Entretien Annuel Projet
TAGS / (NA)²STARS & e-Shape

SUBATECH : E. Bonnet, S. Durand, M. Estienne, M. Fallot, L. Le Floch, J. Pépin, V. Piau, A. Porta

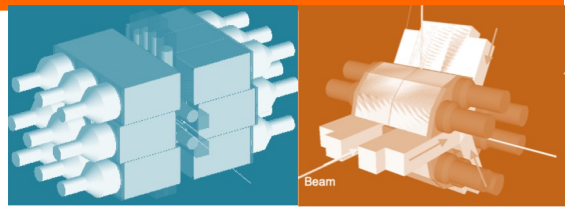
Subatech

cnrs

IMT Atlantique
Bretagne-Pays de la Loire
École Mines-Télécom

Nantes Université

(NA)²STARS Collaboration



- SUBATECH: E. Bonnet, S. Durand, M. Estienne, M. Fallot, L. Le Floch, J. Pépin, V. Piau, A. Porta
- IFIC Valencia: A. Algora, E. Nacher, S. Orrigo, B. Rubio, J.-L. Tain
- GANIL : J.-C. Thomas, H. 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

TAGS/(NA)²STARS : Équipes in2p3 concernées

Equipe 1 Subatech
Eric Bonnet
Magali Estienne
Muriel Fallot
Amanda Porta
Julien Pépin (doc)
Samuel Durand (doc)
Lena Le Floch (doc)
Valentin Piau (postdoc)

Equipe 2
IP2I
Camille Ducoin,
N. Millard-Pinard,
Olivier Stezowsky

Equipe 3
GANIL
J.-C. Thomas, B. Rebeiro, H. Guérin,
…

Responsabilités :
porteurs projets TAGS/e-Shape/(NA)²STARS

Projet (NA)²STARS : p-process & beta decay

Projet (NA)²STARS @ LISE, S³, DESIR

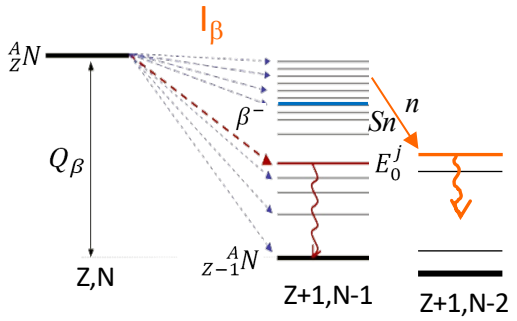
CONTEXTE SCIENTIFIQUE

Getting access to the β decay properties

- Gamma-ray spectroscopy:

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

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



- Electron measurement:

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

Courtesy M. Estienne

Getting access to the β decay properties

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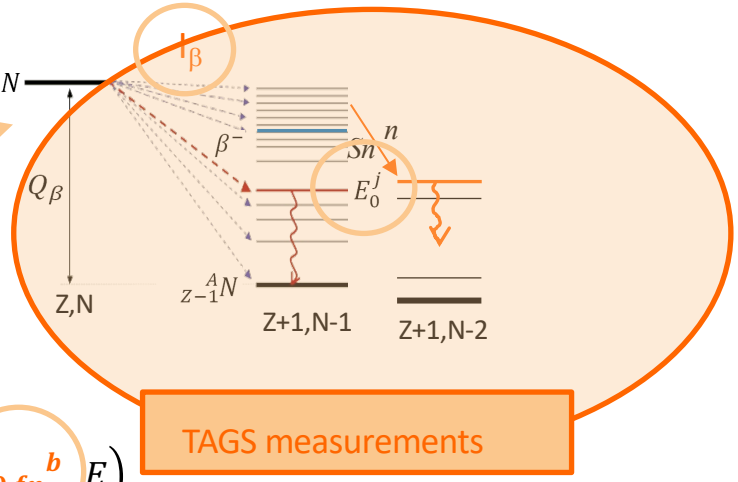

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Courtesy M. Estienne

Getting access to the β decay properties

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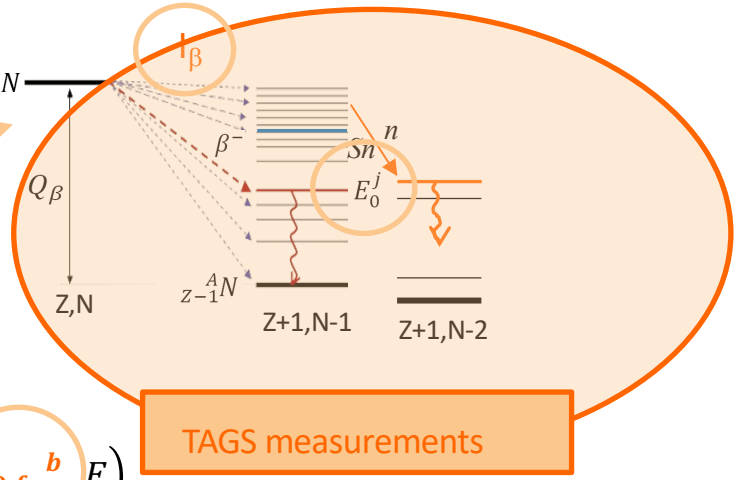


TAGS measurements

- Electron measurement:

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

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

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

eShape measurements

Courtesy M. Estienne

γ Measurement Caveat

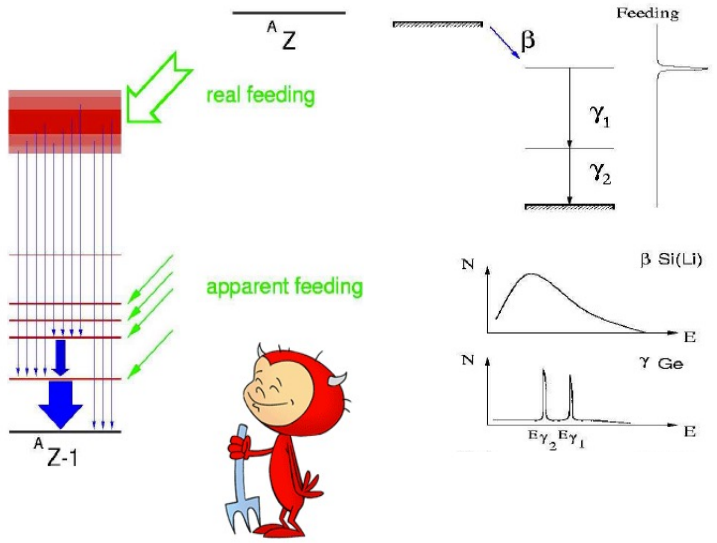
- Before the 90s, conventional detection techniques: high resolution γ-ray spectroscopy
  - Excellent resolution but efficiency which strongly decreases at high energy
  - Danger of overlooking the existence of β-feeding into the high energy nuclear levels of daugther nuclei (especially with decay schemes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

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

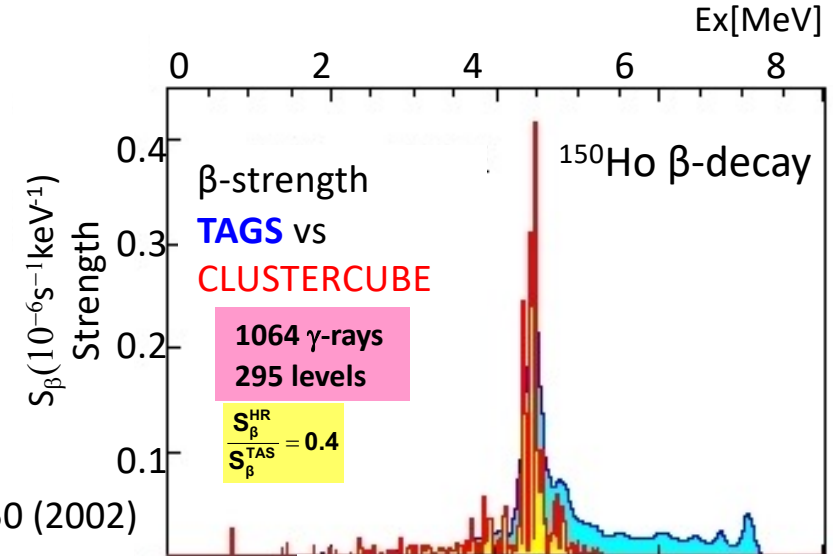
- Phenomenon commonly called « pandemonium effect** » by J. C Hardy in 1977

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

Picture from A. Algora



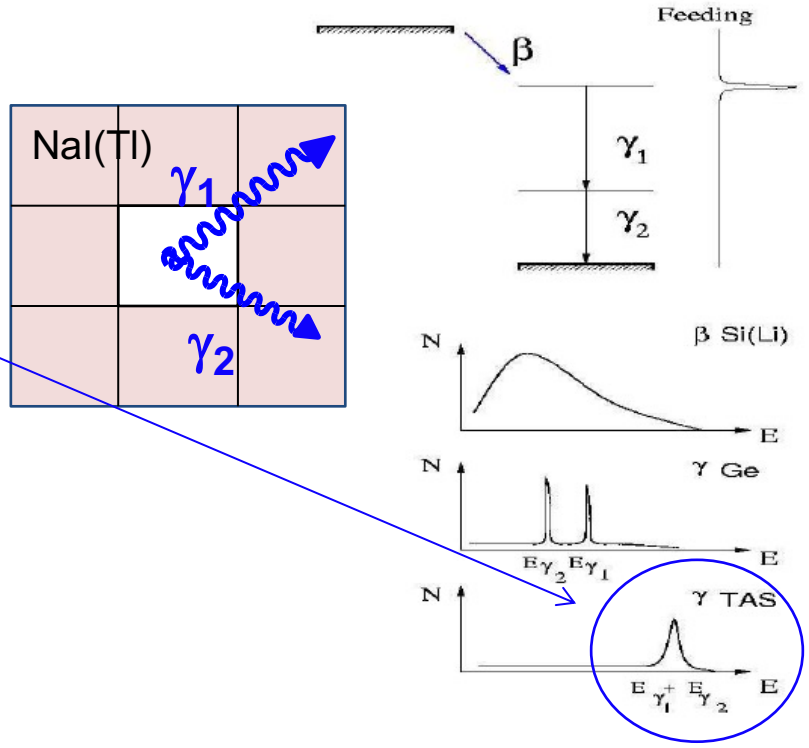
➡ **Strong potential bias in nuclear data bases and all their applications**



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

TAGS: a Solution to the Pandemonium Effect

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



- First TAS developed in the 70's but too small detectors to be efficient. Development of the TAGS method efficient and systematic since the 90's (Greenwood & al.)

- 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

$$d_i = \sum_{j=1}^{m} R_{ij} \cdot f_j \Rightarrow I_i = \frac{f_i}{\sum_k f_k}$$

J. L. Tain & D. Cano-Ott, NIMA 571 (2007) 728

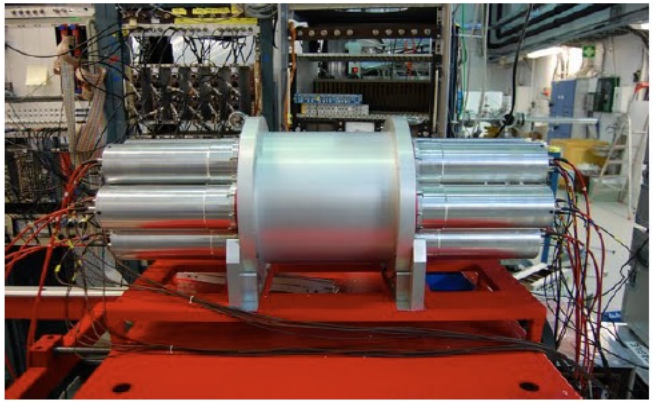
3 TAGS Campains at IGISOL Jyväskylä in 2009, 2014 and 2022

- IGISOL@Jyväskylä:
  - Proton induced fission ion-guide source
  - Mass separator magnet
  - Double Penning trap system to clean the beams

- 2 (segmented) TAS campains : E. Valencia+, PRC 95 (2017)

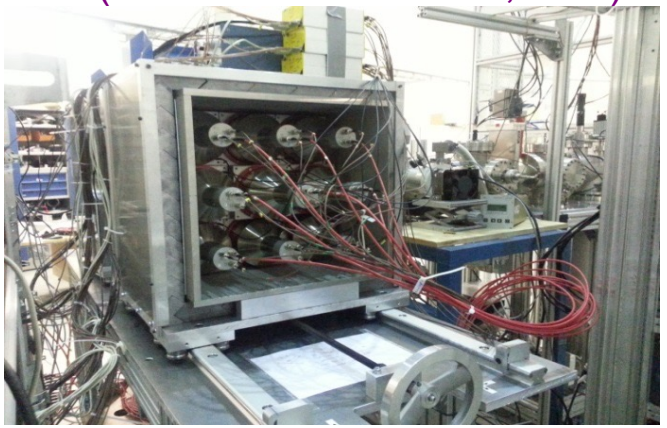
J.L. Tain+, NIM A 803 (2015)
V. Guadilla et al., NIM A (2018)

❑ ROCINANTE (IFIC Valencia/Surrey):



- ✓ 12 BaF_2 crystals
- ✓ Compact, γ-multiplicity
- ✓ ε^p=40% @E_γ=5 MeV
- ✓ ΔE=15% @E_γ=0.66 MeV
- ✓ Low n-sensitivity
- ✓ Good timing Δt=1 ns
- ✓ Coupled with a Si detector for β

❑ DTAS (NUSTAR – DESPEC, IFIC):

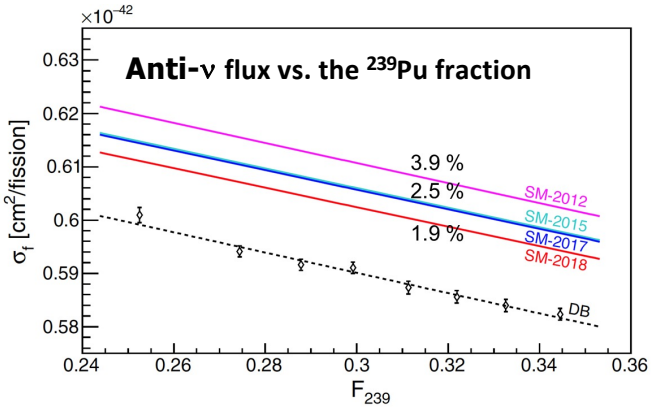


- ✓ 18 NaI(Tl) crystals of 15cm × 15cm × 25 cm
- ✓ Movable, γ-multiplicity
- ✓ ε^p=48% @E_γ=5 MeV
- ✓ ΔE=8% @E_γ=0.66 MeV
- ✓ Moderate n-sensitivity
- ✓ Coupled with a plastic detector

TAGS @ Jyväskylä in 2009, 2014 and 2022

Neutrino Physics

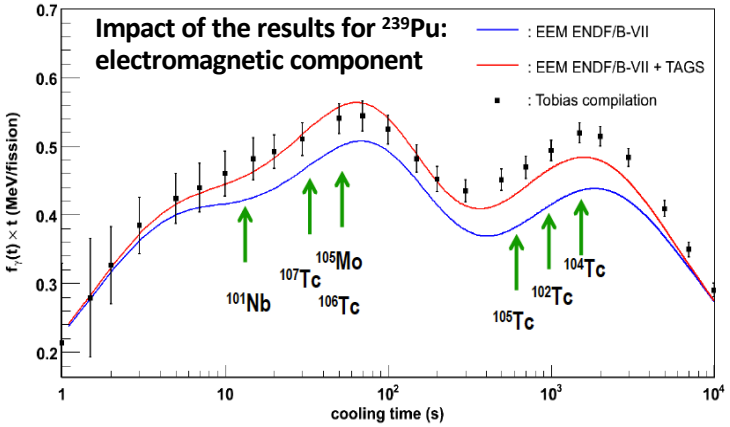
M. Estienne et al., PRL 123, 022502 (2019)



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
V. Guadilla et al. Phys. Rev. C 100, 044305 (2019)
V. Guadilla et al. Phys. Rev. C 106, 014306 (2022)
+ 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)

laboratoire commun CEA/DRF — GANIL — SPIRAL2 — CNRS/IN2P3

PROPOSAL E891_23

GANIL PAC 14/11/2023

Total Absorption Spectroscopy for Nuclear Structure and Nuclear Astrophysics

Spokespersons: M. Fallot[1], S. E. A. Orrigo[2], A. M. Sánchez Benítez[3],

B. Rubio[2], A. Algora[2,4], J.-C. Thomas[5], W. Gelletly[6], B. Blank[7], L. Acosta[8], J. Agramunt[2], P. Aguilera[9], O. Aktas[5], G. Alcala[2], P. Ascher[7], D. Atanasov[7], B. Bastin[5], A. Beloeuvre[1], E. Bonnet[1], S. Bouvier[1], M. J. G. Borge[10], J. A. Briz[11], A. Cadiou[1], D. Cano Ott[12], G. de Angelis[13], G. de France[5], Q. Delignac[7], F. de Oliveira Santos[5], N. de Séréville[14], C. Ducoin[15], J. Dueñas[3], M. Estienne[1], A. Fantina[7], M. Flayol[7], C. Fonseca[2], C. Fougeres[16], L. M. Fraile[11], H. Fujita[17], Y. Fujita[17], D. Galaviz[18], E. Ganioglu[19], F. G. Barba[18], M. Gerbaux[7], J. Giovinazzo[7], D. Godos[8], S. Grevy[7], V. Guadilla[20], F. Gulminelli[21], F. Hammache[14], J. Mrázek[22], O. Kamalou[5], T. Kurtukian-Nieto[10], I. Martel[3], N. Millard-Pinard[15], F. Molina[23], E. Nacher[2], S. Nandi[1], S. Parra[2], J. Pépin[1], J. Piot[5], Z. Podolyak[6], A. Porta[1], B. M. Rebeiro[5], P. Regan[6], D. Rodriguez[2], O. Sorlin[5], C. Soto[15], O. Stezowski[15], C. Stodel[5], J. L. Tain[2], O. Tengblad[10], P. Teubig[18], L. Trache[24]

[1] *Subatech, Nantes, France*
[2] *IFIC-CSIC, Valencia, Spain*
[3] *UHU, Spain*
[4] *Atomki, Debrecen, Hungary*
[5] *GANIL Caen, France*
[6] *Univ. Surrey, UK*
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[8] *Instituto de Física-UNAM, Mexico*
[9] *Univ. Padova and INFN, Italy*
[10] *IEM-CSIC, Spain*
[11] *UCM Madrid, Spain*
[12] *CIEMAT, Spain*
[13] *LNL-INFN, Italy*
[14] *IJCLab, Orsay, France*
[15] *IP2I, Lyon, France*
[16] *ARGONNE, USA*
[17] *RCNP Osaka, Japan*
[18] *LIP-Lisboa, Portugal*
[19] *Univ. Istanbul, Turkey*
[20] *Univ. Warsaw, Poland*
[21] *LPCCAEN, France*
[22] *NPI CAS, Czech Republic*
[23] *CCHEN, Santiago, Chile*
[24] *NIPNE, Romania*

FAITS MARQUANTS 2025

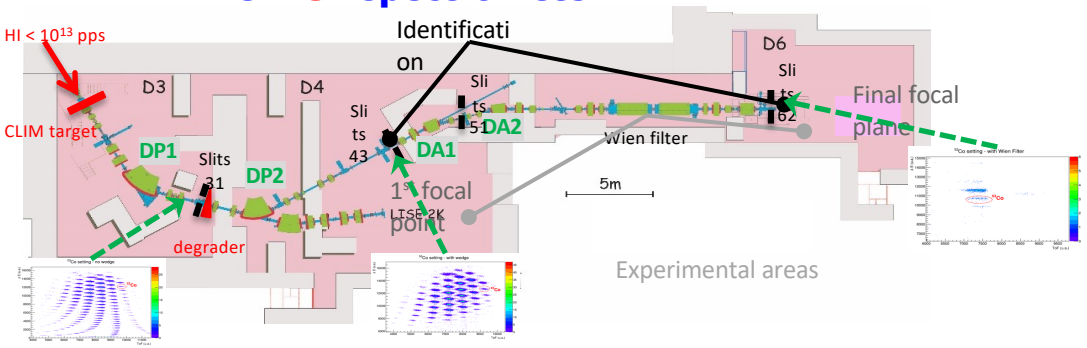
(NA)²STARS

(NA)²STARS Project: upgrade of the existing TAS

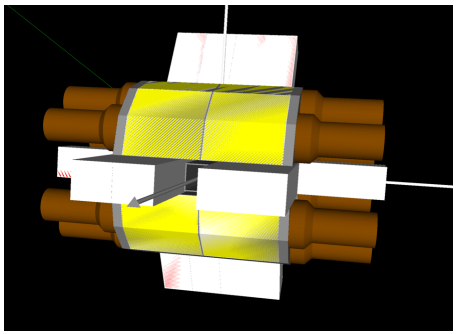
- **(NA)²STARS project: Kick-off meeting in Nantes Dec. 2024**

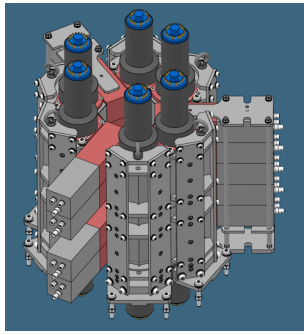
- **Preparation of the "Commissioning experiment" @ LISE, June 2026**
- **New DSSSD (GANIL) 1 mm-thick, 40x40 mm²**
- **Rocinante (12 BaF_2, refurbished) + 16 $LaBr_3$ crystals**

The LISE spectrometer



Refurbished Rocinante **+ $LaBr_3$ modules** **+ New DSSSD**





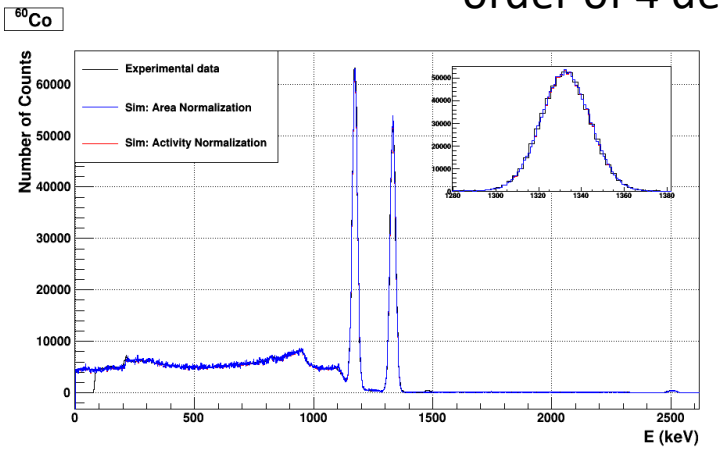
Workshop Aprende Strasbourg Jan. 25,
IAEA 3rd TM Apr. 25, Isol France Apr. 25
Conférences : ND2025, EuNPC2025

Subatech – IP2I - IFIC – GANIL - CIEMAT – CSIC Madrid – NPI CAS - Istanbul – Surrey - Huelva

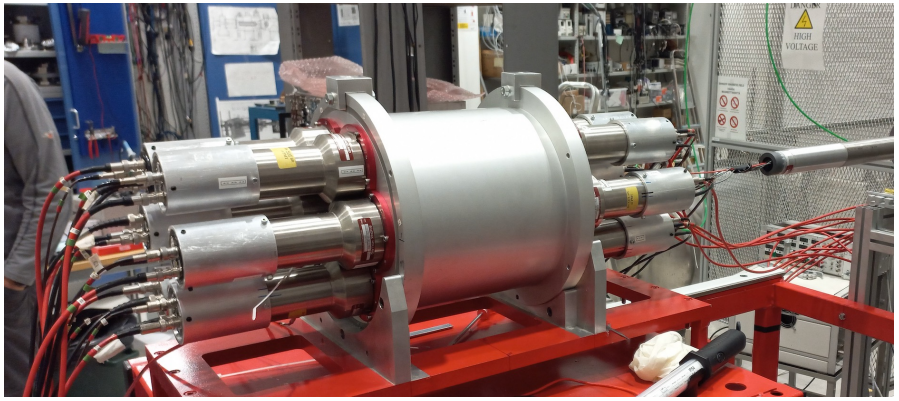
(NA)^{2}STARS

- R&D on-going also on DSSSD det. @ GANIL
- R&D Plastics + SiPMs for central beta detector @ Subatech
- Electronics & DAQs, @ GANIL and Subatech (S. Bouvier, H. Guérin, B. Rebeiro, J.-C. Thomas et al.)
- First individual module tests by CIEMAT and IFIC, design based on design studies performed for DESPEC TAS (DTAS)
- New tests on-going @Subatech (V. Piau et al., M1 & M2 internship students: N. Payan, O. Chettir, N. Trimech)
- Mechanics: new mission @ GANIL with engineers from Subatech and IP2I Nov. 6-7. Preparation for LISE && DESIR.
- 16 $LaBr_3$ modules for the GANIL experiment thanks to GANIL order of 4 detectors in advance w.r.t planning

FASTER

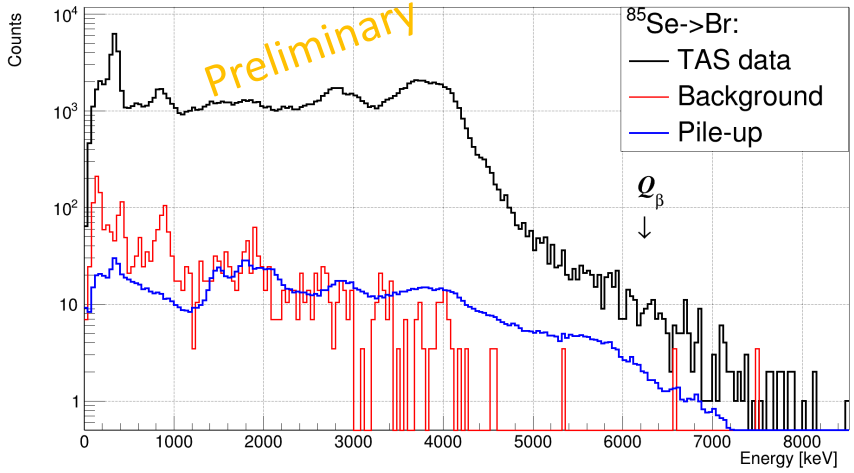


TAGS Campaign 2022



Campagne TAGS@IGISOL (Jyväskylä) en Sept. 2022 :

- Analyse effectuée par **Julien Pepin, doctorant en co-tutelle Nantes - Valencia**
- Nouveaux codes d'analyse des données bruts (alignement des 12 cristaux et calibration en énergie)
- Phase de préparation des données terminée (alignement, calibration, soustraction des contaminants)
- Réponse du détecteur obtenue avec la simulation GEANT4
- **Premiers résultats pour l'estimation de l'intensité bêta du ^{85}Se identifié comme priorité 1** pour puissance résiduelle combustible ^{233}U/^{232}Th (IAEA INDC-577 Report, 2010)
- Soutenance de thèse prévue Mars 2026



Présentations :

- GDR SciNEE Pole 1, Grenoble, Décembre 2024
- ISOL France, Orsay, avril 2025
- ND 2025, Madrid, juin 2025
- EuNPC 2025, Caen, septembre 2025

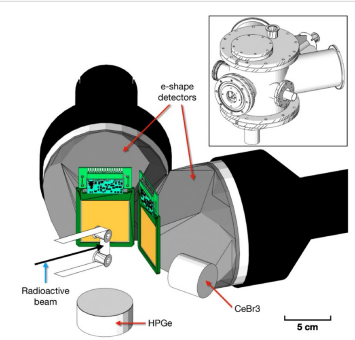
E-Shape First Results

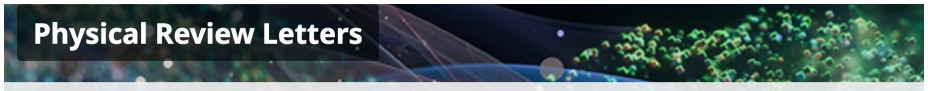
⇒ **Form factor calculations for forbidden beta decay transitions**: several models disagree, broadest predictions from L. Hayen et al. PRC.100.054323

⇒ Effect of first forbidden transitions: one of the best hypotheses for the reactor antineutrino shape anomaly !!!

⇒ Very scarce existing data because very challenging measurements !!!

⇒e-Shape experiment first results:





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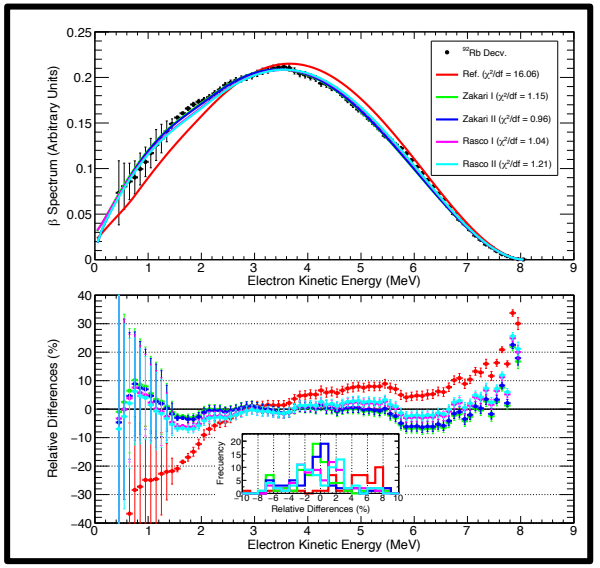
Study of the Beta Spectrum Shape of ^{92}Rb and ^{142}Cs Decays for the Prediction of Reactor Antineutrino Spectra

G. A. Alcalá[1,*], A. Algora[1,2,†], M. Estienne[3], M. Fallot[3], V. Guadilla[3,4], A. Beloeuvre[3], W. Gelletly[5], R. Kean[3], A. Porta[3] *et al.*

Phys. Rev. Lett. **135**, 142502 (2025)



- **The shape of the beta spectrum of two of the most relevant decays for the prediction of the reactor antineutrino spectrum have been measured: ^{92}Rb, ^{142}Cs**
- **No significant deviation from the allowed shape is evidenced for these two 0$^-$ first forbidden transitions, as predicted by the models**
- **Still predicted large shape factors to be measured (S. Durand's PhD on-going…)**

17

G. Alcala et al. arXiv:2505.05929
https://doi.org/10.1103/hyj7-l22h

Futures expériences

- **Discussions pour de nouveaux proposals (NA)²STARS au GANIL : campagne longue sur LISE par ex. : finalement pas de temps de faisceau ouvert au PAC pour 1 à 2 ans**

- **Planning de l'expérience prévue en 2026 sur LISE : début faisceau 1er juin 2026**

- **Nouvelle proposition d'expérience soumise à Jyväskylä avec (NA)²STARS en sept. 2025**

- **Co-tutelle de thèse en préparation, avec demi-financement finlandais, recherche de la moitié française**

- **Decay Station @ DESIR : discussions débutées avec Iolanda Mattea, Bertram Blank, Jean-Charles Thomas début 2025, à suivre**

JALONS

Propositions d'expériences TAGS				
	Jalon 1	Jalon 2		
TAGS@JYFL	Expérience antineutrinos et decay heat Jyväskylä	Expérience structure et astro-nucléaires Jyväskylä		
Date	**Campagne Sept. 2022** **Nouvelle Proposition soumise PAC sept. 2025** (spokespersons: M. Estienne, A. Porta, A. Algora et S. Orrigo), avec (NA)^{2}STARS	2020 => re-soumise 2023 (PAC) 2023 => finalement sera re-soumise plus tard (2026?)		
TAGS@ISOLDE	Expérience TAGS@ISOLDE acceptée en 2021			
Date	Réalisée en 2023 Pour l'instant pas de manpower pour analyse côté Nantes et Valencia	2025-26 : Participation aux expériences de la collaboration TAGS		

JALONS

Projet (NA)²STARS :				
	Actuellement	**Jalon 1**	**Jalon 2**	**Jalon 3**
(NA)²STARS : Upgrade des TAS Rocinante et DTAS avec des $LaBr_3$	4 $LaBr_3$ Ciemat 1 1(+1) $LaBr_3$ Valencia 6 $LaBr_3$ Subatech 5 LaBr3 GANIL 1 CSIC Madrid + HV + quelques modules FASTER **2024 : commande de 5 cristaux de plus**	Tests à Subatech, électronique FASTER, HV. Simulations Geant4 Subatech pour upgrade DTAS (A. Beloeuvre)	L'IP2I rejoint la collaboration: in-beam x-section meas. For p-process @ NFS. M2 internship (J. Pépin)	MoU collaboration. Nouveaux collaborateurs (NPI CAS, U. Istanbul). Installation de 2 LaBr3 sur FASLTAFF@NFS fin 2023
	17 (+1) $LaBr_3$		2021	2022 et 2023 => 2024 : MoU circule parmi collaborateurs

Jalon 4	(NA)²STARS@GANIL Nouvelles expériences TAGS++ à GANIL (LISE + DESIR + NFS)
	⇒ proposal accepté PAC 2023, exp. prévue juin 2026 : (NA)²STARS @ LISE, R&D en cours

PUBLICATIONS et THESES

Publications in peer-reviewed journals:

- G. Alcala et al. Phys. Rev. Lett. 135, 142502 (2025)

Communications orales :

1 GDR Scinee déc. 2024
1 contrib. APRENDE Workshop Jan. 2025 (WP2, Strasbourg)
1 contrib. ISOL-France Avril 25
4 contributions ND 2025 (Madrid) + proceedings à venir
2 workshops IAEA (Vienne déc. 2024, Séoul April 25)
4 contributions EuNPC 2025 (Caen)
1 contrib. GDR Resanet Nov. 2025
2 contribs JEFF meeting Nov. 2025

Plusieurs articles en préparation…

Thèses :

+ 1 thèse en co-tutelle Nantes – Valencia (2022-mars 2026) : Julien Pépin (en cours)
+ 1 thèse débutée en 2024 E-Shape
+ 1 thèse débutée en 2025 $(NA)^2$STARS

Utilisation budget année N

Obtenus : Jyväskylä : 0, TAGS : 0, OPALE : 14 (principalement pour E-Shape,
hors NACRE ()),
hors APRENDE (~0 missions dans APRENDE, mais financement ½ thèse en recherche de co-financement)
$(NA)^2$STARS : 32 in2p3 + 9 GANIL (mécanique) + 4 LaBr3 achetés par GANIL en 2025 (en avance de phase sur le projet)

⇒ Complètement dépensés

Demandes année N+1

Demande totale:
Jyväskylä : 0 (car pas d'exp. en 2024)
ISOLDE : 3 (car finalement pas d'exp. en 2025)
OPALE : 13 (missions + sources)
$(NA)^2$STARS :

- GANIL : budget demandé au TGIR selon plan de financement du projet
- in2p3 : budget demandé à l'in2p3 selon plan de financement du projet : 32k€ (dont 2k€ missions)

Demande de poste permanent pour compenser le départ d'Axel Laureau au LPSC (profil initial : TAGS/$(NA)^2$STARS @ GANIL…)

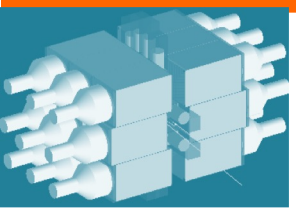
1 postdoc demandé pour $(NA)^2$STARS pour 2026

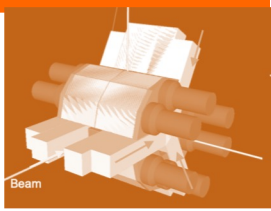
Budget APED approuvé, remplacera OPALE et NEEDS ?

Budget pluri-annuel

Demandes futures :
selon plan de financement $(NA)^2$STARS : expérience acceptée au GANIL, démarrage $(NA)^2$STARS@GANIL, analyse TAGS en cours et réunions de collab., …
Prochaines expériences : GANIL, Jyväskylä

Thank You





- SUBATECH: E. Bonnet, S. Durand, M. Estienne, M. Fallot, L. Le Floch, J. Pépin, V. Piau, A. Porta
- IFIC Valencia: A. Algora, E. Nacher, S. Orrigo, B. Rubio, J.-L. Tain
- GANIL : J.-C. Thomas, H. 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

cnrs NUCLÉAIRE & PARTICULES
RÉGION PAYS DE LA LOIRE
GANIL
APRENDE
GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
IFIC INSTITUT DE FÍSICA CORPUSCULAR

laboratoire commun CEA/DRF — GANIL — SPIRAL2 — CNRS/IN2P3

PROPOSAL E891_23

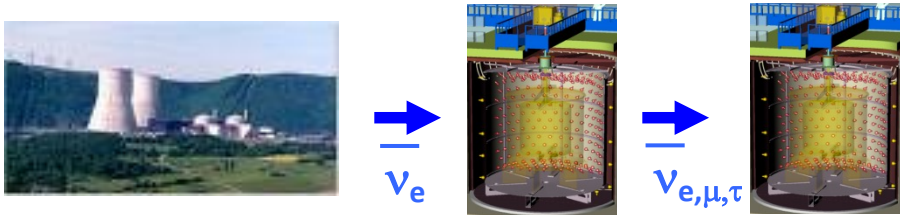
GANIL PAC 14/11/2023

Total Absorption Spectroscopy for Nuclear Structure and Nuclear Astrophysics

- 1st experiment with **STARS**
- Measure the β-decay properties of several p-rich nuclei in the Cr-Zn region of great interest for:
  - Nuclear structure: β-decay of selected T_z=-2 nuclei (^{44}Cr, ^{48}Fe, ^{52}Ni, ^{56}Zn)
    - To study isospin symmetry free of Pandemonium
  - Nuclear astrophysics: β-decay of ^{46}Mn and ^{48}Mn
    - To constrain reaction rates of interest for the ^{44}Ti nucleosynthesis
      - ^{45}V(p,γ)^{46}Cr and ^{47}V(p,γ)^{48}Cr

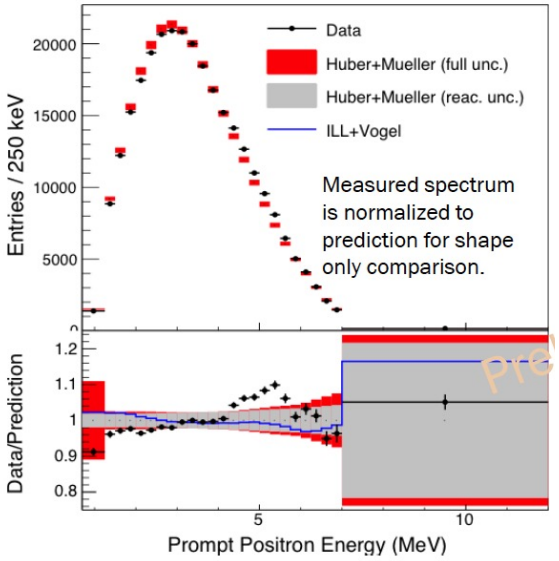
Reactor Antineutrinos & Fundamental Physics

- Measurement of the θ_{13} oscillation param by Double Chooz, Daya Bay, Reno
  - Independent computation of the anti-ν spectra using nuclear DB: conversion method



- Sterile neutrino measurement to explain the "reactor anomaly"
  - 6% deficit of the absolute value of the measured flux compared to the best prediction ILL data
  - Shape anomaly (spectral distorsion) in the full spectrum (btw 4.8-7.3 MeV)
  - Daya Bay PRL points-out a pb in the converted antineutrino spectra from ^{235}U measured beta spectrum @ILL

- Absolute shape comparison of data and prediction: χ^2/ndf = 41.8/21



- Next generation reactor neutrino experiments like JUNO or background for other multipurpose experiment

➡ Putting integral beta measurement of ^{235}U of Scheckenbach *et al.* and sterile neutrinos into question.

➡ Growing interest in Summation Method (SM) to calculate anti-ν spectra, but new measurements needed due to Pandemonium problem