Beta decay of $^{66-64}$Ge and $^{66-64}$Ga: Total Absorption Spectroscopy

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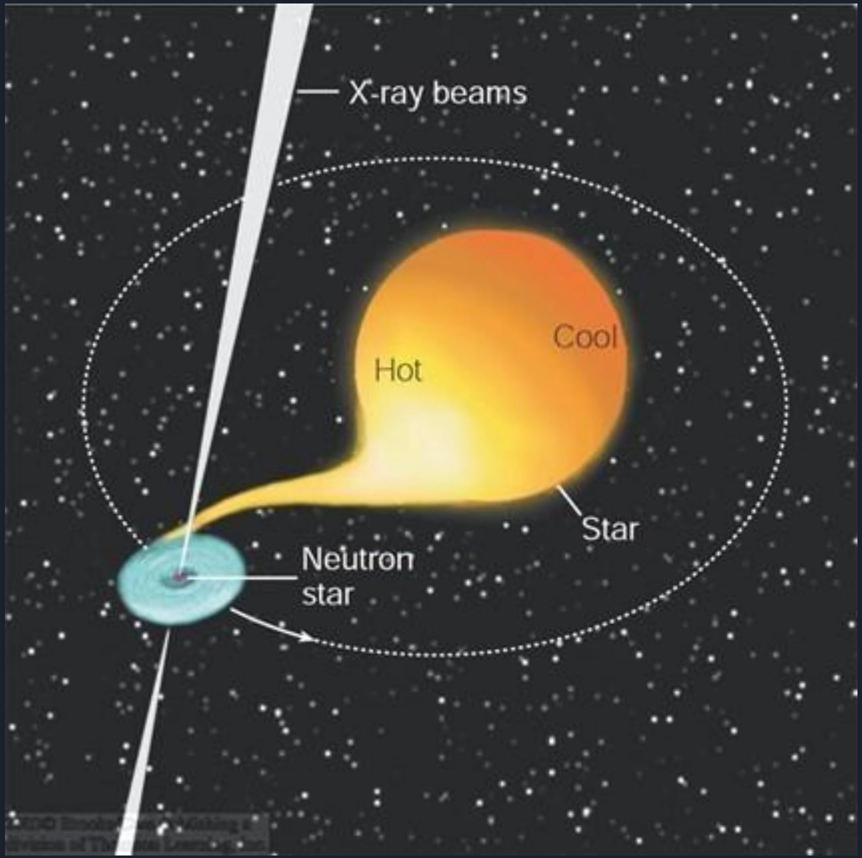
Type I x-ray bursts

- 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

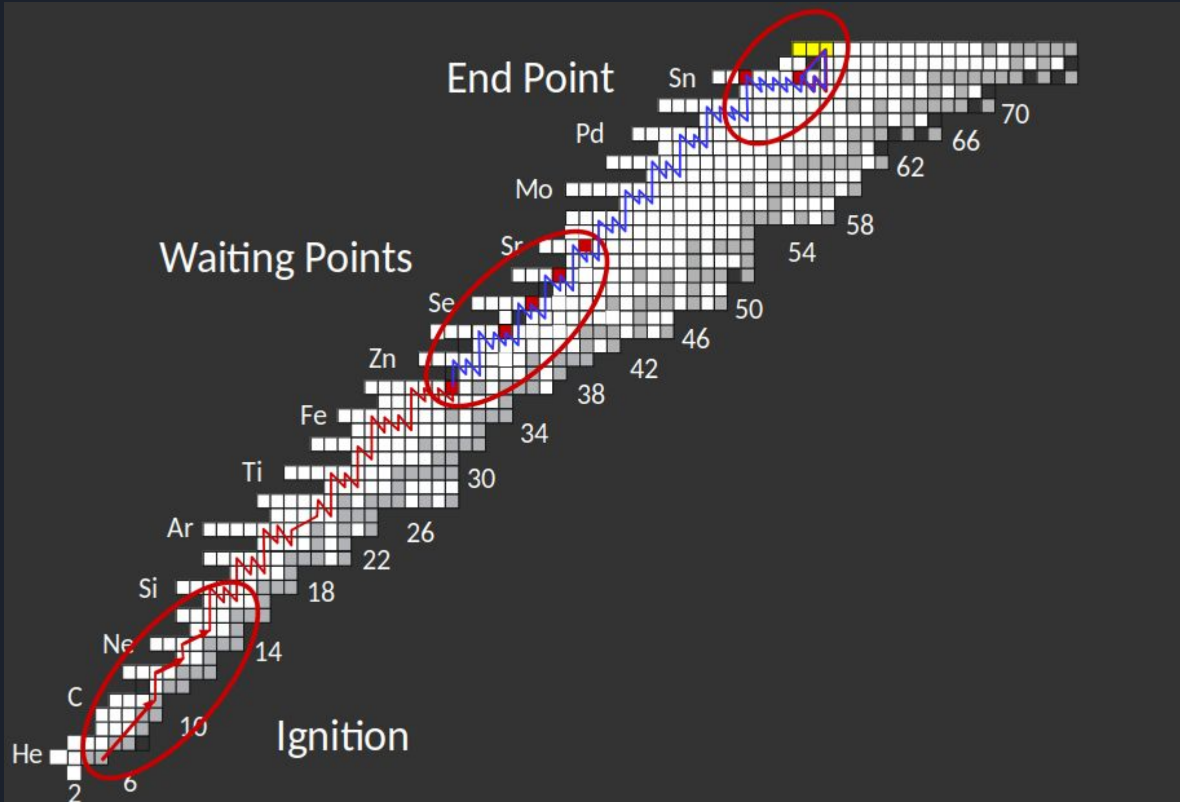
$T_{peak} = 1 – 3$ GK and $\rho = 10^6 – 10^7$ g cm^{-3}

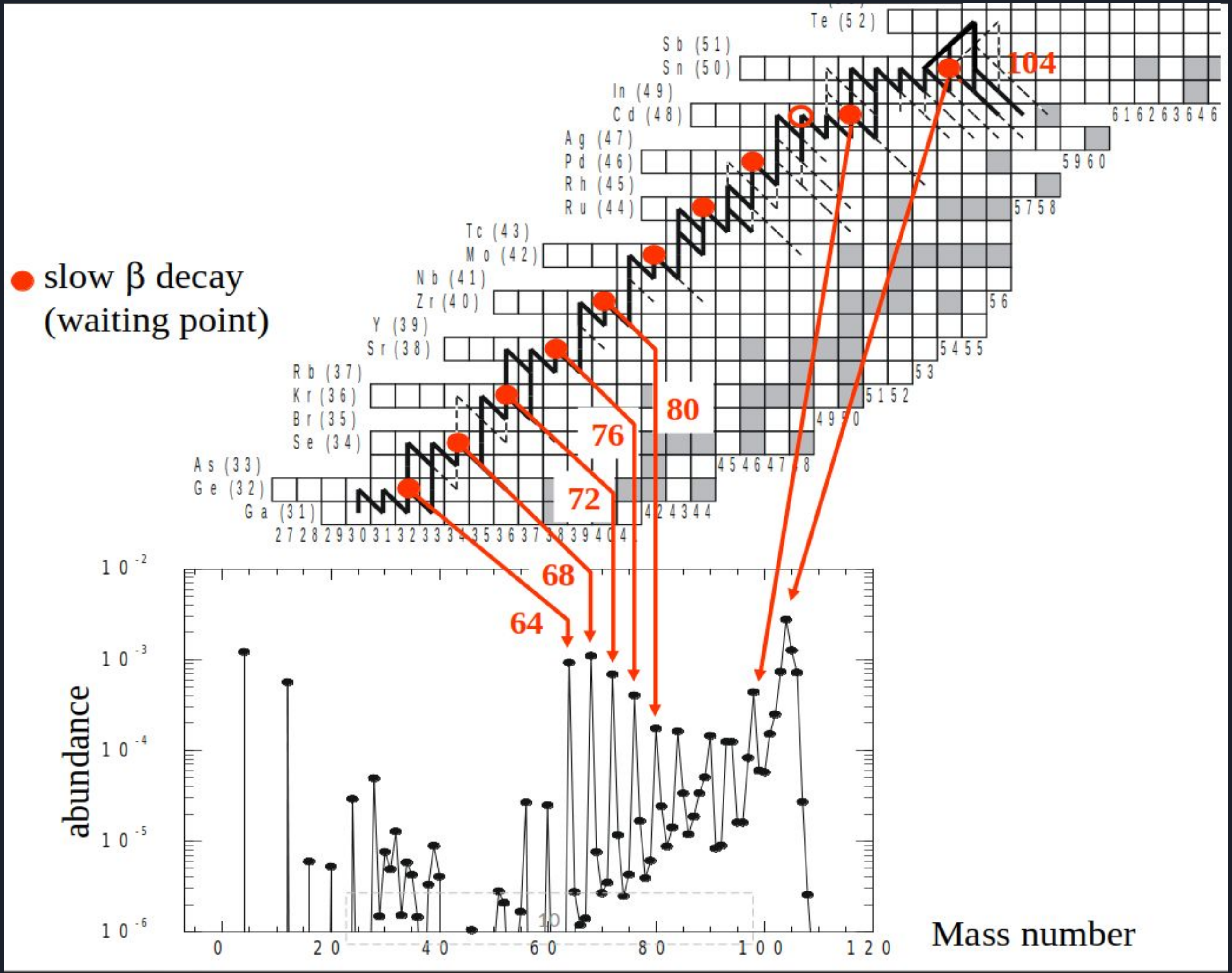


Nucleosynthesis pushed towards the proton drip-line through rapid proton capture reactions (rp)

When β-decay competes with proton capture: waiting point

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

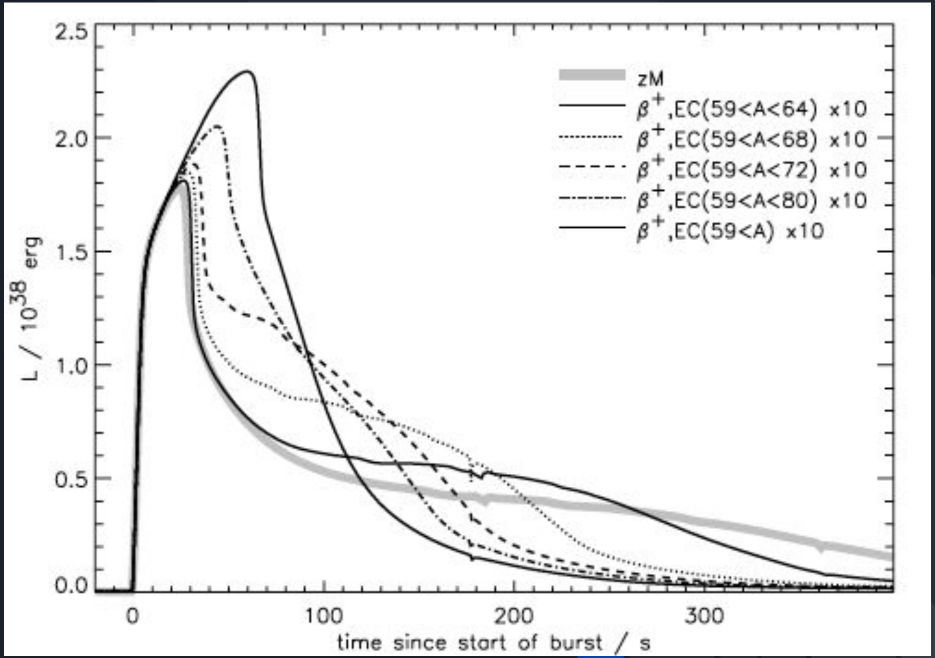




slow β decay
(waiting point)
Te (52)
Sb (51)
Sn (50)
In (49)
Cd (48)
Ag (47)
Pd (46)
Rh (45)
Ru (44)
Tc (43)
Mo (42)
Nb (41)
Zr (40)
Y (39)
Sr (38)
Rb (37)
Kr (36)
Br (35)
Se (34)
As (33)
Ge (32)
Ga (31)
104
80
76
72
68
64
abundance
Mass number

Physical observable:

- Luminosity curve
- No matter is released

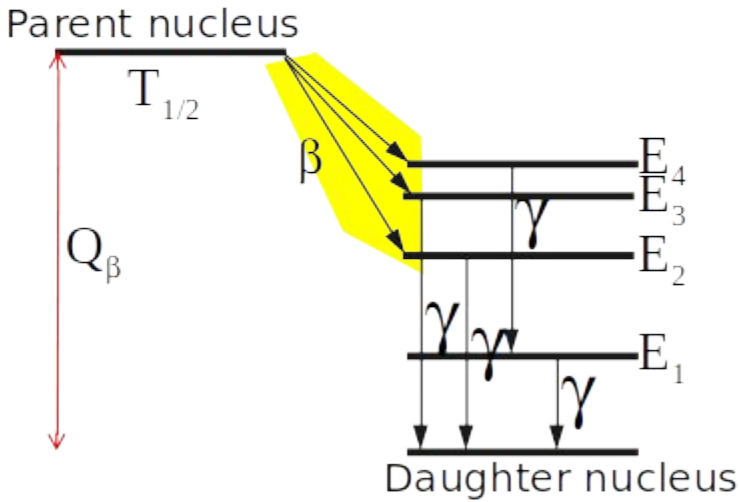


Network calculations:

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

What we measure in beta decay

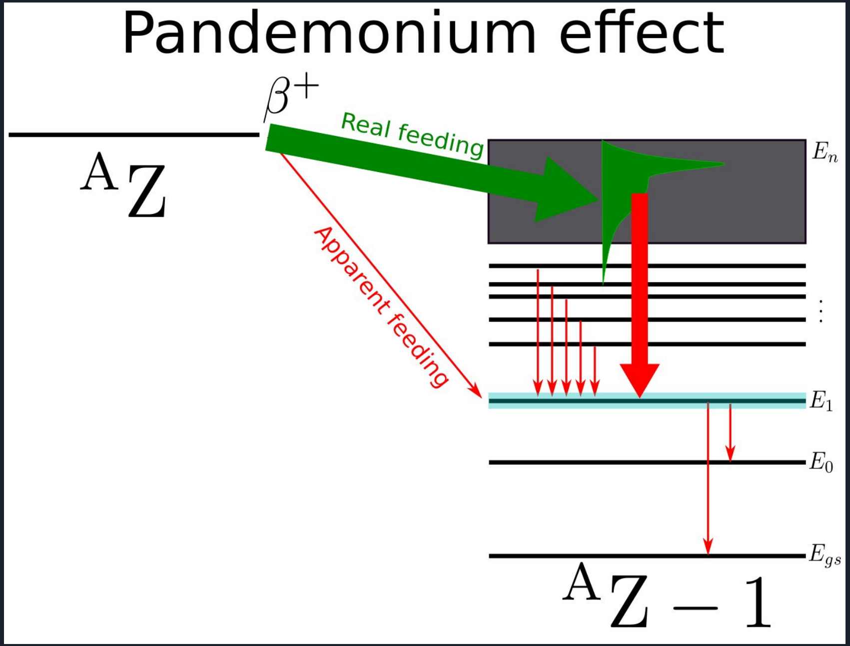
$$B(GT) = \left| \langle \phi_f | \sum_k \sigma_k \tau_k^{\pm} | \phi_i \rangle \right|^2 \equiv \langle \sigma\tau \rangle^2 \leftrightarrows S_\beta = \frac{I_\beta(E)}{f(Q_\beta - E)\, T_{1/2}}$$



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.

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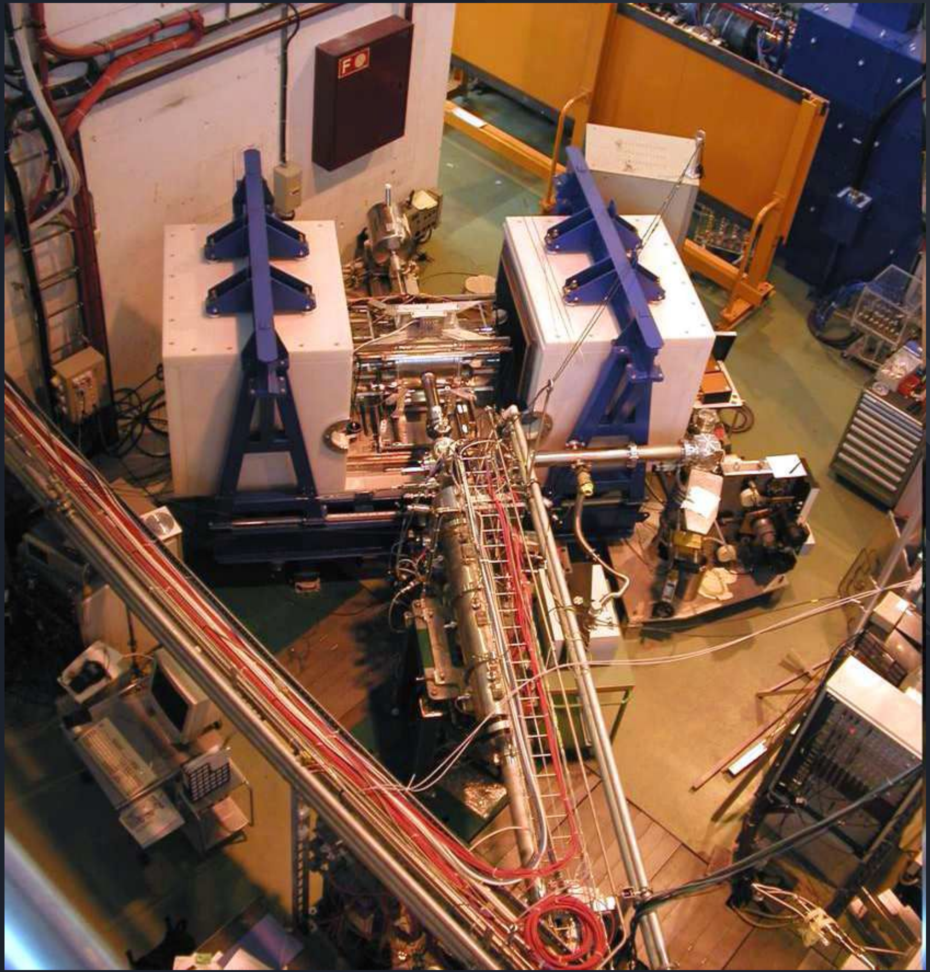
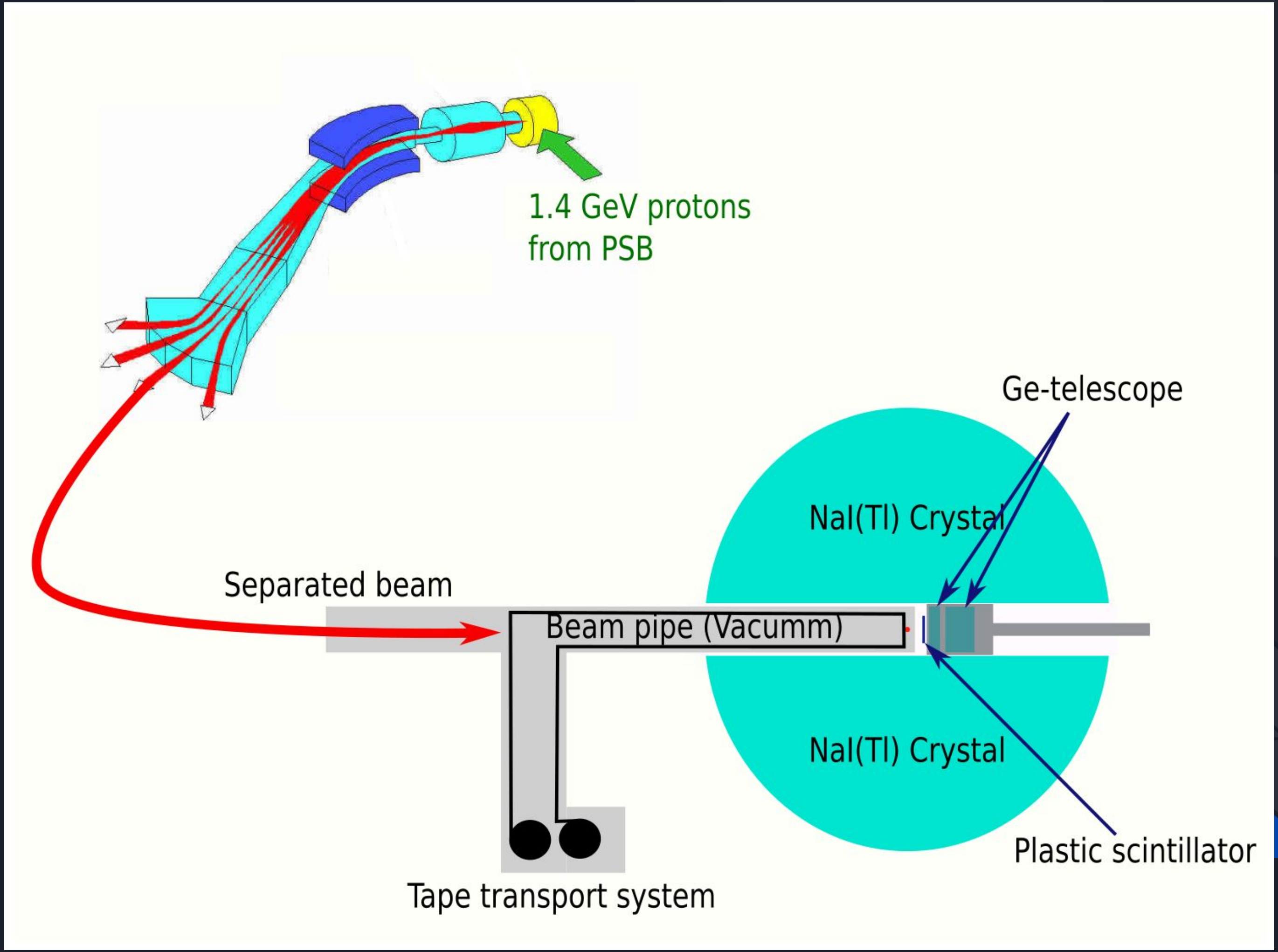
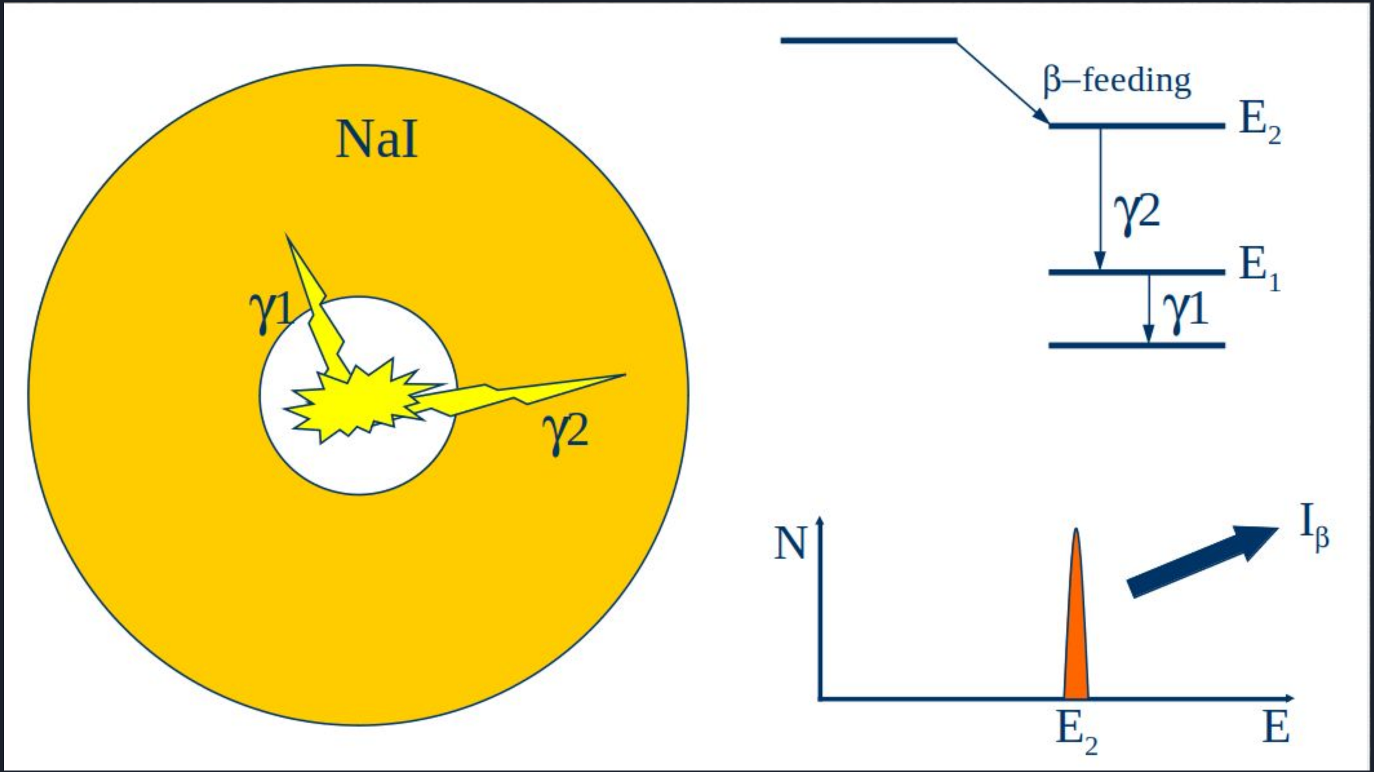
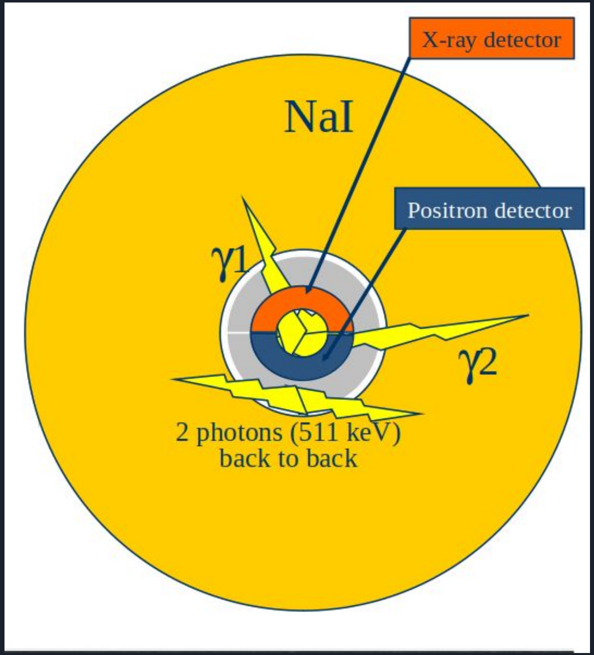


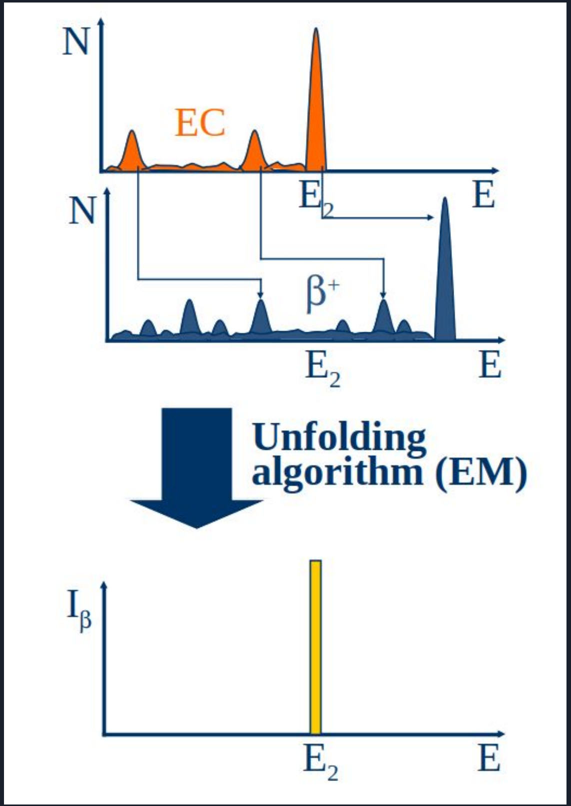

1.4 GeV protons
from PSB
Ge-telescope
NaI(Tl) Crystal
Separated beam
Beam pipe (Vacumm)
NaI(Tl) Crystal
Plastic scintillator
Tape transport system

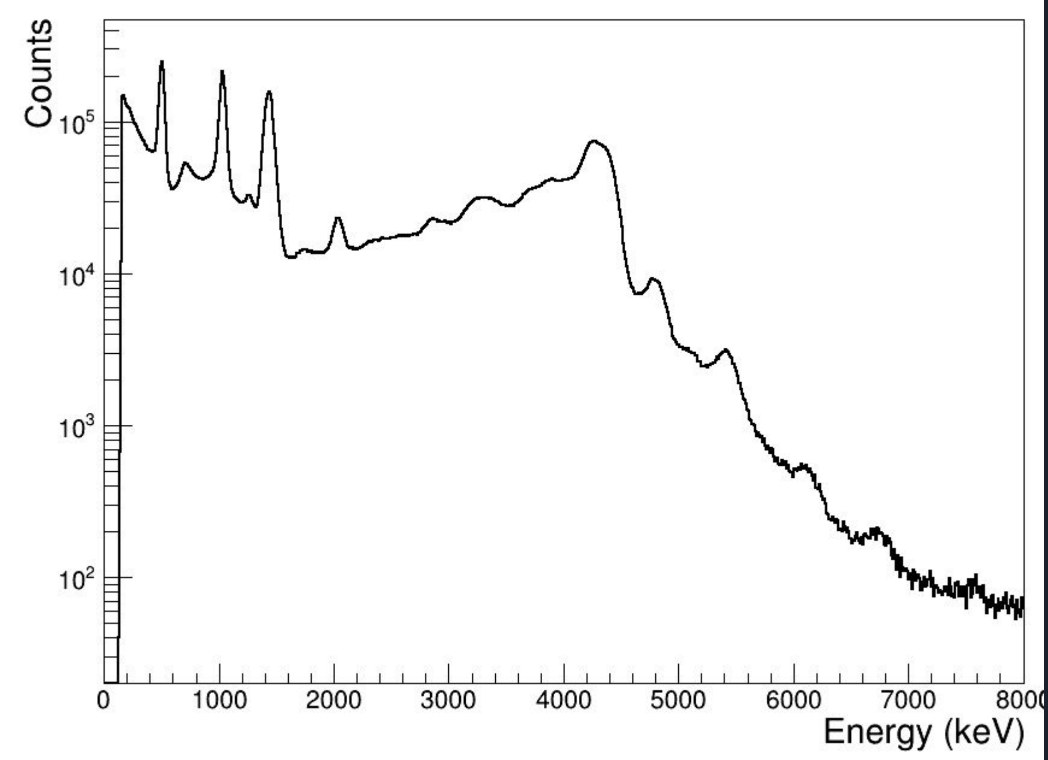
Total Absorption Spectroscopy (TAS)



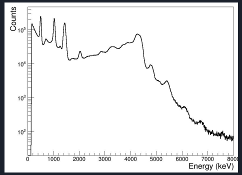
Total Absorption Spectroscopy (TAS)

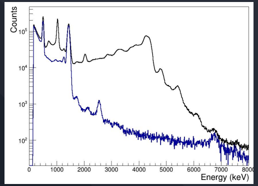


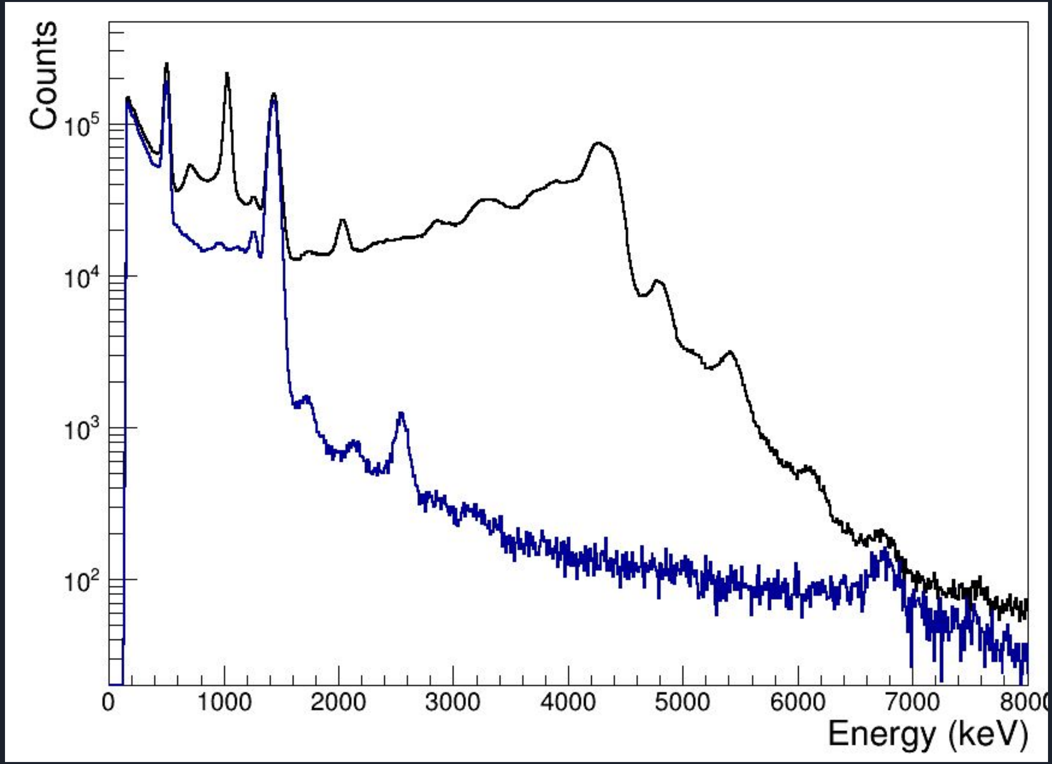




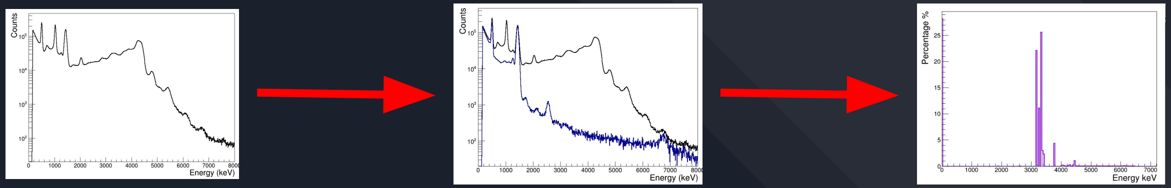
Measuring the Isotope of interest with the TAS method

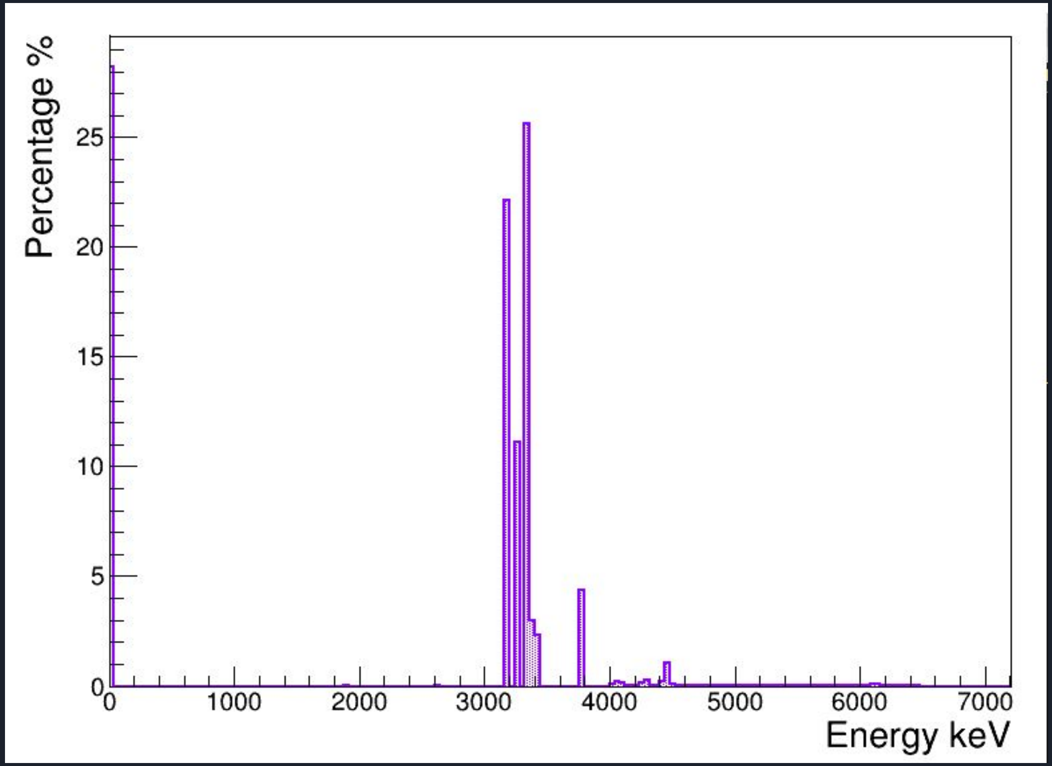




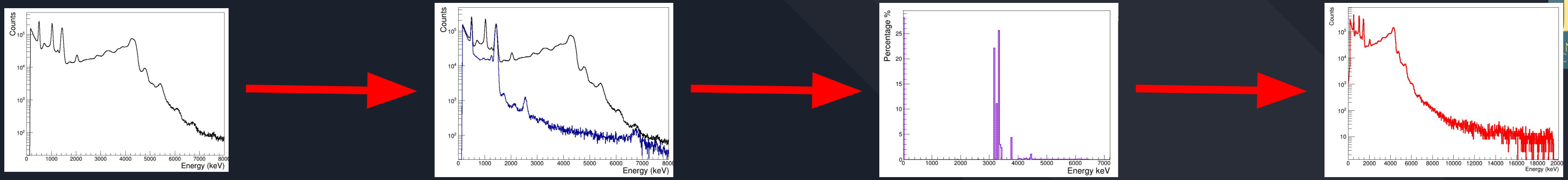


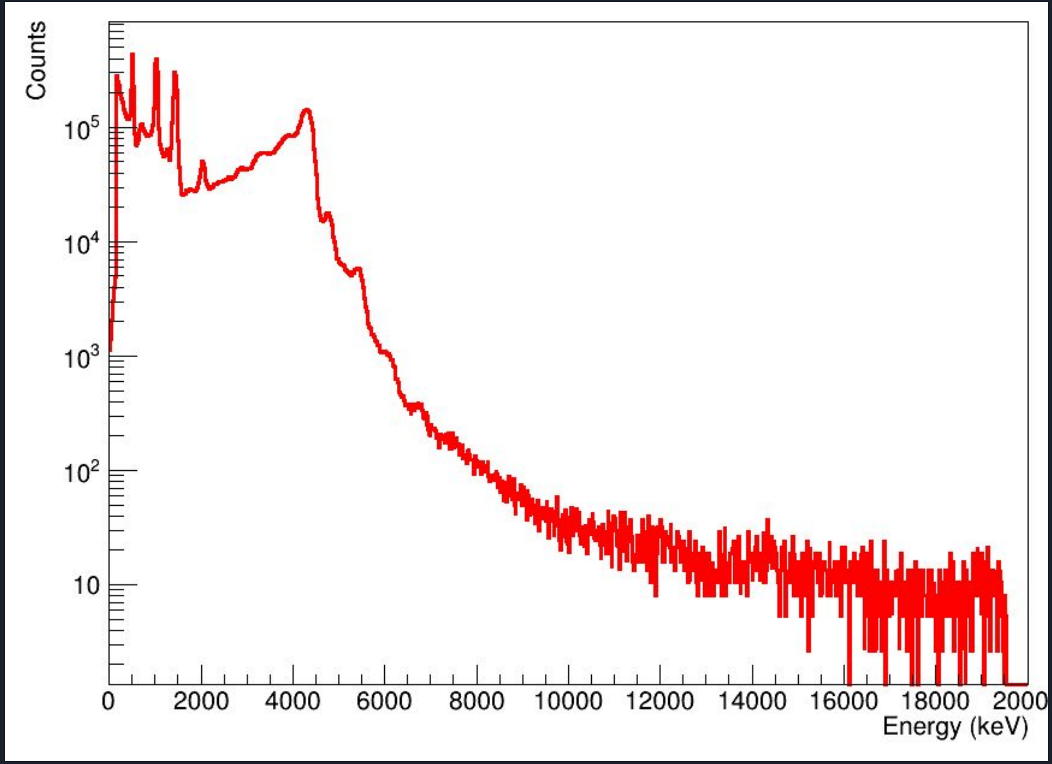
Then it must be identify every contaminant (background, pileup, daughter’s decay, etc)





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





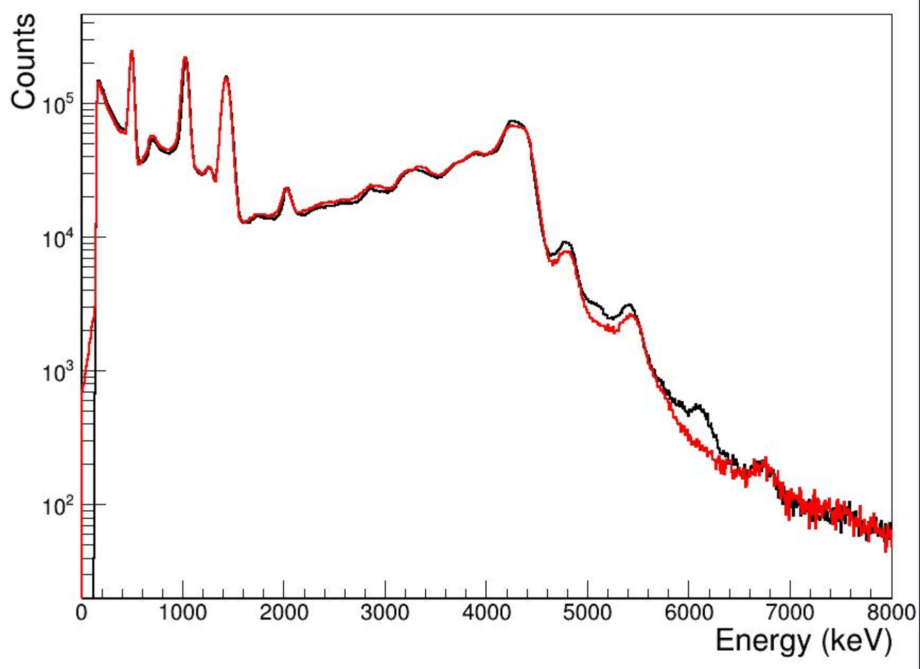
Finally with the new feeding by the unfolding algorithm we can recalculated a new gamma spectrum and compare with the TAS data

Preliminary results

- ^{64}Ga

- A very good fit with ENSDF data until 4500 keV

- a peak at ~6000 keV not present in the ENSDF data

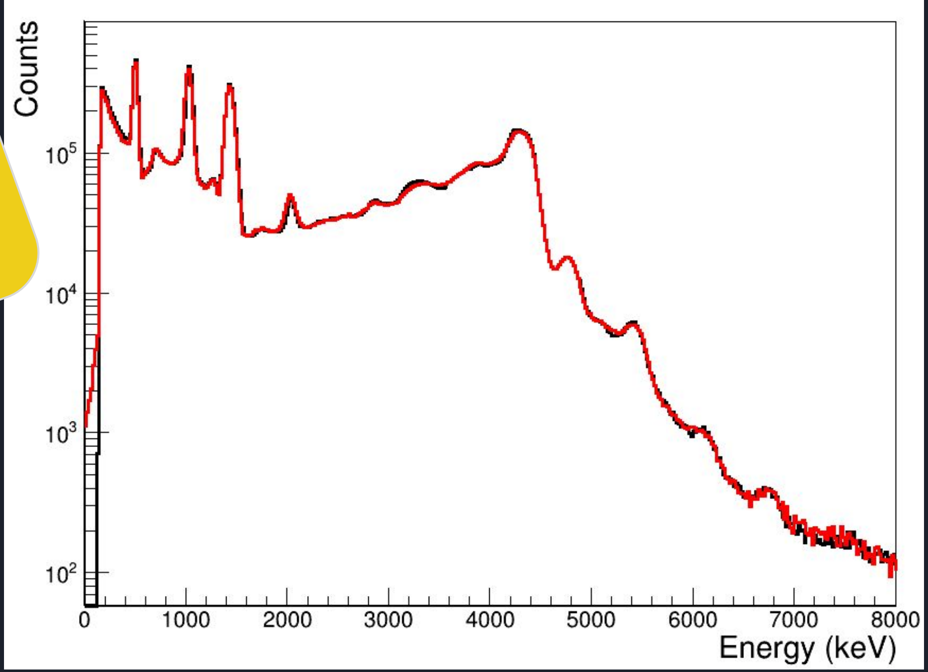


Preliminary results

- ^{64}Ga

- A very good
  dat
  keV not
  in the ENSDF data

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

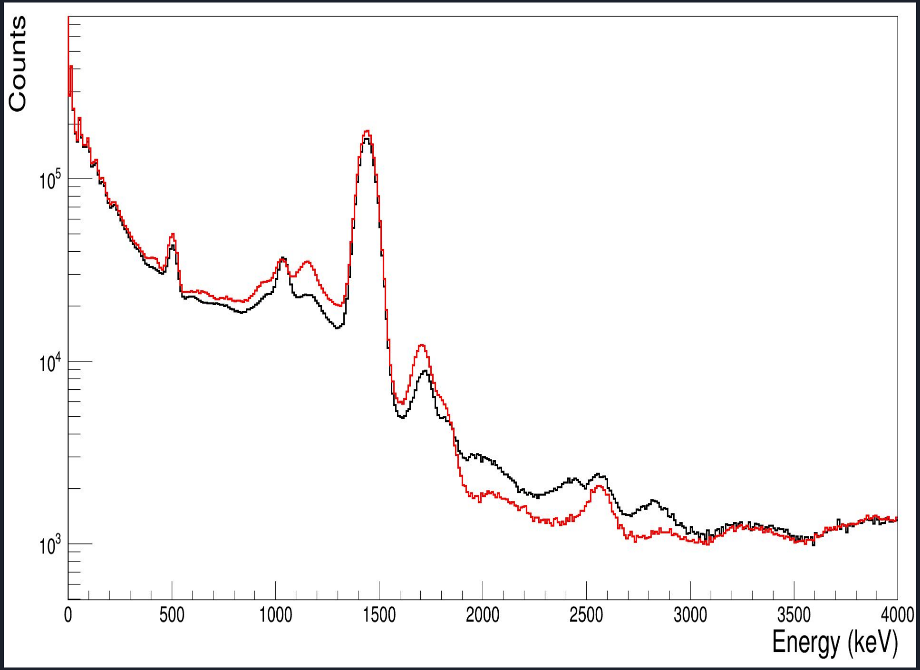


Preliminary results

- ^{64}Ge

- ENSDF data has a good fit at low energies and close to the Q-value (4517 keV)

- There are clearly cascade from previously unseen levels close to the Q-value

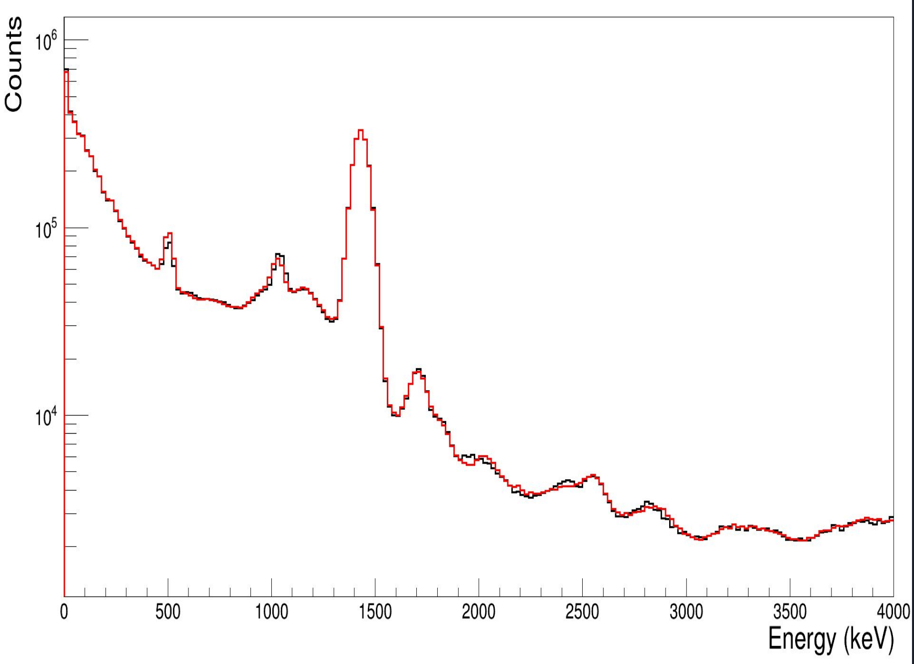


Preliminary results

- ^{64}Ge

- ENSDF data has a
  at low en
  th
  ue
  y unseen
  s close to the Q-value

a better fit in the energy emission range

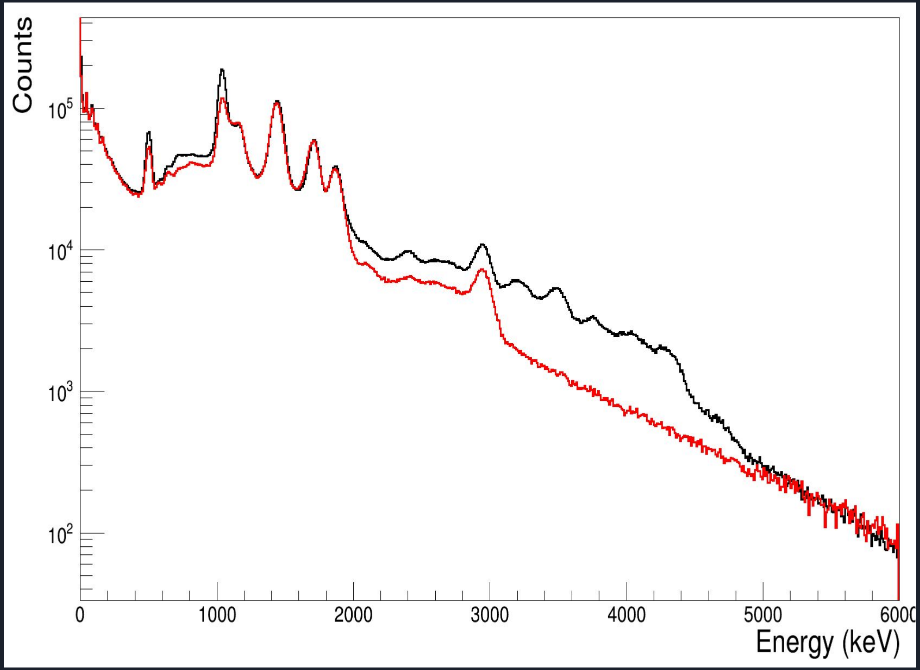


Preliminary results

- ^{65}Ge

- The data from the ENSDF had a good fit until ~2000 keV

- There are many cascades from unseen levels



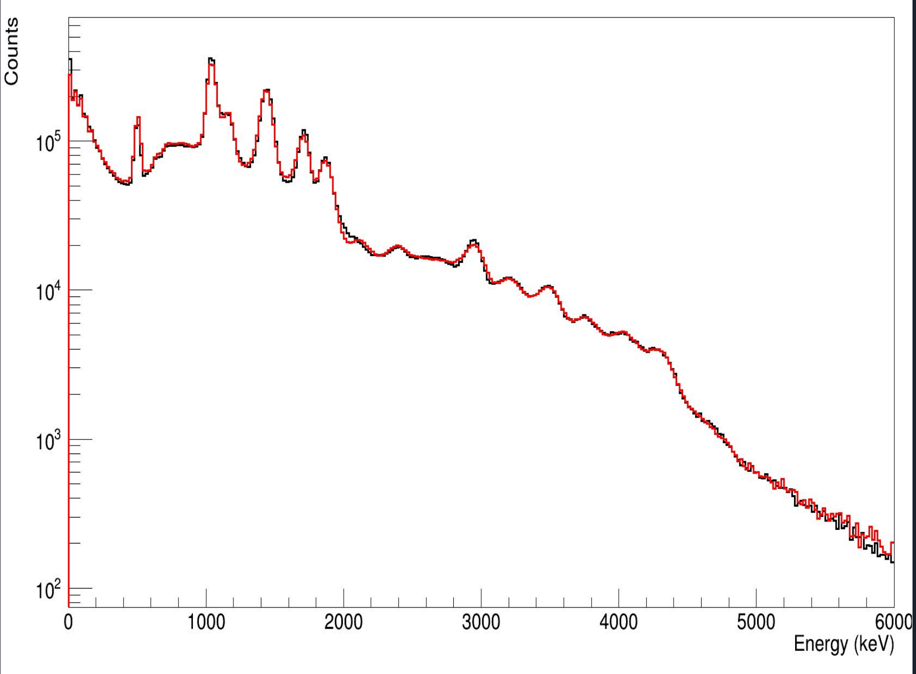
Preliminary results

- ^{65}Ge

- The data from th
  had a g

a much better fit accounting for the missing part of the spectrum

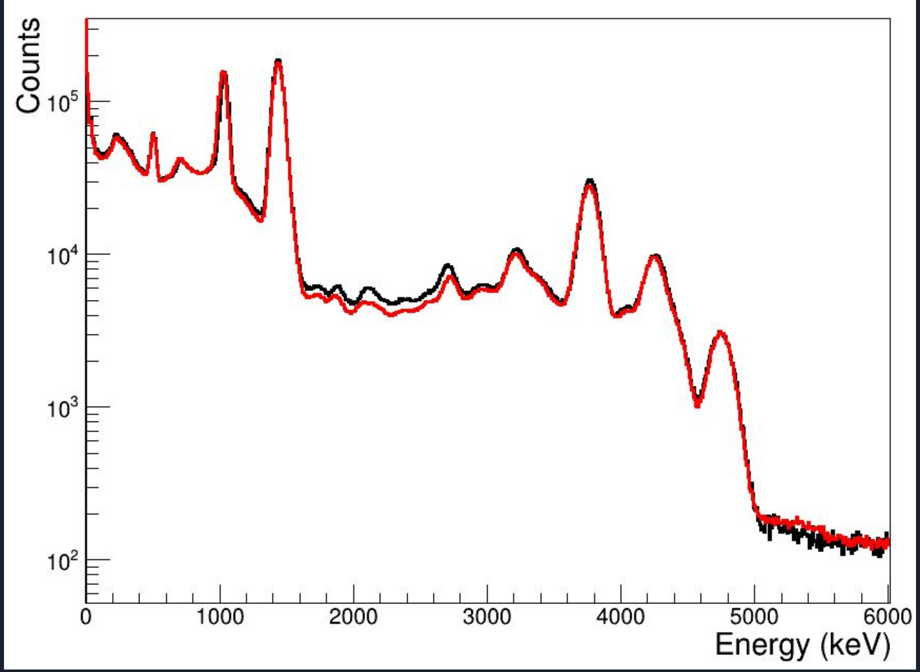
  here are many cascades
  from unseen levels



Preliminary results

- ^{66}Ga

- ENSDF data has a overall a really good fit but has less statistic in the region from 1800 keV to 3000 keV



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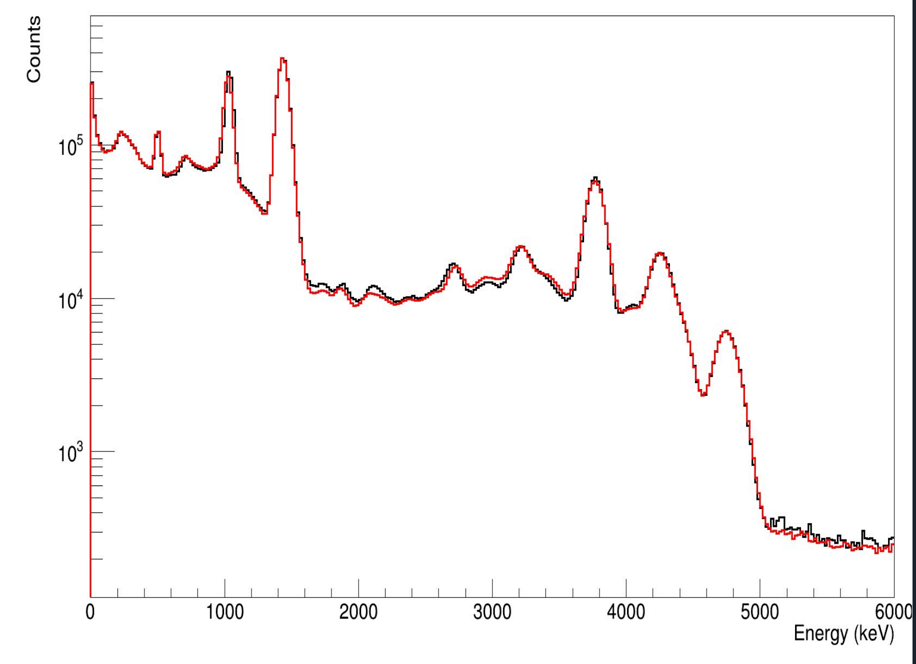
Preliminary results

- ^{66}Ga

- ENSD… …egion …eV to 3000

better fit in the region of 1800 keV to 3000 keV

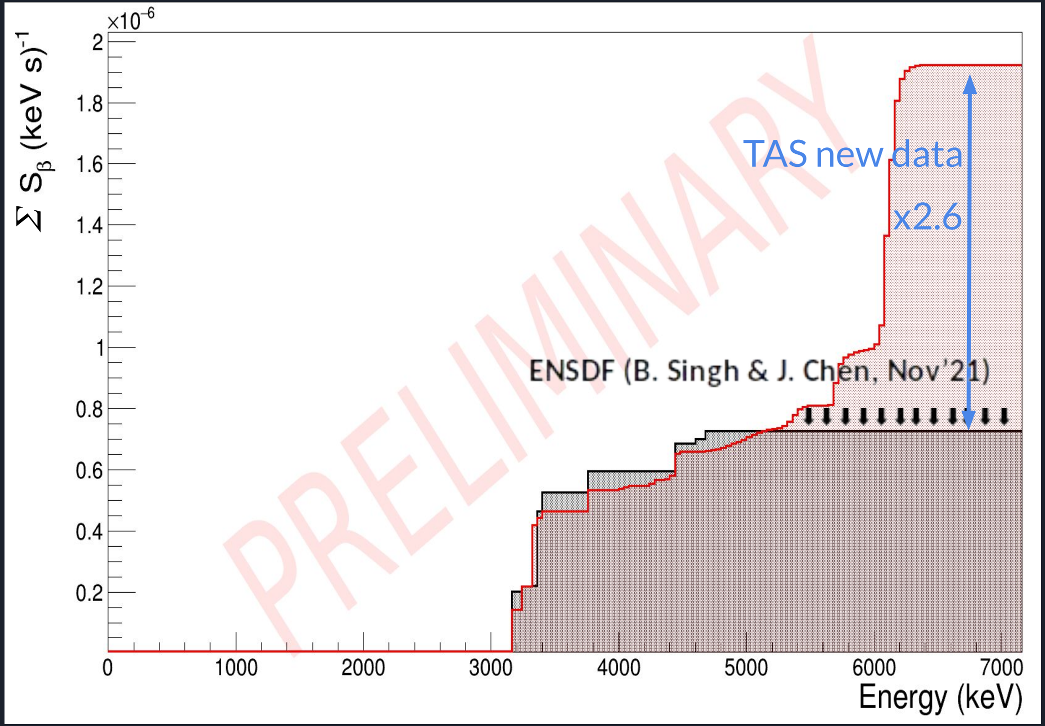


Preliminary results

- ^{64}Ga S_β

- The reconstruction of the peak in the gamma spectrum at ~6000 keV result in feeding above 5000 keV

- redistribution of the feeding on the known levels



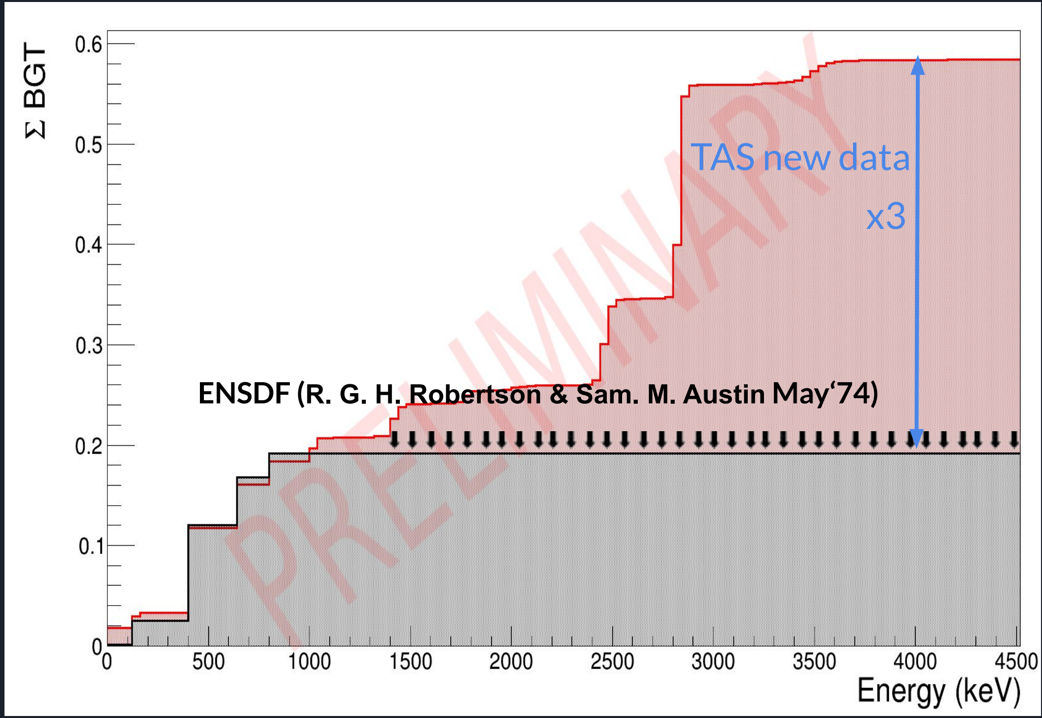
Preliminary results

- ^{64}Ge B(GT)

- We are able to obtain feeding above the last know level (817 keV)

- Noticeable change in the feeding at the ground state

- Good agreement on the knows feeding even though so much of the gamma levels was unknown

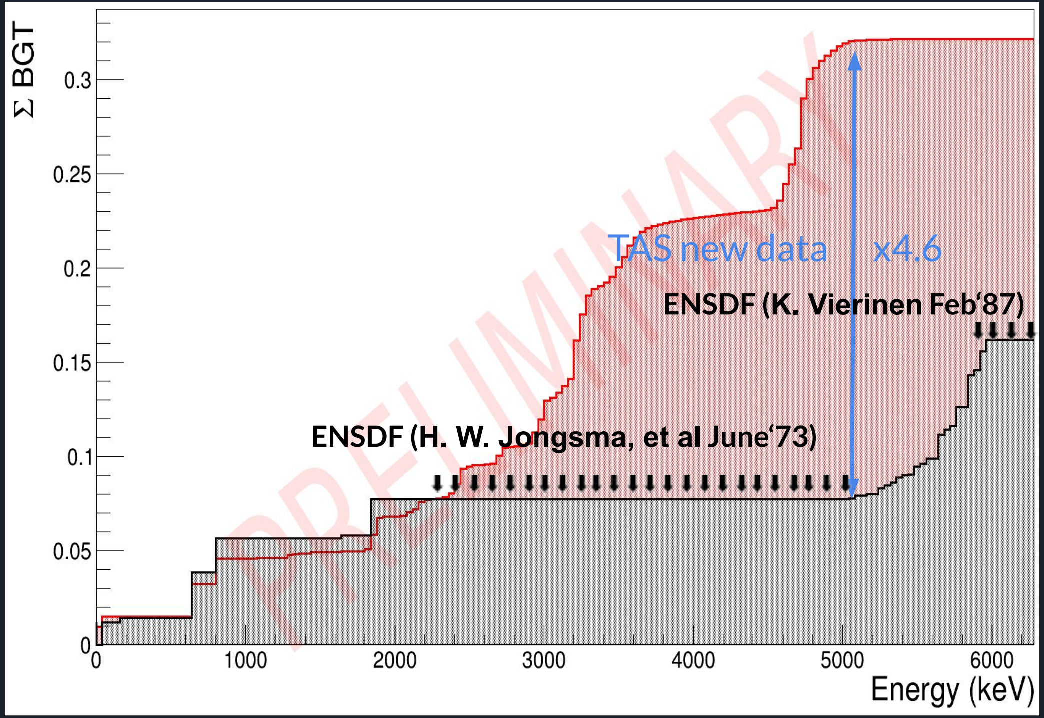


Preliminary results

- ^{65}Ge B(GT)

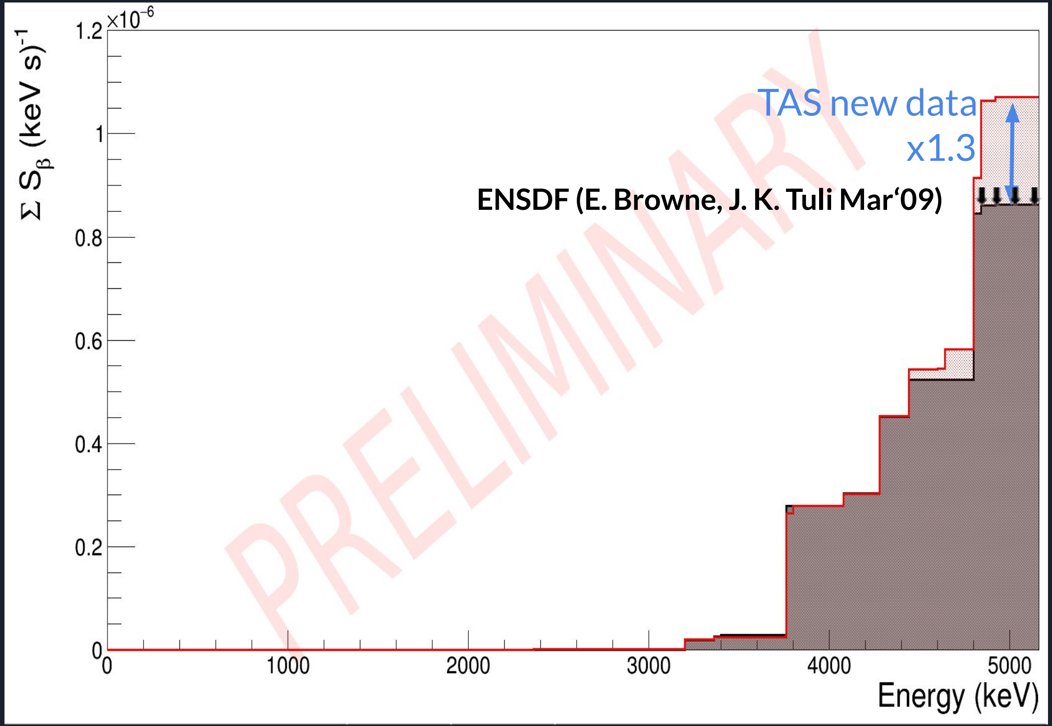
- sets densities of energy levels found between ~2500 and ~5000 keV

- Noticeable two big ‘jumps’ on the BGT



Preliminary results

- $^{66}Ga\ S_\beta$



- 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

Preliminary results

- ^{66}Ga S_{β}

- We observe a higher co
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from the gamma spectrum

- There is also a change in the
the fundamental level

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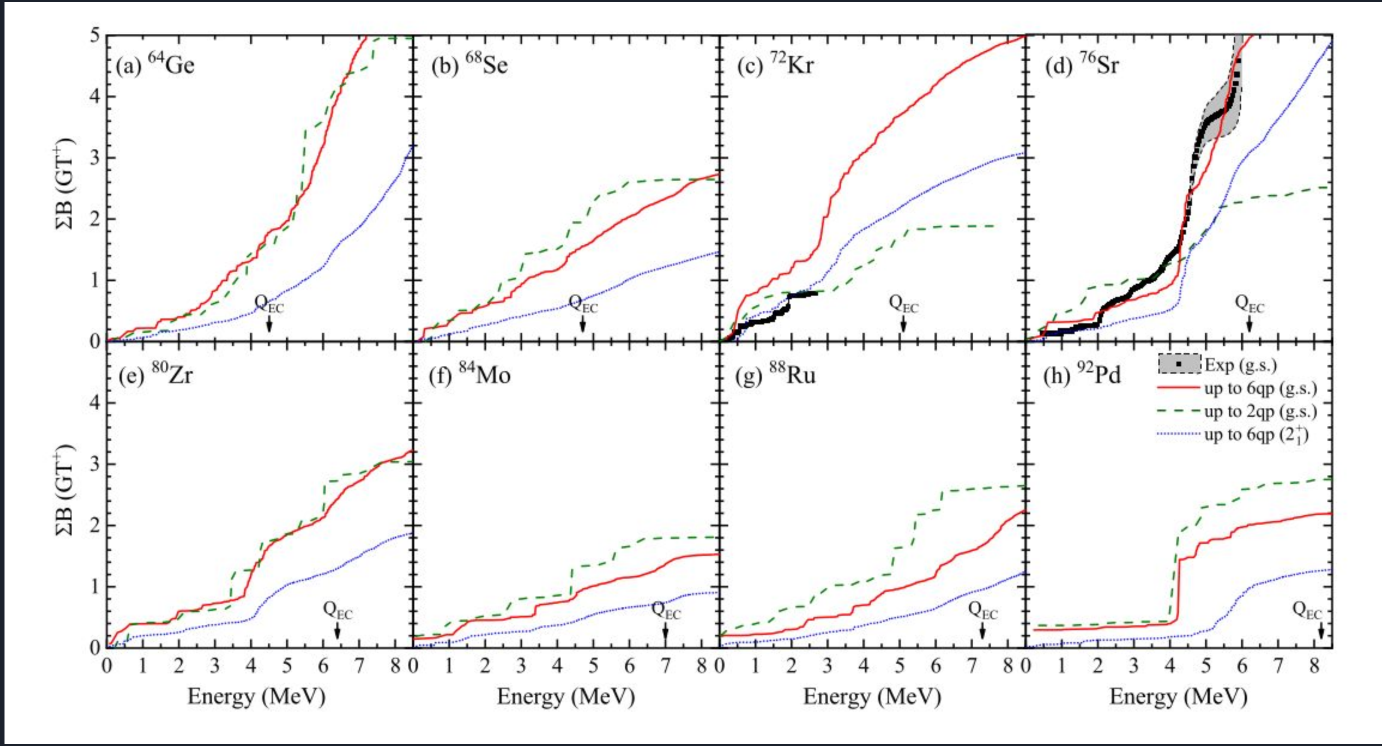
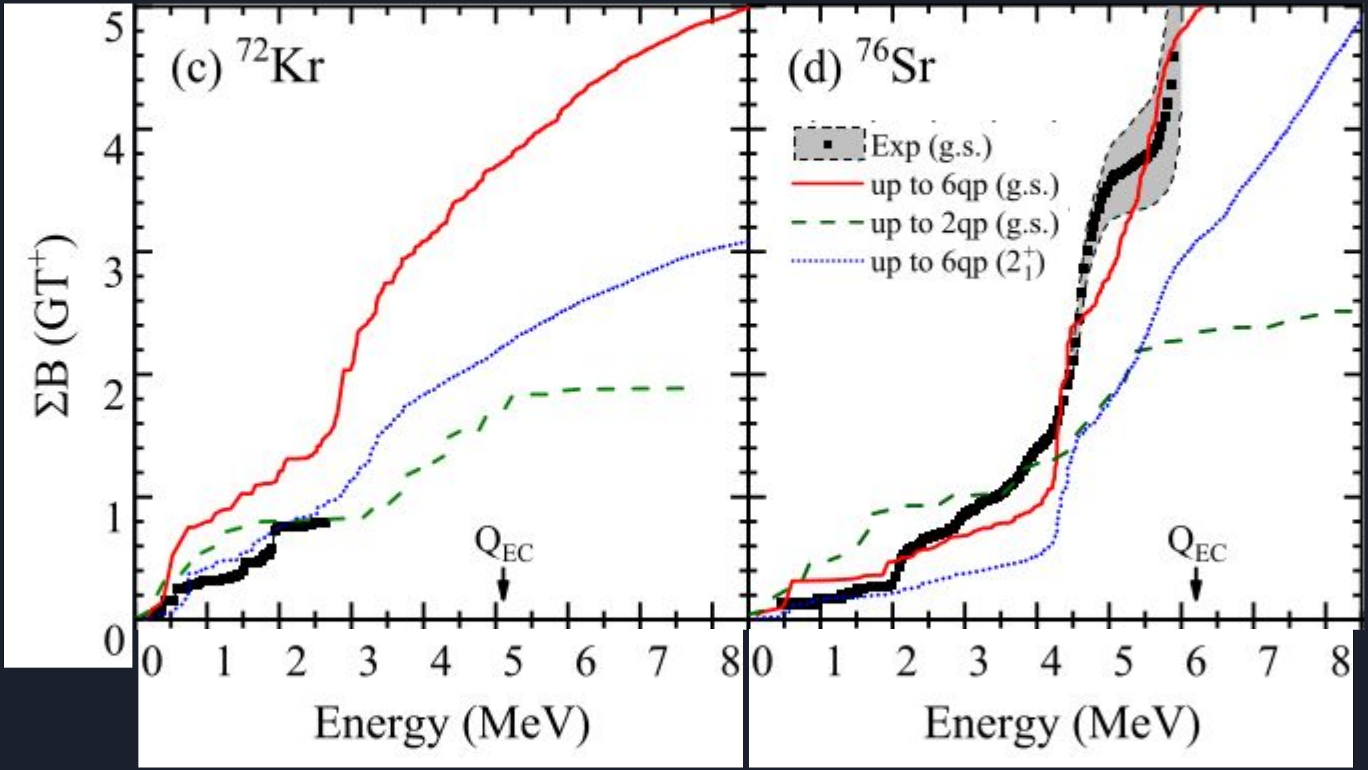
Letter

Stellar weak-interaction rates for *rp*-process waiting-point nuclei from projected shell model

Zi-Rui Chen, Long-Jun Wang *

School of Physical Science and Technology, Southwest University, Chongqing 400715, China


(a) 64Ge
(b) 68Se
(c) 72Kr
(d) 76Sr
(e) 80Zr
(f) 84Mo
(g) 88Ru
(h) 92Pd
ΣB (GT+)
Energy (MeV)
QEC
Exp (g.s.)
up to 6qp (g.s.)
up to 2qp (g.s.)
up to 6qp (2+1)


(c) 72Kr
(d) 76Sr
ΣB (GT+)
Energy (MeV)
Energy (MeV)
QEC
QEC
Exp (g.s.)
up to 6qp (g.s.)
up to 2qp (g.s.)
up to 6qp (2+1)
0
1
2
3
4
5
0
1
2
3
4
5
6
7
8
0
1
2
3
4
5
6
7
8

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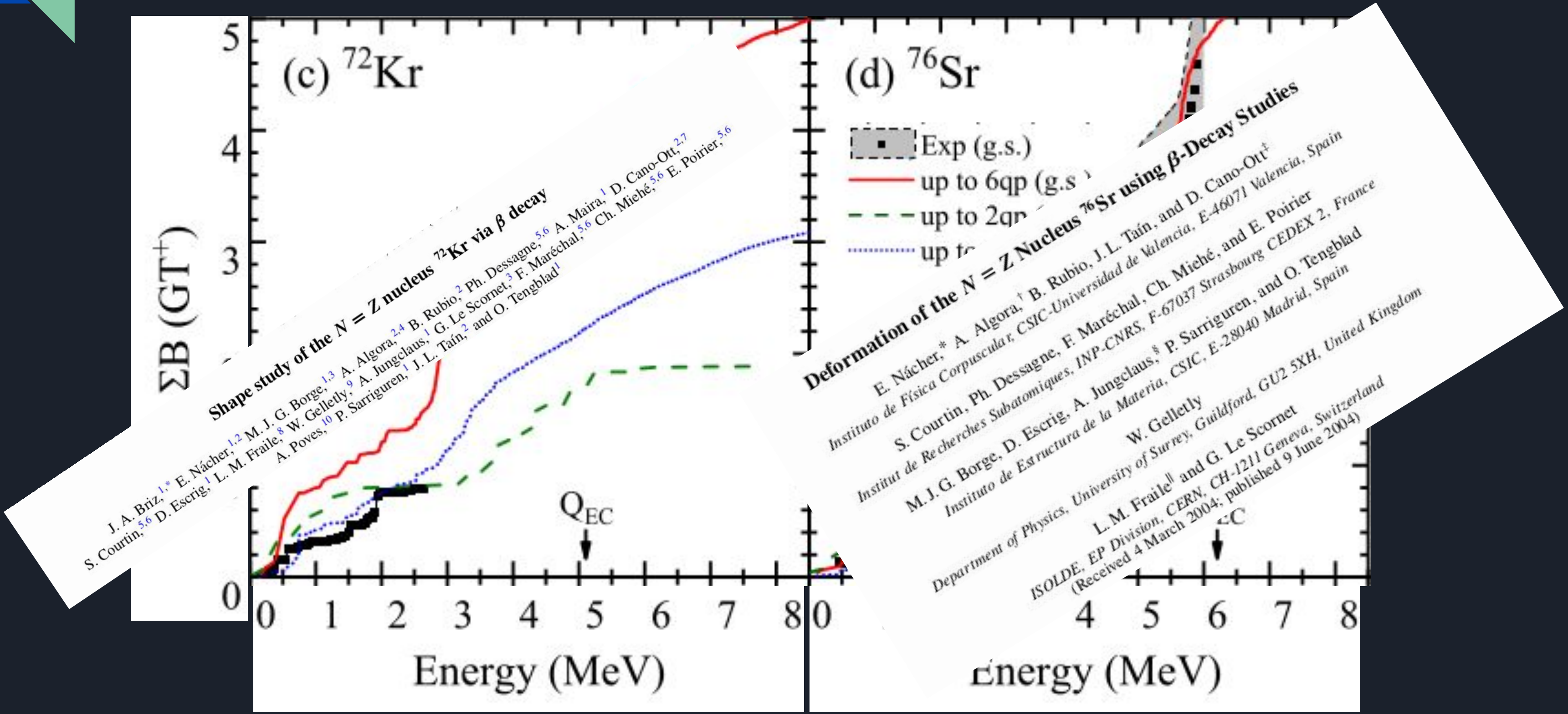
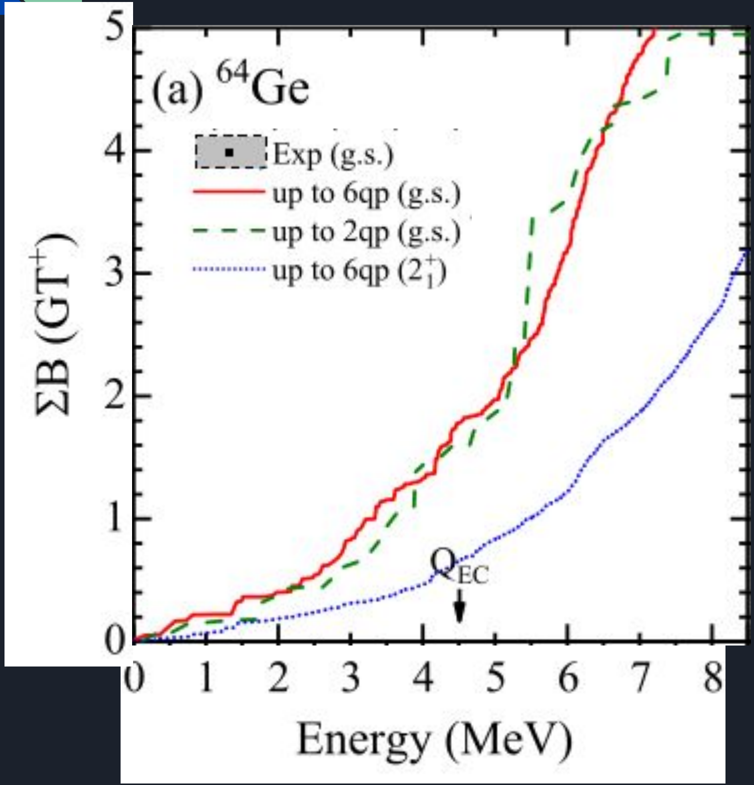
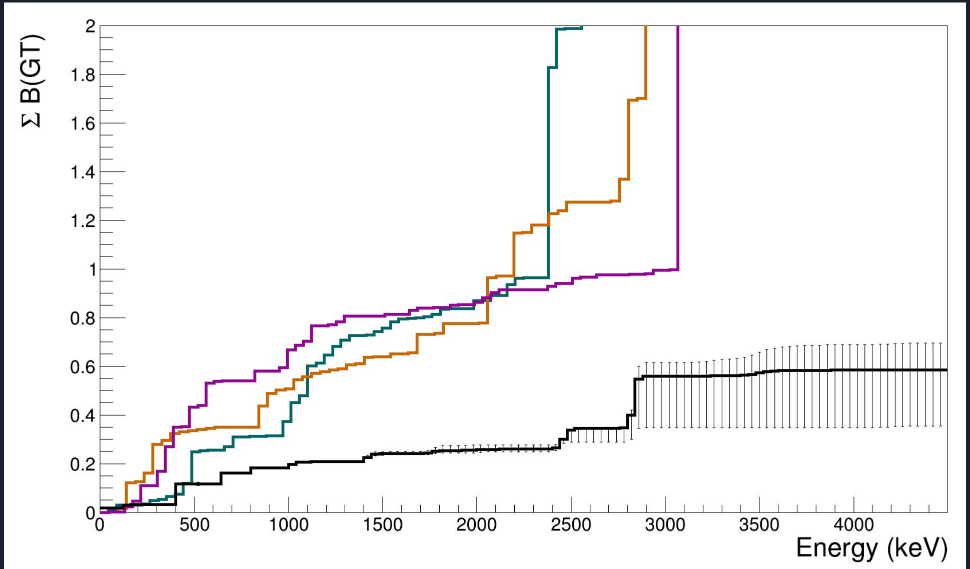



(a) ^{64}Ge
Exp (g.s.)
up to 6qp (g.s.)
up to 2qp (g.s.)
up to 6qp (2_1^+)
Q_{EC}
ΣB (GT$^+$)
Energy (MeV)


Σ B(GT)
Energy (keV)

Conclusions

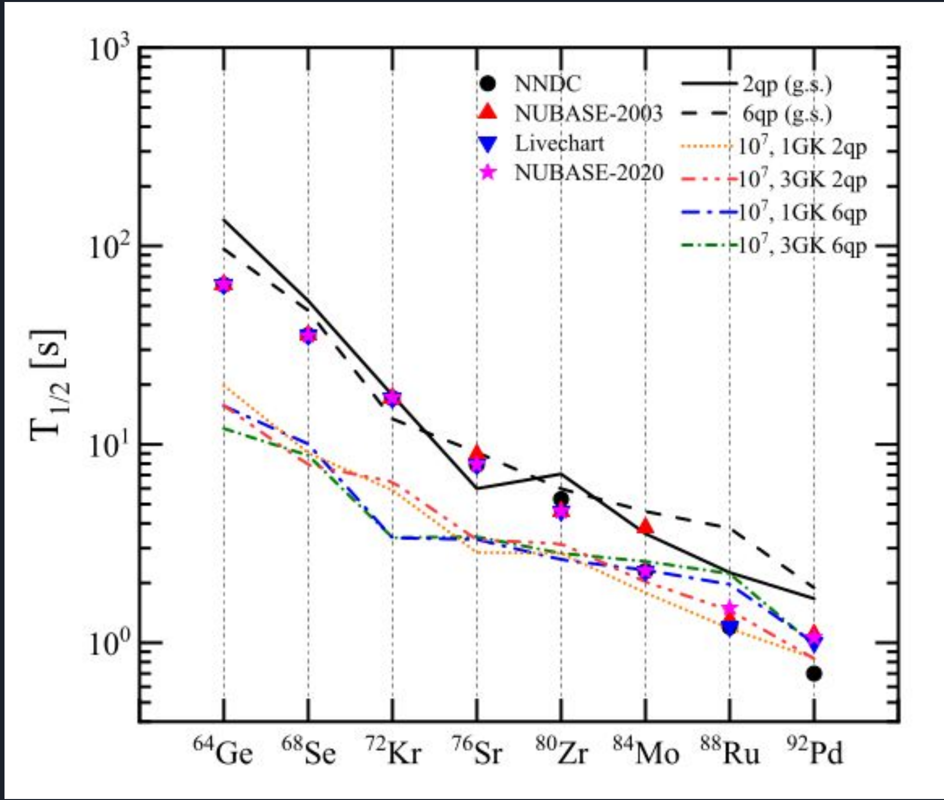
- Astrophysical network calculations rely quite often on theoretical predictions that must be constrained. For this the $T^{1}/_{2}$ is not enough in general and the B(GT) must be used

- 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. We have the B(GT) of $^{64,65}Ge$, sadly ^{66}Ge was contaminated so was unable to be analyzed and the S_{β} of $^{64,66}Ga$

- Our work is important to develop a better model for nuclear structure necessary to understand stellar process as the case of the stellar evolution of type I x-ray burst

Thank you for your attention

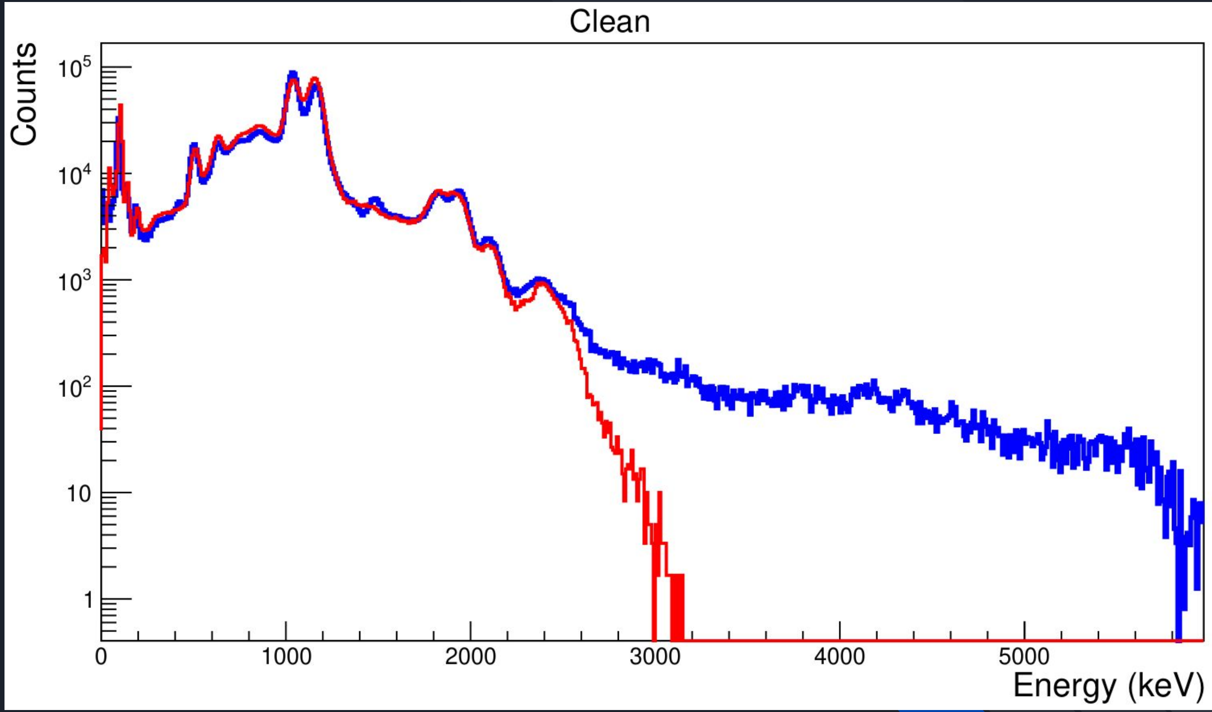
Extra



NNDC
NUBASE-2003
Livechart
NUBASE-2020
2qp (g.s.)
6qp (g.s.)
10^7, 1GK 2qp
10^7, 3GK 2qp
10^7, 1GK 6qp
10^7, 3GK 6qp
T_1/2 [s]
10^0
10^1
10^2
10^3
64Ge
68Se
72Kr
76Sr
80Zr
84Mo
88Ru
92Pd

Extra

- ^{65}Ga



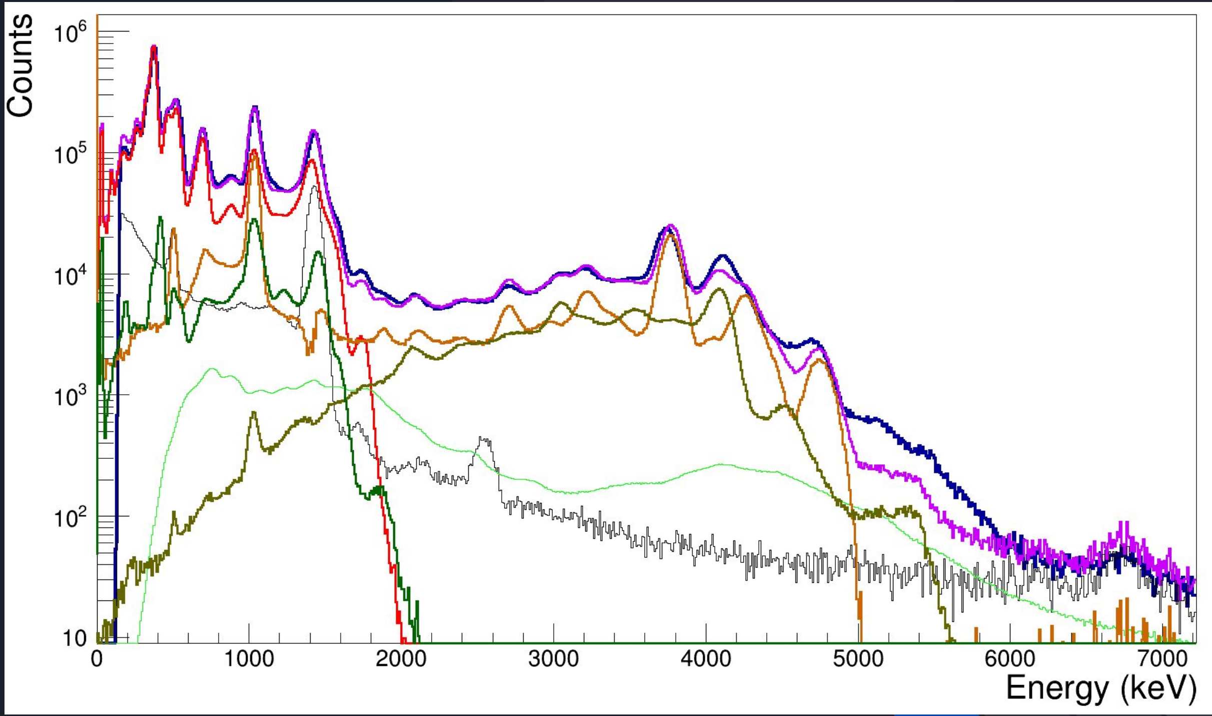
- Unknown contamination above the Q-value (3254 keV)

- We believe it is may be ^{69}Se and ^{69}As as we have ^{70}Se and ^{70}As contamination on ^{66}Ge

Extra • ^{66}Ge

- Contamination from ^{70}Se and ^{70}As

- It's very apparent that ^{70}As is affected by the pandemonium effect so its not well measure making the analysis of ^{66}Ge impossible without a measurement of ^{70}Se - ^{70}As



Extra

- ^{66}Ge

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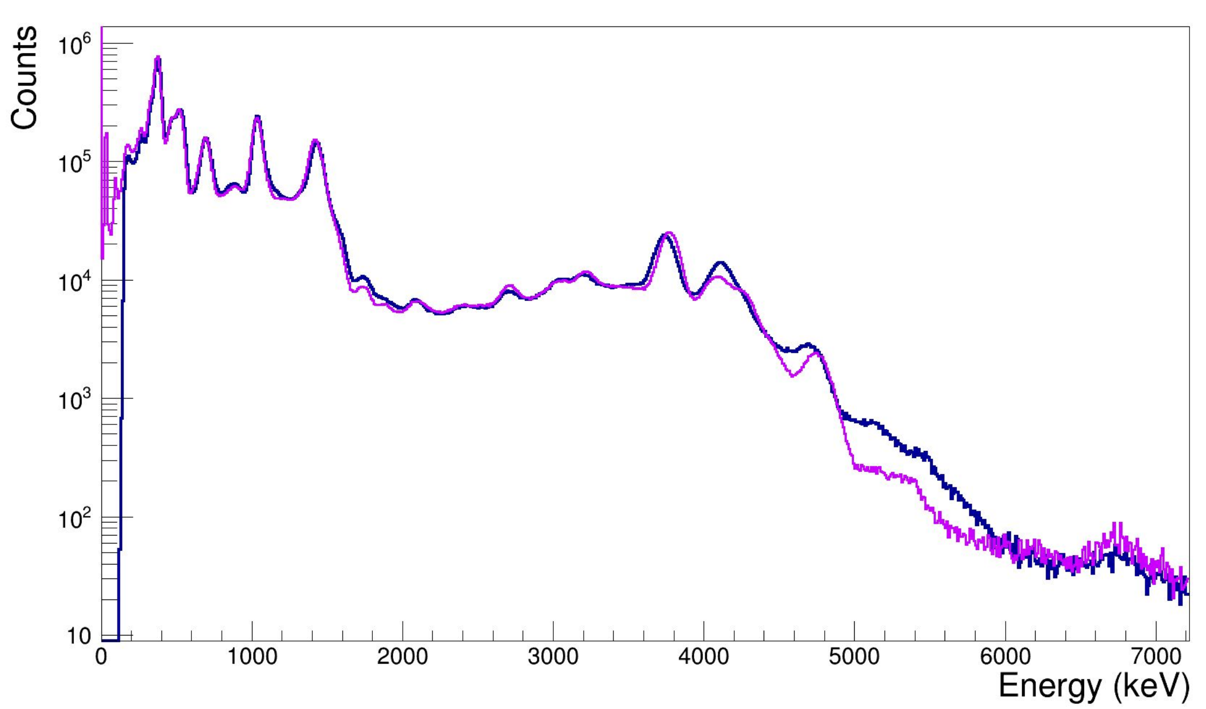
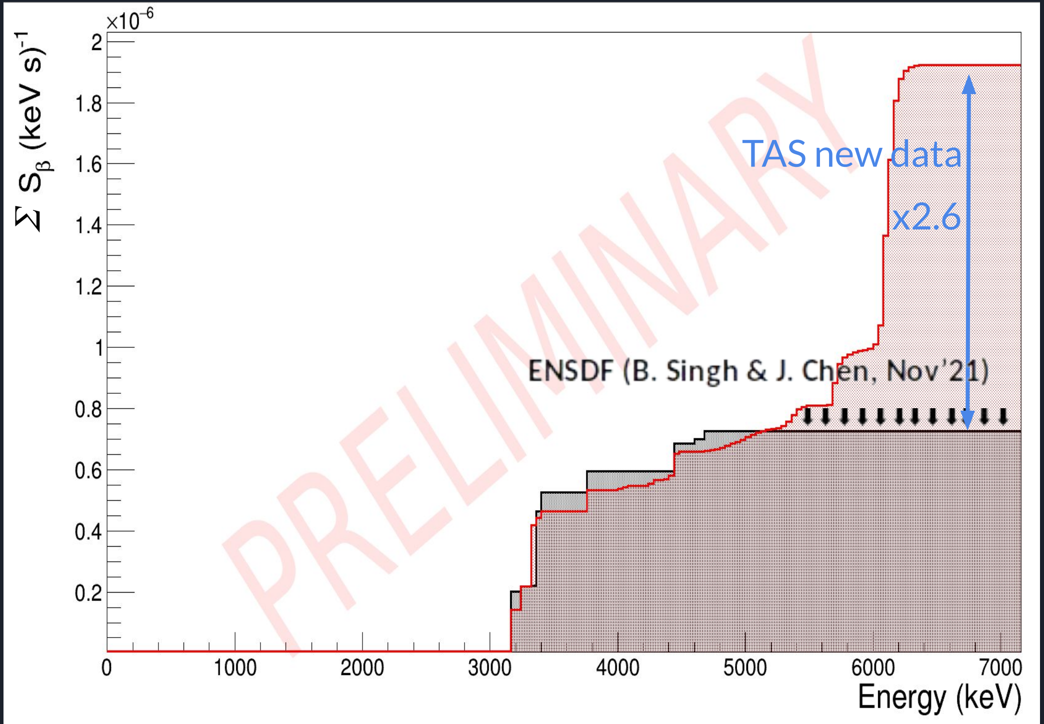


Preliminary results

- ^{64}Ga S_β

Decay from 0+ to 0+ gs

	TAS	ENSDF
feeding	28.2 %	24.7 %
log ft	6.59	6.65

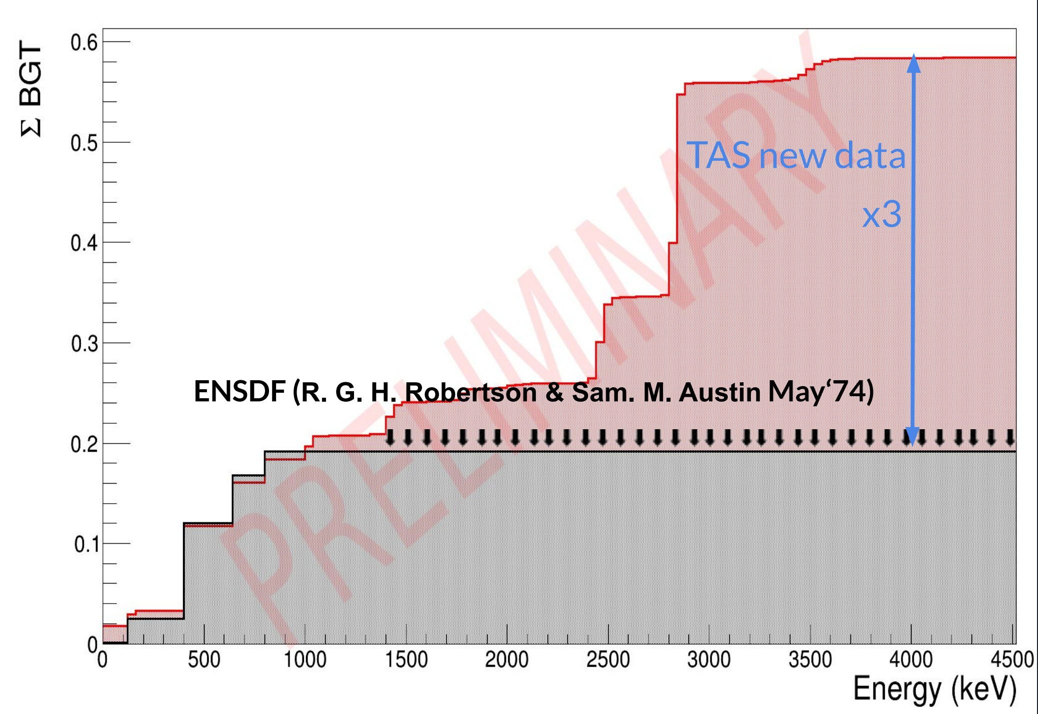


Preliminary results

- ^{64}Ge B(GT)

Decay from 0+ to 0+ gs

	TAS	ENSDF
feeding	15.6 %	<1.3 %
log ft	5.3	>6.4

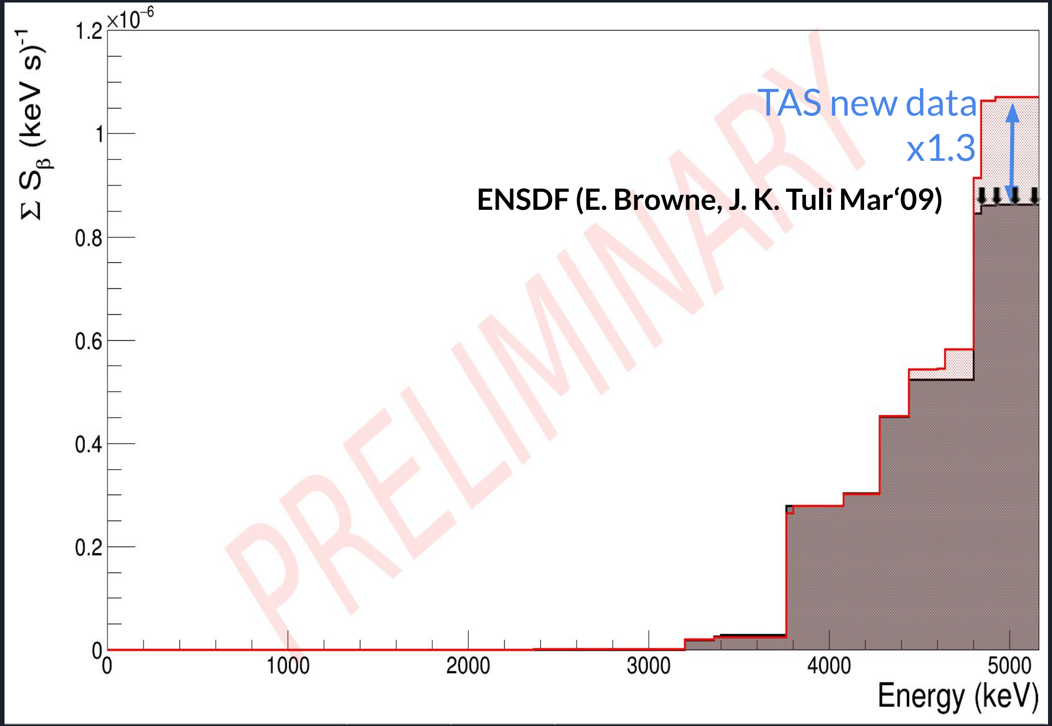


Preliminary results

- ^{66}Ga S_β

Decay from 0+ to 0+ gs

	TAS	ENSDF
feeding	45.5 %	51 %
log ft	7.93	7.88



Preliminary results

- ^{64}Ga S_β

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

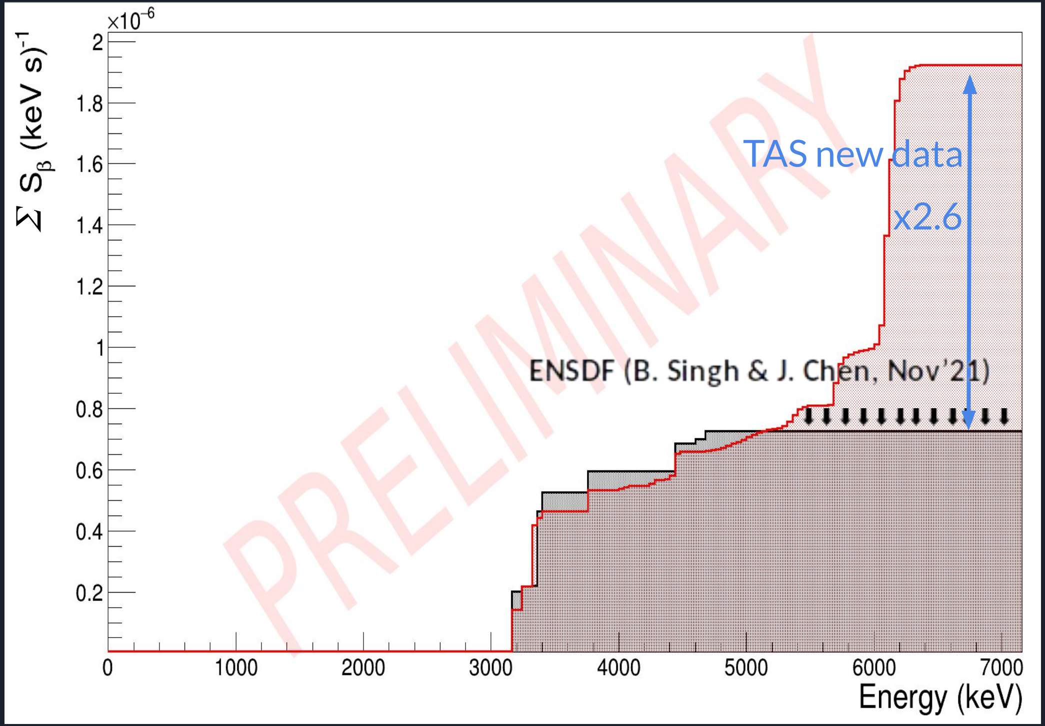
$$\alpha = M_F/\sqrt{2T}$$

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

- 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).



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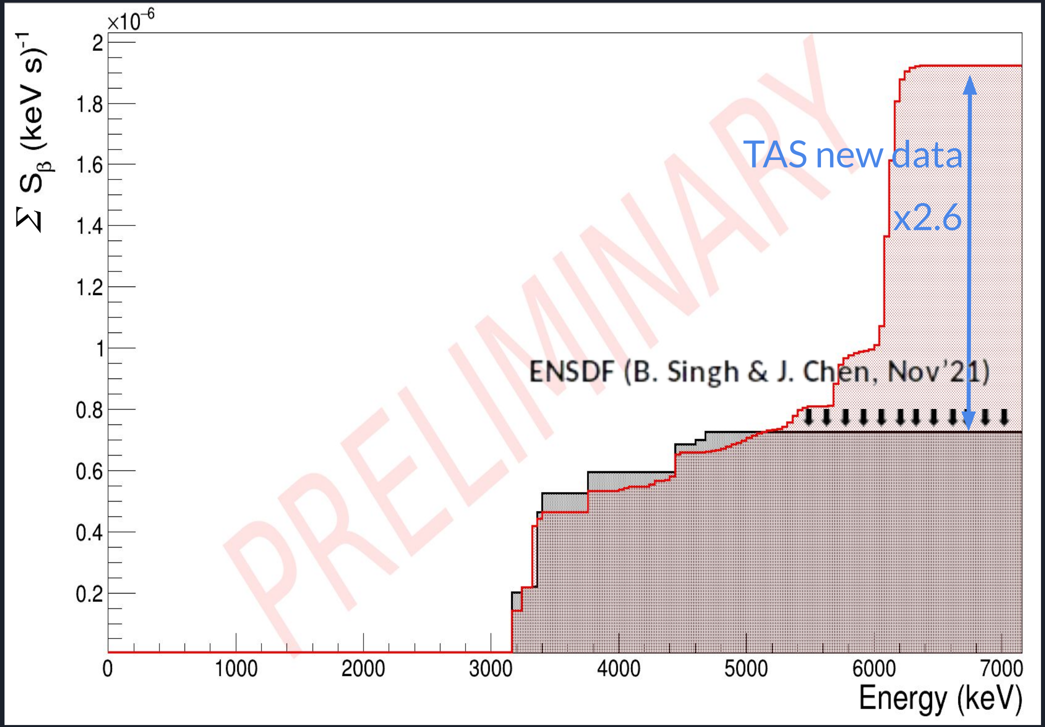
Preliminary results

- $^{64}Ga\ S_\beta$

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.

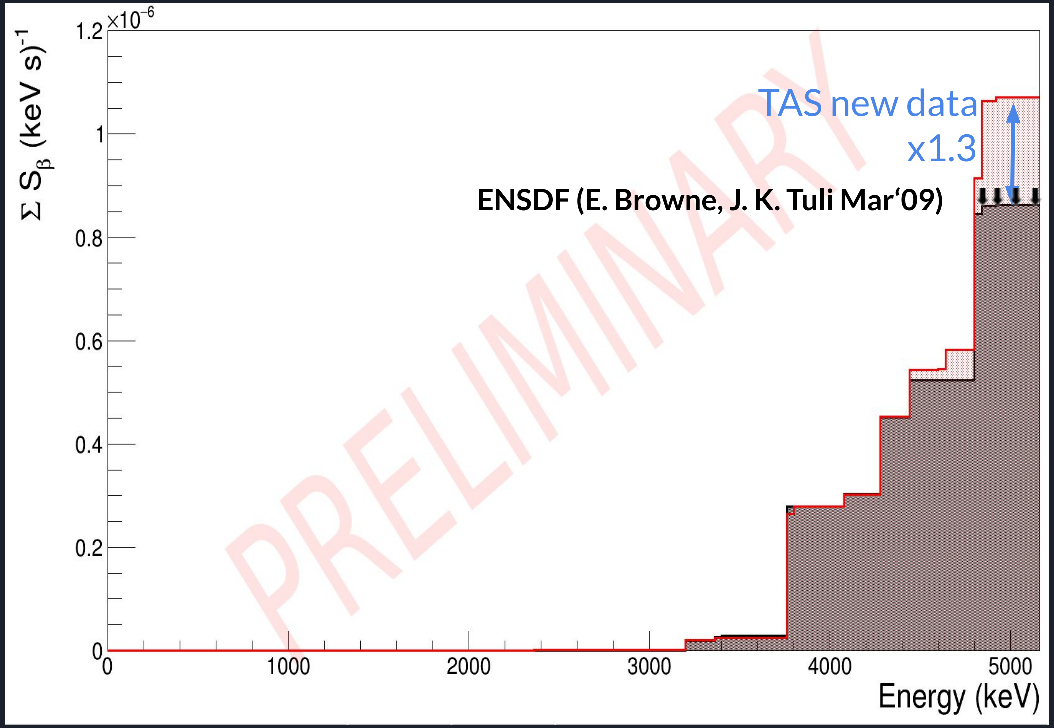


Preliminary results

- ^{66}Ga 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.