Structure et Energie Nucléaires – Nuclear Structure and Energy (SEN)

Members of the team

Photo: **SEN team @ Subatech in 2019**

- **5 staff researchers/teaching researchers:**
  - **Eric Bonnet** (CRCN) section 01
  - **Magali Estienne** (CRHC) section 01
  - **Muriel Fallot** (MCF, HDR) section 29
  - **Lydie Giot** (MA)
  - ***Axel Laureau*** *(CRCN section 01) => LPSC Grenoble*
  - **Amanda Porta** (MA)
- **3 PhD students:**
  - **Arthur Beloeuvre** (planned topic: *TAGS measurements for nuclear structure and astrophysics*, changed for *Experimental and Theoretical study of Shape Factors for Forbidden Transitions*)
    - Co-supervision: M. Estienne – M. Fallot, started Oct. 2019, funding NEEDS
    - PhD defense in 2023, due to Covid-19 crisis)
  - **Yohannes Molla** (topic: *Decay heat uncertainty calculations with associated sensitivity studies. Impact of nuclear data*)
    - Supervision: L. Giot (dir. C. Hartnack – F. Haddad), started Oct. 2021, funding IMT Atlantique – Nantes University
  - **Julien Pépin** (topic: *TAGS measurements for Nuclear Structure, Astrophysics and Applications*)
    - Co-supervision: A. Algora, A. Porta – M. Fallot, started Sept. 2022, funded by SANDA, co-tutelle IMT Atlantique - Valencia
- **0 post-doc since 2021: 1 postdoc contract provided by in2p3 to start in Sept. 2023**

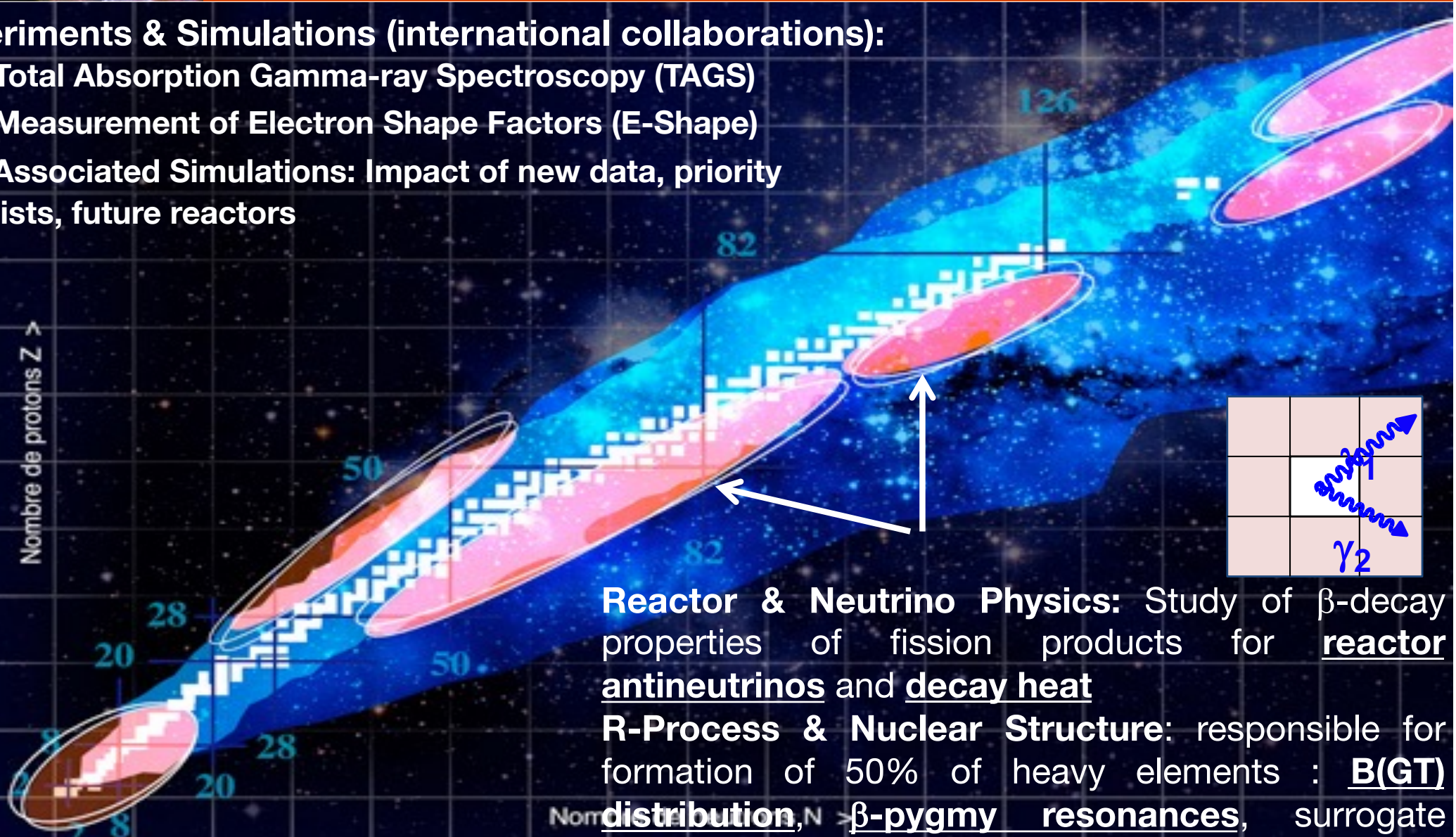
Recent Evolutions

- **+3 perm. researchers, -1 perm. researcher:**
  - **Magali Estienne** (CRHC) thematic change, 100% in SEN since 2017
  - **Eric Bonnet** (CRCN) arrived in SEN by end 2020
  - **Axel Laureau** (CRCN) arrived 1st Nov. 2020 *left August 2022*
- **2 defended PhD:**
  - **Abdoul- Aziz Zakari-Issoufou** (2015 co-supervision M. Fallot – A. Porta, dir. F. Haddad) – « Mesures TAGS pour les antineutrinos et la puissance résiduelle des réacteurs » (→ Postdoc @ l'IPNO, now industry)
  - **Loïc Le Meur** (2018 co-supervision M. Fallot – A. Porta, Dir. T. Sami) – « Mesures TAGS pour la structure et l'astrophysique nucléaires, les antineutrinos et la puissance résiduelle des réacteurs » (→ permaculture)
- **1 HDR defended:**
  - **Muriel Fallot** (planned March 2020, postponed July 2020 due to Covid) « Etudes de physique nucléaire et des réacteurs à l'interface avec la physique des neutrinos, la structure et l'astrophysique nucléaires »
- **3 post-docs:**
  - **Jose Antonio Briz-Monago**
    - postdoc IN2P3 18 mois sur l'analyse de la campagne TAGS de 2014 à Jyväskylä (→ parti en février 2016, postdoc CERN puis postdoc CSIC à Madrid en protonthérapie)
  - **Victor Guadilla**
    - Postdoc IN2P3 2 ans sur E-Shape et l'analyse de la campagne TAGS de 2014 à Jyväskylä (octobre 2017 -> novembre 2019, postdoc en Pologne)
  - **Ratha Kean** (postdoc Pays de Loire région 1 year from Jan. 2020, prolonged until May 6. 2021)
    - Analysis of the E-Shape commissioning @ Jyväskylä in May 2019.

Research Topics

Experiments & Simulations (international collaborations):

- ⇒ **Total Absorption Gamma-ray Spectroscopy (TAGS)**
- ⇒ **Measurement of Electron Shape Factors (E-Shape)**
- ⇒ **Associated Simulations: Impact of new data, priority lists, future reactors**



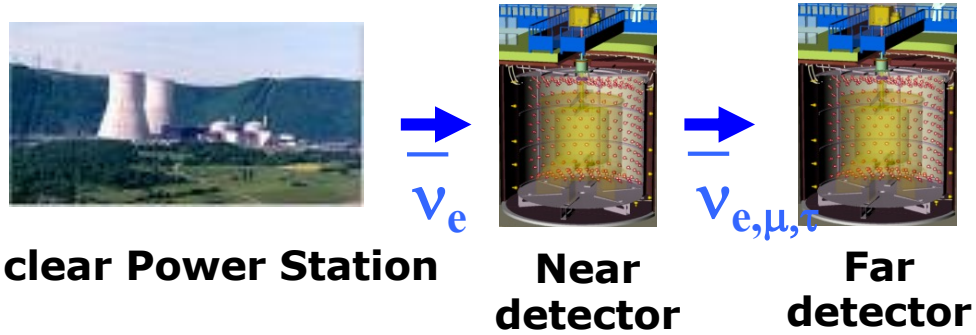
Reactor & Neutrino Physics: Study of β-decay properties of fission products for **reactor antineutrinos** and **decay heat**

R-Process & Nuclear Structure: responsible for formation of 50% of heavy elements : **B(GT) distribution**, **β-pygmy resonances**, surrogate method for (n,γ) cross-sections

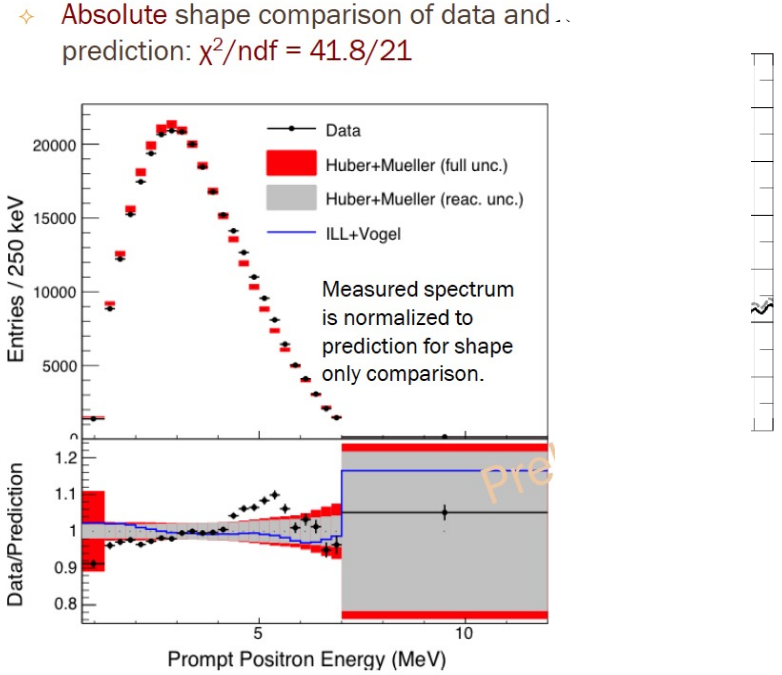
Projects 2018-2023

Reactor Antineutrinos & Fundamental Physics

- **Measurement of the θ_{13} oscillation param by Double Chooz, Daya Bay, Reno**
  - Independent computation of the anti-neutrino 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

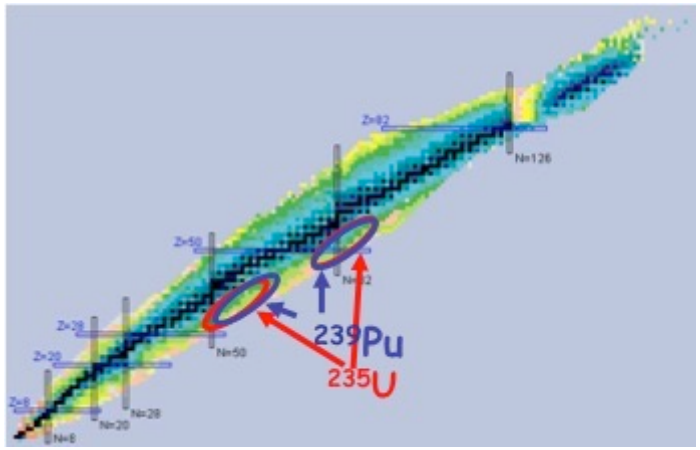


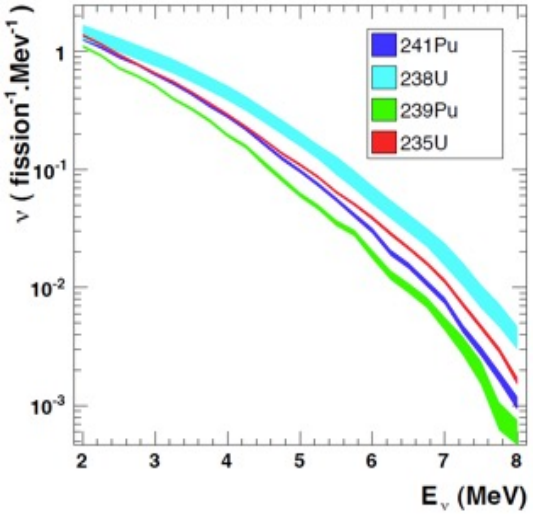
- **Next generation reactor neutrino experiments like JUNO or background for other multipurpose experiment**

➡ **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…)**

Previously…

Expertise developed in the frame of Double Chooz:

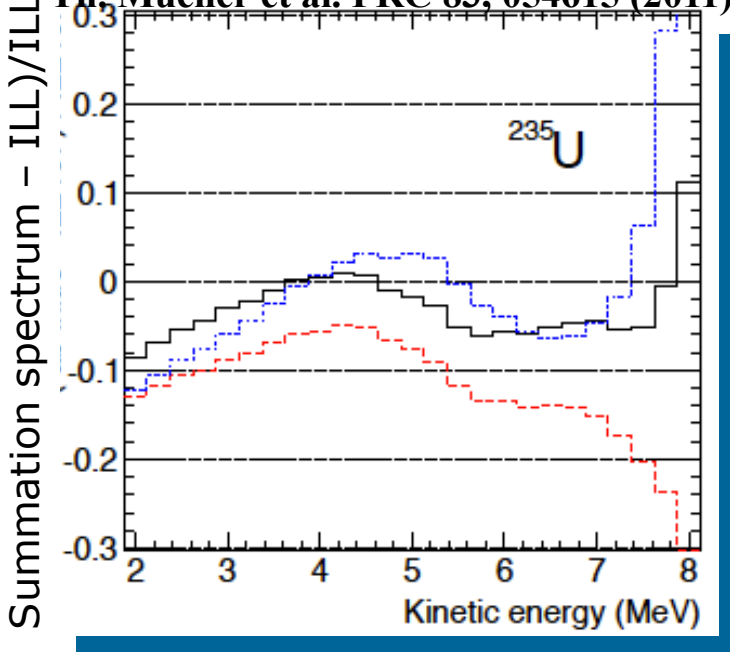
$$N(E_\nu) = \sum_n Y_n(Z,A,t) \cdot \sum_i b_{n,i}(E_0^i) P_\nu(E_\nu, E_0^i, Z)$$

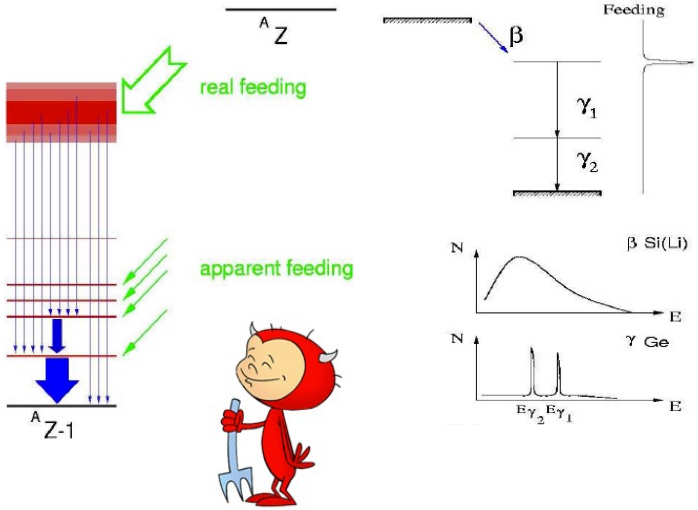
- **Reactor Simulations for Double Chooz (-> 2016), Nucifer (->2013), SoLid and predictions for reactor monitoring (safeguards) (->2013)**
- **Coupling nuclear databases and reactor simulations**
- **Nuclear database testing: Pandemonium effect in reactor antineutrino spectra ! (M. Fallot et al. PRL 2012) (synergy with reactor decay heat)**
- **Motivate first lists of nuclei for new TAGS experiments (1st proposal 2009, 1st contact with Valencian Colleagues at ND2007, 1st IAEA consultant meeting 2009)**

- **Now Improved and Reknown Summation Method Model**

Current Projects: TAGS, OPALE, E-Shape, NACRE, SAMOSAFER, SANDA, PIRT, SUDEC + IRP & IRN: ASTRANUCAP and ACnu

Th. Mueller et al. PRC 83, 054615 (2011)





Picture from A. Algora

γ Measurement Caveat

- **Before the 90's, 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)**

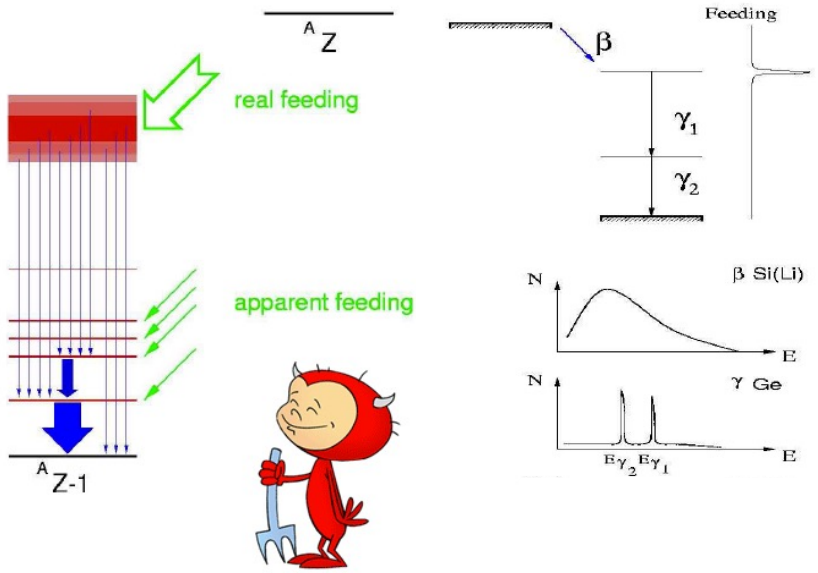
- **Incomplete decay schemes: overestimate of the high-energy part of the FP β spectra**

- **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



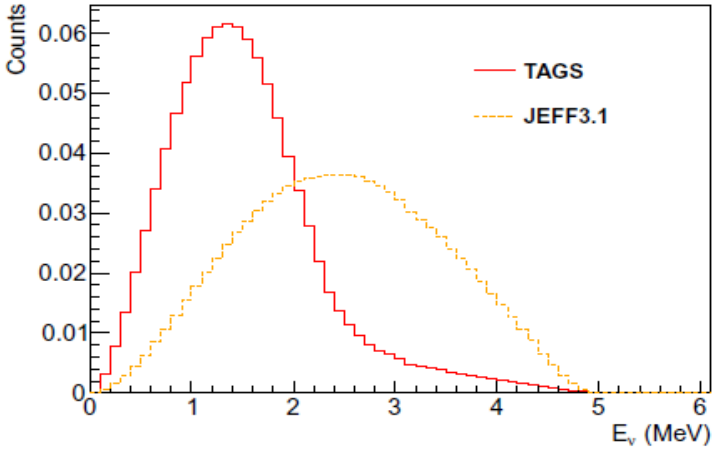
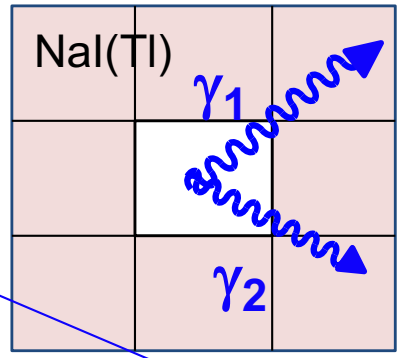
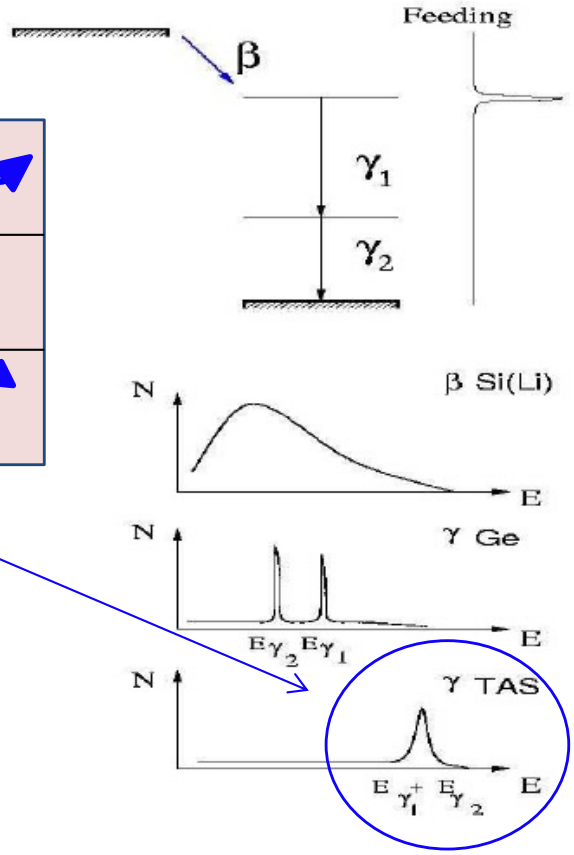


FIG. 1. Illustration of the pandemonium effect on the ^{105}Mo nucleus anti-ν energy spectrum presents in the JEFF3.1 data base and corrected in the TAS data.

TAGS: a Solution to the Pandemonium Effect

- **Total Absorption γ-ray Spectroscopy**
  - 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





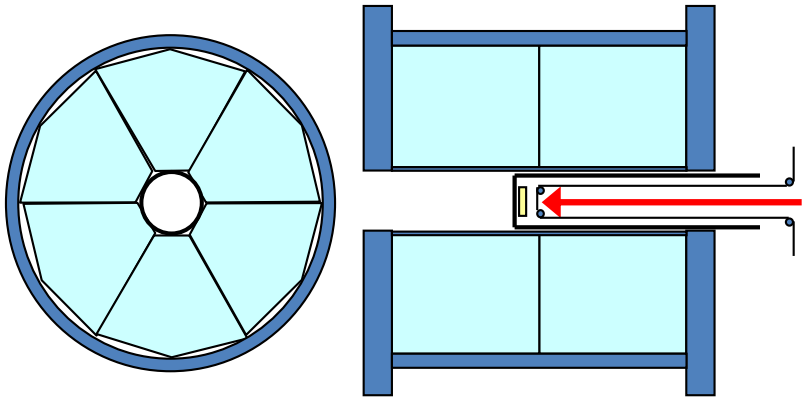
- **First TAS developed in the 70's but too small detectors to be efficient. Development of the TAGS method efficient and systematic since the 90's (Greenwood & al.)**

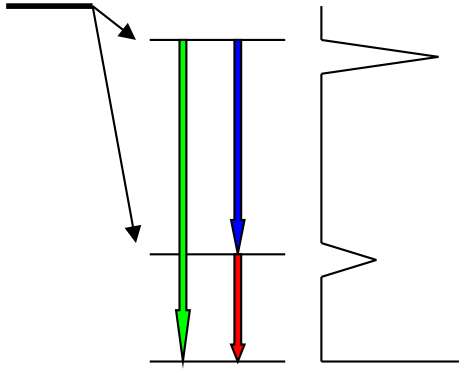
- **Calculation of level energy feeding through the resolution of the inverse problem by deconvolution**
  - R_{ij} = matrix detector response
  - d_i = measured data
  - Extract f_j the level feeding by deconvolution

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

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

Total Absorption γ-ray Spectroscopy (TAGS)





Observable:

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

$$S_i = \frac{I_i}{f(Q_\beta - E_i)T_{1/2}} \qquad \left[s^{-1}\right]$$

Statement of the problem:

$$I_i = \frac{f_i}{\sum_k f_k}$$

Relation between TAS data and the β-intensity distribution:

$$d_i = \sum_j R_{ij} f_j$$

$$\mathbf{R_j} = \sum_{k=0}^{j-1} b_{jk} \mathbf{g_{jk}} \otimes \mathbf{R_k}$$

Deconvolution (Inverse problem) algorithms

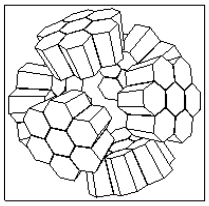
Monte Carlo simulations + Nuclear statistical model

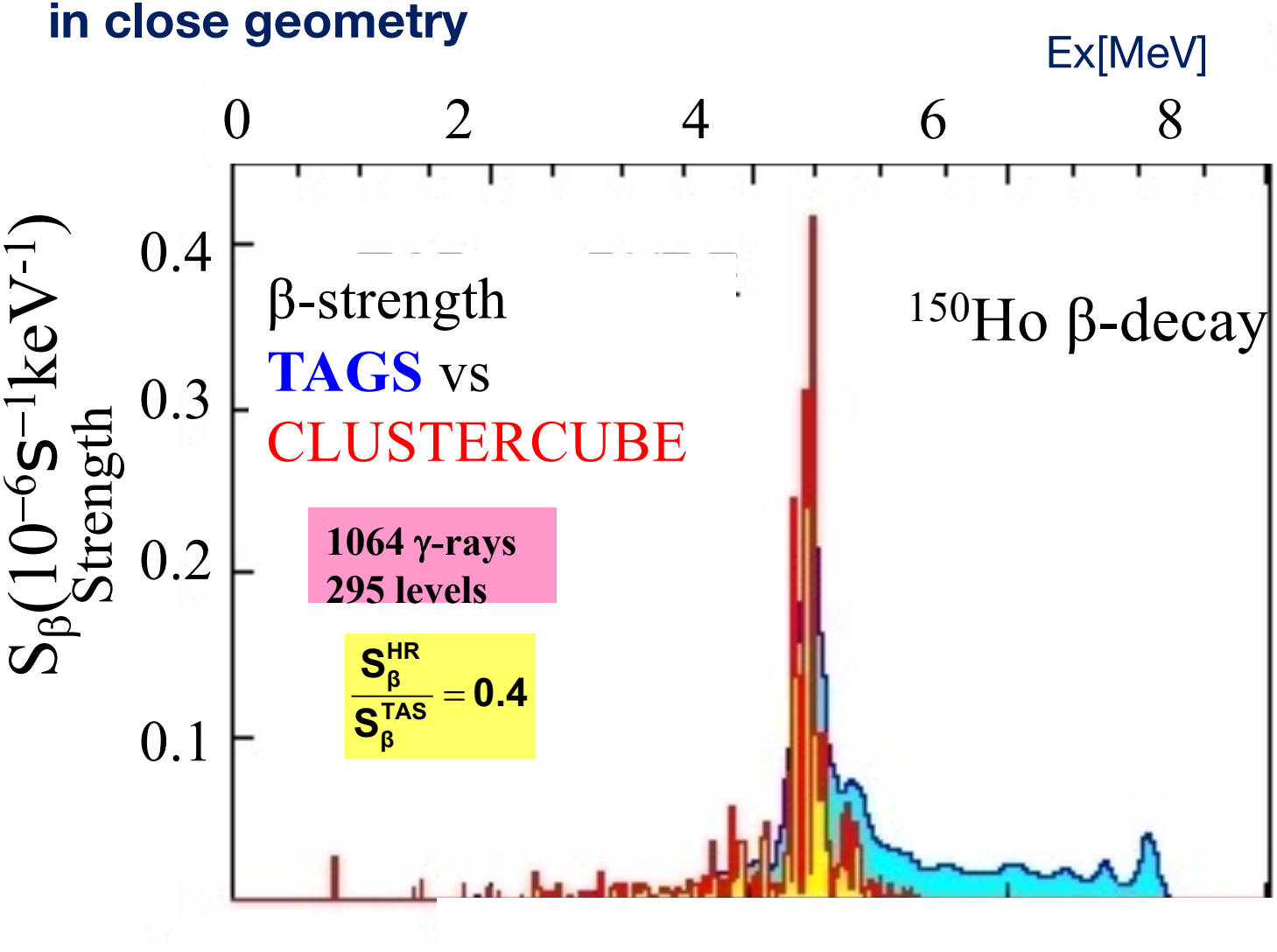
- **Spectrum must be clean**
- **Response must be accurately known**
- **Solution of inverse problem must be stable (requires calorimetry)**

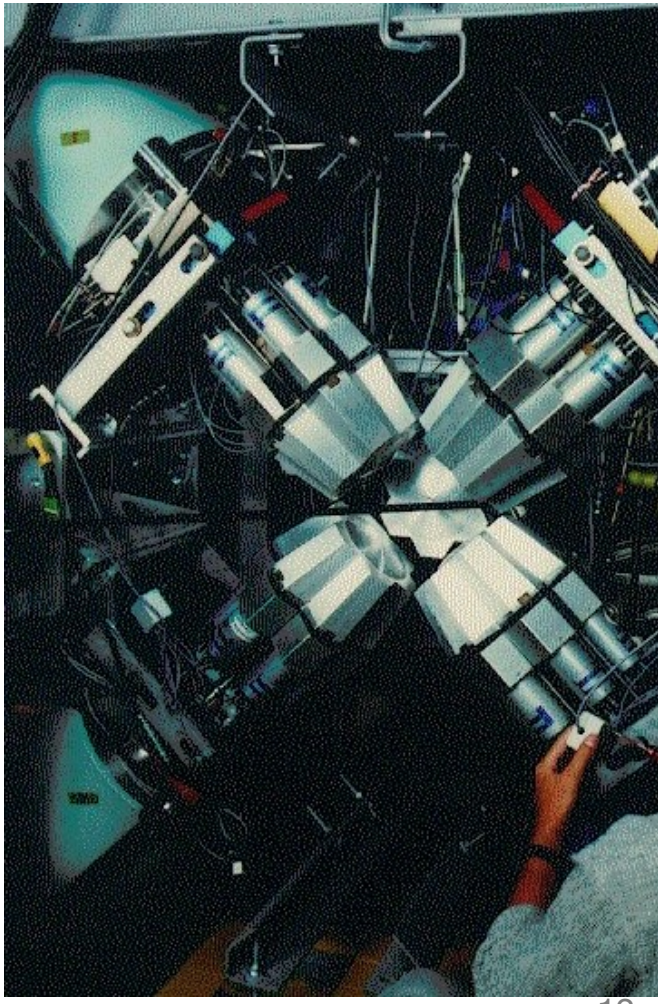
NIM A430 (1999) 333 NIM A571 (2007) 719
NIM A430 (1999) 488 NIM A571 (2007) 728

High Resolution & TAGS Complementarity

Six EUROBALL CLUSTER detectors in close geometry





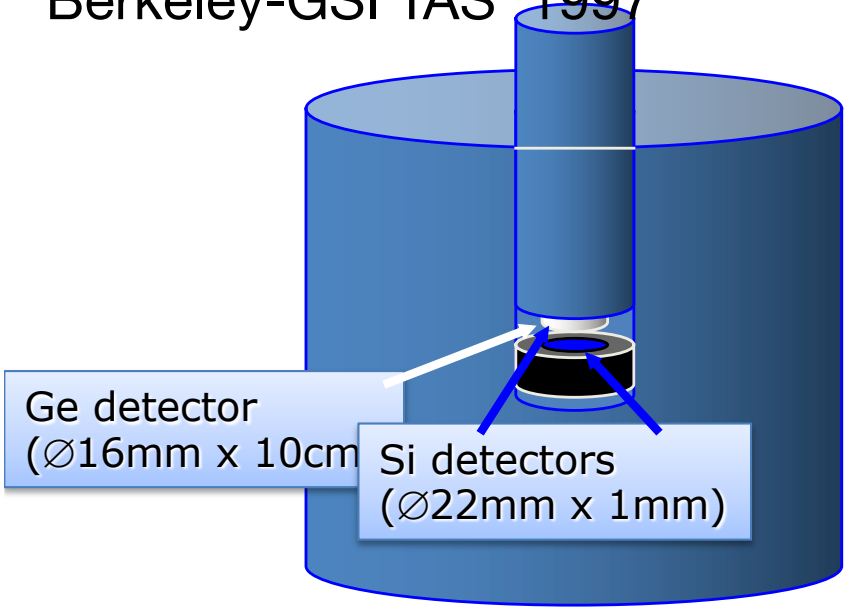


A. Algora, B. Rubio et al PRC 50 (2002)

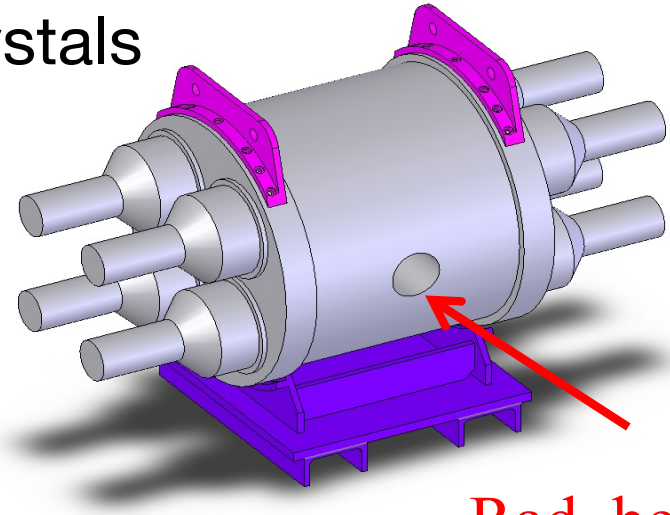
Past and Presently used TAS

TAS "Lucrecia" @ ISOLDE, CERN

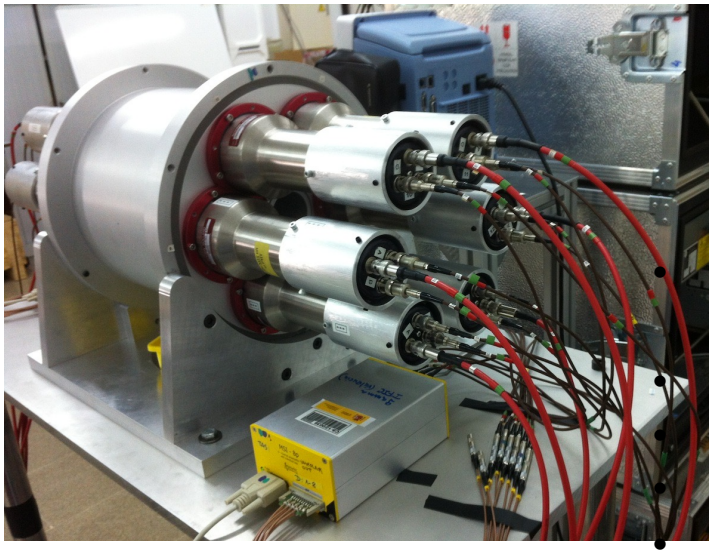
Berkeley-GSI TAS 1997



NaI large monocrystals



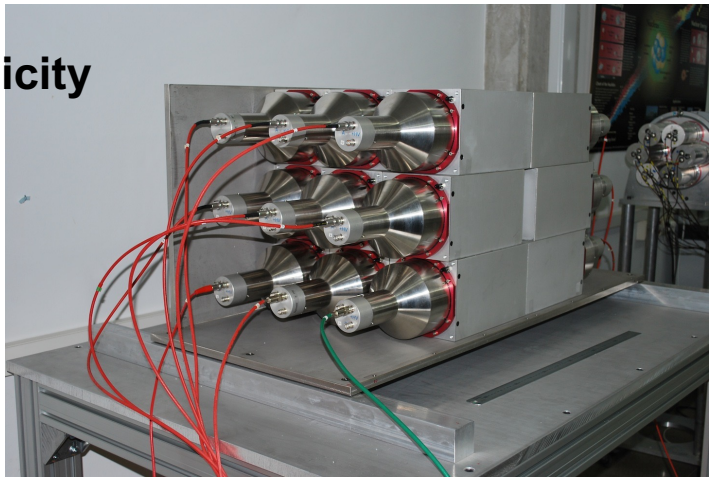
Rad. beam



"Rocinante" TAS

- **Compact 12-fold segmented BaF_2 spectrometer**
- **Low neutron sensitivity**
- **Cascade multiplicity information**
- **Good timing**
- **Resolution 10%@1.33MeV**

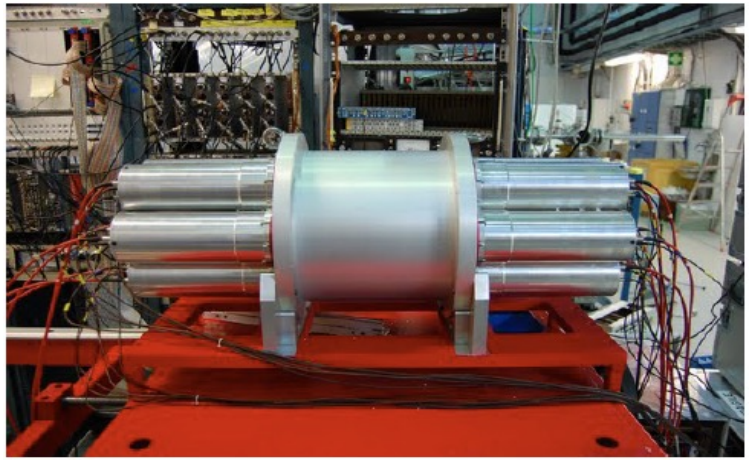
- **Large 18-fold segmented NaI spectrometer**
- **Cascade multiplicity information**



DTAS (NUSTAR) + AIDA DSSSD

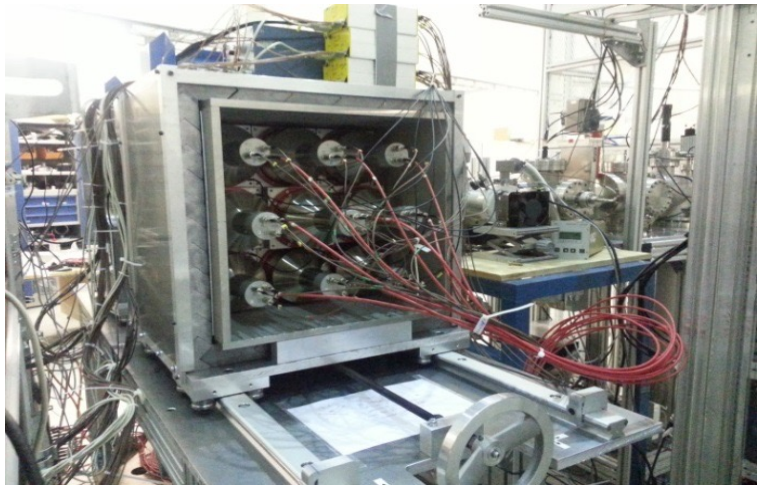
2 TAGS Campains at IGISOL Jyväskylä in 2009 and 2014

- **2 Segmented TAS campains @ IGISOL, Jyväskylä:**
  - ROCINANTE (IFIC Valencia/Surrey):



- ✓ 12 BaF_2 covering ~4π
- ✓ Detection efficiency of γ ray cascade >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):



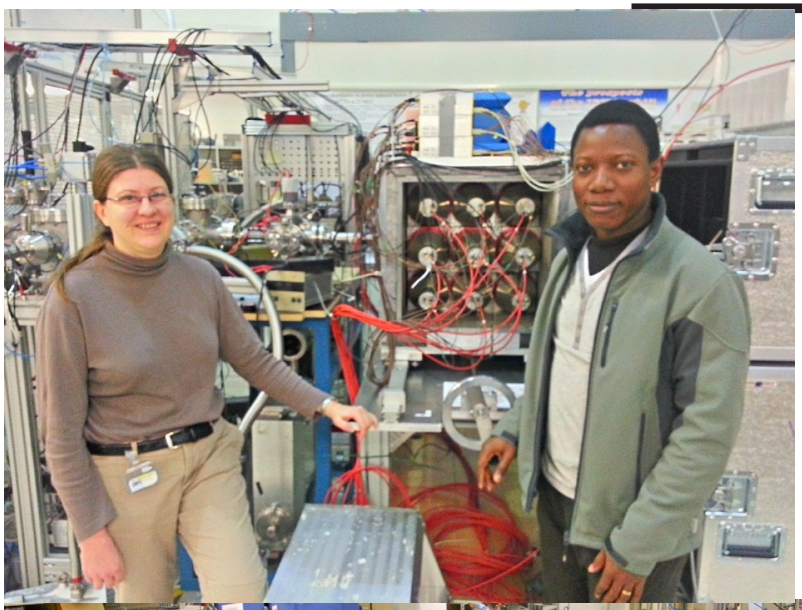
- ✓ 18 NaI(Tl) crystals of 15cm × 15cm × 25 cm
- ✓ Individual crystal resolutions: 7-8%
- ✓ Total efficiency: 80-90%
- ✓ Coupled with plastic scintillator for β
- ✓ 12 nuclei for anti-ν measured & 11 for DH

Collaboration: Nantes-Valencia-Surrey
Projects/Funding: MP TAGS, OPALE, BESTIOLE, EU CHANDA/SANDA, NEEDS/NACRE, IRP Astranucap, IRP ACnu
Main Pub./Com.: PRC 2011, PRL 2012, PRLs 2015, PRLs 2019, EPJ A 2021, EPJ A 2023, PRCs …
Manpower: ~1.1 FTE + 3 PhD & 2 Post-docs

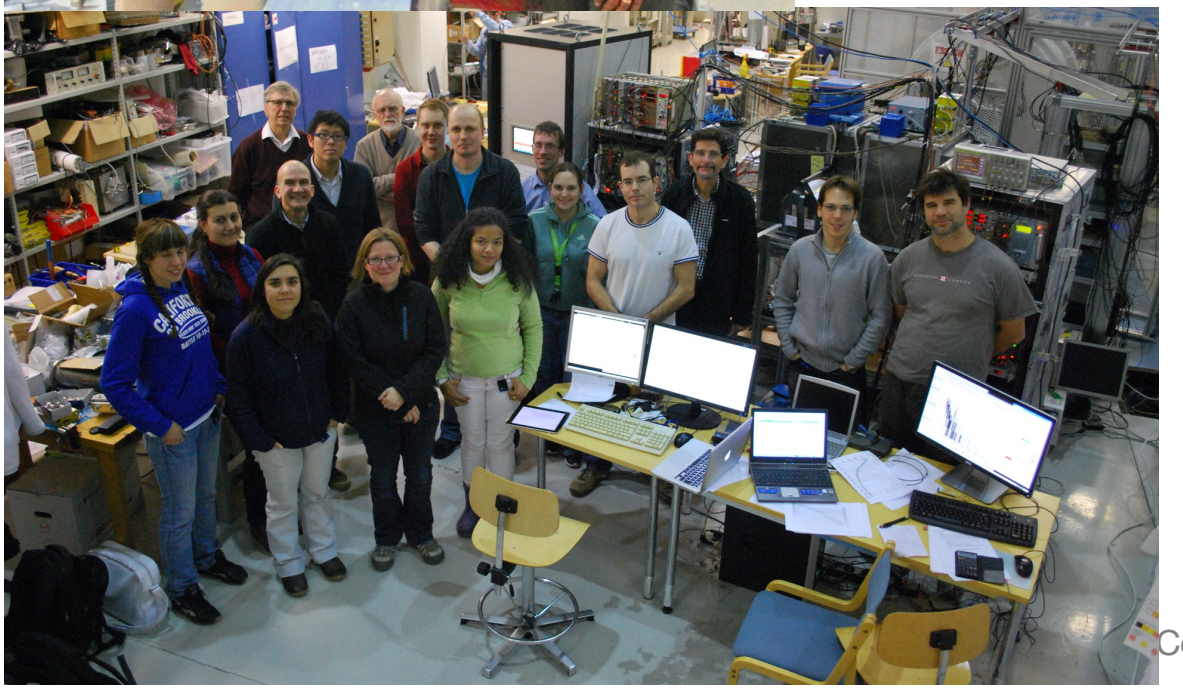
JYFL Accelerator News

Accelerator Laboratory, Department of Physics
University of Jyväskylä, Finland

Volume 22, No. 1 February 2014



« In the past month, an impressive group of approximately 25 visitors mainly from Valencia in Spain, and Subatech, Nantes, in France arrived along with three tonnes of equipment. In two back-to-back experiments geared at measurements of the beta-decay strength of 100Tc and a study of nuclei relevant for precise predictions of reactor neutrino spectra, JYFLTRAP has been used to provide high purity beams for a new total absorption gamma ray « spectrometer (DTAS). »



TAGS & Reactor Antineutrinos

Motivations: fundamental ν physics: reactor rate & shape anomalies, reactor monitoring

- **Our Summation Model provided the priority list from IAEA-NDS Report 676**
- **14 nuclei from priority list measured in TAGS campaigns**
- **Improved Summation Method**
- **Estimated impact of inclusion of 17 published TAGS decays on reactor antineutrino spectra: 10 years of measurements**

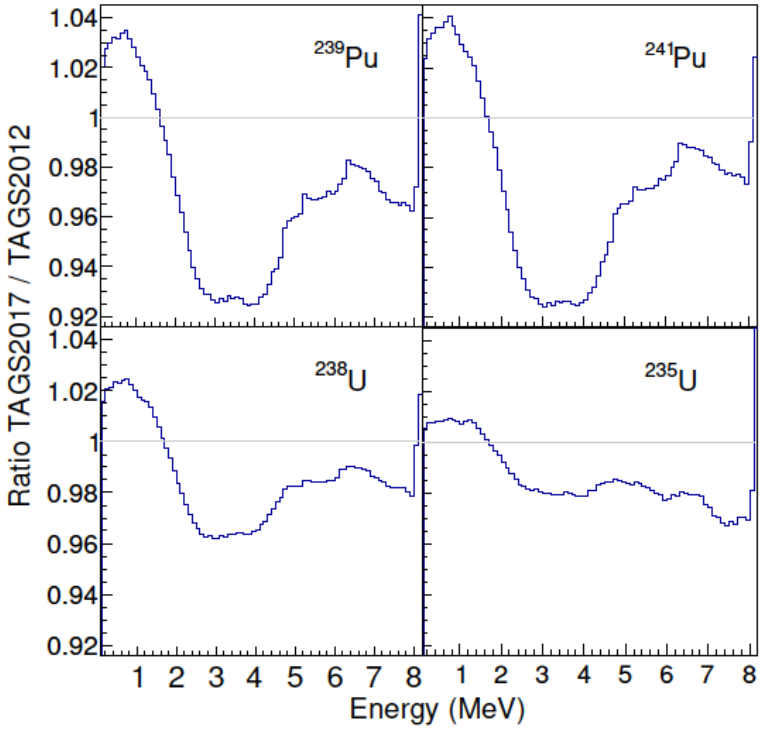


Fig. 17. Accumulated impact of the beta intensities of the ^{86,87,88}Br and ^{91,92,94}Rb [24,62,67] decays measured with the total absorption spectrometer *Rocinante* on the antineutrino spectra with respect to that published in [99] (relative ratios) for the thermal fissions of ^{235}U, ^{239}Pu and ^{241}Pu, and the fast fission of ^{238}U [107].

Review Paper Algora et al., Eur. Phys. J. A 57, 85 (2021)

Collabs.: Valencia, Surrey, IAEA NDS, K.-H. Schmidt, LNHB, CEA-DAM
Projects/Funding: OPALE, Jyvaskyla, NEEDS/NACRE, SANDA
Main Pubs./Com.: IAEA-NDS Reports 676 and 786, Review Paper Eur. Phys. J. A 57, 85 (2021), Nucl. Data. Sheets 2021, PRLs 2019 + 2 Accepted proposals @Jyväskylä, 1 LoI @ ALTO
Social Impact: 9 TAGS nuclei in JEFF3.3
Quality: Consultant/Expert, review papers, invited conferences (Neutrino 2020, WONDRAM 2021, SNOWMASS, JEFF 2022, IAEA 2019, 2021 & 2023), organisation of workshops (Nantes 2015, IAEA 2019, ISOL-France), …

TAGS & Reactor Decay Heat (DH)

Motivation: decay heat released after reactor shut-down (6-12% of the nominal power), essentially radioactive decays of FP and actinides => safety & economics

- **New! Summation Calculations with the SERPENT code:**

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

β,γ decay — Decay constant and Fission Yield

- **Still issues with nuclear decay data: Pandemonium Effect**
- **11 new nuclei from priority list measured in TAGS campaign**
- **Review paper coordinated per IAEA "Improving Fission product decay data for reactor applications"**
- **International blind test coordinated by SKB & Vattenfall (paper 2022)**
- **Decay heat uncertainty calculations with associated sensitivity studies. Impact of nuclear data: TMC approach (Cocodrilo code), PhD Y. Molla (2021-2024)**

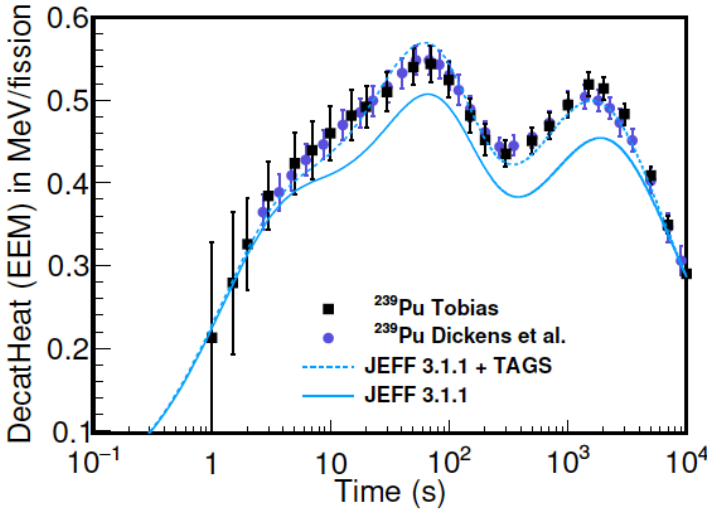


Fig. 13. Impact of the inclusion of the total absorption measurements performed for 13 decays (^{86,87,88}Br, ^{91,91,94}Rb, ^{101}Nb, ^{105}Mo, ^{102,104,105,106,107}Tc) published in Refs. [7,8,24, 62,67] in the gamma component of the decay heat calculations for ^{239}Pu.

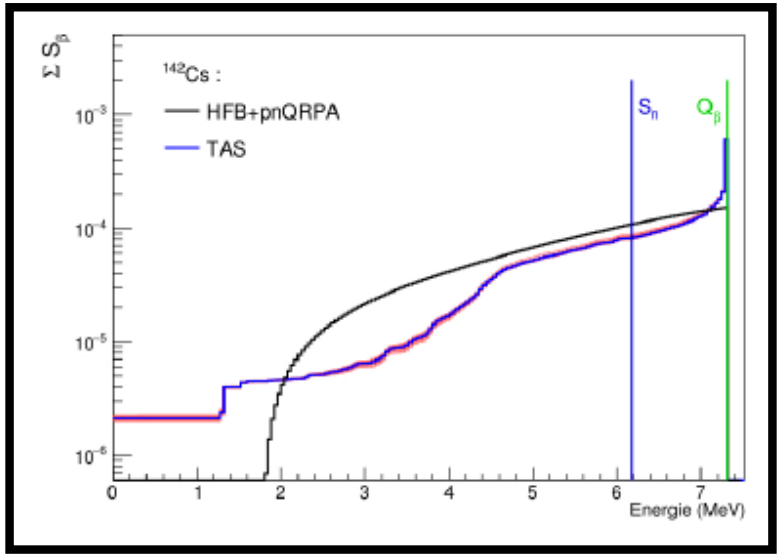
Review Paper Algora et al., Eur. Phys. J. A 57, 85 (2021)

Collabs.: NEA, IAEA NDS, K.-H. Schmidt, LNHB, CEA-DAM + CEA Cadarache and EDF, LPSC
Projects/Funding: OPALE, NEEDS/NACRE, NEEDS/SUDEC, PIRT, SANDA, SAMOSAFER, PIA4, MIMOSA
Main Pubs./Com.: TAGS & Decay Heat Review Paper with IAEA-NDS 2023, IAEA-NDS Reports 676 and 786, Review Paper Algora et al., Eur. Phys. J. A 57, 85 (2021) + 2 Accepted proposals @Jyväskylä, 1 LoI @ ALTO
Social Impact: 9 TAGS nuclei in JEFF3.3
Quality: Consultant/Expert, PhD Committees, invited talk @ IAEA (2022)

TAGS & Nuclear Structure and Astrophysics

Motivations: R-process: A short and very high neutron flux produces very n-rich nuclei in a short time, which then decay to stability. Requires nuclear properties for ~5000 exotic nuclei!

- **TAGS technique:**
  - **Best suited for accessing the β-strength -> B(GT) distribution**
  - **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: the 1st to propose the idea in 2013**
  - **Test of gamma strength functions and density levels in TAGS data analysis, compare β-strength with theory**



L. Le Meur's PhD 2018 (Subatech)

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

$$I_i = \frac{f_i}{\sum_k f_k}$$

Collab.: Nantes-Valencia, CEA-DAM with pn-QRPA model
Projects/Funding: SANDA, TAGS, BESTIOLE, IRP ASTRANUCAP & ACnu
Main Pub./Com.: 3 accepted proposals @ ALTO 2014, Jyväskylä 2018 & CERN-ISOLDE 2020, Review Paper Algora et al., Eur. Phys. J. A 57, 85 (2021)
+Organisation of 1 int. workshop « β-pygmy » in 2015 & ISOL-France Workshop 2019
Manpower: 1 defended PhD (L. Le Meur) & 1 Post-Doc

INDRA/FAZIA & Nuclear Astrophysics

Motivations: Study the equation of state of nuclear matter. Provide experimental constraints for the modelling of compact astrophysical objects using heavy ion collisions at Fermi energies accessible at GANIL

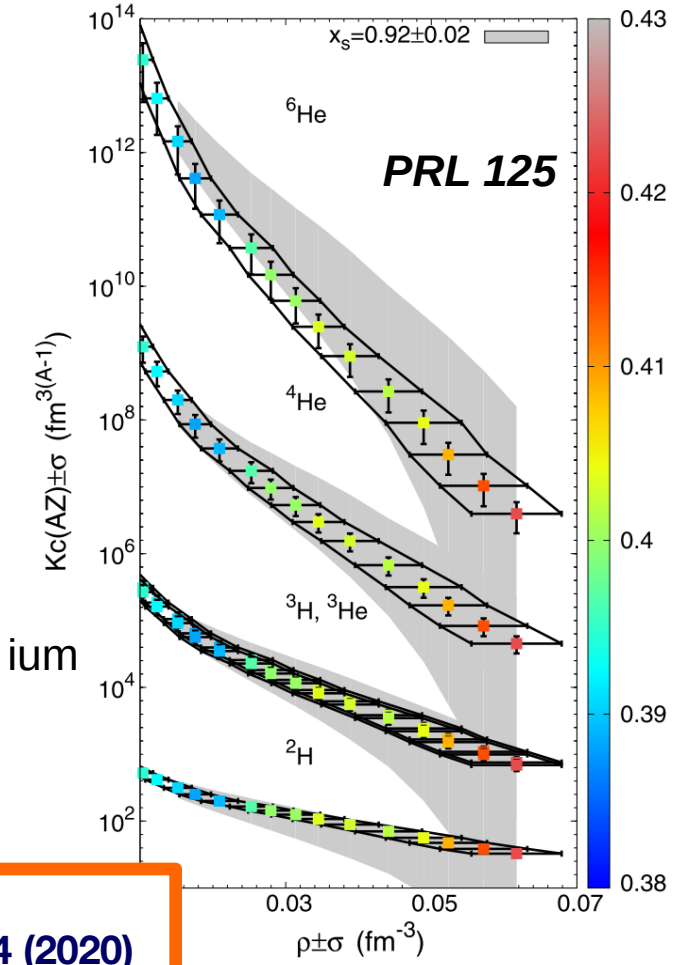
- **Data analysis on existing nuclear physics experiments results (INDRA coll.)**
  - Studing clusterisation process in warm dilute nuclear matter (NM)
  - Application to region explored during dynamical phase of SN II explosion
  - Collaboration with theoreticians (LPC Caen/Coimbra Univ., Portugal)

H. Pais et al, Phys. Rev. Lett. 125, 012701 (2020)

$$K_c(Z,A) = \frac{\rho_{Z,A}}{\rho_{1,1}^{Z}\rho_{0,1}^{A-Z}}$$

- **Since 2019, New experimental campaign at GANIL (FAZIA coll.)**
  - Nuclear Matter symmetry energy and isospin physics.
- **TDHF model (Dywan) for collisions and neutron star:**
  - Collaboration with Theory team

G. Besse, V. de la Mota, E. Bonnet, et al. Phys. Rev. C 101, 054608 (2020)



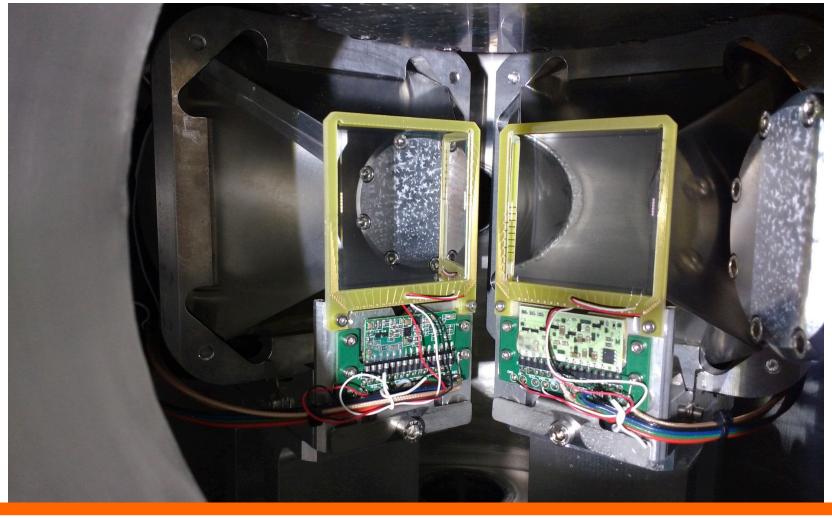
ium

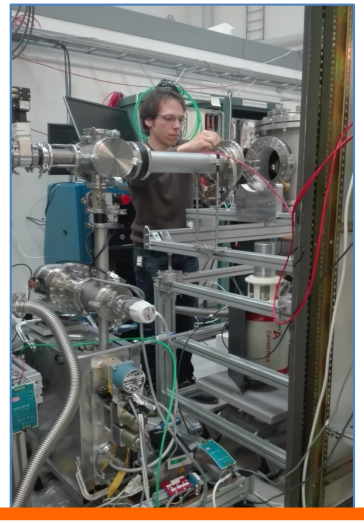
Collab.: INDRA/FAZIA: France, Italie, Espagne, Corée, Pologne
Main Pub. Com.: H. Pais et al, J. Phys. G: Nucl. Part. Phys. 47 105204 (2020)
H. Pais et al, Phys. Rev. Lett. 125, 012701 (2020)
R. Bougault et al, Journal of Physics G : Nucl. Part. Phys. 47, 025103 (2020),
G. Besse, V. de la Mota, E. Bonnet, et al. Phys. Rev. C 101, 054608 (2020)
Manpower: 0.7-0.8 FTE researcher

E-Shape

Motivations: measure electron shape factors from forbidden decays = best hypotheses to explain the shape anomaly in antineutrino spectra + impact on r-process calculations

- **Mechanical & electronical designs, detector assembly @Subatech, First tests @CENBG in March 2019**
- **Commissioning experiments in May 2019, Experiment in Jan. 2022, analysis on-going (R. Kean@Subatech, G. Alcala@Valencia, A. Beloeuvre@Subatech)**
- **Successful use of FASTER from LPC Caen with help from D. Etasse**
- **Since Automn 2020, Theoretical part of A. Beloeuvre's PhD with S. Péru & M. Martini: inclusion of forbidden operators in pn-QRPA model**





Collab.: Technical services, Nantes-Valencia-Surrey, + CEA-DAM pn-QRPA model
Projects/Funding: SANDA European project, NEEDS/NACRE, OPALE, PICS, Région Pays de Loire (AAP Petits Equipements)
Main Pub. Com.: 2 accepted proposals @ Jyväskylä 2017 & 2019
Manpower: 0.3 FTE researchers, 41 mths postdocs, + 0.6 FTE technical services & mechanical workshop (2017-> 2019) + 1 electronics engineer 0.25 FTE since Sept. 2020 + 1 PhD (A. Beloeuvre 0.5FTE)

(NA)^{2}STARS

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

- **Addition of 16 2" x 2" x 4" $LaBr_3$:Ce modules between the two halves of the existing TAS (DTAS, Rocinante)**

⇒ **large efficiency combined with the very good energy resolution and timing of the $LaBr_3$: solution to the study of more exotic nuclei with the TAGS technique, n/γ discrimination with TOF**

⇒ **segmentation: γ-γ coincidences and angular correlations of specific γ-ray cascades: study of more exotic nuclei or cross-section measurements.**

⇒ **knowledge of γ-cascade multiplicity = good control of the uncertainty on the sum peak efficiency**

⇒ **Broad physics case: n-rich, n-deficient nuclei**

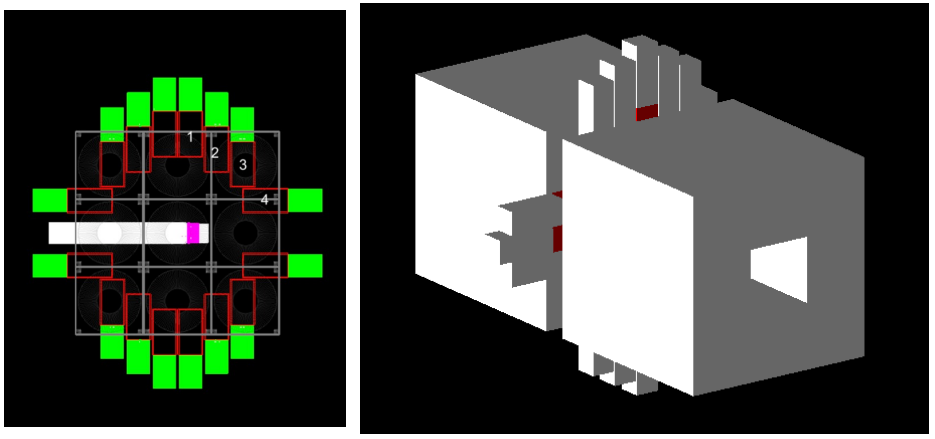


Fig. 4 : view of possible arrangement of the 16 LaBr3:Ce (red) in the middle of the NaI crystals (grey) (courtesy A. Beloeuvre).

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

(NA)^{2}STARS

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

- **Addition of 16 2” x 2” x 4” $LaBr_3$:Ce modules between the two halves of the existing TAS (DTAS, Rocinante)**

⇒ **large efficiency combined with the very good energy resolution and timing of the $LaBr_3$: solution to the study of more exotic nuclei with the TAGS technique, n/γ discrimination with TOF**

⇒ **segmentation: γ-γ coincidences and angular correlations of specific γ-ray cascades: study of more exotic nuclei or cross-section measurements.**

⇒ **knowledge of γ-cascade multiplicity = good control of the uncertainty on the sum peak efficiency**

⇒ **Broad physics case: n-rich, n-deficient nuclei**

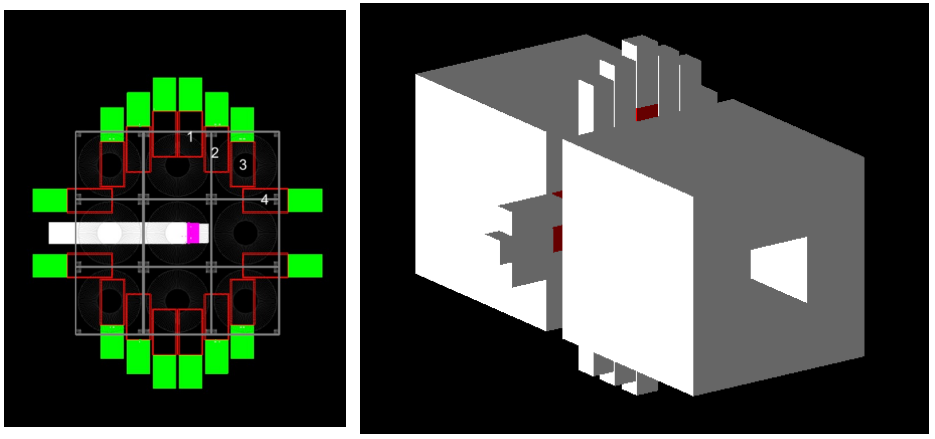


Fig. 4 : view of possible arrangement of the 16 LaBr3:Ce (red) in the middle of the NaI crystals (grey) (courtesy A. Beloeuvre).

Collab.: IP2I Lyon, IFIC Valencia, Ciemat Madrid, Surrey Univ.
Project/Funding: 7 $LaBr_3$ crystals in the collab. (2 @ Subatech), 2 ANR demands: 2020 (rejected phase 2), 2021 (rejected phase 1!), supported by the Nantes University (Pepite project), on-going discussions for support from GANIL and in2p3
Manpower: SEN team + 1 electronics engineer 0.25 FTE since Sept. 2020 + A. Beloeuvre’s PhD (0.5 FTE in 2020)
Conferences: invited talk @ ISOL-France 2021 & Ganil Community Meeting 2022, presentation @ GANIL Scientific Council 2023

Team management

- **Scientific Animation**
  - Organisation of **Seminars** (about 10), organisation of **workshops@Subatech** (3 overs the period)
  - Invitation of: **K-H. Schmidt** (2 months in 2018, 1 month in 2019), **L. Hayen** (1 month in 2020, postponed to May 2022 due to Covid)
  - Circulate infos on papers, workshops, conference, talks, etc.
- **Team meetings**
  - All team members participate to the experiments proposed by team members
  - Regular full team meetings
  - Meetings specific to projects (TAGS analysis, NACRE, ν spectra, decay heat, FASTER, E-Shape…)
- **Interaction with other team and service of the laboratory**
  - **Technical Services: Electronics, Mechanics**, computing: A. Cadiou, J.-S. Stutzmann, J. Simmonneau, F. Lefèvre, G. Bouvet, S. Bouvier, L.-M. Rigalleau, S. Acounis & **Mechanical Workshop** on E-Shape, TAGS et $(NA)^2$STARS
  - **Radiochemistry**: since 2021, used fuel simulation expertise for radiochemistry projects
  - **Neutrino:** SoLid experiment (reactor & spectrum WG), previously Double Chooz (-> 2016) and Nucifer.
  - **Xenon:** via network funding demand COST (« Networking Nuclear, Neutrino and New Physics » submitted late 2020), new GDR and future discussions on nuclear models & TAGS experiments for double beta decay (2021 ?), PhD & HDR committees
  - **PRISMA**: first discussions (2021) around SMILES
  - **Theory:** using eTDHF model (DYWAN), comparison btw transport models and multifragmentation experimental data

Local, regional, national & international ecosystem

- **International:**
  - 5 European Projects: CHANDA (1 Task), SANDA (3 Tasks), SAMOSAFER (Task Leader), PREDIS, MIMOSA
  - TAGS and E-Shape Collab. with IFIC Valencia and Surrey
  - IAEA and NEA experts/consultants
  - IAEA Coordinated Research Project (β-delayed neutrons, fission yields)
  - (NA)^{2}STARS project with IFIC Valencia, CIEMAT Madrid, Univ. of Surrey, IP2I
  - Collab. With VTT Finlande (SERPENT)
  - NuBall collab. (J. Wilson et al. IJCLab since 2014)
  - IRP/IRN ASTRANUCAP, ACNu
  - GANIL, Jyväskylä, ISOLDE, ALTO
  - INDRA/FAZIA collab.
  - SoLid (resp. WG until 2020)
- **National:**
  - ISOL-France, MP OPALE, GDR RESANET, GDR SCINEE
  - GANIL & LPC Caen (B. Bastin, F. Gulminelli, A. Fantina) for core-collapse SNe
  - Collab. With IP2I (C. Ducoin, O. Stezowski et al.): p-process, (NA)^{2}STARS
  - Collab. with LPSC Grenoble (MSFR), VTT Finlande (SERPENT)
  - Collab. with theoreticians from CEA DAM (theoretical parts of Arthur Beloeuvre's PhD, Loïc Le Meur's PhD, Zakari Issoufou's PhD)
  - NEEDS/NACRE collab. (resp. WP3, LNHB, CEA Cadarache, LPSC), NEEDS/PIRT, NEEDS/SUDEC
  - ORANO, EDF, FRAMATOME
  - SOPRAANO project on antineutrino spectra with LNHB et CEA DAM
  - FUGACE project on a new Gas Cell for DESIR (CENBG, LPC Caen)

Local, regional, national & international ecosystem

- **Implications in the life of the University:**
  - Member of the doctoral school committee 3M/Université Bretagne Loire and of the PhD admission committee

- **Implications at the national level:**
  - 1 member CoCNRS 01 up to 2016
  - 1 member of Nat. Univ. Council (CNU) 29: 2019 - 2023

- **Implications in the life of the laboratory:**
  - 1 elected member of the lab. Council of Subatech
  - 1 member NEA Officer for Subatech
  - 1 member Coordinator of the Gender Balance Committee of Subatech
  - Participation to the lab. prospectives (2019)
  - 1 member Web committee

- **French Physics Society:**
  - President of the nuclear physics division

Contribution to the teaching “par la recherche”

- **Masters & Parcours @ Univ. Nantes/IMT Atlantique**
  - Resp. Master Fundamental Physics and Applications (PFA, NU/IMT A), Co-Resp M1 PFA, Co-Resp. Parcours Nuclear Modelling and Dismantling of the M2 PFA (NU / IMT A)
  - Resp. Engineering Option STAR -> 2017
  - Resp. 9 UE IMTA, resp. of univ. courses: speciality course on nuclear energy, MC simulations (MCNP, SERPENT, GEANT4), nuclear physics, radiation detection
- **Supervision of internships L3, M1 et M2**
  - Internship Students: 20 during the period
- **Supervision of PhD**
  - **Abdoul- Aziz Zakari-Issoufou** (2015 co-supervised M. Fallot – A. Porta, dir. F. Haddad) – « Mesures TAGS pour les antineutrinos et la puissance résiduelle des réacteurs » (→ Post-doc @ IJCLab, now industry)
  - **Loïc Le Meur** (2018 co-supervised M. Fallot, – A. Porta, Dir. T. Sami) – « Mesures TAGS pour la structure et l’astrophysique nucléaires, les antineutrinos et la puissance résiduelle des réacteurs » (→ permaculture)
  - **Arthur Beloeuvre** (2019 ->2023), originally TAGS, switched to E-Shape due to Covid-19
  - **Yohannes Molla** (2021 -> 2024), Decay heat uncertainty calculations with associated sensitivity studies. Impact of nuclear data
  - **Julien Pépin** (2022 -> 2025), TAGS measurements for Nuclear Structure, Astrophysics and Applications
- **Participation to teachings & comm. for CNRS members:**
  - resp. of university course on modelling for engineering L2&M1 EEA-SPI, course in M2 RPS
  - Presentations to lycéens/collégiens

Highlights 2018-2023

Publications

PHYSICAL REVIEW C

covering nuclear physics

Highlights Recent Accepted Authors Referees Search Press About

Improved predictions of reactor antineutrino spectra

Th. A. Mueller, D. Lhuillier, M. Fallot, A. Letourneau, S. Cormon, M. Fechner, L. Giot, T. Lasserre, J. Martino, G. Mention, A. Porta, and F. Yermia
Phys. Rev. C **83**, 054615 – Published 23 May 2011

Article References Citing Articles (359) PDF HTML Export Citation

ABSTRACT

Precise predictions of the antineutrino spectra emitted by nuclear reactors is a key ingredient in

PHYSICAL REVIEW LETTERS

Highlights Recent Accepted Collections Authors Referees Search Press About

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

M. Fallot, S. Cormon, M. Estienne, A. Algora, V. M. Bui, A. Cucoanes, M. Elnimr, L. Giot, D. Jordan, J. Martino, A. Onillon, A. Porta, G. Pronost, A. Remoto, J. L. Taín, F. Yermia, and A.-A. Zakari-Issoufou
Phys. Rev. Lett. **109**, 202504 – Published 13 November 2012

10

Article References Citing Articles (58) PDF HTML Export Citation

PHYSICAL REVIEW LETTERS

Highlights Recent Accepted Collections Authors Referees Search Press About

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

J. L. Tain *et al.*
Phys. Rev. Lett. **115**, 062502 – Published 6 August 2015

7 More

PHYSICAL REVIEW LETTERS

Highlights Recent Accepted Collections Authors Referees Search Press Abo

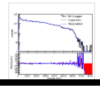
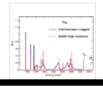
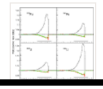
Total Absorption Spectroscopy Study of ^{92}Rb Decay: A Major Contributor to Reactor Antineutrino Spectrum Shape

A.-A. Zakari-Issoufou *et al.*
Phys. Rev. Lett. **115**, 102503 – Published 4 September 2015

Article References Citing Articles (29) PDF HTML Export Citation

ABSTRACT

The antineutrino spectra measured in recent experiments at reactors are inconsis
calculations based on the conversion of integral beta spectra recorded at the ILL
the dominant contribution to the reactor antineutrino spectrum in the 5–8 MeV ra
properties are in question. We have studied ^{92}Rb decay with total absorption spe
Previously unobserved beta feeding was seen in the 4.5–5.5 region and the GS t
found to be 87.5(25)%. The impact on the reactor antineutrino spectra calculated
method is shown and discussed.

Physics

ABOUT BROWSE PRESS COLLECTIONS CELEBRATING 10 YEARS

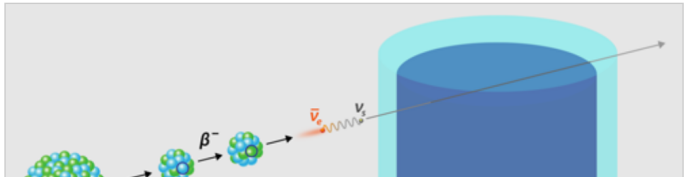
Search articles

Viewpoint: Getting to the Bottom of an Antineutrino Anomaly

Muriel Fallot, SUBATECH, CNRS/IN2P3, University of Nantes, Institut Mines-Telecom Atlantique, Rue Alfred Kastler, F-44307 Nantes, France

June 19, 2017 • *Physics* 10, 66

The Daya Bay Collaboration reports that sterile neutrinos probably aren't behind a puzzling deficit in detected antineutrinos at nuclear reactors.



PDF Version Print

Evolution of the Reactor Antineutrino Flux and Spectrum at Daya Bay
F.P. An *et al.* (Daya Bay Collaboration)
Phys. Rev. Lett. 118, 251801 (2017)
Published June 19, 2017

Read PDF

Features

Award-Winning Fluid Videos
Videos of shaking blue drops, oscillating flames, and dripping fluids win the top prize of the APS Division of Fluid Dynamics.

March 16. 2023

Publications

PHYSICAL REVIEW LETTERS

Highlights Recent Accepted Collections Authors Referees Search Press About

Large Impact of the Decay of Niobium Isomers on the Reactor $\bar{\nu}_e$ Summation Calculations

V. Guadilla *et al.*
Phys. Rev. Lett. **122**, 042502 – Published 30 January 2019

Article References Citing Articles (3) Supplemental Material PDF HTML Export Citation

ABSTRACT

Eve

Total Absorption Sp
Contributor to Reac

A.-A. Zakari-Issoufou *et al.*
Phys. Rev. Lett. **115**, 102503 – P

Article References Citi

ABSTRAC

The antineutrino
calculations bas
the dominant co
properties are in
Previously unobs
found to be 87.5
method is show

from the Summation
ts

r, L. Giot, D. Jordan, J. Martino, A.
-Issoufou

Export Citation

Press About

tes Populated

Issue

PHYSICAL REVIEW LETTERS

Highlights Recent Accepted Collections Authors Referees Search Press About

Updated Summation Model: An Improved Agreement with the Daya Bay Antineutrino Fluxes

M. Estienne, M. Fallot, A. Algora, J. Briz-Monago, V. M. Bui, S. Cormon, W. Gelletly, L. Giot, V. Guadilla, D. Jordan, L. Le Meur, A. Porta, S. Rice, B. Rubio, J. L. Taín, E. Valencia, and A.-A. Zakari-Issoufou
Phys. Rev. Lett. **123**, 022502 – Published 9 July 2019

Article References No Citing Articles Supplemental Material PDF HTML Export Citation

ABSTRACT

A new summation method model of the reactor antineutrino energy spectrum is presented. It is

Issue
Vol. 123, Iss. 2 — 12 July 2019

Division of Fluid Dynamics.

Publications

PHYSICAL REVIEW C
covering nuclear physics

Highlights Recent Accepted Collections Authors Referees Search

PHYSICAL REVIEW C
overing nuclear physics

ighlights Recent Accepted Collections Authors

Determination of β-decay ground state feeding of nu
importance for reactor applications

V. Guadilla *et al.*
Phys. Rev. C **102**, 064304 – Published 2 December 2020

Total absorption γ-ray spectroscopy of niobium isomers

V. Guadilla *et al.*
Phys. Rev. C **100**, 024311 – Published 9 August 2019

PHYSICAL REVIEW C
covering nuclear physics

Highlights Recent Accepted Collections Aut

Total absorption γ-ray spectroscop
emitters ^{137}I and ^{95}Rb

V. Guadilla *et al.*
Phys. Rev. C **100**, 044305 – Published 9 October 2019

PHYSICAL REVIEW C
covering nuclear physics

Highlights Recent Accepted Collections Authors Referees Search Press Abou

Total absorption γ-ray spectroscopy of the β decays of ^{96gs,m}Y

V. Guadilla *et al.*
Phys. Rev. C **106**, 014306 – Published 13 July 2022

Article References No Citing Articles Supplemental Material PDF HTML Expo

ABSTRACT

The β decays of the ground state (gs) and isomeric state (m) of ^{96}Y have been studied with the tota
absorption γ-ray spectroscopy technique at the Ion Guide Isotope Separator On-Line facility. The

Publications

Nuclear Data Sheets
Volume 173, March–April 2021, Pages 144-238

Development of a Reference Database for Beta-Delayed Neutron Emission

P. Dimitriou [a], I. Dillmann [b c], B. Singh [d], V. Piksaikin [e], K.P. Rykaczewski [f], J.L. Tain [g], A. Algora [g], K. Banerjee [h], I.N. Borzov [i j], D. Cano-Ott [k], S. Chiba [l], M. Fallot [m], D. Foligno [n], R. Grzywacz [o f], X. Huang [p], T. Marketin [q], F. Minato [r], G. Mukherjee [h], B.C. Rasco [s f o t], A. Sonzogni [u]...N.D. Scielzo [v]

Show more

Open Access
Review
Eur. Phys. J. A (2021) **57**: 85
https://doi.org/10.1140/epja/s10050-020-00316-4
Review

Beta-decay studies for applied and basic nuclear physics

A. Algora[1,2a], J. L. Tain[1], B. Rubio[1], M. Fallot[3] and W. Gelletly[4]

[1] IFIC (CSIC-Univ. Valencia), Paterna, Spain
[2] Institute of Nuclear Research (ATOMKI), Debrecen, Hungary
[3] Subatech (CNRS/in2p3-Univ. Nantes-IMTA), Nantes, France

Nuclear Science and Engineering

Improving Fission-product Decay Data for Reactor Applications: Part I - Decay Heat

A.L. Nichols[1,2], P. Dimitriou[a,3], A. Algora[4,5], M. Fallot[6], L. Giot[6], F.G. Kondev[7], T. Yoshida[8], M. Karny[9], G. Mukherjee[10], B.C. Rasco[11], K.P. Rykaczewski[11], A.A. Sonzogni[12], J.L. Tain[4]

[1]Department of Physics, University of Surrey, Guildford, GU2 7XH, Surrey, UK
[2]Manipal Academy of Higher Education, Manipal, Karnataka 576104, India
[3]Nuclear Data Section, International Atomic Energy Agency, A-1400 Vienna, Austria
[4]Instituto de Fisica Corpuscular (IFIC), CSIC-Universidad de Valencia, 46071 Valencia, Spain
[5]Institute of Nuclear Research (ATOMKI), Debrecen, Hungary
[6]Laboratoire Subatech, University of Nantes, CNRS/IN2P3, Institut Mines Telecom Atlantique, 44307 Nantes, France
[7]Physics Division, Argonne National Laboratory, Lemont, Illinois 60439, USA
[8]Institute of Innovative Research, Tokyo Institute of Technology, Tokyo 152-8550, Japan
[9]Physics Faculty, University of Warsaw, PL-02-093, Warsaw, Poland
[10]Variable Energy Cyclotron Centre, Kolkata 700064, India
[11]Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA
[12]Nuclear Science and Technology Department, Building 817, Brookhaven National Laboratory, Upton, NY 19973-5000, USA

Received: date / Revised version: date

Abstract Effort has been expended to assess the relative merits of undertaking further decay-data measurements of the main fission-product contributors to the actinides generated via neutron capture along with their heavy-element decay products and various activation products [1,2]. Such decay heat is extremely sig-

nt) (Online) Journal homepage: https://www.tandfonline.com/loi/unse20

enchmark Exercise for Spent Nuclear Fuel Heat

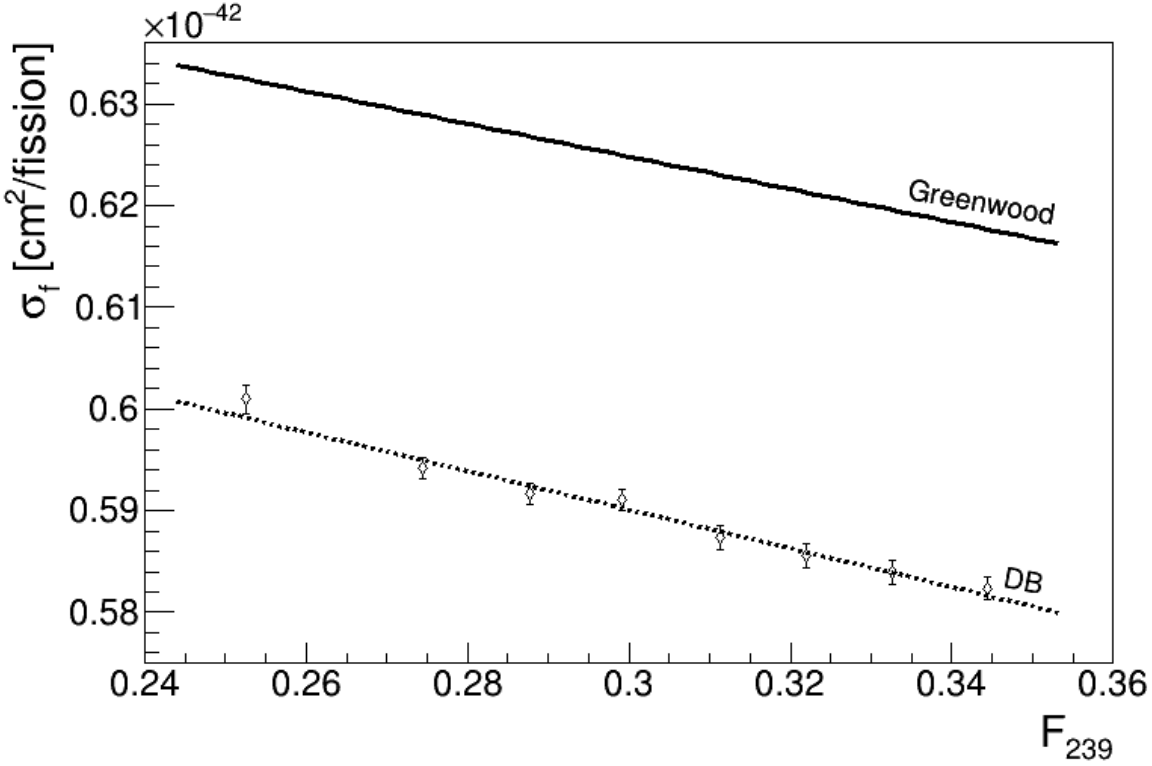
on, Martin Bengtsson, Ulrika Bäckström, Francisco Álvarez-
šan Čalič, Stefano Caruso, Ron Dagan, Luca Fiorito, Lydie Giot,
rs, Augusto Hernandez Solis, Volker Hannstein, Germina Ilas,

Extensive Study of the Quality of Fission from Experiment, Evaluation and GEF fo Antineutrino Studies and Applications

K.-H. Schmidt [a], M. Estienne [a], M. Fallot [a], S. Cormon [a], A. Cucoan
B. Jurado [b], K. Kern [c], Ch. Schmitt [d]

Highlight 1

- The IBD yields dependency with F239 including TAGS data published in 2012, 2015, 2017 and 2019 has been calculated using our summation calculation



- Impact of the inclusion of the TAGS data (Pandemonium free):

⇒ **Systematic reduction of the detected flux**

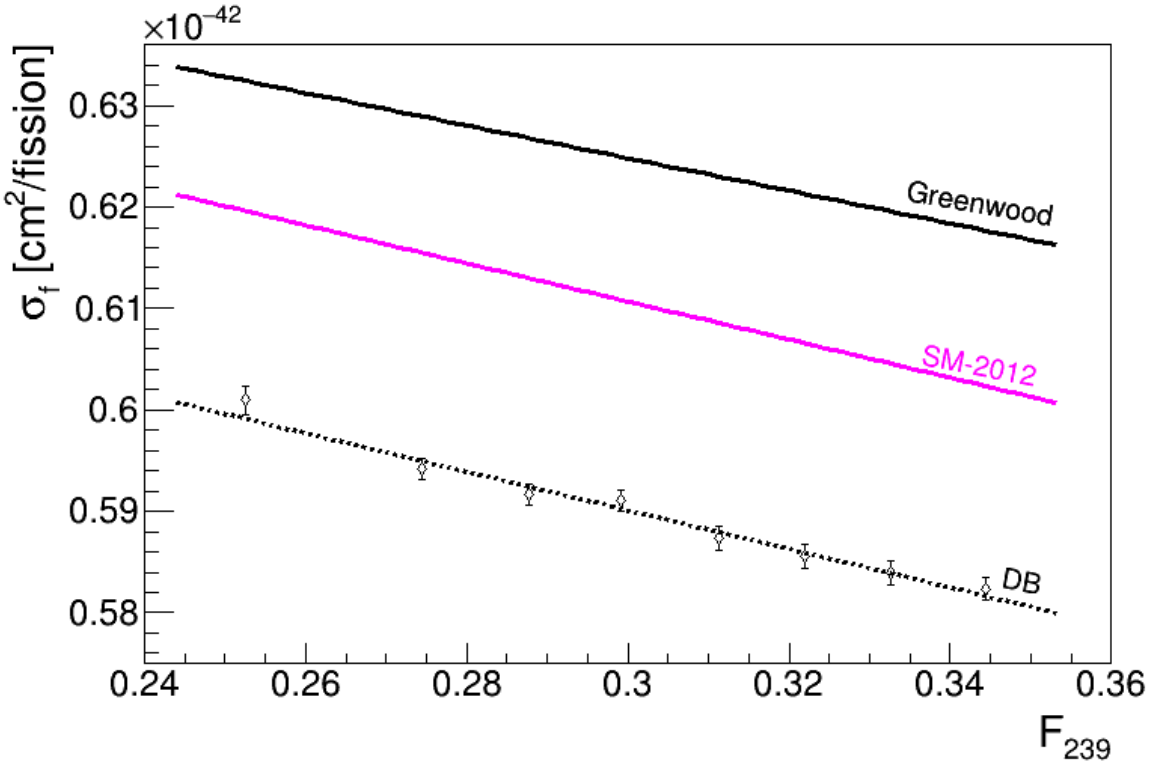
⇒ **Systematic reduction of the discrepancy with Daya Bay results**

⇒ Implies an increasingly smaller discrepancy with the inclusion of future TAGS data, **leaving less and less room for a reactor anomaly.**

M. Estienne et al. PRL 123, (2019) 022502 http://arxiv.org/abs/1904.09358

Highlight 1

- The IBD yields dependency with F239 including TAGS data published in 2012, 2015, 2017 and 2019 has been calculated using our summation calculation



- Impact of the inclusion of the TAGS data (Pandemonium free):

⇒ **Systematic reduction of the detected flux**

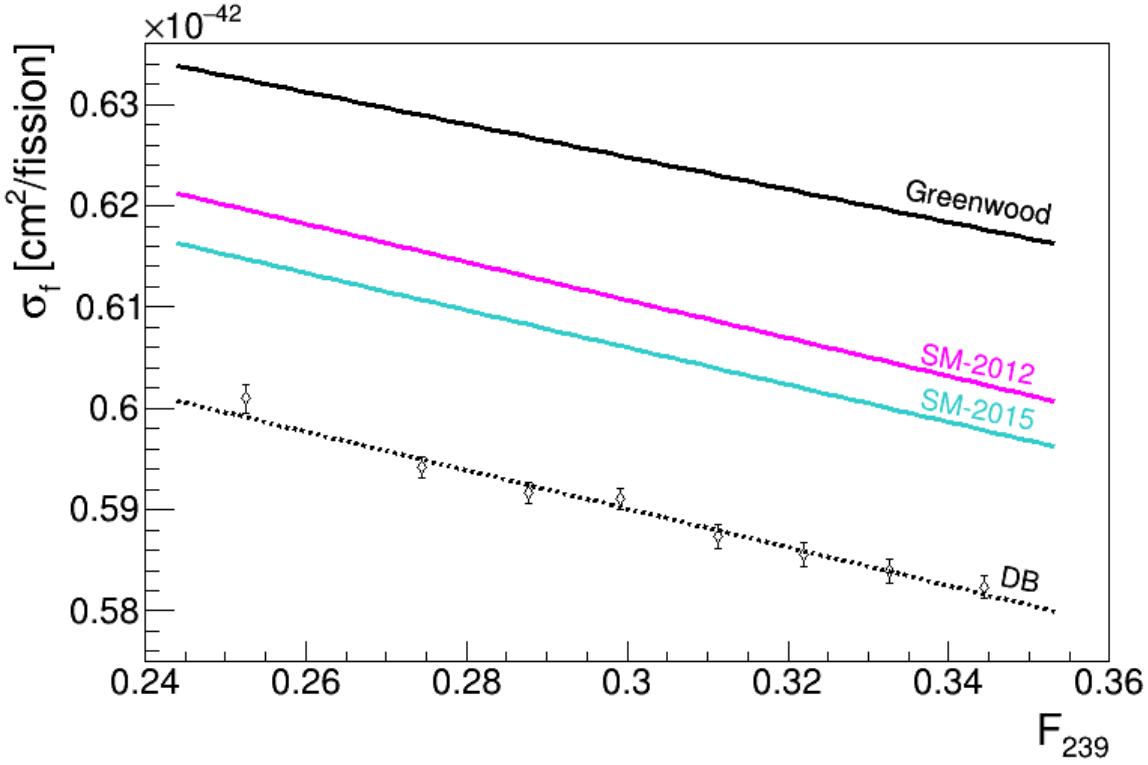
⇒ **Systematic reduction of the discrepancy with Daya Bay results**

⇒ Implies an increasingly smaller discrepancy with the inclusion of future TAGS data, **leaving less and less room for a reactor anomaly.**

M. Estienne et al. PRL 123, (2019) 022502 http://arxiv.org/abs/1904.09358

Highlight 1

- The IBD yields dependency with F239 including TAGS data published in 2012, 2015, 2017 and 2019 has been calculated using our summation calculation



- Impact of the inclusion of the TAGS data (Pandemonium free):

⇒ **Systematic reduction of the detected flux**

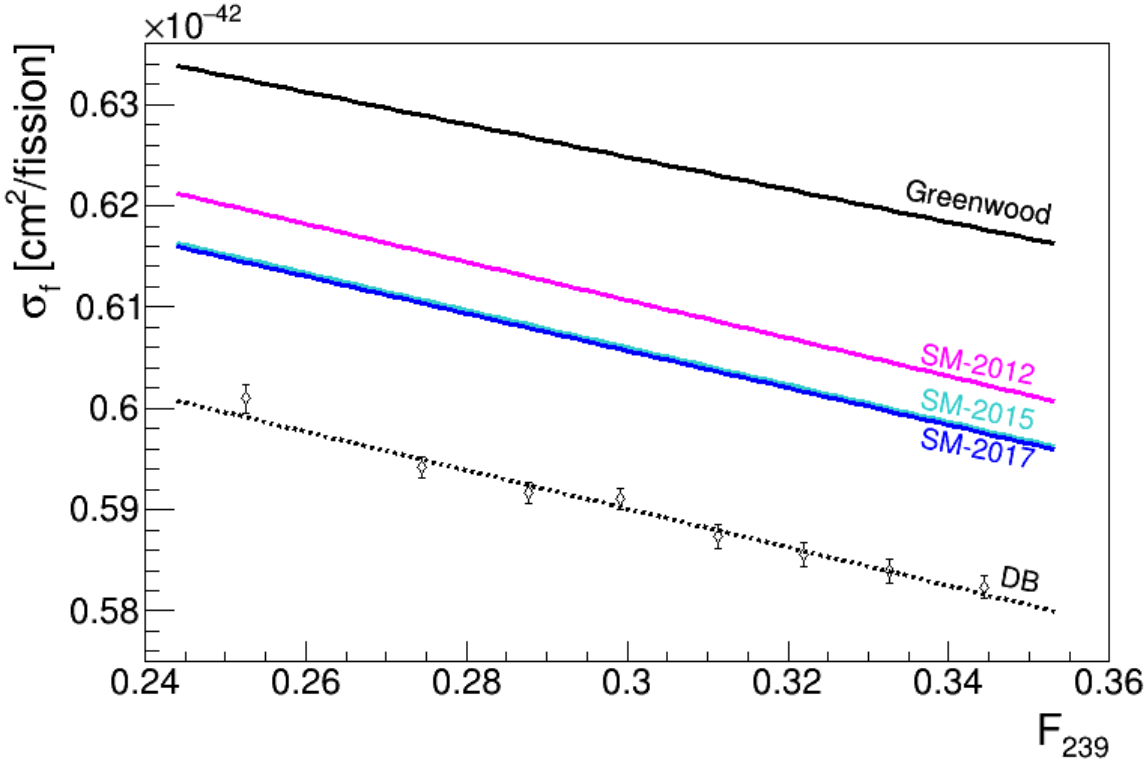
⇒ **Systematic reduction of the discrepancy with Daya Bay results**

⇒ Implies an increasingly smaller discrepancy with the inclusion of future TAGS data, **leaving less and less room for a reactor anomaly.**

M. Estienne et al. PRL 123, (2019) 022502 http://arxiv.org/abs/1904.09358

Highlight 1

- The IBD yields dependency with F239 including TAGS data published in 2012, 2015, 2017 and 2019 has been calculated using our summation calculation



- Impact of the inclusion of the TAGS data (Pandemonium free):

⇒ **Systematic reduction of the detected flux**

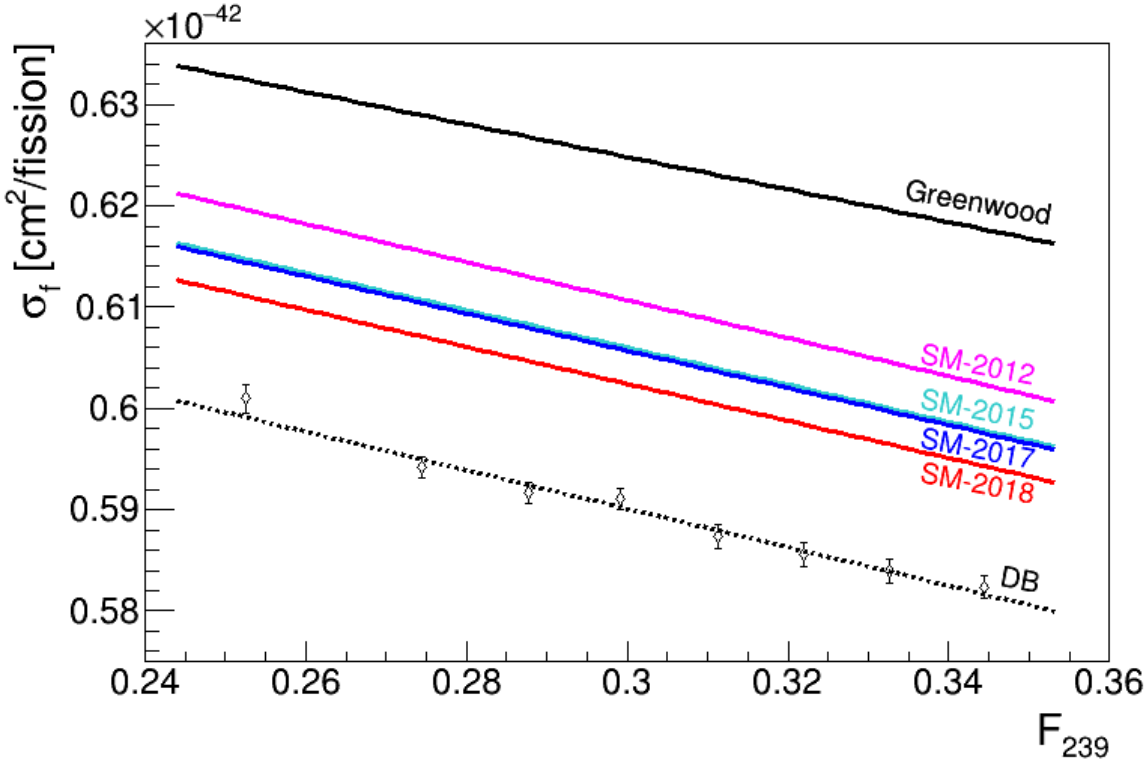
⇒ **Systematic reduction of the discrepancy with Daya Bay results**

⇒ Implies an increasingly smaller discrepancy with the inclusion of future TAGS data, **leaving less and less room for a reactor anomaly.**

M. Estienne et al. PRL 123, (2019) 022502 http://arxiv.org/abs/1904.09358

Highlight 1

- The IBD yields dependency with F239 including TAGS data published in 2012, 2015, 2017 and 2019 has been calculated using our summation calculation



- Impact of the inclusion of the TAGS data (Pandemonium free):

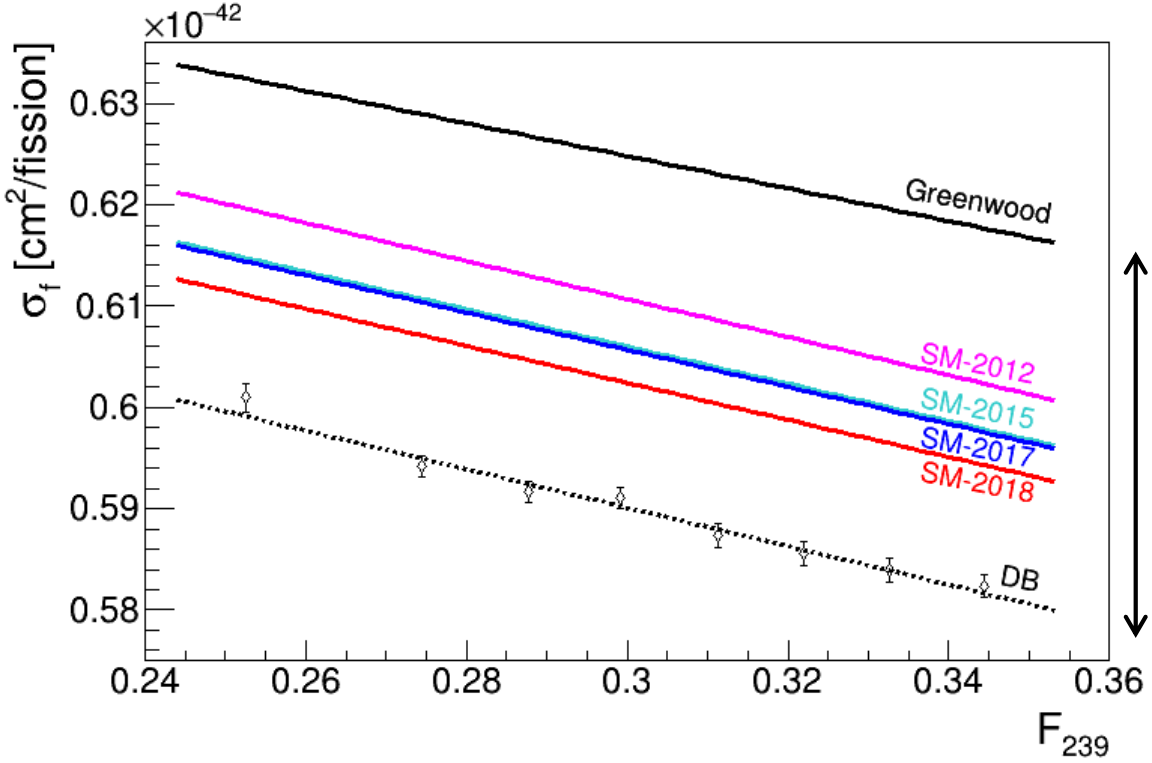
⇒ **Systematic reduction of the detected flux**

⇒ **Systematic reduction of the discrepancy with Daya Bay results**

⇒ Implies an increasingly smaller discrepancy with the inclusion of future TAGS data, **leaving less and less room for a reactor anomaly.**

M. Estienne et al. PRL 123, (2019) 022502 http://arxiv.org/abs/1904.09358

Highlight 1



M. Estienne et al. PRL 123, (2019) 022502
http://arxiv.org/abs/1904.09358

6% (Greenwood TAGS, ~Huber-Mueller)

3% (+TAGS 2012, ~< Hayes et al. 3.5%)

2.4% (+TAGS 2015 & 2017)

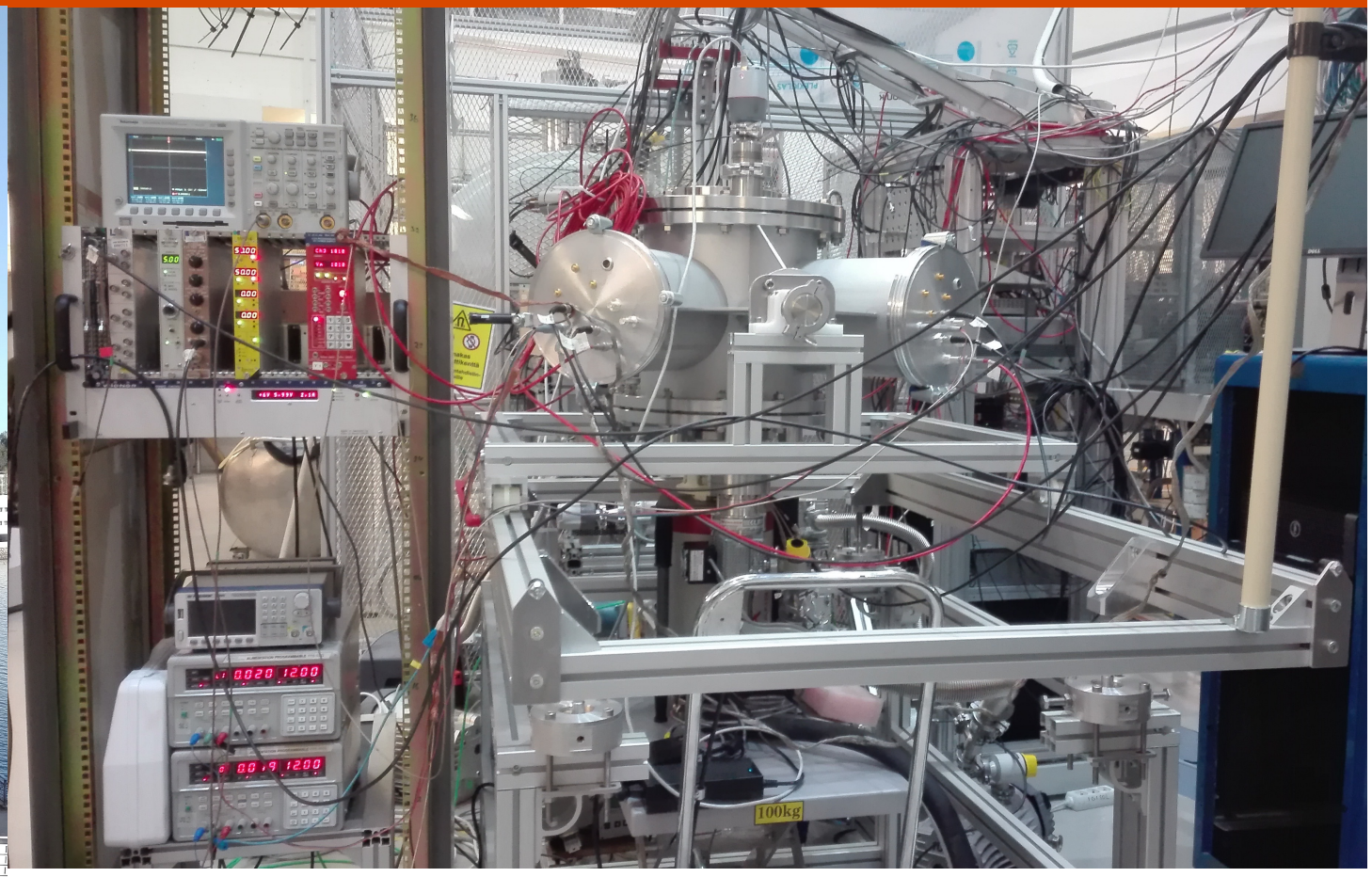
1.9% (+ TAGS 2018)

- **The remaining discrepancy with the Daya Bay flux reduces to only 1.9%**
- **Even with the inclusion of the 2018 TAGS data, the bump is still there i.e. for the moment, it still cannot be explained by ingredients of the nuclear databases.**
- **In2p3 "Fait Marquant"**

Highlight 2: IAEA Technical Meeting 2019 & 2023

- **Technical Meeting on Antineutrino Spectra and Applications I & II, Organized by the Nuclear Data Section of IAEA April 23-26 2019 – *Report INDC(NDS)786 (2019)* And January 2023**
- **~30 participants, representatives from ~all reactor neutrino experiments** (Daya Bay, Reno, Juno, Juno-Tao, Double Chooz, SoLid, Prospect, DANSS, Neutrino-4, NEOS, Coherent, Chandler, …) **+ representatives from modelling** (theorists, nuclear data specialists) **+ representatives nuclear experimentalists from US and Europe**
- **All Communities acknowledged the huge experimental effort with TAGS, « Bringing the Summation Method to another level »**
- **Outlooks:**
  - **Of course, keep improving with more TAGS results**
  - **Measurement of electron shapes**
  - **High stats Highly Enriched Uranium reactor measurements crucial for understanding**
  - **Significant improvement in energy resolution proposed by JUNO-TAO could constitute a benchmark for nuclear data, evidencing the individual components of the fission products**
  - **Shape Anomaly not understood yet (best candidate for explanation: forbidden transitions)**
  - **Uncertainties on summation model**

Highlight 3: E-Shape Construction & Commissioning

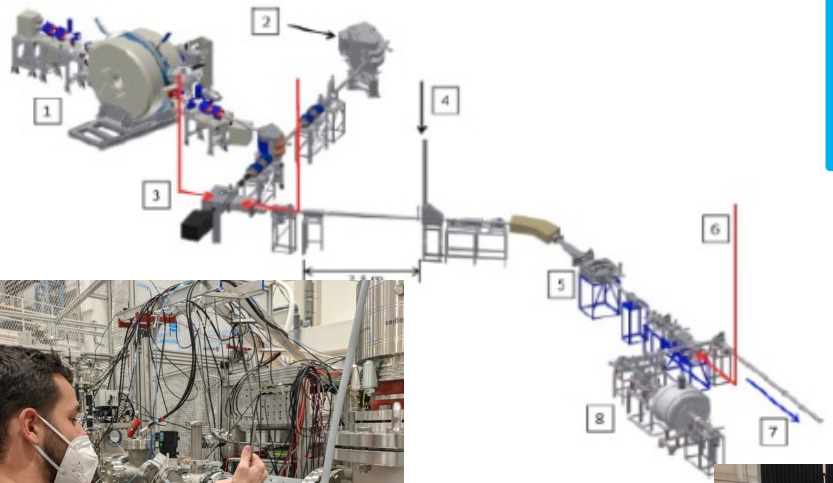


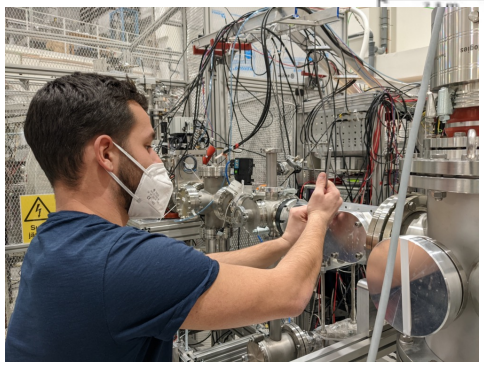
- **Calibration measurements DONE as planned in 2019, experiment in Spring 2020**
- Analysis on-going by Ratha Kean @ Subatech (and G. Alcala @ Valencia)
- **Experiment postponed due to COVID-19 !!!**

Highlight 3: E-Shape Experiment January 2022

- : **E-Shape campaign @IGISOL (Jyväskylä) in Jan. 2022:**

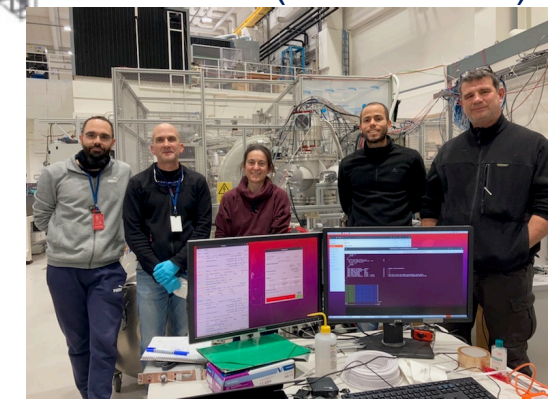
E-Shape Motivations: measure electron spectral shapes from First-Forbidden β-decays for Reactor Antineutrinos and Nuclear Structure and Astrophysics





2 PhD students:
G. Alcala (Valencia) and A. Beloeuvre (Nantes)
Analysis on-going

Huge technical involvement by Subatech (Technical Services and SEN team): Mechanics + Electronics (Faster DAQ) very successful



Coming Next: 1 E-Shape experiment accepted @ Jyväskylä in 2023 (1 PhD funding)

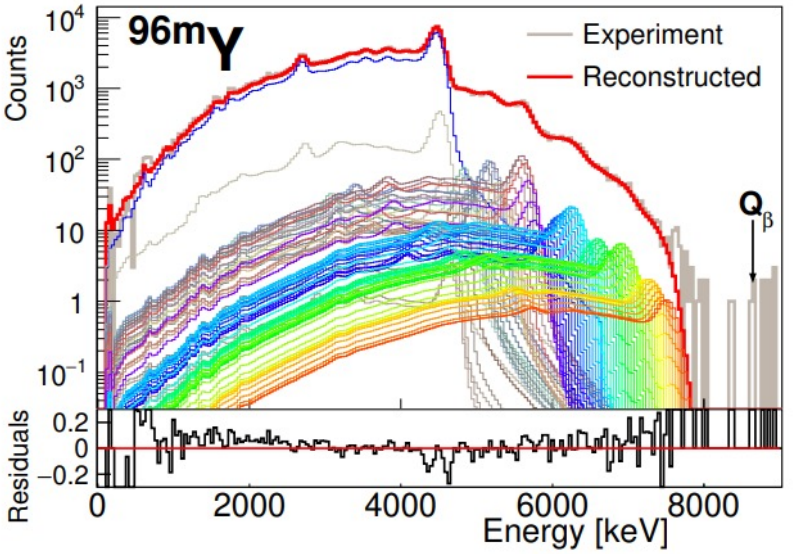
G. Alcala et al. Proceedings of the Nuclear Data 2022 Conference

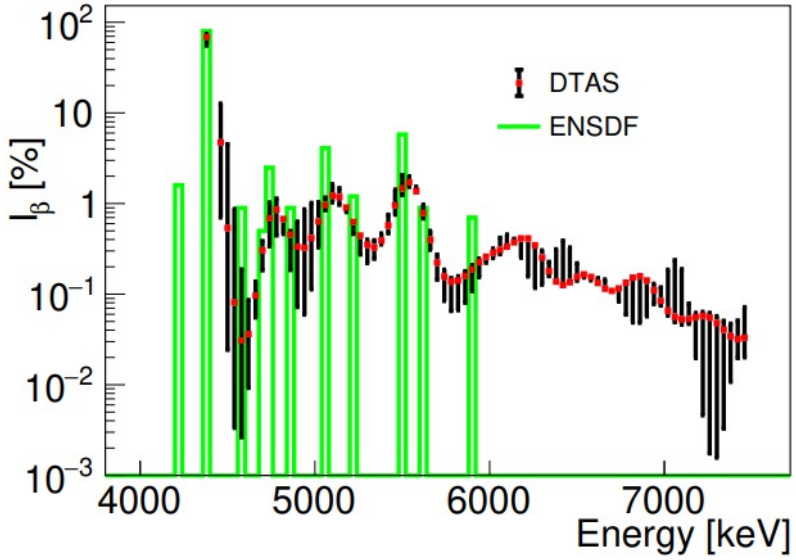
Highlight 4: New TAGS Results on ^{96,96m}Y decays

- **^{96}Y Beta decays:**
  - ^{96gs}Y (0^-) → ^{96}Zr (0^+) , $T_{1/2}$=5.34s, 95%, Q_β = 7103keV
  - ^{96m}Y (8^+) → ^{96}Zr (0^+) , $T_{1/2}$=9.6s, Q_β = 7103+1540keV
  - Particular case of ^{96gs}Y, E0 de-excitation at 1581.6keV to GS not taken into account in previous publications

- **Main results:**
  - E0 transition for the first time taken into account in TAGS analysis!
  - Isomer separated for the first time!
  - A clear pandemonium scheme
    - 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

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

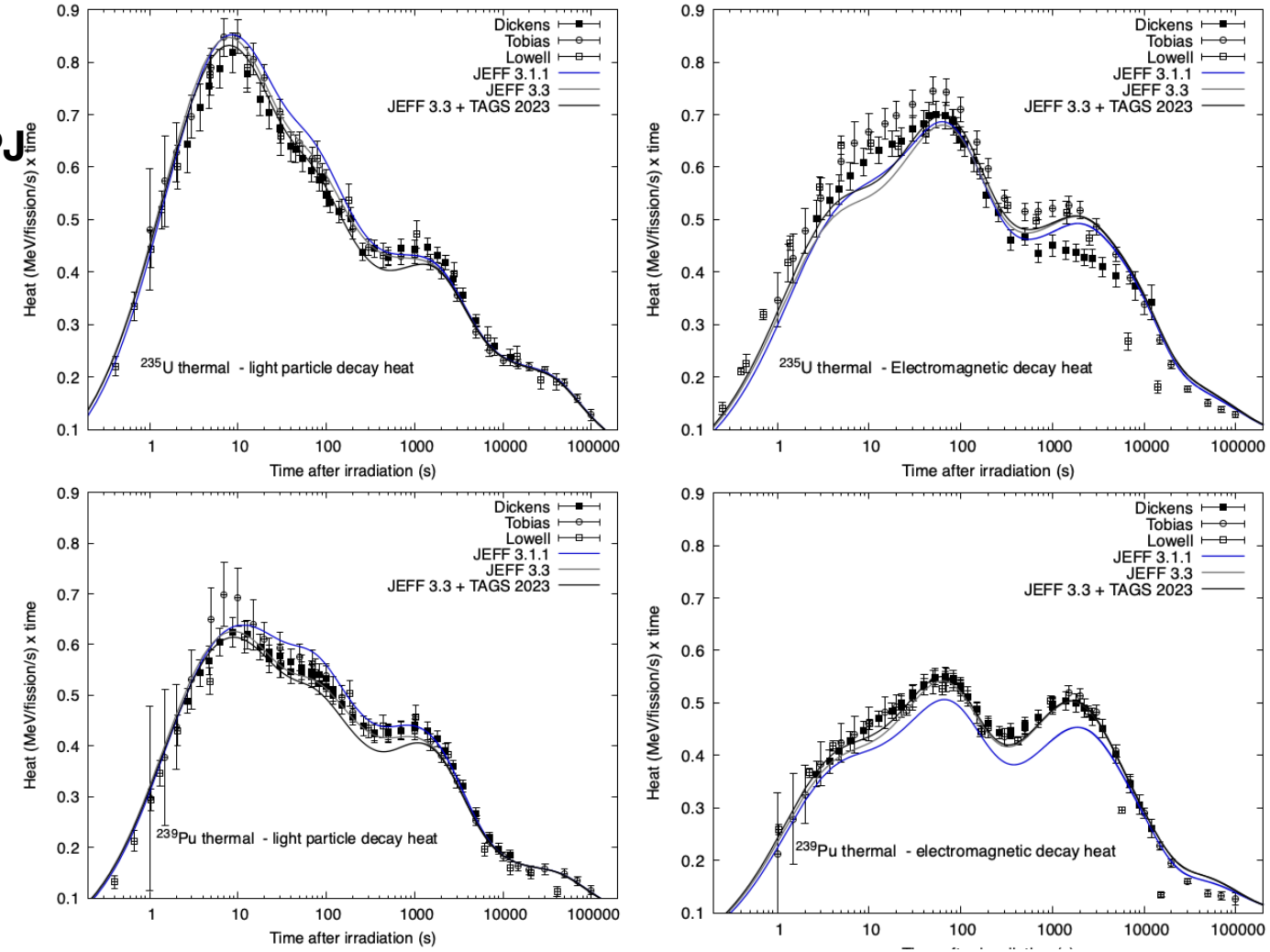




Highlight 5: Review Paper TAGS & Decay Heat

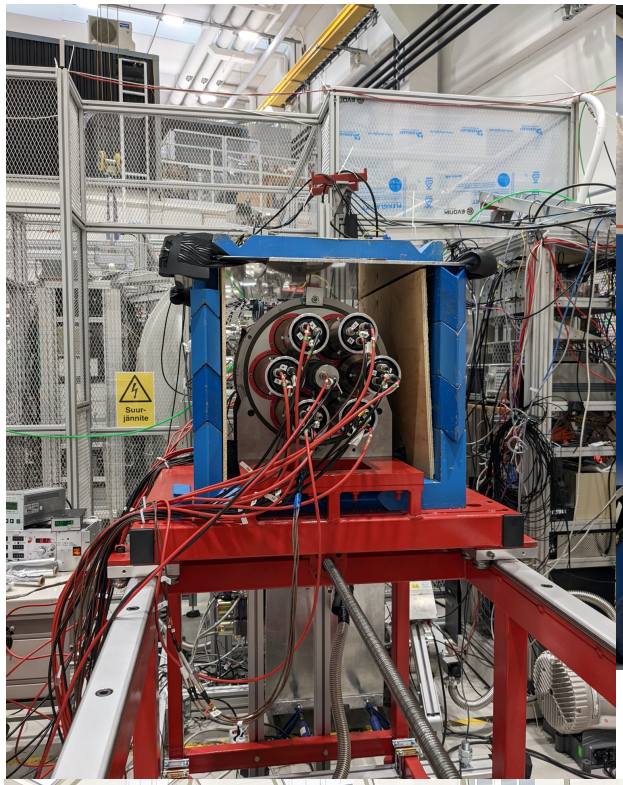
A.L. Nichols et al. Accepted in EPJ A, (2023)
https://arxiv.org/abs/2212.10335

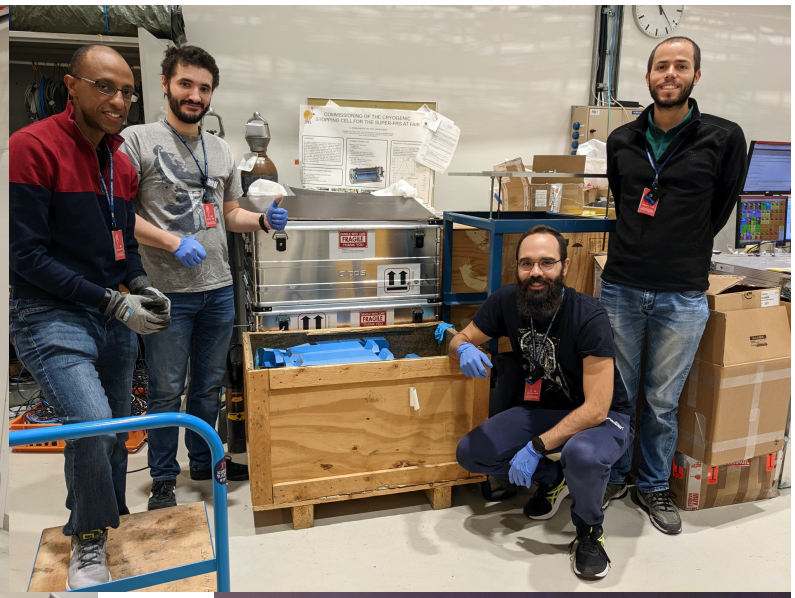
Improving Fission-product Decay Data for Reactor Applications: Part I -- Decay Heat

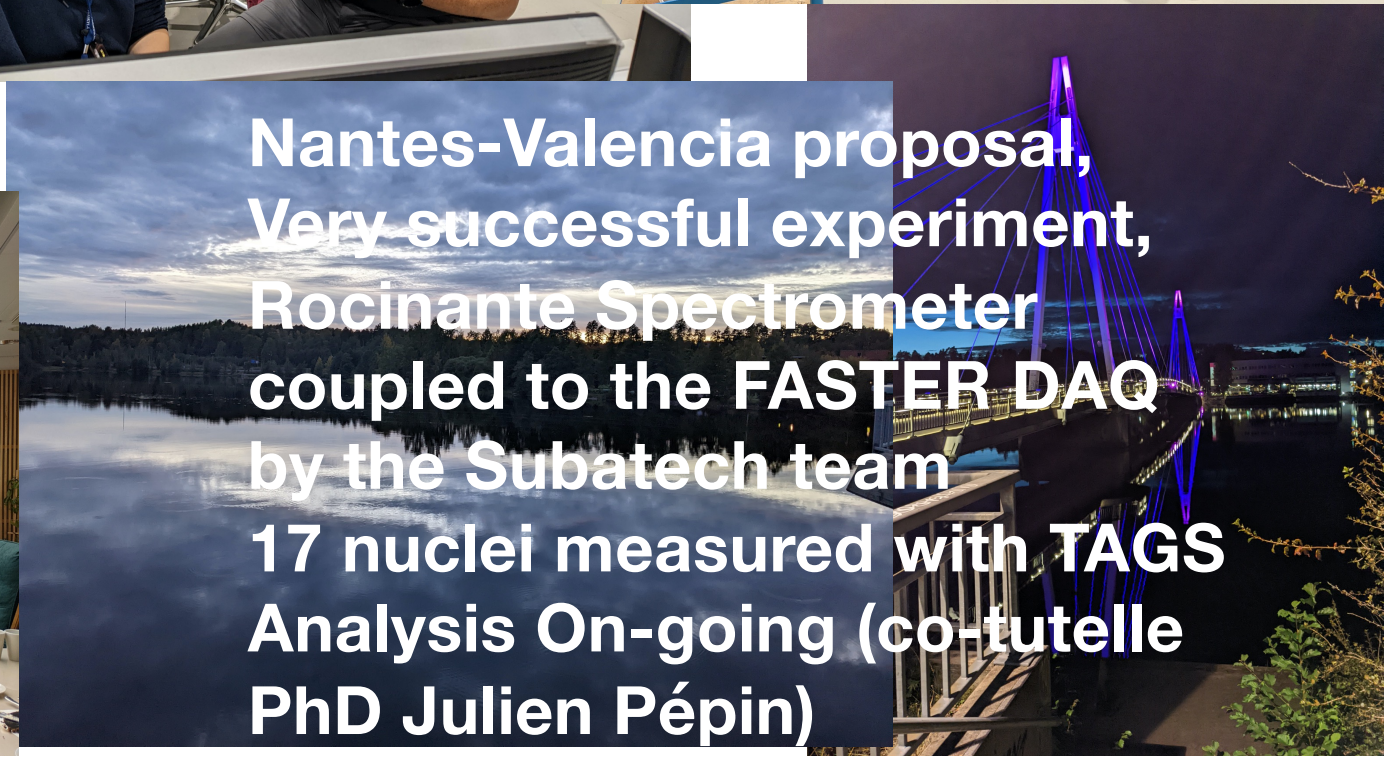


^{235}U and ^{239}Pu thermal fission decay heat as a function of cooling obtained with the JEFF-3.1.1 and JEFF-3.3 libraries with the addition of TAGS data published until Jan. 2023 [Algo21, Guad22, Rasco16, Fija17]. Experimental points were taken from the CoNDERC IAEA database.

Highlight 6: New TAGS Campaign @ Jyväskylä Sept. 2022







Nantes-Valencia proposal,
Very successful experiment,
Rocinante Spectrometer
coupled to the FASTER DAQ
by the Subatech team
17 nuclei measured with TAGS
Analysis On-going (co-tutelle
PhD Julien Pépin)

Highlight 7

- **Participation to 5 European Projects:**

www.chanda-nd.eu
Solving Challenges in Nuclear Data for the Safety of European Nuclear Facilities

⇒ **Involved in 1 task**

SANDA
Supplying Accurate Nuclear Data for energy and non-energy Applications

HORIZON2020

⇒ **Involved in 2 WP/ 3 tasks**

SAMSAFER

⇒ **Responsibility of Task 3.1 on source term estimate**

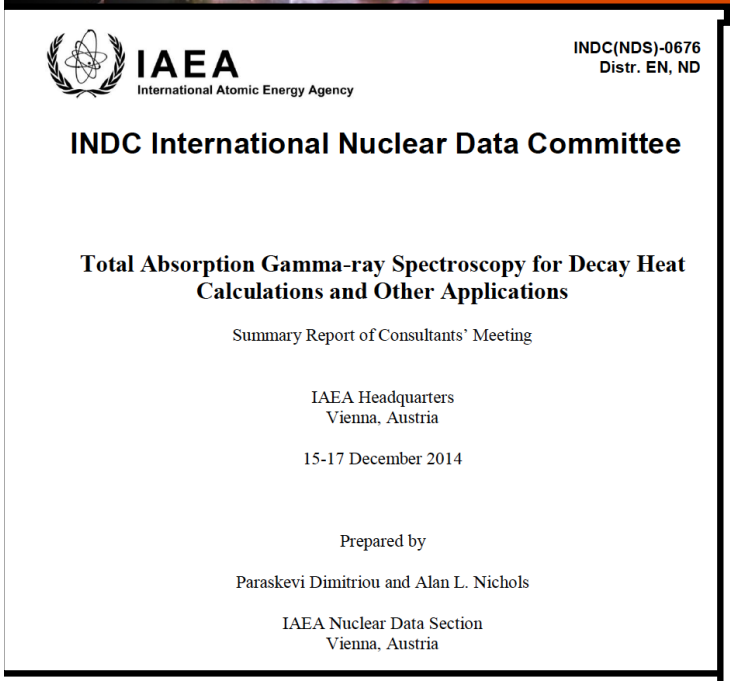
MIMOSA

PREDIS
EU-project PREDIS
Pre-disposal management of radioactive waste

⇒ **Involved in 1 task**

Research products and activities

Societal Impact


IAEA International Atomic Energy Agency

INDC(NDS)-0676
Distr. EN, ND

INDC International Nuclear Data Committee

Total Absorption Gamma-ray Spectroscopy for Decay Heat Calculations and Other Applications

Summary Report of Consultants' Meeting

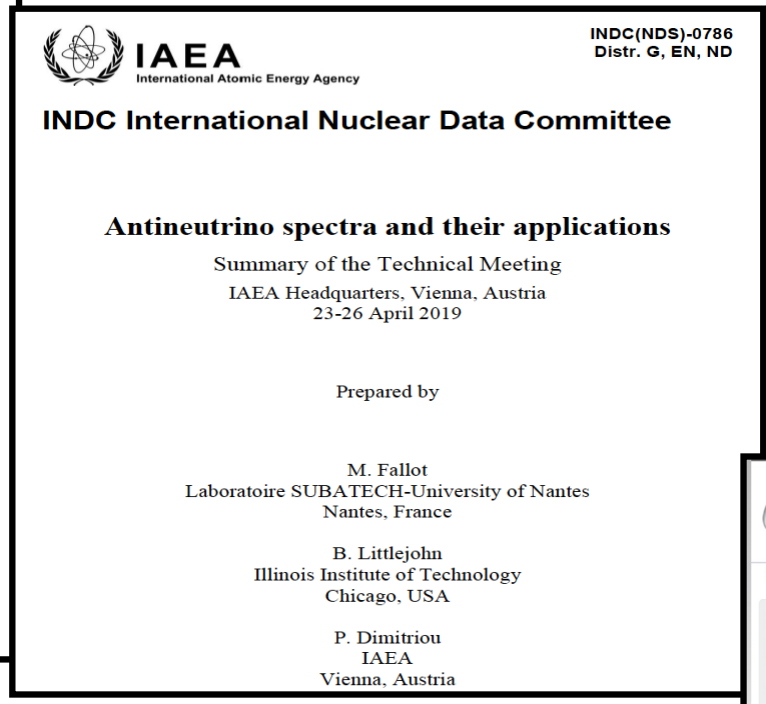
IAEA Headquarters
Vienna, Austria

15-17 December 2014

Prepared by

Paraskevi Dimitriou and Alan L. Nichols

IAEA Nuclear Data Section
Vienna, Austria


IAEA International Atomic Energy Agency

INDC(NDS)-0786
Distr. G, EN, ND

INDC International Nuclear Data Committee

Antineutrino spectra and their applications

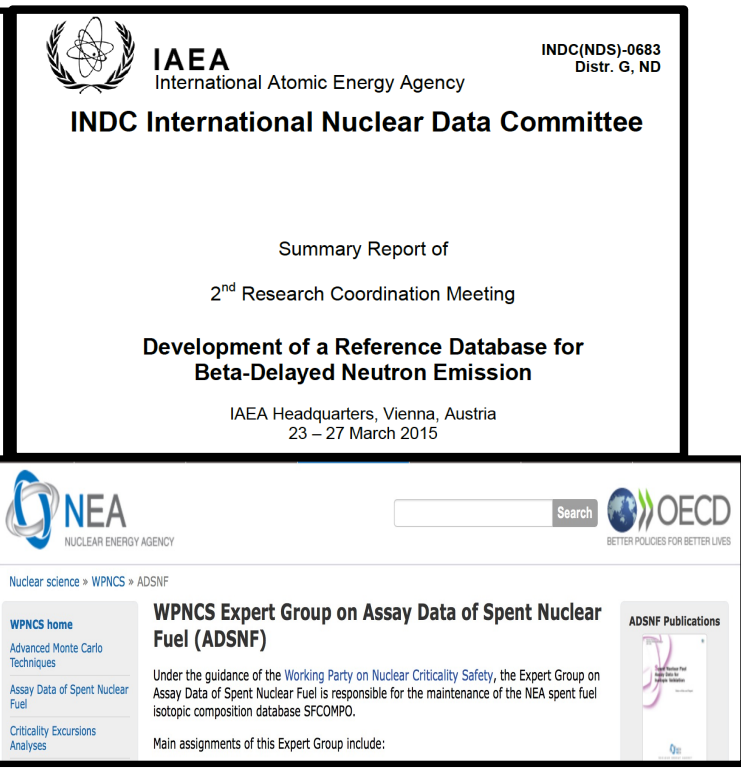
Summary of the Technical Meeting
IAEA Headquarters, Vienna, Austria
23-26 April 2019

Prepared by

M. Fallot
Laboratoire SUBATECH-University of Nantes
Nantes, France

B. Littlejohn
Illinois Institute of Technology
Chicago, USA

P. Dimitriou
IAEA
Vienna, Austria


IAEA International Atomic Energy Agency

INDC(NDS)-0683
Distr. G, ND

INDC International Nuclear Data Committee

Summary Report of

2nd Research Coordination Meeting

Development of a Reference Database for Beta-Delayed Neutron Emission

IAEA Headquarters, Vienna, Austria
23 – 27 March 2015

It is important to ensure that the measured data will be made available for the "users" worldwide, this is done through the data evaluation process:

- Participation (invitations) to Consultant Meetings or Coordinated Research Projects of Nuclear Data Section of the IAEA, to JEFF meetings organized by the NEA, **gathering data evaluators**, **experimentalists worldwide and theoreticians**
- Member of NEA Expert group: international benchmarking of codes
- Included in our participation to **SANDA and NACRE** projects: **collaboration with decay data evaluators, acquire some skills in data evaluation**

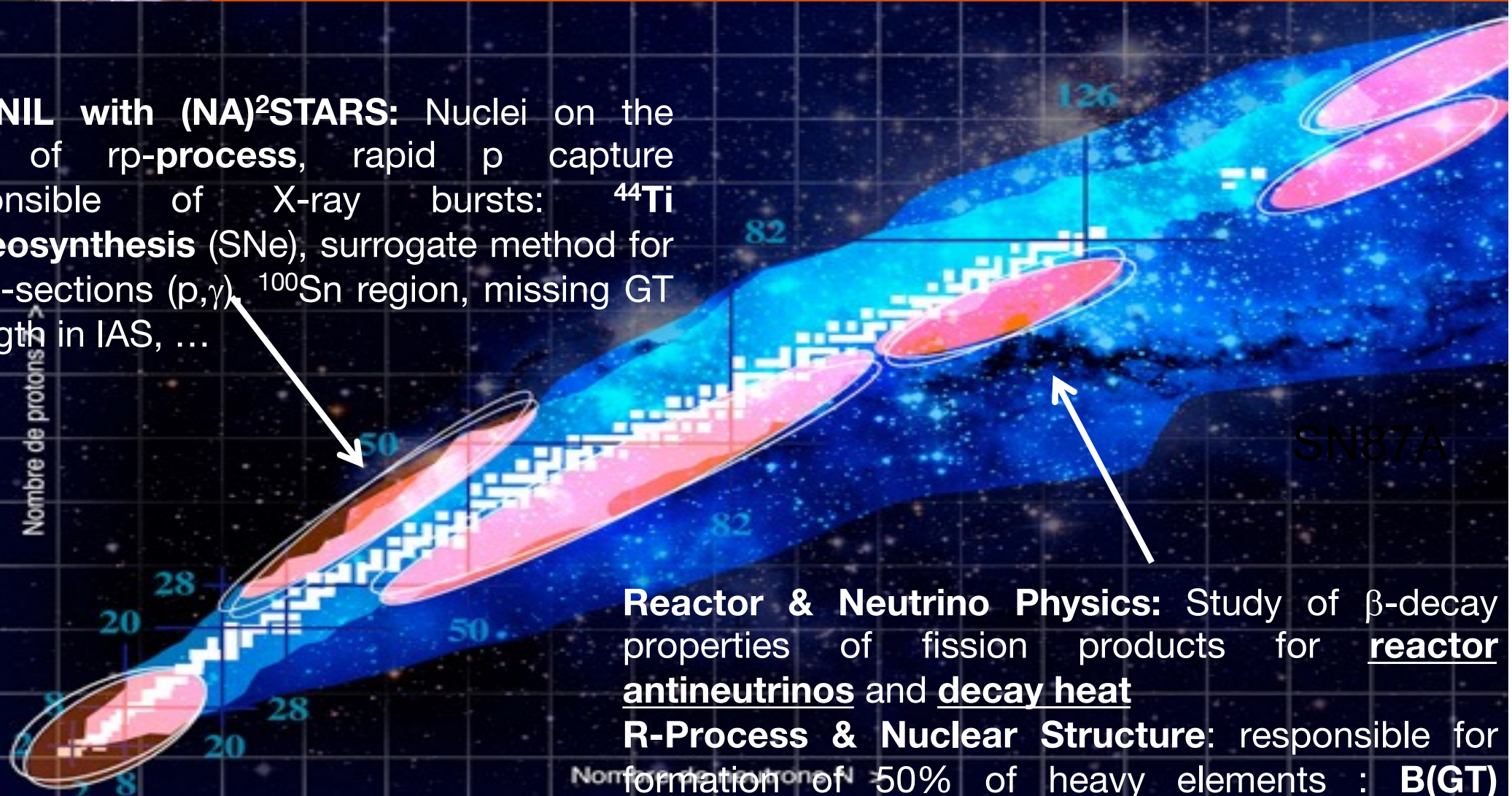
Publications, Conferences, …

- **Publications in Peer-Reviewed Journals: ~45**
- **Oral Communications (first rank): ~30**
- **Expertises:** Consultant/expert for IAEA Nucl. Data Section, NEA, French Member Support Program, STFC (UK), DOE (US), Illinois Inst. Of Tech. (US)
- **Grants:** 1 France-Finland (2017, VTT), 1 Aasgard (Cyclotron Lab. Oslo)
- **7 PhD committees** (nat. And internat.) & **1 HDR committee**
- **Referees** for Peer-Reviewed Journals
- **Members of**: Scientific Council GDR Resanet (until 2022) & Ecole Joliot-Curie, DESIR Committee, SAC of INPC 2019, co-organisation of GANIL Colloquium, …

Perspectives 2023-2028

Scientific Perspectives

@GANIL with (NA)²STARS: Nuclei on the path of rp-**process**, rapid p capture responsible of X-ray bursts: **^{44}Ti nucleosynthesis** (SNe), surrogate method for cross-sections (p,γ), ^{100}Sn region, missing GT strength in IAS, …

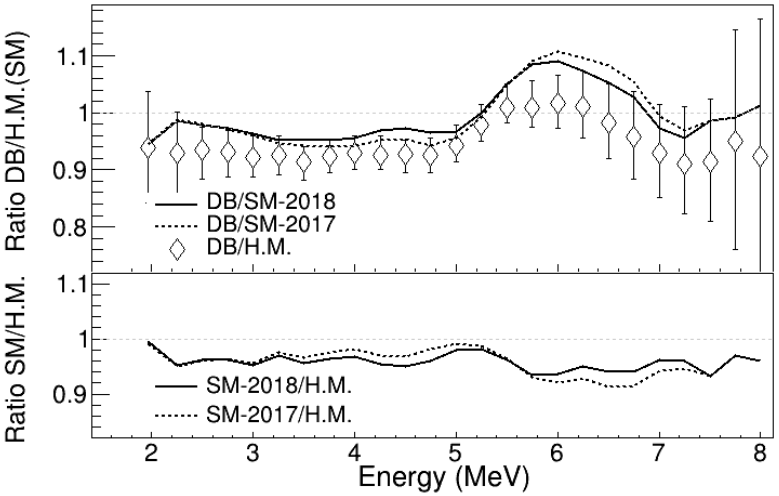


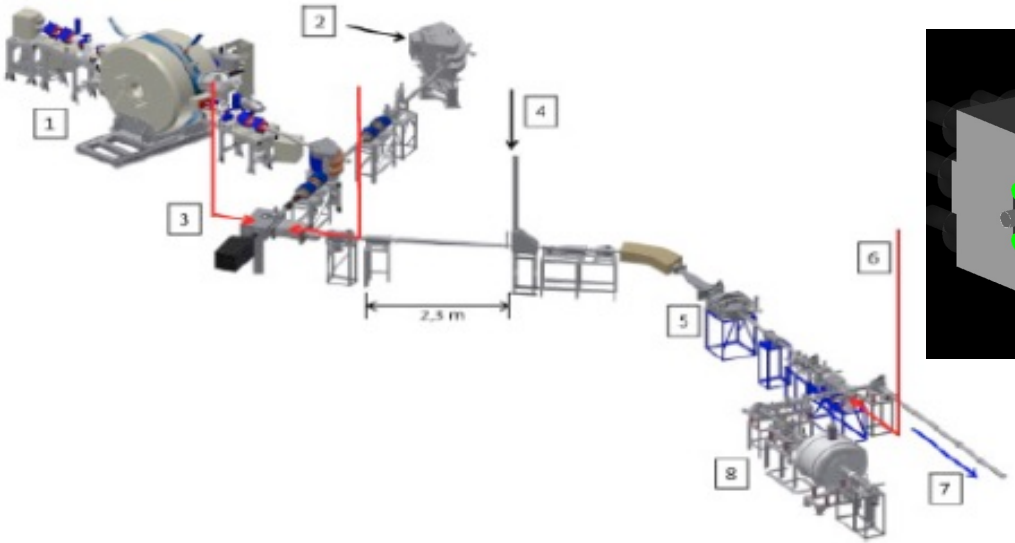
Reactor & Neutrino Physics: Study of β-decay properties of fission products for **reactor antineutrinos** and **decay heat**

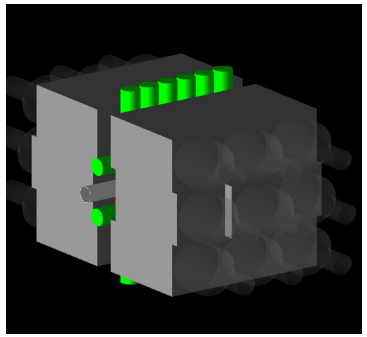
R-Process & Nuclear Structure: responsible for formation of 50% of heavy elements : **B(GT) distribution**, **β-pygmy resonances**, surrogate method for (n,γ) cross-sections

Core-collapse SNe

Perspectives on Reactor Antineutrinos







M. Estienne et al. PRL 123, (2019) 022502
http://arxiv.org/abs/1904.09358

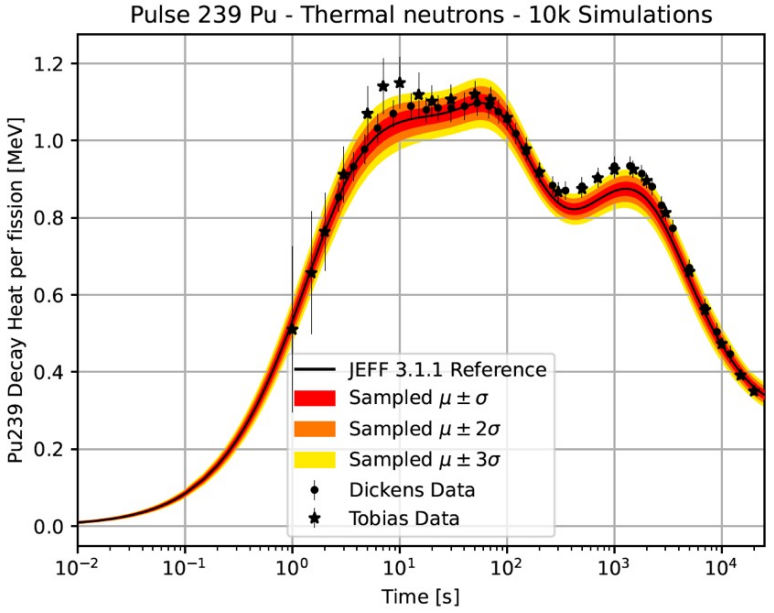
- New TAGS campaigns @ ISOLDE and Jyväskylä or/and Riken/GSI-FAIR (depending on the production yields), (NA)²STARS ' funding will determine how far we could go
- New E-Shape experiments @ Jyväskylä or elsewhere
- Analysis of 2022 TAGS & E-Shape Experiments (A. Beloeuvre & J. Pépin's PhD's)
- Uncertainty calculation on the SM model with the GEF code (collab. K.-H. Schmidt)
- Calculation of Shape Factors with the pn-QRPA model of the CEA-DAM (collab. S. Péru-Désenfants & M. Martini)

Collab.: IFIC Valencia, Surrey, Ciemat Madrid, CEA DAM, LNHB, IAEA NDS, IRP ASTRANUCAP…
Projects: SANDA EU project, NEEDS/NACRE, MP in2p3: TAGS, OPALE, BESTIOLE,…
New ANR demands in preparation ((NA)²STARS, SOPRAANO)

Perspectives on Reactor Decay Heat

- **Fission Pulses:** "Total Absorption Gamma-ray Spectroscopy for Decay Heat Calculations and Other Applications" IAEA – INDC(NDS)-0676, 2015: **8 nuclei contribute to more than 5% of the total DH btw 0 and 10^4 seconds and up to 20% btw 1 and 1000 seconds**
  ⇒ **New TAGS proposals**

- **Decay Heat for reactor fuel assemblies**:
  - OCDE/NEA report foreseen for 2023 « Guidance for decay heat calculations » => New DH measurements (EPRI 2023), benchmark Serpent/OpenMC/Scale (ORNL)



COCODRILO

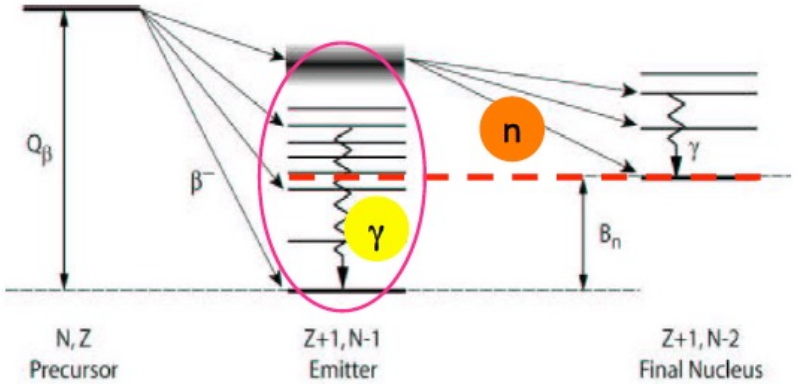
- **Decay heat uncertainty calculations with associated sensitivity studies. Impact of nuclear data: decay data & Fission yields.** Total Monte Carlo approach (Cocodrilo code), **PhD Y. Molla (2021-2024)**

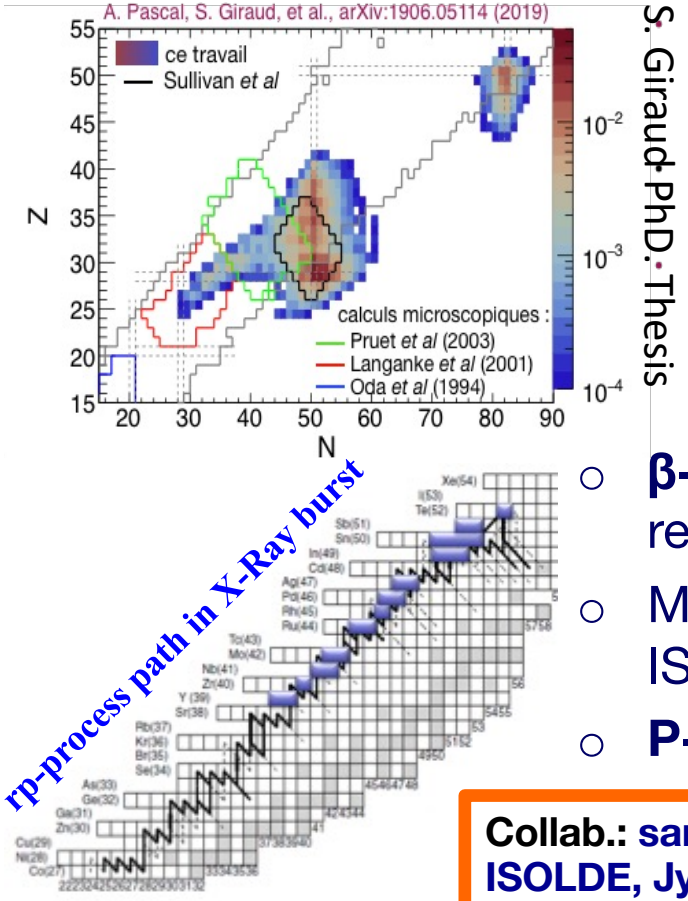
- **New list of key nuclei for TAS measurements for Molten Salt concepts:** Th/U & U/Pu cycles (SAMOSAFER), actinides converter (PhD grant **PIA4 ISAC, LPSC-Subatech, 2023-2026**)

Collab.: same as previous slide + LPSC, NEA
Projects: PIA4 ISAC, SANDA, SAMOSAFER, MIMOSA , NEEDS/NACRE, NEEDS/SUDEC, MP in2p3 OPALE, (NA)²STARS

Nuclear Structure and Astrophysics

- **r-process:**
  - **β-decay of delayed neutron emitters as a "surrogate"** of the (n,γ) reaction:
  - Probe the presence **of low-lying collective modes with β-decay** (ISOLDE, Jyväskylä)





S. Giraud PhD. Thesis

- **Influence of forbidden non-unique β transitions on r-process path ? => E-Shape exp. + TAGS + Theory**
- **Core-collapse SNe:** Study the electron capture properties of targetted nuclei (=> Jyväskylä and GANIL)
- **β-decay of delayed proton emitters as a "surrogate"** for key (p,γ) reactions for astrophysics @ GANIL (LISE) (ex. **^{44}Ti)**
- Measure the **beta strength of rp-process waiting points** (GANIL, ISOLDE)
- **P-process:** measure (p,γ) and (α,γ) key cross-sections: @ NFS

Collab.: **same as previous slide + ((NA)²STARS, GANIL/LISE/S3/DESIR, LPC Caen, IP2I, ISOLDE, Jyväskylä, ALTO, ...**
Projects: **same as previous slide + IRP Acnu, ASTRANUCAP**

INDRA/FAZIA & Nuclear Astrophysics

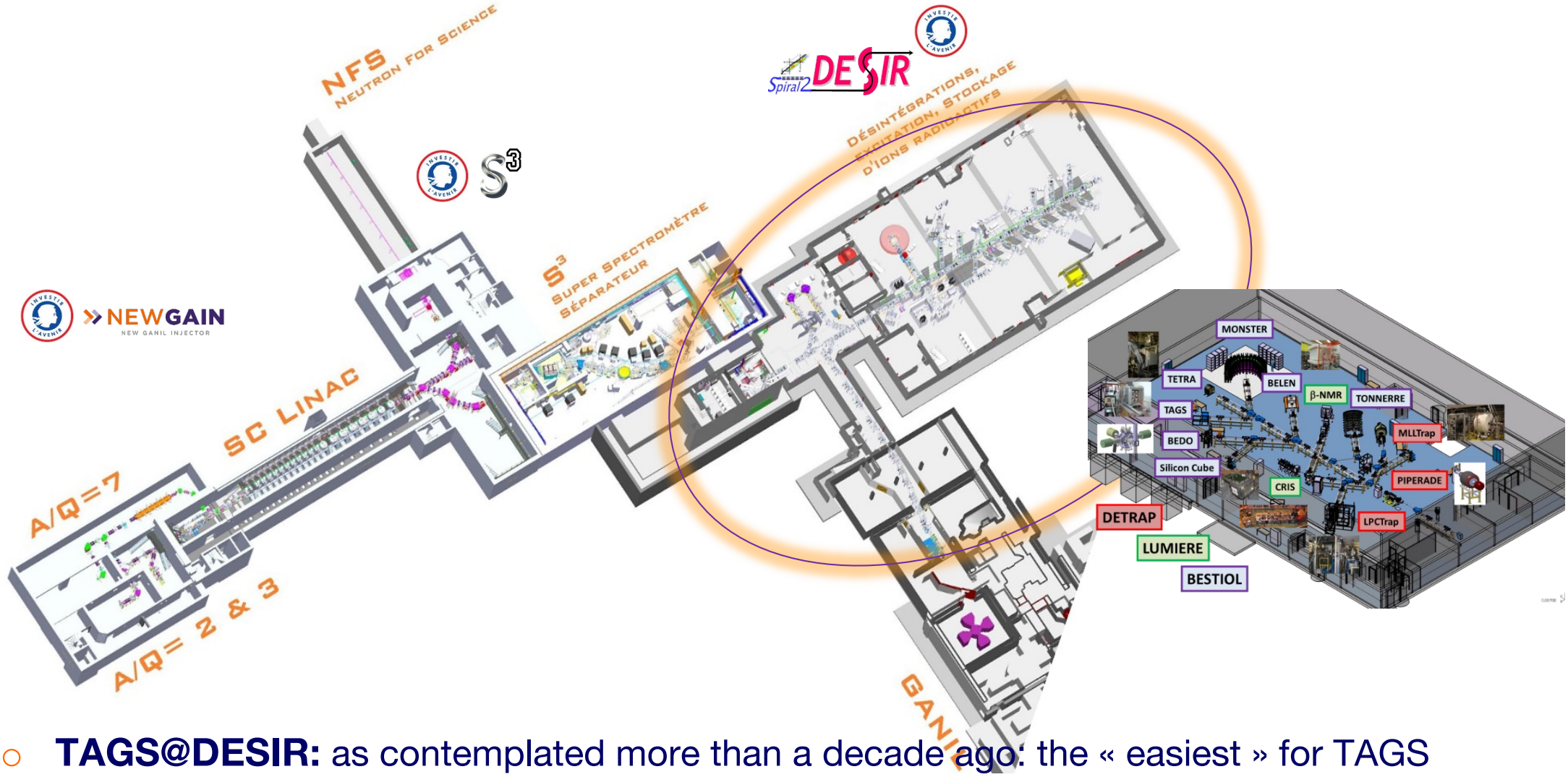
Motivations: Type II supernova explosions are one of the astrophysical phenomena where information extracted from experimental data from heavy ion collisions at Fermi energies accessible at GANIL can be used.

- **Participate to the ongoing INDRA-FAZIA experimental measurements at GANIL.**
- **Discussions on-going on the future of Heavy Ions collisions with exotic beams in the Fermi energy domain:**
  - **exploration of the phase diagram by varying the isospin**
  - **study the effects of symmetry energy more easily**

- **Within the framework of the (NA)^{2}STARS project, intensify collaboration with the Normandy teams (LPC Caen, GANIL) to propose measurements of astrophysical interest.**

- **Explore the possibility to use the E-TDHF code DYWAN for common physics goals in the SEN team: nuclear astrophysics, compact stars…**

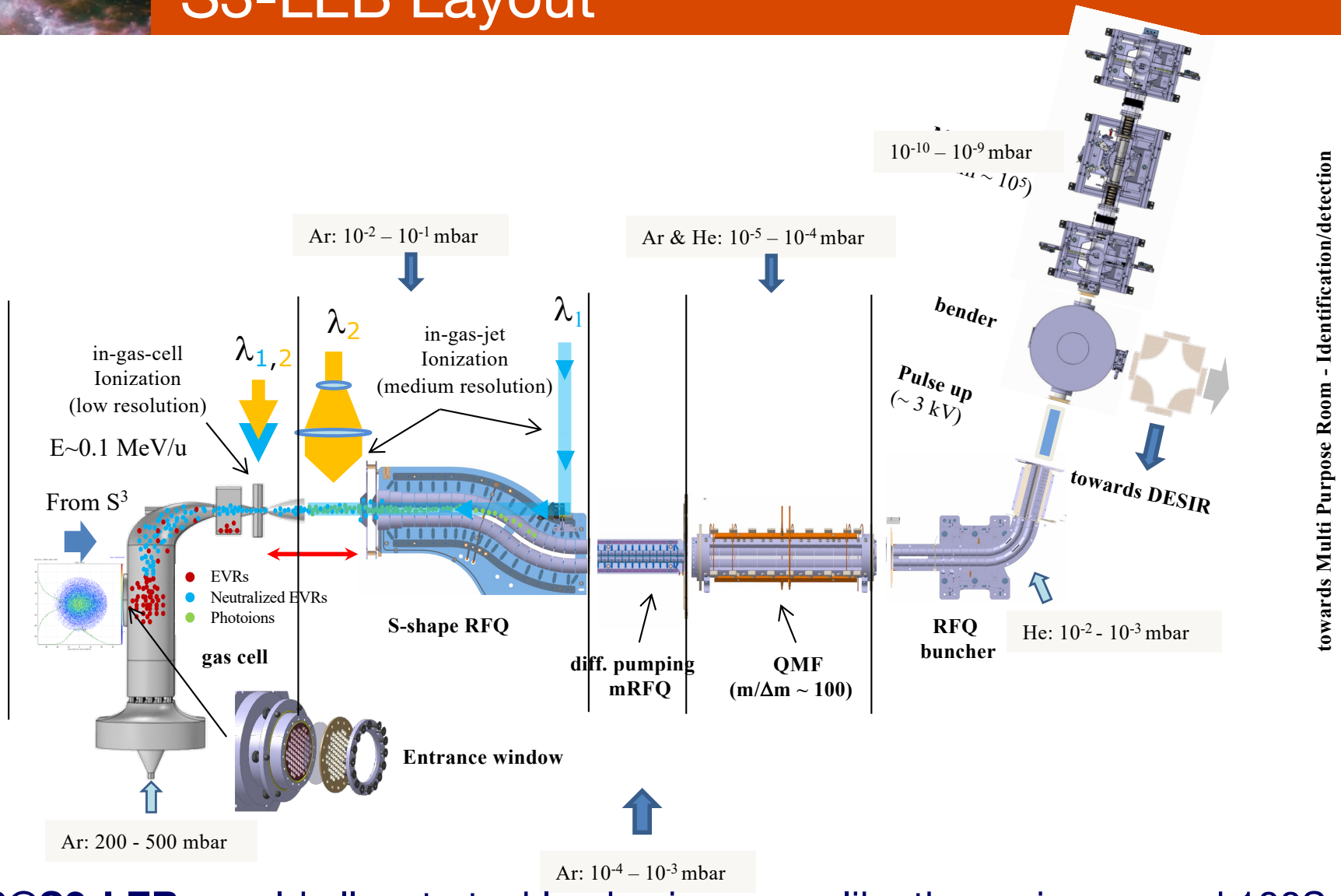
DESIR, NFS



- **TAGS@DESIR:** as contemplated more than a decade ago: the « easiest » for TAGS experiments: pure beams after the PIPERADE Penning trap. Horizon 2027-2028, neutron-deficient physics goals ;
- **TAGS@NFS:** cross-section measurements for p-process. Horizon 2027-2028 ;

DESIR Layout: Courtesy J. –C. Thomas

S3-LEB Layout

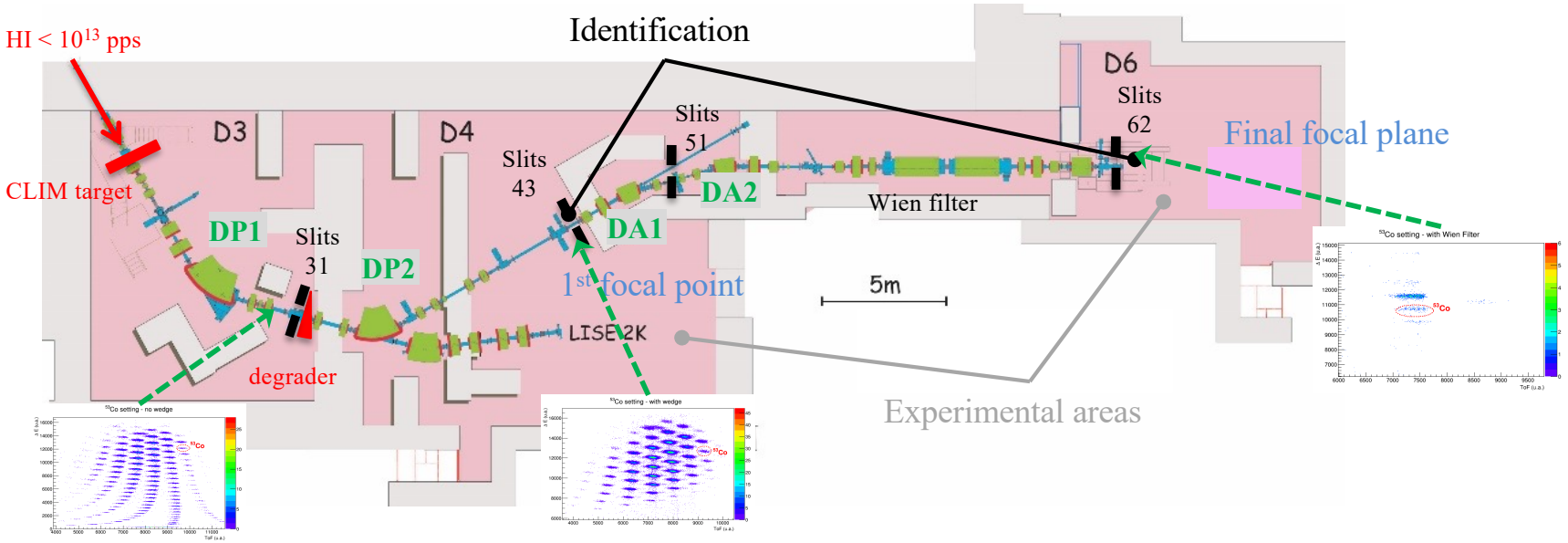


- **TAGS@S3-LEB:** would allow to tackle physics cases like the region around 100Sn (TAGS LoI in 2011) before. Day-1 experiments@S3-LEB: investigate technical possibility to install the STARS after the MR-TOF-MS, horizon 2025-2026 ;

S3-LEB Layout: Courtesy J. –C. Thomas

LISE

The LISE spectrometer (44 m)



- TAGS@LISE3: **discussions on-going. First proposal with the STARS could be in 2024, depending on the funding timeline**. Take advantage of the $LaBr_3$ better energy resolution for the study of very short-lived nuclei:
  - ❑ N-rich cases @ LISE not possible (NB: some cases may be possible SP1 beam @ LIRAT)
  - ❑ N-deficient cases:
    - ➢ i.e. for ^{44}Ti nucleosynthesis: measurement of γ-rays above the p emission threshold ;
    - ➢ or nuclear structure cases already investigated @LISE3 by IFIC-Valencia with high-resolution spectroscopy: ^{48}Fe, ^{52}Ni, ^{56}Zn. Goals: Missing β-strength, γ-rays above p-emission threshold. **Set-up and beam conditions currently under investigation**.

LISE Layout: Courtesy J. –C. Thomas

Swot : weakness and strength

Strength	Weakness
Recognized national and international expertize, visibility	
Unique positioning: simulations/experiments & fundamental/applied, coherence	Several communities, diverse funding origins = a lot of energy spent
International collaborations, European Projects, PIA4 MSFR	Difficulties to fund an innovative TAS
Teachings & Students	3 teaching researchers = less availability for experiments and research

Swot : opportunities and menaces

Opportunities	Threats
(NA)²STARS : support from GANIL and in2p3 (on-going), PEPITE Univ. Nantes	Lack of funding for instruments
Theory in the group: TDHF & n-stars, forbidden decays	More and more funding demands, evaluations, etc.
Develop Experimental Program @ GANIL	Lack of Funding for PhD & Post-docs
Very positive scientific eval. from SC in2p3 2017, HCERES, 2022 SC in2p3 for Energy	Strong international competition
Consultant/Expert meetings @ IAEA & NEA	Postponed experiments due to Covid-19 crisis
	Departure of the CRCN recruited to reinforce the experimental activities of the team

Conclusions

Conclusion slides

- **SEN team:**
  - Dynamic & committed to national and international projects
  - Fundamental and applied research
  - Multidisciplinarity
- **Bilan/highlights**
  - Recognized expertize in reactor antineutrino spectra, TAGS experiments, reactor decay heat simulations
  - Worldwide highlights in reactor antineutrinos
  - Lack of manpower for experimental program (departure of 1 CRCN)
- **Perspectives**
  - Consolidation of the current projects (Antineutrinos, Decay Heat, Nuclear Astrophysics, $(NA)^2$STARS)
  - Opportunities
  - Increasing number of HDRs