^{205}Tl(n,γ) cross section measurement at n_TOF EAR1

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Outline of the presentation

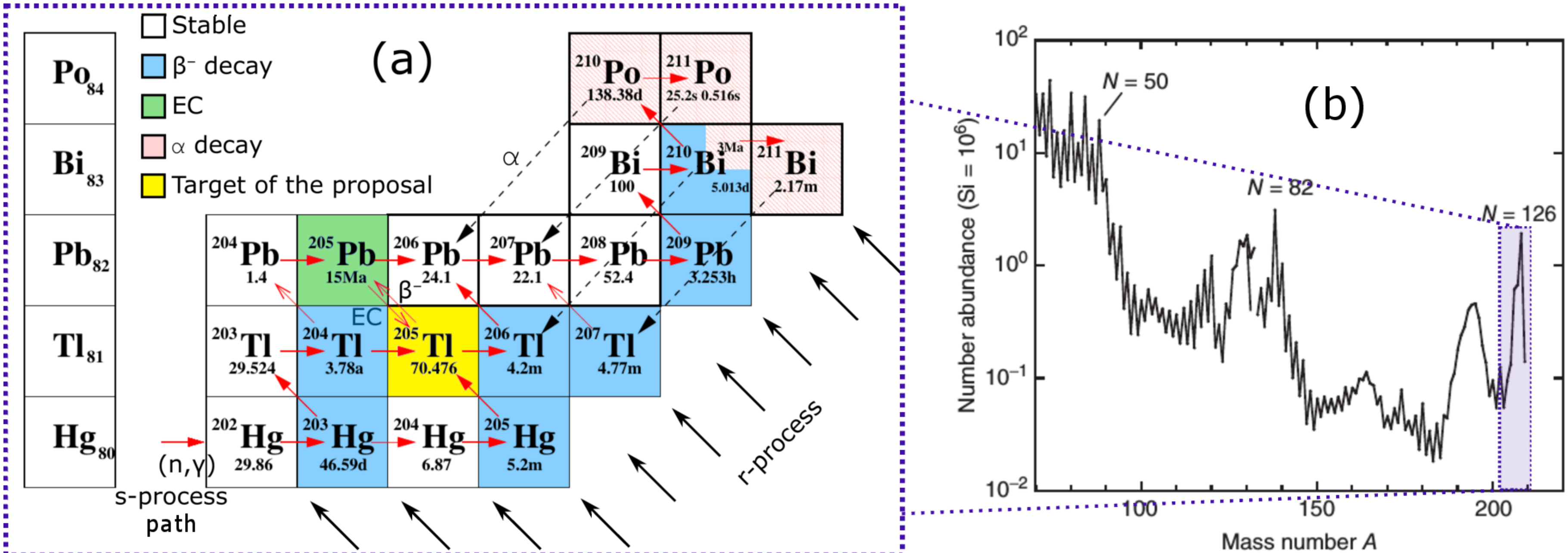
- Introduction and motivations
  - s-process nucleosynthesis at the heaviest isotopes
  - The astrophysical importance of the ^{205}Tl(n,γ) reaction rate
  - Current status of the ^{205}Tl(n,γ) data
  - Nucleosynthesis calculations

- Experimental setup, counting rate estimation and beam time request

Overview of ths s-process at 203<A<210

- Thallium, and especially, lead isotopes, are mainly produced by the s-process
- The third s-process peak: abundance peak around double magic ^{208}Pb
- Accurate model of the s-process should describe faithfully the third peak

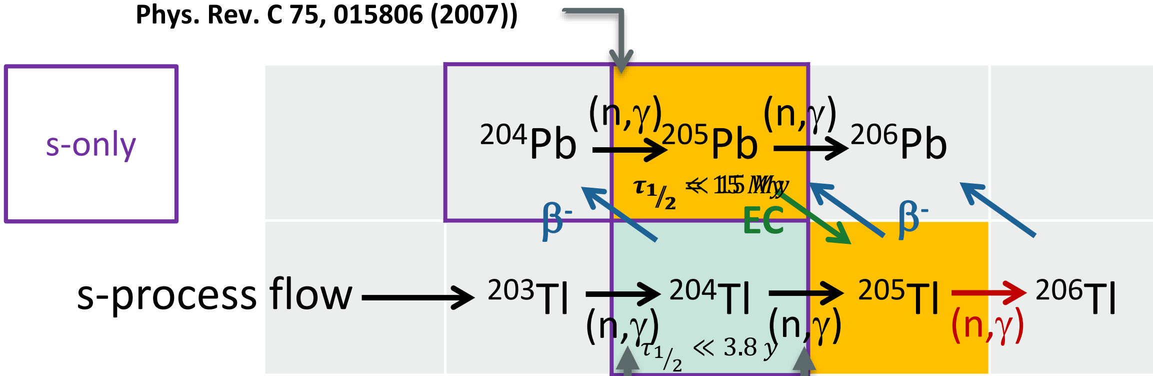
  ➡ requires best nuclear data (beta decay rates & capture rates) available



The ^{205}Pb-^{205}Tl decay system

- ^{205}Tl is the most abundant (71%) stable (at earth) thallium isotope (Z=81)

Already measured at n_TOF(C. Domingo-Pardo et al., Phys. Rev. C 75, 015806 (2007))



Already measured at n_TOF (A. Casanovas Ph.D. thesis, 2018)

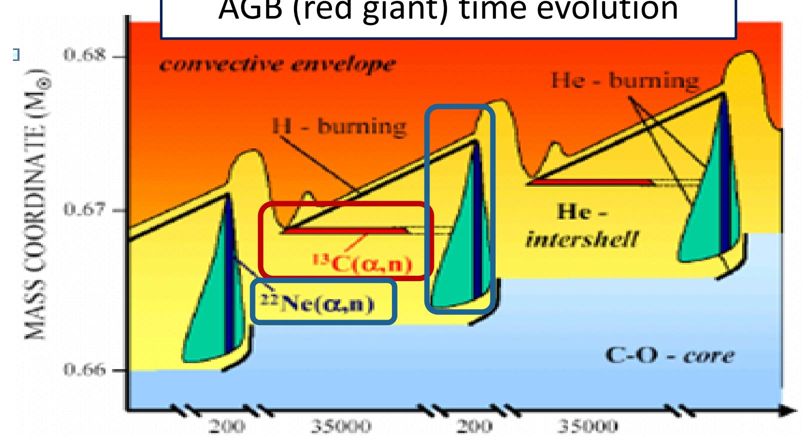
After s-process

C-13 pocket s-process
$T\sim10^8\ K\ (kT\sim8\ keV)$

TP s-process
$T\geq3\cdot10^8\ K\ (kT\sim25\ keV)$

- The **^{205}Pb/^{204}Pb ratio** could be used as a "chronometer" of the s-process[1,2,3]
  - Time elapsed since the last injection of main s-process products into the pre-solar nebula
- Stellar effects on ^{205}Pb: at s-process sites temperature, EC decay is so strongly enhanced that its **survival is compromised**
- Activation of the **bound state β decay** of ^{205}Tl

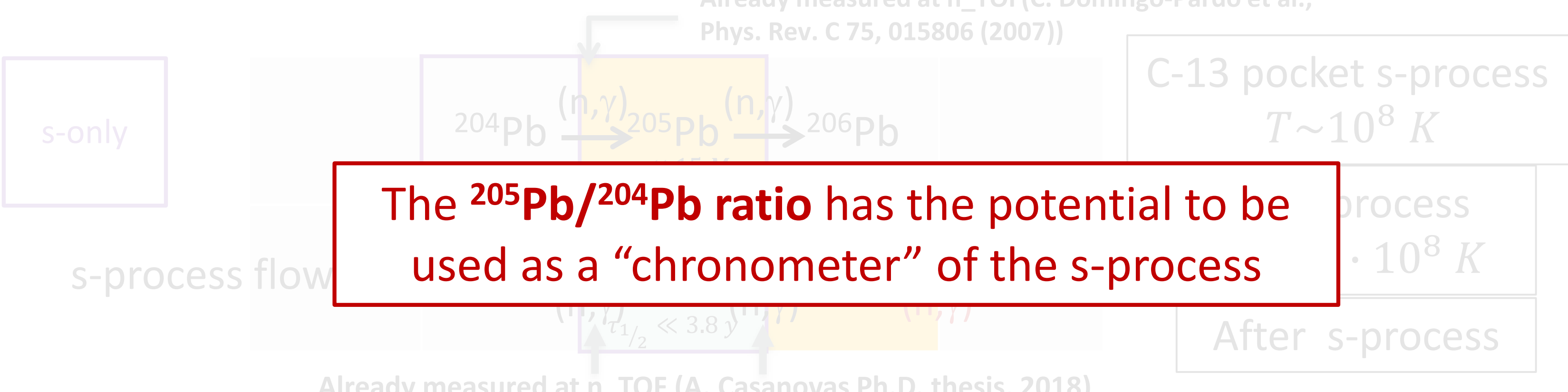
AGB (red giant) time evolution



1. K. Yokoi et al., ***The production and survival of Pb-205 in stars, and the ^{205}Pb/^{205}Tl s-process chronometry***, Astronomy and Astrophysics 145, 339-346 (1985)
2. R.G.A. Baker et al. , ***The thallium isotope composition of carbonaceous chondrites — New evidence for live ^{205}Pb in the early solar system***, Earth and Plan. Sc. Lett (2010)
3. Mowlavi, N., Goriely, S., Arnould, M., ***The survival of ^{205}Pb in intermediate-mass AGB stars***, Astron. Astrophys. 330, 206–214 (1998)

Main ideas

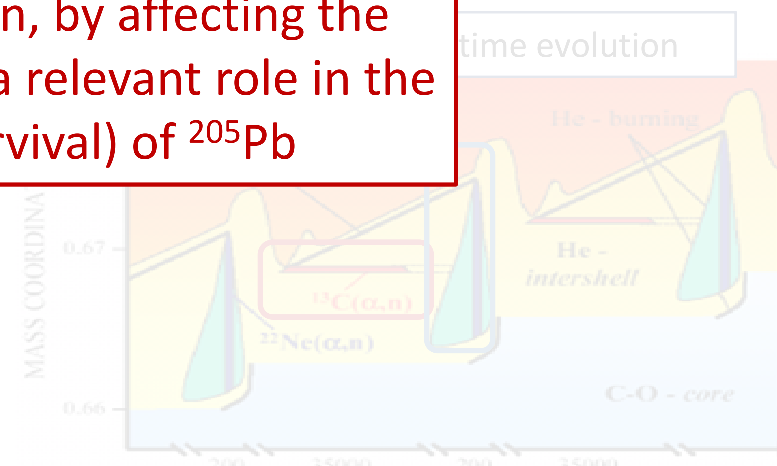
- ^{205}Tl is the most abundant (71%) stable (at earth) thallium isotope (Z=81)



The ^{205}**Pb/**^{204}**Pb ratio** has the potential to be used as a "chronometer" of the s-process

The ^{205}Tl(n,γ) capture reaction, by affecting the abundance of ^{205}Tl, could play a relevant role in the final abundance (and survival) of ^{205}Pb

- Stellar effects … temperature, … that its surviv…
- Activation of the bound state β decay of ^{205}Tl
- The ^{205}**Pb/**^{204}**Pb ratio** could be used as a "chronometer" of the s-process[1,2,3]
  - Time elapsed since the last injection of main s-process products into the pre-solar nebula



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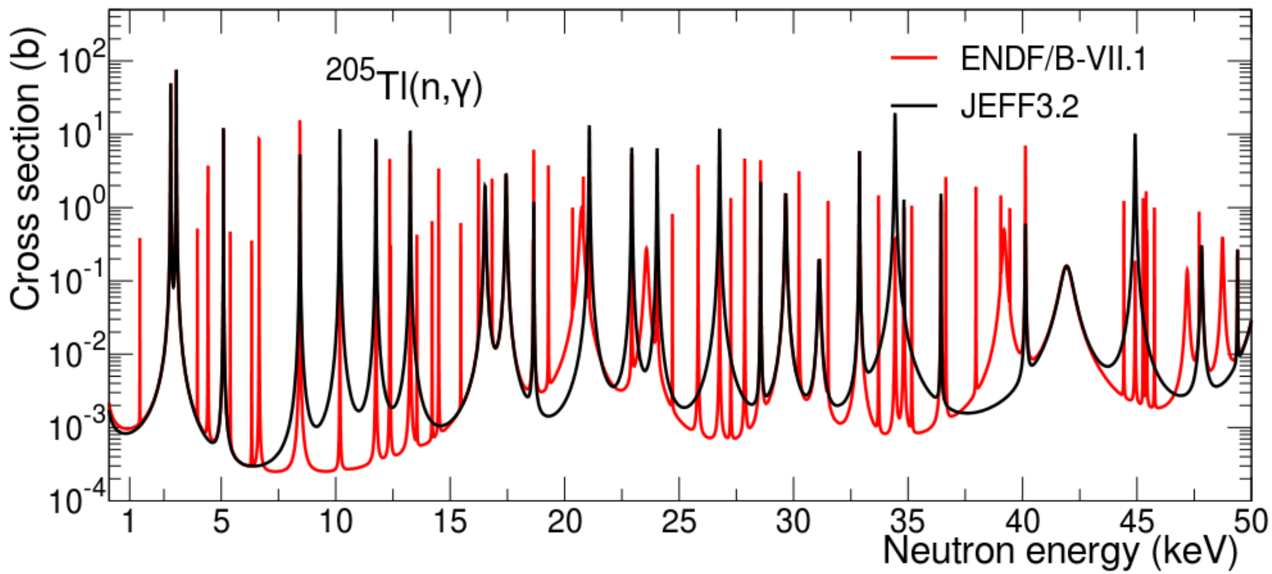
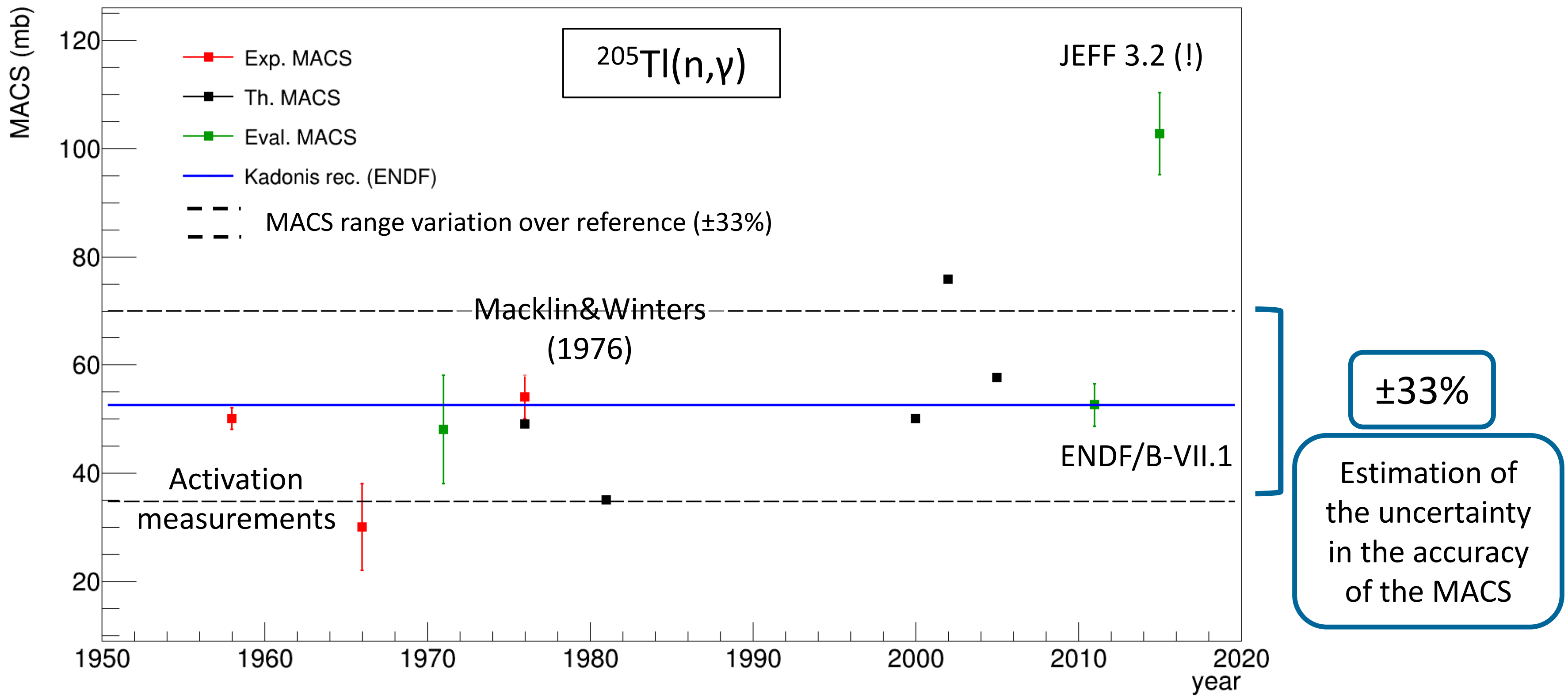
Status of the data for ^{205}Tl(n,γ) : cross section

- Only one previous measurement: R. L. Macklin and R. R. Winters, *Stellar neutron capture in the thallium isotopes*, Astrophys. J. **208**, 812 (1976)
  - Experimental capture cross section or resonance parameters never published
  - Related EXFOR data: only resonance kernels, no uncertainties
  - Explicit correction factor for systematic error at ORNL: not known (0.95 for ^{203}Tl)
- Most recent evaluations show **important discrepancies**:



Status of the data for $^{205}Tl(n,\gamma)$: MACS

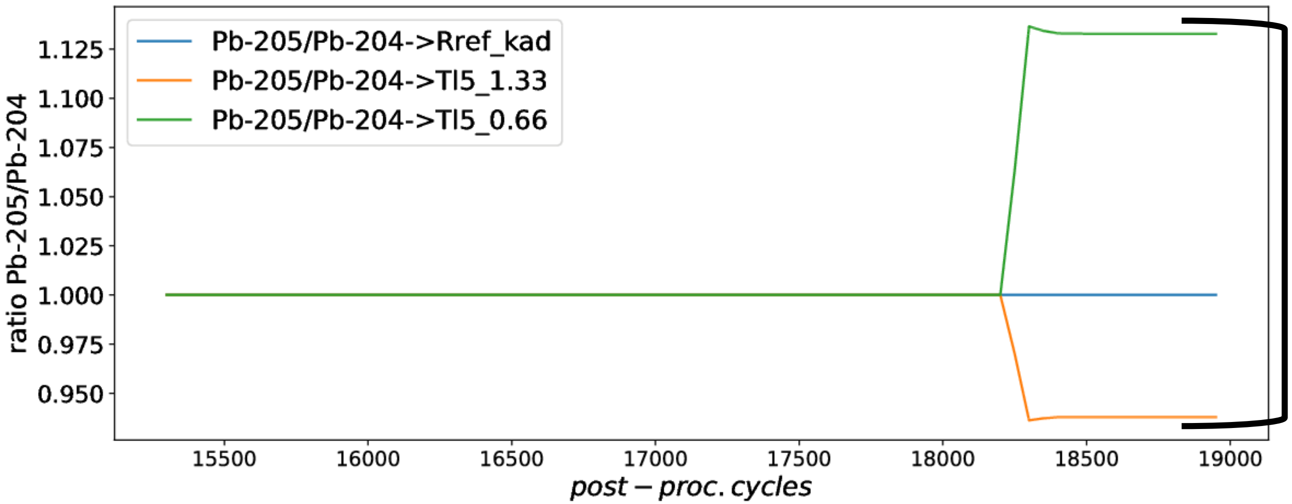
- MACS at 30 keV comparison:
  - Kadonis reference value: 52.6 ± 3.9 mb (ENDF evaluation)
  - Examination of ENDF data suggests it is based on 1976 ORNL measurement
  - No direct uncertainty assessment in the whole energy range (8 keV to 50 keV)



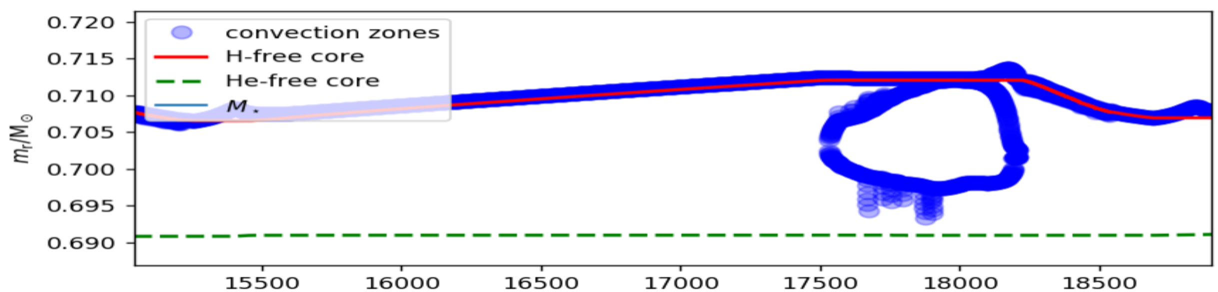
^{205}Tl(n,γ) impact: Nucleosynthesis calculations

- Post-processing calculation employing MSun = 3, Z=0.006 (half solar) star model from NuGrid set 1 ext. (C. Ritter et al. 2017[1])
- Reference Kadonis ^{205}Tl(n,γ) MACS has been varied ±33% in this simulations

^{205}Pb/^{204}Pb abundance ratio in the stellar envelope (normalized to the ref. rate)



~18% uncertainty in the ^{205}Pb/^{204}Pb ratio



[1] *NuGrid Stellar Data Set. II. Stellar Yields from H to Bi for Stellar Models with Mzams = 1 to 25Msun and Z = 0.0001 to 0.02*, C. Ritter, F. Herwig, S. Jones, M. Pignatari, C. Fryer, R. Hirschi, , ArXiv e-prints, arXiv:1709.0867

Main points

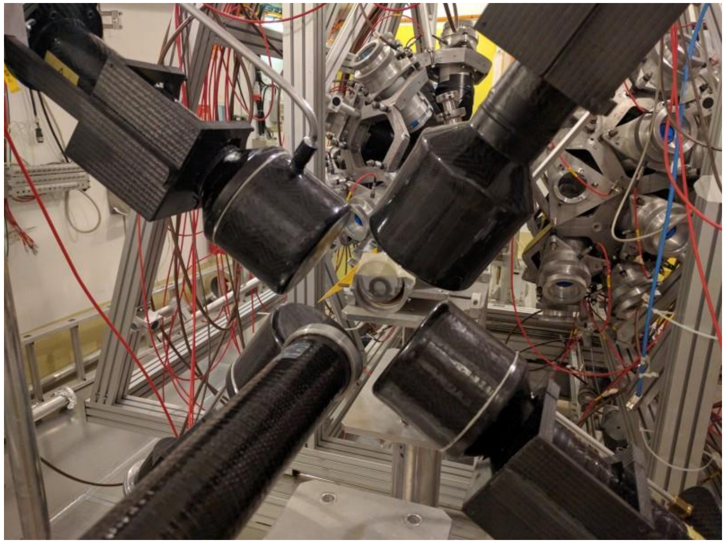
- From the current status of the data a **±33%** uncertainty in the value of the 205Tl(n,γ) is assumed

- This leads to an approx. **18%** global uncertainty in the **^{205}Pb/^{204}Pb ratio** only due to this reaction

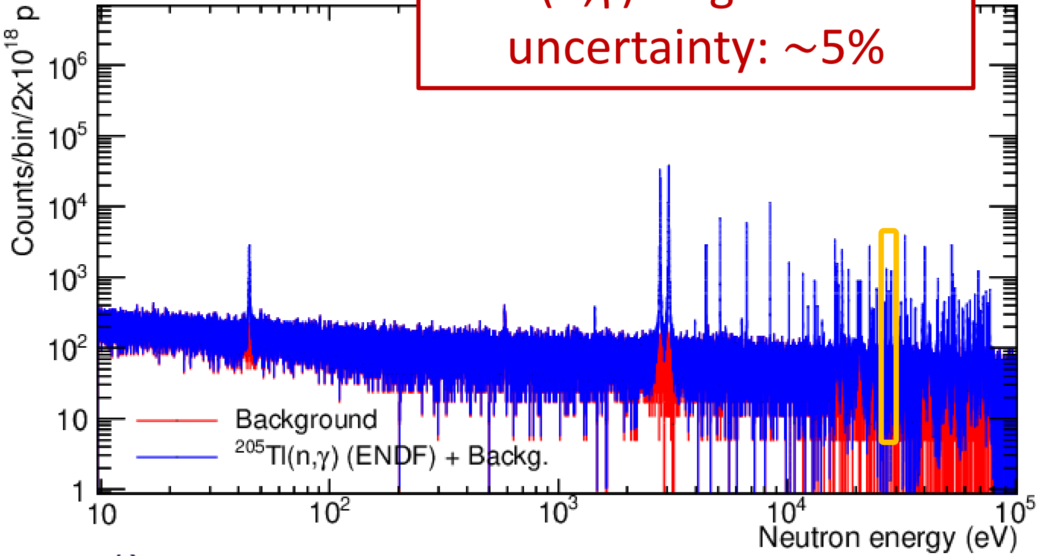
- Goal: increase precision and accuracy of ^{205}Tl(n,γ) to reduce the uncertainty in the ^{205}Pb/^{204}Pb ratio

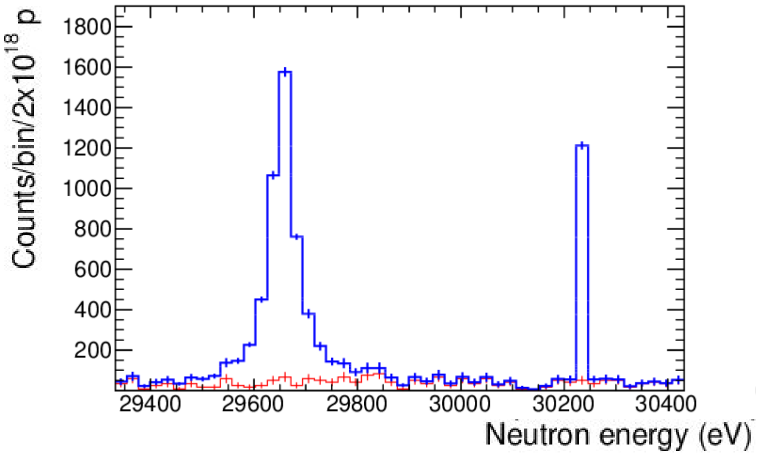
Experimental set-up and counting rate estimation

- 4 C_6D_6 detectors in n_TOF EAR1
  - Best energy resolution at the astrophysical energy range (1-100 keV range)
- Sample: 4 g of 99% pure ^{205}Tl oxide (to be acquired). Size: 30 mm D., 1 mm thick.
- 2×10^{18} protons to achieve a 2.5% statistical uncertainty at the 30 keV ^{205}Tl predicted resonances



^{205}Tl(n,γ) targeted total uncertainty: ~5%





Summary of requested beam time

Sample	Purpose	Protons
^{205}Tl	^{205}Tl(n,γ) with C6D6	$2{\cdot}10^{18}$
Dummy	^{205}Tl sample background	$5{\cdot}10^{17}$
Au, Pb, C	Normalization, beam induced background estimation	$5{\cdot}10^{17}$
TOTAL		**$3{\cdot}10^{18}$**

Final remarks

- The examination of the literature and databases shows that the cross section for the $^{205}Tl(n,\gamma)^{206}Tl$ reaction in the regions of astrophysical interest remains still uncertain (33% assumed uncertainty in the MACS value).

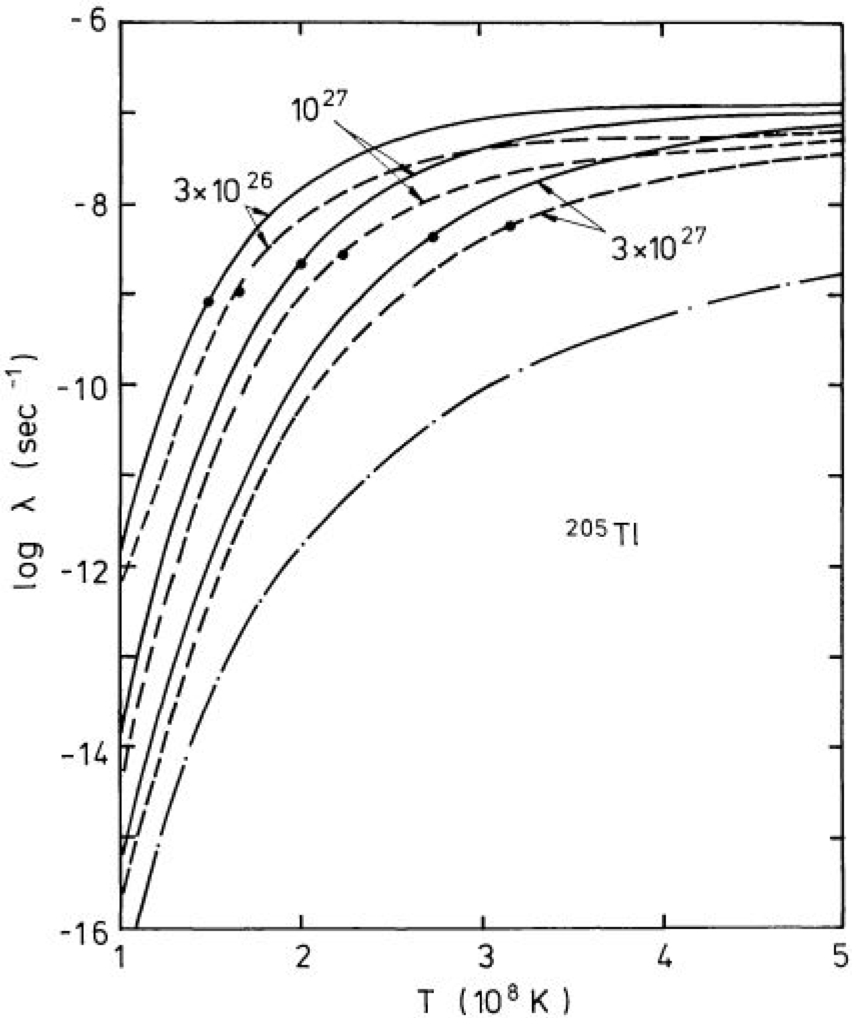
- The measurement proposed for EAR1 would improve the accuracy and precision of the $^{205}Tl(n,\gamma)$ cross section in the astrophysical energy range (1-100 keV, 5% goal of total uncertainty).

- The new CS will lead to an improvement of the $^{205}Pb/^{204}Pb$ ratio estimation (with the targeted CS uncertainty, down to **2.5%**)

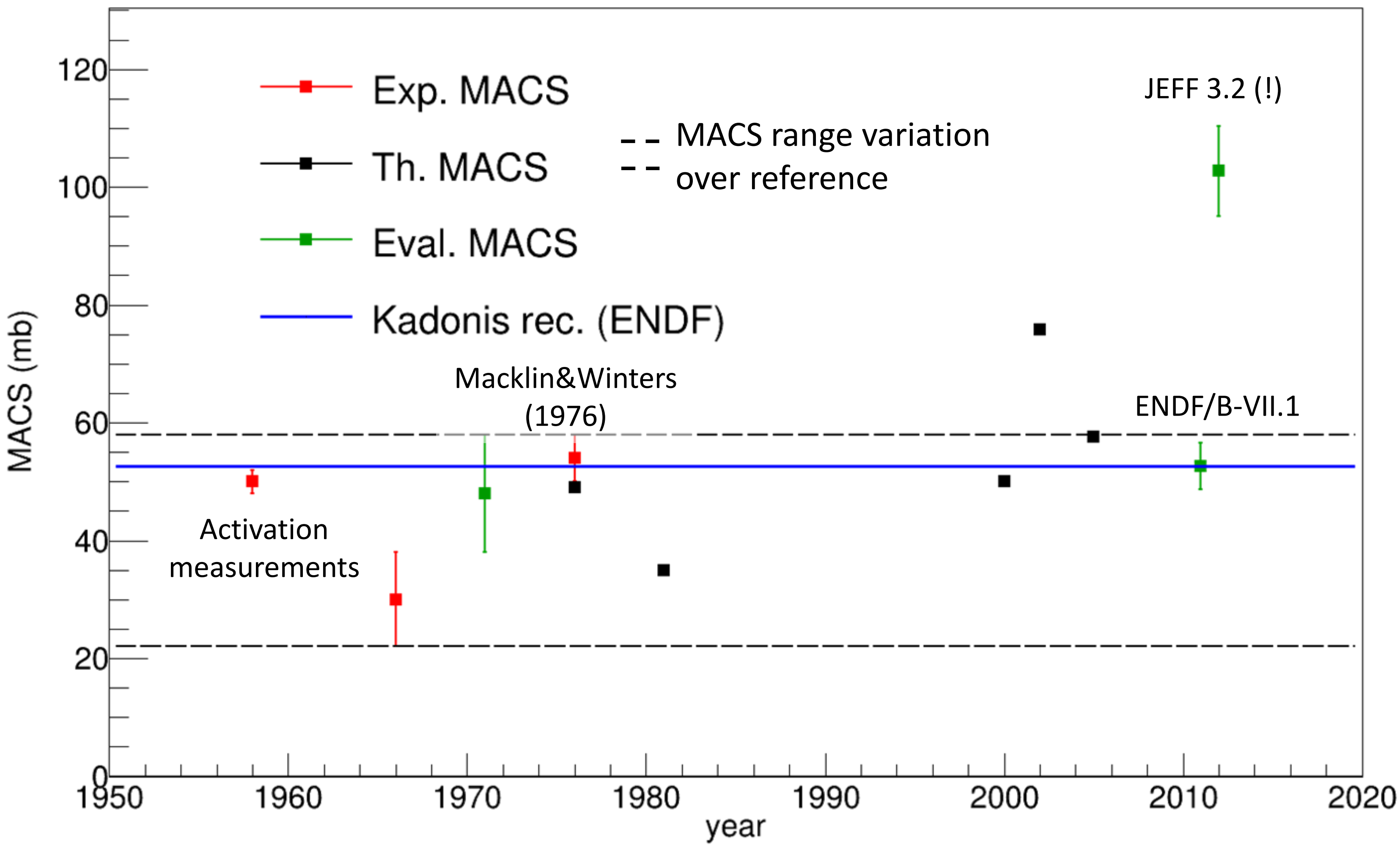
- It will, as well, contribute to a complete and reliable interpretation of the branching pattern around ^{204}Tl (whose capture cross-section results we expect to publish this year), important for the study of the third s-process lead isotopes peak

Thank you for your attention.

^{205}Tl decay vs ^{205}Pb decay

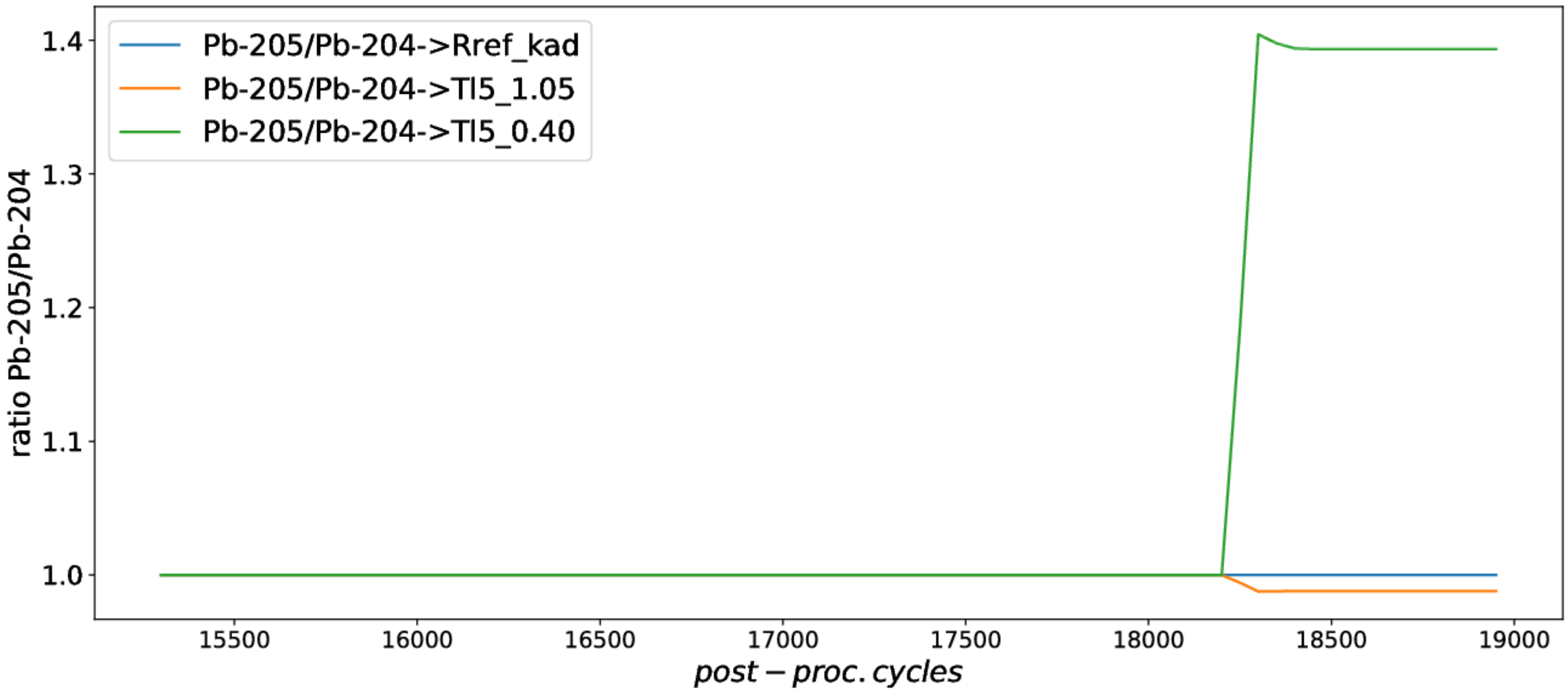


^{205}Tl(n,γ) MACS: -40% to +5%



$^{205}Tl(n,\gamma)$ MACS: -40% to +5%

$^{205}Pb/^{204}Pb$ abundance ratio in the stellar envelope (normalized to the ref. rate)



Sensibility study from A. Koloczek et al. (2016)

- Atomic Data and Nuclear Data Tables 108 (2016) 1–14
- Sensitivity:

$$s_{ij} = \frac{\Delta N_j / N_j}{\Delta r_i / r_i}$$

Table K
Reactions with strongest local sensitivities in the ^{13}C-pocket for each isotope.

Isotope	Most important reactions with respective sensitivities					
^{205}Tl	^{205}Tl(n, γ)	−0.849	^{142}Nd(n, γ)	0.174	^{202}Hg(n, γ)	0.127

Table L
Reactions with strongest local sensitivities in the TP for each isotope.

Isotope	Most important reactions with respective sensitivities					
^{205}Tl	^{205}Tl(n, γ)	−0.520	^{205}Pb(n, γ)	−0.446	^{205}Pb(β^+)	0.413