# SPES project

1 febbraio 2018

Gianfranco Prete
SPES Project leader

# OUTLOOK

- SPES goals
- Layout and components
- Installation planning
- Resources

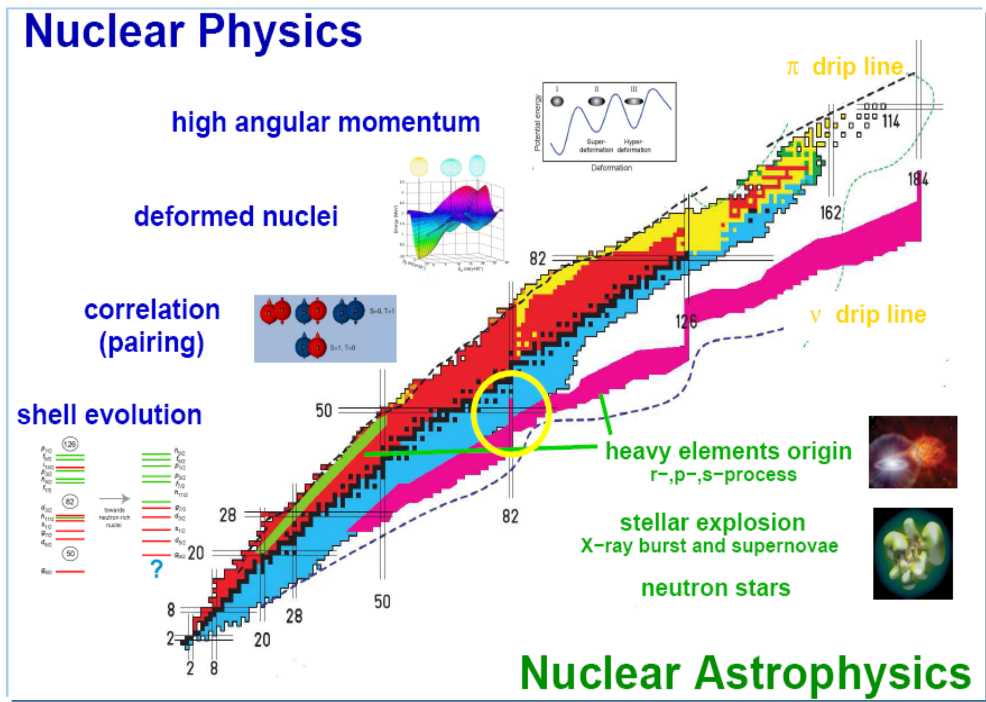
# SPES goals

➢ **Second generation ISOL facility** integrated in the European road-map for Nuclear Physics (EURISOL DS)

**1_ Production** of **exotic beams**

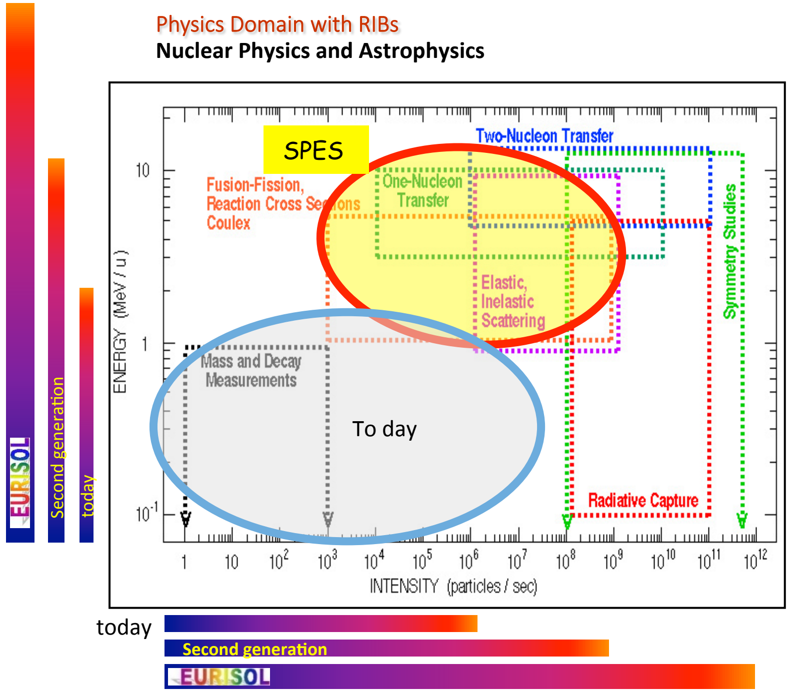
**2_ Re-acceleration** of exotic beams with the ALPI linac

(Mainly **Neutron–rich ions** by p-induced Fission on **UCx** )



# Performance up-grade for a Second generation ISOL facility

- ❑ More beam intensity: $10^7$-$10^8$ pps (n-rich: $10^{13}$ fission/s
- ❑ More beam energy: 10 MeV/n
- ❑ More pure (selected) beam: 1/20.000




**SPES choice**

New target-ion source design

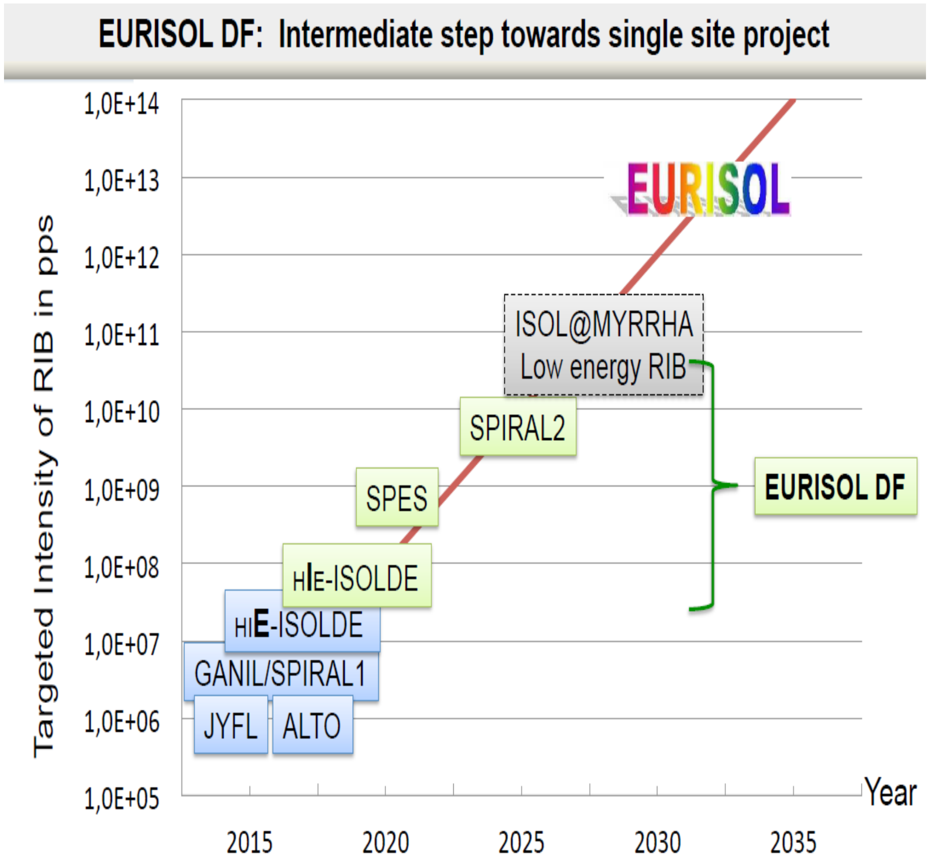
200uA 40MeV (8kW) protons on UCx -> $10^{13}$f/s

ALPI superconductive linac reaccelerator: 10 MeV/n

High resolution mass separator with beam cooler

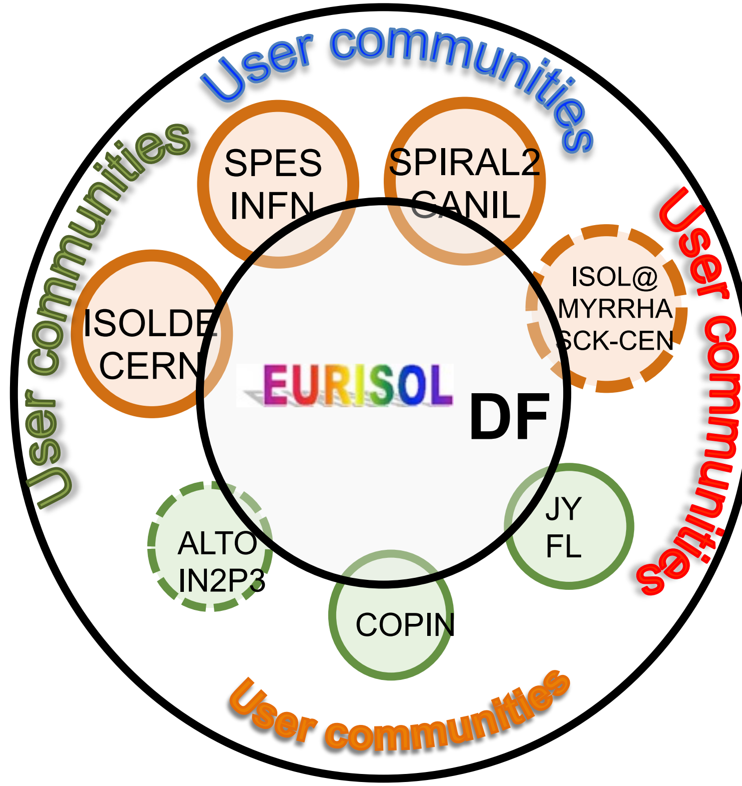
EURISOL Distributed Facility (DF) Initiative

Project to be submitted for the 2020 update of the ESFRI roadmap




Complementarities: Instrumentation eg. AGATA, FAZIA, GASPARD, PARIS
Challenges: High-power targets & sources, purification of RIB

EURISOL DF




- A **distribute laboratory** for radioactive beams:
- **More exotic beams** available
- **Coordination of competences** to face EURISOL technologic challenges
- **Joint effort** to manage the activity at European level

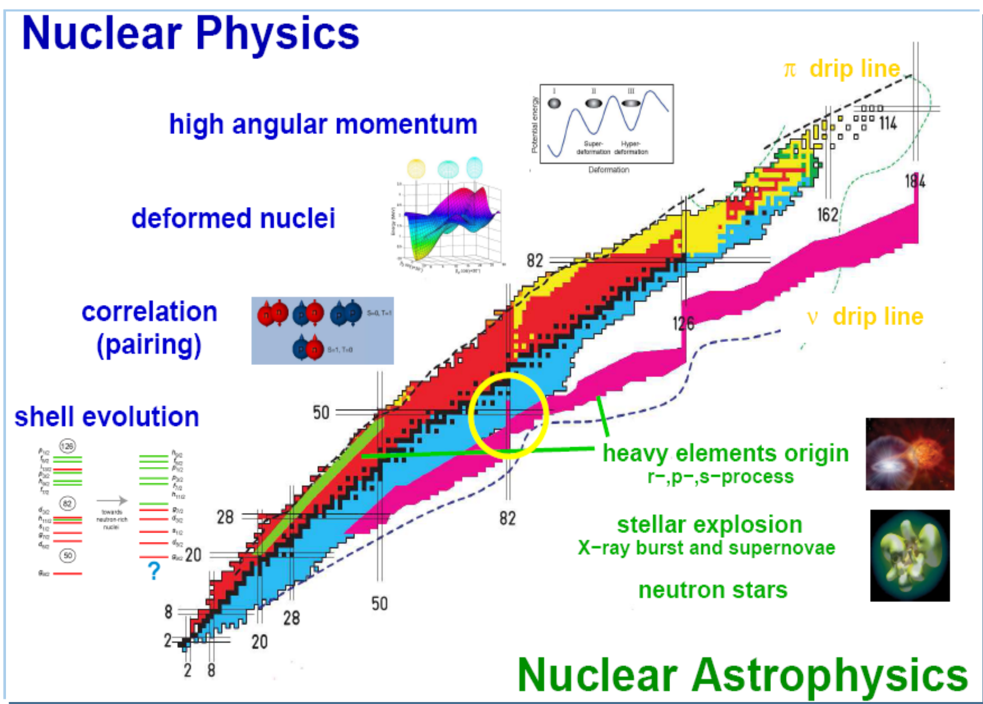
# SPES physics

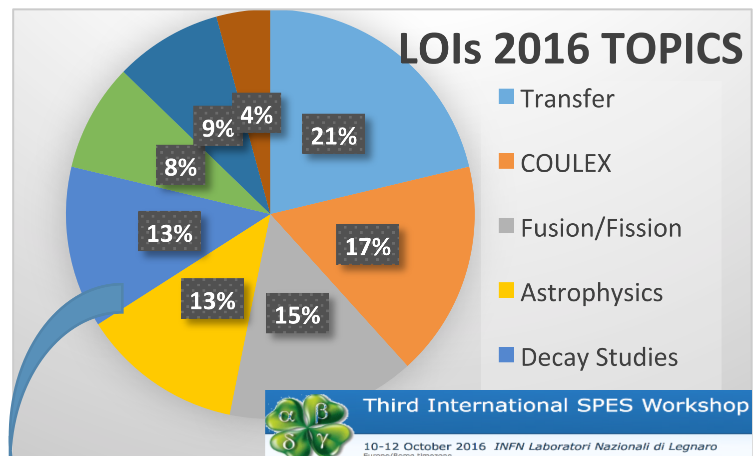
First SPES Physics workshop: 2008

International workshop: 2010, 2014, 2016

One-day workshop:

- 2012, Napoli Transfer reactions,
- 2012, Firenze Coulomb Excitation
- 2013, Milano Collective excitations
- 2015, Milano Physics with non reaccelerated beams
- 2015, Caserta Nuclear astrophysics
- 2018, Pisa Fundamental symmetries and interactions



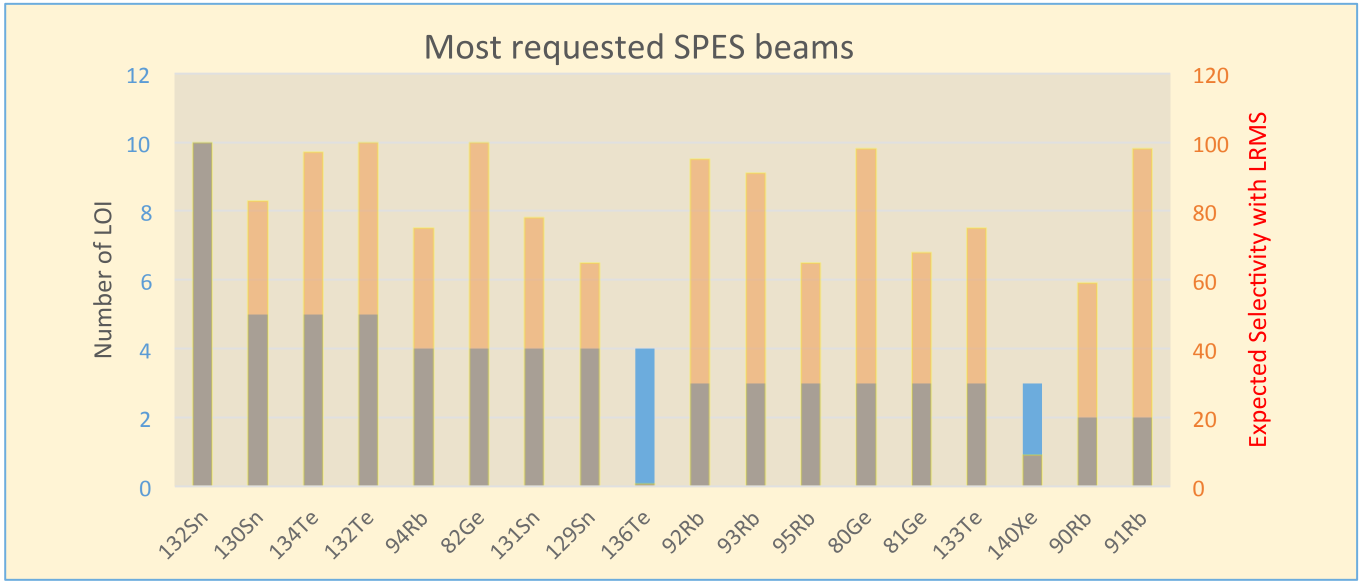

47 LOIs submitted to SAC

15% with non re-accelerated RIBs

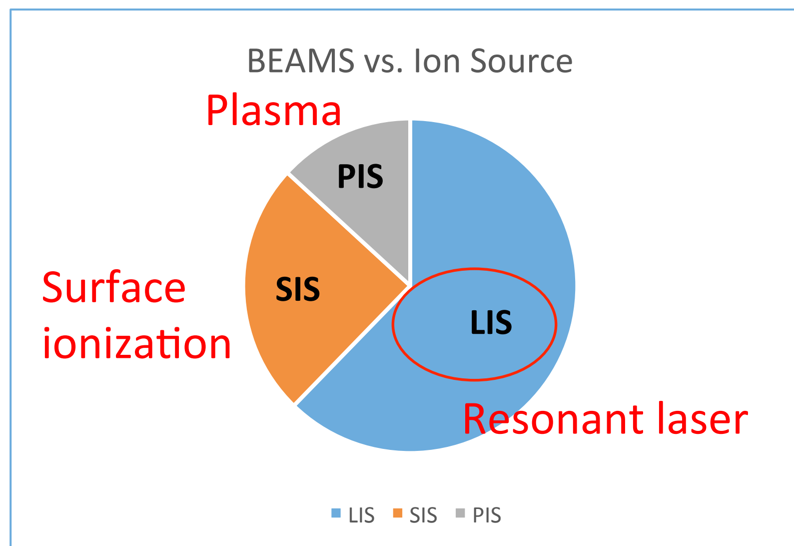
21% with 132Sn

# LOI n-rich RIBs

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



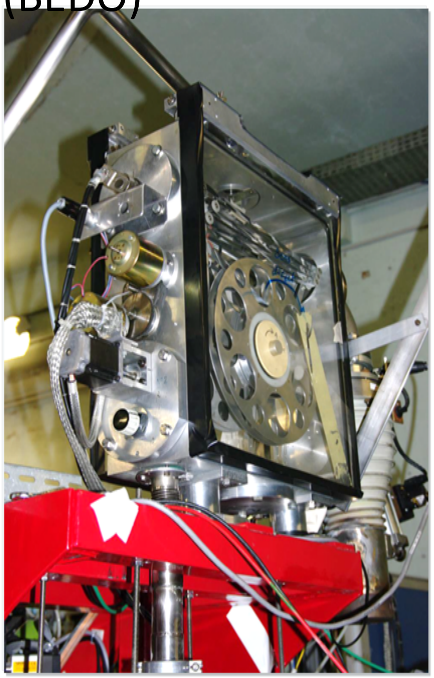

| | | **19 Elements** | |
|---|---|---|---|
| Total beams | 89 | in 47 LOIs | LOI % |
| Beams with 200_LRMS | 47 | | 53% |
| Benefit with 5.000_HRMS | 3 | → 50 beams | 56% |
| Benefit with 10.000_HRMS | 17 | → 67 beams | 75% |
| Benefit with 15.000_HRMS | 15 | → 82 beams | 92% |
| Benefit with 20.000_HRMS | 7 | → 89 beams | 100% |



# Instrumentation@SPES: Tape system

Tape station based on Orsay design (BEDO)

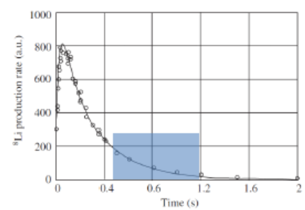
Collaboration ALTO-INFN-iThembaLabs



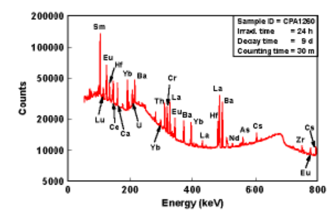
**Diagnostics** for SPES: tape stations **to characterize RIBs**

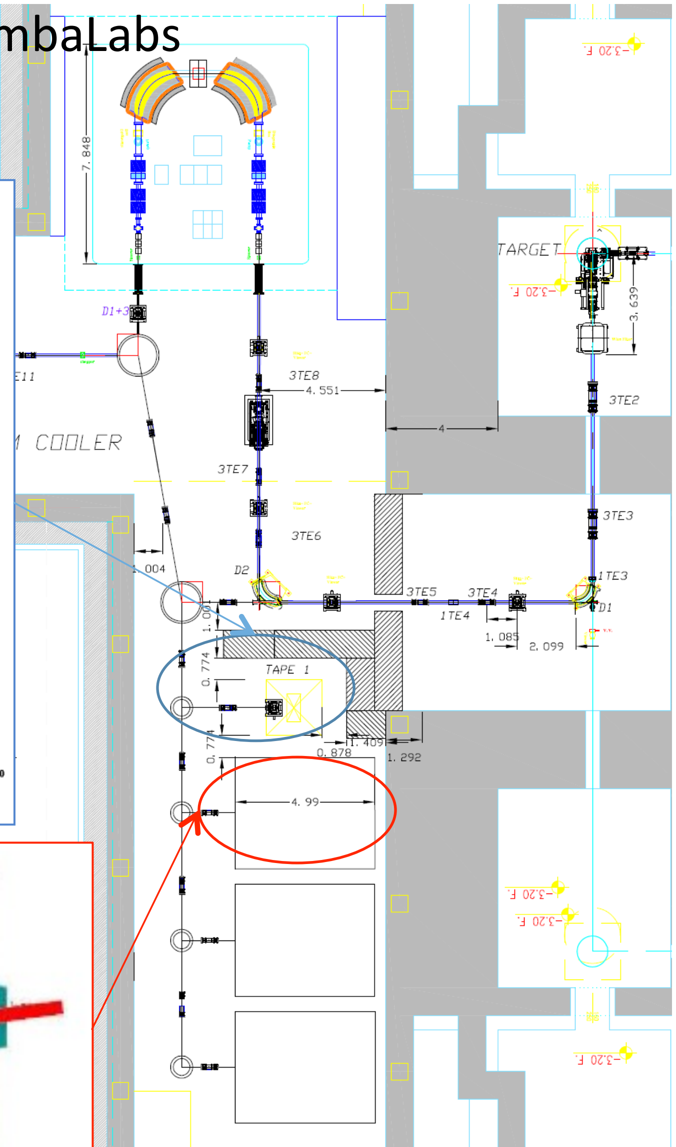
**Beam characterization:**

- Release Curve

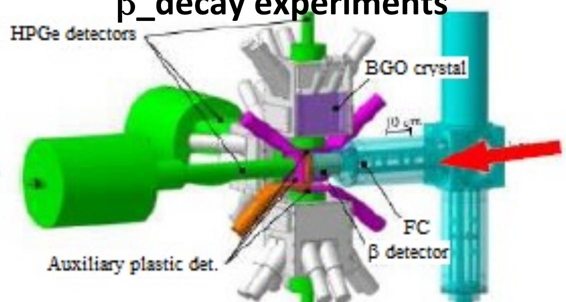



- Beam Composition and Isotopic Yields




**β_decay experiments**

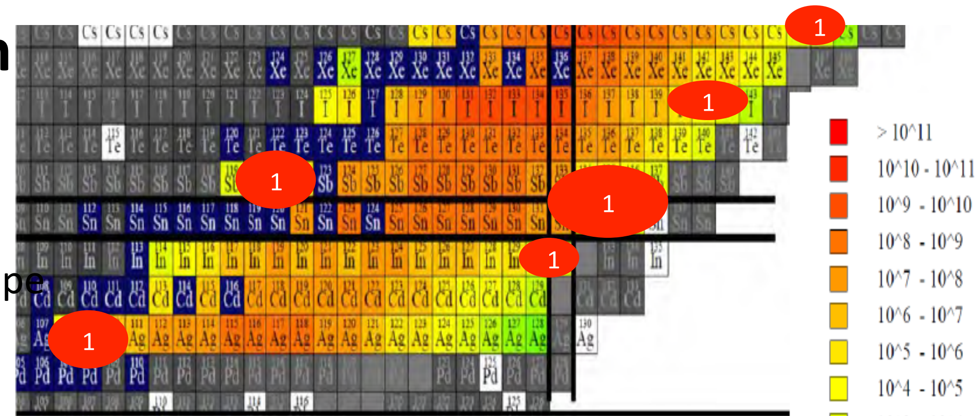



G. Benzoni (INFN Mi) contact person

**Beta decay station as a permanent and flexible setup**

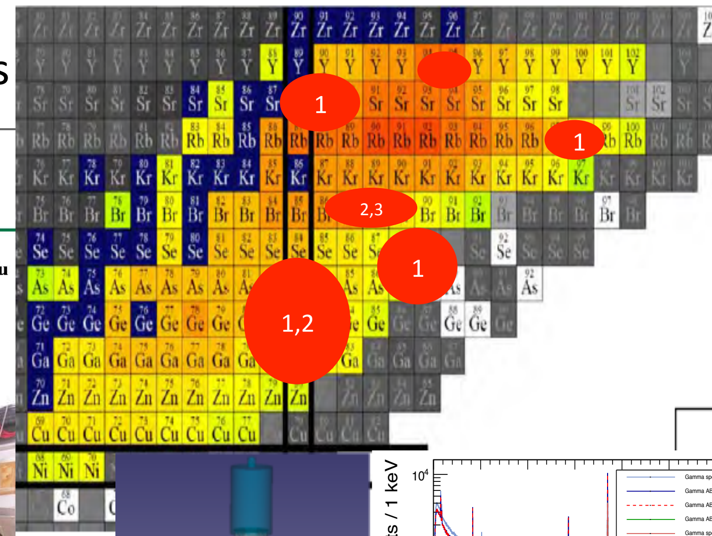
- Tape station + β detector
- Coupling to HPGe, LaBr3, neutron detectors etc…

# SPES LoI's for beta decay station




**1_Astrophysics:** input for r and s process
**2_Nuclear structure:** Shell evolution and nuclear shape
**3_Exotic decay :** Pygmy resonance by β_decay

Additional instrumentation and collaborations

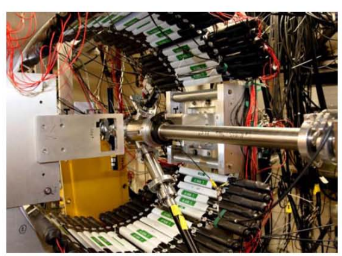



Courtesy of T. Marchi

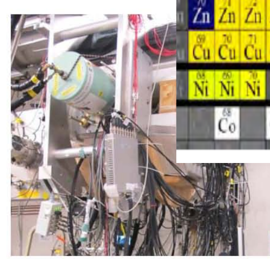
## Decay spectroscopy techniques to study neutron-rich fission fragments at SPES


Krzysztof P. Rykaczewski, Robert Grzywacz, Carl J. Gross, Daniel W. Stracener, Yuan Liu
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6371, USA
in collaboration with
C. Mazzocchi, A. Korgul, M. Karny, K. Miernik, U. of Warsaw, Warsaw, Poland
W. Krolas, Institute of Nuclear Physics PAN, Krakow, Poland


MTAS = Modular Total Absorption Spectrometer



VANDLE = Versatile Array of Neutron Detectors for Low Energy



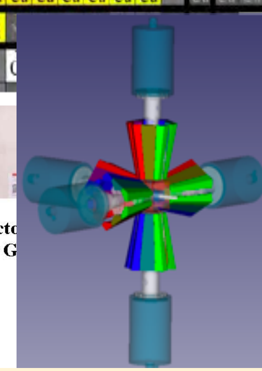
3Hen = Helium-3 Neutron Detecto
Hybrid-3Hen = 3Hen + Clover G

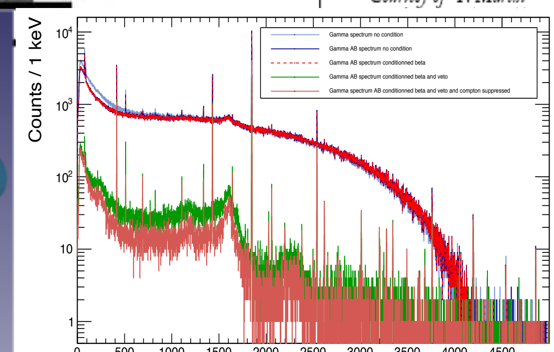
The physics of neutron-rich fission fragments

- nuclear structure evolution as N >> Z
- spectroscopy near and above the neutron separation energy
- rapid-neutron capture half-lives and beta-delayed neutron branchings
- societal impact in better data for modeling neutron-rich environments such as nuclear reactors
- more detailed understanding of the anti-neutrino spectra from reactors

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATI
MANAGED BY UT-BATTELLE

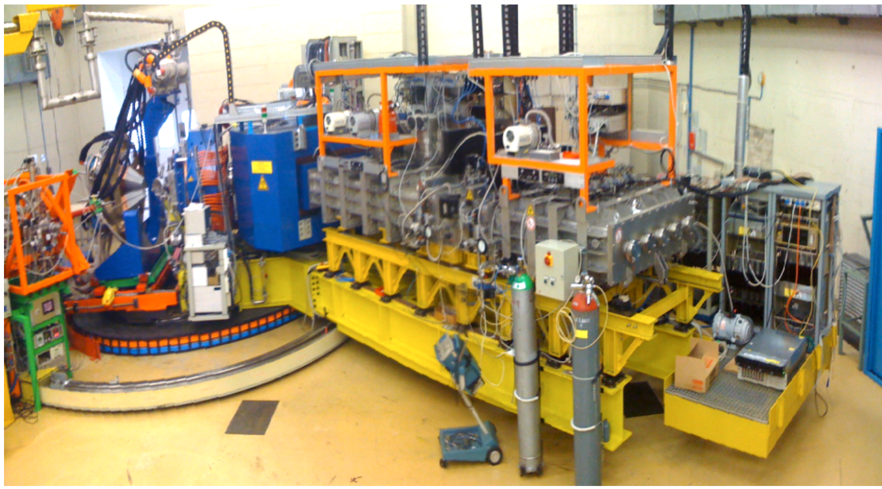




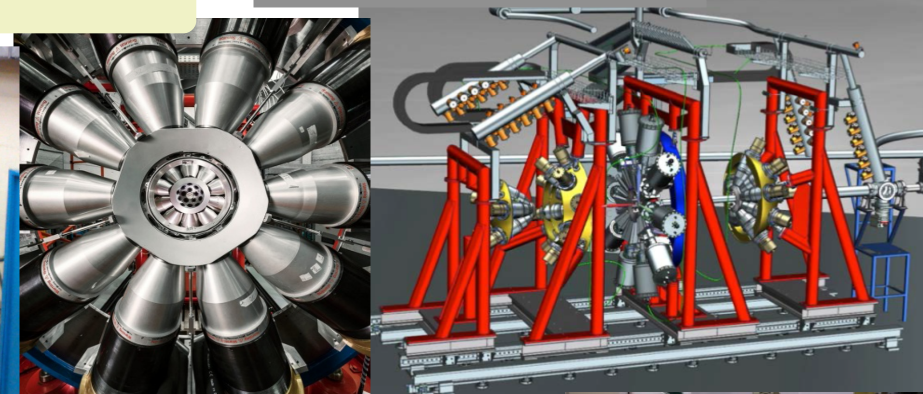

Left panel: 3D rendering of the compact geometry having 5 Triple Cluster Ge detectors with BGO shields. The tape is coming from the right side of the figure. In the right panel the simulated spectrum for the decay $^{33}Si \rightarrow {}^{33}P$ is shown in different simulated conditions.

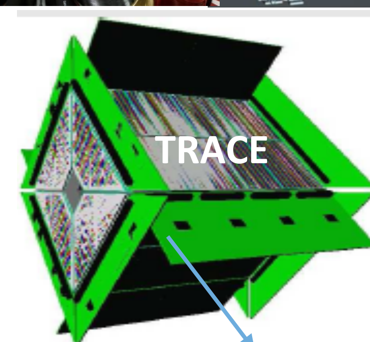
# Instrumentation @ SPES

**PRISMA** large acceptance **magnetic spectrometer**
$\Omega \approx 80$ msr; $B\rho_{max} = 1.2$ Tm $\Delta A/A \sim 1/200$
Energy acceptance ~ ±20%

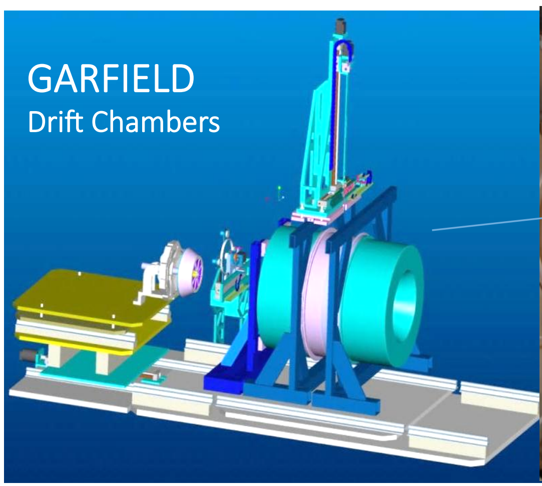


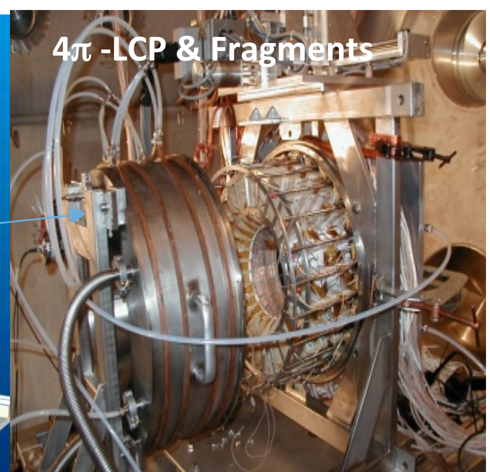
GALILEO $\gamma$-array







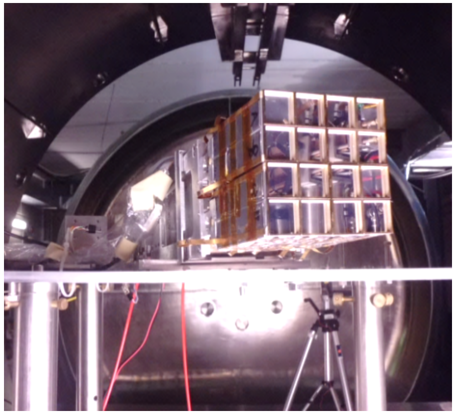


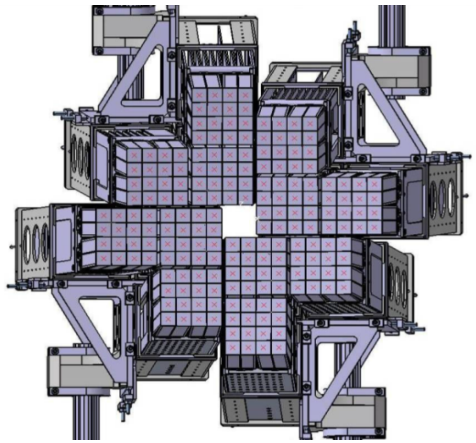




# Instrumentation @ SPES

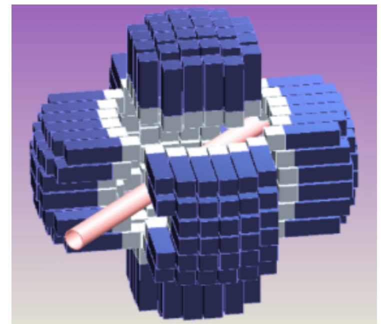
## International Collaborations:
## itinerant detectors

**FAZIA**: **LCP & fragments detection**

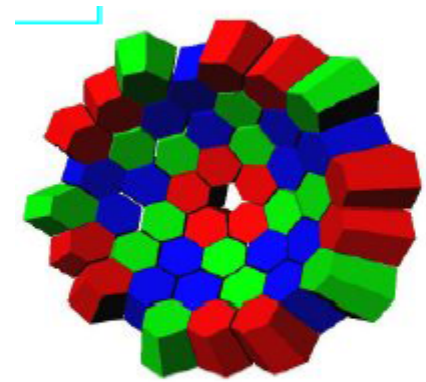


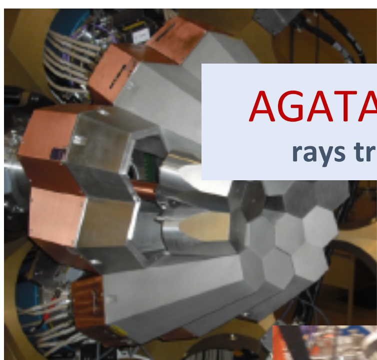


**PARIS** **(High Energy γ-ray Detector Array)**

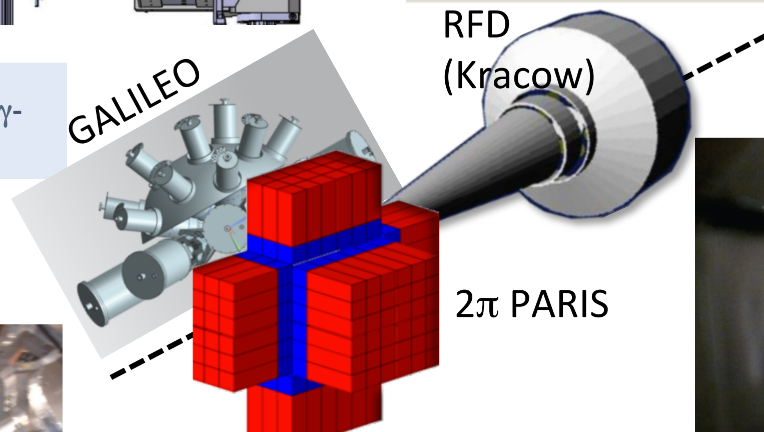


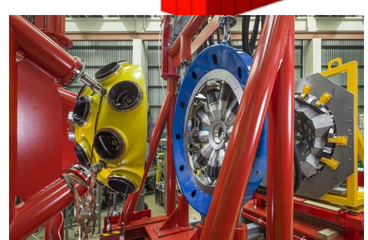
**NEDA** **(NEutron Detector Array)**



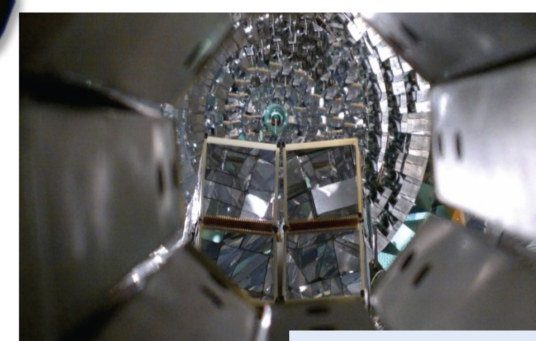


**AGATA** : **innovative γ-rays tracking array**)

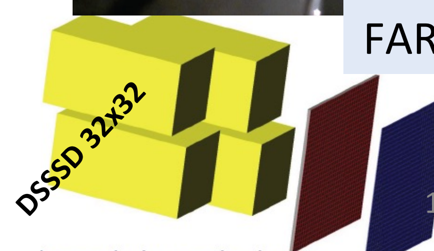


GALILEO
+nWall



FARCOS



# SPES goals: applications

- Research and Production of **Radio-Isotopes for Nuclear Medicine**
- Advanced phase: in construction

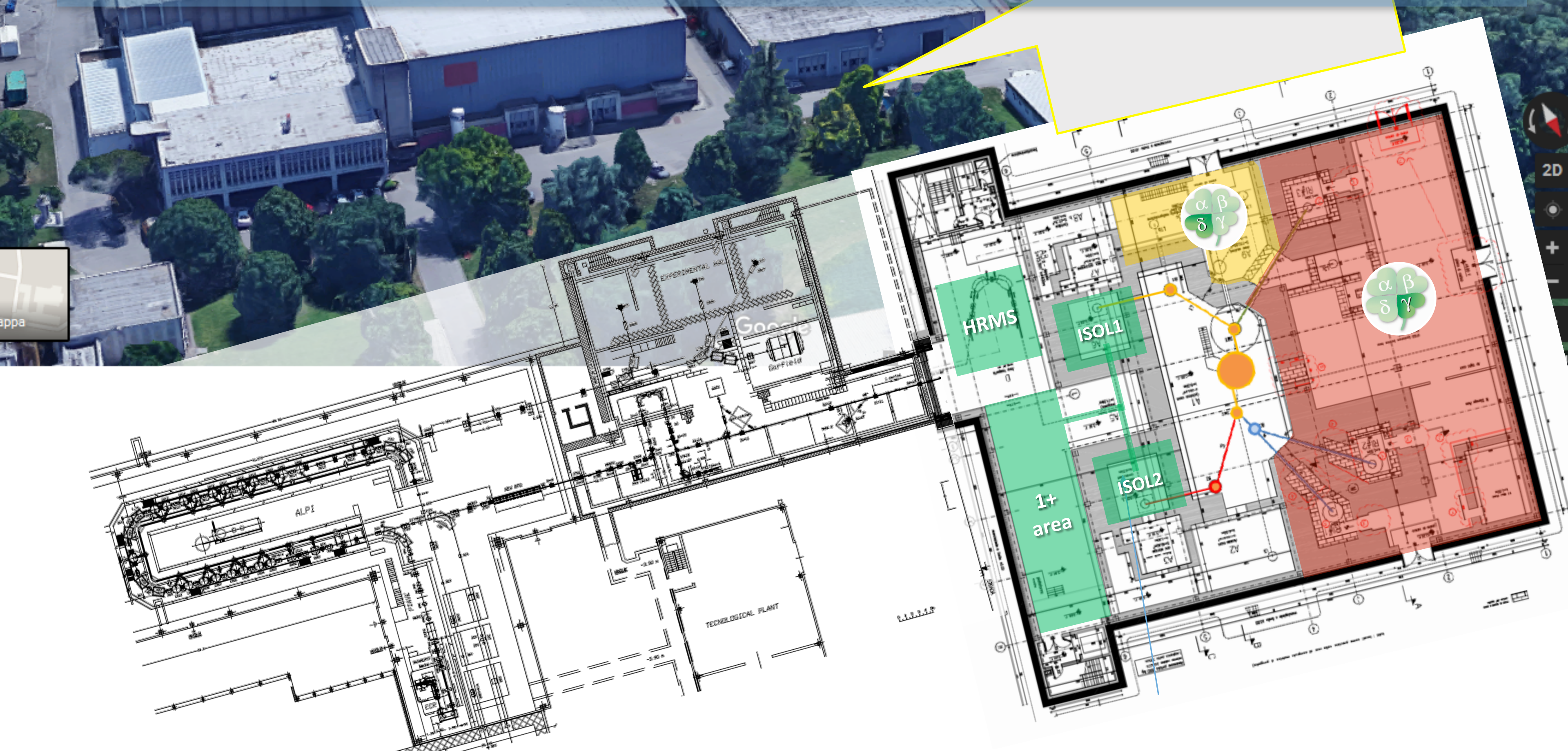
  - LARAMED project: production of radioisotopes by proton induced reaction
  - ISOLPHARM project: production of radioisotopes by ISOL method, with very high specific activity (5-6 order of magnitude more than standard)
  - Possible INFN-industry joint venture for radioisotopes production

- Accelerator-based neutron source (**Proton and Neutron Facility for Applied Physics**) : NEPIR project (Technical Design)
- Design study

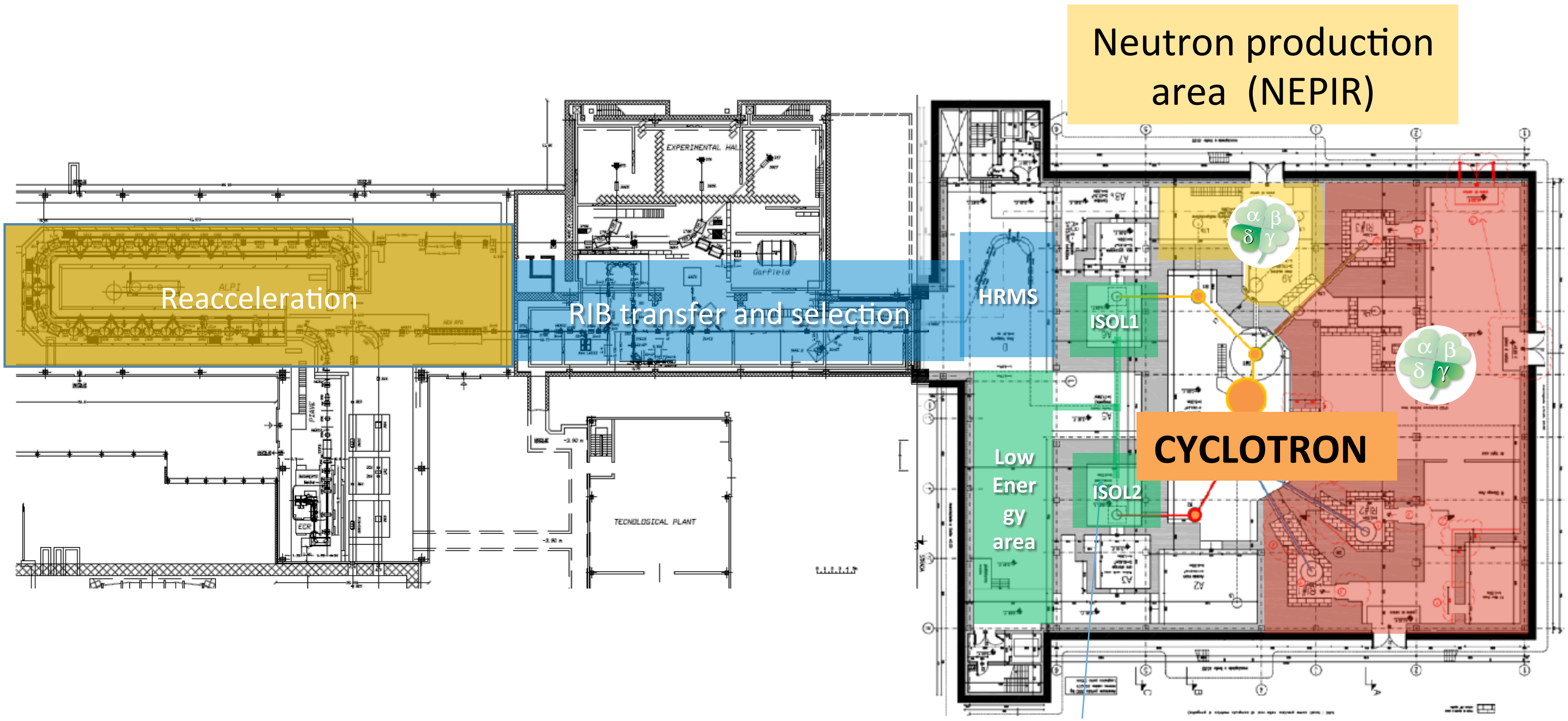
  - SPARE (MIUR - Progetto Premiale 2015)
  - Participation to the international Union of Accelerator-based Neutron Sources (UCANS)

# SPES infrastructure - layout

- ❑ New High power compact CYCLOTRON 70 MeV 750 microA (BEST company)
- ❑ New configuration of High power ISOL System (8 kW Target ion source)
- ❑ ALPI superconductive linac (up-graded) for RIB’s reacceleration



# SPES layout and components




| RIB reacceleration: | 1/20.000 Mass separator | ISOL bunkers | Radioisotopes |
| --- | --- | --- | --- |

RIB reacceleration:

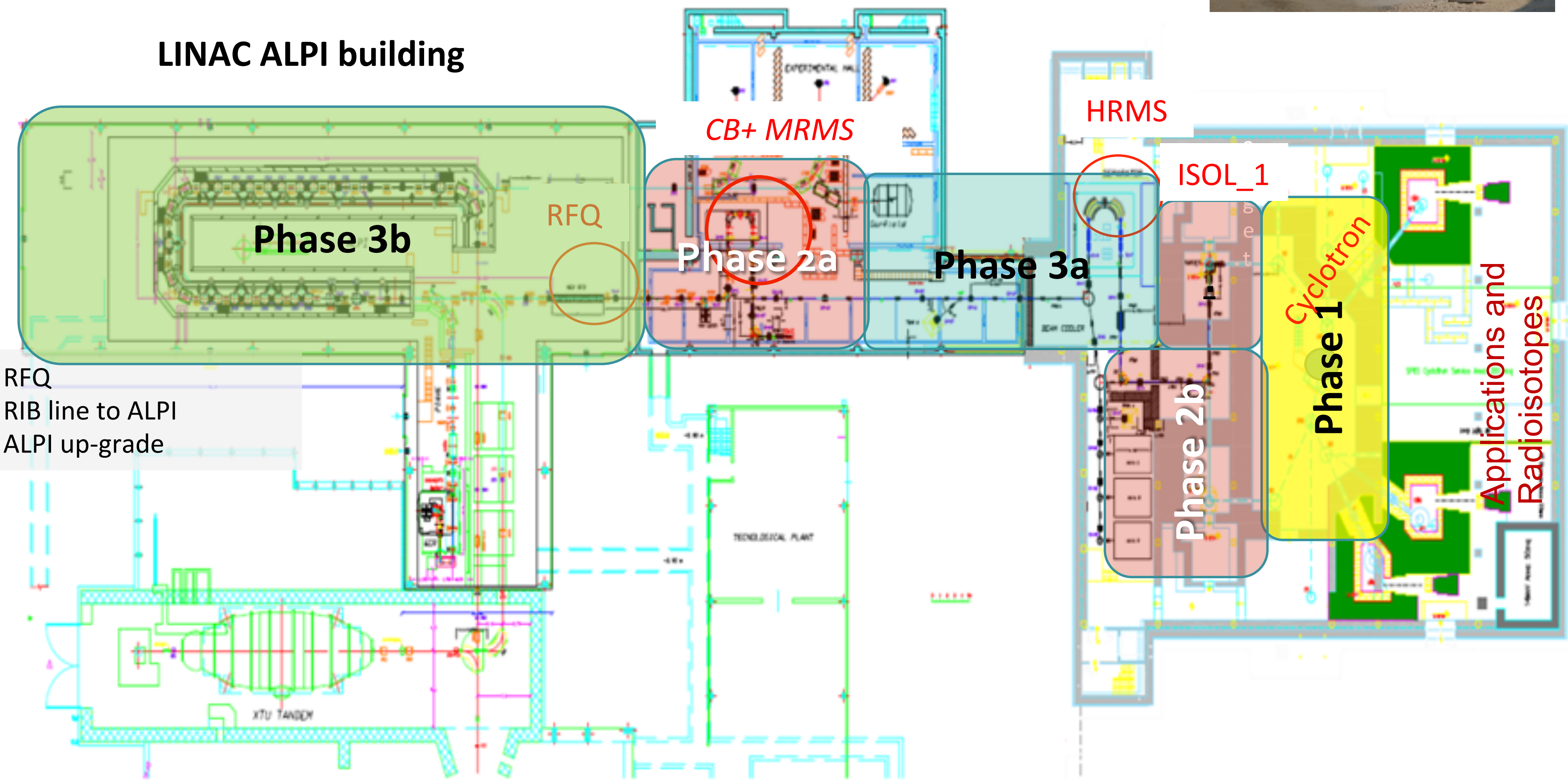
- new RFQ
- ALPI

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

ISOL bunkers
1/150 mass separator
low energy experimental area

Radioisotopes production area (LARAMED)

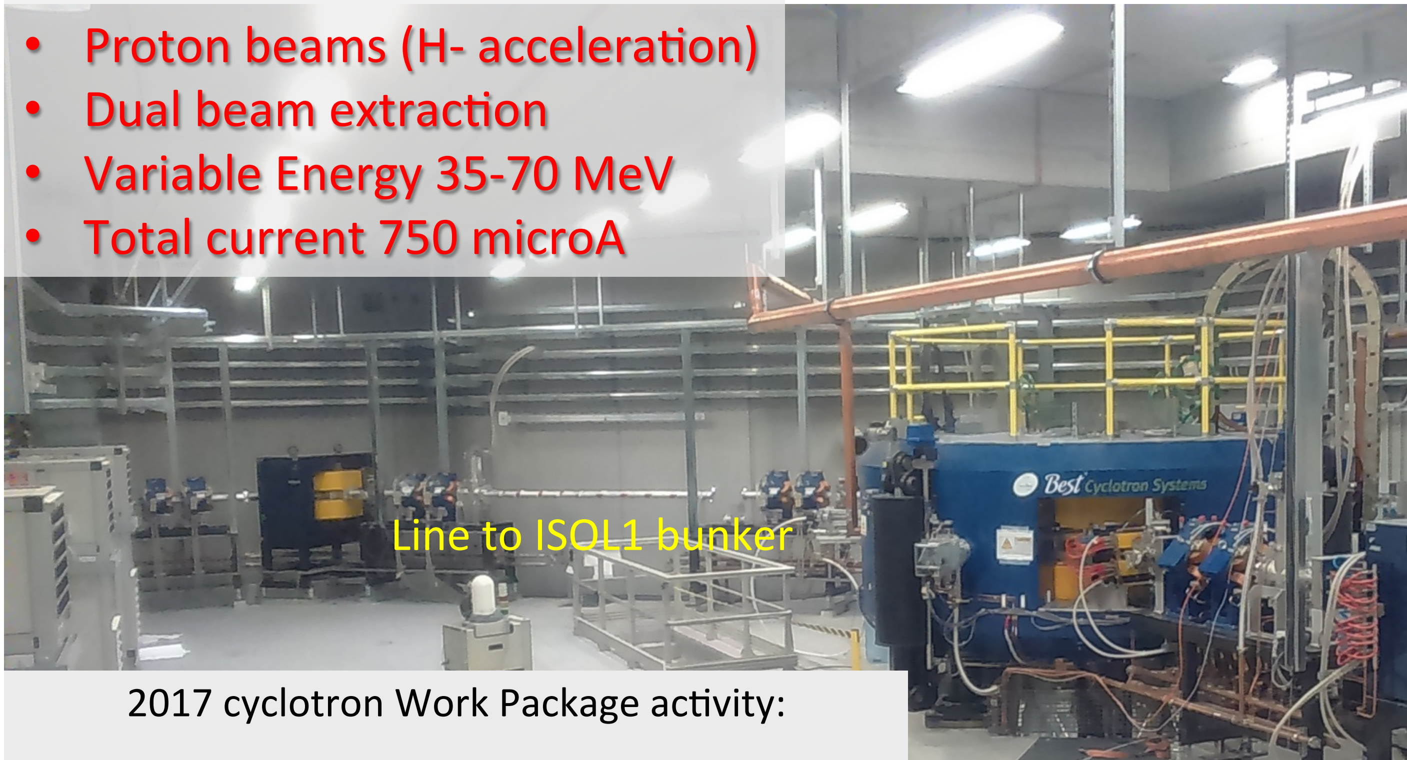
# ISOL facility  installation phases




- RFQ
- RIB line to ALPI
- ALPI up-grade

# Cyclotron and beam lines

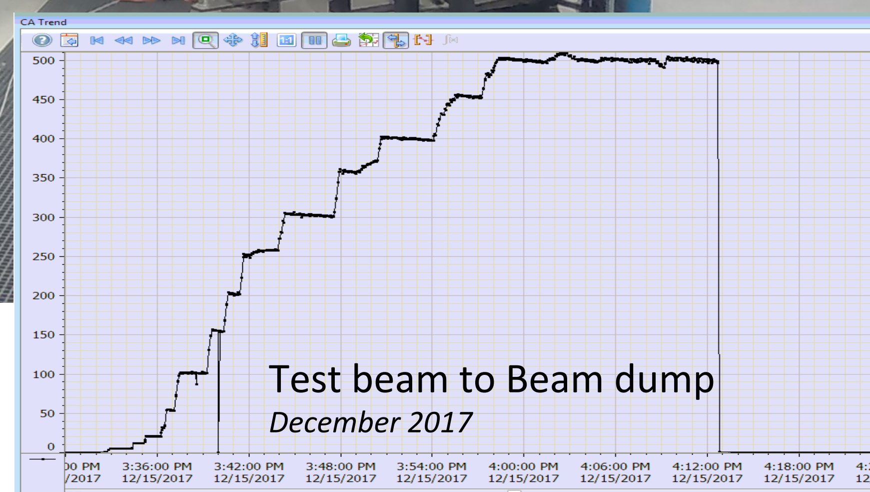
- Proton beams (H- acceleration)
- Dual beam extraction
- Variable Energy 35-70 MeV
- Total current 750 microA





2017 cyclotron Work Package activity:

1. Completed the cyclotron commissioning
2. Personnel trained for operation and maintenance
3. LNL personnel start the cyclotron test up to Beam Dump at 70 MeV 500 microA



# SPES CYCLOTRON
load work per year

Compact, high current, H- cyclotron:
70 MeV, 0.7 mA shared on 2 exits

2 proton beams are available
at the same time

**2 weeks per shift**
Beam preparation 2 days
Beam on target 12 days

Beam on target →280 hours per shift

Each bunker will cool down for 14 days after target irradiation.

**Expected Beam on target:
10.600 hours per year**

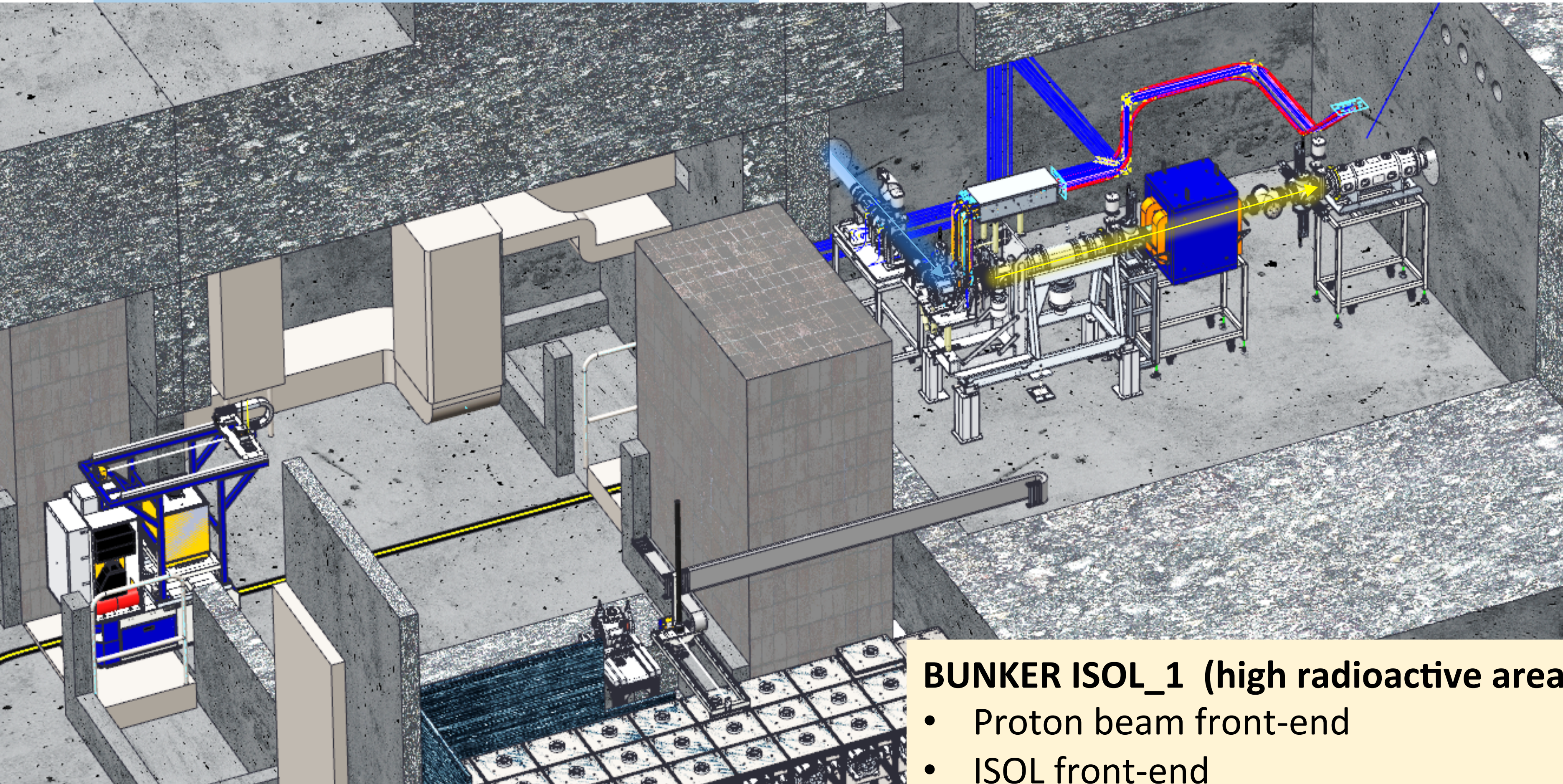
Beam sharing

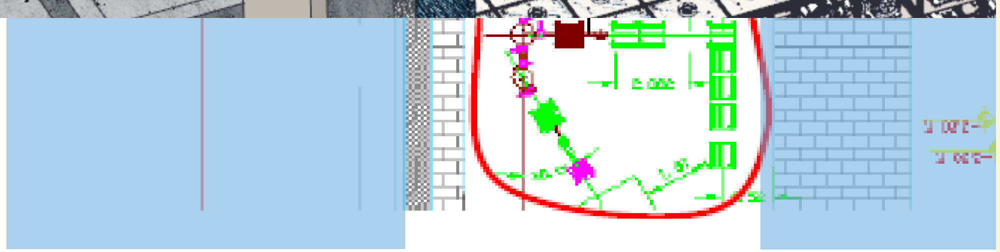
| | Proton beam | N.rs of SHIFTS | Beam on target: Total 10600 hours |
|---|---|---|---|
| ISOL 1 | 250µA 40MeV | 10 | 2800 |
| Irradiation 1 | 500 µA 70MeV | 9 | 2500 |
| Irradiation 2 | 500 µA 70MeV | 10 | 2800 |
| ISOL 2 | 250 µA 40MeV | 9 | 2500 |
| | | | |
| Maintanance | | 7 | 7x14x24= 2350 |
| Cyclotron Operation | | 19 | 19x12x24= 5462 esperiment 19X2x24= 912 beam preparation |

| Main Tasks | 2017 | | | | 2018 | | | | 2019 | | | | 2020 | | | | 2021 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| PHASE 2B: ISOL SYSTEM and wien filter | PRELIMINARY ASSEMBLY | | | | | INSTALLATION | | | | HW COM | | RIB COM | | | | | | | | |
| PHASE 2B: 1+ beam line operation | PRELIMINARY ASSEMBLY | | | | | | INSTALLATION | | | HW COM | | RIB COM | | | | | | | | |
| PHASE 2A: ADIGE 1+ source | | INSTALL | | HW COM | | 1+ SOURCE COM | | | | | | | | | | | | | | |
| PHASE 2A: CHARGE BREEDER & MRMS | | INSTALLATION | | | | | HW COMM | | CB & MRMS COMM AND OPERATION | | | | | | | | RIB COM | | | |
| PHASE 3B: RFQ e bunchers | Construction & installation | | | | | | | | | | | HW COMM | | COMM with BEAM | | | RIB COM | | | |
| PHASE 3A: 1+ beam line up to Charge Breeder | | | | | | | | | CONSTRUCTION | | | INSTALL | | | HW COMM | | | | | |
| PHASE 3A: BEAM COOLER | | | | CONSTRUCTION | | | | | | | | INSTALL | | COMM | | | | | | |
| PHASE 3A: HRMS | | | | | DESIGN | | | | TENDER | | | CONSTRUCTION | | | | | | | | |

# Phase 2B

## ISOL bunkers



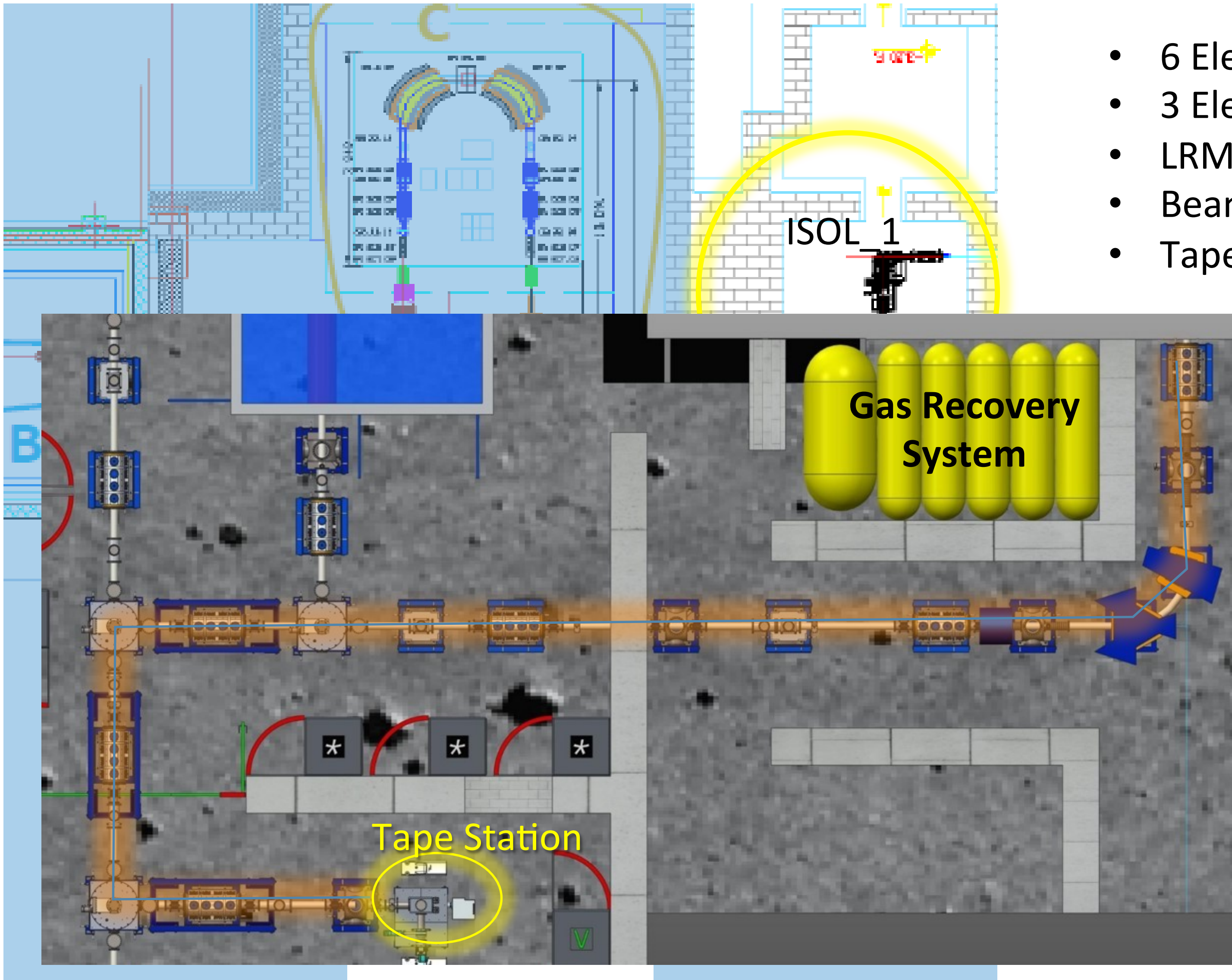


**BUNKER ISOL_1 (high radioactive area)**

- Proton beam front-end
- ISOL front-end
- TIS (HV platform)
- First Electrostatic triplet
- Wien Filter
- Beam instrumentation
- Second Electrostatic triplet

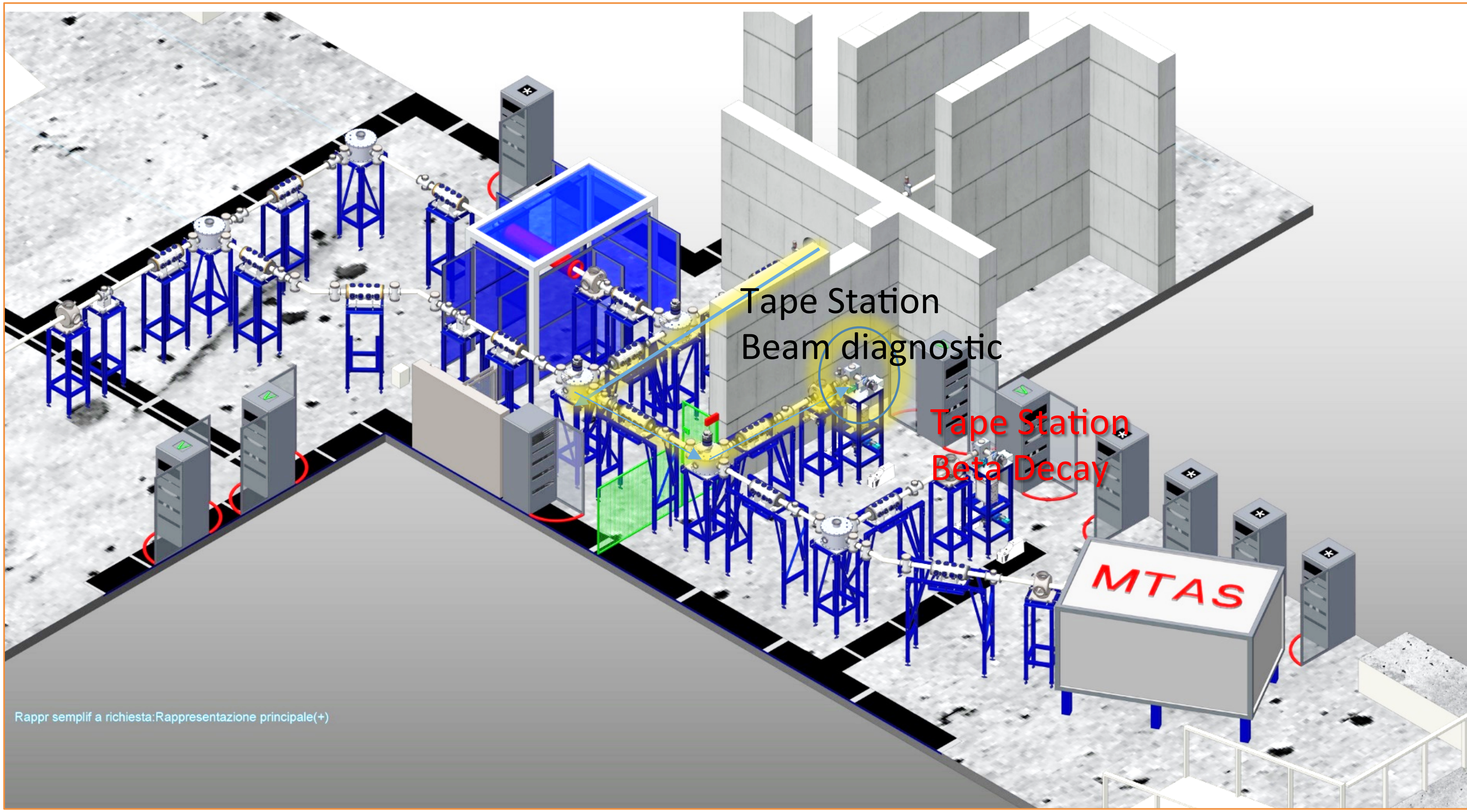
# Phase 2B

## Low Energy beam line to Tape Station

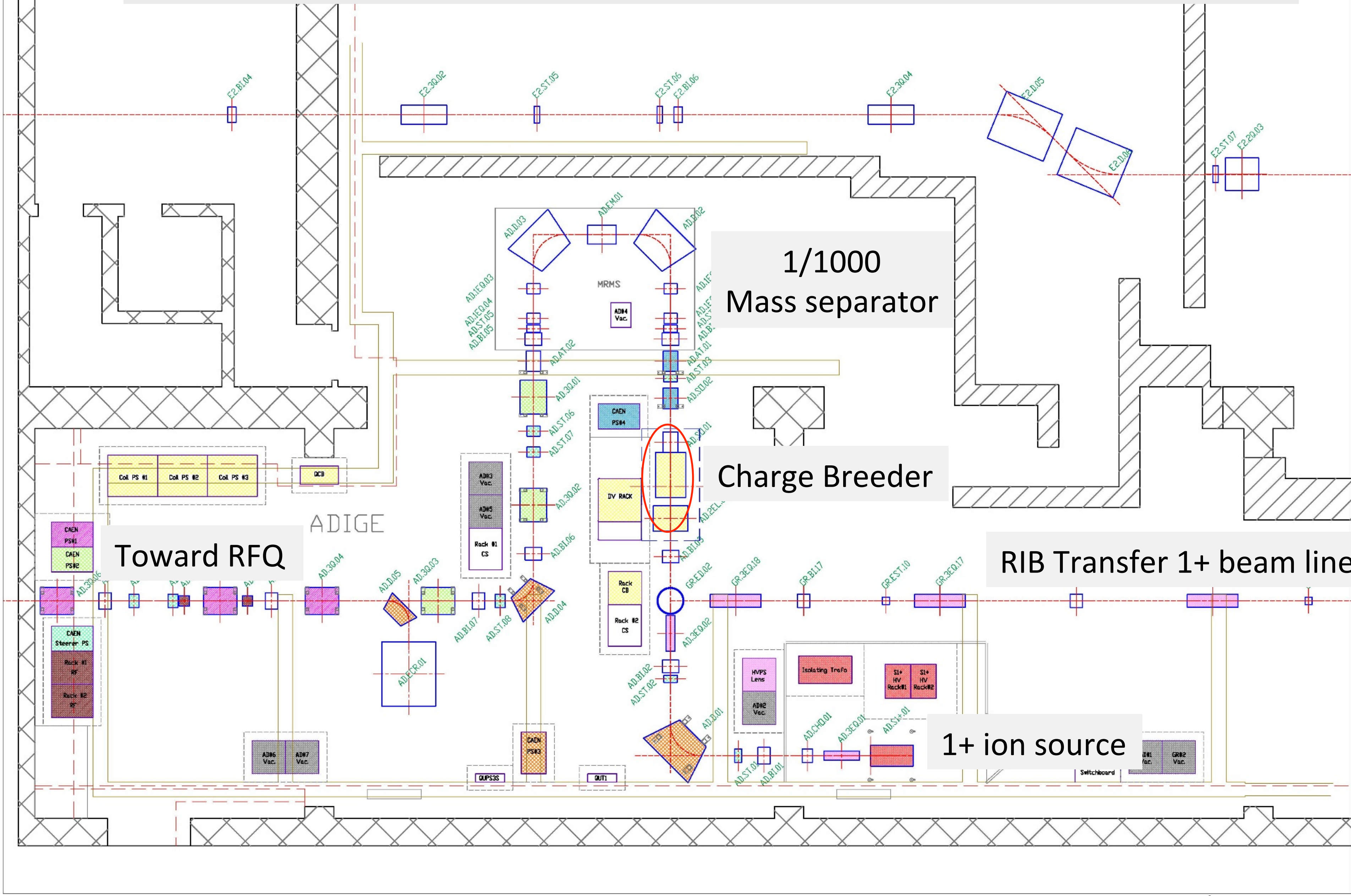



- 6 Electrostatic triplets
- 3 Electrostatic dipoles
- LRMS
- Beam instrumentation
- Tape Station

# Low energy experimental area

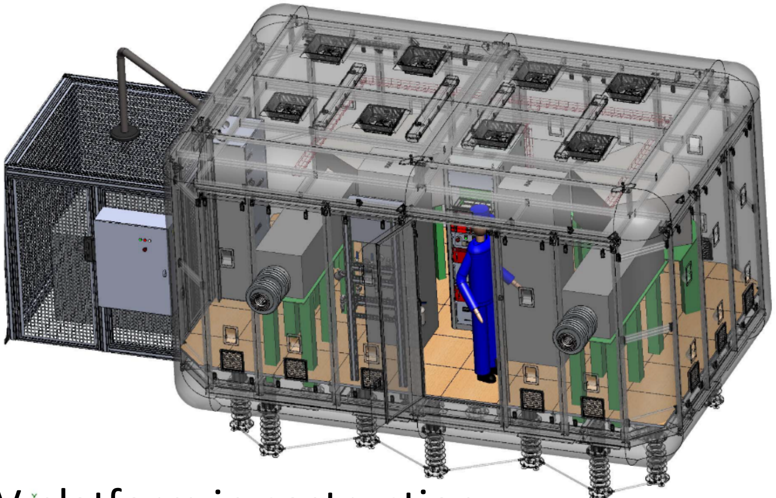


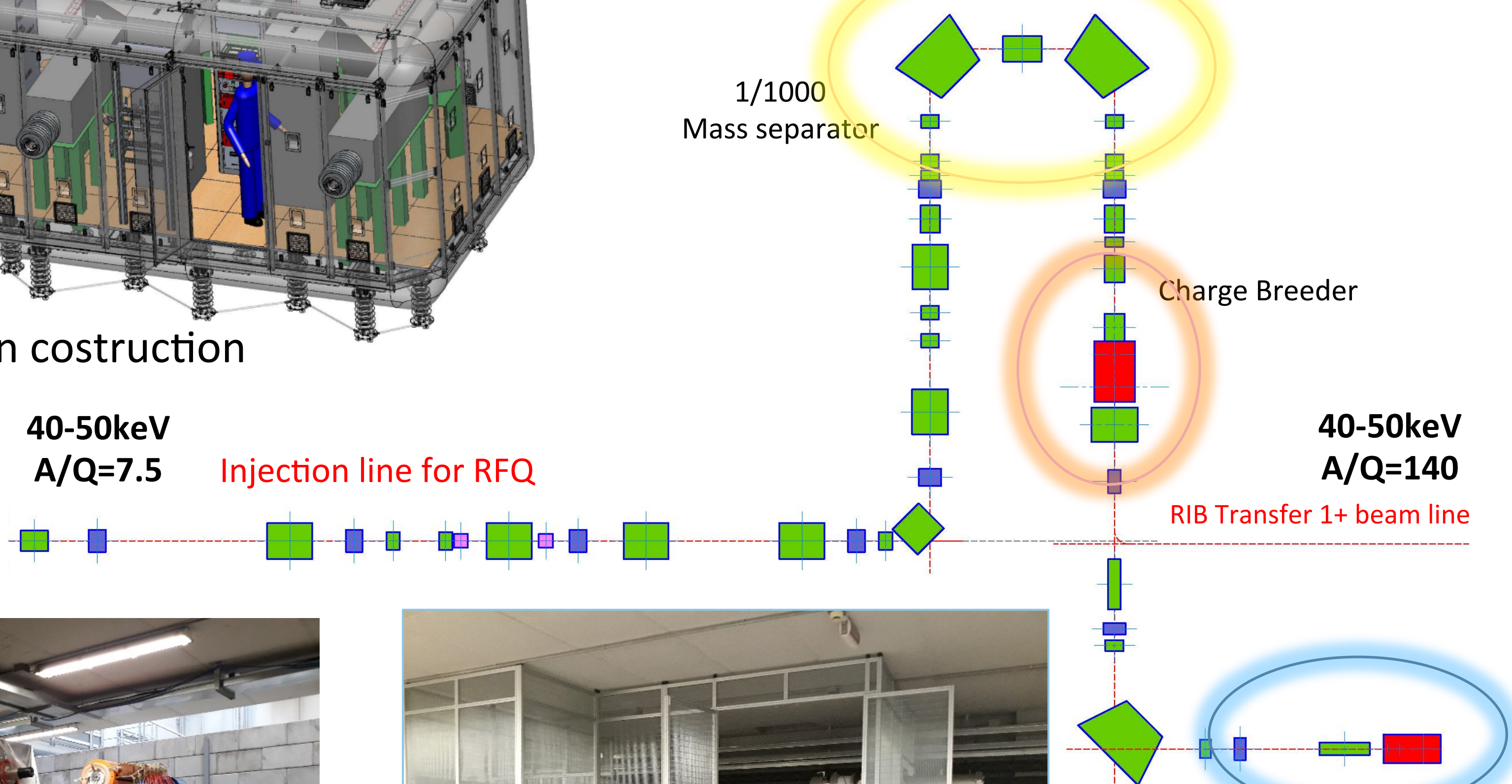
# Phase 2A: Installation of Charge Breeder and n+ beam line



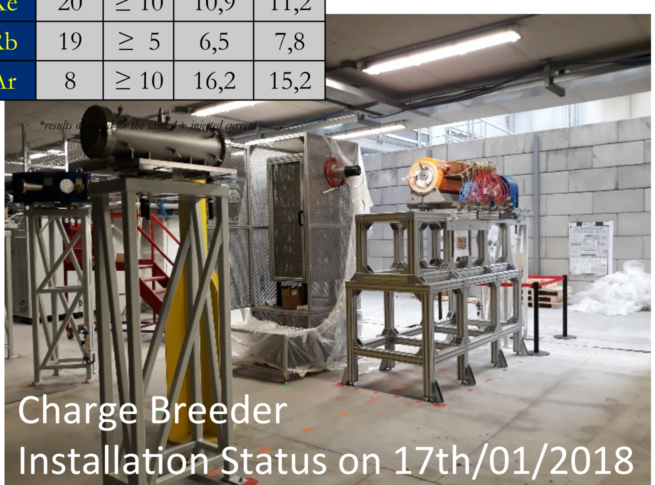

*C.Roncolato*

# Phase 2A: Installation of Charge Breeder and n+ beam line

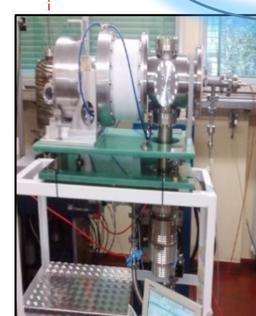

HV platform in costruction




| LPSC 2015 | | EFFICIENCY* [%] | | |
|---|---|---|---|---|
| ION | Q | SPES req | Best LPSC | SPES-CB |
| Cs | 26 | ≥ 5 | 8,6 | 11,7 |
| Xe | 20 | ≥ 10 | 10,9 | 11,2 |
| Rb | 19 | ≥ 5 | 6,5 | 7,8 |
| Ar | 8 | ≥ 10 | 16,2 | 15,2 |

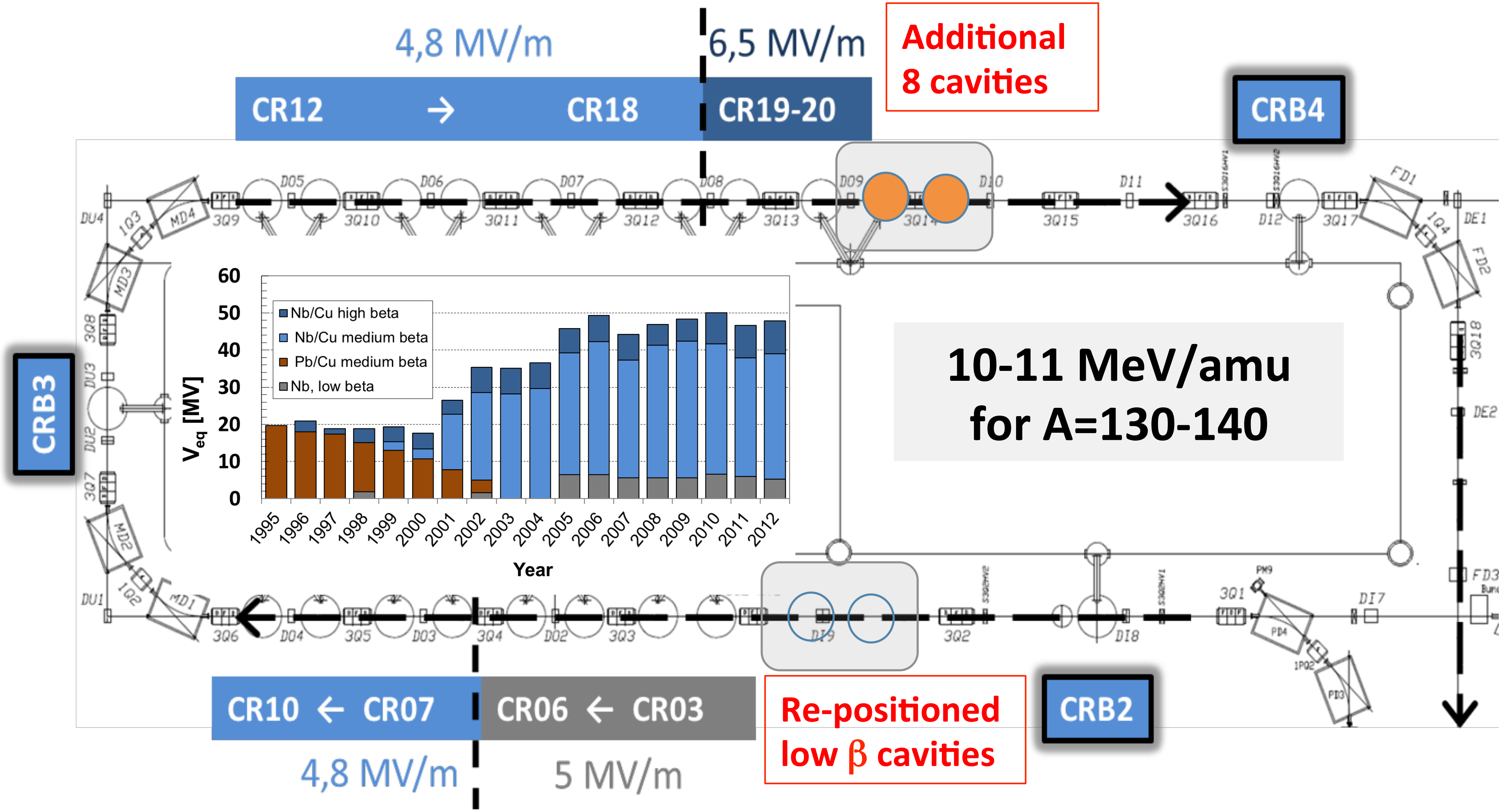

Charge Breeder
Installation Status on 17th/01/2018

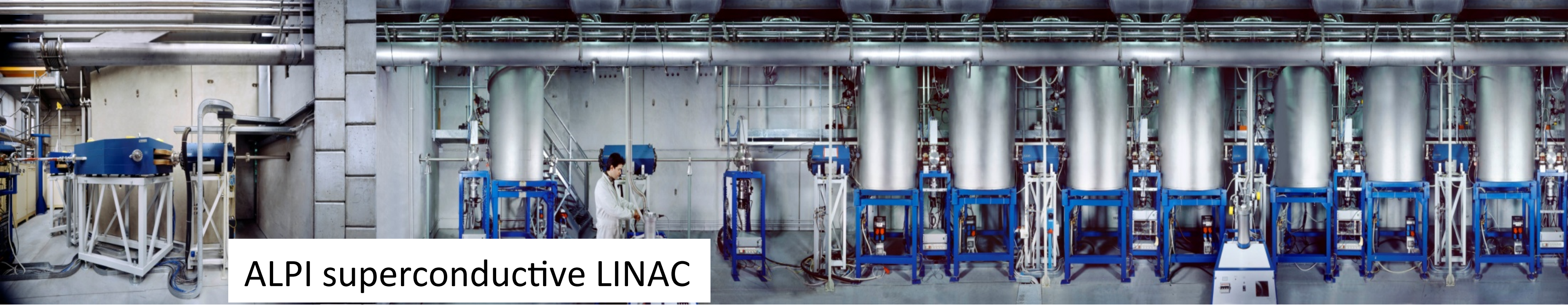

Pilot beam Ion Source
Installation Status on 17th/01/2018



*C.Roncolato*

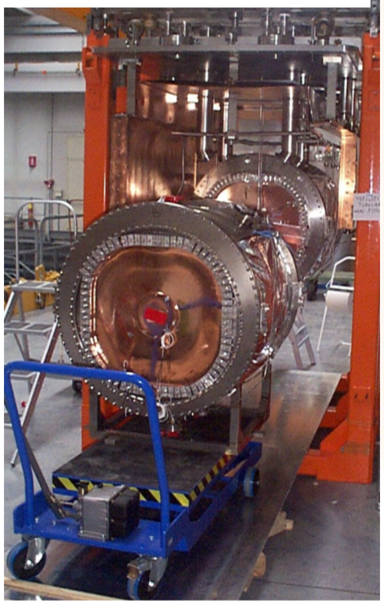
# Matching into ALPI SC linac

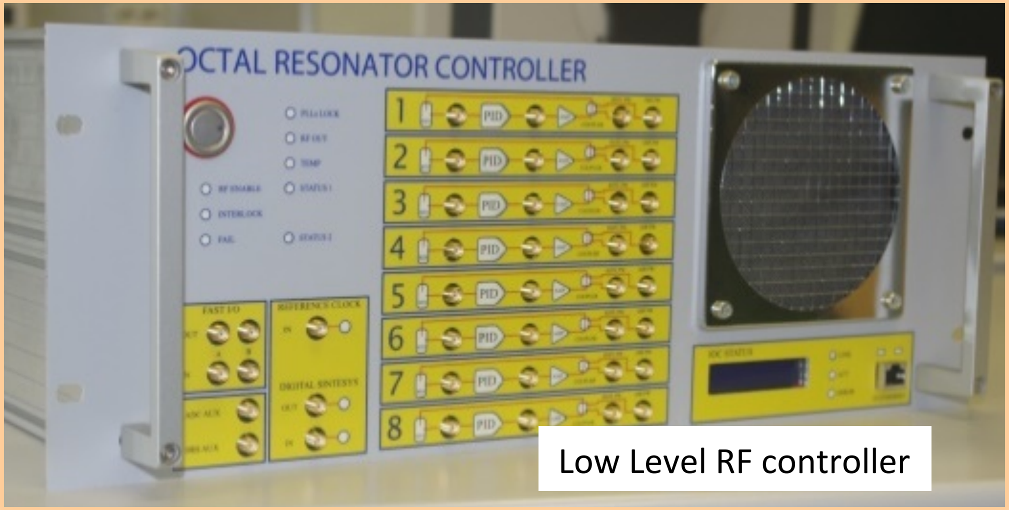



ALPI superconductive LINAC

## RF development and control

PIAVE
Superconductive RFQ

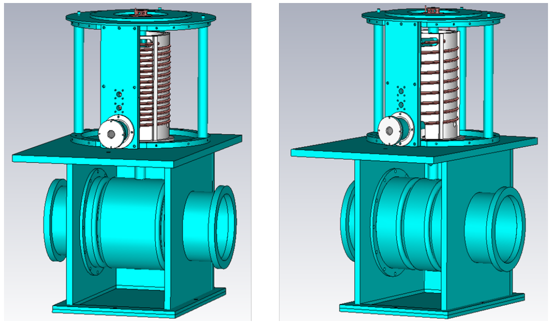




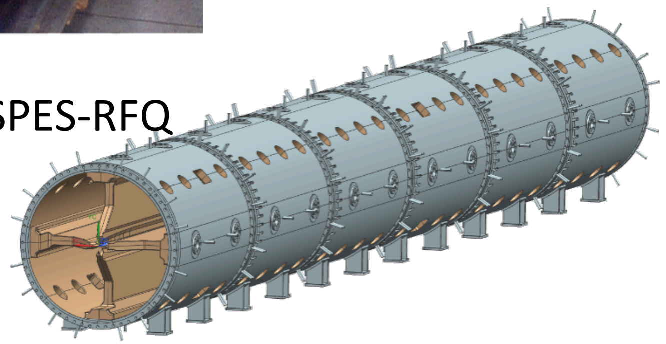
Low Level RF controller

ALPI resonators

RF Buncher

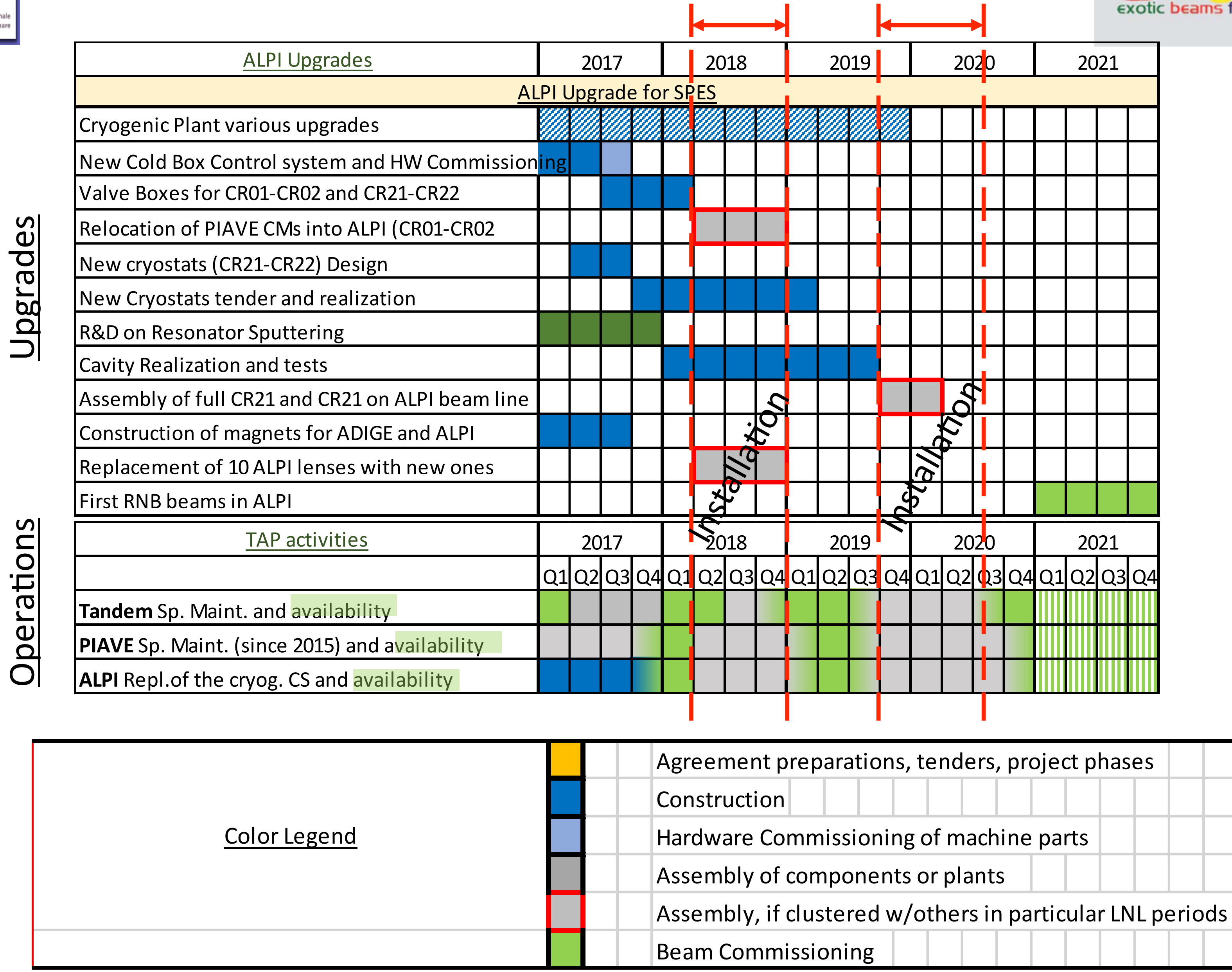

5 and 10 MHz structures

SPES-RFQ

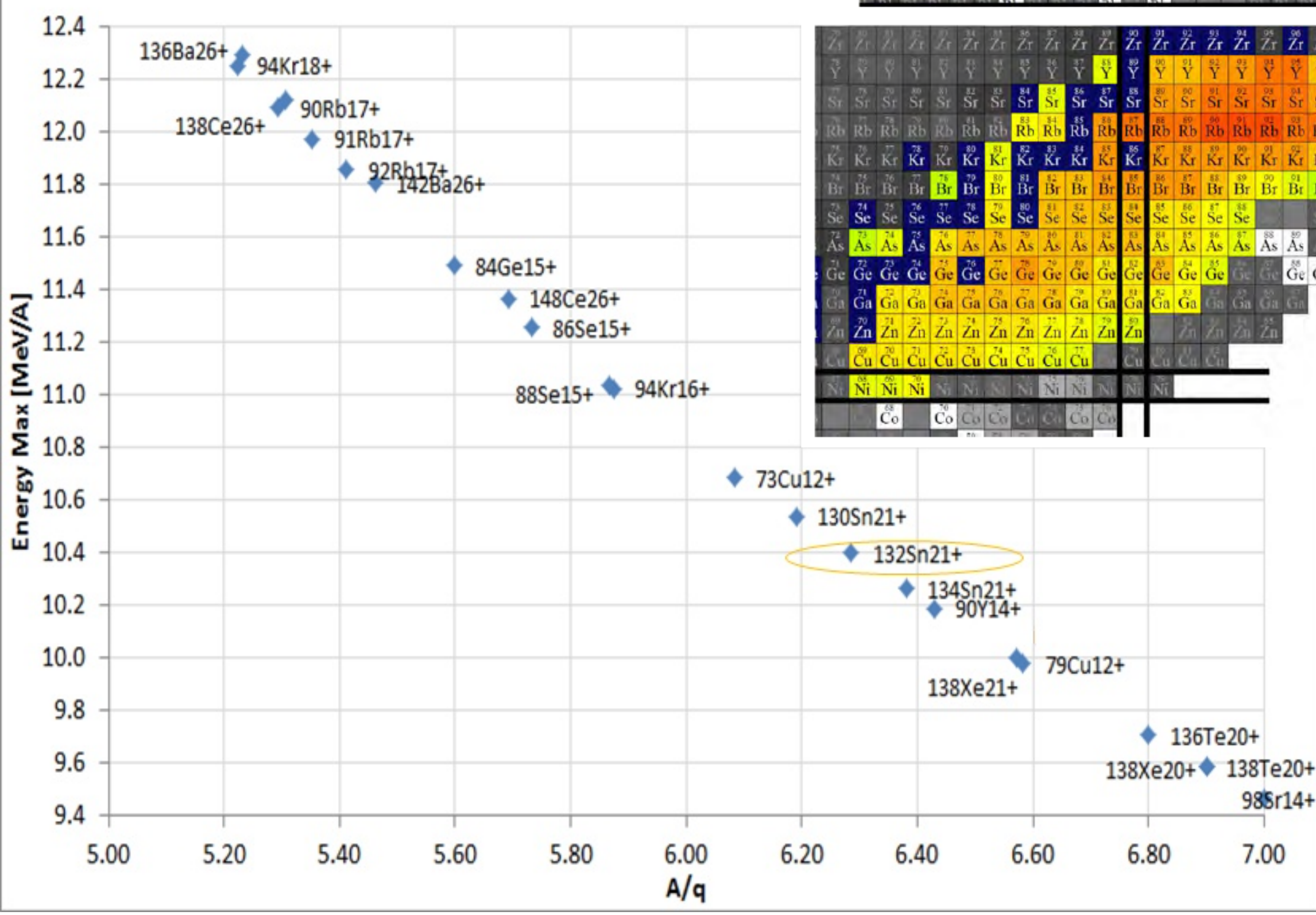


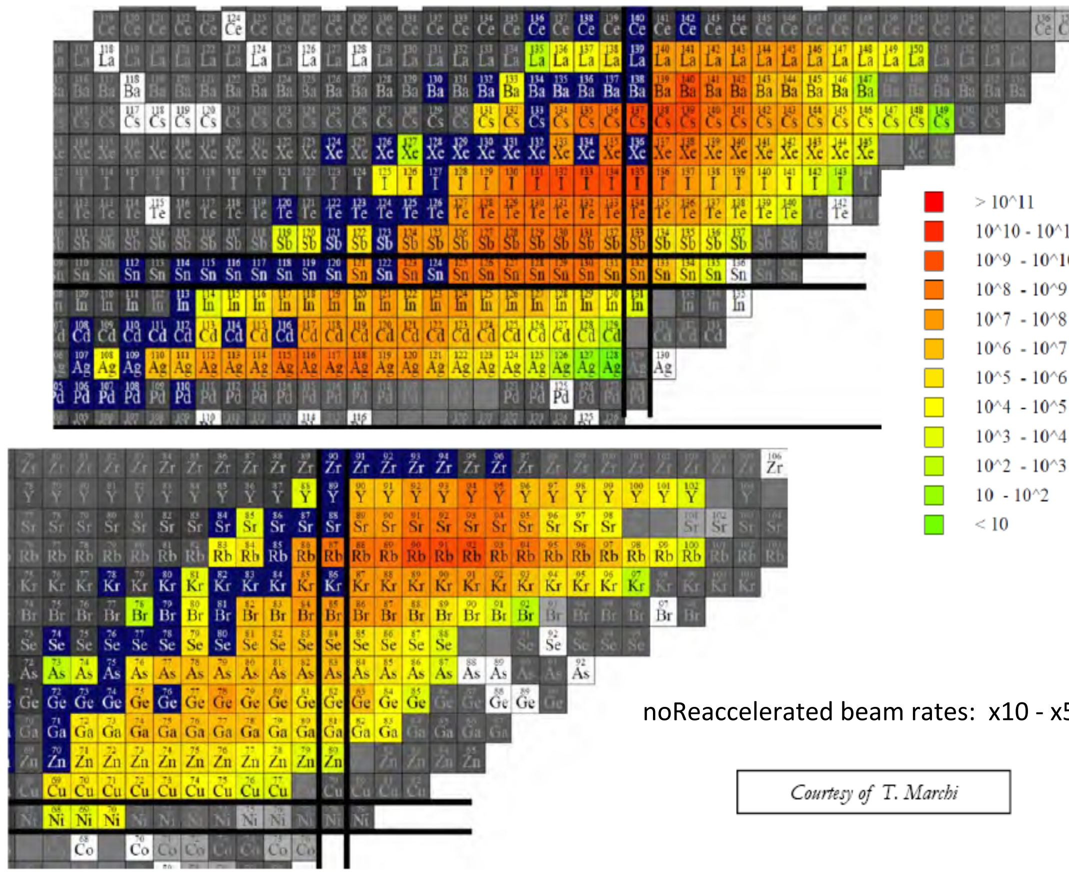
EPICS

# ALPI upgrades and Operation



# Reacceleration with ALPI superconductive linac



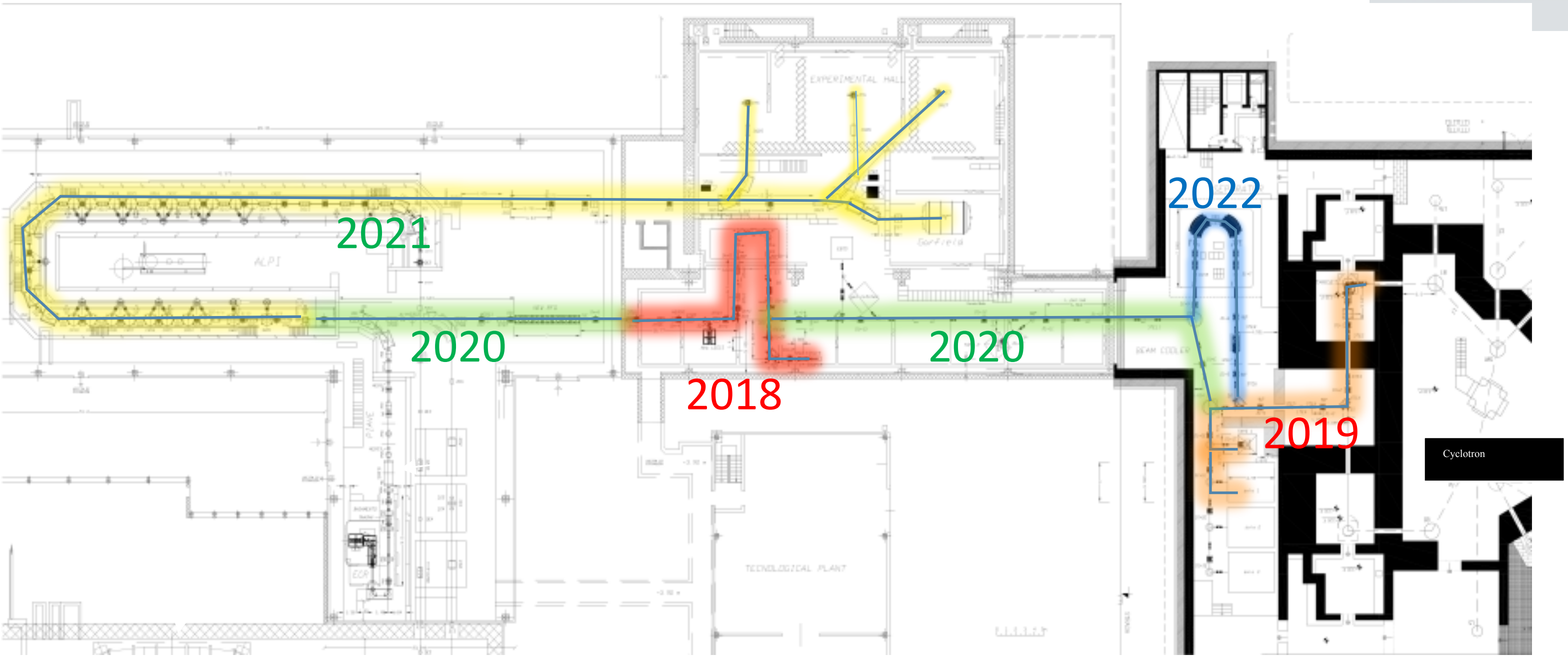

noReaccelerated beam rates: x10 - x50

*Courtesy of T. Marchi*

# Status of others components

| component | Status December 2017 | milestones |
|---|---|---|
| **HRMS** high resolution mass separator | • Physical design ready, integration with beam cooler and beam lines under way<br>• Preliminary dipole design and feasibility check with potential manufacturer done | • Critical Design Review in April 2018<br>• Authorization to tender October 2018<br>• Commissioning 2022 |
| **Beam Cooler** | Collaboration with LPC_Caen for Beam Cooler development (expertise: SCIRaC - SPIRAL2) | • Construction 2018<br>• Commissioning 2020 |
| **Normal conductive RFQ** | 6 modules of RFQ in construction.<br>First 4 electrodes under dimensional commissioning (delivered in April 2017)<br>2nd set of 4 electrodes brazed in May 2017 | • Constraction 2018<br>• Installation 2019-2020 |
| **1+ Beam line transfer** | Electrostatic triplets of quadrupoles designed<br>Electrostatic dipoles under construction<br>Vacuum systems delivered | • Tender for triplets 2018<br>• Installation 2019 - 2020 |
| **Safety** | Safety system analysis and design: Bid assigned (PILZ), risk analysis completed | • Design completed 2018<br>• Installation and commissioning 2019 |

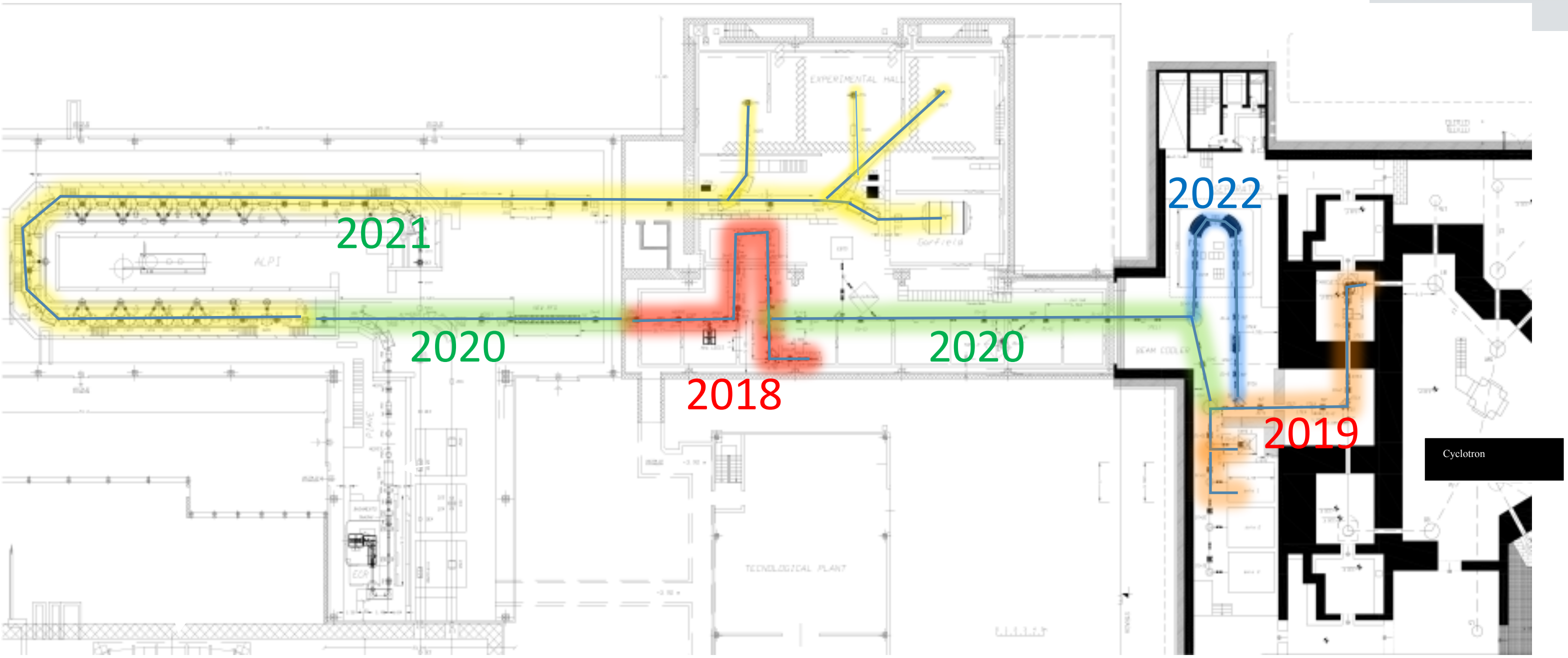
# Installation phases



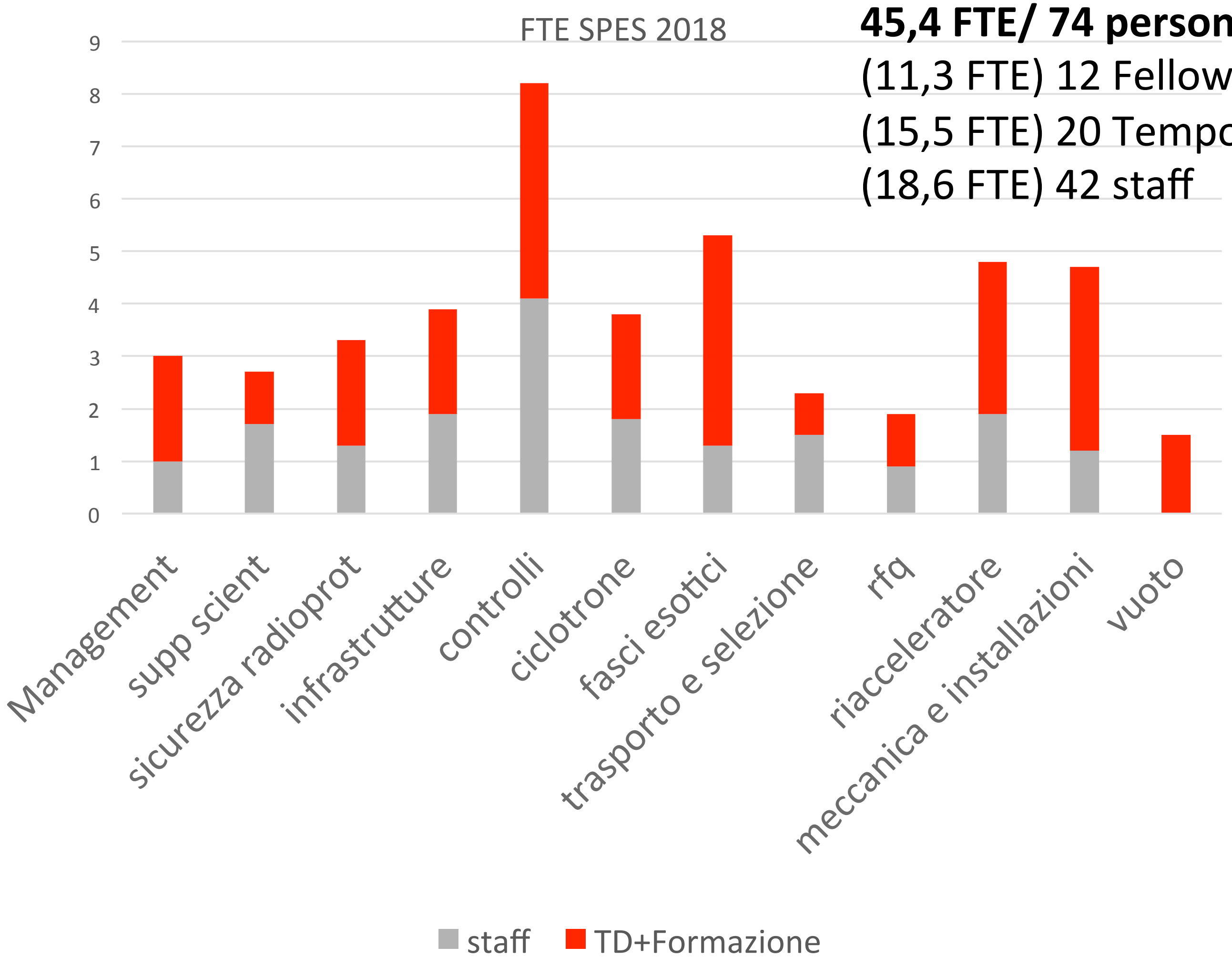

| Main Tasks | 2017 | | | | 2018 | | | | 2019 | | | | 2020 | | | | 2021 | | | | 2022 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| PHASE 2a: CHARGE BREEDER & MRMS installation | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| PHASE 2B: ISOL SYSTEM and wien filter | | | | | | | | | | | | | | | | | | | | | | | | |
| PHASE 2B: 1+ beam line operation | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| PHASE 3A: 1+ beam line up to Charge Breeder | | | | | | | | | | | | | | | | | | | | | | | | |
| PHASE 3B: bunchers & RFQ | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| PHASE 3A: BEAM COOLER | | | | | | | | | | | | | | | | | | | | | | | | |
| PHASE 3A: HRMS | | | | | | | | | | | | | | | | | | | | | | | | |

Experiments with non-reaccelerated beams 2020

# Installation phases



# Allocated Manpower




**45,4 FTE/ 74 persons**

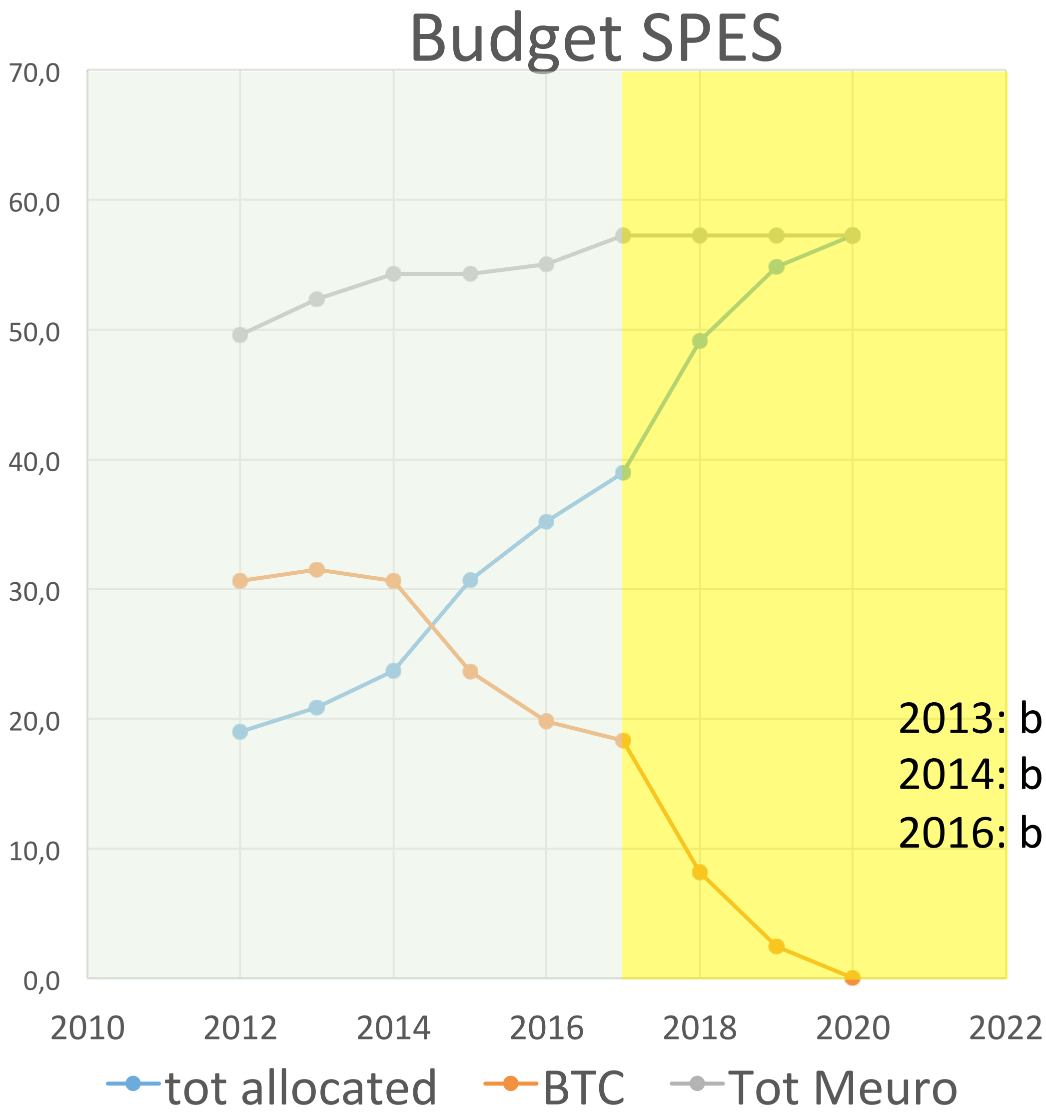
(11,3 FTE) 12 Fellow

(15,5 FTE) 20 Temporary

(18,6 FTE) 42 staff

Staff effort increased for installation:
+ 10 FTE /15 staff

# Revisione dicembre 2017 analisi globale costo totale




| | year | tot allocated | Expected to complete | Tot Meuro |
|---|---|---|---|---|
| gen-13 | 2012 | 19,0 | 30,6 | 49,6 |
| dic-13 | 2013 | 20,9 | 31,5 | 52,4 |
| dic-14 | 2014 | 23,7 | 30,6 | 54,3 |
| dic-15 | 2015 | 30,7 | 23,6 | 54,3 |
| dic-16 | 2016 | 35,2 | 19,8 | 55,0 |
| dic-17 | 2017 | 39,0 | 18,3 | 57,2 |
| dic-18 | | 49,1 | 8,2 | 57,2 |
| dic-19 | | 54,8 | 2,4 | 57,2 |
| dic-20 | | 57,2 | 0,0 | 57,2 |

2013: building upgrade (more infrastructures)
2014: budget revision
2016: building upgrade and low energy beam line

# CONCLUSION

Main highlights 2017:

- Completed the Cyclotron commissioning
- Started the installation phase of Charge breeder and mass separator
- Completed the prototype test of:
  - ISOL system
  - first selection system (wien filter)
  - transport line components (electrostatic triplets and dipole)

Expected milestones:

- 2020 first experiments with low energy exotic beams (non re-accelerated)
- 2021 first experiments with re-accelerated exotic beams
- 2022 operation of High resolution mass separator

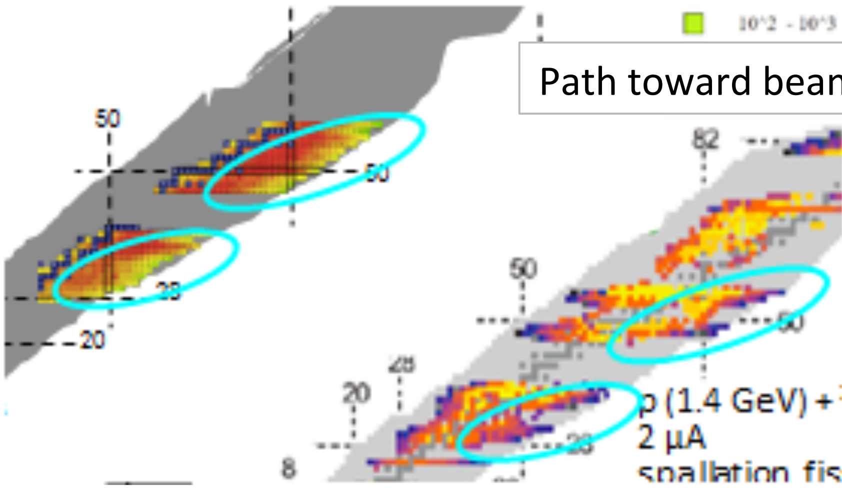
Grazie dell'attenzione

# ISOL and in-flight RIBs international Facilities

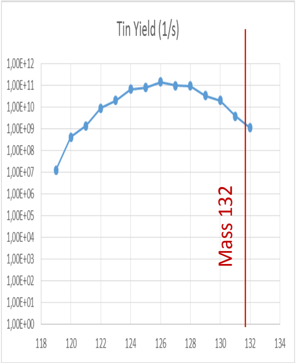
| Laboratory | New RIB projects | Beam to experiment | notes |
|---|---|---|---|
| LNL | SPES | 2020 (no reacc)<br>2022 (reacc 10A MeV) | Second generation ISOL_UCx |
| CERN | HIE_ISOLDE | 2017 (reacc 5A MeV)<br>2021 (High Intensity to be funded) | Second generation ISOL_UCx |
| TRIUMF | ARIEL | 2020 (no reacc) | Second generation ISOL_UCx |
| CIAE Beijing | BRIF | (2014 cyclotron commissioned) | ISOL under construction |
| VECC Kolkata | ANURIB | (2025) | ISOL design study |
| Corea | RISP | 2022 | In-flight & ISOL_UCx |
| GANIL | SPIRAL2 | 2023 | High intensity Fusion-Evaporation |
| GSI | FAIR | 2025 | In-flight |
| MSU | FRIB | 2022-24 | In-flight |
| *RIKEN* | *RIBF* | *2006* | *In-flight* |
| *ANL* | *CARIBU* | *2010* | *252Cf Catcher* |

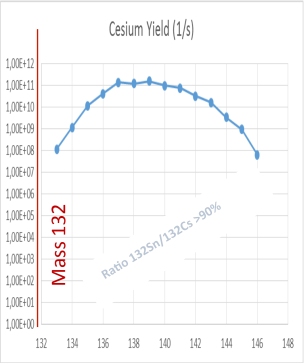
# Details about the requested beams at SPES according to the Letters of Intent

47 LOIs submitted to SAC
15% with non re-accelerated RIBs
21% with 132Sn
19 elements, 89 isotopes

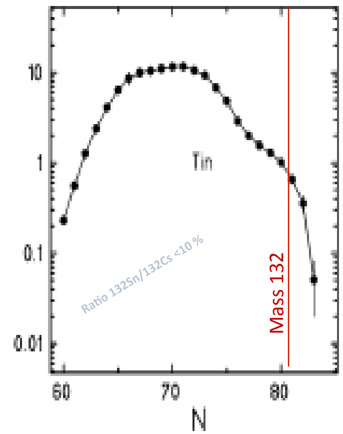


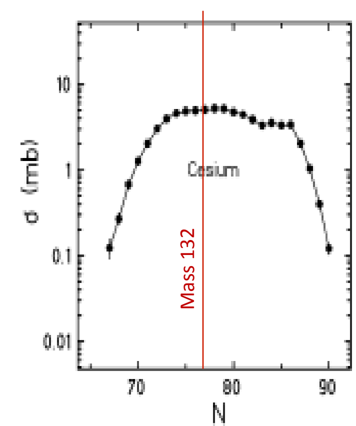

Path toward beam selectivity: **Reaction** → ion-source → mass separation




| | | 19 Elements | |
|---|---|---|---|
| Total beams | 89 | | LOI % |
| Beams with 200_LRMS | 47 | | 53% |
| Benefit with 5.000_HRMS | 3 | → 50 beams | 56% |
| Benefit with 10.000_HRMS | 17 | → 67 beams | 75% |
| Benefit with 15.000_HRMS | 25 | → 82 beams | 92% |
| Benefit with 20.000_HRMS | 7 | → 89 beams | 100% |



# Planning for installation PHASE 2B
# (ISOL system and low energy RIB production)

| **Phase 2B: ISOL system – low energy beam line to Tape Station** | 2017 | | | | 2018 | | | | 2019 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| A6 room (bunker) | | | | | | | | | | | | |
| test with stable beams: ionization and trasport (ISOL laboratory) | | | | | | | | | | | | |
| install. of the main plants and subs. required in the ISOL rooms | | | | | | | | | | | | |
| mech. Install. of the proton and iSOL FrontEnd | | | | | | | | | | | | |
| beam line test with stable ion beams | | | | | | | | | | | | |
| primary and secondary beam lines commissioning | | | | | | | | | | | | |
| Laser installation end test | | | | | | | | | | | | |
| A5 and A13 rooms (experimental hall) | | | | | | | | | | | | |
| completion of the general 1+ beam line design & layout | | | | | | | | | | | | |
| construction of the electrostatic dipoles and triplets | | | | | | | | | | | | |
| magnetic dipole construction | | | | | | | | | | | | |
| installation of the main components of the 1+ beam line | | | | | | | | | | | | |
| operation with stable ion beams along the 1+ beam line | | | | | | | | | | | | |
| SPES facility | | | | | | | | | | | | |
| RIBs delivered at the tape station | | | | | | | | | | | | |

Color Legend

- Study phase, bid, preparatory work
- Construction and installation
- Beam Commissioning

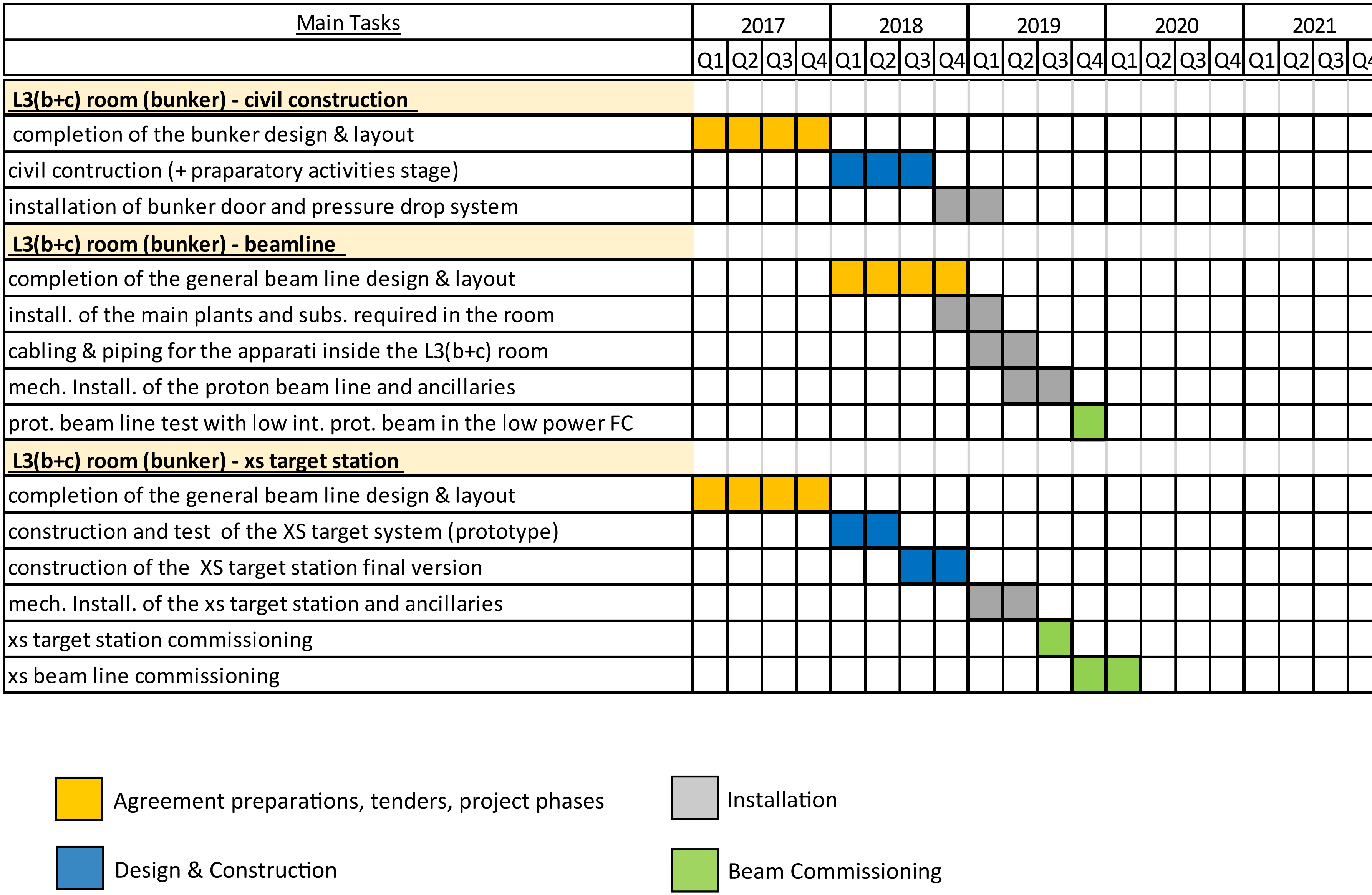
# Planning for installation PHASE 2A – 3B
# Exotic beam re-acceleration

| **Phase 2B: Charge breeder (w/1+ source) - MRMS - to RFQ** | 2017 | | | | 2018 | | | | 2019 | | | | 2020 | | | | 2021 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| Tests at LPSC on CB contaminants | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| Experimental Phase 1 (SI+PIS before the CB) | | | | | | | | | | | | | | | | | | | | |
| CB characterization with MRMS (no injected beam) | | | | | | | | | | | | | | | | | | | | |
| CB characterization with MRMS (w/injected beam) | | | | | | | | | | | | | | | | | | | | |
| Beam Line completion MRMS to RFQ | | | | | | | | | | | | | | | | | | | | |

| | | |
|---|---|---|
| Color Legend | | Study phase, bid, preparatory work |
| | | Construction and installation |
| | | Beam Commissioning |

| **Phase 3B: Bunchers – RFQ preaccelerator** | 2017 | | | | 2018 | | | | 2019 | | | | 2020 | | | | 2021 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| | | | | | | | | | | | | | | | | | | | | |
| Bunchers (tender/construction) | | | | | | | | | | | | | | | | | | | | |
| Beam Line completion MRMS to RFQ | | | | | | | | | | | | | | | | | | | | |
| Beam injection tests to RFQ Input | | | | | | | | | | | | | | | | | | | | |
| Installation from RFQ to ALPI | | | | | | | | | | | | | | | | | | | | |
| RFQ Construction and Installation | | | | | | | | | | | | | | | | | | | | |
| RFQ HW Commissioning | | | | | | | | | | | | | | | | | | | | |
| Beam Commissioning Phase 3B. (RFQ-to-ALPI) | | | | | | | | | | | | | | | | | | | | |

# Scheduled plan for LARAMED
# RILAB (L3b/c –xs meas.) bunker installation



# SPES LoI's for beta decay station

1_F.C.L.Crespi (INFN_Mi, Italy)
**Pygmy Dipole States** in Neutron-rich Zr and Kr Isotopes Investigated with Beta Decay

2_T. Kurtukian-Nieto (CENBG, IN2P3/CNRS / Université Bordeaux, France)
Measurement of the decay characteristics of nuclei around A=90 relevant to **the r-process nucleosynthesis**.

3_K.P. Rykaczewski (ORNL Oak Ridge, USA)
**Nuclear structure** of neutron-rich nuclei determined through beta decay spectroscopy of fission fragments

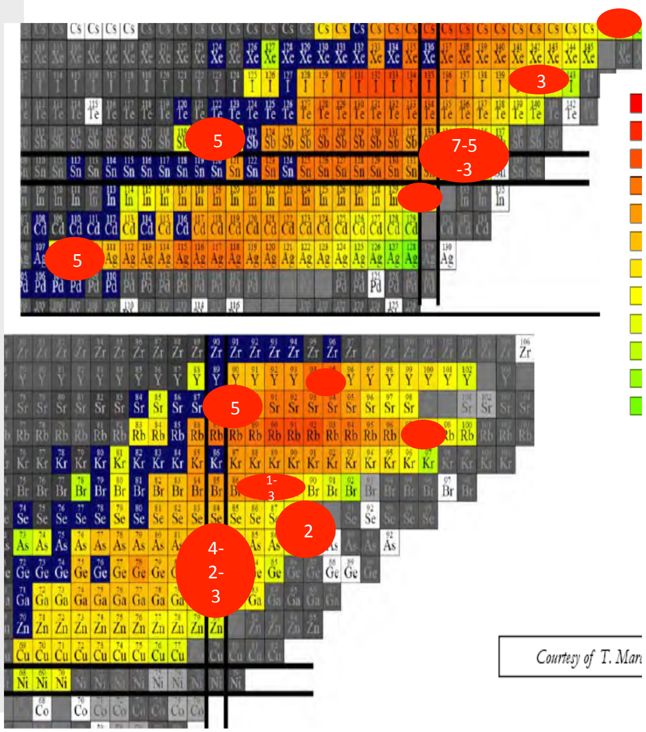
4_A.Gottardo (IPNO, France)
**Shell structure and collective excitations** and resonances at and beyond N=50 with decay spectroscopy

5_S.Cristallo (INAF, Italy)
Letter of Intents for measurements at SPES on beta-decay properties of nuclei belonging to **the s-process path**.

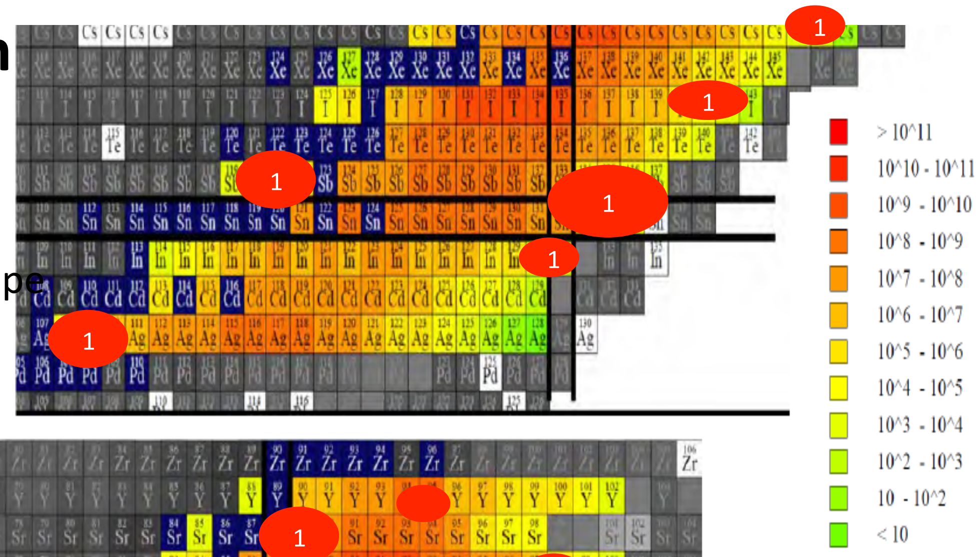
6_A.Nannini (INFN_Fi, Italy)
Electron conversion measurements at SPES 1+ beam line: measurement of **E0 transitions** in 96Sr

7_D.Testov (JINR, Dubna, Russia)
Study of beta-decay properties of neutron-rich isotopes approaching **the r-process path**.

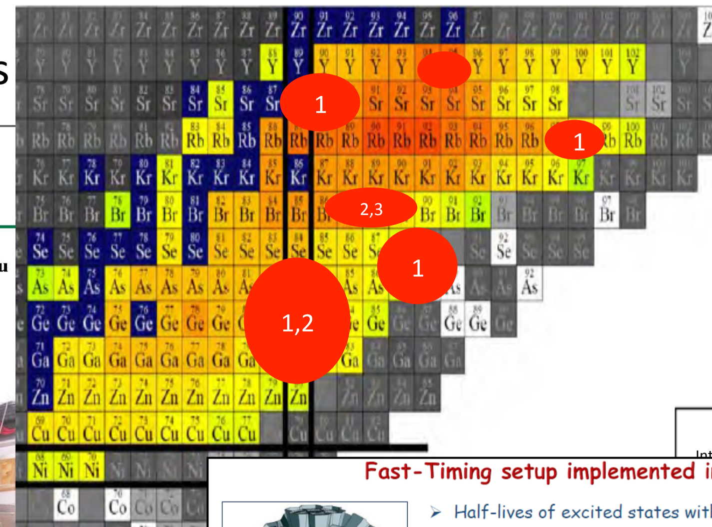
**Astrophysics:** input for r and s process
**Nuclear structure:** Shell evolution and nuclear shape
**Exotic decay :** Pygmy resonance by Bdecay



# SPES LoI's for beta decay station




**1_Astrophysics:** input for r and s process
**2_Nuclear structure:** Shell evolution and nuclear shape
**3_Exotic decay :** Pygmy resonance by β_decay

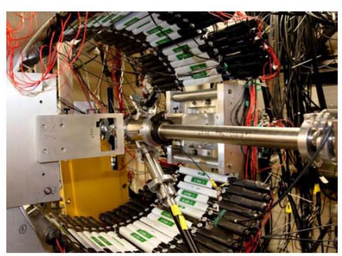



Additional instrumentation and collaborations

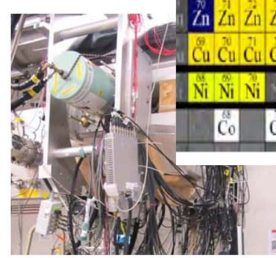
**Decay spectroscopy techniques to study neutron-rich fission fragments at SPES**


Krzysztof P. Rykaczewski, Robert Grzywacz, Carl J. Gross, Daniel W. Stracener, Yuan Liu
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6371, USA
in collaboration with
C. Mazzocchi, A. Korgul, M. Karny, K. Miernik, U. of Warsaw, Warsaw, Poland
W. Krolas, Institute of Nuclear Physics PAN, Krakow, Poland


MTAS = Modular Total Absorption Spectrometer



VANDLE = Versatile Array of Neutron Detectors for Low Energy



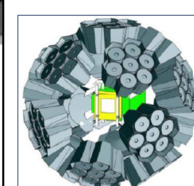
3Hen = Helium-3 Neutron Detectors
Hybrid-3Hen = 3Hen + Clover Ge

The physics of neutron-rich fission fragments
- nuclear structure evolution as N >> Z
- spectroscopy near and above the neutron separation energy
- rapid-neutron capture half-lives and beta-delayed neutron branchings
- societal impact in better data for modeling neutron-rich environments such as nuclear reactors
- more detailed understanding of the anti-neutrino spectra from reactors

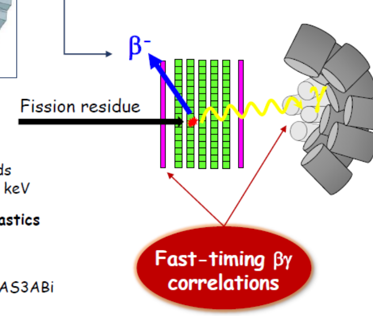
U.S. DEPARTMENT OF ENERGY — OAK RIDGE NATIONAL LABORATORY, MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Courtesy of T. Marchi
Intensities for re-accelerated beams

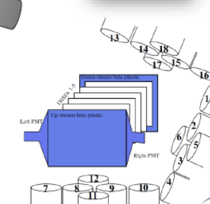
**Fast-Timing setup implemented in spring 2013**



- Half-lives of excited states within the ps-ns range
  - ✓ Measure $\beta_2$ of 2⁺, 4⁺ states in even-even deformed nuclei
  - ✓ Inspect configuration mixing, seniority scheme in spherical nuclei
  - ✓ Search for β-delayed short-lived isomers




- 18 LaBr$_3$(Ce)
  - 1.5"x 2"
  - 5 mm lead shields
  - Eff 1.5% @ 660 keV
- 2 BC-418 fast plastics
  - 45x150 mm$^2$
  - 2 mm thick
  - 3-5 mm from WAS3ABi
  - Eff ~ 50%

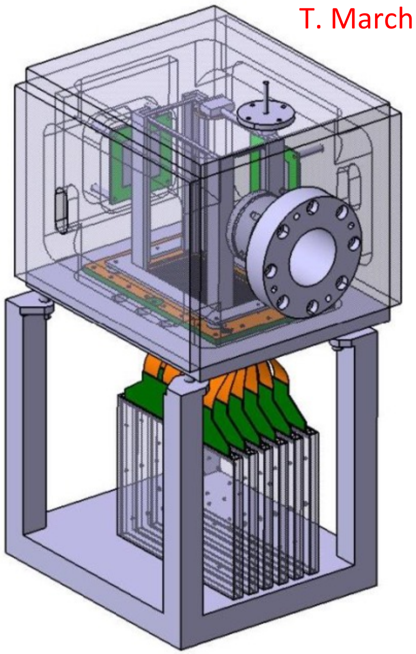


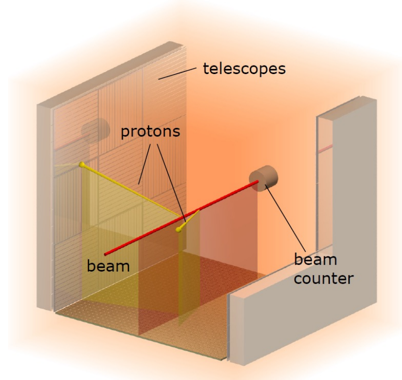
EUREKA collaboration

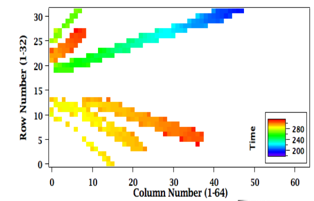
# Instrumentation @ SPES

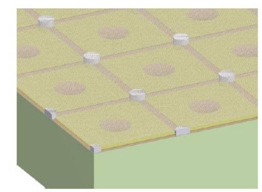
ATS @ SPES within the NUCL-EX collaboration
(LNL, Bologna, Fi, Pd, Mi, Na) + LNS_Stream

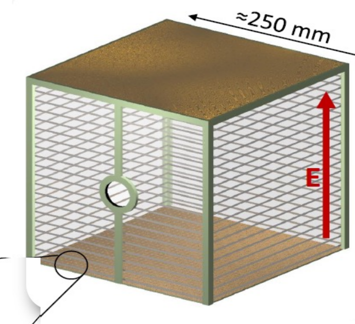
T. Marchi KU Leuven – contact person

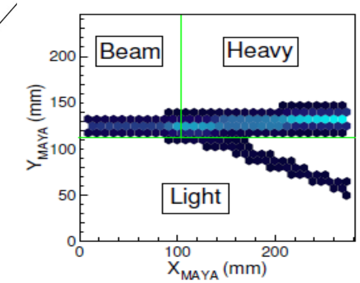




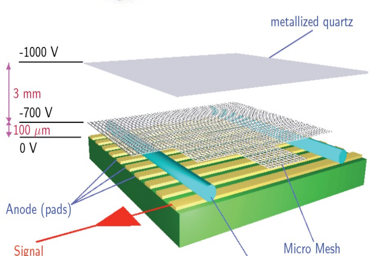


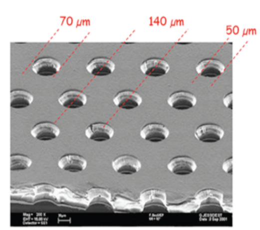

## ACTAR : Active Target Detector

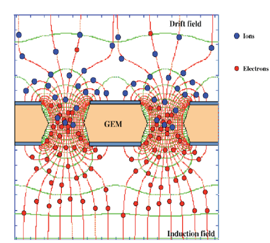
Starting activity with ACTAR collaboration:
ENSAR2 GDS network and PRIN national project (submitted)

The **ACTAR TPC** collaboration is actually composed by:
Centre d'Etudes Nucleaires de Bordeaux Gradignan (CENBG), France
Grand Accelerateur National d'Ions Lourds (GANIL), France
Institut de Physique Nucleaire d'Orsay (IPNO), France
Institut de Recherche sur les lois Fondamentales de l'Univers (IRFU), France
University of Leuven (KUL), Belgium
Universidade de Santiago de Compostela (USC), Santiago, Spain




Micro-megas technology for the amplification region : low cost 5€/cm




Gas Electron Multipliers: GEM

Courtesy of R. Raabe & G.F. Grinyer

GDS – Network within ENSAR2 – INFN WP leader

# SPES γ: Radioisotope Production & research

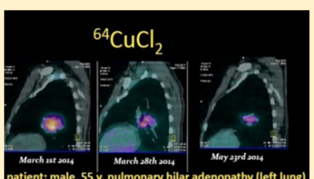
- ❑ LARAMED: use of cyclotron for production of standard and new radioisotopes by proton induced reactions
- ❑ ISOLPHARM: use of ISOL technique to produce radioisotopes with very high specific activity (5-6 order of magnitude more than standard)

## LARAMED

Production of radionuclides for medicine using the SPES cyclotron (production&research)

Joint Research lab of INFN, CNR, Universities and external companies:

- Cross Section measurements through target activation
- High power targets tests
- Radio-isotope/radio-pharmaceutical Production test facility ($^{99m}Tc$, $^{64}Cu$, $^{67}Cu$, $^{82}Sr$, ...)




Production laboratory in Joint Venture with external companies:

Selected isotopes of medical interest

**Sr-82/Rb-82 generator**

**T1/2: 25.6 d** EC 100% **/ 1.3 min** photons 511keV, 776keV

STATUS:

- Building and infrastructures under development
- Design of radiochemistry labs
- Design of beam line and target management
- Contract with company for radioisotopes production to be finalized

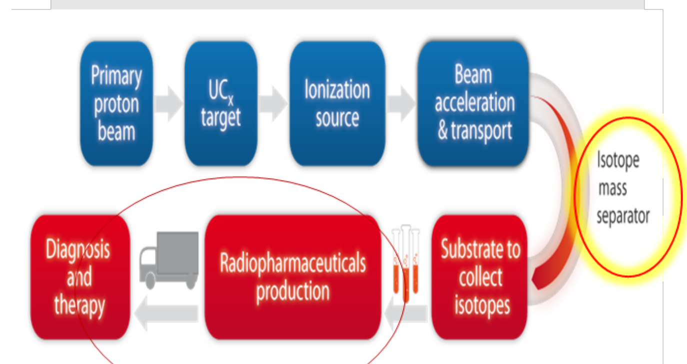
**Facility under construction**

ARRONAX (Nantes) – SPES collaboration:
Isotopes and high-Power target developments

*A.Duatti*

## ISOLPHARM*

Use of ISOL technique for Direct isotope on-line separation : very high specific activity ($10^{4-5}$ than standard)




| Radiopharm aceutical | Targeted organs | Half-life | Specific Activity (GBq/mg) | |
|---|---|---|---|---|
| | | | SPES production | Neutron capture reaction |
| $^{89}Sr$-$SrCl_2$ | Bone | 50.5 d | ≥ 597 | ≥ 0,004 |

After 2 days of irradiation: 4.1E+15 atoms of $^{89}Sr$ = 18 mCi (patient dose: 4 mCi every 6 months).

* INFN Patent

**Collaboration with Pd_University (Pharmacy) and hospitals for preliminary test**

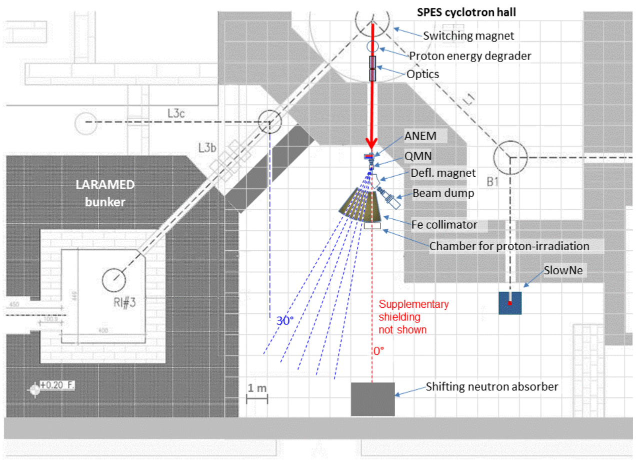
*A.Andrighetto*

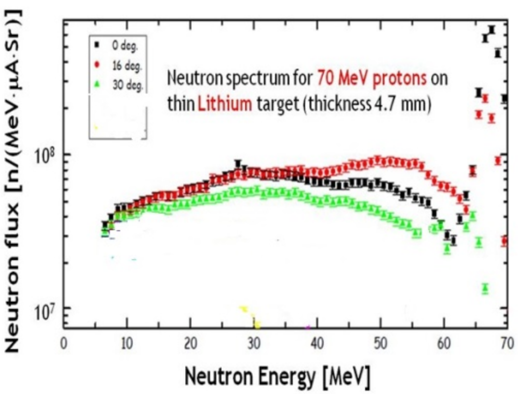
# Neutron facility at SPES

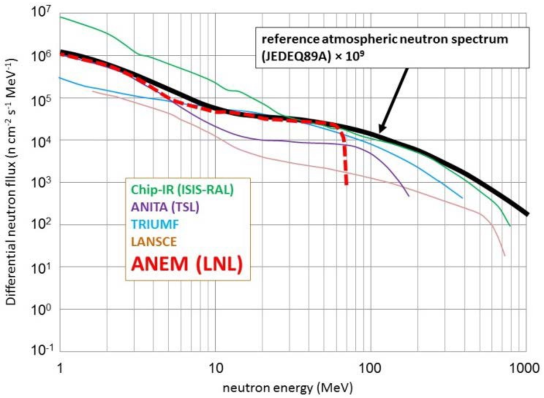
Neutron production by interaction of protons with heavy and light targets

- Fast neutron production: $\sim 6 \cdot 10^{14}\ s^{-1}$
- Neutron flux $\Phi_n$ @ 2.5 m: $5\times10^{8}$ n $cm^{-2}\ s^{-1}$

  - Continuum spectra: SEE, Single Event Effect study
  - Quasi mono-energetic spectra




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

## Per il confronto fra le facility di fasci esotici si devono considerare molti parametri

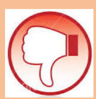
- **La competitività del progetto va analizzata in dettaglio rispetto alla capacità di fornire fascio per gli esperimenti.**

- Le facility per fasci radioattivi hanno specificità che le rendono complementari:
    - le facility ISOL forniscono fasci di più alta purezza e precisione
    - le facility in-flight forniscono fasci di ioni «neutron-poor»
    - Il processo ISOL è piu' lento e non è efficiente per produrre isotopi a bassa vita media
    - solo la reazione di fissione produce ioni «neutron-rich»
    - La tecnica ISOL è ideale per produrre isotopi «neutron-rich»

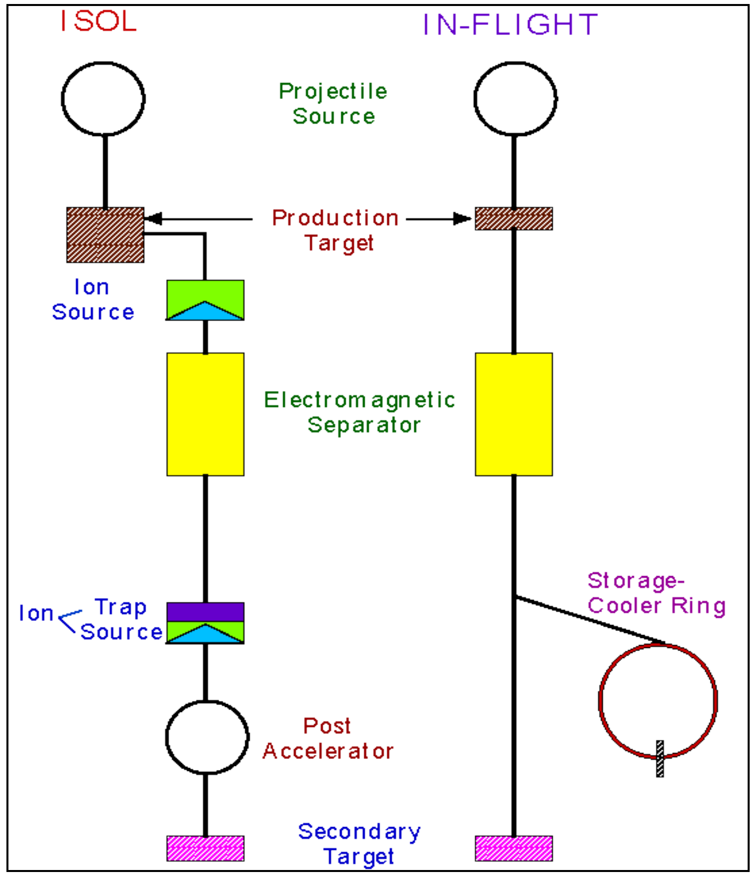
Dettaglio dei fasci richiesti nelle LOI

# Two (main) methods for RIB production

- High intensity
- Different beam energy
- High beam quality (pencil beam)

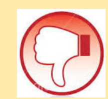


- No short half-life
- Isobar contaminations




- High Energy RIBs (to 1GeV)
- Pure beams

- Very short half-life



- Bad beam quality (large emittance)

- Low Intensity

**Rare-isotope beam physics is a rapidly growing field worldwide with major production facilities using the so-called in-flight approach and the ISOL (isotope separation on-line) method,**

In the **ISOL facilities**, the rare isotopes are produced inside a thick target at rest. They effuse out of the target matrix as neutral atoms and are ionized by a method that depends on the chemical element (for example using resonant laser ionization). The ions are then electrostatically accelerated to several tens of keV and formed into a beam, mass separated, and delivered to the experiments or post-accelerated.

With **in-flight facilities**, the primary heavy-ion beam hits a thin target at energies of some tens to hundreds of MeV/u. Rare isotopes are produced in the target and immediately emerge at energy similar to the primary beam. The rare-isotope beam is formed independently of the chemical element and can be separated using a combination of electric and magnetic fields. The beam is then delivered to the experiments at the same high energy.

**The two different production processes are complementary** as they provide access to different beams for different applications. ISOL production allows the production of many different isotopes but is limited by the chemical selection (refractory elements don't diffuse out of the target matrix) and the half-life of the isotope (the half-life limit is about 5 ms).

**In-flight** production provides rare isotopes of all chemical elements (no target or ion source selectivity) and can reach very short half-lives (sub-ms). Ultimately, in-flight facilities will have a larger range of produced isotopes available for experiments. The secondary beam, however, is often less mass resolved (different charge states are simultaneously produced, limiting unambiguous identification) and can have poorer beam quality (higher longitudinal and transversal energy spread). It has discovery potential for new isotopes but will not provide for most of the science sought.

For example, the high energy beams (50–1000 MeV/u) of rare isotopes are not suitable for probing the relevant regime for nuclear astrophysics. To provide partial access and to take advantage of the inherent beam properties of ISOL-type facilities, recent programs have started at several in-flight facilities (RIKEN, MSU, GSI) to establish low-energy programs by stopping high-energy rare-isotope beam in a gas-stopper cell from which it can be extracted to form a low-energy beam for use with stopped or post-accelerated beams.
Once fully developed, such systems will be able to provide the good beam quality needed for efficient post-acceleration, however, they are still limited in yields of rare isotopes.

The **advantages of ISOL-type beams** are the high intensity, excellent beam quality, and variable beam energy for experiments with stopped or post accelerated beam.

The ISOL technique is the only method that can provide very high beam intensities of specific rare isotopes for experiments in nuclear astrophysics or for the high-precision experiments aiming to discover physics beyond the SM.

**Existing and operational major in-flight facilities** (E > 50 MeV/u) are:
- GSI Darmstadt, Germany
- HIRFL-CSR, Institute of Modern Physics Lanzhou, China
- NSCL, Michigan State University, U.S.A.
- RIBF, RIKEN, Japan
- SPIRAL, GANIL, France

**New in-flight facilities** under construction are:
- FAIR Darmstadt, Germany
- FRIB Michigan, U.S.A.

**Major planned in-flight facilities** are
- RISP, Institute for Basic Science, Daejeon, Rep. of Korea

**Existing major ISOL facilities** are:

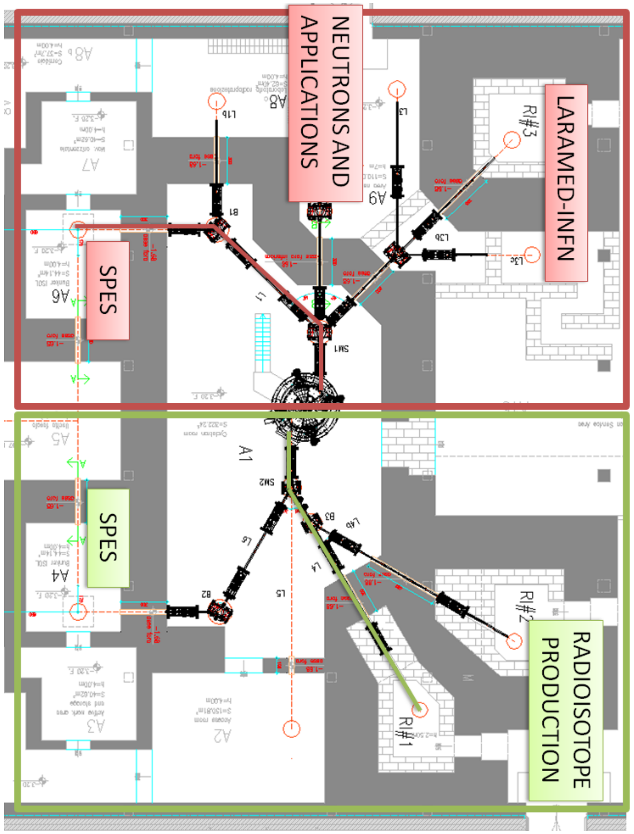
- ALTO, Orsay, France
- CARIBU, ATLAS, ANL, U.S.A. (based on a Cf-252 radioactive source)
- HRIBF, ORNL, U.S.A. (currently not operational)
- IGISOL, Jyvaskyla, Finland
- ISAC, TRIUMF, Canada
- ISOLDE, CERN, Switzerland

**New or major upgrades for ISOL facilities** are:

- ANURIB, VECC, India
- ARIEL, TRIUMF, Canada
- BRIF, Bejiing, China
- HIE-ISOLDE, CERN, Switzerland
- RISP, Institute for Basic Science, Daejeon, Rep. of Korea
- SPES, INF Legnaro, Italy
- SPIRAL2, GANIL, France

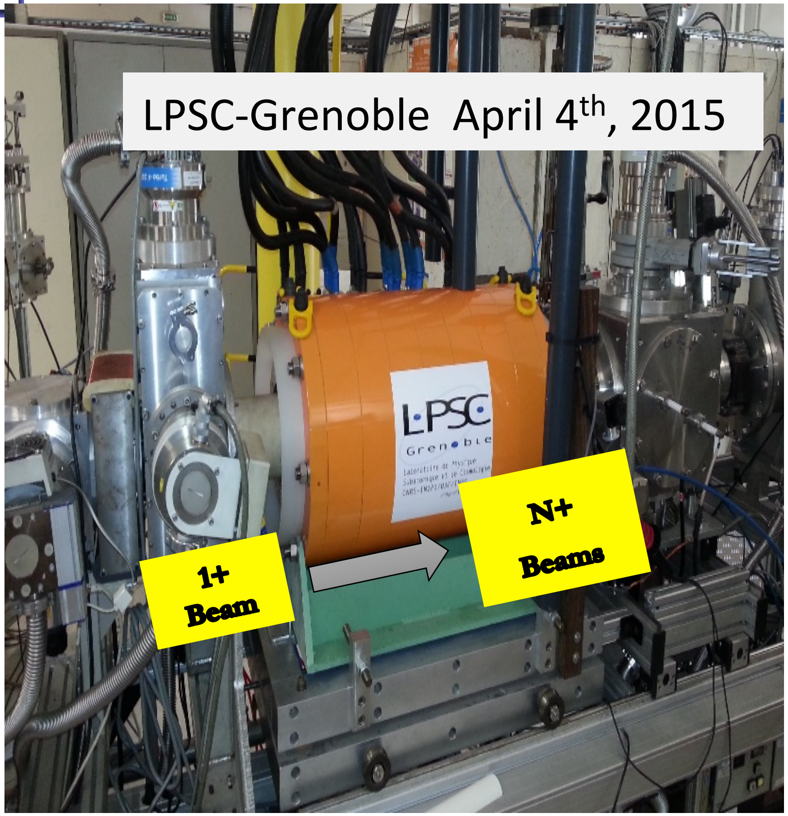
# Beam Sharing (example)

| 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 |



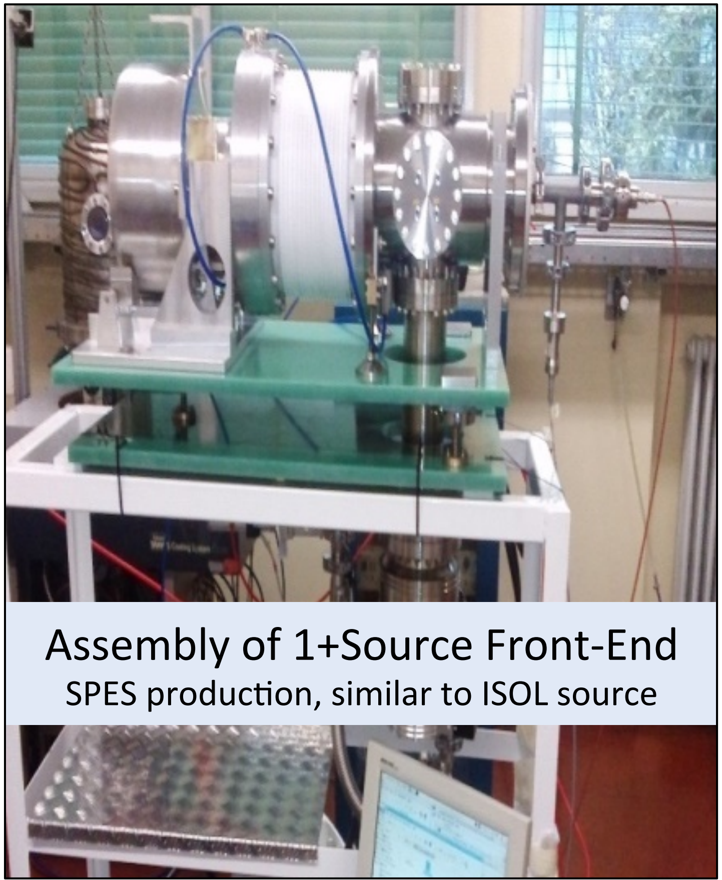

| STATIONS | | week 1 | | week 2 | | week 3 | | week 4 | | week 5 | | week 6 | | week 7 | | week 8 | | week 9 | | week 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Energy | Current | Energy | Current | Energy | Current | Energy | Current | Energy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

# Validation of the SPES-Charge Breeder




**Development at LPSC (Grenoble). Upgraded PHOENIX booster as Part of a MoU** in the frame of the European Associated Laboratories (LEA-Colliga)

- 2015 Commissioning at LPSC
- 2015 Delivery to LNL
- 2016-17 Installation and test



Assembly of 1+Source Front-End
SPES production, similar to ISOL source

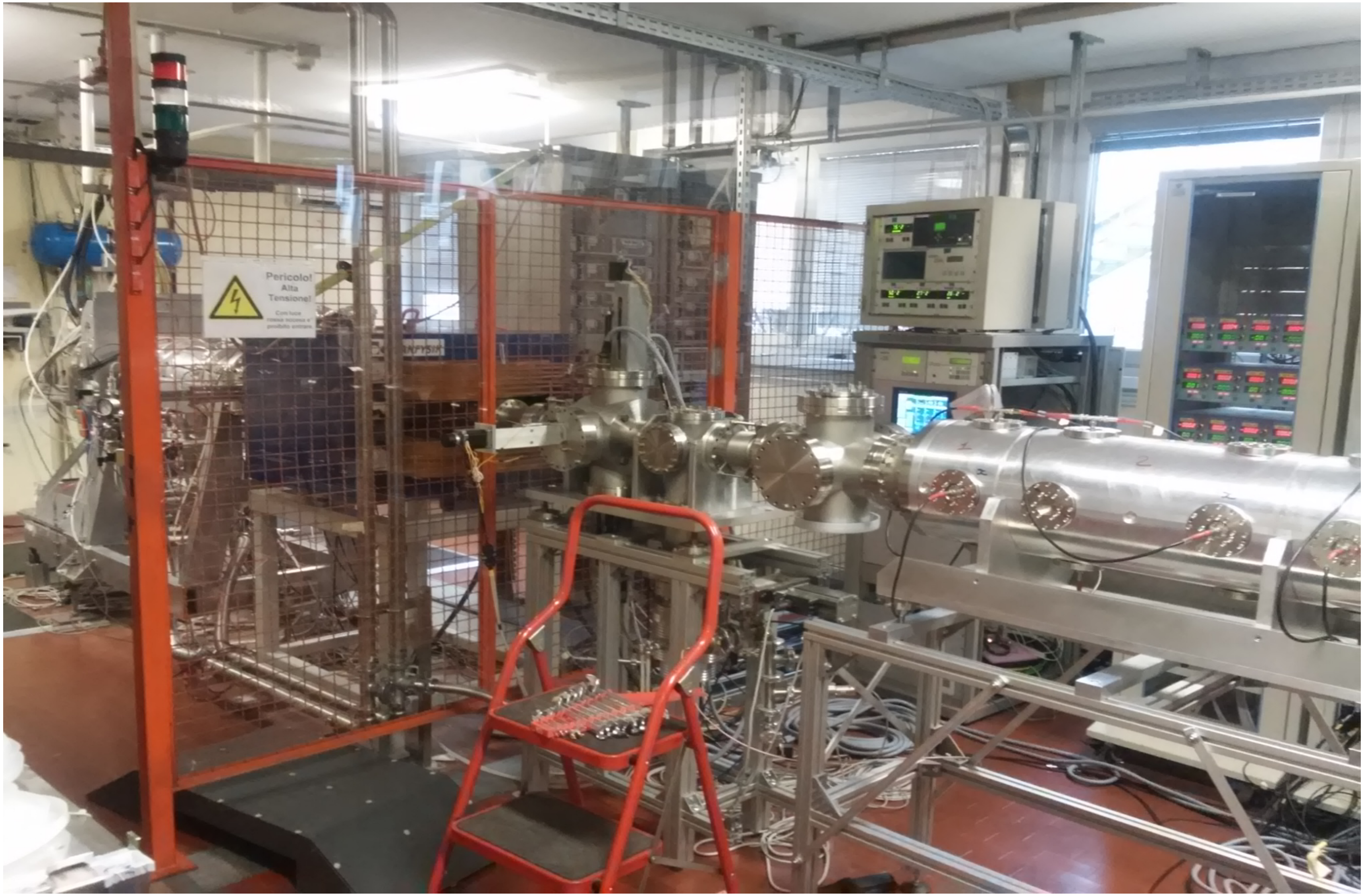
| | | EFFICIENCY* [%] | | |
|---|---|---|---|---|
| ION | Q | SPES req | Best LPSC | SPES-CB |
| Cs | 26 | ≥ 5 | 8,6 | 11,7 |
| Xe | 20 | ≥ 10 | 10,9 | 11,2 |
| Rb | 19 | ≥ 5 | 6,5 | 7,8 |
| Ar | 8 | ≥ 10 | 16,2 | 15,2 |

*results obtained for the same 1+ injected current*

INFN-LPSC: Study for CB contaminants reduction

- plasma chamber
- Materials
- Cleaning & conditioning
- vacuum

# RIB Bunker set-up



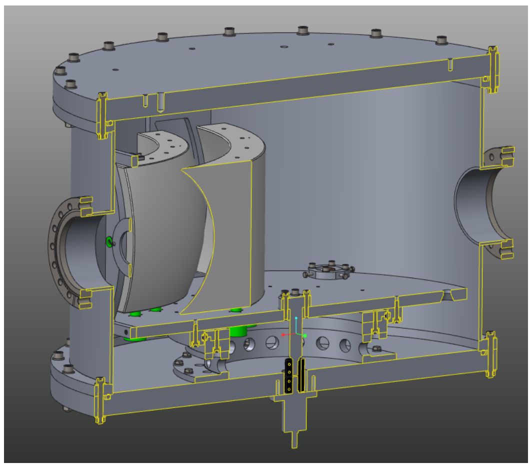
# 1+ beam line operation: Electrostatic Dipole

| INFN Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali di Legnaro | SPES exotic beams for science | | |
|---|---|---|---|
| MANAGEMENT SYSTEM OF SPES QUALITY AND SAFETY | | | |

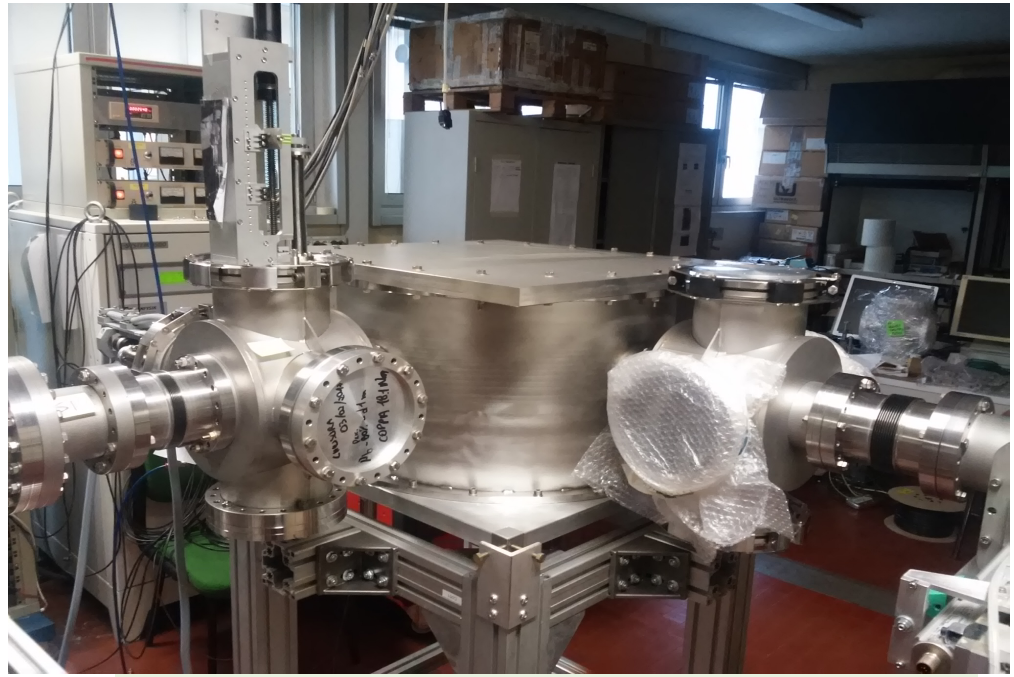
| Code doc. | DOC_00000XX | PROGETTAZIONE MECCANICA DEL DIPOLO ELETTROSTATICO PER IL TRASPORTO DEL FASCIO LUNGO LA LINEA 1+ DELL'EDIFICIO SPES | Rev. | 00 |
|---|---|---|---|---|
| | | | Pag. | 1 di 9 |

**Contenuto**

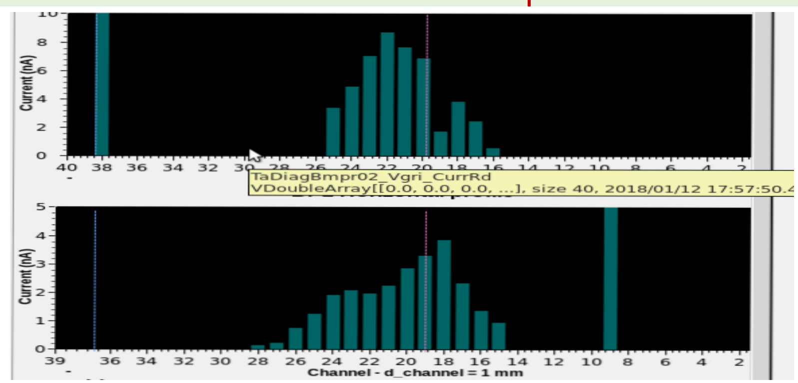
Questo documento riassume i criteri seguiti è i punti salienti relative al lavoro di progettazione del dipole elettrostatico (steerer) per la curvature del fascio di ioni 1+ instabili prodotti nell'ambito del progetto SPES. Nel documento sarà inserita la descrizione della fase di progettazione del prototipo.



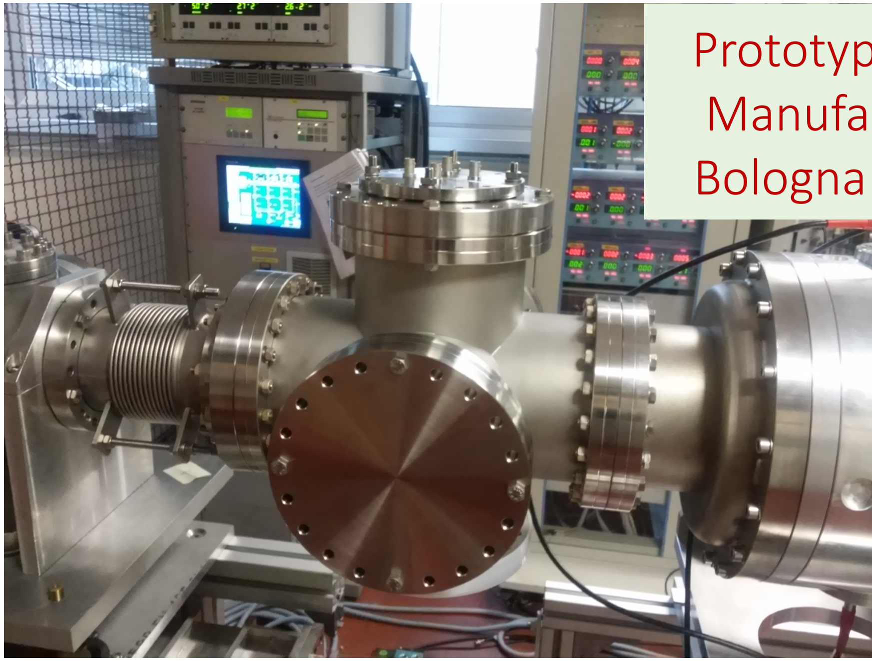
| Rev. | Data | Writer | Verifica | Approvazione | Motivo revisione |
|---|---|---|---|---|---|
| 01 | 12 February 2017 | A. Monetti<br>A. Andrighetto | | | Prima emissione |
| | | | | | |



Prototype tested & Manufactured by LNL Workshop



# 1+ beam line operation: Steerers



Prototype tested & Manufactured by Bologna Workshop