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Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

Experimental Results of β-delayed Neutron Branching Ratios for heavy Species

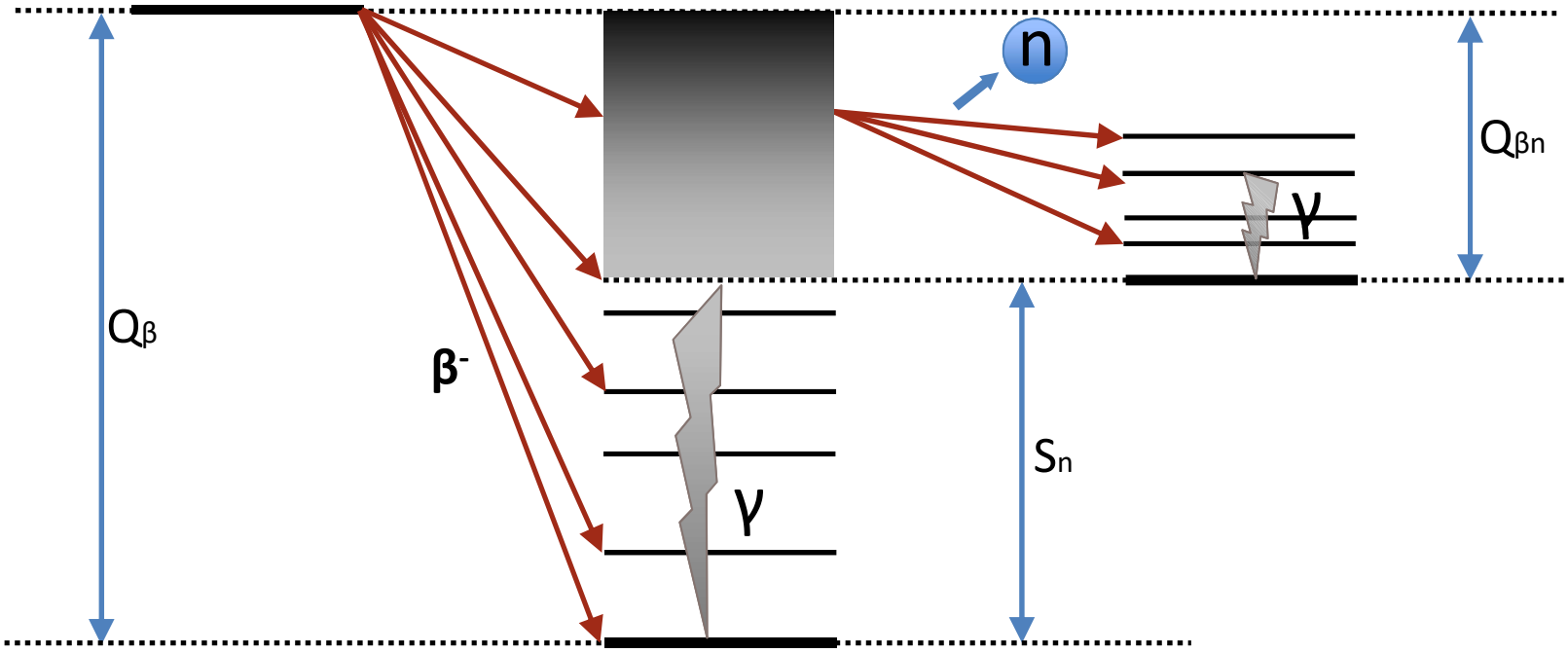
Roger Caballero-Folch
Postdoc researcher | TRIUMF

BANFF AB, 18 de febrer de 2017 | WNPPC 2017

Outline

- Motivation
- Half lives and Pn-values results at N>126 region
- Heaviest double neutron emitter measured
- BRIKEN project and future goals

β-delayed one-neutron emission



Parent nucleus
Z, N

Daughter nucleus
Z+1, N-1

Final nucleus
Z+1, N-2, A-1

^{137}I → ^{137}Xe → ^{136}Xe

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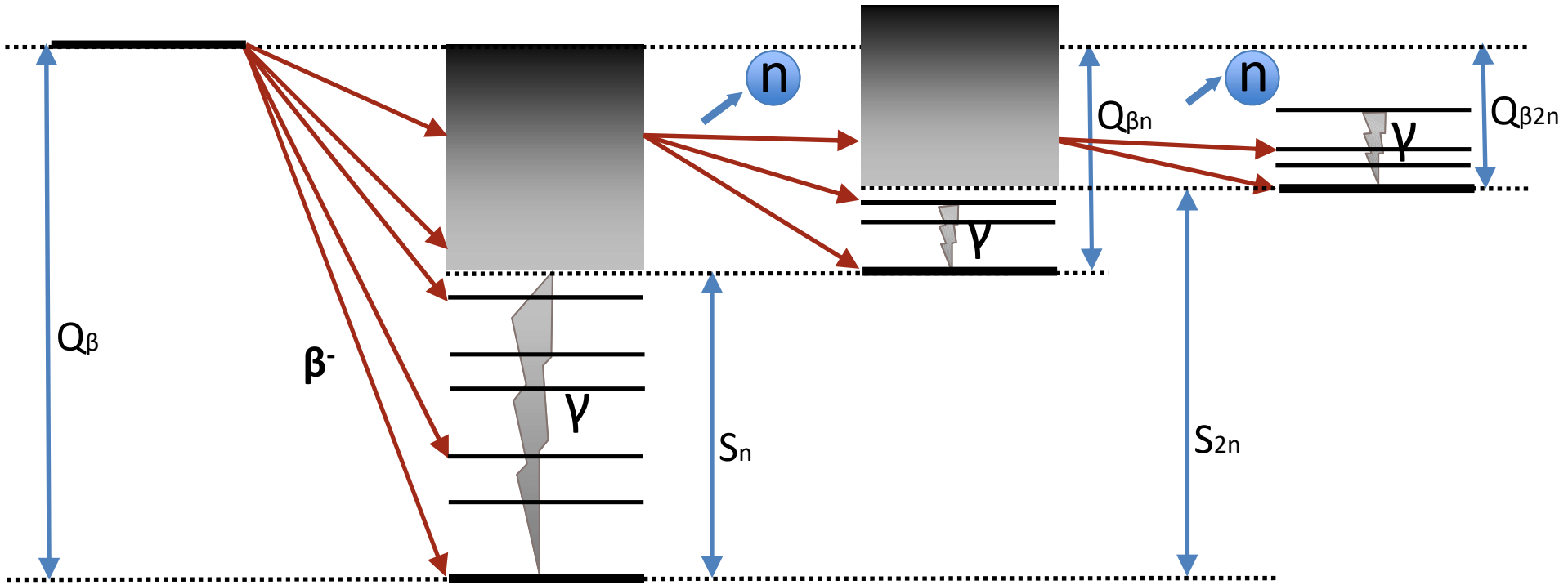
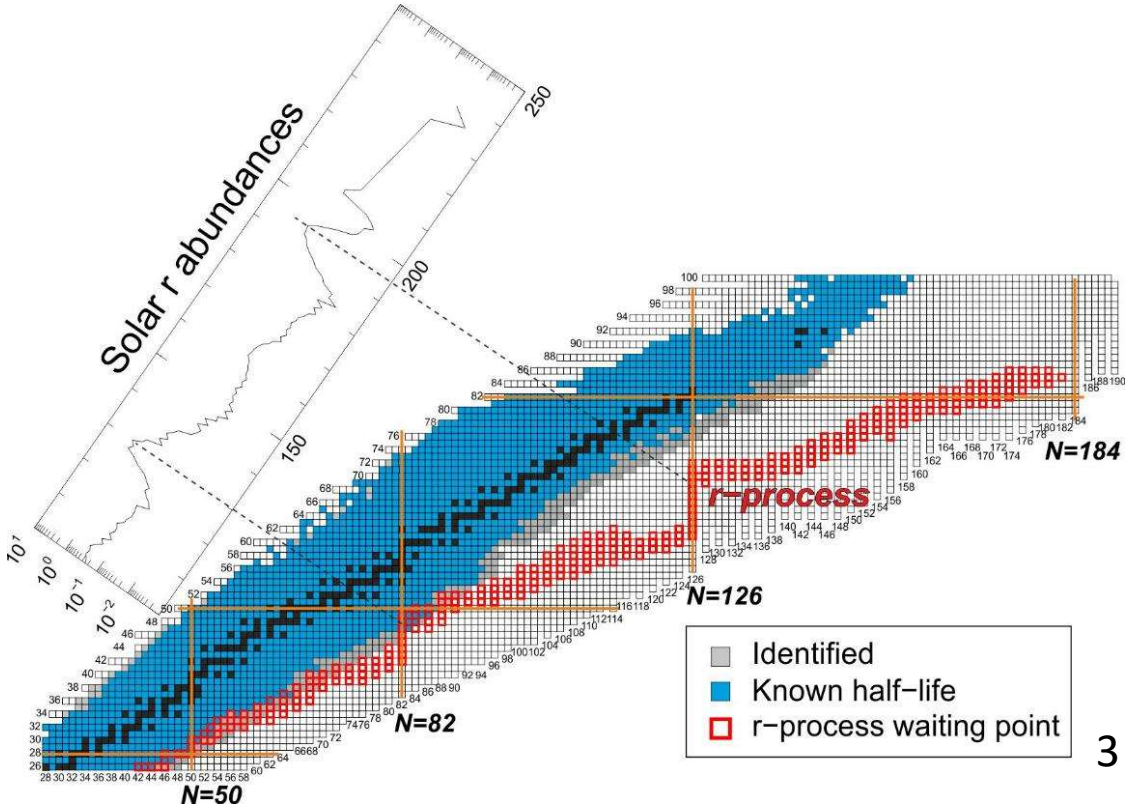
β-delayed two-neutron emission



The origin of the elements: r-process nucleosynthesis

β-delayed neutron emission has a twofold impact:

- It increases the neutron density of the environment after freeze-out (re-capture).
- It shifts the abundances towards lower masses.



Astrophysics motivation

The origin of the elements: r-process nucleosynthesis

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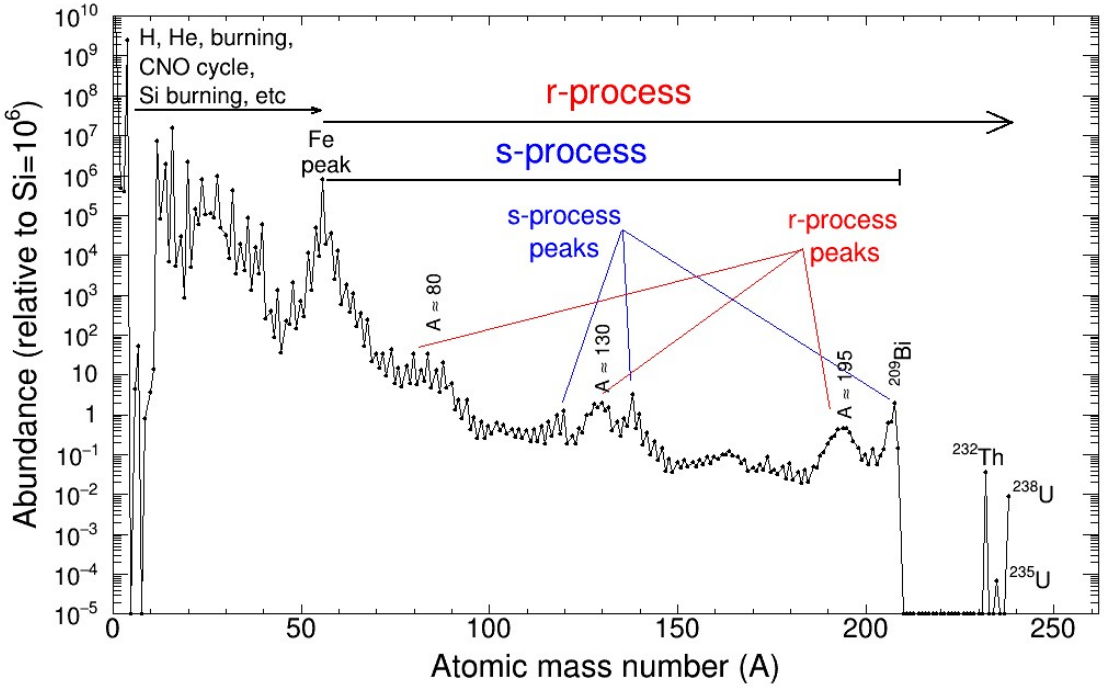
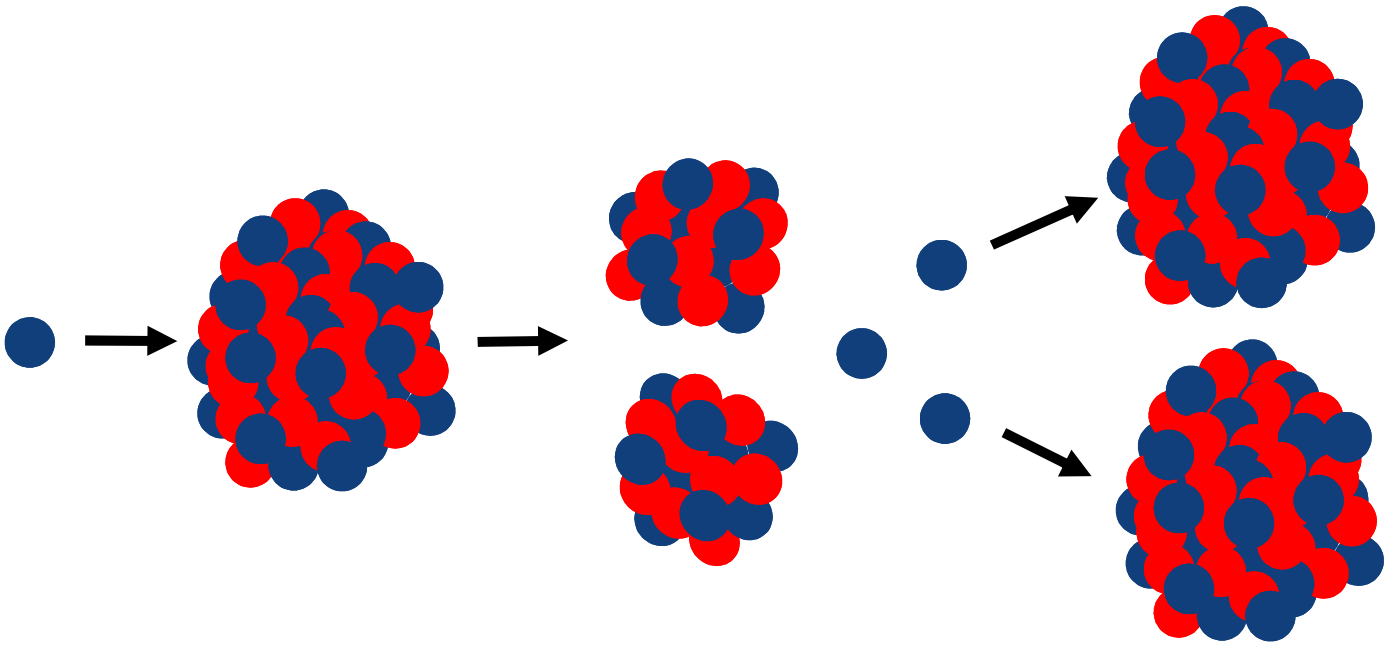


Technological applications

Reactor kinetics in the nuclear power reactors

- Important role in the reactor control.
- Maintaining the reactor in promt subcritical condition.



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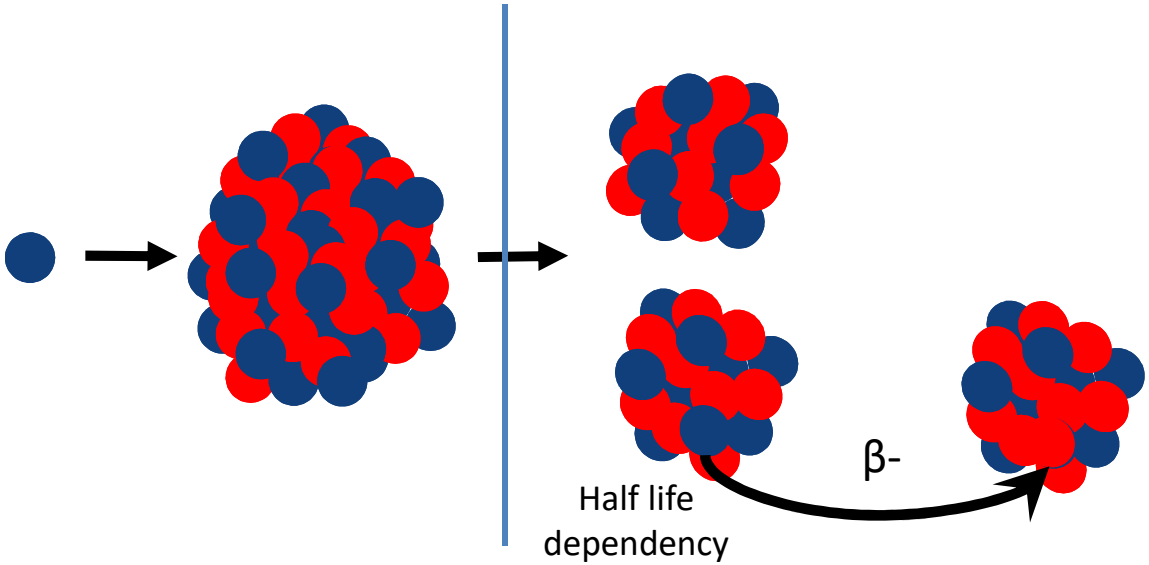

Technological applications

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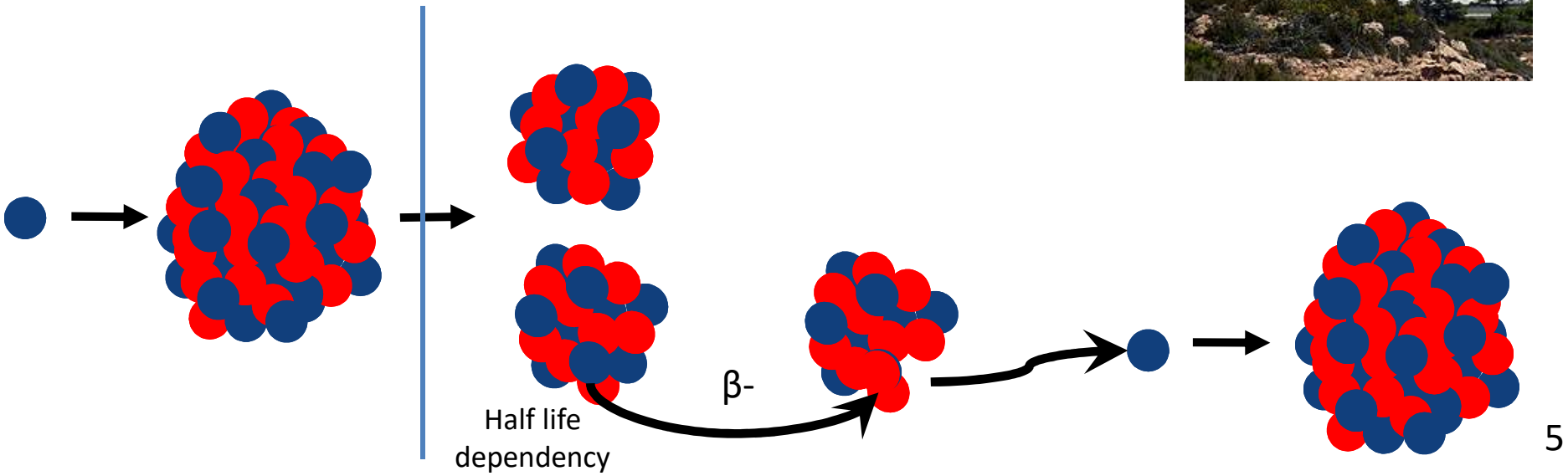
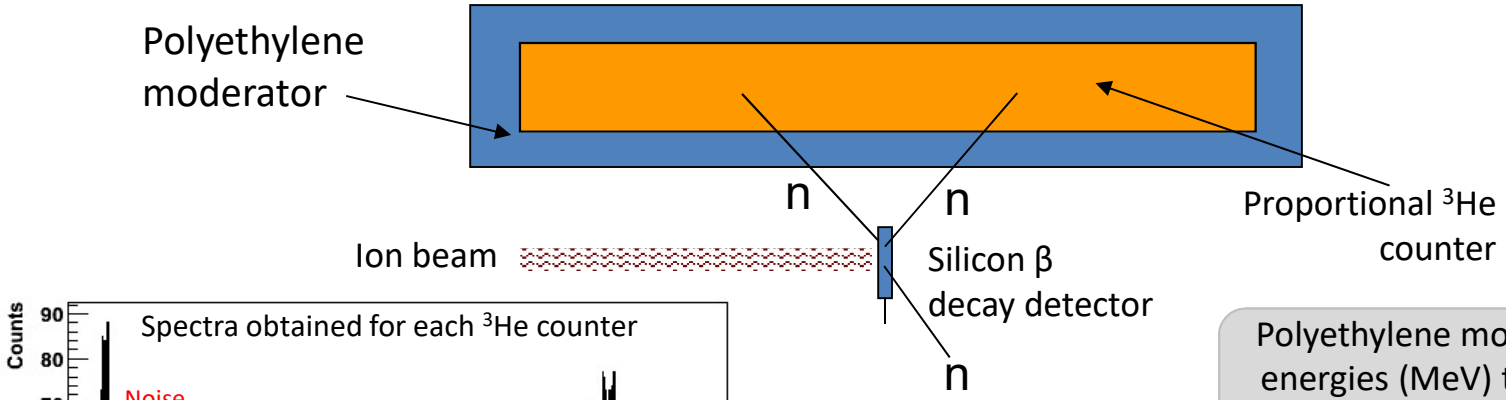
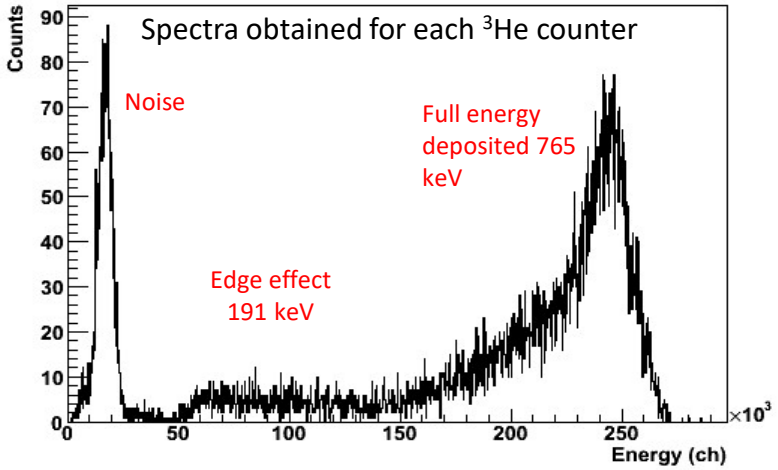


The detection of the neutron is based on the detection of products of the following reaction of the neutron with ^{3}He counters



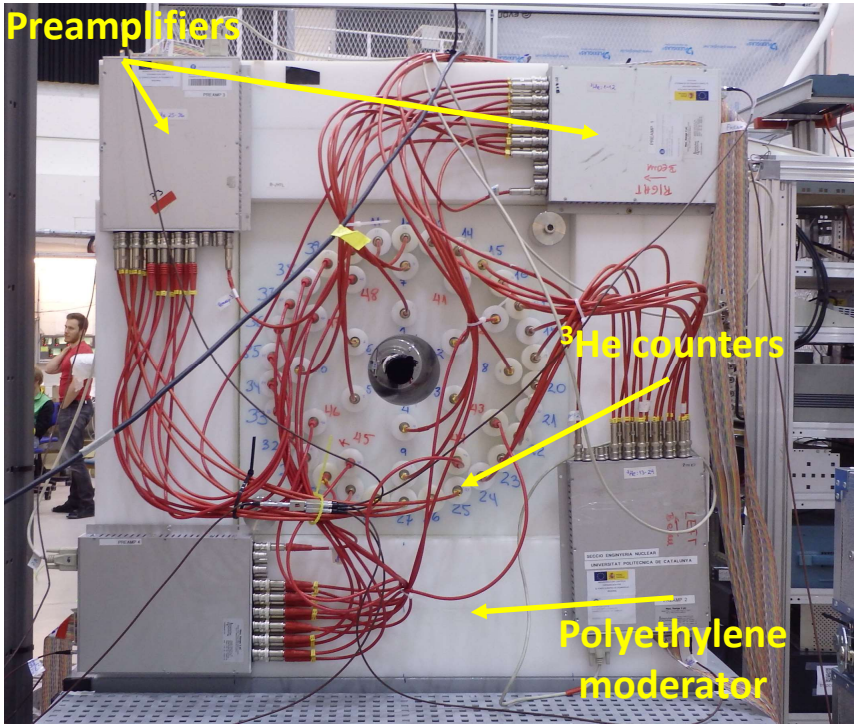


Polyethylene moderates neutron energies (MeV) to thermal to be able to be detected by ^{3}He.

$$^3He + n \longrightarrow {}^3H + {}^1H + 765\ keV$$

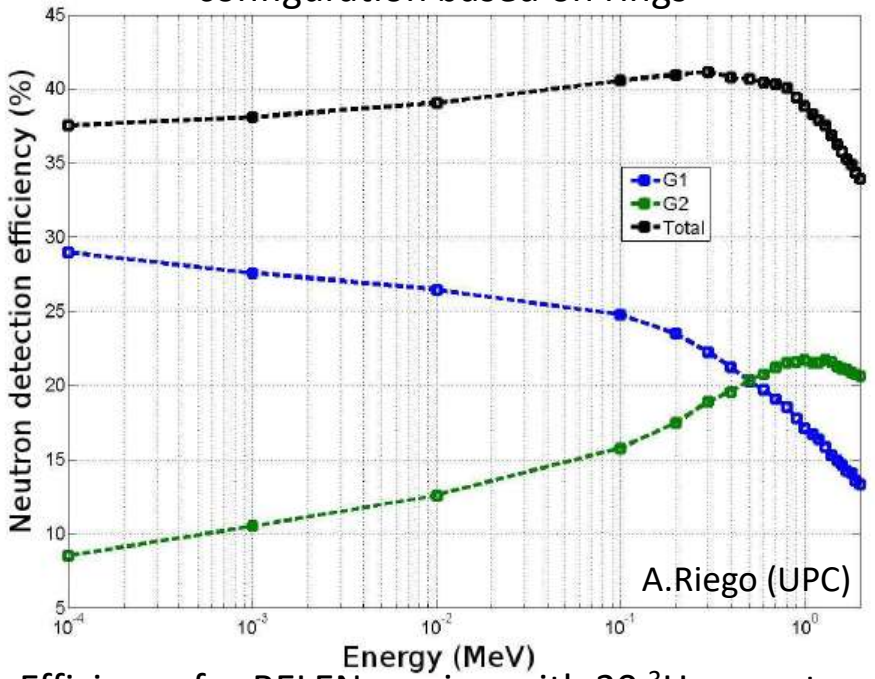
The Beta dELayEd Neutron (BELEN) detector

BELEN setup used at IGISOL Jyväskylä (Finland), GSI Darmstadt and PTB Braunsschweig (Germany)



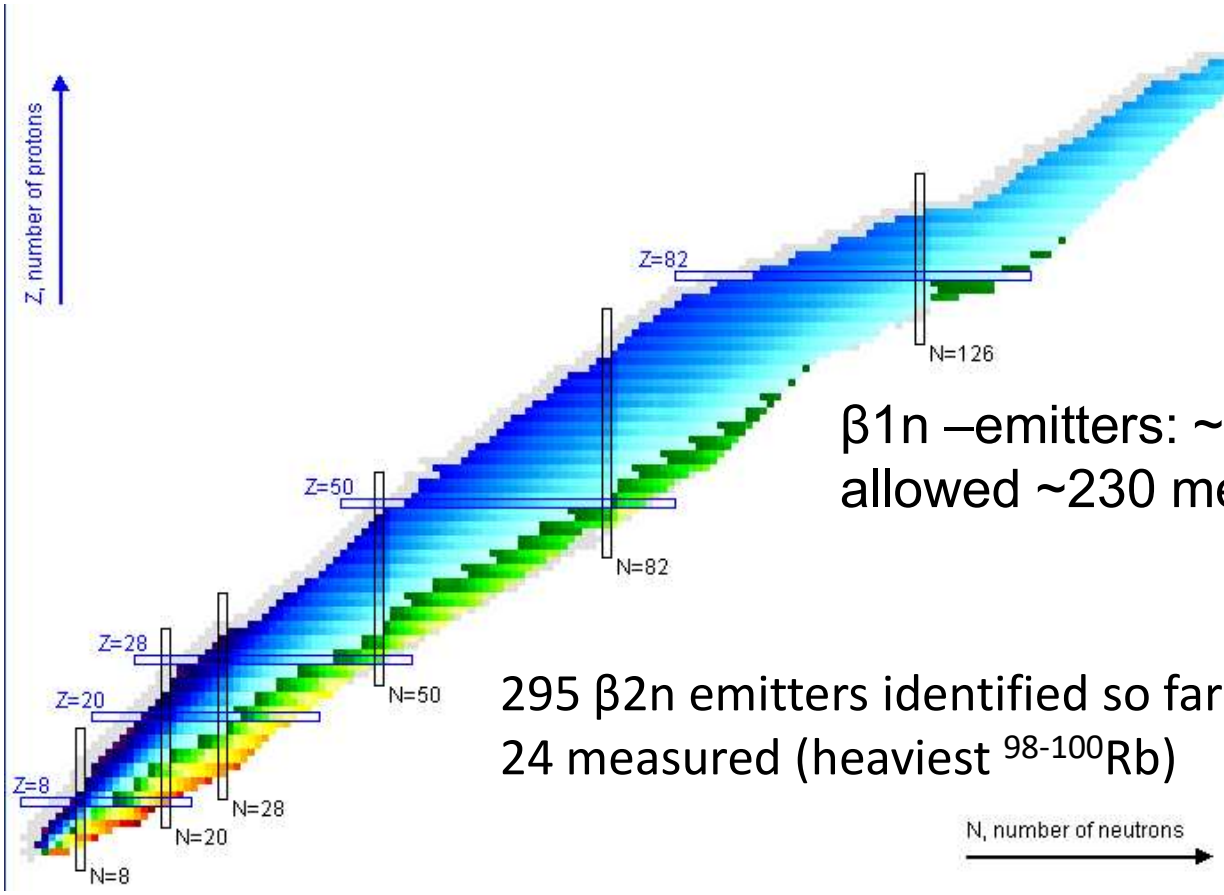
BELEN version setup with 48 ^{3}He counters distributed in 3 rings used at IGISOL Jyväskylä.

Flat efficiency required and obtained with a configuration based on rings



Efficiency for BELEN version with 30 ^{3}He counters distributed in 2 rings used at GSI Darmstadt.

State of the art

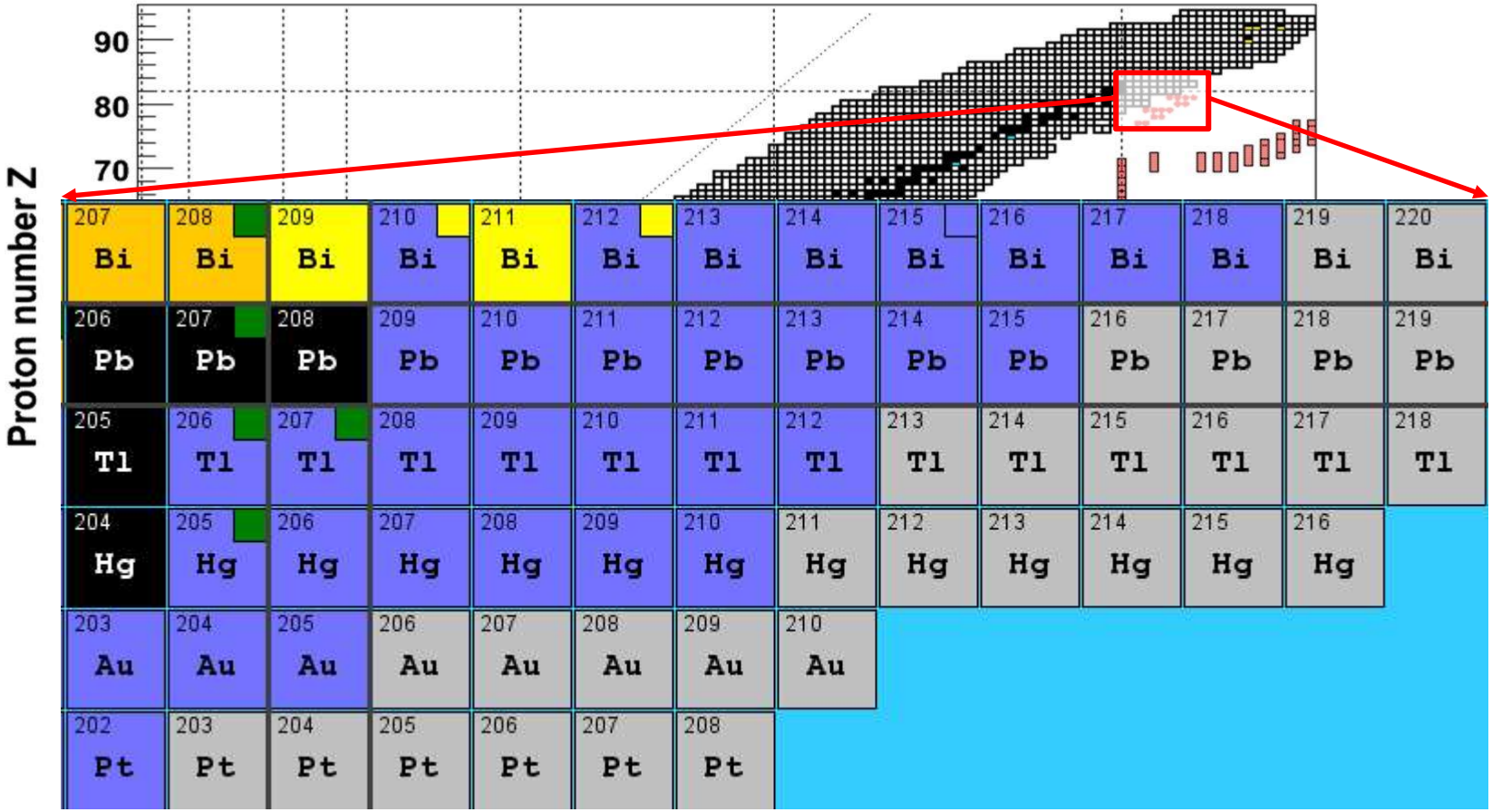


β1n –emitters: ~600 energetically allowed ~230 measured so far

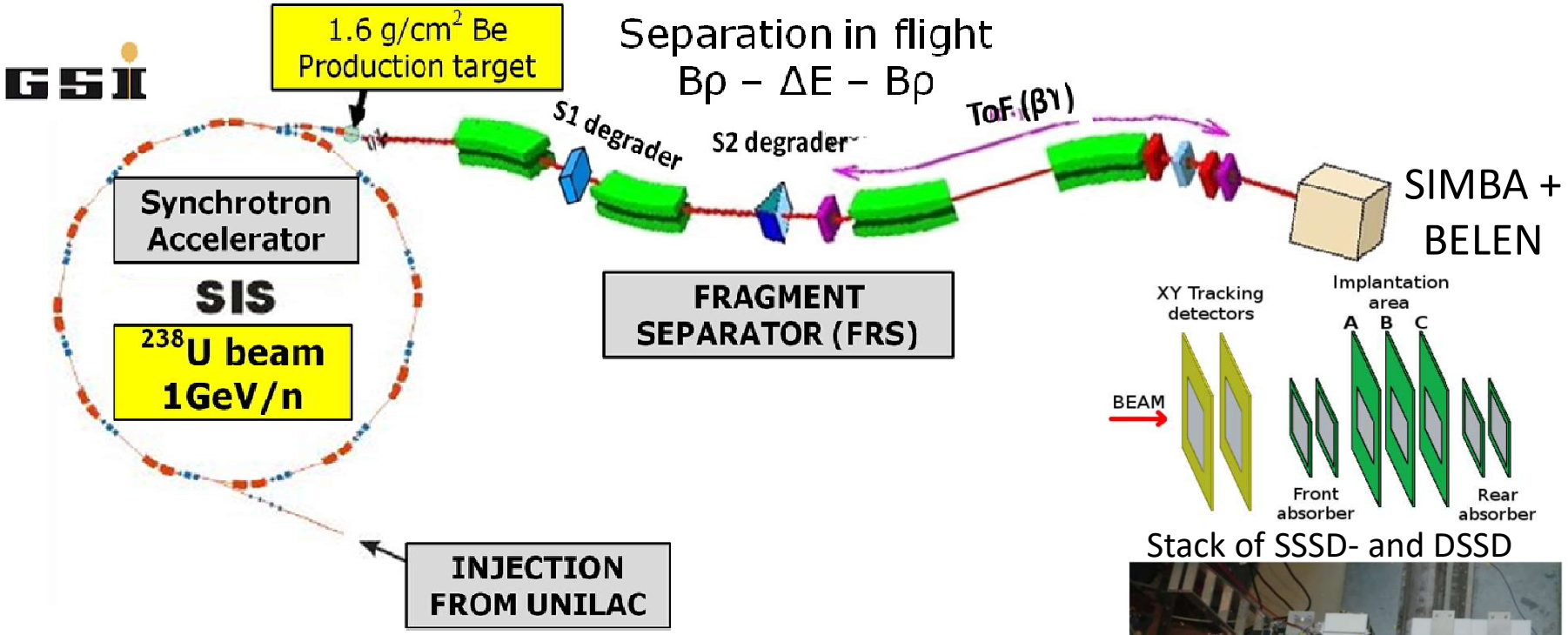
295 β2n emitters identified so far
24 measured (heaviest $^{98\text{-}100}$Rb)

Measurement of the heaviest neutron emitters N>126

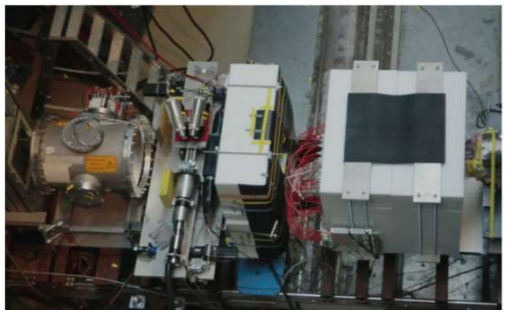
Experiment at GSI : Region of interest Au, Hg, Tl, Pb, Bi N≥126



Experimental setup UNILAC + SIS18 + FRS + SIMBA + BELEN



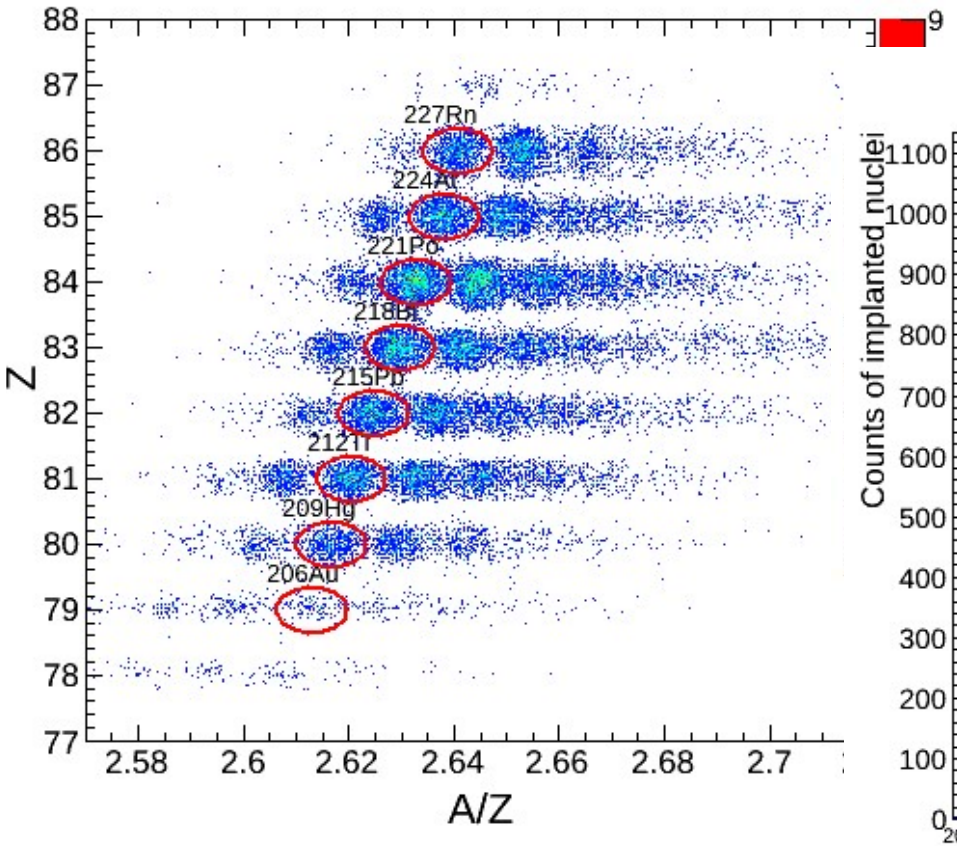
Stack of SSSD- and DSSD



✓Geissel, H, et al. Nucl.Instr.Meth.B, 70, (1992)

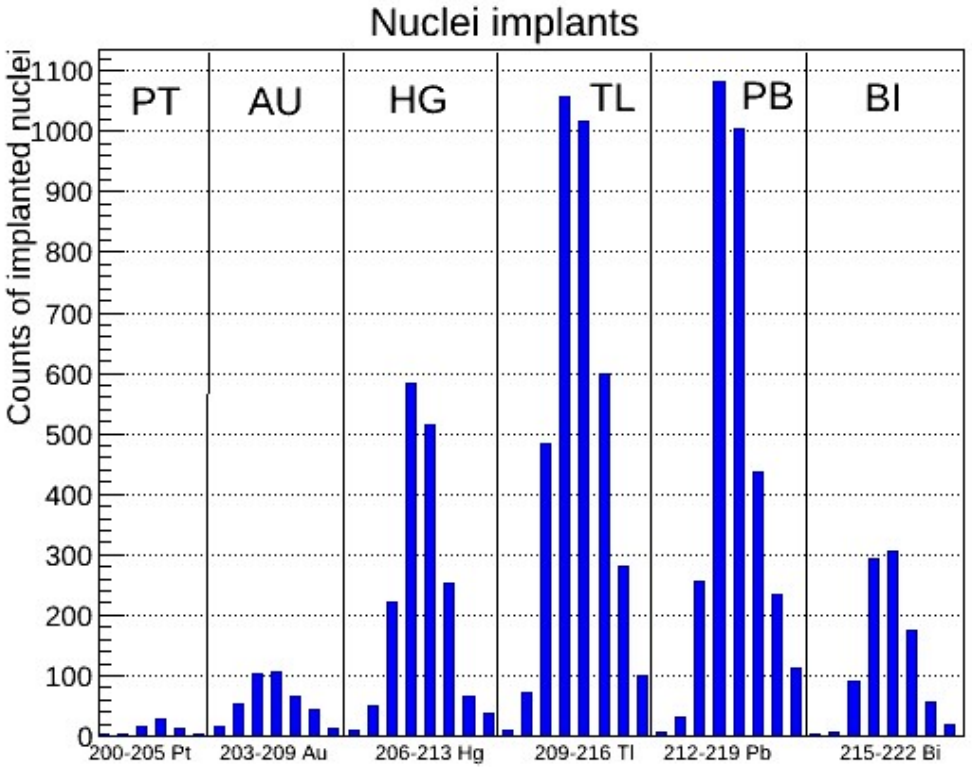
✓C.B. Hinke, et al. *Nature,* 486(7403):341–345, (2012)

PID and implanted isotopes

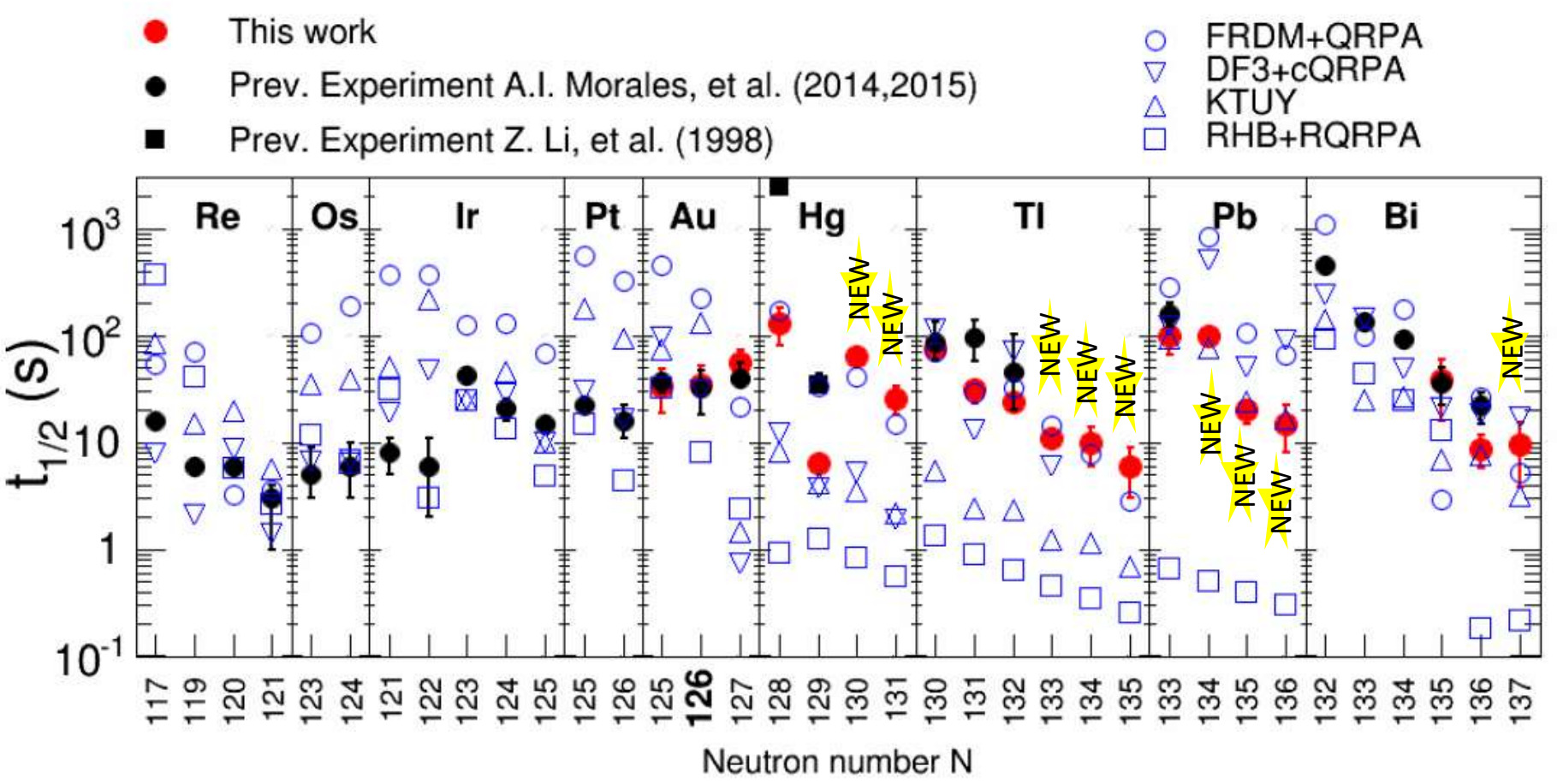


Identified isotopes

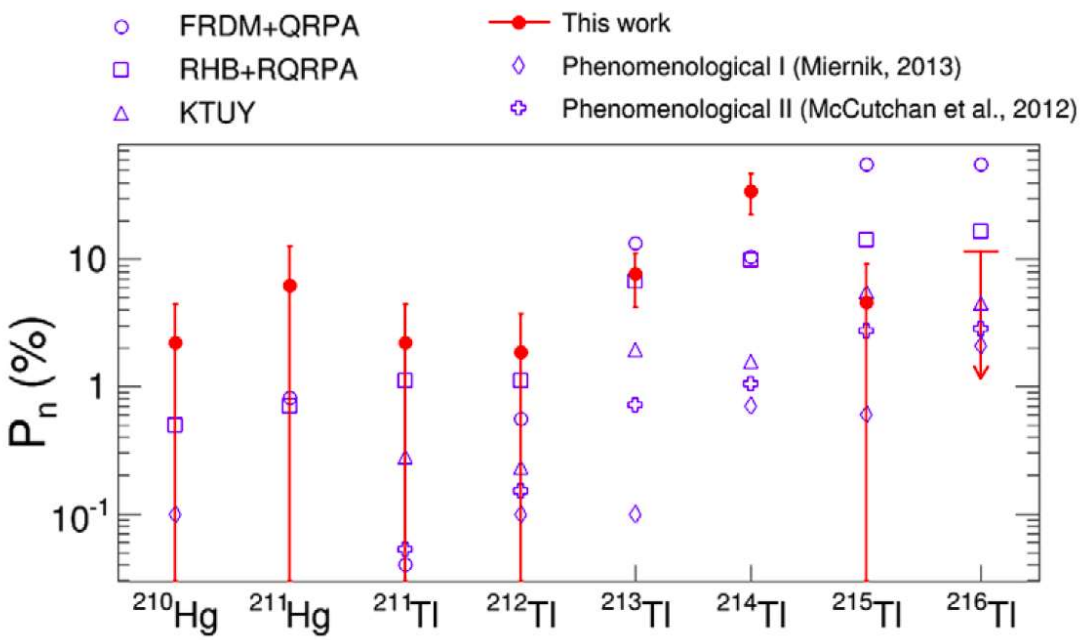
List of isotopes implanted in SIMBA



Results: Half-lives for Au, Hg, Tl, Pb & Bi isotopes



Results: Neutron branching ratios (P_n)



Heaviest β-delayed neutron emitter measured so far.

Apart of a measurement of ^{210}Tl in 1962, the heaviest βn –emitter measured was ^{150}La.

Technical details submitted to Phys. Rev. C (In review process)

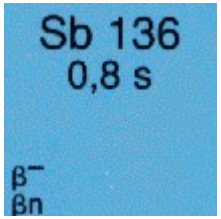
https://arxiv.org/abs/1701.03845

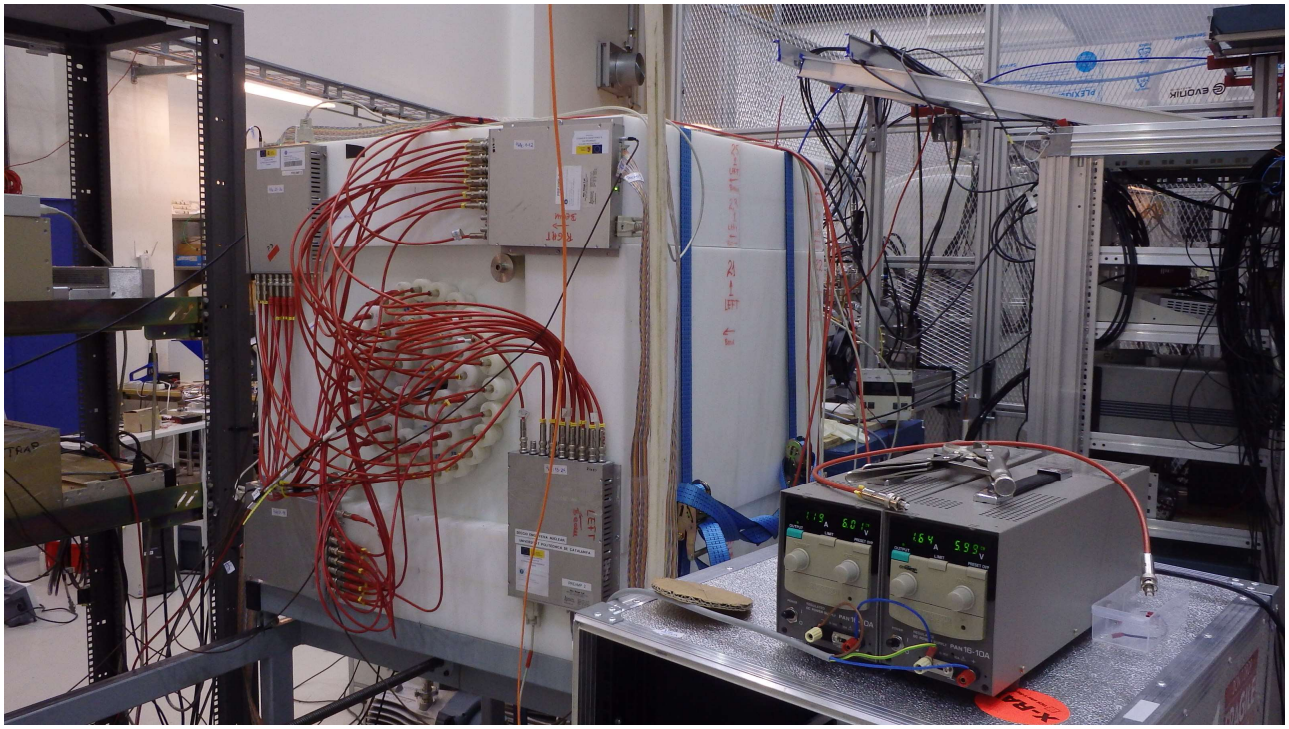
PRL 117, 012501 (2016) PHYSICAL REVIEW LETTERS week ending 1 JULY 2016

First Measurement of Several β-Delayed Neutron Emitting Isotopes Beyond $N = 126$

R. Caballero-Folch,[1,2] C. Domingo-Pardo,[3,*] J. Agramunt,[3] A. Algora,[3,4] F. Ameil,[5] A. Arcones,[5] Y. Ayyad,[6] J. Benlliure,[6] I. N. Borzov,[7,8] M. Bowry,[9] F. Calviño,[1] D. Cano-Ott,[10] G. Cortés,[1] T. Davinson,[11] I. Dillmann,[2,5,12] A. Estrade,[5,13]

^{136}Sb measurement (β2n emitter) with BELEN-48

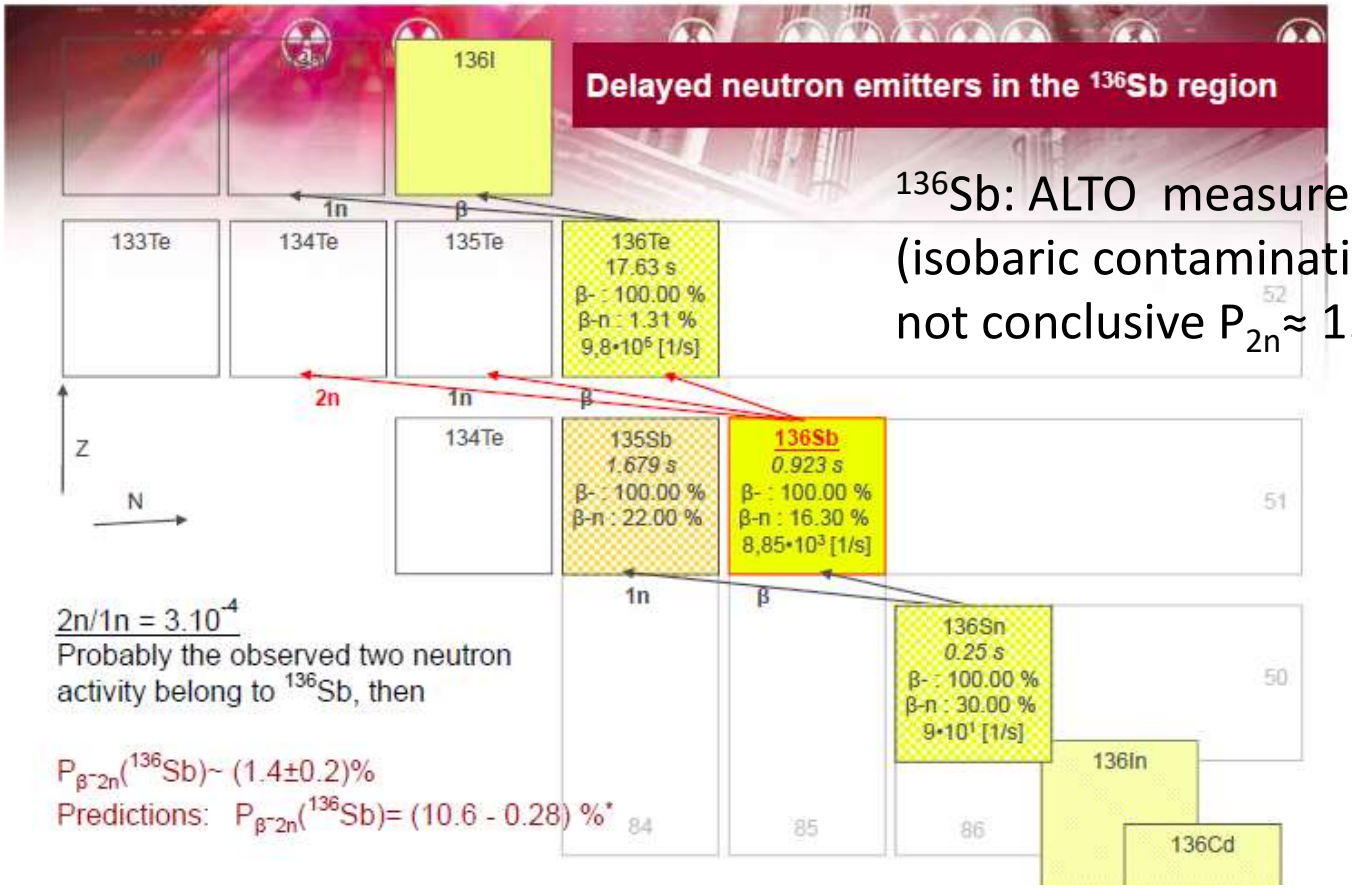




IGISOL facility, Jyväskylä – Finland (Nov. 2014)
Isotope production using a penning trap

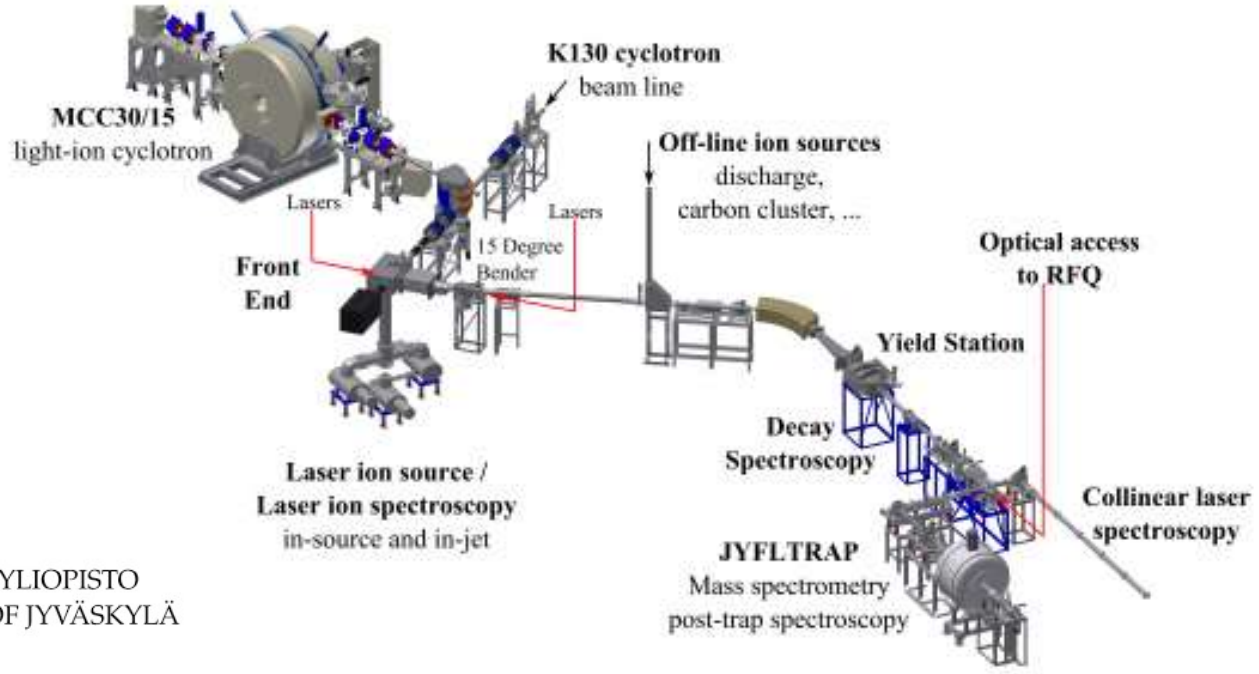
Why ^{136}Sb?

D.Testov at ESP-RUS conference (2011)



^{136}Sb: ALTO measurement (isobaric contaminations) not conclusive $P_{2n} \approx 1.4\%$?

Isotope production at JYFL with IGISOL - Layout



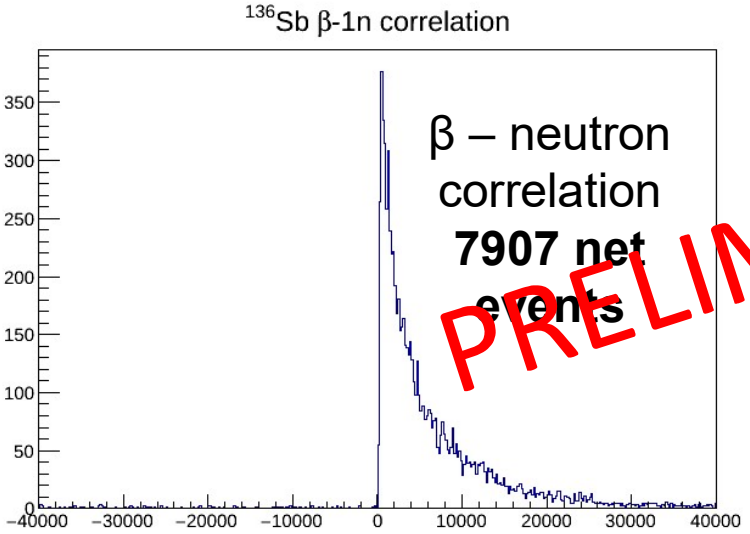
JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

Figure 1: Schematic layout of the new IGISOL-4 facility at JYFL.

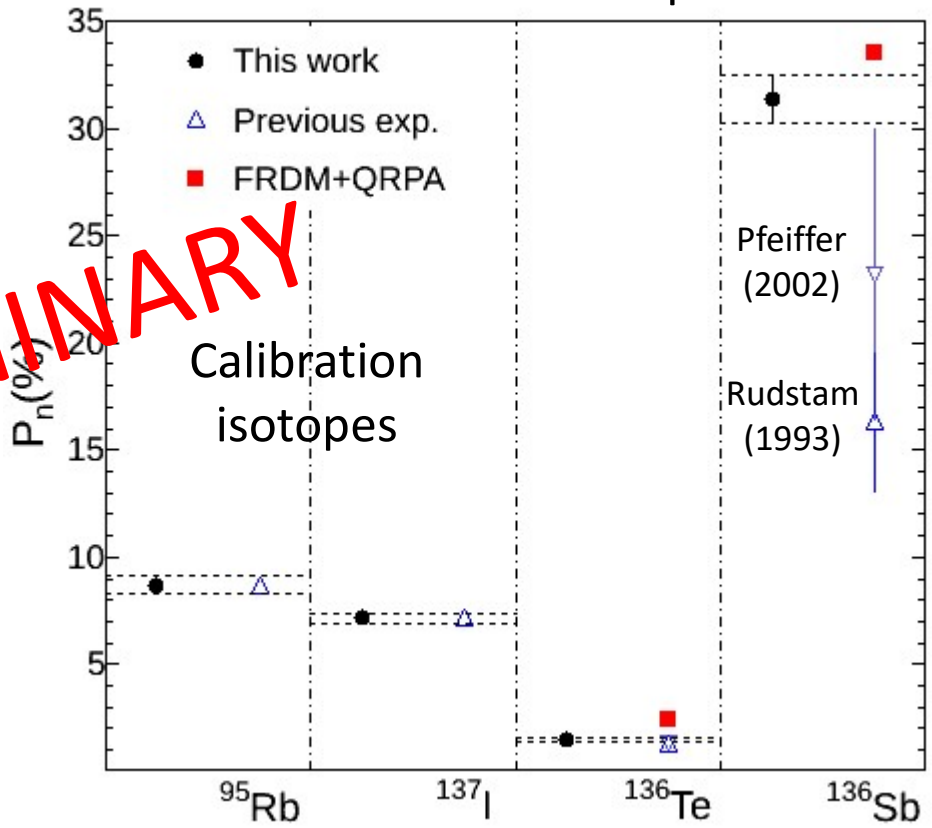
[1] J. Äystö, T. Eronen, A. Jokinen, A. Kankainen, I.D. Moore and H. Penttilä. Hyperfine interactions **223**, 1 (2014).

IGISOL: no isobars!

^{136}Sb β1n correlation
(~6 days of beamtime)



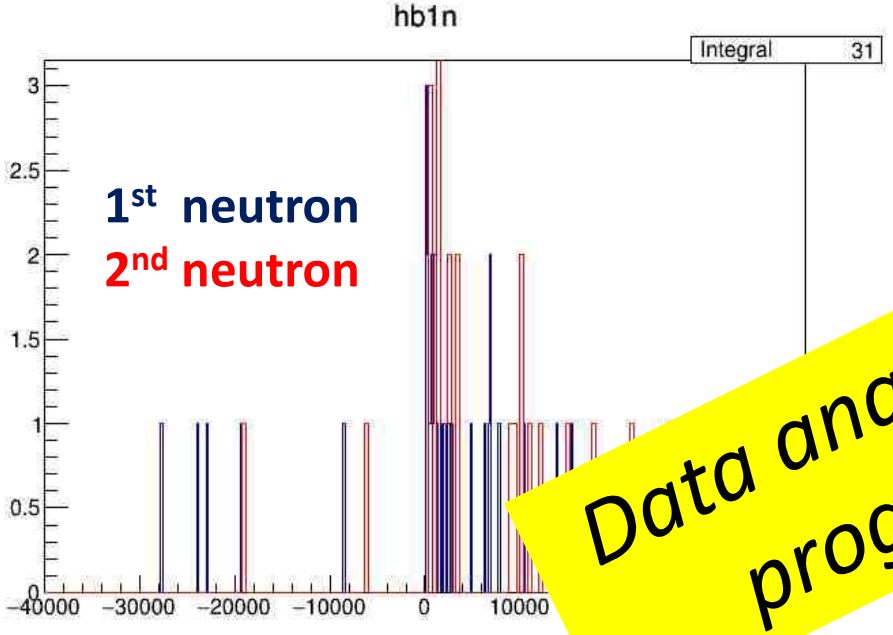
P1n results for β1n correlation of measured isotopes



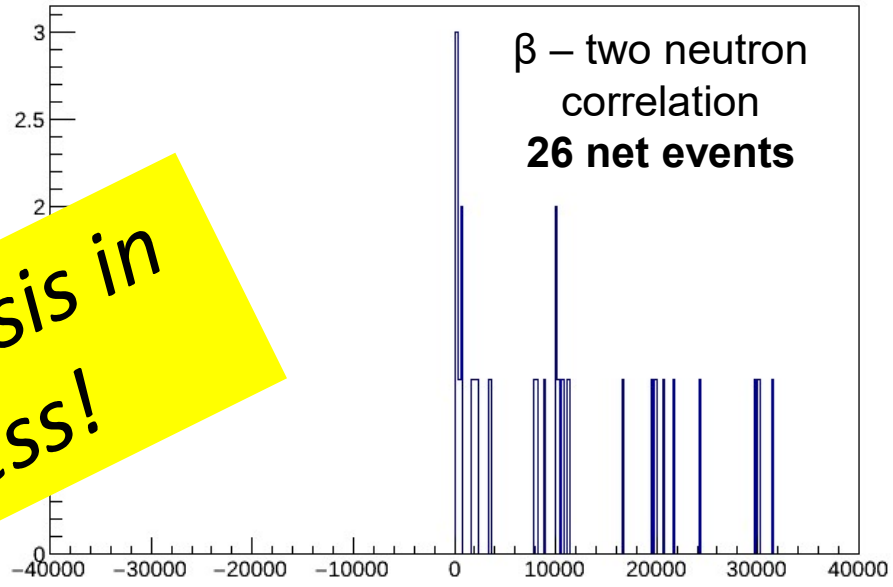
^{136}Sb measurement (β2n emitter)

After 6 days of beamtime, βnn-events confirmed!

β-1st n & β-2nd n correlated events



nn correlation (β conditioned)



Data analysis in progress!

Heaviest β2n-emitter so far!

The preliminary analysis yield a P_{2n} < 1%

I138 – JYFL experiment collaboration

R. Caballero-Folch, I. Dillmann, J. Agramunt, J.L. Taín, A. Algora, J. Aystö, F. Calviño, G. Cortes, T. Eronen, W. Gelletly, V. Guadilla, D. Gorelov, A. Jokinen, M. Marta, E. Mendoza, A. Montaner-Pizá, I. Moore, S. Orrigo, H. Pentillä, A. Riego, S. Rinta Antila, B. Rubio, P. Salvador, et al.

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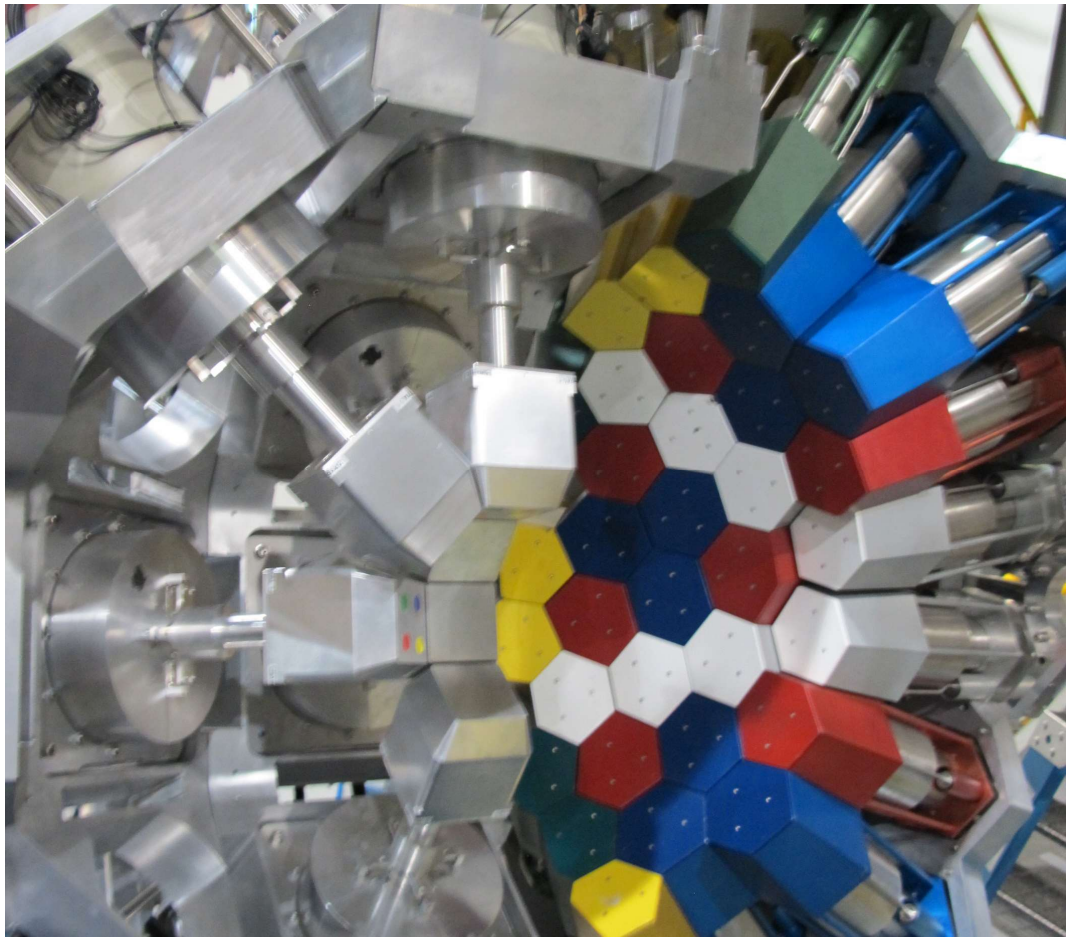
Universitat Politècnica de Catalunya (UPC)
Institut de Física Corpuscular de València (IFIC)
Helmholtzzentrum für Schwerionenforschung GmbH (GSI)
CIEMAT (Madrid)
Department of Physics, University of Surrey (UK)
Department of Physics, University of Jyväskylä (JYFL)

Partially supported by:

CHANDA SOLVING CHALLENGES IN NUCLEAR DATA FOR THE SAFETY OF EUROPEAN NUCLEAR FACILITIES

DESCANT detector at TRIUMF



DESCANT is coupled with GRIFFIN HPGe array

J. Turko talk Feb 17 mentioned details of this system and compared simulations MC / Geant 4 and experiments

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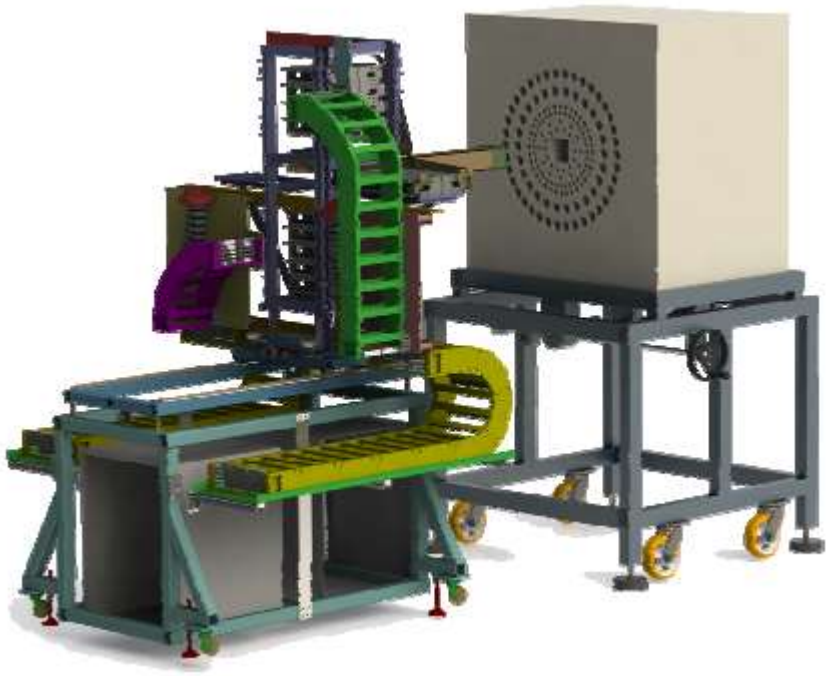
BRIKEN collaboration project

140 ^{3}He counters

Courtesy of
Jorge Agramunt

BRIKEN collaboration project



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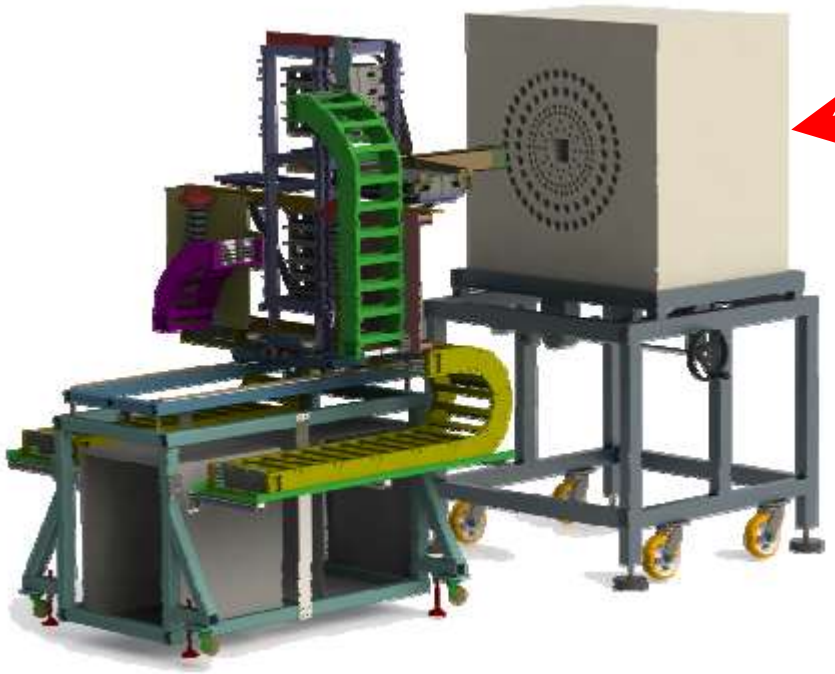
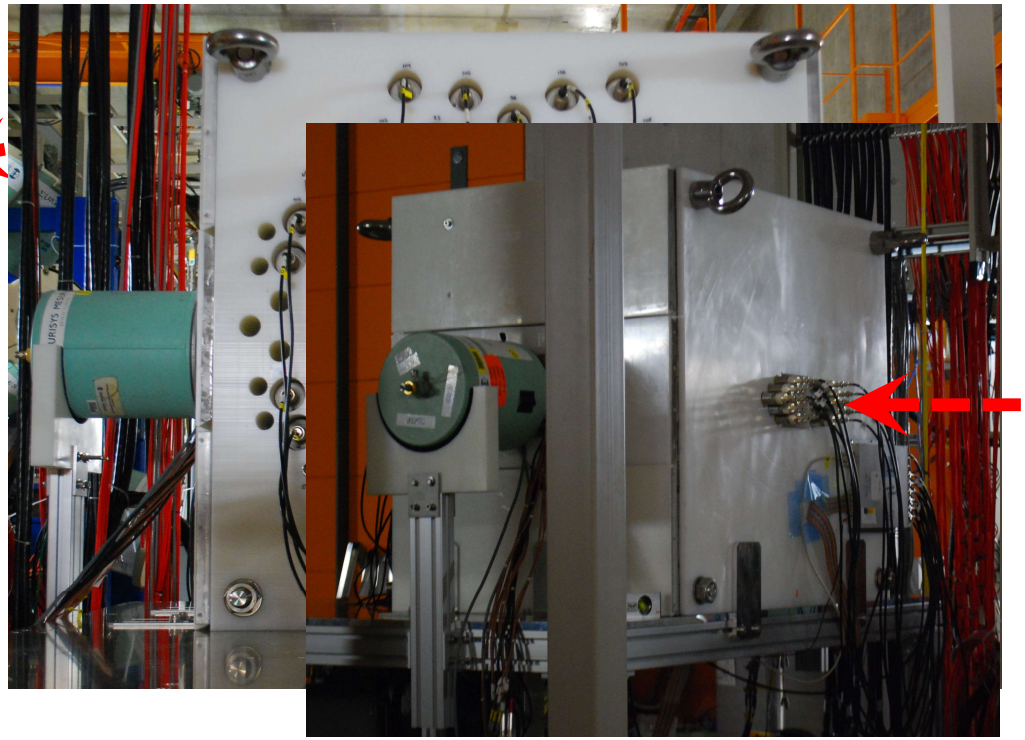
BRIKEN collaboration project

Courtesy of
Jorge Agramunt

BRIKEN collaboration project





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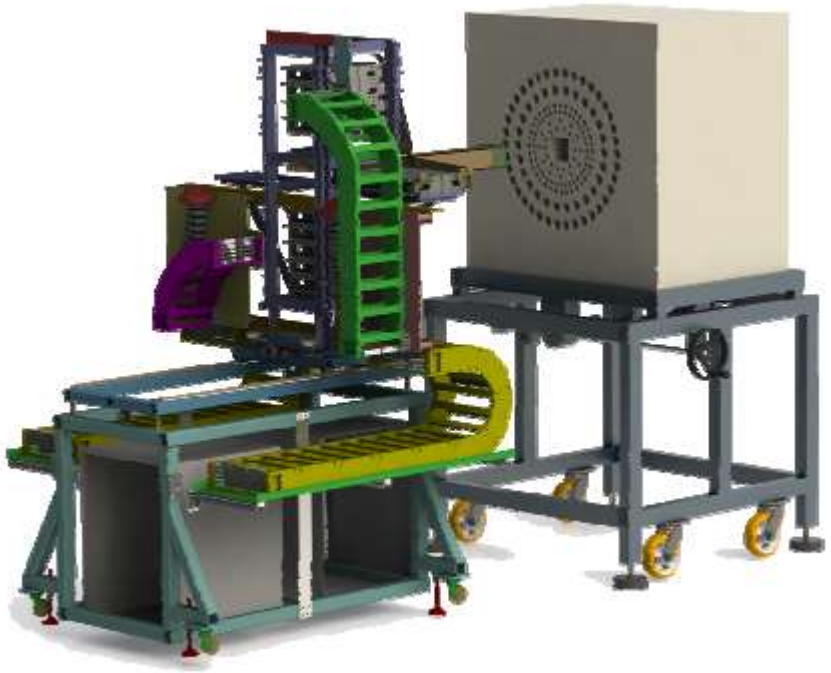
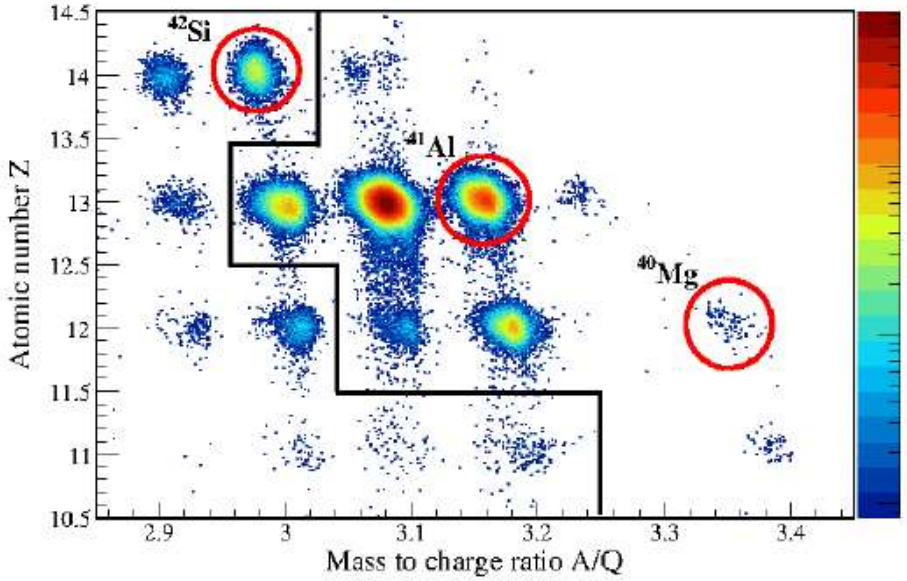
BRIKEN collaboration project

DACQ is tested and ready to operate





V.H. Phong, RIKEN annual report

PID of implanted ions on AIDA during Nov. parasitic beam

BRIKEN collaboration project

Exp. number	Title	Spokepersons	Date approved
NP1406-RIBF128	Measurement of β-delayed neutron emission probabilities relevant to the A = 130 r-process abundance peak	A.V. Estradé, G.Lorusso, F.Montes	14th Program Advisory Committee
NP1412-RIBF127R1	Measurements of new beta-delayed neutron emission properties around doubly-magic ^{78}Ni	K.P.Rykaczewski, J.L.Tain, R.K.Grzywacz, I.Dillmann	15th Program Advisory Committee
NP1512-RIBF139	Decay properties of r-process nuclei in deformed region around A = 100 ~ 125	S. Nishimura, A. Algora	16th Program Advisory Committee
NP1612-RIBF148	Masses, half-lives and beta delayed neutron emission probabilities relevant to understand the formation of the rare earth r process peak	G. Kiss, A.I. Morales, A. Tarifeño-Saldiva	The 17th Program Advisory Committee

More info at https://www.wiki.ed.ac.uk/display/BRIKEN/

Outlook

- Heaviest β1n and β2n –emitters measured
- First neutron branching ratios measured for several nuclei beyond the neutron shell closure N=126.

- β-decay half-lives have been determined for 18 isotopes, 9 of them for the first time, together with the P_{1n} of 5 isotopes.
- ^{136}Sb has been confirmed as a double neutron emitter. Analysis is ongoing.

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Moltes gràcies!
Thank you!
Merci!

NSERC CRSNG IsoSiM

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