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

From the lab to the cosmos: Measuring neutron-rich isotopes at TRIUMF (and Jyväskylä) and RIKEN

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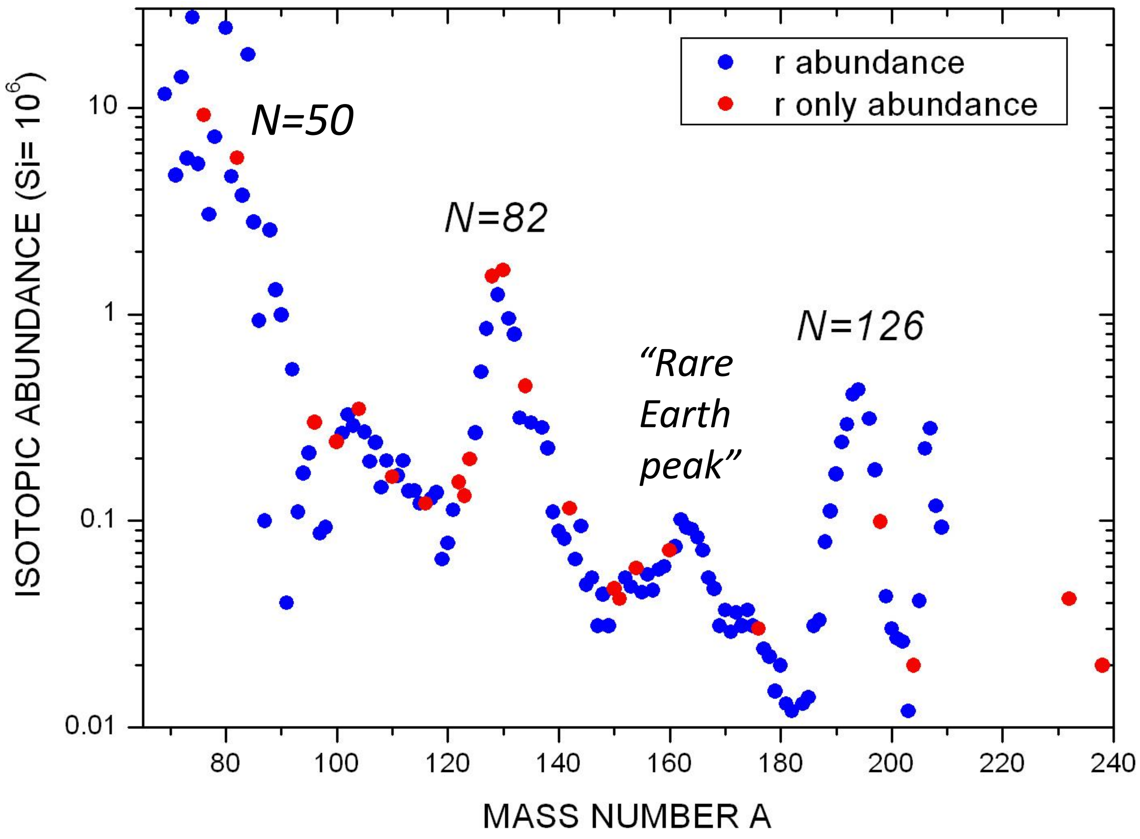
Adjunct Professor (University of Victoria)

June 28, 2017

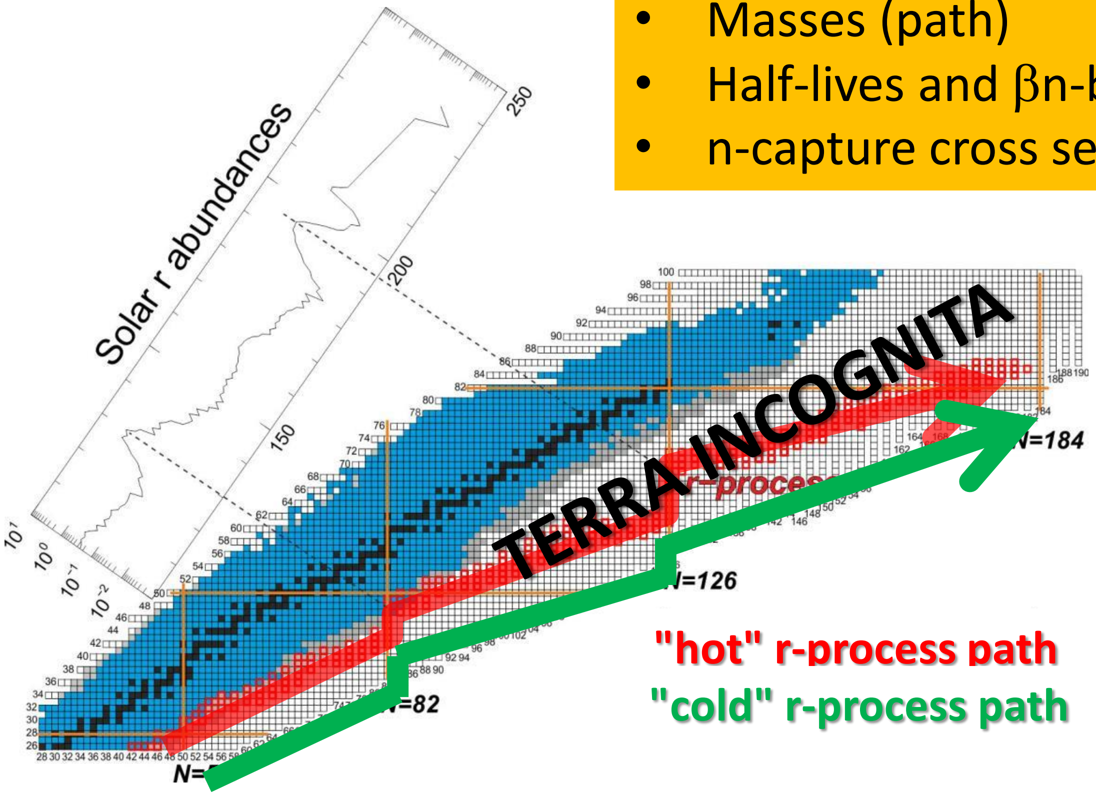
Connecting observations with the lab

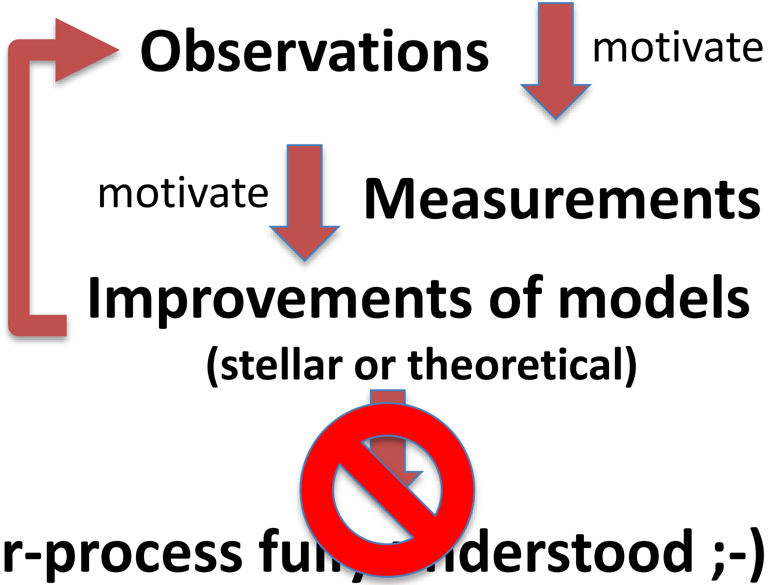


Connection between **nuclear structure far off stability** and **"observed" abundances** !

Most important nuclear physics inputs:

- Masses (path)
- Half-lives and βn-branching ratios (peak shape)
- n-capture cross sections (peak shape)





Outline

1. γ-Spectroscopy of neutron-rich isotopes

   ⇨ half-lives, (nuclear structure)

2. Measurement of β-delayed neutron emitters

   ⇨ half-lives, β-delayed neutron branching ratios

3. Measurement of i-process key reactions

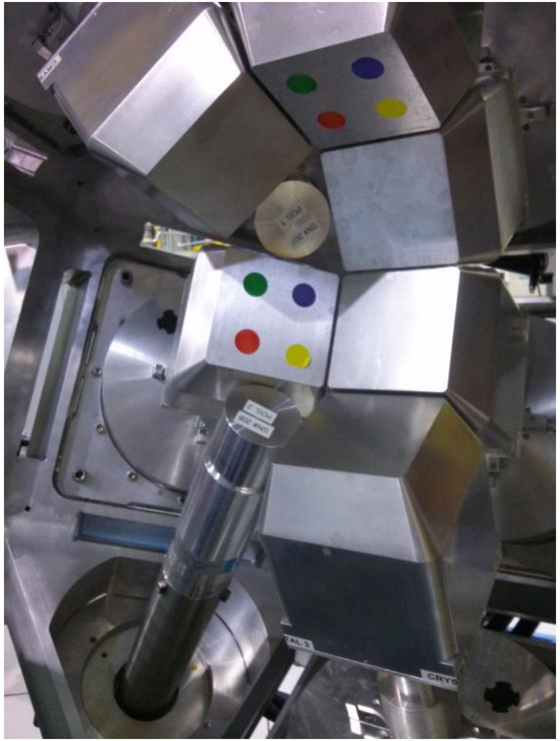
   ⇨ (n,γ) reaction rates

γ-Spectroscopy of neutron-rich isotopes at TRIUMF

The GRIFFIN spectrometer

GRIFFIN

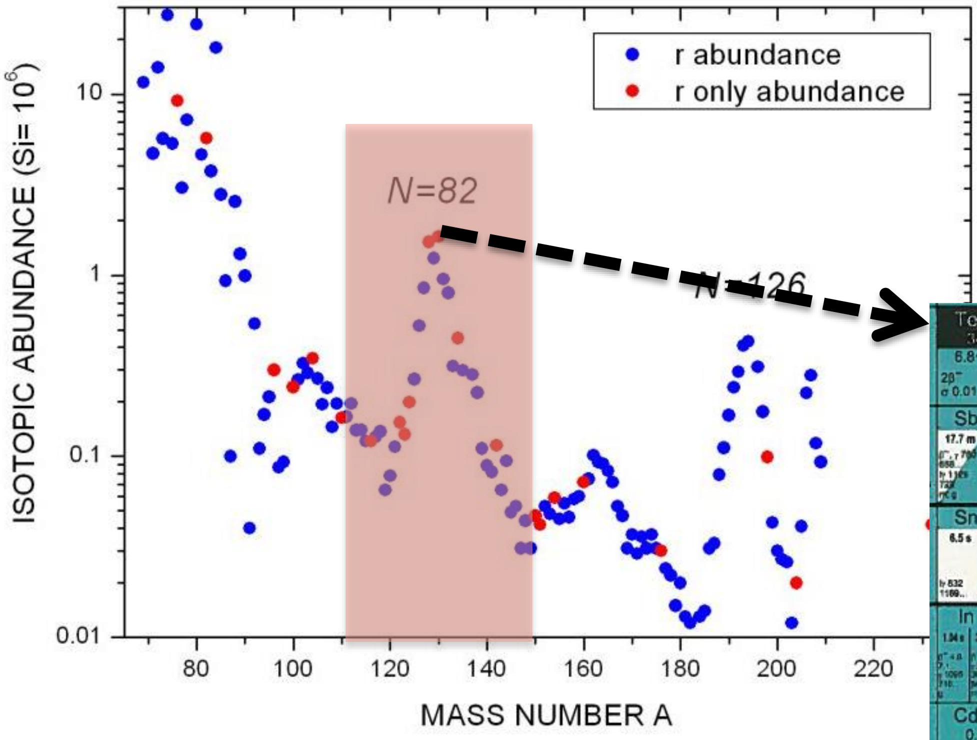
Gamma-**R**ay
Infrastructure **F**or
Fundamental
Investigations
of **N**uclei



- High efficiency γ-ray spectrometer
- 16 HPGe Clovers
- Coupled with ancillary detectors: plastic scintillators, conversion electron spectrometer, $LaBr_3$ fast timing array, neutron detectors,...

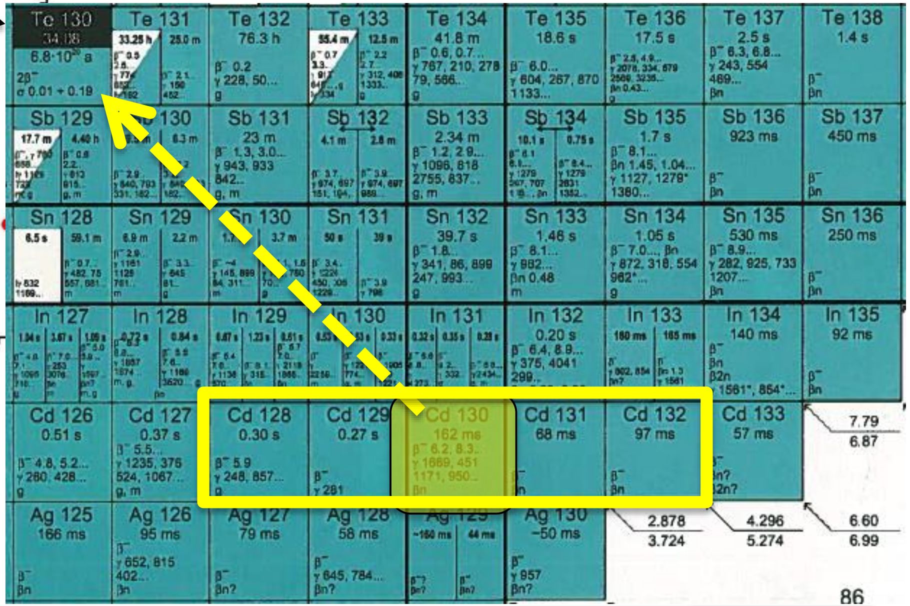
In operation since fall 2014

N=82 isotopes: ^{130}Cd



Solar r-abundance at A=130: Stable ^{130}Te from decay of N=82 ^{130}Cd and neighbors

N=82



First GRIFFIN science publication: ^{130}Cd controversy solved

PHYSICAL REVIEW C 93, 062801(R) (2016)

Half-lives of neutron-rich $^{128-130}$Cd

R. Dunlop,[1,*] V. Bildstein,[1] I. Dillmann,[2,3,†] A. Jungclaus,[4] C. E. Svensson,[1] C. Andreoiu,[5] G. C. Ball,[2] N. Bernier,[2,6] H. Bidaman,[1] P. Boubel,[1] C. Burbadge,[1] R. Caballero-Folch,[2] M. R. Dunlop,[1] L. J. Evitts,[2,7] F. Garcia,[5] A. B. Garnsworthy,[2] P. E. Garrett,[1] G. Hackman,[2] S. Hallam,[2,7] J. Henderson,[2] S. Ilyushkin,[8] D. Kisliuk,[1] R. Krücken,[2,6] J. Lassen,[2,9] R. Li,[2] E. MacConnachie,[2] A. D. MacLean,[1] E. McGee,[1] M. Moukaddam,[2] B. Olaizola,[1] E. Padilla-Rodal,[10] J. Park,[2,6] O. Paetkau,[2] C. M. Petrache,[11] J. L. Pore,[5] A. J. Radich,[1] P. Ruotsalainen,[2] J. Smallcombe,[2] J. K. Smith,[2] S. L. Tabor,[12] A. Teigelhöfer,[2,9] J. Turko,[1] and T. Zidar[1]

^{130}Cd half-life:

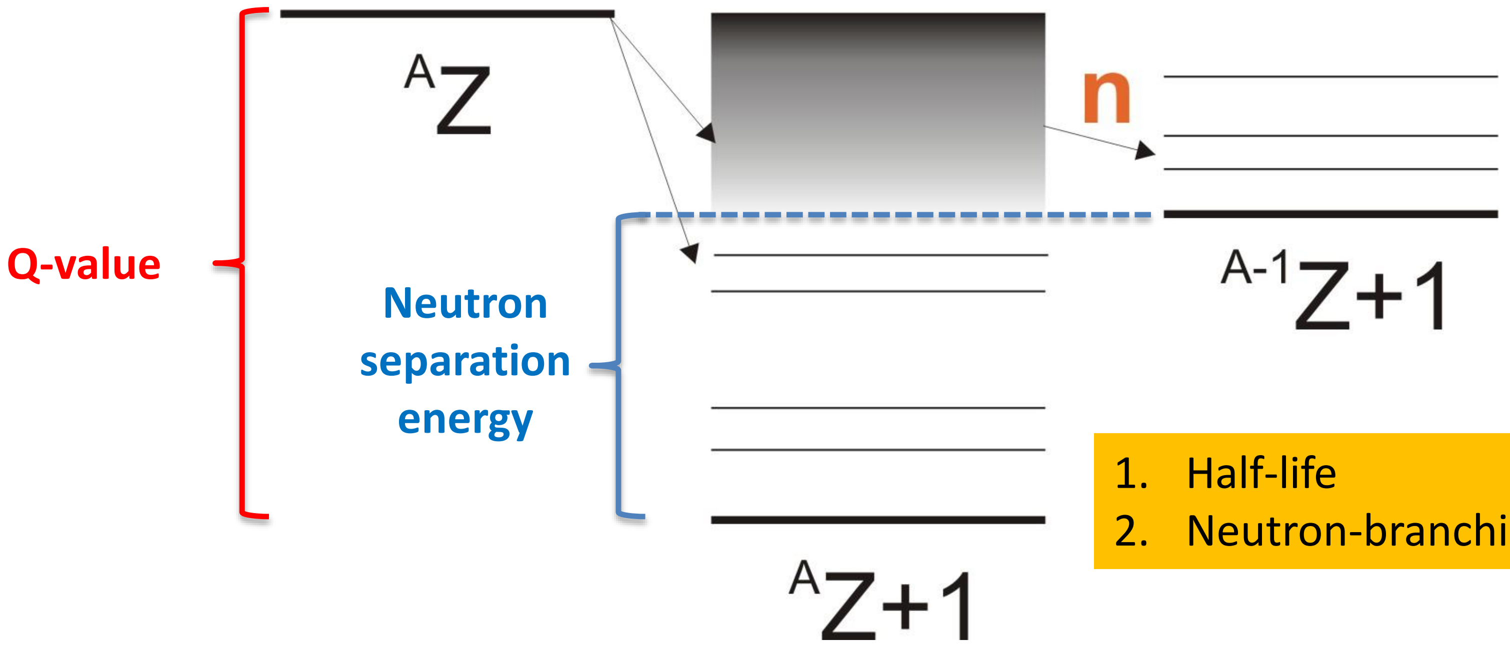
ISOLDE (1986):	$t_{1/2}$= 195(35) ms		K.-L. Kratz, et al., Z. Phys. A 325, 489 (1986).
ISOLDE (2001):	$t_{1/2}$= 162(7) ms	**22% lower!**	M. Hannawald et al., NP A688, 578 (2001).
EURICA (2015):	$t_{1/2}$= 127(2) ms		G. Lorusso et al., PRL 114, 192501 (2015).
GRIFFIN (2016):	***$t_{1/2}$= 126(4) ms***		*R. Dunlop et al., Phys. Rev. C93 (2016)*

Previous ^{130}Cd half-life was used to ***adjust Gamow-Teller quenching factor*** *for lighter N=82 isotopes: New predictions will yield* ***shorter half-lives for ^{128}Pd, ^{127}Rh, ^{126}Ru…***

Measurement of β-delayed neutron emitters

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

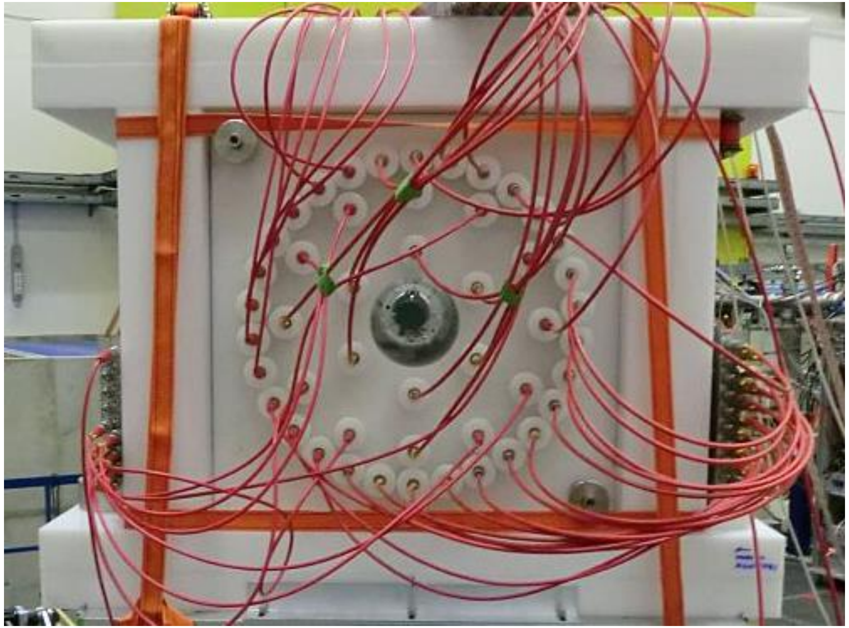
RIKEN NiSHiNA CENTER



1. Half-life
2. Neutron-branching ratio (P_n)

Dominant decay mechanism for very neutron-rich isotopes

BEta deLayEd Neutron detector (BELEN)



Universidad Politecnica de Cataluna, Barcelona

IFIC Valencia

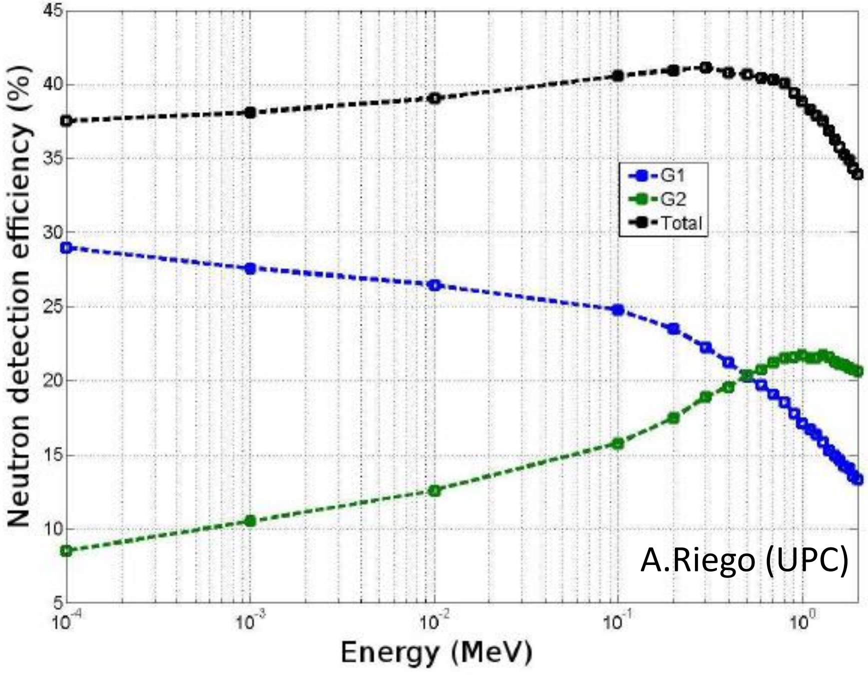
CIEMAT Madrid

GSI Helmholtz Center Darmstadt

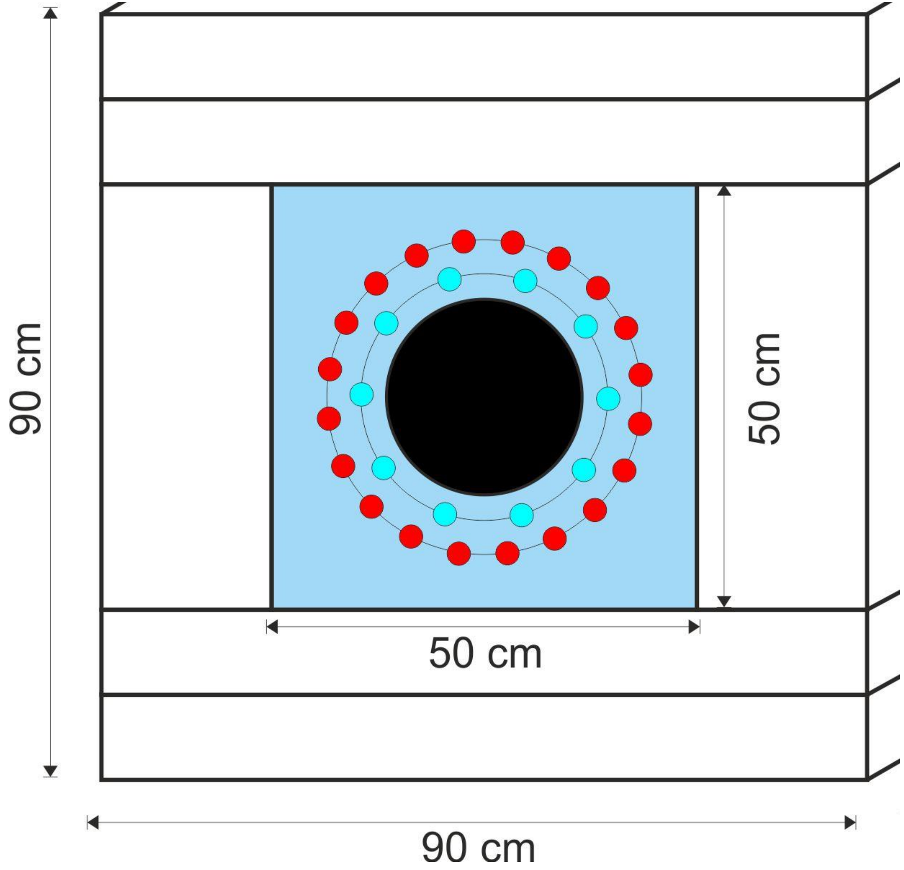
High-pressure ^{3}He long counters in polyethylene moderator:
$^3He + n \rightarrow {}^3H + p + 765\ keV$

BELEN-30 efficiency (GSI Darmstadt 2011)

Setup with implantation detector in center

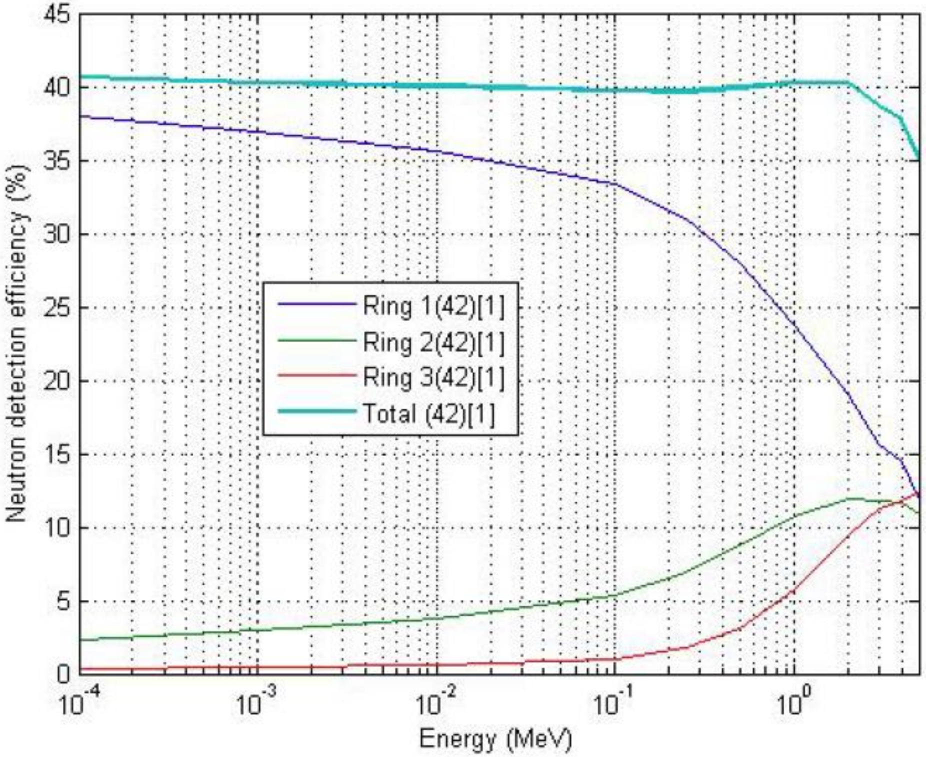


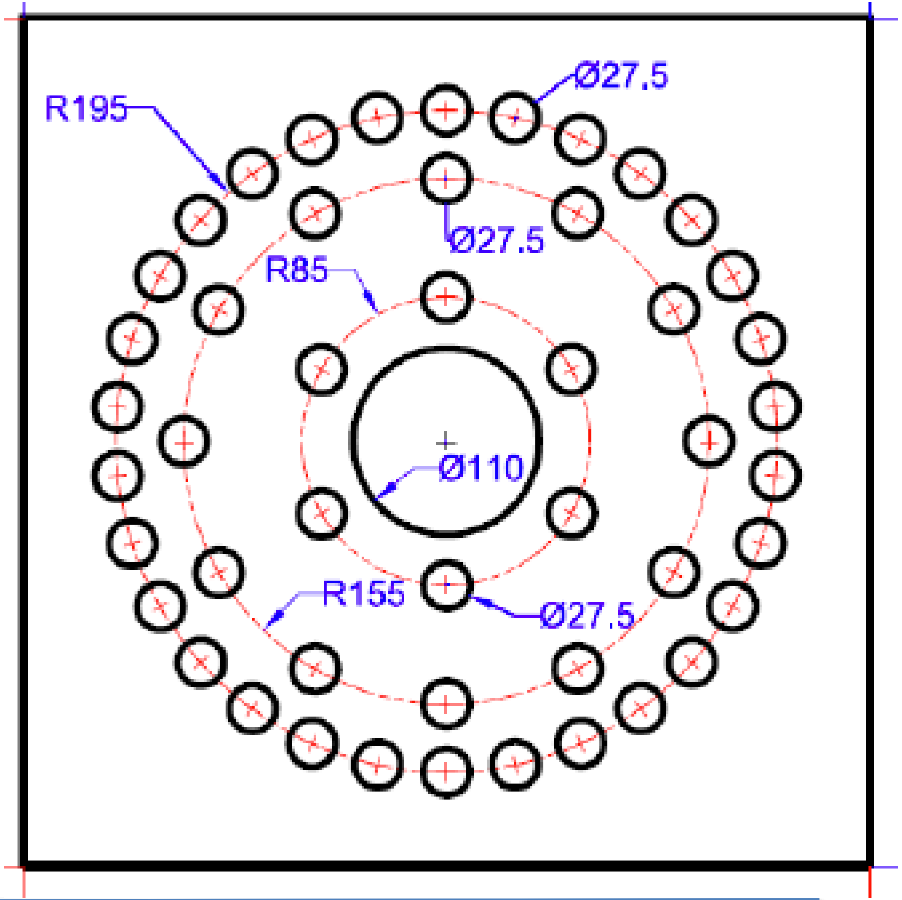
Efficiency for BELEN version with 30 ^{3}He counters



BELEN-48 Hybrid Efficiency (Jyväskylä 2014)

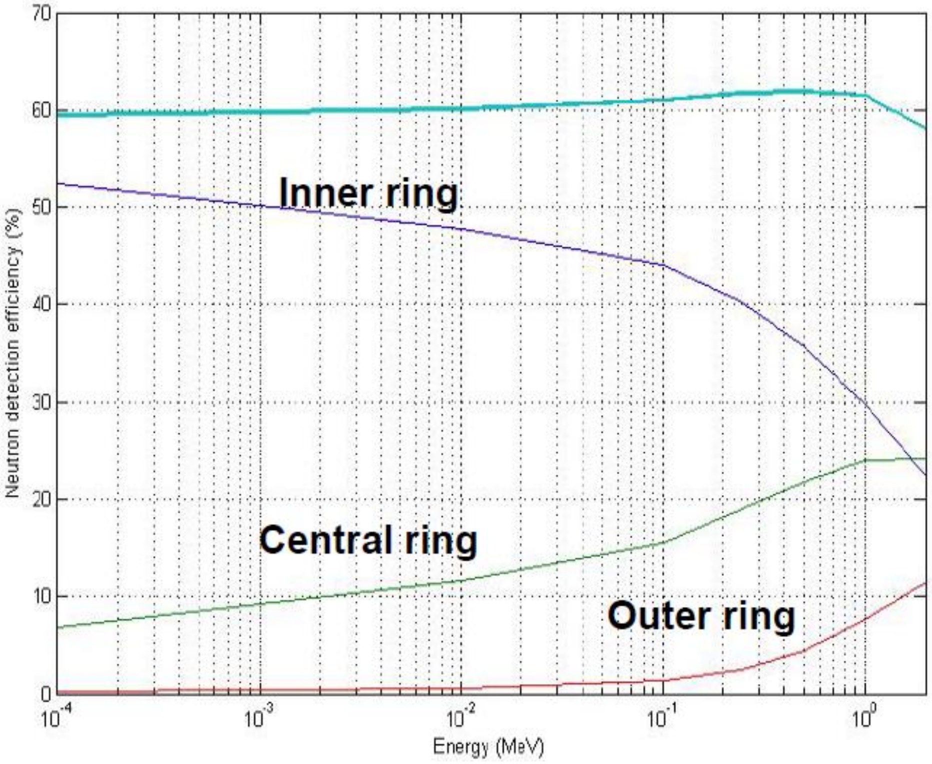
⇨ Hybrid setup with space for one HPGe

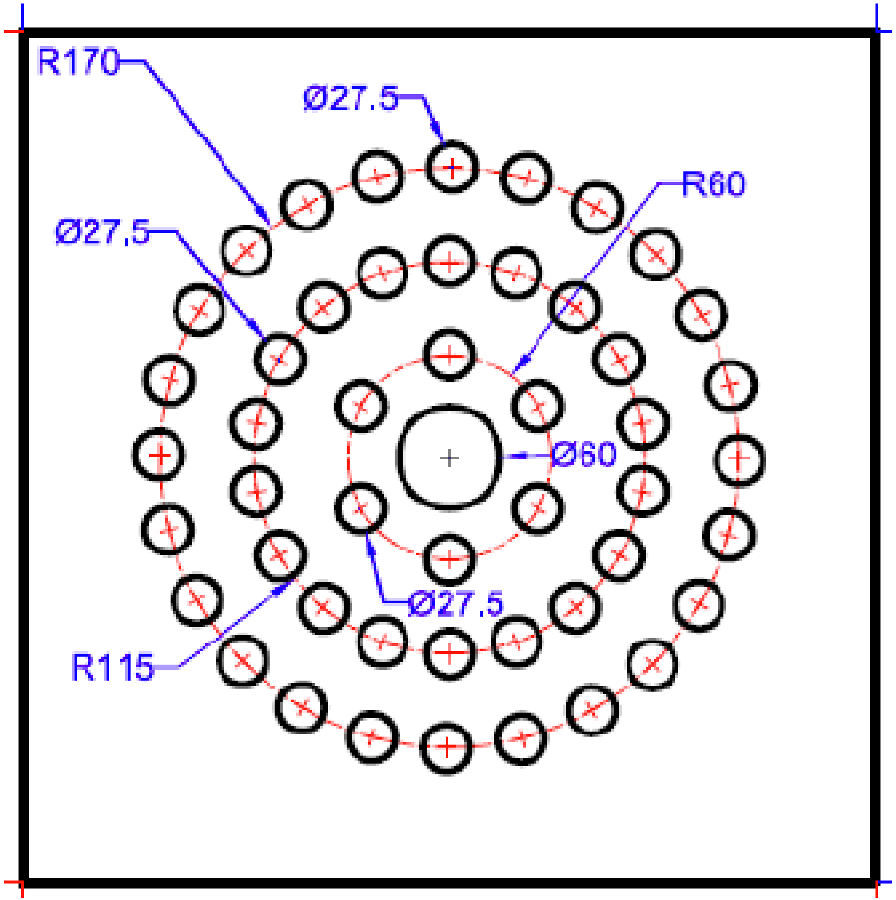




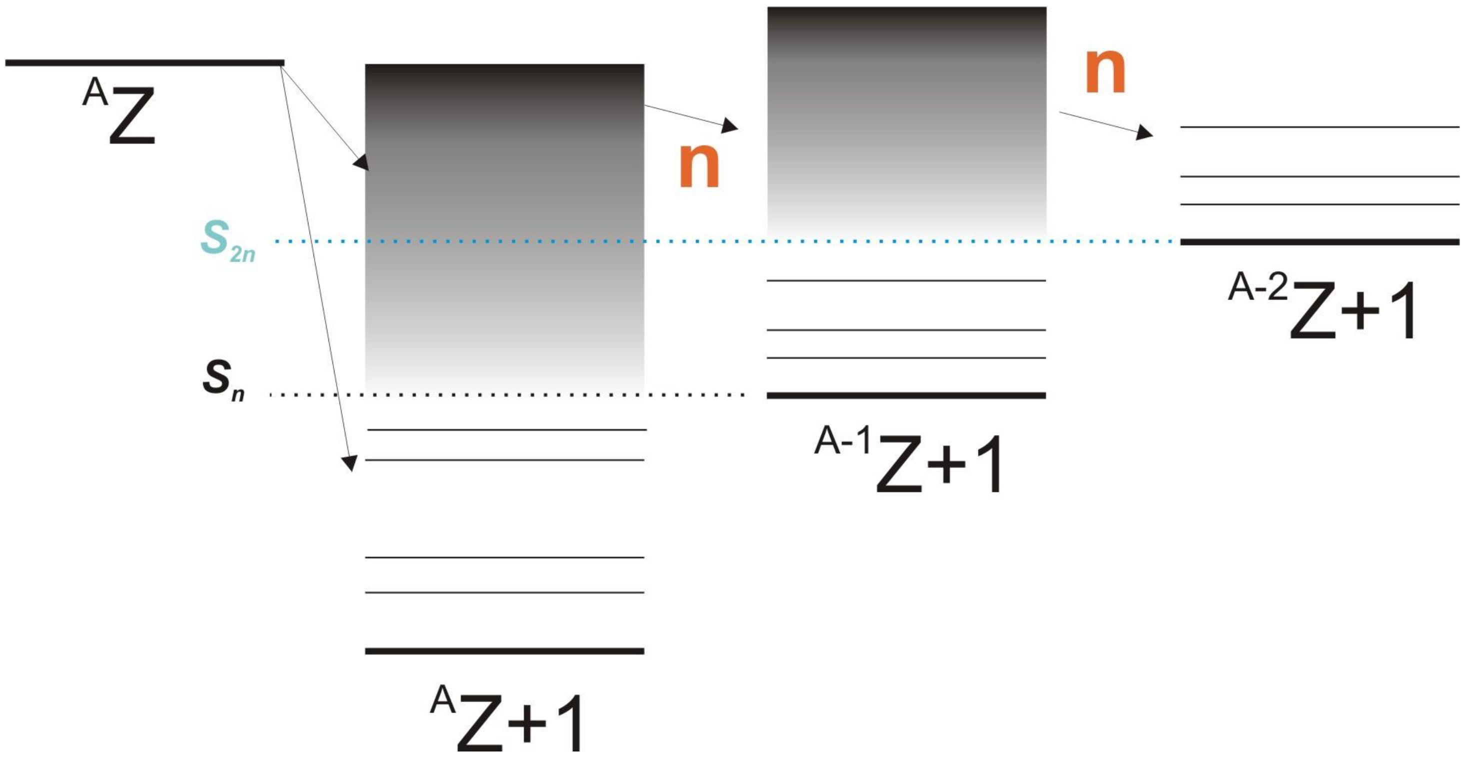
BELEN-48 High Efficiency (Jyväskylä 2014)

Up to 60% detection efficiency
⇨ β-delayed 2-neutron emitters



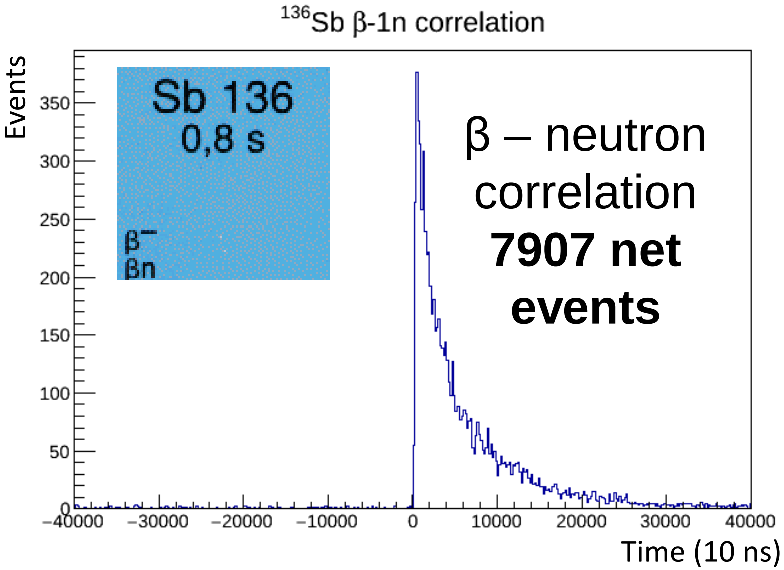


β-delayed 2-neutron emission



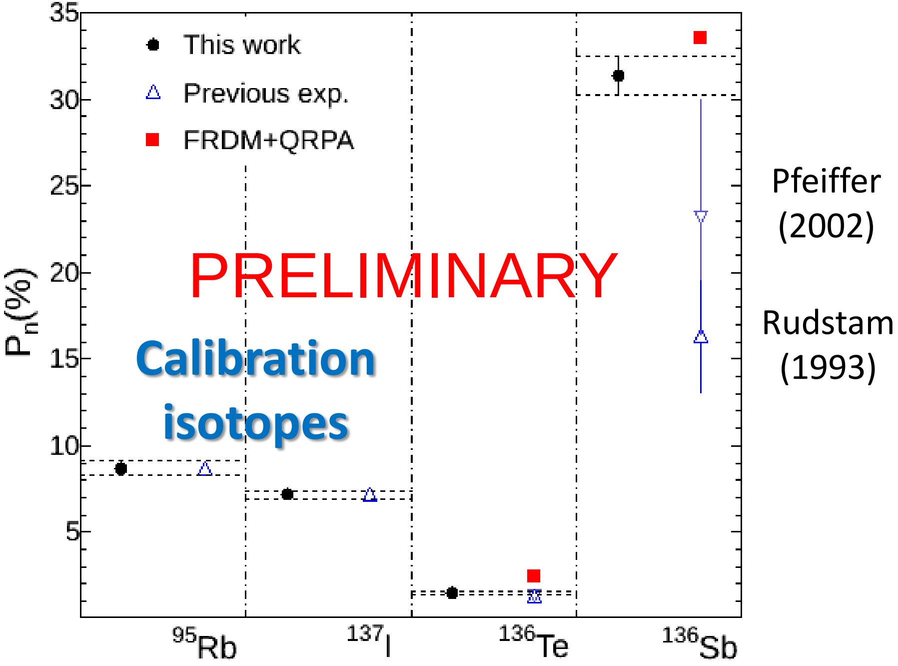
^{136}Sb: P_{1n} measurements (Jyväskylä 2014)

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



Roger Caballero et al., presented at Zakopane (2016) and Nuclear Data Conf. (Bruges 2016); in prep. for PRC (2017)

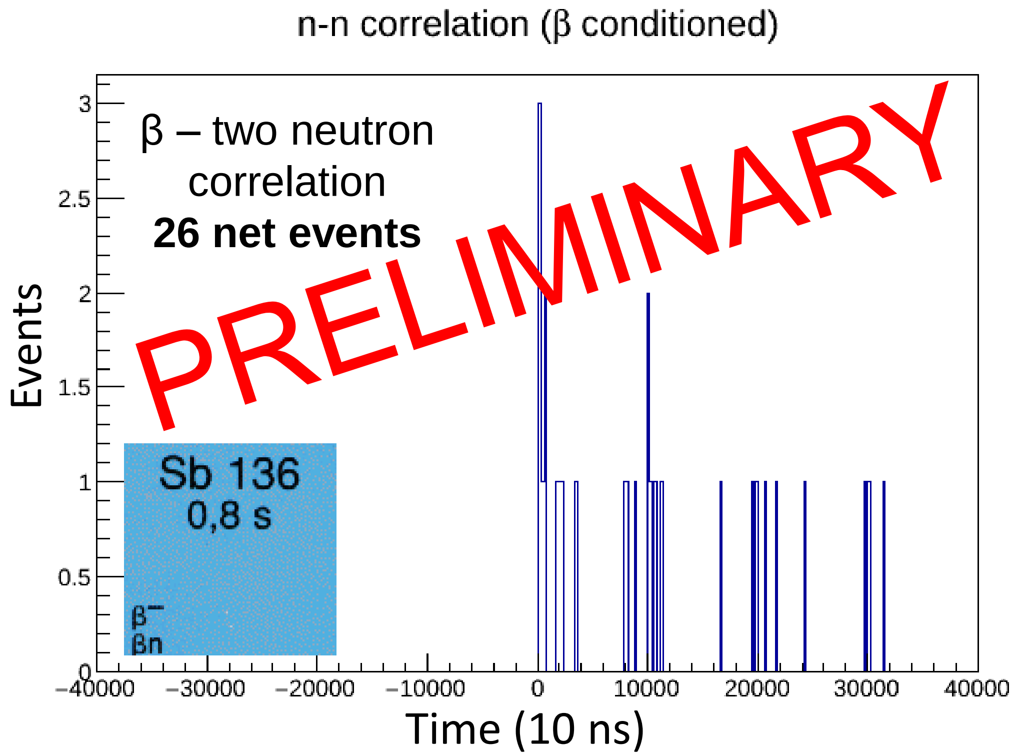
P_{1n} results



^{136}Sb: Higher P_{1n} than previously measured

^{136}Sb: P_{2n} measurements (Jyväskylä 2014)

After 6 days of beamtime, **26** β2n-events confirmed!



Preliminary result:

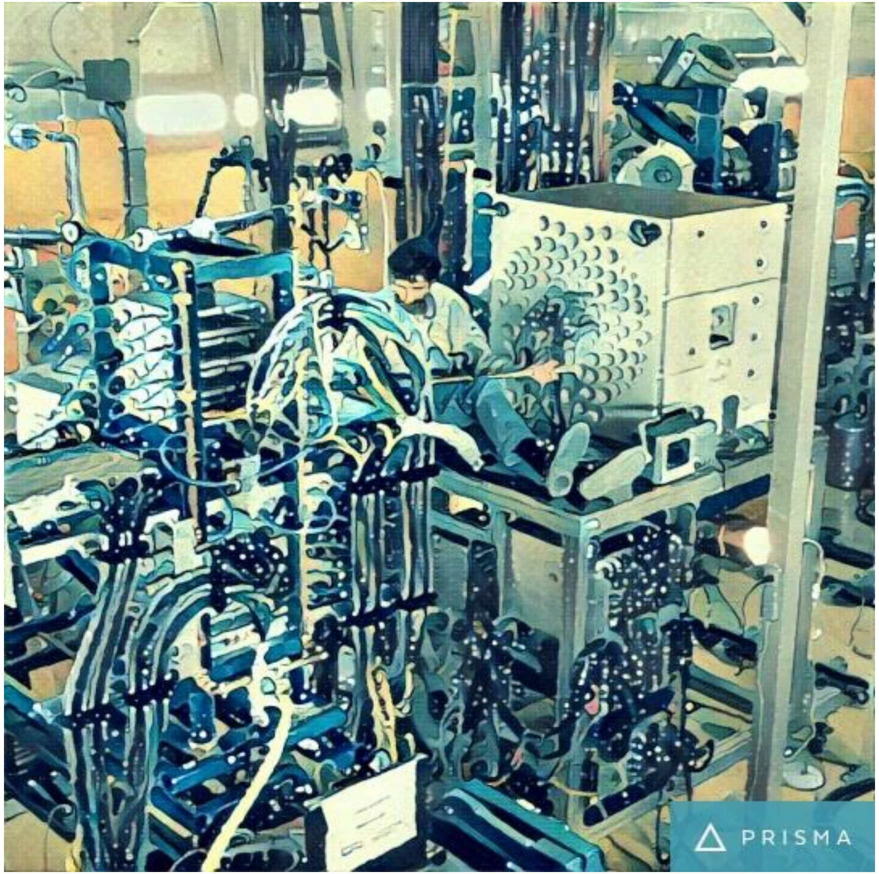
$P_{2n} \approx 0.1\text{-}0.2\%$

(Theoretical predictions: P_{2n}= 6.2%)

Moeller et al. 2003

Roger Caballero et al., presented at Zakopane (2016) and Nuclear Data Conf. (Bruges 2016); in prep. for PRC (2017)

The BRIKEN project (2016-...)



"Beta-delayed neutron measurements at RIKEN for nuclear structure, astrophysics, and applications"

RIKEN NiSHiNA CENTER · IFIC Institut de Física Corpuscular · The University of Edinburgh · UPC · Oak Ridge National Laboratory · TRIUMF

Jinst

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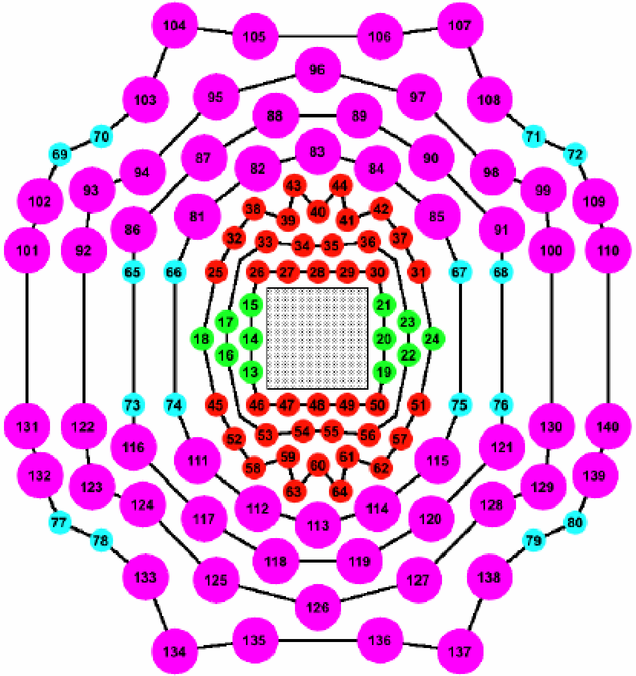
Conceptual design of a hybrid neutron-gamma detector for study of β-delayed neutrons at the RIB facility of RIKEN

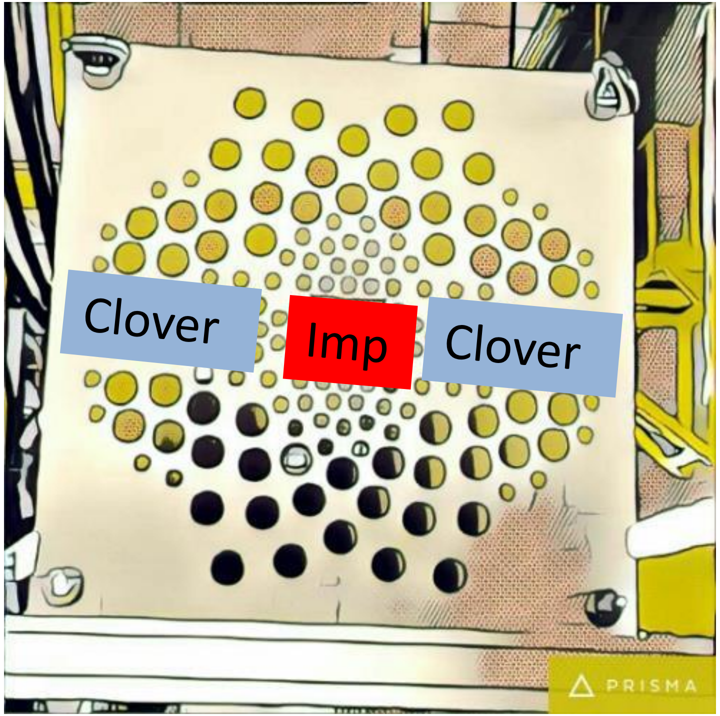
The BRIKEN collaboration

A. Tarifeño-Saldivia,[a,b,1] J.L. Tain,[b] C. Domingo-Pardo,[b] F. Calviño,[a] G. Cortés,[a] V.H. Phong,[c] A. Riego,[a] J. Agramunt,[b] A. Algora,[b,p] N. Brewer,[d,f] R. Caballero-Folch,[g] P.J. Coleman-Smith,[k] T. Davinson,[h] I. Dillmann,[g] A. Estradé,[h,n,o] C.J. Griffin,[h] R. Grzywacz,[e] L.J. Harkness-Brennan,[j] G.G. Kiss,[c,p] M. Kogimtzis,[k] M. Labiche,[k] I.H. Lazarus,[k] G. Lorusso,[s,i] K. Matsui,[c] K. Miernik,[r] F. Montes,[m,n] A.I. Morales,[b] S. Nishimura,[c] R.D. Page,[j] Z.S. Podolyák,[i] V.F.E. Pucknell,[k] B.C. Rasco,[d,f] P. Regan,[i] B. Rubio,[b] K.P. Rykaczewski,[d] Y. Saito,[c,g] H. Sakurai,[c] J. Simpson,[k] E. Sokol,[t] R. Surman,[q] A. Svirkhin,[t] S.L. Thomas,[l] A. Tolosa[b] and P. Woods[h]

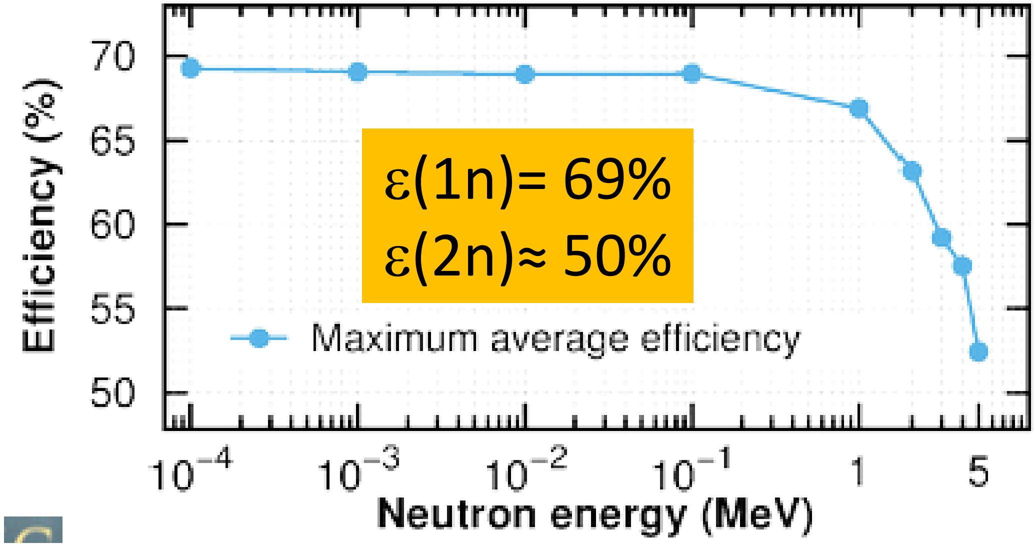


A. Tarifeño et al., J. Instrum.12, P04006 (2017)

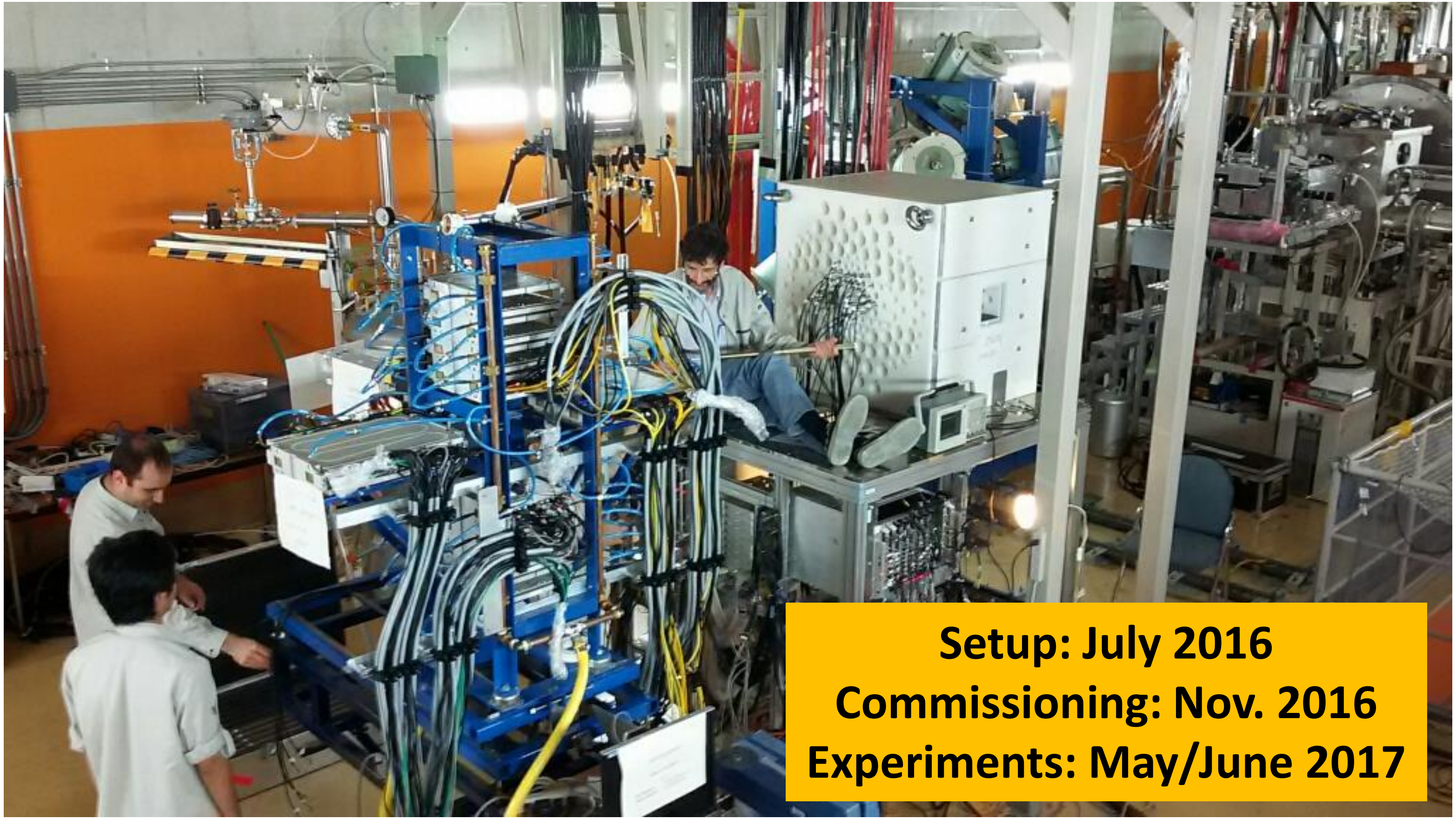
BRIKEN Hybrid detector



- 148 ^{3}He counters from Japan, Russia, Spain, USA
- 2 HPGe clovers (ORNL)
- Implantation detector AIDA (Edinburg, Daresbury, Liverpool)



Setup at RIKEN (July 2016)

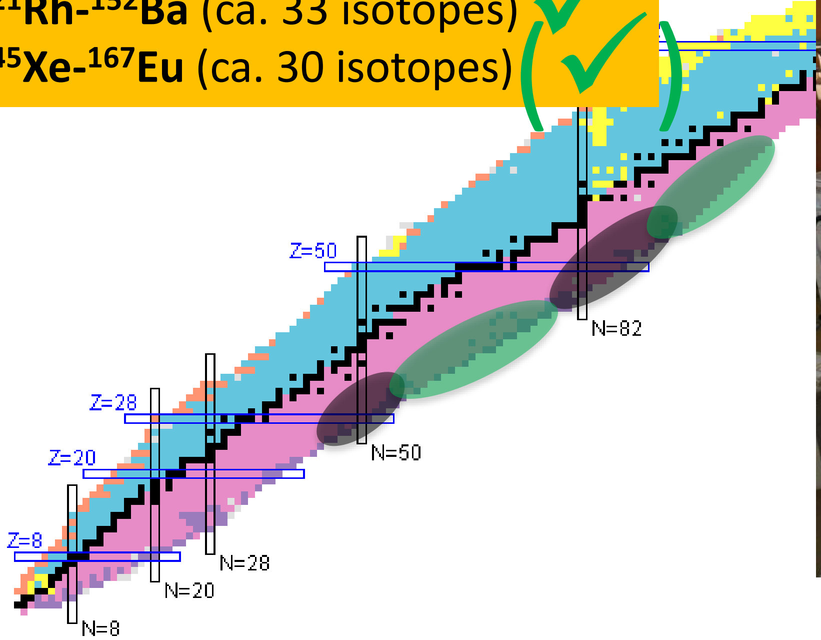


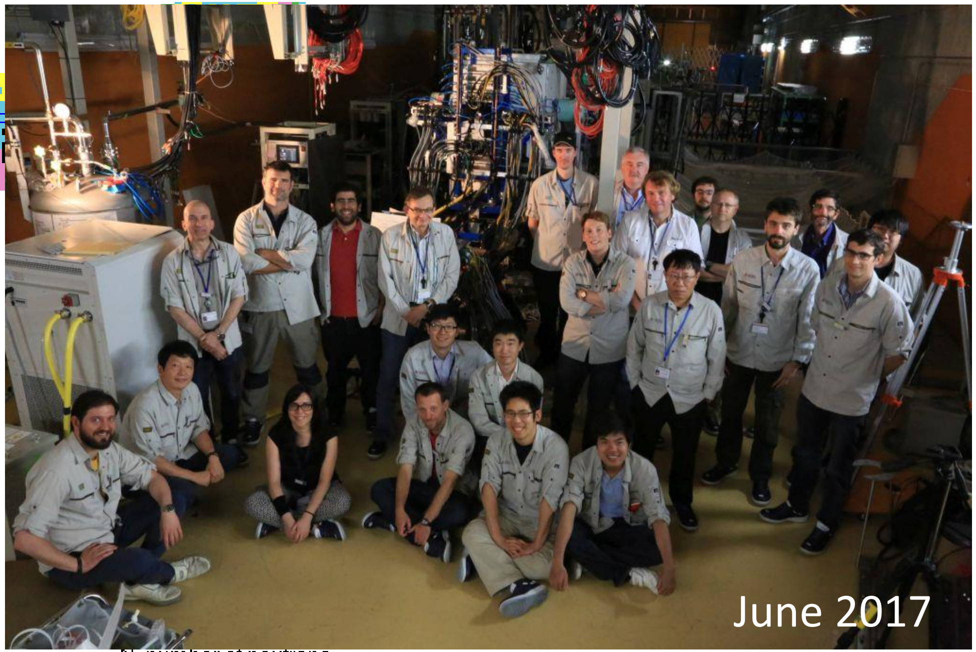
Setup: July 2016
Commissioning: Nov. 2016
Experiments: May/June 2017

BRIKEN: Approved experiments

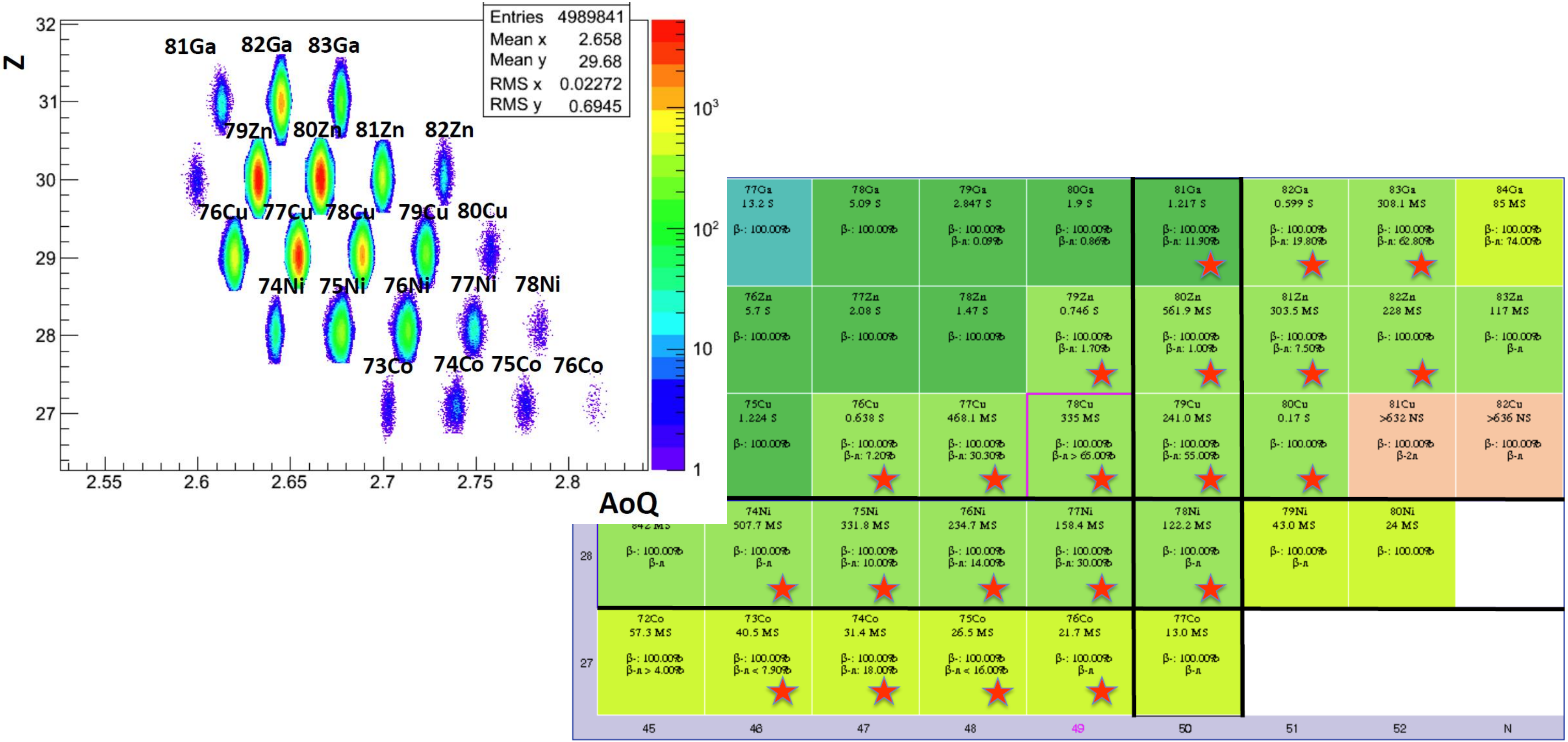
^{76}Co- ^{92}Se (ca. 30 isotopes) ✓
^{93}Se-^{121}Tc: 90 new P_{1n}, 20 new P_{2n}, 23 new half-lives
^{121}Rh-^{152}Ba (ca. 33 isotopes) ✓
^{145}Xe-^{167}Eu (ca. 30 isotopes) (✓)

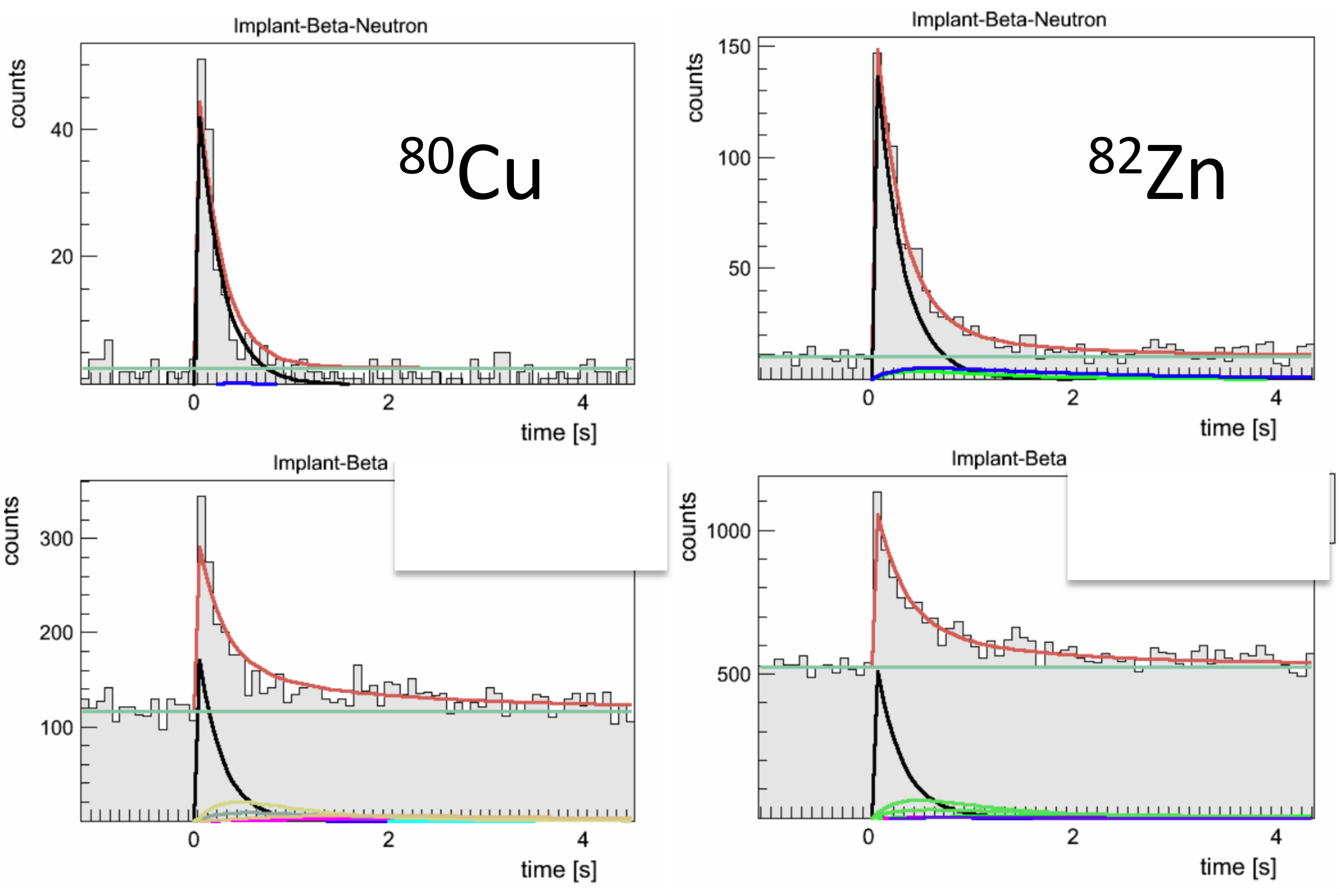
Largest global investigation of βn-emitters so far





Parasitic run (November 2016)

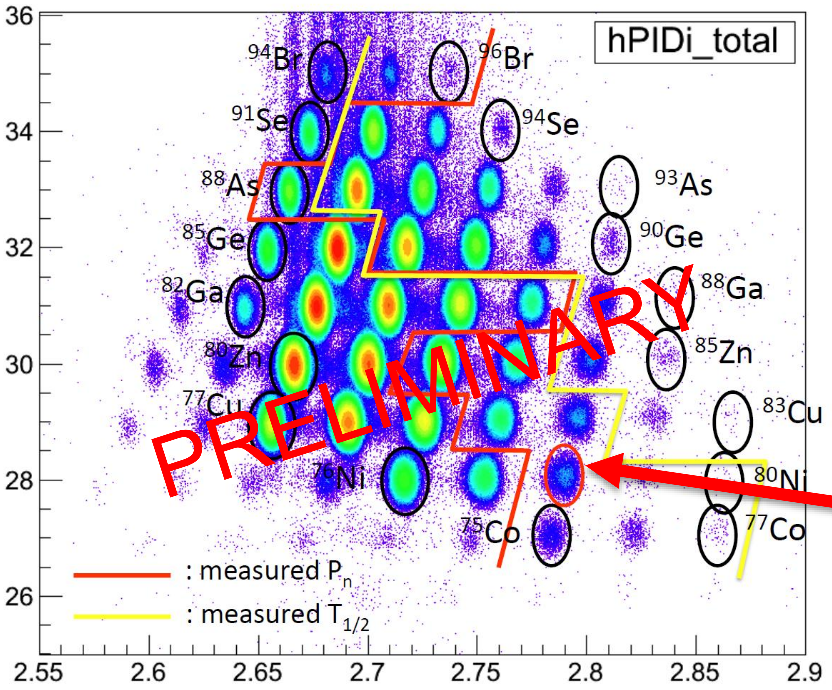




11h of data

19 P_{1n} measured
5 for the first time

June 2017: ^{78}Ni region (full statistics)

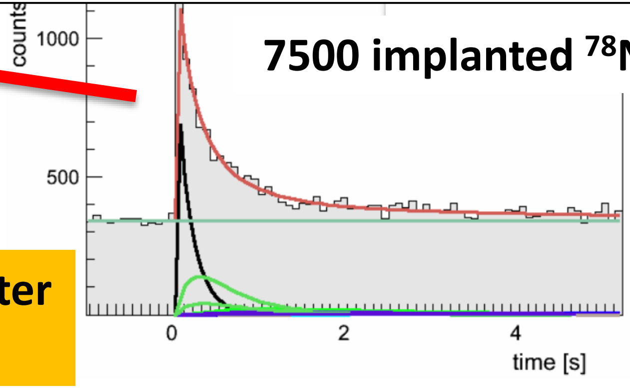



Iris Dillmann
@Spacegirl1978

78Ni stats: @NSCL (Hosmer PRL 2005): 11 events in 104h. BRIKEN @RIBF 2017: >100 implants PER HOUR... 3 orders of magnitude in 12 years 🙄🤘

Retweet 1 Likes 2

8:04 PM - 29 May 2017

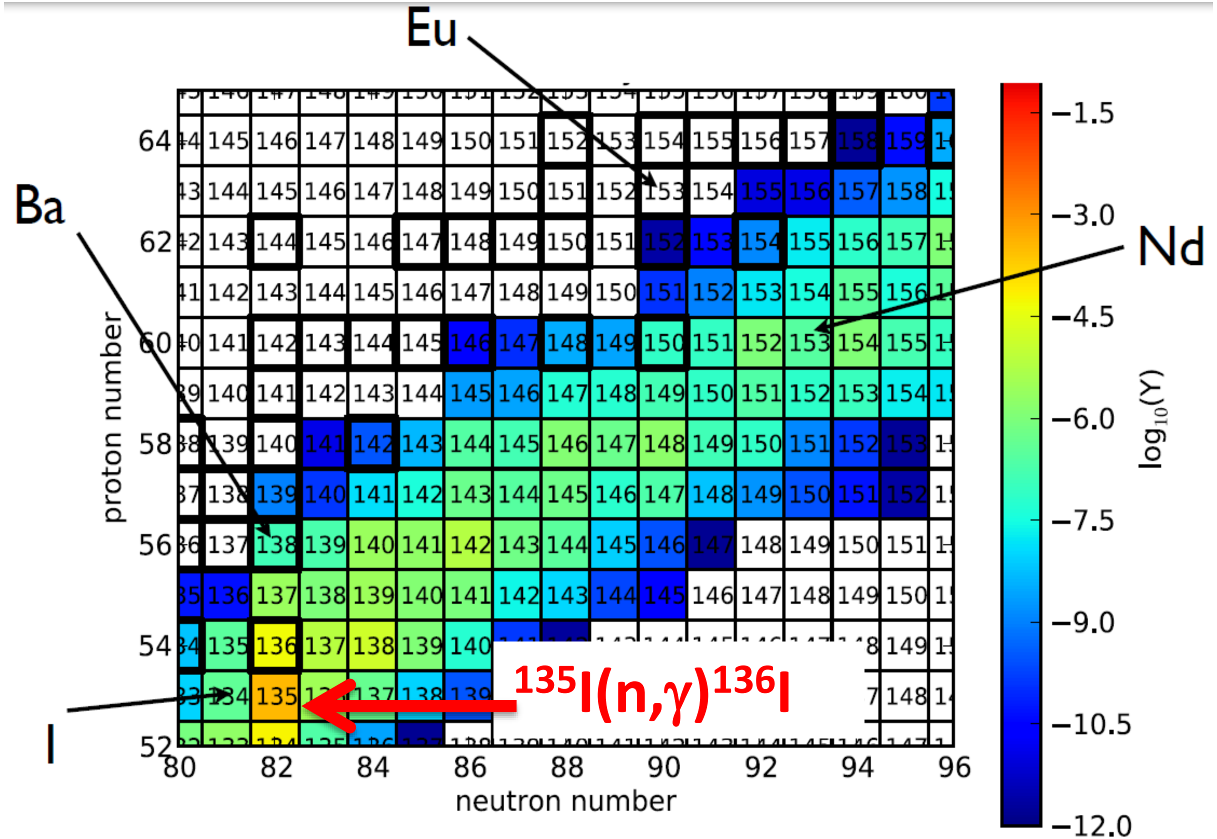


7500 implanted ^{78}Ni

(Spokespersons: Tain, Rykaczewski, Grzywacz, Dillmann)

≈29 new P_{1n}/P_{2n} emitter
≈ 20 new $t_{1/2}$ (tbc)

Measurement of i-process key reactions



"i process" calculations (F. Herwig et al., UVic)

Neutron densities **up to 10^{15} cm^{-3}**: **„intermediate neutron capture process“** (Cowan and Rose, 1977)

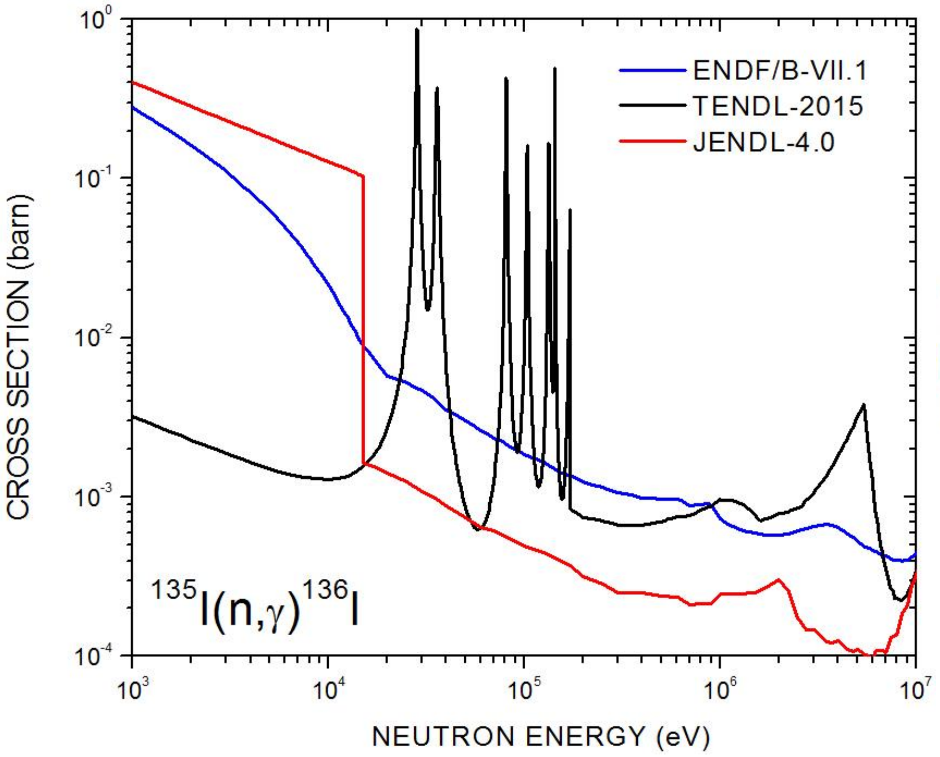
Needs neutron capture data **outside** valley of stability

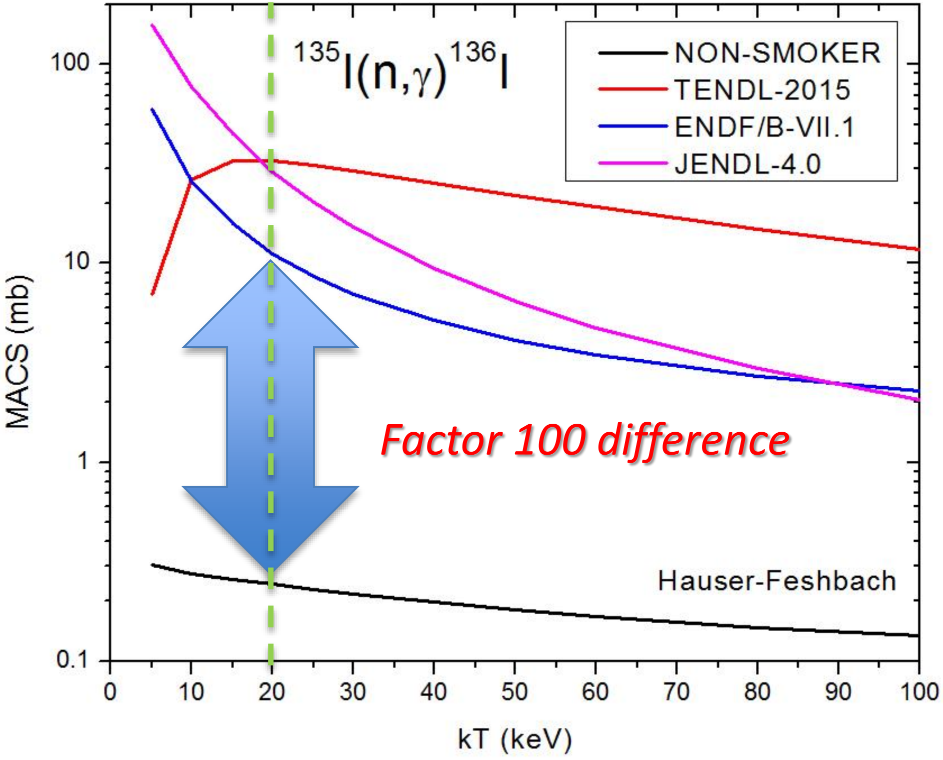
^{135}I(n,γ): So close to stability...

... but far away for direct measurements.

- Needed: (n,γ) cross section at kT≈20 keV (He burning)
- Why not using Hauser-Feshbach calculations?
  ⇨ low level density at N=82 shell closure, not applicable at low temperatures (e.g. up to kT= 25 keV for NON-SMOKER)

Comparison of (n,γ) cross sections and MACS





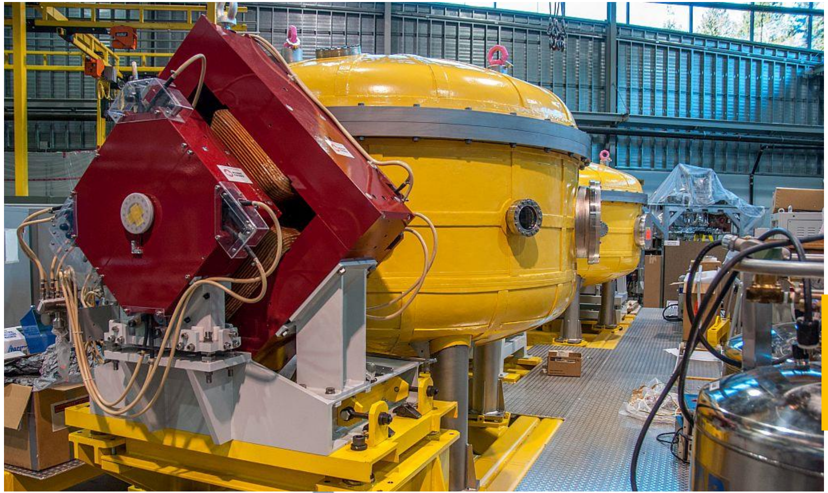
Solution: (d,p) with radioactive beams to constrain (n,γ) cross section

(n,γ) vs. (d,p) reactions

$$n + {}^{A}Z \rightarrow {}^{A+1}Z + \gamma$$

$$d + {}^{A}Z \rightarrow {}^{A+1}Z + \gamma + p$$

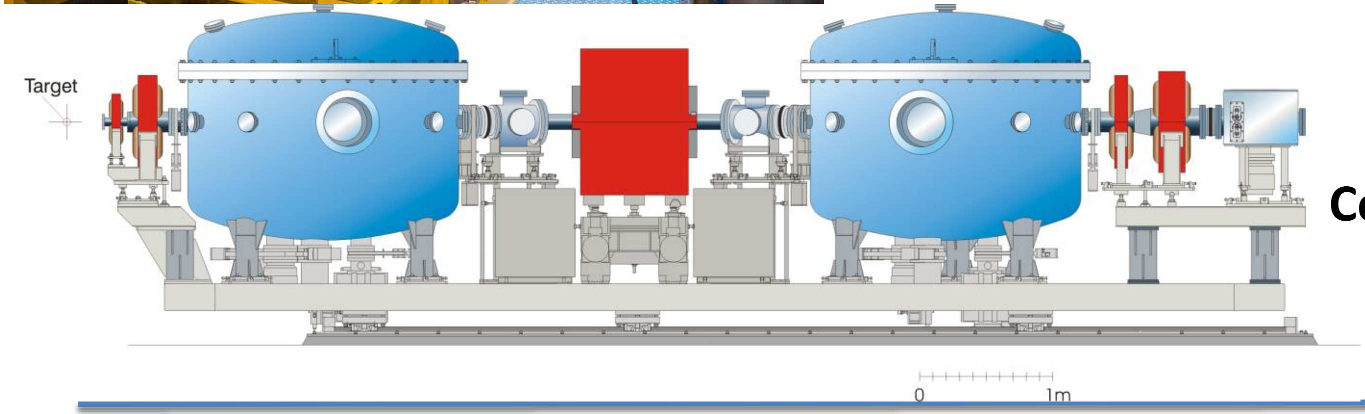
Surrogate method: deduce spectroscopic strength which is needed for direct and radiative (n,γ) capture measurements



ElectroMagnetic Mass Analyser

Recoil mass spectrometer designed with M/ΔM>300 to separate recoils from beam

Proposal to be submitted in 2017 (with Barry Davids)
Experiment can be performed from late 2018 on



Commissioned in 2016

- Experimentalists need to know which isotopes/ physical properties they should measure
  ⇨ Observational constraints
  ⇨ Sensitivity studies

- r-process nucleosynthesis :
  ⇨ Isotopes around N=50, 82, 126 shell closure (spherical nuclei)
  ⇨ Isotopes/isobars around A≈100 and 165 (deformed nuclei)
  ⇨ any other isotopes?

- i process nucleosynthesis:
  ⇨ bottle neck at ^{135}I (N=82)
  ⇨ Need measurements where statistical model not applicable due to low level density

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and accelerator-based science

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Merci!

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