Importance of beam diagnostics: real life of mass separation, collection, and operations

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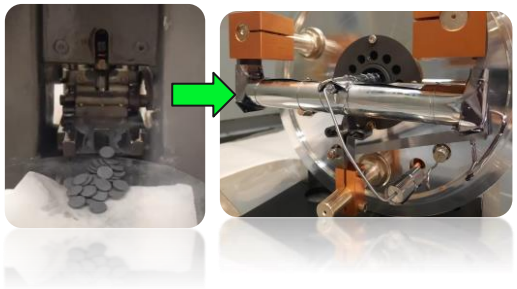
Summary

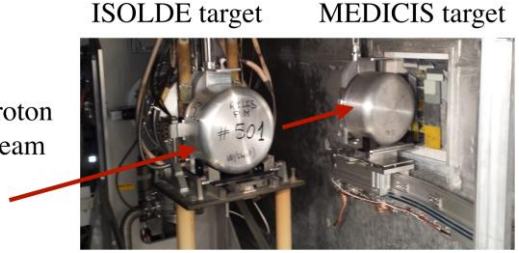
- Overview
- Irradiated target
- Beam production
- Mass separation
- Diagnostics
- Retrieval and shipping

The full MEDICIS chain

Sample preparation

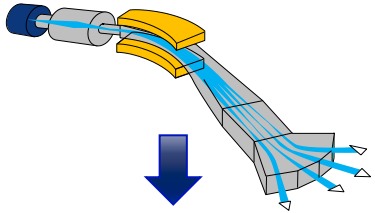


Irradiation



Transfer

Off-line separation

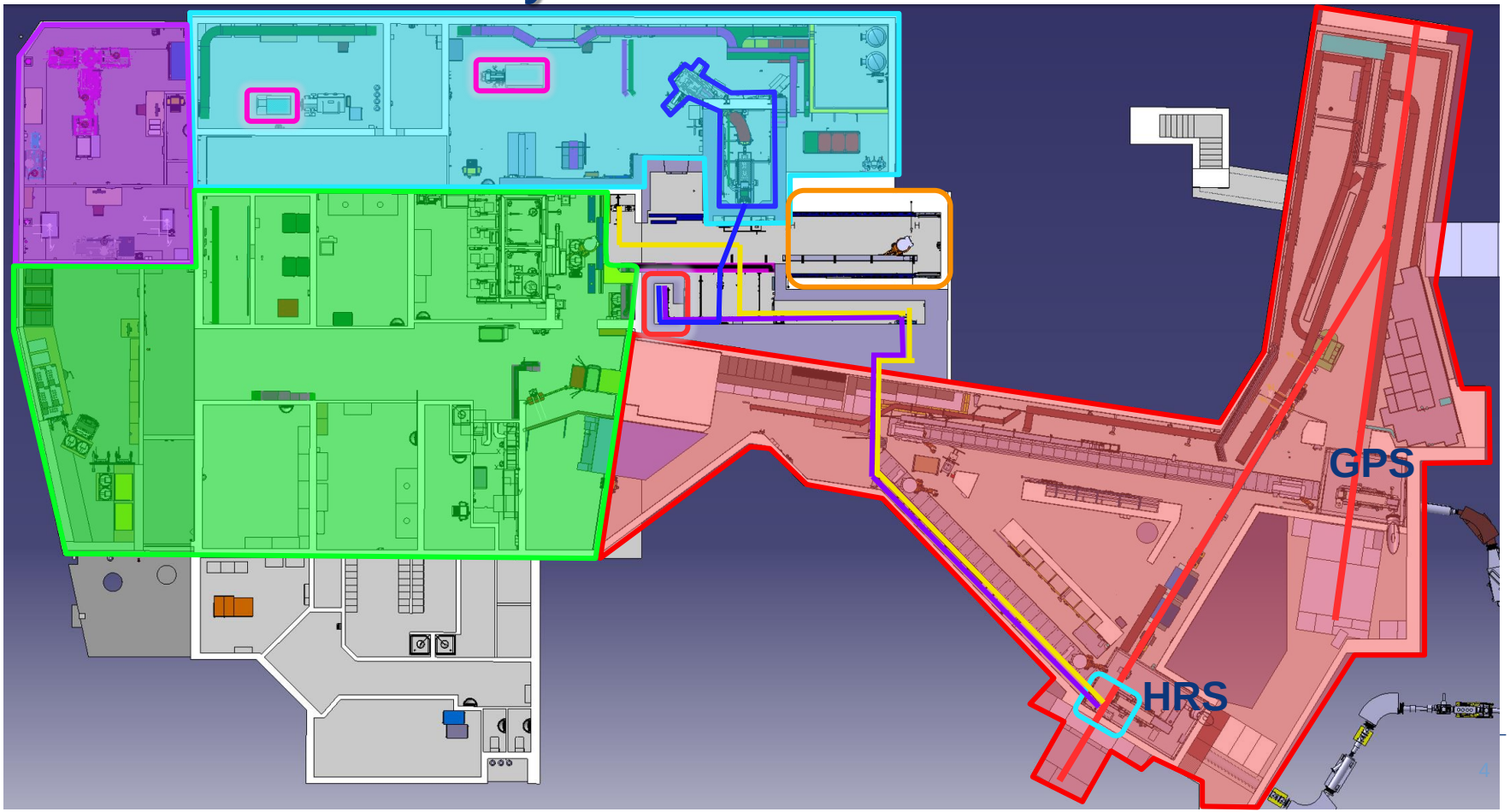


Radiochemistry

Pure Isotope

QC & Shipping

Class A Laboratory



Workflow → one prod. per week

!! During LS/when no protons at CERN: strong interaction with external collaborators to receive externally irradiated target materials

Irradiation defined and scheduled
3 to 6 months in advance

Involvement of logistics and shipping service to find the best means of transport
HSE-RP, SCE-SSC

Planification of the shipping & EDH request
2 months in advance

G-spectrometry request via TREC
2 months in advance
HSE-RP

Work and dose planning established with RP
2 months in advance
HSE-RP

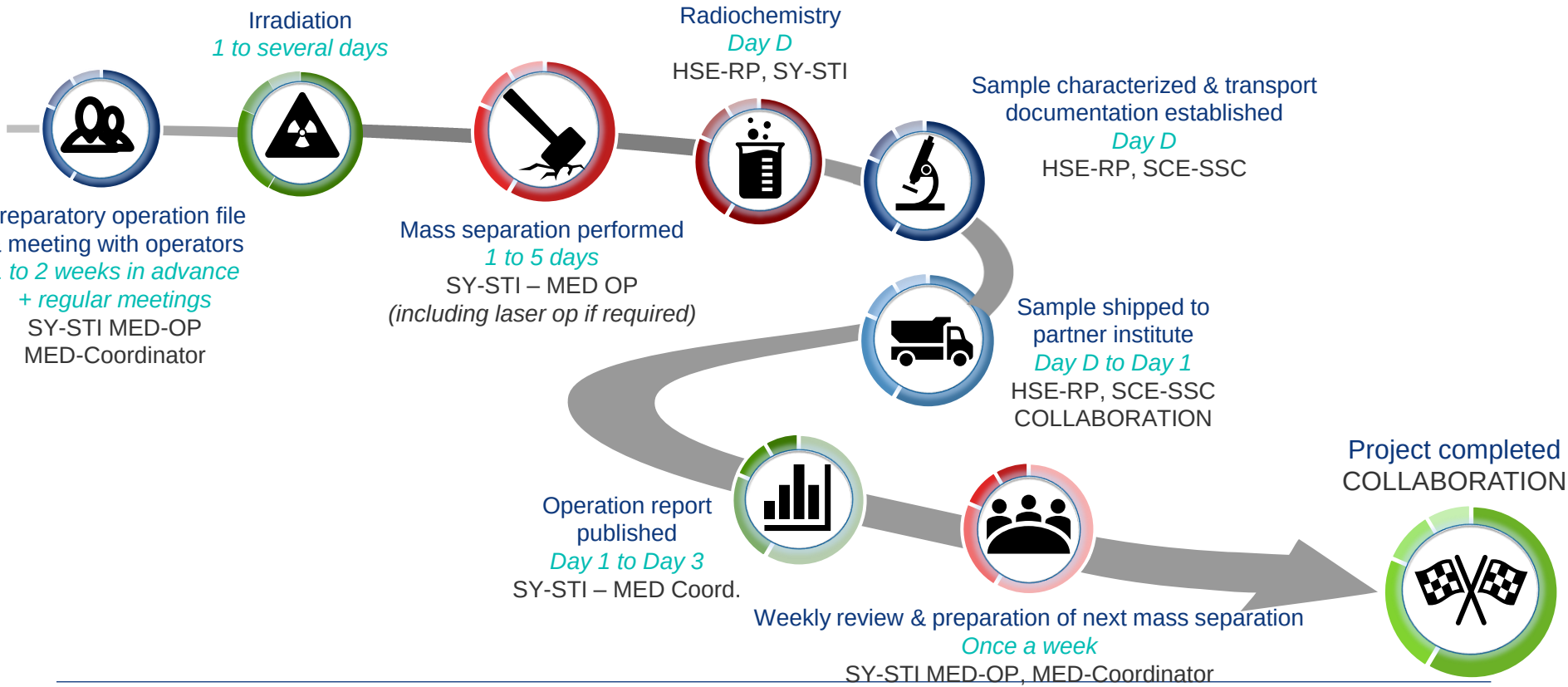
Request sent to remote handling team
1 month in advance and regular updates
BE-CEM

Interaction between MEDICIS coordinator, ISOLDE physics coordinator and ISOLDE operators

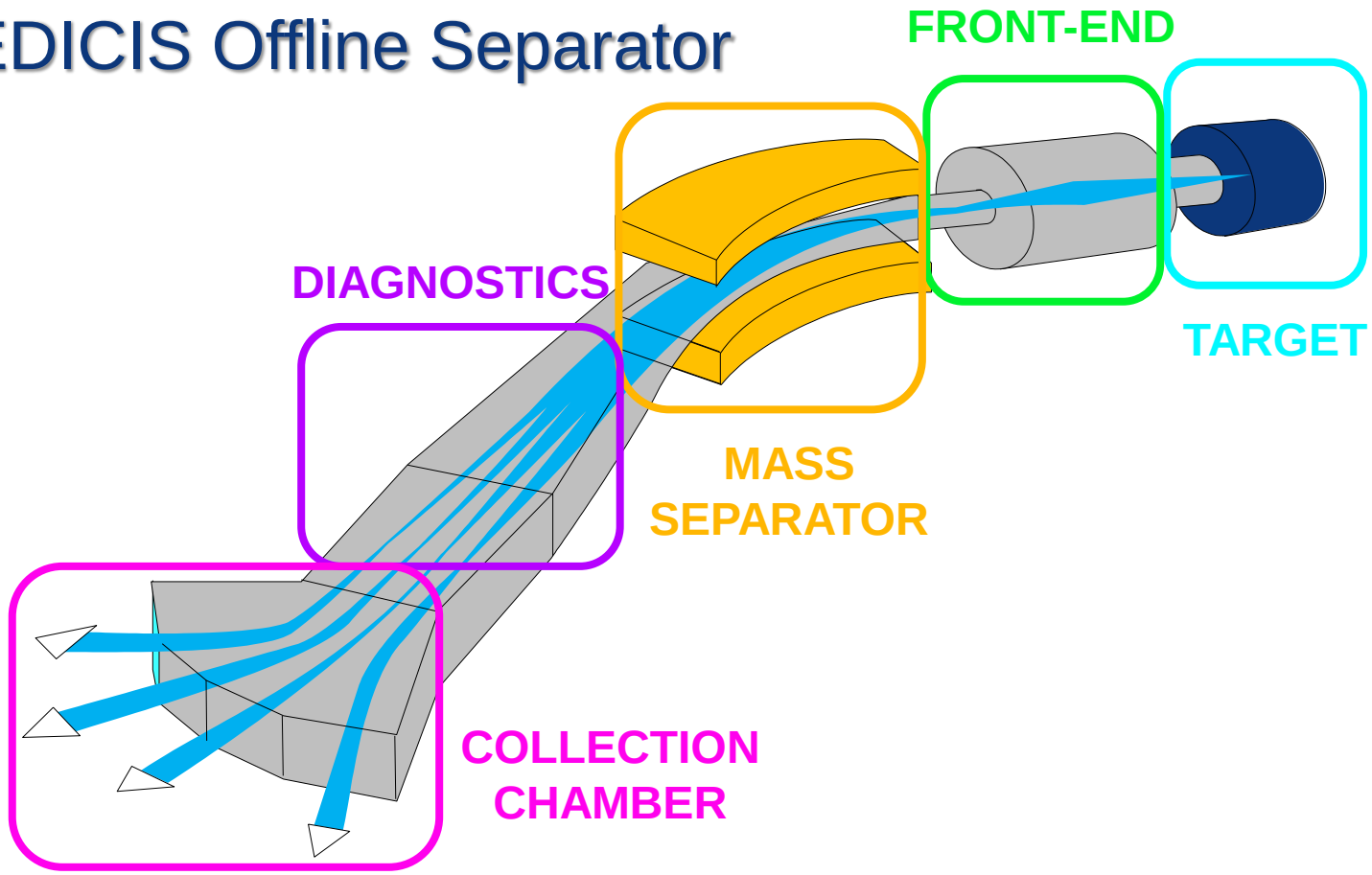
Operation planning
2 to 6 months in advance
SY-STI

Completely dependent of ISOLDE events & schedule

Workflow → one prod. per week



MEDICIS Offline Separator



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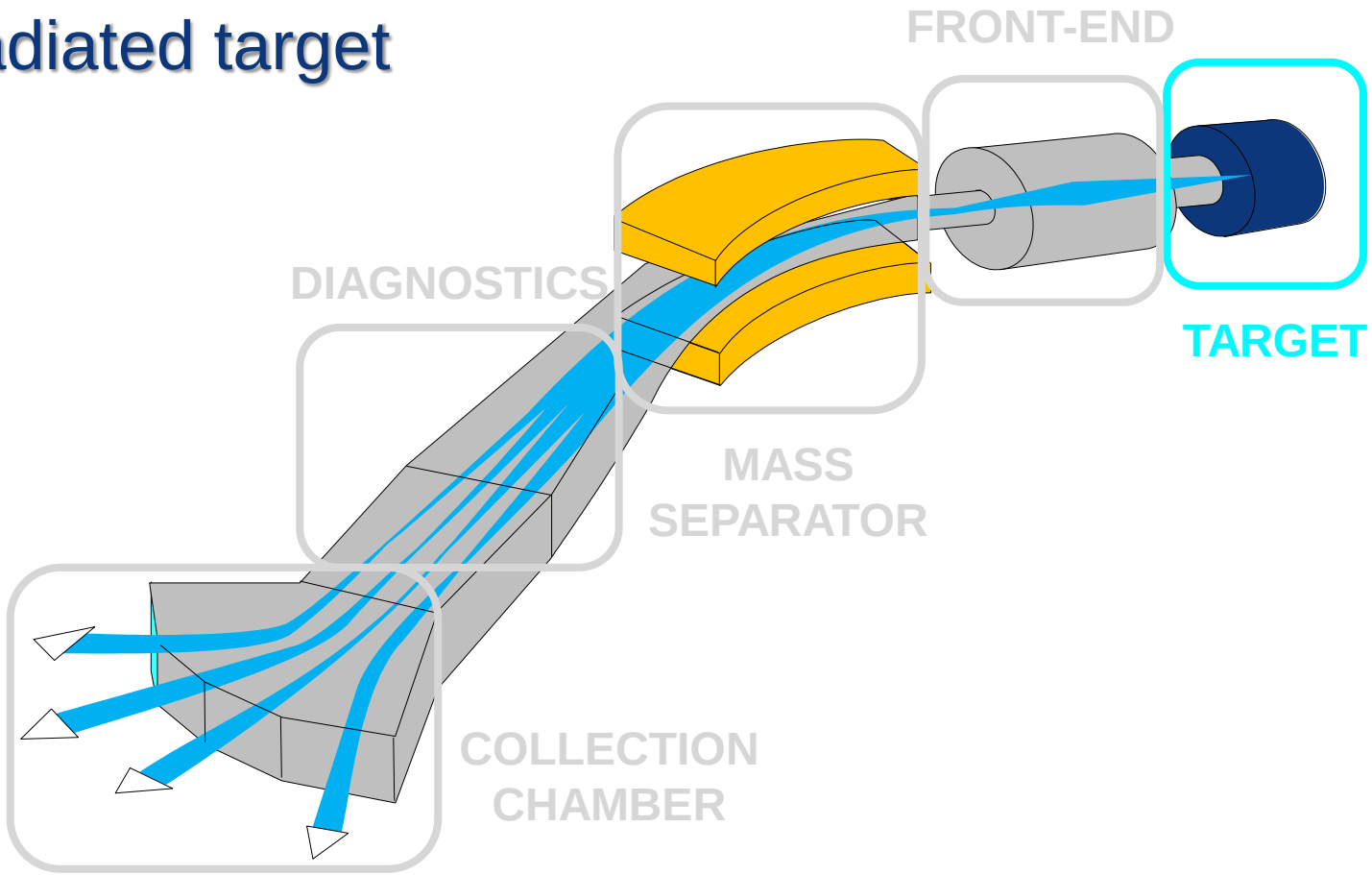
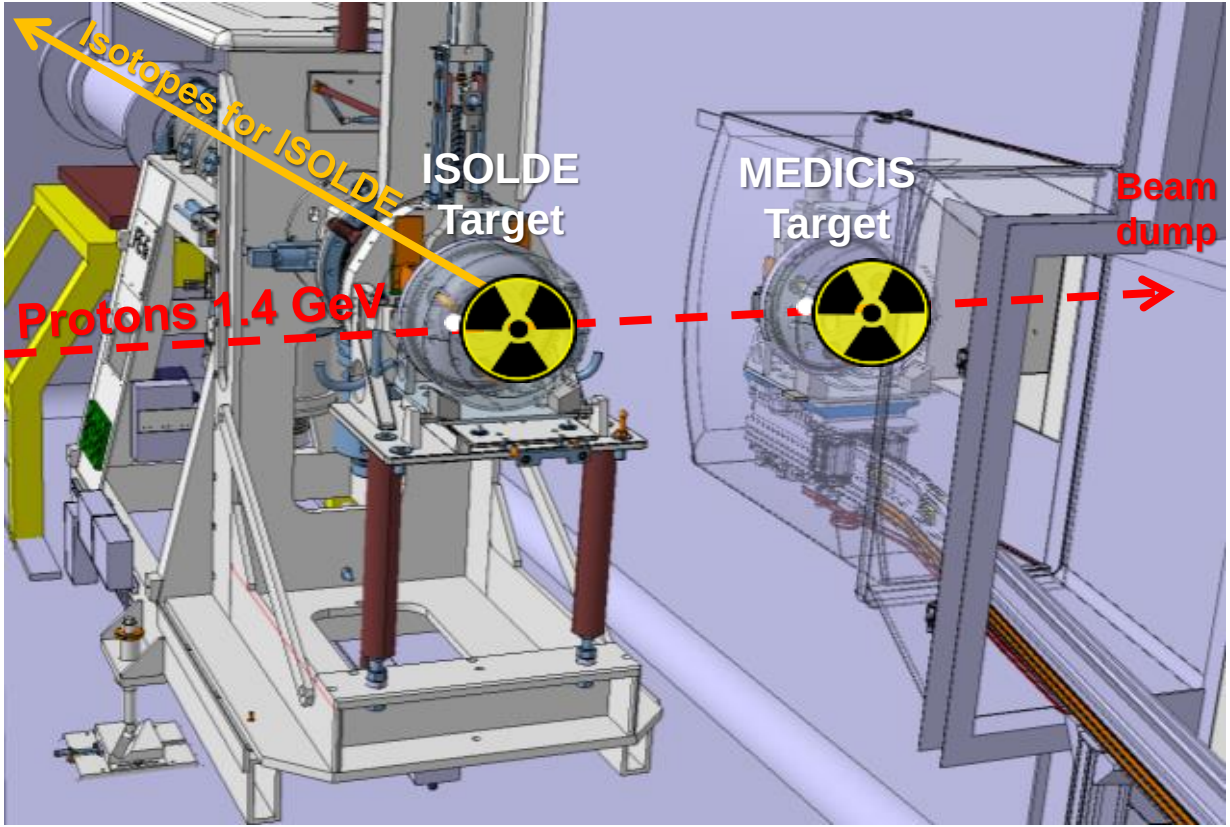
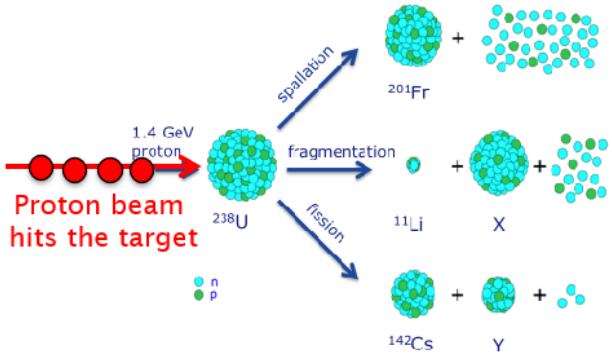
Irradiated target

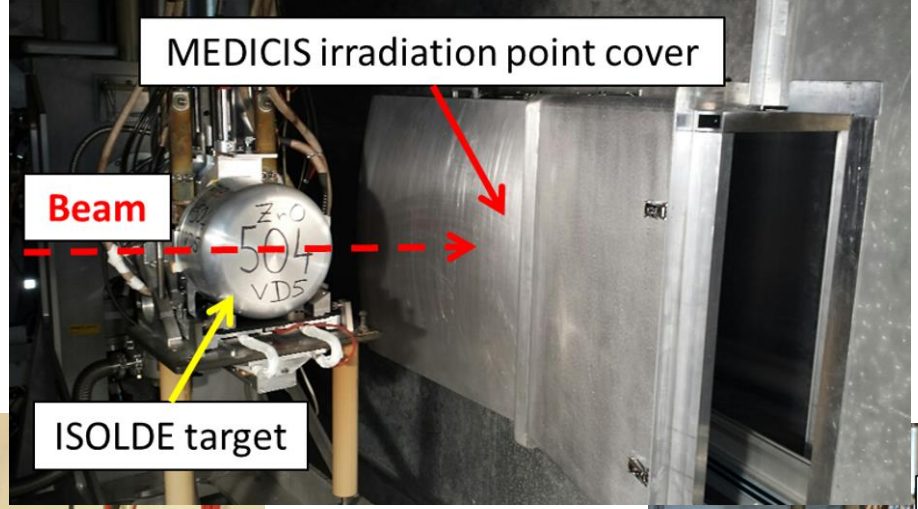


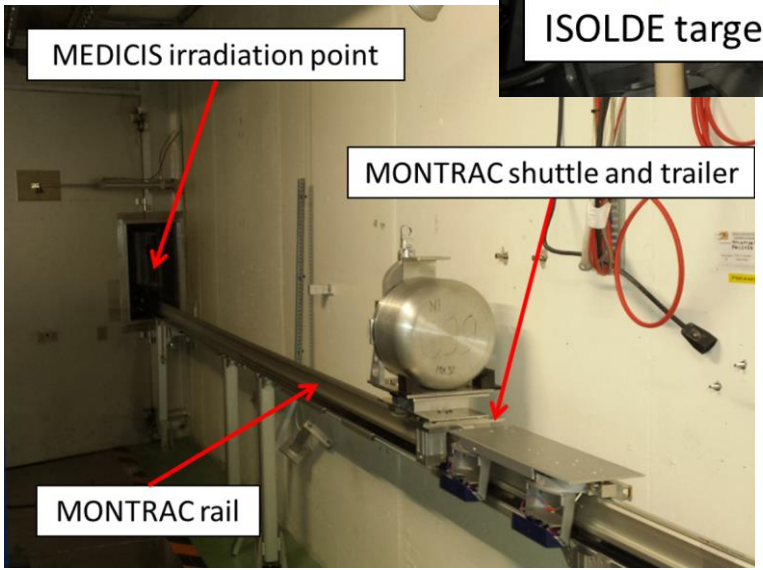
Target irradiation

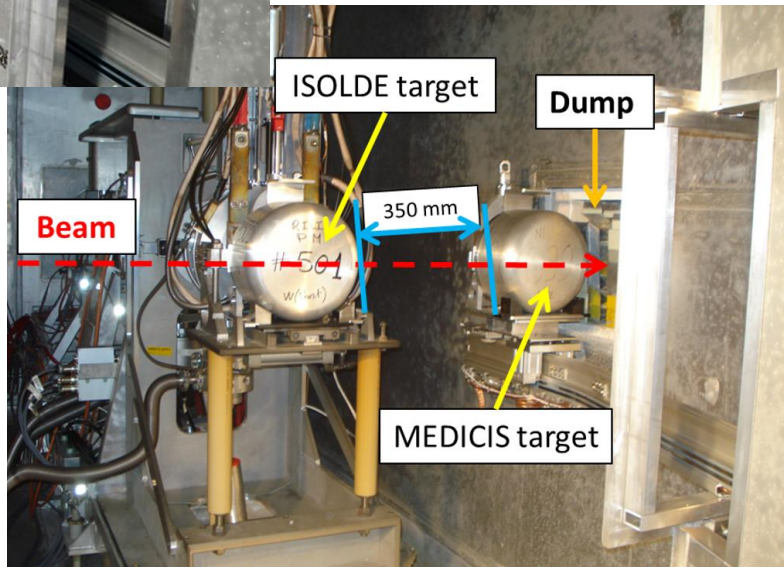




Target irradiation

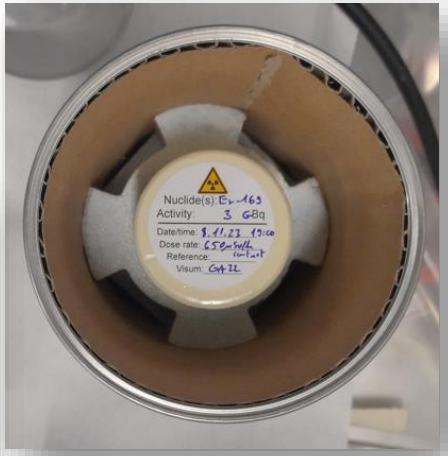


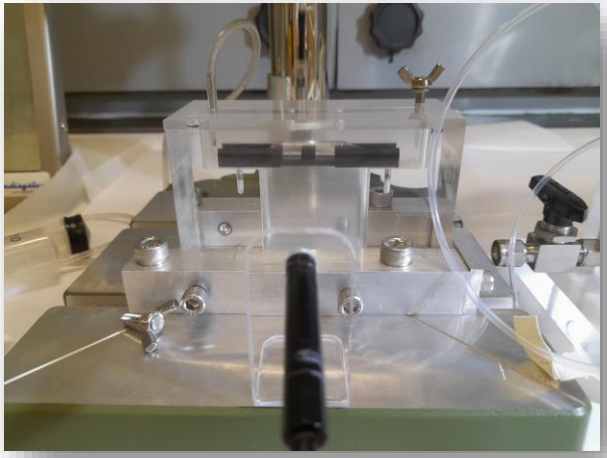


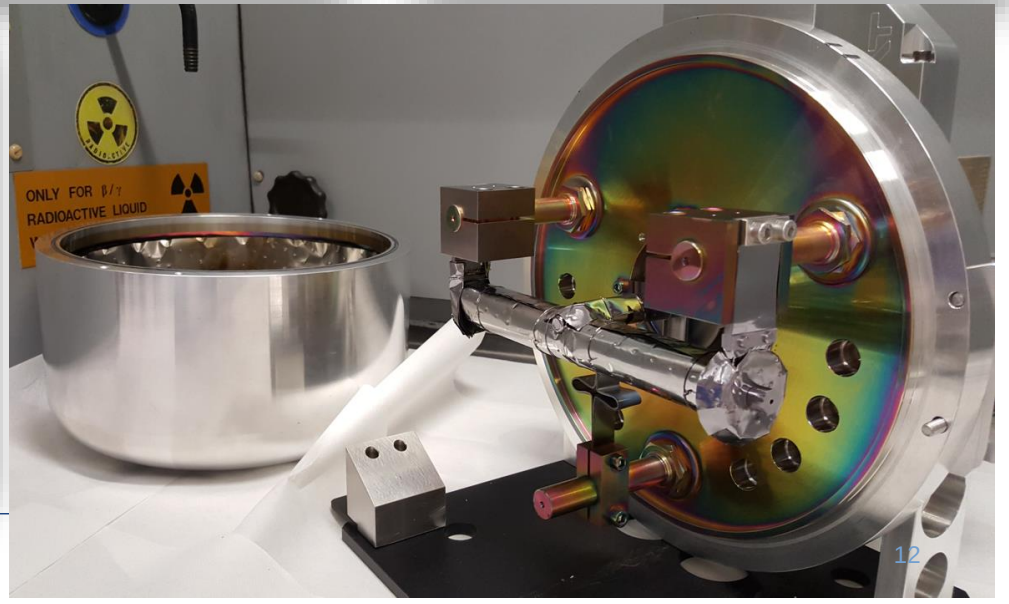


External Sources

- From partner institutes
- Only mode of operation when no proton beam







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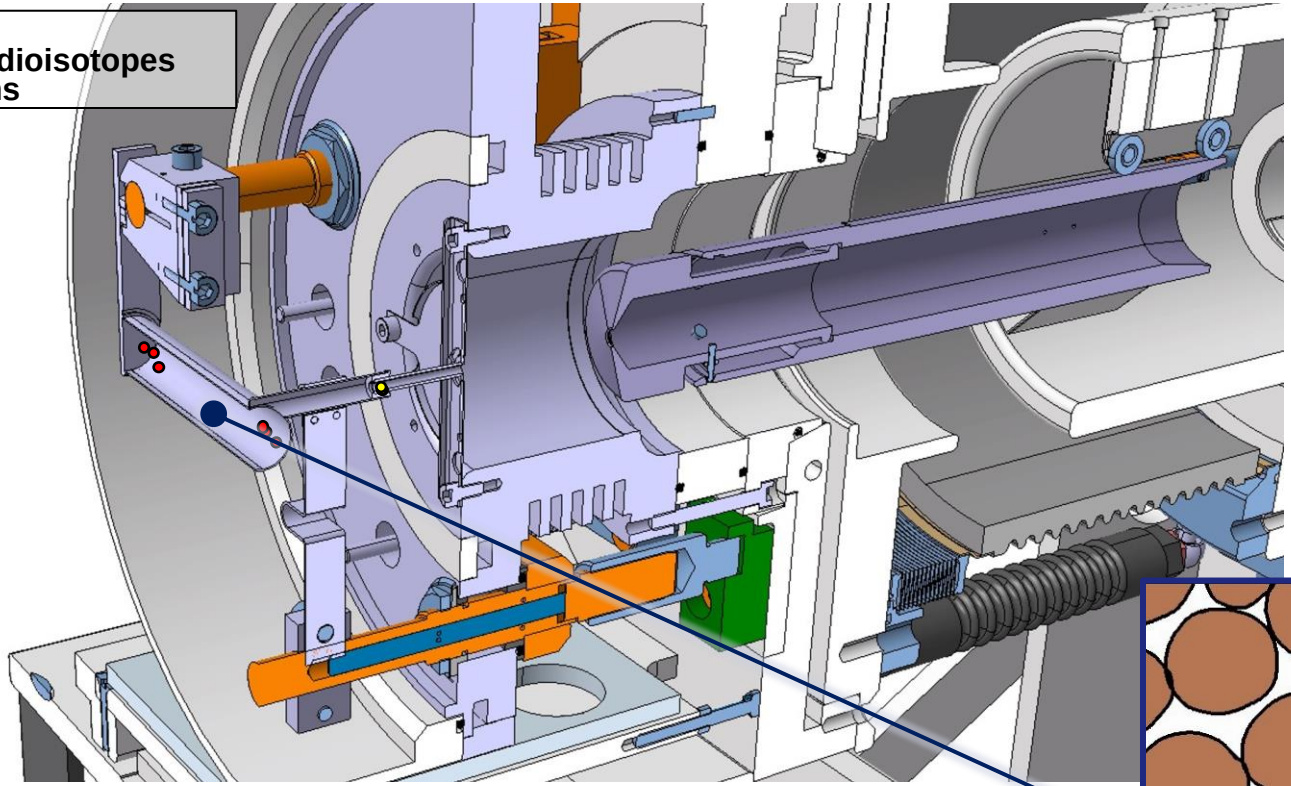
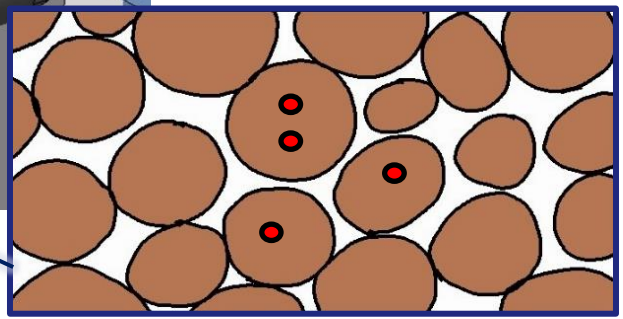
Radioisotopes
Ions

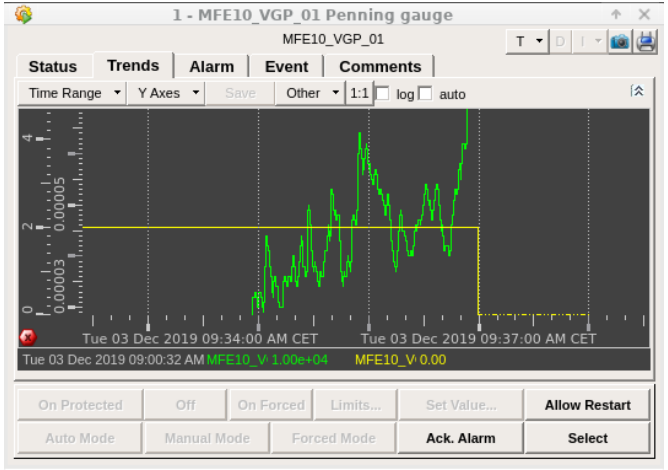


Standard ISOLDE target unit with **surface** ion source



Beam production

Fig 1. Target tripped



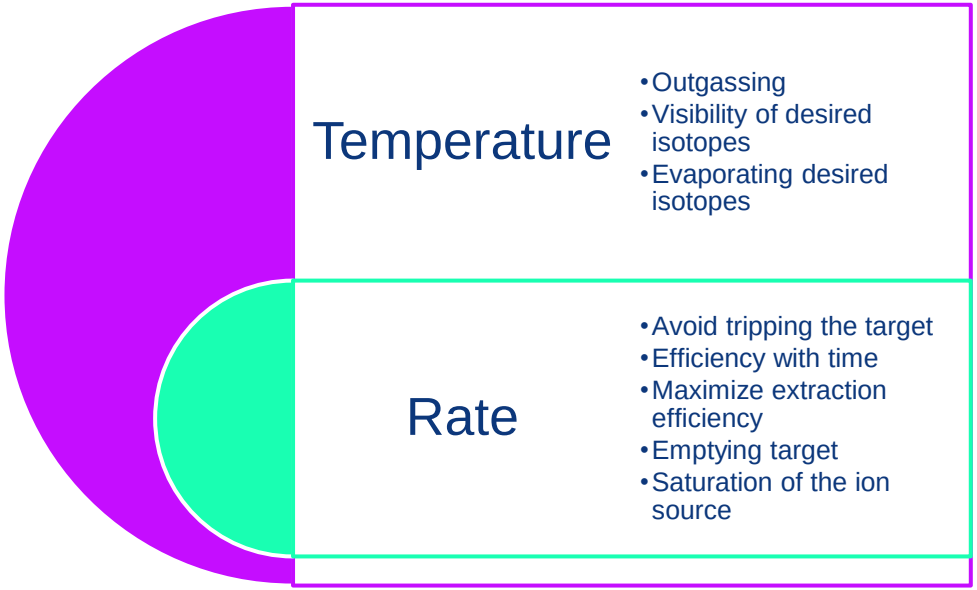
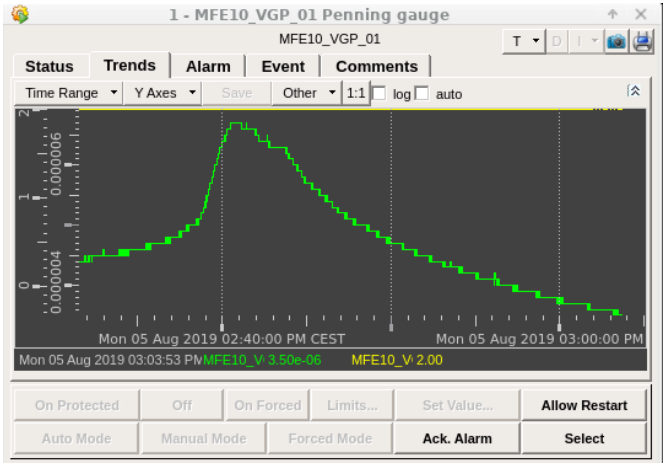
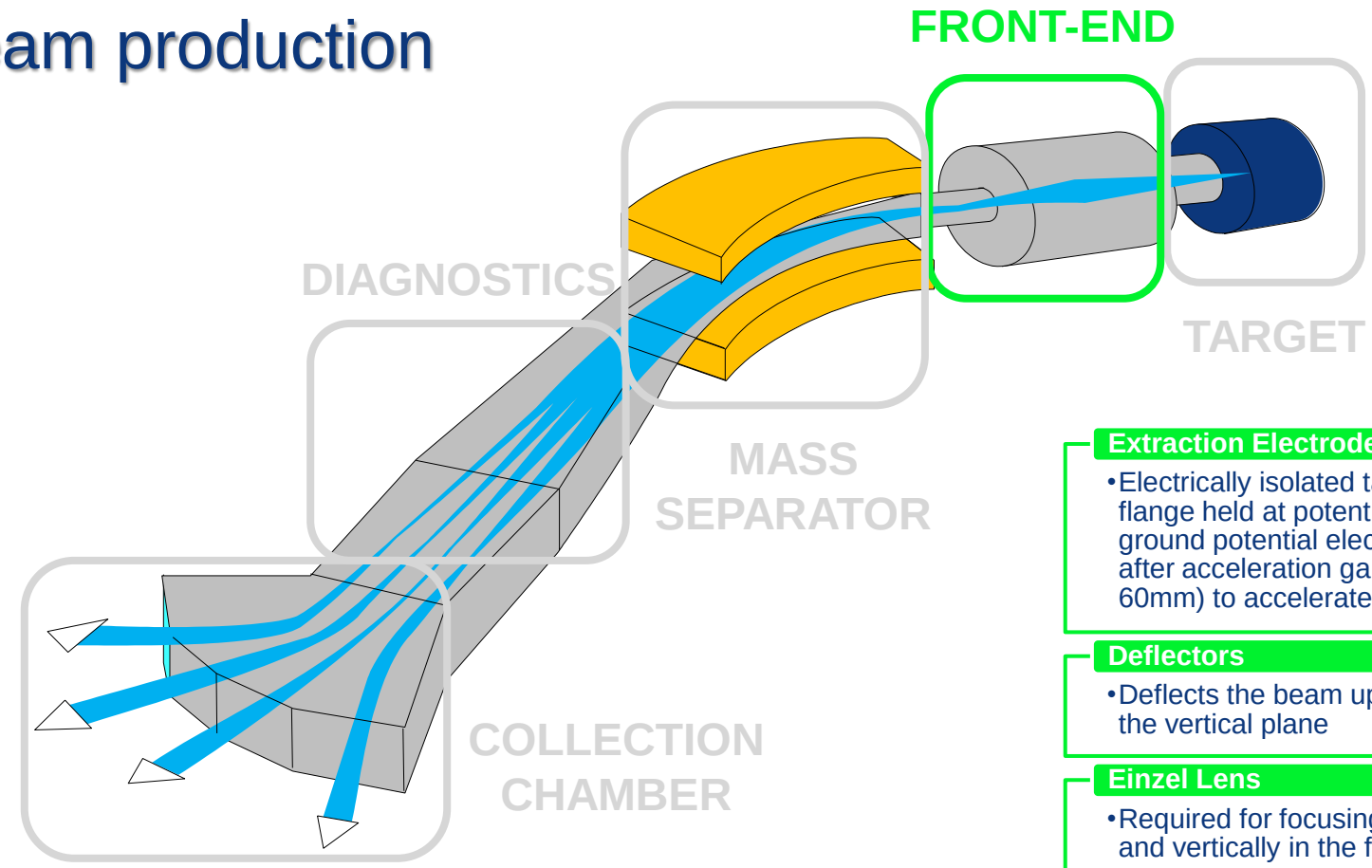


Fig 2. Optimised heating



Beam production



Extraction Electrode

- Electrically isolated target coupling flange held at potential of 60kV and ground potential electrode placed after acceleration gap (typically 60mm) to accelerate ions

Deflectors

- Deflects the beam up or down in the vertical plane

Einzel Lens

- Required for focusing horizontally and vertically in the focal plane

Beam production

Why do we have beam optics?

What are some beam production limitations?

Beam production

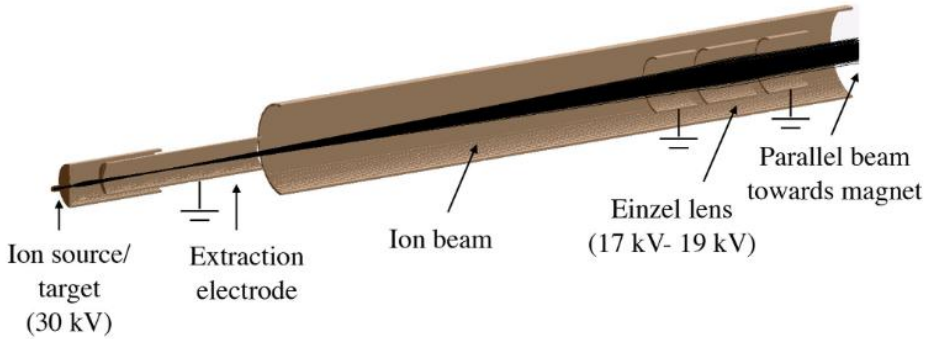


FIGURE 4 | Geometry of the MEDICIS beamline simulated with SIMION showing the electromagnetic elements included in the simulations. The black lines show the charged particle trajectories.

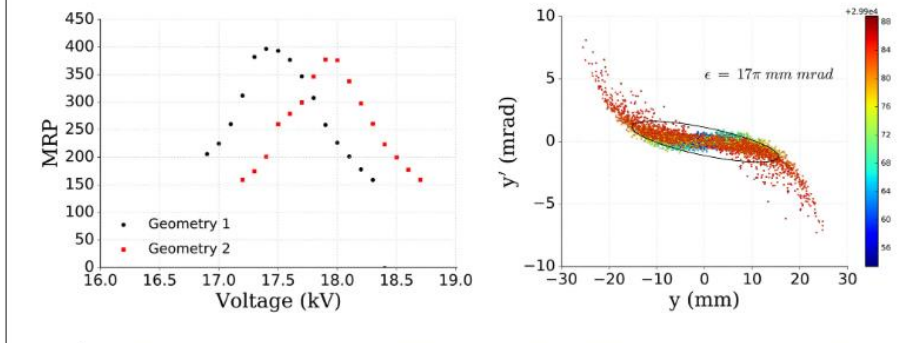
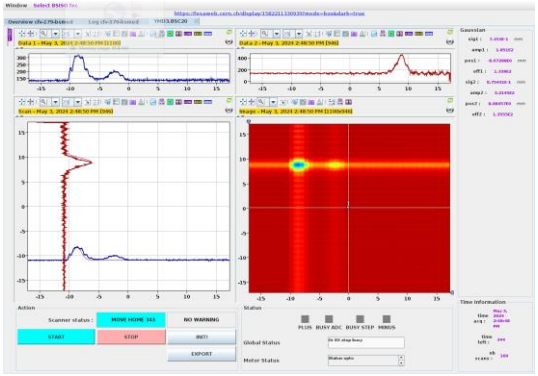


FIGURE 5 | MRP vs. einzel lens voltage for geometry 1 (black circles) and geometry 2 (red squares). These geometries differ in the position of the einzel lens within the beamline, geometry 2 having the einzel lens further away from the ion source **(Left)**. Beam emittance for geometry 2 (final geometry) with the ellipse encompassing 95% of the simulated events. The colorbar is the energy range of the particles: 2.99e4 + 0.0056 keV to 0.0088 keV **(Right)**.

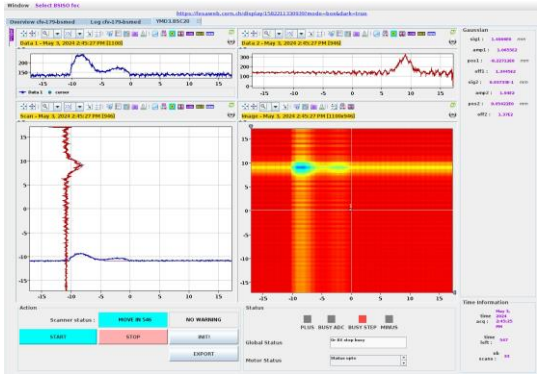
Reference: Y. Martinez, et al. The CERN-MEDICIS Isotope Separator Beamline. *Front. Med., 8 (2021), Article 689281*

Beam production → extraction electrode

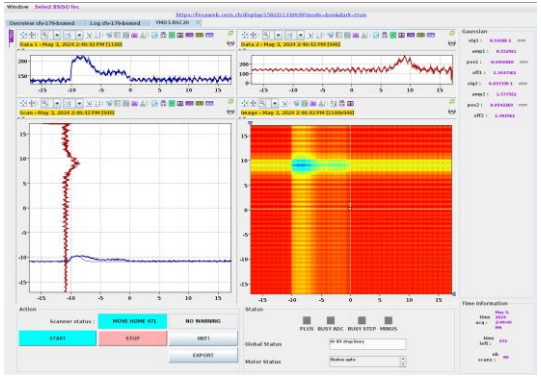
60mm



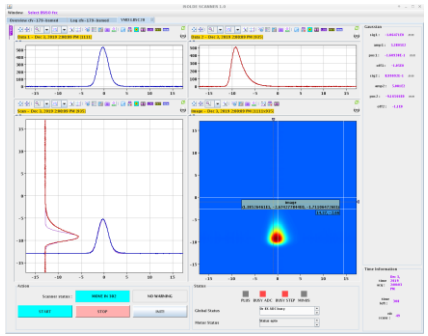
65mm



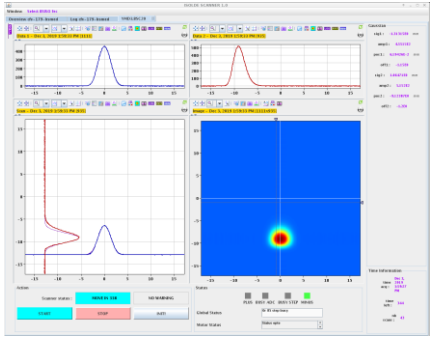
70mm



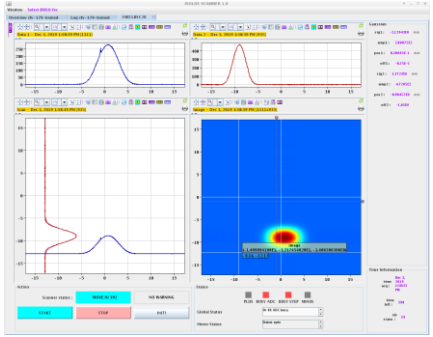
55mm



60mm

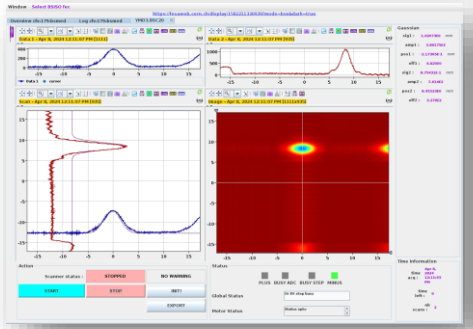


70mm

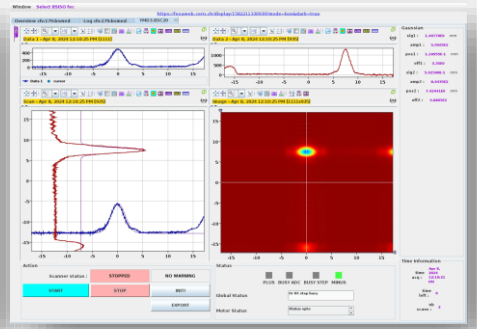


Beam production→einzel lens

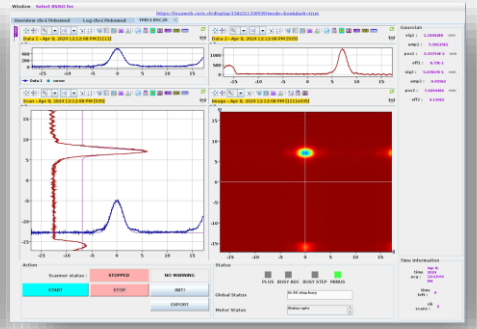
22 kV



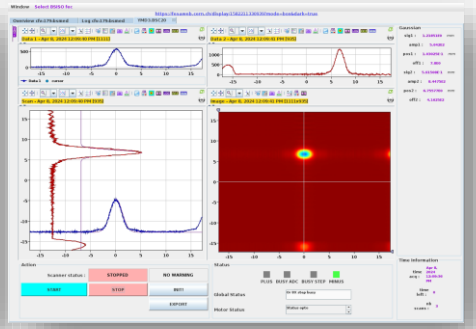
22.5 kV



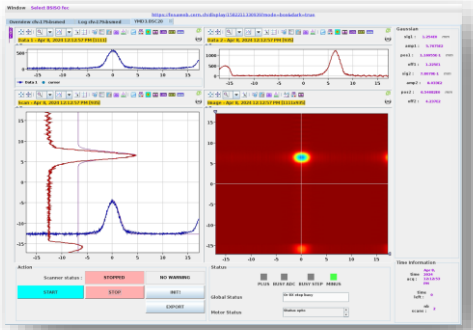
22.75 kV



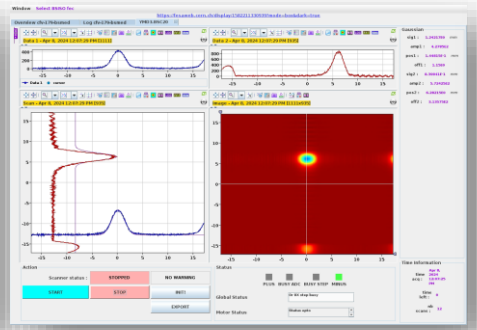
23 kV



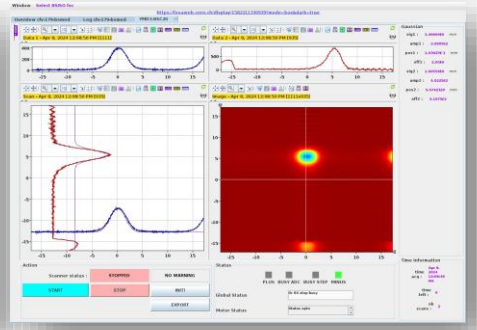
23.25 kV



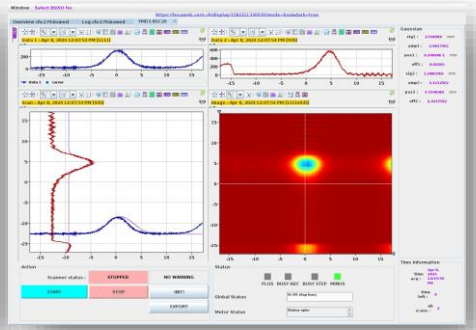
23.5 kV



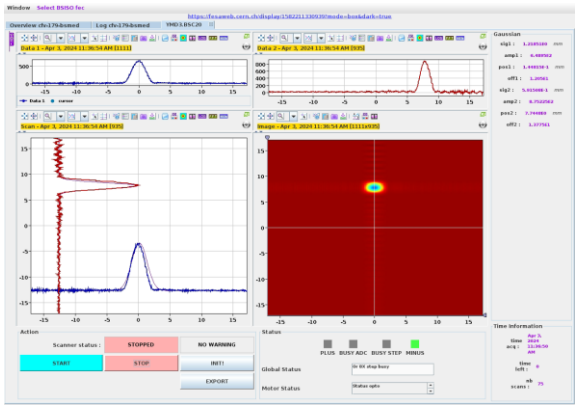
24 kV



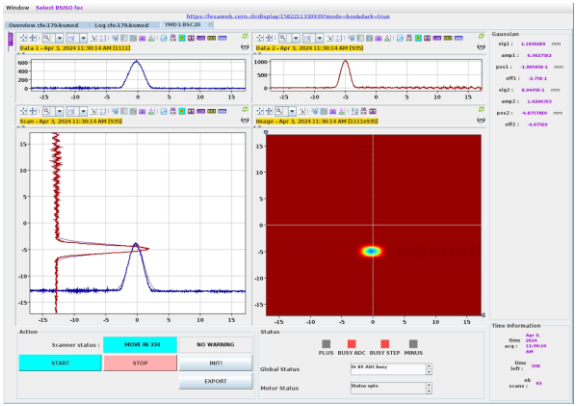
24.5 kV



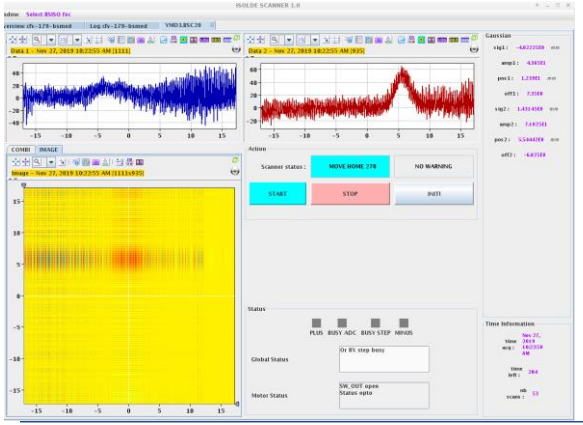
Beam production → deflectors



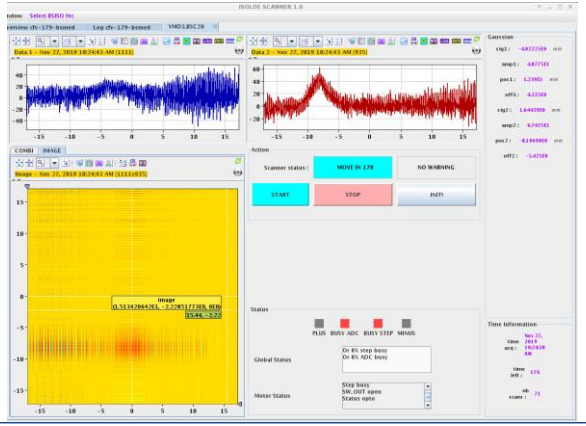
+/- 250 V



0 V

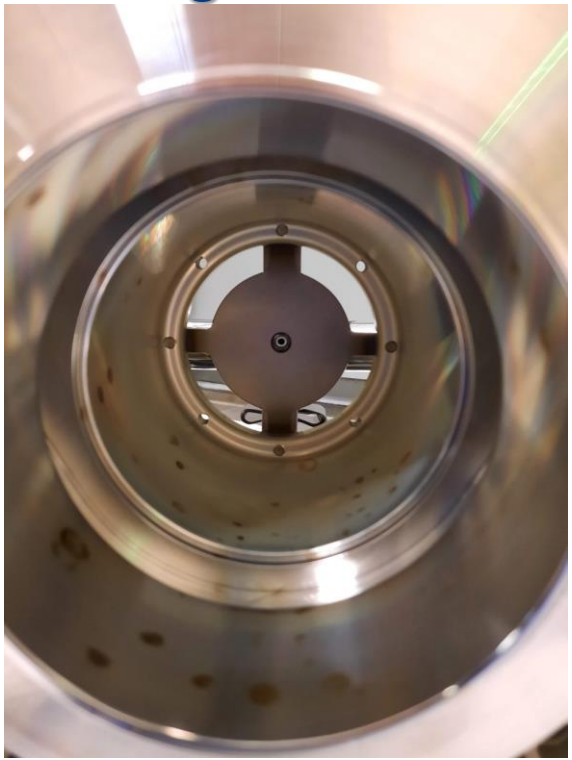


+/- 250 V



0 V

Beam production → finding the limits



The importance of interlocks

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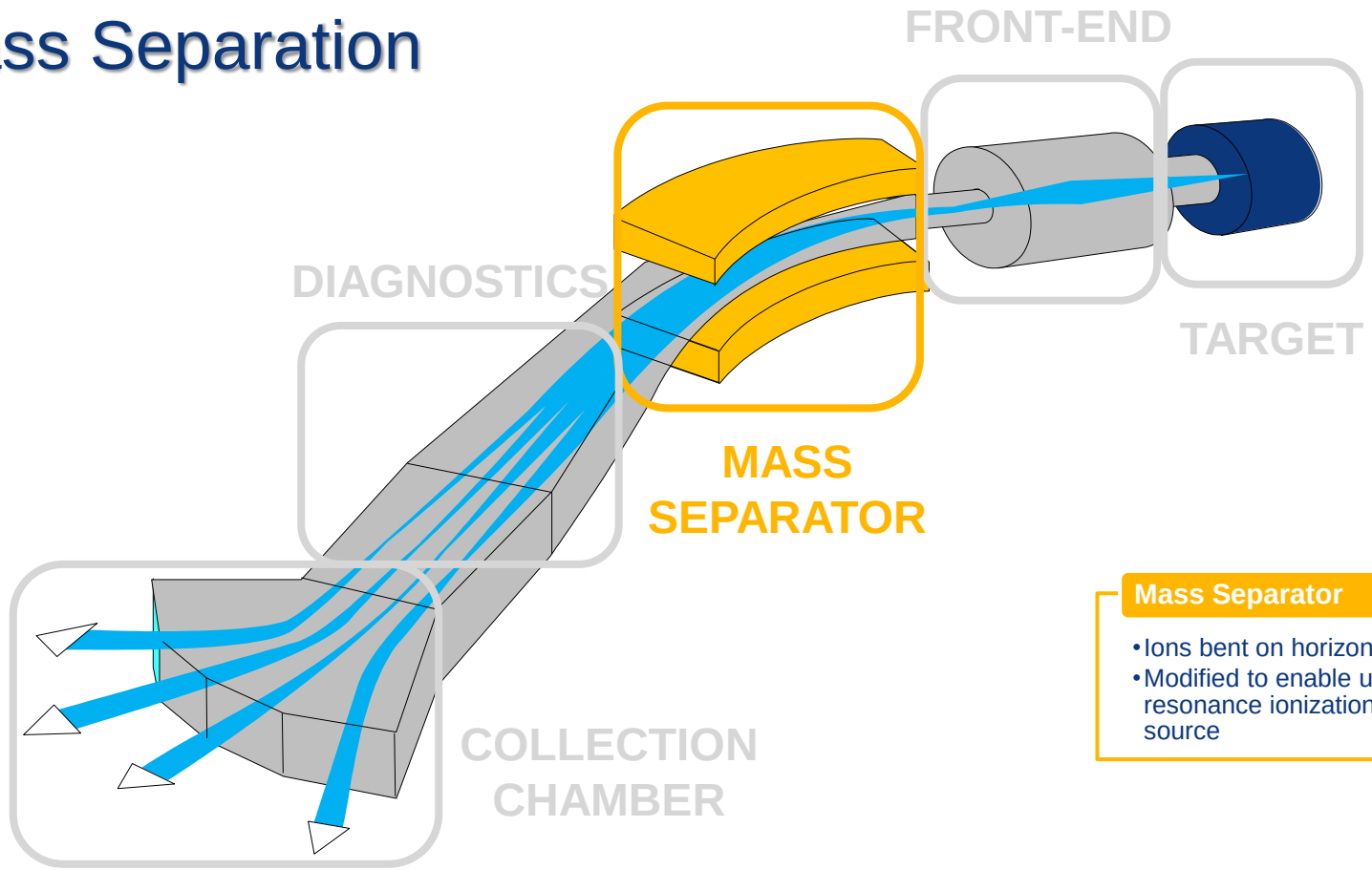
Mass Separation



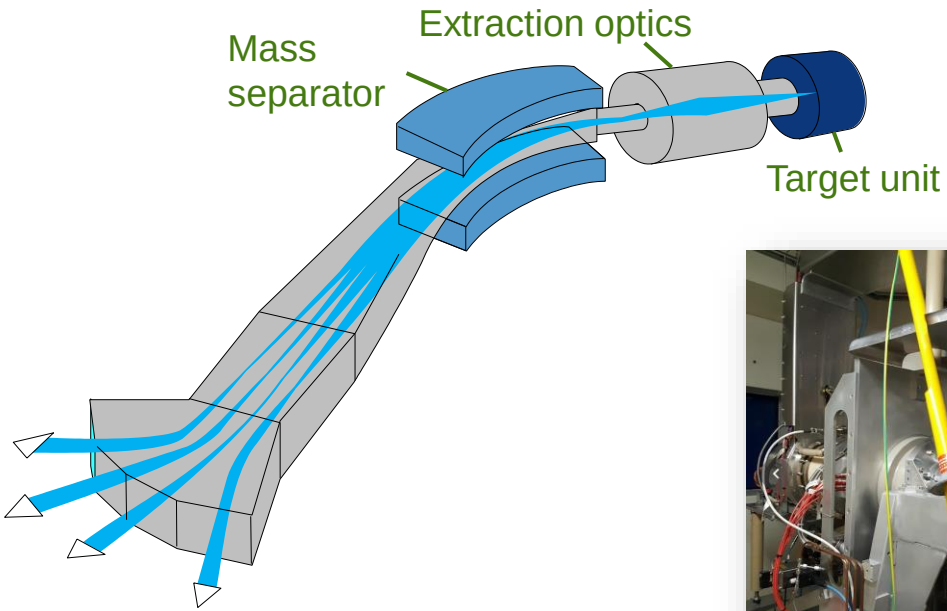
Mass Separator

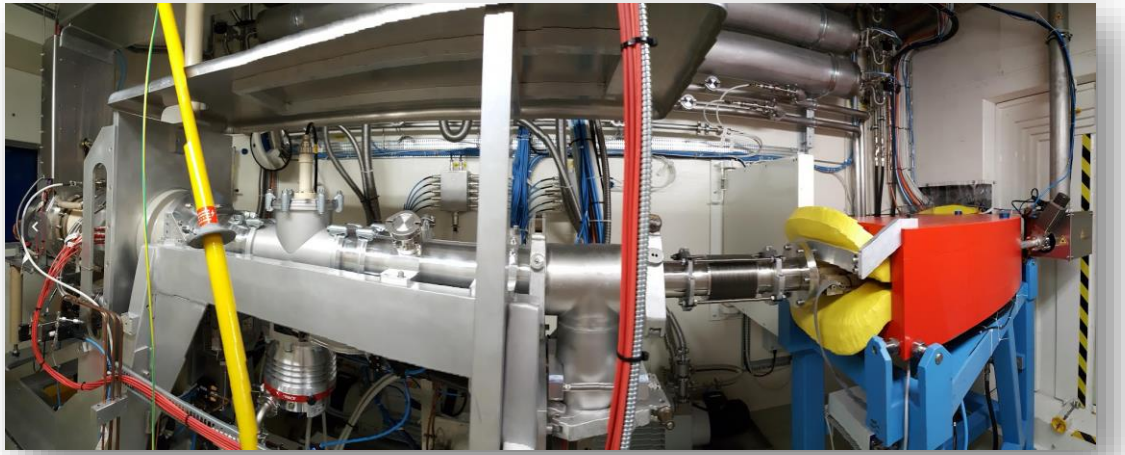
- Ions bent on horizontal plane
- Modified to enable use with a resonance ionization laser ion source

Mass Separation

Why do we require mass separation?

Mass separation



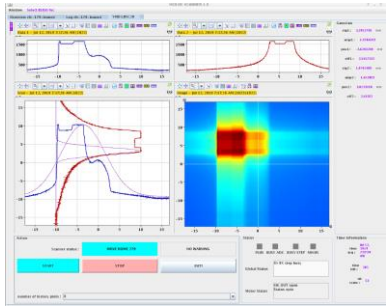
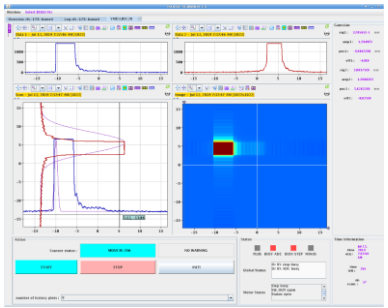
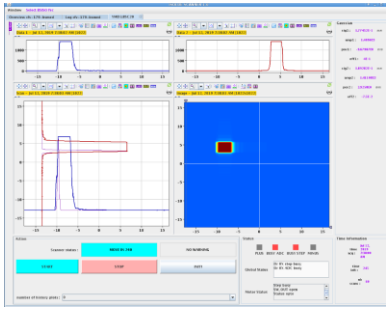
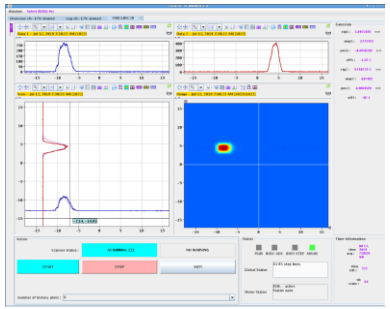


Mass Separation

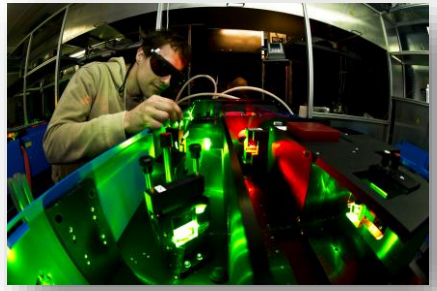
Contaminants:
Profiles of mass 168 with different sensitivities, mass 169 centered
→ cross contamination of stable Er168 on Er169 collection

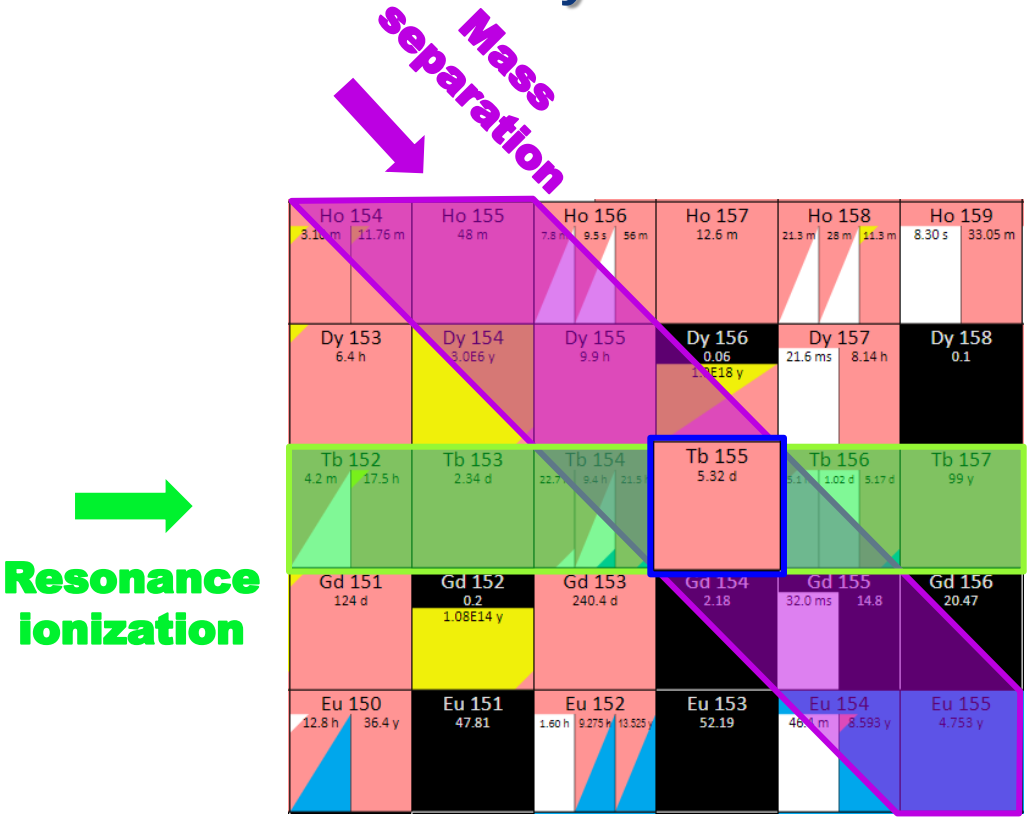
$$^{168}Er\ (n, \gamma) \rightarrow\ ^{169}Er$$
1000 : 1

Less sensitivity → More sensitivity

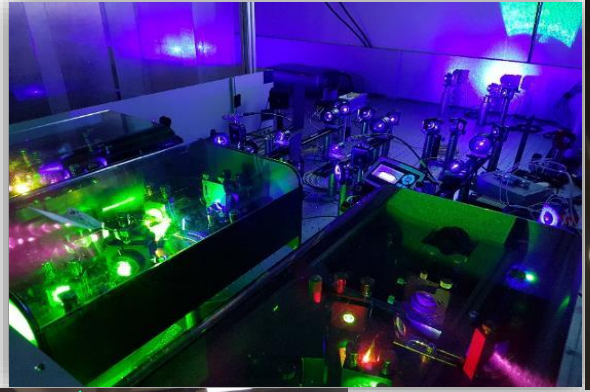





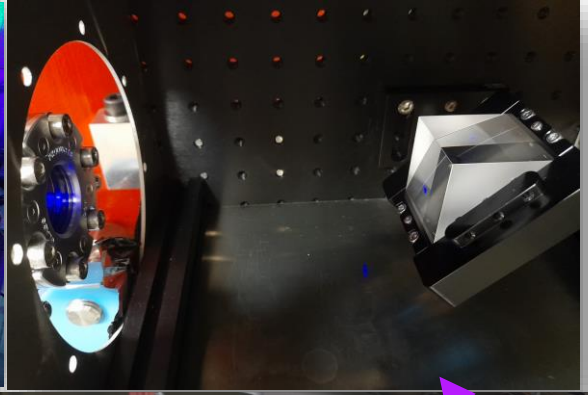
Radionuclide selectivity

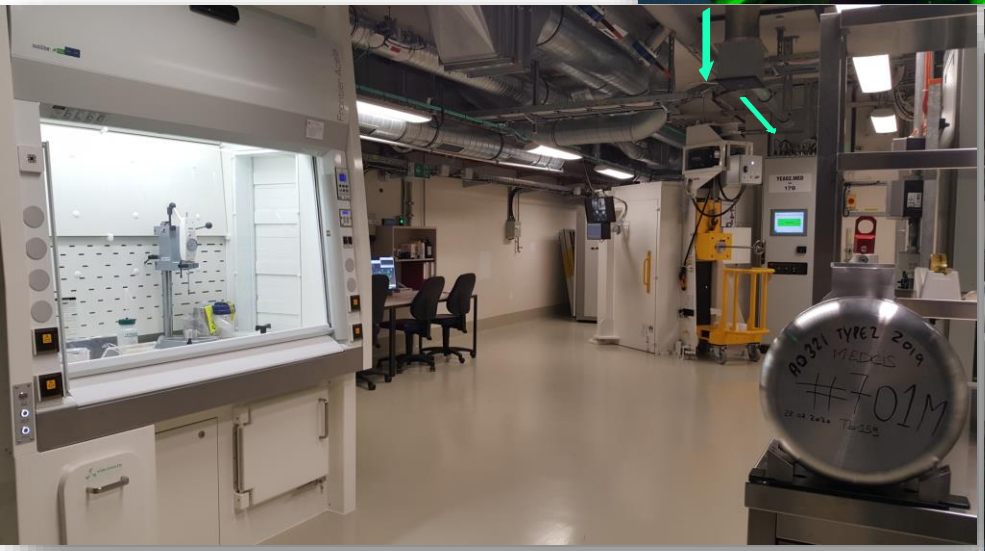


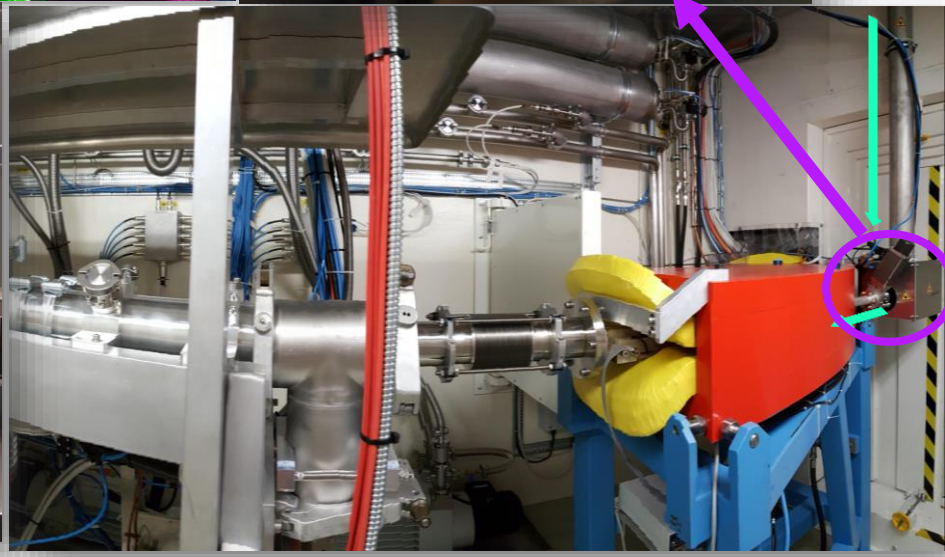


MELISSA



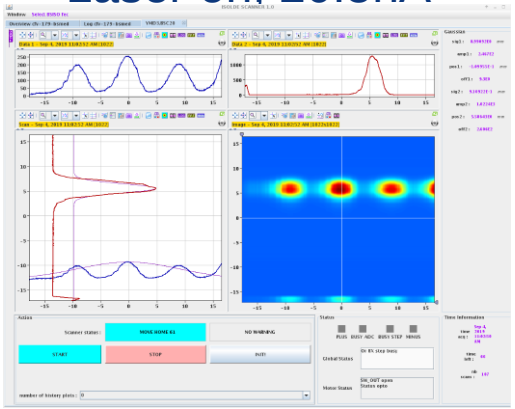


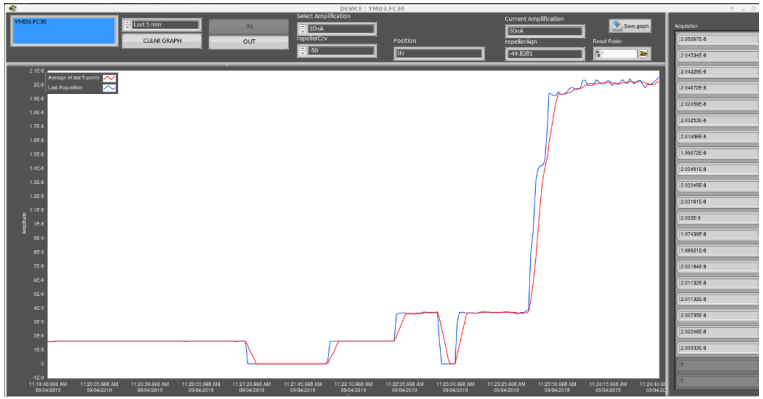




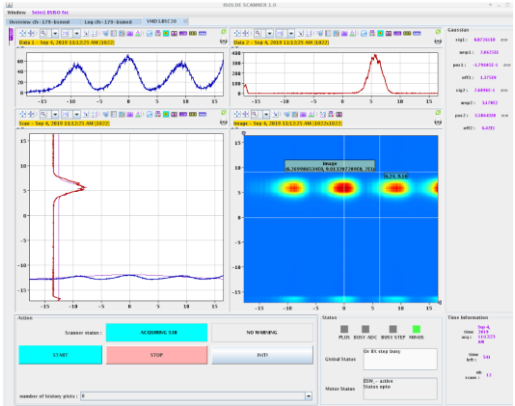
Beam optimisation

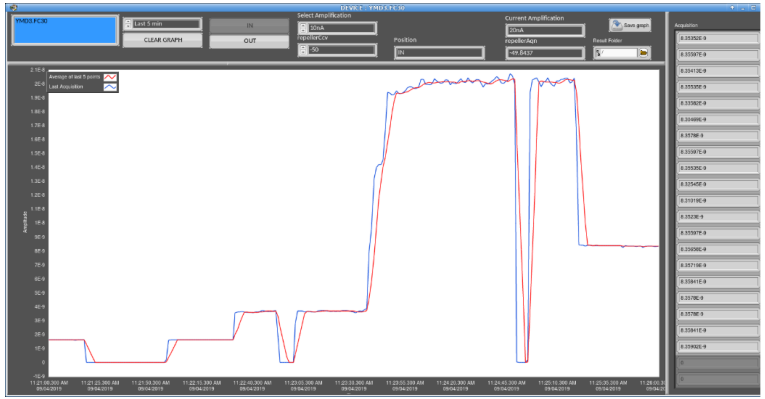
Laser on, 20.5nA





Laser off, 8.3nA

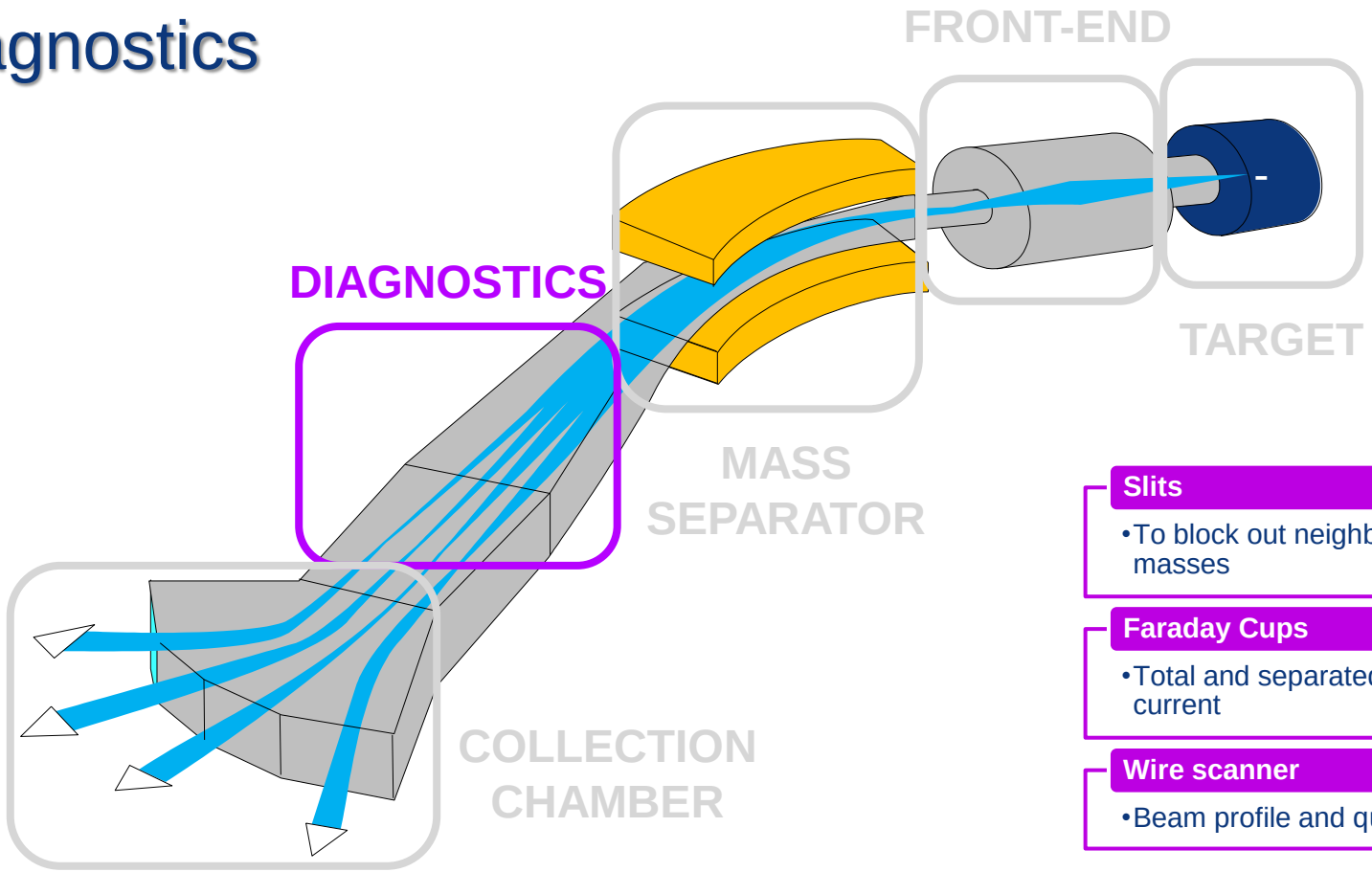




Summary

- Overview
- Irradiated target
- Beam production
- Mass separation
- **Diagnostics**
- Retrieval and shipping

Diagnostics



Slits
- To block out neighboring masses

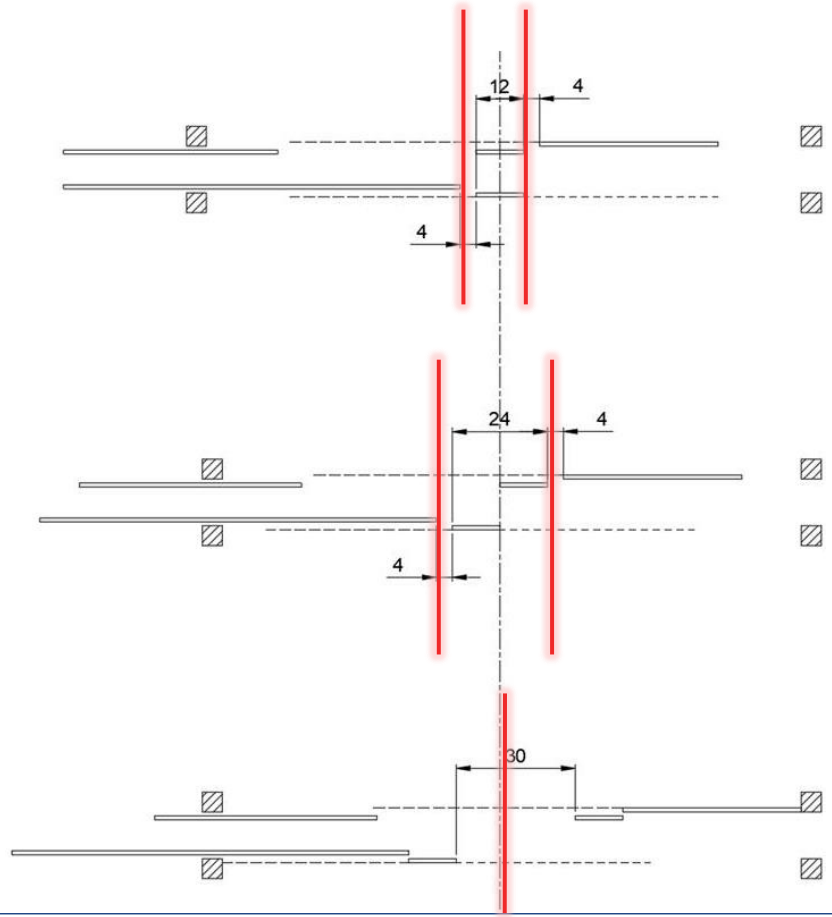
Faraday Cups
- Total and separated beam current

Wire scanner
- Beam profile and quality

Diagnostics

Why do we need beam diagnostics?

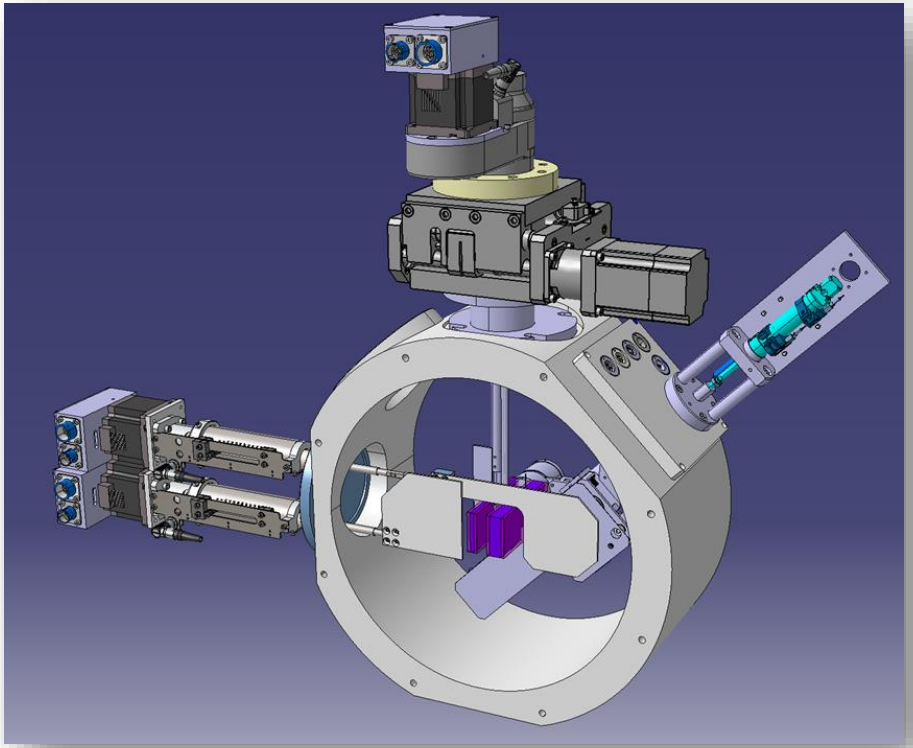
Slits



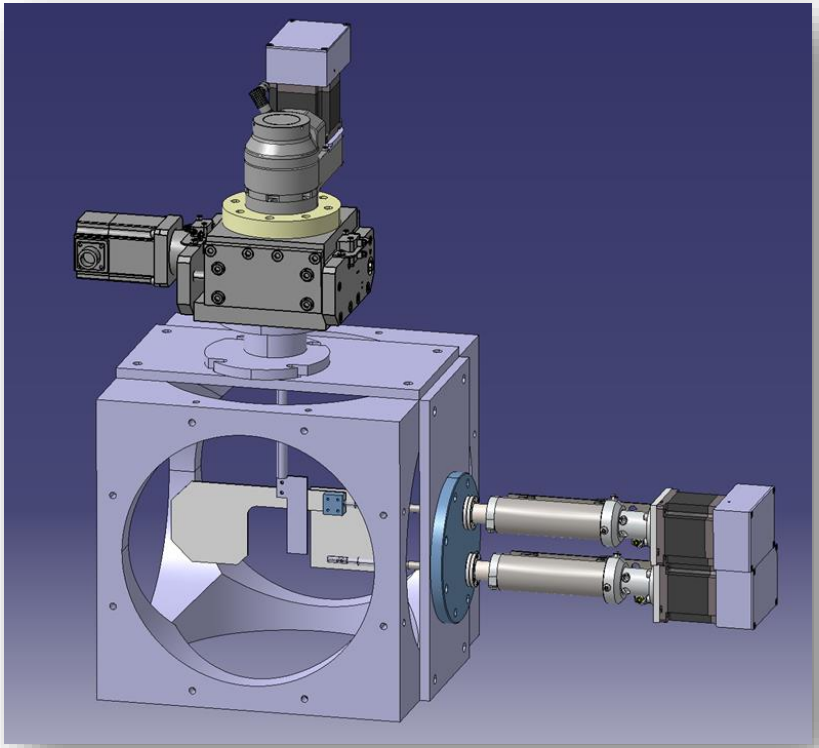
- Example: 225Ac, 227Ac

- Example: 44Sc, 47Sc
- 149Tb, 152Tb
- 152Tb, 155Tb

Slits



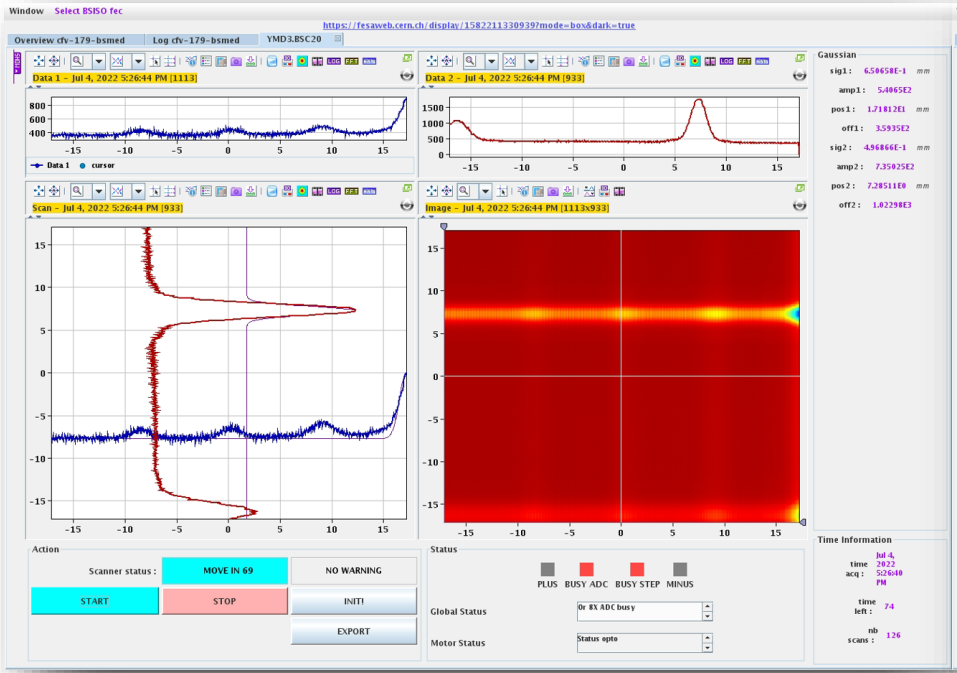
Diagnostic box – slit system

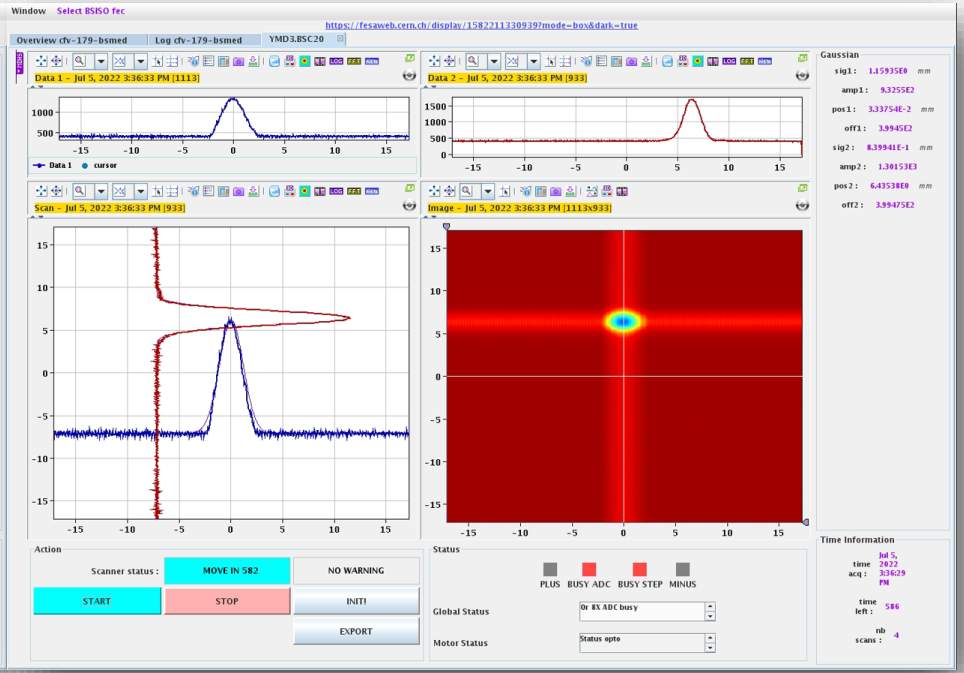


Test bench

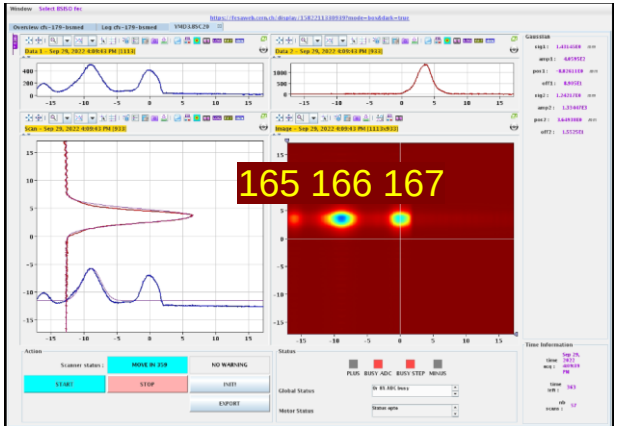
Slits

155-Tb centered

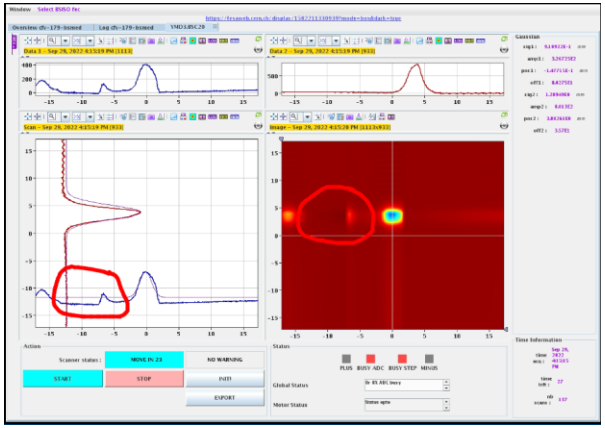


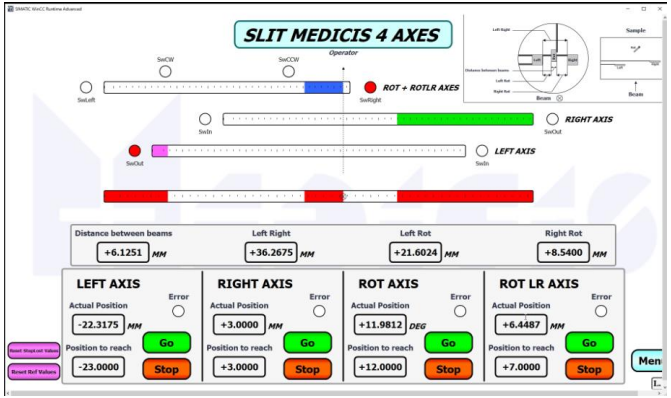


Slits

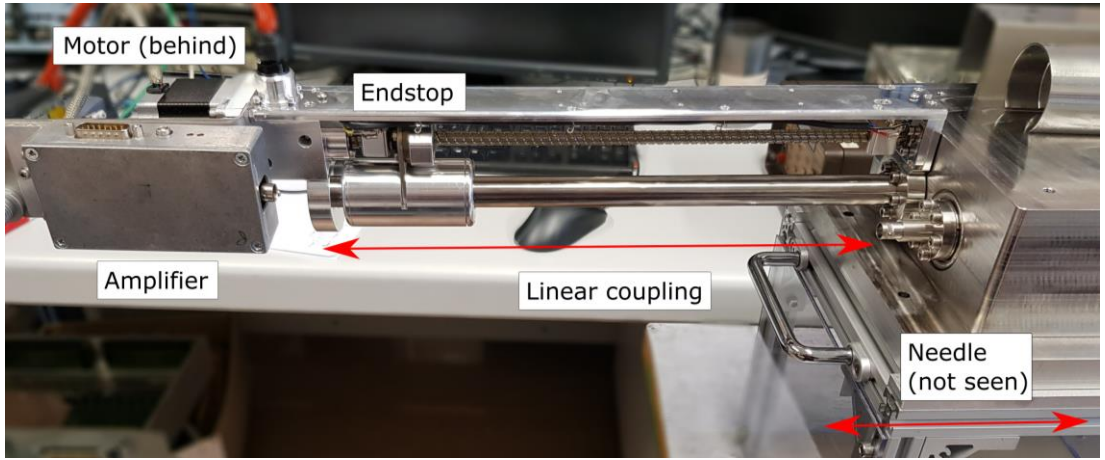


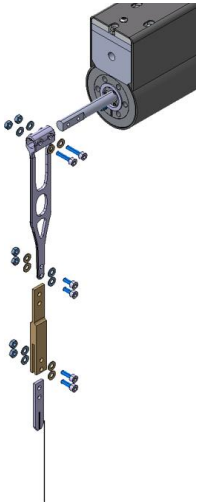
167-Tm
centered

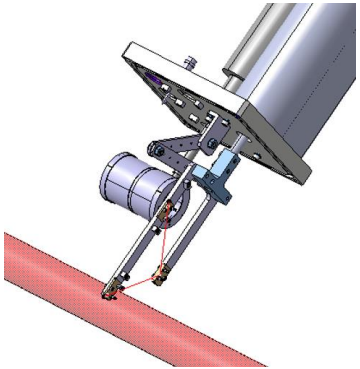


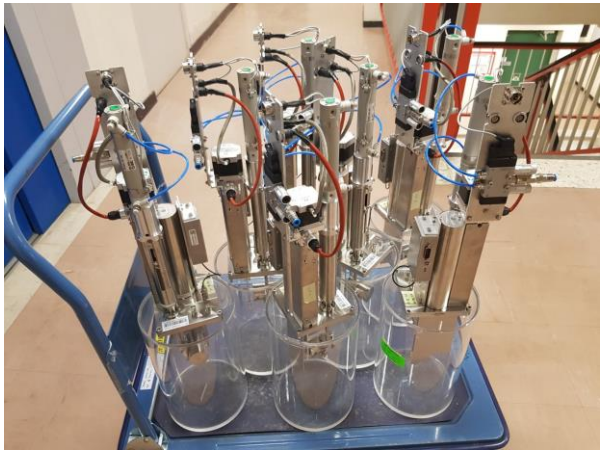


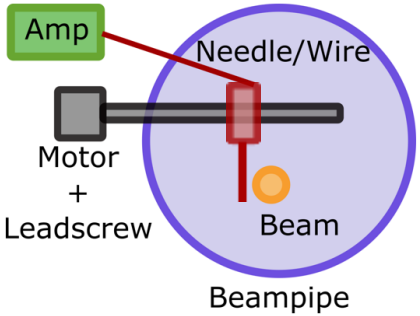
Diagnostics

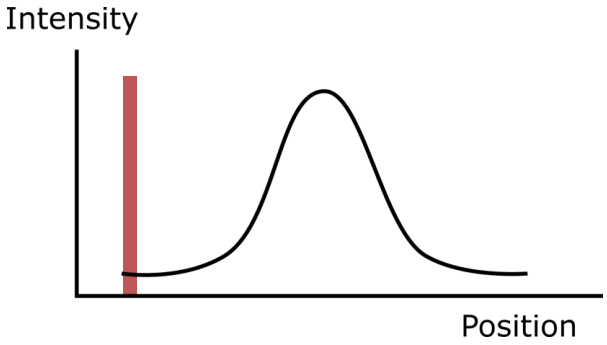




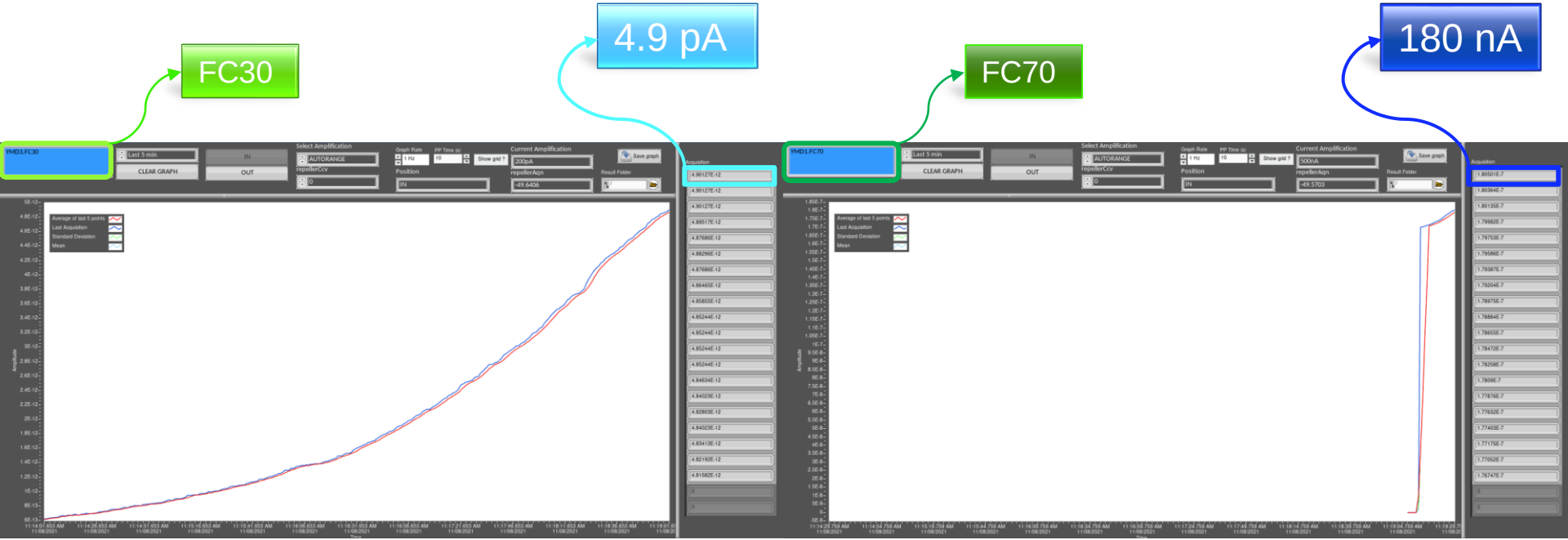






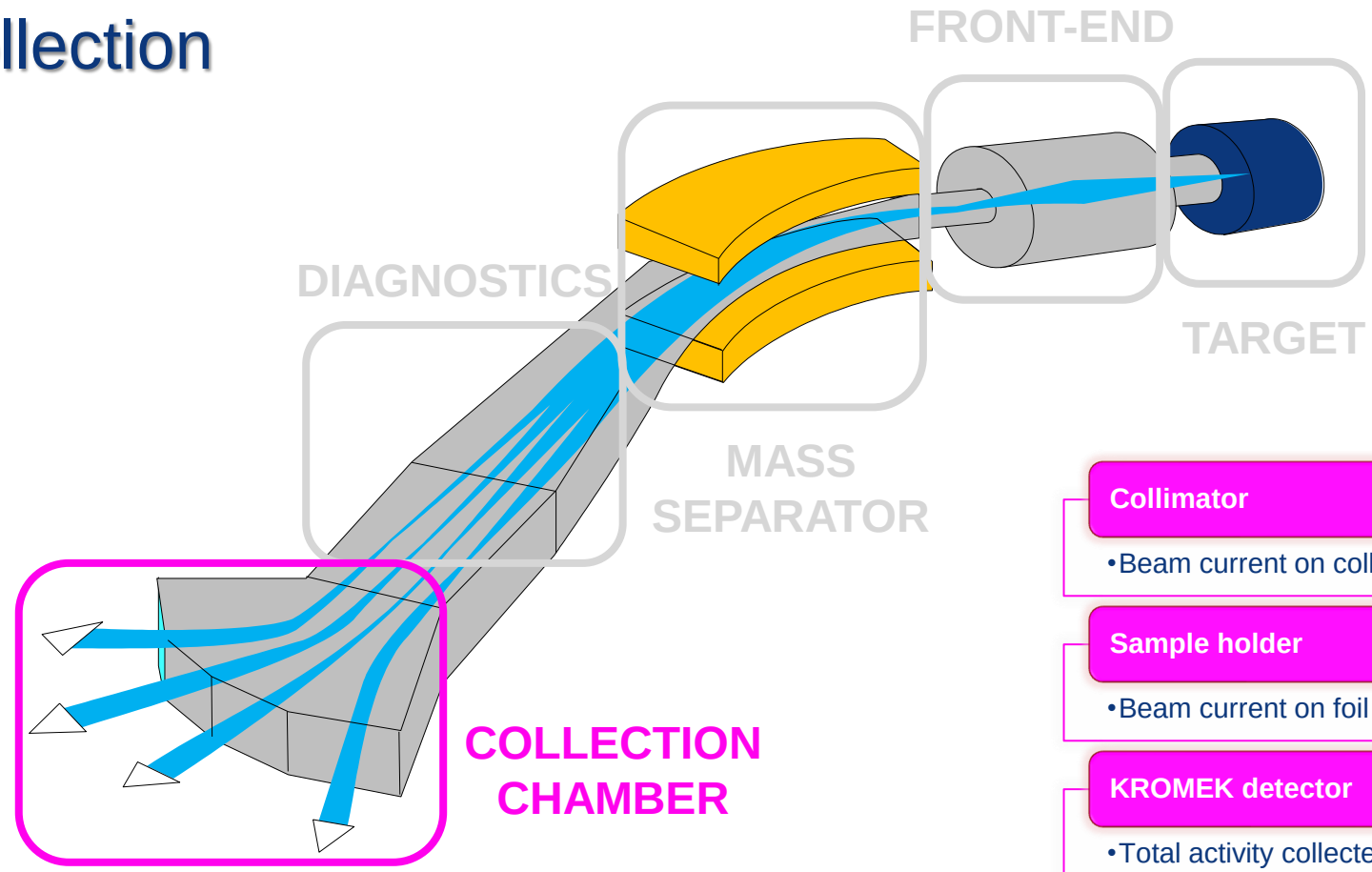


Diagnostics



Resolution as low as ~0.5 pA

Collection



Collimator

- Beam current on collimator

Sample holder

- Beam current on foil

KROMEK detector

- Total activity collected

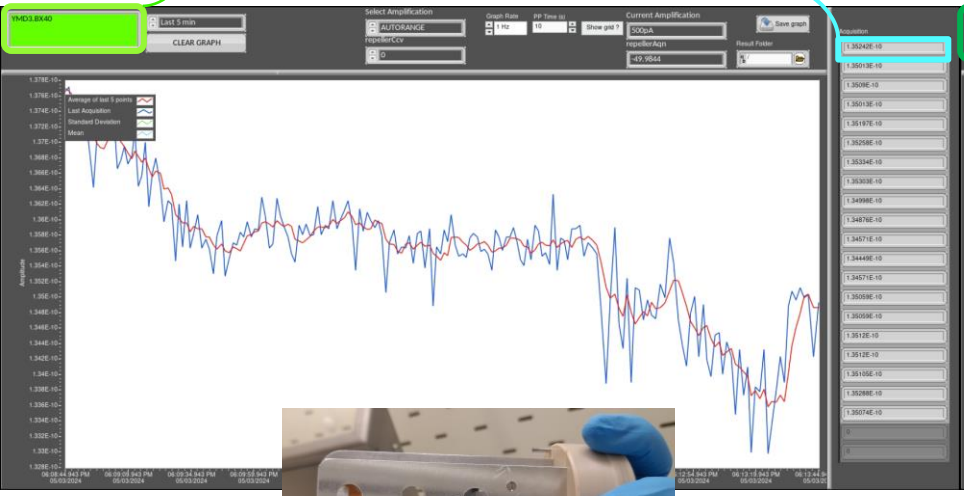
Diagnostics

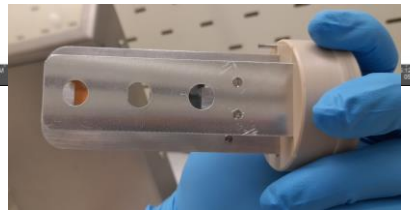
BX40

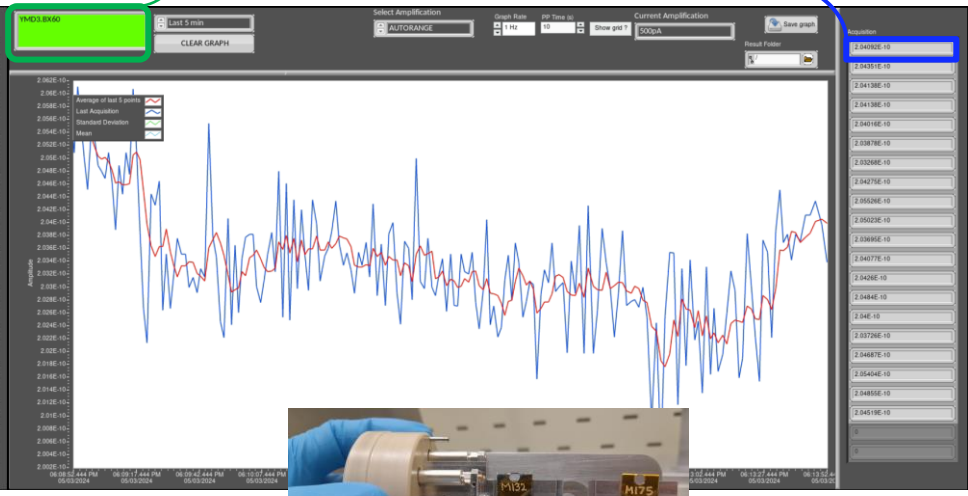
135 pA

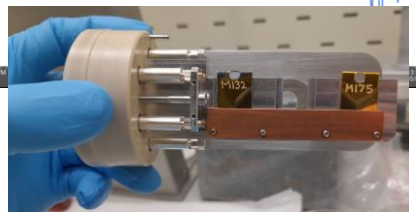
BX60

204 pA

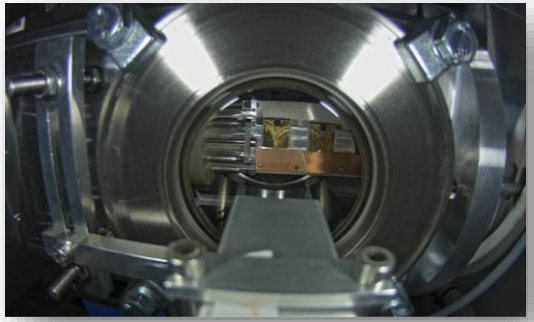


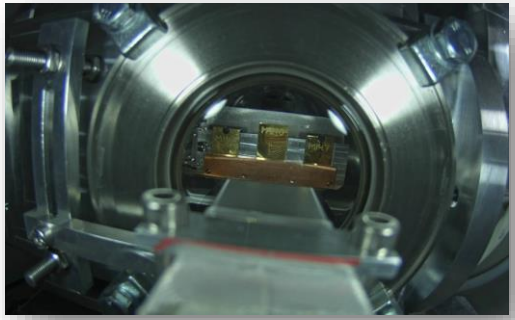


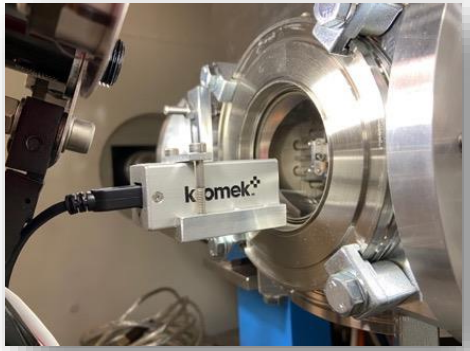




Diagnostics

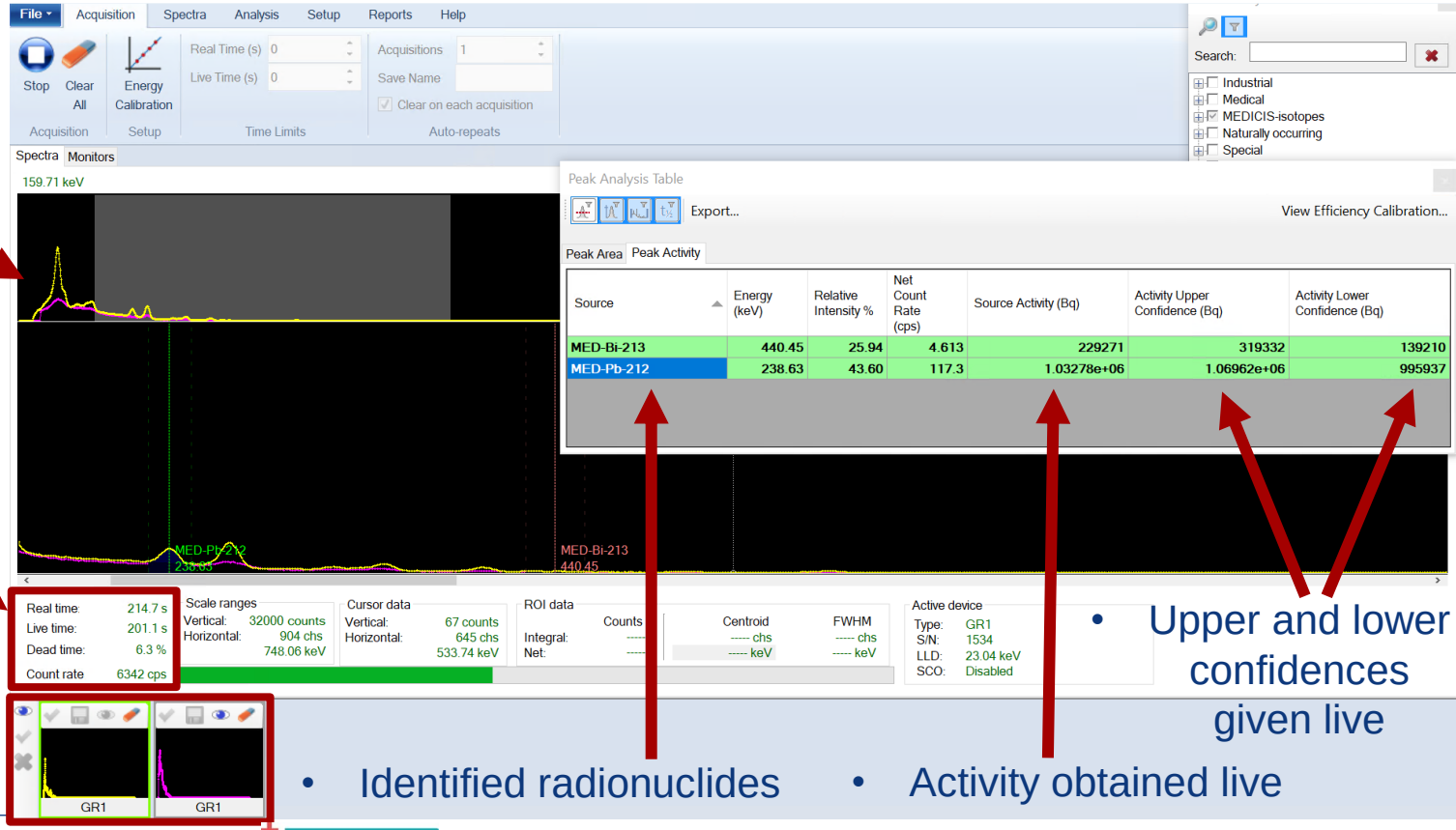






Diagnostics

- γ-ray spectra: can acquire as many spectra as KROMEK connected
- Real and live time in seconds
- Dead time in %
- Count rate in cps
- Detector selection



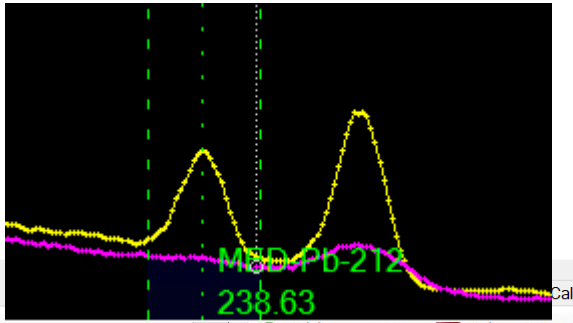
- Identified radionuclides
- Activity obtained live
- Upper and lower confidences given live

Diagnostics

Gaussian fitting done live to give activity in real time

Diagnostics

- Below the chamber
- Max eff. -> 8.9E-6 at 283 keV



- In front of window
- Max eff. -> 2.6E-4 at 238 keV

Device Settings - GR1 1857

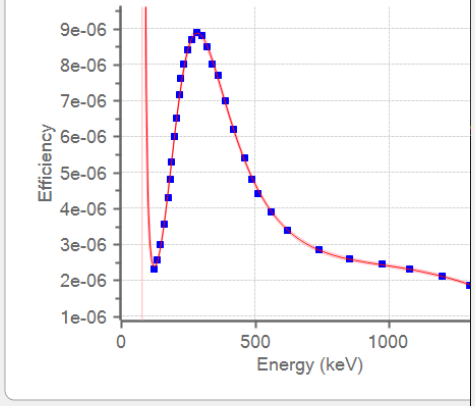
General | Energy Calibration | Resolution Calibration | Efficiency Calibration

Add Cursor Point | Delete Point | Reset | Copy Calibration From... | Favourites

Peak ROI width factor: 0.9545

Energy	Efficiency	Eff. Error
121.78	2.3200E-006	7.6600E-008
133.36	2.5700E-006	8.4800E-008
144.95	3.0000E-006	9.9000E-008
159.11	3.5500E-006	1.1700E-007
175.00	4.3000E-006	1.4200E-007
182.00	4.8000E-006	1.5800E-007
186.15	5.3000E-006	1.7500E-007
197.74	6.0000E-006	1.9800E-007
205.12	6.5000E-006	2.1500E-007
217.00	7.1500E-006	2.3600E-007
221.00	7.6000E-006	2.5100E-007
234.00	8.0000E-006	2.6400E-007
249.00	8.4000E-006	2.7700E-007
263.00	8.7000E-006	2.8700E-007
283.00	8.9000E-006	2.9400E-007
300.00	8.8000E-006	2.9000E-007
318.00	8.5000E-006	2.7800E-007
337.00	8.0100E-006	2.6200E-007

Order of fit: 6

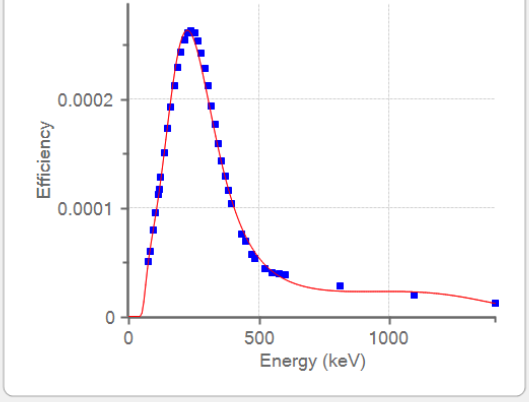


Add Cursor Point | Delete Point | Reset | Copy Calibration From... | Favourites | Linear

Peak ROI width factor: 0.9545

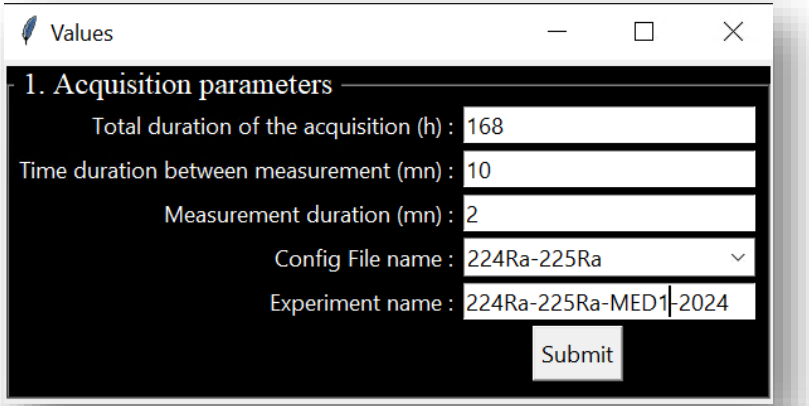
Energy	Efficiency	Eff. Error
73.75	5.0200E-005	5.0200E-007
80.16	5.9600E-005	5.9600E-007
92.98	7.9700E-005	7.9700E-007
102.61	9.5600E-005	9.5600E-007
112.22	1.1200E-004	1.1200E-006
115.43	1.1700E-004	1.1700E-006
121.80	1.2800E-004	1.2800E-006
134.79	1.5100E-004	1.5100E-006
147.78	1.7300E-004	1.7300E-006
160.77	1.9300E-004	1.9300E-006
173.77	2.1200E-004	2.1200E-006
186.75	2.2900E-004	2.2900E-006
199.75	2.4300E-004	2.4300E-006
212.74	2.5400E-004	2.5400E-006
225.73	2.6100E-004	2.6100E-006
238.73	2.6300E-004	2.6300E-006
251.72	2.6100E-004	2.6100E-006
264.71	2.5300E-004	2.5300E-006

Order of fit: 6

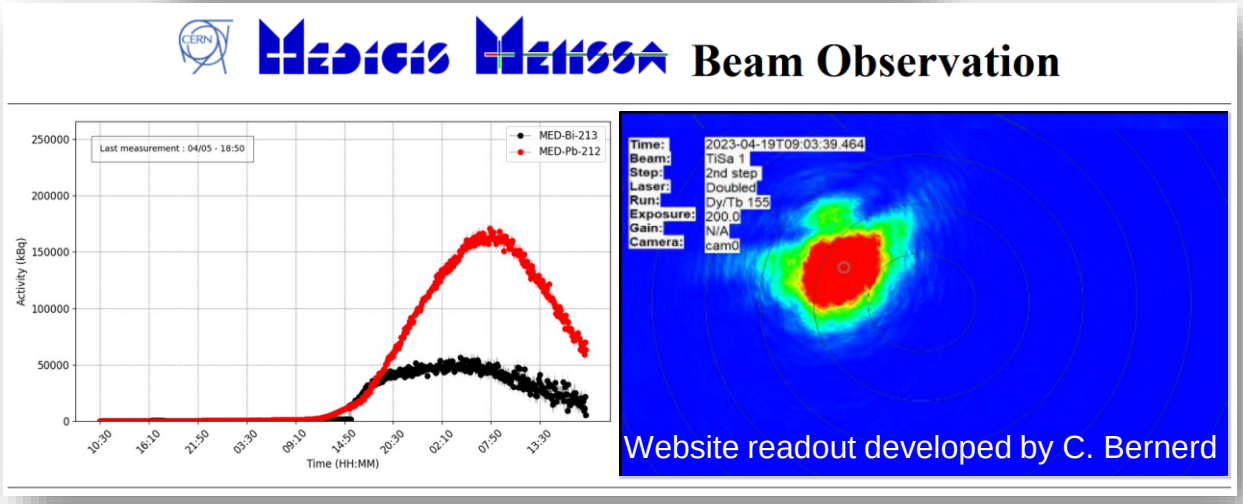


Diagnostics

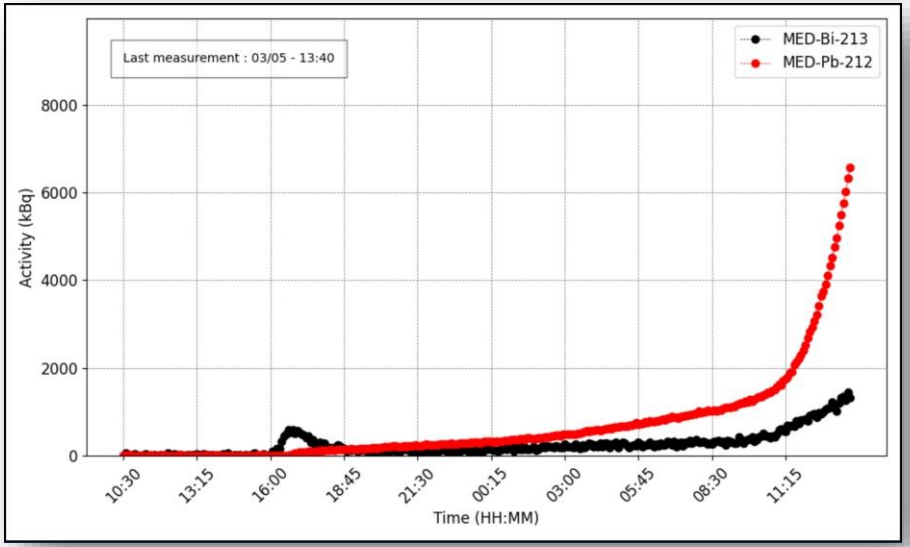
- Activity values registered every x minutes for y time



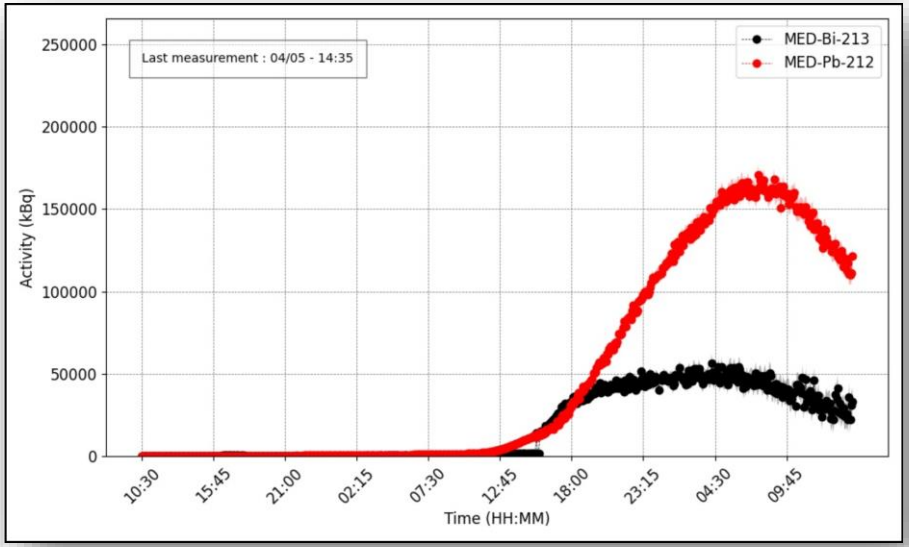
- Essential tool to assess the implantation rate



Diagnostics

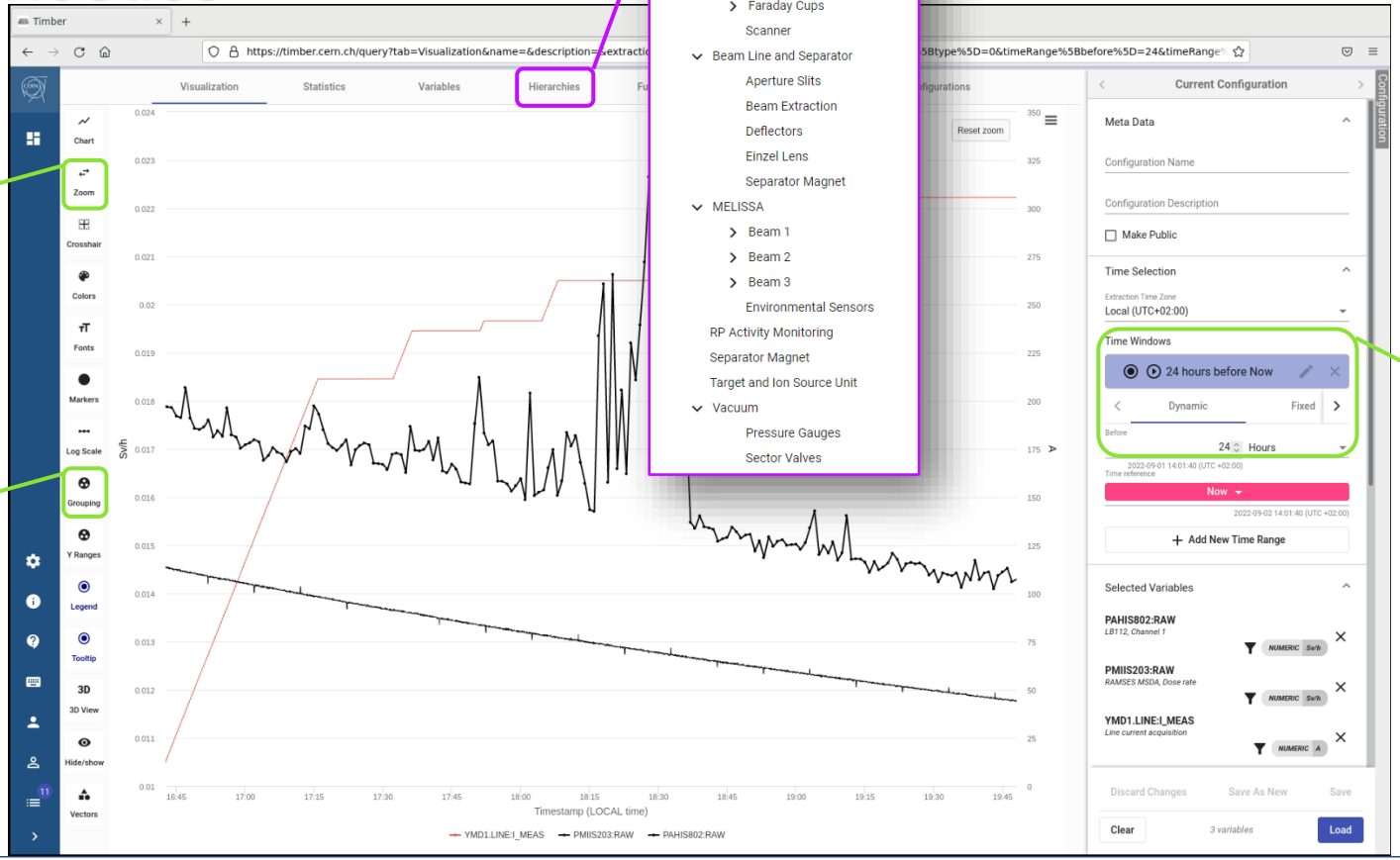


Consistent implantation rate



Saturation due to high dead time

Diagnostics



Choice of variables

Zoom on both x and y axis

Grouping options for data sets

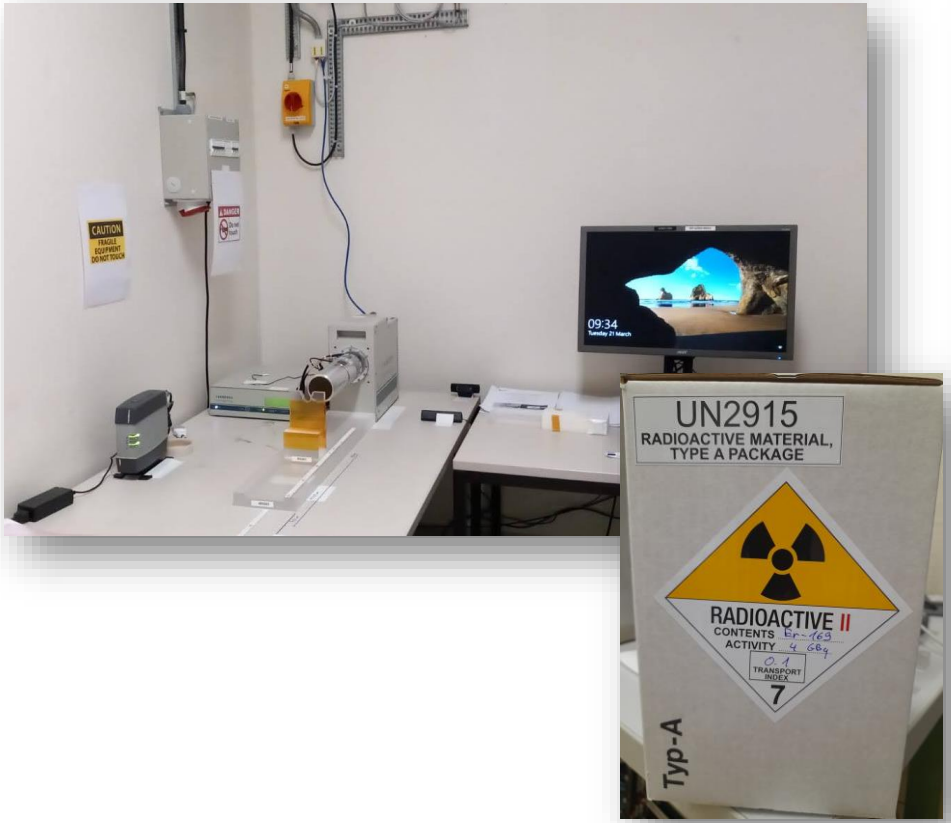
Time selection

Summary

- Overview
- Irradiated target
- Beam production
- Mass separation
- Diagnostics
- Retrieval and shipping

MEDICIS laboratory

QC and shipping



CERN Apex-Gamma

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Analysis Report for CORMED-Sm-153-3-24112023
CORMED-Sm-153-3-24112023

HSE-RP RADIO-ANALYTICAL LAB - GAMMA SPECTROSCOPY ANALYSIS

Sample Number	: 344176
Sample Identification	: CORMED-Sm-153-3-24112023
Sample Description	: CORMED-Sm-153-3-24112023
Sample Type	: CORMED
Sample Size	: 1.000E+00 units

11/24/2023 3:44:45PM Page 3 of 5

Analysis Report for CORMED-Sm-153-3-24112023
CORMED-Sm-153-3-24112023

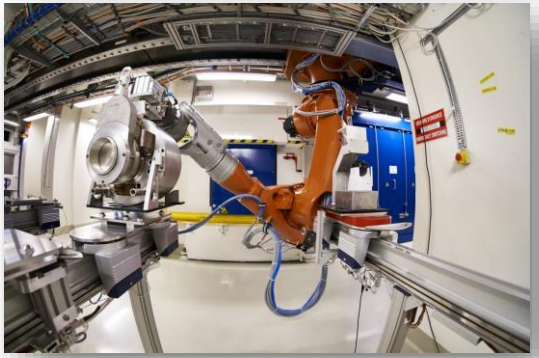
Nuclide Name	Half Life	Nuclide Id Confidence	Wt mean Activity (Bq/units)	Wt mean Activity Unc. (%)	MDA (Bq/units)	Comments
Sm-153 @	1.94 d	0.999	7.39E+08	- 3.81	5.24E+05	

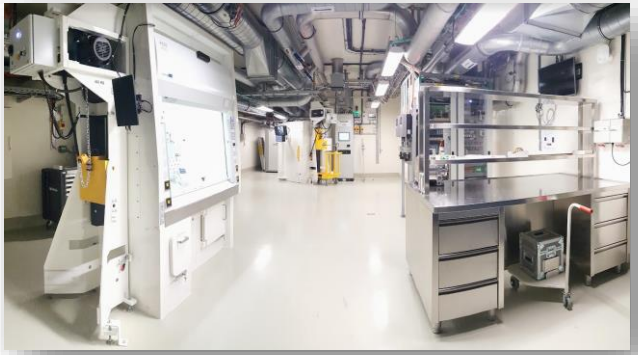
? = nuclide is part of an undetermined solution
X = nuclide rejected by the interference analysis
@ = nuclide contains energy lines not used in Weighted Mean Activity

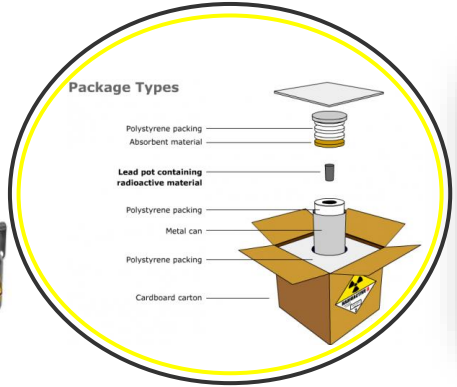
Errors quoted at 2.000sigma

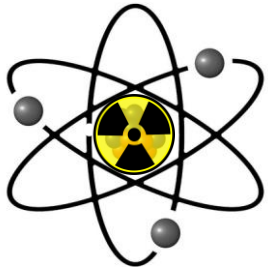
740 MBq

From CERN-MEDICIS to the Lab / Hospital









Thank you!

Merci!