Novel irradiation methods for theranostic radioisotope production with solid targets at the Bern medical cyclotron

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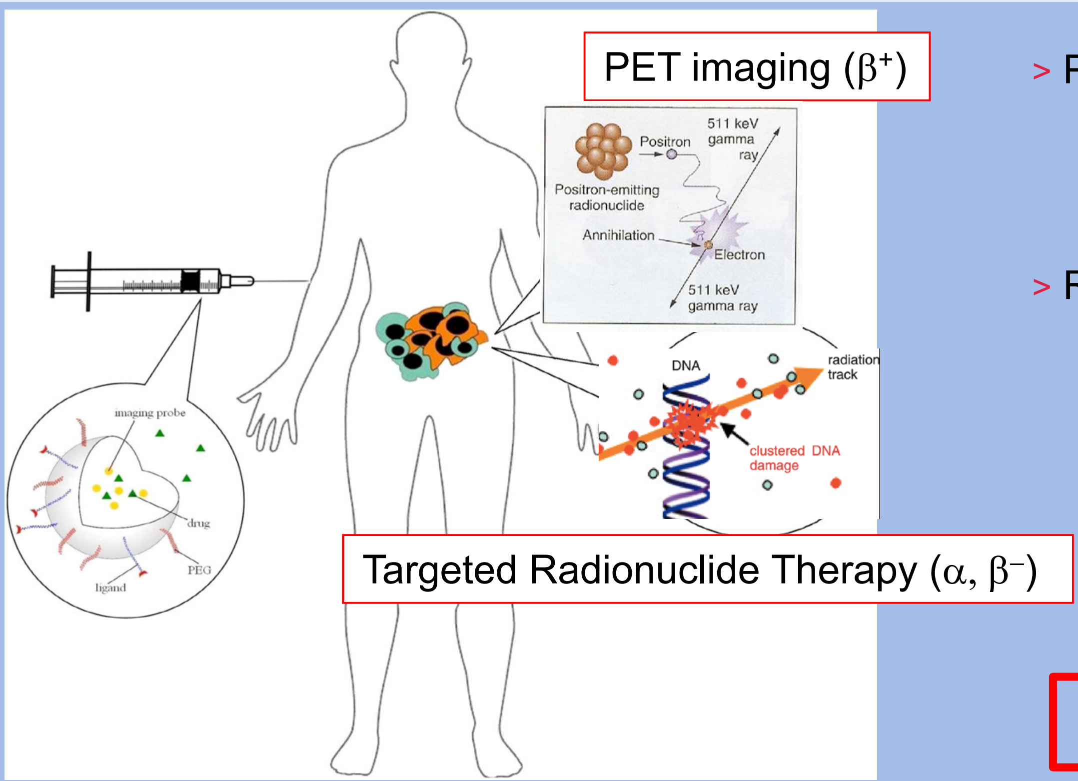
Theranostics in nuclear medicine



> Promising pairs:

- $^{64}Cu/^{67}Cu$
- $^{44}Sc/^{47}Sc$ and $^{43}Sc/^{47}Sc$

> Radiometals

- **Sc with cyclotron?**
- ^{44}**Ca**(p,n)^{44}Sc, ^{43}**Ca**(p,n)^{43}Sc, ^{46}**Ti**(p,α)^{43}Sc

Solid target

The Bern medical cyclotron and its Beam Transport Line (BTL)

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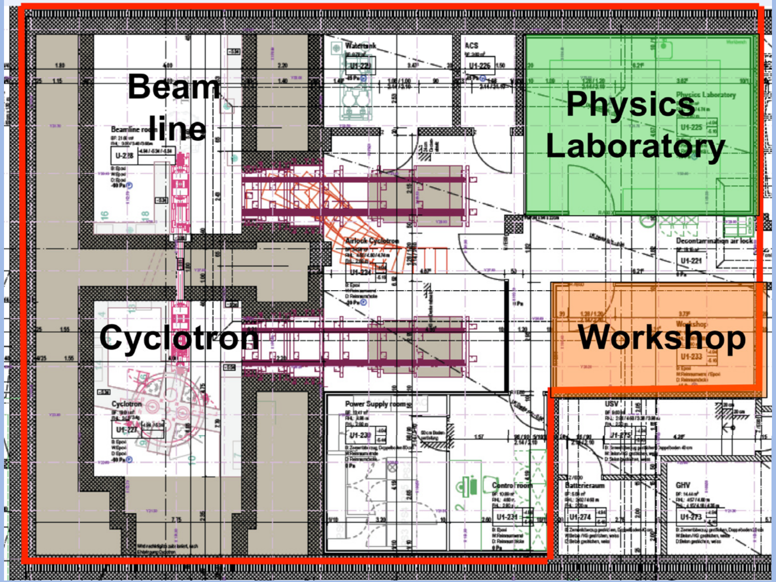
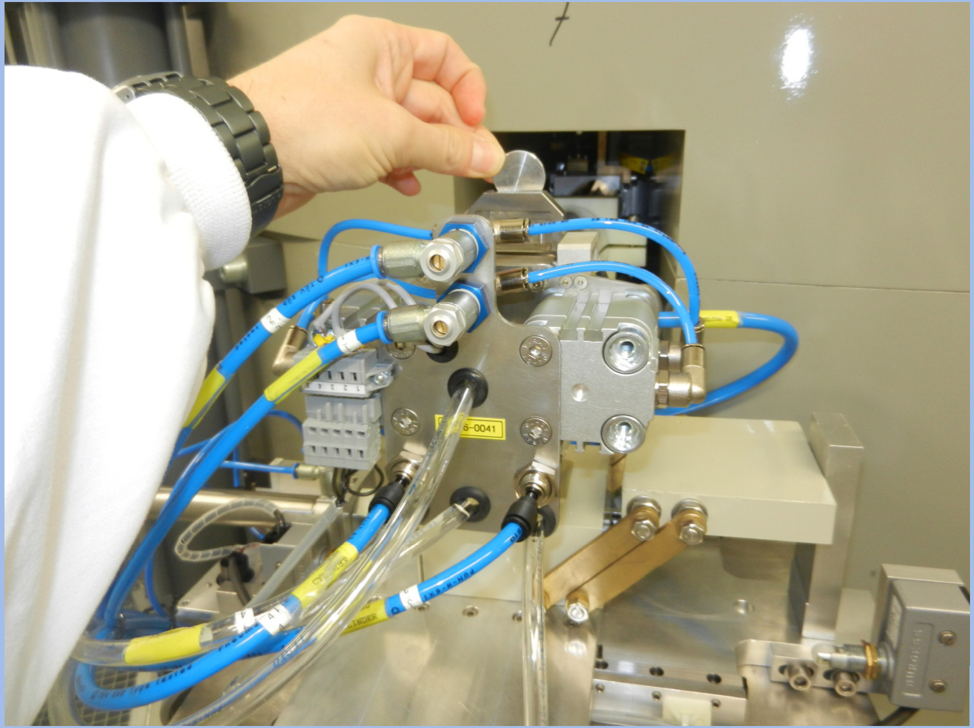


- IBA 18 MeV “twin” (two H^- ion sources) high current (150 μA) cyclotron
- 8 out ports: 4 ^{18}F liquid targets [industrial production], **BTL, solid target [research]**
- GMP radio-pharmacy

Solid target station
IBA Nirta (commercial solution)



- Target:
  - 24 mm diameter 2 mm thick disk
  - electro-plated materials
- Manual insertion and recovery of the disk
- Cooling:
  - water in the back
  - helium in the front

Challenges for the production of radiometals

- Target materials in form of powder (ex. $CaCO_3$, CaO, TiO_2, Zn, ZnO, …)
  - Enriched target material very expensive
- Cooling issues
  - Poor heat conduction
- Radiation protection issues
  - Degassing during/after irradiation [$^{16}O(p,\alpha)^{13}N$]
- High activities (GBq) and high purity needed
  - Accurate knowledge of cross sections and beam characteristics

Novel method to measure cross sections with a medical cyclotron

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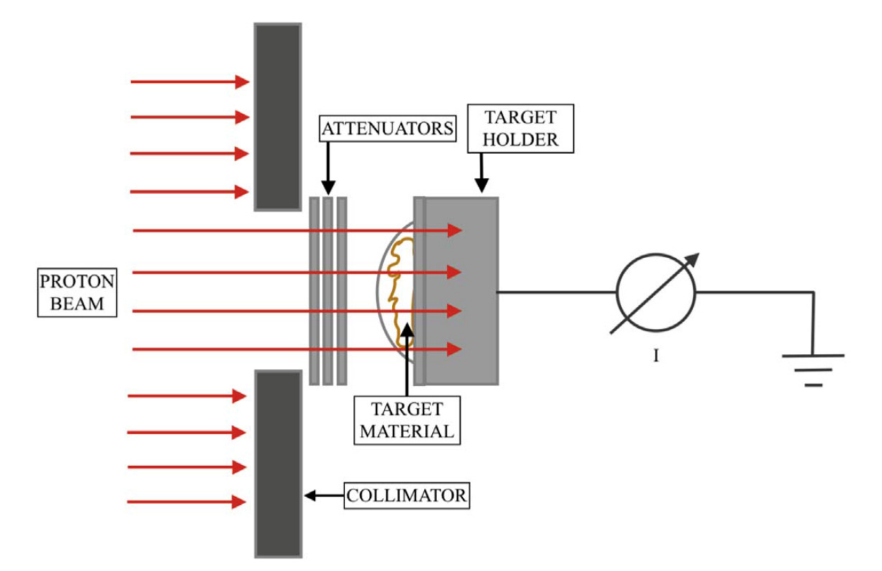

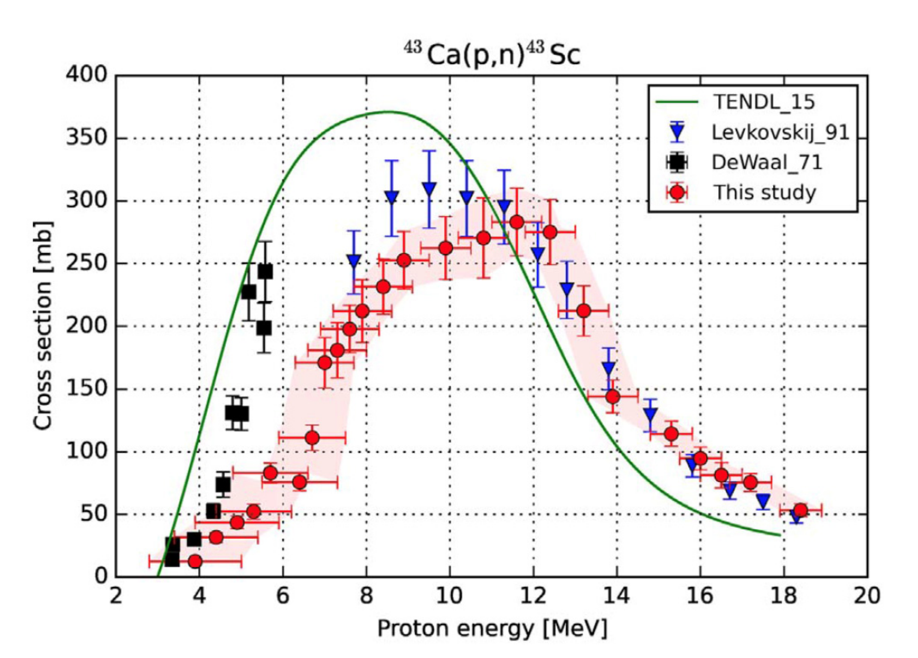

- Irradiation of the full mass by a flat beam
- Beam monitoring is essential

S. Carzaniga et al., Applied Radiation and Isotopes 129 (2017) 96–102.

Our strategy for the production of radiometals

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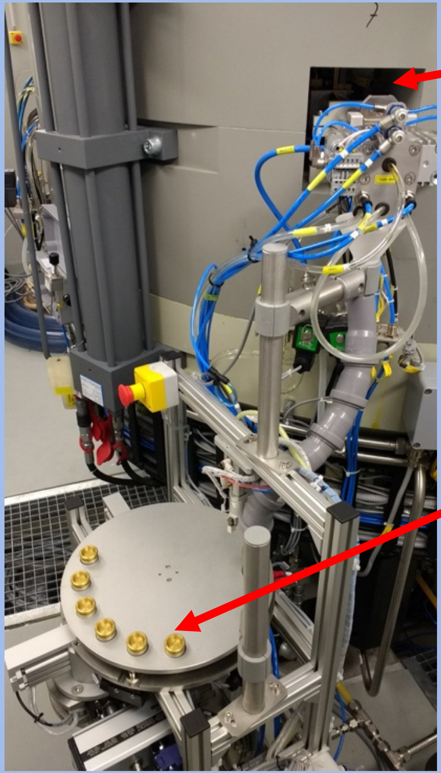
- Commercial solution for the transfer of the irradiated disk
  - Pneumatic system (STTS by TEMA Sinergie, Italy)
  - Two delivery pathways:
    - Hot cell in the radio-pharmacy (standard)
    - BTL bunker (unconventional)

- Compress the power material into pellets
  - Ex. 6 mm diameter, 500 um thick, ~30 mg of CaO, ~100 mg of Zn
- Develop a new kind of target “coin”
- Activity/purity assessment at EoB
  - CZT detector

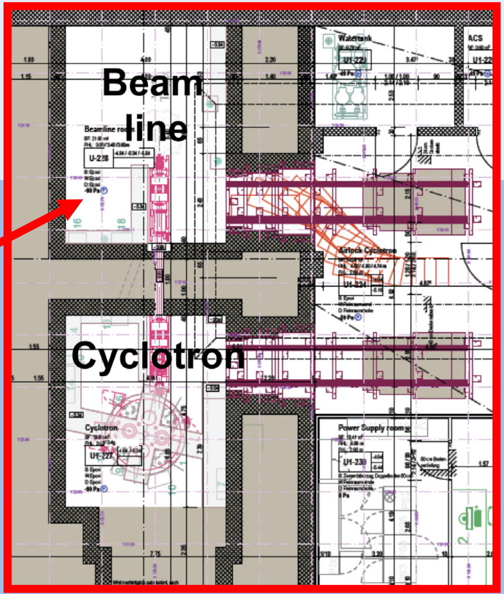
The solid target station and the pneumatic transfer system



Coin charger (up to 3 disks)

- 6 shuttles
- 2 delivery pathways

The receiving station in the BTL

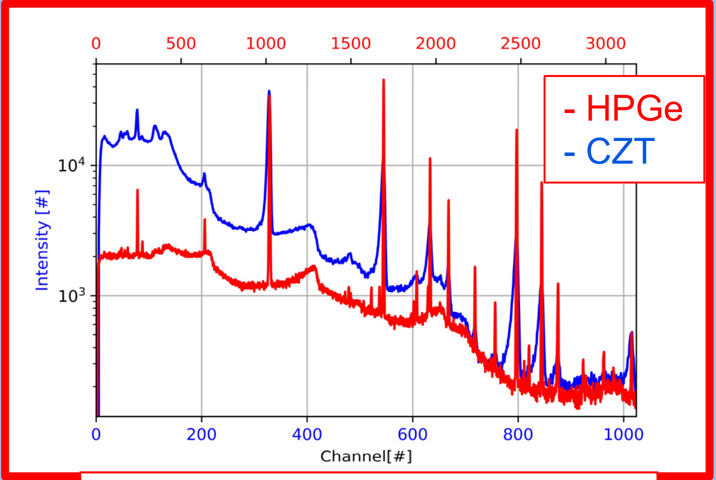


Lead pot

CZT detector

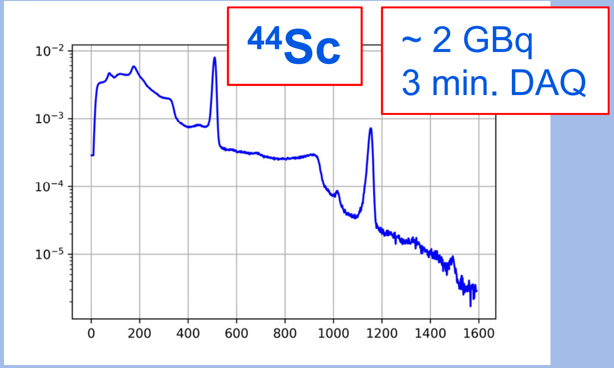
- ~ 1 cm^3 CdZnTe (CZT) crystal
- ~ 40 cm from target
- Gamma spectroscopy

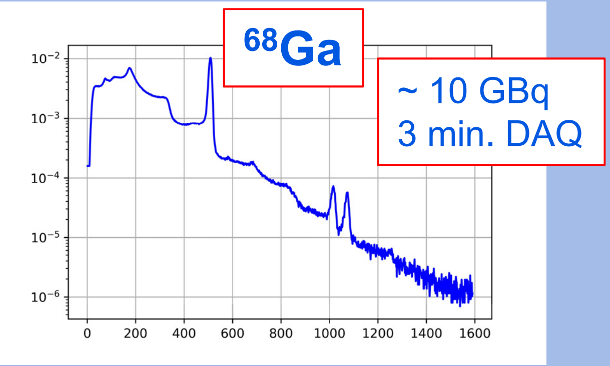
Activity and purity assessment at EoB with the CZT detector



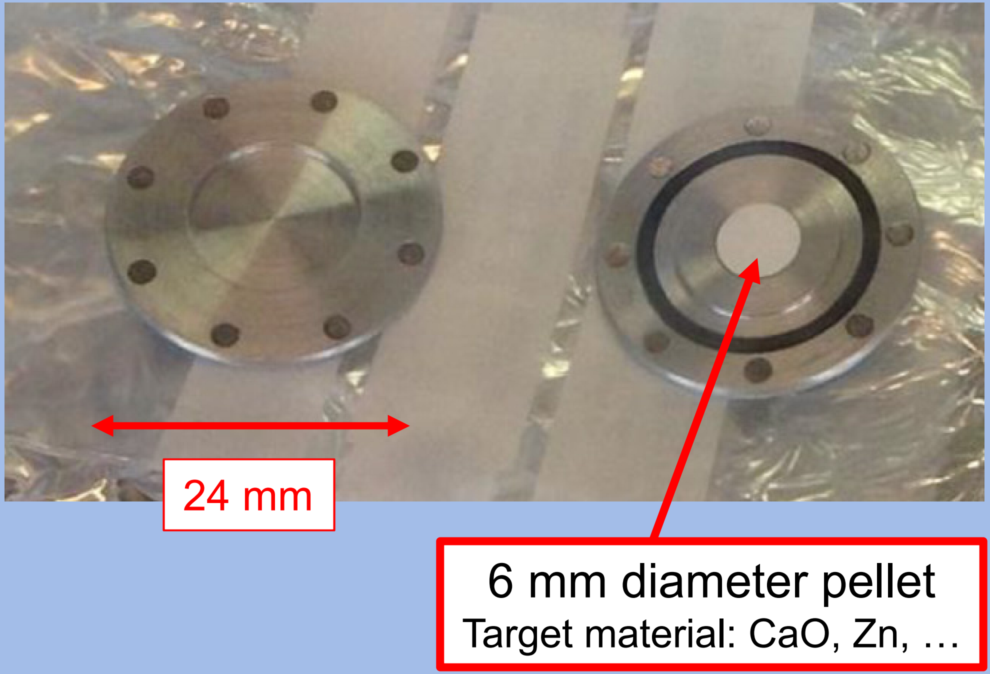
HPGe vs CZT for an irradiated Al coin

> Good resolution
> Assess activity of single isotopes
> Benchmark for production





The "coin"



- High-purity aluminum
- Two halves kept together by permanent magnets
  - SmCo, 350ºC Curie temperature
- O-ring to contain radioactive gas
- Variable thickness of the front for energy variation

First results

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Isotope	Reaction	Target material	Current [μA]	Time [h]	A_{EOB} [GBq]
^{44}Sc	(p,n)	^{enr}CaO pellet	5	5	~15
^{64}Cu	(p,n)	^{enr}Ni electrodeposition	15	10	~20
^{68}Ga	(p,n)	^{enr}Zn pellet	5	0.5	~15 *
^{48}V	(p,n)	Ti metal disc	10	1	~0.15 **
^{165}Er	(p,n)	Ho metal disc	10	10	~1.5

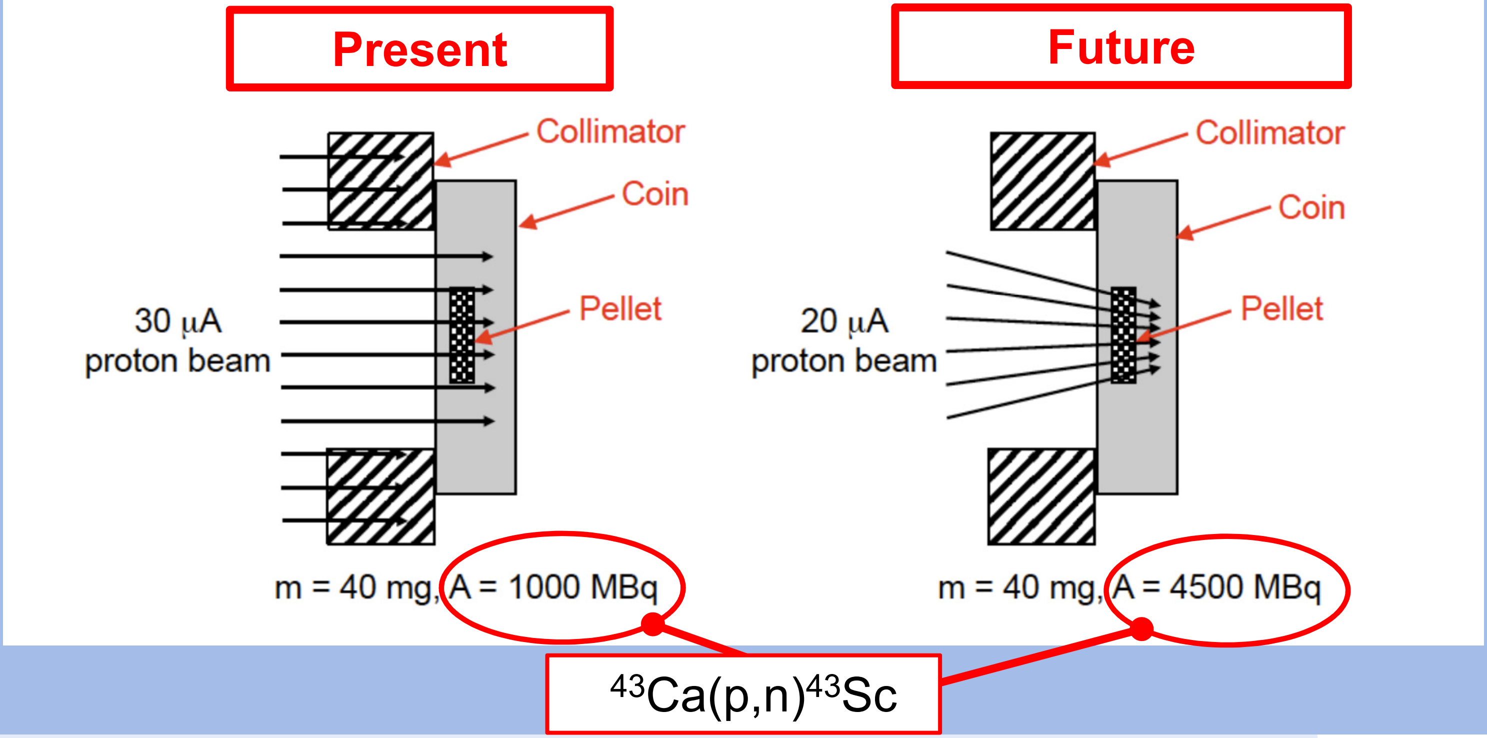
> ^{44}Sc: ~15 GBq in 5 hours

> The impinging energy is crucial (cross sections)

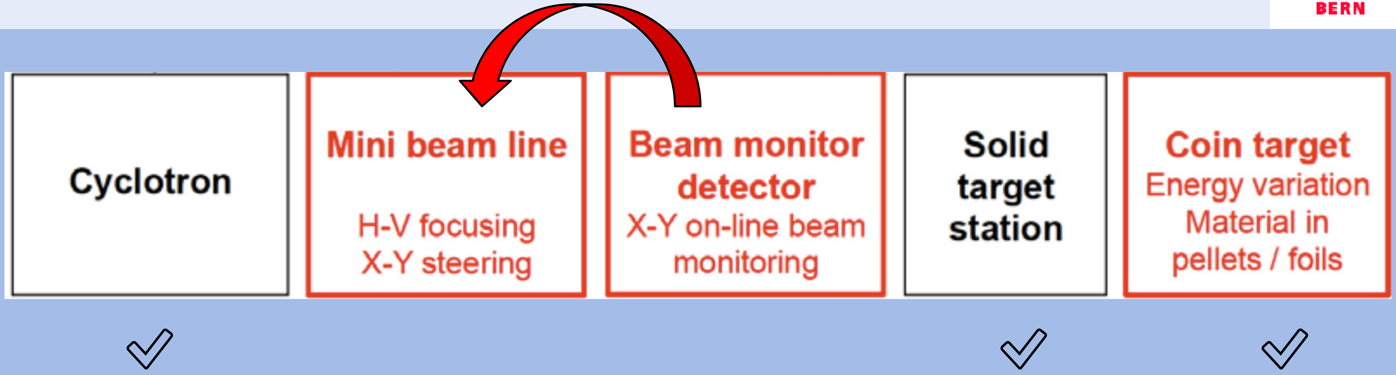
> Near future: ^{43}Sc (~5 GBq) and ^{47}Sc (~10 GBq)

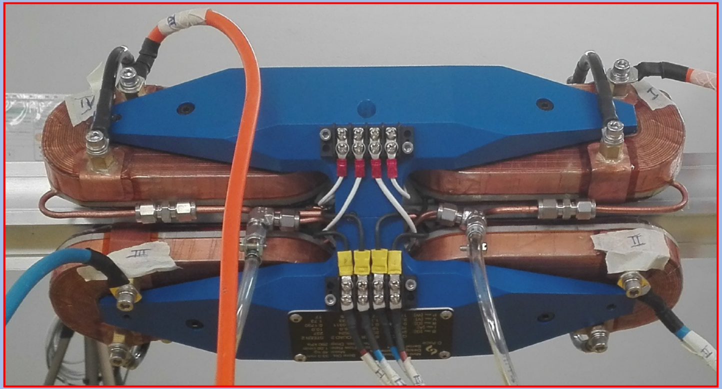
* Diana Wüthich, Master thesis, U. Bern, 2018.
** L. Gerchow et al., High Efficiency Cyclotron Trap Assisted Positron Moderator, Instruments 2 (2018) 10.

On-going developments



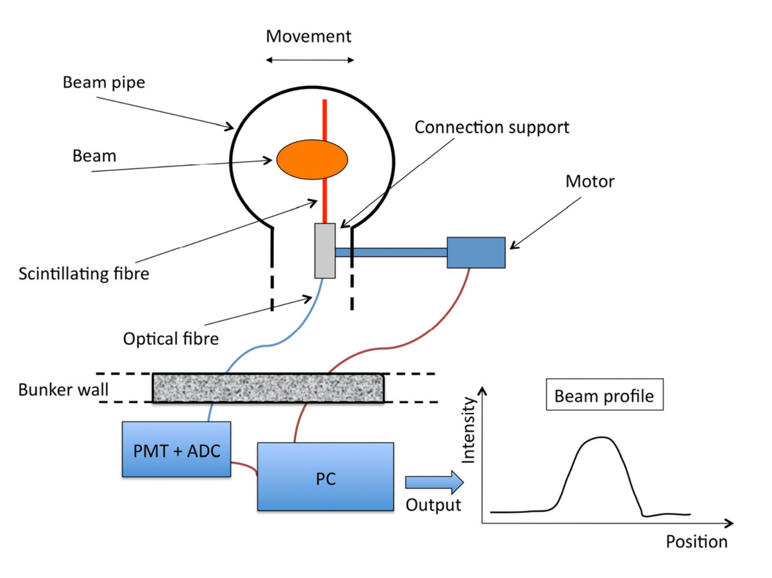
An active irradiation system to enhance the performance of solid targets

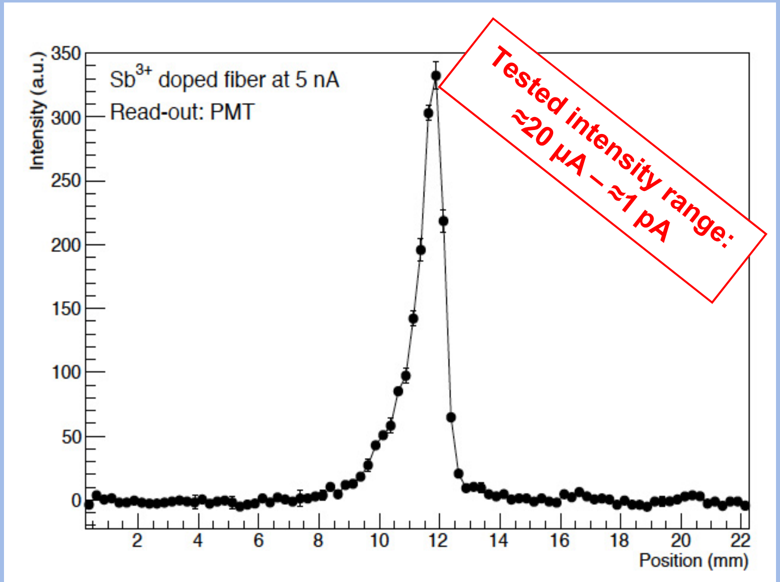




- MiniBeamLine (D-Pace, Canada)
- Quad doublet + XY steering in a single magnet
- Compact: 40 cm long, 54 kg
- Does not need a second bunker!

Beam monitoring detector – Option 1: UniBEaM

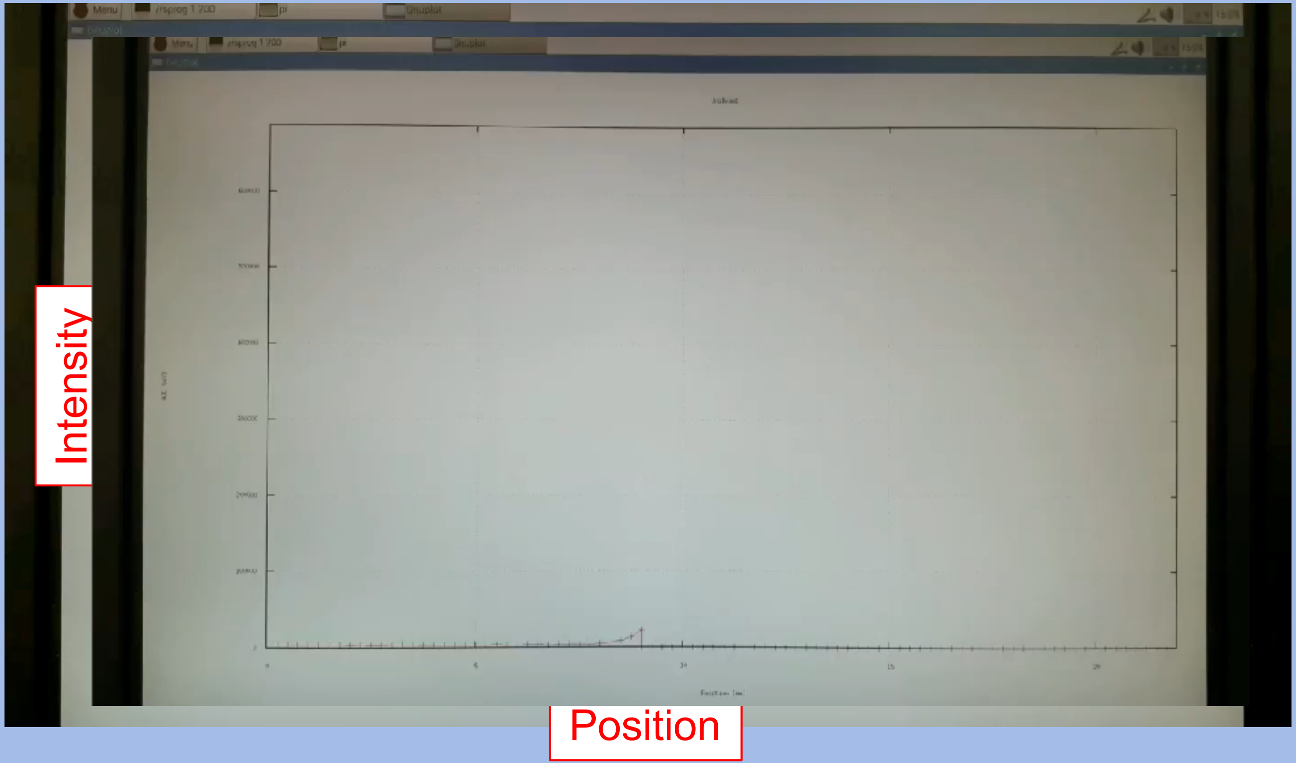




- 1D beam profiler based on (doped) optical fibres passed through the beam
- On-line, minimal interference with the beam

S. Braccini et al., 2012 JINST 7 T02001, 2016 JINST 11 P03027, 2018 JINST 13 P01011

On-line monitoring with UniBEaM



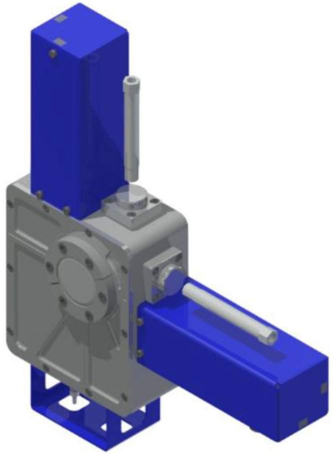
UniBEaM commercialized by D-Pace

D-Pace

UniBEaM25

Ion Beam Profiler using Optical Fiber Sensor
Single and Dual Axis Systems

UniBEaM25-S – Single Axis Probe

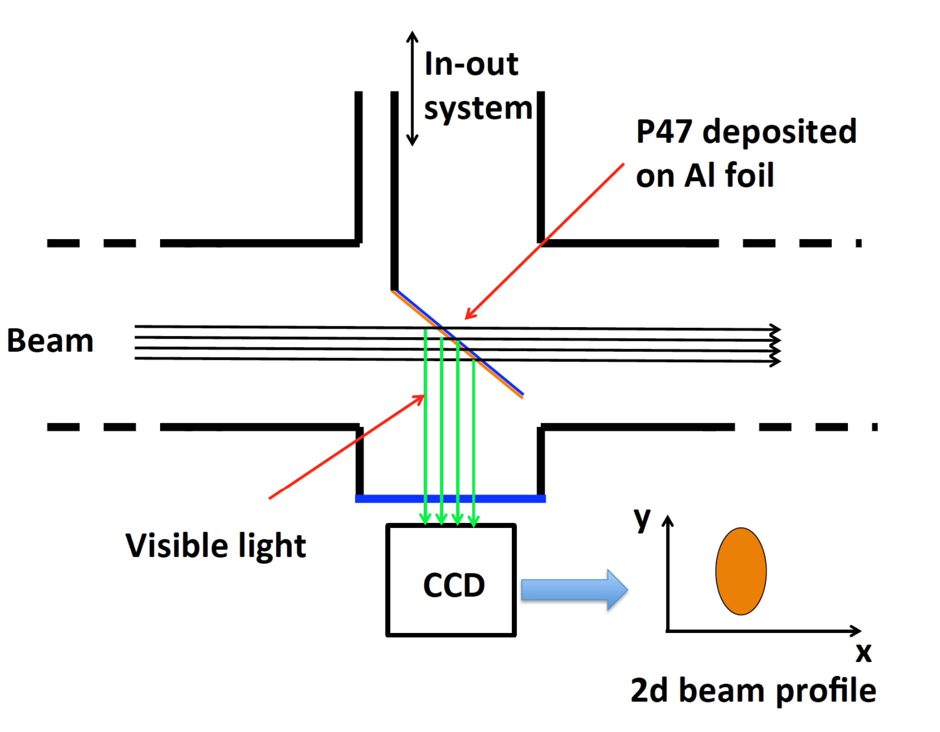


UniBEaM25-D – Dual Axis Probe

UniBEaM was conceived by the **AEC-LHEP** of the **University of Bern**[1] and commercialized by **D-Pace.**

Beam monitoring detector – Option 2:

π^2



First preliminary results with π^2

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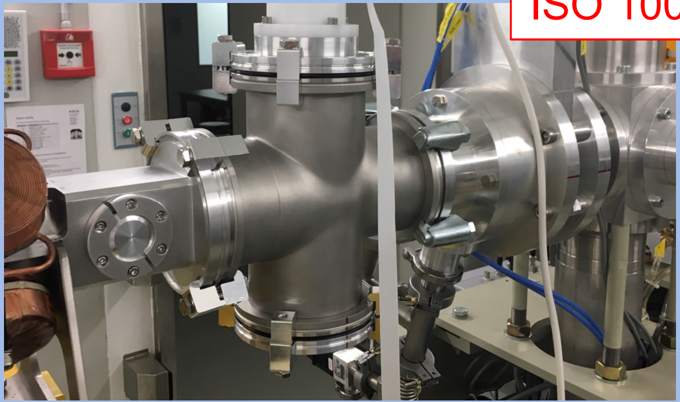
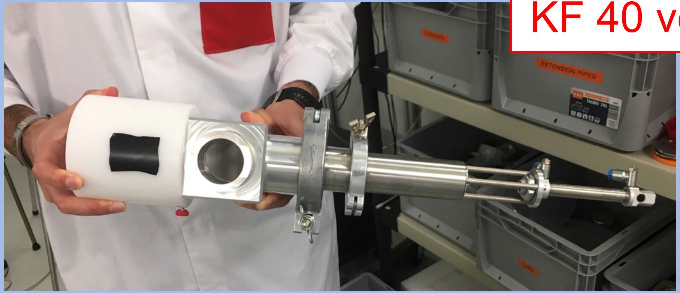
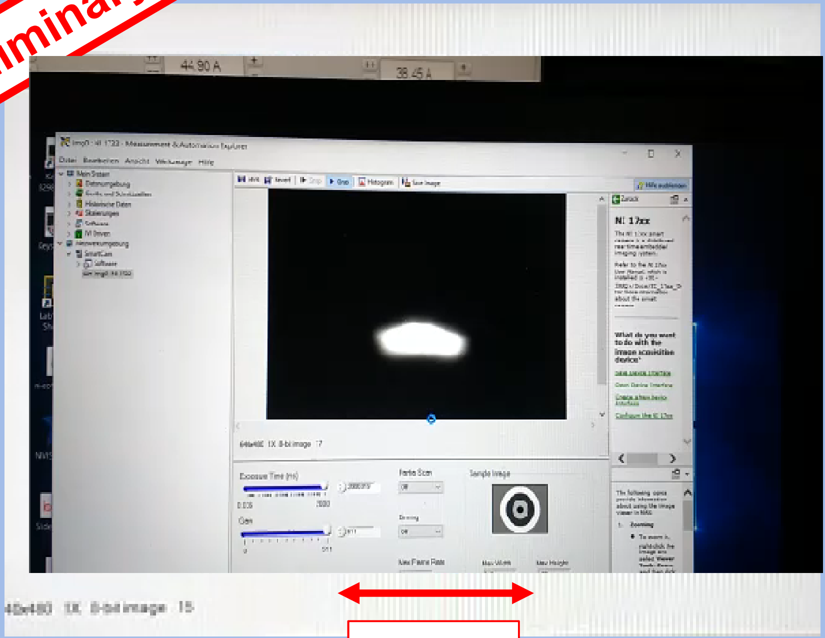
ISO 100 version



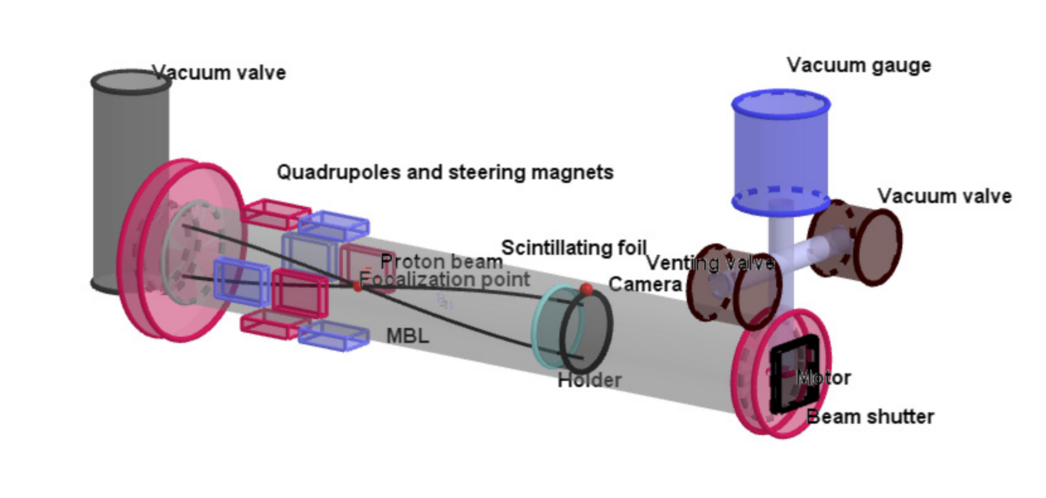
KF 40 version

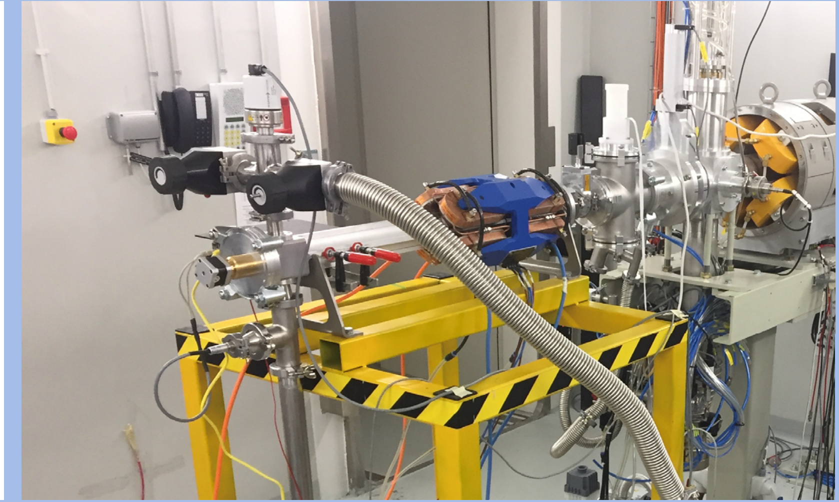


Preliminary



A novel 3-D beam monitoring detector: π^3

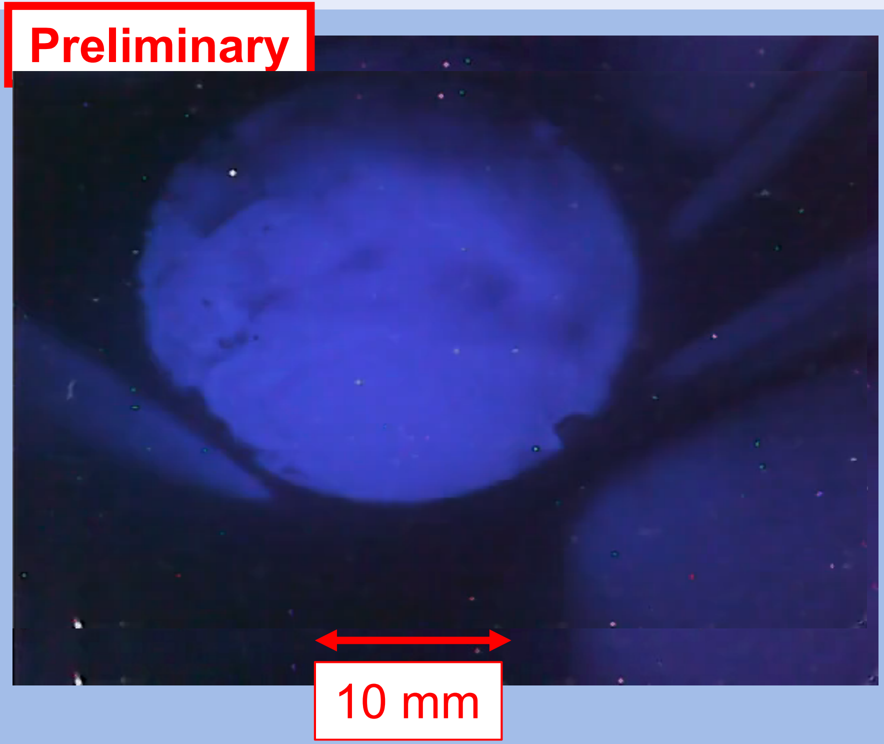


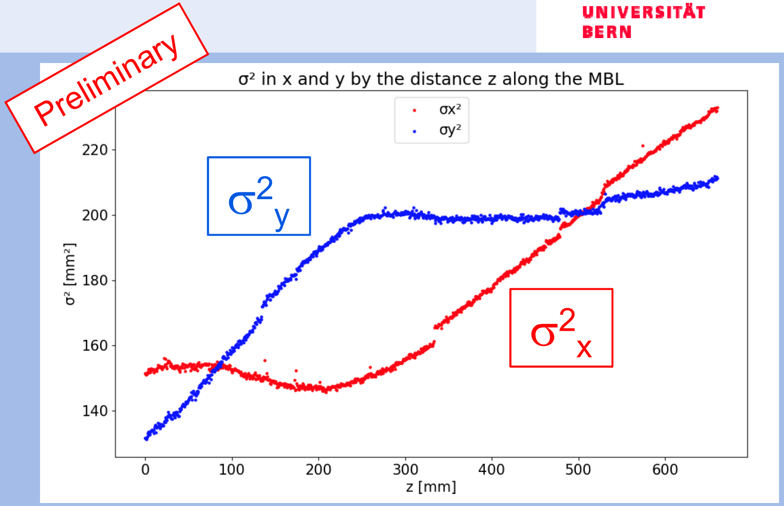


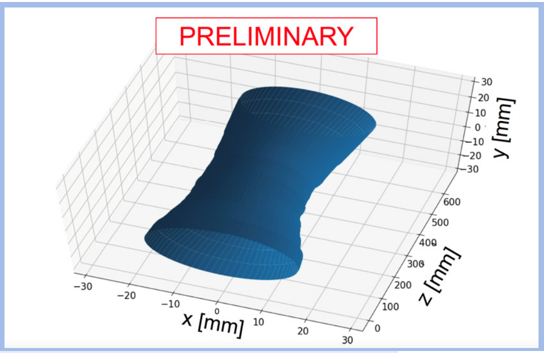
- 3 cm diameter P47 coated Al foil + small CDD camera in vacuum
- Both moved inside the beam pipe as an “endoscope”
- Full 3-D characterization of the MiniBeamLine

A. Gsponer, Bachelor thesis, University of Bern, 2018.

First preliminary results with π^3







Conclusions and Outlook

- Research program on theranostic radioisotopes at the Bern medical cyclotron

- Developments based on accelerator and detector physics
  - Cross section measurement method
  - Novel target “coin” to irradiate materials in pellets
  - 1, 2 and 3 D beam monitoring detectors
  - Active irradiation system

- First promising results in the production of radiometals
  - ^{44}Sc, ^{48}V, ^{64}Cu, ^{68}Ga

- Developments for any medical cyclotron