Nuclear cross section measurements of the $^{48,49,50}Ti(p,x)^{47}Sc$ reactions: Preliminary results of the REMIX project

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18th Workshop on Targetry and Target Chemistry (WTTC18)- Whistler, BC – 22-26 August 2022

Medical Radionuclides @ INFN-LNL

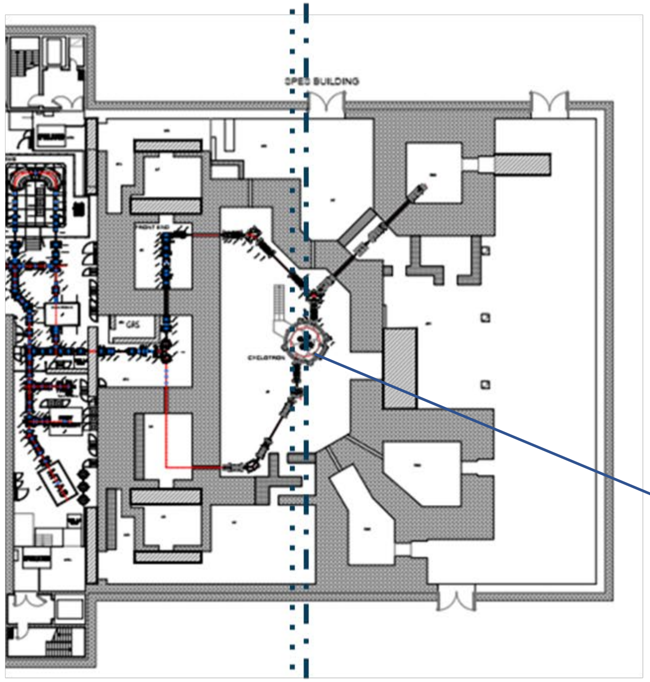
"Radioisotope Service for Medicine and Applications"

SPES-γ

The production of radionuclides for applications

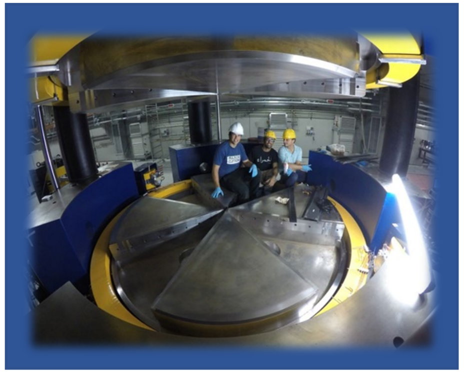
ISOLPHARM
SPES exotic beams for medicine

ISOL technique
A. Andrighetto
Resp. ISOLPHARM



Direct activation
J. Esposito
Resp. LARAMED

PRISMAP
Medical Radionuclides



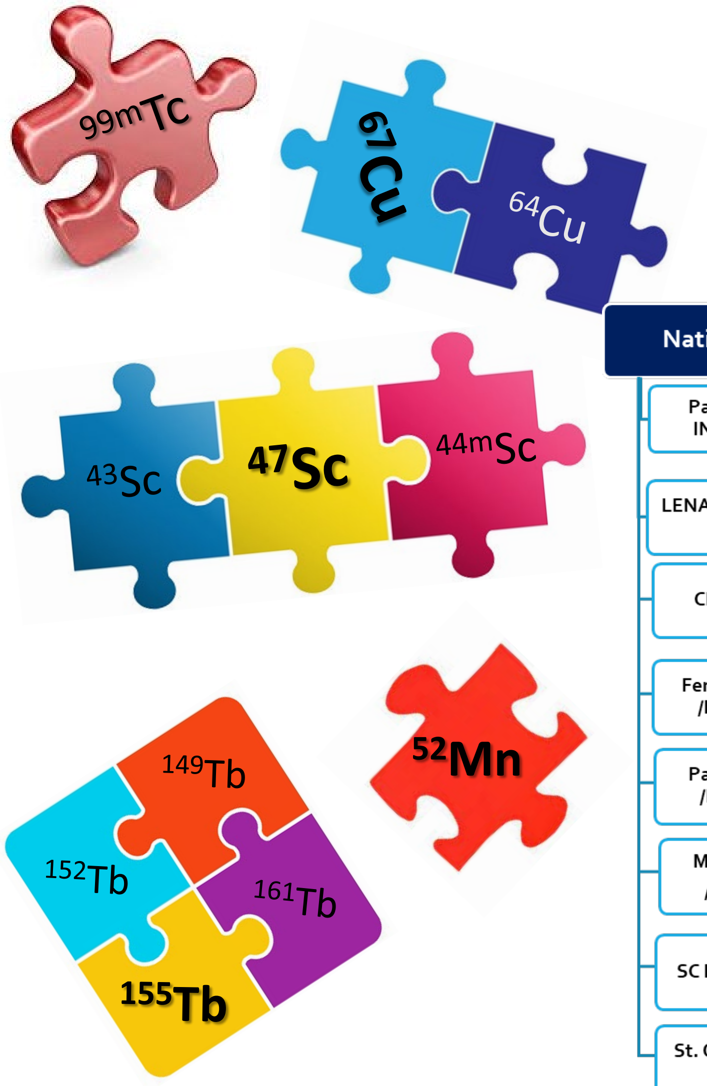
https://isolpharm.pd.infn.it/web/

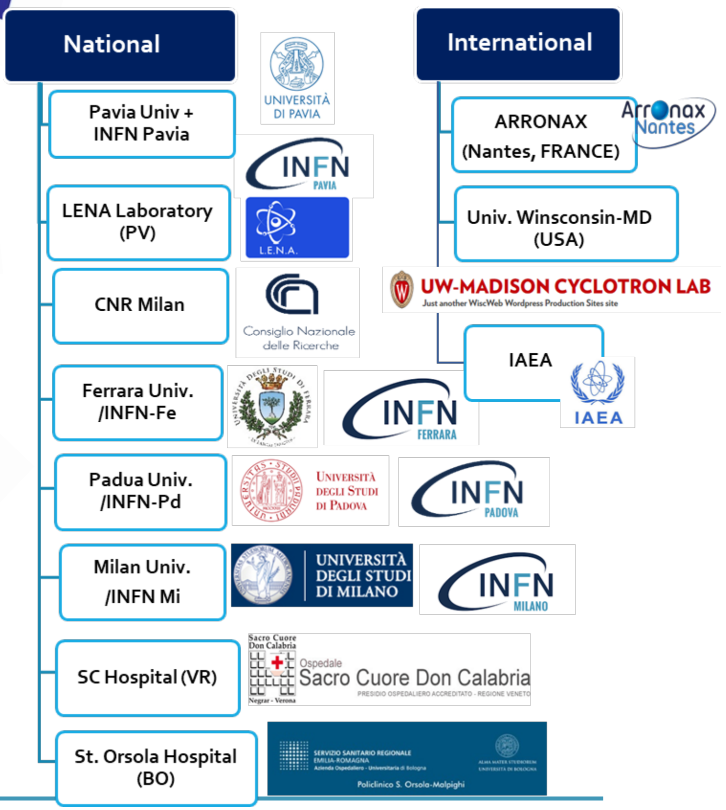
https://www.lnl.infn.it/en/spes-laramed-range

Medical Radionuclides of interest for LARAMED

Research lines and international projects	Years
Accelerator ^{99m}**Tc** direct production route through hospital cyclotrons	**APOTEMA (2012-2014)** **TECHNOSP (2015-2017)**
"Alternative, non HEU-based, ^{99m}**Tc**/^{99}**Mo** supply" IAEA	**IAEA CRP (2011-2015)**
COpper MEasurement: ^{70}**Zn(p,x)**^{67}**Cu**	**COME (2016)**
Production with Accelerator of ^{47}**Sc** for Theranostic Applications	**PASTA (2017-2018)**
"Radiopharmaceuticals Labelled with New Emerging Radionuclides (^{67}**Cu**, ^{186}**Re**, ^{47}**Sc**)" IAEA	**IAEA CRP (2016-2019)**
High Power Target concepts R&D	**TERABIO (2016-2019)**
High intensity vibrational powder plating (HIVIPP)	**E_PLATE (2018-2019)**
Multimodal pET/mRi Imaging with Cyclotron-produced $^{52/51}$**Mn** and stable paramagnetic Mn iSotopes	**METRICS (2018-2021)**
Research on Emerging Medical radIonuclides from the X-sections: ^{47}**Sc e** ^{149}**Tb**, ^{152}**Tb e** ^{155}**Tb (and therapeutic** ^{161}**Tb)**	**REMIX (2021-2023)**
TOTEM (magneTron sputtering cyclotrOn TargEt Manufacturing)	**TOTEM (2021-2022)**

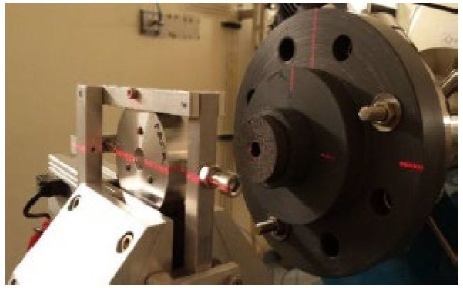
J. Esposito et al, Molecules 24(1), 20 DOI:10.3390/molecules24010020 (2019)





REMIX is funded by INFN-CSN5 for the years 2021-2023
With the goals:

Arronax Nantes



- **New XS measurements** for cyclotron-based production of ^{47}Sc, ^{149}Tb, ^{152}Tb, ^{155}Tb and ^{161}Tb

[N.B. the ^{49}Ti(p,x)^{47}Sc is unexplored!]

- **Nuclear codes** are used to estimate yield & purity of the produced radionuclides, also considering the experimental data
- **Computational dosimetric studies** with radiopharmaceuticals labelled with the produced RN (and contaminant isotopes) are performed to find out the best production routes

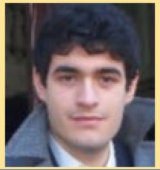
I.O.V. Istituto Oncologico Veneto I.R.C.C.S

- ^{155}Tb **Thick Target Yield (TTY)** measurement of the ^{155}Gd(p,n)^{155}Tb reaction @ the **SCDC hospital 19 MeV** cyclotron (solid target station)

SACRO CUORE DON CALABRIA IRCCS
Istituto Don Calabria
IRCCS Ospedale
Sacro Cuore Don Calabria
Presidio Ospedaliero Accreditato - Regione Veneto

REMiX

WP1. Production and target characterization
Sara Cisternino (INFN-LNL & UniPD)



WP7. Devices for INFN-LNL beam-line
Gabriele Sciacca (INFN-LNL & UniPD)

WP2. XS measurements with ^{49}Ti e ^{50}Ti
Liliana Mou (INFN-LNL)

WP6. ^{155}Tb TTY production @ The SCDC hospital
Petra Martini (UniFE & INFN-FE)

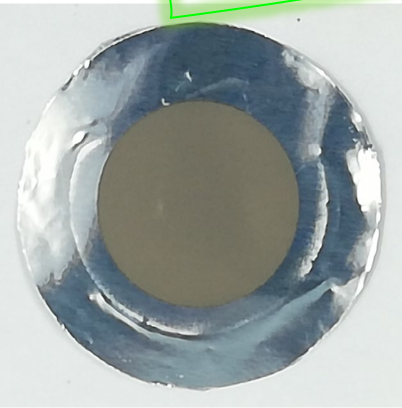
WP3. XS measurements with ^{nat}Dy, ^{159}Tb, ^{nat}Eu
Simone Manenti (UniMI & INFN-MI)

WP5. Dosimetric calculations
Laura De Nardo (UniPD & INFN-PD)
Laura Melendez-Alafort (IOV)

WP4. Nuclear codes (TALYS, EMPIRE, FLUKA)
Luciano Canton (INFN-PD)
Andrea Fontana (INFN-PV)

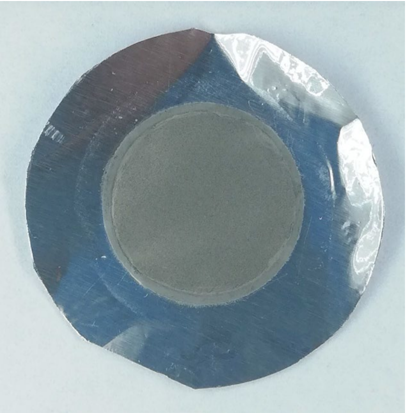
REMIX: WP1 Target manufacturing and characterization

HIVIPP depositions



No. 20 ^{49}Ti targets

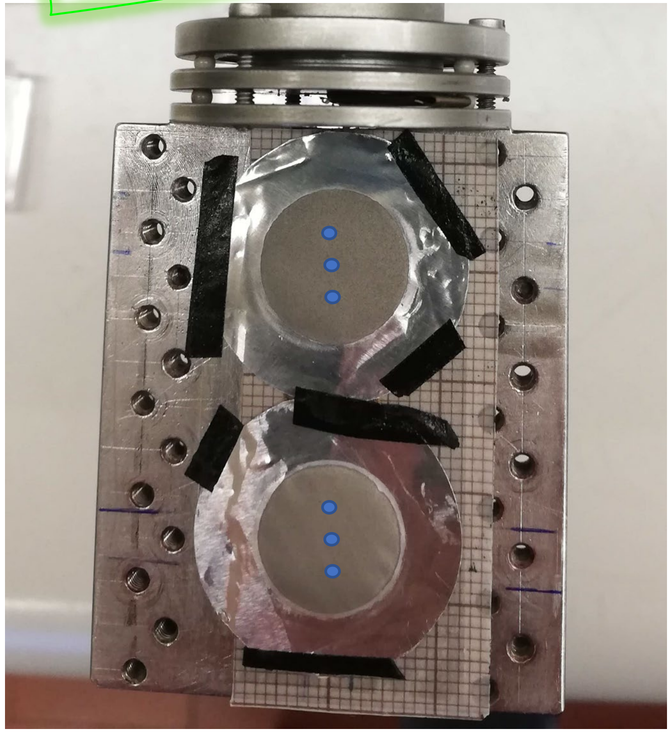
Mass thickness
measured by weigh
486±110 μg/cm²
(n=20)



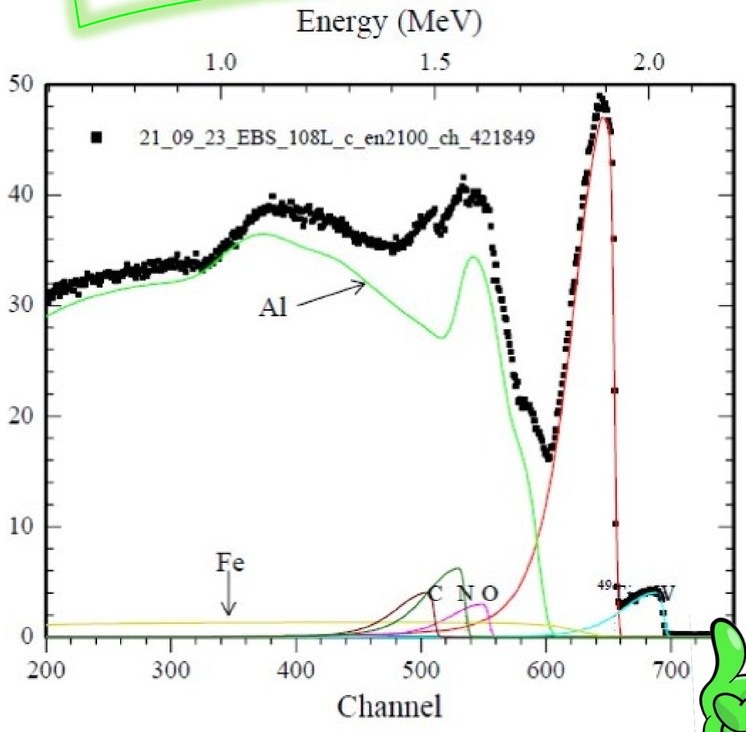
No. 20 ^{50}Ti targets

Mass thickness
measured by weigh
637±200 μg/cm²
(n=20)

Uniform thickness



Low contamination traces (about 10s ppm)



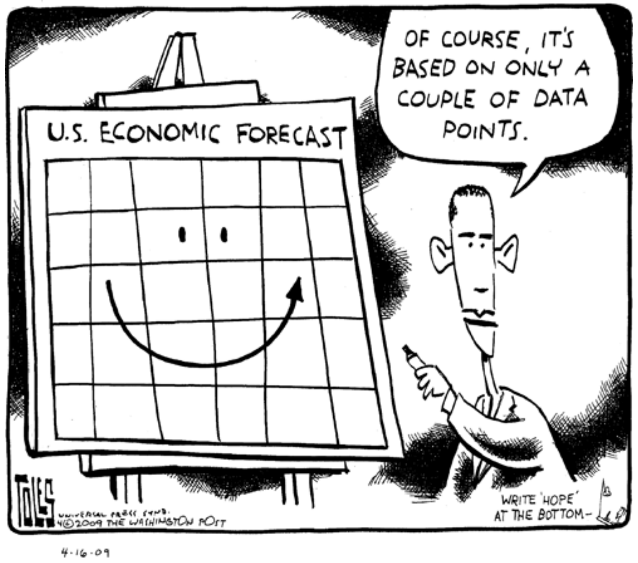
S. Cisternino et al., Upgrade of the HIVIPP deposition apparatus for nuclear physics thin targets manufacturing, Instruments (2022)

REMIX: WP2 Nuclear xs measurements for ^{47}Sc production

Interesting targets for proton-induced reactions

PASTA project, funded in 2017/2018 by INFN-CSN5

Only few literature data on enriched ^{xx}Ti..



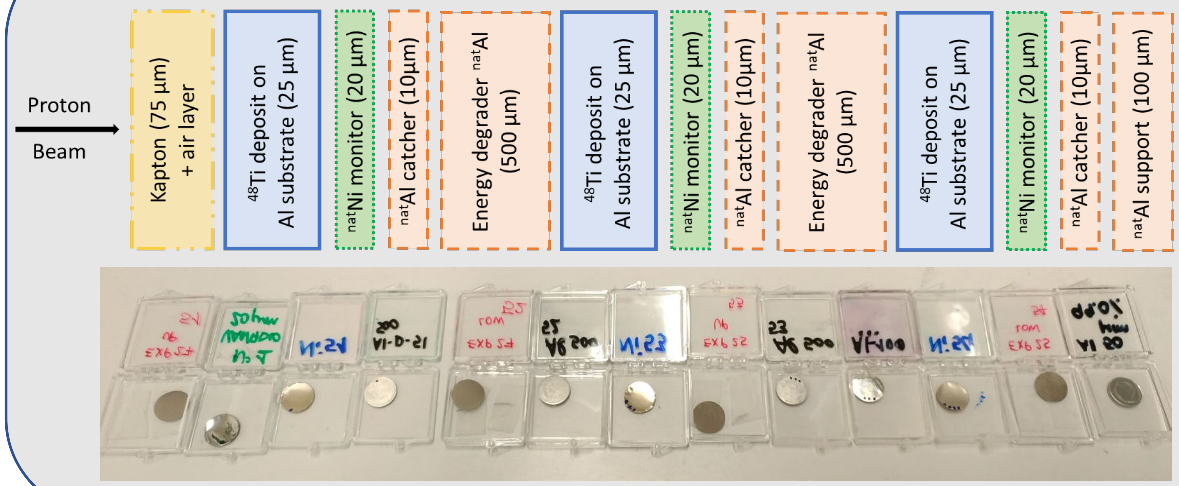
.. I am going to show you the xs results obtained with **proton-beams and enriched Ti targets** irradiated at the ARRONAX facility!

Arronax Nantes

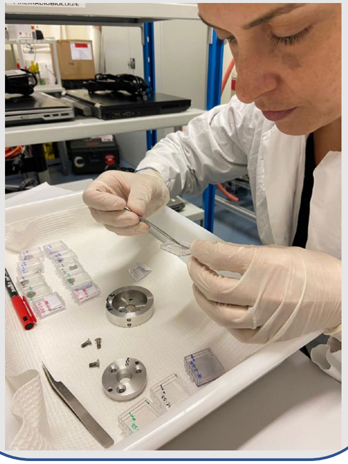
G. Pupillo et al., Journal of Radioanalytical and Nuclear Chemistry 297, 3 (2019) doi: 10.1007/s10967-019-06844-8
F. Barbaro et al., Physical Review C (2021) arXiv:2107.13773, doi: 10.1103/PhysRevC.104.044619

REMIX: WP2 ^{47}Sc nuclear cross section measurements

Scheme of a typical stacked-foils target

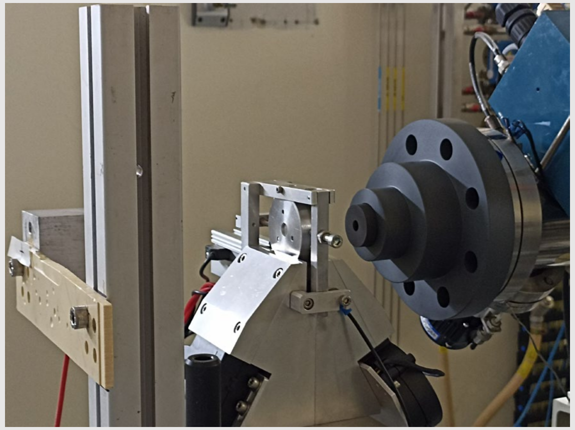


Stacked-foils target assembly

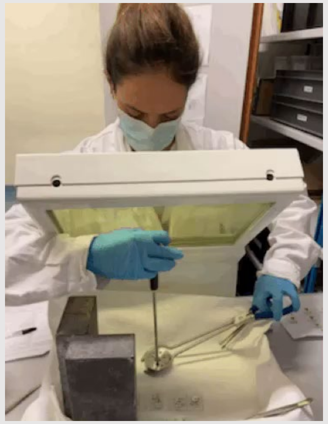


Beam setting with alumina

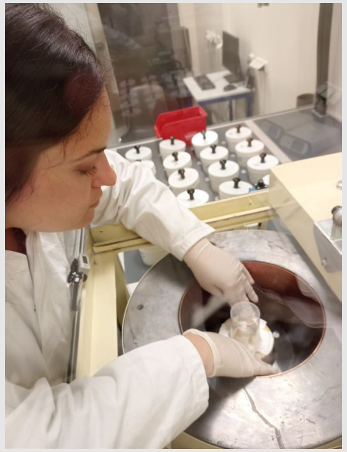
Irradiation runs on the AX3 beam-line



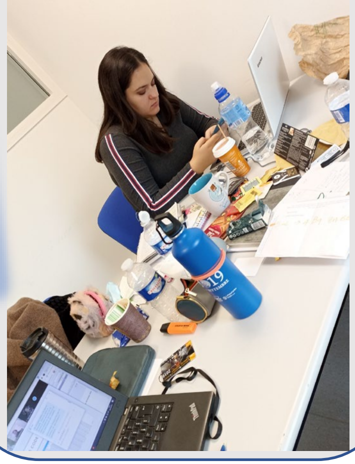
Target disassembly

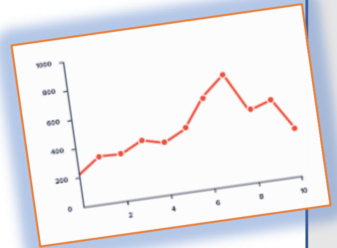


γ-spectrometry

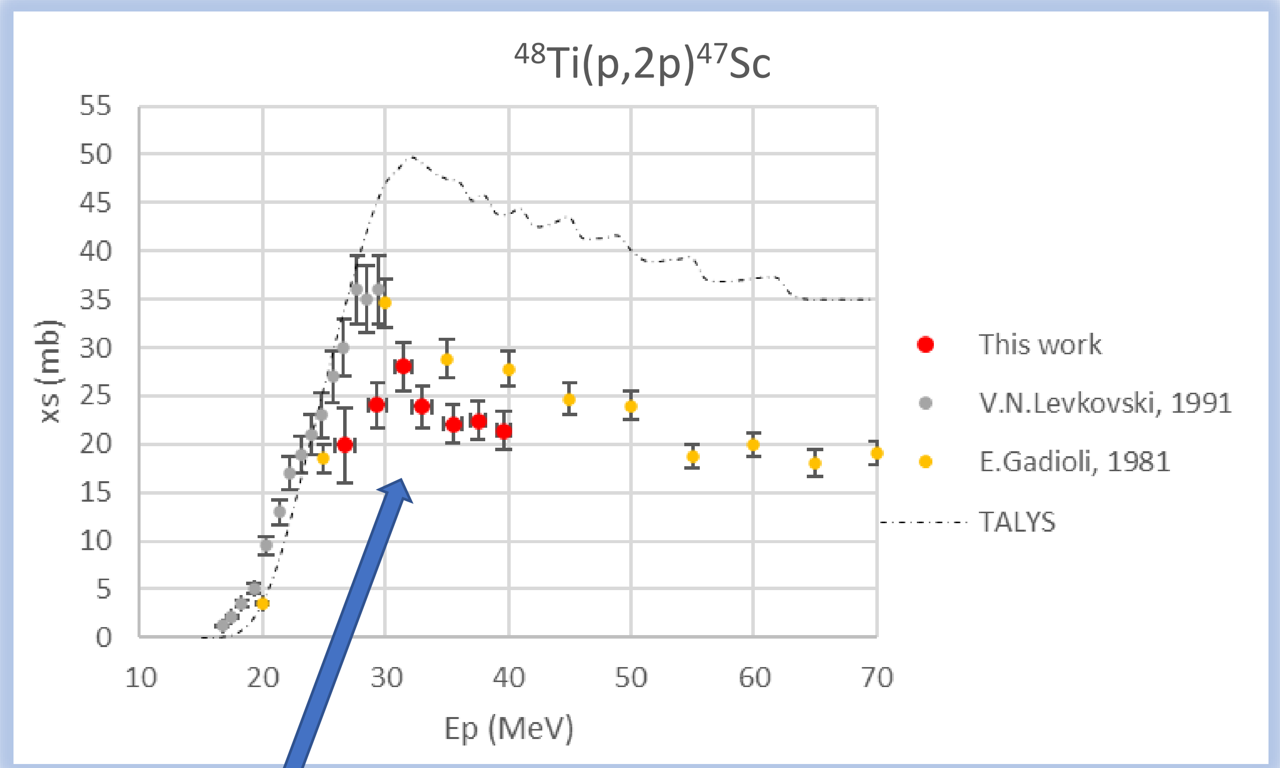


Data analysis

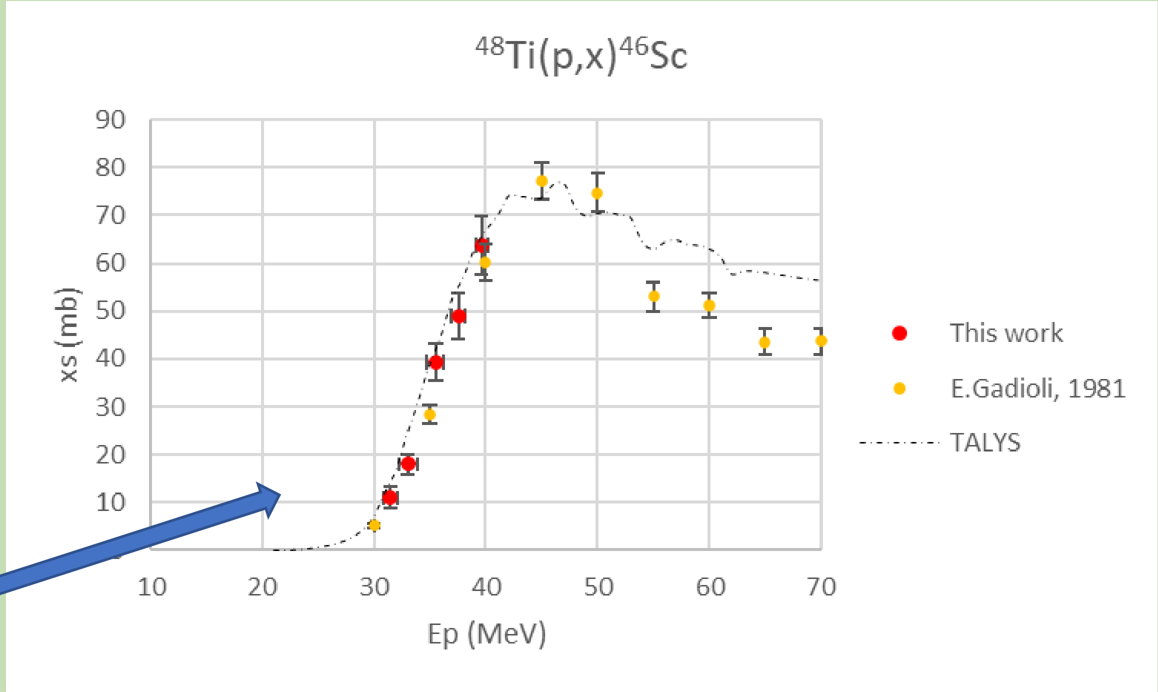




Proton-induced reactions on ^{48}Ti targets: ^{47}Sc and ^{46}Sc



^{47}Sc half-life **3.3492 d**
^{46}Sc half-life **83.79 d**

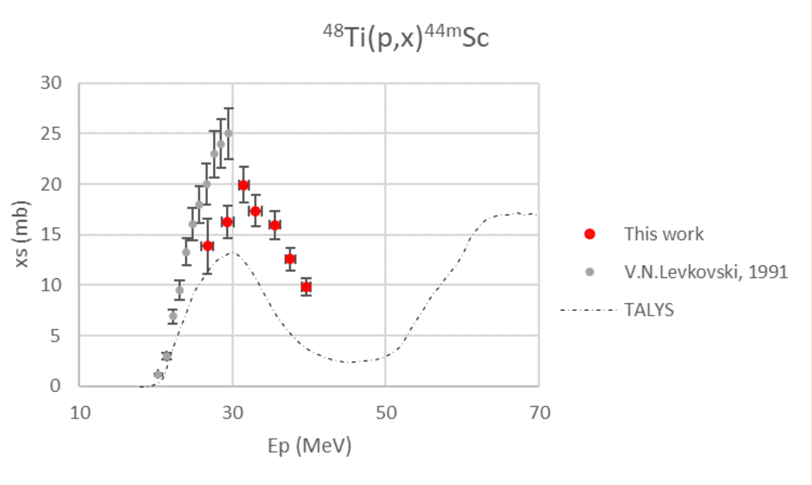


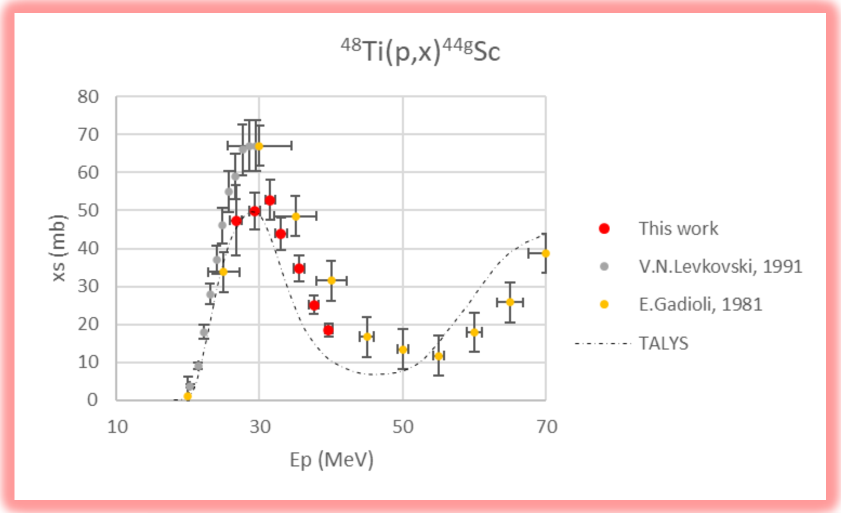
Up to 20% discrepancy with literature data

Good agreement

L. Mou et al., Nuclear cross sections of proton-induced reactions on enriched ^{48}Ti targets for the production of the theranostic ^{47}Sc radionuclide (..) (2022) Submitted

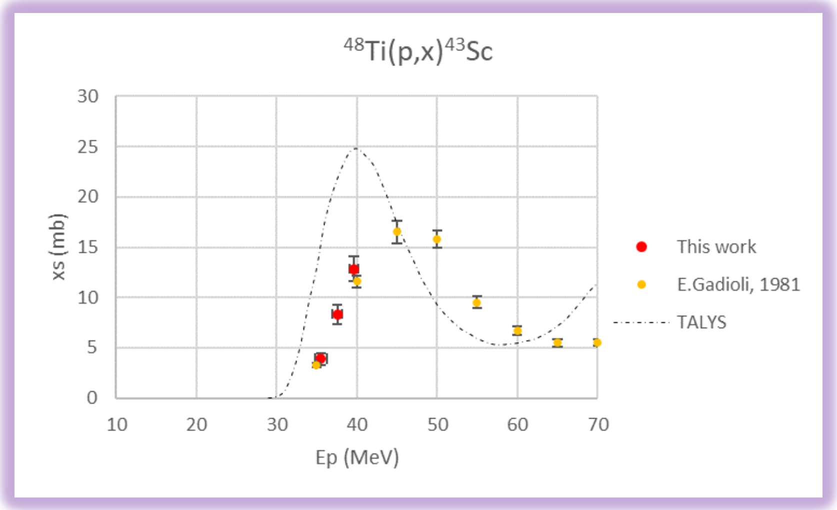
Proton-induced reactions on ^{48}Ti targets: ^{44m}Sc, ^{44}Sc, ^{43}Sc, ^{48}V

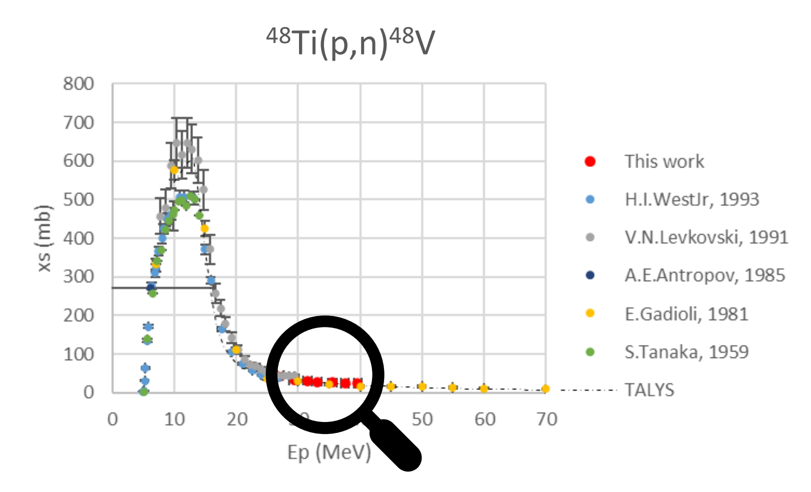


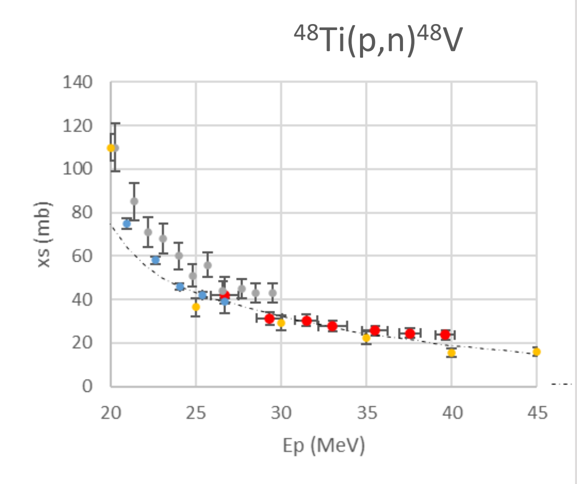


^{44m}Sc half-life **58.61 h**
^{44}Sc half-life **3.97 h**
^{43}Sc half-life **3.891 h**

^{48}V half-life **15.974 d**



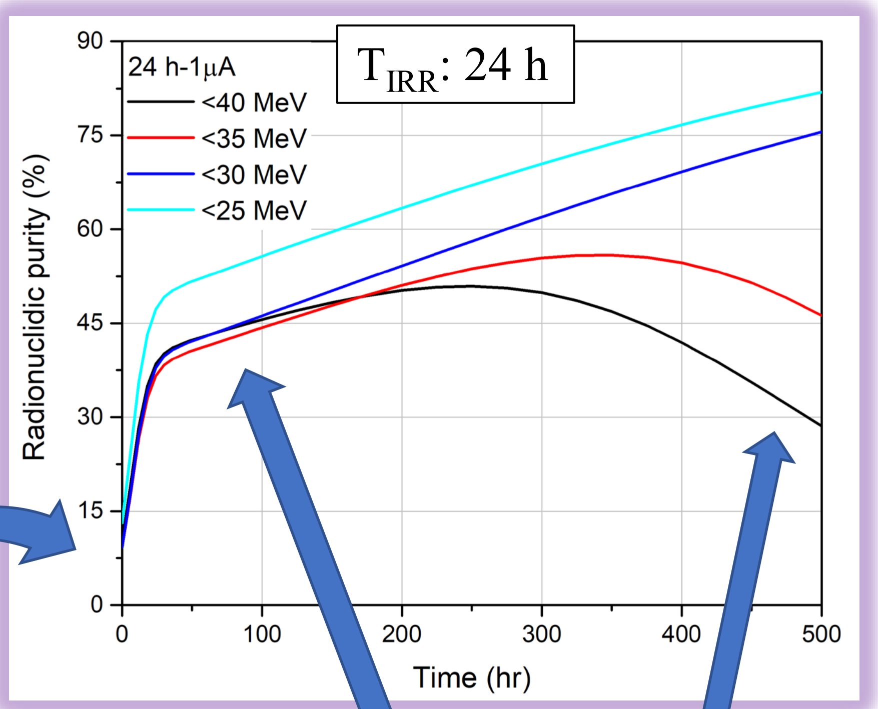


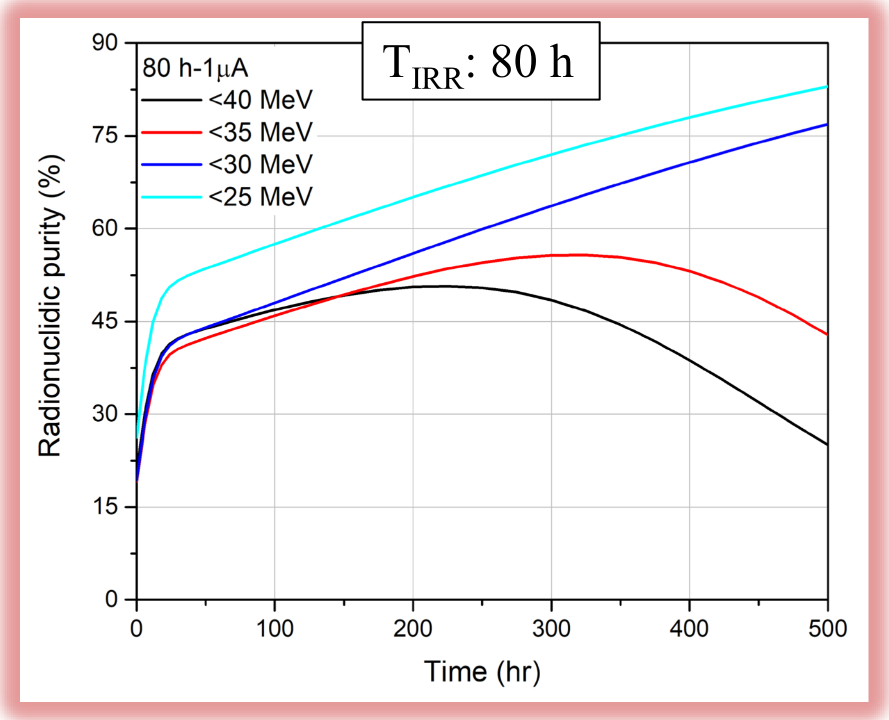


L. Mou et al., Nuclear cross sections of proton-induced reactions on enriched ^{48}Ti targets for the production of the theranostic ^{47}Sc radionuclide (..) (2022) Submitted

The ^{47}Sc Radionuclidic Purity (RNP) with ^{48}Ti targets

$E_P < 30$ MeV, co-production of ^{44m}Sc and ^{44}Sc ; $E_P > 30$ MeV co-production of ^{43}Sc, ^{44m}Sc, ^{44g}Sc and ^{46}Sc





Decay of the short half-time impurities ^{43}Sc and ^{44g}Sc

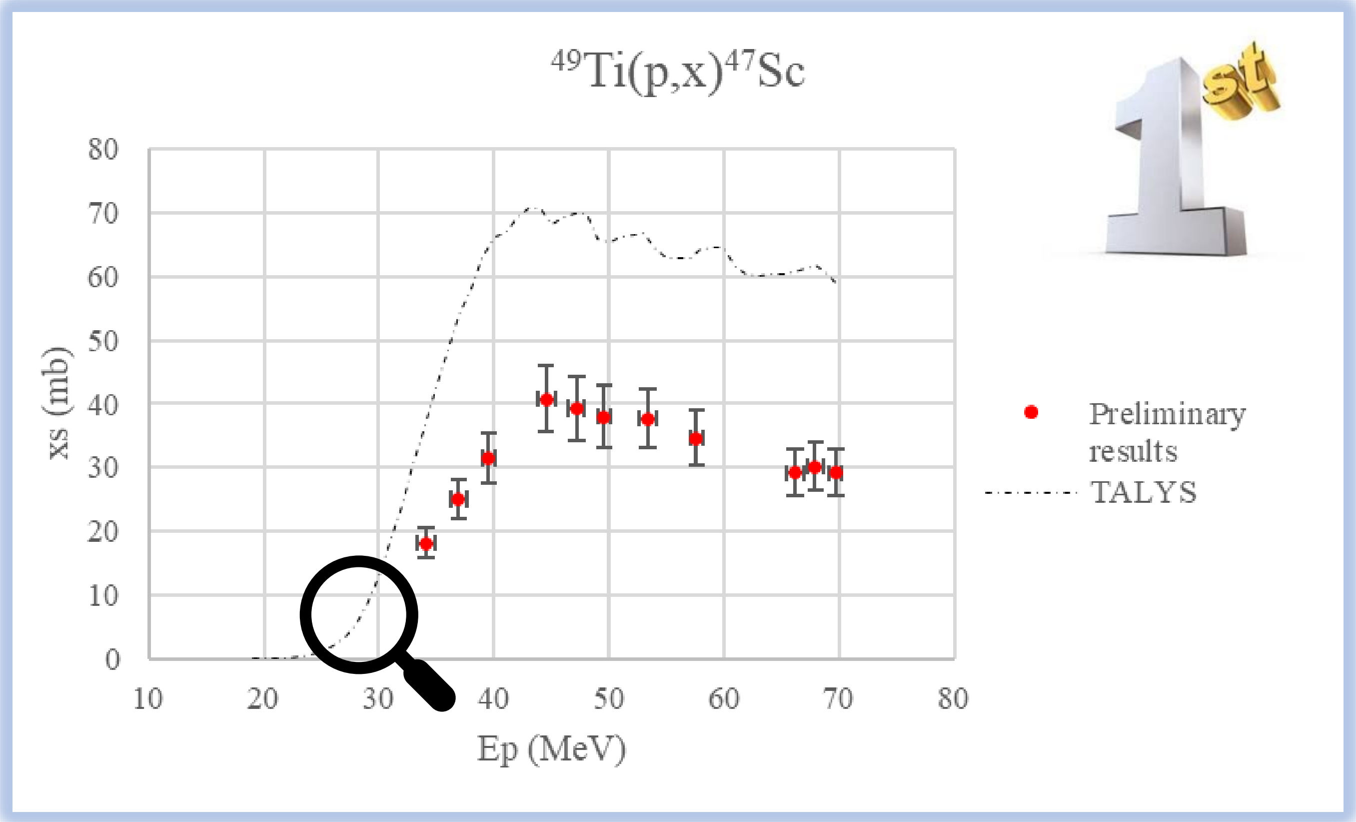
Decay of ^{44m}Sc

^{46}Sc activity

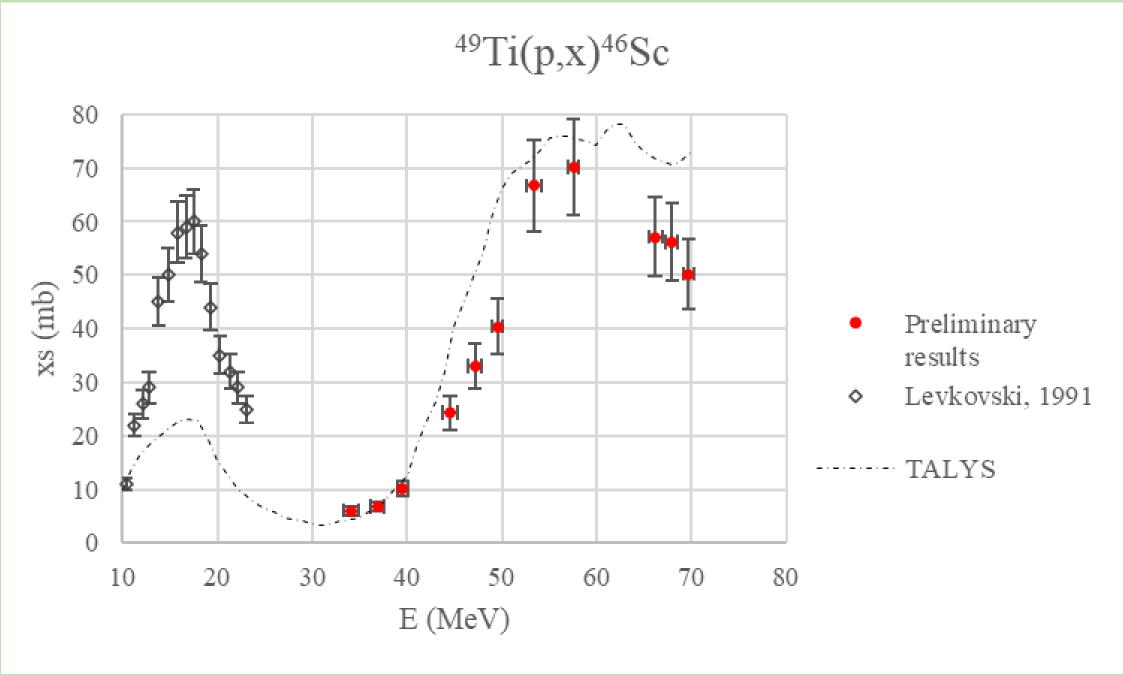
^{48}Ti targets are not suitable for a p-induced ^{47}Sc production!

L. Mou et al., Nuclear cross sections of proton-induced reactions on enriched ^{48}Ti targets for the production of the theranostic ^{47}Sc radionuclide (..) (2022) Submitted

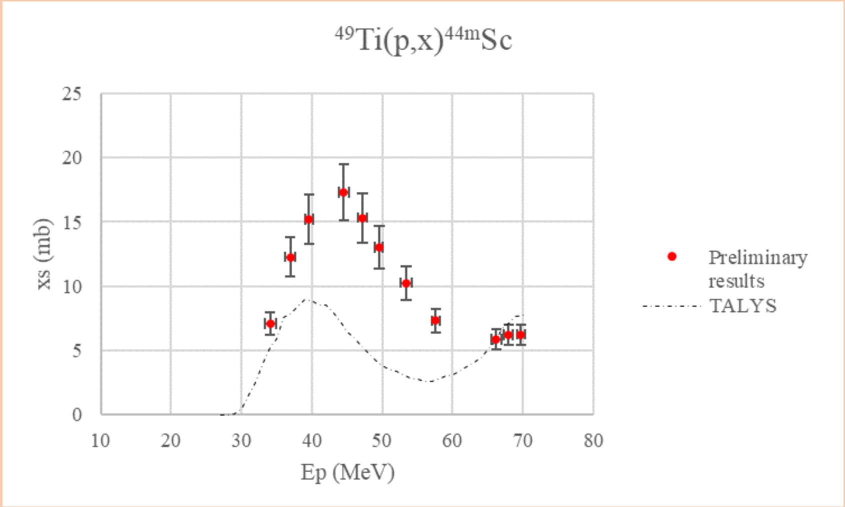
Proton-induced reactions on ^{49}Ti targets: Preliminary results

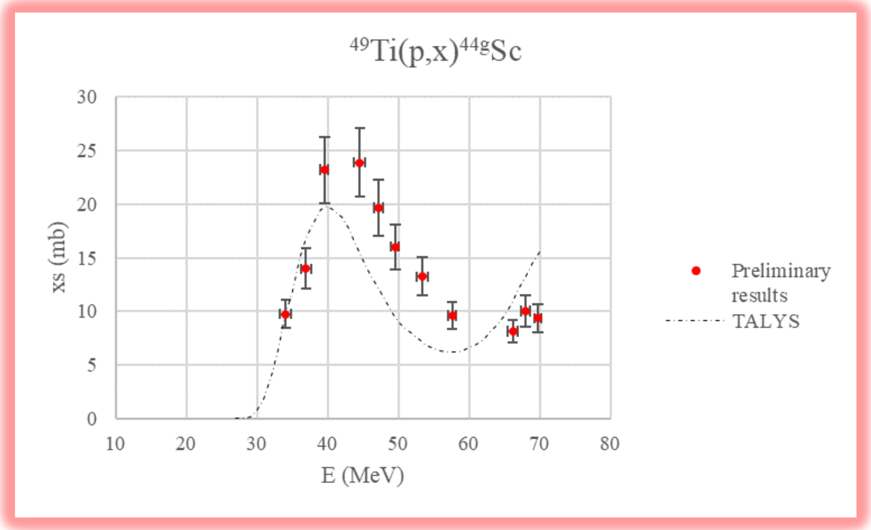


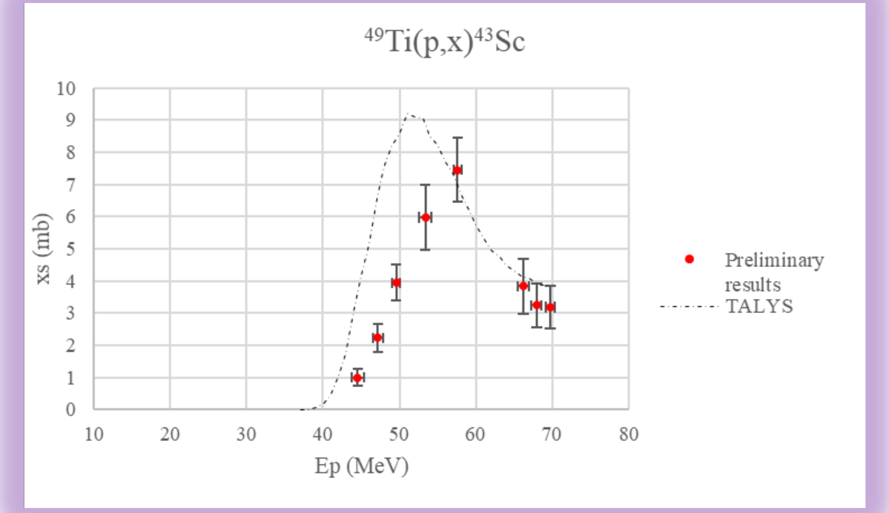
Preliminary data since we used the weighting values, but soon the **^{49}Ti EBS** values will be available!

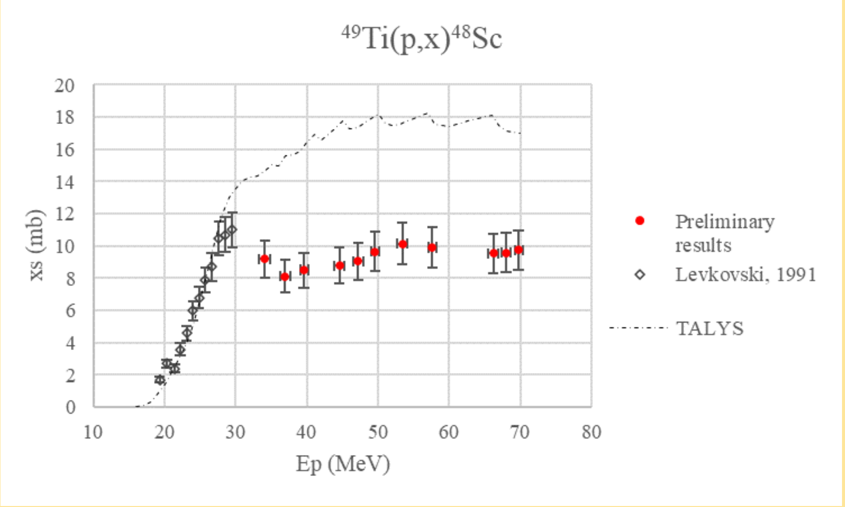


Proton-induced reactions on ^{49}Ti targets: Preliminary results





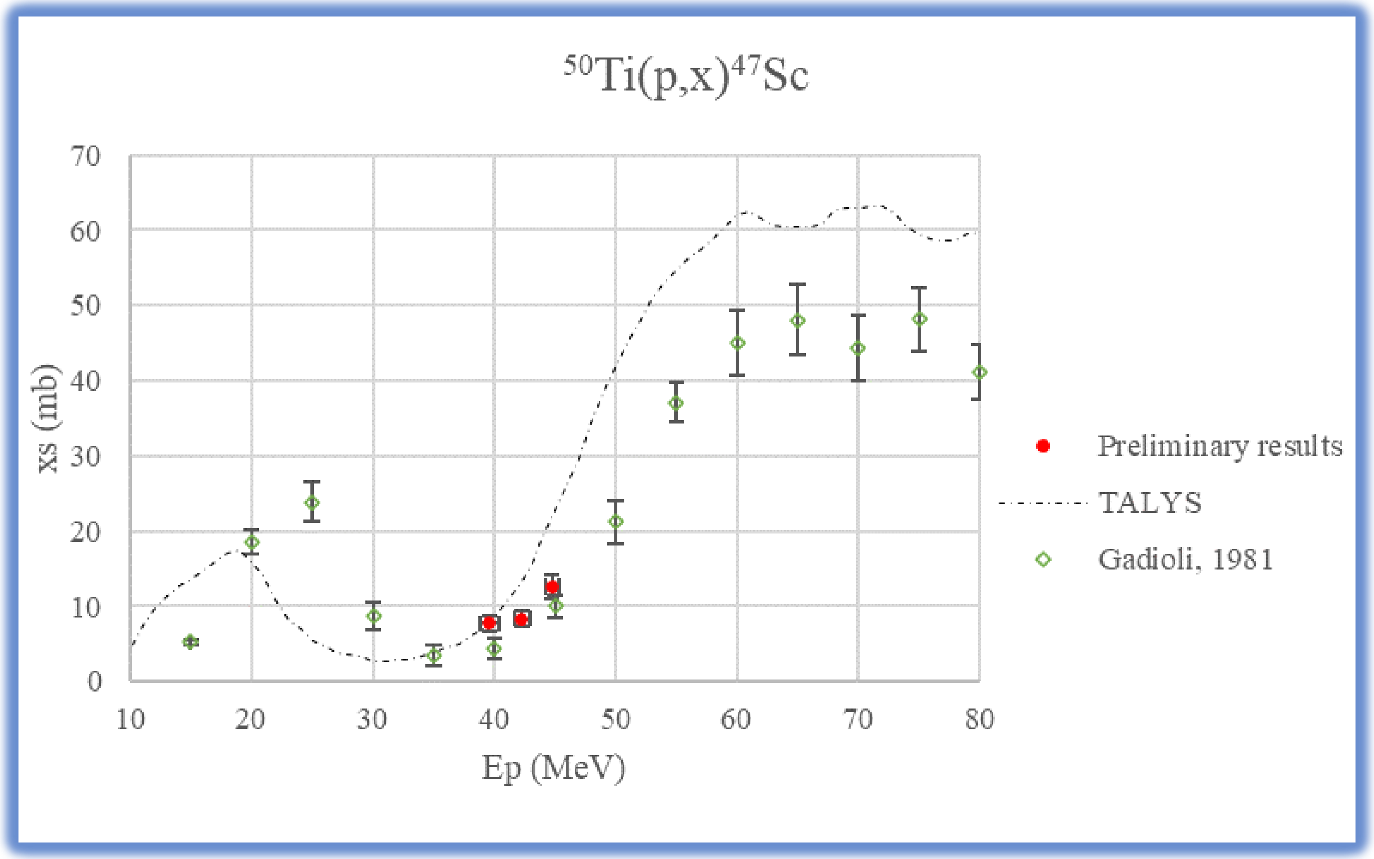




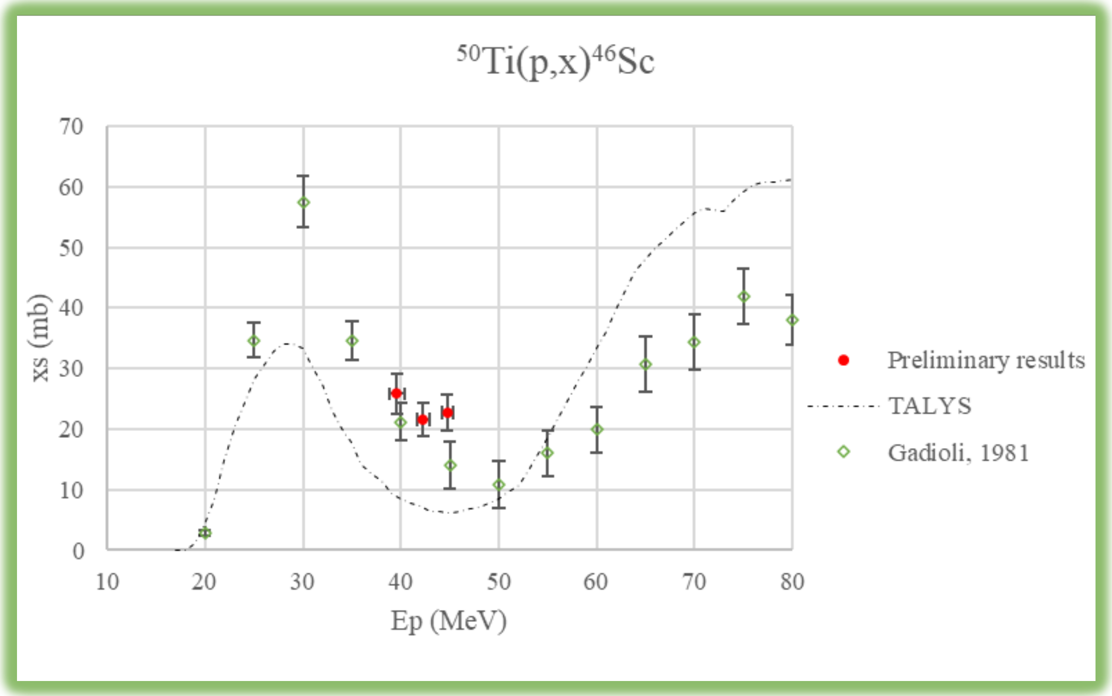
^{44m}Sc half-life **58.61 h**
^{44}Sc half-life**3.97 h**
^{43}Sc half-life **3.891 h**
^{48}Sc half-life **43.67 h**

Since the most interesting energy range with ^{49}Ti targets is below 40 MeV, before RNP calculations we would **measure the xs also at E_p < 35 MeV**

Proton-induced reactions on ^{50}Ti targets: Extra preliminary data

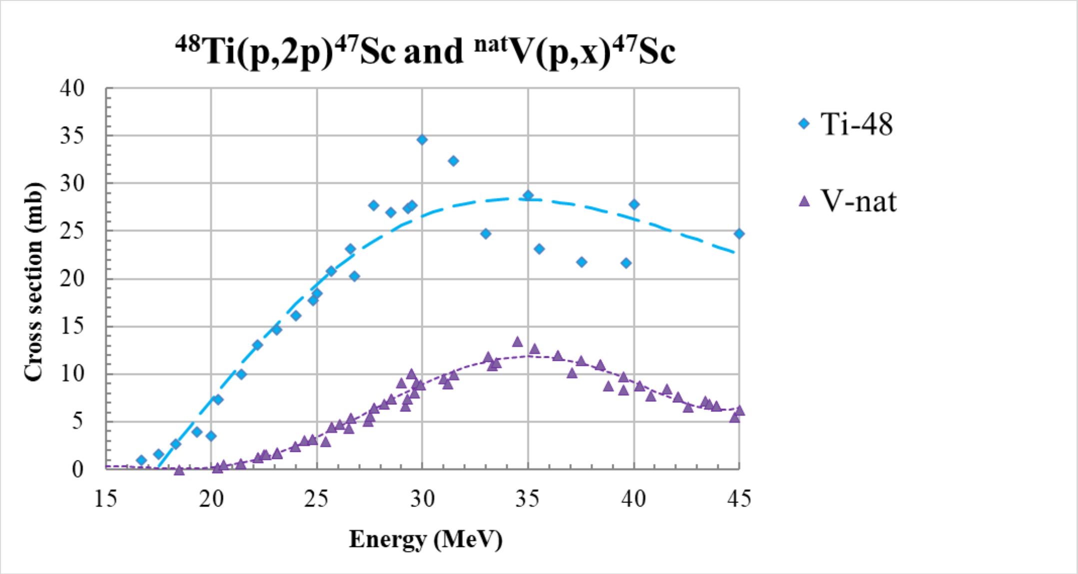


Extra preliminary data because the irradiation runs are ongoing!



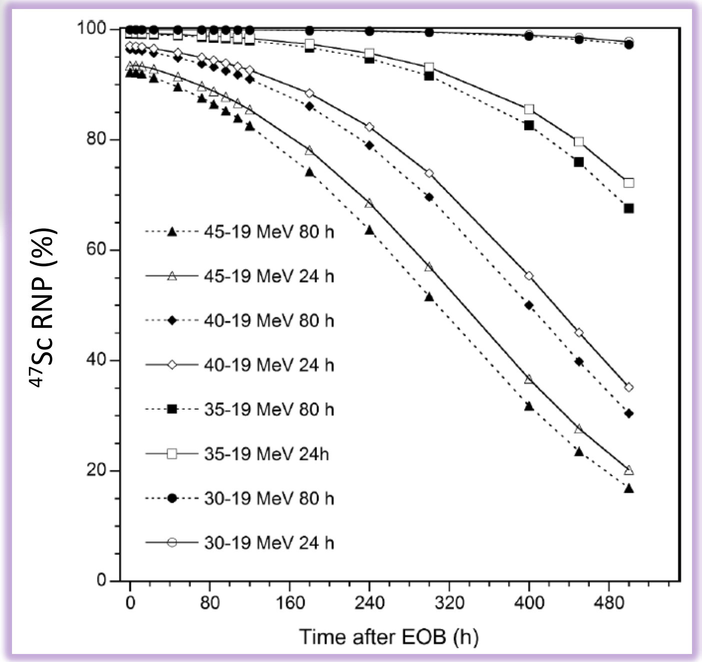
Weighting values for the ^{50}Ti deposit thickness

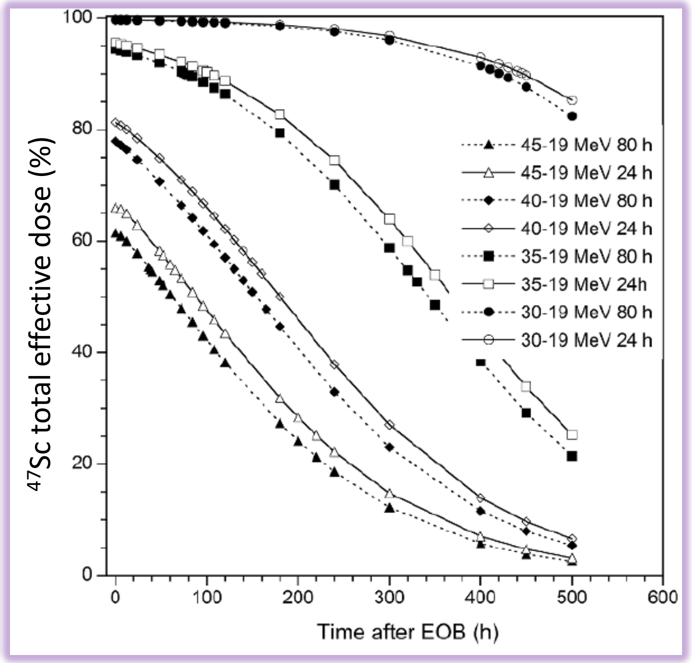
Comparison of ^{47}Sc production: ^{48}Ti vs ^{nat}V targets



The use of ^{48}Ti targets gives a larger ^{47}Sc yield in comparison to ^{nat}V, however the RNP is too low for medical applications!

Considering ^{nat}V targets, low ^{46}Sc co-production for E_P > 30 MeV but at E_P > 35 MeV also ^{48}Sc is co-produced!

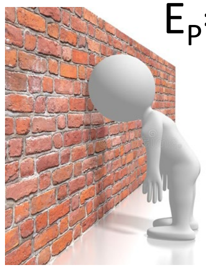




^{47}Sc produced with ^{nat}V (100 µA, 80 h) **RNP > 99%** :

E_P= 35-19 MeV ; t_{MAX} = 30 h ; ca. 28 GBq

E_P= 30-19 MeV ; t_{MAX} = 375 h ; ca. 11 GBq



As expected, higher the ^{47}Sc purity lower the yield!

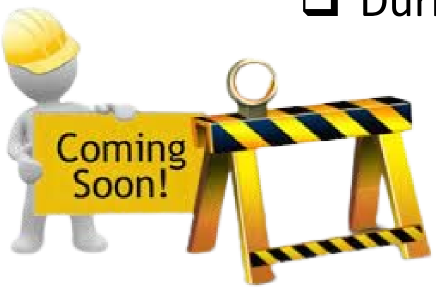
L. De Nardo et al., Physics in Medicine and Biology DOI:10.1088/1361-6560/abc811 (2021)

Future works and conclusions

- ✓ Thin homogeneous enriched metallic **^{xx}Ti-targets** manufactured and characterized (WP1)
- ✓ **Irradiation runs** ongoing at ARRONAX to measure the xs for ^{47}Sc (and contaminant) production (WP2)
- ✓ Cross sections always show a regular trend and a **general agreement** with few literature data

- ○ **Modeling** with nuclear codes to find out the best parameters to describe the xs of interest (WP4)
- ○ **Dosimetric calculations** to find out the best irradiation conditions for ^{47}Sc production (WP5)
- ○ **New irradiation runs** @ ARRONAX to describe the nuclear xs using enriched ^{49}Ti and ^{50}Ti targets (WP2)

- ❑ During 2023 it is expected to perform the **first tests @ INFN-LNL** for xs measurements (WP7)



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Dosimetric calculations of ^{47}Sc-cm10 using ^{nat}V targets

- Calculation of the ^{47}Sc and ^{xx}Sc-contaminants production for different scenarios with ^{nat}V targets

$E_P < 35$ MeV → only ^{46}Sc low amount & low ^{47}Sc yield
$E_P > 35$ MeV → ^{46}Sc, ^{48}Sc contaminants & high ^{47}Sc yield

- Biodistribution considered for ^{xx}Sc-cm10 (literature data: Müller et al., 2014) rescaled to the human case
- OLINDA code to estimate the total effective dose and the absorbed dose to each organ due to ^{47}Sc and ^{xx}Sc-contaminants

➢ Irradiation parameters suitable for medical use of ^{47}Sc-cm10!

Table 6. Calculated absorbed dose in the main organs (Gy) after a therapeutic treatment with $^{47/46}$Sc-cm10 radiopharmaceutical (11.625 GBq) performed at t_{max} and comparison with the absorbed dose limits values (Gy).

Organs	Absorbed dose per unit administered activity at t_{max} (Gy/GBq)	Absorbed dose (Gy) per treatment (11.625 GBq)	Dose limits (Gy)
Kidneys	0.750	8.719	23–40
Salivary glands	0.110	1.279	25–35
Liver	0.078	0.907	30
Bone marrow	0.013	0.151	2
Whole body	0.021	0.244	2

^{47}Sc produced for 80 h irradiation with 100 μA of 35-19 MeV protons on ^{nat}**V** targets should be enough for **2-6** treatments with ^{47}Sc-cm10!

L. De Nardo et al., Physics in Medicine and Biology DOI:10.1088/1361-6560/abc811 (2021)