



HAL
open science

New measurements for Proton and Deuteron Beam Monitor Reactions

Arnaud Guertin, Charlotte Duchemin, Eric Garrido, Ferid Haddad, Vincent Métivier, Nathalie Michel

► **To cite this version:**

Arnaud Guertin, Charlotte Duchemin, Eric Garrido, Ferid Haddad, Vincent Métivier, et al.. New measurements for Proton and Deuteron Beam Monitor Reactions. 8th International Conference on Isotopes and Expo, Aug 2014, Chicago, United States. <in2p3-01955608>

HAL Id: in2p3-01955608

<https://in2p3.hal.science/in2p3-01955608v1>

Submitted on 15 Jan 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization



IN2P3

Institut national de physique nucléaire
et de physique des particules

GUERTIN Arnaud
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

Experimental set-up and data measurements

Results and comparisons

Conclusions and outlooks



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

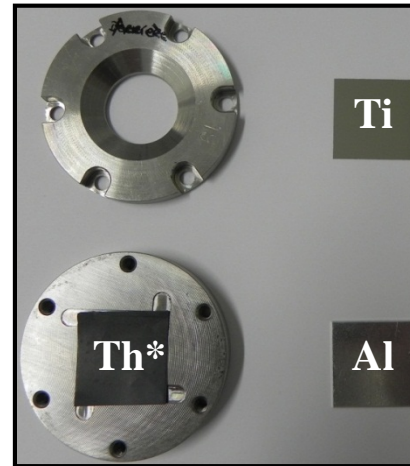
* Medium Energy Accelerators for Isotope Production in Europe, F. Haddad, Subatech, GIP ARRONAX, August 27, 3:40 p.m., Crystal A

Stacked-foil technique:

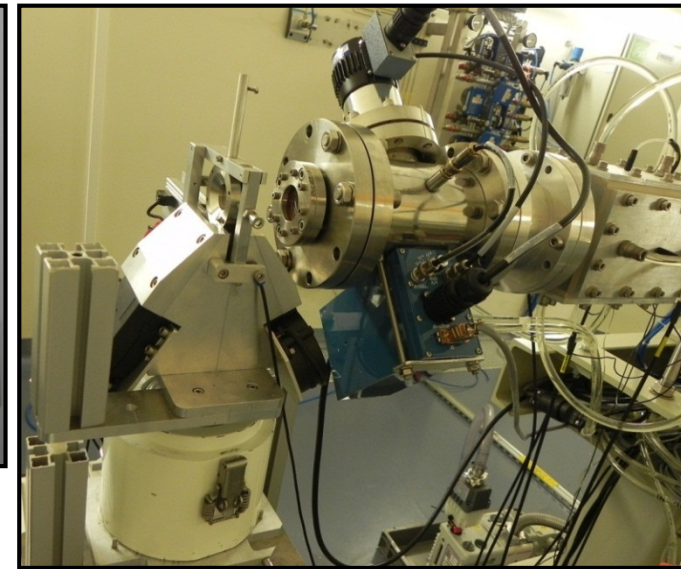
- Target/monitor/degrader **pattern**
- **Thin foils:**
 - E loss small and constant
- One cross section value per foil

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:

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

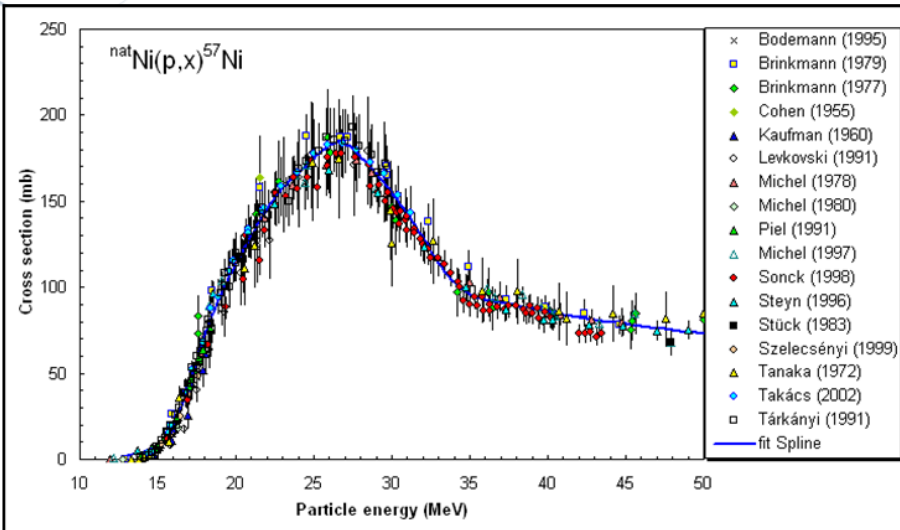
- error on e, e': $\leq 1\%$
- error on t: negligible

IAEA recommended cross sections:

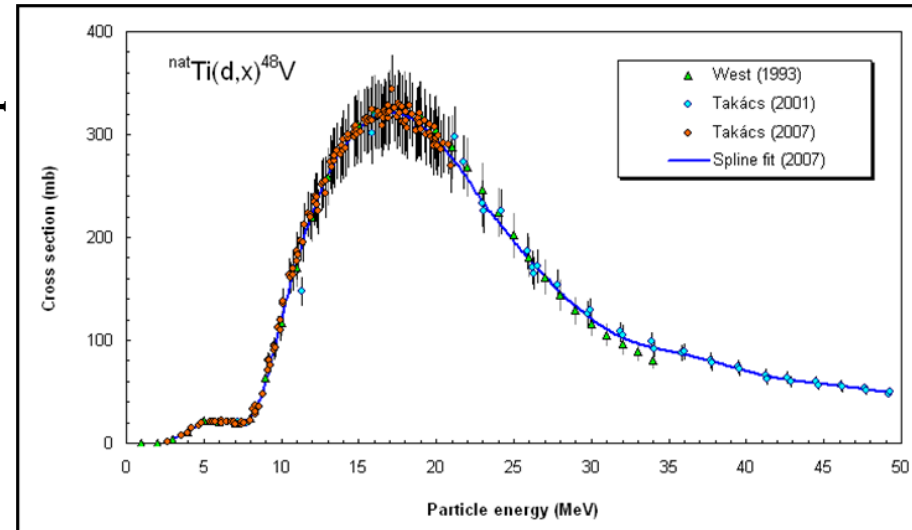
- 8 reactions available for protons
 ^{27}Al (2), $^{\text{nat}}\text{Ni}$, $^{\text{nat}}\text{Ti}$ and $^{\text{nat}}\text{Cu}$ (5)
- 5 reactions available for deuterons
 ^{27}Al (2), $^{\text{nat}}\text{Fe}$, $^{\text{nat}}\text{Ni}$ and $^{\text{nat}}\text{Ti}$

* *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

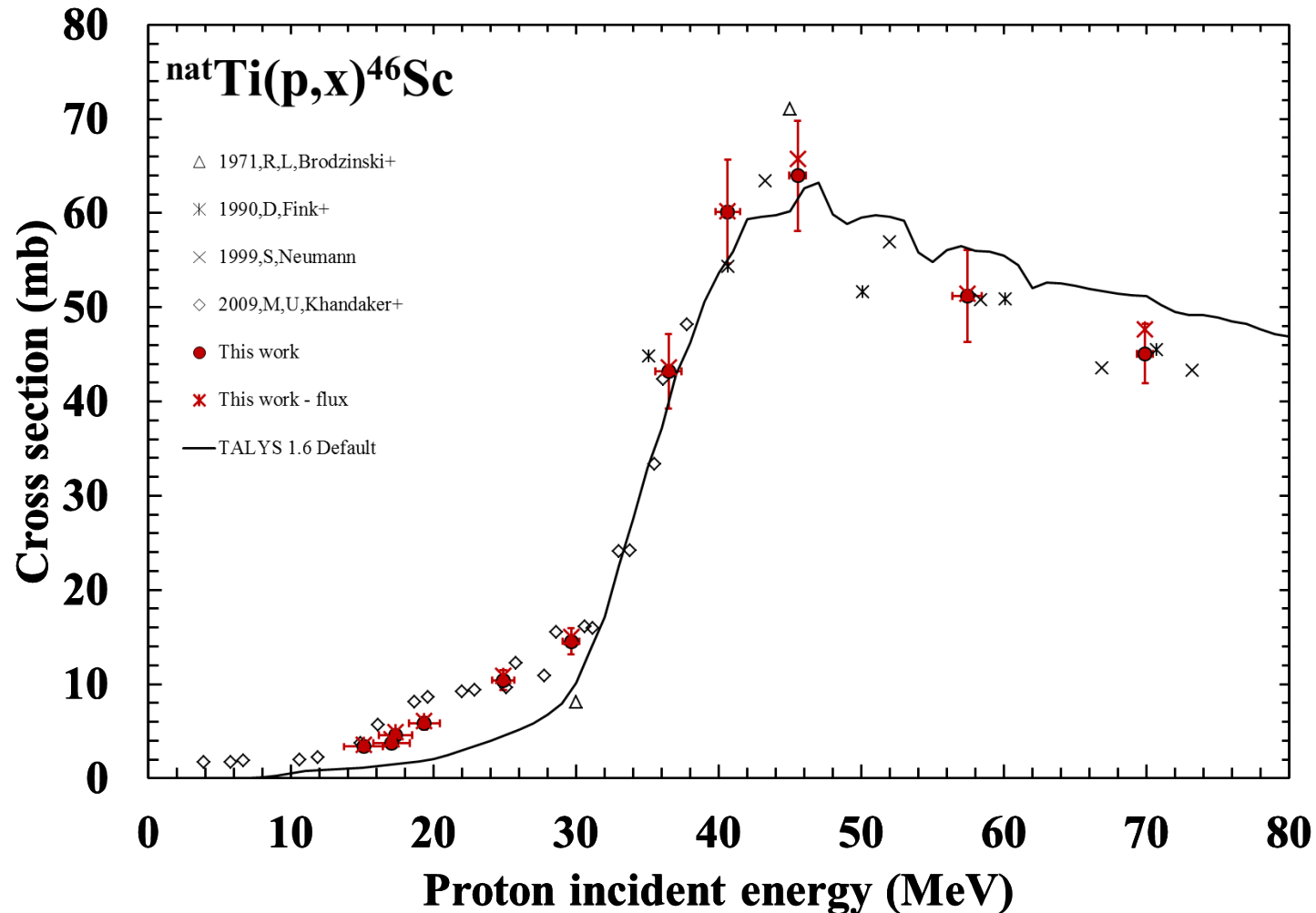
Results and comparisons

Conclusions and outlooks

Results and comparisons

^{46}Sc : IAEA requirement list

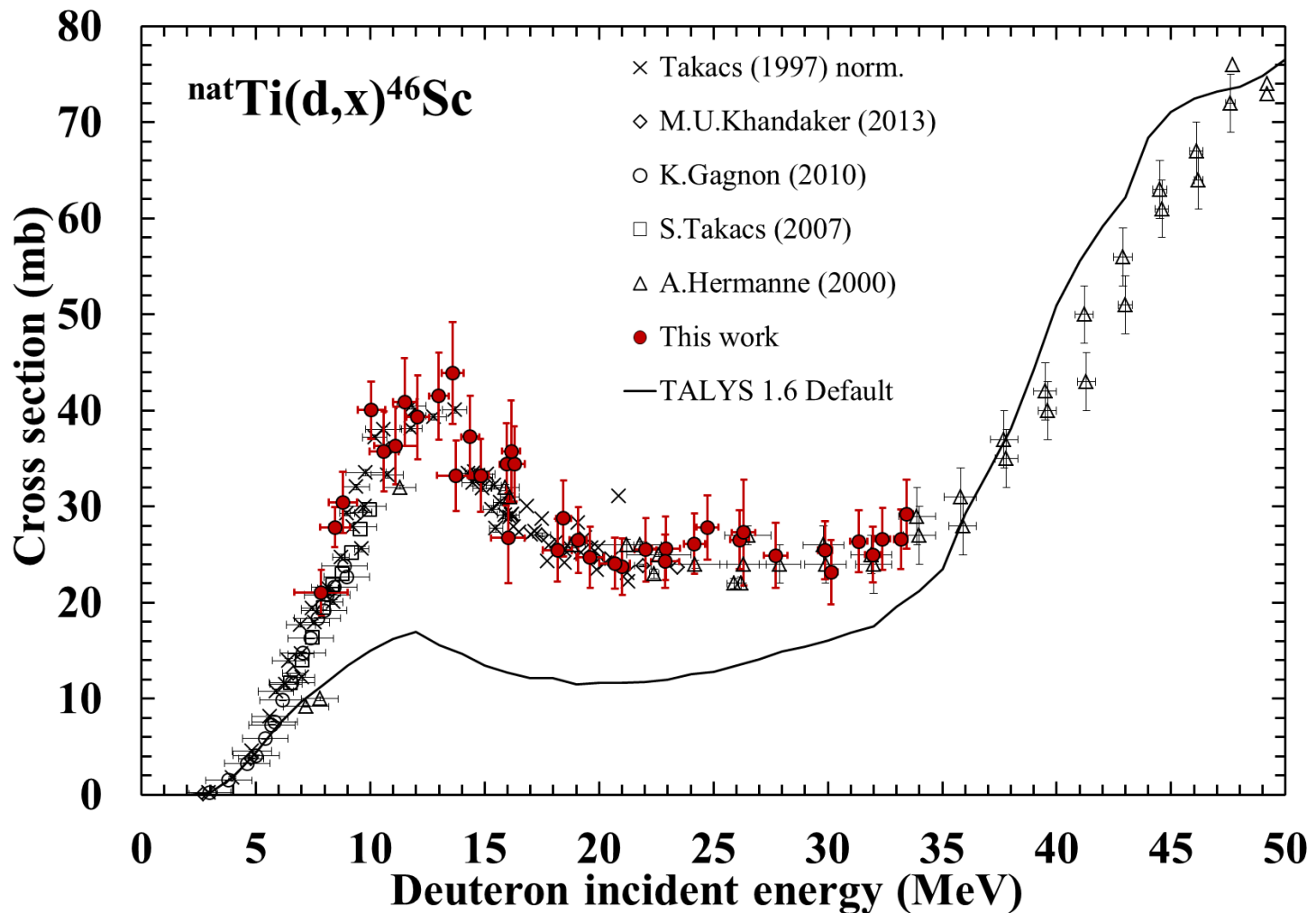
- β^- , $T_{1/2} = 83.79$ d, $E_\gamma = 889.3, 1120.5$ keV - $^{nat}\text{Ti}(p,x)^{46}\text{Sc}$ and $^{nat}\text{Ti}(d,x)^{46}\text{Sc}$



Results and comparisons

⁴⁶Sc: IAEA requirement list

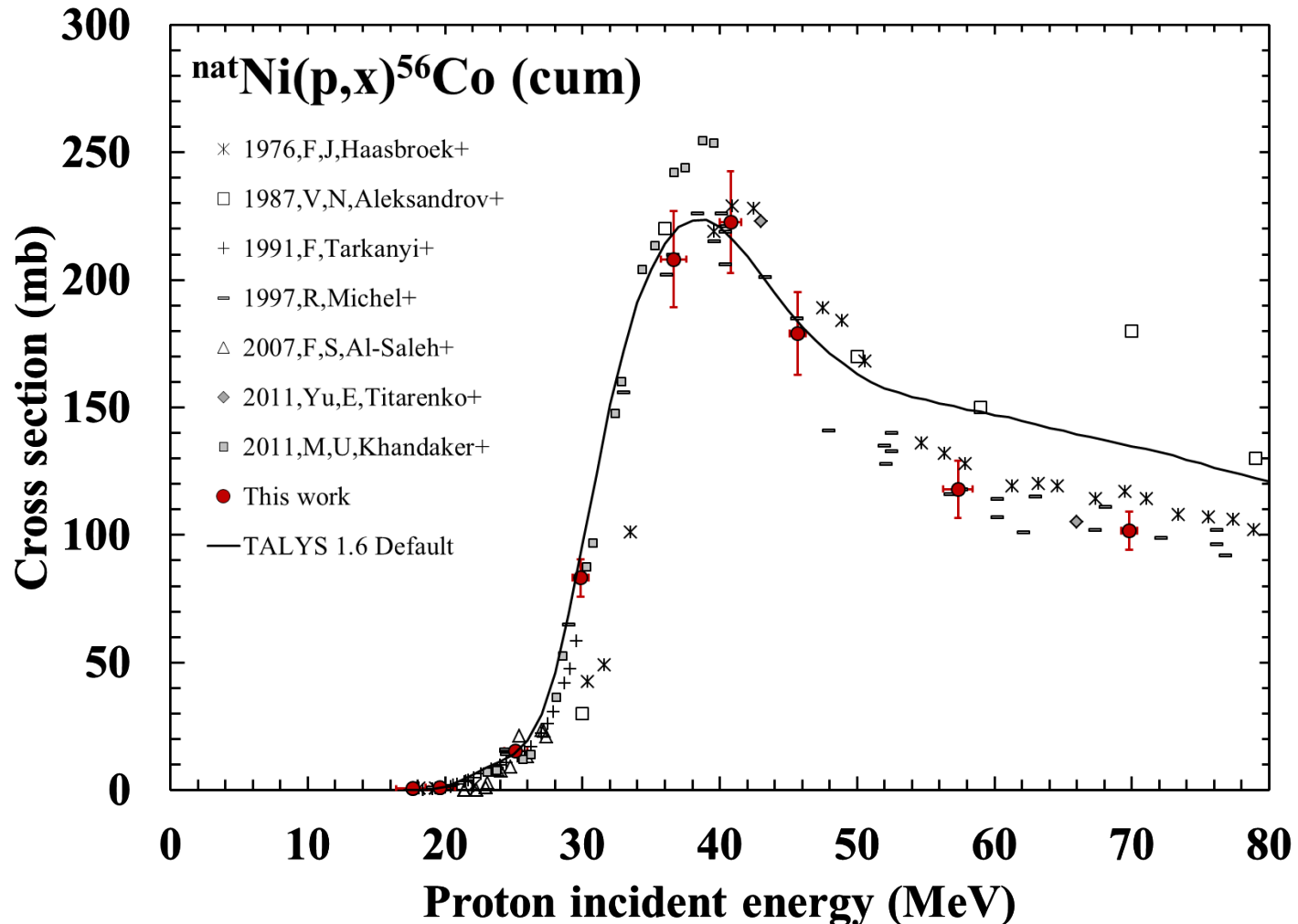
- β^- , $T_{1/2} = 83.79$ d, $E_\gamma = 889.3, 1120.5$ keV - $^{nat}\text{Ti}(p,x)^{46}\text{Sc}$ and $^{nat}\text{Ti}(d,x)^{46}\text{Sc}$



Results and comparisons

⁵⁶Co: IAEA requirement list

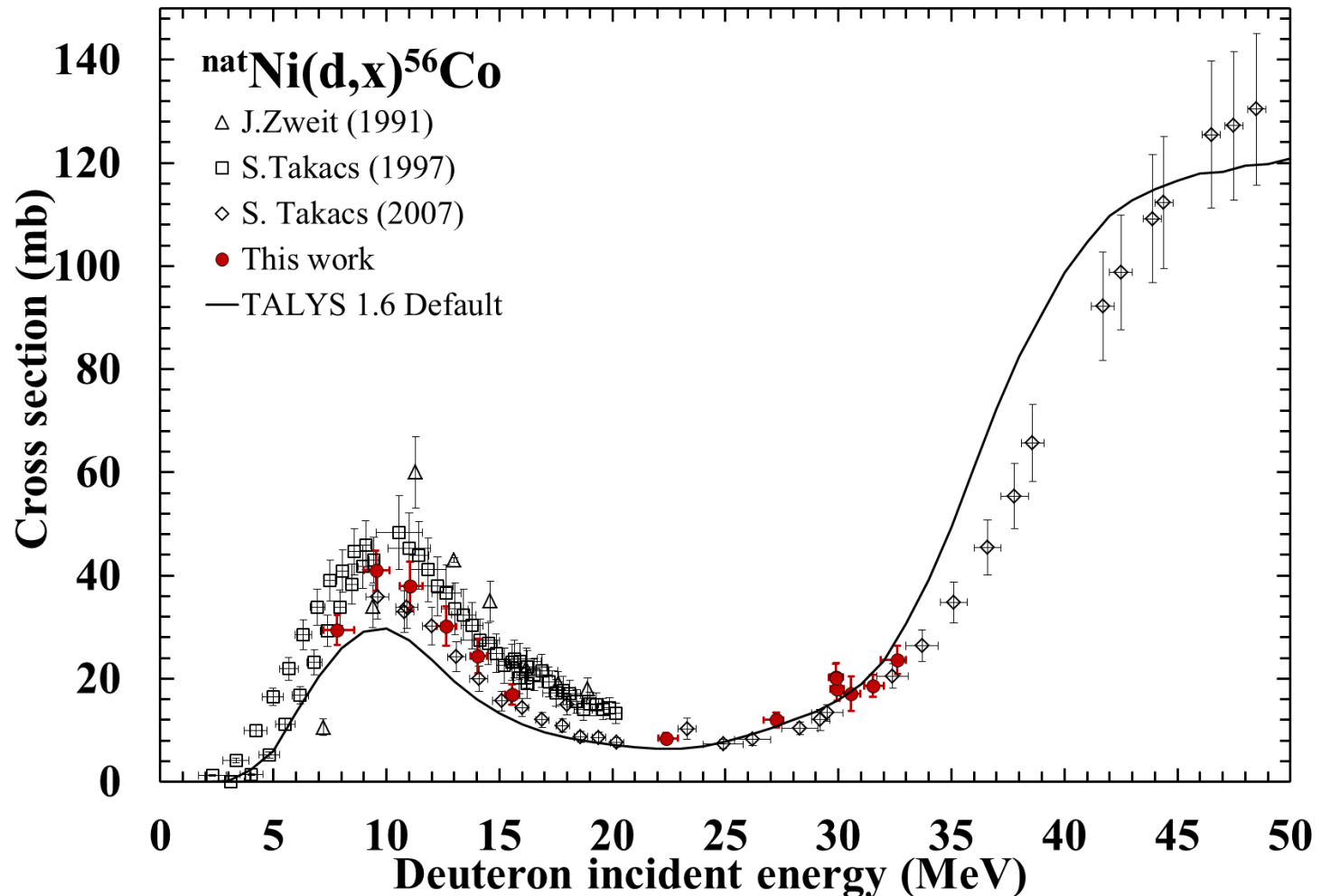
- β^+ , $T_{1/2} = 77.27$ d, $E_\gamma = 846.8, 1238.3$ keV - $^{nat}\text{Ni}(p,x)^{56}\text{Co}$ and $^{nat}\text{Ni}(d,x)^{56}\text{Co}$



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 $^{nat}\text{Ni}(d,x)^{56}\text{Co}$

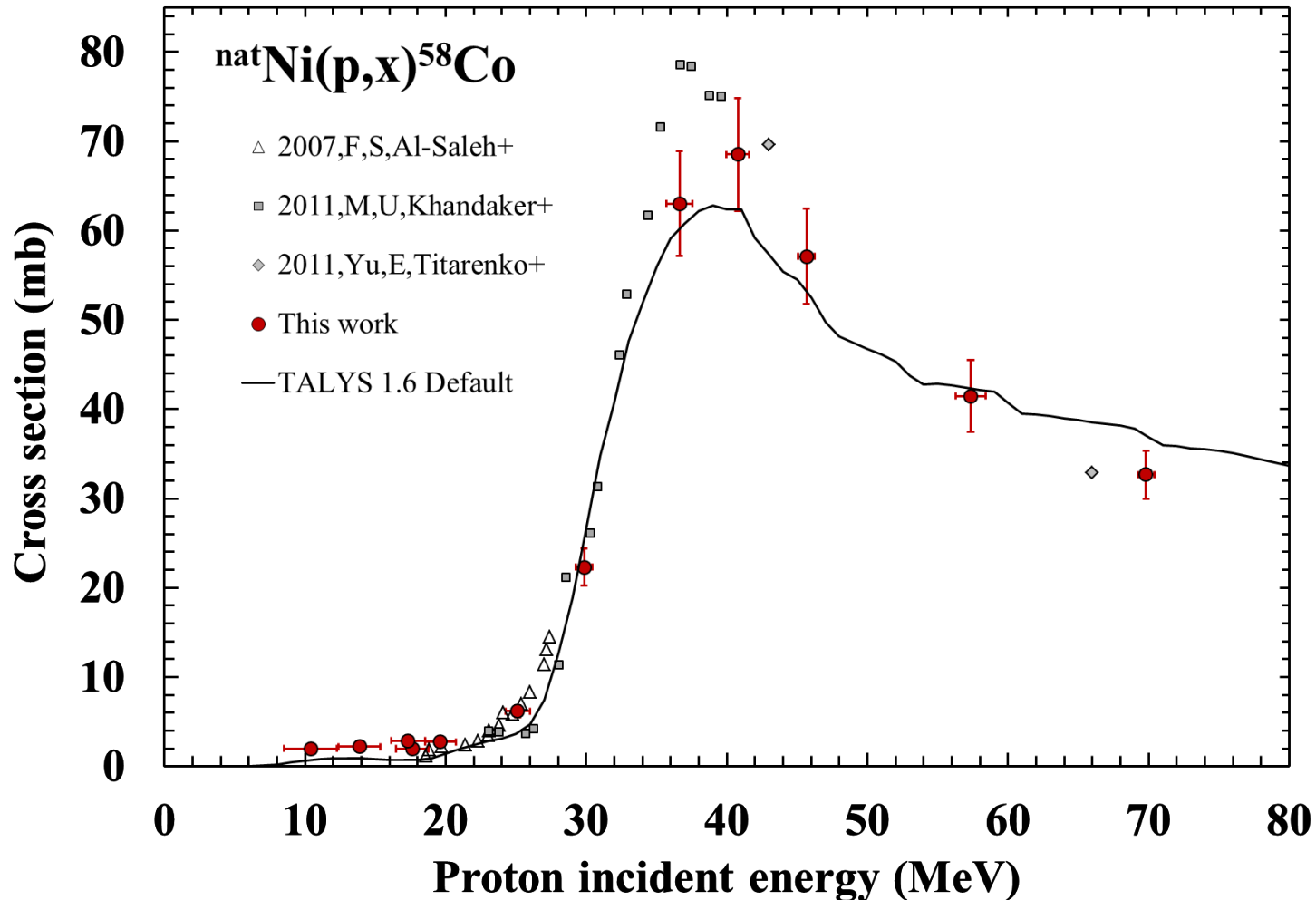


Results and comparisons

^{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 $^{nat}\text{Ni}(d,x)^{58}\text{Co}$

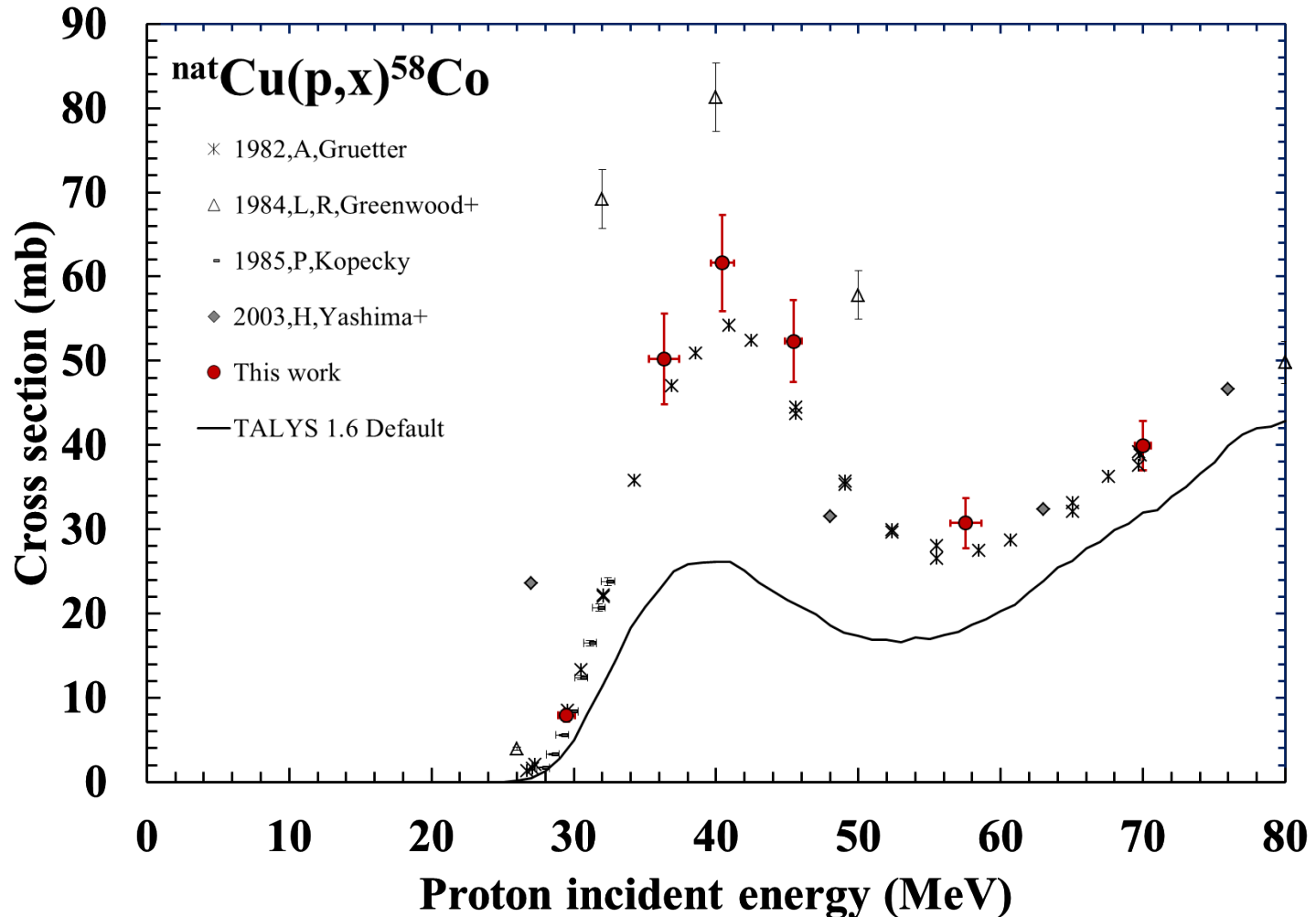


Results and comparisons

⁵⁸Co: IAEA requirement list

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

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

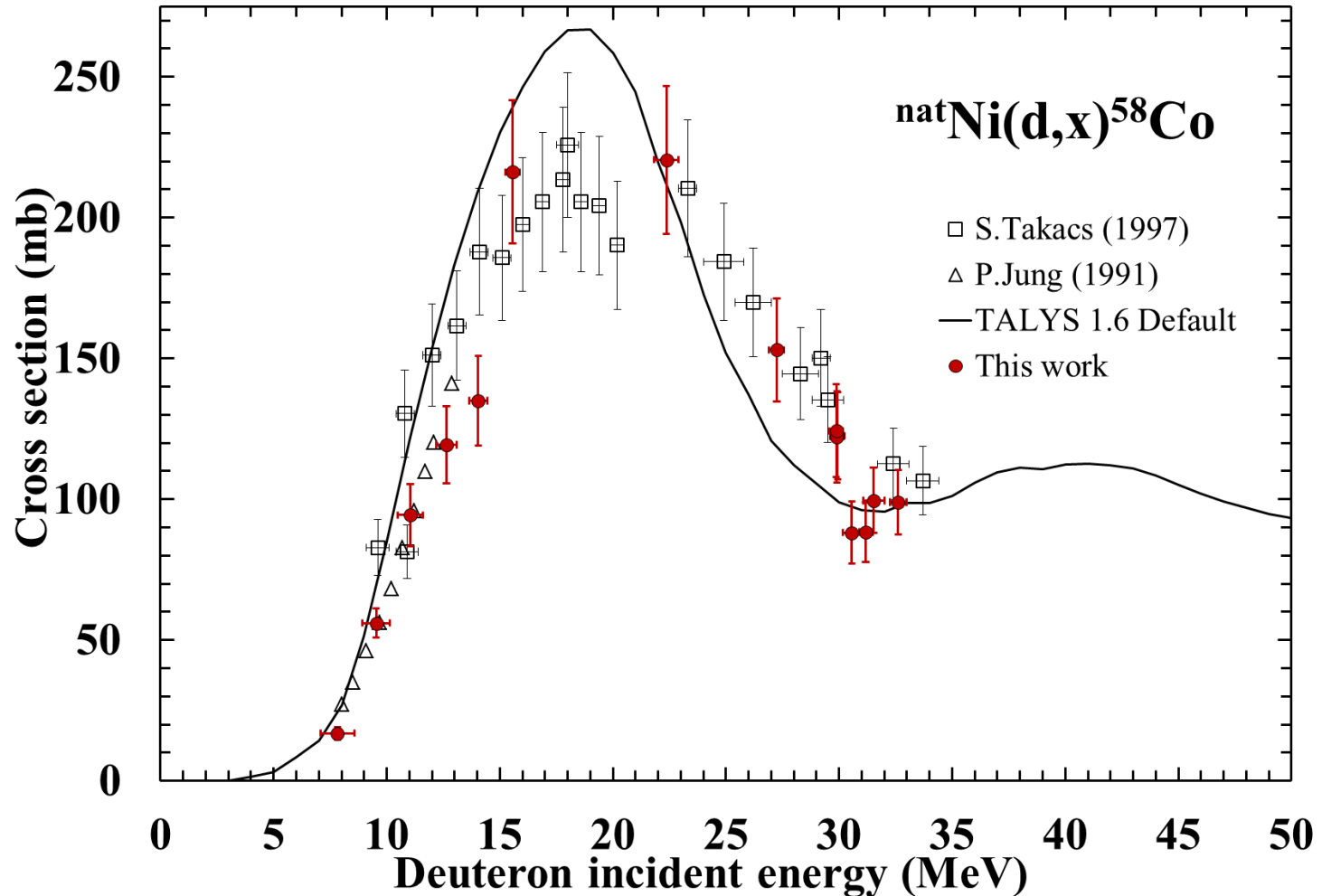


Results and comparisons

^{58}Co : IAEA requirement list

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

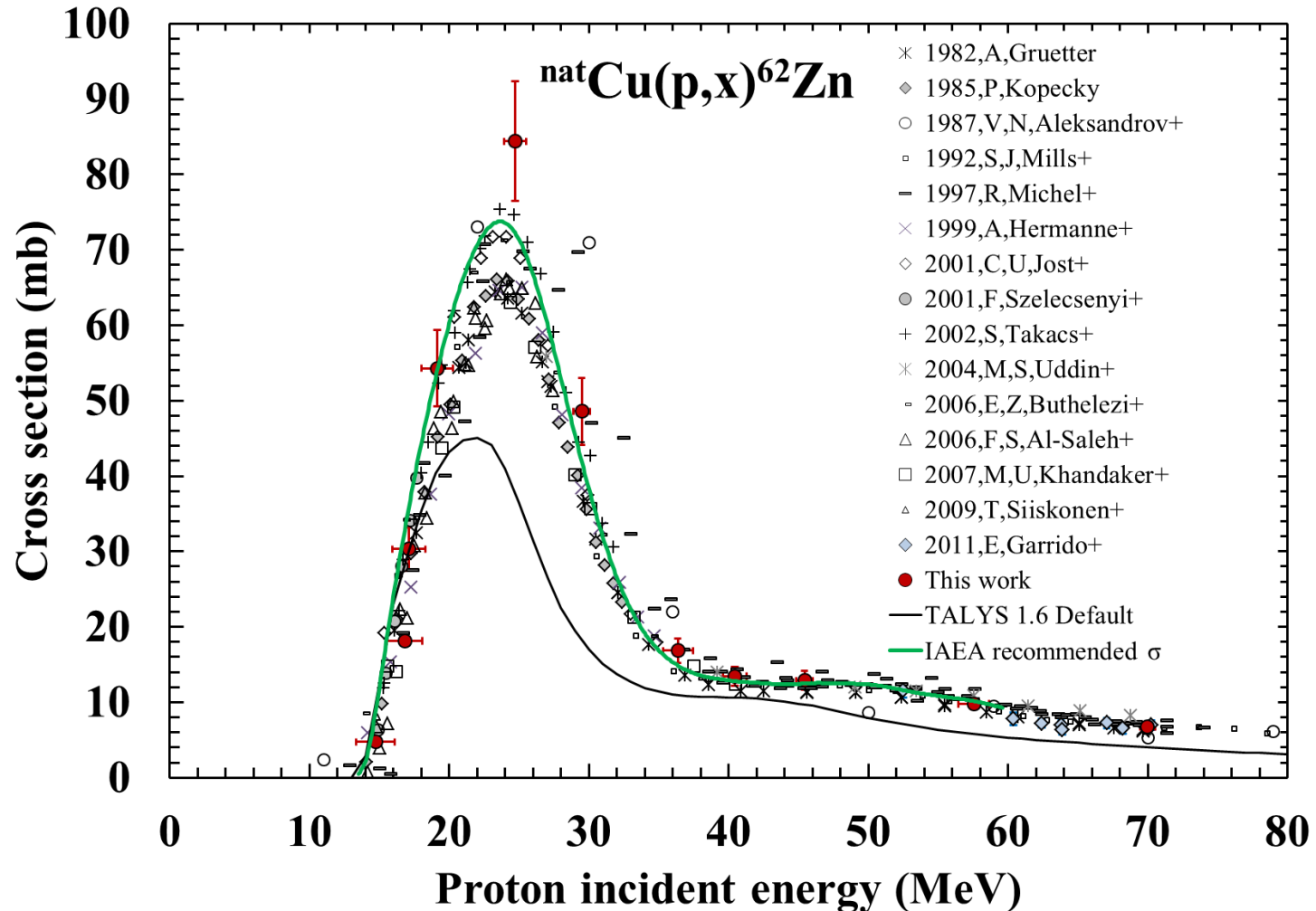
- $^{nat}\text{Ni}(p,x)^{58}\text{Co}$, $^{nat}\text{Cu}(p,x)^{58}\text{Co}$ and $^{nat}\text{Ni}(d,x)^{58}\text{Co}$



Results and comparisons

^{62}Zn : IAEA requirement list

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

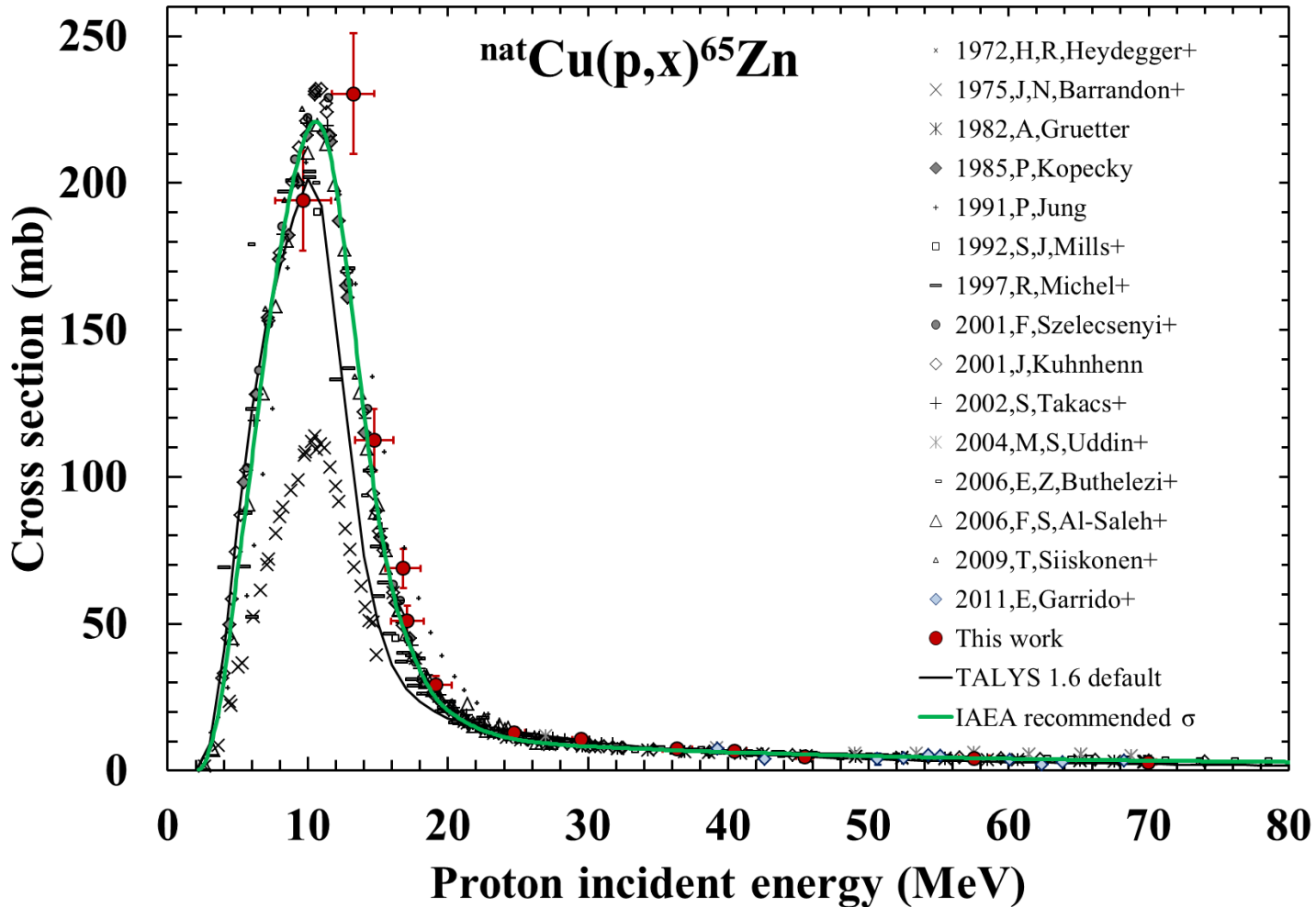


Results and comparisons

^{65}Zn : IAEA requirement list

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

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

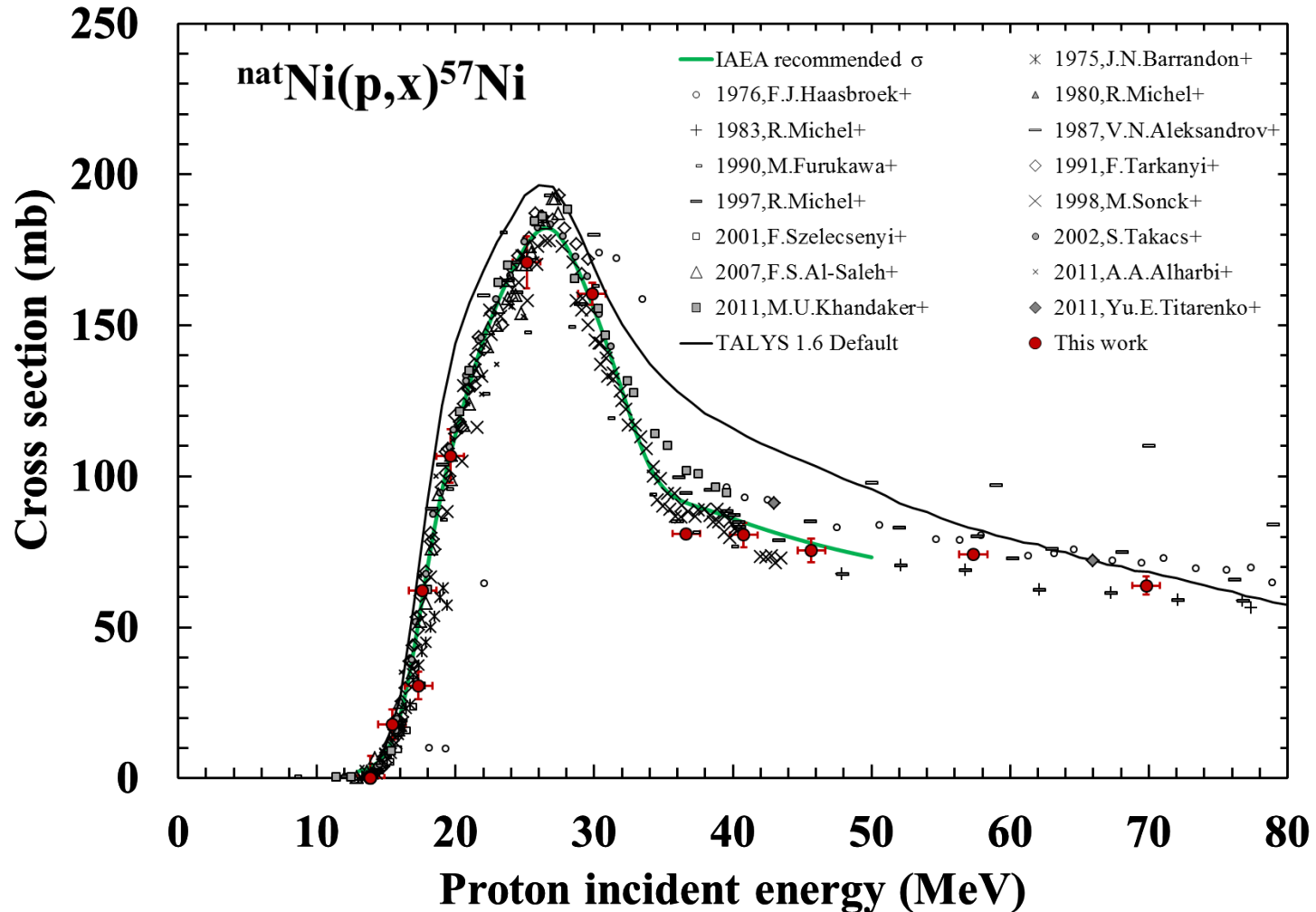


Results and comparisons

^{57}Ni : IAEA requirement list

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

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

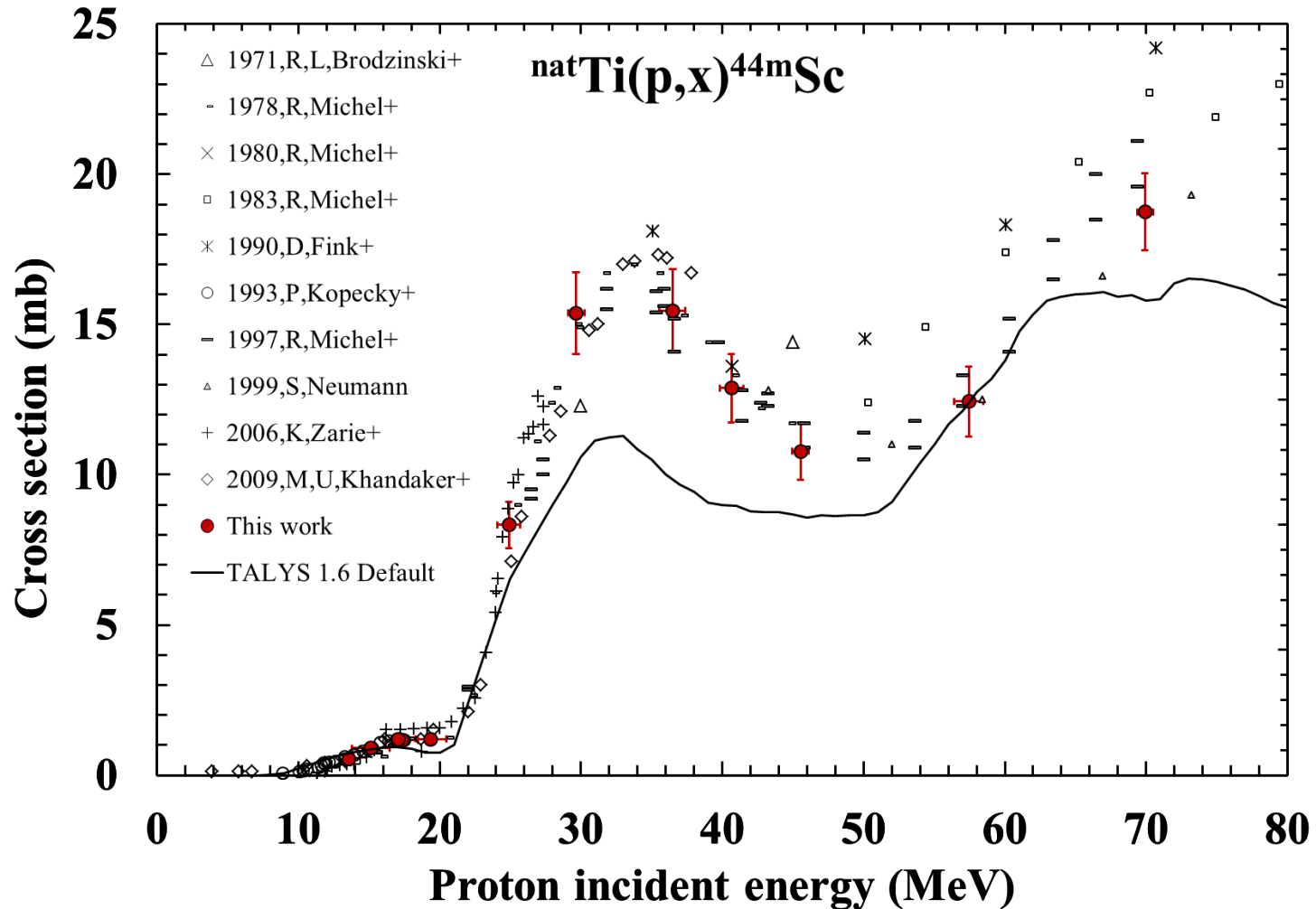


Results and comparisons

^{44m}Sc : additional monitor reaction proposed

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

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

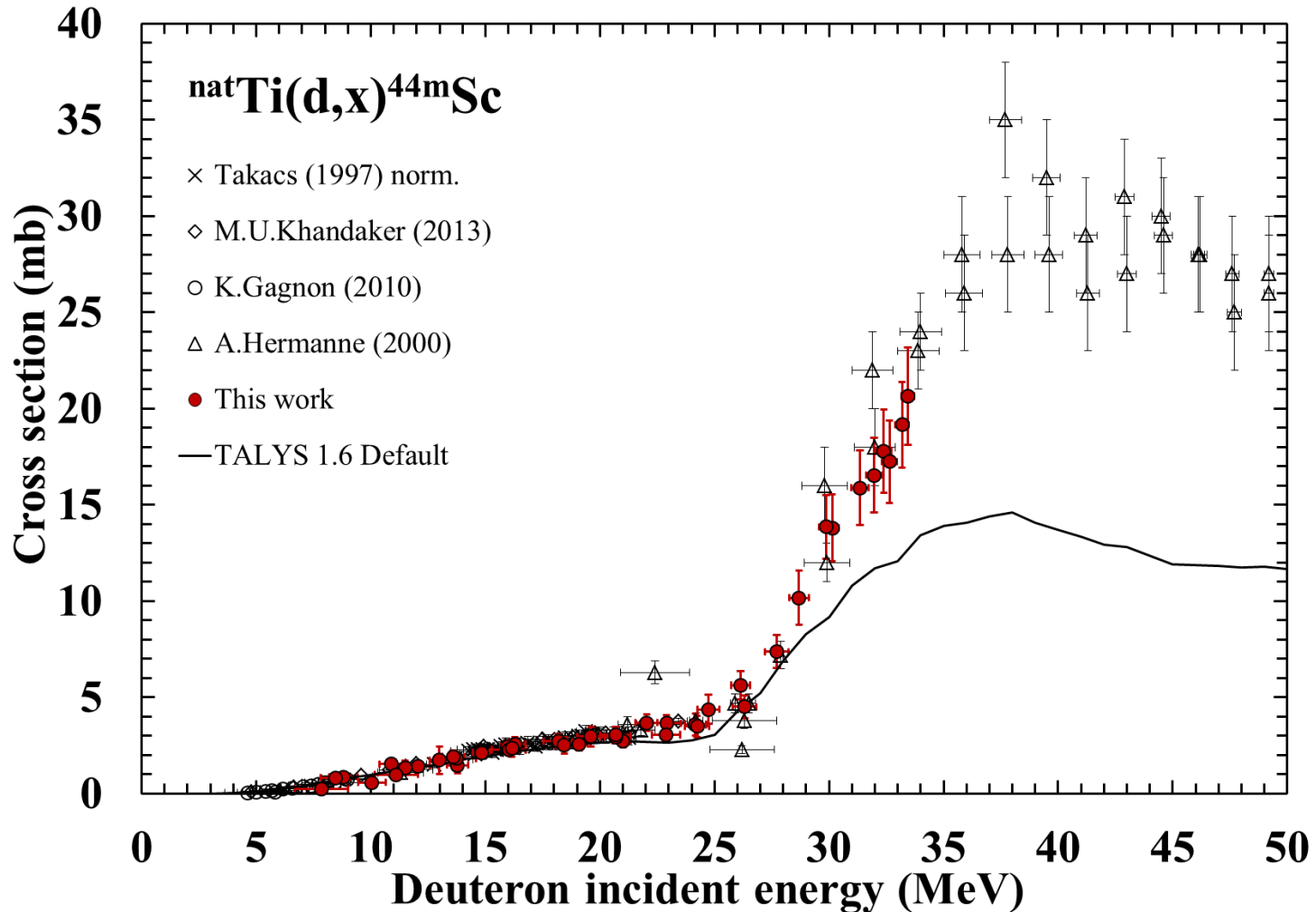


Results and comparisons

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

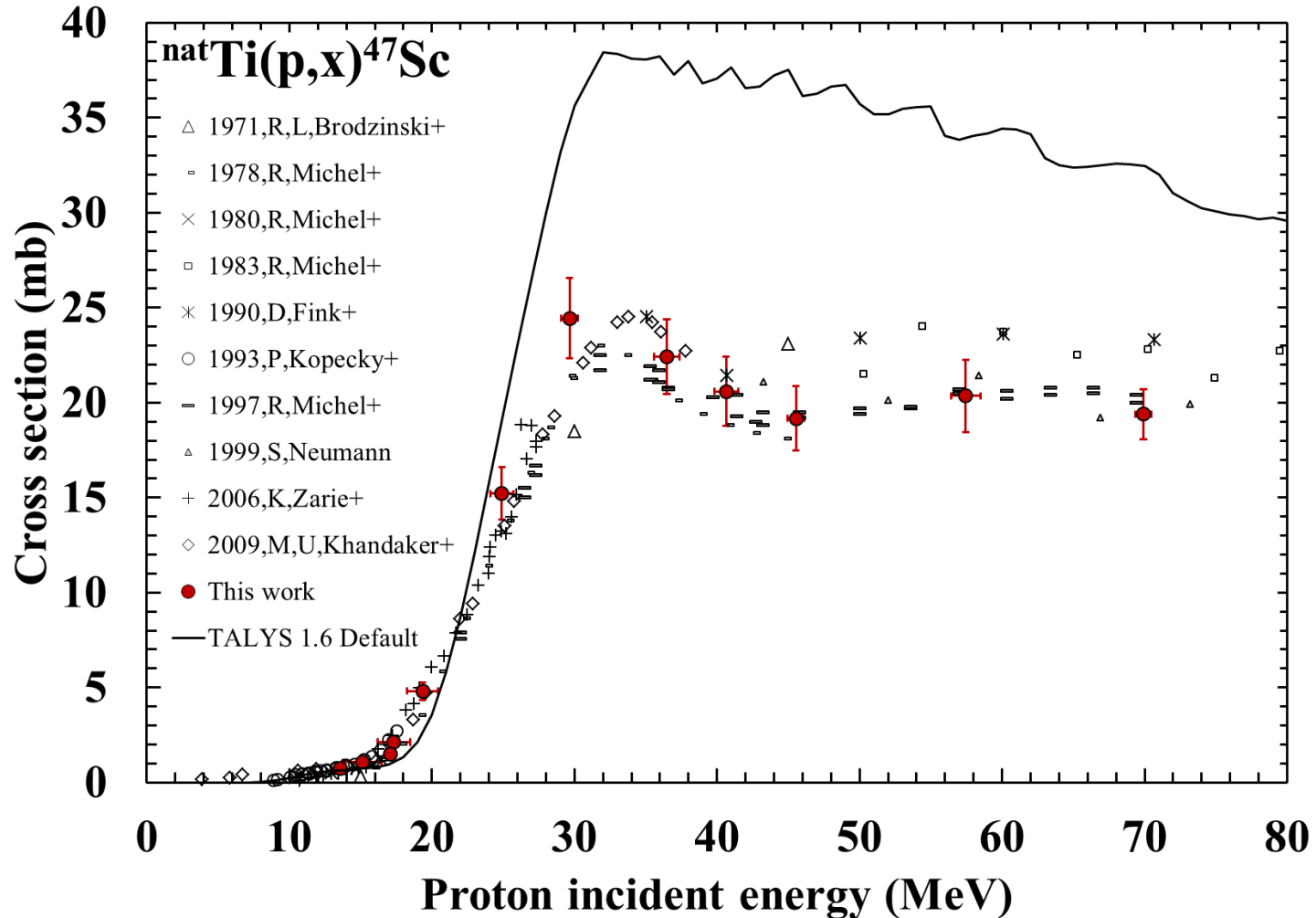


Results and comparisons

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

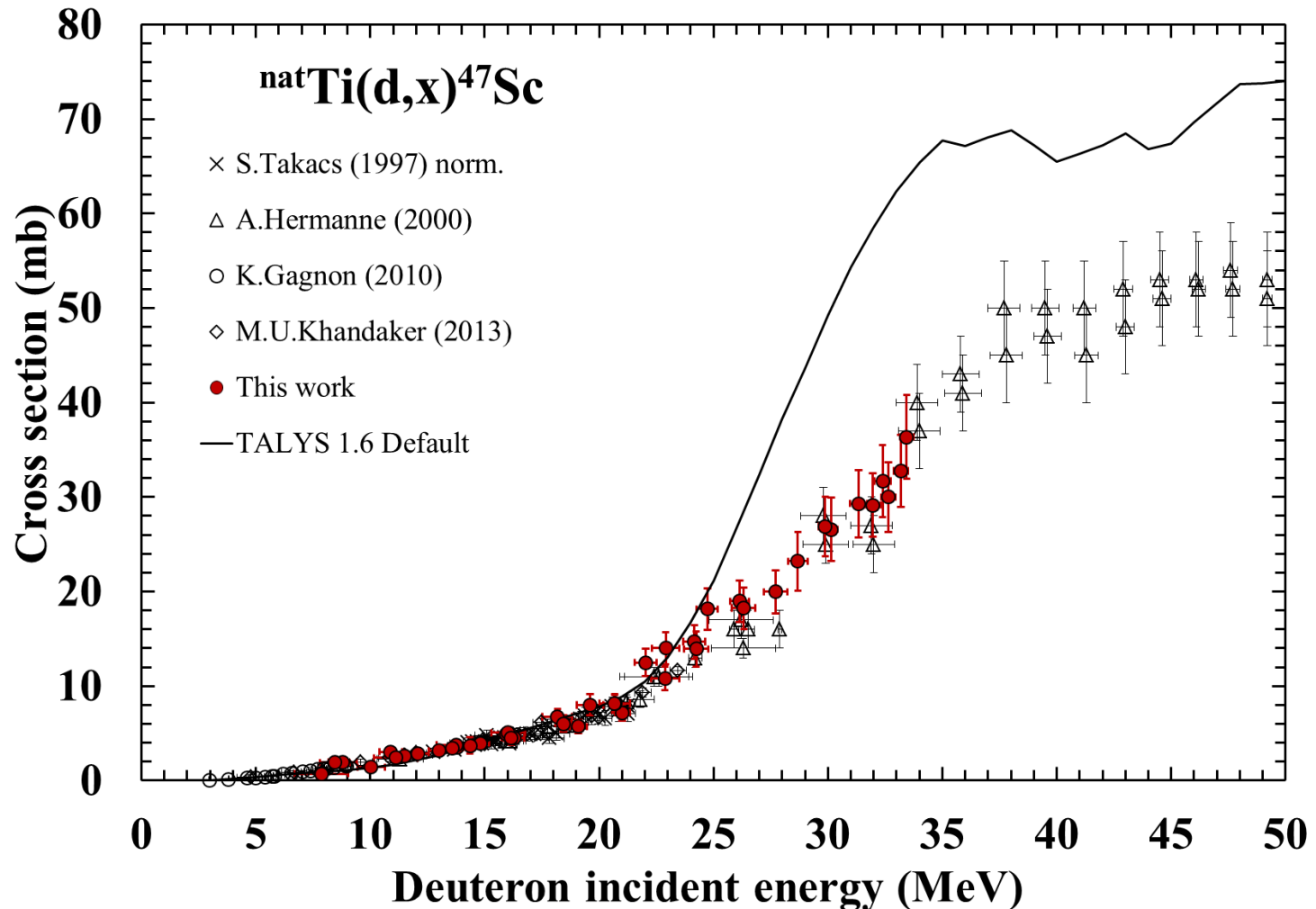


Results and comparisons

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



Motivations

Experimental set-up and data measurements

Results and comparisons

Conclusions and outlooks

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

A. Guertin,^a C. Duchemin,^a E. Garrido,^{a, b} F. Haddad,^{a, c} V. Metivier,^a N. Michel,^{a, c}

^aSUBATECH, Ecole des Mines de Nantes, Université de Nantes, CNRS/IN2P3, Nantes, France

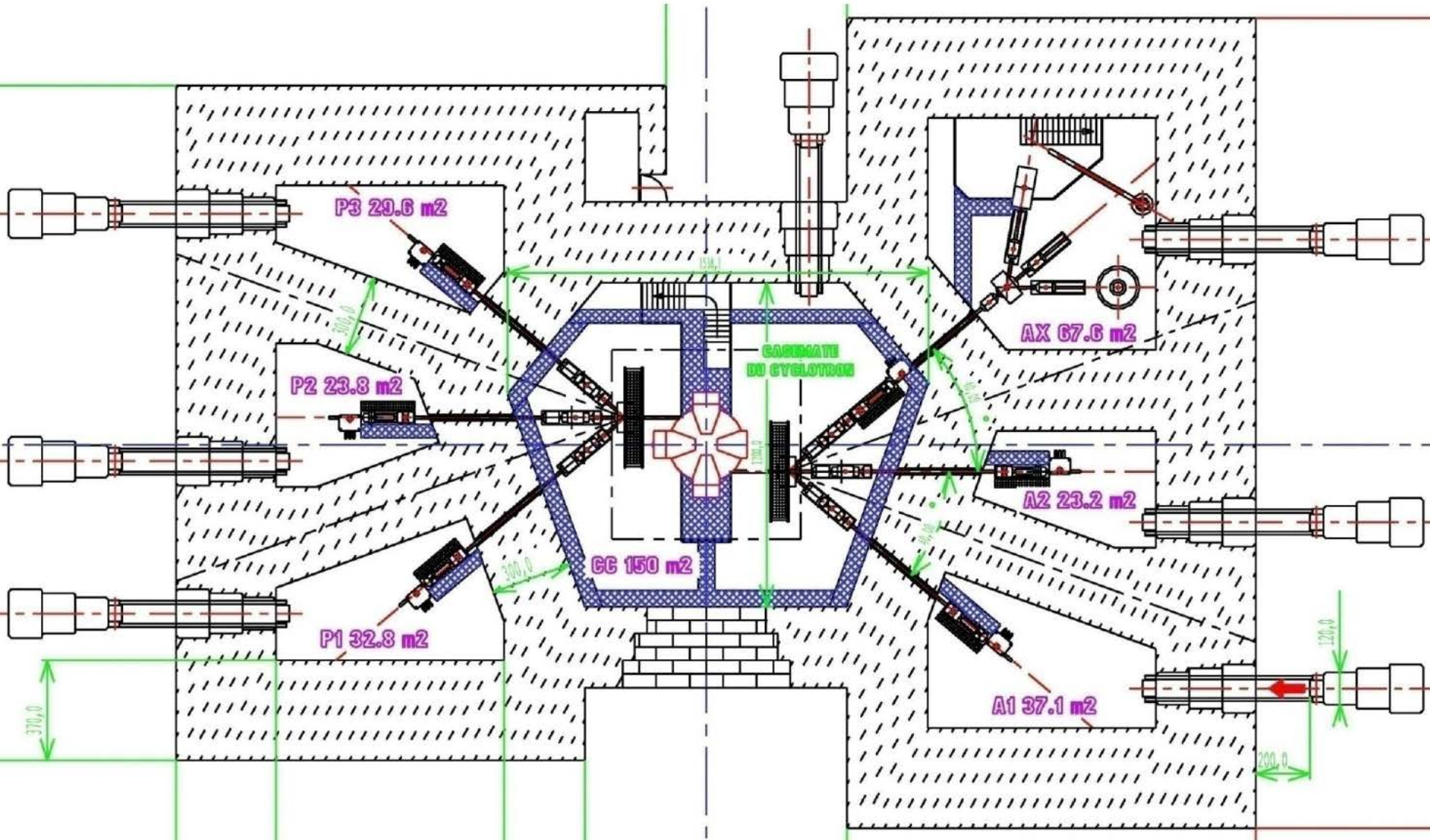
^bINSERM UMR 1101 LaTIM, CHU Morvan, 29609 Brest, France

^cGIP Arronax, 1 rue Aronnax, 44817 Saint-Herblain, France

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.

This work has been, in part, supported by a grant from the French National Agency for Research called “Investissements d’Avenir”, Equipex Arronax-Plus n°ANR-11-EQPX-0004 and Labex n°ANR-11-LABX-0018-01

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
He ²⁺	68	70
HH ⁺	17	50

