Applications of nuclear reaction theory in medical radionuclide production

47Sc production from enriched Titanium/nat Vanadium targets

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155Tb production from enriched gadolinium targets

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52gMn production from natural Vanadium/Chromium targets

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Within the REMIX Project: Research on the Emerging Medical radIonuclides from the X-sections
Coordinated by **Gaia Pupillo** (INFN-LNL)

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^{47}Sc ^{155}Tb ^{52g}Mn

REMIX, METRICS projects of INFN-LNL
In collaboration with PD,MI,FE,PV…

Which production route is adequate
for clinical applications?

RadioIsotope	Half-life	Main Use	Additional Use	Context
^{47}Sc	3.35 d	**β⁻** THERAPY	SPECT	Theranostic ^{44,43}Sc
^{155}Tb	5.32 d	SPECT	AUGER THERAPY	Theranostic ^{149,152,161}Tb
^{52g}Mn	5.59 d	PET	NMR	Multimodal Imaging

Main contaminants

^{46}Sc $T_{1/2}$ = 83.79 d ; ^{48}Sc $T_{1/2}$ = 43.67 h

^{156}Tb $T_{1/2}$ = 5.35 d

^{54}Mn $T_{1/2}$ = 312.12 d

Preequilibrium models - in TALYS

- **PE 1 → Exciton model**: Analytical transition rates with energy-dependent matrix element
- **PE 2 → Exciton model**: Numerical transition rates with energy-dependent matrix element.
- **PE 3 → Exciton model**: Numerical transition rates with optical model for collision probability
- **PE 4 → Multi-step** direct/compound model
- **PE 5 → Geometry Dependent Hybrid (GDH)** model

from TALYS-G implementation provided by KIT

Level density models - in TALYS

- LD 1 → Constant temperature + Fermi gas model
- LD 2 → Back-shifted Fermi gas model
- LD 3 → Generalised superfluid model

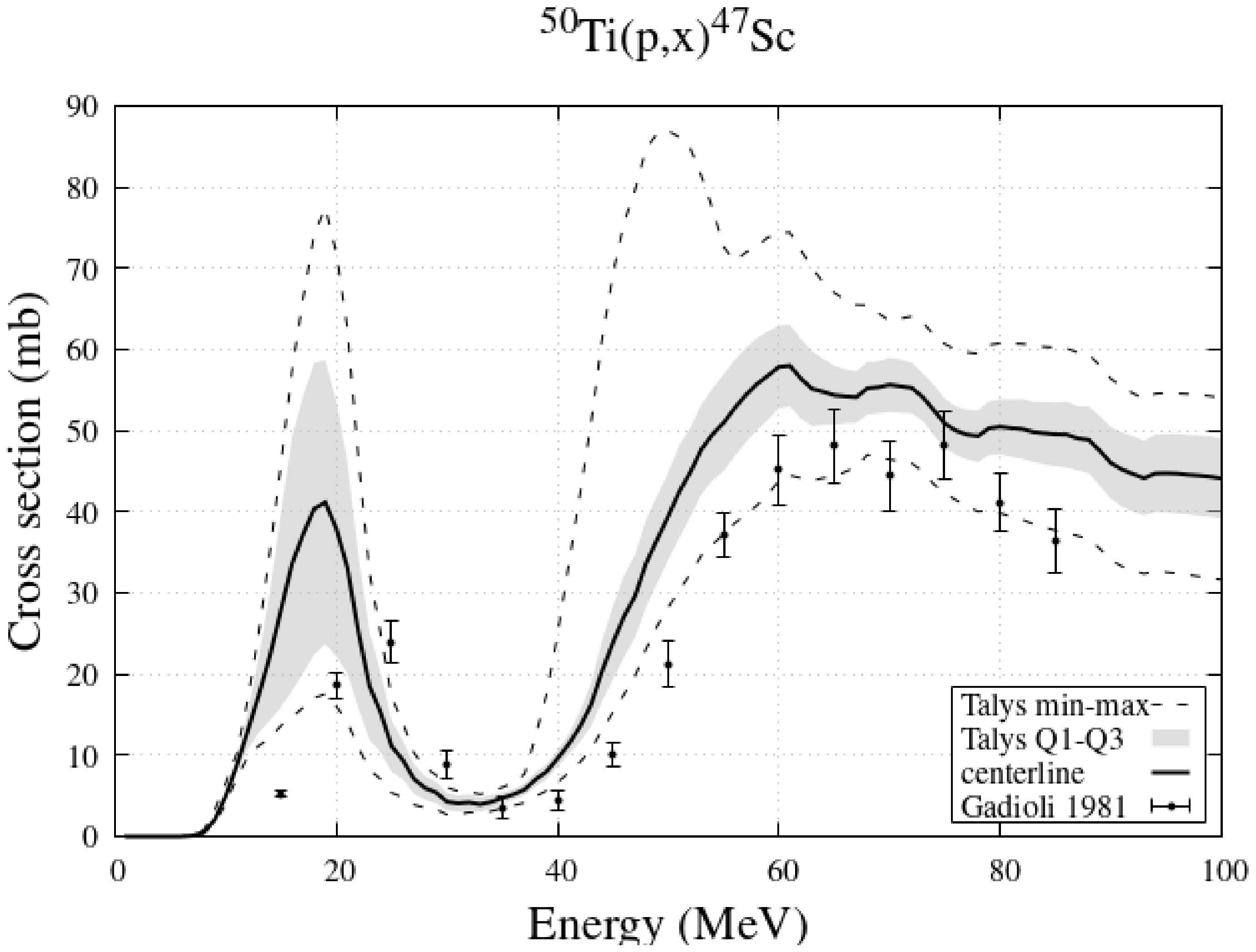
phenomenological

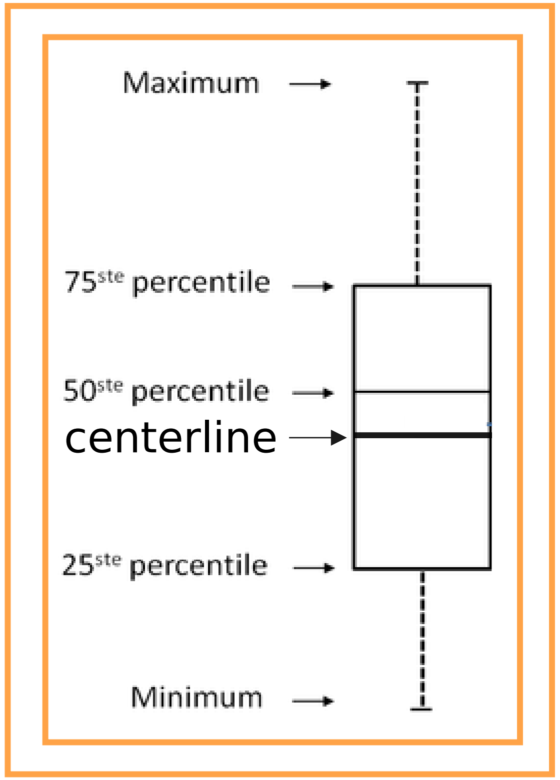
- LD 4 → Microscopic level densities (Skyrme force) from Goriely's tables
- LD 5 → Microscopic level densities (Skyrme force) from Hilaire's combinatorial tables
- LD 6 → Microscopic level densities (temperature dependent HFB, Gogny force) from Hilaire's combinatorial tables

microscopic

$^{50}Ti(p,\alpha)^{47}Sc$

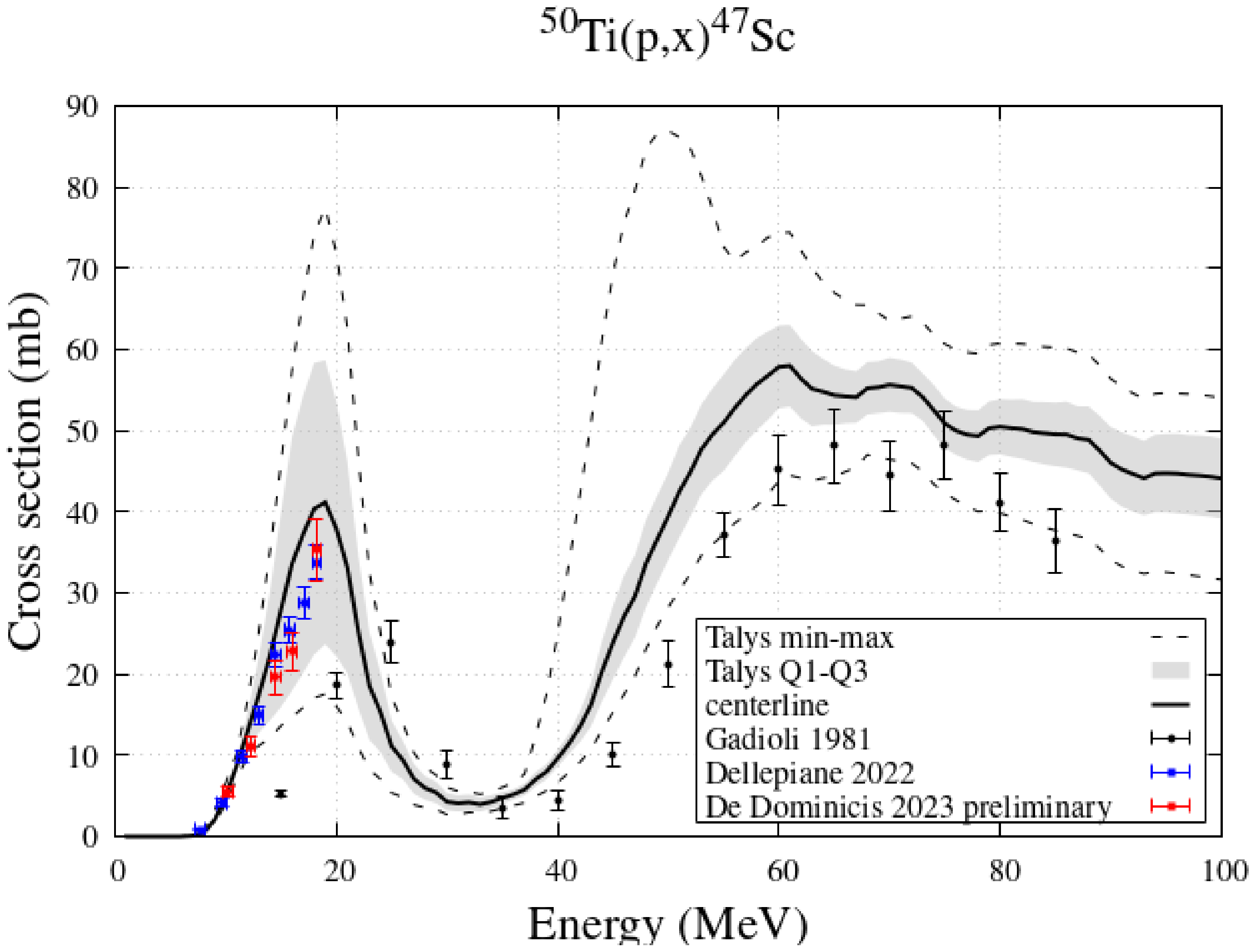
Representing the model variability of Talys calculations

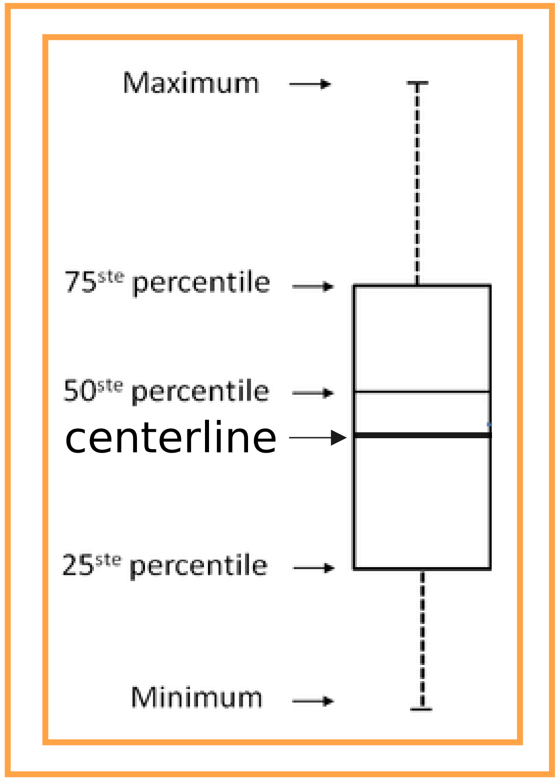




Box-Whisker Plot

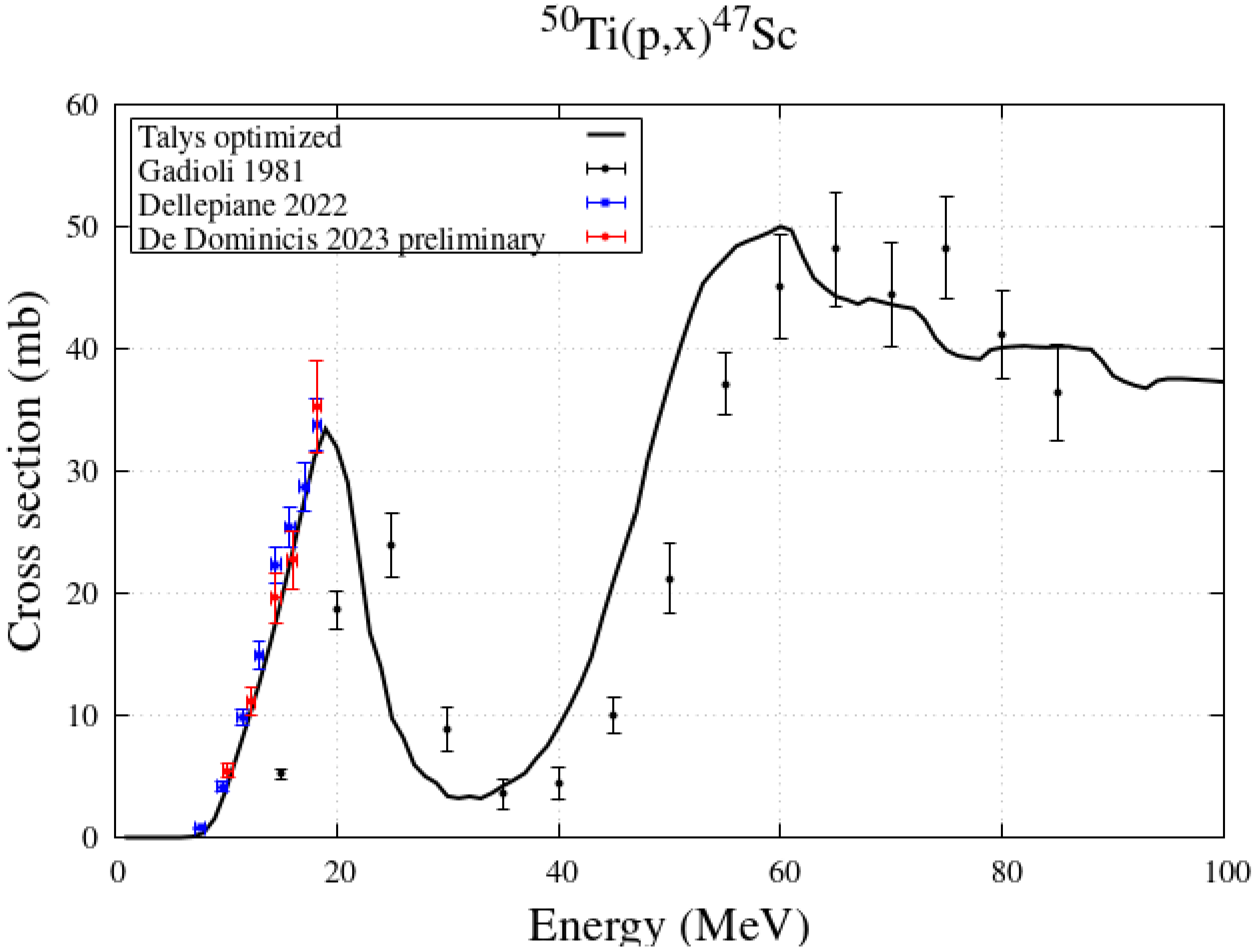
The new experimental data are very promising!





Box-Whisker Plot

Optimization of level density parameters to get curves guided by data



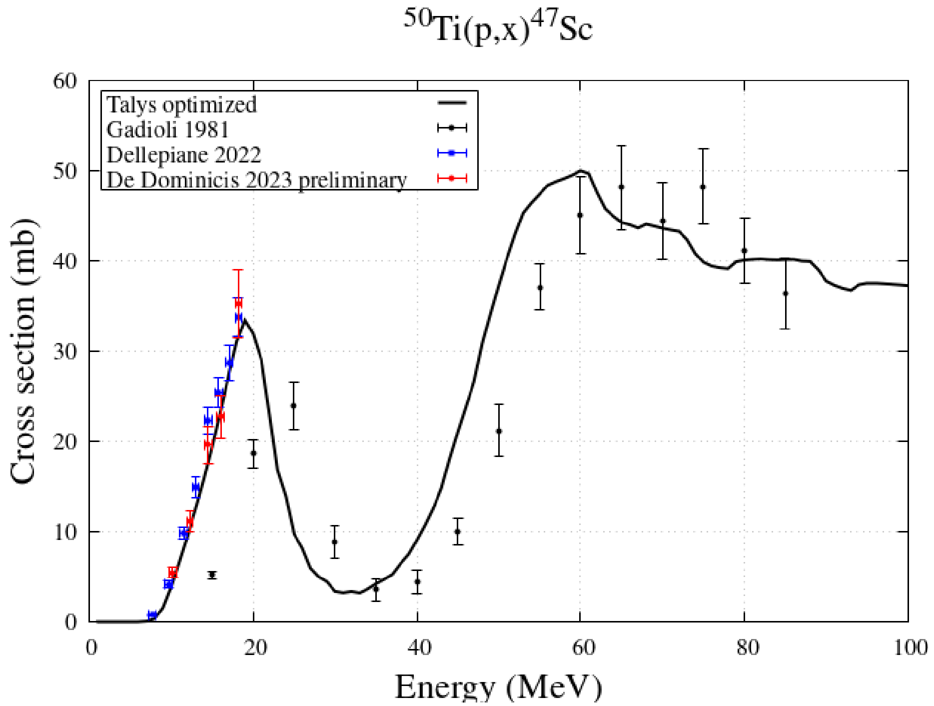
$$\rho(E) = \exp\left(c\sqrt{E-p}\right)\rho(E-p)$$

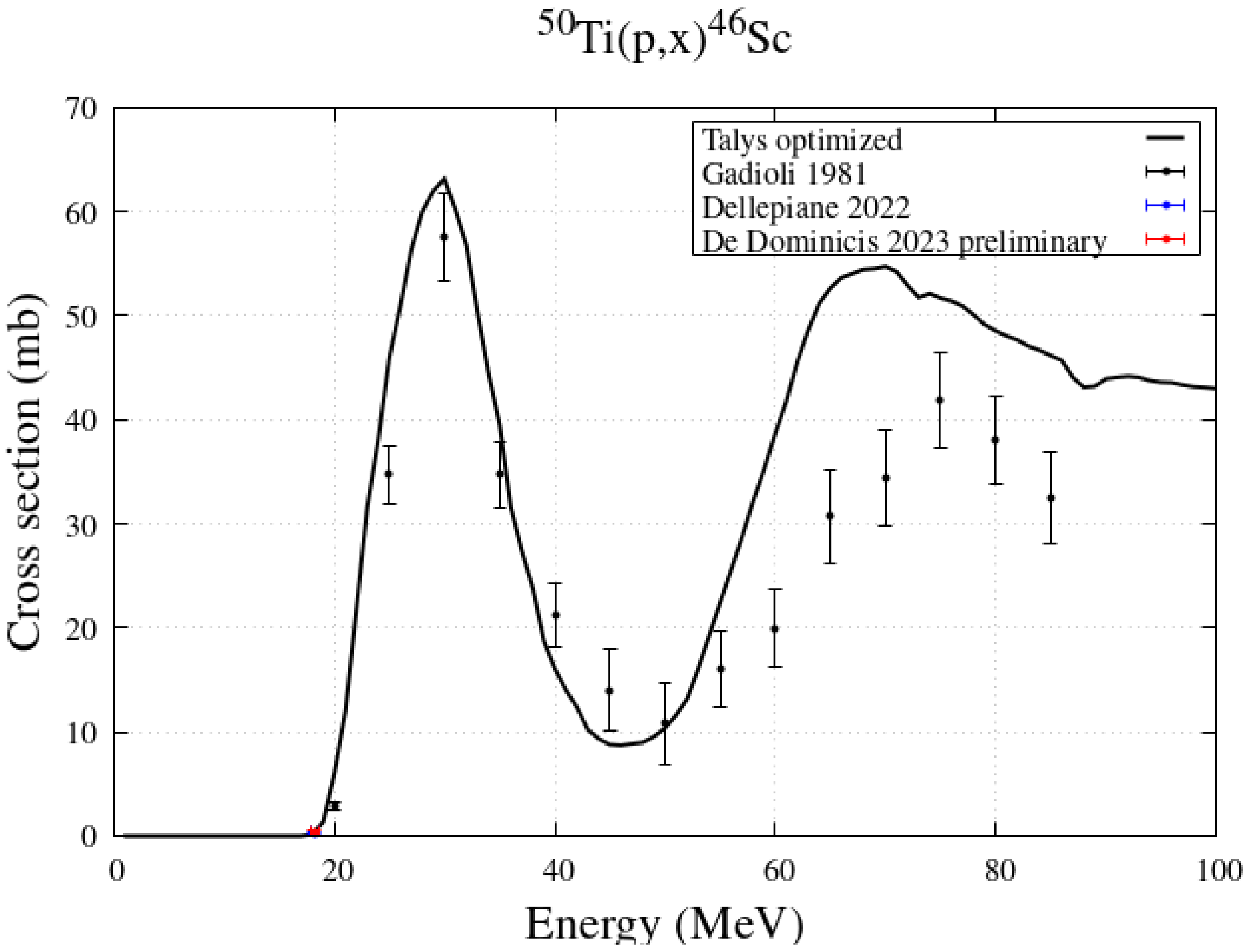
Modified level density of ^{47}Sc compound

PE 3 – LD 4

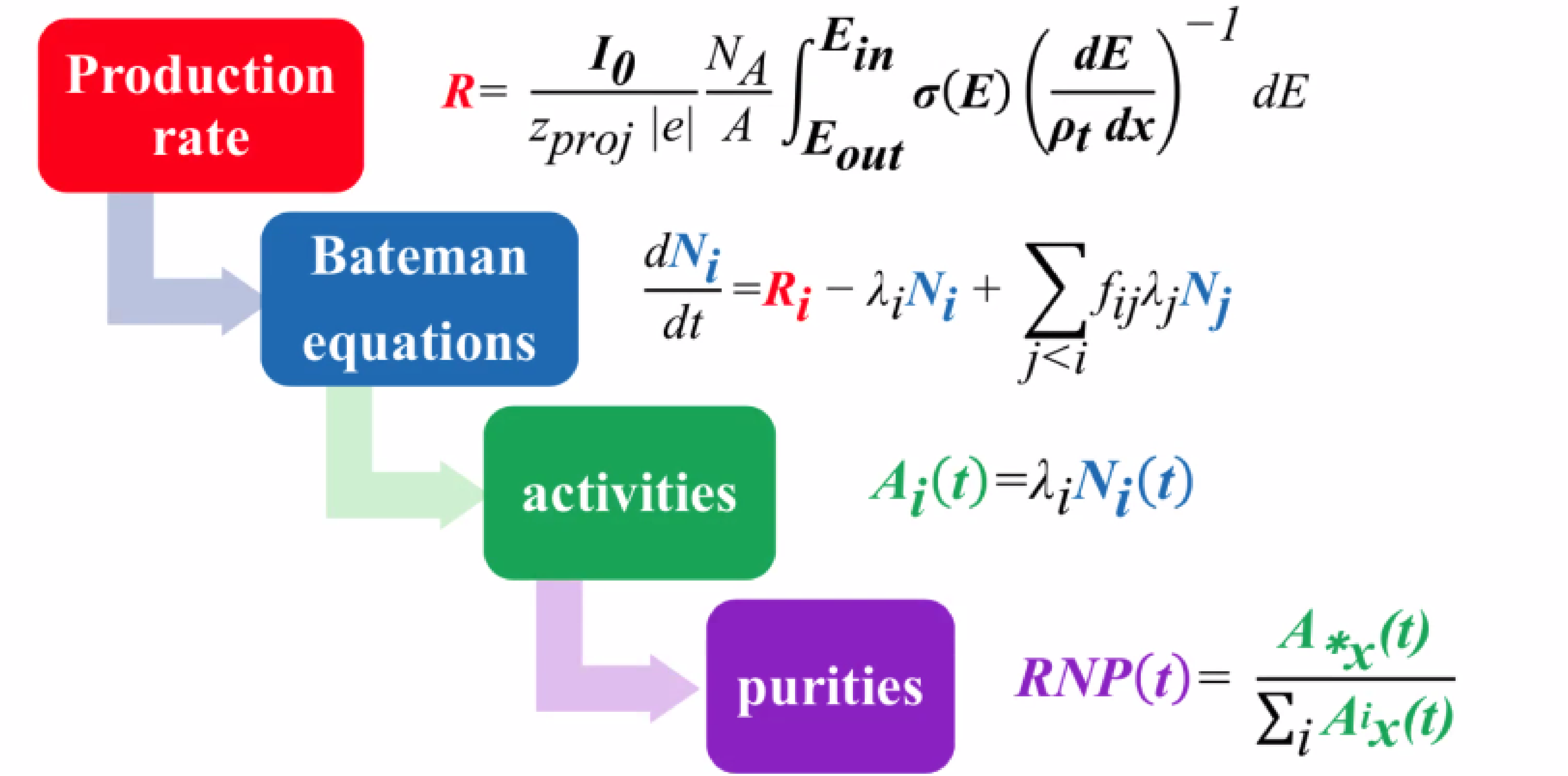
c = 0.0 MeV$^{-1/2}$
p = 0.5 MeV

… and contaminants cross-sections

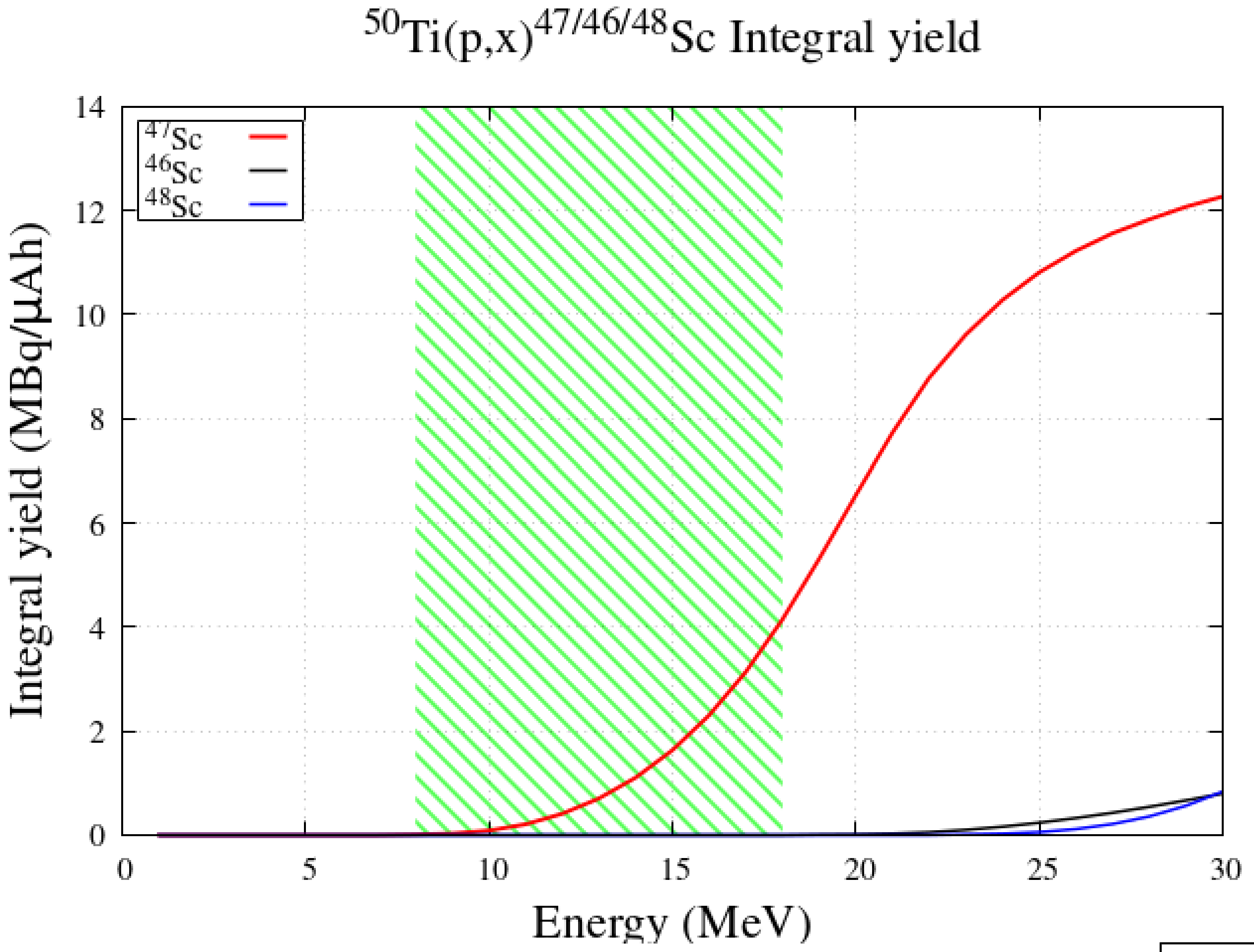




From Cross-Sections to Yields and RNP Purities



Significant Yield of ^{47}Sc



Irradiation conditions

t_{irr} = 1 h

i = 1 μA

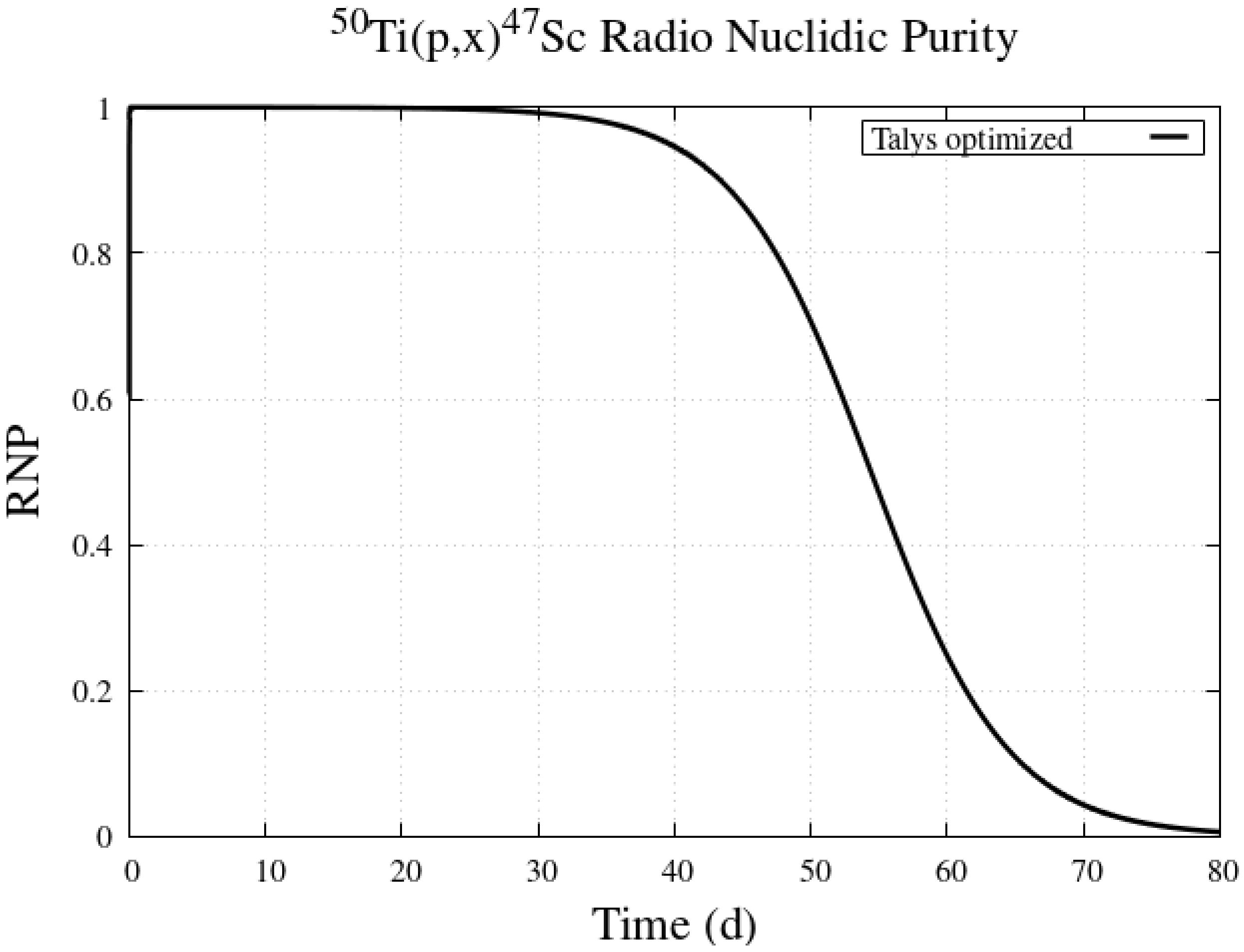
E_{max} = 18 MeV

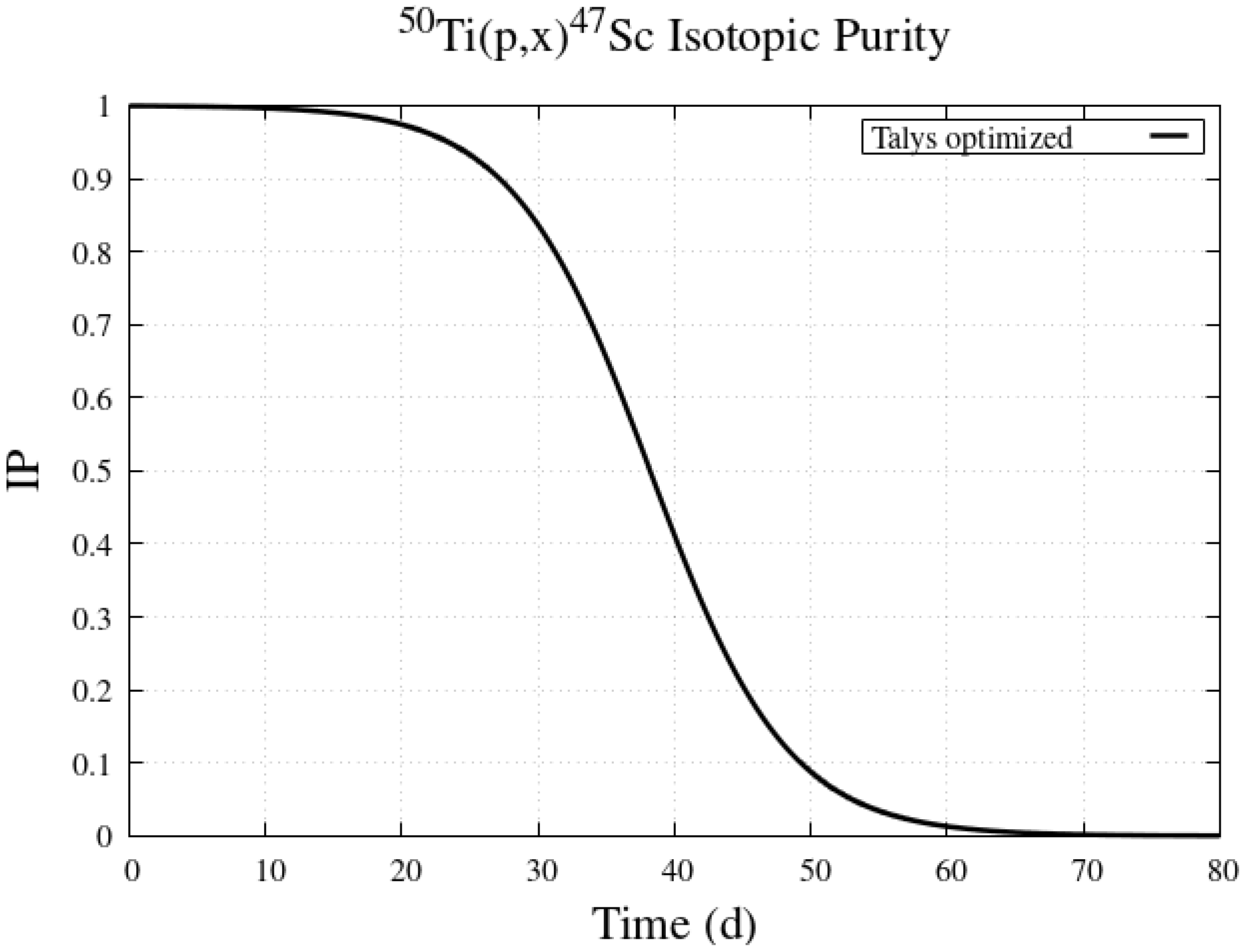
E_{min} = 8 MeV

Yield (MBq/(μA·h))		
^{47}Sc	^{46}Sc	^{48}Sc
4.138	8.35E-05	0.0

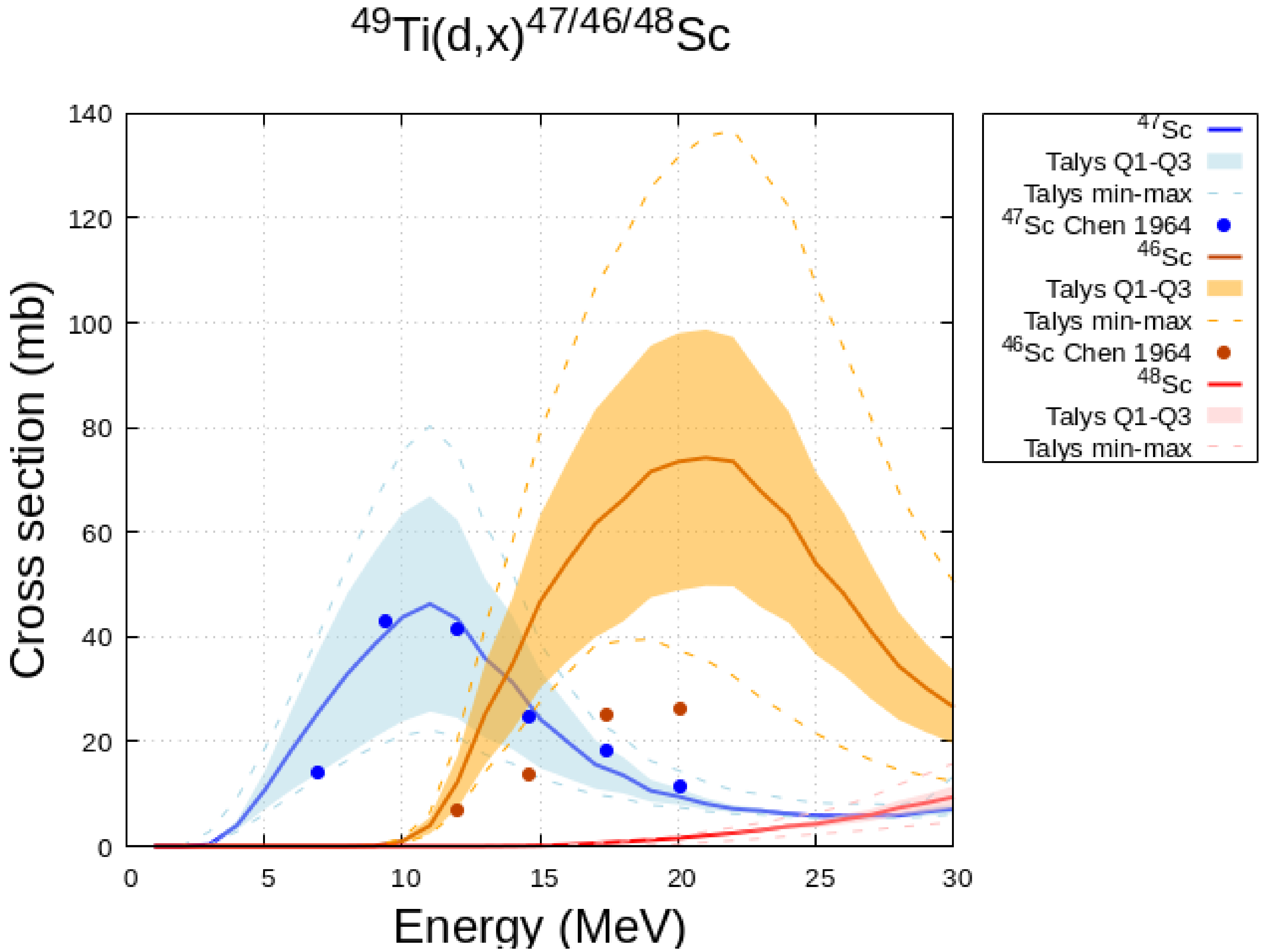
$$\text{RNP} = \frac{A^{47Sc}}{\sum_i A_i}$$

$$\text{IP} = \frac{n^{47Sc}}{\sum_i n_i}$$

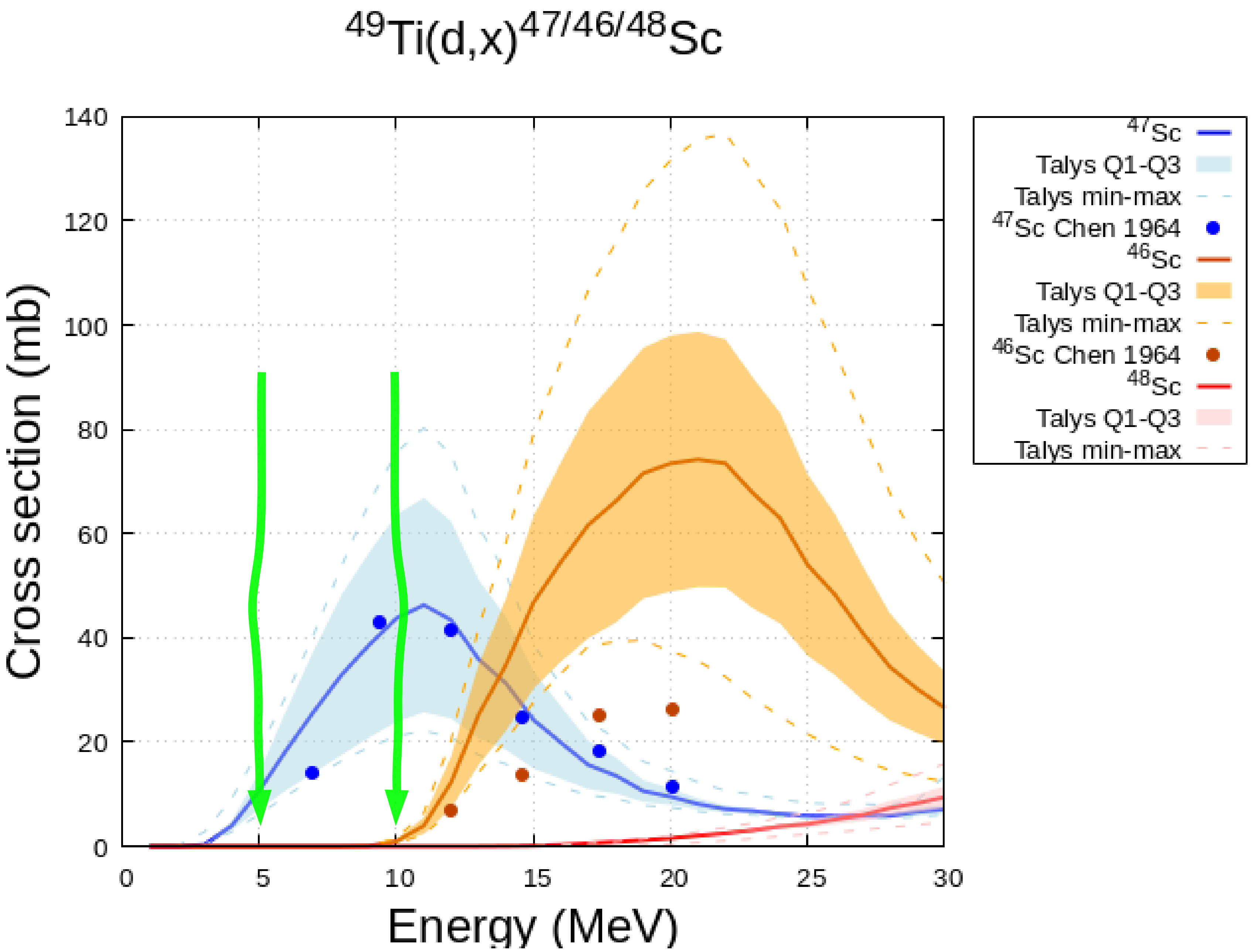




$^{49}Ti(d,\alpha)^{47}Sc$

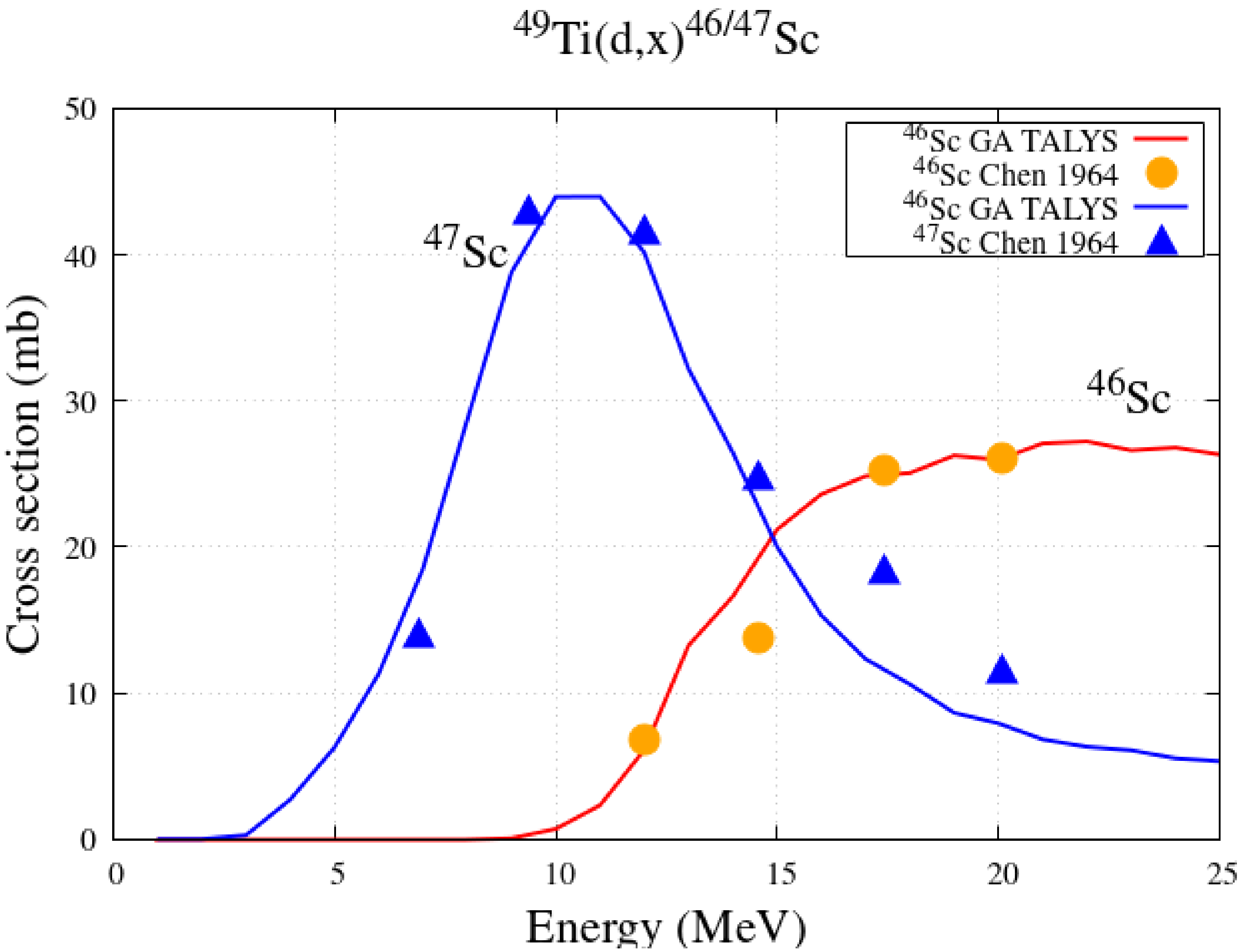


Model variability in TALYS



Promising route below 10 MeV

Optimization by genetic algorithms

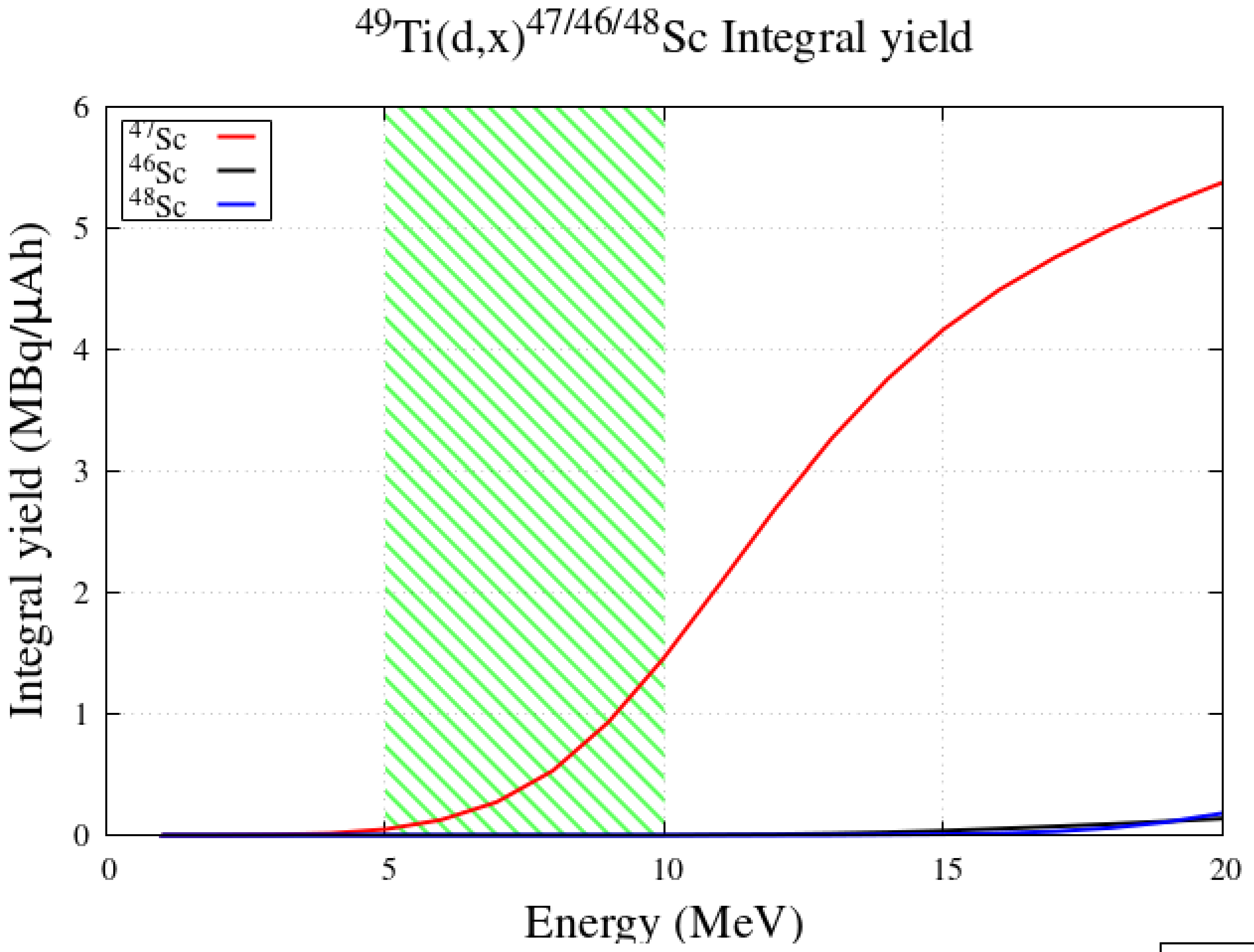


PE 3 – LD 6

^{46}Sc c = 1.573 MeV$^{-1/2}$, p = 0.390 MeV

^{47}Sc c = -0.029 MeV$^{-1/2}$, p = 1.327 MeV

Yield



Irradiation conditions

t_{irr} = 1 h

i = 1 μA

E_{max} = 10 MeV

E_{min} = 5 MeV

Yield (MBq/(μA·h))		
^{47}Sc	^{46}Sc	^{48}Sc
1.418	2.14E-04	0.0

Conclusions

arxiv.org/abs/2310.02825

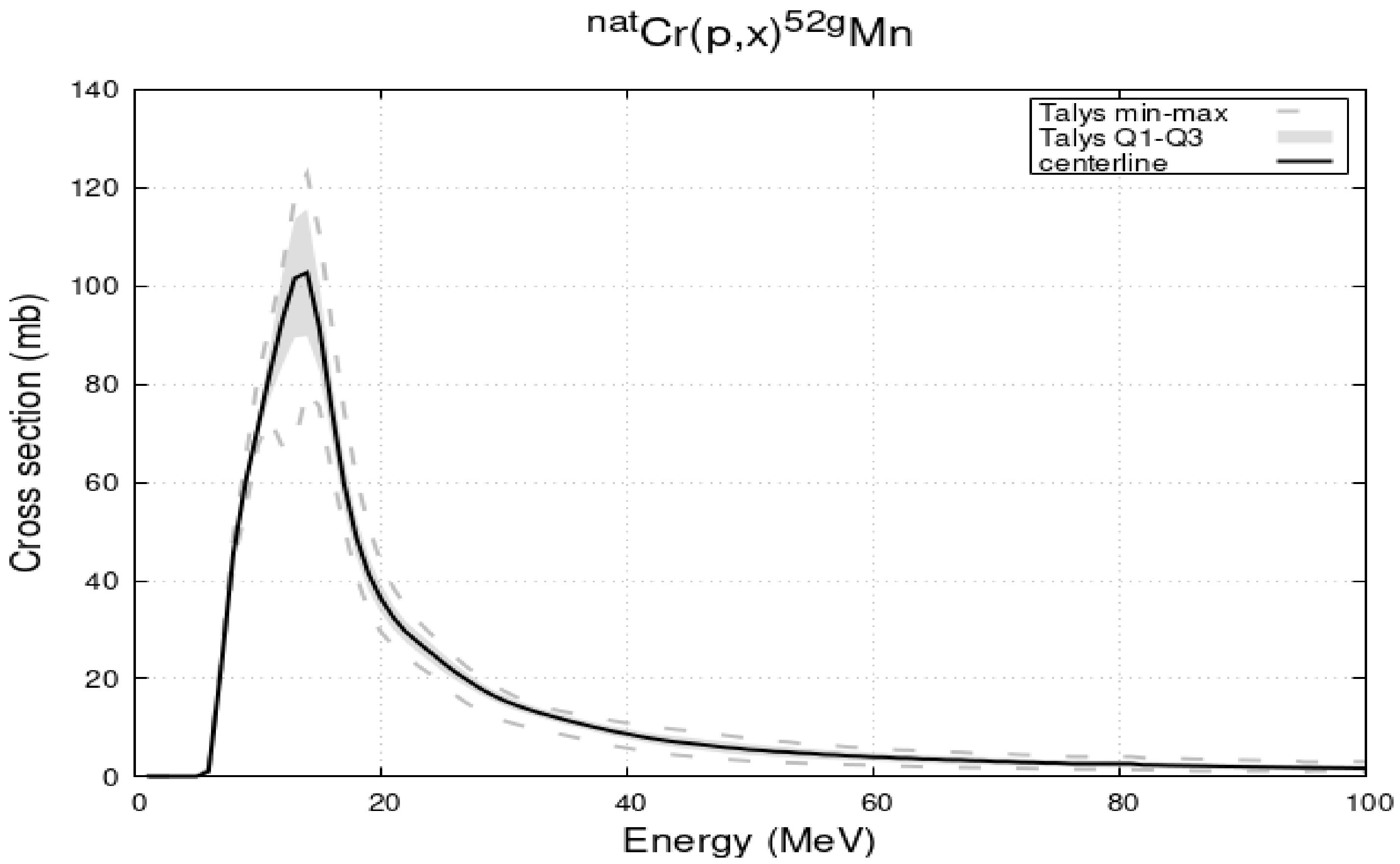
Both $^{50}Ti(p,\alpha)^{47}Sc$ and $^{49}Ti(d,\alpha)^{47}Sc$ are promising routes for hospital-cyclotron production

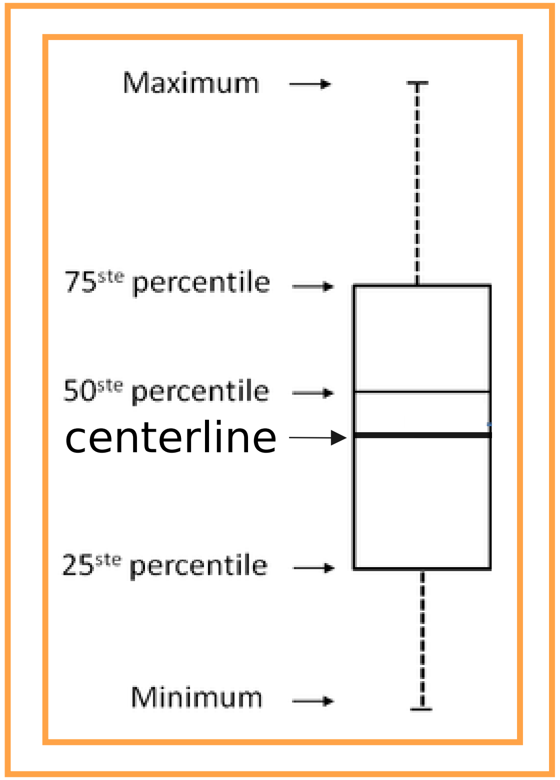
- ✓ High purity (RNP >99%)
- ✓ Yield 4.1 MBq/(μA·h) for $^{50}Ti(p,\alpha)$ @ 18 MeV
  1.4 MBq/(μA·h) for $^{49}Ti(d,\alpha)$ @ 10 MeV

$^{50}Ti(p,\alpha)$ → The new data by Dellepiane 2022 and the – still preliminary – confirmation 2023 by REMIX experiment (Pupillo, Mou, De Dominicis etc) changed dramatically the perspectives for this reaction, in positive!

$^{49}Ti(d,\alpha)$ → Promising but the 1964 data by Cheng need to be confirmed!

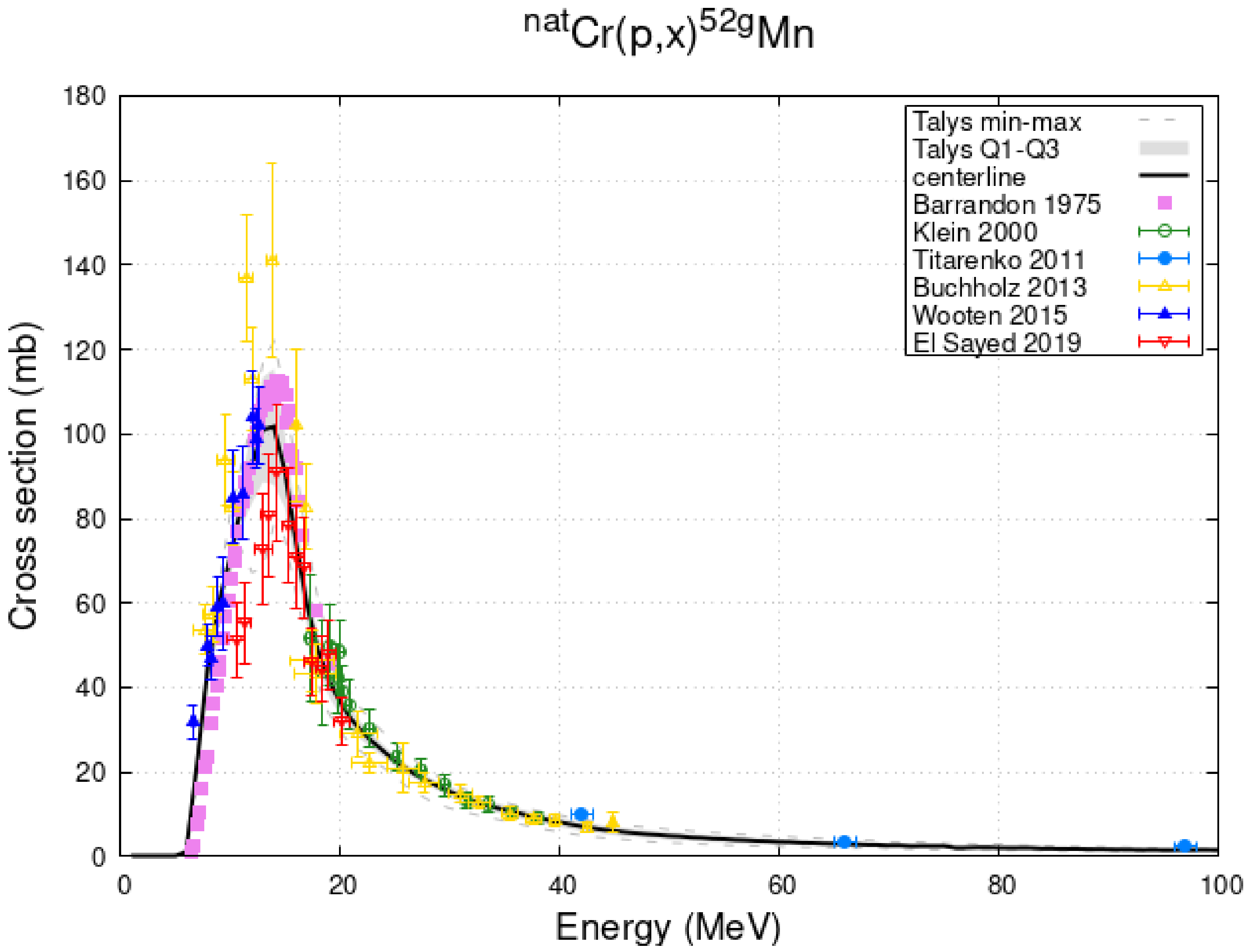
Representing the model variability of TALYS calculations

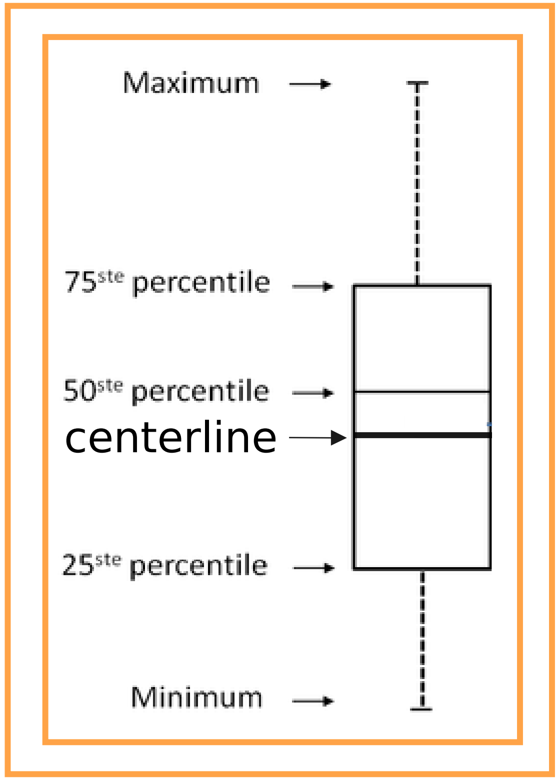




Box-Whisker Plot

Not always the model dispersion is large !





Box-Whisker Plot