Photoneutron Calibration Standard: extracting cross sections of GDR response in the heavy nucleus ^{169}Tm

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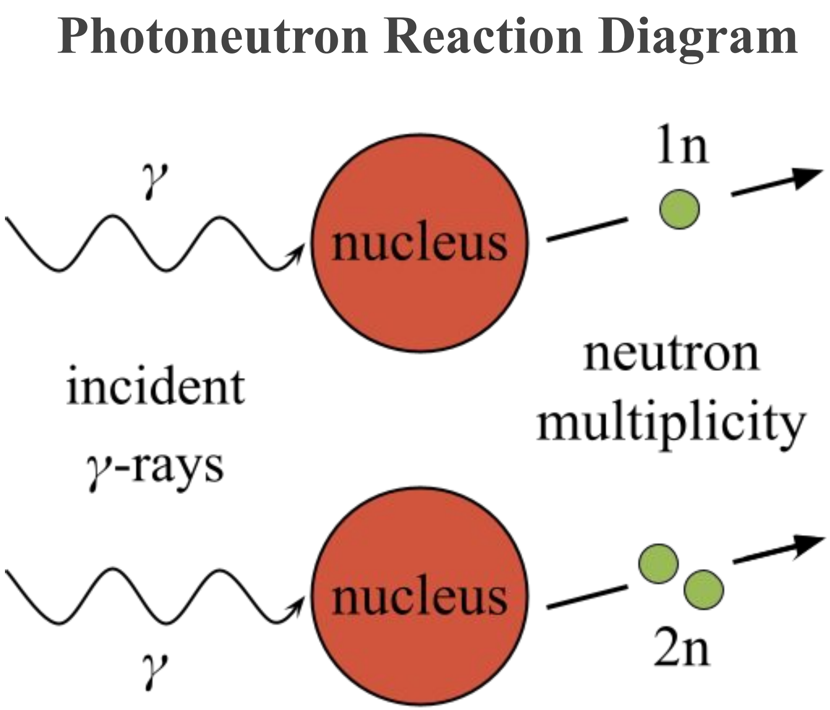
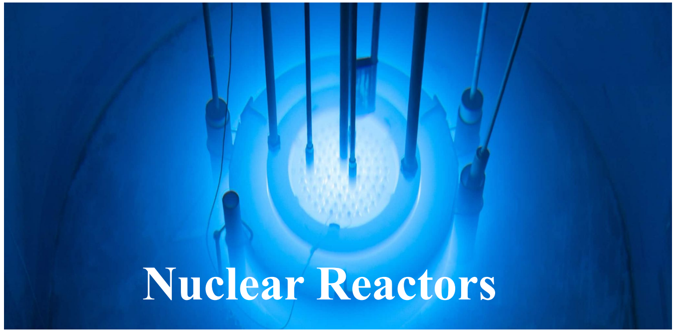
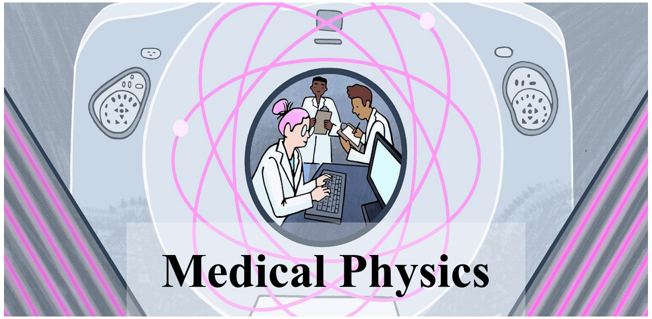
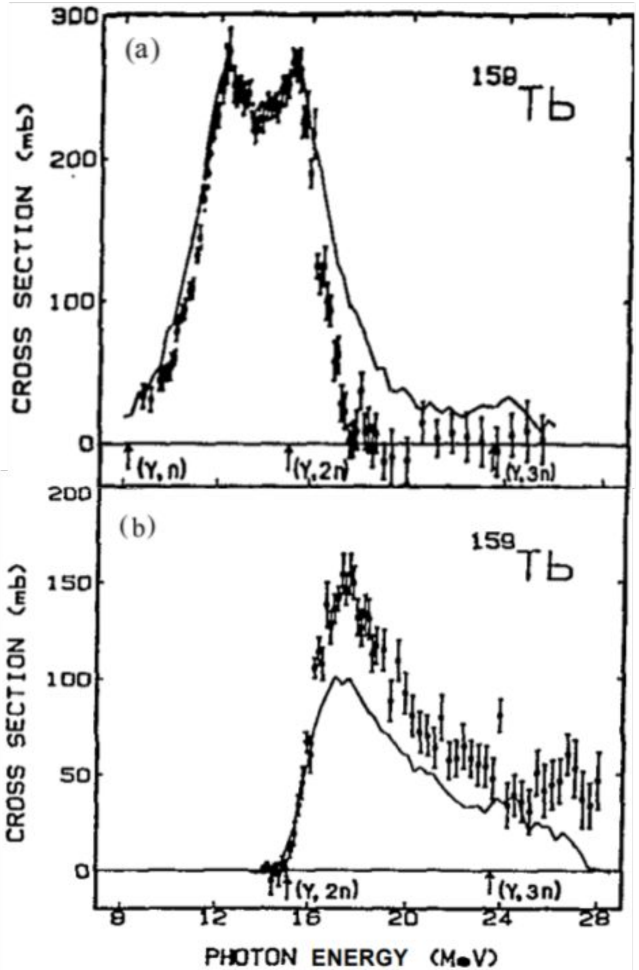
Reaction Relevance







Discrepancies & Detection Difficulties

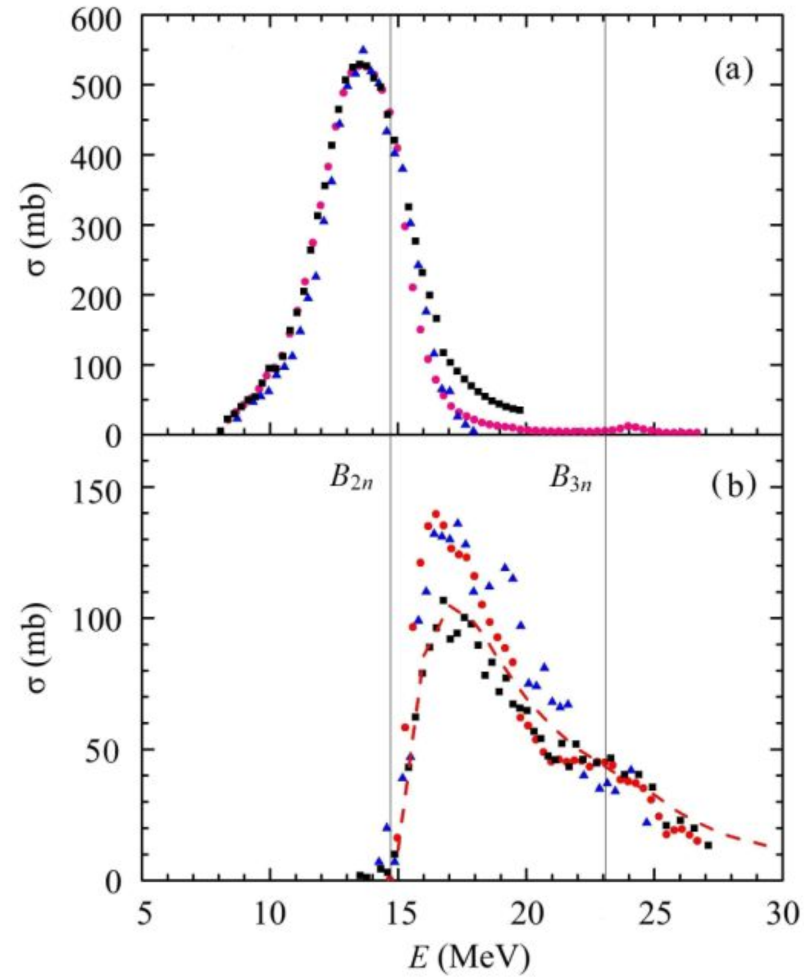


LEFT

(a) ^{159}Tb(γ,1n) and (b) ^{159}Tb(γ,2n) cross sections from Saclay (solid line) and Livermore (data points).

RIGHT

(a) ^{197}Au(γ,1n) and (b) ^{197}Au(γ,2n) cross sections from Saclay (squares) and Livermore (triangles), compared with evaluated data (circles and dotted line).



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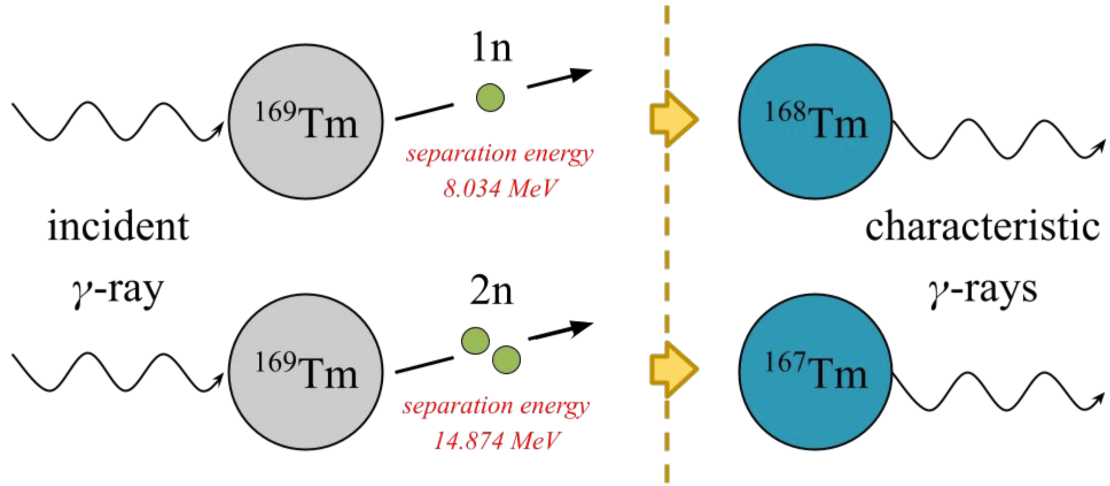
Benefits of Thulium:

- Monoisotopic *(no random byproducts to sift through)*
- Reaction products are unstable nuclei with well-understood decays of characteristic γ-rays.

Reaction Diagram



$$N_{act} = N_{tar} \int_{E_{th}}^{E_0} \sigma_{\gamma,n}(E, E_0)\ \Phi_\gamma(E, E_0)\ dE$$

N_{act} activated atoms

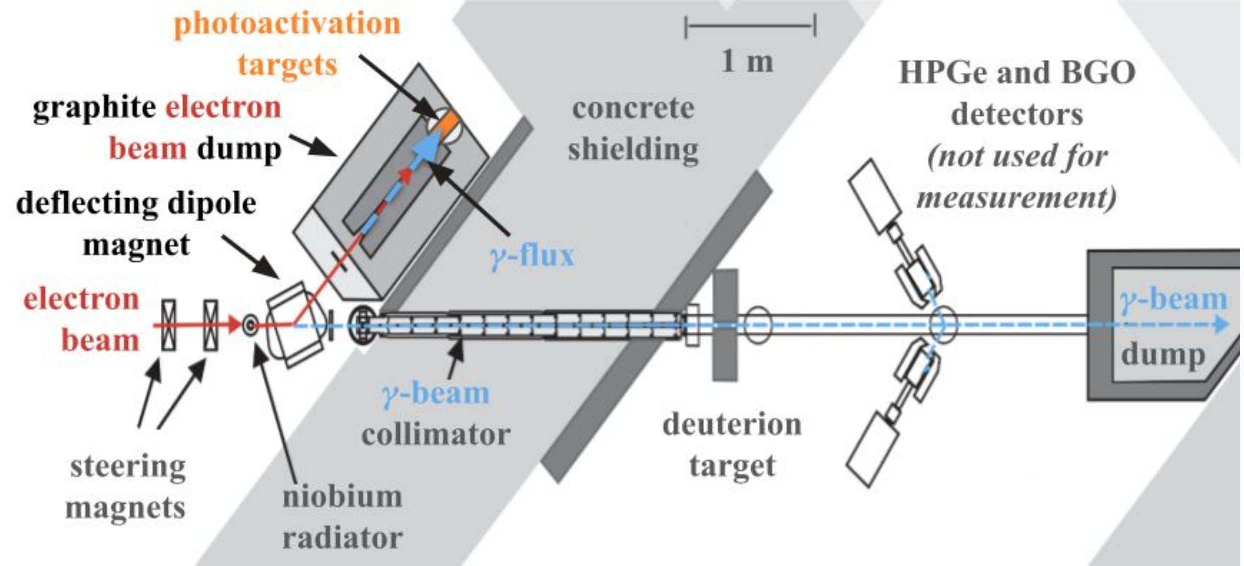
N_{tar} target atoms

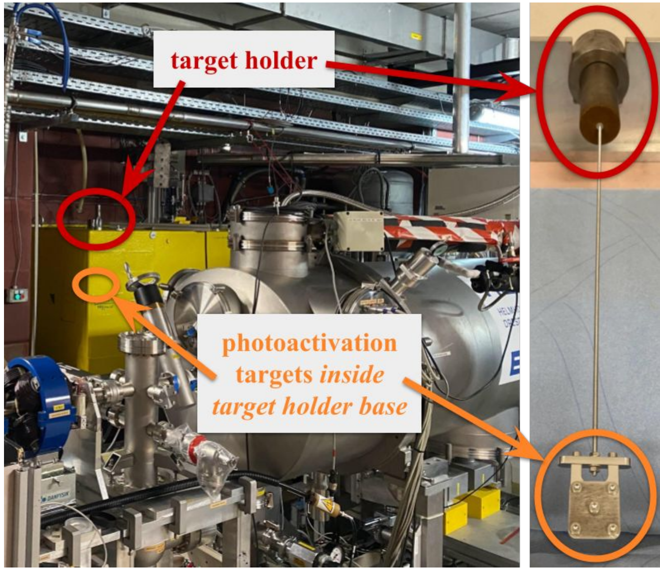
ϕ_γ absolute photon fluence

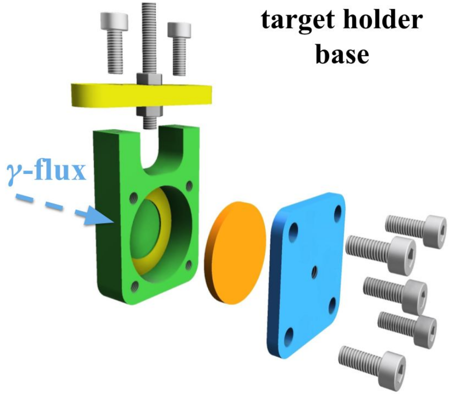
$\sigma_{\gamma,n}$ photoneutron cross section

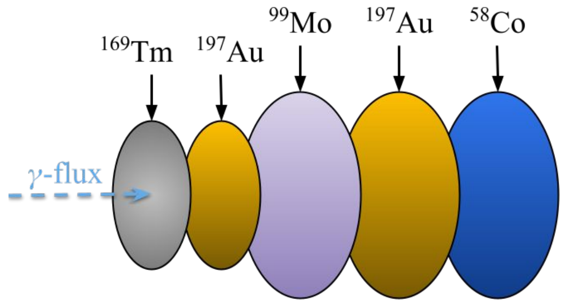
Activation equation (left) connects the number activated target atoms (a measurable quantity) to the cross section.

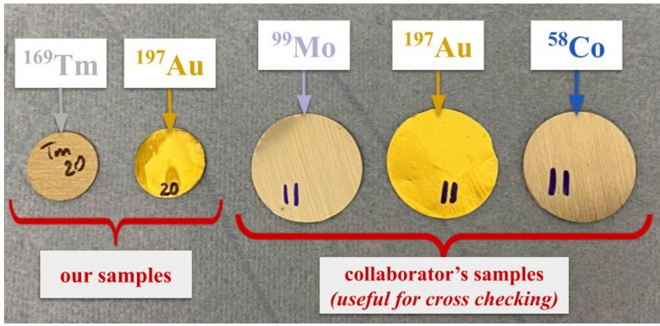
γELBE Facility: Irradiation











γELBE Facility: Detection Setup

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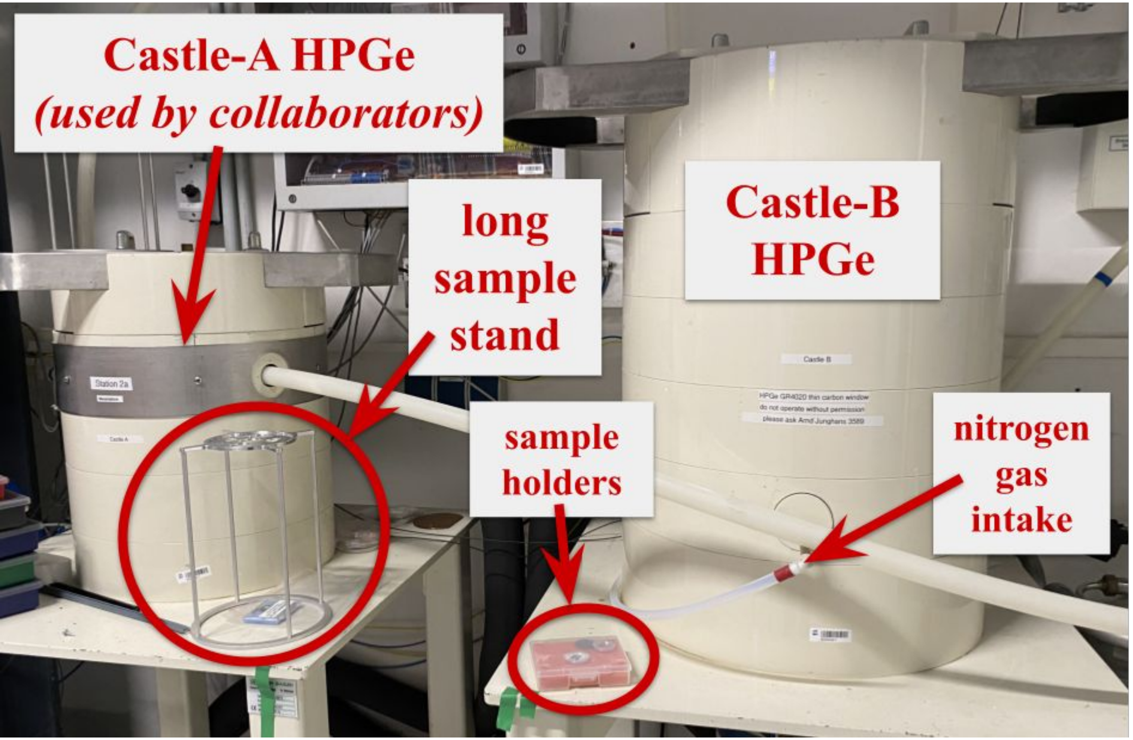
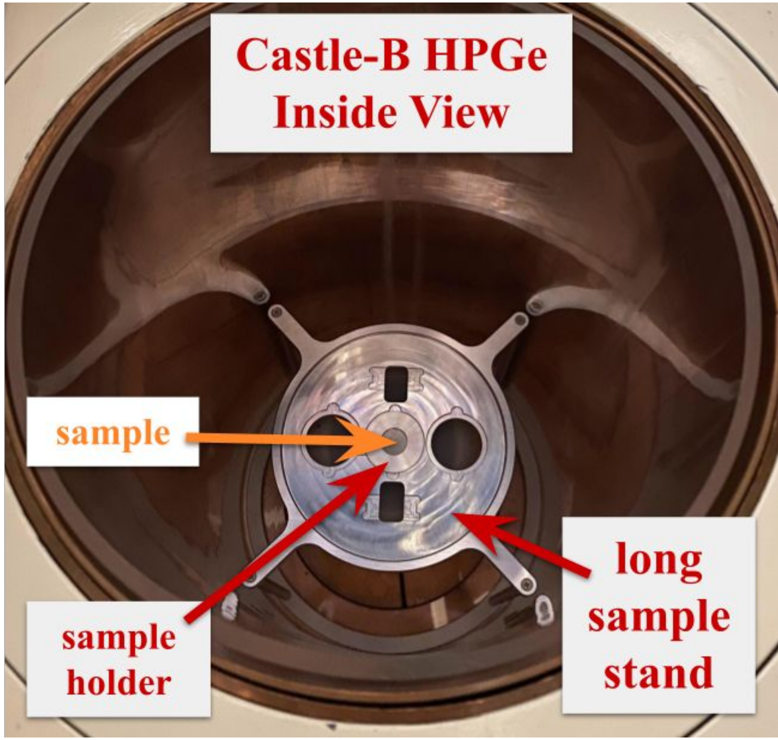
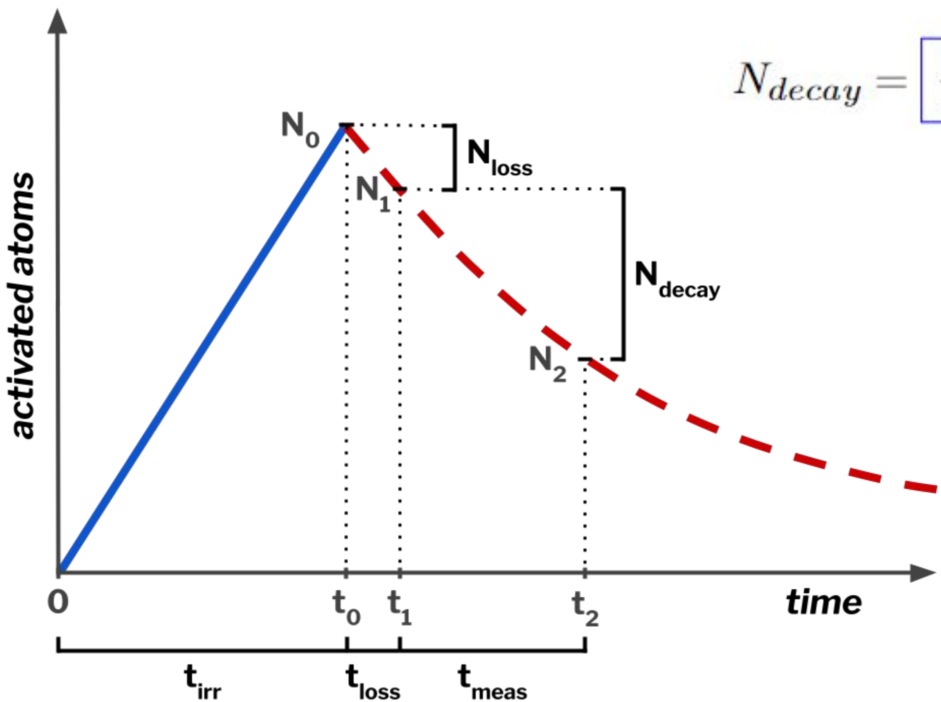




Analysis Methodology



$$N_{decay} = \underbrace{\frac{P}{\lambda}(1 - e^{-\lambda t_{irr}})}_{\text{activation}} \; \underbrace{e^{-\lambda t_{loss}}}_{\text{decay loss}} \; \underbrace{(1 - e^{-\lambda\, t_{meas}})}_{\text{measurement}}$$

t_{irr}	irradiation time	t_{meas}	measurement time
t_{loss}	time from irradiation end to measurement start		
N_{decay}	activated atoms which decayed during t_{meas}		

$$N_{decay} = N_{meas} \;/\; \eta(E_\gamma)$$

N_{meas} total corrected counts during t_{meas}

η total detector efficiency at γ-energy E_γ

$$N_{act}(t) = \frac{P}{\lambda}(1 - e^{-\lambda t}), \qquad 0 \le t \le t_{irr}$$

P production rate $\qquad$ λ decay constant

End Result

$$\sigma_{\gamma,n}(E_{\gamma,i-1}, E_{\gamma,i}) = \frac{N_{act}(E_{\gamma,i}) - N_{act}(E_{\gamma,i-1})}{N_{tar}\; \Phi_\gamma(E_{\gamma,i-1}, E_{\gamma,i})}$$

Measurement Results: Spectra

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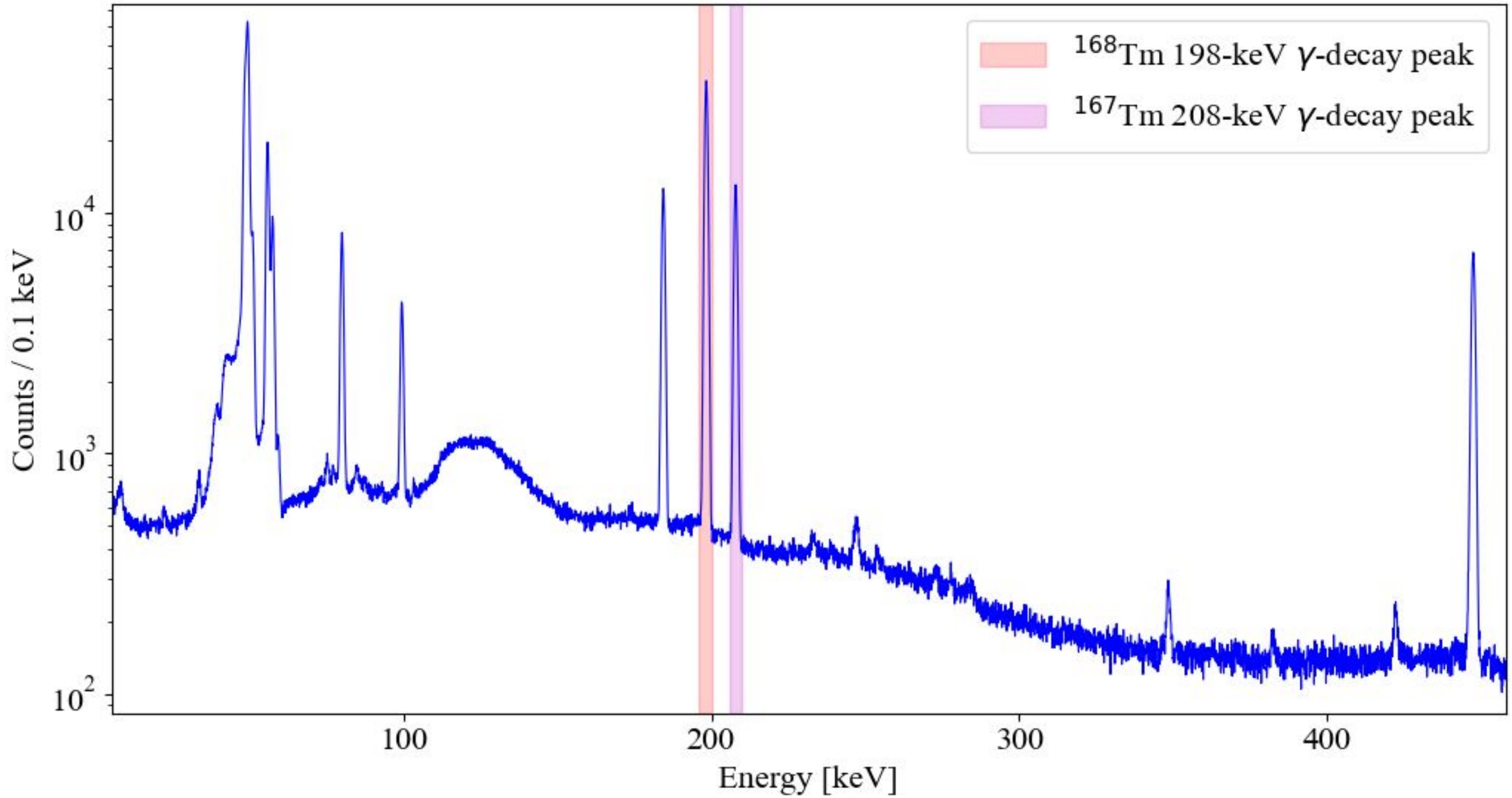


^{169}Tm target spectrum, irradiated at 18-MeV endpoint-energy γ-rays. Prominent 198-keV and 208-keV decay channel peaks from ^{169}Tm(γ,1n)^{168}Tm and ^{169}Tm(γ,2n)^{167}Tm, respectively.

Thanks!

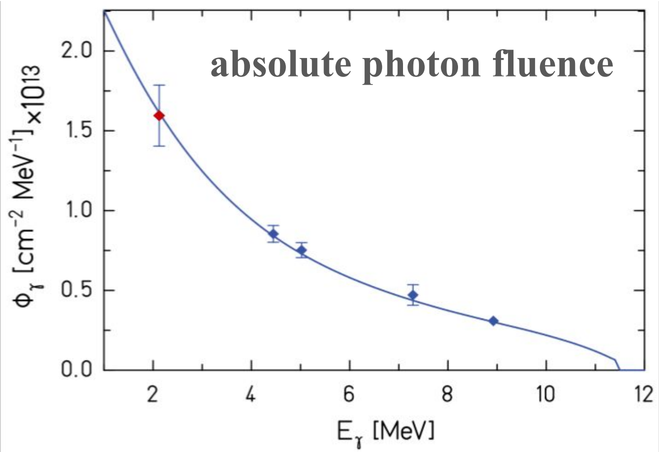
Questions?

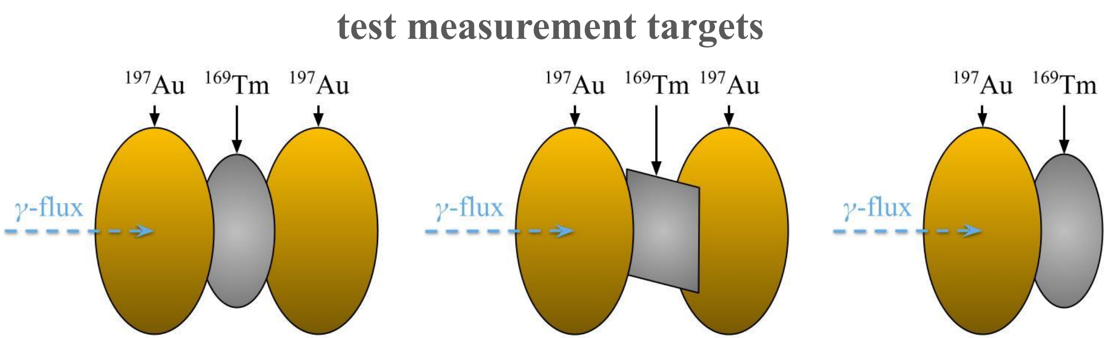
Bonus Slide 1: Bremsstrahlung Creation

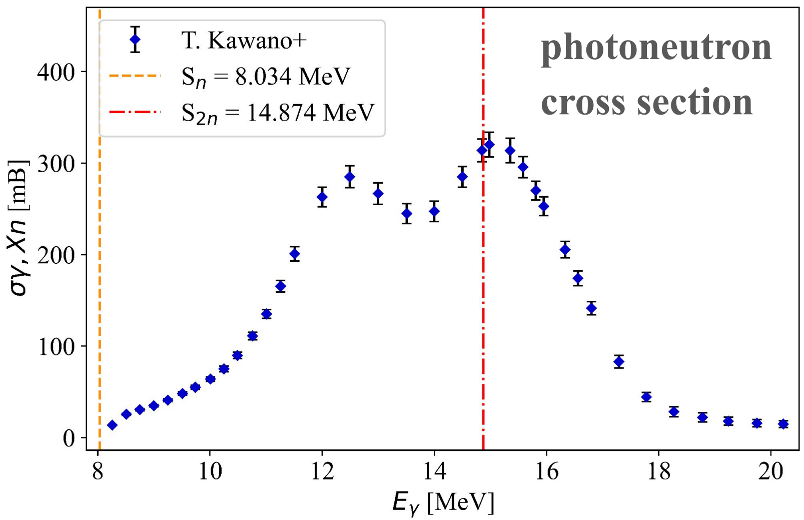
Eq. 1 shows the differential cross section for the creation of a Bremsstrahlung with an energy E_γ in a thin target, assuming incident electron with total energy E_0 (our endpoint energy).

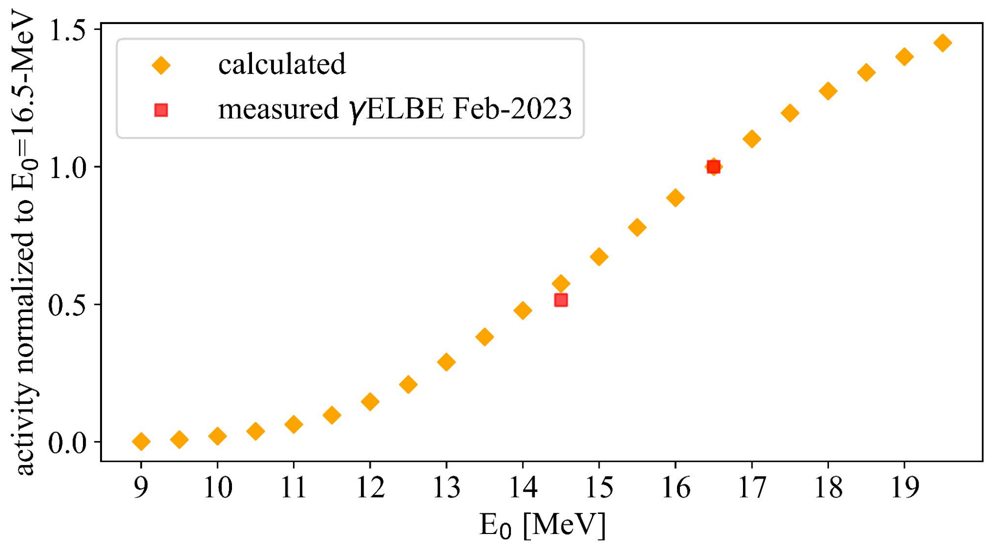
$$\frac{d\sigma}{dE_\gamma} = \frac{2\alpha Z^2 r_e^2}{E_\gamma}\left[\left(\frac{E_0^2+E_e^2}{E_0^2} - \frac{2E_e}{3E_0}\right)\left(\ln M + 1 - \frac{2}{b}\arctan b\right) + \frac{E_e}{E_0}\left(\frac{2}{b^2}\ln\left(1+b^2\right) + \frac{4}{3}\frac{2-b^2}{b^3}\arctan b - \frac{8}{3b^2} + \frac{2}{9}\right)\right] \quad (1)$$

$$M = \left[\left(\frac{m_e E_\gamma}{2E_0 E_e}\right)^2 + \frac{Z^{2/3}}{C^2}\right]^{-1} \qquad b = \frac{2E_0 E_e Z^{1/3}}{C m_e E_\gamma}.$$


absolute photon fluence
Φγ [cm⁻² MeV⁻¹]×10¹³
Eγ [MeV]


test measurement targets
197Au
169Tm
197Au
γ-flux


T. Kawano+
Sn = 8.034 MeV
S2n = 14.874 MeV
photoneutron
cross section
σγ, Xn [mB]
Eγ [MeV]


calculated
measured γELBE Feb-2023
activity normalized to E0=16.5-MeV
E0 [MeV]