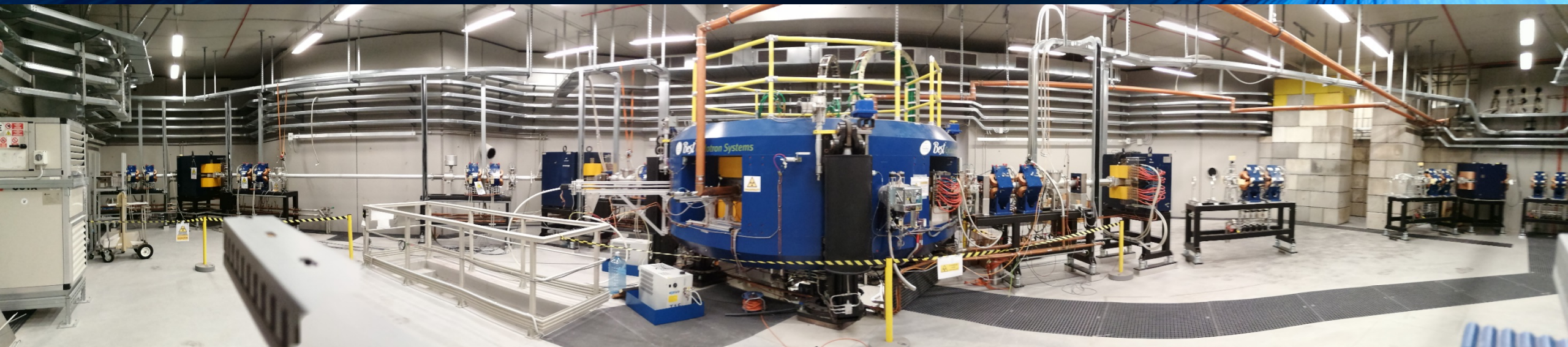
INFN
Istituto Nazionale di Fisica Nucleare

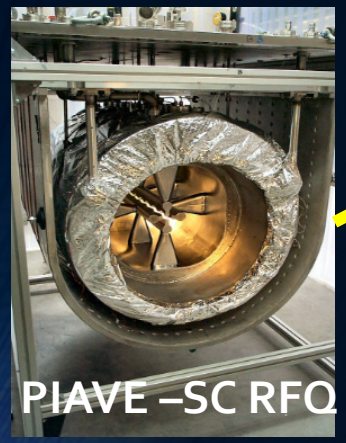
Status of SPES Cyclotron at Laboratori Nazionali of Legnaro -INFN

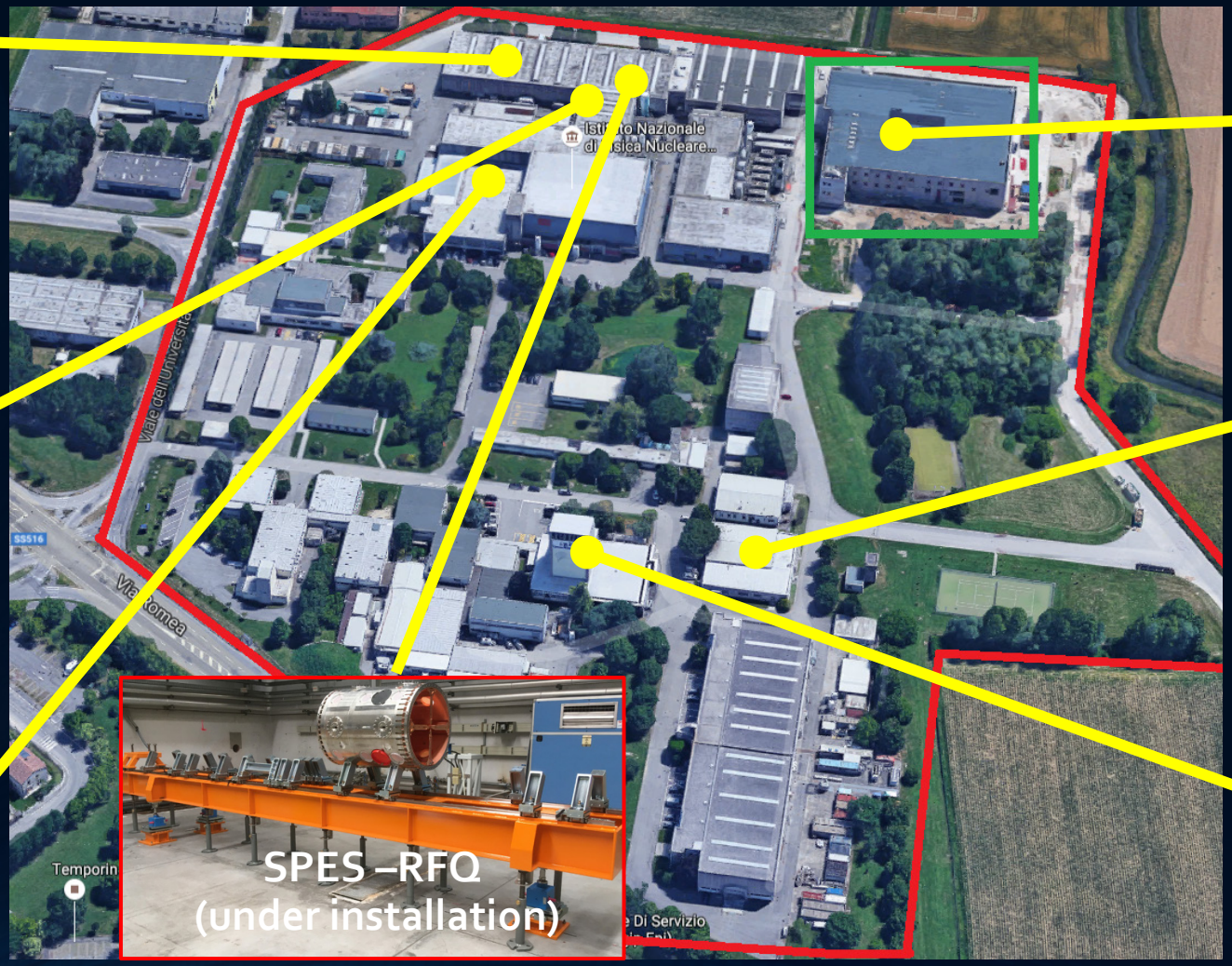
MARIO MAGGIORE ON BEHALF OF LNL CYCLOTRON TEAM

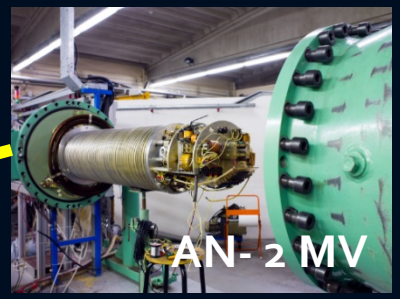


Laboratori Nazionali di Legnaro -INFN

Accelerators at Legnaro Labs



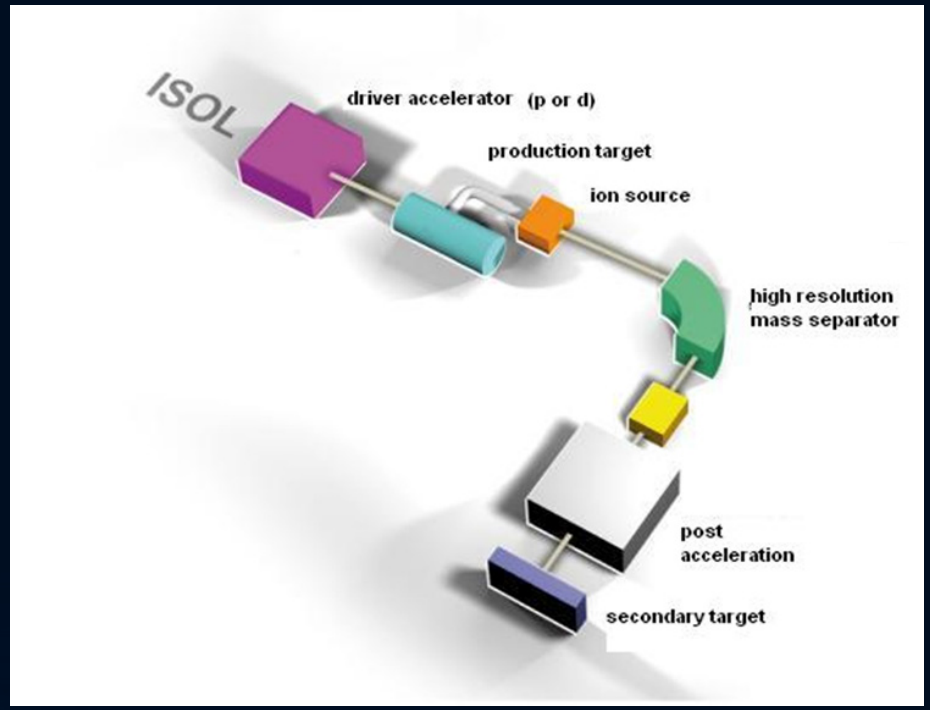




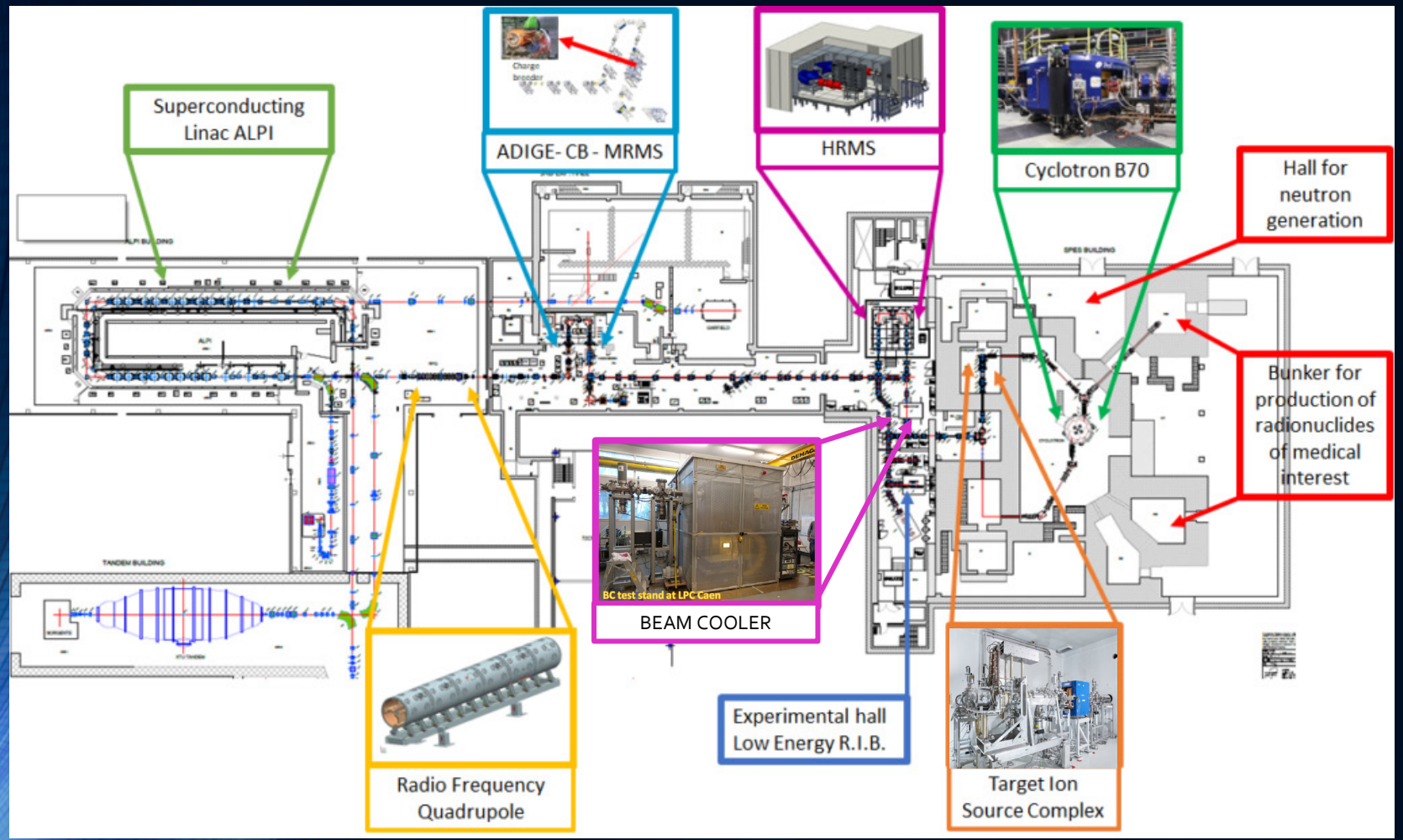
SPES: Selective Production of Exotic Species

- Flagship of INFN on Nuclear Physics and Astrophysics Research
- ~ 58 Meuro budget fully funded (Alpha and Beta phases)
- It consists of 4 phases:
  - **Alpha**: Cyclotron (proton beam driver) and High Intensity Beam Delivering
  - **Beta**: RIBs production and Physics at Low and High Energy (Re-acceleration)
  - **Gamma**: R&D on Radioisotope for Medical Application (LARAMED project)
  - **Delta**: Neutron sources generation and Applications
- Construction phase started in 2010 with Cyclotron and in 2012 with the dedicated building
- Completion of SPES Project (Alpha and Beta-low energy) is expected in 2025

Second generation ISOL facility for nuclear physics: Production & re-acceleration of exotic beams. Neutron–rich ions from p-induced Fission on **UCx (10^{13} f/s), 10 MeV/amu**



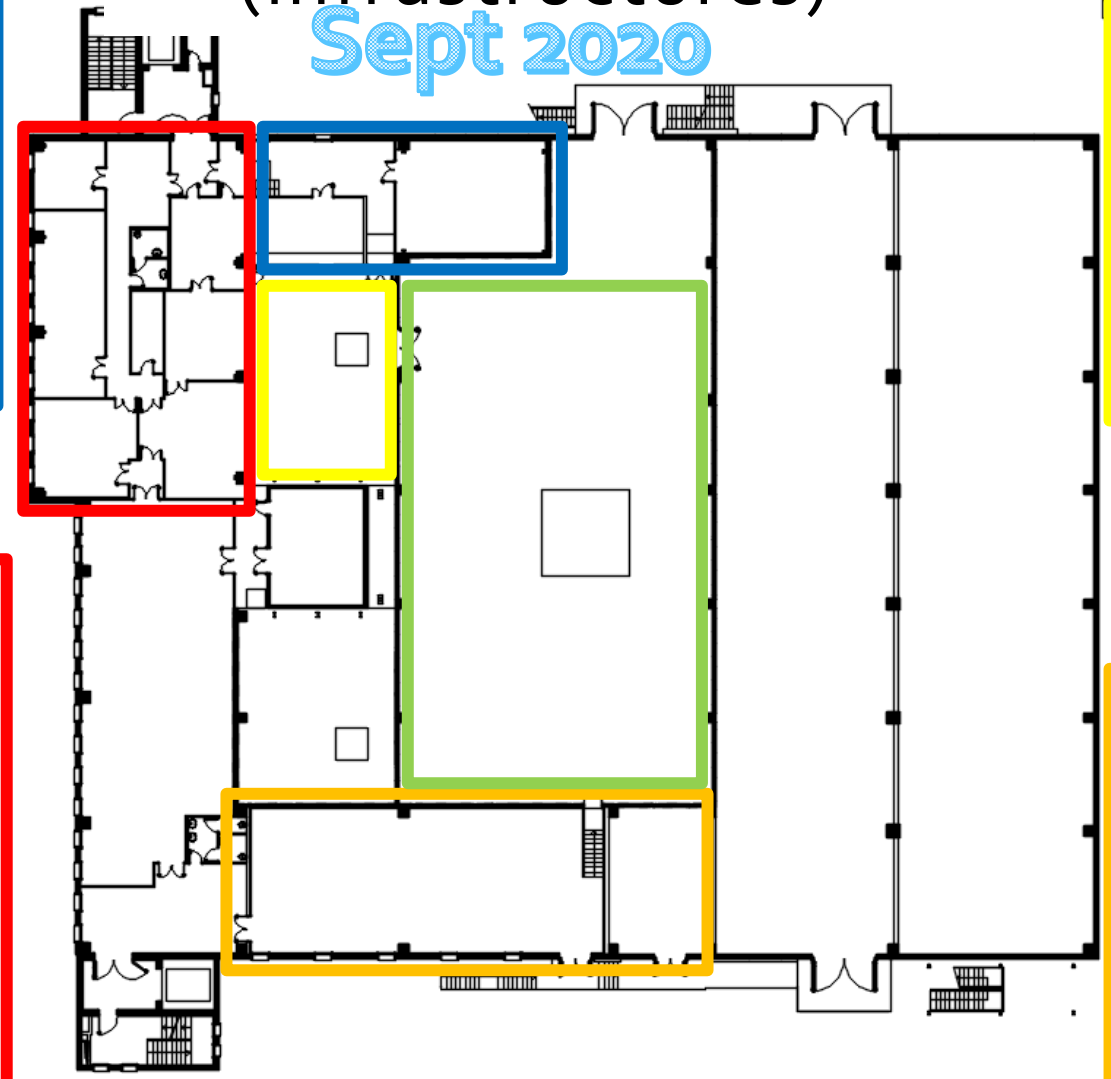
SPES project status (accelerator systems)



- Cyclotron and beamline to ISOL target is commissioned and actually the plants are being upgraded
- ISOL target installed and ancillary plants are being installed
- 1+ transport line, first section (ISOL-BC-LE area) under installation
- Beam Cooler under beam testing at LPC (Caen, France)
- HRMS: tender for magnets supply has been awarded, construction and installation within 3 years.
- ADIGE (Charge breeder and MRMS) is under completion. Ion source for stable beams is commissioned.
- RFQ (new injector of ALPI) under installation

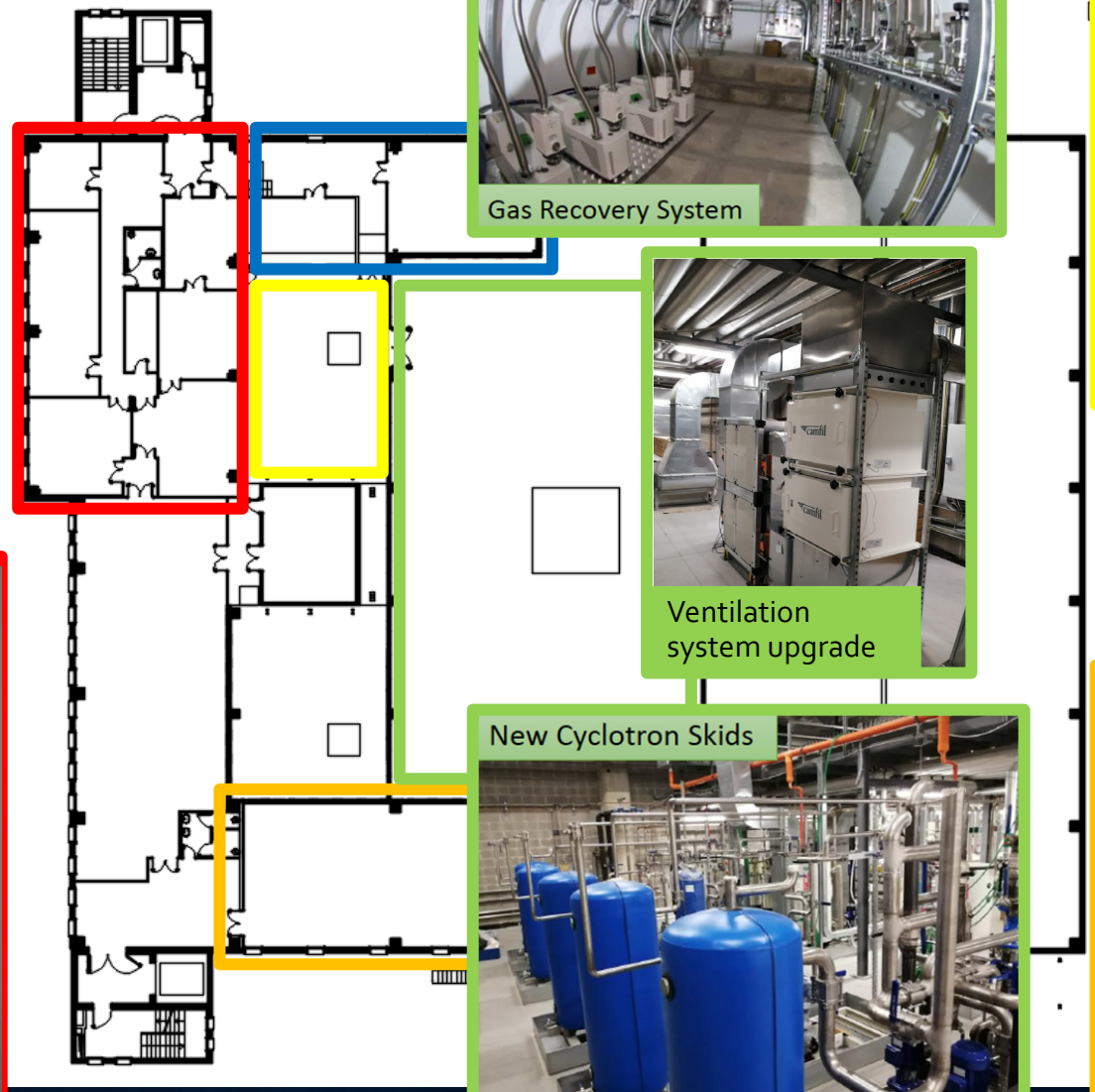
SPES project status (infrastructures)

Sept 2020



UCx laboratories

Nov 2022



Gas Recovery System

ISOL HV platform

Ventilation system upgrade

New Cyclotron Skids

ISOL target laboratories

Power supply room

Works Progress in SPES building in 2022

- More than 20 companies have been engaged in 2022 to carry on any kind of works:
  - Structures (civil works and surfaces finishing)
  - Mechanics and thermomechanics plants
  - Electrics works, cabling
  - Accelerators systems and ancillary equipment (HV platform, beamlines,…)

	Descrizione lavori	Ditte	Resp.	Jan-22				Feb-22				Mar-22					Apr-22				Mag-22				Jun-22					Jul-22				Aug-22					Sep-22				OTT-22					Nov-22				Dec-22			
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
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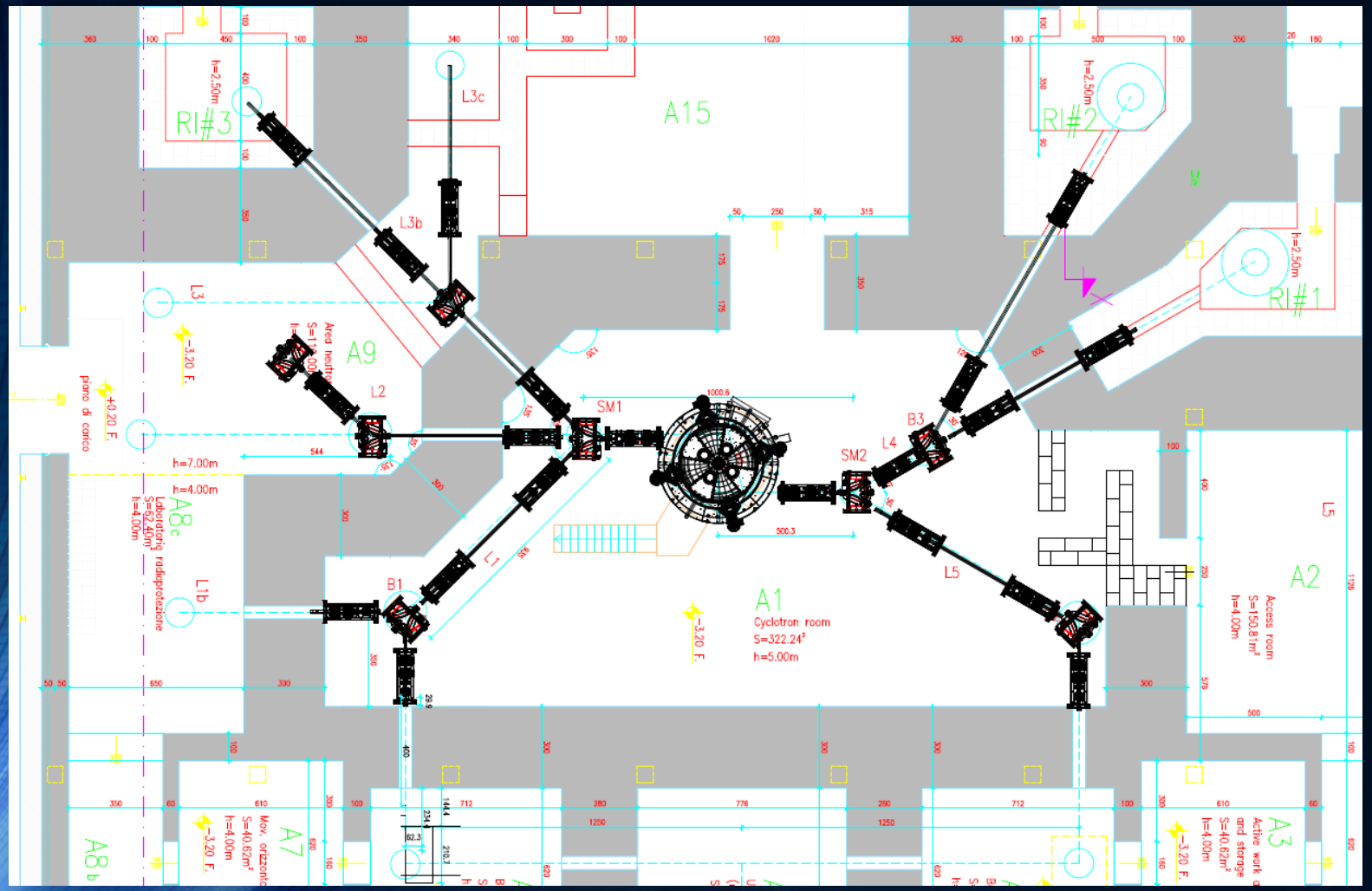
2	Lavori finitura area A16B	MIGLIORATI	Maniero																																																		
3	Campo prova per infiltrazioni	varie Ditte	Modanese																																																	
4	Lavori finitura aree A5 e A8 (prima fase)	ROTARI	Evangelisti																																																	
5	Completamento laboratori chimica fredda LARAMED	PHAMM	Evangelisti																																																	
6	Lavori ripristino circuito primario raffr. skid ciclo.	BOSCARO	Calore																																																	
7	Lavori uffici e lab. Ciclotrone II piano	AEFFE	Maniero																																																	
8	Installazione piattaforma AT	TECOELETTRA	Manzolaro																																																
9	Test PILZ su sistema sicurezza	PILZ	DeRuvo																																																
10	Montaggio compound accesso lato SUD	LUPO	Evangelisti																																																
11	Upgrade controllo porte TEMA	TEMA	DeRuvo																																																
12	Lavori impiantistica 'ground' ISOL target	IMISCA	Manzolaro																																																
13	Installazione linee fascio ISOL2 e LARAMED	BEST THERATR.	Maggiore																																																
14	Cablaggio strutturato	AXIANS	Gulmini																																																
15	Demolizioni e realizzazione trincee -1 SPES	LA STRADA	Modanese																																																
16	Impianto ventilazione estrazione TSS e GRS	TM Group	Calore																																																
17	Lavori di compartimentazione AI	TECNO mont.	Maniero																																															
18	Lavori elettrici preliminari per impermeabilizz.	ELETTRO imp.	Calore																																															
19	Lavori di iniezioni resina muri bunker edificio SPES	STEVANATO	Modanese																																															
20	Lavori di sigillatura edificio SPES	SPERANDIO	Modanese																																															
21	Foritura sistema mov. meccanico TSS	VETTORELLO	Monetti																																															
22	Lavori di posa in opera muro A5/13	MELATO	Maggiore																																															
23	Installazione carpenterie e pedane mobili	GATTO	Evangelisti																																															
24	Lavori adeguamento ventilazione e AI	BON	Calore																																															

High Intensity Proton Beam Facility for SPES



- Up to 9 irradiation target points
- 2 ISOL target stations (A6, A4)
- 3 Shielded bunkers (RI #1,#2,#3) for High Intensity irradiation
- 4 medium and low intensity target areas (A8, A9, A15)

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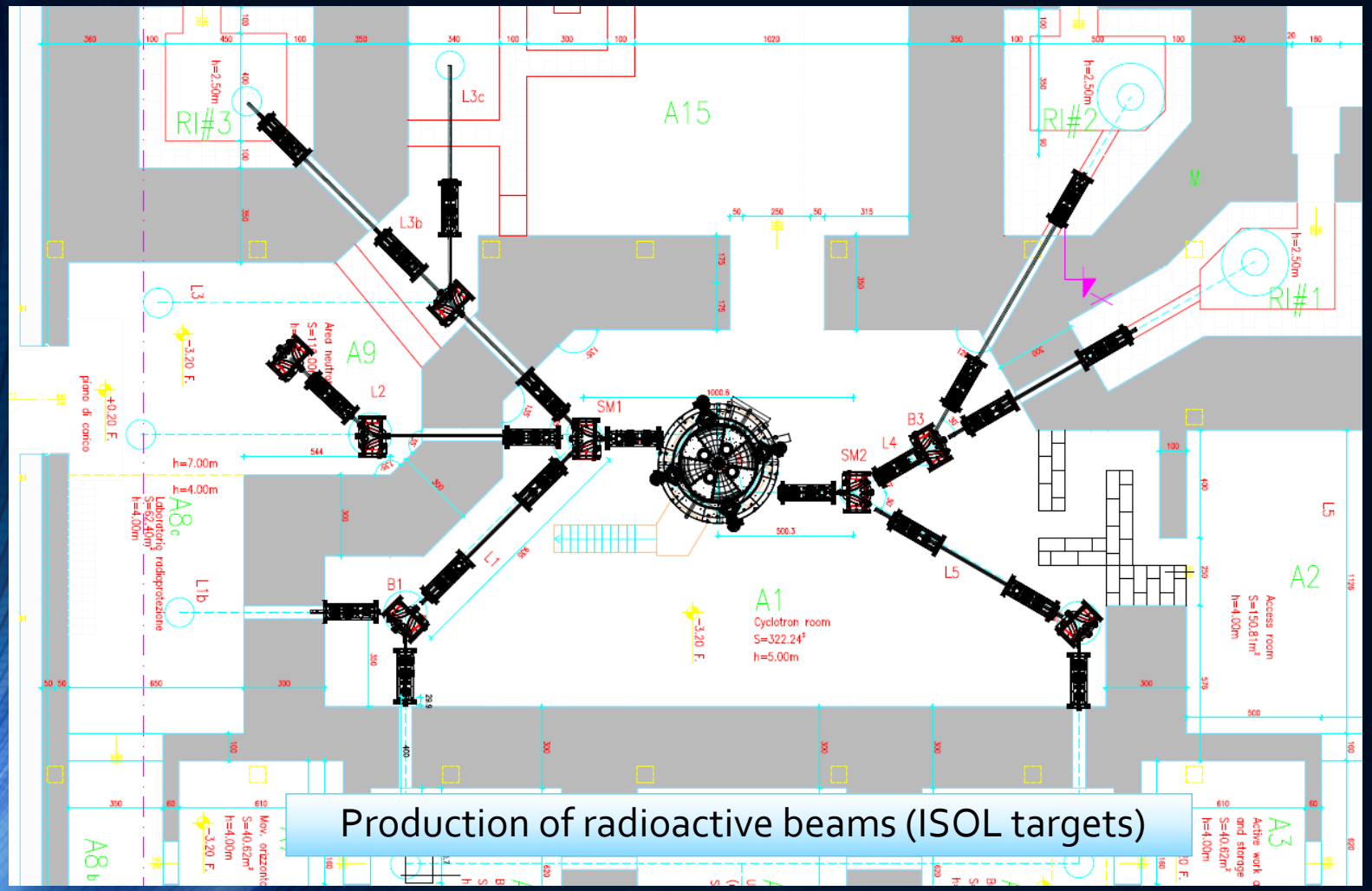

Production of radioactive beams (ISOL targets)

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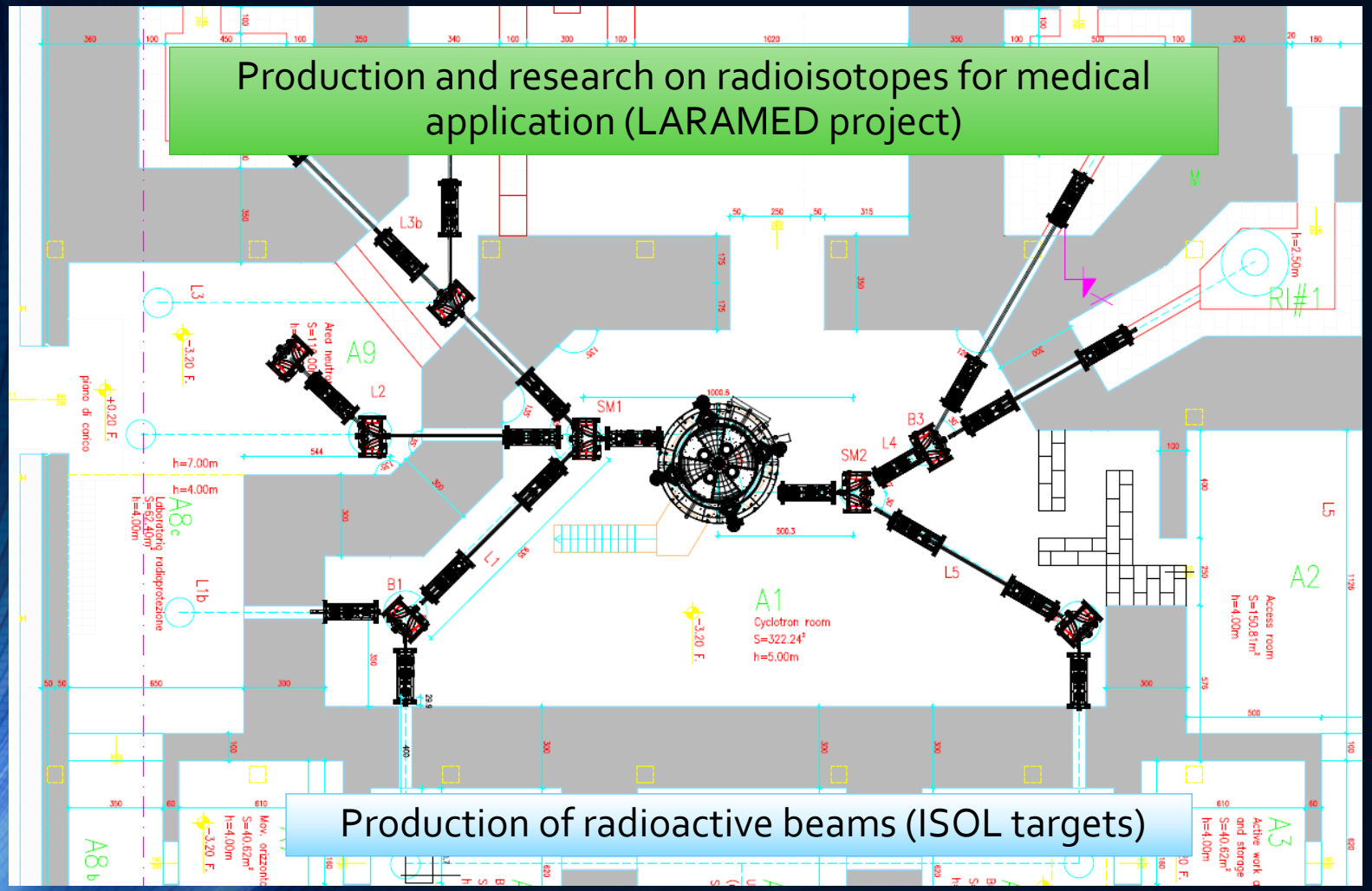

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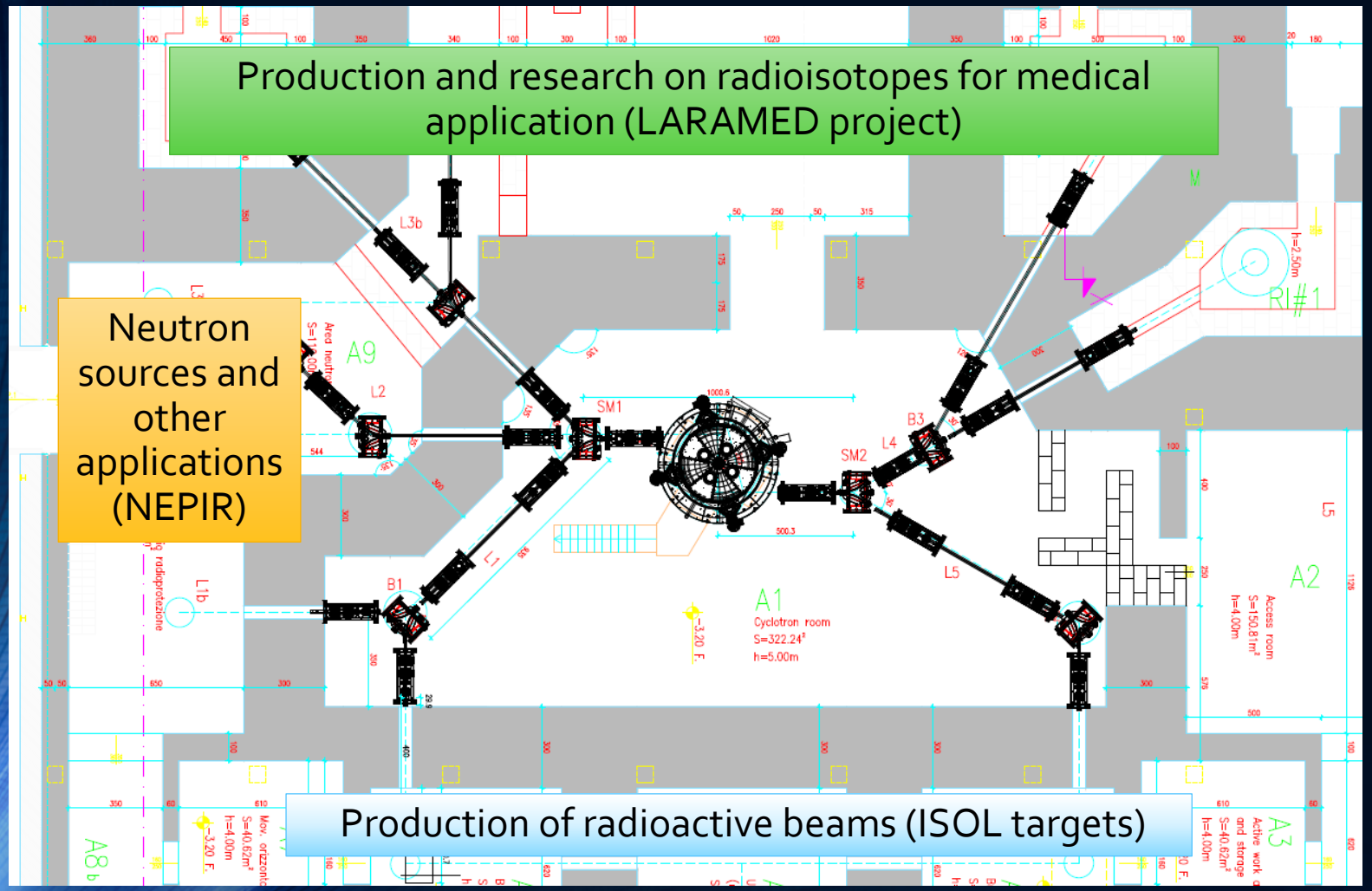

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The 70 MeV Cyclotron

Vacuum system → 4 cryopumps → 5 x 10^{-8} torr (beam OFF)

Main Parameters	
Accelerator type	Cyclotron AVF with 4 sectors, Resistive Magnet
Particle	Protons (H^- accelerated)
Energy range	35-70 MeV
Max Current Intensity	700 µA (variable within the range 1µA-700µA)
Extraction	Dual stripping extraction
Max Magnetic Field	1.6 T (Bo = 1 T)
RF System	nr. 2 delta cavities; harmonic mode=4; f_{RF} =56 MHz; 70 kV peak voltage; 50 kW RF power (2 RF amplifiers)
Ion Source	Multi-cusp volume H^- source; I_{ext} =8mA; V_{ext}=40 kV; axial injection
Dimensions	Φ=4.5 m, h=2 m, W=190 tons

Cyclotron story: it began in 2010 (contract signed with Best Ther.)

2011-2014 Study, Design ,Construction and factory tests

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2015
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2016
First beam and
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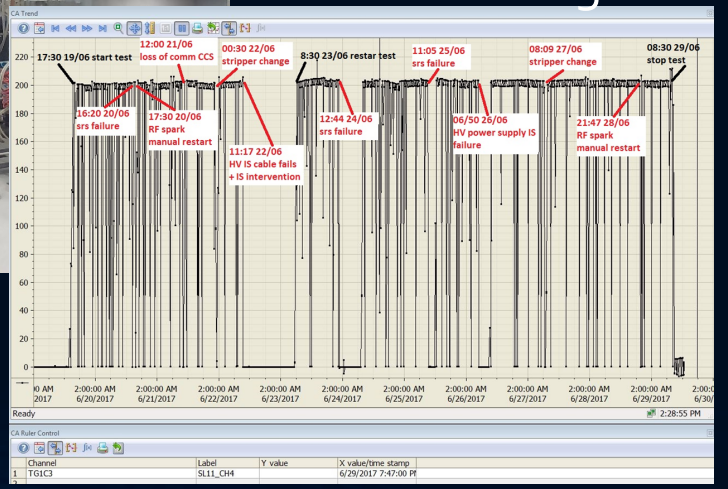
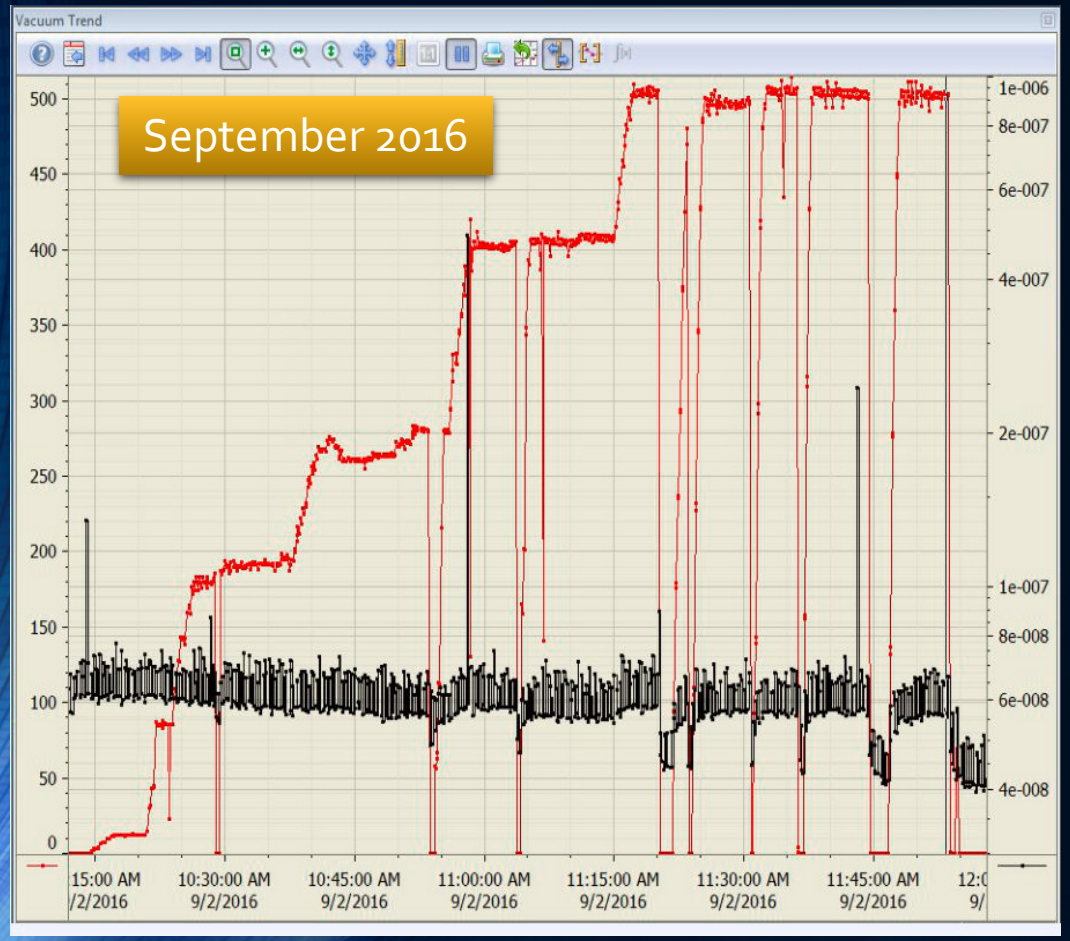
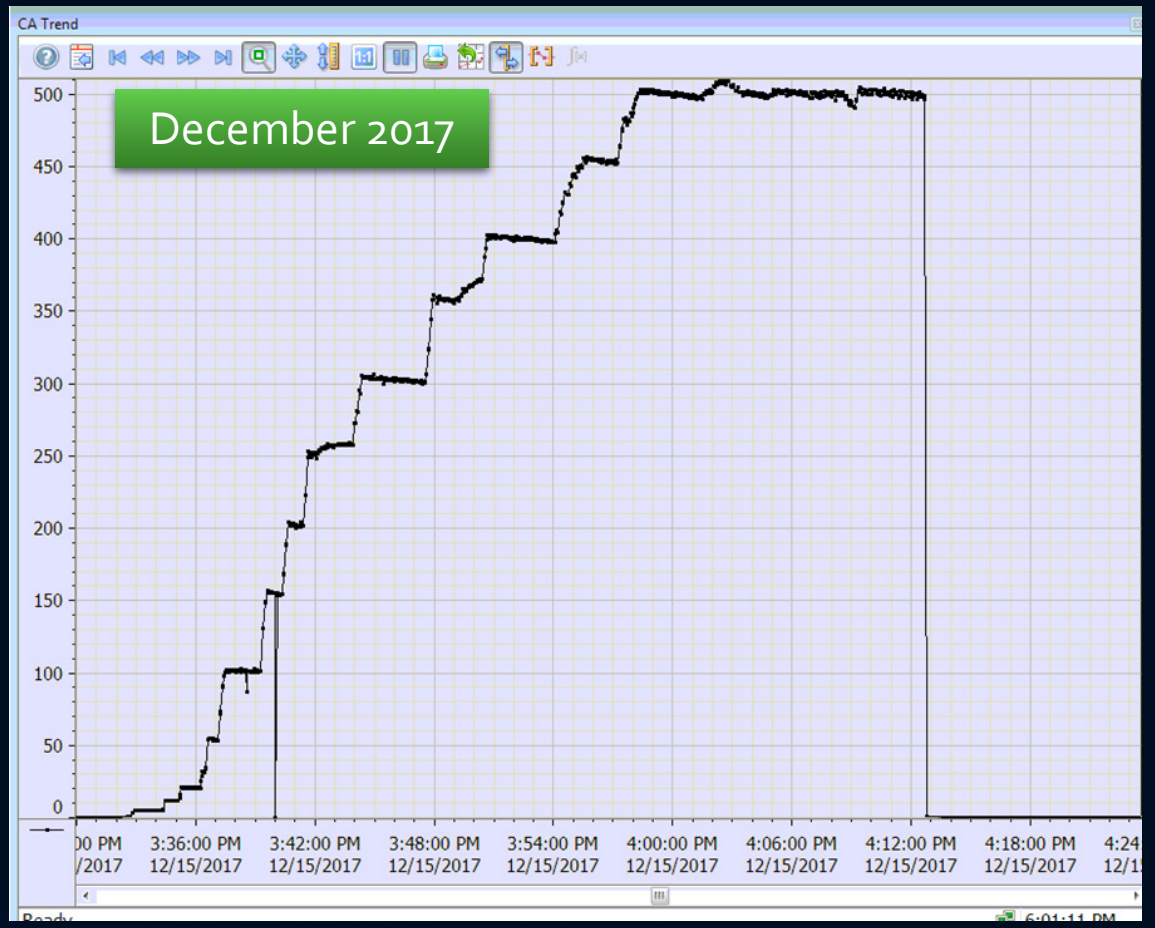


2017
Site Acceptance
Test and final
delivery

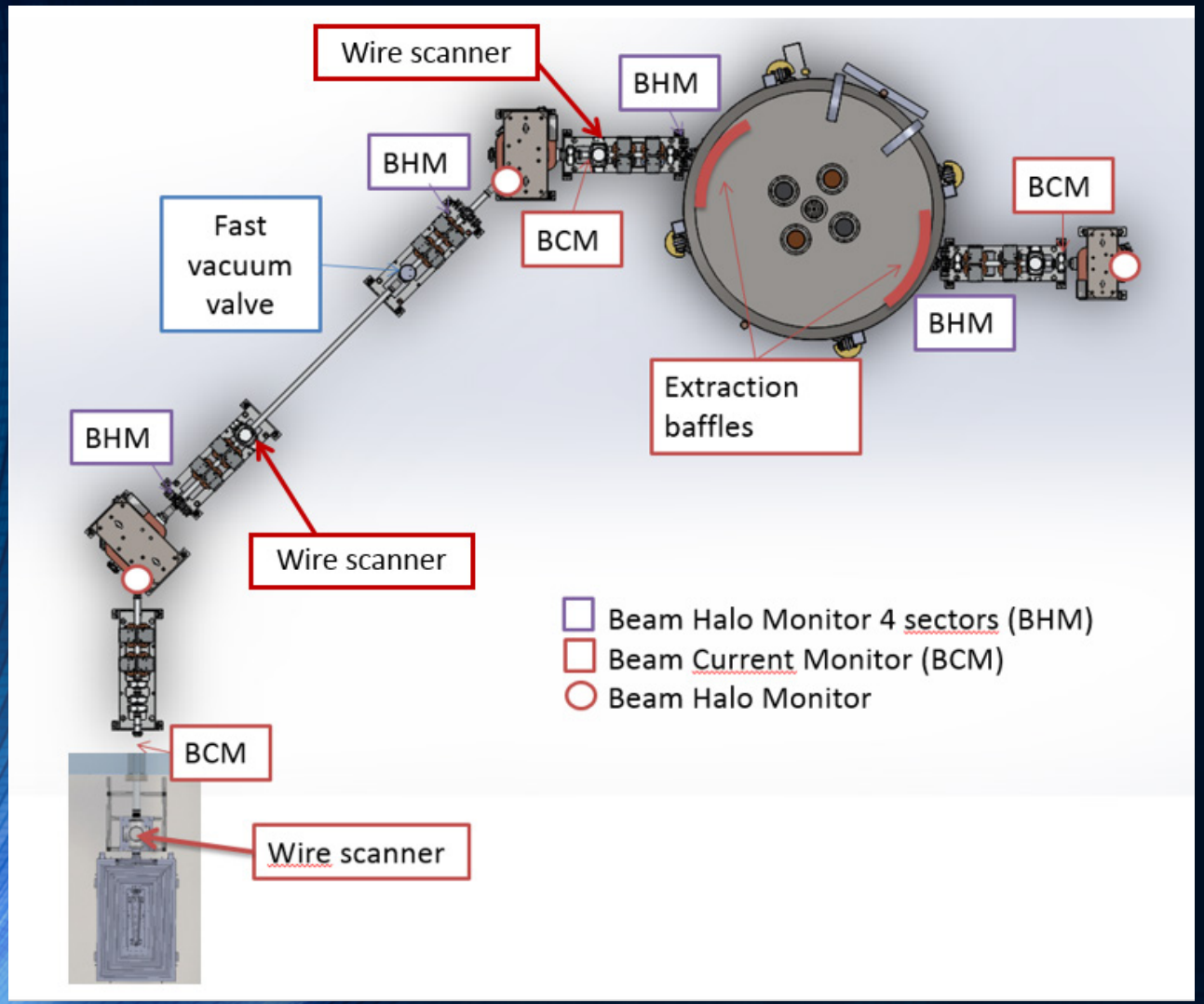
2018
INFN operation

Intensity ramp-up→ beam stability improvements

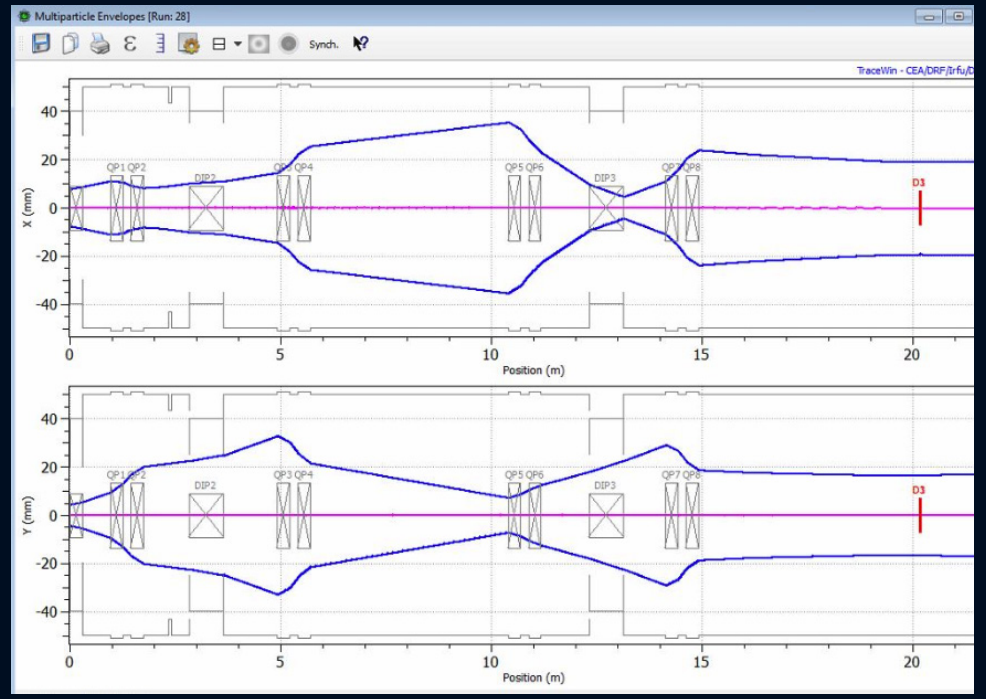




Diagnostics and beam optics check (2018)



TRACEWIN beam optics calculation



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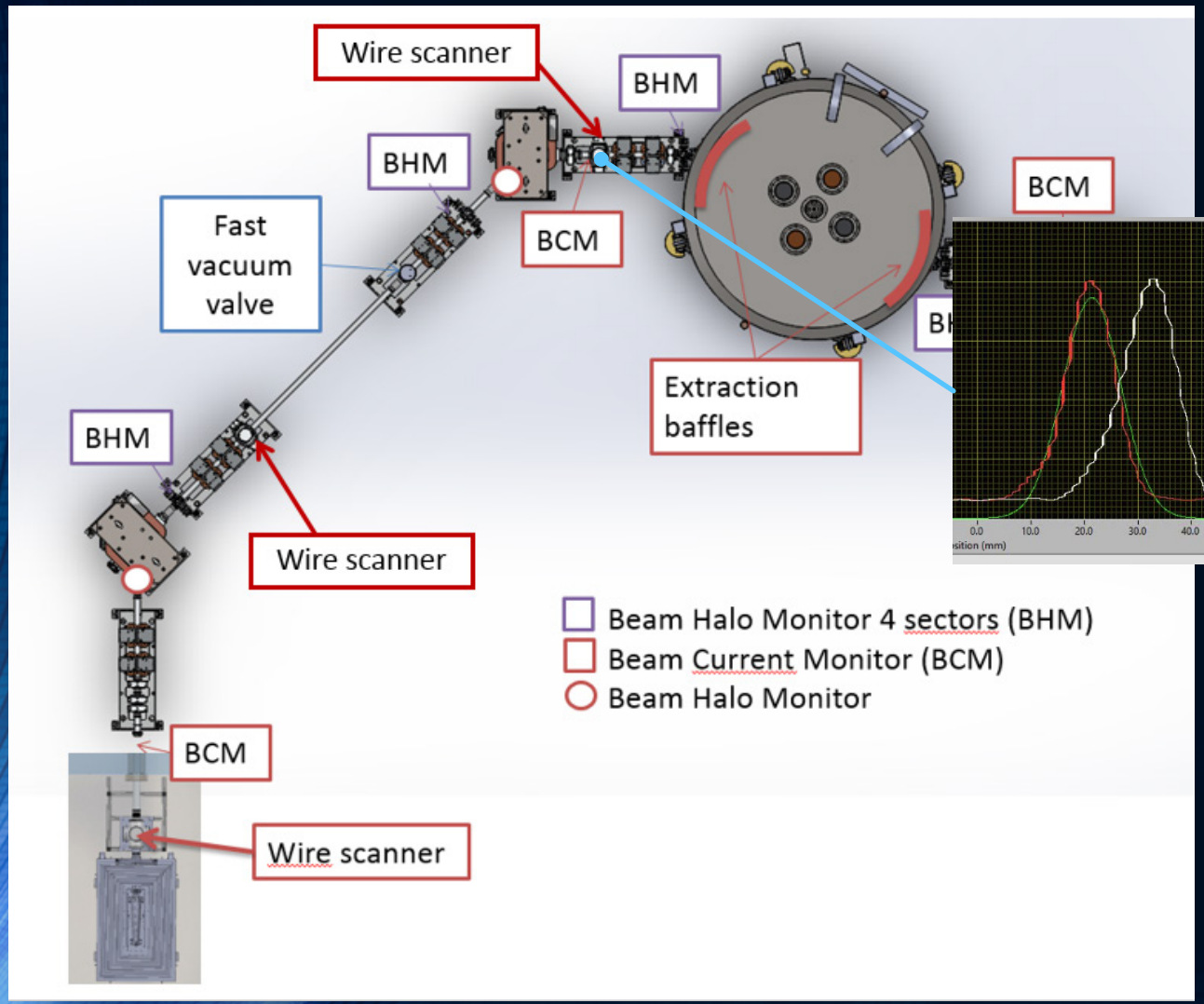

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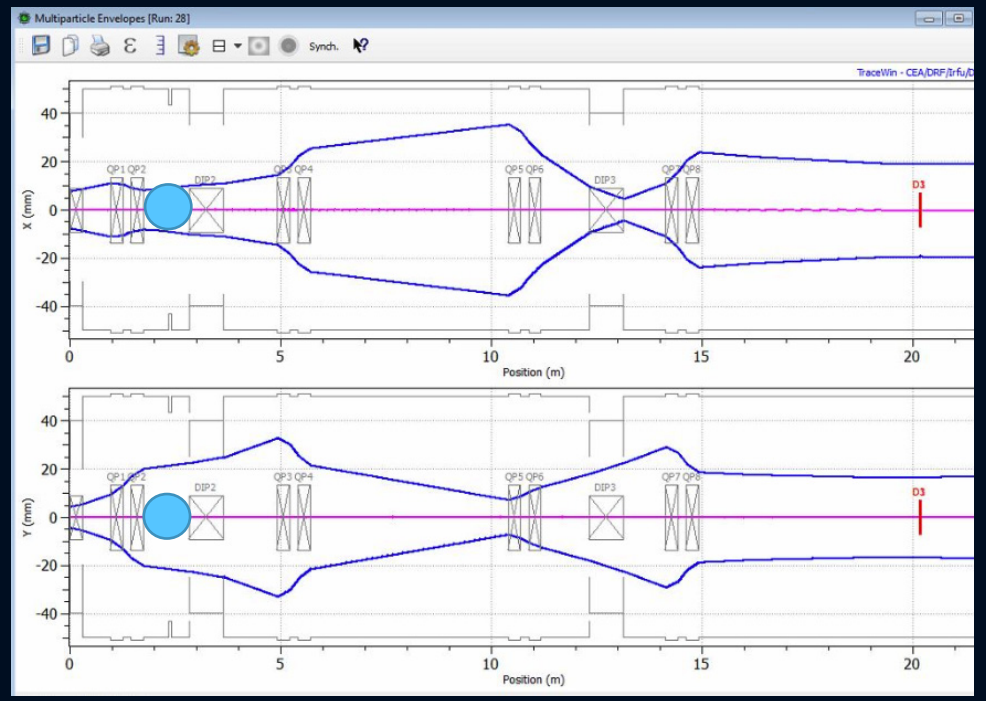

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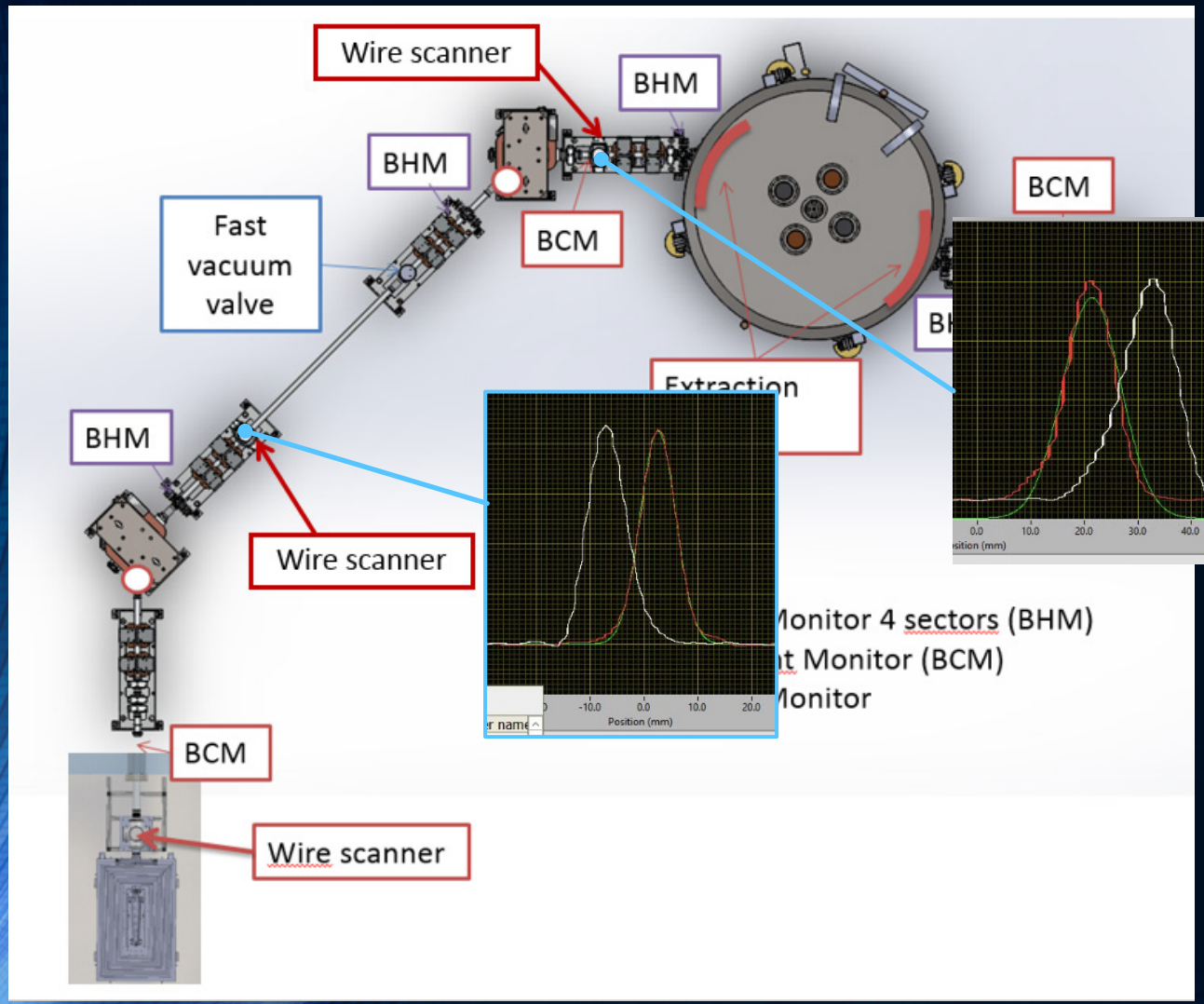

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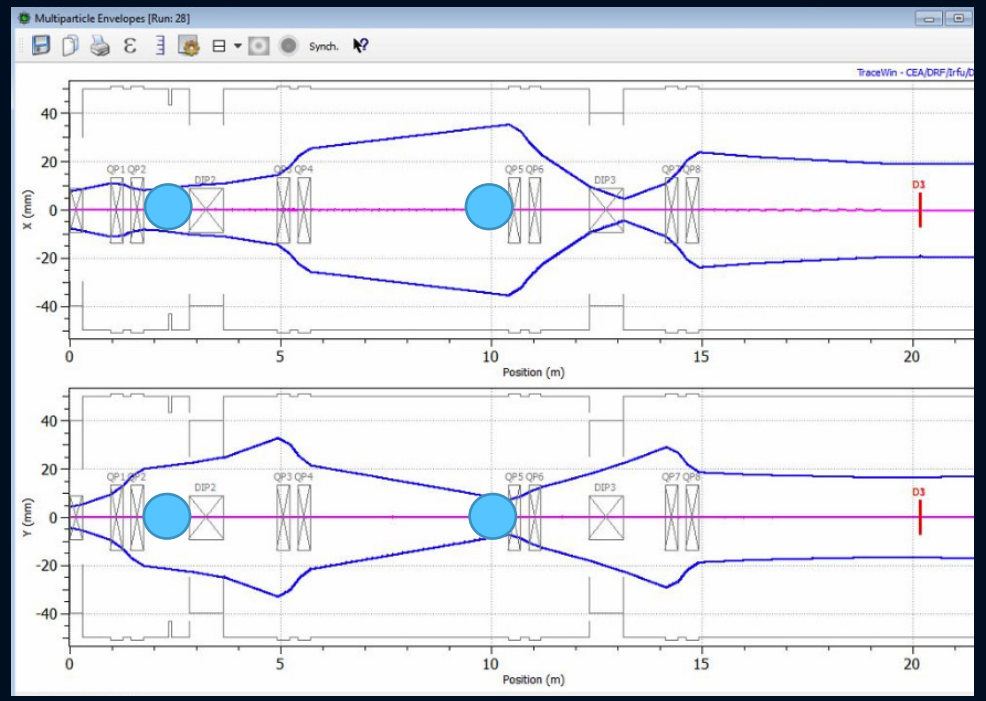

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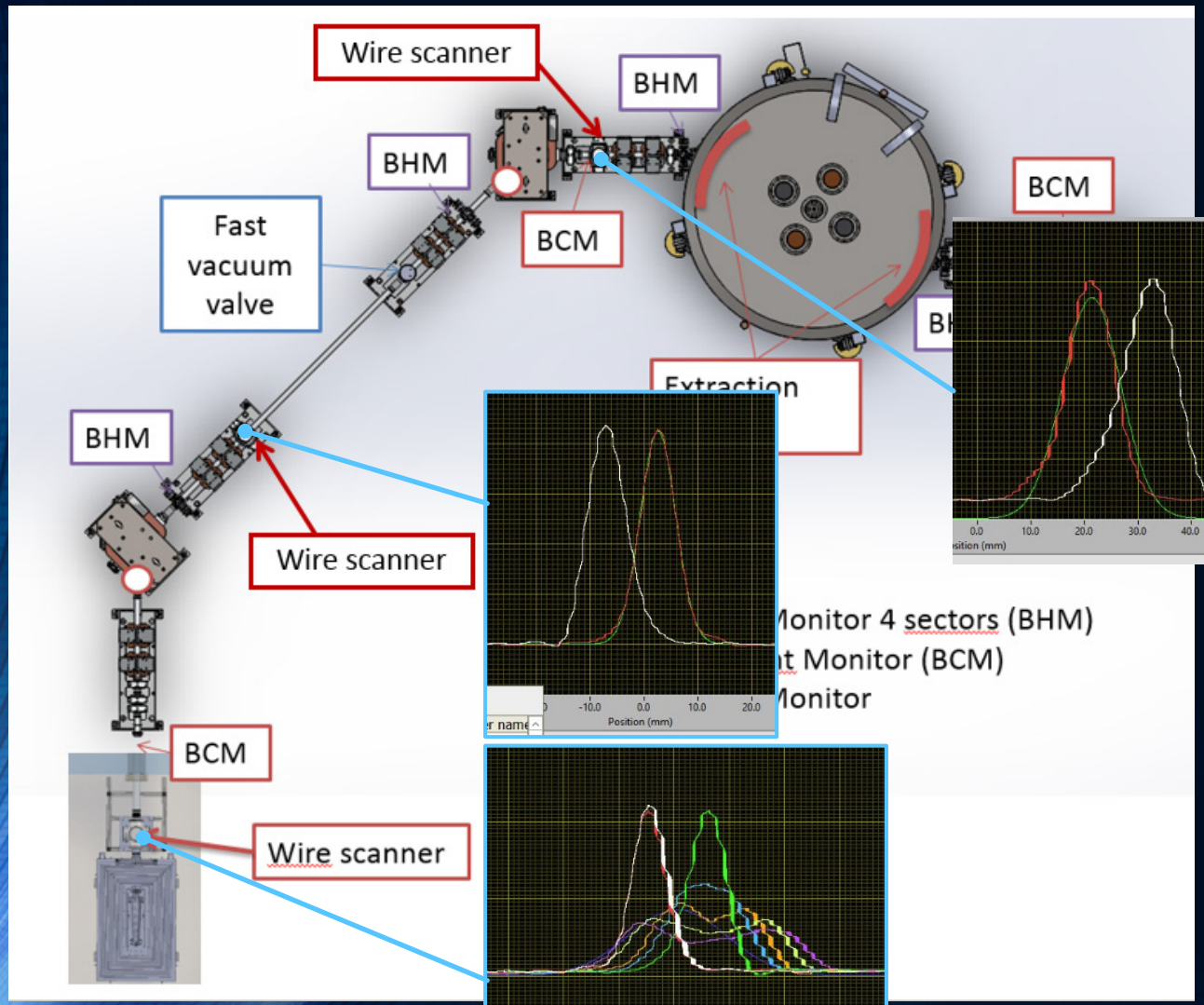

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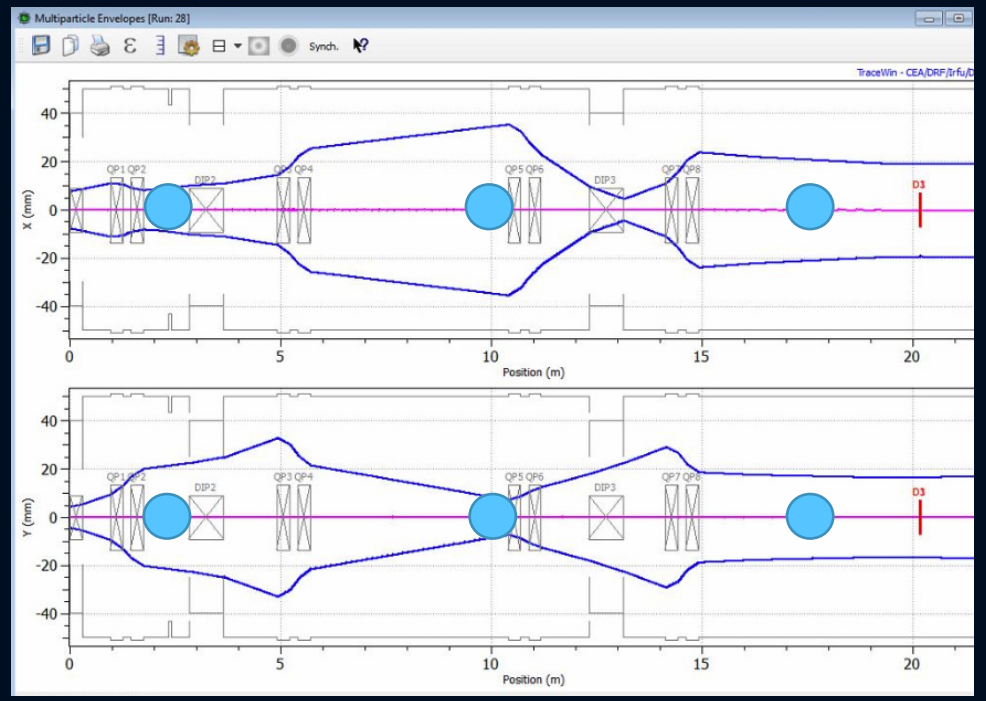

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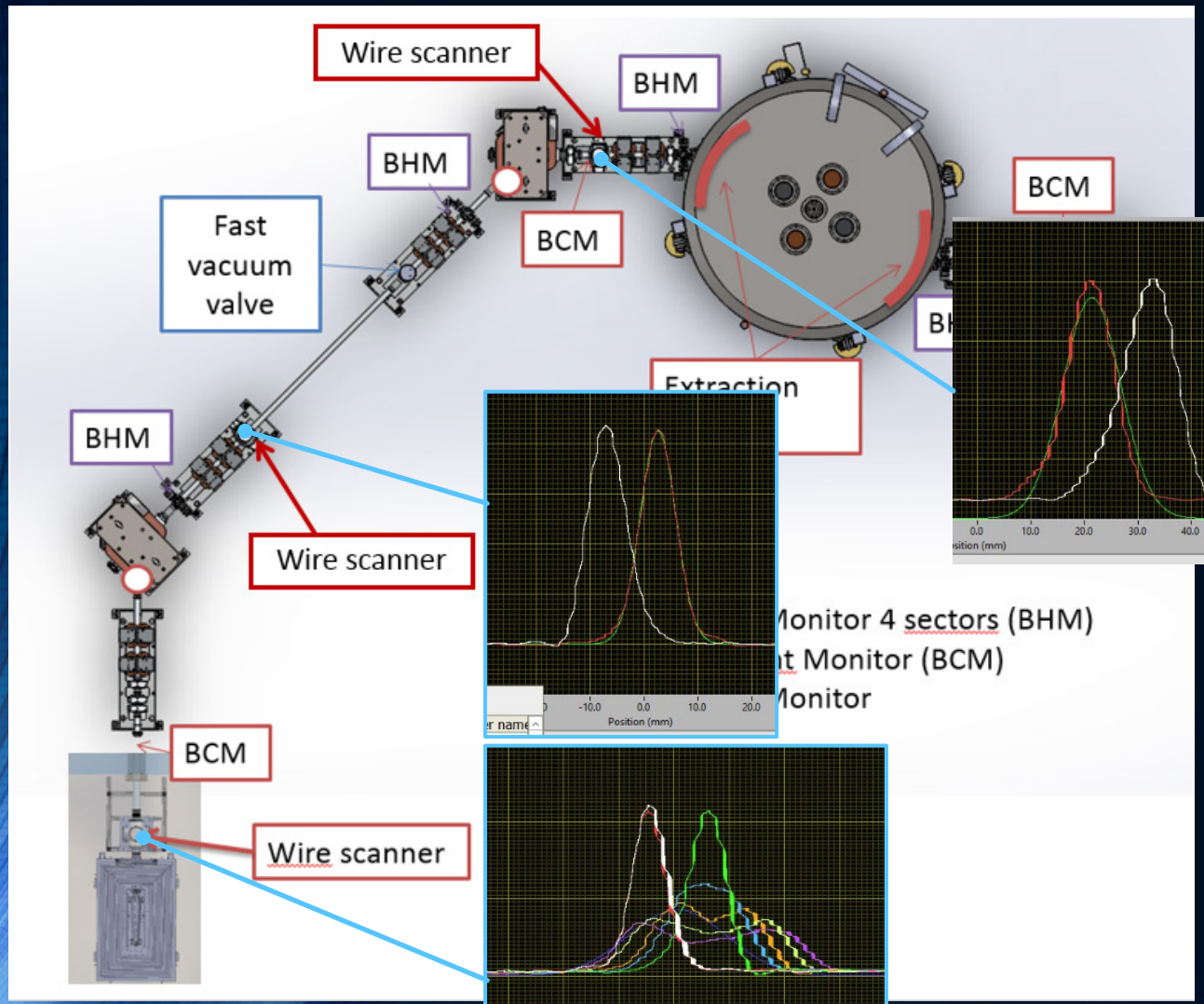

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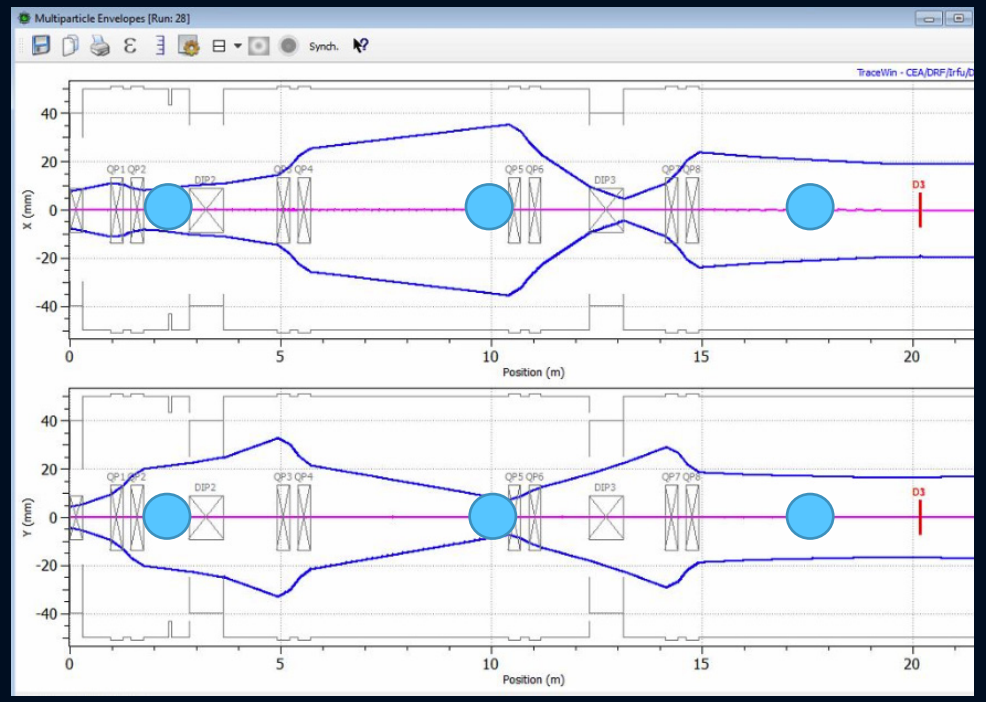
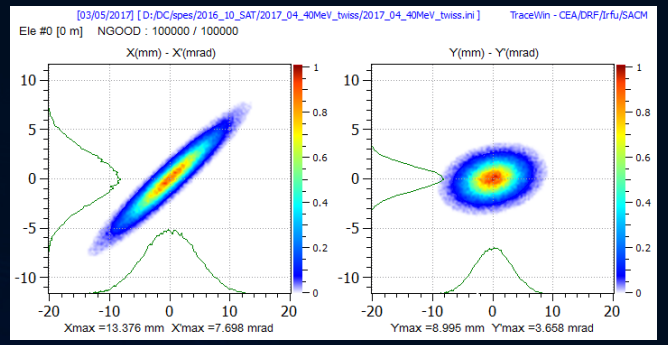
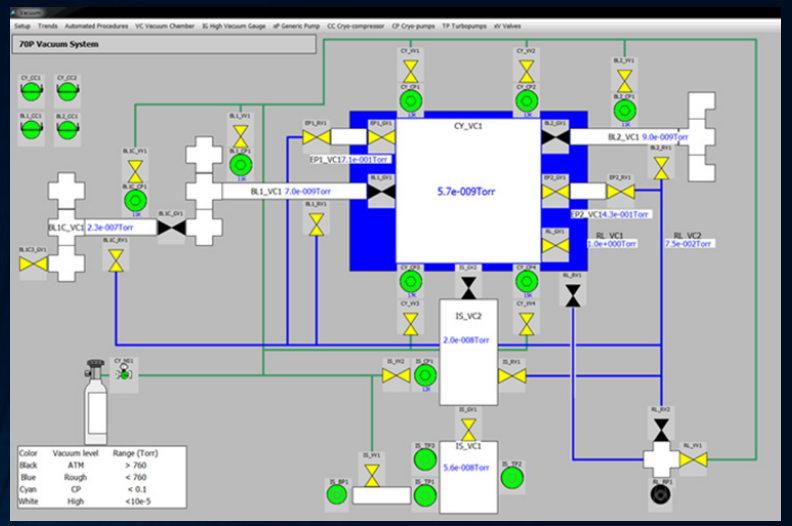
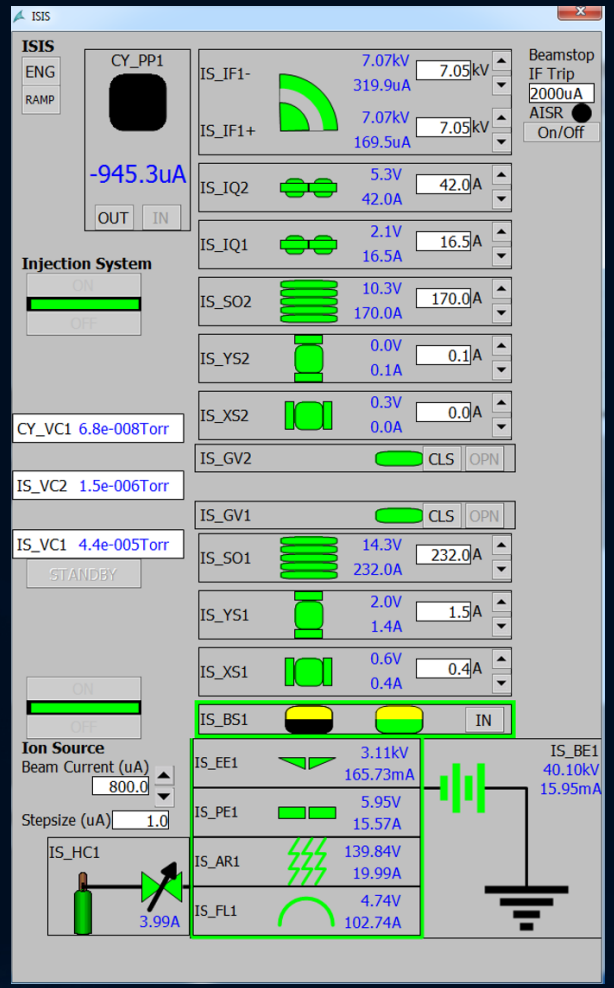
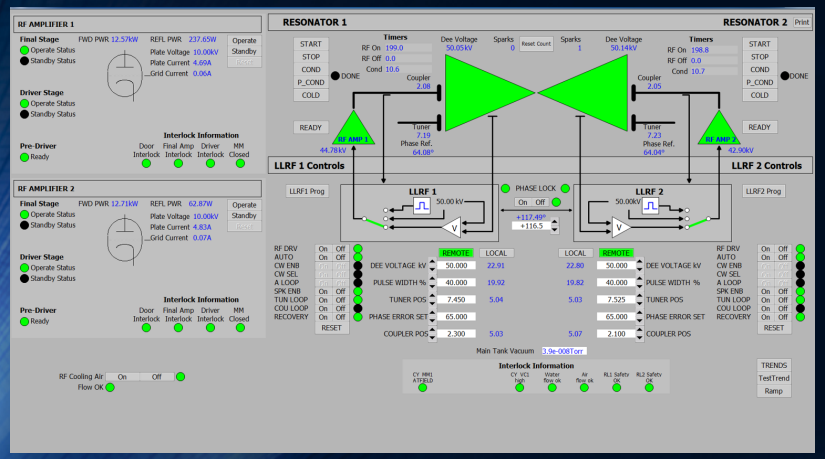


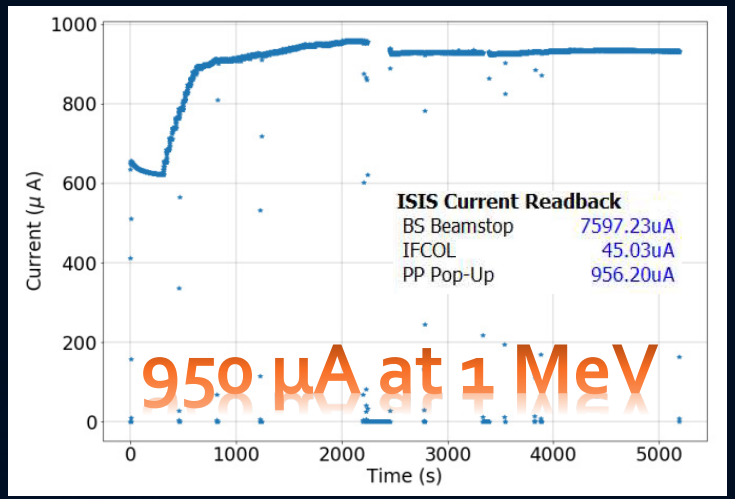


2020- Systems Restarting → 1 MeV operation



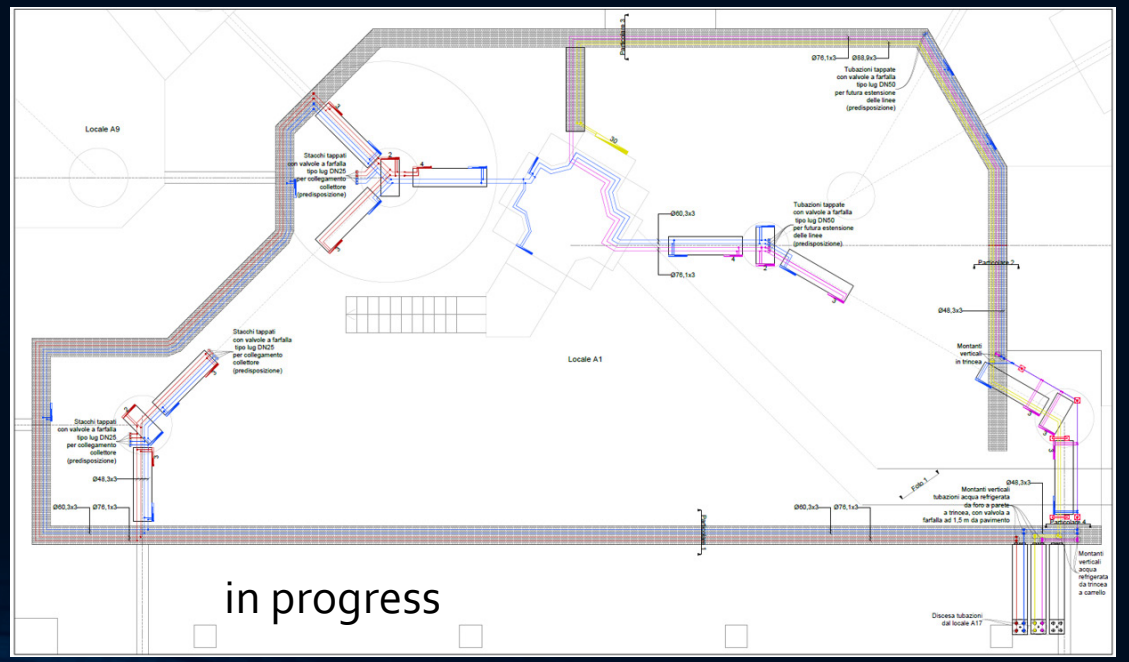






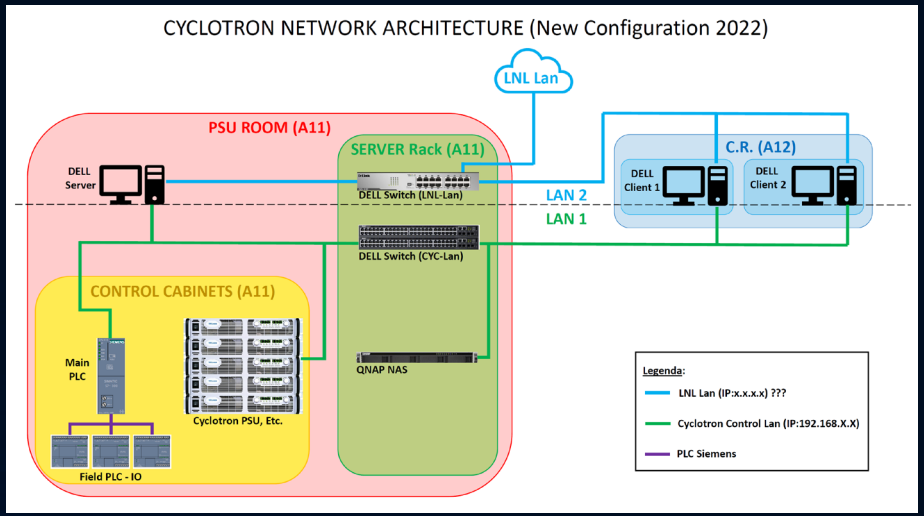
Water Cooling System Upgrade (2021-2023)

- The cyclotron was originally supplied with one skid capable to dissipate 300 kW of thermal power for Cyclotron, beamlines, RF system and ancillaries (crio-compressors)
- In order to improve the redundancy and the reliability of the overall system, the single skid has been replaced by 5 dedicated water cooling packages and related circuits:
  - Cyclotron, injection line and ion source
  - Beamlines on cyc. left side
  - Beamlines on cyc. right side
  - RF system (power amplifiers) and criocompressors
  - Cooling of activated parts (collimators, Faraday cups, probes)



Control System Upgrade (2022-2023)

- Replacement and update of cyclotron P70 Server and Clients
- Network architecture reorganization
  (flexible and Ready for future integration and implementation).
- Network rewiring and centralization
- New Schneider control cabinet
  (DELL Server, NAS, UPS, Cyclotron Control System Network Patch Panel)
- Server and Clients software upgrade (OS and licenses)
  (Windows Server 2019/2022 - Win10 Pro for Workstation)
- Main PLC upgrade and control system migration



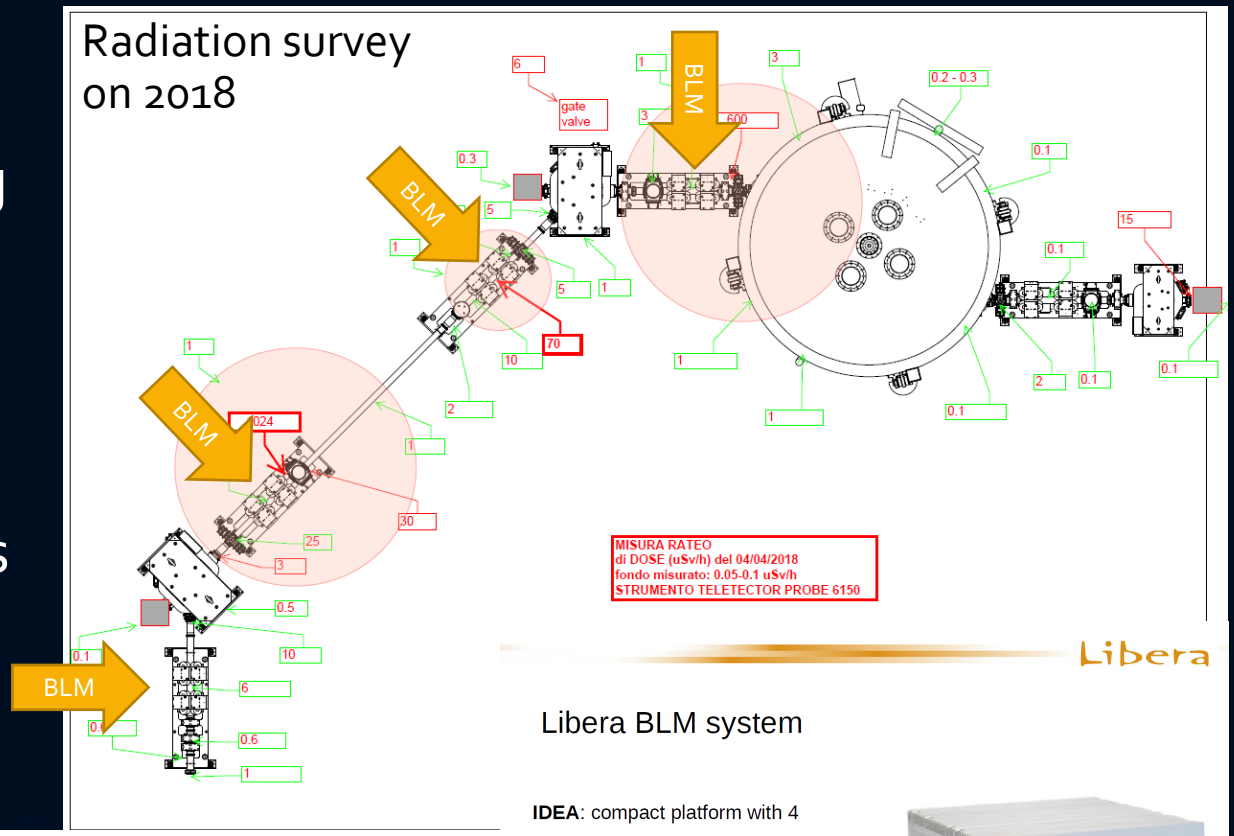
Integration of Cyclotron System with Global Safety System and MPS of SPES (2022-2023)

- HV safety to be implemented with new control access system
- Cyclotron Safety Devices to be interfaced with Machine Protection System of SPES target (beam trips management)
- Very fast interlock (~ 1µsec) to be implemented for beam switching off to avoid any damage of ISOL target


HV ion source cabinet and safety cage

Beam Loss Monitors

- To prevent beam losses due to wrong tuning of beam transport lines
- BLMs detect secondary particles generated by the lost beam
- The BLM will be placed in strategic positions where we expect the beam size increasing (i.e. in the mid of two quads)
- Very good partnership with Libera (Instrumentation Tech.) for testing their devices at LNL



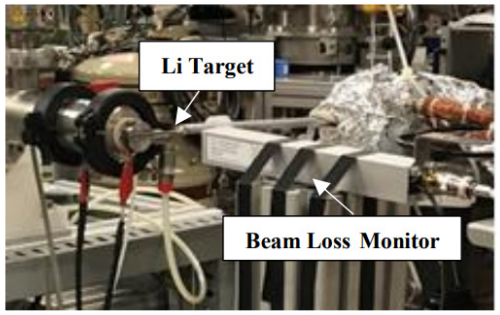


Fig. 1. Experimental setup at CN accelerator

Libera

Libera BLM system

IDEA: compact platform with 4 channels, ns time resolution and 60dB dynamic range plus a scintillator-based beam loss detector.

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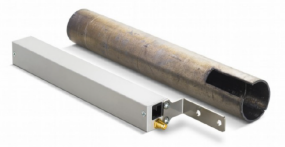


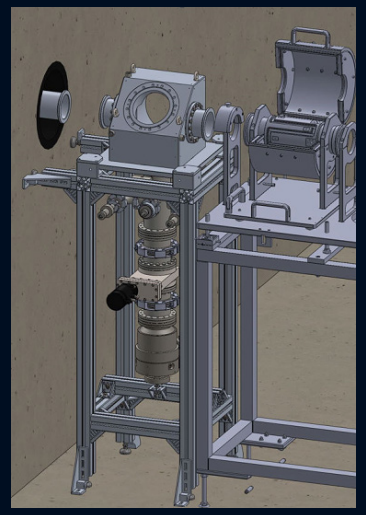
Platform advantages:

- Based on SoC, simple
- Low power → PoE and passive
- Low cost

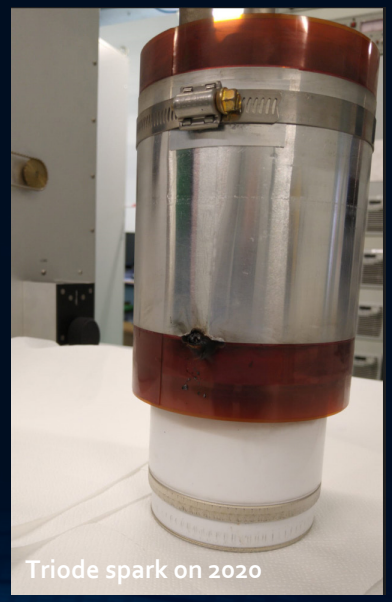
Supply of new beamlines: towards the full configuration

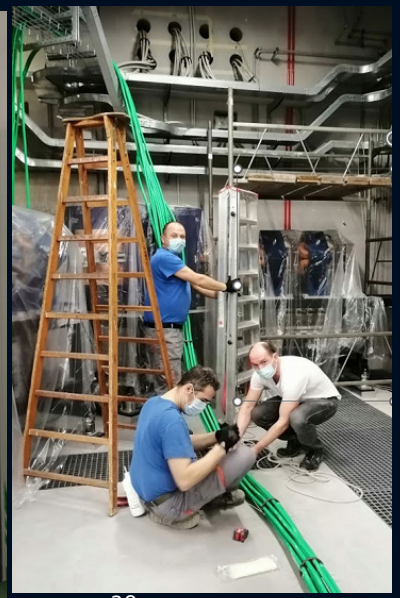
Cyclotron team activity: maintenance

- Design and realization of new beamline components (diagnostics box)
- Cryopumps and He gas lines and compressors
- RF power amplifiers and components
- Vacuum gauges calibration
- Cyclotron hydraulic system purge and oil replacing
- Control System bugs fixing
- Cabling for new magnets of beamlines
- New local electrical panel dedicated to cyclotron systems



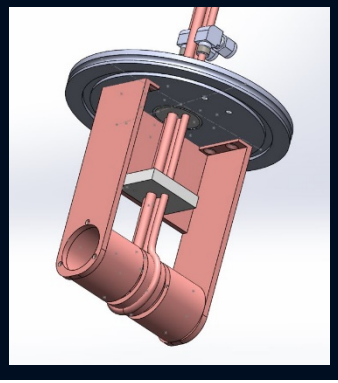
Cryopumps removal activity


Triode spark on 2020



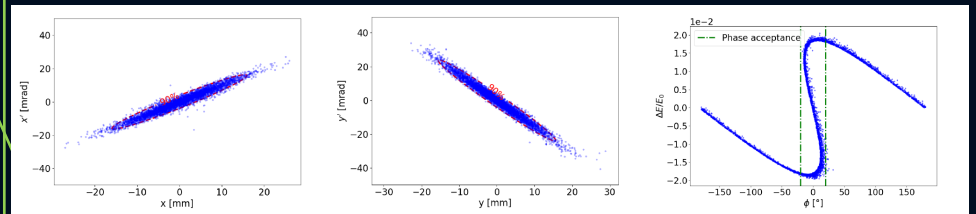
New upgrade of Cyclotron systems

- Active system for varying the injected current into the cyclotron: chopper device is under study
- The Buncher system is completed. The construction starts in 2023
- New high power beam dump for cyclotron tests



V_0 [V]	ϵ	$\frac{N_{bunch}}{N_{tot}}$	$\Delta E_{max}/E_0$
0	1.0	11%	10^{-4}
600	4.1	46%	0.015
700	4.7	52%	0.018
800	5.1	57%	0.020
850	5.2	58%	0.021
900	4.4	49%	0.023
1000	3.0	33%	0.026

$\beta\lambda/2$



(m) *X-emittance at* **5** (n) *Y-emittance at* **5** (o) *Longitudinal distribution at* **5**

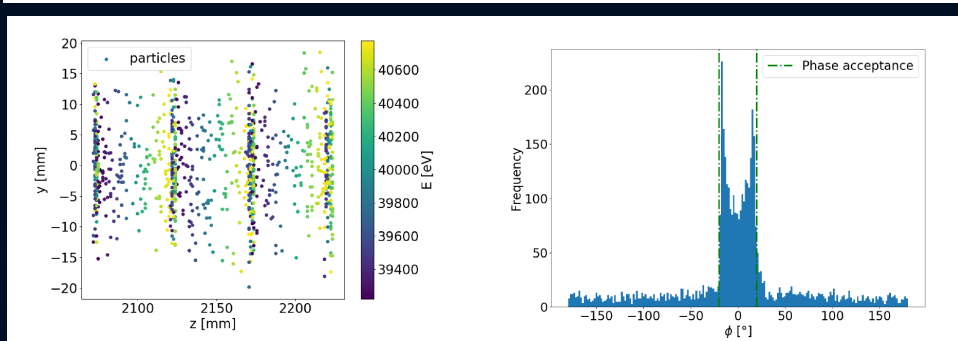
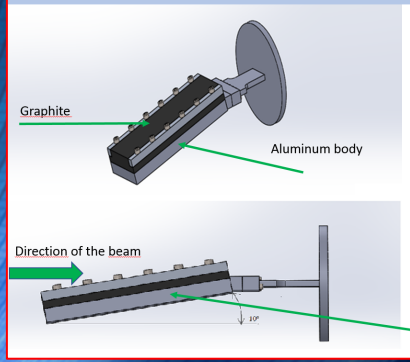


Figure 26: Space distribution of particles before the inflector

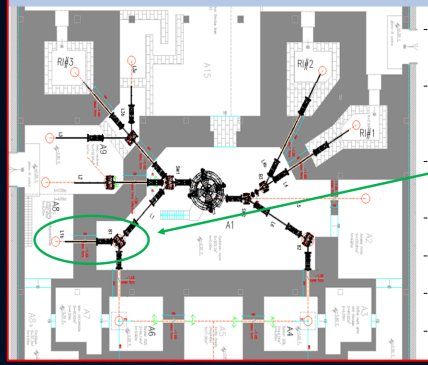
Figure 27: ϕ distribution at the inflector at 850 V

4. Design of the Beam Dumper



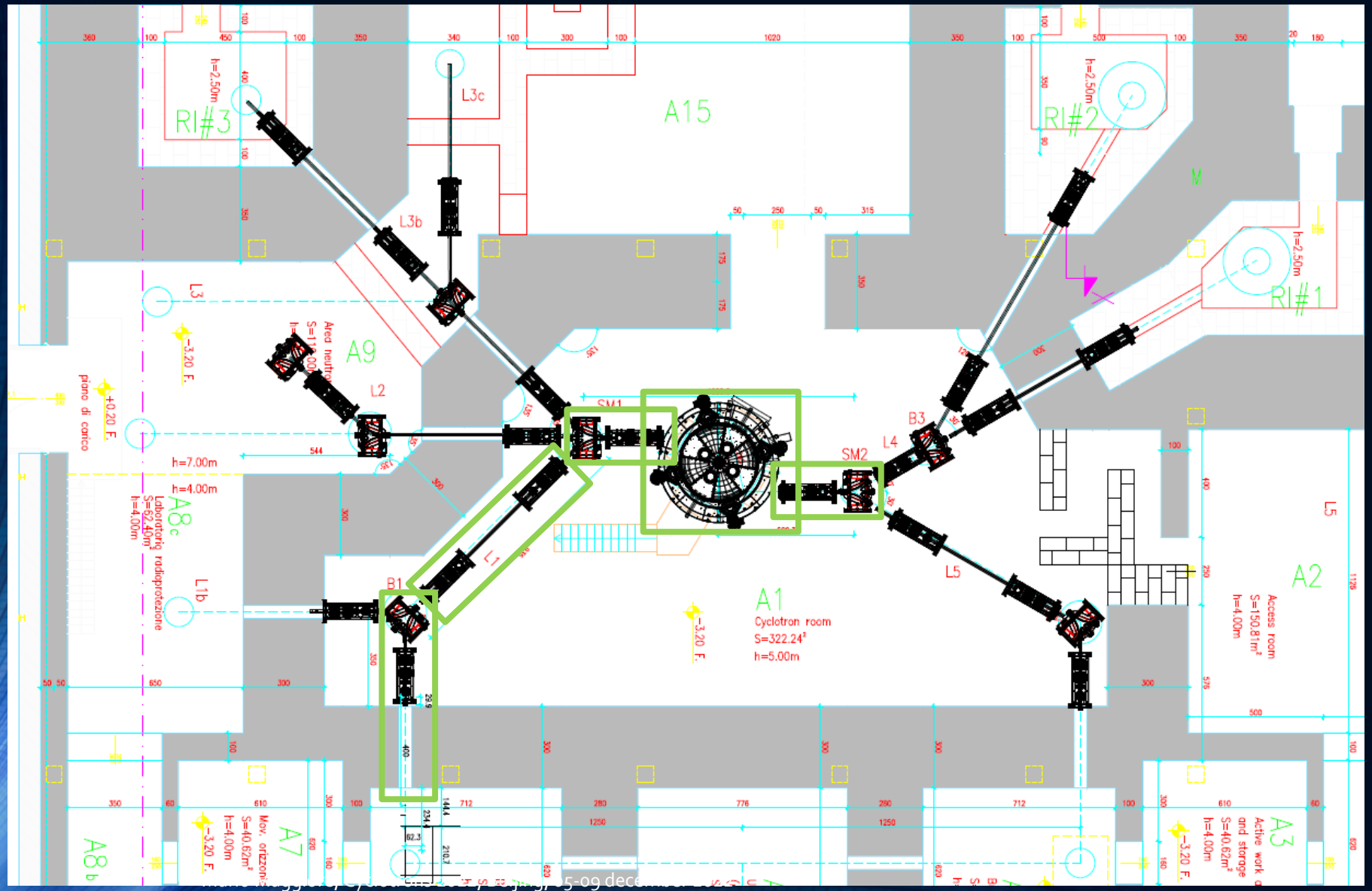
- Designed to fit inside of the beam line with diameter of 150 mm
- Maximum delivered power of ~50 kW
- Dimensions of the Graphite plate 80 mm x 220 mm x 22 mm
- Exposed area which will stop the beam of 176 cm^2
- Plate is positioned on 10° angle
- Calculated mass of 1.4 kg
- Water cooling channels inside the aluminum body. Temperature of water 15°C and speed of 0.3 m/s.

6. Activation and residual dose rate calculations



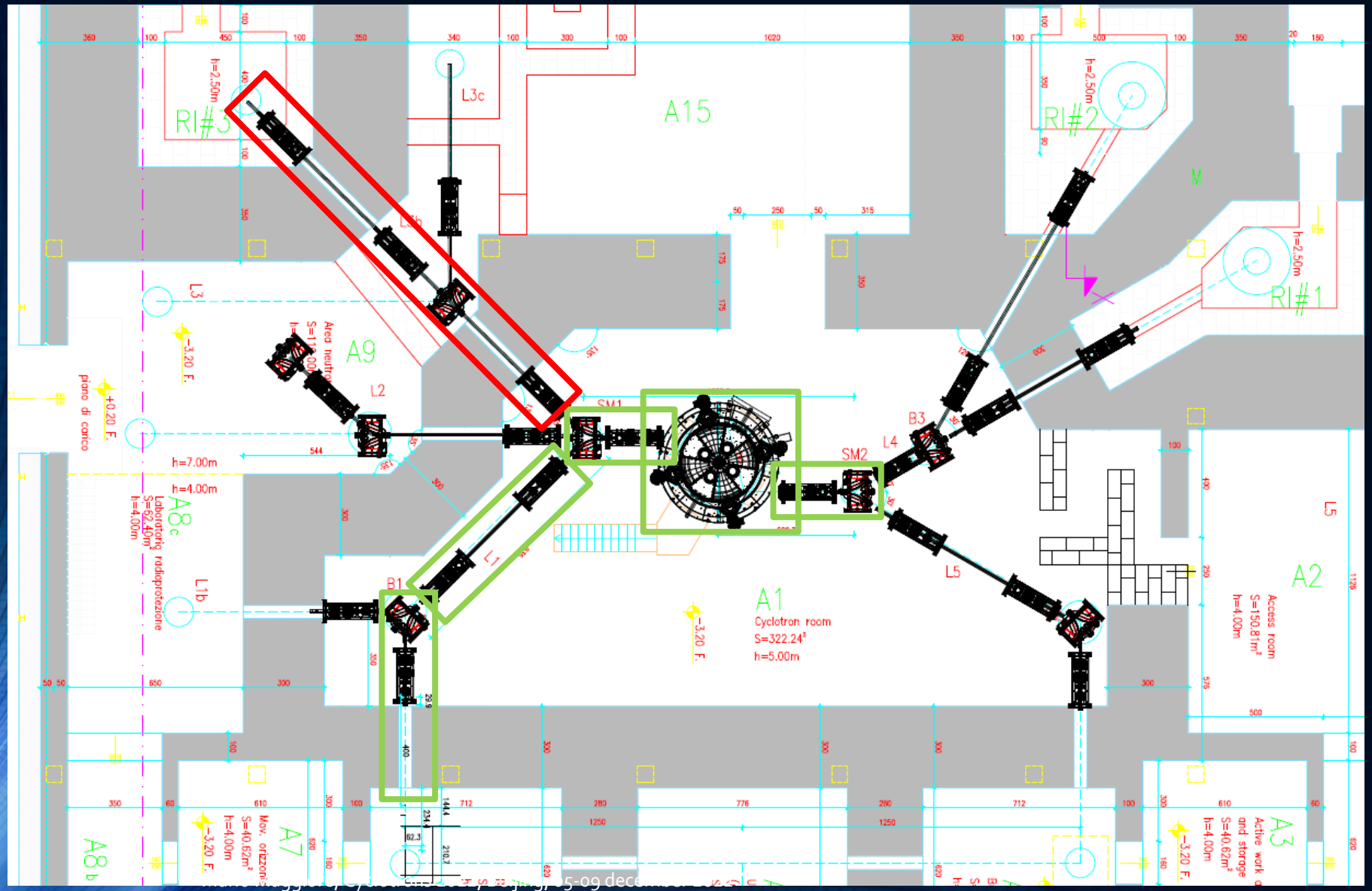
- The geometry and design and the position of the dumper and drawn into the Fluka software.
- The cyclotron is positioned in bunker A1 while the dumper is positioned in the hole that connects bunker A1 and A9.
- The Beam Dumper is positioned inside the hall of the wall between A1 and A9.
- Maximum beam energy of 70 MeV
- Maximum beam current of 750 µA
- Total power of ~50 kW.
- Irradiation time, 5 hours per day in period of two weeks.

Extension plan of high intensity facility



Actual Installation: Cyclotron and ISOL1 beamline

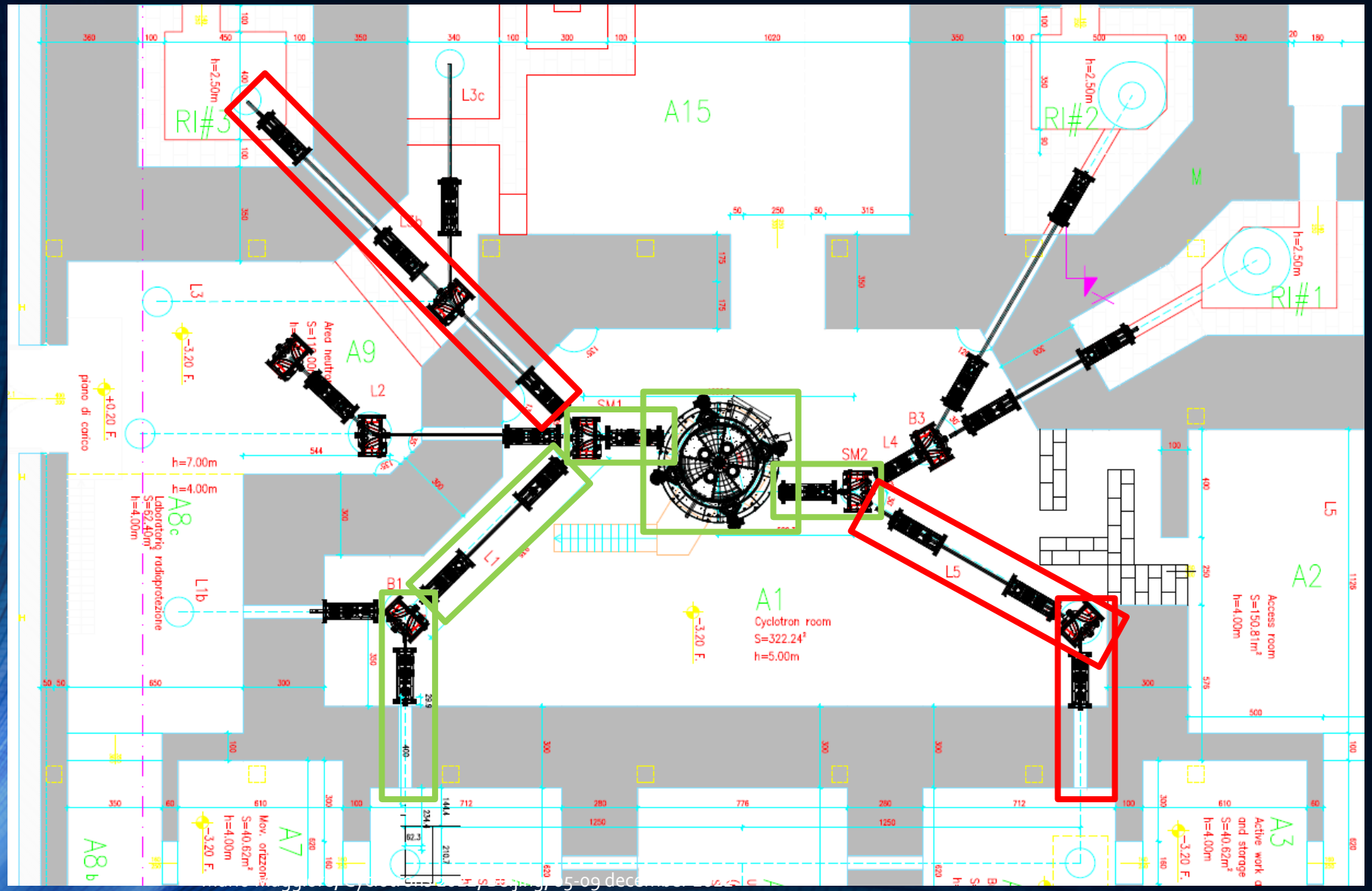
Extension plan of high intensity facility



Actual Installation: Cyclotron and ISOL1 beamline

LARAMED beamline (high power beam: 30-70 MeV, 300μA): completed by Feb 2023

Extension plan of high intensity facility

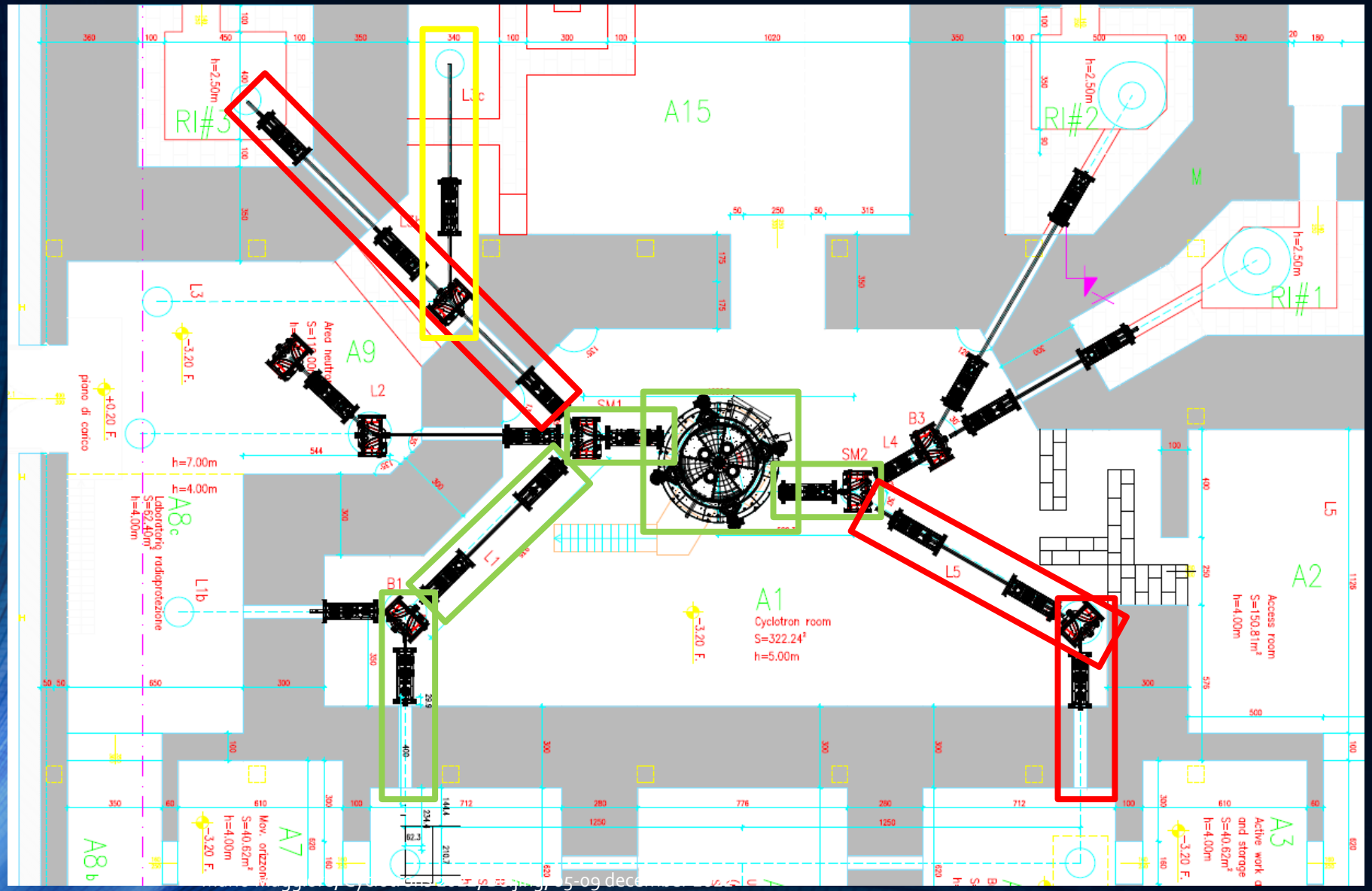


Actual Installation: Cyclotron and ISOL1 beamline

LARAMED beamline (high power beam: 30-70 MeV, 300μA): completed by Feb 2023

ISOL2 beamline (high power beam: 30-70 MeV, 300μA): completed by Feb 2023

Extension plan of high intensity facility



Actual Installation: Cyclotron and ISOL1 beamline

LARAMED beamline (high power beam: 30-70 MeV, 300μA): completed by Feb 2023

ISOL2 beamline (high power beam: 30-70 MeV, 300μA): completed by Feb 2023

LARAMED (low power: 30-70 MeV, 200 nA): tender was awarded in 2022, installation expected in 2024

Summary

- The high intensity facility whose core is the cyclotron is operational at LNL:
  - The commissioning of cyclotron supplied by BEST Theratr. was accomplished out in 2017 and main performances were established (500 μA @70 MeV).
  - Beam operations were done in 2018 by INFN staff in order to test the capability and full performance of the machine.
- After the first shutdown and Covid-19 break (mid 2018- mid 2020), the overall systems resumed with minor troubles and once again beam tests showed very good performance in terms of maximum injected current, reaching the value of 950 μA at 1 MeV, with good stability.
- In March 2021, the cyclotron was again turned off to allow the installation of SPES equipment and proceed with the completion of the facility (new safety system, plants upgrading, civil works, compliance with fire brigade directives). Meanwhile the major upgrades of cyclotron systems are still proceeding.
- The restart of operations is expected by the end of 2023 with the goal to deliver the first proton beam to ISOL target so that SPES project begins.

Thank you