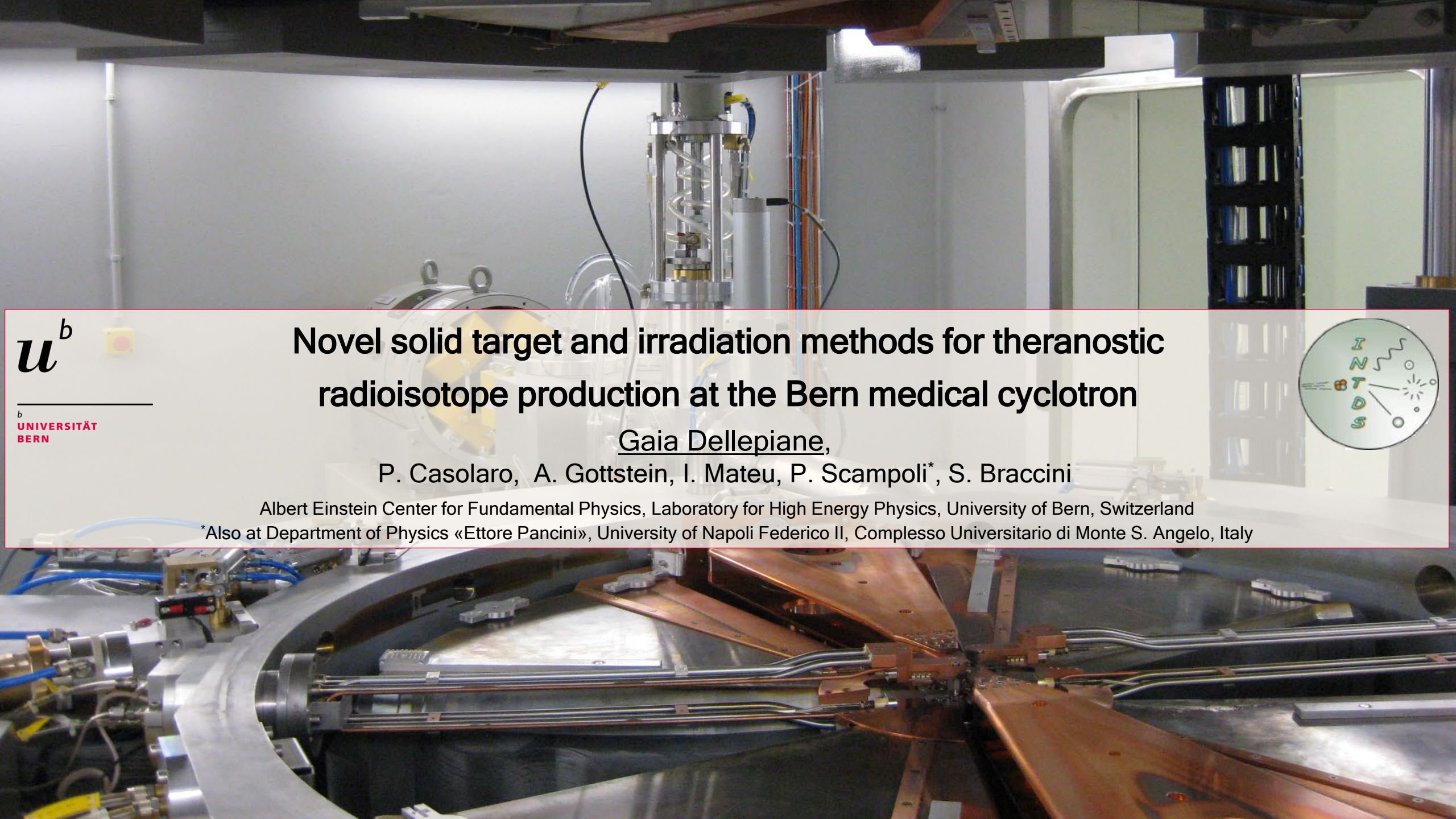

Novel solid target and irradiation methods for theranostic radioisotope production at the Bern medical cyclotron

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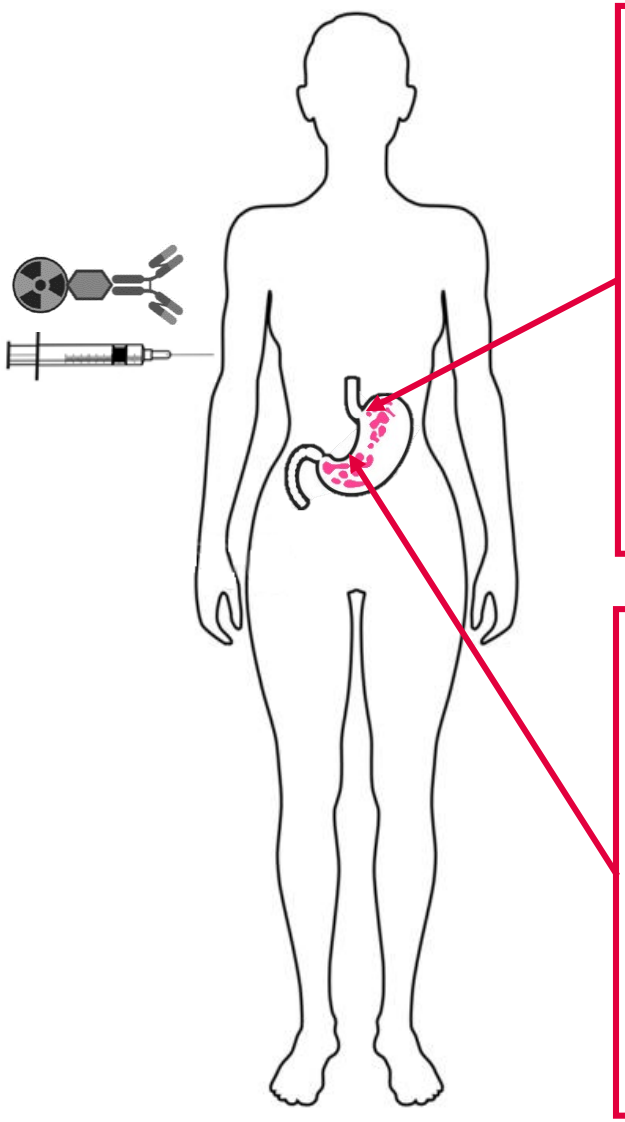
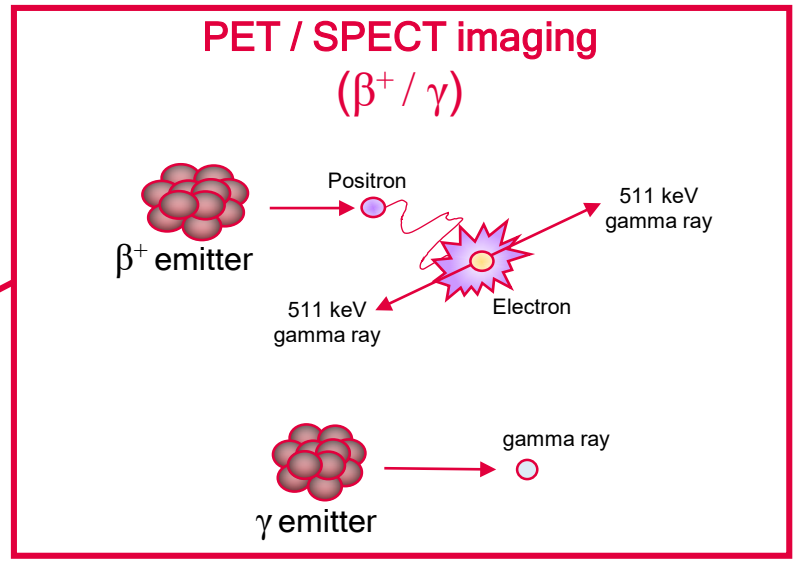
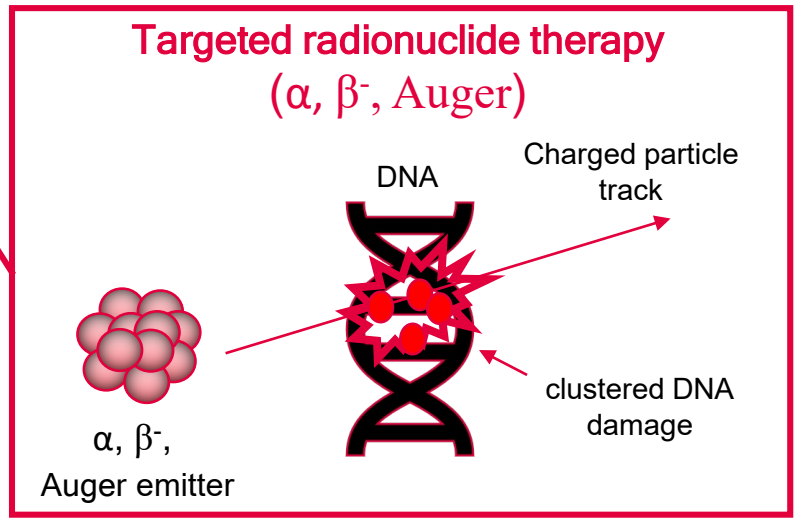
*Also at Department of Physics «Ettore Pancini», University of Napoli Federico II, Complesso Universitario di Monte S. Angelo, Italy

Theranostics in nuclear medicine







Promising theranostic pairs:

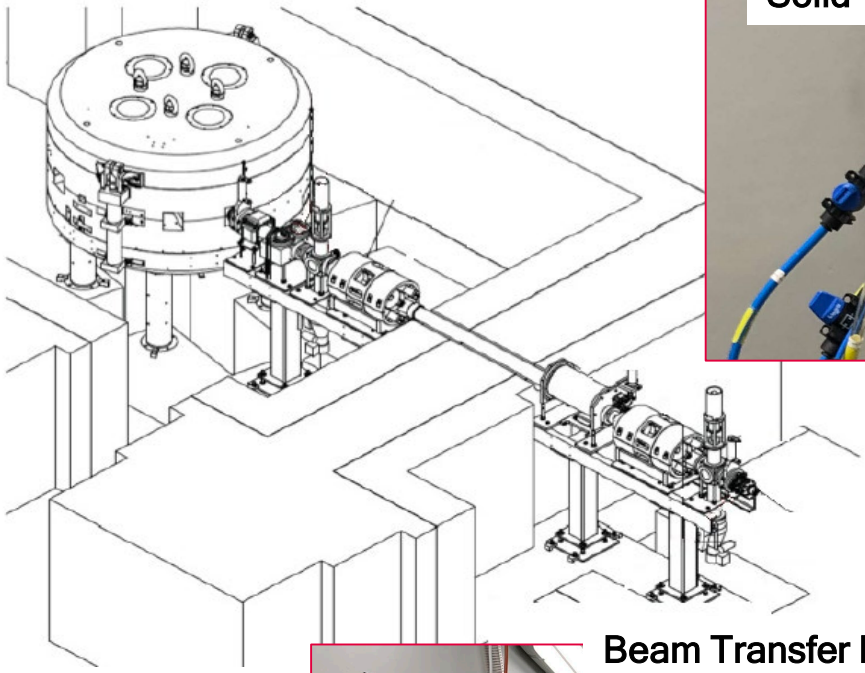
- ^{68}**Ga**/^{177}Lu and ^{68}**Ga**/^{225}Ac;
- ^{43}**Sc**/^{47}**Sc** and ^{44}**Sc**/^{47}**Sc**;
- ^{61}**Cu**/^{67}**Cu** and ^{64}**Cu**/^{67}**Cu**;
- ^{155}**Tb**/^{149}Tb and ^{155}**Tb**/^{161}Tb

Research program ongoing at the Bern cyclotron laboratory:

- Theranostic and non-standard radioisotope **production** with solid targets**;**
- **Accelerator** and **detector** physics developments;
- Proton **beam energy** measurement;
- Nuclear **cross-section** measurements.

The Bern medical cyclotron laboratory

18 MeV Bern medical cyclotron

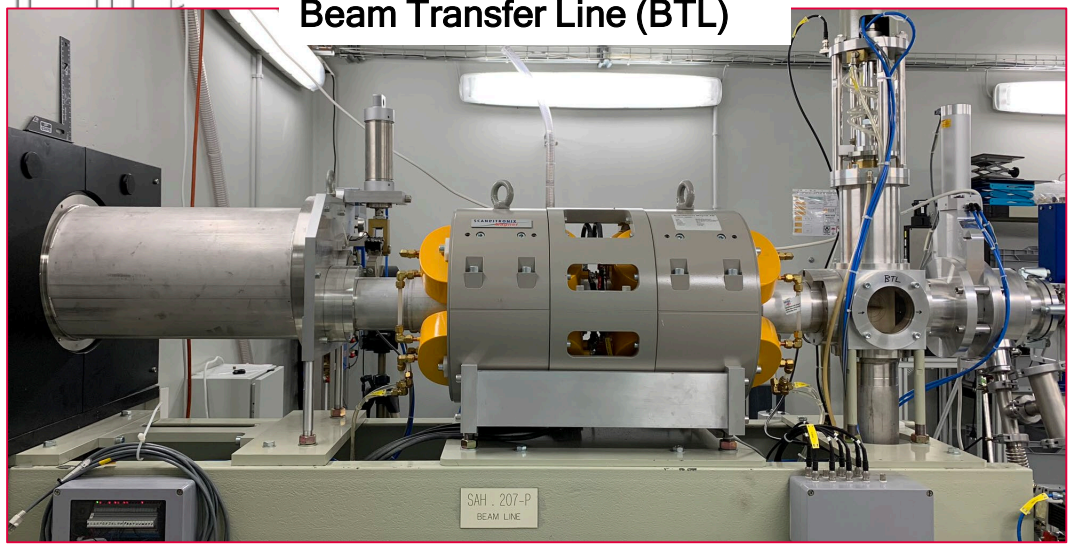


Solid Target Station (STS)

IBA 18/18 HC cyclotron

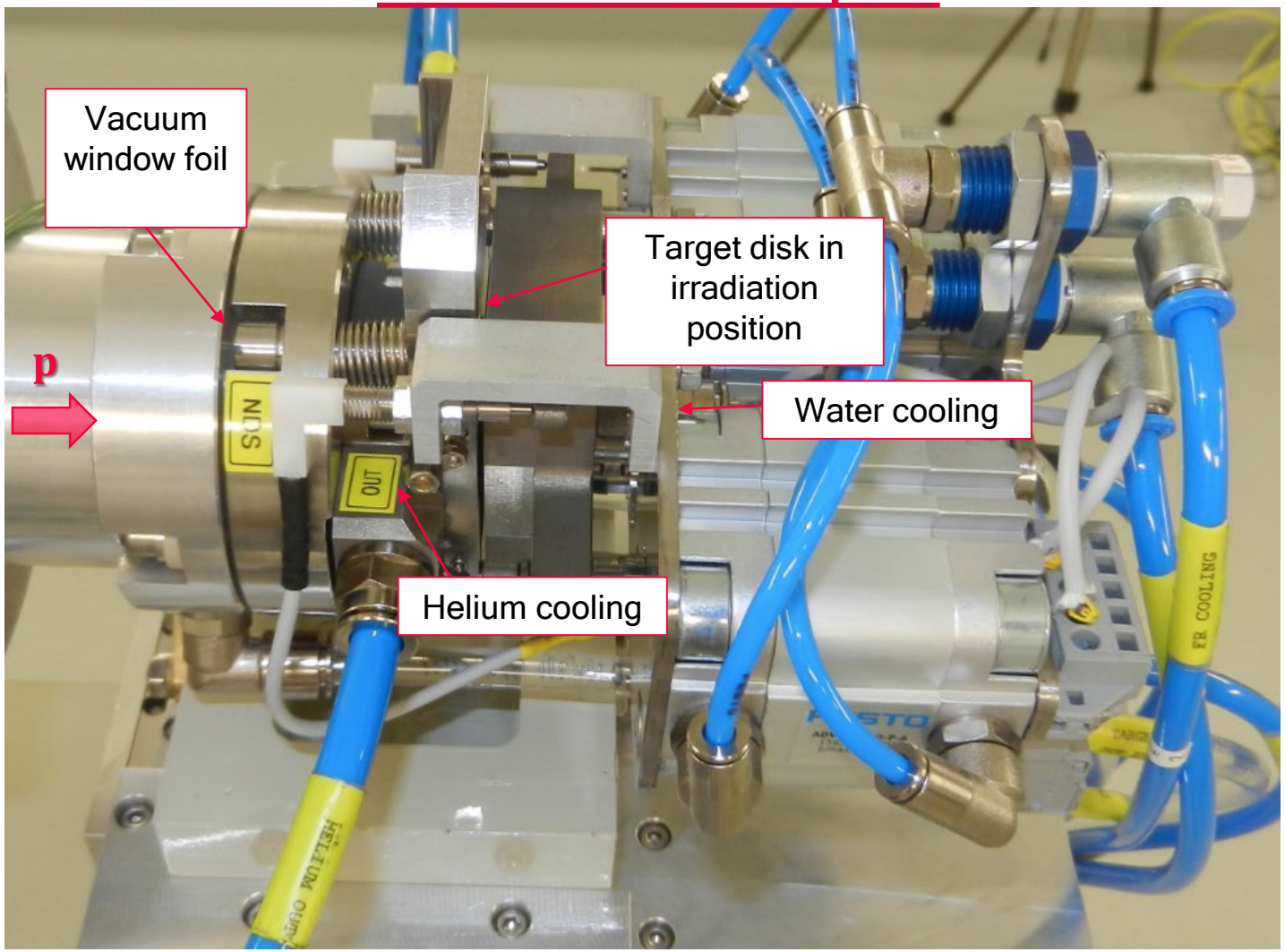
- Two H^- ion sources
- High current (max 150 μA)
- 8 out ports:
  - 6 ^{18}F liquid targets [industrial production]
  - **Solid Target Station (STS) [research]**
  - **Beam Transfer Line (BTL) [research]**

Beam Transfer Line (BTL)

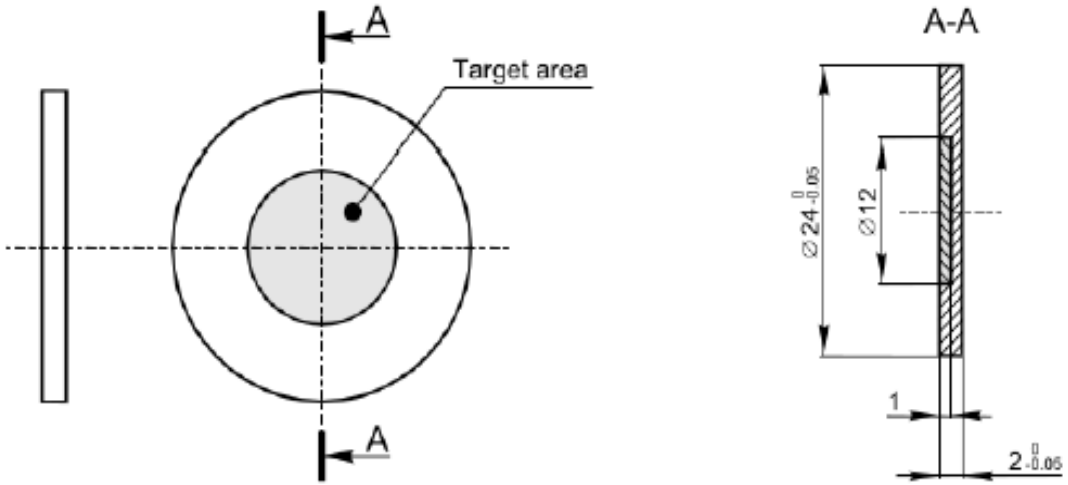


The Solid Target Station (STS)

IBA Nirta Solid Compact



Target disk



Solid targets

Solid foils

Pressed powder pellets

The Novel Coin Target by LHEP

Covering lid:
degradation of the impinging energy to the desired value

Containing cup:
complete stopping of the proton beam

The Solid Target Station (STS)

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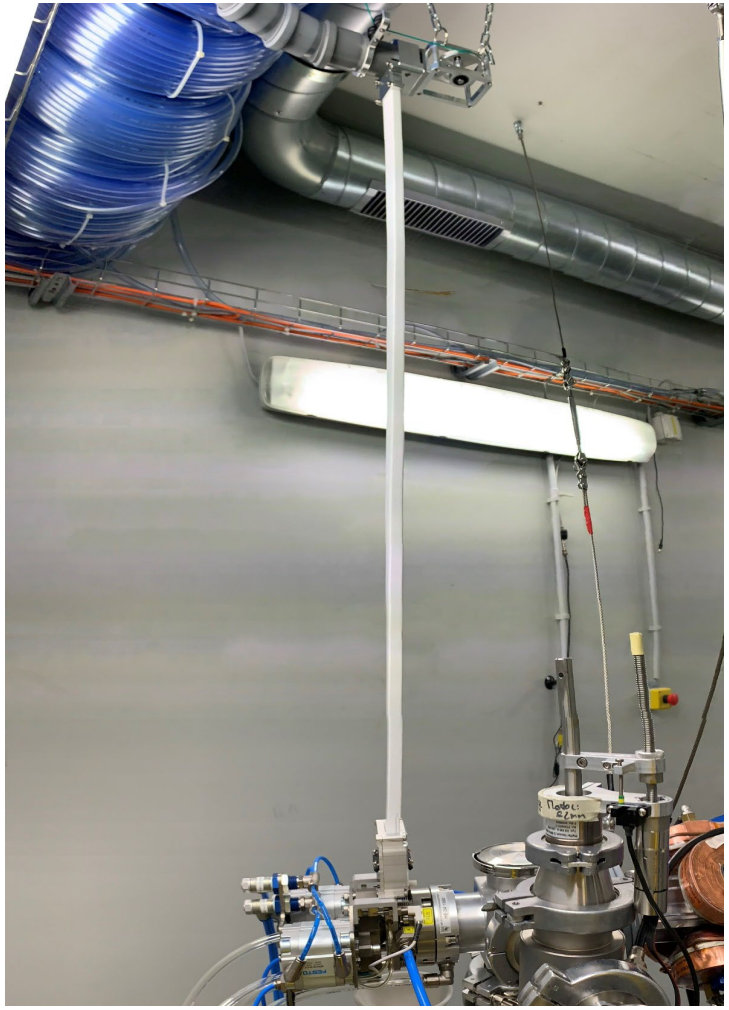
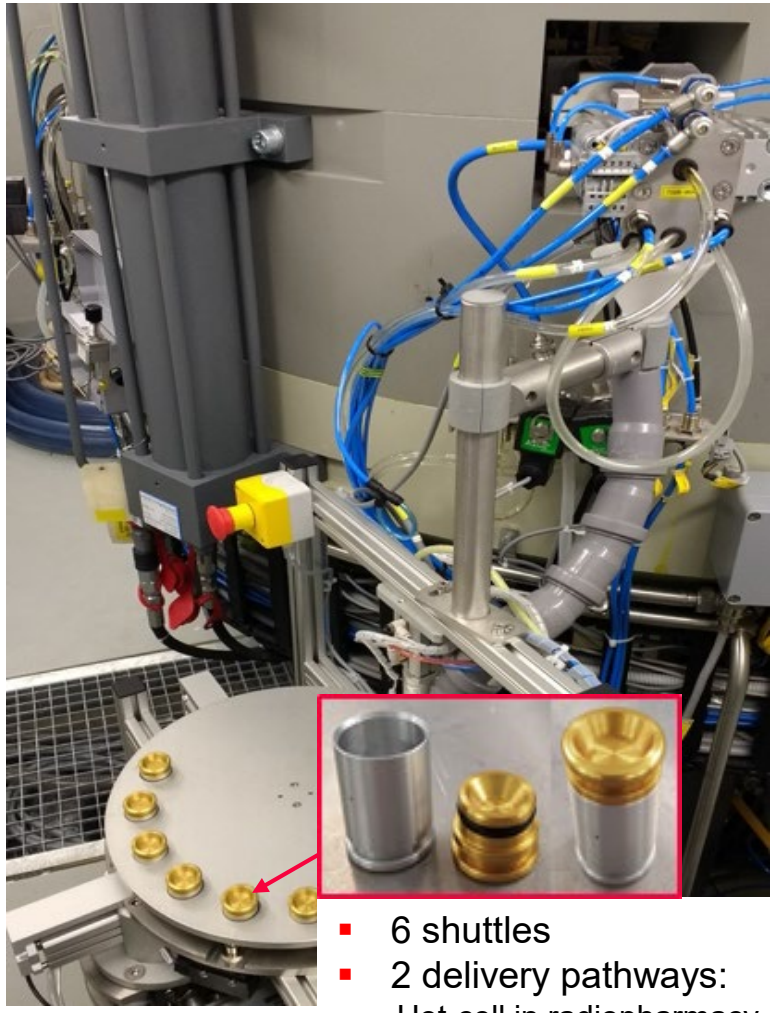
Hyperloop

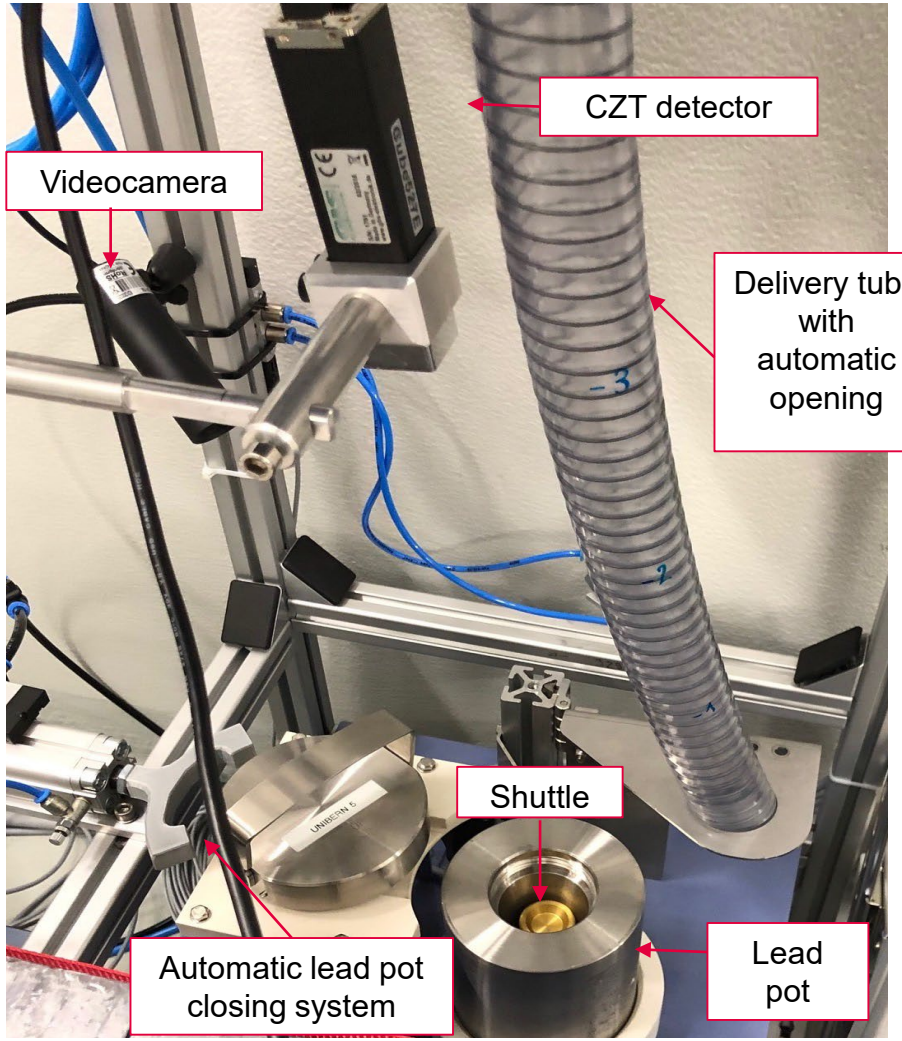


STTS by TEMA Sinergie

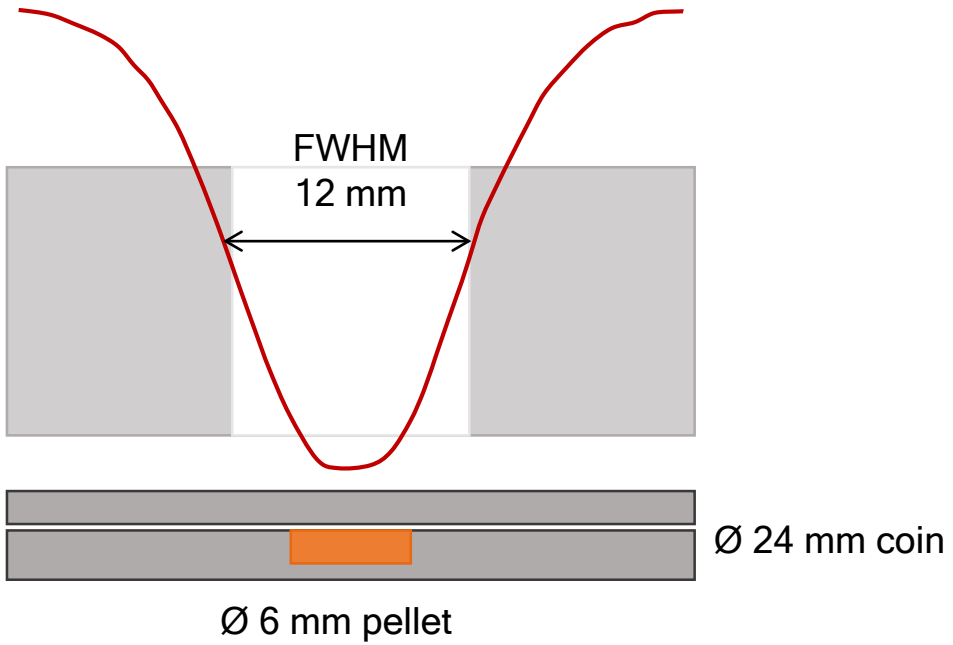


- 6 shuttles
- 2 delivery pathways:
  - Hot-cell in radiopharmacy
  - BTL bunker

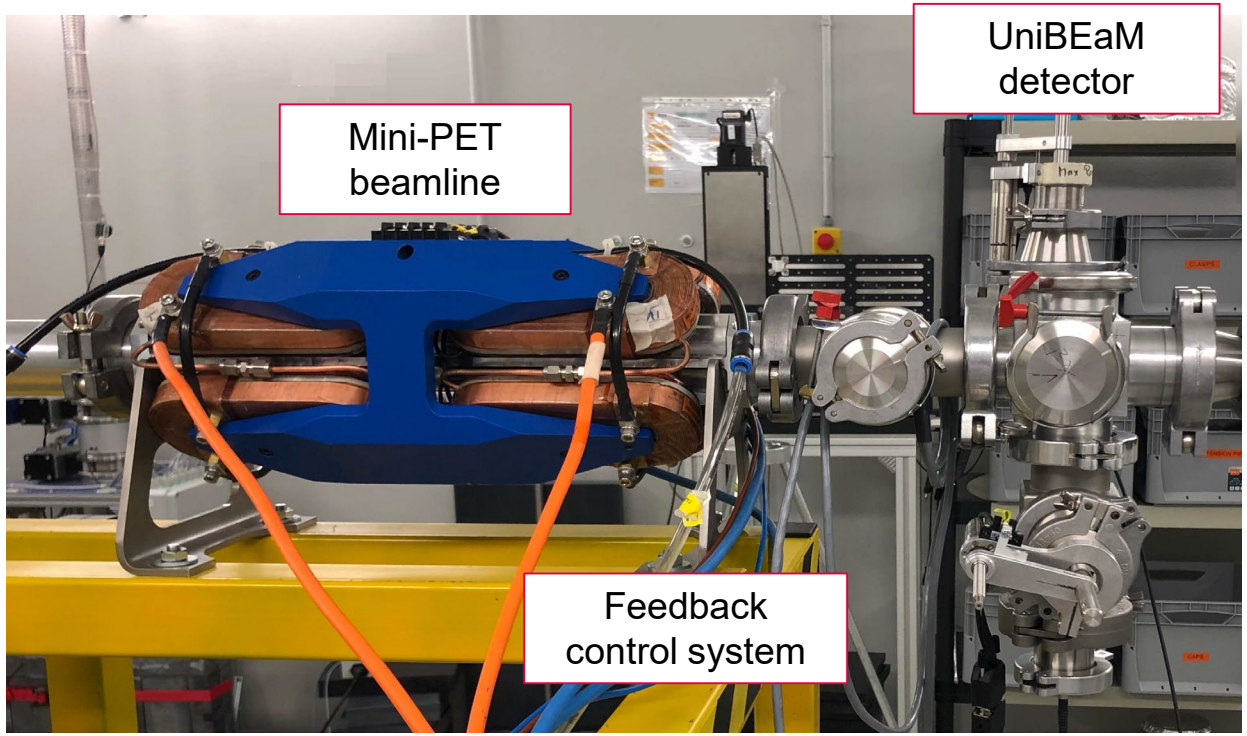
Receiving station in the BTL bunker

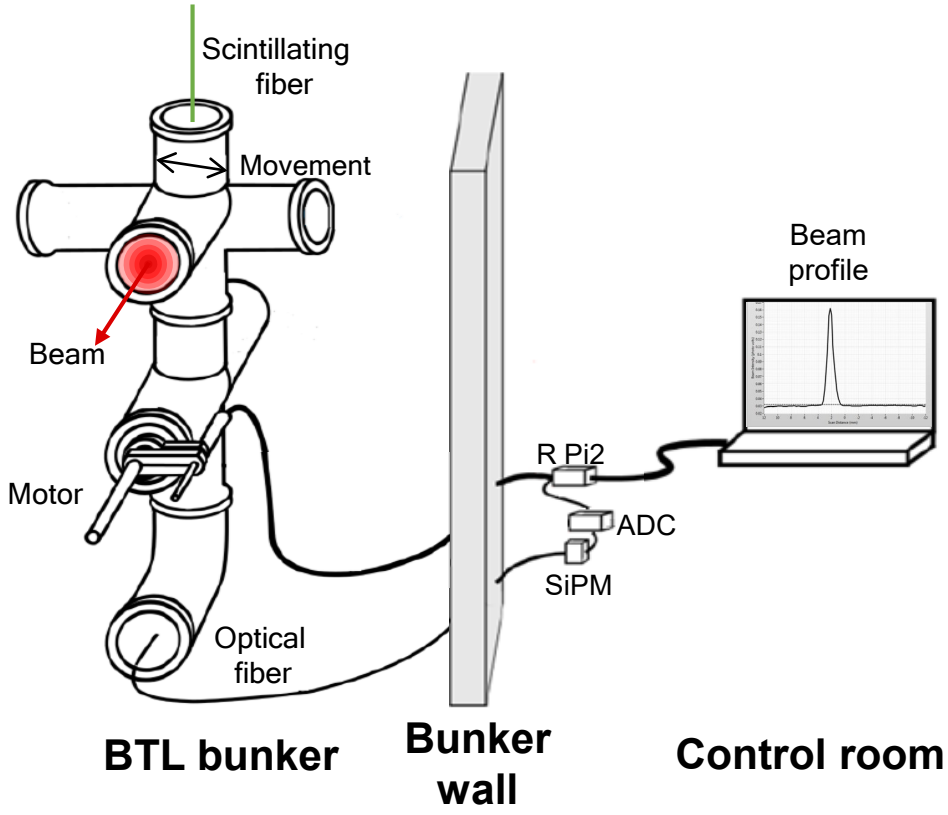


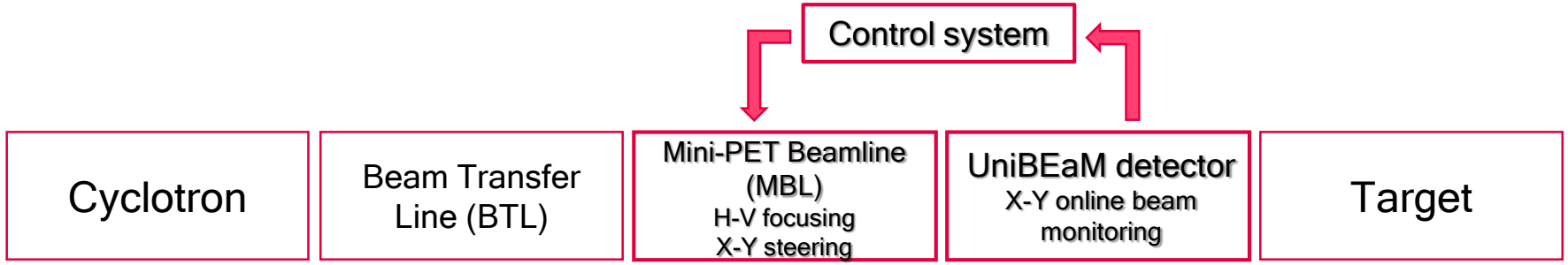
The Solid Target Station (STS)



The Automatic Focalization System (AFS)

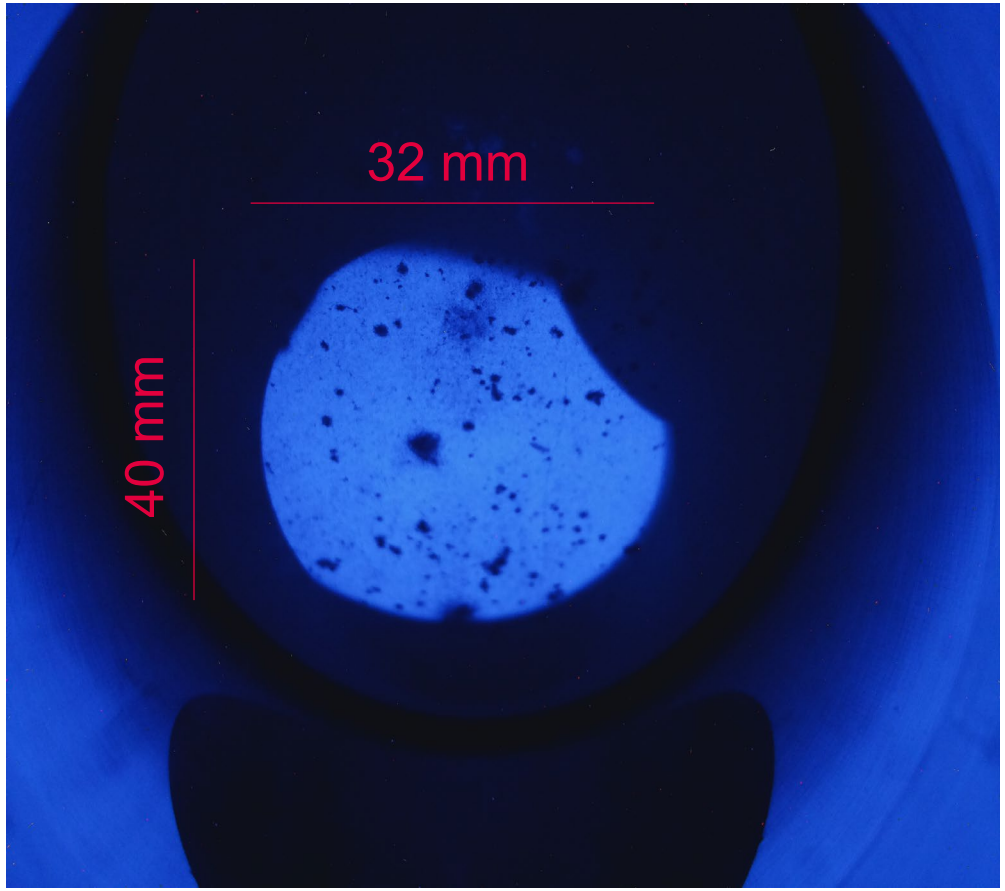




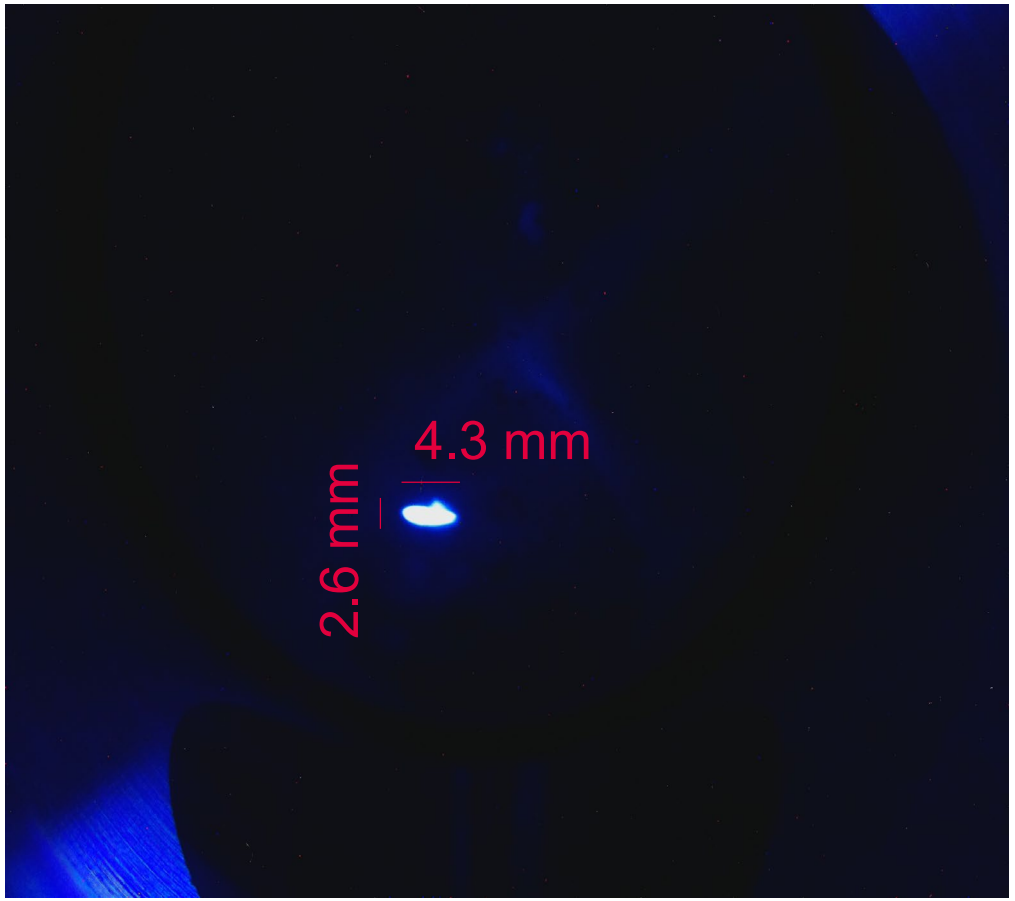


Tests in the BTL: focusing with the AFS

Before AFS

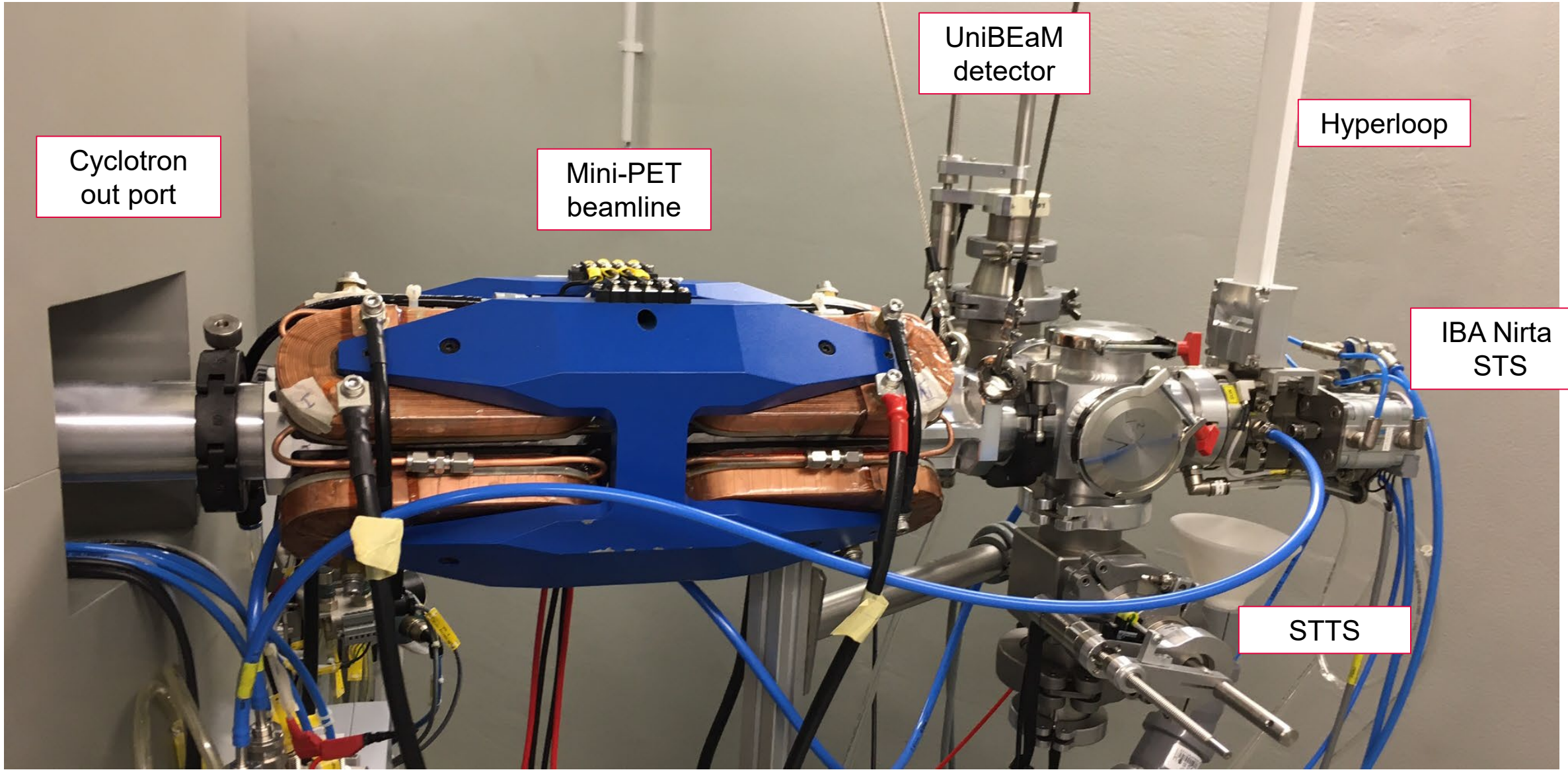


After AFS



P.D. Häffner et al, *Appl. Sci.* **2021**, *11(6)*, 2452

AFS system + STS



Beam energy measurement: special coin for the STS

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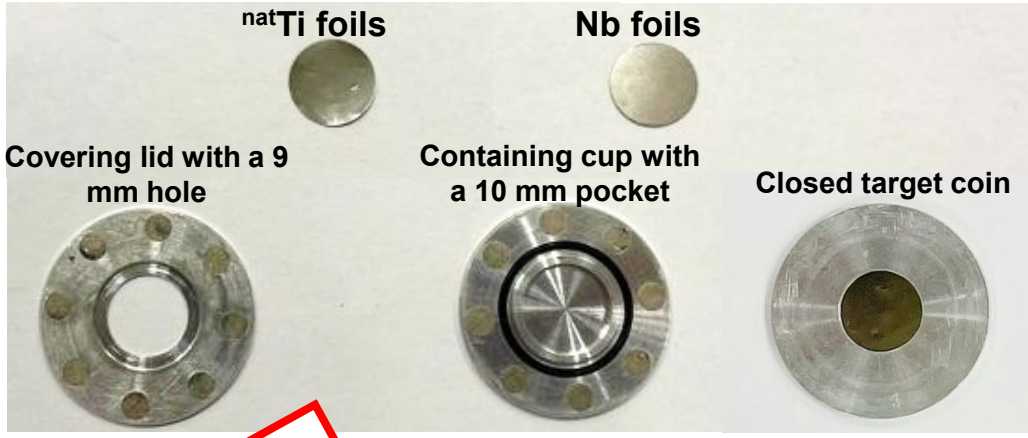
Monitor reaction

^{nat}Ti(p,X)^{48}V

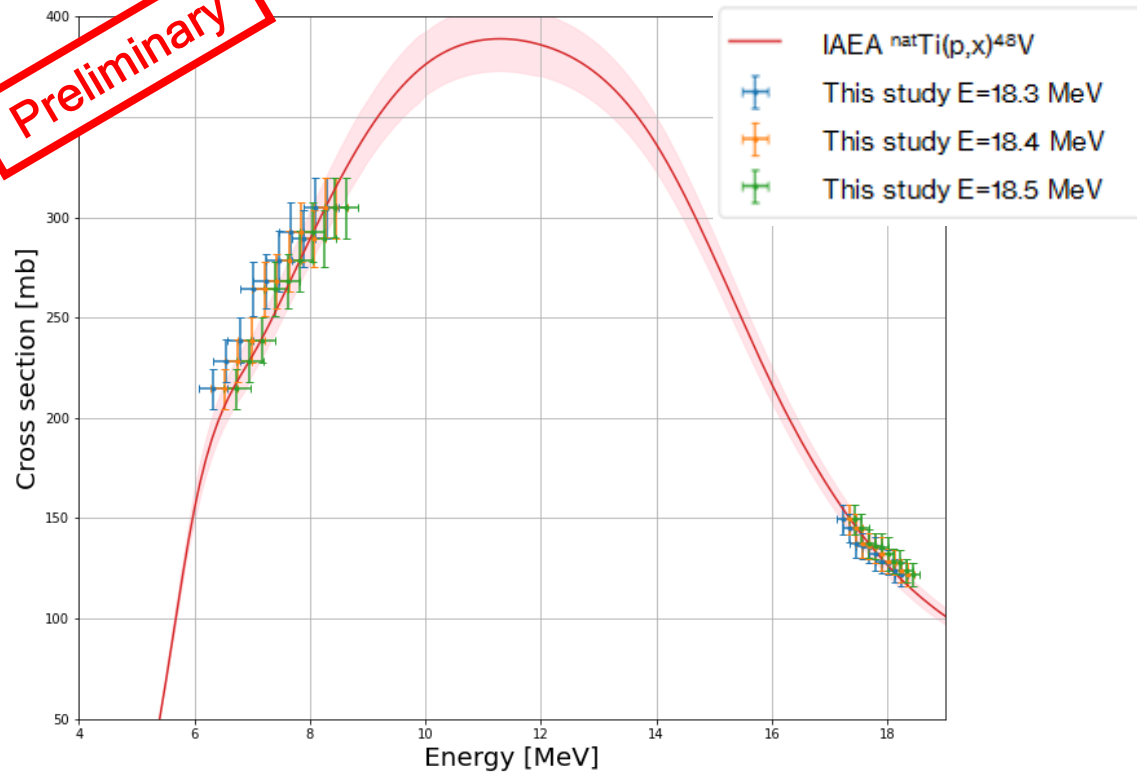
Titanium
10 × 12.5 µm

Niobium
4 × 125 µm

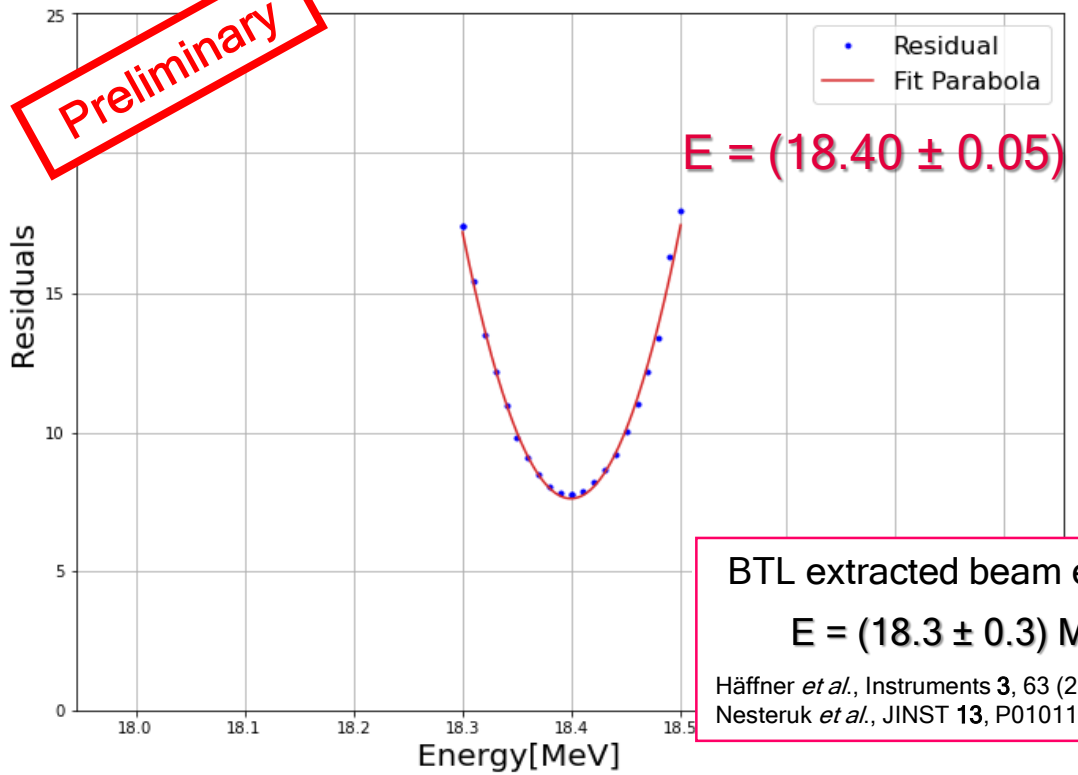
Titanium
10 × 12.5 µm



Preliminary



Preliminary



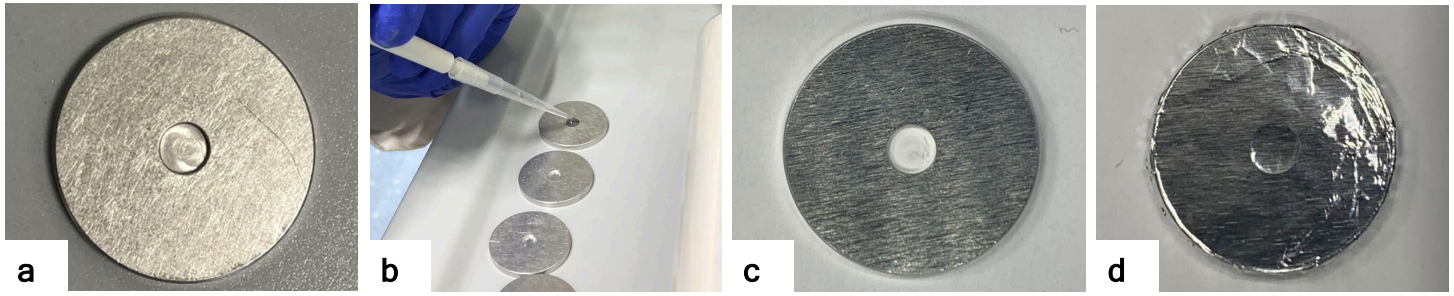
E = (18.40 ± 0.05) MeV

BTL extracted beam energy:

E = (18.3 ± 0.3) MeV

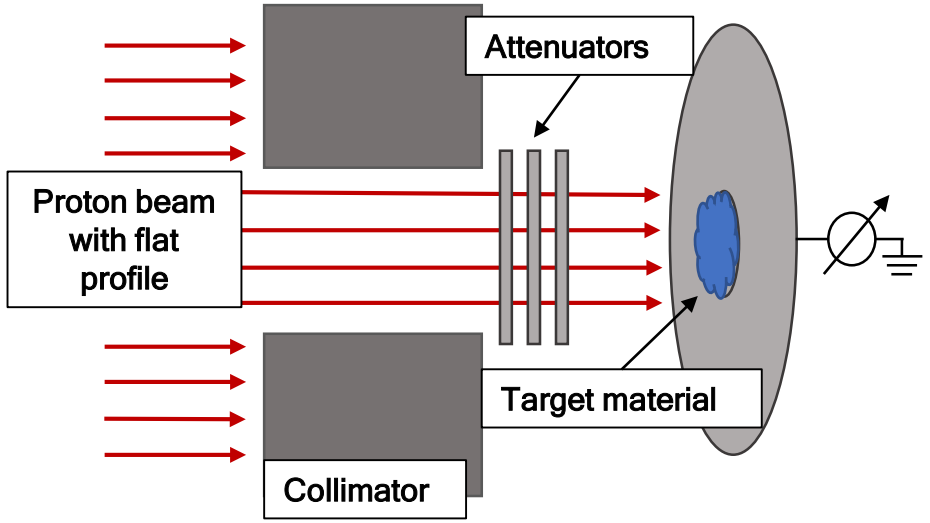
Häffner *et al.*, Instruments **3**, 63 (2019)
Nesteruk *et al.*, JINST **13**, P01011 (2018)

Cross-section measurements



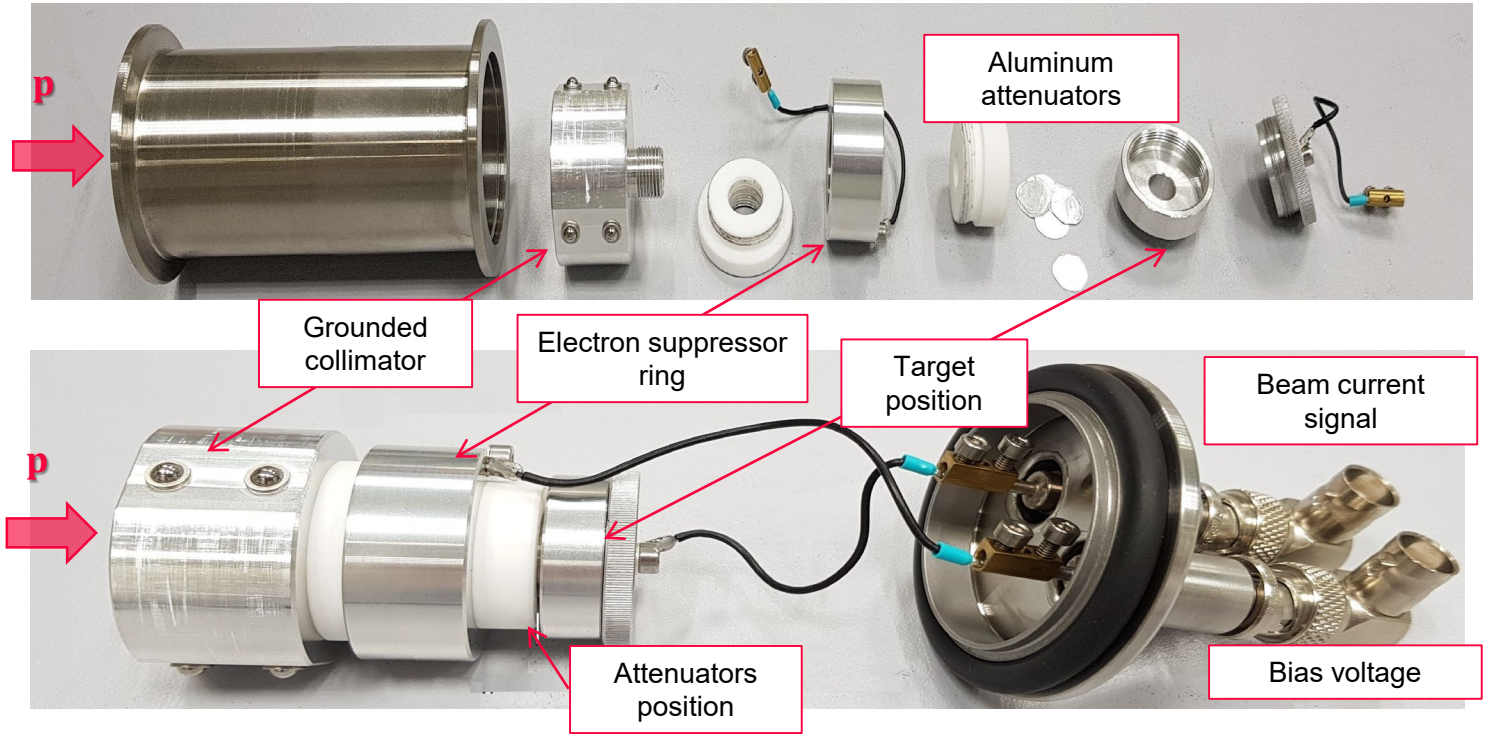
Target for cross section measurement: (a) empty aluminum disc (24 mm diameter, 2 mm thick); (b) deposition procedure; (c) pocket filled; (d) aluminum disc covered with a thin aluminum foil

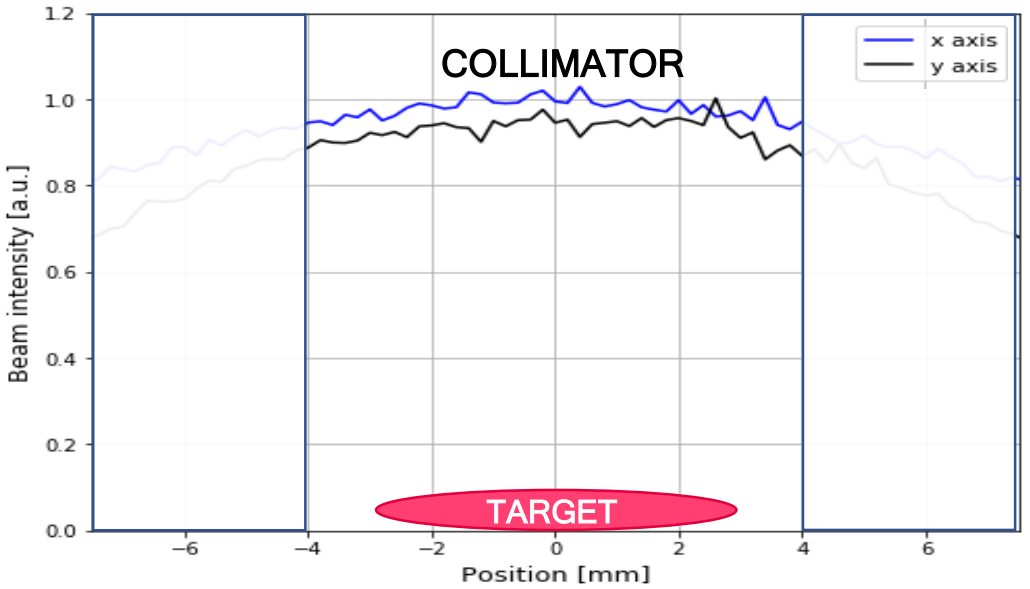
Flat beam procedure



Adapted from T.S. Carzaniga et al, *Appl. Radiat. Isot.* **2017**, *129, 96*

Cross section-measurements





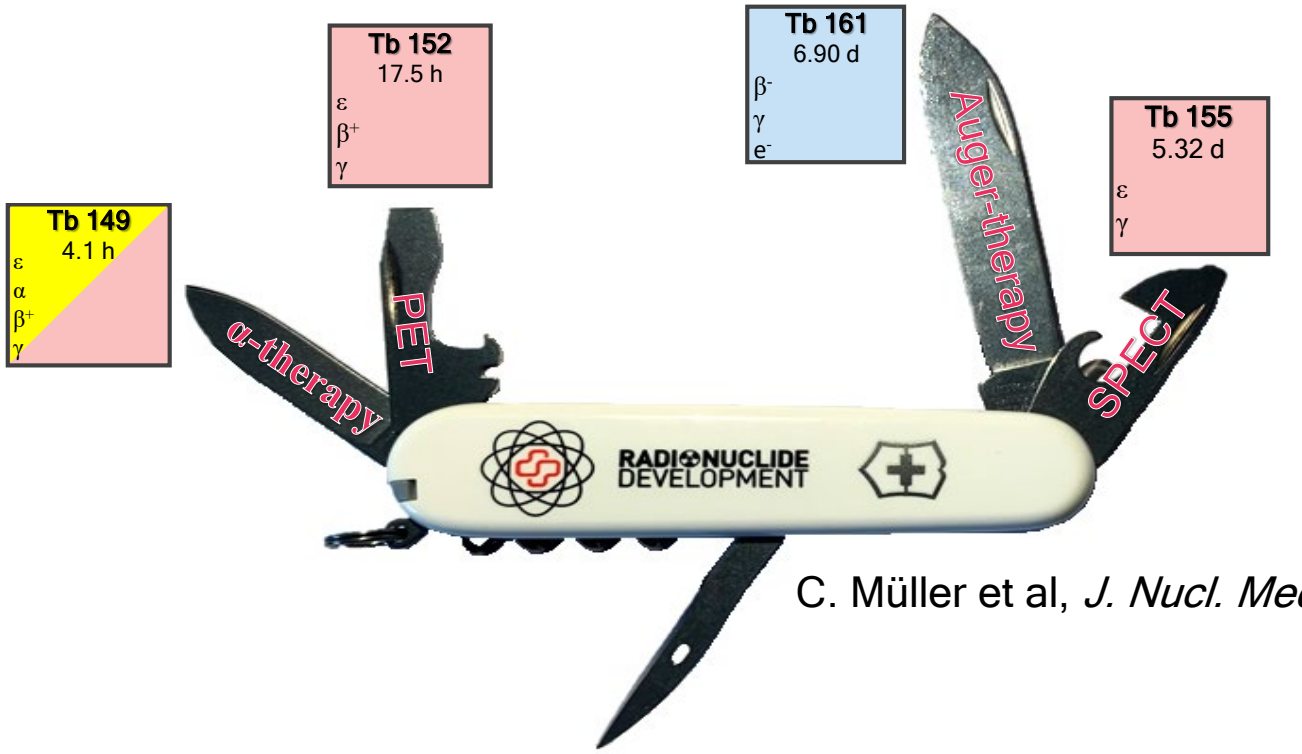
Measured cross sections:

^{43}Sc, ^{44}Sc, ^{47}Sc, ^{48}V, ^{61}Cu, ^{64}Cu, ^{67}Cu, ^{67}Ga, ^{68}Ga, ^{155}Tb, ^{165}Er, ^{165}Tm, ^{167}Tm

(and impurities)

Cross sections and radionuclidic purity: the case of ^{155}Tb

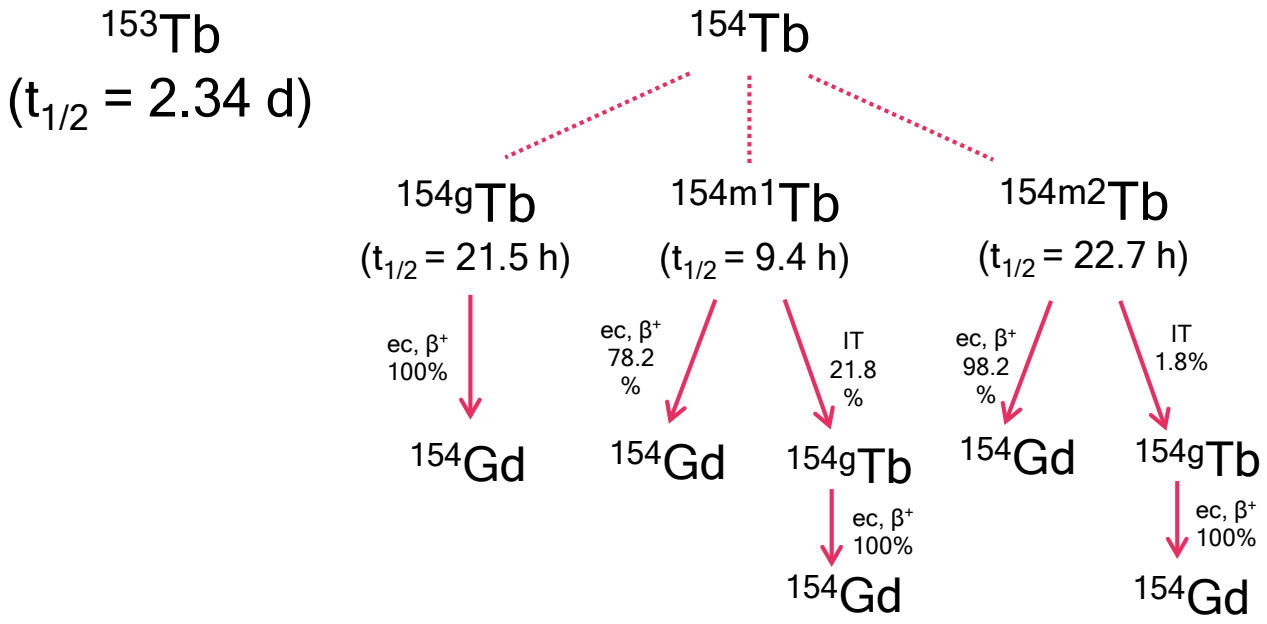
Terbium: the Swiss Army Knife

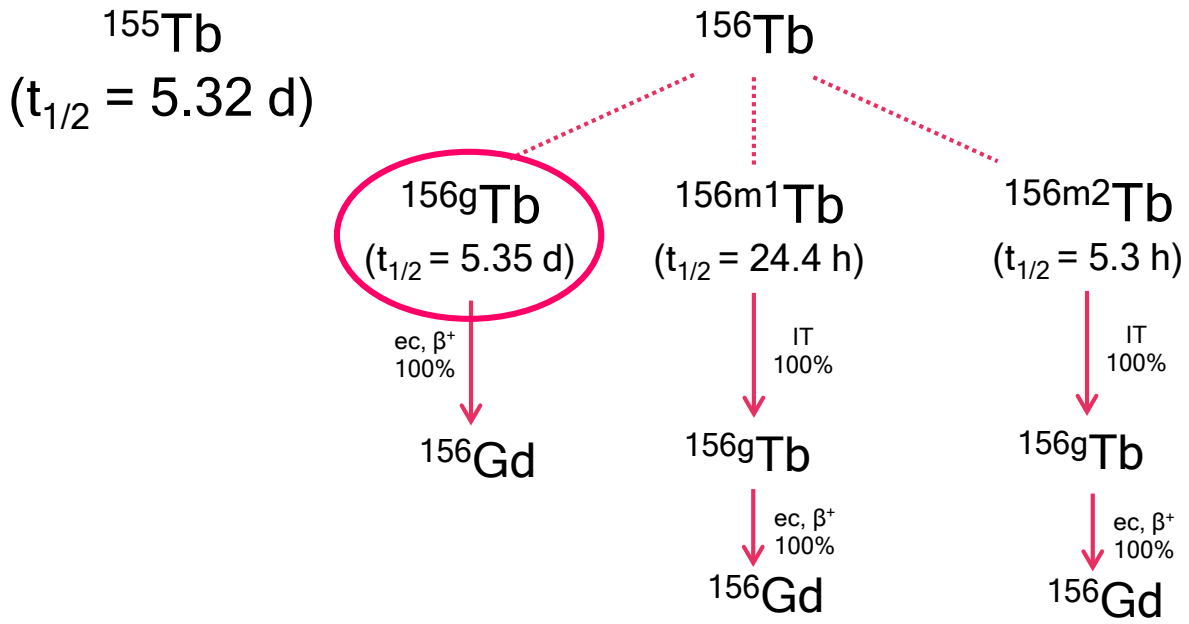


C. Müller et al, *J. Nucl. Med.*, **2012,** *53*, 1951

Cross sections and radionuclidic purity: the case of ^{155}Tb

	^{152}Gd	^{154}Gd	^{155}Gd	^{156}Gd	^{157}Gd	^{158}Gd	^{159}Gd
$^{156}Gd_2O_3$ [%]	<0.01	0.05	0.87	**93.30*(10)***	4.38	1.08	0.32

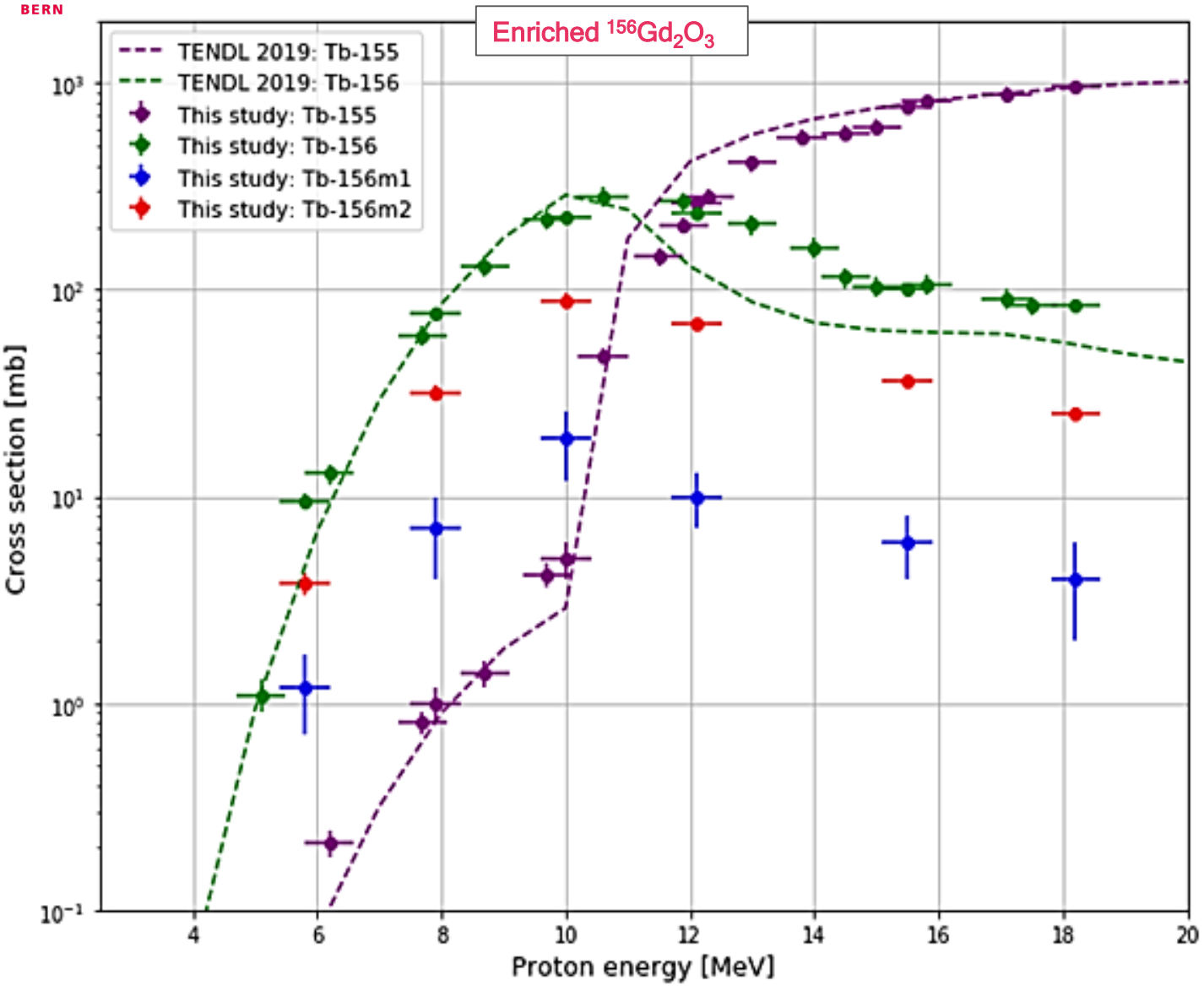




G. Dellepiane et al, *Appl. Radiat. Isot.* **2022**, *184,* 110175

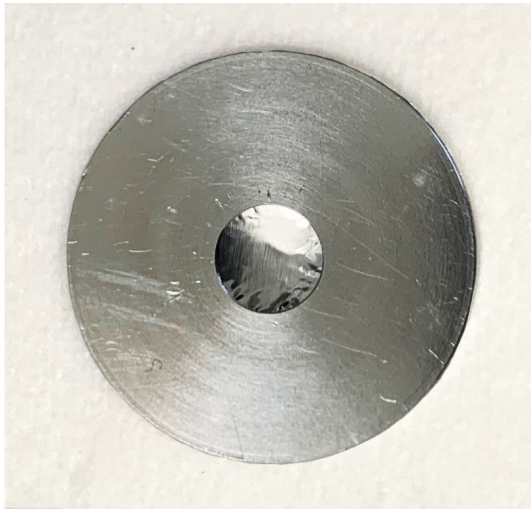
C. Favaretto et al, *EJNMMI radiopharm. chem.* **2021**, *6,* 37

Cross sections and radionuclidic purity: the case of ^{155}Tb



Covering lid

Containing cup



Closed coin

First results in radioisotope production

Radiosotope	Reaction	Target material	Mass [mg]	Y [GBq/μAh]
^{44}Sc[1,2]	(p,n)	enr-^{44}CaO pellet	~30	0.6
^{47}Sc[3]	(p,α)	enr-^{50}Ti pellet	~35	0.001
^{61}Cu[4]	(p,α)	enr-^{64}Zn pellet	~40	0.08
^{64}Cu[5]	(p,n)	enr-^{64}Ni deposition	~63	0.13
	(p,α)	enr-^{67}Zn pellet	~59	0.016
^{67}Cu	(p,α)	enr-^{70}Zn pellet	~34	0.001
^{68}Ga[6]	(p,n)	enr-^{68}Zn pellet	~100	6
^{155}Tb[7,8]	(p,n)	enr-$^{155}Gd_2O_3$ pellet	~40	0.004
	(p,2n)	enr-$^{156}Gd_2O_3$ pellet	~40	0.014
^{165}Er	(p,n)	^{nat}Ho metal disk	~24	0.015
^{165}Tm	(p,2n)	enr-$^{166}Er_2O_3$ pellet	~59	0.07
^{167}Tm	(p,n)	enr-$^{167}Er_2O_3$ pellet	~38	0.002

(1) N. P. van der Meulen et al., *Molecules* **2020**, 25(20), 4706.
(2) T. S. Carzaniga et al, *Appl. Radiat. Isot.* **2019**, *143,* 18-23.
(3) G. Dellepiane et al, *Appl. Radiat. Isot* ***2022,*** *189*, 110428.
(4) G. Dellepiane et al, *Appl. Radiat. Isot* ***2022,*** *190, 110466..*
(5) G. Dellepiane et al, Under review at *Appl. Radiat Isot* ***2022.***
(6) S. Braccini et al, *Appl. Radiat. Isot.* **2022**, *186,* 110252.
(7) G. Dellepiane et al, *Appl. Radiat. Isot.* **2022**, *184,* 110175.
(8) C. Favaretto et al, *EJNMMI radiopharm. chem.* **2021**, *6,* 37.

Conclusions and outlook

- Compact medical cyclotrons: tools of choice for radioisotope production in a hospital-based environment

- New instruments and methods to optimise radioisotope production:
  - Beam monitoring detectors
  - Novel target coin to irradiate solid materials
  - Cross-section measurement procedure
  - Beam energy measurement procedure

- First promising results on

  ^{43}Sc, ^{44}Sc, ^{47}Sc, ^{61}Cu, ^{64}Cu, ^{67}Cu, ^{68}Ga, ^{155}Tb, ^{165}Er, ^{165}Tm, ^{167}Tm

- Development and testing of a novel compact Automatic Focalization System

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Thank you all for your attention!

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