Measurement of β-delayed neutron emission probabilities close to the 2nd and 3rd peak in the r-process path

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GSI Darmstadt / JLU Giessen, Germany

for the S323/410 collaboration

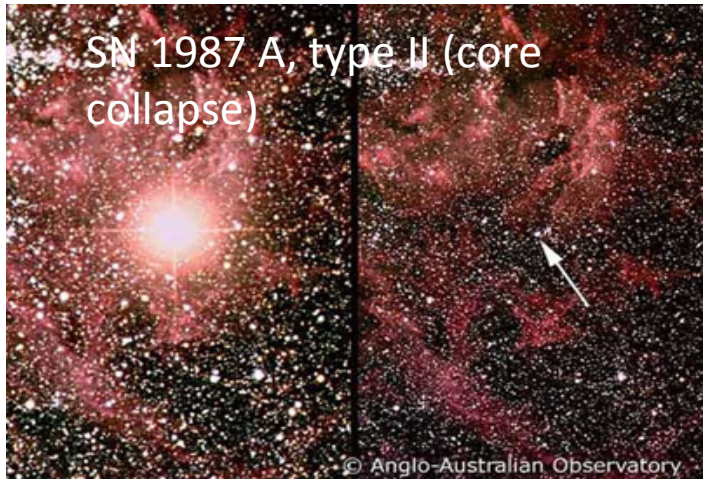
NAVI annual meeting 2013

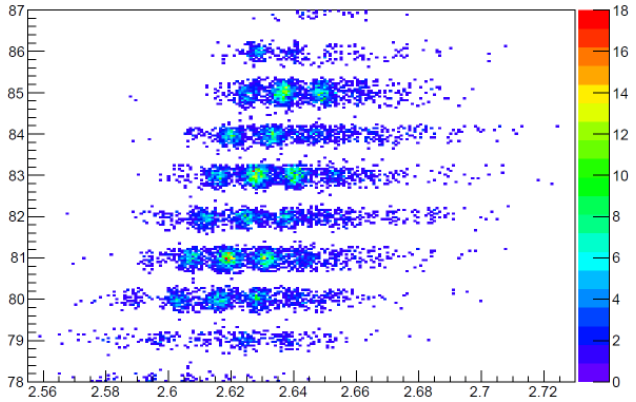
GSI Darmstadt, 16.12.2013

Supported by the Helmholtz Association via the Young Investigators Group LISA

Outline

- r process, beta-delayed neutron emission
- The experiment at the FRagment Separator @ GSI
- Implanted species, ongoing analysis
- Summary and outlook

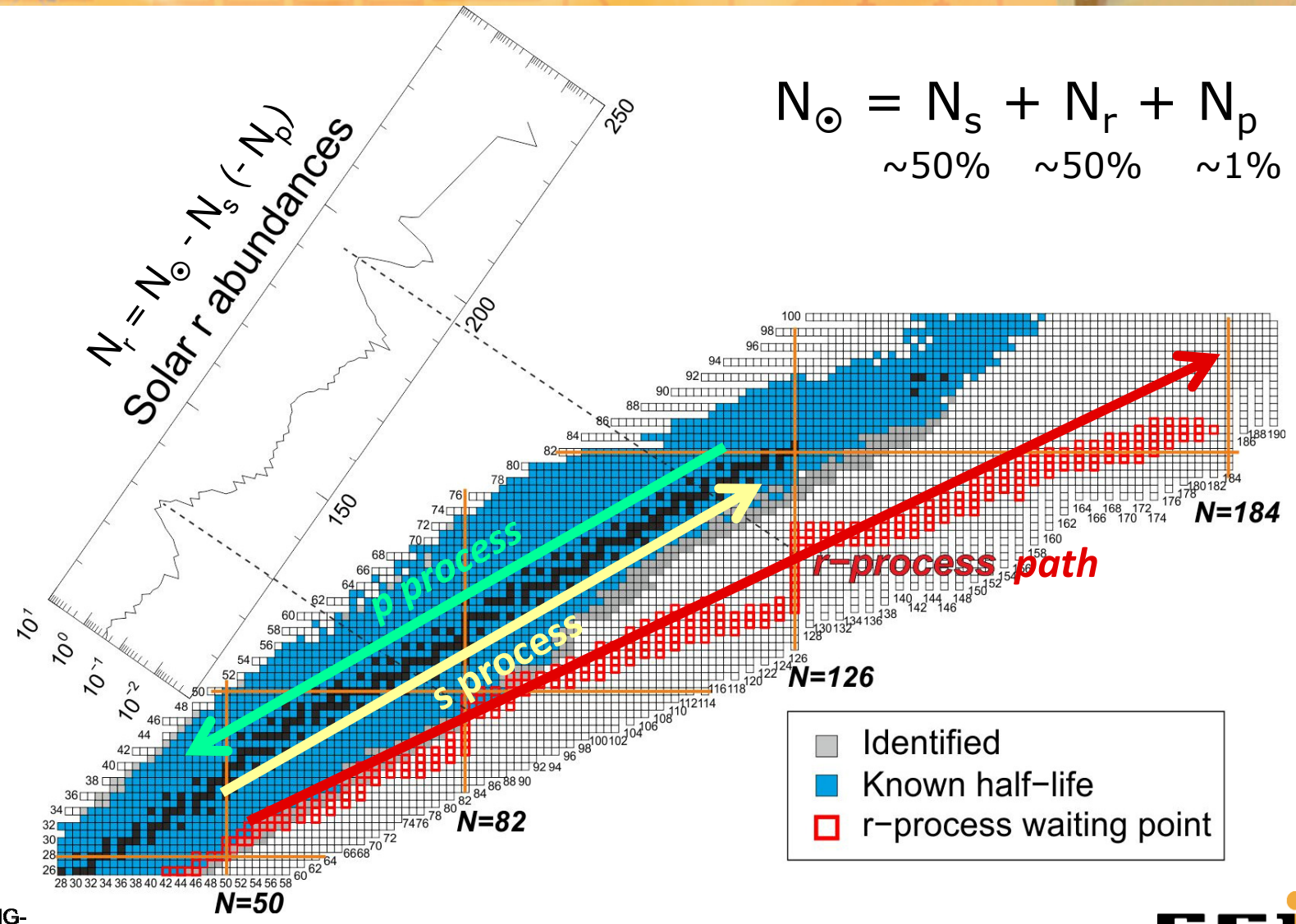




Nucleosynthesis beyond iron

$$N_\odot = N_s + N_r + N_p$$

~50% ~50% ~1%



Understanding the r process

Ingredients for a (successful) r-process nucleosynthesis:

- astrophysical site (debated, neutron star mergers / CCSN ?)
  → physical conditions (explosive scenario)
  - Neutron density (>> 10^{20} cm^{-3}), exposure time τ , Y_e
  - Temperature (1-2 GK) / density vs time (trajectory)

- nuclear input (rely on theoretical calculations tuned to few experimental data available)
  - Masses (→ Q_β, S_n)
  - $t_{1/2}$ (β)
  - (n,γ) cross sections
  - β-delayed neutron branching
  - others: fission parameters, $t_{1/2}$ (α)…

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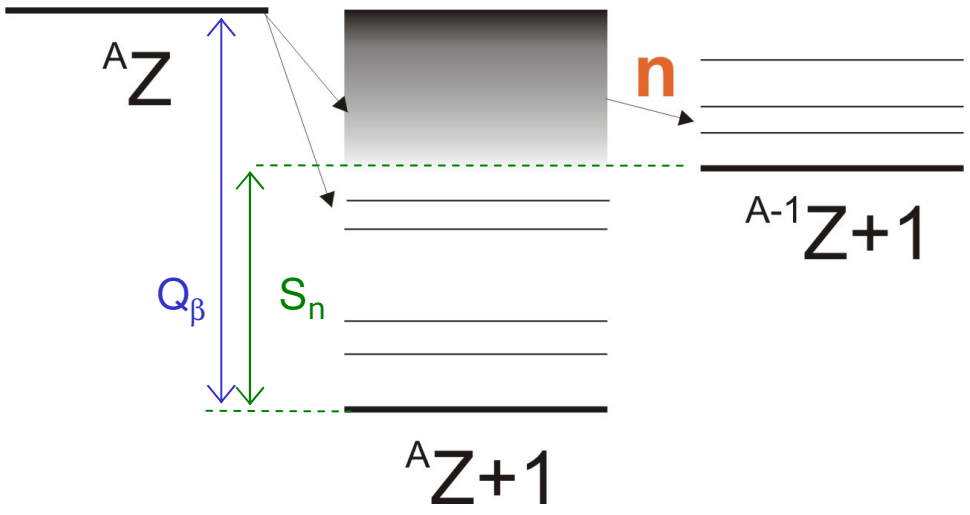
  → r process "path", waiting points, progenitors' abundances

  → Modified path back to stability and additional neutron source

  - others: fission parameters, $t_{1/2}$ (α)…

β-delayed neutron emission

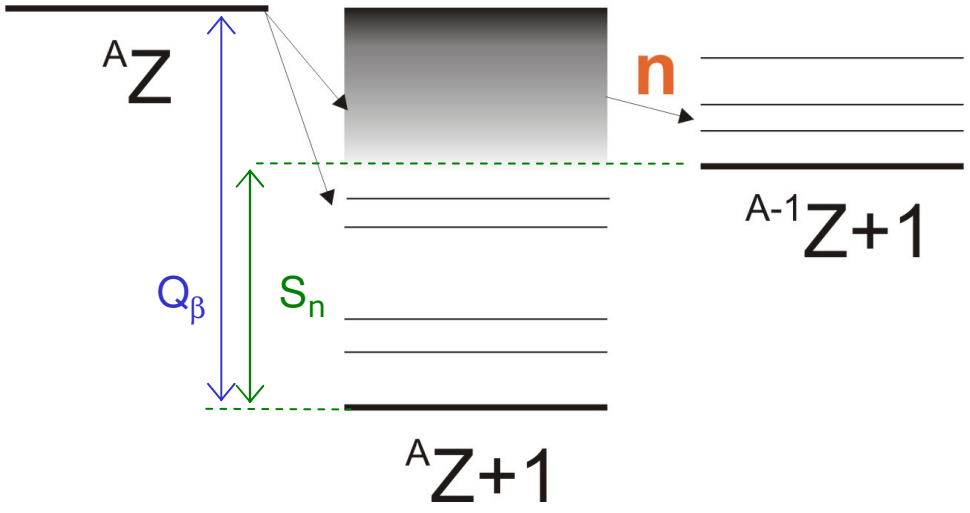


Detecting n →

- obtain $t_{1/2}$ (^{A}Z)
- P(n) branching
- study β-strength function above S_n

- $Q_\beta > S_n$ (or > $S_{2n,\,3n}$)
- Discovered in 1939 by Roberts et al.
- $t_{1/2}$≈ few ms – 55.65 s (^{87}Br)
- ^{8}He- ^{150}La: ≈ 230 datasets available
- Only one for A>150 (^{210}Tl)

β-delayed neutron emission



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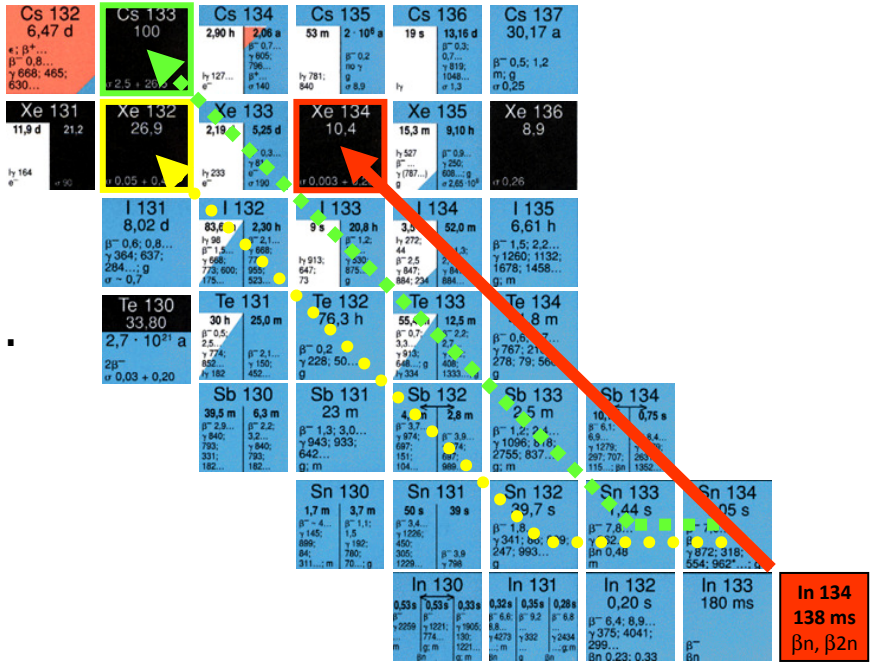

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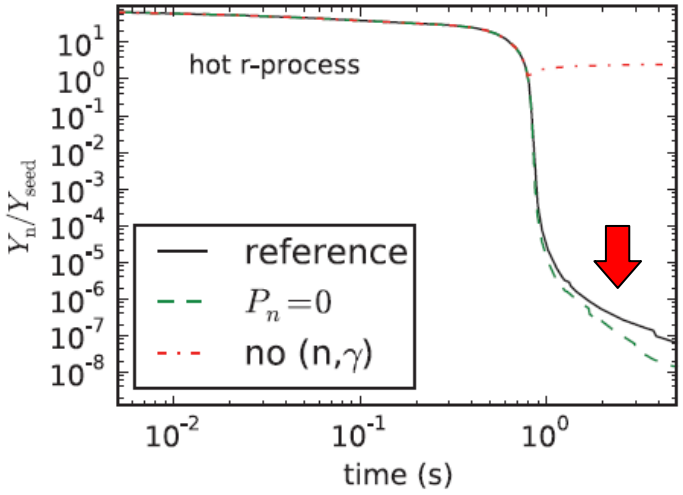
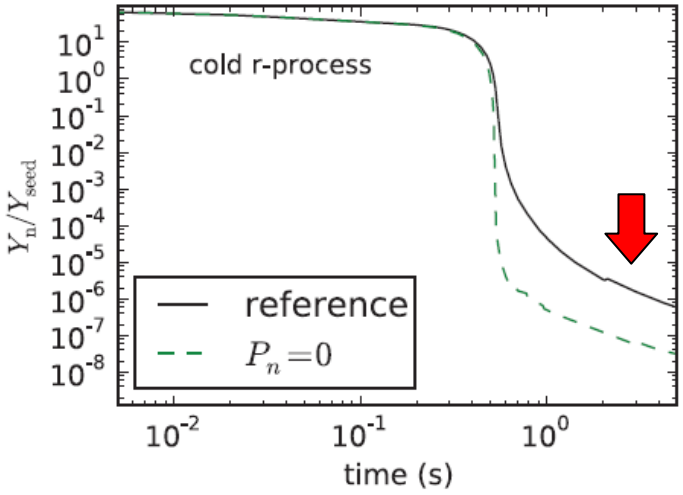
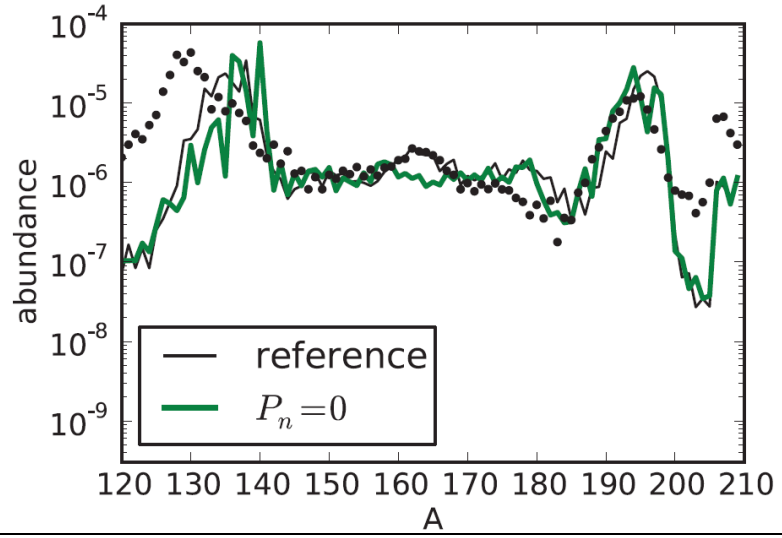
Late-time influence in r-process

- Production of additional neutrons, influence on n/seed ratio at later times

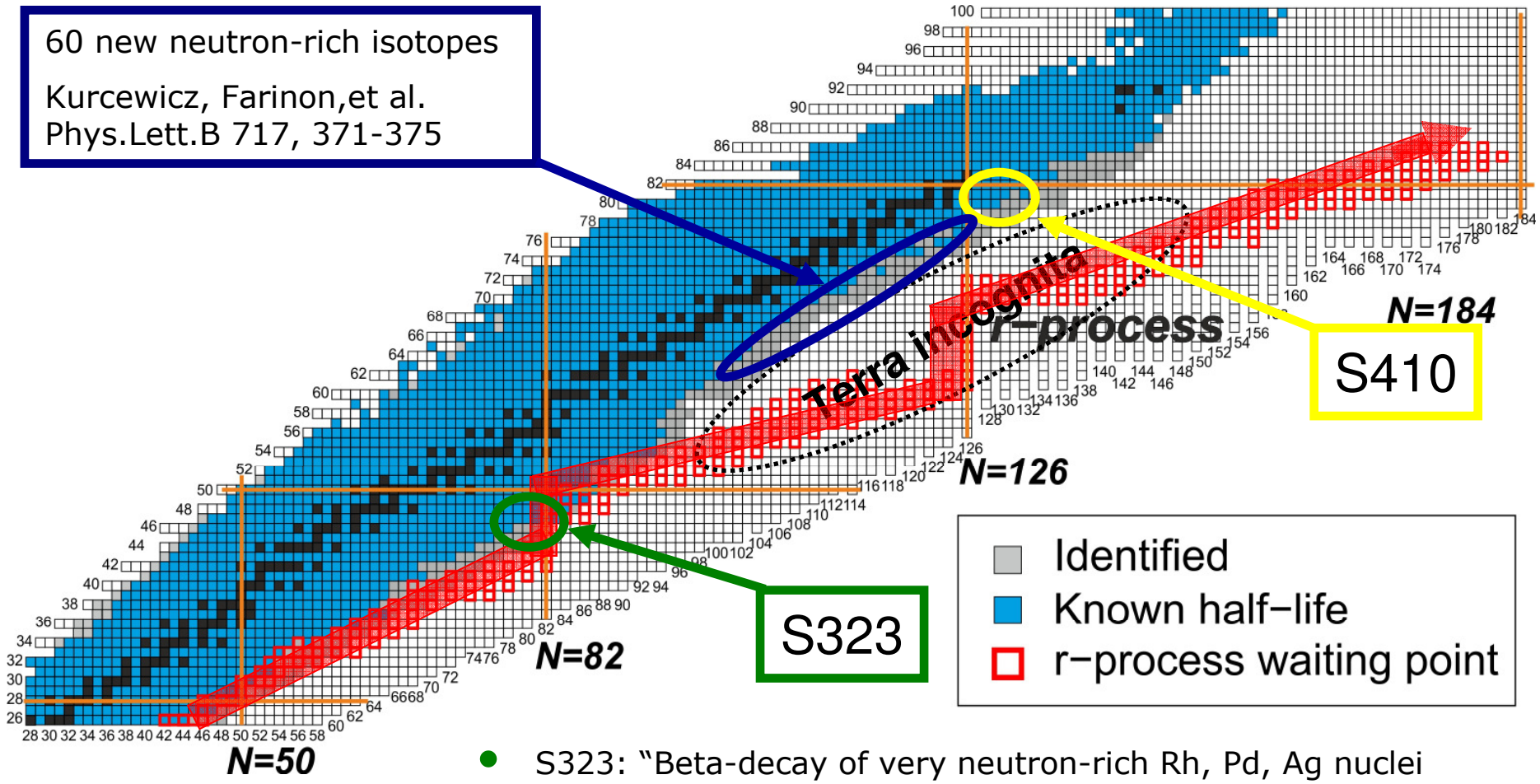






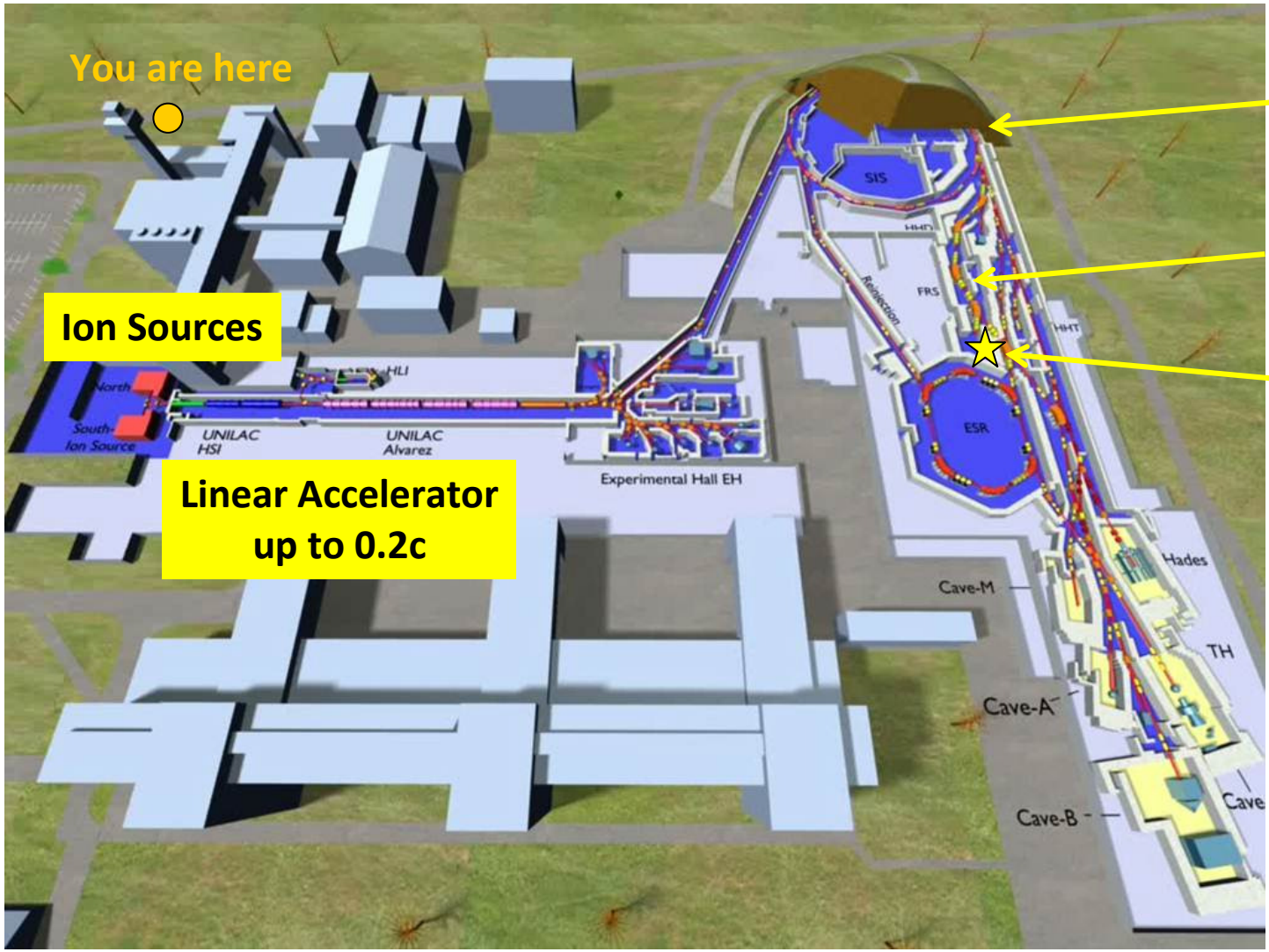
A. Arcones and G. Martinez-Pinedo, PRC83, 045809 (2011)

Aim of GSI campaign



- S323: "Beta-decay of very neutron-rich Rh, Pd, Ag nuclei including the r-process waiting point ^{128}Pd". (F. Montes et al.)
- S410: "Measurement of beta-delayed neutrons around the third r-process peak". (C. Domingo et al.)

Experimental setup @ GSI



SchwerIonen Synchrotron (up to 0.9c)

FRagment Separator

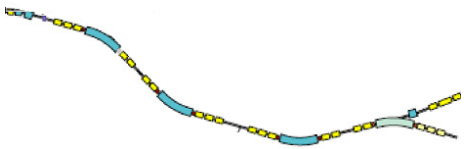
Experimental Area

1 GeV/u $^{238}U^{73+}$
10^9 ions/spill
on 1-3 g/cm² Be

Experiment at FRS in one slide

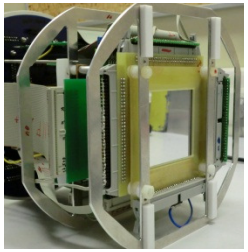
1. Produce, separate, identify fragments of interest

FRS **FR**agment **S**eparator at GSI and its monitors



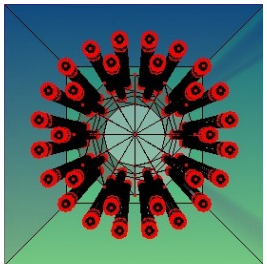
2. Implant in a silicon array and detect the corresponding beta decay

SIMBA **S**ilicon **IM**plantation detector and **B**eta **A**bsorber



3. Detect the neutron(s) in coincidence with such decay event

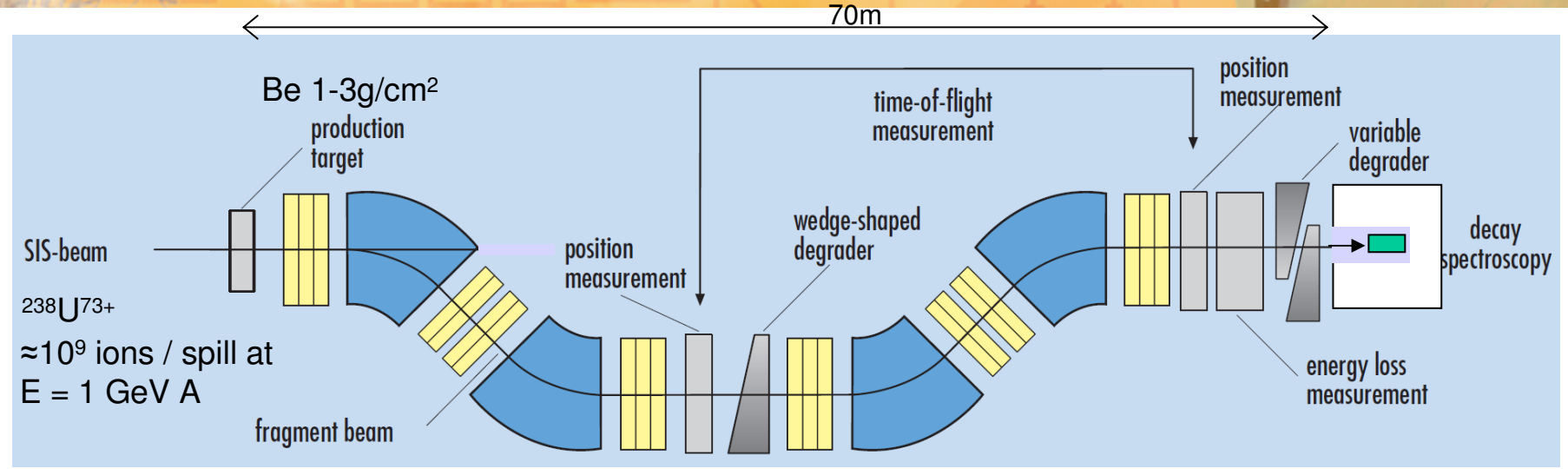
BELEN **BE**ta de**L**ay**E**d **N**eutron detector



Obtain:

- Beta decay half-lives
- Beta-delayed neutron branchings P_n

FRS: fragment production, in-flight separation and identification



- Separation Bρ – ΔE – Bρ
- In-flight particle identification:
  - 2x Plastic Scintillators — ToF → β
  - 4x Time Projection Chambers — x,y position → ρ
  - 2x MUSIC (MUltiple Sampling Ionisation Chamber) — E loss → q → Z
- m/q and Z identify the fragment (validation with Isomer TAGging)

H. Geissel et al., NIM B 70, 286 (1992)

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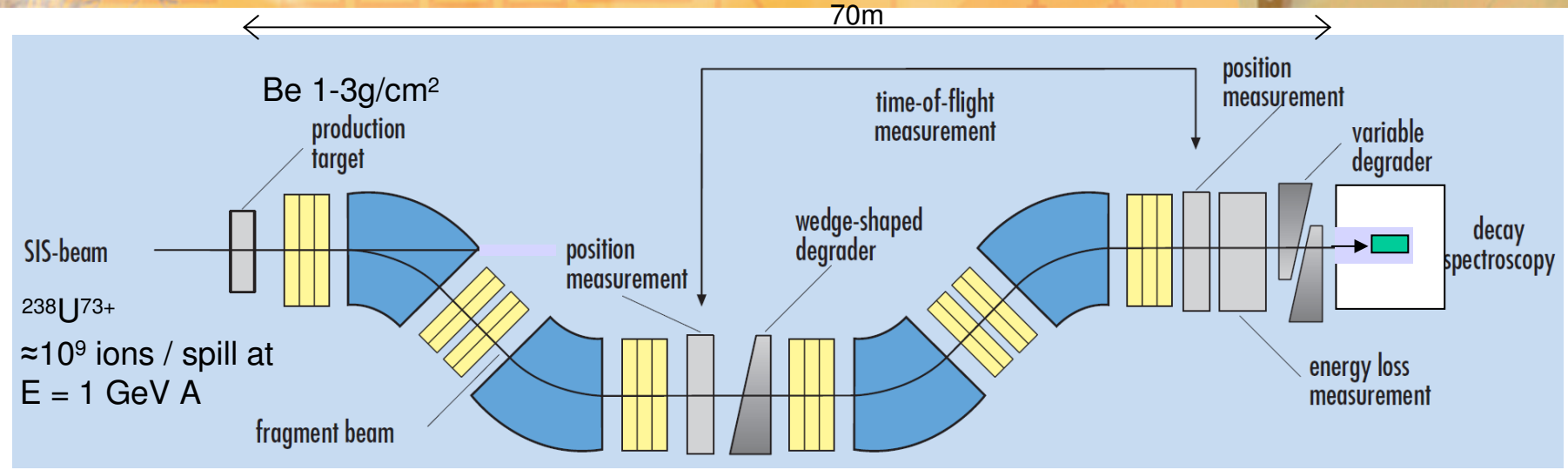

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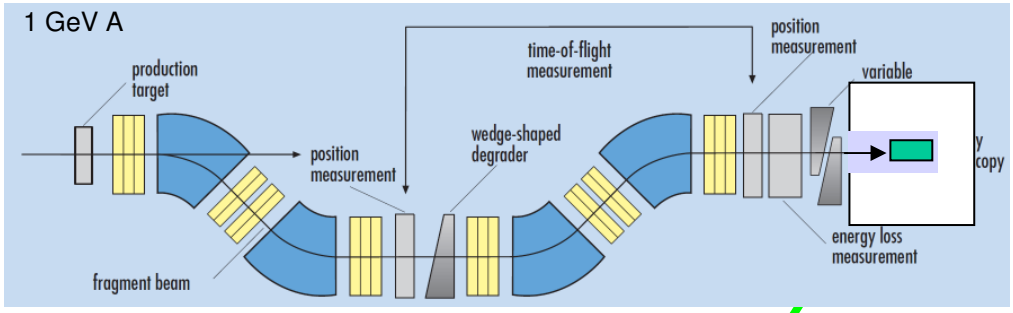
$$B\rho = \frac{m}{q} c\beta \frac{1}{\sqrt{1-\beta^2}}$$

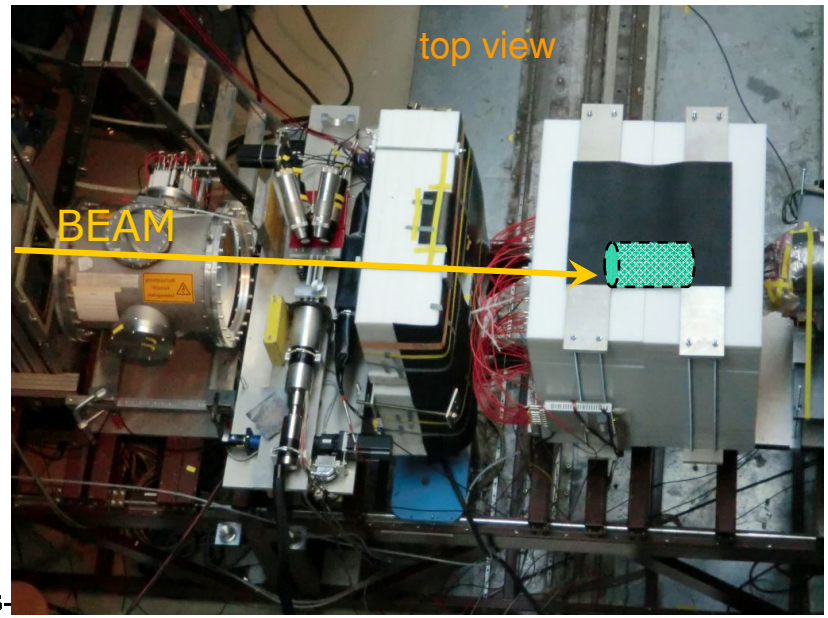
→ m/q

H. Geissel et al., NIM B 70, 286 (1992)

Setup at FRS final focal plane

$^{238}U^{73+}$





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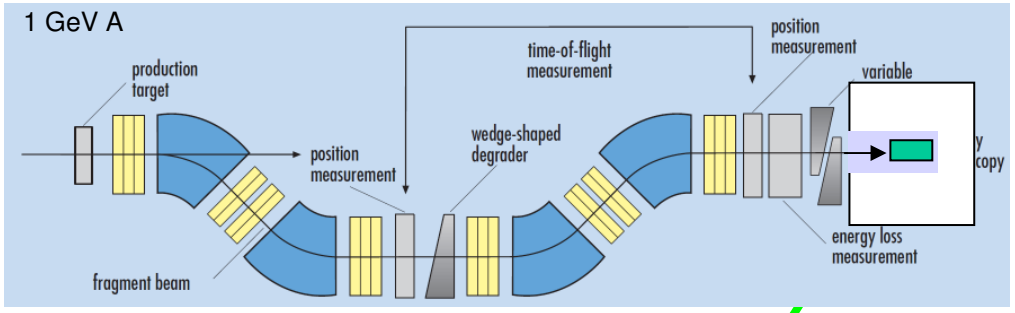
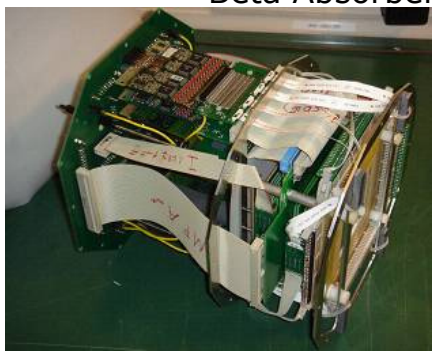


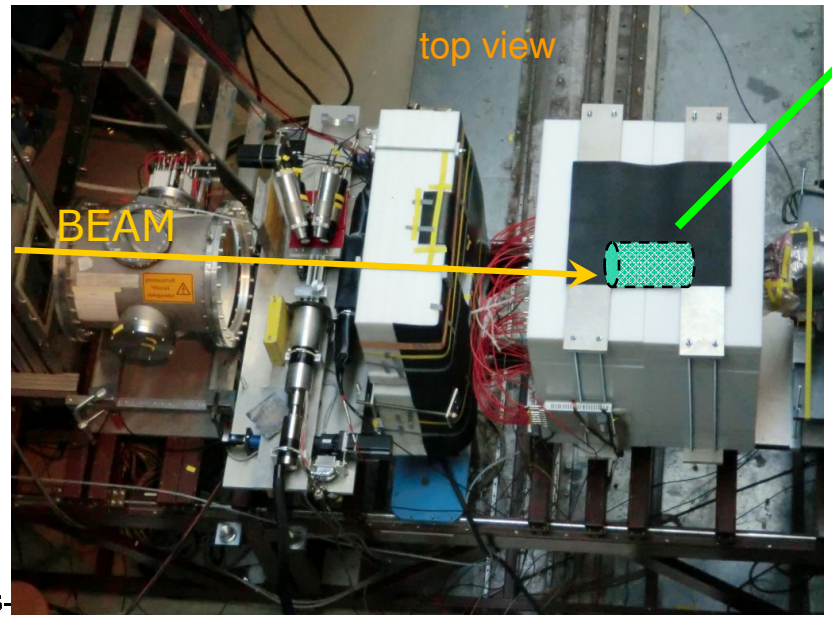
SIMBA Silicon IMplantation detector and Beta Absorber

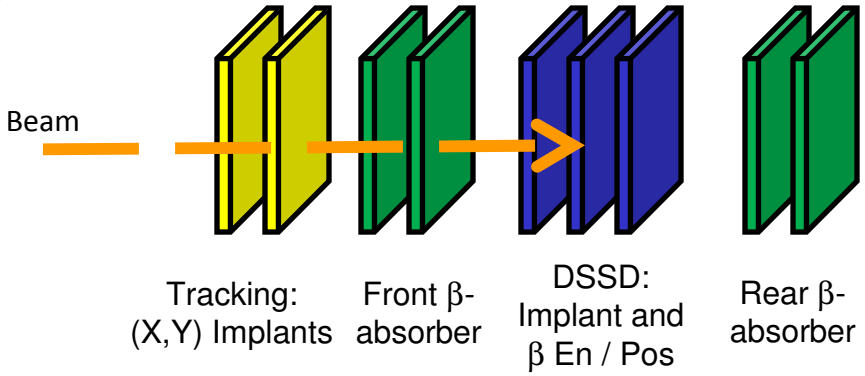


Constructed and developed by

Technische Universität München

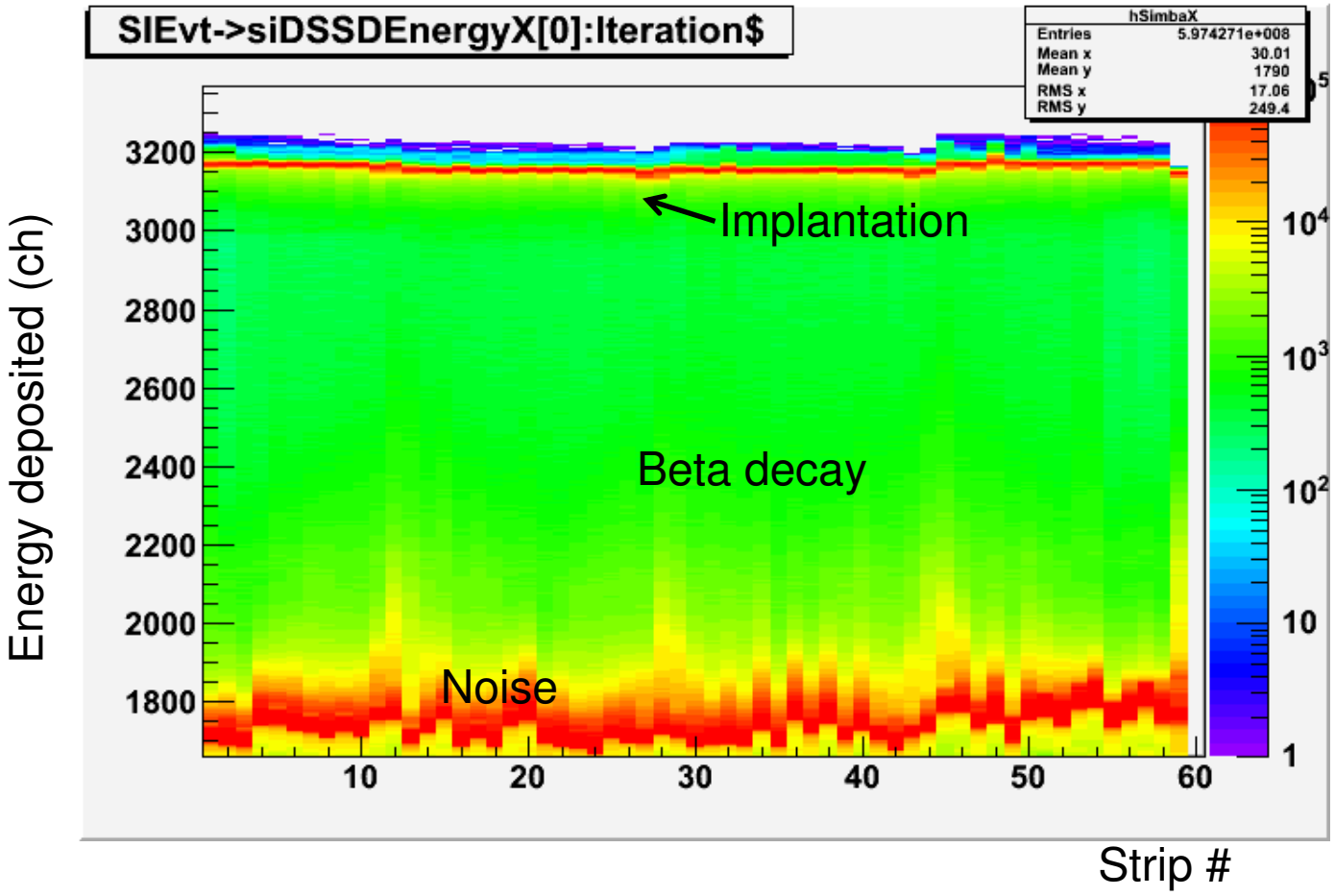
Lehrstuhl E12





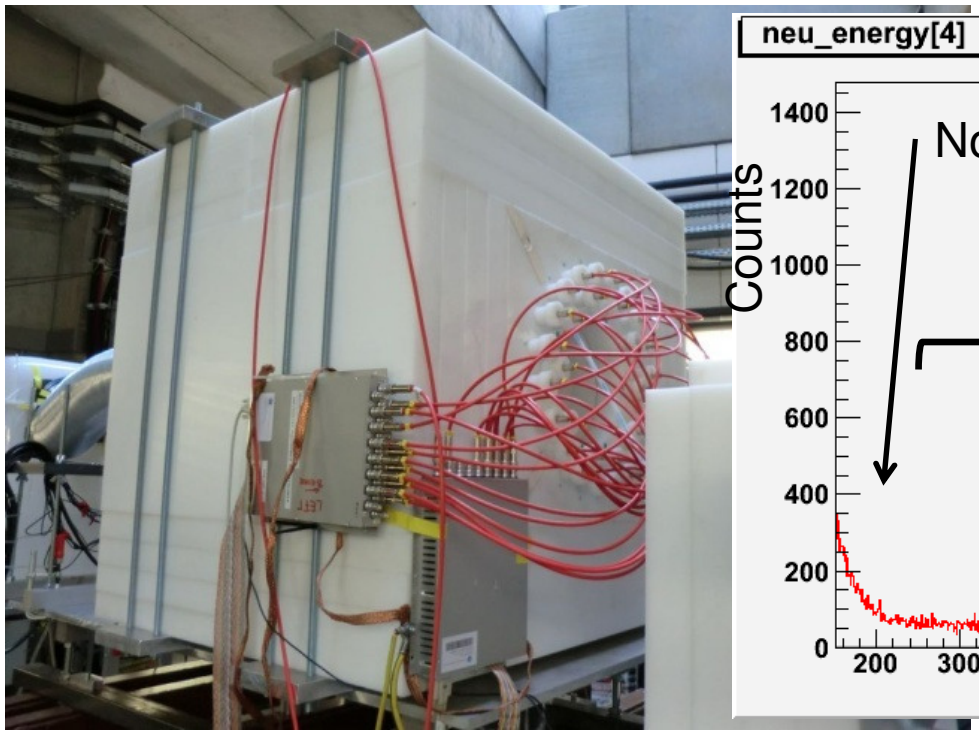
- 60x segm. X and Y-detector
- 7x segm. β-absorber (front and back)
- Implantation area: DSSD, 60x40 segm.

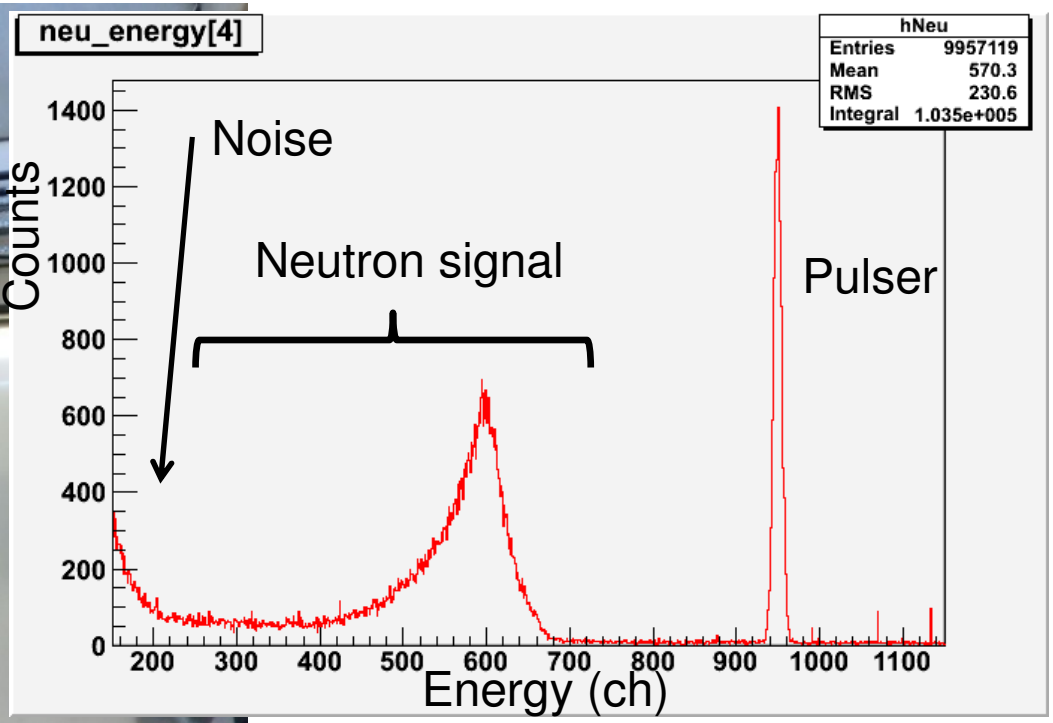
SIMBA: Energy deposited in Si strips



BELEN Beta deLayEd Neutron detector

- Designed for use in DESPEC @ FAIR
- $^{3}He + n \rightarrow {}^{3}H + p + 780\ keV$ $\sigma_{th} = 5400\ b$
- No info about initial E_n , but large efficiency
- Thermalization time $\tau \approx 100\ \mu s$





BELEN-30 Beta deLayEd Neutron detector

- BELEN-30 (90x90x80cm^3 PE)
  - 20 ^{3}He counters (20 atm) outer ring
  - 10 ^{3}He counters (10 atm) inner ring
  - Simul. Efficiency (1keV-1MeV) ~40%
  - self-triggered digital data acquisition system, integrated into MBS

JUSTUS-LIEBIG-UNIVERSITAT GIESSEN

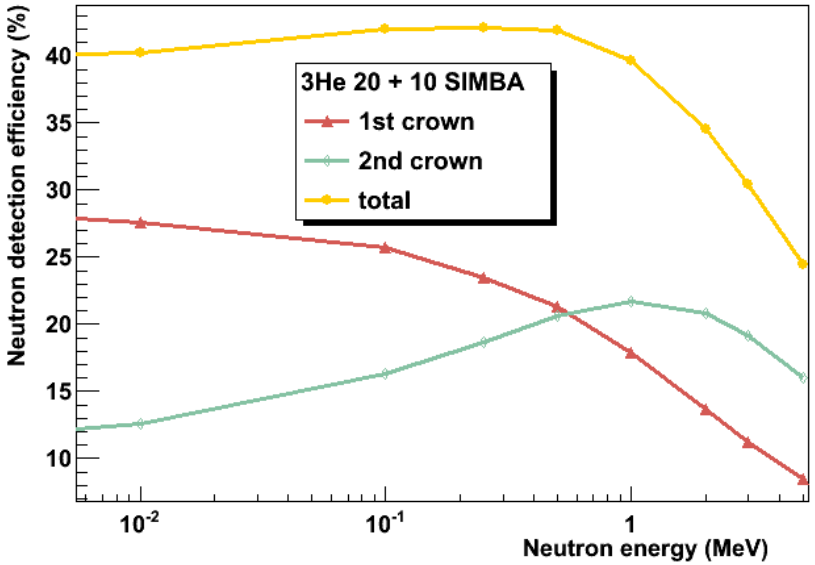
GSI

Universidad Politecnica de Cataluna, Barcelona

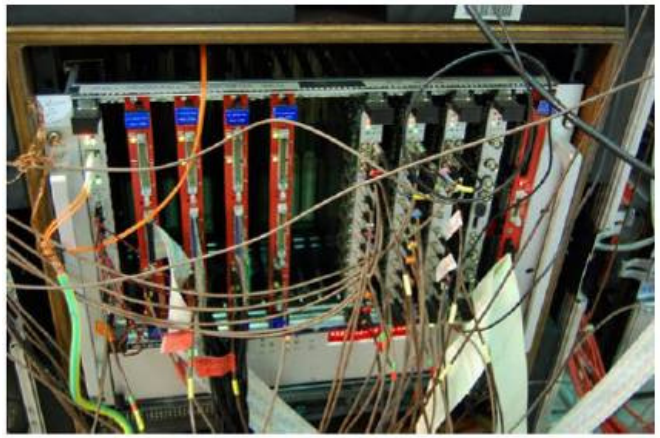
IFIC Valencia

CIEMAT Madrid

Monte Carlo simulation code MCNPX, by B.Gomez



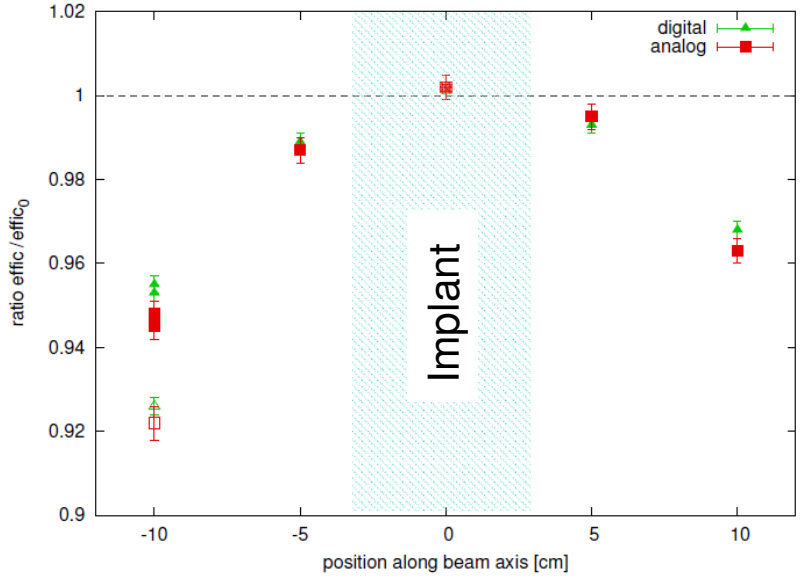
DDAS: self-triggered DAQ



BELEN-30 calibration

- ^{252}Cf source: neutron activity calibrated to 1.6% in PTB (German Institute of Metrology)
- Source centered in BELEN: exper (35±1)%, simul (34.5±0.5)%
- Position dependent efficiency (< 2% relative, for +-3cm shift from center)

Position dependent efficiency



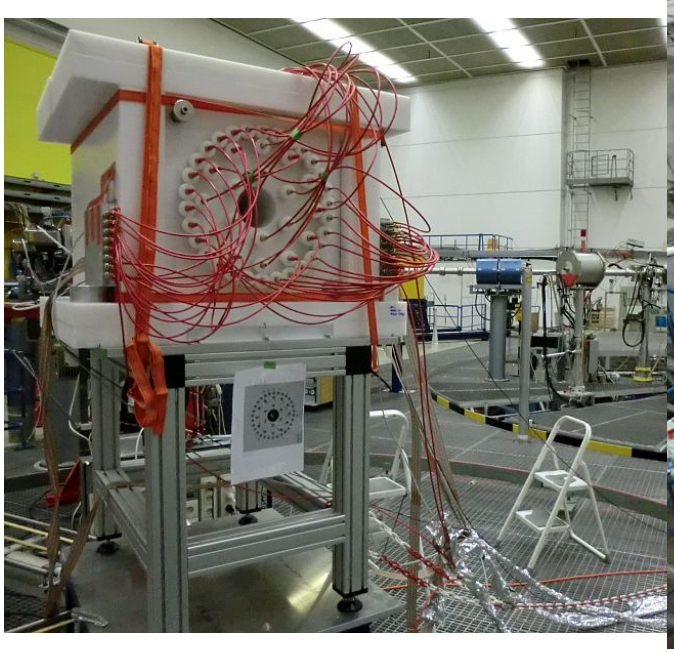
BELEN-48 calibration

Measurement at PTB – Braunschweig, neutron metrology facility:
improve energy-dependent detection efficiency calibration with known (angular/yield) (p,n) (a,n) reactions:

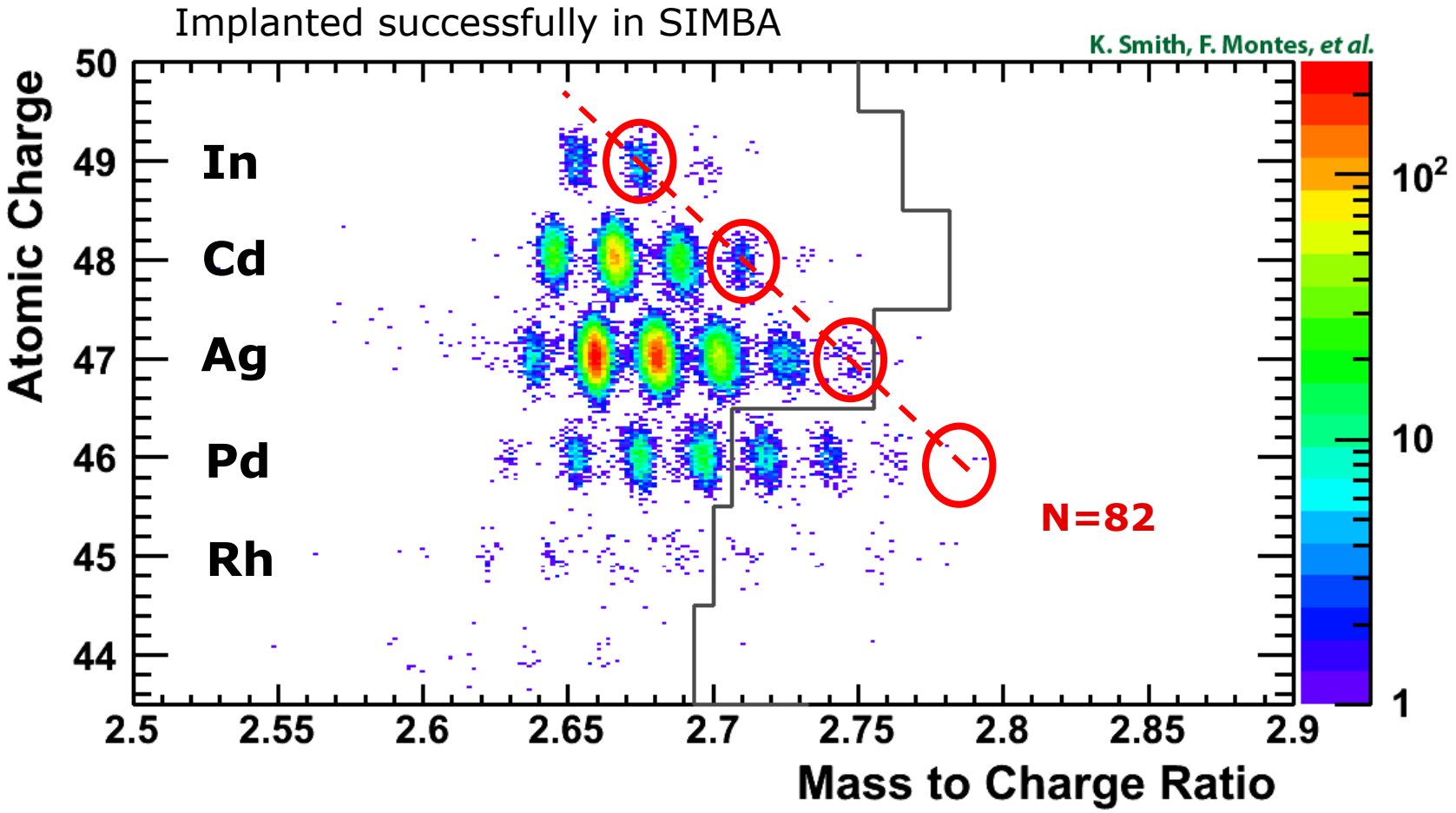
$^{51}V(p,n)^{51}Cr$, E_n= 0.2, 0.6MeV

$^{13}C(p,n)^{13}N$, E_n= 1.0 MeV

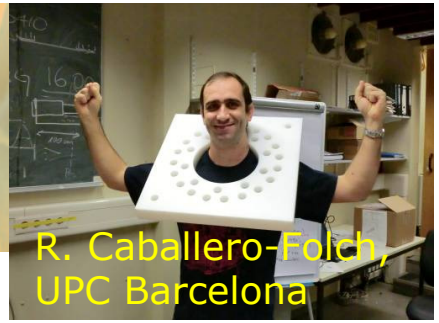
$^{13}C(\alpha,n)^{16}O$, E_n= 2.8, 4.4MeV

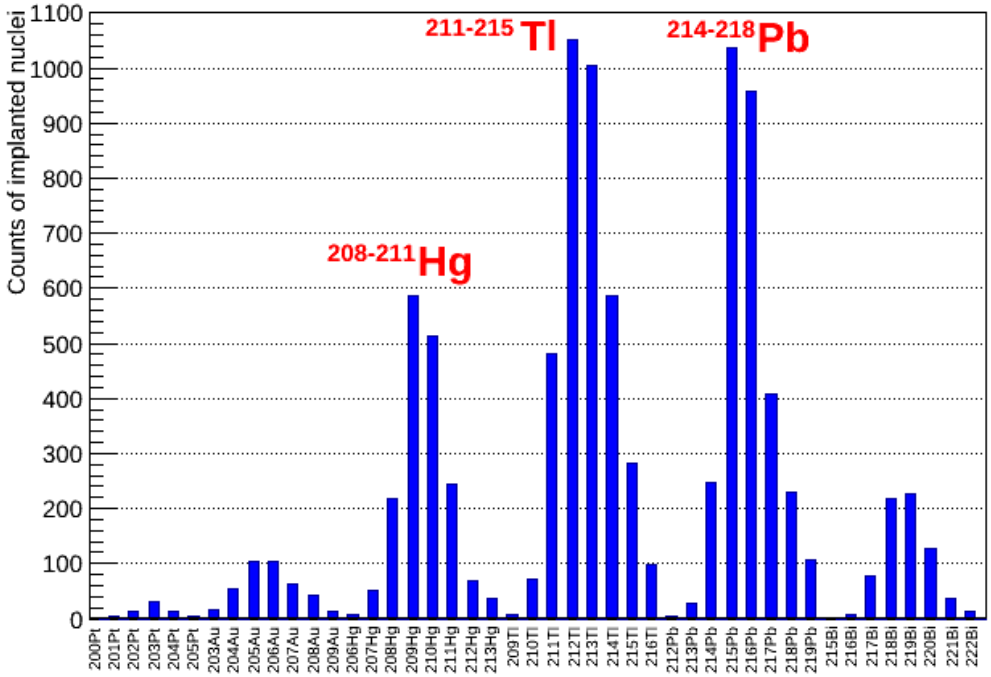


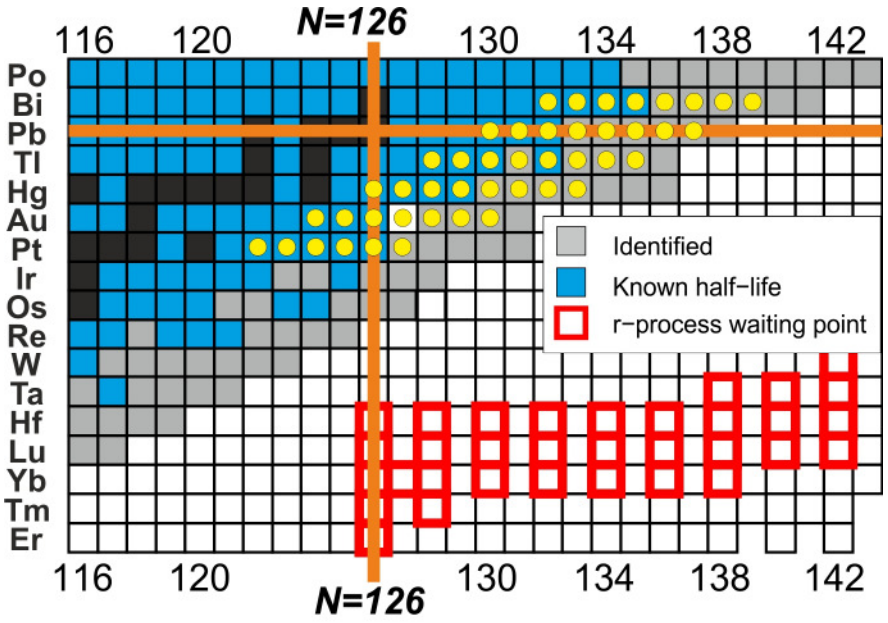
Identified+implanted fragments: S323



Identified+implanted fragments: S410



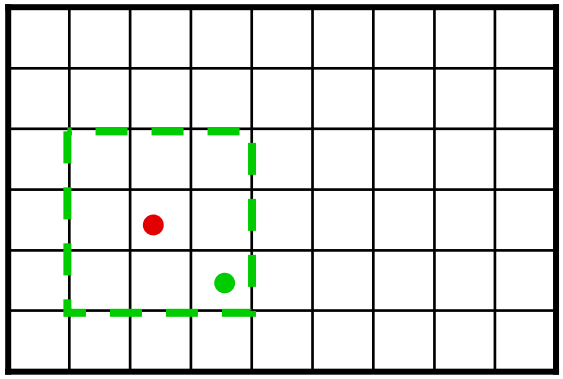




Heaviest βn emitters measured so far

Obtaining half-lives and neutron branchings

- Beta candidates for one implantation event (energy, distance, multipl)
- Time correlation implant – beta (all or only first beta events)
- Background estimation (random position, time backward)



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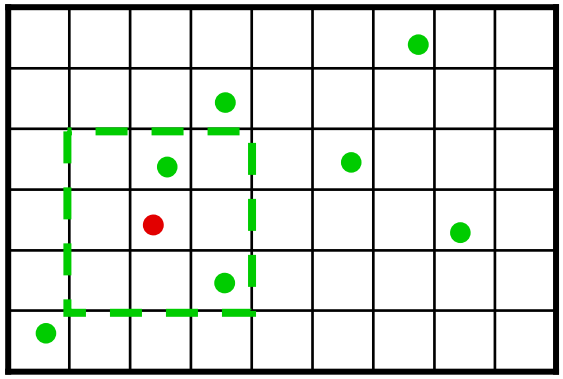

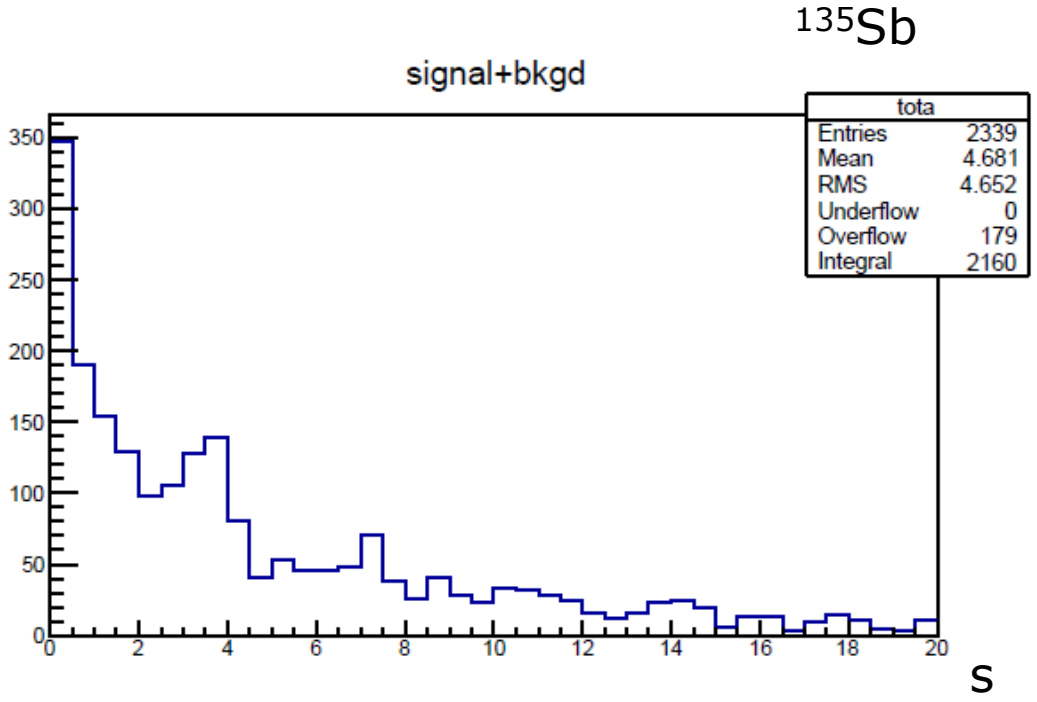

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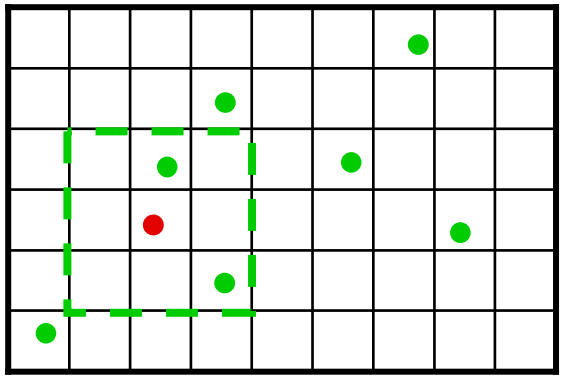

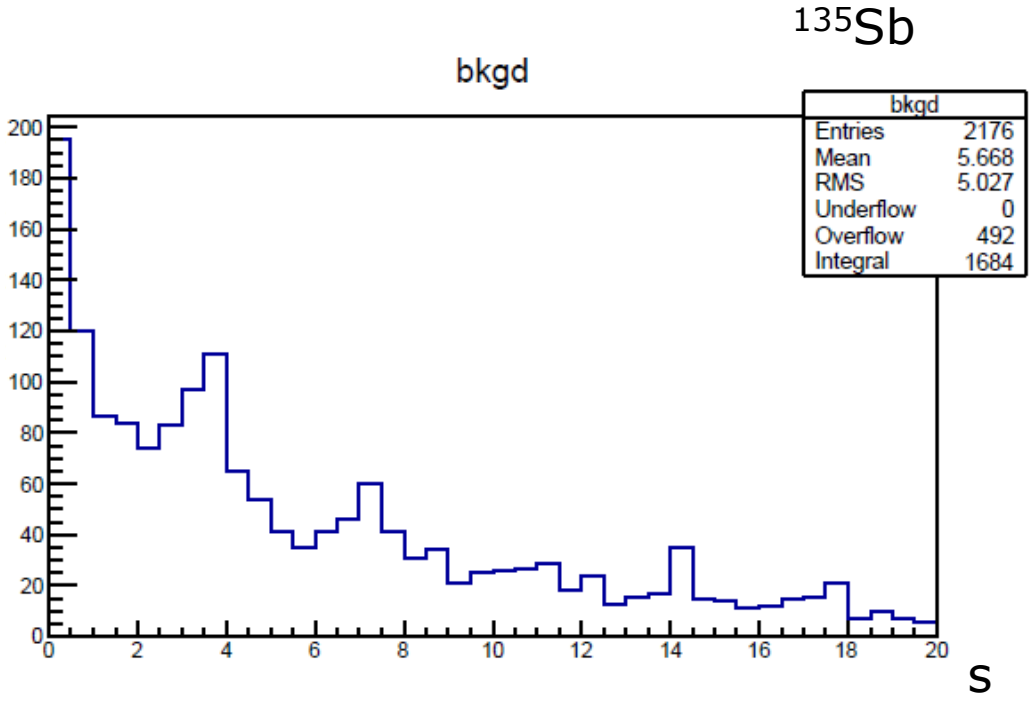

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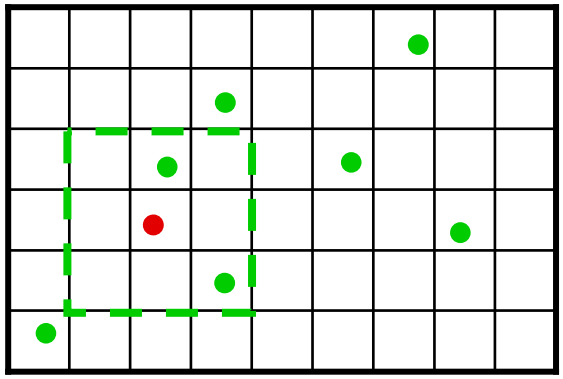

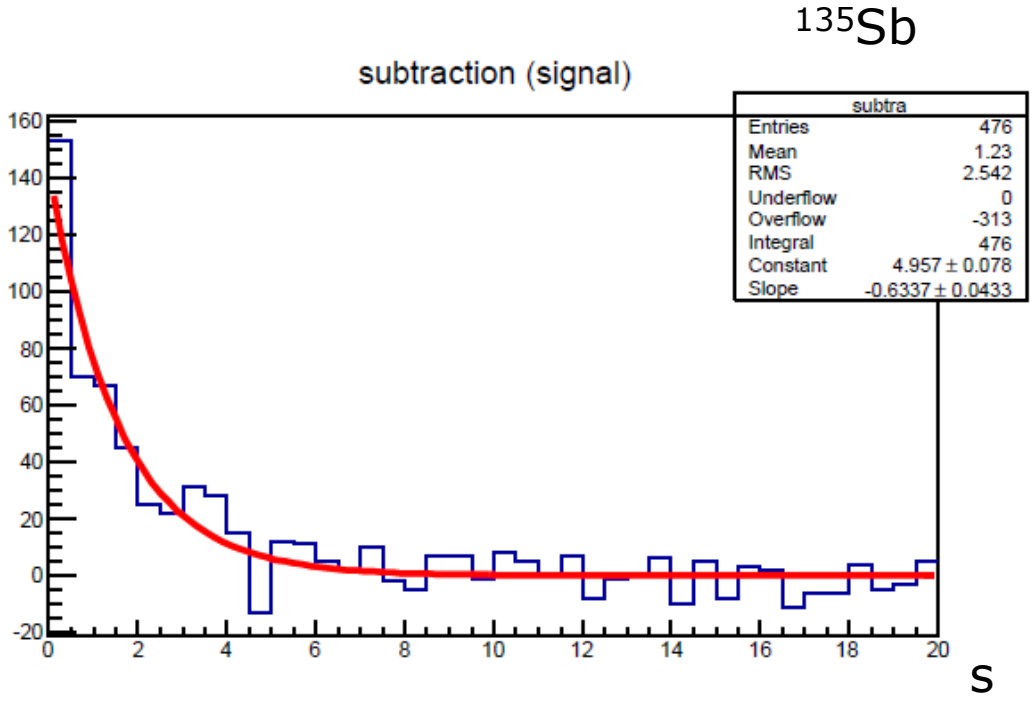

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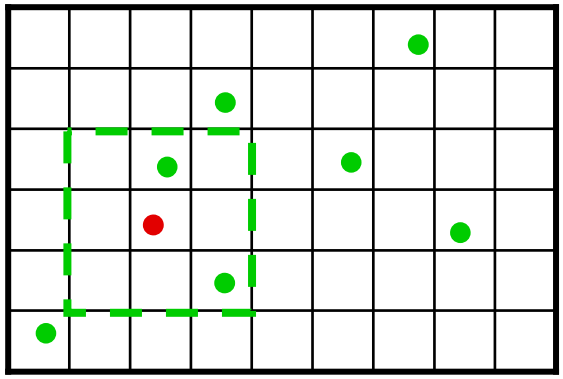
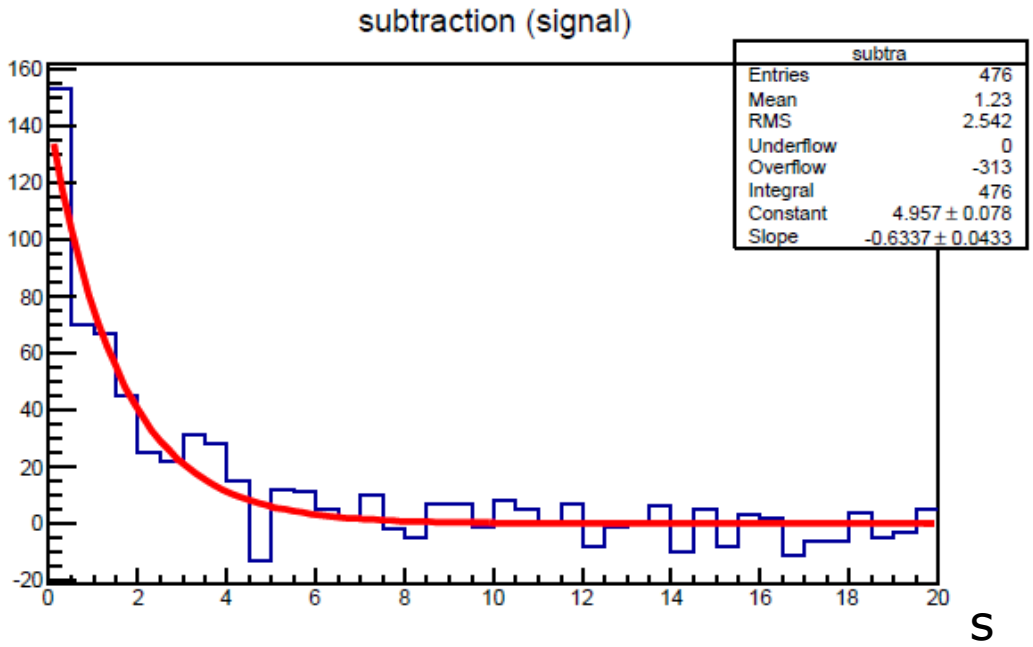


$$P_n = \frac{1}{\varepsilon_n}\frac{N_{\beta n}}{N_\beta}$$

^{135}Sb



- Repeat procedure for neutrons: implant – beta – n correlation

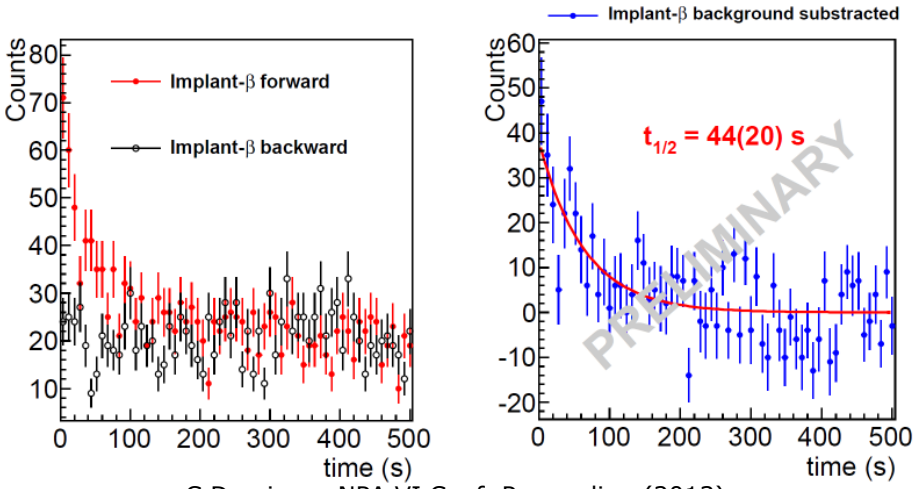
Where do we stand?

- S323, 2nd peak, region Pd Ag Cd:
  - Agreement with literature half-lives
  - 11x preliminary half-lives and Pn
  - K. Smith PhD thesis (beginning next year): "Beta Decay studies of neutron rich Pd and Ag Isotopes "

- S410, 3rd peak, region Au Hg Tl Pb:
  - Preliminary half-lives and Pn presented in Nuclear Data Conference New York
  - R. Caballero-Folch PhD thesis to be submitted next year

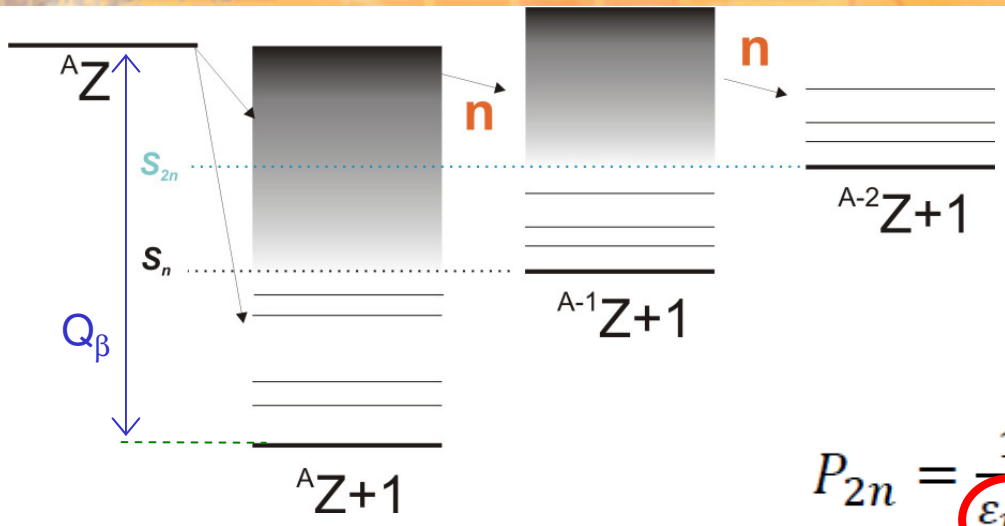
- Almost finished, stay tuned!

^{212}Tl



C.Domingo: NPA VI Conf. Proceeding (2013)

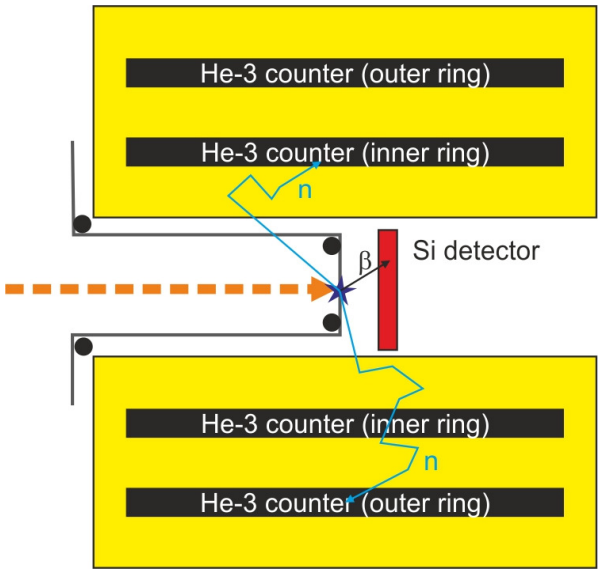
Next experiments: measure β2n



- 18 β2n-emitter known
- New AME2012:
  $Q_b > S_{2n}$
  $Q(\beta 2n) > 500keV$
  } 300 cases

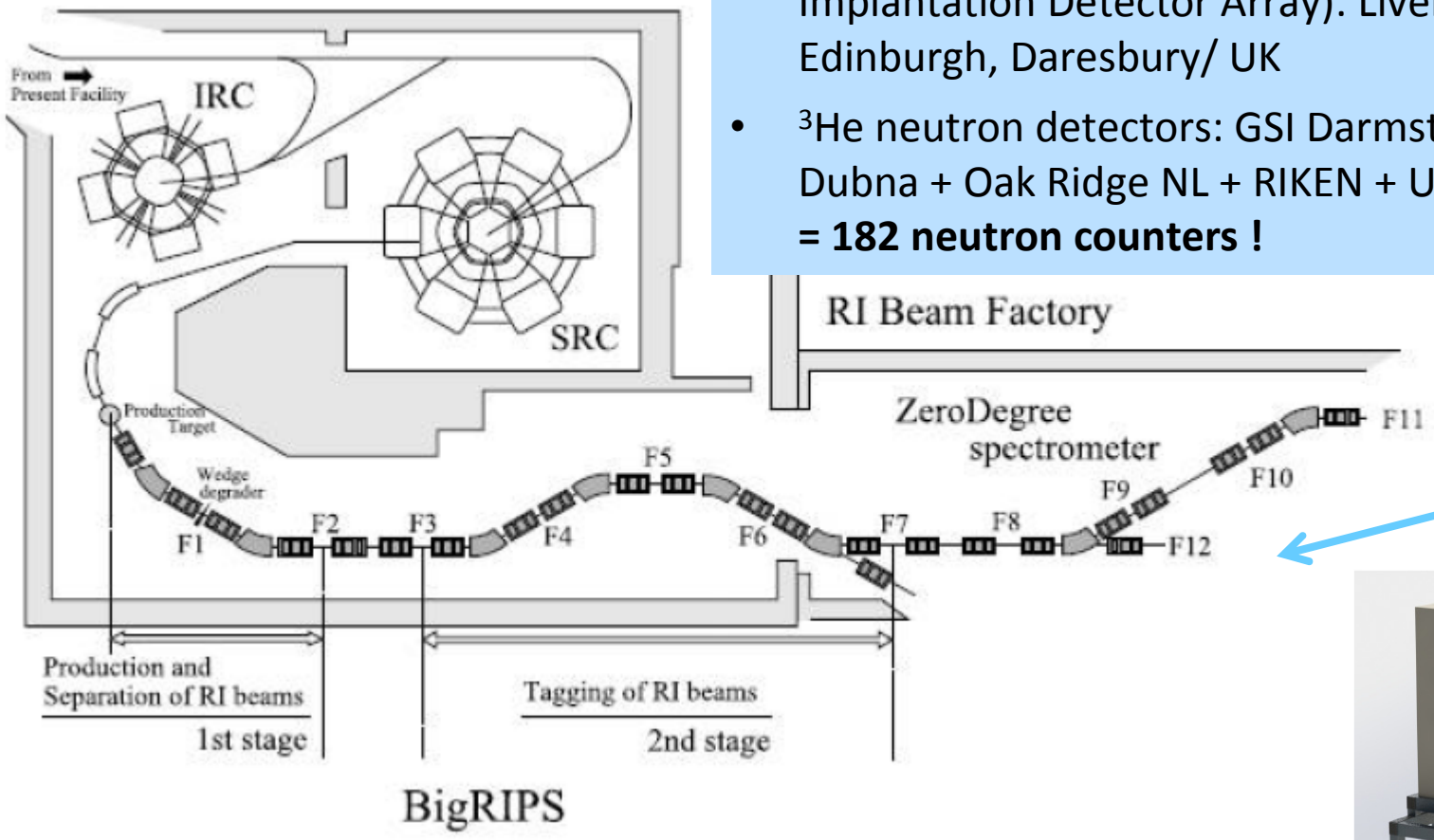
$$P_{2n} = \frac{1}{\varepsilon_n^{\,2}} \frac{N_{\beta nn}}{N_\beta}$$

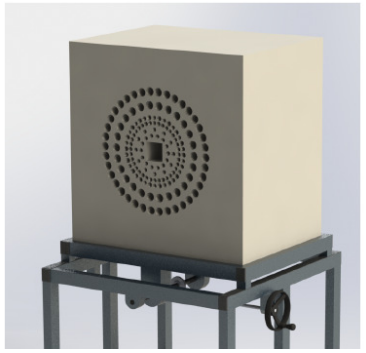
- Upgrade to BELEN-48
- Accepted proposal for IGISOL@Jyväskylä/Finland: P_{2n} (^{136}Sb) and P_n (Sb,I)



RIKEN - Japan

- Implantation setup: **AIDA** (Advanced Implantation Detector Array): Liverpool, Edinburgh, Daresbury/ UK
- ^{3}He neutron detectors: GSI Darmstadt + JINR Dubna + Oak Ridge NL + RIKEN + UPC Barcelona **= 182 neutron counters !**





BRIKEN collaboration

"Beta delayed neutron emission measurements at RIKEN"

- 63 people from
  20 institutes

Institution	Country	Representative(s)
CIEMAT	Spain	D. Cano-Ott
Daresbury Laboraotry	UK	J. Simpson
GSI	Germany	M. Marta
IFIC		
JINR		
JYFL		
Louisiana State Universit		
Mississippi State Universi		
MTA-Atomki	Hungary	Z. Fulop
NSCL-MSU	USA	F. Montes
ORNL	USA	K. Rykaczewski
RIKEN Nishina Center	Japan	G. Lorusso
		S. Nishimura
The University of Tokyo	Japan	K. Matsui
TRIUMF	Canada	I. Dillmann
UPC	Spain	G. Cortés
University of Edinburgh	UK	A. Estrade
University of Guelph	Canada	P. Garrett
University of Liverpool	UK	R. Page
University of Tennessee	USA	R. Grzywacz
University of Warsaw	Poland	A. Korgul

Detector Construction Proposal submitted to RIKEN-PAC, decision in December 2013

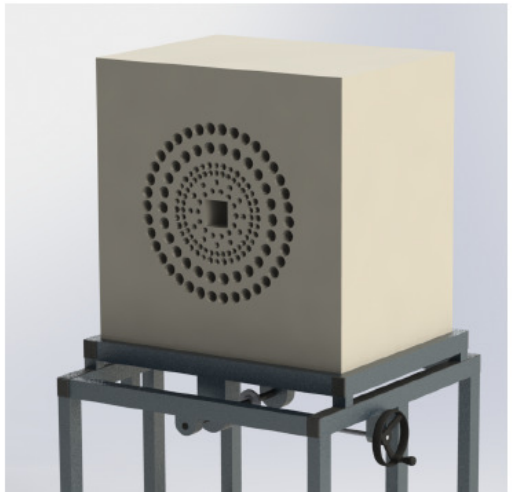
Spokespersons:
Cesar Domingo-Pardo (IFIC Valencia)
Giuseppe Lorusso (RIKEN)

BRIKEN neutron detectors

2 configurations planned:

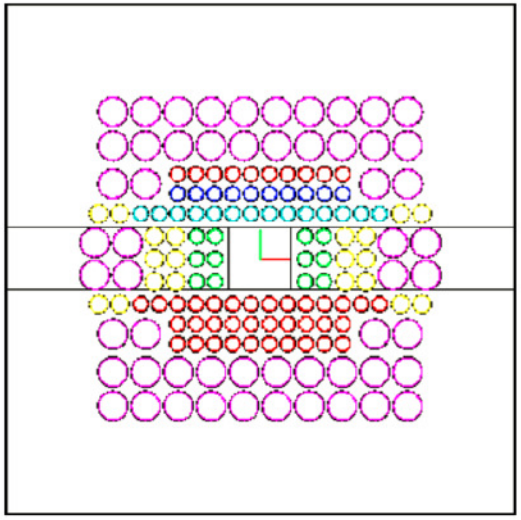
High-efficiency setup

- $\varepsilon_{\beta n}$~80% (E_n= eV- 5 MeV)
- $\varepsilon_{\beta 2n}$~64% (E_n= eV- 5 MeV)

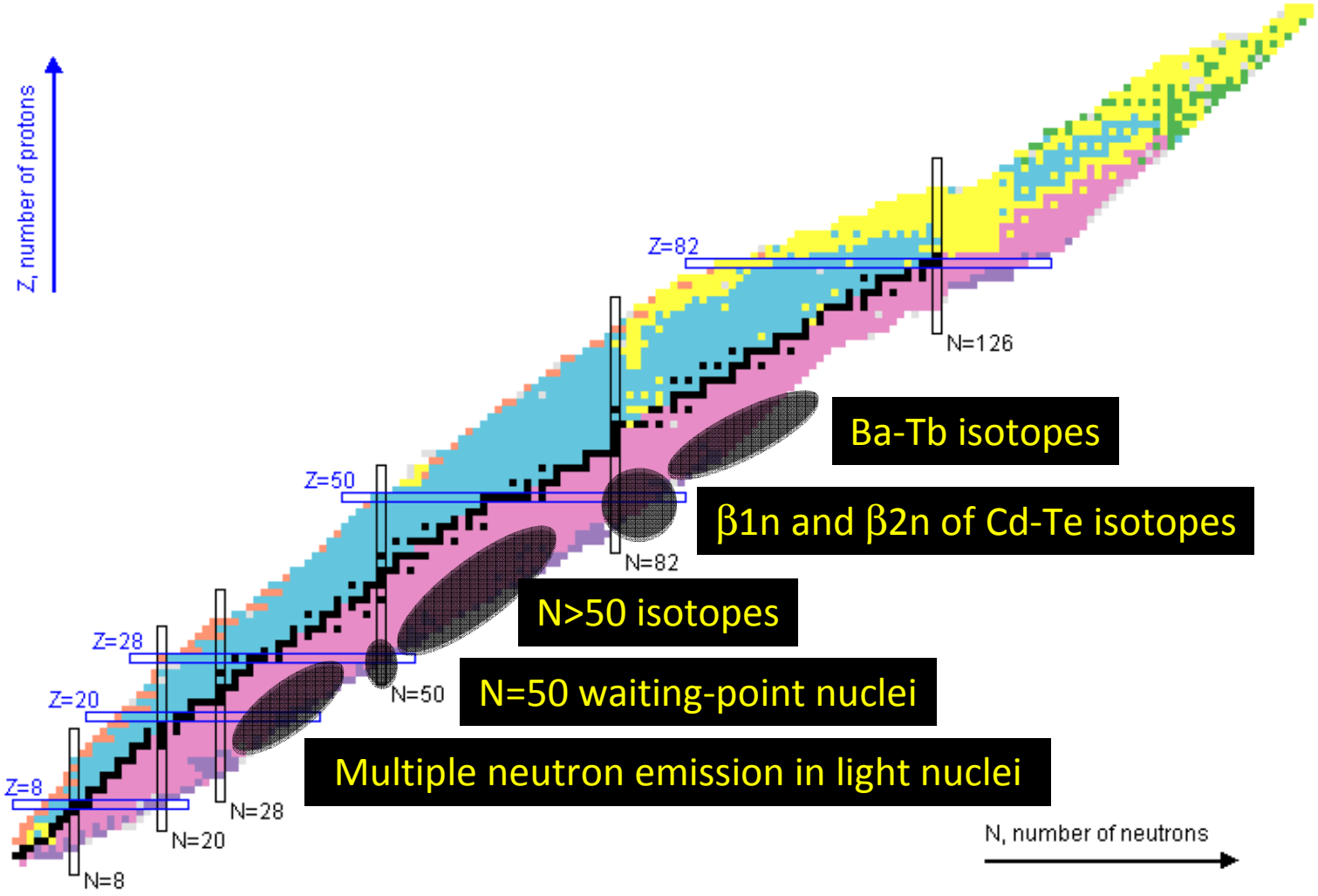


Hybrid setup

- incl. 2 HPGe clovers
- ε_n=76-66% (E_n= 0.5- 2.5 MeV)



BRIKEN: Proposed program



Summary / Outlook

- Need of experimental data for r process

- Two experiments at GSI:
  1. r process nuclei around N=82
  2. South-east of ^{208}Pb: heaviest βdn emitters measured
  - Data analysis almost finished

- Future experiments
  - BELEN upgraded design (higher efficiency)
  - New physics cases: beta-delayed multiple neutron emitters
  - More exotic nuclei with FAIR

Thank you for your attention!

S323-410 Collaboration

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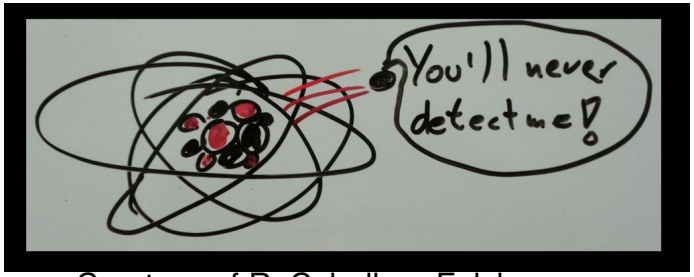

Courtesy of R. Caballero-Folch

EXTRA SLIDES