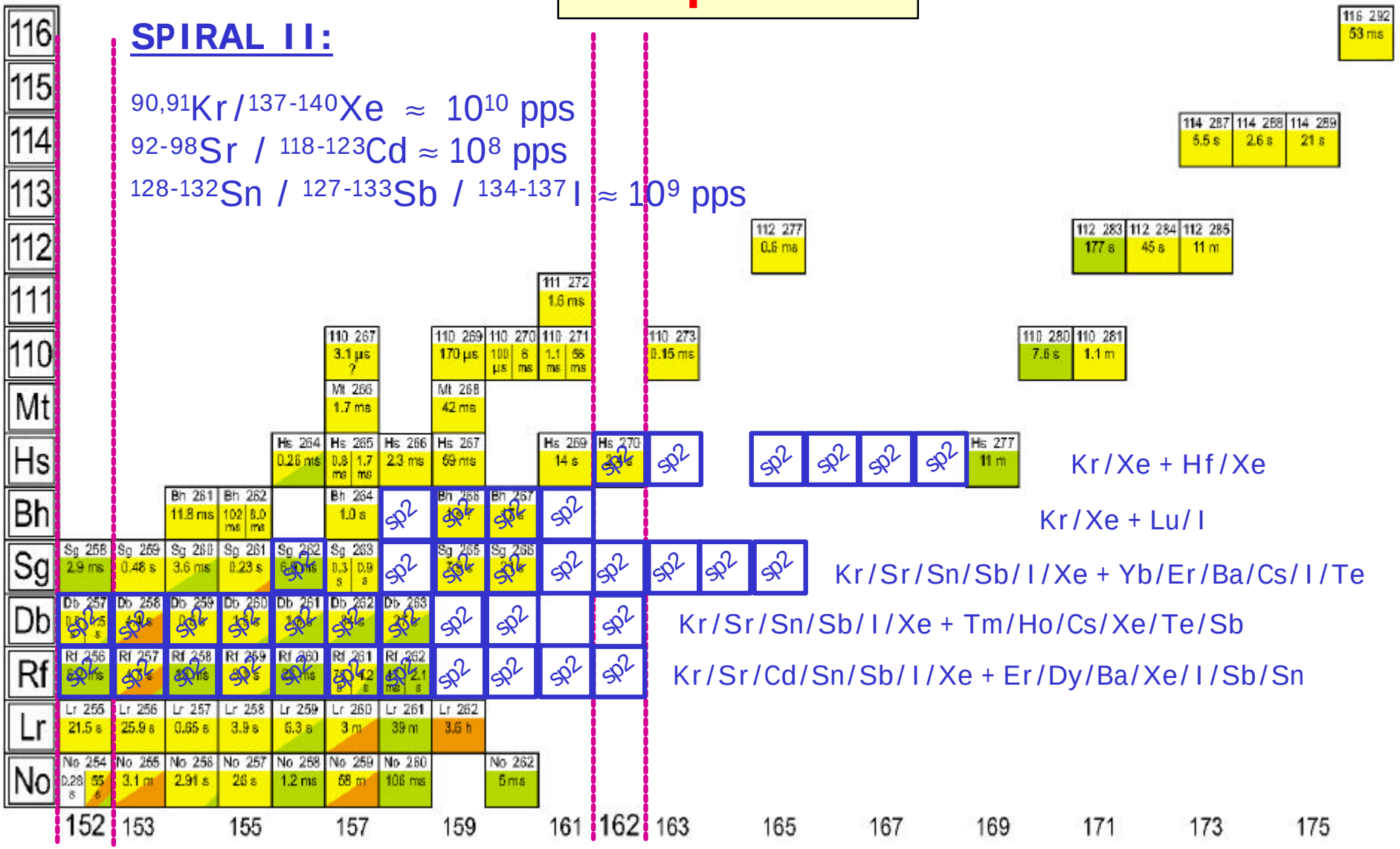
↦ - direct kinematics : 37% possible; ~ 60%: 2 new Q-poles
and larger gap in filter...

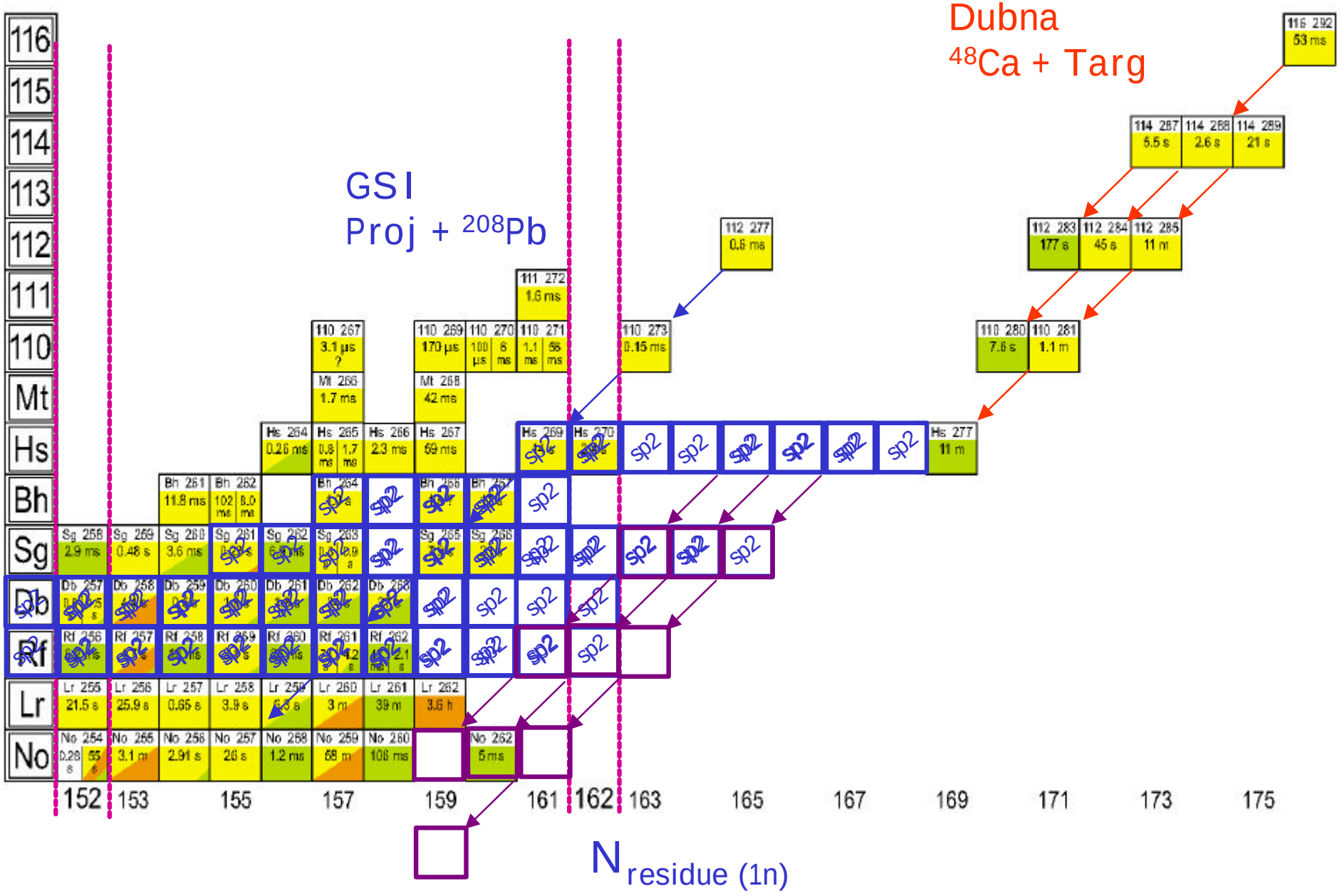
- inverse kinematics : present: ~70 % strong Pb... source
- ~symmetric kinematics : ~60 %

Radioactive beams

SPIRAL II → symmetric reactions + neutron rich reaction products : σ = ????
Beam time ????

Perspectives




Dubna
48Ca + Targ
GSI
Proj + 208Pb
N residue (1n)
116
115
114
113
112
111
110
Mt
Hs
Bh
Sg
Db
Rf
Lr
No
152
153
155
157
159
161
162
163
165
167
169
171
173
175

Developments
Experimental set-up

- Wien Filter transmission (first triplet)
- Beam developments
- BEST II : resolution of implantation detectors (preamps)

  resolution of electron box (detectors)

  less constraining mechanics
- Target laboratory at GANIL:
  - More than 300 ^{208}Pb targets (400 µg/cm2) + ^{209}Bi with evaporation technique
  - Need for other techniques : sputtering… for various materials
- Specific electronics with digital fast analysis for separating and measuring energies from a-particles or fission emitted in a few µs after implantation.

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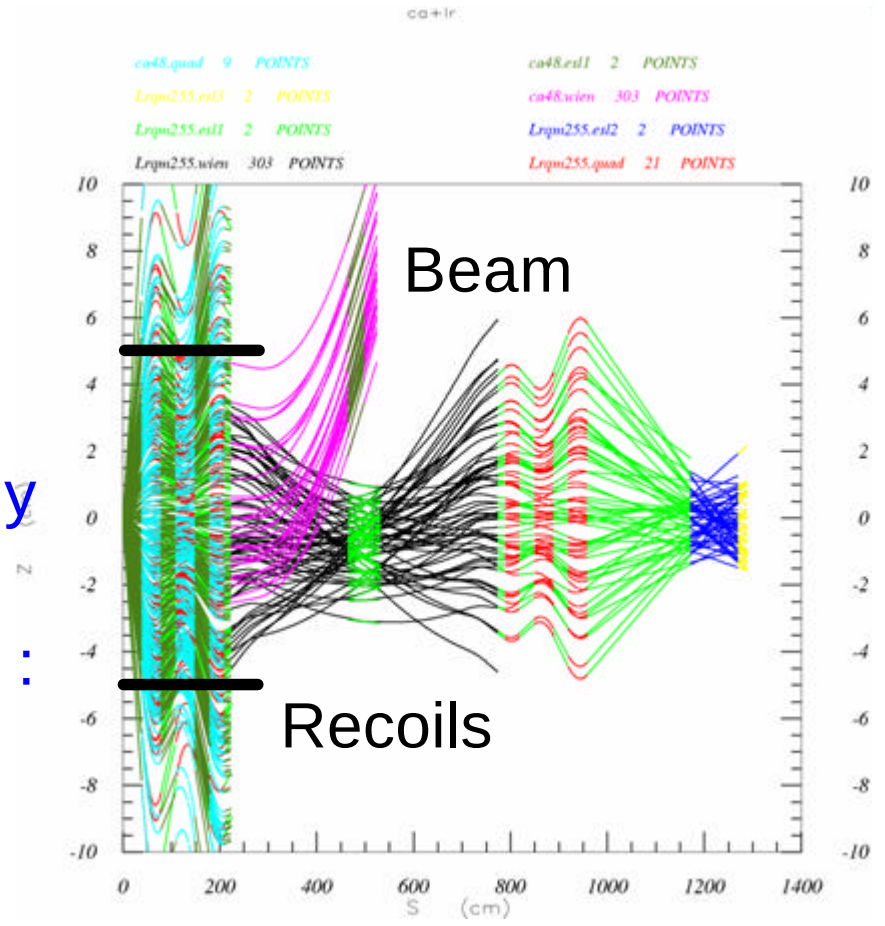
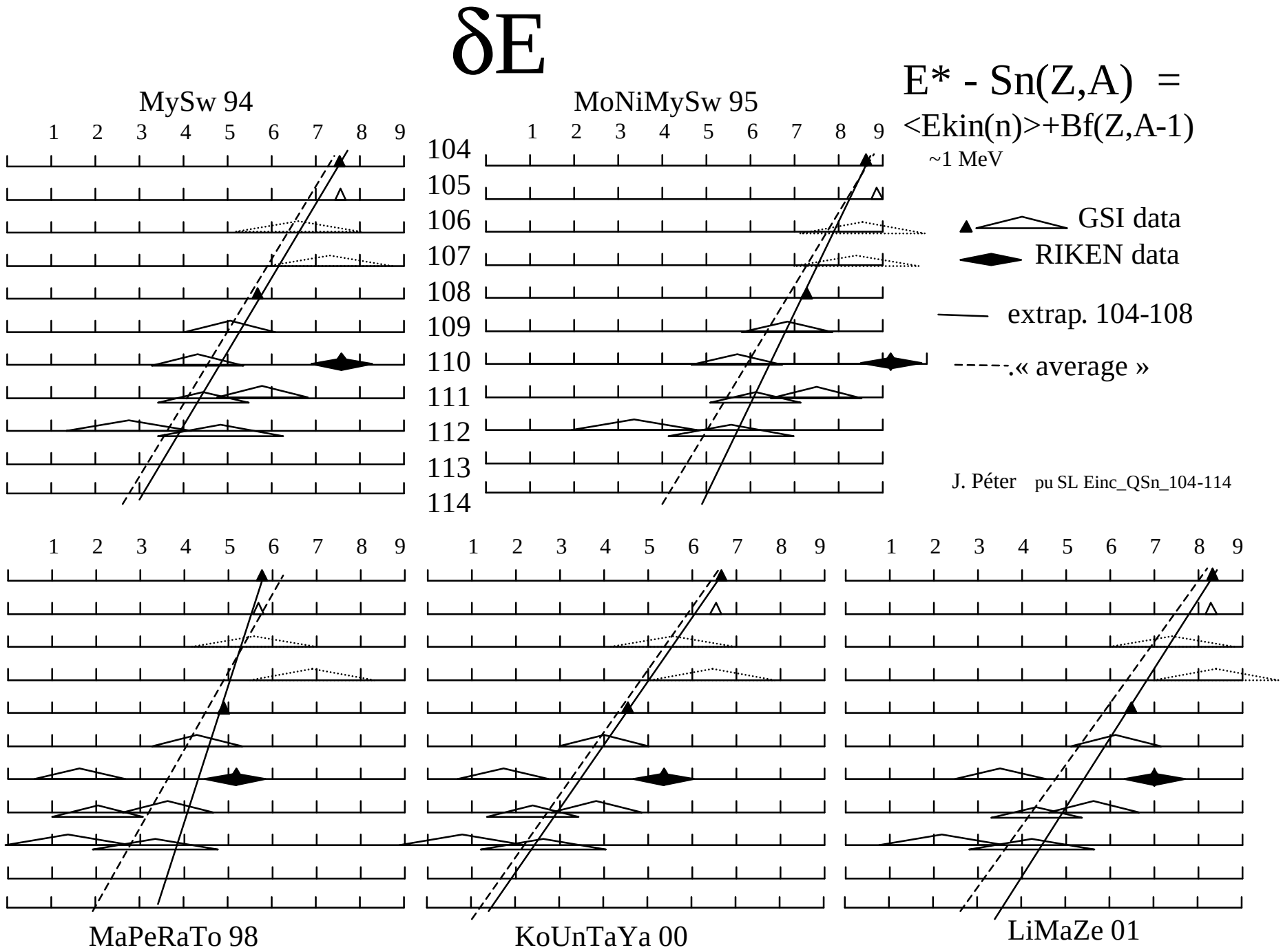
Z. Sosin
A. Wieloch

And the technical support of GANIL, LPC, CEN Saclay and GSI

Wien filter transmission (E375)

- Depends on reaction kinematics
- Strong influence of target straggling
- Limitation due to first quadrupole triplet
- Optics optimised with Zgouby code
- Transmission of first triplet : 15-20 %
- Transmission after first triplet ~ 100%




δE
E* - Sn(Z,A) =
<Ekin(n)>+Bf(Z,A-1)
~1 MeV
MySw 94
MoNiMySw 95
1 2 3 4 5 6 7 8 9
104
105
106
107
108
109
110
111
112
113
114
GSI data
RIKEN data
extrap. 104-108
.« average »
J. Péter pu SL Einc_QSn_104-114
MaPeRaTo 98
KoUnTaYa 00
LiMaZe 01

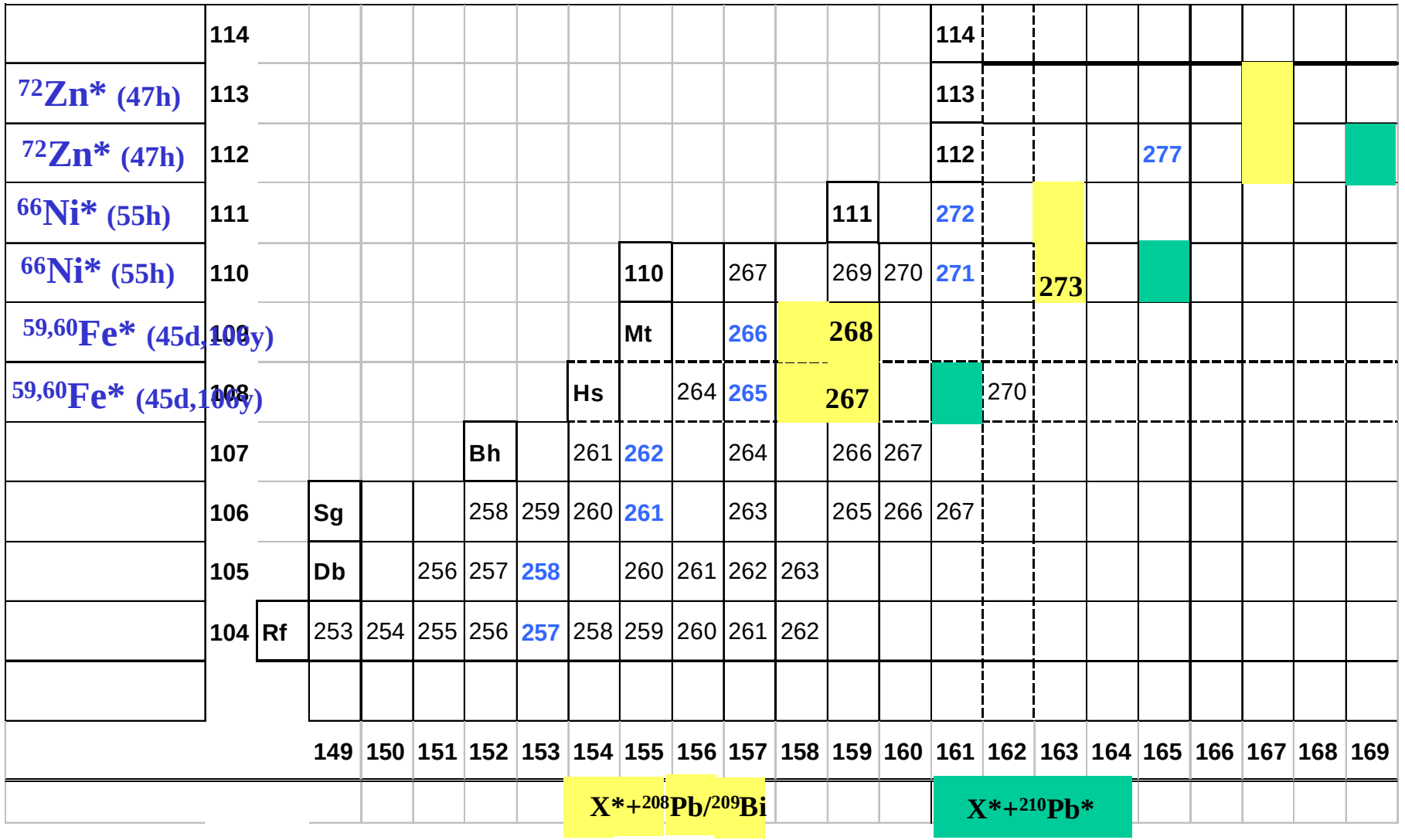
- redundant information very useful: direct approximate values of Z and M of the implanted nucleus in inverse or symmetric kinematics : **ionization chamber** ;

next: **proportional counter and scintillation in gas**.

Later, ~ Z in direct kinematics (scintillation) : Krakow and LPC.

- New isotopes → Long lived radioactive beams

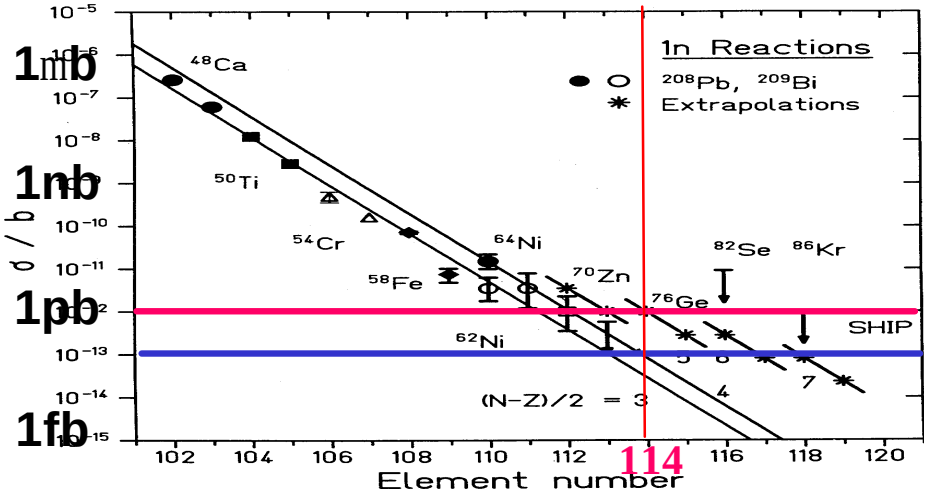
^{210}Pb (22.3 y) target



Search for $^{283}114$

Information from Experiments

- Extrapolation: 0.1 pb (N-Z)/2 effect : 1 pb
  but effect not observed for 70Zn⇒112,113



S. Hofmann , G. Münzenberg, Rev. Mod. Phys., 72,(2000)733

Theoretical predictions

Adamian,Antonenko, Scheid	Nuc. Phys A678(2000)24	0.03 pb
	June 2003	0.2
Giardina et al	Eur. Phys. J.A. 8(2000)205	1 if fission barrier ↗ 8 MeV !
Ohta, Aritomo	2002	0.15 (0.02 - 0.8)
Swiatecki et al.	Zakopane School Sep. 2002. Acta Pol. B	0.13 (0.22 at peak)
Bouriquet, Abe, Kosenko	Aug. 2003	0.25-0.4

Proposal

Sensitivity: 1 event = 0.2 pb
prop. to Ibeam (1 pμA),
transmission (75%), effective time