SPES: technological challenges and prospective for new applications at LNL

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INFN Acceleratori Seminar, June 10th 2022

OUTLINE

- Research with SPES

- Cyclotron
- Target Ion Source complex
- High Resolution Mass Separator
- ADIGE: Charge breeder and Medium Resolution Mass Separator
- RFQ
- ALPI
- Radionuclides of medical interest

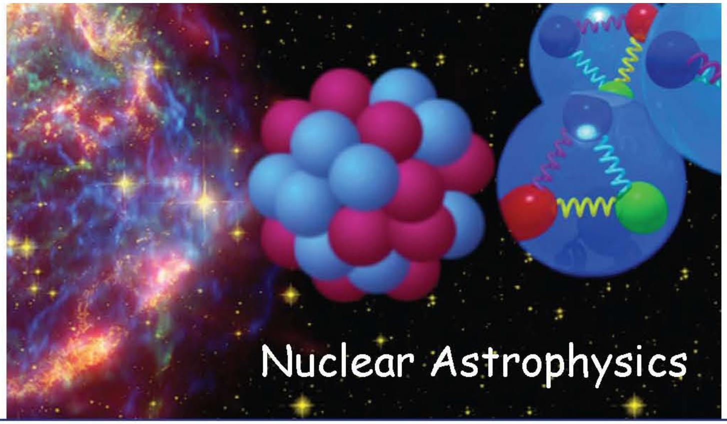
- Status of SPES

The SPES project

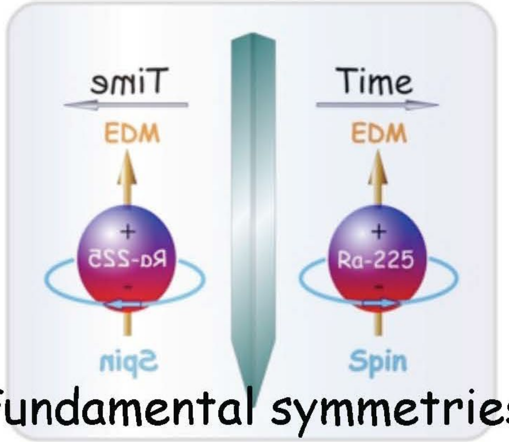
The SPES project – **S**elective **P**roduction of **E**xotic **S**pecies aims at the realization of an accelerator facility for research activity in different fields:

- Fundamental physics: nuclear physics (nuclear matter in extreme conditions) and nuclear astrophysics (stellar evolution) with **radioactive ion beams**
- Interdisciplinary physics: **production of radionuclides of medical interest**, generation of neutrons for material study, nuclear technologies, …….

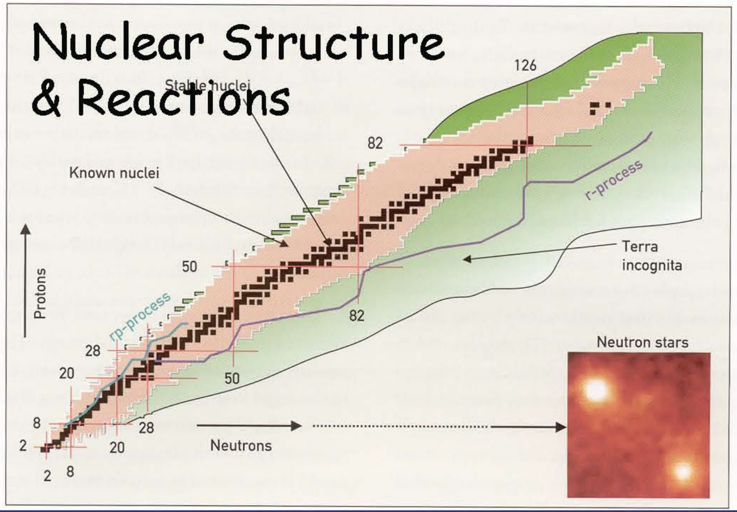
Research prospective with SPES



Origin of new elements, rare isotopes powering stellar explosions, neutron star crust



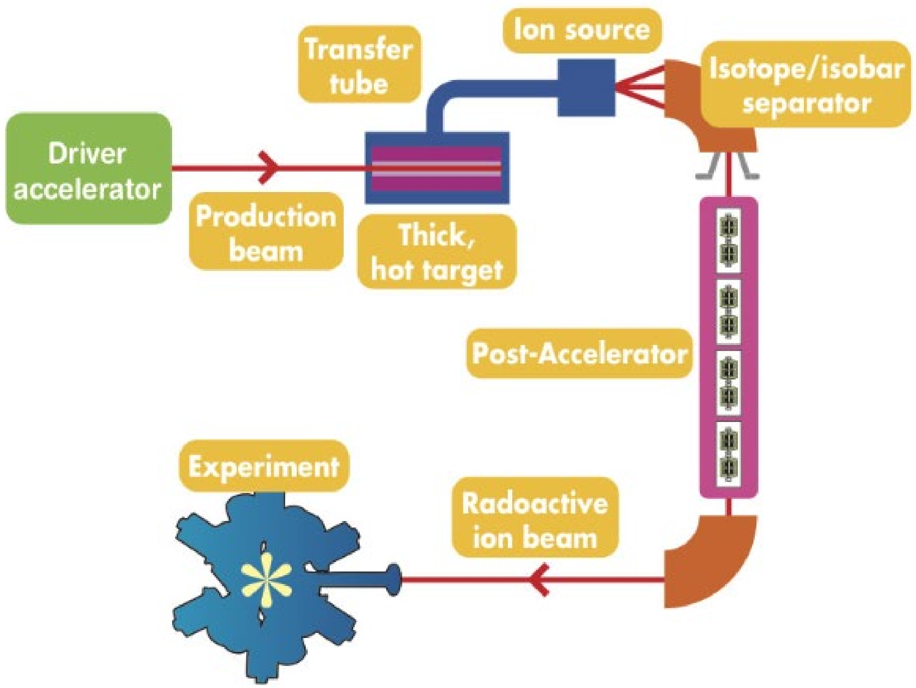
Use of rare isotopes as laboratories where symmetry violations are amplified.

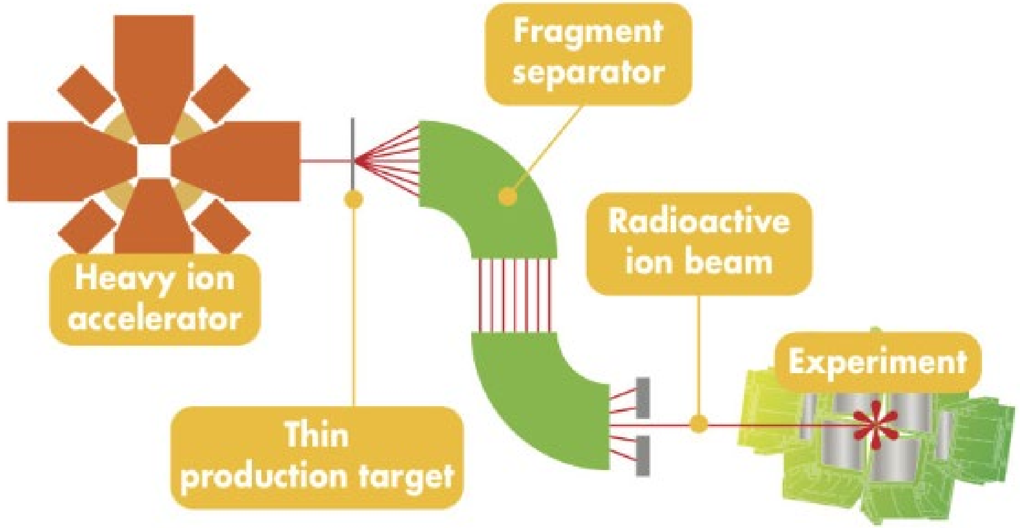


Limits of existence: what makes nuclei stable? New shapes, new collective behavior.

Materials, medical physics,

RIB production techniques





ISOL

Small beam emittance
Small energy spread
Pure beams (HRMS+lasers)
Slow
Technologically complex
Needs post-acceleration

In-flight

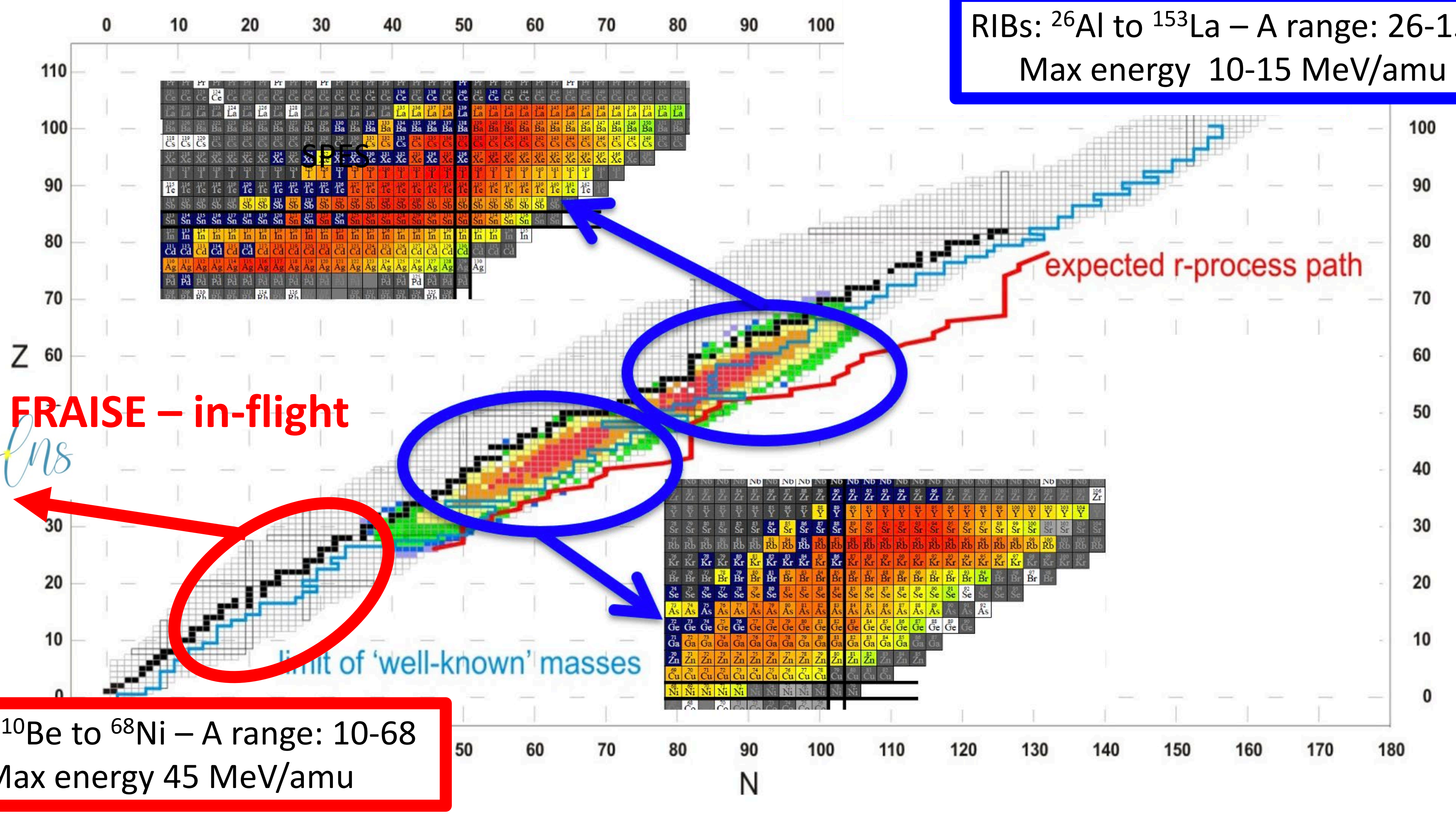
Fast
Technologically simple

Limited to high energy
Cocktail beam tagging

LNL – LNS complementarity

LNL SPES - ISOL

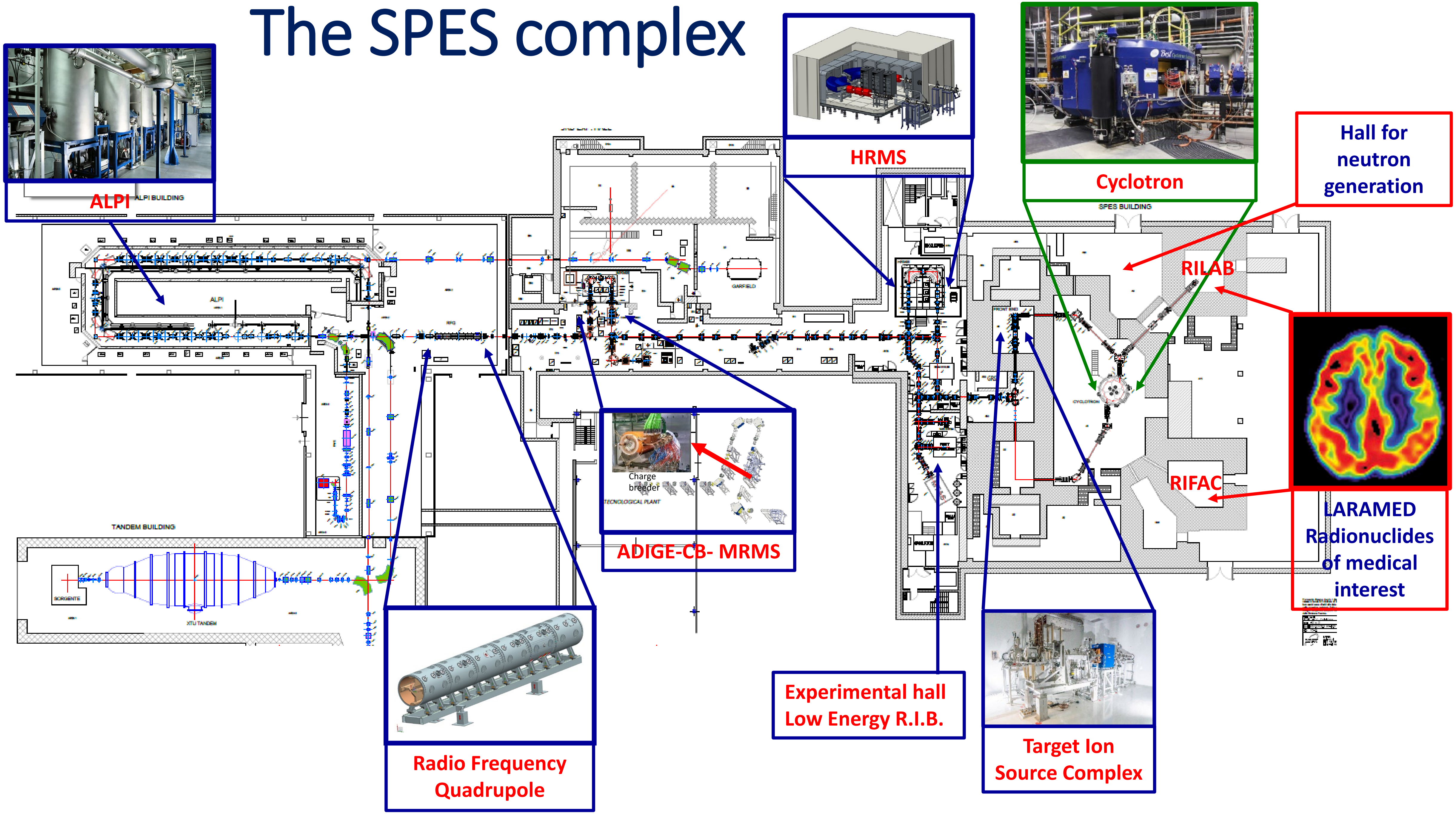
RIBs: ^{26}Al to ^{153}La – A range: 26-153
Max energy 10-15 MeV/amu



LNS FRAISE – in-flight

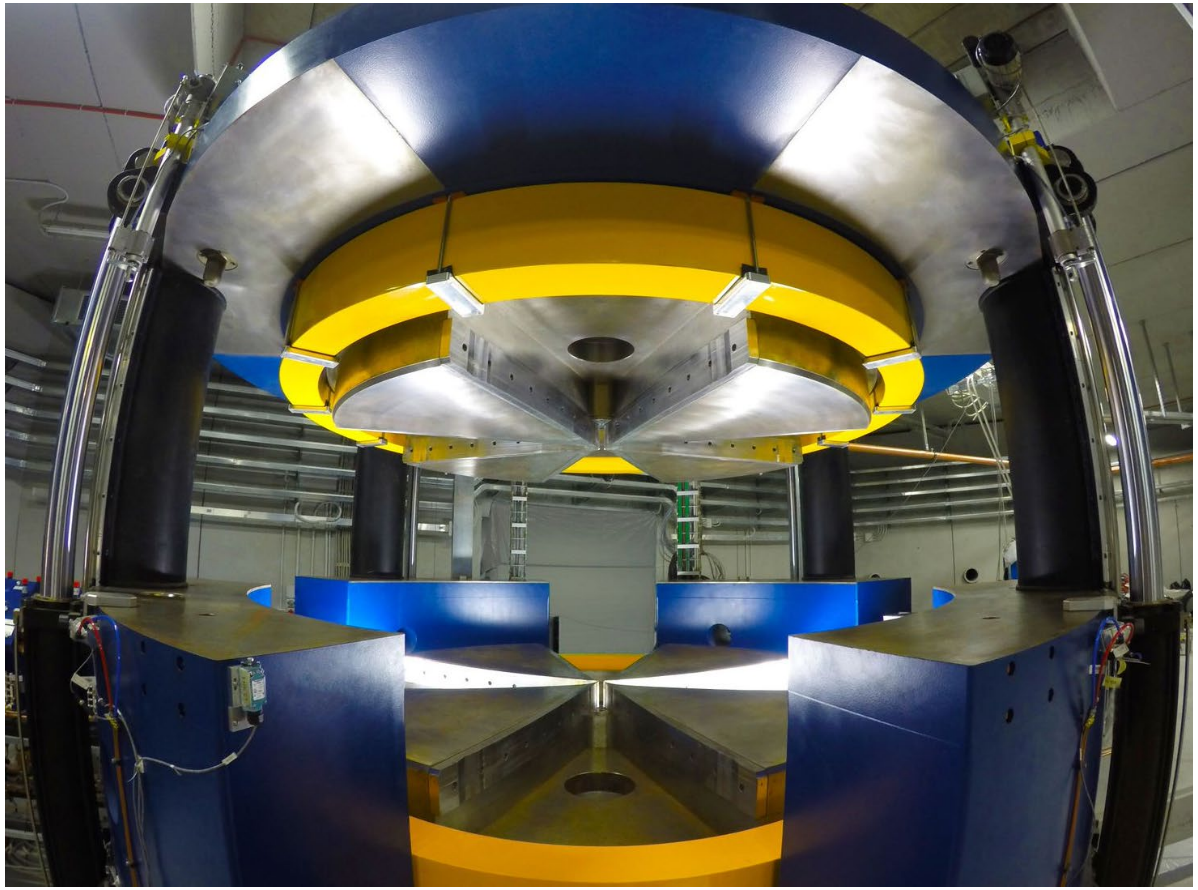
RIBs: ^{10}Be to ^{68}Ni – A range: 10-68
Max energy 45 MeV/amu

The SPES complex



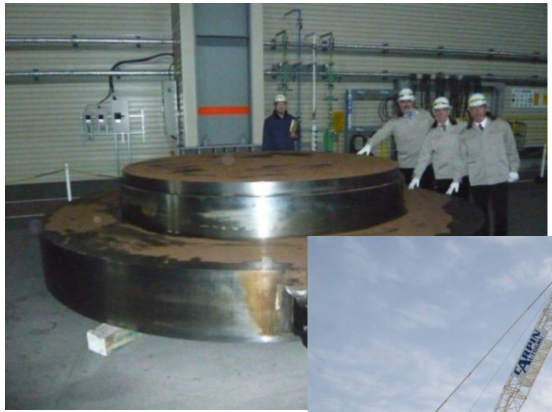
The SPES Cyclotron

Designed and constructed by BEST Theratronics, Canada



Main Parameters	
Accelerator Type	Cyclotron AVF 4 sectors
Particle	Protons (H^- accelerated)
Energy	Variable within 35-70 MeV
Max Current Accelerated	750 µA (52 kW max beam power)
Available Beams	2 at the same energy
Max Magnetic Field	1.6 Tesla, resistive magnet, 25kW DC power supply
RF frequency	2 cavities, f_{RF}= 56 MHz, 4^{th} harmonic mode, 50 kW power
Vacuum	4 cryo-pumps → P=$2x10^{-8}$ Torr
Ion Source	External Multicusp H^- I=15 mA, Axial Injection
Dimensions	Φ=4.5 m, h=2 m
Weight	150 tons

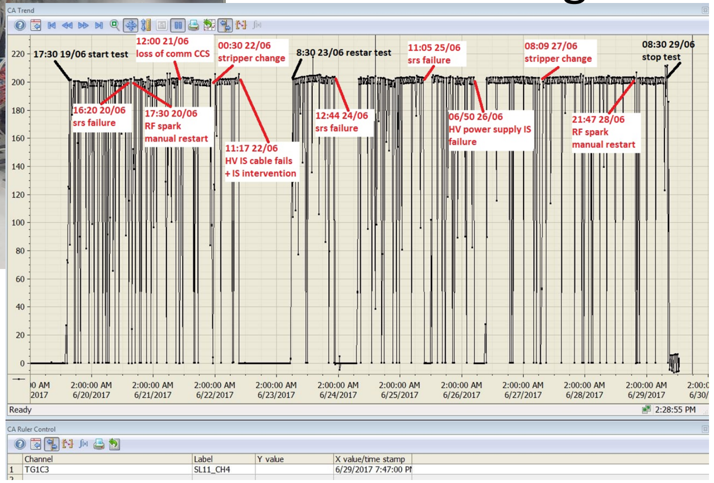
SPES Cyclotron timeline



2011-2014 Study, Design ,Construction and factory tests

2015
Installation at LNL

2016
First beam and commissioning

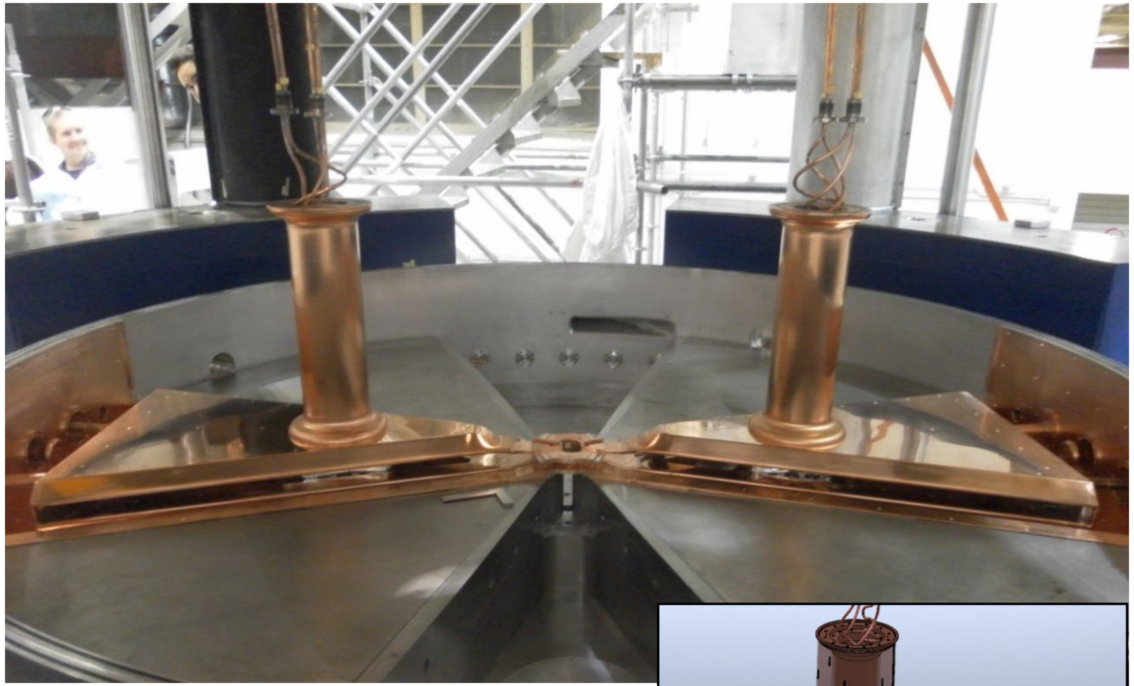


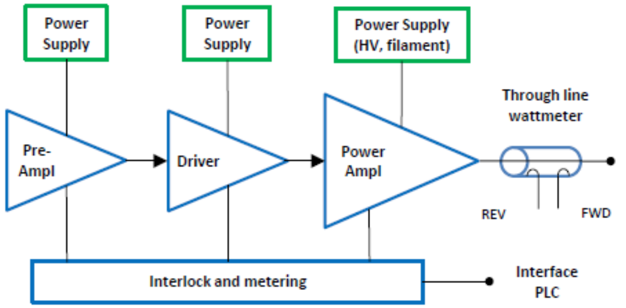
2017
Site Acceptance Test

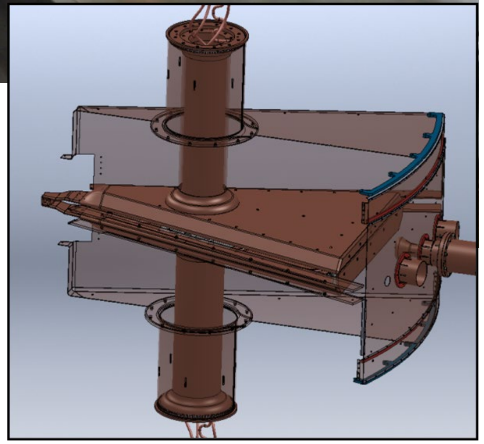
2018
INFN operation

RF system

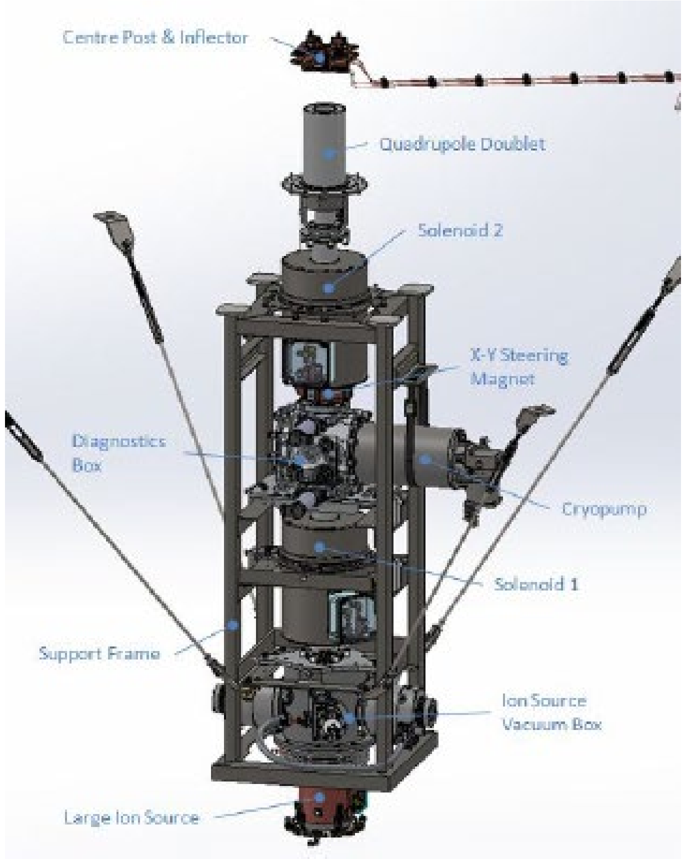
- Two RF cavities Cu made (dees structure Al made), single stem (lambda/2 configuration)
- Two radial capacitor couplers and related trimmers for fine tuning
- Two power amplifiers (double stage, tube based) of 55 kW each feeding power thru rigid coaxial lines (35 m)
- Fixed operational frequency: 56.1 MHz (4th harmonic mode)
- 70 kV maximum voltage (10^{-4} of stability)
- Quality factor ~ 7000
- Cavities operate independently at the same RF frequency and phase

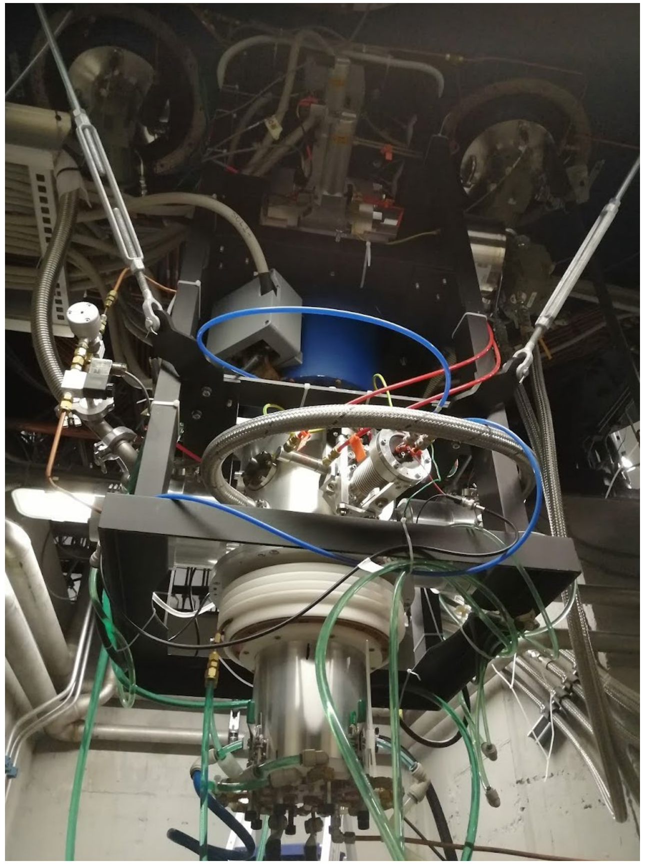




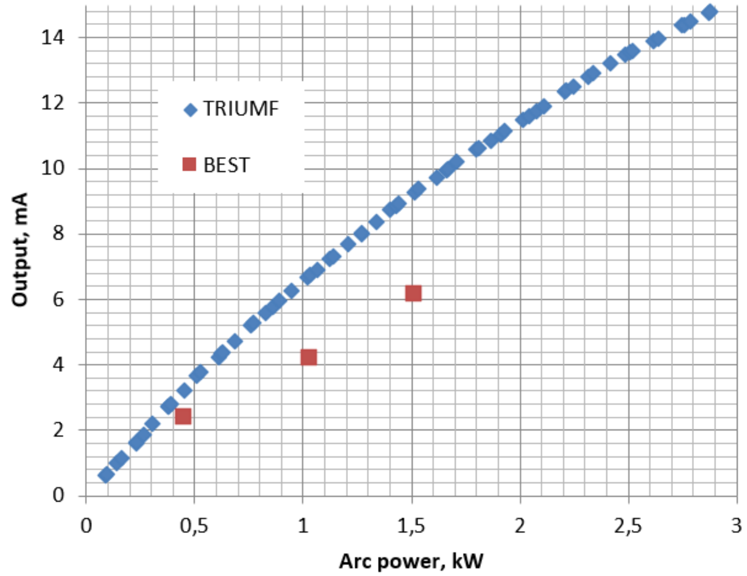


Injection system



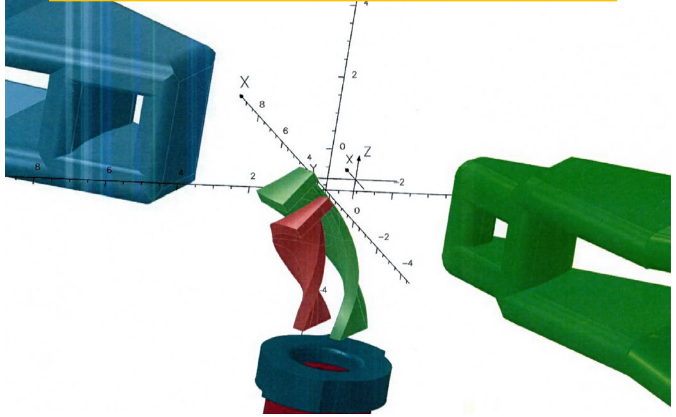


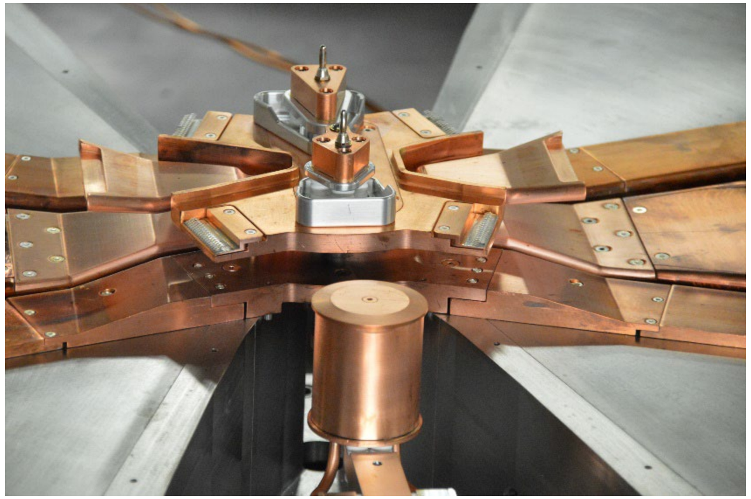
- Axial injection from external ion source to inflector
- H^- ion source: volume multicusp type (TRIUMF design based)
- 8 mA extracted current at 2 kW arc power



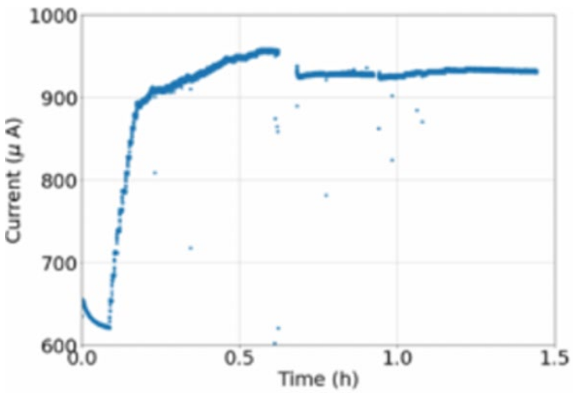
Central region

Inflector view

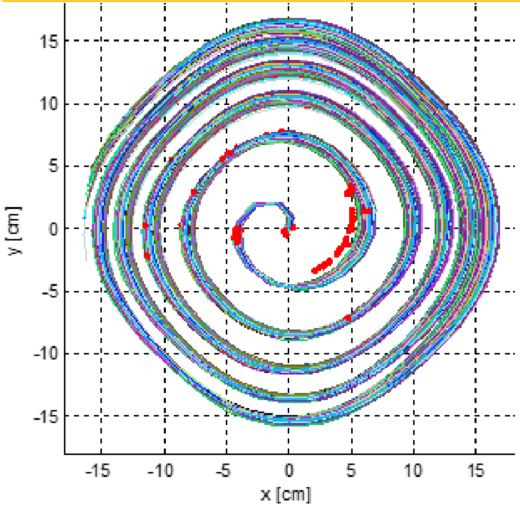




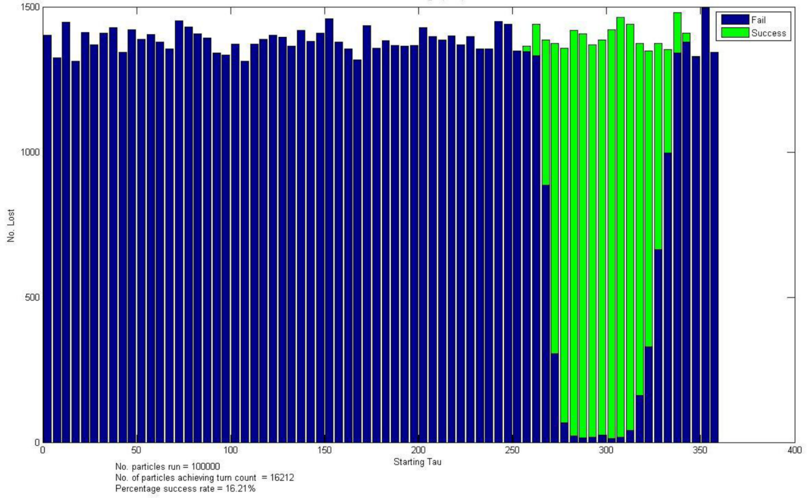
1 MeV maximum current



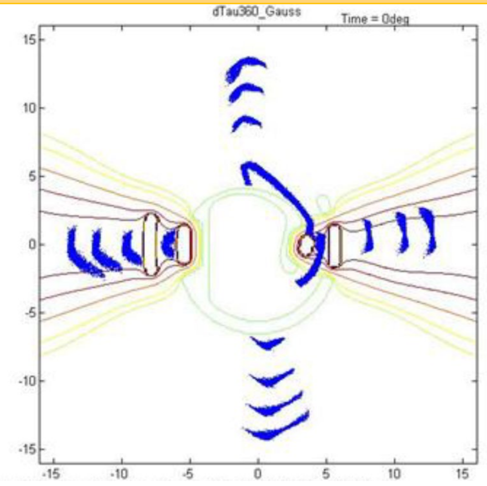
1 MeV particles trajectory



Phase Acceptance of Central Region



1 MeV bunch formation

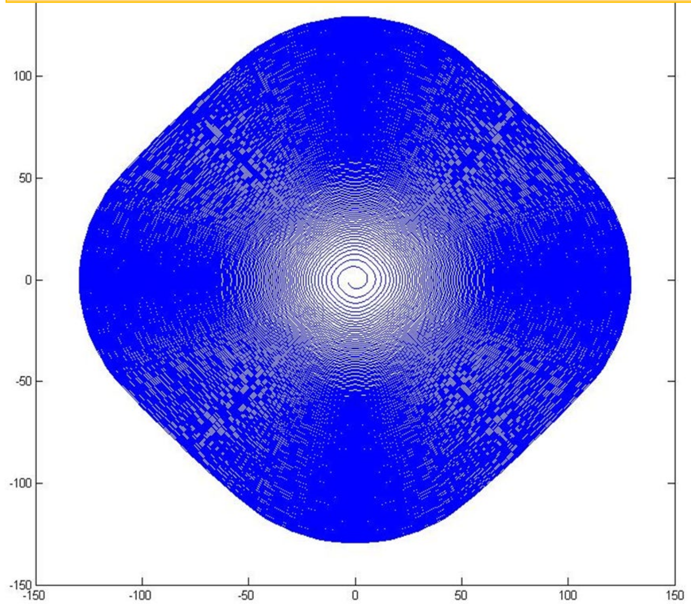


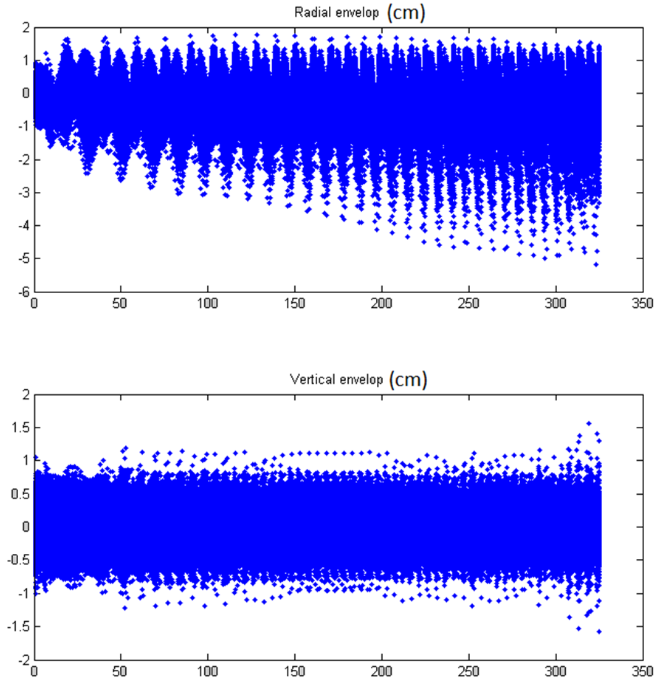
Acceleration, beam dynamics

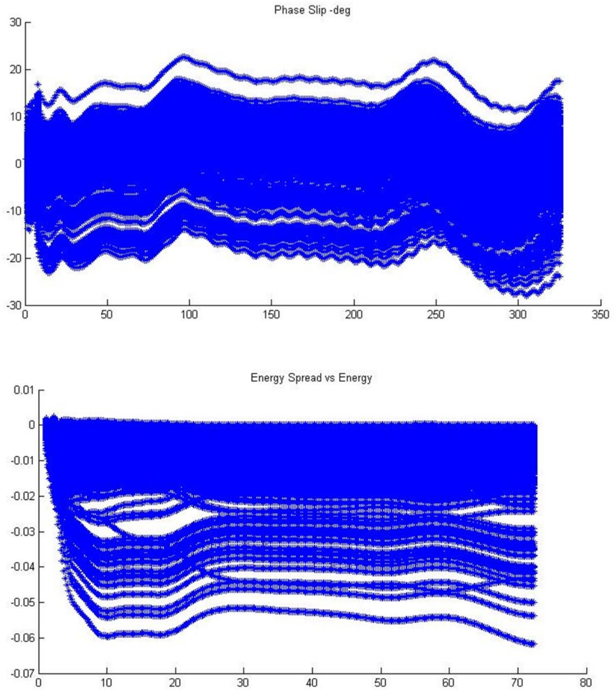
- Once the bunch is shaped after the first turns, particles accelerate to high energy
- Isochronous cyclotron means no phase stability → Phase spread depends on the accuracy of isochronism → $\Delta\phi \approx 2 \cdot \pi \cdot h \cdot \frac{\Delta B}{B_{isocrono}} \cdot n$

h acceleration harmonic,
n number of turns 300

Single particle accelarated trajectory

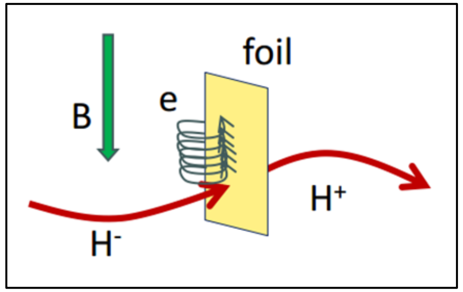


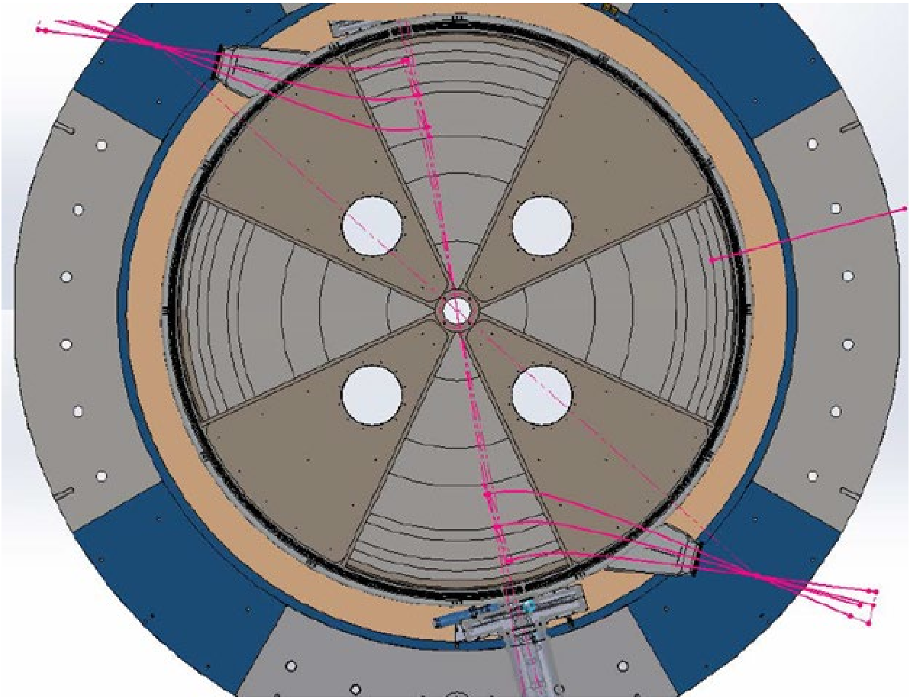




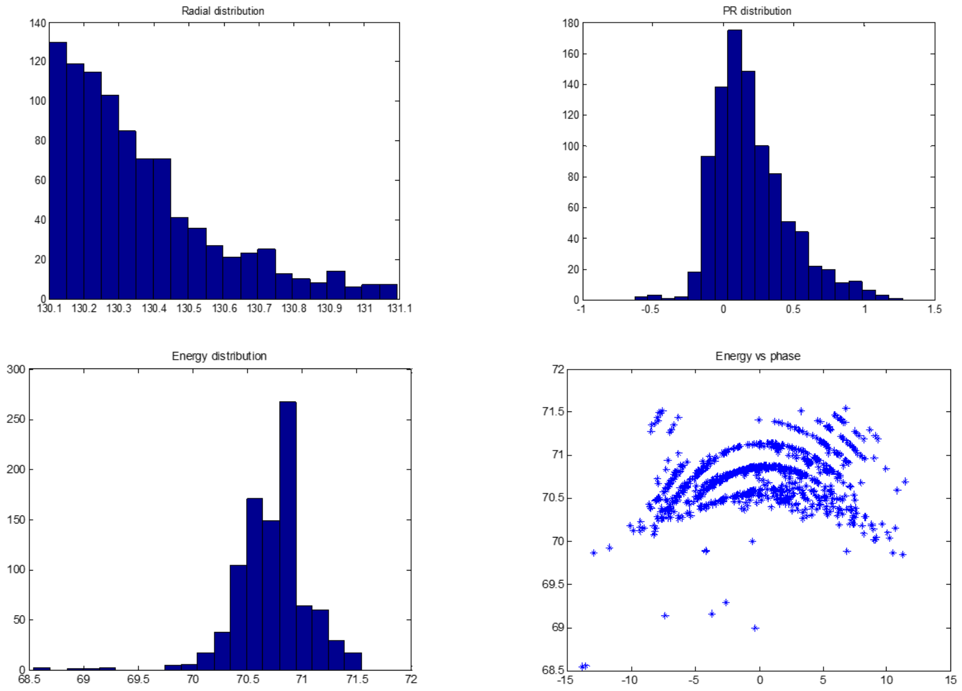
Beam extraction

- Stripping process → H^- → $H^+ + 2e^-$
- 99% transmission efficiency despite multi-turns extraction
- Dual (multi) extraction
- Extraction at different energy (35-70 MeV)

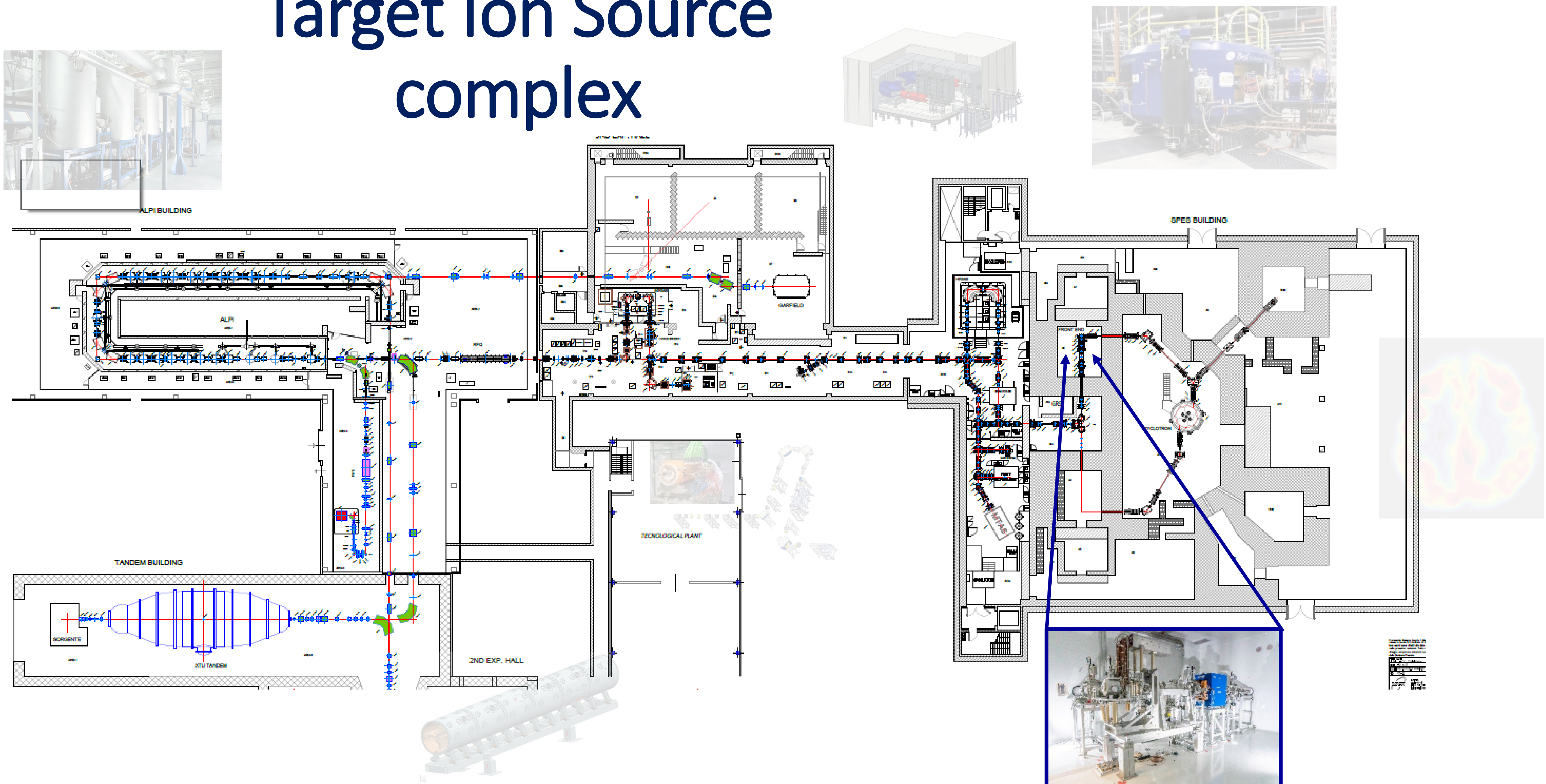




Rmin=130.1 cm, E=70.7MeV, DE/E=1%

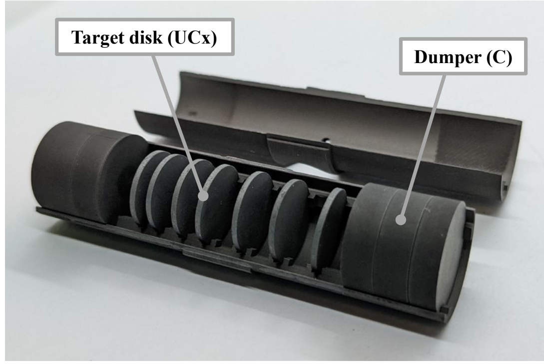


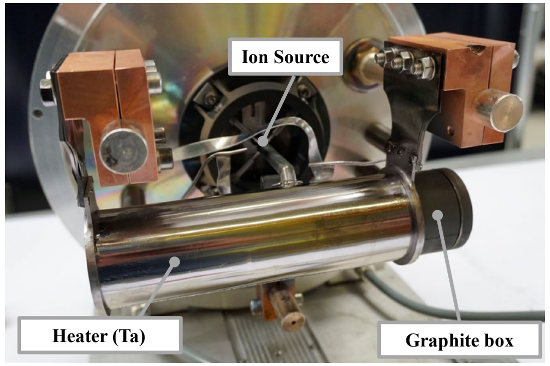
Target Ion Source complex

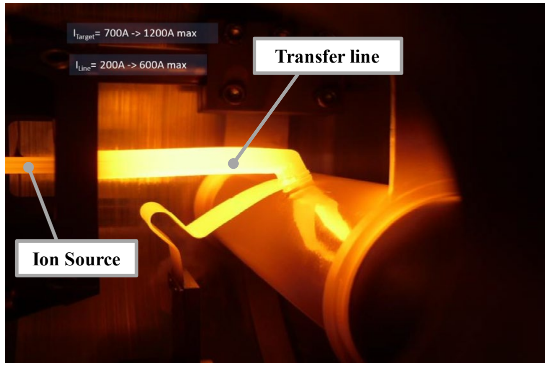


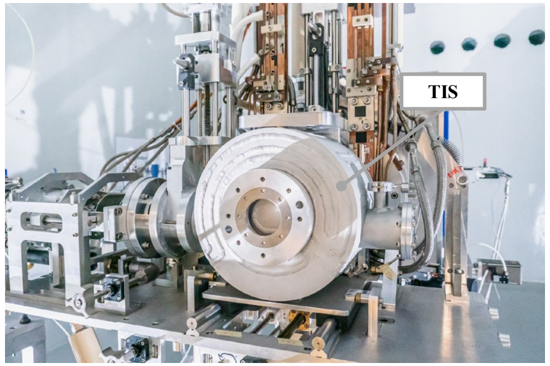
Target Ion Source Complex

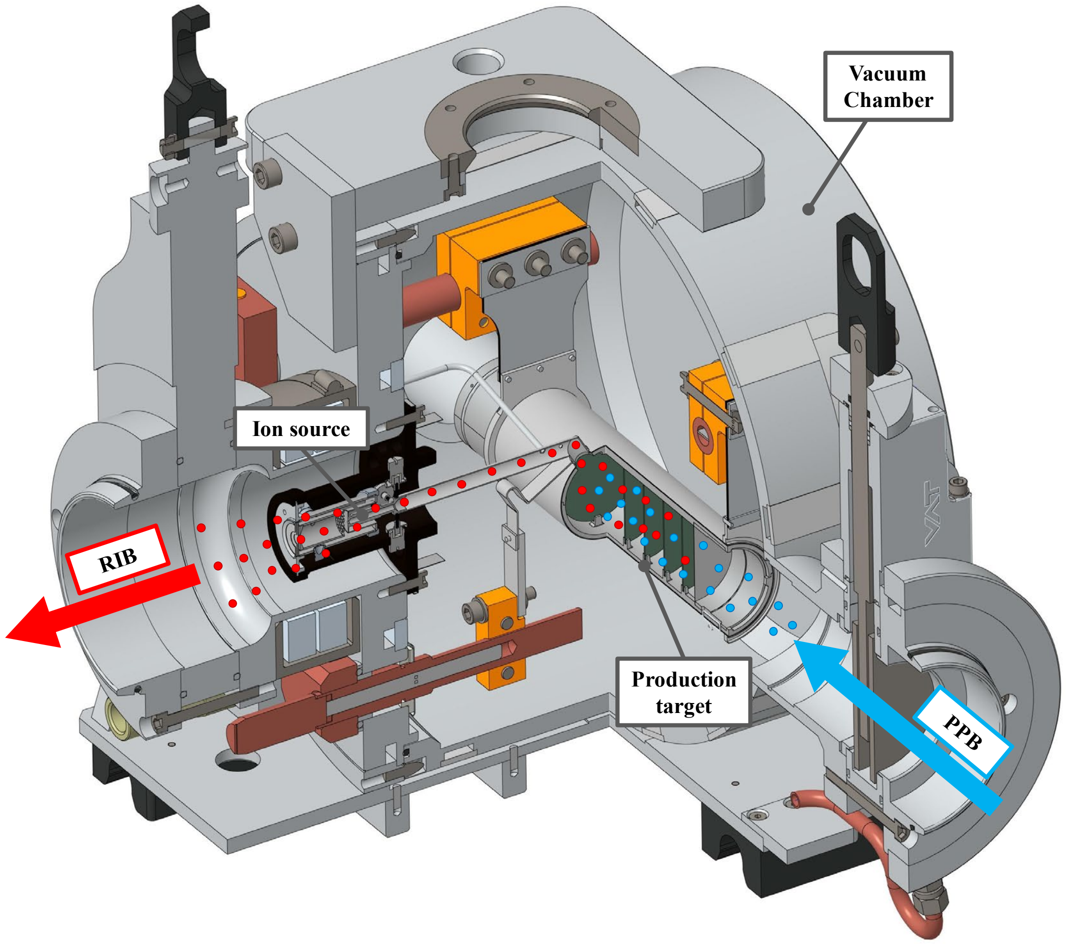
The Target Ion Source unit



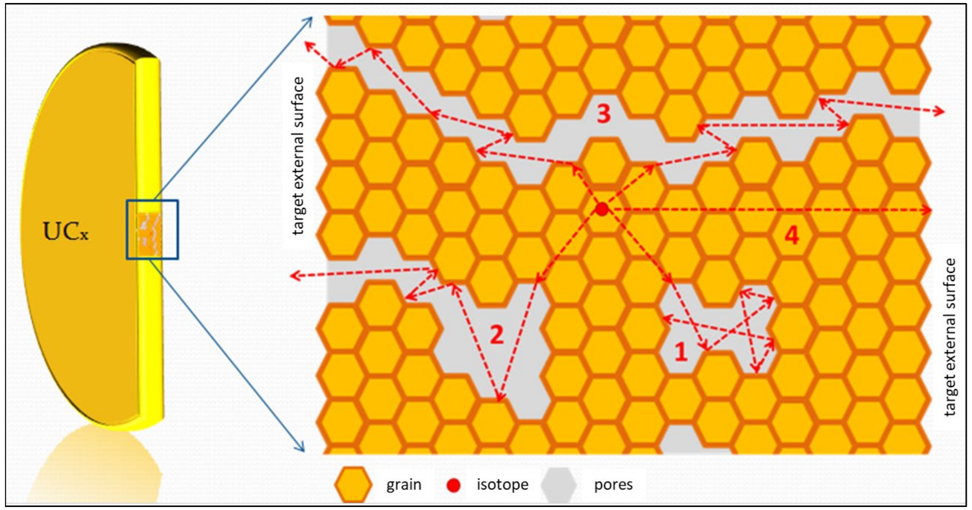








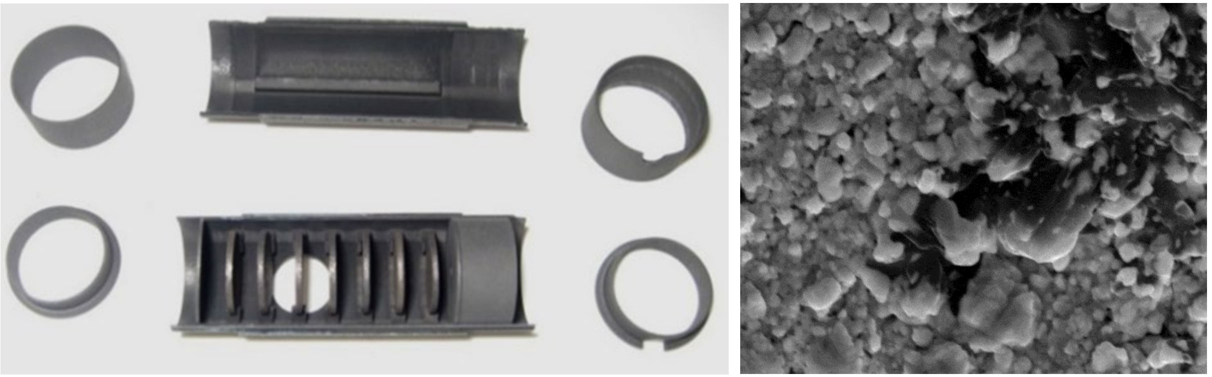
ISOL Targets



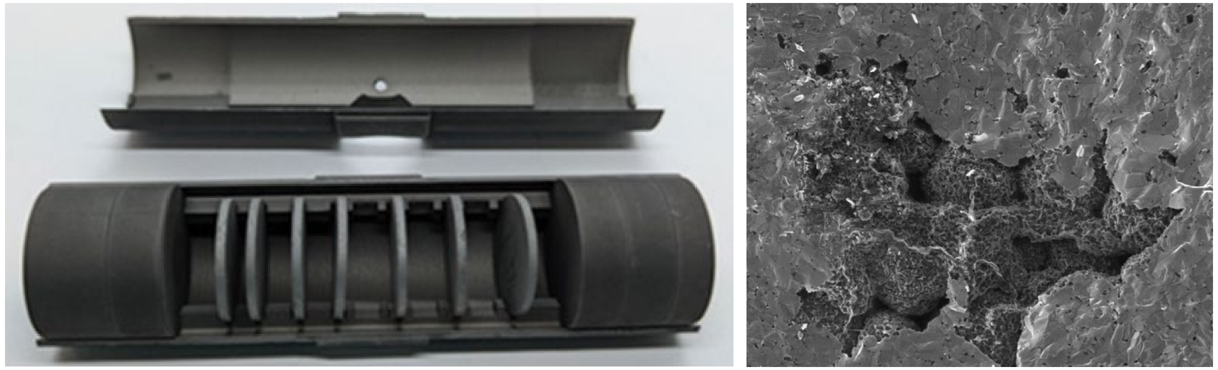
Porosity optimization to achieve fast release of isotopes

Thermal properties optimization to work at high temperature (~2000 °C)

Uranium carbide

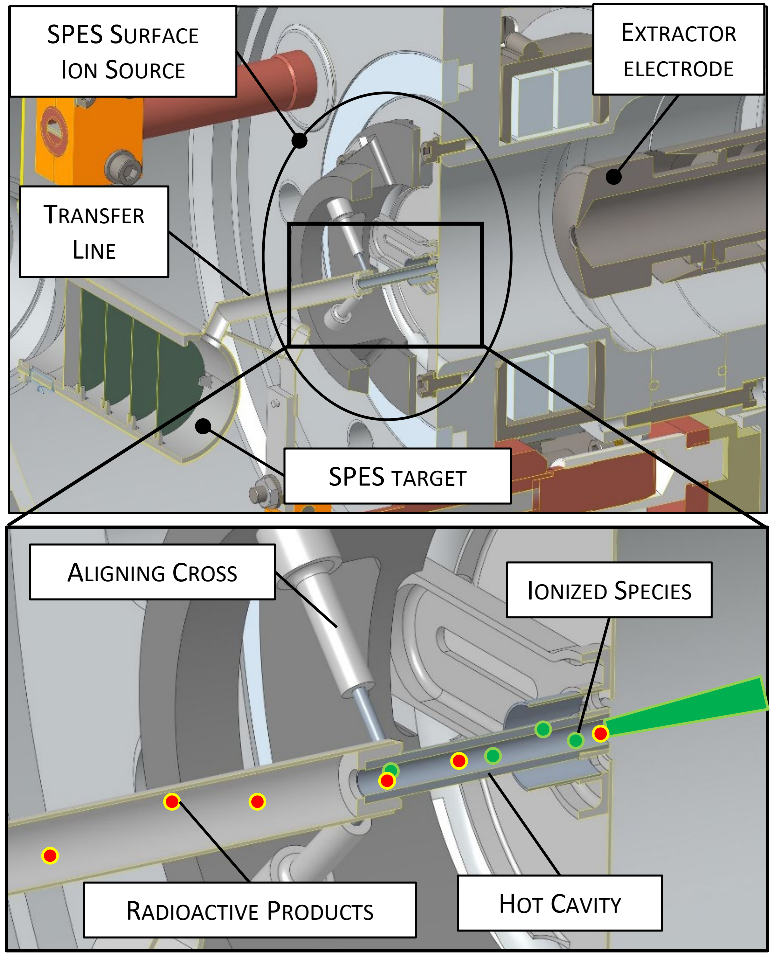


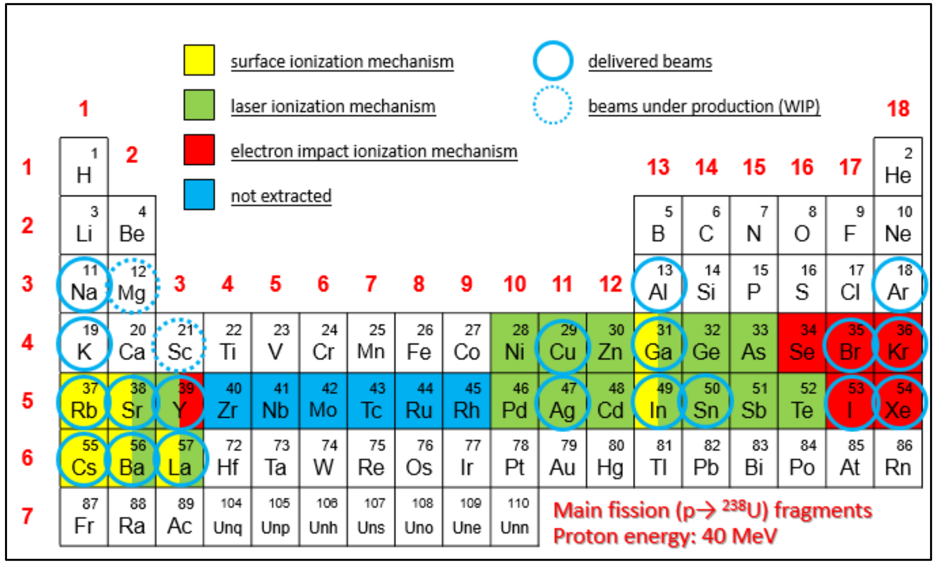
Silicon carbide



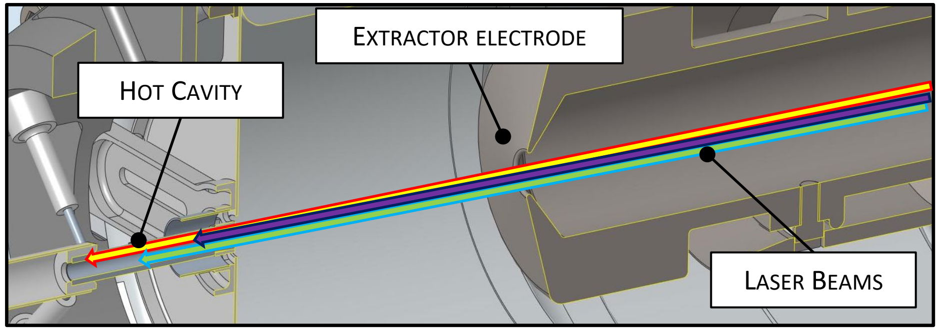
ISOL Ion sources

The SPES Surface Ion Source (SIS)

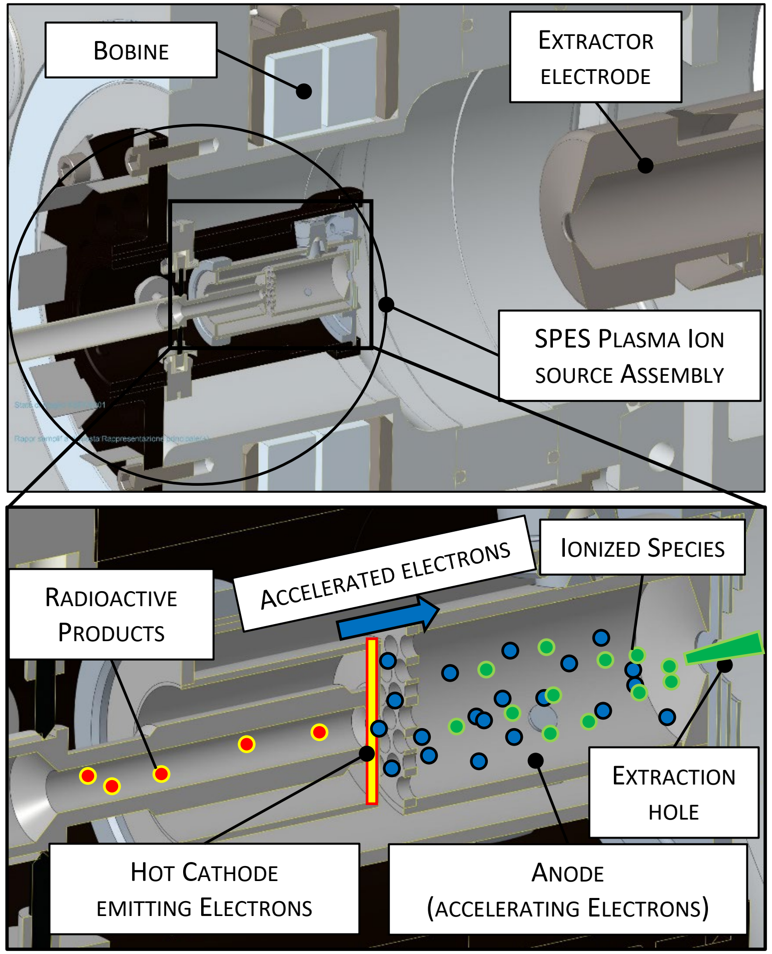




The SPES Laser Ion Source
(SIS + laser beams)



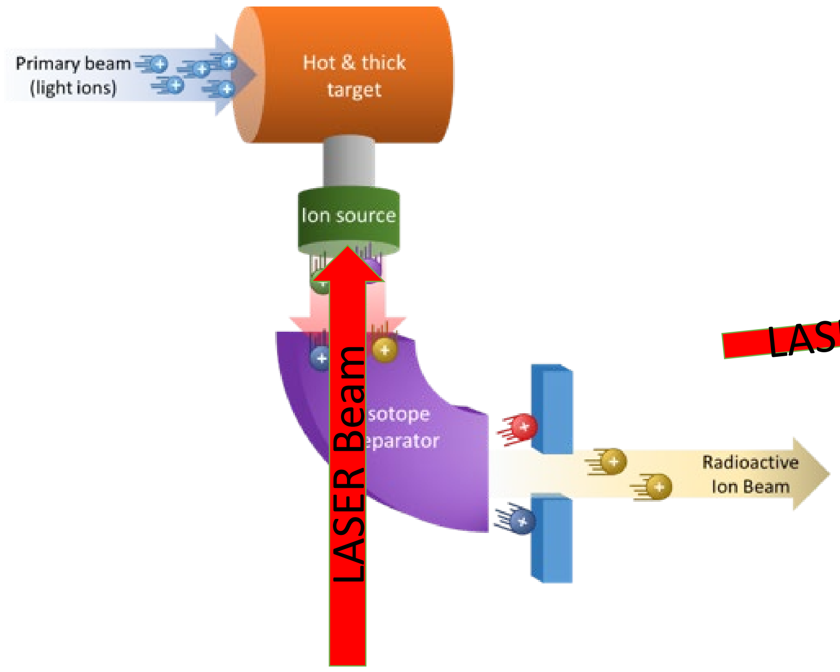
The SPES Plasma Ion Source

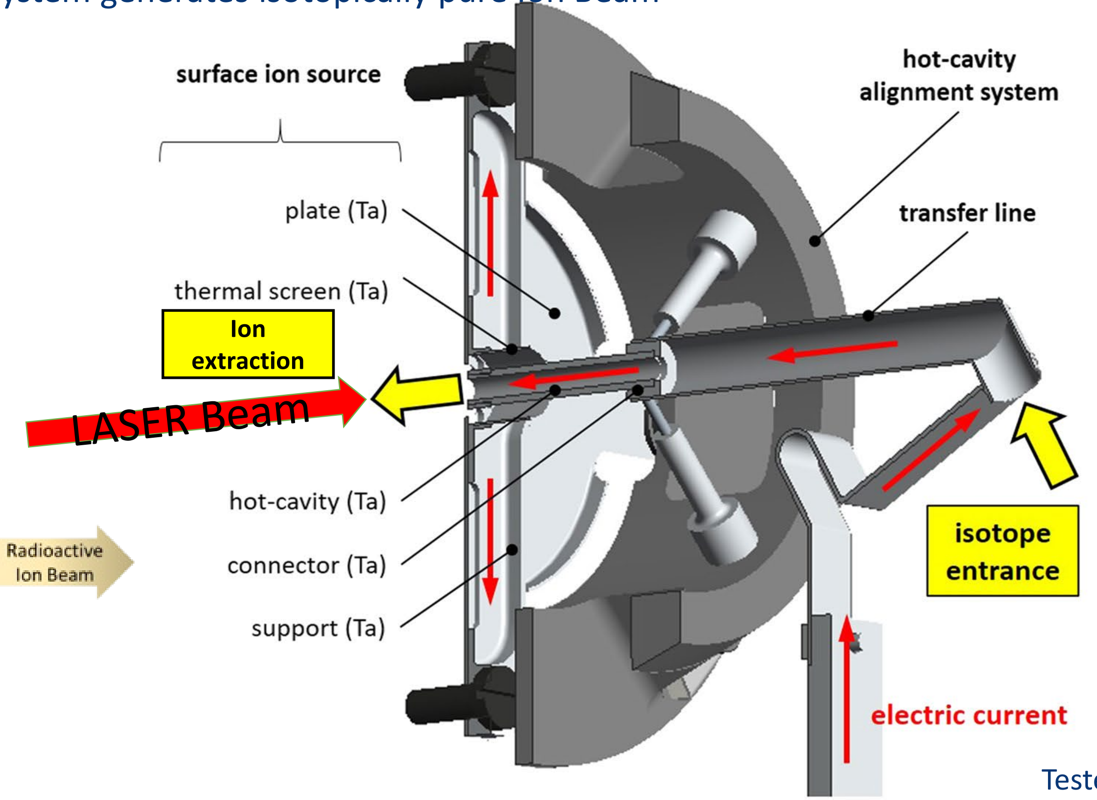


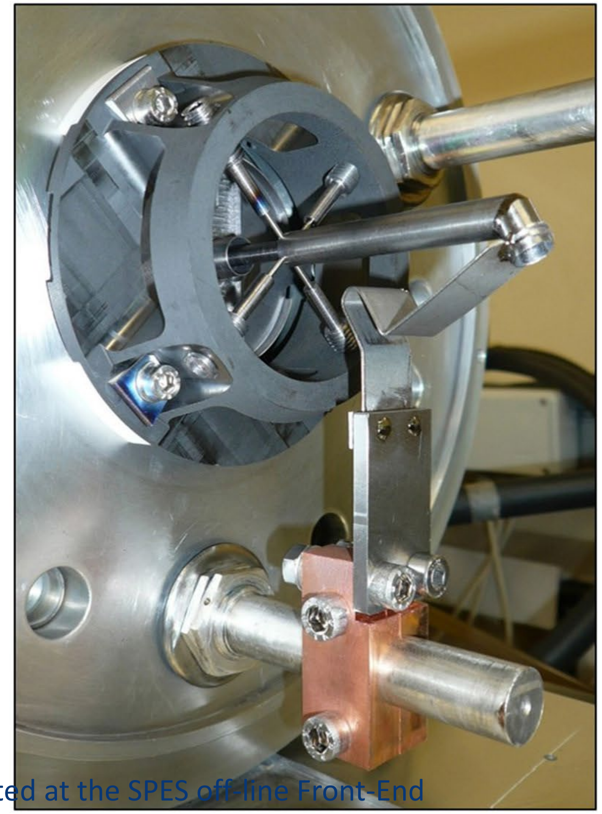
The Laser Ion Source

Use of SPES SIS coupled with laser beams:

- Especially for transition elements
- Eefficiency ≈ 10 %
- Coupled with Mass Separation system generates isotopically pure Ion Beam





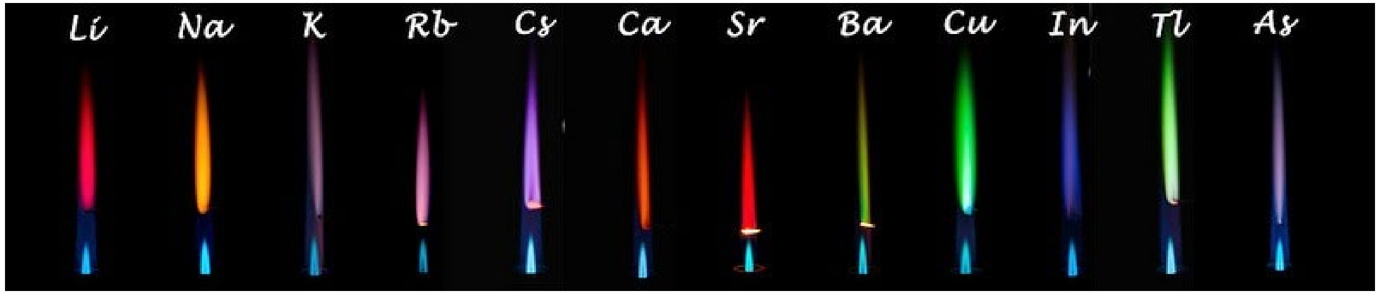


Tested at the SPES off-line Front-End

The Laser Resonant Ionization

Flame test:

- ✓ Different elements "respond" with different colors
- ✓ The color depends on internal electrons energy level structure

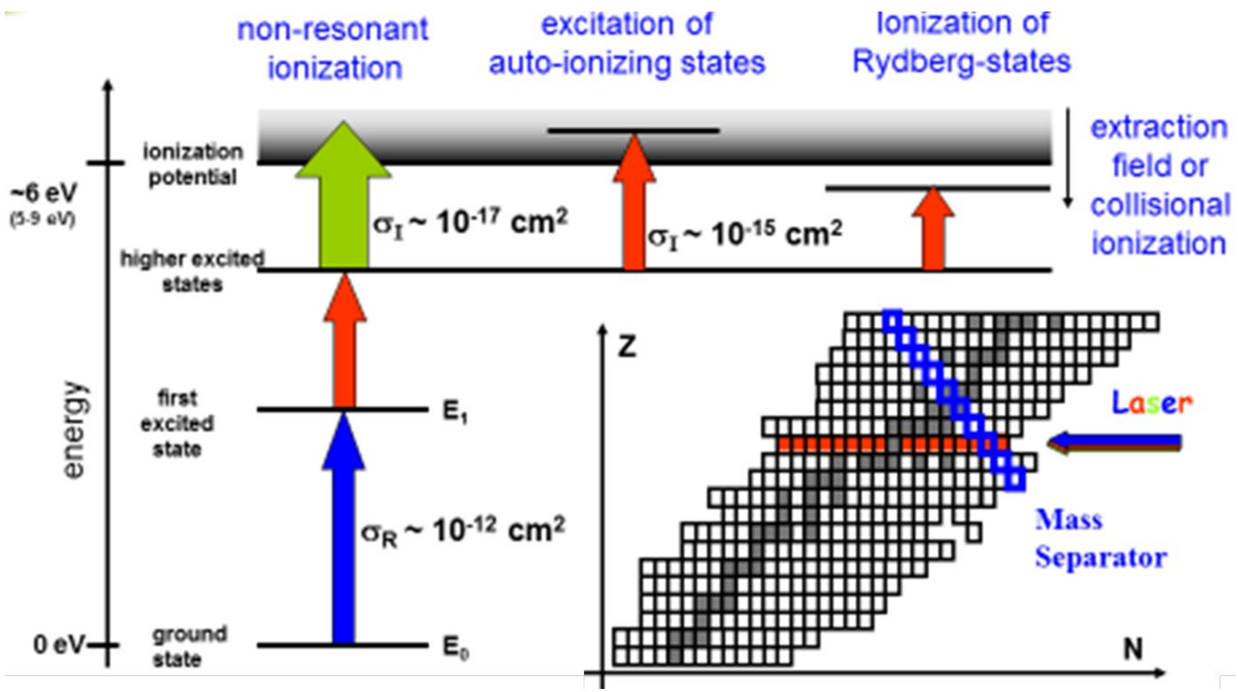


Laser Resonant Ionization:

- ✓ Use of wavelength (i.e. photon energy) tunable lasers to match energy level
- ✓ Use of multiple tunable lasers according to element of interest's energy level structure

Advantages for ISOL facilities:

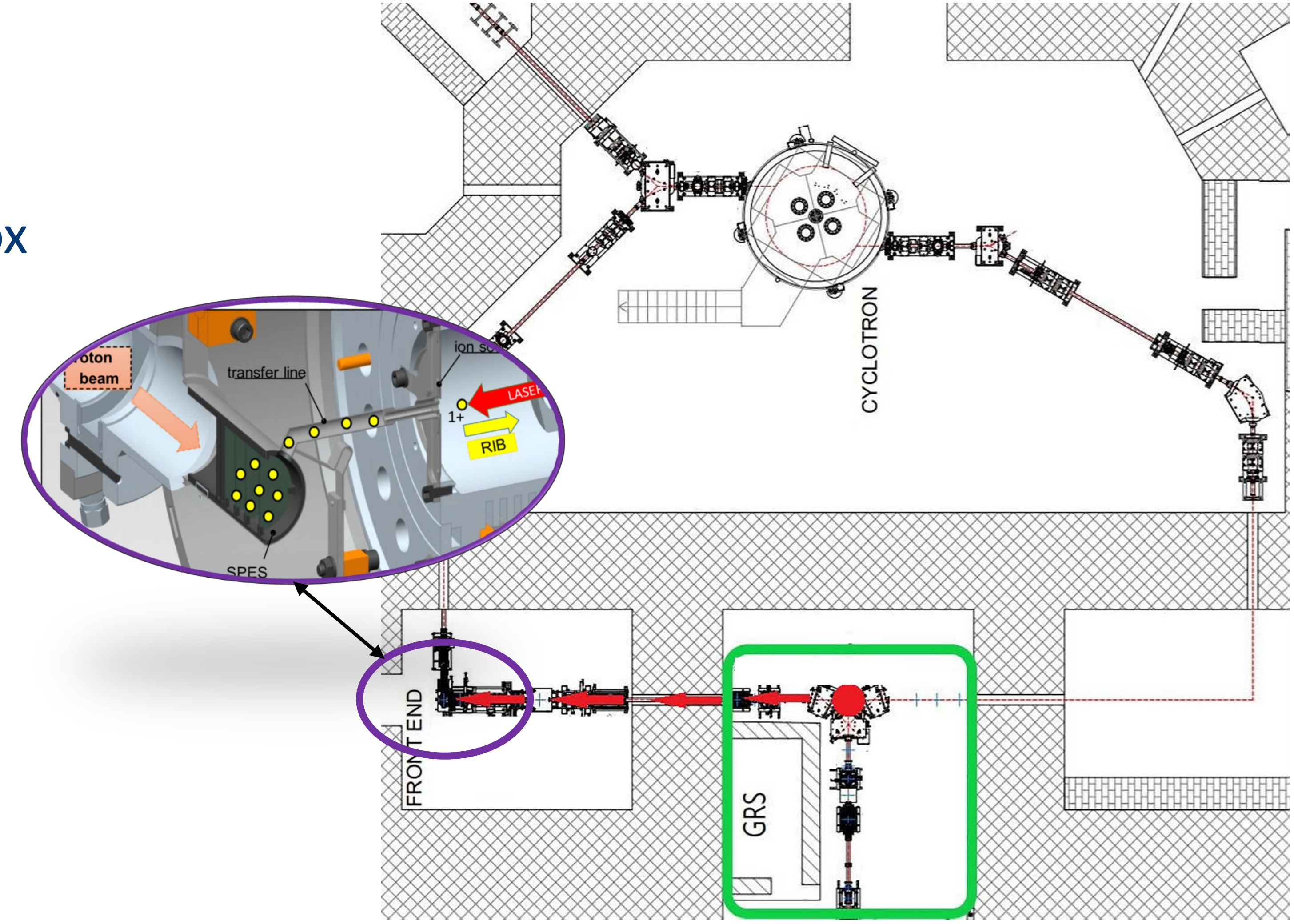
- ➢ This technique combined to mass separation can achieve high isotopic purity for the delivered ion beam



The Laser Resonant Ionization

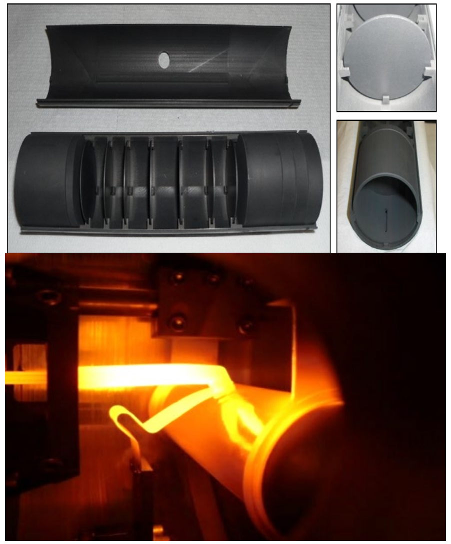
Laser Online @ SPES:

- ✓ 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 superposed, but opposite to ion beam direction (red arrows in figure)

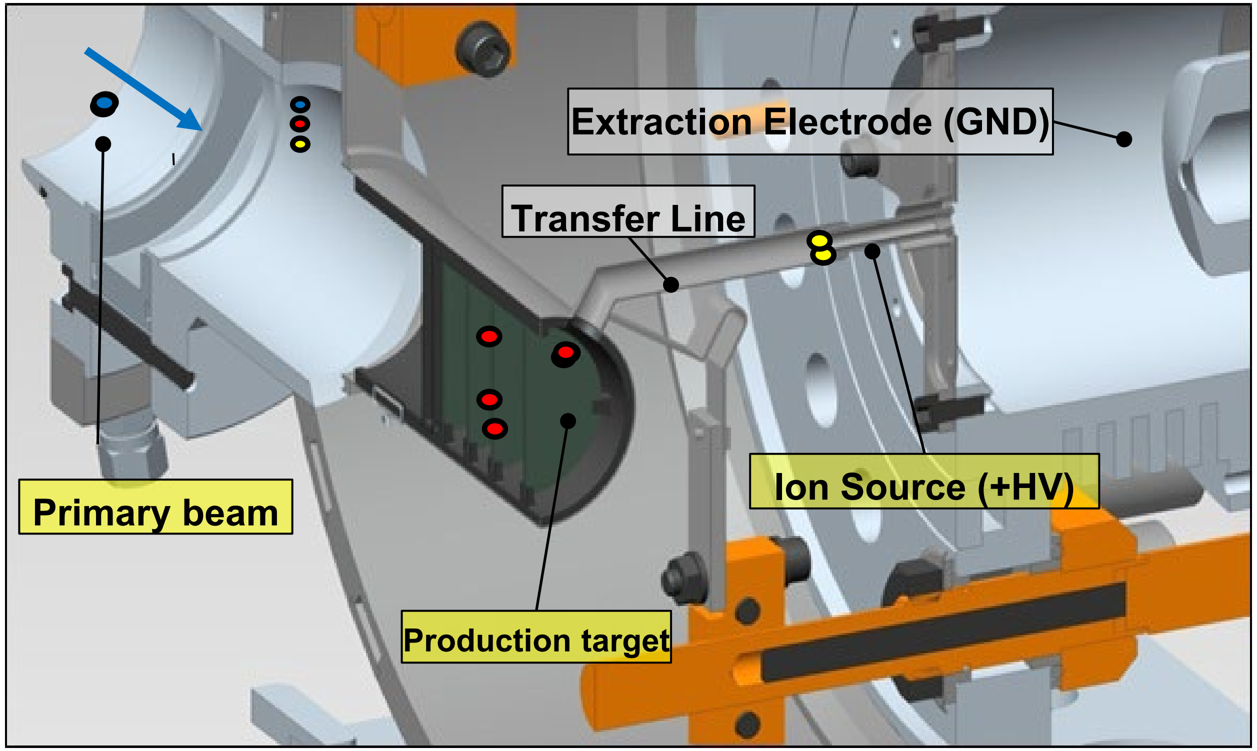


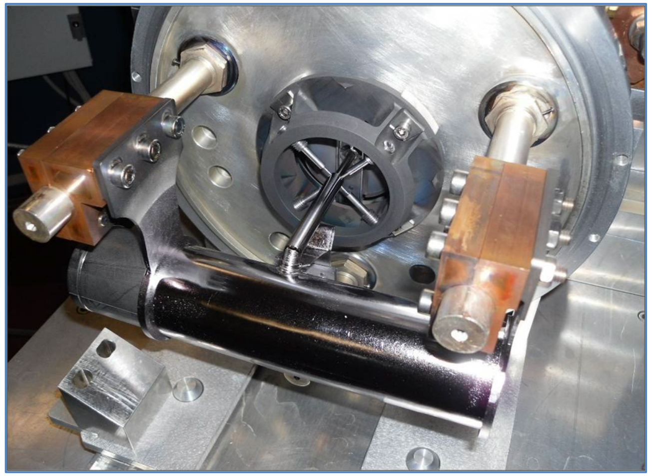
SPES beams

Target



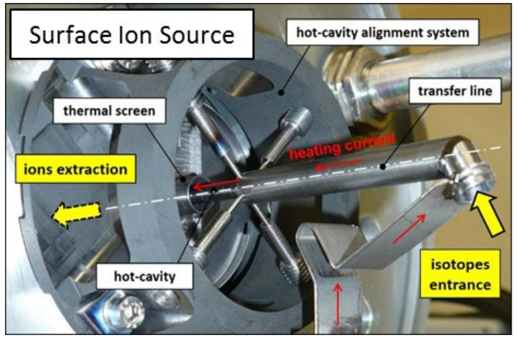
- UCx
- SiC
- ZrGe
- TiC



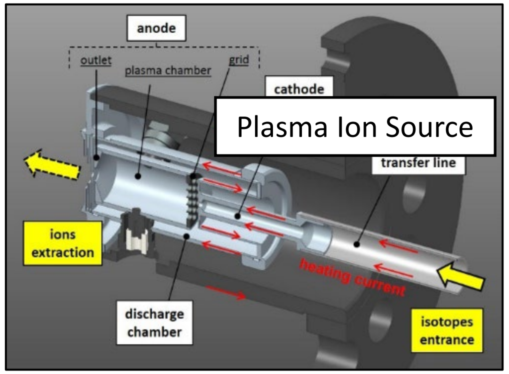


TIS UNIT

Sources



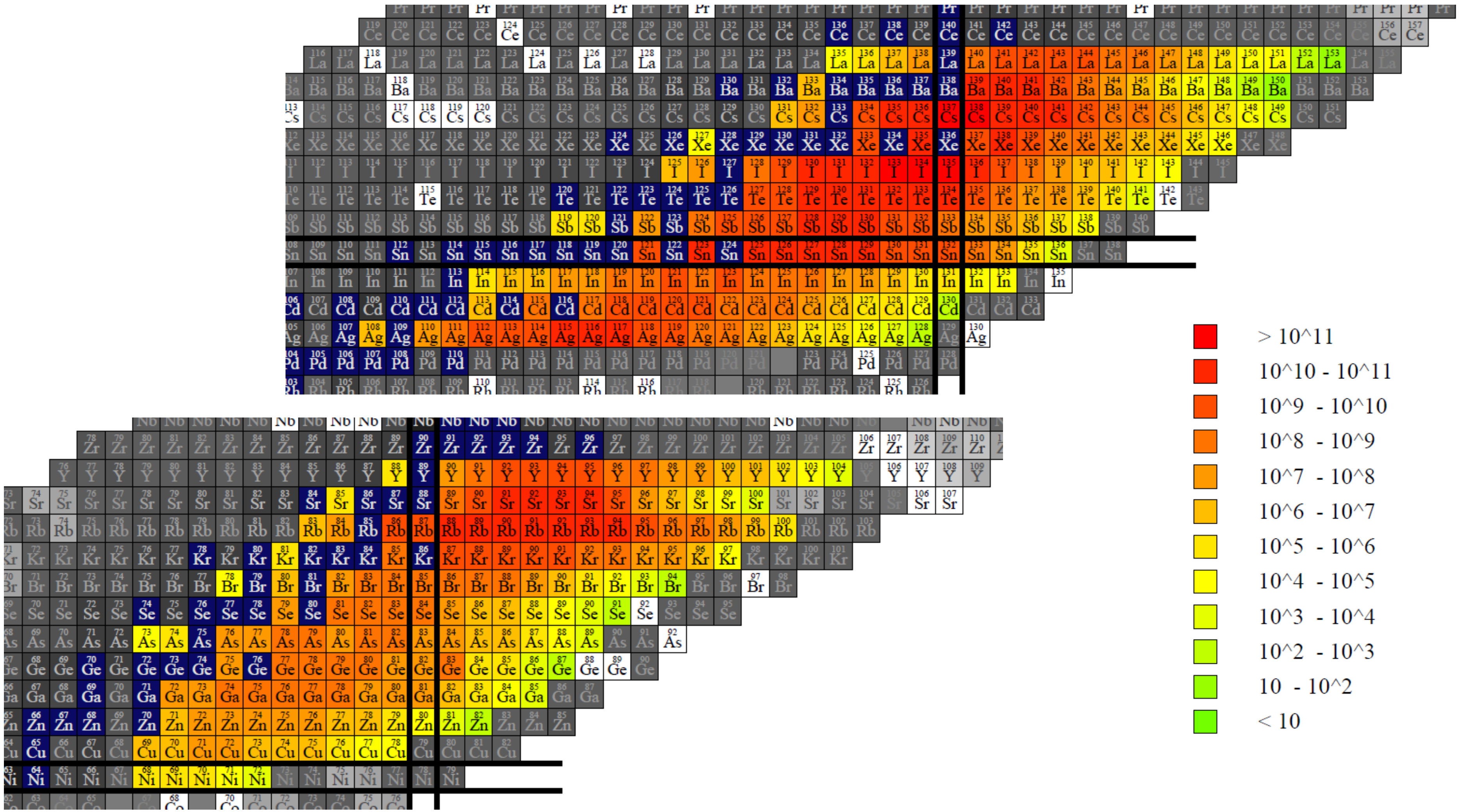
SIS: Rb, Cs, Sr, Ba



PIS: Kr, Xe, Br, I, Se

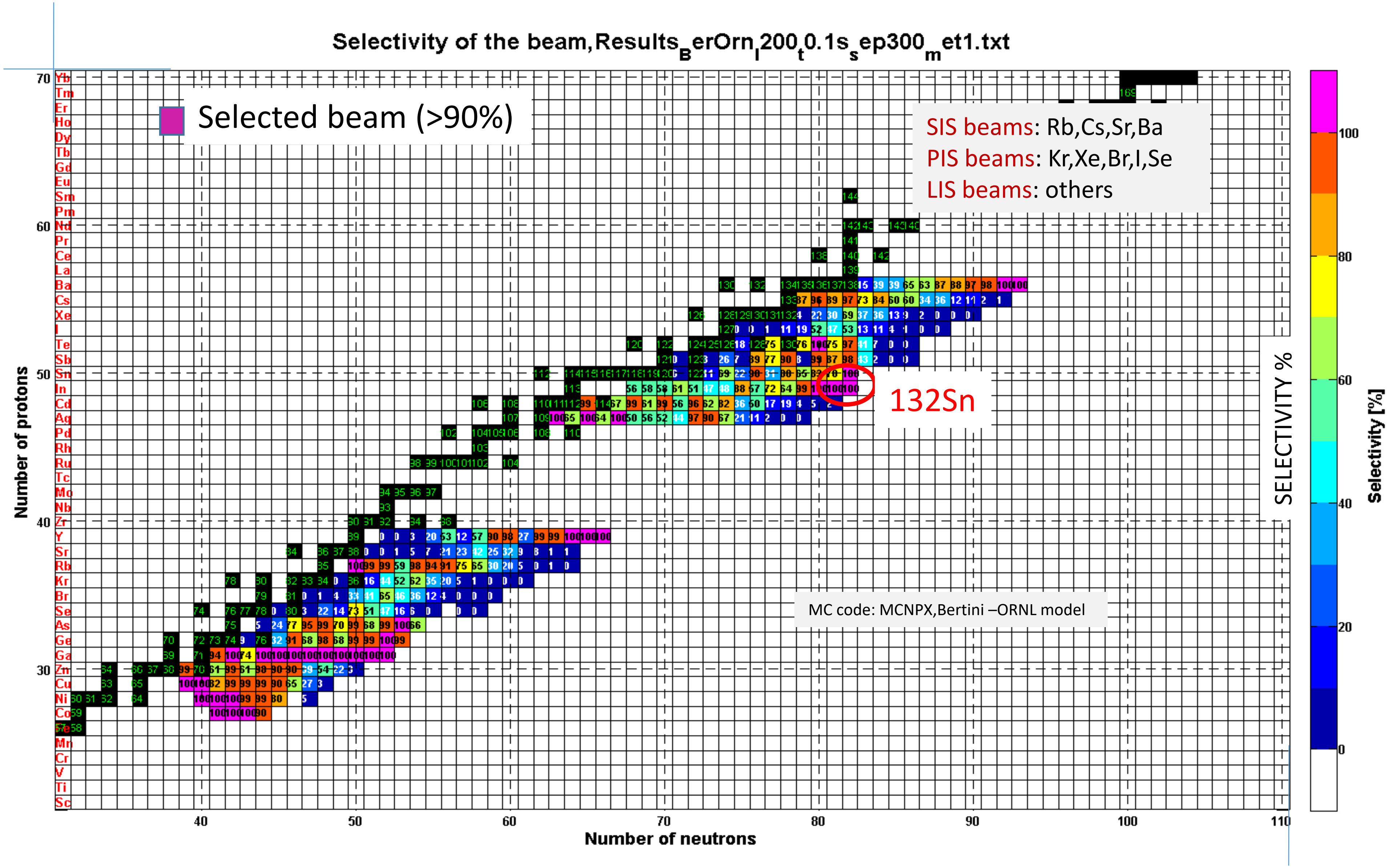
LIS (Laser -> SIS)

SPES beams



https://web.infn.it/spes/index.php/characteristics/spes-beams-7037/spesbeamstable

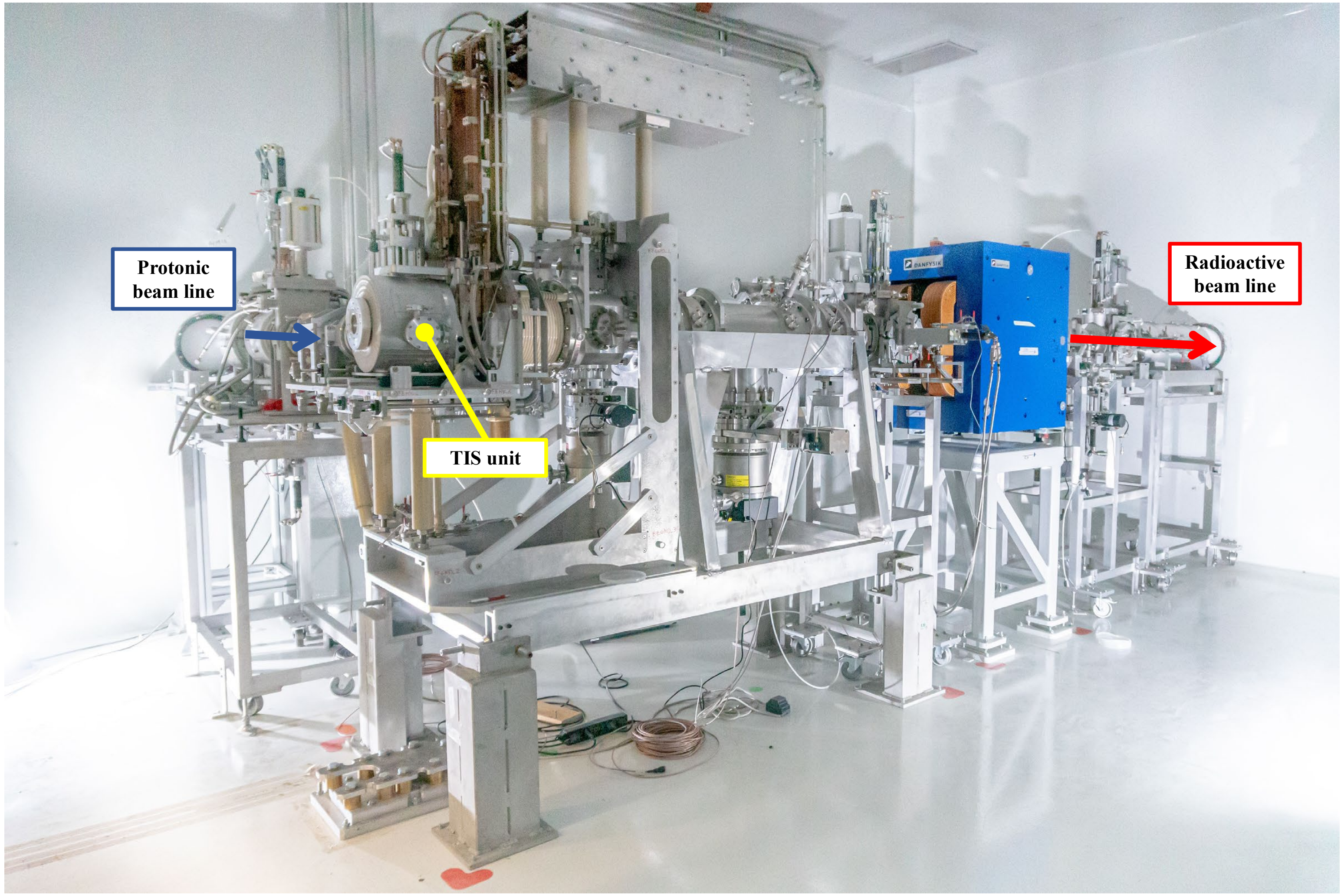
Beam selectivity with LRMS ($\Delta M/M=1/200$)



The SPES Front End

ISOL Hall:

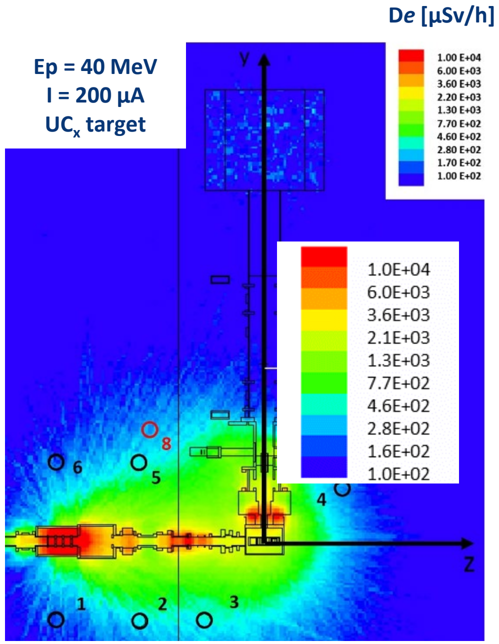
- ✓ Pre-commissioning done
- ✓ Front End and RIB line installed and aligned
- ✓ Vacuum leak measure
- High-Voltage cabling ongoing
- ➢ Next step: Ground cabling installation



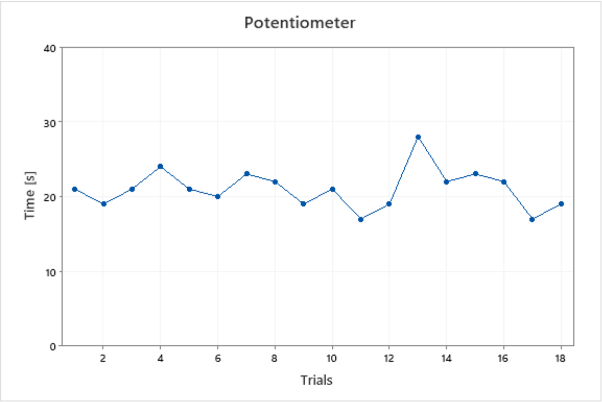
The SPES Front End: Safety and Maintenance

Safety and Maintenance Optimization:

- Training of specialized operators, Procedures, PPEs (ALARA principle: As Low As Reasonably Achievable)
- Experimental test campaign:
  - Time and working position Estimation
  - Work and Dose Planning (WDP)
- Optimization process:
  - Identification of proper tools
  - Design for assembly review



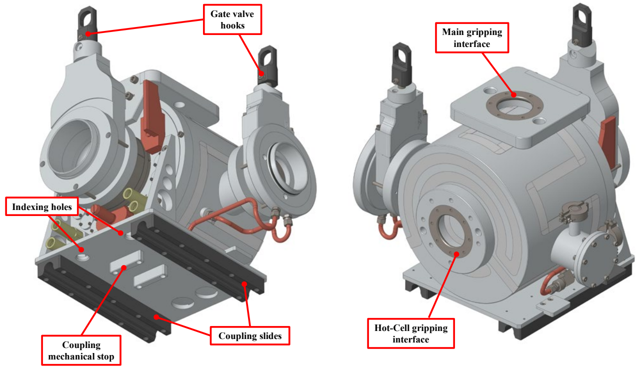
Ambient equivalent dose rate on the Front-End after 10 irradiation cycles (no target, no contamination)

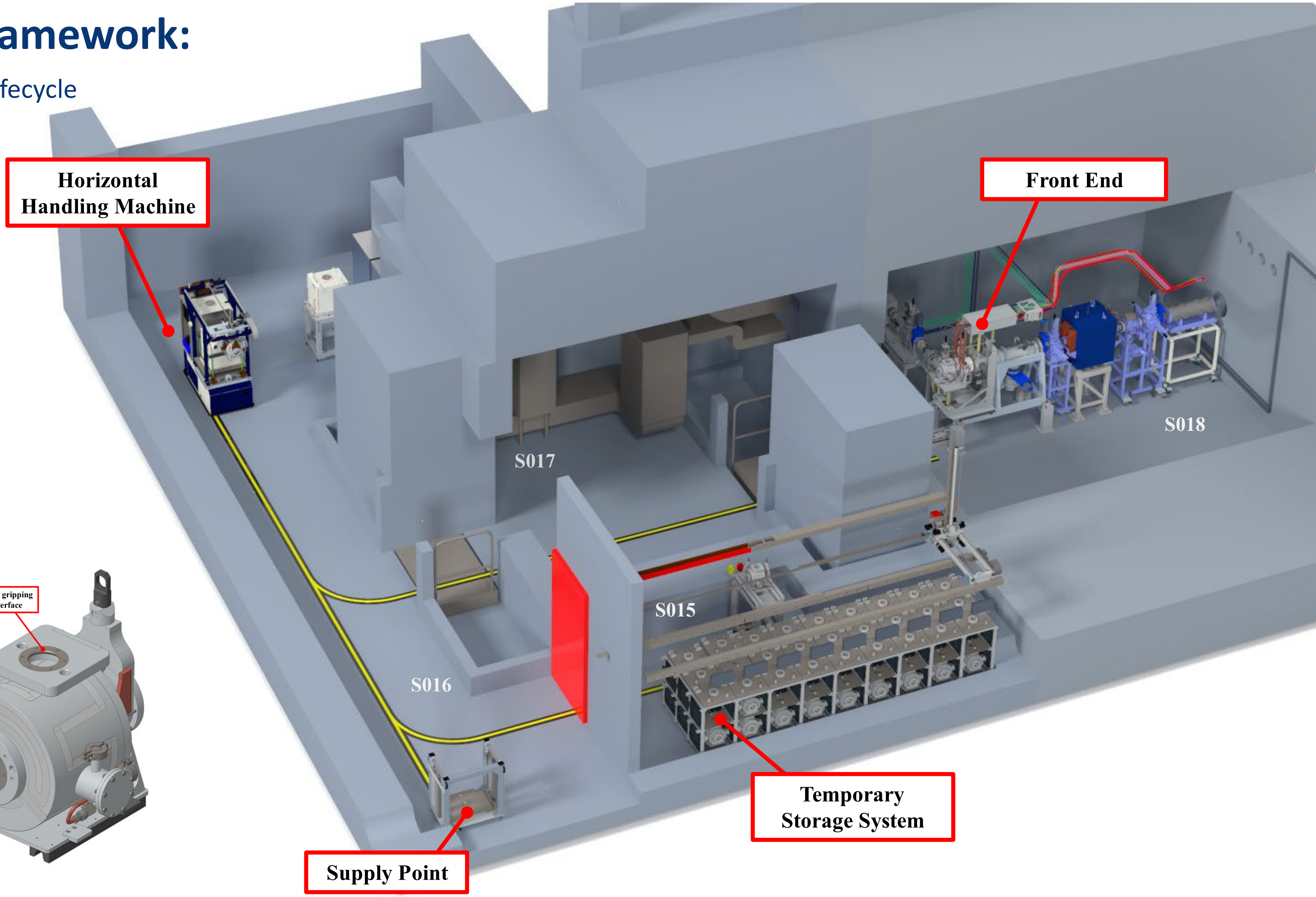


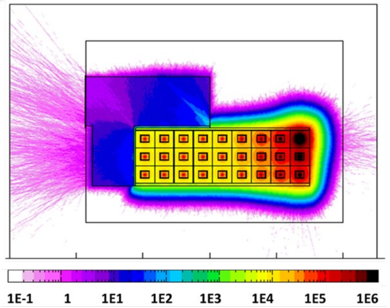
Remote handling

Remote Handling Framework:

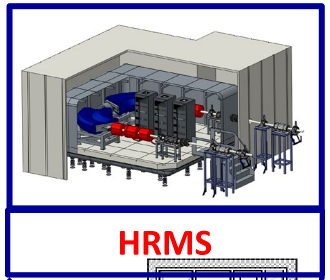
- Design driven by the TIS unit lifecycle

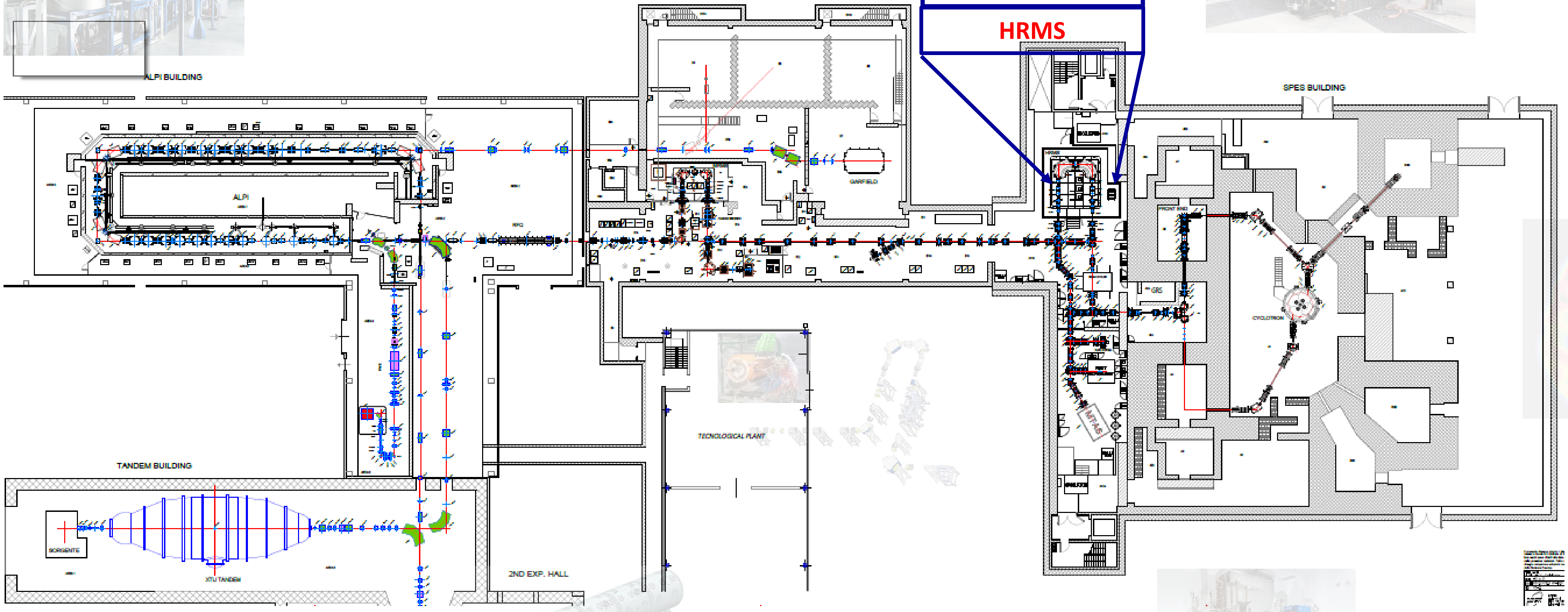


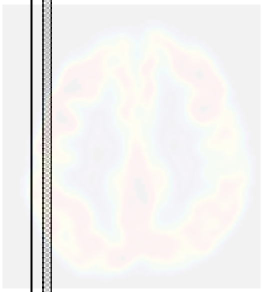


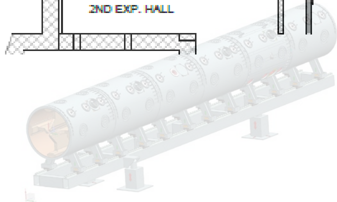


High Resolution Mass Separator





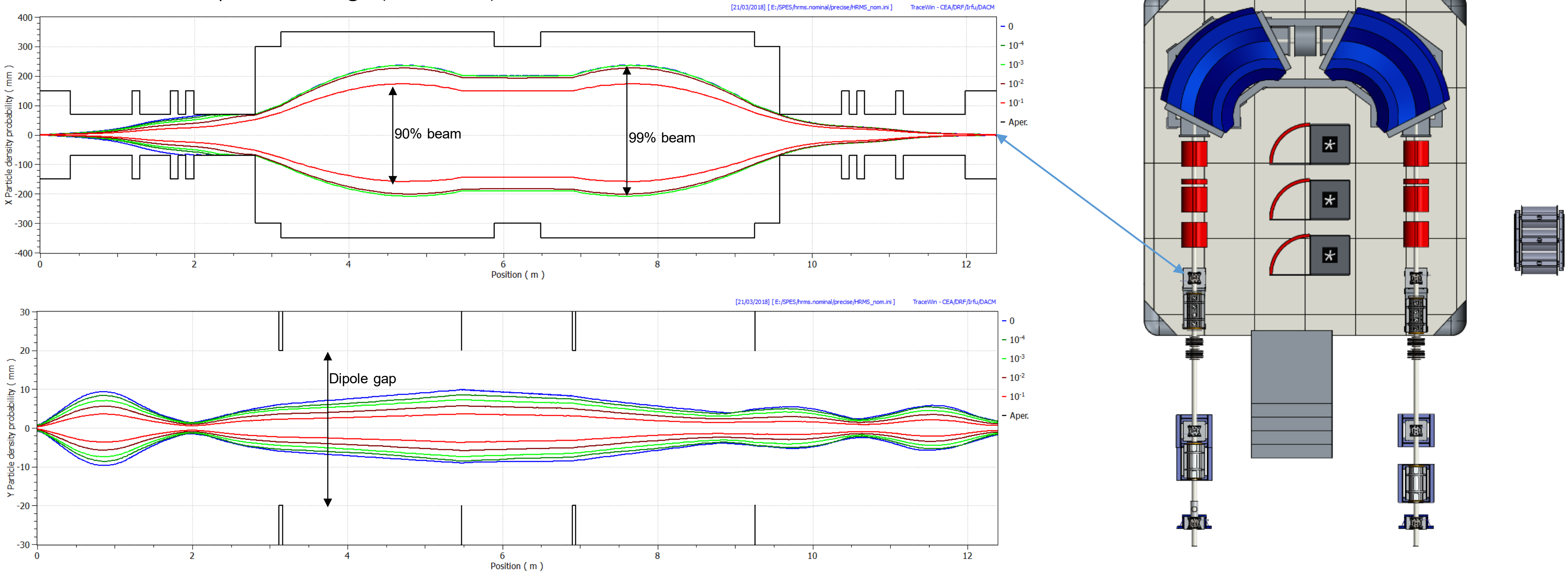




High Resolution Mass Separator

$\Delta M/M=1/20000$

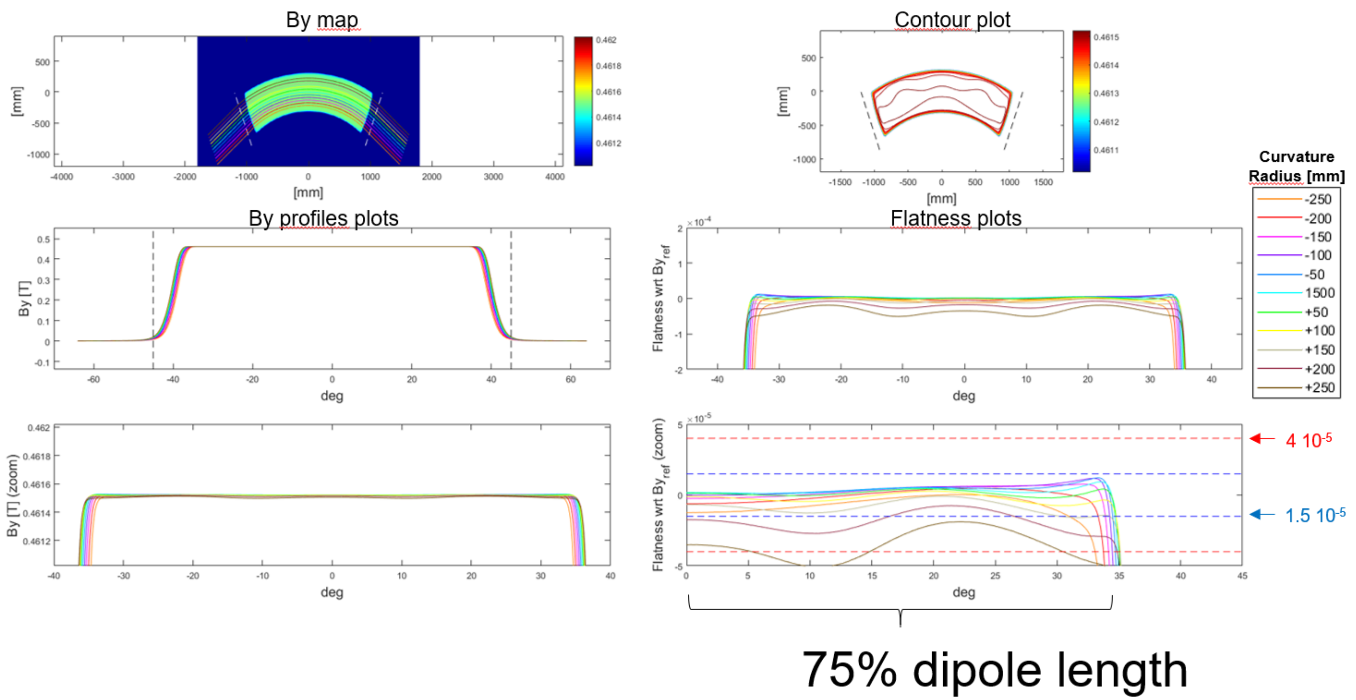
Frozen Multiparticle design (nonlinear) from 2019

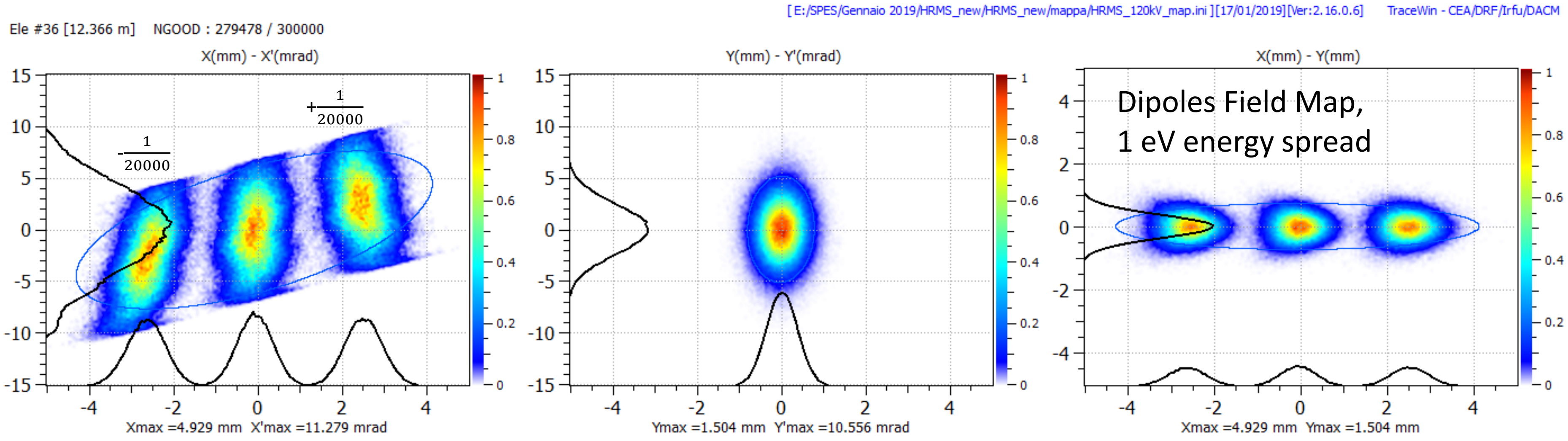


New HRMS specification after the CDR (2018)

High resolution mass separator (SPES)					
general parameters					
Beam energy (from RFQ cooler)	40	kV		Range 20-40 keV	
Platform voltage	-120	kV		Negative	
Energy at separation	160	keV		Fix energy	
nominal mass	132			Mass range	
Magnetic rigidity	0.661	Tm		0.66165509	
beta	0.001613234			v/c	
Nominal emittance	5.2	mmmrad	95%	Gaussian dist.	
Nominal energy spread	1.5	eV	sigma		
Nominal dm/m resolution	5*10^-5			=1/20000	
at n sigma	4			<1% ?	
Acceptance	6.2	mmmrad	With slits (+/- 0.9 mm)		
RFQ cooler beam requirements					
Normalized emittance	0.0083	mmmrad	95% beam		
energy spread	1	eV	sigma	Including extraction voltage jitter	
transmission	?				
common ground with paltform		V	maximum fluctuation		
dipole specifications					
radius	1.5	m			
magnetic field	0.441	T		0.441103	
bending angle	90	deg			
focussing angle	27.16	deg			
EB curvature radius	2.918	m			
good field region HxV	250x15	mm mm	half		

Dipole field homogeneity

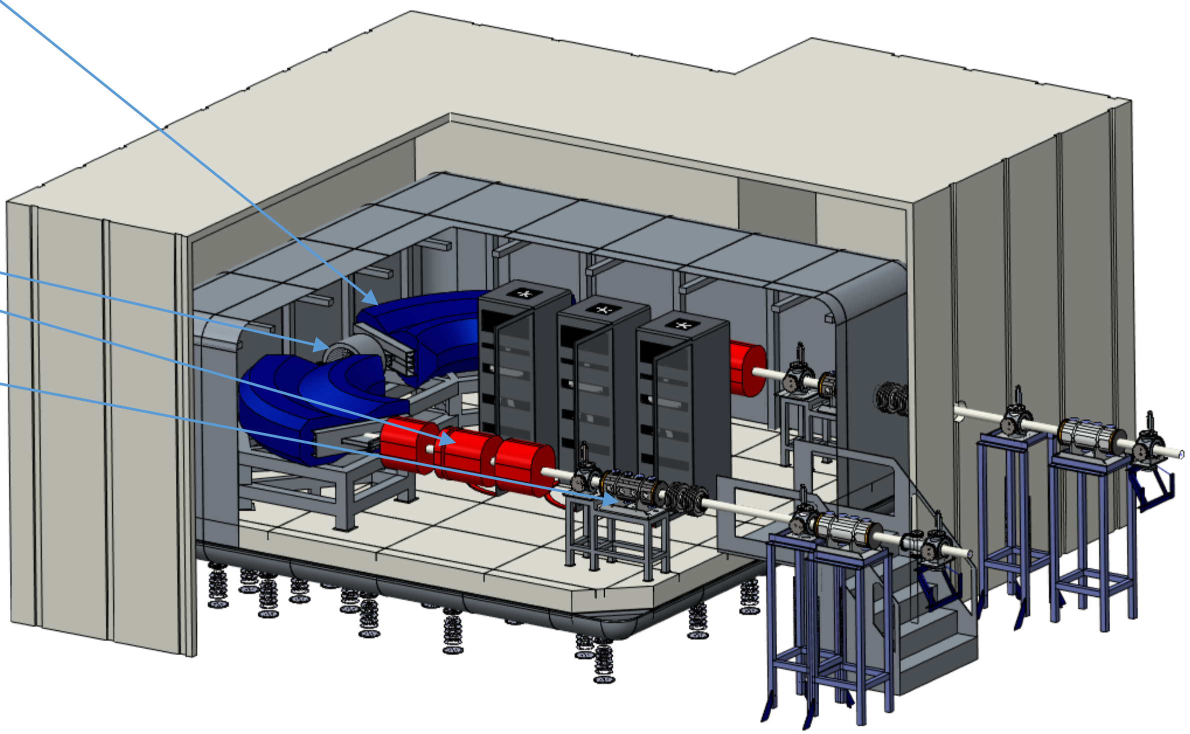




HRMS procurement

The running tender is for:

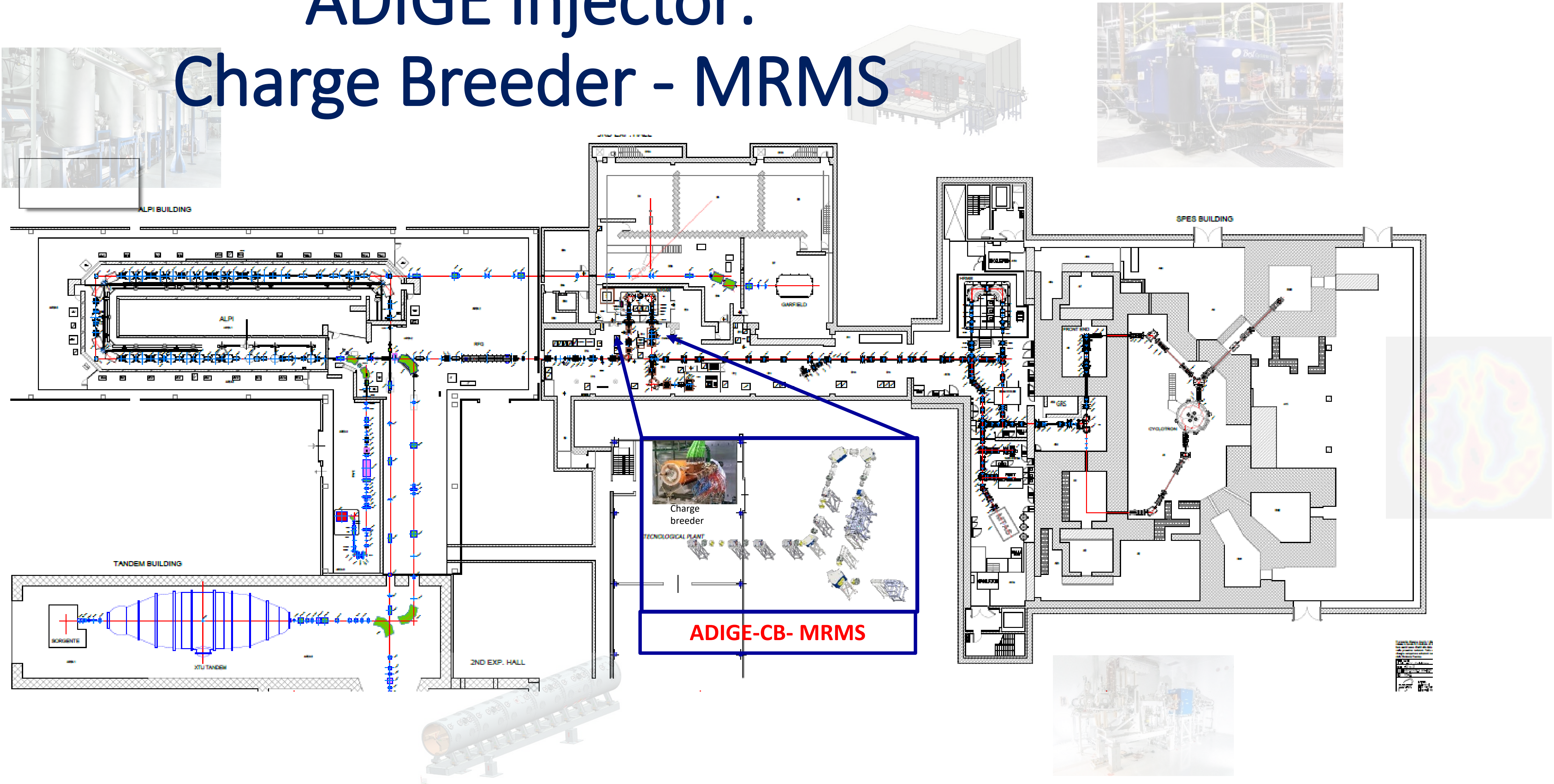
- Dipoles, power supplies, vacuum chambers and supports
- Multipole
- Electrical quadrupoles
- Electrical triplets



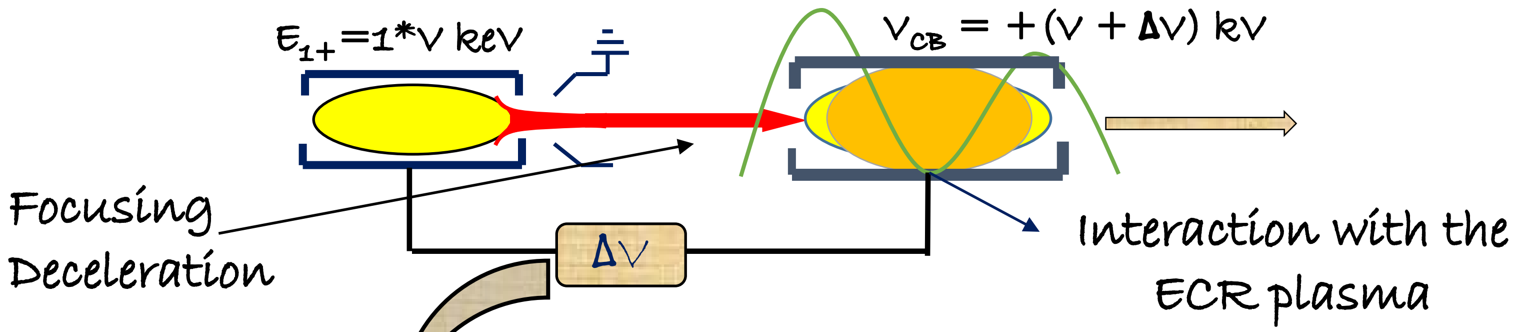
- Tender started: Dec 2021
- Tender completed: Jan 2023
- Delivery: mid of 2024
- Installation: mid 2025

The design and integration in the building of the HV platform is going on and the spec will be ready for the end of 2022

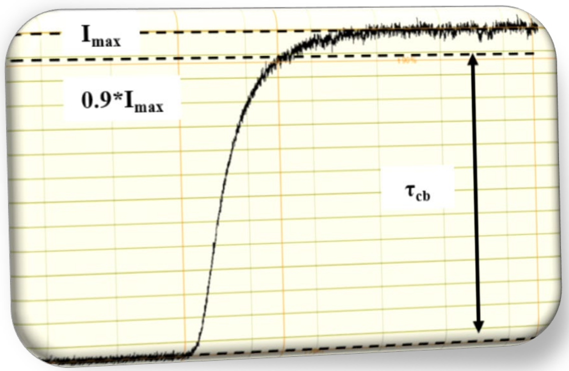
ADIGE injector:
Charge Breeder - MRMS

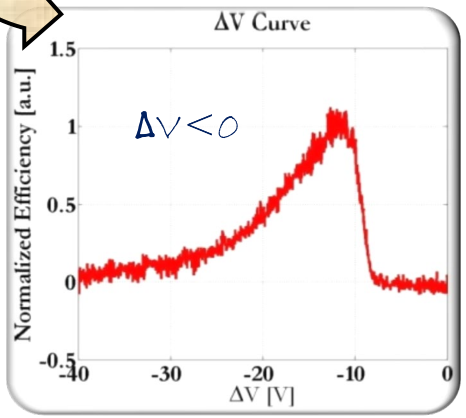


The SPES ECR based charge breeder



τ_{CB} (half life) | <q+> (energy) | Efficiency (Intensity)





$$\varepsilon_{q^+} = \frac{I_{q^+}}{q * I_{1^+}}$$

$$\varepsilon_{tot} = \sum_i \varepsilon_{q_i^+}$$

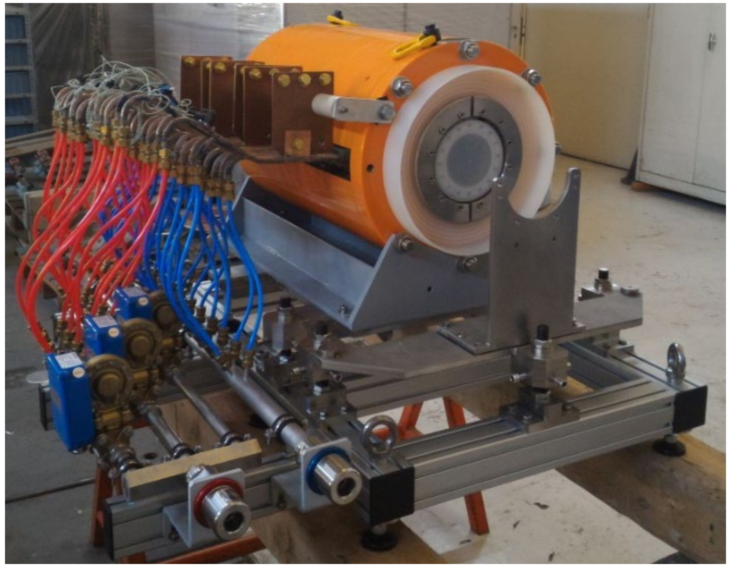
FUNDAMENTAL PARAMETER!

The SPES ECR based charge breeder

- June 2014: Research Collaboration Agreement INFN (LNL)-CNRS (LPSC)
- 2015: Acceptance tests and delivery @ LNL
- Results of the acceptance tests

			$\varepsilon_{rms,norm}$ [p*mm*mrad]	
Ion	M/q	η [%]	full	ion
Cs^{26+}	5.1	11.3	0.044	0.020
Xe^{20+}	6.6	11.2	0.030	0.010
Rb^{19+}	4.5	7.8	0.040	0.010
Ar^{8+}	5	15.2	0.04	0.030

Excellent beam quality!



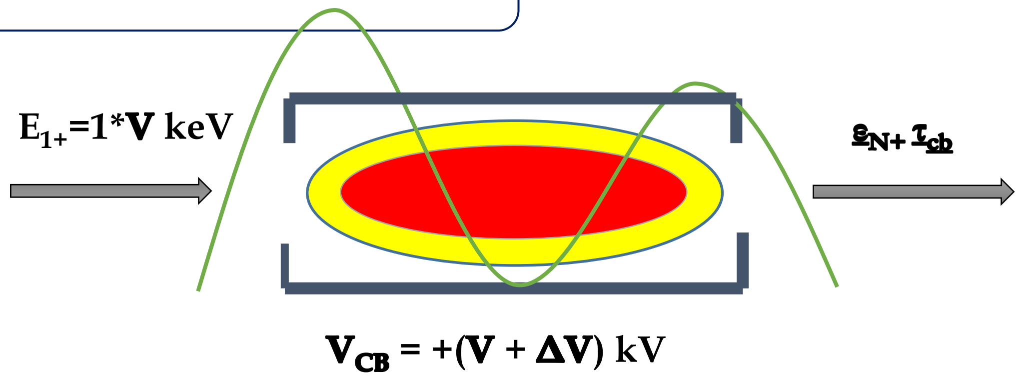
Latest results obtained at LPSC with a new magnetic configuration will be applied to the SPES-SB

	Na 2017	Na 2020	K 2017	K 2020	Rb 2017	Rb 2020	Cs 2017	Cs 2020
Charge state	8+	8+	10+	9+	19+	18+	26+	26+
Eff. (%)	12.9	18.7	11.7	22.7	10.4	11.3	13.0	14.1
Total Eff. (%)	54.1	59.9	63.4	78.7	63.9	85.08	71.9	91.8
Rise time (ms/q)	12.9	26.8	8.2	13.5	29	16.7	44.2	12.8
Support gas	He	He	He	H_2	He	He	O_2	He
Binj (T)	1.57	1.56	1.57	1.58	1.57	1.58	1.57	1.56
Bmin (T)	0.47	0.46	0.44	0.45	0.45	0.46	0.46	0.47
Bext (T)	0.83	0.84	0.83	0.83	0.88	0.85	0.86	0.84
MW power (W)	486	770	290	520	480	700	500	670
Pinj ($\times 10^{-8}$ mbar)	46	5	44	14	40	5	52	4

CHARACTERISTICS	
f [GHz]	14.5
Max Power [kW]	2
Binj [T]	1.2
Bmin [T]	0.4
Bext [T]	0.8
Brad [T]	0.8
Chamber length [m]	0.288
Chamber radius [m]	0.036

The beam purity issue

ECRIS CONTAMINANTS



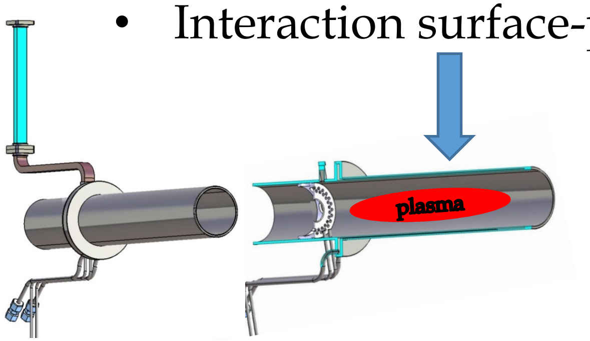
Hypothesis: 1+ RIBs are pure

Sources of contamination

- **Gaseous Contaminants** (C, N, O, Ar, Kr)
  - Gas bottles used
  - Outgassing of the surfaces

SURFACE TREATMENTS

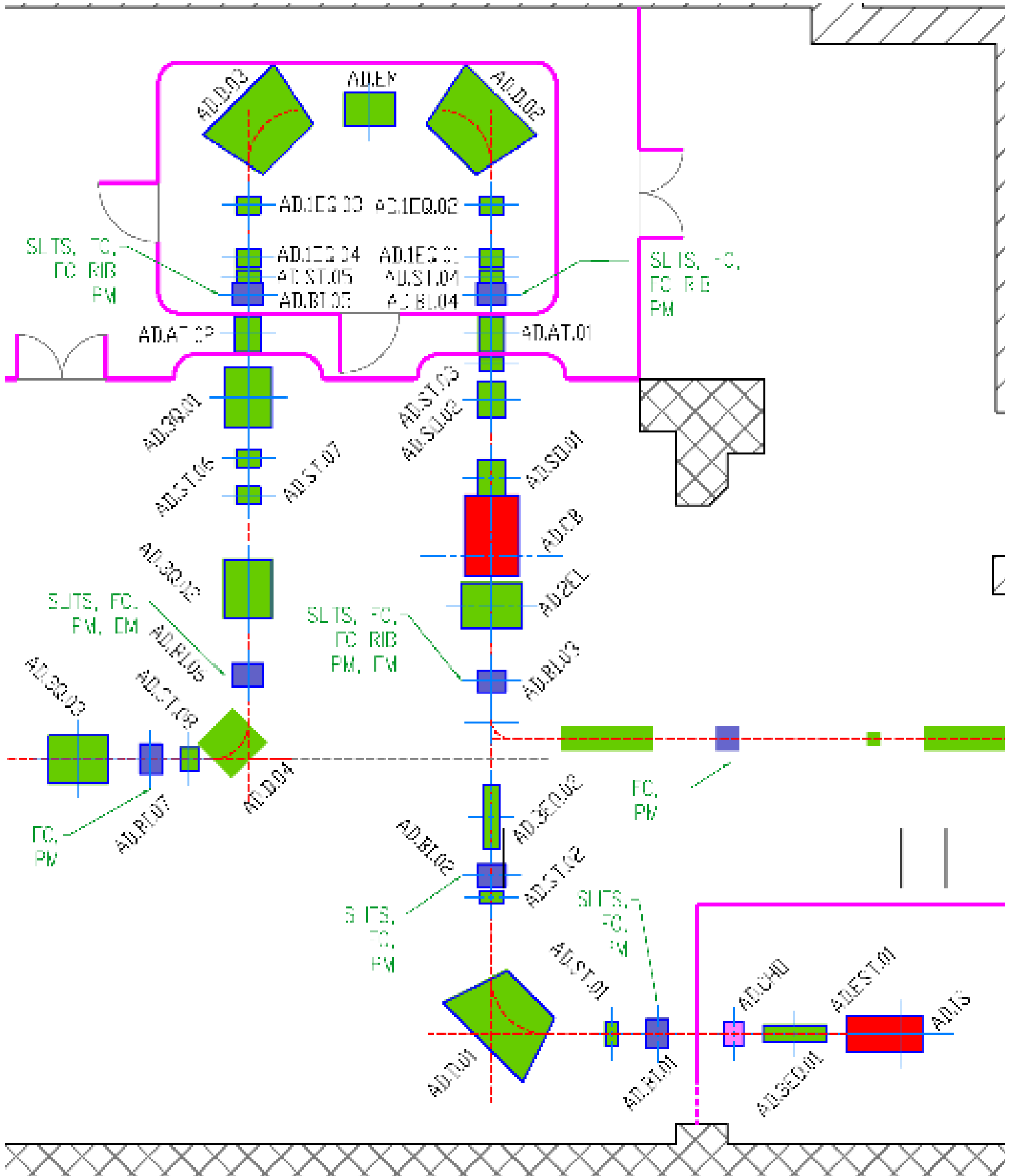
- **Solid contaminants**
  - Heavy elements
  - Interaction surface-plasma



Plasma chamber
Plasma electrode

AISI 316 L			AU4G		
Species	Mass [amu]	Abundance [%]	Species	Mass [amu]	Abundance [%]
Fe	54,56-58		Fe	54,56-58	0.7
Cr	50,52-54	17-20	Cr	50,52-54	0.1
Ni	58,60-62,64	10-12.5	Al	27	
Mo	92,94-98,100	2-2.5	Zn	64,66-68,70	0.25
Si	28-30	1	Si	28-30	0.2-0.8
Mn	55	2	Mn	55	0.4-1
P	31	≤0.045	Mg	24-26	0.4-1
S	32-34,36	≤0.03	Cu	63,65	3.5-4.5
Co	59	≤0.2			

The Medium Resolution Mass Separator



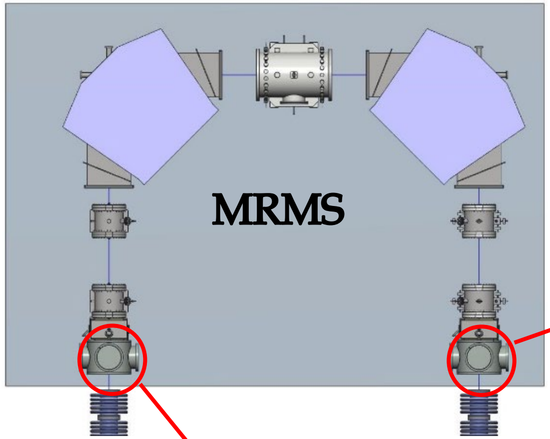
$\Delta M/M=1/1000$

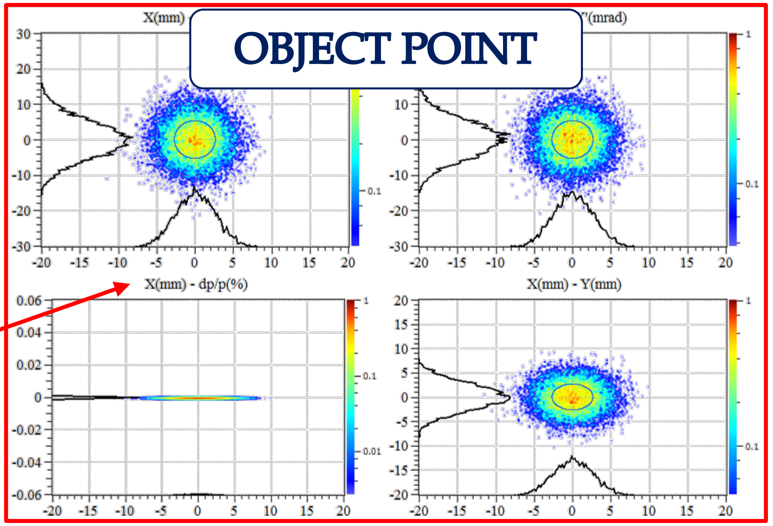
The beam purity issue

EXPECTED PERFORMANCE OF THE MRMS

Nominal beam parameters

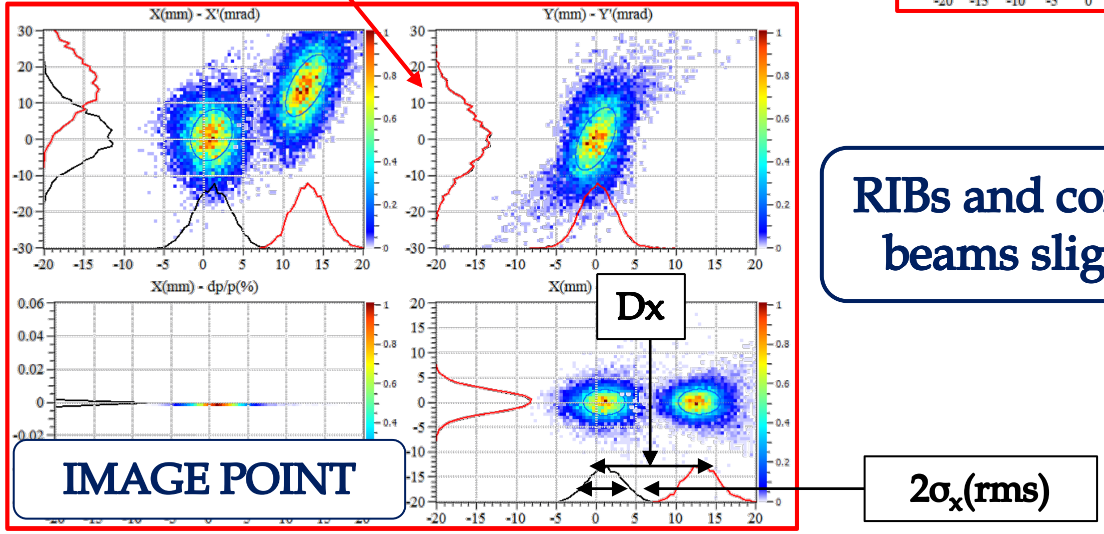
- ε_{rms}= 0.1 π mm mrad (conservative)
- $\Delta m/m=1/1000$
- E=23 keV/amu
- ΔE=15 eV
- M/q~7





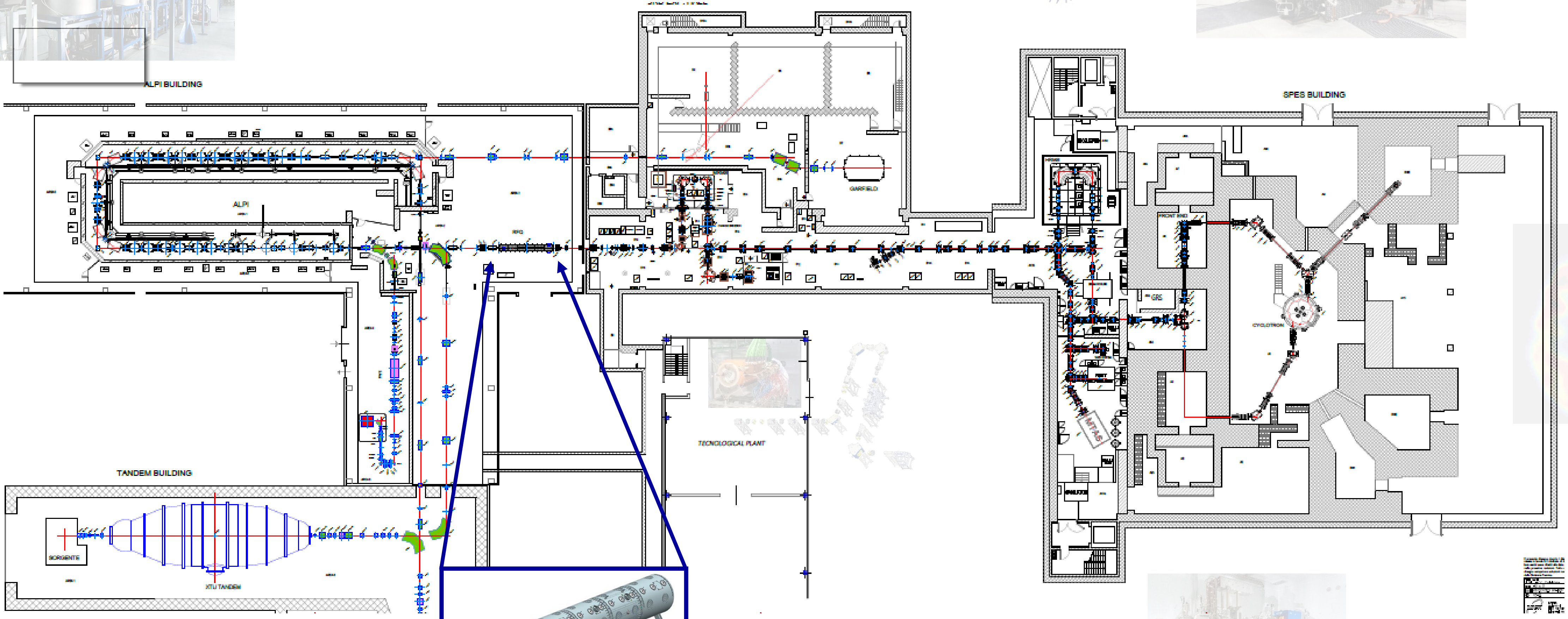
Separation

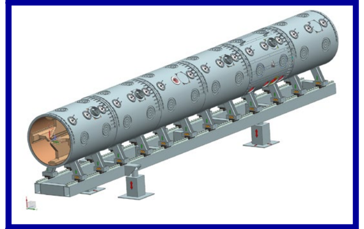
- σ_x(rms)=2.611 mm
- Dx=12 mm=4.6*σ_x(rms) for $\Delta(m/q)/(m/q)$=0.1%



RIBs and contaminant: two identical beams slightly separated in mass.

Radio Frequency Quadrupole



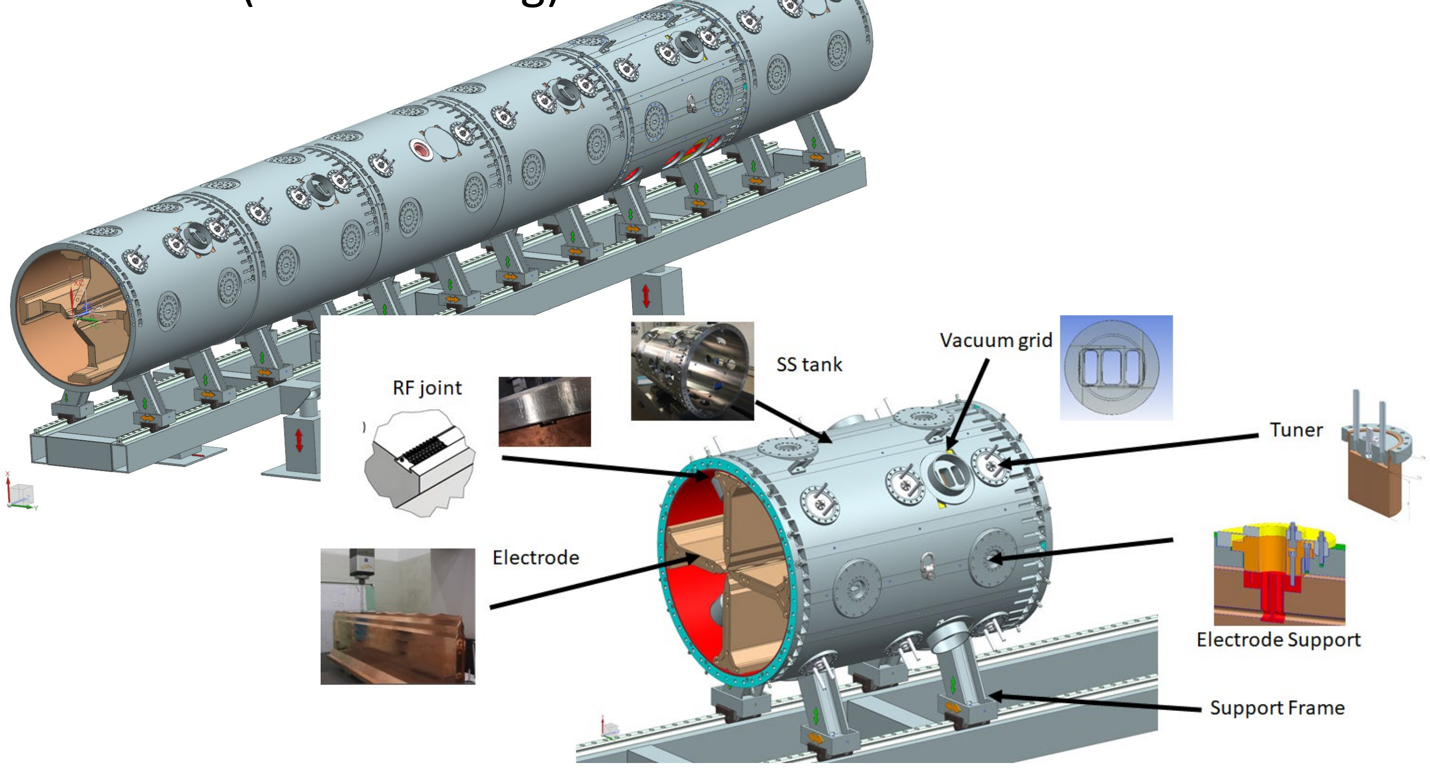


Radio Frequency Quadrupole

RFQ main parameters and features

Paramater [units]	Design value
Frequency [MHz]	80
In/out. Energy [keV/u]	5.7-727 (β=0.0035-0.0359)
V_{iv}[kV]	63.76-85.85
Beam current [μA]	100
Vane Length [m]	6.95
R_0[mm]	5.29-7.58
ρ/R_0	0.76
Synchronous phase (deg.)	-90 ÷ -20
Focusing Strength B	4.7 ÷ 4
Shunt impedance [kΩ*m]	419-438 (30% margin)
Stored Energy [J]	2.87
RF Power [kW]	115 (with 30 %margin for 3D details and RF joint, and 20% margin for LLRF regulation)
Q_0 value (SF)	16100 (30% margin)
Max power density [W/cm^2]	0.31 (2D), 13 (3D)
max $\delta V_{iv}/V_{iv}$ [%]	±3
Transmission [%]	94
Output Long RMS Emit [keV deg /u]	4.35

SPES RFQ accelerates beams in CW (A/q=3÷7). It is composed of 6 modules, each ~1.2 m long, with a AISI LN 304 Cu-plated Tank and OFE-Cu Electrodes. Spring joint between tank and electrode (for RF sealing)

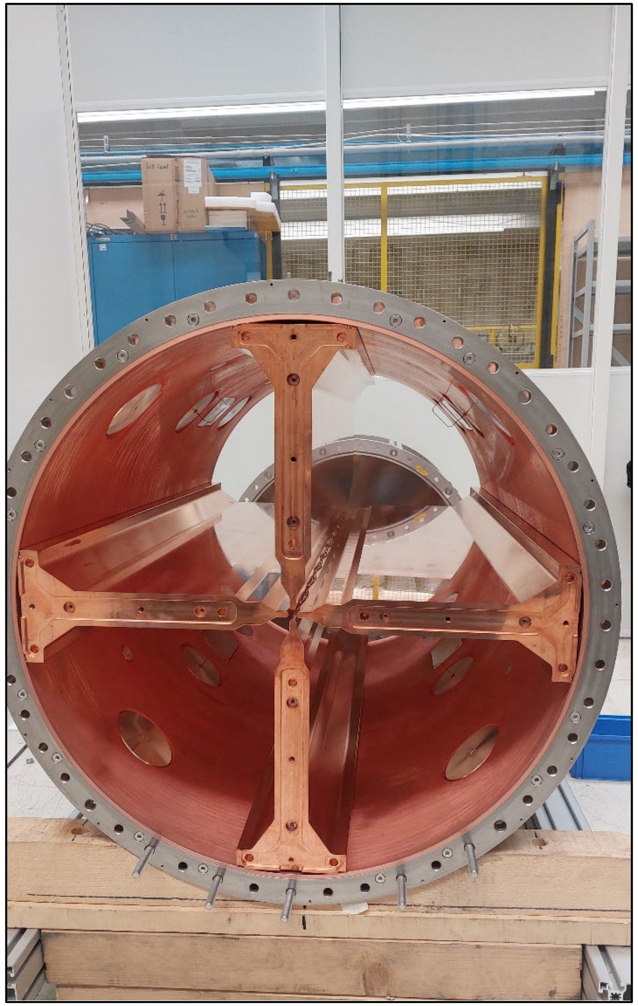


RFQ, Beam Dynamics group

RFQ assembly

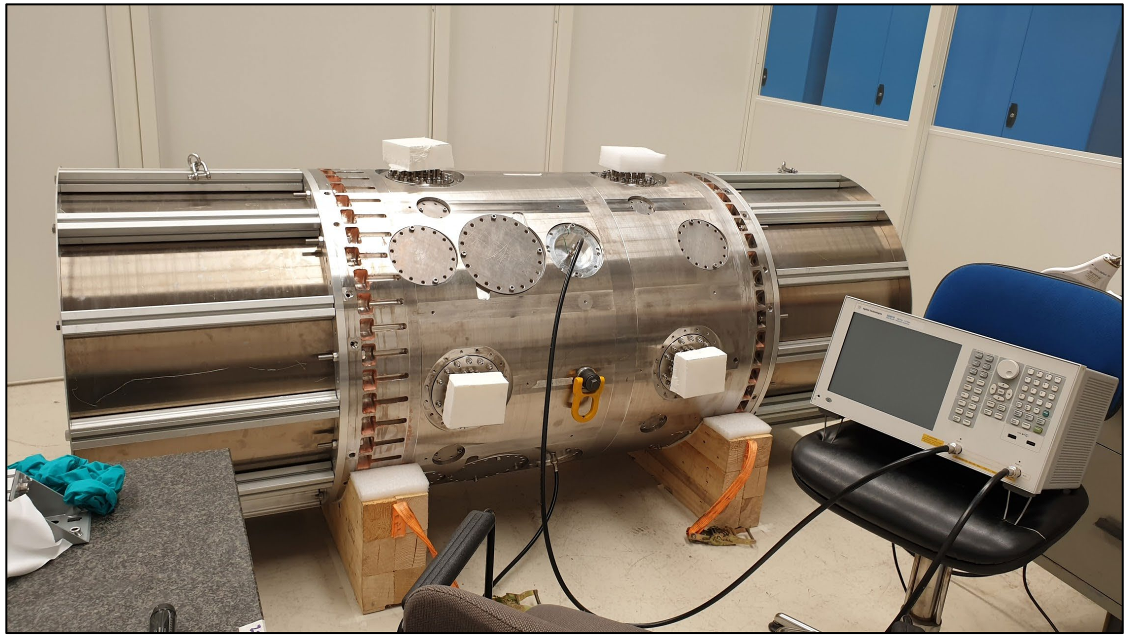
Initial positioning of the tank vs electrodes in vertical position

Completion of the positioning of the tank vs electrodes



Final assembly of the RFQ module

RFQ: RF measurements and installation on support



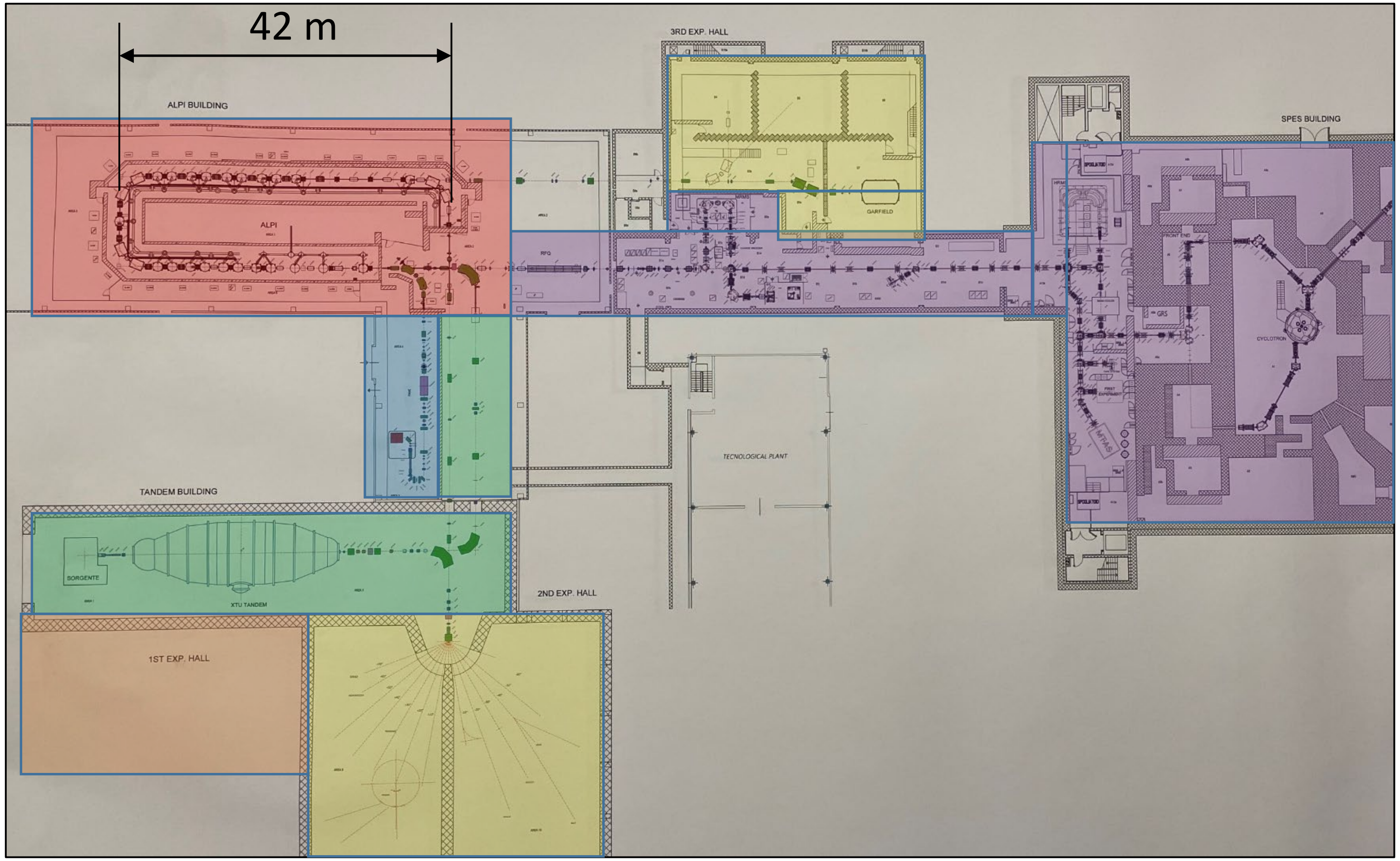
- RFQ setup for RF measurements: the final ΔR0 measured with RF is 3 um. Both mechanical and RF measurements are compliant with specs (10 kHz frequency difference wrt simulations).
- Prior to installation, the module underwent successful leak testing with He in order to assess the electrode sealing

RFQ module installed on support in Area 2 (final location)

The other 5 modules are planned to be completed by the end of 2022

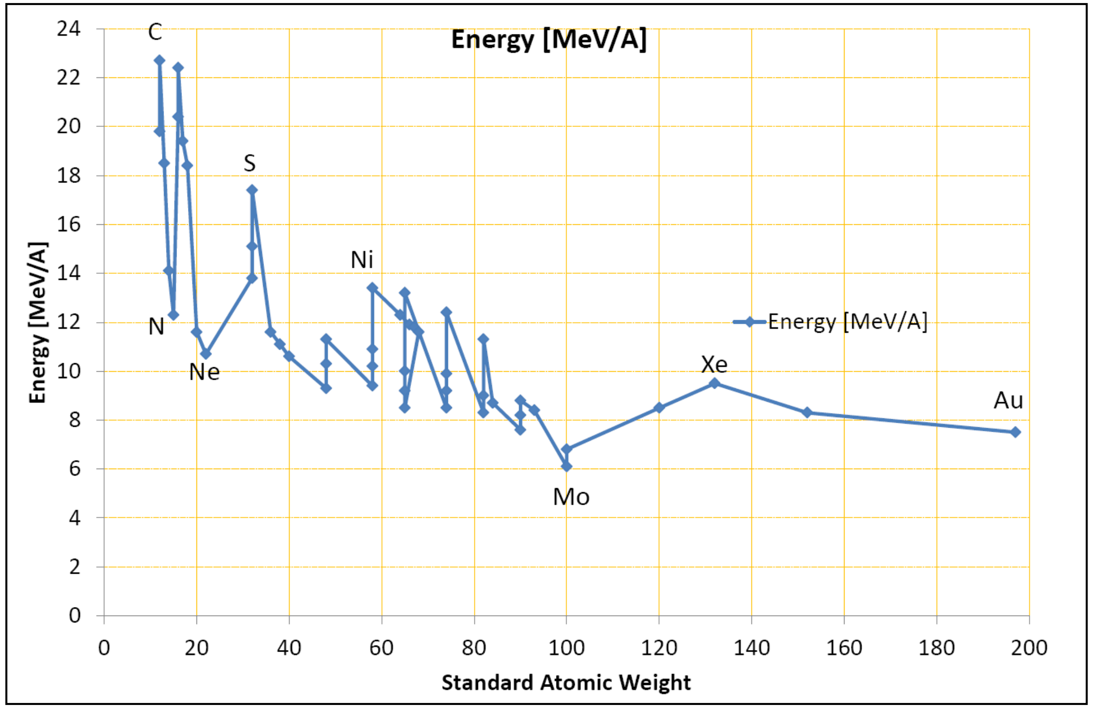
The RF tests are planned to be completed by the end of 2023

ALPI LINAC : periodic structure

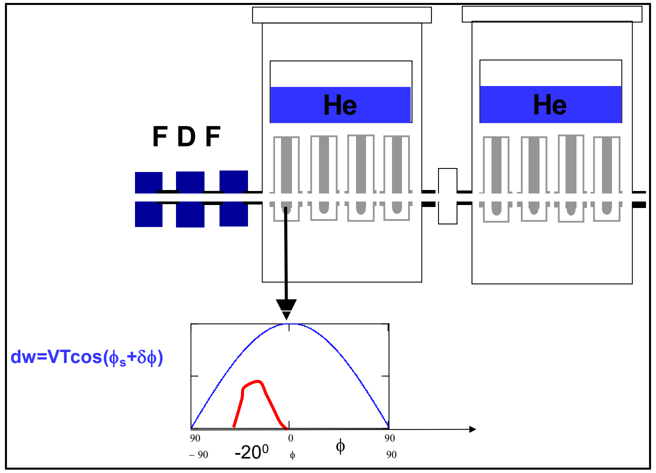


- **ALPI** linac **period** consists of **1 triplet + 2 cryostats**.
- This long period (composed by **8 cavities**/16 gaps with very high accelerating field) requires to set some cavities at fs = +20°, to mitigate radial defocusing effects.
- The **SPES-ALPI complex** will be able to accelerate beams **up to A/q = 7**.

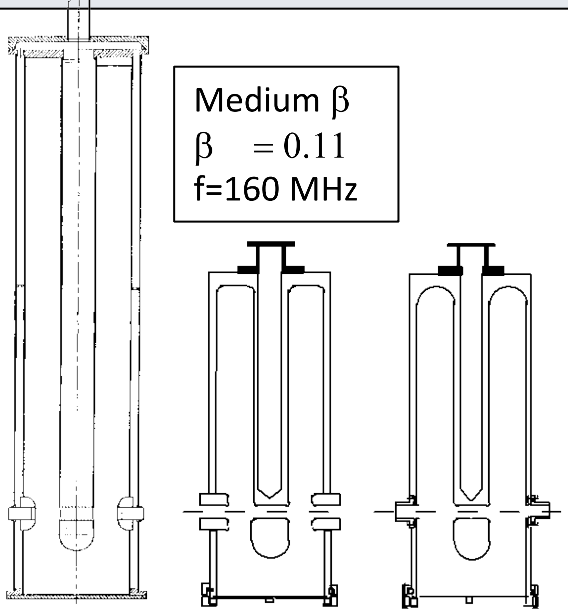
ALPI : current energy performance



- SPES RFQ **injection energy: 727.3 KeV/A**
- **SC Linac** with **76 QWRs** (Nb, Nb/Cu) at 4.5K in **19** cryostats **V_{eq} ~ 48 MeV/q**, beams **from ^{12}C to ^{238}U***
- **CR01 → CR06 - 80 MHz** Nb bulk QWRs **5 MV/m** accelerating gradient
- **CR07 → CR10 - 160 MHz** Nb/Cu QWRs **4.3 MV/m** accelerating gradient
- **CR12 → CR18 - 160 MHz** Nb/Cu QWRs **4.3 MV/m** accelerating gradient
- **CR19 → CR20 - 160 MHz** Nb/Cu QWRs **6.5 MV/m** accelerating gradient

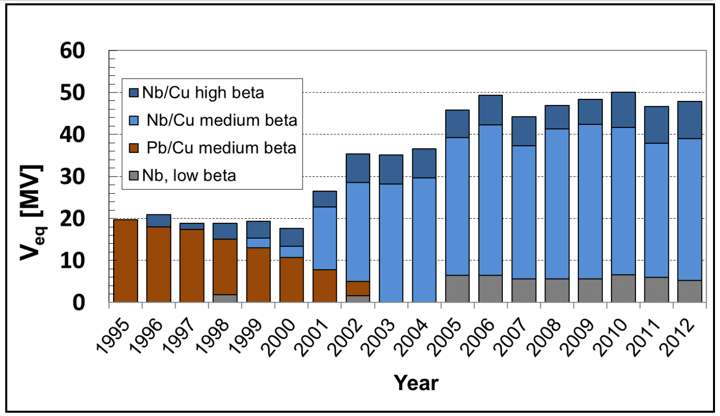


Low β
β= 0.047
β= 0.056
f=80 MHz



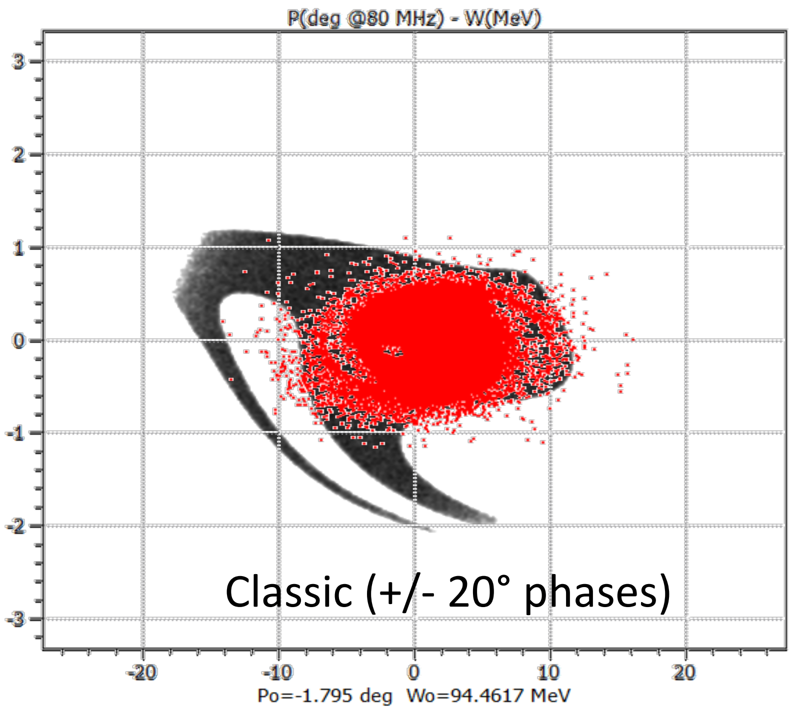
Medium β
β = 0.11
f=160 MHz

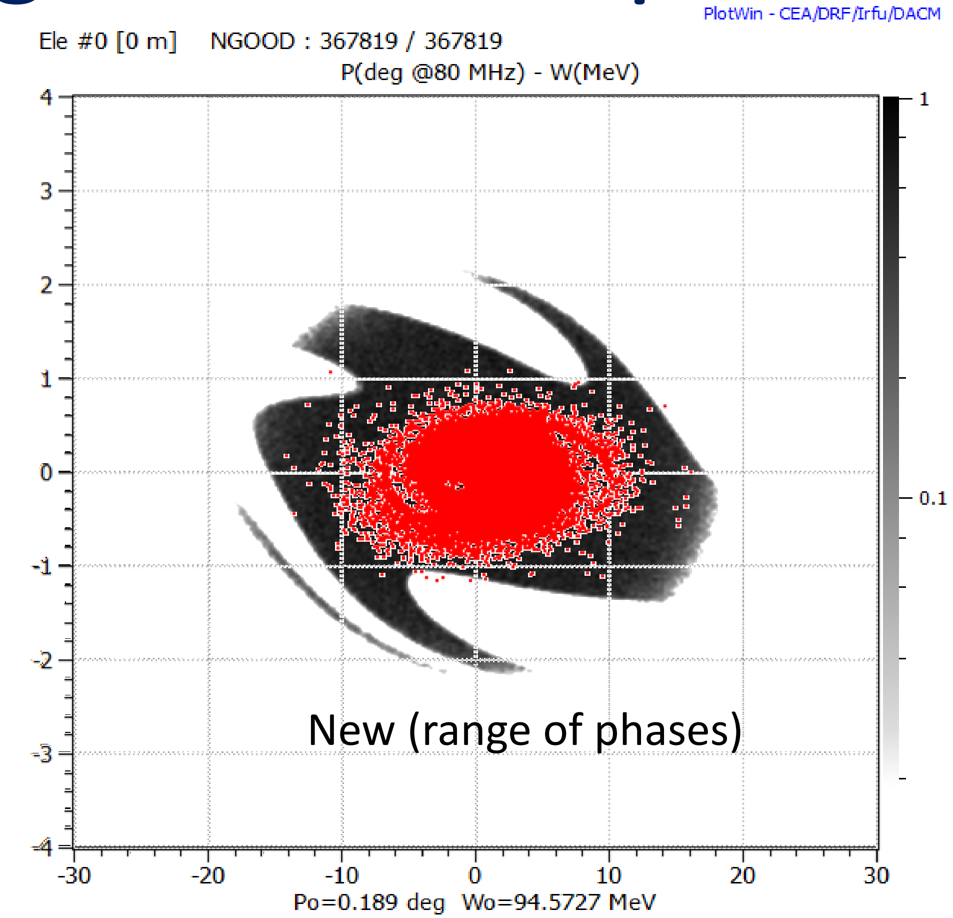
High β
β = 0.13
f=160 MHz

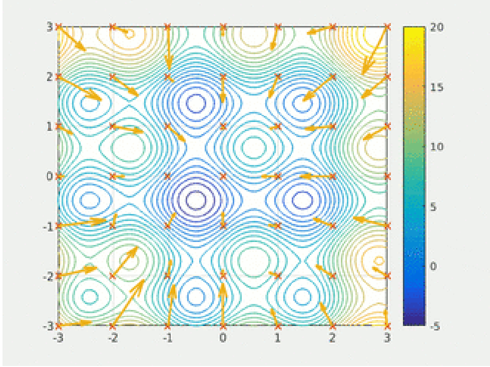


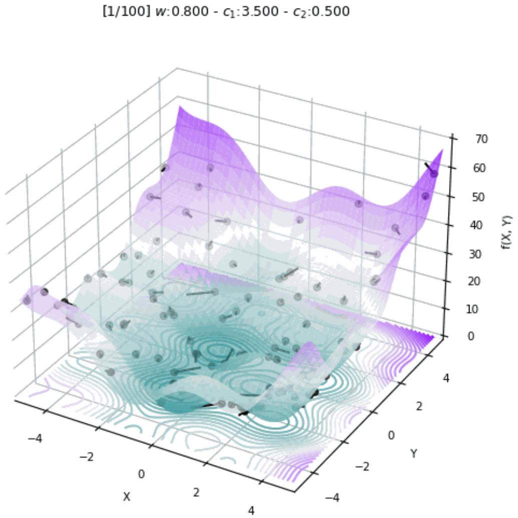
*acquiring authorization

ALPI : accommodation of SPES beam inside longitudinal acceptance









The new solution increases the longitudinal capture in the whole linac and the longitudinal acceptance is increased by a factor 2

ALPI : status on beam dynamics improvements

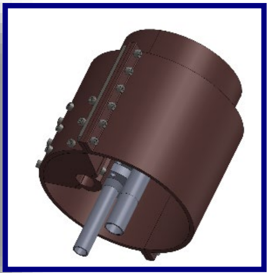
- At the state of the art the new set improved:
  - **Large increase of longitudinal acceptance (200%)** with a small improvement of transverse acceptance (about 11%) w.r. classic solution
  - **Half the losses**
- Drawbacks:
  - 4.4% energy loss **at the end** of the acceleration chain
  - Higher longitudinal emittance -> **13% increase** in longitudinal emittance
- Next steps:
  - Error study -> Test of the overall robustness of the new configuration
  - Commissioning test with PIAVE
  - Introduce the new configuration as routine operation

ALPI cavities and cryostats improvement: CR07

- During 2021 CR07 used as prototype for future developments to be implemented on other cryostats. Main improvements on:
  - **Alignement**
  - **Piping and safety**
  - **Thermal shielding**
  - **Closure plates and tuners connections**
  - **Thermal joints**
  - **New thermal sensors**

Piping and Safety

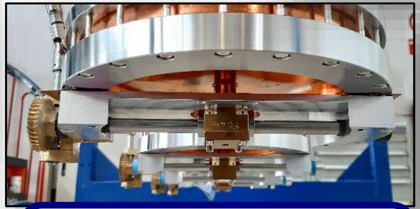
Thermal shielding



New thermal sensors

New cooling system

New thermal joints



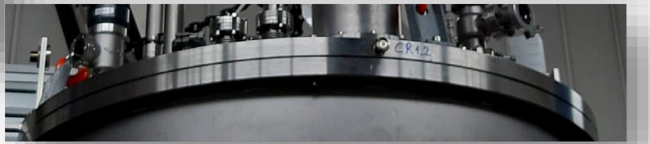
Closure plates and tuner connections

ALPI cavities and cryostats improvement: CR01

- During 2021 CR01 used as prototype for future developments to be implemented on other low beta cryostats. Main improvements on:
  - **Tuner revision**
  - **Plate characterization**
  - **New reference for alignement**
  - **New shielding**
  - **LN2 circuit replacement**
  - **Safety**

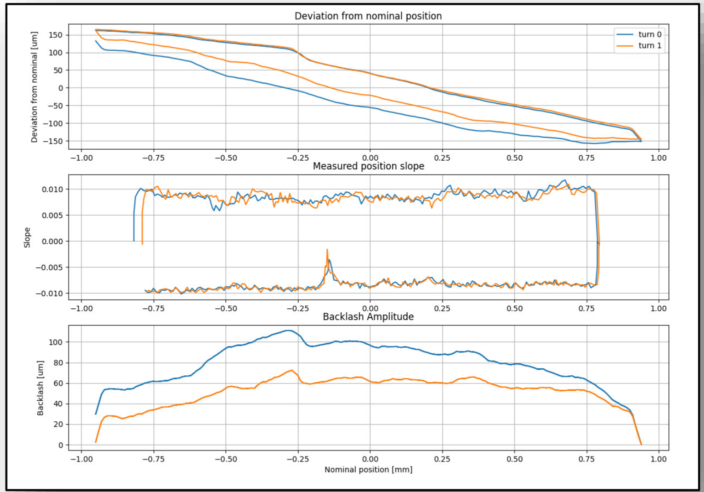
Tuner mechanical revision

New reference for alignement

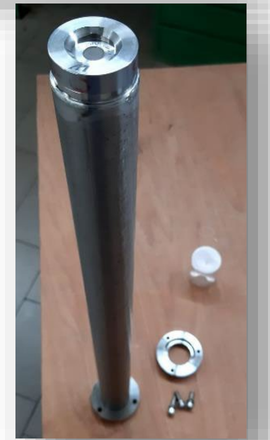


Mechanical test in LN2

Tuner RF characterization



Cavity move check during vacuum pumping and cooldown

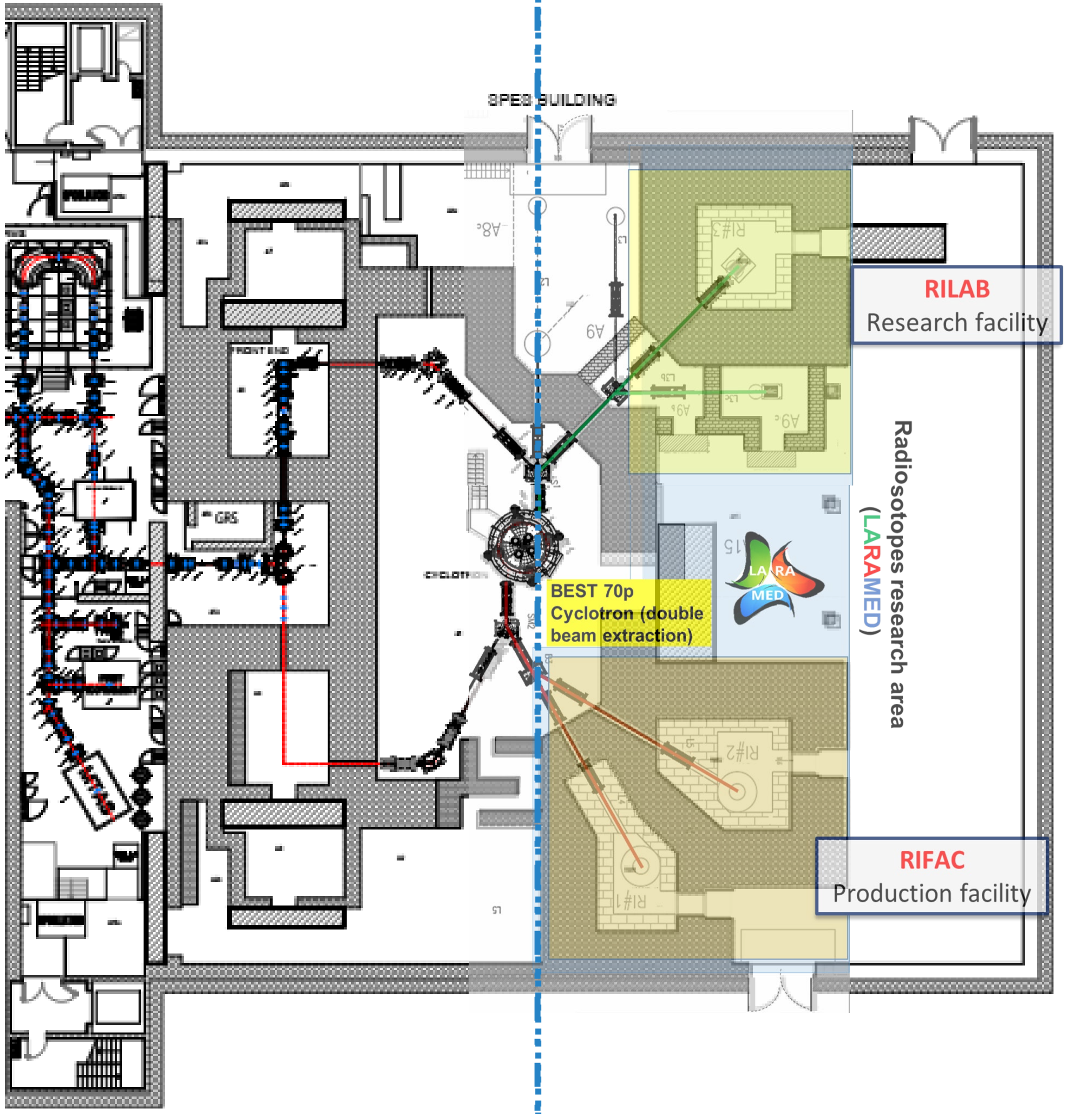


Study and production of novel medical radionuclides

ISOL technology

ISOLPHARM

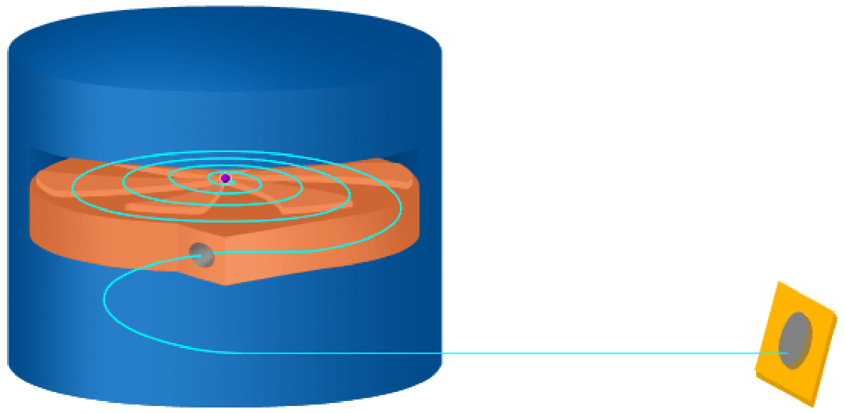
SPES exotic beams for medicine



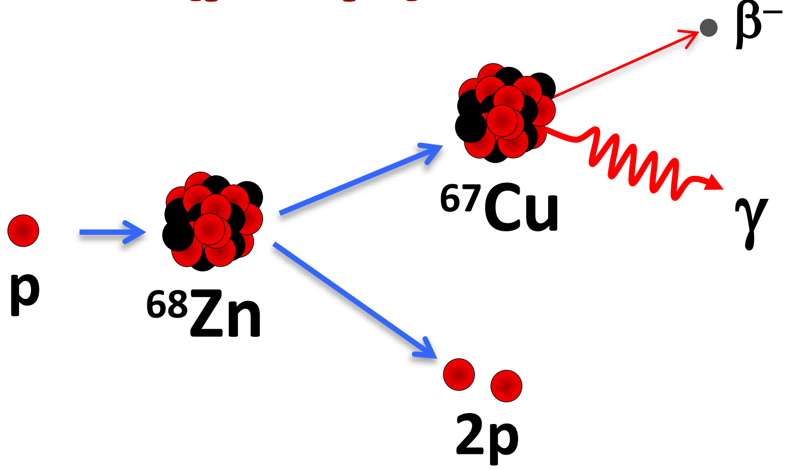
DIRECT technology

LAboratory of
Radionuclides for
MEDicine

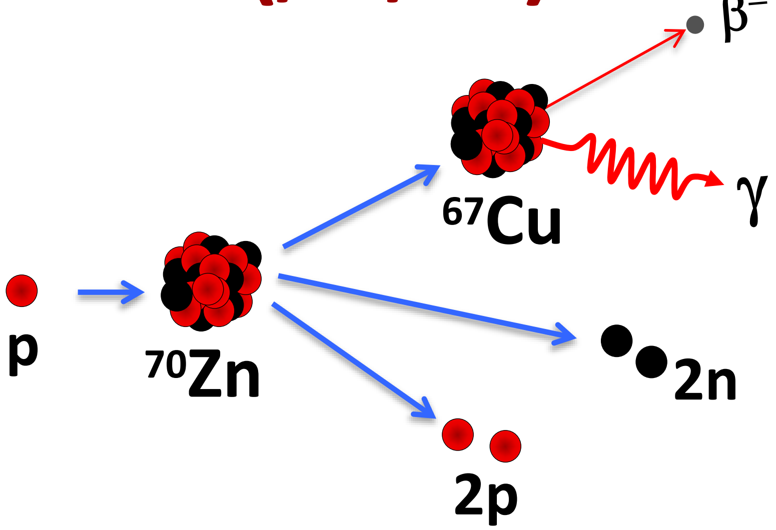
Production of medical radionuclides with proton beams



$^{68}Zn(p,2p)^{67}Cu$

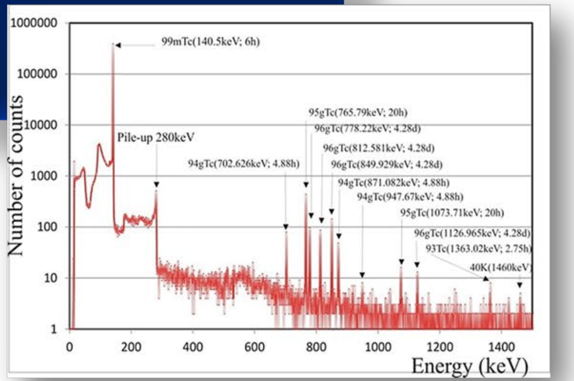


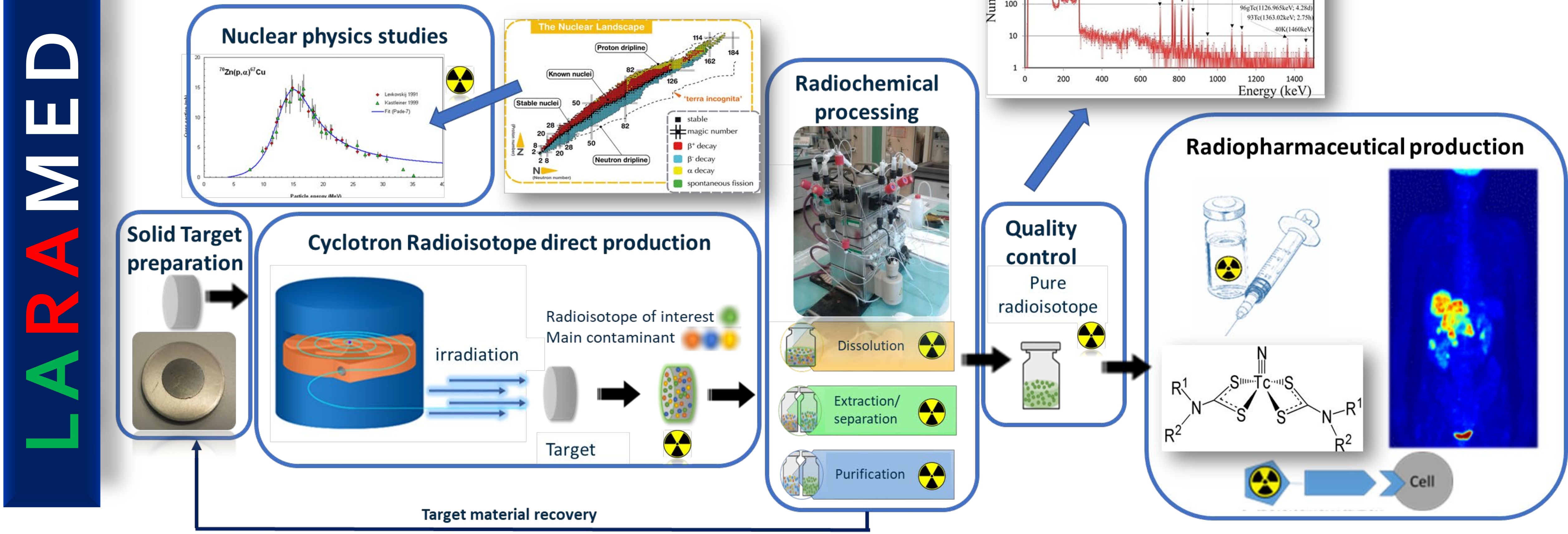
$^{70}Zn(p,2p2n)^{67}Cu$



LARAMED: the radionuclides direct production

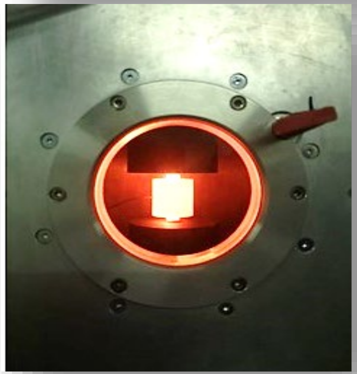
Capable of producing several radionuclides (different isotopes and chemical species) **in**
- **large radioactive amounts**
- **good quality (i.e. high Radionuclidic purity & Specific activities)**

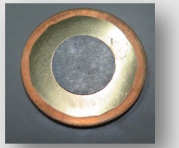
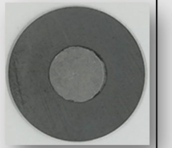
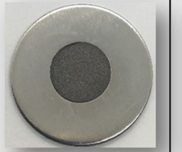




LARAMED: solid target manufacturing techniques under development at LNL

Spark Plasma Sintering (SPS)

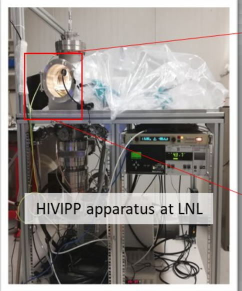


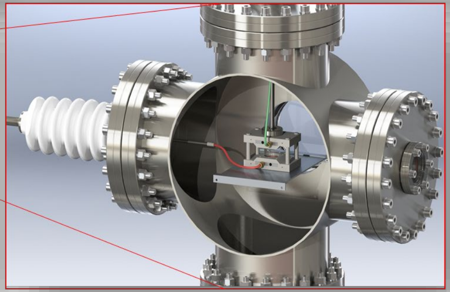
$^{100}Mo \rightarrow ^{99m}Tc$		$Cr\text{-}nat \rightarrow ^{52}Mn$		$Y \rightarrow ^{89}Zr$	$ZnO \rightarrow ^{64,67}Cu$
^{100}Mo pellet	^{nat}Mo pellet	^{nat}Cr pellet	^{nat}Cr pellet	^{nat}Y foil	ZnO pellet
Cu backing Au protective layer	Graphite backing	Cu backing Au protective layer	Nb backing	Nb backing	
					

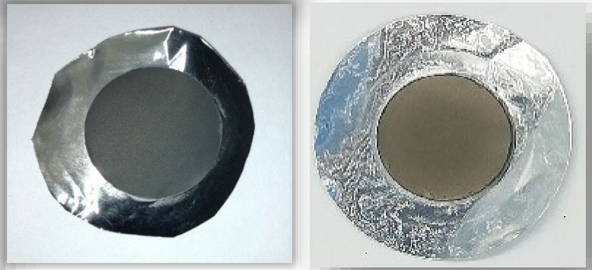
SPS advantages:

- ✓Sintering of high melting point materials
- ✓Starting materials: powder or foil
- ✓More clean approach: no brazing technique
- ✓99% efficiency: no loss of isotope-enriched material during manufacturing
- ✓200 µm - mm thickness pellet

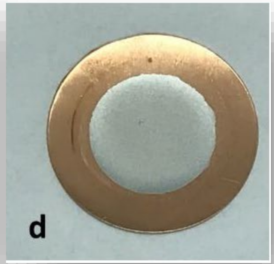
High Energy Vibrational Powder Plating (HIVIPP)







^{48}Ti (left) and ^{49}Ti (right) deposited (0.2–2 mg/cm²) on Al foil (25 µm)

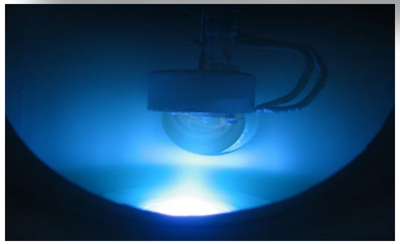


^{nat}Mo on Cu foil (250 µm)

HIVIPP advantages:

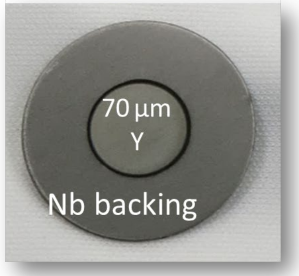
- ✓ Thickness suitable for xs measurem.: 0.1-20 µm
- ✓ Starting material powder
- ✓ Efficiency 95-98%: no losses of material
- ✓ Two targets are deposited simultaneously
- ✓ Low amout of starting material is needed

Magnetron Sputtering (MS)



Mo target → ^{99m}Tc

Y target → ^{89}Zr



MS advantages:

- ✓ Deposition on any support material
- ✓ Excellent adhesion on substrate
- ✓ High thickness range (0.1 µm-1 mm)
- ✓ High deposition uniformity
- ✓ High bulk density (>98%)

The LARAMED research network

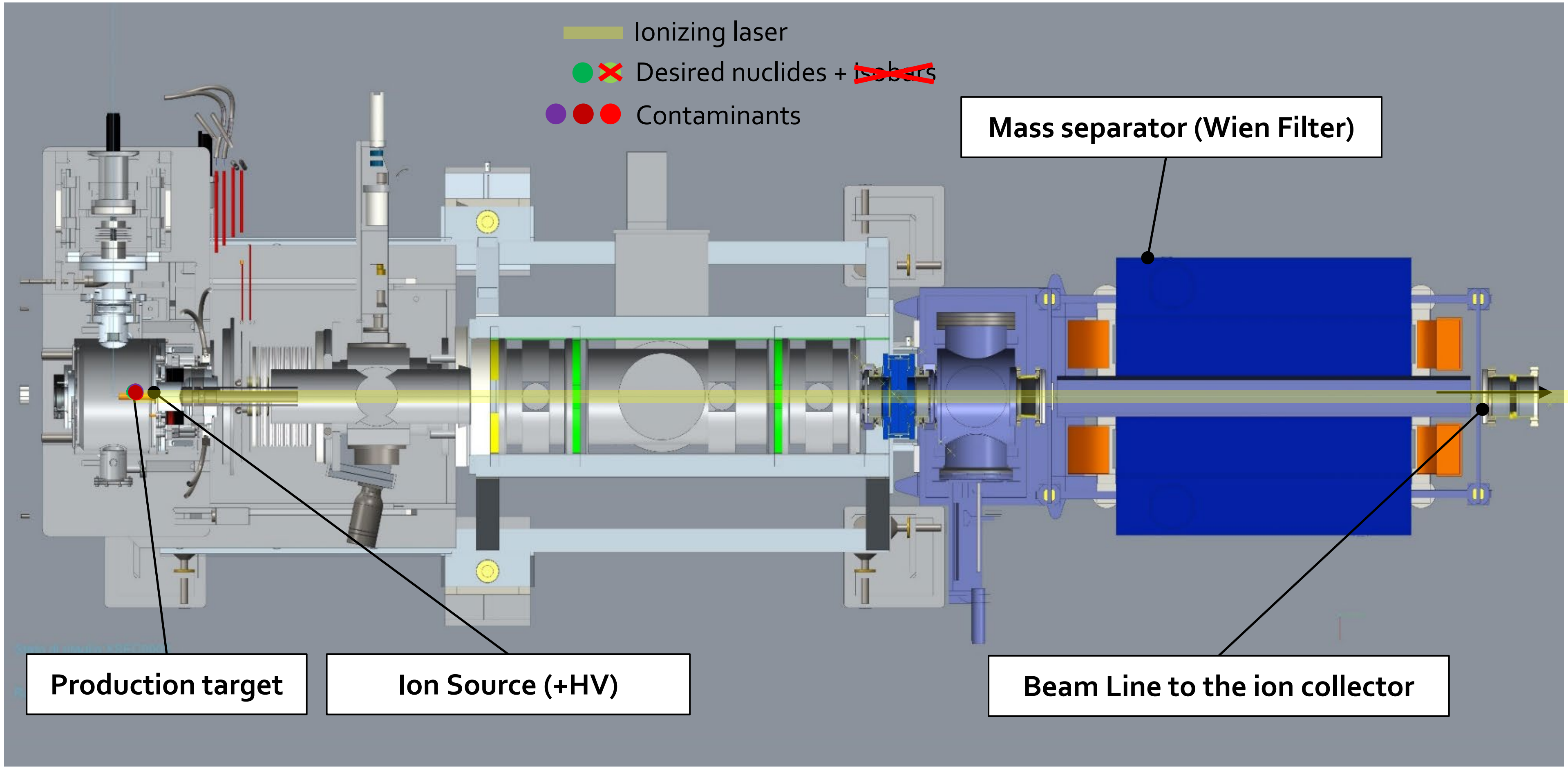
National collaboration

- Pavia University + INFN Pv
- LENA Laboratory (PV)
- Bicocca University + CNR Milan
- Ferrara University + INFN-Fe
- Padua University + INFN-Pd
- Milan University + INFN-Mi
- SCDC Hospital – Negrar (VR) - Cyclotron Unit
- St. Orsola Hospital (BO) – Cyclotron Unit
- Turin University DBMSS
- Veneto Institute of Oncology (IOV)

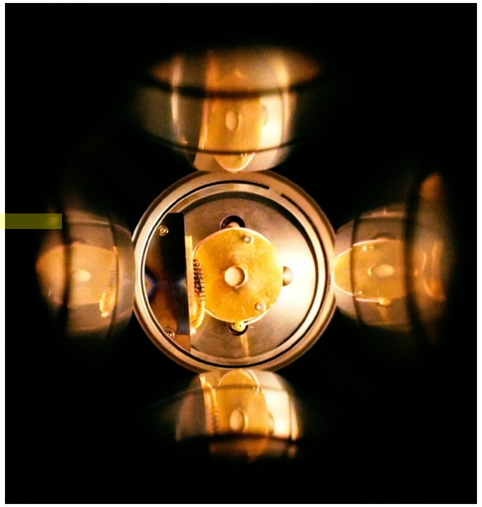
International collaboration

- ARRONAX (Nantes, FRANCE)
- Univ. Winsconsin-MD (USA)
- IAEA (Vienna, AUSTRIA)
- European Medical Radionuclide program

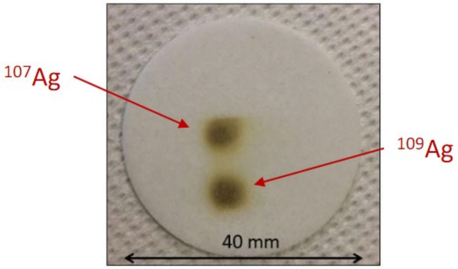
ISOLPHARM: production, mass separation and ion collection



The **ion collection target**



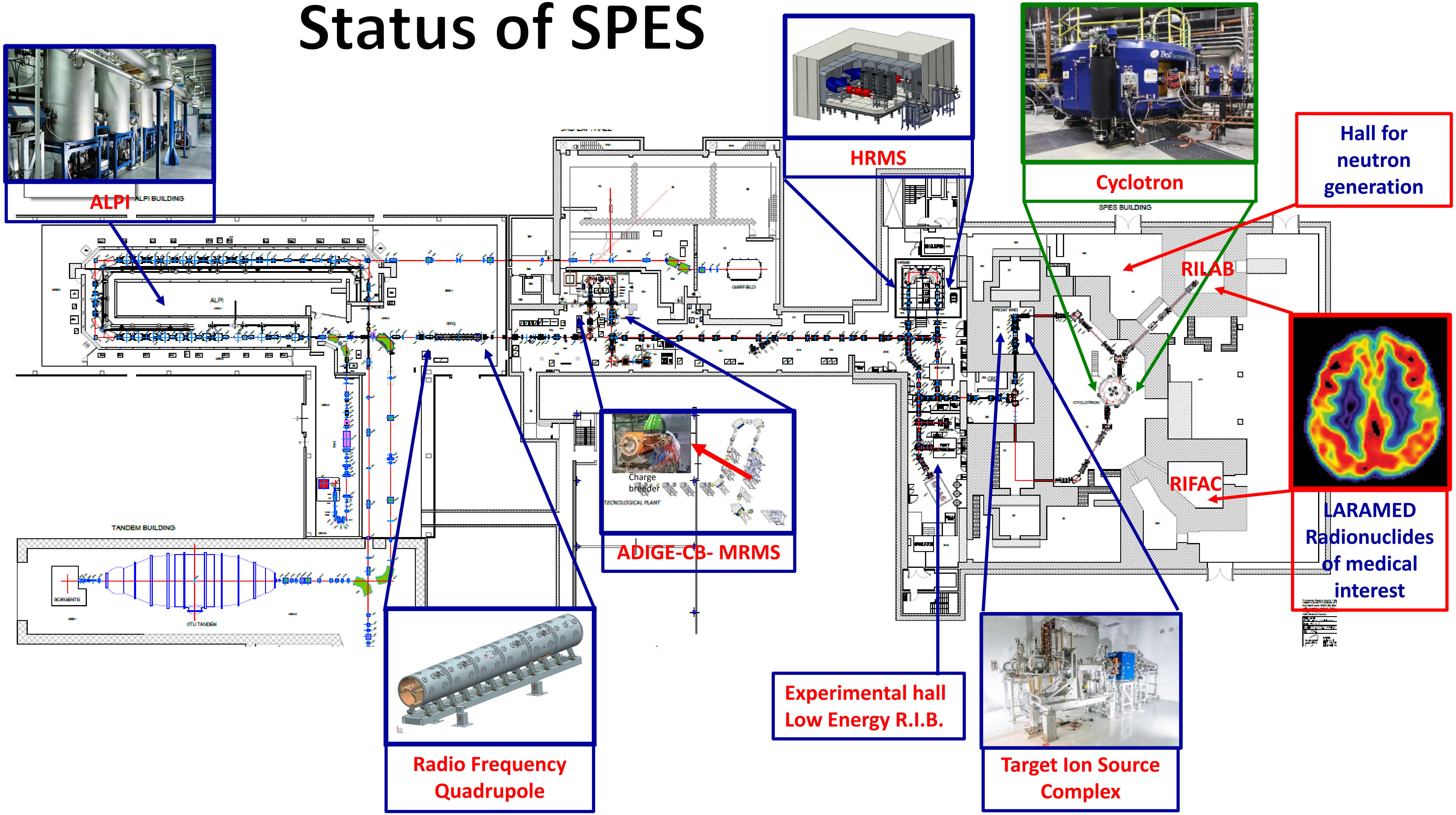
Collection on $NaNO_3$ substrate



+ Laser = Only desired nuclides!!

No Chemical purification is needed! -> Carrier free radionuclides

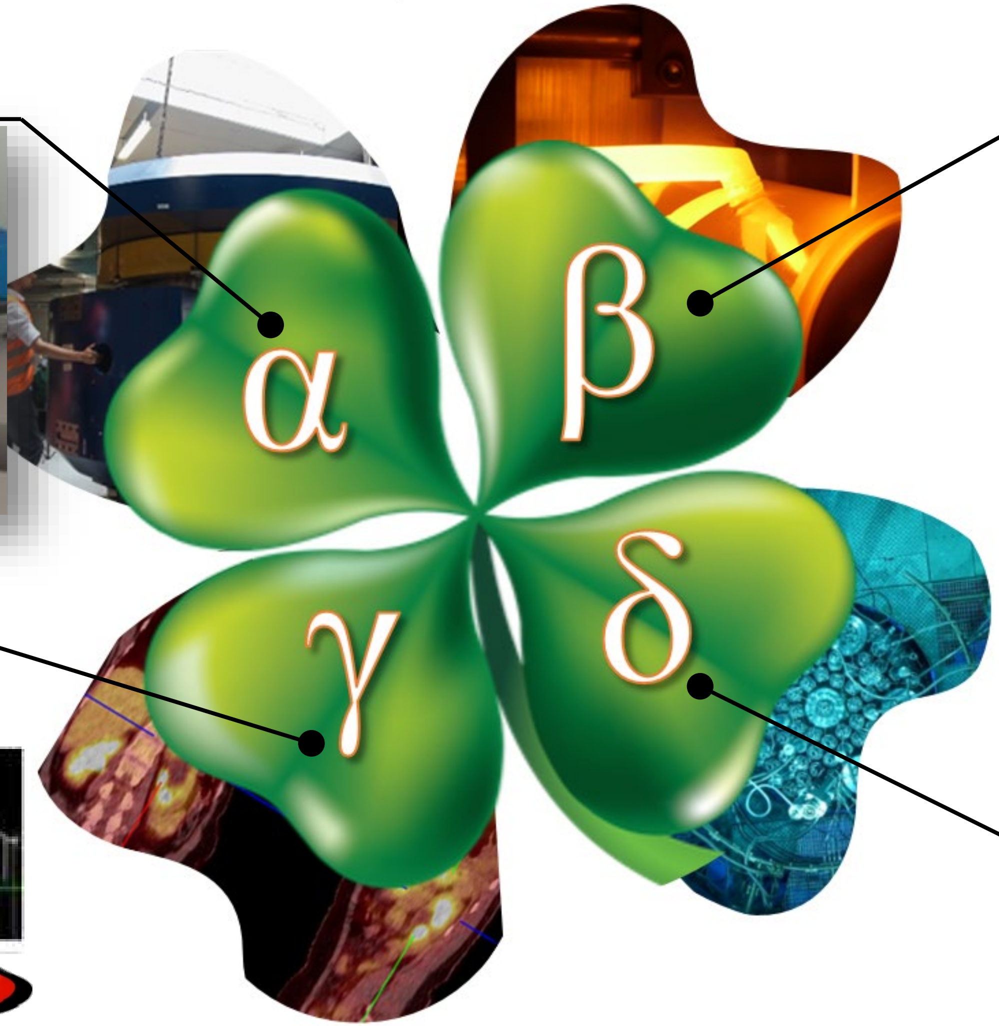
Status of SPES



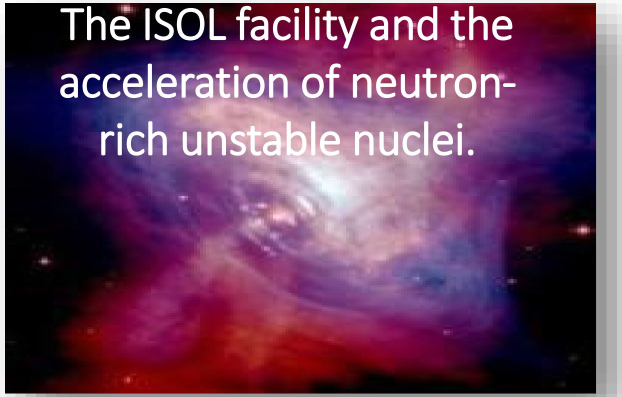
SPES @ LNL
Selective Production of Exotic Species

SPES-α

Cyclotron installation and commissioning (and related infrastructure)



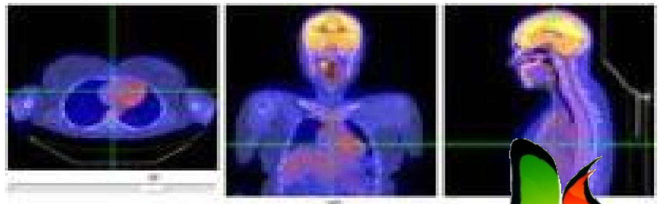
SPES-β



The ISOL facility and the acceleration of neutron-rich unstable nuclei.

SPES-γ

Study and production of novel radionuclides of medical interest



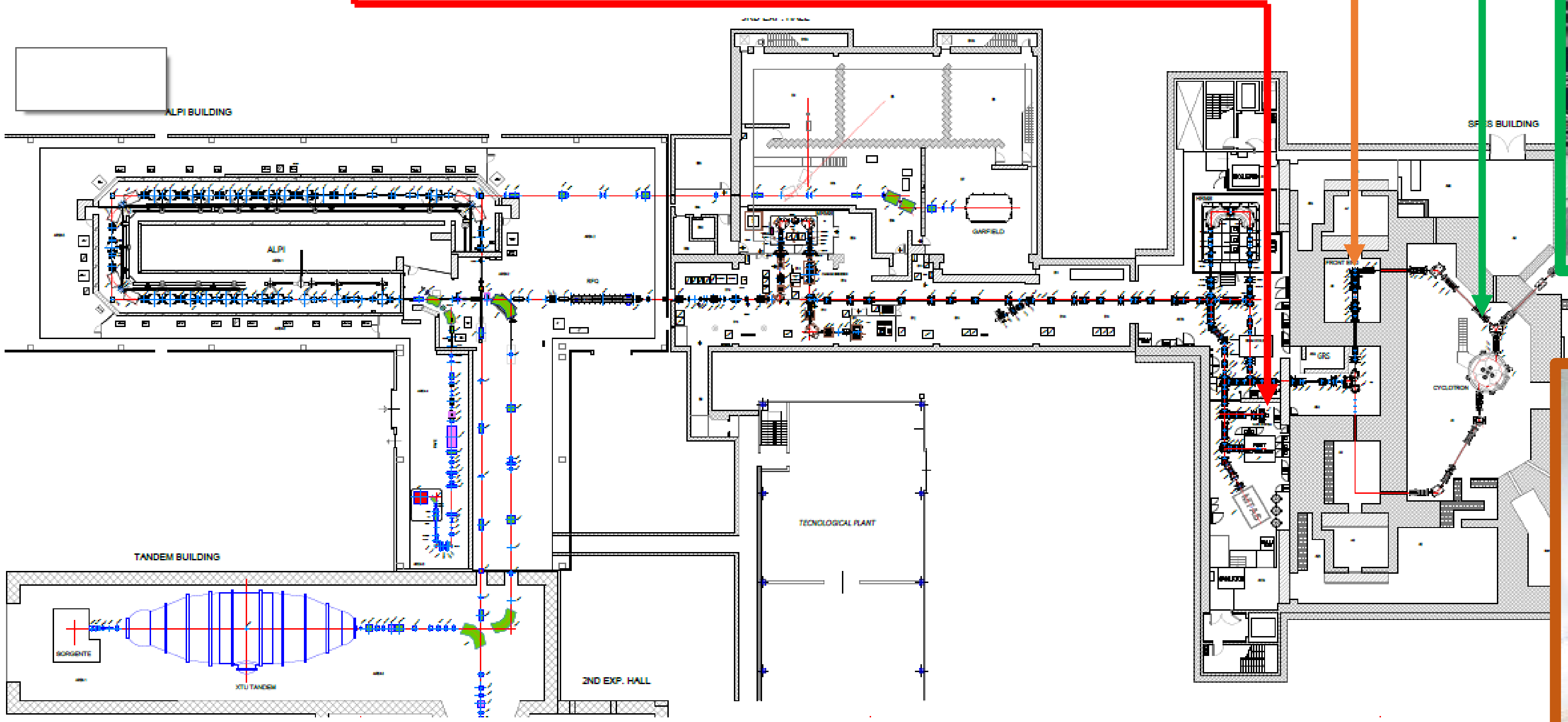
ISOLPHARM SPES exotic beams for medicine & LARAMED

SPES-δ

Neutron sources for material study, nuclear technologies and medicine

Short term objectives

- Cyclotron high intensity operation
- Cyclotron beam delivery on Target Ion Source complex and production of radioactive beams
- Experimental activity with L.E. radioactive beams



Authorization to operate

D.I. (Permission Decrees) issued by ISIN, National Inspectorate for Nuclear Safety and Radioprotection

Phase alfa – Permission Decree D.I. 11/09/2012

- Production of 70 MeV, 750 μA proton beams with the Cyclotron
- Production of radioactive beams with conventional targets (SiC, C, LaC2, …) and re-acceleration with ALPI, production of radioactive beams with UCx targets and 40 MeV, 5 μA proton beam for commissioning

Phase beta – Permission Decree D.I. 05/06/2019

Production of radioactive beams with UCx targets and 40 MeV, 200 μA proton beam and re-acceleration with ALPI

Phase gamma – Permission Decree D.I. 05/06/2019

Production of innovative radioisotopes, both for medical purposes and for applied research

Fire Prevention Certificate is needed too, to be released by the Fire Brigade

January 2021: fire prevention design for phase alfa presented to the Fire Brigade

Padova 22/01/2021

Ministero dell'Interno

Dipartimento dei Vigili del Fuoco del Soccorso Pubblico e della Difesa Civile

Comando dei Vigili del Fuoco di PADOVA

OGGETTO : VALUTAZIONE DI CONFORMITA' **POSITIVA CONDIZIONATA** DEL PROGETTO AI SENSI DELL'ART. 3 D.P.R. N. 151/2011.
Pratica VV.F. n. 4124 relativa all'attività n. 58.2.C - del D.P.R. n 151/2011.
Ditta I.N.F.N. LEGNARO – VIA DELL' UNIVERSITÀ 2 LEGNARO.-

January 22, 2021: a document of positive evaluation of compliance issued, conditioned to the realization of what has been declared

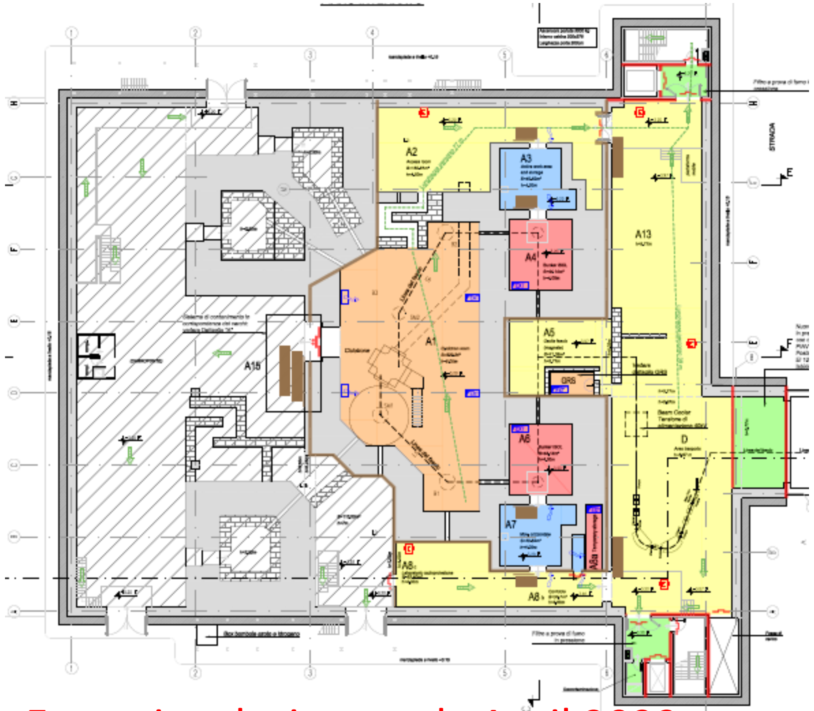
Before starting the facility operation, a communication (S.C.I.A.) has to be presented to the Fire Brigade in order to get the C.P.I. (Fire Prevention Certificate)

Fire prevention infrastructures: ongoing activities

Fire prevention design phase alfa: Risk assessment and protection actions

1. General safety objectives (normal operation and emergency)
2. Nuclear safety objectives
3. Confinement objectives (static and dynamic): Reaction to fire of materials, Fire resistance of structures, Fire compartmentalization, Evacuation, Fire control, Fire detection & Alarms

Fire compartmentalization and fire sealing implementation

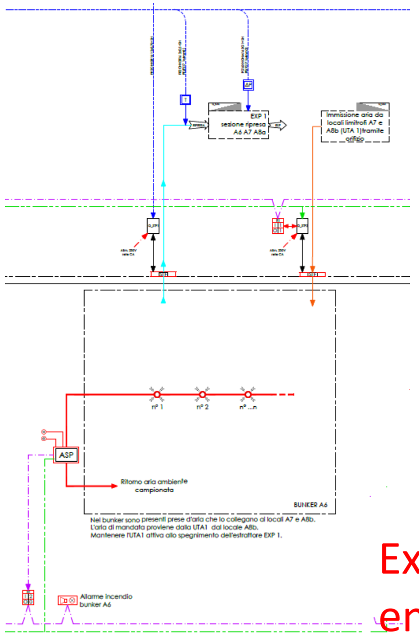


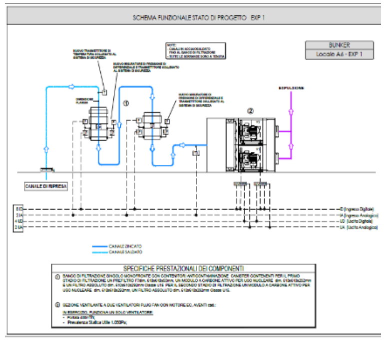
Executive design ready April 2022

Infrastructural Actions for fire prevention

Tender: May-Jul 2022
Works: Sep-Nov 2022

Upgrade of the ventilation system according to ISO 17873 - Criteria for the design and operation of ventilation systems for nuclear installations different from nuclear reactors

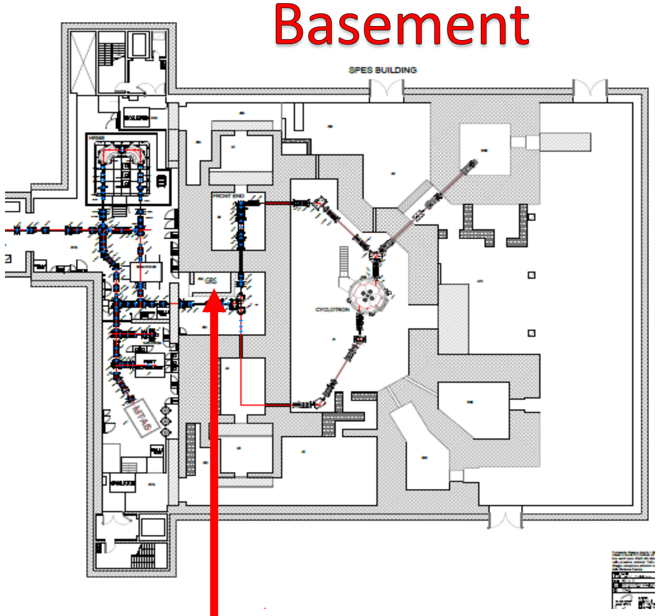


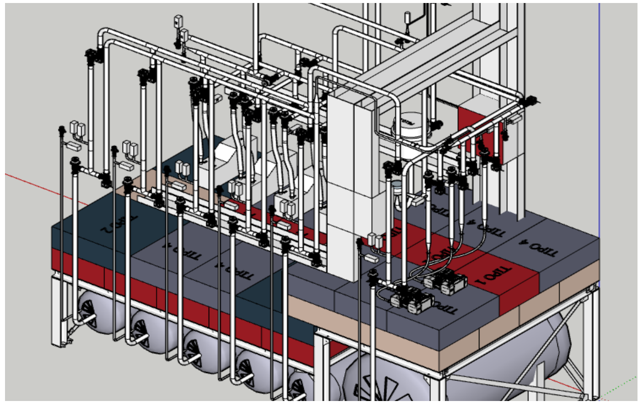


Executive design ready end 2021

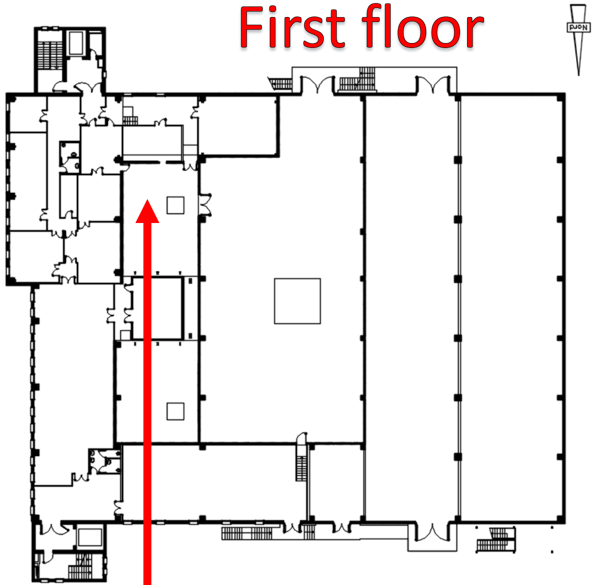
Safety activities: Gas Recovery System completed

Basement





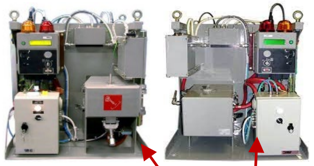
First floor

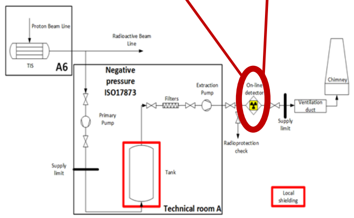


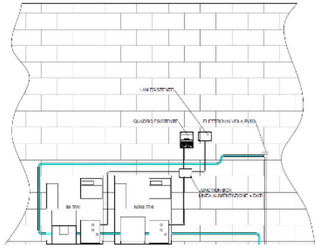
Jun 2021

TECNO DELTA S.r.l.

Jan 2022







TNE TECHNOLOGY NUCLEAR ELECTRONICS SPA

Detector for **iodine** (NaI Scintillator) and detector for **noble gases** (Dual PIPS type)

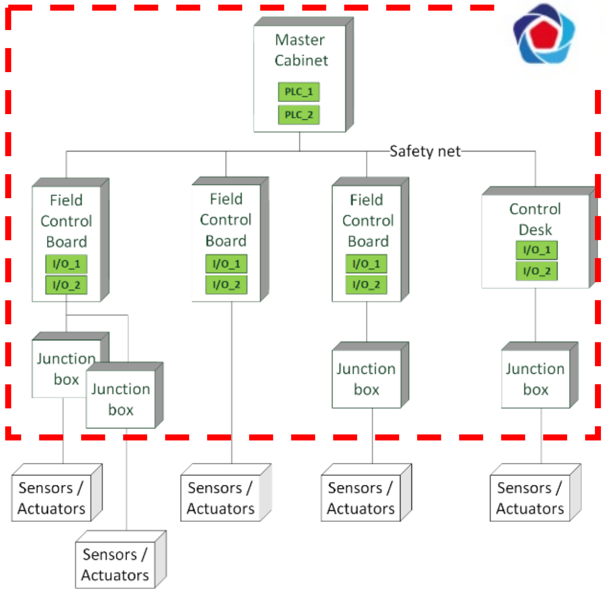
Safety activities: Final tests of the safety system

The SPES safety system was designed by the LNL safety group in collaboration with PILZ according to the safety guidelines and rules for nuclear installations

Safety network installed

PLCs, safety I/O modules, local nodes, racks and junction boxes

Mar 2021 – Jan 2022



Penta System
TECNOLOGIE IMPIANTISTICHE
Engineering

SPES building
+
III sala

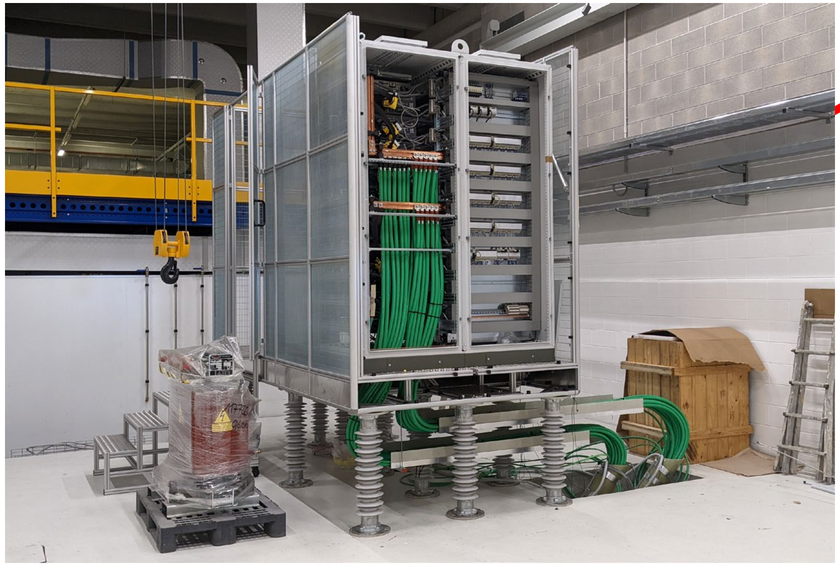
Final tests will be accomplished after the installation of all the safety instrumentation including access control hardware

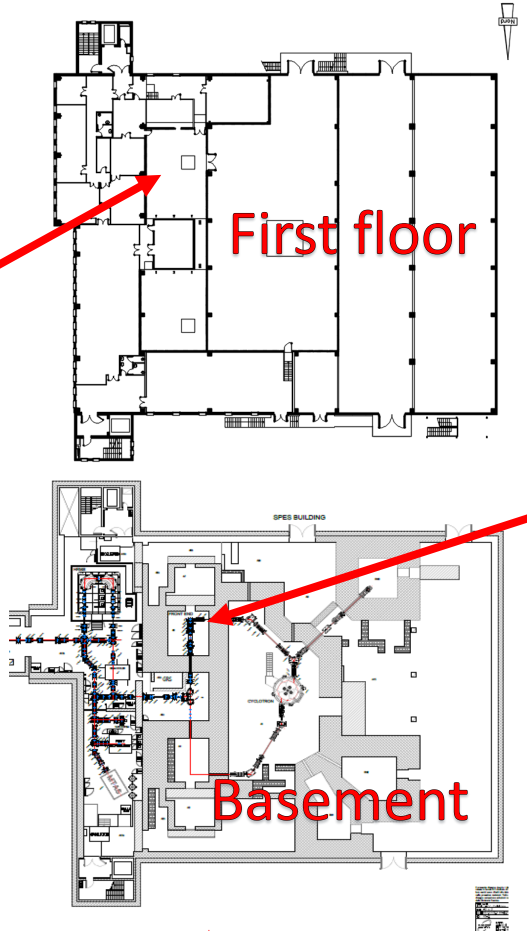
Expected date: Nov 2022

ISOL installation: TIS complex installed in the ISOL bunker

ISOL installation ongoing activities: TIS HV platform

Feb-Jun 2022

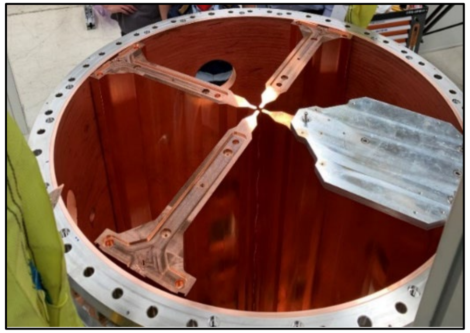


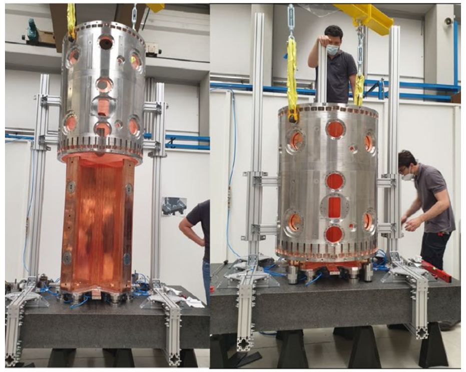


Installation of electrical, hydraulic, pneumatic plants: **Jun-Nov 2022**

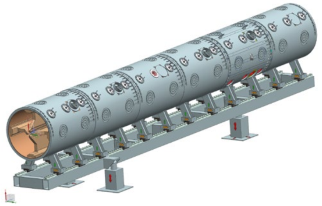
Tests of the Target Ion Source complex with stable beams: **Dec 2022**

Re-acceleration activities: RFQ, ADIGE, HRMS

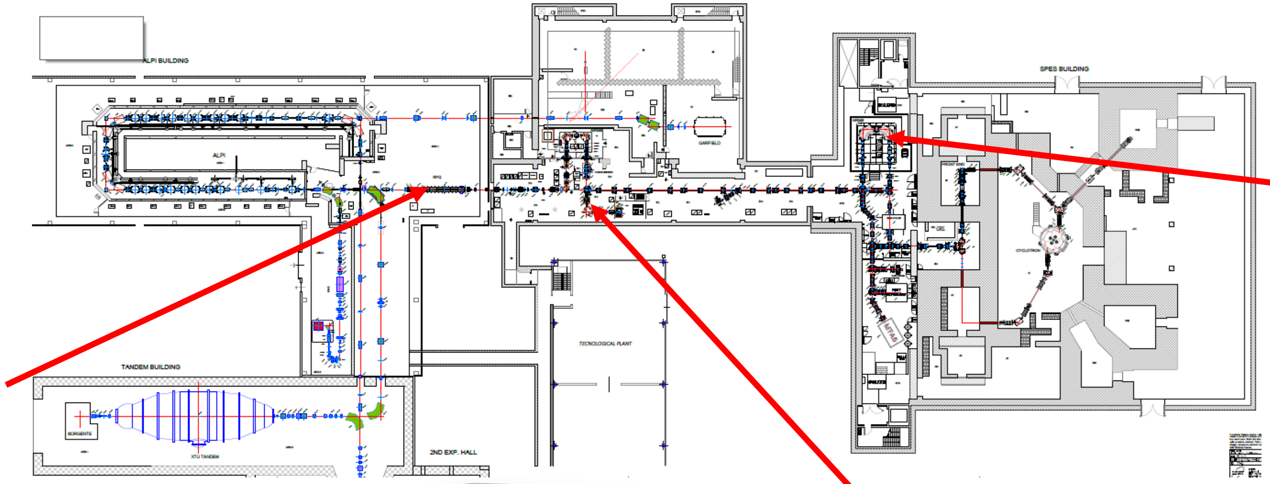


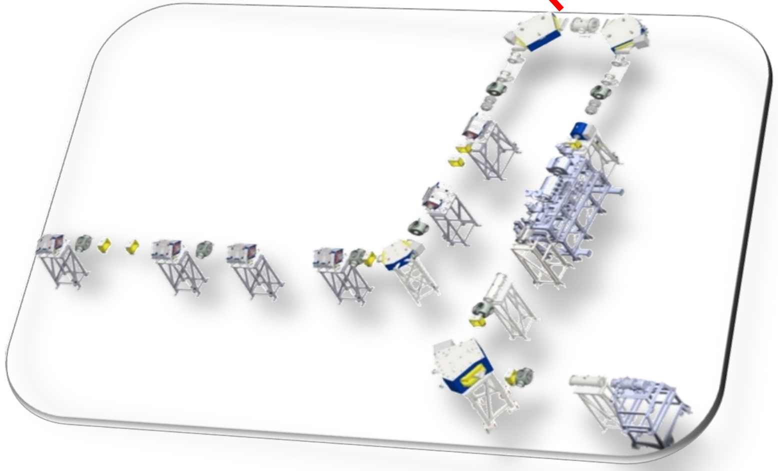


Electrodes and tank assembly



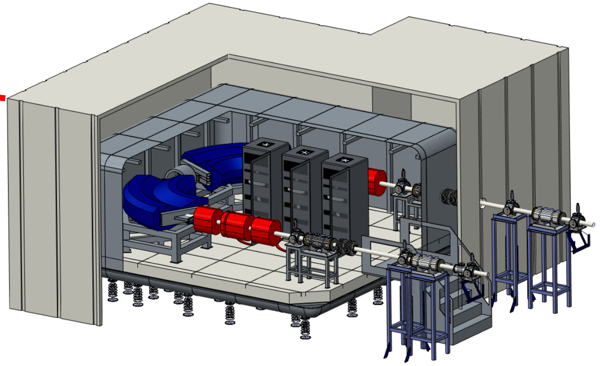
- First module assembled in 2021
- 5 modules to be assembled in 2022
- RF tests and tuning mid 2023
- Expected to be operative end 2023



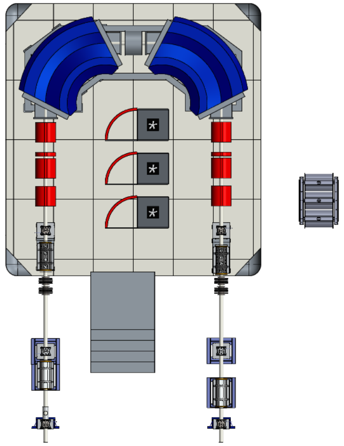


- Source characterization operations
- Beam pipe installations
- Beam line operations
- Charge breeder tests

Expected to be operative 2024



- Tender started: Dec 2021
- Tender completed: Jan 2023
- Delivery: mid of 2024
- Installation: mid 2025

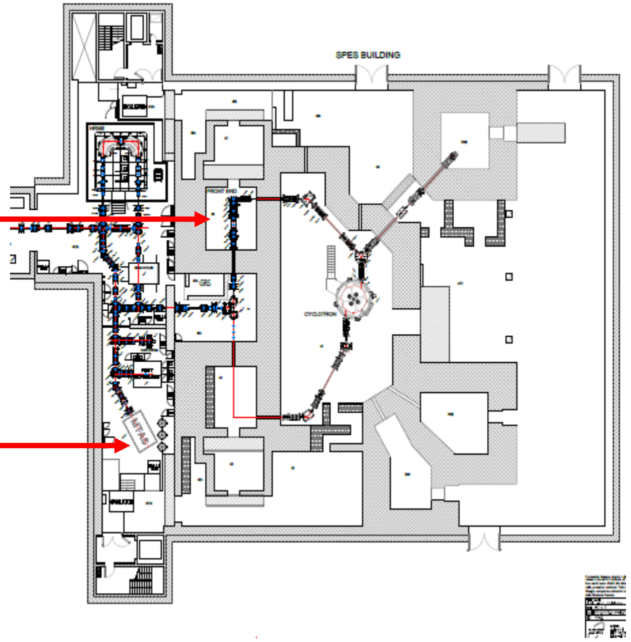


Time expectation short term objectives

Authorization to operate SPES phase alfa: end 2022

Cyclotron beam on TIS@ISOL bunker: 2023
Production of L.E. (40 keV) radioactive ion beams: 2023

Equipment of A13 exp. hall: end 2023
Experiments with L.E. radioactive ion beams: end 2023

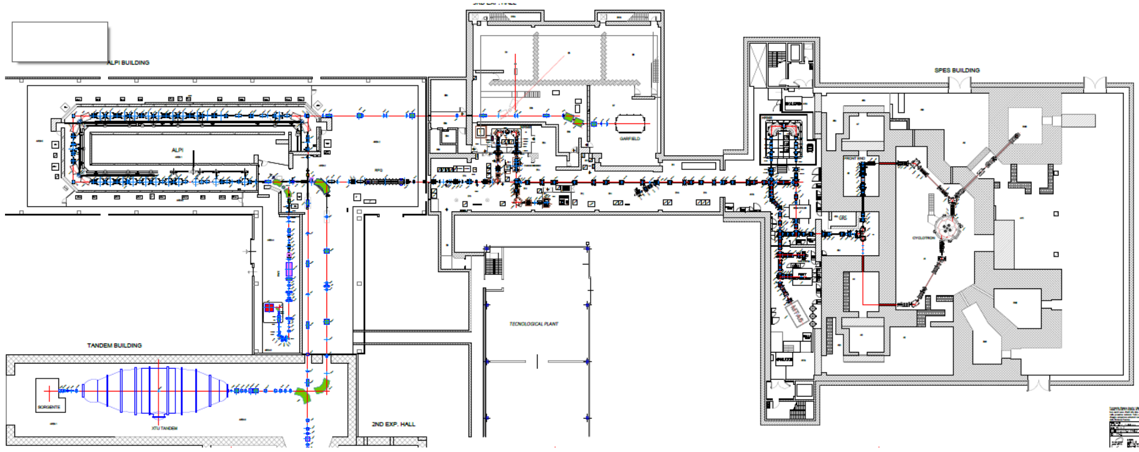


Time expectation post-acceleration

Authorization to operate SPES phase beta: end 2023
ADIGE and RFQ operative: 2024

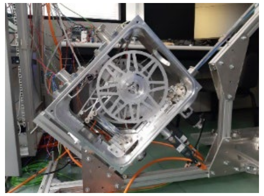
Post acceleration operation no HRMS: 2024

Installation of HRMS: 2025
Post acceleration operation with HRMS: end 2025

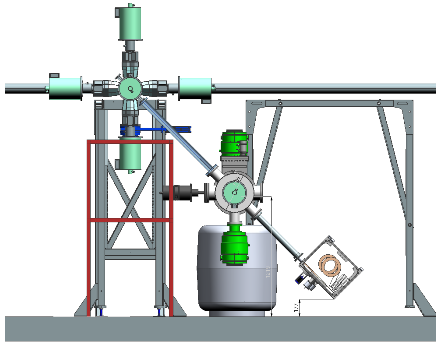


SPES beams to the Low Energy experimental area - 2023

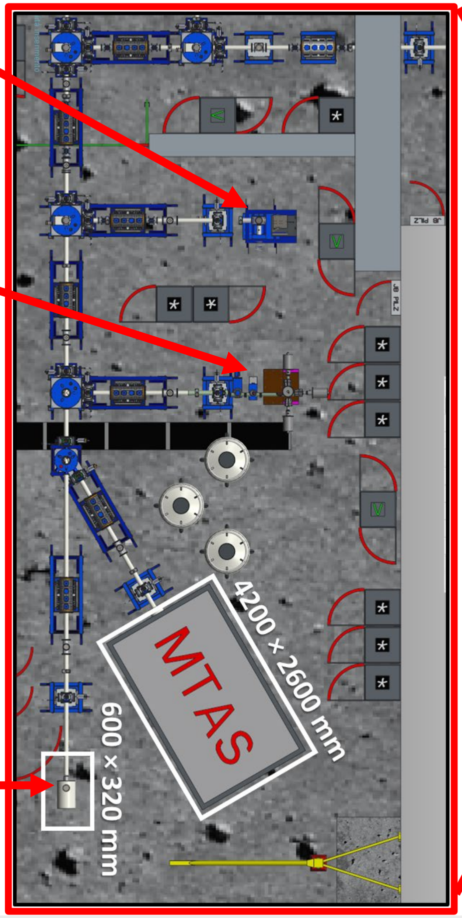
Beam diagnostics - Tape station



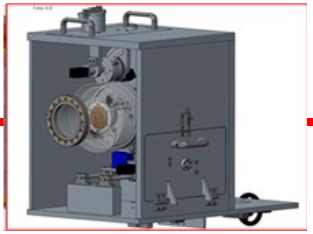
Beta decay station - SLICES

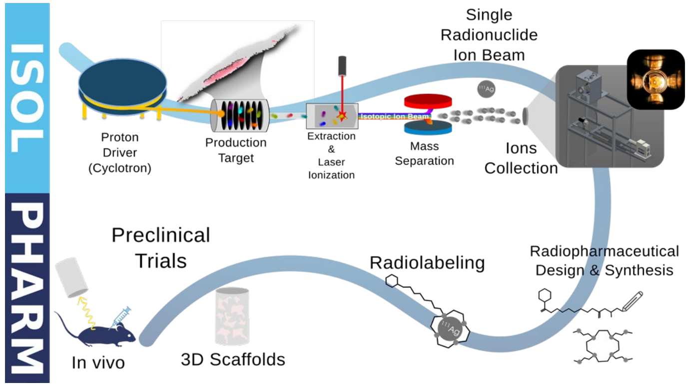


β-DS: decay spectroscopy following β decay (mylar tape + beta detectors + HPGe)
SLICES: conversion electrons and E0 transitions following β decay (mylar tape + Si(Li) + HPGe)



ISOLPHARM





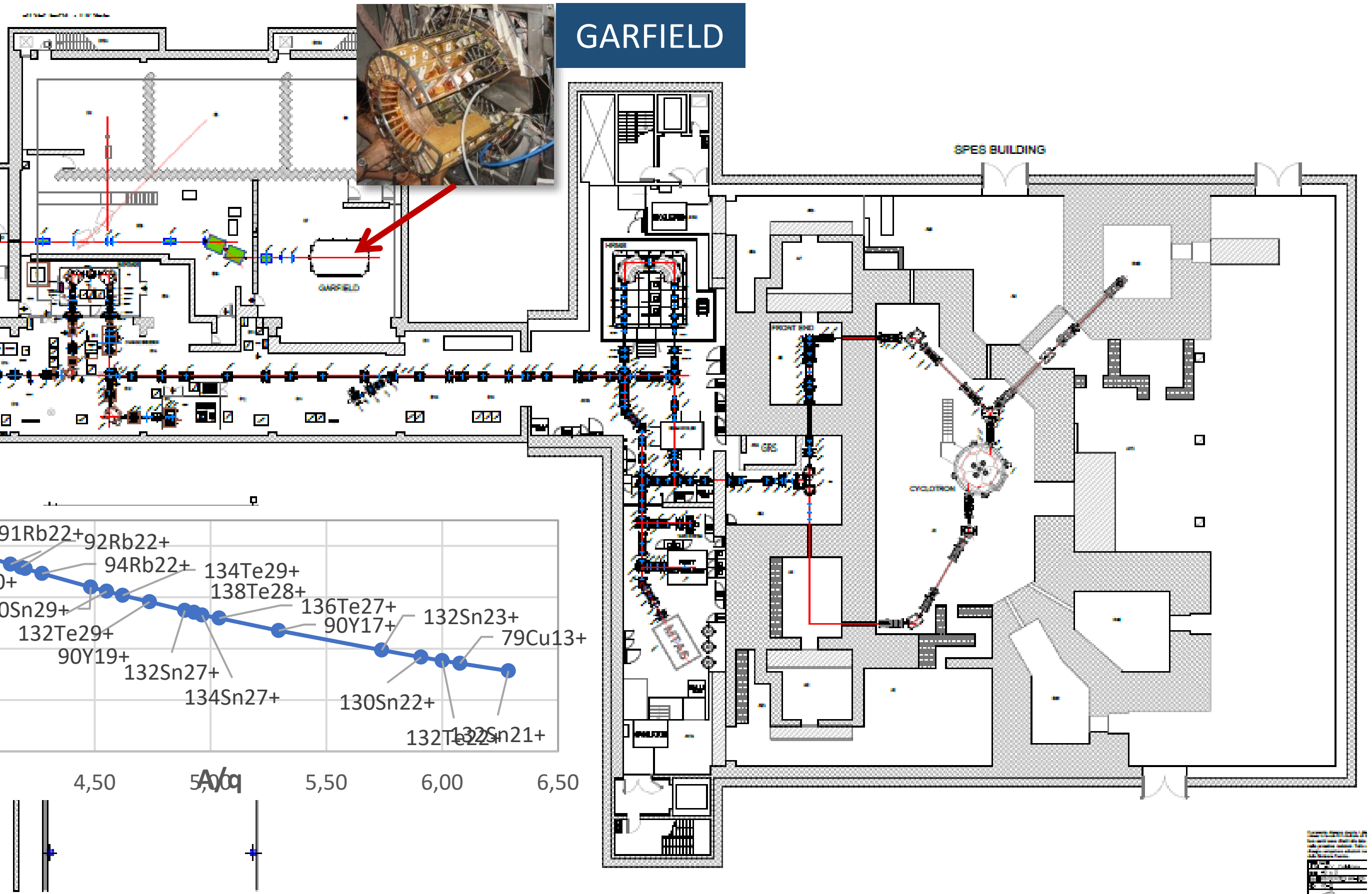
- ^{111}Ag can be produced with **high purity**, but also with **high production rate:** up to 2 Ci in target after 5 days (8kW UC_x target)
- All **Ag isotopic contaminants will be removed** using the **on-line mass separation.**
- In the market **No radiopharmaceutical** Silver-based yet!

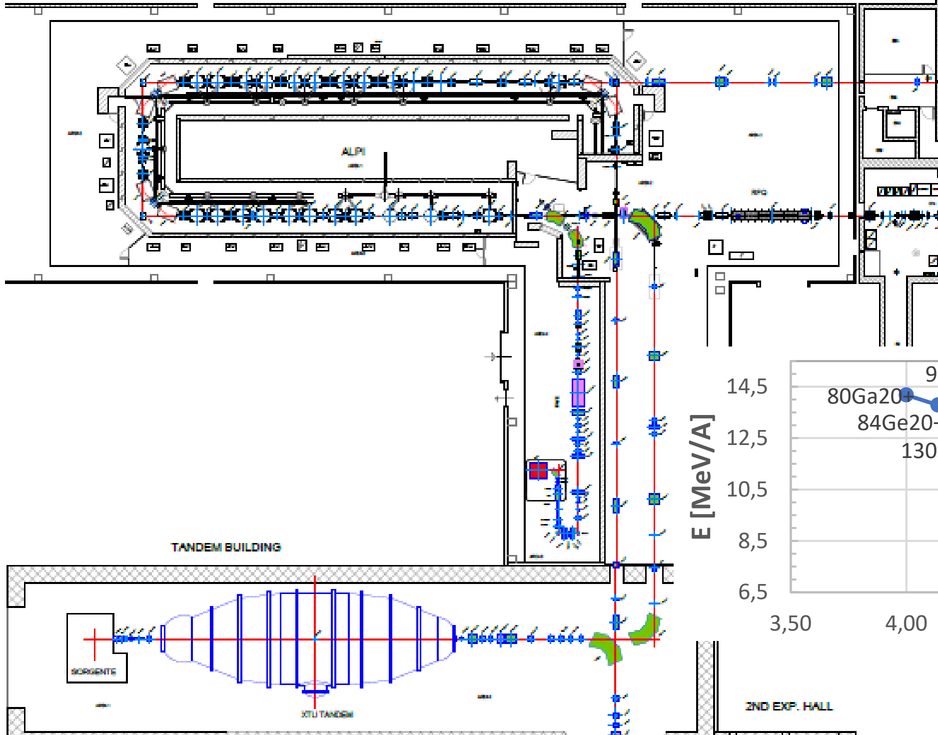
Beam	Purity (%)	Target	Source	Yield (pps)
^{83}Ge	100	UCx	LIS	$2.5\cdot10^{8}$
^{84}Ge	100	"	LIS	$6.6\cdot10^{5}$
^{80}Ga	100	"	LIS	$3\cdot10^{7}$
^{82}Ga	100	"	LIS	$3.3\cdot10^{6}$
^{110}Ag	100	"	LIS	$9.6\cdot10^{7}$

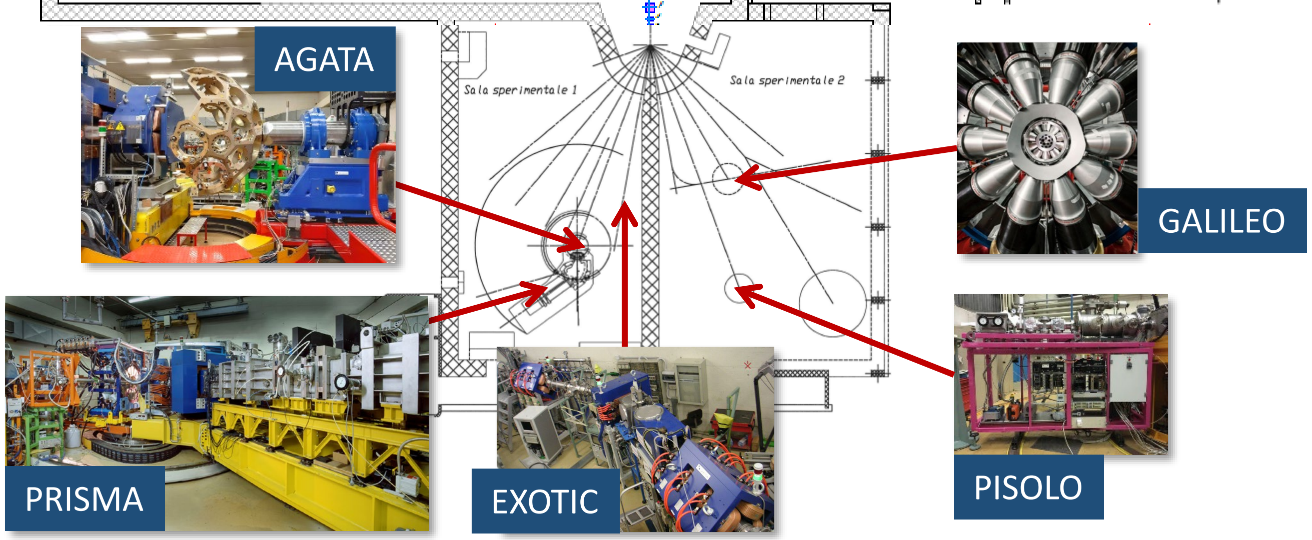
From the LOIs

3° Int. SPES Workshop

SPES beams to the High Energy exp. Area 2024-2025







From the LOIs

3° Int. SPES Workshop

Beam	Purity (%)	Target	Source	Yield (pps)
^{84}Ge	100	UCx	LIS	$1.3\cdot10^4$
^{80}Ga	100	"	LIS	$6.1\cdot10^5$
^{132}Sb	100	"	LIS	$3.8\cdot10^7$
^{132}Sn	100	"	LIS	$3.1\cdot10^7$
^{132}Te	100	"	LIS	$8.4\cdot10^8$
^{130}Sn	83	"	LIS	$1.6\cdot10^8$
^{134}Te	97	"	LIS	$2.3\cdot10^8$
^{94}Rb	75	"	SIS	$2.7\cdot10^8$
^{91}Rb	100	"	SIS	$1.9\cdot10^9$
^{92}Rb	100	"	SIS	10^9
^{138}Cs	76	"	SIS	$2.4\cdot10^9$

Cappella degli Scrovegni
Giotto

Thank you very much