Beta Strength of 92 and 93 Rb Measured With The Total Absorption Spectroscopy Technique

A. Porta for TAGS Collaboration

European Nuclear Physics Conference 2025

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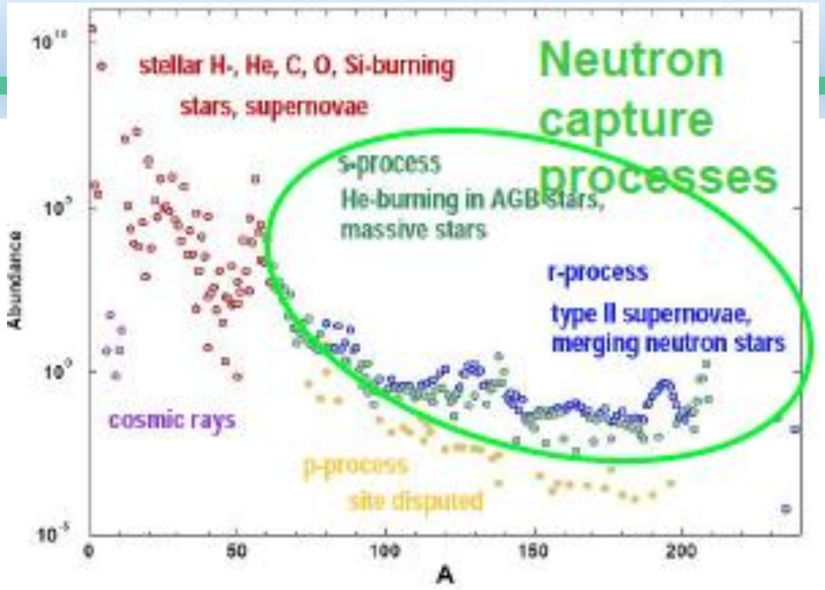
- Reminders of motivations for beta decay data measurements
- The Pandemonium effect
- The Total Absorption Gamma-Ray Spectroscopy (TAGS) solution
- TAGS experiment at Jyvaskyla
- Results for $^{92,93}Rb$
- Conclusions

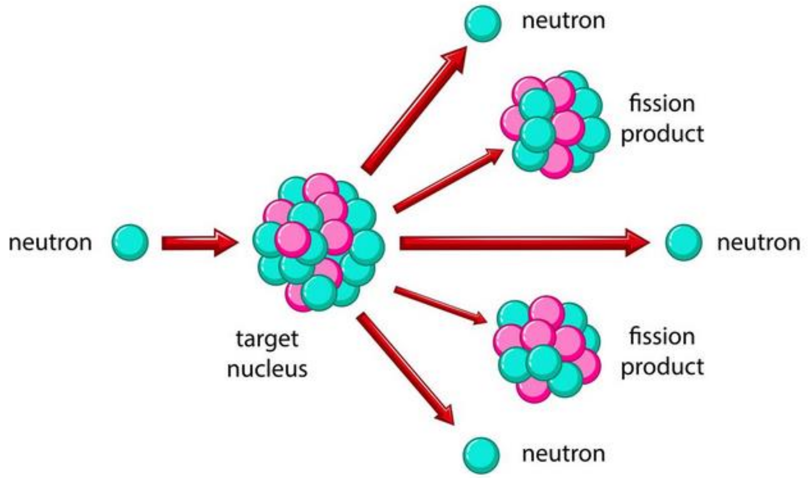
Beta decay of neutron rich nuclei



In stars:

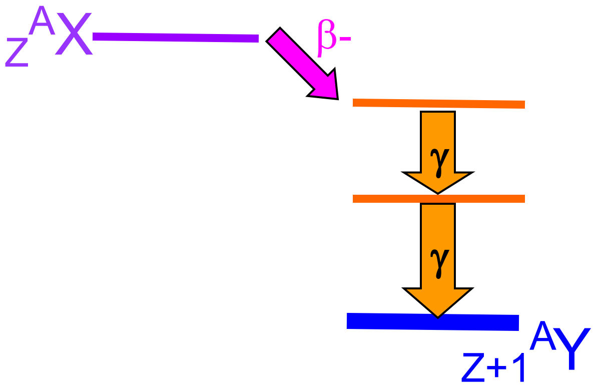
- R-process: responsible of formation of 50% of heavy elements
- A short and intense neutron flux produces very neutron-rich nuclei in a short time, which then decay to stability. Requires nuclear properties for ~5000 exotic nuclei!!!

In nuclear reactors, fission process gives thermal energy:
n + ^{235}U -> ^{236}U* -> PF$_1$ + PF$_2$ + neutrons (200 MeV)



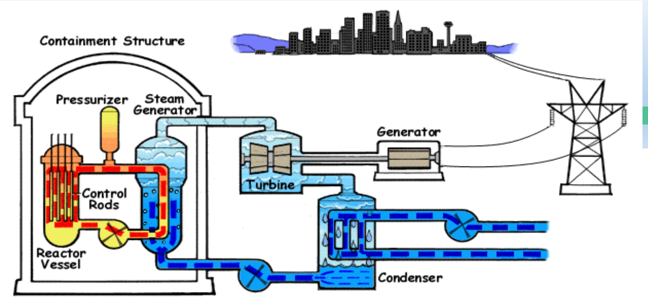
Fission Products (FP) are neutron-rich nuclei, undergoing β or β-n decay

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



- The released γ and β contribute to the *"decay heat"*
- *The antineutrinos* escape and can be detected
- β-n emitters: *delayed neutron fractions*

Decay heat



Interests:

- Residual power (~7% of nominal power):
- Safety and economical reasons

Estimate through the « summation method »: summation of all the fission product contributions

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

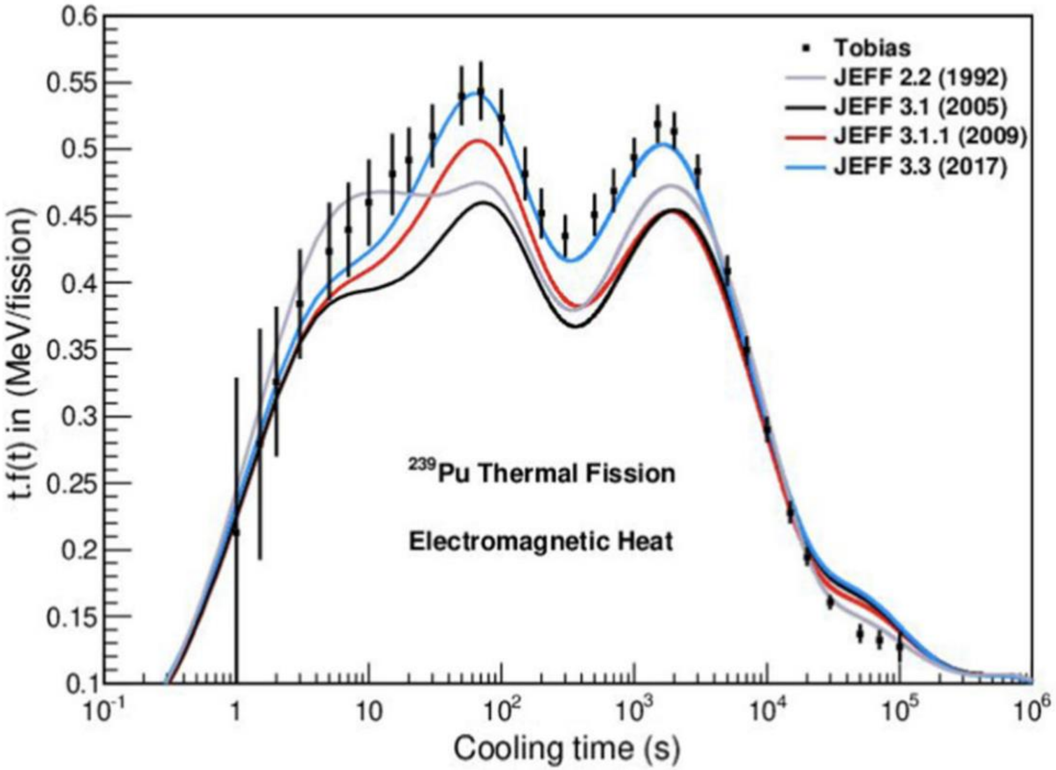
⇒ The only predictive method for future reactors

⇒ Usually cross-checked through comparison with integral experiments

⇒ Discrepancies observed between integral measurements and simulations based on data bases

Nuclear Science NEA/WPEC-25 (2007), Report INDC(NDS)-0577 (2009), Report INDC(NDS-0551, Report INDC(NDS)-0676 (2015), CCFC report 2015 Fispact II

A. L. Nichols et al. Eur. Phys. J. A (2023) 59:78



We need to improve our knowledge about beta decay properties of FP

Reactor Antineutrinos

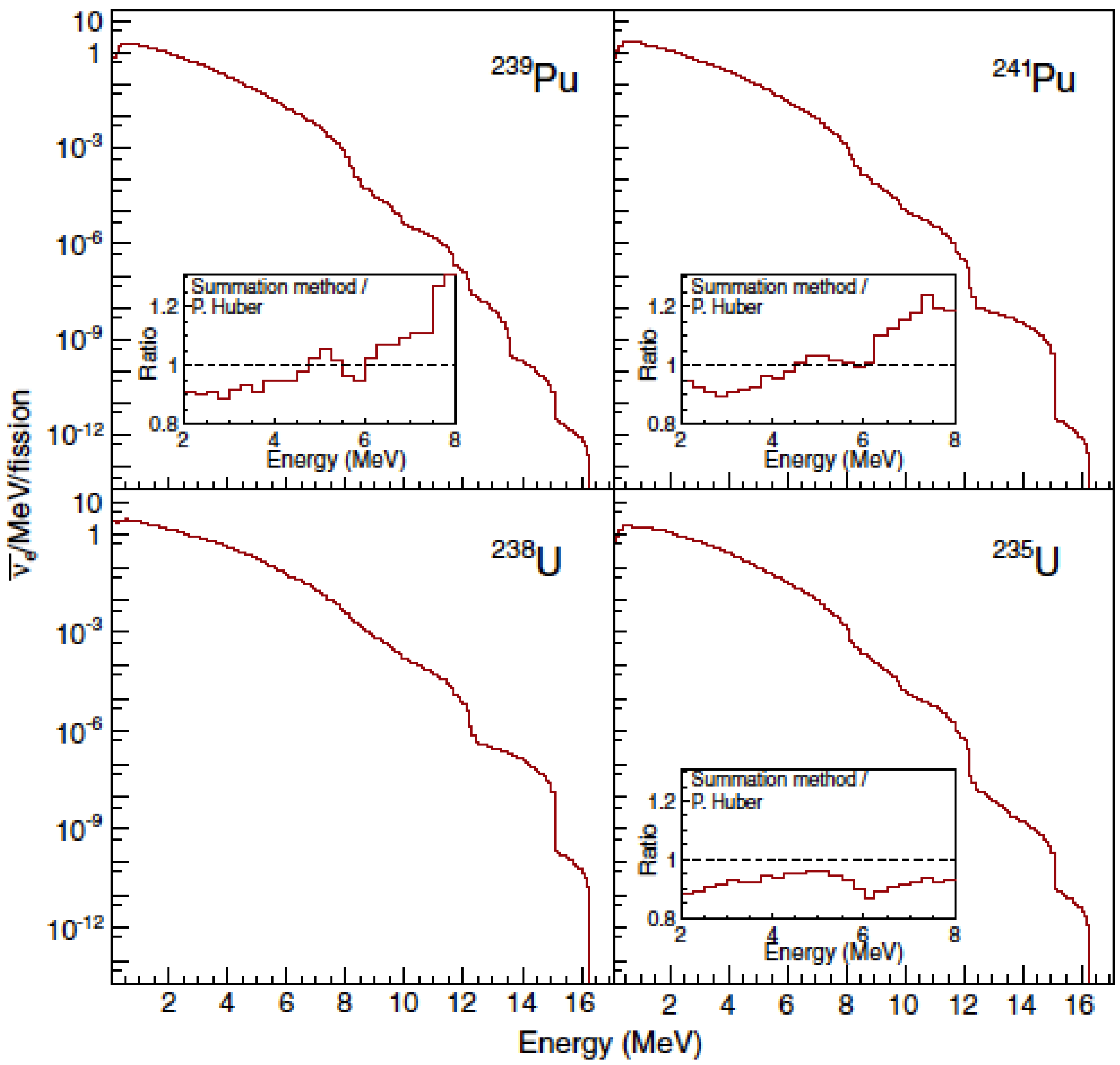
⇒ reactor applied physics

✧ Fuel composition and reactor monitoring

⇒ neutrino fundamental physics

✧ Measurement of neutrino physics parameters

✧ Anomalies between measured and calculated fluxes and spectra



M. Fallot et al., Phys. Rev. Lett. 109, 202504 (2012)

Summation Method for reactor antineutrinos:

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

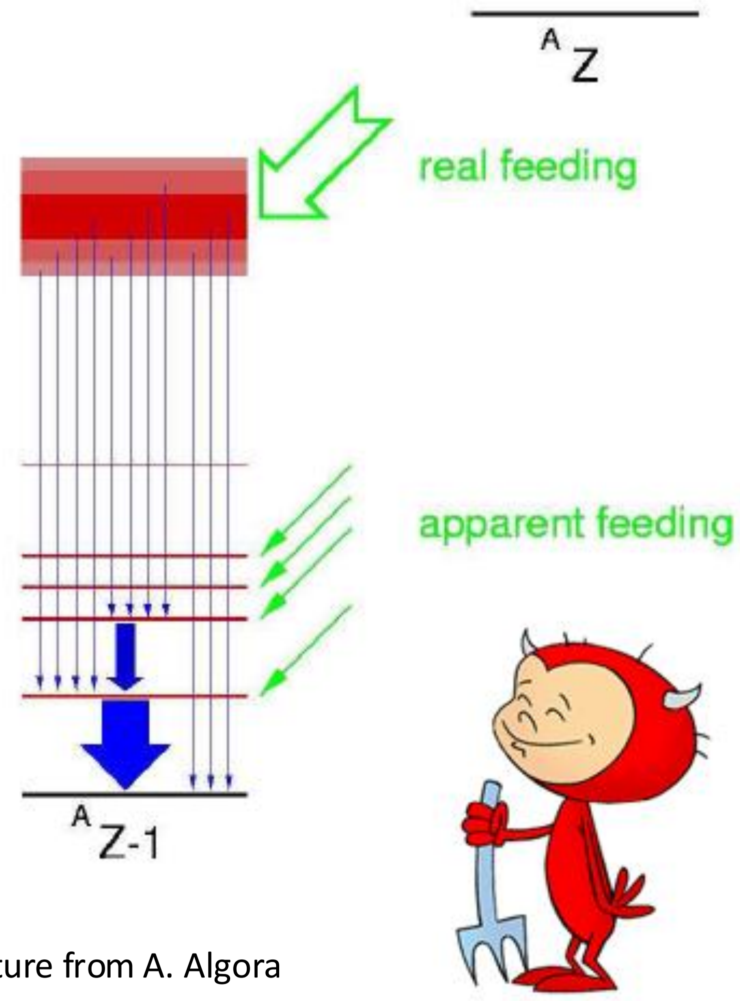
Ratio between spectra calculated with summation method and converted spectra from ILL measurements, this second is overestimated of about 5% respect to the summation one

⟶ The reactor antineutrino estimate also suffer from bias of beta decay data basis

For more information see the talk of **M. Estienne** Session **NNDS13** on Thursday 16h10

Pandemonium effect **

Due to the use of Germanium detectors to measure the decay schemes by single γ-ray spectroscopy: lower efficiency at higher energy



Picture from A. Algora

- At high energy: high level density and many possible decay paths

- High energy gammas difficult to be detected by Ge.

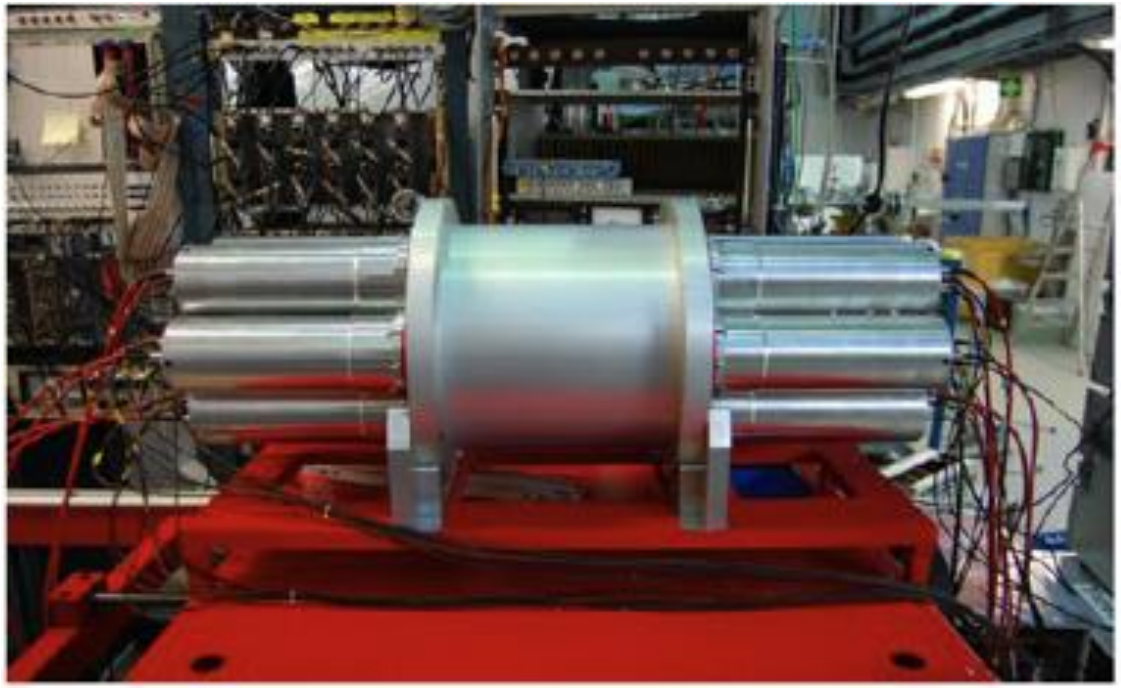
→ underestimate of β branches towards high energy excited states: overestimate of the high energy part of the FP β spectra

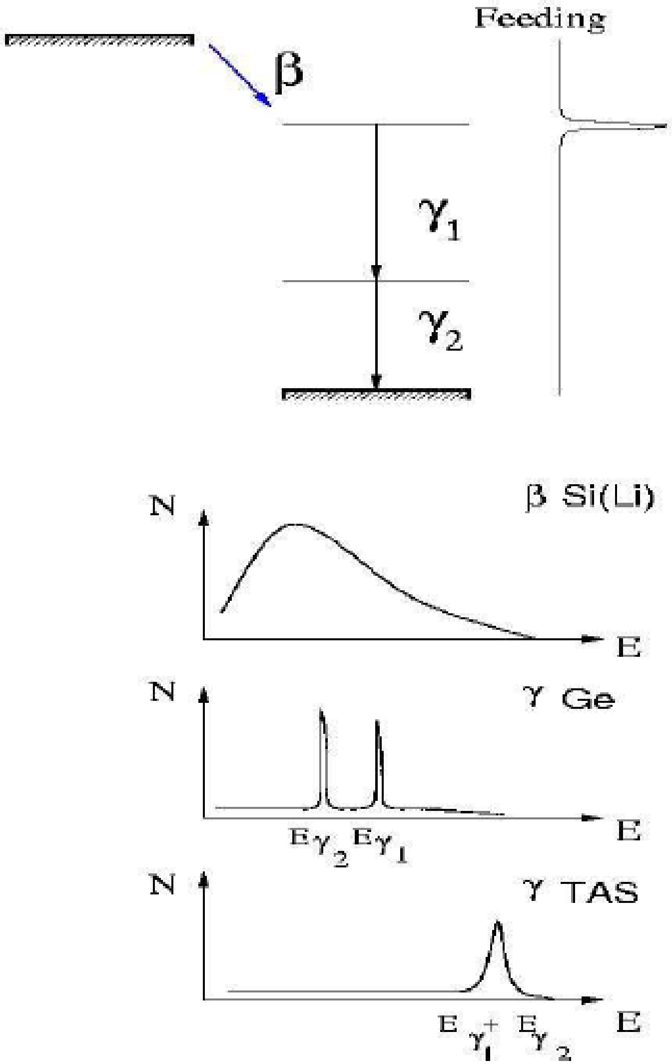
** J.C.Hardy et al., Phys. Lett. B, 71, 307 (1977)

TAGS solution

Solution: Total Absorption Gamma-ray Spectroscopy (TAGS)
Big crystal, 4π => A TAS (Total Absorption Spectrometer) is a calorimeter with efficiency as close as possible to 100%

Rocinantes: 12 BaF_2 and a Si detector for β coincidence



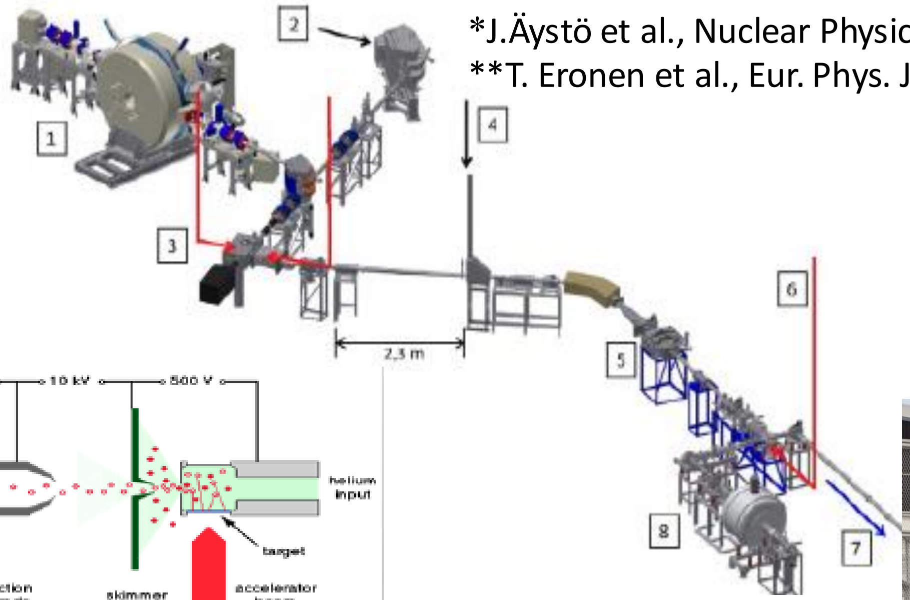


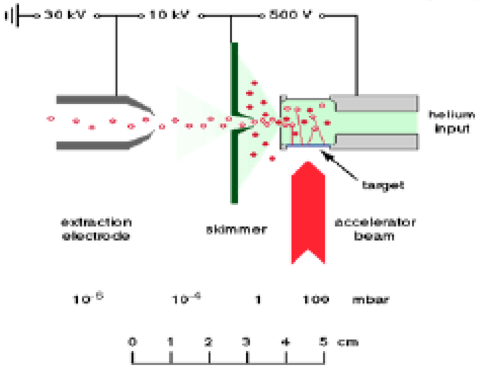
TAGS developed by the IFIC Valencia team (Spain, , A. Algora, J.L. Tain, B. Rubio, et al.) : E. Valencia et al., Phys. Rev. C 95, 024320 (2017)

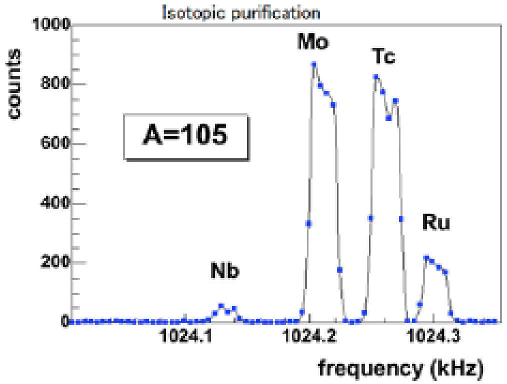
2009 Jyväskylä measurements of Rb92 and 93

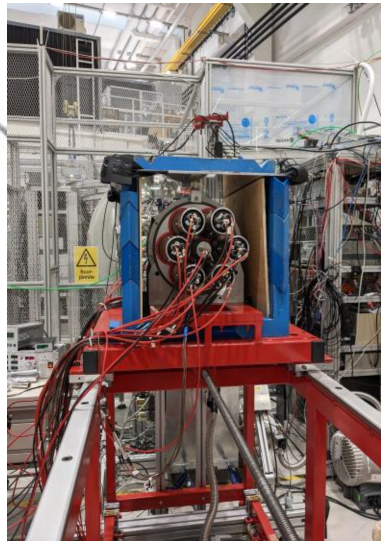
JYFL: good selection of the measured nucleus needed
→ IGISOL* + double penning trap JYFLTRAP**

*J.Äystö et al., Nuclear Physics A 693 (2001) 477–494
**T. Eronen et al., Eur. Phys. J. A 48, 46 (2012)









Motivations for those nuclei:

- candidates pandemonium nuclei
- Big contribution in ^{235}U and ^{339}Pu ν spectra
- ^{92}Rb also priority 2 for Decay Heat in U/Pu cycle and Priority 1 in Th/U cycle

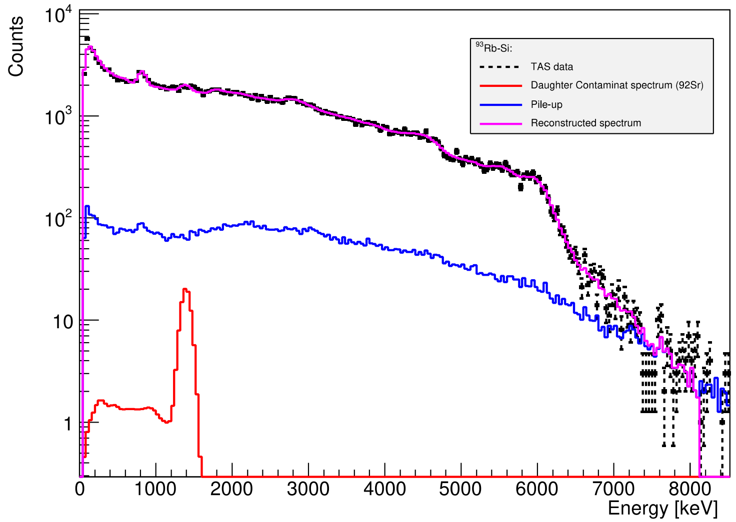
TABLE I. Main contributors to a standard PWR antineutrino energy spectrum computed with the MURE code coupled with the list of nuclear data given in [12], assuming that they have been emitted by ^{235}U (52%), ^{239}Pu (33%), ^{241}Pu (6%)and ^{238}U (8.7%) for a 450 day irradiation time and using the summation method described in [12].

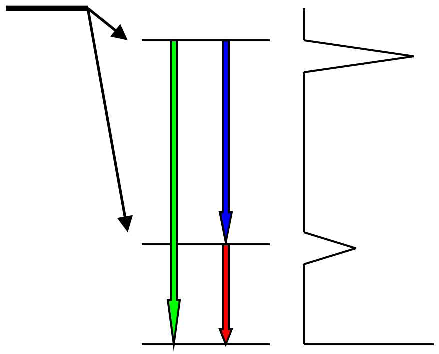
	4 - 5 MeV	5 - 6 MeV	6 - 7 MeV	7 - 8 MeV
^{92}Rb	4.74%	11.49%	24.27%	37.98%
^{96}Y	5.56%	10.75%	14.10%	-
^{142}Cs	3.35%	6.02%	7.93%	3.52%
^{100}Nb	5.52%	6.03%	-	-
^{93}Rb	2.34%	4.17%	6.78%	4.21%

A.A. Zakari-Issofou et al., PRL2015 Sep 4;115(10):102503

talk of **Zhuang GE** Session **NNDS2** on Monday 15h45

Analysis to obtain β-feeding ➔ β-strength





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

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

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

Statement of the problem:

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) algorithm→ expectation minimization method

Monte Carlo simulations
+
Nuclear statistical model

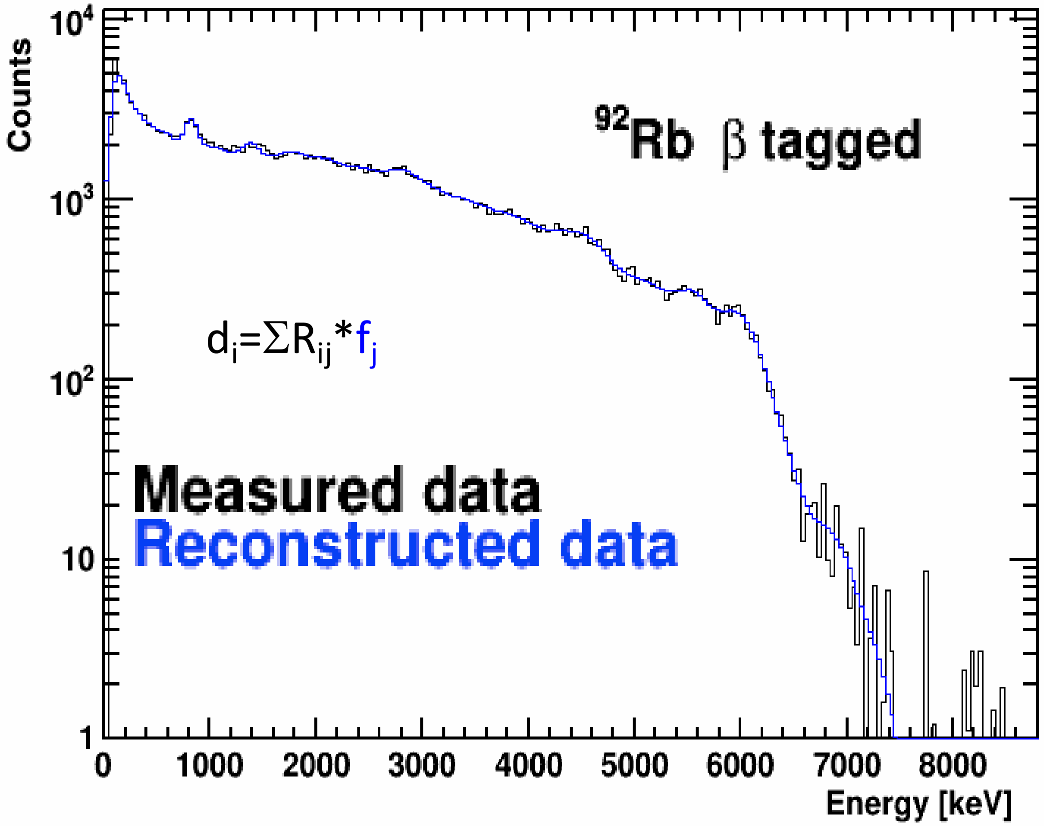
Tain et al. NIM A571 (2007) 719,728

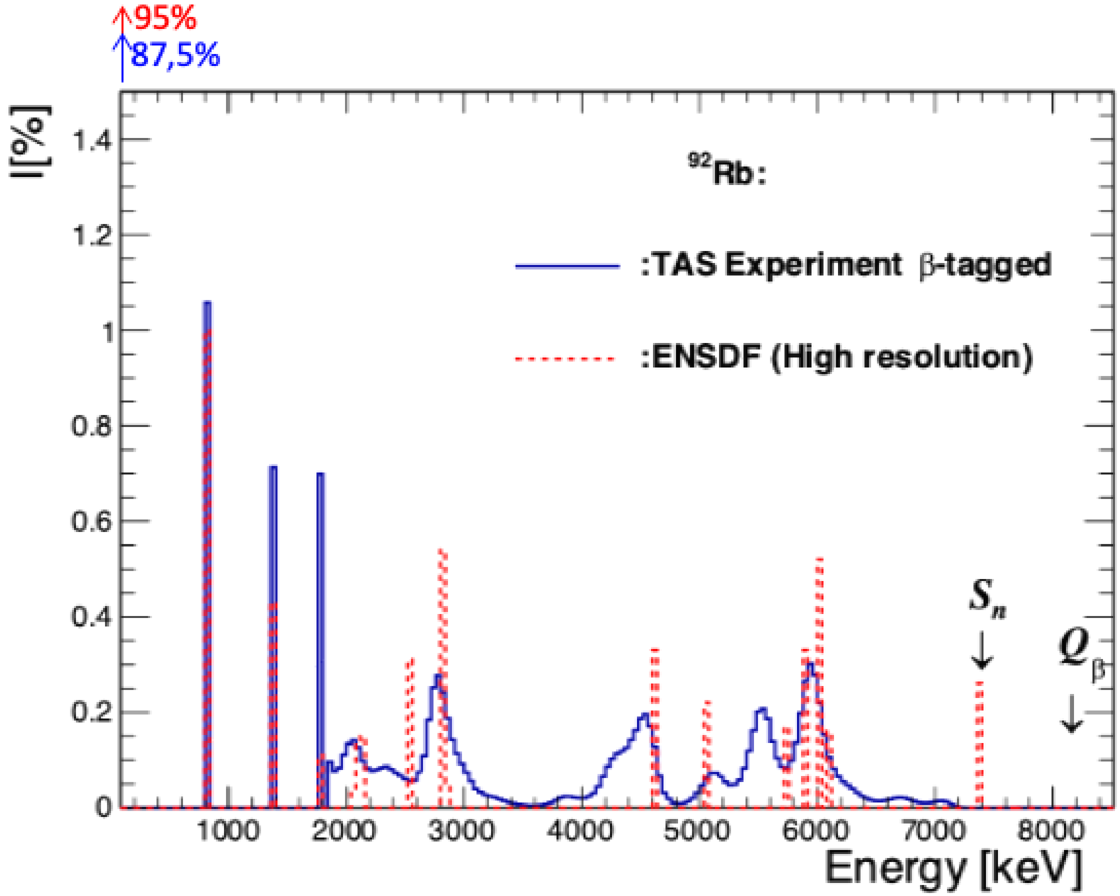
- Spectrum must be clean from background and contaminants
- Response must be accurately known
- Solution of inverse problem must be stable

NIM A430 (1999) 333
NIM A430 (1999) 488

Results for ^{92}Rb

Reconstructed beta feeding from data compared with ENSDF

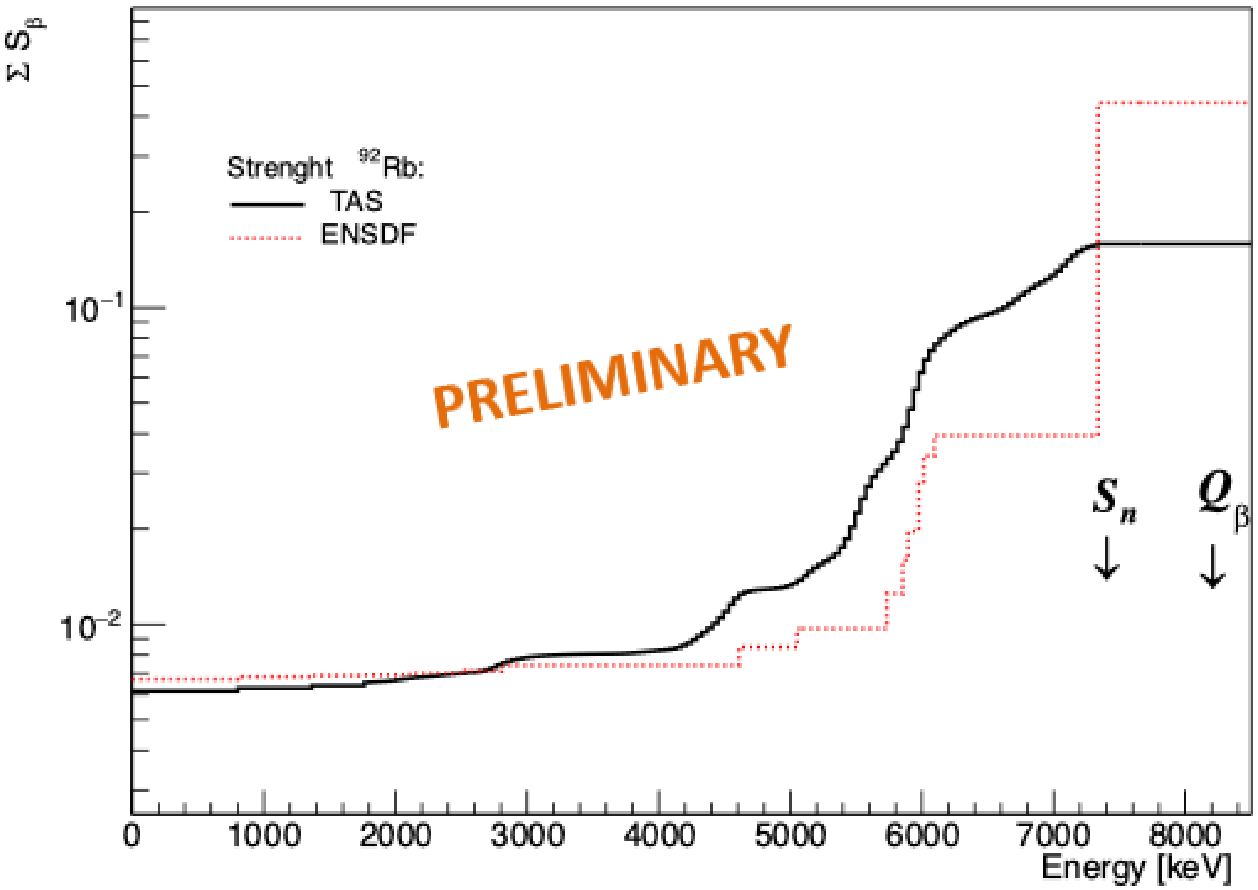




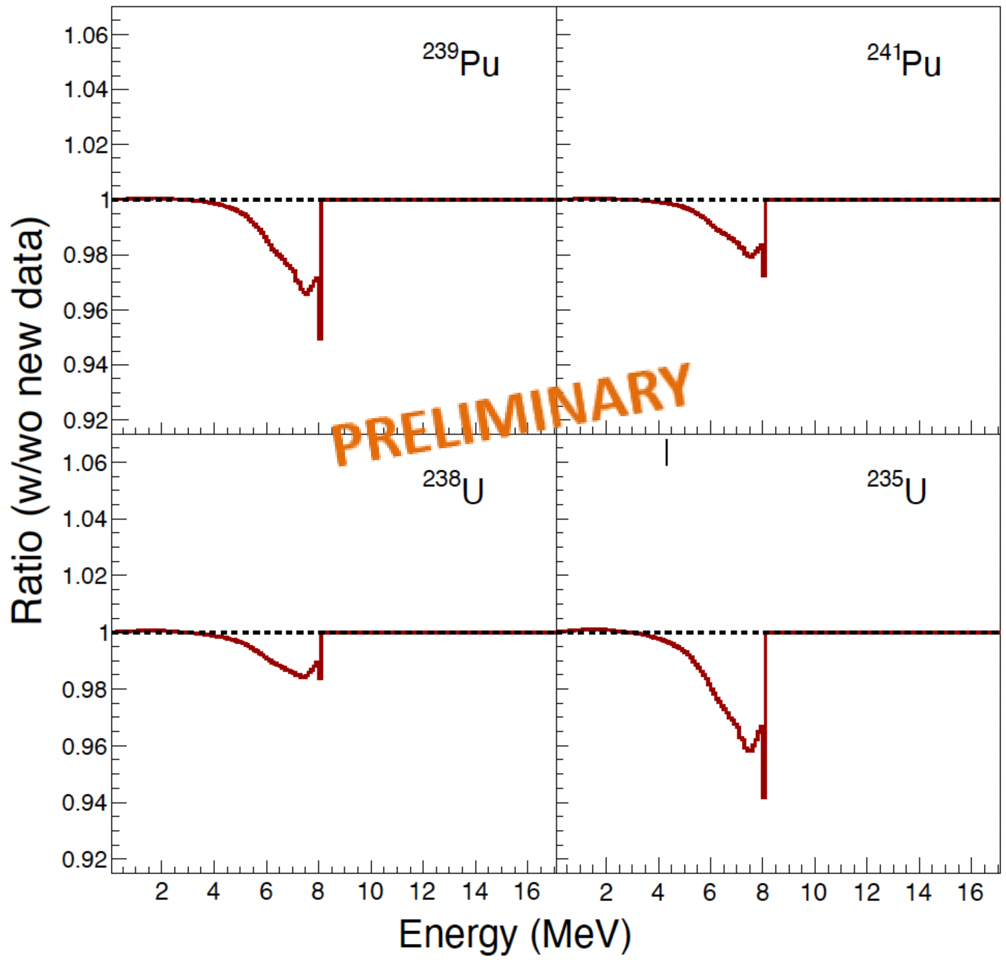
A.-A. Zakari-Issoufou et al., Phys. Rev. Lett. 115, 102503 (2015) arXiv:1504.05812 [nucl-ex]

Results for ^{92}Rb

Cumulated beta strength



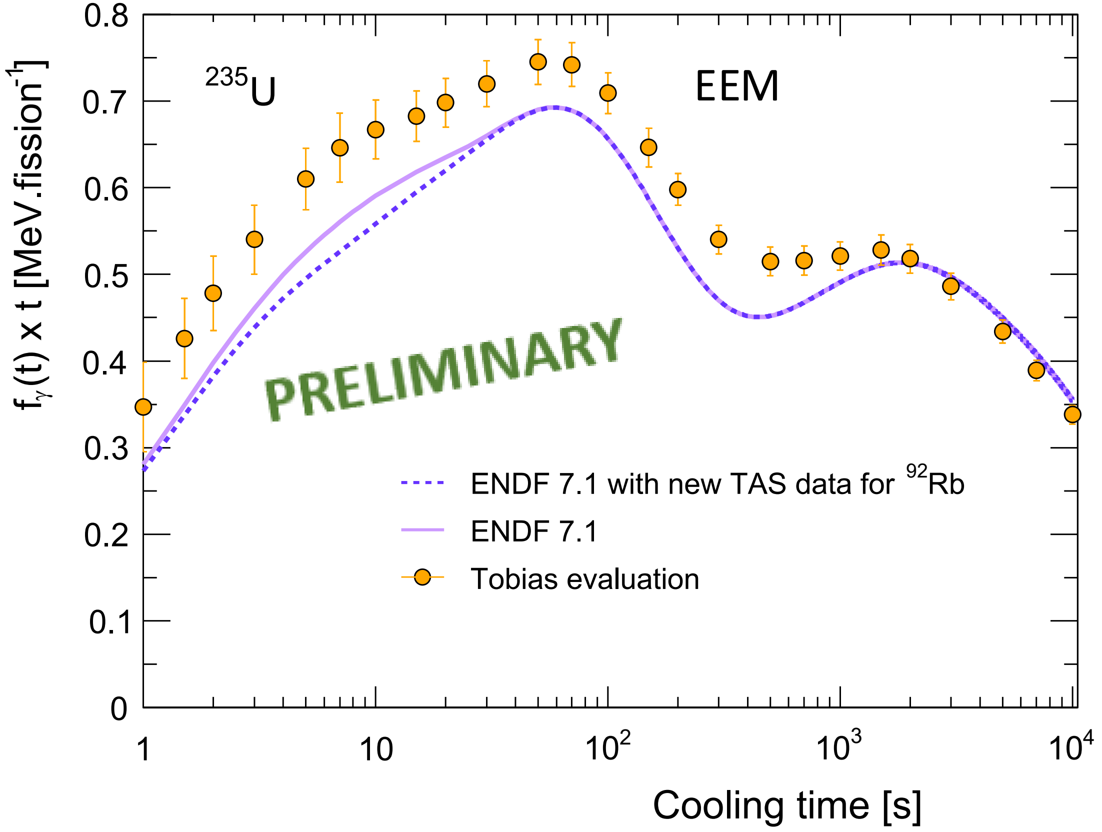
Ratio between neutrino spectrum calculated with and without new data

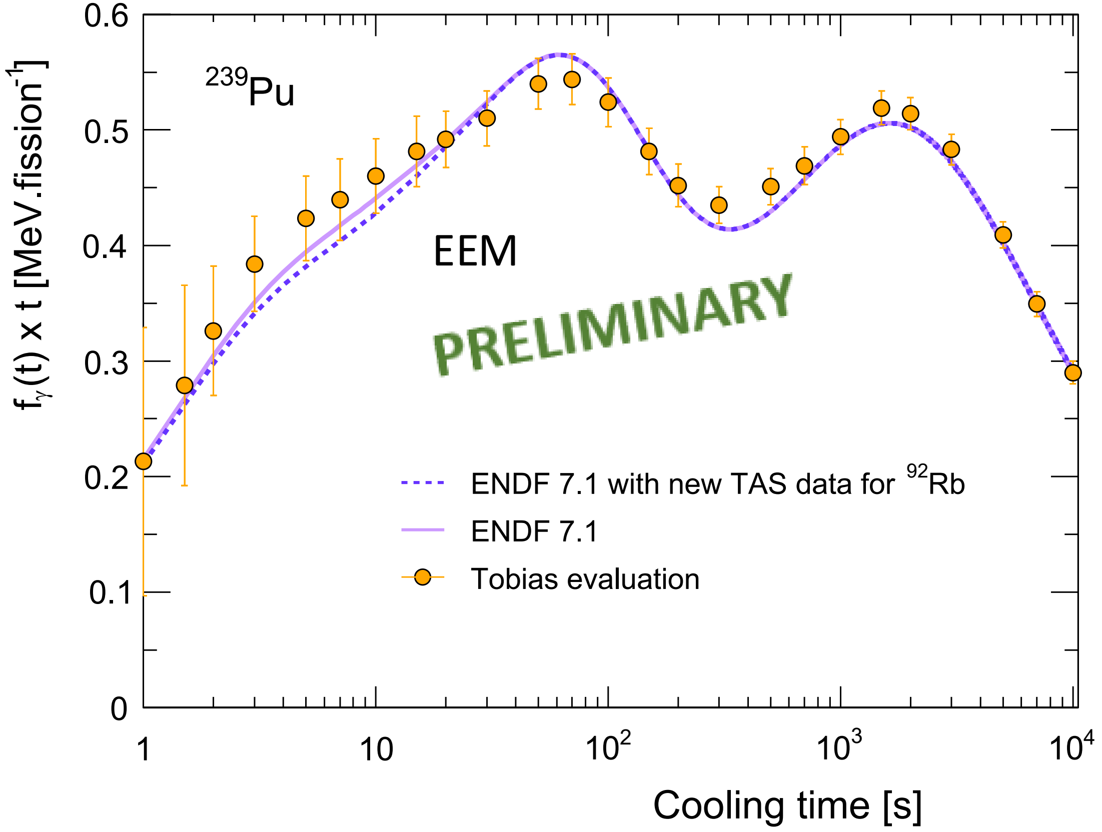


A.-A. Zakari-Issoufou PhD thesis

Results for ^{92}Rb

Decay heat computation done by A. Sonzogni (BNL):





New EEM mean value: 459.5keV, New ELP value: 3.49MeV

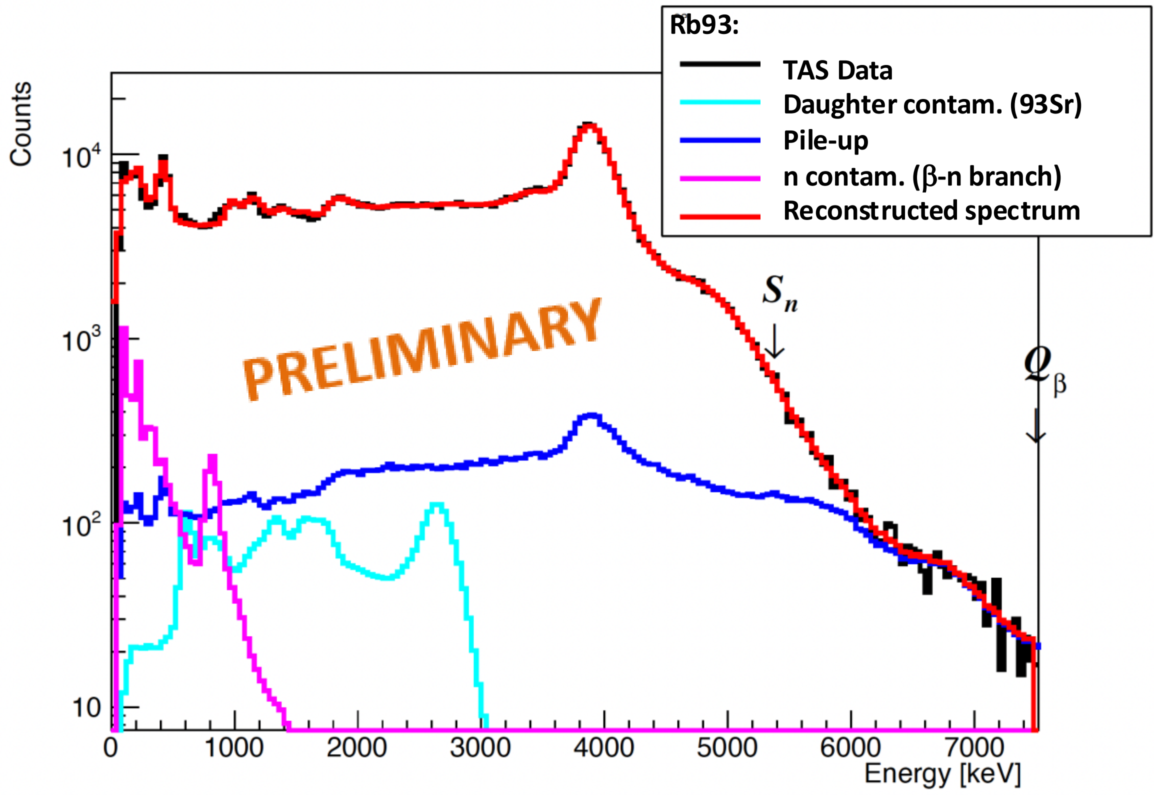
Compared with ENDF7.1 (G.S. to G.S. feeding 51%): EEM 2.15MeV ELP 2.87MeV

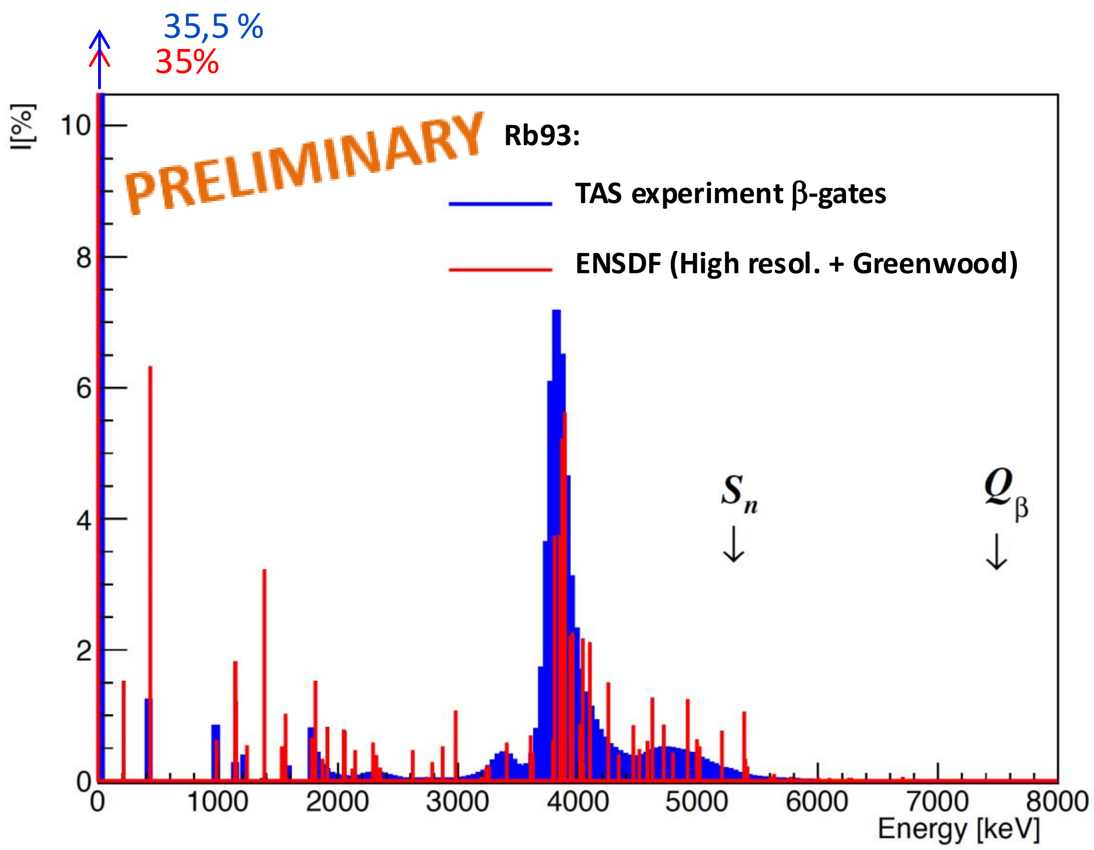
Compared with ENDF7.1.1 (G.S. to G.S. feeding 95.2%): EEM 170keV ELP 3.63MeV

Results for ^{93}Rb

Reconstructed beta feeding from data compared with ENSDF (containing Greenwood data)

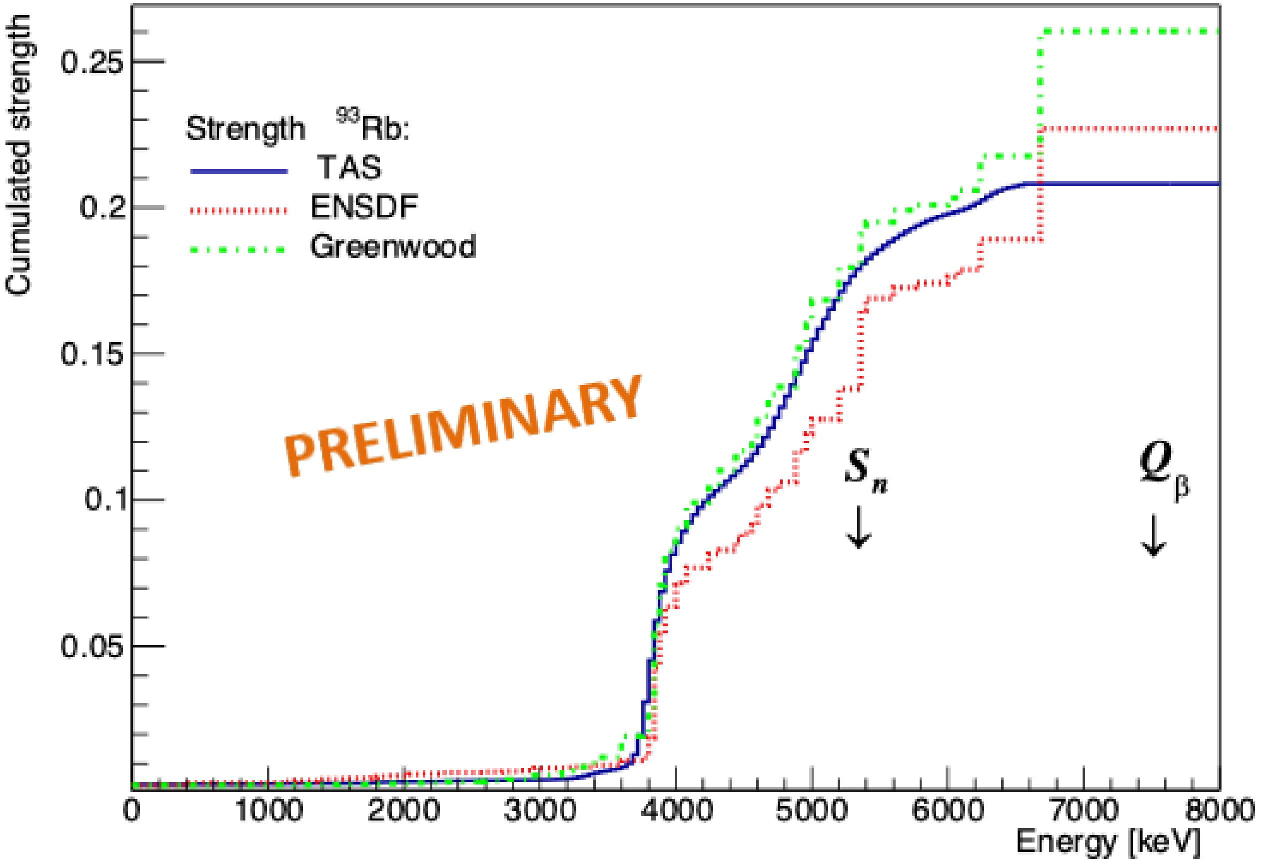
Greenwood et al. Nucl. Instr. Methods Phys. Res. A 314, 514 (1992)





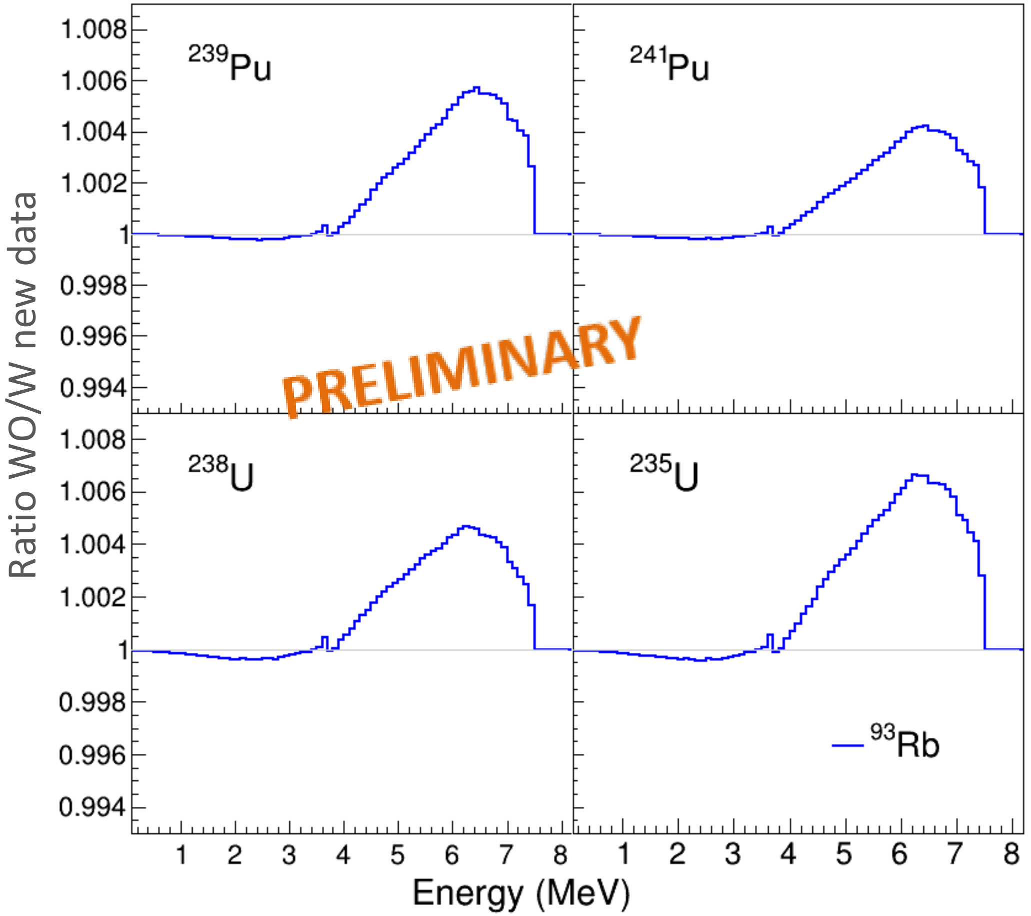
Results for ^{93}Rb

Cumulated beta strength



Greenwood et al. Nucl. Instr. Methods Phys. Res. A 314, 514 (1992)

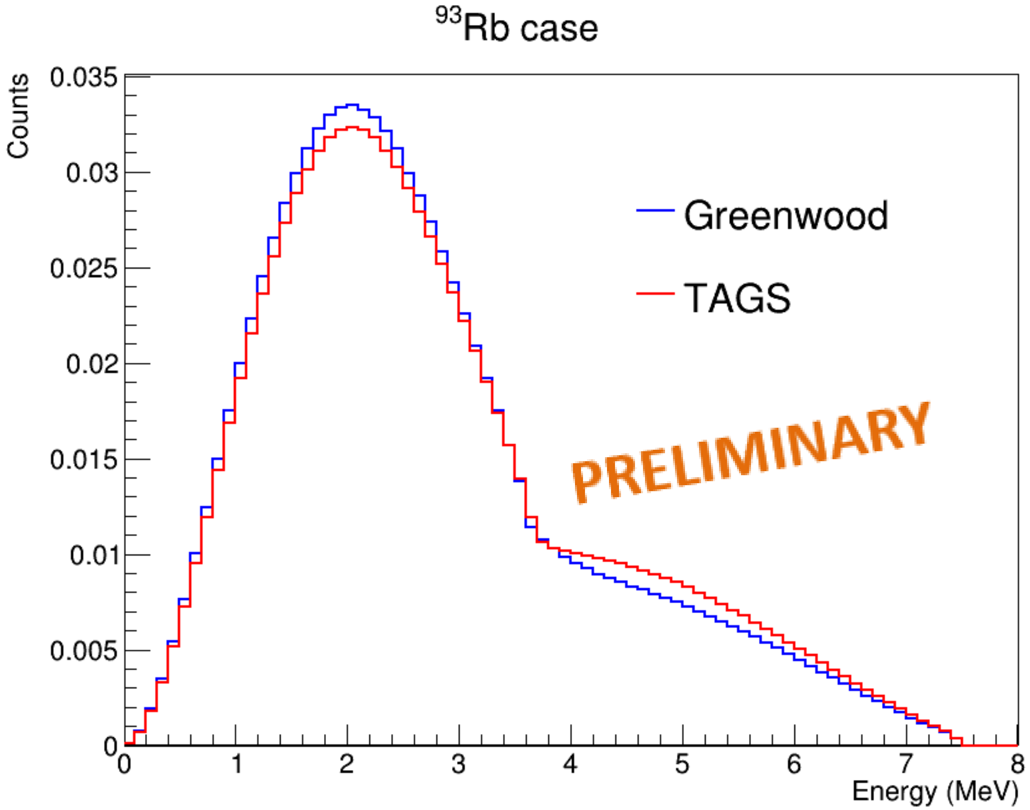
Ratio between neutrino spectrum calculated with and without new data

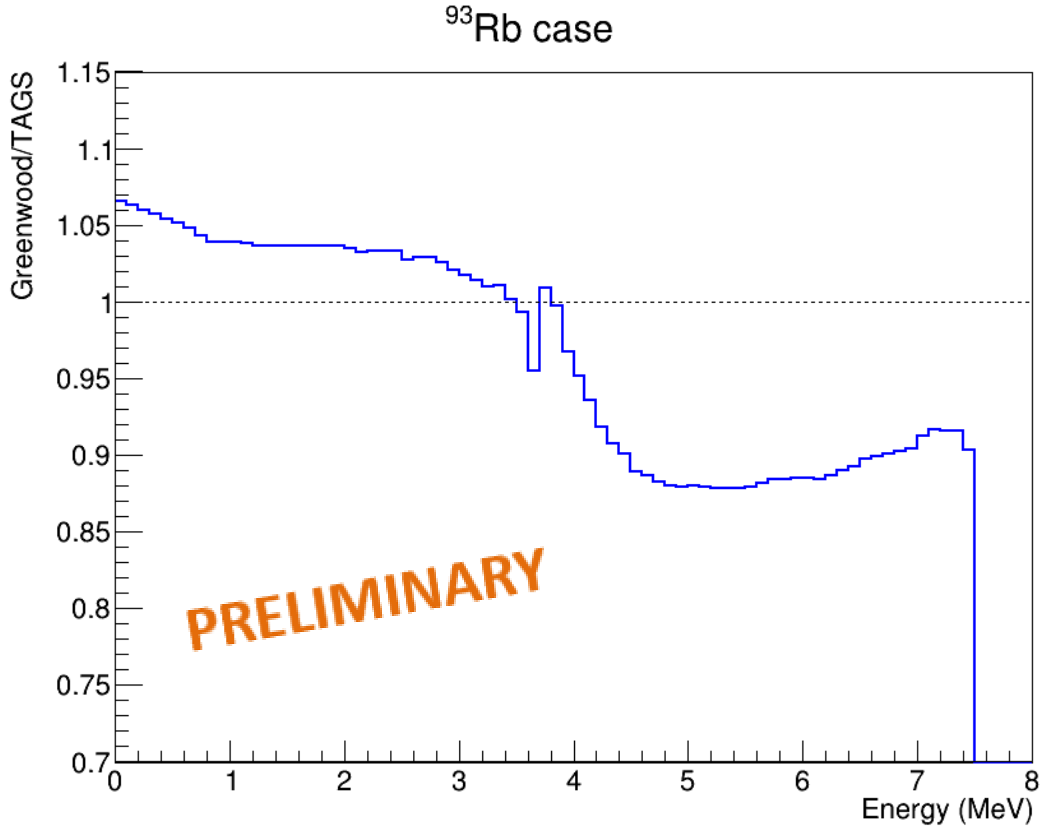


ν spectrum calculation from M. Estienne

Results for ^{93}Rb

Comparisons with previous TAGS measurements by Greenwood et al.





ν spectrum calculation from M. Estienne

Conclusions

- Precise knowledge of beta decay properties are needed in several fields from fundamental and applied physics
- Pandemonium effect affects beta decay data bases
- TAGS technique can solve this problem
- Last analysis for ^{92}Rb with strength calculation
- Last analysis for ^{93}Rb with impact on its reactor antineutrino spectrum
- New analysis of G.S. feeding ongoing

Thank you for your attention

Others TAGS presentations at this conference :

- Session **NNSD1 on Monday** 14h45, **J. Pepin** « Study of exotic nuclei of interest for applied and fundamental nuclear physics with Total Absorption Gamma-ray Spectroscopy (TAGS) »
- Session **AI5** on Thursday 14h20, **M. Fallot** « The (NA)2STARS: Neutrinos, Applications and Nuclear Astrophysics with a Segmented Total Absorption with higher Resolution Spectrometer, a combination of calorimetric and spectroscopic tools for beta decay and in-beam measurements »
- Session **NNDS13** on Thursday 16h10, **M. Estienne** « Update of the summation calculations for reactor antineutrino spectra »

SANDA
Supplying Accurate Nuclear Data for energy and non-energy Applications
HORIZON2020
APRENDE

The TAGS collaboration

IFIC Valencia: A. Algora, J. Agramunt, B. Rubio, J.L. Tain, S. Orrigo, D.Rodriguez, G.Alcala, J.A.Victoria

SUBATECH Nantes: M. Estienne, M. Fallot, J. Pepin, A. Porta, S. Nandi, E. Bonnet, S.Bouvier, L. Giot, Y. Molla

U. Surrey: W. Gelletly

IGISOL Jyvaskyla: H. Penttilä, T. Eronen, A. Kankainen, I. Moore, M. Hukkanen, A. Jokinen, M. Mougeot, A. Raggio, M. Reponen, J. Ruotsalainen, O. Beliuskina,V. Virtanen, W. Gins, L. Al Ayoubi, S. Kujanpää, J. Romero, M. Stryjczyk, A. Jaries, S. Nikas, I. Pohjalainen, Z. Ge

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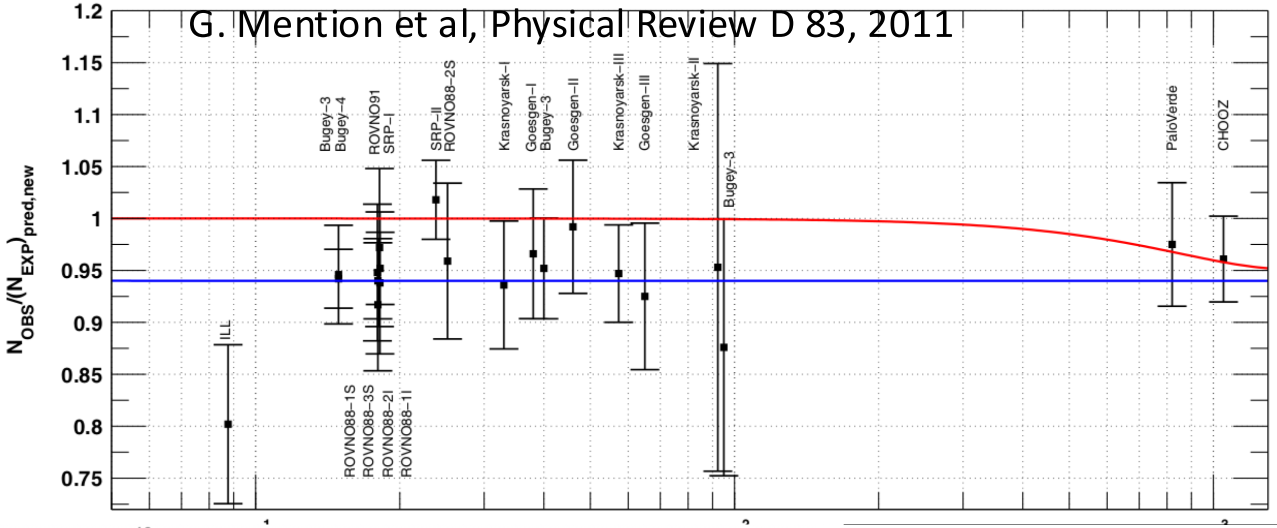
HUN-REN ATOMKI: D.Sohler, G.Kiss, I.Kuti

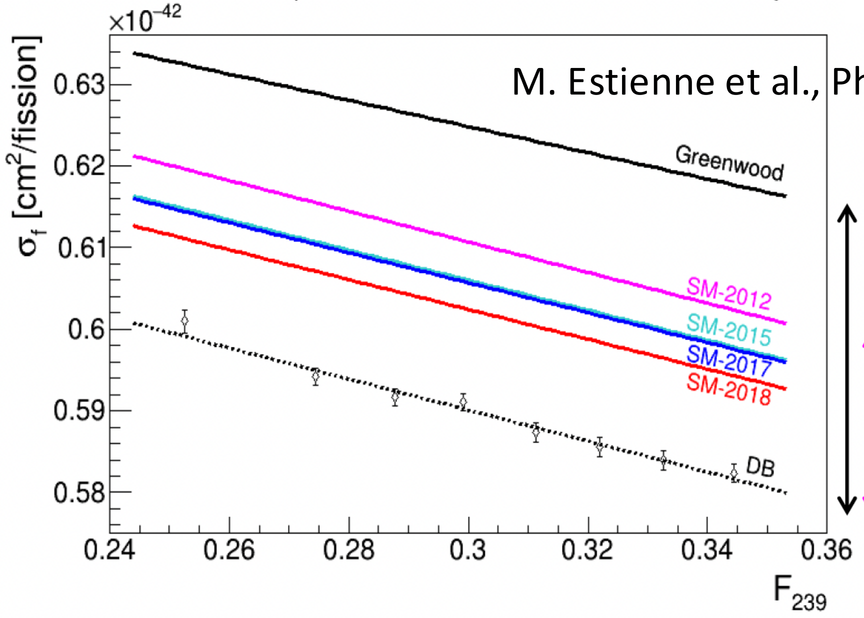
Back Up

Reactor anomaly and spectral distorsion

G. Mention et al, Physical Review D 83, 2011



M. Estienne et al., Phys. Rev. Lett. 123 (2019) 022502



6% (Greenwood TAGS, ~Huber-Mueller)

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

A. C. Hayes et al. PRL 120 (2018) 022503

2.4% (+TAGS 2015 & 2017)

1.9% (+ TAGS 2018)

Daya Bay

CPC 41, 1 (2017) 013002