Latest results from the BRIKEN campaign

A. Algora

IFIC (CSIC-Univ. of Valencia)

For the BRIKEN Collaboration

1932: Annus Mirabilis for Nuclear Physics

Wine: ???

Physics:

Anderson: positron discovery

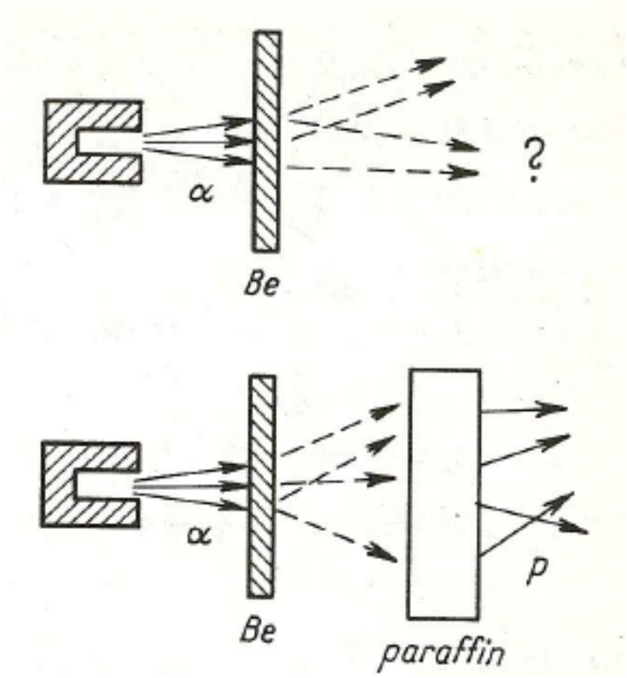
Cockroft and Walton: first reaction with accelerated particles

Chadwick: discovery of the neutron

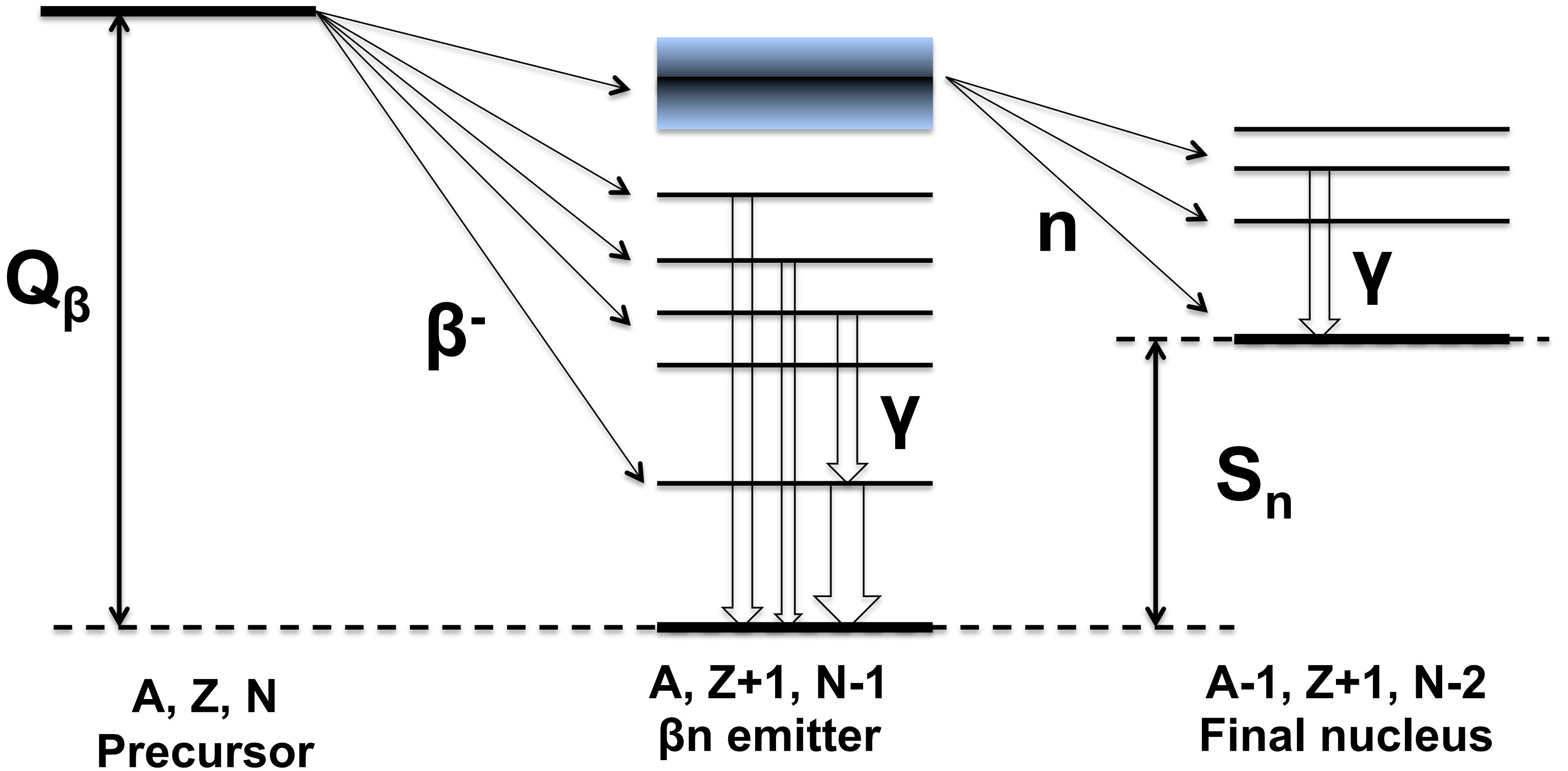
Fermi: first steps in the theory of beta decay

(based on Bothe-Geiger, Joliot-Curie, and his own measurements, it was already predicted by Rutherford in 1920)

Marks the beginning of proton-neutron nuclear model



Beta delayed neutrons



Discovered in 1939, by Roberts *et al.* Phys. Rev. 55, 510 (1939)

(represent approximately 1 % of the neutrons emitted in fission)

Possible when $Q_\beta > S_n$

far enough from stability multiple emission $Q_\beta > S_{xn}$ (x = 1, 2, 3, ..)

Beta delayed neutrons: $Q_{\beta n}$ according to NuDat2

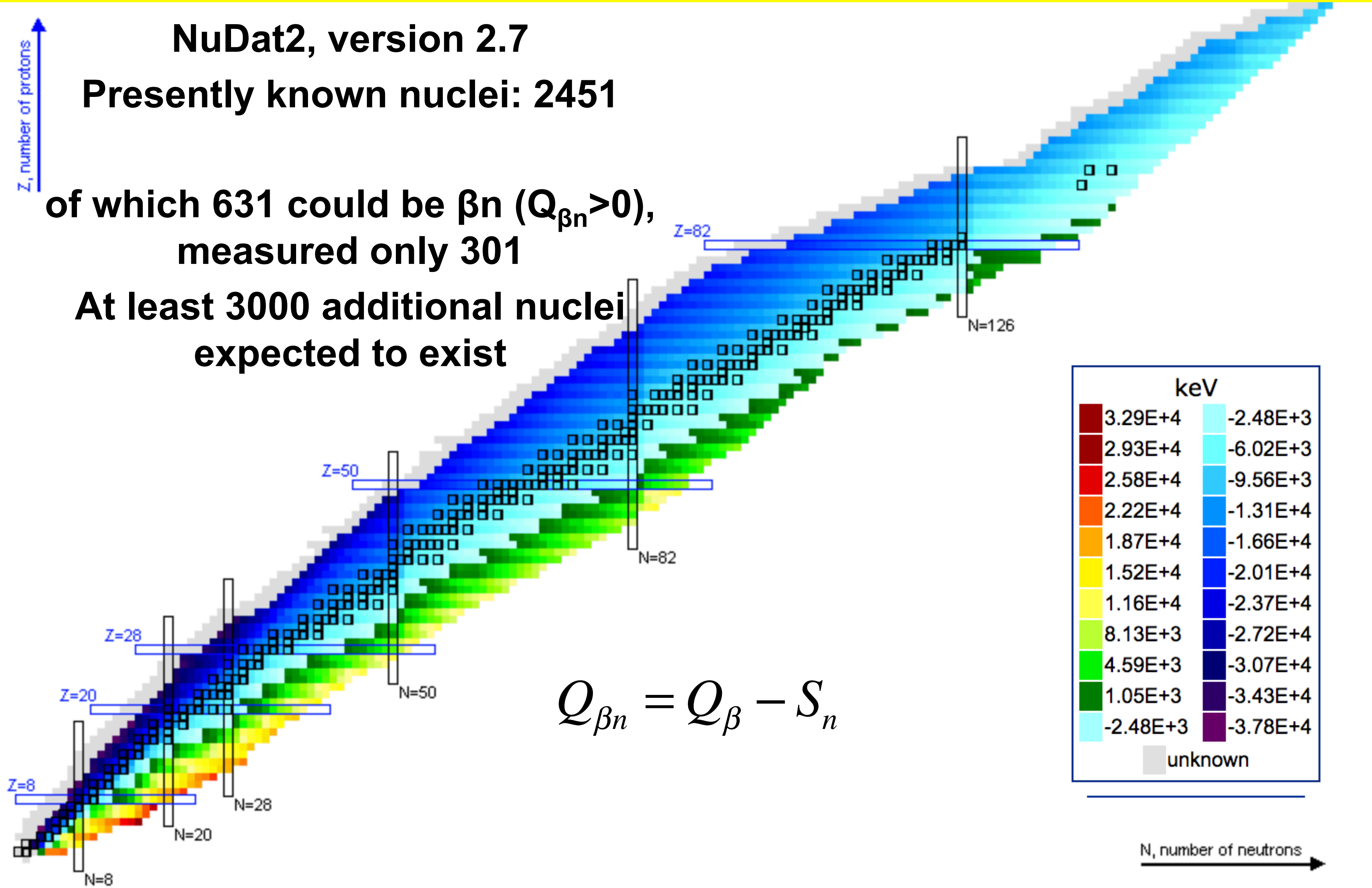
NuDat2, version 2.7

Presently known nuclei: 2451

of which 631 could be βn ($Q_{\beta n}$>0), measured only 301

At least 3000 additional nuclei expected to exist

$$Q_{\beta n} = Q_{\beta} - S_n$$



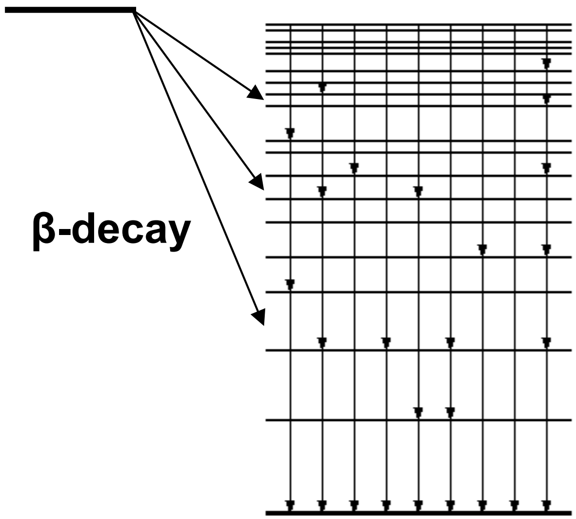
Summary of present knowledge of beta delayed neutron emitters

Isotopes with $Q_{\beta xn} > 0$ based on AME2016 (out of 2451 known nuclei)

Taken from P. Dimitriou *et al.* (to be submitted to NDS)

	Identified No of isotopes	Measured No of isotopes	Measured fraction	Measured mass region
β1n	631	298	48.0 %	^{8}He - ^{216}Tl
β2n	300	23	7.7 %	^{11}Li -^{136}Sb
β3n	138	4	2.9 %	^{11}Li -^{31}Na
β4n	58	1	1.7 %	^{17}B

Some definitions related to beta decay



Primary experimental information

$T_{1/2}$, Q_β, $P_\beta(E)$

Experimental beta strength

$$S_\beta(E) = \frac{P_\beta(E)}{f(Z', Q_\beta - E)T_{1/2}} = \frac{1}{ft(E)}$$

$$f(Z',Q) = const \cdot \int_0^{p_{\max}} F(Z',p)p^2(Q-E_e)^2\,dp$$

Theoretical beta strength

Fermi / Gamow-Teller:

$$B_{i\to f} = \frac{1}{2J_i+1}\left|\left\langle \Psi_f \middle| \tau^\pm \; or \; \sigma\tau^\pm \middle| \Psi_i \right\rangle\right|^2$$

$$S_\beta = \frac{1}{6147 \pm 7}\left(\frac{g_A}{g_V}\right)^2 \sum_{E_f \in \Delta E} \frac{1}{\Delta E} B_{i\to f}$$

Integral quantities in beta decay

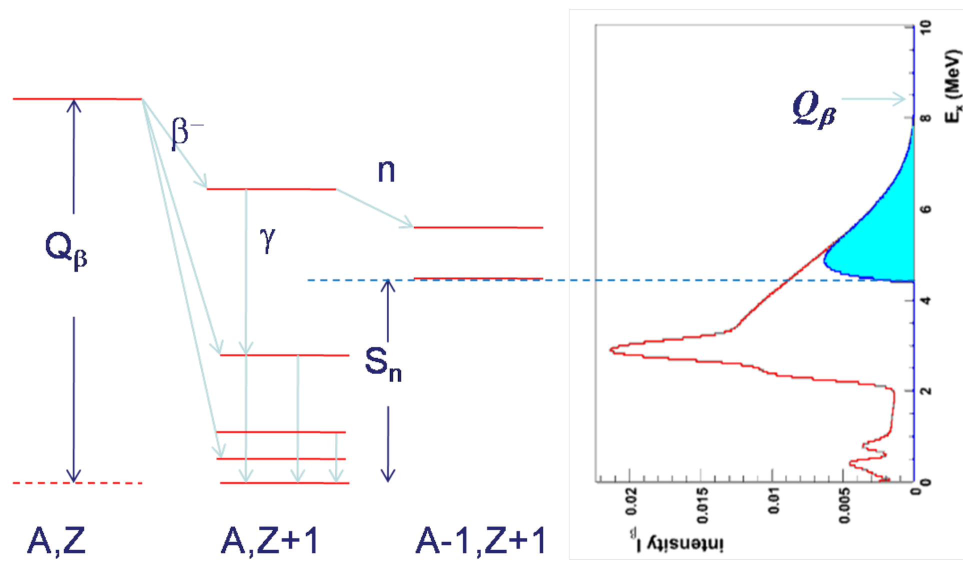
The (inverse of the) half-life $T_{1/2}$ is the weighted average of the β-strength S_β

$$\frac{1}{T_{1/2}} = \int_0^{Q_\beta} S_\beta(E_x)\cdot f(Q_\beta - E_x)\,dE_x$$

The neutron emission probability P_n measures the fraction of β-strength above the neutron separation energy S_n

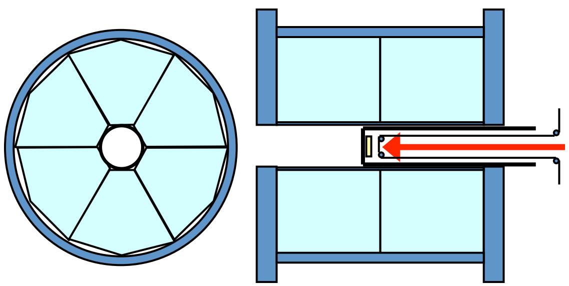
$$P_n = \frac{\int_{S_n}^{Q_\beta} S_\beta(E_x)\cdot f(Q_\beta - E_x)\cdot \frac{\Gamma^n}{\Gamma^n + \Gamma^\gamma}\,dE_x}{\int_0^{Q_\beta} S_\beta(E_x)\cdot f(Q_\beta - E_x)\,dE_x}$$

For n-rich nuclei very far from stability measurements of $T_{1/2}$ and P_n will provide access to nuclear structure information

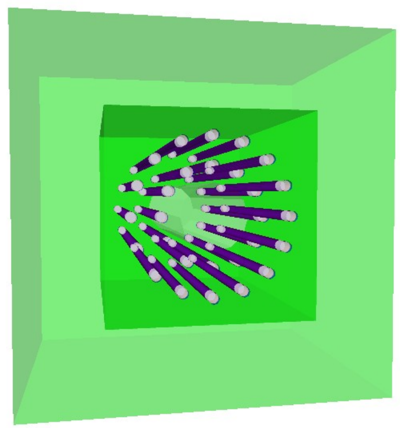


Beta strength measurements: combination of techniques

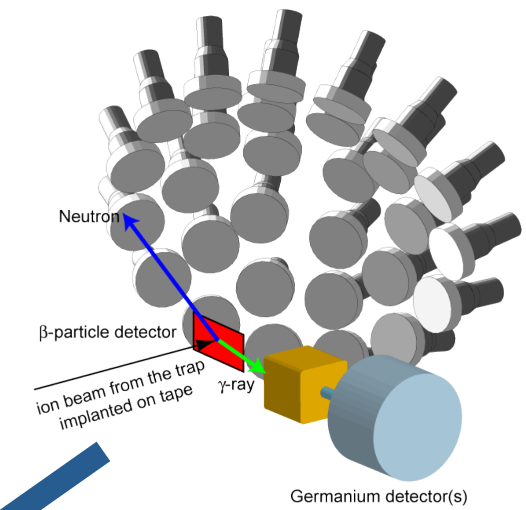
Total Absorption γ-Ray Spectrometer

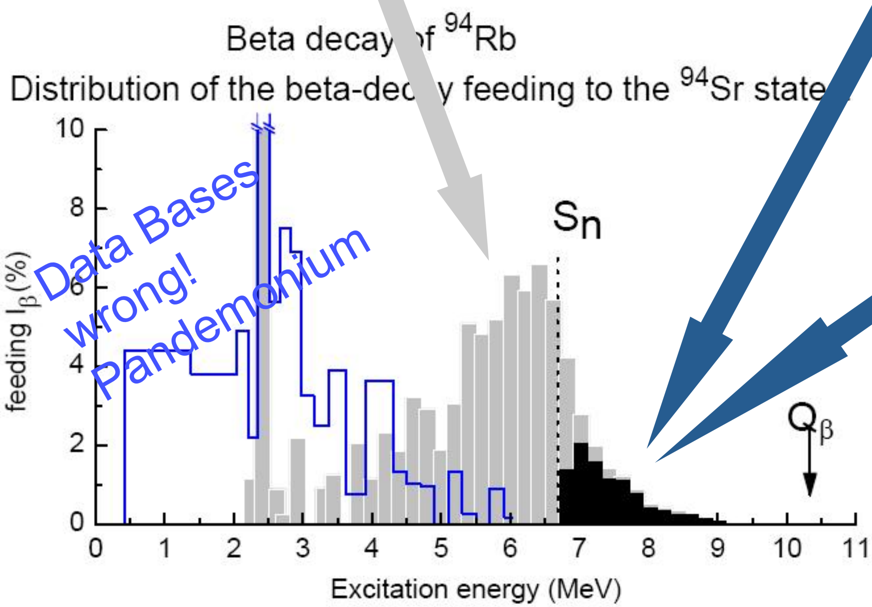


4π Neutron Counter



Neutron Time of Flight Spectrometer





- TAGS provides data free of "Pandemonium" systematic error
- 4π n-counter provides P_n
- n-ToF Array provides the E_n distribution

P1n “experimental” definition

The neutron branching ratio of a nucleus into the β-1n channel is defined as:

$$P_{1N} = \frac{N_{1n}}{N_{decays}}$$

Most common ways to measure the Pn

1. **Neutron and beta counting**

$$P_{1N} = \frac{\varepsilon_{\beta}}{\varepsilon_{1n}} \frac{N_{\det 1n}}{N_{\det \beta}} \Rightarrow P_{1N} = \frac{\langle \varepsilon_{\beta} \rangle}{\langle \varepsilon_{1n} \rangle} \frac{N_{\det \mathrm{1n}}}{N_{\det \beta}}$$

2. **Beta-neutron coincidences**

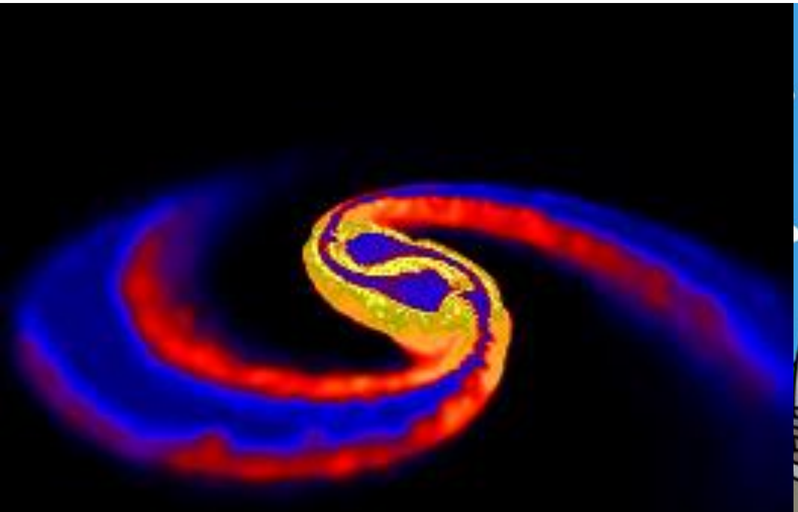
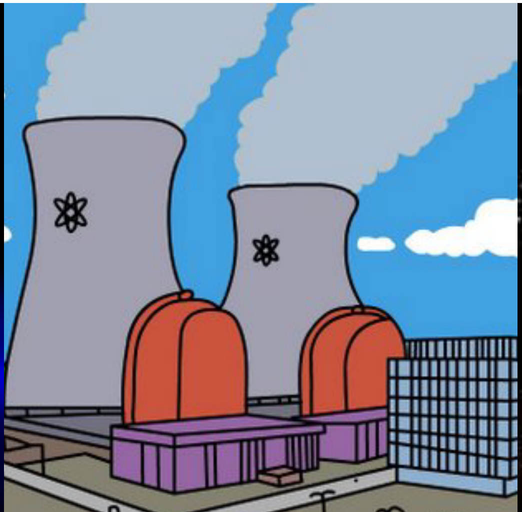
$$P_{1N} = \frac{\varepsilon_{\beta}}{\varepsilon_{1n}\varepsilon_{\beta}^{*}} \frac{N_{\det \beta 1n}}{N_{\det \beta}} \Rightarrow P_{1N} = \frac{\langle \varepsilon_{\beta} \rangle}{\langle \varepsilon_{1n} \rangle \langle \varepsilon_{\beta}^{*} \rangle} \frac{N_{\det \mathrm{1n}}}{N_{\det \beta}}$$

Why beta delayed neutrons are relevant?

Reactor kinetics: actually thanks to beta delayed neutrons we can control reactors. They represent approximately 1 % of the total number of neutrons emitted in fission.

Nuclear structure: they can provide information about the states populated in beta decay above the neutron separation energy (probe of the strength). For very exotic nuclei, they might be the only source of information.

Astrophysical applications: in relation to the r- process, they represent an additional neutron source that reshapes the final element abundance curve.


Role in rapid neutron capture process

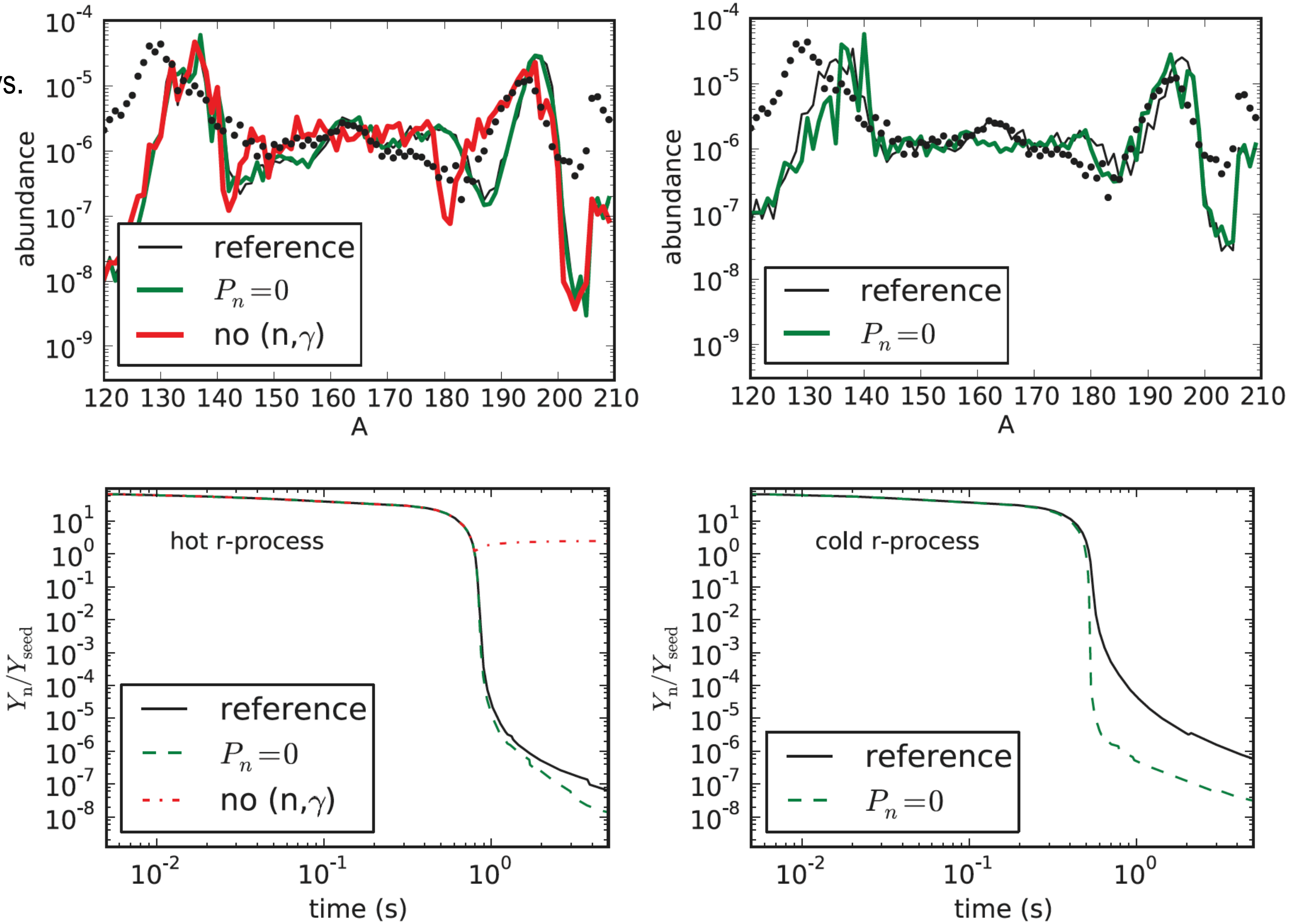
As a result of beta delayed neutrons, the additional neutrons influence the neutron to seed ratio at later times.

Consequences: smothing and shift of the final distributions

Black line: standard nucl. phys. input

Red line: n capture and photodissociation suppresed

Green line: Pn=0



Figures from Arcones et al. PRC 83 045089 based on FRDM

See also Mumpower et al., etc

Renewed interest: KILONOVA event
Multi messenger ERA

LETTER

doi:10.1038/nature24453

Origin of the heavy elements in binary neutron-star mergers from a gravitational-wave event

Daniel Kasen[1,2], Brian Metzger[3], Jennifer Barnes[3], Eliot Quataert[1] & Enrico Ramirez-Ruiz[4,5]

Selected for a Viewpoint in *Physics*
PRL **119**, 161101 (2017) PHYSICAL REVIEW LETTERS week ending 20 OCTOBER 2017

GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral

B. P. Abbott *et al.**
(LIGO Scientific Collaboration and Virgo Collaboration)

(Received 26 September 2017; revised manuscript received 2 October 2017; published 16 October 2017)

Physics

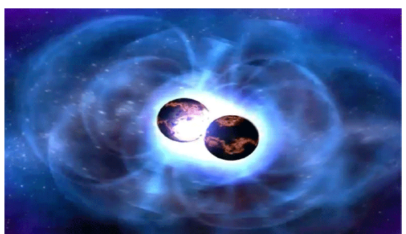
VIEWPOINT

Neutron Star Merger Seen and Heard

For the first time, researchers have detected both light and gravitational waves from the same event in space.

by Maura McLaughlin*

Over thousands of years, astronomy has evolved from hand-drawn maps of the night sky to breath-taking telescope images of the far-away cosmos. Yet despite this advance in technology, most of our information about the Universe has come from photon messengers. This changed in September 2015 with the detection of gravitational waves from a black hole merger at the Laser Interferometer Gravitational-Wave Observatory (LIGO) [1], an achievement that was recognized with this year's Nobel Prize in Physics. The chirp-like signal, caused by a traveling ripple through spacetime, gave us a new way to sense the Universe, like being able to hear, when before



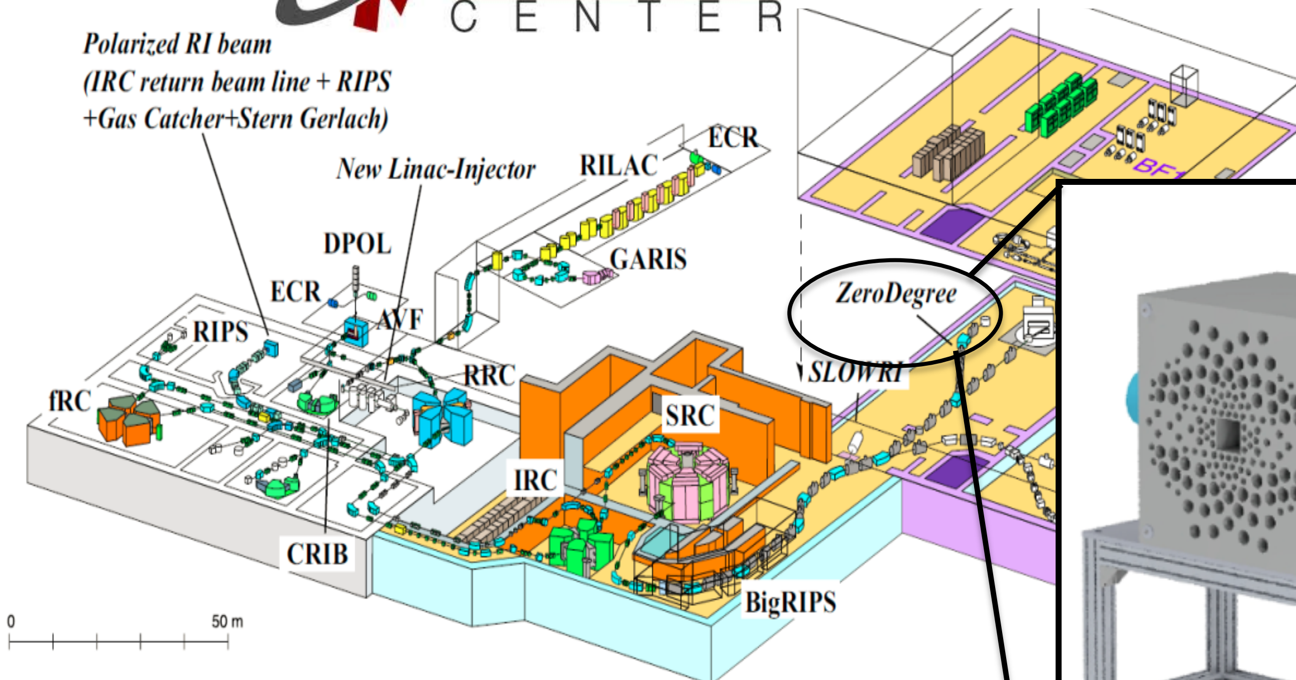
RESEARCH

NEUTRON STAR MERGER

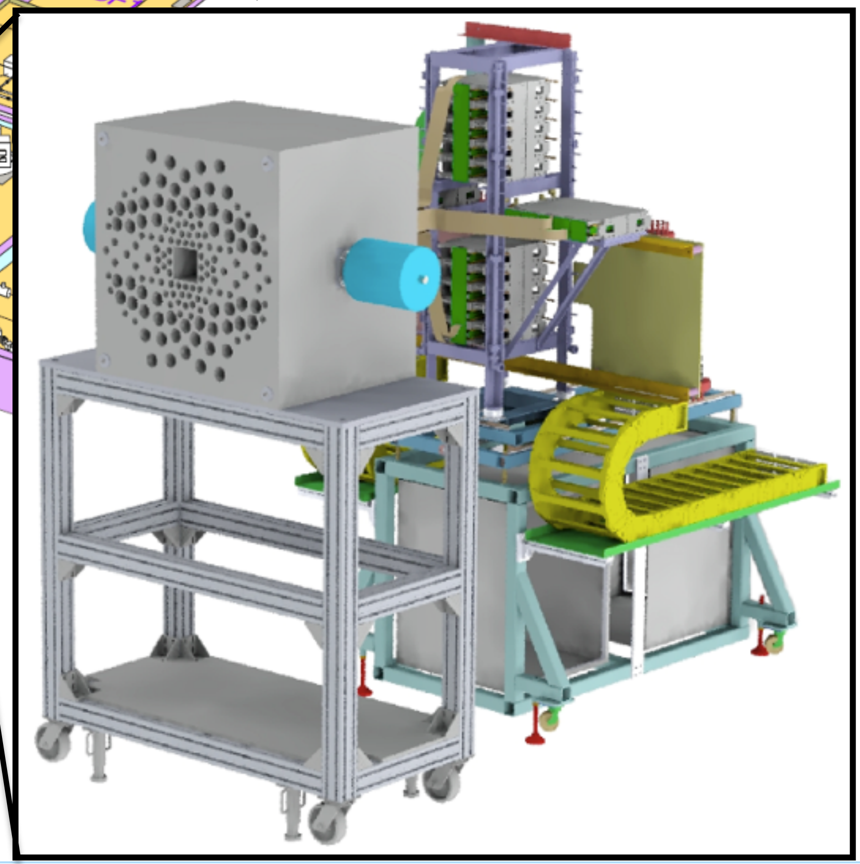
Light curves of the neutron star merger GW170817/SSS17a: Implications for r-process nucleosynthesis

M. R. Drout,[1*] A. L. Piro,[1] B. J. Shappee,[1,2] C. D. Kilpatrick,[3] J. D. Simon,[1] C. Contreras,[4] D. A. Coulter,[3] R. J. Foley,[3] M. R. Siebert,[3] N. Morrell,[4] K. Boutsia,[4] F. Di Mille,[4] T. W.-S. Holoien,[1] D. Kasen,[5,6] J. A. Kollmeier,[1] B. F. Madore,[1] A. J. Monson,[1,7] A. Murguia-Berthier,[3] Y.-C. Pan,[3] J. X. Prochaska,[3] E. Ramirez-Ruiz,[3,8] A. Rest,[9,10] C. Adams,[11] K. Alatalo,[1,9] E. Bañados,[1] J. Baughman,[12,13] T. C. Beers,[14,15] R. A. Bernstein,[1] T. Bitsakis,[16] A. Campillay,[17] T. T. Hansen,[1] C. R. Higgs,[18,19] A. P. Ji,[1] G. Maravelias,[20] J. L. Marshall,[21] C. Moni Bidin,[22] J. L. Prieto,[13,23] K. C. Rasmussen,[14,15] C. Rojas-Bravo,[3] A. L. Strom,[1] N. Ulloa,[17] J. Vargas-González,[4] Z. Wan,[24] D. D. Whitten[14,15]

The BRIKEN project



International collaboration of more than 20 institutions



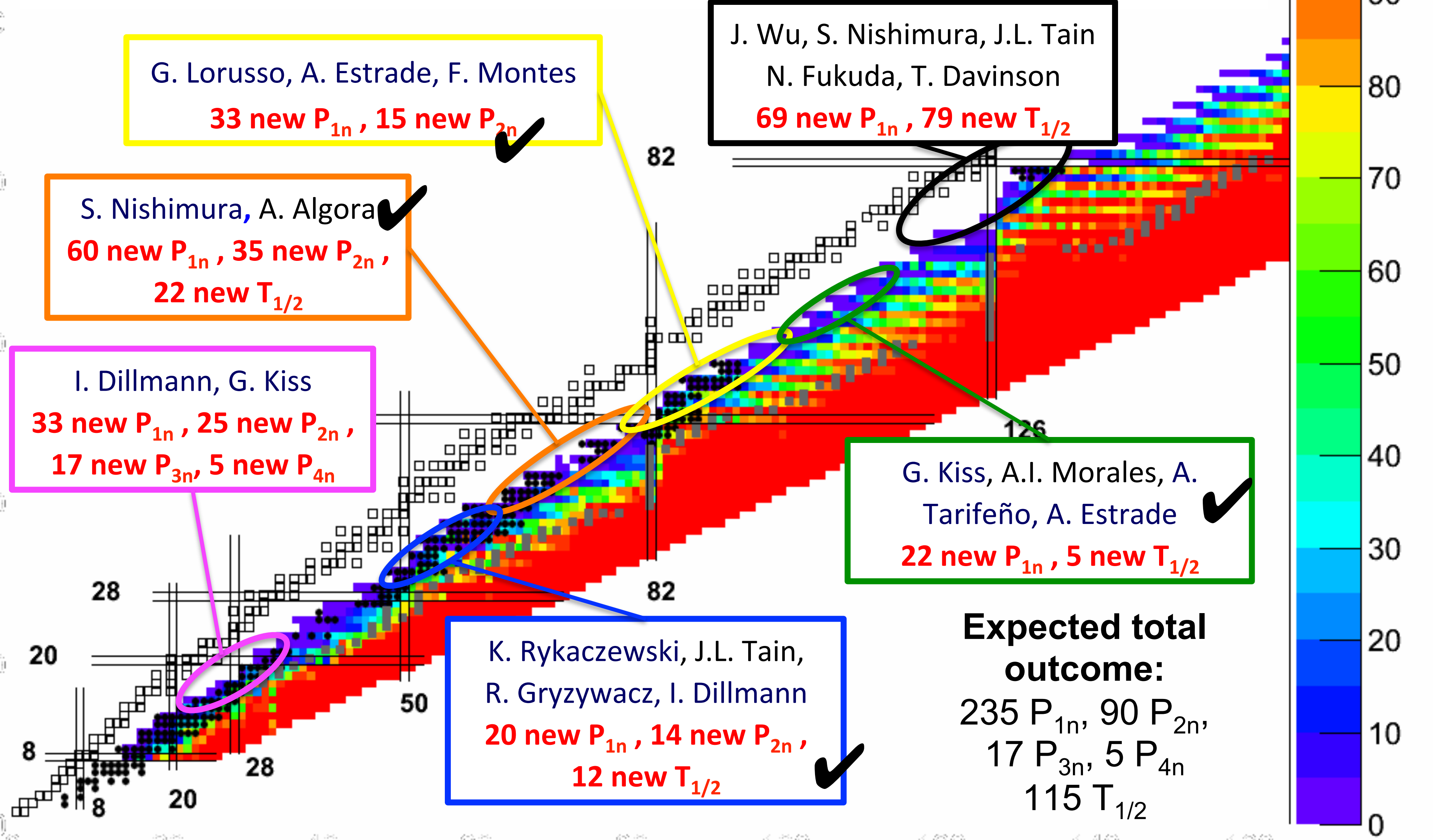
The largest 3He moderated n counter ever built combined with the AIDA detector @ BigRips+ZeroDegree spectrometer

Exploits RIKEN very high beam intensities

Exploring the limits of nuclear existence*

Main goals: astrophysics and nuclear structure

Six proposals were accepted until now to measure $T_{1/2}$, P_{xn} of nuclei around A~20, 80, 110, 130, 150 and 200

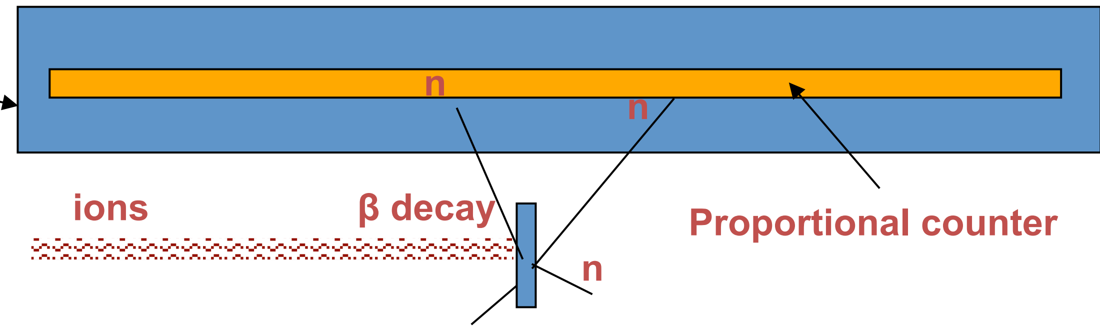


Basics of the technique: just counting

$$P_N = \frac{N_n}{N_\beta}$$

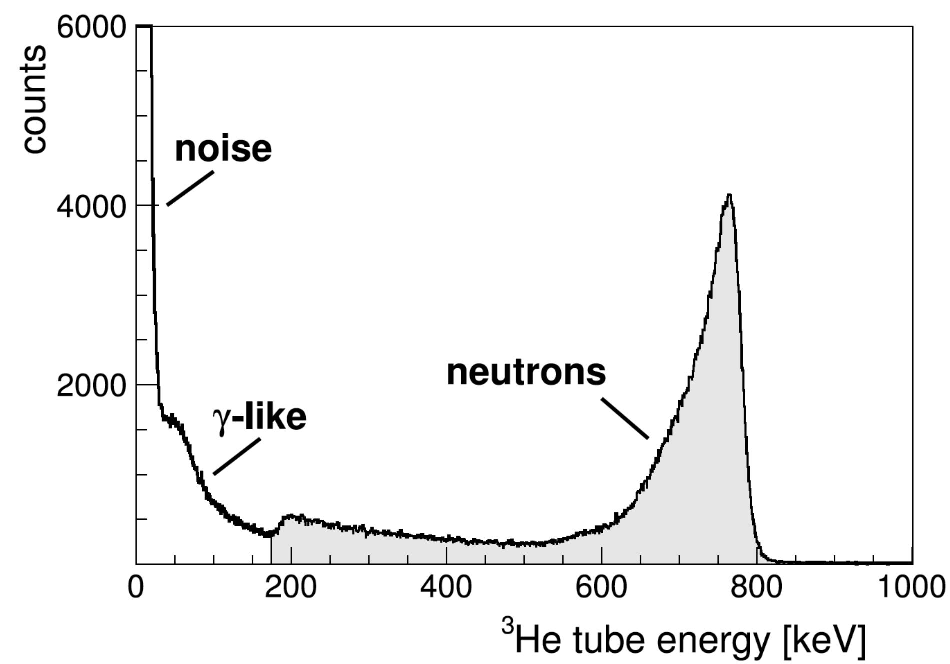
N_n is the number of beta decays going through neutron emission

N_β is the number of decays

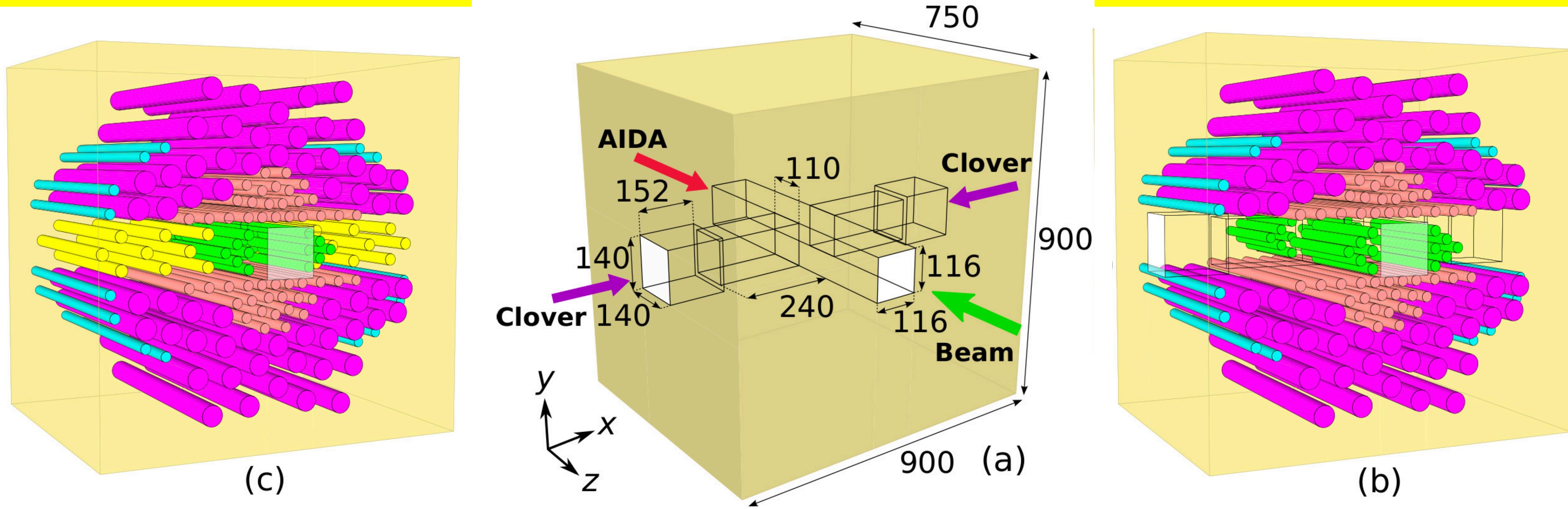


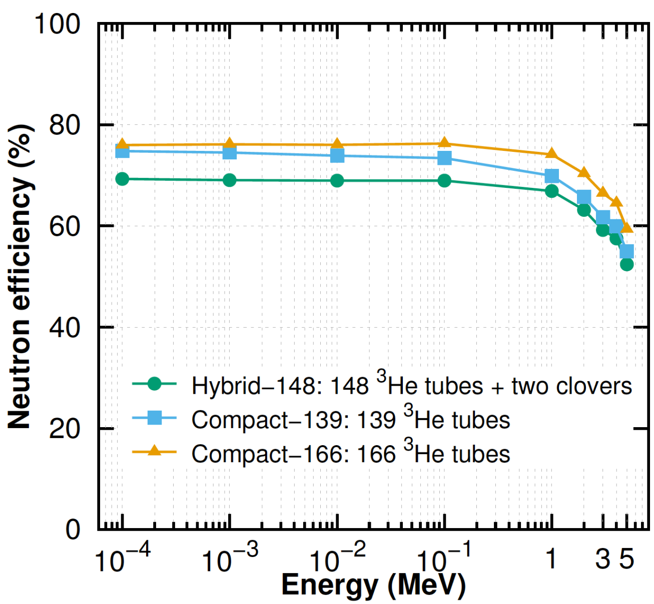
$$n + {}^3He \rightarrow {}^3H + {}^1H + 765\ keV$$

Moderation is needed. This detectors provide a clear signature of neutrons and have very limited sensitivity to gammas. Because of that they are superb neutron detectors.



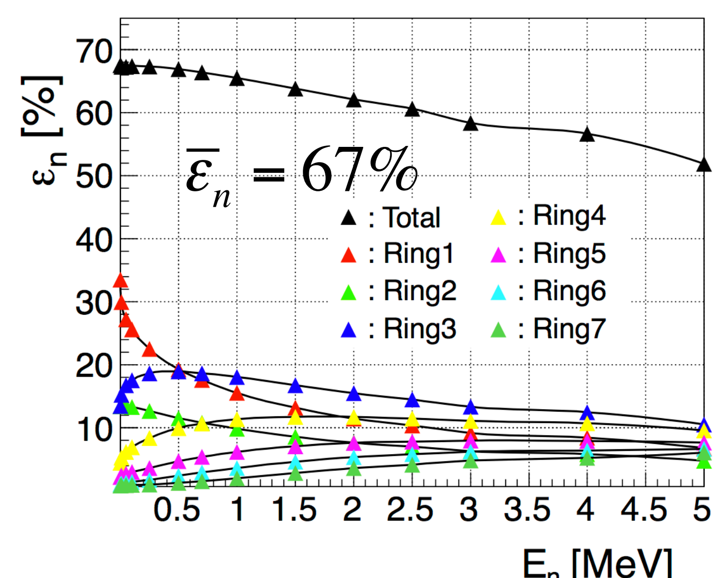
Monte Carlo optimization of the detector





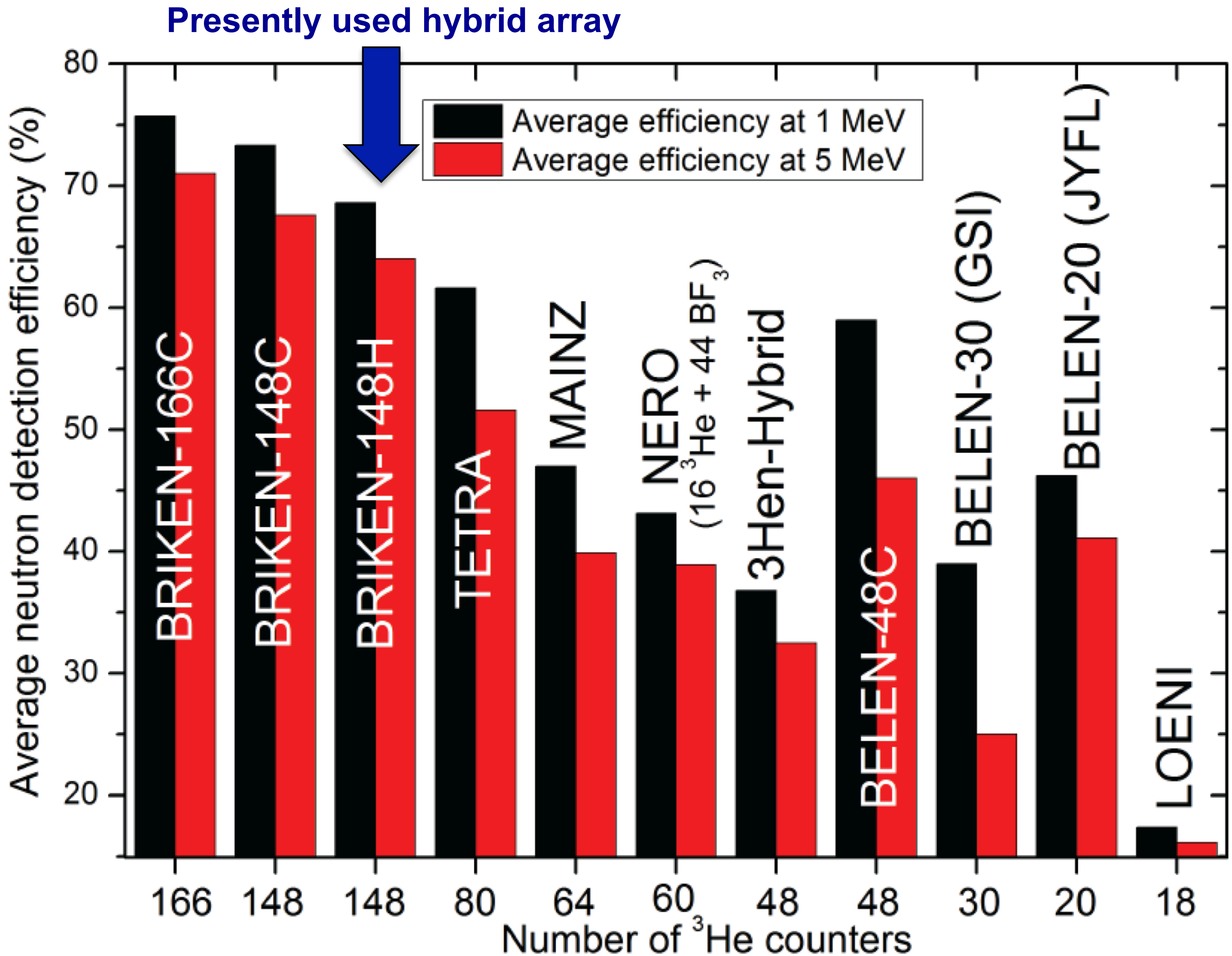
In use:

Hybrid arrangement of 140 3He tubes (UPC, ORNL, RIKEN …) + 2 clovers (ORNL)



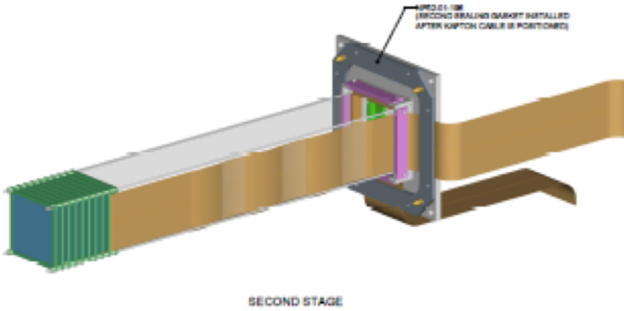
A. Tarifeño et al. JNIST 12. P04006 (2017)

BRIKEN is the most efficient neutron array ever built (that we know)



I. Dillman, A. Tarifeño, NPN 28, page 28, 2018

Implantation detectors



AIDA (Advanced Implantation Detector Array)

Edinburgh, Daresbury, Liverpool

Stack of six Si DSSD

Size: 1mm×72mm×72mm

Granularity: 128×128 pixels (0.51mm strip)

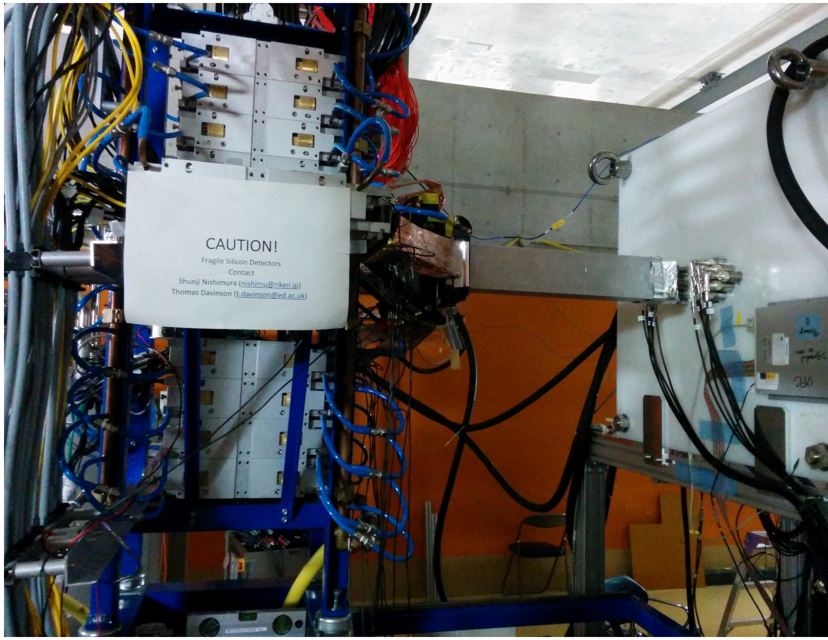
Low gain (implants) and high gain (betas) preamplifiers

Total data readout DACQ (1536 ch)

WAS3ABI + segmented YSO detector

Japan, UTK (USA), used in two exp.

Griffin et al, JPSConfProc14 (2016) 020622

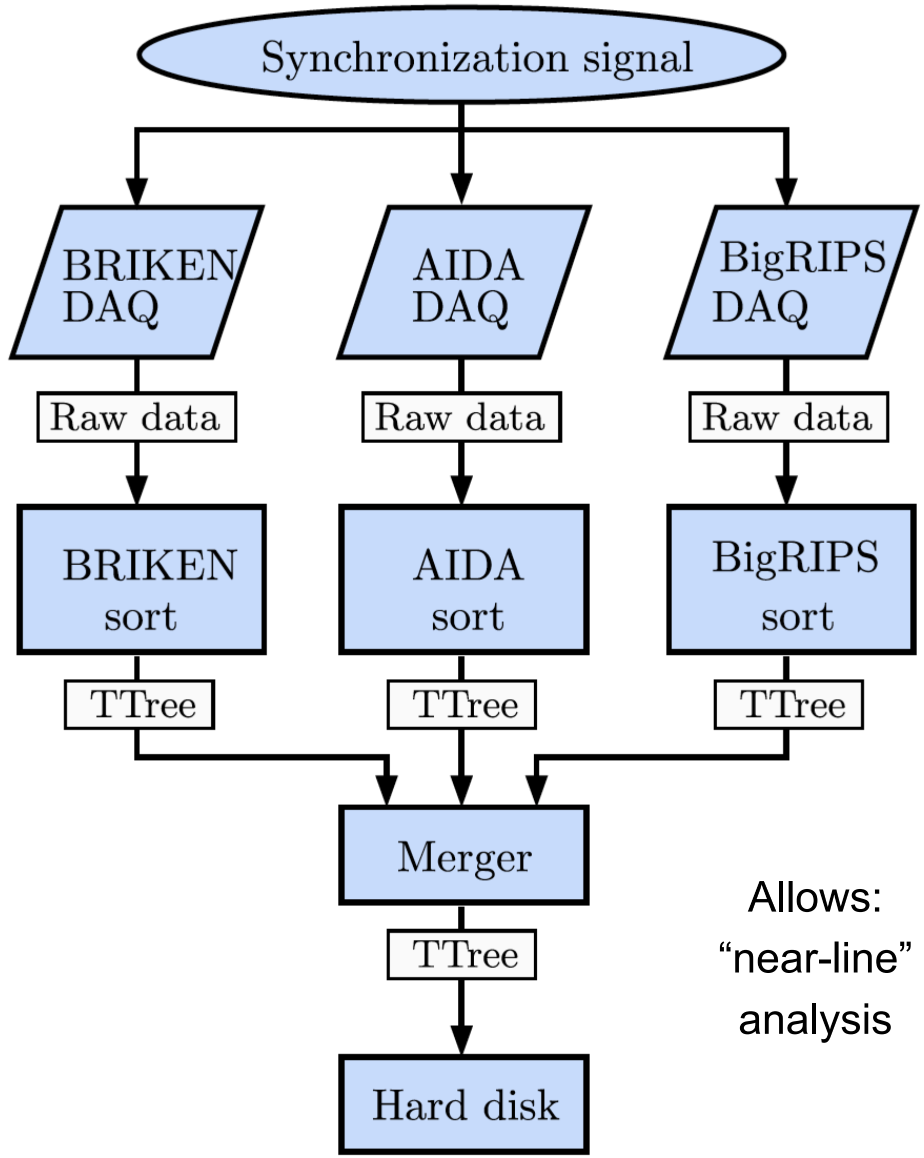


DATA Acquisition System

BRIKEN GASIFIC70 DACQ
(developed at IFIC,
up-scaled system)

- Based on Struck SIS 3316 and SIS3302 digitizers
- Self-triggering system with a common clock
- Software development to merge the events of the diff. systems and have quick access to the combined events ("time grouping")

Agramunt et al., NIM A 807 (2016) 69



Allows:
"near-line"
analysis

Analysis (very brief summary)

Two different approaches (for the moment), one by the Valencia group (presented in the next slides), and the other by the Oak Ridge group

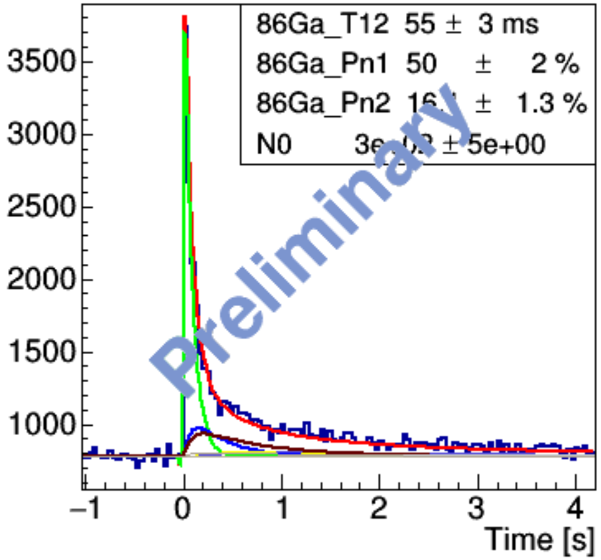
Details can be seen in the original publications:

Tolosa, Agramunt, Tain et al, **NIM A 925** (2019) 133

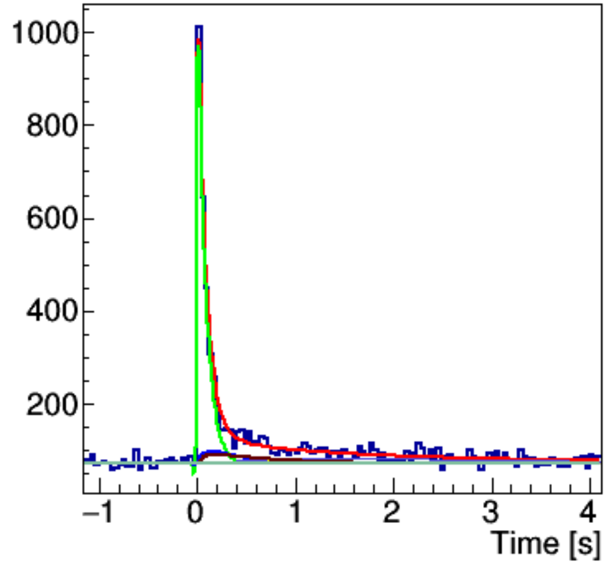
Rasco, Brewer, Yokoyama, et al., **NIM A 911** (2018) 79

Example of analysis case

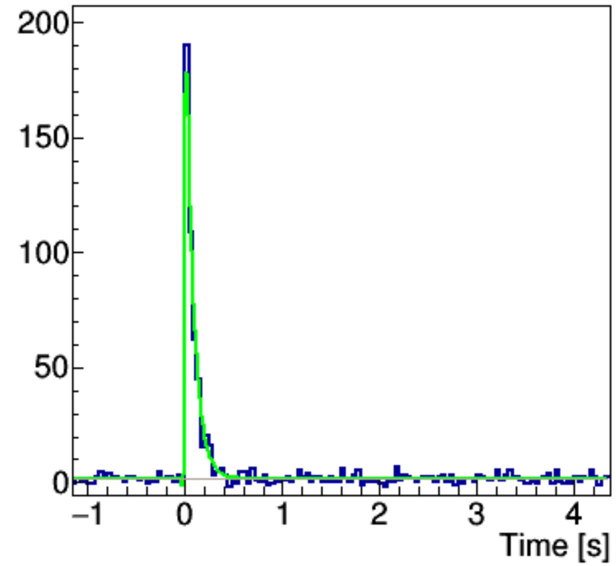
Ti - Tβ



Ti – Tβ [1n gated]



Ti – Tβ [2n gated]

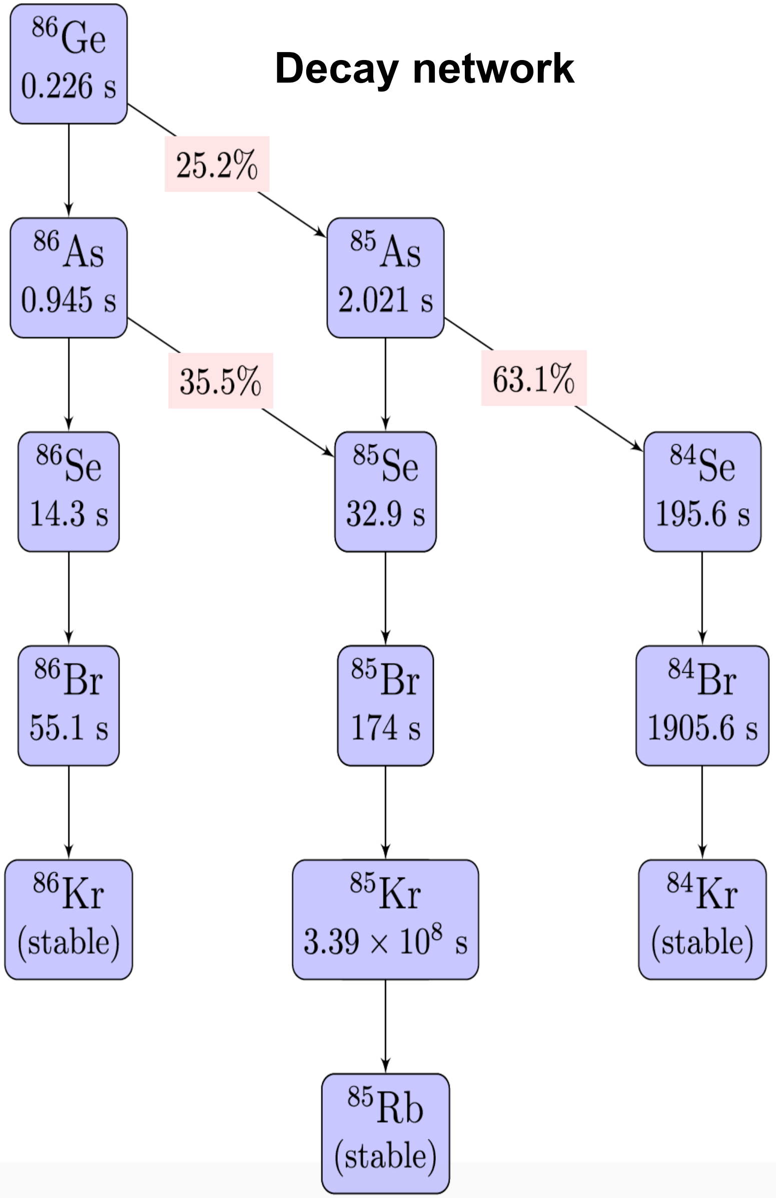


- Sort the corresponding implant-beta histogram spectra with 0, 1, 2, … neutron multiplicity conditions
- Simultaneuously fit of the histograms using the 86Ga entire decay chain, leaving as free parameters parent T1/2, P1n, P2n and the number of parent decays. Histograms must be corrected by random correlations

Analysis by Alvaro Tolosa (IFIC)

Complex Analysis

Decay network



$$f_\beta(t) = \sum_{i\in\beta} \bar{\varepsilon}_\beta^i \lambda_i N_i(t) + \mathrm{bck}_\beta(t)$$

$$f_{\beta 1n}(t) = \sum_{j\in\beta 1n} \bar{\varepsilon}_\beta^j \bar{\varepsilon}_n^j P_{1n}^j \lambda_j N_j(t) + \mathrm{bck}_{1n}(t)$$

$$f_{\beta 2n}(t) = \sum \bar{\varepsilon}_\beta^k \left(\bar{\varepsilon}_n^k\right)^2 P_{2n}^k \lambda_k N_k(t) + \mathrm{bck}_{2n}(t)$$

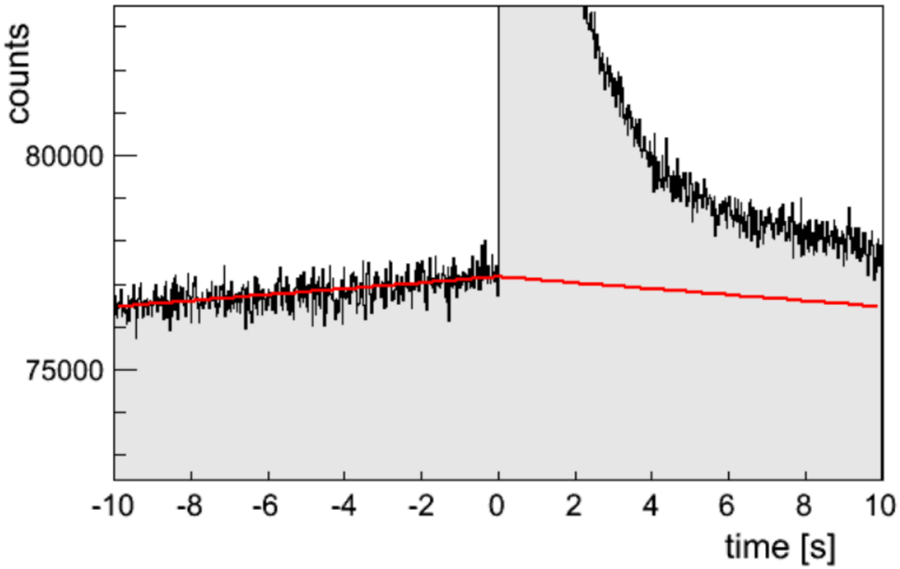
$$N_k(t) = N_1 \prod_{i=1}^{k-1}\left(b_{i,i+1}\lambda_i\right) \times \sum_{i=1}^{k} \frac{e^{-\lambda_i t}}{\prod_{j=1\neq i}^{k}\left(\lambda_j - \lambda_i\right)}$$

$$b_{i,i+1} = P_{1n}^i,\ P_{2n}^i\ or\ 1 - P_{1n}^i - P_{2n}^i$$

Details in Tolosa et al, NIM A 925 (2019) 133

The devil is in the details: the relevance of corrections

Implant-beta



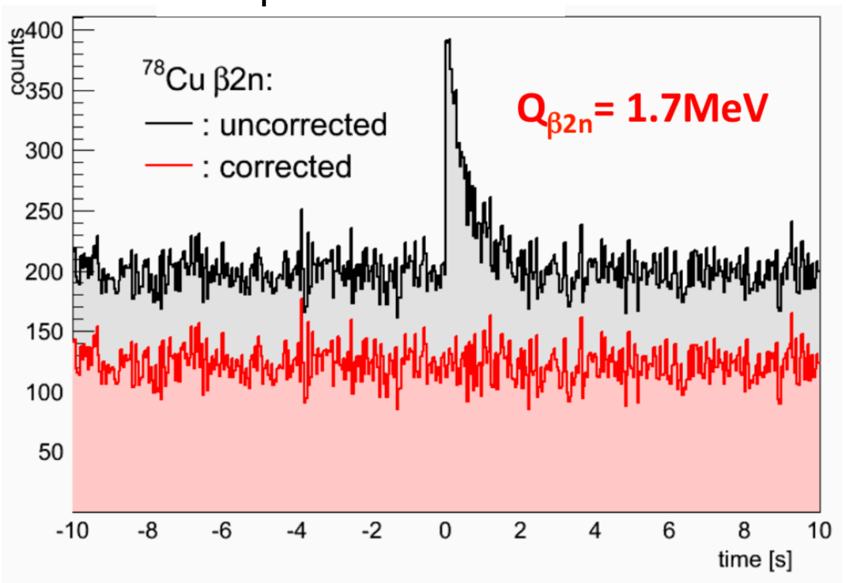
Uncorrelated beta background

Sometimes not completely flat

(because interruptions in the beam)

Corrected using backward time correlations

Implant-beta-2n



Beta-implant-2n correlation

Red: after correction of accidentals

Not taking into account accidental corrections can be very misleading !!!

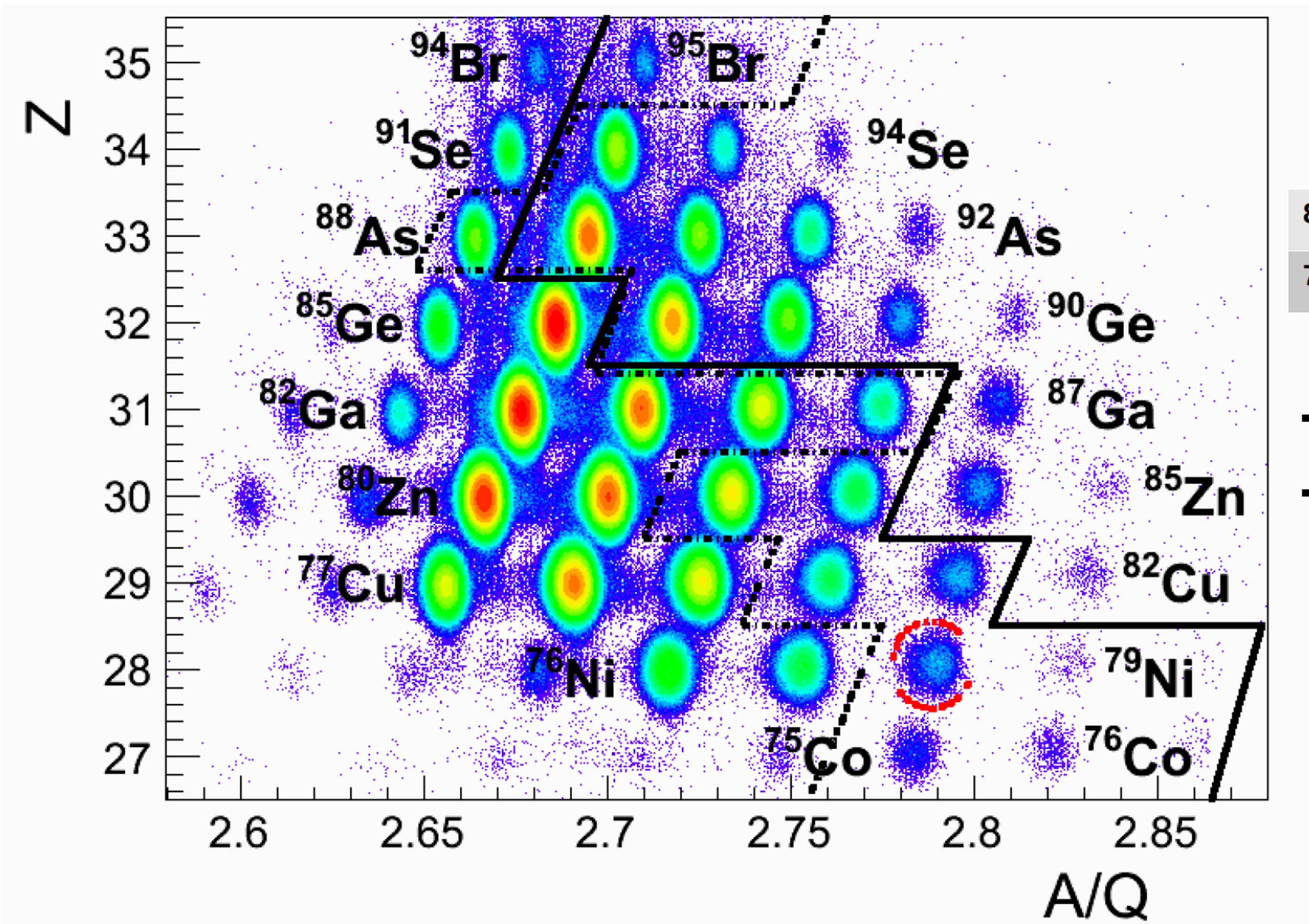
see Tolosa et al, NIM A 925 (2019) 133

Measurements of new beta-delayed neutron emission properties around doubly-magic 78Ni

Spokespersons: K. P. Rykaczewski, J. L. Tain, R. K. Grzywacz, I. Dillmann

Expected outcome: 20 new P1n , 14 new P2n , 12 new T1/2

Region characterized by a large spread of the predicted theoretical $T_{1/2}$, and Pn values



June 2018

^{86}Ge	$6.6\cdot10^{6}$
^{78}Ni	$7.6\cdot10^{3}$

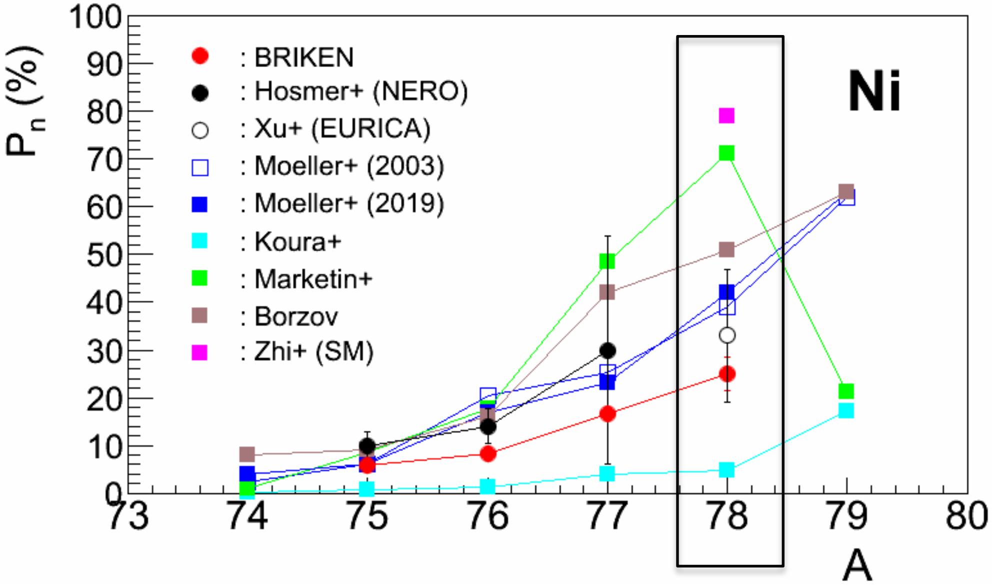
--- New P_{xn}

— New $T_{1/2}$

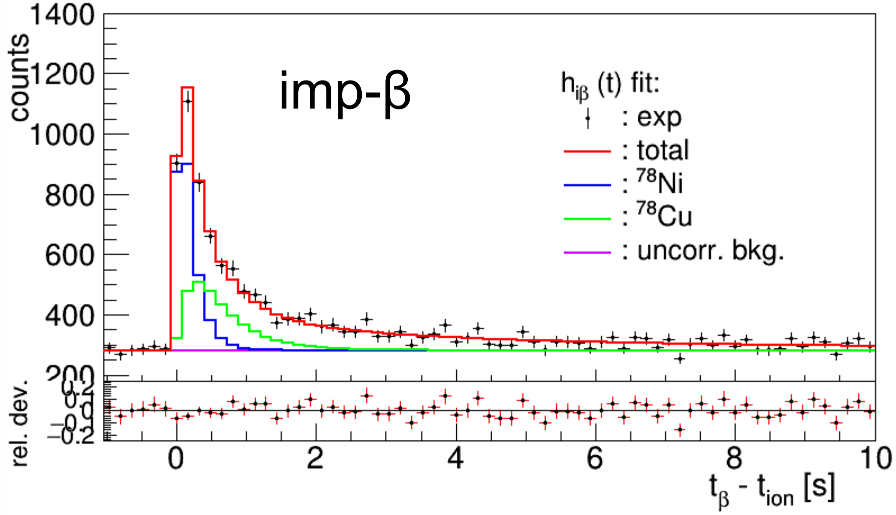
Ps. In a later experiment 35000 implants of 78Ni were collected

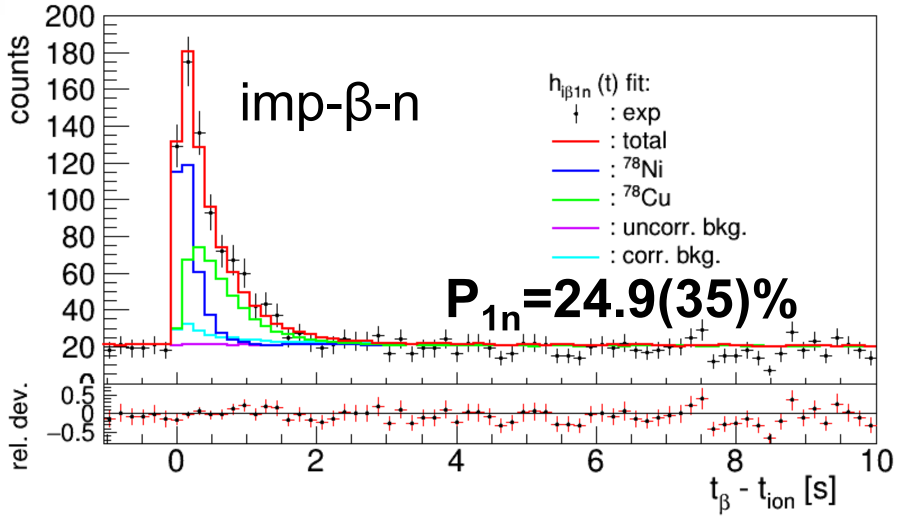
(director discretional beamtime for KPR)

Some **preliminary** results from the 78Ni experiment



^{78}Ni fits





Hosmer et al., PRC 82 (2010) 025806

Z.Y.Xu, PhD Thesis (2014)

Borzov, PRC 71 (2005) 065801

Zhi et al., PRC 87 (2013) 025803

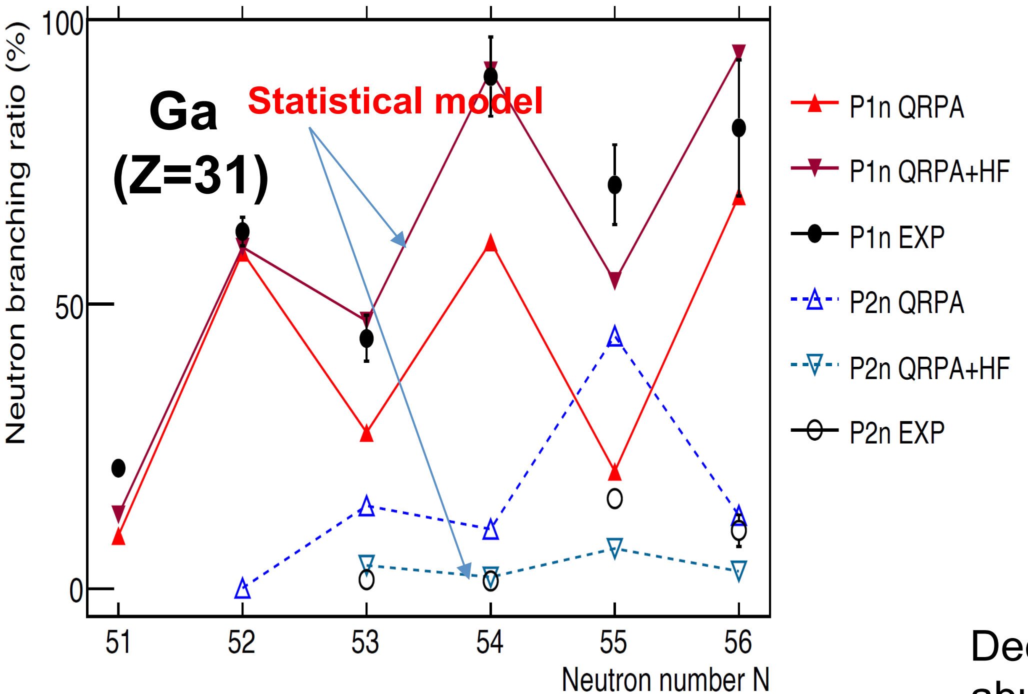
Large spread of the predicted theoretical values

(Analysis by Alvaro Tolosa)

Strong one-neutron emission from two-neutron unbound states in β-decays of $^{86-87}$Ga isotopes.

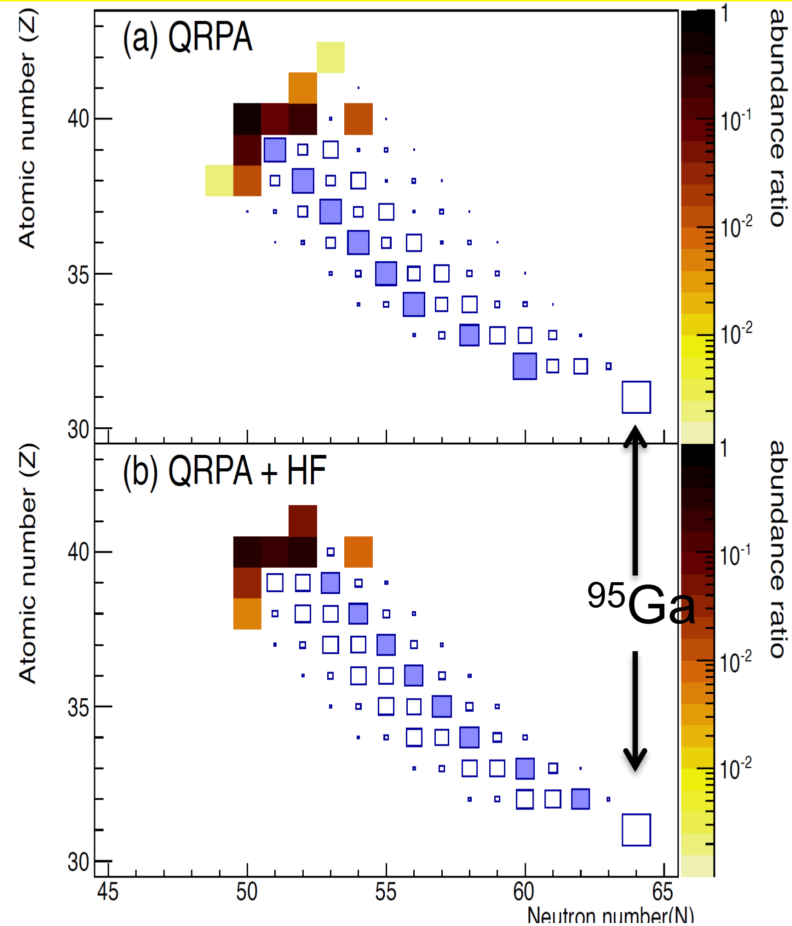
R. Yokoyama et al. submitted to PRL

- New P2n values by BRIKEN are lower than QRPA prediction.
- Inclusion of Hauser-Feshbach statistical model reproduces exp data well.



QRPA: Möller *et al*., PRC 67 055802 (2003)

QRPA+HF: Möller *et al*., At. Dat. Nucl. Dat. Tabl. 125 1 (2019)



Decay path of 95Ga decay chain and the final abundance simulated by using Pxn values by QRPA and QRPA+HF

Inclusion of stat. model changes the r-process abundance calculations significantly

Slide by Yokoyama

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

	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
Ba (56)	Ba128	Ba129		Ba131		Ba133						Ba139	Ba140	Ba141	Ba142	Ba143	Ba144	Ba145	Ba146	Ba147	Ba148	Ba149	Ba150	Ba151	Ba152
Cs (55)	Cs127	Cs128	Cs129	Cs130	Cs131	Cs132		Cs134	Cs135	Cs136	Cs137	Cs138	Cs139	Cs140	Cs141	Cs142	Cs143	Cs144	Cs145	Cs146	Cs147	Cs148	Cs149	Cs150	Cs151
Xe (54)		Xe127						Xe133		Xe135		Xe137	Xe138	Xe139	Xe140	Xe141	Xe142	Xe143	Xe144	Xe145	Xe146	Xe147	Xe148	Xe149	Xe150
I (53)	I125	I126		I128	I129	I130	I131	I132	I133	I134	I135	I136	I137	I138	I139	I140	I141	I142	I143	I144	I145	I146	I147	I148	I149
Te (52)				Te127		Te129		Te131	Te132	Te133	Te134	Te135	Te136	Te137	Te138	Te139	Te140	Te141	Te142	Te143	Te144	Te145	Te146	Te147	Te148
Sb (51)		Sb124	Sb125	Sb126	Sb127	Sb128	Sb129	Sb130	Sb131	Sb132	Sb133	Sb134	Sb135	Sb136	Sb137	Sb138	Sb139	Sb140	Sb141	Sb142	Sb143	Sb144	Sb145	Sb146	Sb147
Sn (50)		Sn123		Sn125	Sn126	Sn127	Sn128	Sn129	Sn130	Sn131	Sn132	Sn133	Sn134	Sn135	Sn136	Sn137	Sn138	Sn139	Sn140	Sn141	Sn142	Sn143	Sn144	Sn145	Sn146
In (49)	In121	In122	In123	In124	In125	In126	In127	In128	In129	In130	In131	In132	In133	In134	In135	In136	In137	In138	In139	In140	In141	In142	In143	In144	In145
Cd (48)	Cd120	Cd121	Cd122	Cd123	Cd124	Cd125	Cd126	Cd127	Cd128	Cd129	Cd130	Cd131	Cd132	Cd133	Cd134	Cd135	Cd136	Cd137	Cd138	Cd139	Cd140	Cd141	Cd142	Cd143	Cd144
Ag (47)	Ag119	Ag120	Ag121	Ag122	Ag123	Ag124	Ag125	Ag126	Ag127	Ag128	Ag129	Ag130	Ag131	Ag132	Ag133	Ag134	Ag135	Ag136	Ag137	Ag138	Ag139	Ag140	Ag141	Ag142	Ag143
Pd (46)	Pd118	Pd119	Pd120	Pd121	Pd122	Pd123	Pd124	Pd125	Pd126	Pd127	Pd128	Pd129	Pd130	Pd131	Pd132	Pd133	Pd134	Pd135	Pd136	Pd137	[illegible]	[illegible]	Pd140	[illegible]	Pd142
Rh (45)	Rh117	Rh118	Rh119	Rh120	Rh121	Rh122	Rh123	Rh124	Rh125	Rh126	Rh127	Rh128	Rh129	Rh130	Rh131	Rh132	Rh133	Rh134	Rh135	Rh136	Rh137	Rh138	Rh139	Rh140	Rh141
Ru (44)	Ru116	Ru117	Ru118	Ru119	Ru120	Ru121	Ru122	Ru123	Ru124	Ru125	Ru126	Ru127	Ru128	Ru129	Ru130	Ru131	Ru132	Ru133	Ru134	Ru135	Ru136	Ru137	Ru138	Ru139	Ru140

r-process path

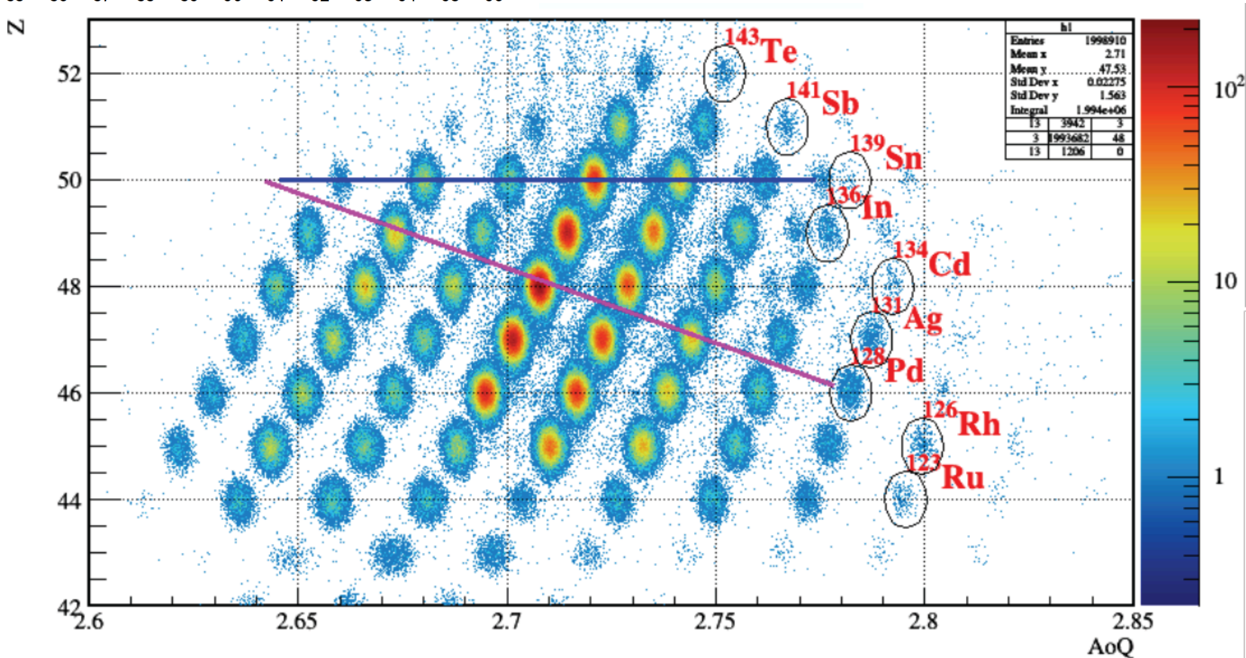
Spokespersons: A. Estrade, G. Lorusso, F. Montes

:aim P_n values

June 2018

Expected outcome:

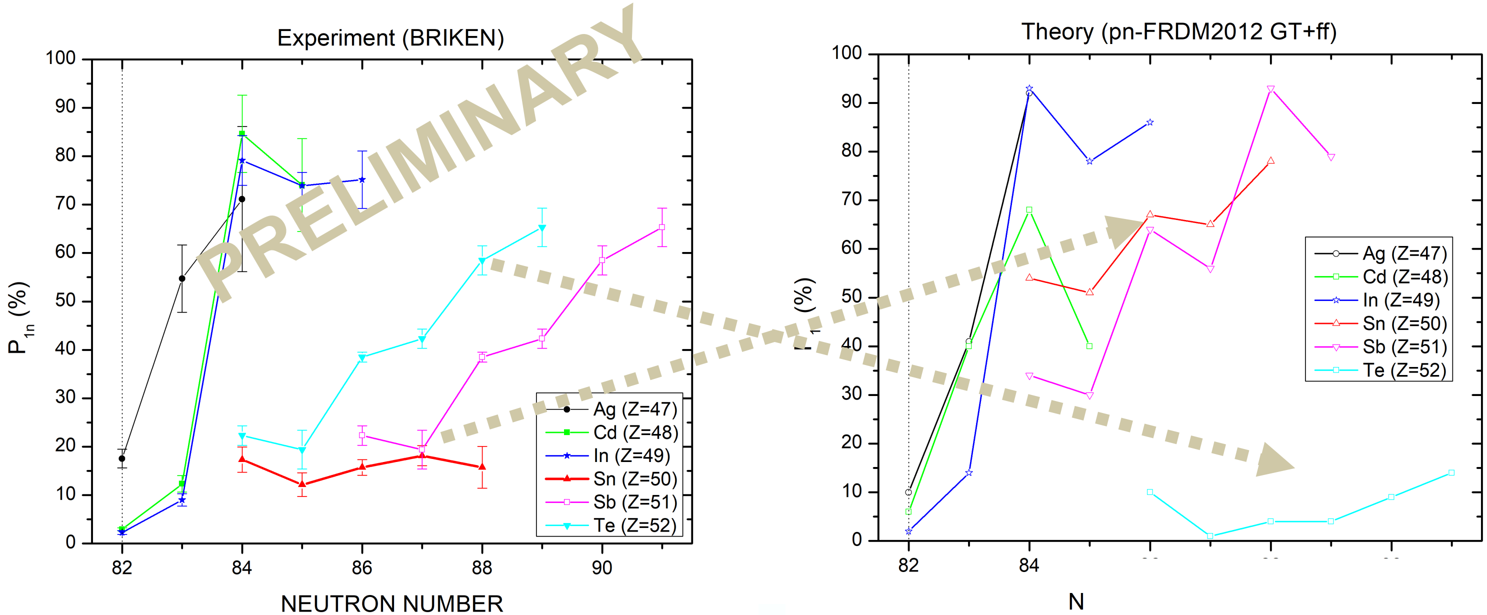
33 new P1n , 15 new P2n



Preliminary impact of A~130 P_{1n} values

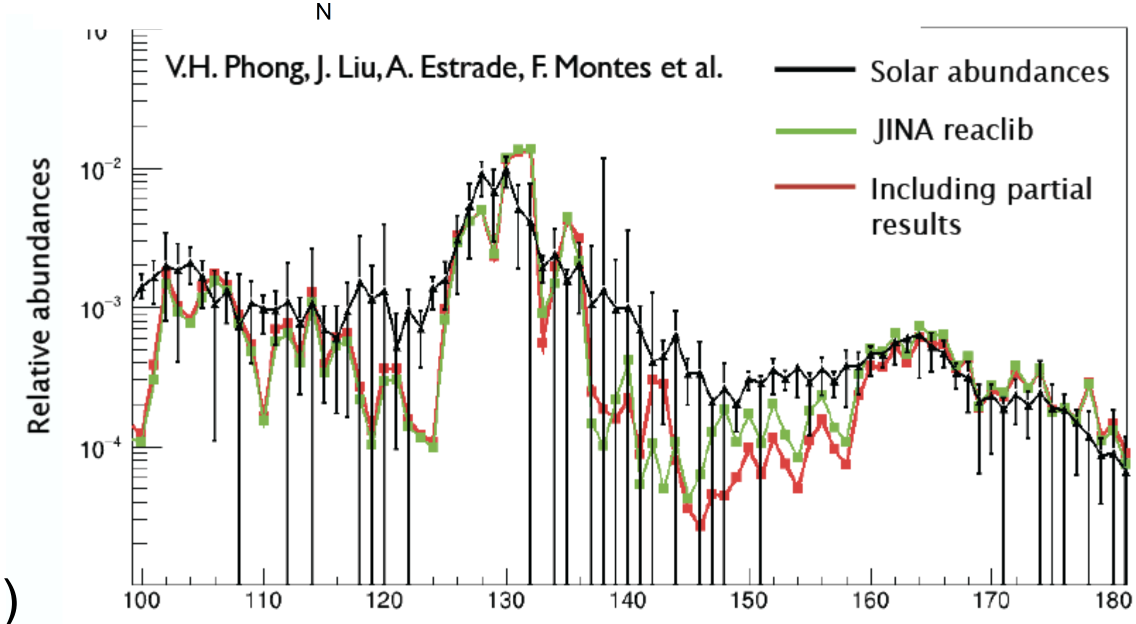
BRIKEN

Moeller et al. 2019



Comparison with theory shows marked differences for some isotopic chains

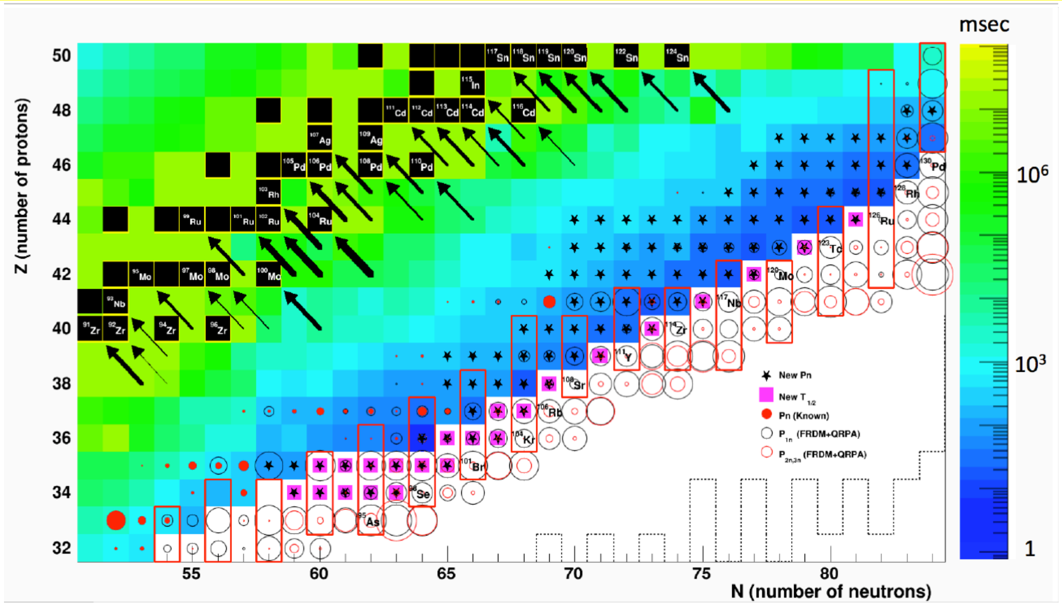
New partial data has significant effect on abundances between 2nd and REP peak



(from Fernando Montes et al.)

Decay properties of r-process nuclei in deformed region around A = 100 ~ 125

Spokespersons: S. Nishimura, A. Algora



- ★ New Pn
- New T1/2
- Pn (known)
- P1n (Mol03)
- P2n (Mol03)

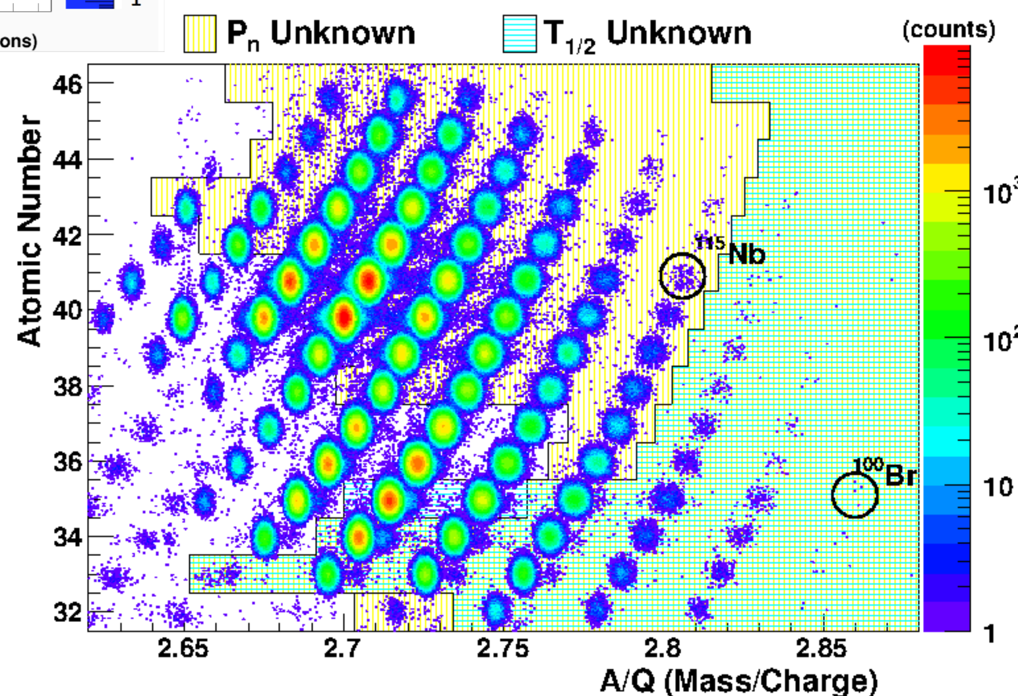
r-process path

Expected outcome:

60 new P1n , 35 new P2n ,

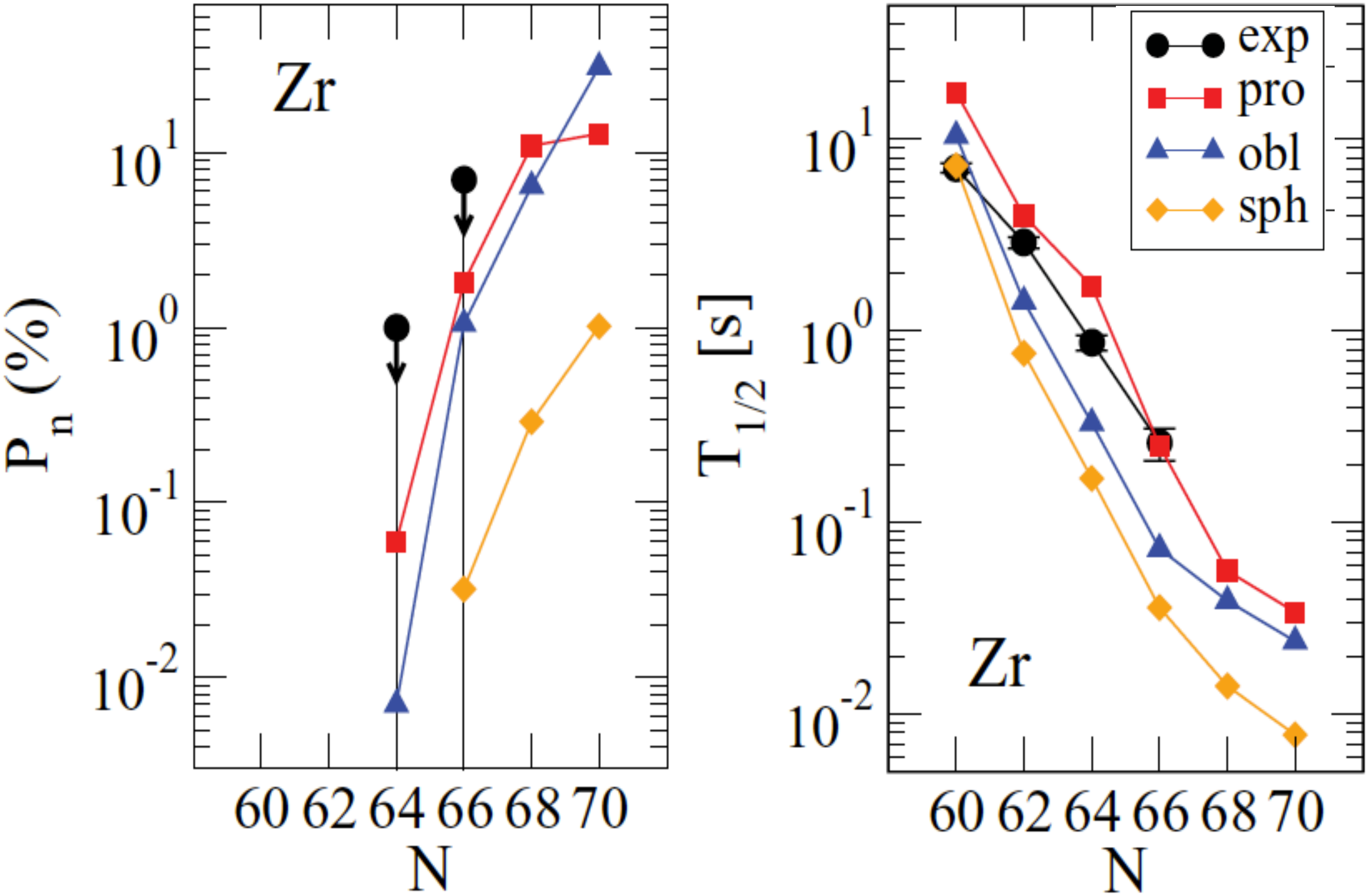
22 new T1/2

November 2017



(ID plot from S. Nishimura)

Decay properties of r-process nuclei in deformed region around A = 100 ~ 125, shape effects



Dependence of the T1/2 and Pn values on the deformation of the parent. Example for Zr, similar situation for Mo.

Several questions:

- Transition to oblate shapes for Z=40 ?
- Is there an spherical shell for N=70 ? (astrophysical implications)

QRPA calculations (using SLy4)

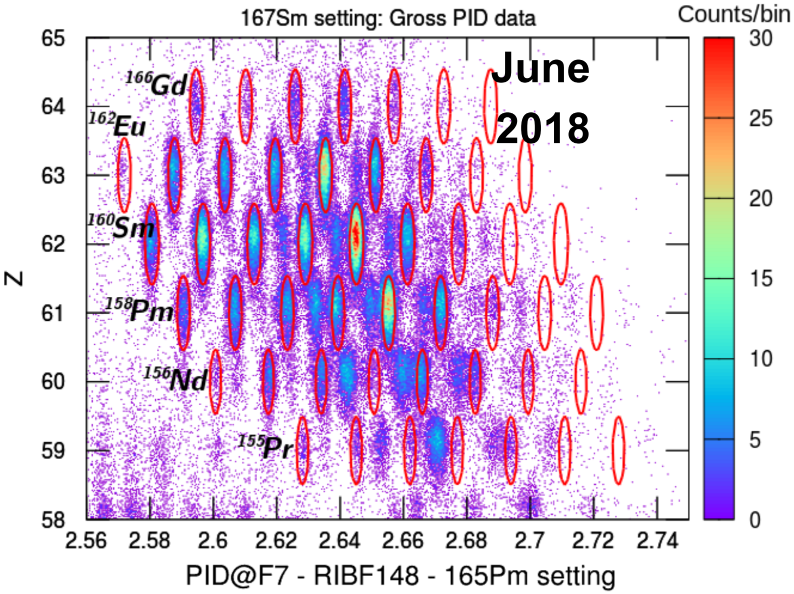
Sarriguren, Pereira PRC **81** (2010) 064314

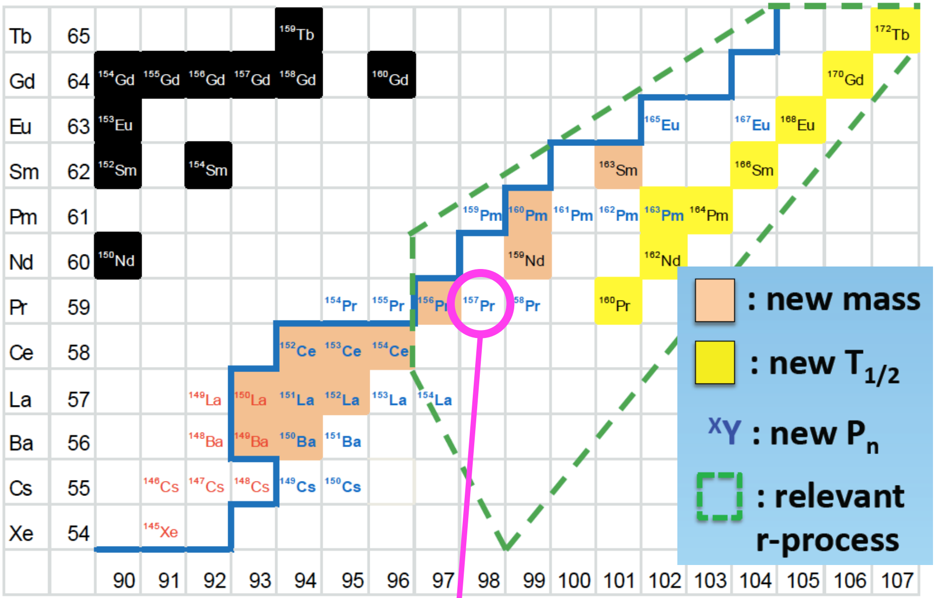
Sarriguren, Algora, Pereira, PRC 89 (2014) 034311

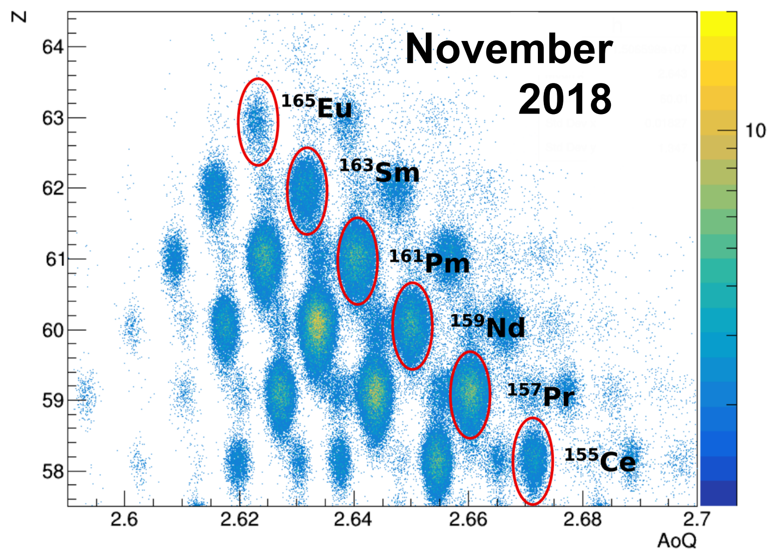
Masses, half-lives and beta delayed neutron emission probabilities relevant to understand the formation of the rare earth r process peak

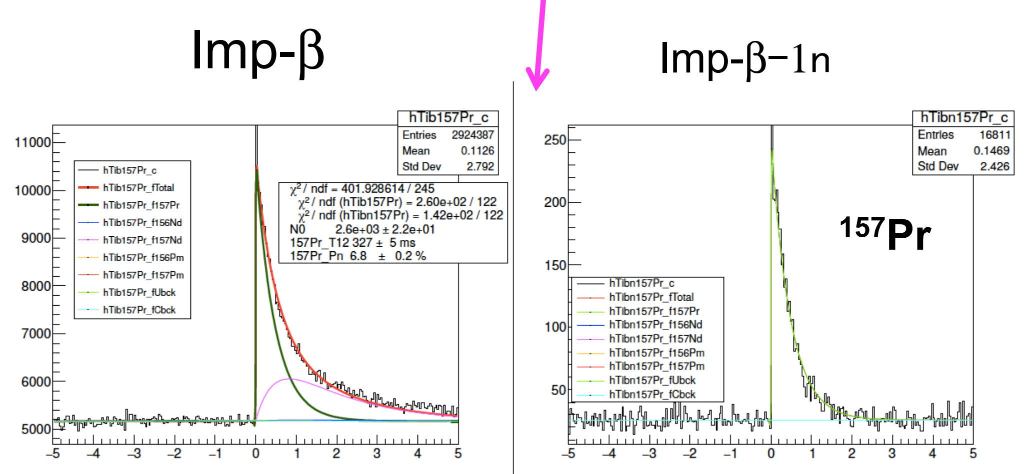
Spokespersons: G. Kiss, A. I. Morales, A. Tarifeño-Saldivia, A. Estrade

Expected outcome: 22 new P1n , 5 new T1/2







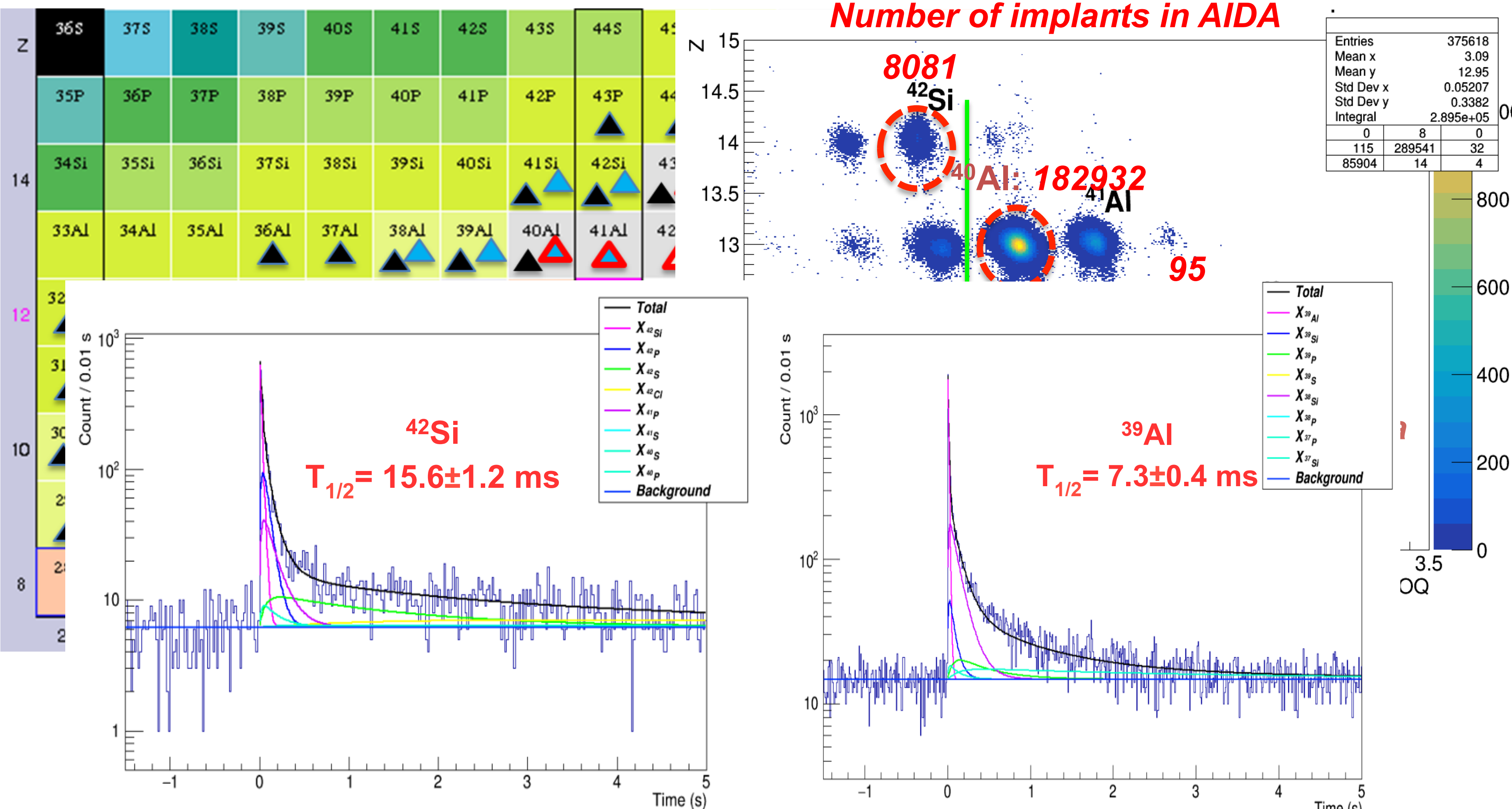


(from Ariel Tarifeño)

Results of the test beamtime (parasitic measurements done in 2016 & 2017)

Spokespersons: I. Dillmann, G. Kiss

Expected outcome (original experiment): 33 new P1n , 25 new P2n ,17 new P3n, 5 new P4n



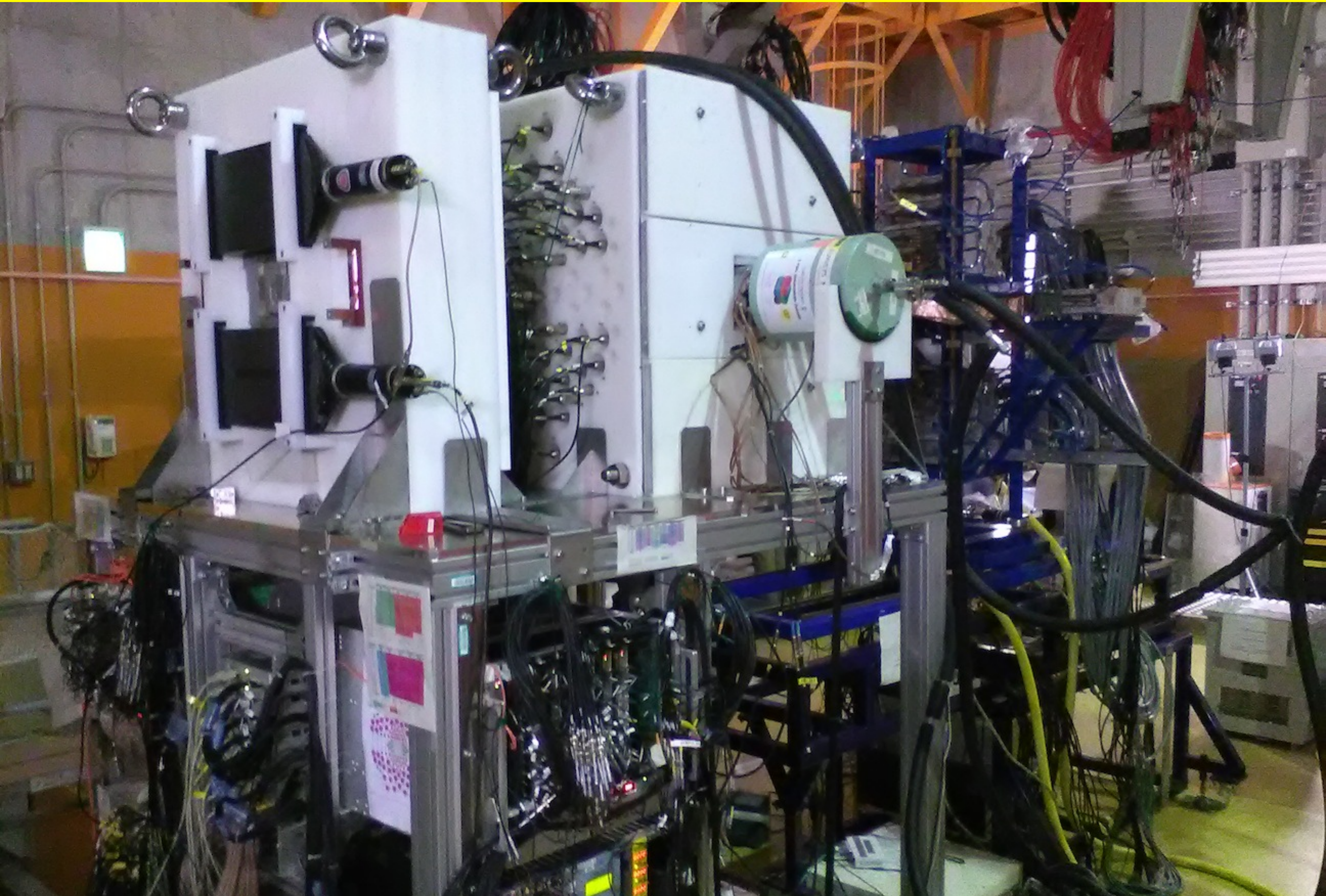
S. Grevy et.al PLB 594(2004) 252-259

$T_{1/2}$= 12.5±3.5 ms

S. Grevy et.al PLB 594(2004) 252-259

$T_{1/2}$= 7.6±1.6 ms

BRIKEN itself



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IAEA
International Atomic Energy Agency
Atoms for Peace and Development

IAEA Coordinated Research Project on Reference Database for beta-delayed neutron emission

2013-2017:

Research Coordination Meeting 1: 26-30 August 2013

Research Coordination Meeting 2: 23-27 March 2015

Research Coordination Meeting 3: 16-20 October 2016

Coordinated by P. Dimitriou (IAEA)

Objective

To create a Reference Database for Beta-Delayed Neutron Emission that contains both a compilation of existing data and recommended data for individual precursors and aggregate quantities (nu-bars, group constants)

Final Coord. Research Project summary paper

Development of a Reference Database for Beta-Delayed Neutron Emission

P. Dimitriou,[1,*] I. Dillmann,[2,3] B. Singh,[4] V. Piksaikin,[5] K.P. Rykaczewski,[6] J.L. Tain,[7] A. Algora,[7] K. Banerjee,[8] I.N. Borzov,[9,10] D. Cano-Ott,[11] S. Chiba,[12] R. Grzywacz,[13,6] X. Huang,[14] T. Marketin,[15] F. Minato,[16] G. Mukherjee,[8] M. Fallot,[17] D. Foligno,[18] B.C. Rasco,[6] A. Sonzogni,[19] M. Verpelli,[1] A. Egorov,[5] D. Gremyachkin,[5] M. Madurga,[13] E.A. McCutchan,[19] K.V. Mitrofanov,[5] M. Estienne,[17] L. Giot,[17] M. Narbonne,[17] E. Mendoza,[11] P. Romojaro,[11] A. Sanchez-Caballero,[11] and N. Scielzo[20]

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Will be published as Nuclear Data Sheets Special Issue (June 2019)

https://www-nds.iaea.org/beta-delayed-neutron/database.html

Summary

- BRIKEN has completed 4 experiments of the 6 already approved. Additional proposals might be coming.
- Considerable work has been invested in the development of analysis tools and on the evaluation of systematic errors.
- Large amount of new Pxn and T1/2 values are expected from these measurements.
- It will provide data to further test theoretical models. First results are coming out
- Increased evidence of the importance of the inclusion of gamma-n competition (need for an statistical model treatment)
- Will contribute dramatically to the improvement of r-process calculations

Expected results

Isotopes with $Q_{\beta xn} > 0$ based on AME2016 (out of 2451 known nuclei)

Data taken from P. Dimitriou *et al.* (to be submitted to NDS)

	Identified No of isotopes	Measured No of isotopes	Meas. fraction	Expected BRIKEN results
β1n	631	298	48.0 %	+ ~250
β2n	300	23	7.7 %	+ ~50
β3n	138	4	2.9 %	+ ~10
β4n	58	1	1.7 %	+ ~5

THANK YOU

Many slides and contributions from: I. Dillman, J. L. Tain, G. Kiss, F. Montes, A. Tarifeño, R. Yokoyama, C. Rasco, N. Neerajan, S. Nishimura, A. Estrade

Discussions with : A. Tolosa, J. L. Tain