NIC XII - Satellite workshop on r-process nucleosynthesis

β delayed neutron emission measurements around the third r-process peak

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Cairns QLD (Australia)

Contents

- Astrophysics and Nuclear Physics motivation
- Experiment: Setup and detectors
- Beta delayed neutron detector (BELEN)
- Analysis - Ongoing work

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- **Astrophysics and Nuclear Physics motivation**
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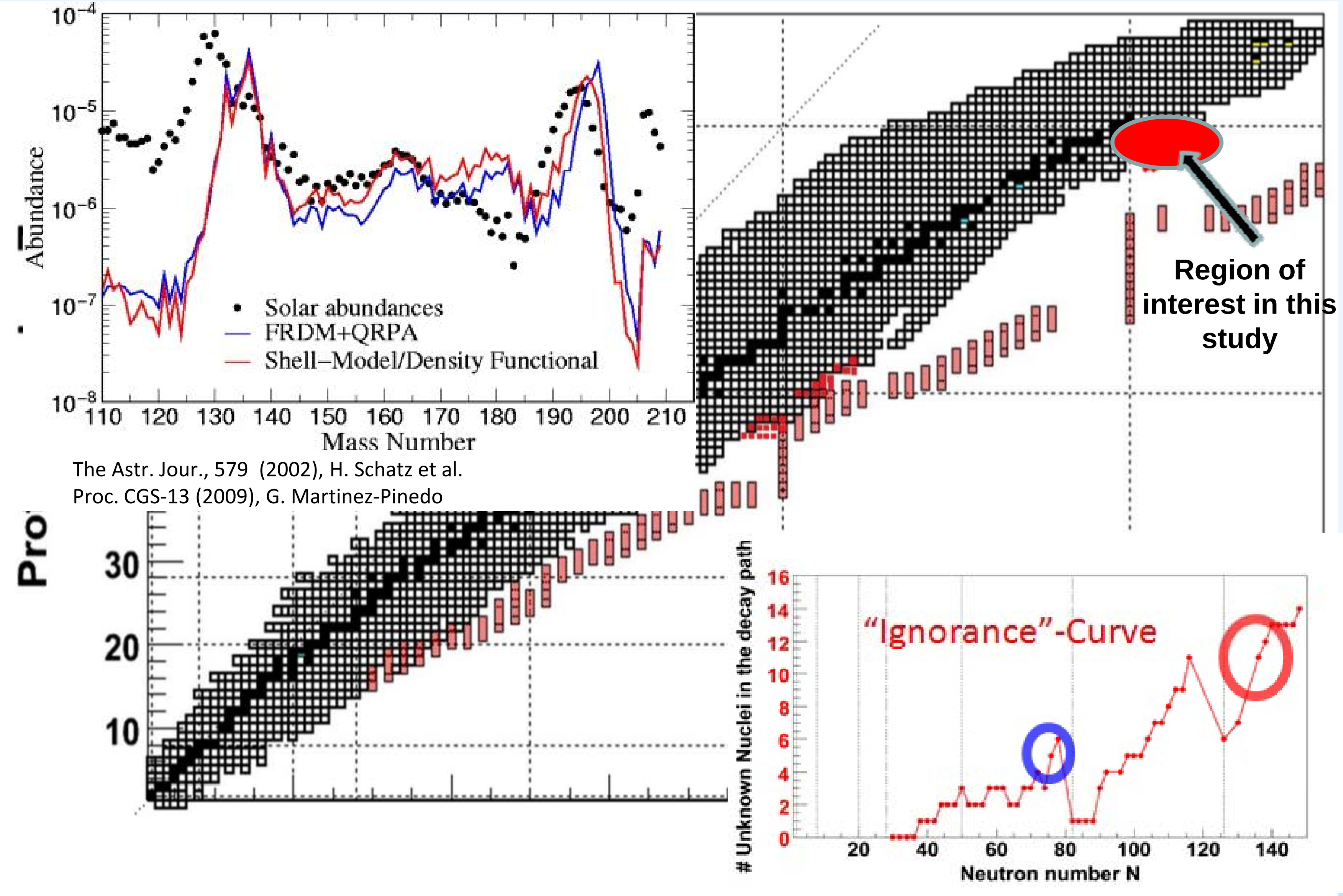
R-process & region of interest

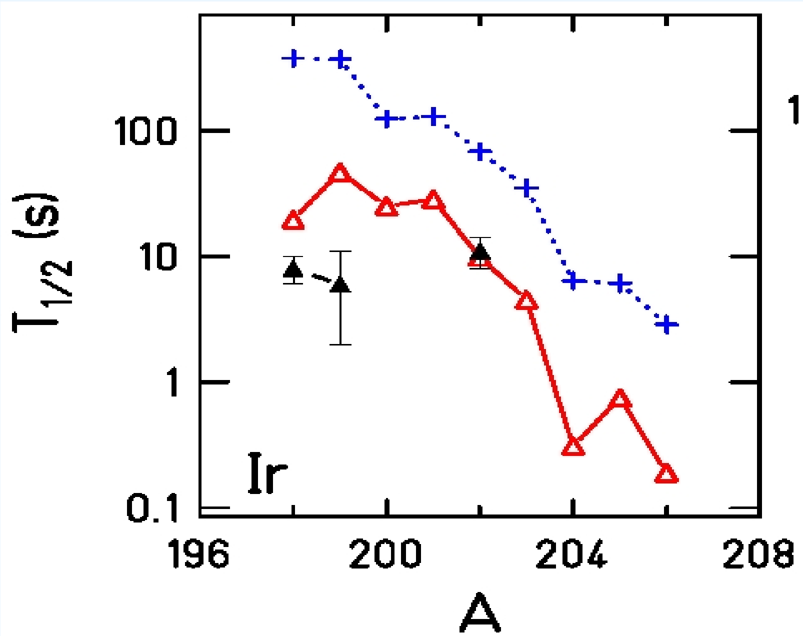


The Astr. Jour., 579 (2002), H. Schatz et al.
Proc. CGS-13 (2009), G. Martinez-Pinedo

Motivation

Goal: to measure for first time **half life** and **β-delayed neutron emission probability (P_n)** for exotic nuclei near the third *r-process* peak.

- ✓ N=126 is one of the regions most difficult to reproduce with *r-process* model calculations.
- ✓ Scarce experimental information available for β-decay half-lives, masses and β-delayed neutrons.



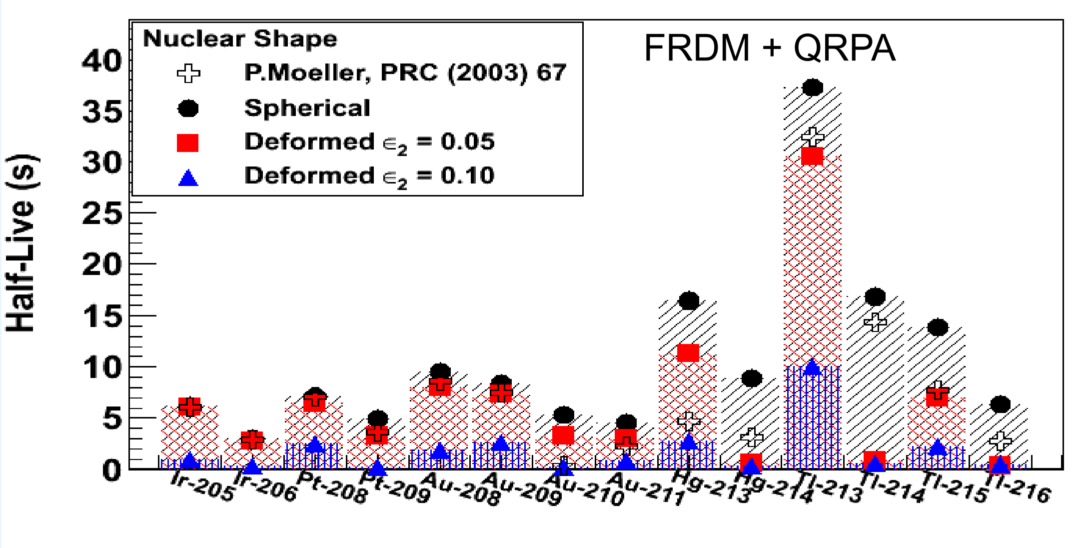
- ✓ Theoretical models have discrepancies of one order of magnitude for masses of Ir. Furthermore the trend of the unique experimental measurement seems to be in the opposite direction.

▲ DF3 + QRPA (I.Borzov, et al. 2003)

\+ FRDM + QRPA (P.Moeller, et al. 2003)

▲ **Exp. T. Kurtukian et al.** Phys. Lett. B (Submitted)

Theoretical predicitons in the region

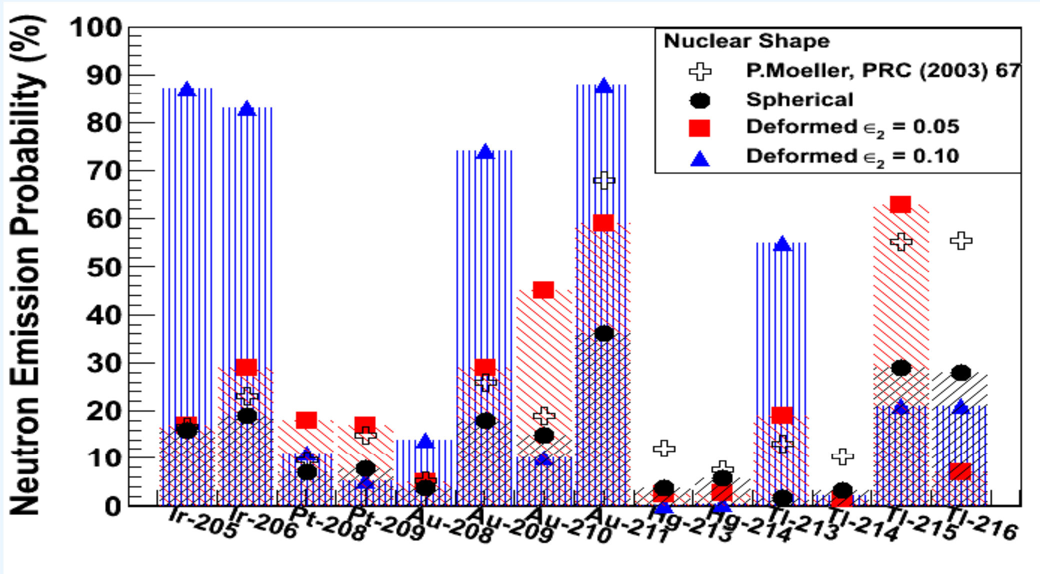


Half lives ($T_{1/2}$)

Theoretical models give different values depending on the nucleus shape in the region of Hg and Tl.

Neutron emission probablity (P_n)

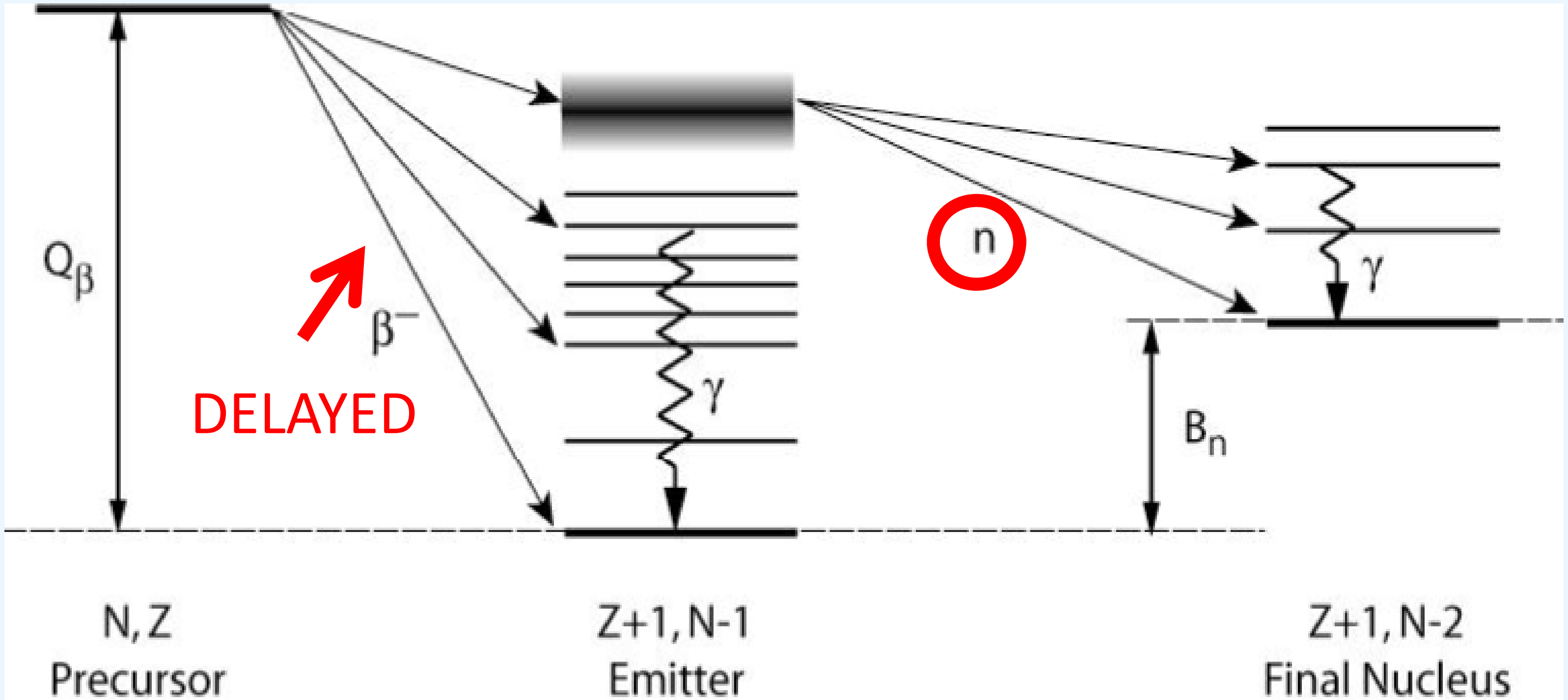
Predictions for Pn are also very different according its deformation



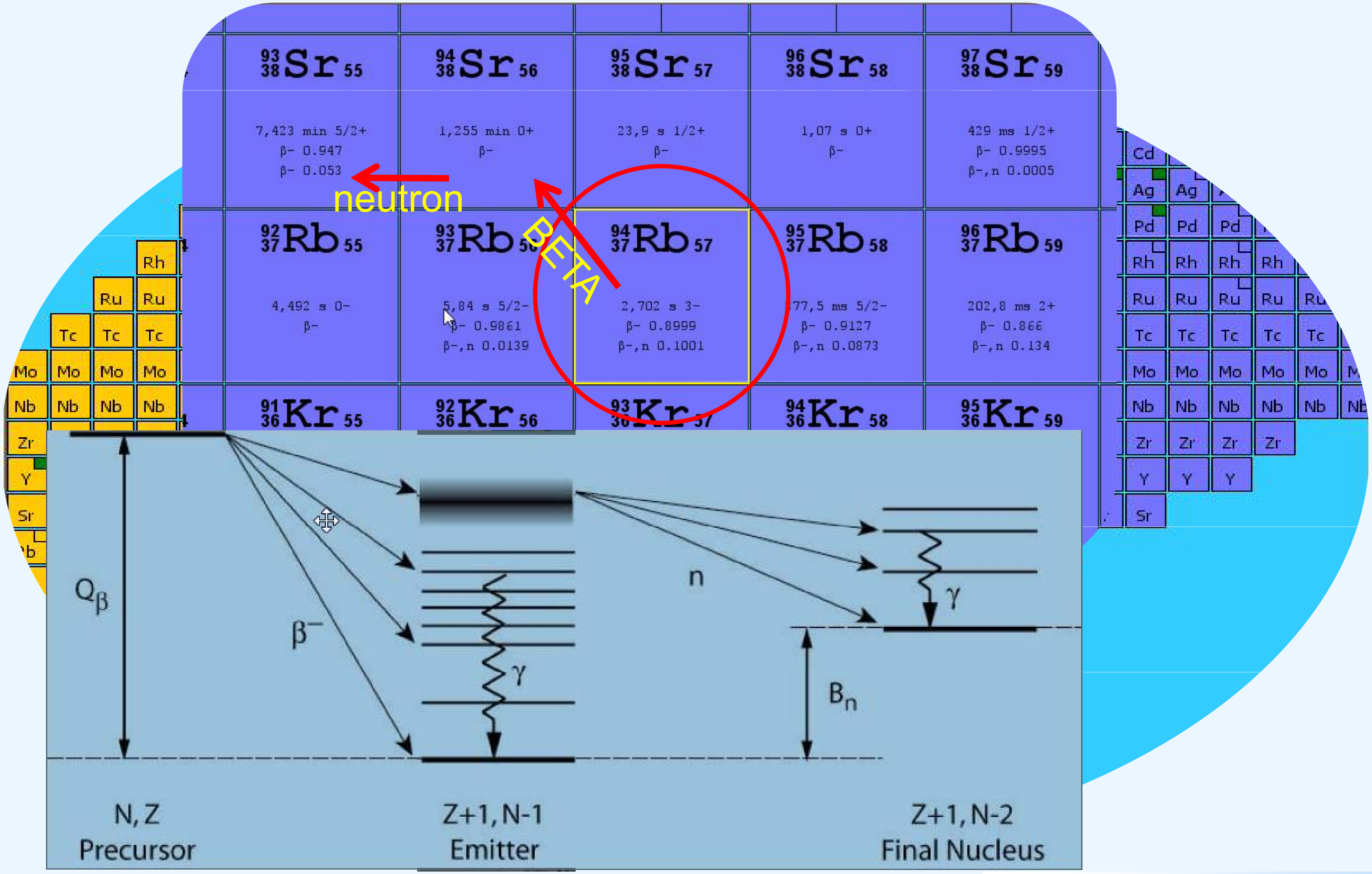
Information from K.-L. Kratz, (priv. comm. 2010)

β-delayed neutron emission

Neutron emission after β^- decay scheme



Example of β⁻delayed neutron emission



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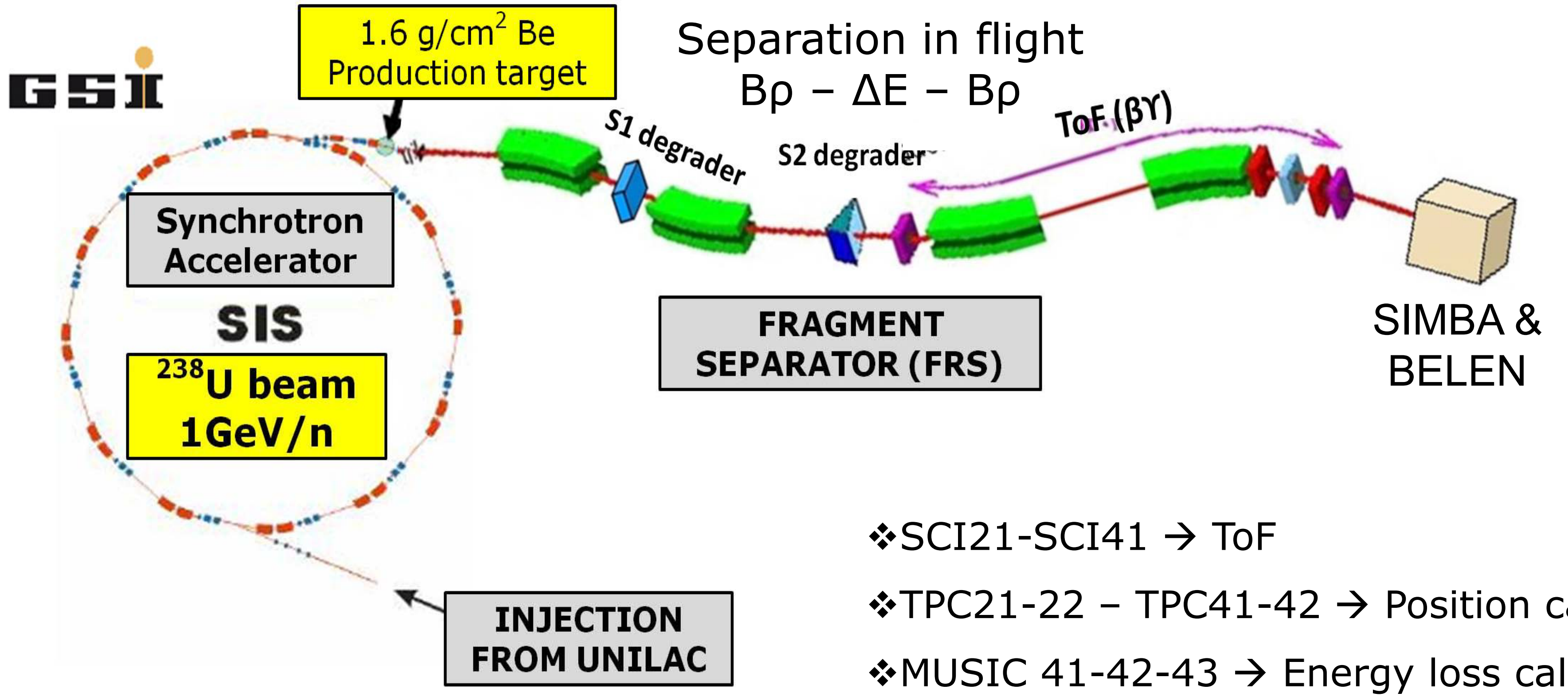
GSI facility. Fragment separator spectrometer (FRS) and Beam characteristics.



- SCI21-SCI41 → ToF
- TPC21-22 – TPC41-42 → Position calib.
- MUSIC 41-42-43 → Energy loss calib.

$$B\rho = \frac{m}{q} * v = \frac{A}{Q} * \left(\frac{L}{Tof}\right) \rightarrow \frac{A}{Q} = B\rho * \left(\frac{L}{Tof}\right)$$

$$Z \,\alpha \sqrt{E_{Loss}}$$

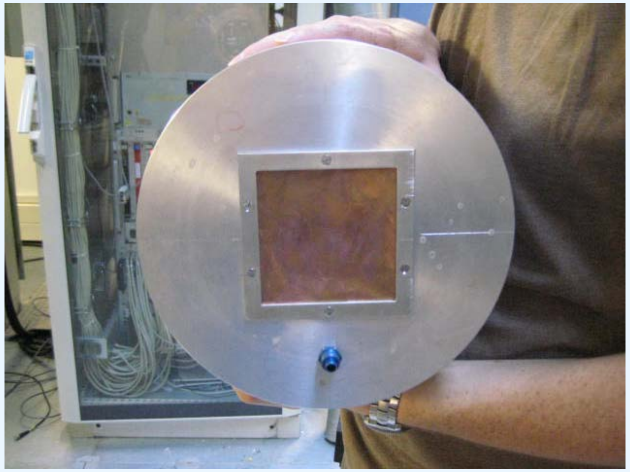
Implantation detector: SIMBA (Silicon Implantation Detector and Beta Absorber)

Multilayer silicon detector

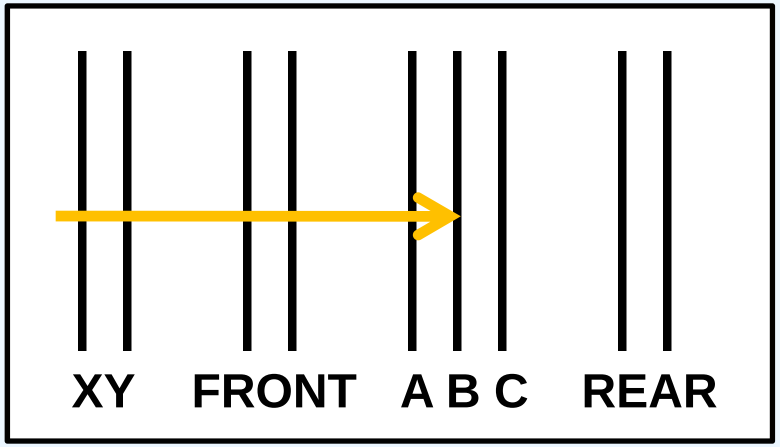
Allows to measure both ion implants and β-decays.

Decay events can be correlated in time with the detection of neutrons.

SIMBA detector



Front view



3 DSSD (implantation area, 60x40 segm.): 60x40 mm^2 (0.7mm thick)

PhD thesis C. Hinke, TUM (2010)

Diploma thesis K. Steiger, TUM (2009)

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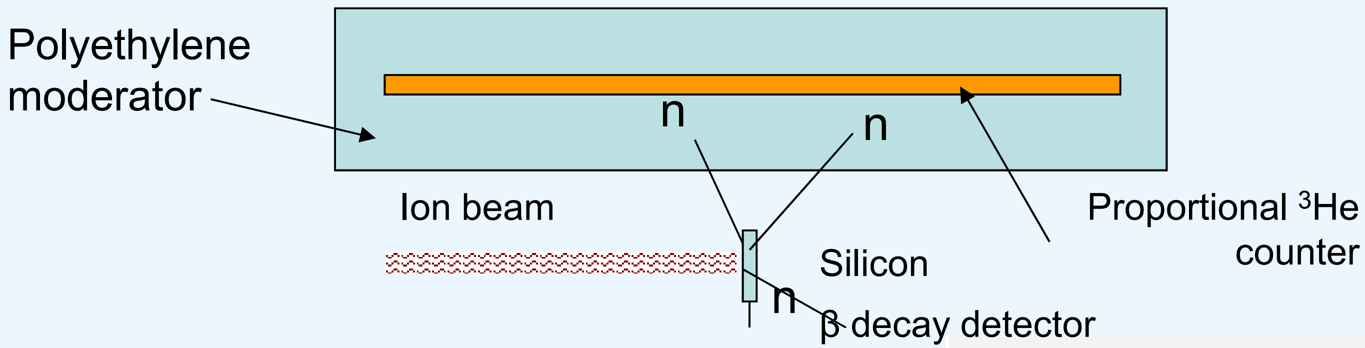
Beta Delayed Neutron detector - **BELEN**

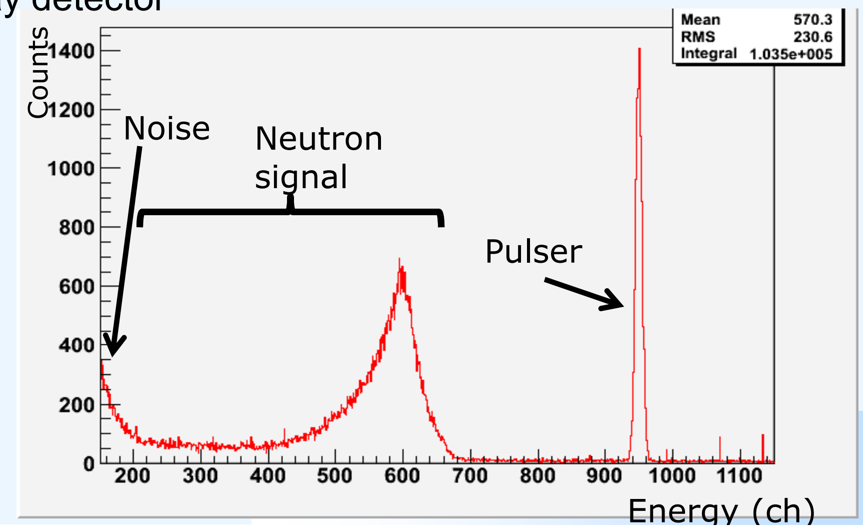
Developed at the technical university UPC-Barcelona

✓ The detection of the neutron is based on the detection of products of the reaction of the neutron with 3He counters :

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



- ✓ Polyethylene matrix moderator
- ✓ Approx 700 kg weight
- ✓ Dimensions: 80cmx80cmx60cm

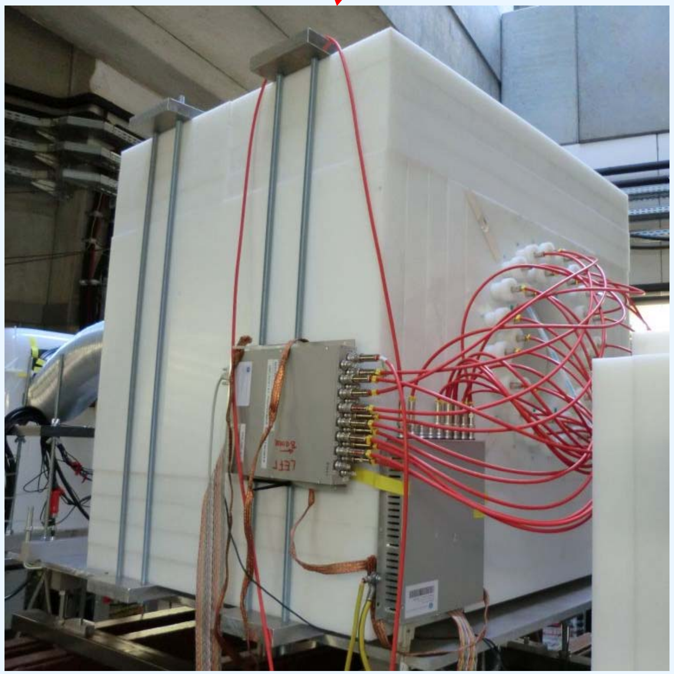


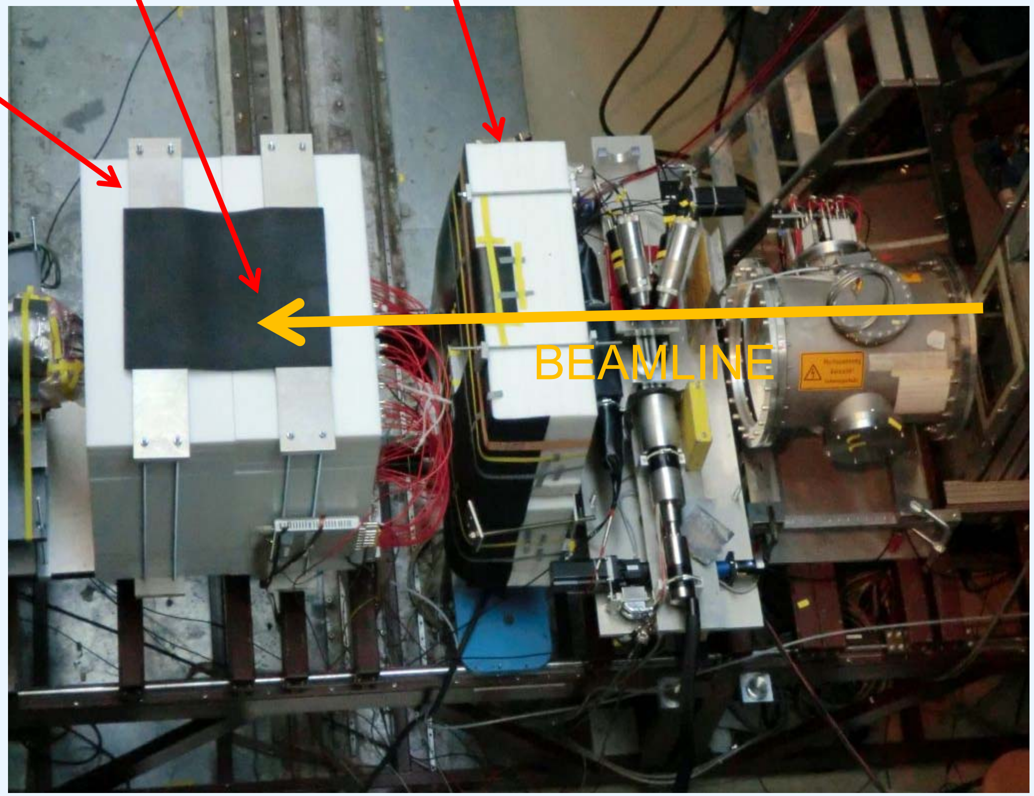
Beta Delayed Neutron detector - **BELEN**

BELEN-30 neutron detector

Neutron shielding

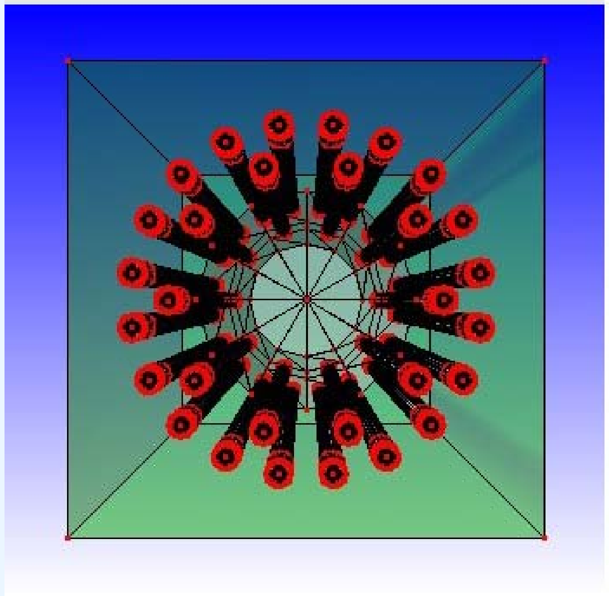
SIMBA inside
the matrix

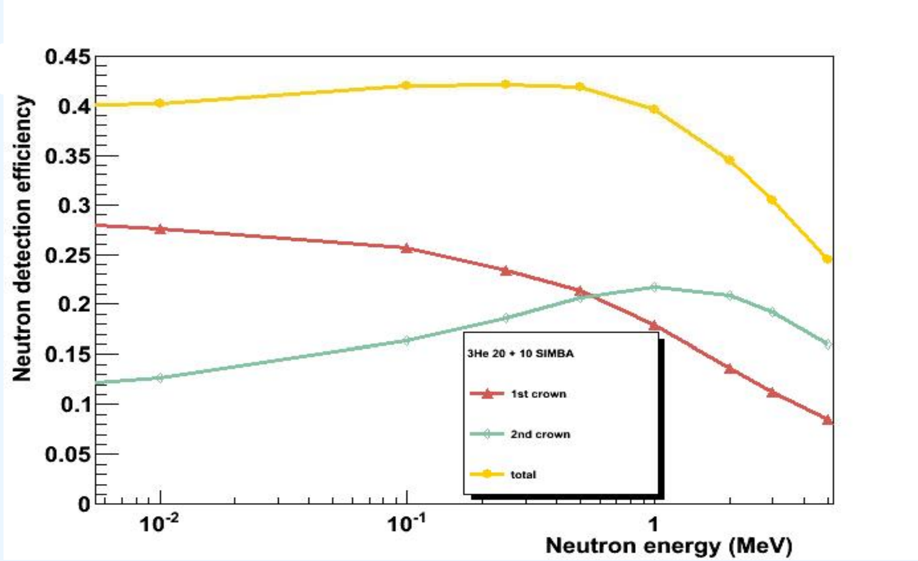




Beta Delayed Neutron detector - **BELEN**

Design of the prototype of the BELEN detector with MCNPX and GEANT4 simulations





Name	^{3}He counters	Pressure	Experiment	Average Efficiency
BELEN-20	20	20 atm	JYL-2009	27%
BELEN-20	20	20 atm	JYL-2010	35%
BELEN-30	20+10	20 & 10 atm	GSI-2011	40 %
BELEN-52	42+10	8 & 10 atm	JYL-2013	In progress
BELEN-96	42+10+44	8 & 10 atm	DESPEC	In progress

Tests and experiments with BELEN detector

BELEN-20 (20atm) for JYFL. Experiments at JYFLTRAP (Finland). Measurements of β delayed neutron emission of fission fragments (UPC, IFIC, CIEMAT):

Nov 2009: ^{95}Rb, ^{88}Br, ^{94}Rb, ^{138}I. (cal. and nucl. Structure)

Jun 2010 : ^{95}Rb, ^{88}Br, ^{85}As, ^{86}As, ^{85}Ge, ^{91}Br, ^{137}I.(decay heat and testing models)

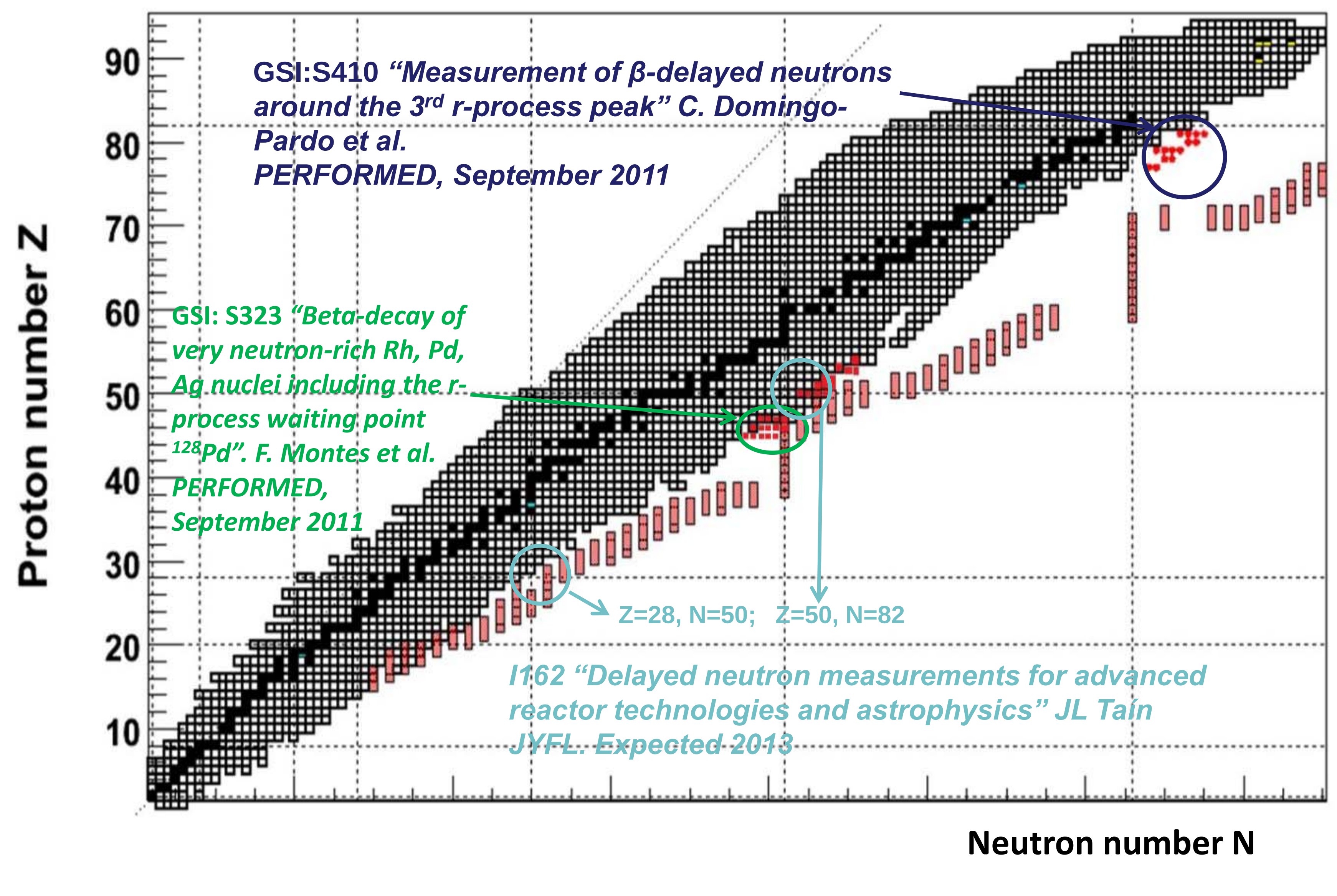
Background measurements at GSI and Canfranc underground laboratory.

BELEN-30 (20 (20atm), 10 (10 atm)) for FRS-GSI. Two experiments at GSI with & SIMBA September 2011, nuclei of astrophysical interest:

S323: ^{127}Pd, ^{126}Pd, ^{128}Ag

S410: ^{215}Tl, ^{211}Hg

Tests and experiments with BELEN detector

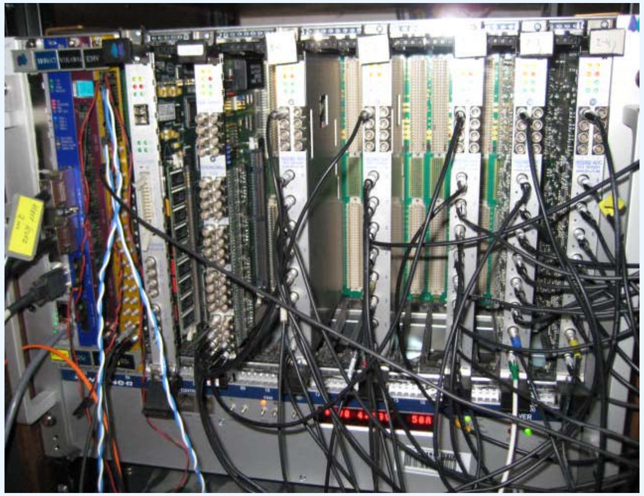


Digital Data Acquisition System (DDAS)

✓Triggerless digital data acquisition system used for the first time in this type of experiments at GSI.

✓Struck digitizer modules (SIS3302): provide time-stamps very versatile for time correlations.

✓Developed at IFIC (València-Spain)

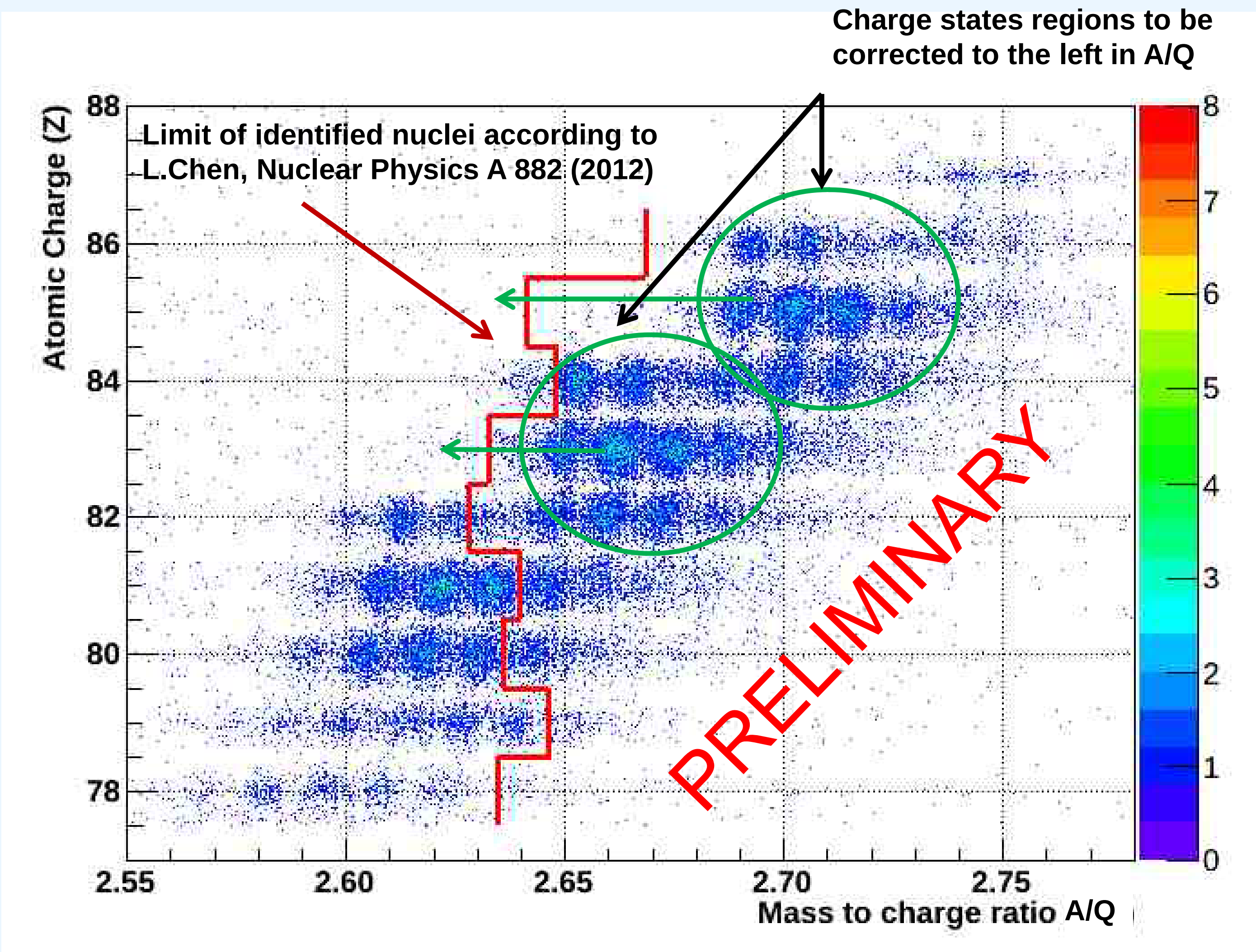


-Advantages:

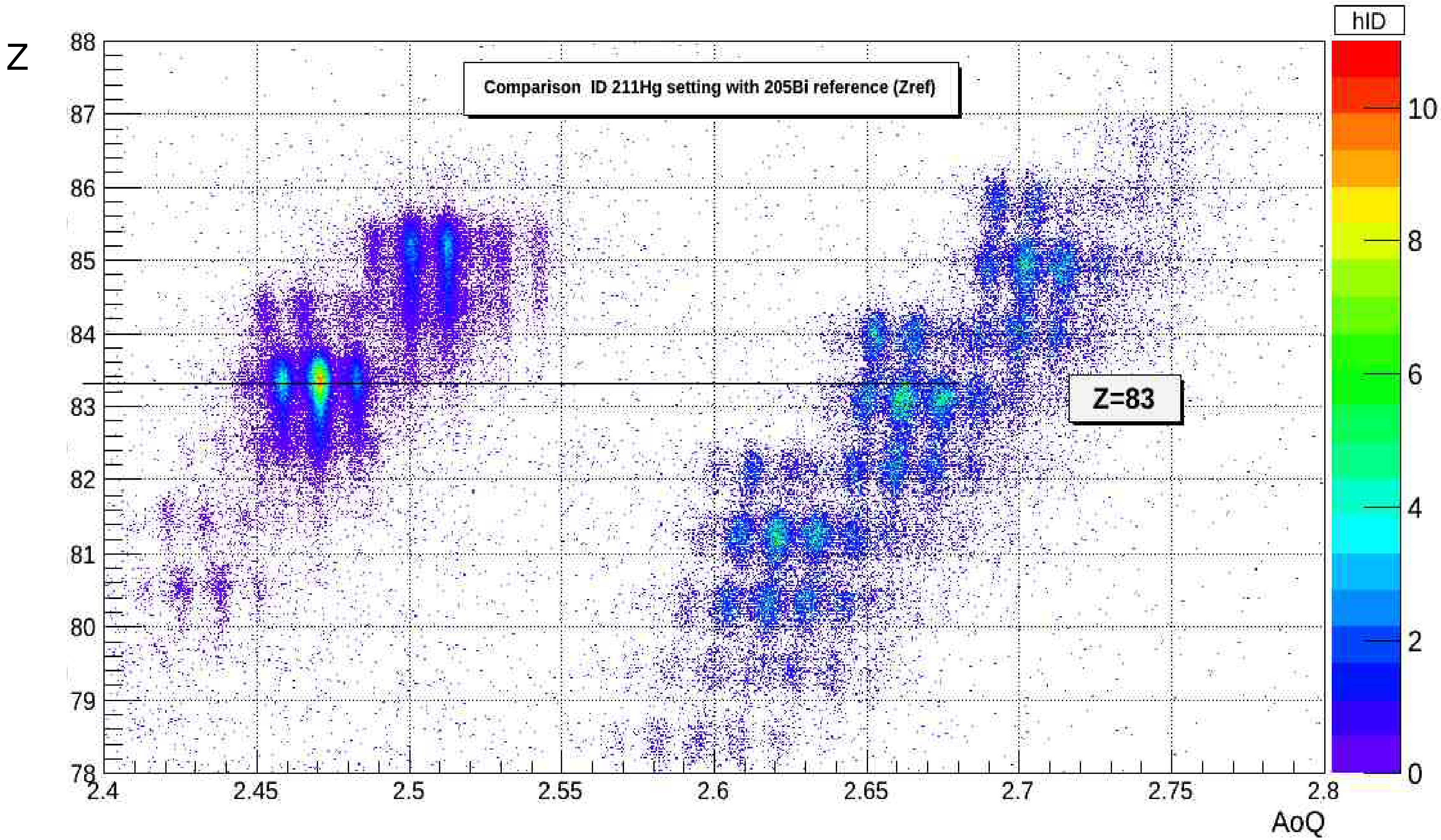
1. Negligible dead-time when compared to analog systems.
2. Increase the efficiency by about 8% (from 27 to 35%)
3. Flexibility for large time correlation (fundamental to obtain correlations with all neutron and to change the gates offline)
4. Allows to correct some experimental effects, e.g. To reduce neutron background from uncorrelated neutrons.

Contents

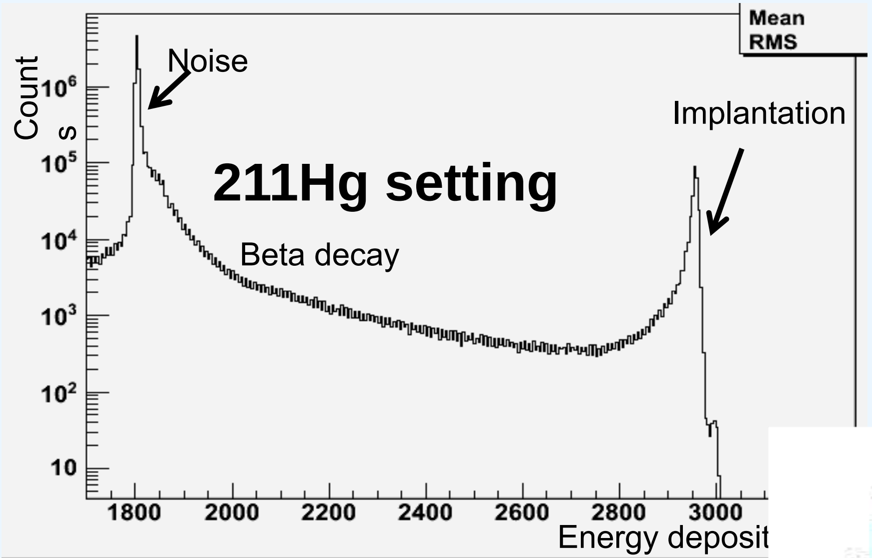
Analysis status: Identification preliminary plot for of ^{211}Hg setting (all statistics)

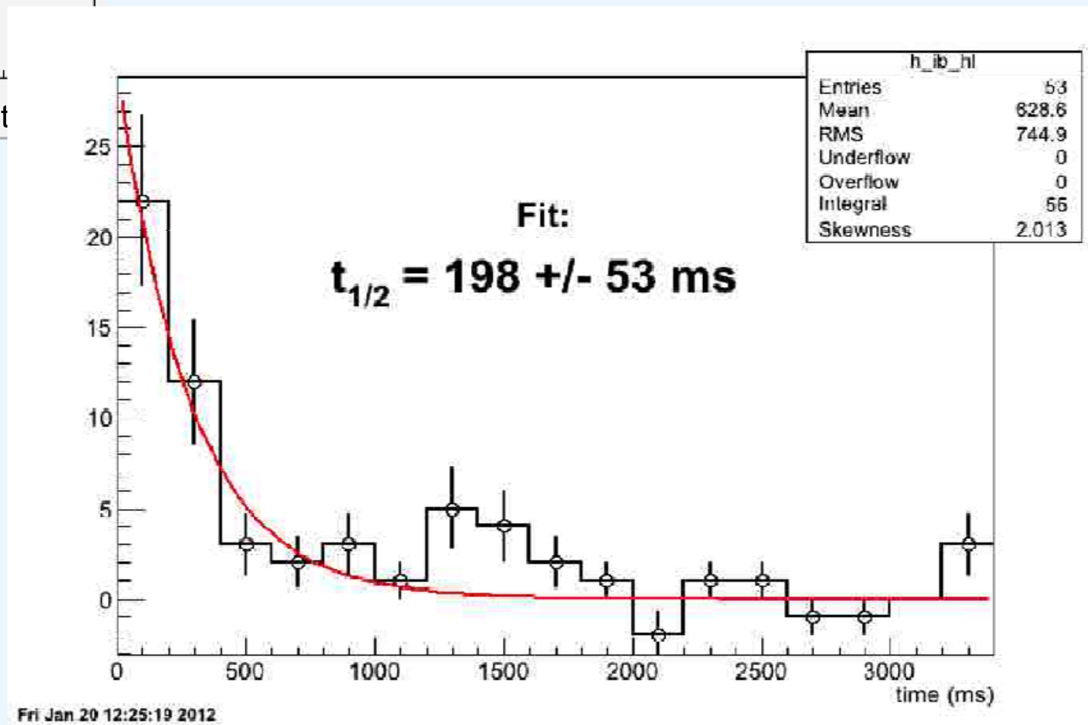


Analysis status: Verification of identification plots via gamma isomers of ^{205}Bi



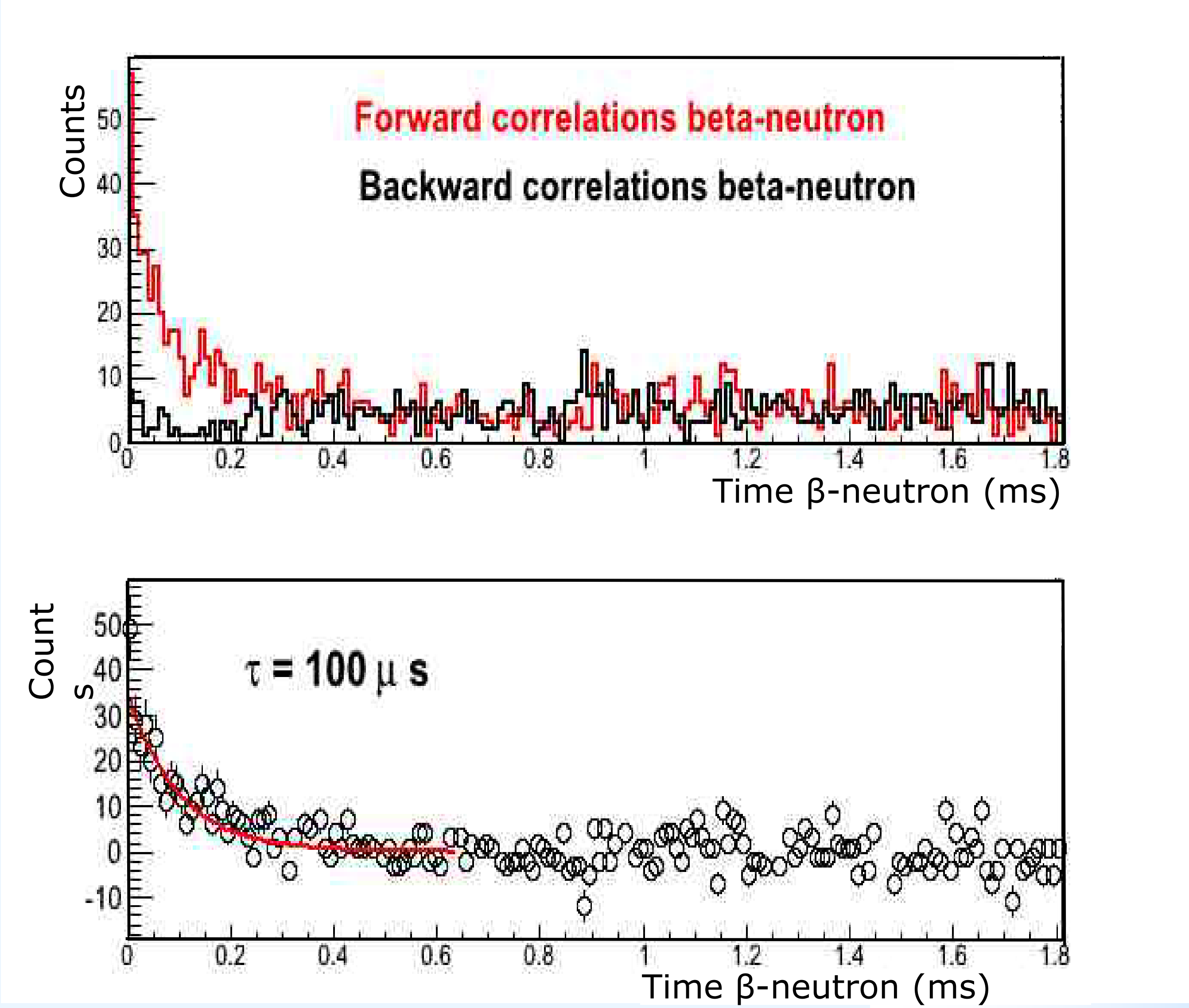
SIMBA analysis. Preliminary tests.





First estimation of 216Po half life of 150 ms (ENDF).

Performance test time correlation between neutron and β-decay for ^{213}Tl

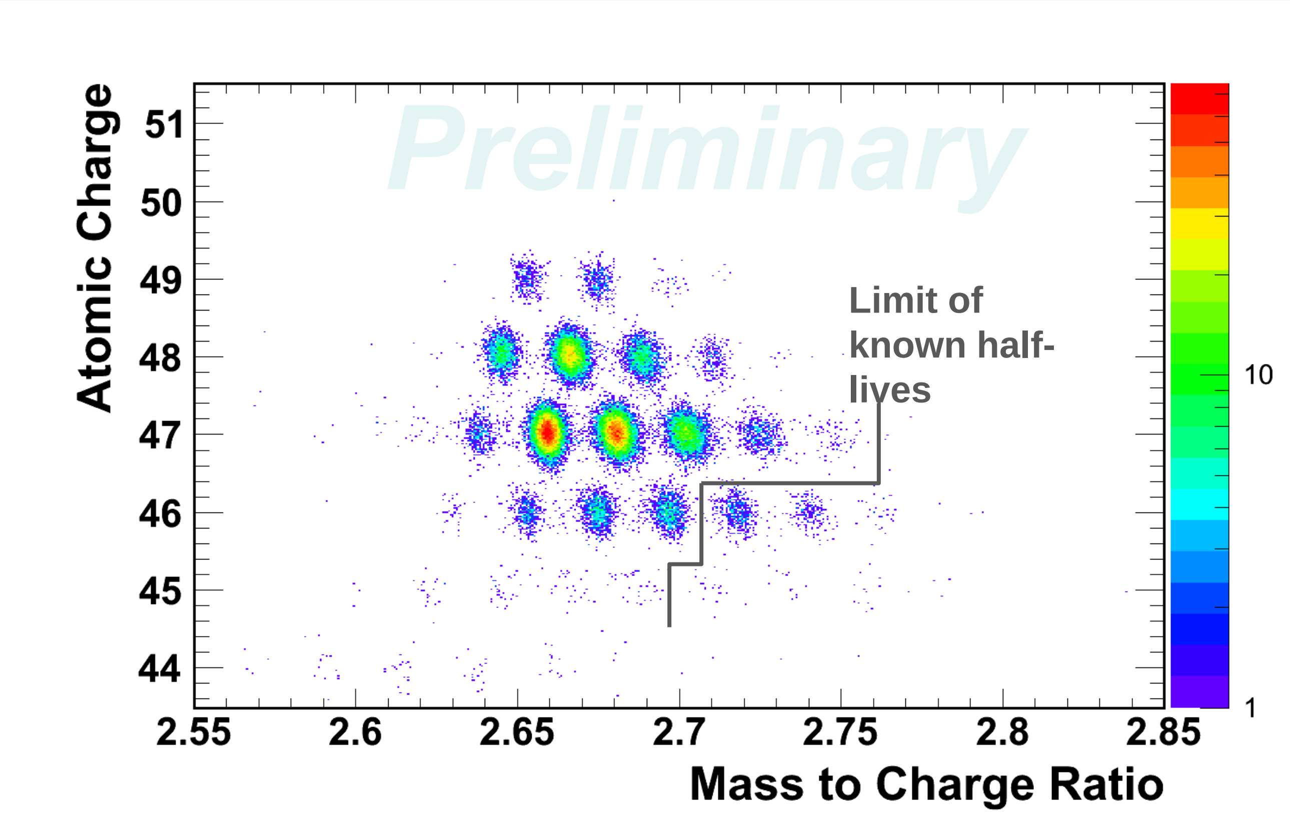


S323 analysis status: β-decay of very neutron-rich Rh, Pd and Ag nuclei

✓N = 82 nuclei act as bottleneck in r-process.

✓β-decay sets the timescale for the following nucleosynthesis.

✓Set abundances in the important A = 115 - 125 region

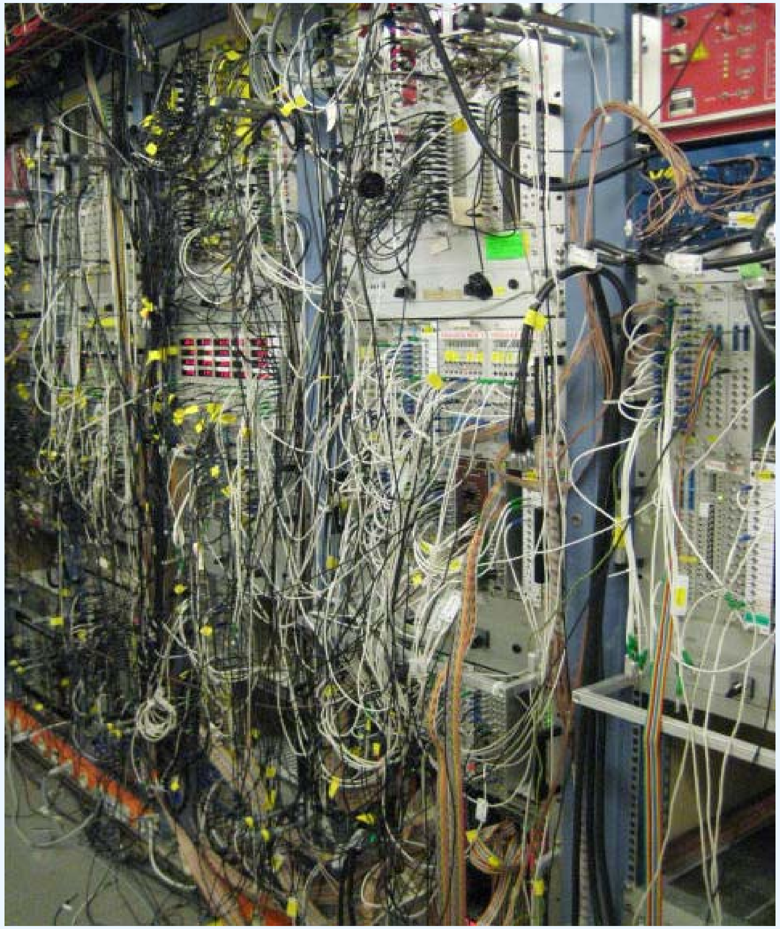


K. Smith, F. Montes, S323 Collaboration

Future analysis work

- Improved ID-Plot via final calibrations of frs detectors
- Determine implantation rates for each identified isotope
- Determine implant-beta correlations and neutron-beta correlations
- Implement an analysis method for deriving half-lifes and for determining beta-delayed neutron emission probabilities.
- In collaboration with theoreticians, study the impact of these results on nuclear models, as well as on r-process nucleosynthesis calculations.

The end!



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