Status report of the JYFL-ACCLAB in-flight separators MARA and RITU

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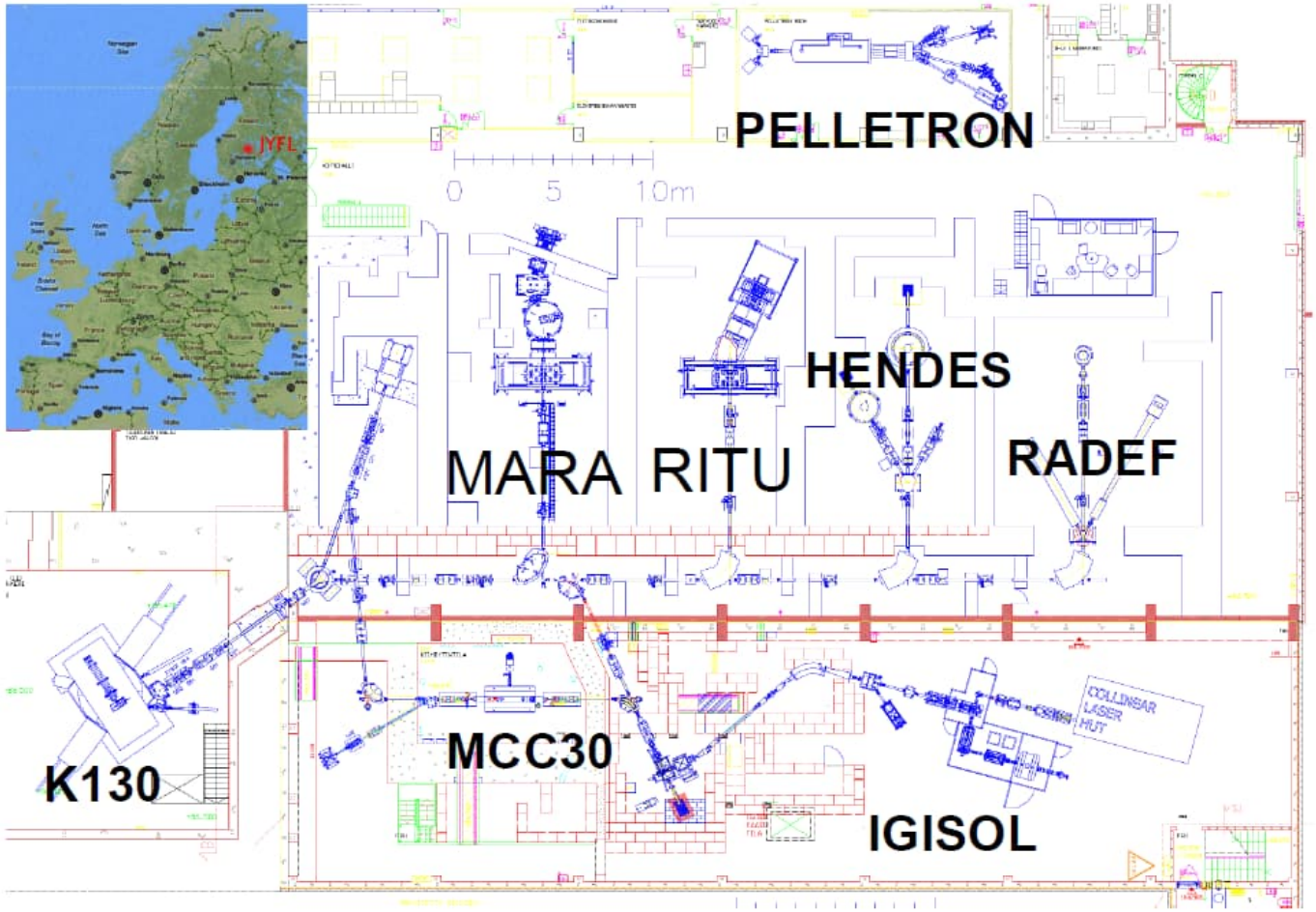
University of Jyväskylä (JYFL)
Finland

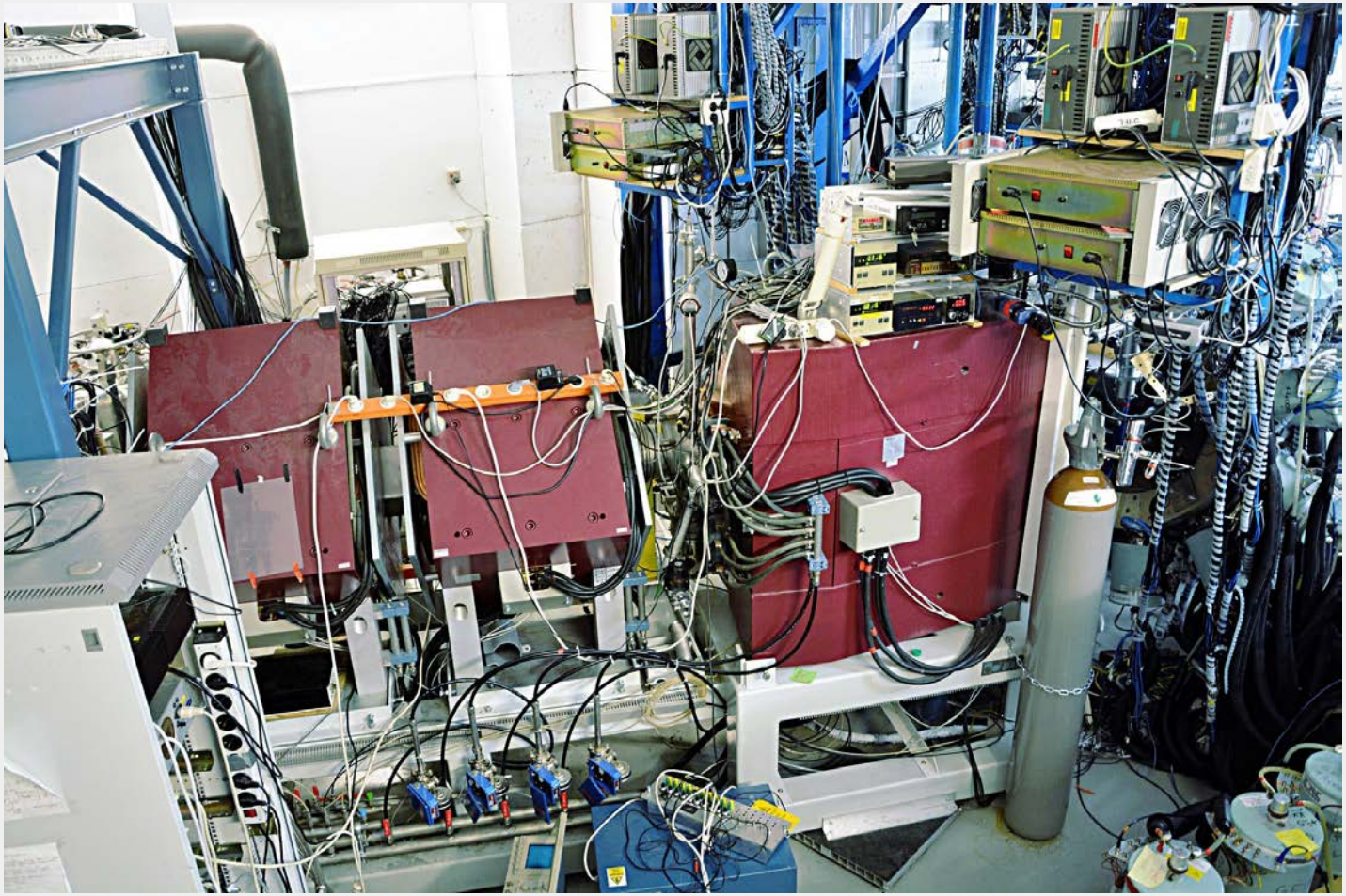
Content:

- Introduction
- MARA and RITU separators
- Some recent results
- Plans for the near and distant future
- See presentations:
  - J. Louko
  - K. Auranen

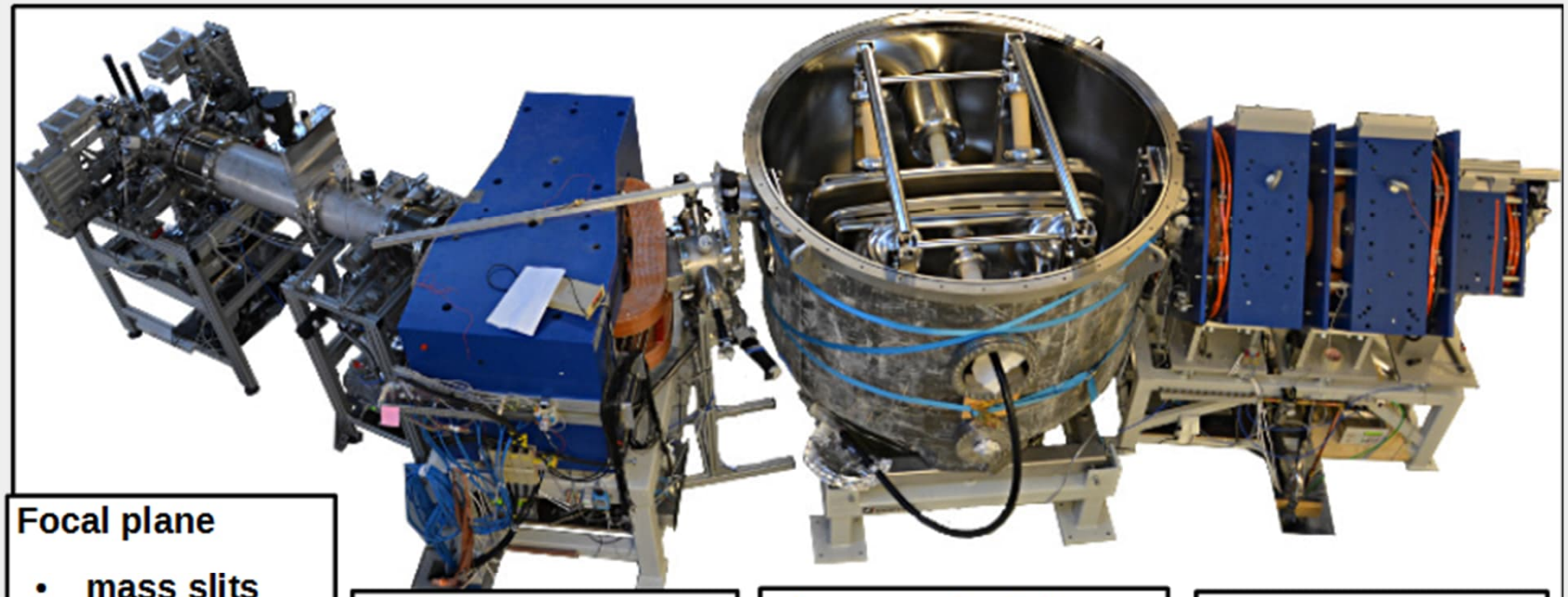


Since last TASCA workshop (21-23.06.2021) NSG have had ~ 110 days of beam time (12 experiments) mainly using MARA.

RITU, Recoil Ion Transport Unit
In operation since 1994
In avg. > 10 ref. publications/y



MARA – *Mass Analysing Recoil Apparatus*



Focal plane

- mass slits
- MWPC, DSSD, Box detector and Ge array

Magnetic dipole

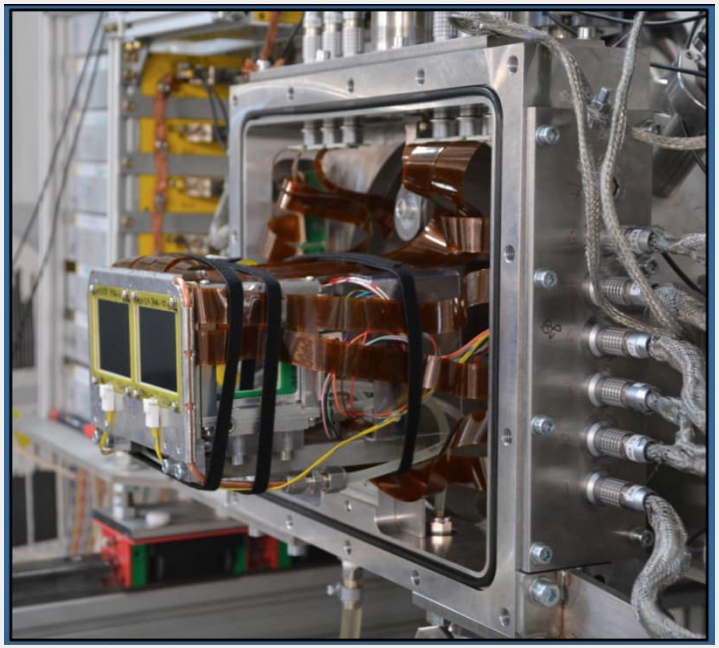
- 1 T, 1 m radius
- adjustable surface coils to change focal plane position

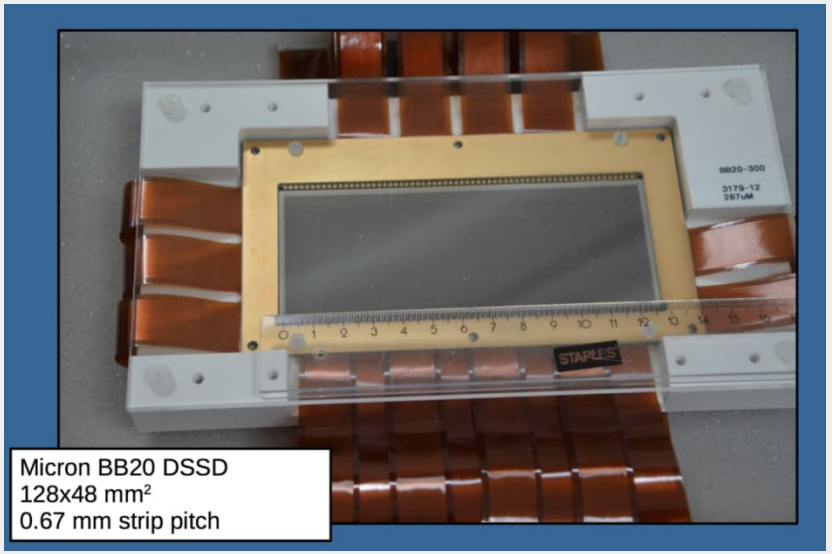
Electrostatic deflector

- beam separation
- +- 230 kV, 4 m radius
- split anode and a beam dump

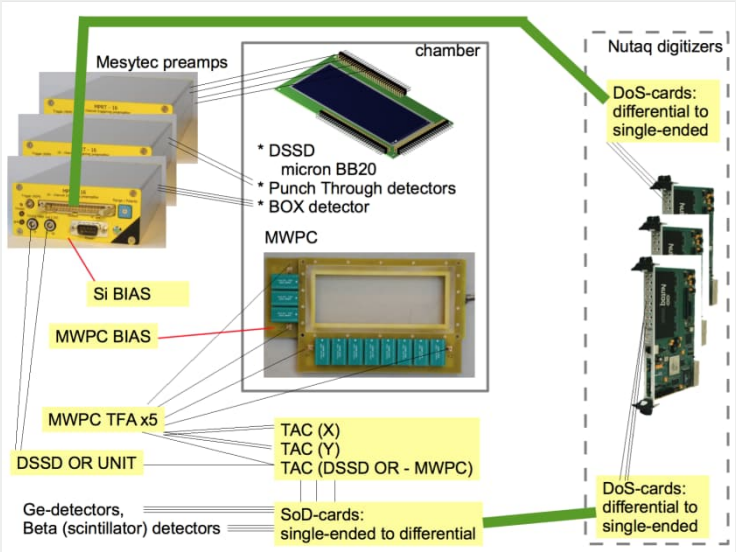
Quadrupole triplet

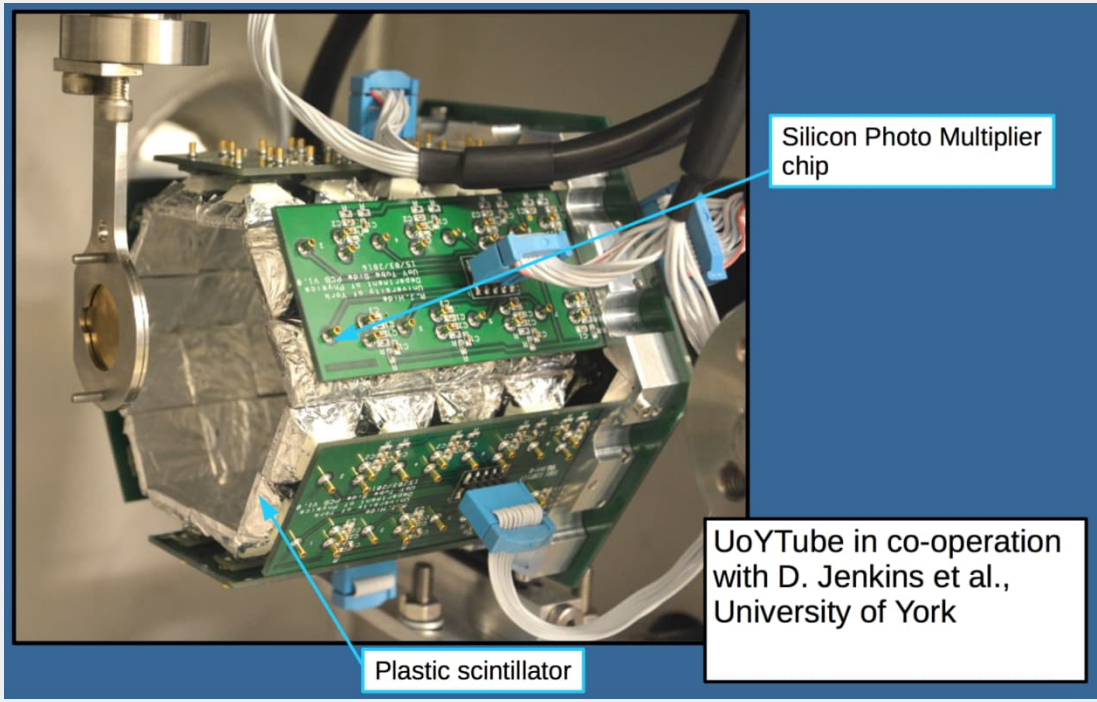
- scalable first order resolving power



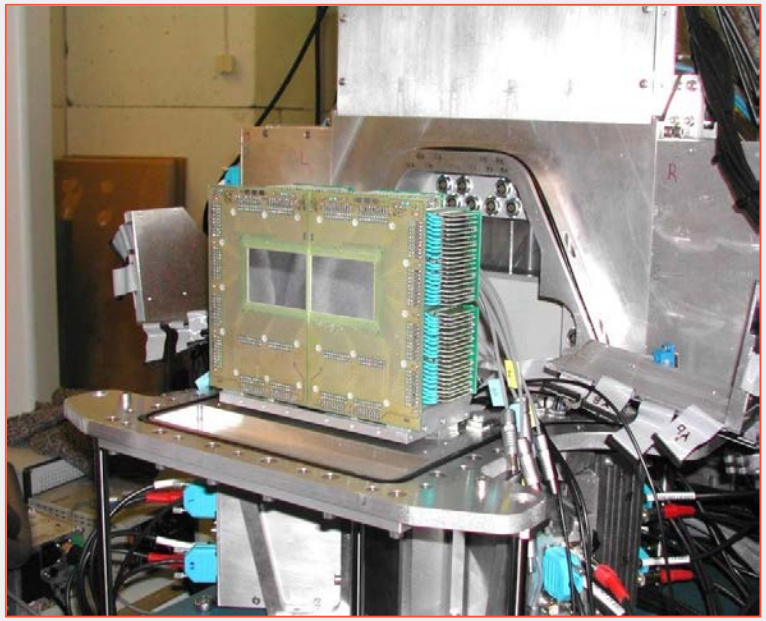


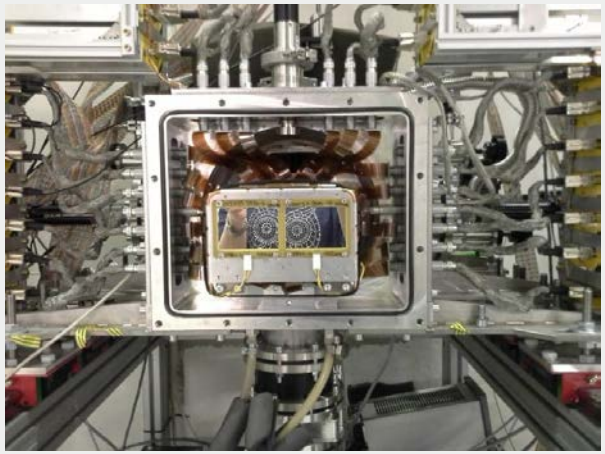
192x72=
13824
pixels

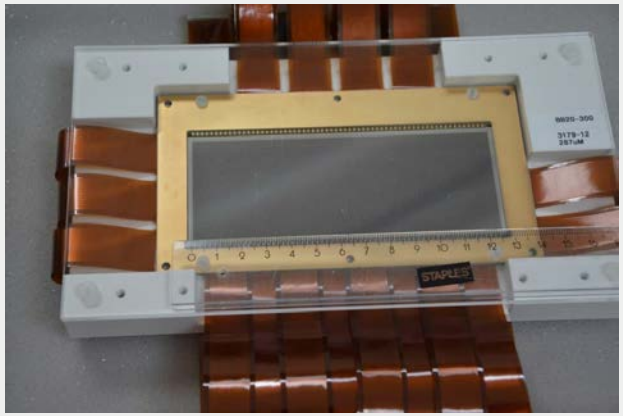




RITU focal plane upgrade



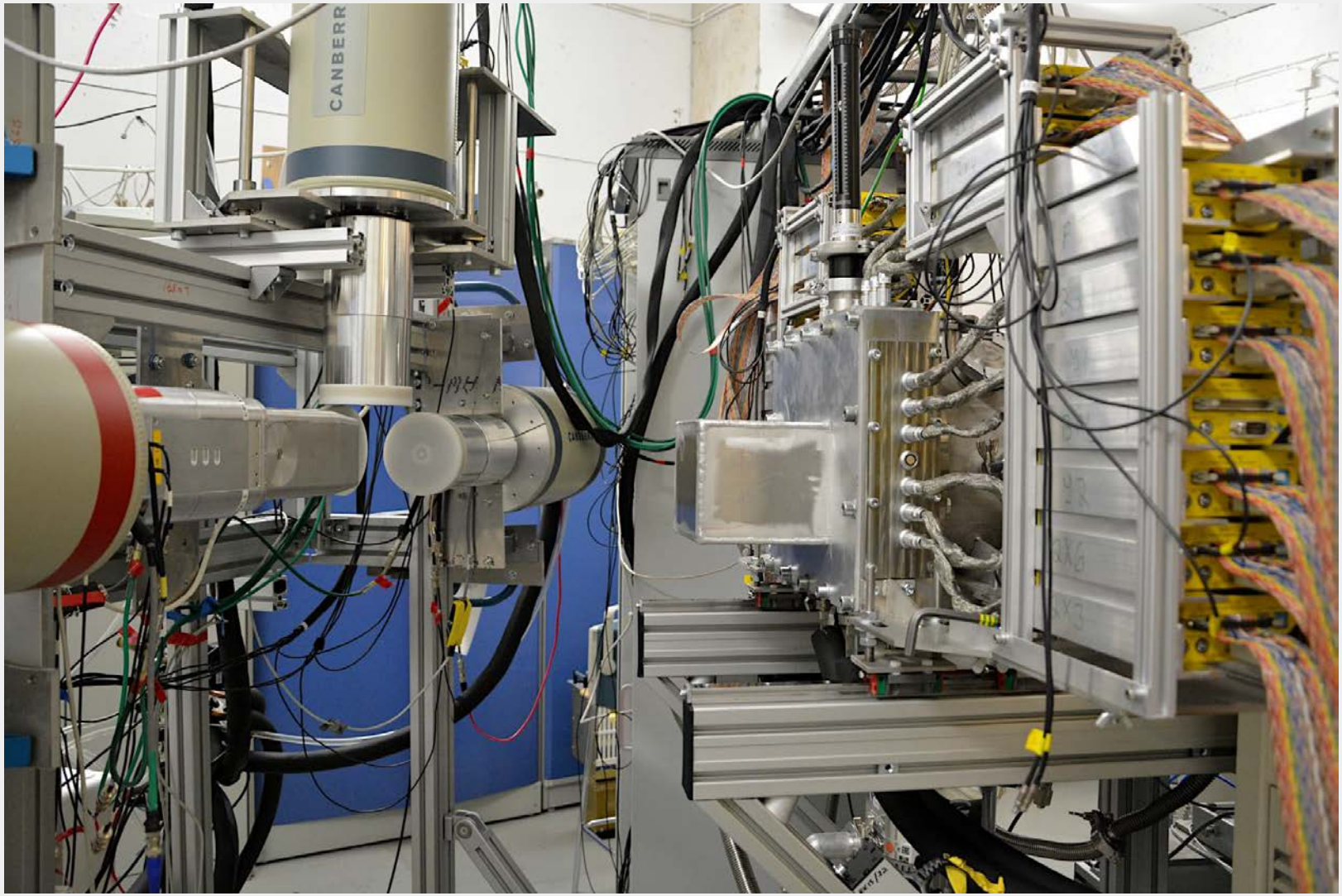


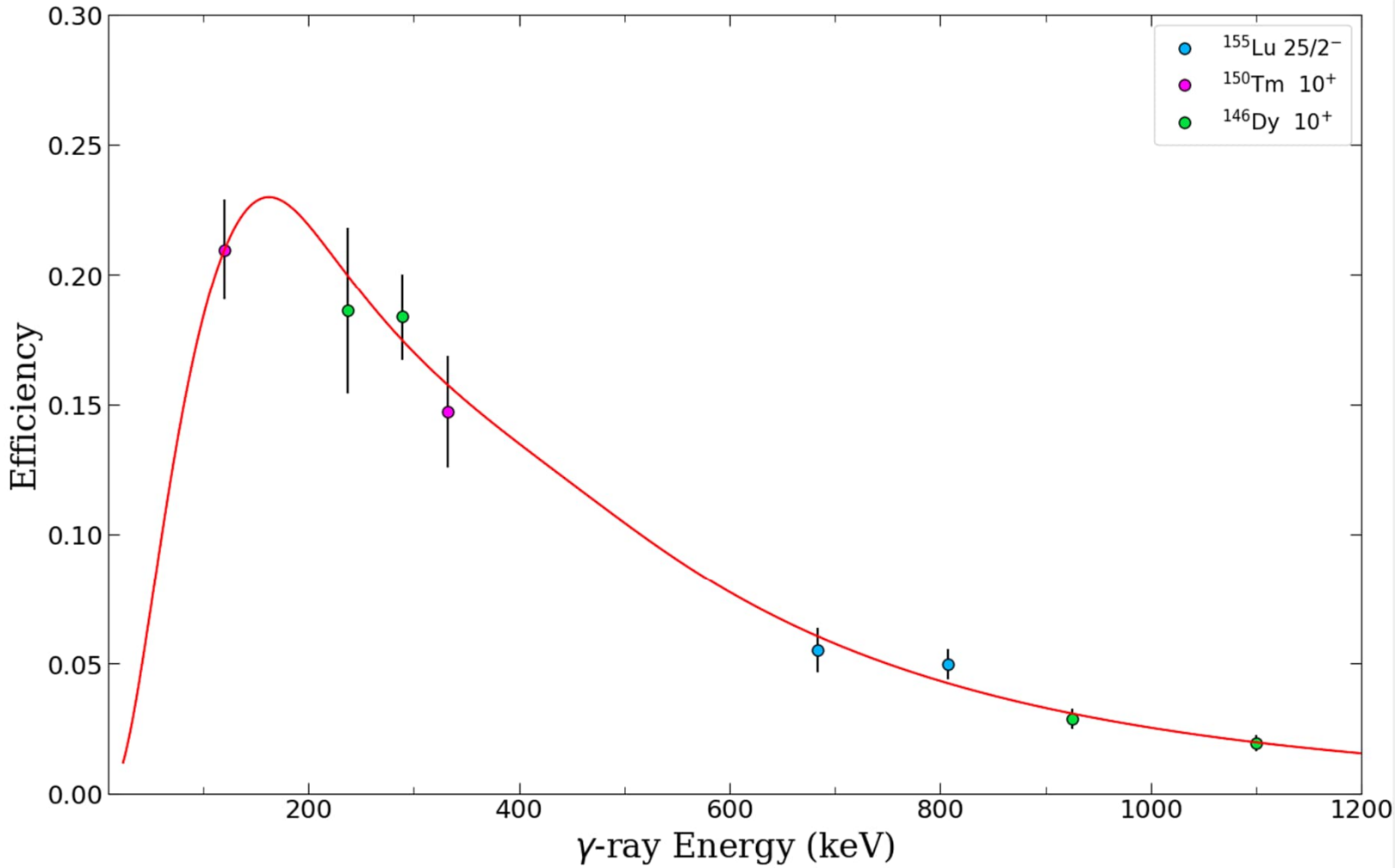


GREAT DSSD 2 x 40 x 60 strips
2 x 40 mm x 60 mm (10 % of strips missing)
5-6 mm wide gap between

MARA DSSD 72 X 192 strips
48 mm x 128 mm (typically ~ 2-3 strips missing)

MWPC ugrade 90 % → 94 % transmsission
wire planes made out from 20 μm wires instead of 50 μm
cathode: foil → wire plane (less material for recoils to enter the implantation detector


CANBERR



^{58}Ni + ^{102}Pd

M15: Decay of Isomeric States near the Proton Drip Line, D. Joss et. al.,

Physics Letters B 784 (2018) 199–205

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Study of non-fusion products in the $^{50}Ti + ^{249}Cf$ reaction

A. Di Nitto [a,b], J. Khuyagbaatar [b,c,*], D. Ackermann [b,1], L.-L. Andersson [c,d], E. Badura [b], M. Block [a,b,c], H. Brand [b], I. Conrad [b], D.M. Cox [d], Ch.E. Düllmann [a,b,c], J. Dvorak [c], K. Eberhardt [a,c], P.A. Ellison [e,f], N.E. Esker [e,f], J. Even [a,c,2], C. Fahlander [g], U. Forsberg [g], J.M. Gates [e], P. Golubev [g], O. Gothe [e,f], K.E. Gregorich [e], W. Hartmann [b], R.D. Herzberg [d], F.P. Heßberger [b,c], J. Hoffmann [b], R. Hollinger [b], A. Hübner [b], E. Jäger [b], B. Kindler [b], S. Klein [a], I. Kojouharov [b], J.V. Kratz [a], J. Krier [b], N. Kurz [b], S. Lahiri [h], B. Lommel [b], M. Maiti [h,3], R. Mändl [b], E. Merchán [b], S. Minami [b], A.K. Mistry [d], C. Mokry [a,c], H. Nitsche [e,f], J.P. Omtvedt [i], G.K. Pang [e], D. Renisch [a], D. Rudolph [g], J. Runke [b], L.G. Sarmiento [j,4], M. Schädel [b,k], H. Schaffner [b], B. Schausten [b], A. Semchenkov [i], J. Steiner [b], P. Thörle-Pospiech [a,c], N. Trautmann [a], A. Türler [l,m], J. Uusitalo [n], D. Ward [g], M. Wegrzecki [o], P. Wieczorek [b], N. Wiehl [a], A. Yakushev [b], V. Yakusheva [c]

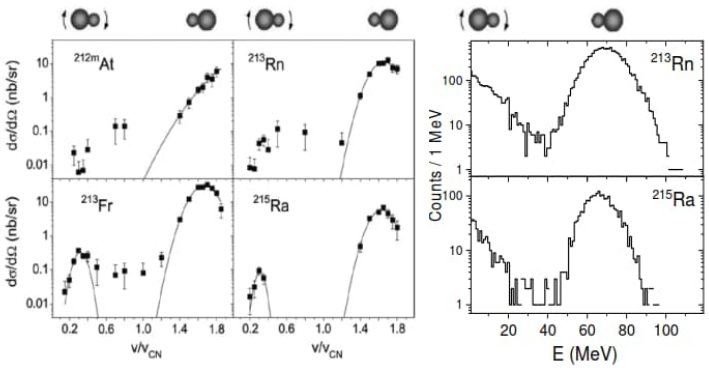


Figure 2. Left panel: The measured velocity (normalized to velocity of CN) distributions of non-fusion products in $^{64}Ni+^{207}Pb$ reaction at SHIP (figure is adopted from [26]). To get the cross sections at 10msr forward acceptance angle, the values given in the vertical axis has to be multiplied by a factor 100. Right panel: The measured energy distribution of non-fusion products in $^{50}Ti+^{249}Cf$ reactions at TASCA. Illustration of the different orientations as being the origin of the low and high velocity and energy components are given.

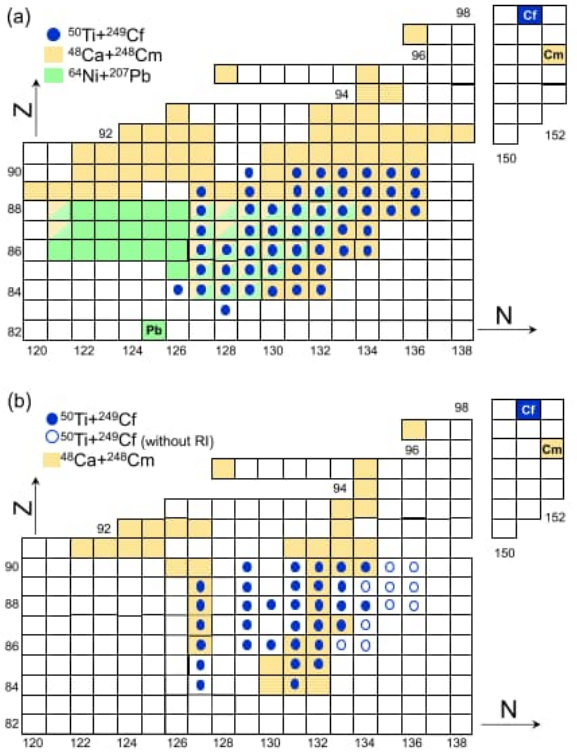


Fig. 3. (Color online.) Cut out of the chart of nuclei in the relevant region [38]. (a) The isotopes identified by their α decay and genetic correlations in $^{50}Ti + ^{249}Cf$ reactions (blue circles) are compared with those identified in $^{64}Ni + ^{207}Pb$ [43] and $^{48}Ca + ^{248}Cm$ [26] reactions marked in green and orange, respectively. (b) Isotopes directly implanted into the focal plane detector. The filled (empty) blue circles correspond to $^{50}Ti + ^{249}Cf$ reaction products identified in correlation analyses with (without) RI-like events. The orange frames relate to $^{48}Ca + ^{248}Cm$ reaction products observed in correlation with RI-like events [26,25].

Nuclear reaction dynamics study at MARA

J. Khuyagbaatar[1,2], J. Uusitalo[3], M. Block[1,2,4], Ch. E. Düllmann[1,2,4], R. Herzberg[5], K. Nishio[6], A. Yakushev[2] and the Nuclear Spectroscopy Group[3]

[1]*Helmholtz Institut Mainz, Germany,*
[2]*GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany,*
[3]*Department of Physics, University of Jyväskylä, Jyväskylä, Finland,*
[4]*University of Mainz, Mainz, Germany,*
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[6]*Japan Atomic Energy Agency (JAEA), Tokai, Japan*

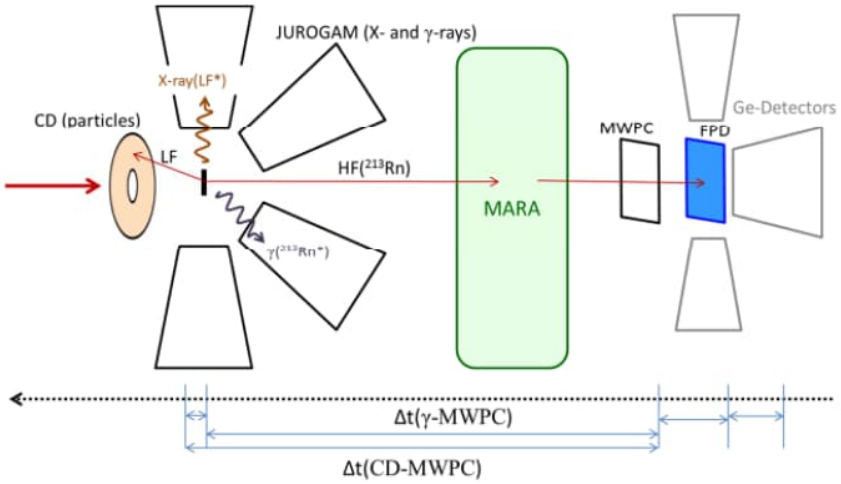
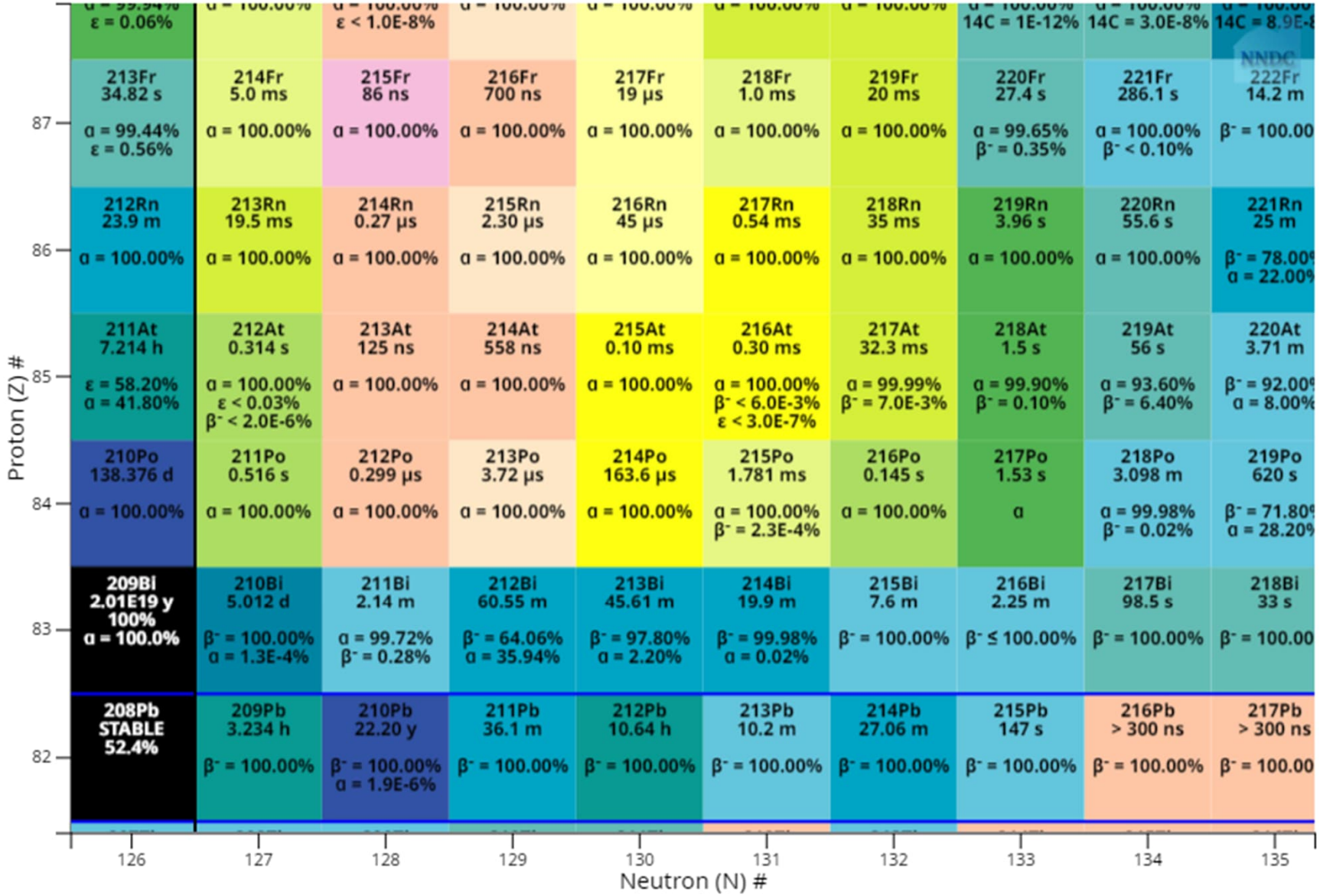
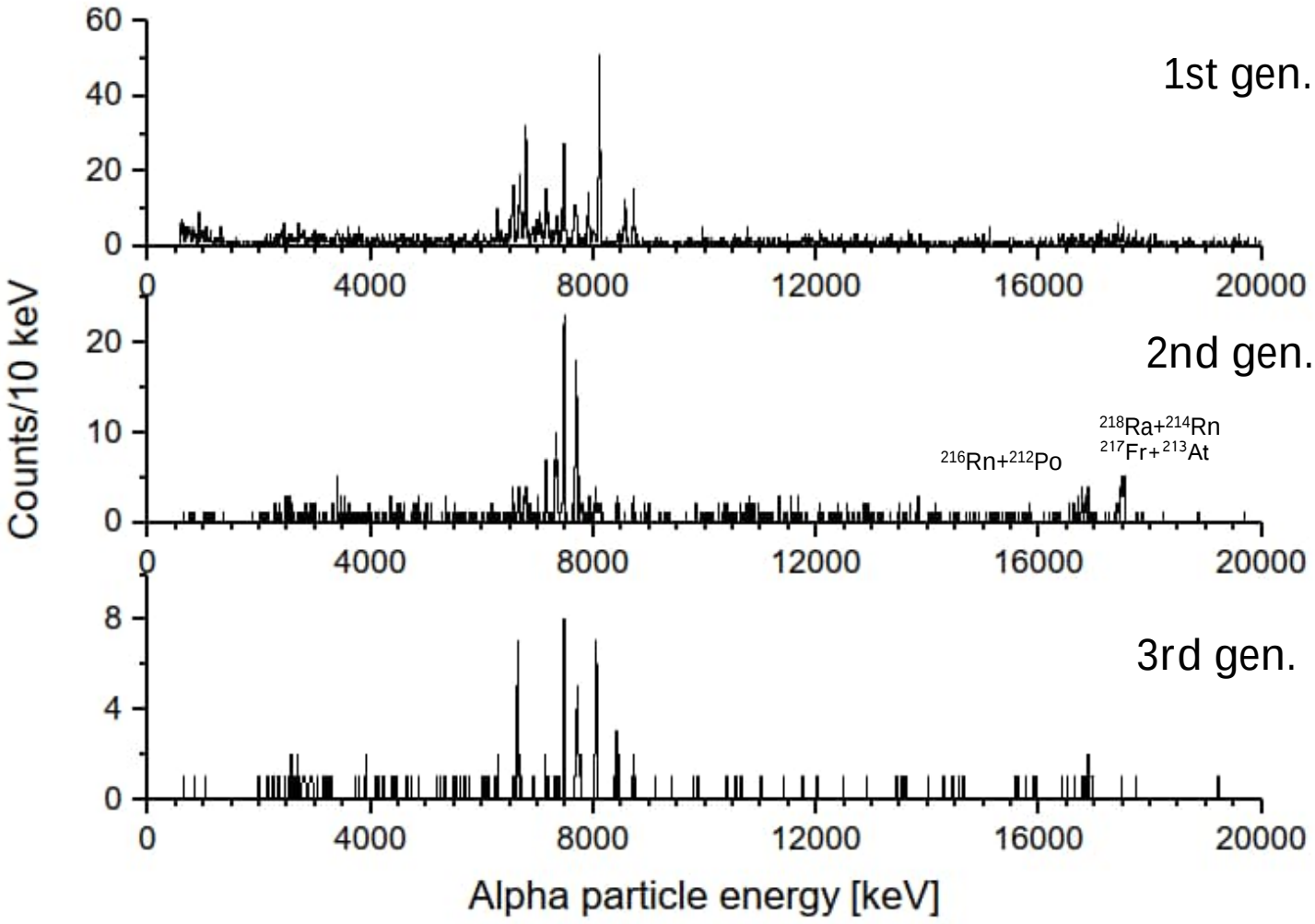
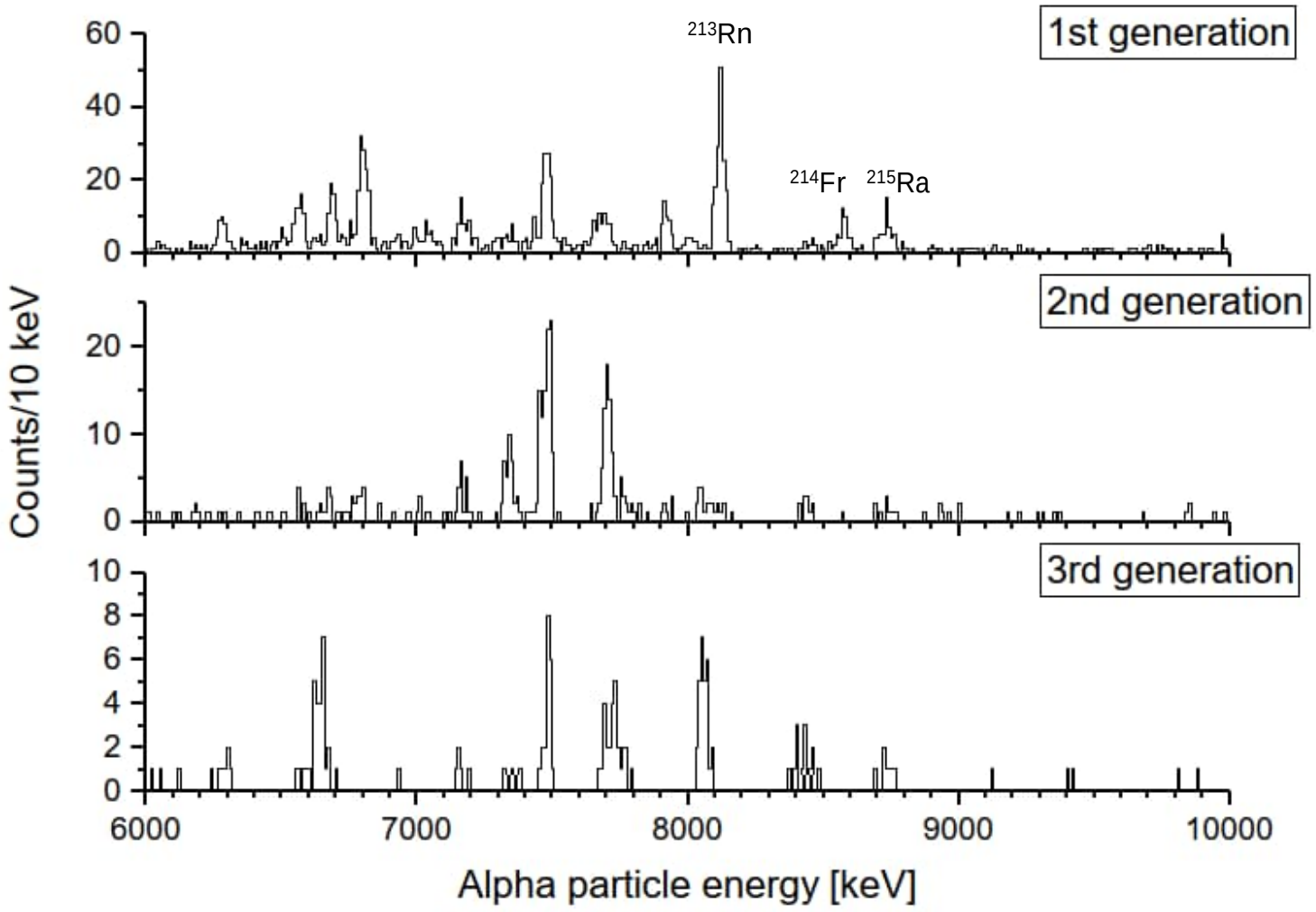


Figure 4. Schematic of the experimental setup and measurement scenario. Notations of the each instrument are given. The horizontal line marks the time scale in a backward direction showing the concept of the delayed coincident technique. See text for details.

$^{65}Cu + ^{238}U$
$^{65}Cu + ^{209}Bi$


ε = 0.06%
ε < 1.0E-8%
14C = 1E-12%
14C = 3.0E-8%
213Fr 34.82 s α = 99.44% ε = 0.56%
214Fr 5.0 ms α = 100.00%
215Fr 86 ns α = 100.00%
216Fr 700 ns α = 100.00%
217Fr 19 µs α = 100.00%
218Fr 1.0 ms α = 100.00%
219Fr 20 ms α = 100.00%
220Fr 27.4 s α = 99.65% β- = 0.35%
221Fr 286.1 s α = 100.00% β- < 0.10%
222Fr 14.2 m β- = 100.00
212Rn 23.9 m α = 100.00%
213Rn 19.5 ms α = 100.00%
214Rn 0.27 µs α = 100.00%
215Rn 2.30 µs α = 100.00%
216Rn 45 µs α = 100.00%
217Rn 0.54 ms α = 100.00%
218Rn 35 ms α = 100.00%
219Rn 3.96 s α = 100.00%
220Rn 55.6 s α = 100.00%
221Rn 25 m β- = 78.00 α = 22.00
211At 7.214 h ε = 58.20% α = 41.80%
212At 0.314 s α = 100.00% ε < 0.03% β- < 2.0E-6%
213At 125 ns α = 100.00%
214At 558 ns α = 100.00%
215At 0.10 ms α = 100.00%
216At 0.30 ms α = 100.00% β- < 6.0E-3% ε < 3.0E-7%
217At 32.3 ms α = 99.99% β- = 7.0E-3%
218At 1.5 s α = 99.90% β- = 0.10%
219At 56 s α = 93.60% β- = 6.40%
220At 3.71 m β- = 92.00 α = 8.00%
210Po 138.376 d α = 100.00%
211Po 0.516 s α = 100.00%
212Po 0.299 µs α = 100.00%
213Po 3.72 µs α = 100.00%
214Po 163.6 µs α = 100.00%
215Po 1.781 ms α = 100.00% β- = 2.3E-4%
216Po 0.145 s α = 100.00%
217Po 1.53 s α
218Po 3.098 m α = 99.98% β- = 0.02%
219Po 620 s β- = 71.80 α = 28.20%
209Bi 2.01E19 y 100% α = 100.0%
210Bi 5.012 d β- = 100.00% α = 1.3E-4%
211Bi 2.14 m α = 99.72% β- = 0.28%
212Bi 60.55 m β- = 64.06% α = 35.94%
213Bi 45.61 m β- = 97.80% α = 2.20%
214Bi 19.9 m β- = 99.98% α = 0.02%
215Bi 7.6 m β- = 100.00%
216Bi 2.25 m β- ≤ 100.00%
217Bi 98.5 s β- = 100.00%
218Bi 33 s β- = 100.00
208Pb STABLE 52.4%
209Pb 3.234 h β- = 100.00%
210Pb 22.20 y β- = 100.00% α = 1.9E-6%
211Pb 36.1 m β- = 100.00%
212Pb 10.64 h β- = 100.00%
213Pb 10.2 m β- = 100.00%
214Pb 27.06 m β- = 100.00%
215Pb 147 s β- = 100.00%
216Pb > 300 ns β- = 100.00%
217Pb > 300 ns β- = 100.00
87
86
85
84
83
82
126
127
128
129
130
131
132
133
134
135
Proton (Z) #
Neutron (N) #


1st gen.
2nd gen.
3rd gen.
Counts/10 keV
Alpha particle energy [keV]
^{216}Rn+^{212}Po
^{218}Ra+^{214}Rn
^{217}Fr+^{213}At


1st generation
2nd generation
3rd generation
213Rn
214Fr
215Ra
Counts/10 keV
Alpha particle energy [keV]
60
40
20
0
20
10
0
10
8
6
4
2
0
6000
7000
8000
9000
10000

Goals

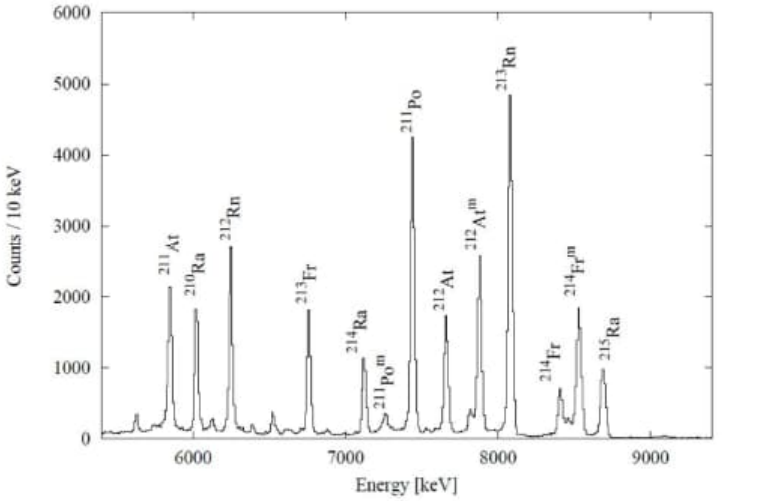
1. Nuclear reaction dynamics study at zero degrees
2. Yields for MARA-LEB based spectroscopy
3. Yields for in-beam spectroscopy

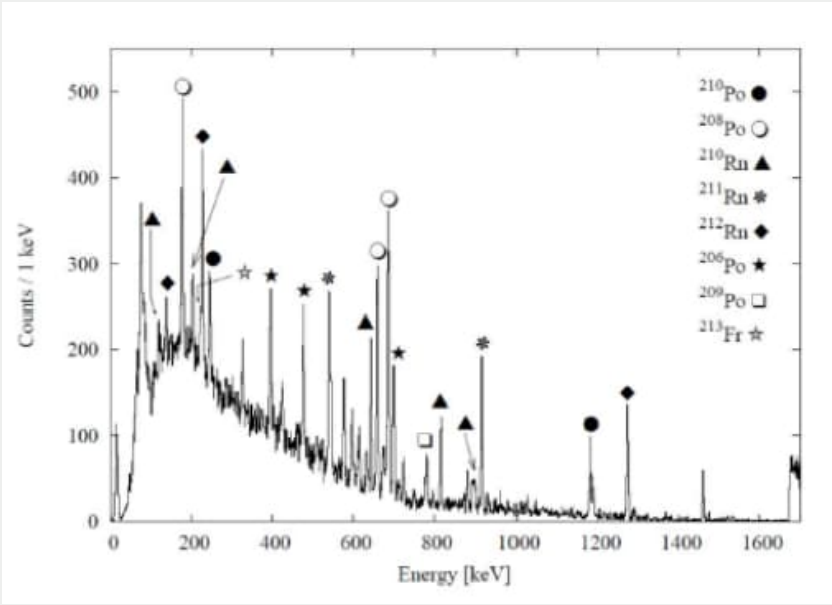
Next step:

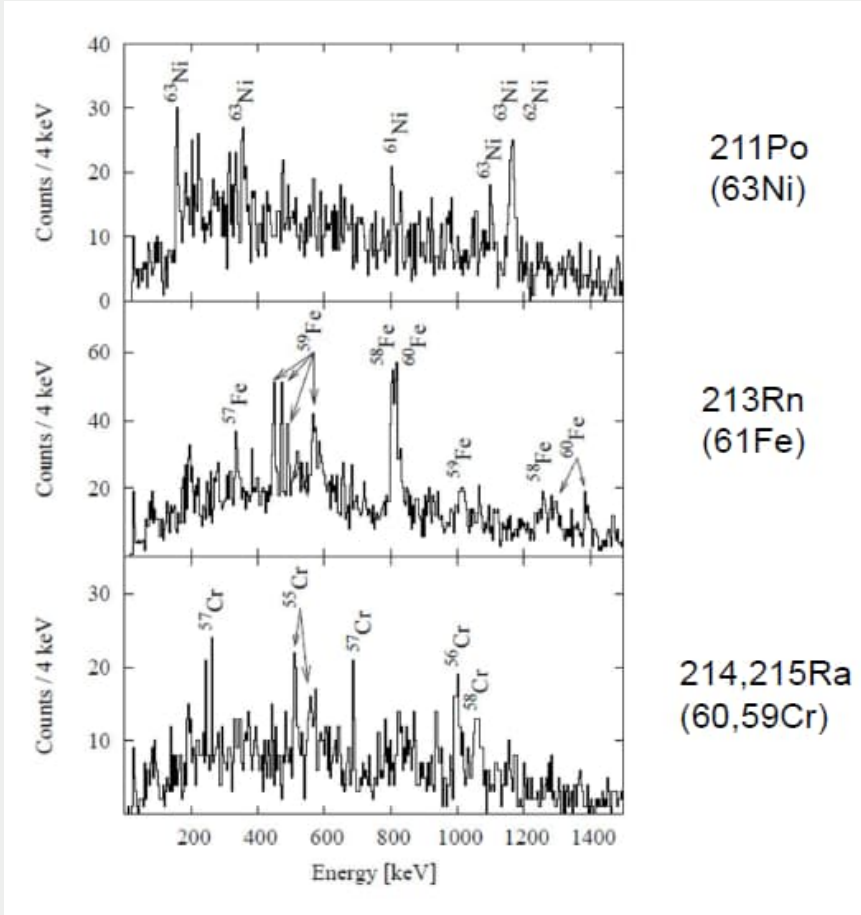
Select a case and perform an experiment with fixed settings to see the feasibilty for in-beam studies.

JUROGAM1 + RITU + GREAT

$^{65}Cu + {}^{209}Bi$







211Po (63Ni)

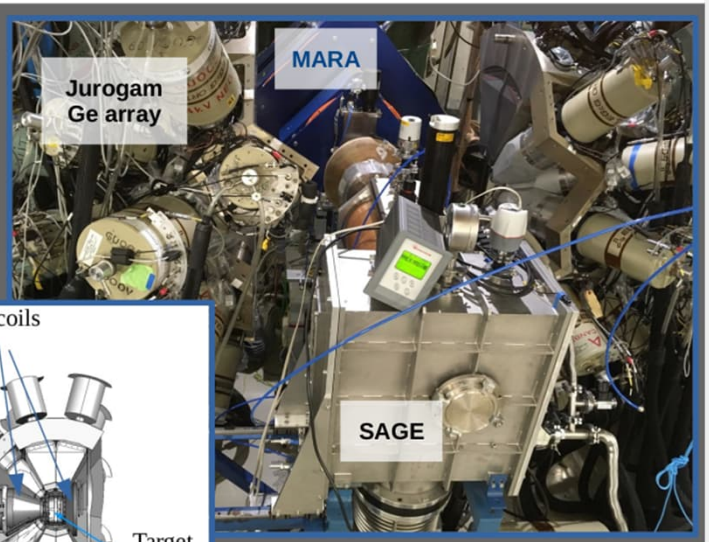
213Rn (61Fe)

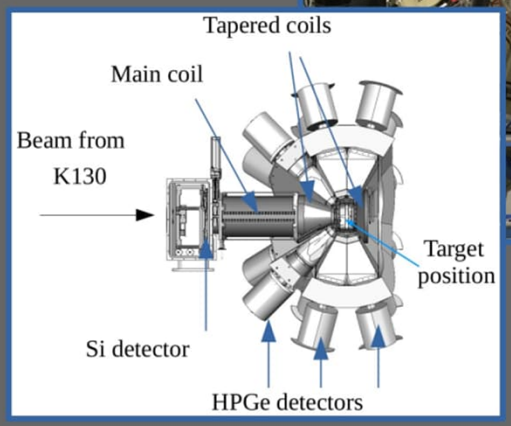
214,215Ra (60,59Cr)

SAGE Spectrometer for prompt conversion electrons

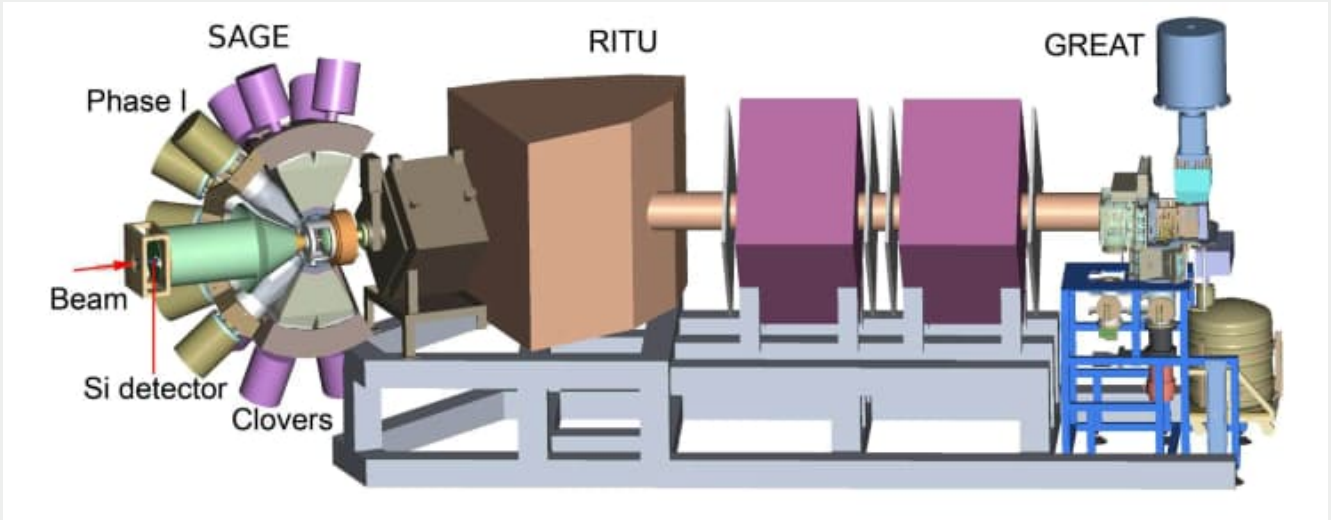
Solenoidal B-field transports conversion electrons from the target to the cooled Si-detector.

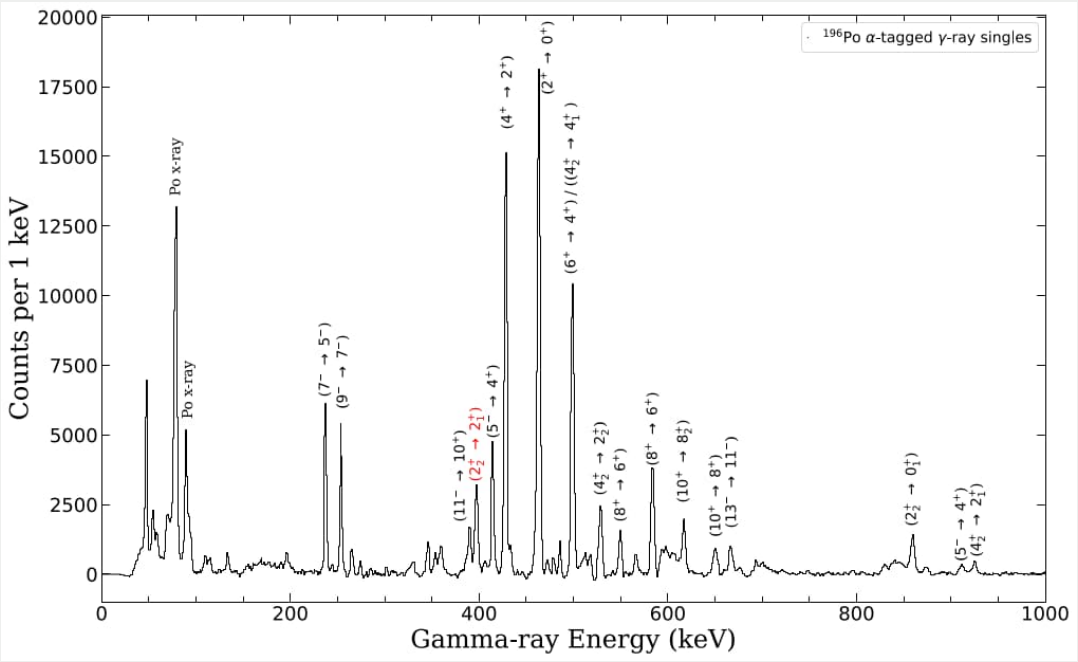
HV-barrier shields for delta electrons.

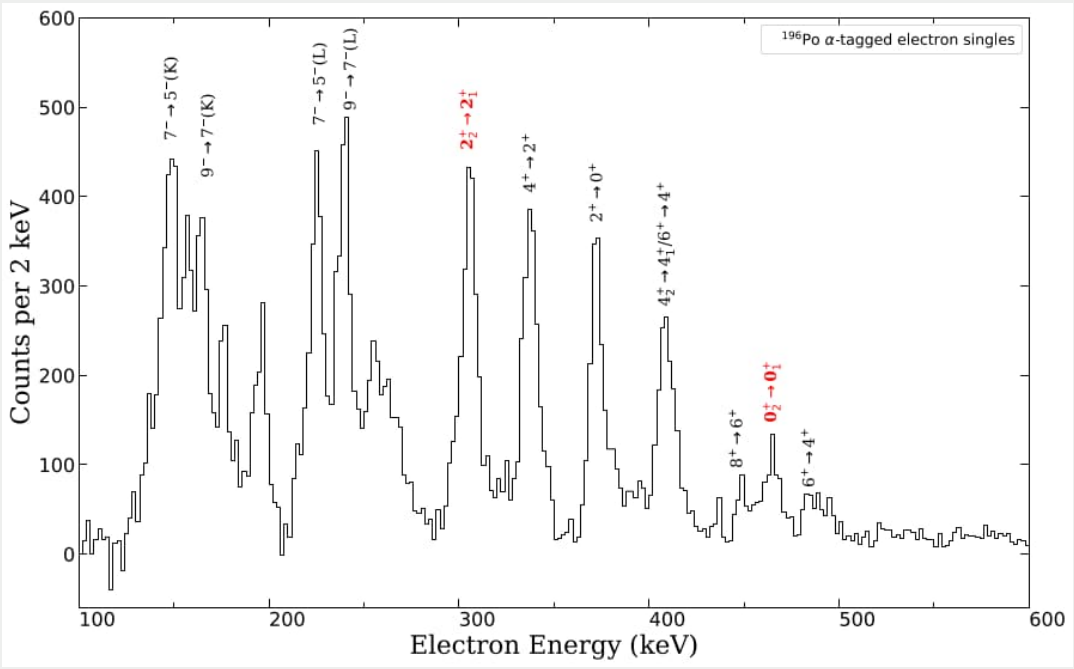




Jurogam and SAGE can be used simultaneously!
→ Electron – gamma – coincidences!



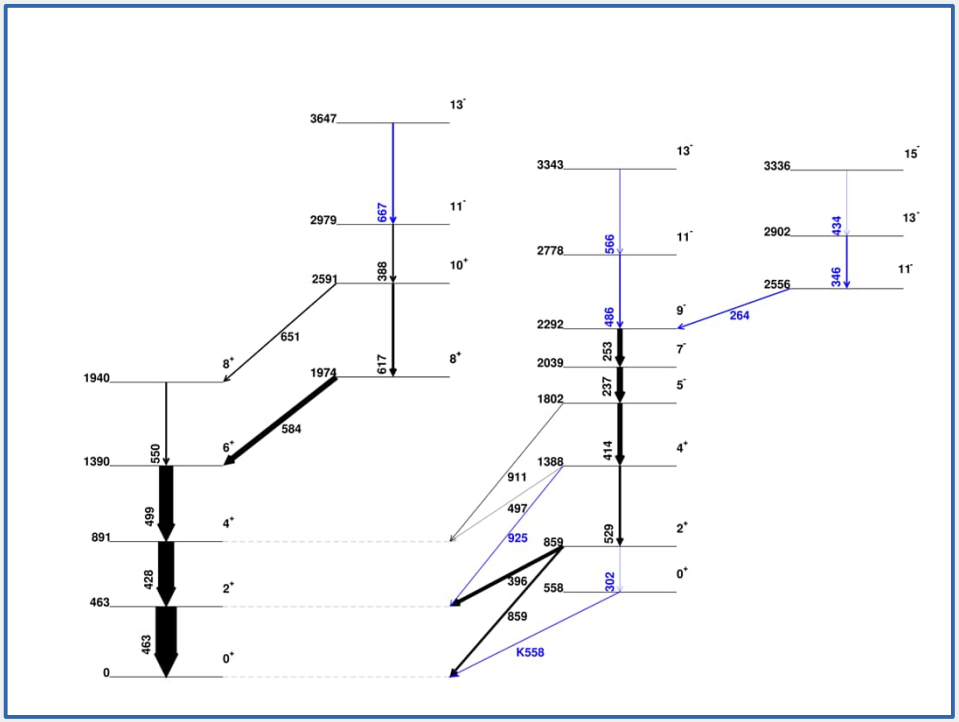


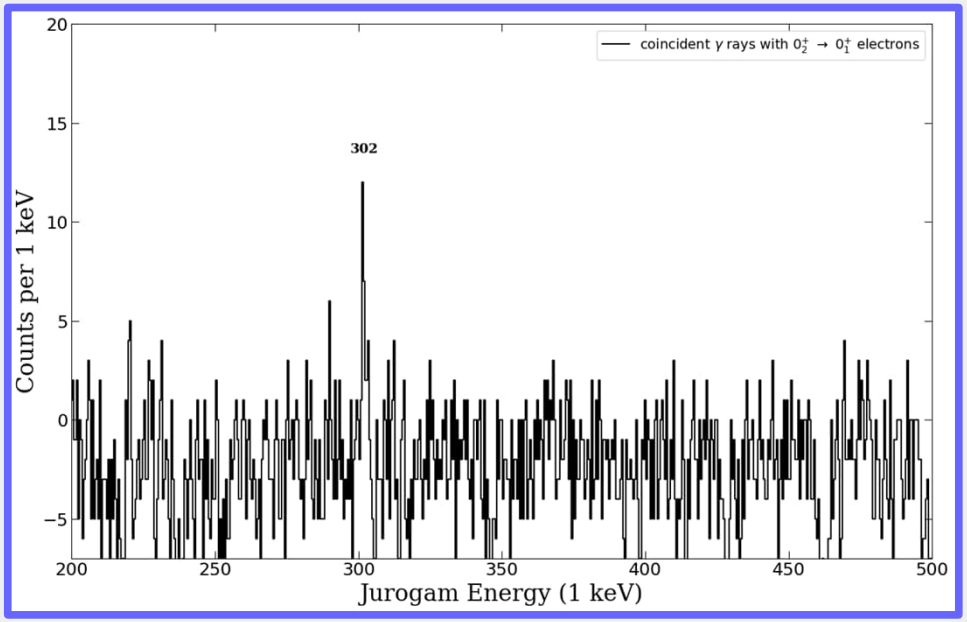


S28: ^{40}Ar + ^{149}Sm -> ^{185}Hg + 4n

S29: ^{35}Cl + ^{165}Ho -> ^{196}Po + 4n

S24: ^{35}Cl + ^{159}Tb -> ^{190}Pb + 4n


3647
13⁻
2979
11⁻
667
2591
10⁺
388
1940
8⁺
651
1974
617
8⁺
584
1390
6⁺
550
891
4⁺
499
463
2⁺
428
0
0⁺
463
3343
13⁻
2778
11⁻
566
2292
9⁻
486
2039
7⁻
253
1802
5⁻
237
1388
4⁺
414
911
497
925
859
529
2⁺
396
558
0⁺
302
859
K558
3336
15⁻
2902
13⁻
434
2556
11⁻
346
264


coincident γ rays with $0_2^+ \rightarrow 0_1^+$ electrons
302
Counts per 1 keV
Jurogam Energy (1 keV)
20
15
10
5
0
−5
200
250
300
350
400
450
500

$^{32}S + ^{152}Sm$
1 mg/cm^2 with
1.5 mg/cm2 Ta fronting
Stretched 0.29 mg/cm^2
Ni charge reset foil.
2 pnA

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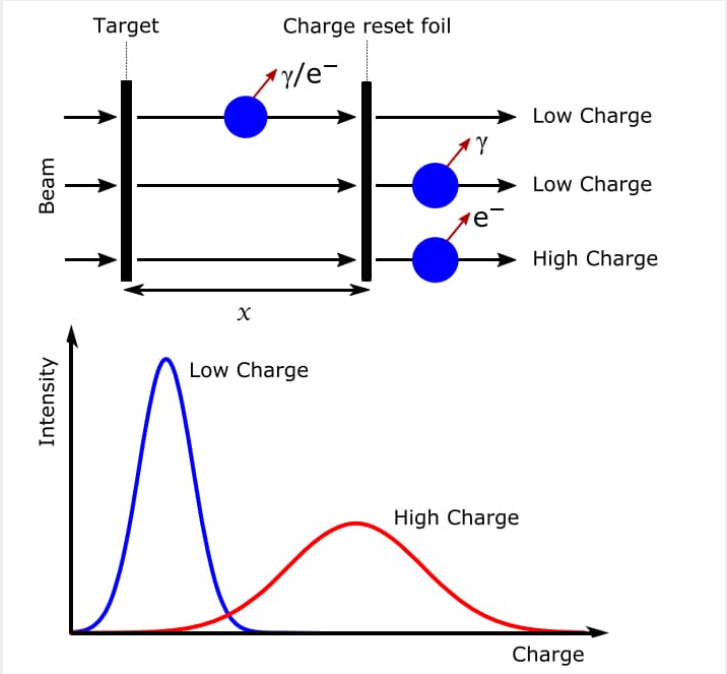
https://doi.org/10.1140/epja/s10050-021-00425-8

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article - Experimental Physics

Lifetime measurements of yrast states in ^{178}Pt using the charge plunger method with a recoil separator

J. Heery[1,a], L. Barber[2], J. Vilhena[3], B. S. Nara Singh[3], R.-D. Herzberg[1], D. M. Cullen[2], C. Müller-Gatermann[4,7], G. Beeton[3], M. Bowry[3], A. Dewald[4], T. Grahn[5], P.T. Greenlees[5], A. Illana[5], R. Julin[5], S. Juutinen[5], J. M. Keatings[3], M. Leino[5], M. Luoma[5], D. O'Donnell[3], J. Ojala[5], J. Pakarinen[5], P. Rahkila[5], P. Ruotsalainen[5], M. Sandzelius[5], J. Sarén[5], J. Sinclair[3], J. F. Smith[3], J. Sorri[6,8], P. Spagnoletti[3,9], H. Tann[1,5], J. Uusitalo[5], G. Zimba[5]



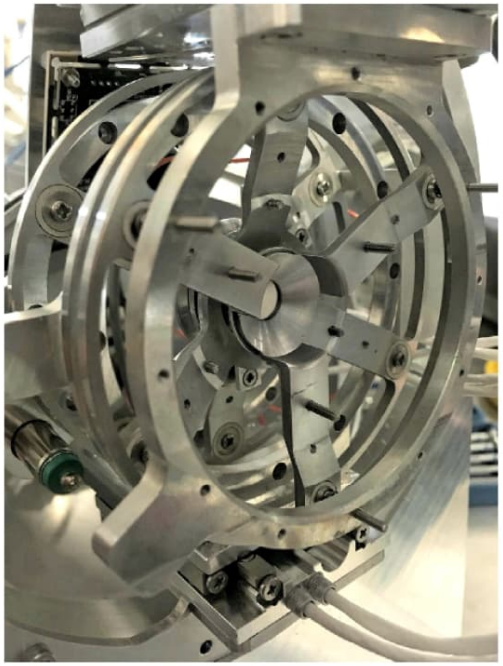
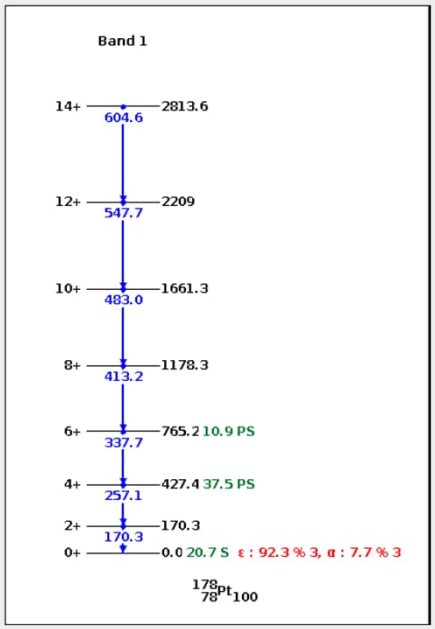


Fig. 7. A photograph of the TPEN. The stopper foil can be seen mounted on a LPS-45 motor on the right of the image. The foil mounts for the degrader and target foils can also be seen.

V ≈ 5 mm/ns

430(30) ps

Tot Conv. 0.47



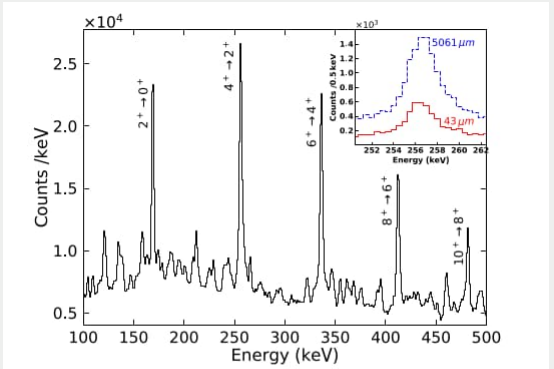


Fig. 5 Part of the JUROGAM 3 spectrum for γ-ray-recoil coincidences. Yrast transitions for the ^{178}Pt ground-state rotational band are labelled. This spectrum is a summation of all distances. The $4_1^+ \rightarrow 2_1^+$ (257 keV) transition shown inset for reset foil distances of $x = 43\,\mu$m (all transitions occur after reset foil) and $x = 5061\,\mu$m (all transitions occur before reset foil)

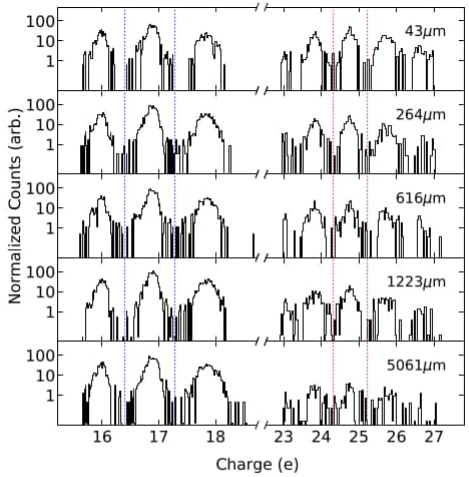


Fig. 6 Charge spectra at the focal plane of MARA when gating on the $4_1^+ \rightarrow 2_1^+$ transition at 257 keV. In each spectrum counts have been normalised using coulomb excitation in the target. The central peaks lie at 17e and 25e. The evolution with distance of low and high charge components is shown for five distances. The integration limits of the central charge peaks are shown as blue ($q = 17\,$e) and red ($q = 25\,$e) dotted lines

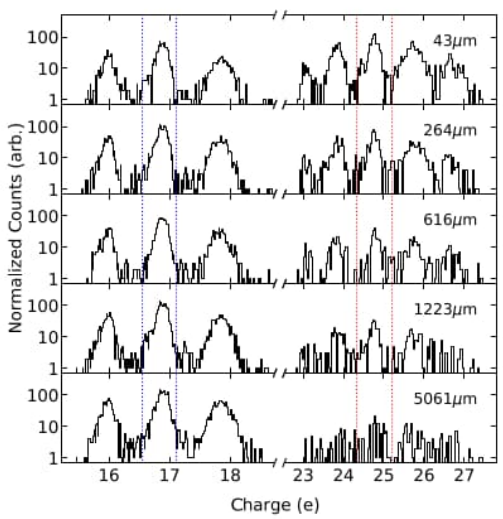


Fig. 10 Charge spectra at the focal plane of MARA in coincidence with an alpha decay of ^{178}Pt. Normalization is the same as in Fig. 6. The evolution with distance of low and high charge components is shown for five distances. The integration limits of the central charge peaks are shown as blue ($q = 17\,$e) and red ($q = 25\,$e) dotted lines

$^{18}O + {}^{208}Pb \rightarrow {}^{226}Th^*$

$^{48}Ca + {}^{208}Pb \rightarrow {}^{256}No^*$

Recommissioning of RITU

- New focal plane setup
  - DSSD and MWPC
- New He gas-handling system
- New control system (Rockwell)

^{40}Ar + ^{165}Ho, ^{169}Tm, ^{175}Lu
^{40}Ca + ^{159}Tb

Ca beam development from metallic calsium
100 pnA beam, 5 days without renewing the sample
ECR group Ville Toivanen

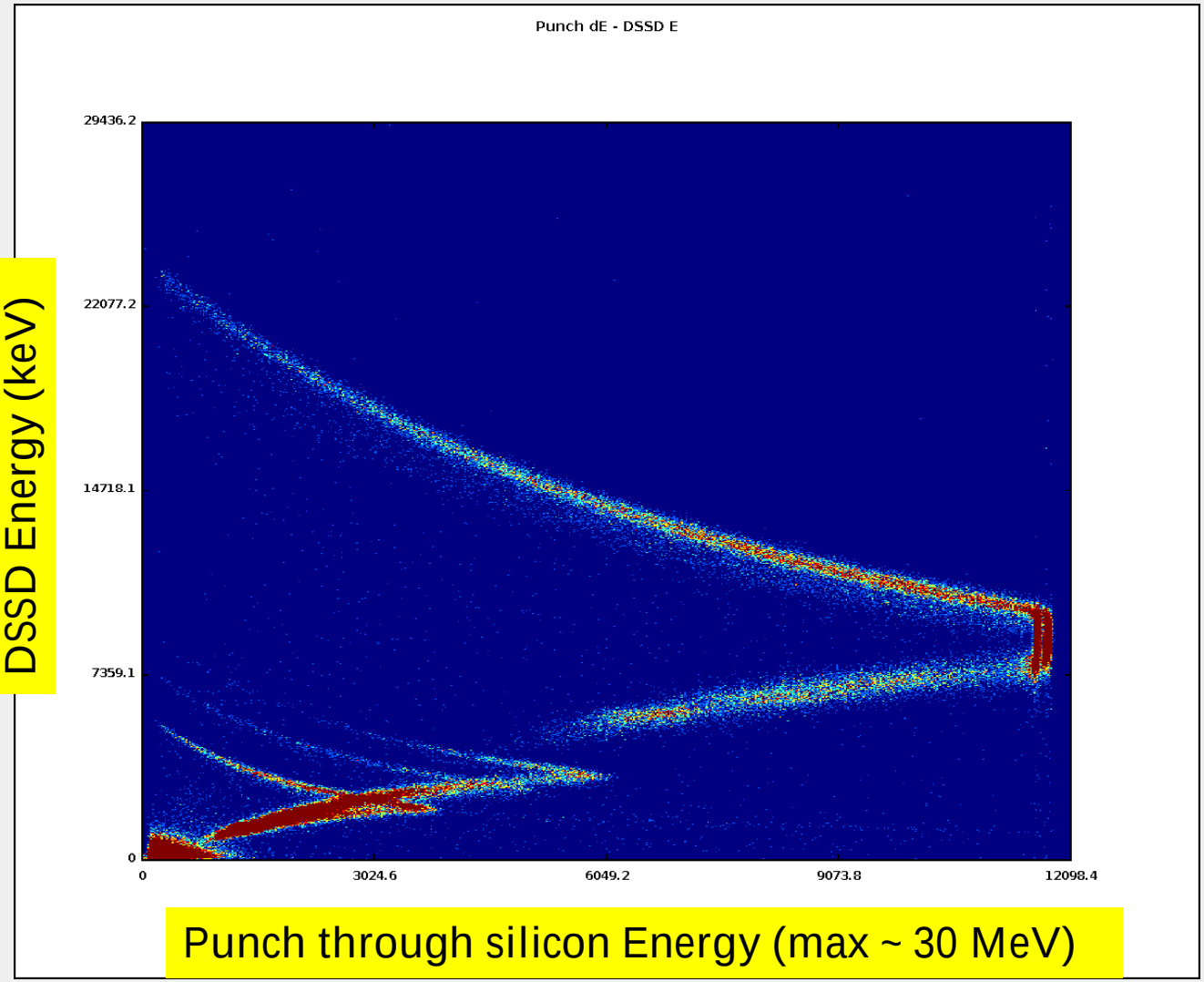
For example:
100 pnA ^{40}Ca beam ^{232}ThF target 330 ug/cm2 rotating foil
RITU tuned for SHE, He 0.8 mbar
Typical rates MWPC < 100 Hz, DSSD rates < 20 Hz

Proposal: Attempt to synthesize ^{268}Hs (and ^{267}Hs) in two-body reaction
C. Borcea et. al.,

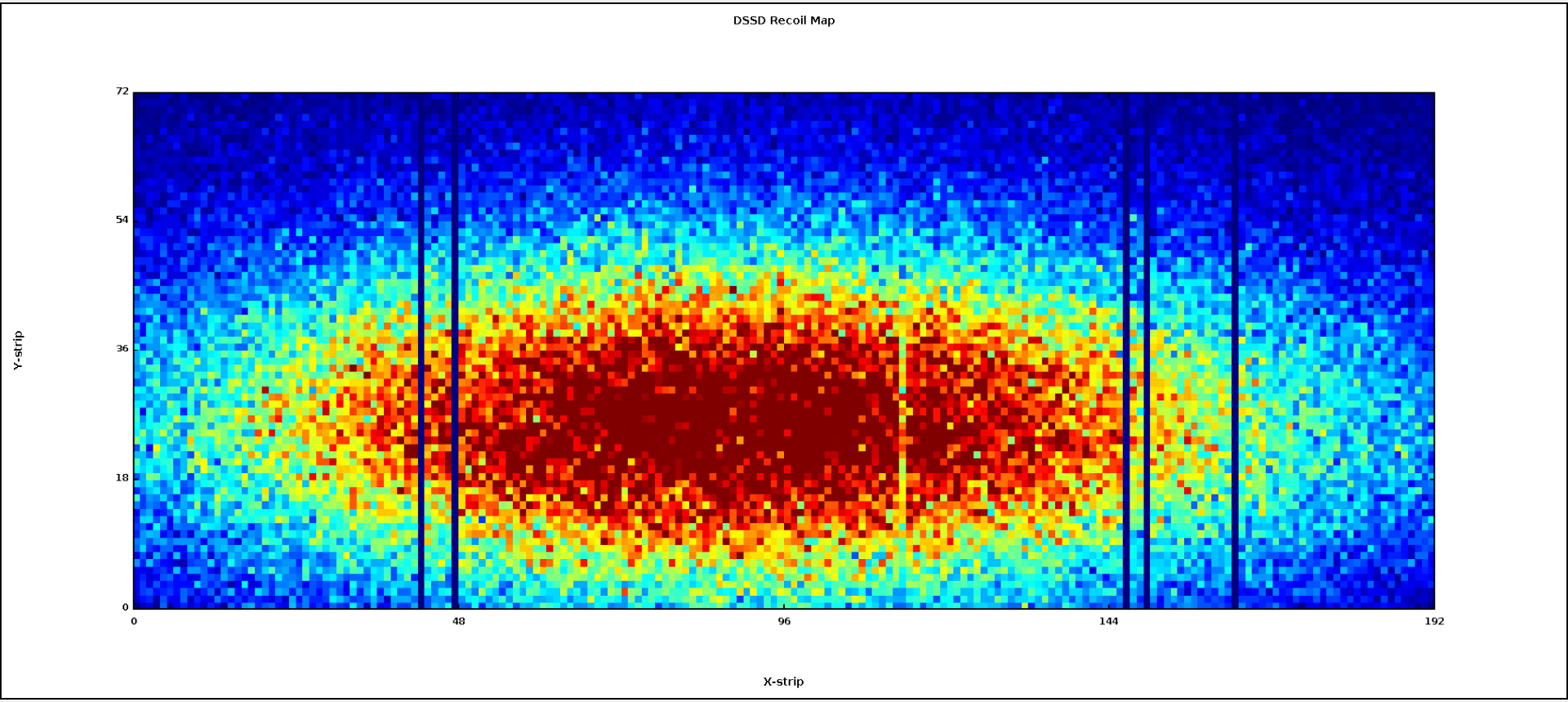
$^{40}Ca + ^{232}ThF$ @ 240 MeV

300 μm Si

24 MeV α
6 MeV p
8 MeV d
9,5 MeV t

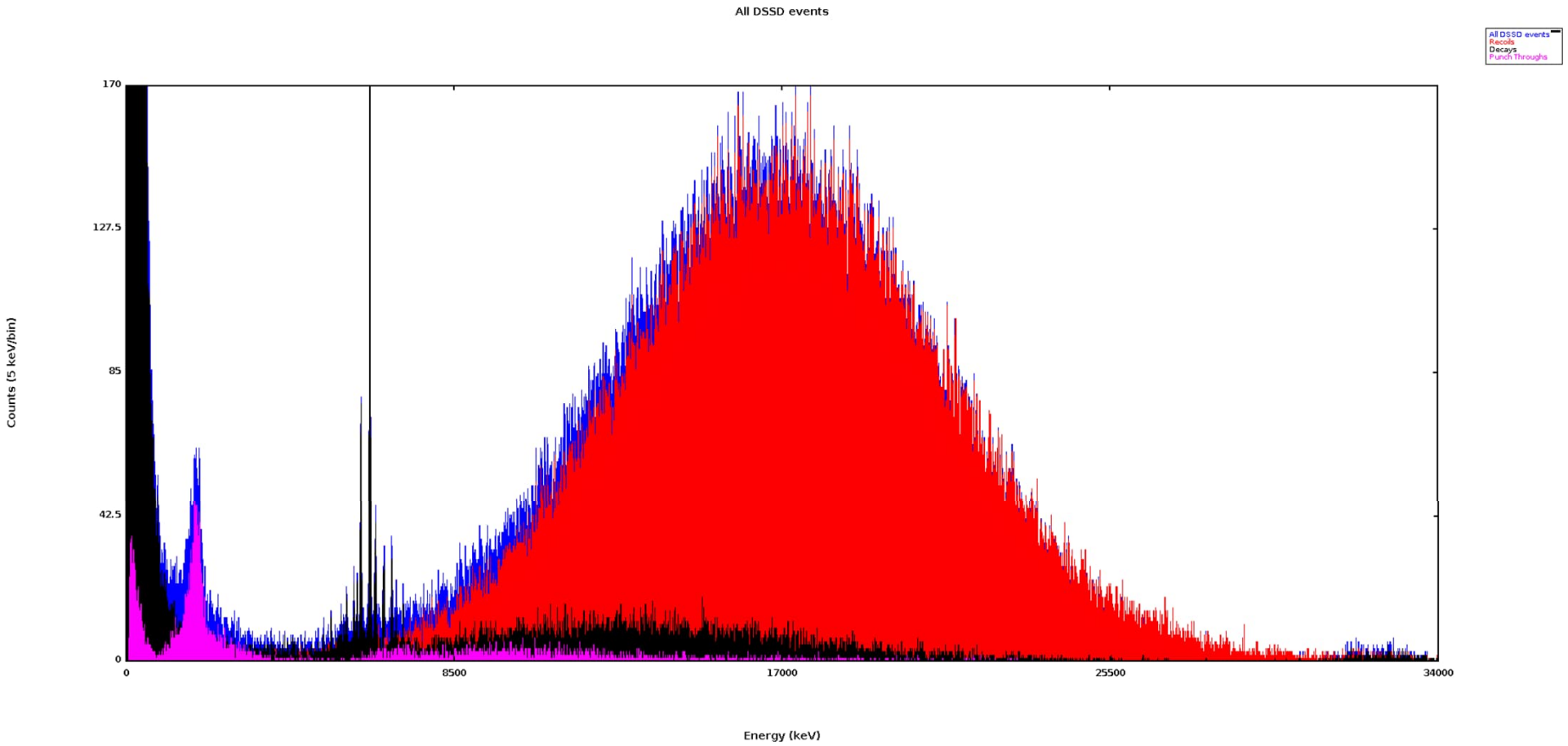


$^{40}Ca + ^{159}Tb$ @ 240 MeV



BB20 DSSD, 128 mm x 48 mm, 192 x 72 strips, 13824 pixels

$^{40}Ca + ^{159}Tb$ @ 240 MeV



Energy resolution ~ 25-30 keV for alphas

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Towards saturation of the electron-capture delayed fission probability: The new isotopes ^{240}Es and ^{236}Bk

J. Konki [a], J. Khuyagbaatar [b,c,*], J. Uusitalo [a], P.T. Greenlees [a], K. Auranen [a,1], H. Badran [a], M. Block [b,c,d], R. Briselet [e], D.M. Cox [f,2], M. Dasgupta [g], A. Di Nitto [c,d], Ch.E. Düllmann [b,c,d], T. Grahn [a], K. Hauschild [h], A. Herzán [a,3], R.-D. Herzberg [f], F.P. Heßberger [c], D.J. Hinde [g], R. Julin [a], S. Juutinen [a], E. Jäger [c], B. Kindler [c], J. Krier [c], M. Leino [a], B. Lommel [c], A. Lopez-Martens [h], D.H. Luong [g], M. Mallaburn [i], K. Nishio [j], J. Pakarinen [a], P. Papadakis [a], J. Partanen [a], P. Peura [a,4], P. Rahkila [a], K. Rezynkina [h], P. Ruotsalainen [a], M. Sandzelius [a], J. Sarén [a], C. Scholey [a], J. Sorri [a], S. Stolze [a], B. Sulignano [e], Ch. Theisen [e], A. Ward [f], A. Yakushev [b,c], V. Yakusheva [b,c]

~ 150 pnA ^{34}S beam for 10 days

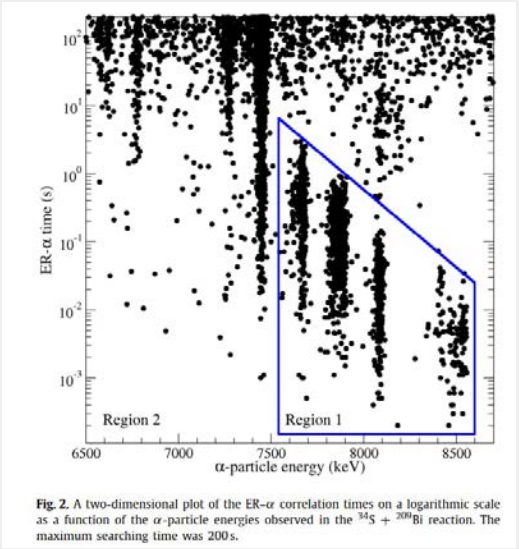

Fig. 2. A two-dimensional plot of the ER–α correlation times on a logarithmic scale as a function of the α-particle energies observed in the ^{34}S + ^{209}Bi reaction. The maximum searching time was 200 s.

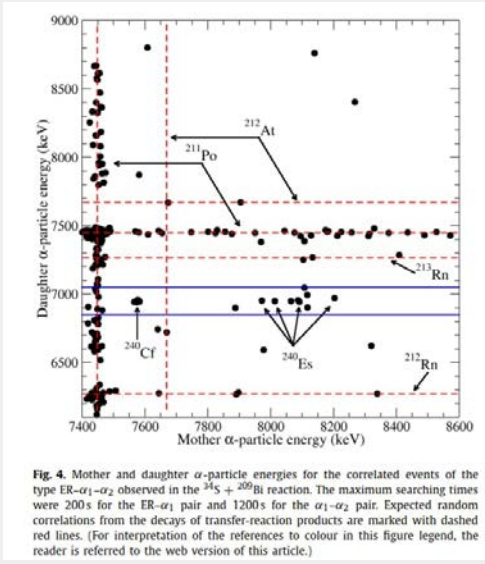

Fig. 4. Mother and daughter α-particle energies for the correlated events of the type ER–α_1–α_2 observed in the ^{34}S + ^{209}Bi reaction. The maximum searching times were 200 s for the ER–α_1 pair and 1200 s for the α_1–α_2 pair. Expected random correlations from the decays of transfer-reaction products are marked with dashed red lines. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Search for the new neutron-deficient isotope ^{238}Es and study of electron-capture delayed fission in ^{238}Es, ^{234}Bk and ^{230}Am

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Probing the $N = 126$ shell closure: α-decay spectroscopy of ^{220}Pu

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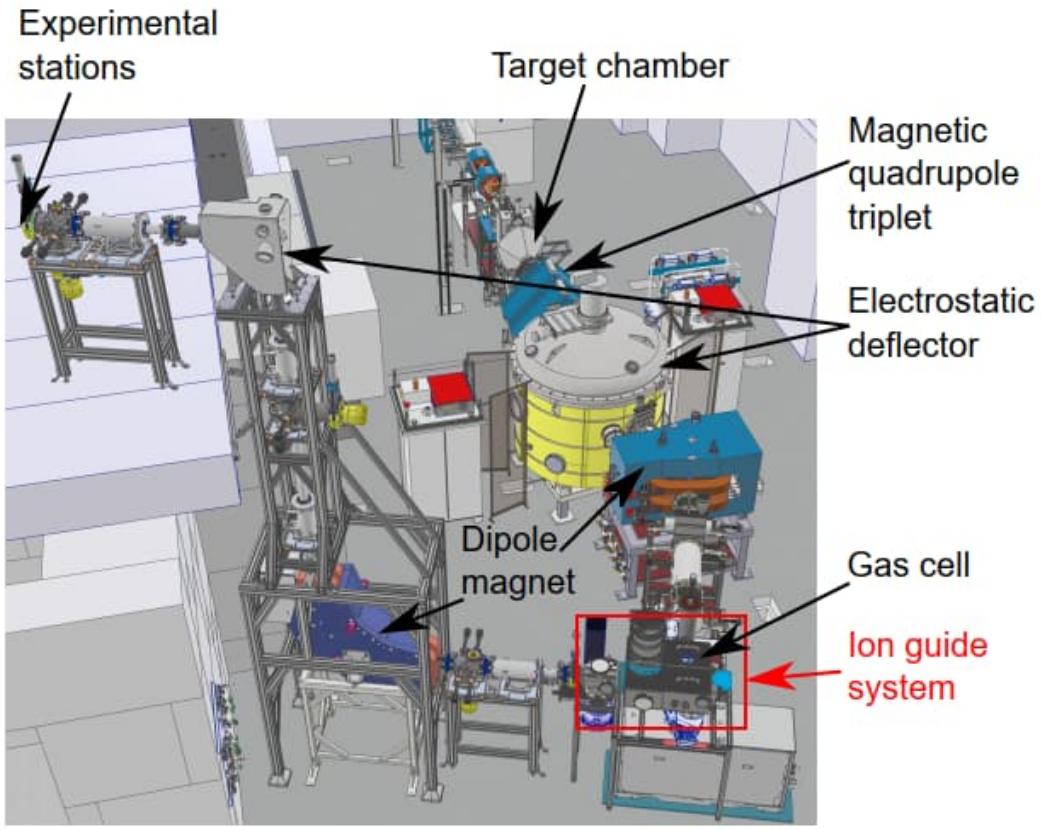
Simulation and design of the ion guide system for the MARA Low-Energy Branch

Master's thesis, 16.12.2021

Author:
JARKKO LIIMATAINEN



Kuva 1: MARA and the current design of MARA-LEB. Experimental stations are not shown in this figure.

Thank you!

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K. Auranen, A. Briscoe, J. Louko, J. Saren

MWPC, Institut of Physics, Slovak Academy of Sciences
BB20 and Mesytec preamps., University of Liverpool Department of Physics
C-foils and targets, GSI-target laboratory

Main collaborators:
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