ENTRETIEN ANNUEL PROJET
TAGS & (NA)^{2}STARS

Collaboration

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

TAGS : Équipes in2p3 concernées

Equipe 1 Subatech
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Amanda Porta
Samuel Durand (doc exp)
Yohannes Molla (doc simul)
Jad Hawalni(doc simul)
Soumen Nandi (postdoc)

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

Equipe 3
GANIL
J.-C. Thomas
…

Responsabilités :
connaissance de la technique, de l'analyse
Faire en sorte de pouvoir installer un TAS sur les installations françaises

Projet $(NA)^2$STARS@NFS
mesure x-sections in beam
γ-summing technique

Projet $(NA)^2$STARS @ LISE, S^3, DESIR

CONTEXTE SCIENTIFIQUE

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)

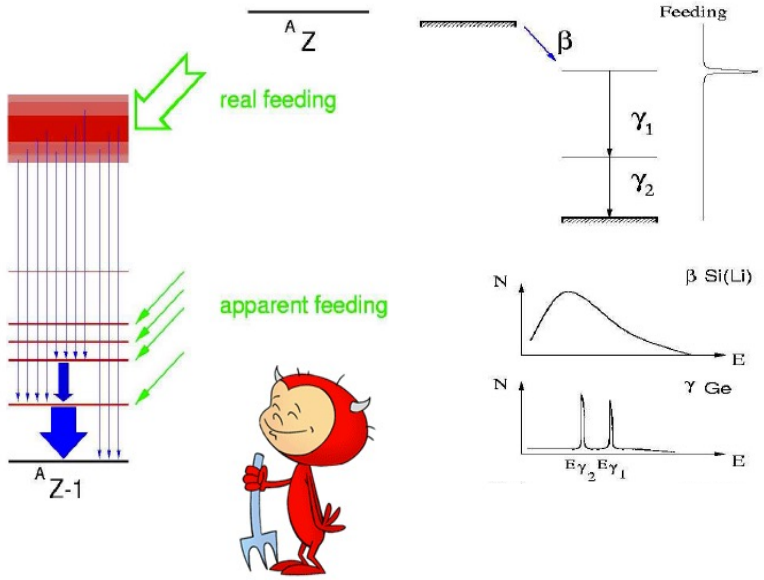
- Incomplete decay schemes: overestimate of the high-energy part of the FP β spectra

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

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

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

Picture from A. Algora



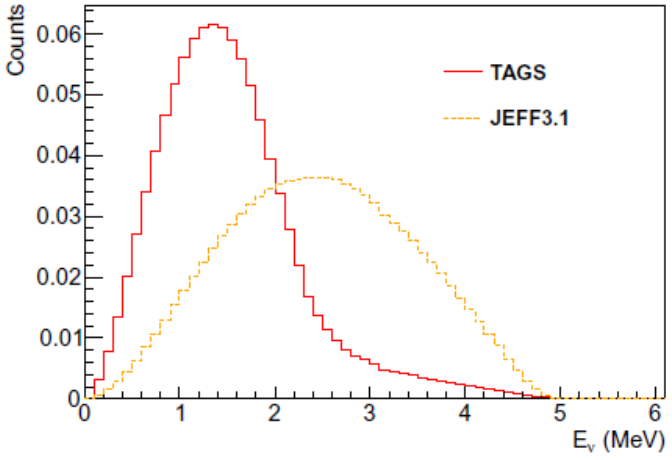
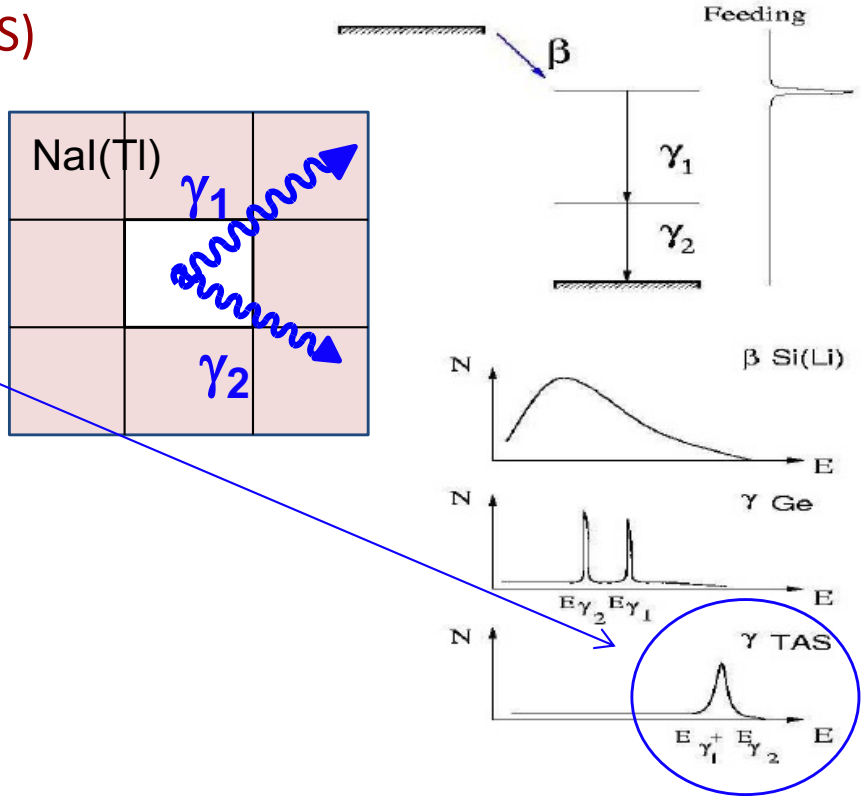


FIG. 1. Illustration of the pandemonium effect on the ^{105}Mo nucleus anti-ν energy spectrum presents in the JEFF3.1 data base and corrected in the TAS data.

TAGS: a Solution to the Pandemonium Effect

- Total absorption γ-ray spectroscopy (TAGS)
  - A TAS is a calorimeter
  - It contains big 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.)

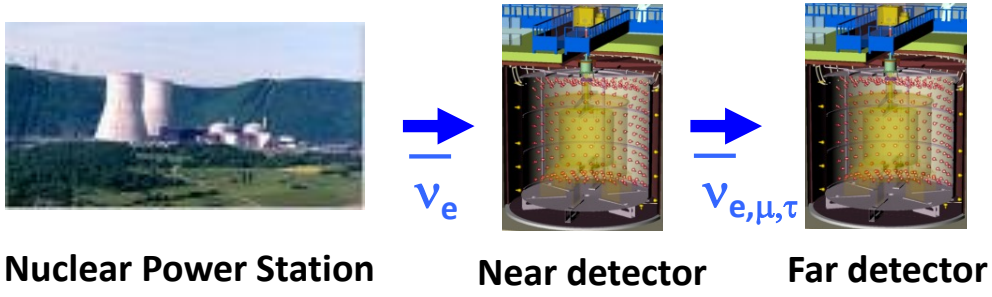
- Calculation of level energy feeding through the resolution of the inverse problem by deconvolution
  - R_{ij} = matrix detector response
  - d_i = measured data
  - Extract f_j the level feeding by deconvolution

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

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

Reactor Antineutrinos & Fundamental Physics

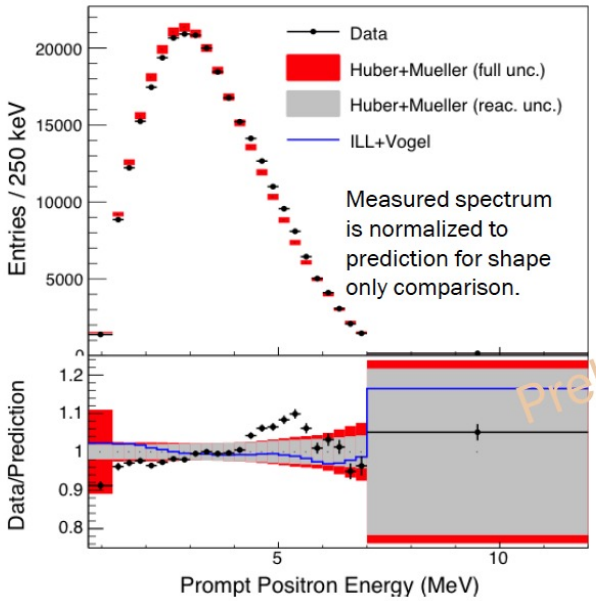
- Measurement of the θ_{13} oscillation param by Double Chooz, Daya Bay, Reno
  - Independent computation of the anti-ν spectra using nuclear DB: conversion method



- 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

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

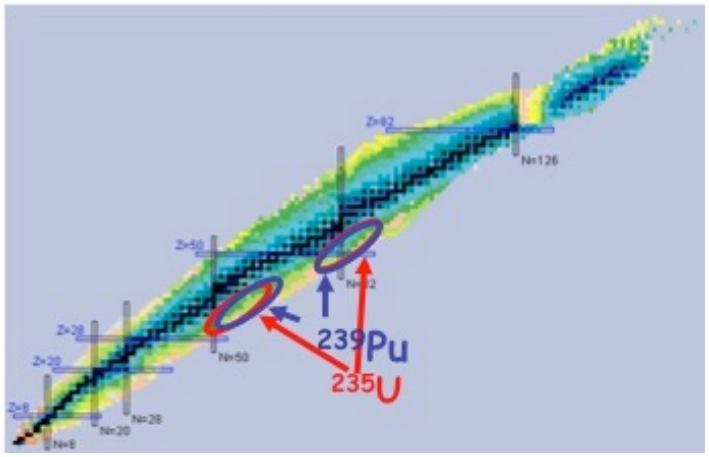
✧ Absolute shape comparison of data and prediction: χ^2/ndf = 41.8/21

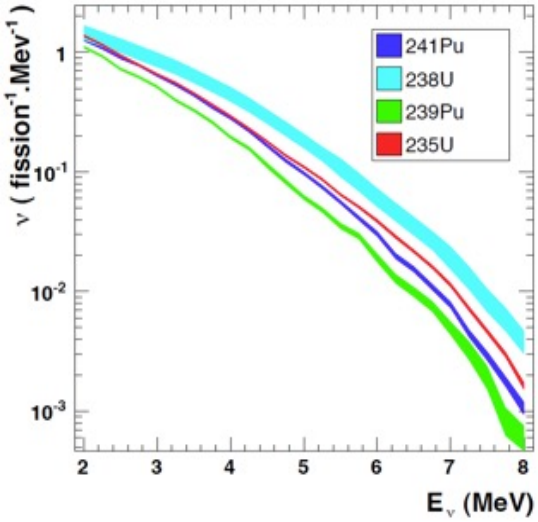


➡ Putting integral beta measurement of ^{235}U of Scheckenbach *et al.* and sterile neutrinos into question.

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

Antineutrinos for Peace





About 6 antineutrinos emitted per fission

→ **About 10^{21} antineutrinos/s emitted by a 1 GW_e reactor**

- Use the discrepancy between antineutrino flux and energies from U and Pu isotopes to infer reactor fuel isotopic composition and power
  - Reactor monitoring, non-proliferation and interest for the IAEA IAEA Report SG-EQGNRL-RP-0002 (2012)
  - Idea born in the 70s, demonstrated in the 80s/90s but developed lately

The Summation Method, relying on nuclear data, is the only predictive one (for innovative reactors & fuels):

⇒ The IAEA Nuclear Data section includes the measurements for reactor antineutrino spectra in their Priority lists (CRP meetings, TAGS consultant meetings…)

Reactor Decay Heat (DH)

- **Definition:** following the shut-down of the chain reaction in a reactor, **the nuclear fuel continues to release energy called decay heat.**
- Evaluation of the **reactor safety** as well as **various economic aspects** of nuclear power
- **Emitters: essentially made up of FP and actinides**
  - ❑ DH: residual power of **6-12% of the nominal power** of the reactor just after its shut-down

- Estimate through **the only predictive method** for future reactors: **the « summation method »**

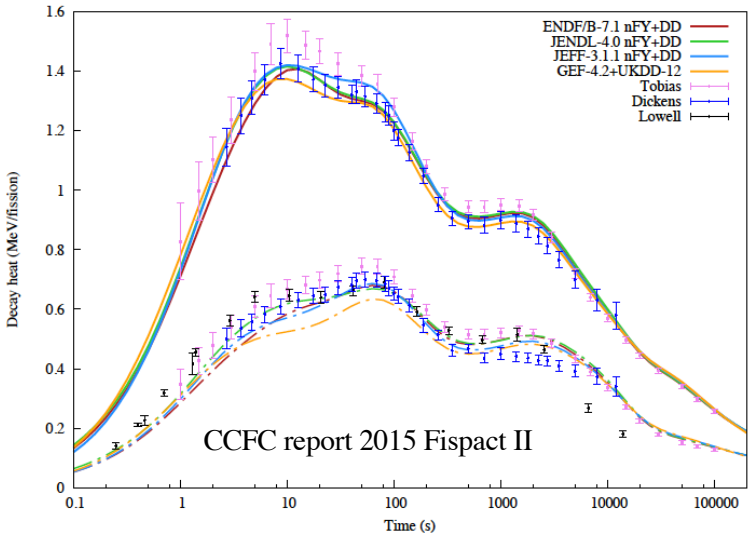
⇒ Summation of all the fission product and actinide contributions:

$$\mathbf{f}(t) = \sum_i (\bar{E}_{\beta,i} + \bar{E}_{\gamma,i})\boldsymbol{\lambda}_i \mathbf{N}_i(t)$$

β,γ decay — Total decay constant (half-life) and Fission Yield

⇒ **Comparisons btw nuclear data & integral measurements show that there remains important discrepancies between data and simulations using different DataBases**

⇒ **Pandemonium effect + unknown decay schemes**

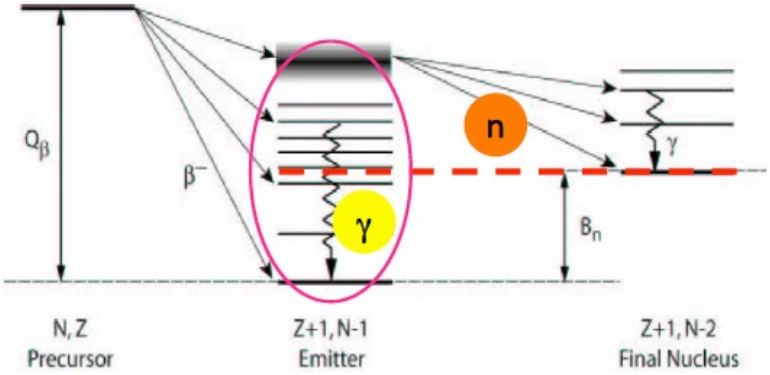


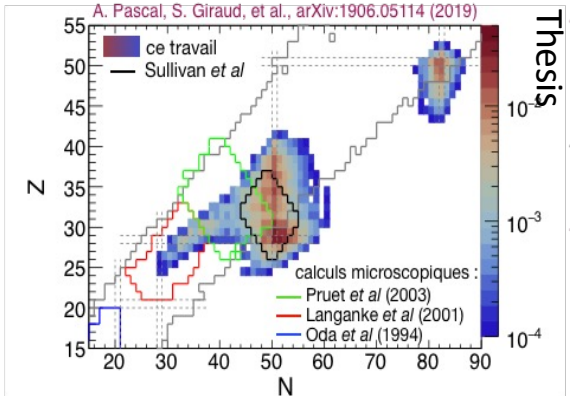
Figur **Total (solid) and gamma (dashed) decay heat from thermal pulse on ^{235}U**

Nuclear Science NEA/WPEC-25 (2007), Report INDC(NDS)-0577 (2009), Report INDC(NDS-0551, Report INDC(NDS)-0676 (2016)

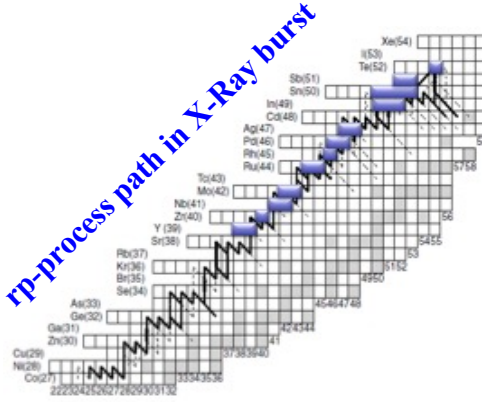
TAGS experiments for nuclear astrophysics

- **R-process:**
  - β-decay of delayed neutron emitters as a "surrogate" of the (n,γ) reaction: **enhanced Γγ measured in some nuclei impacting (n,γ) cross sections => general trend ?**
  - Probe the presence **of low-lying collective modes with β-decay** as it impacts the r-process paths





- **Influence of forbidden non-unique b transitions on r-process path ? => E-Shape exp. + TAGS + Theory**
- **Core-collapse SNe:** Study the electron capture properties of targetted nuclei which play an important role in core-collapse supernovae



- **^{44}Ti production rate**: probes the **innermost shells** of the SN explosion: measure the γ emission from unbound proton states in key nuclei to constrain reaction rates playing a role in the ^{44}Ti abundance (« surrogate method »)
- Measure the **beta strength of rp-process waiting points**
- **P-process: measure (p,γ) and (α,γ) key cross-sections: @ NFS**

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

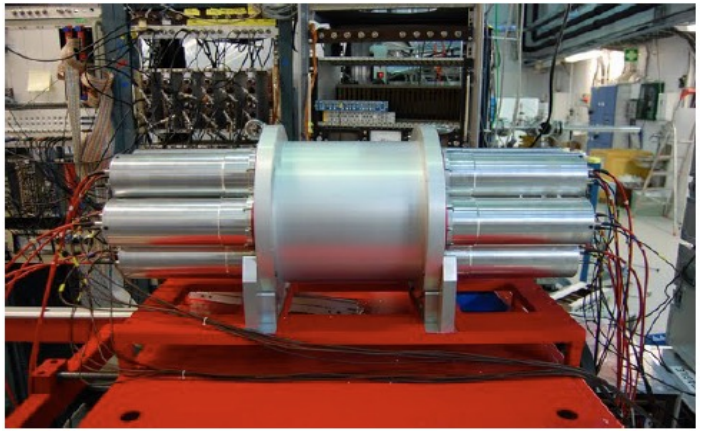
- IGISOL@Jyväskylä:
  - Proton induced fission ion-guide source
  - Mass separator magnet
  - Double Penning trap system to clean the beams

B. Rubio, J. L. Tain, A. Algora et al., Proceedings of the Int. Conf. For nuclear Data for Science and technology (ND2013)

J.L. Tain et al., NIMA 803 (2015) 36
V. Guadilla et al., submitted to NIMA (2018)

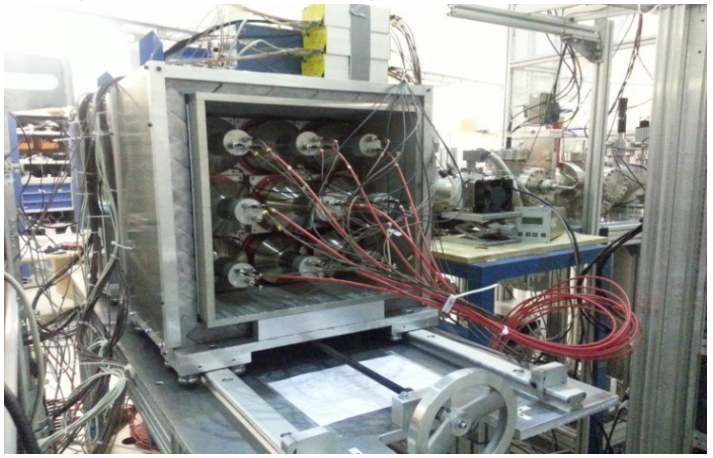
- 2 (segmented) TAS campains :

❑ ROCINANTE (IFIC Valencia/Surrey):



- ✓ 12 BaF_2 covering 4π
- ✓ Detection efficiency of a single γ ray >80% (up to 10 MeV)
- ✓ Coupled with a Si detector for β
- ✓ 7 nuclei (4 delayed neutron emitters) measured (6 for DH and 2 for anti-ν)

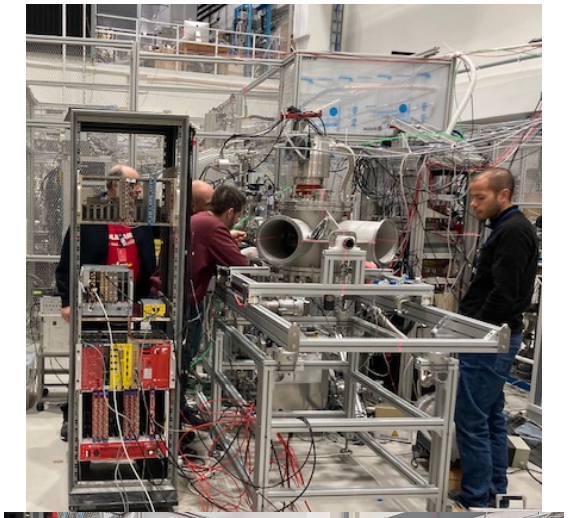
❑ DTAS (IFIC Valencia):

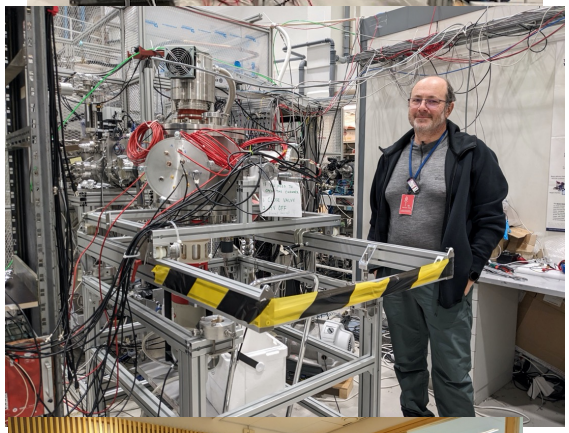


- ✓ 18 NaI(Tl) crystals of 15cm × 15cm × 25 cm
- ✓ Individual crystal resolutions: 7-8%
- ✓ Total efficiency: 80-90%
- ✓ Coupled with plastic scintillator for β
- ✓ 12 nuclei for anti-ν measured & 11 for DH

FAITS MARQUANTS 2024

E-Shape New Experimental Campaign in Dec. 2023



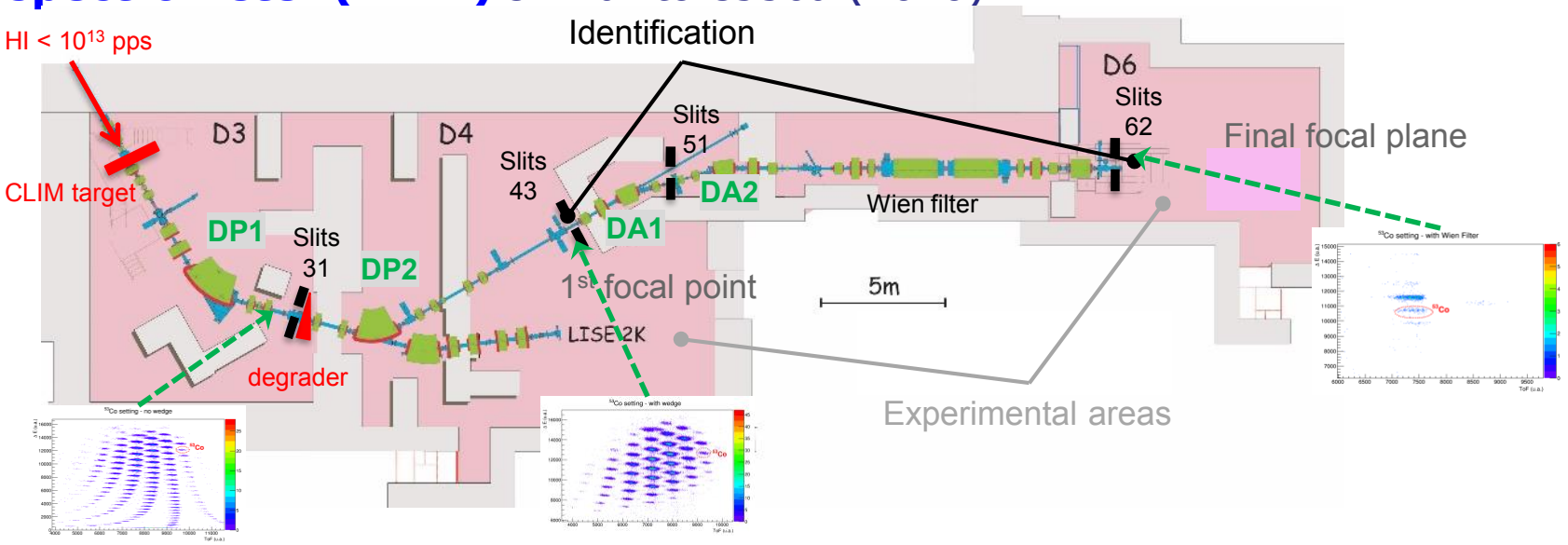


- The IGISOL team had some issues in Jan. 2022 to tune properly the beam
- We were granted some extra-time for a new campaign in Dec. 2023 (I233 Addendum) to be able to measure the full list of nuclei of the initial proposal
- e-Shape with some small changes has been sent to Jyvaskylä last December
  - **Einzel lens** added to improve the beam focusing + extra collimator
  - **Small Silicon detector** to monitor the beam position
  - Buy a **new ^{207}Bi source** for the experiment
  - **Thinner Si detector:** 300µm thickness, same active area 50x50 mm2 => to lower the detection threshold
- Successful re-measurement of nuclei from 2022 and measurement of some new nuclei
- PhD thesis in Subatech starting in fall 2024 for the analysis of the data

E-Shape New Experimental Campaign in Dec. 2023

(NA)²STARS ' proposal @ GANIL

The LISE spectrometer (44 m) similar to e556a (2010)



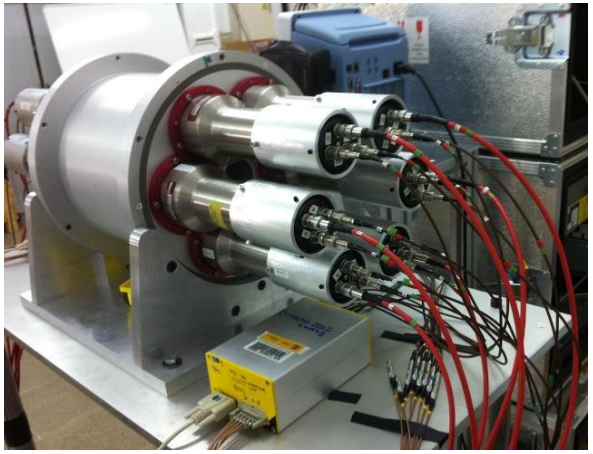
New DSSSD (GANIL) +

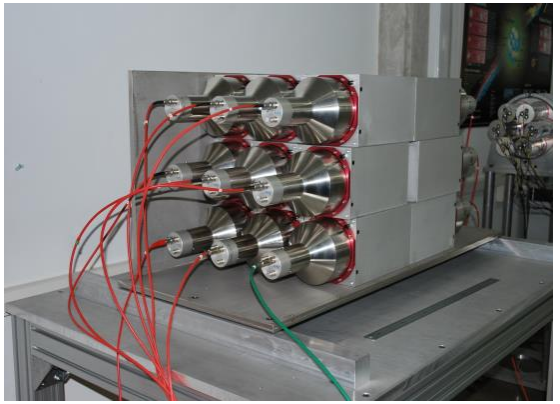
1 mm-thick, 40x40 mm2, 1 mm pitch

"Rocinante" TAS

DTAS (NUSTAR)

(NA)²STARS: TAS upgrade with $LaBr_3$ modules





- Compact 12-fold segmented BaF_2 spectrometer (to be refurbished)
- Cascade multiplicity information
- Good timing

- Large 18-fold segmented NaI spectrometer
  - Cascade multiplicity information

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],

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[13] *LNL-INFN, Italy*
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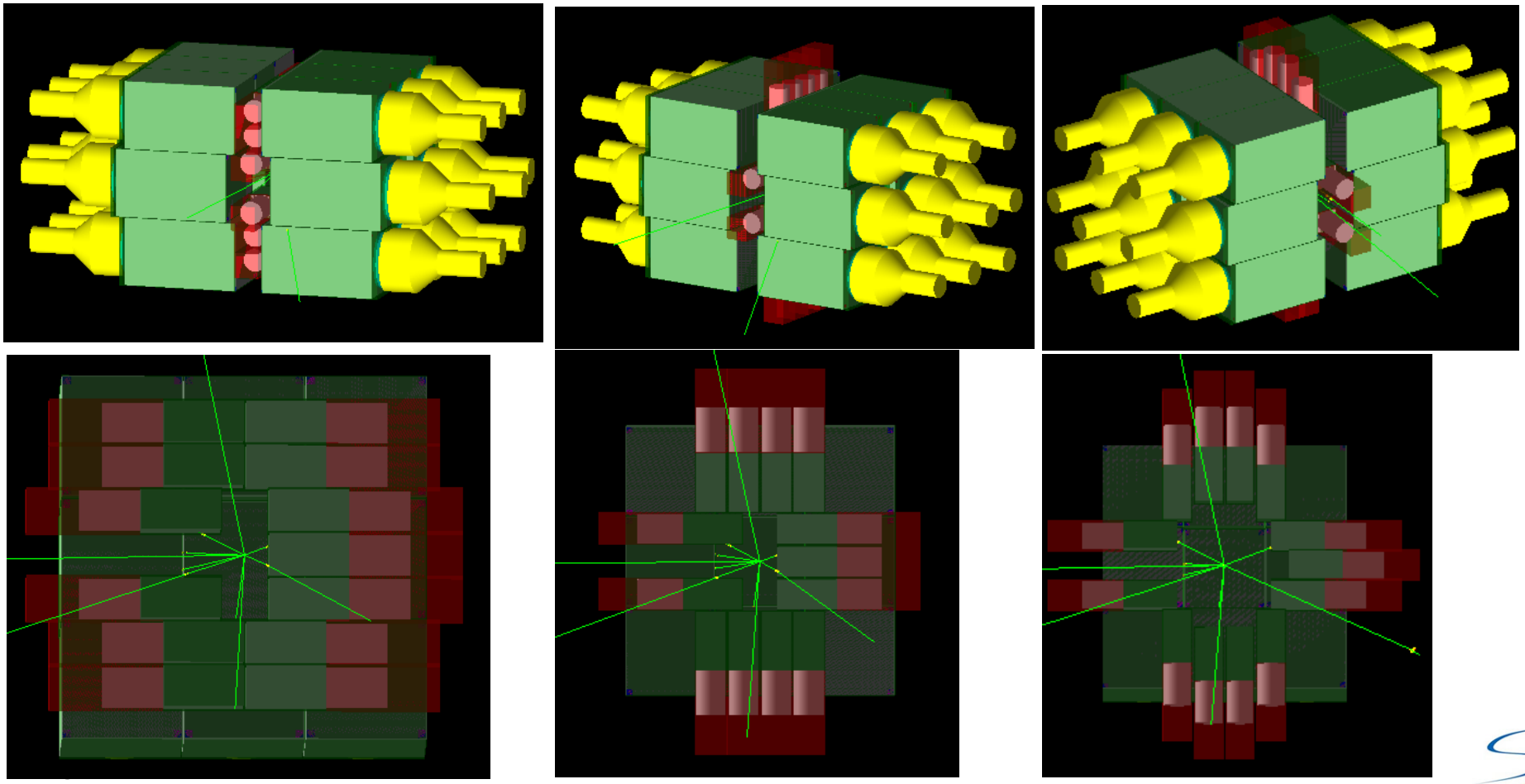
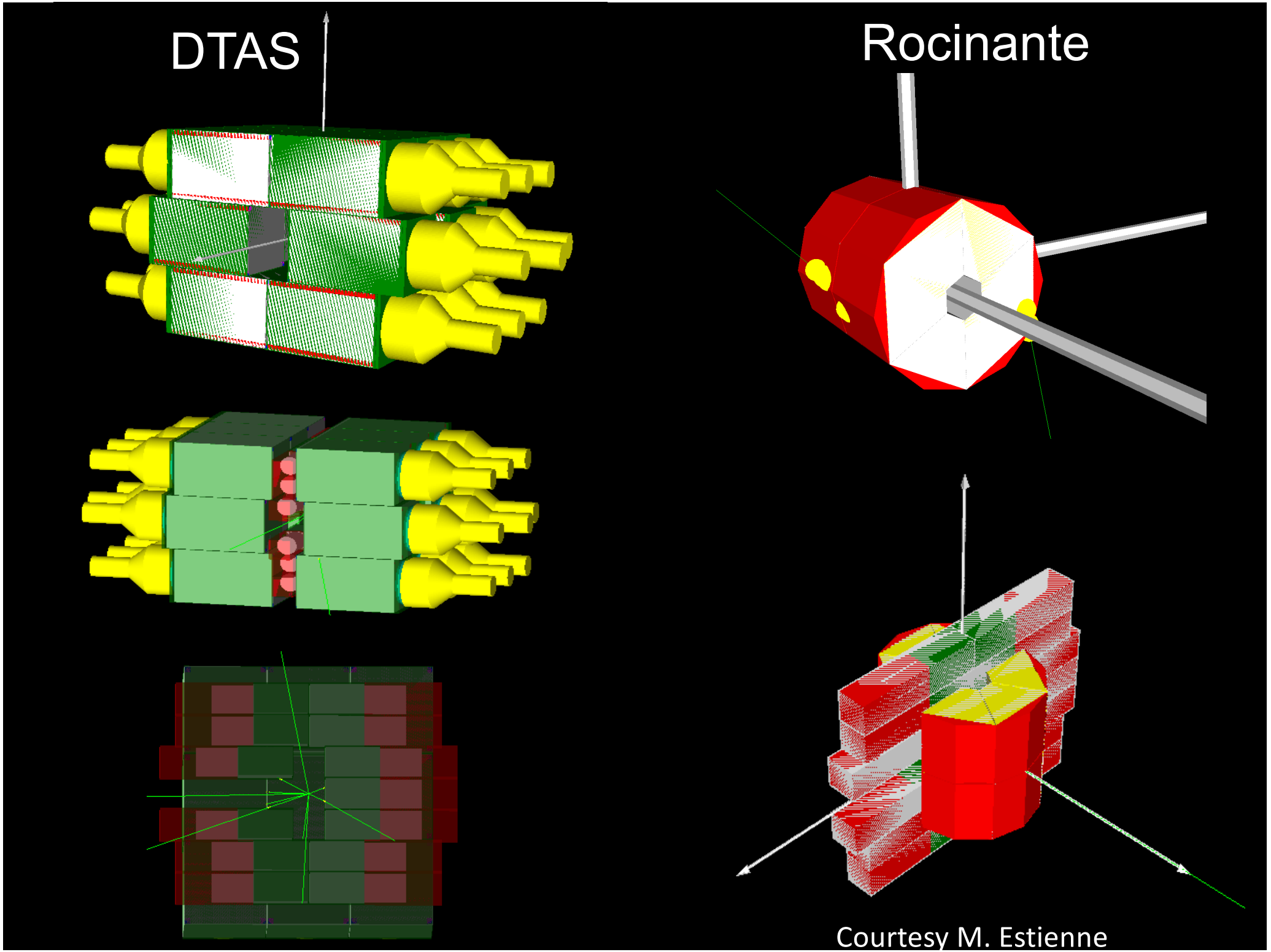
[16] *ARGONNE, USA*
[17] *RCNP Osaka, Japan*
[18] *LIP-Lisboa, Portugal*
[19] *Univ. Istanbul, Turkey*
[20] *Univ. Warsaw, Poland*
[21] *LPCCAEN, France*
[22] *NPI CAS, Czech Republic*
[23] *CCHEN, Santiago, Chile*
[24] *NIPNE, Romania*

The (NA)^{2}STARS project

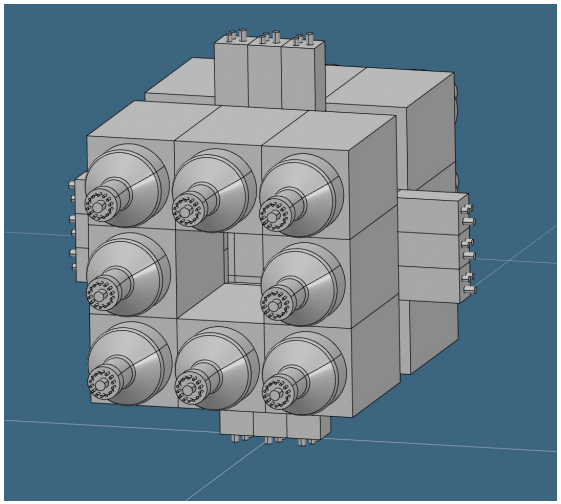
- E891_23: first proposal approved by GANIL PAC (11/2023)
  - Experiment @ LISE in early 2026
  - 13 crystals for the 1st experiment
  - On-going design studies: example of Geant4 simulations with DTAS (M1 internship student E. Lancien, supervised by M. Estienne and A. Porta)



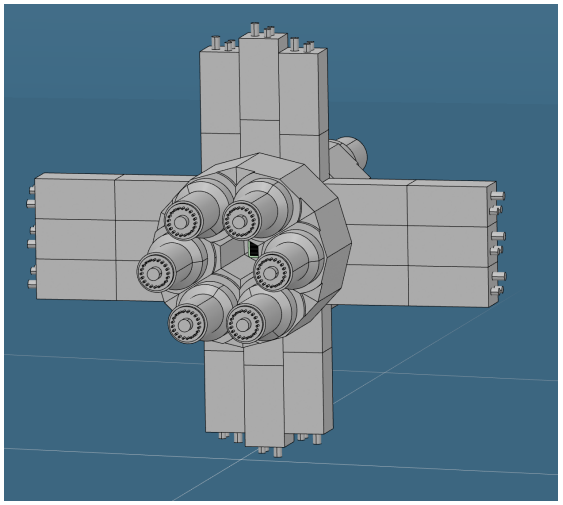

DTAS
Rocinante
Courtesy M. Estienne

The (NA)^{2}STARS project

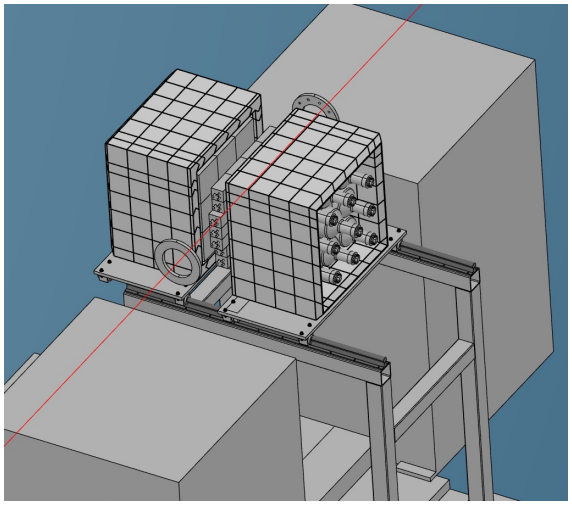
- E891_23: first proposal approved by GANIL PAC (11/2023)
  - Experiment @ LISE in early 2026
  - 13 crystals for the 1st experiment
  - On-going design studies: “technical trip” @ GANIL in May 2024 of our mechanical engineers, example of CATIA simulations with DTAS (courtesy B. Madiot, J.-S. Stutzmann):



Config. With DTAS



Config. With Rocinante

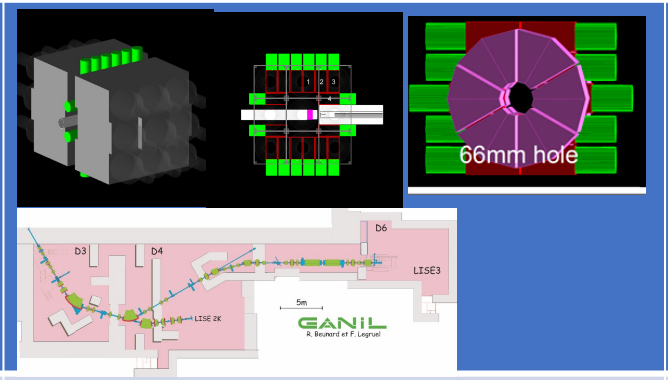
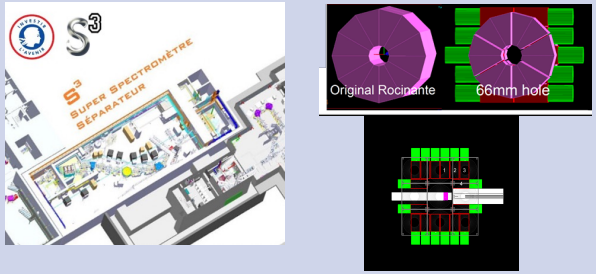
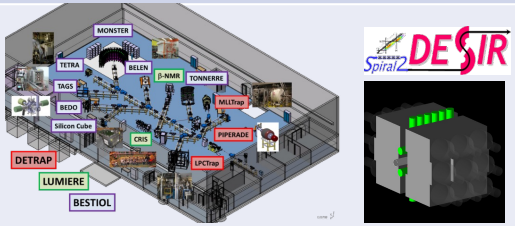
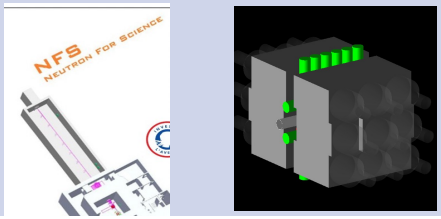


Config. On the LISE beamline

  - DSSSD: on-going tests@ GANIL & Subatech: Micron 40x40mm^2, tests of charge pre-amps, Numexo2 response, FASTER & Numexo2 coupling… : 1 electronician research engineer from Subatech in collaboration with J.-C. Thomas and Hugo Guérin

Subatech

The (NA)^{2}STARS project

Mechanics and electronics developments for upgrade of first TAS/ GEANT4 simulations for β-decay experiments / Mechanical adaptation to LISE beam line / implantation and ancillary detectors / 9, 10 or 16 $LaBr_3$ depending on funding timeline		**⇒First experiment @ GANIL on LISE: 2025-2026** **⇒Next proposals (or LoI) to the PAC on LISE or S^3 or DESIR: 2026-2027**
Mechanics and electronics developments for upgrade of second TAS with 16 $LaBr_3$ / GEANT4 simulations for β-decay experiments / Mechanical adaptation to S^3 beam line / implantation and ancillary detectors		⇒ Second experiment @ GANIL on LISE: 2027-2028 ⇒ Or LoI @ GANIL on S^3 and/or DESIR: 2027-2028
Mechanical adaptation to DESIR beam line / implantation and ancillary detectors / GEANT4 simulations for in-beam experiments		⇒ First experiment @ GANIL on DESIR 2028-2029 (depending on the DESIR schedule) ⇒ Proposal on NFS in 2028 (if feasible)
If feasible: mechanics developments for in-beam experiments with TAS + 16 $LaBr_3$ / Mechanical adaptation to NFS beam line / ancillary detectors		⇒ if feasible: New Experiment @ GANIL on NFS: 2029 ⇒ Experiment @ GANIL on DESIR 2028 and beyond, and on other facilities

JALONS

Propositions d'expériences TAGS				
	Jalon 1	Jalon 2		
TAGS@JYFL	Expérience antineutrinos et decay heat Jyväskylä	Expérience beta-pygmée, structure et astro-nucléaires Jyväskylä		
Date	2020 ou 2021 ? => **Sept. 2022**	2020 => re-submit 2023 (PAC) 2023 => finalement sera re-soumise plus tard (2024-2025)		
TAGS@ISOLDE	Expérience TAGS@ISOLDE acceptée en 2021			
Date	Réalisée en 2023 Pour l'instant pas de manpower pour analyse côté Nantes et Valencia			

JALONS

Projet $(NA)^2$STARS :				
	Actuellement	**Jalon 1**	**Jalon 2**	**Jalon 3**
$(NA)^2$STARS : Upgrade des TAS Rocinante et DTAS avec des $LaBr_3$	4 LaBr3 à Madrid 2 LaBr3 à Valencia 2 LaBr3 à Nantes + 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
	Goal: 16 LaBr3		2021	2022 et 2023 => 2024 : MoU circule actuellement parmi collaborateurs

Jalon 4	$(NA)^2$STARS@GANIL Nouvelles expériences TAGS++ à GANIL (LISE + DESIR + NFS) basées sur prog. scientifique TAGS
	⇒ Un proposal soumis au PAC 2023 et accepté ⇒ $(NA)^2$STARS @ LISE, R&D en cours

PUBLICATIONS et THESES

Publications in peer-reviewed journals:

- V. Guadilla et al., JINST 19 (2024) 02, P02027, e-Print: 2305.13832 : « First measurements with a new β-electron detector for spectral shape studies"
- 1 papier de revue : C. Zhang, X. Qian, M. Fallot, Prog. Part. Nucl. Phys. 136 (2024) 104106 : « Reactor Antineutrino Flux and Anomaly"

Communications orales :
DESIR workshop 2024
LISE workshop 2024
GCM 2024
DESIR/BESTIOL 2024

Thèses :
+ 1 thèse soutenue : Arthur Beloeuvre 2019 - 2023
+ 1 thèse en co-tutelle Nantes – Valencia (2022-2025) : Julien Pépin (en cours)
+ 1 nouvelle thèse débute en 2024 (E-Shape) (prioritaire lab.)
(+ 2 thèses simulation puissance résiduelle et MSFR en cours)

Utilisation budget année N

Obtenus : Jyväskylä : 0, TAGS : 0, OPALE : 10 (principalement pour E-Shape,
hors NACRE (15)),
hors SANDA (~0 missions dans SANDA, mais financement ½ thèse en co-tutelle)

⇒ Complètement dépensés : missions relatives aux projets dont notamment l'expérience E-Shape en 2023 à Jyväskylä

Demandes année N+1

Demande totale:
Jyväskylä : 0 (car pas d'exp. en 2024)
ISOLDE : 3 (car finalement pas d'exp. en 2025)
OPALE : 15.8 (missions + 1 Mosahr)
$(NA)^2$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 thèse demandée pour $(NA)^2$STARS pour 2025

Budget pluri-annuel

Demandes futures :

au même niveau car selon plan de financement $(NA)^2$STARS : expérience acceptée au GANIL, démarrage $(NA)^2$STARS@GANIL, analyse TAGS en cours et réunions de collab., …

Prochains proposals envisagés : GANIL, Jyväskylä

Thank You