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New measurements for Proton and Deuteron Beam Monitor Reactions

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IN2P3

Institut national de physique nucléaire
et de physique des particules

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SUBATECH Laboratory
CNRS Research Officer



New Measurements for Proton and Deuteron Beam Monitor Reactions

Motivations

Experimental set-up and data measurements

Results and comparisons

Conclusions and outlooks

Nuclear medicine

Many useful / potentially useful isotopes identified for applications in nuclear medicine

Cyclotrons and accelerators being used in an increasing number of countries along with reactors

- Radionuclides for diagnostic and therapeutic purposes
- Specific activation and fission products

Nuclear data and IAEA

Nuclear data needs addressed by successive Coordinated Research Projects initiated in the 90's

- Accurate and reliable sets of data
- Well defined production routes and decay properties
- Optimum production of specific radionuclides, minimization / elimination of impurities, realistic dose calculations

IAEA report INDC(NDS)-0630, February 2013 *INDC(NDS)-0591, September 2011*

Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production

Requirements for improved and extended excitation functions for monitor reactions producing

$^{22,24}\text{Na}$, $^{96\text{m}+g}\text{Tc}$

^{46}Sc , ^{57}Ni , $^{56,58}\text{Co}$, $^{62,63,65}\text{Zn}$

Independent new data to constrain shape and amplitude of the recommended cross section curve

Additional monitor reactions proposed producing

$^{44\text{m}}\text{Sc}$, ^{47}Sc

Half lives interesting and gamma rays easily detectable

Motivations

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C70 Cyclotron* build by IBA:

- 4 sectors isochron cyclotron
- 2 multi-particle sources:
 - H⁻, D⁻: multicusp
 - He²⁺, HH⁺: supernanogan ECR
- 2 extraction lines:
stripper or electrostatic deflector

Extracted	Energy (MeV)	Max. current (μA)
H ⁺	30 – 70	2 x 375
D ⁺	15 – 35	2 x 50
He ²⁺	68	70
HH ⁺	17	50

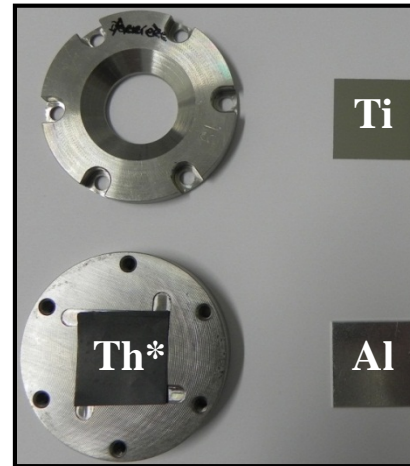
* *Medium Energy Accelerators for Isotope Production in Europe, F. Haddad, Subatech, GIP ARRONAX, August 27, 3:40 p.m., Crystal A*

Stacked-foil technique:

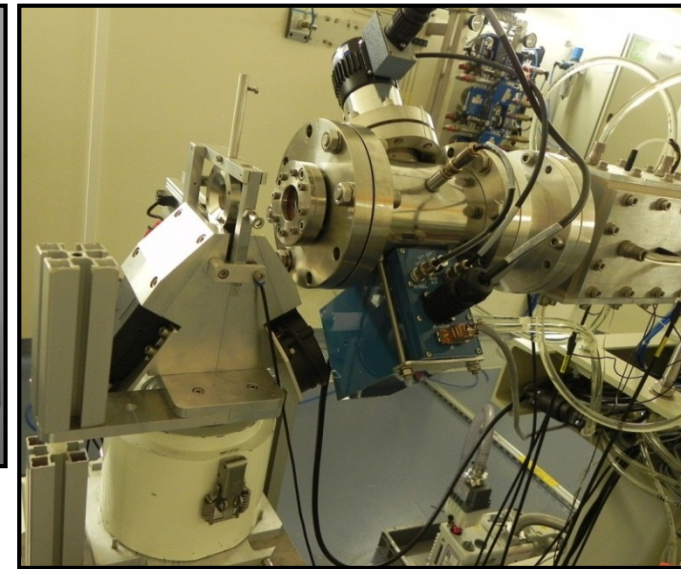
- Target/monitor/degrader **pattern**
- **Thin** foils:
E loss small and constant
- One cross section value per foil

Activity and cross section:

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



Capsule and foils



Irradiation station and beam line

Use of a Faraday cup:

- Beam dump placed at the end of the stack to measure the intensity during the irradiation

Use of a monitor foil:

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

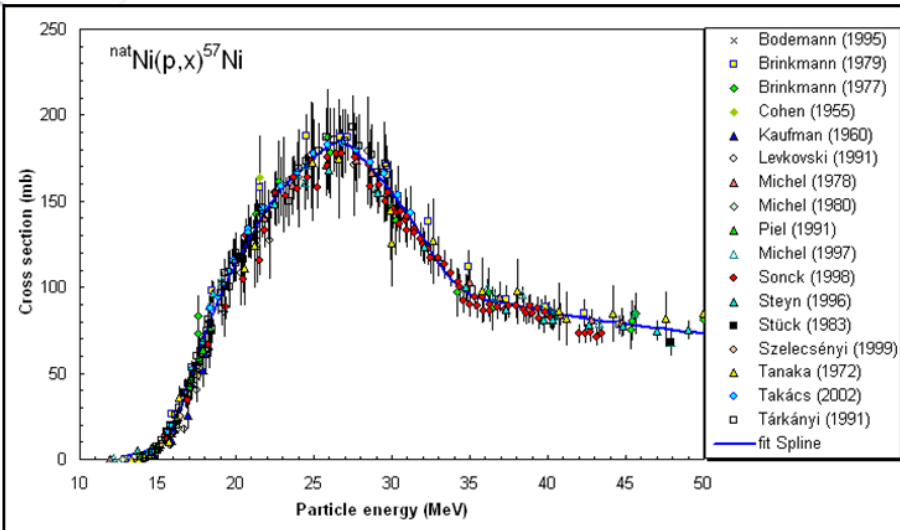
- error on e, e': $\leq 1\%$
- error on t: negligible

IAEA recommended cross sections:

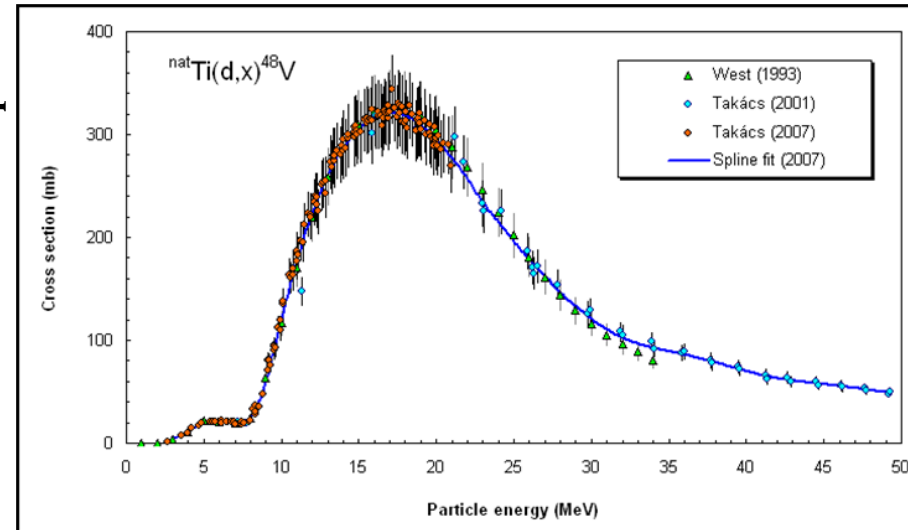
- 8 reactions available for protons
 ^{27}Al (2), $^{\text{nat}}\text{Ni}$, $^{\text{nat}}\text{Ti}$ and $^{\text{nat}}\text{Cu}$ (5)
- 5 reactions available for deuterons
 ^{27}Al (2), $^{\text{nat}}\text{Fe}$, $^{\text{nat}}\text{Ni}$ and $^{\text{nat}}\text{Ti}$

* *Production of Medical Isotopes from a Thorium Target Irradiated by Light Charged Particles up to 70 MeV, C. Duchemin, Subatech, August 27, 4:55 p.m., Crystal A*

IAEA recommended monitor reactions used:



From NDS-IEAE medical portal



Protons:

- $^{nat}\text{Ti}(p,x)^{48}\text{V}$, $E < 15 \text{ MeV}$
- $^{nat}\text{Ni}(p,x)^{57}\text{Ni}$, $15 \text{ MeV} < E < 50 \text{ MeV}$
- $^{nat}\text{Cu}(p,x)^{62}\text{Zn}$, $50 \text{ MeV} < E < 60 \text{ MeV}$
- $^{nat}\text{Cu}(p,x)^{56}\text{Co}$, $60 \text{ MeV} < E$

Deuterons:

- $^{nat}\text{Ti}(d,x)^{48}\text{V}$, $E < 35 \text{ MeV}$

Gamma spectroscopy:

- **HPGe** coaxial detector
- Dead time: $< 10\%$ (sum peak)
- Activity values: FitzPeaks
- $T_{1/2}$, E_γ , I_γ : Lund/LBNL, NNDC

- γ spectra recorded on **8192 channels**
- FWHM: 1.04 keV at 122 keV (^{57}Co)
1.97 keV at 1332 keV (^{60}Co)
- Energy and efficiency calibrations: Co and Eu

Motivations

Experimental set-up and data measurements

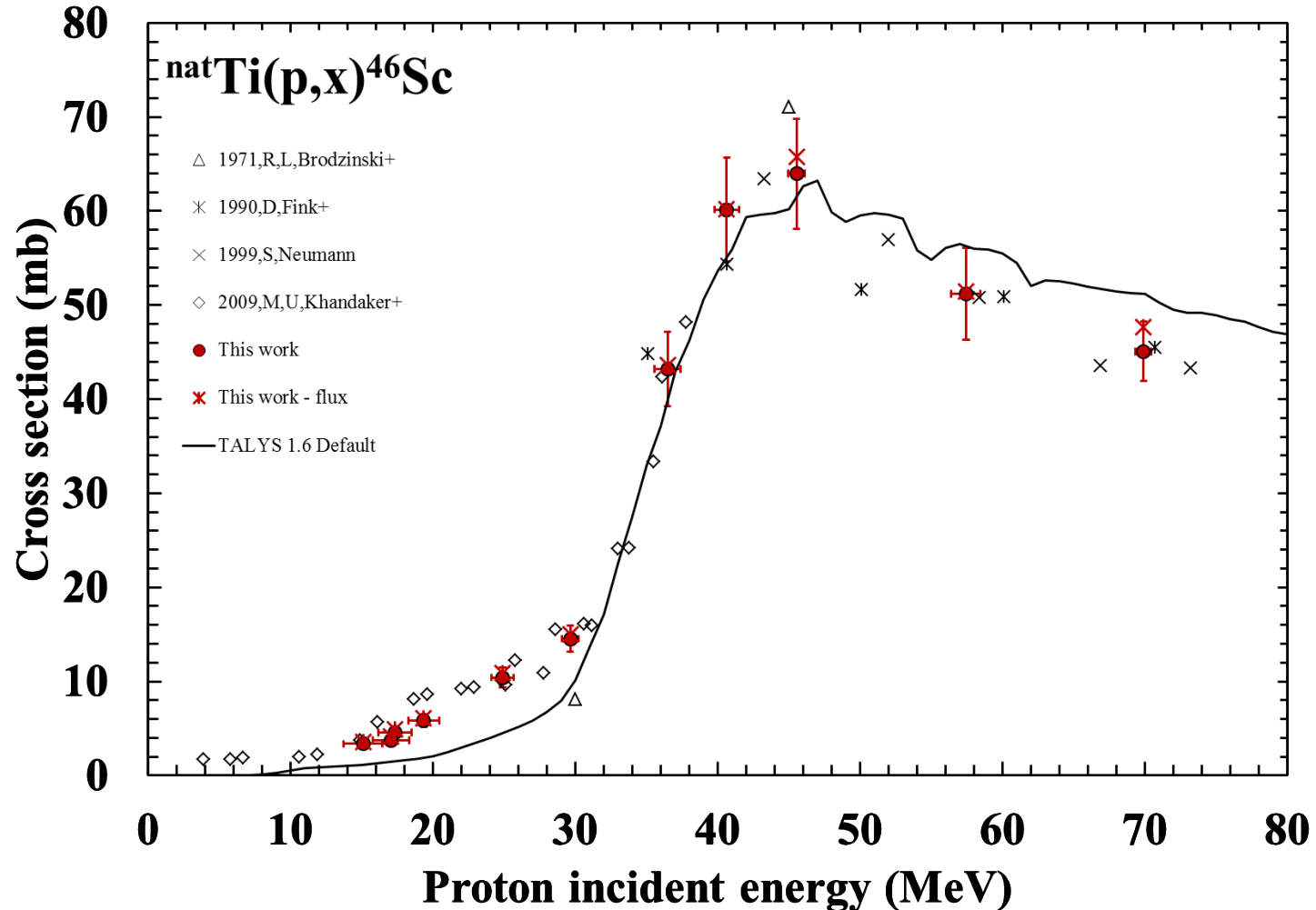
Results and comparisons

Conclusions and outlooks

Results and comparisons

⁴⁶Sc: IAEA requirement list

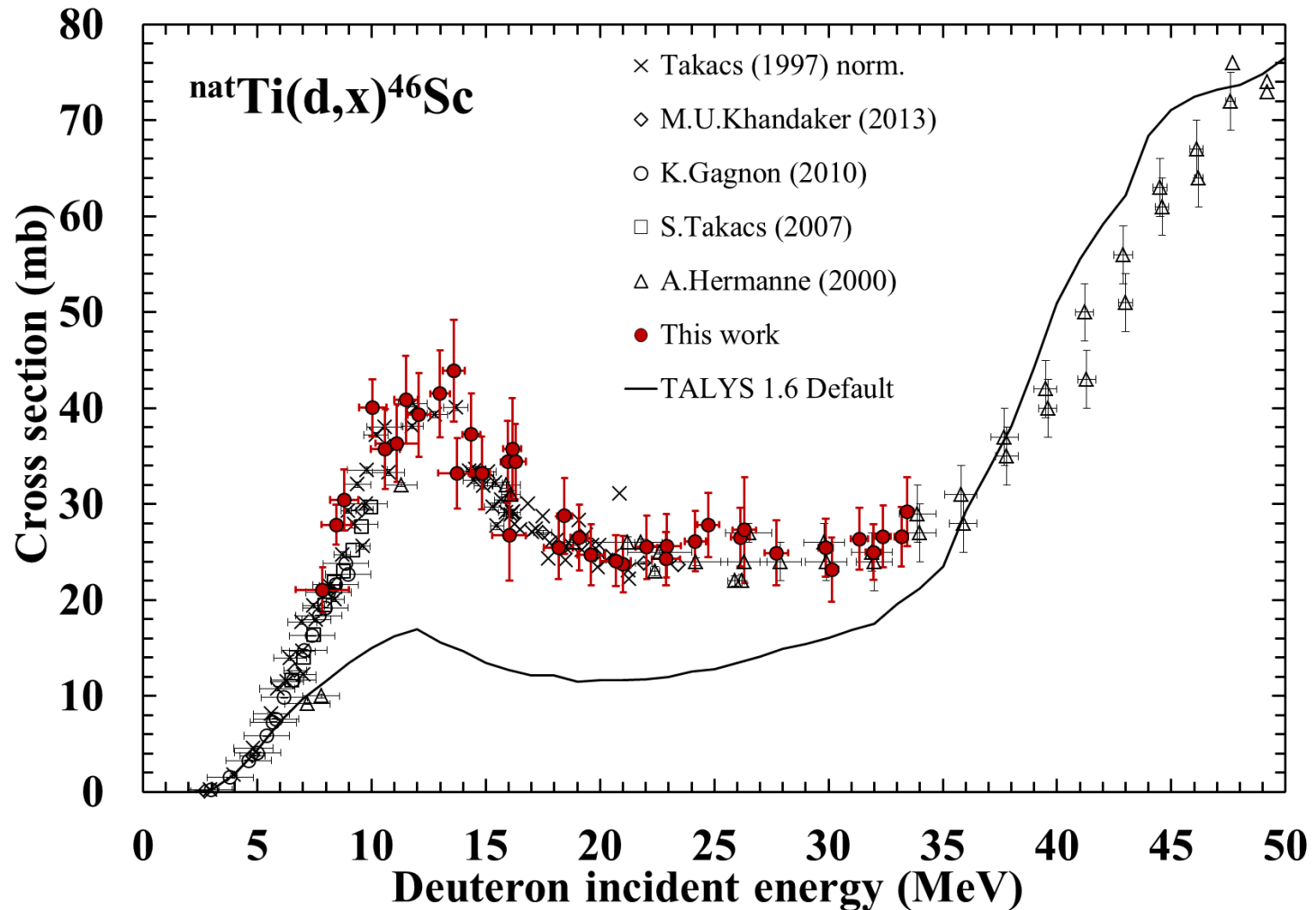
- β^- , $T_{1/2} = 83.79$ d, $E_\gamma = 889.3, 1120.5$ keV - $^{nat}\text{Ti}(p,x)^{46}\text{Sc}$ and $^{nat}\text{Ti}(d,x)^{46}\text{Sc}$



Results and comparisons

⁴⁶Sc: IAEA requirement list

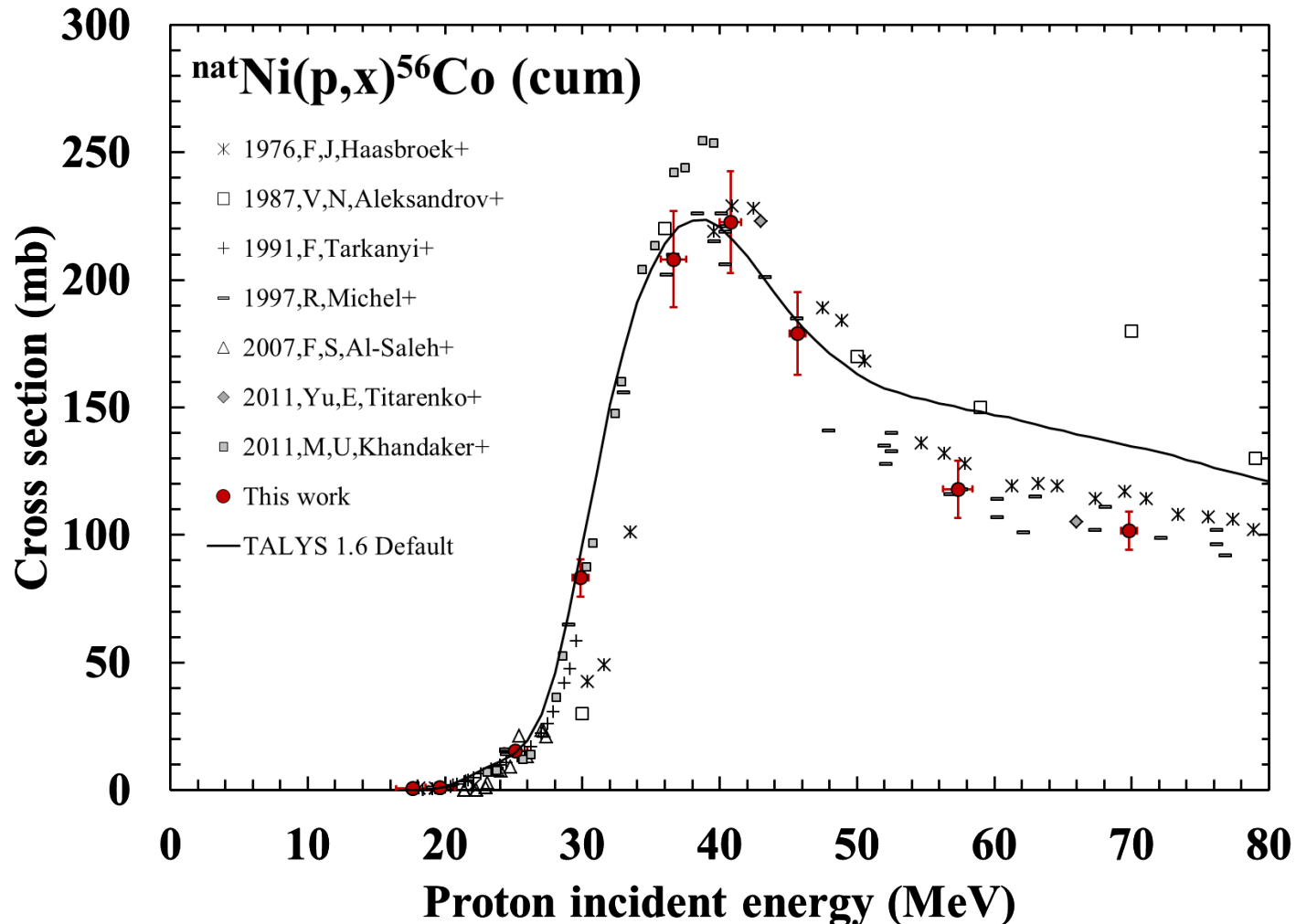
- β^- , $T_{1/2} = 83.79$ d, $E_\gamma = 889.3, 1120.5$ keV - $^{nat}\text{Ti}(p,x)^{46}\text{Sc}$ and $^{nat}\text{Ti}(d,x)^{46}\text{Sc}$



Results and comparisons

⁵⁶Co: IAEA requirement list

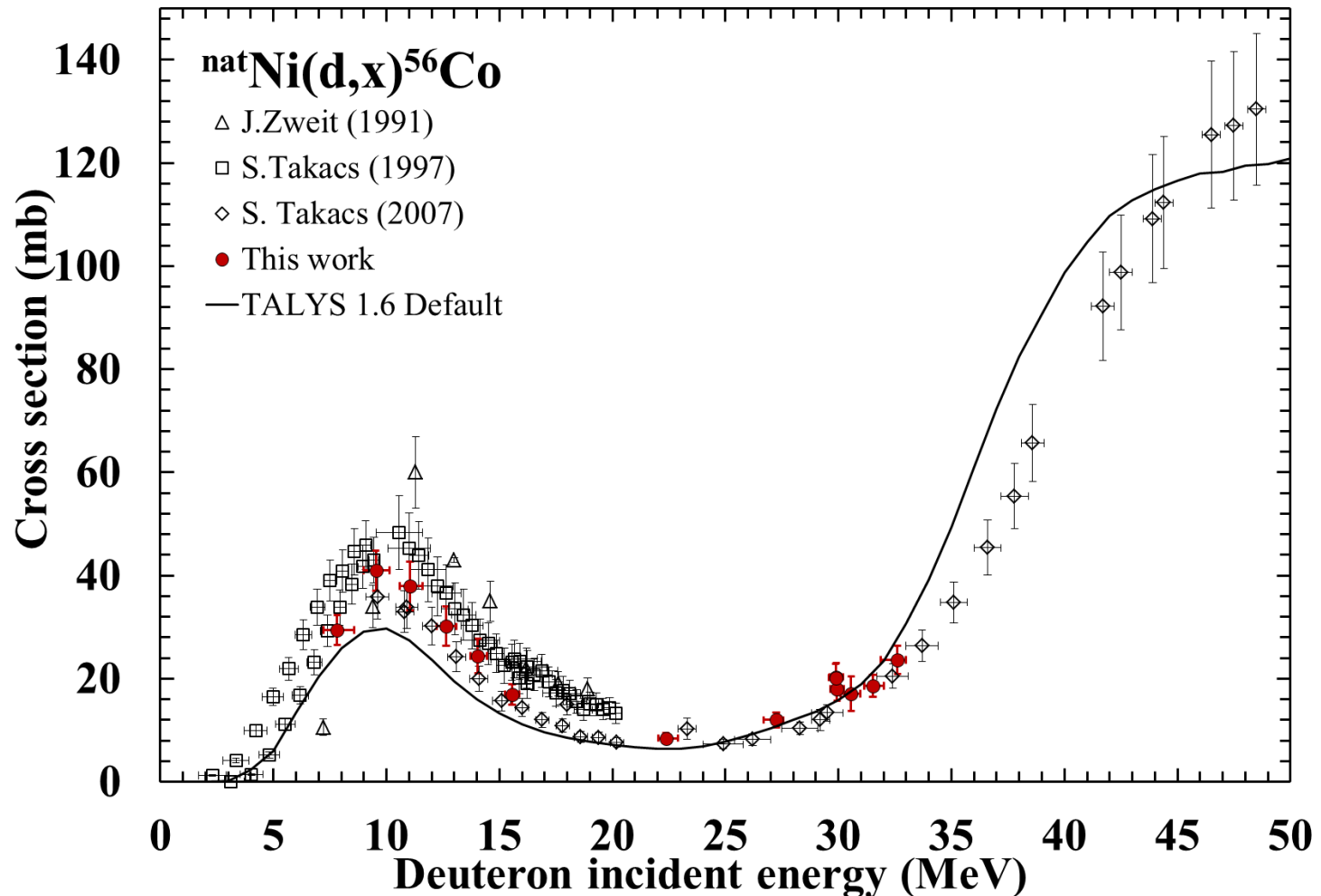
- β^+ , $T_{1/2} = 77.27$ d, $E_\gamma = 846.8, 1238.3$ keV - ${}^{\text{nat}}\text{Ni}(p,x){}^{56}\text{Co}$ and ${}^{\text{nat}}\text{Ni}(d,x){}^{56}\text{Co}$



Results and comparisons

⁵⁶Co: IAEA requirement list

- β^+ , $T_{1/2} = 77.27$ d, $E_\gamma = 846.8, 1238.3$ keV - $^{nat}\text{Ni}(p,x)^{56}\text{Co}$ and $^{nat}\text{Ni}(d,x)^{56}\text{Co}$

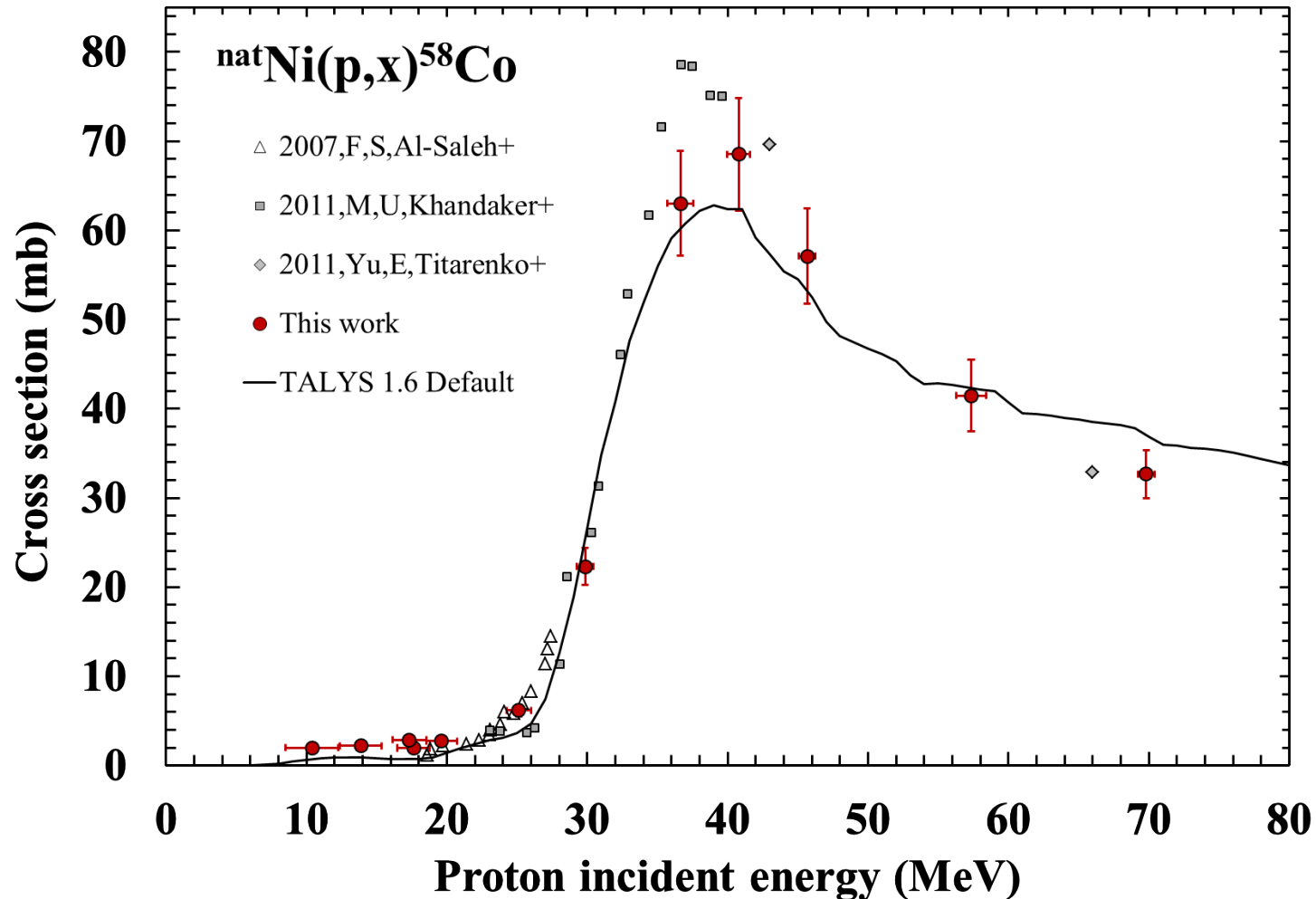


Results and comparisons

^{58}Co : IAEA requirement list

- β^+ , $T_{1/2} = 70.86$ d, $E_\gamma = 810.8$ keV

- $^{nat}\text{Ni}(p,x)^{58}\text{Co}$, $^{nat}\text{Cu}(p,x)^{58}\text{Co}$ and $^{nat}\text{Ni}(d,x)^{58}\text{Co}$

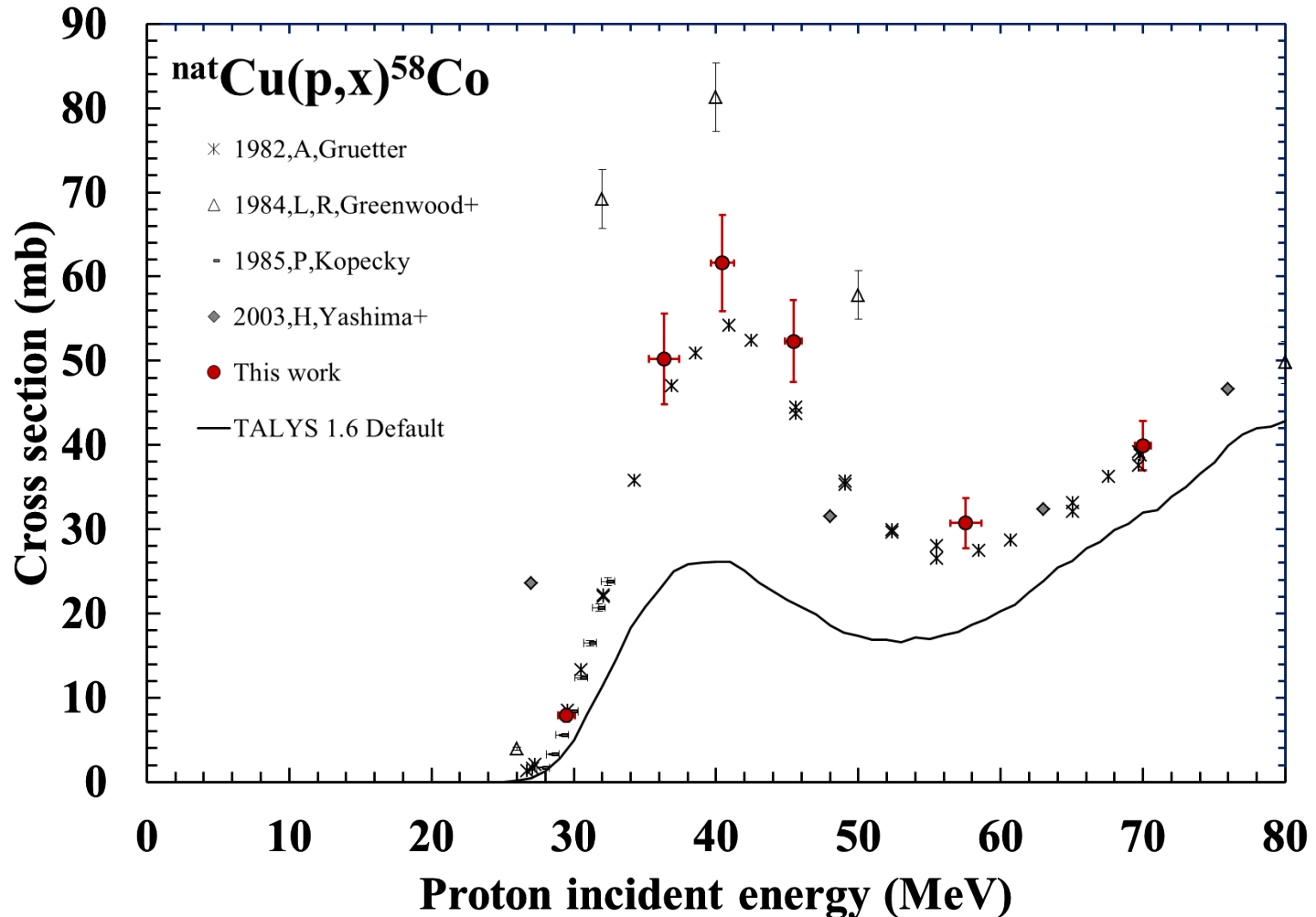


Results and comparisons

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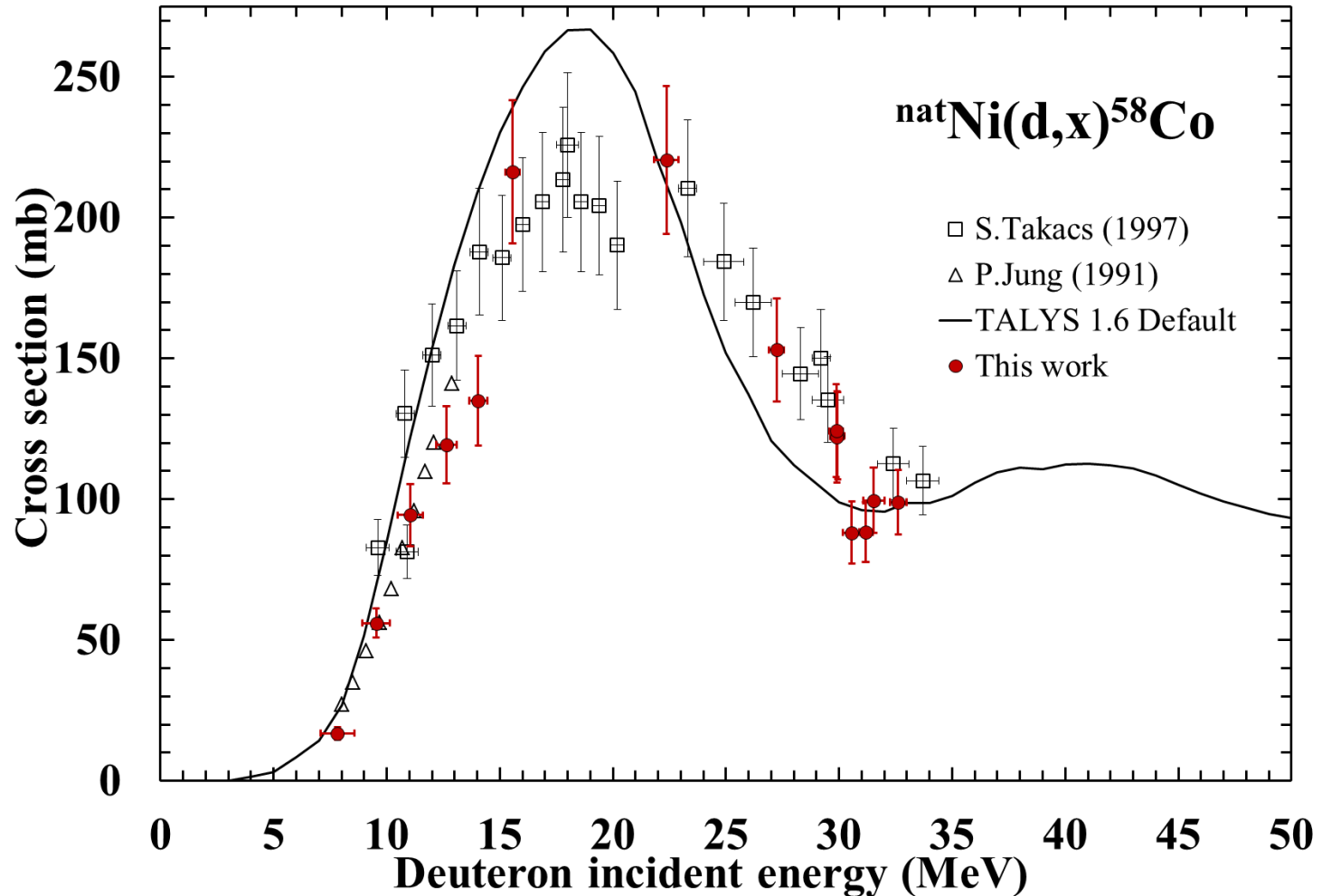


Results and comparisons

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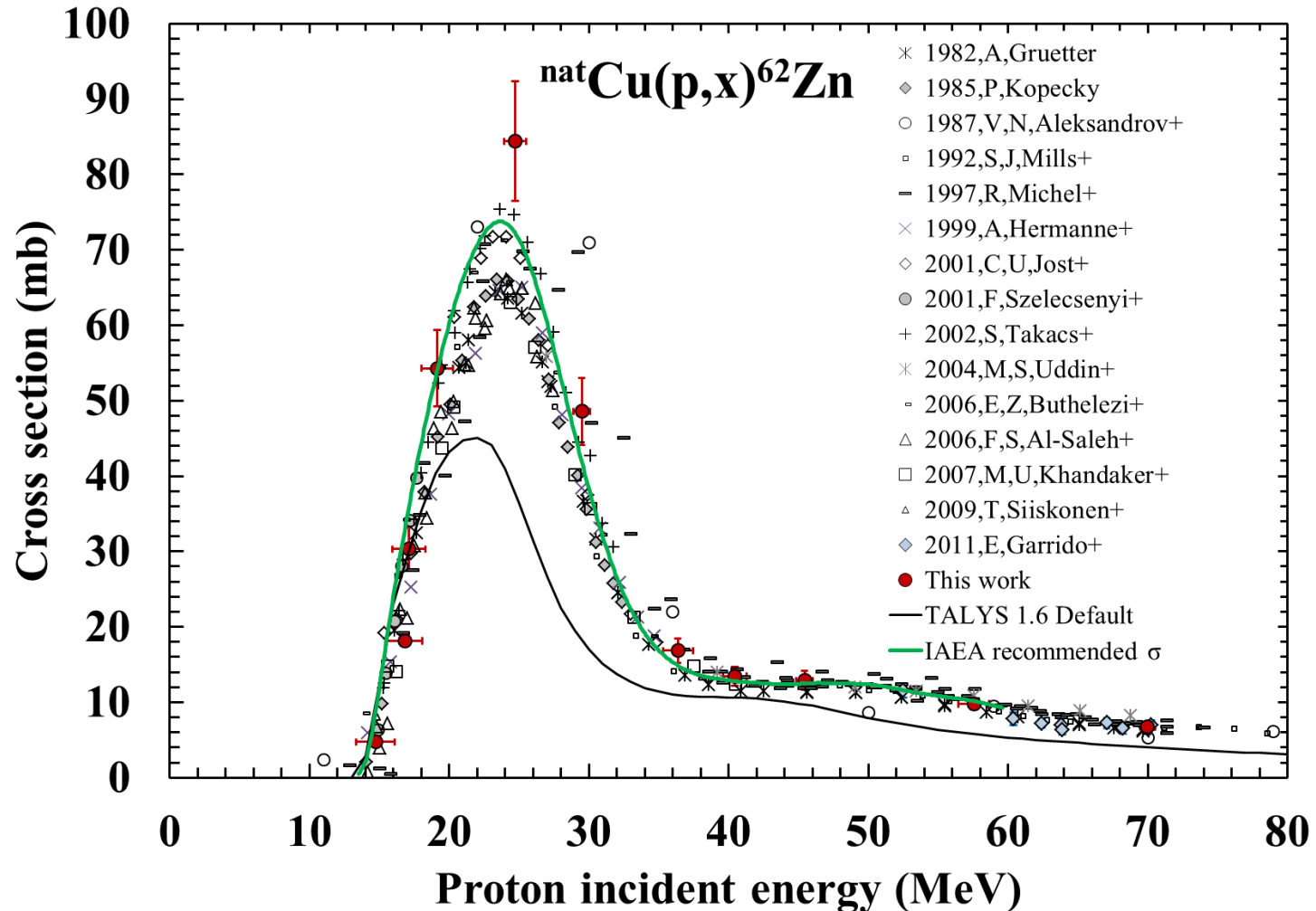
- $^{nat}\text{Ni}(p,x)^{58}\text{Co}$, $^{nat}\text{Cu}(p,x)^{58}\text{Co}$ and $^{nat}\text{Ni}(d,x)^{58}\text{Co}$



Results and comparisons

^{62}Zn : IAEA requirement list

- β^+ , $T_{1/2} = 9.186$ h, $E_{\gamma} = 596.56, 548.35$ keV - $^{\text{nat}}\text{Cu}(p,x)^{62}\text{Zn}$

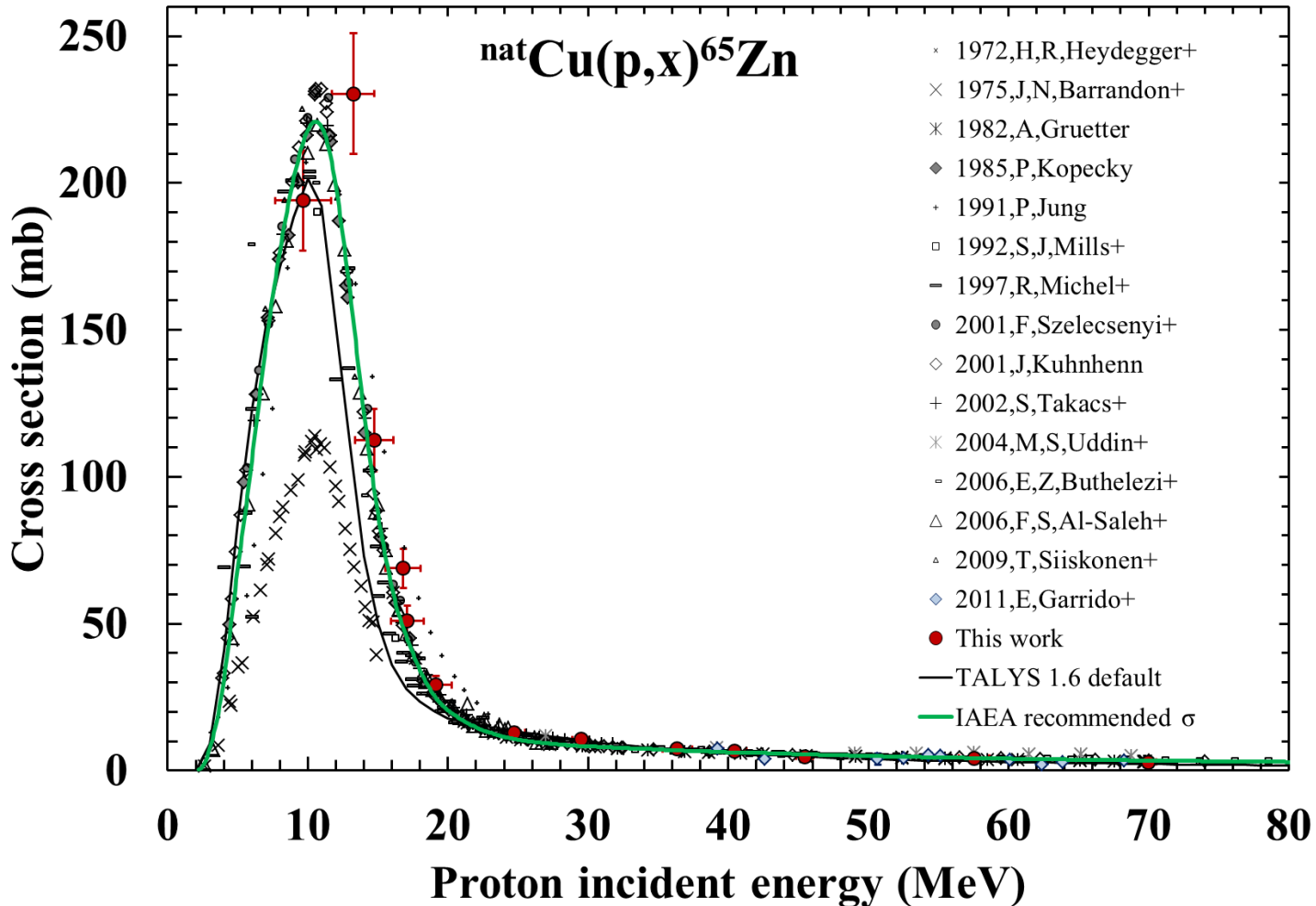


Results and comparisons

^{65}Zn : IAEA requirement list

- β^+ , $T_{1/2} = 244.26$ d, $E_\gamma = 1115.55$ keV

- $^{\text{nat}}\text{Cu}(p,x)^{65}\text{Zn}$

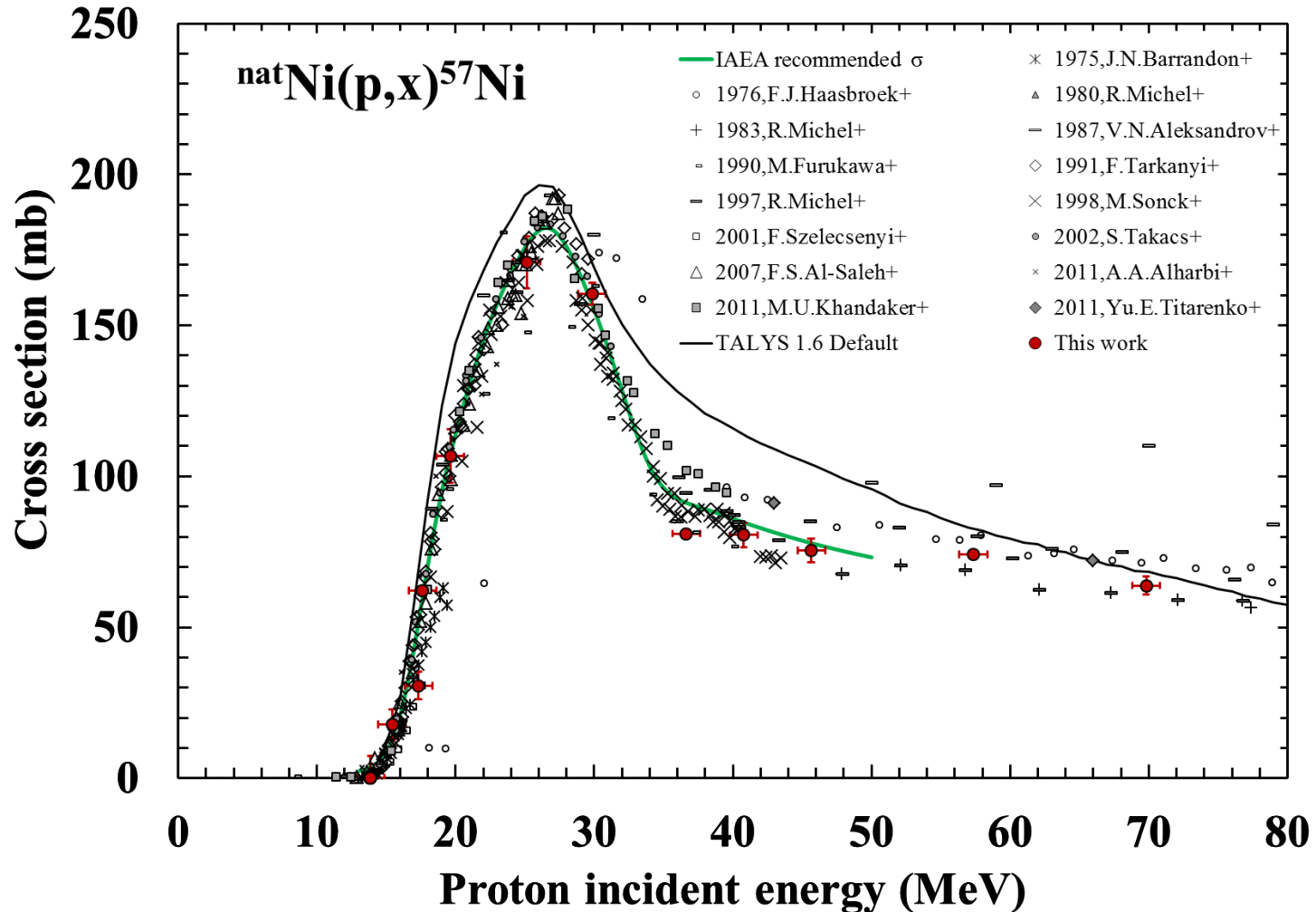


Results and comparisons

^{57}Ni : IAEA requirement list

- β^+ , $T_{1/2} = 35.60$ h, $E_\gamma = 127.16, 1377.63$ keV

- $^{nat}\text{Ni}(p,x)^{57}\text{Ni}$

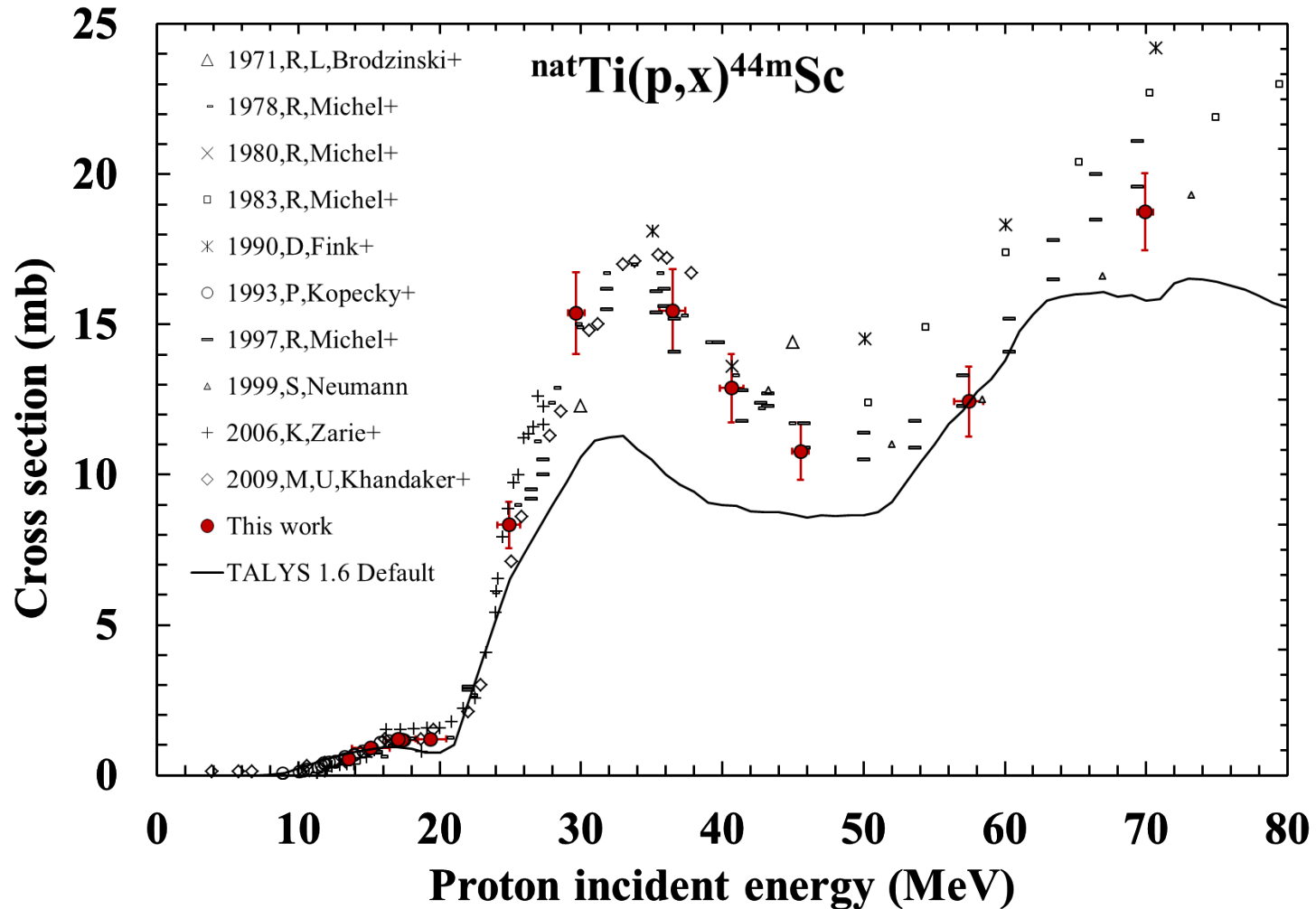


Results and comparisons

^{44m}Sc : additional monitor reaction proposed

- β^+ , $T_{1/2} = 58.6$ h, $E_\gamma = 271.1$ keV

- $^{nat}\text{Ti}(p,x)^{44m}\text{Sc}$ and $^{nat}\text{Ti}(d,x)^{44m}\text{Sc}$

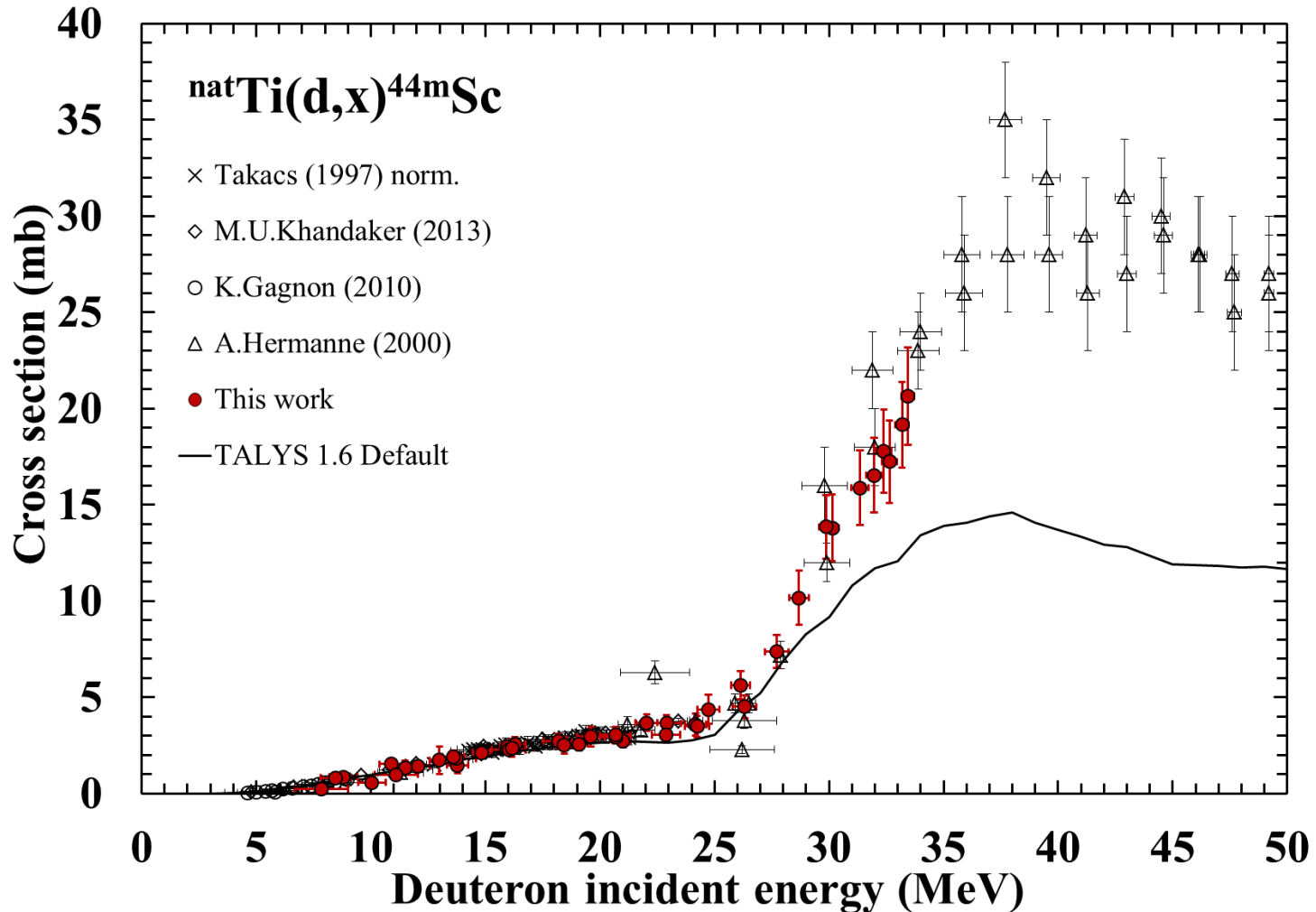


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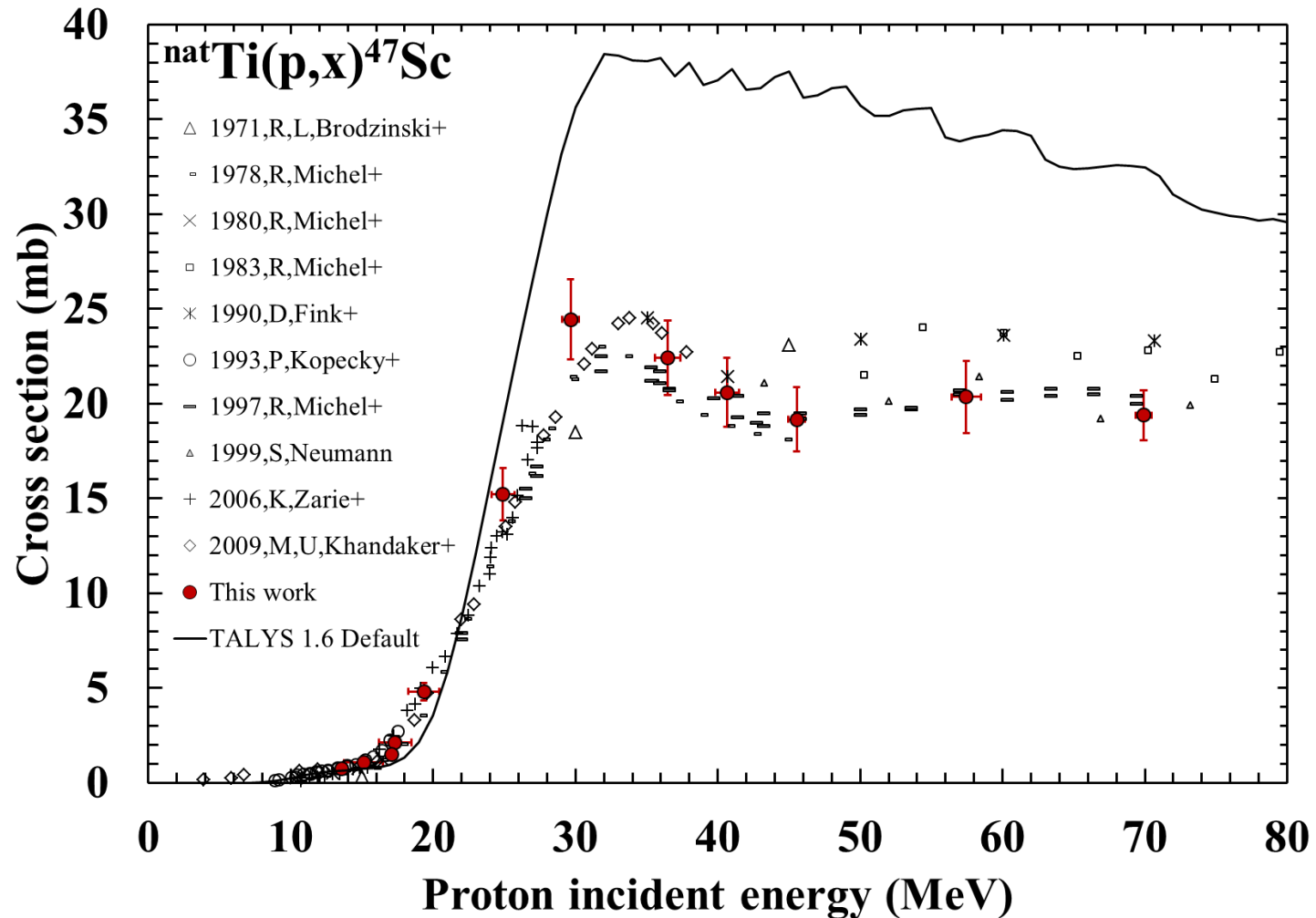


Results and comparisons

^{47}Sc : additional monitor reaction proposed

- β^- , $T_{1/2} = 3.3492$ d, $E_\gamma = 159.38$ keV

- $^{nat}\text{Ti}(p,x)^{47}\text{Sc}$ and $^{nat}\text{Ti}(d,x)^{47}\text{Sc}$

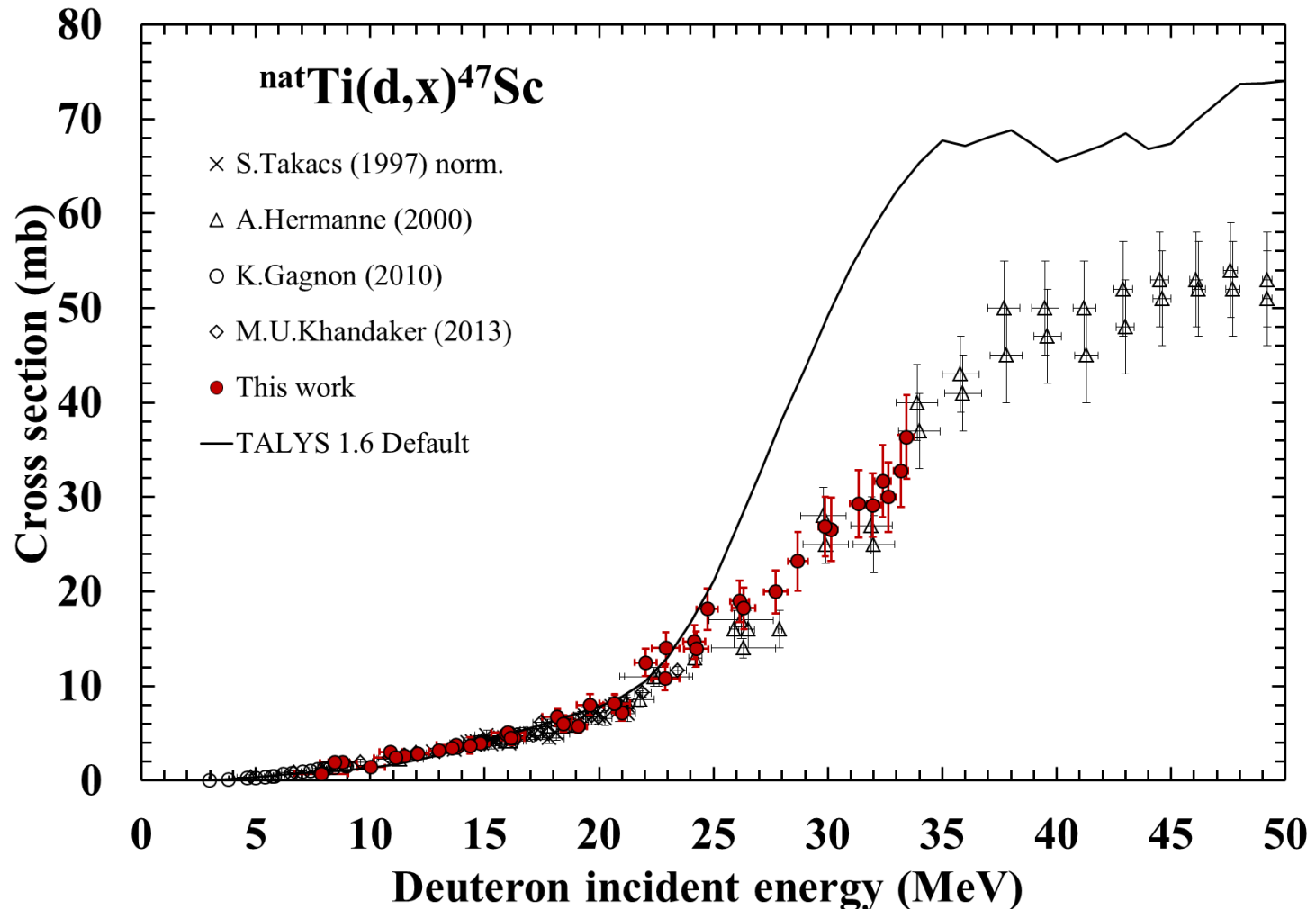


Results and comparisons

^{47}Sc : additional monitor reaction proposed

- β^- , $T_{1/2} = 3.3492$ d, $E_\gamma = 159.38$ keV

- $^{nat}\text{Ti}(p,x)^{47}\text{Sc}$ and $^{nat}\text{Ti}(d,x)^{47}\text{Sc}$



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Conclusions:

New data sets obtained to fulfill the need of coherent and reliable nuclear data for nuclear medicine

- ✓ For both proton and deuteron beams
- ✓ Strengthen the existing IAEA recommended monitor reactions
- ✓ Complete the range in energy
- ✓ Open the door to new monitor reactions

TALYS 1.6 calculations : reasonable agreement in this mass range

Outlooks:

Innovative radio-isotope program for PET imaging, β^- and α targeted radiotherapy at ARRONAX is **ongoing**: $^{82}\text{Sr}/^{82}\text{Rb}$ – ^{44}Sc – ^{64}Cu , ^{47}Sc – ^{67}Cu , ^{186}Re , ^{211}At , ^{230}Pa ...

- ✓ Performing cross section measurements and production calculation (TTY)
- ✓ For beam monitor reactions and isotopes of medical interest
- ✓ Producing a global set of data to constrain theoretical models

TALYS parameter tuning: best combination for whole mass range

- optical models (5) - level density models (5) - pre-equilibrium models (4) - ...

Thank you for your attention

Acknowledgments to the 8ICI organization committee

New Measurements for Proton and Deuteron Beam Monitor Reactions

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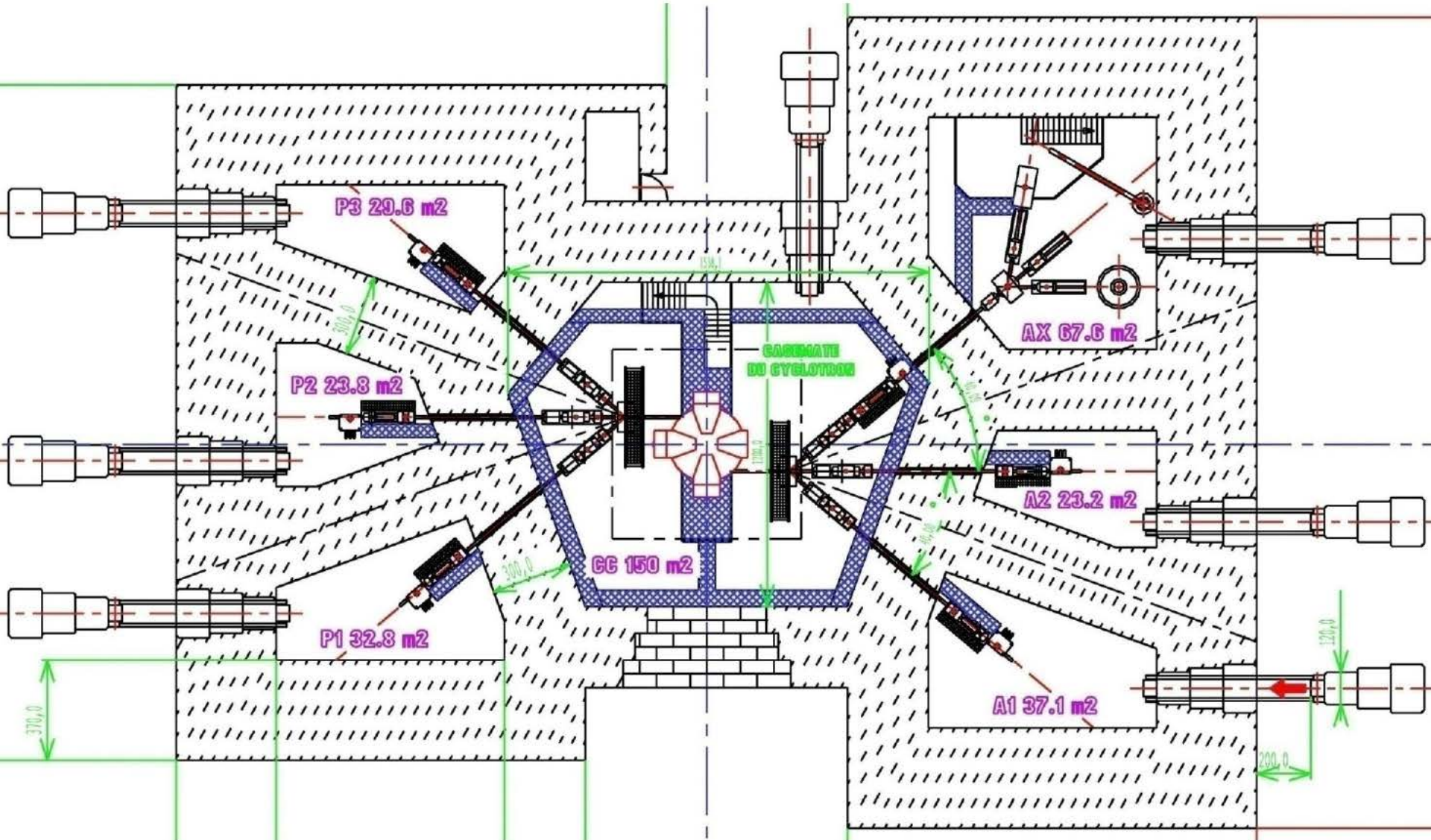
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The ARRONAX cyclotron is a project promoted by the Regional Council of Pays de la Loire financed by local authorities, the French government and the European Union.

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ARRONAX facility



C70 Cyclotron build by IBA:

- **4 sectors isochron cyclotron** (~ 4m of diameter)
 - RF: 30.45 MHz
 - Acceleration Voltage: 65 kV
 - Max magn. field : 1.6 T
 - Max kin. energy/n: 30-70 MeV
- **2 multi-particle sources:**
 - H⁻, D⁻: multicusp, 5 mA max.
 - He²⁺, HH⁺: supernanogan ECR
- Extraction: stripper (-) or electrostatic deflector (+)

Extracted	Energy (MeV)	Max. current (μA)
H ⁺	30 – 70	2 x 375
D ⁺	15 – 35	2 x 50
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