CENBG

Neutron-induced capture cross sections of short-lived nuclei via the surrogate reaction method

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Outlook

- **Motivation**
- How to overcome experimental difficulties for Actinides $\sigma(n,\gamma)$
- **(^{3}He,pγ) as a surrogate :**
  - **- ^{234}Pa measurement**
  - - ^{175}Lu measurement
- Summary

Cross section measurements of short-lived nuclei are they important ?

✓ Reactor designs & waste management

- ☒ Transmutation of Minor Actinides produced in U/Pu cycle

  → In transmutation the intention is to convert the MAs into fission products.

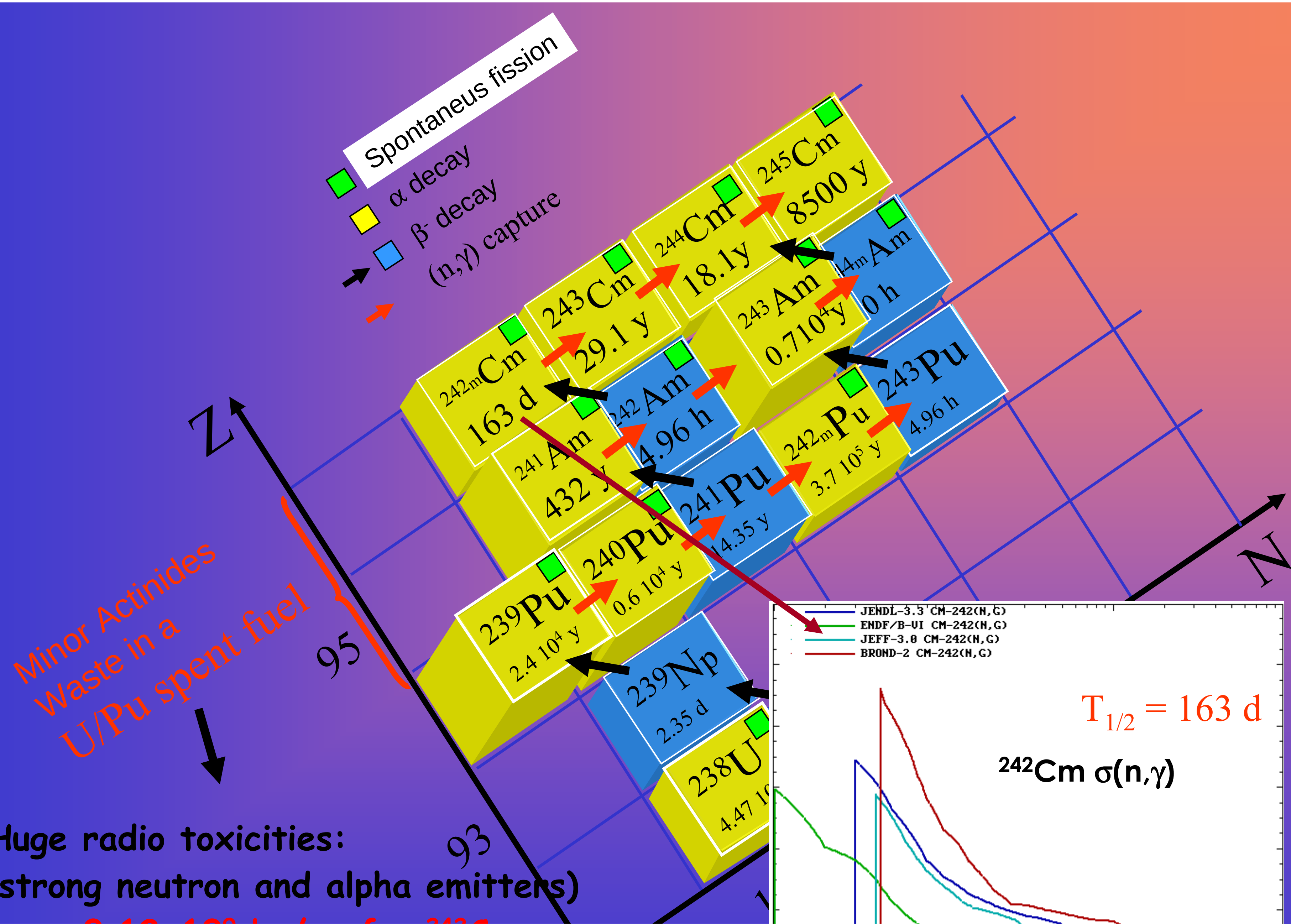
- ☒ Nuclear data needs for Thorium/Uranium fuel cycle

  → innovative fuel cycle for GEN IV reactors

Under neutron flux the heavy nuclei primarily undergo …

$\sigma(n,\gamma)$ ⟶ Production of heavier nuclei

$\sigma(n,f)$ ⟶ fission products



Huge radio toxicities:
(strong neutron and alpha emitters)

Difficult to produce and handle minor actinides targets

- Motivation
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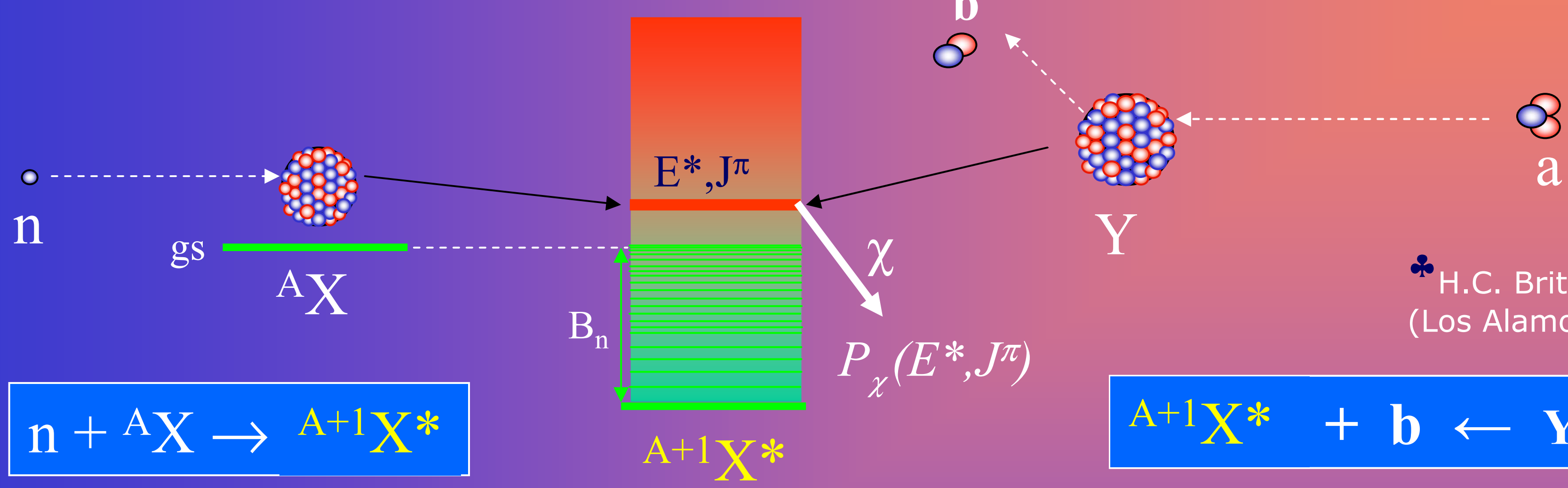
An alternative solution exists…: transfer reactions

Neutron-induced reaction

Surrogate reaction♣



♣H.C. Britt et al. (Los Alamos 1970…!!)

$$n + {}^{A}X \rightarrow {}^{A+1}X^*$$

$$^{A+1}X^* + b \leftarrow Y + a$$

$$\frac{N_{\chi}}{\phi_n \cdot n_{^{A}X} \cdot t} = \sigma_{\chi}^{A}(E_n) = \sigma_{CN}^{A+1}(E_n) \cdot P_{\chi}(E_n)$$

Measured ($P_{\chi}(E_n)$)

Microscopic optical model calculation (BIII), TALYS ($\sigma_{CN}^{A+1}(E_n)$)

$$\sigma_{\chi}^{A}(E_n) = \sum_{J^{\pi}} \sigma_{CN}^{A+1}(E_n, J^{\pi}) \cdot P_{\chi}(E_n, J^{\pi}) = \sigma_{CN}^{A+1}(E_n) \sum_{J^{\pi}} \alpha^{A+1}(E_n, J^{\pi}) \cdot P_{\chi}(E_n, J^{\pi})$$

Ewing-Weisskopf limit : $P_{\chi}(E_n, J^{\pi}) = P_{\chi}(E_n) \quad \Rightarrow \sigma_{\chi}^{A}(E_n) = \sigma_{CN}^{A+1}(E_n) \cdot P_{\chi}(E_n) \quad (\sum_{J^{\pi}} \alpha^{A+1}(E_n, J^{\pi}) = 1)$

$\alpha^{A+1}(E_n, J^{\pi})$ are quite similar in neutron-induced and surrogate reaction

$$P_{\chi}(E_n) = \sum_{J^{\pi}} \alpha^{A+1}(E_n, J^{\pi}) \cdot P_{\chi}(E_n, J^{\pi})$$

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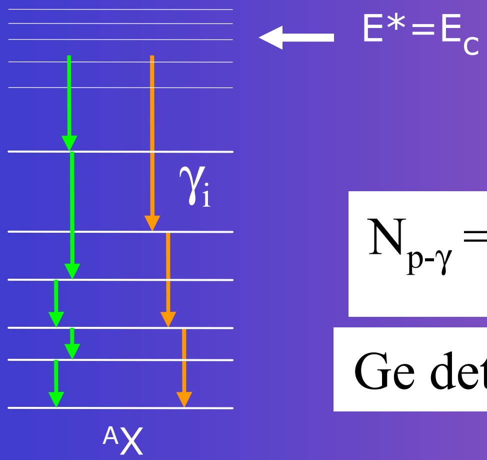
capture cross section measurement

γ-rays decay scheme



$$P_\gamma(E_c) = \frac{N_{p-\gamma}}{N_p \cdot \varepsilon_\gamma}$$

$N_{p\text{-}\gamma} = I_\gamma \pm ?$

Ge detectors

$$\varepsilon_{E_\gamma} \xrightarrow{?} \varepsilon_{E_c}$$

C_6D_6 detectors

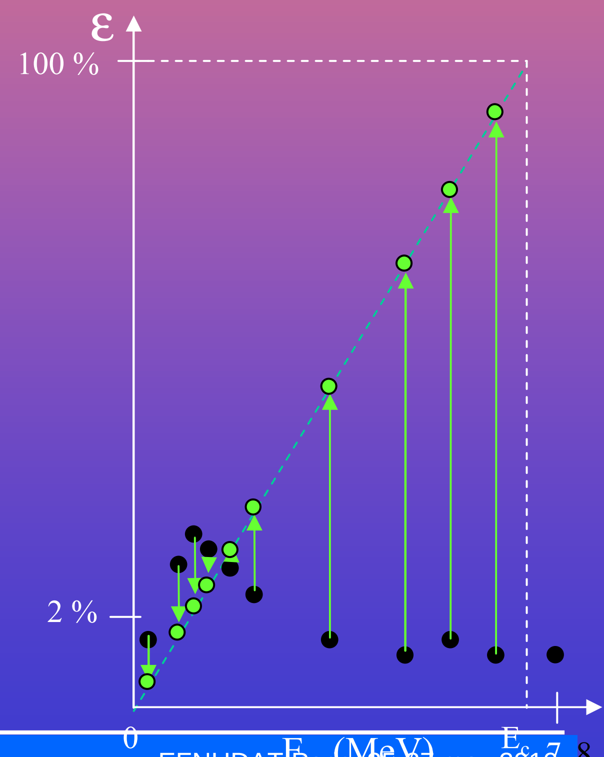
$$\varepsilon_c = 1 - \prod_{i=1}^{m} (1 - \varepsilon_{\gamma_i}) \quad \text{if} \quad \varepsilon_{\gamma_i} << 1 \quad \Rightarrow \quad \varepsilon_c \approx \sum_{i=1}^{m} \varepsilon_{\gamma_i}$$

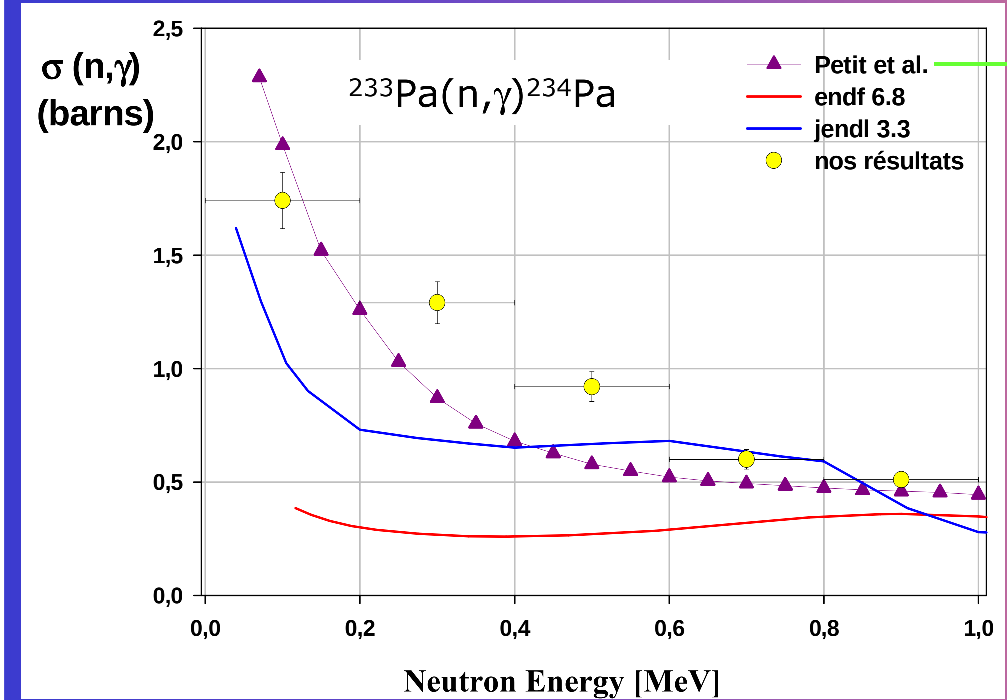
Suppose $\varepsilon_i = k\, E_{\gamma i} \Rightarrow \varepsilon_c = k \sum_{i=1}^{m} E_{\gamma i} \quad \Rightarrow \quad \varepsilon_c = k\, E^*$

$R_{\gamma_i}(E_d)$ response function t o a given E_{γ_i} and $\sum_d R_{\gamma_i}(E_d) = \varepsilon(E_{\gamma i})$

$$\chi^2 = \sum_i \left(\sum_d W(E_d) \cdot R_{\gamma_i}(E_d) - k \cdot E_i \right)^2$$

Efficiency ε determined with MCNP simulations
and validated with a set of γ-calibration and nuclear reactions.





^{232}Th (^{3}He,pf) ^{234}Pa

Unfortunately there is no neutron-induced data for comparison.

Validation of the Transfer réaction with existing (n,γ) data

^{236}U (^{3}He,p) ^{238}Np ⟶ ^{237}Np(n,γ)
^{236}U (^{3}He, α) ^{235}U ⟶ ^{234}U(n, γ)
^{238}U (^{3}He, t) ^{238}Np ⟶ ^{237}Np(n, γ)
^{238}U (^{3}He, α) ^{237}U ⟶ ^{236}U(n, γ)

Difficult to produce evaporated actinides targets

⟶ Validation of the surrogate method for capture reactions in the rare earth nuclei

S. Boyer *et al*. Nucl. Phys. A775 (2006) 175
J. N. Wilson et al, Nucl. Instr. and Meth. A511, 388-399 (2003)

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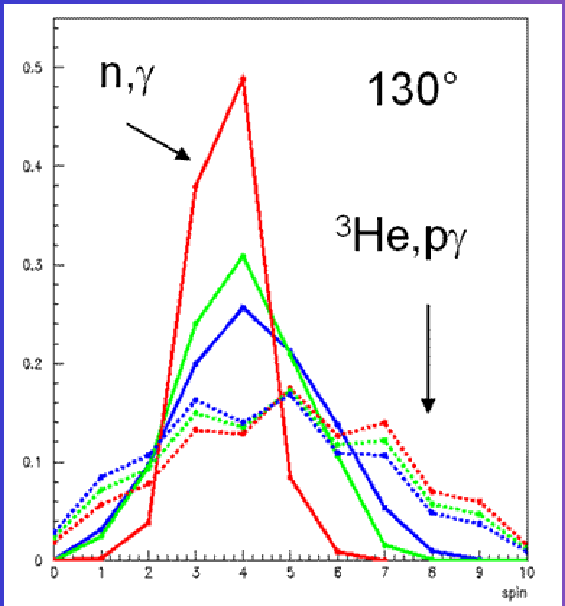
Theoretical studies

$^{174}Yb\ (^{3}He,p\gamma)\ ^{176}Lu$ as a surrogate reaction → $^{175}Lu(n,\gamma)^{176}Lu$



Spin distribution of the compound nucleus ^{176}Lu for :

En=100 keV **1 MeV** and **2 MeV**

Calculations

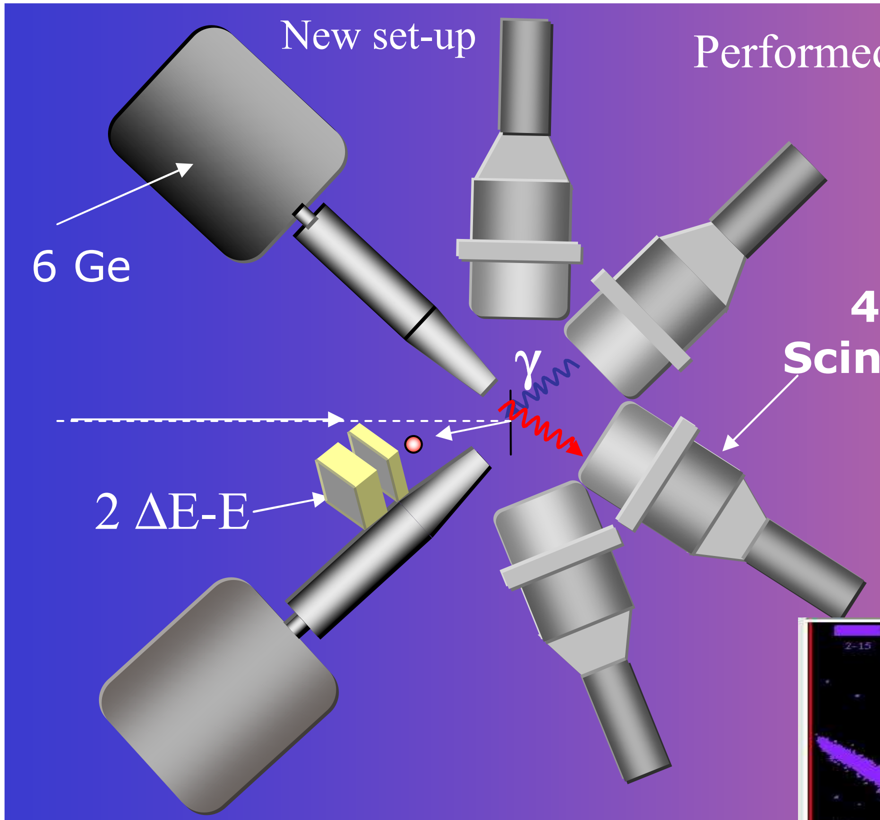
-solid line, extracted from TALYS code

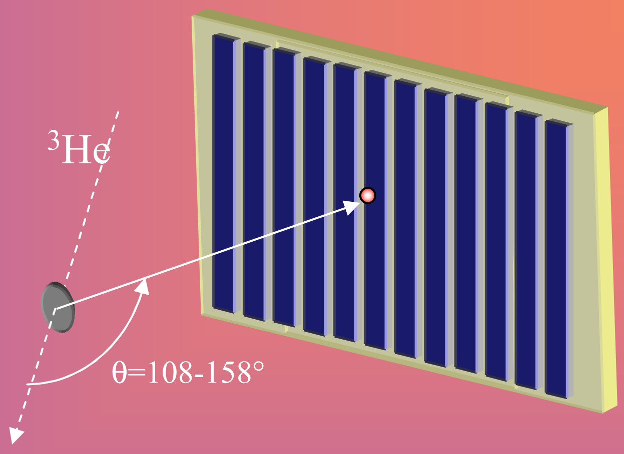
-dotted line, extracted from FRESCO DWBA code

$\alpha^{A+1}(E_n, J^{\pi})$ are quite similar in neutron-induced and surrogate reaction

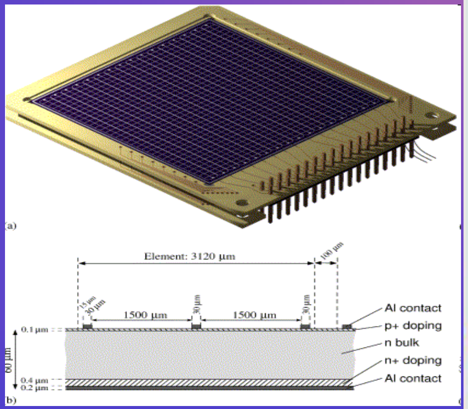
$$\rightarrow \quad P_{\chi}(E_n) = \sum_{J^{\pi}} \alpha^{A+1}(E_n, J^{\pi}) \cdot P_{\chi}(E_n, J^{\pi})$$

Performed @ Tandem-Orsay/ 24 MeV / 15nAe/ Feb 2010

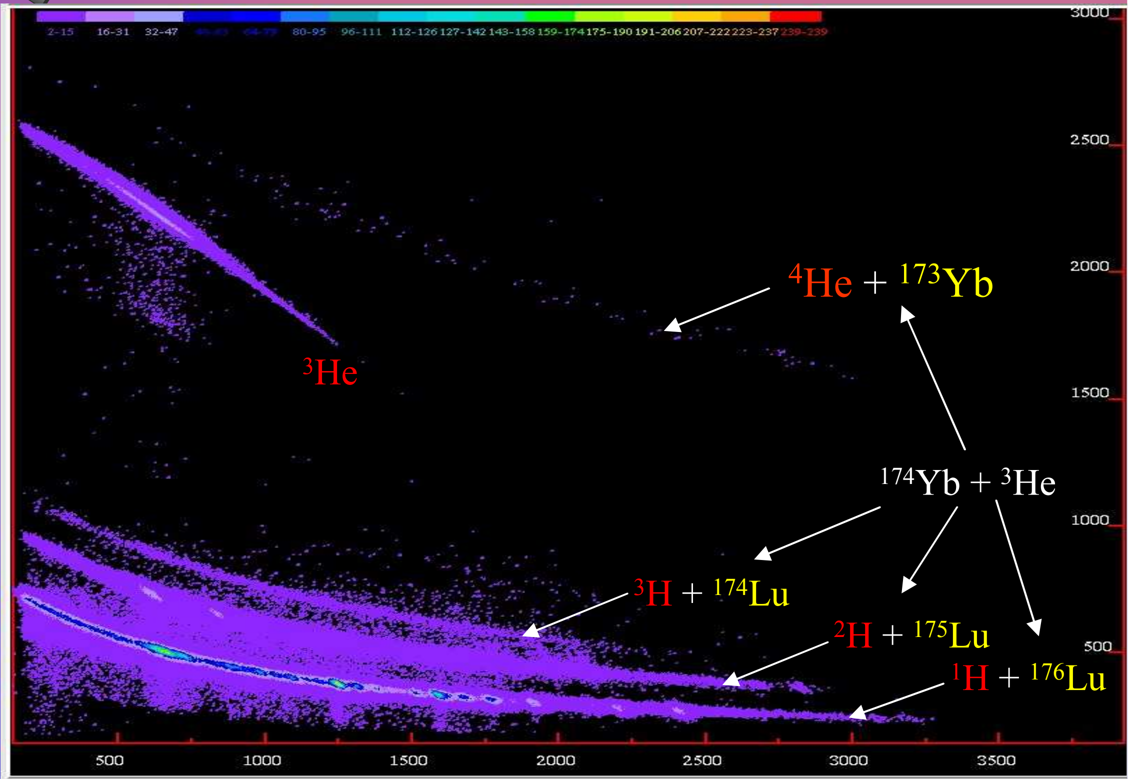




16x16 strips



Large ΔE : 50x50 mm²

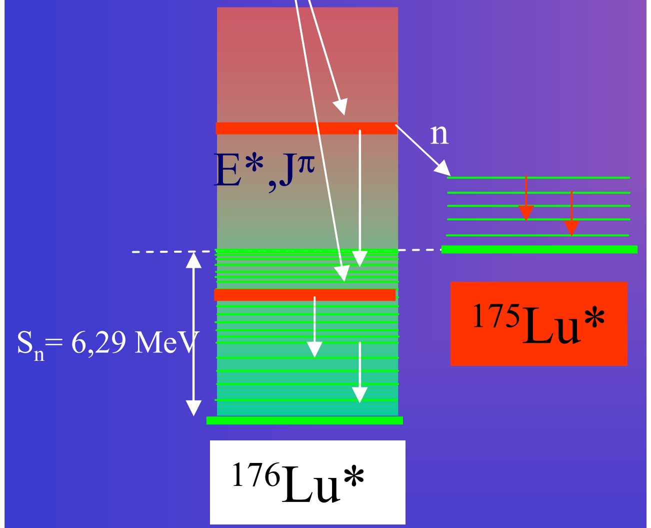


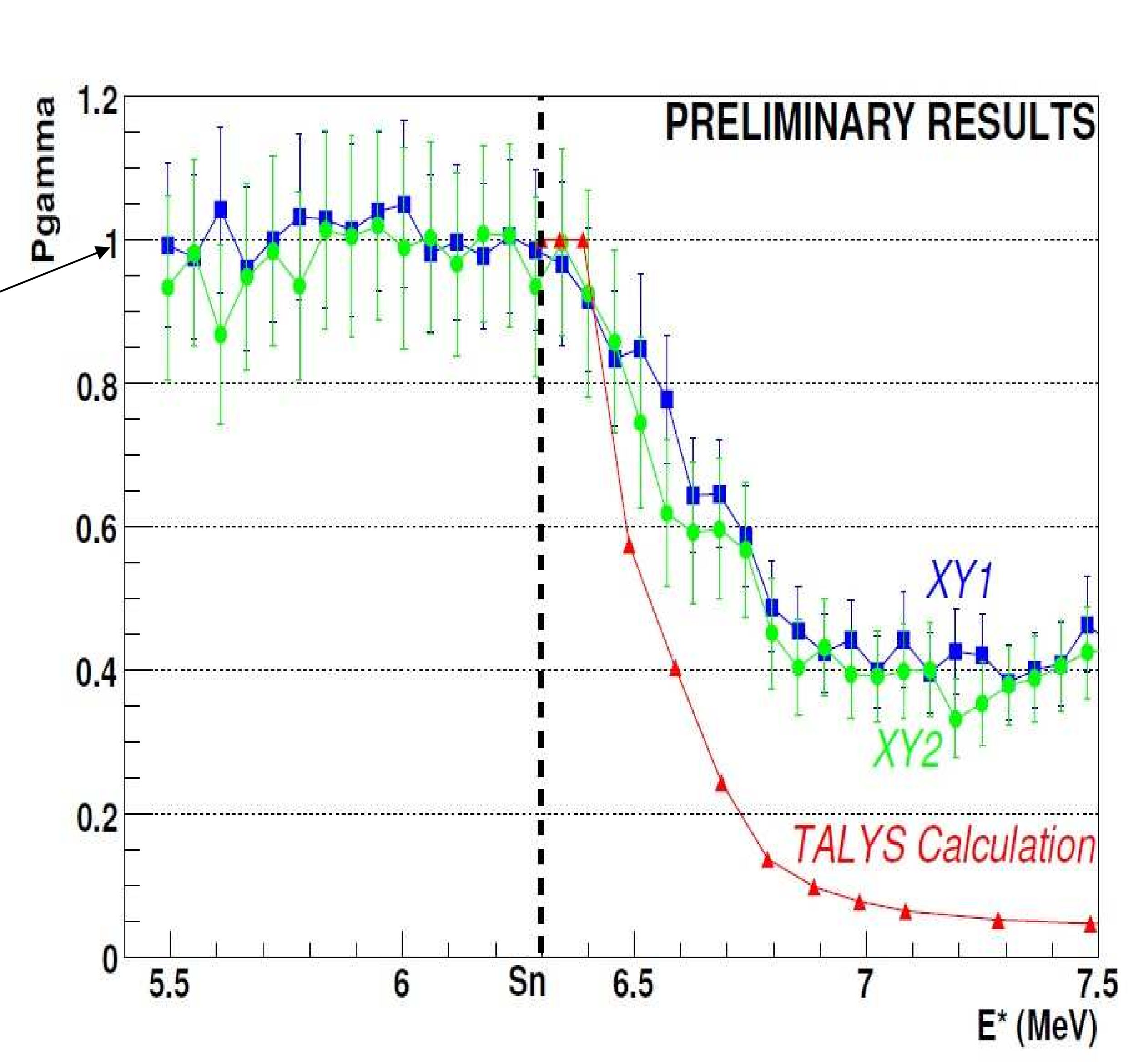
C_6D_6 in coincidence with ΔE-E

$$P_\gamma(E_c) = \frac{N_{p-\gamma}}{N_p \cdot \varepsilon_\gamma}$$

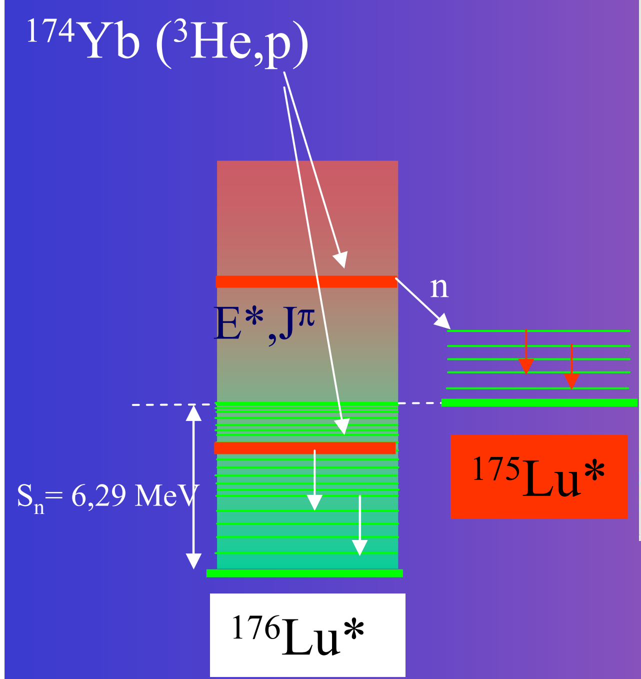
Normalized to 1

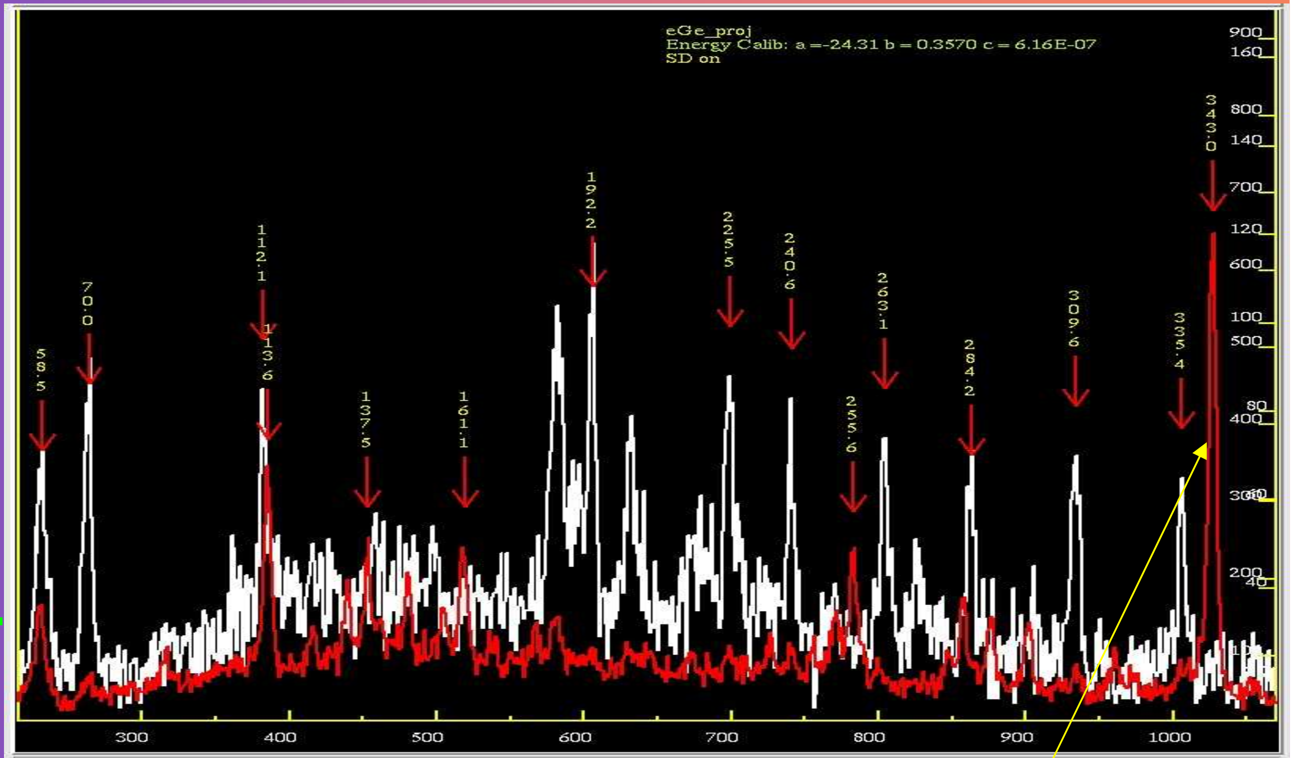
^{174}Yb (^{3}He,p)

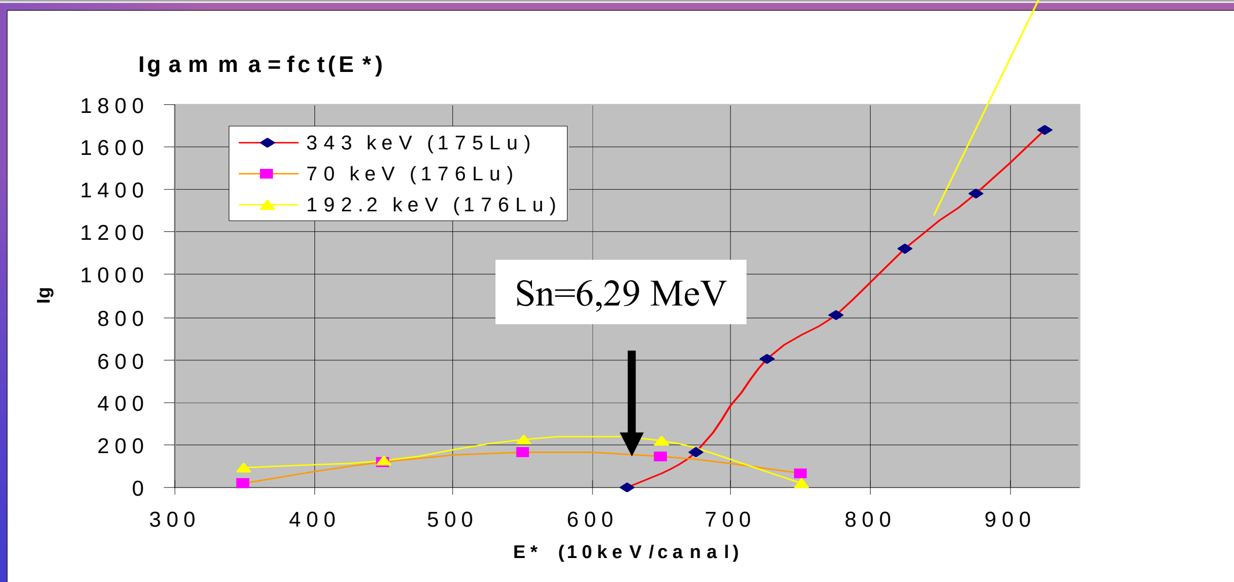


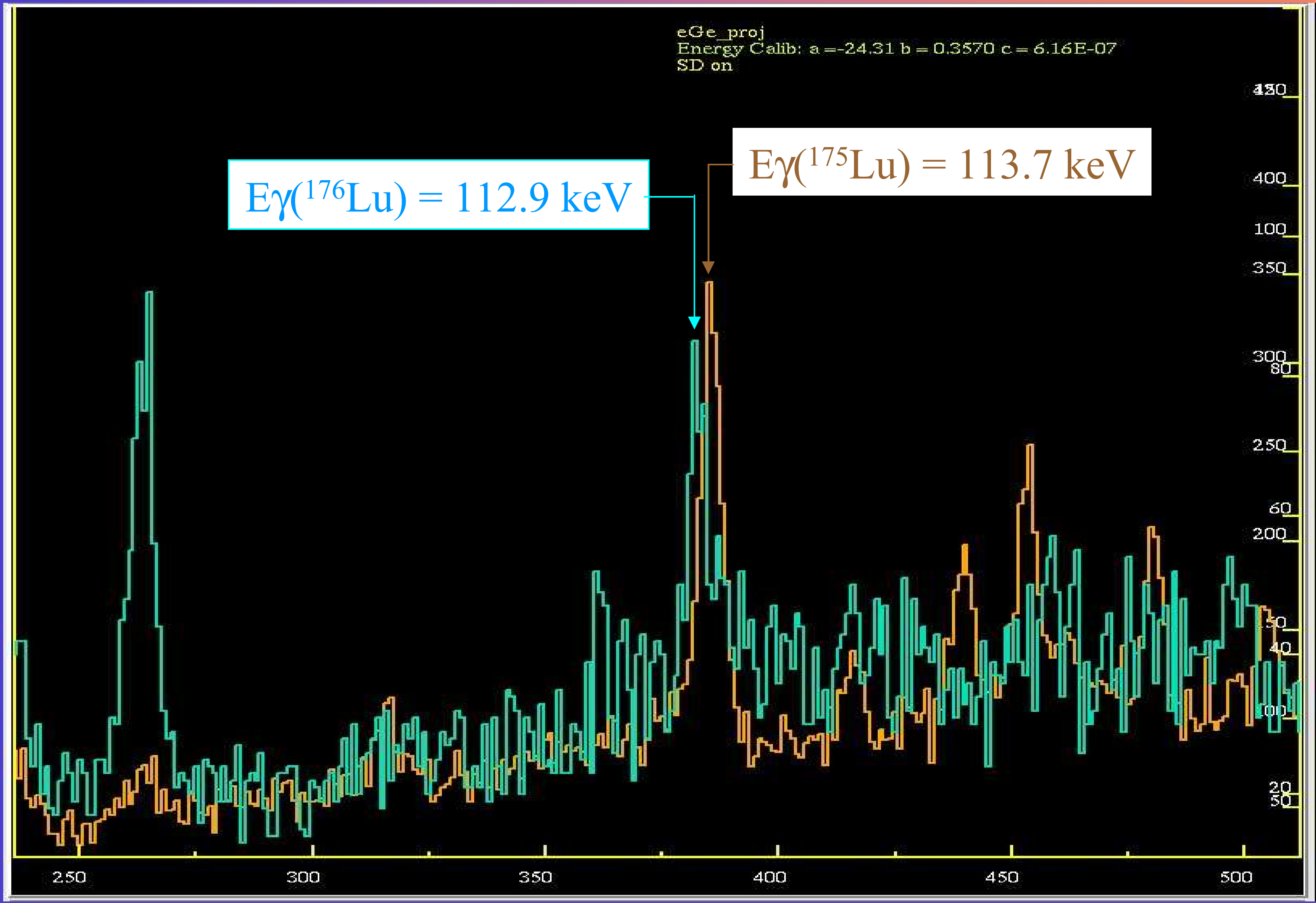


Ge in coincidence with ΔE-E

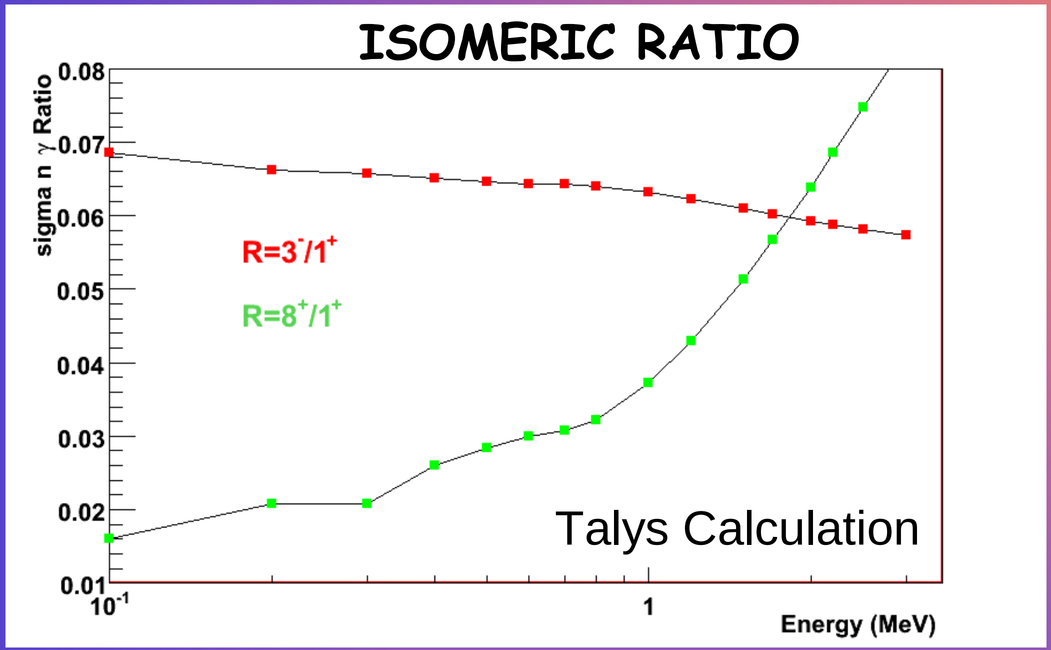







eGe_proj
Energy Calib: a =-24.31 b = 0.3570 c = 6.16E-07
SD on
Eγ(176Lu) = 112.9 keV
Eγ(175Lu) = 113.7 keV
250
300
350
400
450
500

$\alpha^{A+1}(E_n, J^\pi)$ are they quite similar in neutron-induced and surrogate reaction



8^+ : 425 keV $t_{1/2}$ ~ 2 ns

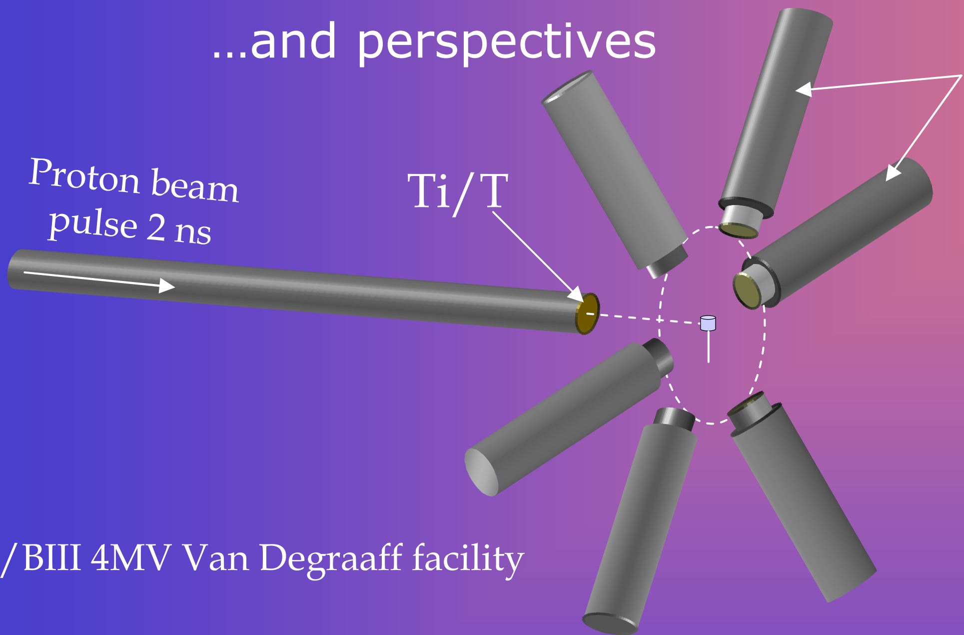
1^+ : 195 keV $t_{1/2}$ ~ 35 ns

3^- : 658 keV $t_{1/2}$ ~ 6.3 ns

Summary and perspectives…

- Alternative and powerful technique to measure σ(n,γ) of short-lived nuclei
- ^{175}Lu (n,γ) ^{176}Lu scheduled for June 2010 @ CEA/BIII 4MV Van De graaff facility

…and perspectives



@ CEA/BIII 4MV Van Degraaff facility

^{175}Lu(n,γ)^{176}Lu
ToF: 7.3 ns @ 1 MeV
γ-γ coincidences

^{236}U (^{3}He,p) ^{238}Np ⟶ ^{237}Np(n,γ)
^{236}U (^{3}He, α) ^{235}U ⟶ ^{234}U(n, γ)
^{238}U (^{3}He, t) ^{238}Np ⟶ ^{237}Np(n, γ)
^{238}U (^{3}He, α) ^{237}U ⟶ ^{236}U(n, γ)

… If one of these targets is available !