Istituto Nazionale di Fisica Nucleare

# Status of High Intensity Proton Beam Facility at LNL

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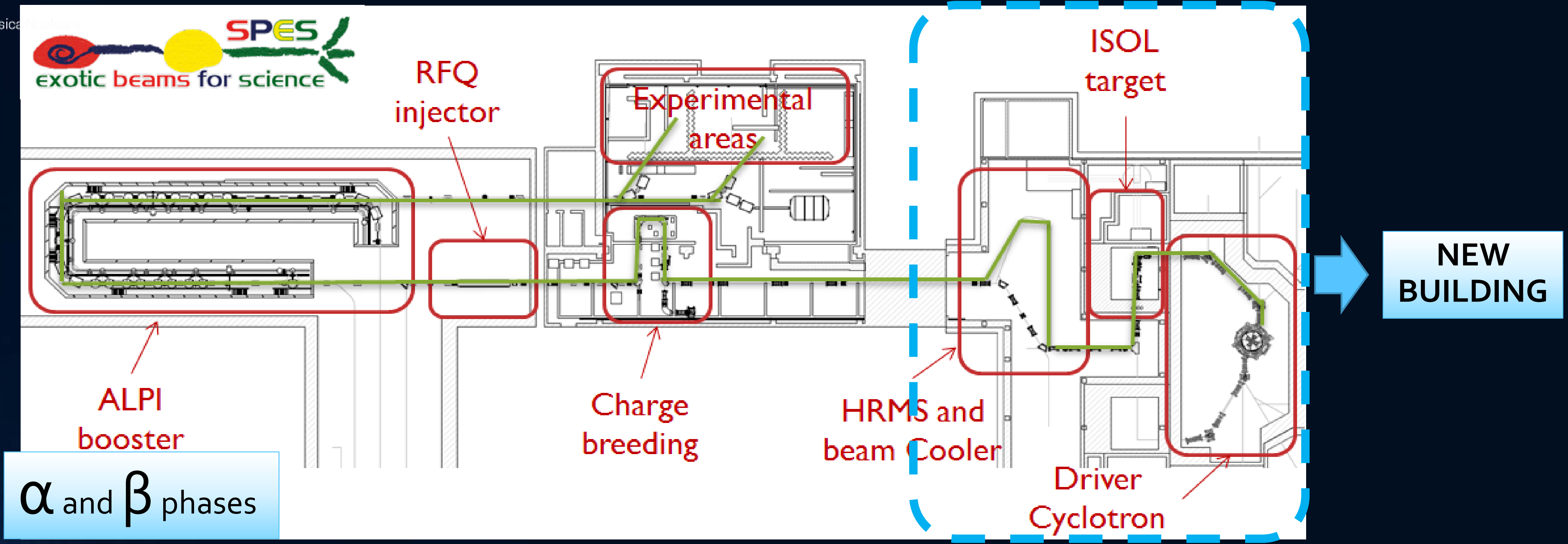
# Outline

- From SPES project to High Intensity Beam Facility
- High Intensity Beam Applications
- Building Overview
- Status of Cyclotron Installation and Commissioning

# SPES: Selective Production of Exotic Species

- Flagship of INFN on Nuclear Physics and Astrophysics Research
- 50 Meuro budget fully funded (Alpha and Beta phases)
- It consists of 4 phases:
  - **Alpha**: Cyclotron (primary beam driver) and High Intensity Beam Deliver
  - **Beta**: RIBs production and Physics at Low and High Energy (Re-acceleration)
  - **Gamma**: R&D on Radioisotope for Medical Application (LARAMED project, partially funded)
  - **Delta**: Neutrons and Applications (TDR under study)
- Construction started in 2010 with Cyclotron and in 2012 with Building
- Completion of SPES Project is expected in 2019

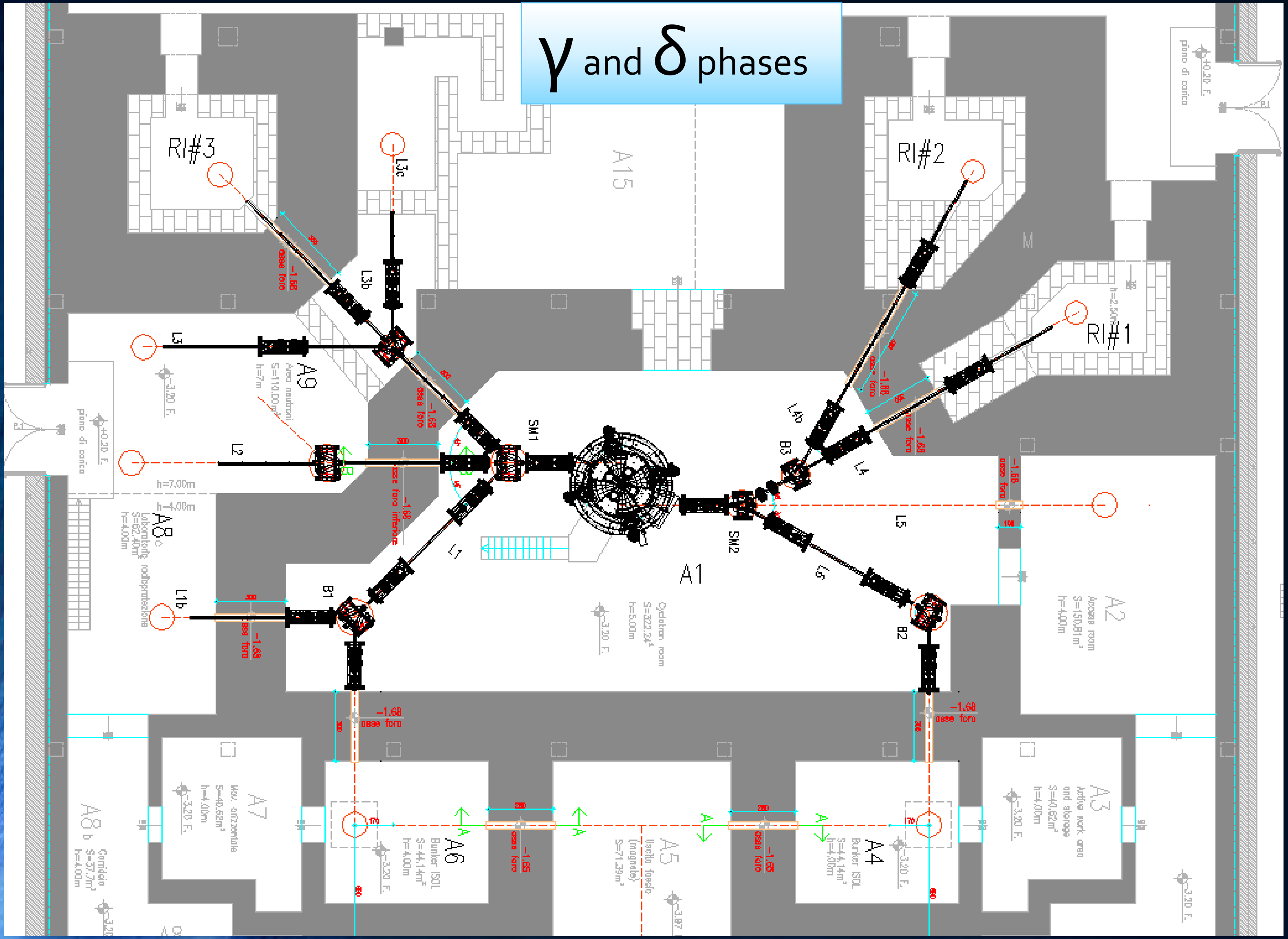



- Cyclotron and beamline under commissioning
- ISOL target on test stand
- HRMS and beam cooler under study
- Charge Breeder ready to be installed
- RFQ injector under study, final design is in progress
- ALPI upgrade is ongoing

# An High Intensity Accelerator for doing what

- In 2009 the Cyclotron was chosen as driver of SPES ISOL target to provide high intensity proton beam (700 μA @ 70 MeV)
- Cyclotron: compact and very versatile machine, easy operational and most suitable choice for delivering medium-high intensity beam (50kW).
- This kind of accelerator allows:
  - To provide proton beams at different energy and different current
  - To extract simultaneously two proton beams to be used in separated ways

# An High Intensity Accelerator for doing what (cont'd)




γ and δ phases

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

# Beam Cyclotron Sharing

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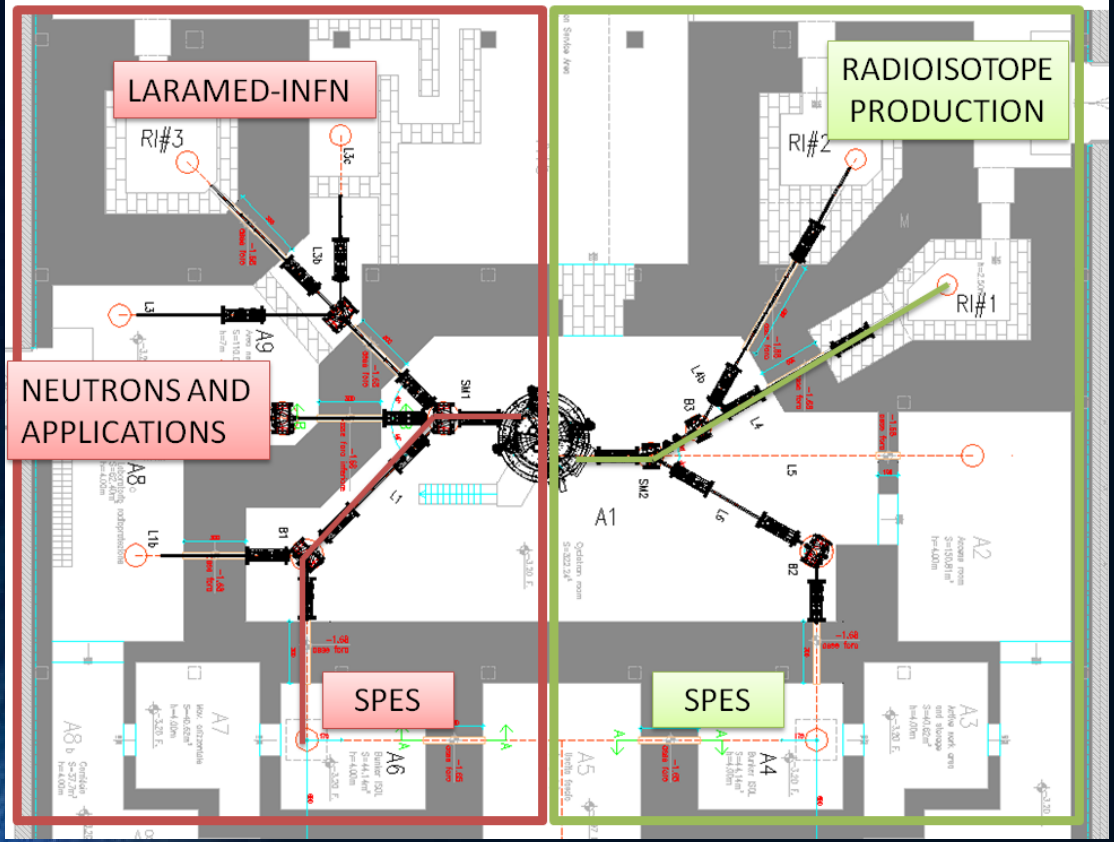
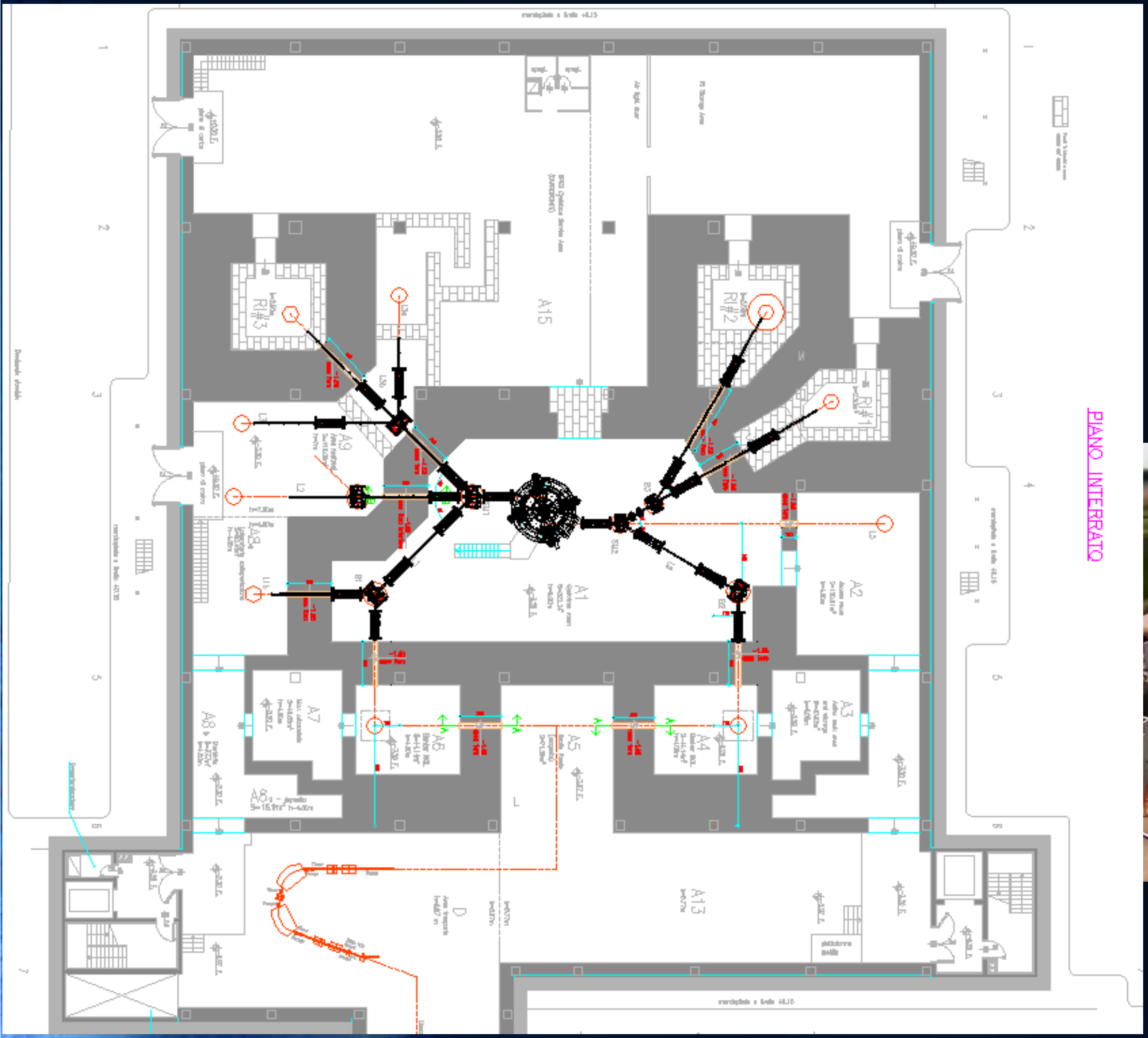
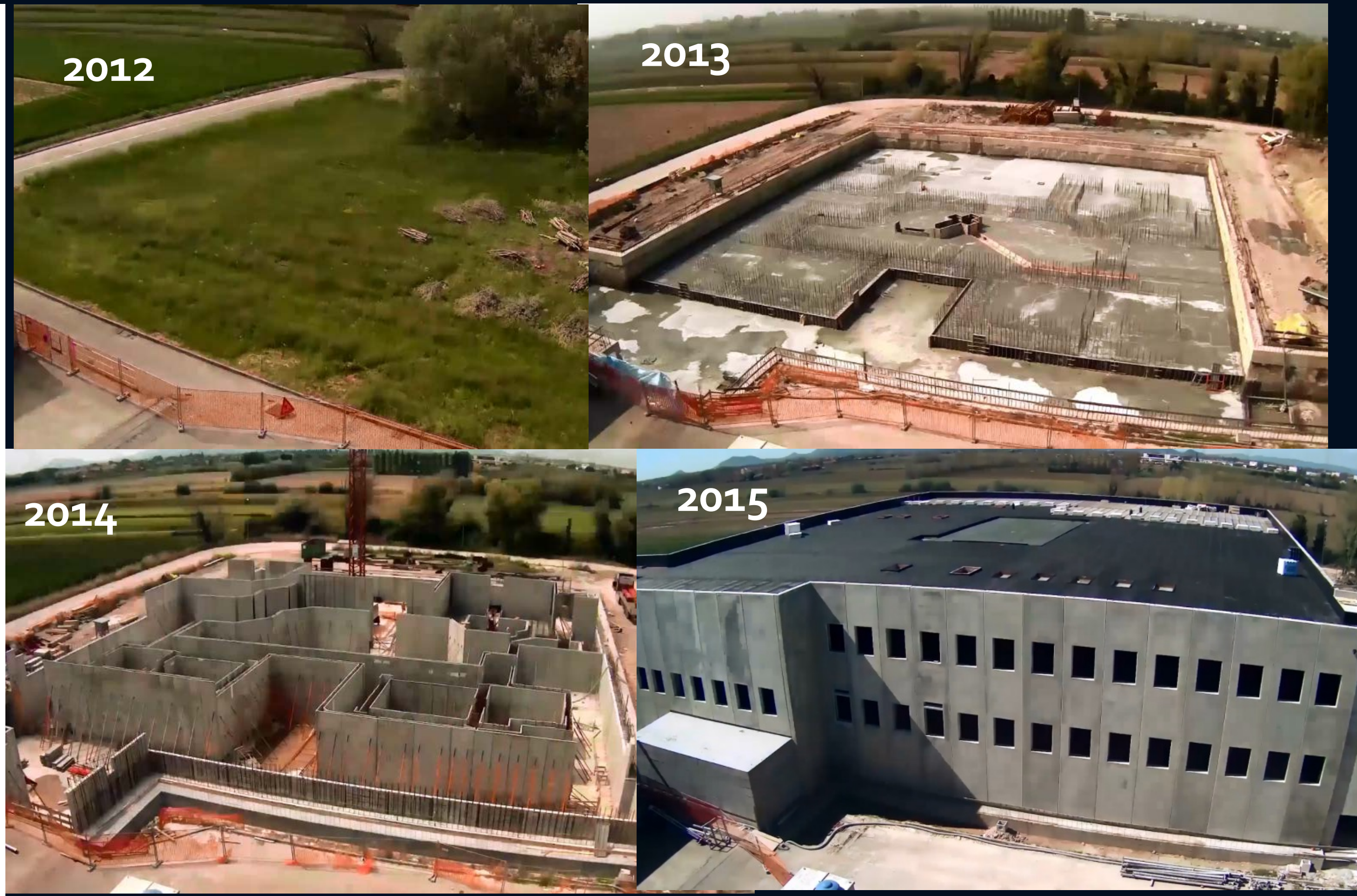



| ROOM | BTL name | MAIN USE | MAX ENERGY AND CURRENT BEAM (protons) |
|---|---|---|---|
| A6 | L1 | SPES ISOL TARGET 1 | 40 MeV, 250uA |
| A8 | L1B | TBD | |
| A9 | L2 | NEUTRONS (NEPIR) | 35-70 MeV, 50 uA |
| A9 | L3 | NEUTRONS (NEPIR) | TBD (low power) |
| RI3 | L3b | LARAMED-INFN | 35-70 MeV, 200uA |
| 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 |

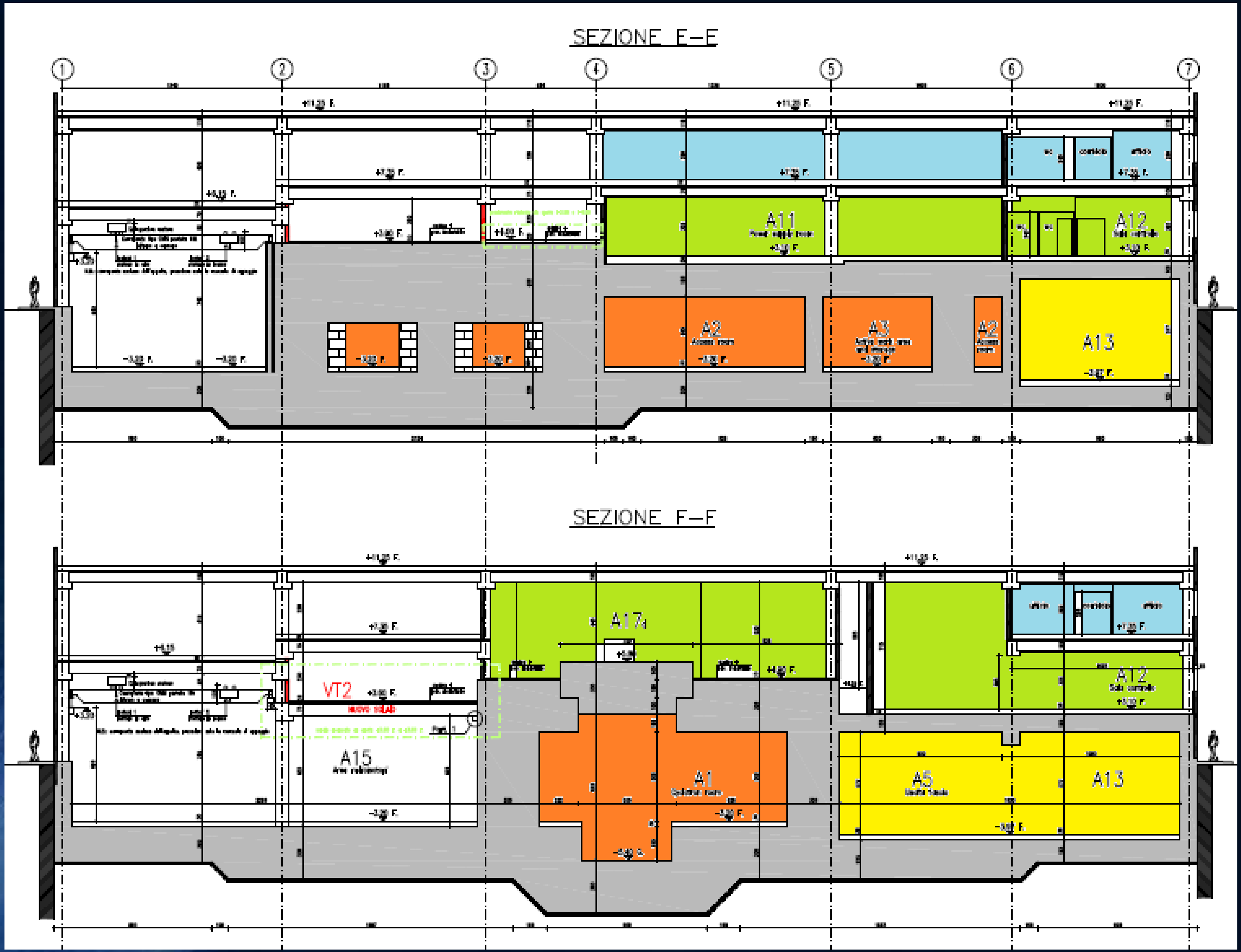
| STATIONS | | week 1 | | week 2 | | week 3 | | week 4 | | week 5 | | week 6 | | week 7 | | week 8 | | week 9 | | week 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Energy | Current | Energy | Current | Energy | Current | Energy | Current | Energy | 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 | | | | | | |

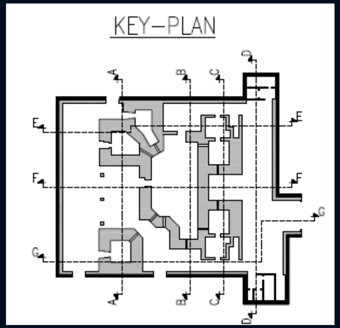
# The New Building for SPES project




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



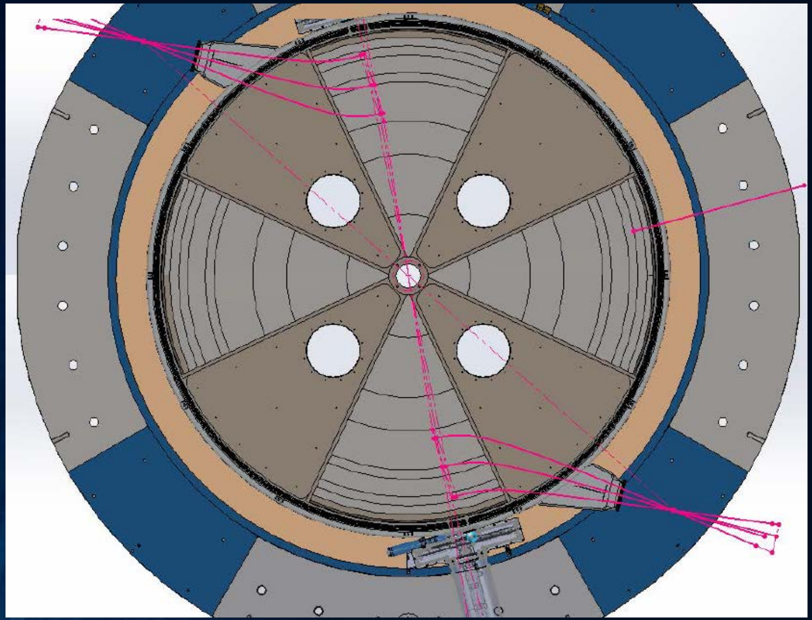




- 3 levels :
  - -1 floor : heavy shielded section to hold cyclotron and high activation areas (bunkers, ISOL target and RIBs transport)
  - 1th floor: services, conventional and special plants, ancillary laboratories and control room
  - 2nd floor: offices

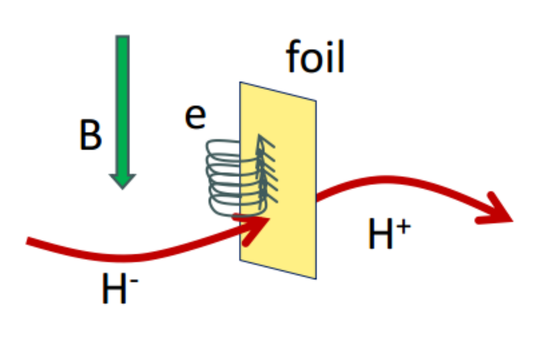
# The Cyclotron

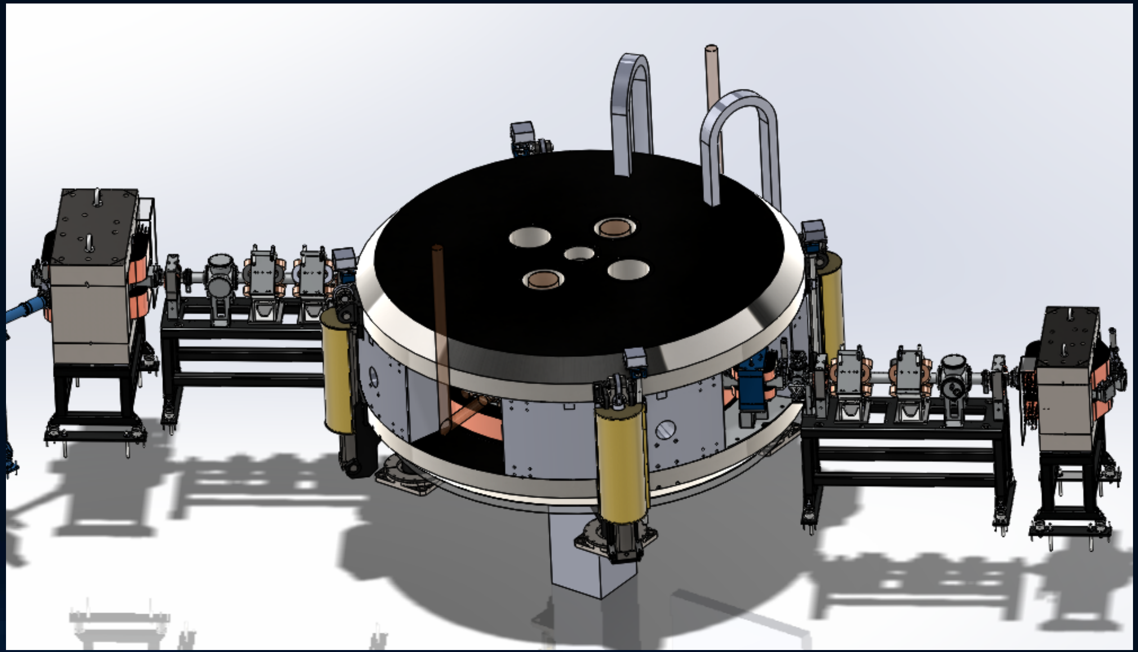

| Main Parameters | |
|---|---|
| Accelerator type | Cyclotron AVF with 4 sectors, Resistive Magnet |
| Particle | Protons ($H^-$ accelerated) |
| Energy range | 35-70 MeV |
| Max Current Intensity | 700 µA (variable within the range 1µA-700µA) |
| Extraction | Dual stripping extraction |
| Max Magnetic Field | 1.6 T (B0 = 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 |

# Dual Beam Extraction



- Simultaneous extraction of two beams at the same energy
- Extraction energy varies between 35-70 MeV
- Tuning of current of extracted beams from few μA to 700μA ($I_{tot}$ = 700 μA).



# Brief Summary of Cyclotron Roadmap

- Supplied (including one beamline) by BEST Theratronics company (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 on Sept. 2014
- Factory Acceptance Test concluded on Nov. 2014

# Cyclotron installation at LNL


Ottawa, Jan 2015, Cyclotron leaving Factory


Legnaro, May 2015, Cyclotron at LNL


LNL, May, first day of operation


Upper pole cap installation during 2nd day

# BEST and INFN "joint venture"

# During the 2015 not only the cyclotron has been installed…


Power Supply room


Services room


Water plant

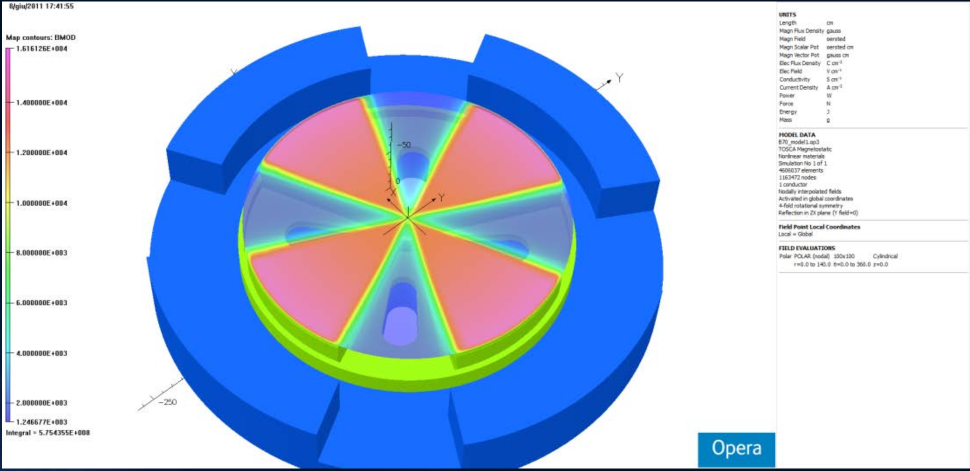

beamline

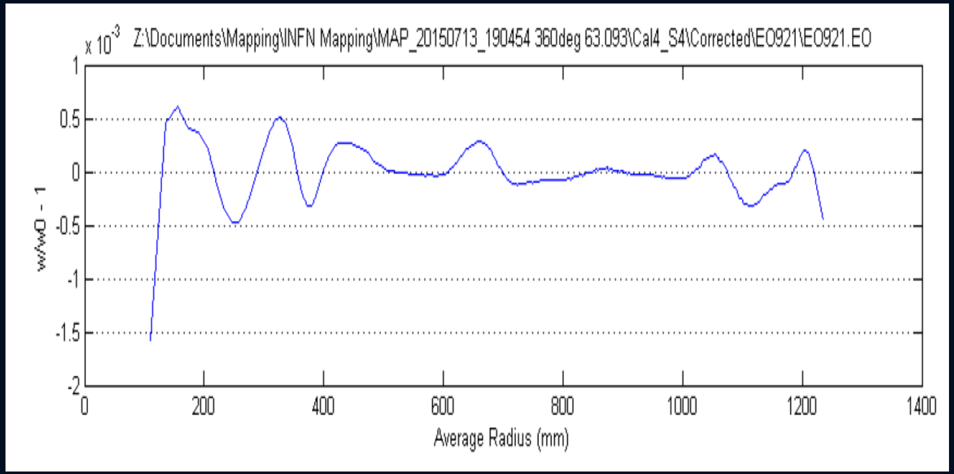

Sliding shielded doors

# Cyclotron and beamlines today

# Cyclotron performance stated to date

- Magnetic Field Mapping done in Site (LNL) on July shows a good isochronism $|\Delta B/B| < 5 \cdot 10^{-4}$ and negligible values of harmonic content




- Vacuum reaches $7{,}5 \cdot 10^{-8}$ torr (no beam) in few hours of pump down
- Amplitude and Phase stability of RF cavities achieve respectively $|\Delta f/f| < 10^{-4}$ and $\phi \sim \pm 1$ deg

# Acceptance Test @ 1 MeV : Central Region performance

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- On Dec 2015 BEST Company carried out the acceptance test of injection and acceleration up to 1 MeV and 800μA current
- 2 hrs beam dumping on 1MeV probe at 800μA without operator intervention
- Only 2 beam trips (inflector spark and RF) and auto recovery of the system
- Very good performance:
  - Stable beam current : ripple within ±0.4%
  - 13% of injection efficiency (10% requested)
  - Large acceptance of the machine (more than 50 RF deg)
  - 820 μA at 1 MeV for 10 minutes and 900 μA as peak value we get without any problem
  - Ion source performance are good

# Low Power Acceleration Test

- On Feb 2016 BEST Company provides the first full acceleration of beam at low power without extraction
- $H^-$ beam at 3 µA current was accelerated from 1MeV to 70 MeV with 5MeV step and stopped on the internal radial probe (water cooled).
- No current losses have been detected along the acceleration path
- Vacuum keep low : $9 \cdot 10^{-8}$ torr
- Final test to prove the beam dynamic at maximum permitted

power (700W):

  - 10 µA @ 70 MeV
  - 20 µA @ 35 MeV

# Next Steps

- The facility must to be implemented to allow the extraction and the beam transport at full power:
  - Safety and RP issues (labyrinth to access in A1)
  - Cleaning of building
  - Last section of beamline to get A6 bunker
  - Beam dump at 50 kW (R&D and construction by LNL)

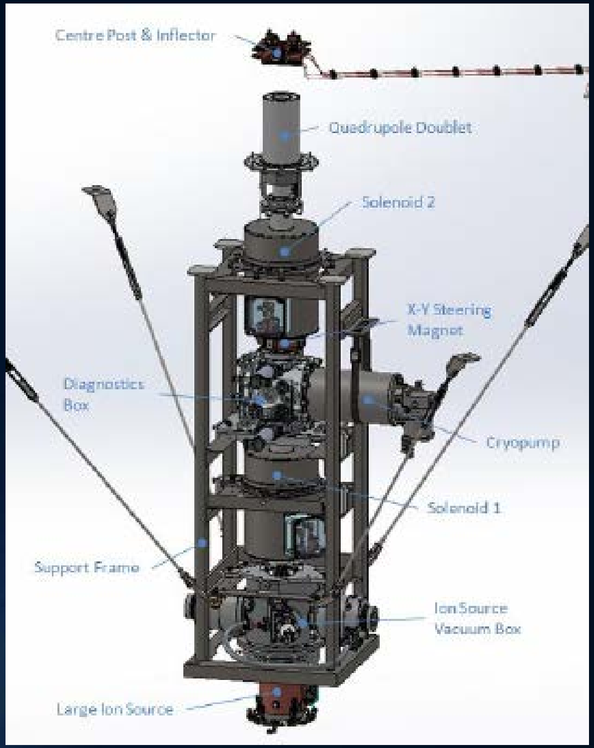
- On May, we should start the final commissioning of the machine and beamline at full power

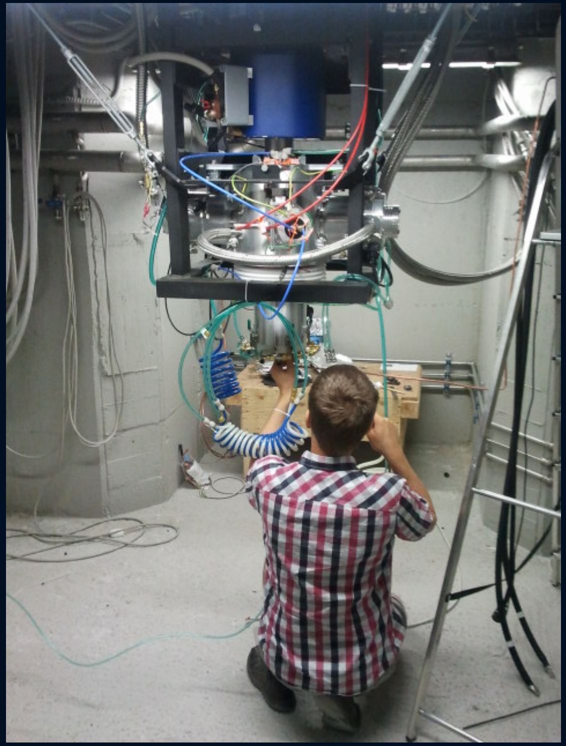
# Conclusions

- The SPES project is now entering its construction stage. The project is fully funded and its completion is expected in 2019.
- The high intensity facility whose core is the cyclotron is developing: the implementation of SPES alpha phase is going on and different applications of high intensity beam are in design phase (LARAMED) and under evaluation (Fast Neutron Source program)
- The installation of cyclotron supplied by BEST is concluded and the commissioning of the accelerator and beamline is in progress
- First important test about the central region performance and the acceleration at full energy prove the robust design of the machine and it raises high expectations.
- In 2016 the cyclotron should be fully operational: very exciting perspectives for LNL future in nuclear physics and interdisciplinary research.

thanks

# Ion source



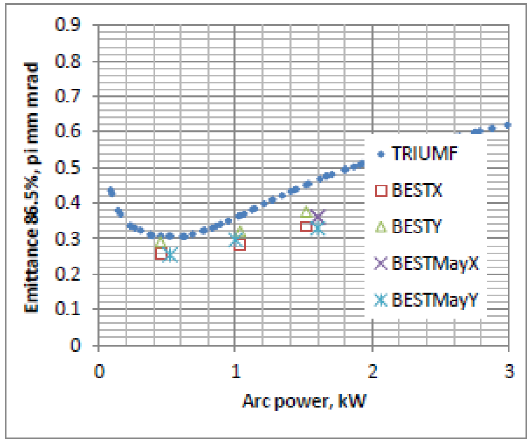



Figure 11. Emittance measurements.

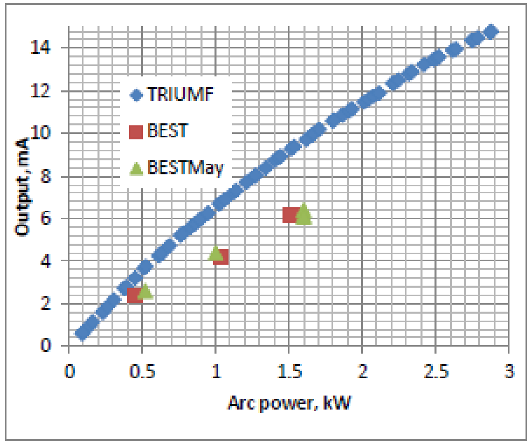



Figure 12. Ion source output.