# SPES project

## SPES status


Gianfranco Prete

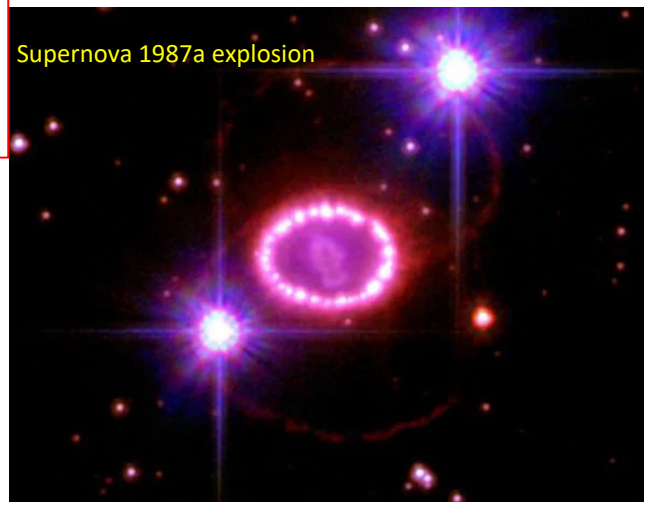
15 settembre 2020

# SPES

## Selective Production of Exotic Species

Second generation ISOL facility

High intensity → $10^{13}$ fission/s
High beam purity → HRMS 1/20.000
High beam energy → ALPI linac 10A MeV

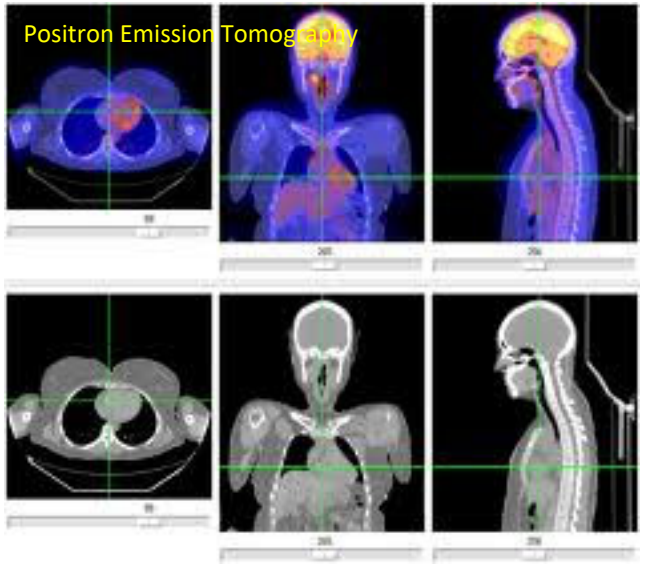



**Nuclear Physics:**

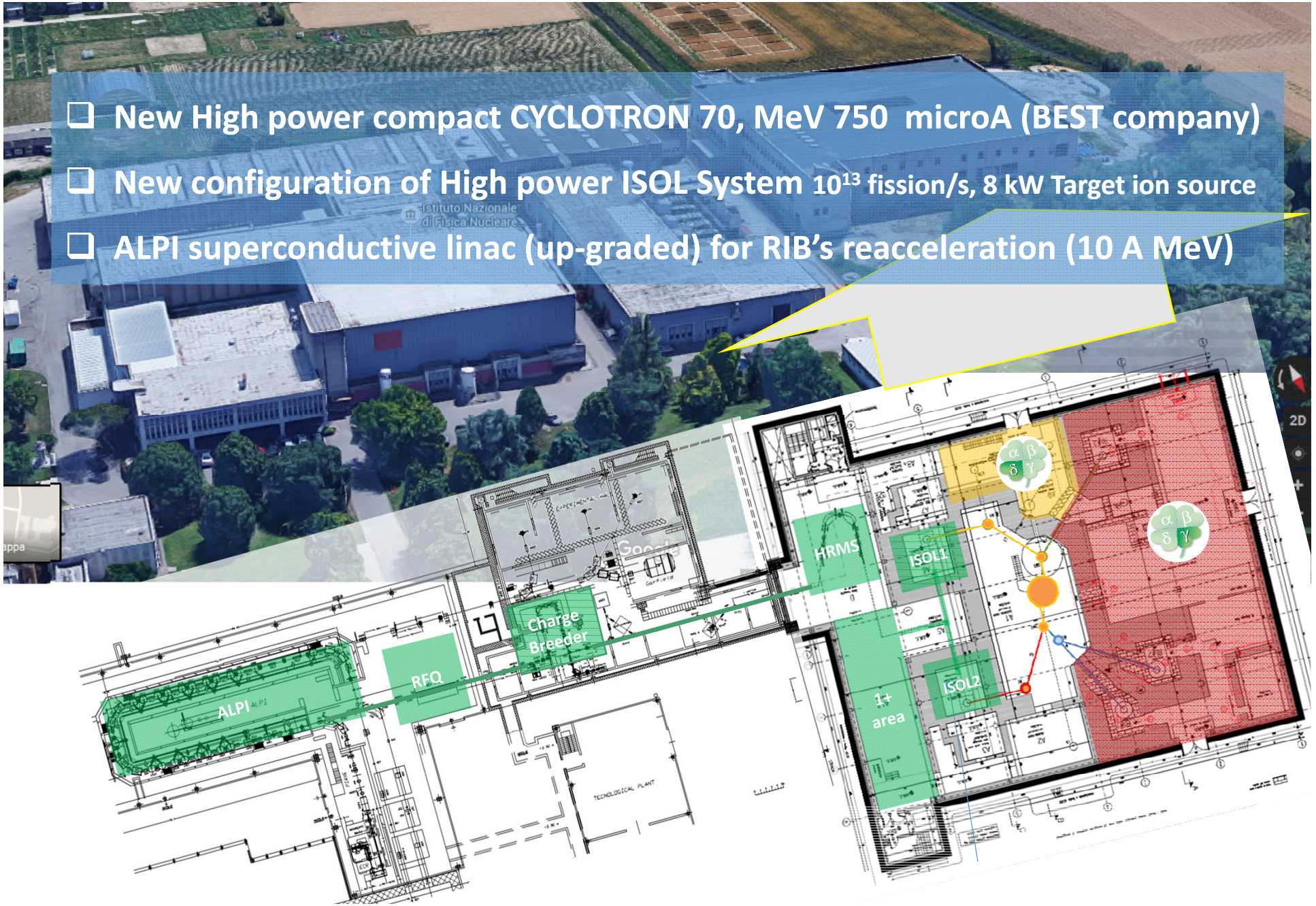
- Study of atomic nuclei produced in the star evolution process (nuclei far from stability)

**Applications:**

- Production of radioisotopes of medical interest
- Production of neutron beams

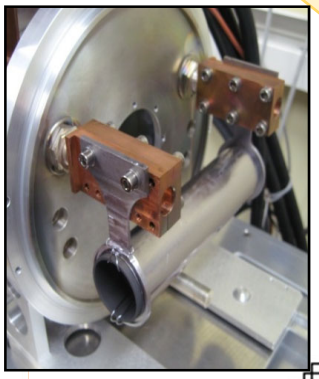


# SPES infrastructure - layout



# Nuclei produced with SPES

40 MeV Proton induced fission on U target



SPES radioactive nuclei

SPES beams

114

Super Heavy stability ???

$^{144}Xe+$ $^{208}Pb$

82

terra incognita

184

126

r-process path

Neutron Drip Line

82

Radioactive nuclei produced in star evolution

28

20

50

8

28

2

Z

N

RIB Intensity on Target (ions/sec)

$10^8$
$10^7$
$10^6$
$10^5$
$10^4$
$<10^3$

Stable Ion Beams

Half-life Range
Unknown
<0.1 s
0.1 - 5 s
5 - 100 s
100 s - 1 h
1 h - 1 y
1 y - 1 Gy
Stable

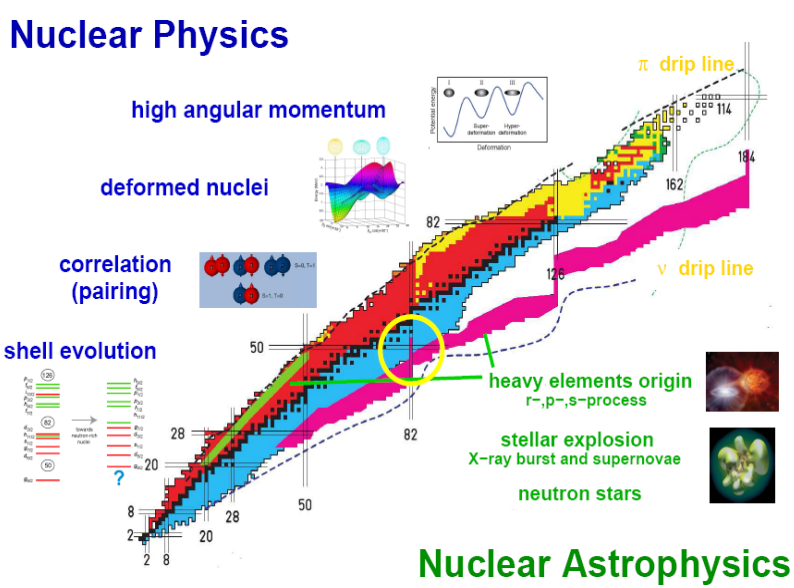
# SPES physics

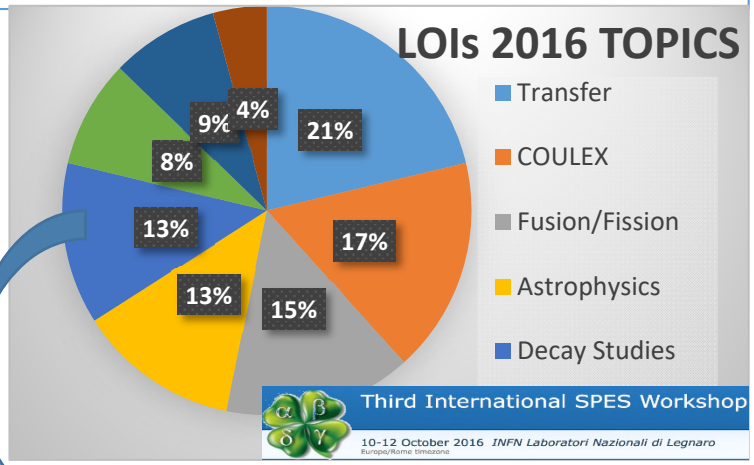
First SPES Physics workshop: 2008

International workshop: 2010, 2014, 2016

One-day workshop:

- 2012, Napoli Transfer reactions,
- 2012, Firenze Coulomb Excitation
- 2013, Milano Collective excitations
- 2013, Catania Iso-spin on reaction machanism with RIBs
- 2015, Milano Physics with non reaccelerated beams
- 2015, Caserta Nuclear astrophysics
- 2018, Pisa Fundamental symmetries and interactions
- 2019, Ferrara Interdisciplinary activities and applications

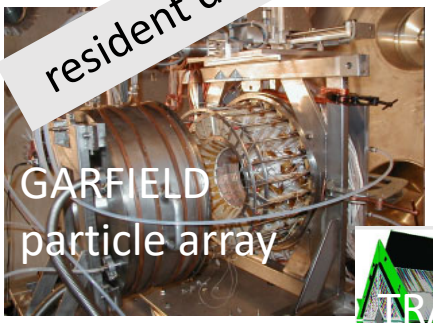


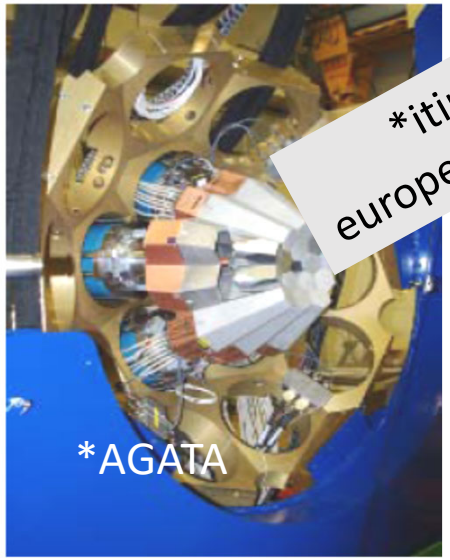

47 LOIs submitted to SAC for 89 RIBs
15% with non re-accelerated RIBs
21% with 132Sn

# Instrumentation at SPES

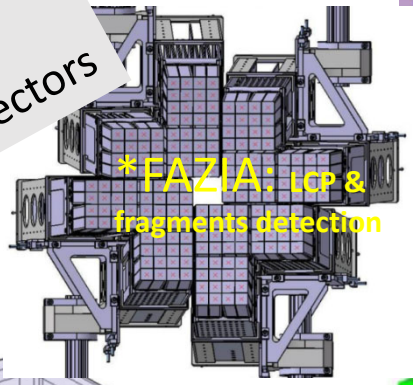

resident detectors

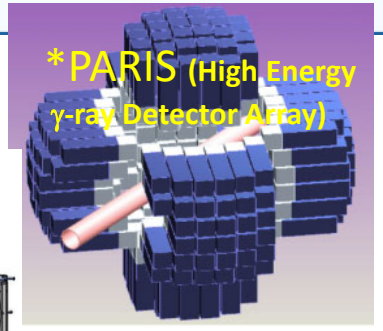


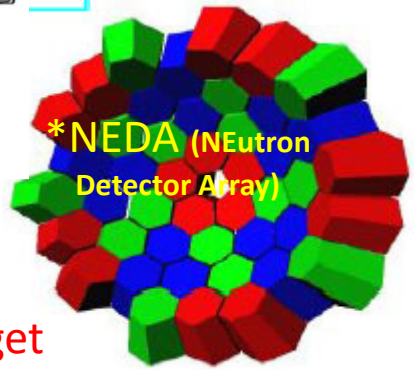


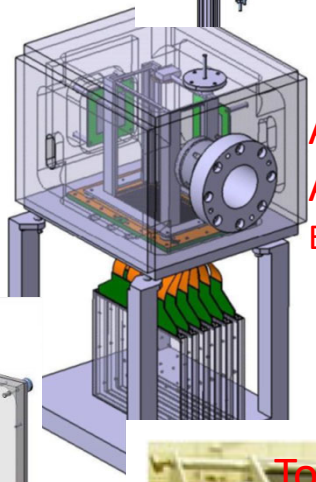




*itinerant european detectors



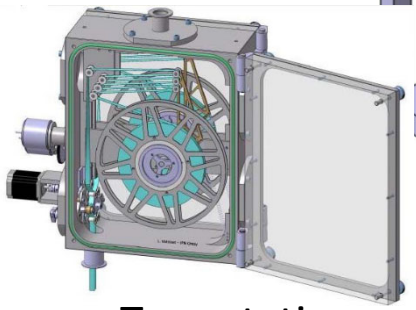



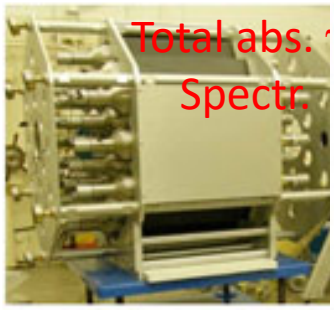
ACTAR
Active Target
ENSAR2

(ORNL collaboration)

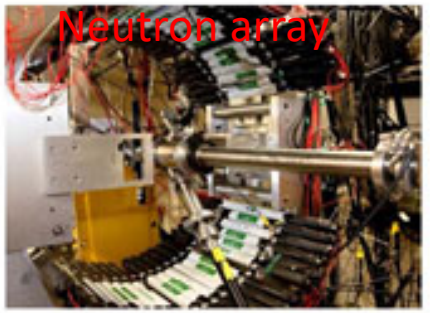


Tape station
(ALTO-INFN-iThembaLabs)

MTAS
Total abs. Spectr.

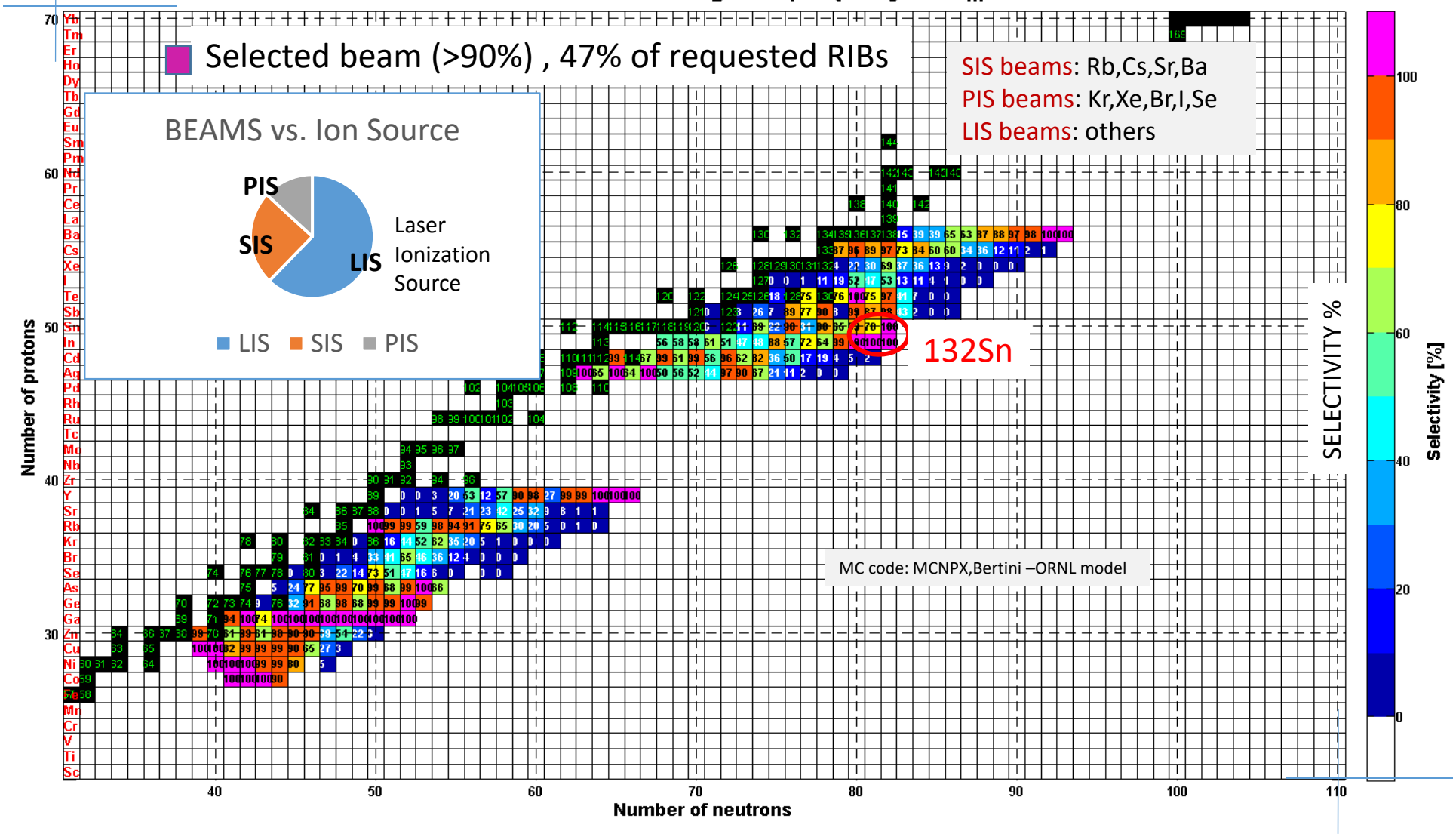


VANDLE
Neutron array

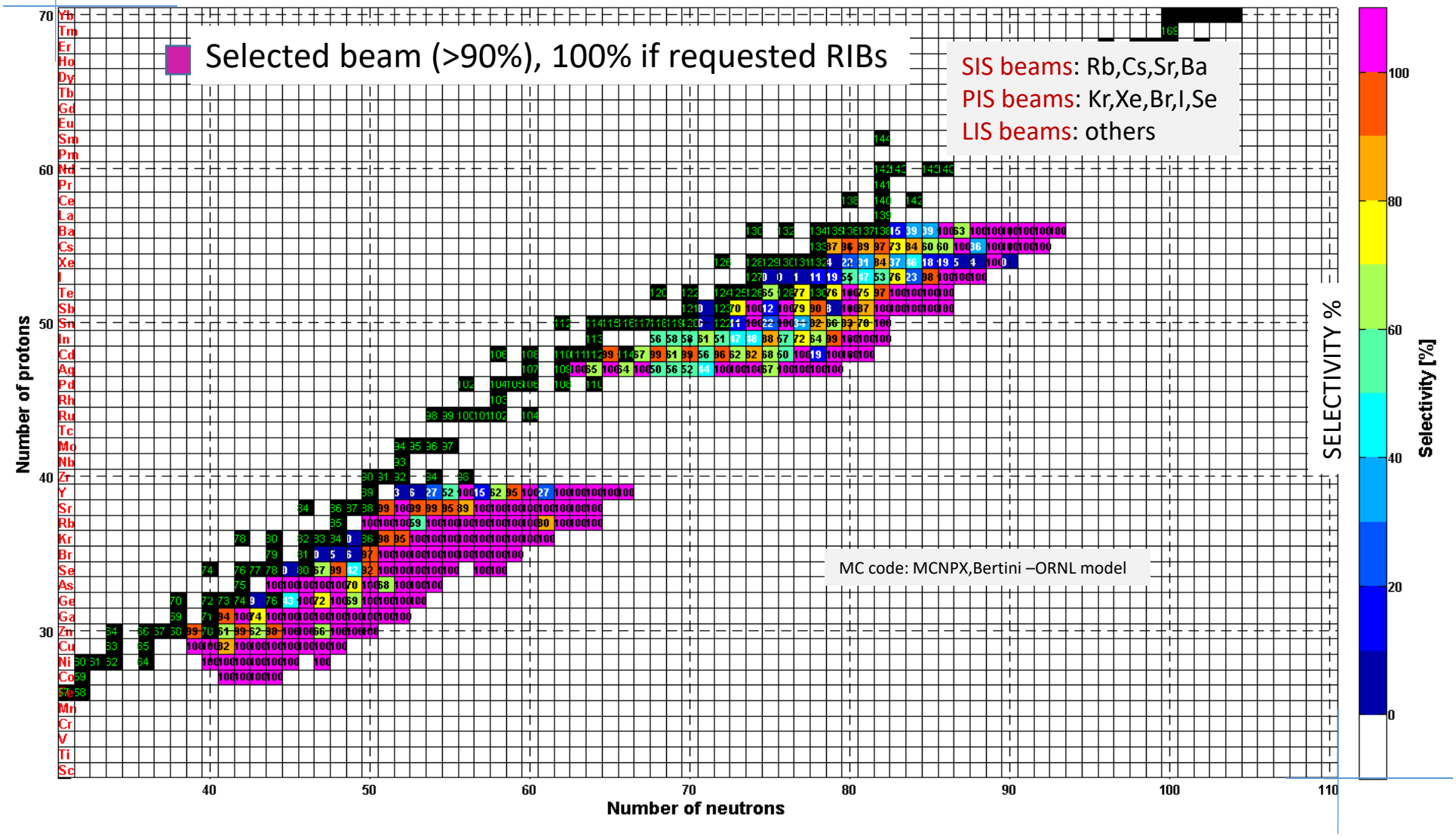


# Beam Selectivity with LRMS (1/200)

Path toward beam selectivity: **in-target reaction** → ion-source → mass separation



# Beam Selectivity with HRMS (1/20.000)



# HRMS High Resolution Mass Separator

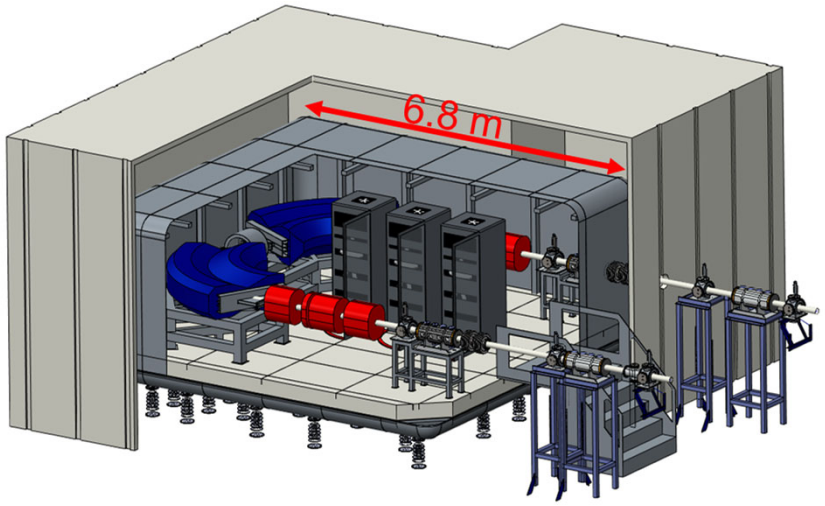
Design goal: 1/20.000

- Physical design ready*, integration with beam cooler and beam lines under way
- Preliminary dipole design and feasibility check with potential manufacturer done
- Evolution:

–Critical Design Review in October 2018

–Authorization to tender January 2021

–Commissioning 2023




*Preliminary design in collaboration with LNS, following the design of "modern" mass separators as CARIBU_ANL, DESIR_SPIRAL2, ARIEL_TRIUMF

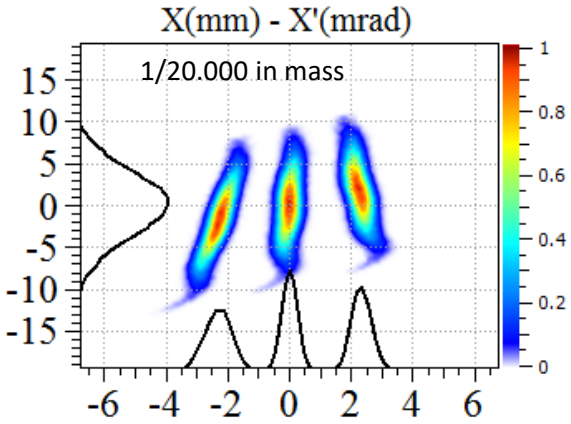
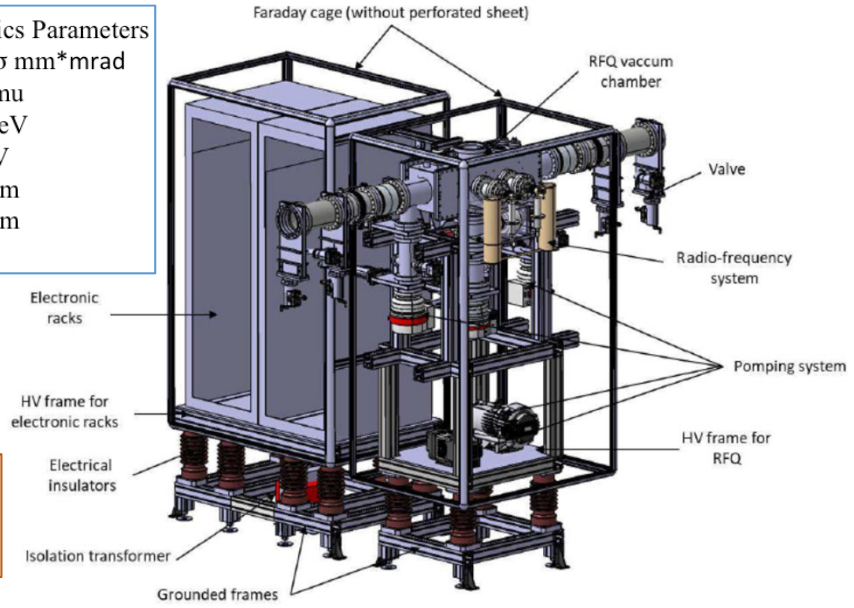



Table 2: Beam Dynamics Parameters

| | | |
|---|---|---|
| Geometric Emittance | 2.7 | 4σ mm*mrad |
| Ion Mass (q=1) | 132 | amu |
| Beam Energy | 260 | KeV |
| RMS Energy Spread | 1 | eV |
| RMS Spot size at image | 0.3 | mm |
| Maximum X range | 440 | mm |



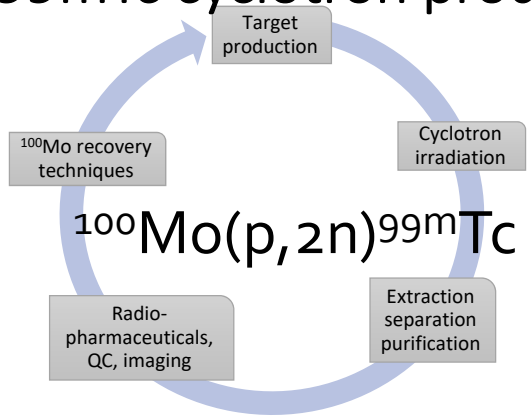

**RFQ beam cooler** is necessary to match the entrance beam requirements (under construction with LPC_Caen)

# Application: Radioisotopes for medicine

## Laramed project

Direct use of the Cyclotron proton beam

Direct 99mTc cyclotron production




- New routes for producing novel radionuclides having potential interest in Nuclear Medicine
- Reaction cross-section measurements

- Radiochemical developments
- Radiopharmaceuticals Labelling

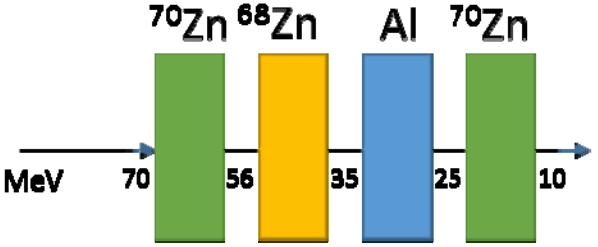
(vedi presentazione Petra Martini)

## Theranostic Radionuclides

*Therapy* *alpha, beta , Auger e-*

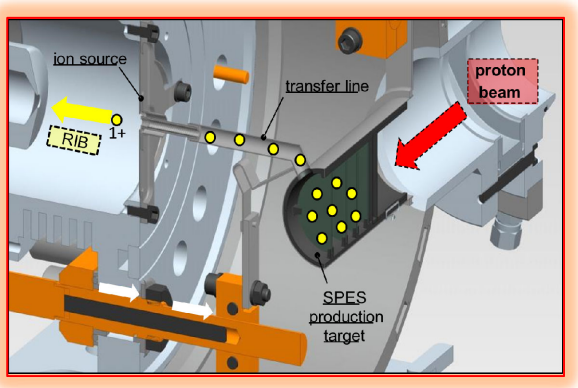
*Diagnostic* *gamma or positrons*

$^{70}Zn(p,x)^{67}Cu$, $^{64}Cu$ cross sections at 45-70 MeV on composite target



# Application: Radioisotopes for medicine

ISOLPHARM *
SPES exotic beams for medicine




Use of ISOL method for the production of **unconventional radioisotopes** (difficult to produce with traditional techniques), carrier-free with large radionuclide purity.




(vedi presentazione Stefano Corradetti)

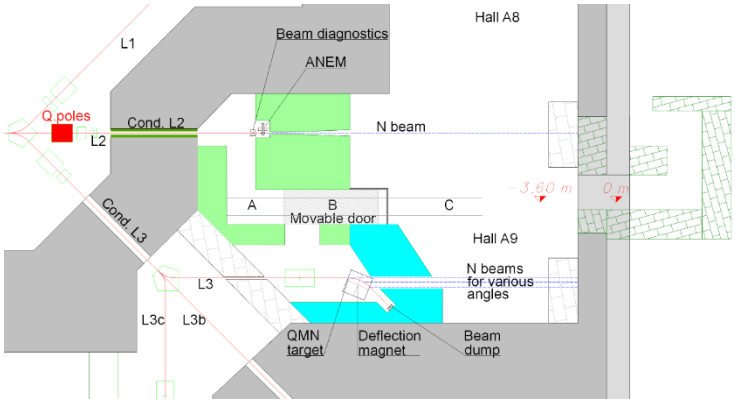
*INFN PATENT

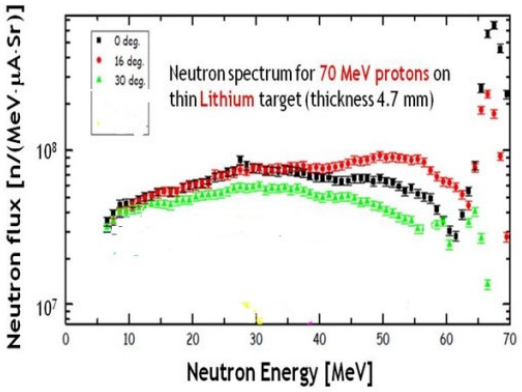
# Application: Neutron facility at SPES

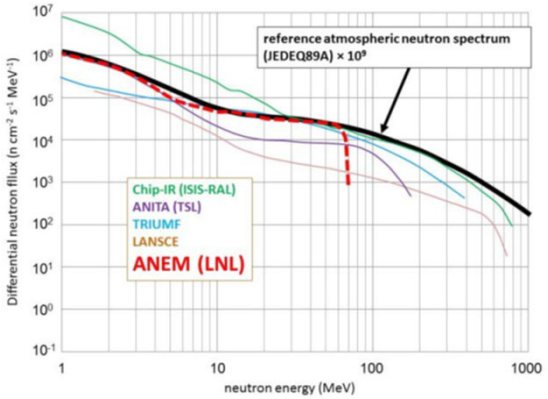
Neutron production by interaction of protons with heavy and light targets

- Fast neutron production: ~ $6 \cdot 10^{14}$ $s^{-1}$
- Neutron flux $\Phi_n$ @ 2.5 m: $5 \times 10^8$ n $cm^{-2}$ $s^{-1}$

  - Continuum spectra: SSE, Single Event Effect study (thick Be-W rotating target)
  - Quasi mono-energetic spectra (thin Li target)

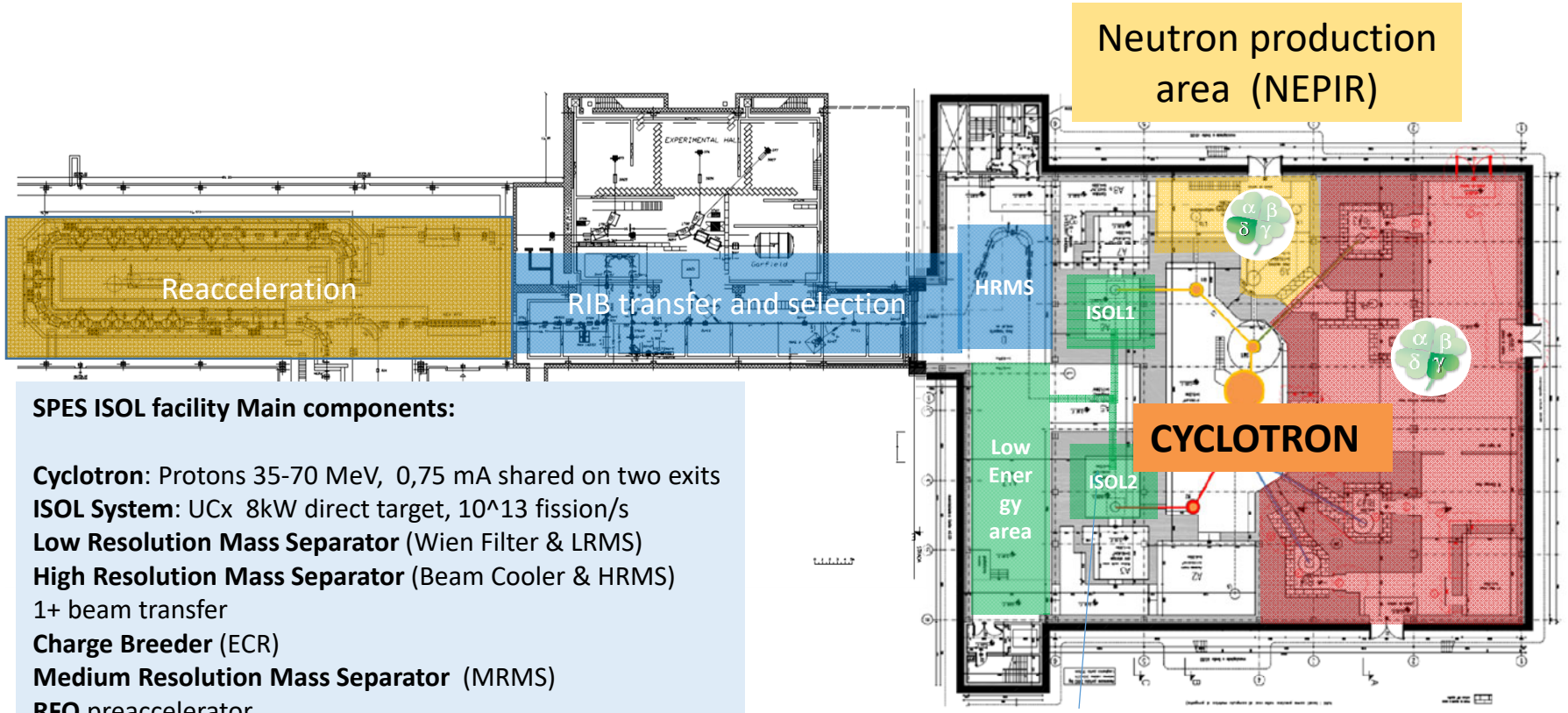



Progetto Premiale SPARE:
**Spa**ce **R**adiation Shi**e**lding

# SPES layout and components




**SPES ISOL facility Main components:**

**Cyclotron**: Protons 35-70 MeV, 0,75 mA shared on two exits
**ISOL System**: UCx 8kW direct target, 10^13 fission/s
**Low Resolution Mass Separator** (Wien Filter & LRMS)
**High Resolution Mass Separator** (Beam Cooler & HRMS)
1+ beam transfer
**Charge Breeder** (ECR)
**Medium Resolution Mass Separator** (MRMS)
**RFQ** preaccelerator
**ALPI** superconductive linac

RIB reacceleration:

- new RFQ
- ALPI

1/20.000 Mass separator
(Beam Cooler + HRMS)
Elettrostatic beam transport
Charge Breeder (n+)
1/1000 mass separator

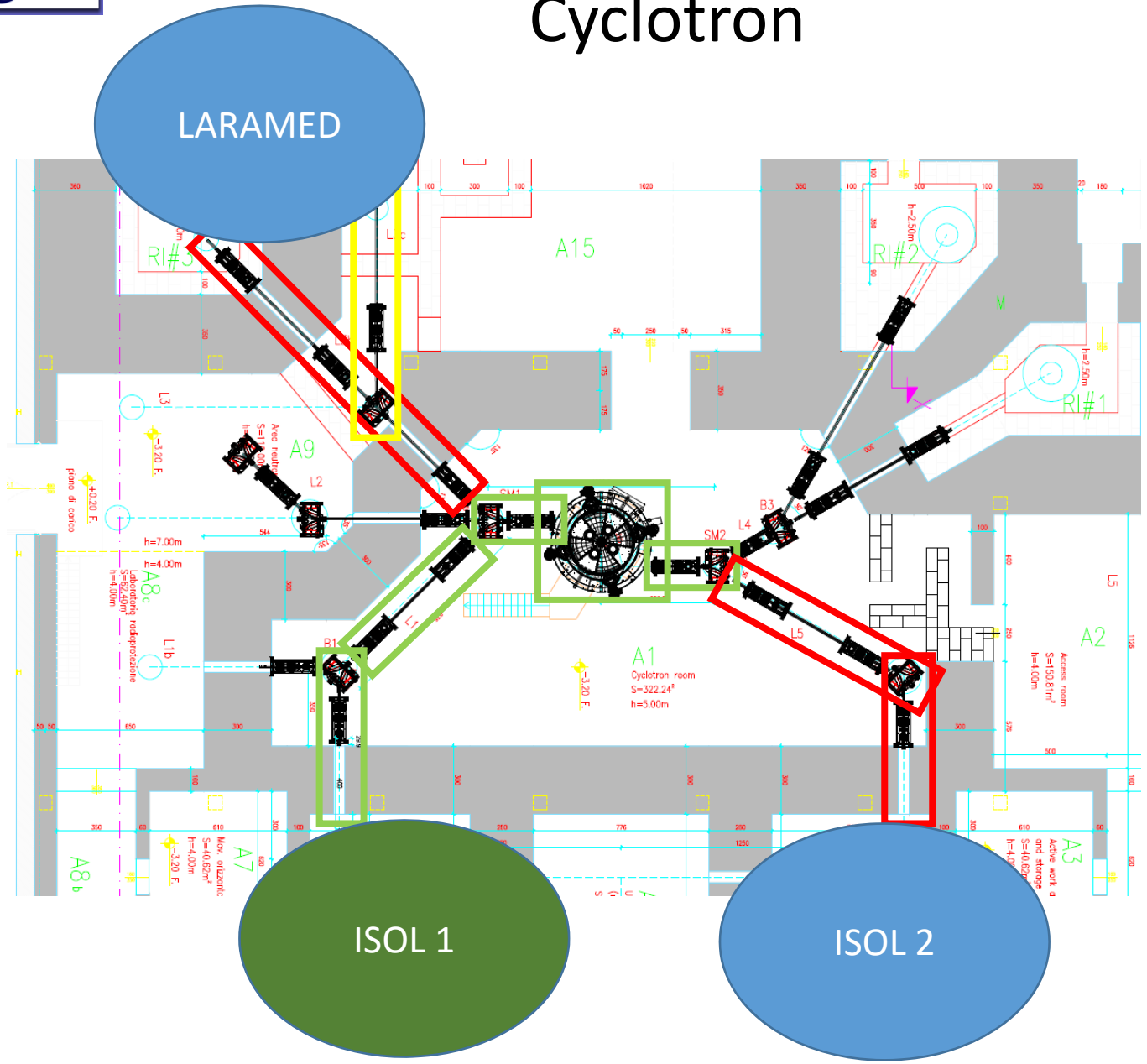
ISOL bunkers
1/200 mass separator
low energy experimental area

Radioisotopes production area (LARAMED)

# WP_B5 Cyclotron


Cyclotron operation is restarting after the beam lines upgrade (LARAMED and ISOL2). First operation step: proton source and injection (950 microA accelerated at 1 MeV)

# Upgrade planning for SPES Cyclotron




Actual Installation: Cyclotron and BL1, BL2 lines

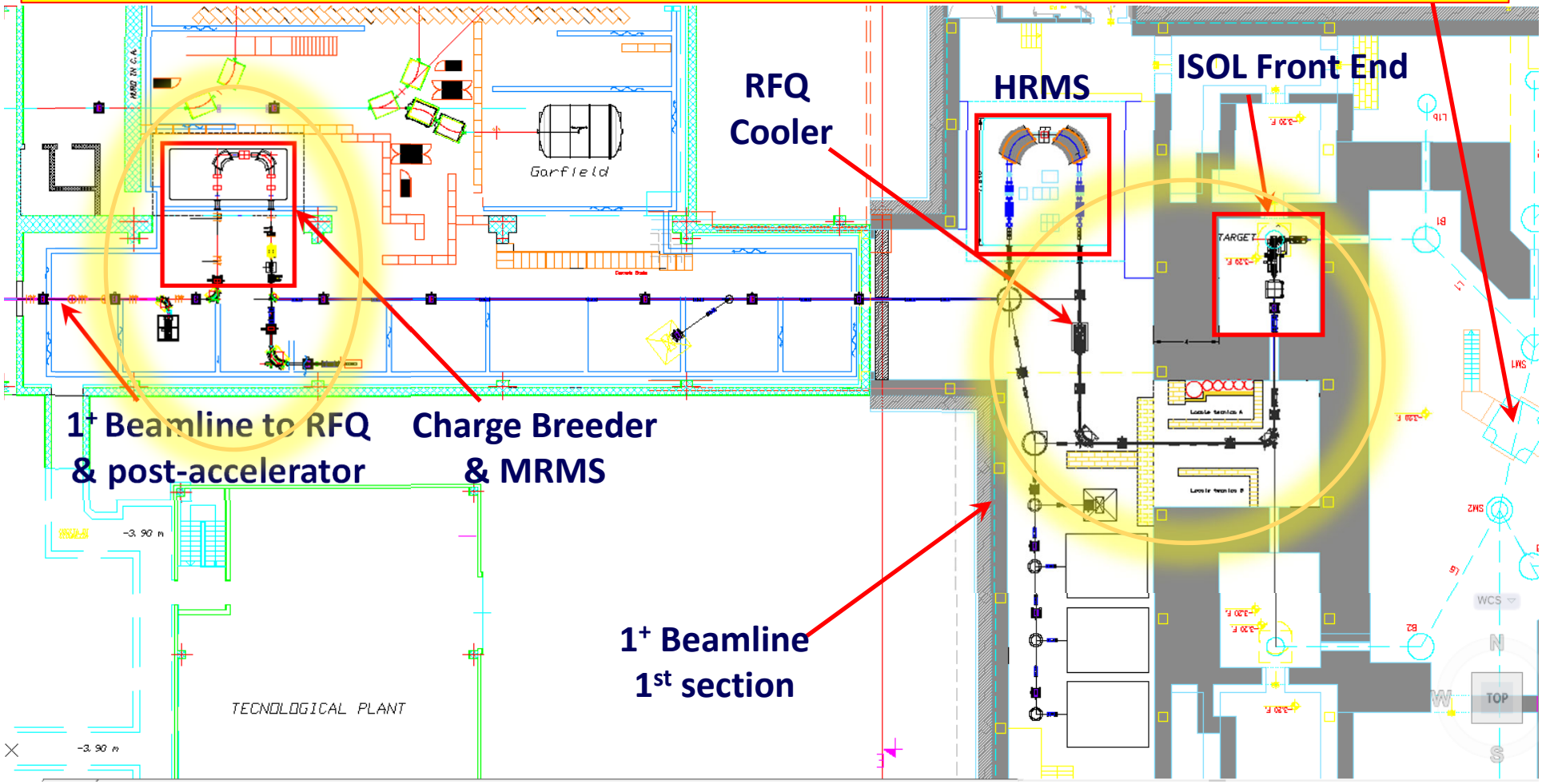
LARAMED (high power beam: 30-70 MeV, 10uA): Installation started in April and completed in Nov 2019

ISOL 2 beamline Installation started in April and completed in Nov 2019

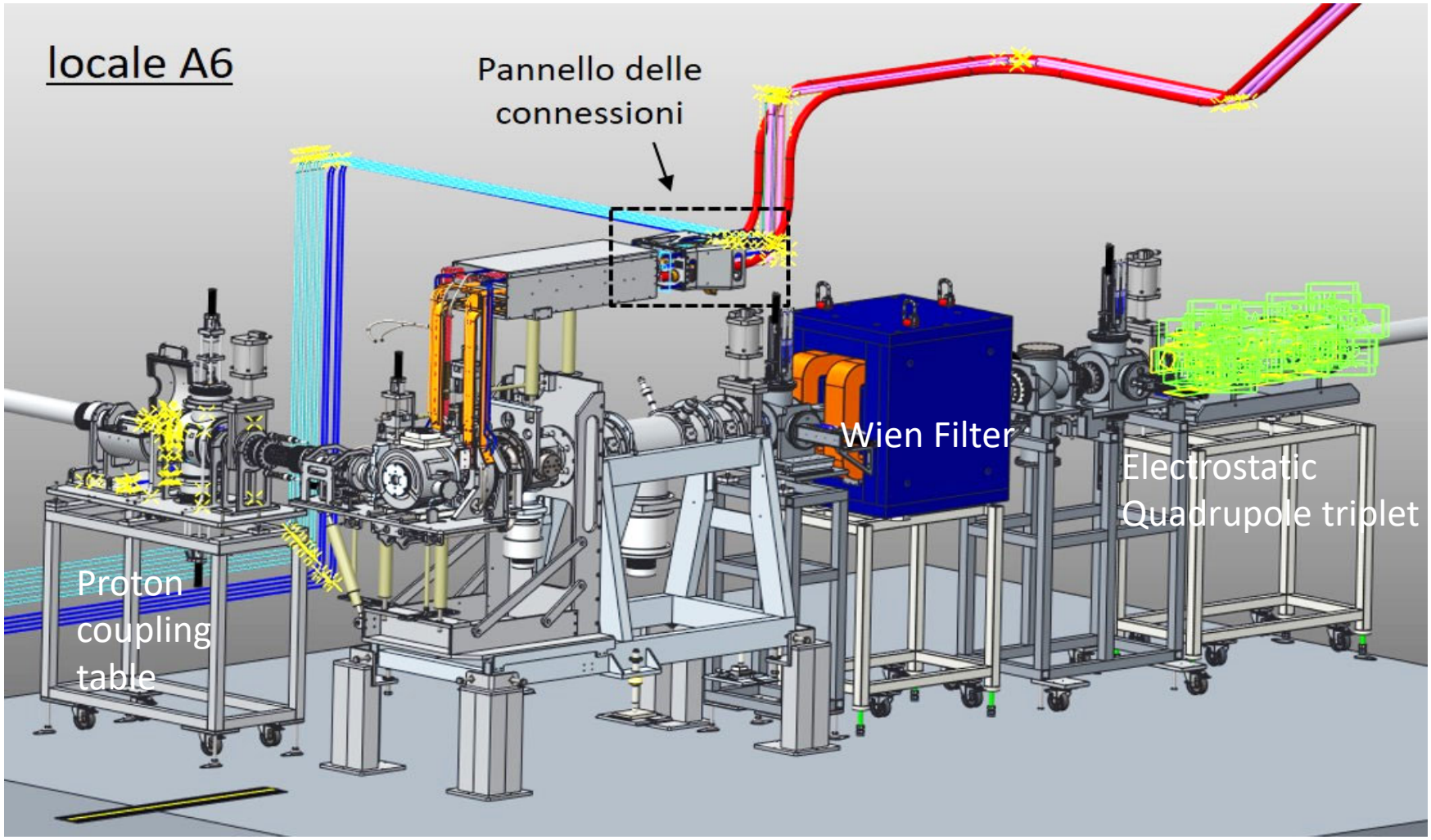
LARAMED (low power: 30-70 MeV, 100 nA): beamline BL3c under design, tender in Sept 2019, installation in 2021

# SPES Layout

Phase 2 installation: Charge Breeder and medium resolution mass separator MRMS
ISOL system and production of low energy RIB's (20keV, 1+ charge state)



# Installation phase 2B
# ISOL system

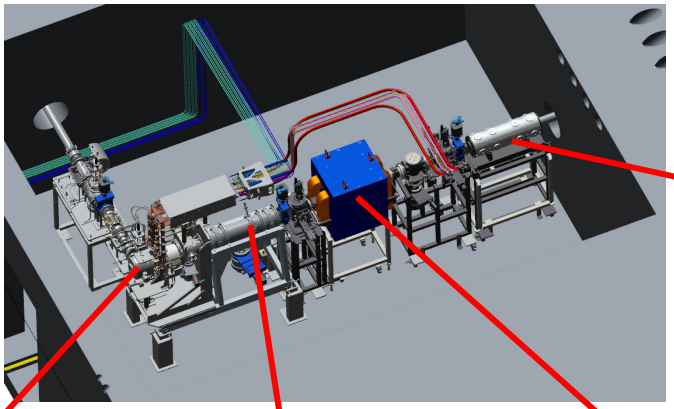



Updated version of ISOL system was developed:

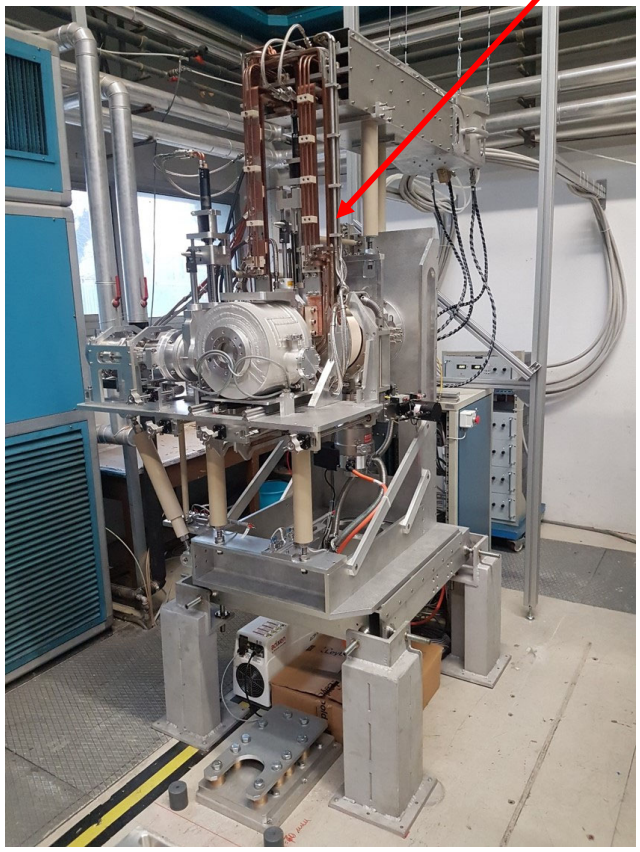
- More radiation hard design (no plastic near to target)
- Fast coupling-decopling panel board

New Wien Filter magnet: delivery on September 2020
Quadrupole triplet: ready

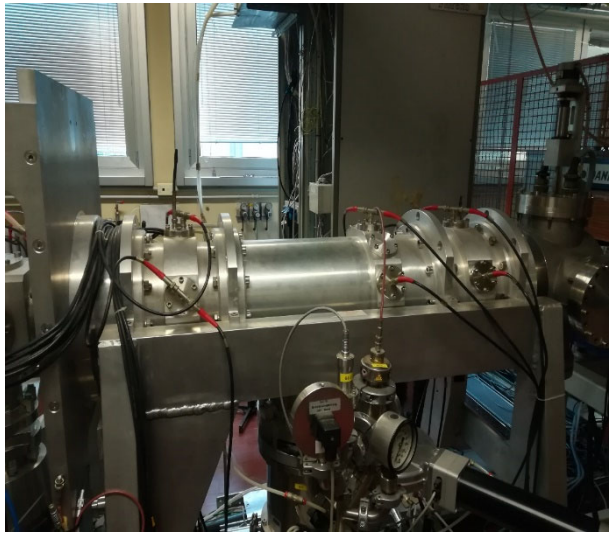
# ISOL system components



TIS (Target Ion Source)



First electrostatic triplet

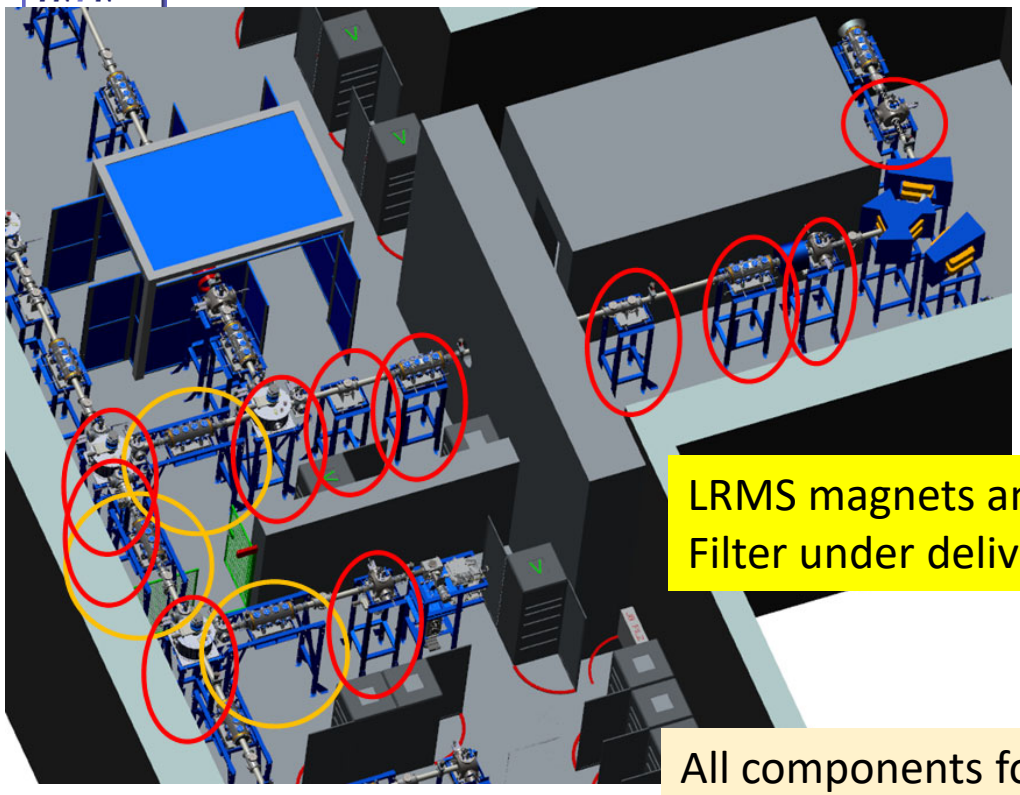


Beam Line electrostatic triplet

Electrostatic assembly of WF ready
(used in FE offline)
Magnet under delivery (July 2020)

Wien Filter

# 1+ beam line: elements



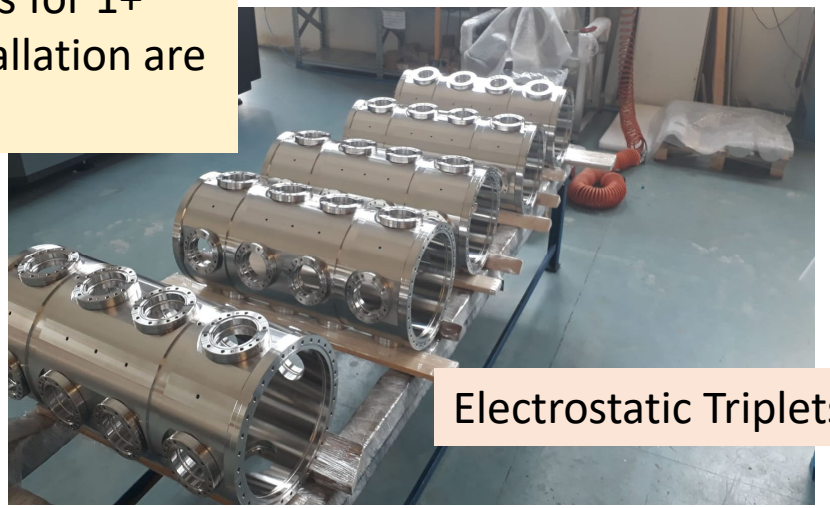
LRMS magnets and Wien Filter under delivery

Support frames

Steerers

All components for 1+ beam line installation are available

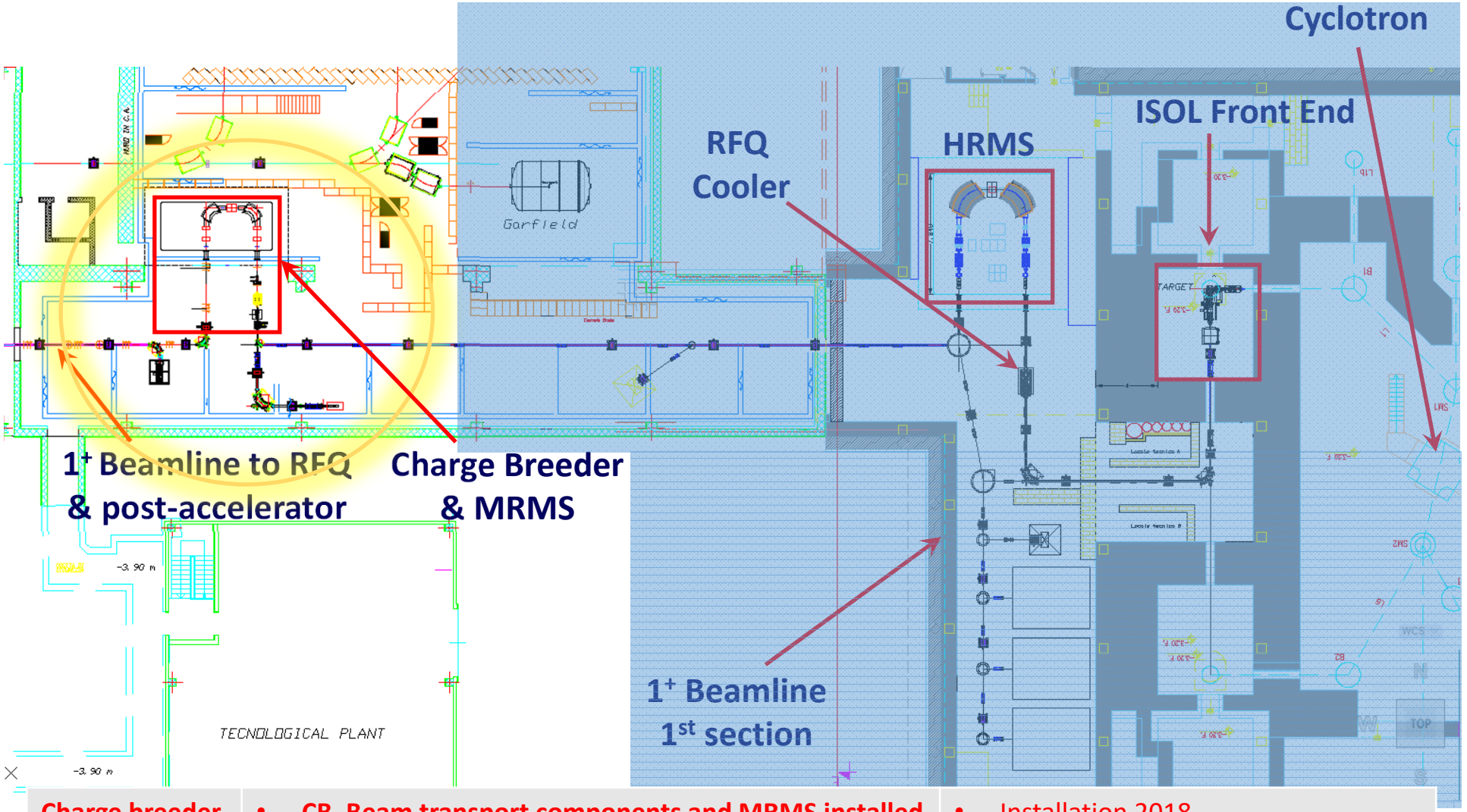
Electrostatic Dipoles



Electrostatic Triplets

# SPES Layout phase 2A

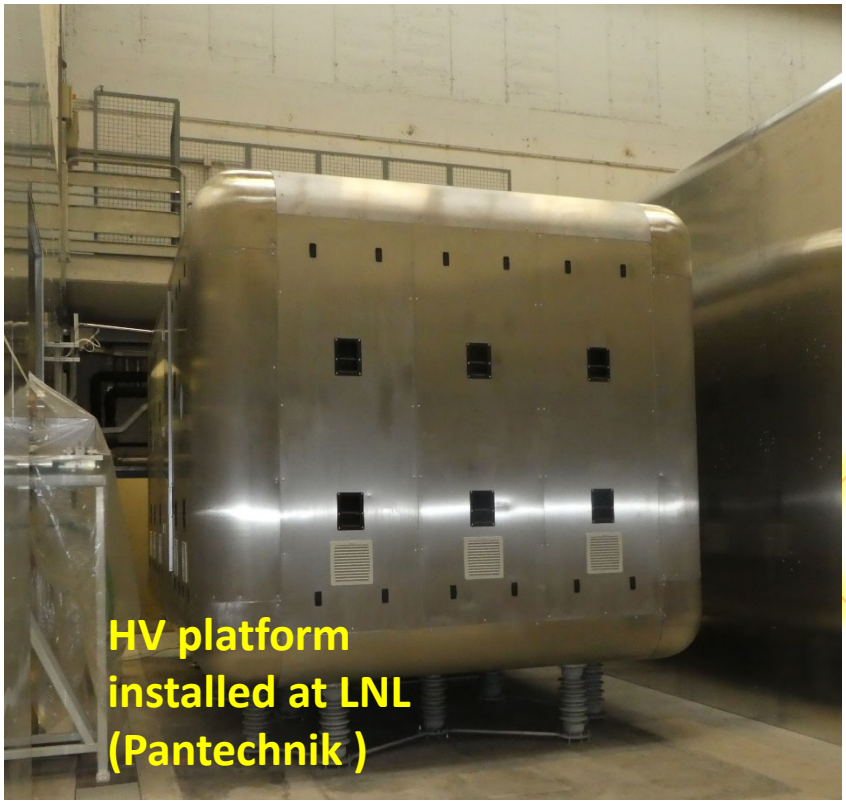
## Charge breeder and MRMS

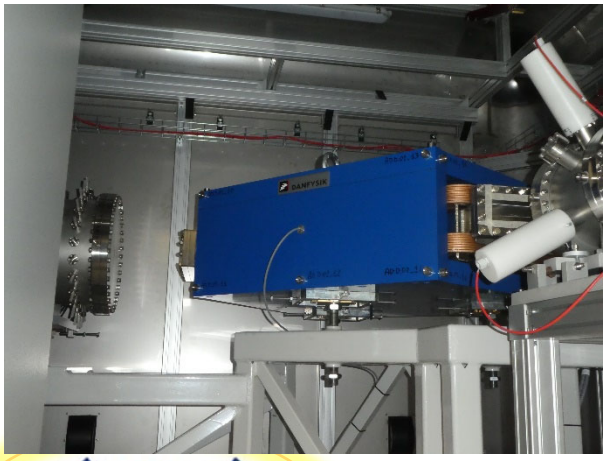


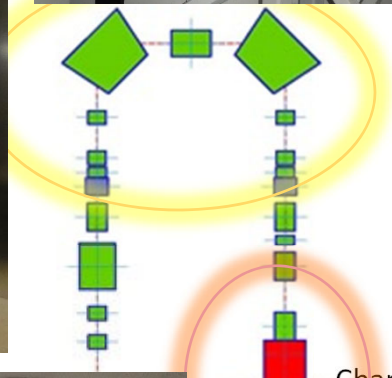

| | | |
|---|---|---|
| **Charge breeder and MRMS** | • **CB, Beam transport components and MRMS installed**<br>• **1+ source under commissioning. CB commissioning will follow.** | • Installation 2018<br>• Commissioning 2019 - 2020 |

# Installation phase 2A: Charge Breeder & n+ beam line

## MRMS and HV platform





MRMS: 1/1000
Mass separator

Charge Breeder

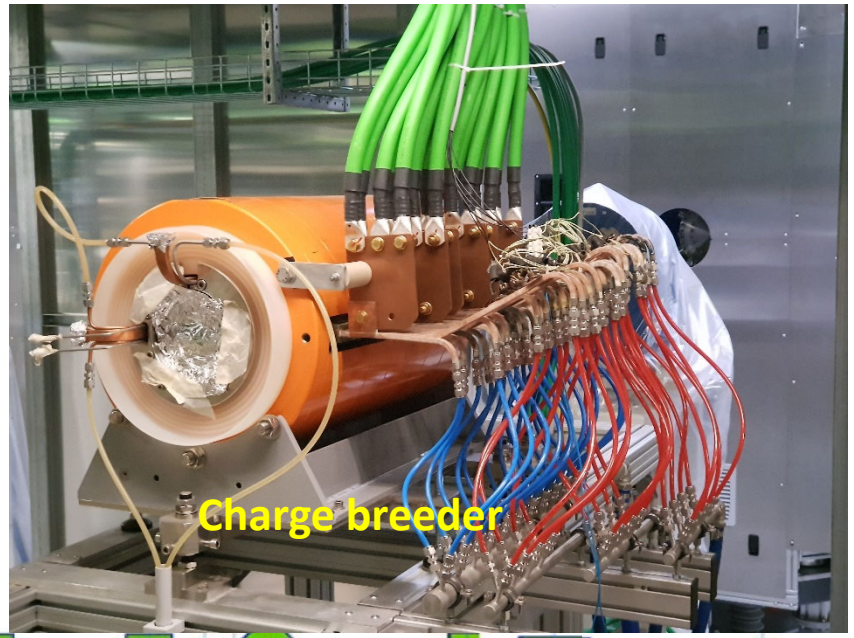
RIB Transfer 1+ beam line

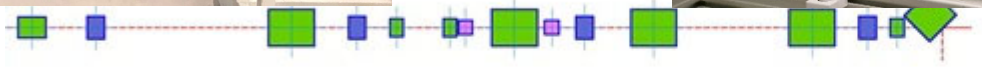
Injection line to RFQ

Pilot Beam
Ion source
(SPES-ISOL type

# Installation phase 2A: Charge Breeder & n+ beam line

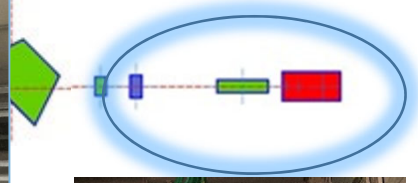
Installation Status on 15th/10/2018

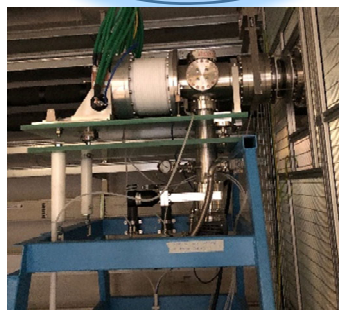


RIB Transfer 1+ beam line



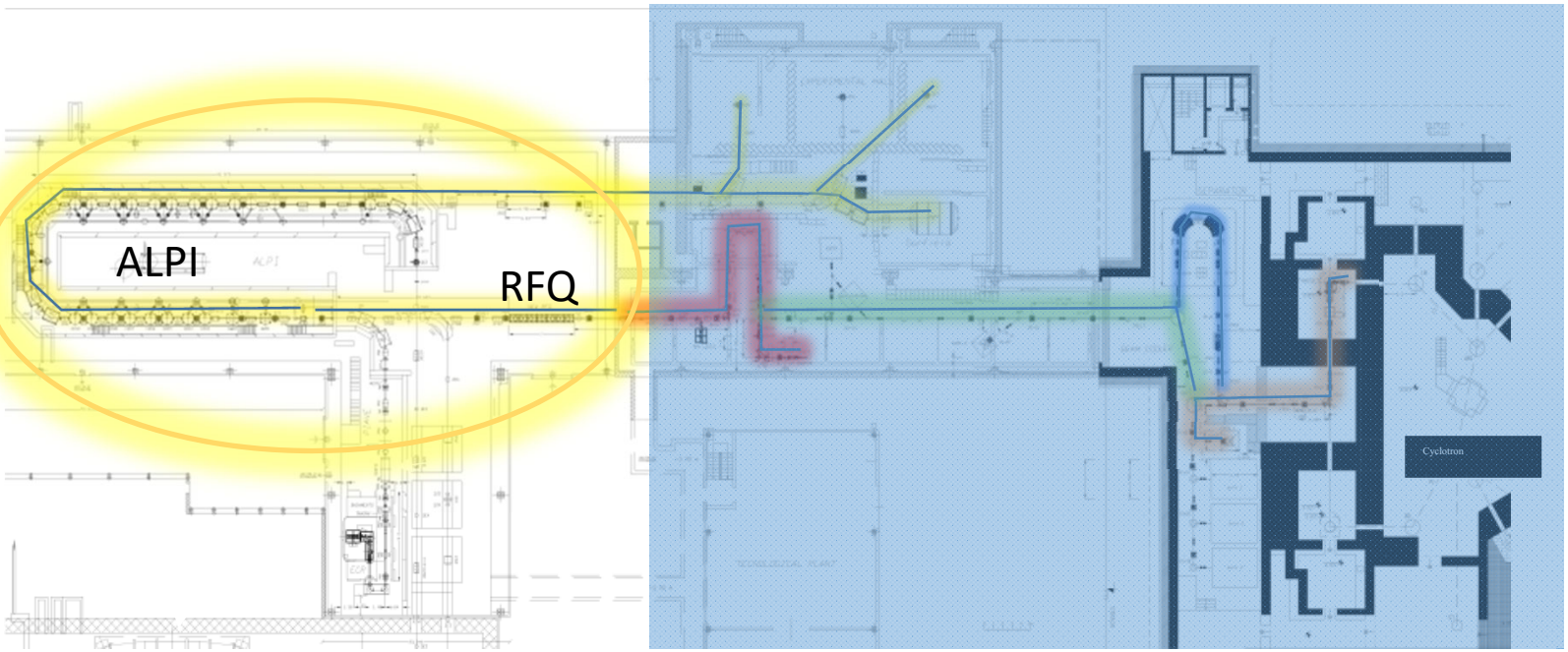




# SPES Layout phase 3B

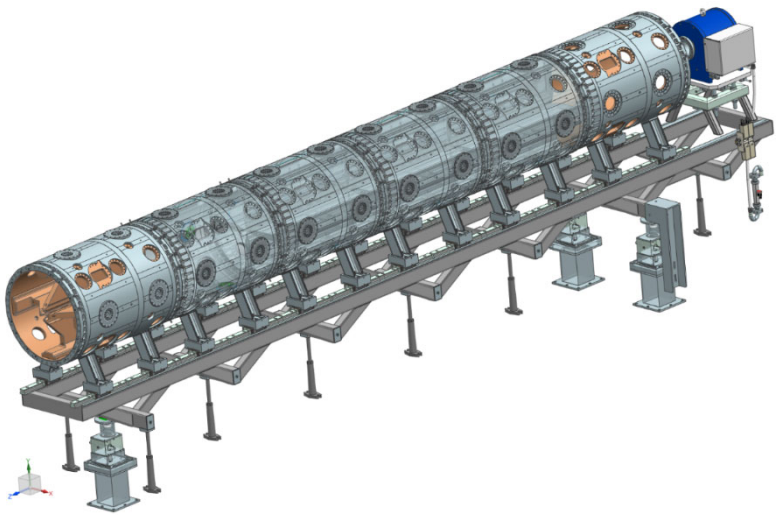
WP_B8 RFQ, WP_B9 Reaccelerator

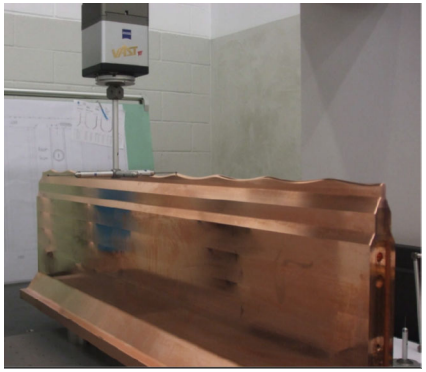
**RFQ and ALPI re-accelerator**




| | | |
|---|---|---|
| **SPES_RFQ** (Normal conductive) | **6 modules of RFQ in construction.**<br>**(24 electrodes delivered, 6 tanks delivered)** | • Construction 2018-20<br>• Installation 2021-2022 |
| **ALPI linac** | Beam transport upgrade (new quadrupoles with higher B)<br>Two criostats to increase beam energy | • New Quadrupoles Installation 2017<br>• 2 low β cryostats reinstalled 2018<br>• 2 high β Cryostats construction 2021<br>• Cryostats installation 2022 |

# RFQ & RIB transfer line





24 electrodes

6 tanks

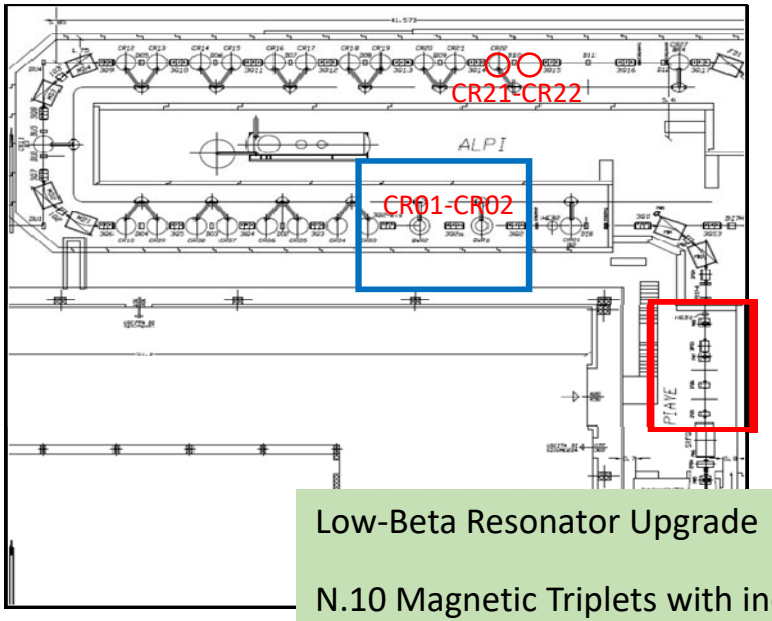
- Energy 5.7 –> 727.3 keV/A [β=0.0395] (A/qv=7)
- Beam transmission >93% for A/q=3÷7
- RF power (four vanes) 100 kW (f=80 MHz) for up to 1 mA beam (…future high current stable beams)

- Start of tender for 24 electrodes : dec2015
- Start of electrode production sept 2016
- First set of four electrodes : apr2017
- Completion of all 24 electrodes nov2018
- Start of tender for tank : Jul 2017
- Start of tank production Jun 2018
- Completion of all tanks (2020)
- Assembly and power testing (2021)
- Commissioning (2022)

Ancillaries (power coupler, tuners, dummy and final end plates, etc) as well as Support construction, RF system (incl. Amplifier refurbishment, waveguides etc), Vacuum system, LCS, Cooling system go in parallel.

ALPI superconducting LINAC

## ALPI Upgrades

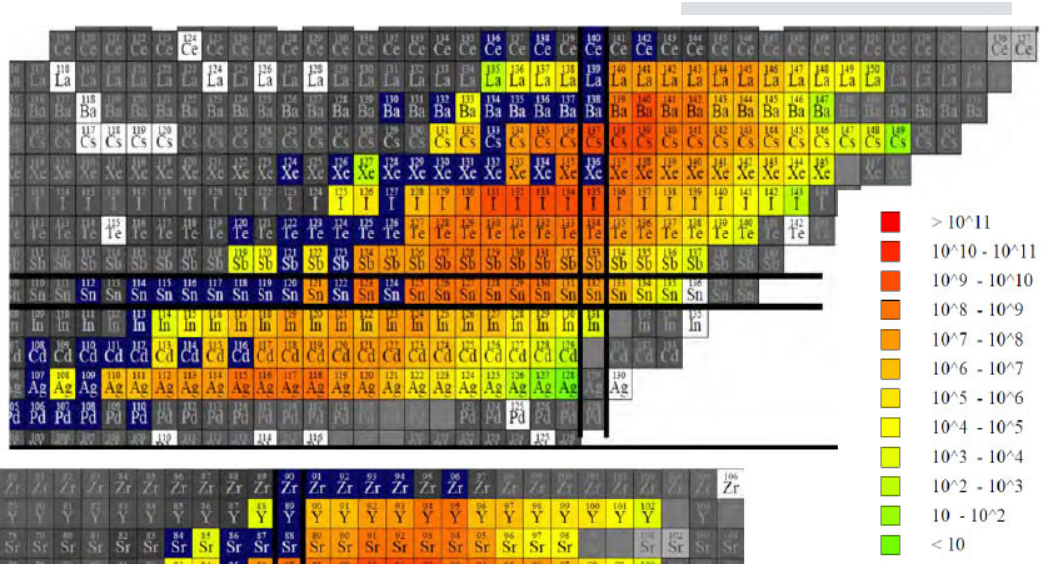


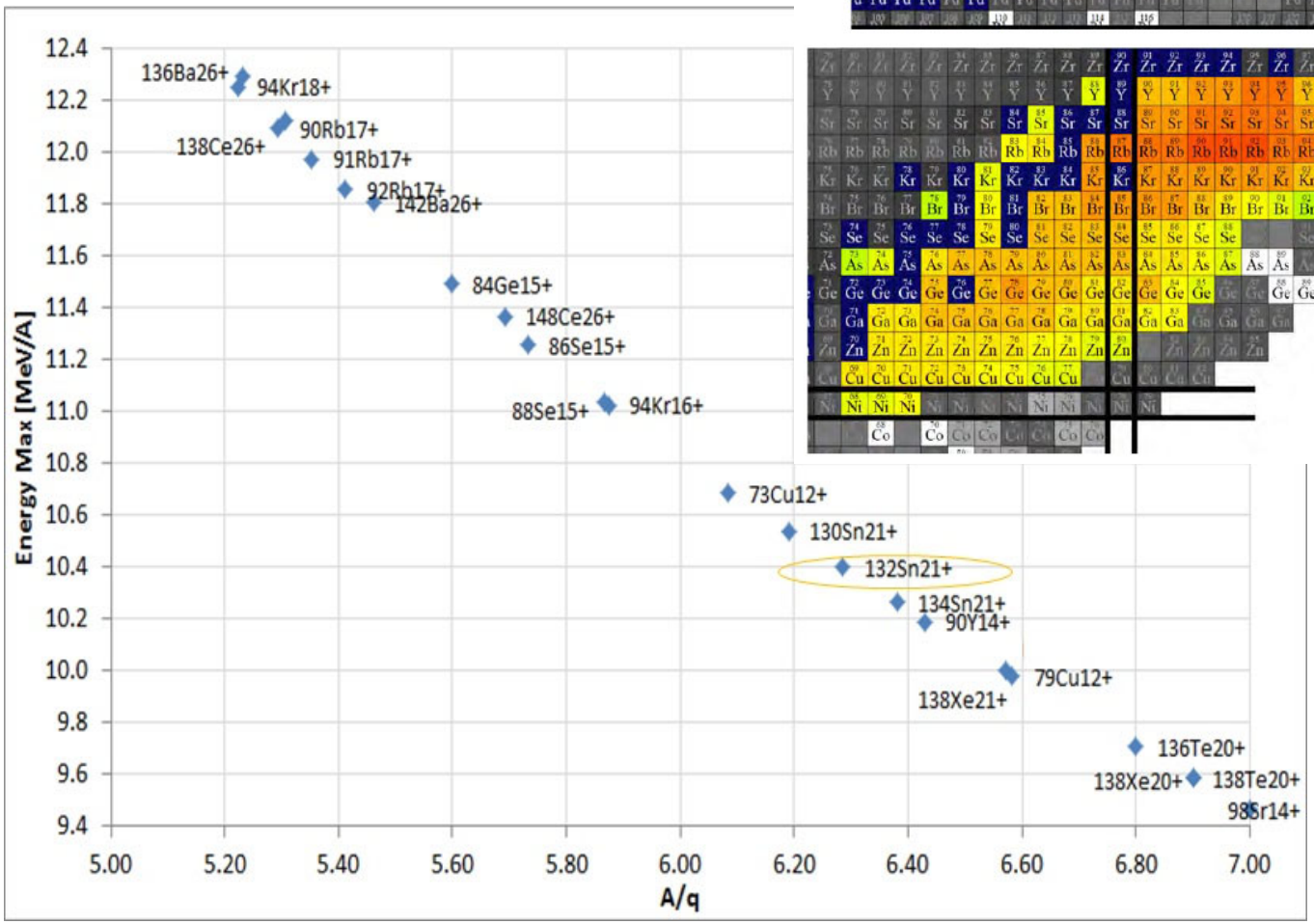

New triplets installed

CR01-CR02 relocated

| | |
|---|---|
| Low-Beta Resonator Upgrade | Done |
| N.10 Magnetic Triplets with increased gradient (20→30 T/m) | Done 2018 |
| Relocation of PIAVE QWR Cryostats on ALPI (CR01-CR02) | Done 2018-19 |
| New high energy cryostats (CR21 and CR22) | Bid 360k€ 2020 |
| New RFQ and injection into ALPI | 2021-22 |

# Reacceleration with ALPI superconductive linac



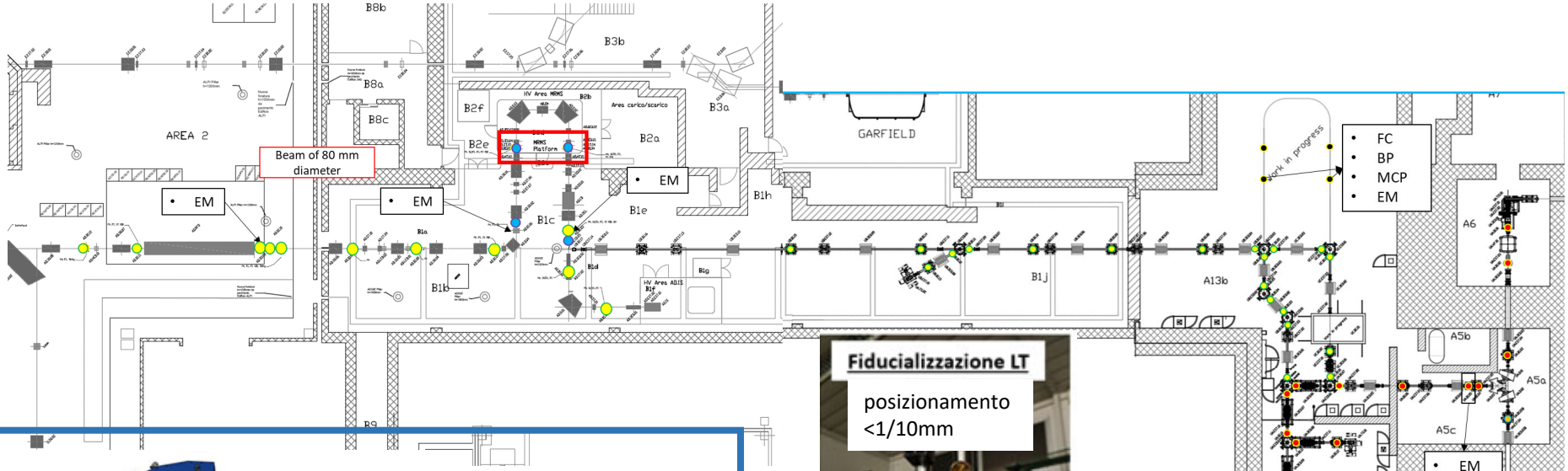




noReaccelerated beam rates: x10 - x50

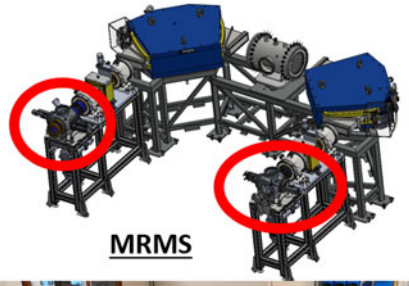
*Courtesy of T. Marchi*

# SPES beam diagnostics (WP_B1 scientific support)

**(about 50 diagnostic boxes are under constructioon)**




Camere raffreddate per ADIGE



MRMS

RIVELATORI - FC - COLLIMATORI

COLLIMATORI

**Fiducializzazione LT**

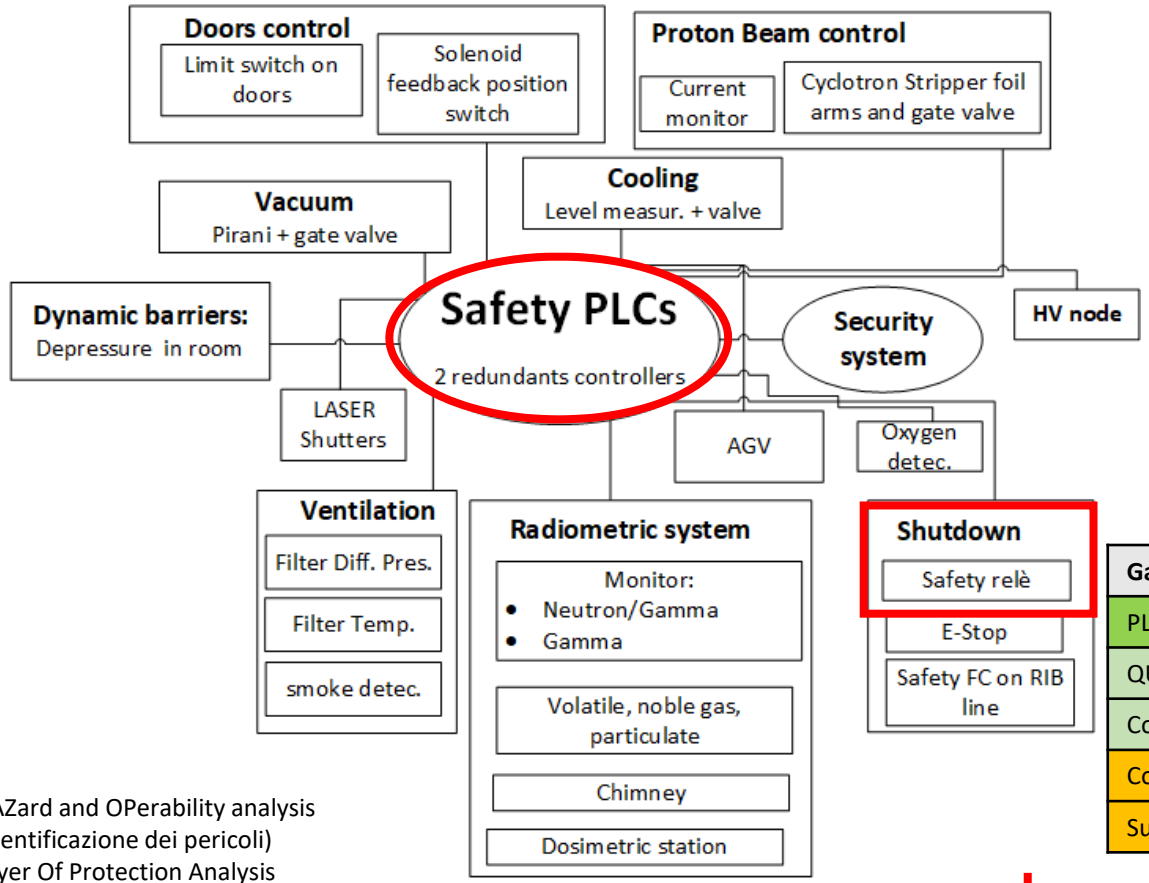
posizionamento <1/10mm

**Profilatore - PCB**

**Test sotto fascio**

Banco prove servizio sorgenti

# SPES Safety and Access Control System




**Gruppo Sicurezza SPES**:

- Maria Luisa Allegrini
- Daniela Benini
- Luca de Ruvo

**Supporto Controlli SPES**:

- Fabio Gelain

**Analisi rischi, progetto, software, validazione**:

- Ditta PILZ

| Gare | K€ | stato |
|---|---|---|
| PLC | 90 | consegnato |
| QUADRI e Junction Box | 122 | assegnazione |
| Collegamenti Dorsale Quadri | 157 | pubblicazione |
| Collegamenti sensori Campo | 172 | preparazione |
| Supporto e verifica installazioni | 40 | preparazione |

HAZard and OPerability analysis
(identificazione dei pericoli)
Layer Of Protection Analysis
(analisi quantitativa del **rischio)**

2017 2018 2019 2020 2021 2022

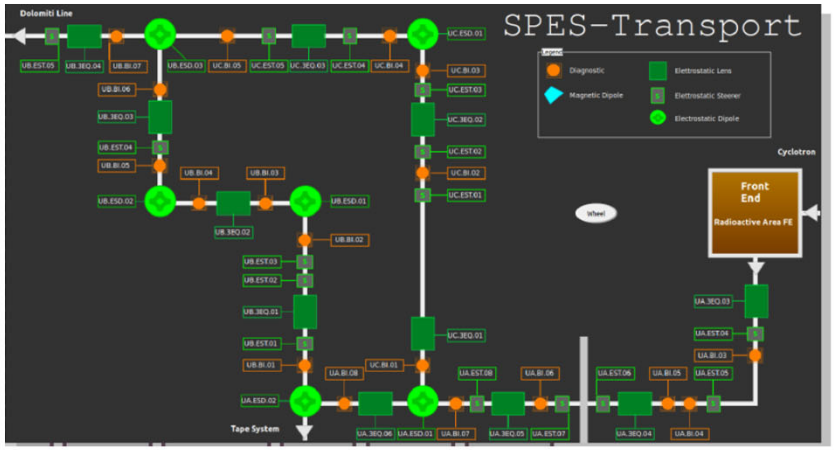
Risk analysis (HAZOP – LOPA) — PILZ + INFN

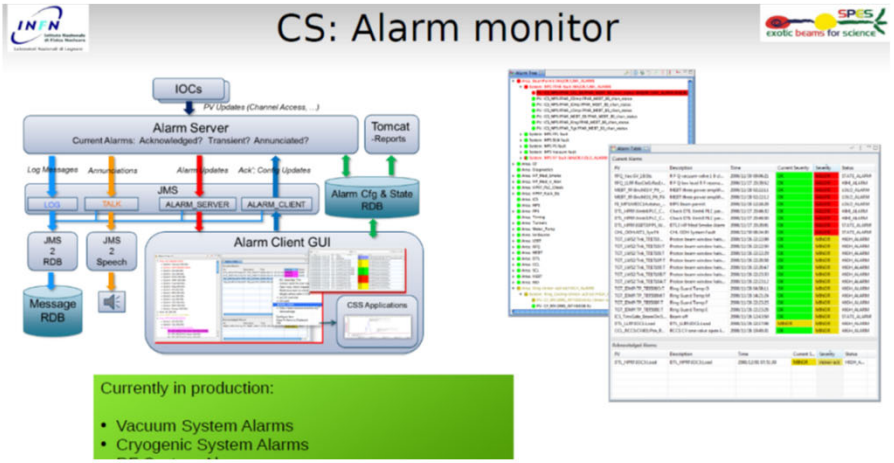
Design — PILZ

HW delivery an installation — INFN

Validation and first operation — PILZ + INFN

# SPES control system




Provides...

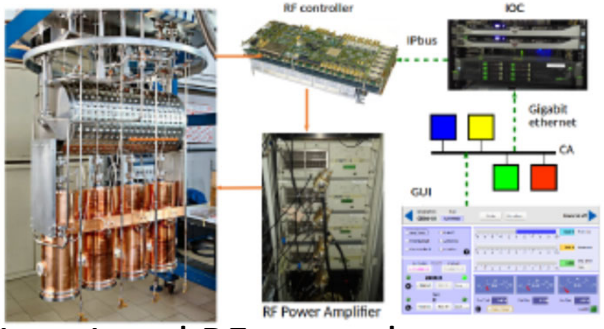
EPICS IOC (SW Framework)

...is controlled by…

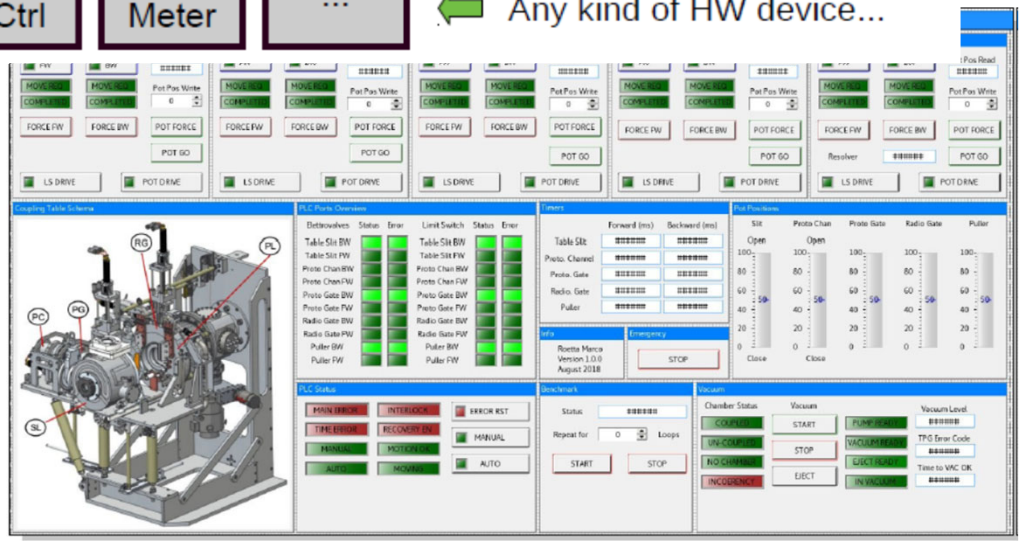
...through any kind of interface… (Ethernet, Serial etc.)

Any kind of HW device...

Dig./Analog IO | Motor Ctrl | PLC memory | HV/HC PSU | LLRF Ctrl | Tesla Meter | …

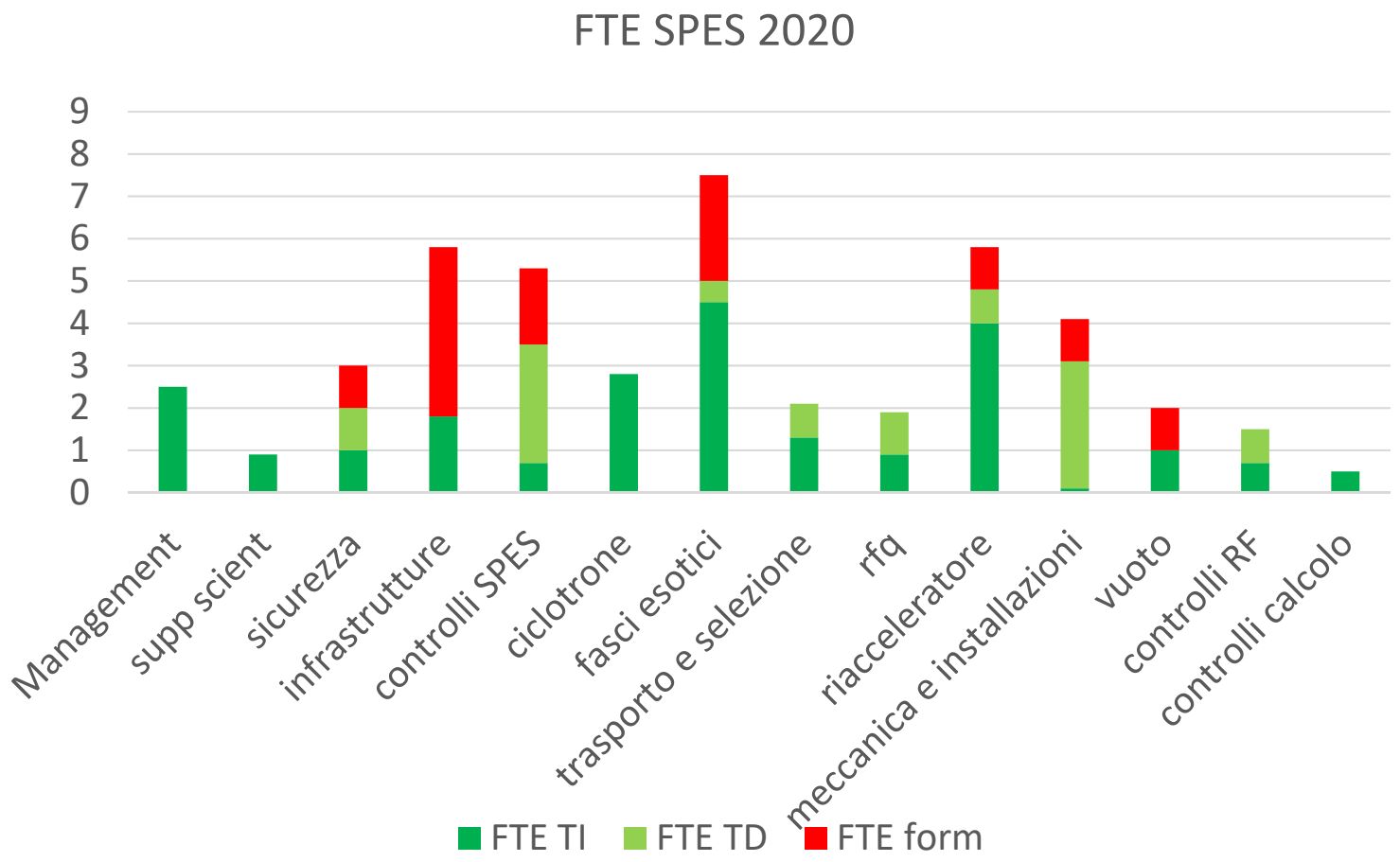



Low Level RF control
(prototype commisioned)

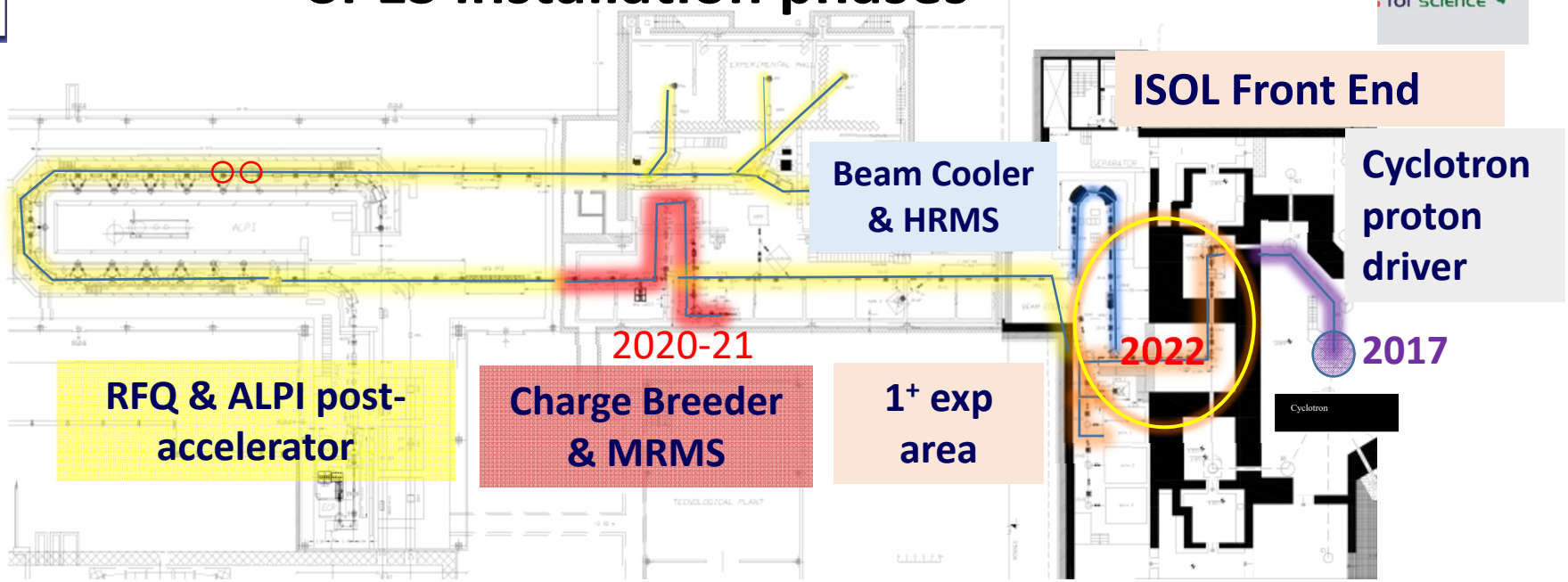


# SPES personnel

| 2020 | TOT | personale Formazione (borse a assegni | Tempo Determinato (TD) | Tempo Indeterminato (TI) |
|---|---|---|---|---|
| persone | 70 | 13 | 15 | 42 |
| FTE | 46,7 | 12,3 | 11,7 | 22,7 |



# SPES installation phases




| Installation phase | Main Tasks |
|---|---|
| PHASE 0: | Building and Infrastructures |
| PHASE 1: | CYCLOTRON |
| | |
| PHASE 2A: | CHARGE BREEDER & MRMS installation |
| | |
| PHASE 2B: | ISOL SYSTEM and wien filter |
| PHASE 2B: | 1+ beam line components |
| | |
| PHASE 3A: | 1+ beam line up to Charge Breeder |
| PHASE 3B: | bunchers & RFQ, ALPI upgrade |
| | |
| PHASE 3A: | BEAM COOLER & HRMS |

# Conclusions

- **SPES is in the installation phase**
- **In 2022 radioactive beams with no-reacceleration is expected to be commissioned**
- **Commissioning of Charge Breeder and MRMS will be completed by 2021**
- **Reacceleration using RFQ and ALPI will follow to reach 10-11 MeV/n**

*Thank you for attention*