Low Energy RIB @ SPES for nuclear physics and medical applications

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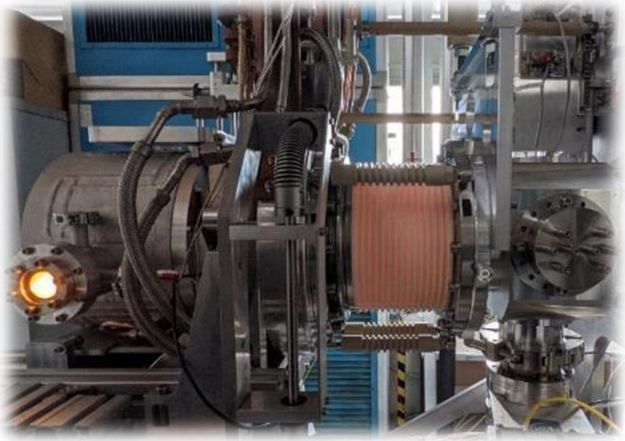
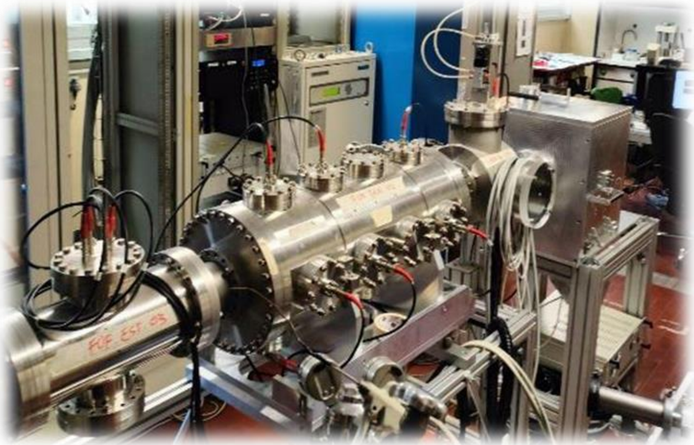
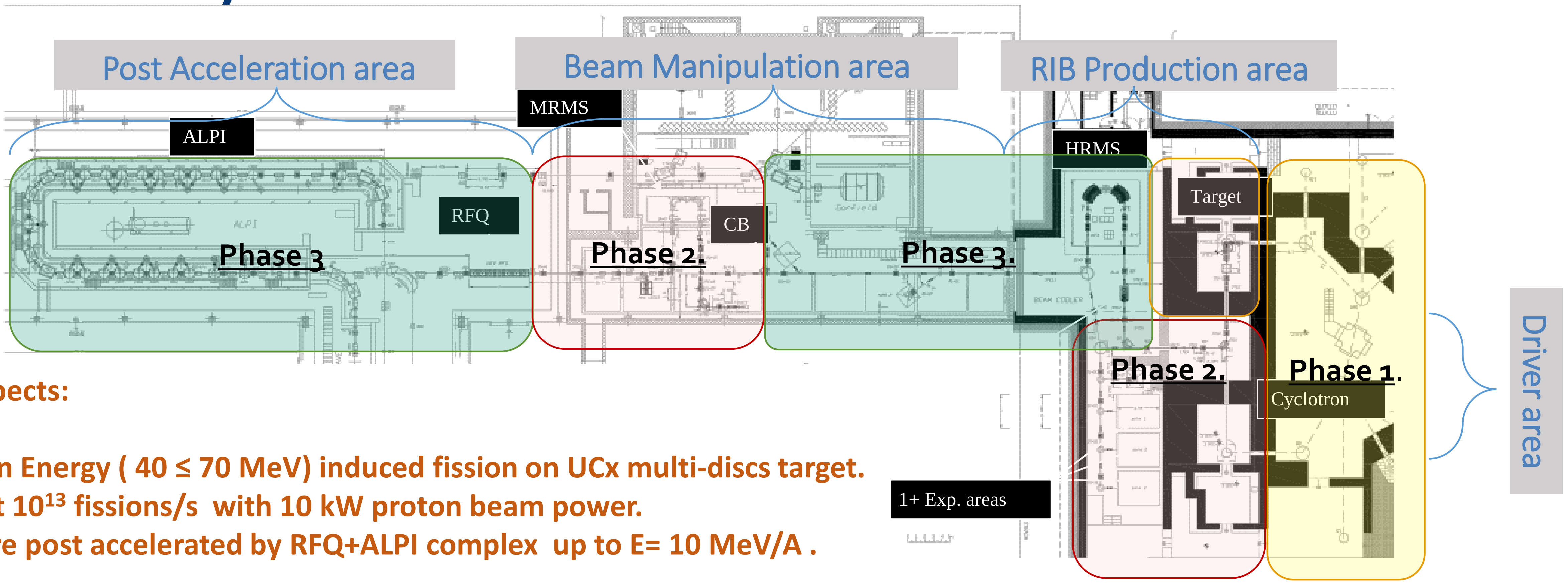
SUMMARY

- The SPES Facility
- The RIB Source
- Pre-commissioning tests
- Beam Lines Installations
- ISOLPHARM: radioisotopes for medicine





SPES Facility overview



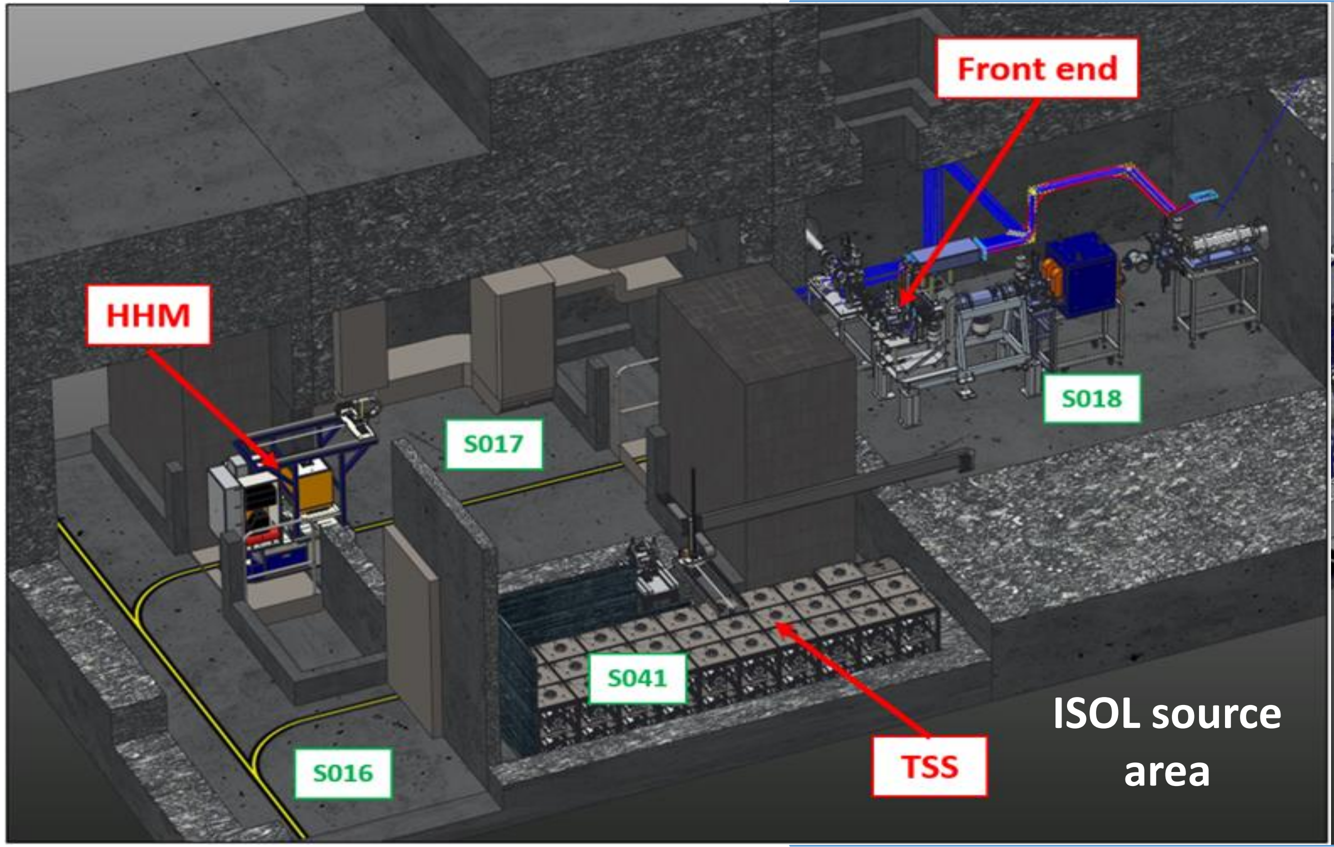
Key aspects:

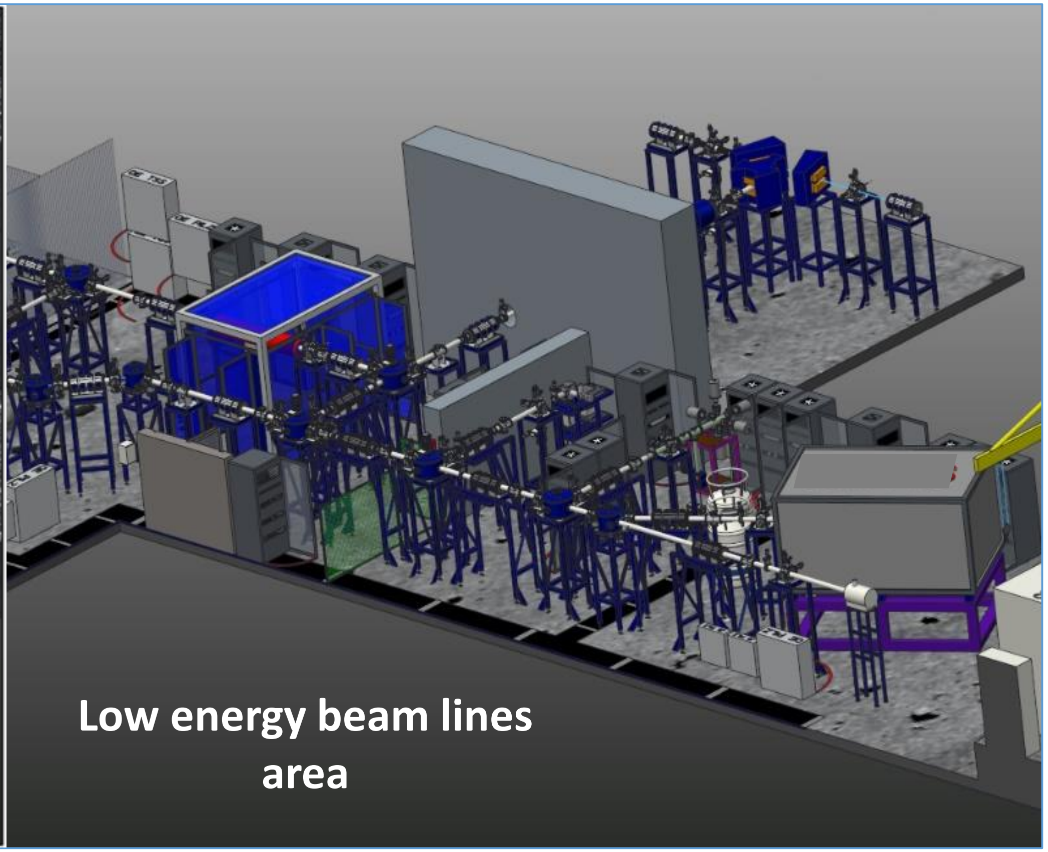
- **Proton Energy (40 ≤ 70 MeV) induced fission on UCx multi-discs target.**
- **About 10^{13} fissions/s with 10 kW proton beam power.**
- **RIB are post accelerated by RFQ+ALPI complex up to E= 10 MeV/A .**

- **Phase 1.** - Building first plants + preliminary operations with the cyclotron — DONE
- **Phase 2. (a+b)** - From C.B. to RFQ + ISOL source, first RIBs on 1+ Lines — WORK IN PROGRESS
- **Phase 3.** - From the LRMS to the CB + rib from RFQ to ALPI

Short term objectives:

1) Operations with high intensity cyclotron beams.
2) Delivery 40 MeV Protons on Target Ion Source complex (low intensity first).
3) Experimental activity with Low Energy RIBs.

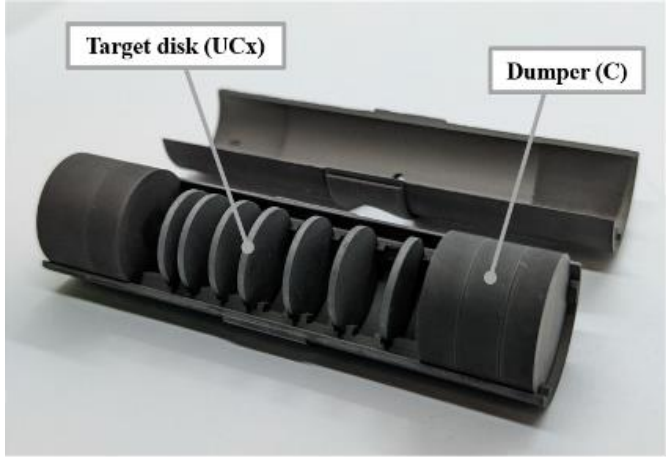


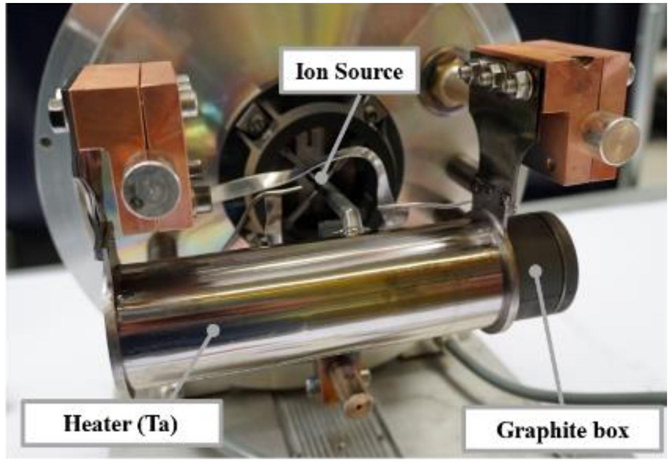


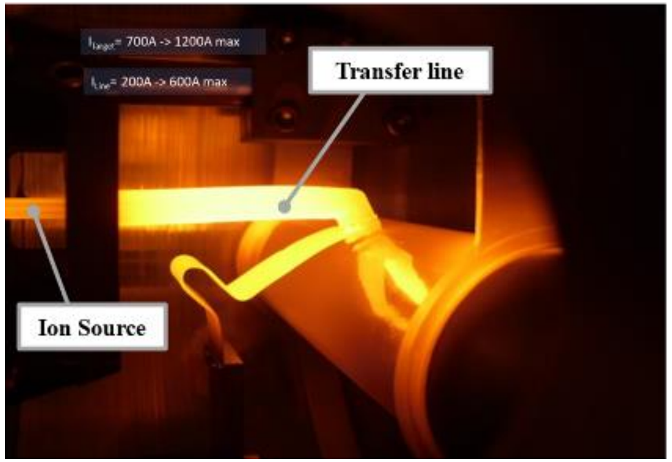
The RIB source

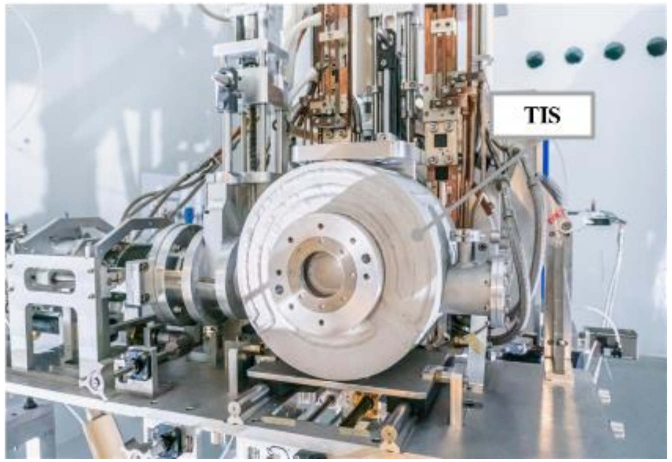
The Target Ion Source system

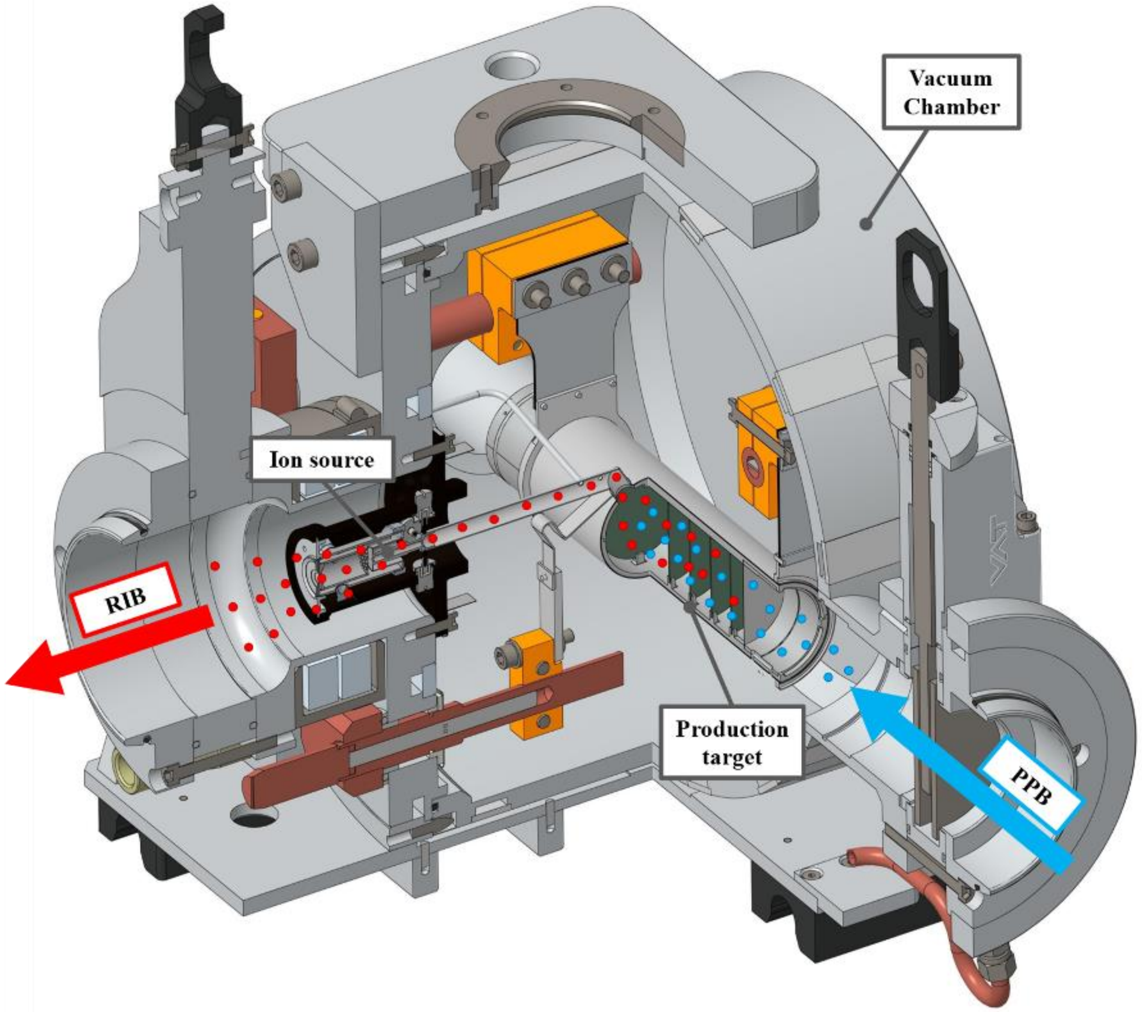
The Target Ion Source (TIS) unit:





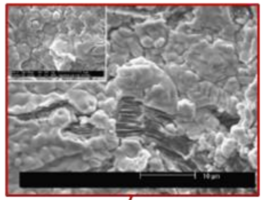




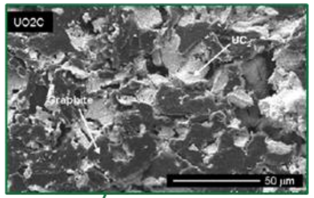


R&D on Targets materials: work in the last of 15 years…

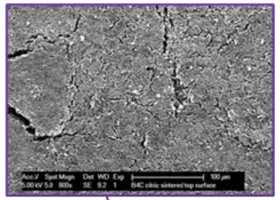
LaC_x Carturan et al. Nucl. Instrum. Meth. B 583 (2007) 256.
LaC_x Tonezzer et al. Eur. Phys. J. Special Topics 150 (2007) 281.



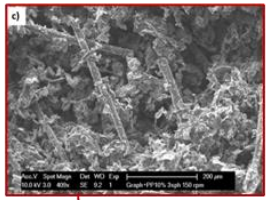
UC_x Biasetto et al. J. Nucl. Mater. 404 (2010) 68.



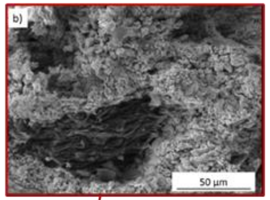
B_4C Corradetti et al. J. Nucl. Mater. 432 (2013) 212.



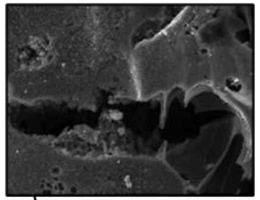
LaC_x fibers Corradetti et al. Ceram. Int. 42 (2016) 17764.



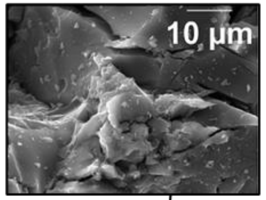
LaC_x graphene Corradetti et al. Ceram. Int. 43 (2017) 10824.

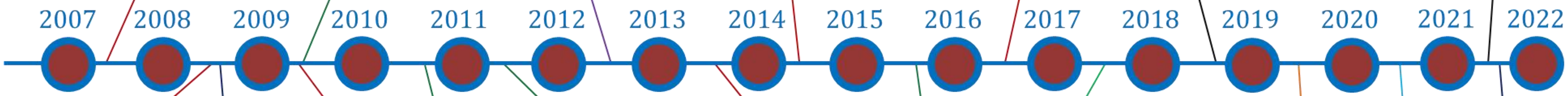


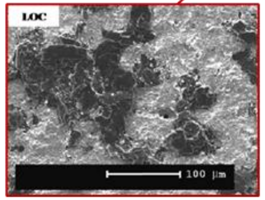
TiC mesoporous Corradetti et al. Ceram Int. 46 (2020) 9596.



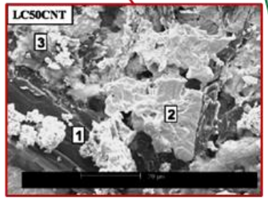
TiC sucrose Zanini et al. Micr. Mes. Mater. 337 (2022) 111917.



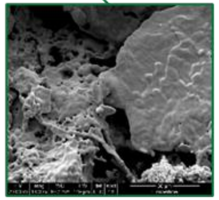




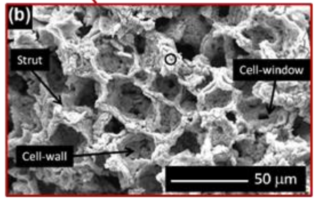
LaC_x Biasetto et al. J. Nucl. Mater. 378 (2008) 180.



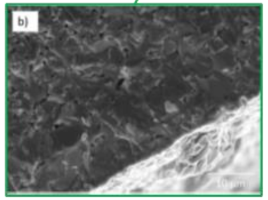
LaC_x-CNT Biasetto et al. J. Nucl. Mater. 385 (2009) 582.



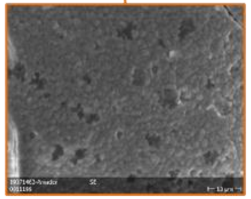
UC_x–CNT Corradetti et al. Eur. Phys. J. A 49 (2013) 56.



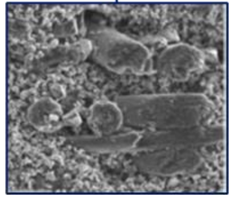
LaOC PMMA Biasetto et al. J. Nucl. Mater. 440 (2013) 582.



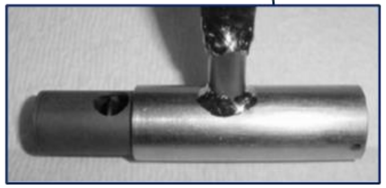
UC_x graphene Biasetto et al. Sci. Rep. 8 (2018) 8272.



ThC_x graphene Corradetti et al. Sci. Rep. 11 (2021) 9058.



SiC/Cf Silvestroni et al. J.Eur. Ceram. Soc. 42 (2022) 6750.



SiC Barbui et al. Nucl. Instrum. Meth. B 266 (2008) 4289.

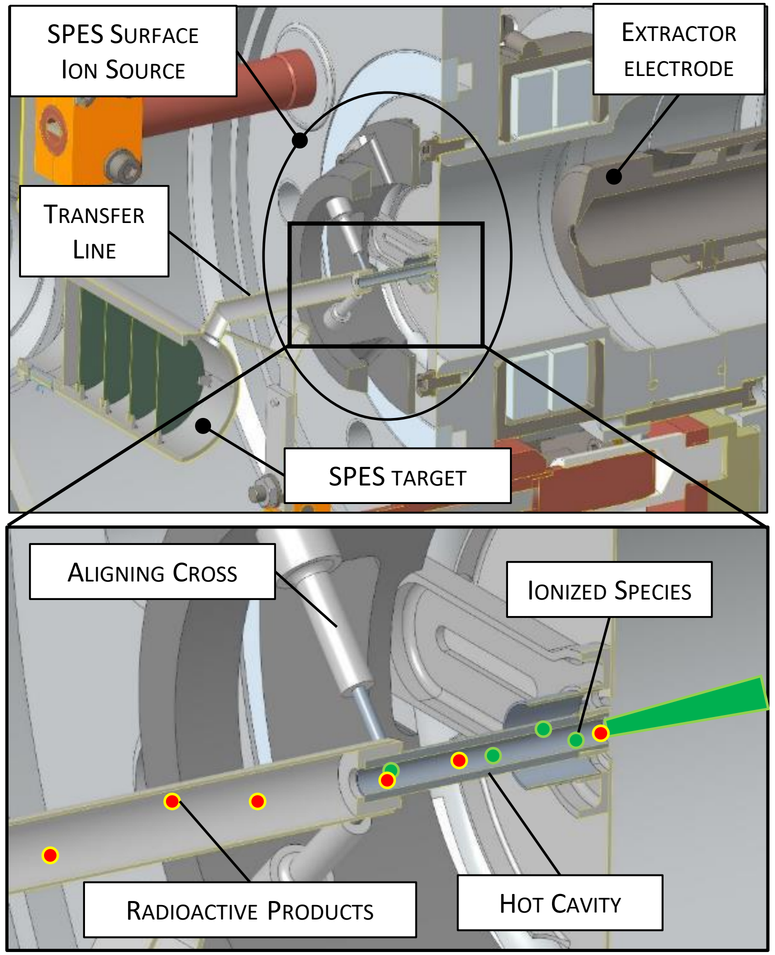
UC_x Corradetti et al. Eur. Phys. J. A 47 (2011) 119.

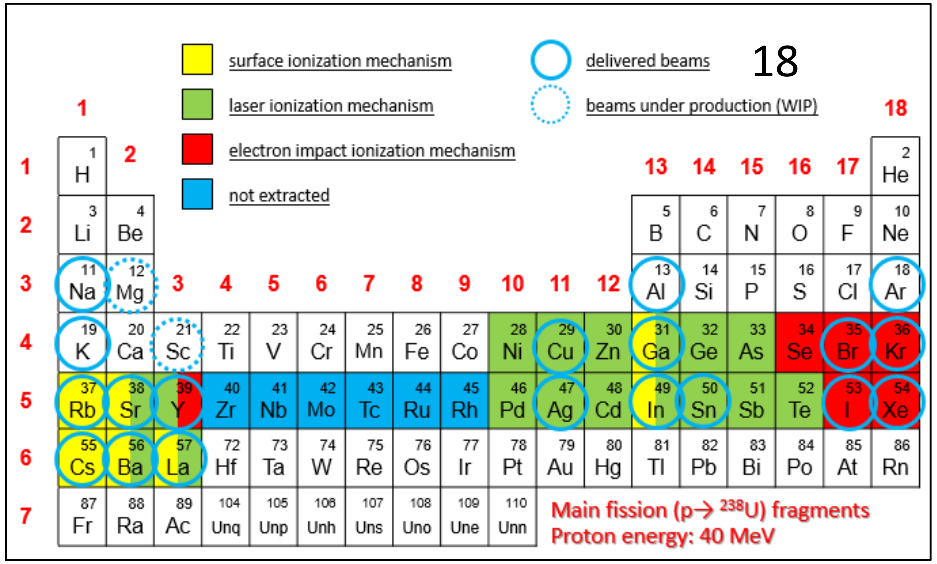
UC_x Corradetti et al. Nucl. Instrum. Meth. B 360 (2015) 46.

Review Corradetti et al. Nucl. Instrum. Meth. B 488 (2021) 12.

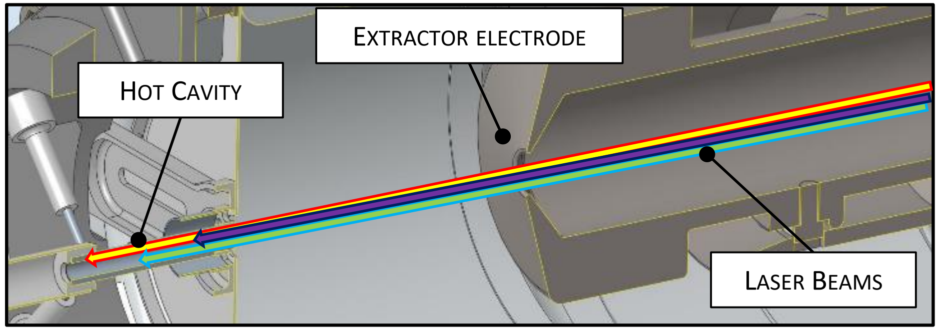
R&D on Ion Sources

The SPES Surface Ion Source (SIS)

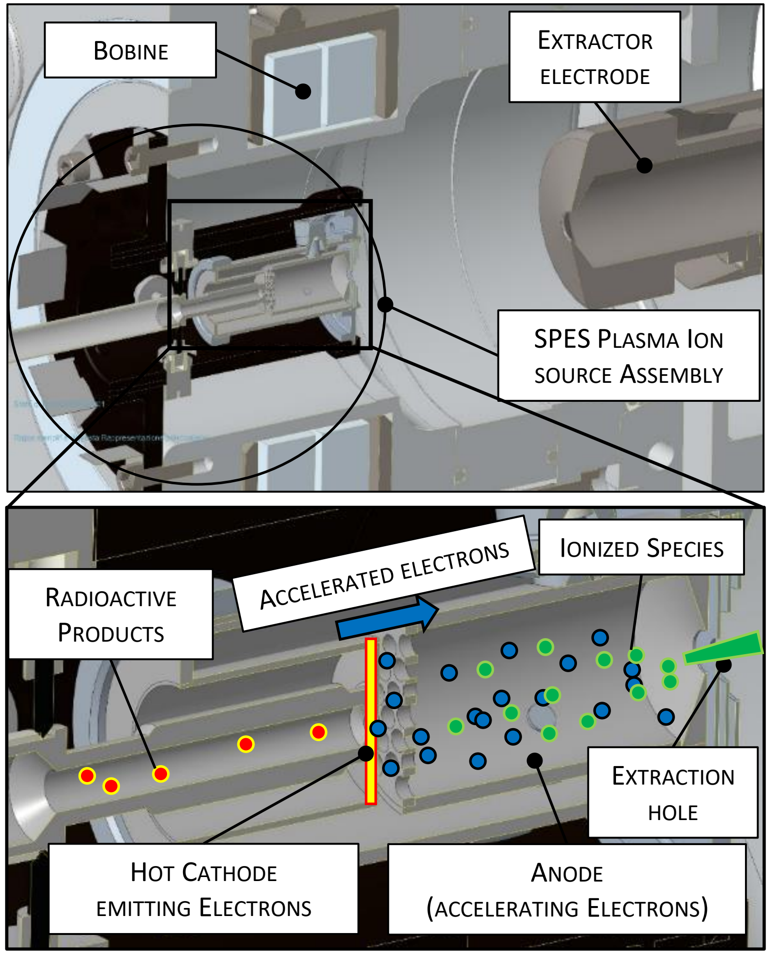




The SPES Laser Ion Source
(SIS + laser beams)



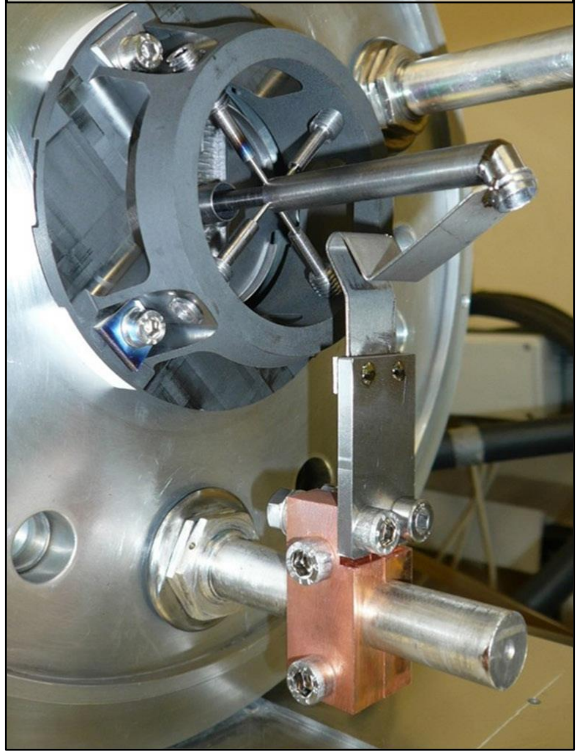
The SPES Plasma Ion Source



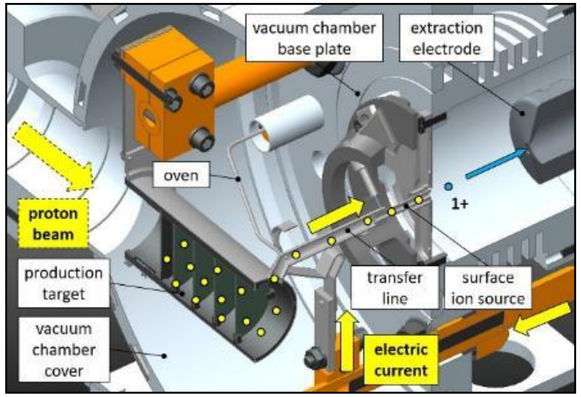
Ion Sources: The Surface Ion Source

Selective Ion source: Used for Alcali, Metal Alcali and transition elements (coupled with Laser):

- High Efficiency: ≈ 50% for Cs, Rb, K, Na, Ba; 20% for Sr, La;
- Low emittance: $\varepsilon_{RMS} \approx 2\,\pi$ mm mrad @ 25 keV


Before tests


After tests
(17 days @ high temperature)

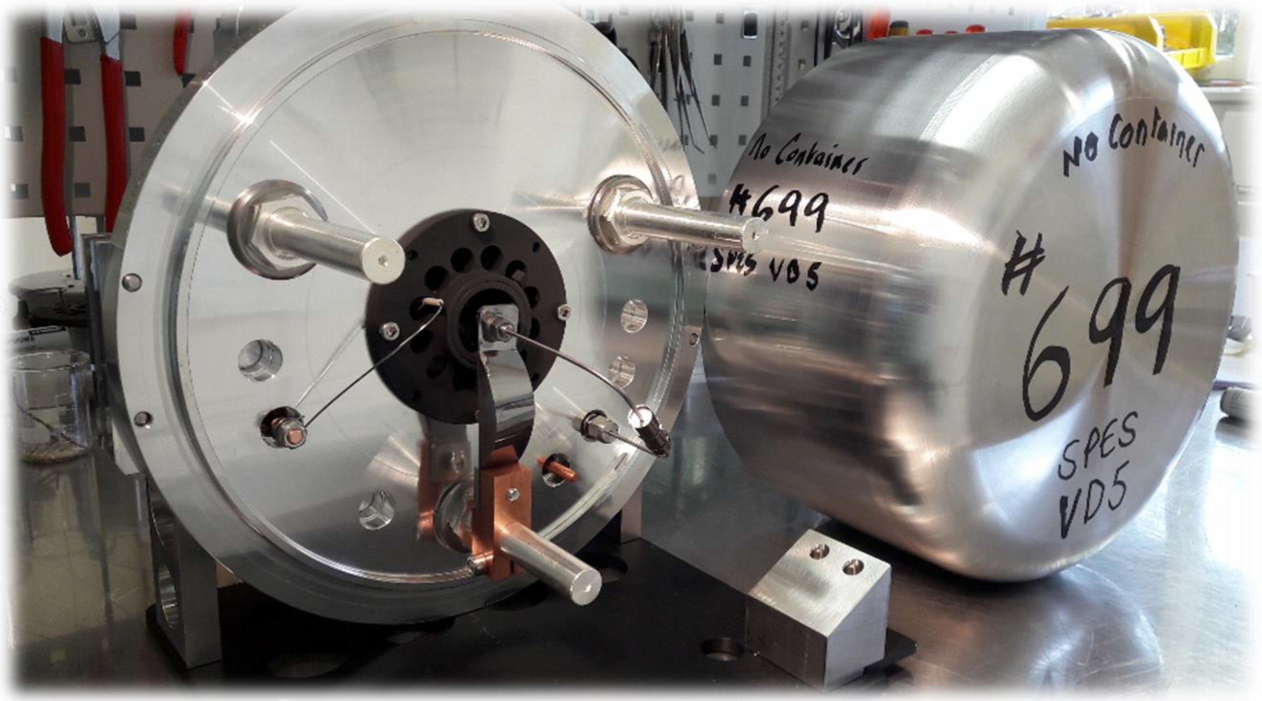


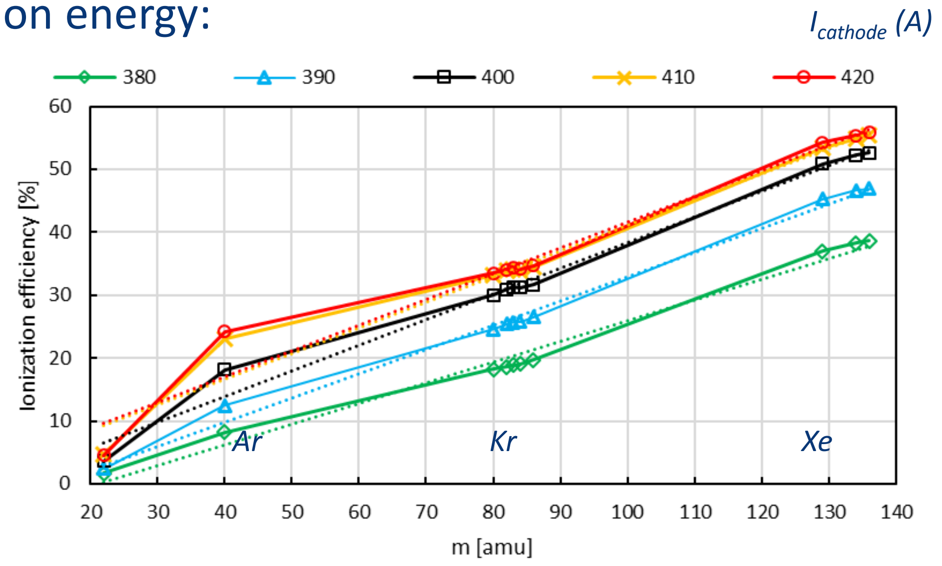
beam	ion. eff. (%)	hot-cavity temp. (°C)	hot-cavity material
Na	47,6	2200	Ta
K	55,4	2200	Ta
Ga	1,4	2200	Ta
Rb	**54,5**	**2200**	**Ta**
Sr	**18,5**	**2200**	**Ta**
In	3,2	2200	Ta
Cs	**43,2**	**2200**	**Ta**
Ba	**58,8**	**2200**	**Ta**
La	20,1	2200	Ta

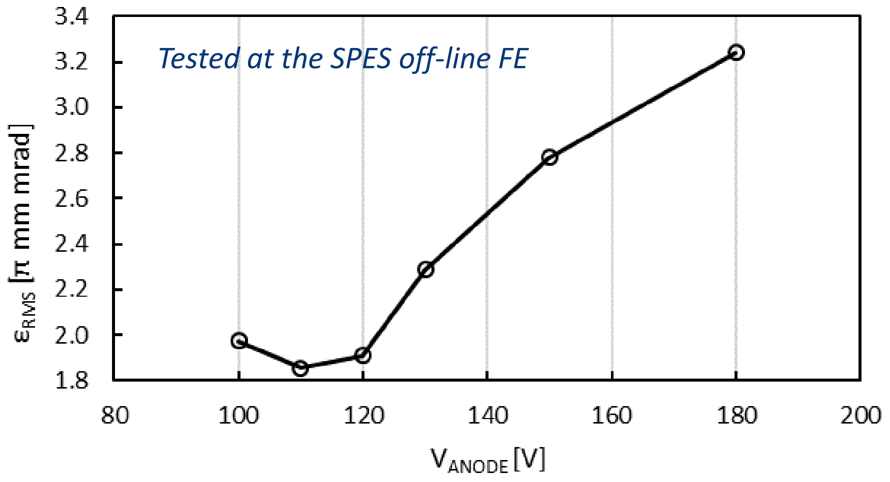
Ion Sources: The Plasma Ion Source (febiad)

General purpose source, (not selective) ; good for element with high ionization energy:

- High Efficiency for heavy masses: ≈ 55% for Xe, 35% for Kr, 20% for Ar
- Higher emittance: $\varepsilon_{RMS} \approx 3\ \pi$ mm mrad @ 25 keV







Results are submitting for publishing in international peer-review journals

Ion Source: The Laser Ion Source (off-line-> dye lasers)

Very selective Ion source; good for a large part of SPES elements :

"OFF-Line" Laser Laboratory:

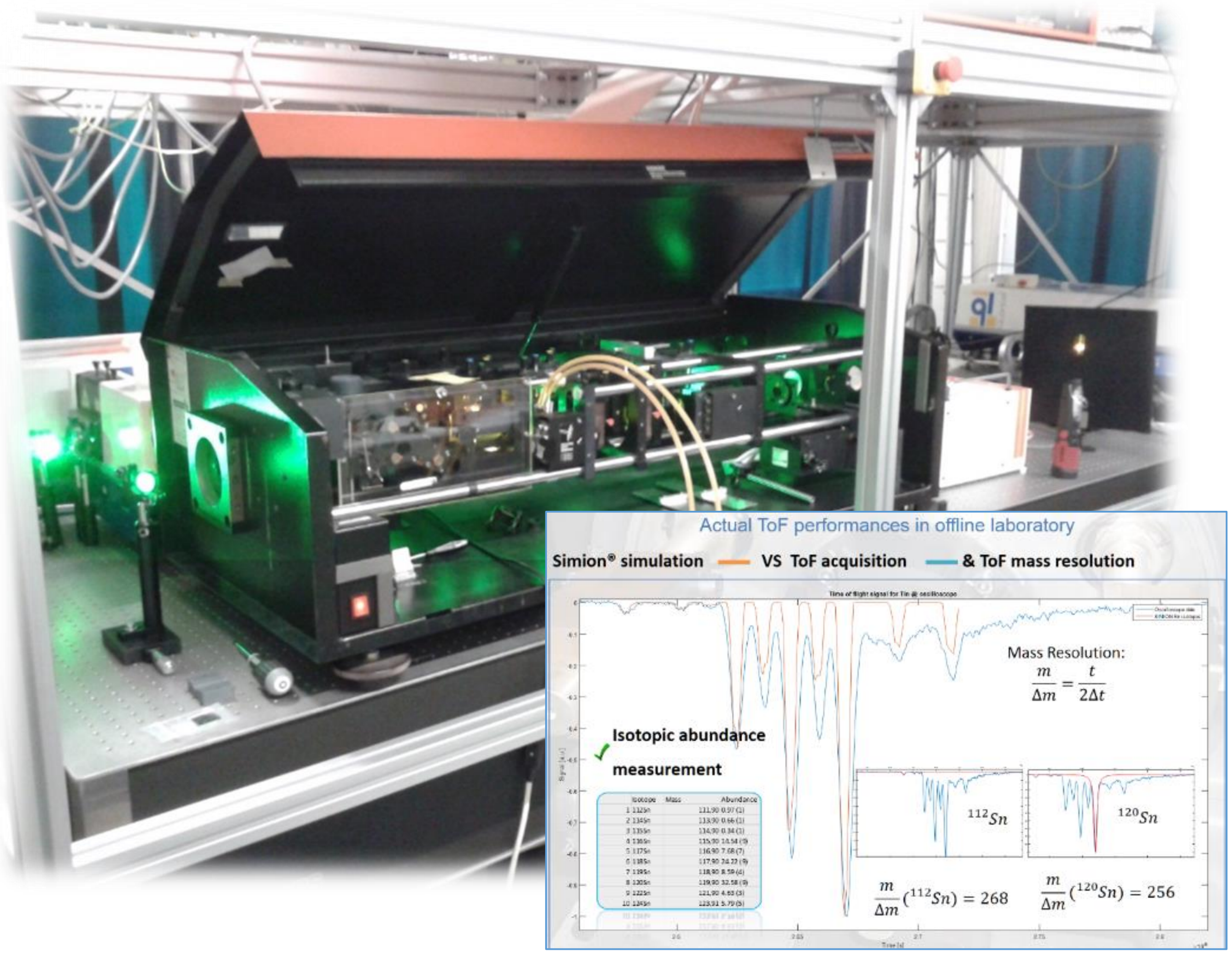
- ✓ Active since 2013
- ✓ Use of two low rep rate (10 Hz) dye laser to study different element energy level structure
- ✓ Try ionization schemes, measure efficiency and feasibility

Measure/proof of Ionization:

- ✓ Hollow Cathode Lamps and use of optogalvanic signals
- ✓ Time of Flight mass spectrometer with ablation laser source

Advantages for SPES facility:

- ➢ Studies and tests are carried on independently respect on-line shifts/user time schedule
- ➢ Results are suitable for on-line lab



Ion Source: The Laser Ion Source (on-line -> solid state lasers)

- 3 independent diode-pumped solid state lasers
- 3 Ti-Sapphire Tunable lasers
- 10 kHz repetition rate: wavelength 650-980 nm (+ higher harmonics)

“ON-Line” concept:

✓ Laser beam must reach the ions source/target chamber by direct view of the destination point

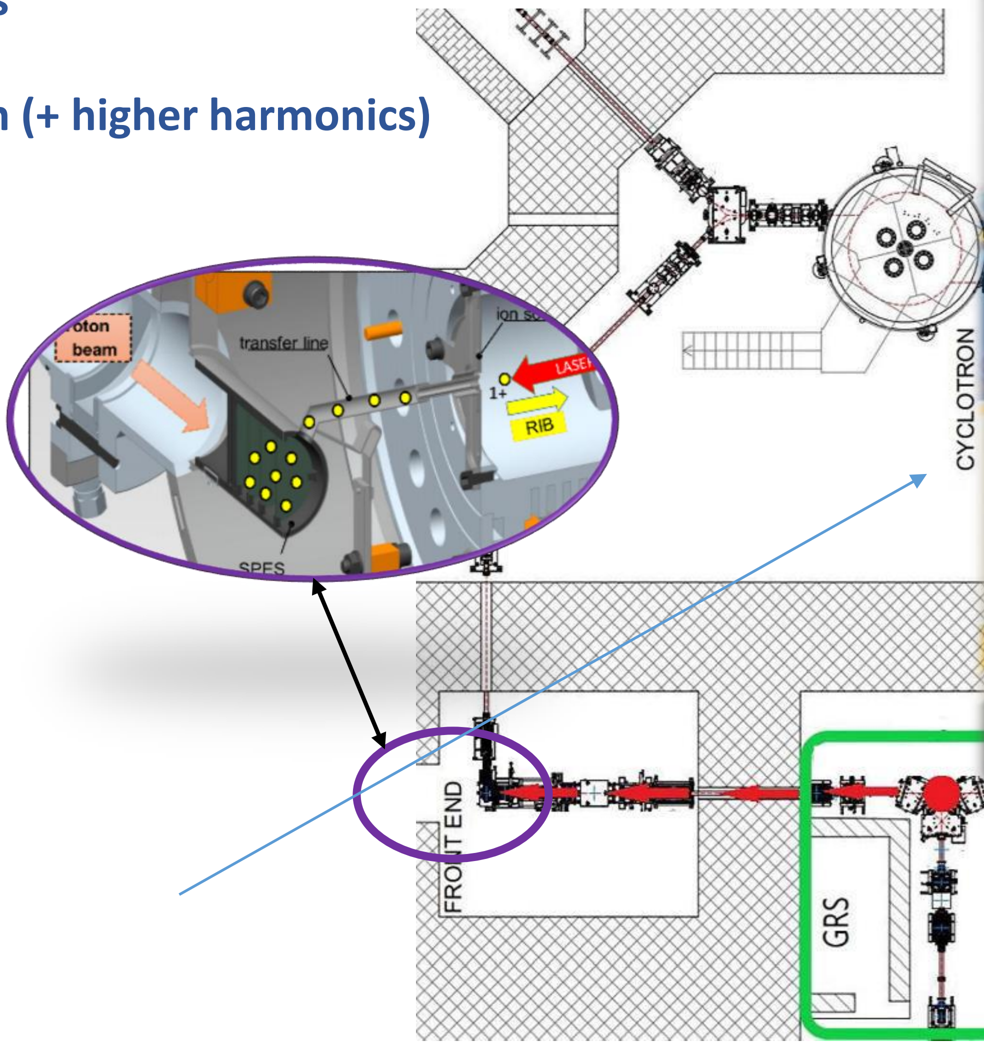
✓ Needs to overlap several laser beam at destination (usually 3 laser beams at 20÷25 m from the starting point)

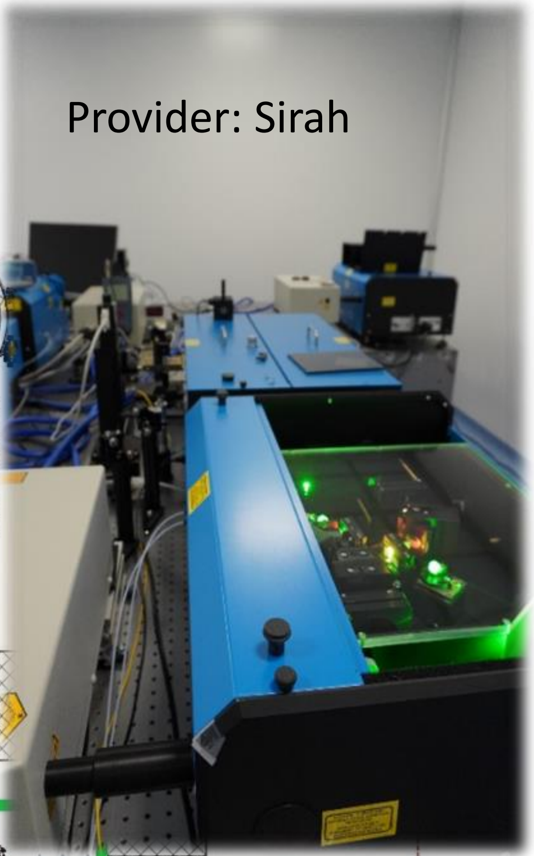
On-Line @ SPES:

✓ Laser Online Lab is on the top of LRMS Hall (green box on figure)

✓ LRMS magnet is used as entry point for the laser beams (red circle in figure)

✓ Laser beam reaches the ion-source traveling 20 m superposed, but opposite to ion beam direction (red arrows in figure)

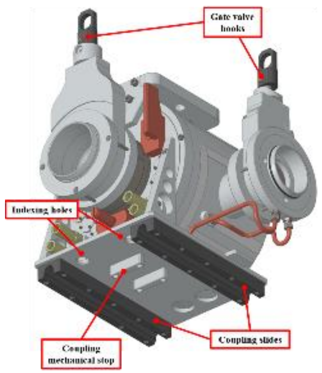


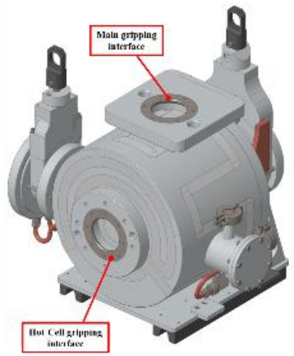


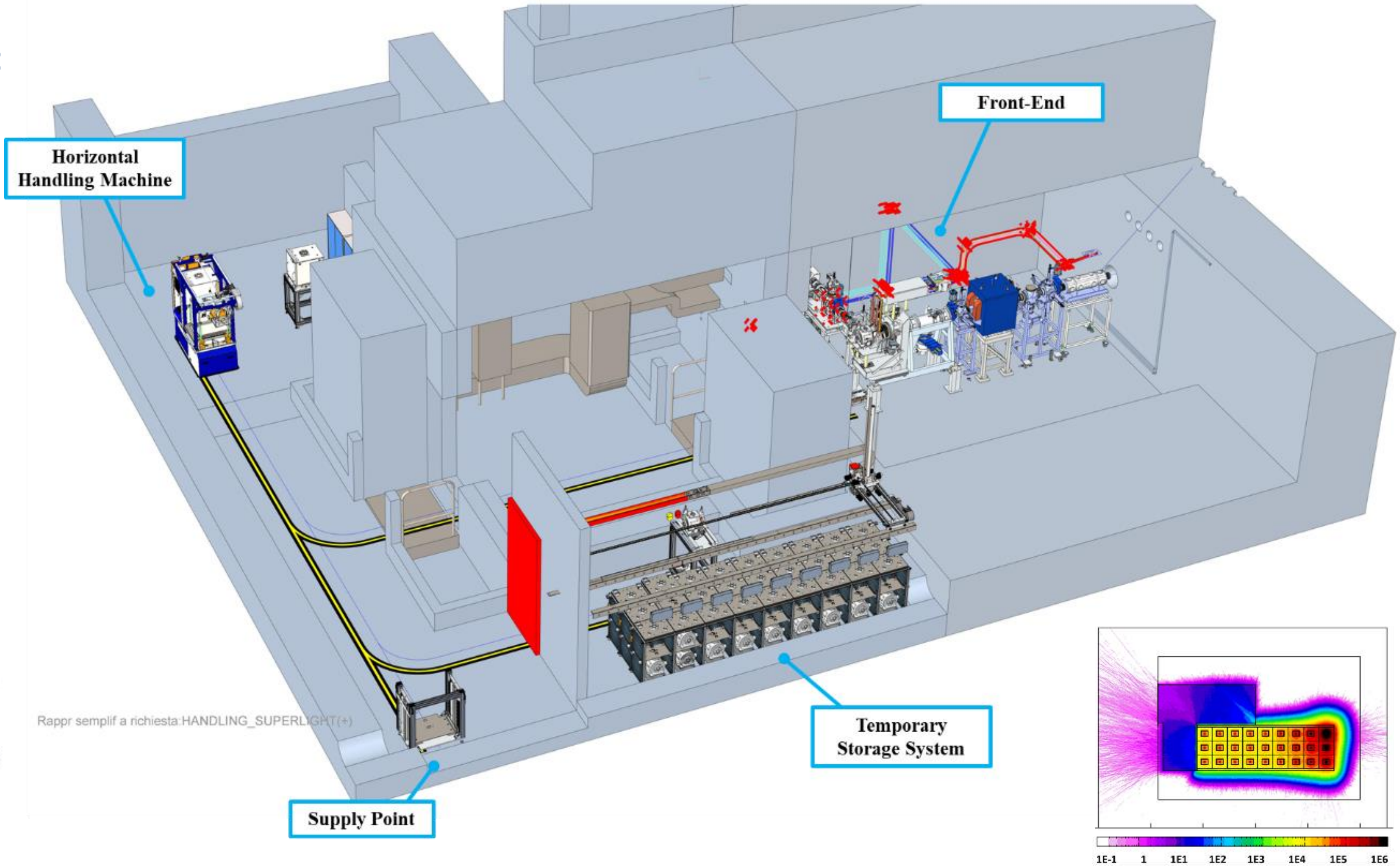
TIS Remote Handling

Remote Handling Framework:

- Design driven by the TIS unit lifecycle







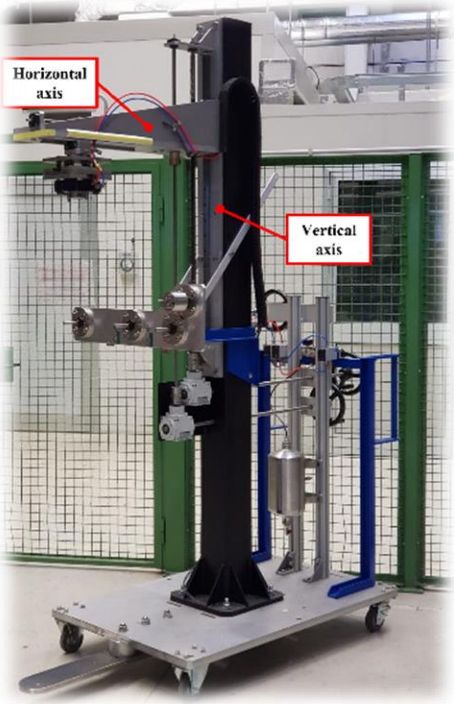
R&D on TIS Remote Handling

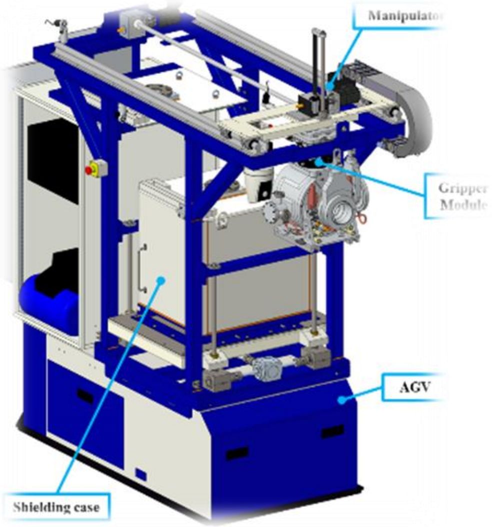
Consolidation of existing systems:

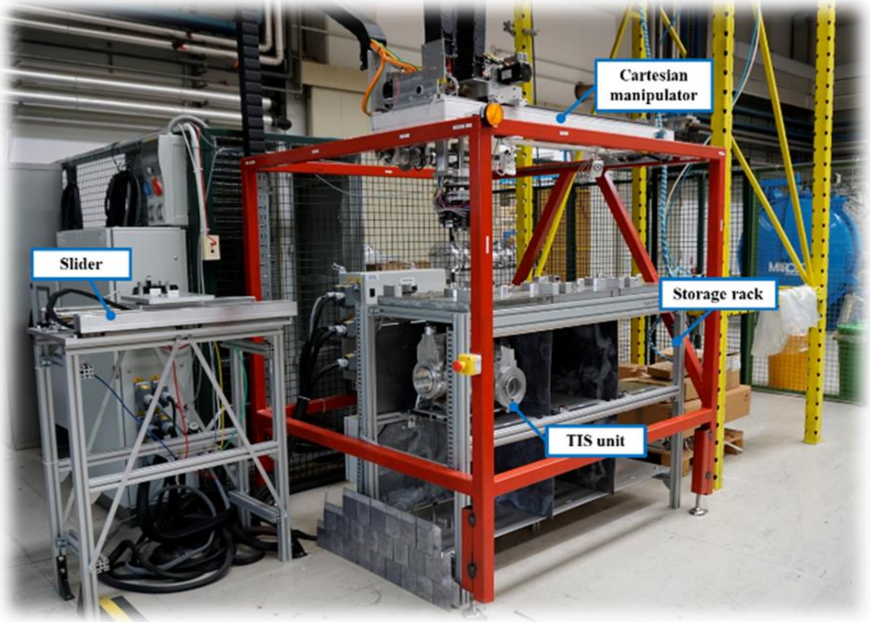
- Horizontal Handling Machine:
  - Electrical upgrade ongoing
  - First commissioning tests: 11/2022
- Temporary Storage System:
  - Construction ongoing (focus on next slide)
- Front End Coupling Table
  - Hardware validated
  - Maintenance optimization ongoing.
  - Control software development ongoing
- Manual Handling Machine (Auxiliary)
  - First operational tests: 05/2022
- Supply Point
  - Hardware validated
  - Control architecture under definition

Optimization:

- Hardware review
- Reliability study:
  - Failure Mode, Effect and Criticality Analysis (FMECA)
  - Fault Tree Analysis (FTA)



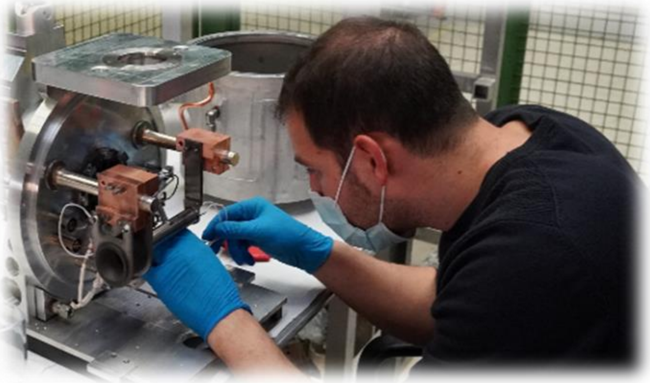


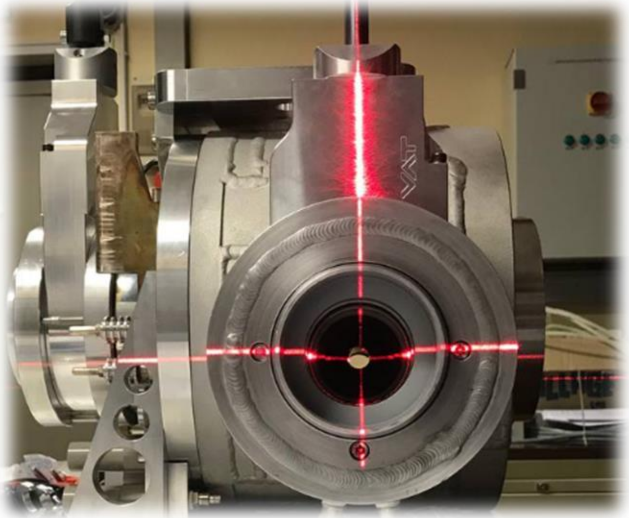


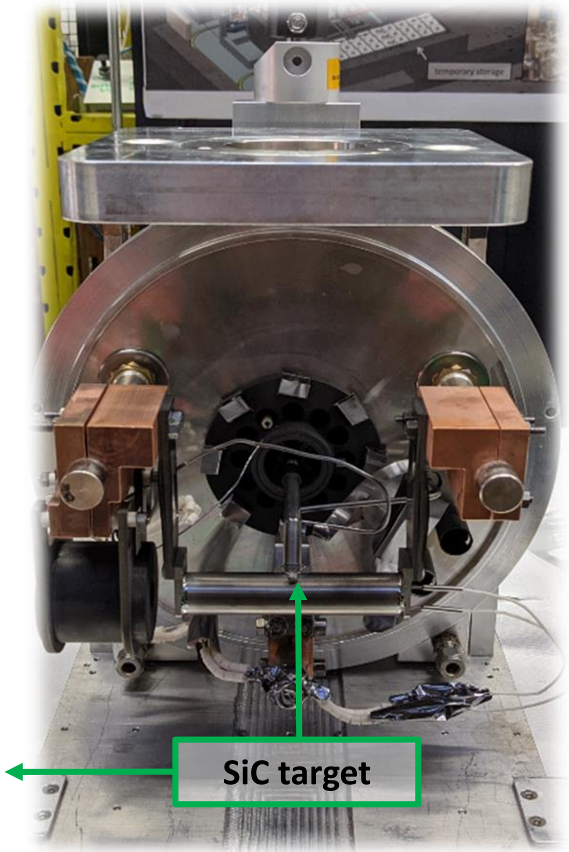
Pre-commissioning tests

Pre-commissioning : TIS unit preparation

Preparation: ultrasonic cleaning of components → Installation of the Ion Source → Installation of the SiC Target, Collimator assembly and laser alignment → Sensors and thermocouples assembly and test







Pre-commissioning : front-end preparation

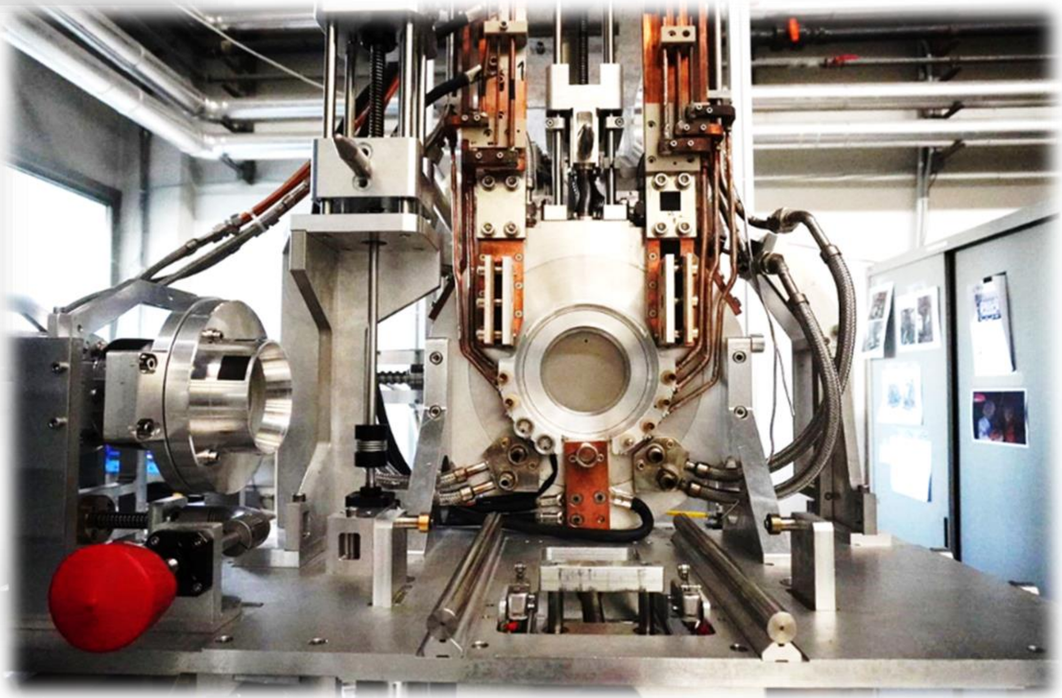
Vacuum test: < 1E-6 mbar -> many metal seals installed

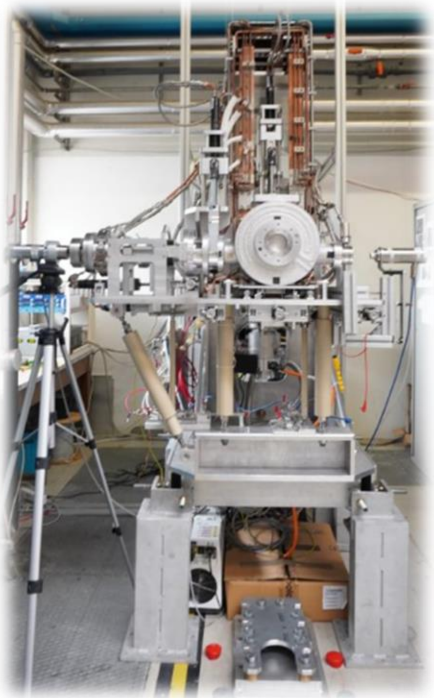
Electrical feedings, checked at nominal range:

- Target: 1300 A
- Source: 400 A
- Oven: 80 A

Waterflow, checked at nominal range: 250 l/h

Map of FE Temperature -> OK , no critical points





Pre-commissioning: high power on TIS unit and FE (14 days)

Maximum total power
P ≃ 8500 W

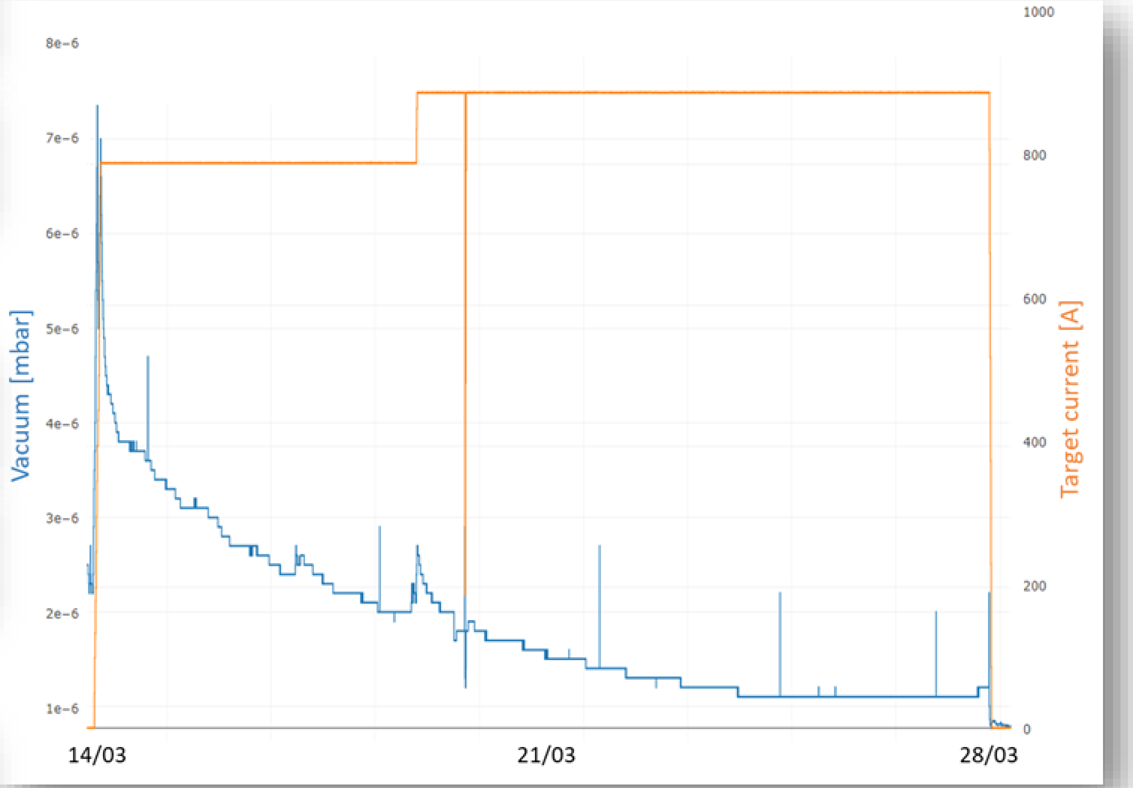
Time at maximum power
t > 10 days

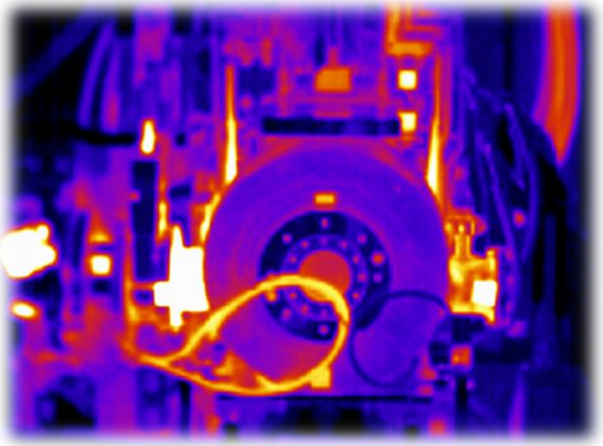
Maximum target heat current
I = 900 A

Average target temperature
T ≃ 1700°C

Maximum ion source heat current
I = 380 A

Average ion source temperature
T ≃ 2000°C

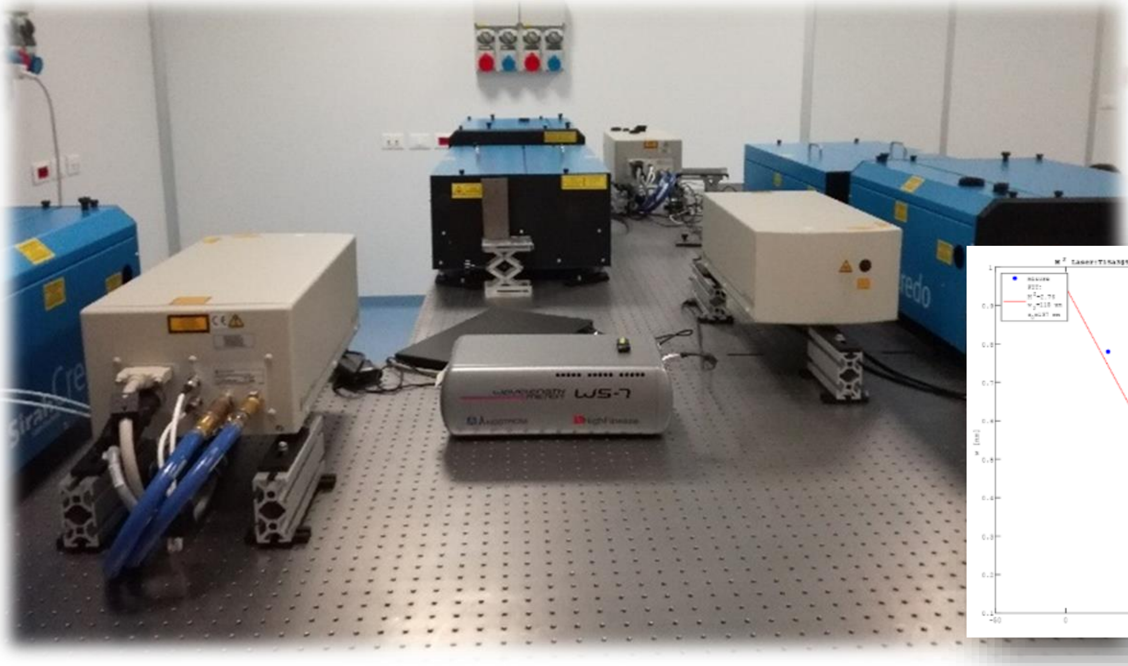


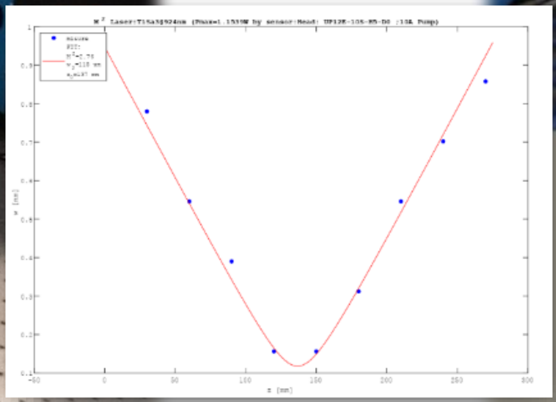


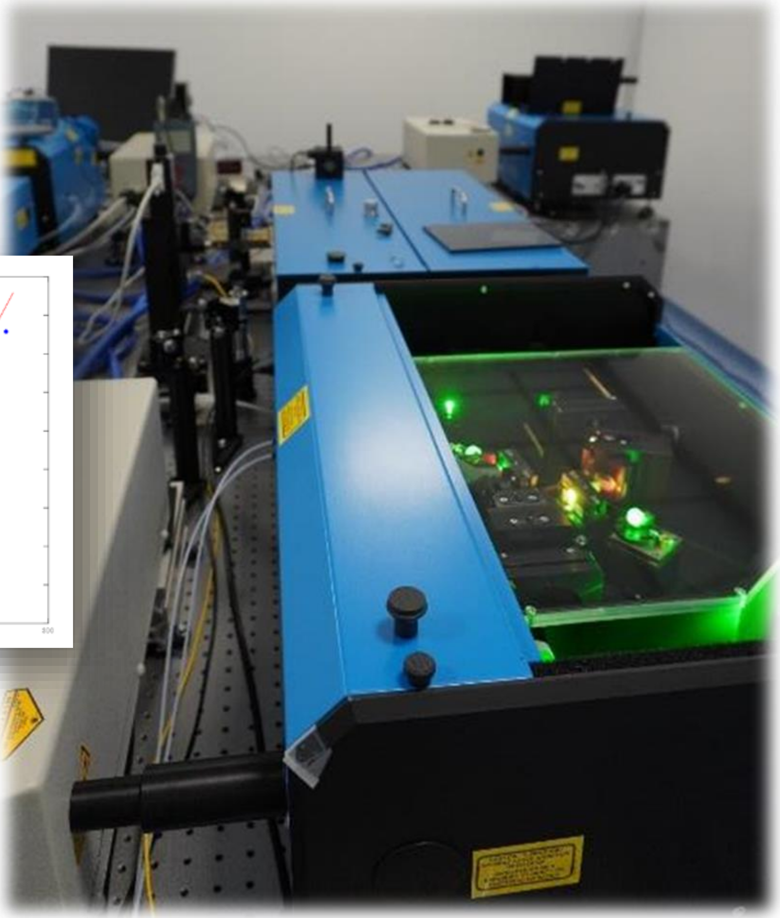
Vacuum level reached during test
P ≃ 1.1E-6 mbar

Pre-commissioning : test of the on-line laser system

On-line LASER lab for Laser Ion Source: current state -







- Performance evaluation tests after some adjustments from company
- Fine parameters measurements (M2, bandwidth, tuning)
- Setting up laboratory (whit new Instrumentations and Mechanics)

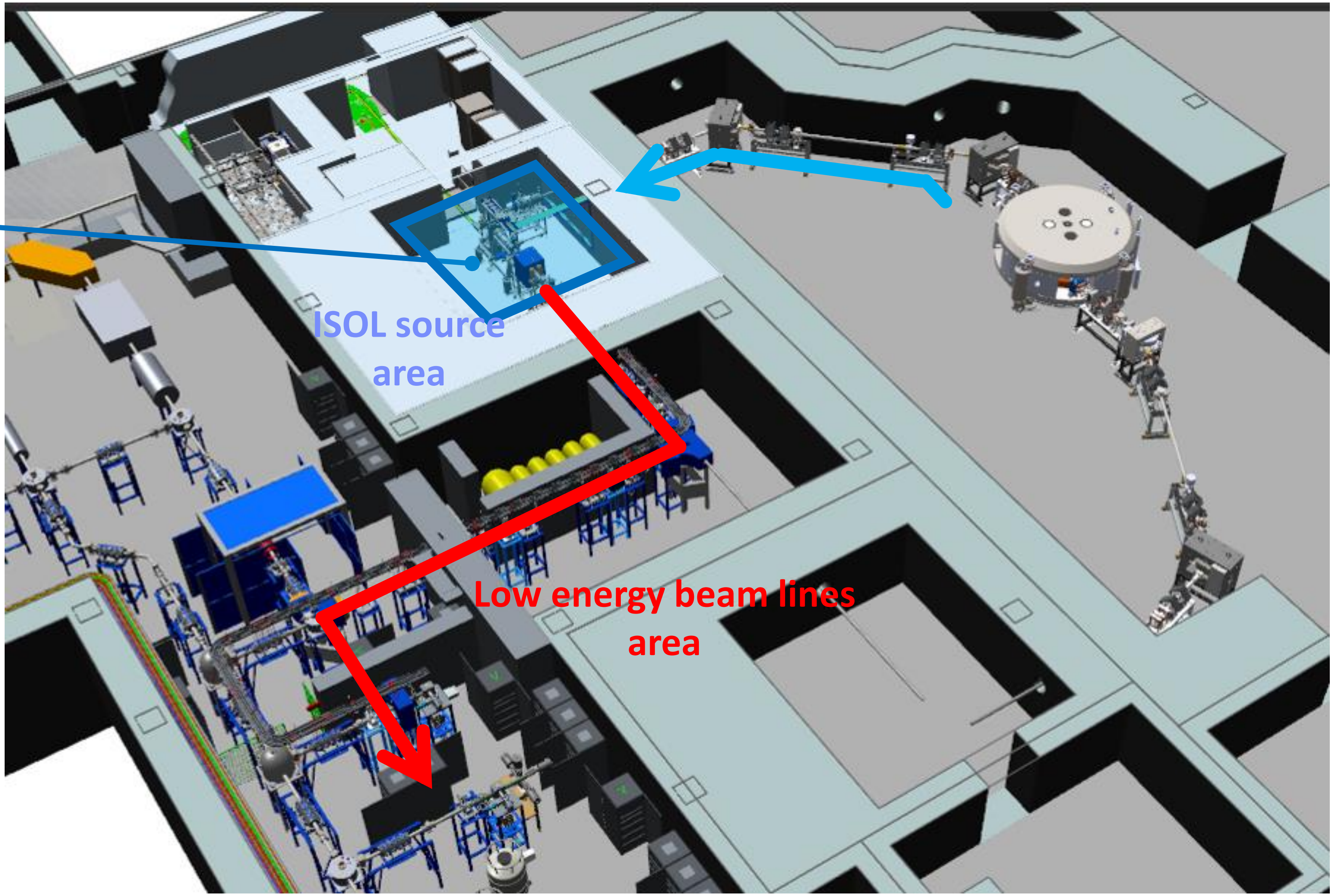
Beam Lines Installations

The low energy complex: general layout

ISOL hall
(A6 room)

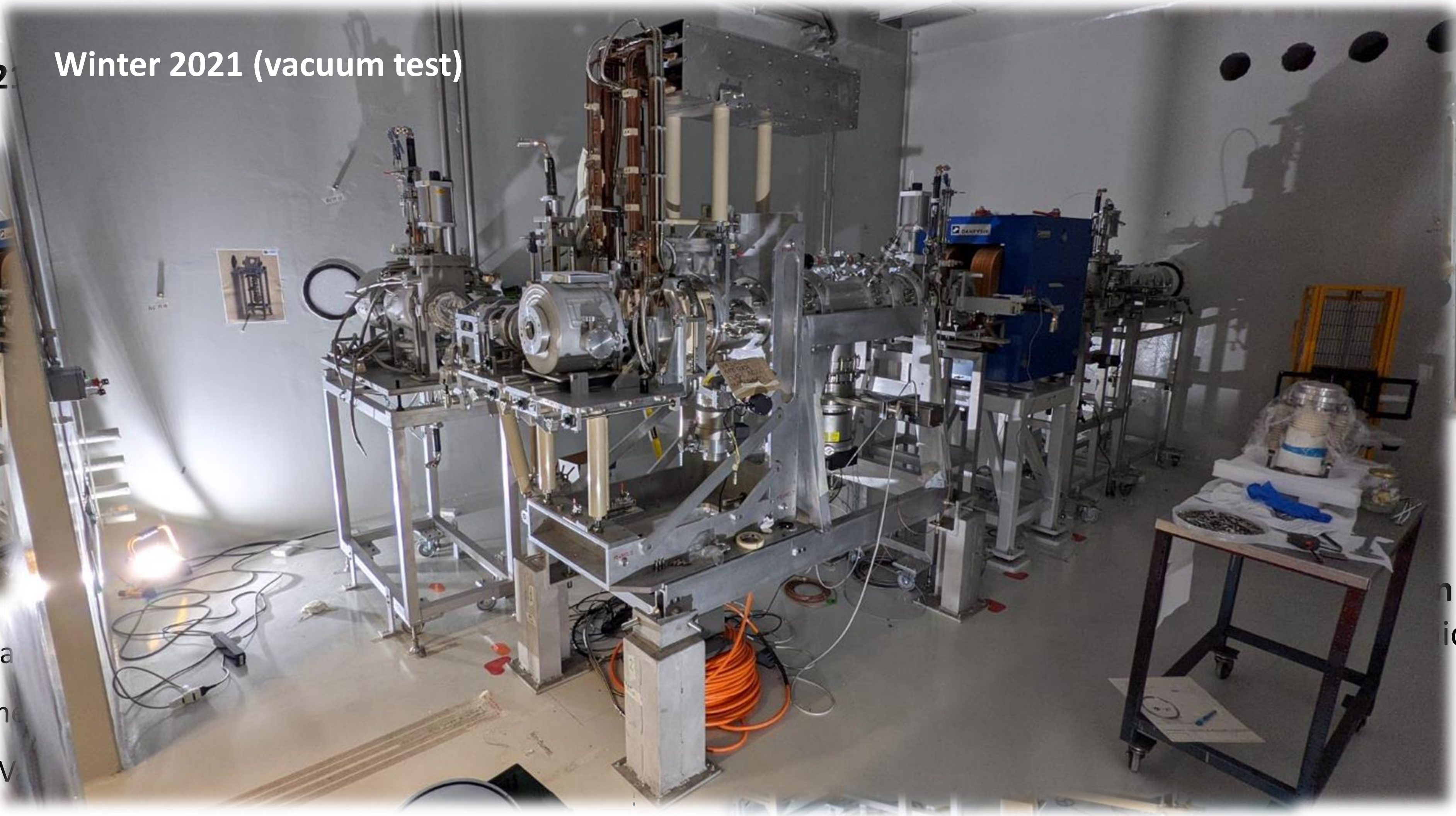
40 MeV 200 µA primary proton beam

1^{+} RIB @ LE



Installation of the ISOL source: Main devices

April 202



n 2021

ic front-end)

- First pa
- Alignm
- Good V

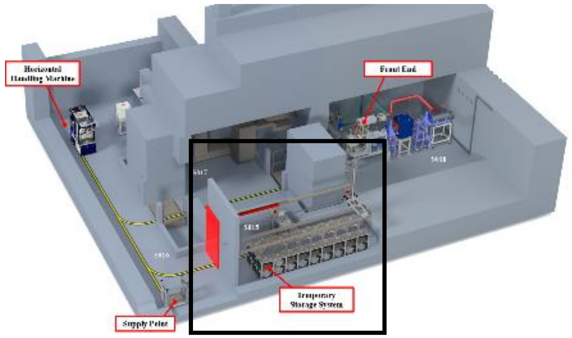
Installation of the ISOL source: Bunker plants

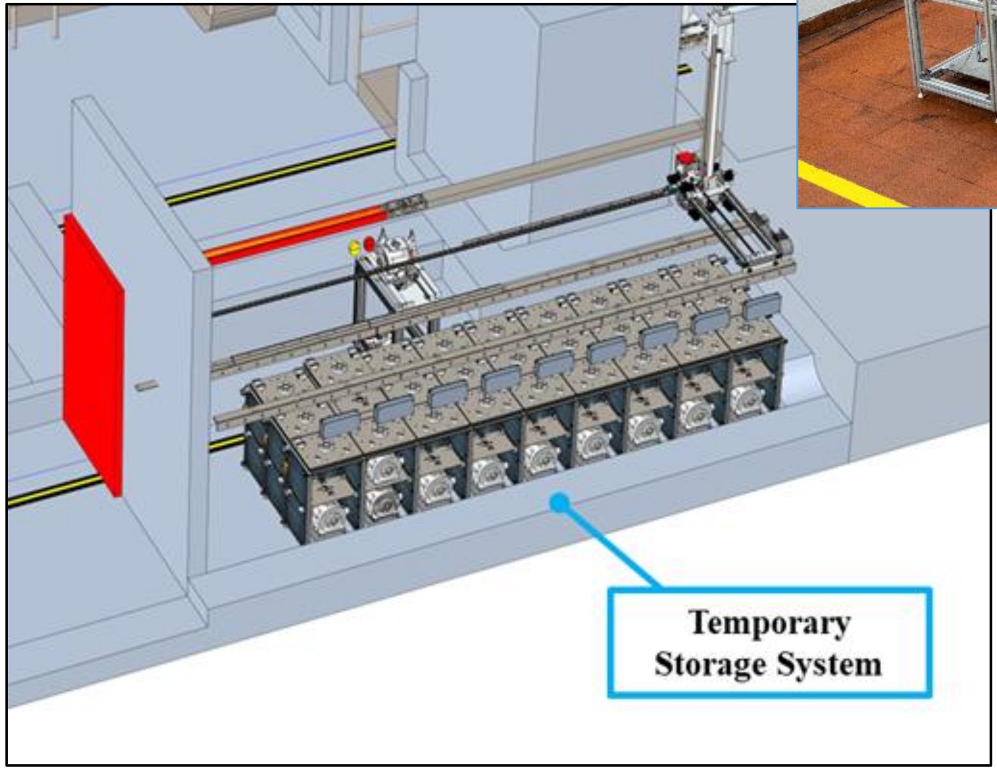
<u>**Summer 2022**</u>

Installation of the ISOL source: Temporary Storage construction

Status:

- Tender for construction/installation assigned .
- Contract signed in april/2022
- Schedule agreed with the company: (on Track)
    - Executive project: 06/2022
    - Construction till 09/2022
    - FAT: 10/2022
    - Installation at LNL: 12/2022





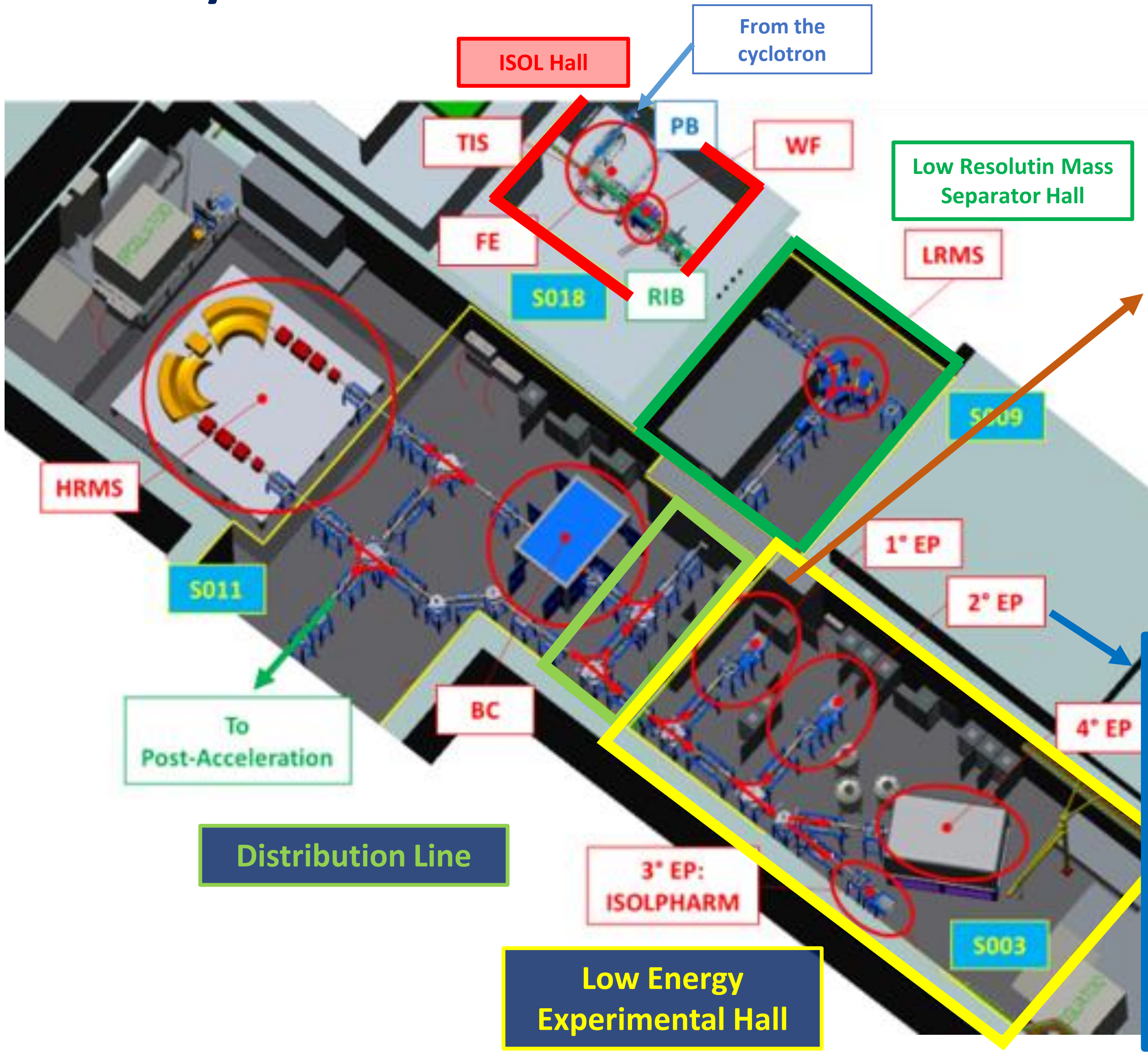
The low energy beam lines: layout

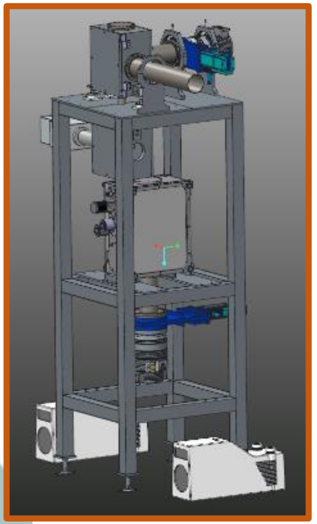
All devices and frames stored at LNL

Final CAD & beam transport calculation ready

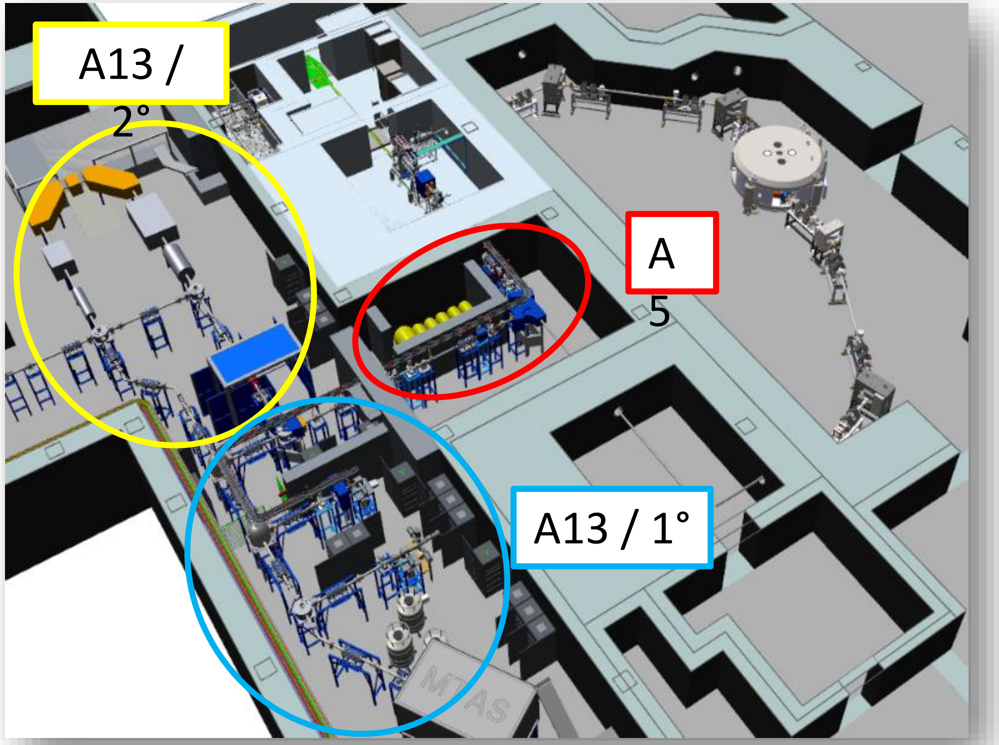
- 1st experimental point: **Tape Station (RIB Diagnostic)**
  - Mechanical device: ready
  - Ion beam delivery characteristics: fixed
  - Occupation area: fixed
- 2nd experimental point: **The Beta Decay Station**
  - Detailed design in advance status
  - Preliminary ion beam delivery characteristic defined
  - Preliminary occupation area defined
- 3rd experimental point: **ISOLPHARM**
  - **Detailed design in advance status**
- 4rd experimental point: **new Experiment**

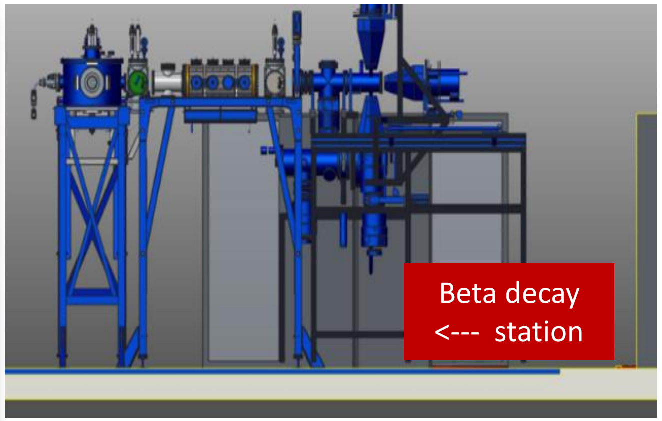
Beam lines Installations: before end 2023

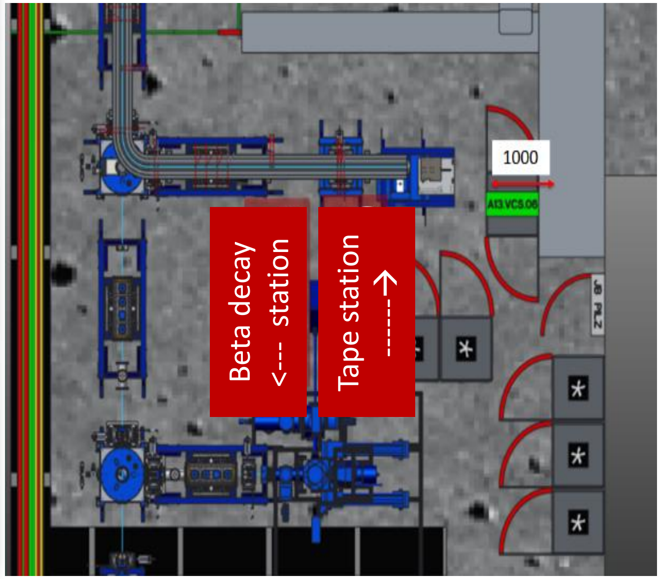




The low energy beam lines: devices ready for installations



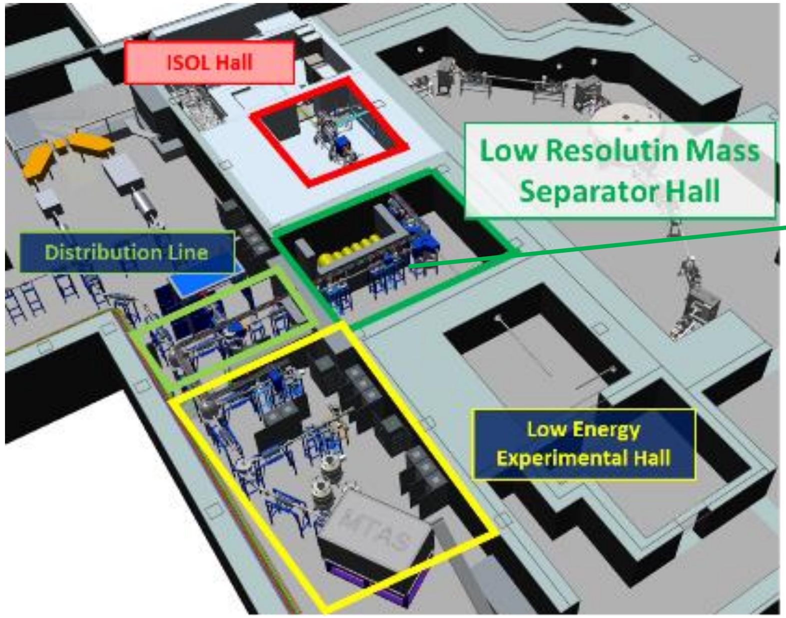


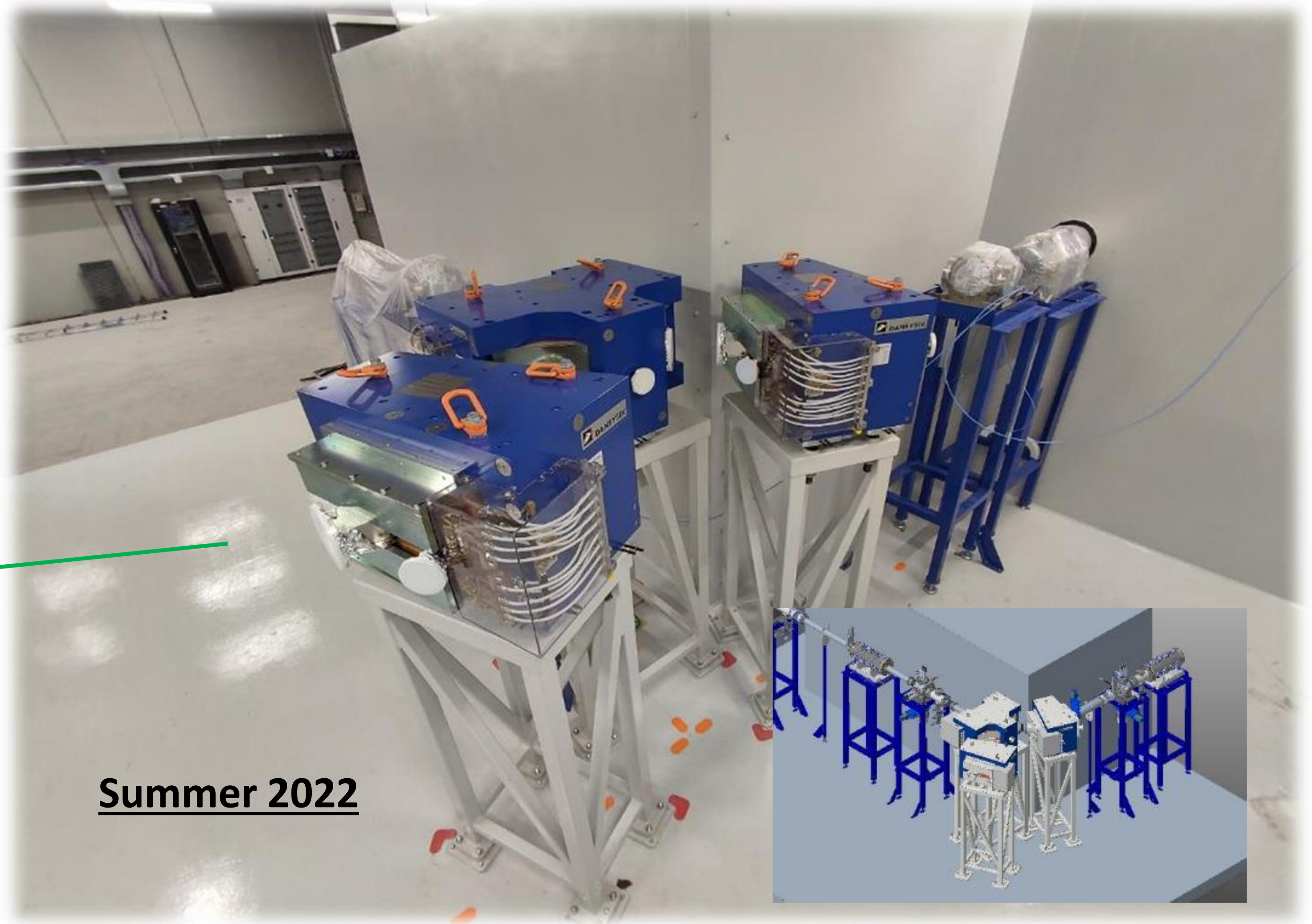


The low energy beam lines: first installations

A5: Low Resolution Mass Separator Hall:

- Hall staging started in march 2022
- All elements positioned in summer 2022
- Detailed CAD & beam transport calculations ready
- Tender for Plants installation in the preparatory phase





Summer 2022

ISOLPHARM

SPES exotic beams for medicine

The ISOLPHARM method

Whit the ISOL technique is able to produce & isolate, the SINGLE RADIO-ISOTOPE

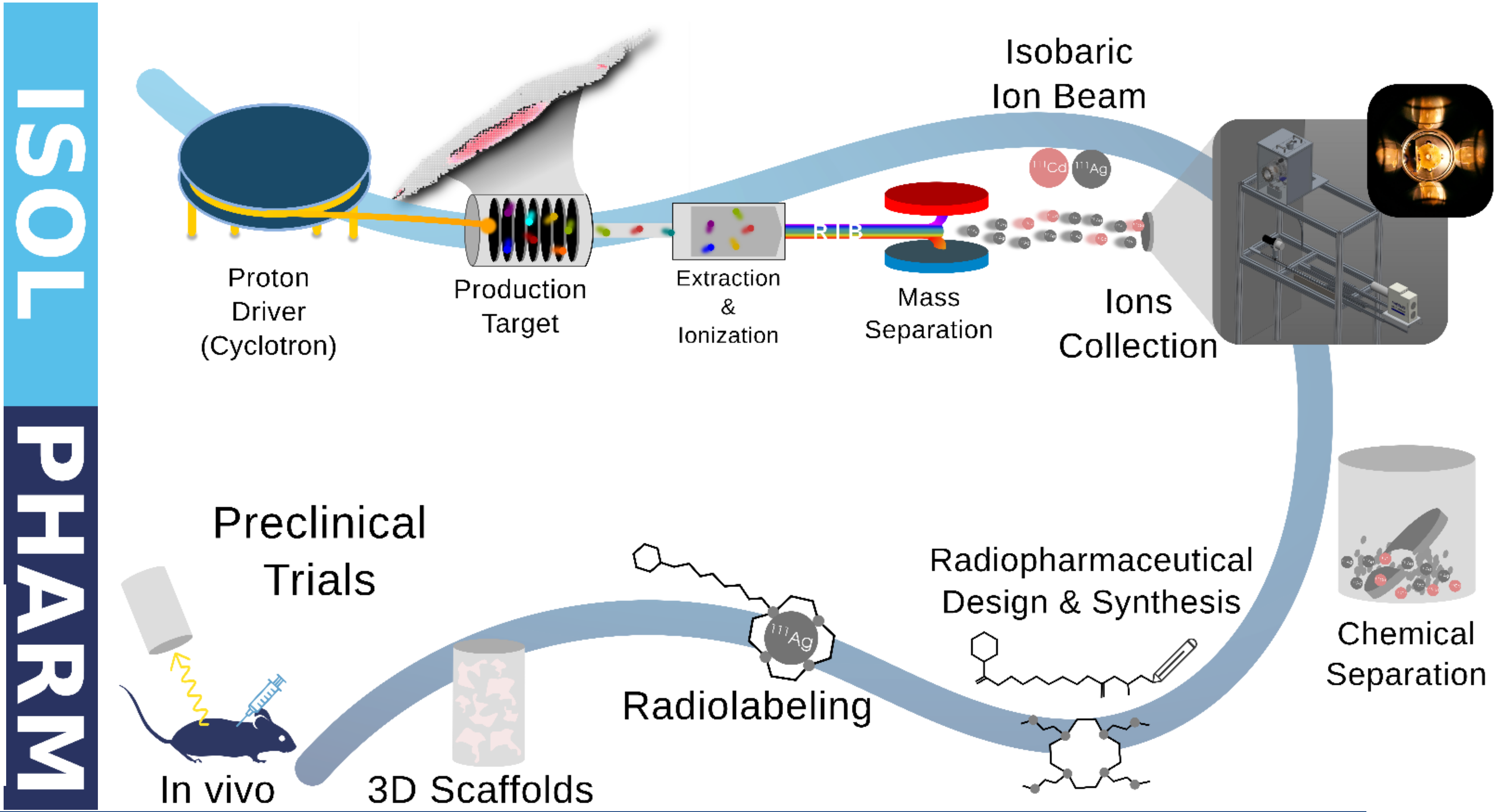
Consequence

⬇

the sample collected has:

- high specific activity

- high radionuclidic purity



The Isolpharm Collaboration

Development of cell-lines, *in-vitro* and *in-vivo* studies, imaging

Unconventional radionuclide (e.g. ^{111}Ag) production with an innovative method

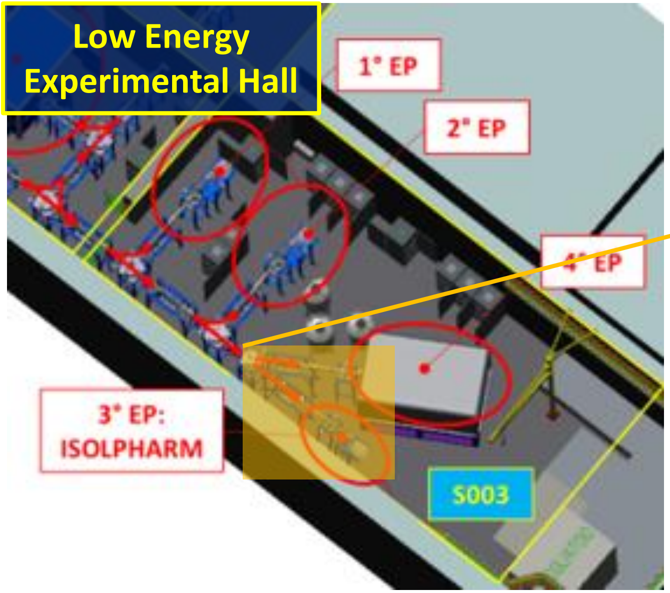
Development and synthesis of small molecules for cancer treatment

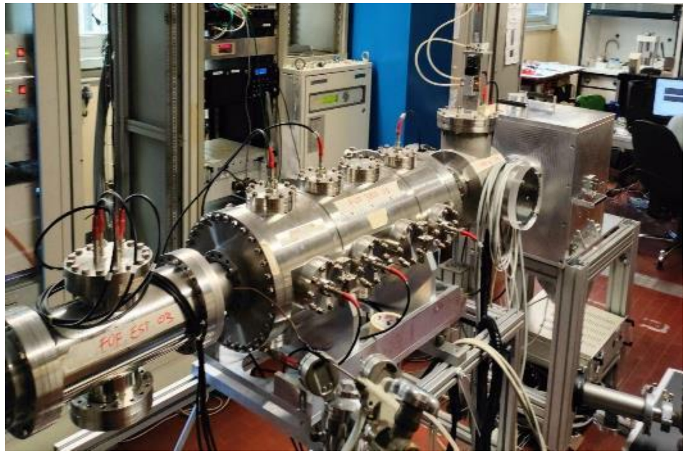
Study and development of tumor targeting agents for specific targets (e.g. CCK2R)

Development of chemical purification procedures and innovative chelators

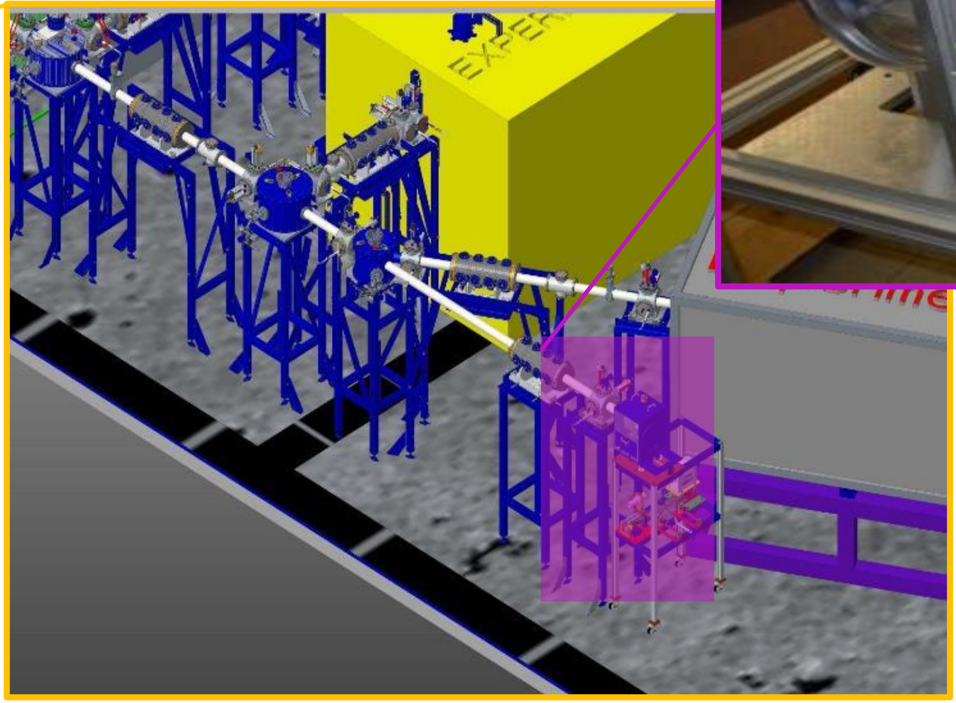
ISOLPHARM started as a spontaneous gathering of local competences, now coordinated by INFN-LNL

The ISOLPHARM facility





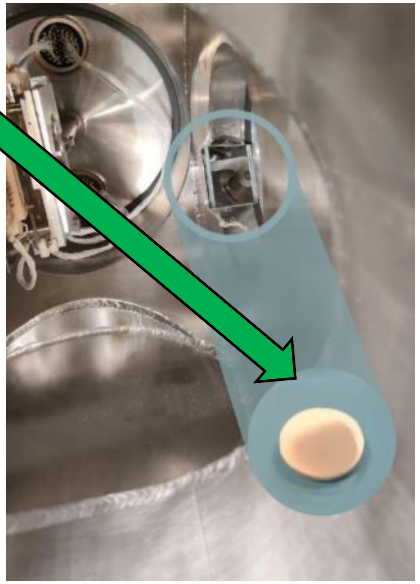
ISOLPHARM beamline and IRIS (ISOLPHARM Radionuclide Implantation Station) system



Beamline design complete!

IRIS system built and on line tested

^{63}Cu deposited

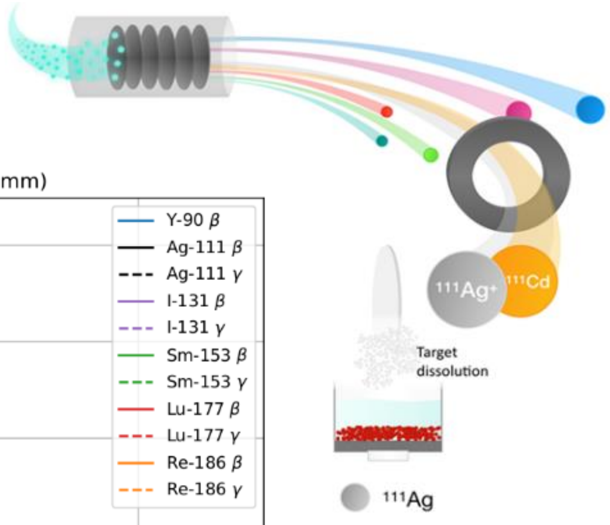


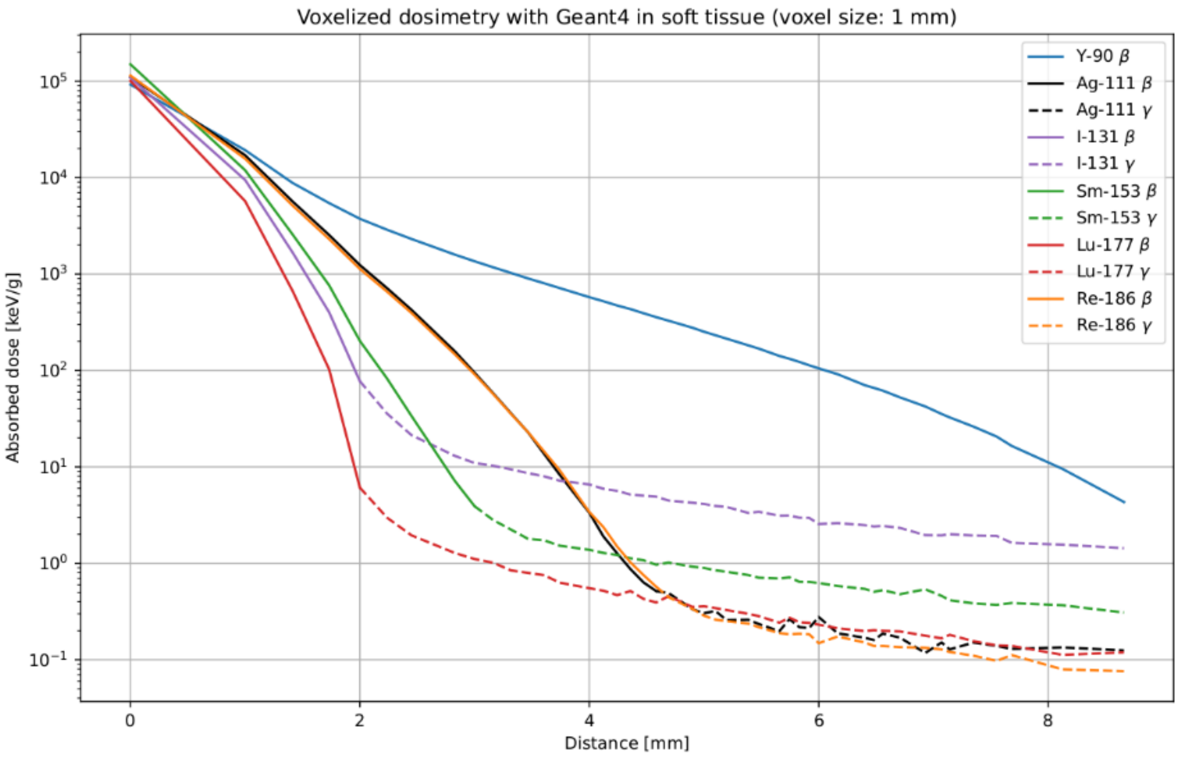
Radiopharmaceutical radiolabeled with ^{111}Ag

^{111}Ag properties

- **β⁻ emitter** (average energy **360 keV**)
- Good half-life (**7.45 days**)
- Average tissue penetration (**1.8 mm**)
- Medium energy γ rays -> SPECT candidate

ISOLPHARM Ag ISOLPHARM_EIRA





→No radiopharmaceuticals radiolabeled with 111Silver in the market.

→ Silver-111 can be produced @ SPES with high purity & with high production rate

→ No Isobaric contamination in the secondary target (also with LASER off)!

→ ^{111}Ag exhibits possible 'theranostic' properties similar to ^{177}Lu which was recently approved by FDA.

→ ^{111}Ag has dosimetric behavior equal to ^{186}Re, which was recently studied in Phase I / II trials

111 Isobaric chain	Half-Life $T_{½}$	Decay	Target Yield
Cadmium-111	Stable		**Low yield production**
Silver-111	7.45 days	β⁻	**Good yield production**
Palladium-111	23.4 min	β⁻	**Bad release, short $T_{1/2}$**
Rhodium-111	11 sec.	β⁻	**No release, very short $T_{1/2}$**

^{111}Ag production at LENA

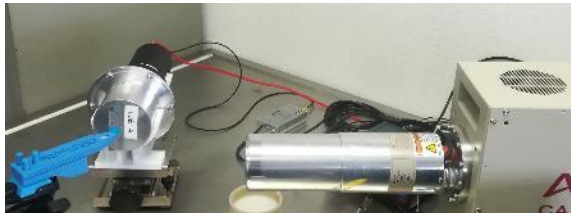
^{nat}Pd and ^{110}Pd samples irradiations

The **production** of ^{111}Ag was performed with the Pavia **LENA Triga Mark II Research Reactor,** and the results were compared with MC simulations

Quality Control System

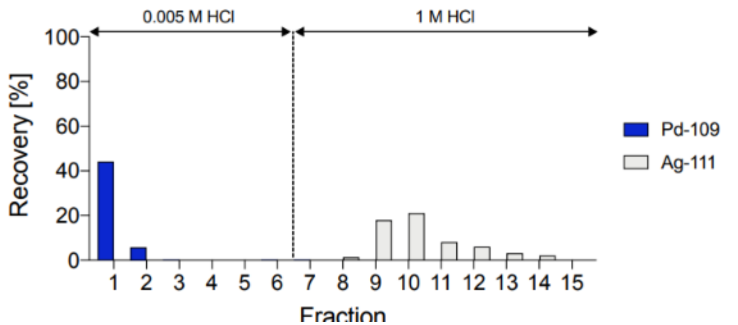
Irradiated samples were measured with different spectroscopic systems:

$LaBr_3$ + HPGe or **LBC**

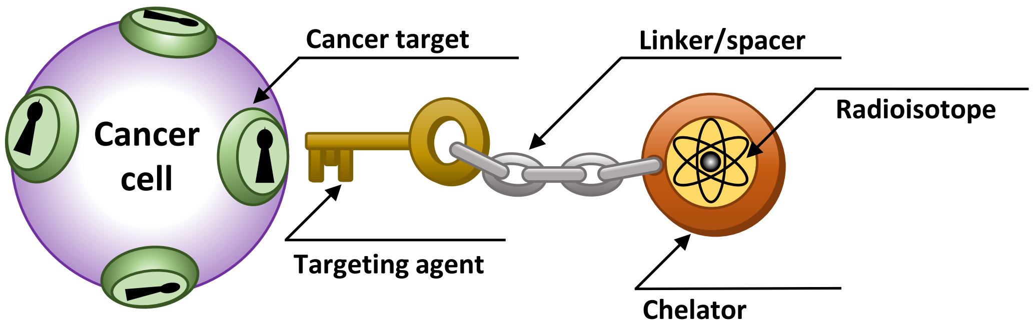


Ag/Pd chemical separation

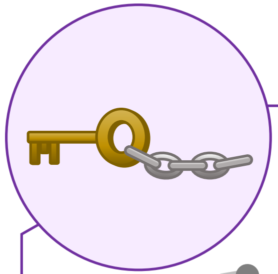
A novel method for **purifying ^{111}Ag from ^{nat}Pd** target was tested.



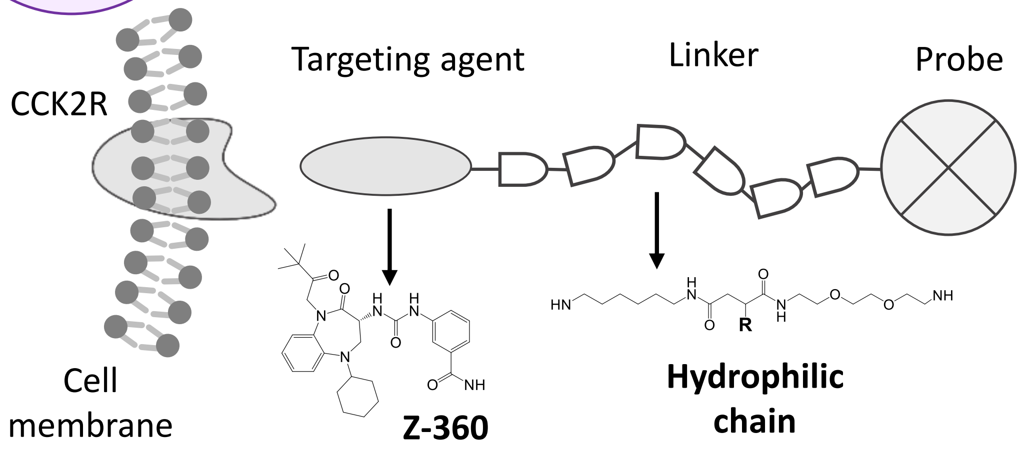
Radiopharmaceutical production

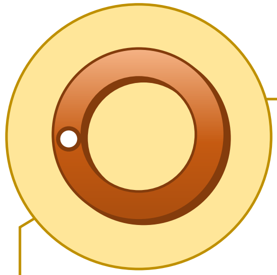


Macromolecules with different solubility and chelating agents for silver were developed and characterized

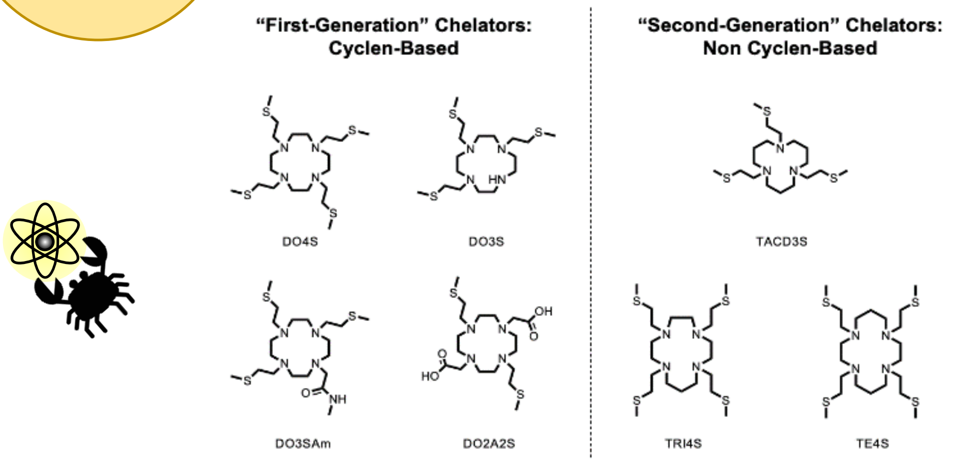


THE MACROMOLECULES



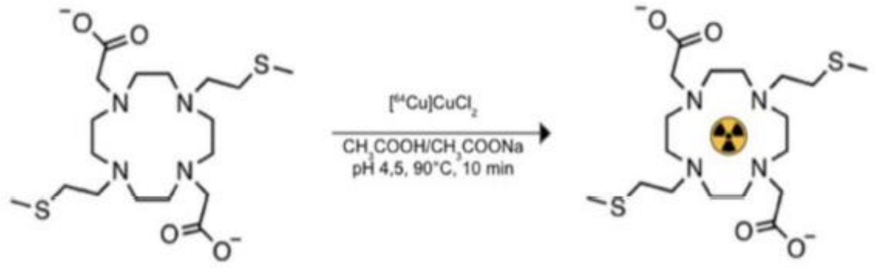


THE CHELATING AGENT

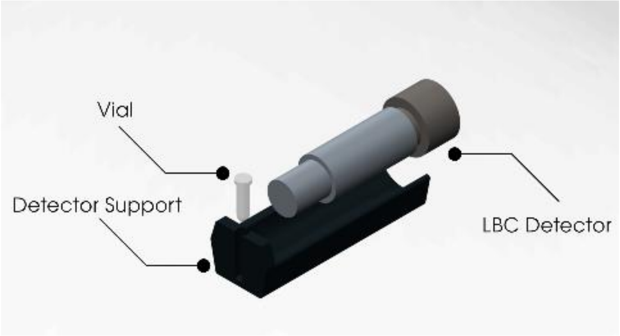


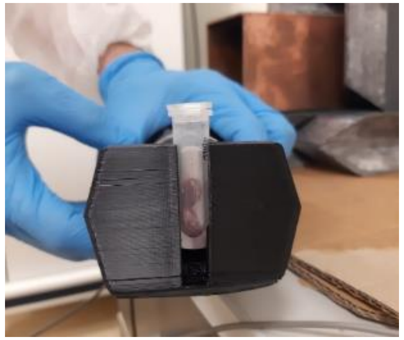
Preliminary in-vivo Experiments

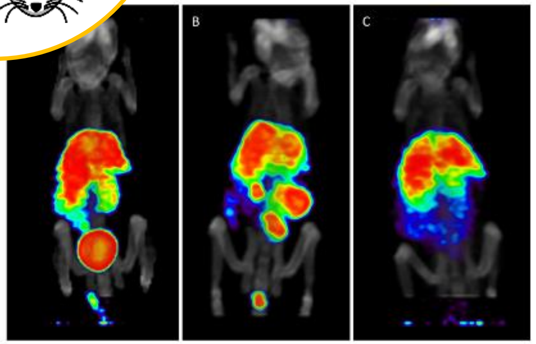
[64Cu][Cu(DO2A2S)] Biodistribution

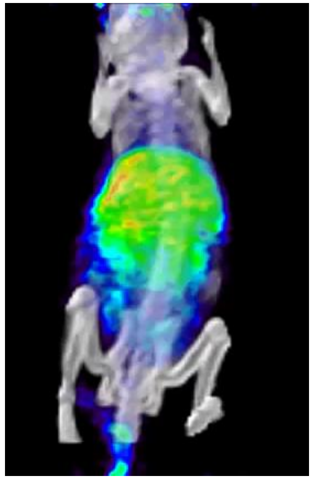


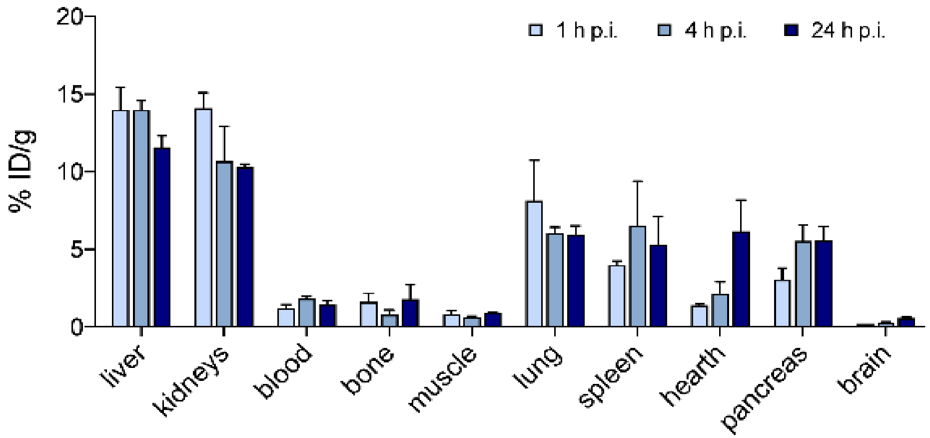
Organs biodistribution was measured with a dedicated gamma detection system (compact and portable)











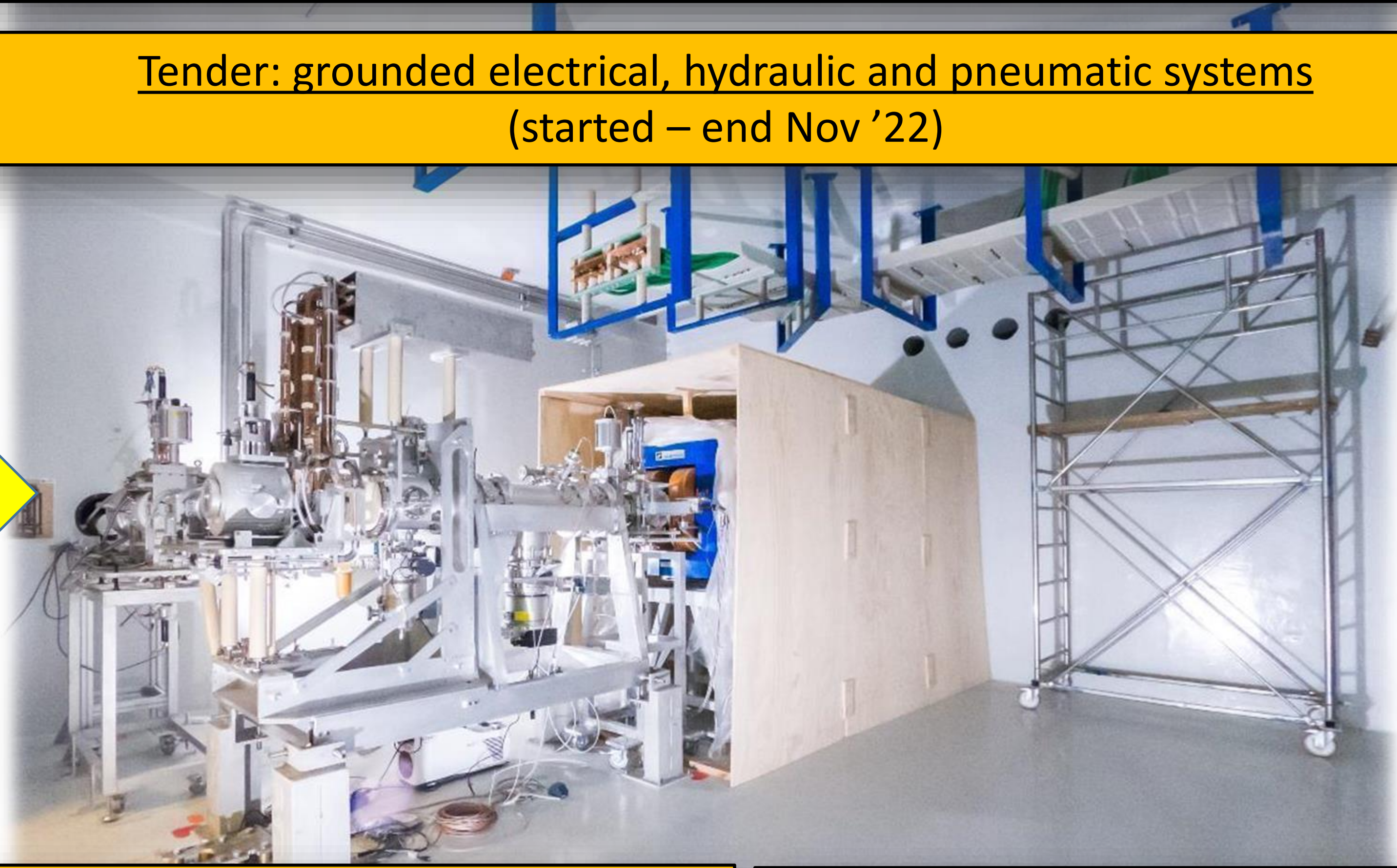
Conclusions

Concluding Remarks: status of Low Energy RIB lines

- ✓ Pre-commissioning : done
- ✓ Front End: installed and aligned
- ✓ Vacuum leak measure: done
- ✓ High-Voltage cabling: done
- ✓ Ground cabling installation: wip
- ✓ Low Energy Line: wip
- ✓ Tender for plants: wip

Tender: electrical, hydraulic and pneumatic systems at HV (end Sept '2022)

Tender: grounded electrical, hydraulic and pneumatic systems (started – end Nov '22)



Tender : temporary storage (started – end Dec '22)

Tender : hot cell (preparatory phase)

Concluding Remarks: Collaborations

SPES project
Exotic beam team

INFN PAVIA
INFN MILANO
dtg
UNIVERSITÀ DEGLI STUDI DI BRESCIA
DIAM
INFN PADOVA
INFN BOLOGNA
IMI
POLO MECCATRONICA
UNIVERSITÀ DEGLI STUDI DI PADOVA
DIPARTIMENTO DI INGEGNERIA INDUSTRIALE
CERAMGLASS RESEARCH GROUP
HIT HUB INNOVAZIONE TRENTINO
OAK RIDGE National Laboratory
PRISMAP Medical Radionuclides
TRIUMF
CERN
ISOLDE

THANKS FOR YOUR ATTENTION!

The presented activities are the result of the work of the whole SPES ISOL & Isolpharm teams

- Alberto Andrighetto (SPES Technical Coordinator)
- Mattia Manzolaro (SPES WP6 Coordinator)
- Daniele Scarpa (Laser Ionization, System Integration)
- Stefano Corradetti (Target Materials)
- Alberto Monetti (Front-End and Beam Lines)
- Michele Ballan (Target Ion Source R&D)
- Giordano Lilli (Handling System)
- Lisa Centofante (Target Ion Source unit preparation)
- Luca Morselli (Detectors)
- Michele Lollo (Manufacturing of Components)