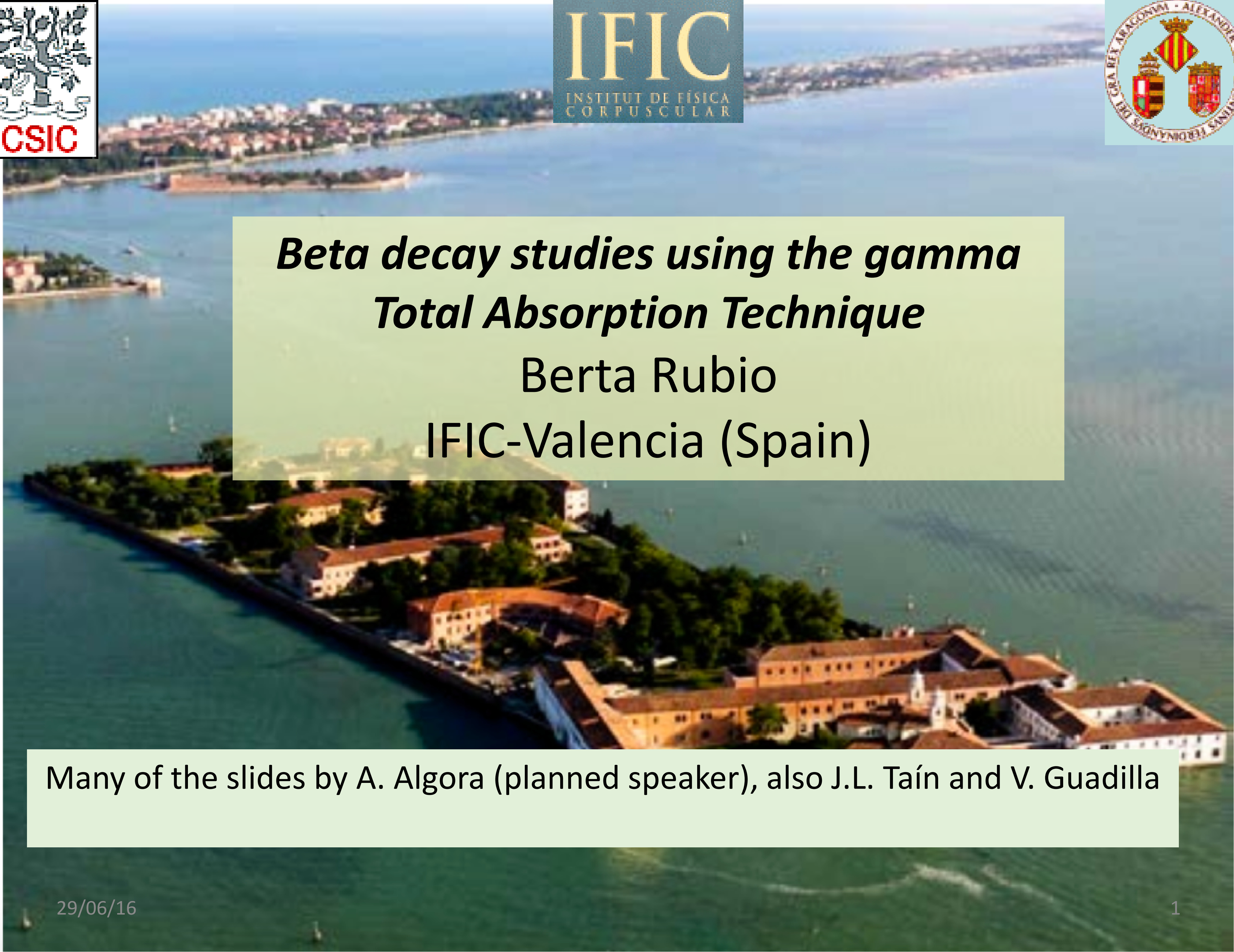


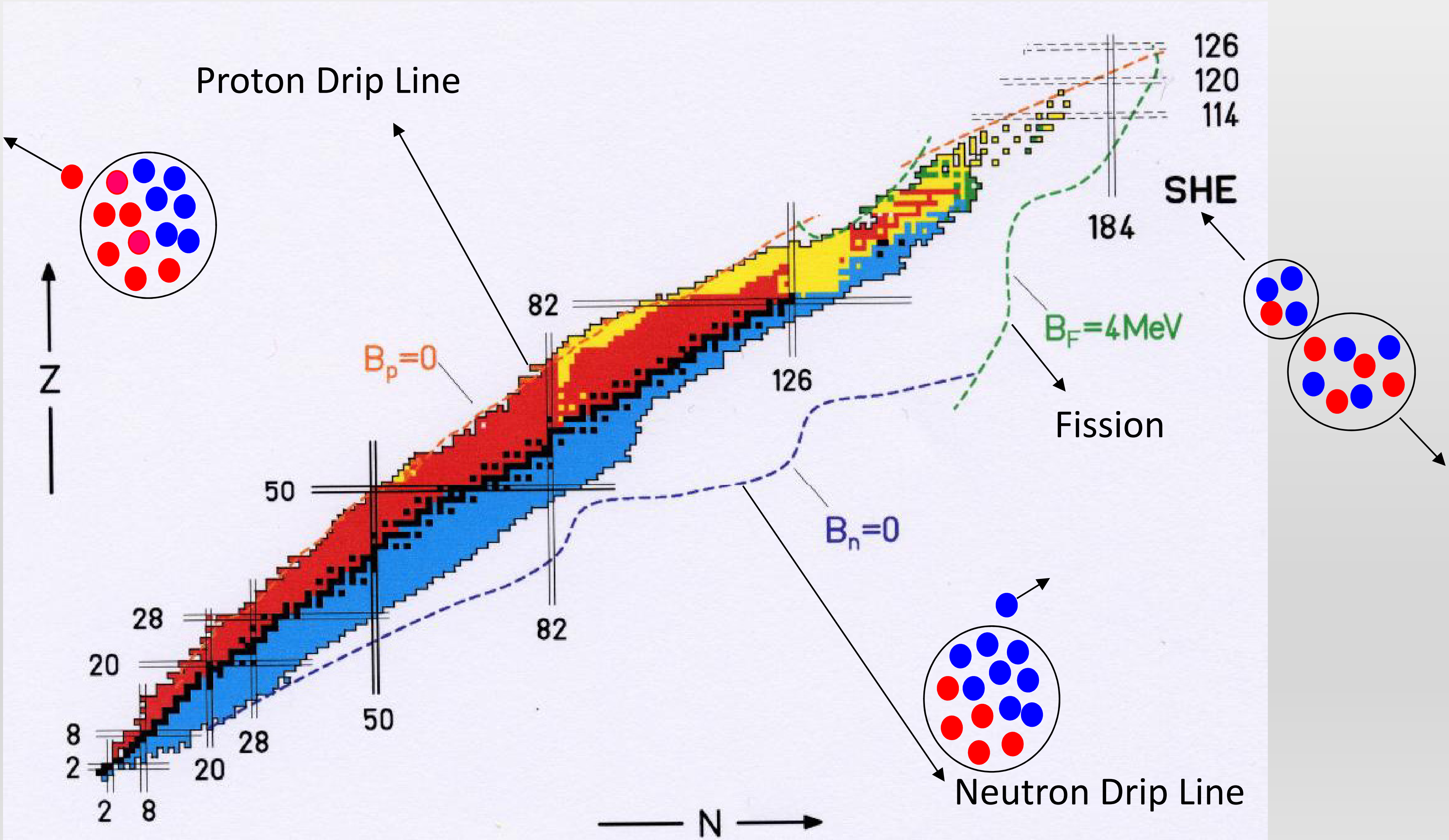
Beta decay studies using the gamma Total Absorption Technique

Berta Rubio

IFIC-Valencia (Spain)

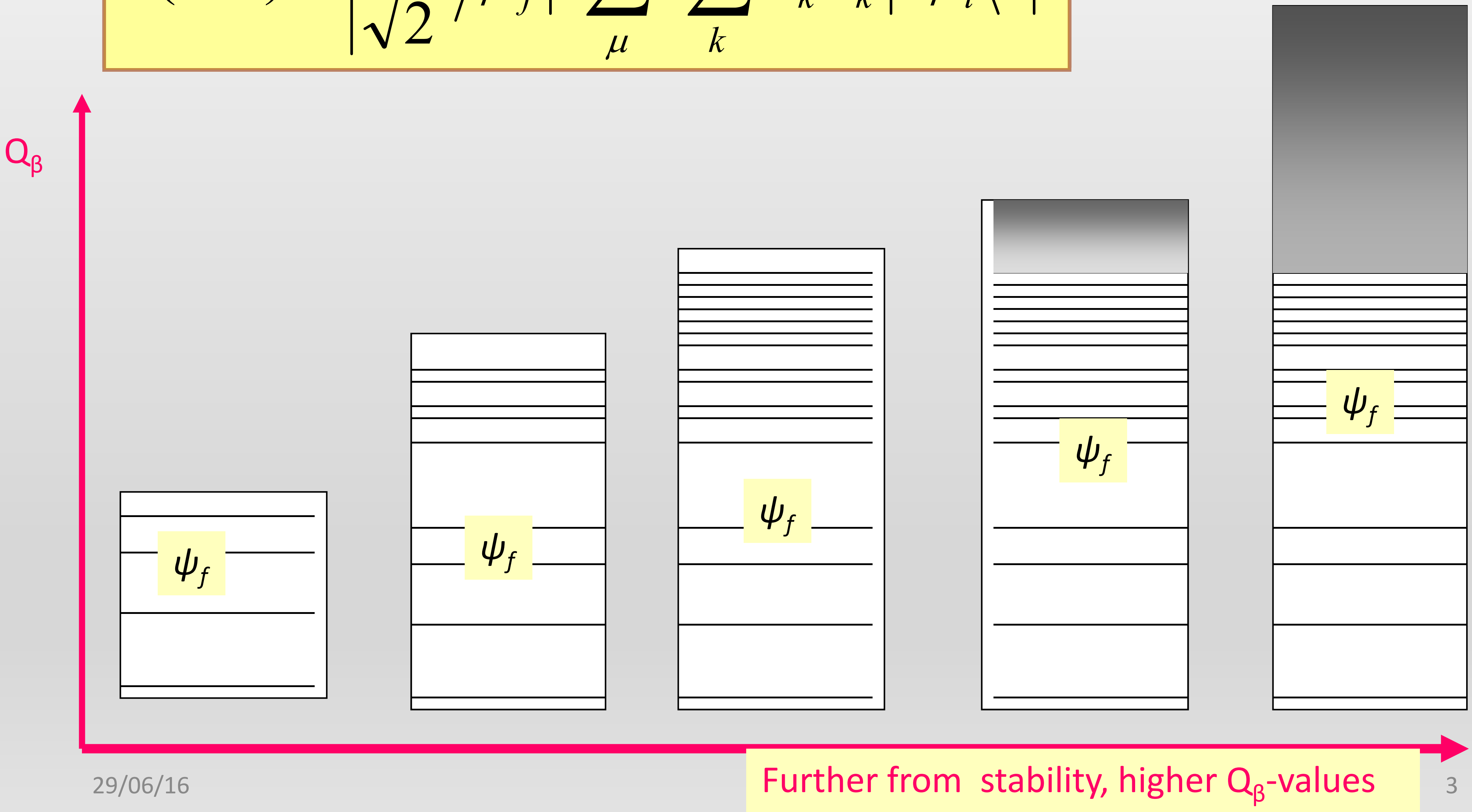
Many of the slides by A. Algora (planned speaker), also J.L. Taín and V. Guadilla

Most unstable nuclei decay
by either β^+ or β^- decay



Most of the beta decay are dominated by Gamow Teller transitions
Definition of Gamow teller strength:

$$B(GT) = \left| \frac{1}{\sqrt{2}} \rangle \psi_f \right| \sum_{\mu} \sum_{k} \sigma_k^{\mu} \tau_k^{\pm} \left| \psi_i \langle \right|^2$$



The beta Gamoe Teller strength or transition probability
Theory versus experiment

Theoretically

$$B(GT) = \left| \frac{1}{\sqrt{2}} \rangle \psi_f \right| \sum_{\mu} \sum_{k} \sigma_k^{\mu} \tau_k^{\pm} \left| \; \psi_i \langle \; \right|^2$$

Experimentally

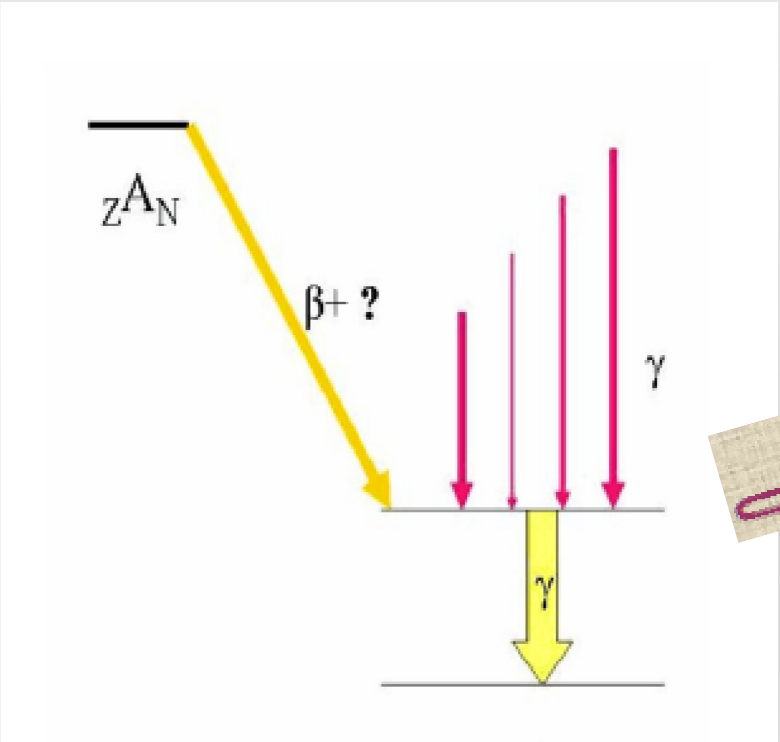
$$B(GT) = k \frac{I_\beta(E)}{f(Q_\beta - E, Z) T_{1/2}} = k \frac{1}{ft}$$

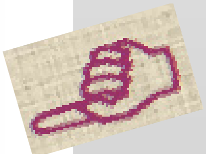
From the experiment

- $I_\beta(E)$ Beta feeding to states in the daughter nucleus
- Q_β Q-value
- $T_{1/2}$ Parent half life

This talk

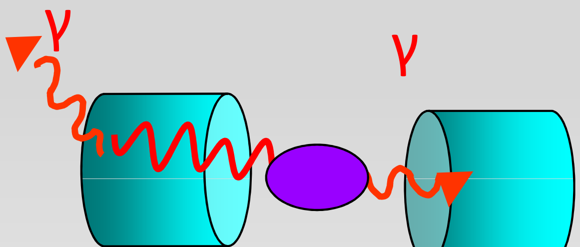
How to measure beta feeding intensity
To each of the levels in the daughter nucleus



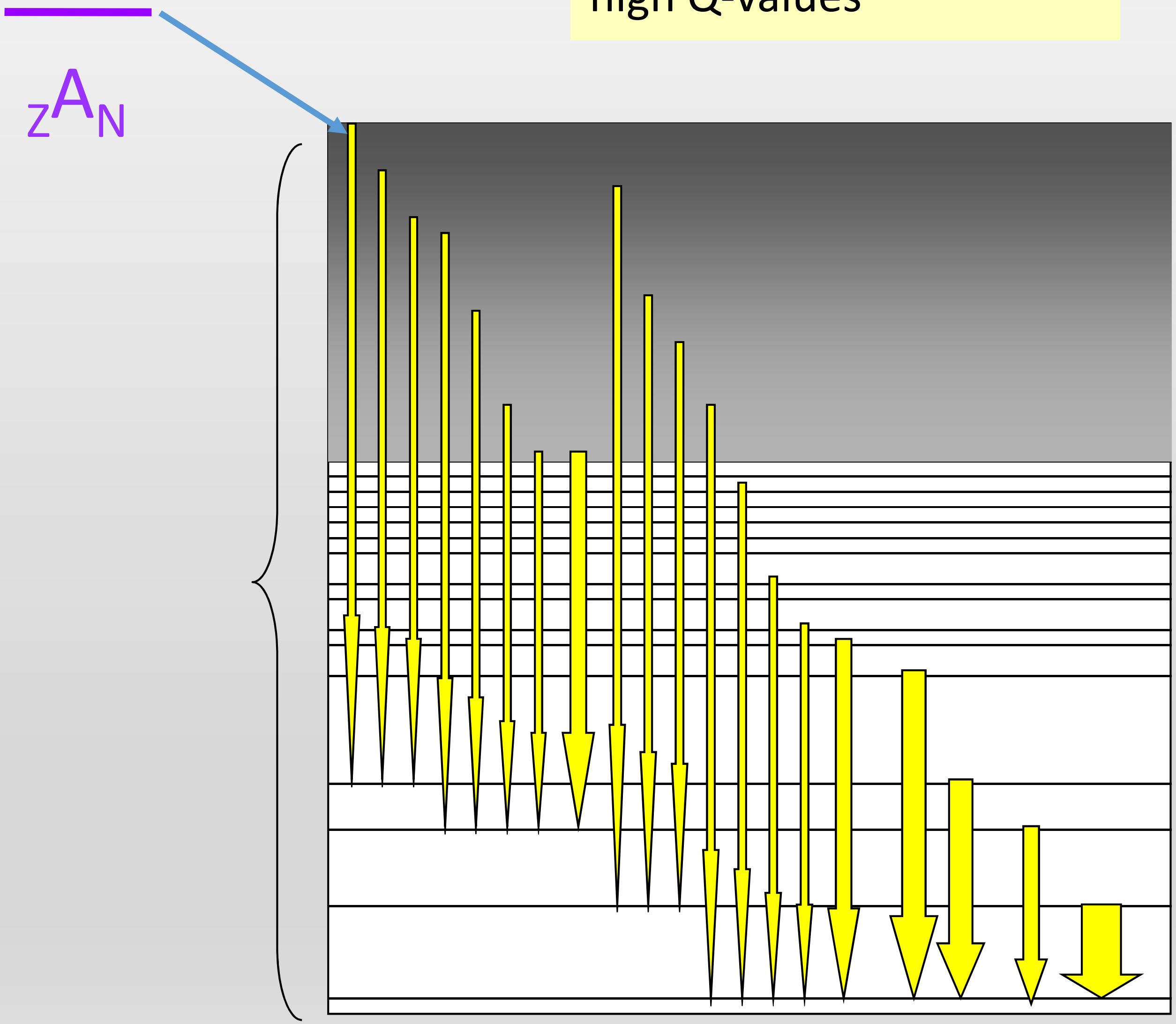


$$B(GT) = k \frac{I_{\beta}(E)}{f(Q_{\beta} - E, Z)T_{1/2}}$$

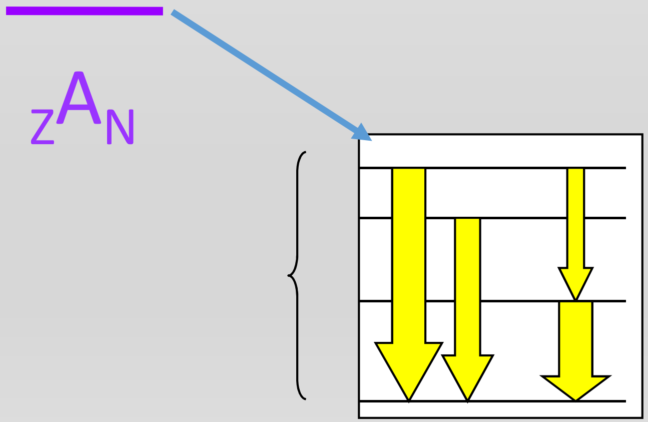
$$I_{\beta}(E)$$



But fails for decays with high Q-values



This works very well close to the stability



John Matin´s 1825 engraving "Pandemonium".

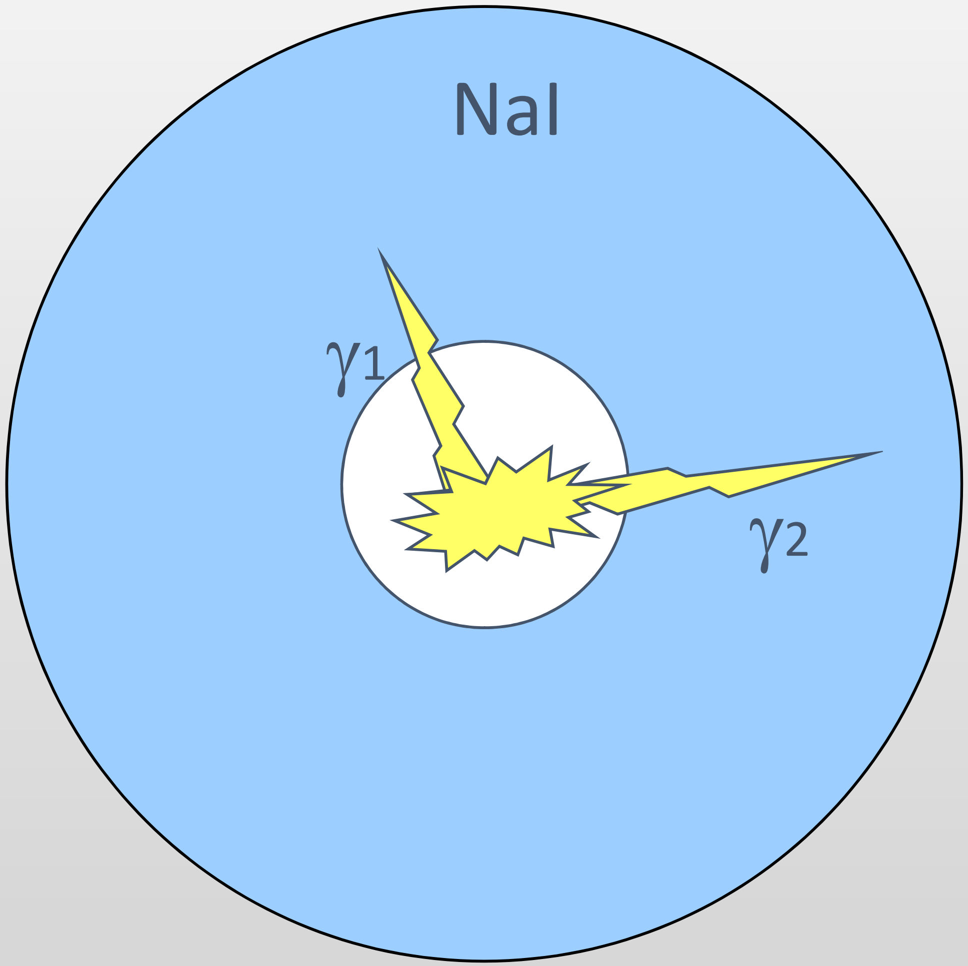
Volume 71B, number 2 PHYSICS LETTERS 21 November 1977

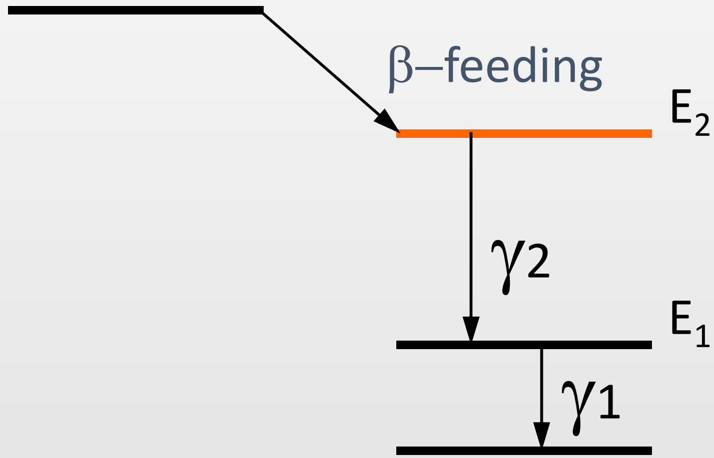
THE ESSENTIAL DECAY OF PANDEMONIUM:
A DEMONSTRATION OF ERRORS IN COMPLEX BETA-DECAY SCHEMES

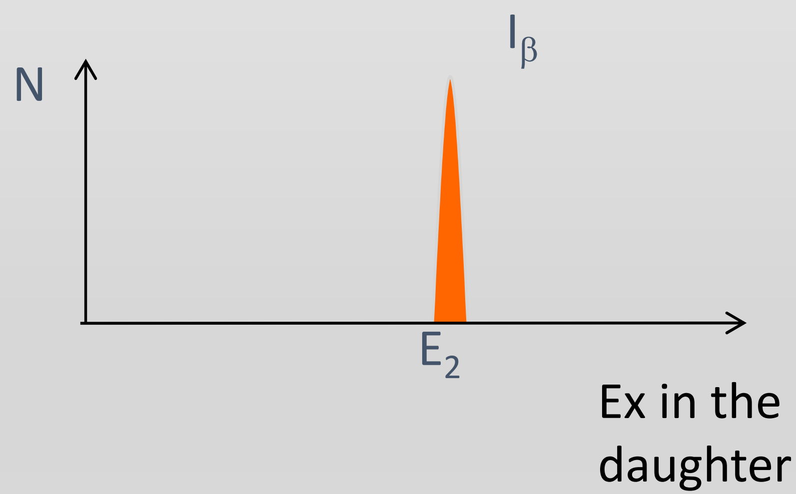
J.C. HARDY *, L.C. CARRAZ, B. JONSON ‡ and P.G. HANSEN ‡
CERN, Geneva, Switzerland

J. Milton, *Paradise Lost, Book I (1667)*

Total Absorption spectroscopy







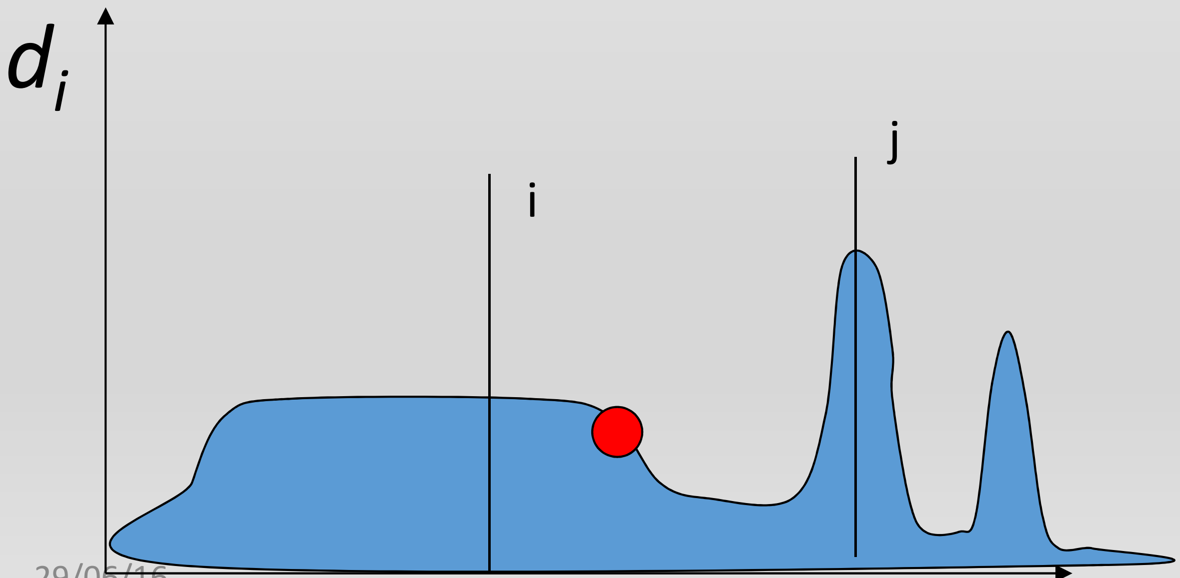
Ideal case

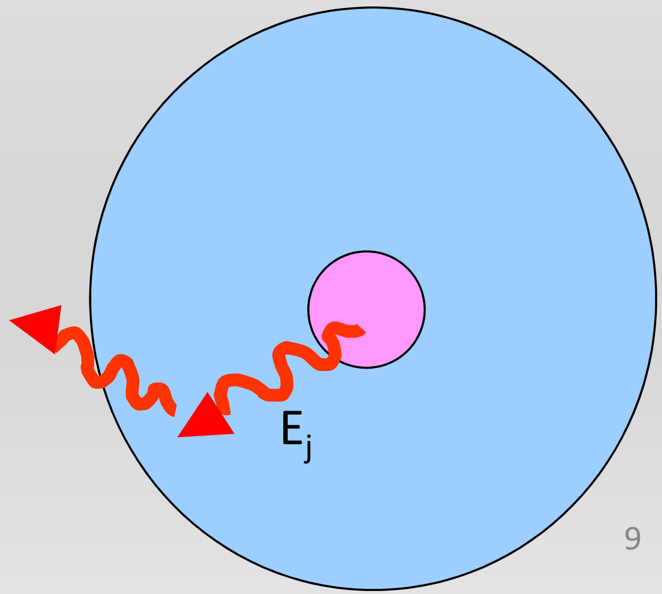
The main problem is not the intrinsic efficiency
but the material placed inside the detector or the holes
Needed to put the activity inside

One has to solve the following equation:

$$d_i = \sum_{j=1}^{j_{\max}} R_{ij} f_j$$

J.L.Tain, D. Cano–Ott, Nucl. Instr. and Meth. in Phys. Res. A **571**, 719 (2007)
J.L.Tain, D. Cano–Ott, Nucl. Instr. and Meth. in Phys. Res. A **571**, 728 (2007)



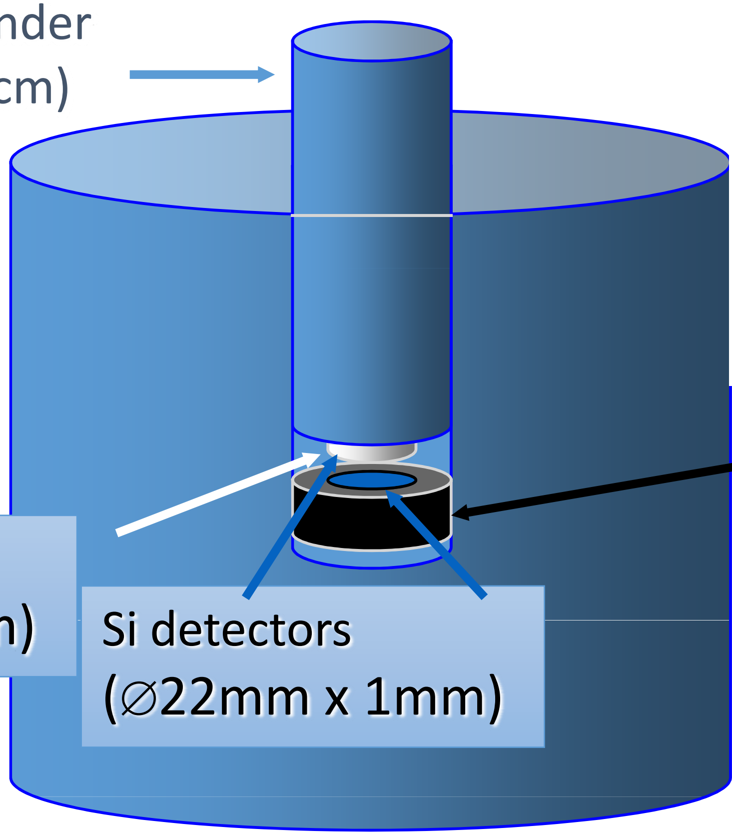


A big step forward came with the construction and exploitation of the Berkeley-GSI TAS 1997

Mainly for proton rich nuclei

TAS at GSI

Detector "Plug": cylinder of NaI (∅4.7cm x 15cm)

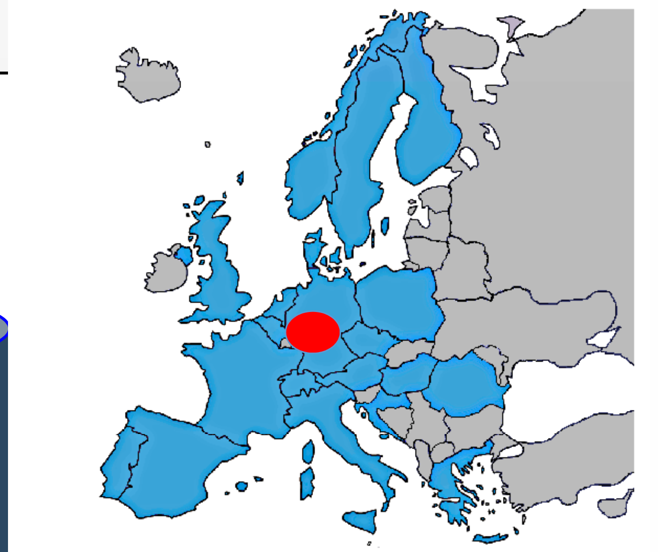


Ge detector (∅16mm x 10cm)

Si detectors (∅22mm x 1mm)

Positron absorber: polyethylene (∅51mm x 21mm)

Main Crystal: NaI cylinder (∅35.6cm x 35.6cm)



Spokesperson B. Rubio

PHYSICAL REVIEW C **93**, 014308 (2016)

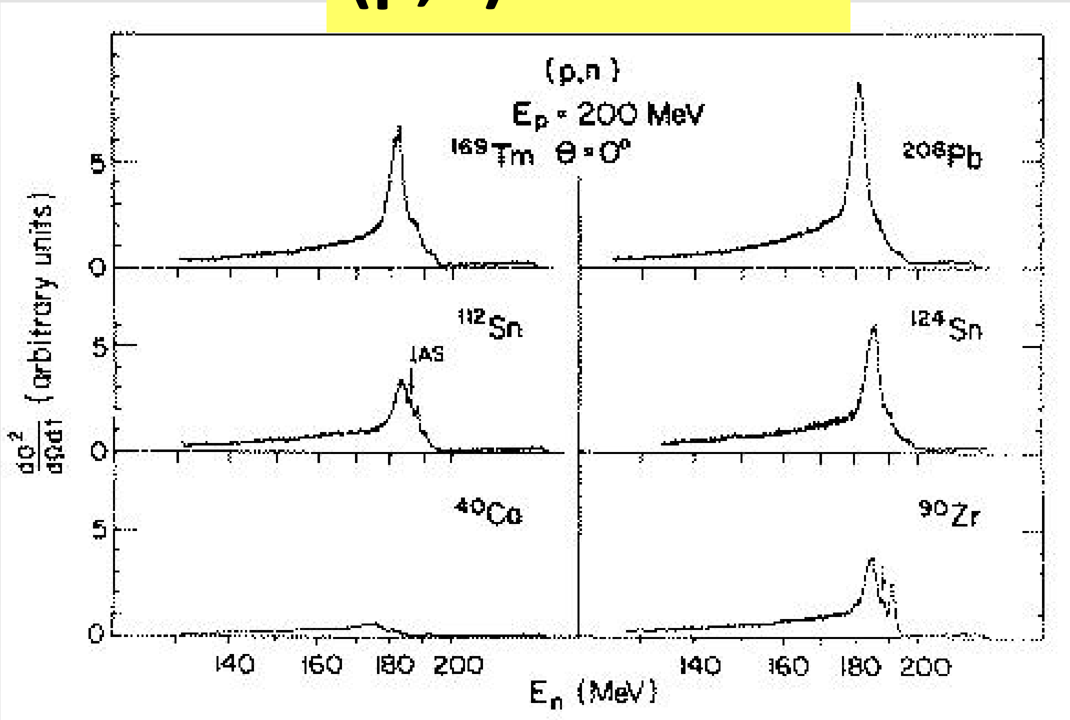
Observations of the Gamow-Teller resonance in the rare-earth nuclei above ^{146}Gd populated in β decay

E. Nácher,[1,*] B. Rubio,[1,†] A. Algora,[1,‡] D. Cano-Ott,[1,§] J. L. Taín,[1] A. Gadea,[1] J. Agramunt,[1] M. Gierlik,[2] M. Karny,[2] Z. Janas,[2] E. Roeckl,[3] A. Blazhev,[3,‖] R. Collatz,[3] J. Döring,[3,¶] M. Hellström,[3] Z. Hu,[3] R. Kirchner,[3,#] I. Mukha,[3] C. Plettner,[3] M. Shibata,[3] K. Rykaczewski,[4] L. Batist,[5] F. Moroz,[5] V. Wittmann,[5,**] and J. J. Valiente-Dobón[6,††]
[1]*IFIC, CSIC-Universidad Valencia, Apartado Postal E-22085, 46071 Valencia, Spain*
[2]*Faculty of Physics, University of Warsaw, PL-02-093 Warsaw, Poland*
[3]*Gesellschaft für Schwerionenforschung, D-64291 Darmstadt, Germany*
[4]*Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6371, USA*
[5]*St. Petersburg Nuclear Physics Institute, 188-350 Gatchina, Russia*
[6]*Department of Physics, University of Surrey, Guildford GU2 5XH, United Kingdom*
(Received 26 October 2015; published 13 January 2016)

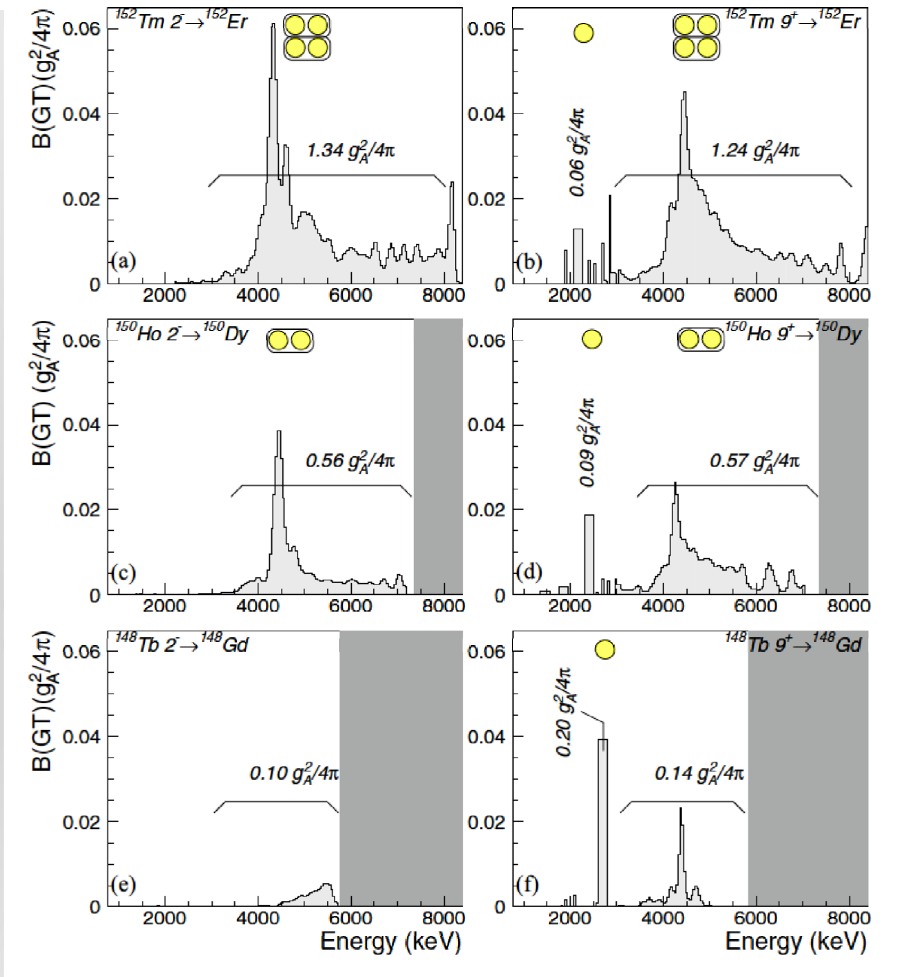
P.h.D E. Nacher

Beta-decay!!!

(p,n) reaction



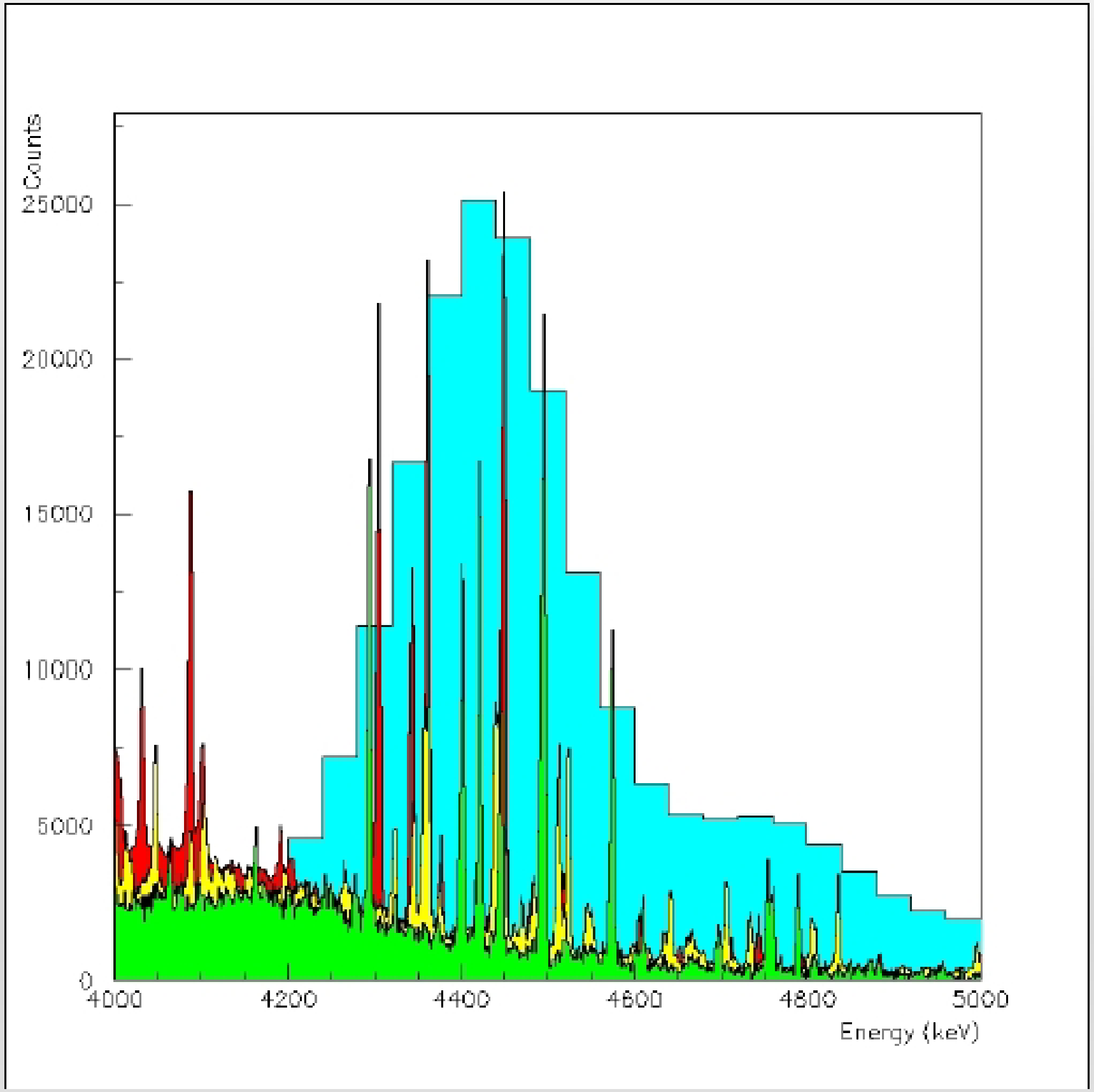
Gaarde NPA369(1981)258

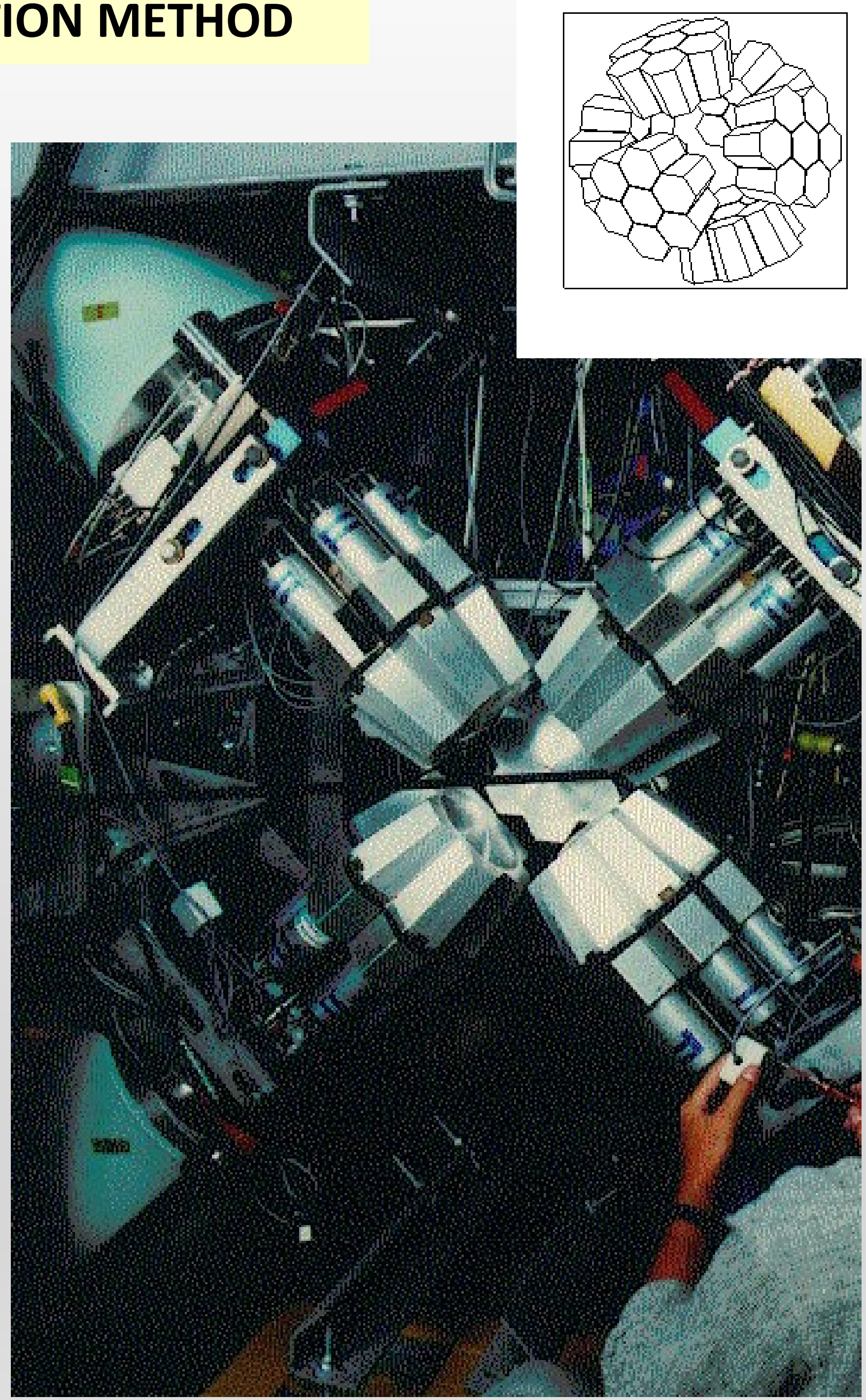


Open Parenthesis

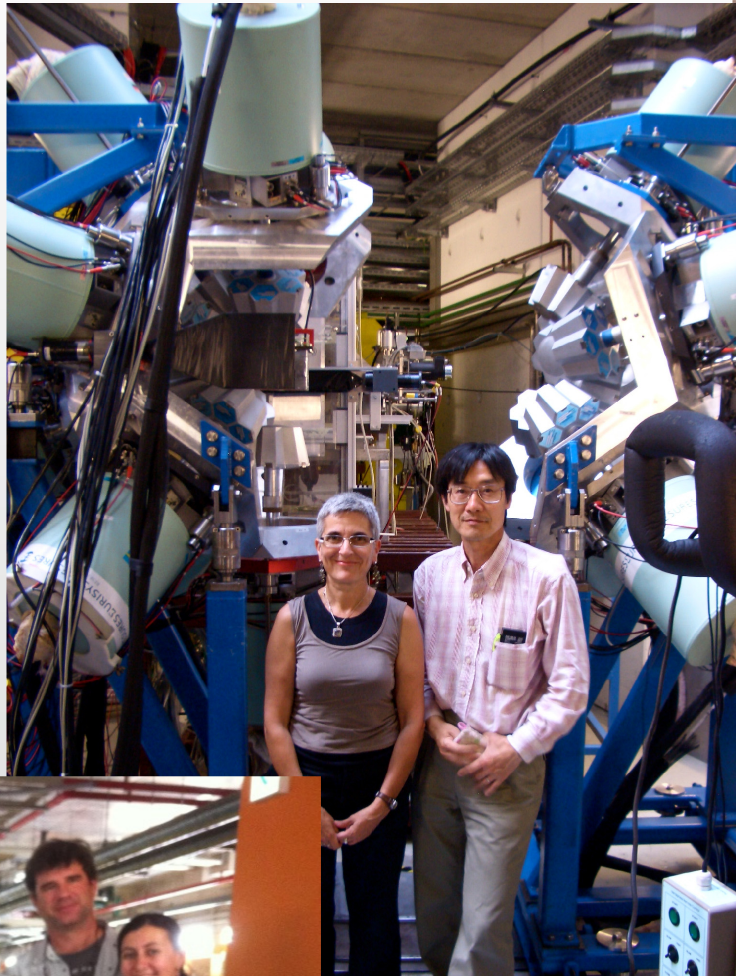
COMPARISON WITH THE HIGH RESOLUTION METHOD

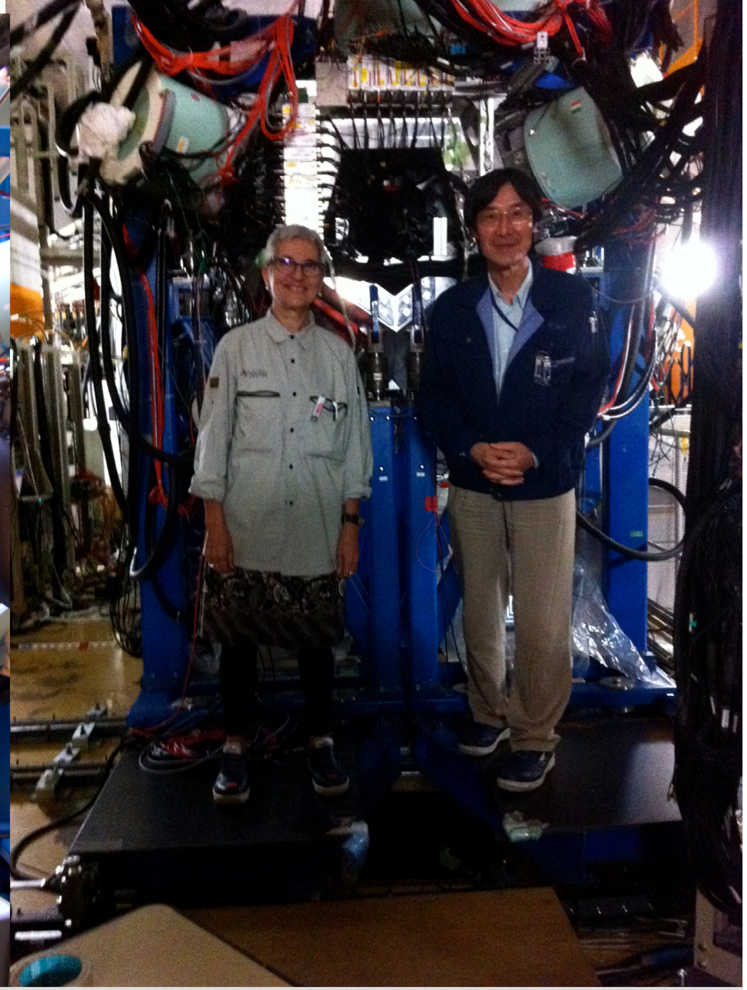
Six EUROBALL CLUSTER Ge detectors
in close geometry



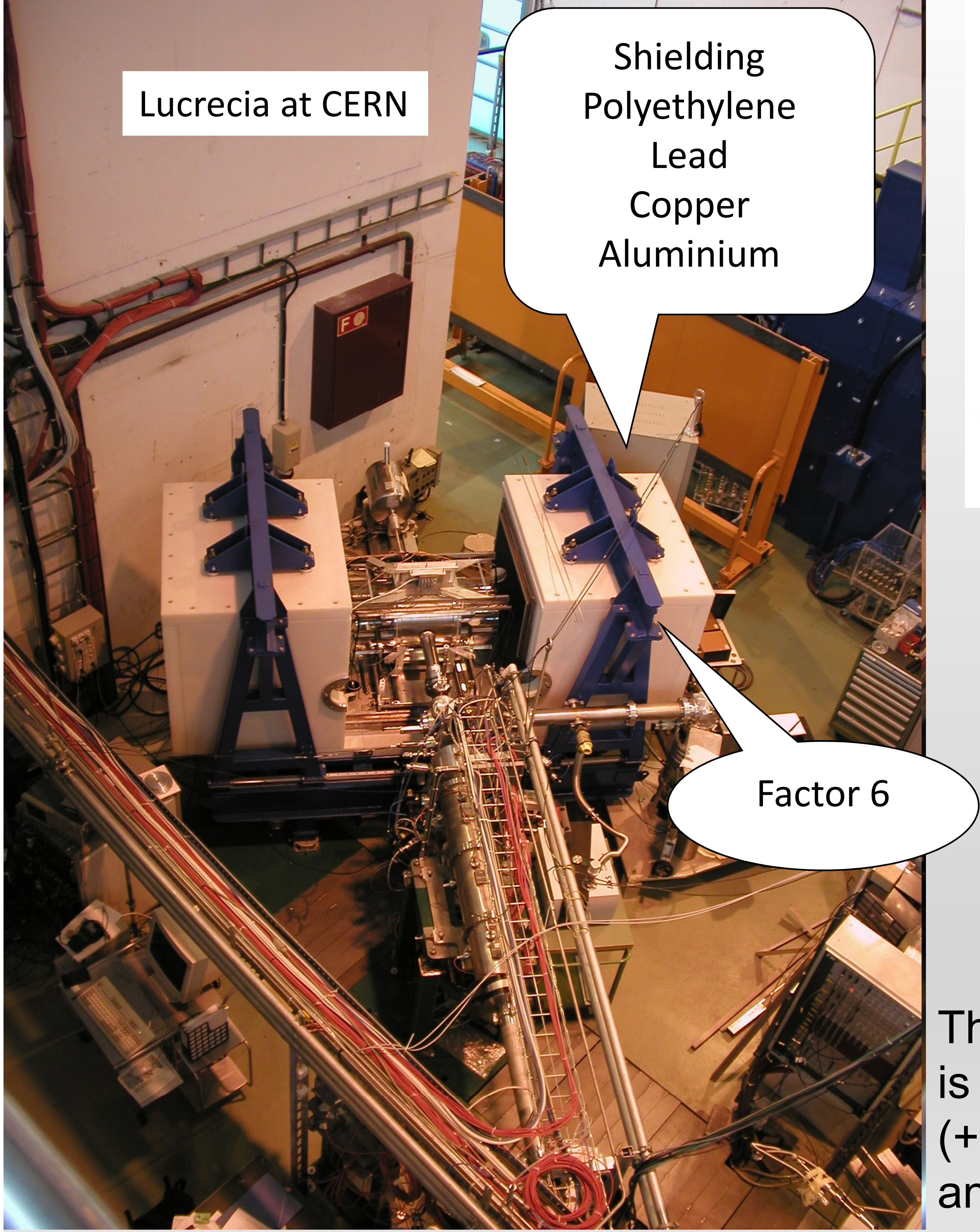


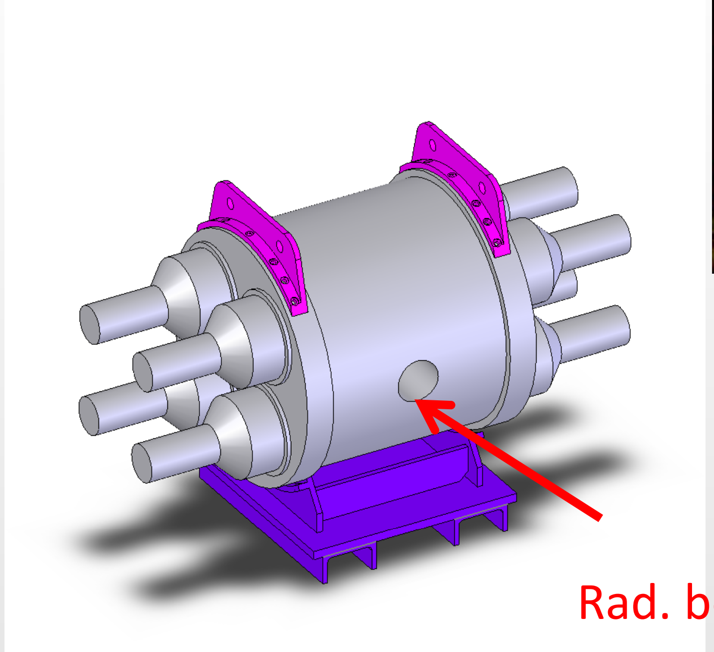
Tribute to the Euroball CLUSTER Detectors and to Our chairman RISING (GSI) and EURICA (RIKEN) Campaigns for DECAY Studies

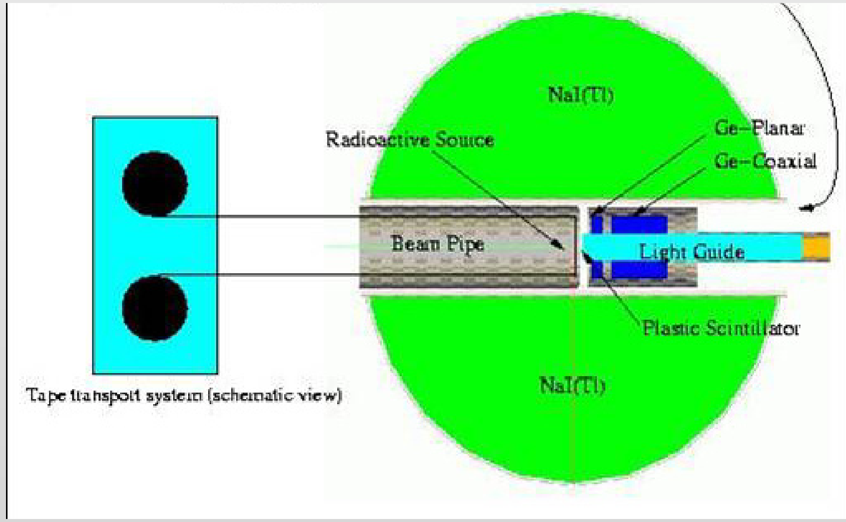




Close Parenthesis

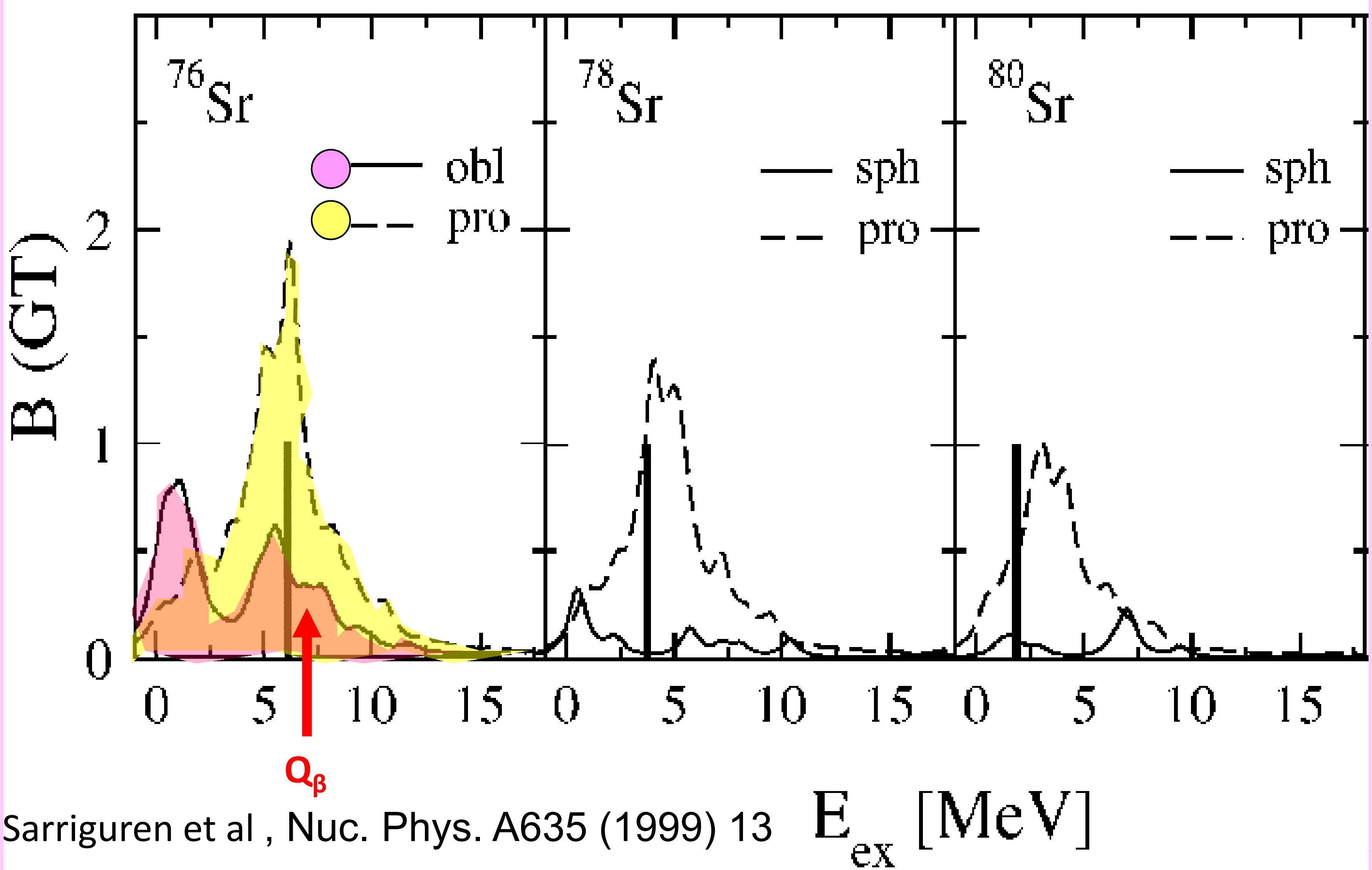




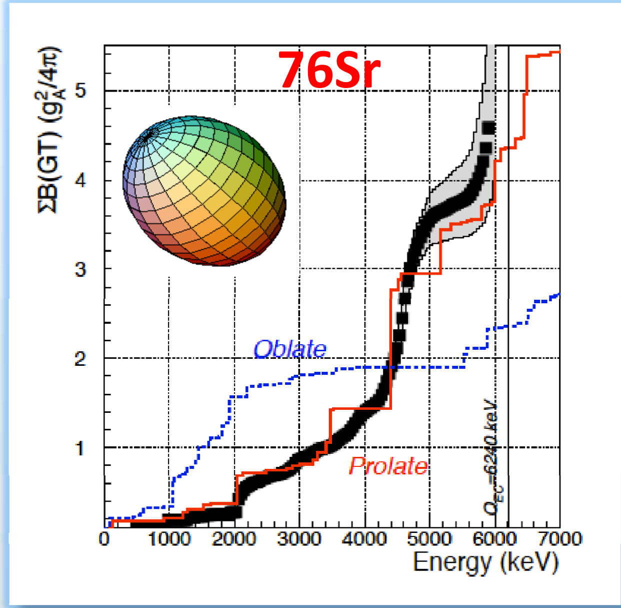


The Lucrecia TAS at Isolde
is a NaI single-crystal Φ38cm x 38cm
(+ ancillary detectors)Ge for X-rays
and plastic for β particles

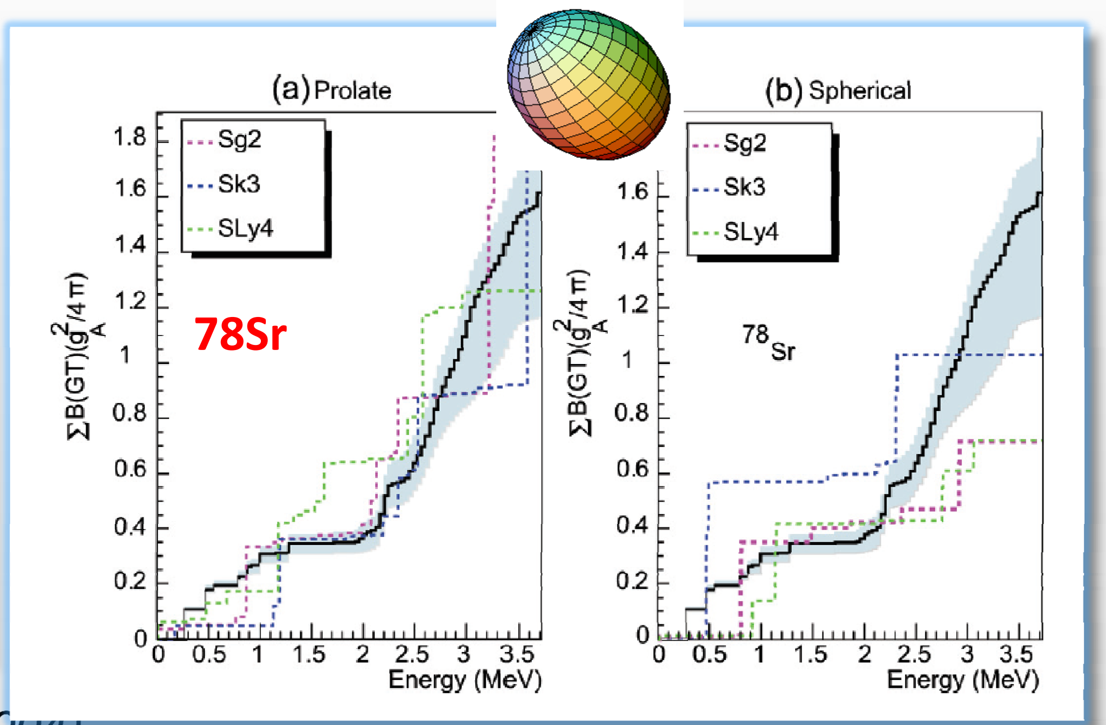
Deducing the deformation of the ground state of 76Sr from its B(GT) distribution



Sarriguren et al , Nuc. Phys. A635 (1999) 13



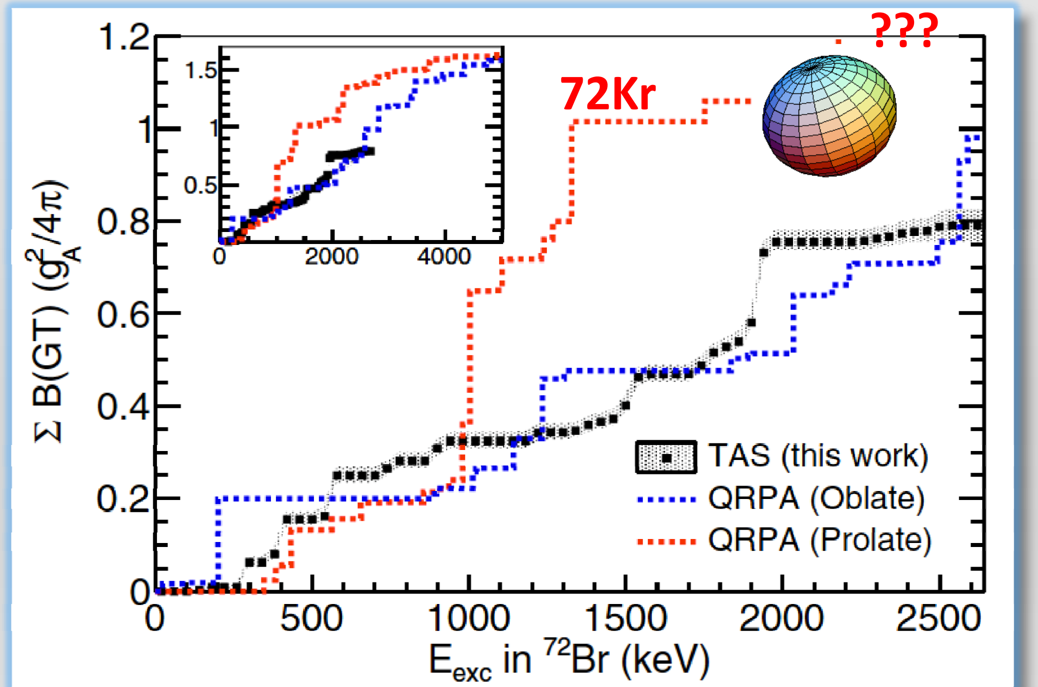
E. Nacher *et al., PRL.92, 232501 (2004)*



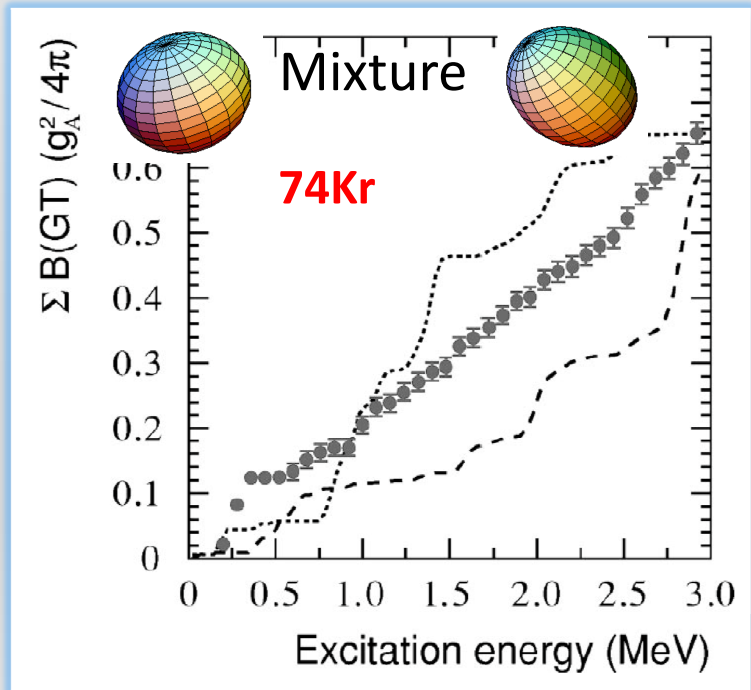
A. Pérez-Cerdán et al. PRC88 (2013) 014324

Ph.D´s
E.Poirier
E. Nacher
A. Pérez-Cerda
B. J. Briz

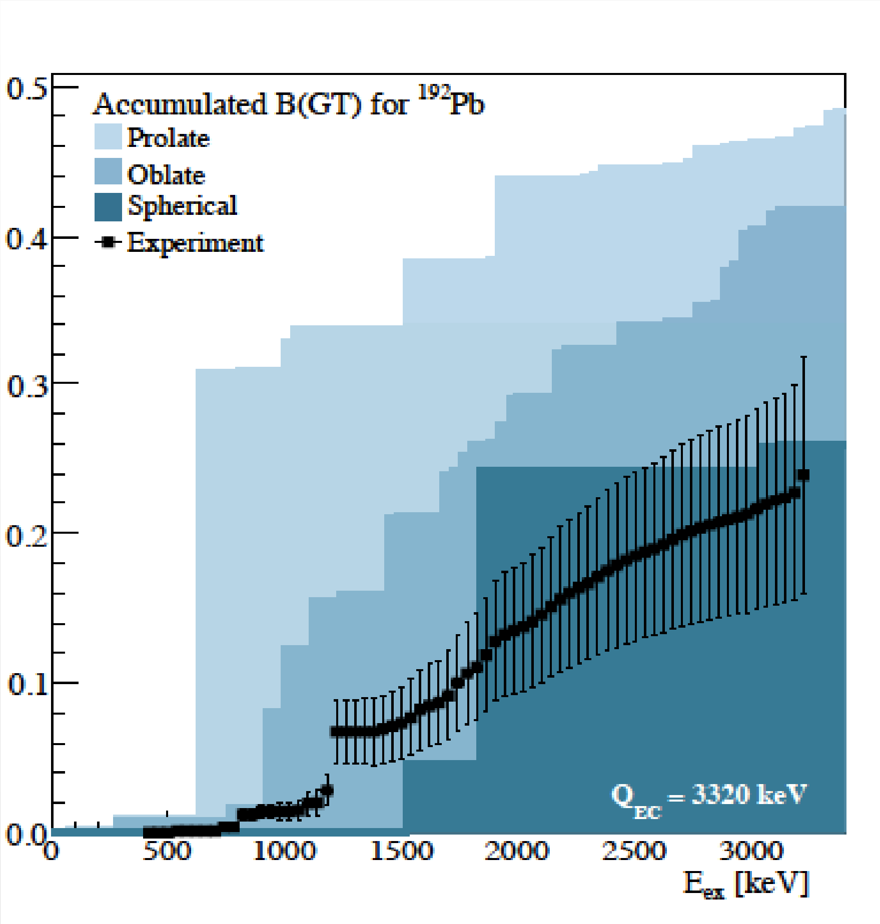
Calculations by Sarriguren



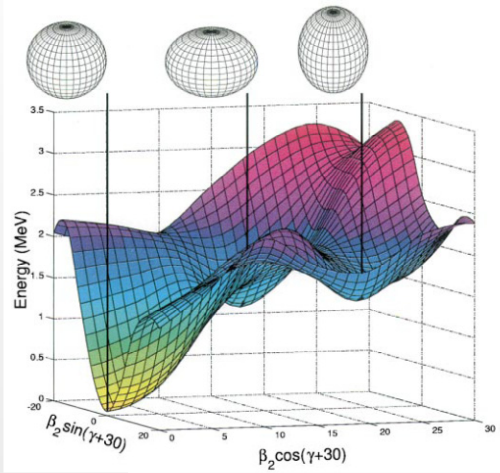
J. Briz et al, PRC 92(2016) 054326



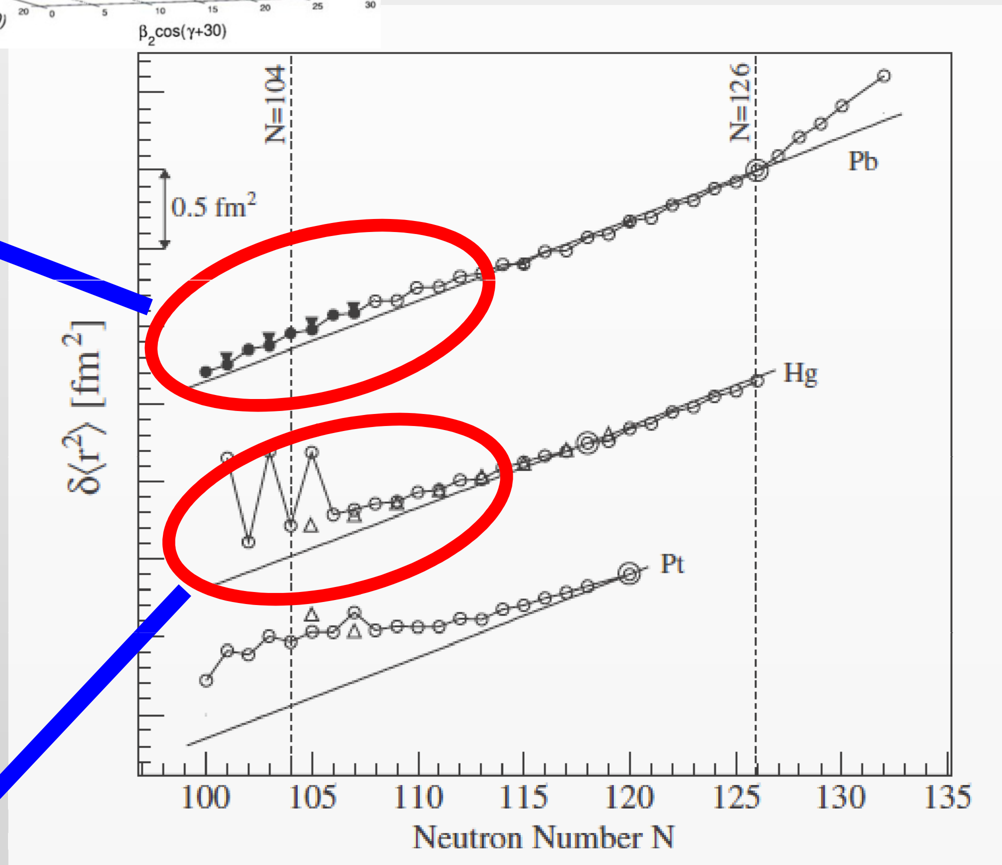
E. Poirier *et al., PRC 69, 034307 (2004)*



E. Estévez et al. PRC 92, 044321 (2015)



A. Andreyev
Nature 405 (2000) 430



Also T. Cocolios *et al. PRL 106, 052503*

H. De Witte *et al. PRL 98, 0112502*

Spokespersons
A. Algora, E. Nácher, L. M. Fraile

- X-ray Bursts: luminosity curves highly dependent on the EC/β^+ ratios
- EC component neglected so far in network calculations (naked atoms at this T…)
- Calculations on the cEC process prove that this is a mistake → need for a measurement

Experiment performed at Isolde
May 2016

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

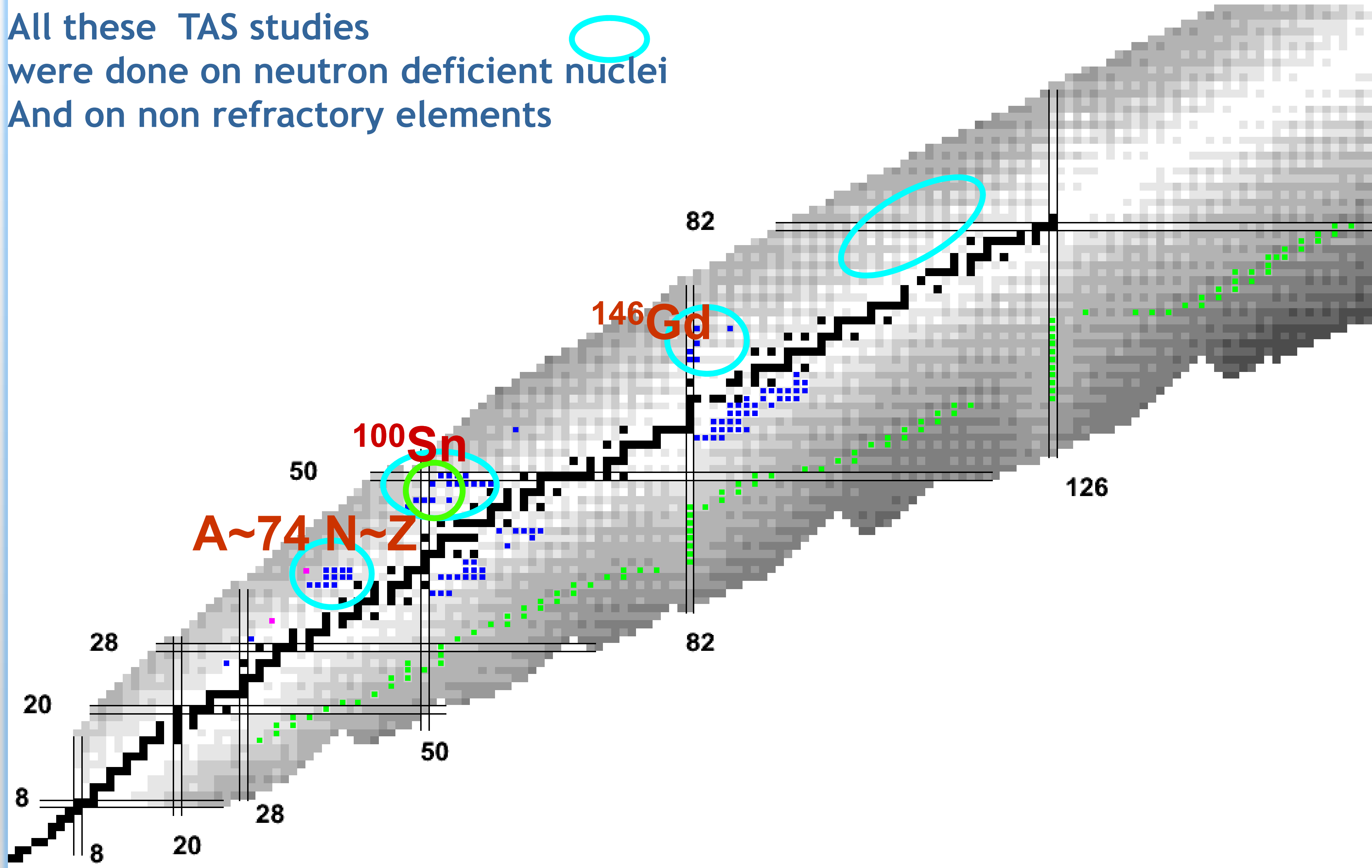
Beta decay of the *N*=*Z*, rp-process waiting points: ^{64}Ge, ^{68}Se and the *N*=*Z*+2: ^{66}Ge, ^{70}Se for accurate stellar weak-decay rates

[May 29th - 2013]

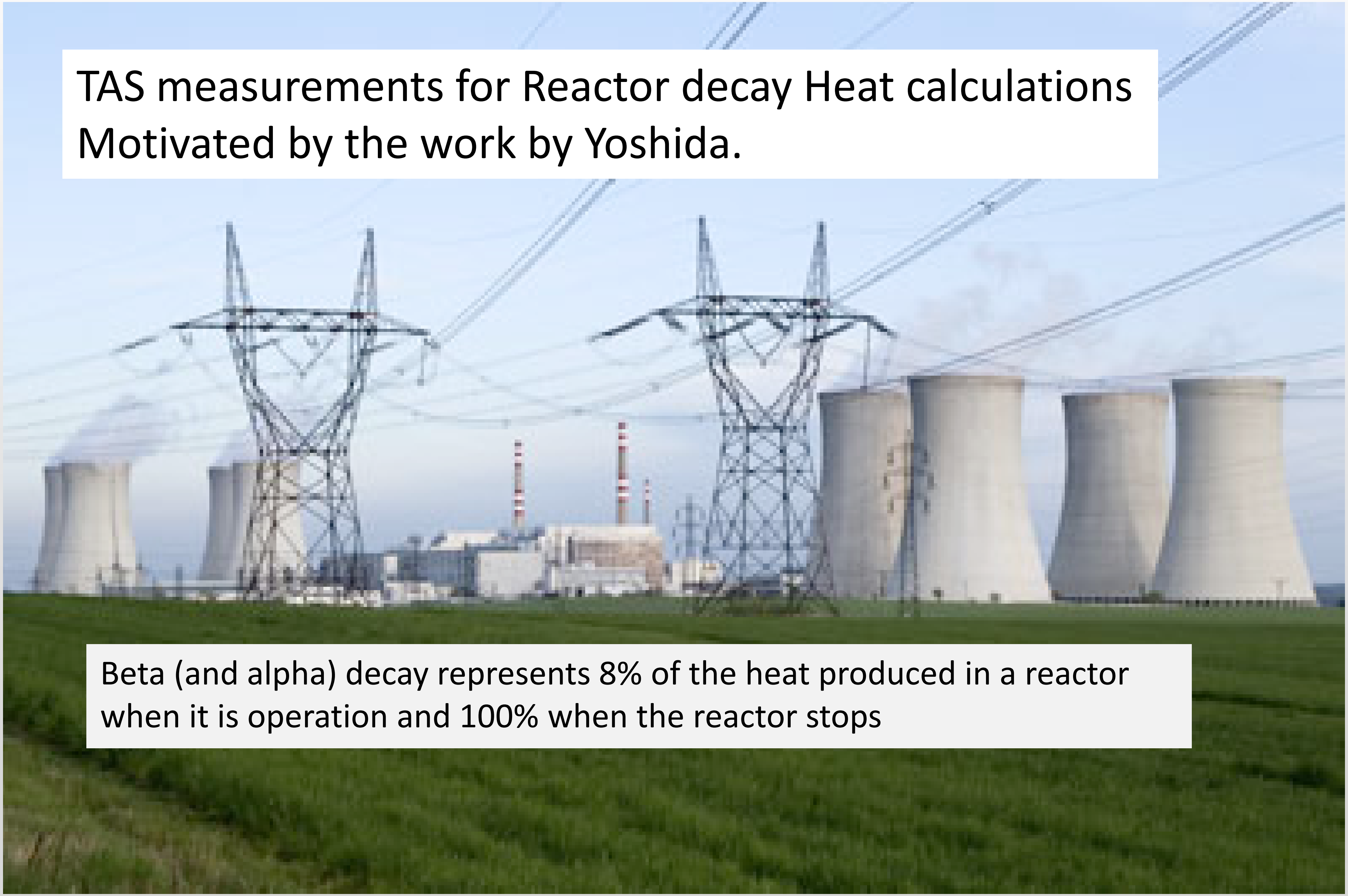
E. Nácher, J.A. Briz, M. Carmona, A. Illana, A. Jungclaus, A. Perea, V. Pesudo, G. Ribeiro, J. Sánchez-del-Río, P. Sarriguren, J. Taprogge, O. Tengblad
Instituto de Estructura de la Materia – CSIC, Madrid (Spain)

C. Domingo, A. Algora, J. Agramunt, G. Giubrone, V. Guadilla, A. Montaner, S.E.A. Orrigo, B. Rubio, J. L. Taín, E. Valencia
Instituto de Física Corpuscular, CSIC – Universidad de Valencia (Spain)

All these TAS studies
were done on neutron deficient nuclei
And on non refractory elements



TAS measurements for Reactor decay Heat calculations Motivated by the work by Yoshida.

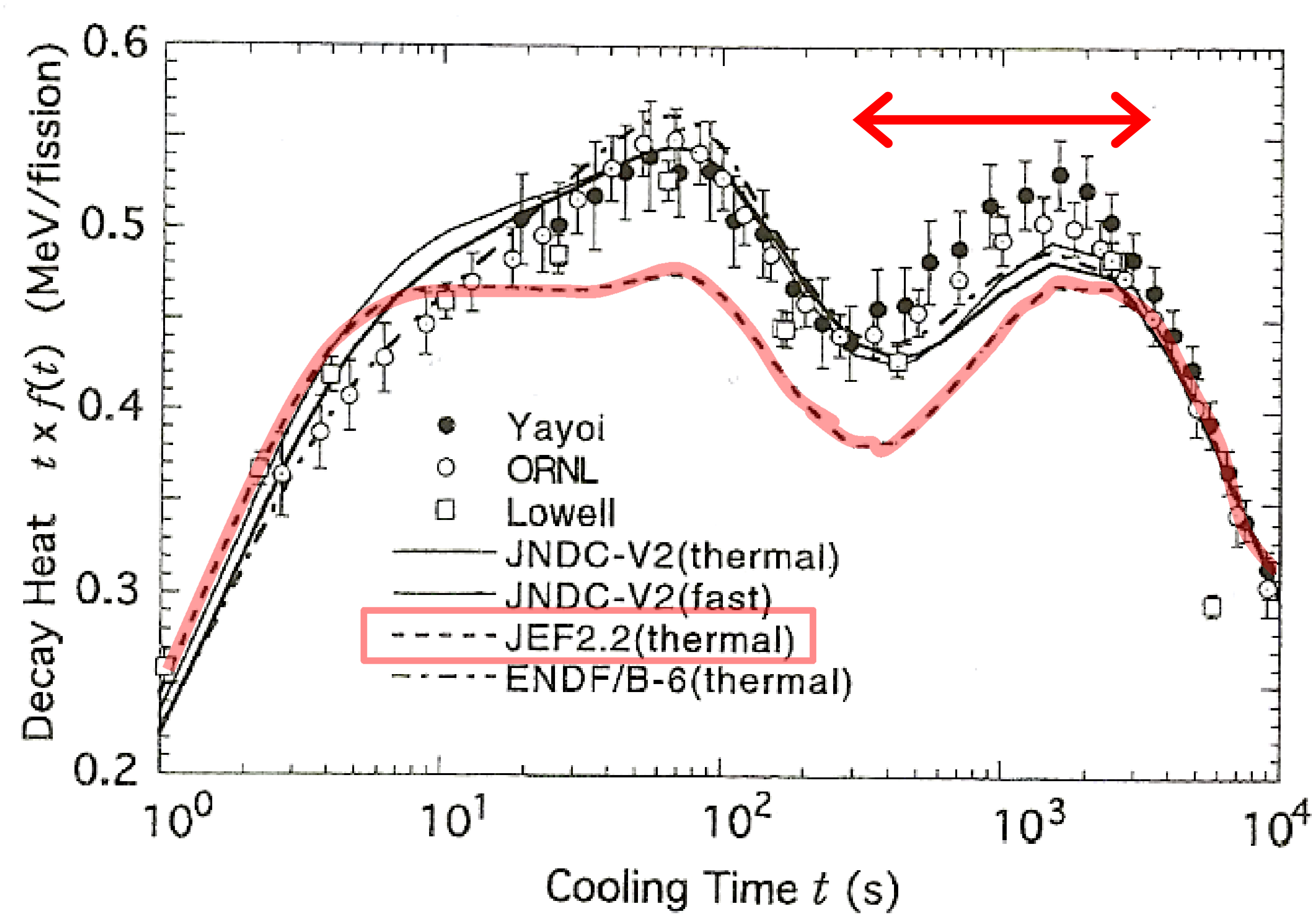


Beta (and alpha) decay represents 8% of the heat produced in a reactor when it is operation and 100% when the reactor stops

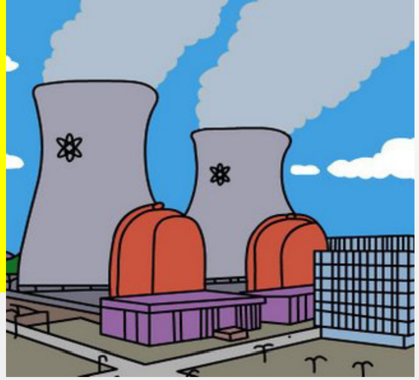
A long standing problem: “The γ-ray discrepancy between decay heat summation calculations and experimental data for reactors decay heat calculations”

Yoshida and co-workers (Journ. of Nucl. Sc. and Tech. 36 (1999) 135)

^{239}Pu example (γ component)



Decay heat: summation calculations



$$f(t) = \sum_i E_i \lambda_i N_i(t)$$

E_i Decay energy of the nucleus i (gamma, beta or both)

λ_i Decay constant of the nucleus i $\lambda = \frac{\ln(2)}{T_{1/2}}$

N_i Number of nuclei i at the cooling time t

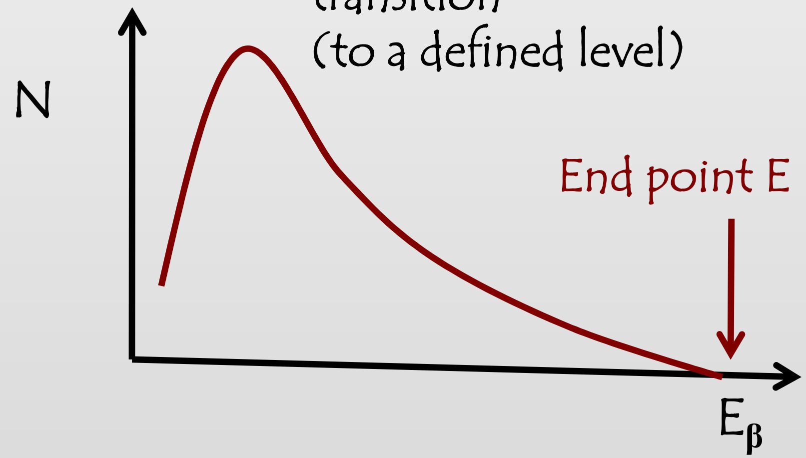
Requirements for the calculations: large databases that contain all the required information (half-lives, mean ©- and β-energies released in the decay, n-capture cross sections, fission yields, this last information is needed to calculate the inventory of nuclides)

How the mean energies are determined ?

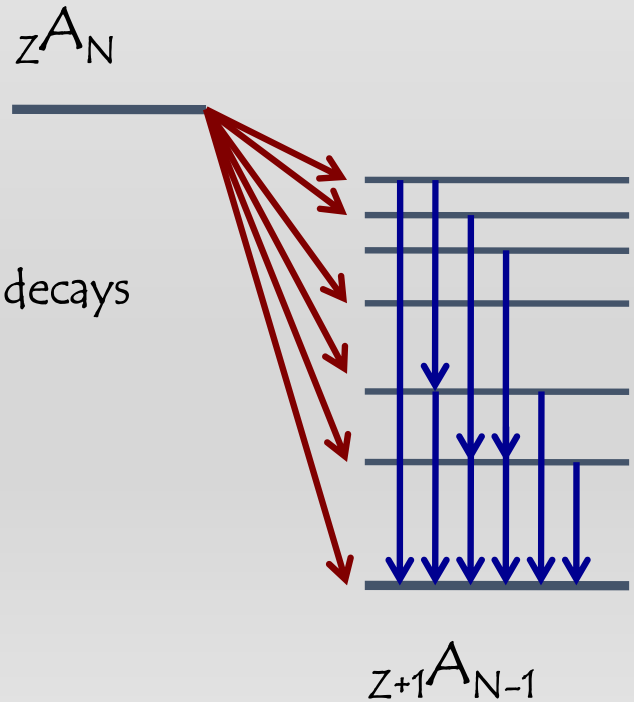
$$f(t) = \sum_i E_i \lambda_i N_i(t)$$

DATA bases:
feeding or beta
decay prob.
distributions

Beta spectrum for a beta
transition
(to a defined level)



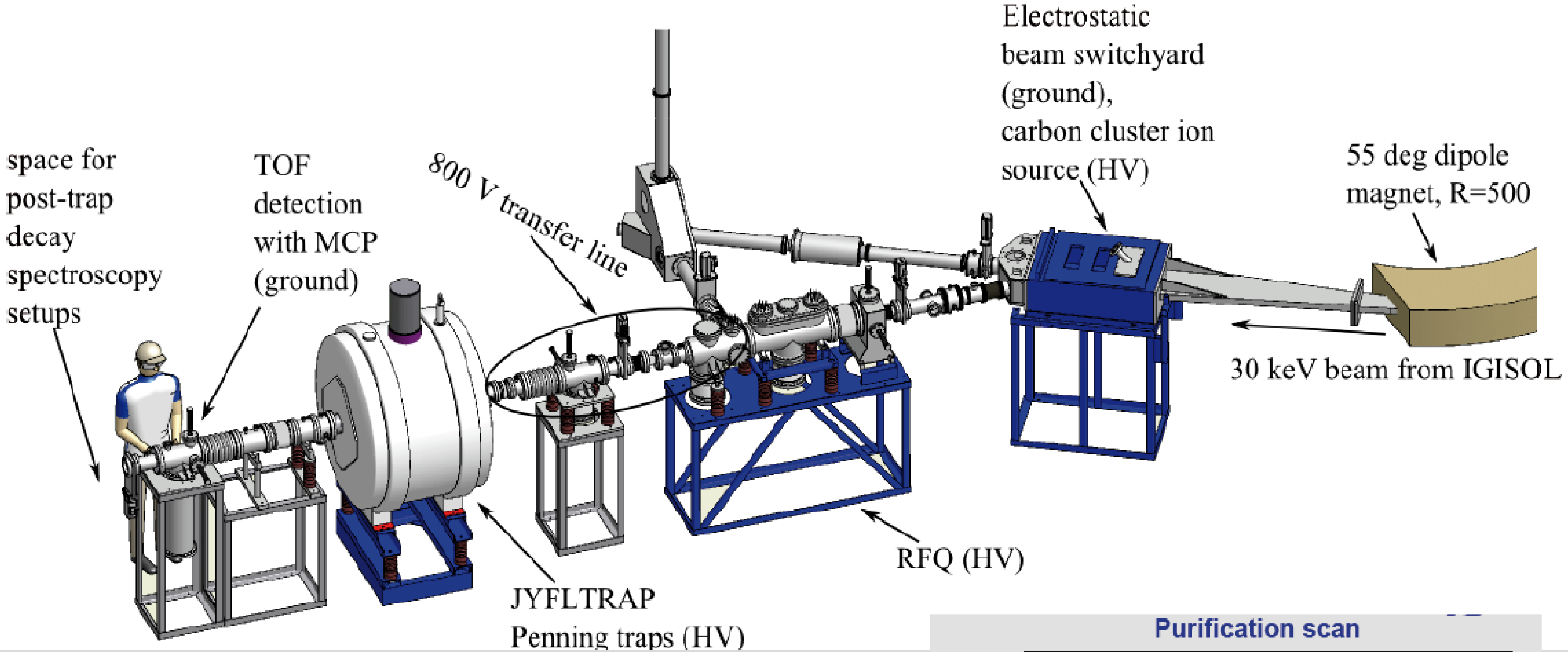
β- decays



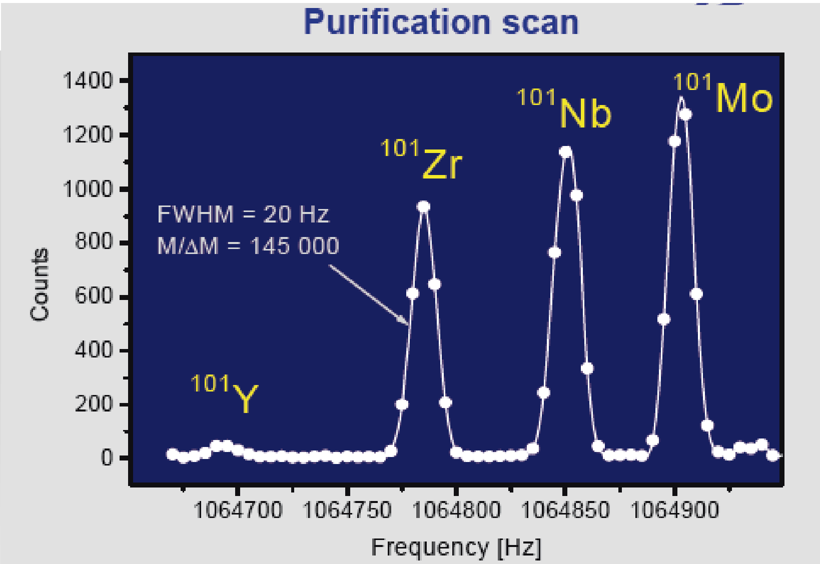
$$\overline{E}_\beta = \sum_i I_\beta(E_i)\langle E_{\beta,i}\rangle$$

$$\overline{E}_\gamma = \sum_i I_\beta(E_i)E_i$$

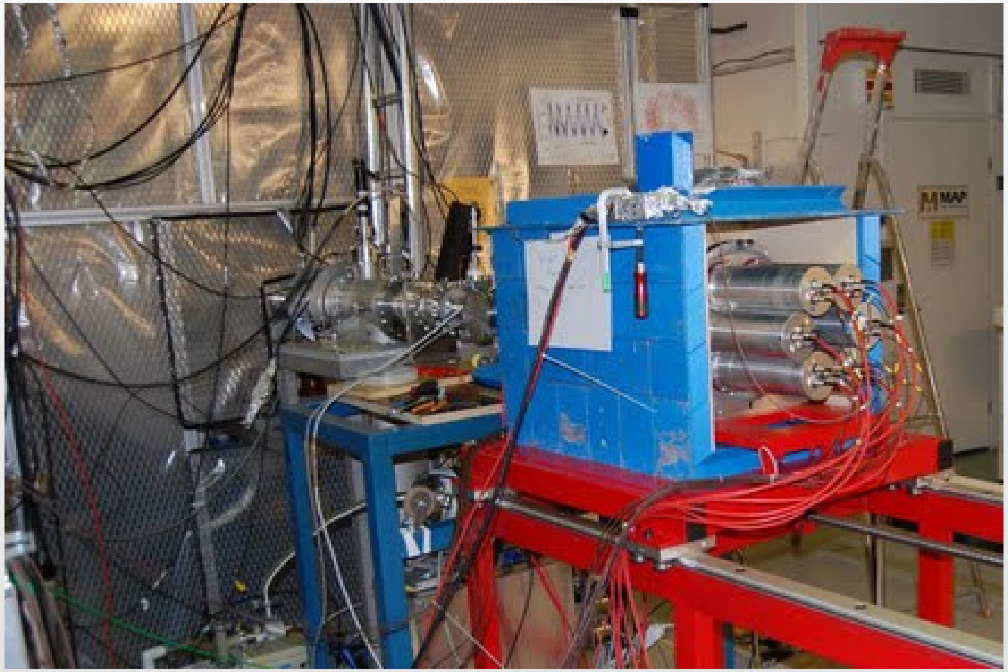
Why JYFL: IGISOL + JYFLTRAP

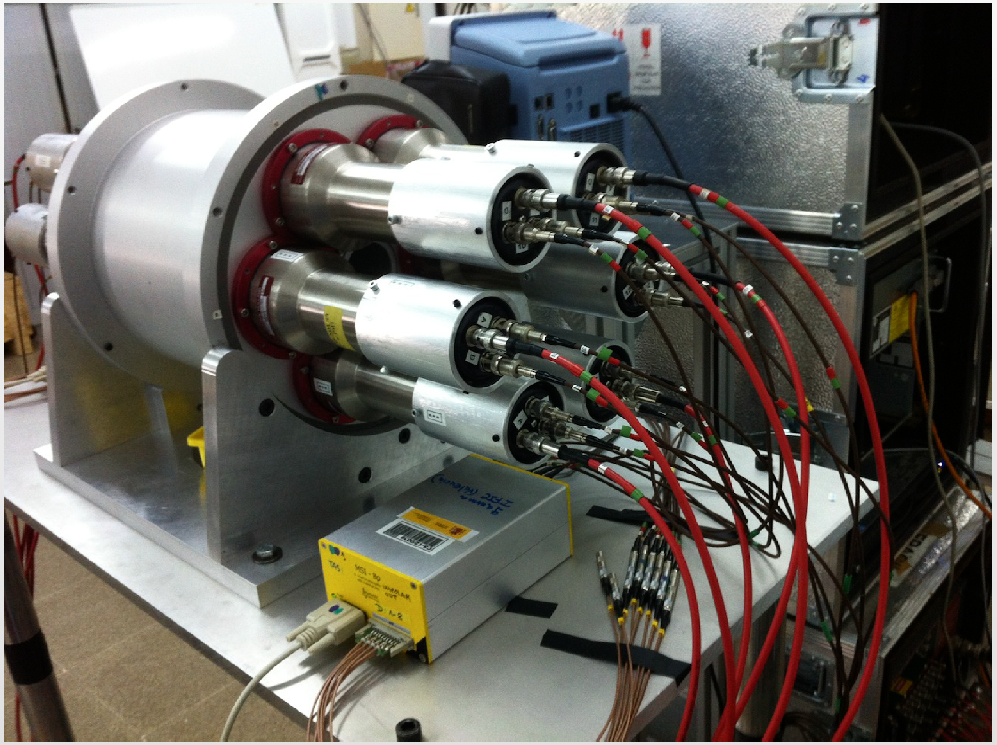


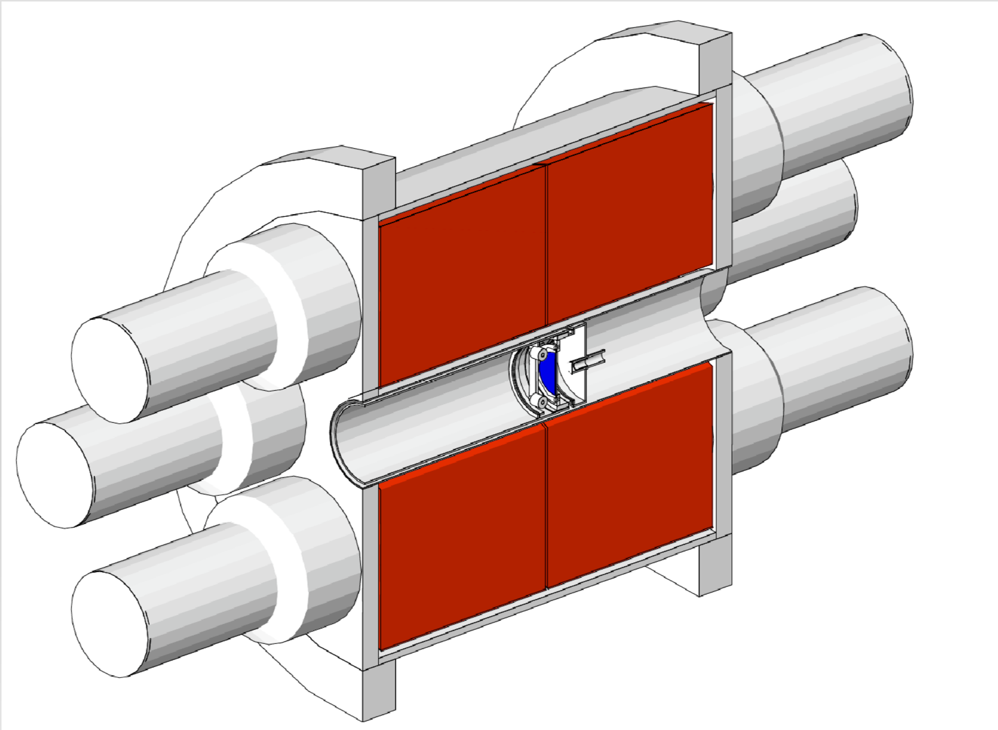
The main reasons are the chemical insensitivity (ion guide technique), high purity by means of purification of the beam using the JYFLTRAP and acceptable yields!



Segmented BaF2 Total Absorption Spectrometer: Rocinante (Valencia-Surrey)

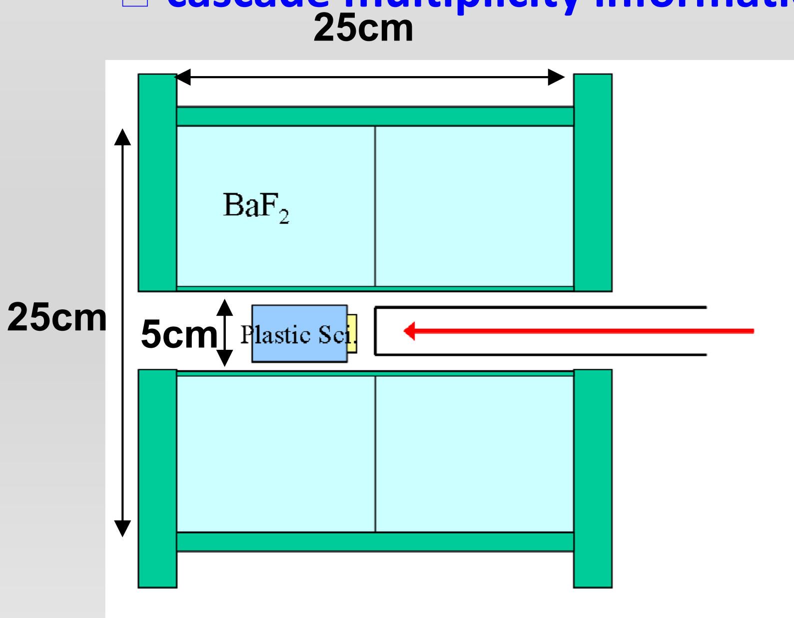






: 12× BaF_2 crystals / 3” Q-PMT

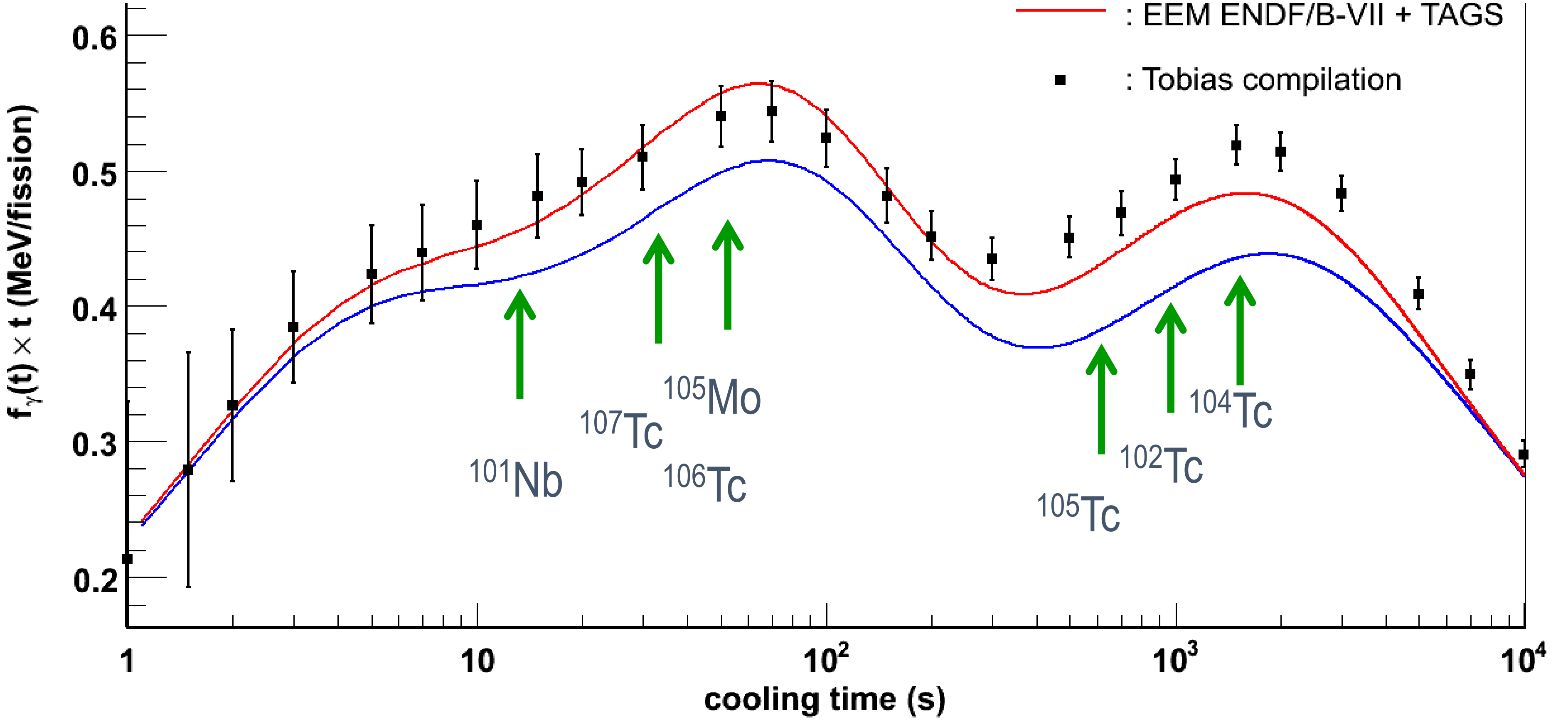
 cascade multiplicity information



Selected for a Viewpoint in *Physics*
PRL **105**, 202501 (2010) PHYSICAL REVIEW LETTERS week ending 12 NOVEMBER 2010

Reactor Decay Heat in ^{239}Pu: Solving the γ Discrepancy in the 4–3000-s Cooling Period

A. Algora,[1,2,*] D. Jordan,[1] J. L. Taín,[1] B. Rubio,[1] J. Agramunt,[1] A. B. Perez-Cerdan,[1] F. Molina,[1] L. Caballero,[1] E. Nácher,[1] A. Krasznahorkay,[2] M. D. Hunyadi,[2] J. Gulyás,[2] A. Vitéz,[2] M. Csatlós,[2] L. Csige,[2] J. Äysto,[3] H. Penttilä,[3] I. D. Moore,[3] T. Eronen,[3] A. Jokinen,[3] A. Nieminen,[3] J. Hakala,[3] P. Karvonen,[3] A. Kankainen,[3] A. Saastamoinen,[3] J. Rissanen,[3] T. Kessler,[3] C. Weber,[3] J. Ronkainen,[3] S. Rahaman,[3] V. Elomaa,[3] S. Rinta-Antila,[3] U. Hager,[3] T. Sonoda,[3] K. Burkard,[4] W. Hüller,[4] L. Batist,[5] W. Gelletly,[6] A. L. Nichols,[6] T. Yoshida,[7] A. A. Sonzogni,[8] and K. Peräjärvi[9]



Spokespersons
A. Algora, J.L. Taín

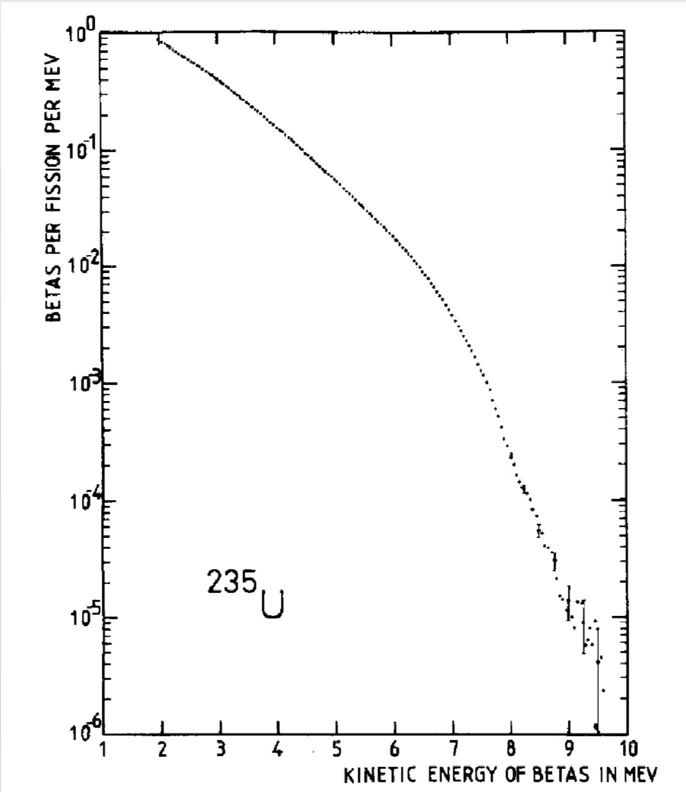
Courtesy A. Sonzogni

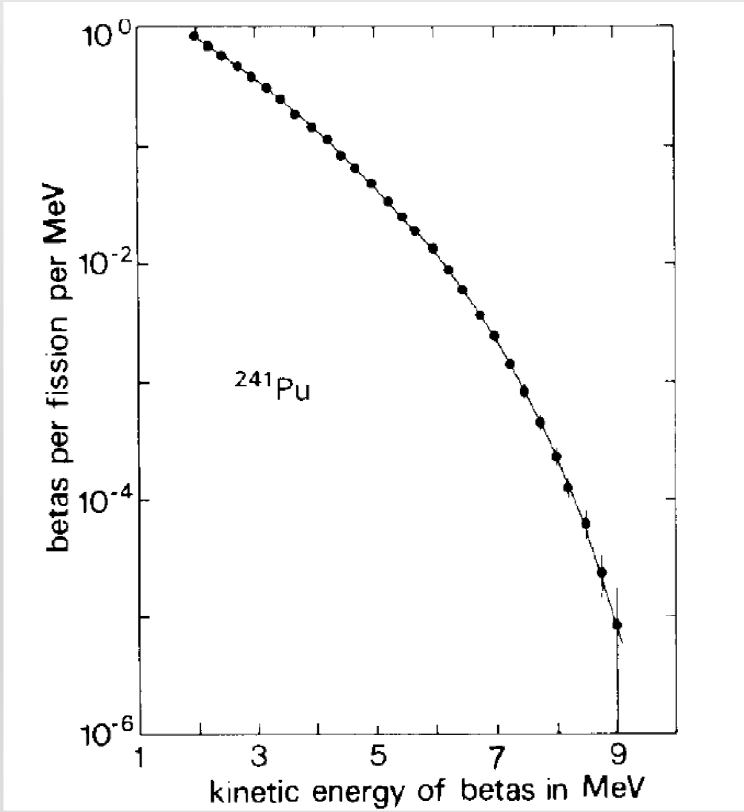
Another impact of our data

TAS measurements for the prediction of the neutrino spectrum from Reactors. Important for experiments of neutrino oscillations such as DOUBLE CHOOZ.
Impact in the energy range where the antineutrino anomaly has been observed
Spokespersons: M. Fallot, A. Algora, J.L. Taín…

Determination of the primary neutrino spectrum: neutrino physics, non-proliferation applications

- Using the beta spectrum measured by Schreckenbach et al. from different fissile nuclides (^{235}U, $^{239,241}Pu$) and more recently ^{238}U (Haag et al.), which requires complex conversion procedures





PRL **109,** 202504 (2012) PHYSICAL REVIEW LETTERS week ending 16 NOVEMBER 2012

New Antineutrino Energy Spectra Predictions from the Summation of Beta Decay Branches of the Fission Products

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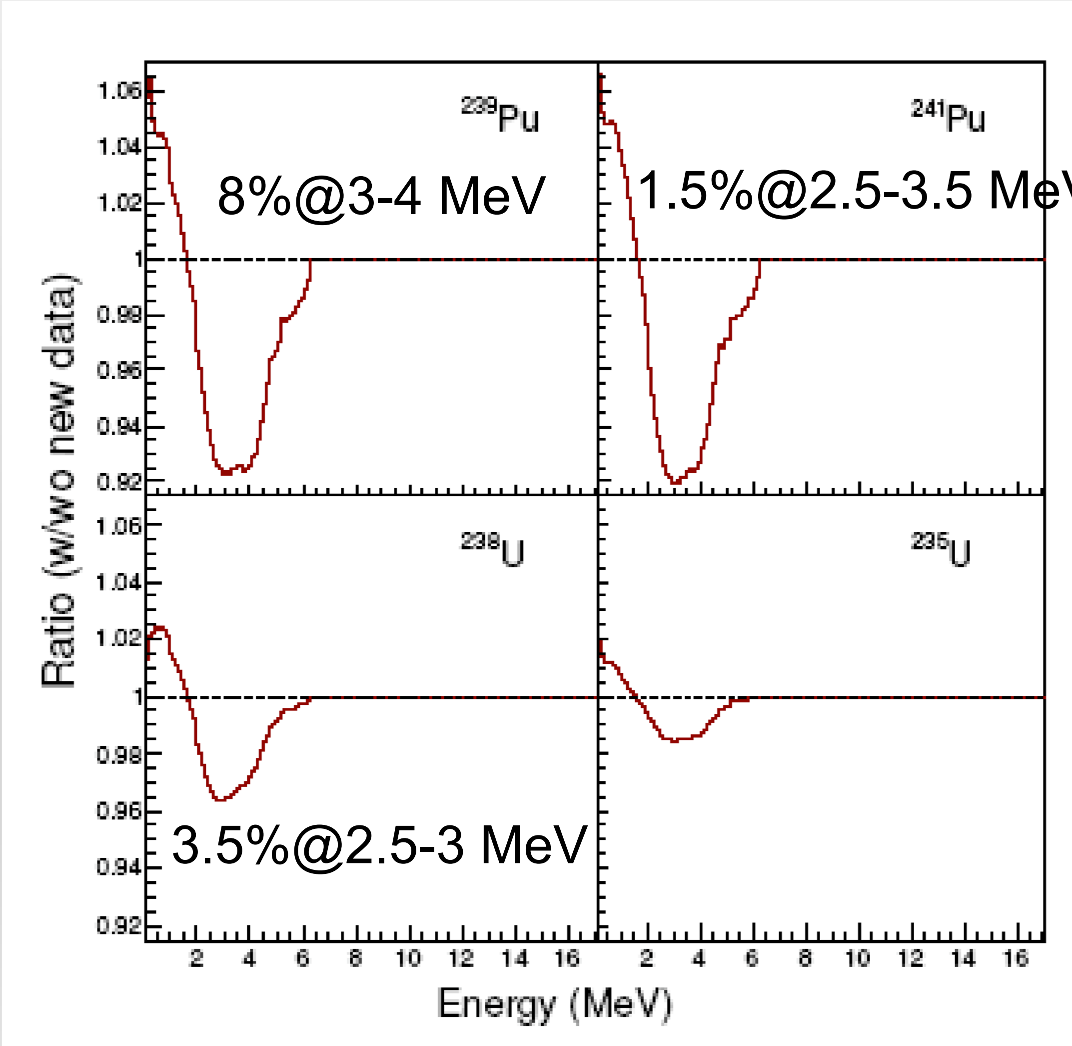
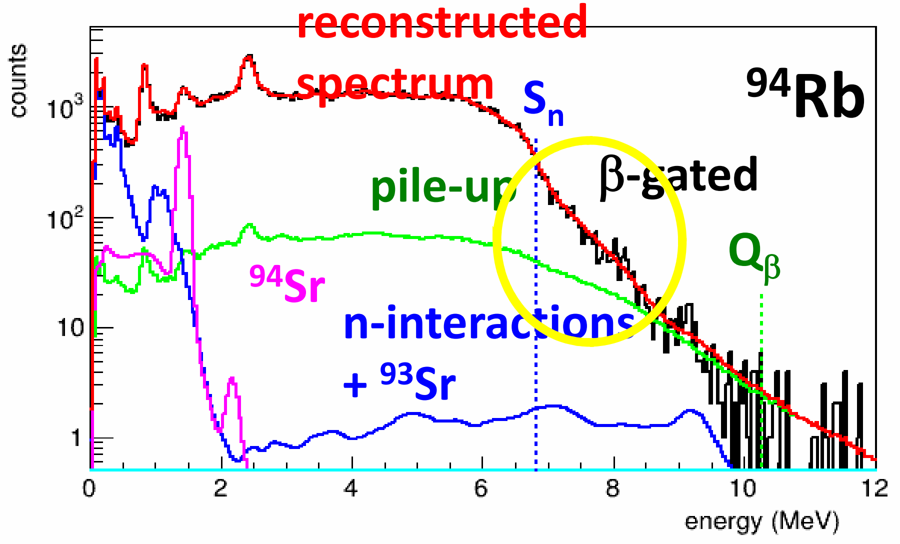
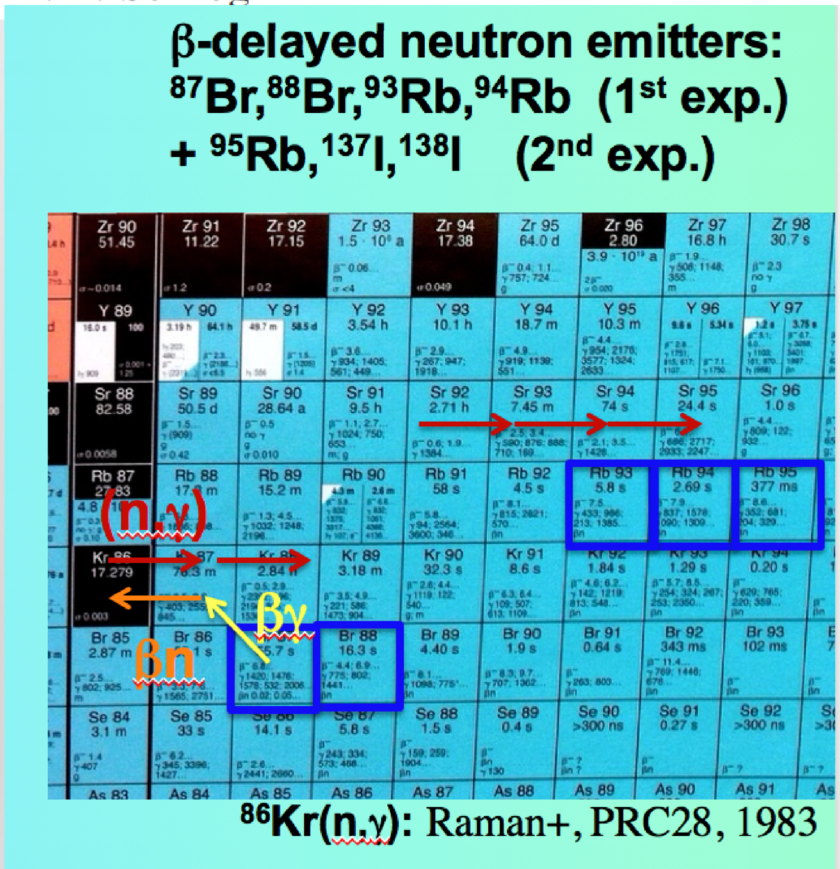
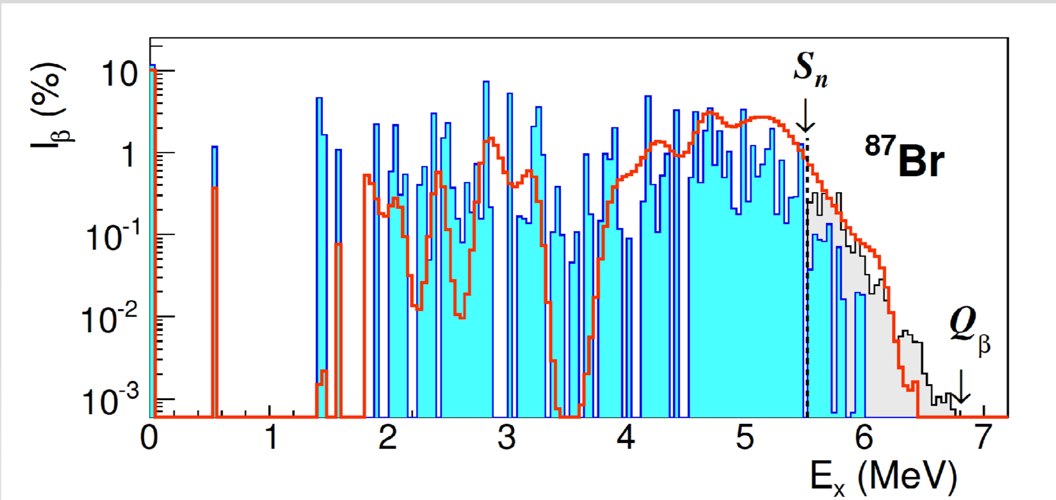


Enhanced γ-Ray Emission from Neutron Unbound States Populated in β Decay

J. L. Tain,[1,*] E. Valencia,[1] A. Algora,[1] J. Agramunt,[1] B. Rubio,[1] S. Rice,[2] W. Gelletly,[2] P. Regan,[2] A.-A. Zakari-Issoufou,[3] M. Fallot,[3] A. Porta,[3] J. Rissanen,[4] T. Eronen,[4] J. Äystö,[5] L. Batist,[6] M. Bowry,[2] V. M. Bui,[3] R. Caballero-Folch,[7] D. Cano-Ott,[8] V.-V. Elomaa,[4] E. Estevez,[1] G. F. Farrelly,[2] A. R. Garcia,[8] B. Gomez-Hornillos,[7] V. Gorlychev,[7] J. Hakala,[4] M. D. Jordan,[1] A. Jokinen,[4] V. S. Kolhinen,[4] F. G. Kondev,[9] T. Martínez,[8] E. Mendoza,[8] I. Moore,[4] H. Penttilä,[4] ...en,[4] V. Sonnenschein,[4] and A. A. Sonzogni[10]

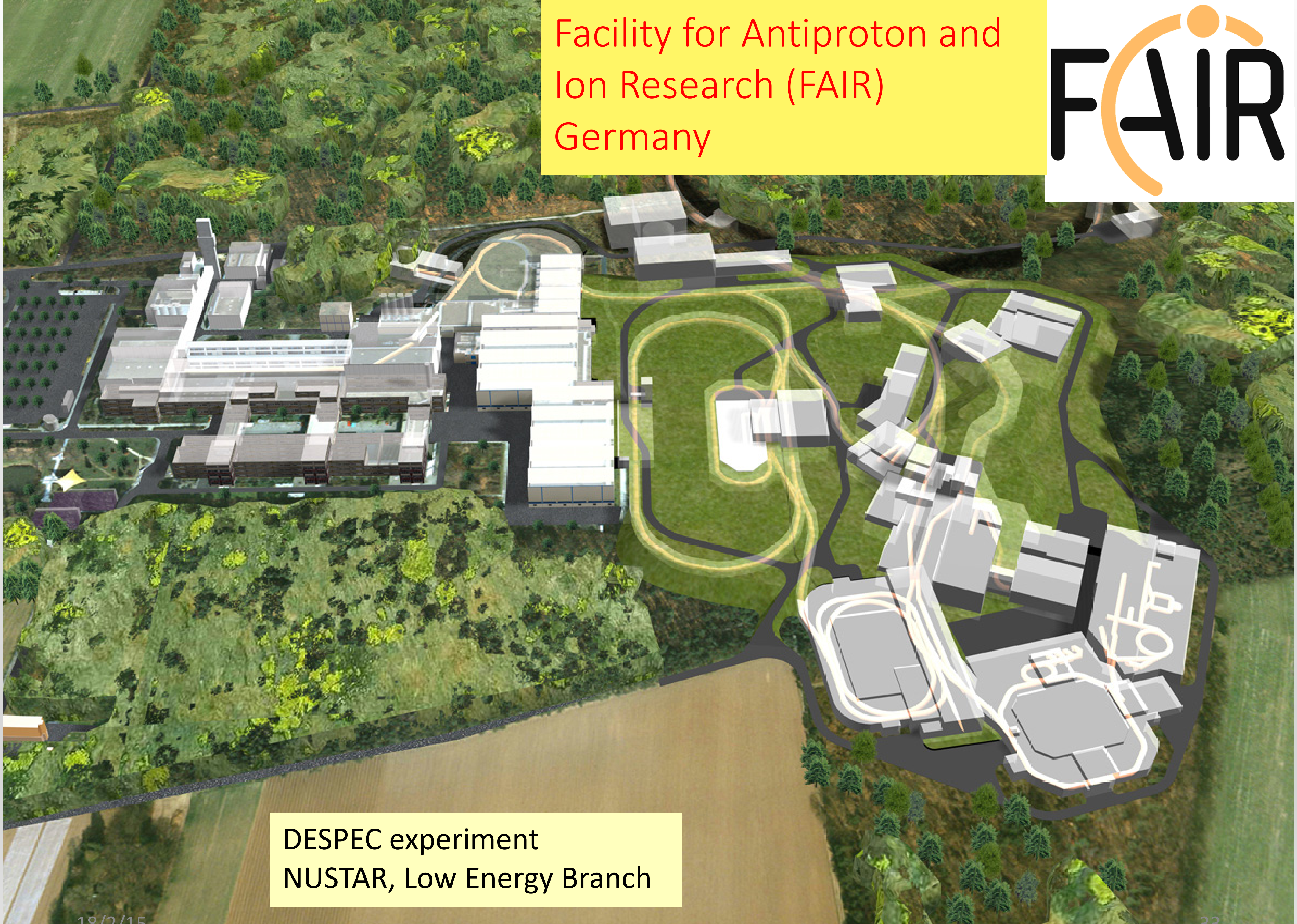






Facility for Antiproton and Ion Research (FAIR) Germany

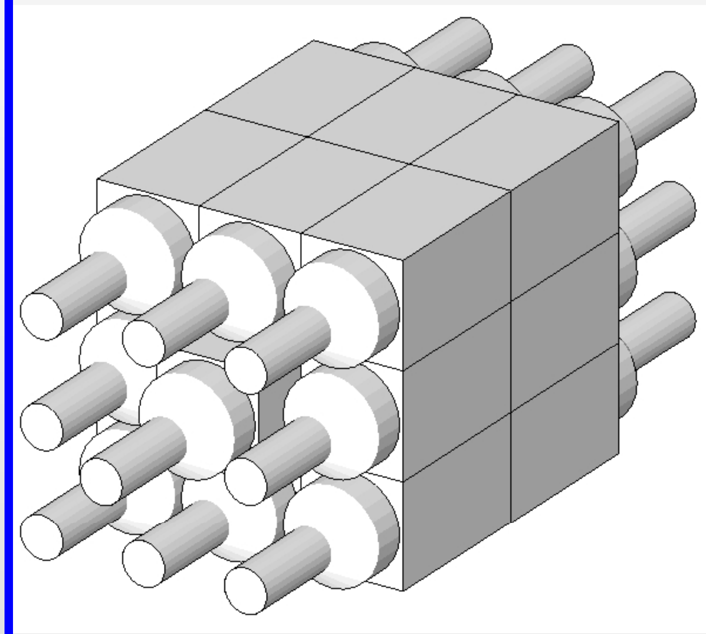
FAIR



DESPEC experiment
NUSTAR, Low Energy Branch

DTAS 17 independent NaI crystals (Valencia-Surrey-Madrid)

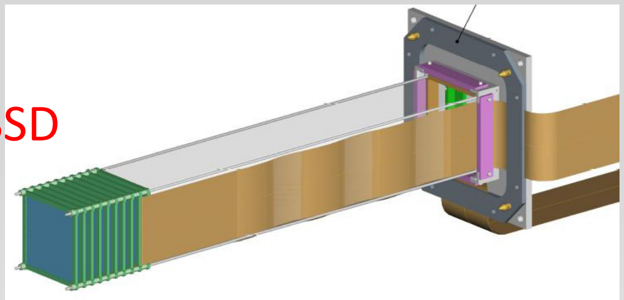
A new DTAS was designed and constructed to work at FAIR (DESPEC experiment)



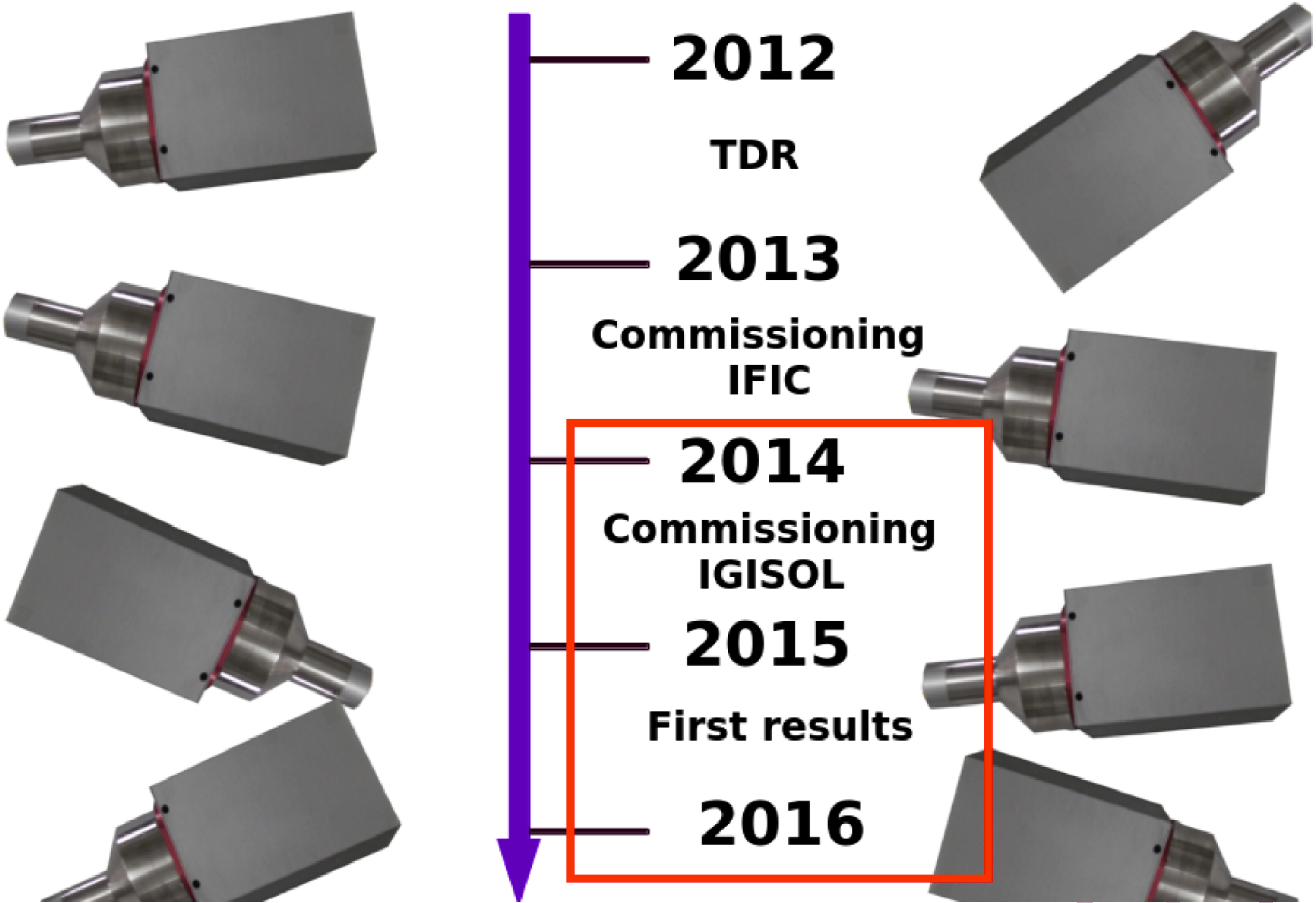
16 × NaI(Tl) crystals:

- $15 \times 15 \times 25$ cm^3
- Minimum dead-material
- 5” PMT: ETL9390

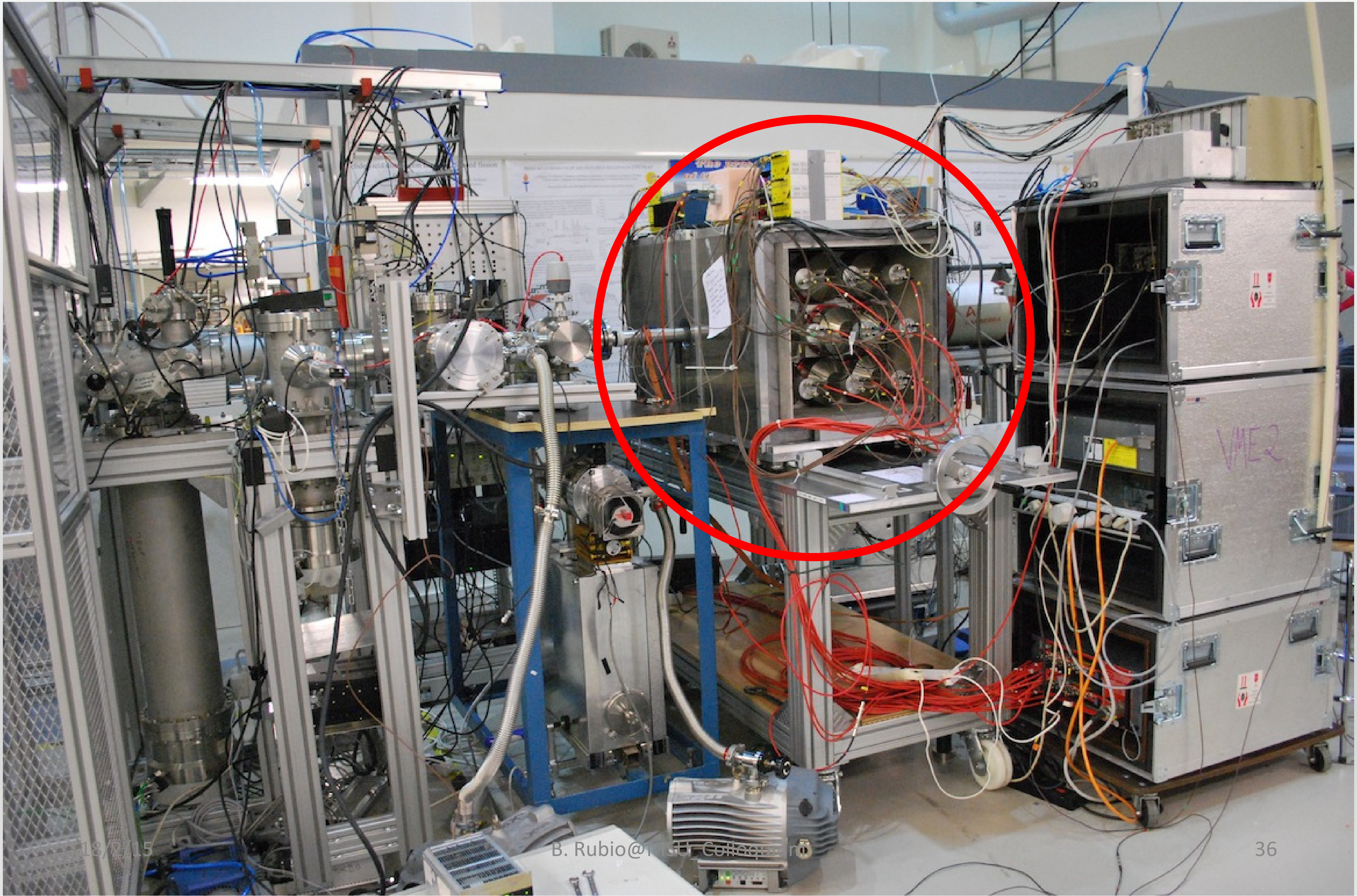
Designed to be coupled to AIDA implantation detector



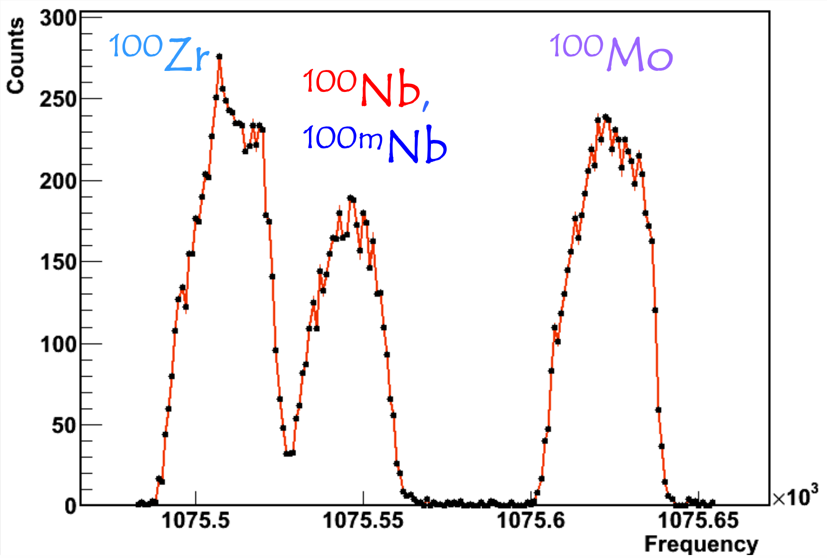
Chronology

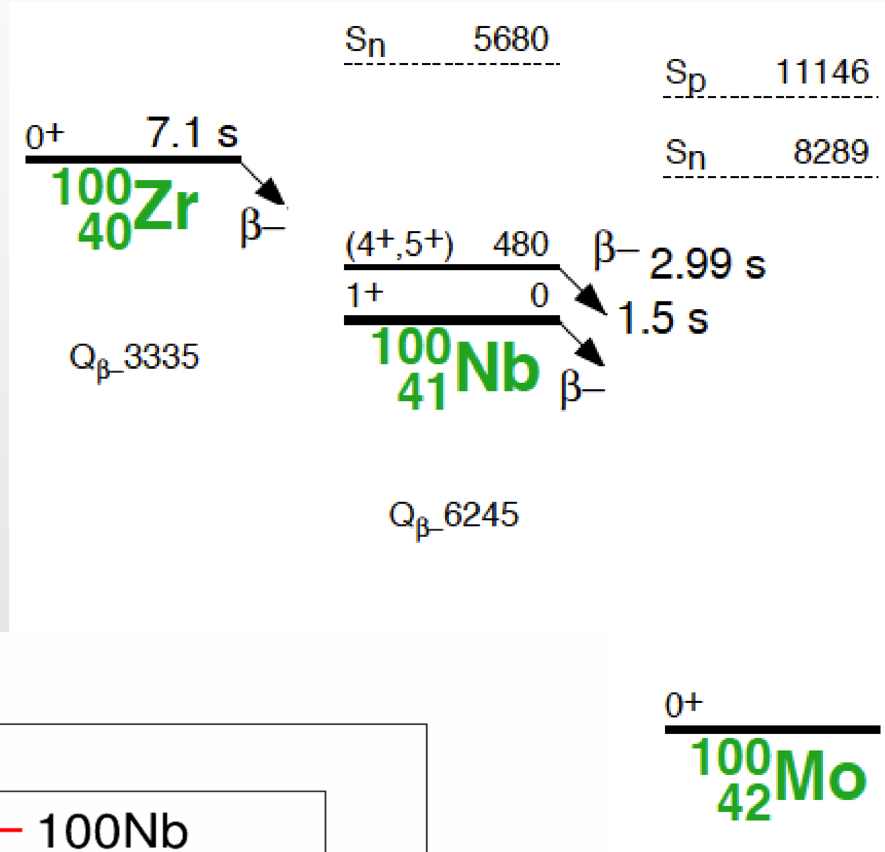

2012
TDR
2013
Commissioning
IFIC
2014
Commissioning
IGISOL
2015
First results
2016

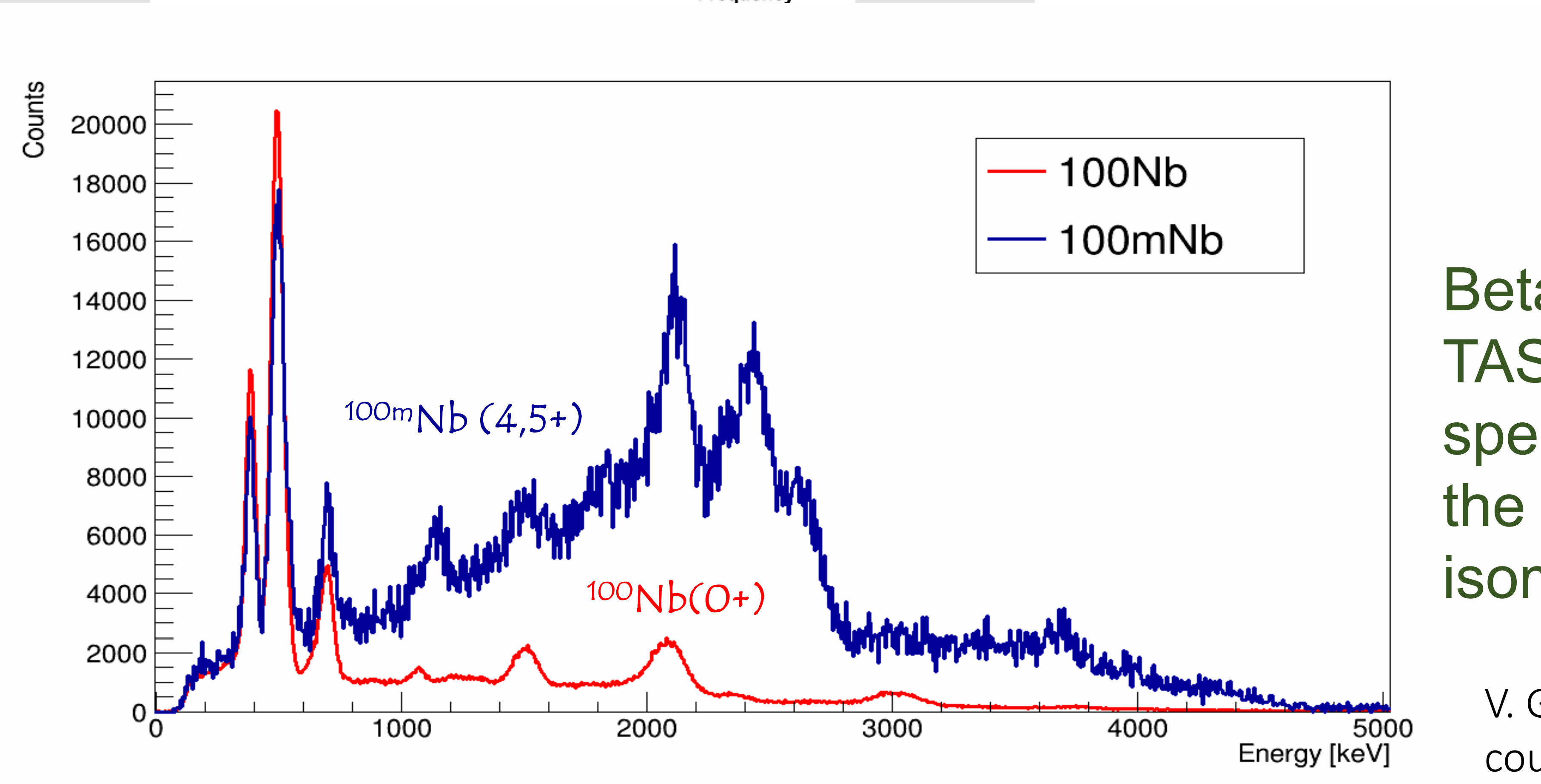
March 2014



JYFLTRAP, A=100 Mass Scan







Beta gated TAS spectra of the two isomers

V. Guadilla courtesy

New questions: reactor anomaly ?

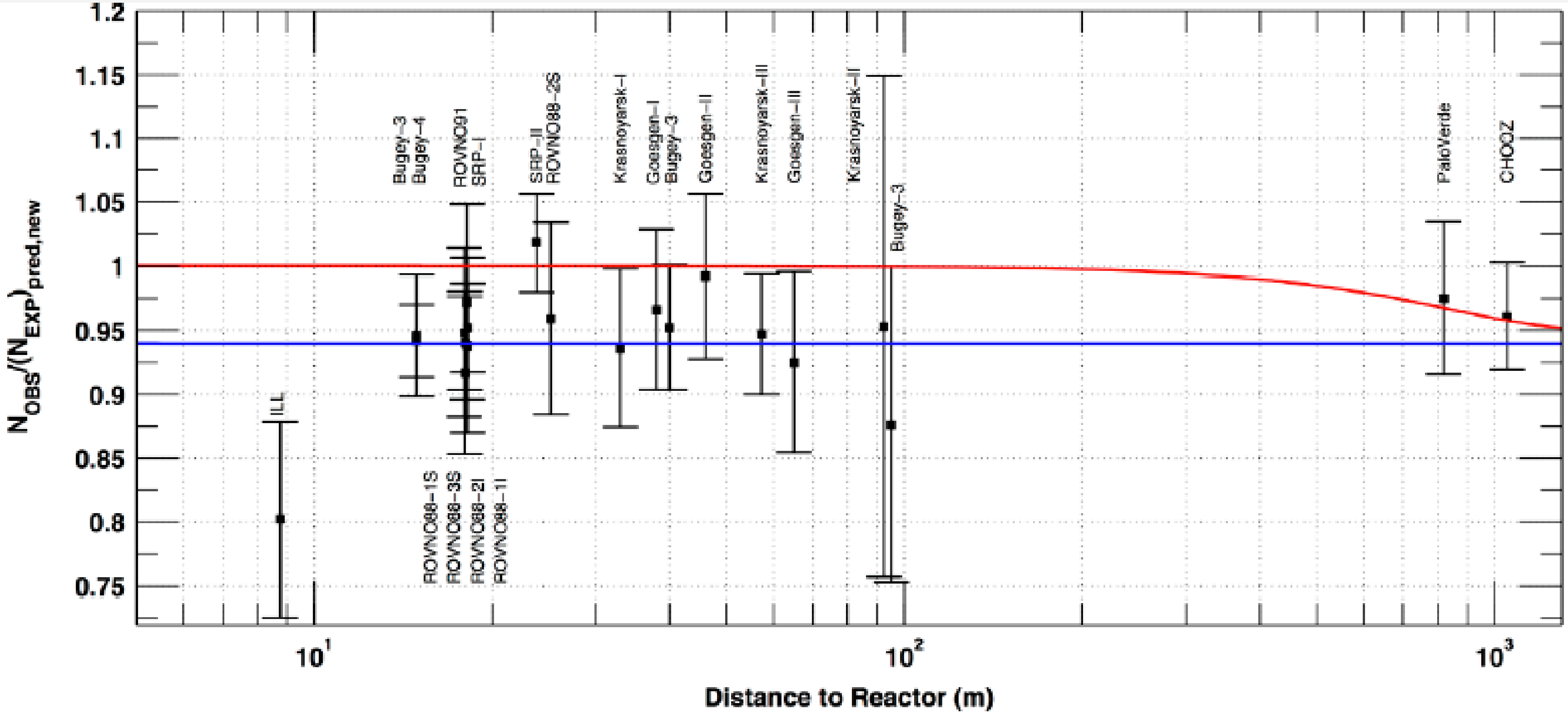


Illustration of the reactor anomaly. Rates in various experiments are compared with the expectations based on the Mueller et al. (2011) spectrum. The mean is 0.943+-0.023.

Possible explanation:

1)Wrong reactor flux or its error

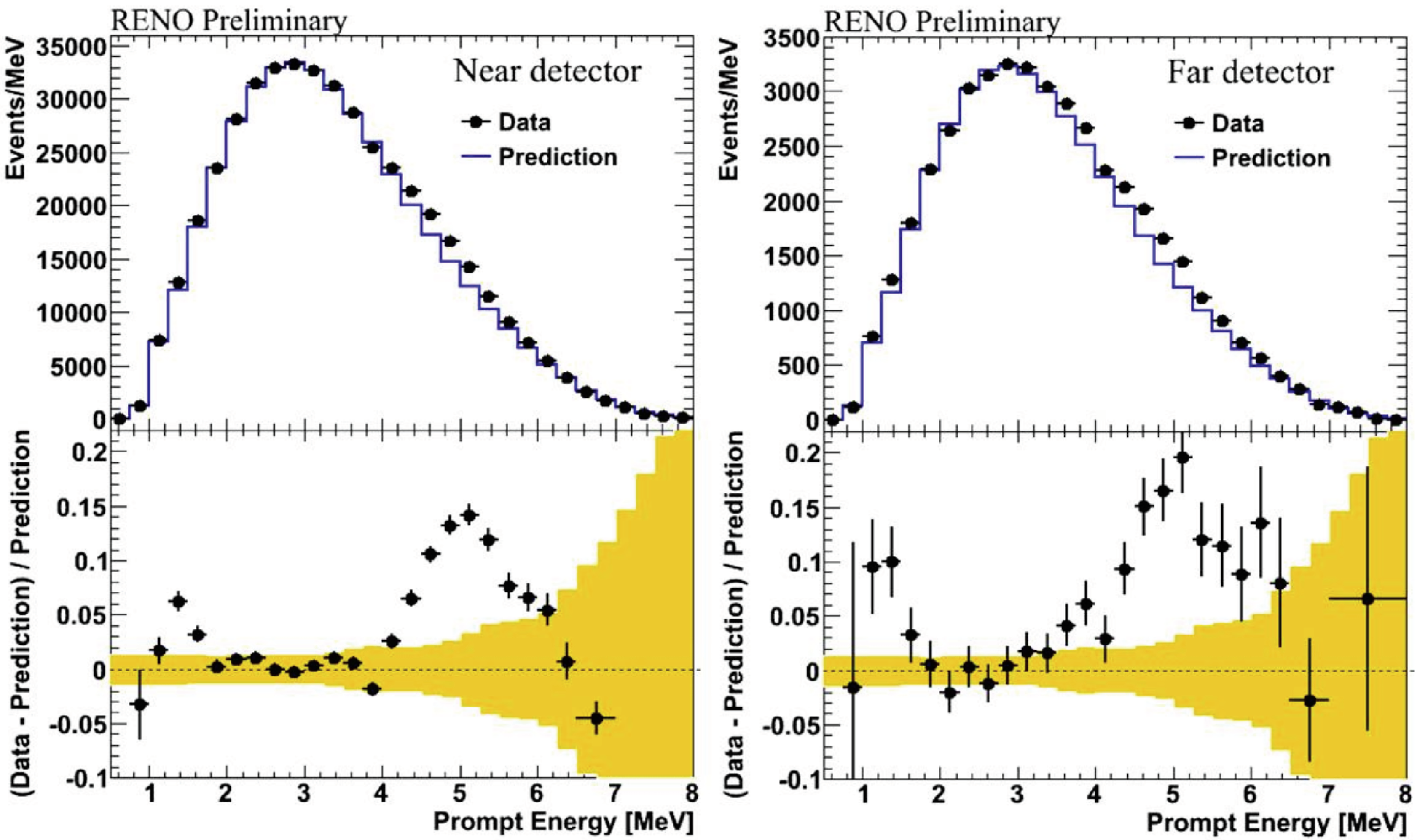
2)Bias in all experiments

3)New physics at short baseline involving a sterile 4th neutrino ν_{new} with $\Delta m^2 \sim 1eV^2$ and mixing with ν_e with $\theta_{new} \sim 10^0$

From P. Vogel

The explanation 3) could be supported by several other, so far unconfirmed anomalies. It would involve unexpected but significant "New Physics"

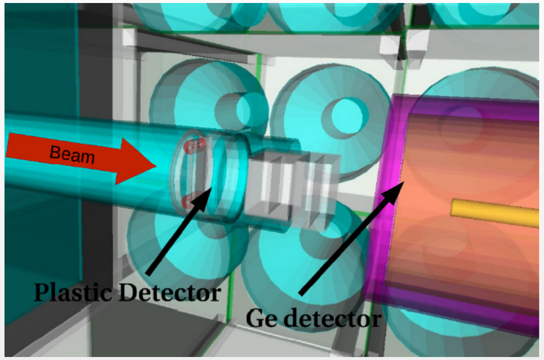
A new famous bump !!!

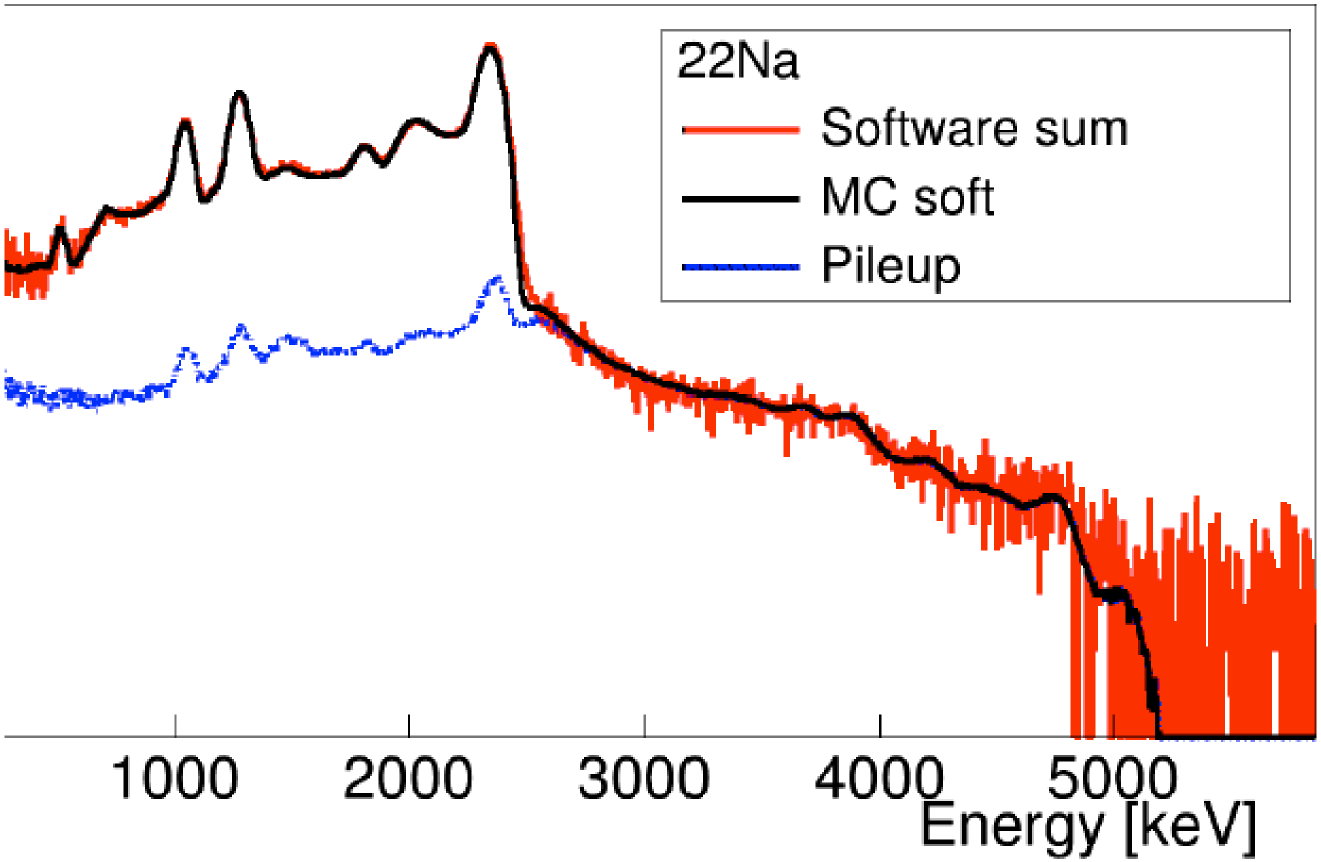


RENO results, arXiv:1504.08268
Also seen in DAYA BAY

Monte Carlo simulation of full detector response

- Geant 4.9.6.p03
- Inclusion of light yield non-proportionality function
- Detailed geometry description



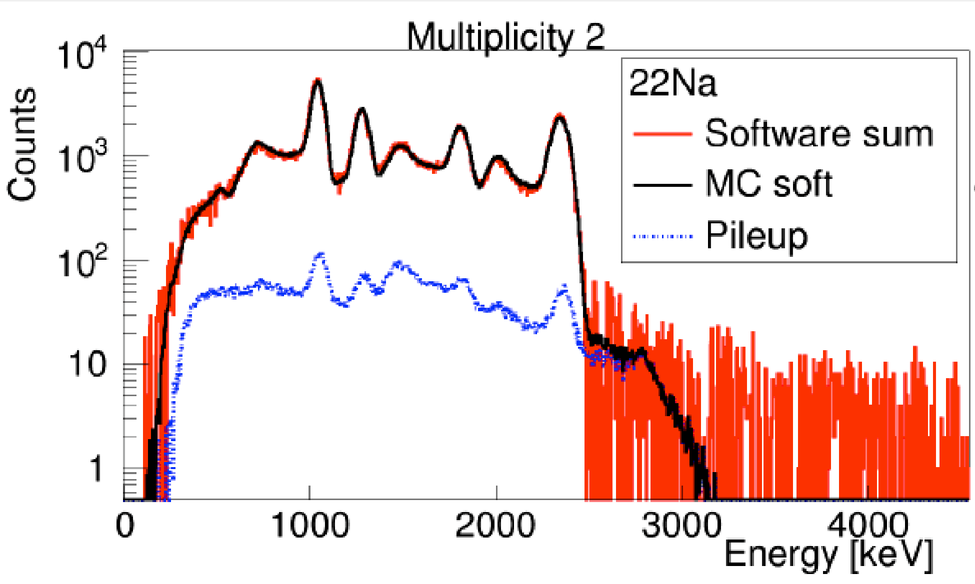


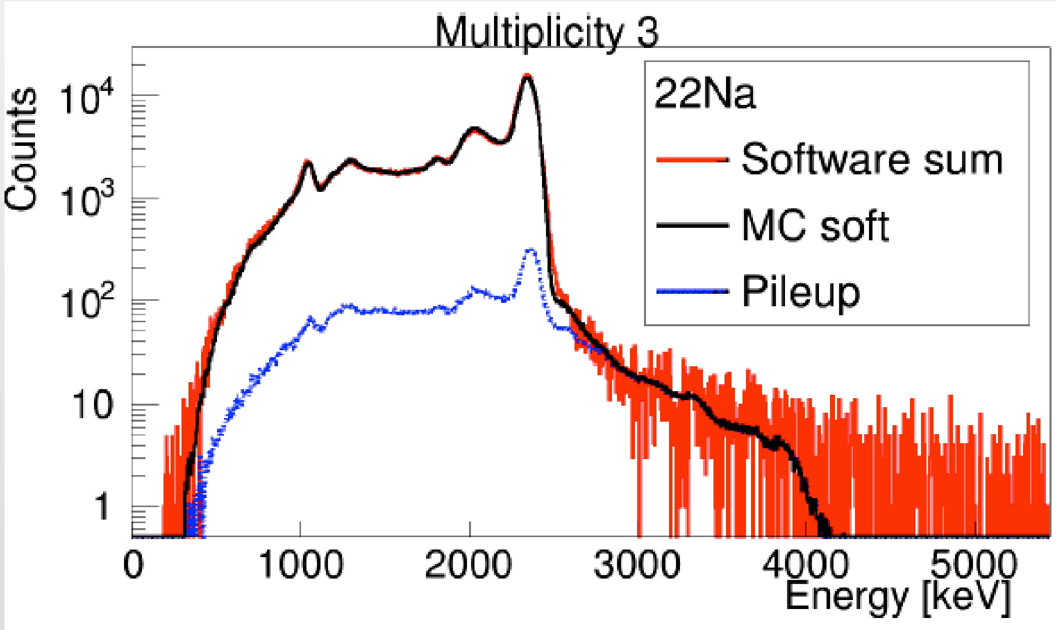
Summing-pileup calculatio

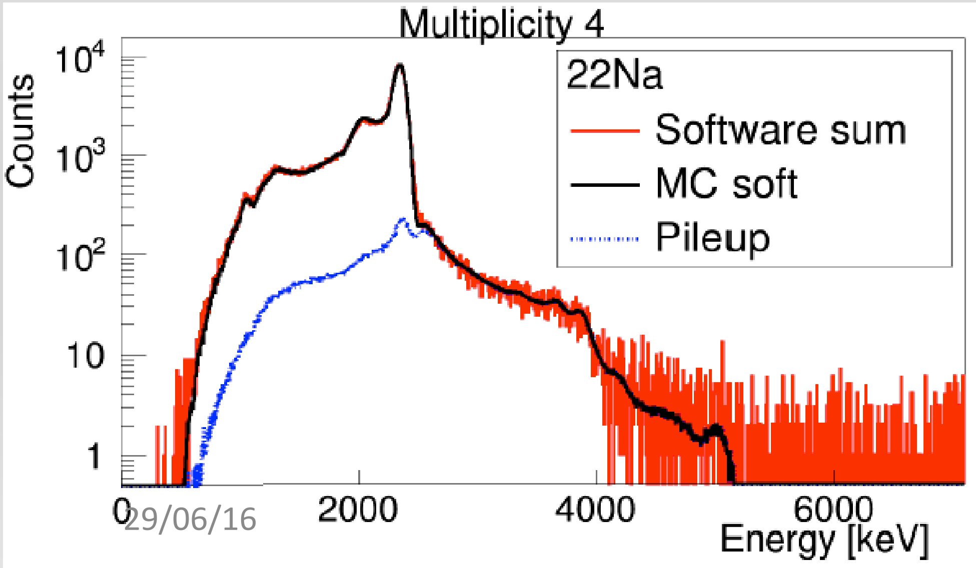
- Monte Carlo method base recorded events or Geant4 generated events
- Uses the measured pulse shape

Monte Carlo simulation of crystal multiplicity response

- More stringent test of Monte Carlo simulation

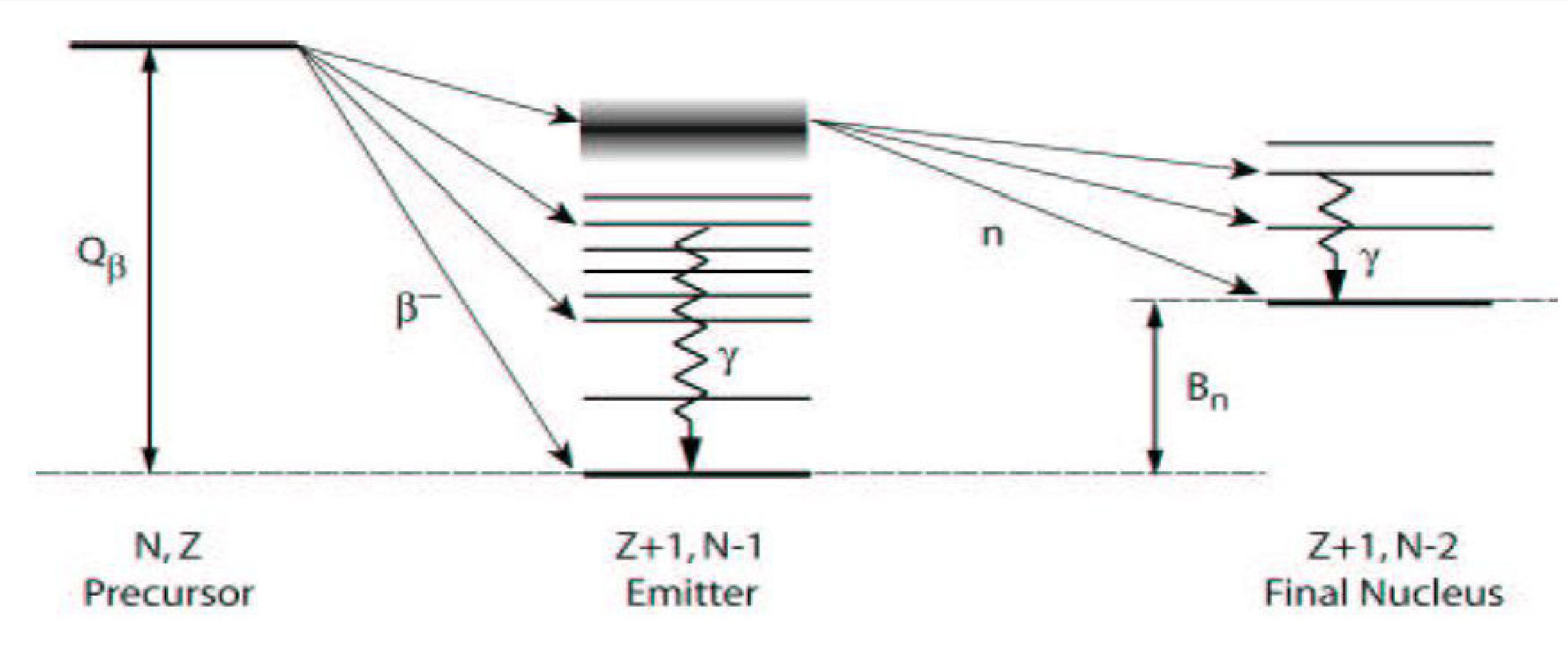






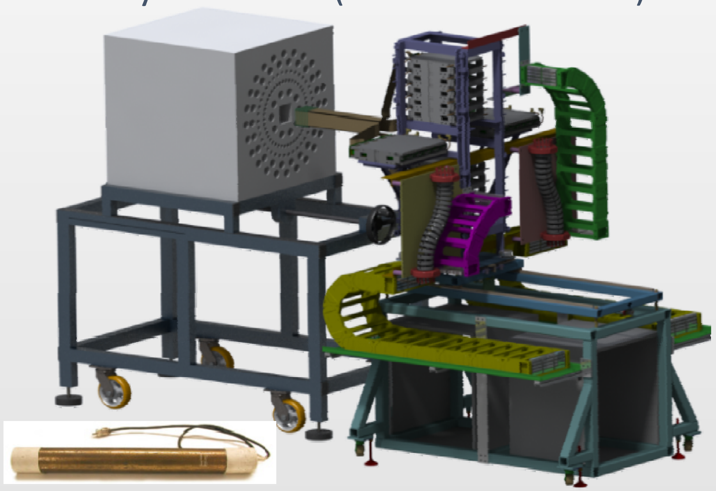
- The sensitivity to cascade gamma-ray multiplicity will add accuracy to the response calculation for deconvolution process, allowing adjustments to the unknown part of b.r.

One can also measure beta-delyed neutrons directly

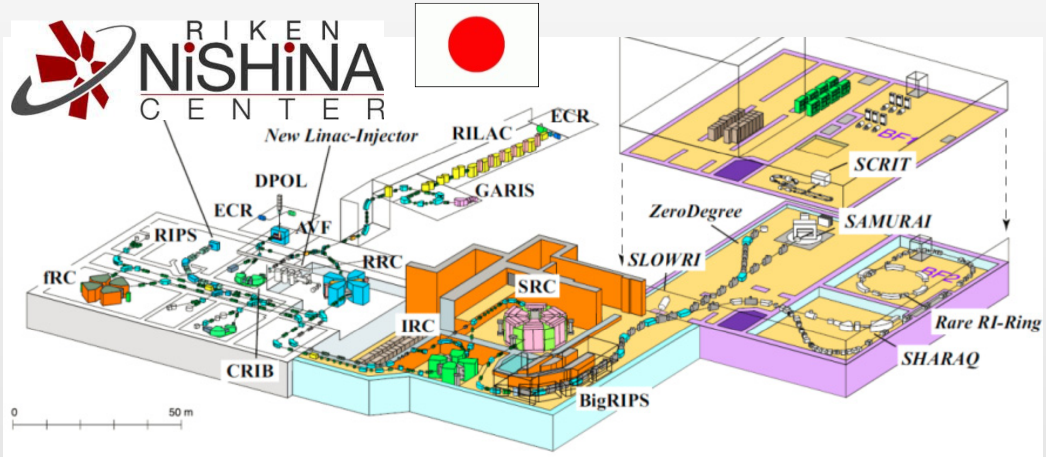


BRIKEN Project: Beta delayed neutron measurements at RIKEN

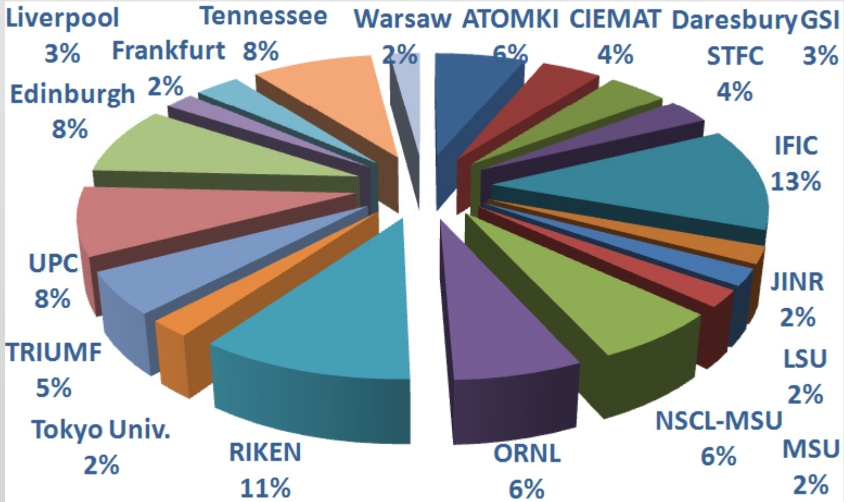
→ Largest ^{3}He array ever built (**182 tubos de ^{3}He**)



^{3}He-Proportional Counter Mega-Array



60 scientists from 24 institutions



➢ **Astrophysics, nuclear structure, reactor technology**

✓1st BRIKEN Workshop, Valencia 17-18/12/2012
http://indico.ific.uv.es/indico/event/briken

✓2nd BRIKEN Workshop, Tokyo 30-31/07/2013
http://indico.ific.uv.es/indico/event/briken2

✓3rd BRIKEN Workshop, Valencia 22-24/07/2015
http://indico.ific.uv.es/indico/event/briken3

✓ Construction Proposal

✓ 3 Exp. Proposals approved 2014-2015

✓ **23 days of beam-time approved at RIKEN / BigRIPS!**

BRIKEN Project: Beta delayed neutron measurements at RIKEN

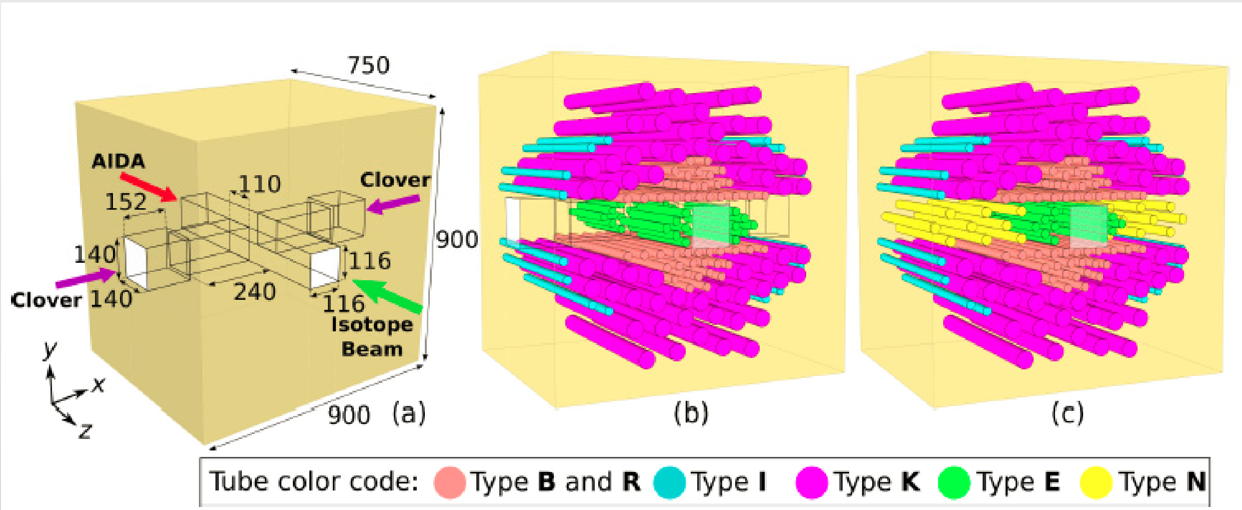
arXiv.org > physics > arXiv:1606.05544

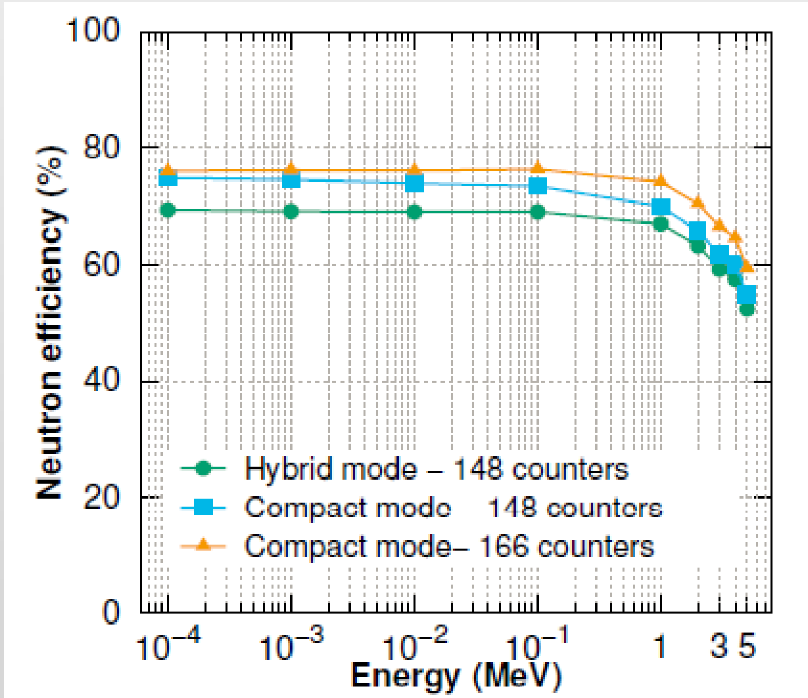
Physics > Instrumentation and Detectors

Conceptual design of the BRIKEN detector: A hybrid neutron-gamma detection system for nuclear physics at the RIB facility of RIKEN

A. Tarifeño-Saldivia, J. L. Tain, C. Domingo-Pardo, F. Calviño, G. Cortes, V. H. Phong, A. Riego, The BRIKEN collaboration

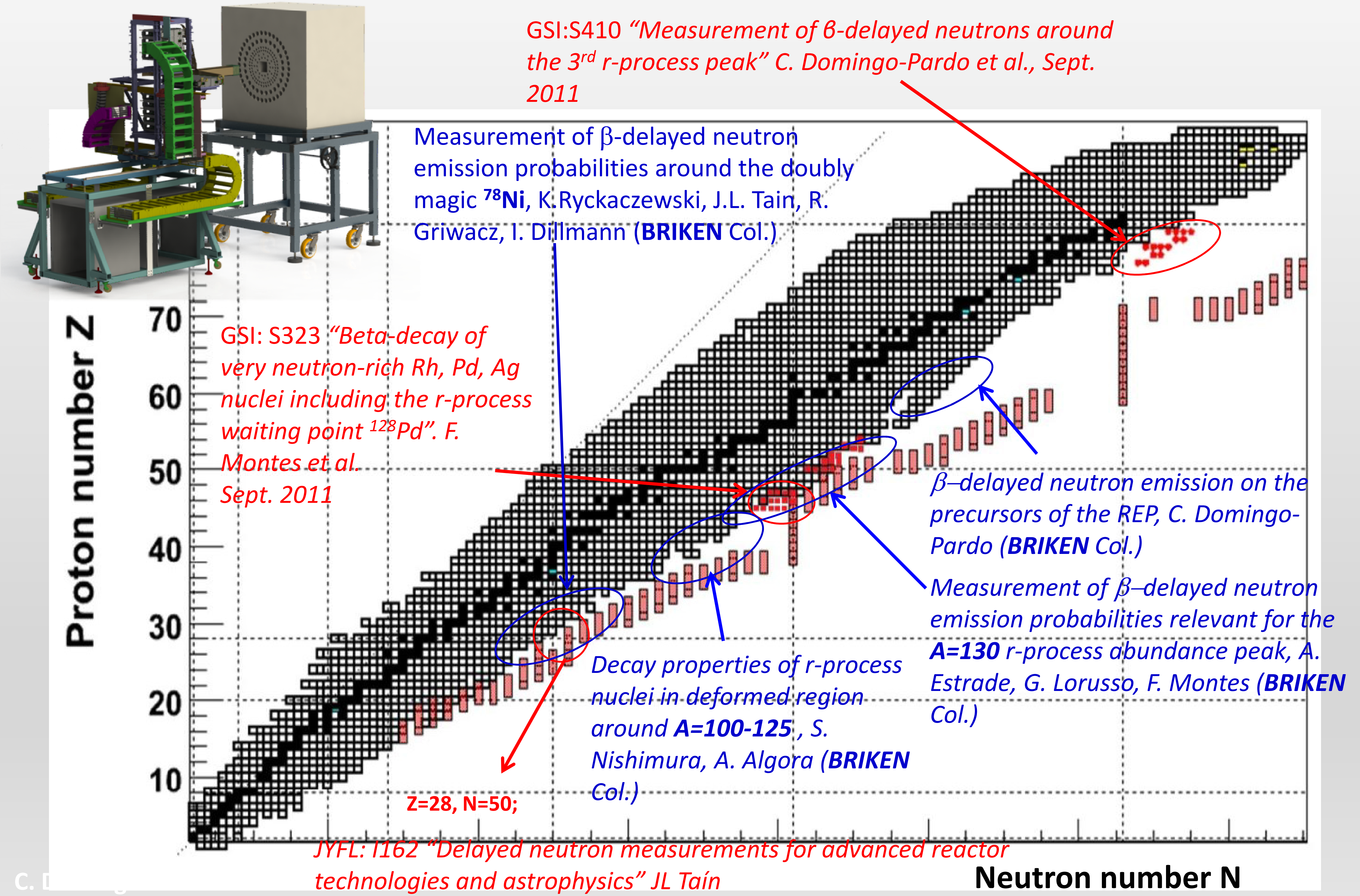
http://arxiv.org/abs/1606.05544





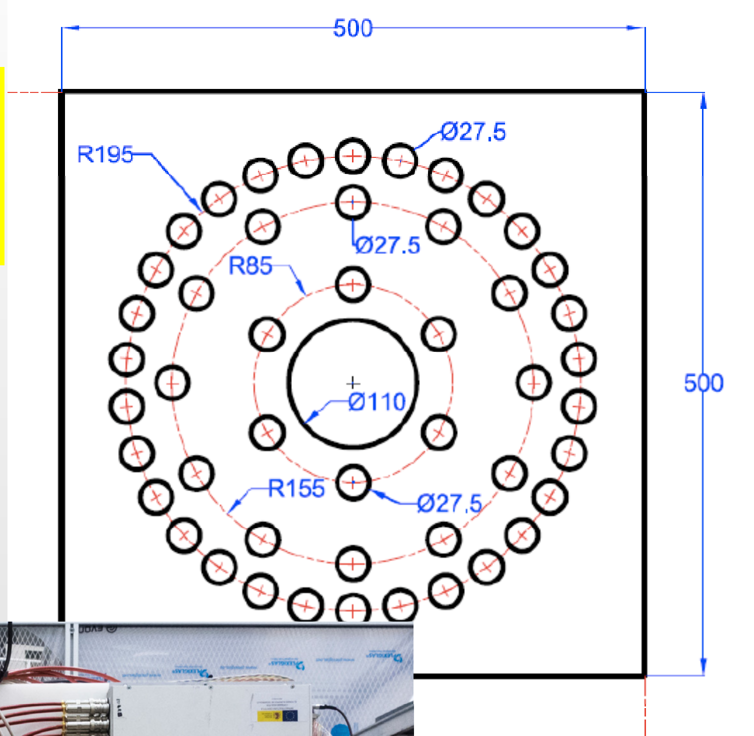
The Spanish 3He tubes belong to the UPC

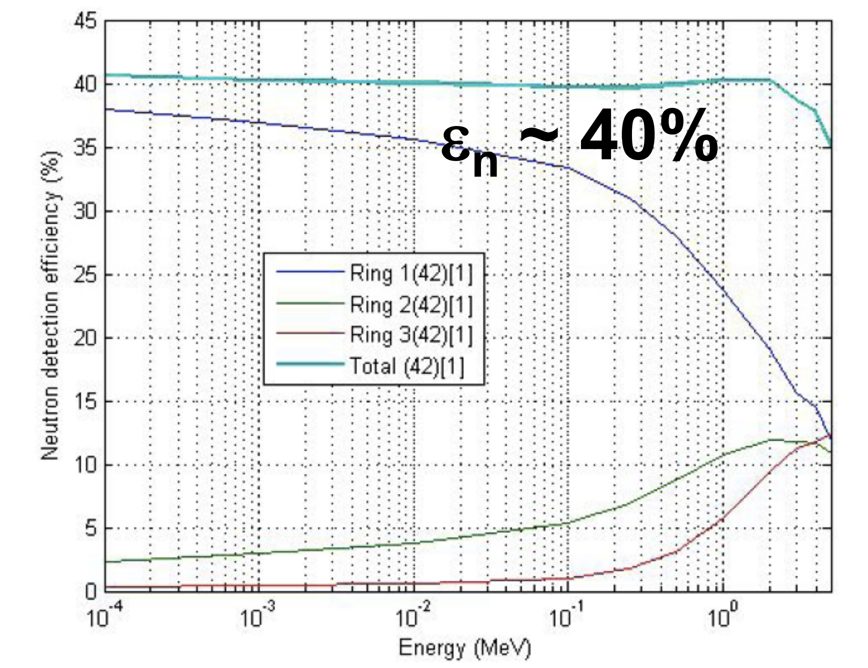
BRIKEN Project: Beta delayed neutron measurements at RIKEN

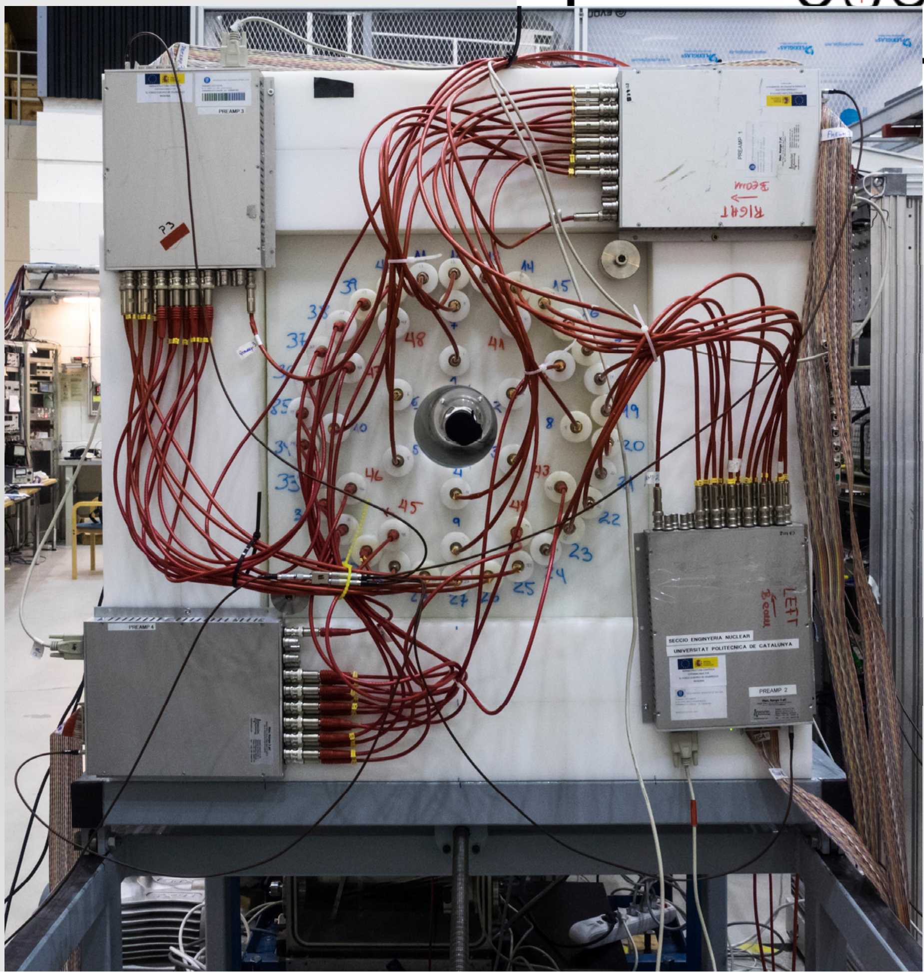


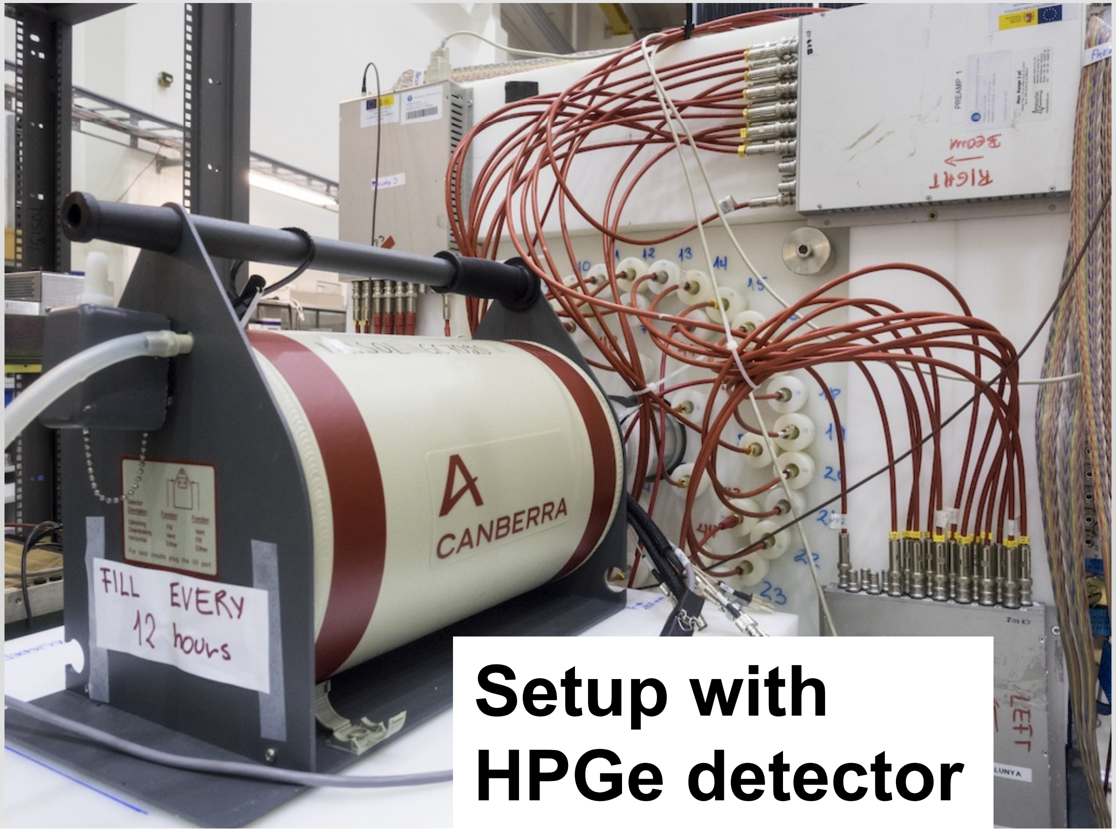
I162: BELEN-48a

48x 3He tubes
@ 8 & 10 atm



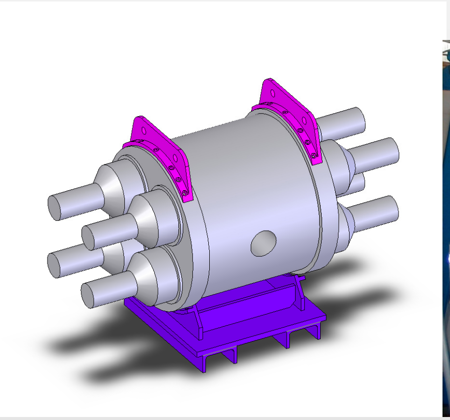


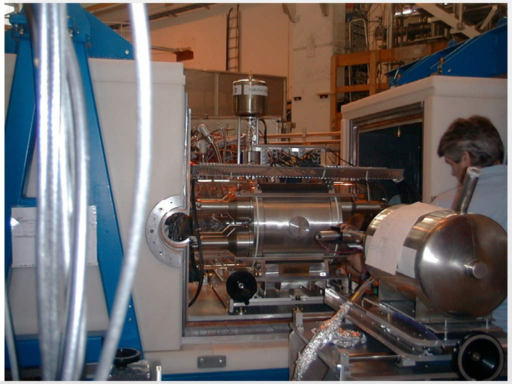


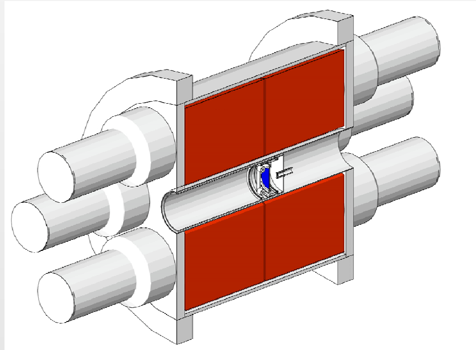


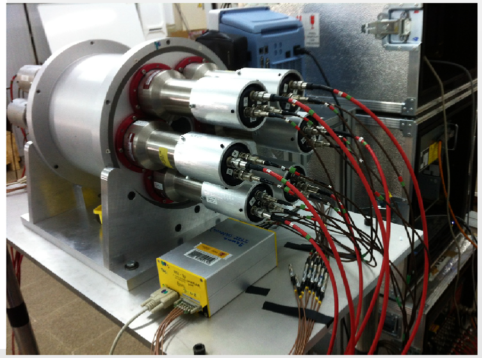
Setup with HPGe detector

Future







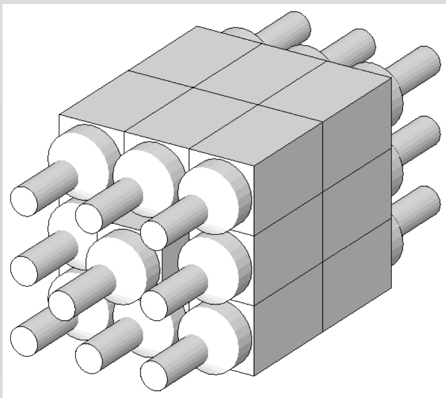


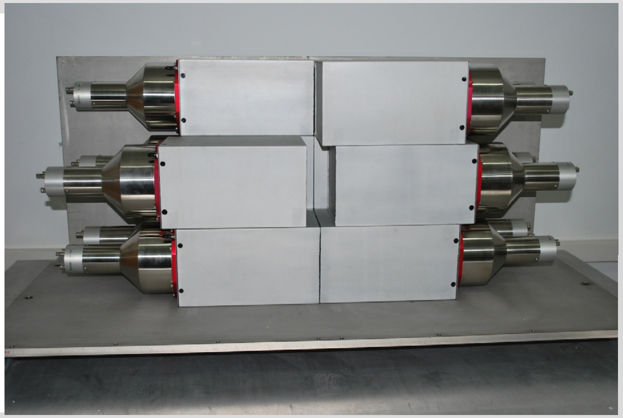
Rocinante, 12 BaF crystals

In a common canning, moving

Lucrecia, fix setup

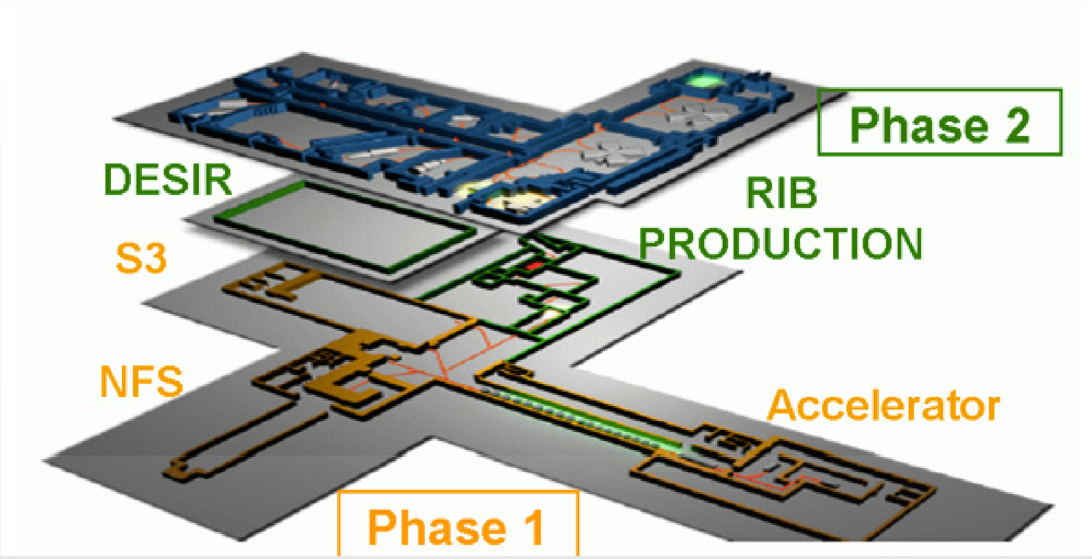
At Isolde, on-going programme





DTAS, 18 NaI crystals, modular

Moving detector



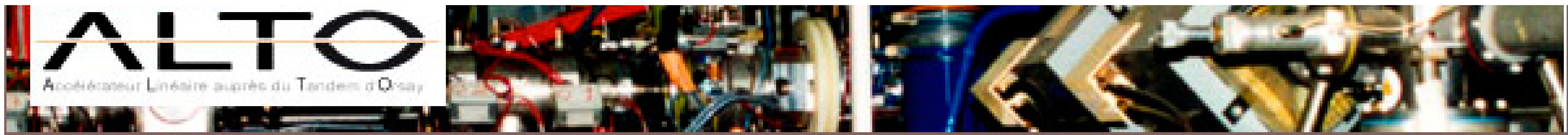
Spiral2 DESIR

RIKEN NISHINA CENTER

TOTAL ABSORPTION SPECTROSCOPY FOR NUCLEAR STRUCTURE, NUCLEAR ASTROPHYSICS, NEUTRINO AND REACTOR PHYSICS

Spokespersons: A. Algora, M. Fallot, A. Porta, B. Rubio, J.-L. Taín

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE

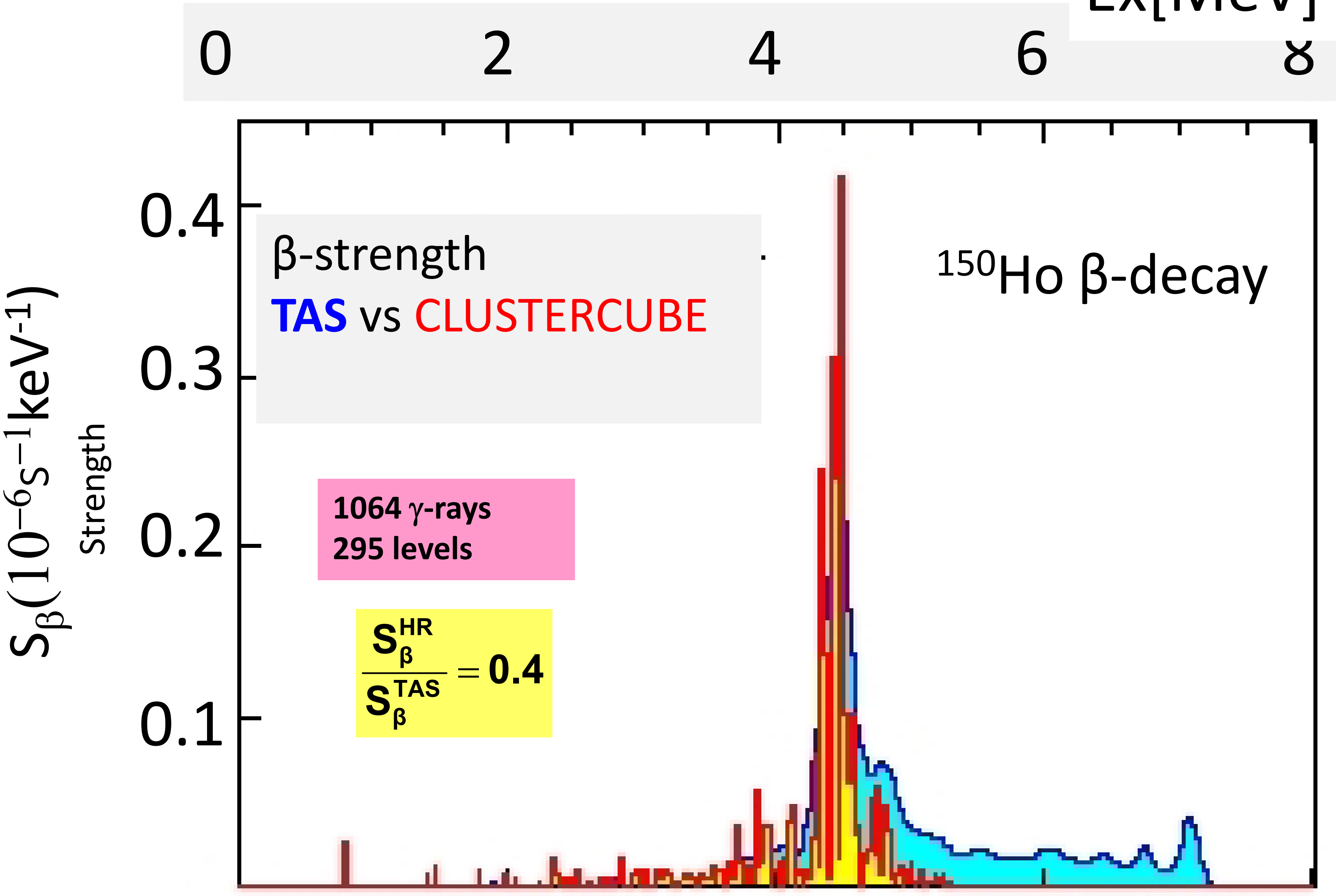


Home > accelerator and separator > yields at ALTO

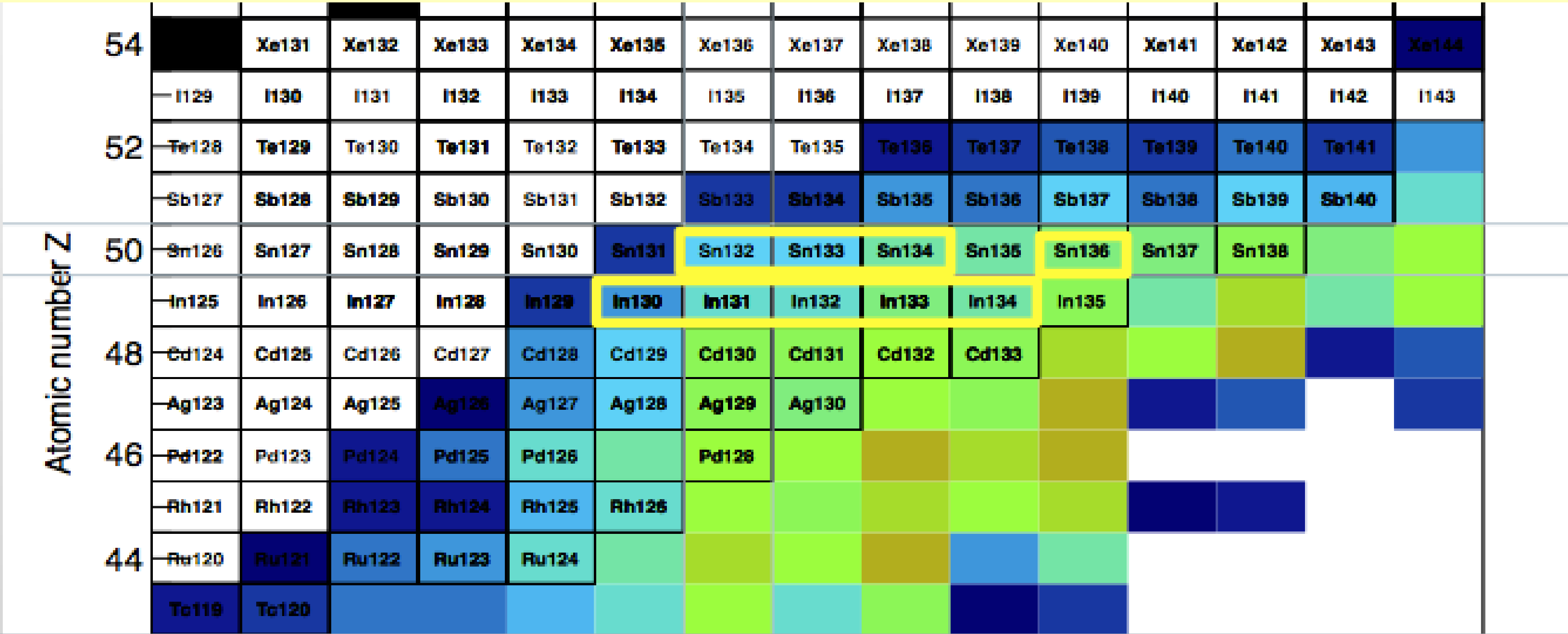

FIN

Mr. Miller estimated that demand for helium 3 was about 65,000 liters per year through 2013 and that total production by the only two countries that produce it in usable form, the United States and Russia, was only about 20,000 liters. In a letter to President Obama, he called the shortage “a national crisis” and said the price had jumped to $2,000 a liter from $100 in the last few years, which threatens scientific research.

A. Algora, B. Rubio et al PRC 50 (2002)



Proposal at ALTO (2014), its feasibility is based on ionization schemes for the desired spices



TOTAL ABSORPTION SPECTROSCOPY FOR NUCLEAR STRUCTURE, NUCLEAR ASTROPHYSICS, NEUTRINO AND REACTOR PHYSICS

Spokespersons: A. Algora, M. Fallot, A. Porta, B. Rubio, J.-L. Taín

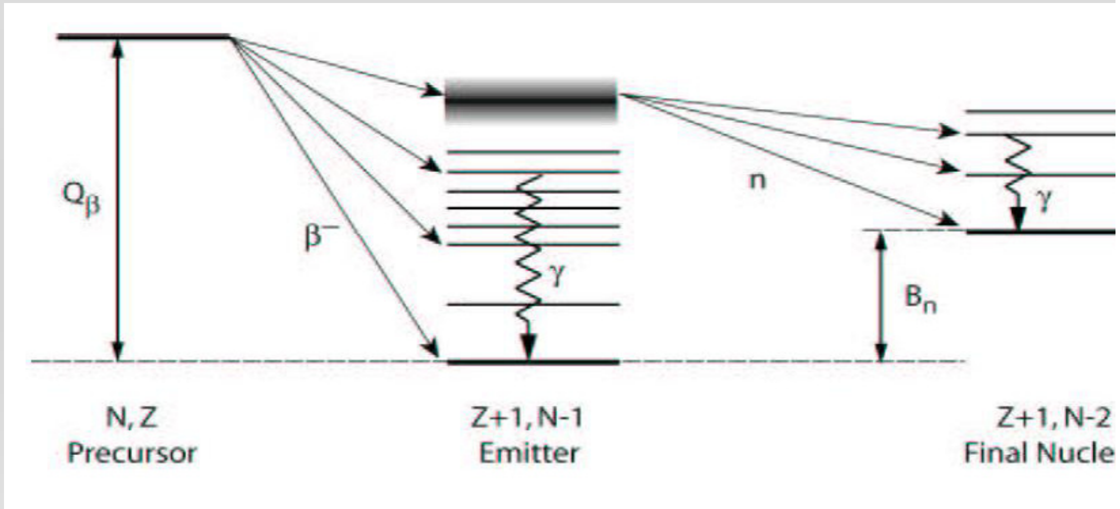
Approved proposal 2014, to be realised 2015

Motivation of recently analyzed cases: ^{87}Br,^{88}Br

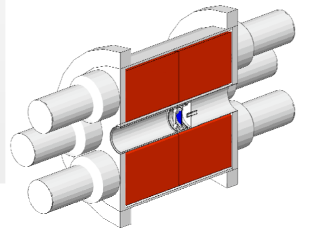
- Priority one in the IAEA list (decay heat)
- Moderate fission yields
- Pandemonium cases ?
- Interest from the structure point of view: vicinity of n closed shell
- Measurement of competition between gamma and neutron emission above the Sn value, which is conventionally neglected in astrophysical calculations

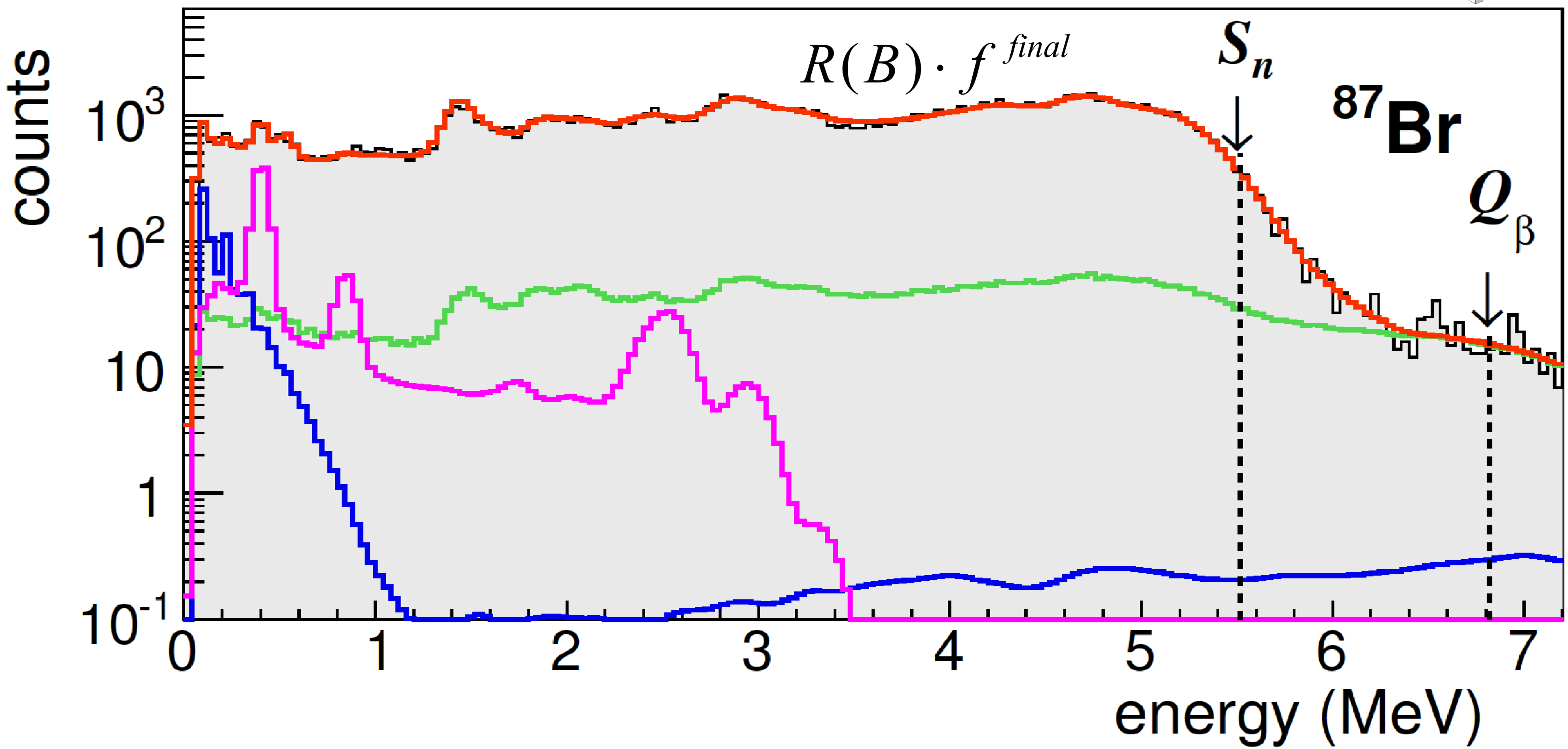
$$\frac{1}{T_{1/2}} = \int_0^{Q_\beta} S_\beta(E_x)\cdot f(Q_\beta - E_x)\,dE_x$$

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



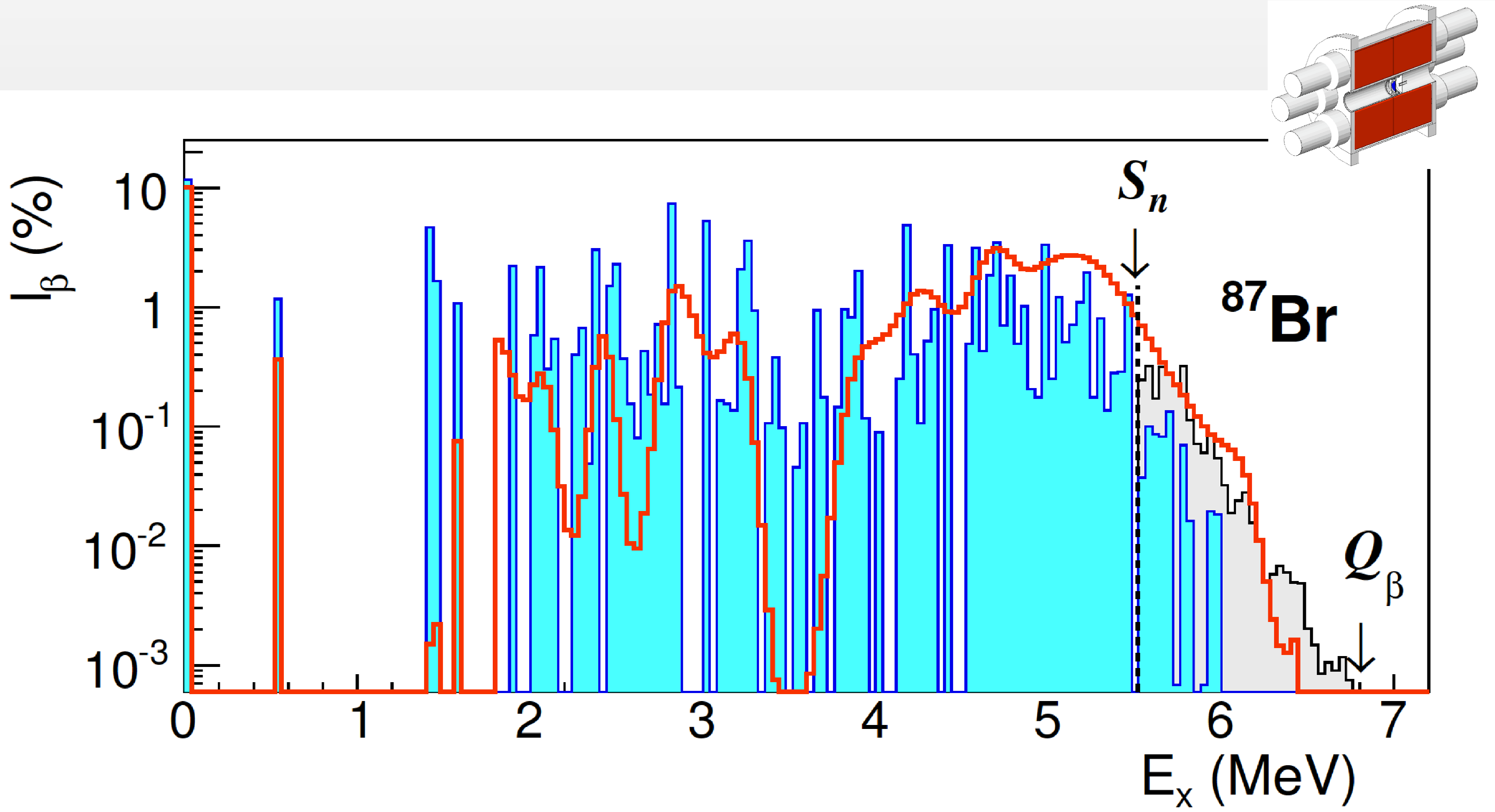
Beta delayed neutron emitters, example: ^{87}Br





E. Valencia, JL Tain, A. Algora et al, in preparation
Tain et al. PRL 115, 062502

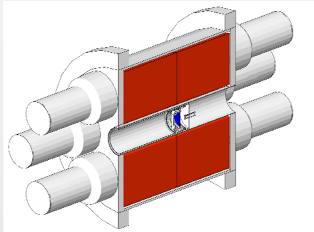
Beta delayed neutron emitters, example: 88Br



E. Valencia, JL Tain, A. Algora et al, in preparation
Tain et al. PRL 115, 062502

Impact of the studied (bdn) cases with strong astrophysical implications

E. Valencia, JL Tain, A. Algora et al, in preparation



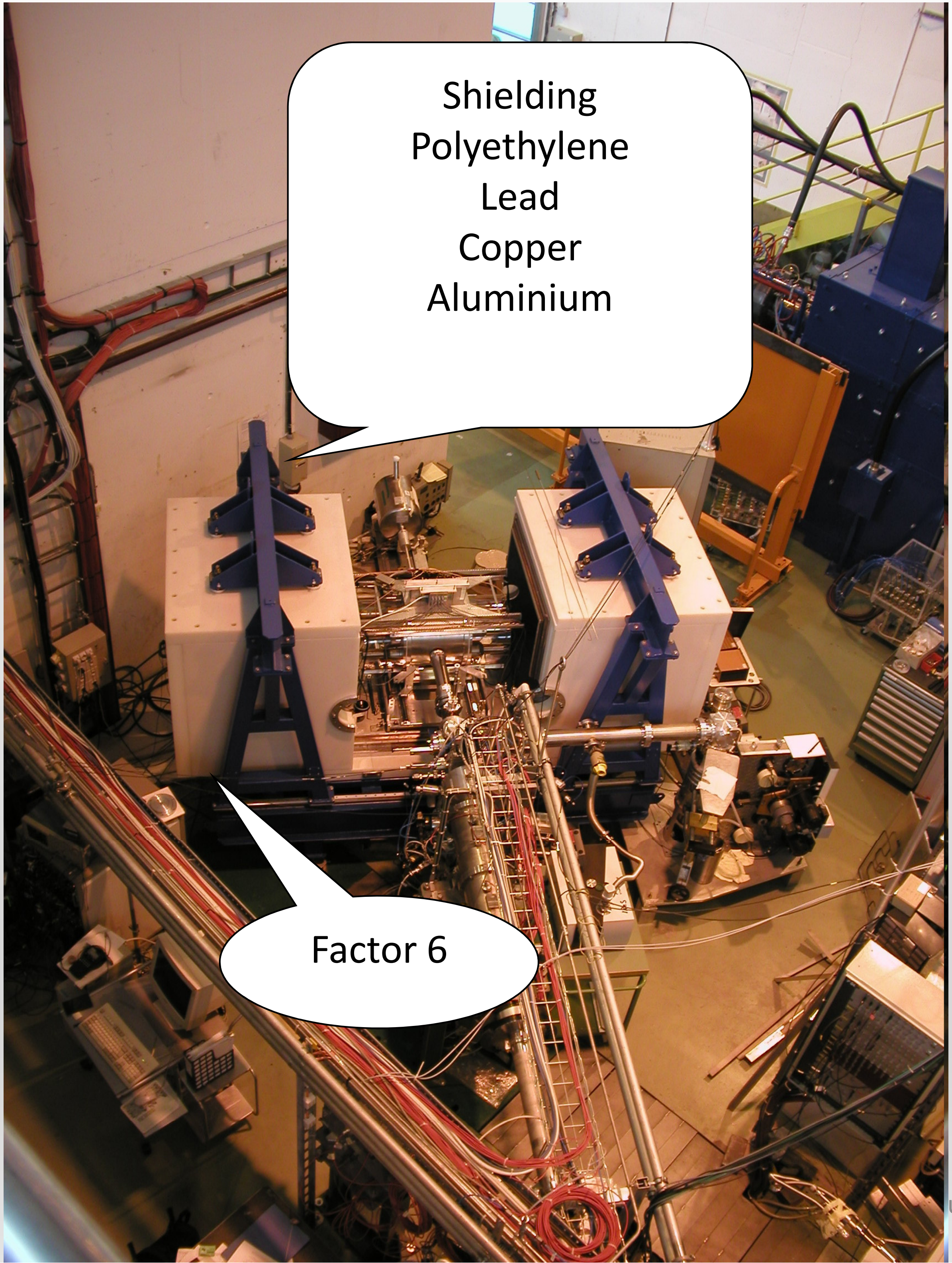
	$\bar{E}_\gamma$(keV)		$\bar{E}_\beta$(keV)	
Isotope	ENSDF	TAGS	ENSDF	TAGS
^{87}Br	3009	3938^{+40}_{-67}	1599	1159^{+32}_{-19}
^{88}Br	2892	4609^{+78}_{-67}	2491	1665^{+32}_{-38}
^{94}Rb	1729	4063^{+62}_{-66}	2019	2329^{+32}_{-30}

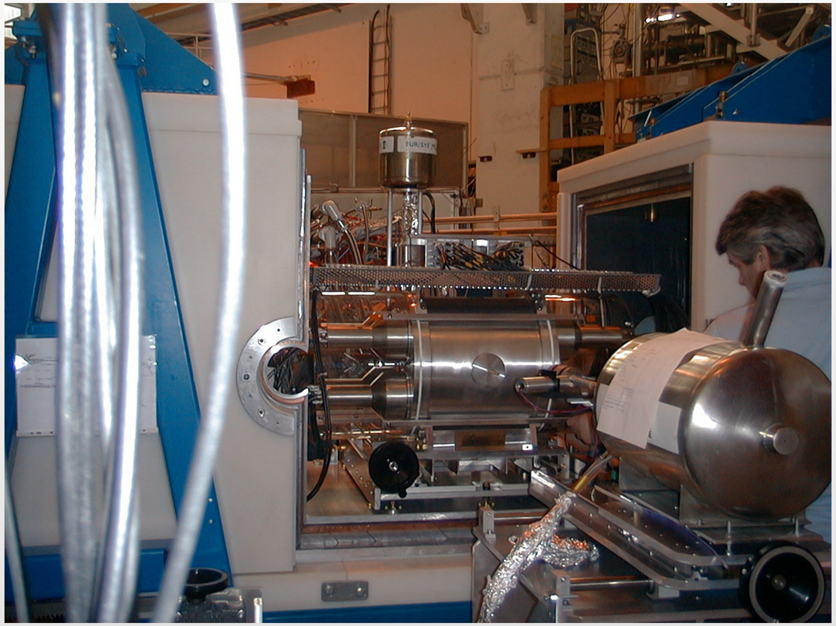
	$\bar{E}_\beta$(keV)	
Isotope	This work	Ref. [58]
^{87}Br	1170^{+32}_{-19}	1410 ± 10
^{88}Br	1706^{+32}_{-38}	1680 ± 10
^{94}Rb	2450^{+32}_{-30}	2830 ± 70

Isotope	P_γ (%)	P_n (%)
^{87}Br	3.50^{+49}_{-40}	2.60(4)
^{88}Br	1.59^{+27}_{-22}	6.4(6)
^{94}Rb	0.53^{+33}_{-22}	10.18(24)

Astrophysics implications discussed in Tain et al. PRL 115, 062502

Can provide constraints for (n,γ) cross section far from stability (r-process)





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