β decay of 64-66Ga: Total Absorption Spectroscopy and Isospin Mixing

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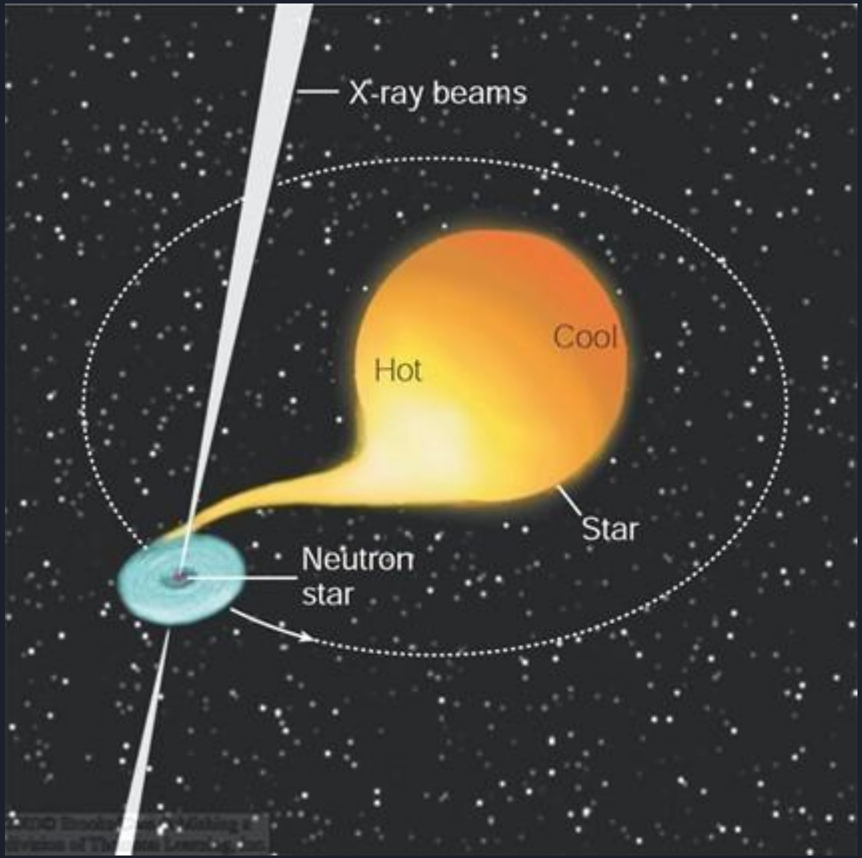
Type I x-ray bursts

- Binary systems: a neutron star accretes hydrogen-rich material from a low-mass companion (Red-Giant or Main-seq. star)
- Breakout from the hot CNO cycle, thus leading to the rp-process
- It happens at the surface of the neutron star
- Peak in 1 to 10 seconds, tail lasts 10 seconds to several minutes and the recurrence is 1 to several hours

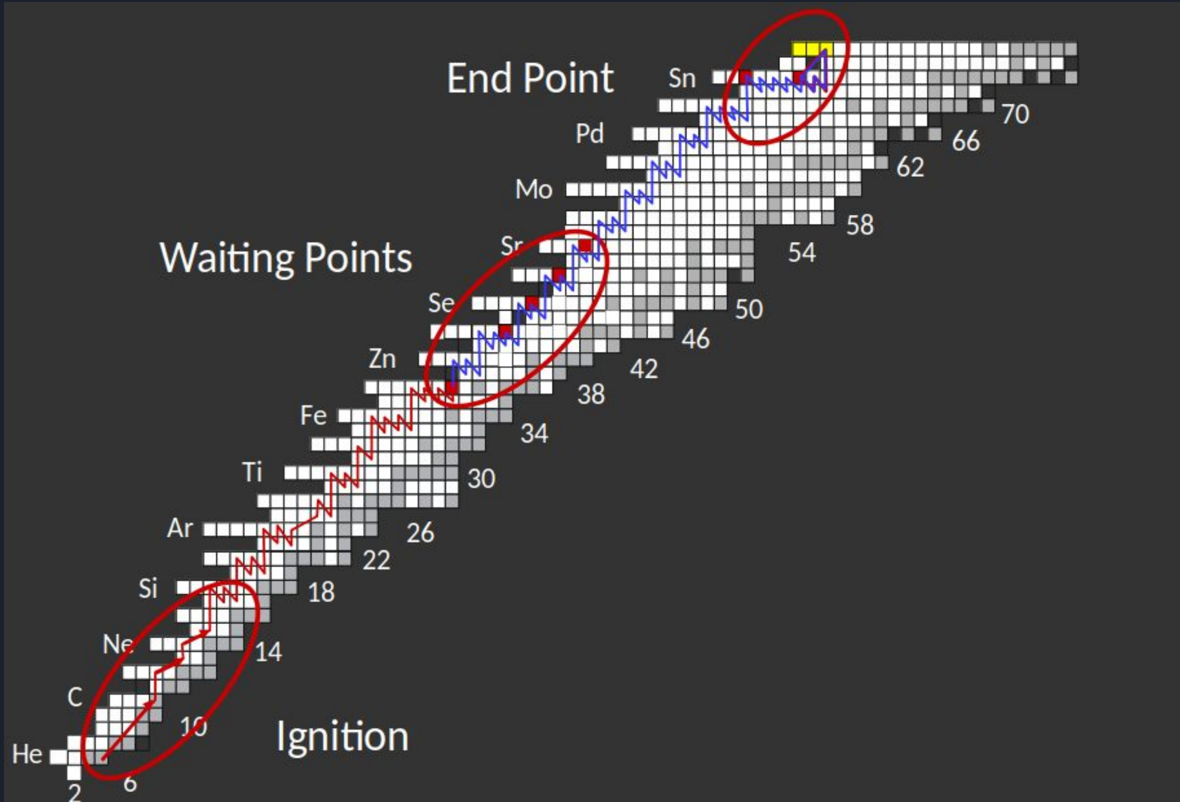
$T_{peak} = 1 – 3$ GK and $\rho = 10^6 – 10^7$ g cm^{-3}

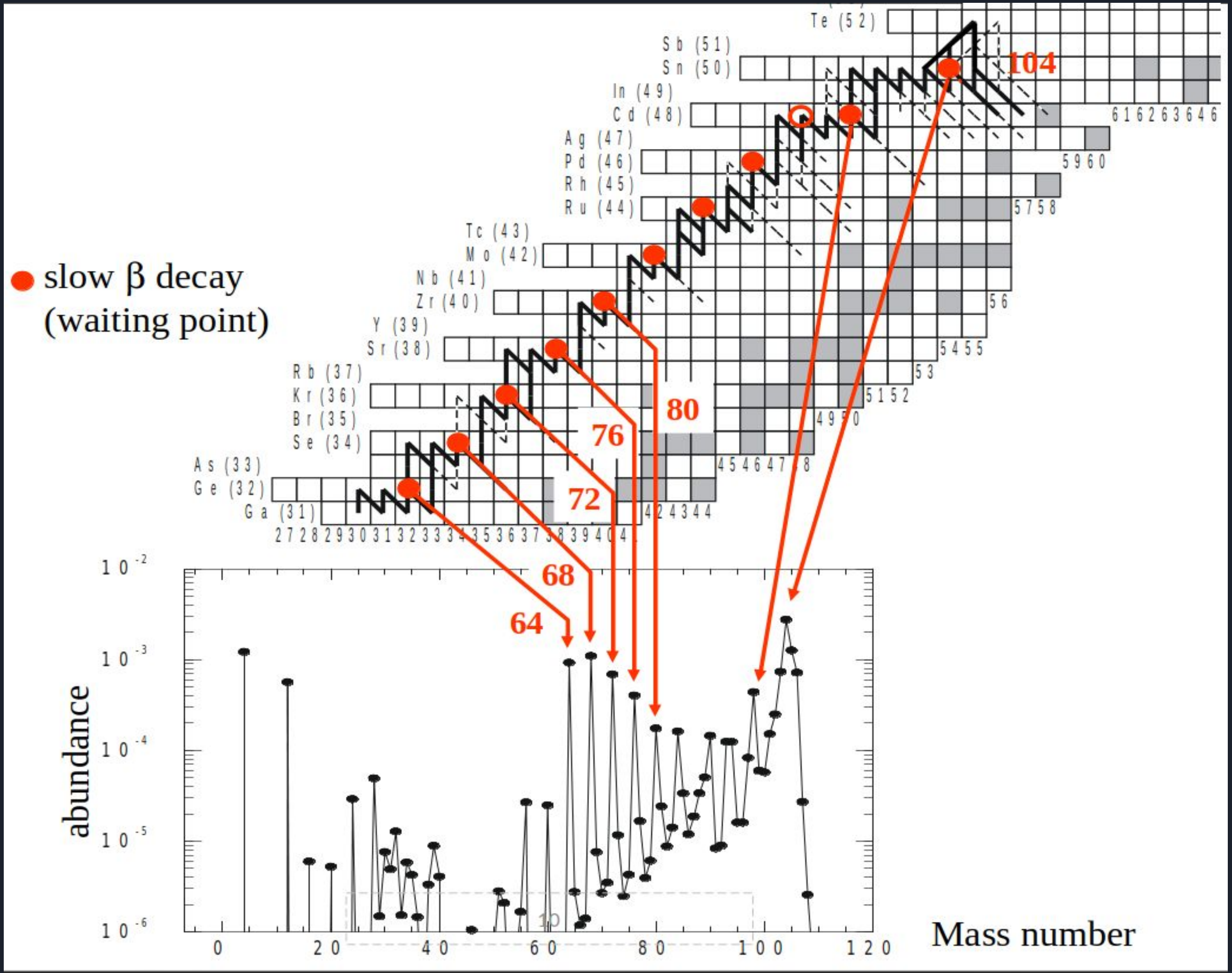


Nucleosynthesis pushed towards the proton drip-line through rapid proton capture reactions (rp)

When β-decay competes with proton capture: waiting point

(along the N=Z line ^{64}Ge, ^{68}Se, ^{72}Kr, ^{76}Sr)



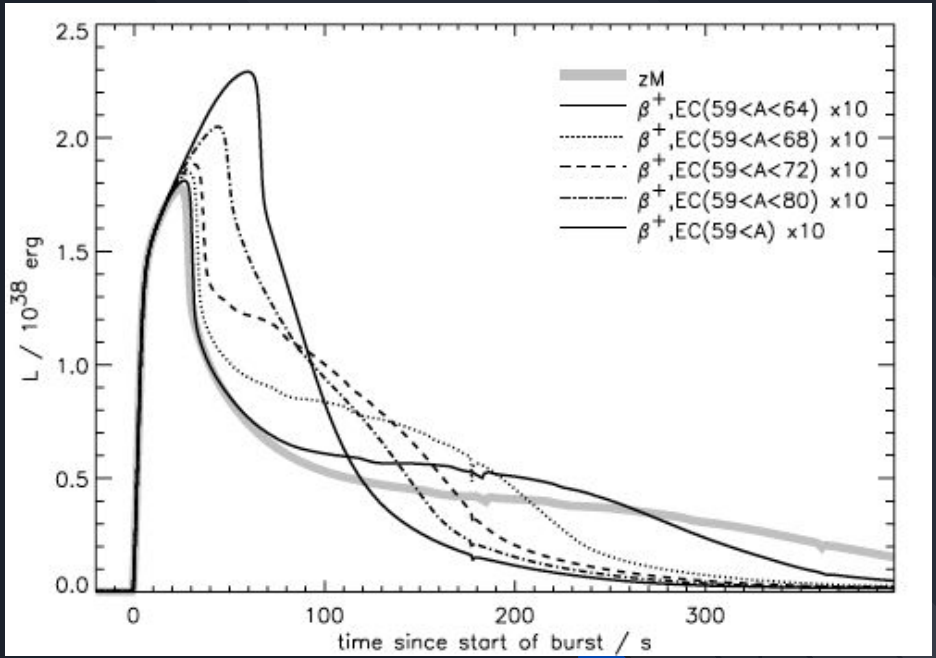

slow β decay
(waiting point)
Te (52)
Sb (51)
Sn (50)
In (49)
Cd (48)
Ag (47)
Pd (46)
Rh (45)
Ru (44)
Tc (43)
Mo (42)
Nb (41)
Zr (40)
Y (39)
Sr (38)
Rb (37)
Kr (36)
Br (35)
Se (34)
As (33)
Ge (32)
Ga (31)
104
80
76
72
68
64
abundance
Mass number
0
20
40
60
80
100
120

Physical observable:

- Luminosity curve
- No matter is released

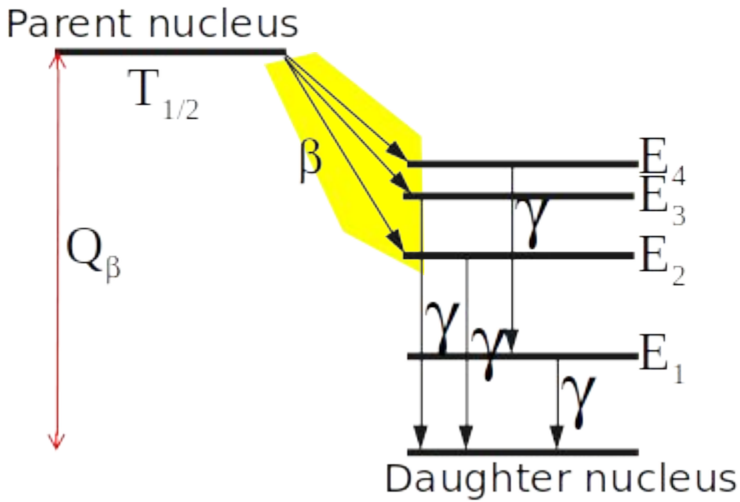
Network calculations:

- Decay and reaction rates
- 1300 isotopes included, e.g. in *Woosley et al. ApJS 151 (2004)*



What we measure in beta decay

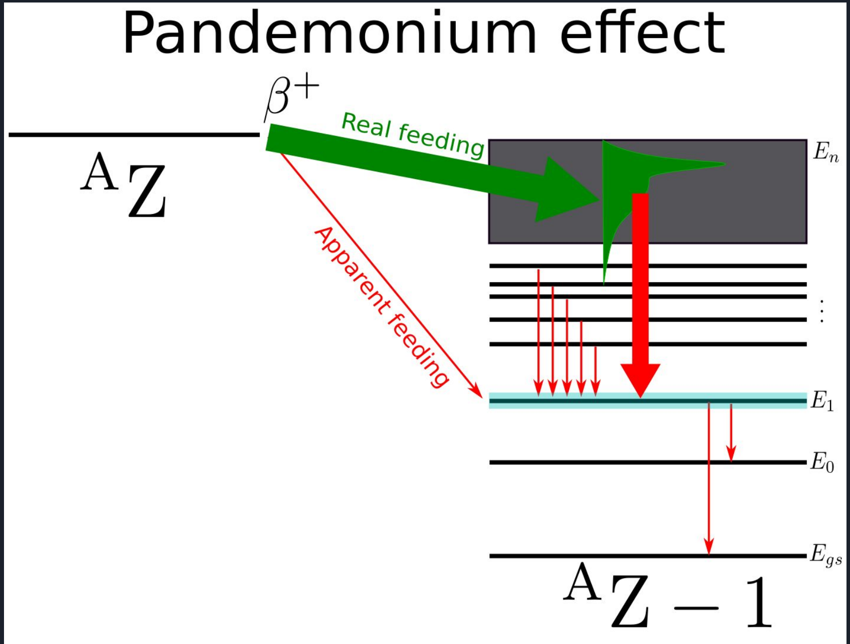
$$B(GT) = \left| \left\langle \phi_f \left| \sum_k \sigma_k \tau_k^{\pm} \right| \phi_i \right\rangle \right|^2 \equiv \left\langle \sigma\tau \right\rangle^2 \quad \leftrightarrows \quad S_\beta = \frac{I_\beta(E)}{f(Q_\beta - E)\, T_{1/2}}$$



We can estimate the feeding from gamma intensity balance.

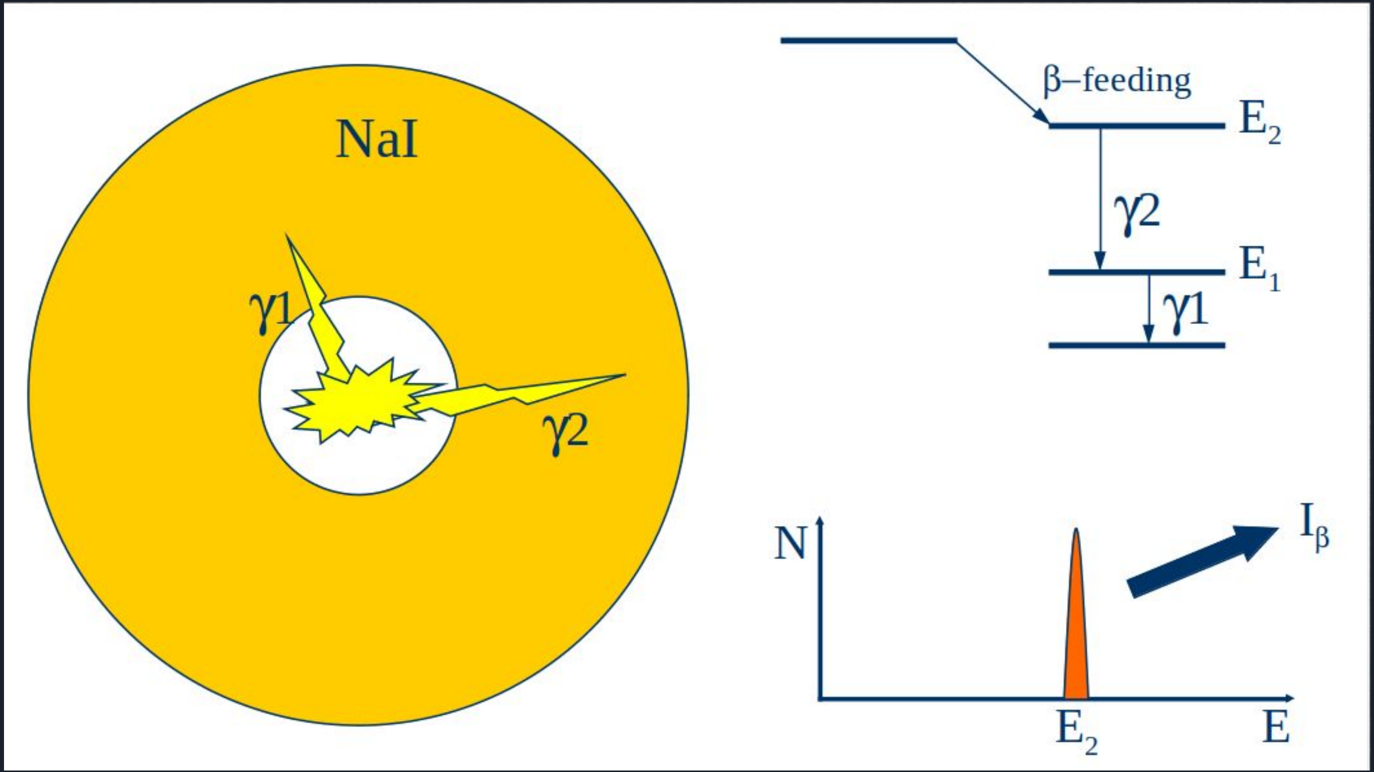
But this is only true for light isotopes, in general this is not so trivial, mainly because a phenomena called pandemonium

Pandemonium

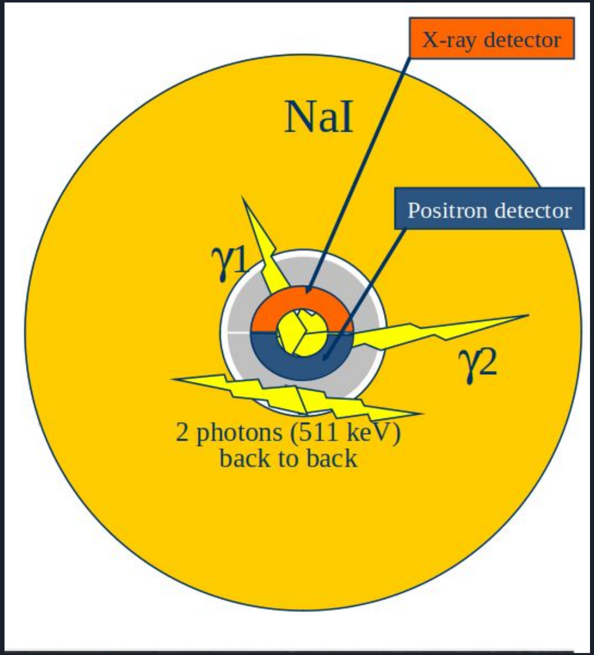


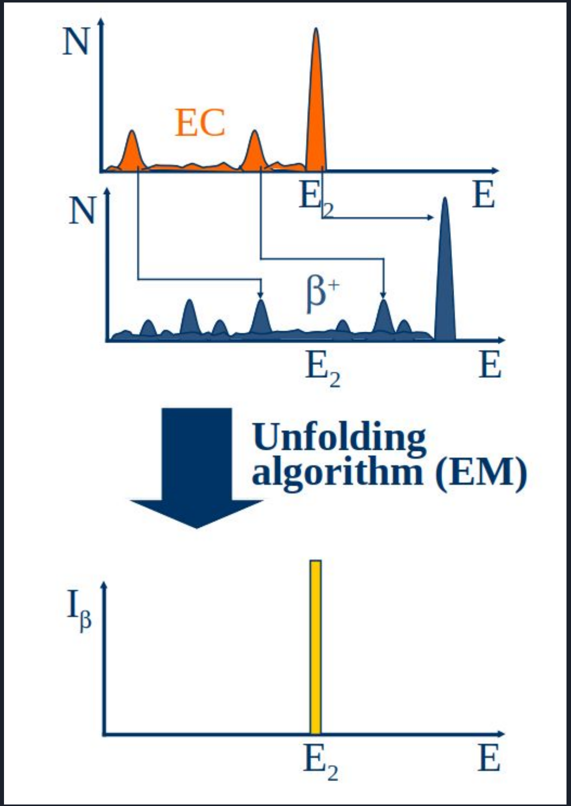
- Medium mass and heavy nuclei: large level density at high energy.
- Very fragmented β-feeding distribution and γ de-excitation pattern.
- HPGe arrays fail to detect systematically the upper part of the γ-cascade resulting in a wrong feeding and B(GT) distr.

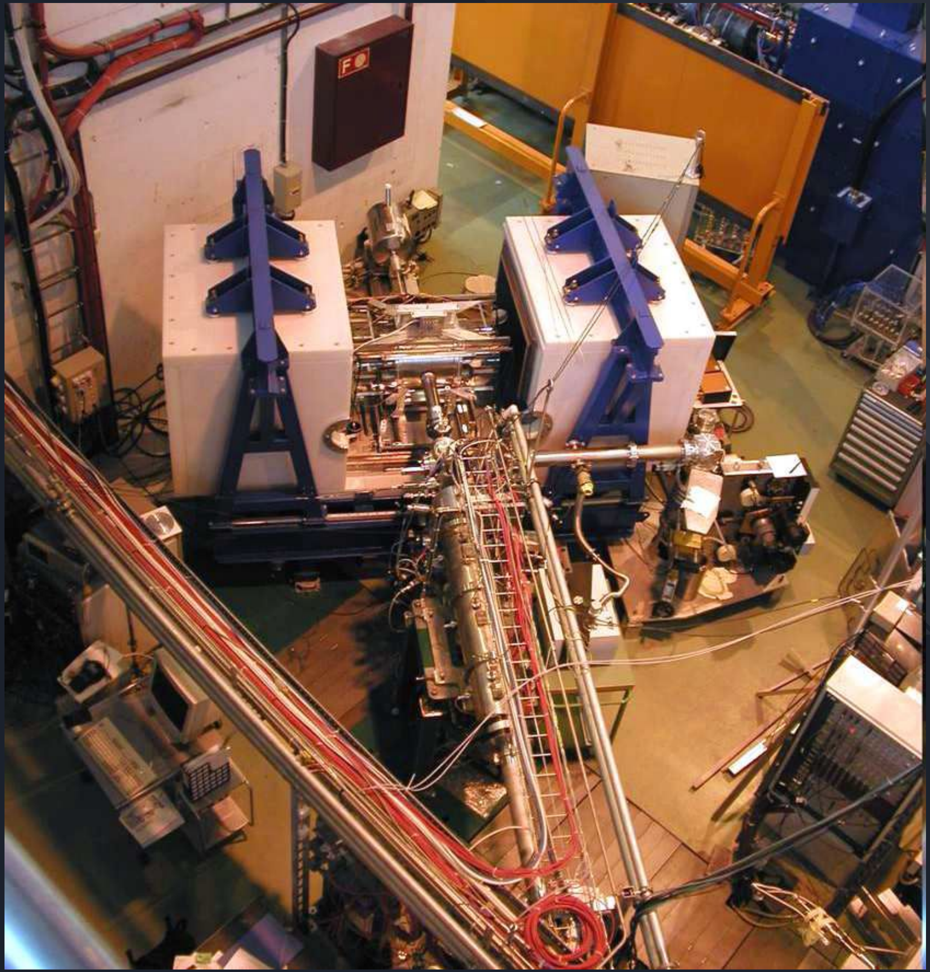
Total Absorption Spectroscopy (TAS)

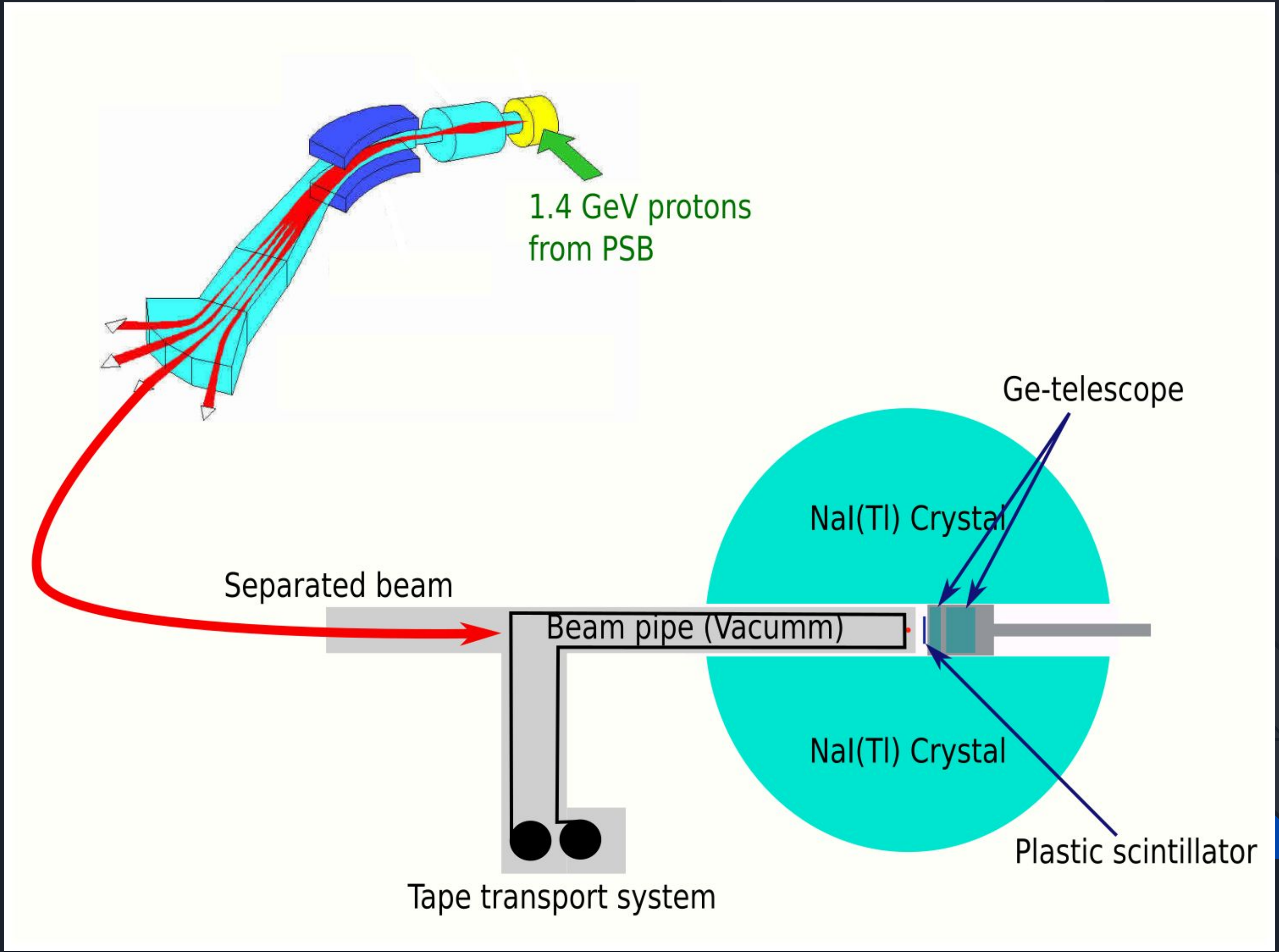


Total Absorption Spectroscopy (TAS)

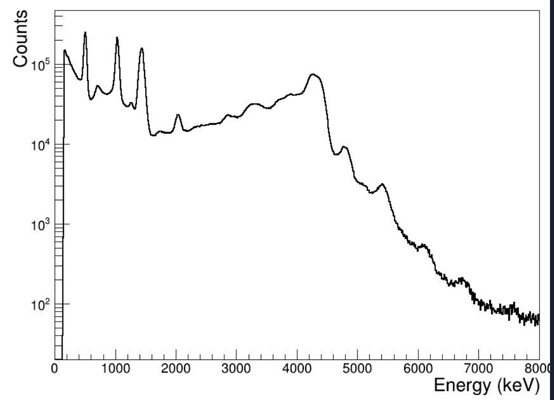


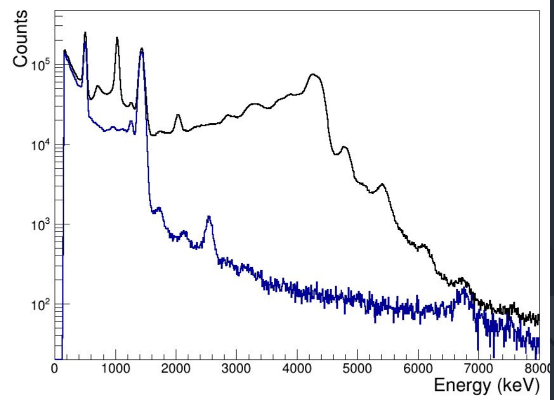


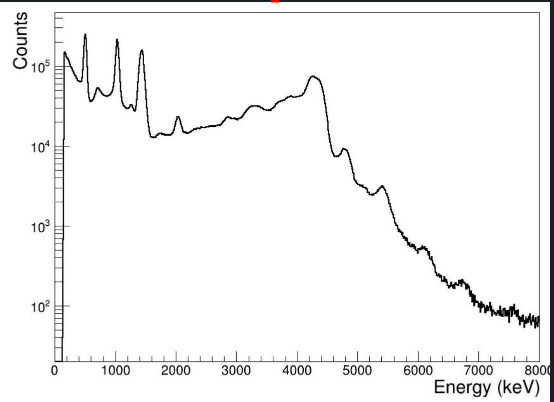



1.4 GeV protons
from PSB
Ge-telescope
NaI(Tl) Crystal
Separated beam
Beam pipe (Vacumm)
NaI(Tl) Crystal
Plastic scintillator
Tape transport system

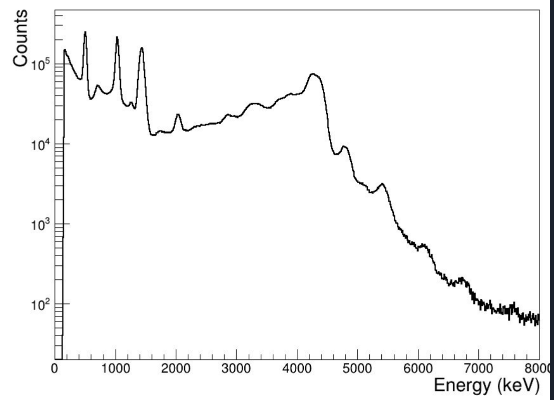
Measuring the Isotope of interest with the TAS method

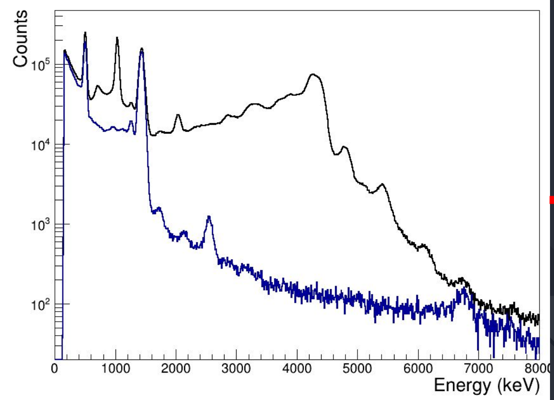


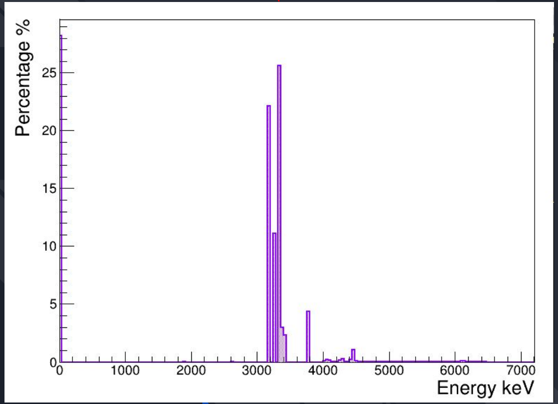




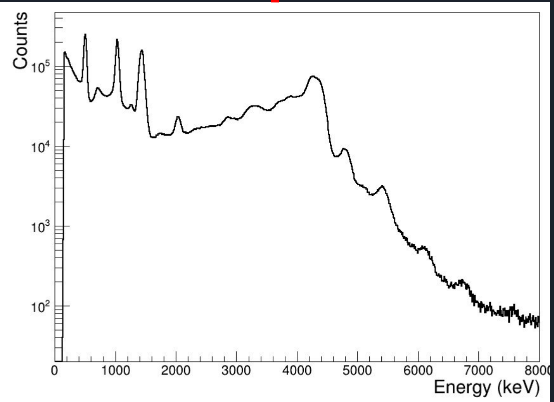
Then it must be identify every contaminant (background, pileup, daughters decay, etc)

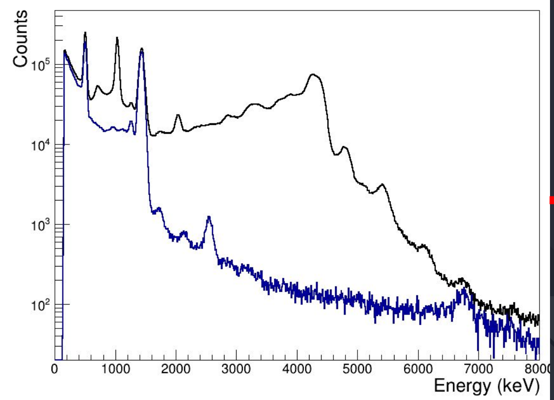




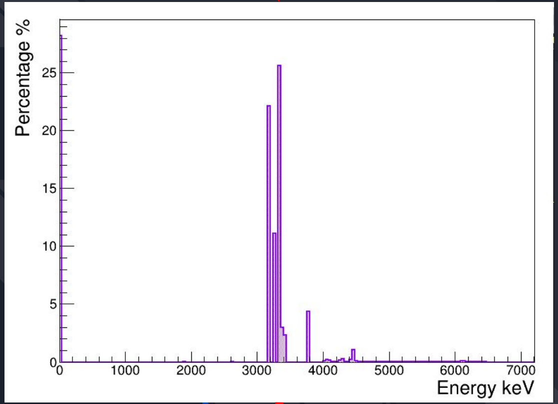


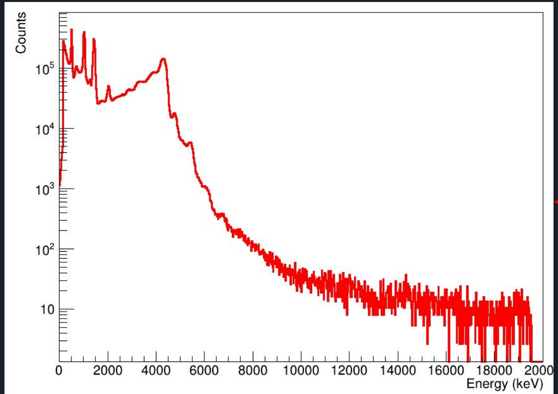
When everything in the gamma spectrum is well understood then is time for the unfolding algorithm (EM)





Finally with the new feeding by the unfolding algorithm we can recalculated a new gamma spectrum and compare with the TAS data

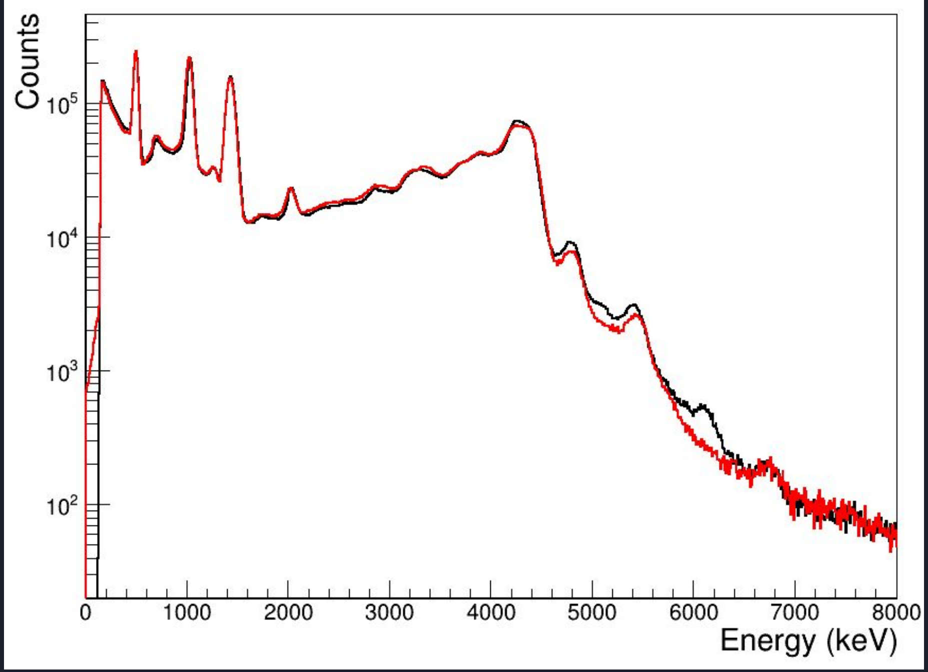




Preliminary results

- 64Ga

- virtually perfect fit until 4.5 MeV excitation energy
- unfit resonance by ENSDF data at ~6 MeV

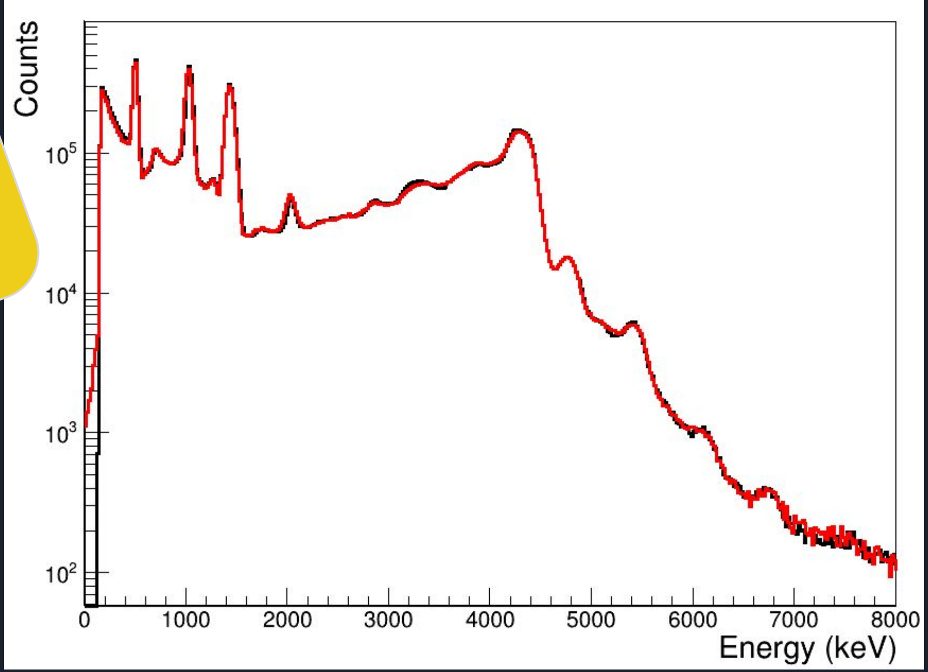


Preliminary results

- 64Ga

- virtually n…
  4.5…

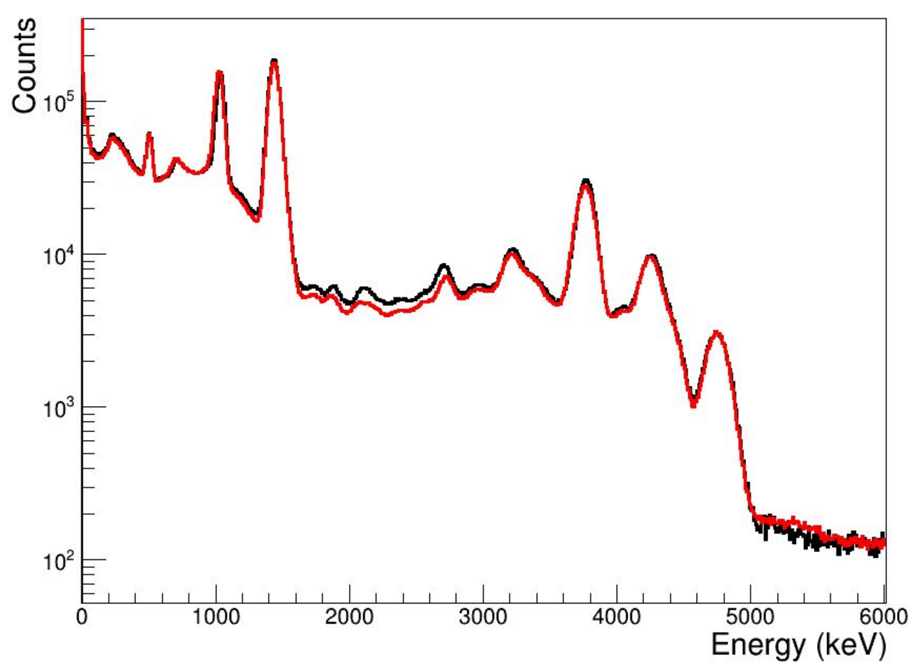
through deconvolution we obtain a recalculated spectrum that have the peak at ~6 MeV!



Preliminary results

- 66Ga

- virtually perfect fit but in the region 1800 keV to 3000 keV

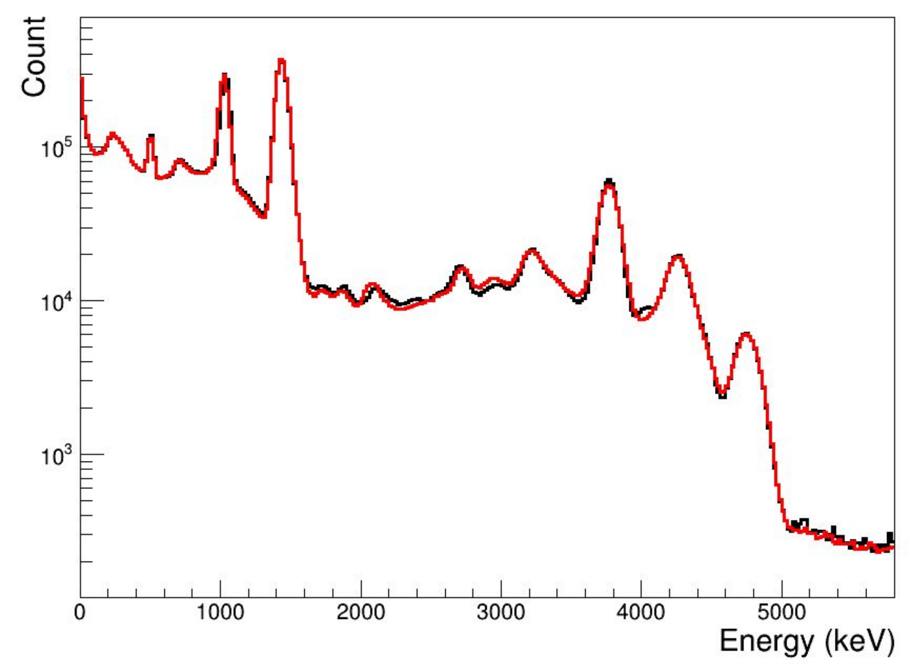


Preliminary results

- 66Ga

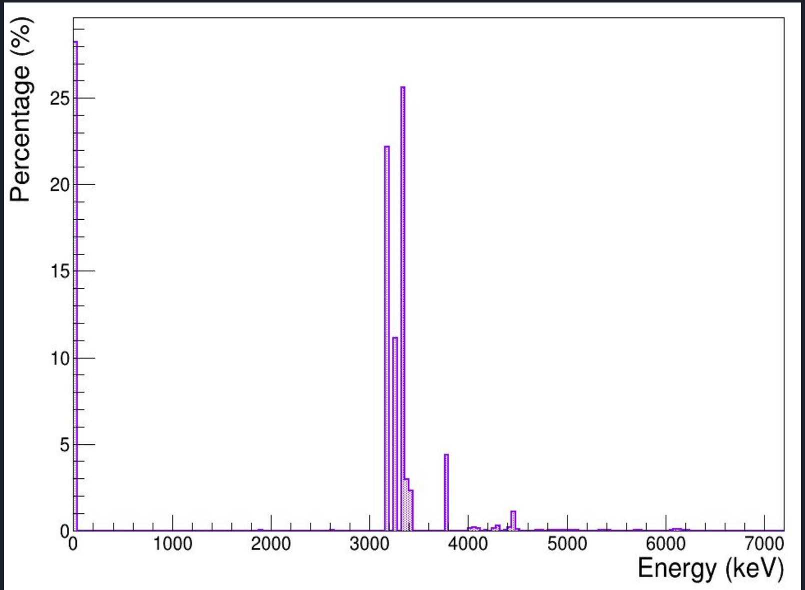
- virtu

better fit in the region of 1800 keV to 3000 keV

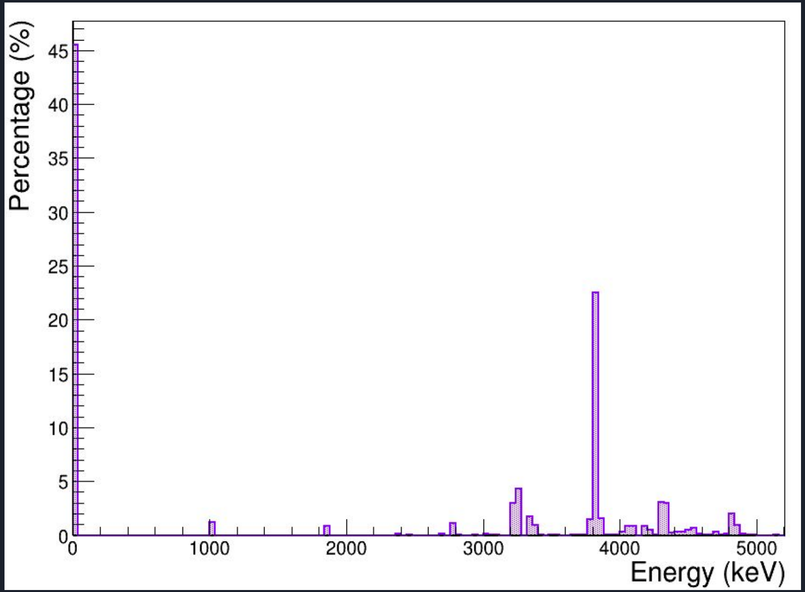


Preliminary results
Feeding

64Ga

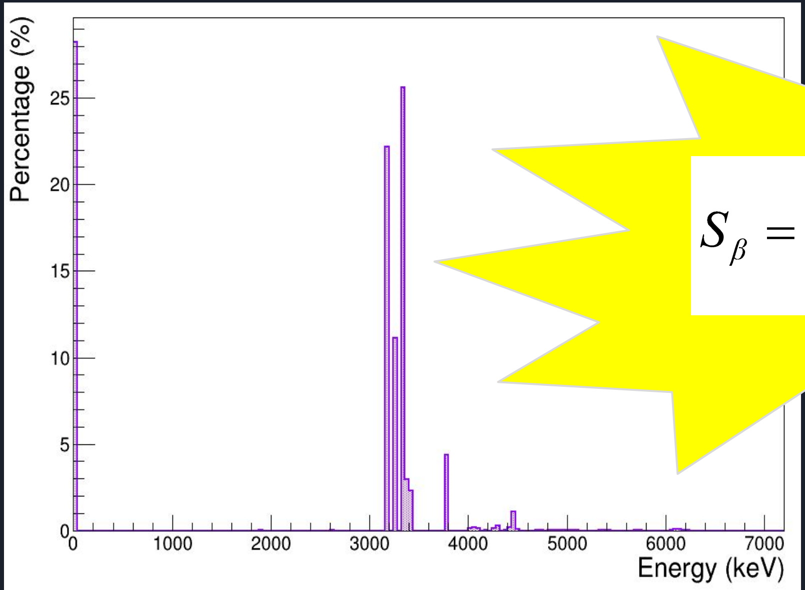


66Ga

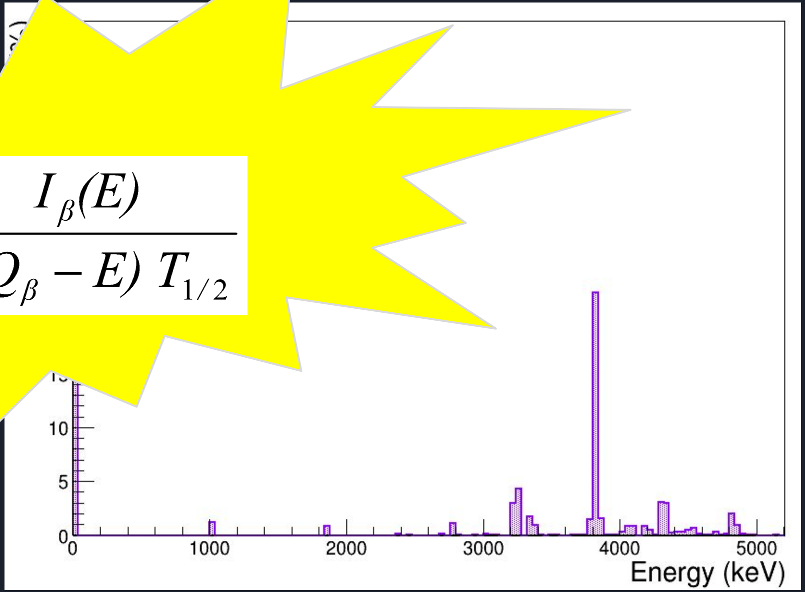


Preliminary results
Feeding

64Ga



66Ga



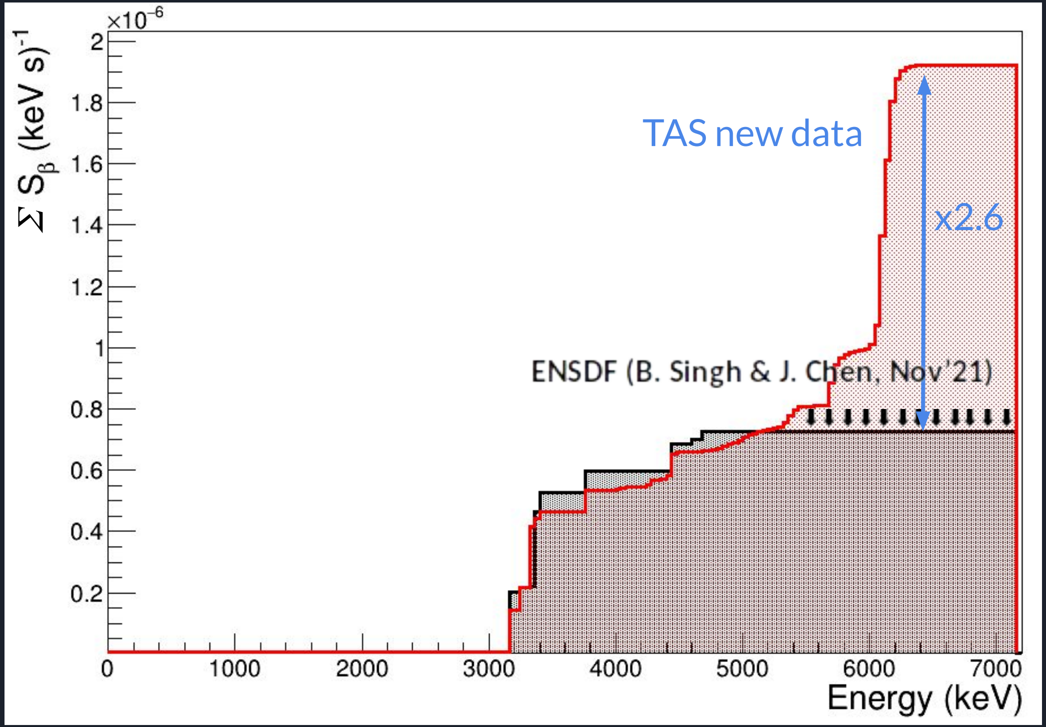
$$S_\beta = \frac{I_\beta(E)}{f(Q_\beta - E)\; T_{1/2}}$$

Preliminary results

- 64Ga S_β

- We manage to detect feeding previously unknown

- With this new feeding distribution we also have a new feeding to the fundamental level, This is a Isotope with Isospin Mixing so this change in the fundamental feeding also affect the calculus for the Isospin Mixing

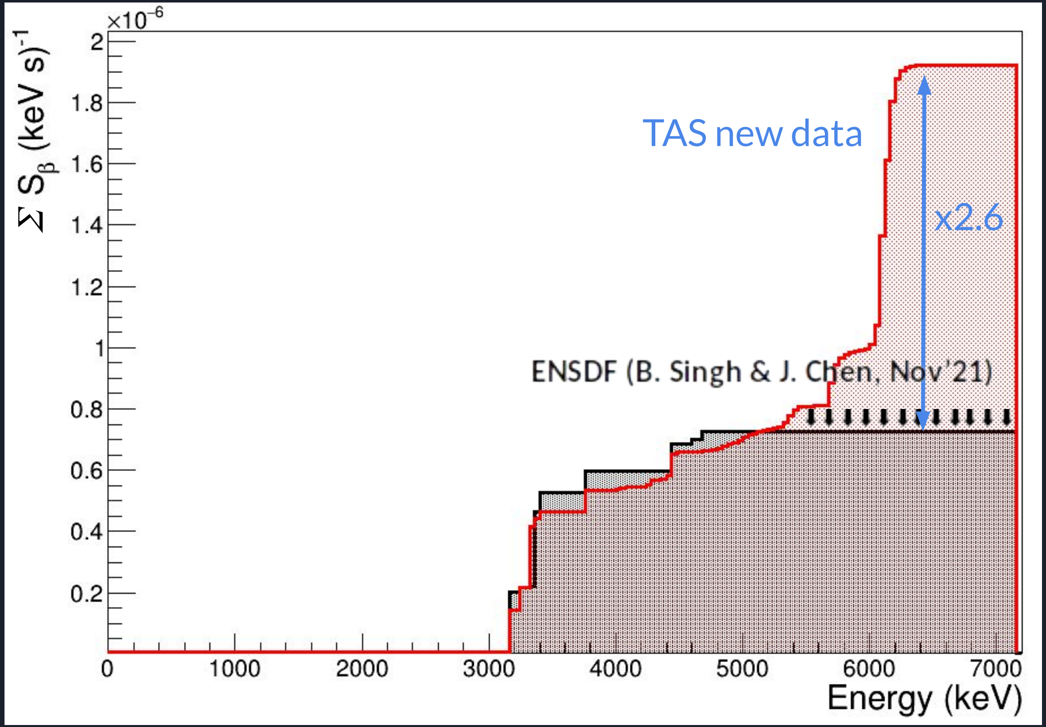


Preliminary results

- 64Ga S_β

Decay from 0+ to 0+ gs

	TAS	ENSDF
feeding	28.2 %	24.7 %
log ft	6.59	6.65



Preliminary results

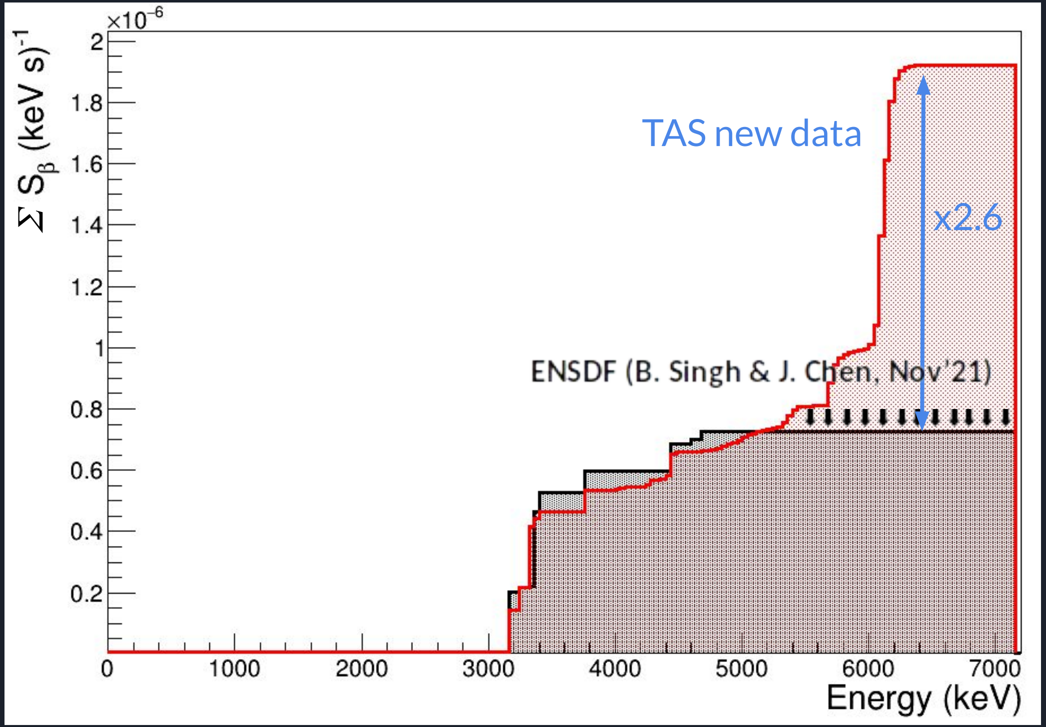
- 64Ga S_β

$$M_F = \sqrt{\frac{2ft(\text{superallowed})}{ft(\text{case under study})}}$$

$$\alpha = M_F/\sqrt{2T}$$

$$H_c = \alpha \cdot (\Delta E_c - Q - 782)$$

- Raman S. et al, Nucl. Phys, A254 (1975), 131



Values for Coulomb displacement energy from Antony, M., Pape, A., & Britz, J. Atomic Data and Nuclear Data Tables, (1997) 66(1), 1–63

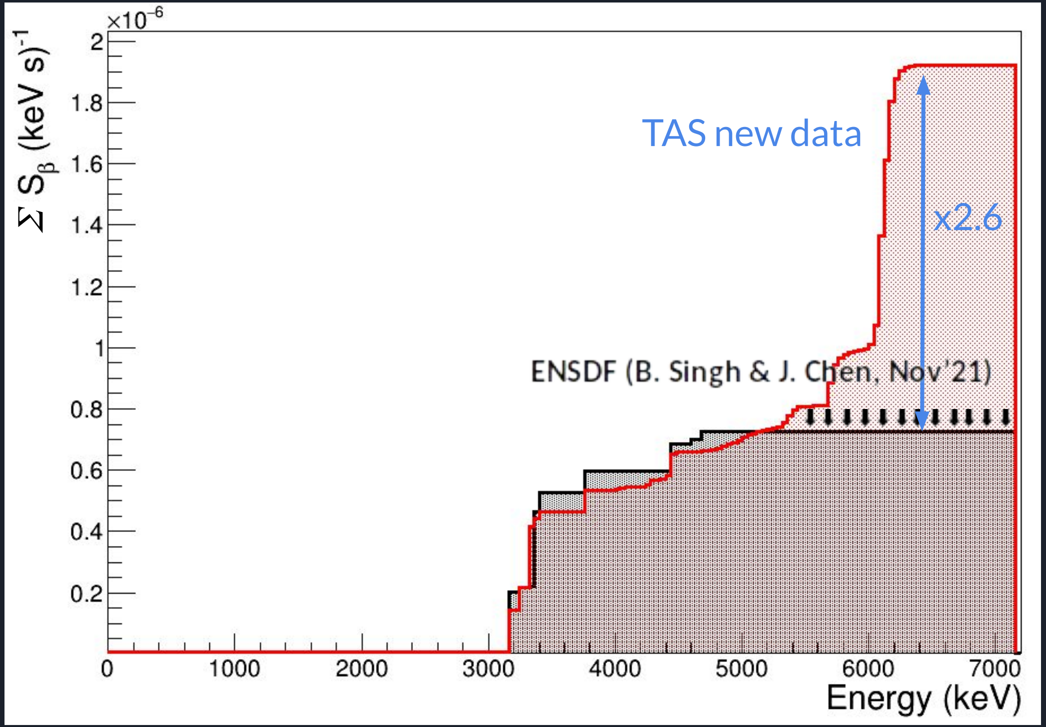
and super allowed ft from Hardy, J. C., & Towner, I. S. Physical Review C, (2020) 102(4).

Preliminary results

- 64Ga S_β

Decay from 0+ to 0+ gs

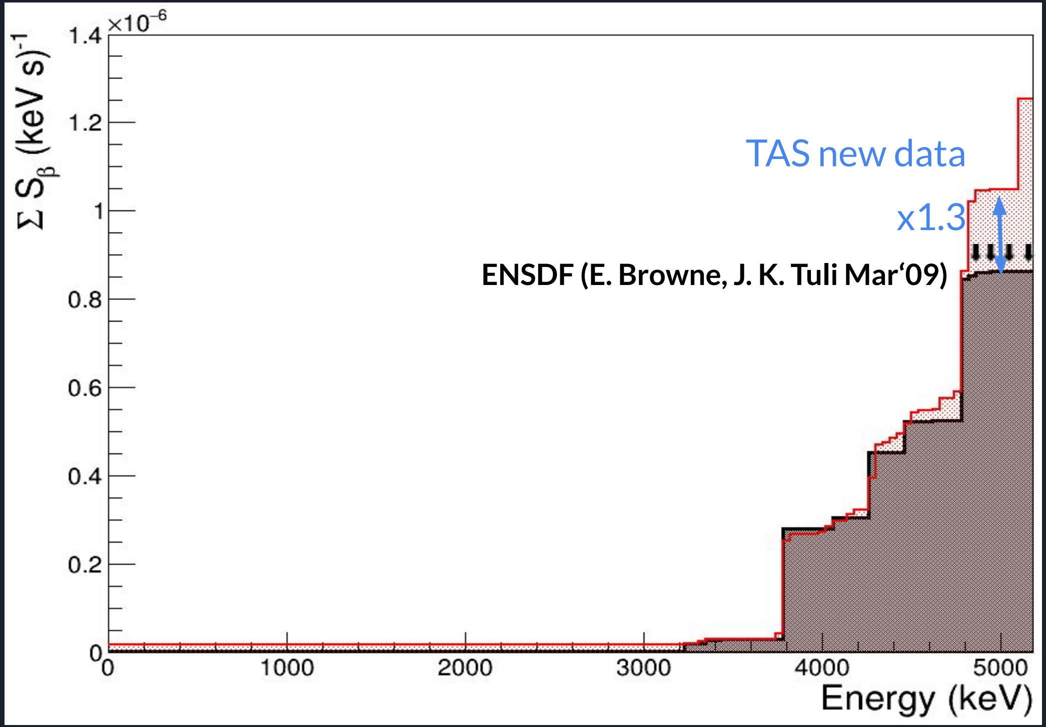
	TAS	Reported
α (10^{-3})	19.85	19.5
Hc (keV)	37.30	39.6



- Bertsch, G.F. and Mekjian, A. (1972) "Isospin impurities in nuclei," *Annual Review of Nuclear Science*, 22(1), pp. 25–64.

Preliminary results

- 66Ga S_β



- We observe a higher contribution at around 5 MeV that wasn't obvious from the gamma spectrum

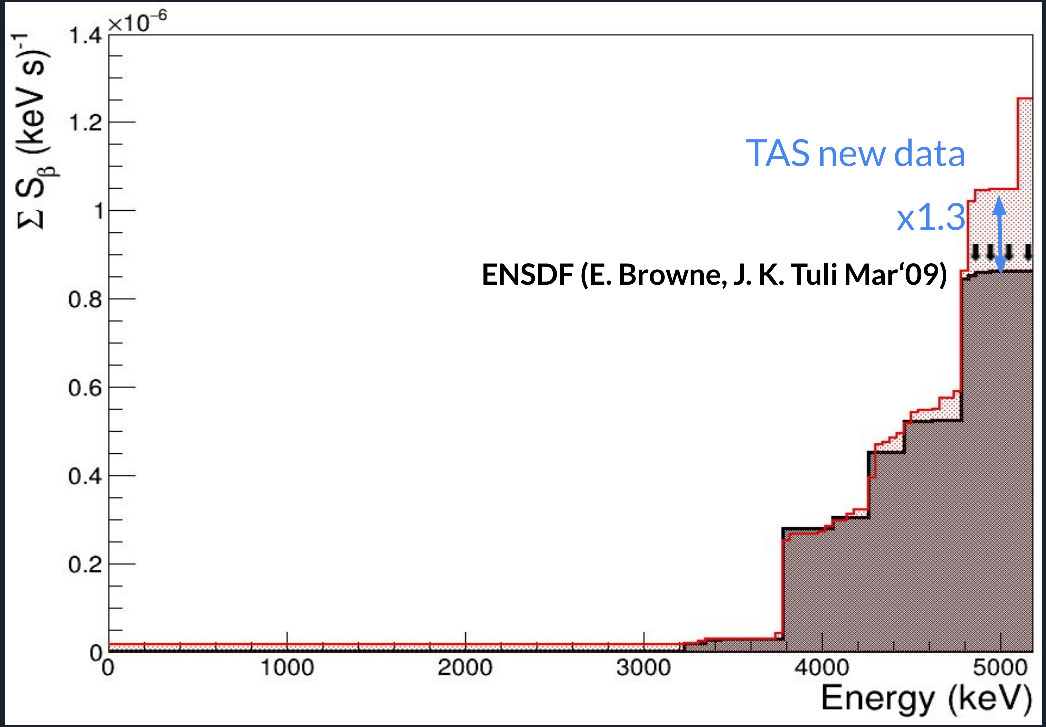
- There is also a change in the feeding to the fundamental level, this Isotope also have Isospin mixing so this is

Preliminary results

- 66Ga S_β

Decay from 0+ to 0+ gs

	TAS	ENSDF
feeding	45.5 %	51 %
log ft	7.93	7.88

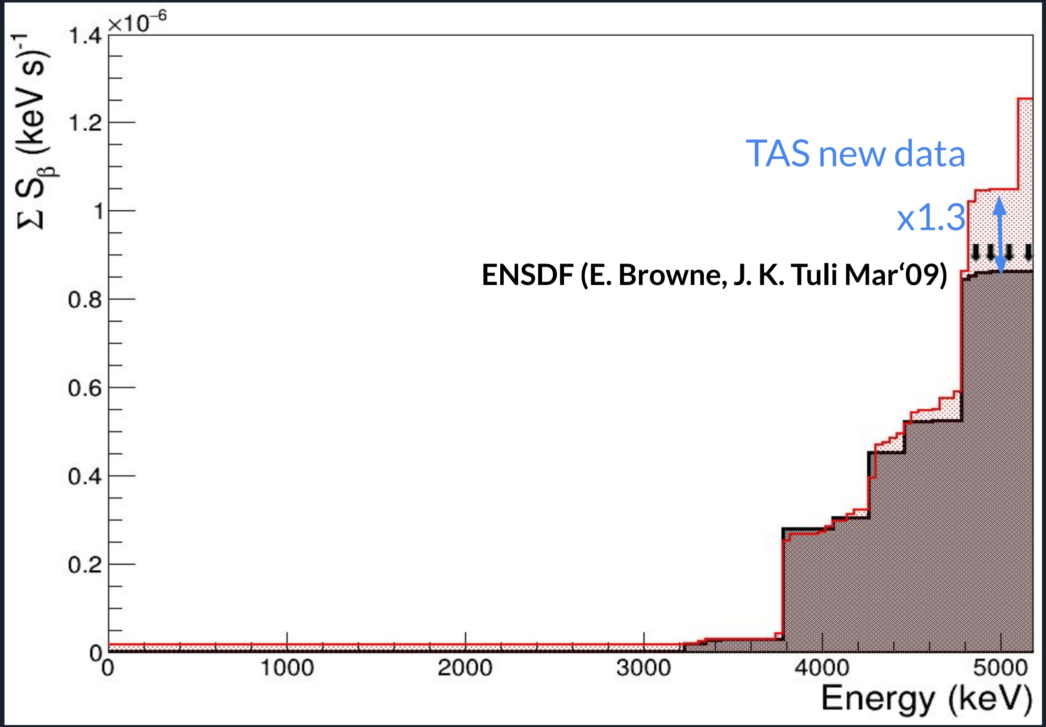


Preliminary results

- 66Ga S_β

Decay from 0+ to 0+ gs

	TAS	Reported
α (10^{-3})	3.5	3.5
Hc (keV)	13.3	13.6



- Bertsch, G.F. and Mekjian, A. (1972) "Isospin impurities in nuclei," *Annual Review of Nuclear Science*, 22(1), pp. 25–64.

Conclusions

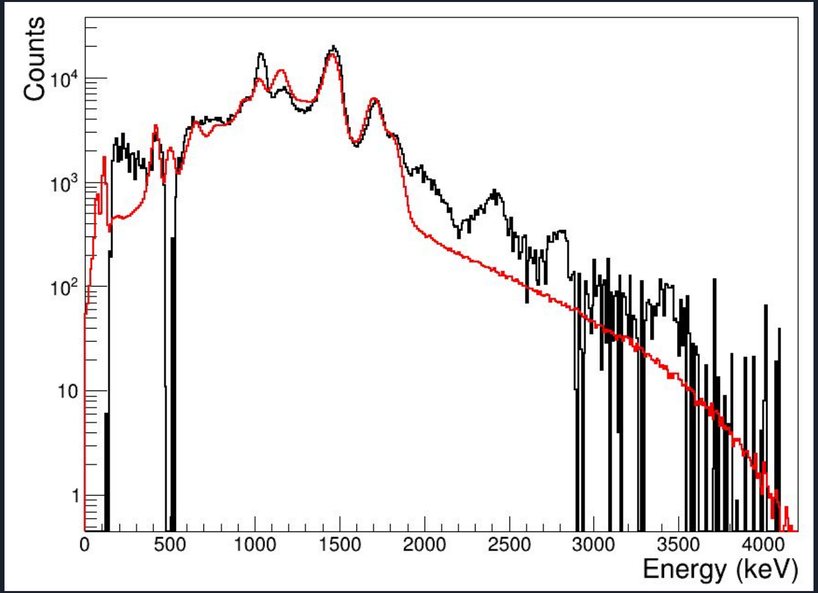
- Astrophysical network calculations rely quite often on theoretical predictions that must be constrained. For this the T1/2 is not enough in general and the B(GT) must be used

- We have measured the B(GT) in the β-decay around the N=Z region for their importance in the weak-decay rates for astrophysical processes. 64,66Ge under analysis and 64,66Ga with preliminary results

- Since we can provide an overall a better estimation of the β-feeding we can give a better estimation of the Isospin mixing in this Isotopes

Future work

64Ge



64Ge already clean, and ready for analysis

65-66Ge Are next to be analyzed