β-decay study of neutron rich nuclei with the Total Absorption Spectroscopy method

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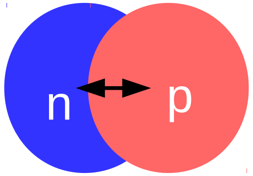
Outline

- Context and motivations for β decay studies and TAS experiment
- Description of TAS method and analysis
- Experimental setup at Jyväskylä
- Preliminary results
- Conclusions and outlooks

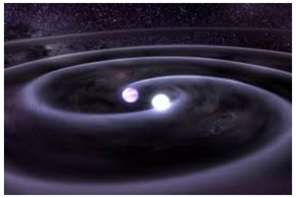
Context

→ Nuclear structure



- Neutron-skin
- Pygmy Resonance
- Deformation parameter
- Equation of state of neutron matter

→ Astrophysical phenomena : r-process



- Rapid neutron capture
- Knowledge of capture/decay competition
- Need for predictive microscopic models

→ Nuclear reactor

- <u>Decay heat :</u>

- Residual power (~8% of nominal power)

- Reactor safety

- Predictive method = Summation of all the fission product contributions

- <u>Antineutrino spectra :</u>

- Fuel monitoring for non-proliferation (ν flux depends on fuel composition)

- Neutrino fundamental physics

Systematic discrepancies between measurements and calculations

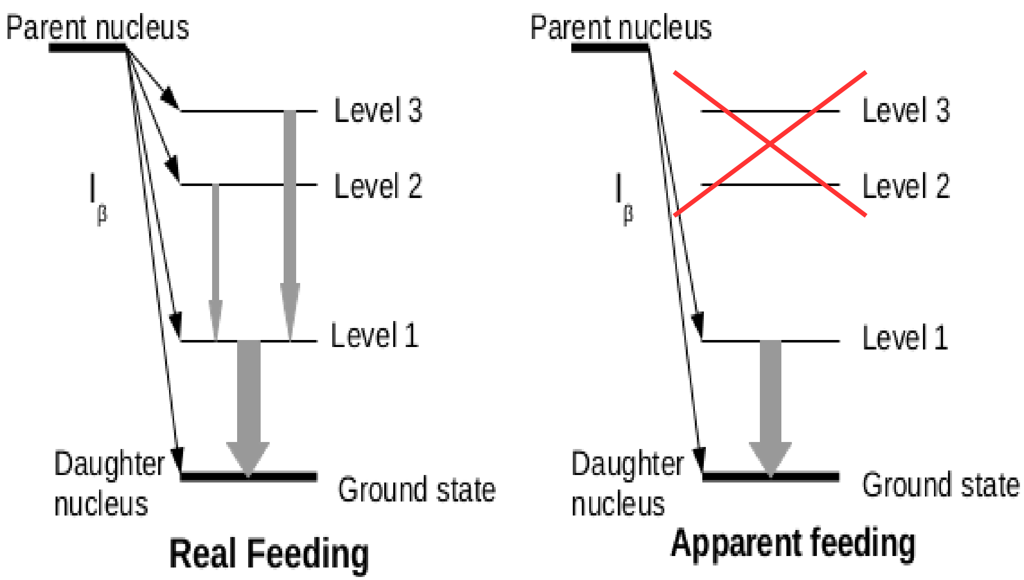
↳ Improve knowledge of beta-decay properties

Motivation : Why a TAS experiment ?

→ The Pandemonium effect

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

- Weak point of the Ge detectors (mainly used for β-decay study)



- <u>Causes :</u>

  Very low geometrical and intrinsic efficiency

- <u>Consequences :</u>

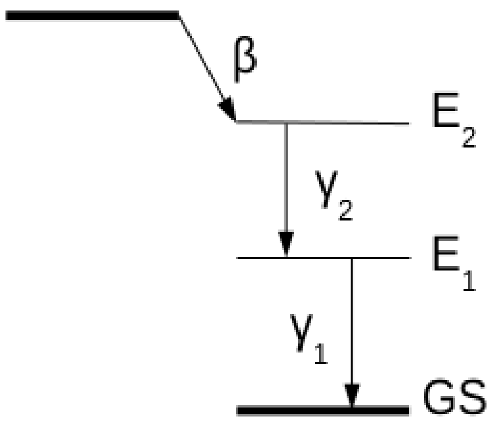
  Overestimation of the feeding of the low energy levels

⟹ Solution : Total Absorption Spectroscopy

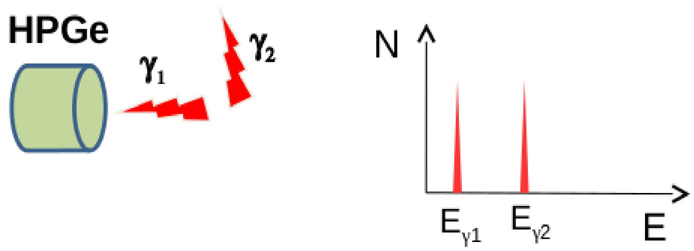
TAS method

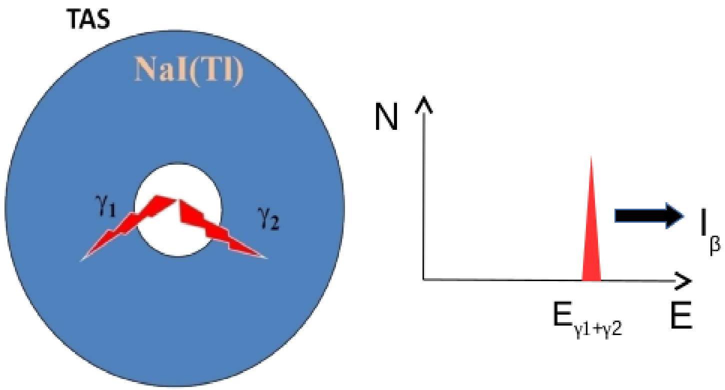
→ A complementary approach

- Germanium detectors : **High resolution**
  single γ-ray detection
- TAS detectors : **High efficiency + 4π = Calorimeter**
  γ-ray cascade detection



- Advantages :
  - Almost 100% detection efficiency
  - Direct access to the β intensity distribution I_β
  - Much less sensitive to the Pandemonium effect
- Drawbacks :
  - Deal with a complex analysis
  - Lower energy resolution than Ge detectors
  - Detailed knowledge of the daughter nucleus





Data analysis

- Aim of TAS analysis = β feeding

→ Solve the Inverse Problem $$d_i = \sum_j R_{ij} . f_j$$ → Requires clean spectrum

d_i : Experimental data

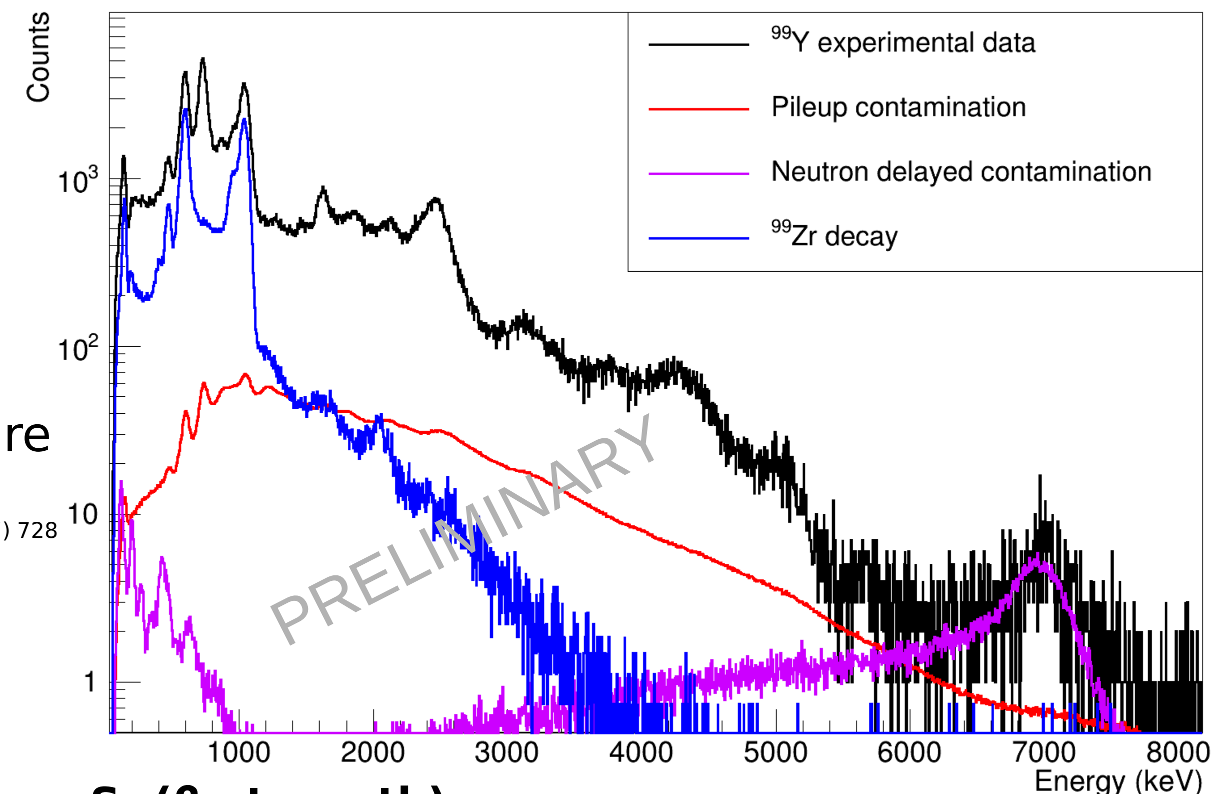
R_{ij} : Detector response matrix
- branching ratio matrix
- γ-response and β-response

f_j : beta feeding

Solved by an iterative procedure based on the Bayes Theorem

J.L. Tain, D. Cano-Ott, Nucl. Inst. and Meth. in Phys. Res. A 571 (2007) 728

^{99}Y + Contaminants



Beta feeding → Beta Intensity → S_β (β-strength)

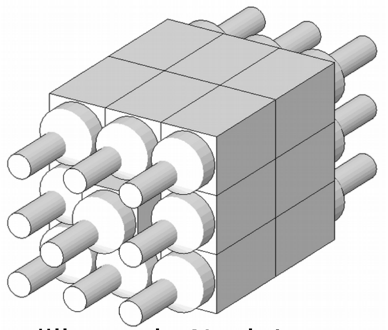
f_β → I_β → S_β (β-strength)

$$I_\beta = \frac{f_\beta}{\sum_k f_k}$$

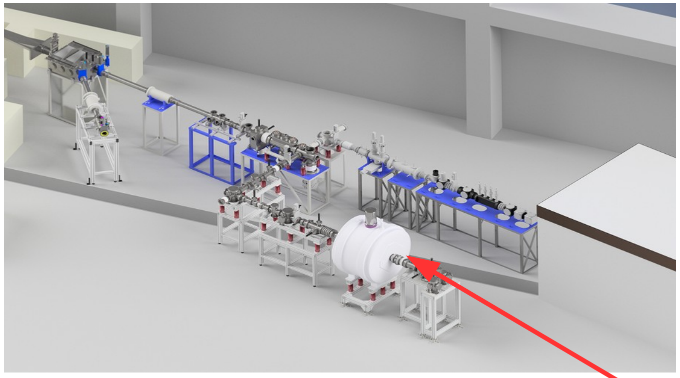
$$S_\beta(E) = \frac{I_\beta(E)}{f(Z, Q_\beta - E) T_{1/2}}$$

comparison with theoretical models

Experimental setup at Jyväskylä (^{142}Cs, ^{99}Y, ^{138}I, ^{96,96m}Y)



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



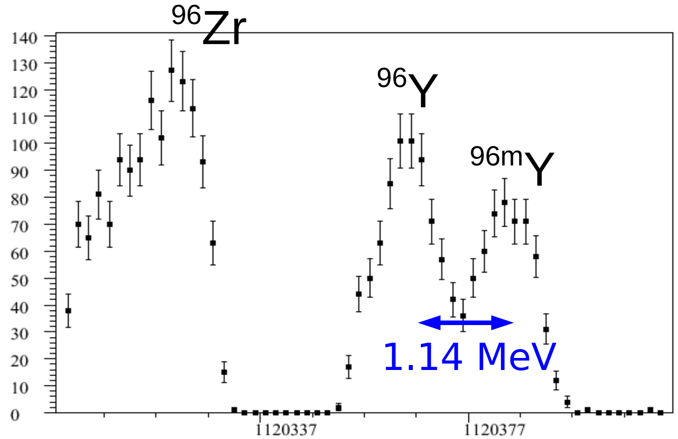
- DTAS = 18 crystals of NaI(Tl)
  - ~90% total efficiency for a 1 MeV gamma
  - ΔE/E ~ 5% at 1.3 MeV
- β detector = plastic detector
  - In coincidence with γ → suppression of the background
  - 30% detection efficiency
- HPGe detector
  - Allow identification of possible contaminants coming from the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

Why Jyväskylä IGISOL-4 facility ?

→ Because of the JYFLTRAP, a double Penning Trap

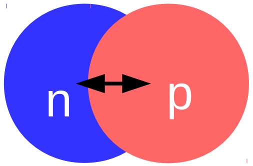
→ Mass resolution of $\delta m/m \sim 10^{-6}$

→ A very pure beam is needed



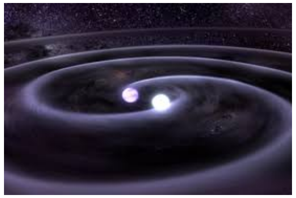
Preliminary results for the ^{142}Cs : Motivations

→ Nuclear structure



- ✔ Possible neutron-skin in the vicinity of the ^{132}Sn
- ➢ Neutron orbital influence
  (T. Rązca-Urban, Phys. Rev .C 75, 054319, 2007)

→ Astrophysical phenomena : r-process

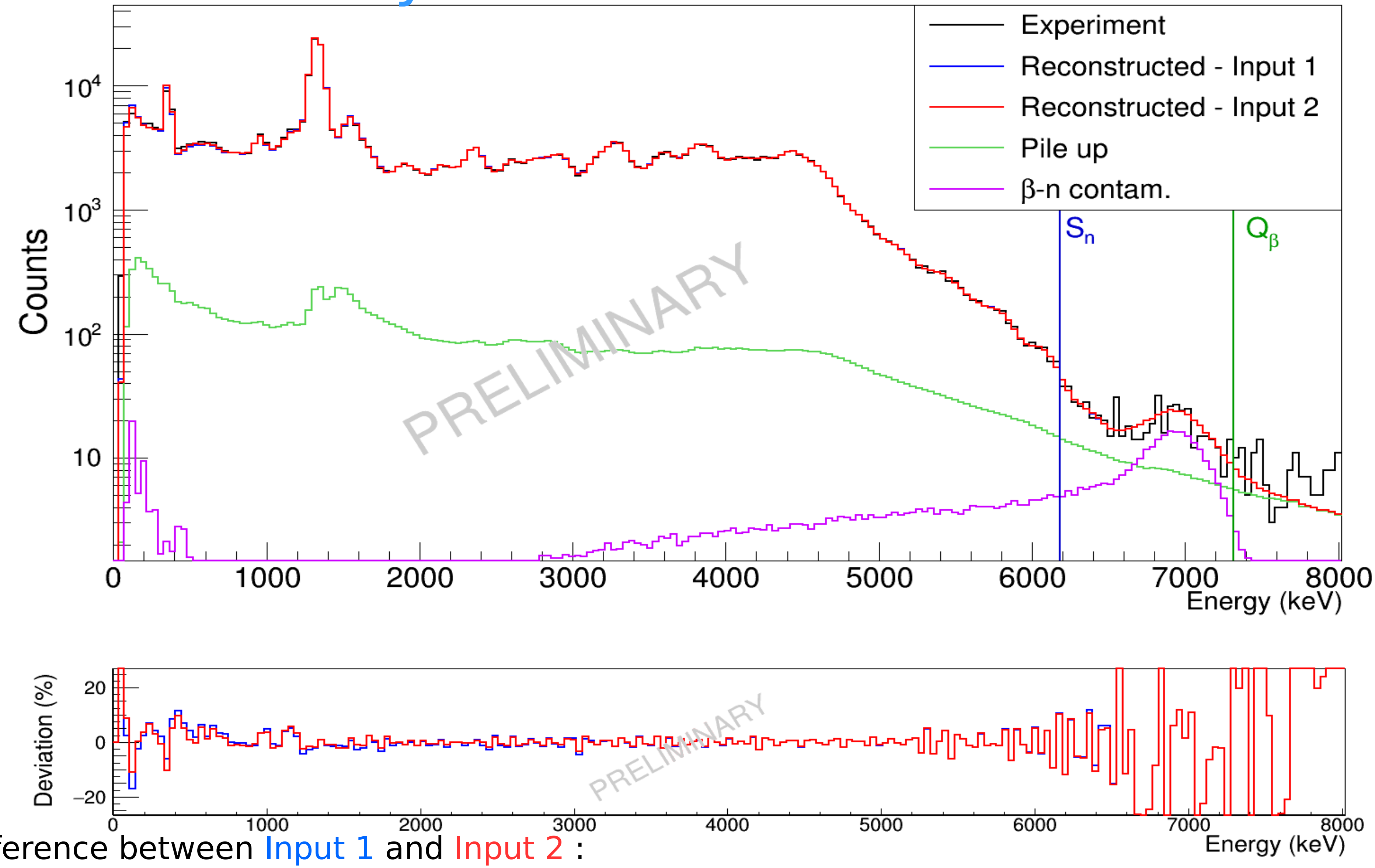


- ✔ Pygmy resonances
  (S. Goriely, Phys. Lett. B 436, 1998)
- ➢ β-decay : new probe below and above S_n
  (M. Scheck, PRL 116, 132501, 2016)

→ Nuclear reactor

- ✔ Priority 1 as contributor to antineutrino spectra (A.-A. Zakari-Issoufou PRL 115, 102503 (2015) + IAEA – INDC (NDS) 0676)
- ✔ Priority 3 as contributor to reactor decay heat
  (IAEA - WPEC-SG25: http://www.nea.fr/html/science/wpec/volume25/volume25.pdf)

Preliminary results for the ^{142}Cs



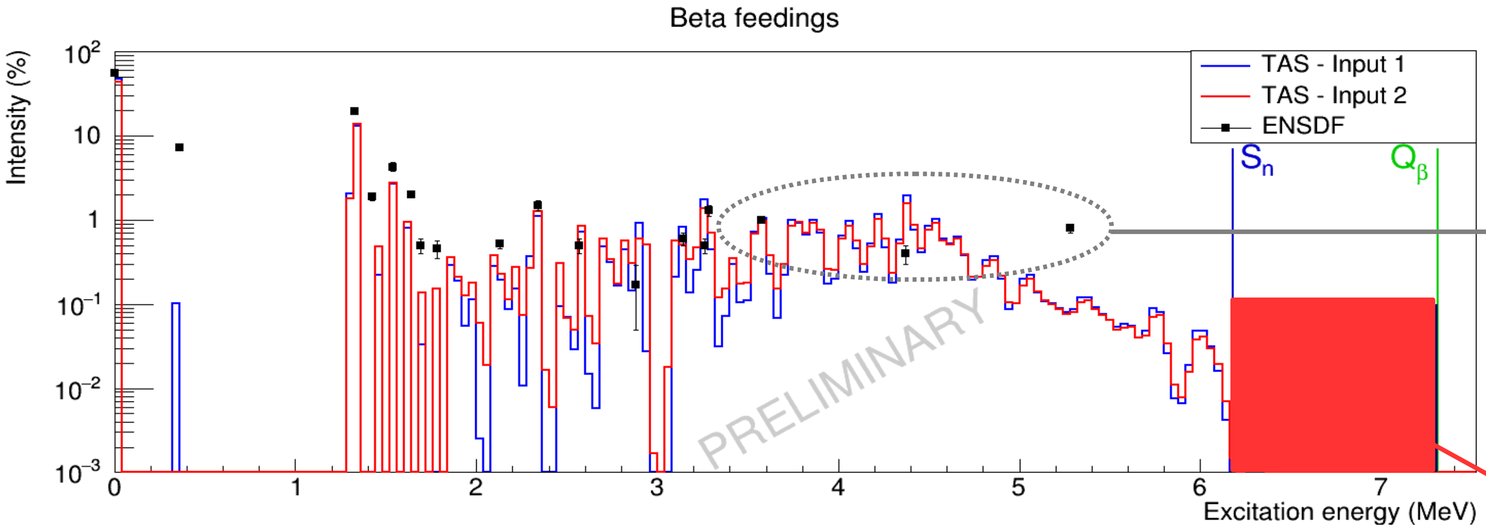
Difference between Input 1 and Input 2 :

- γ-strength E1 and M1

  Generalized Lorentzian (GL) (J. Kopecky and M. Uhl, Phys. Rev. C 41 (1990) 1941)

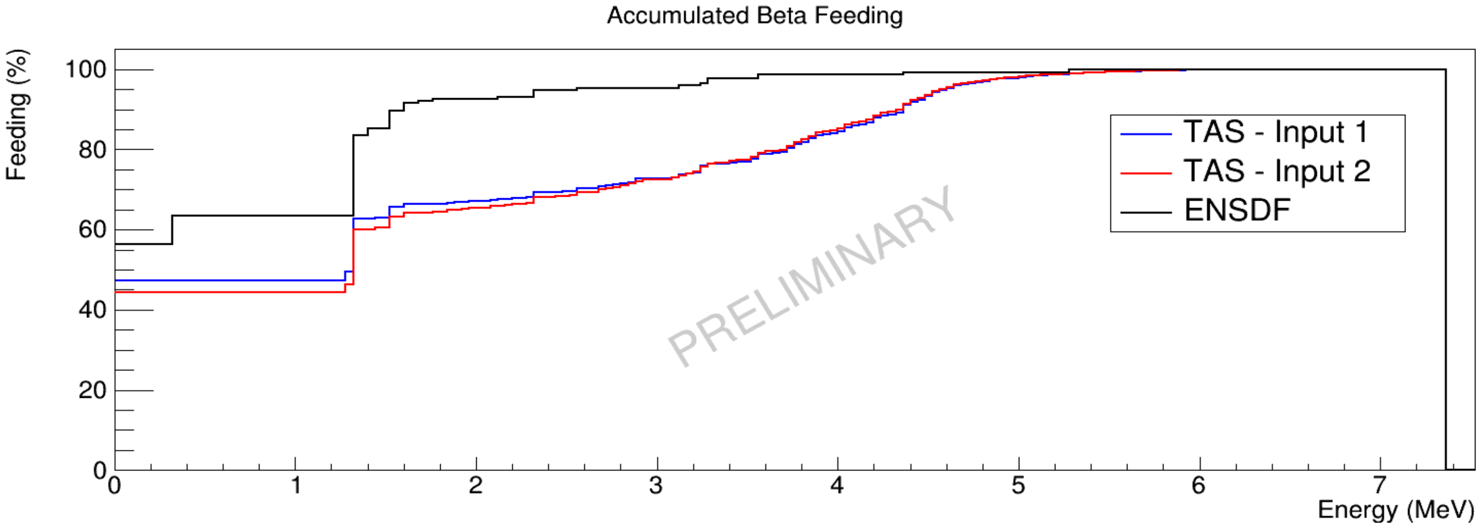
  Modified GL (HFB+QRPA and Gogny-D1M) (M. Martini, S. Péru, S. Hilaire, S. Goriely and F. Lechaftois, Phys. Rev. C 94 (2016) 014304)

Preliminary results for the ^{142}Cs



Only 3 values above 3.5 MeV in ENSDF

I_γ above S_n study on-going

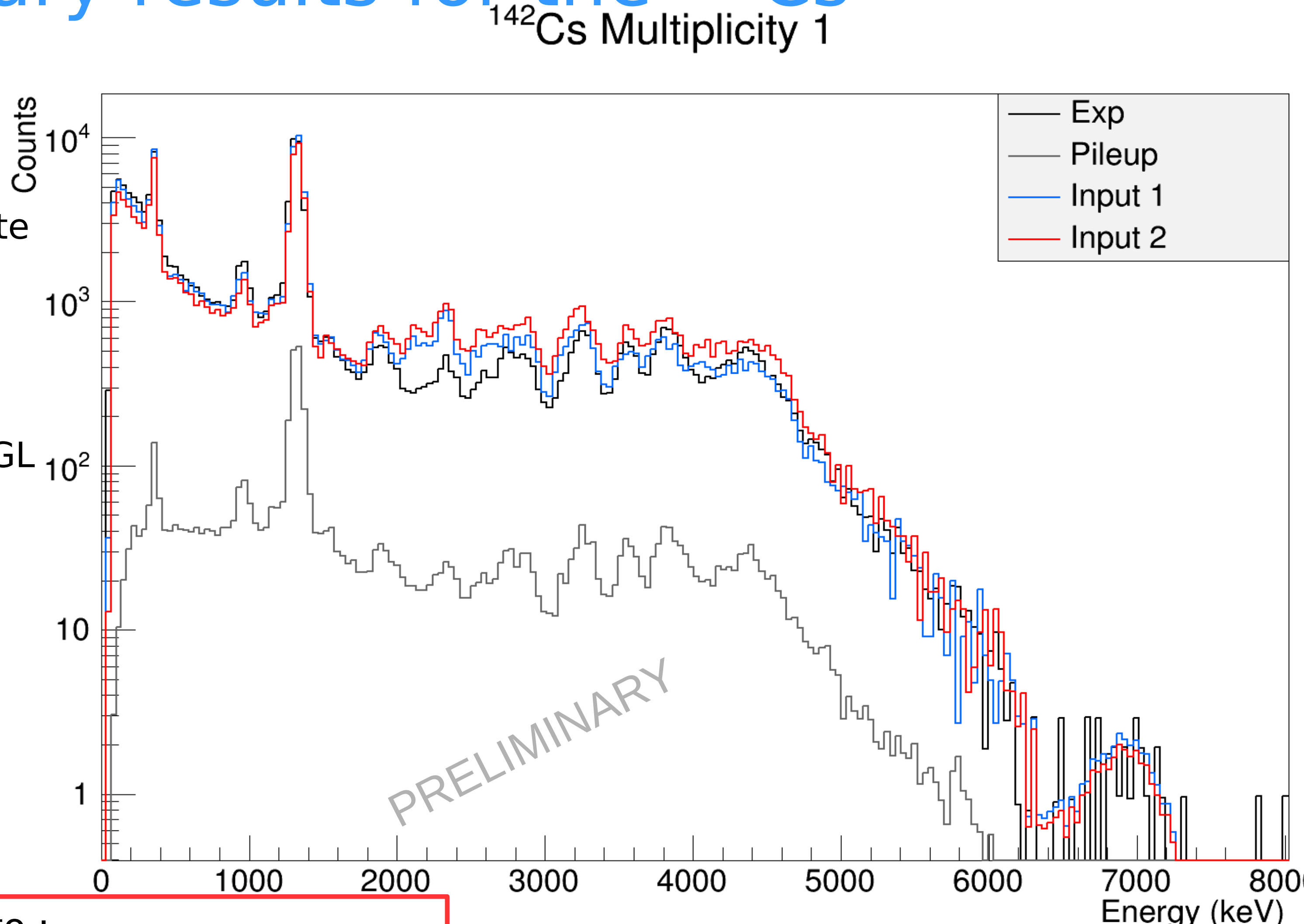


→ At low energy : lower value of β-feeding
Ground State feeding = 47%(Input 1) 44%(Input 2) 56%(ENSDF)

→ At high energy : continuous part beyond 3.5 MeV, missing in the ENSDF database

PANDEMONIUM EFFECT

Preliminary results for the ^{142}Cs



- D1M strength overestimate M1 above 1.5 MeV and underestimate it below
- Better reproduction with GL strength but needs improvement

Multiplicity study used to :

- verify/improve branching ratio matrix
- obtain a more detailed comparison between different sets of input parameters
- may constrain models

Study ON-GOING

Conclusion and outlook

TAS experiment :

- An alternative method compared to High Resolution experiments...
- ... which gives additional data to complete nuclear databases, with a potential non-negligible impact on :
  - Decay heat and $\bar{\nu}_e$ spectra calculations
  - Constraints on model dedicated to calculate $T_{1/2}$, deformation and P_n values
  - Nuclear structure and r-process modeling

Current analysis :

^{142}Cs, ^{99}Y, ^{138}I, ^{96,96m}Y

New feedings : nucleus affected by the Pandemonium effect

Result → I_β ➡ Calculate the beta strength to compare with theoretical models.

- Multiplicity study : may to use as a tool to constrain the different models

ON - GOING

Thank you !

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