Measurements of β-delayed neutron emission around the third r-process peak

ROGER CABALLERO-FOLCH (DFEN –UPC)
& S410 experiment collaboration
Barcelona, 14 de juny de 2013

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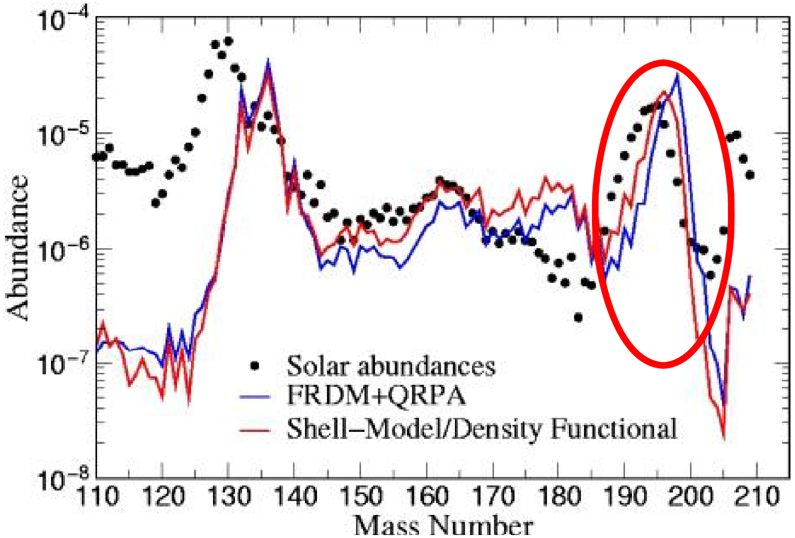
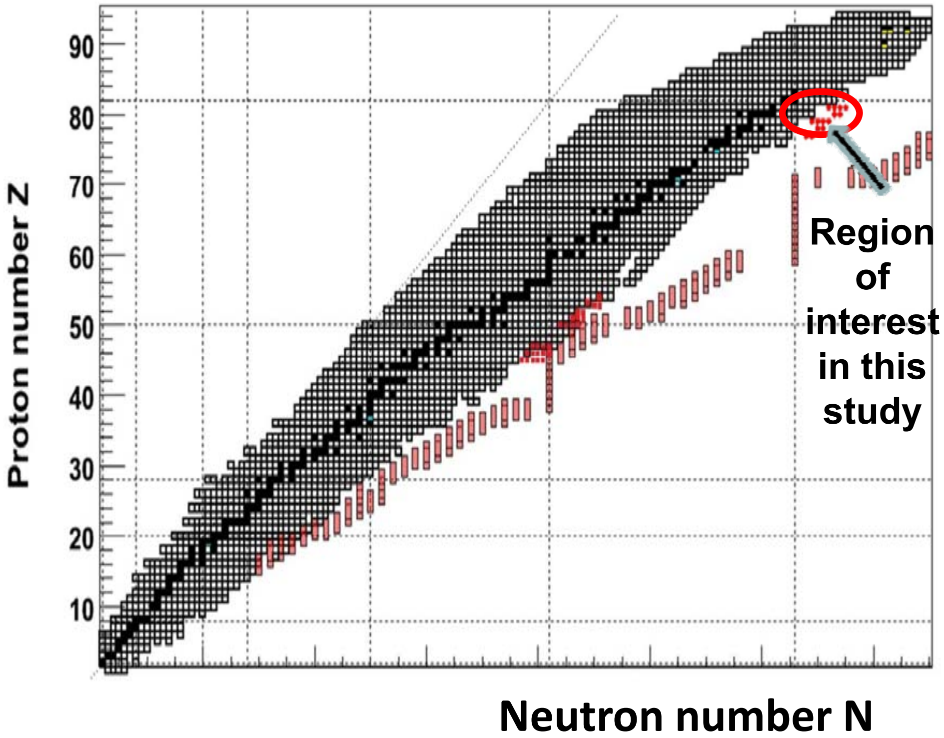
- Astrophysics motivation
- Experimental setup at GSI-FRS facility
- Detection System: SIMBA & BELEN detector
- Ongoing analysis and preliminary results
- Future measurements: BRIKEN
- Summary and outlook

Goal: Experimental determination of half lives and neutron branchings of several exotic nuclei in the neutron rich region beyond N=126

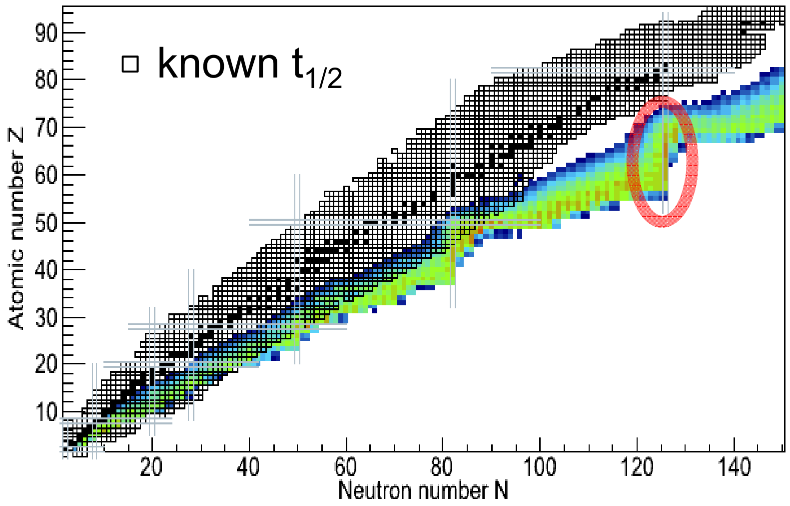


The Astr. Jour., 579 (2002), H. Schatz et al.
Proc. CGS-13 (2009), G. Martinez-Pinedo

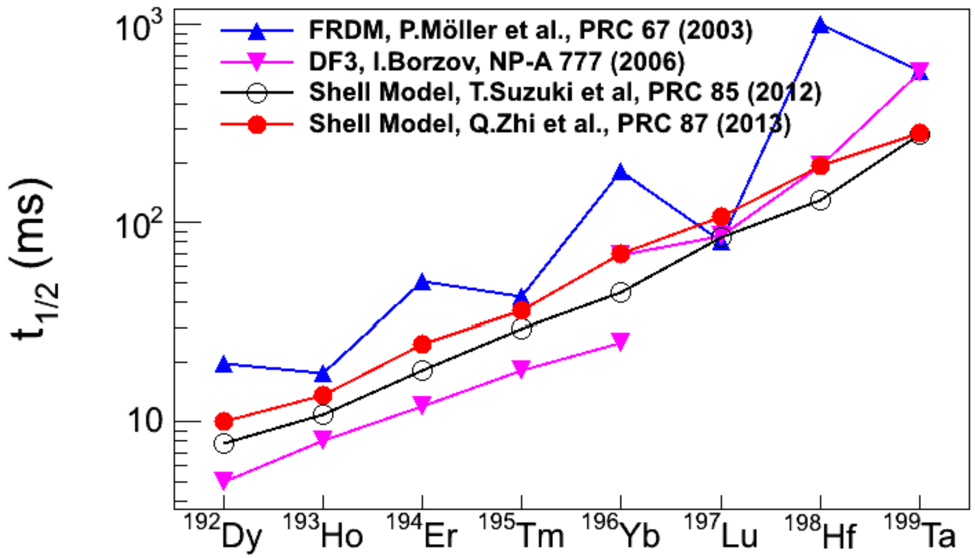


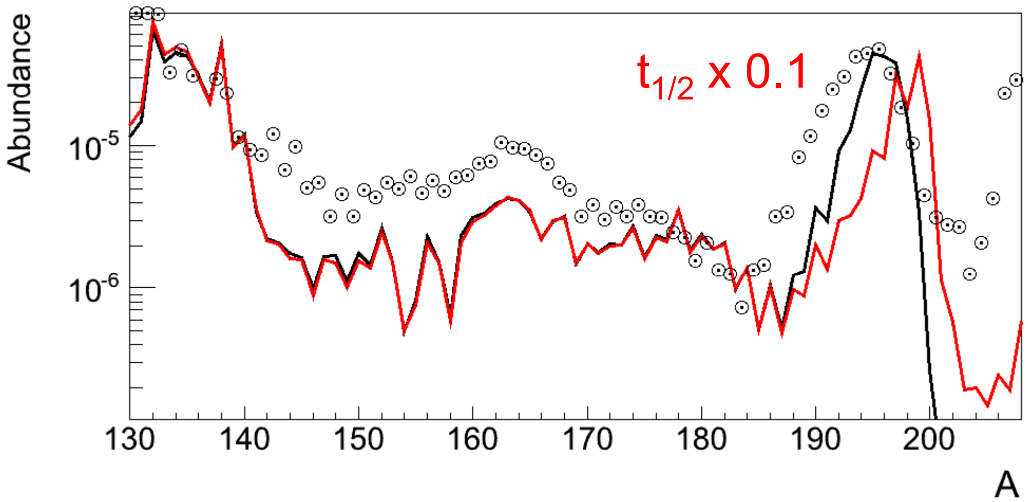
Understanding of A=195 peak in the r-process abundance pattern.

R-process calculations rely on theoretical predictions (QRPA & FRDM), with remarkable discrepancies and large uncertainties.



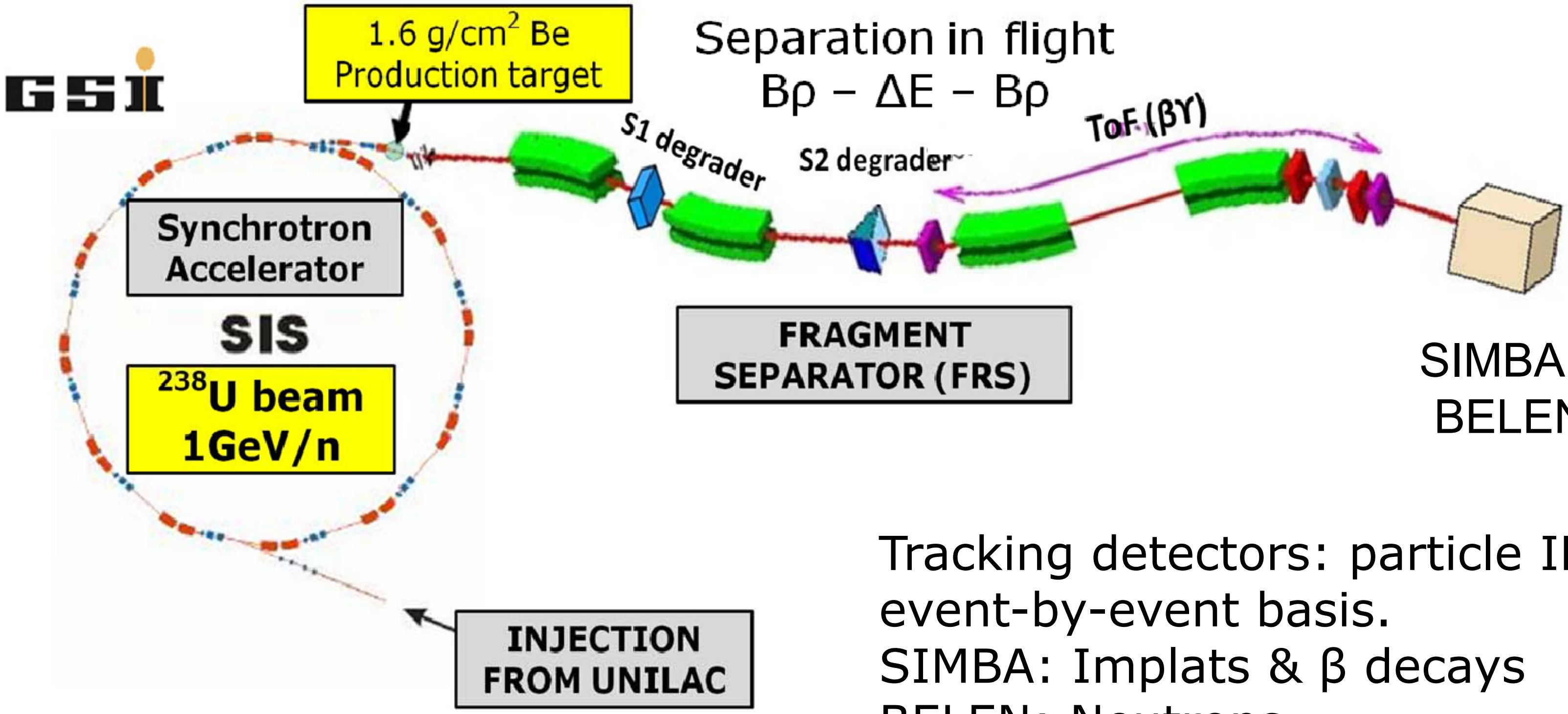
N=126





C.Domingo-Pardo Priv. Com.

Large intensity ($2x10^9$ ions/pulse) & high-energy (1 GeV/u) for ^{238}U beams



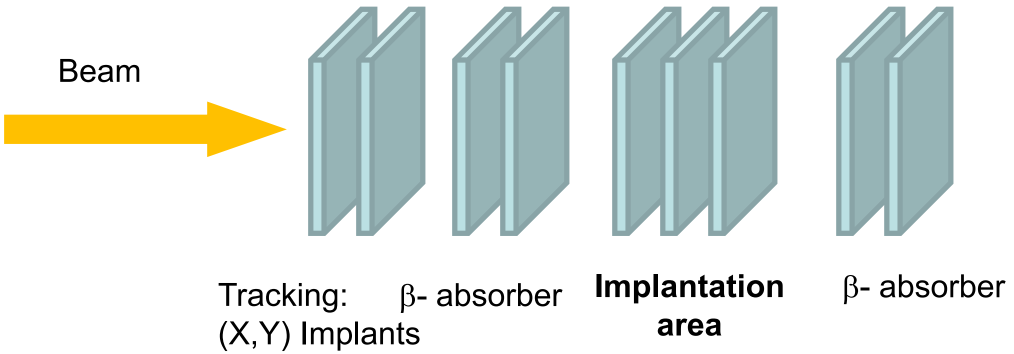
SIMBA +
BELEN

Tracking detectors: particle ID on an event-by-event basis.
SIMBA: Implats & β decays
BELEN: Neutrons

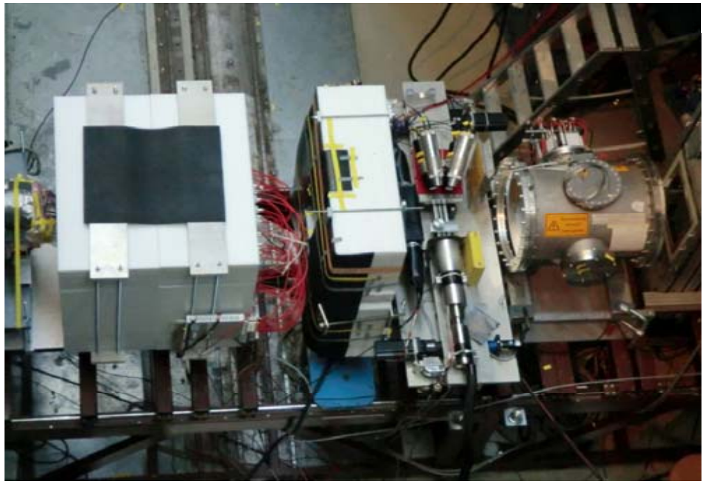
The detection system is based on a stack of SSSD- and DSSD-detectors for measuring ion-implants and beta-decays (SIMBA). Implants-region was surrounded by the 4π neutron detector BELEN.

Implantation, β decay & neutron detection: SIMBA + BELEN

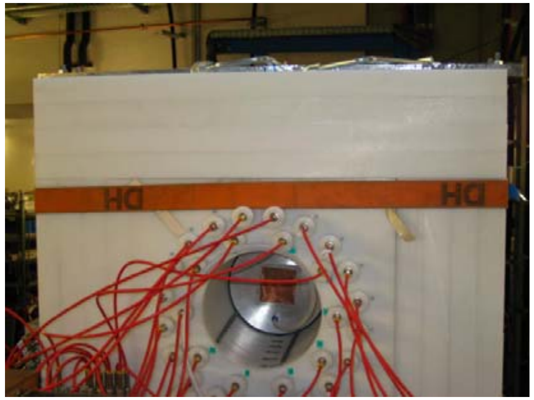
Silicon striped detectors (SSSD's and DSSD's)



PhD thesis C. Hinke, TUM (2010)
Diploma thesis K. Steiger, TUM (2009)



BELEN efficiency was about 40% (checked experimentally)



The Beta dELayEd Neutron (BELEN) detector, based in ^{3}He counters embedded in a polyethylene matrix, located around Silicon IMplantation Beta Absorber (SIMBA).

Neutron detection 3He counters as detector

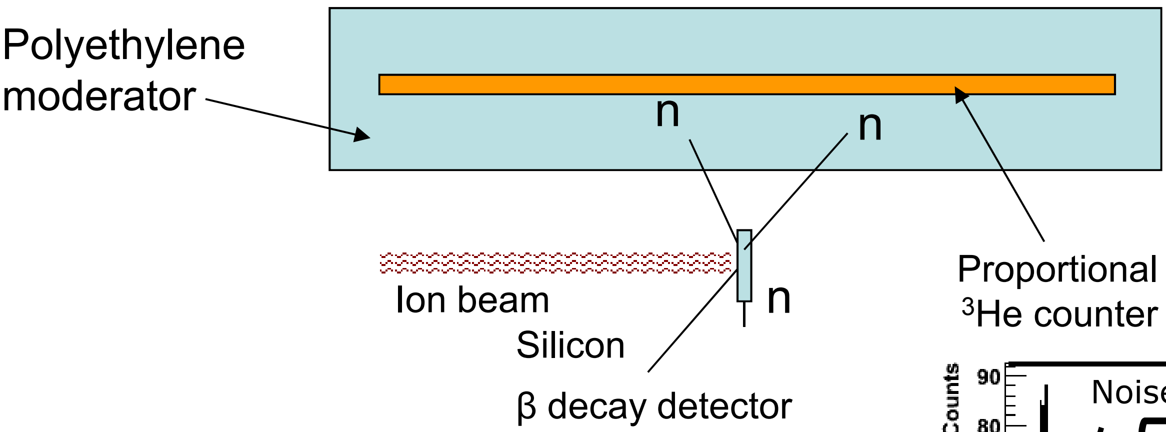
- ✓ The detection of the neutron is based on an indirect method: the detection of the products of the reaction of the neutron with ^{3}He counters:

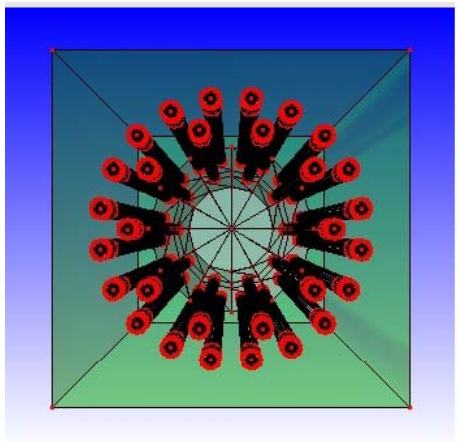
$$^{3}He + n \rightarrow {}^{3}H + {}^{1}H + 765\ keV$$

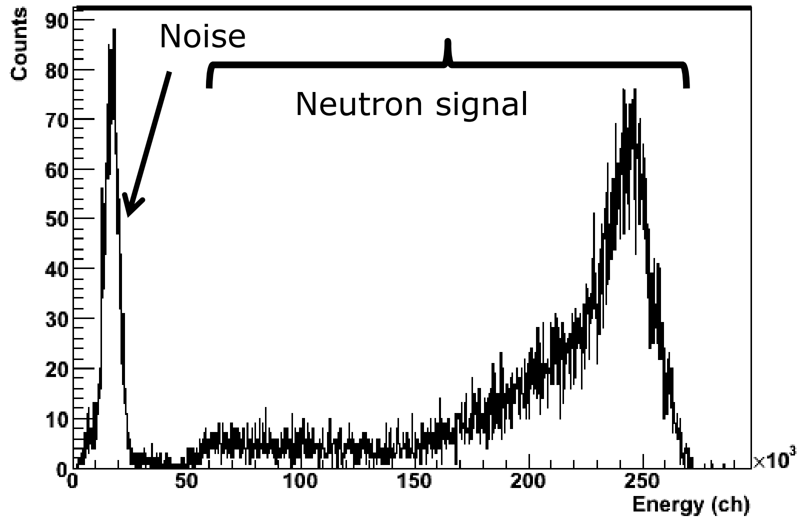
Other reactions:

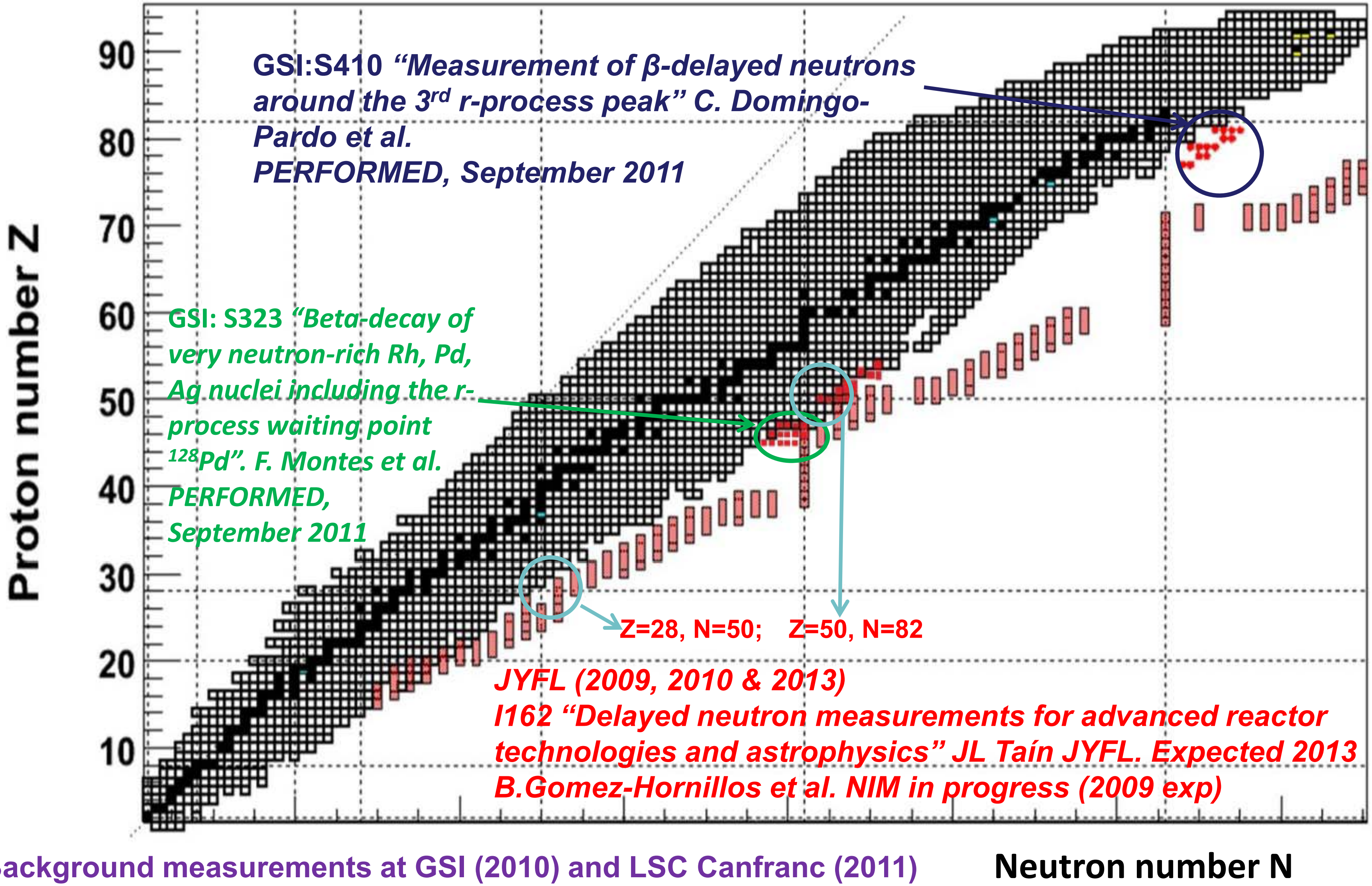
$^{10}B + n \rightarrow {}^{7}Li^{*} + {}^{4}He + 2310\ keV$

$^{7}Li^{*} \rightarrow {}^{7}Li + 480\ keV$



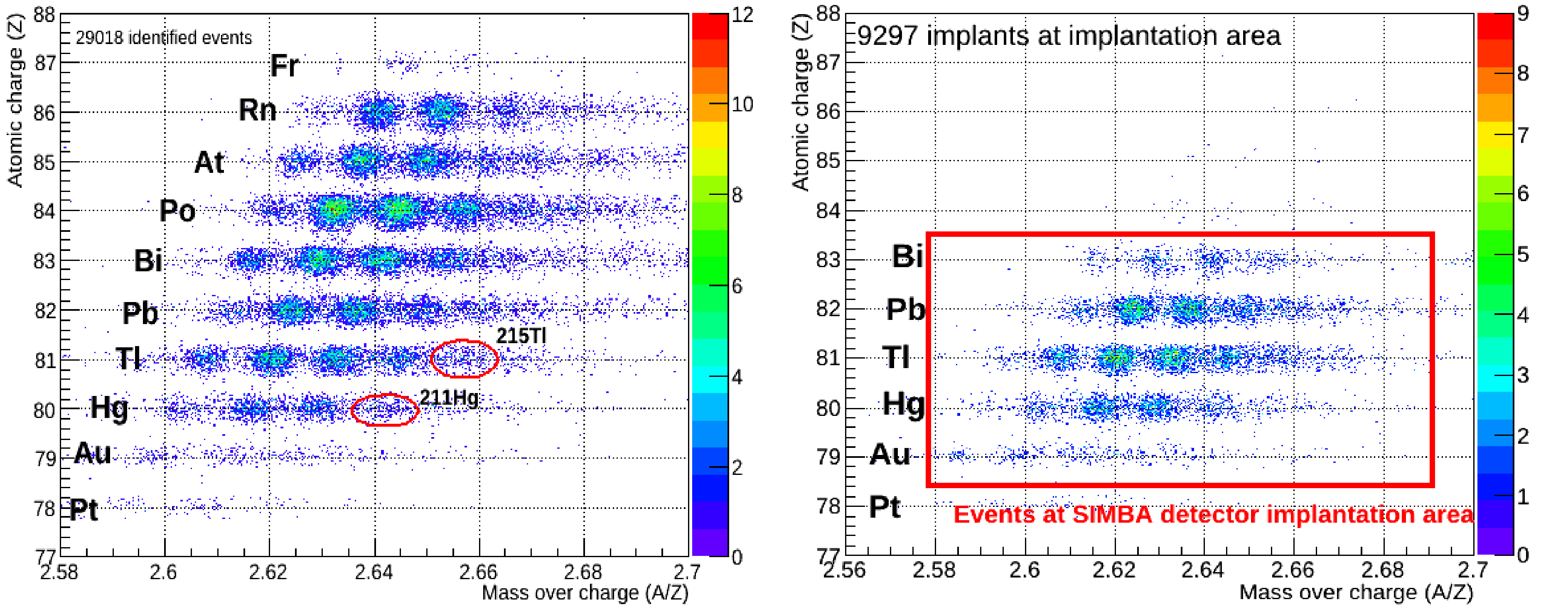






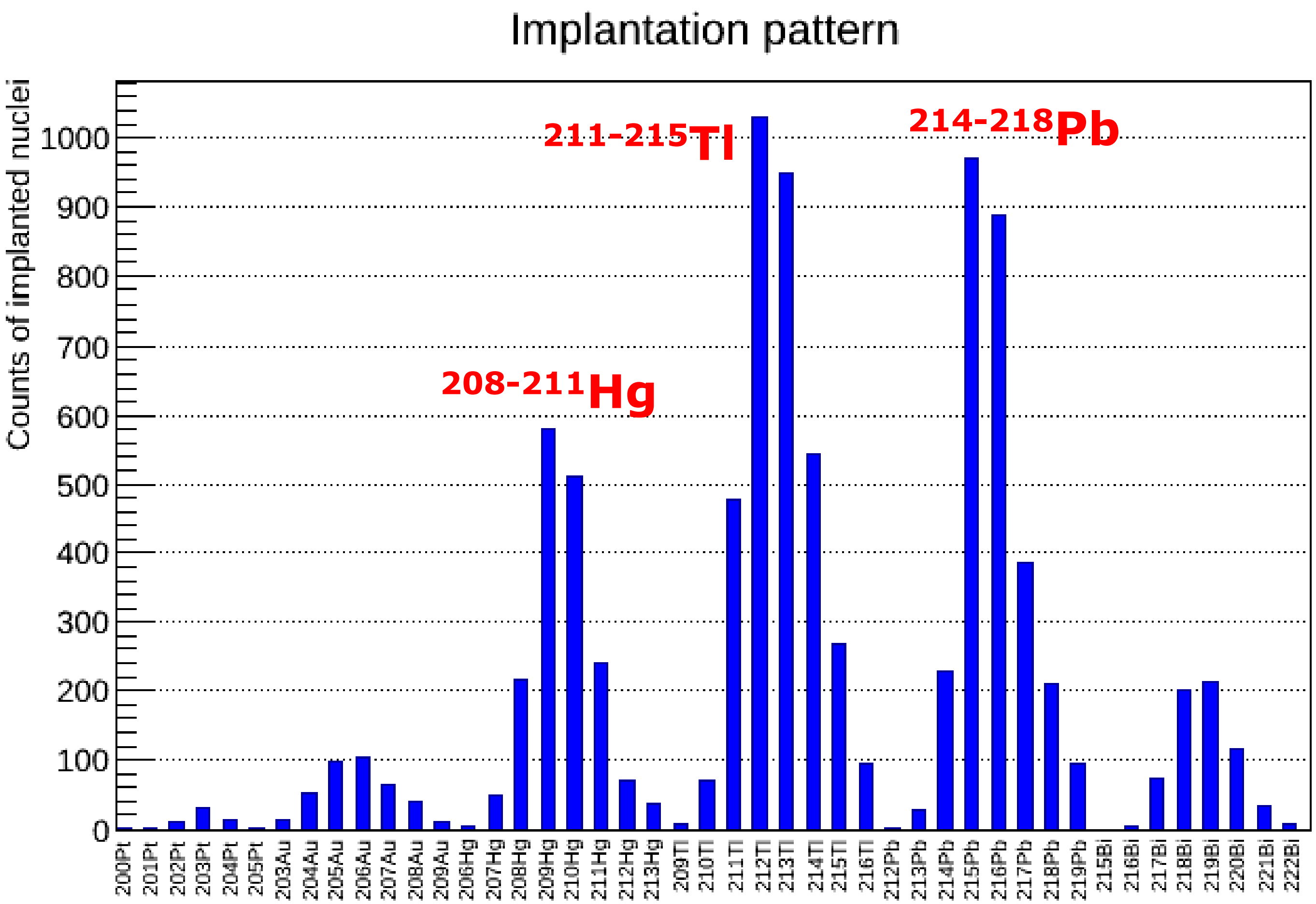
Background measurements at GSI (2010) and LSC Canfranc (2011)
D.Jordan et al. Astr.Phys Vol.42, Feb 2013, p.1–6

Isotopes of Pt, Au, Hg, Tl, Pb, Bi, Po, At, Rn and Fr identified

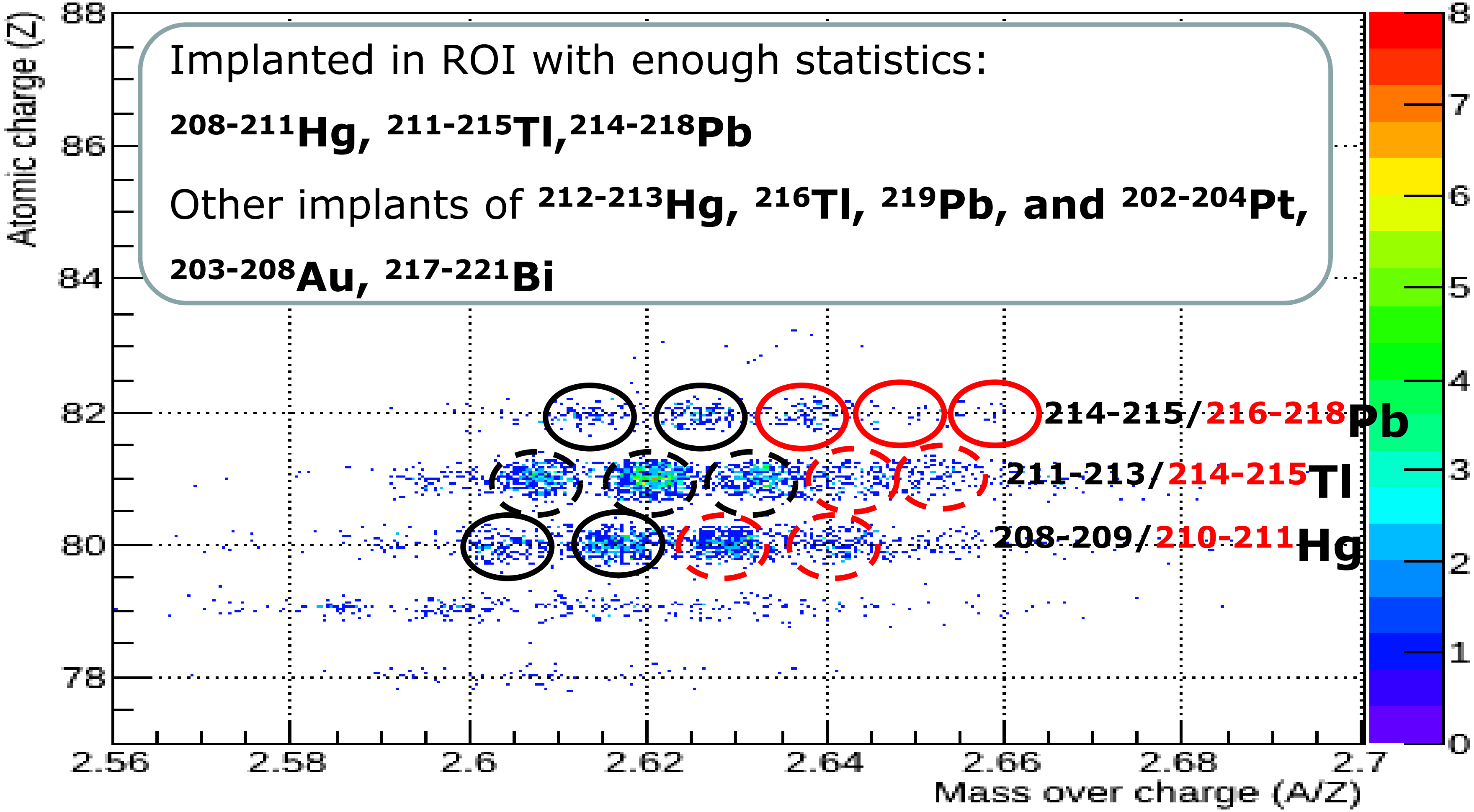


Isomer tagging was used for Z identification and two centred settings on ^{211}Hg and ^{215}Tl were measured during 4.5 days. The implantation area was optimized for Hg and Tl region where good resolution has been obtained.

Good statistics implantation for $^{208-211}$Hg, $^{211-215}$Tl and $^{214-218}$Pb



Implants on the high segmented layers of SIMBA detector

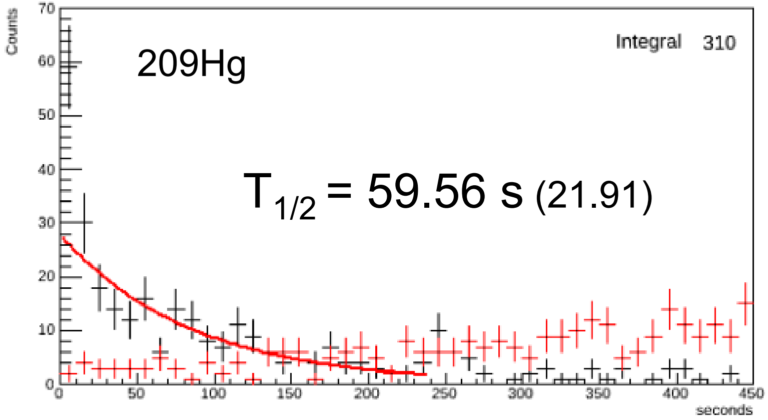


Possible evaluation of more nuclei implanted implanted in other layers.

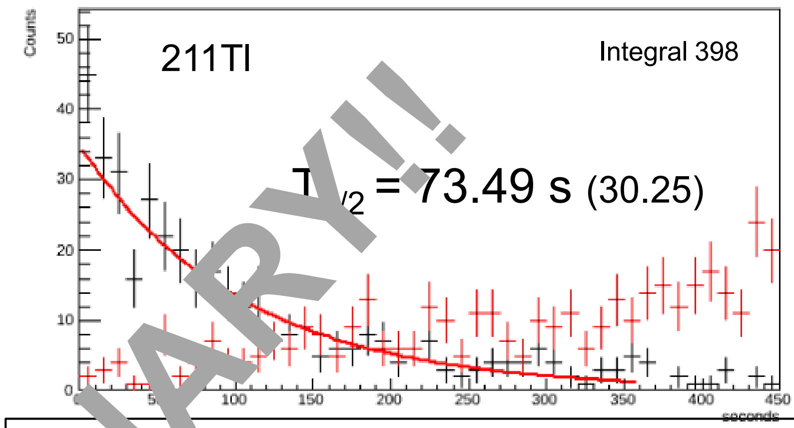
http://www.nndc.bnl.gov

- - - **G.Benzoni-A.I.Morales et al, Ph.Lett.B 715 (2012)**

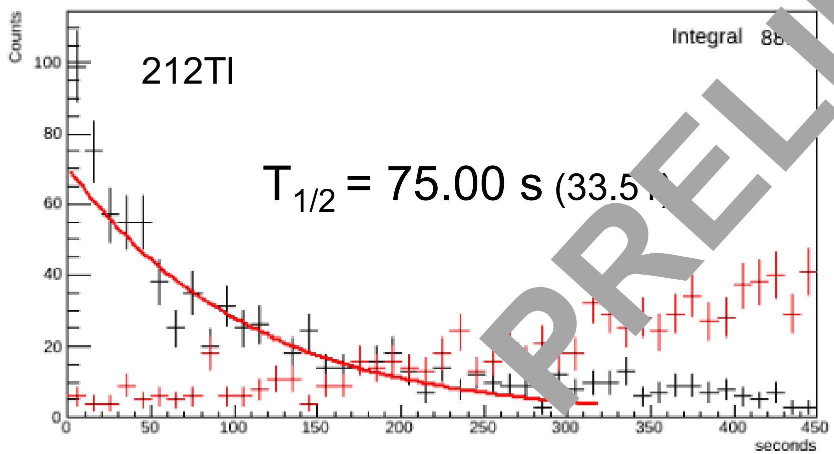
PRELIMINARY results for half lives



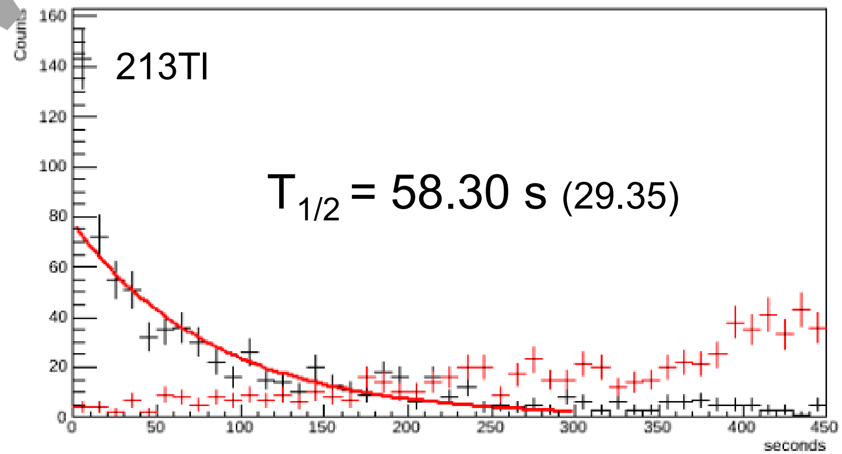
$t_{1/2}$ = 36.5(+/-7.5) s



G.Benzoni et al. PLB 715 (2012)
$t_{1/2} = 88\ (^{+46}_{-29})$ s

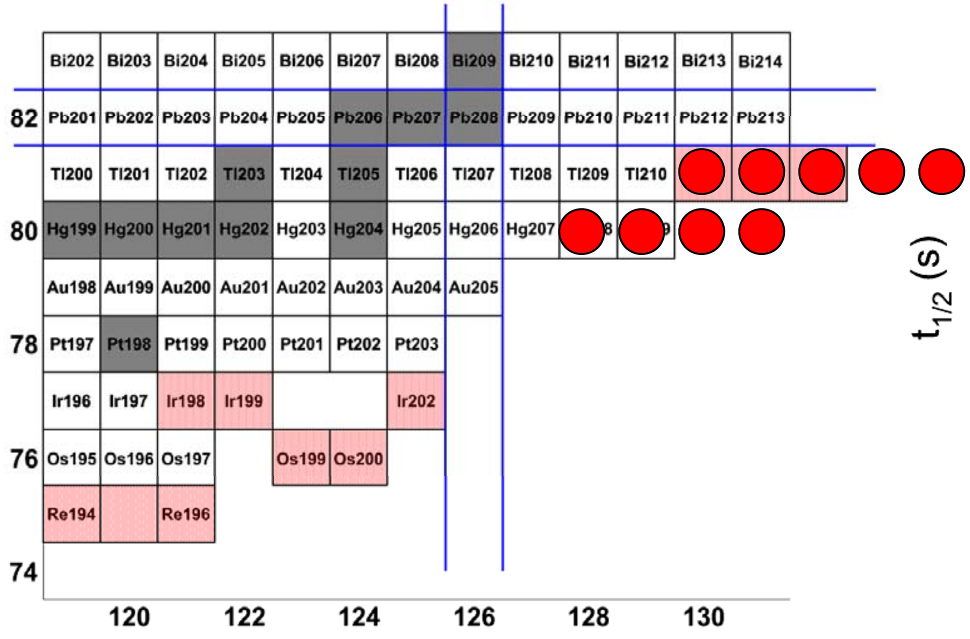


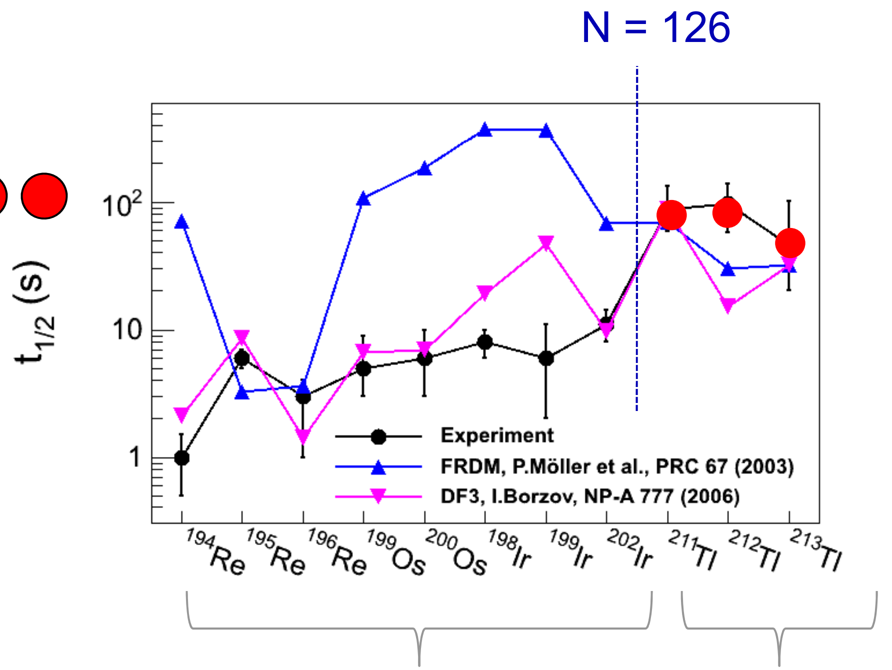
G.Benzoni et al. PLB 715 (2012)
$t_{1/2} = 96\ (^{+42}_{-38})$ s



How theoretical models compare with experiment?

- No experimental information along N=126 region nuclei
- Only possibility is to benchmark the performance of models in the neighbourhood



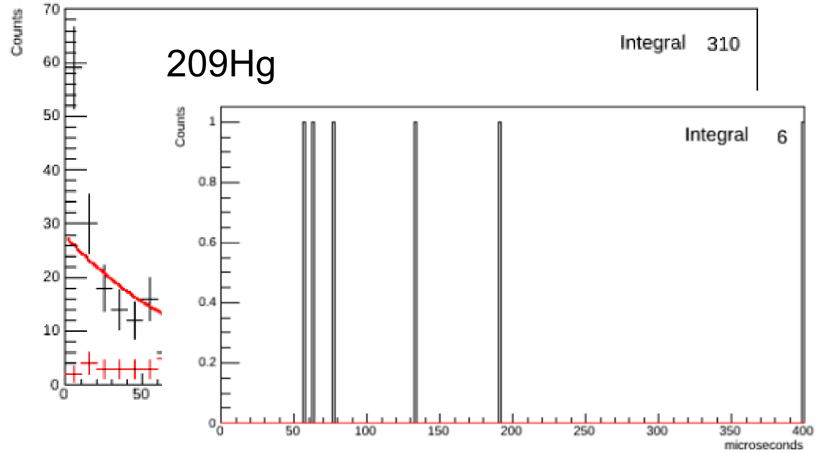


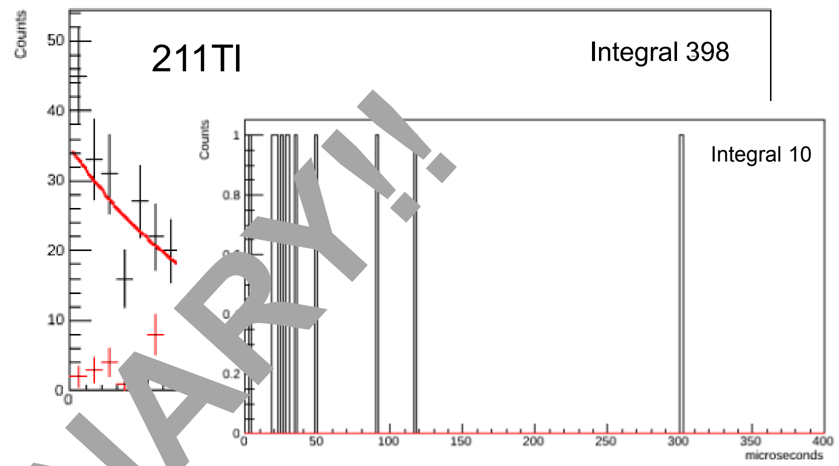
T. Kurtukian-Nieto et al., arXiv:0711.0101v1
J.Benlliure et al. NPA-V, 2012

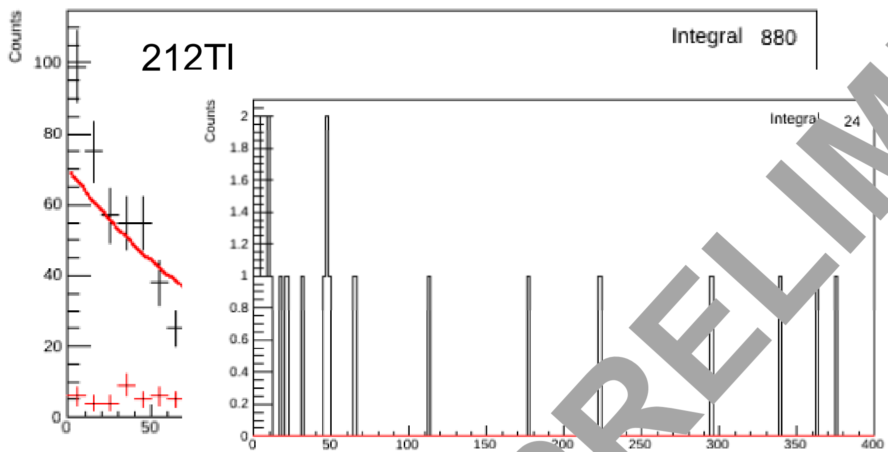
G.Benzoni et al., Phys.Lett. B 715 (2012)

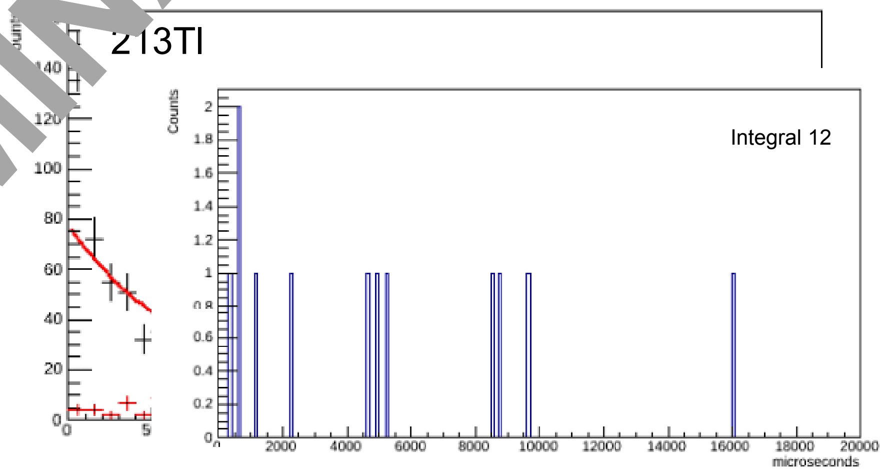
→ It seems that nuclear models tend to overestimate the b-decay half-live at N<126 and to underestimate it for N>126…

PRELIMINARY neutron correlations

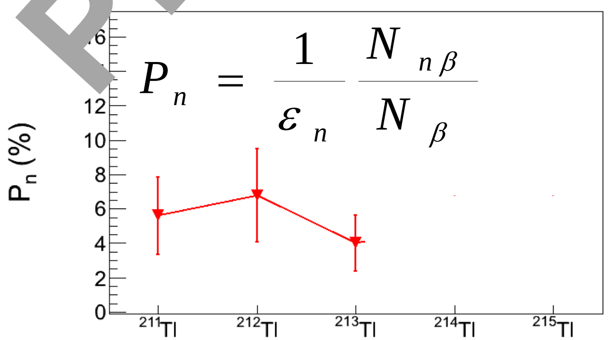








PRELIMINARY!!



$$P_n = \frac{1}{\varepsilon_n} \frac{N_{n\beta}}{N_\beta}$$

(Efficiency ~40%)

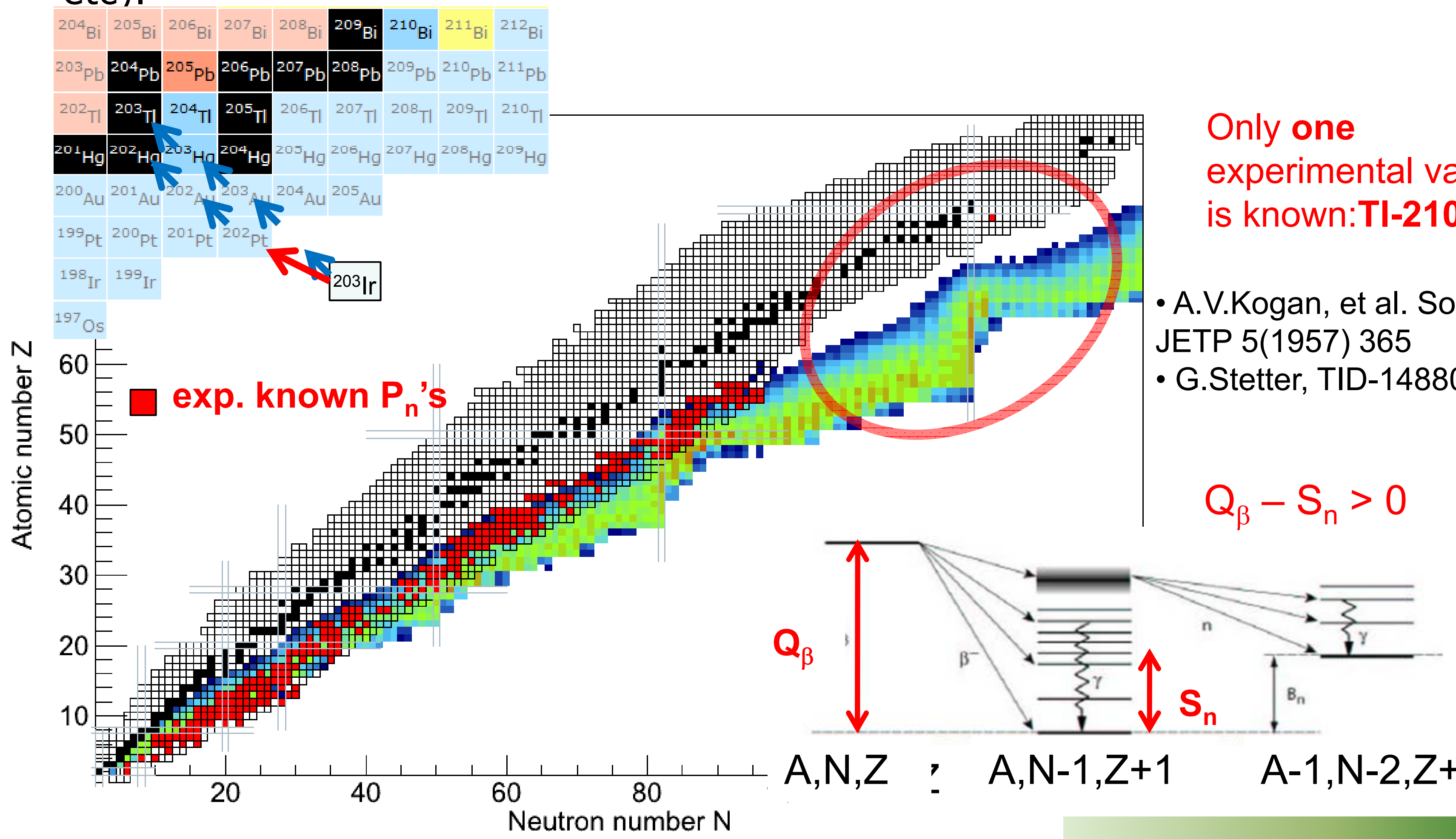
Beta-delayed neutron emission has a twofold impact in the nucleosynthesis:

- It enhances the neutron density of the environment after freeze-out (re-activation).
- It shifts the abundances towards lower masses (Pn: A → A-1, P2n: A → A-2, etc).

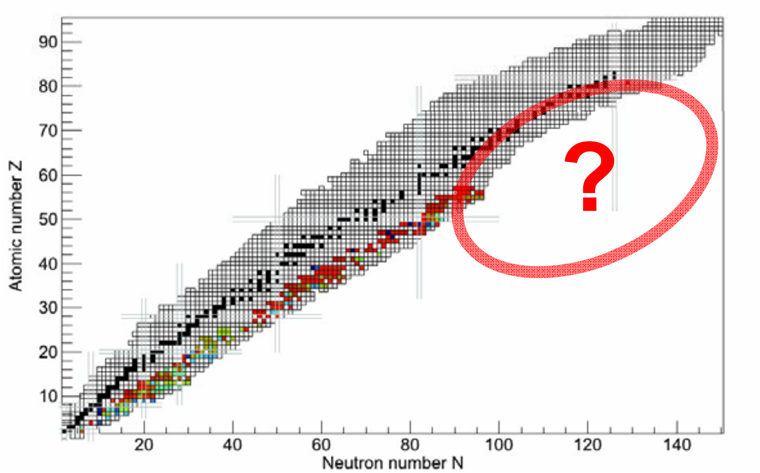
Only **one** experimental value is known:**Tl-210** ! !

- A.V.Kogan, et al. Sov. Phys. JETP 5(1957) 365
- G.Stetter, TID-14880(1961)

$Q_\beta - S_n > 0$

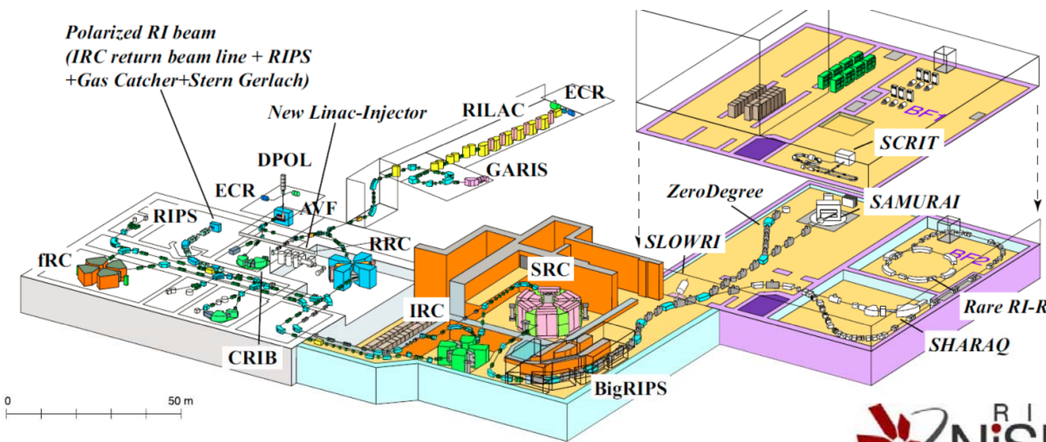


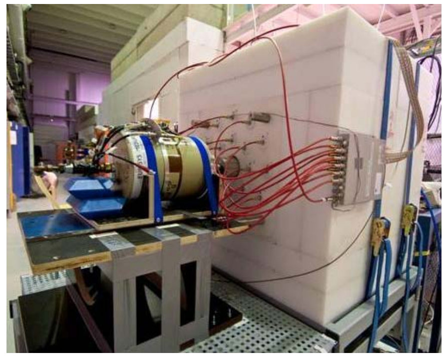
New campaign for the measurement of β-delayed neutrons at RIKEN:



Large need of b-delayed neutron emission measurements!!!

BRIKEN Campaign:
Opportunities with the **BELEN** neutron detector at **RIKEN**





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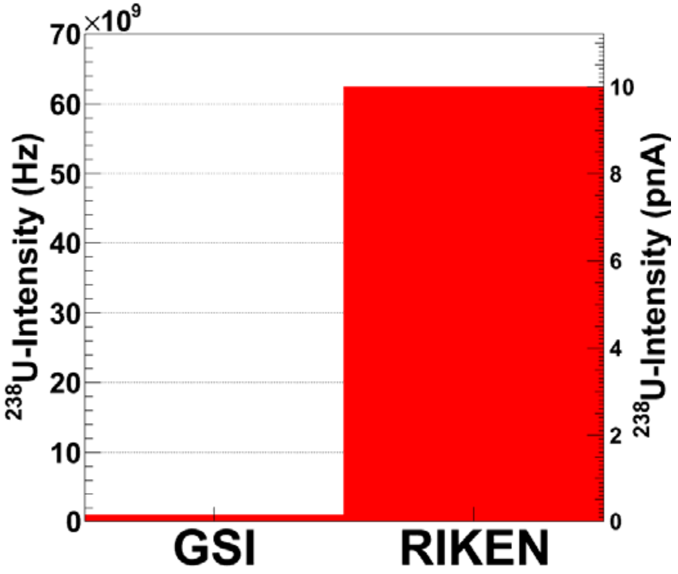
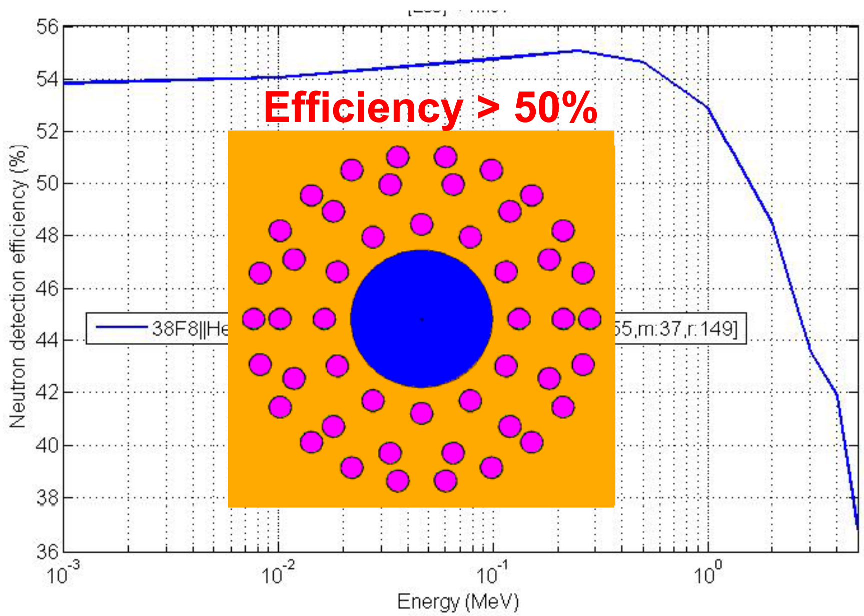
TRIUMF

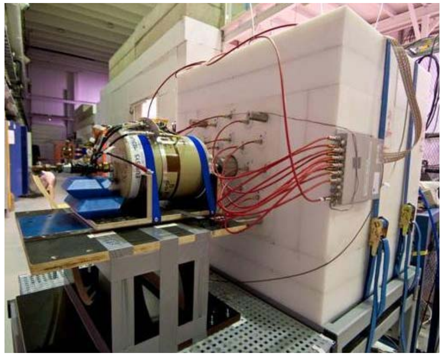
Future plans: improved detectors + larger RIB intensities





2nd **BRIKEN WORKSHOP**: 30-31 July at **RIKEN**

Collaborators are welcome to join!!!



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Summary and outlook

- Several species of neutron rich heavy nuclei have been produced and identified in the Hg/Tl/Pb region, beyond the shell closure N=126.

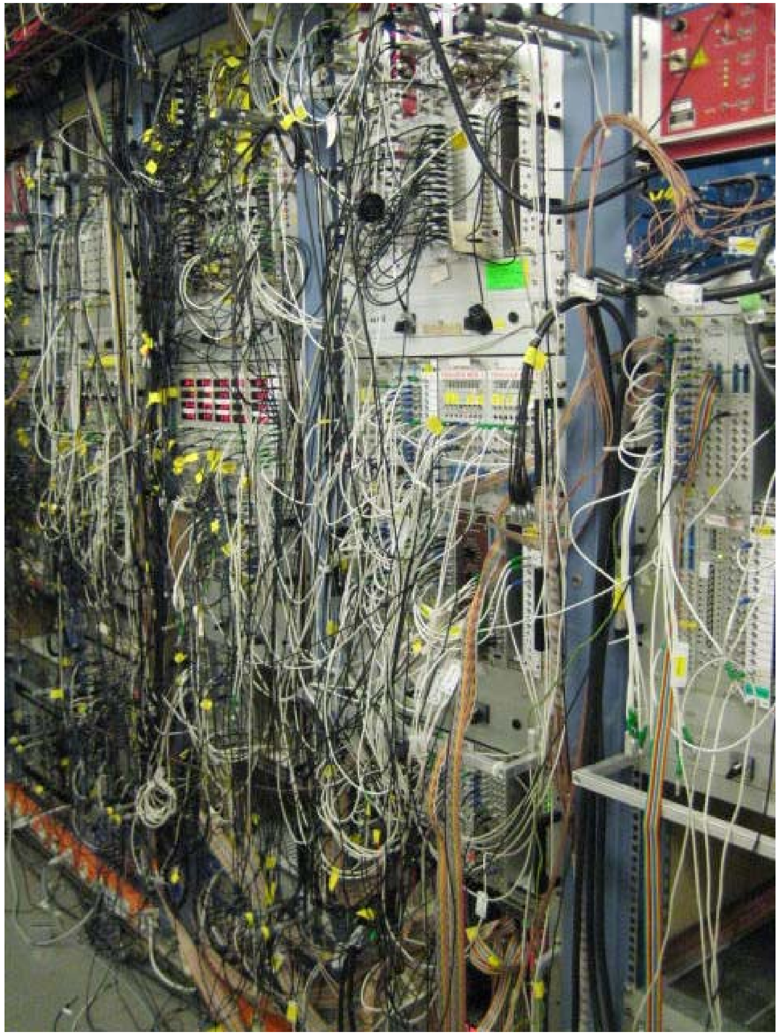
-Preliminary **half-lives** have been obtained by implant-beta correlation method with DSSD detectors. They must be rechecked with other numerical methods.

- In order to obtain final results, we need to improve several aspects in our data-analysis (simulation, statistical comparator, spatial correlations, time-correlations, etc).

- The analysis of **β-delayed neutron emission** probabilities is ongoing.

-We plan to measure a large amount of neutron-rich nuclei in a campaign at the RIB facility of RIKEN (Japan).

S410 experiment collaboration



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CIEMAT (Madrid)

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Department of Physics, University of Liverpool (UK)

STFC, Daresbury Laboratory (UK)

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CENBG, Université Bordeaux (France)

et al.

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