^{94}Nb(n,γ) proposal

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nTOF

n_TOF Collaboration Meeting, CERN, 11th June 2020

Outline

- Motivation
  - Astrophysical.
  - Nuclear waste.
  - State of art for $^{94}Nb(n,\gamma)$.
- Samples and experimental setup
  - Samples and detectors.
  - Threshold and efficiency.
- Expected counting rate
  - Level of the different components.
- Monte Carlo experiment
  - Feasibility of RRR and URR.
- Possible (future) activation measurement in NEAR
- Summary and conclusions

Astrophysical motivation

Plasmas for Astrophysics, Nuclear Decays Observation and Radiation for Archaeometry

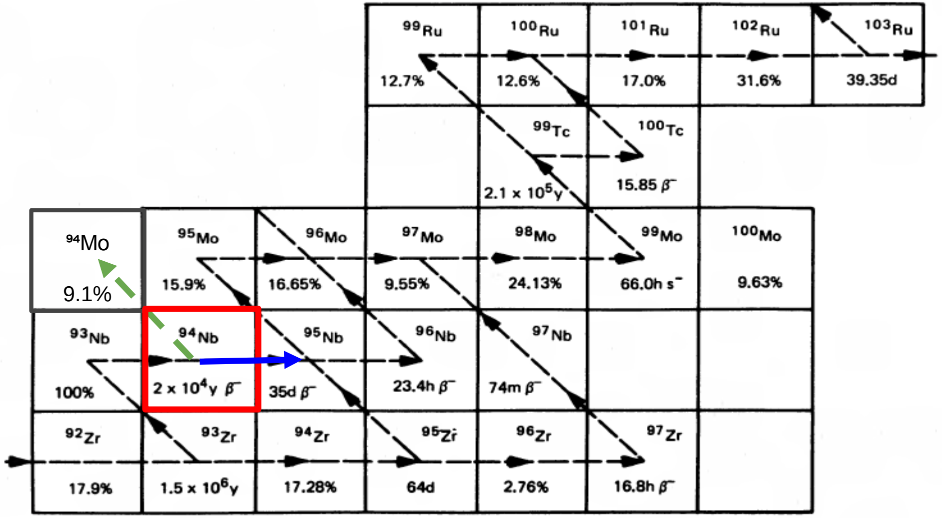


FIG. 1.—The *s*-process path in the molybdenum and technetium mass region

Interesting astrophysical case:

- Anomalies on **Mo isotopes** found in presolar grains.
  Earth and planetary science letters, Vol473, 215-226 (2017) 94

Very Preliminary calculations from **Sergio Cristallo** (Many thanks!):
Increased the MACS by 2 (482 mb reference) @ at 30 keV → **+14% ^{94}Mo/^{96}Mo** ratio.

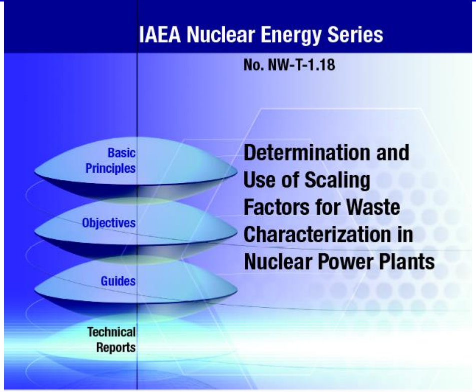
- **Isotope of interest** for **β-decays** in **plasmas** for stellerar nucleosynthesis (**PANDORA** -INFN)
  EPJ Web of Conferences **227**, 010 (2020)

Better constrain the **contributions** from the **s-process and the p-process** to the proton-rich **^{94}Mo.**

Nuclear Energy motivation

^{94}Nb isotope is present in low and intermediate nuclear waste:

- Activation of Zr present in different components of the reactor.
  Applied Radiation and Isotopes 66 (2008) 24–27
- One of the major contribution to radiotoxicity (No actinides).



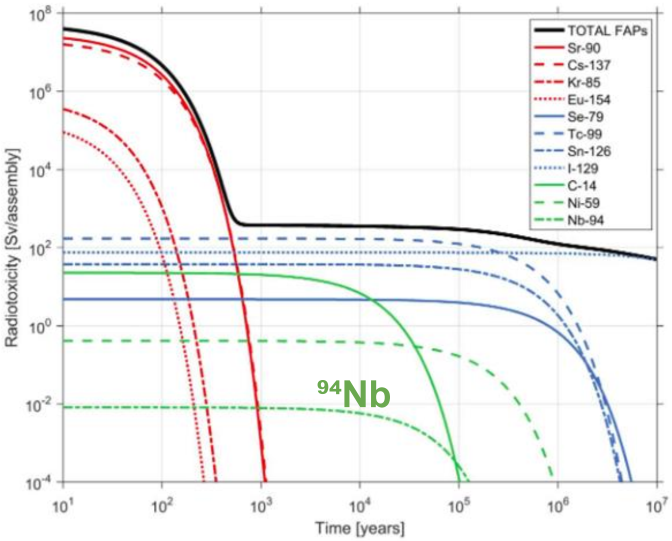
A–3.2. Radionuclides of interest

For OPG's DGR, the main radionuclides of interest for the pre-closure safety assessment are (Table A-7): ^{3}H, ^{14}C, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{241}Am and ^{241}Pu. For the post-closure safety assessment, the main radionuclides of interest are: ^{14}C, ^{36}Cl, ^{93}Zr, ^{94}Nb, ^{99}Tc, ^{129}I, ^{135}Cs, ^{233}U, ^{238}U, ^{233}Pa, ^{237}Np, ^{241}Am and ^{241}Pu.

SFs have also been developed for other DTM nuclides, such as ^{55}Fe, ^{59}Ni, ^{63}Ni, ^{79}Se, ^{126}Sn, ^{242}Cm, ^{244}Cm and ^{243}Am.

TABLE A–11. MAIN RADIONUCLIDES TO BE MEASURED IN LOW AND INTERMEDIATE LEVEL WASTE

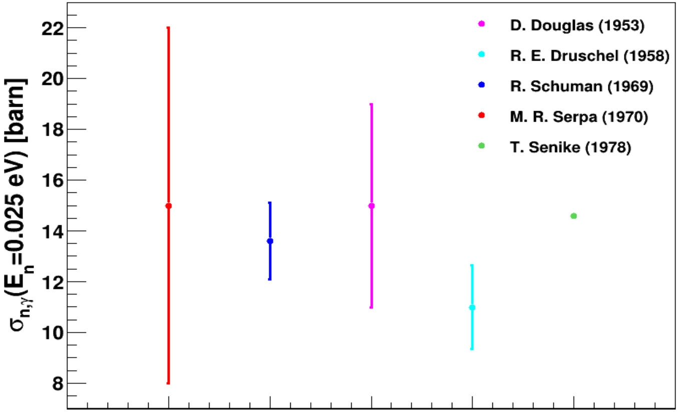
Type of radionuclide	Low and intermediate level waste
CP/AP nuclides	C-14, ^{63}Ni, ^{94}Nb, ^{99}Tc, ^{60}Co
FP nuclides	Sr-90, ^{129}I, ^{137}Cs
Alpha emitting nuclides	Total alpha emitting nuclides

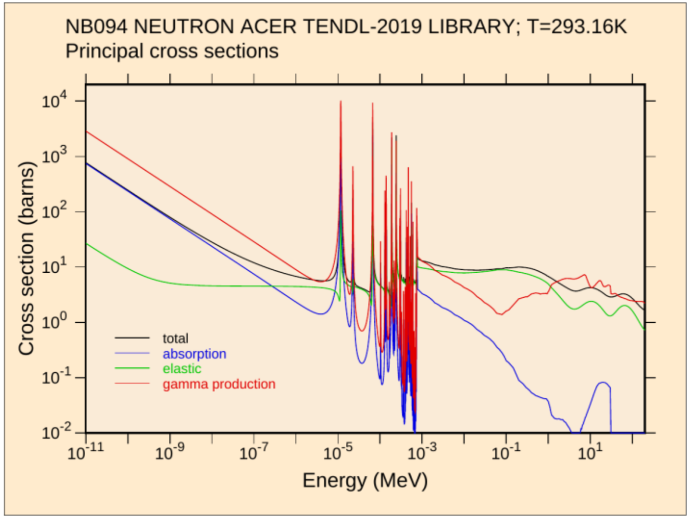


State of art: ^{94}Nb (n,γ) measurements

- Experimental data in the thermal point agree within uncertainties.
- **No experimental data** available for the **Resolved Resonance Region (!)**.
- No data available for the Unresolved Resonance region.

Estimation of Resolved /Unresolved Resonance Region based on **TENDL-2019**





State of art: ^{94}Nb (n,ɣ) measurements

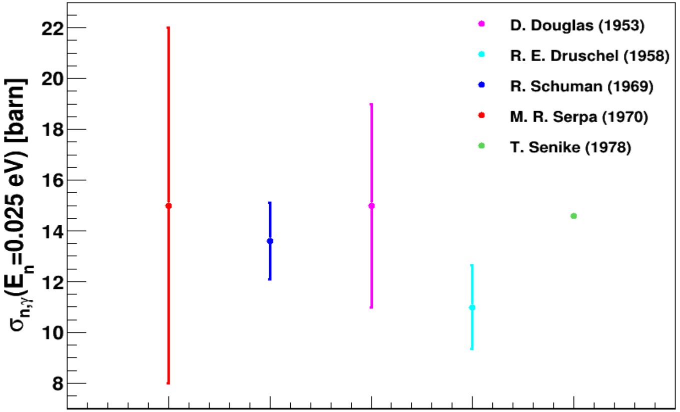
- Experimental data in the thermal point agree within uncertainties.

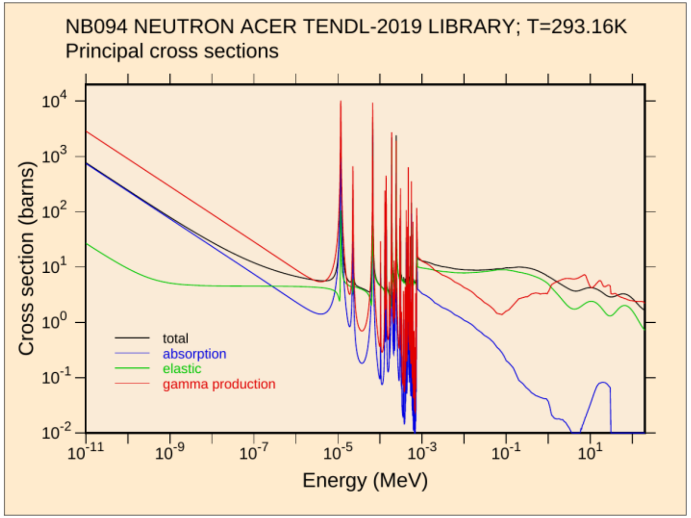
- **No experimental data** available for the **Resolved Resonance Region (!)**.

- No data available for the Unresolved Resonance region.

Estimation of Resolved /Unresolved Resonance Region based on **TENDL-2019**

GOAL: Measure RRR as high in neutron energy as possible.





Available samples and Experimental setup

Sample	A(^{94}Nb+^{60}Co)[Mbq]	N(^{94}Nb) [10^{18}]	ns(^{94}Nb)[barn^{-1}·10^{-6}]	N(^{93}Nb) [10^{20}]	ns(^{93}Nb) [barn^{-1}·10^{-4}]
foil (5) 15x18 mm²	5.39+(1.026)	4.97813	1.84375	8.81	3.26404
foil (6) 8x36 mm²	8.92	8.23838	3.05125	16.00	5.92593
wire (2)	4.85	4.47939		9.39	
wire (3)	5.16	4.47939		10.30	

^{94}**Nb** samples **already produced**:

- Irradiated together with ^{79}Se sample in ILL.
- **Hyper-pure** ^{93}**Nb** raw material.

All the samples were **characterized at PSI** in December 2019:

- Exhaustive analysis carried out.

Foil (6) and (5) have better shape for **ToF** measurement. Wire (2) and (3) require “reshape”.

Considered the **high activity** of the samples (and the expected 94Nb capture yield):

- Experimental setup:
  - **EAR 2.**
  - **4 C_6D_6/ C_6D_6+SiPM**

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- Assumptions in CR estimations:
  - BIF=0.25 (EAR2)
  - 1000 bin per decade
  - Efficiency (n,ɣ)/A (MC)
  - Cross section from TENDL-2019

Detection efficiency and background suppression

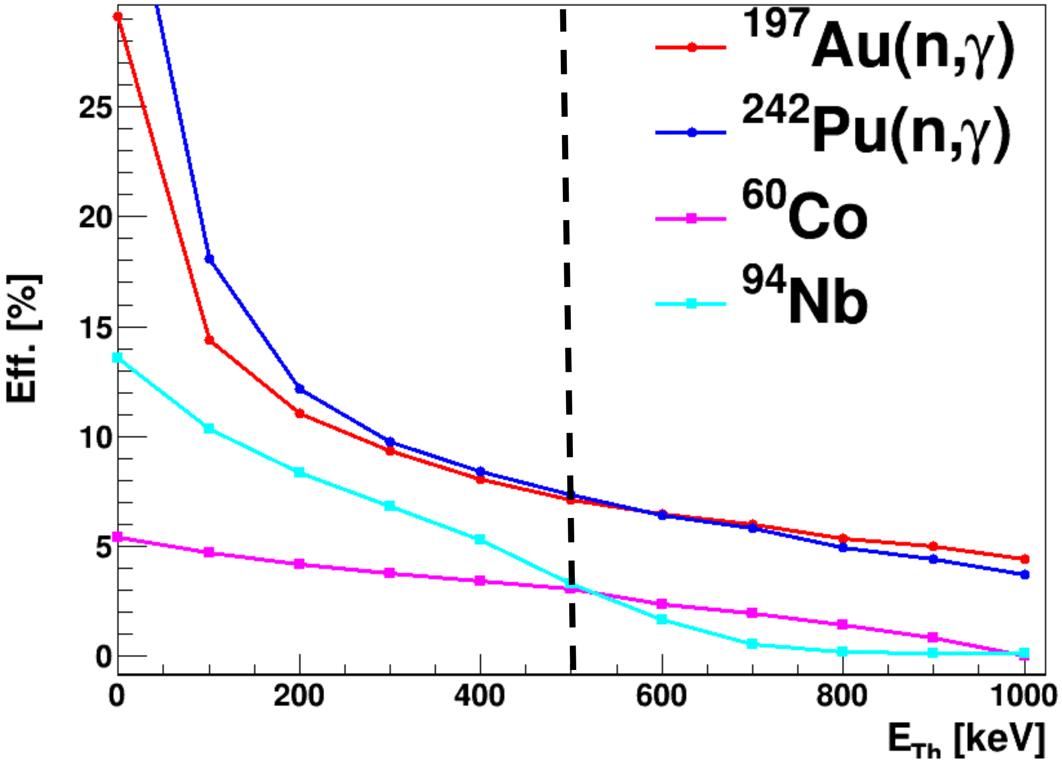
Monte Carlo simulation for 4 C_6D_6 at a reasonable distance (10 cm).

Cascade detection efficiencies calculated for:

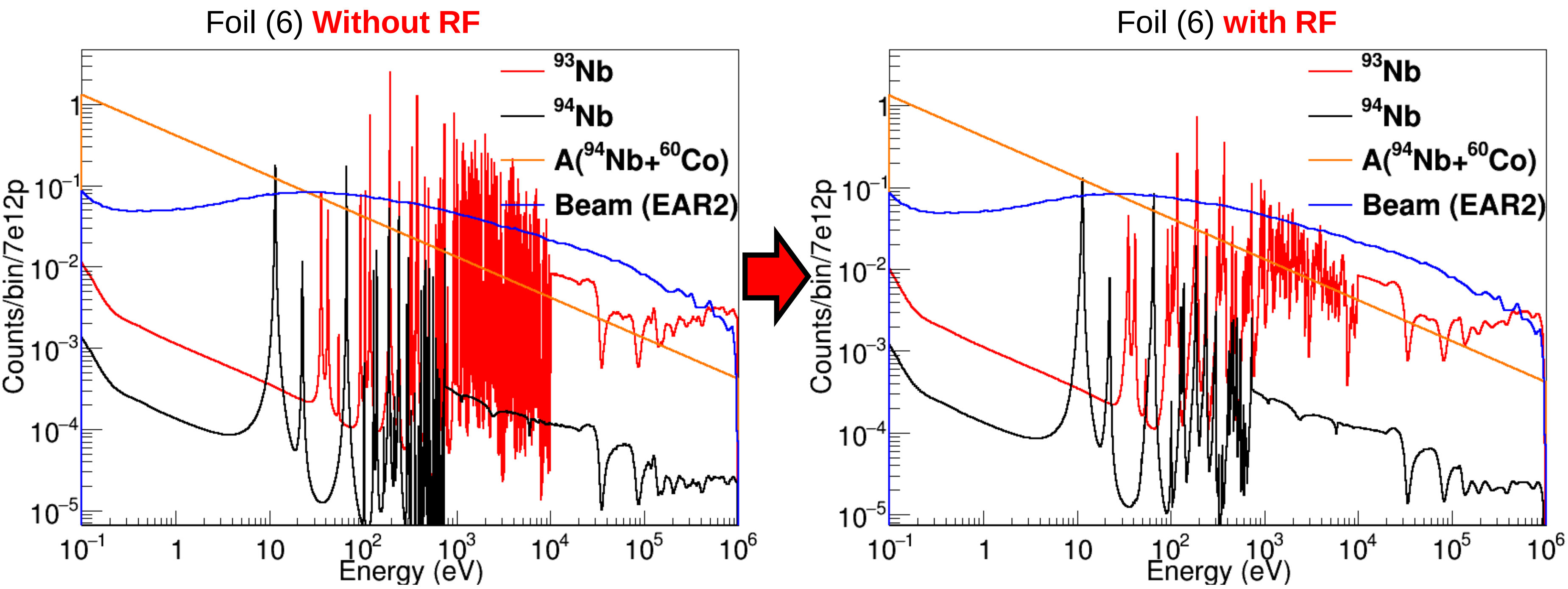
- ^{197}Au(n,ɣ)
- ^{242}Pu(n,ɣ)
- ^{60}Co (1100-1300 keV)
- ^{94}Nb (700-900 keV)

A **reasonable trade off** between (n,ɣ) efficiency and background suppression is **500 keV**.

Low detection efficiency can be compensated by weighting technique.



Counting rate for ^{94}Nb foil in EAR2



- Included the Resolution Function (Phase III) to check the neutron energy limit resolving resonances:
  - Resolution function Phase III is the worst scenario → In 2021 the expected RF should be better.
  - The true yield will lie between the ideal case and RF (Phase III) scenario.

- **C_6D_6+SiPM** development would help to **reduce the level of beam background**.

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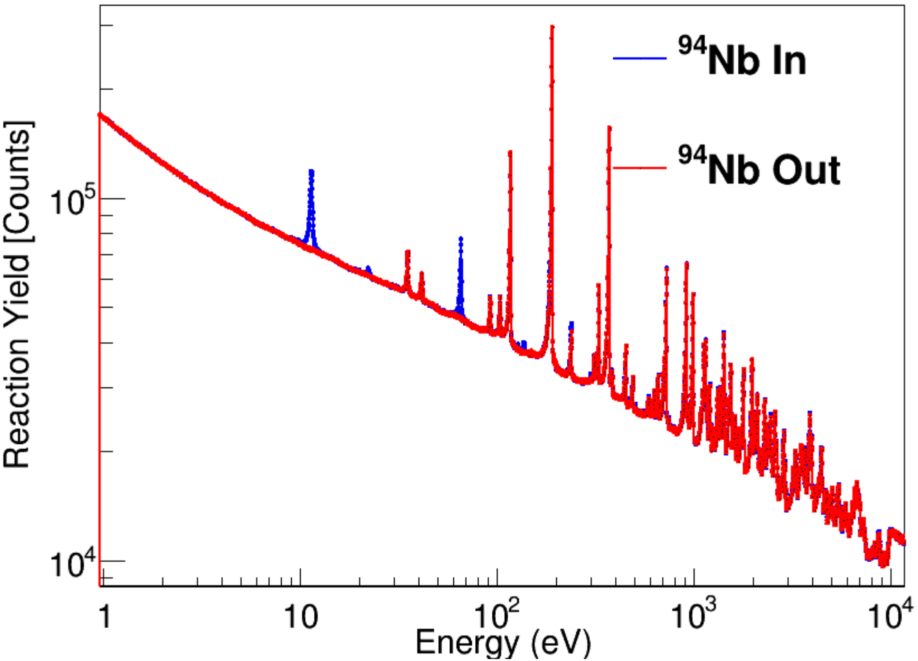
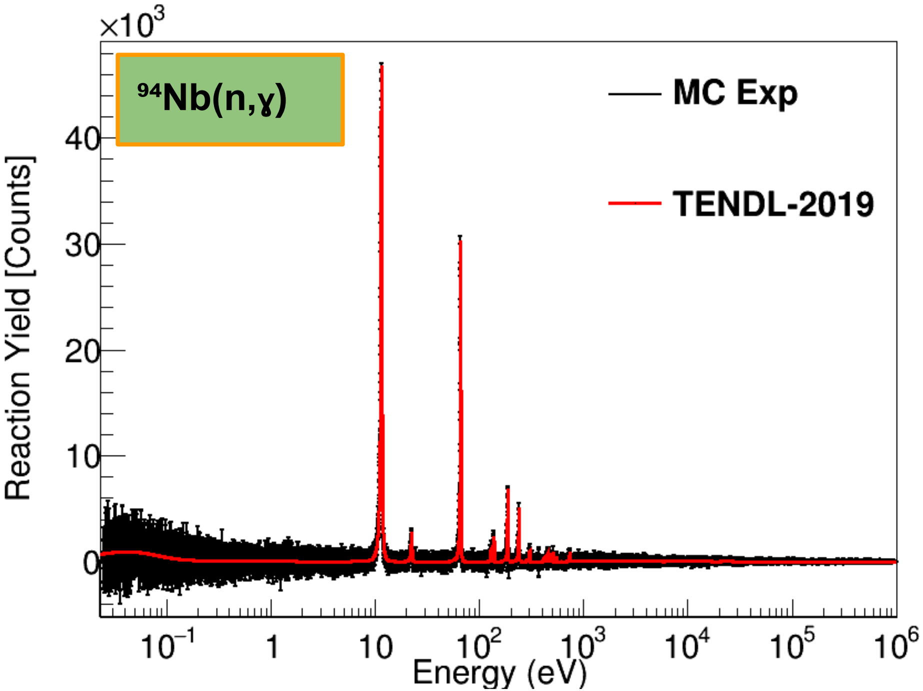
Monte Carlo experiment for ^{94}Nb foil (6)





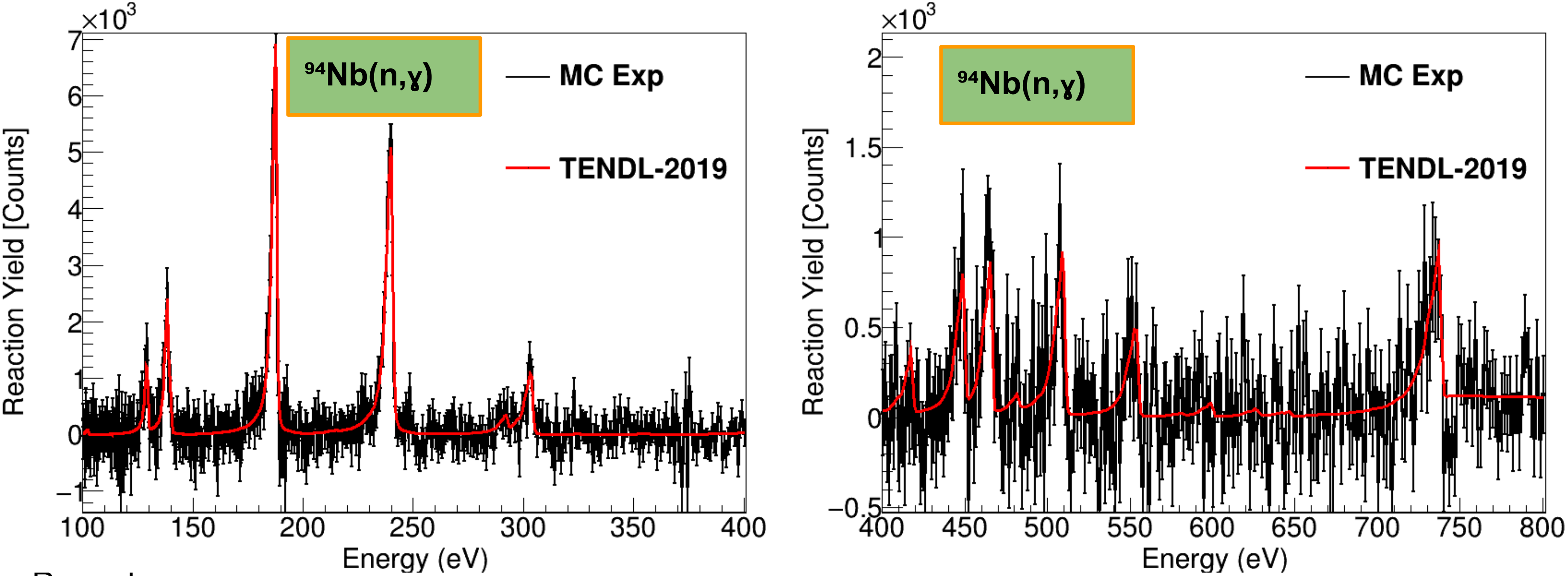
Resampling Monte Carlo experiment to consistently account for feasibility and uncertainties:

- Resampling from individual proton pulses.
- $2.5 \cdot 10^{18}$ p for isotope under study.
- $0.5 \cdot 10^{18}$ p for background estimation.

Background subtraction:

- Regular background subtraction applied for RRR measurement feasibility.
- Expected Statistical uncertainty (Conservative).

Background subtraction in the RRR

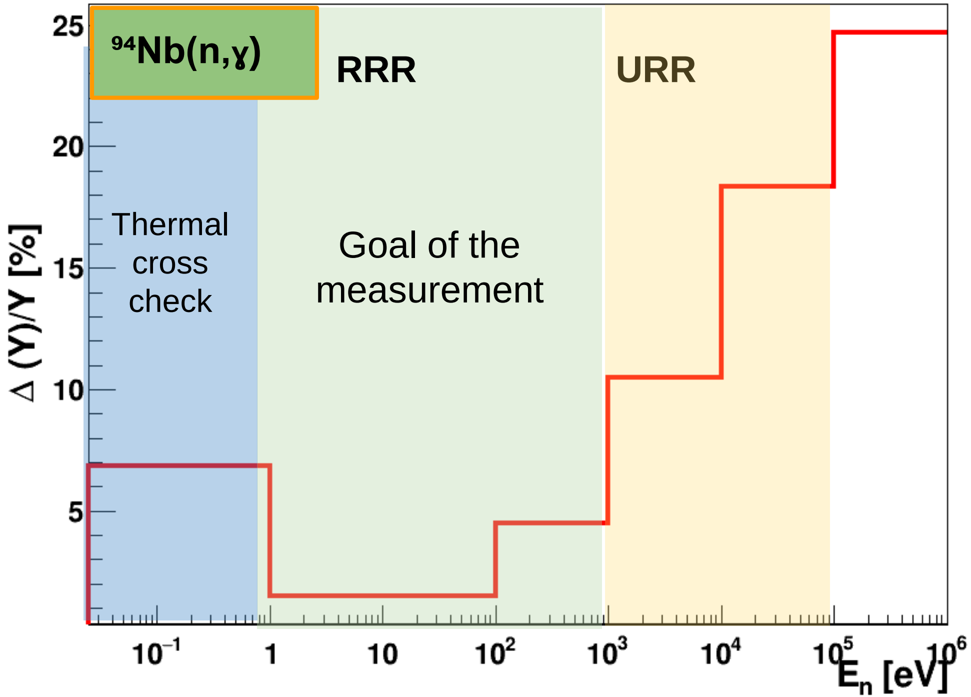


Remarks:

- For neutron energies below 400 eV the individual TENDL resonances are detectable by the background subtraction.
- For neutron energies above 400 eV the individual TENDL resonances are difficult to detect.

Remember yield including the Resolution function (**Phase III**) is the **worst scenario**!

Expected statistical uncertainty



Statistical uncertainty check:

- **Cross check** of cross section at **thermal energies**: Low statistical uncertainty.
- **Goal** of the measurement: **Cross section** measurement would be **feasible** up to < 1keV (RF).
- **Unresolved Resonance Region**: **Complicated** background **subtraction**, still not imposible.

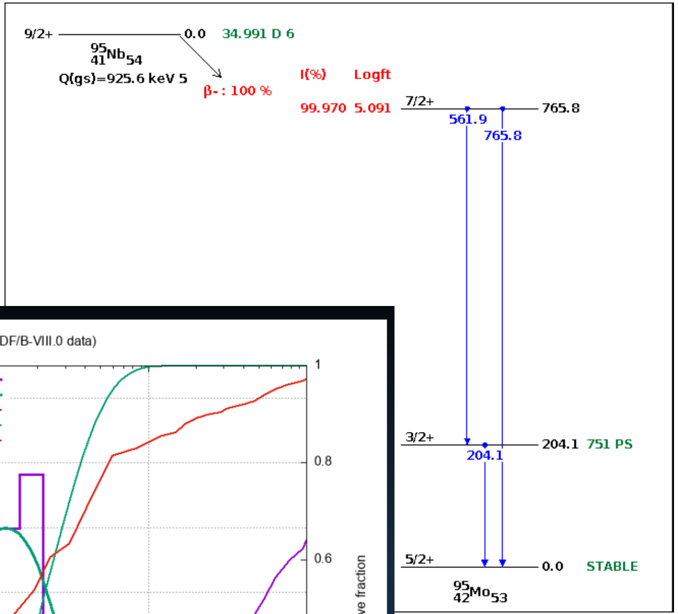
Possible activation measurement in NEAR

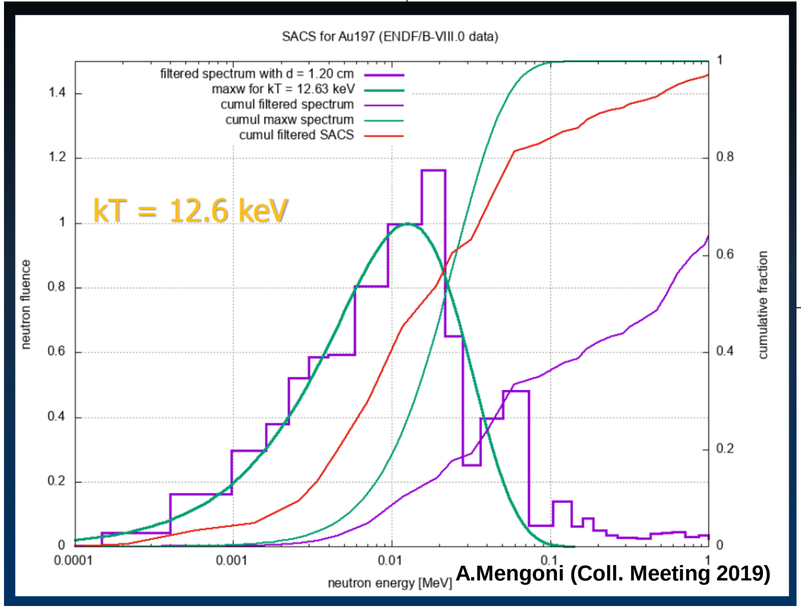
Unfavourable signal to background ratio for URR.

Complicated background **subtraction** for the **Unresolved Resonance Region.**

Activation measurement for NEAR station?

- Flux shaping in the NEAR for MACs or “high” energy flux?
- Four samples available with different shapes.
- Isotope **candidate** for **NEAR** station:
  - **“Short” half life**: ~35 d.
  - **“High” energy ɣ lines** (562,766 keV).





A.Mengoni (Coll. Meeting 2019)

Summary & Outlook

- ^{94}Nb(n,ɣ) is an interesting measurement:
  - **Contributions** from the **s-process and the p-process** to **^{94}Mo/ Isotope of interest** for **β-decays** in **plasmas** .
  - In addition, this is one of the isotopes present in the **nuclear waste**.

- Only a few experimental measurements of this isotope
  - **No experimental data exist yet in the RRR/URR.**

- ^{94}Nb samples already produced -> 2 of them with rectangular shape suitable for ToF:
  - ^{93}Nb/^{94}Nb~1/100.
  - **Activity ~ 6-8 Mbq, "high" energy ɣ lines in the decay**.

- High counting rate due to the high intrinsic activity of the sample:
  - Feasible for **EAR 2**: RRR sure, complicated background subtraction for URR.
  - **High detection threshold** in the detectors for optimal S/B tradeoff (compensated by weighting technique).

- **Reasonable** statistics for RRR using:
  - **$2.5 \cdot 10^{18}$** protons for **isotope** under study.
  - **$0.5 \cdot 10^{18}$** protons for **background** estimation.
  - RF will determine the "high" neutron energy limit resolving resonances.
  - New development **C_6D_6+SiPM** could help to **improve** situation with the **signal/background** ratio.

- Possible isotope **candidate for NEAR station** → "Short" half life, "high" ɣ lines in the decay.

Thank you very much for your kind attention!