New measurements for Proton and Deuteron Beam Monitor Reactions

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

GUERTIN Arnaud
SUBATECH Laboratory
CNRS Research Officer

IN2P3
Institut national de **physique nucléaire** et de **physique des particules**

New Measurements for Proton and Deuteron Beam Monitor Reactions

UNIVERSITÉ DE NANTES

MINES Nantes
Graduate School of Engineering

Outline

- Motivations
- Experimental set-up and data measurements
- Results and comparisons
- Conclusions and outlooks

Motivations

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}Na, $^{96m+g}$Tc

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

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

Additional monitor reactions proposed producing

^{44m}Sc, ^{47}Sc *Half lives interesting and gamma rays easily detectable*

Outline

- Motivations
- Experimental set-up and data measurements
- Results and comparisons
- Conclusions and outlooks

ARRONAX

C70 Cyclotron* build by IBA:

- **4 sectors** isochron **cyclotron**
- **2 multi-particle sources**:
  - H^-,D^-: multicusp
  - He^{2+},HH^+: supernanogan ECR
- **2 extraction lines**:
  stripper or electrostatic deflector

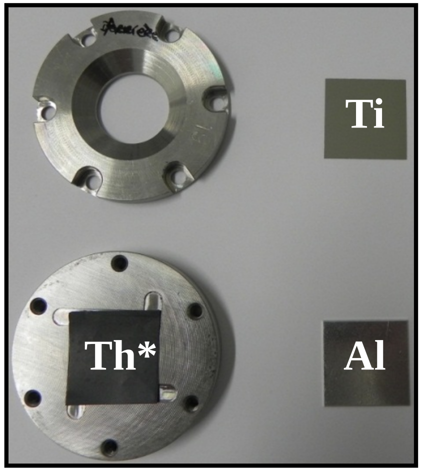
Extracted	Energy (MeV)	Max. current (μA)
H^+	30 – 70	2 x 375
D^+	15 – 35	2 x 50
He^{2+}	68	70
HH^+	17	50

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

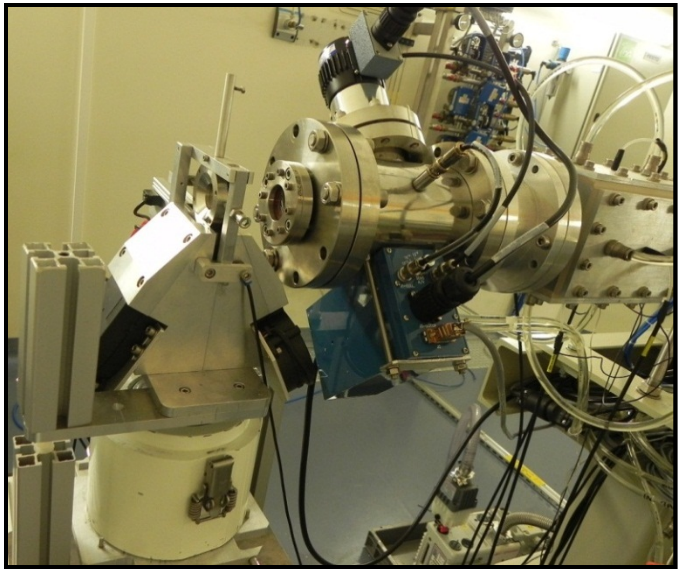
Experimental set-up and data measurements

Stacked-foil technique:

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



Capsule and foils



Irradiation station and beam line

Activity and cross section:

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

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:

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

- error on e, e': ≤ 1%
- error on t: negligible

IAEA recommended cross sections:

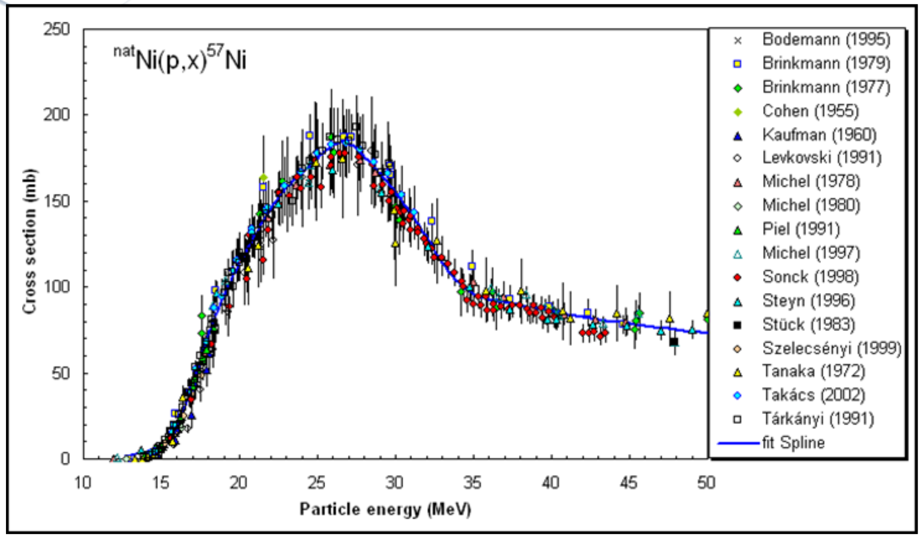
- 8 reactions available for protons
^{27}Al (2), ^{nat}Ni, ^{nat}Ti and ^{nat}Cu (5)

- 5 reactions available for deuterons
^{27}Al (2), ^{nat}Fe, ^{nat}Ni and **^{nat}Ti**

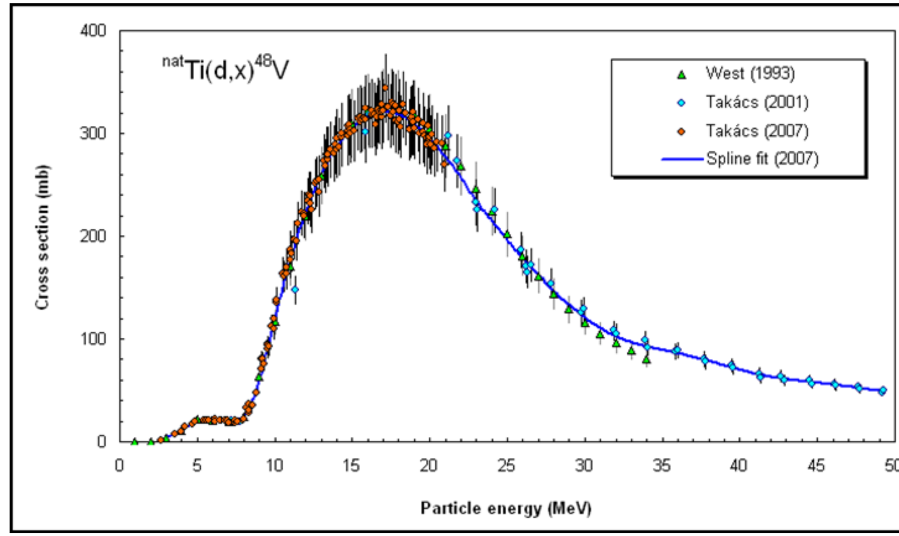
* *Production of Medical Isotopes from a Thorium Target Irradiated by Light Charged Particles up to 70 MeV,* ***C. Duchemin****, Subatech, August 27, 4:55 p.m., Crystal A*

Experimental set-up and data measurements

IAEA recommended monitor reactions used:



From NDS-IEAE medical portal



Protons:

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

Deuterons:

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

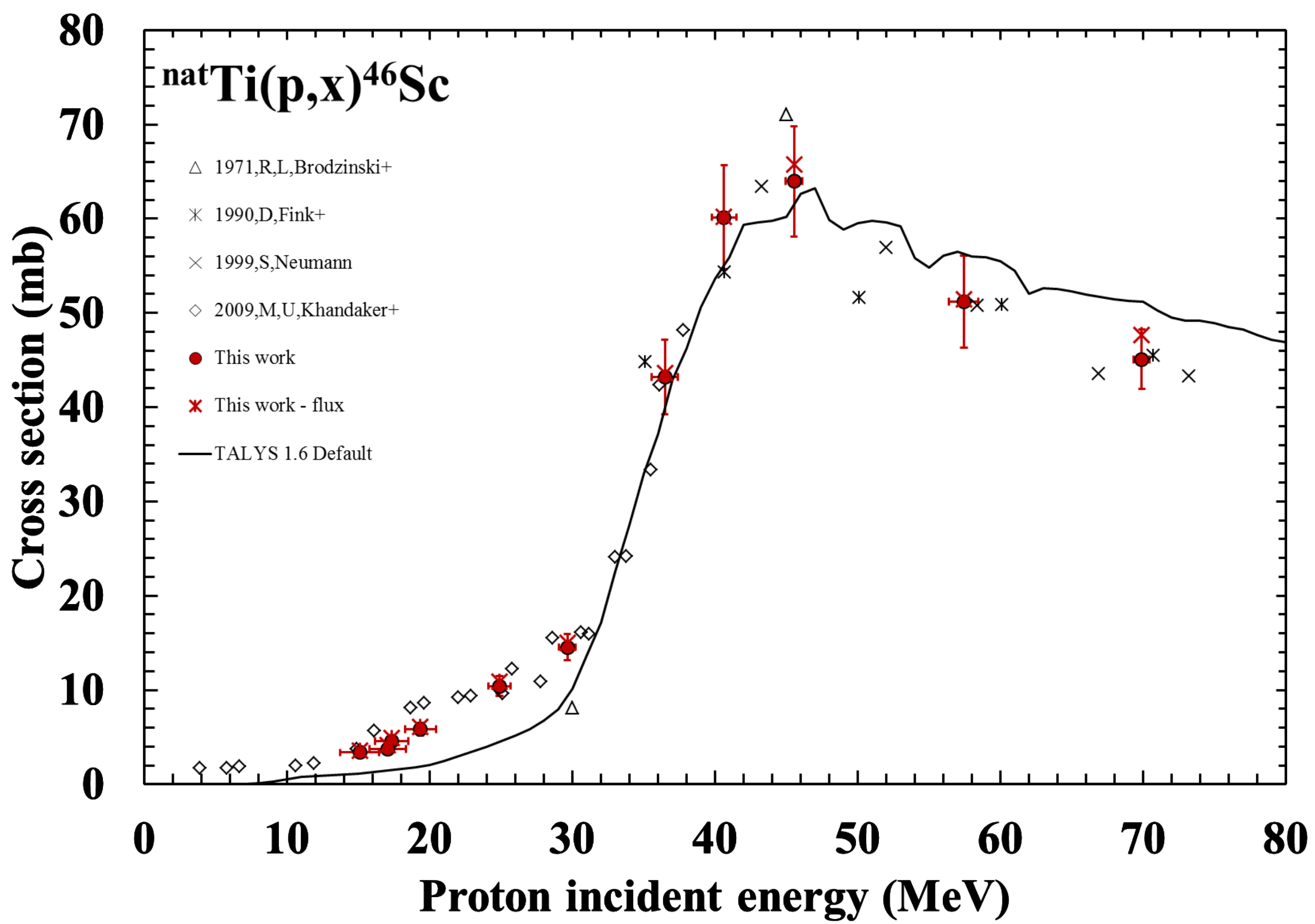
Outline

- **Motivations**
- **Experimental set-up and data measurements**
- **Results and comparisons**
- **Conclusions and outlooks**

Results and comparisons

^{46}Sc: IAEA requirement list

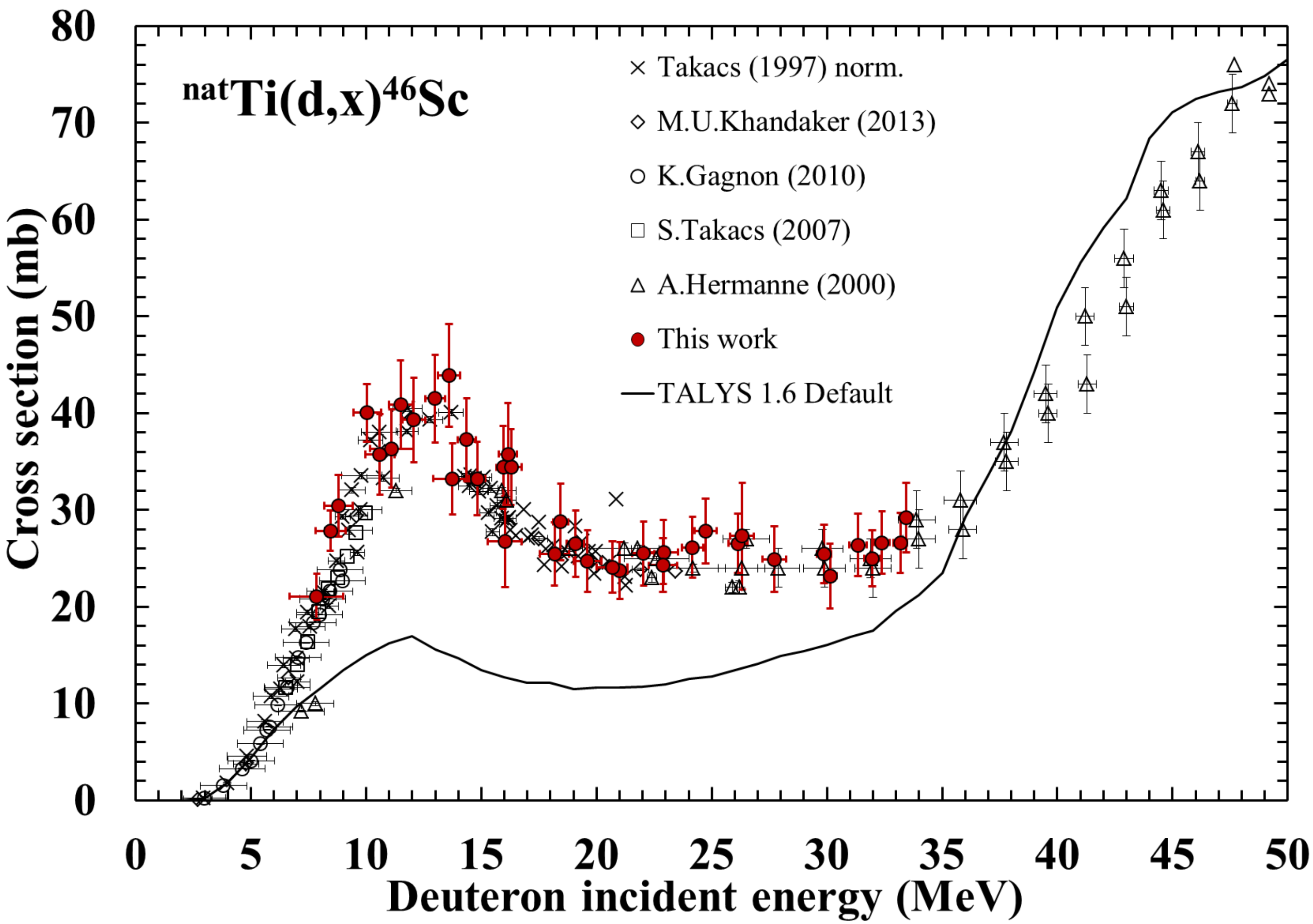
- β^-, $T_{1/2}$= 83.79 d, Eγ= 889.3, 1120.5 keV   - ^{nat}Ti(p,x)^{46}Sc and ^{nat}Ti(d,x)^{46}Sc



Results and comparisons

^{46}Sc: IAEA requirement list

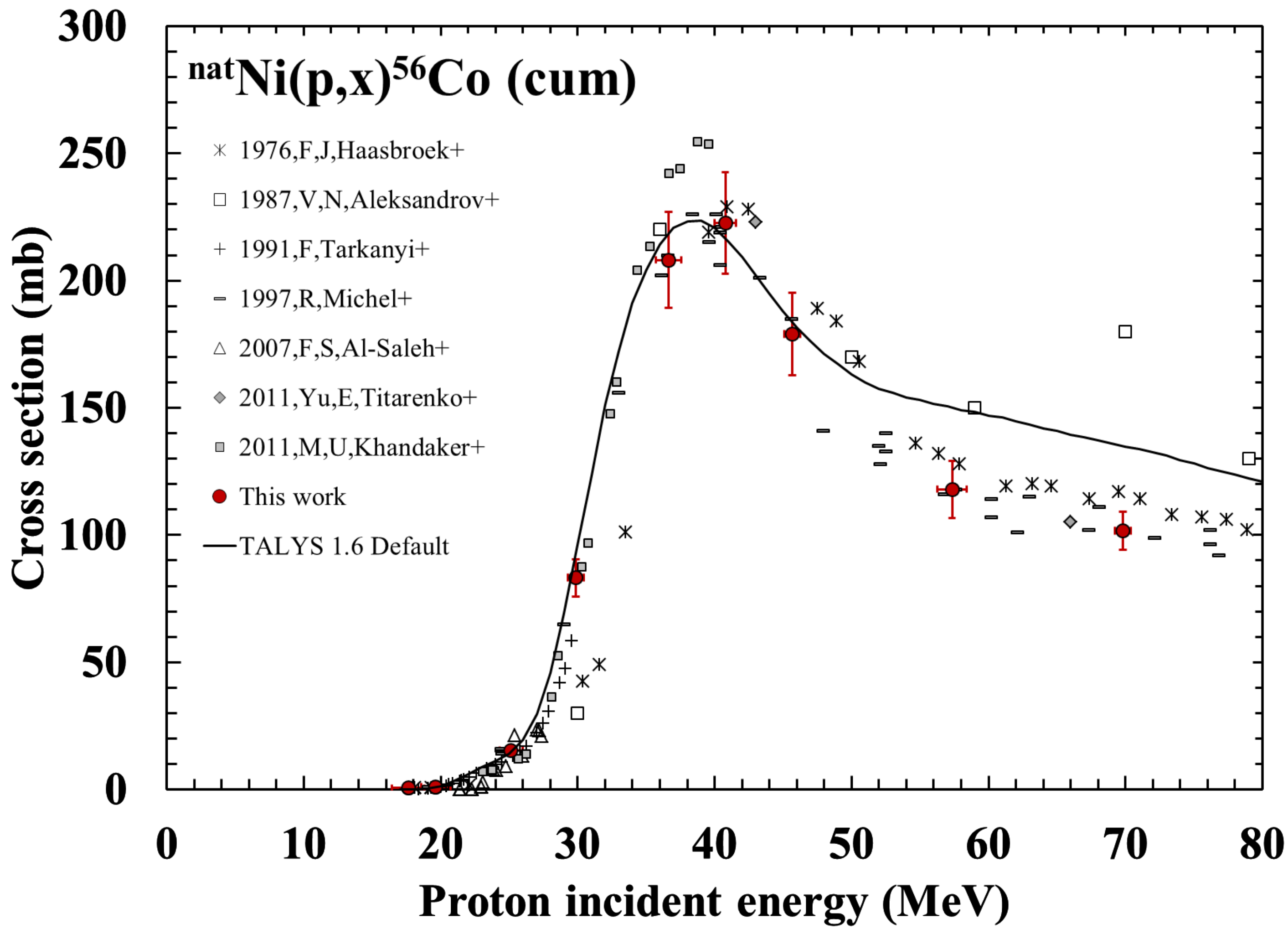
- β^{-}, $T_{1/2}$= 83.79 d, Eγ= 889.3, 1120.5 keV - ^{nat}Ti(p,x)^{46}Sc and ^{nat}Ti(d,x)^{46}Sc



Results and comparisons

^{56}Co: IAEA requirement list

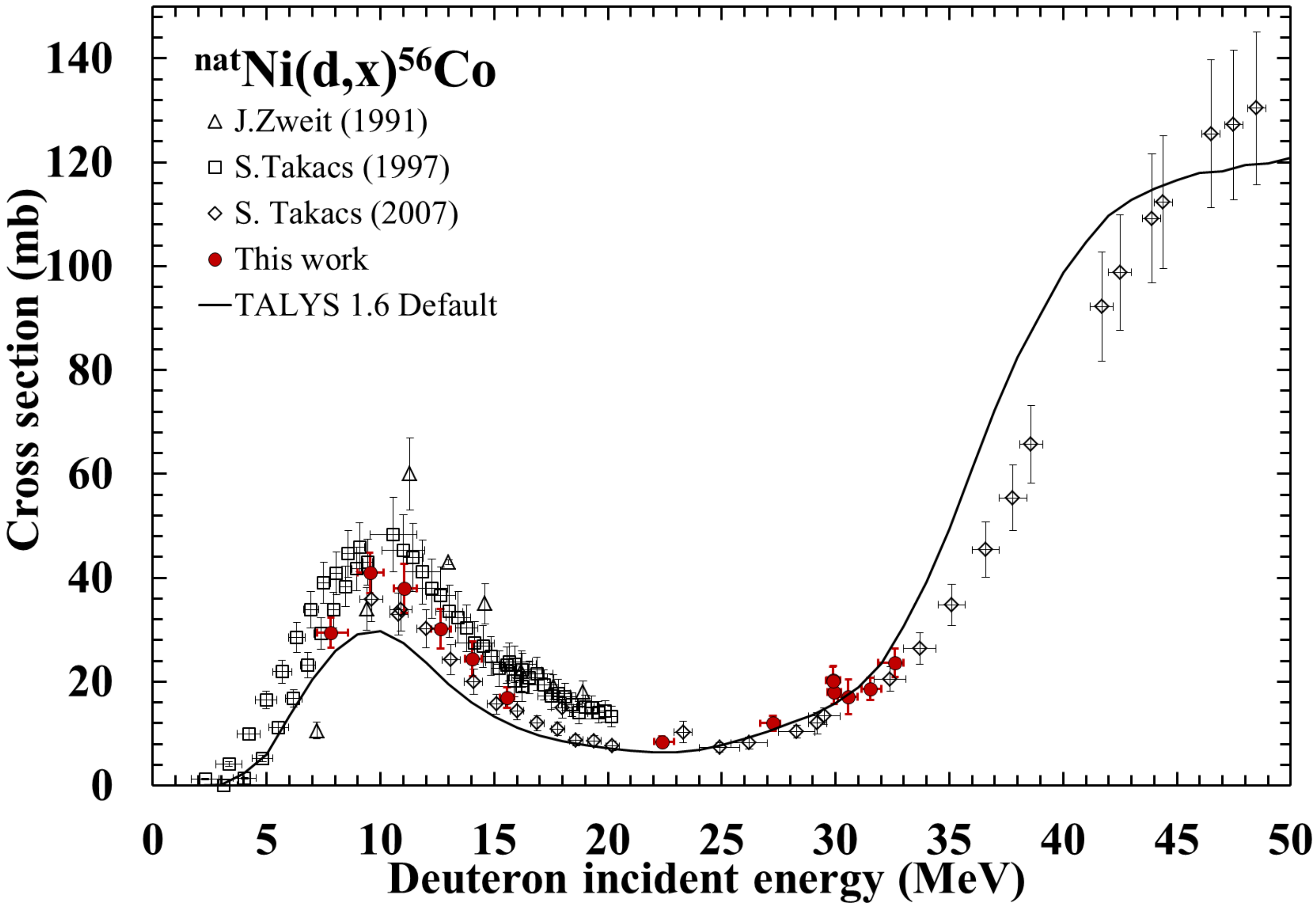
- β^+, $T_{1/2}$= 77.27 d, Eγ= 846.8, 1238.3 keV - ^{nat}Ni(p,x)^{56}Co and ^{nat}Ni(d,x)^{56}Co



Results and comparisons

^{56}**Co**: IAEA requirement list

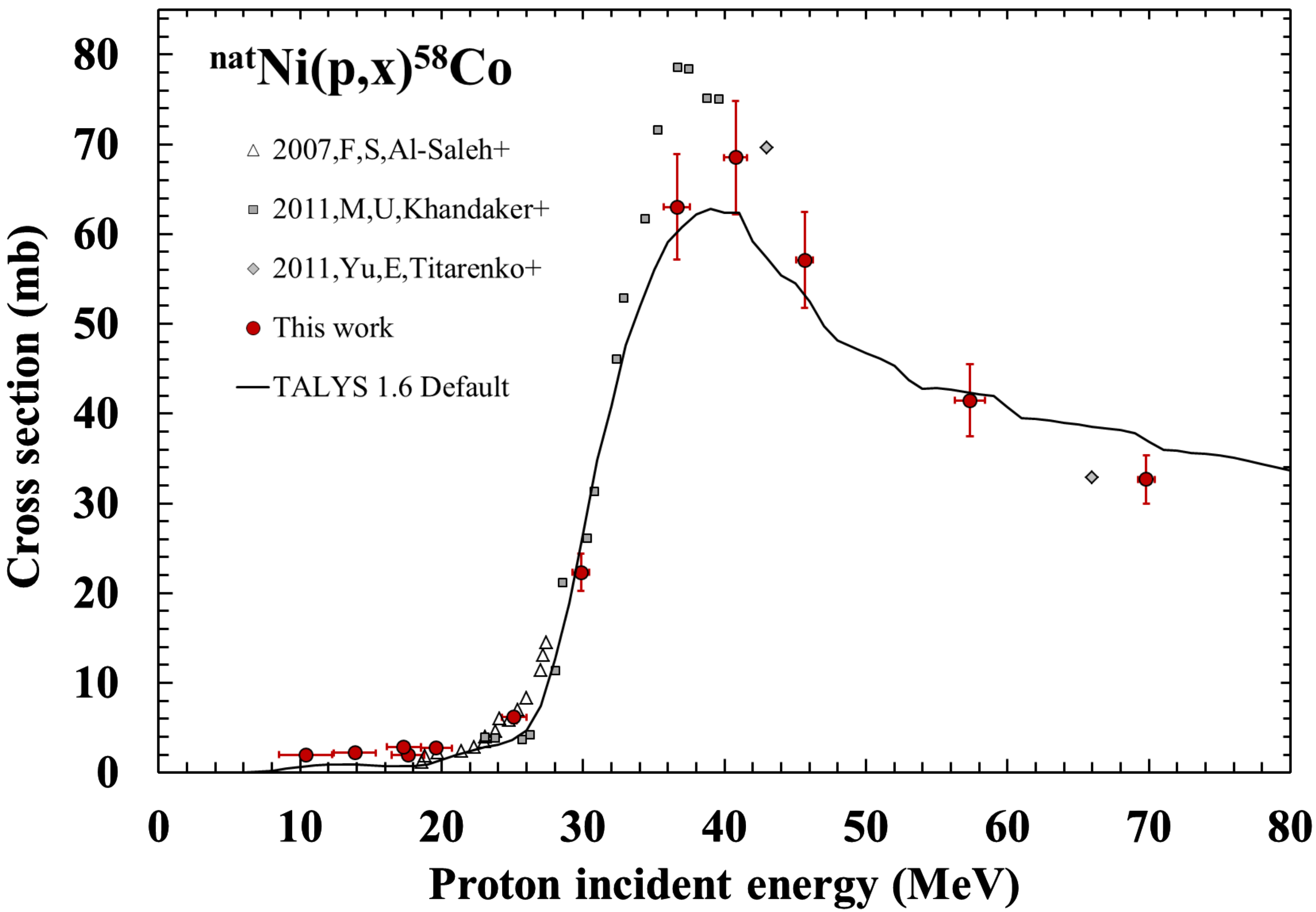
- β^+, $T_{1/2}$= 77.27 d, Eγ= 846.8, 1238.3 keV - ^{nat}Ni(p,x)^{56}Co and ^{nat}Ni(d,x)^{56}Co



Results and comparisons

^{58}**Co**: IAEA requirement list

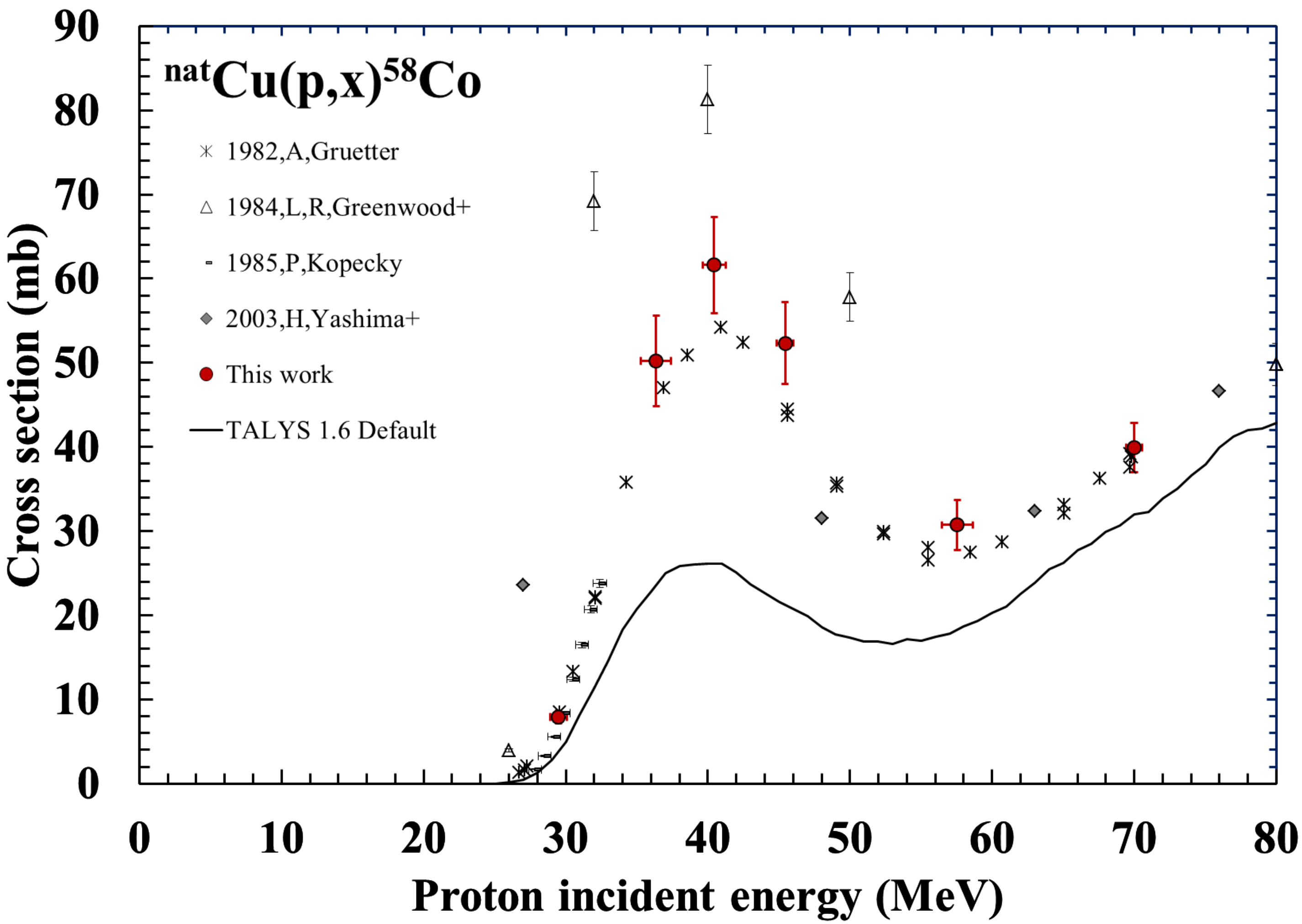
- β^+, $T_{1/2}$= 70.86 d, Eγ= 810.8 keV
- ^{nat}Ni(p,x)^{58}Co, ^{nat}Cu(p,x)^{58}Co and ^{nat}Ni(d,x)^{58}Co



Results and comparisons

^{58}**Co**: IAEA requirement list

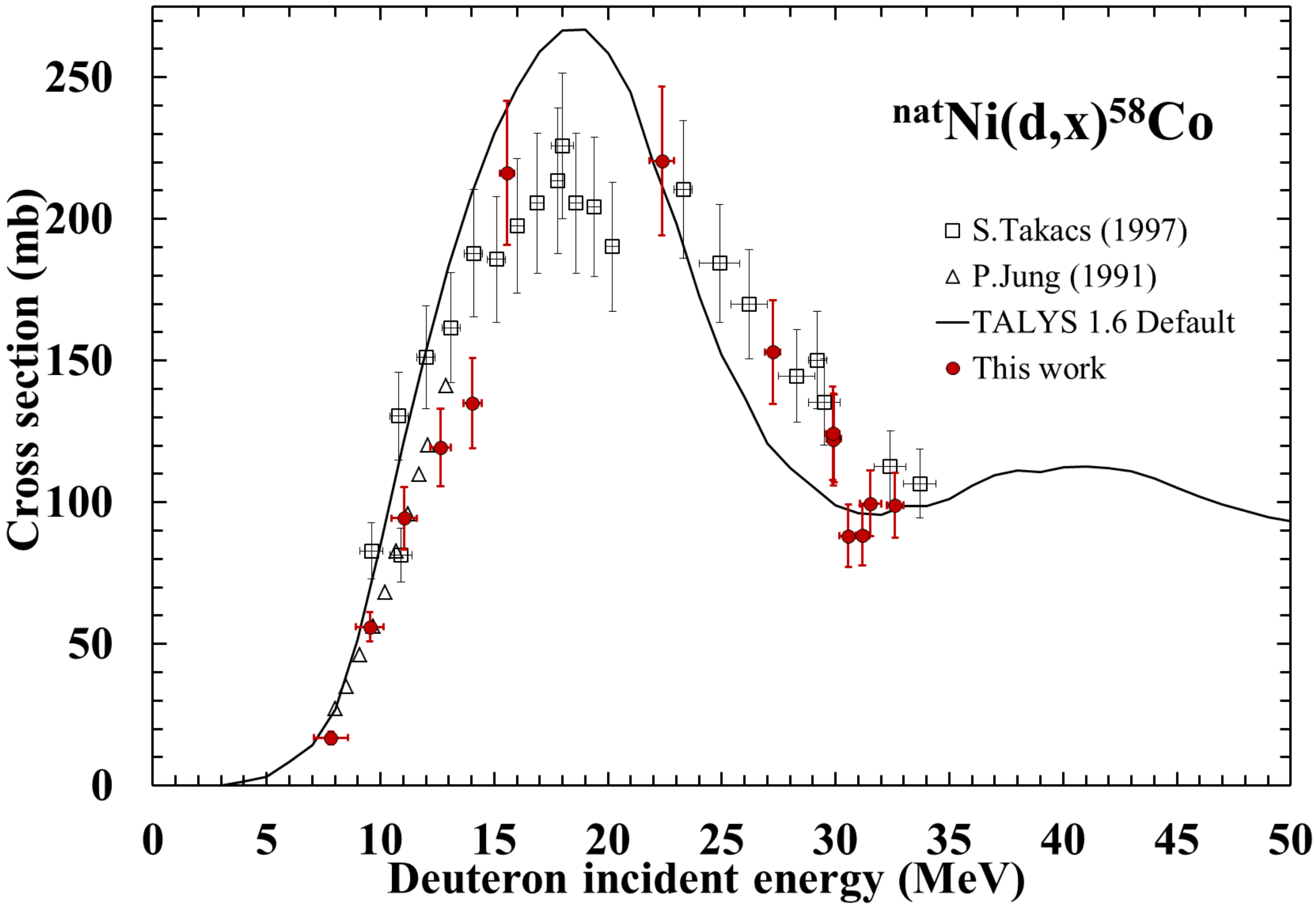
- β^+, $T_{1/2}$= 70.86 d, Eγ= 810.8 keV
- ^{nat}Ni(p,x)^{58}Co, ^{nat}Cu(p,x)^{58}Co and ^{nat}Ni(d,x)^{58}Co



Results and comparisons

^{58}**Co**: IAEA requirement list

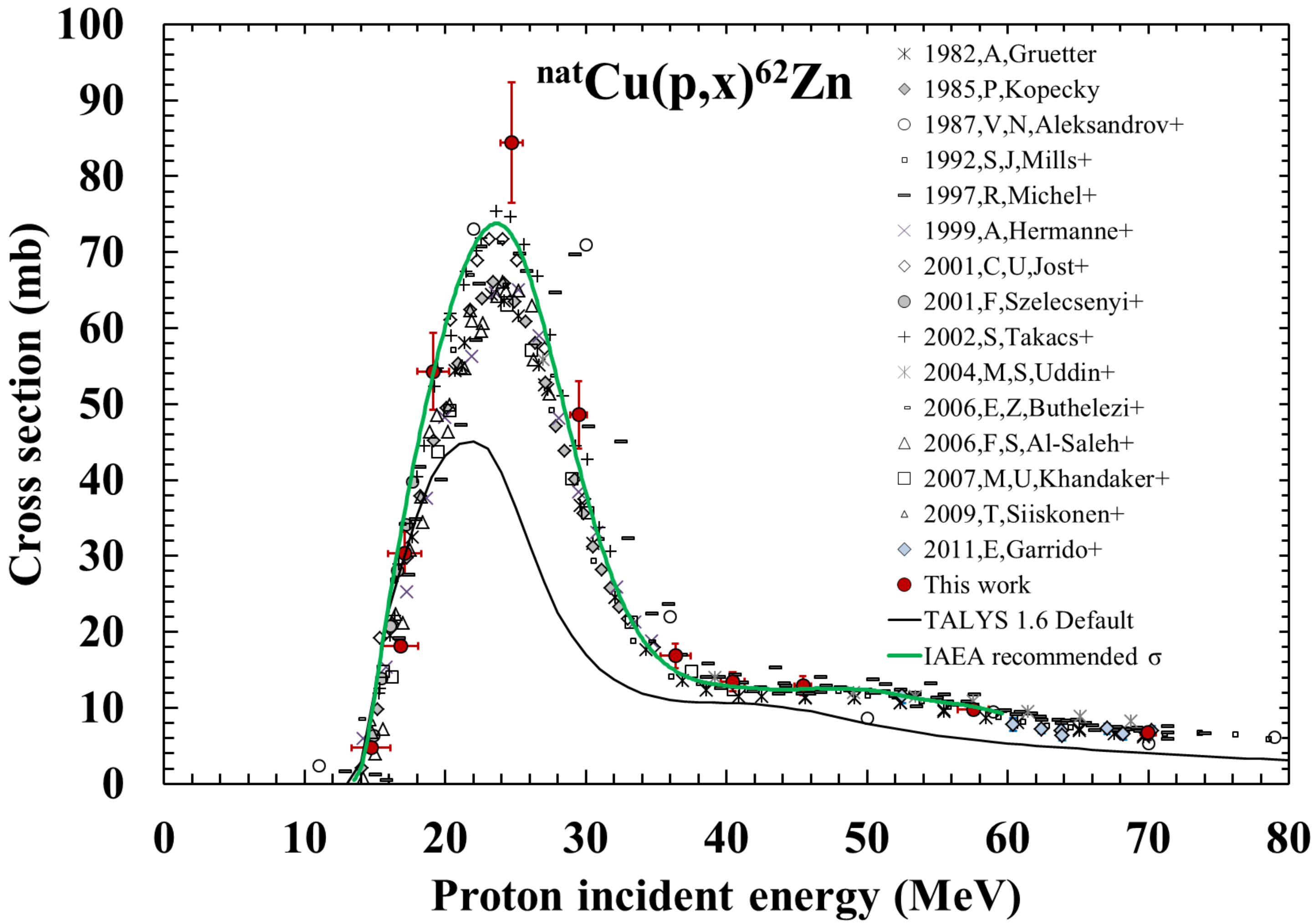
- β^+, $T_{1/2}$= 70.86 d, Eγ= 810.8 keV
- ^{nat}Ni(p,x)^{58}Co, ^{nat}Cu(p,x)^{58}Co and ^{nat}Ni(d,x)^{58}Co



Results and comparisons

^{62}Zn: IAEA requirement list

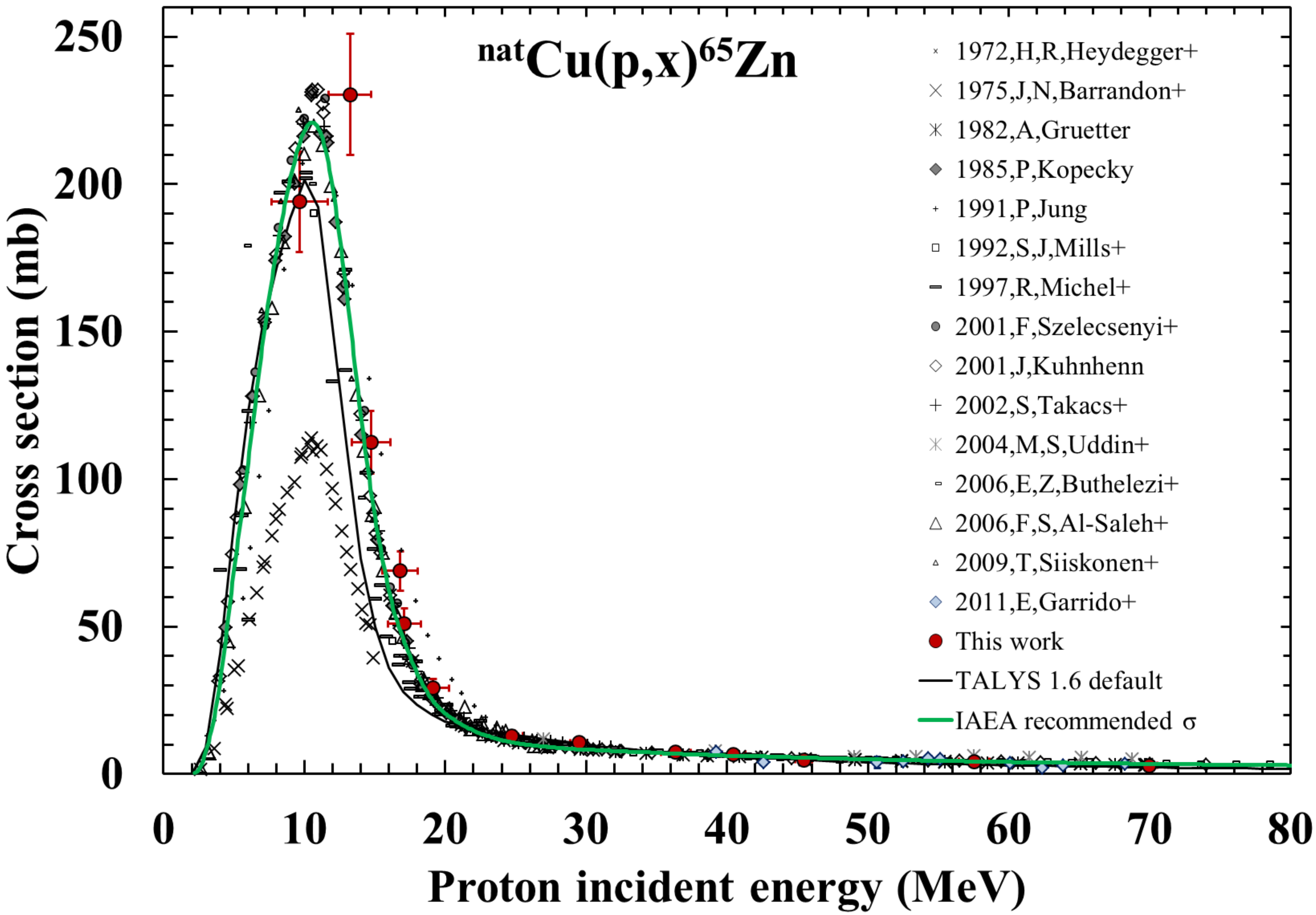
- β^+, $T_{1/2}$= 9.186 h, Eγ= 596.56, 548.35 keV - $^{nat}Cu(p,x)^{62}Zn$



Results and comparisons

^{65}**Zn**: IAEA requirement list

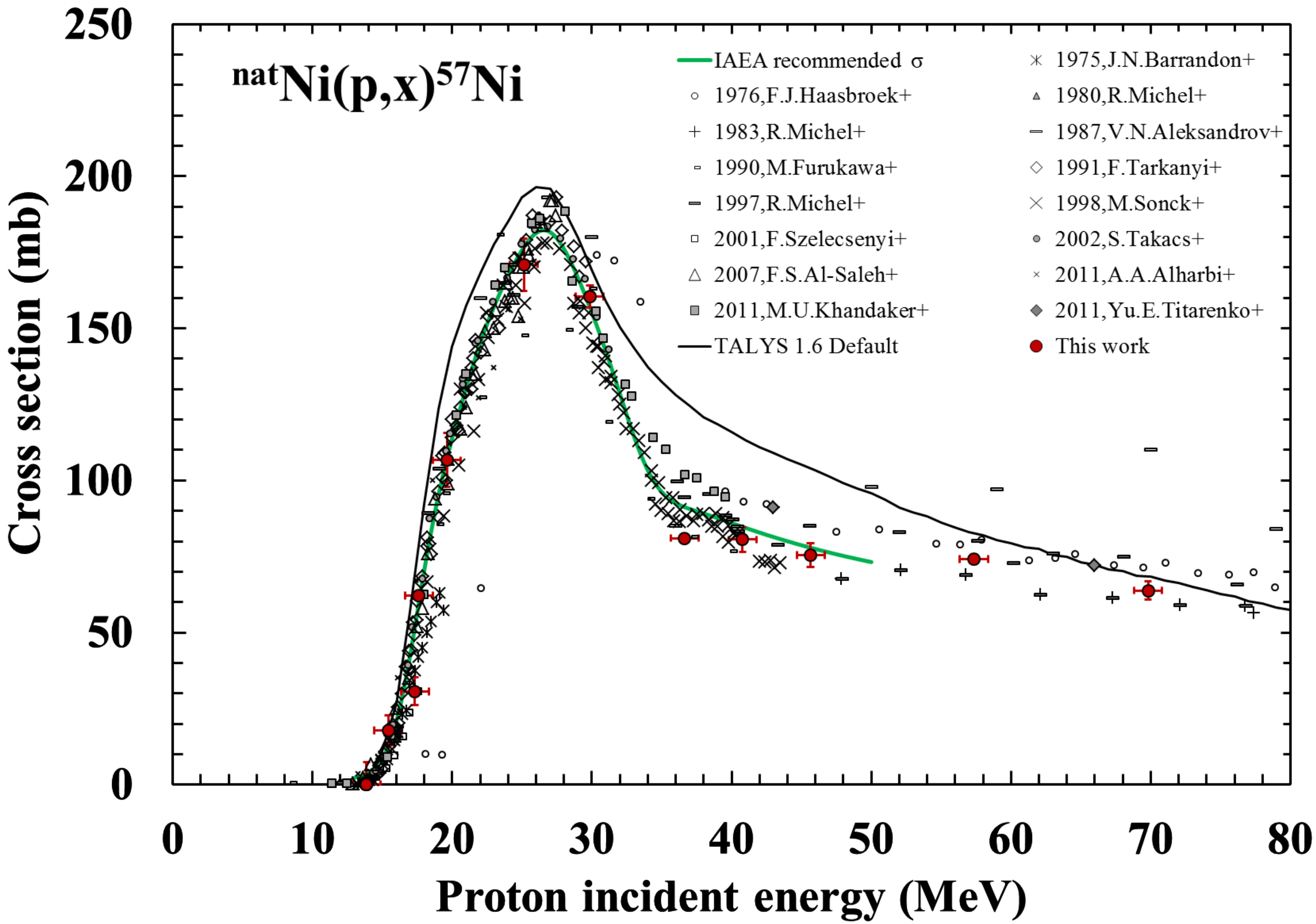
- β^+, $T_{1/2}$= 244.26 d, Eγ= 1115.55 keV
- $^{nat}Cu(p,x)^{65}Zn$



Results and comparisons

^{57}Ni: IAEA requirement list

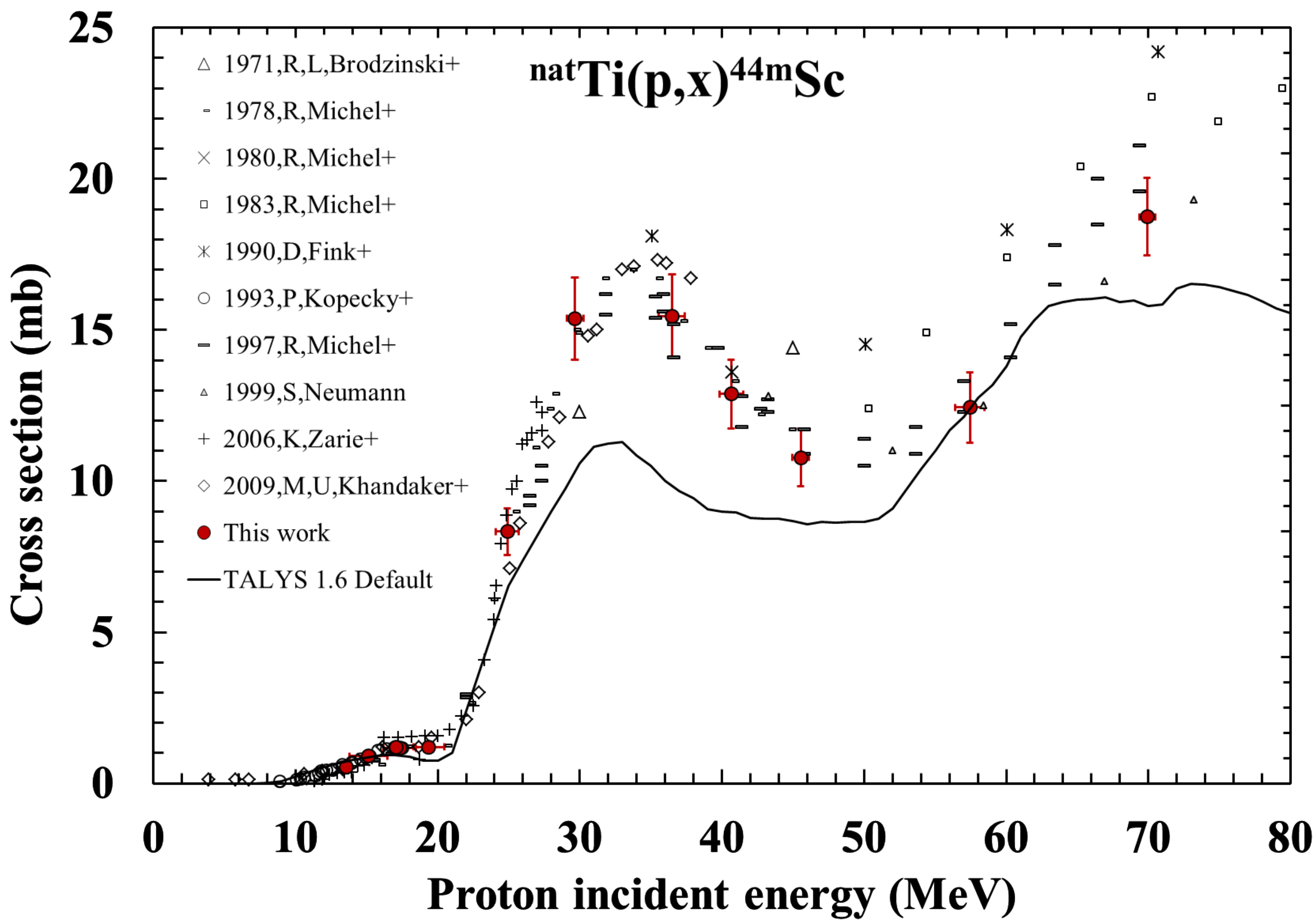
- β^+, $T_{1/2}$= 35.60 h, Eγ= 127.16, 1377.63 keV
- $^{nat}Ni(p,x)^{57}Ni$



Results and comparisons

^{44m}Sc: additional monitor reaction proposed

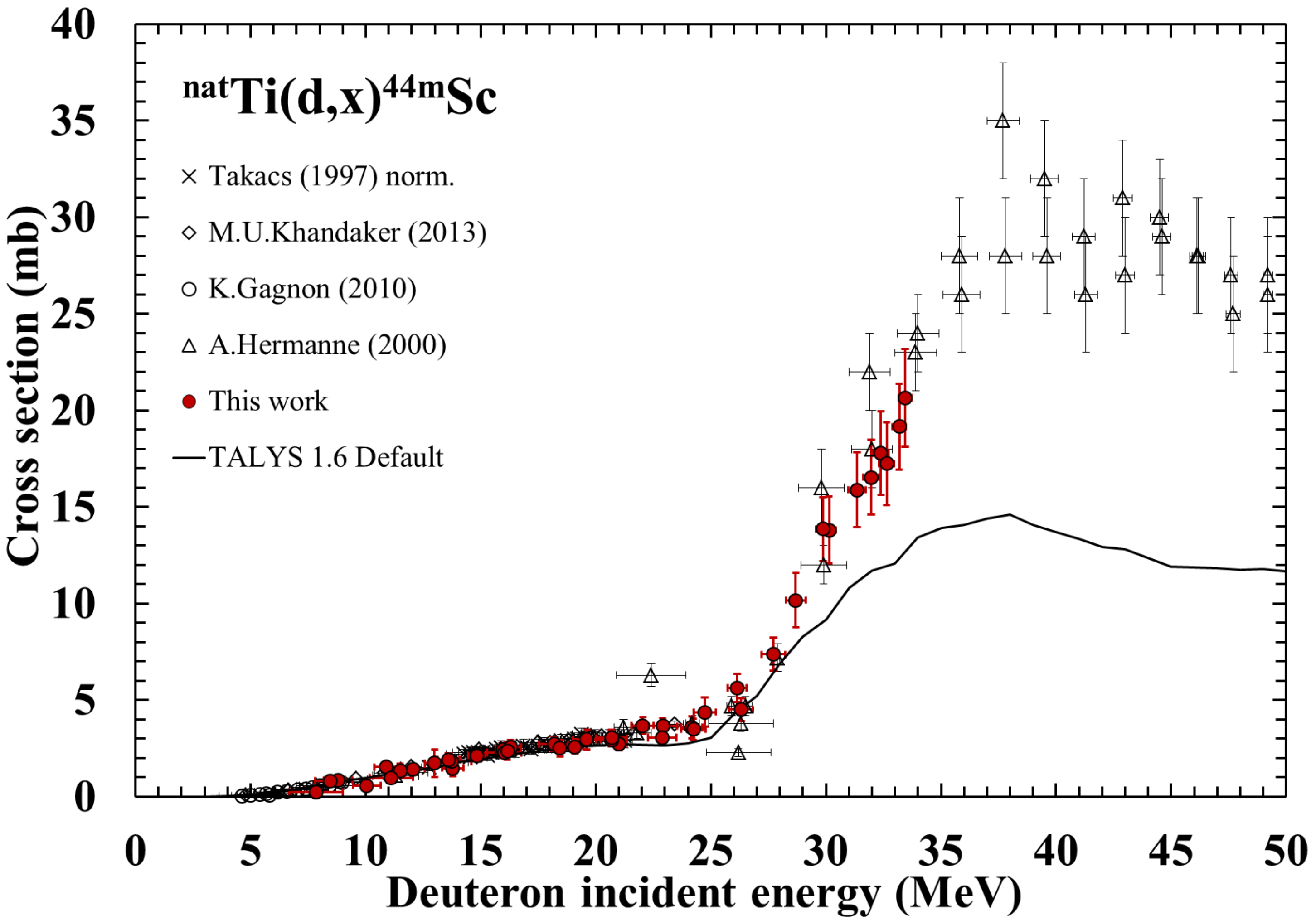
- β^+, $T_{1/2}$= 58.6 h, Eγ= 271.1 keV
- ^{nat}Ti(p,x)^{44m}Sc and ^{nat}Ti(d,x)^{44m}Sc



Results and comparisons

^{44m}Sc: additional monitor reaction proposed

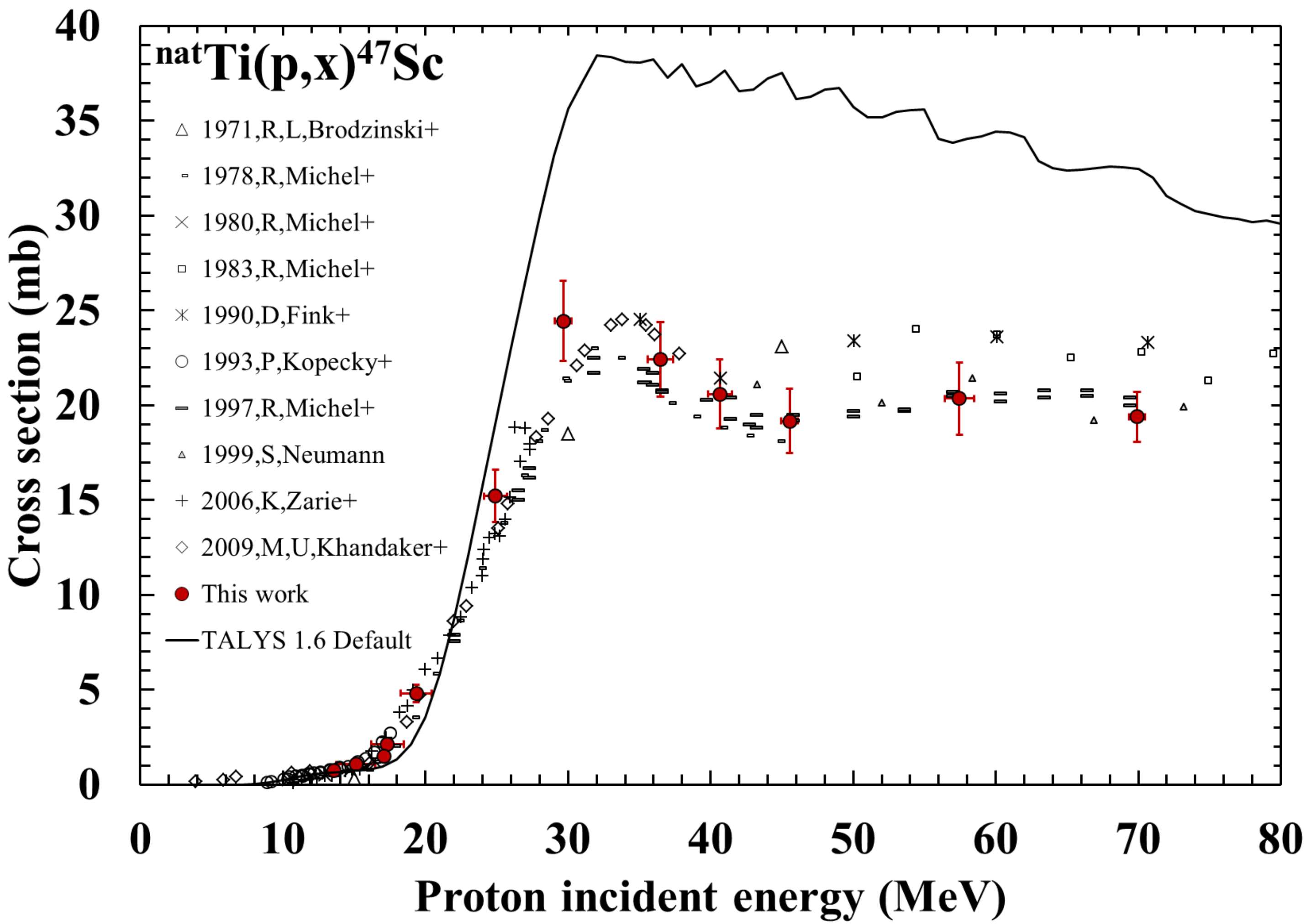
- β^+, $T_{1/2}$= 58.6 h, Eγ= 271.1 keV
- $^{nat}Ti(p,x)^{44m}Sc$ and $^{nat}Ti(d,x)^{44m}Sc$



Results and comparisons

^{47}**Sc**: additional monitor reaction proposed

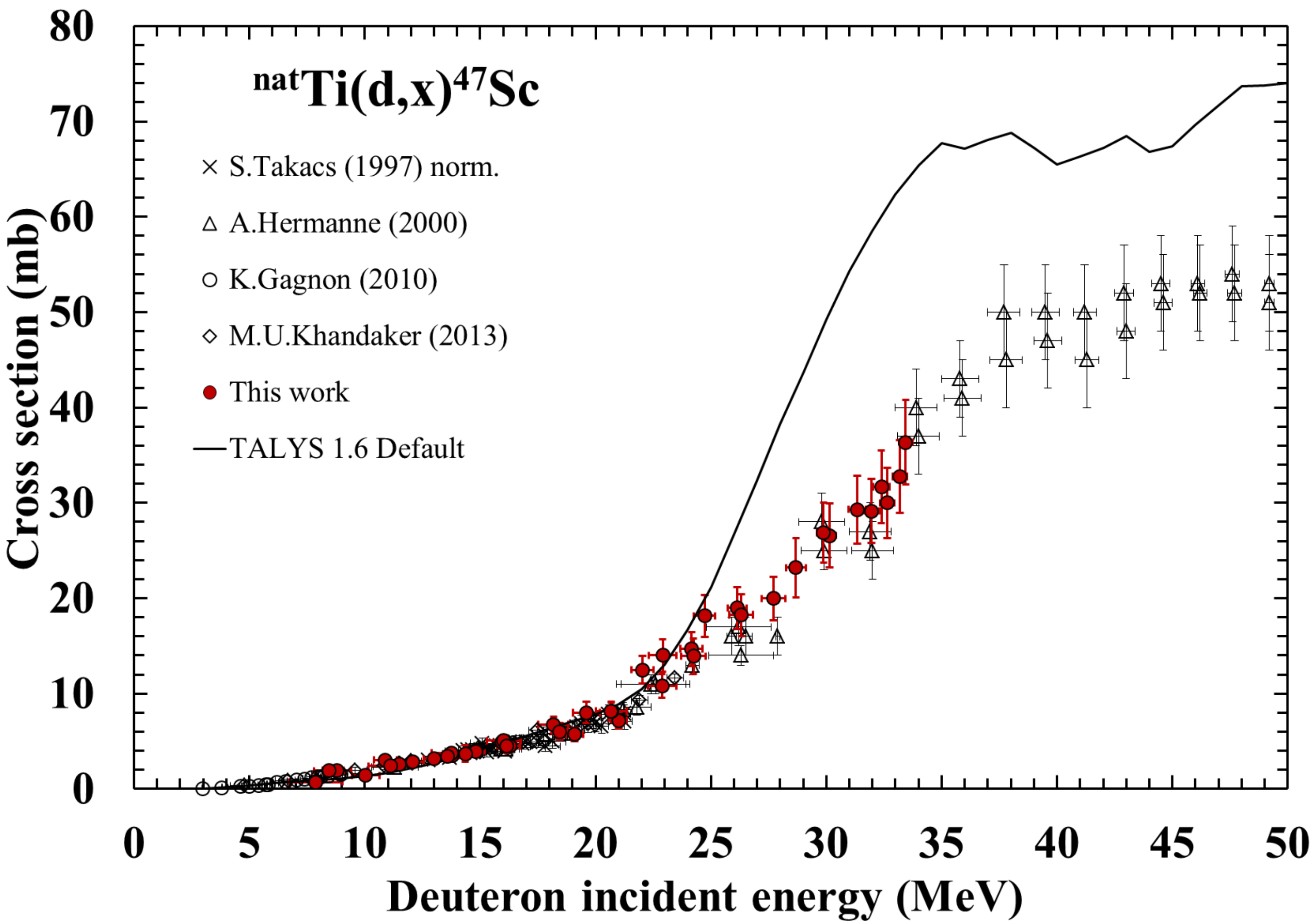
- β^-, $T_{1/2}$= 3.3492 d, Eγ= 159.38 keV
- $^{nat}Ti(p,x)^{47}Sc$ and $^{nat}Ti(d,x)^{47}Sc$



Results and comparisons

^{47}**Sc**: additional monitor reaction proposed

- β^-, $T_{1/2}$= 3.3492 d, Eγ= 159.38 keV
- $^{nat}Ti(p,x)^{47}Sc$ and $^{nat}Ti(d,x)^{47}Sc$



Outline

- **Motivations**
- **Experimental set-up and data measurements**
- **Results and comparisons**
- **Conclusions and outlooks**

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}Sr/^{82}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

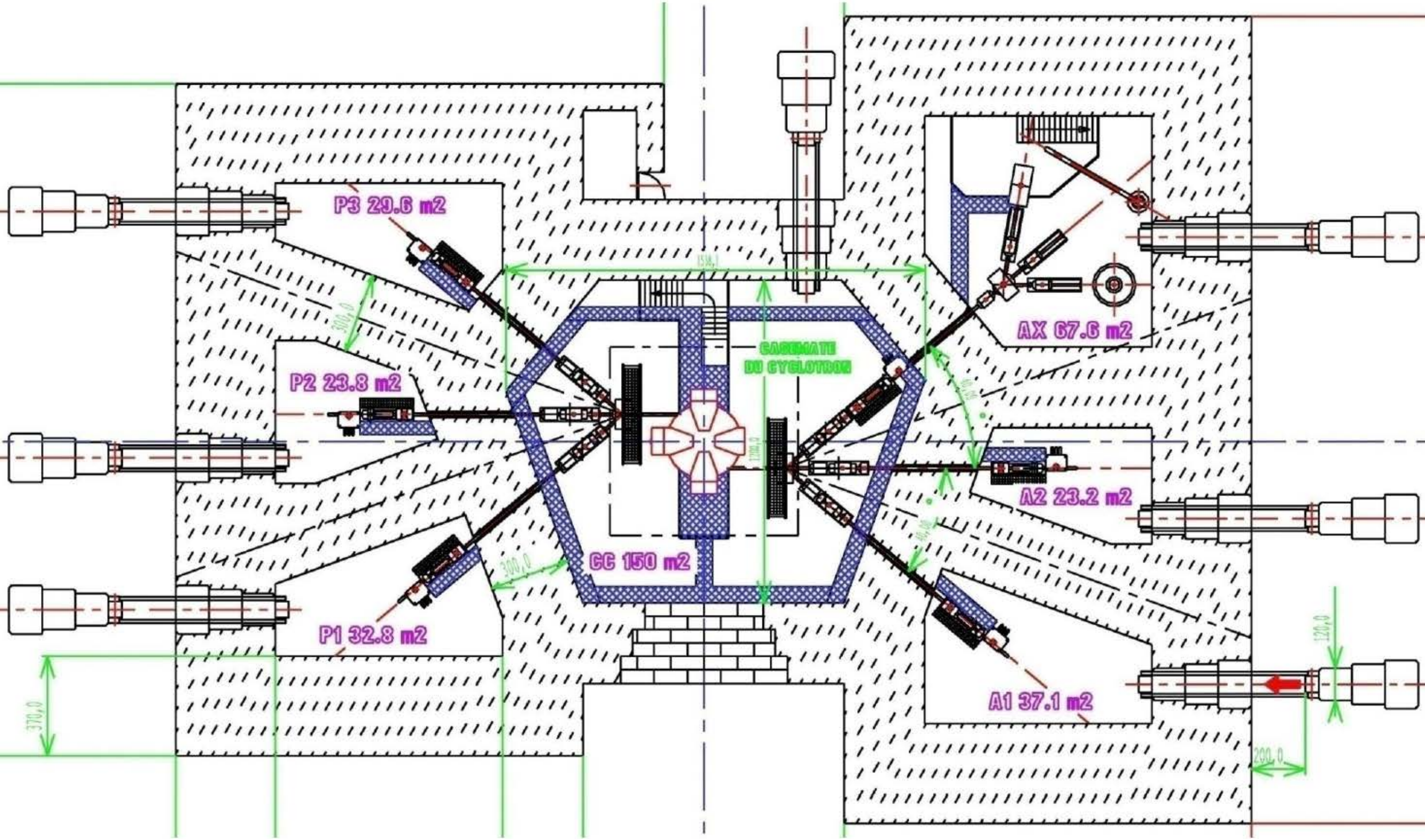
Acknowledgments to the 8ICI organization committee

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]
[a]SUBATECH, Ecole des Mines de Nantes, Université de Nantes, CNRS/IN2P3, Nantes, France
[b]INSERM UMR 1101 LaTIM, CHU Morvan, 29609 Brest, France
[c]GIP 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



ARRONAX cyclotron

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.
  - He^{2+},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