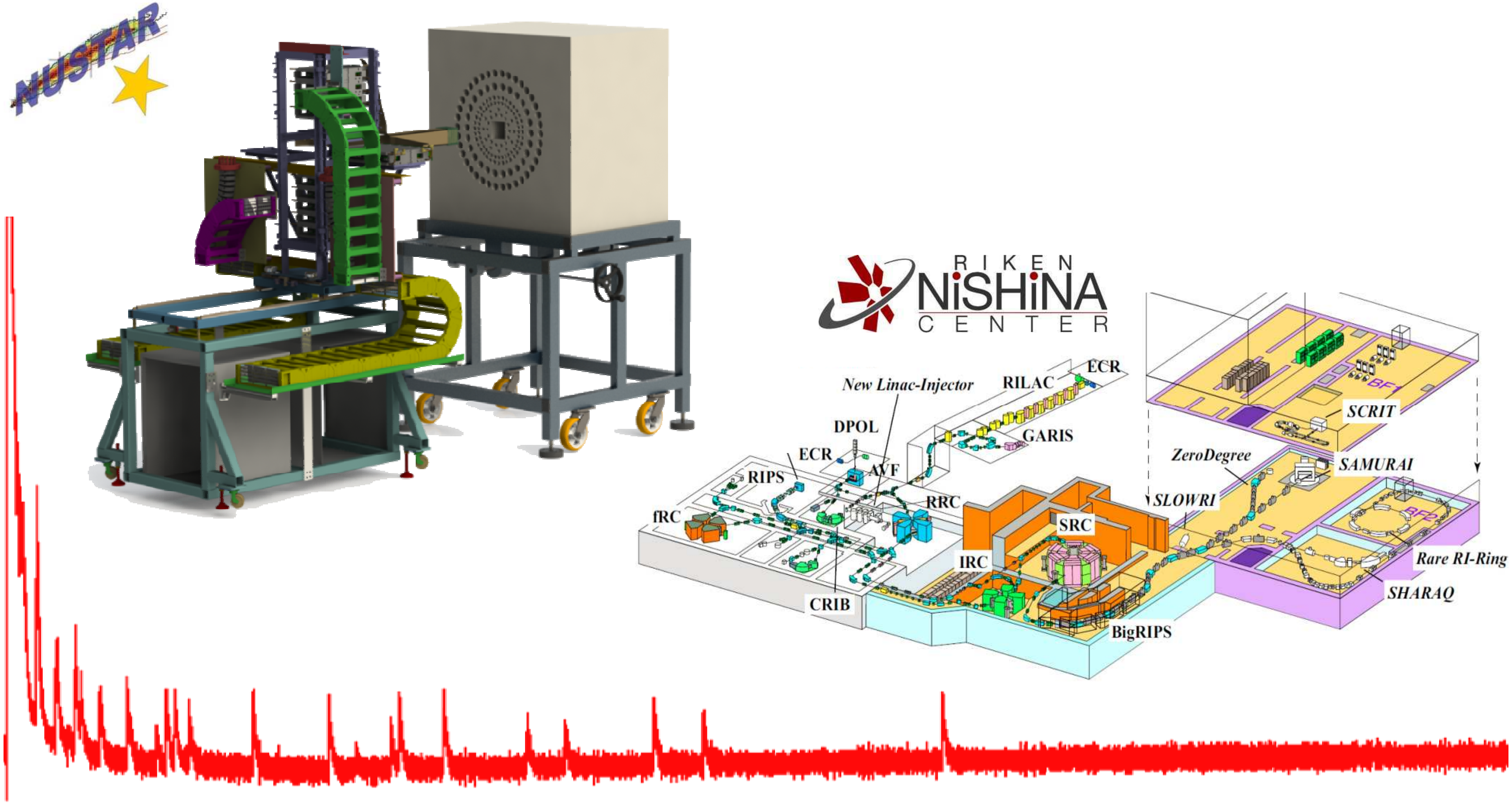
BELEN & The BRIKEN Project



Outline

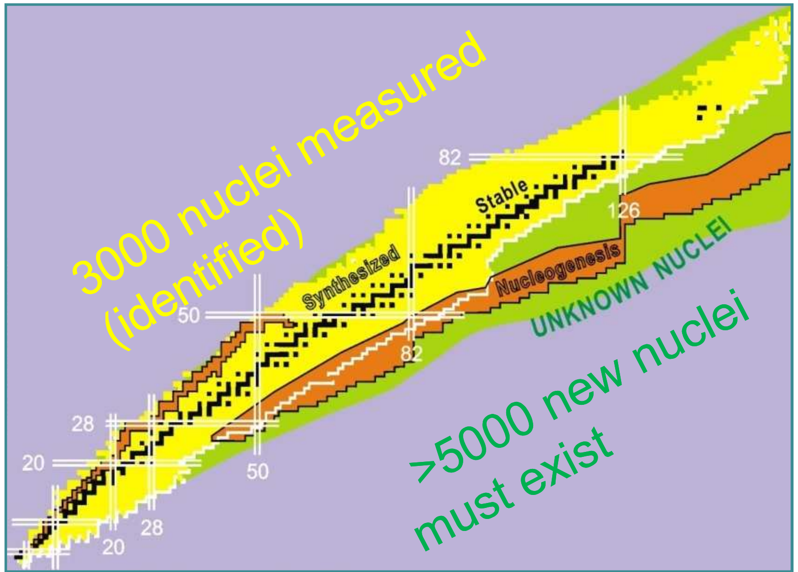
- Motivation & Introduction
- BELEN-20 measurements at JYFL around N=50 (2009) and with

BELEN-48 around N=82 (2014)

- BELEN-30 experiments at GSI around N=82 and N=126 (2011).
- The BRIKEN approach:
  - BRIKEN-Collaboration
  - Detector design: a high- and flat-efficiency detection system
  - First physics proposal around N=82 (2015)
- Summary & Outlook

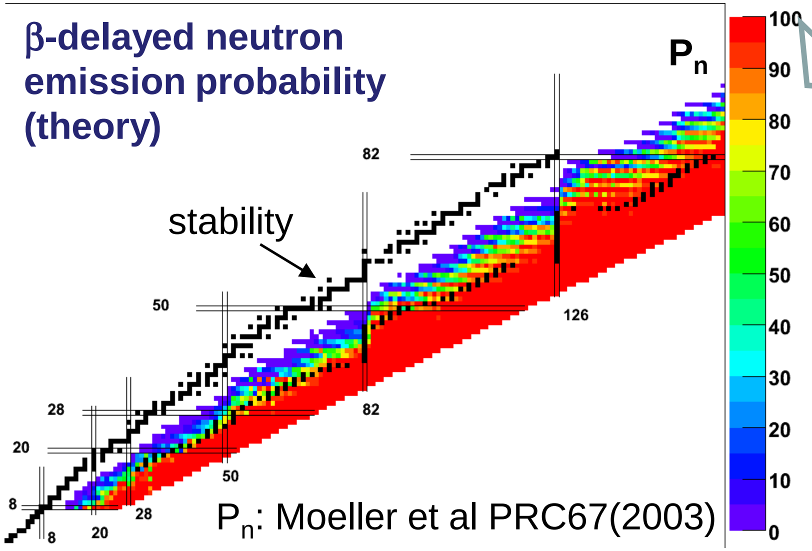
Motivation

The knowledge we have on nuclear structure and dynamics is based on about 3000 nuclei, whereas still more than 5000 new nuclei must exist.



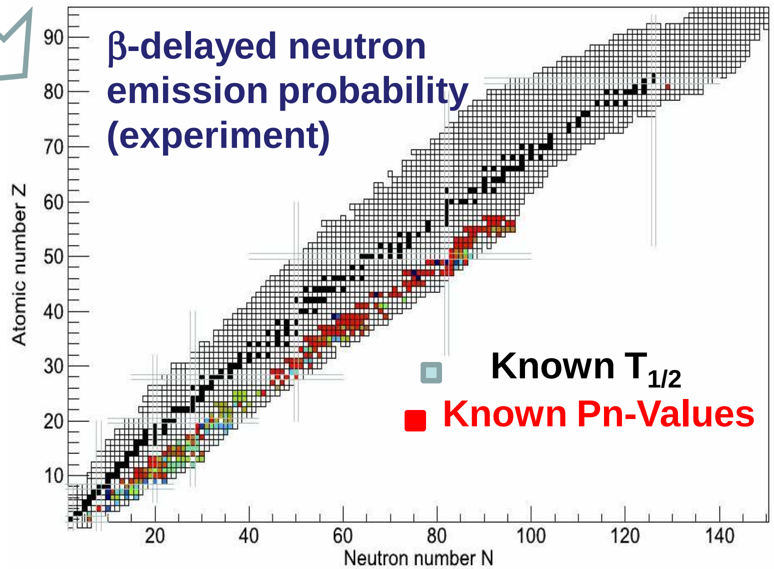
Almost all these new nuclei are expected to be neutron emitters, and hence, an understanding of this property and the involved technique becomes of pivotal impotance for NS and future studies.

What we expect (theory):



!

What we know (experiments):



• Almost all new nuclei are expected to be n-emitters

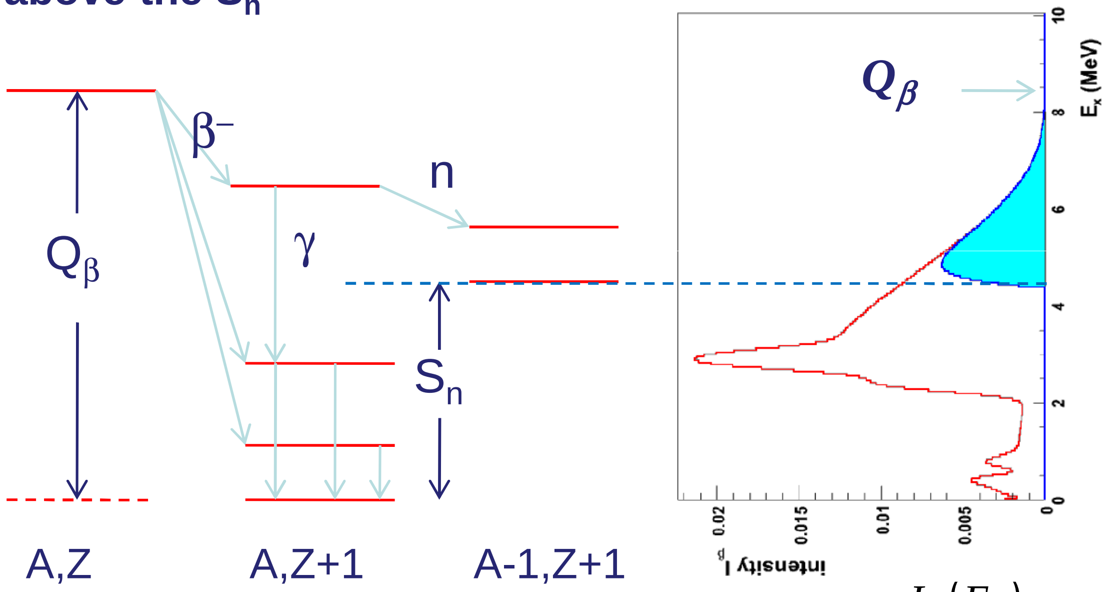
• Only about 200 n-emitters are known

Introduction

- β-delayed neutron emission may happen when the β-decay energy window Q_β exceeds the neutron separation energy S_n in the daughter nucleus. First reported by Roberts et al. in 1939.
- The half-live $T_{1/2}$ yields information on the average β-feeding of a nucleus.
- P_n yields information on the β-feeding **above the S_n**

$$\frac{1}{T_{1/2}} = \sum_0^{Q_\beta} S_\beta(E_x) \cdot f(Q_\beta - E_x)$$

$$P_n = \frac{\sum_{S_n}^{Q_\beta} S_\beta(E_x) \cdot f(Q_\beta - E_x)}{\sum_0^{Q_\beta} S_\beta(E_x) \cdot f(Q_\beta - E_x)}$$



$$S_\beta(E_x) = \frac{I_\beta(E_x)}{f(Q_\beta - E_x) \cdot T_{1/2}}$$

→ First information about the nuclear structure determining the β-decay

Despite of the relatively simple Pn “definition”, Pn values are rather difficult to predict theoretically, as they are reflecting the “shape” of the b-strength distribution and the underlying fine-structure of the nucleus at high excitation energy (!).

Introduction & Motivation

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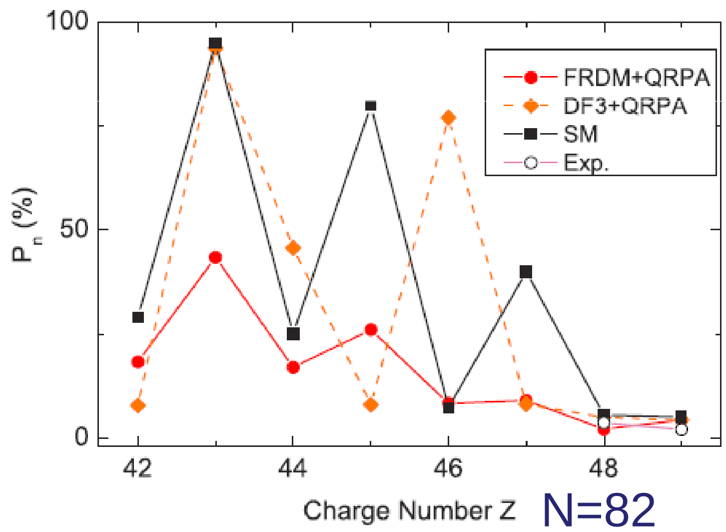
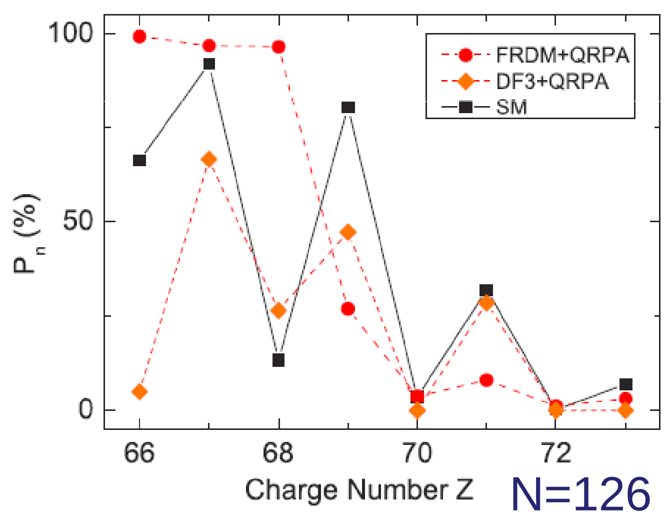
Credit: Q. Zhi et al., Phys. Rev. C 87, 2013

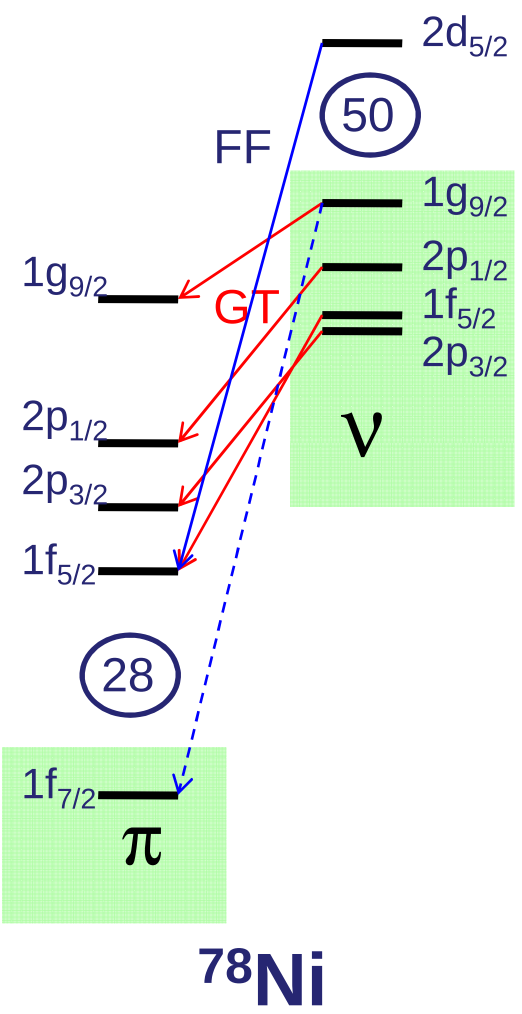


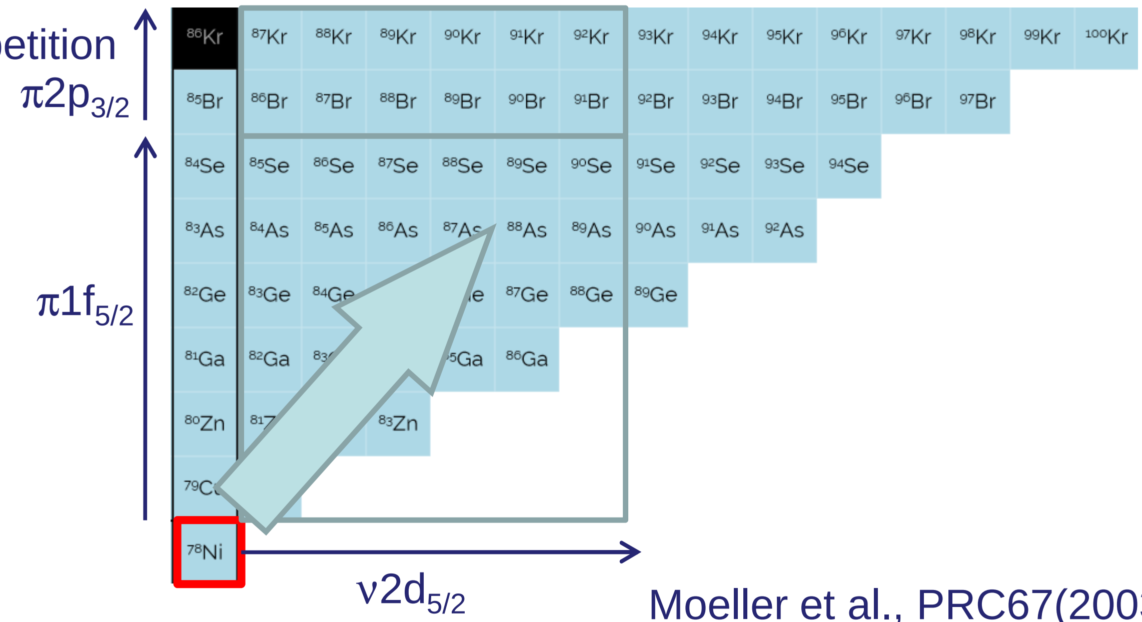


Despite of the relatively simple Pn “definition”, Pn values are rather difficult to predict theoretically, as they are reflecting the “shape” of the b-strength distribution and the underlying fine-structure of the nucleus at high excitation energy (!).

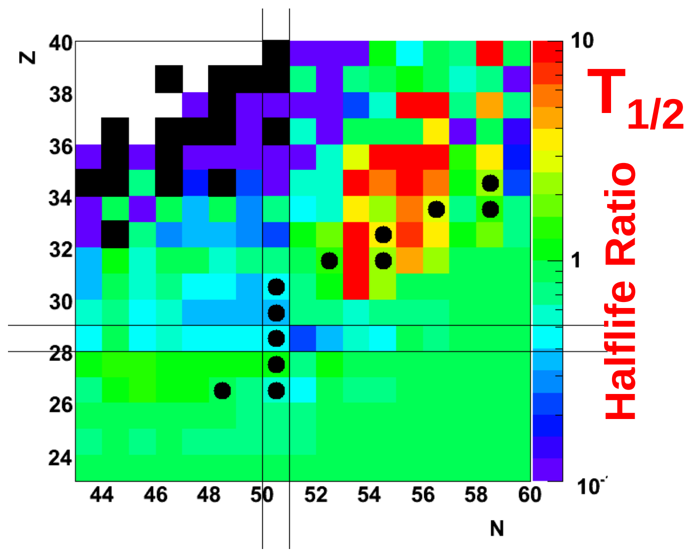
Shell structure and GT- FF- competition

→Nuclear Structure: FF vs. GT competition

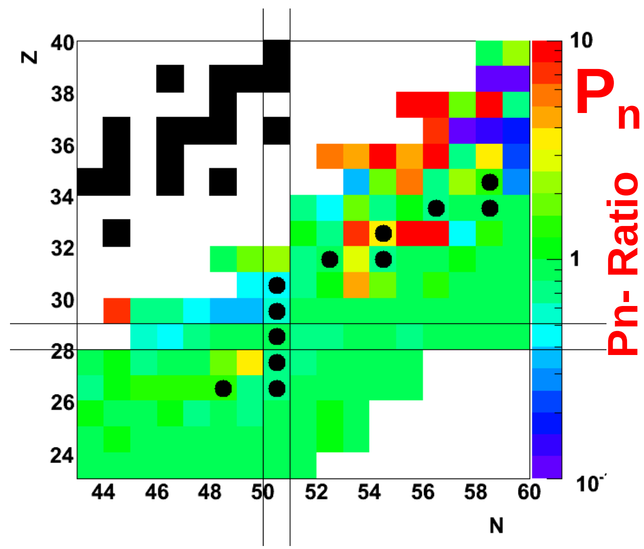




(GT+FF)/GT



Moeller et al., PRC67(2003)
Borzov, PRC71(2005)

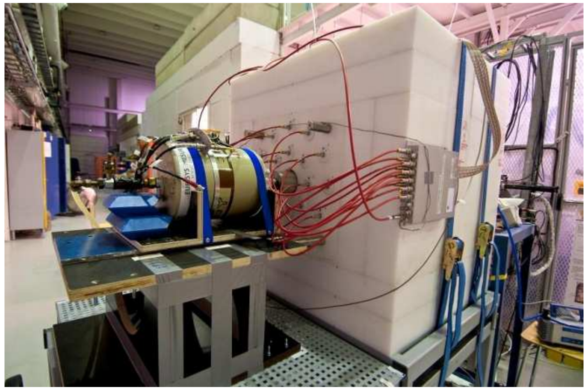


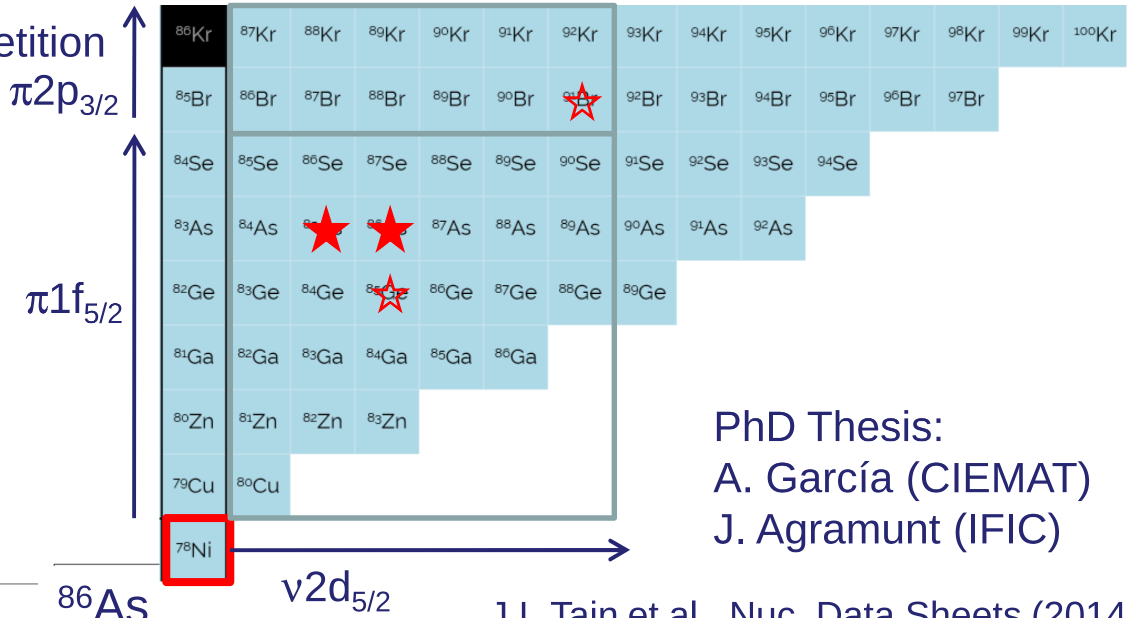
Nuc. Data. Conf., J.L.Tain et al. (2013)

Shell structure and GT- FF- competition

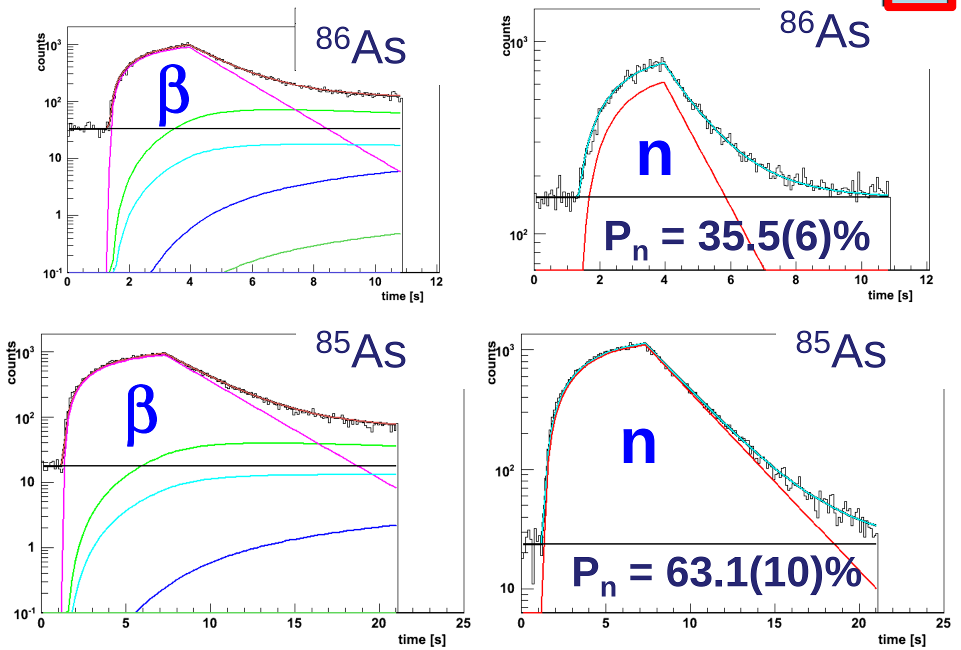
→Nuclear Structure: FF vs. GT competition

BELEN20 @ JYFL, 2009-2010

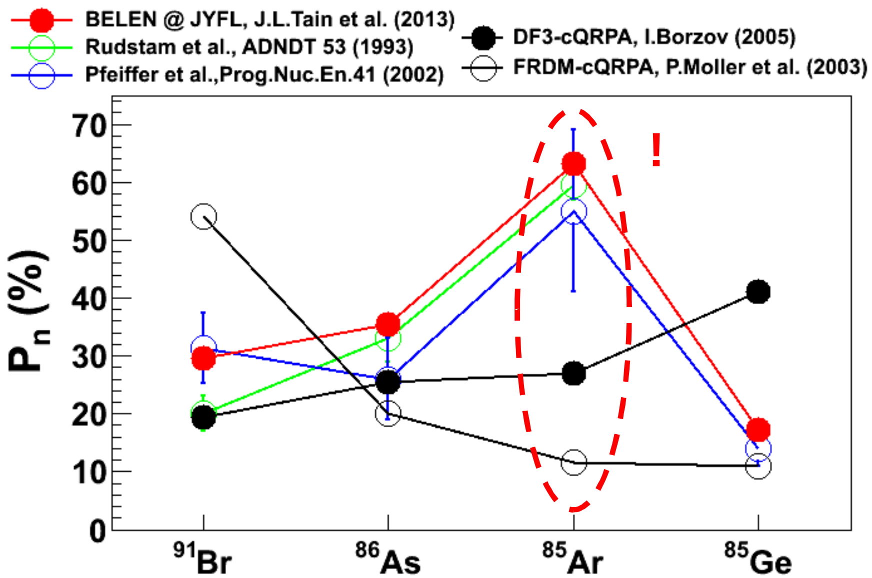




PhD Thesis:
A. García (CIEMAT)
J. Agramunt (IFIC)

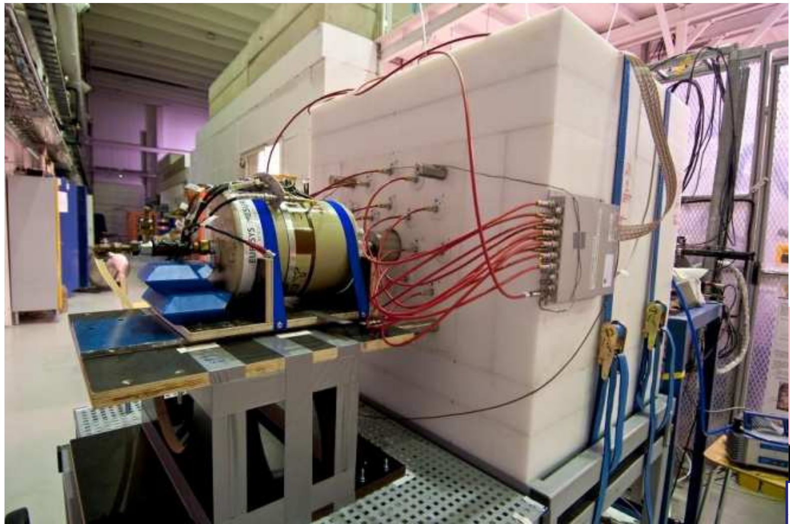


J.L.Tain et al., Nuc. Data Sheets (2014)

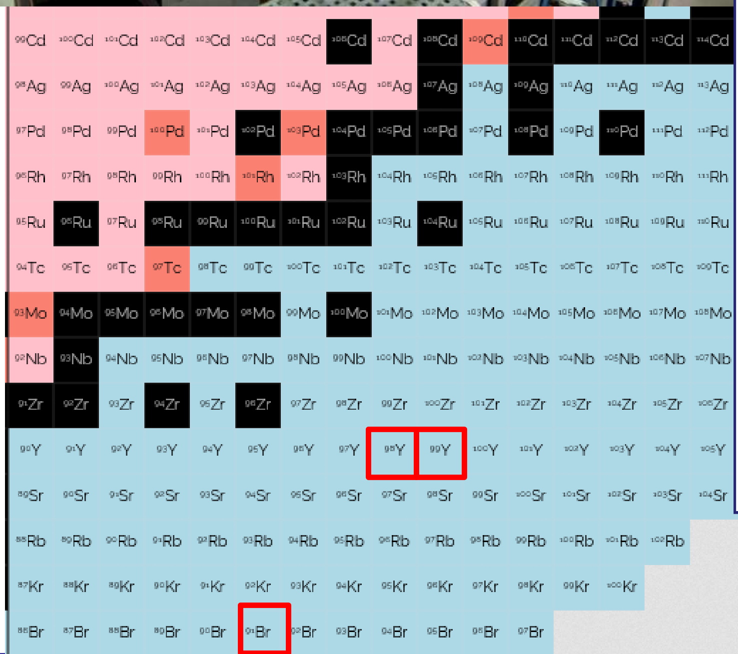


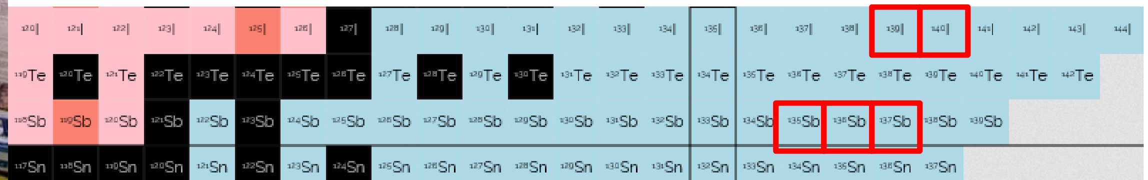
Delayed n-measurements for advanced reactor technologies and astrophysics

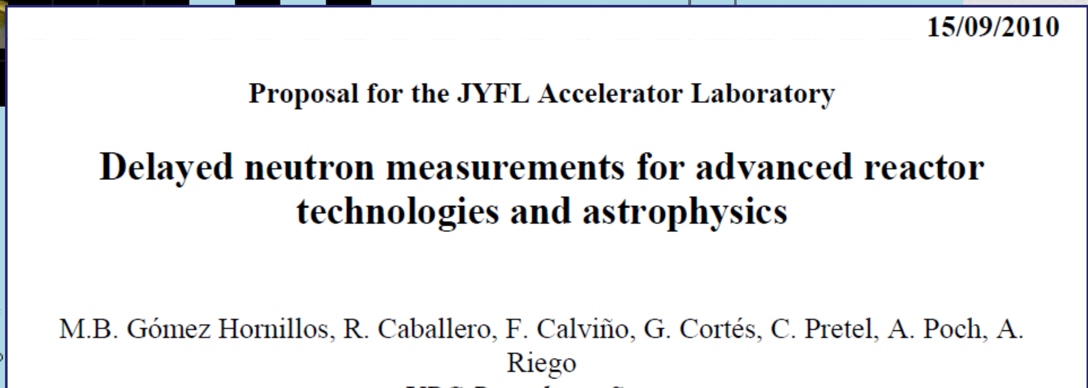
BELEN48 @ JYFL, (November 2014)



→Effective beta-delayed neutron fraction β_{eff}
→ Key parameter in reactor control
→ Major contributors to the number of delayed neutrons in conventional and advanced reactors







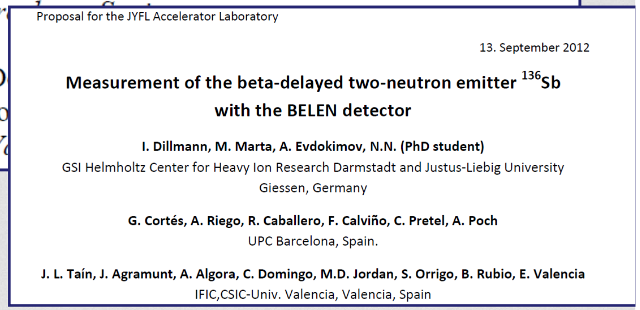
15/09/2010

Proposal for the JYFL Accelerator Laboratory

Delayed neutron measurements for advanced reactor technologies and astrophysics

M.B. Gómez Hornillos, R. Caballero, F. Calviño, G. Cortés, C. Pretel, A. Poch, A. Riego
UPC-Bar

J. L. Taín, J. Agramunt, A. Algora[1], C. D
B. Rubio
IFIC,CSIC-Univ. V



Proposal for the JYFL Accelerator Laboratory

13. September 2012

Measurement of the beta-delayed two-neutron emitter ^{136}Sb with the BELEN detector

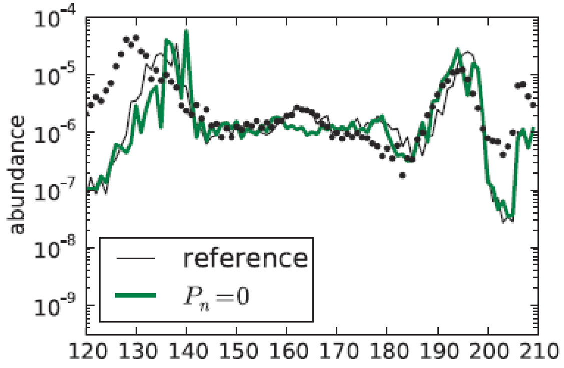
I. Dillmann, M. Marta, A. Evdokimov, N.N. (PhD student)
GSI Helmholtz Center for Heavy Ion Research Darmstadt and Justus-Liebig University Giessen, Germany

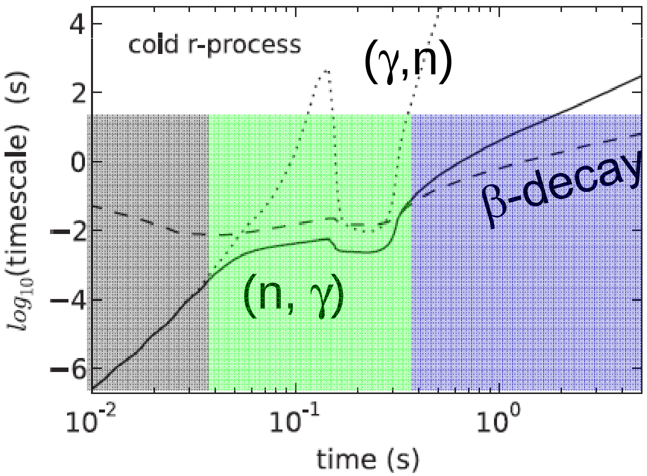
G. Cortés, A. Riego, R. Caballero, F. Calviño, C. Pretel, A. Poch
UPC Barcelona, Spain.

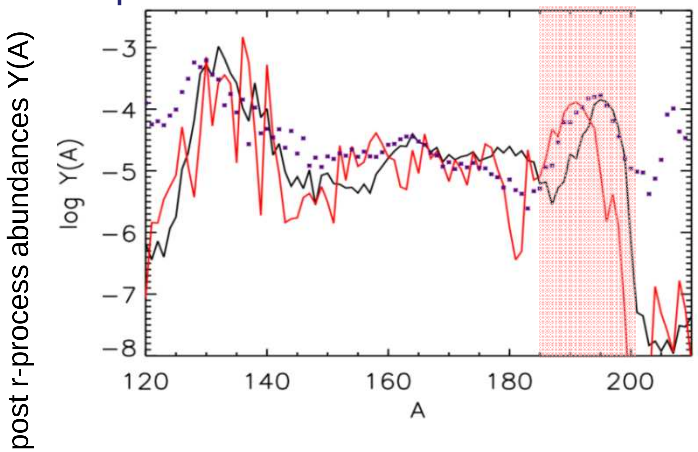
J. L. Taín, J. Agramunt, A. Algora, C. Domingo, M.D. Jordan, S. Orrigo, B. Rubio, E. Valencia
IFIC,CSIC-Univ. Valencia, Valencia, Spain

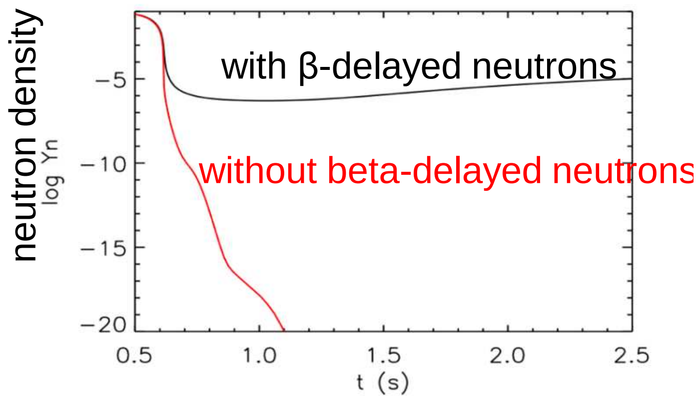
βn impacts final r-process abundances

- Unknown r-process site → r-process models try to reproduce abundances
- Need to fix uncertainty from nuclear physics input









PHYSICAL REVIEW C **83**, 045809 (2011)

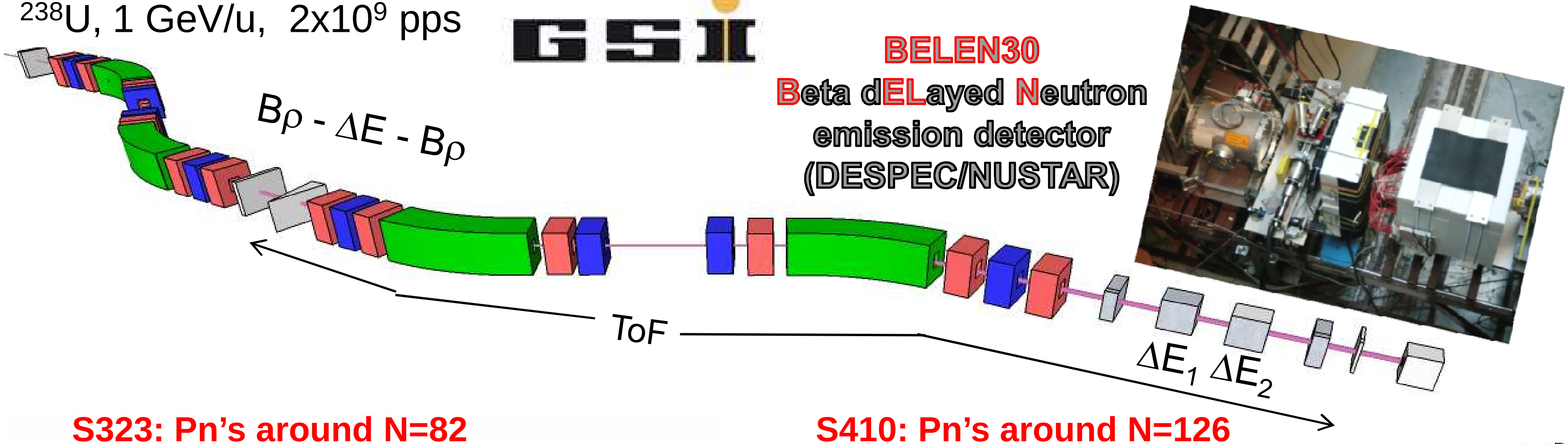
Dynamical *r*-process studies within the neutrino-driven wind scenario and its sensitivity to the nuclear physics input

A. Arcones[1,2,*] and G. Martínez-Pinedo[2]
[1] Institut für Kernphysik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany
[2] GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, D-64291 Darmstadt, Germany

R. Surman, βn-workshop, Oak Ridge, May 2013, Gordon conf., June 2013, at ARIS June 2014

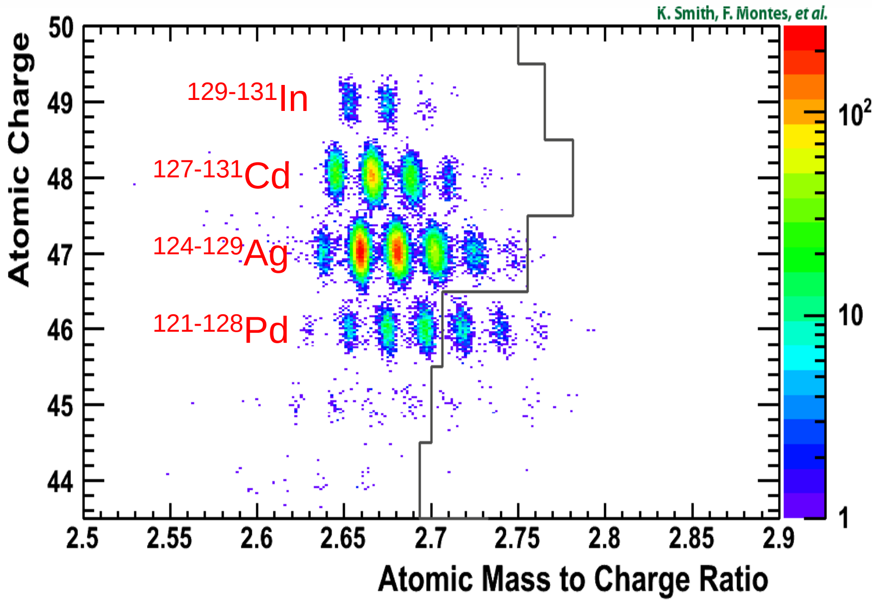
First use of BELEN at a fragmentation facility (!)

^{238}U, 1 GeV/u, 2x10^9 pps



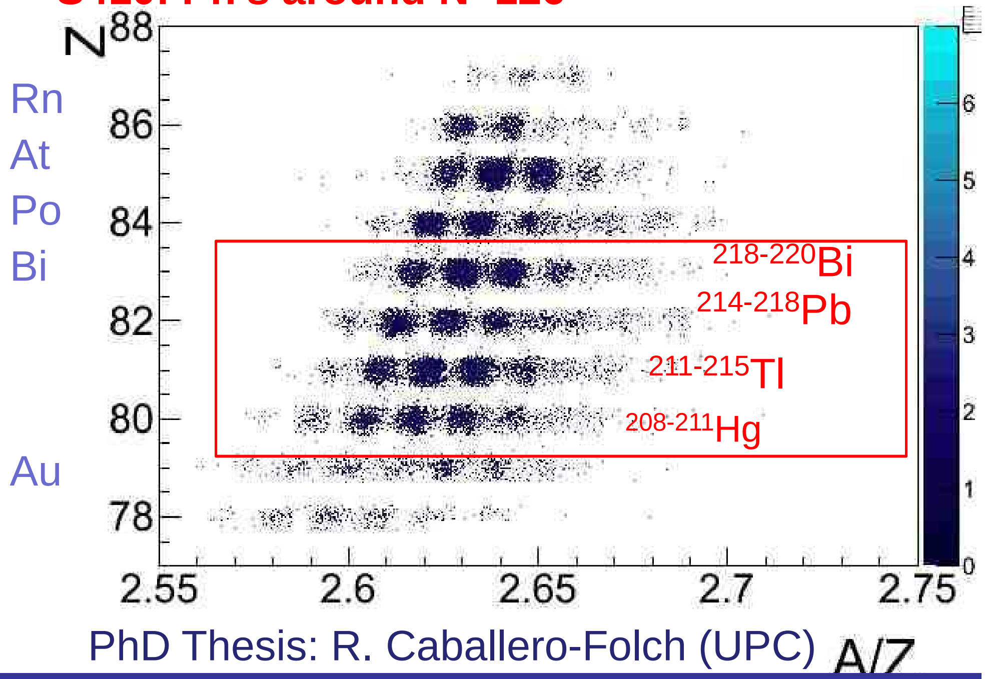
BELEN30
Beta dELayed Neutron emission detector (DESPEC/NUSTAR)

S323: Pn's around N=82



PhD Thesis: K. Smith (NSCL-MSU)

S410: Pn's around N=126

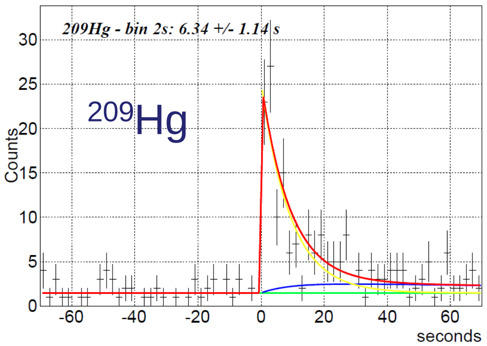


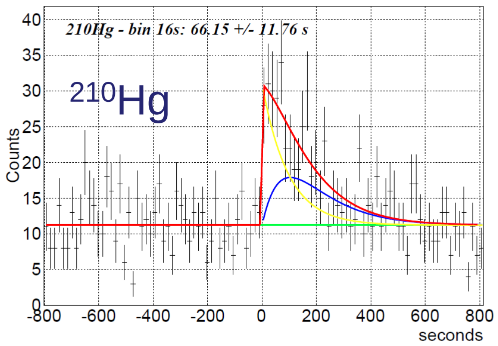
PhD Thesis: R. Caballero-Folch (UPC)

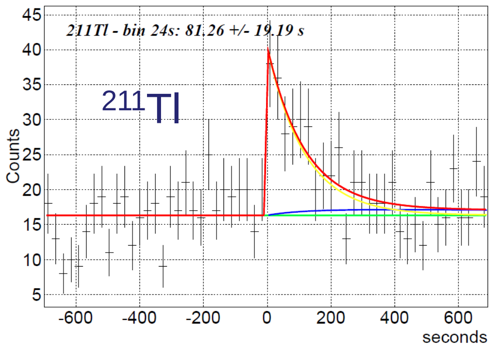
S410: Half-lives and neutron branchings around N=126

Implant-beta-neutron correlations:

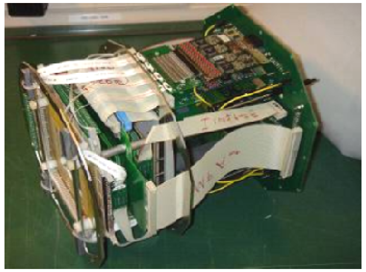
Implant-beta time-correlations:

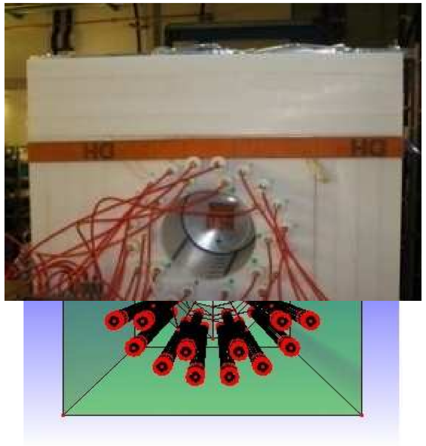


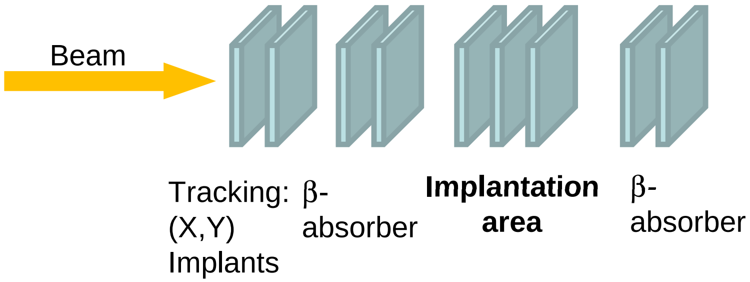


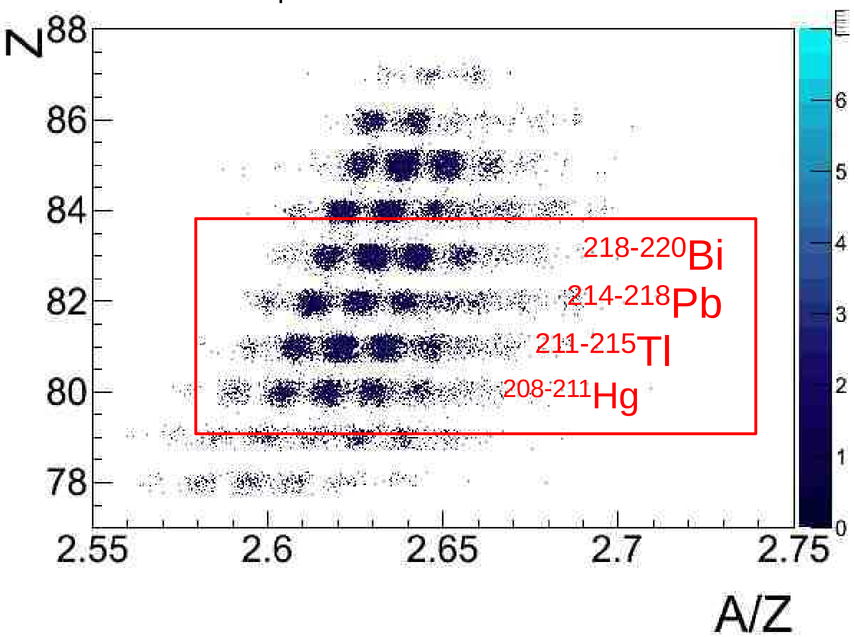


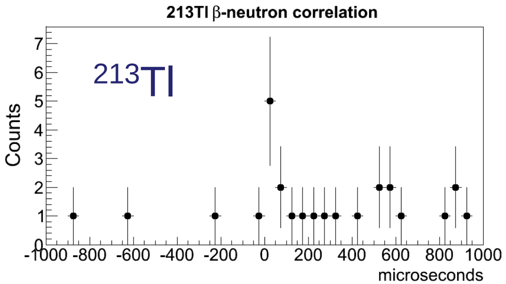
SIMBA
Silicon Implantation Array
(TU-Munich)

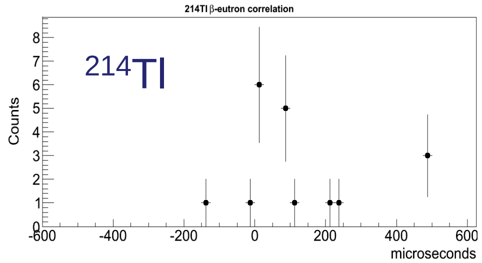




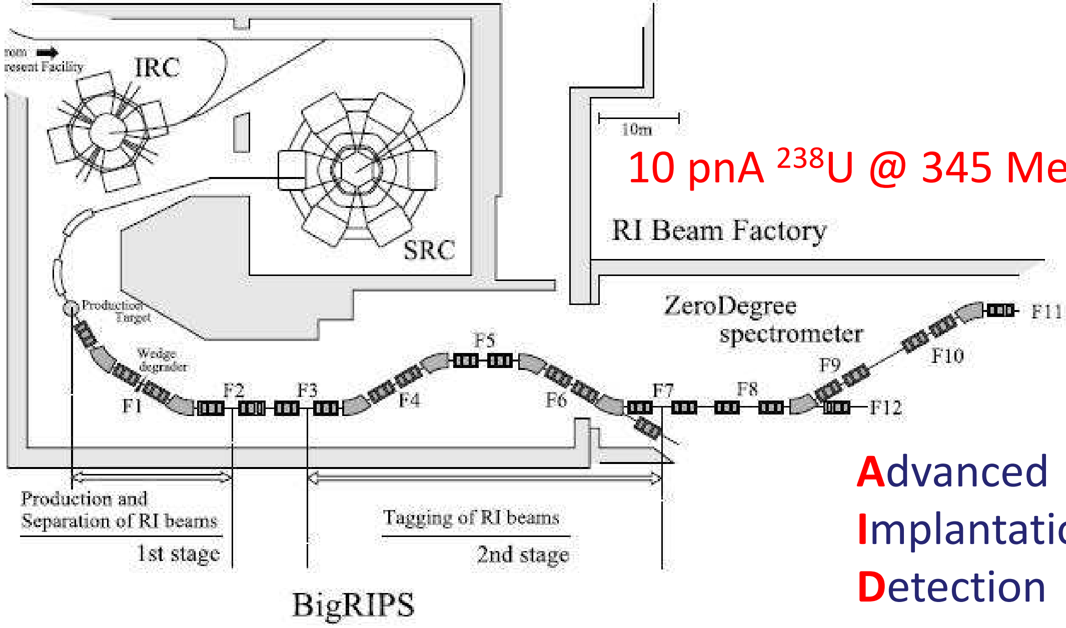








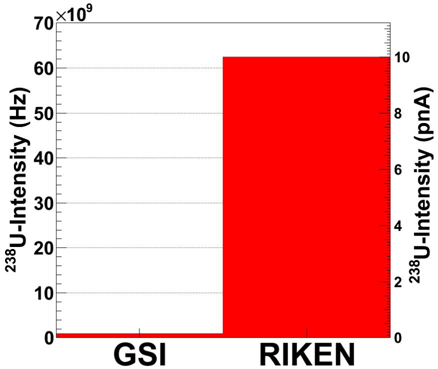
BRIKEN: βn measurements of the most exotic nuclei

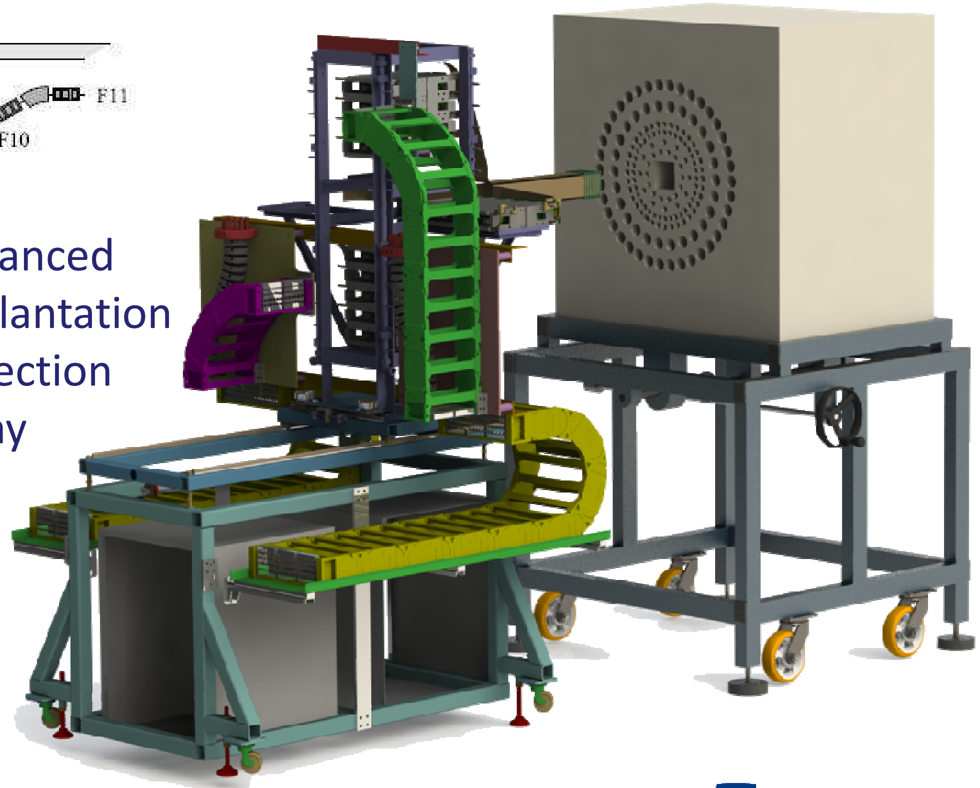


10 pnA ^{238}U @ 345 MeV/u

BRIKEN neutron detection set-up

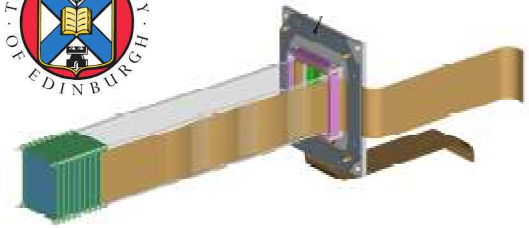
Advanced
Implantation
Detection
Array





BRIKEN: βn measurements of the most exotic nuclei

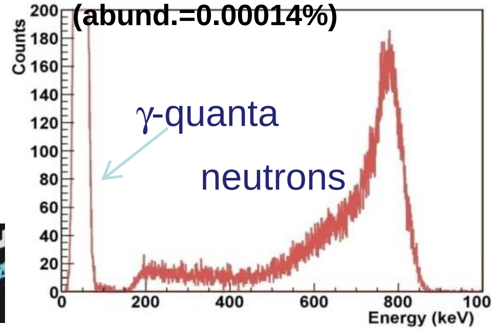
AIDA



P (atm)	# Tubes	
10	**10**	GSI
4	**20**	JINR
10	**67**	ORNL
10	**17**	ORNL
5.13	**26**	RIKEN
8	**42**	UPC
Total	**182**	

NERO (NSCL)	3HEN (ORNL)	BELEN (FAIR)	ALTO (DESIR)
60	74	48	90

n + ^{3}He → ^{3}H + ^{1}H + 0.764 MeV



Advanced
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Detection
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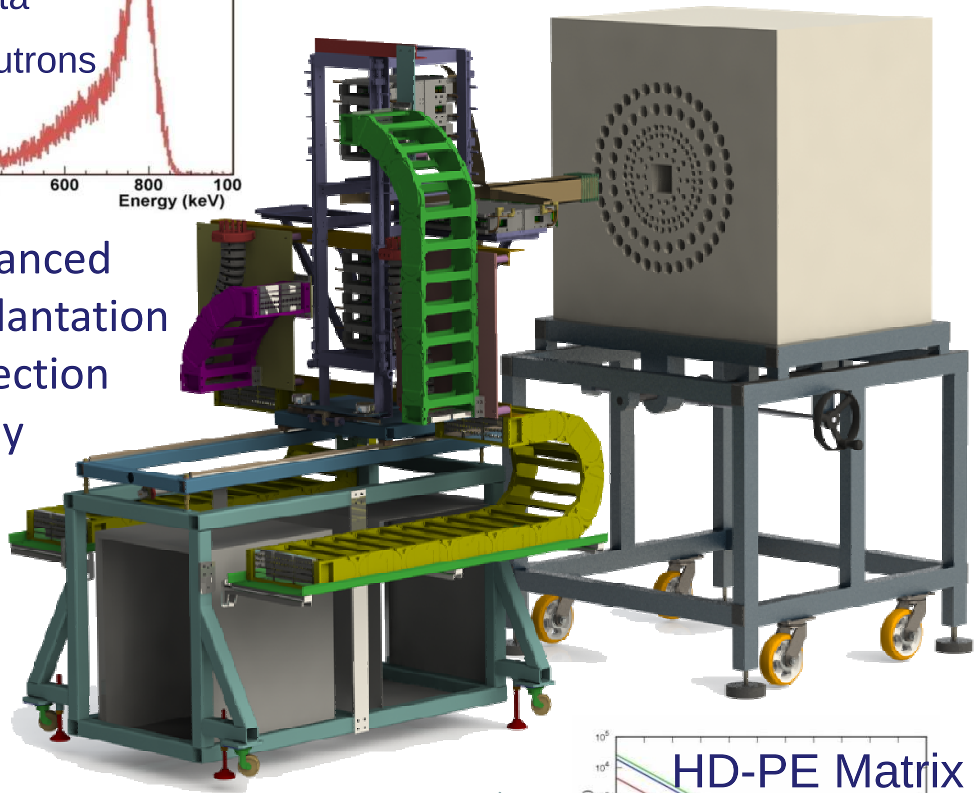
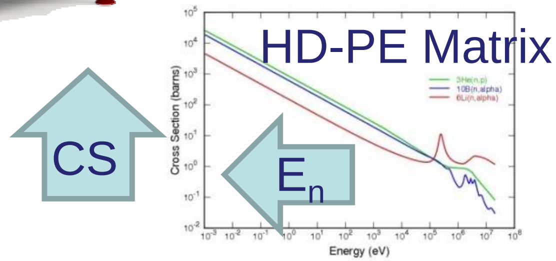
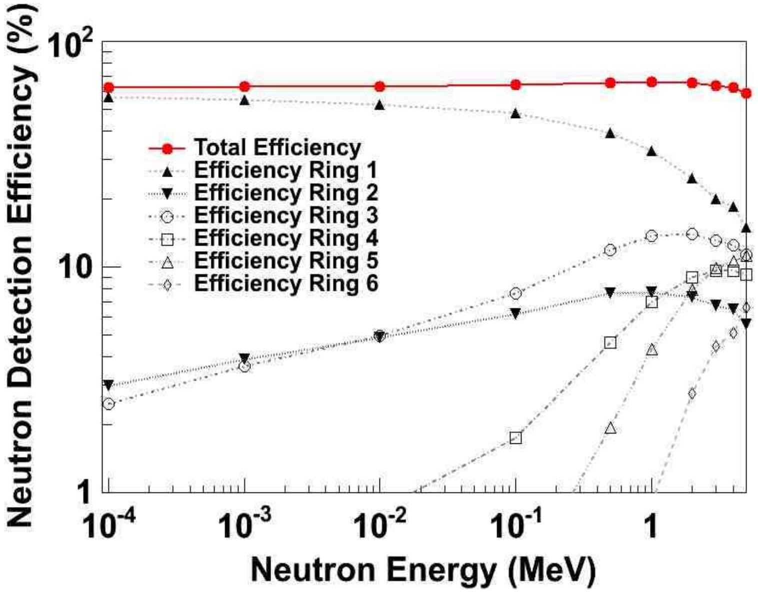
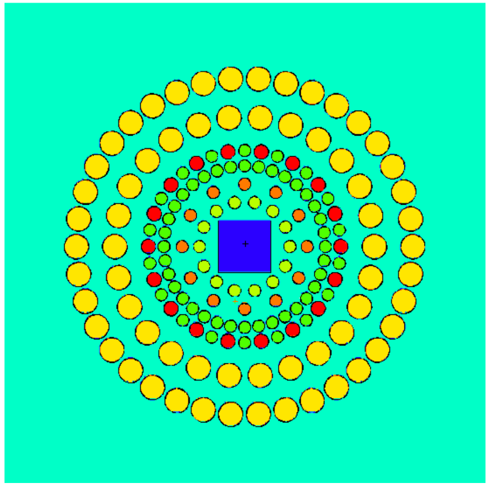
BRIKEN neutron detection set-up

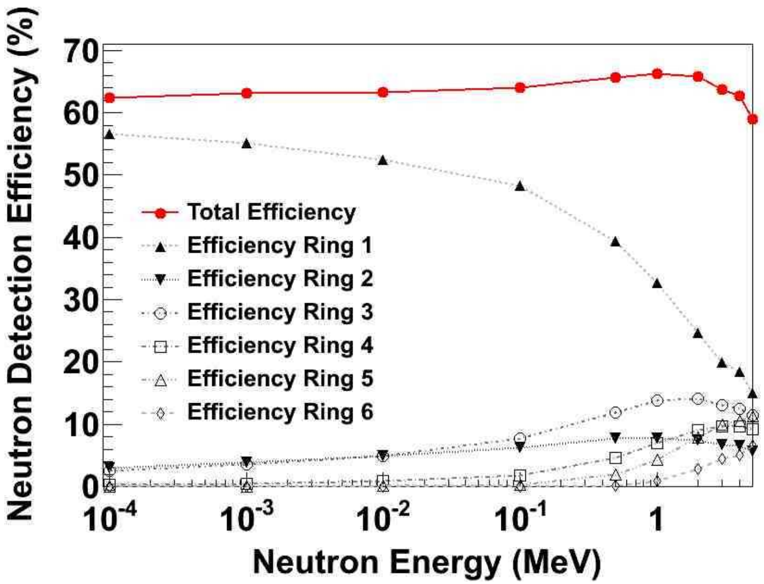




BRIKEN neutron detector array







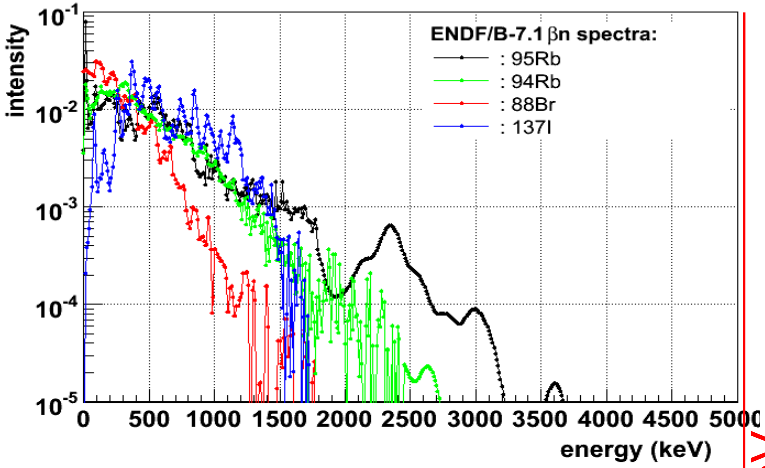
174 ^{3}He tubes of 6 different types:

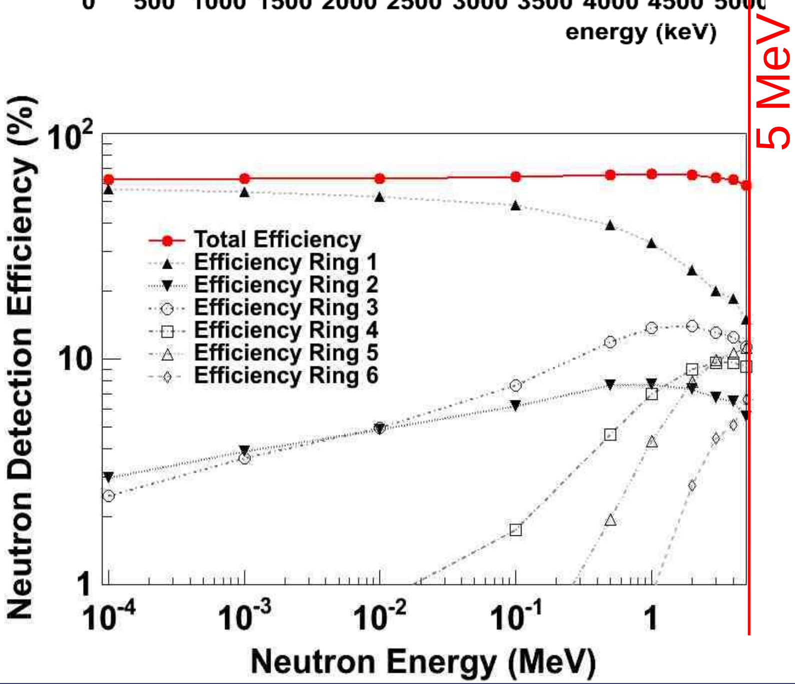
Ring	Radius (cm)	# ^{3}He Tubes	Pressure (atm)	Diameter (inch)	Institute
1	9.4	14	10	1	ORNL
2	13	12+12	5.13	1	RIKEN
3	16.8	10+26	10/8	1	GSI/UPC
4	20	18+18	5/8	1.18/1	JINR/UPC
5	27	26	10	2	ORNL
6	35	38	10	2	ORNL

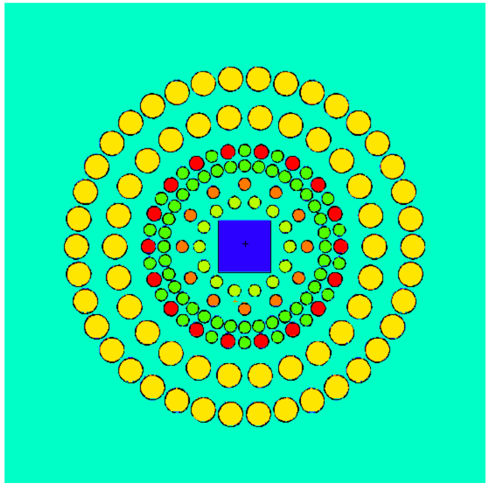
- High average efficiency of > 60 %
- Flat efficiency 6% up to 4 MeV, 12% up to 5 MeV.

BRIKEN neutron detector array

- Eff. independent on neutron E-spectrum.
- E-spectrum can be infered from rings info.







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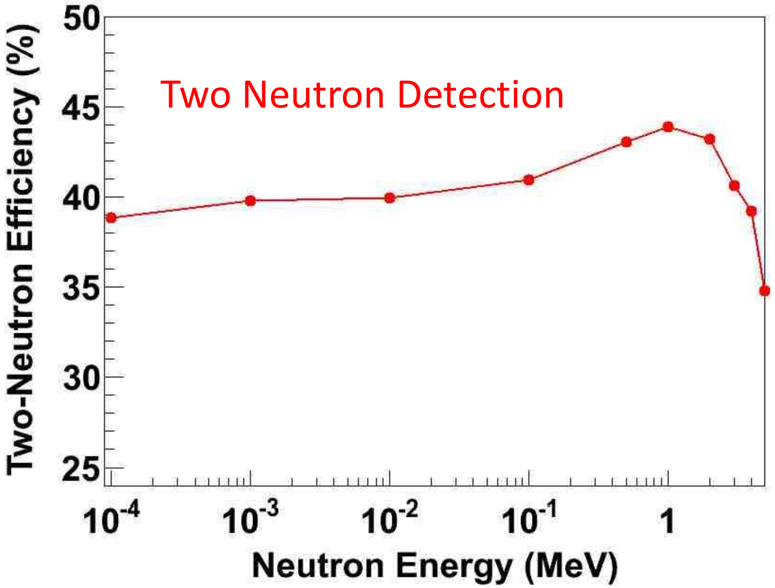
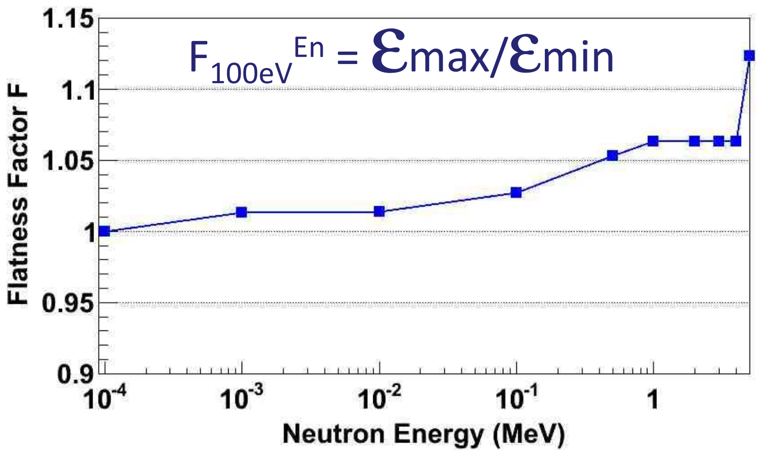
✓ BRIKEN Construction Proposal Approved @ RIKEN-PAC December, 2013

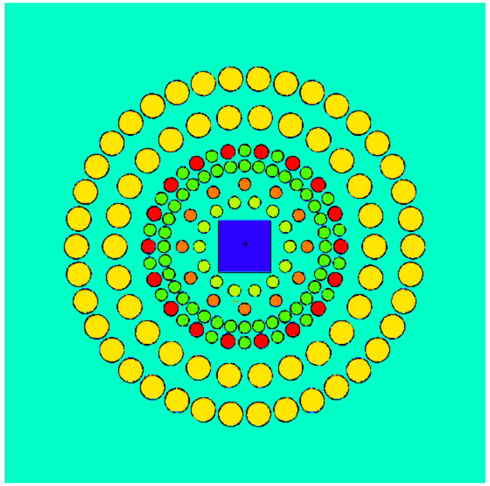
BRIKEN neutron detector array

High efficiency also for two-fold neutron emission:



Flat efficiency → Pn insensitive to neutron spectrum





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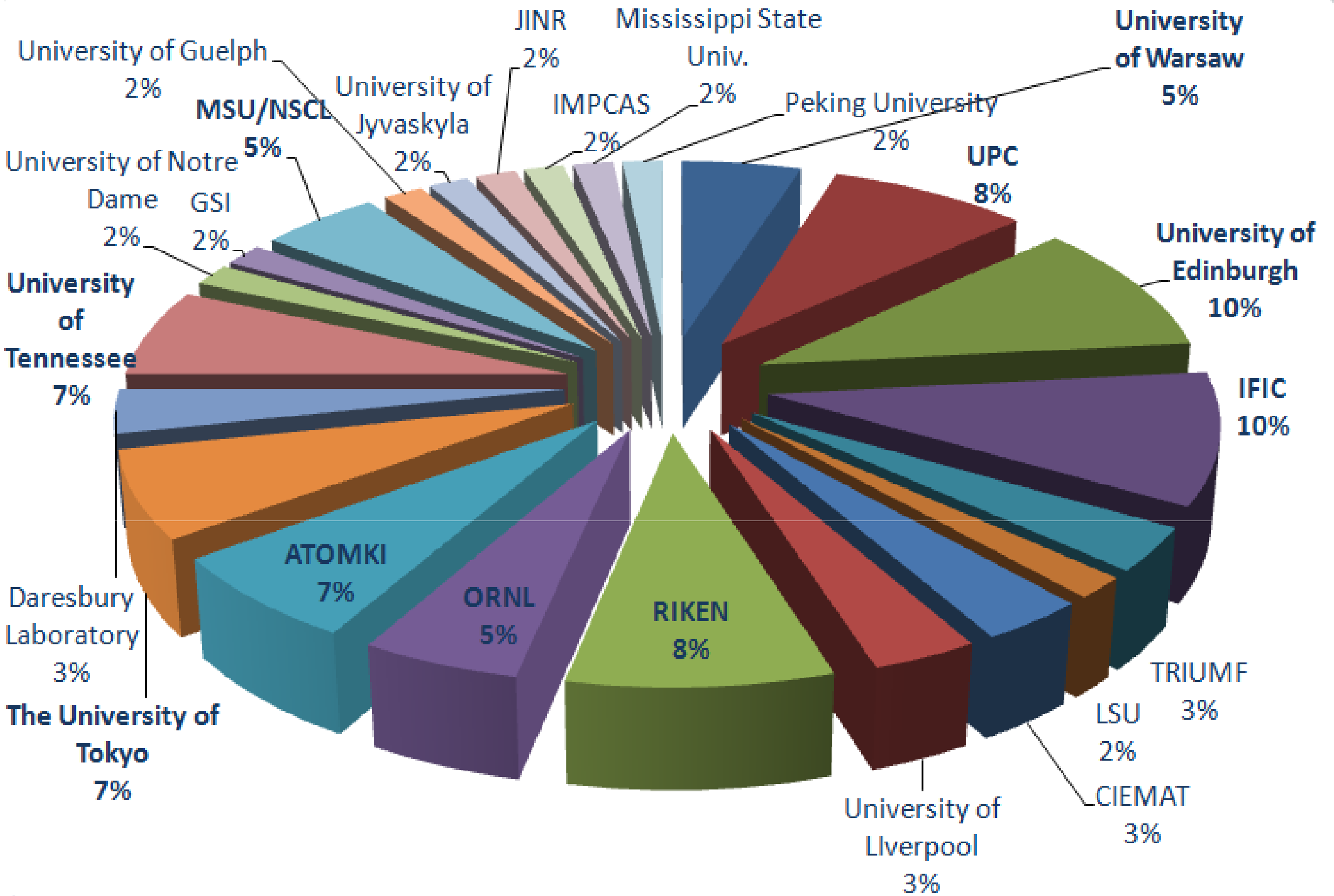
✓ BRIKEN Construction Proposal Approved @ RIKEN-PAC December, 2013

BRIKEN Collaboration



>50 Scientists

>20 Research Centers

Open project, to join: briken.project@gmail.com

http://indico.ific.uv.es/indico/event/briken 1st BRIKEN Workshop, Valencia 17-18 Dec. 2012

http://indico.ific.uv.es/indico/event/briken2 2nd BRIKEN Workshop, Tokyo, 30-31 July 2013

Goals for a Campaign of BRIKEN experiments

Presenter	Topic	Nuclei
S.Nishimura (RIKEN)	Below the 2nd r-process peak	112Zr-129Pd
F. Montes (MSU)	2nd r-process peak	139Sb
C.Domingo (IFIC)	Rare-earth r-process peak	151La-173Tb
G. Lorusso (RIKEN)	2nd r-process peak	129Ag-142Te, 133-134Cd
M.Marta I.Dillmann (GSI/TRIUMF)	Multiple n emission	76Co-81Cu, 134Sn-133Cd
K.Rykaczewski (ORNL)	One and two n emiiters above 78Ni and 132Sn	Ni, Cu ,Zn, Ga, Ge, As, Se, In
R.Griwacz (U.Tennessee)	One and two n-emission below and at 78Ni	Cl, Ar, K, Ca, Sc, Ti, Ni, Cu, Zn, Mn, Fe, Co
A Algora (IFIC)	Deformation A~110	106-110Zr, 110-114Mo
B. Rubio (IFIC)	Nuclear structure ~132Sn	130Ag-138Sb
A.Estrade (Edinburgh)	Masses	Several
J.L. Tain (IFIC)	β-strength NE of 78Ni	85Ge-97Br
D.Cano-Ott (CIEMAT)	Reactor technologies	Ge86,Rb-96,Rb100, Y98m, Cd131, Sb137

PROJECT PROPOSAL

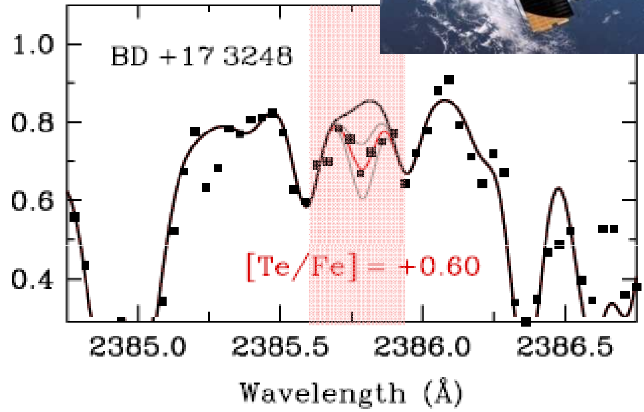
Astrophysics: r-process nucleosynthesis

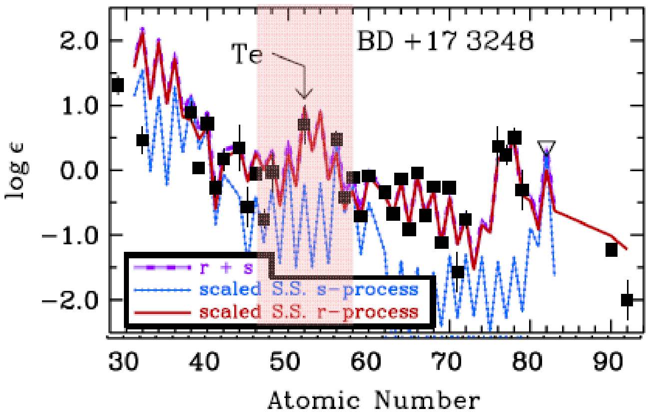
Nuclear Structure: 1n, 2n-competition in heavy nuclei, FF vs. GT, etc

New reactor technologies

The A = 130 peak and Hubble observations in metal poor stars

First observation of Te in metal poor stars (!!)



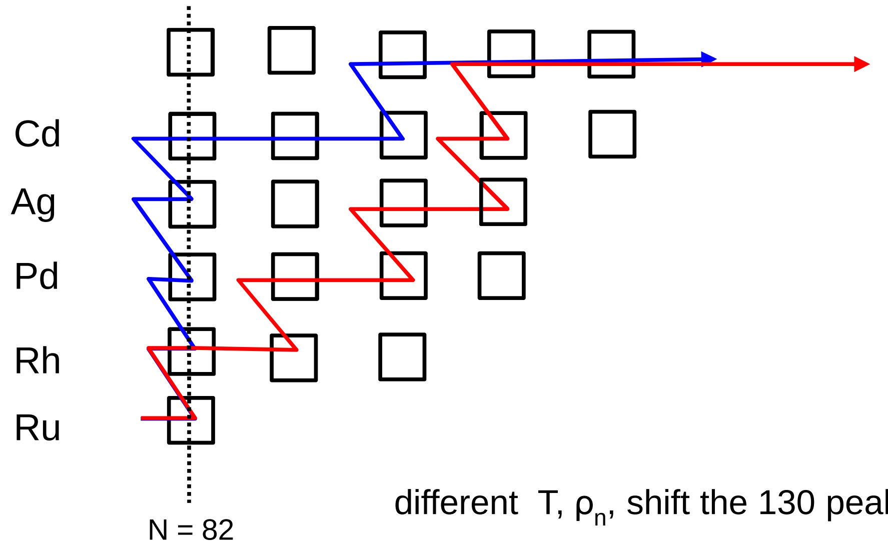


I. Roederer et al., The Astroph. Journ. Lett. 2012

- New Te observation (A ≤ 130) and Ba (A ≥ 140) highlight r-process conditions in single r-process events (!)
- Te-abundance in UMP-Stars offers and independent test on the predicted r-process abundance of Te in the S.S.
- Relevant to constrain the conditions of the r-process operating early in the Galaxy

(not averaged like in the solar)

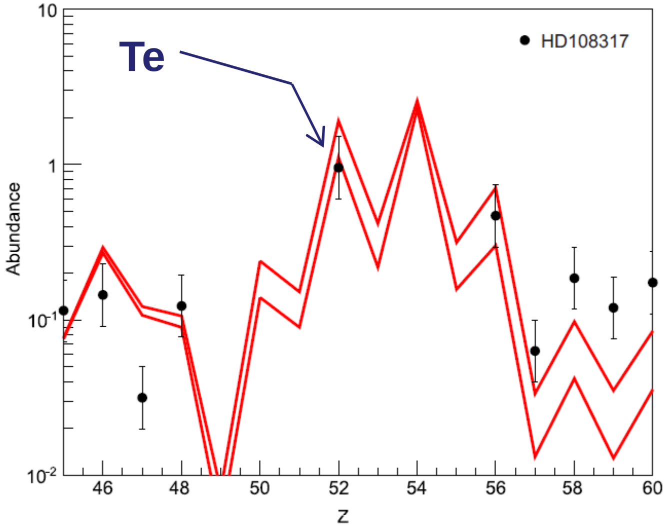
- Te/Ba ratio is sensitive to
  - + r-process conditions
  - + contribution of the weak r-process
- Pn is one of the important unknown affecting the ratio Te/Ba



different T, ρ_n, shift the 130 peak

The A = 130 peak and Hubble observations in metal poor stars

Elemental distribution in HD108317



Main Motivations

1) N = 82 nuclei (^{129}Ag, ^{128}Pd, ^{127}Rh)
   - possibly the most exotic probe of shell model
   - possibly the largest source of neutron during freezout

2) Rh, Pd, Ag are progenitors of Te (^{131}Ag, ^{129}Pd)
   Sb, Sn, In are progenitors of Ba

3) Candidate for b-2n, b-3n emission

Measurement of 33xP1n , 11xP2n and 3xP3n

All relevant to the A=130 peak

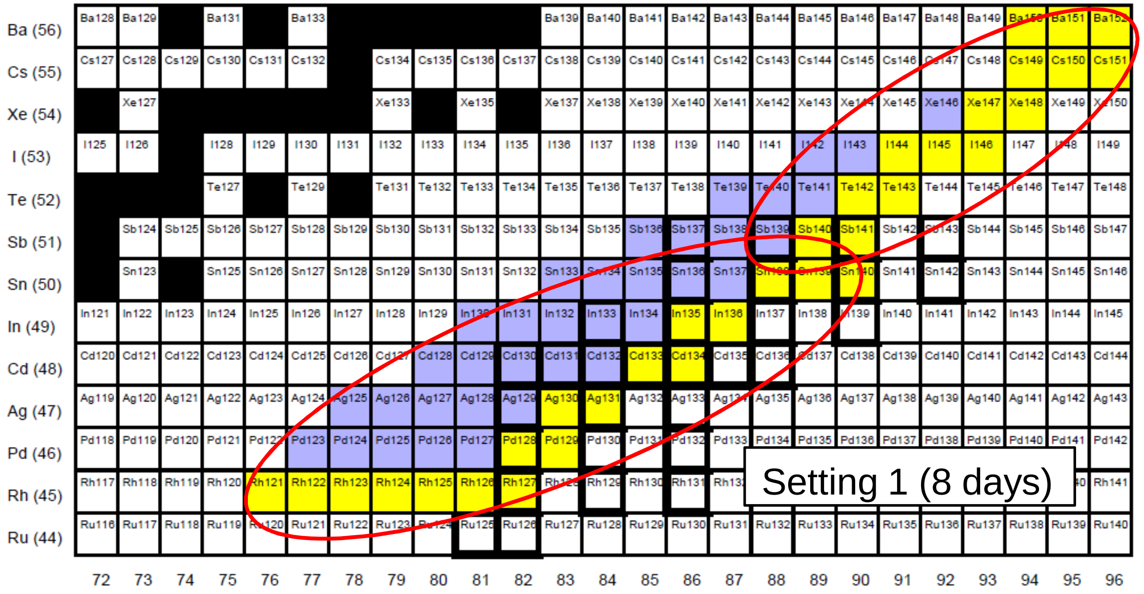
Measurement of β-delayed neutron emission probabilities relevant to the $A = 130$ r-process abundance peak

SUMMARY OF THE EXPERIMENT

We propose to study the β-delayed neutron emission probabilities (P_n-values) of a large range of nuclei in the region around ^{132}Sn, critical to understand the r-process abundance peak $A \approx 130$. These measurements are specially relevant given the recent observations of elements Cd (Z=48) and Te (Z=52) in metal-poor stars. Our proposed measurement will greatly improve the reliability of r-process modeling and will allow to extract specific r-process conditions responsible for the observed Te and Ba abundances in these metal-poor stars. In addition, our measurements will also have implications for nuclear structure models, providing first experimental constraints in a region where in many cases, half-lives are the only experimental ground state property known (e.g. south-east of ^{132}Sn). This proposal is part of the BRIKEN project for which a construction proposal was approved in the 2014 NP-PAC.

NP-PAC14 APPROVED

Setting 2 (2 days)



Spokespersons: A. Estrade, G. Lorusso, F.Montes

The 1st r-process peak and Hubble observations in metal poor stars

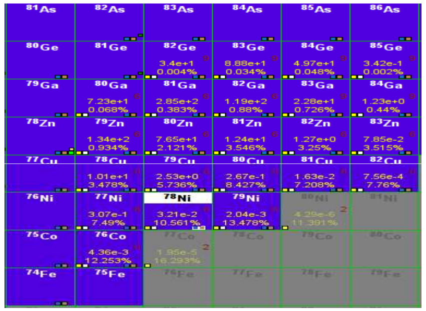
Draft version June 19, 2014
Preprint typeset using LaTeX style emulateapj v. 5/2/11

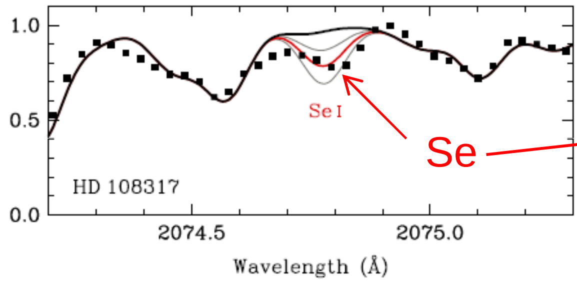
arXiv:1406:4554v1

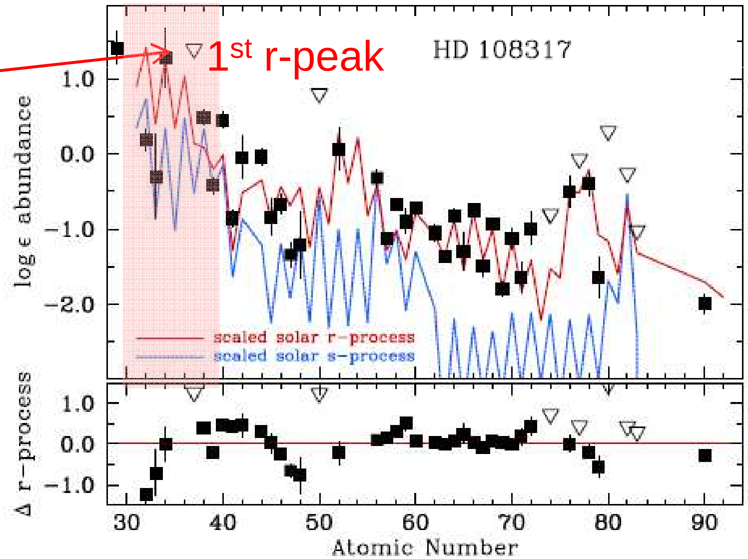
NEW DETECTIONS OF ARSENIC, SELENIUM, AND OTHER HEAVY ELEMENTS IN TWO METAL-POOR STARS[1]

Ian U. Roederer,[2] Hendrik Schatz,[3,4,5] James E. Lawler,[6] Timothy C. Beers,[3,4,7] John J. Cowan,[8] Anna Frebel,[9] Inese I. Ivans,[10] Christopher Sneden,[11] Jennifer S. Sobeck[12]

Draft version June 19, 2014







"Measurements of new beta-delayed neutron emission properties around doubly-magic ^{78}Ni"

presented by
K.P. Rykaczewski (ORNL Oak Ridge), J.L. Tain (IFIC Valencia)
R. Grzywacz (UT Knoxville), I. Dillmann (TRIUMF Vancouver)
on behalf of BRIKEN collaboration

Abstract:
It is proposed to measure new beta-delayed neutron (βn) emission properties for nuclei near doubly-magic ^{78}Ni using the world-largest array of ^{3}He counters BRIKEN and highly segmented array of Silicon detectors AIDA. The RIKEN's Big RIPS fragment separator will be used to select βn-emitting nuclei from all products of the ^{238}U 345 (MeV/u) + ^{9}Be reaction. The experiment will result in **the first measurement of twenty one P_{1n} values for nuclei between ^{76}Co and ^{92}Se including that one of the doubly-magic ^{78}Ni as well as the discovery of thirteen β2n emitters ^{79}Ni and ^{91}As and determination of their P_{2n} values.** The investigated nuclei are located on the r-process path and new data can be used directly in nucleosynthesis network calculations. The observables will also reveal nuclear structure of studied nuclei by yielding data on the allowed and first-forbidden beta transition strength as well as on the competition of β1n and β2n decay modes.

To be presented in December NP-PAC 2014 at RIKEN

Spokespersons: I.Dillmann, R. Grywacz, K.Ryckazewscki & J.L.Tain

Summary & Outlook

• Beta-delayed neutrons will be one of the key Gross properties we will aiming at measuring in the next generation of RIB facilities, like NUSTAR-FAIR.

• βn measurements respresent an stringent test for nuclear models far-off stability and how well the nuclear structure details (beta-strength function) are included.

• In stellar nucleosynthesis β-delayed neutron emission plays a relevant role for understanding both the observed r-process distributions and dynamical evolution.

• We intend to study these aspects in the framework of the BRIKEN Project devoted to the measurement of the most exotic nuclei at the RIB facility of RIKEN.

• BRIKEN is a joint international effort, to join instrumentation and expertise in order to build a high-performance –high+flat efficiency- neutron detector array, to be set-up and operated for an experimental campaign at RIKEN.

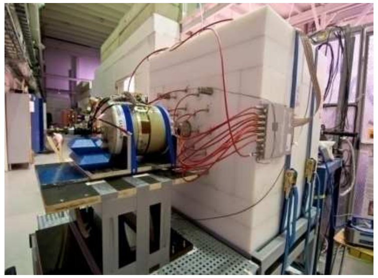
• First physics proposals already approved at RIKEN, to be carried out in 2015.

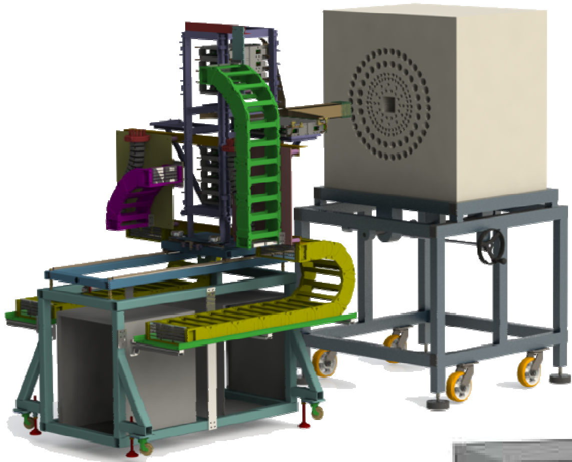
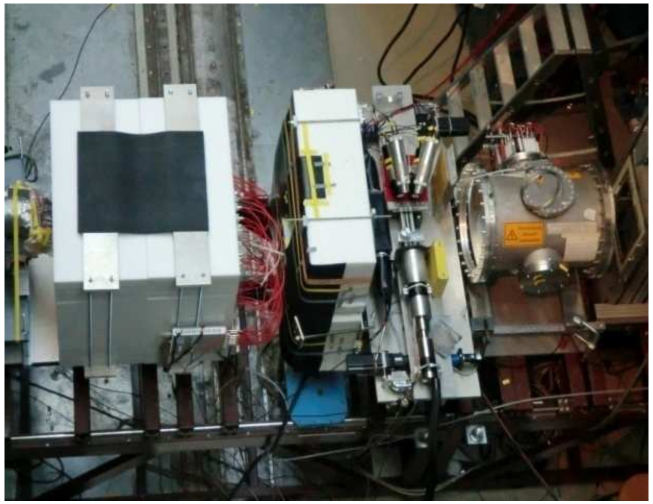
Thank you for your attention!

The “shape evolution” of BELEN: Towards NUSTAR!

BELEN20	BELEN30	BELEN48	BRIKEN-174	BELEN48
JYFL	GSI	JYFL	RIKEN	FAIR NUSTAR
2009-2010	2011	2014	2015	2018-2019

PHASE 0 → PHASE 1




Thanks to BELEN & BRIKEN Collaborators

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Alejandro Algora	IFIC
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Berta Rubio	IFIC
Francisco Calvino	UPC
Cesar Domingo Pardo	IFIC
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Christopher Griffin	University of Edinburgh
Claudia Lederer	University of Edinburgh
Charlie Rasco	LSU
Daniel Cano Ott	CIEMAT
Maria Dolores Jordan	IFIC
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