Accelerator and Detector Developments for the Production of Theranostic Radioisotopes with Solid Targets at the Bern Medical Cyclotron

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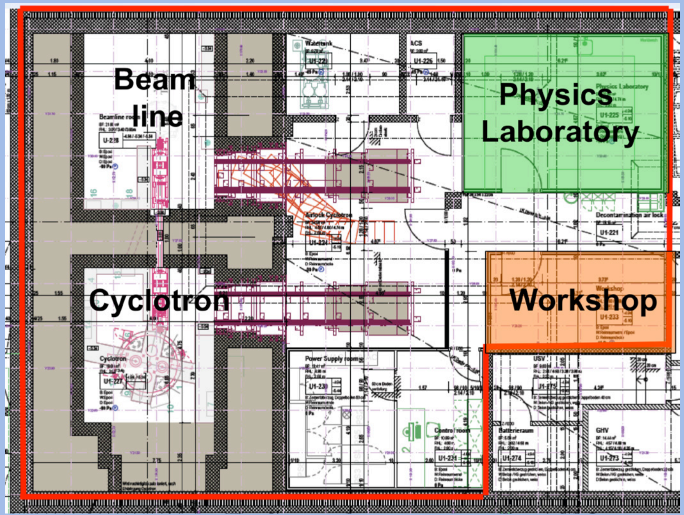
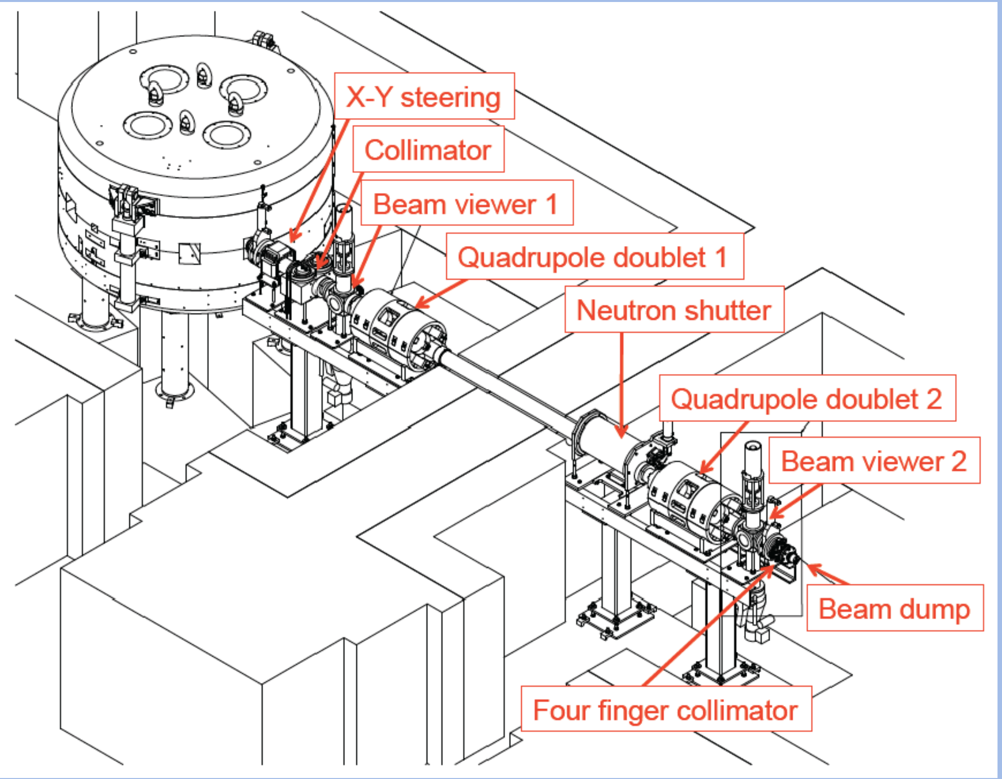
The Bern Medical Cyclotron and its Beam Transport Line (BTL)



- IBA 18 MeV high current cyclotron (up to 150 mA) – two H^- ion sources
- **6 ^{18}F liquid targets for daily production** swan ISOTOPEN
- **External beam line in a separate bunker + solid target station: research**
- Specific method to produce currents down to 1 pA.*

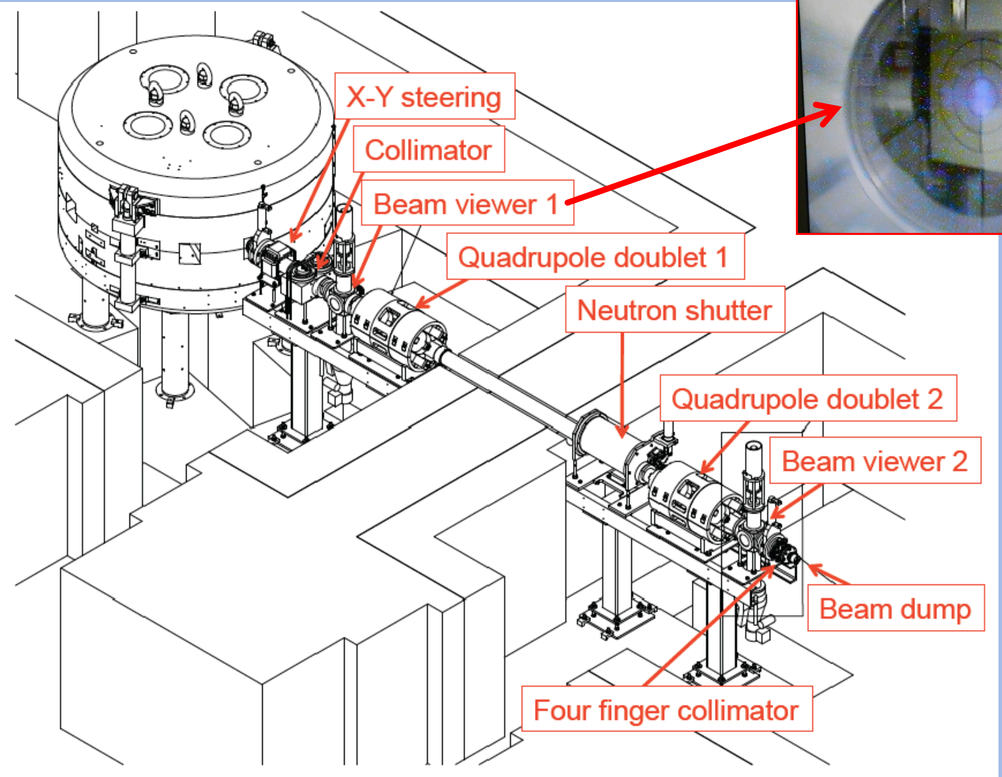
* M. Auger et al., Meas. Sci. Technol. 26 (2015) 094006

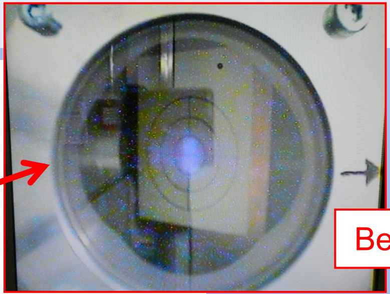
Multidisciplinary Research Activities with the BTL



Source: S. Braccini, *AIP Conf. Proc.* vol. 1525, p. 144, 2013

Multidisciplinary Research Activities with the BTL

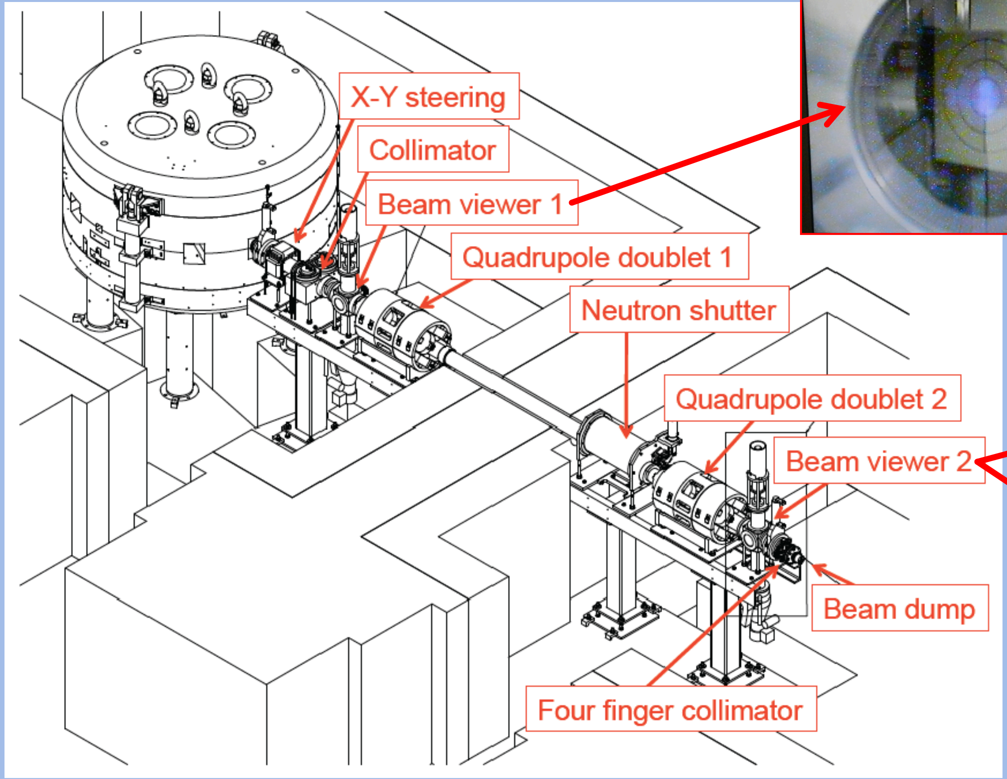


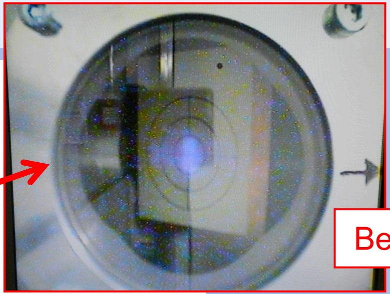


Beam from cyclotron

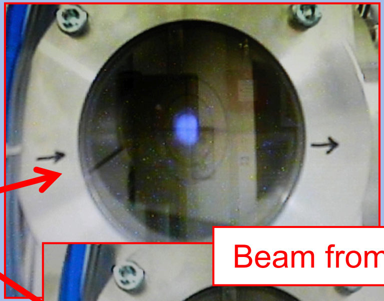
Source: S. Braccini, *AIP Conf. Proc.* vol. 1525, p. 144, 2013

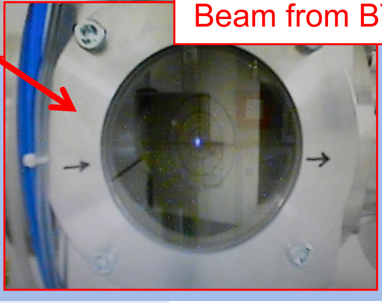
Multidisciplinary Research Activities with the BTL





Beam from cyclotron





Beam from BTL

Source: S. Braccini, *AIP Conf. Proc.* vol. 1525, p. 144, 2013

PET Radioisotope Production

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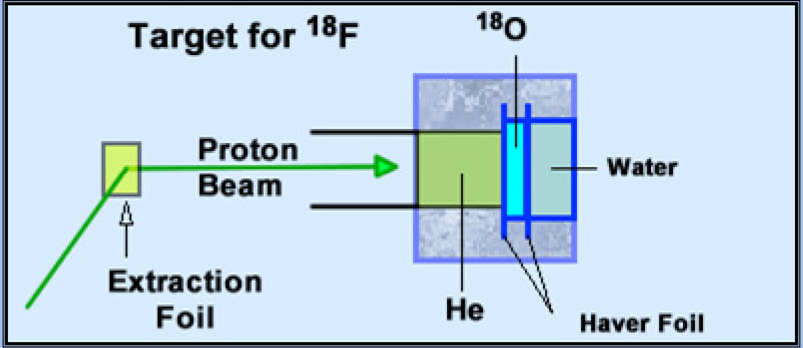
- Main PET radioisotope: **^{18}F** ($t_{1/2} \approx$ 110 min.)



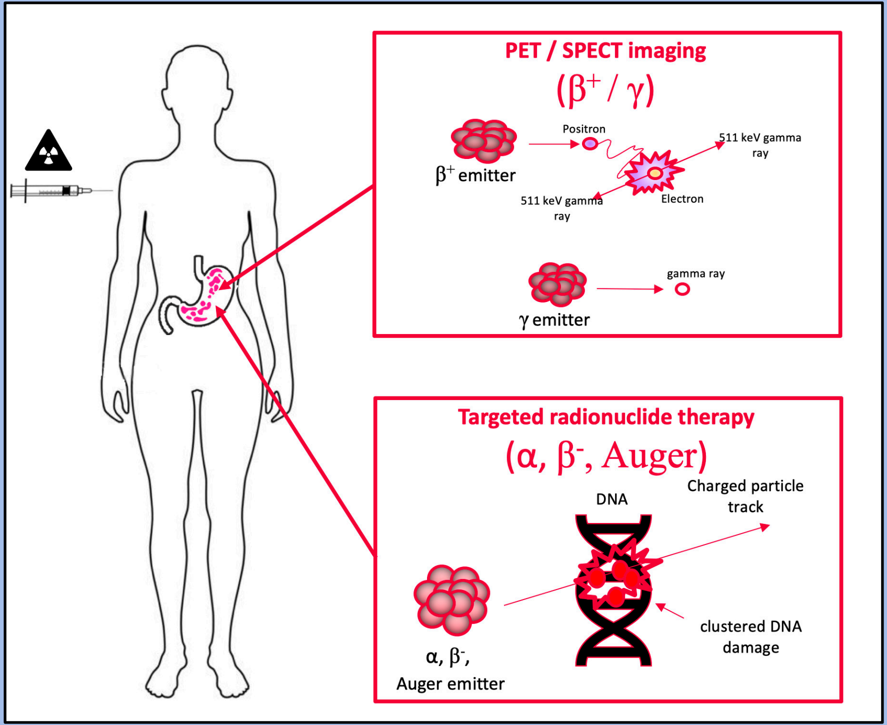
^{18}O (p,n) ^{18}F

Liquid targets:

- ~ 1 g
- ~ 10 mm diameter
- Beam: 12 mm FWHM

- Emerging PET radioisotope: **^{68}Ga**
- Targets: liquid (common), gas and solid (rare)
- Liquid targets are mounted directly after beam extraction
- ^{18}F production: 500 GBq in 2 hours (~150 mA)
- Beam optimization is crucial!

Radionuclides for Theranostics in Nuclear Medicine



> Promising pairs of radionuclides:

> **^{68}Ga**/^{177}Lu and **^{68}Ga/^{225}Ac**

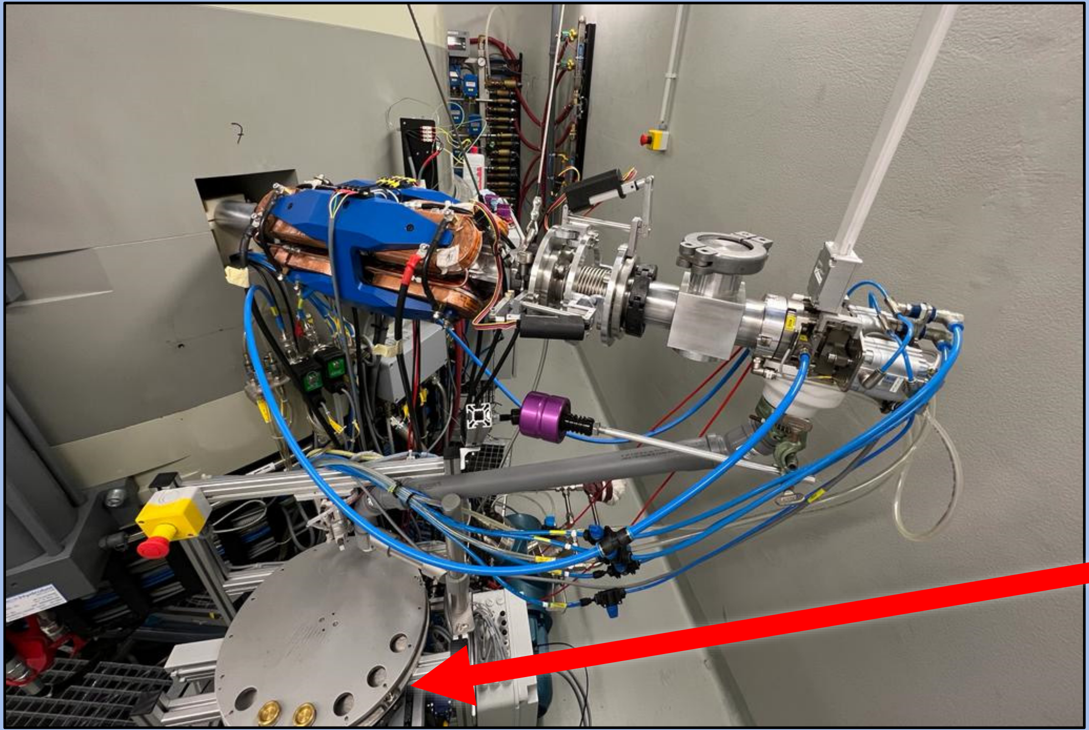
> **^{43}Sc/^{47}Sc** and **^{44}Sc/^{47}Sc**

> **^{61}Cu/^{67}Cu** and **^{64}Cu/^{67}Cu**

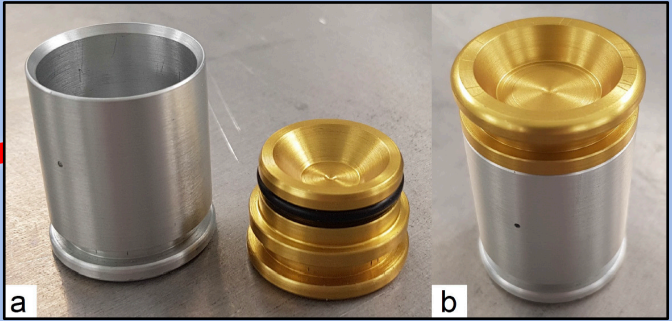
> **^{155}Tb**/^{149}Tb and **^{155}Tb**/^{161}Tb

Solid targets:
- ~ 10 mg
- ~ 5 mm diameter
- Material: powder
- Beam: ???

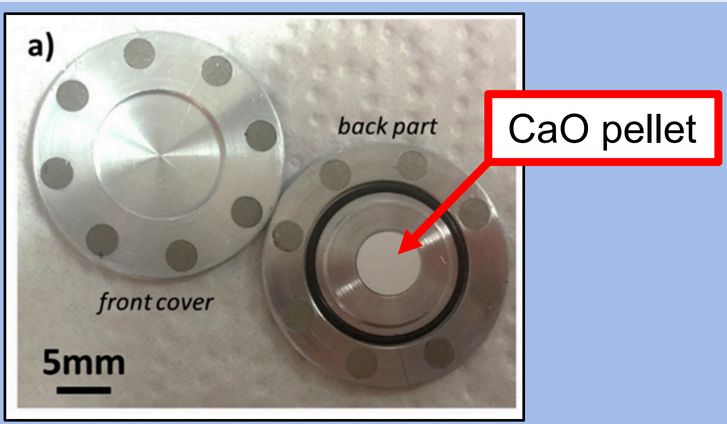
The Solid Target Station (STS)



- IBA *Nirta* Solid Target Station
- Custom mechanical target transfer system (*Hyperloop*)
- Pneumatic Transfer System (TEMA) using shuttles:

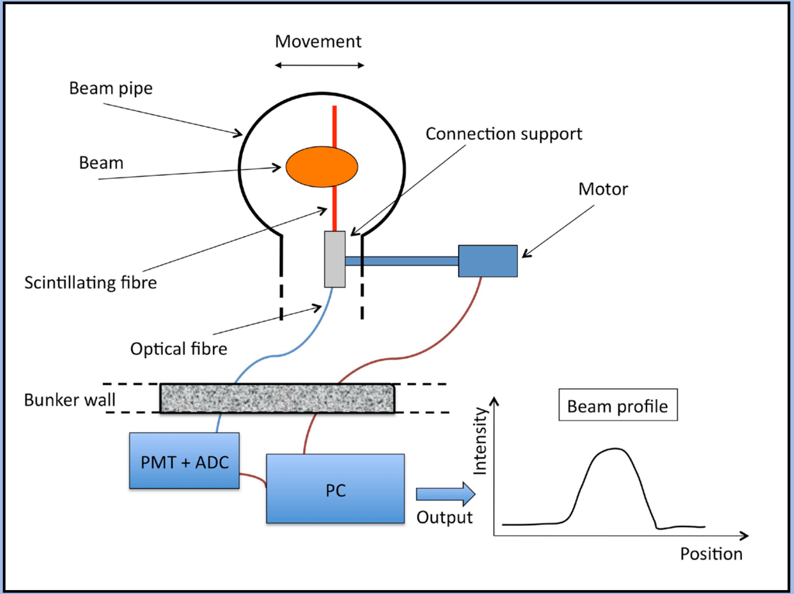


The Target "Coin"



- To bombard enriched targets materials in form of powders
- High-purity aluminum
- Two halves kept together by permanent magnets
  - SmCo → T_{Curie} at 350 °C
- O-ring (Viton) to avoid radioactive degassing
- Variable thickness of the front (energy absorption)

The UniBEaM Detector



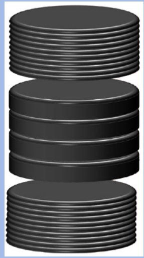
> 1D beam profiler based on (doped) optical fibres passed through the beam
> On-line, minimal interference with the beam
> Developed by LHEP and commercialized by D-Pace (Canada)

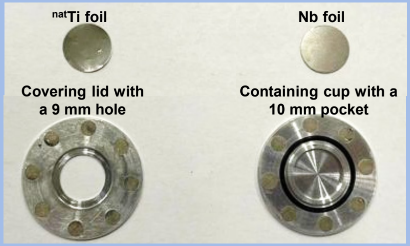
S. Braccini et al., 2012 JINST 7 T02001

Beam Energy Measurement for the STS using the Coin Target

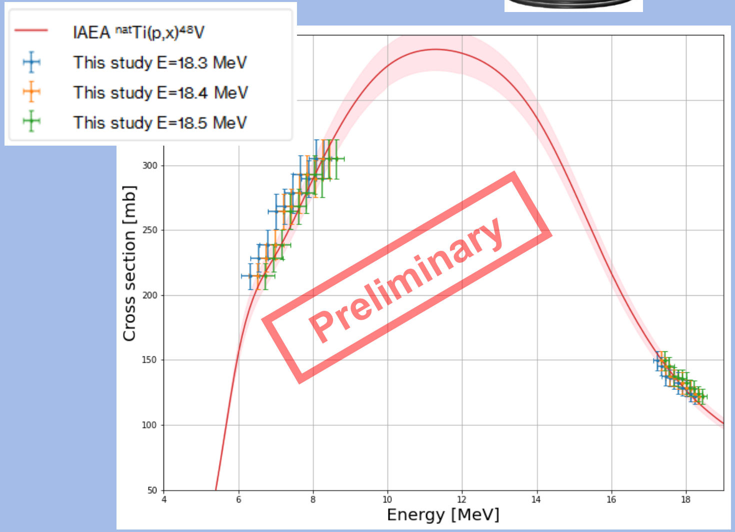
Monitor reaction

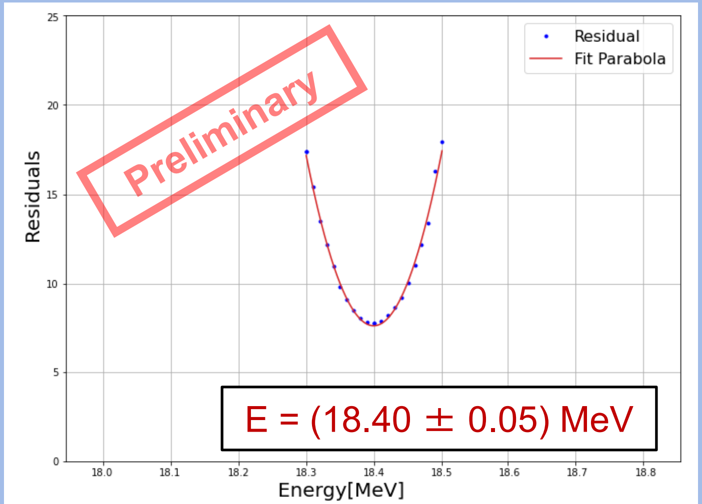
$^{nat}Ti(p,X)^{48}V$





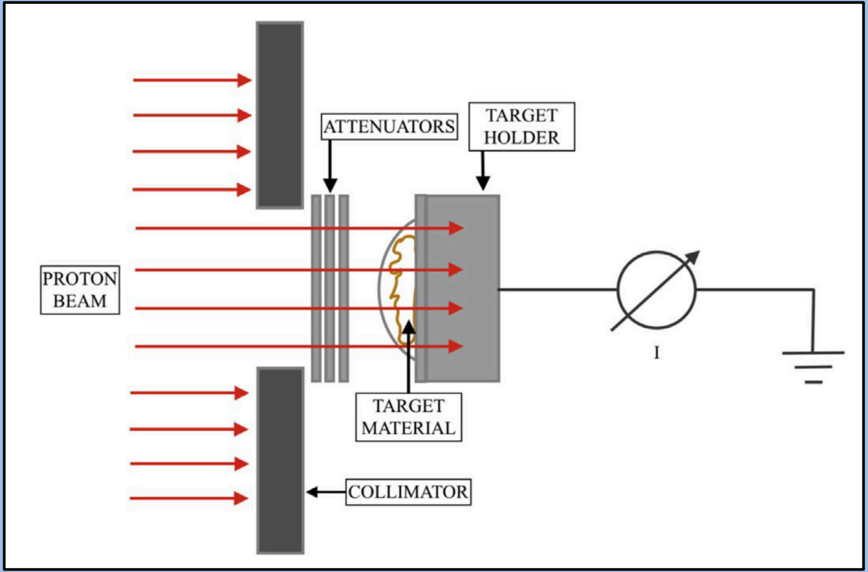
Closed target coin





Elnaz Zyaee, Master Thesis, 2021; paper in preparation

Cross Section Measurements with a Novel Method



T. S. Carzaniga, M. Auger, S. Braccini, M. Bunka, A. Ereditato, K. P. Nesteruk, P. Scampoli, A. Türler, N. P. van der Meulen, *Measurement of Sc-43 and Sc-44 production cross-section with an 18 MeV medical PET cyclotron*, Appl Radiat Isot. 2017 Nov; 129:96-102.

Cross Section Measurements with a Novel Method

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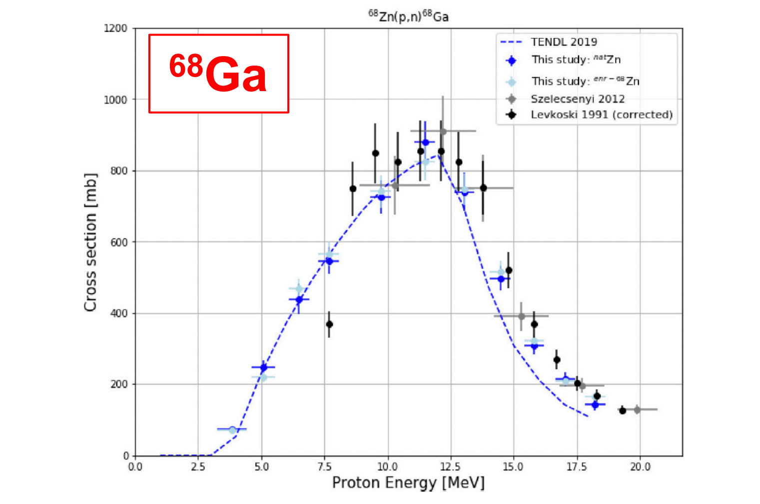


Fig. 4. ^{68}Zn(p,n)^{68}Ga cross section measured from natural and enriched ^{68}Zn targets with the isotopic composition marked as (A) in Table 1.

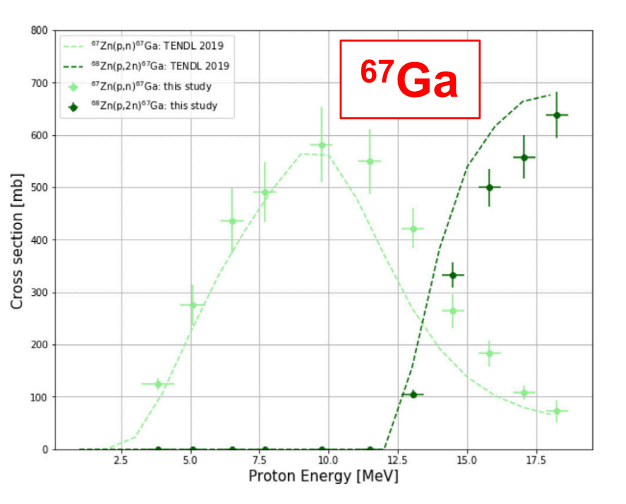
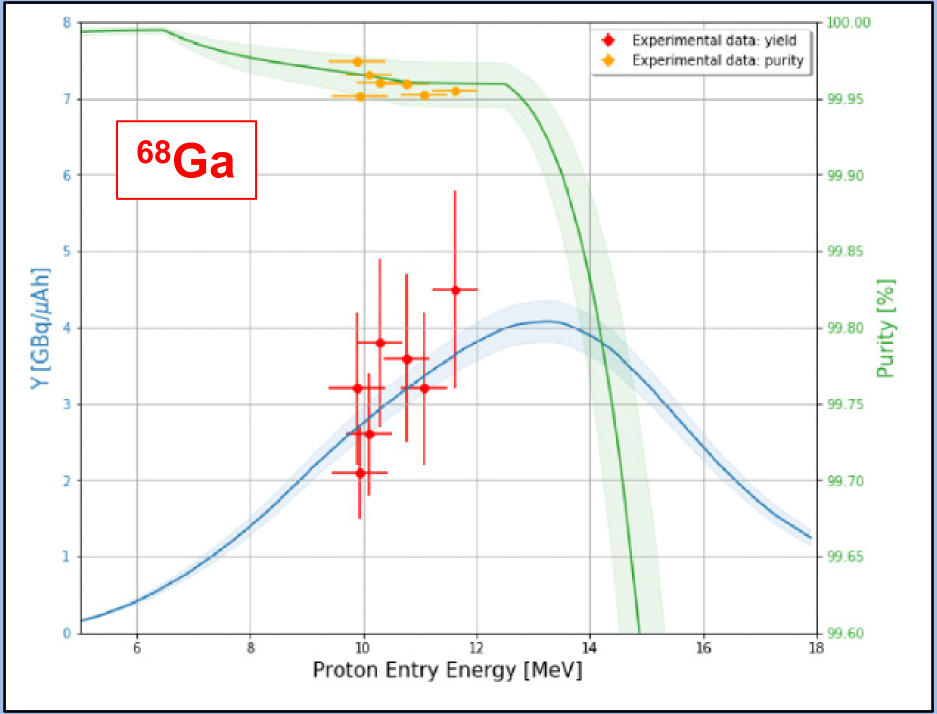


Fig. 6. ^{67}Zn(p,n)^{67}Ga and ^{68}Zn(p,2n)^{67}Ga reaction cross sections.

S. Braccini et al., *Optimization of ^{68}Ga production at an 18 MeV medical cyclotron with solid targets by means of cross-section measurement of ^{66}Ga, ^{67}Ga and ^{68}Ga,* Appl. Radiation and Isotopes, Volume 186, August 2022

Yield, Purity and Production Tests with Solid Targets: Example of ^{68}Ga



Some produced Radioisotopes

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Isotope	Reaction	Target	Current [μA]	Irr. Time [h]	A_{EOB} [GBq]
^{44}Sc	(p,n)	^{enr44}CaO pellet	5	5	~15
^{48}V *	(p,n)	^{nat}Ti metal foil	10	1	~0.15
^{61}Cu	(p,α)	^{enr64}Zn pellet	25	1.9	~1
^{64}Cu	(p,n)	^{enr64}Ni deposition	15	10	~20
^{68}Ga	(p,n)	^{enr68}Zn pellet	5	0.5	~15
^{X}Pm **	(p,X)	^{nat}Nd disc	5	3	$\sim10^{-7}$
^{155}Tb	(p,n)	^{enr155}Gd pellet	2.5	1.15	~0.005
^{165}Er	(p,n)	^{nat}Ho metal disk	10	10	~1.5
^{165}Tm	(p,2n)	^{enr166}Er$_2$O$_3$	2.5	0.5	~1.5

- Further medical radioisotopes under study: **^{43}Sc**, **^{47}Sc**, **^{67}Cu** and **^{167}Tm**
- ^{48}V and ^{X}Pm for fundamental physics research

G. Dellepiane et al., Research on theranostic radioisotope production at the Bern medical Cyclotron, Il Nuovo Cimento, 2021

* High Efficiency Cyclotron Trap Assisted Positron Moderator, Instruments 2 (2018) 10.
** High-resolution laser resonance ionization spectroscopy of $^{143-147}$Pm, Eur. Phys. J. A (2020) 56:69

^{44}Sc is ready for Clinical Applications

molecules

Molecules 2020, 25(20), 4706

MDPI

Article

Developments toward the Implementation of ^{44}Sc Production at a Medical Cyclotron

Nicholas P. van der Meulen [1,2,*], Roger Hasler [2], Zeynep Talip [2], Pascal V. Grundler [2], Chiara Favaretto [2], Christoph A. Umbricht [2], Cristina Müller [2], Gaia Dellepiane [3], Tommaso S. Carzaniga [3] and Saverio Braccini [3]

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> in collaboration with PSI

^{44}Sc is ready for Clinical Applications

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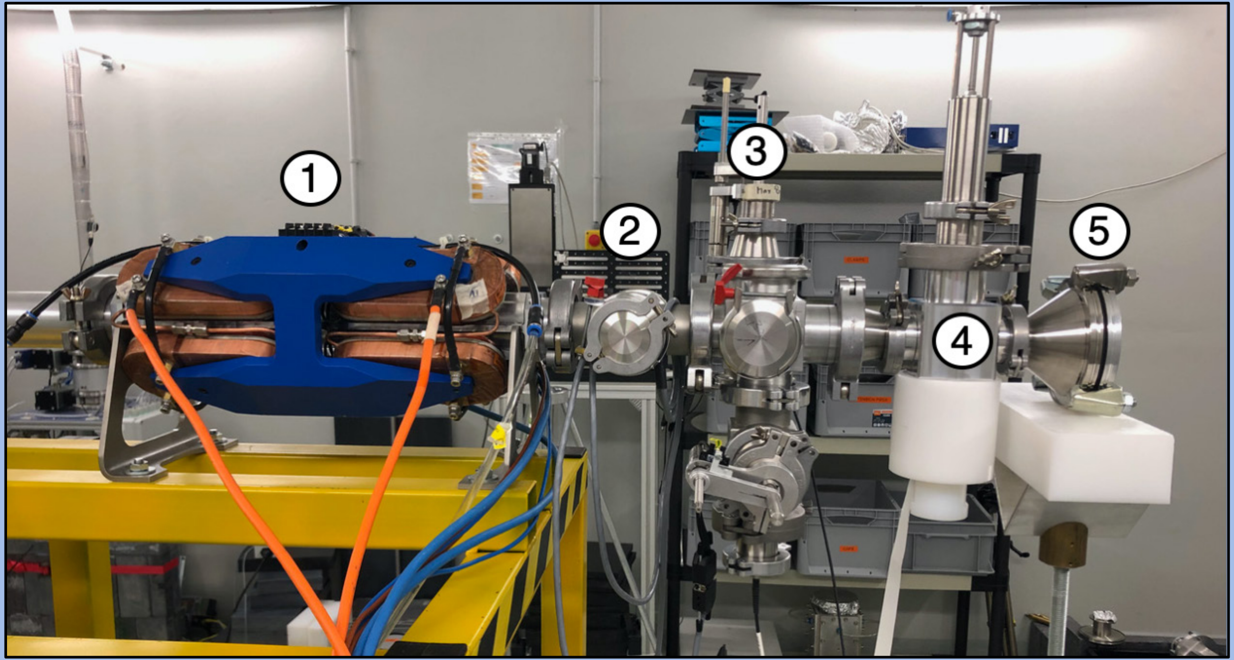
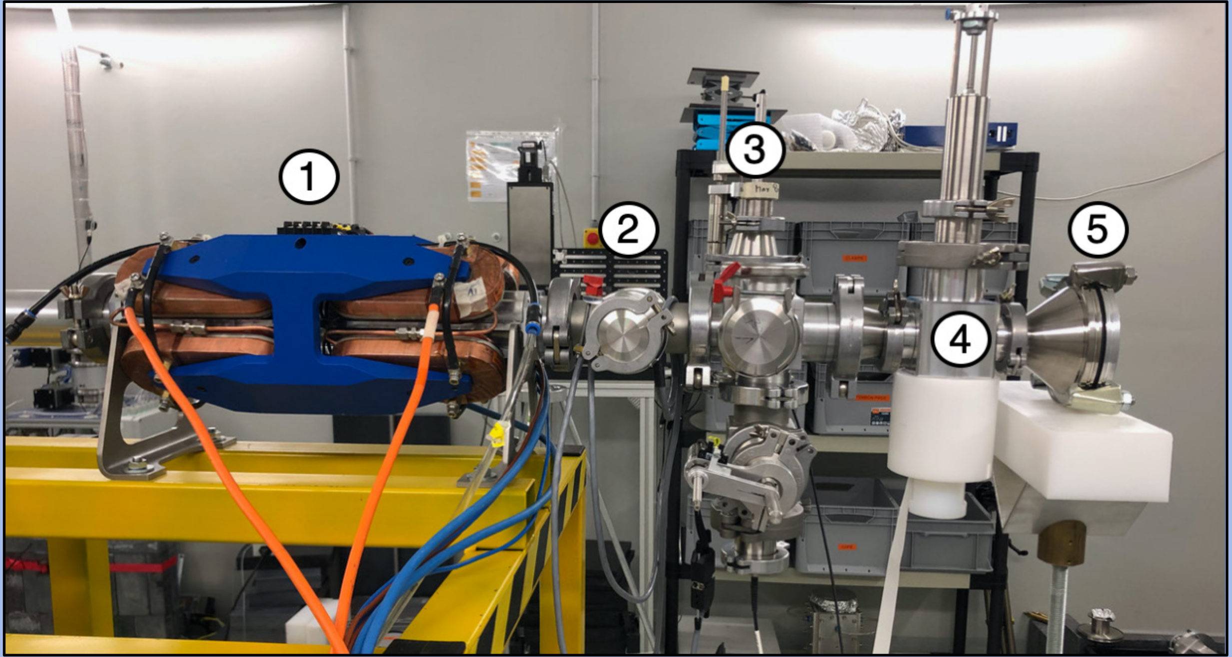
IBA Award 2020

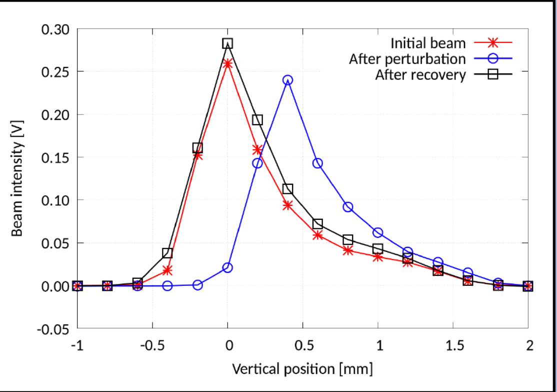
Work in Progress: Automatic Focusing System (AFS)

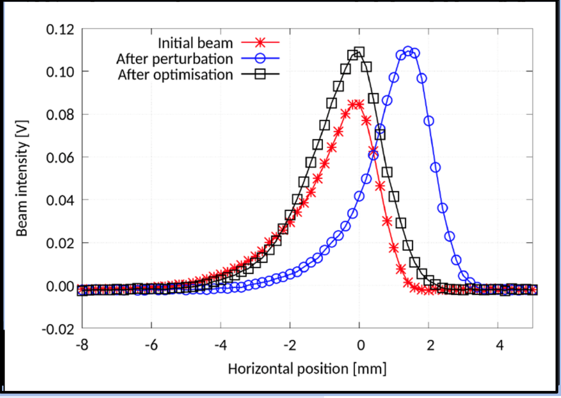


①: Mini-PET Beamline (MBL)
②: Drift space
③: Two-dimensional UniBEaM
④: π^2 detector
⑤: Beam dump

Work in Progress: Automatic Focusing System (AFS)

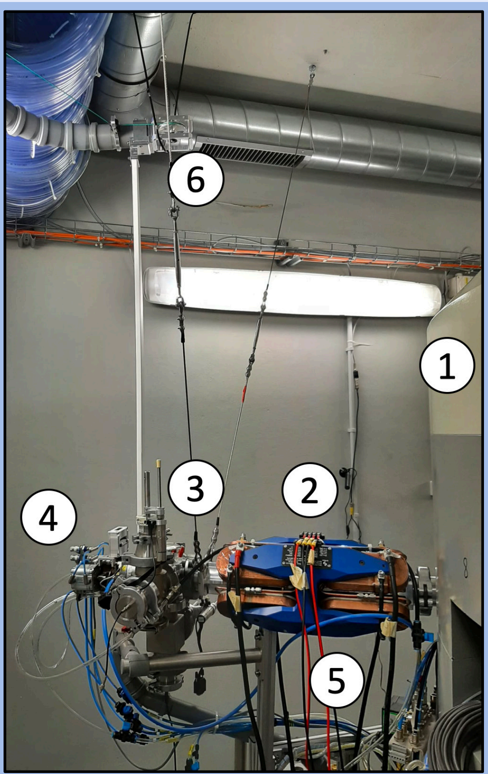






> Production yield improved by a factor 20 if compared to an unfocused beam

AFS installed on the Solid Target Station (STS)

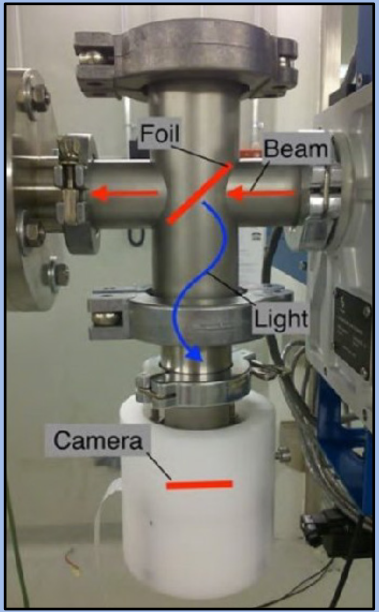


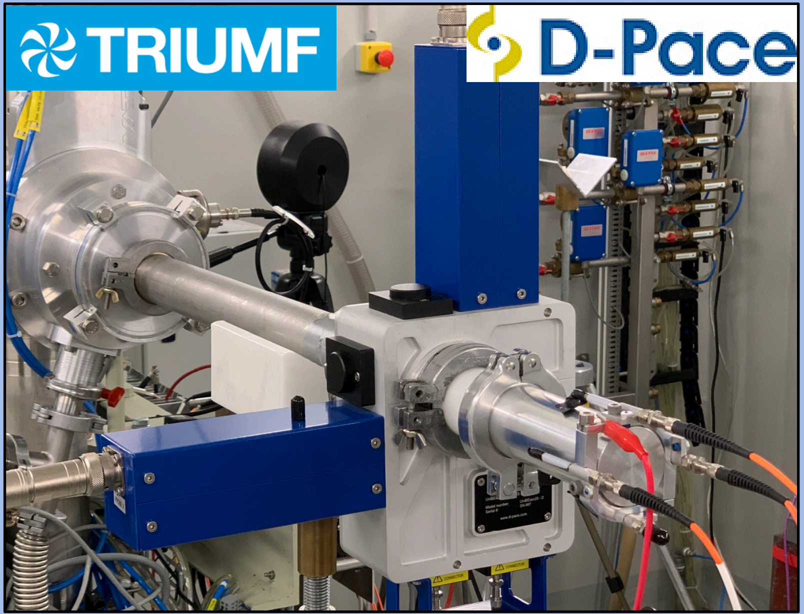
①: Cyclotron
②: Mini-PET Beamline (MBL)
③: Two-dimensional UniBEaM
④: Solid Target Station (STS)
⑤: Solid Target Transfer System (STTS)
⑥: Solid Target Loading System (STLS or Hyperloop)

> Replace ③ with a more suitable device to monitor beam shape and intensity at high dose rates.

Häffner, P. D. et al., An Active Irradiation System with Automatic Beam Positioning and Focusing for a Medical Cyclotron, Appl. Sci. 2021, 11(6), 2452; P. Häffner, PhD Thesis, 2021

2D Beam Monitoring: π^2 and Collar

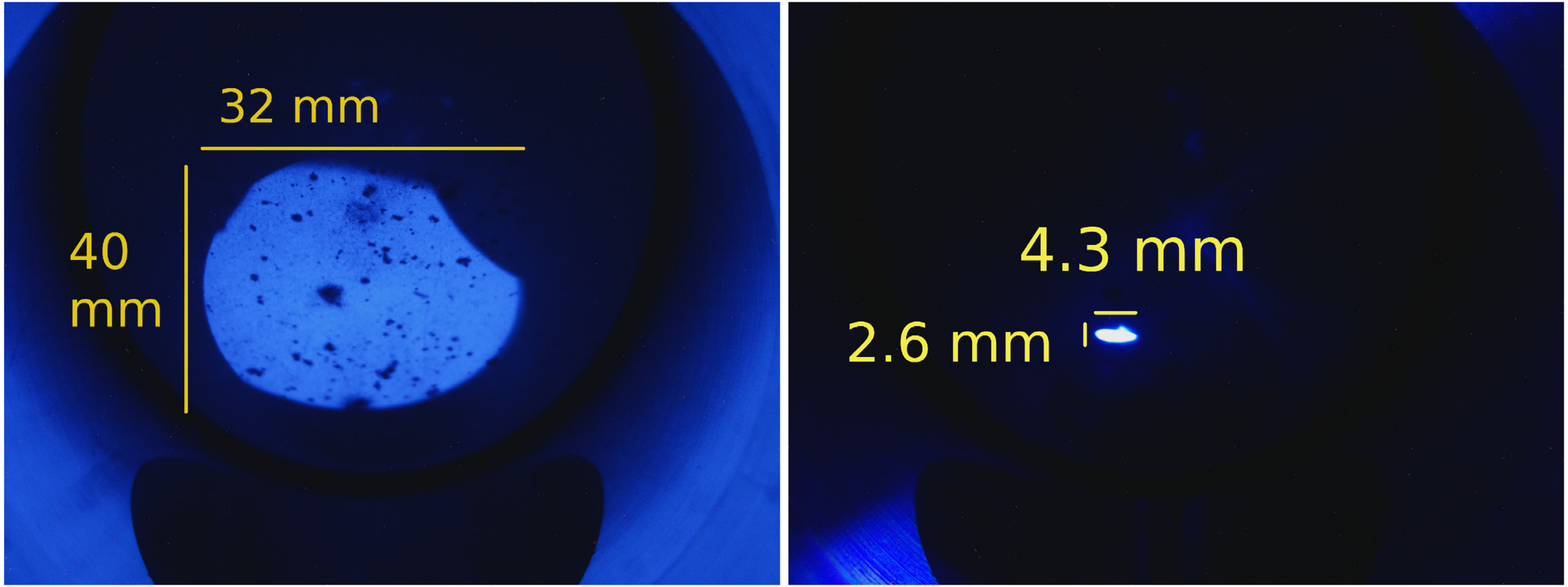




π^2: Beam monitor based on coated aluminium foil and a camera, to measures 2D beam profile and intensity non-destructively.

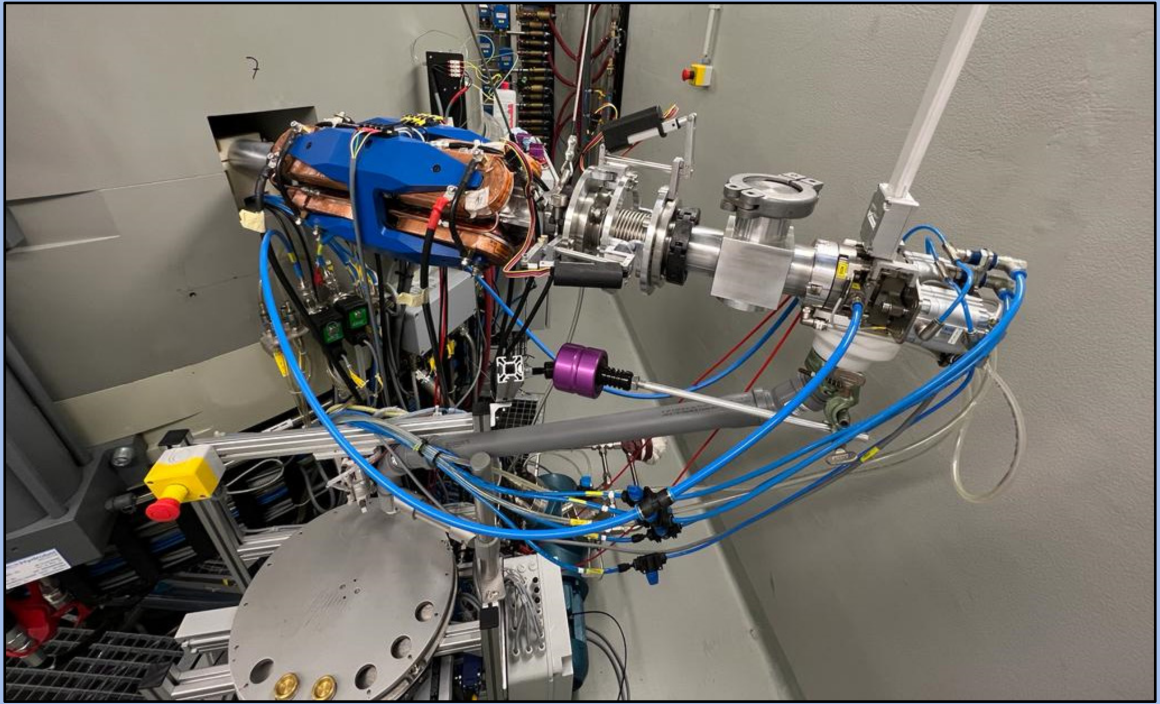
Collar: Non destructive beam monitor based on doped silica fibres to enhance production yield of radioisotopes for theranostics.

π^2 in Action:



2D beam profile measured by the π^2 detector before and after beam optimisation by AFS

Thank you for listening!



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- > Master and Bachelor Students: M. Schmid (2021), E. Zyaee (2021), N. Voeten (2022), D. Wüthrich (2019), J. Askew, D. Wermelinger, M. Wenger, N. Kämpfer (2022)
- > LHEP mechanics and electronics workshop crew

https://www.lhep.unibe.ch/research/medical_applications/