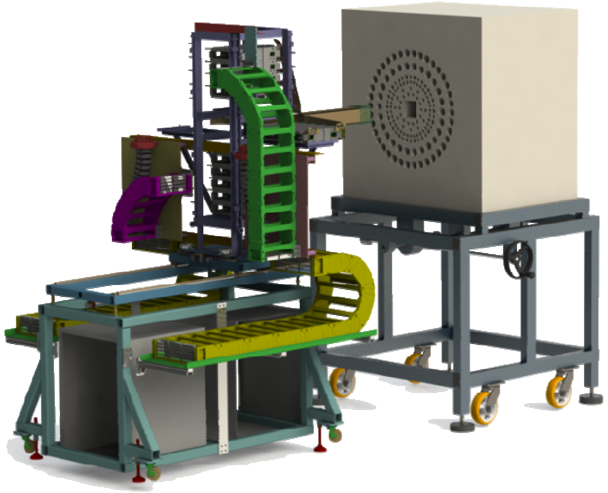
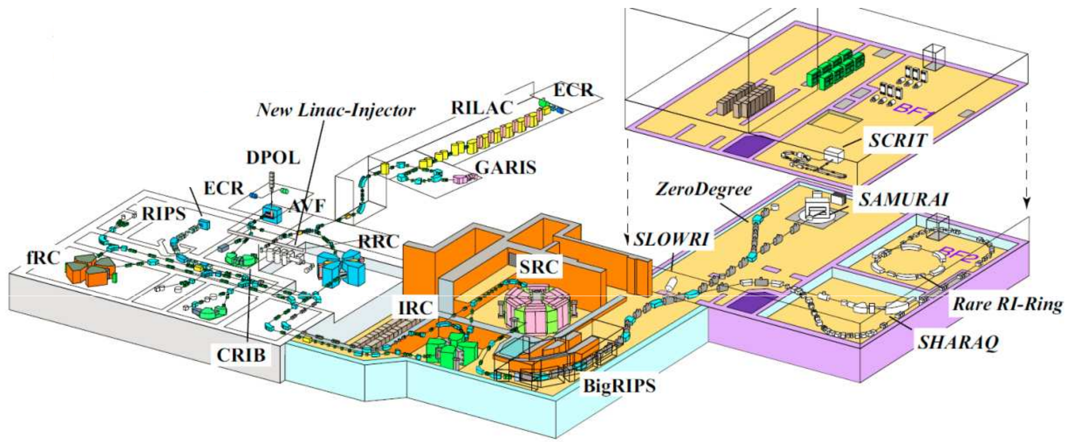
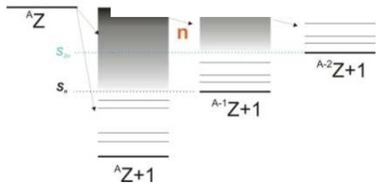
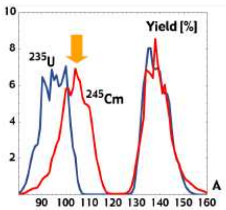
BRIKEN:

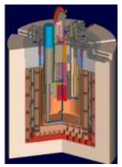
β-delayed neutron measurements at RIKEN for nuclear structure, astrophysics and applications

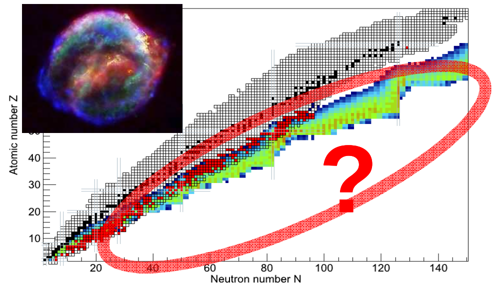










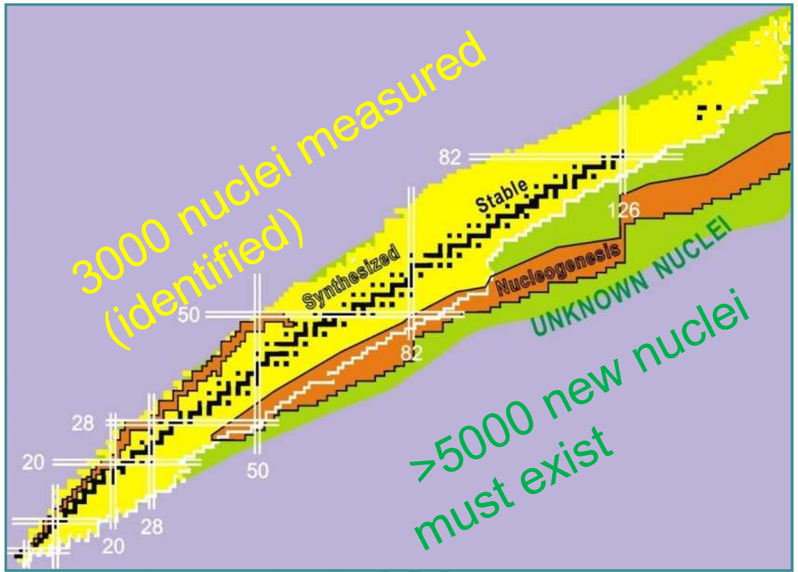


Outline

- Motivation & Introduction
- Recent examples of measurements: 2n-emitters (ORNL), βn around ^{78}Ni (JYFL) and stellar nucleosynthesis around N=126 (GSI).
- The BRIKEN approach:
  - BRIKEN-Collaboration
  - Detector design: a high- and flat-efficiency detection system
- Summary & Outlook

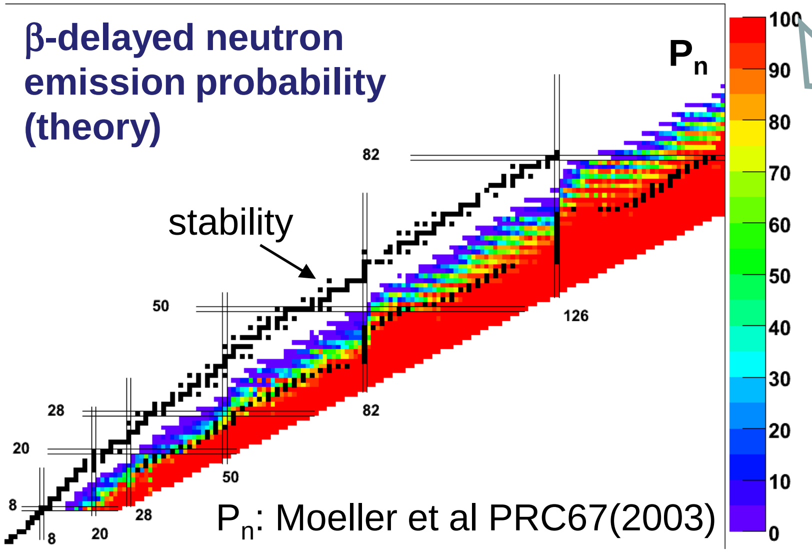
Motivation

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

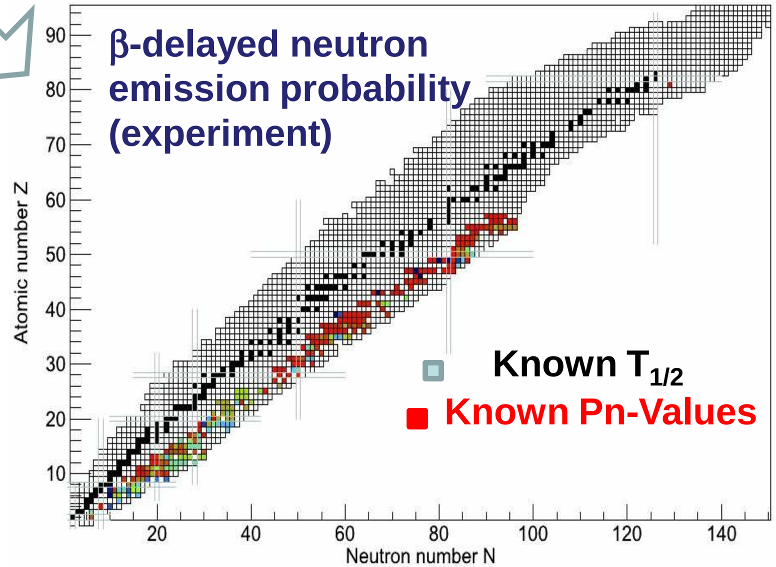


Almost all these new nuclei are expected to be neutron emitters, and hence, an understanding of this property and the involved technique becomes of pivotal impotance for NS and future studies.

What we expect (theory):



What we know (experiments):



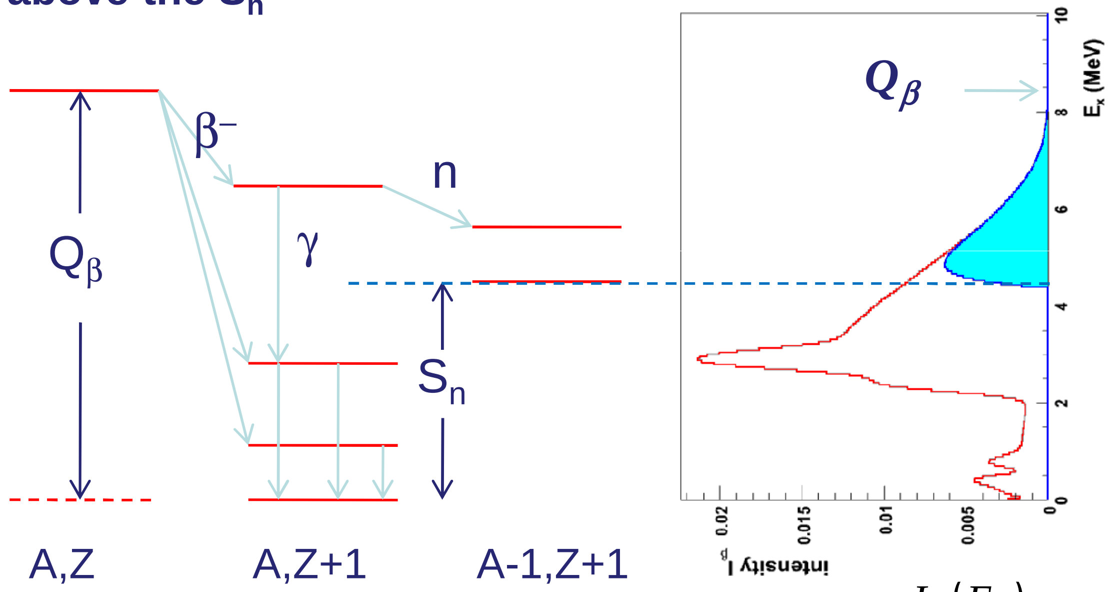
- Almost all new nuclei are expected to be n-emitters
- Only about 200 n-emitters are known

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**

$$\frac{1}{T_{1/2}} = \sum_{0}^{Q_\beta} S_\beta(E_x) \cdot f(Q_\beta - E_x)$$

$$P_n = \frac{\sum_{S_n}^{Q_\beta} S_\beta(E_x) \cdot f(Q_\beta - E_x)}{\sum_{0}^{Q_\beta} S_\beta(E_x) \cdot f(Q_\beta - E_x)}$$



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

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

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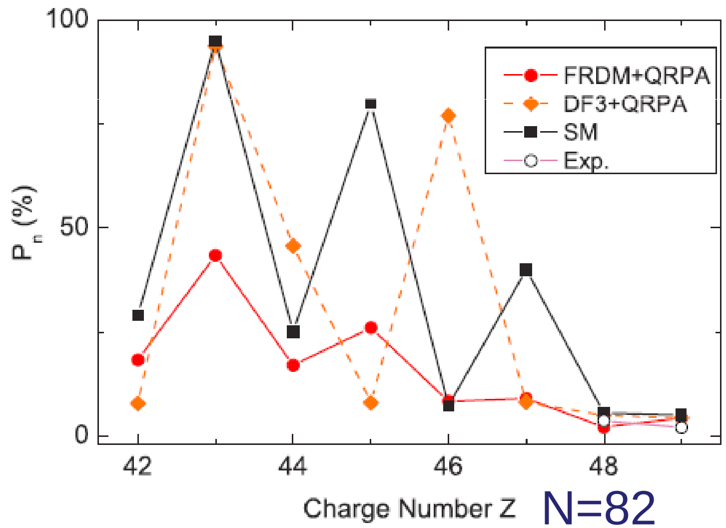
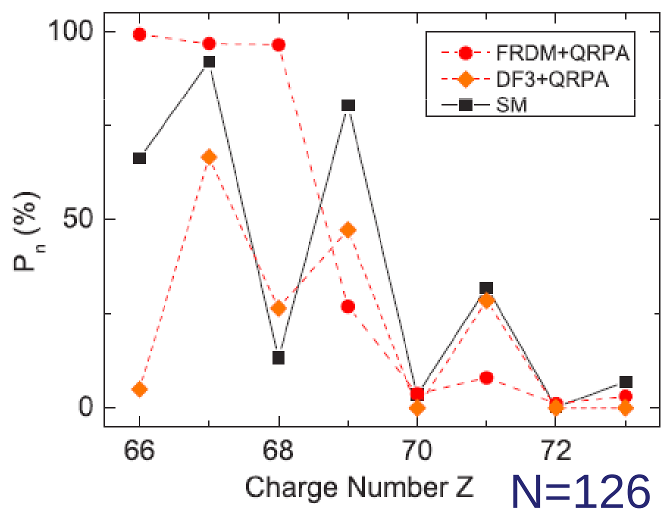
• P_n yields information on the β-feeding **above the S_n**

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

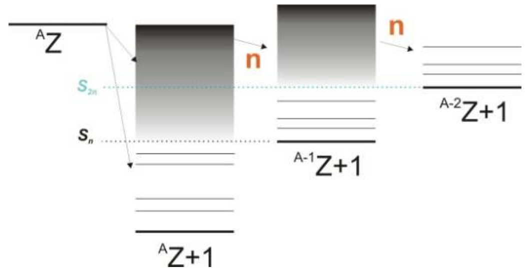




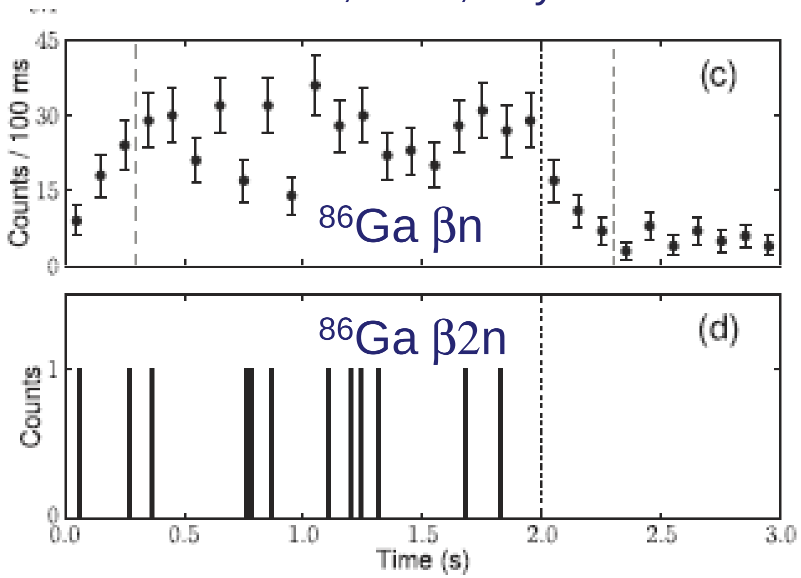
Despite of the relatively simple Pn “definition”, Pn values are rather difficult to predict theoretically, as they are reflecting the “shape” of the b-strength distribution and the underlying fine-structure of the nucleus at high excitation energy (!).

Competition between 1n and 2n emission

→1n-2n competition and theoretical description
→ xn emission is even more difficult to model.
→ Postulated for first time in 1960s (Goldansky et al.)
→ Only 18 b2n emitters, only tree heavier than Fe: ^{86}Ga and ^{98,100}Rb.



Credit: K. Miernik, et al., Phys. Rev. Lett. 111 (2013)



ε_n = 10%

ε_{2n} =1%

Hybrid 3Hen @ HRIBF-LeRIBSS:
48 ^{3}He Counters + 2 HPGe Clovers

Competition between 1n and 2n emission

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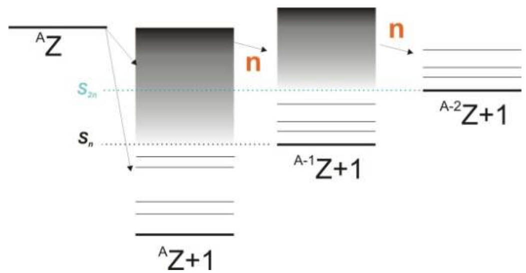
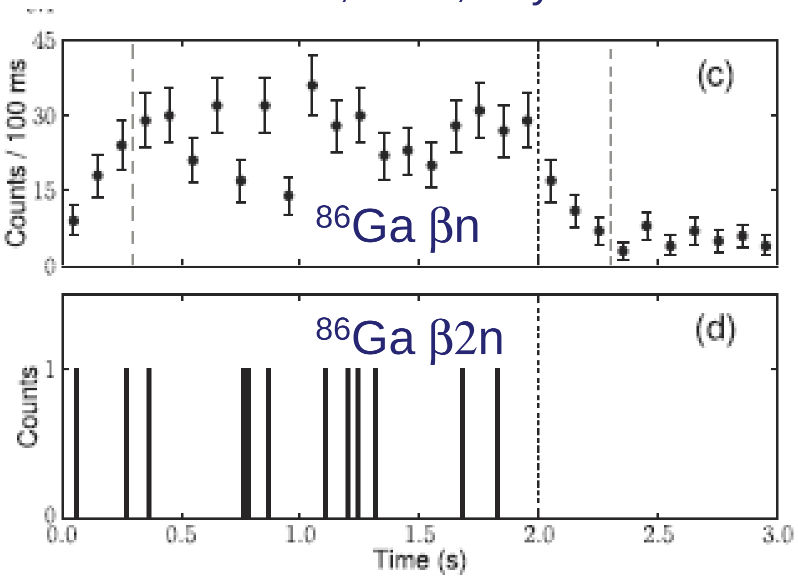


Credit: K. Miernik, et al., Phys. Rev. Lett. 111 (2013)



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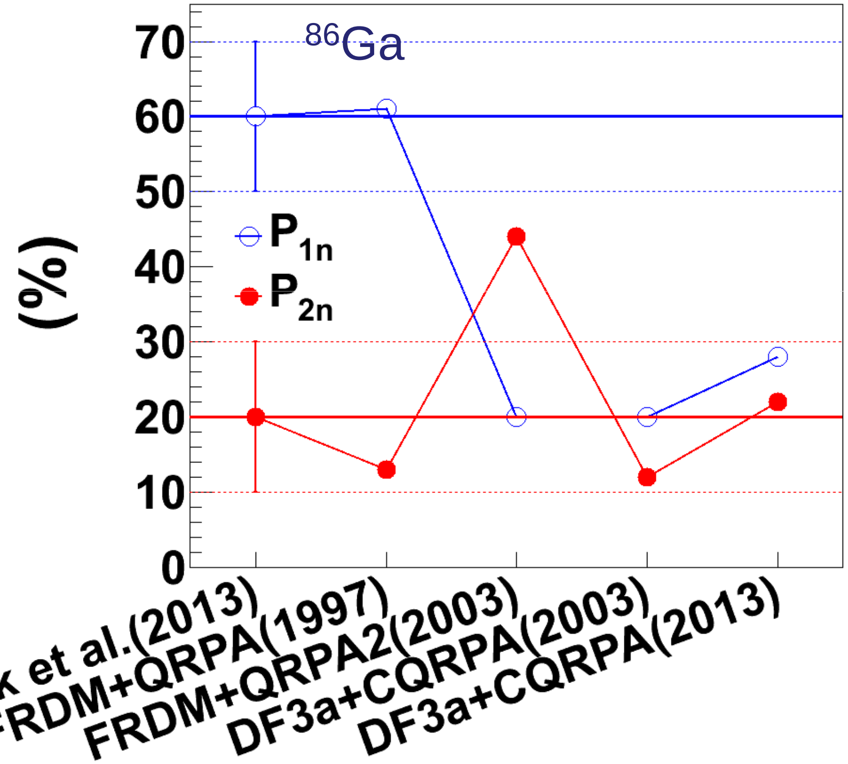
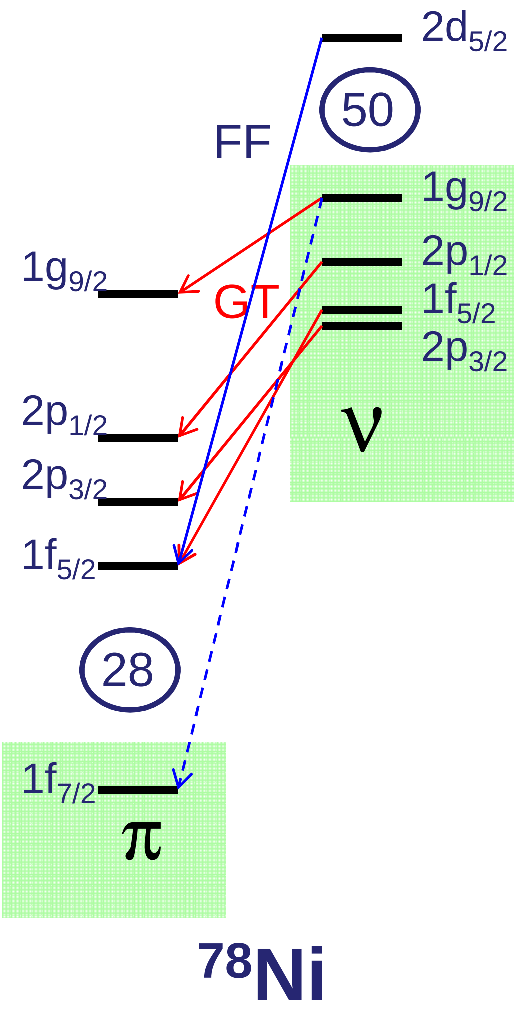
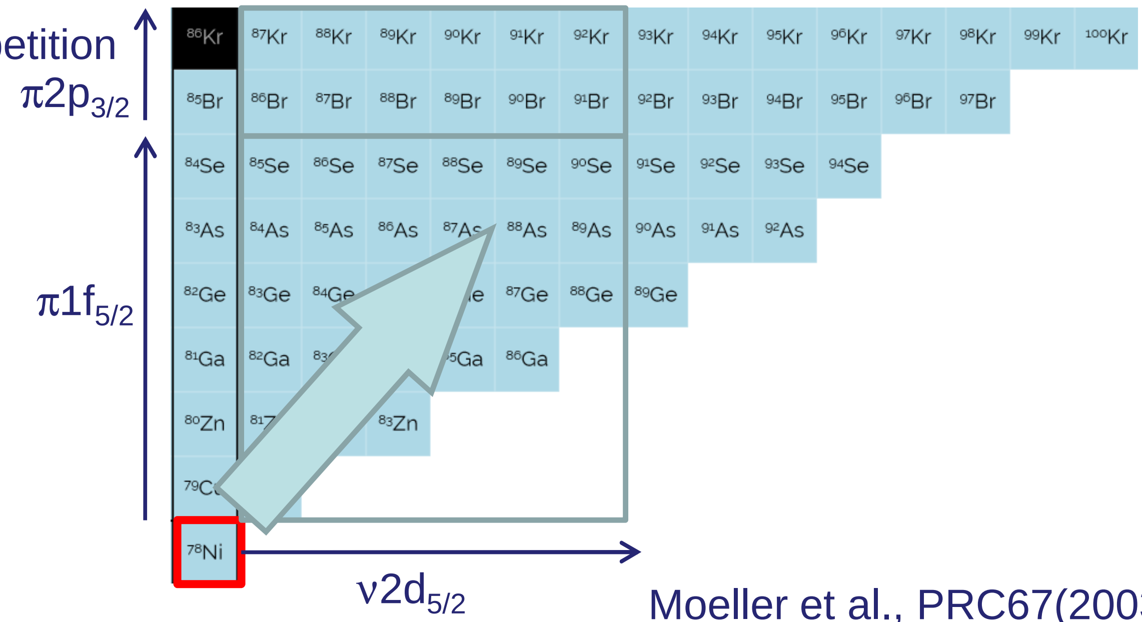


→ P_n and P_{2n} measurements are a very stringent test for theory models far-off stability!

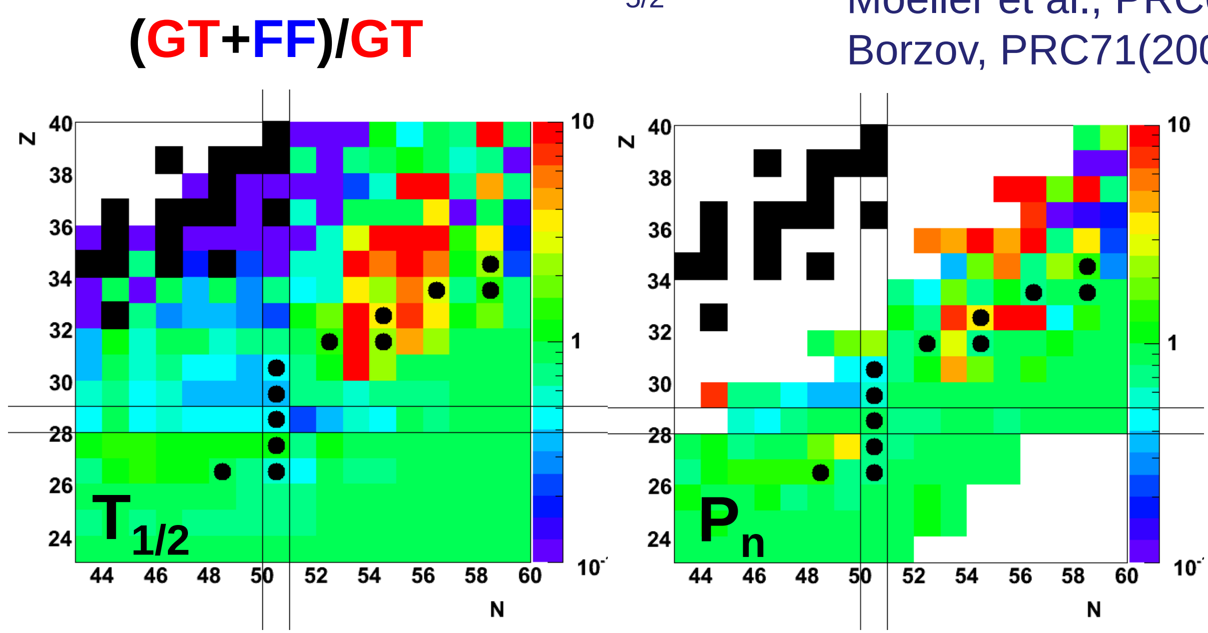
Shell structure and GT- FF- competition

→Nuclear Structure: FF vs. GT competition





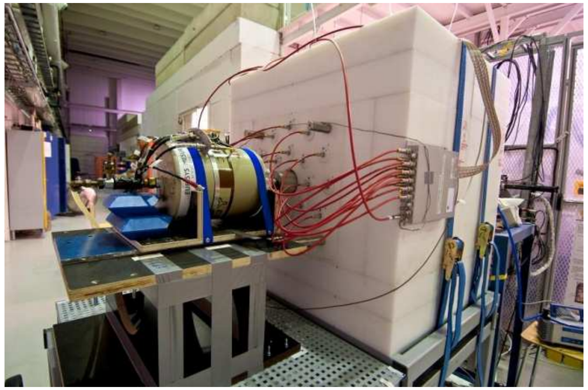
Moeller et al., PRC67(2003)
Borzov, PRC71(2005)

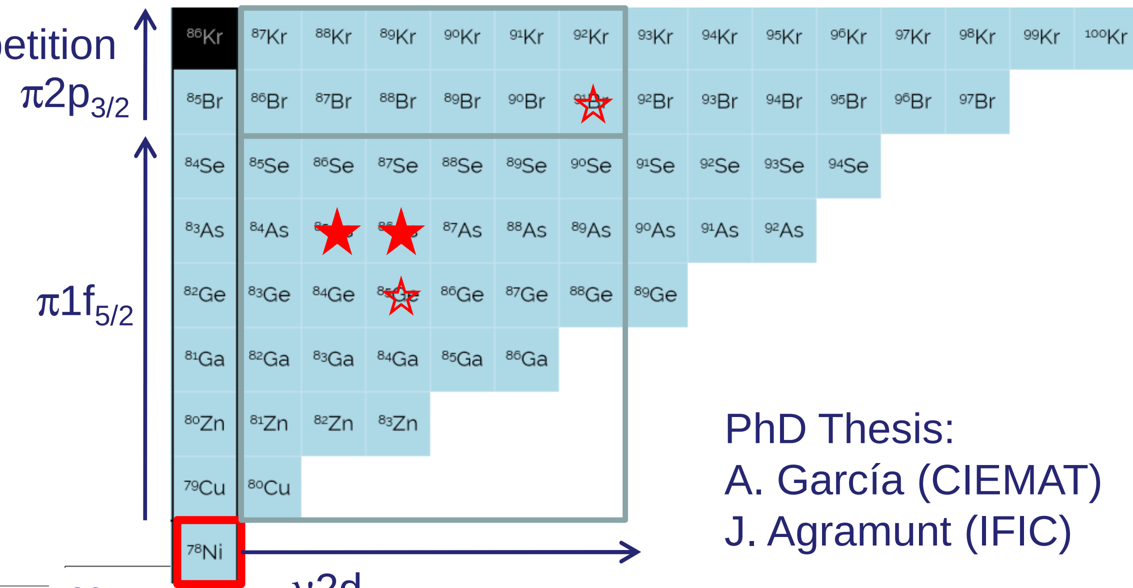


Shell structure and GT- FF- competition

→Nuclear Structure: FF vs. GT competition

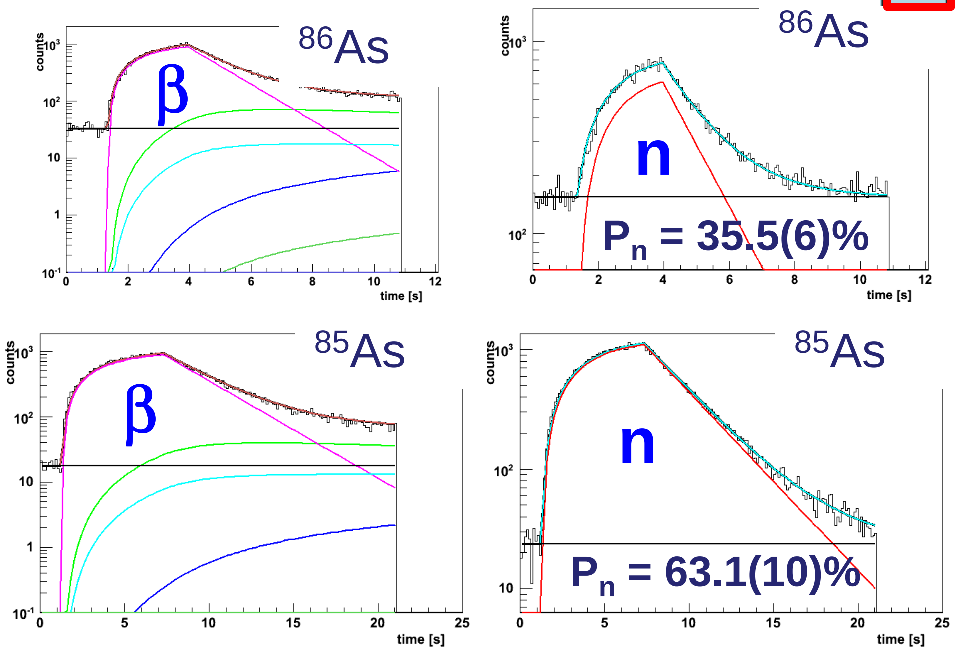
BELEN20 @ JYFL

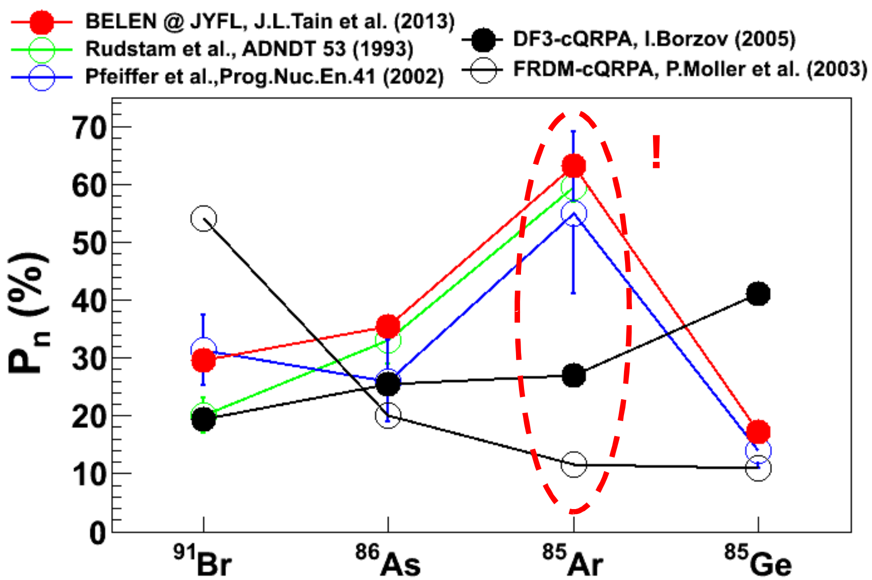




PhD Thesis:
A. García (CIEMAT)
J. Agramunt (IFIC)

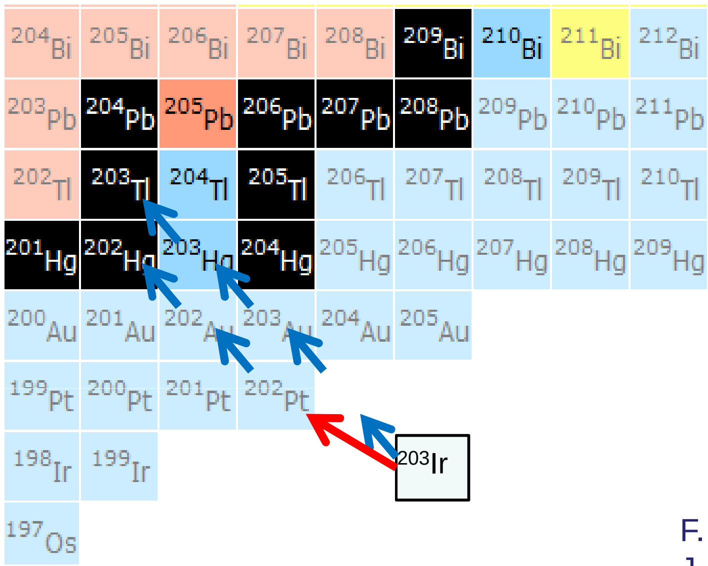
Nuc. Data. Conf., J.L.Tain et al. (2013)

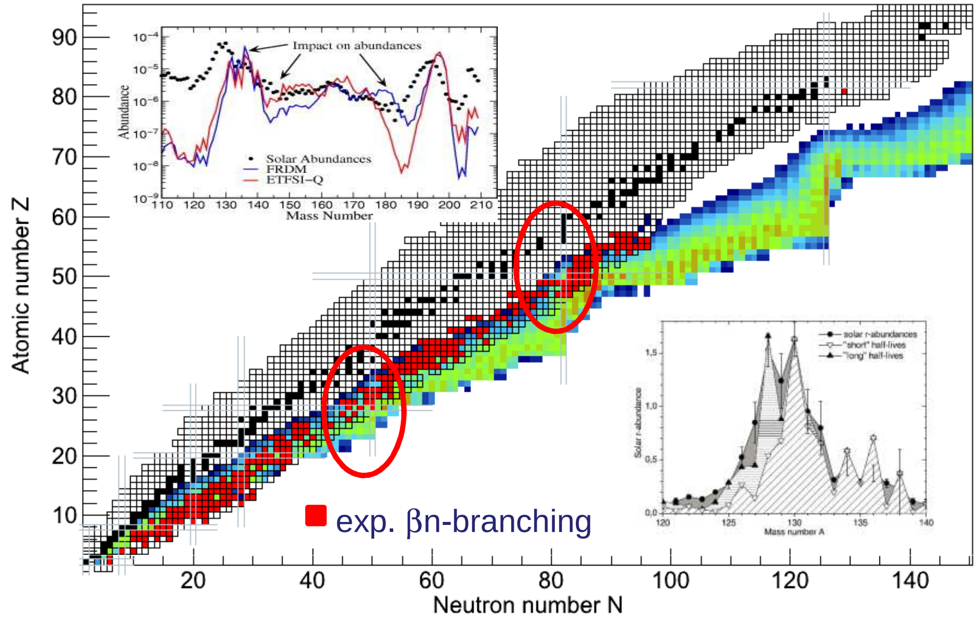




Nucleosynthesis of the heaviest elements

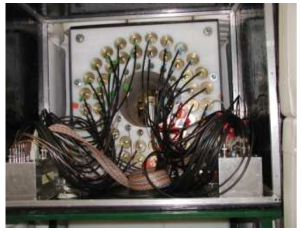
- Re-activation
- Shift towards lower A





F. Montes et al., Phys. Rev. C 73 (2006)
J. Pereira et al., Phys. Rev. C 79 (2009)
P. Hosmer et al., Phys. Rev. C 82 (2010)
H. Schatz et al., The Astr. Jour. 579 (2002)

I.Dillmann et al., Phys. Rev. Lett 91 (2003)
K.L. Kratz et al., Hyp. Int. 129 (2000)
H. Ohm et al., Zeit. Phys. 296 (1980)
K.L. Kratz et al., Phys. Lett. B 103 (1981)
H. Gabelmann et al., Zeit. Phys. A 308 (1982)
K.-L. Kratz et al., Zeit. Phys. A 306 (1982)
J.C. Wang et al., Phys. Lett. B 454 (1999)
M. Hannawald et al., Phys. Rev. C 62 (2000)



NSCL

JYFL ISOLDE

Institut für Kernchemie Universität Mainz

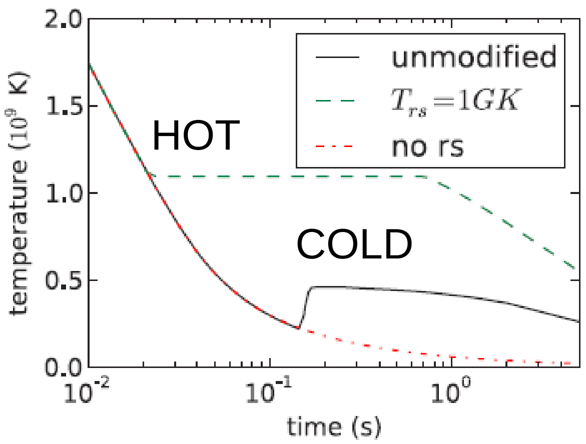
Nucleosynthesis of the heaviest elements

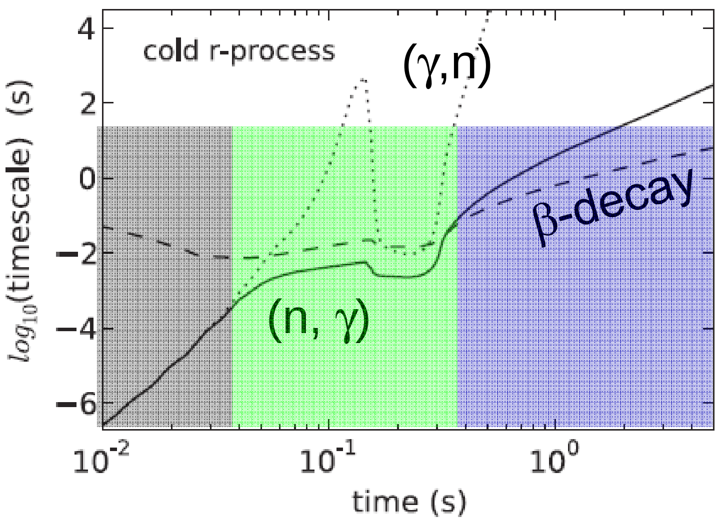
PHYSICAL REVIEW C 83, 045809 (2011)

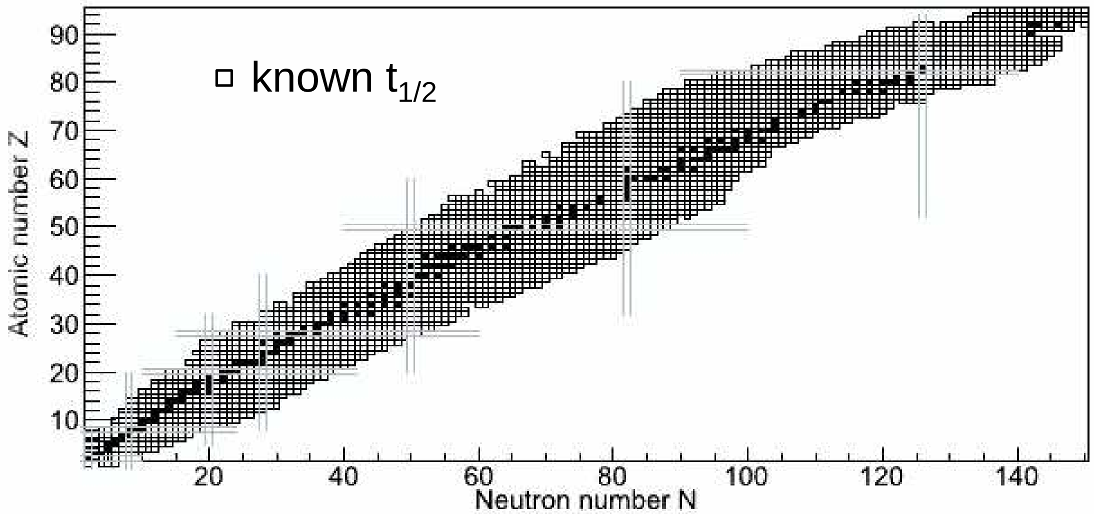
Dynamical r-process studies within the neutrino-driven wind scenario and its sensitivity to the nuclear physics input

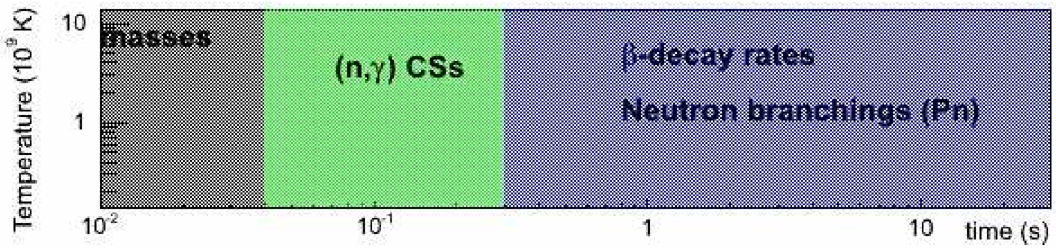
A. Arcones[1,2,*] and G. Martínez-Pinedo[2]

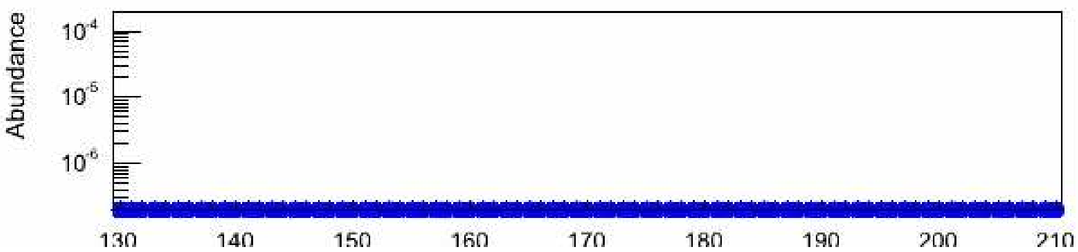
[1] Institut für Kernphysik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany
[2] GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, D-64291 Darmstadt, Germany











NucNet network code, B. Meyer et al., Clemson University
FRDM+QRPA (P. Möller) + JINA Reaclib Database

Nucleosynthesis of the heaviest elements

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

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

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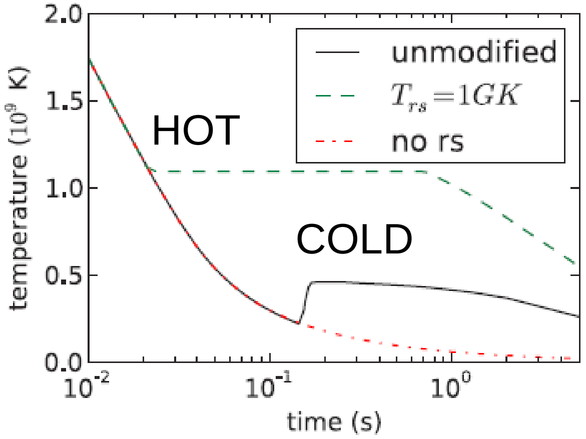
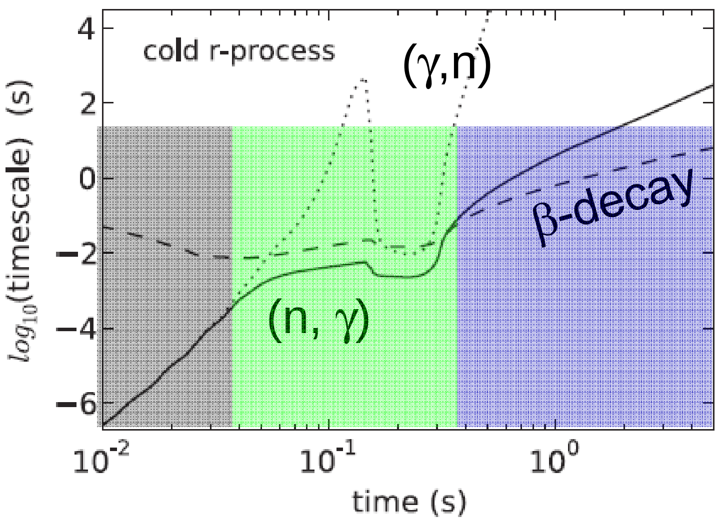
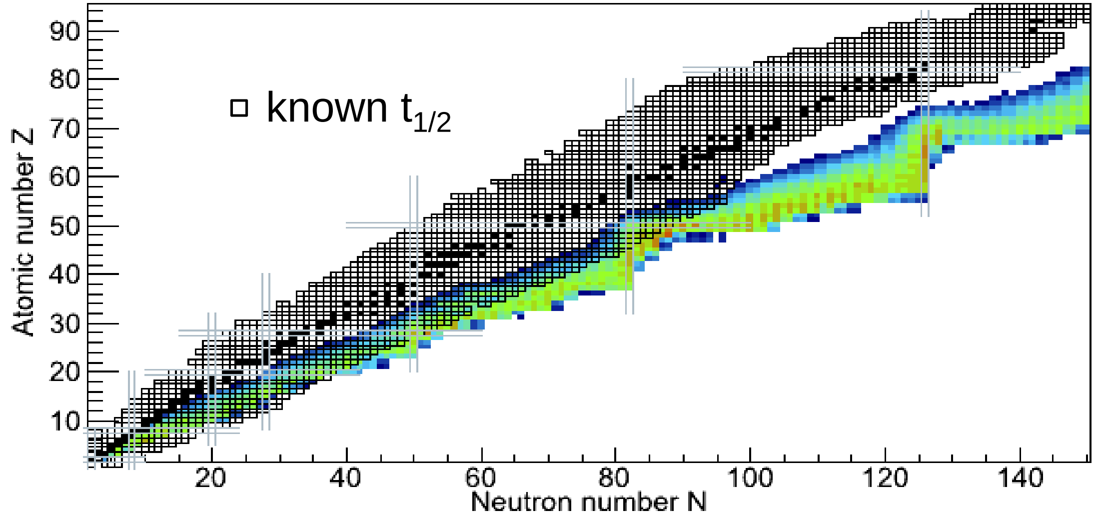
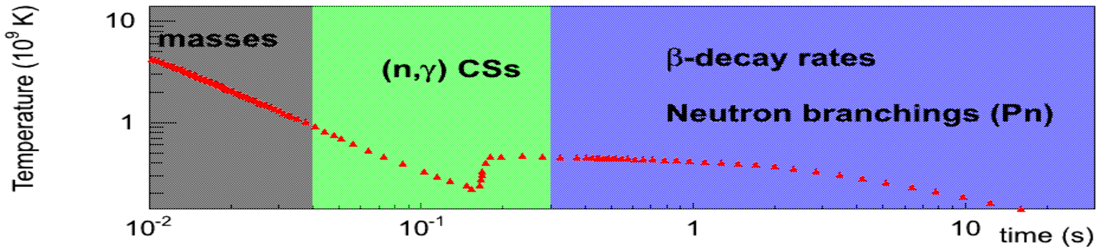
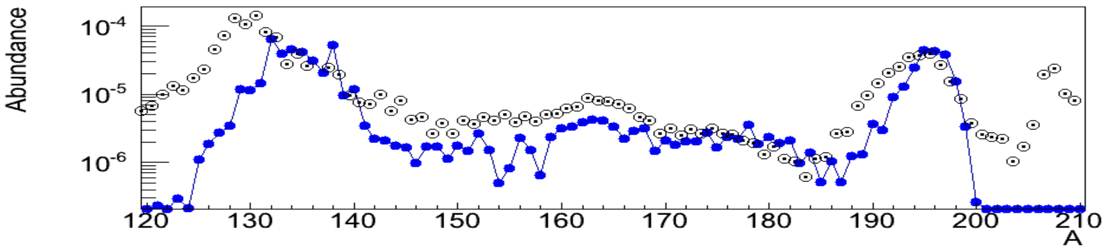


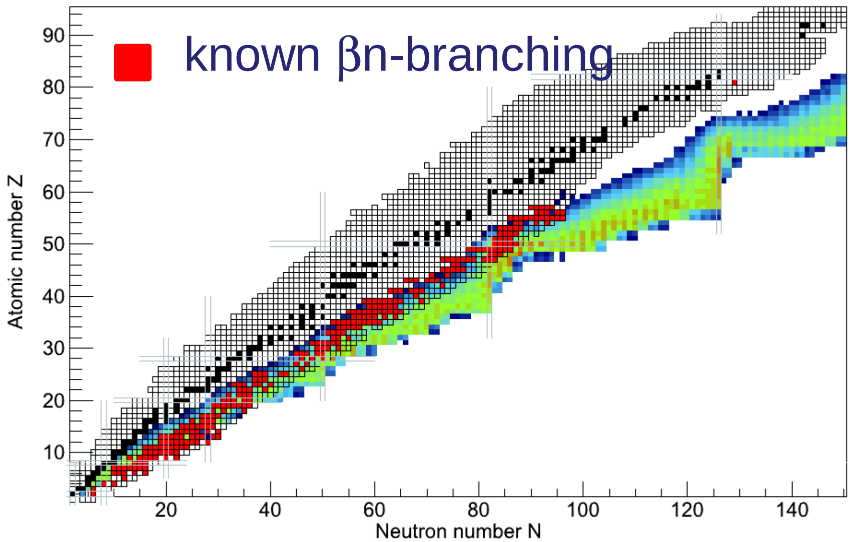


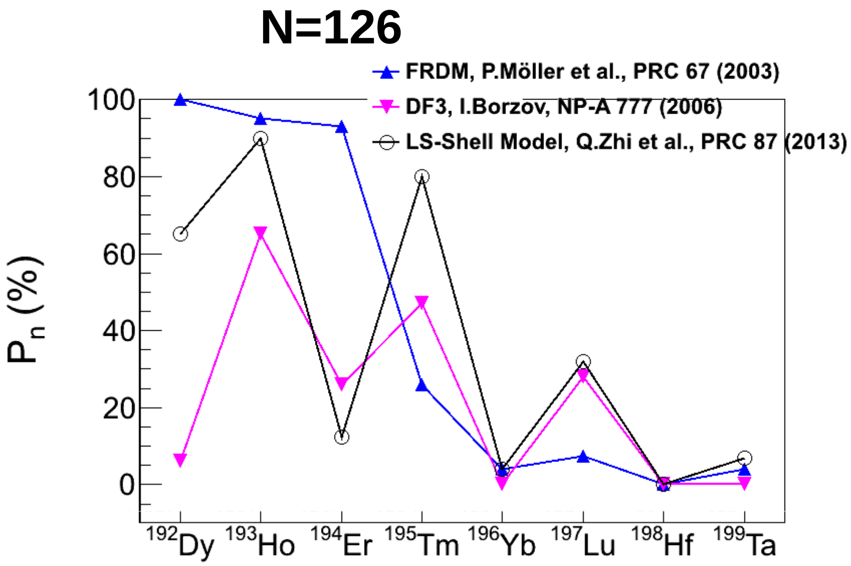


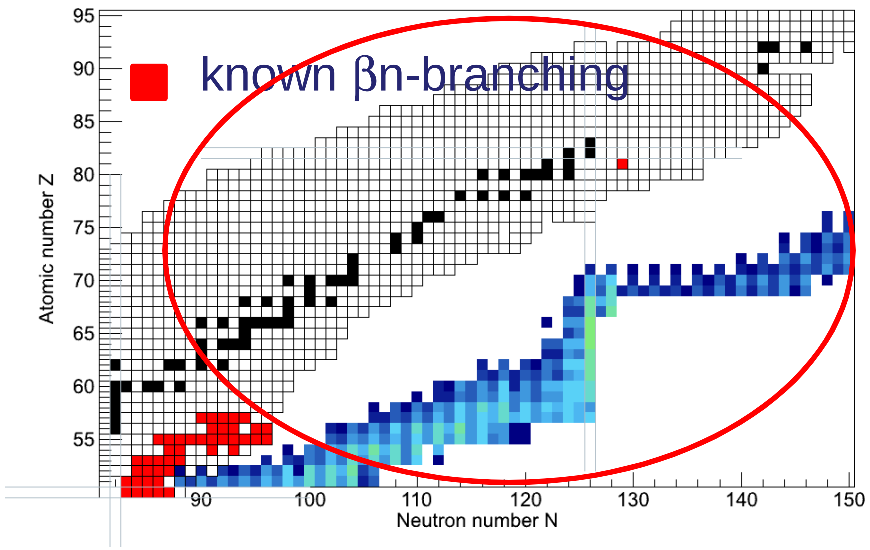




Nucleosynthesis of the heaviest elements





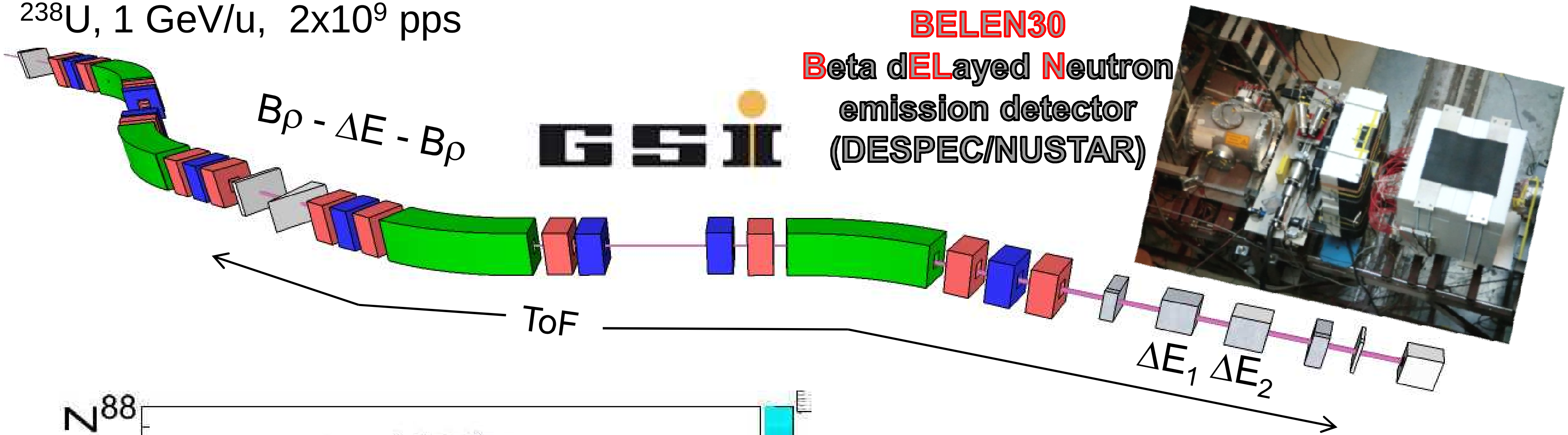


Only **one** experimental value is known:**Tl-210** ! !

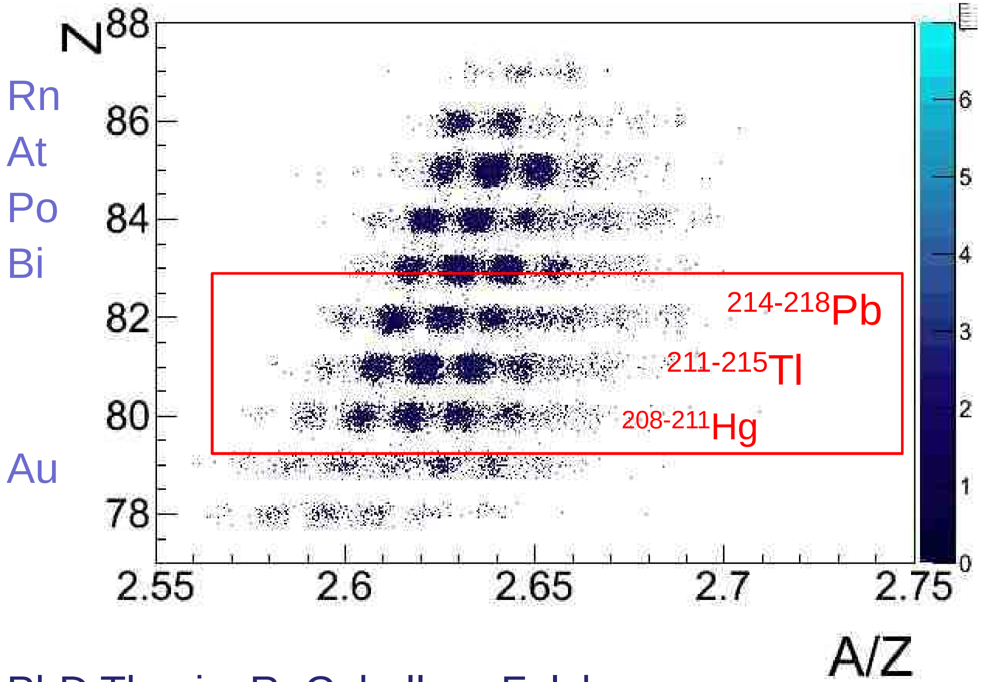
- A.V.Kogan, et al. Sov. Phys. JETP 5(1957) 365
- G.Stetter, TID-14880(1961)

Nucleosynthesis of the heaviest elements

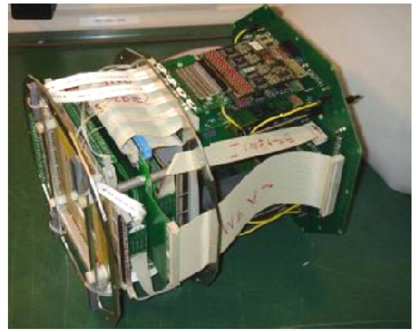
^{238}U, 1 GeV/u, 2x10^{9} pps

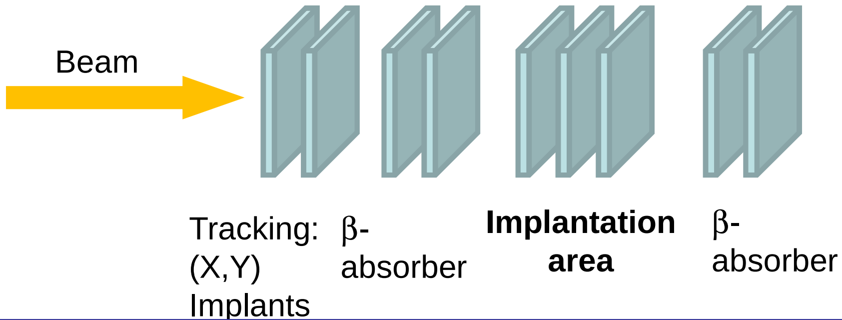


BELEN30
Beta dELayed Neutron emission detector (DESPEC/NUSTAR)



SIMBA
Silicon Implantation Array (TU-Munich)

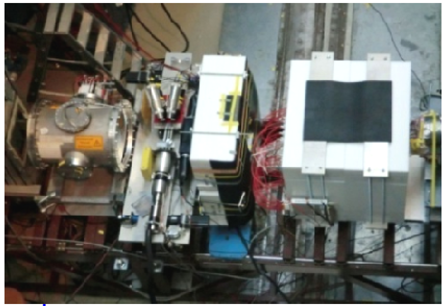


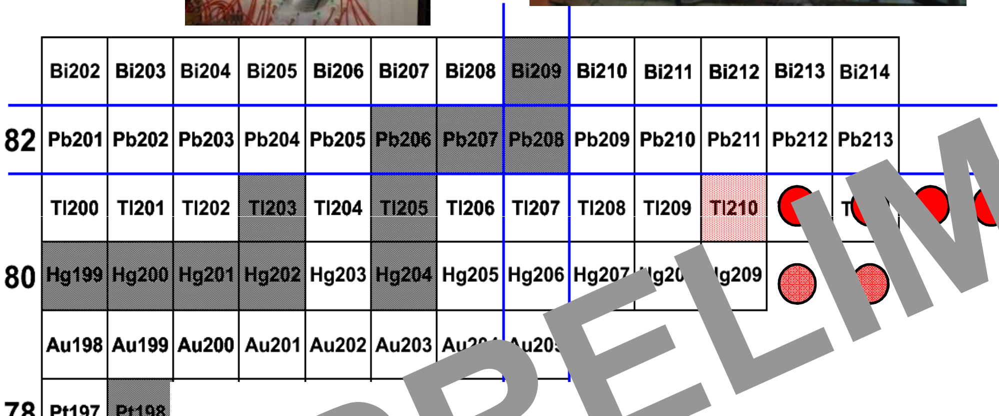


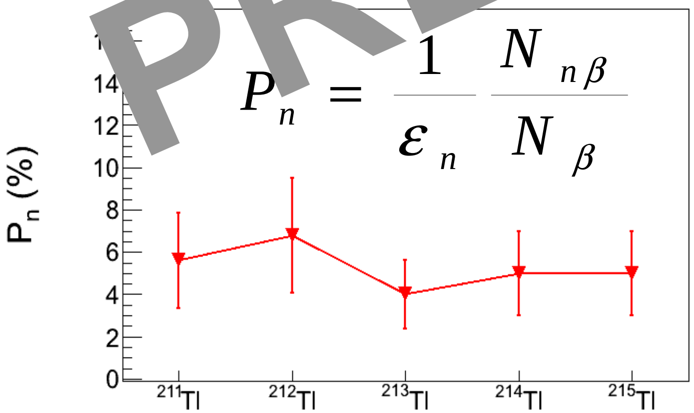
PhD Thesis: R. Caballero-Folch

Nucleosynthesis of the heaviest elements

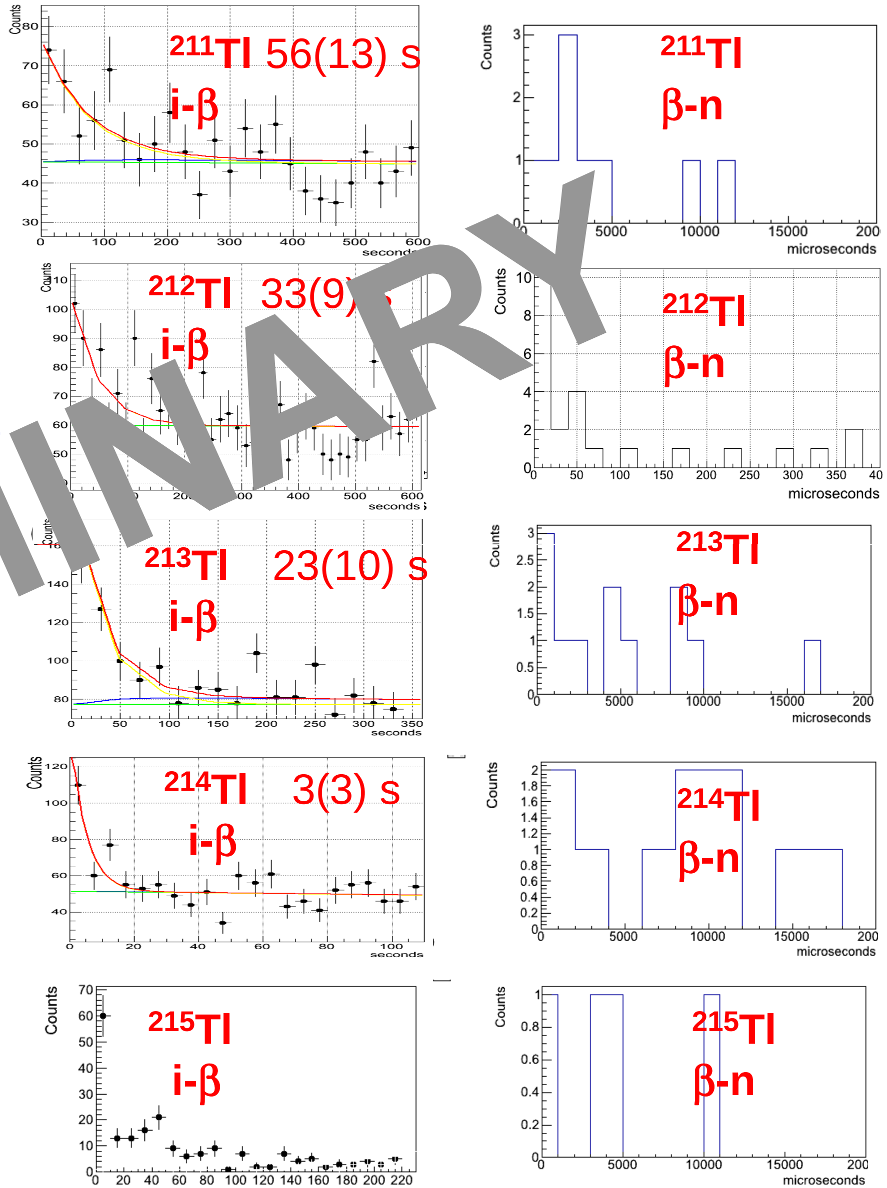
BELEN
Beta dELayed Neutron emission detector







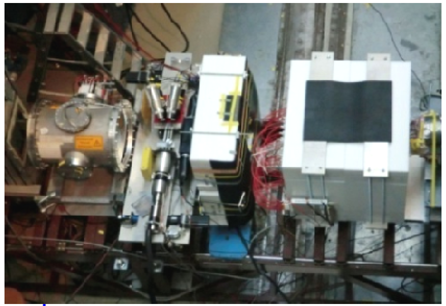
$$P_n = \frac{1}{\varepsilon_n}\frac{N_{n\beta}}{N_\beta}$$

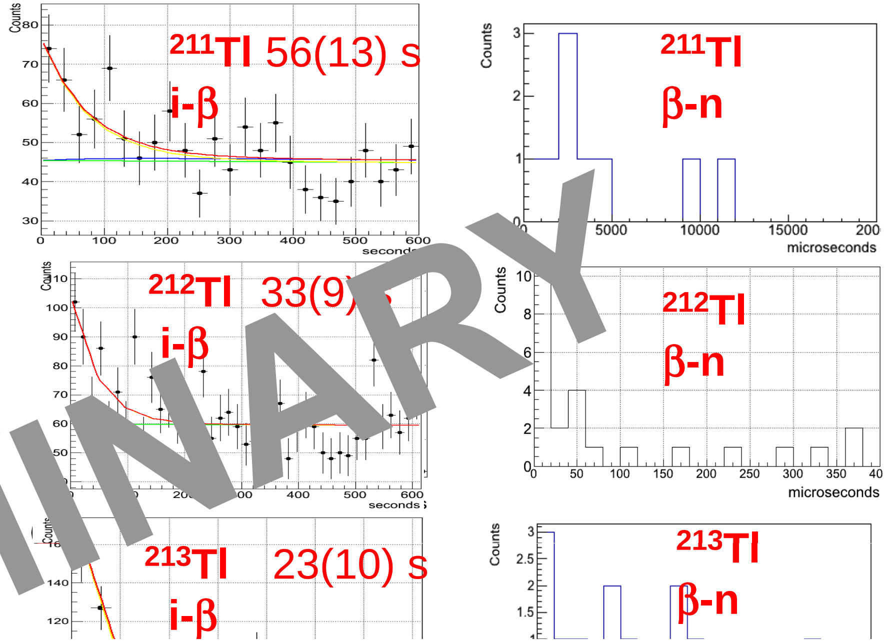


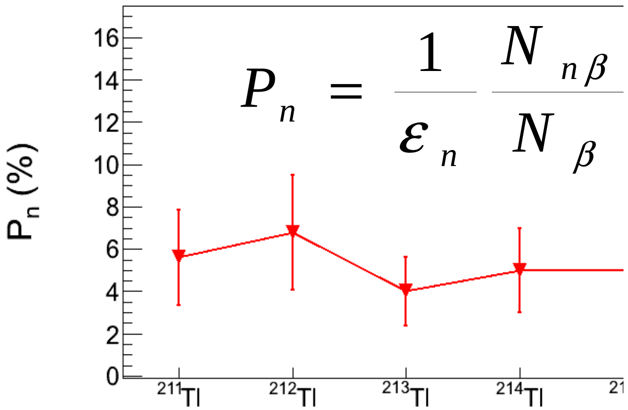
PRELIMINARY

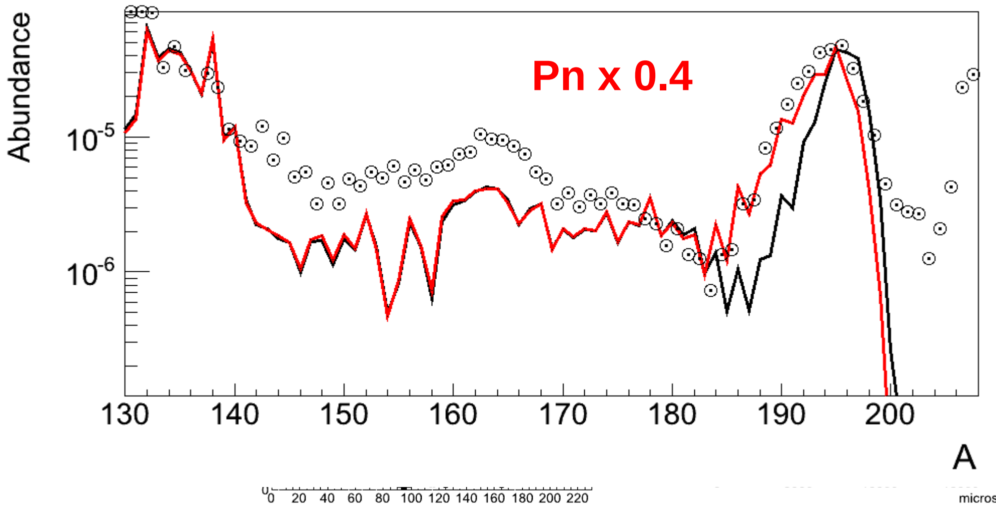
Nucleosynthesis of the heaviest elements

BELEN
Beta dELayed Neutron emission detector

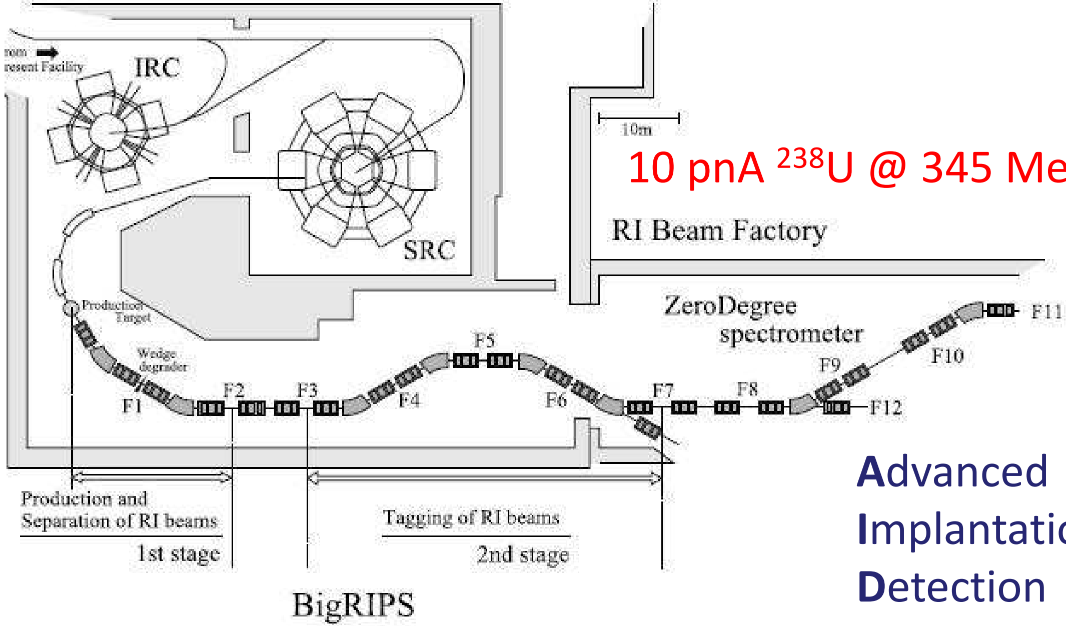








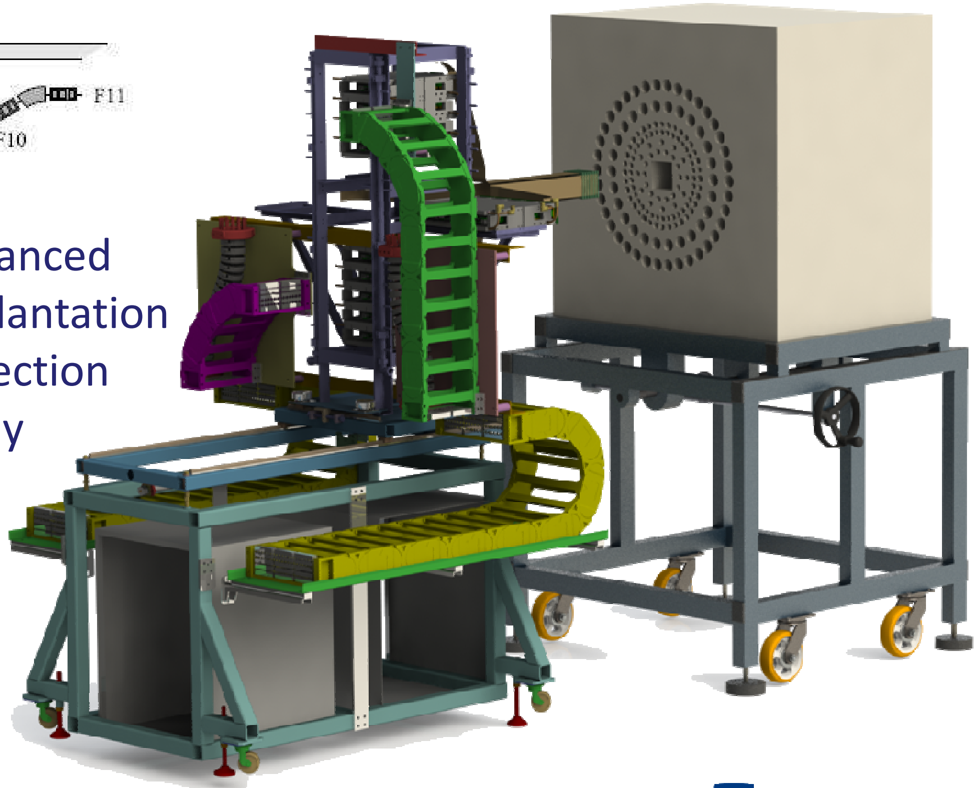
BRIKEN: βn measurements of the most exotic nuclei



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

BRIKEN neutron detection set-up

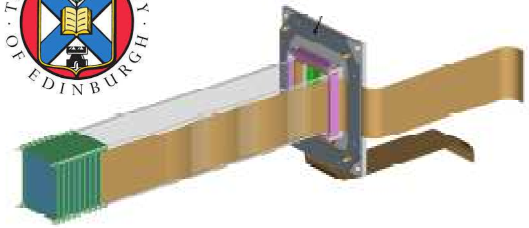
Advanced **I**mplantation **D**etection **A**rray



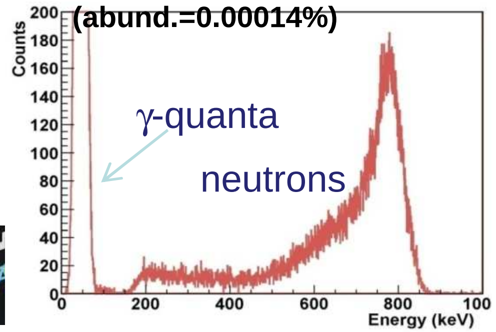
GSI, TRIUMF, IFIC, UPC, JINR, NSCL, Oak Ridge National Laboratory, RIKEN Nishina Center, MTA Atomki Debrecen, University of Liverpool, 東京大学 The University of Tokyo, The University of Edinburgh

BRIKEN: βn measurements of the most exotic nuclei

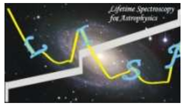
AIDA



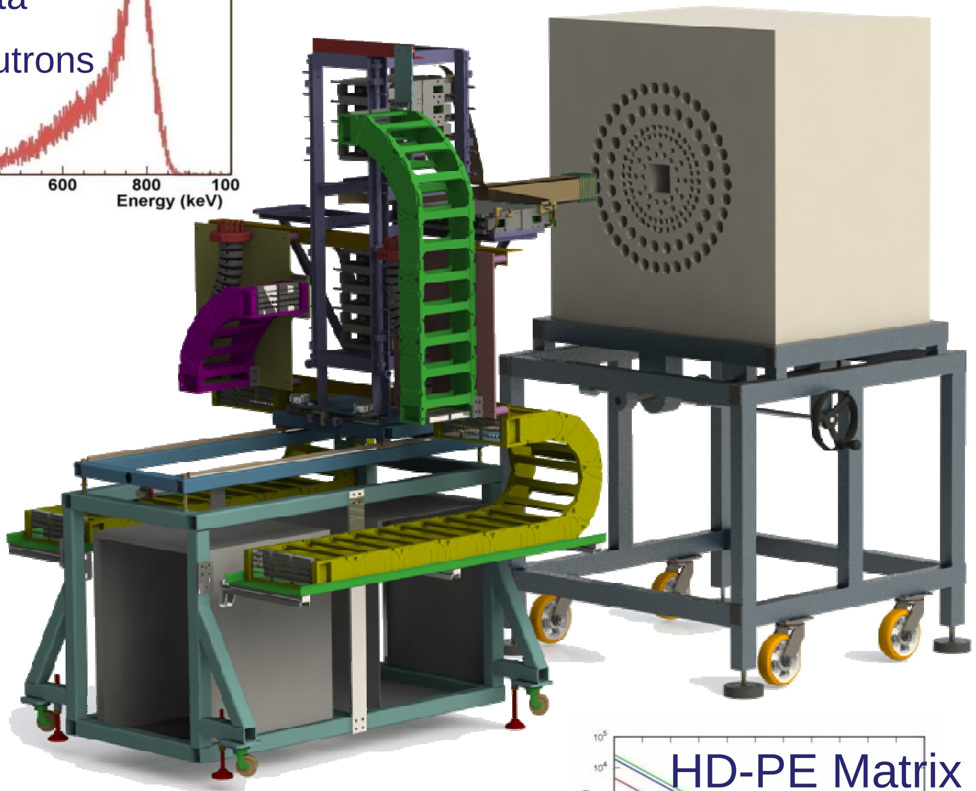
n + ^{3}He → ^{3}H + ^{1}H + 0.764 MeV

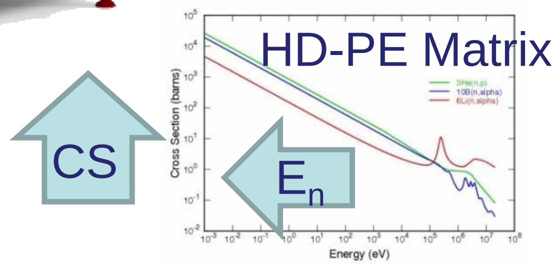


P (atm)	# Tubes	
10	10	GSI
4	20	JINR
10	67	ORNL
10	17	ORNL
5.13	26	RIKEN
8	42	UPC
Total	182	



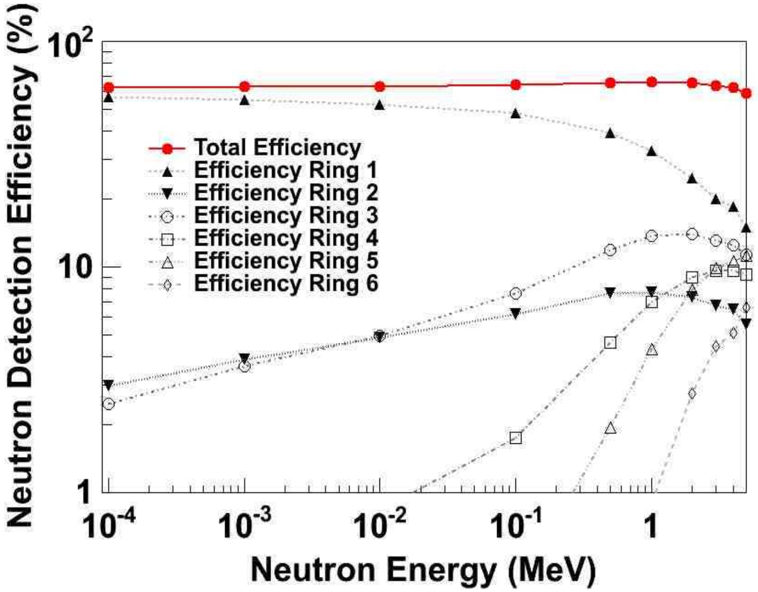
BRIKEN neutron detection set-up

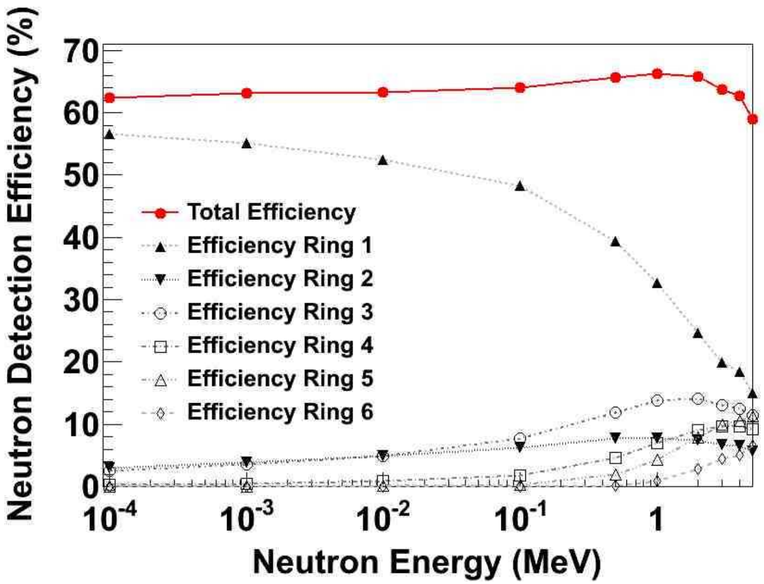


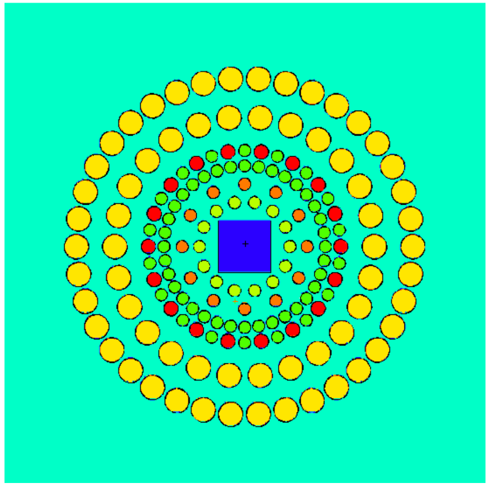


NERO (NSCL)	3HEN (ORNL)	BELEN (FAIR)	ALTO (DESIR)
60	74	48	90

BRIKEN neutron detector array







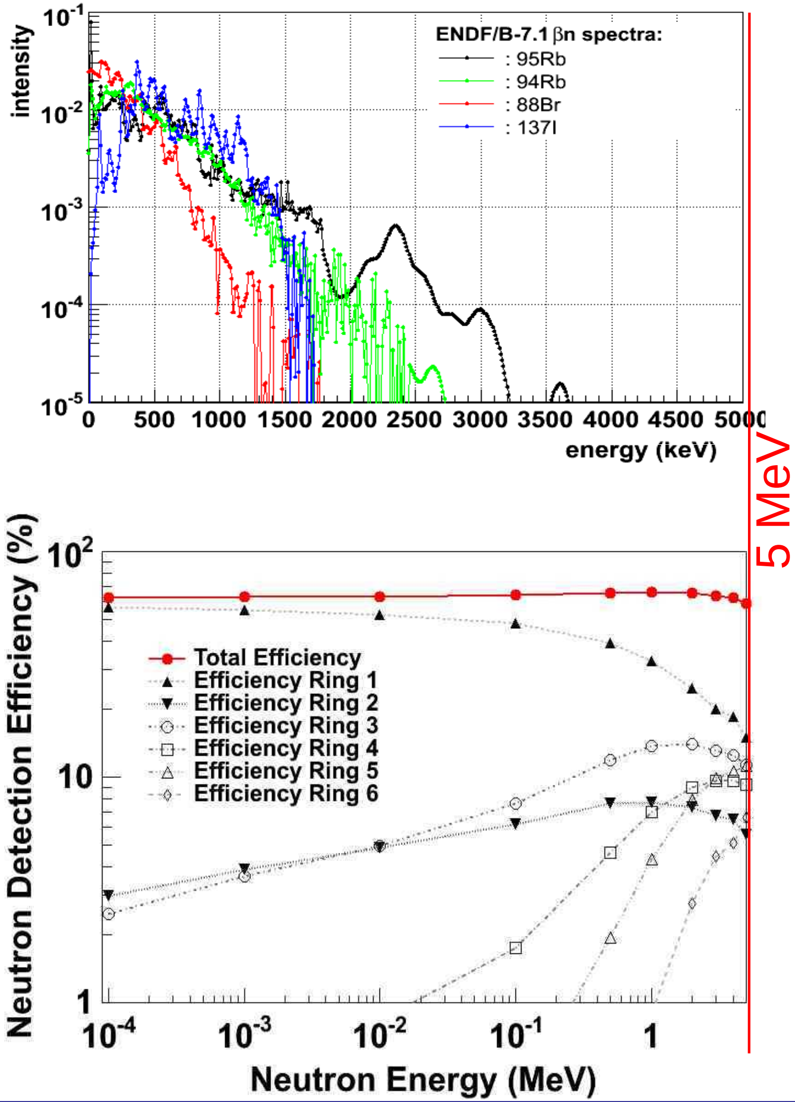
174 ^{3}He tubes of 6 different types:

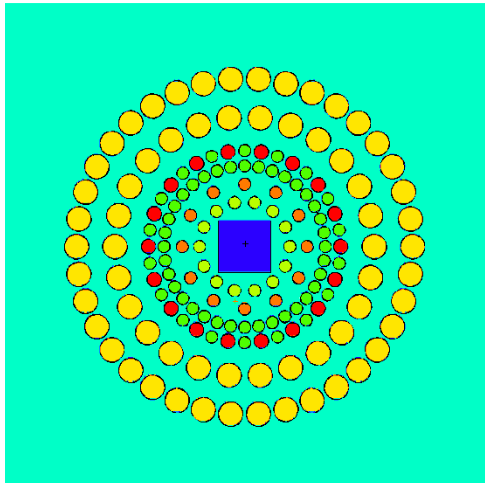
Ring	Radius (cm)	# ^{3}He Tubes	Pressure (atm)	Diameter (inch)	Institute
1	9.4	14	10	1	ORNL
2	13	12+12	5.13	1	RIKEN
3	16.8	10+26	10/8	1	GSI/UPC
4	20	18+18	5/8	1.18/1	JINR/UPC
5	27	26	10	2	ORNL
6	35	38	10	2	ORNL

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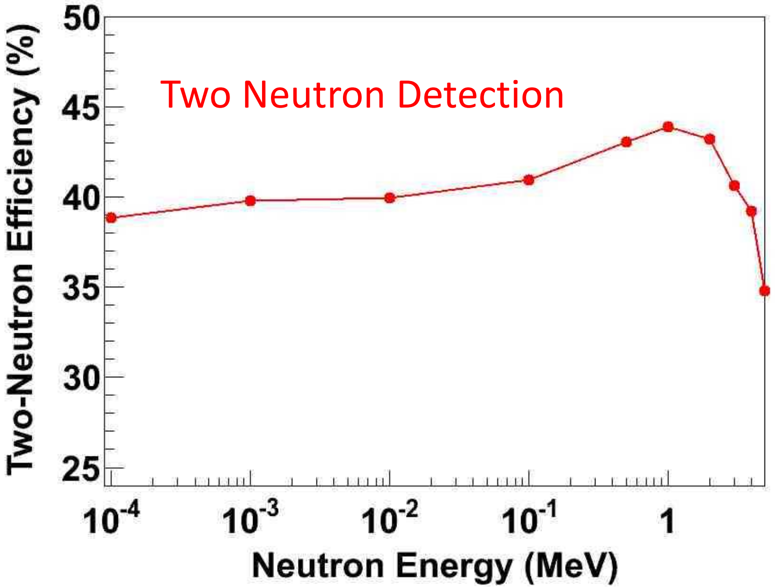
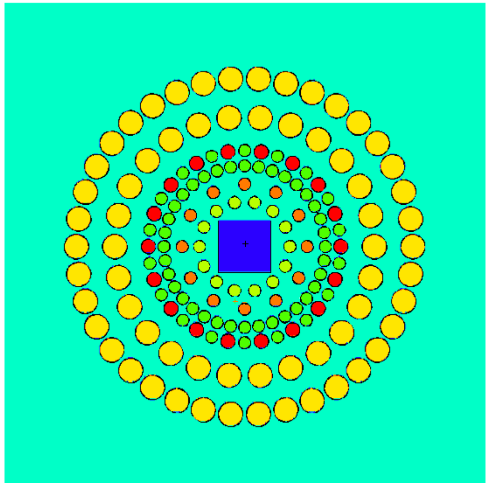
✓ BRIKEN Construction Proposal Approved @ RIKEN-PAC December, 2013

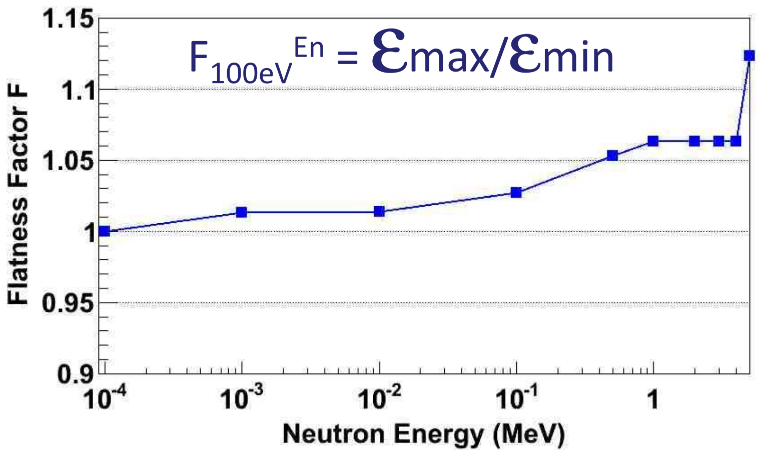
BRIKEN neutron detector array

High efficiency also for two-fold neutron emission:





Flat efficiency → Pn insensitive to neutron spectrum



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BRIKEN Physics Goals for a **Project Proposal** in 2014

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

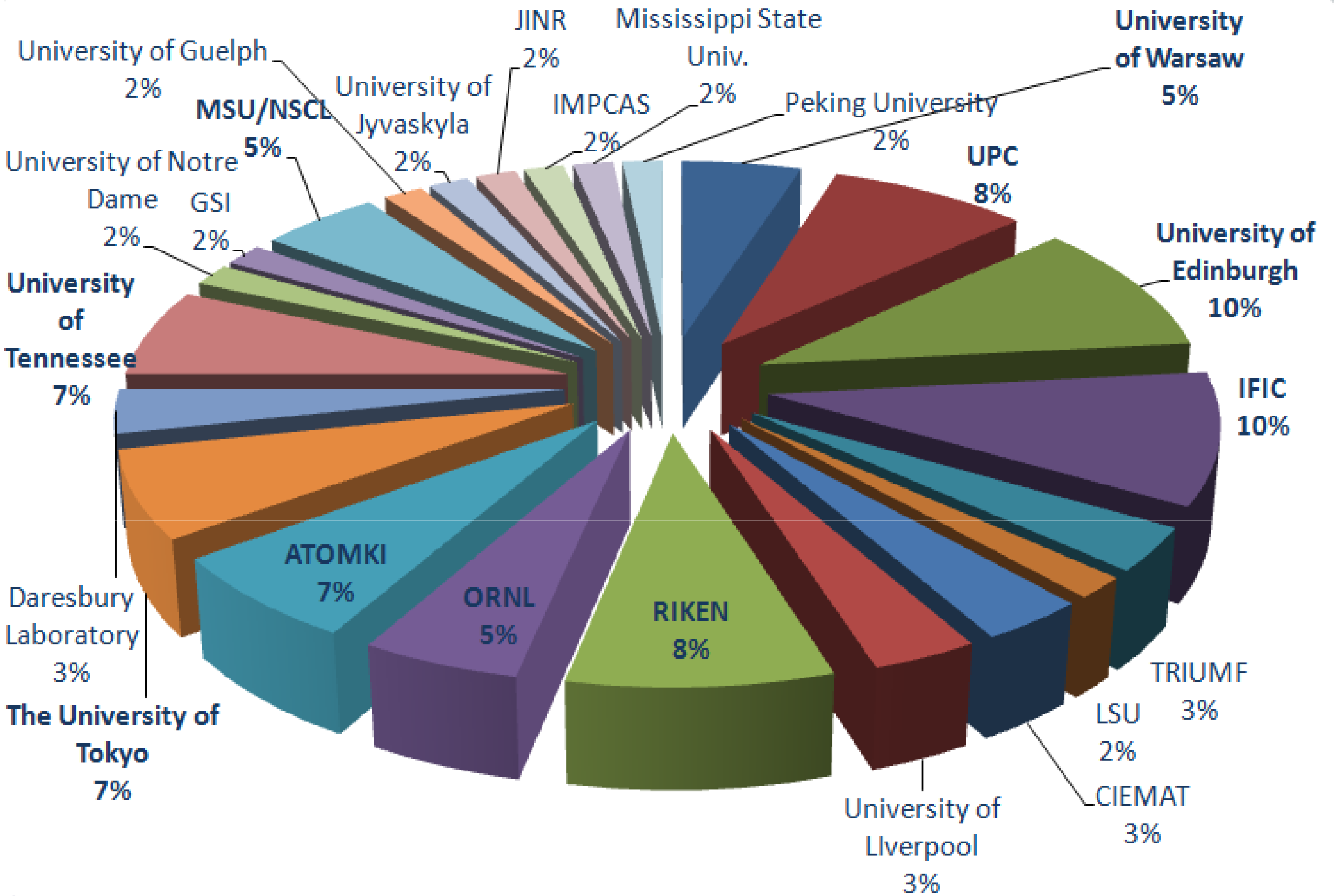
PROJECT PROPOSAL

Astrophysics: r-process nucleosynthesis

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

New reactor technologies

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

BRIKEN: 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.
- Physcis proposals will be submitted within the same BRIKEN “umbrella” at the next NP-PAC in june, 2014. The project is open, new collaborators are welcome to join!

Thank you for your attention!

Thanks to BRIKEN Collaborators

Agnieszka Korgul	University of Warsaw
Albert Riego	UPC
Alfredo Estrade	University of Edinburgh
Alejandro Algora	IFIC
Anu Kankainen	University of Edinburgh
Adam Garnsworthy	TRIUMF
Belen Gomez	UPC
Berta Rubio	IFIC
Francisco Calvino	UPC
Cesar Domingo Pardo	IFIC
Chiara Mazzocchi	University of Warsaw
Christopher Griffin	University of Edinburgh
Claudia Lederer	University of Edinburgh
Charlie Rasco	LSU
Daniel Cano Ott	CIEMAT
Maria Dolores Jordan	IFIC
David Joss	University of LIverpool
Giuseppe Lorusso	RIKEN
Carl J. Gross	ORNL
Guillem Cortes	UPC
Gyurky Gyorgy	ATOMKI
Hiroyoshi Sakurai	The University of Tokyo
H. Ueno	RIKEN
Iris Dillmann	TRIUMF
John Simpson	Daresbury Laboratory
Jorge Agramunt	IFIC
Kiss Gabor	ATOMKI
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K. Miernik	University of Warsaw
Krzysztof P. Rykaczewski	ORNL
Karl Smith	University of Notre Dame
Gabor Gyula Kiss	ATOMKI

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Megum Niikura	University of Tokyo
Michele Marta	GSI
Miguel Madurga	University of Tennessee
Fernando Montes	NSCL
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Shunji Nishimura	RIKEN
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