β-delayed neutron experiments with BELEN

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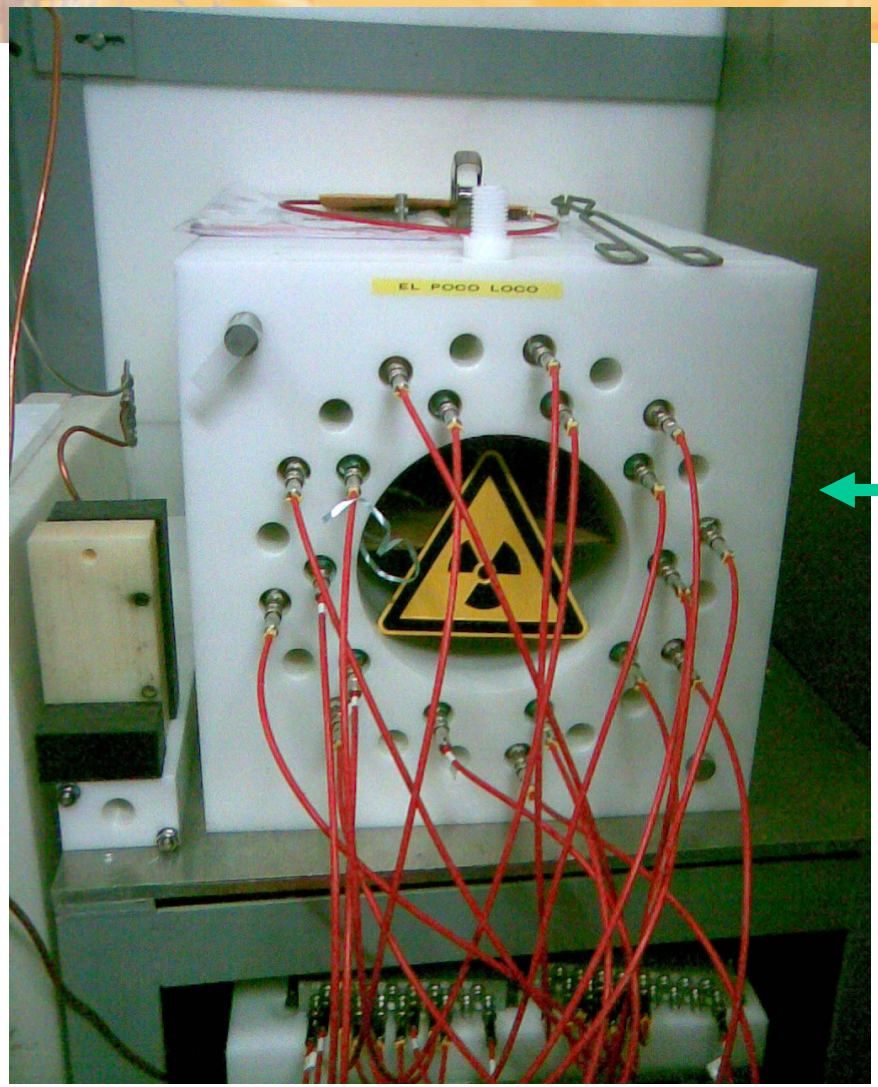
GSI Darmstadt / JLU Giessen, Germany

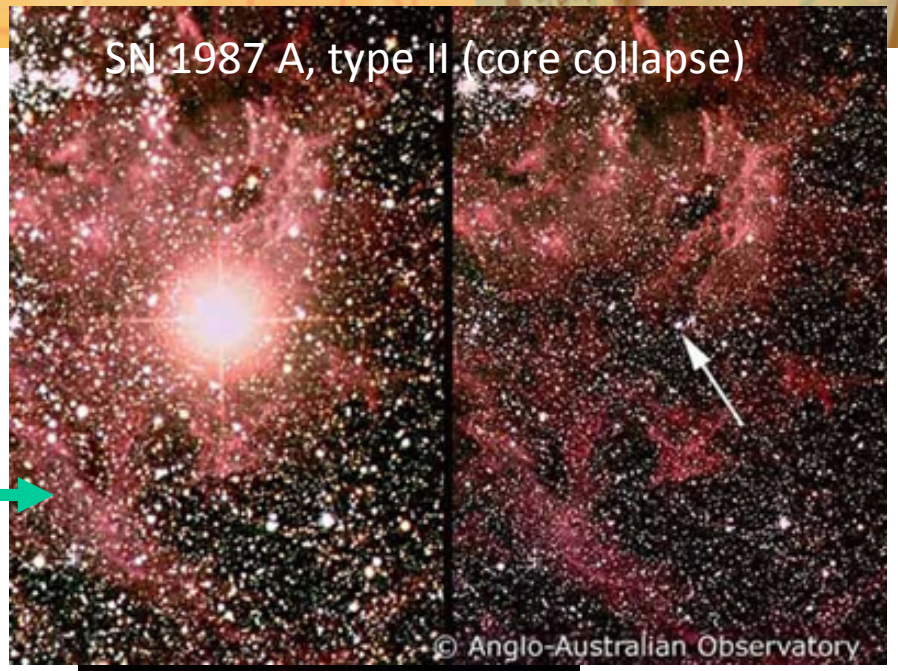
for the BELEN collaboration

NuSTAR annual meeting 2013

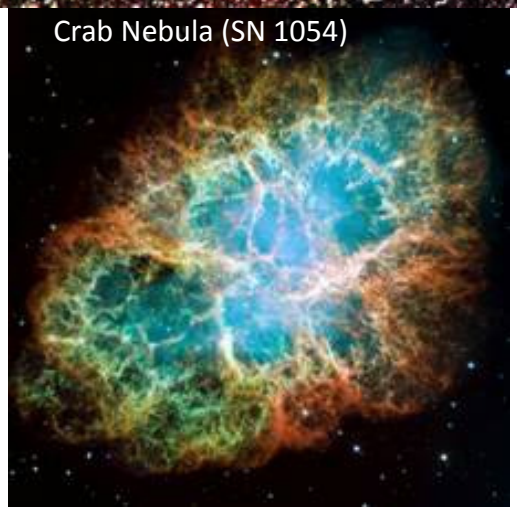
GSI Darmstadt, 28.02.2013

Supported by the Helmholtz Association via the Young Investigators Group LISA





Crab Nebula (SN 1054)



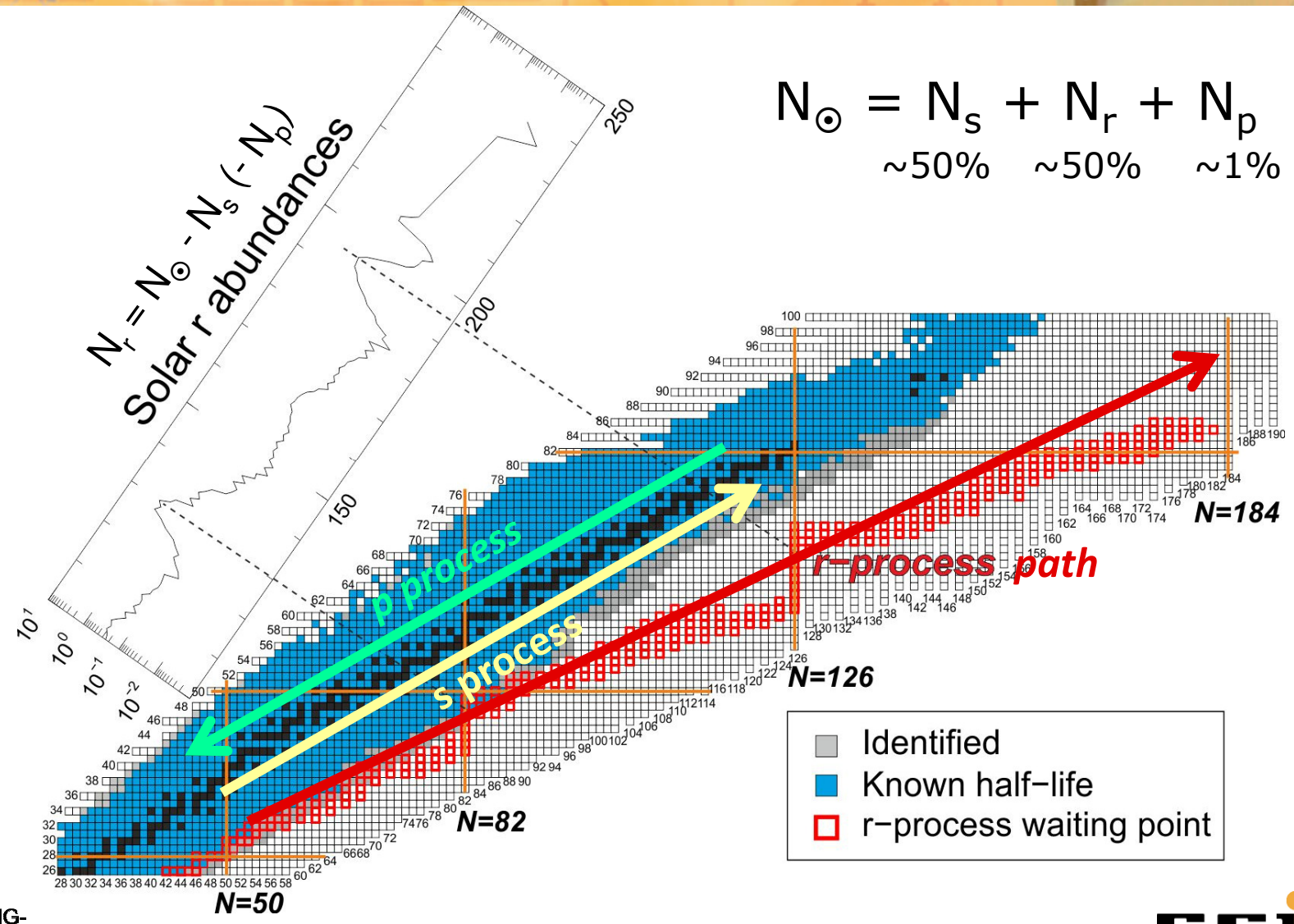
Outline

- r process, beta-delayed neutron emission
- The BEta deLayEd Neutron detector
- Present and future experiments with BELEN
- 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)

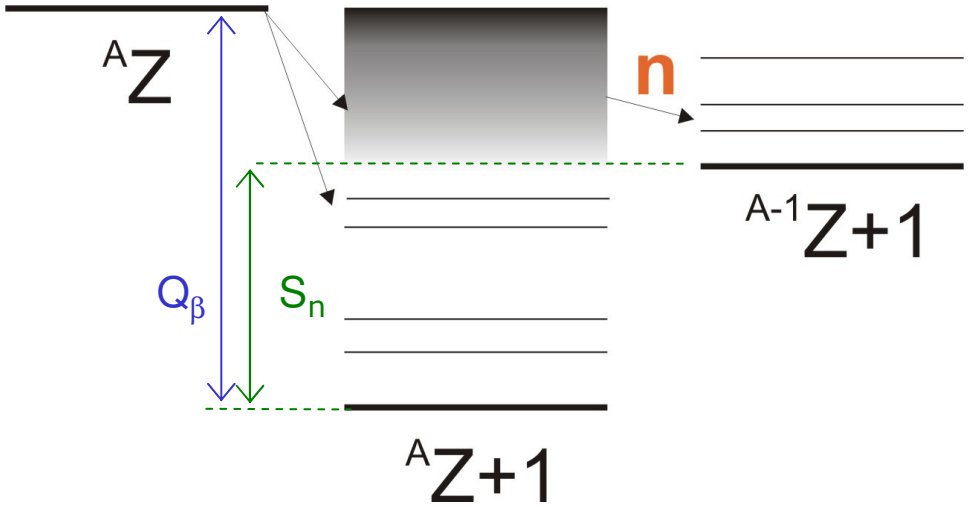
- nuclear input (up to now theoretical calculations tuned to few experimental data available)
  - Masses (→ Q_β, S_n)
  - $t_{1/2}$ (β)
  - (n,γ) cross sections
  - β-delayed neutron branching

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

  → Modified path back to stability and additional neutron source

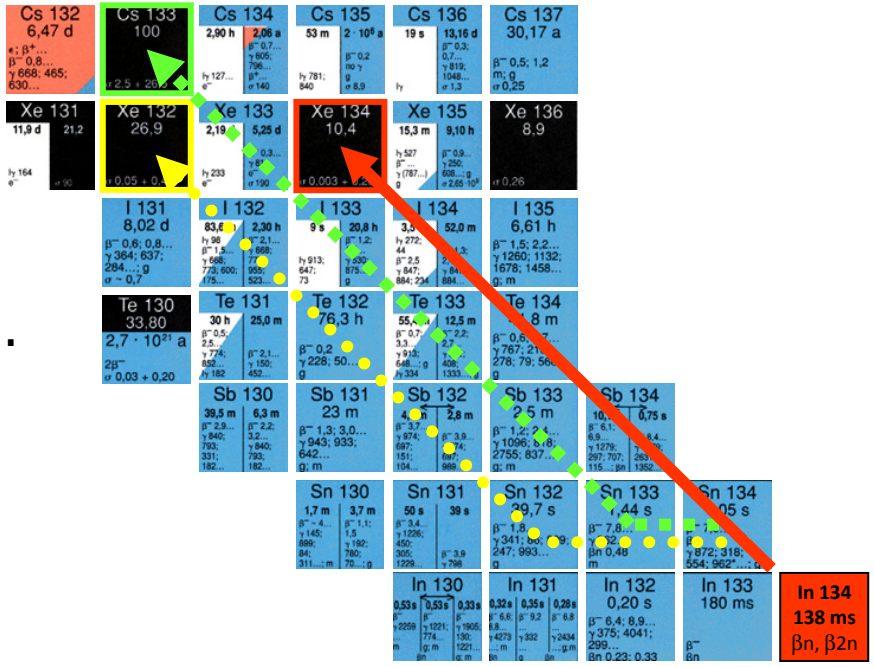
  - others: fission parameters, $t_{1/2}$ (α)…

β-delayed neutron emission



Detecting n →

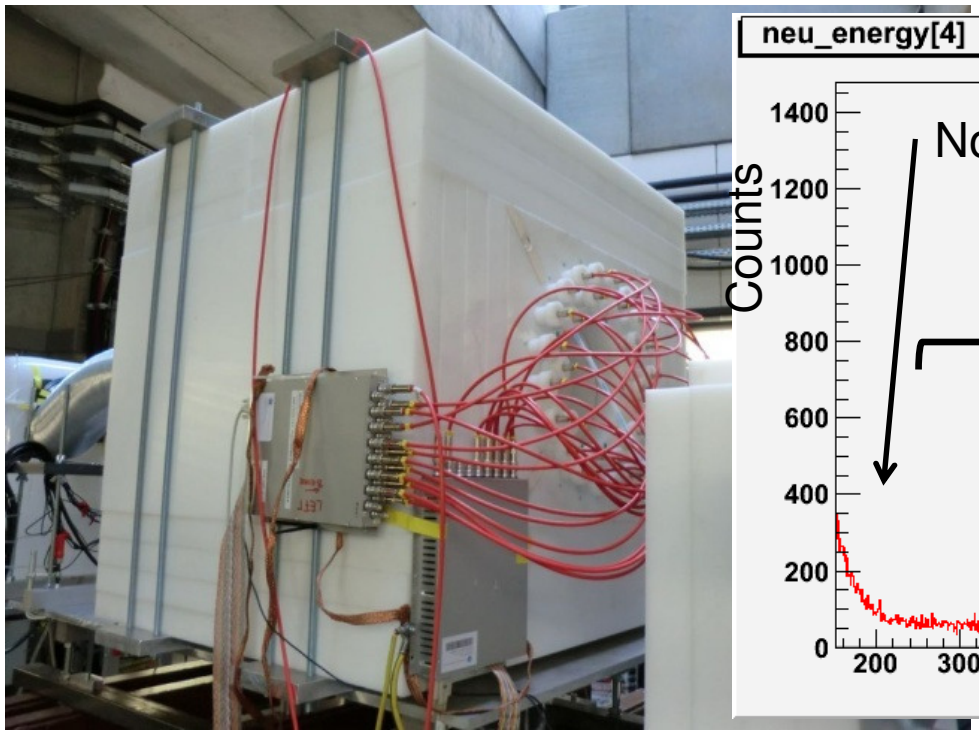
- obtain $t_{1/2}$ (^{A}Z)
- P(n) branching
- study β-strength function above S_n

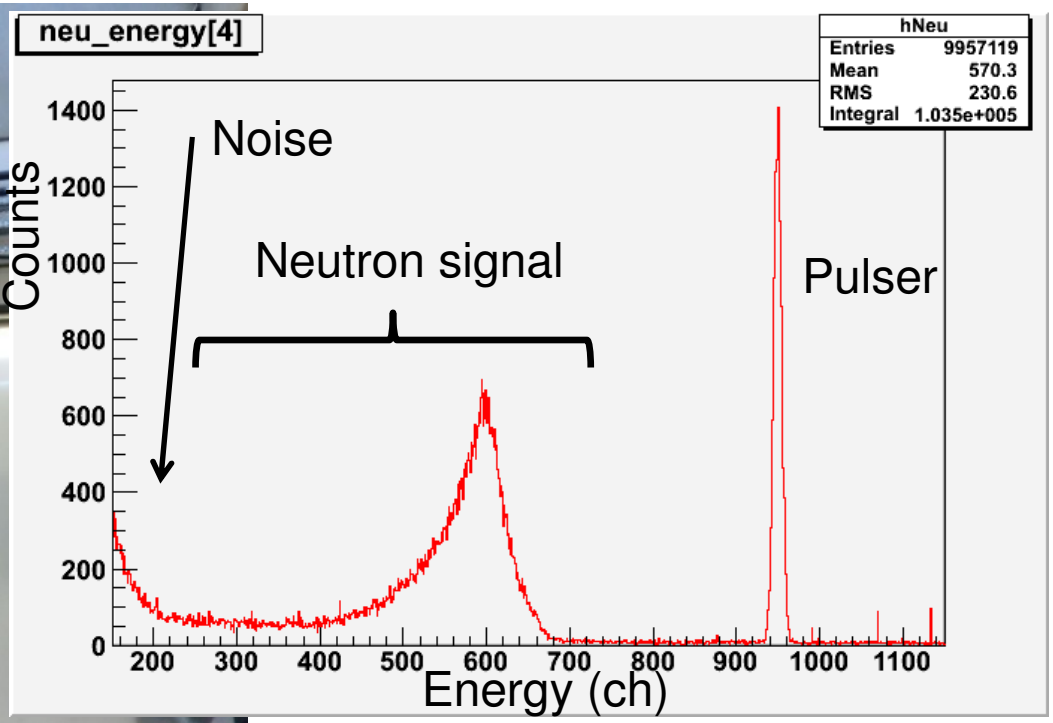


- $Q_\beta > S_n$ (or > $S_{2n,\ 3n}$)
- Discovered in 1939 by Roberts et al.
- $t_{1/2}$≈ few ms – 55.65 s (^{87}Br)
- ^{8}He- ^{150}La: ≈ 230 datasets available
- Only one for A>150 (^{210}Tl)

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

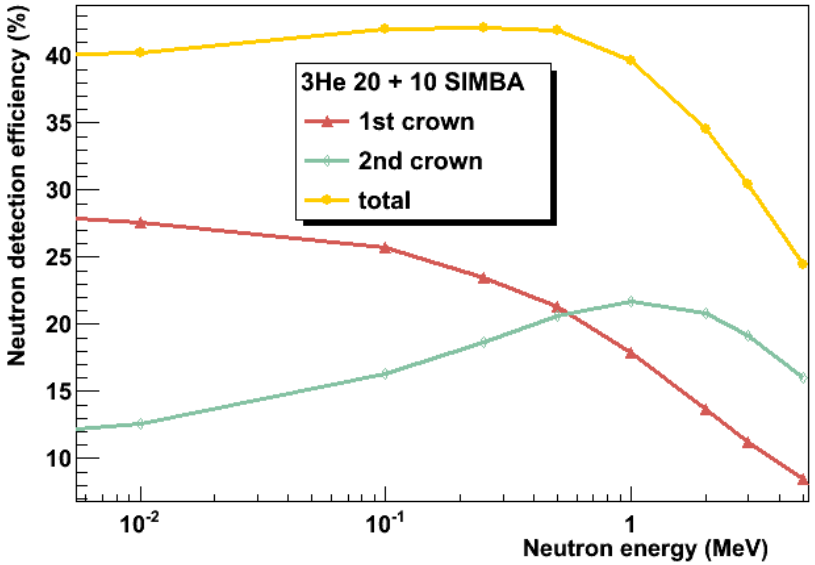
GSI

Universidad Politecnica de Cataluna, Barcelona

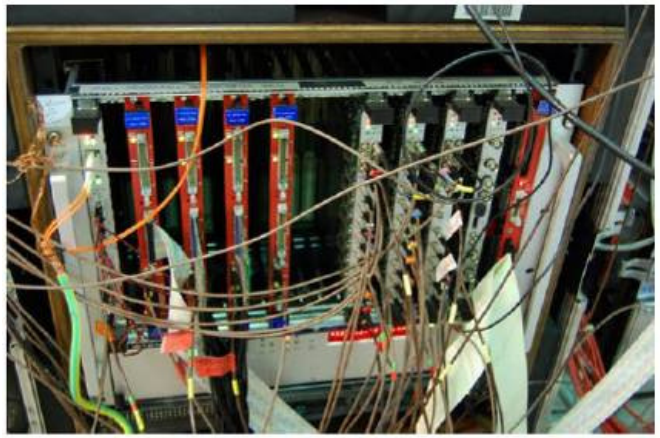
IFIC Valencia

CIEMAT Madrid

Monte Carlo simulation code MCNPX, by B.Gomez



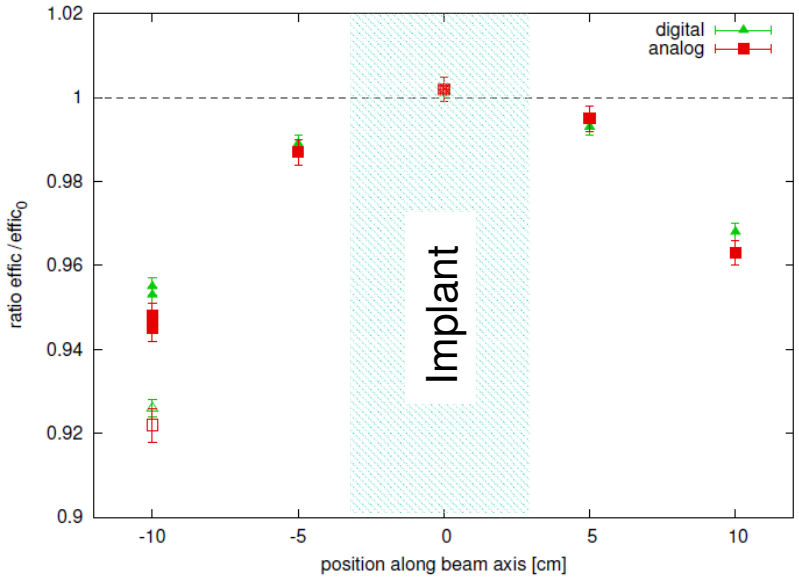
DDAS: self-triggered DAQ



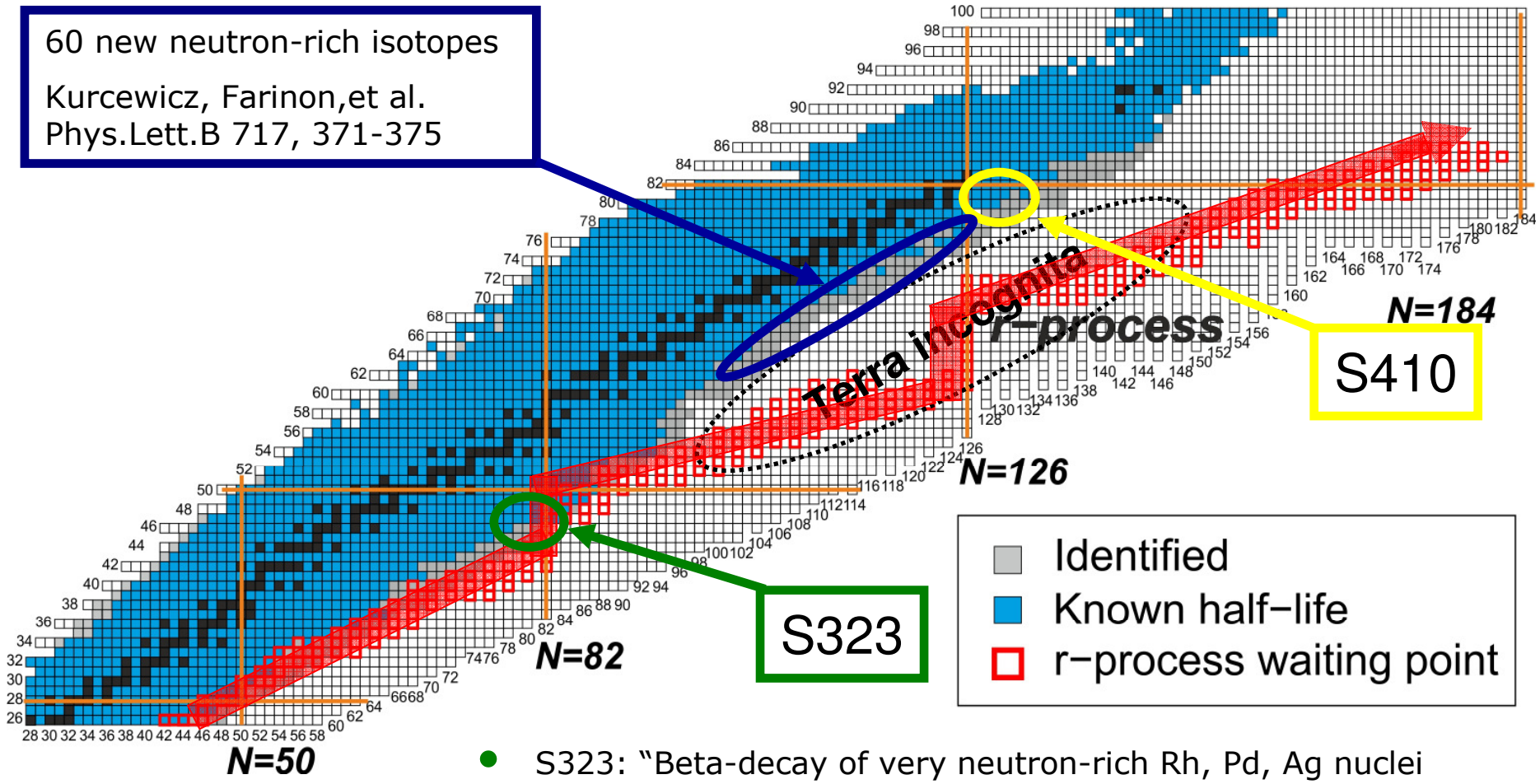
BELEN-30 commissioning

- ^{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



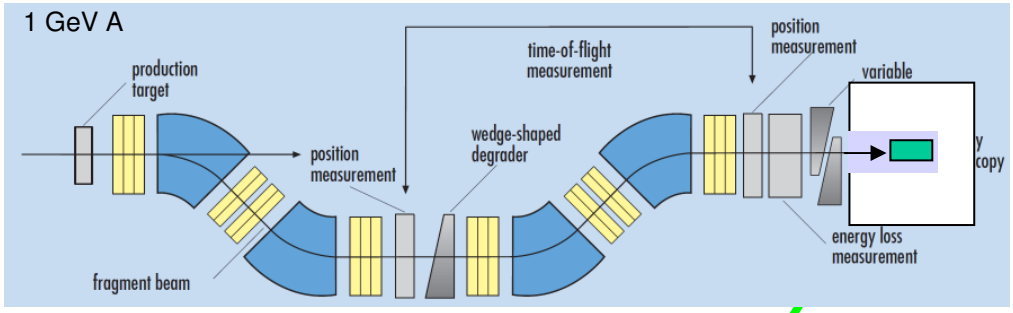
GSI campaign 2011



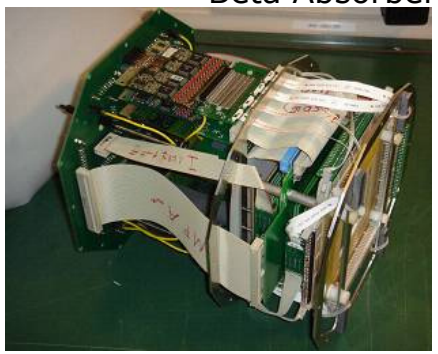
- S323: "Beta-decay of very neutron-rich Rh, Pd, Ag nuclei including the r-process waiting point ^{128}Pd". (F. Montes et al.)
- S410: "Measurement of beta-delayed neutrons around the third r-process peak". (C. Domingo et al.)

Setup at FRS final focal plane

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



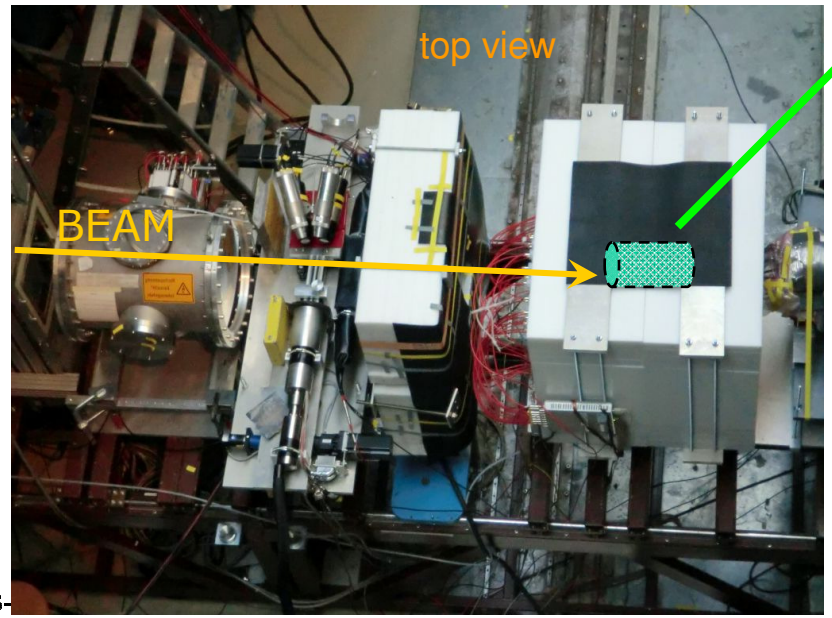
SIMBA Silicon IMplantation detector and Beta Absorber

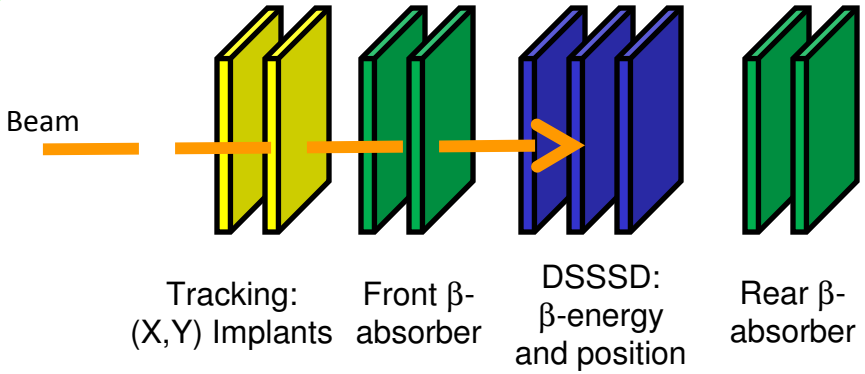


Constructed and developed by

Technische Universität München

Lehrstuhl E12

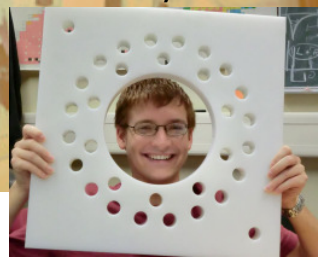




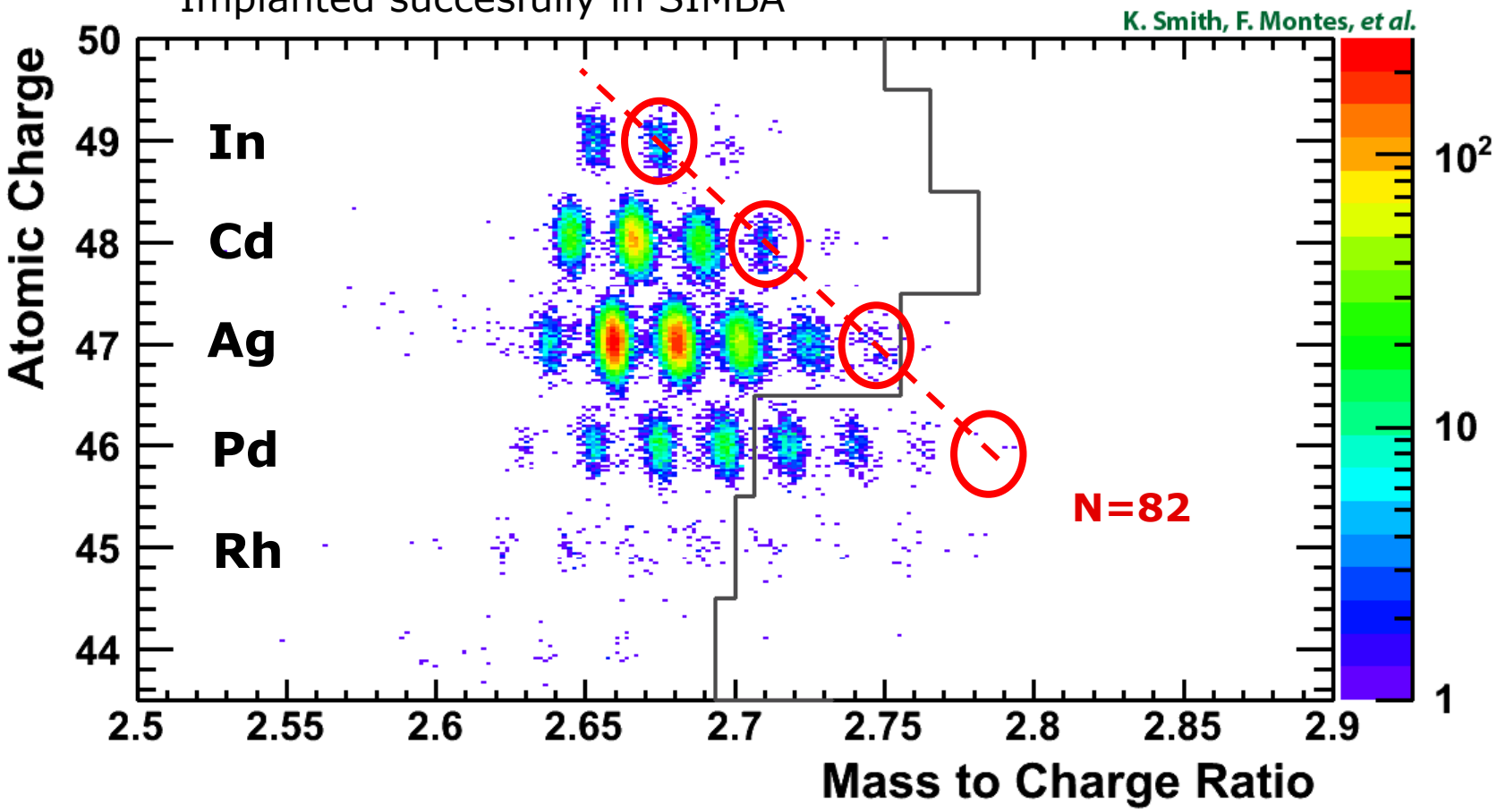
- 60x segm. X and Y-detector
- 7x segm. β-absorber (front and back)
- Implantation area: DSSD, 60x40 segm.

Identified+implanted fragments: S323

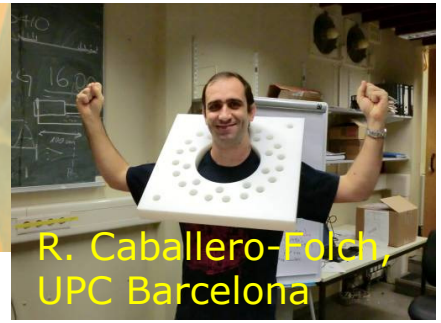
K. Smith, MSU

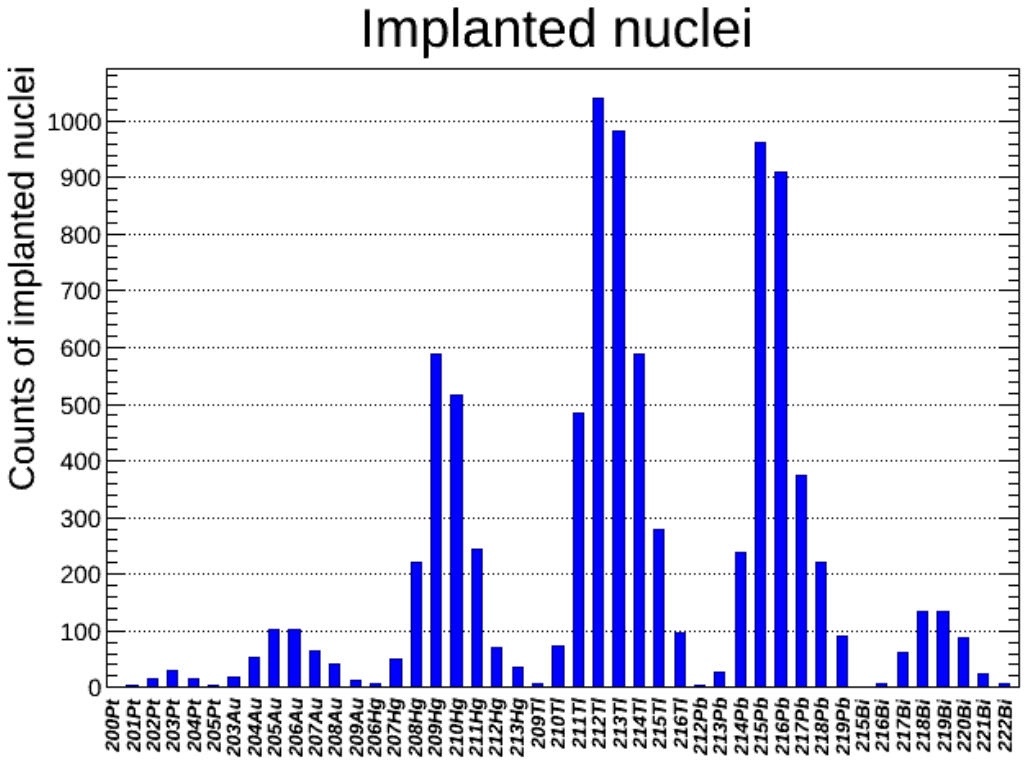


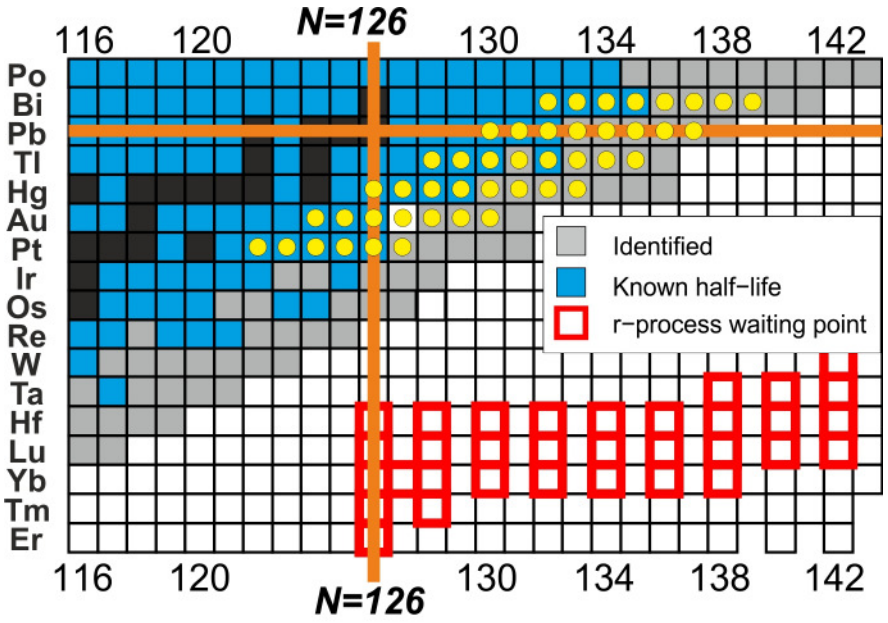
Implanted succesfully in SIMBA



Identified+implanted fragments: S410







Heaviest βn emitters measured so far

intermezzo

- First successful BELEN experiments at GSI:
  - Digital DAQ implemented and working
  - data analysis in progress: $t_{1/2}$ and P_n values
- Two experiments:
  1. r process nuclei around N=82
  2. South-east of ^{208}Pb: heaviest βdn emitters measured

- BELEN development towards FAIR (>2020)
  - Upgraded design (higher efficiency)
  - New physics cases: beta-delayed multiple neutron emitters

BELEN upgrade

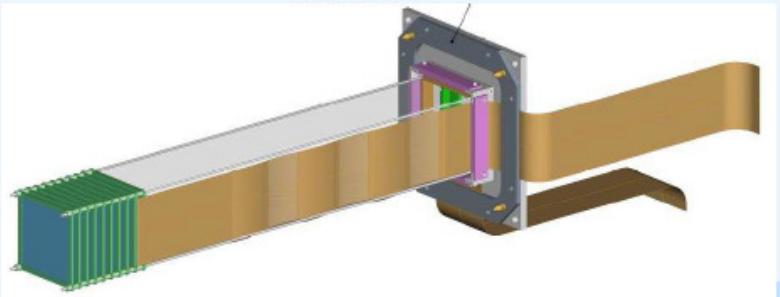
BELEN versions designed

Name	^{3}He counters	Pressure (atm)	Experiment	Average Efficiency	Central hole radius (cm)	
BELEN-20	20	20	JYFL-2009	27%	5.5	2009
BELEN-20	20	20	JYFL-2010	35%	5.5	2010
BELEN-30	20+10	20 & 10	GSI-2011	35 %	11.5 (SIMBA)	2011
BELEN-48	40+8	8 & 10	JYFL-2013	37%-52%	6	2013
BELEN-48	40+8	8 & 10	RIKEN	34%-50%	8 (AIDA)	2014/15
BELEN 48	40+8	8 & 10	RIKEN	???	Local imp. detector	...
BELEN-96	**96**	**3, 8 & 10**	**FAIR/ DESPEC**	**~65%**	**8 (AIDA)**	>2018

See differences:

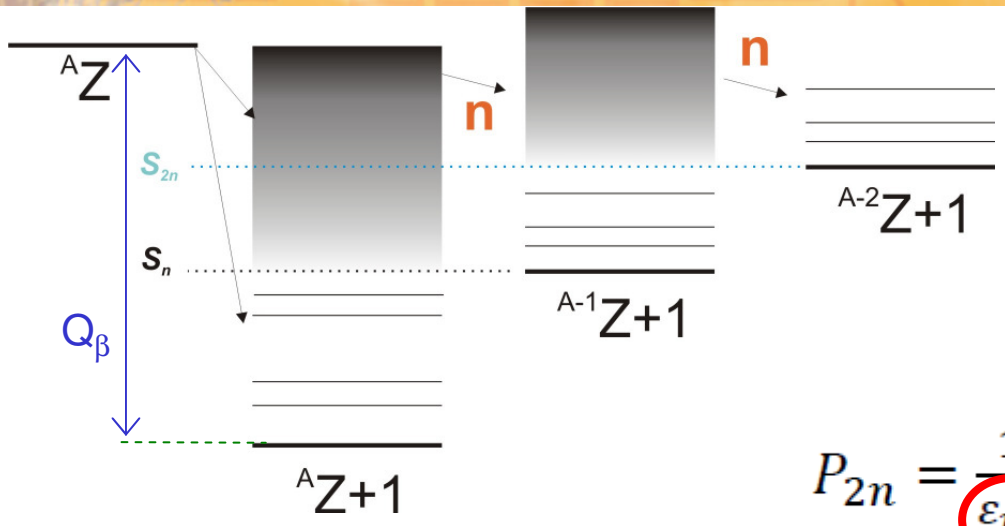
- Central hole
- Number of counters
- Distance of rings

AIDA



R. Caballero, BRIKEN Workshop (17.12.2012)

Next experiments: measure β2n

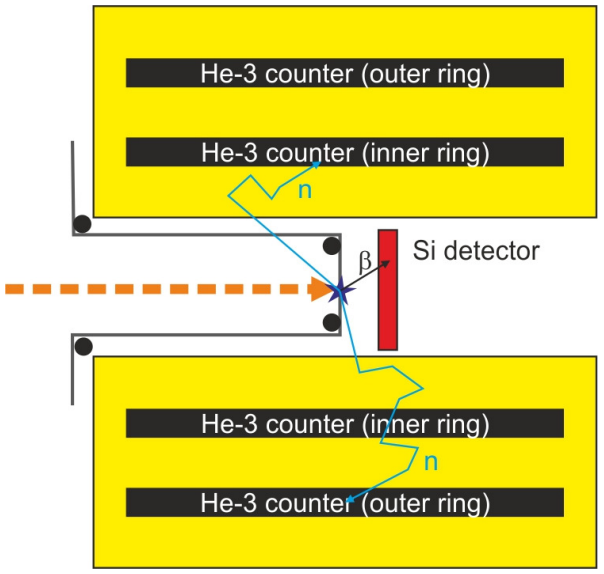


- 18 β2n-emitter known
- New AME2012:
  $Q_b > S_{2n}$
  $Q(\beta 2n) > 500keV$
  } 305 cases

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

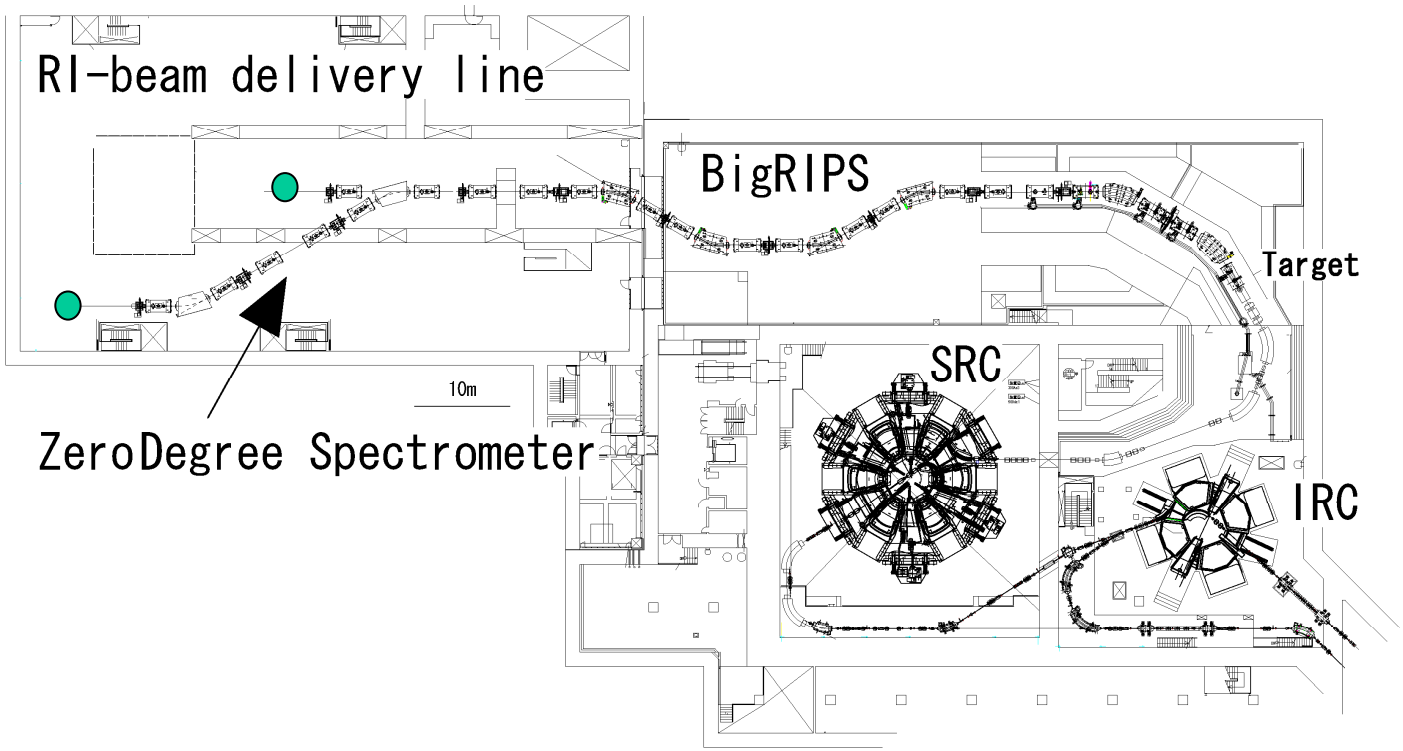
- Upgrade to BELEN-48
- PTB: improve energy-dependent detection efficiency calibration with well known (angular/yield) (p,n) reactions

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



RIKEN / Japan (under discussion)

- First of the next generation RIB facility online
- Best opportunity to test BELEN+AIDA under FAIR-like conditions (plus interesting physics output!!!)
- Workshops: Valencia December 2012, RIKEN summer 2013



Conclusion / Outlook

- First experiment at GSI (2011):
  - $t_{1/2}$ and P_n of very neutron-rich βn emitters: BELEN-30
  - data analysis in progress

- Future of BELEN:
  - Jyväskylä (Finland) 2013: BELEN-48
  - RIKEN (Japan) >2014: BELEN-48 + AIDA?
  - …
  - DESPEC@FAIR: BELEN-96 (including Dubna counters)

- βn in a storage ring (simulations by A. Evdokimov)
  - Complementary method
  - Independent of neutron detection
  - Possible (now!) in ESR, later in CR (ILIMA collaboration)

A. Evdokimov et al., Proceedings of Science, PoS (NIC XII) 115

Thank you!

S323-410 Collaboration

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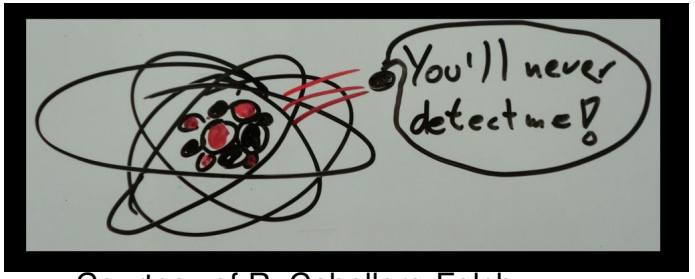

Courtesy of R. Caballero-Folch

EXTRA SLIDES