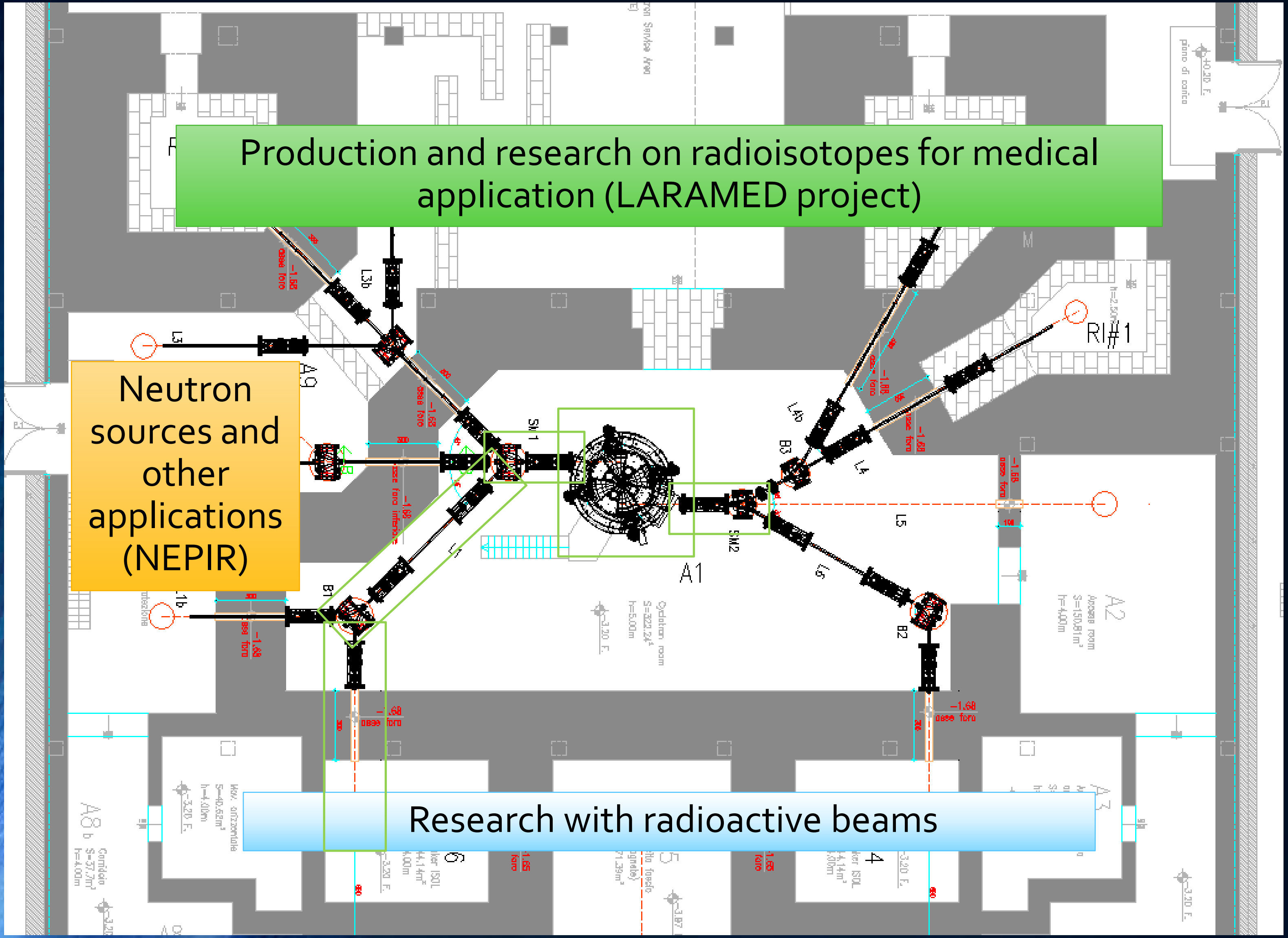
Status of High Intensity Proton Beam Facility at Laboratori Nazionali di Legnaro (INFN)

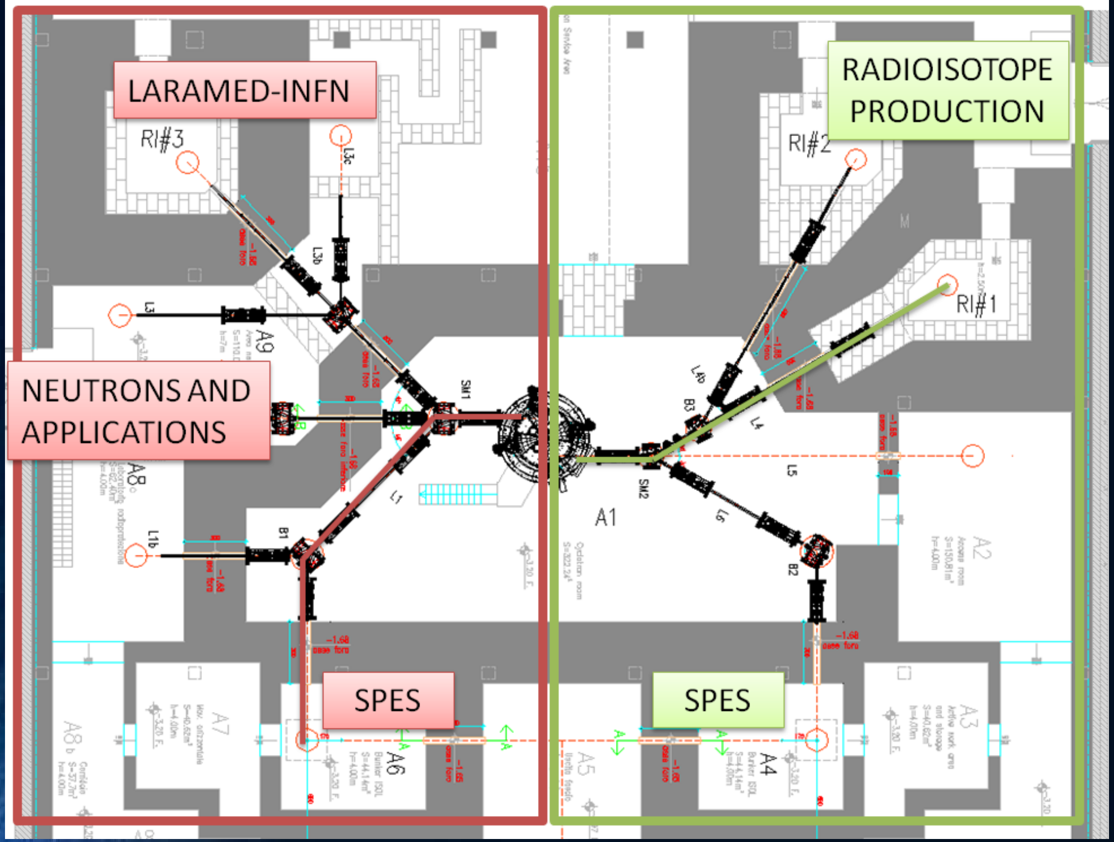
MARIO MAGGIORE ON BEHALF OF LNL CYCLOTRON TEAM

Final Configuration of Cyclotron and Beamlines



- 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)

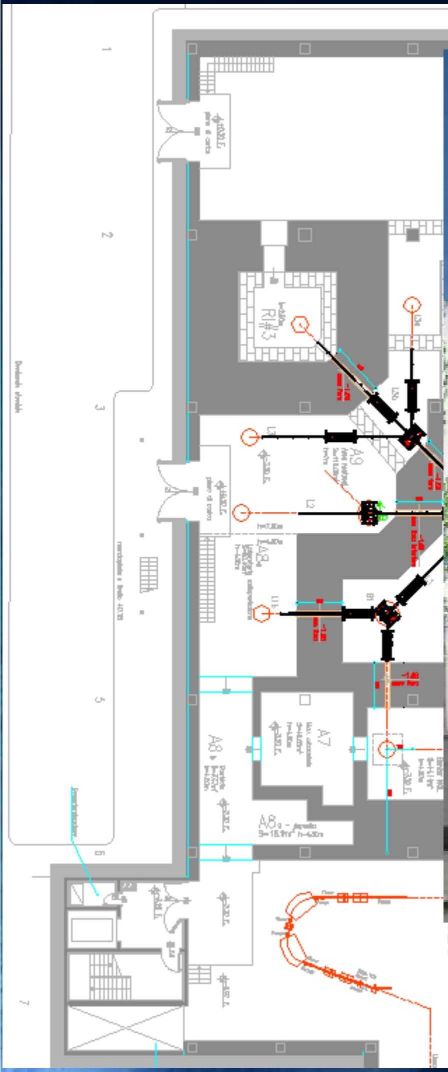
Beam Sharing (example)



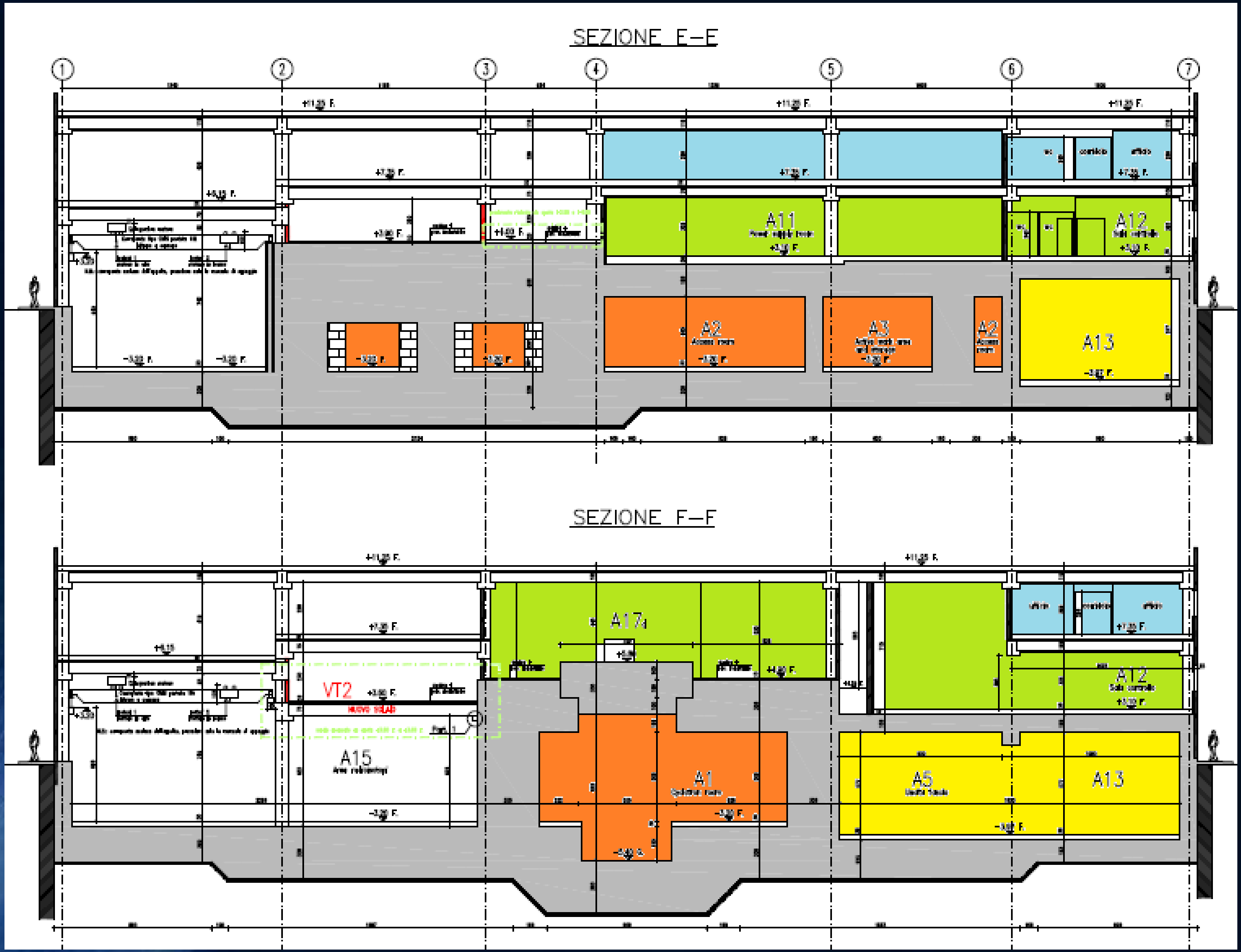
ROOM	BTL name	MAIN USE	MAX ENERGY AND CURRENT BEAM (protons)
A6	L1	SPES ISOL TARGET 1	40 MeV, 250uA
A8	L1B	TBD	
A9	L2	NEUTRONS (NEPIR)	35-70 MeV, 50 uA
A9	L3	NEUTRONS (NEPIR)	TBD (low power)
RI3	L3b	LARAMED-INFN	35-70 MeV, 200uA
A15	L3c	LARAMED-INFN	35-70 MeV, low power
RI1	L4	RADIOISOTOPE PRODUCTION	35-70 MeV, 500-700uA
RI2	L4b	RADIOISOTOPE PRODUCTION	35-70 MeV, 500-700uA
A4	L6	SPES ISOL TARGET 2	40 MeV, 250uA

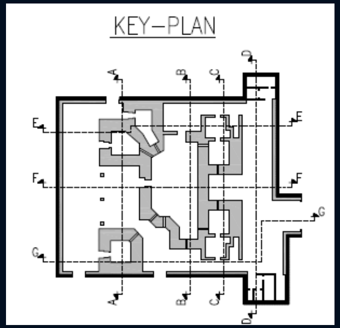
STATIONS		week 1		week 2		week 3		week 4		week 5		week 6		week 7		week 8		week 9		week 10	
		Energy	Current	Energy	Current	Energy	Current	Energy	Current	Energy	Current	Energy	Current	Energy	Current	Energy	Current	Energy	Current	Energy	Current
ISOL (SPES)		40	250	40	250	ISOL mainten.		40	250	40	250	ISOL mainten.		ISOL mainten.		40	250	40	250	CYCLOTRON MAINTENANCE	
RI Production		40	≤ 450	40	≤ 450	> 40	> 350	40	≤ 450	40	≤ 450	> 40	> 350	> 40	> 350	40	≤ 450	40	≤ 450		
Other Apps.						> 40	< 350					> 40	< 350	> 40	< 350						

The New Building for SPES project



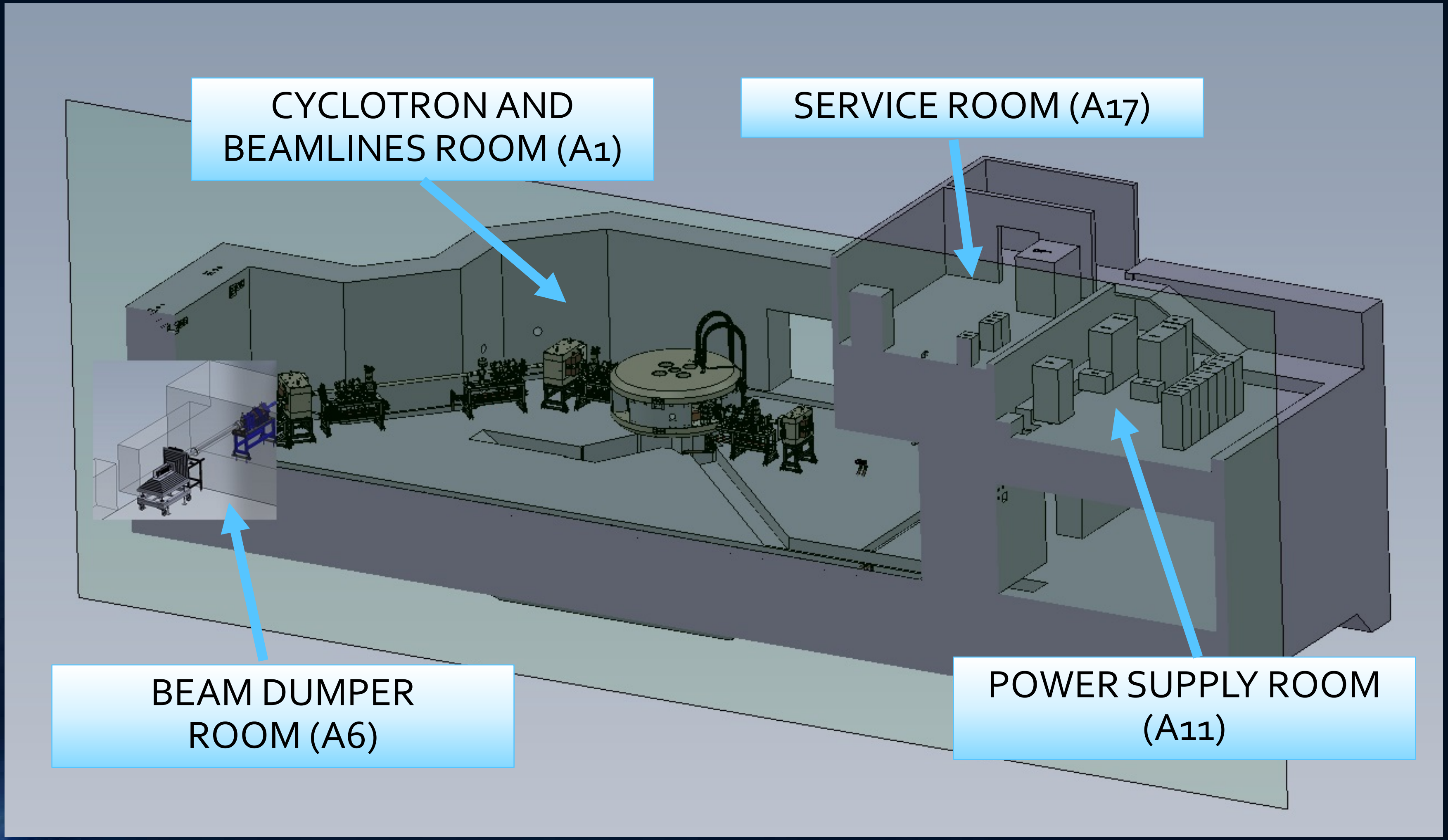
- 4 years to complete the work
- No additional costs respect to the initial budget
- It was a success of public tender management… in Italy



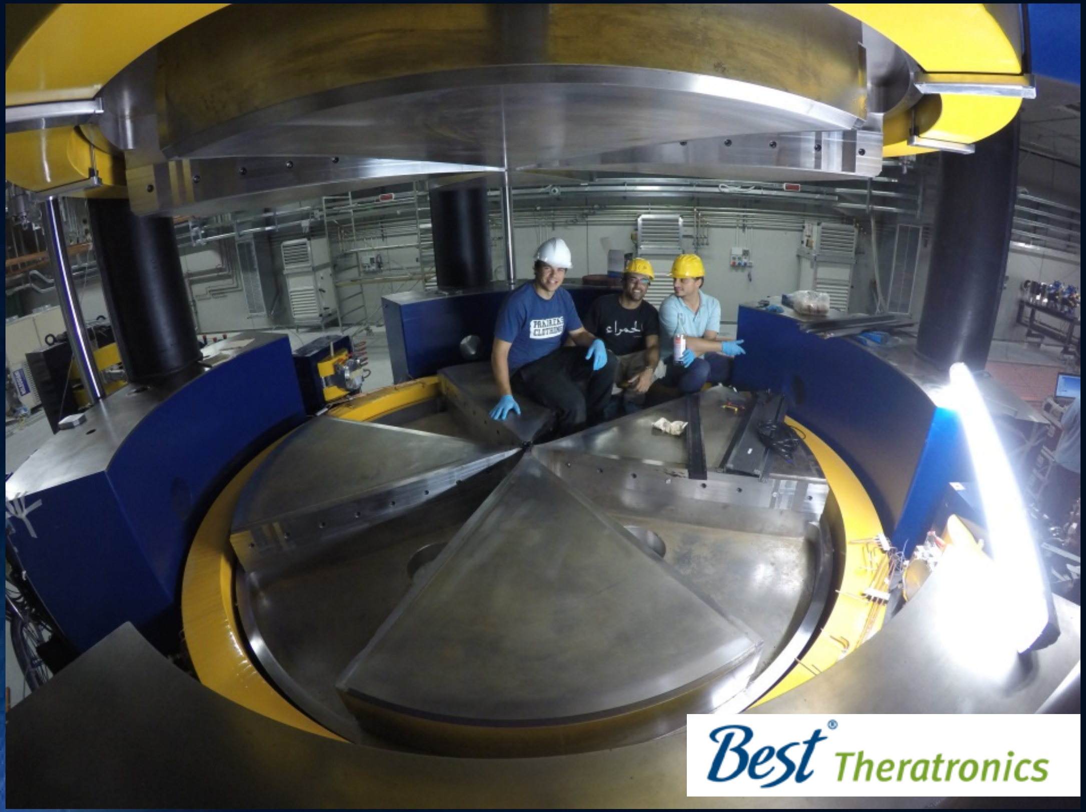


- 3 levels :
  - -1 floor : heavy shielded section to hold cyclotron and high activation areas (bunkers, ISOL target and RIBs transport)
  - 1st floor: services, conventional and special plants, ancillary laboratories and control room
  - 2nd floor: offices and labs

Cyclotron Areas Arrangement



The 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

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Brief Summary of Cyclotron Roadmap till 2014

- <u>Cyclotron and one beamline</u> supplied by BEST Cyclotron System Inc (CAN) who won the public tender in 2010
- Study and Design started in 2011
- Magnet ready in factory (Ottawa) in 2013 (magnetic field mapping)
- RF cavity system installed on mid 2013
- Ion source and injection line installed in 2014
- First beam injected (1 MeV) in factory in Sept. 2014
- Factory Acceptance Test concluded in Nov. 2014

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Cyclotron installation at LNL (2015)

Ottawa, Jan 2015, Cyclotron leaving Factory

Legnaro, May 2015, Cyclotron at LNL

LNL, May 2015, first day of operation

Upper pole installation during 2nd day

BEST and INFN staff partnership

INFN staff supervises the work, providing technical support and supplies some component:

- Low power faraday cups (1kW)
- High power beam dumper (50 kW)
- Last section of beamline (high radiation environment)
- Beam loss monitors (prototypes)
- Safety and Radiological Survey System

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Completion of installation (cyclotron and infrastructure) in 2015- mid2016


Power Supply room


Services room

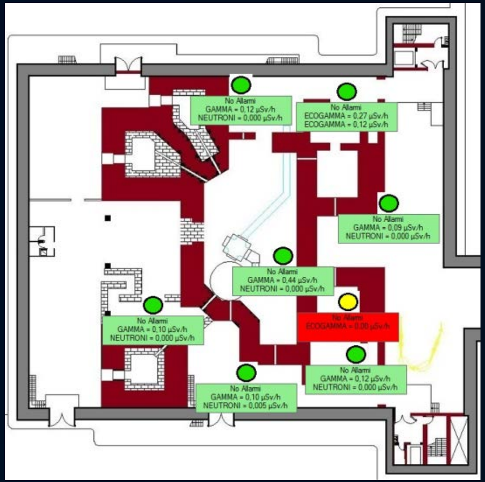

Water plant

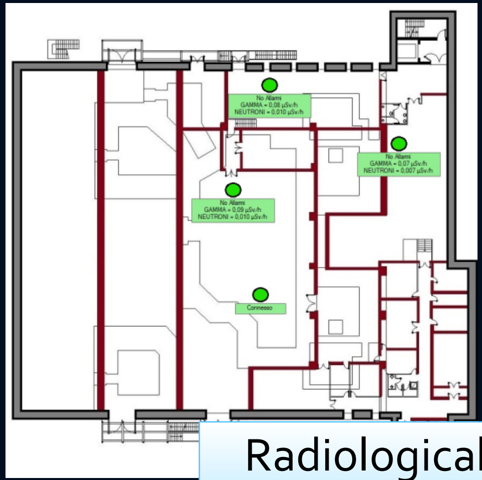

Beamlines installation

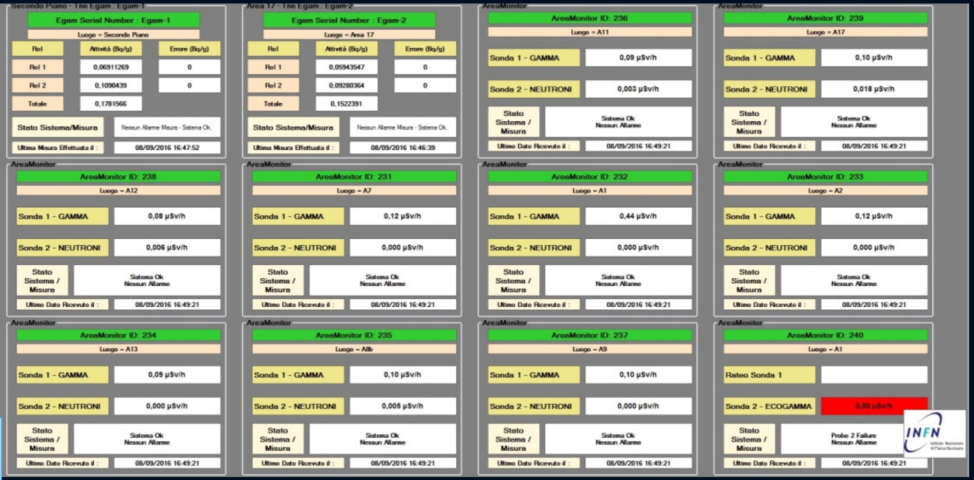

Sliding shielded doors


Labyrinth between A1/A2 rooms

Cyclotron and beamlines today

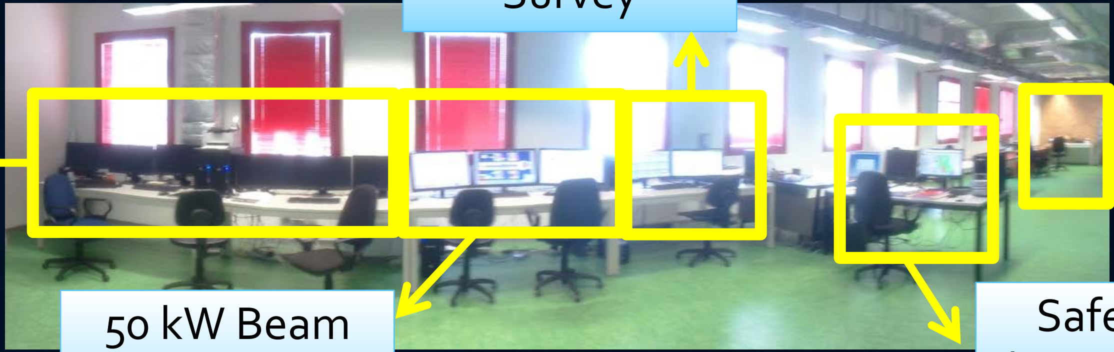






Radiological Survey

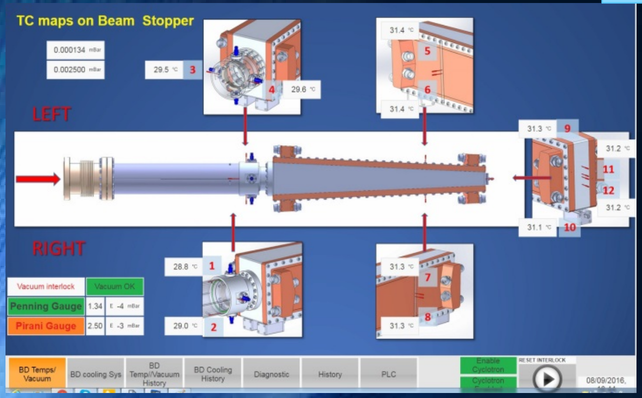
CYCLOTRON & BEAMLINES

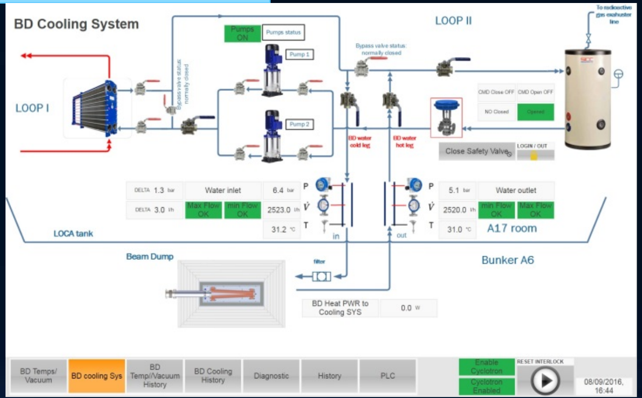


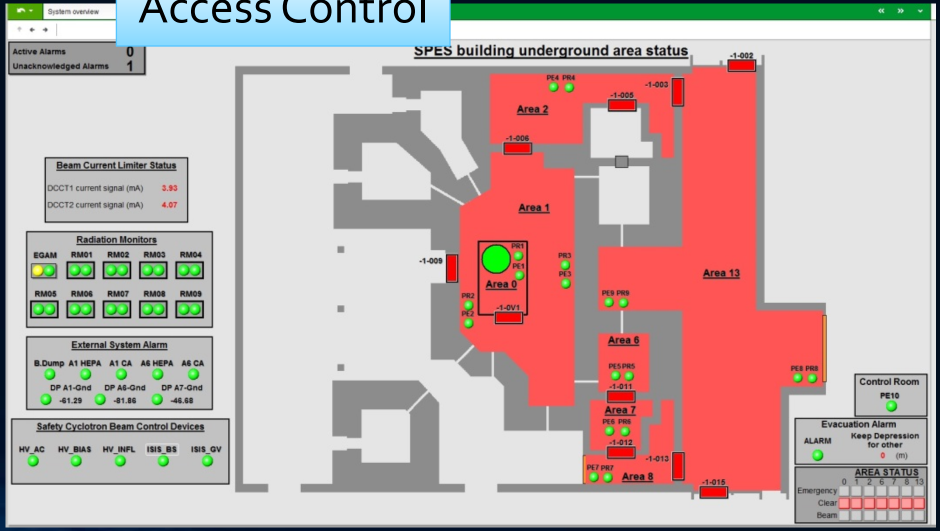
SERVICES AND PLANTS CONTROL

50 kW Beam dumper

Safety and Access Control

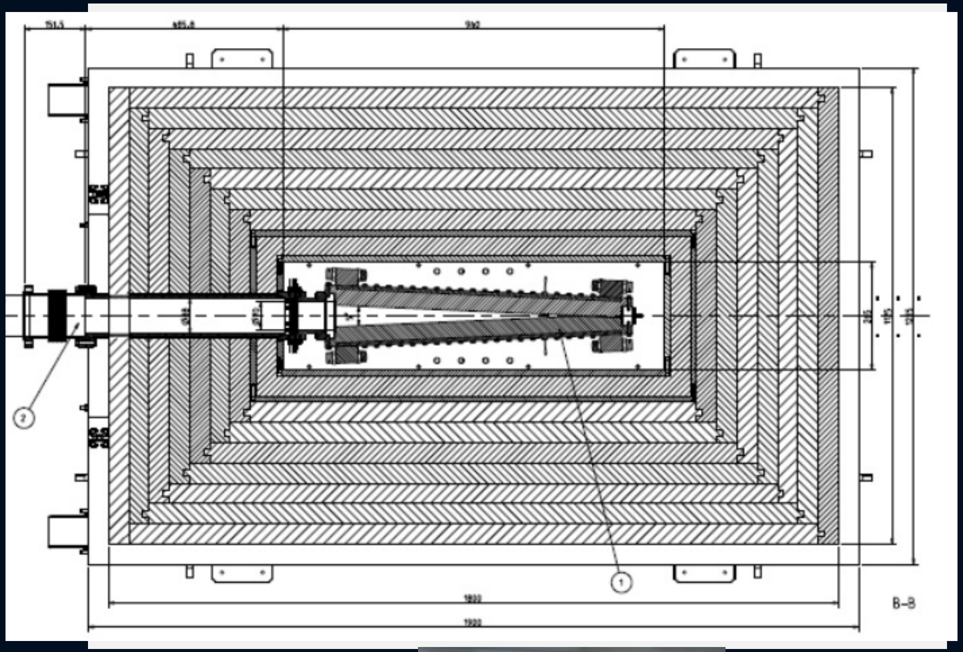




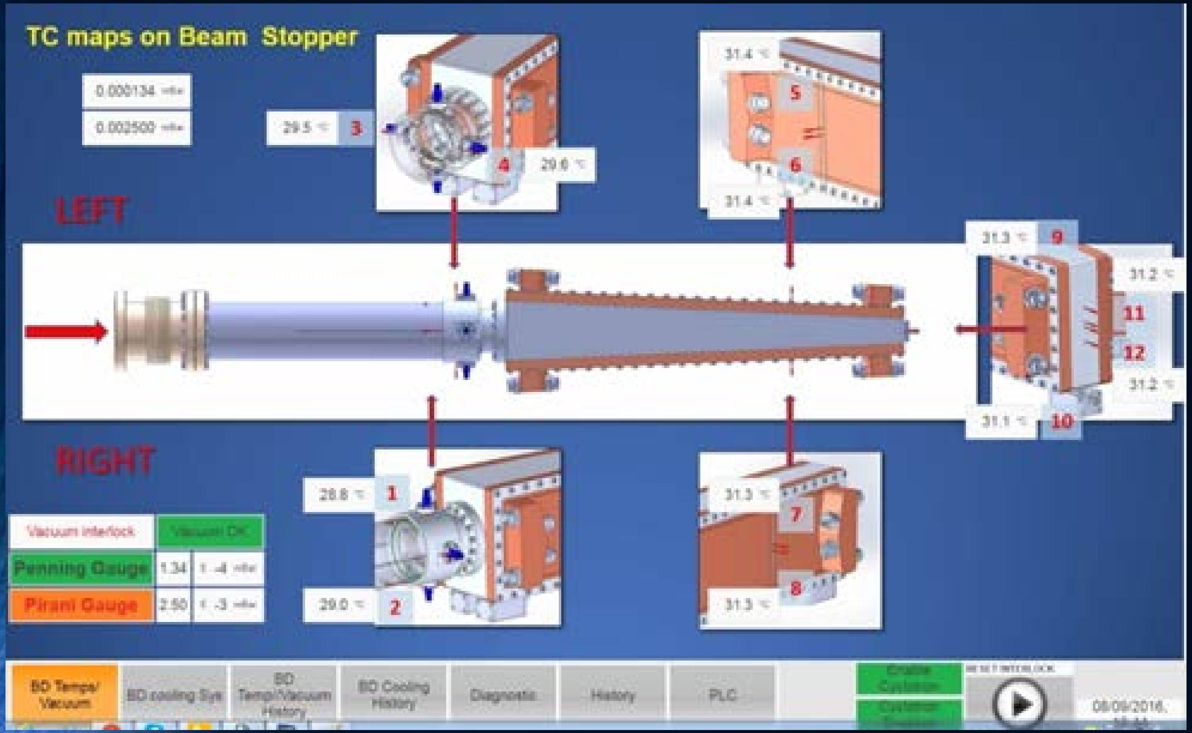


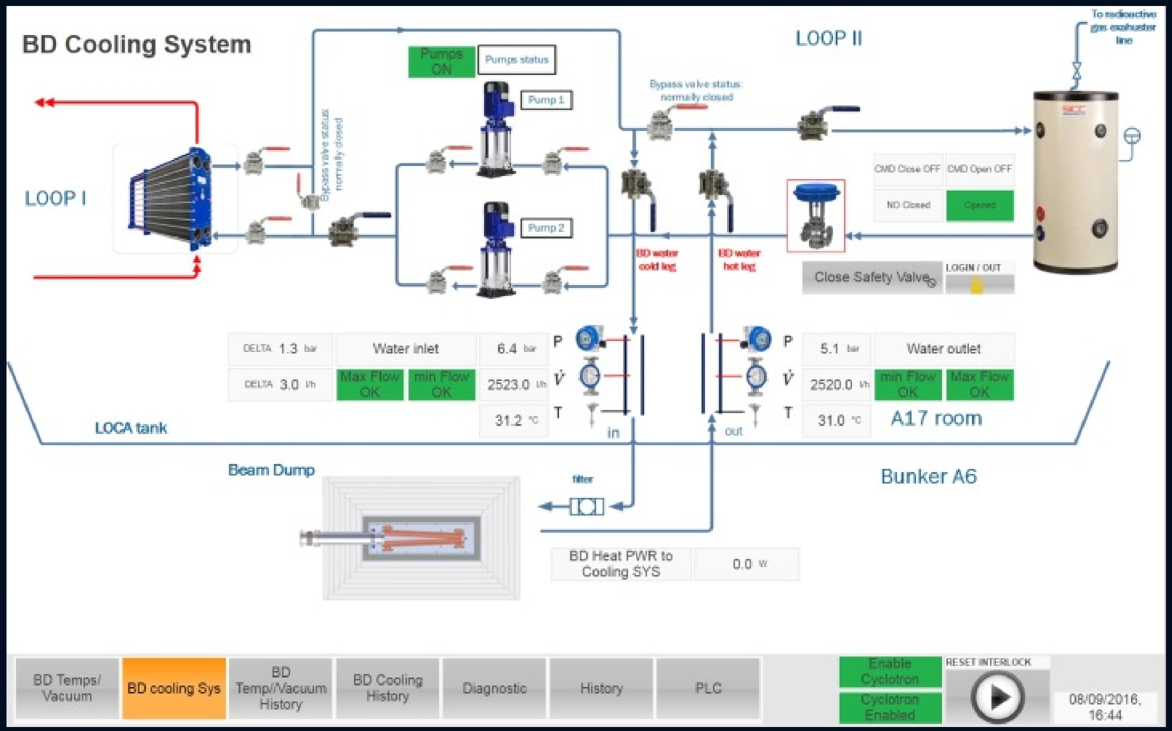
50 kW Beam Dump

- Two copper plates tilted by 10 deg
- Aluminum frame
- Indium sealing between Cu and Al material
- Water cooled (6 bar)
- Lead shielding (gamma radiation) and additional external layers of HDPE for neutron flux reduction
- Up to 12 probes for monitoring of temperature of different sections
- All safety devices are redundant
- In June 2016 the installation in the bunker was accomplished out
- Alignment done by laser tracker system
- Vacuum level (beam OFF) 1.5 x 10^{-5} mbar

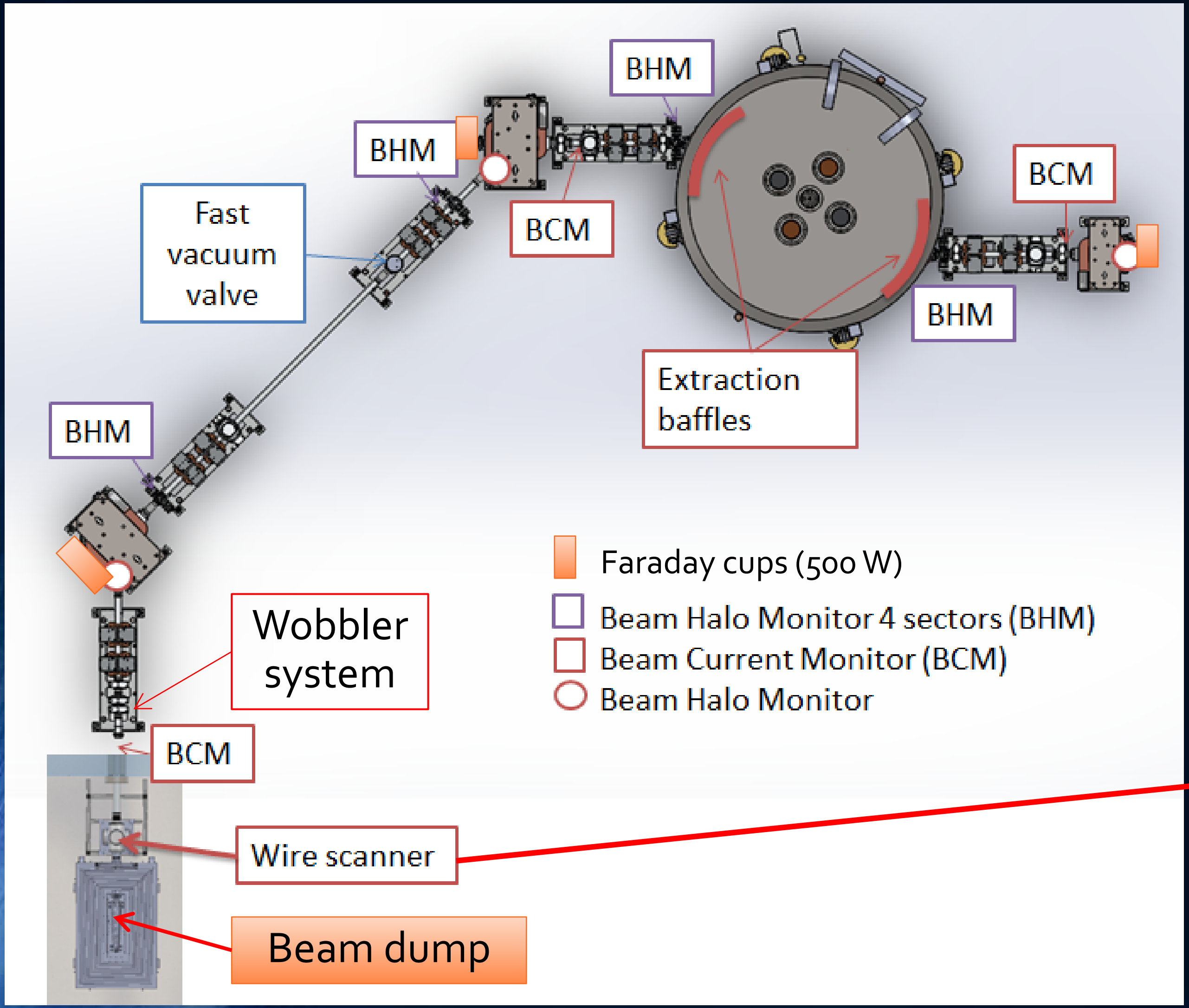


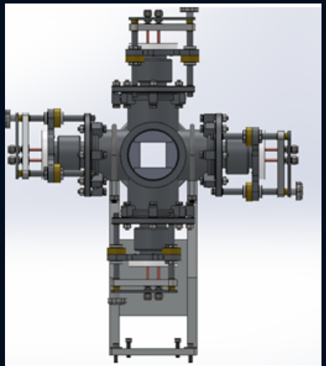
Control system Beam Dump



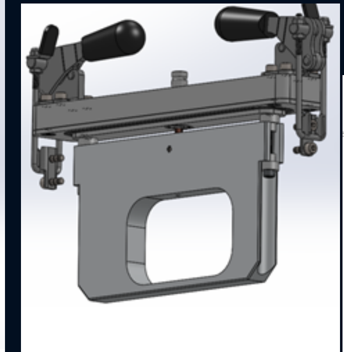


Beam Diagnostics

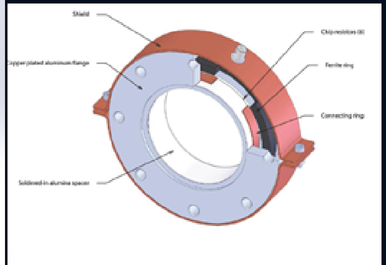




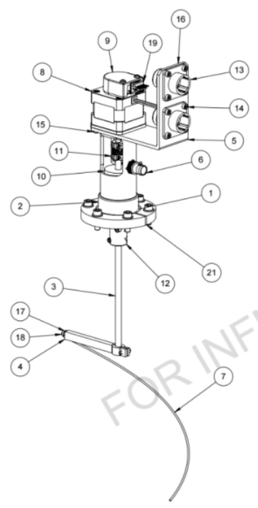
- Beam Halo cutter
- Radial and Vertical Misalignment Beam check

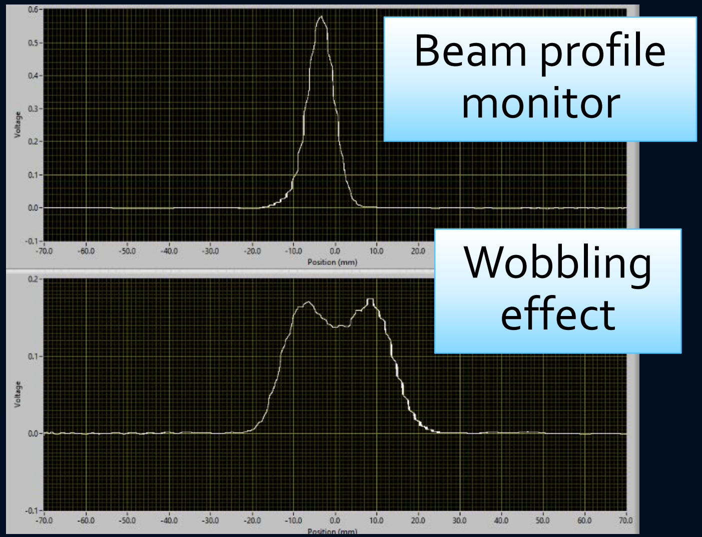


- Beam Halo Monitor
- Misalignment Beam check



- Beam current monitor (DCCT type)



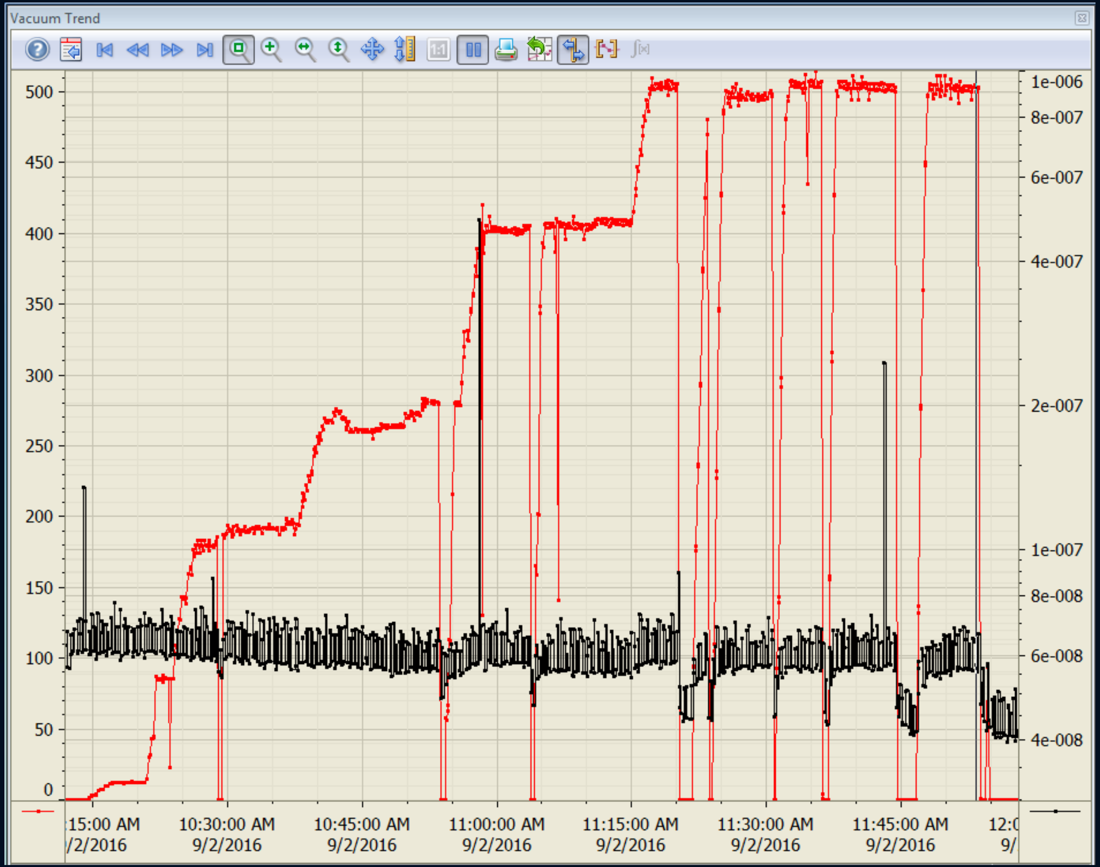


Beam Commissioning (high power tests)

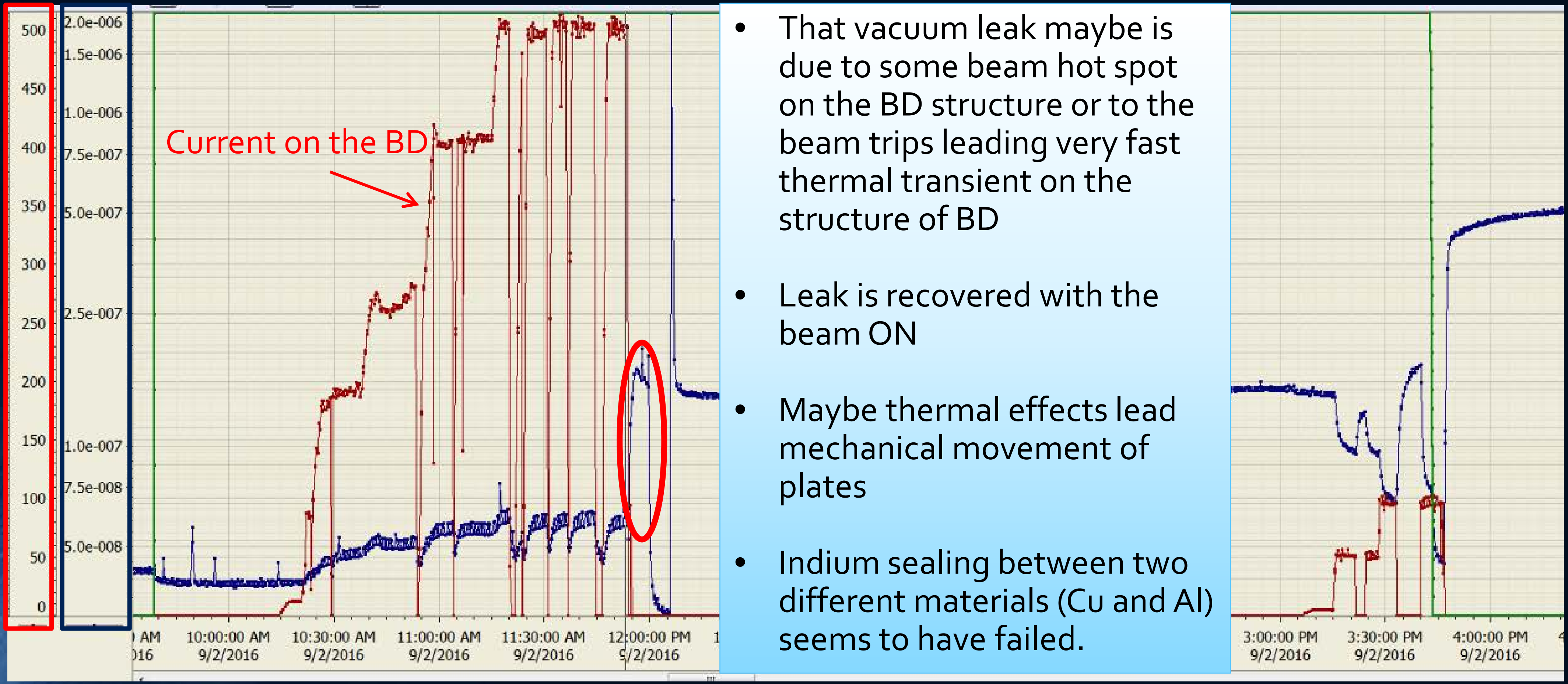
- On Feb 2016 BEST started the beam commissioning and FAT:
  - Low power test (injection): 900 μA at 1 MeV and 8.5 mA ion source current (Feb 2016)
  - Low power beam accelerated and extracted (May 2016)
  - High power beam extracted and delivered to beam dumper (July 2016-September 2016)

Up to 500 μA current and 70 MeV energy proton beam (35 kW) delivered to the BD

Very good Cyclotron vacuum performance (8×10^{-8} mbar with beam ON)



Beam dump vacuum leak



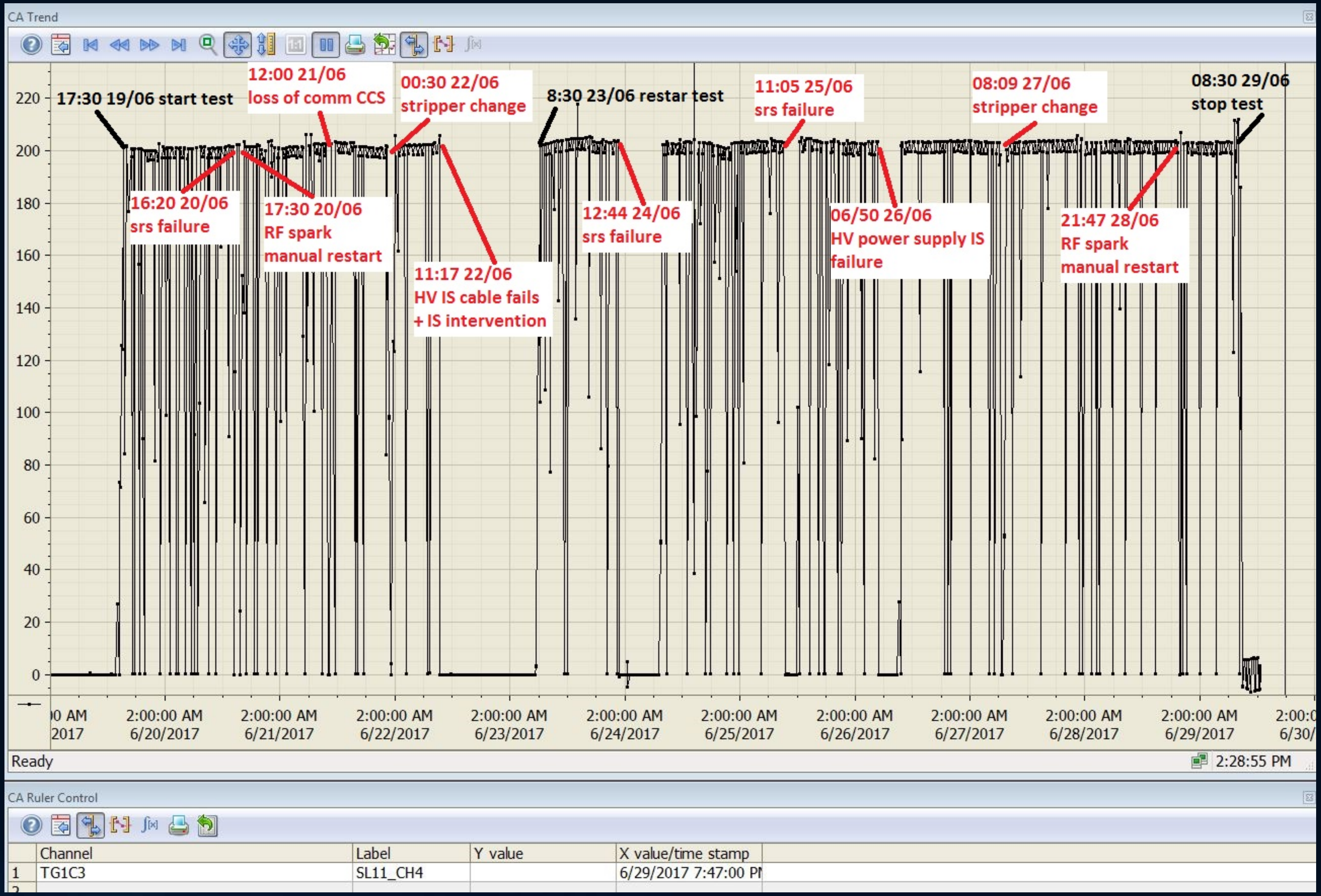
- That vacuum leak maybe is due to some beam hot spot on the BD structure or to the beam trips leading very fast thermal transient on the structure of BD
- Leak is recovered with the beam ON
- Maybe thermal effects lead mechanical movement of plates
- Indium sealing between two different materials (Cu and Al) seems to have failed.

- Beam tests at different power have been done in order to verify the mechanical integrity of the BD structure and its vacuum seal (no visual inspection is available!!).
- The BD appeared not fully compromised and an acceptable vacuum level is achieved (10^{-4} mbar) with beam OFF.
- Nevertheless we decided for safety reason to limit the maximum beam power delivered at 10 kW in order to proceed with the FAT and accomplished out the commissioning.
- Moreover, in January 2017 an additional pumping station has been installed by INFN staff in order to increase the pumping speed of last leg of beamline.

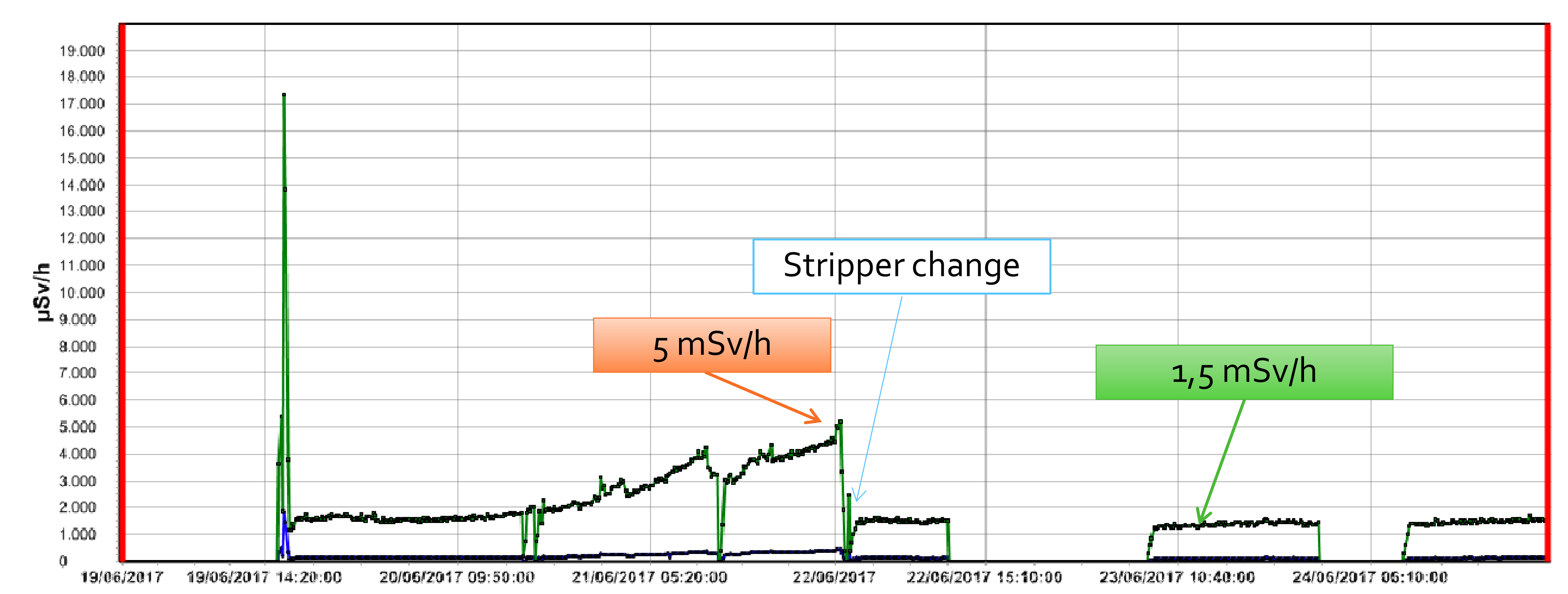
Endurance test

- Final FAT
- 5 days operation 24h
- 200 µA and 40 MeV (SPES target beam parameter)
- Limited number of interventions by the operator
- Automatic procedure to restore the beam after any trip due to accidental sparks (inflector, ion source, RF)

Test passed successfully in June and FAT concluded

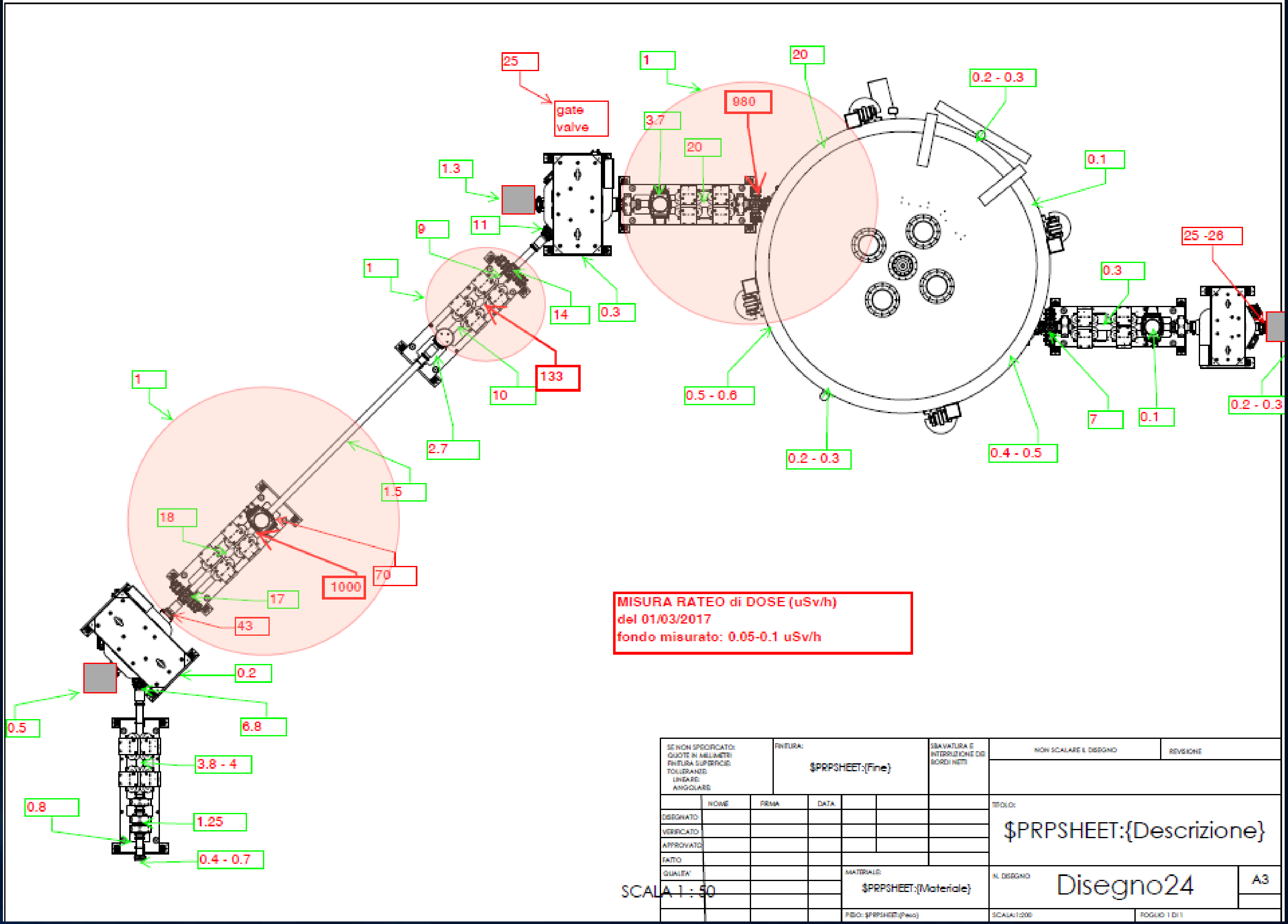


Neutron radiation in A1 during beam run (200μA, 40 MeV)



Very low beam losses along beamline: less than 1% after tuning optimization

Gamma radiation survey of A1 after endurance test



Summary

- The high intensity facility whose core is the cyclotron is developing: two main project for applications of high intensity beam are respectively in advanced phase (LARAMED) and design evaluation (NEPIR)
- The commissioning of cyclotron supplied by BEST is concluded and the training of INFN staff is almost completed.
- The machine achieved 500 μA (35kW) and shows very good performance in terms of vacuum level, acceleration efficiency and transmission as well.
- The endurance test has shown no particular critical issues related the reliability of the machine and the main system as well.
- From October 2017 the supply should be finally delivered to the INFN cyclotron group whose mission is to provide safe and efficiency delivery of high quality and high power proton beam for nuclear physics program (SPES) and applications.

Thanks to people involved in this project:

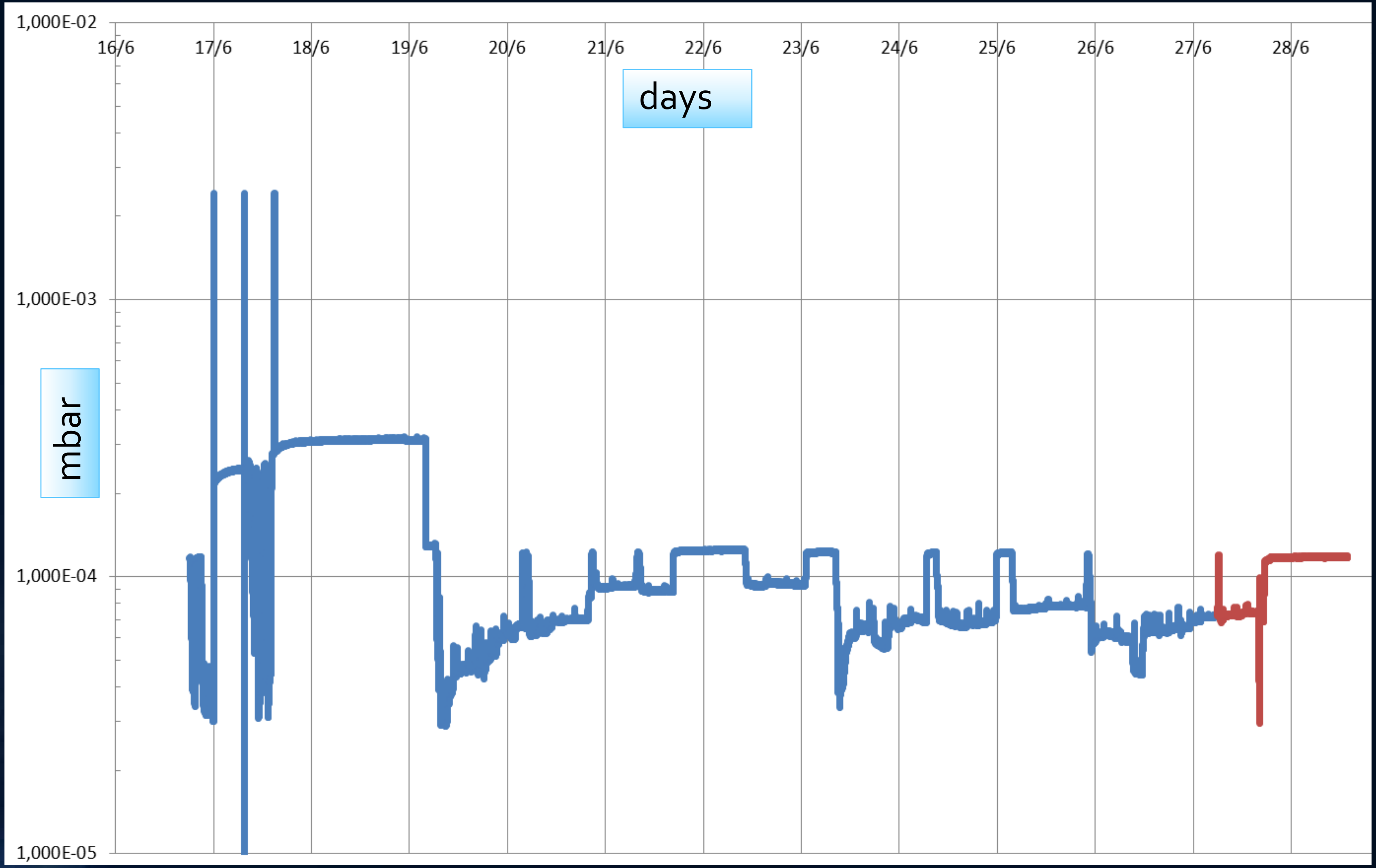
Cyclotron: A. Lombardi, P. Antonini, A. Calore, D.Campo, M. Contran, L. Pranovi

Infrastructure and Service: M. Calderolla, N. Ciatara, P.Favaron
Target and Safety: J. Esposito, D. Benini, L. De Ruvo, E.Boratto
Radioprotection: D. Zafiropulos, L. Sarchiapone
Controls and Diagnostics: M. Bellato, F. Gelain, M. Poggi, E. Fioretto, M. Gulmini
Cyclotron Consultants: L. Calabretta, C. De Martinis

Team of Best Cyclotrons System Inc.

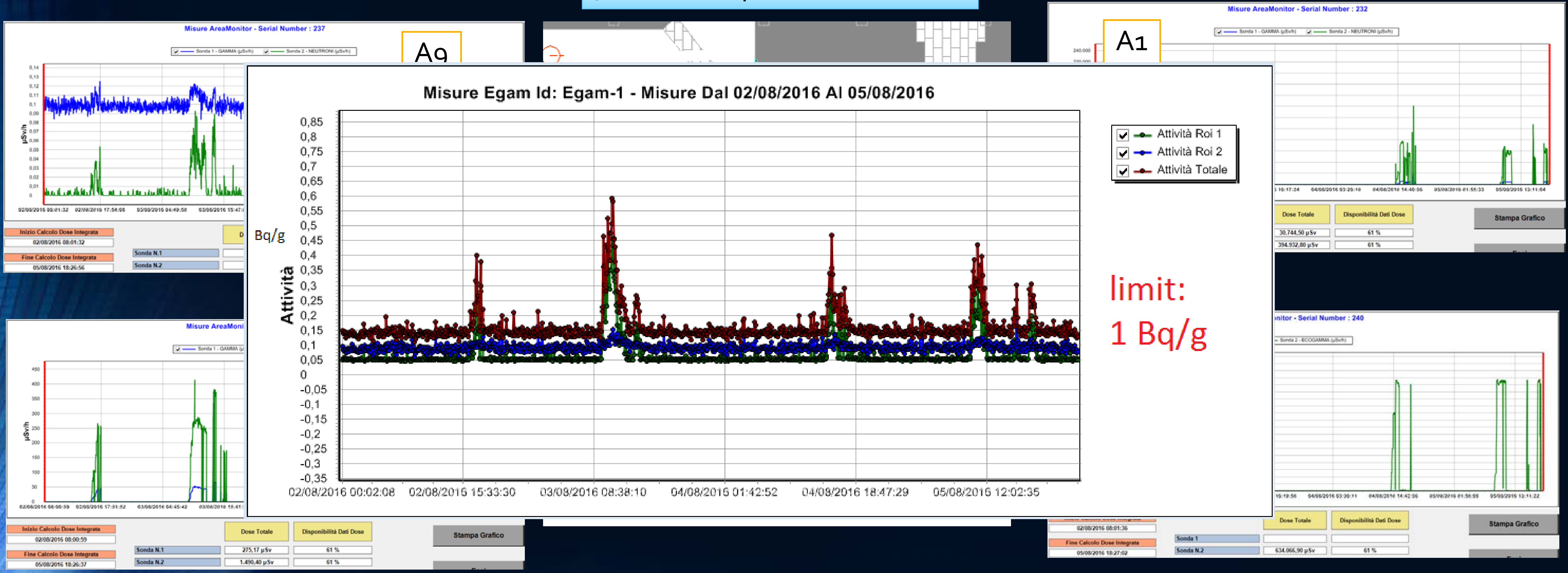
fine

Beam Dump Vacuum trend during endurance test

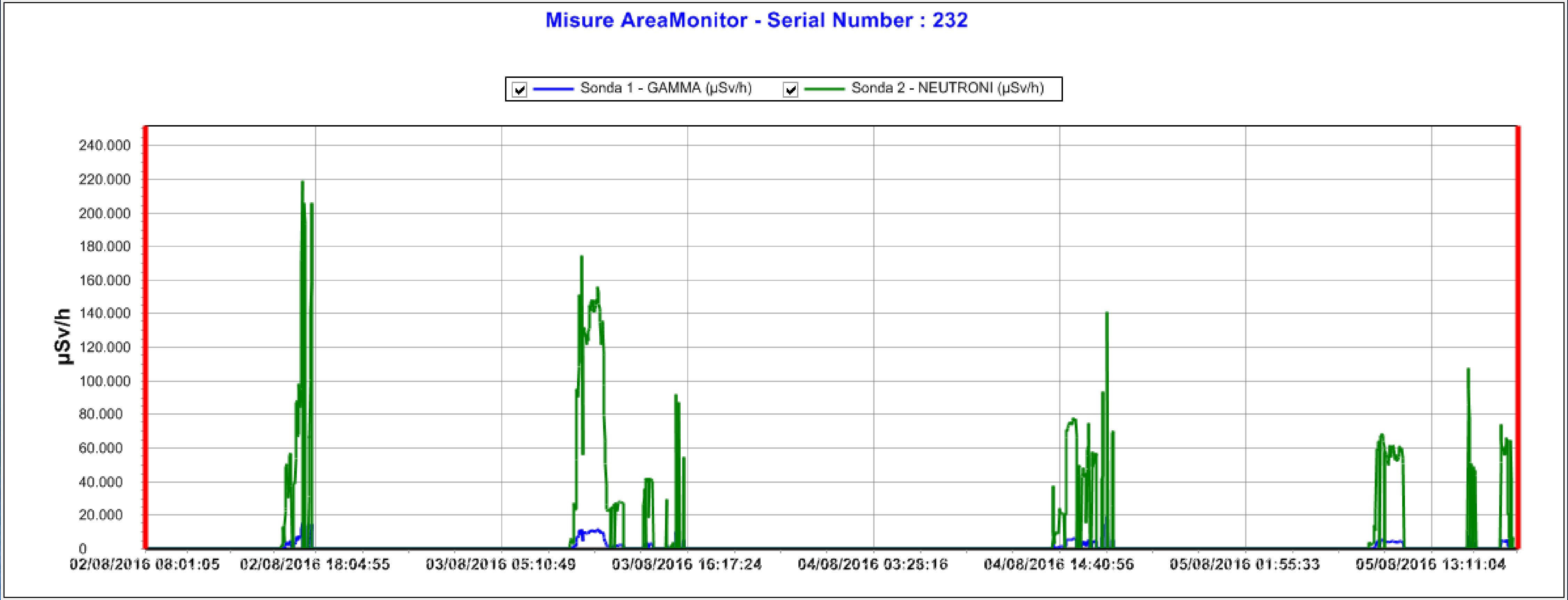


Beam loss monitoring by the Radiation Survey System

70 MeV 100 μA thru BL1 to BD



Dose rate A1 with 70MeV 100uA



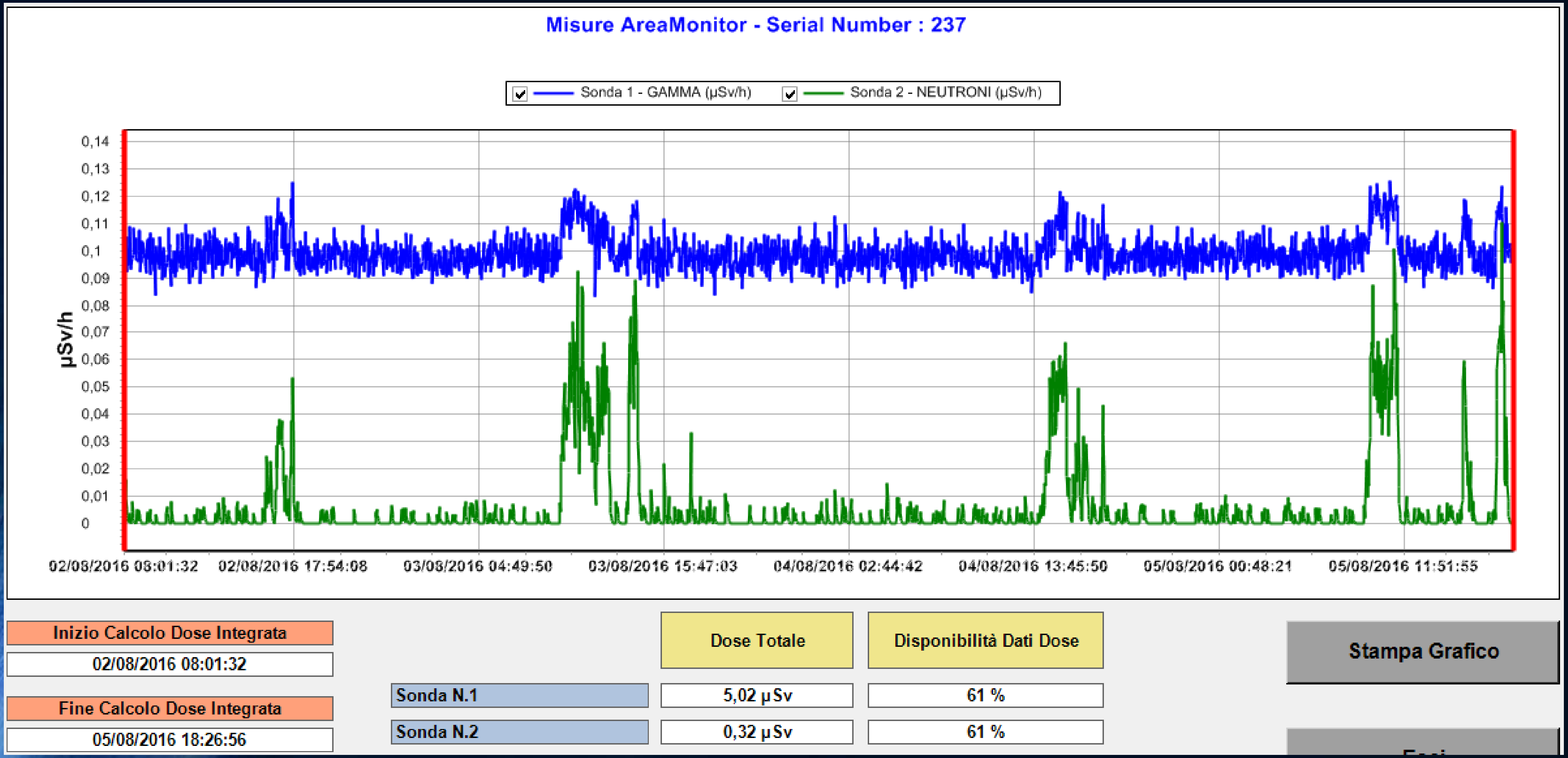
	Dose Totale	Disponibilità Dati Dose
Sonda N.1	30.744,50 µSv	61 %
Sonda N.2	394.932,80 µSv	61 %

Inizio Calcolo Dose Integrata: 02/08/2016 08:01:05

Fine Calcolo Dose Integrata: 05/08/2016 18:26:41

Stampa Grafico

Dose rate A9 with 70MeV 100uA



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Accelerators at Legnaro Labs…