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## **Th-232(d,4n)Pa-230 cross section measurements at ARRONAX facility**

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et de physique des particules

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**$^{232}\text{Th} (d, 4n) ^{230}\text{Pa}$  cross section  
measurements at ARRONAX facility**

# Motivations

# Experimental set-up and data measurements

# Results and comparisons

# Conclusions and outlooks



**Innovative radionuclides:** PET imaging,  $\beta^-$  and  $\alpha$  targeted radiotherapy

**$\alpha$  RIT:** binding an  $\alpha$  emitter to an antibody **to target** and **destroy** tumor cells

- high LET
- important cytotoxic effect
- minimizing damage

**$^{226}\text{Th}$ :** novel therapeutic nuclide, a **more potent**  $\alpha$  emitter for leukemia than  $^{213}\text{Bi}$  (46 min)

- decay: 4  $\alpha$  cascade, 27.7 MeV
- generator system:  $^{230}\text{U}$ (21 d)/ $^{226}\text{Th}$ (31 min)

**Production routes:**  $^{231}\text{Pa}(p,2n)^{230}\text{U}$        $^{232}\text{Th}(p,3n)^{230}\text{Pa} \rightarrow ^{230}\text{U}$        $^{232}\text{Th}(d,4n)^{230}\text{Pa} \rightarrow ^{230}\text{U}$

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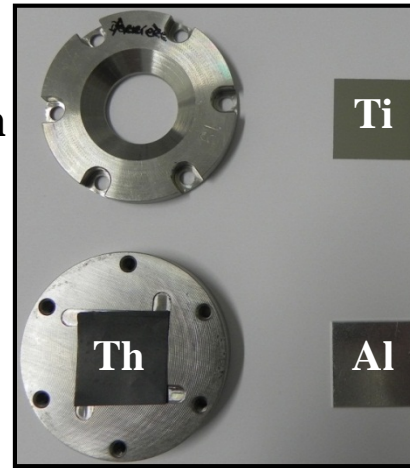
# Experimental set-up and data measurements

## Stacked-foil technique:

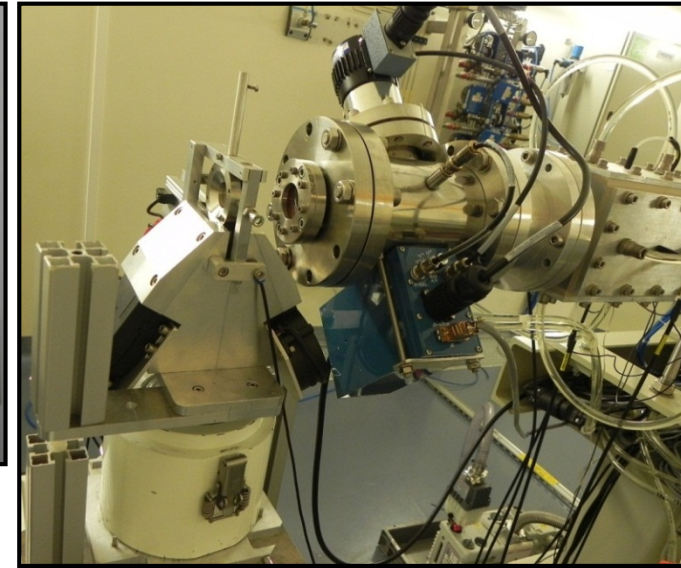
- target / monitor / degrader **pattern**
- **thin foils**

## Activity and cross section:

$$\sigma = \frac{\text{Act} \cdot A}{\Phi \cdot \mathcal{N}_A \cdot \rho \cdot e \cdot (1 - e^{-\lambda \cdot t})}$$



Capsule and foils



Nice III and beam line

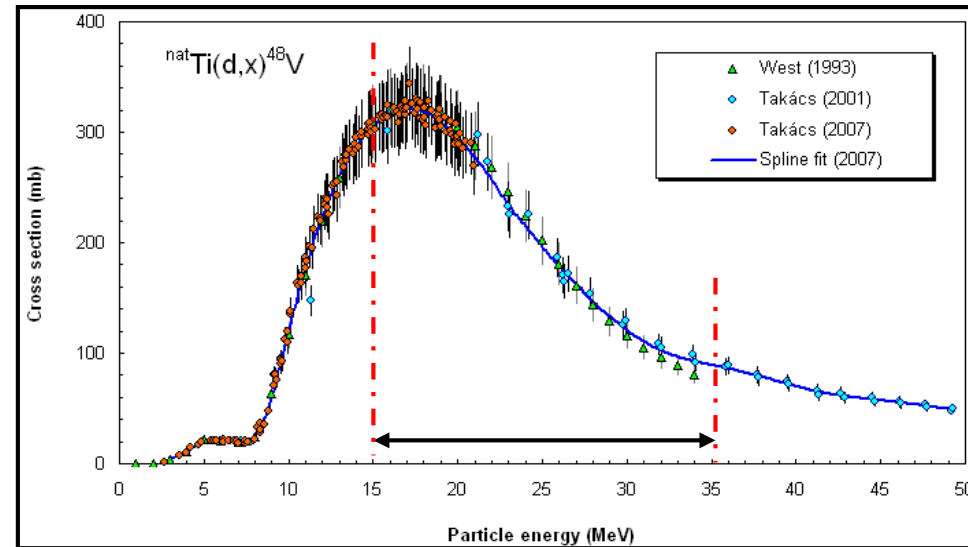
## Use of a monitor foil:

$$\sigma = \sigma' \cdot \frac{\text{Act} \cdot A \cdot \rho' \cdot e' \cdot (1 - e^{-\lambda' \cdot t})}{\text{Act}' \cdot A' \cdot \rho \cdot e \cdot (1 - e^{-\lambda \cdot t})}$$

- error on  $e, e'$ :  $\leq 1\%$
- error on  $t$ : negligible

## IAEA recommended cross sections:

- 5 reactions available for deuteron beam
  - $^{27}\text{Al}$  (2),  $^{\text{nat}}\text{Fe}$  (1),  $^{\text{nat}}\text{Ni}$  (1) and
- $^{\text{nat}}\text{Ti}(d,x)^{48}\text{V}$ 
  - error on  $\sigma$ :  $\leq 12\%$



IAEA recommended cross section

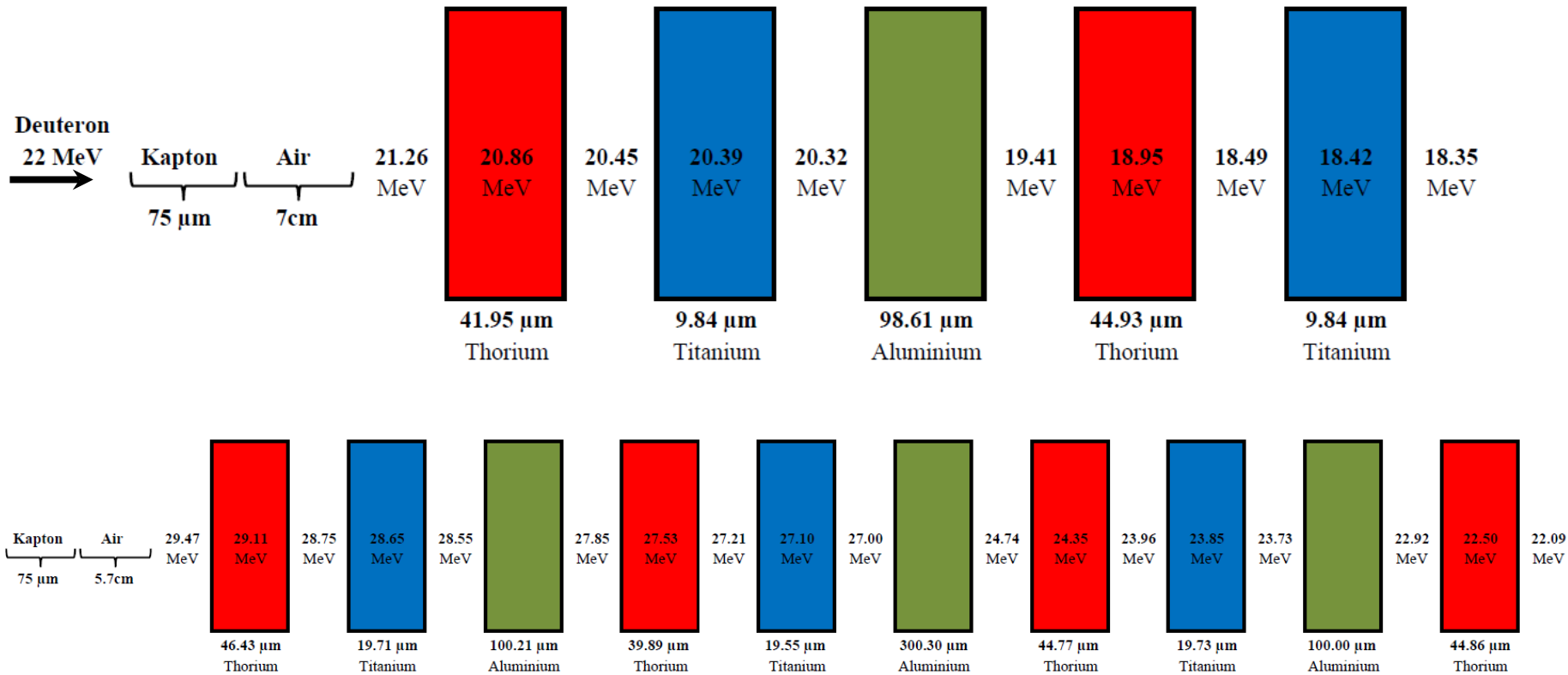
# Stacked-foil set-up

2 stacks irradiated

- deuteron beam: 22 and 30 MeV

- intensity: 100 nA

- irradiation time: 30 min



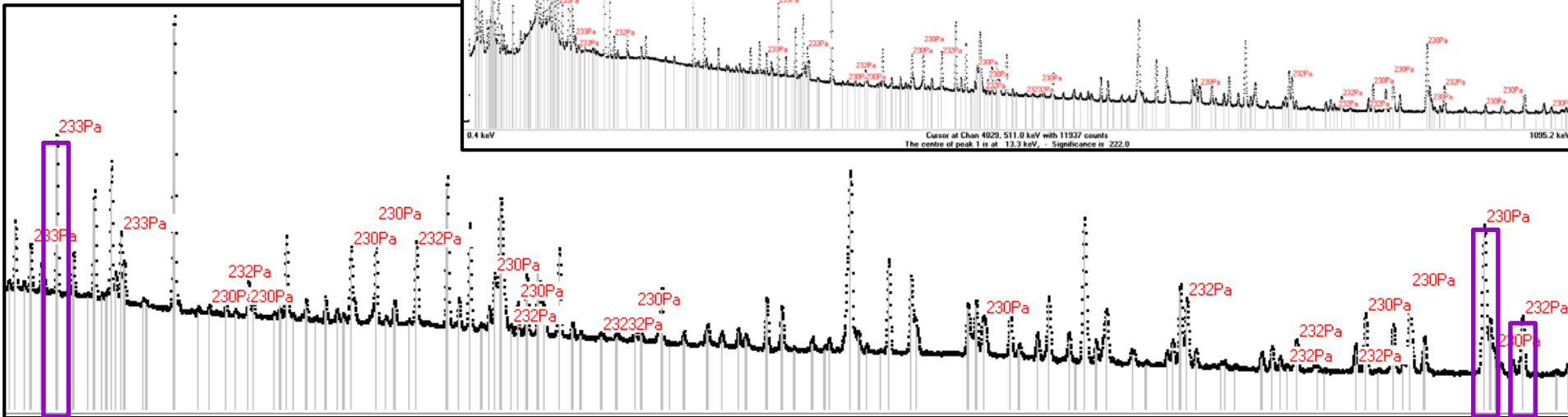
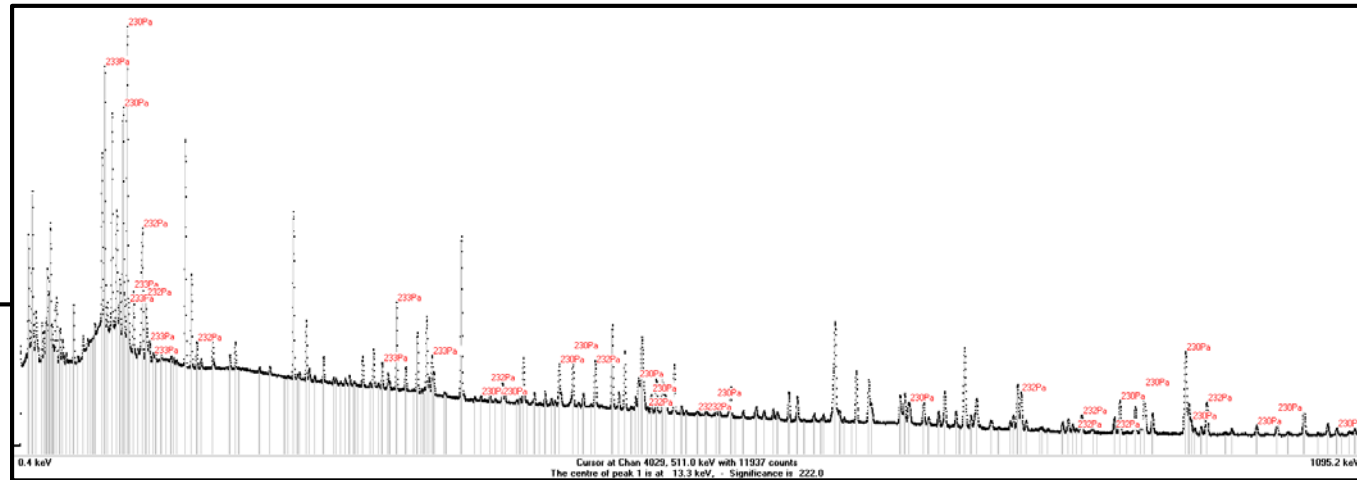
- 6 energy points: 18.95 – 20.86 – 22.50 – 24.35 – 27.53 – 29.11 MeV for  $^{230,232,233}\text{Pa}$

## Gamma spectroscopy:

- **HPGe** coaxial detector
- Dead time: < 10% (sum peak)
- Activity values: FitzPeaks
- $T_{1/2}$ ,  $E_\gamma$ ,  $I_\gamma$ : Lund/LBNL, NNDC
- $\gamma$  spectra recorded on **8192 channels**
- FWHM: 1.04 keV at 122 keV ( $^{57}\text{Co}$ )  
1.97 keV at 1332 keV ( $^{60}\text{Co}$ )
- Energy and efficiency calibrations : Co and Eu

### - Target and monitor:

- ✓ counted twice
- ✓ during > 24 hrs
- ✓ 2 week delay



$\gamma$  rays used to extract production cross section of  $^{230,232,233}\text{Pa}$

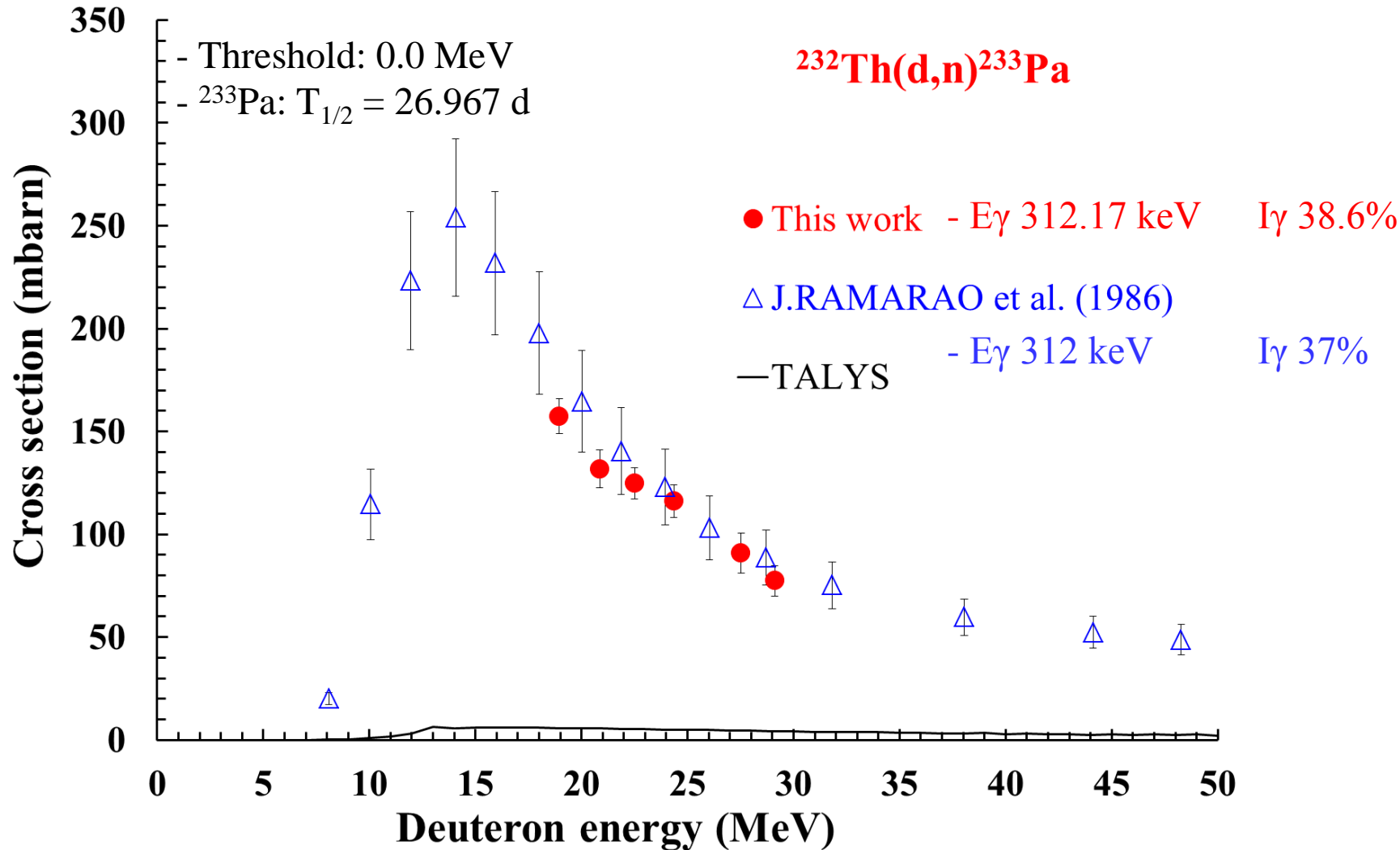
# Motivations

# Experimental set-up and data measurements

# Results and comparisons

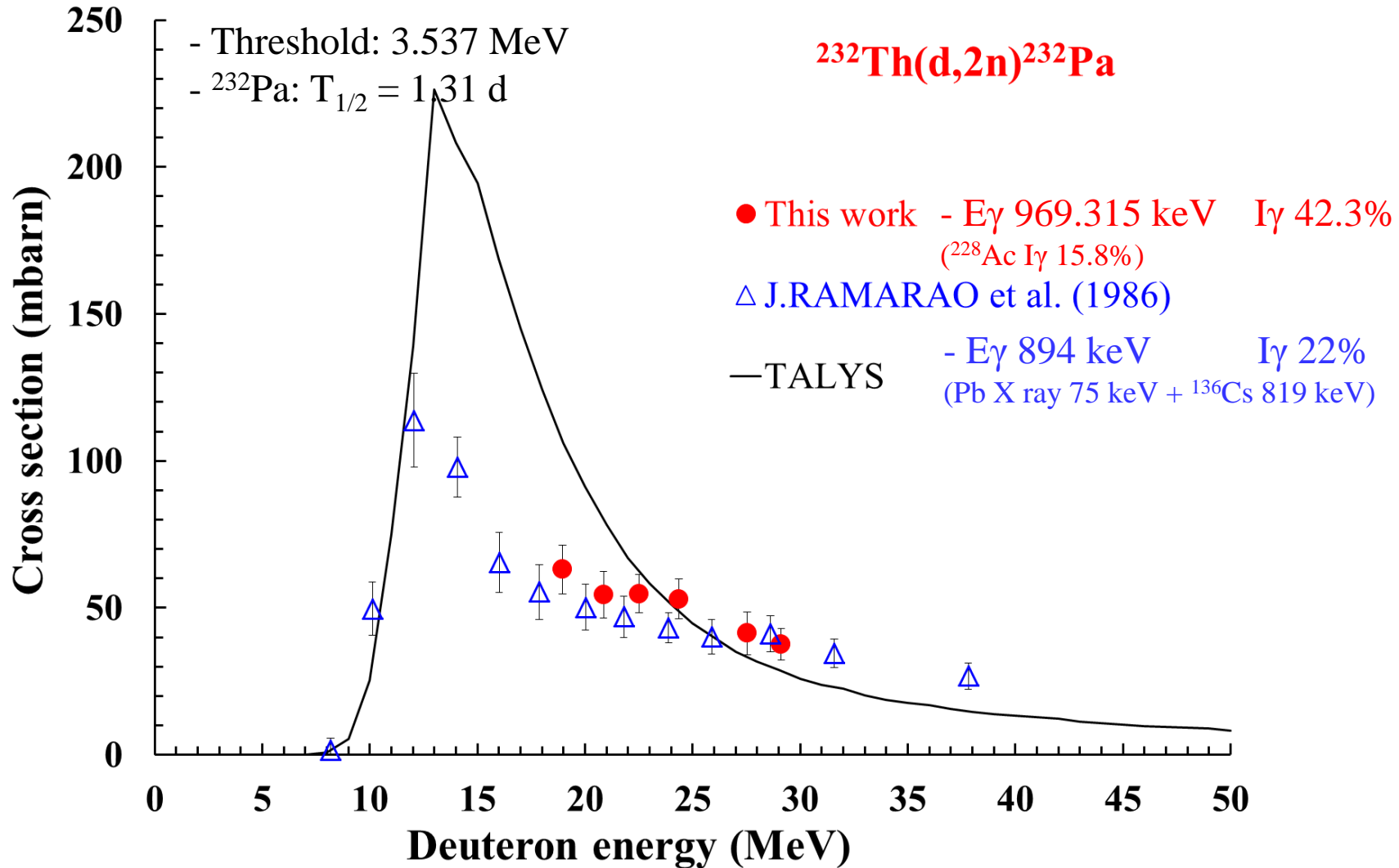
# Conclusions and outlooks

# Results and comparisons



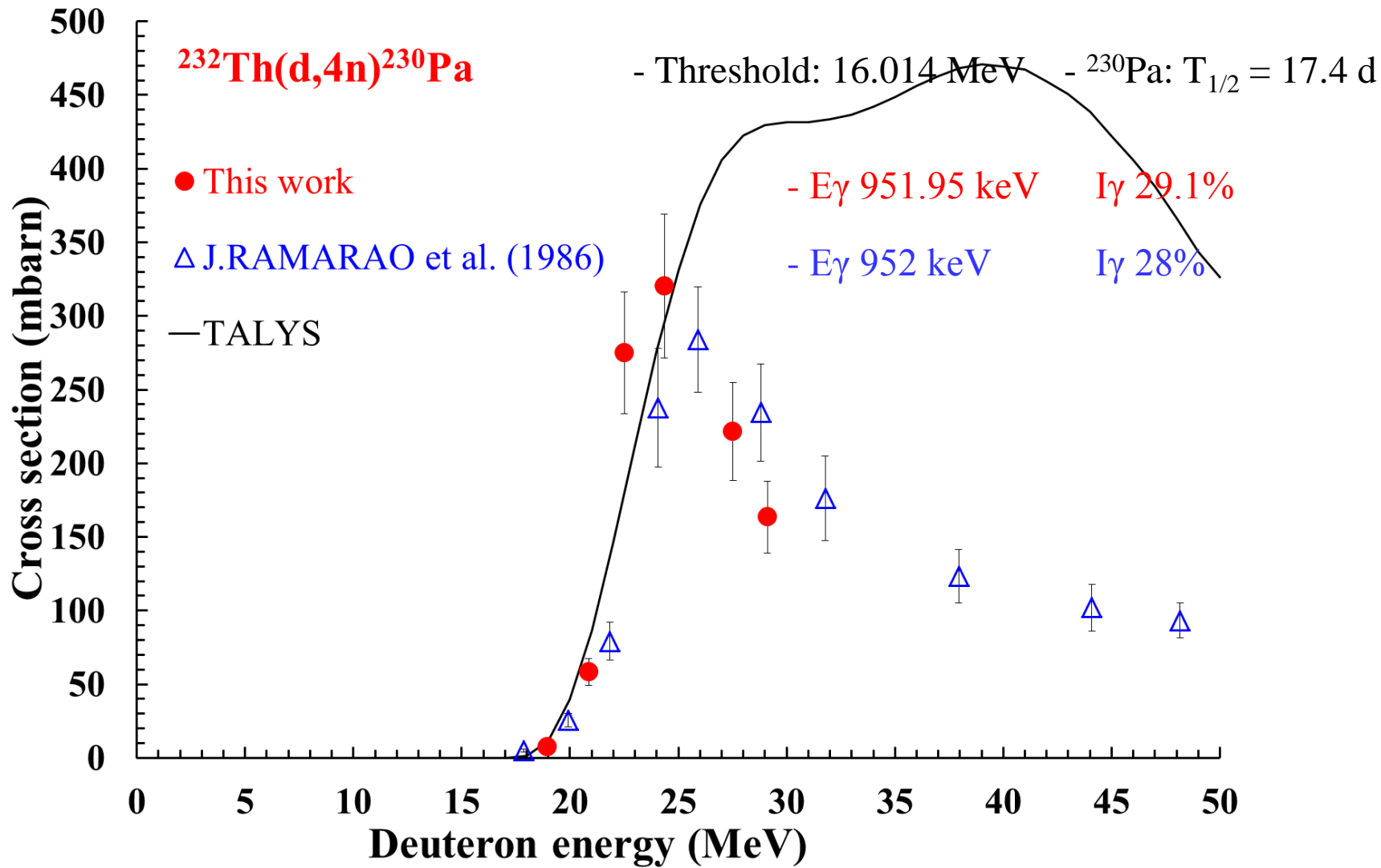
- Same as d.4, default parameters
- Different cross sections than the data base in data 1986

# Results and comparisons



- Same trend
- TALYS 1.4, default parameters
- Difference explained by  $\gamma$  line chosen and the  $I_\gamma$  update in database since 1986
- Not in agreement with data even if the  $\gamma$  shape is not too bad

# Results and comparisons



- Same trend but a small energy shift and a maximum value slightly higher
- TALYS 1.4, default parameters
- Difference not explained by the  $I_\gamma$  update in database since 1986
- Neither the shape nor the maximum value are reproduced

# Motivations

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## Conclusions:

- ✓ **New data** sets obtained:  $^{232}\text{Th}(d,xn)$   $^{230,232,233}\text{Pa}$ 
  - compared with J. Rama Rao et al.
    - $^{232,233}\text{Pa}$ : same trends, influence of the branching ratio values
    - $^{230}\text{Pa}$ : same trend, higher amplitude, shift in energy
  - compared with TALYS calculations
    - default parameters, no satisfactory results
- ✓ Also **new data** sets extracted from the monitors:  $^{\text{nat}}\text{Ti}(d,x)^{43,44,44\text{m},46,47,48}\text{Sc}$

## Outlooks:

- ✓ **Yield** estimation in Bq/A.h
- ✓ **Production route** comparison:
  - yields
  - contaminants
  - chemistry
- ✓ **TALYS** parameter tuning:
  - optical models (5)
  - level density models (5)
  - pre-equilibrium models (4)

Innovative radio-isotope program for PET imaging,  $\beta^-$  and  $\alpha$  targeted radiotherapy at ARRONAX is ongoing:  $^{82}\text{Sr}/^{82}\text{Rb}$  –  $^{44}\text{Sc}$  –  $^{64}\text{Cu}$ ,  $^{47}\text{Sc}$  –  $^{67}\text{Cu}$ ,  $^{211}\text{At}$ ...

## Thank you for your attention

### Acknowledgments to the ND 2013 organization committee

**$^{232}\text{Th}(d,4n)^{230}\text{Pa}$  cross-section measurements**

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