Beta Decay

M. Fallot, A. Algora, M. Estienne, A. Porta et al.

Workshop APRENDE IPHC

Strasbourg, France
Feb. 2025

Subatech, CNRS/IN2P3, Nantes Univ., IMT Atlantique, France

APRENDE

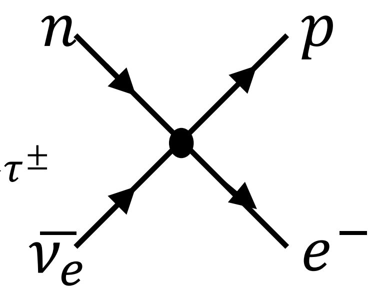
- Intro: beta decay + motivations
- γ and β measurements
- Recent TAGS Results
- $(NA)^2$STARS Project
- e-Shape Experiment
- Conclusions & Outlooks

Subatech, CNRS/IN2P3, Nantes Univ., IMT Atlantique, France

The foundations of Beta Decay

- Long and painful characterization
- First observation of an emission of a charged particle from a nucleus in 1897, identified as an electron in 1900
- 30 years to solve the « beta spectrum puzzle »: existence of a neutrino particle.
- 30 more years to be able to fully characterize the hamiltonian of the weak interaction: V-A type.

- Beta decay driven by some selection rules regarding the isospin and the spin-parity between the parent and daughter nuclei
  - Fermi in the 30's: $\lambda = \frac{2\pi}{\hbar}\left|V_{fi}\right|^2 \rho(E_f)$, $V_{fi} \equiv \langle \psi_f | O_\beta | \psi_i \rangle$
  - β decay first formalized for ΔL=0 (allowed transitions):
    - ✓ Fermi transitions (super-allowed) : isospin change and ΔS=0: $O_\beta = O_F = g_V \tau^{\pm}$
    - ✓ Gamow-Teller transitions: ΔS=1: $O_\beta = O_F = g_A \hat{\sigma}_\mu \tau^{\pm}$
  - Forbidden transitions later identified and characterized: ΔL>=1
    - ✓ For first forbidden transitions: O_β includes 6 operators



- Several domains of applications: Nuclear Energy, Nuclear Astrophyics, Neutrino physics, Medical Applications, etc. and behind all this: Nuclear Structure & Weak interaction

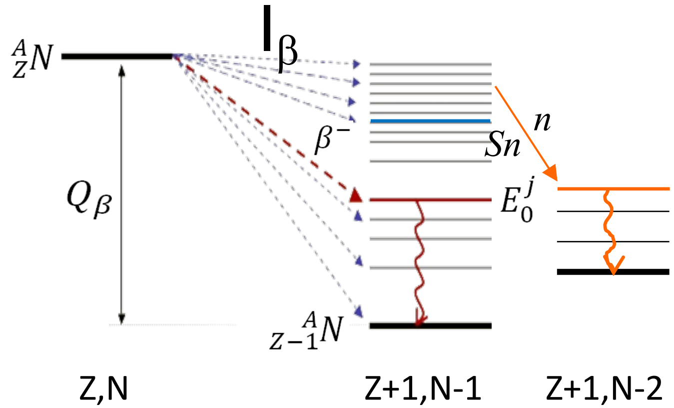
Motivations for Beta Decay Study and its Applications

Applications of Beta Decay from Fission Products

- Getting access to the beta decay properties

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y^{*} + e^{-} + \overline{\nu}_{e}$$

$$\hookrightarrow {}^{A}_{Z+1}Y^{*} \rightarrow {}^{A}_{Z+1}Y + \gamma s$$



- The exploitation of the products of the beta decay is multifold:

Nuclear Energy

- The released γ and β contribute to the "**decay heat**" → critical for reactor safety and economy
- β-n emitters: **delayed neutron fractions** → important for the operation and control of the chain reaction of reactors
- The **antineutrinos** escape and can be detected → reactor monitoring, potential non-proliferation tool and essential for fundamental physics
  - ✓ But γ and β emission → indirect access to antineutrino energy spectra

Neutrino Physics

Nuclear Astrophysics

- β–decay plays an important role in the **r-process**: n-capture (n,γ) and (γ,n) photodisintegration

equilibrium and β-decay

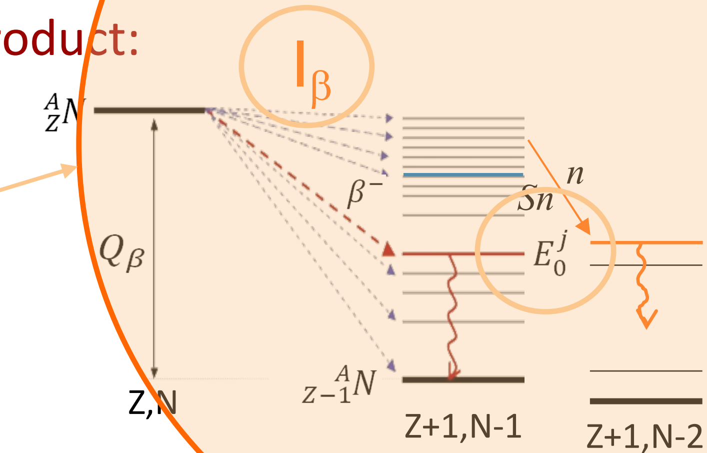
- γ or β measurements: **2 experimental methods**

Getting access to the β / $\bar{\nu}$ energy spectra of a fp

- Measurement of well identified fission product:

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y^{*} + e^{-} + \bar{\nu}_e$$

$$^{A}_{Z+1}Y^{*} \rightarrow {}^{A}_{Z+1}Y + \gamma s$$



γ–spectroscopy measurements (TAGS)

- Total energy spectrum of a fission product:

$$S_{fp}(Z,A,p) \propto \sum_{b=1}^{N_b} I_{\beta\,fp}^{\;b} \times S_{fp}^{\;b}\left(Z_{fp}, A_{fp}, E_{0\,fp}^{\;b}, E\right)$$

- Energy spectrum of a b branch of a fission product:

$$S_{fp}^{b}(p) \propto \underbrace{p^2(Q - T_e)^2}_{\text{Phase space}} \underbrace{F(Z',p)}_{\text{Fermi function}} \underbrace{C(Z,p)}_{\text{Shape factor}} \underbrace{(1+\delta(Z,A,p))}_{\text{Subdominant corrections}}$$

+ Theory: A. Beloeuvre's PhD thesis : collaboration with S. Péru (CEA, DAM) and M. Martini (IPSA)

electron measurements (e-Shape)

Courtesy M. Estienne

γ-Spectroscopy Measurement

γ Measurement Caveat

- Before the 90s, conventional detection techniques: high resolution γ-ray spectroscopy
  - Excellent resolution but efficiency which strongly decreases at high energy
  - Danger of overlooking the existence of β-feeding into the high energy nuclear levels of daughter nuclei (especially with decay schemes with large Q-values)

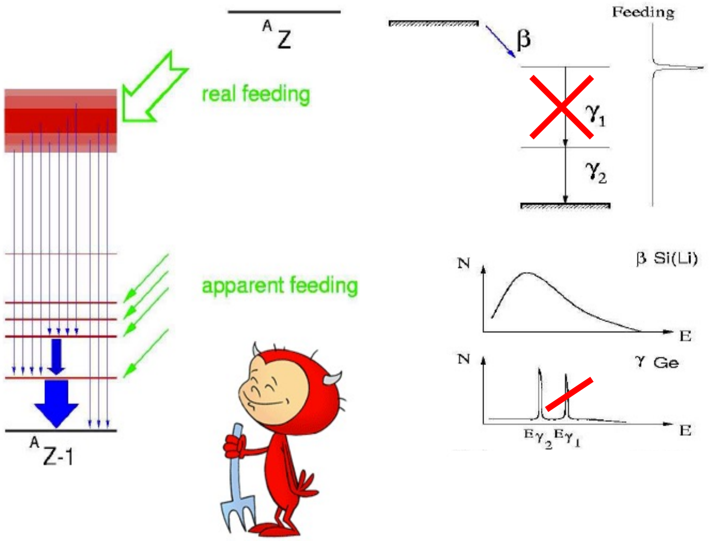
- Incomplete decay schemes: overestimate of the high-energy part of the FP β spectra

- Phenomenon commonly called « pandemonium effect** » by J. C Hardy in 1977

** J.C.Hardy et al., Phys. Lett. B, 71, 307 (1977)

➡ **Strong potential bias in nuclear data bases and all their applications** (i.e. indirect effect on summation calculations for DH and anti-ν energy spectra)

Picture from A. Algora



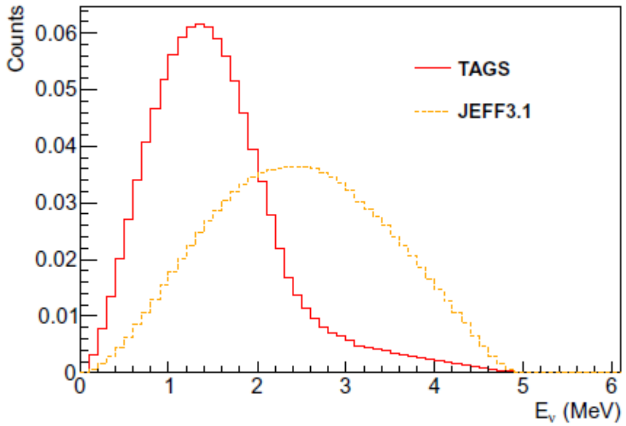
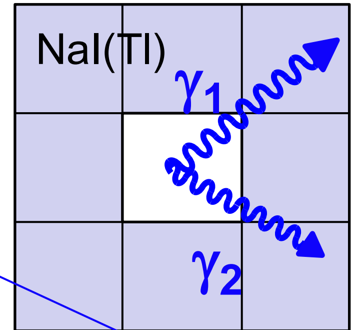
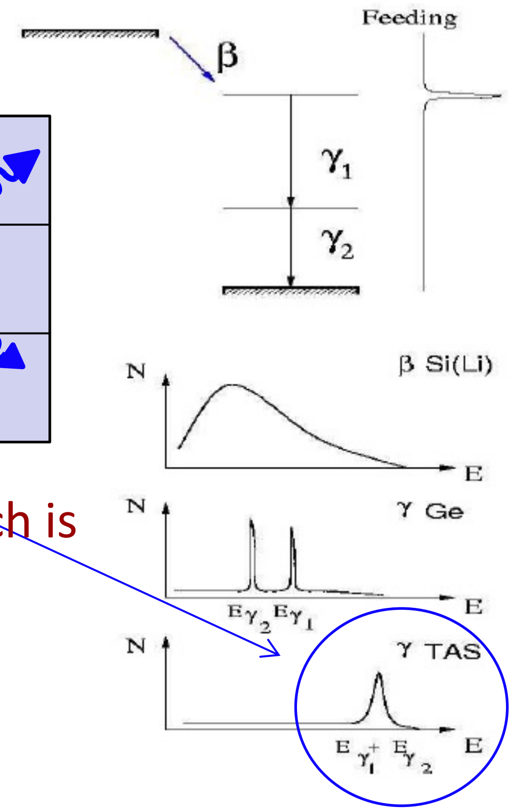


FIG. 1. Illustration of the pandemonium effect on the ^{105}Mo nucleus anti-ν energy spectrum presents in the JEFF3.1 data base and corrected in the TAS data.

TAGS: a Solution to the Pandemonium Effect

- Total absorption γ-ray spectroscopy (TAGS)
  - A TAS is a calorimeter
  - It contains big cristals covering 4π
  - Instead of detecting the individual gamma rays, absorbs the full gamma energy released by the gamma cascades in the β-decay process





- An ideal TAS would give directly the β-intensity I_β which is linked with the β-strength S_β:

$$I_i = \frac{f_i}{\sum_k f_k} \quad \Rightarrow \quad S_i = \frac{I_i}{f(Q_\beta - E_i)T_{1/2}} \quad [s^{-1}]$$

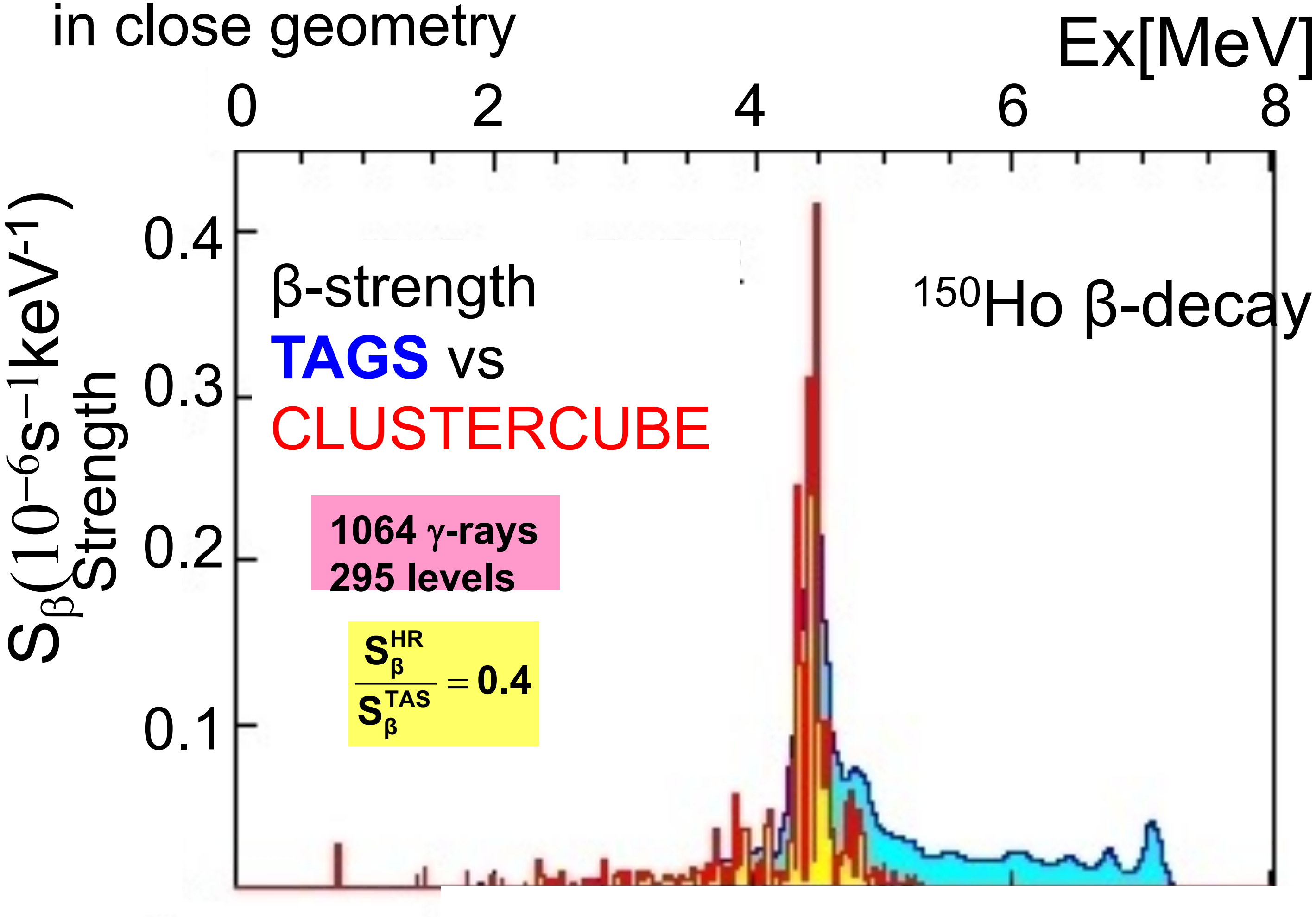
- Calculation of level energy feeding through the resolution of the inverse problem by deconvolution
  - R_{ij} = matrix detector response
  - d_i = measured data
  - Extract f_j the level feeding by deconvolution

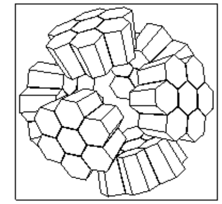
$$d_i = \sum^{m} R_{ij} \cdot f_j$$

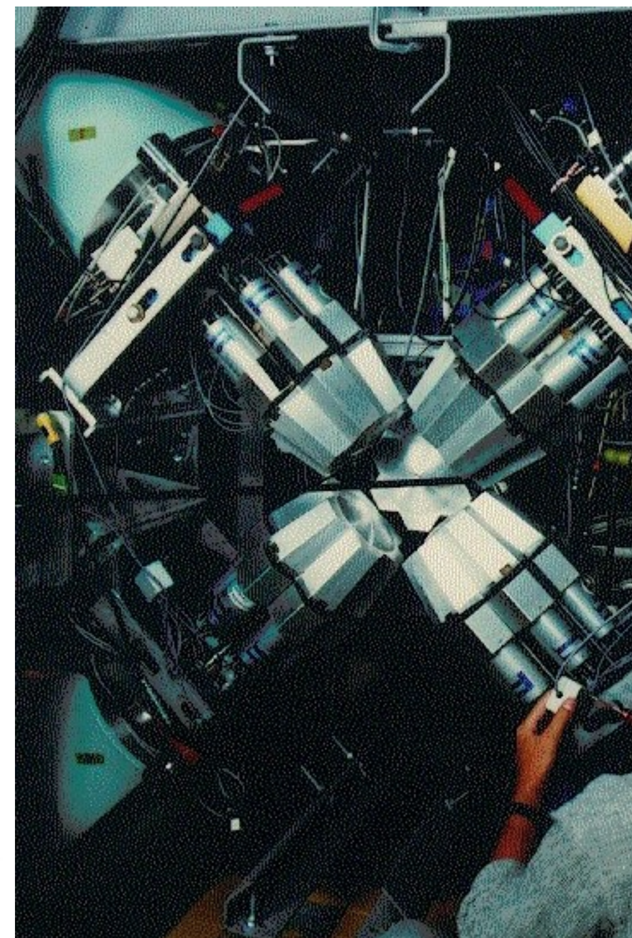
NIM A430 (1999) 333
NIM A430 (1999) 488
NIM A571 (2007) 719
NIM A571 (2007) 728

High Resolution & TAGS Complementarity

Six EUROBALL CLUSTER detectors
in close geometry

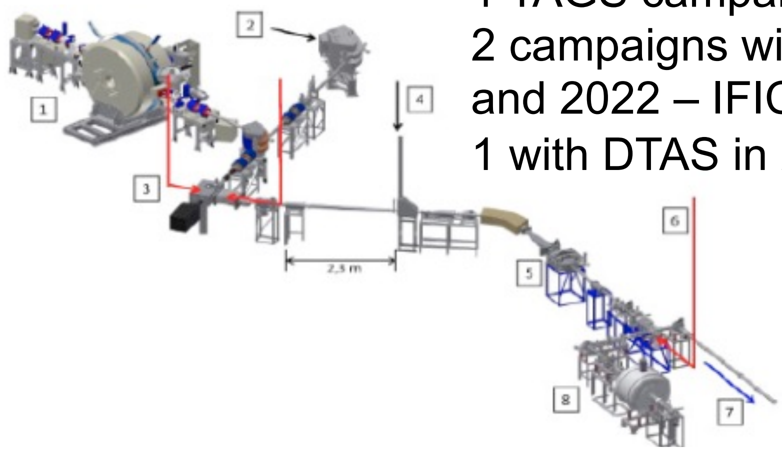




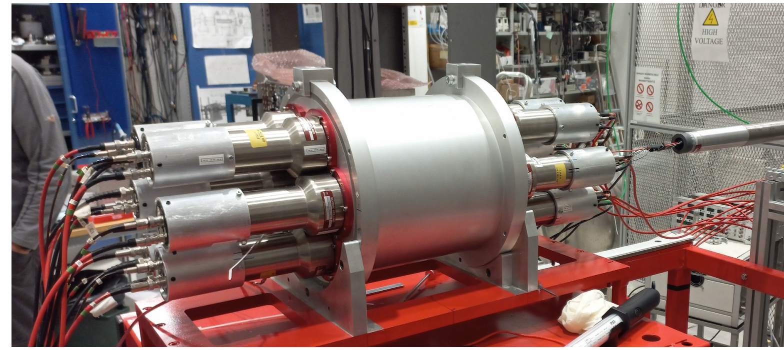


A. Algora, B. Rubio et al PRC 50 (2002)

TAGS Campaigns @ IGISOL

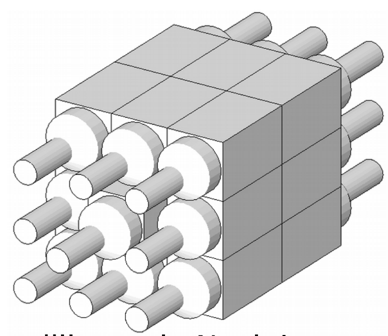


1 TAGS campaign in 2005 IFIC
2 campaigns with Rocinante in 2009 and 2022 – IFIC - Subatech
1 with DTAS in 2014 - IFIC - Subatech



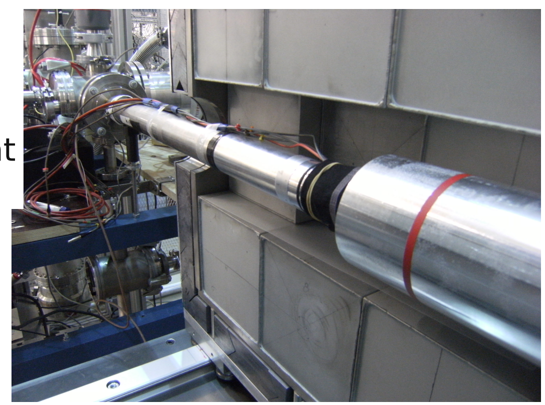
- DTAS = 18 crystals of NaI(Tl)
  - ~90% efficiency for a 1 MeV gamma-ray
  - ΔE/E ~ 5% at 1.3 MeV
- β detector = plastic detector
  - In coincidence with γ → background suppression
  - 30% detection efficiency
- HPGe detector
  - Allows identification of possible contaminant coming from the decay chain

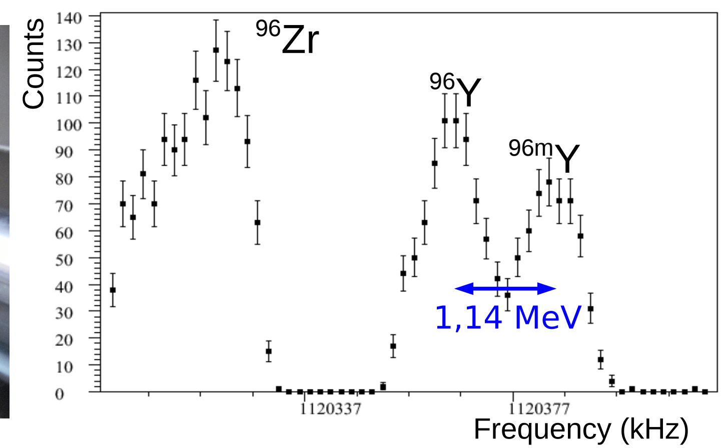
+ Implantation on a tape in the center of the TAS



V. Guadilla et al., Nucl. Instrum. Methods B 376 (2016), p. 334

Why @ IGISOL ?
Because of JYFLTrap
$\Delta m/m \sim 10^{-8}$

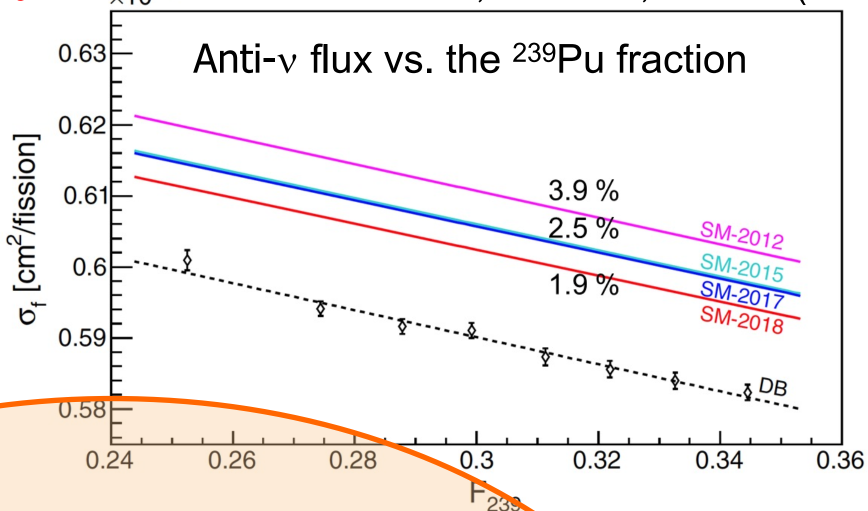




TAGS @IGISOL Jyväskylä

- **Neutrino Physics**

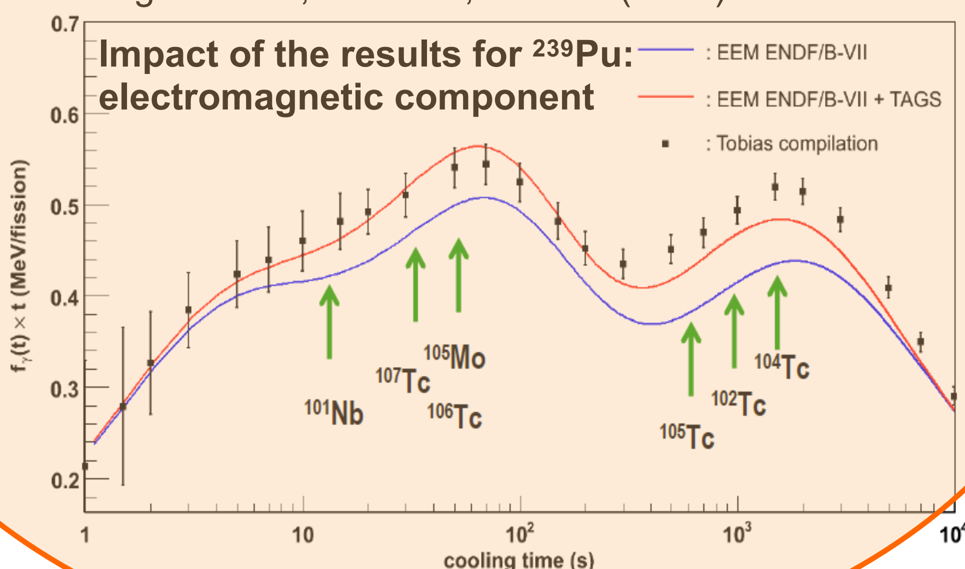
M. Estienne et al., PRL 123, 022502 (2019)



A.Algora et al. PRL 105, 202501 (2010),
M. Fallot et al. PRL 109, 202504 (2012)
D. Jordan et al. PRC 87, (2013) 044318
A.A. Zakari-Issoufou et al. PRL 115, 102503 (2015)
E. Valencia et al., PRC 95, 024320 (2017)
S. Rice et al. PRC 96 (2017) 014320
V. Guadilla et al. PRL 122, (2019) 042502
Review Paper: Algora, Tain, Rubio, Fallot, Gelletly, Eur. Phys. J. A 57, 85 (2021)
+ Data vs model in Daya Bay and STEREO recent papers: DB: PRL 130 (2023) 211801, PRL 129 (2022) 041801, STEREO: Nature 613 (2023) 257

- **Reactor Decay Heat**

A. Nichols et al. Eur. Phys. J. A (2023) **59**: 78
Algora *et al.*, PRL 105, 202501 (2010).



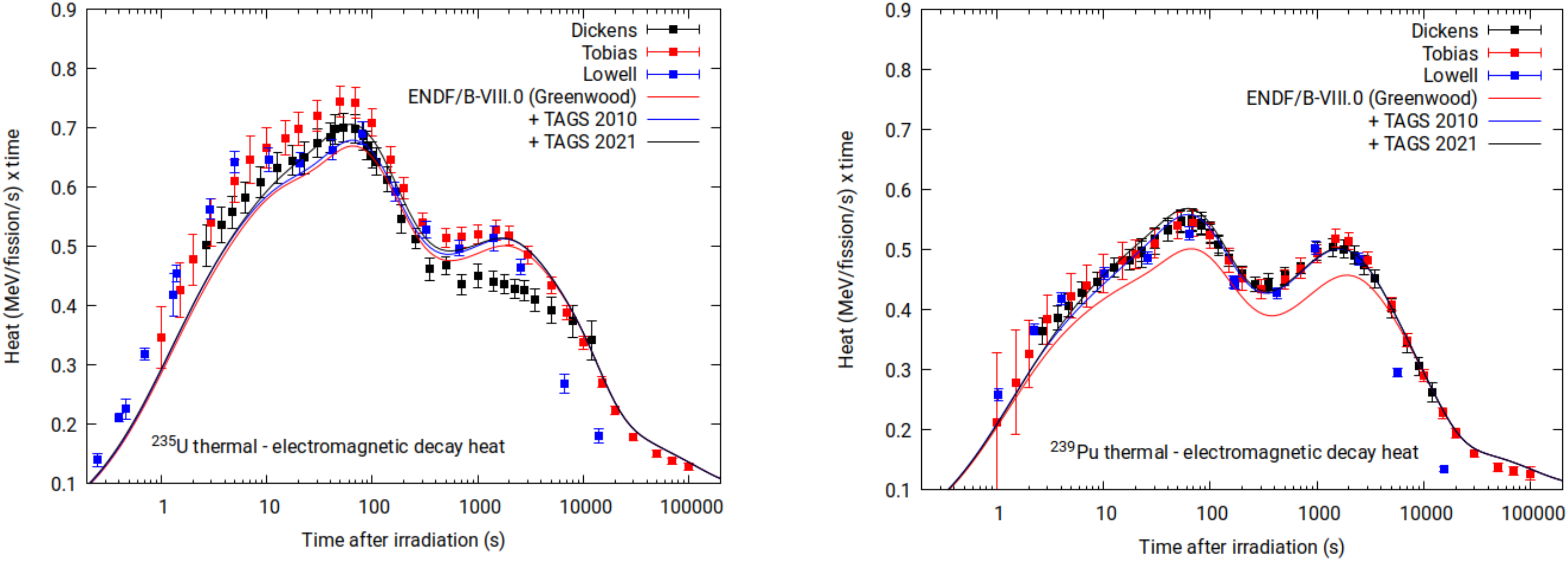
- **R-process & γ/n competition above Sn**

Isotope	$P_\gamma(TAGS)$	P_n
^{87}Br	$3.50^{+0.49}_{-0.40}$	2.60(4)
^{88}Br	$1.59^{+0.27}_{-0.22}$	6.4(6)
^{94}Rb	$0.53^{+0.33}_{-0.22}$	10.18(24)
^{95}Rb	$2.92^{+0.97}_{-0.83}$	8.7(3)
^{137}I	$9.25^{+1.84}_{-2.23}$	7.14(23)

J.L. Tain et al., PRL 115, 062502 (2015)
E. Valencia et al., Phys. Rev. C 95, 024320 (2017).
V. Guadilla et al., Phys. Rev. C 100, 044305 (2019)

Impact of TAGS measurements over the decade

- Improving Fission-product Decay Data for Reactor Applications: Part I - Decay Heat , A. Nichols, P. Dimitriou et al. Eur. Phys. J. A (2023) 59: 78

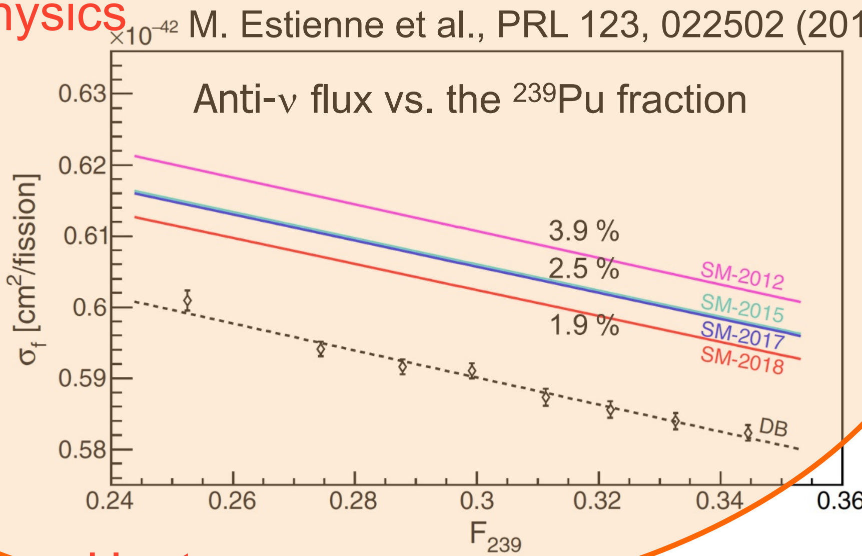


- TAGS 2021 includes decay data with recent measured TAGS data published or communicated before the cut-off date of February 2022 by US MTAS & IGISOL TAGS: clear impact in ^{235}U thermal electromag DH
- TAGS 1st priority: ^{99}Zr, ^{98,99}Nb, ^{106}Tc, ^{130m,132}Sb, ^{138}Cs, ^{142,143}La

TAGS @IGISOL Jyväskylä in 2009, 2014 and 2022

- Neutrino Physics

M. Estienne et al., PRL 123, 022502 (2019)



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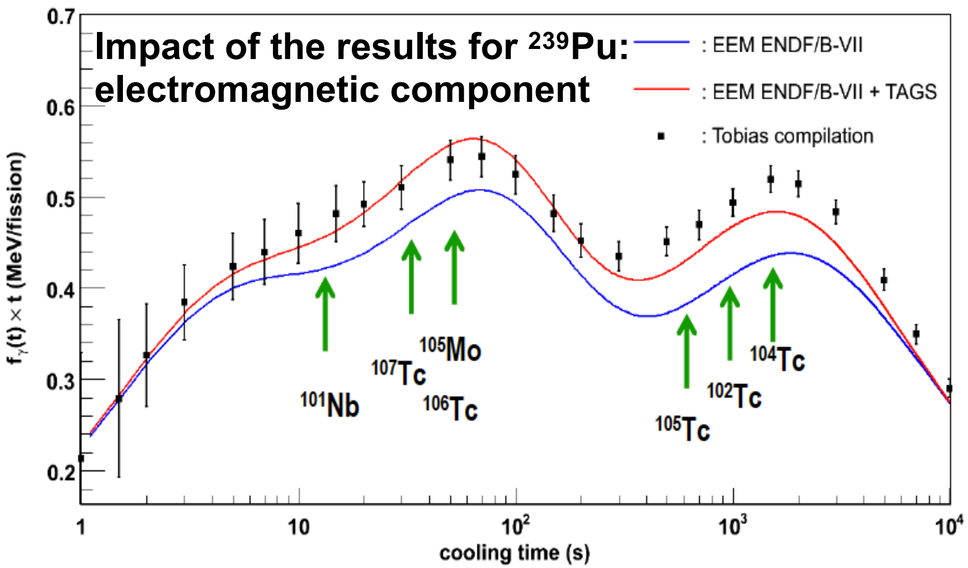

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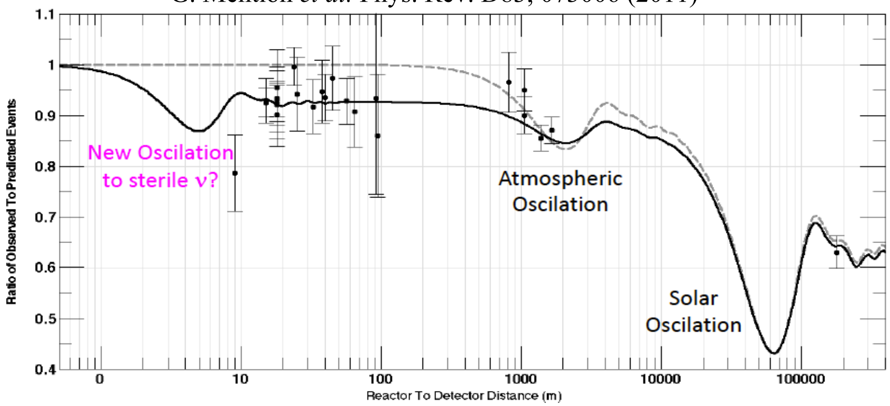
Anomalies of Reactor Antineutrino Energy Spectra

- Measurement of the θ_{13} oscillation parameter by Double Chooz, Daya Bay, Reno in 2012
  - Independent evaluation of anti-ν energy spectra using BDNs
  - 6% deficit in the absolute value of the measured flux compared with the best prediction based on ILL data: reactor anomaly
  - Numerous projects in search of the existence of sterile neutrinos

Y. Abe et al Phys. Rev. Lett. 108, 131801, (2012)
F. P. An et al., Phys. Rev. Lett. 108, 171803 (2012)
J. K. Ahn et al., Phys. Rev. Lett. 108, 191802 (2012)

- In 2014, the same three experiments highlighted a spectrum distortion between 4.8-7.3 MeV compared to nuclear models again! (Shape anomaly)

G. Mention *et al.* Phys. Rev. D83, 073006 (2011)



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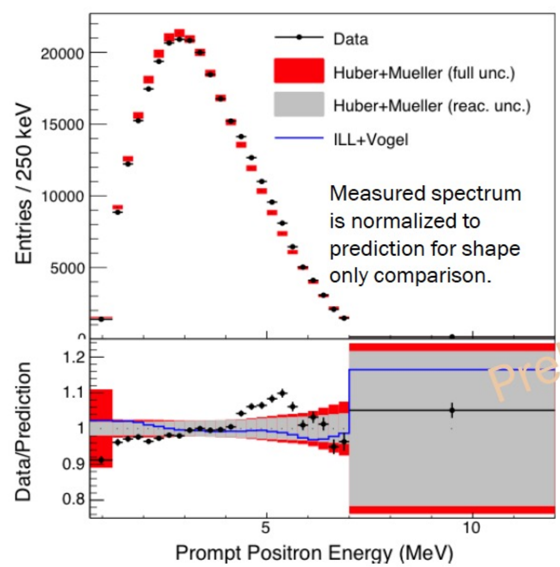
- In 2014, the same three experiments highlighted a spectrum distortion between 4.8-7.3 MeV compared to nuclear models again! (Shape anomaly)
- **Since 2023, issue with the ^{235}U measurement from Schrekenbach et al. confirmed** by Daya Bay, Reno, STEREO, Prospect, Double Chooz, etc. and by **summation calculations based on nuclear data**
- **Research path put forward: first forbidden β-decays could be responsible for the distortion.**

✧ Absolute shape comparison of data and prediction: $\chi^2/ndf = 41.8/21$



- Experimental requirement: direct measurement of electron energy spectra of β decays of well-identified fission products (also known as form factors).

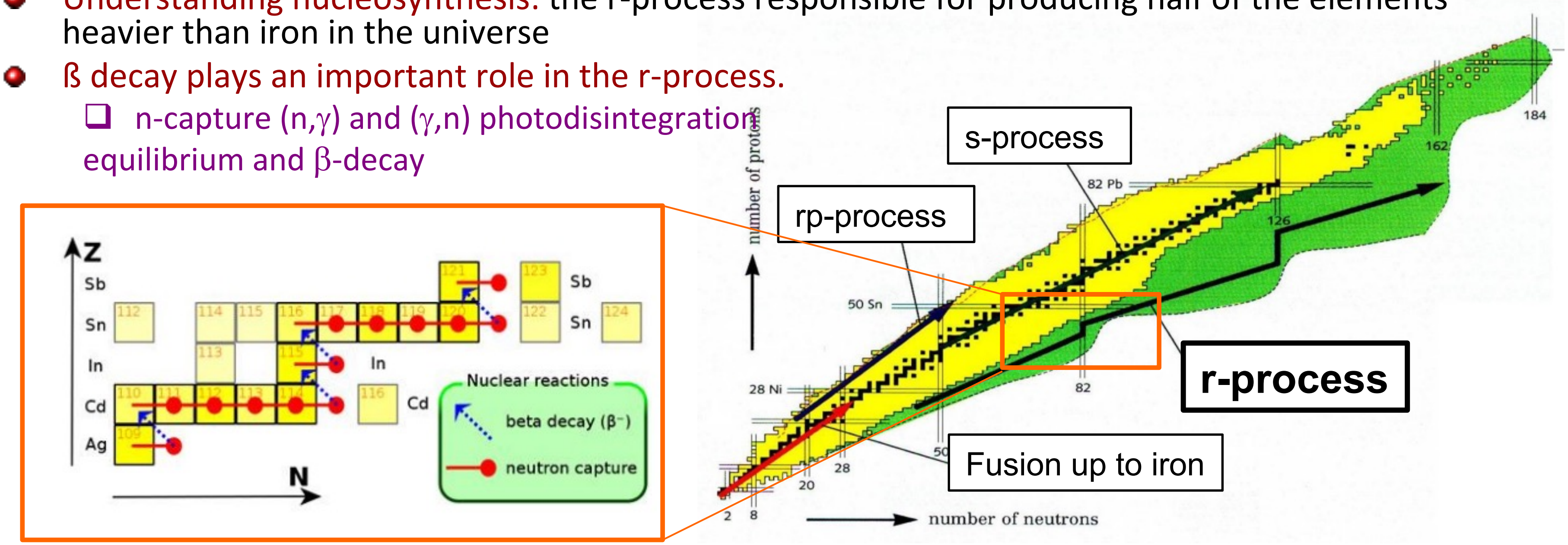
⇨ e-Shape experiment

- Theoretical requirement: take these form factors into account in our calculations for summing antineutrino energy spectra.
- Still more TAGS data: especially for high energy part & future comparison with Juno-TAO

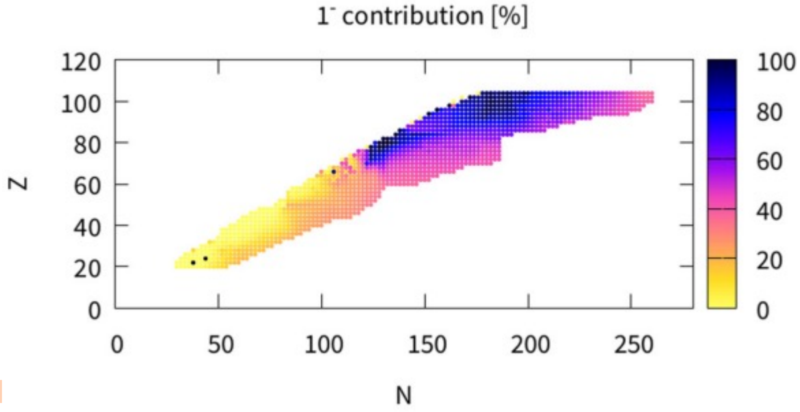
Review paper on the RAA: C. Zhang, X. Qian, M. Fallot, Prog. Part. Nucl. Phys. 136 (2024) 104106

Electron Shape Measurements From Forbidden Decays

- Understanding nucleosynthesis: the r-process responsible for producing half of the elements heavier than iron in the universe
- ß decay plays an important role in the r-process.
  - n-capture (n,γ) and (γ,n) photodisintegration equilibrium and β-decay



- Half-life is an important parameter in r-process models. It represents an integral measure of β-strength.
- First forbidden β decays account for 1⁄3 to ½ of β decays: significant impact on the r-process.



More Recent Results of TAGS experimental campain at IGISOL

Beta decay Study of the ^{96gs}Y and ^{96m}Y

- Physics Motivations for their measurement:
  - DH: their decays produce almost 5% of the DH around 10s after fission in ^{235}U.
    - ✓ 0- ground state: priority 2 for U/Pu and Th/U fuels for IAEA expert committee
    - ✓ 8+ isomeric state: priority 1 for Th/U fuel.
  - Antineutrino spectra: 0^- ground state second most important contributor in 5-7 MeV (11% in 5-6 MeV and 14% in 6-7 MeV)
  - Structure: 8^+ state important to understand the structure of the daughter ^{96}Zr
- In previous measurements of the beta decay of ^{96}Y:
  - Either the 8^+ isomer was not produced
  - Either the beta decay of the GS and the isomer were mixed

    => Analysis of decay pattern relied on previous high-resolution spectroscopy measurements
- Why IGISOL@Jyväskylä?
  - Proton induced fission ion-guide source
  - Mass separator magnet
  - Double Penning trap system to clean the beams
    - ✓ $\delta m/m \sim 10^{-6}$

B.C. Rasco, PRL 117 (2016) 092501
K. Mashtakov et al., PLB 820 (2021) 136569

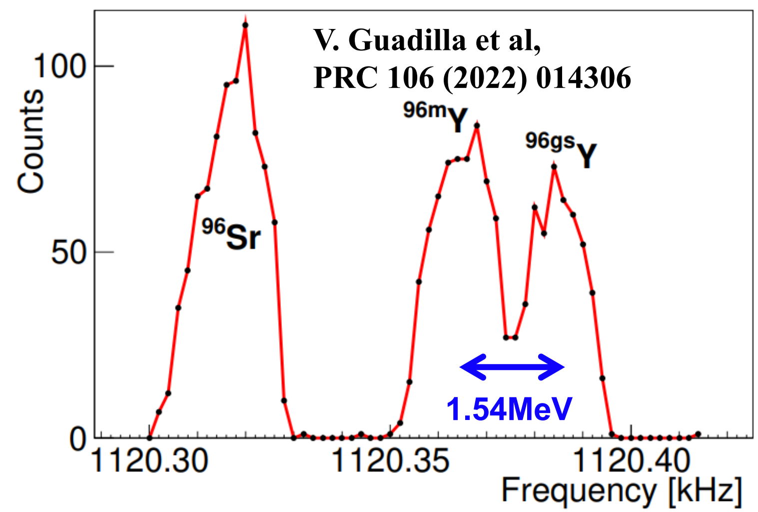
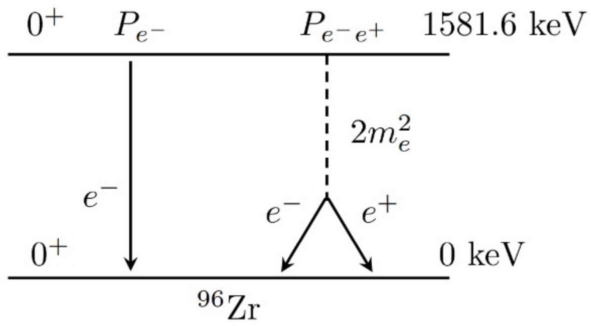


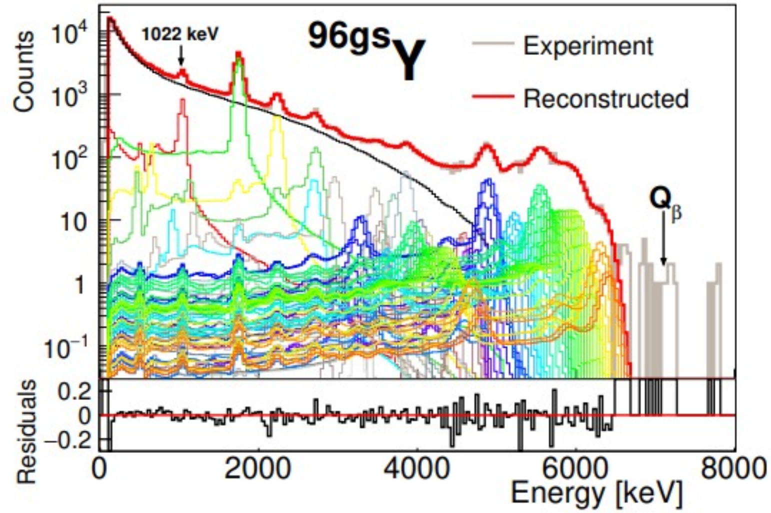
FIG. 1. JYFLTRAP purification trap mass scans for A = 96. The frequency is selected to extract the isobar of interest from the trap.

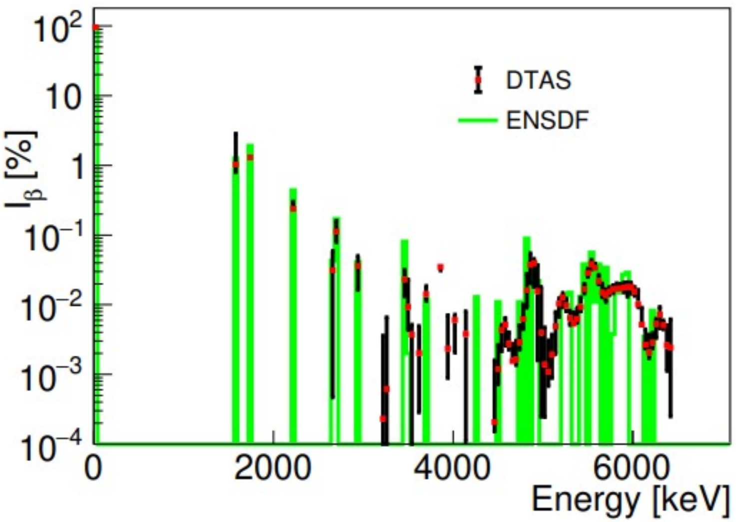
96gsY (0+)



Scheme of the E0 de-excitation of the level at 1581.6keV

V. Guadilla et al, PRC 106 (2022) 014306

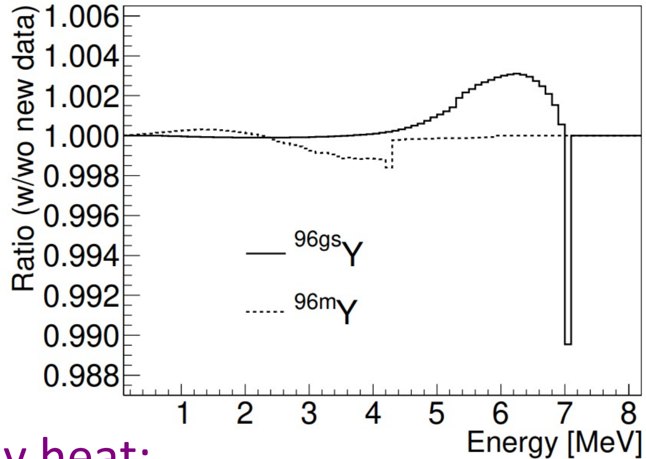




- Main results:
  - ❑ Very good TAGS reconstruction with E0 transition taken into account for the first time!
  - ❑ Nucleus not Pandemonium as expected
  - ❑ Antineutrinos:
    - ✓ No significant change in the flux wrt previous nuclear DB
    - ✓ But important result to validate the uncertainty in the 5-7 MeV range as it is a huge contributor here!
  - ❑ Decay heat:
    - ✓ No significant change in the average beta / gamma energies with respect to JEFF3.3 and ENDF/B-VII.1
    - ✓ Reduced uncertainties

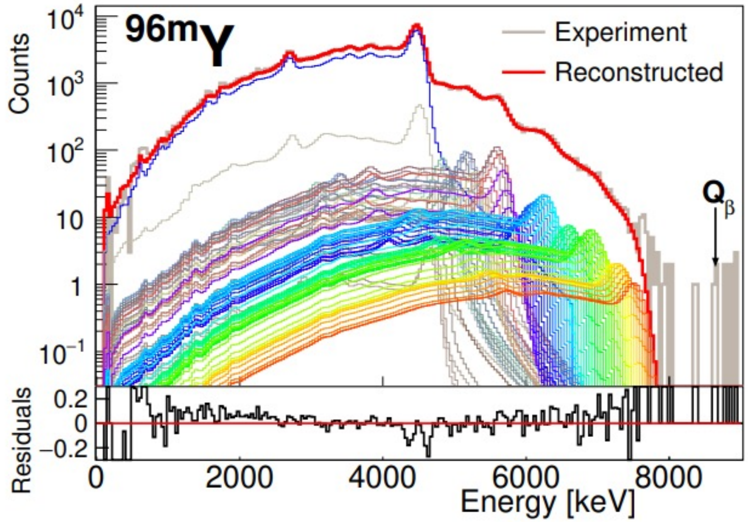
^{96m}Y (8+)

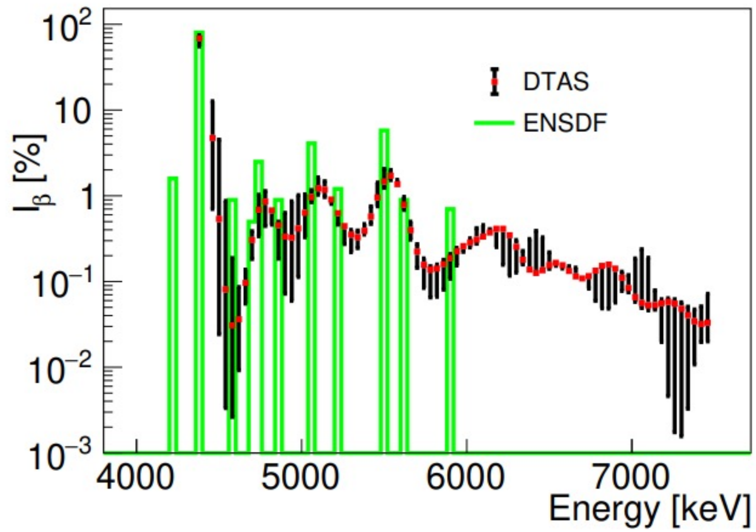
- Main results:
  - Isomer measured for the first time!
  - A clear pandemonium scheme
  - But small contributor in the 5-7MeV range so small impact in antineutrino reactor flux



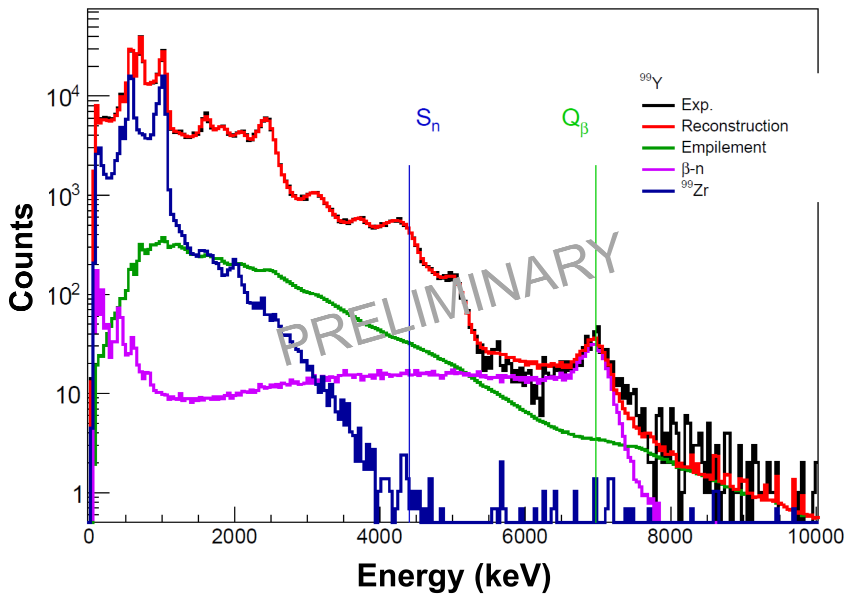
  - Decay heat:
    - ✓ γ average energy larger than 200-300keV w.r.t. JEFF3.3 and ENDF/B-VII.1
    - ✓ β average energy in between JEFF3.3 and ENDF/B-VII
    - ✓ Small impact of both nuclei

V. Guadilla et al, PRC 106 (2022) 014306



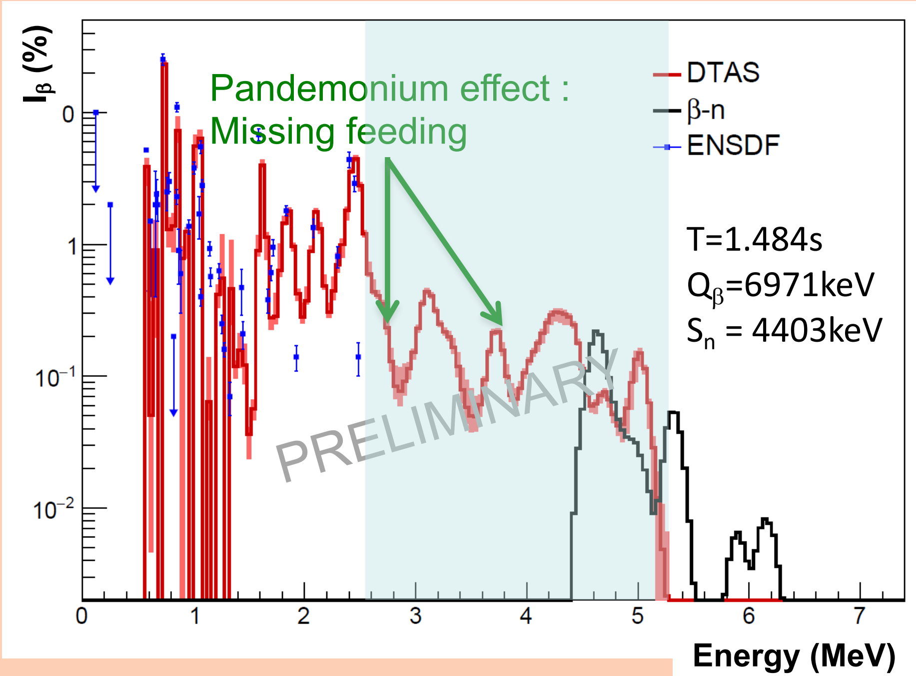


The Case of ^{99}Y



- β–γ coincidences
- $T_{1/2}$ = 1.484s, Q-value: 6971(12) keV
- Contaminants : daughter, pile-up, β-n branch
- ^{99}Y -> ^{99}Zr GS to GS feeding 0%
- Assume Pn value given in ENSDF: 1.77(19)%.

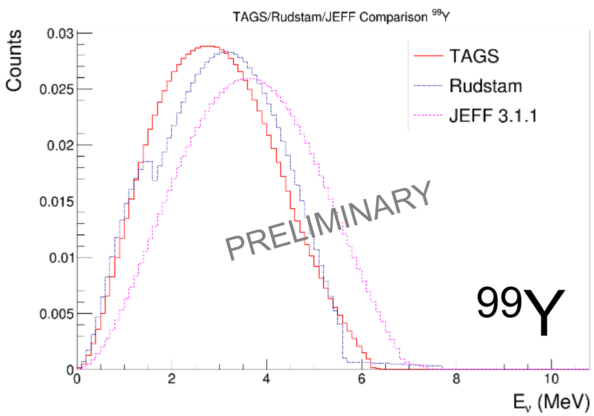
- Physics Motivations for their measurement:
  - Nuclear Structure: ^{99}Y known to be strongly deformed (β2 0.4 + in a region (N=60) of large shape dis- continuity in the Ytrium isotopes
  - Antineutrino spectra: priority 1

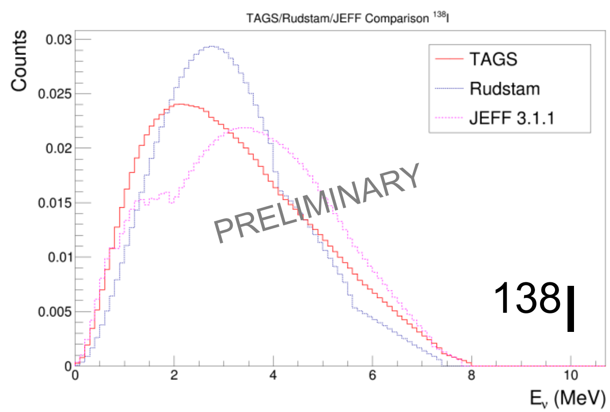


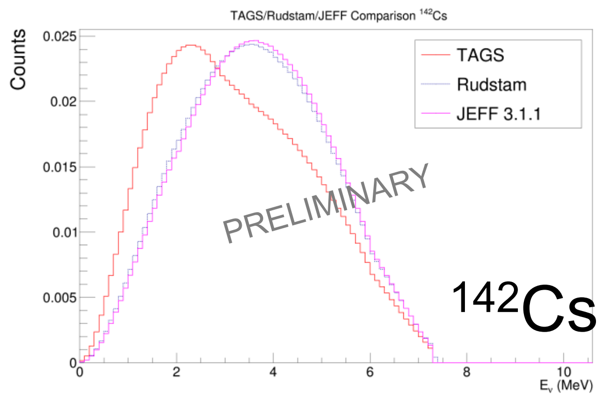
PhD Thesis work:
Loïc Le Meur (Subatech, Nantes)
Publication in preparation

Individual Anti-ν Energy Spectra: ^{99}Y, ^{138}I and ^{142}Cs

- Comparison of the individual antineutrino energy spectra between DTAS and the preferred nuclear database that was used for our previous calculation (Rudstam).
  - Rudstam β spectra converted
  - Non pandemonium free data in JEFF 3.1.1
  - Shift vs low energy in TAS: apparent biases in Rudstam measurement and large error bars
  - Impact the total antineutrino spectrum







Decay	$\overline{E}$	DTAS [keV]	JEFF [keV]	ENDF [keV]
^{142}Cs	γ	1526.3^{+83}_{-54}	676.48	952.37
	β	2535.0^{+25}_{-39}	2919(178)	2919(179)
^{99}Y	γ	1584^{+46}_{-31}	917	1006
	β	2379^{+15}_{-22}	2949(146)	2931(208)
^{138}I	γ	2005^{+106}_{-99}	1325	1420
	β	2475^{+64}_{-33}	2721(125)	3068(290)

PhD Thesis work:
Loïc Le Meur (Subatech, Nantes)
Publication in preparation

The Case of ^{99}Zr

- Physics Motivations for this measurement:
  - Decay Heat: priority 1, from A. Nichols, P. Dimitriou et al. Eur. Phys. J. A (2023) 59: 78
  - Shape coexistence expected
- Experimental spectrum β–γ coincidences
- Daughter contaminants : ^{99}Zr -> ^{99}Nb and ^{99m}Nb ($T_{1/2}$ = 2.1s)
- GS to GS feeding 0%
- Analysis needs a measurement of the daughter: ^{99}Nb, on-going
- ^{99}Nb is also priority 1 for DH, data available, to be continued…

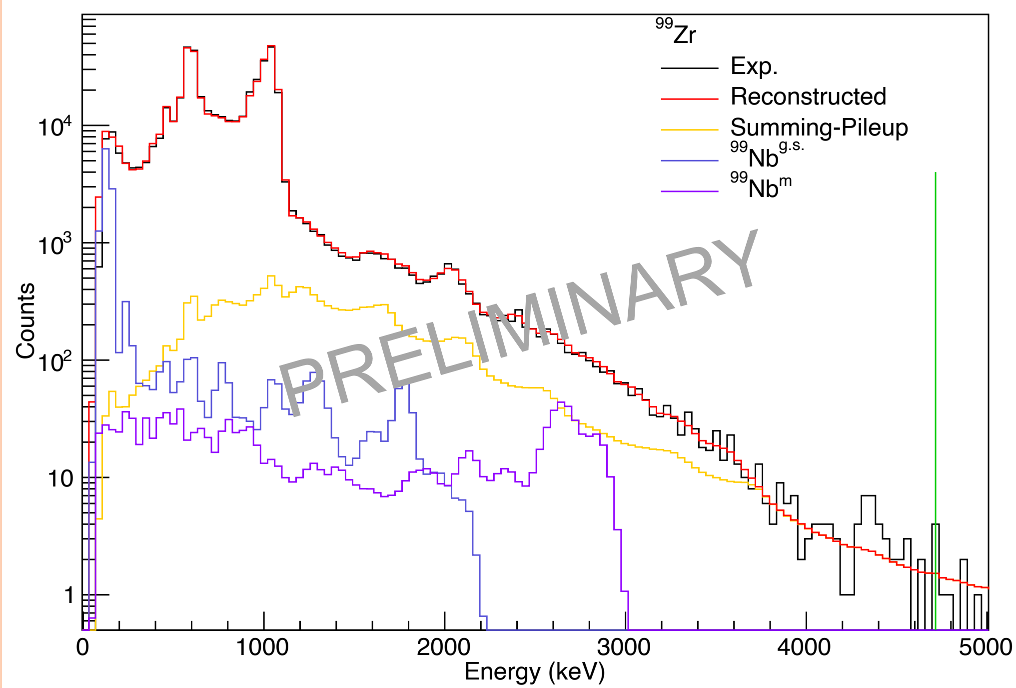


Figure 3.10: *Reproduction of the experimental β-gated spectra with the different contaminants. The Q_β value is drawn in green.*

A. Beloeuvre's PhD thesis

The $(NA)^2$STARS Project

Neutrinos, Applications and Nuclear Structure and Astrophysics with Total Absorption γ-ray Spectroscopy: the $(NA)^2$STARS Project

$(NA)^2$STARS Collaboration

SUBATECH: E. Bonnet, S. Durand, M. Estienne, M. Fallot, S. Nandi, J. Pépin, A. Porta

IFIC Valencia: A. Algora, E. Nacher, S. Orrigo, B. Rubio, J.-L. Tain

GANIL : J.-C. Thomas, U. Guérin, B. Ribeiro

CIEMAT Madrid: D. Cano-Ott

CSIC Madrid: T. Kurtukian Nieto

IP2I: C. Ducoin, N. Millard-Pinard, O. Stézowski

Surrey: W. Gelletly, Z. Podolyak

U. Istanbul: E. Ganioğlu Nutku, L. Şahin Yalçın, M. Yalçınkaya

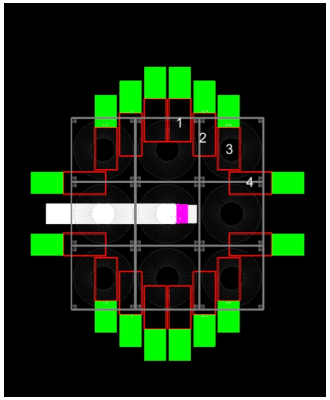
U. Huelva: A. M. Benitez-Sanchez

NPI CAS: A. Cassissa, J. Mrazek, E. Simeckova

$(NA)^2$STARS Project

GOAL: Upgrade of the existent TAS spectrometers **DTAS** and **Rocinante** with **16 $LaBr_3$(Ce) modules** 2”x2”x4”

- Large efficiency of DTAS/Rocinante **+** very good energy resolution and timing of $LaBr_3$
  - Higher segmentation: γ-γ coincidences, angular correlations, γ-cascade multiplicity
  - n/γ discrimination through timing
- Broad physics case: exotic nuclei further away from stability => nuclear structure and astrophysics on the p-rich (p/γ competition >S_p, p-process, rp-process, SNe…) and n-rich sides (n/γ competition >S_n), decay heat, reactor neutrinos…



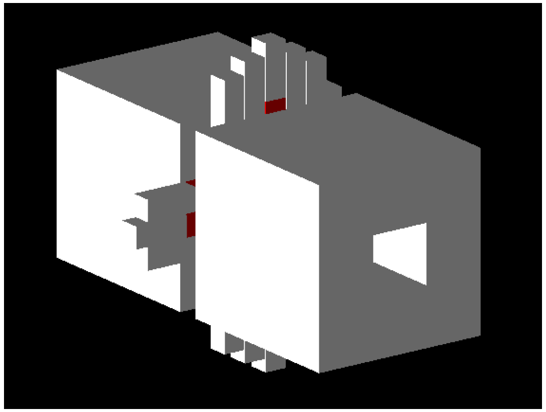


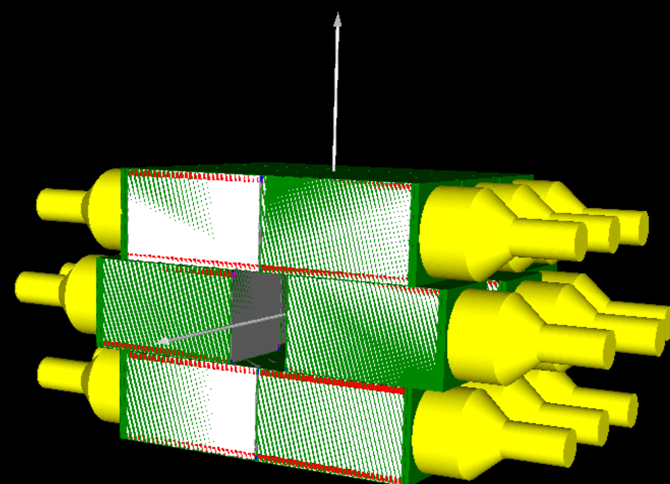
Fig. 4 : view of possible arrangement of the 16 LaBr3:Ce (red) in the middle of the NaI crystals (grey) (courtesy A. Beloeuvre).

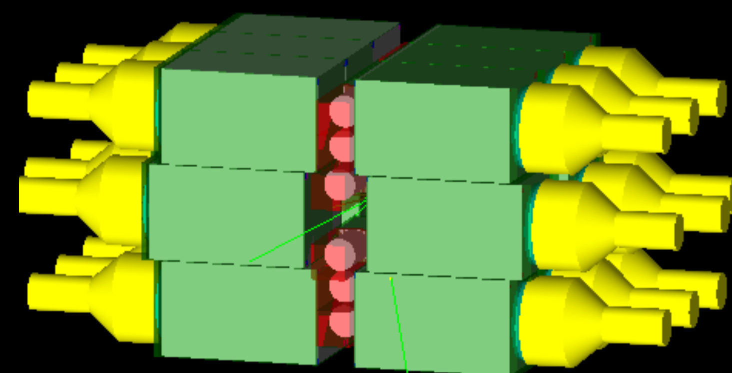
Neutrinos, Applications and Nuclear Astrophysics with a Segmented Total Absorption with higher Resolution Spectrometer

A combination of calorimetric and spectroscopic tools for beta decay and in-beam measurements

The $(NA)^2$STARS project

- E891_23: first proposal approved by GANIL PAC (11/2023)
  - ❑ Experiment @ LISE in early 2026
  - ❑ 13 crystals for the 1st experiment
  - ❑ On-going design studies: example of Geant4 simulations with DTAS





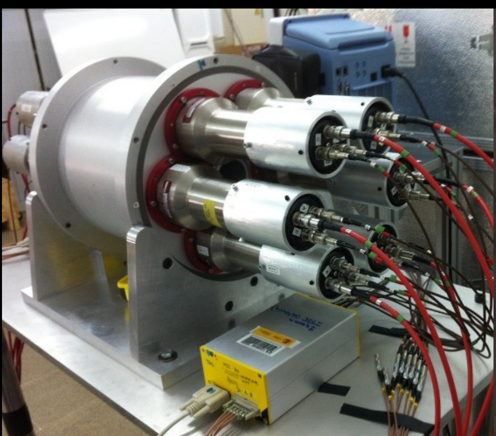
Large 18-fold segmented NaI spectrometer + 13 $LaBr_3$ => enhanced efficiency, improved resolution, good timing

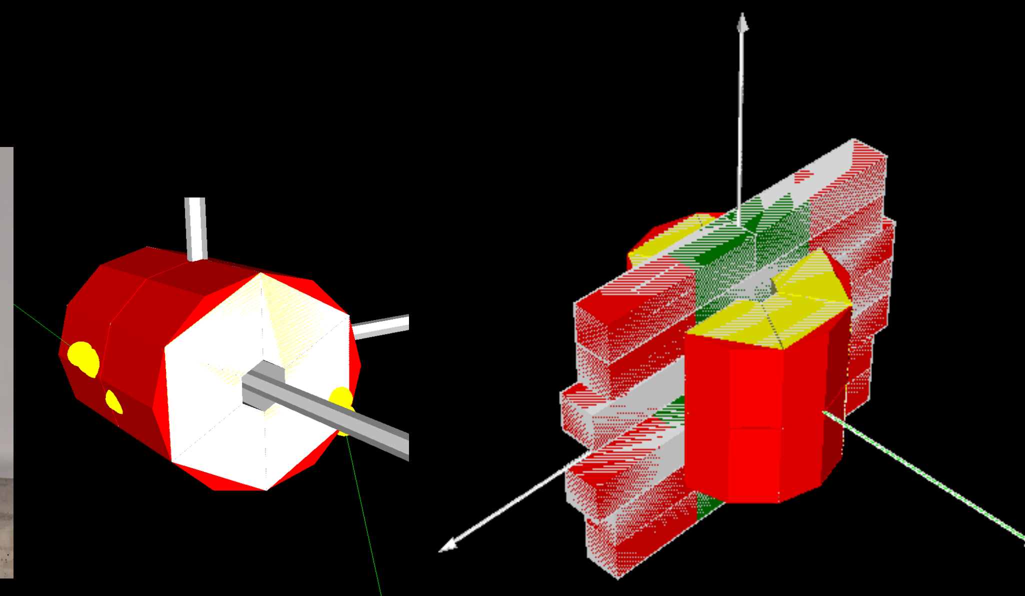
Cascade multiplicity information

Pictures & Drawings: Courtesy A. Algora & M. Estienne

The (NA)^{2}STARS project

- E891_23: first proposal approved by GANIL PAC (11/2023)
  - Experiment @ LISE in early 2026
  - 13 crystals for the 1st experiment
  - On-going design studies: example of Geant4 simulations with Rocinante





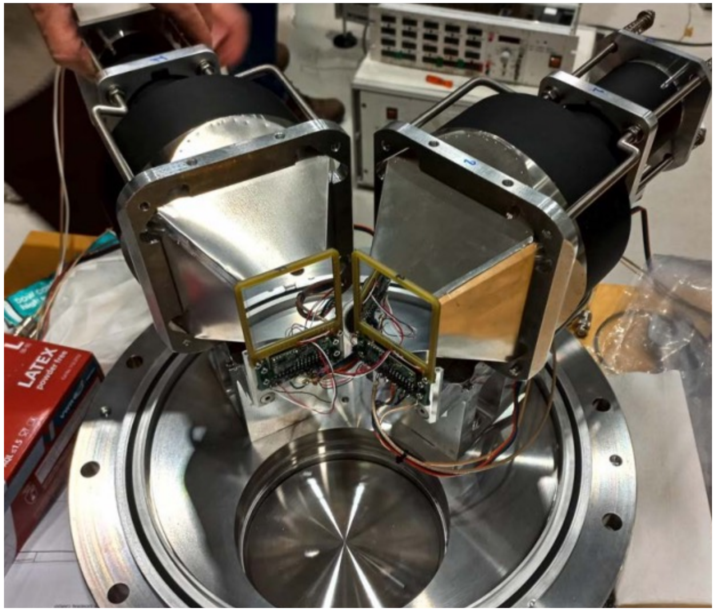
Compact 12-fold segmented BaF_2 spectrometer => refurbished + 13 $LaBr_3$ => improved resolution, good timing, cascade multiplicity information, …

Pictures & Drawings: Courtesy A. Algora & M. Estienne

Electron Spectra Measurement
The e-Shape detector

The e-Shape experiment: Nantes-Surrey-Valencia Collaboration

- ΔE – E telescopes to measure the beta spectrum of selected decays using isotopically pure beams at Jyväskylä with Si and plastic detectors in coincidence
- In vacuum chamber: two **ΔE-E telescopes** as close as possible (solid angle and better efficiency)
- Description of the telescopes:
  - **ΔE**: 500 (or 300) μm thickness Si detector, active area 50x50 mm2
  - **E**: Pl truncated cones, height 110 mm
- Ancillary detectors for gammas: HPGe and CeBr3
- DAQ: successful use of FASTER

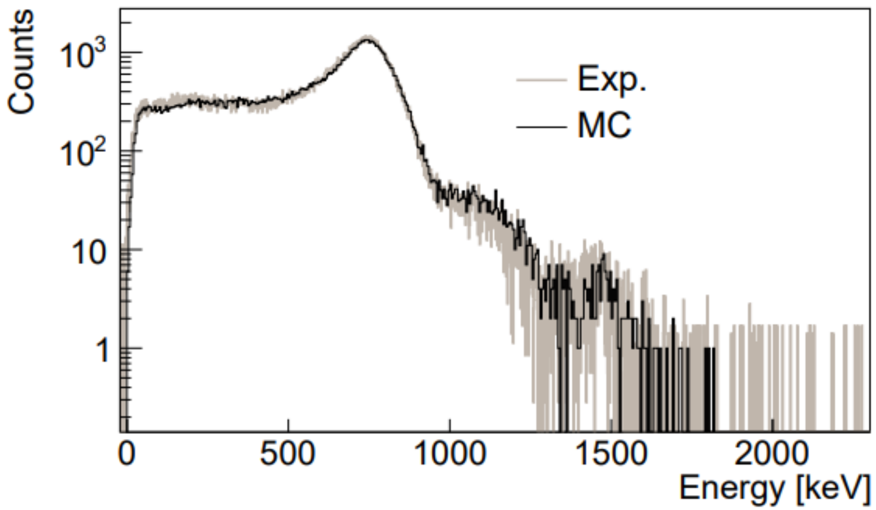


- I206, I233, I233Add IGISOL proposals Univ. of Jyväskylä, Spokespersons: A. Algora, M. Fallot, W. Gelletly, local contact: Tommi Eronen

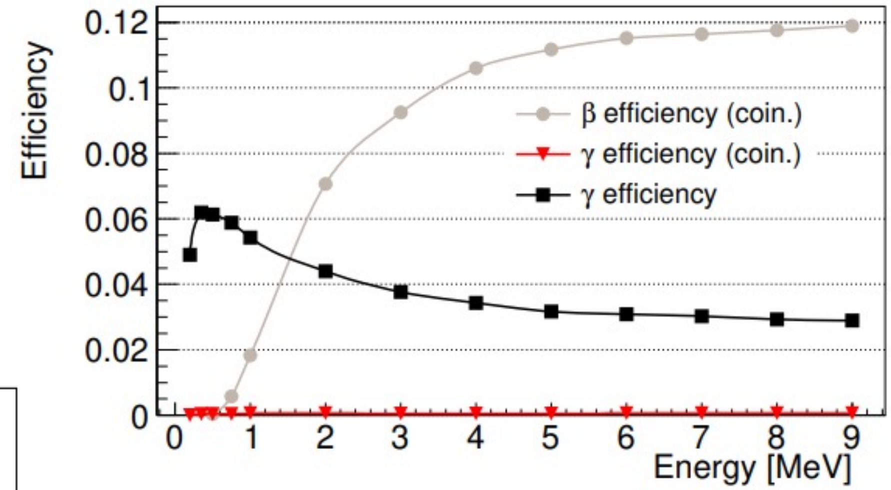
Several works and publications emphasize the need of such measurements:
Hayes et al. PRL 112.202501 (2014), Hayen et al. PRC 99.031311 (2019)
Technical Meeting (IAEA, 2019), Report INDC-NDS-0786, Sonzogni et al. , PRL 119.112501 (2017)

The e-Shape experiment: Detection principle

- **Detection principle:**
  - ❑ ΔE-E system provides very high gamma rejection efficiency
  - ❑ 12% efficiency for β measurements using coincidences

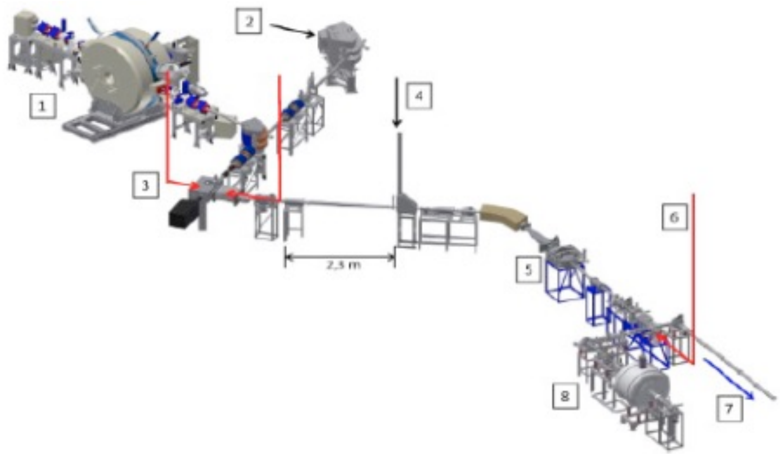


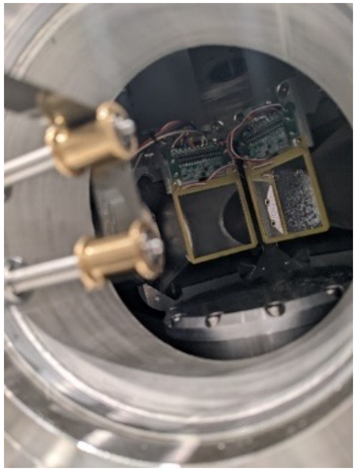
MC reproduction of the ^{207}Bi source at the lab. Plastic detector in coincidence with the silicon detector



- **First commissioning @ex-CENBG Bordeaux, March 2019.**
  - ❑ Monoenergetic electron sources
  - ❑ V. Guadilla *et al.*, accepted to JINST in 2024 (arXiv:2305.13832 [physics.ins-det])

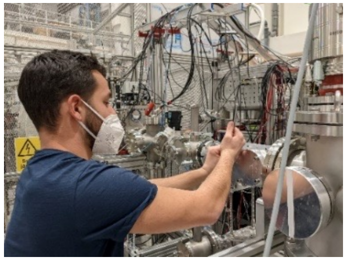
Experimental campaign in 2022





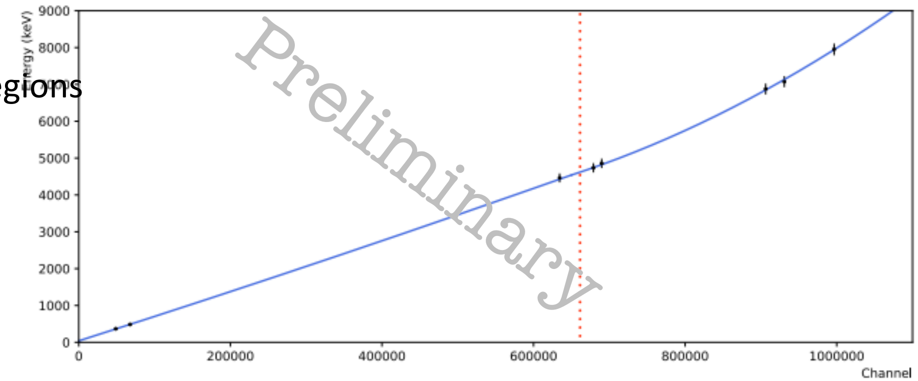
- IGISOL @ Jyväskylä for purified beams
  - Proton induced fission ion-guide source
  - Mass separator magnet
  - Double Penning trap system to clean the beams
- e-Shape experimental campaign **I233&I233Add @ IGISOL (Jyväskylä)**
- A dozen nuclei measured for first forbidden decay interest including nuclei for the detector calibration.
- Analyses ongoing: 2 defended PhD thesis: G. Alcala (IFIC Valencia) and A. Beloeuvre (Subatech)

Ongoing Calibration of 2022 data



- E-Shape calibration: A. Beloeuvre and G. Alcala's PhD thesis
  - ❑ Several aspects covered (in A. Beloeuvre's thesis) due to COVID crisis including first forbidden ß-decay operators in the pnQRPA approach and e-Shape calibration.
  - ❑ A very tricky calibration close to be finalized
    - ✓ Several nuclei for several domains of energy
    - ✓ Iterative procedure and at least two calibration regions

- Simulation: GEANT4 simulation to get the detector response. Validation of the MC for the ^{114}Ag.

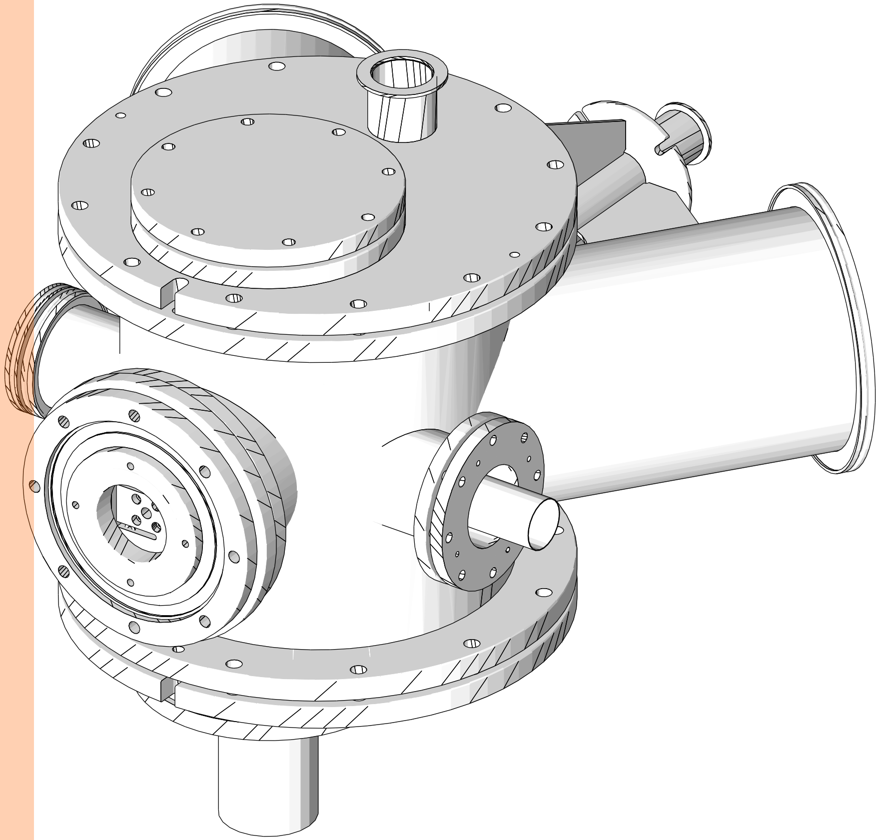


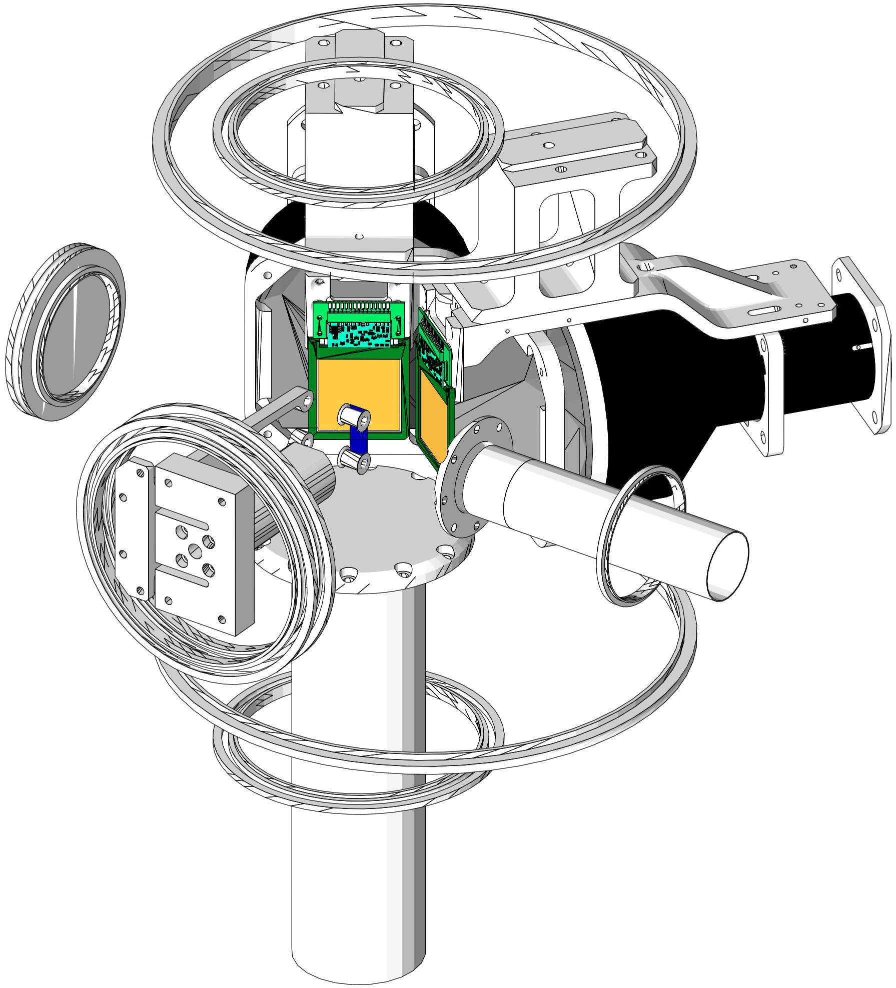
Calibration in energy of the Plastic I

- **A. Beloeuvre's PhD defense in October 2023, Nantes University**

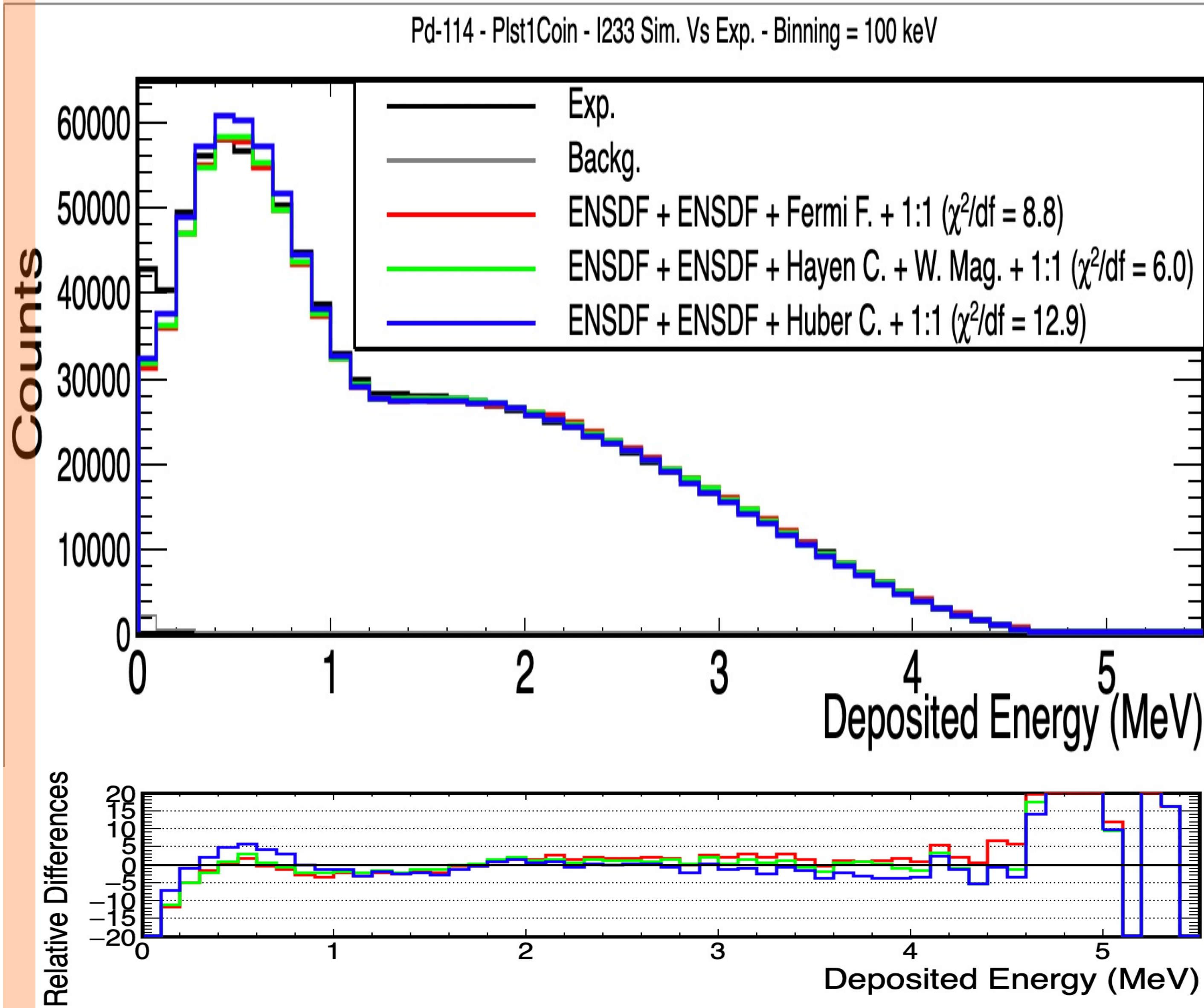
- Next step**:** Analysis using deconvolution techniques of the most relevant contributors using our setup and deduce the spectrum shape for comparison with theoretical predictions.
  - ❑ Master 2 internship in 2024 and new PhD starting in fall 2024: Samuel Durand

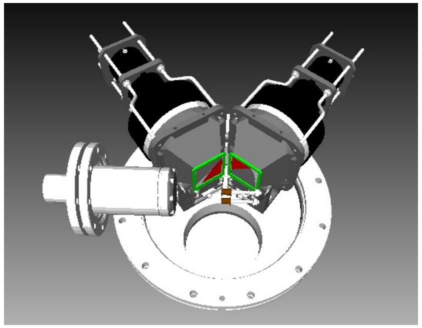
Monte Carlo model of the setup

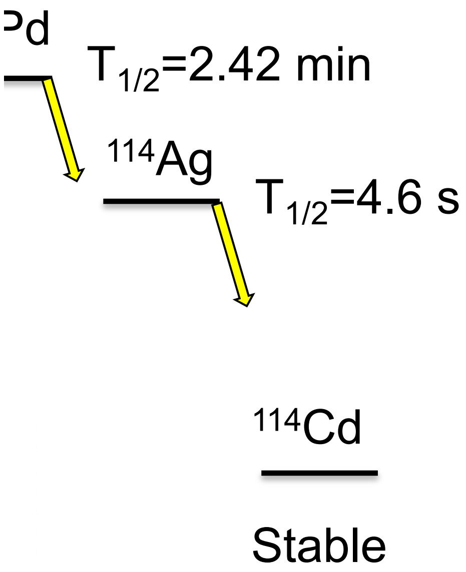




Validation of MC: fresh and preliminary results







G. Alcala PhD thesis IFIC Valencia

Conclusions & Outlooks

Conclusions & Perspectives

- The theoretical and experimental studies of β decays are important for several domains of physics including decay heat and antineutrinos from reactors and nucleosynthesis
- β–intensity can be obtained through g-ray spectroscopy and electron shape measurements
- New TAGS results: publications in preparation
- TAGS Analysis on-going on the newly available data: Julien Pépin's co-directed PhD (IFIC – Subatech) and Soumen Nandi's postdoc (Subatech).
- $(NA)^2$STARS upgrade of the ROCINANTE & DTAS: detector is being developed, MC simulations, mechanical simulations, & laboratory tests on-going. First commissioning mid-2026 at GANIL.
- e-Shape detector built to measured electron spectra from β branches of well identified fission products
- e-Shape detection principle exploits the coincidence between a plastic detector and a silicon detector.
- e-Shape Calibration in good progress and data analysis on-going, ^{92}Rb and ^{96}Y data available
  - A. Beloeuvre's PhD thesis defended October 2023.
  - G. Alcala's PhD thesis in Valencia defended October 2024
  - New PhD starting in Oct. 2024 at Subatech Samuel Durand
  - New Postdoc starting at IFIC 2025 Gustavo Alcala
- Future proposals TAGS & e-Shape foreseen in Jyväskylä, with $(NA)^2$STARS

E-Shape & TAGS COLLABORATION

IFIC Valencia: A. Algora, B. Rubio, J.A. Ros, J.L. Tain, E. Valencia, A.M. Piza, S. Orrigo, M.D. Jordan, J. Agramunt
SUBATECH Nantes: E. Bonnet, S. Bouvier, S. Durand, M. Estienne, M. Fallot, S. Nandi, J. Pépin, A. Porta, J.-S. Stutzmann
U. Surrey: W. Gelletly
IGISOL Jyväskylä: H. Penttilä, Äystö, T. Eronen, A. Kankainen, V. Eloma, J. Hakala, A. Jokinen, I. Moore, J. Rissanen, C. Weber
CIEMAT Madrid: T. Martinez, L.M. Fraile, V. Vedia, E. Nacher
IJCLab: M. Lebois, J. Wilson
BNL New-York: A. Sonzogni
Istanbul Univ.: E. Ganioglu
GANIL: B. Riberio, J.-C. Thomas

Special thanks to my close collaborators from Subatech who were (and are stil!) involved in the instrumental developments for the recent experimental campaigns or new projects making them possible

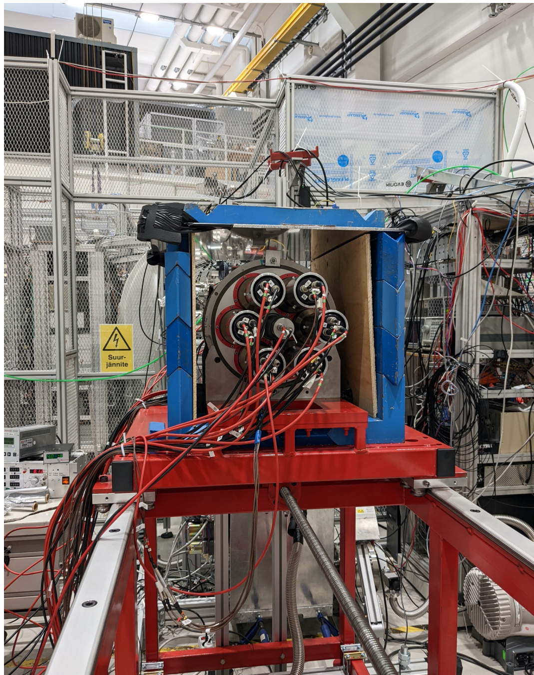
Special thanks to the young researchers working in the project:
J. Pépin, S.Durand, A. Beloeuvre, G. Alcala, V. Guadilla, R. Kean, L. Le Meur, J.A. Briz, E. Valencia, S. Rice, A. -A. Zakari-Issoufou
Discussions with and slides from: A. Algora, M. Estienne, A. Porta, J. L. Tain, B. Rubio, E. Bonnet, S. Orrigo, W. Gelletly, C. Ducoin, O. Stezowski, J.-C. Thomas, P. Chauveau, P. Delahaye, H. Savajol, F. de Oliveira, B. Blank, B. Bastin, A. Sanchez, …are acknowledged

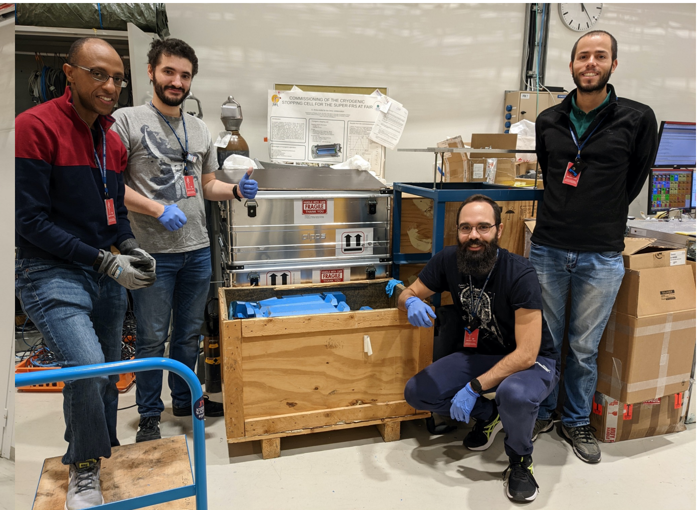
Thank you!

Thanks are due to my colleagues from Nantes, IFIC, Surrey, Warsaw, and Jyväskylä,
Without them this work could have not been possible

Main contributors: Alejandro Algora, Magali Estienne, Amanda Porta, Stéphane Bouvier, Victor Guadilla, Gustavo Alcala, Arthur Beloeuvre, Julien Pépin, Soumen Nandi, Samuel Durand, W. Gelletly, Jean-Sebastien Stutzmann, Basile Madiot, Eric Bonnet, et al.

TAGS Campaign @ Jyväskylä





Nantes-Valencia proposal, Very successful experiment, Rocinante Spectrometer(IFIC-Surrey) coupled to the FASTER DAQ by the Subatech team

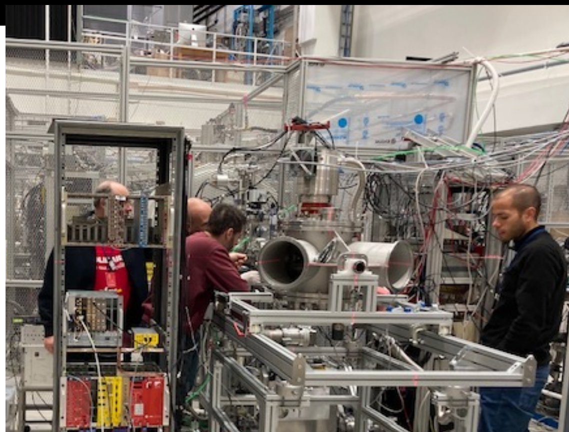
Proposal to the PAC of Jÿvaskÿla

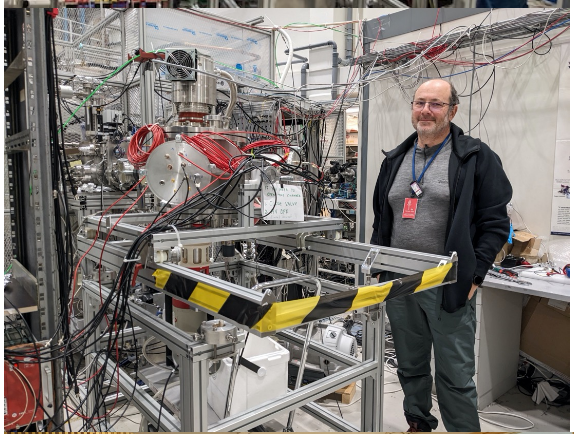
Total absorption spectroscopy measurements for the prediction of the reactor antineutrino spectra

M. Estienne, M. Fallot, V. Guadilla, L. Le Meur, A. Porta
Subatech, CNRS/IN2P3, University of Nantes, EMN, Nantes, France

A. Algora, J. L. Taín, B. Rubio, J. Agramunt, A. Montaner, S. Orrigo, C. Domingo, L. Caballero, A. Tolosa
IFIC,CSIC-Univ. Valencia, Valencia, Spain

E-Shape Campaigns @ Jyväskylä





Thank you Sylvain