SPES project at LNL

Selective Production of Exotic Species

Gianfranco Prete
INFN- Laboratori Nazionali di Legnaro
on behalf of the SPES working group

SPES One day workshop on Interdisciplinary activities and applications

Ferrara January 29th, 2019

Programme
The workshop begins on Tuesday 29 January 2019 at 14.00 and ends on Wednesday 30 January at 16.00.

It takes place at Aula Magna Drigo - IUSS Istituto Universitario Studi Superiori - Corso Porta Mare 2, 44121 Ferrara FE.

TUESDAY 29 JANUARY 2019

14.00 - Welcome adresses
14.30 - Status of the SPES project at the Laboratori Nazionali di Legnaro (Gianfranco PRETE, INFN-LNL)
15.00 - IAEA programs related to the applications of radioisotopes in medicine and industry (Joao Junior OSSO, IAEA)
15.30 - R&D activities for the production of innovative radioelements at GANIL (Anne-Marie Frelin, GANIL)
16.00 - ENSAR2-RITMI activities for improved supply of theranostic nuclides (Ulli KOESTER, Institut Laue-Langevin)

16.30 - Coffee break

16.45 - How nuclear physics helps medicine: LARAMED (Adriano DUATTI, Università di Ferrara)
17.15 - The MEDICIS initiative (Joao Pedro Ramos, CERN)
17.45 - Radioisotope production at LARAMED (Gaia PUPILLO, INFN-LNL)
18.15 - The ISOLPHARM project: ISOL beams for medicine (Alberto ANDRIGHETTO, INFN-LNL)

20.00 - Dinner

WEDNESDAY 30 JANUARY 2019

9.15 - Compact accelerator-driven neutron sources and their applications (Yoshiaki KIYANAGI, Nagoya University)
9.45 - Neutron cross section measurements for astrophysics and applications at the nTOF facility at CERN (Luigi Giovanni COSENTINO, INFN-LNS)
10.15 - A neutron facility at the INFN-LNL (Pierfrancesco MASTINU, INFN-LNL)

10.45 - Coffee break

11.00 - Hadron therapy at LNS: from the conventional approach to the frontiers of biological enhancements and laser-driven applications (Pablo CIRRONE, INFN-LNS)
11.30 - Recent results on proton-CT (Carlo CIVININI, INFN-FI)
12.00 - Micro and nano-dosimetry at LNL (Valeria CONTE, INFN-LNL)
12.30 - Nuclear fragmentation and particle therapy (Vincenzo PATERA, INFN-ROMA1)

13.00 - Lunch

14.15 - Materials science and nanostructures produced with GeV heavy-ions (Christina TRAUTMANN, GSI)
14.45 - Nuclear physics applications with ion beams (Lucio GIALANELLA, INFN-NA)
15.15 - Cyclotron activities at Sofia (Demeter Tonev, Univ of Sofia)
15.30 - Discussion and conclusions (Giovanni CASINI and Adriano DUATTI)

16.00 - Conclusion

SPES Technical Design Report

2008 - 2012

“ The proposed facility has two main goals: to provide an accelerator system to perform forefront research in nuclear physics by studying nuclei far from stability and to develop an accelerator based interdisciplinary research centre ”

“ The SPES facility is designed to supply a second generation of exotic beams able to perform a step forward toward EURISOL and to offer a powerful accelerator based system for research in Astrophysics, Medicine, Applied Physics and Material Science ”

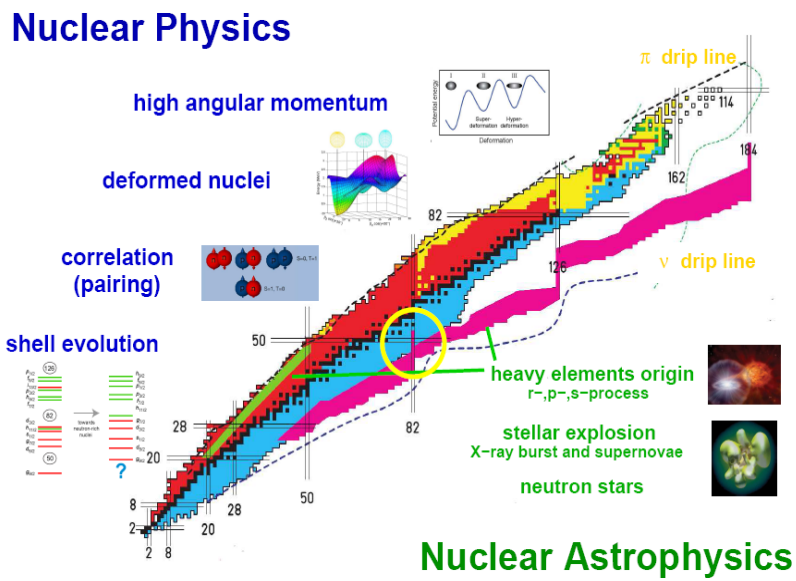
SPES Workshops

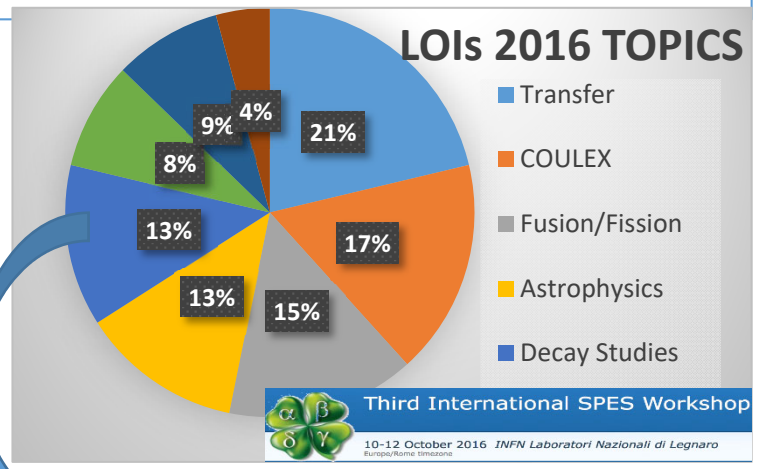
First SPES Physics workshop: 2008

International workshop: 2010, 2014, 2016

One-day workshop:

- 2012, Napoli Transfer reactions,
- 2012, Firenze Coulomb Excitation
- 2013, Milano Collective excitations
- 2013, LNS Isospin on reaction mechanism 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
15% with non re-accelerated RIBs
21% with 132Sn

SPES facilities for radiobiological and medical research

(SPES TDR 2008_Cherubini_Zafiropoulos)

1. *Radiobiological research activity at SPES*

Several radiobiology experiments have shown the dependence of Relative Biological Effectiveness (RBE) on dose [1] and on the atomic number and energy of accelerated ions either when light and heavy ions are used [2-8]. For the same LET, ions with lower Z have higher biological effectiveness, protons being the most effective. Moreover, it has also been demonstrated experimentally that RBE is most strongly influenced by the repair capacity of the cells [9].

2. *Nuclear medicine with SPES beam*

Radioisotopes are widely used in the fields of life science, research and medicine, for example, in nuclear medicine, diagnosis, radiotherapy, biochemical analysis, as well as diagnostic and therapeutic pharmaceuticals. There is a growing interest in specific application for radioisotopes for diagnosis and therapy of diseases, such as cancer and during the last two decades the use of radio-labelled tumor-selective antibodies increased considerably in the cancer diagnosis and therapy. The concept of localizing the cytotoxic radionuclide to the cancer cell is an important supplement to conventional forms of radiotherapy. In theory the intimate contract between a radioactive antibody conjugate and a target cell enables the absorbed radiation dose to be concentrated at the site of abnormality with minimal injury to the normal surrounding cells and tissues.[14]

SPES neutron (and proton) irradiation facility

(SPES TDR 2012_Mastinu_Wyss_Esposito_Silvestrin_Bisello_Prete)

The goal of the NEPIR project is to construct a versatile high flux fast neutron irradiation facility that would be unique in Italy and a reference point for European research, both applied, industrial and basic science

SPES project goals

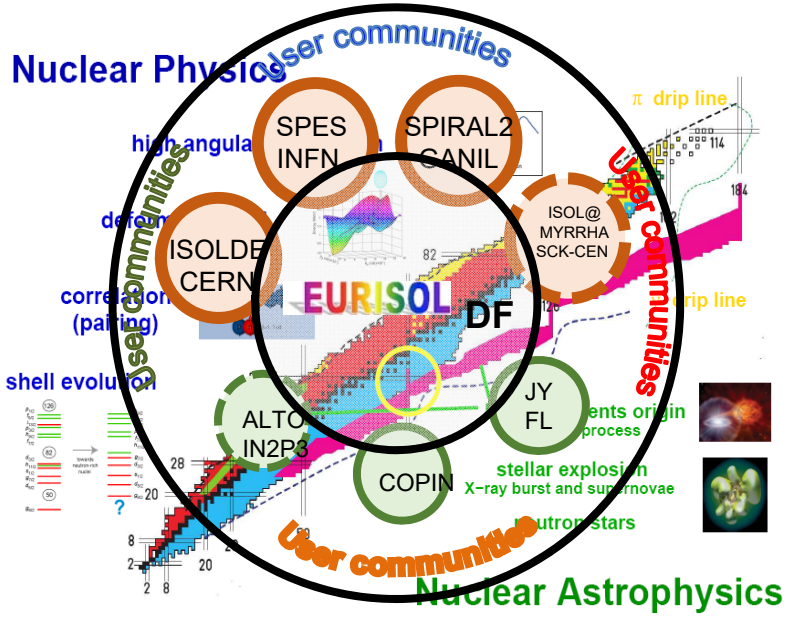
- **Second generation ISOL facility for nuclear physics as part of the EURISOL_DF initiative (ESFRI_2020): Production & re-acceleration** of **exotic beams**
- Research and Production of **Radio-Isotopes for Nuclear Medicine**
- Accelerator-based neutron source (**Proton and Neutron Facility for Applied Physics**)

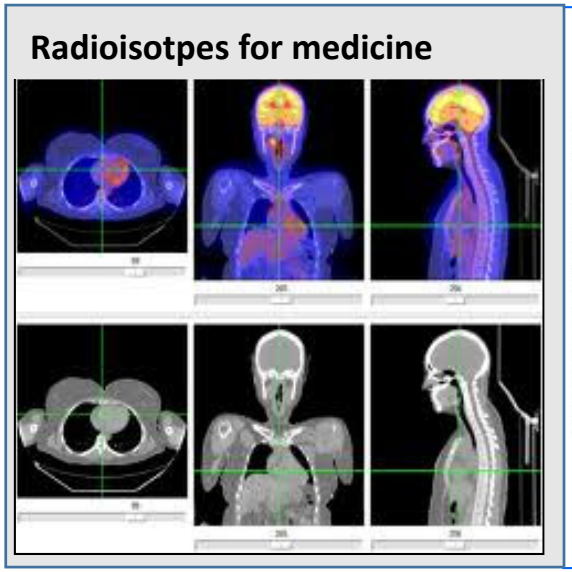
Cyclotron

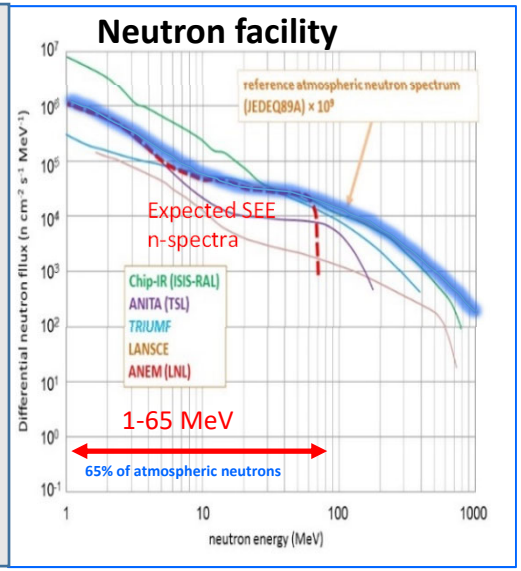
ISOL RIBs+ Post-Acc.

Nuclear Medicine

Nuclear Applications







Performance up-grade for a Second generation ISOL facility

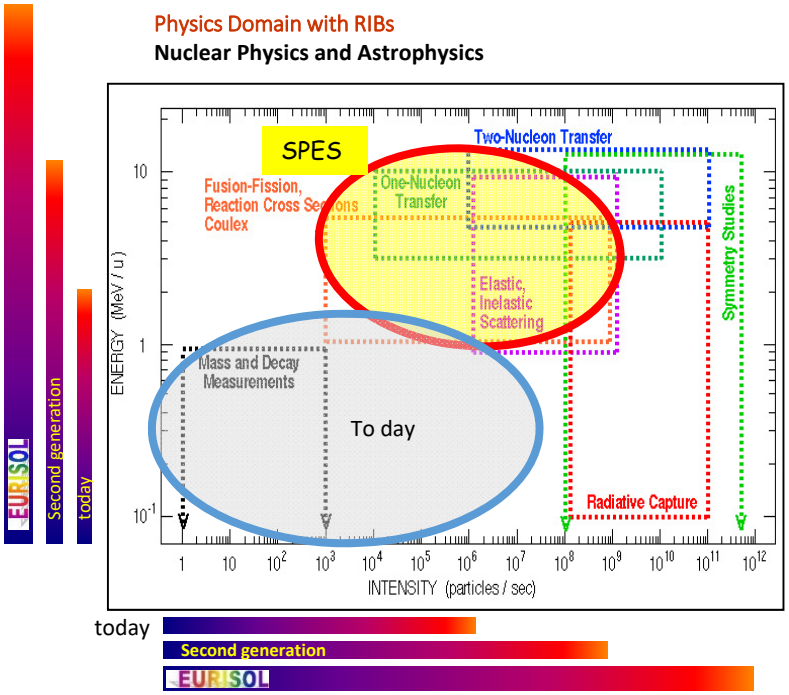
- More beam intensity: 10^7-10^8 pps (n-rich: 10^{13} fission/s
- More beam energy: 10 MeV/n
- More pure (selected) beam: 1/20.000

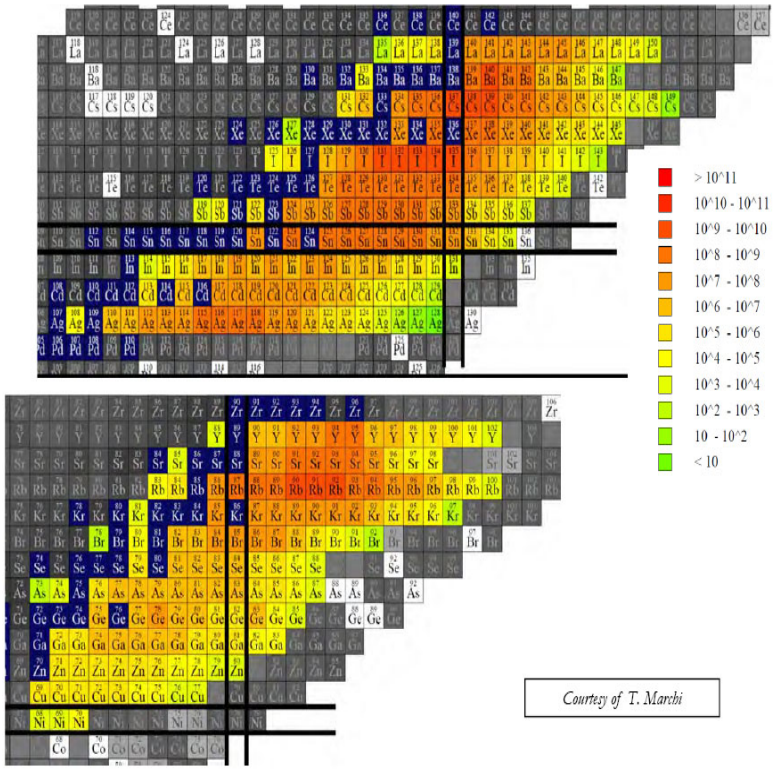
SPES choice

New target-ion source design
200uA 40MeV (8kW) protons on UCx -> 10^{13}f/s

ALPI superconductive linac reaccelerator

High resolution mass separator with beam cooler



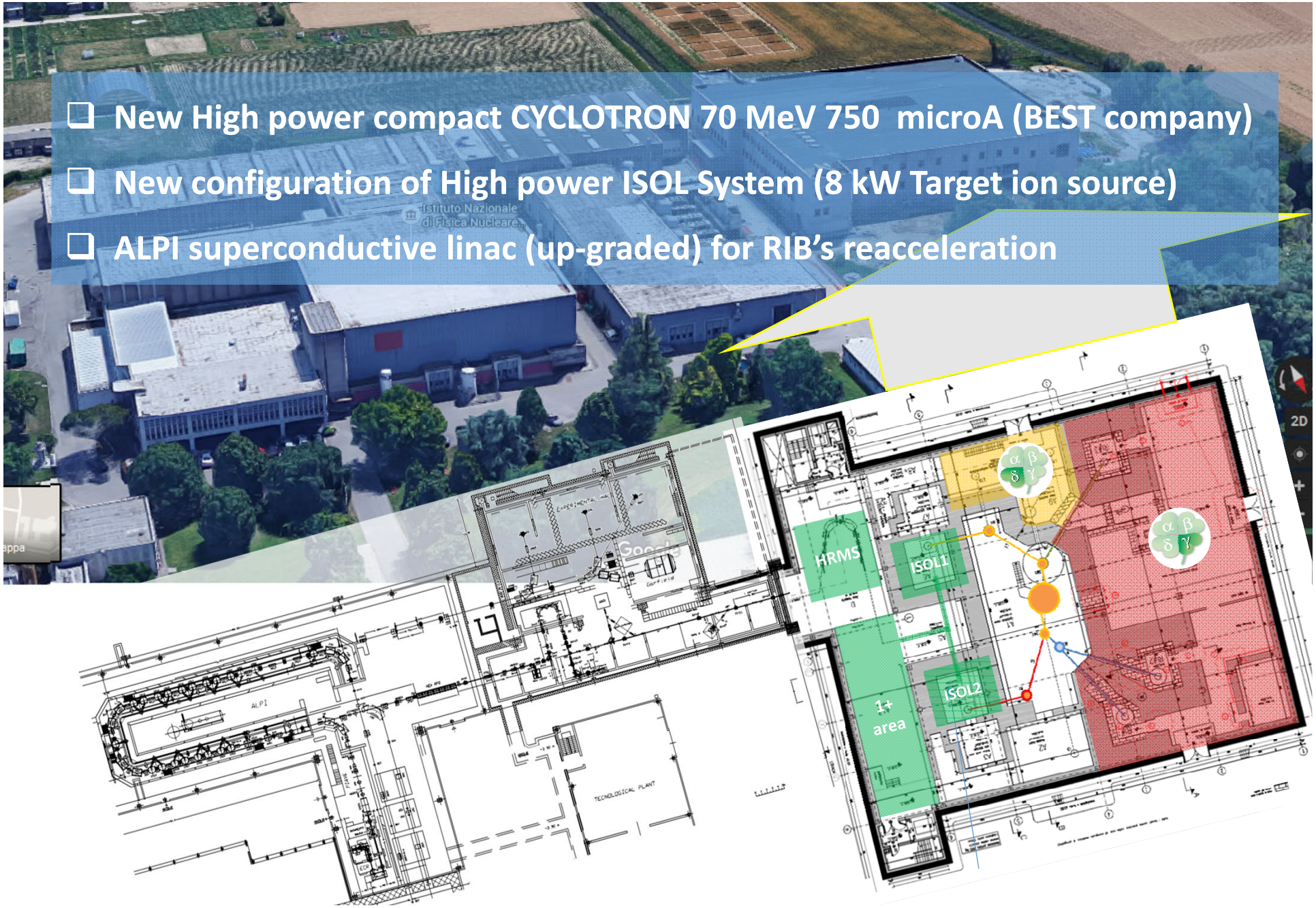


SPES goals: applications

- Research and Production of **Radio-Isotopes for Nuclear Medicine**
- Advanced phase
  - LARAMED project (in construction): production of radioisotopes by proton induced reaction
  - ISOLPHARM project: production of radioisotopes by ISOL method.
  - INFN-industry joint venture for radioisotopes production (INFN-BEST contract signed)

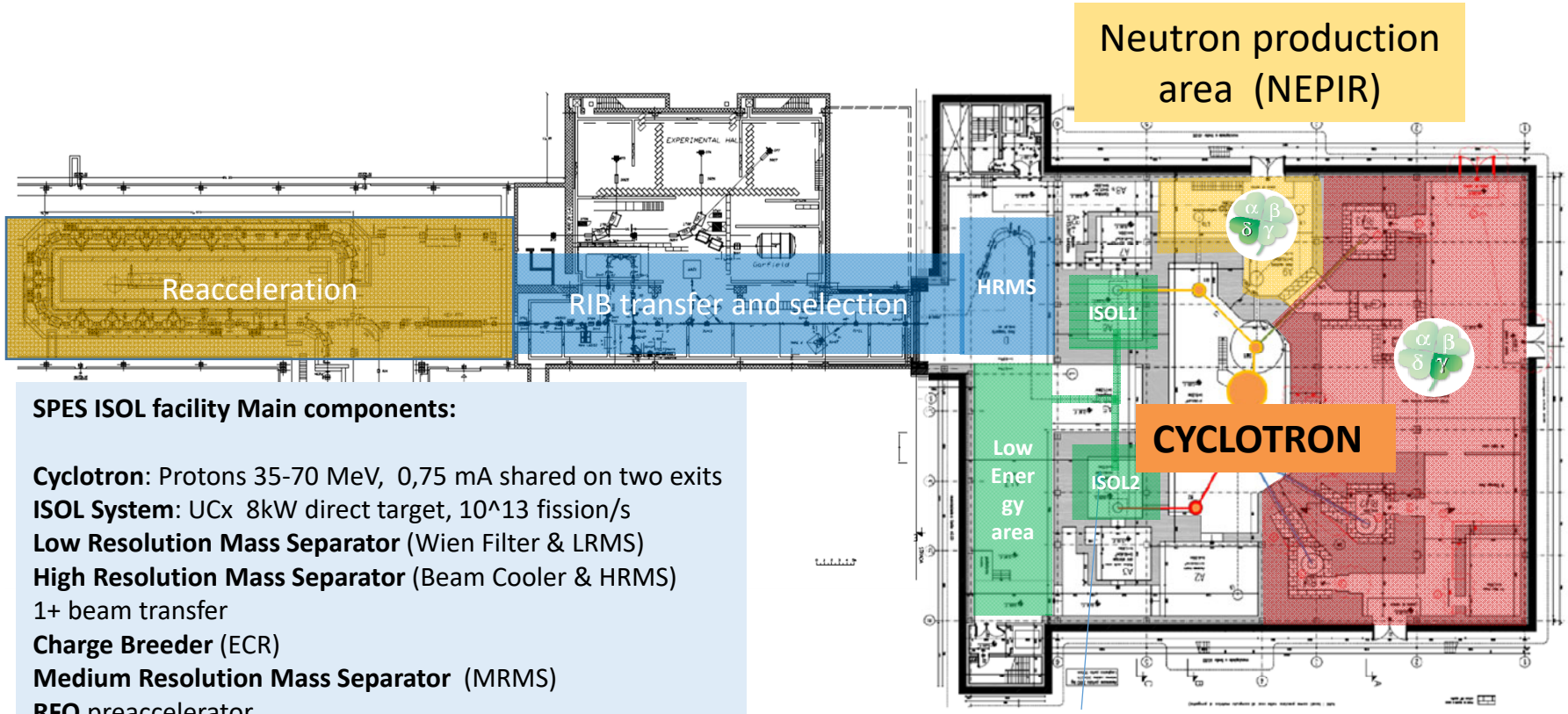
- Accelerator-based neutron source (**Proton and Neutron Facility for Applied Physics**) : NEPIR project (Technical Design)
- Design study
  - SPARE (MIUR - Progetto Premiale 2015)
  - Participation to UCANS (international Union of Accelerator-based Neutron Sources)

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



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

In the first stage, ISOL_2 bunker dedicated to INFN-BEST contract

RIB reacceleration:

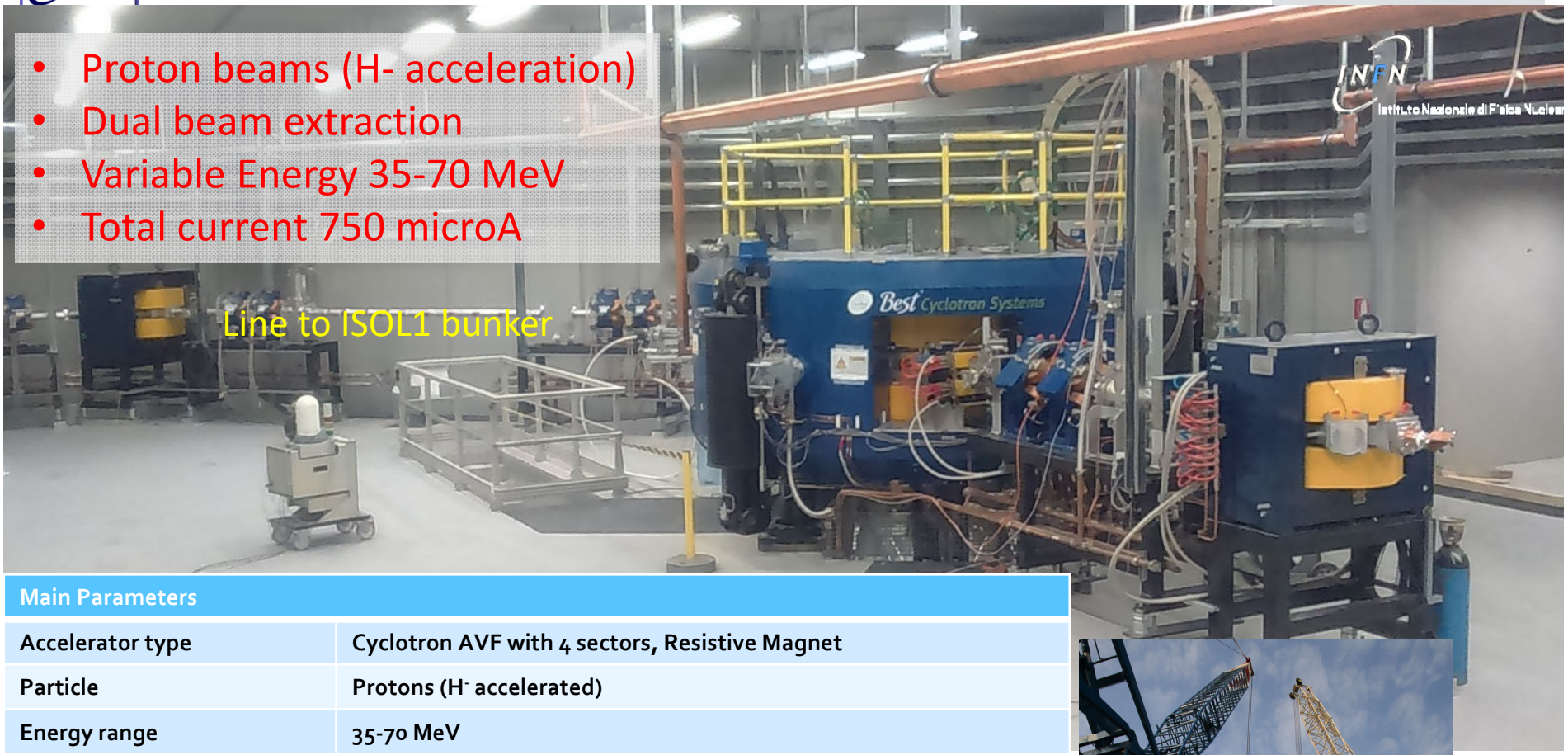
- new RFQ
- ALPI

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)

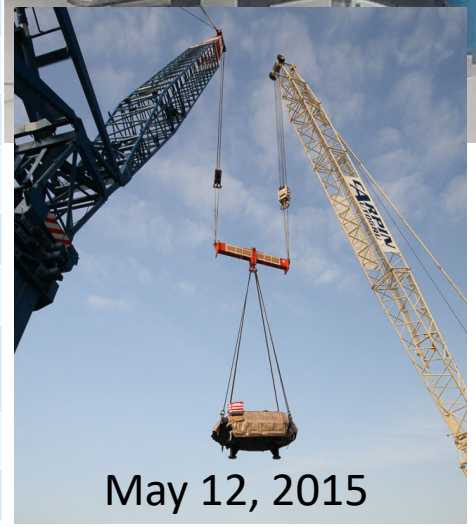
Cyclotron and beam lines



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

Line to ISOL1 bunker

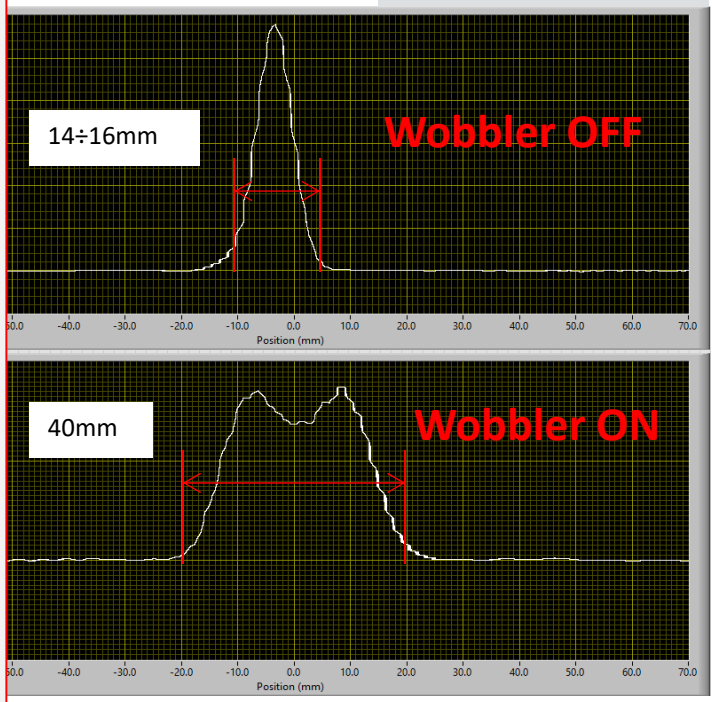
Main Parameters	
Accelerator type	Cyclotron AVF with 4 sectors, Resistive Magnet
Particle	Protons (H^- accelerated)
Energy range	35-70 MeV
Max Current Intensity	700 μA (variable within the range 1μA-700μA)
Extraction	Dual stripping extraction
Max Magnetic Field	1.6 T (Bo = 1 T)
RF System	nr. 2 delta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

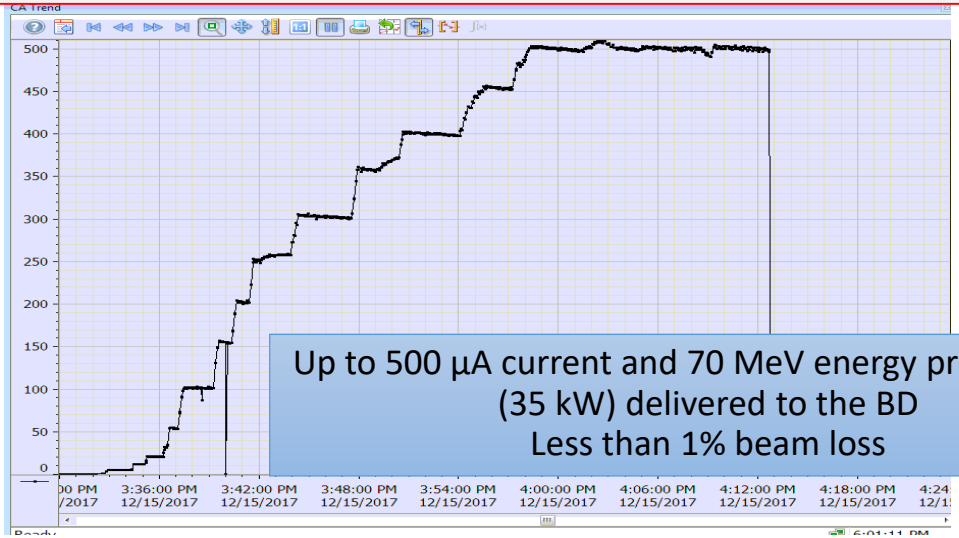


Cyclotron

- May 30th 2016 → dual extraction 70 MeV beam – 3 μA
- Sept 9th 2016 → acceleration 70 MeV beam – 500 μA
- Oct Nov 2016 → preliminary endurance test 250 μA, 40 MeV
- June - July 2017 → endurance test completed
- September 2017 → Cyclotron accepted
- March 2018 → Cyclotron operated in test mode

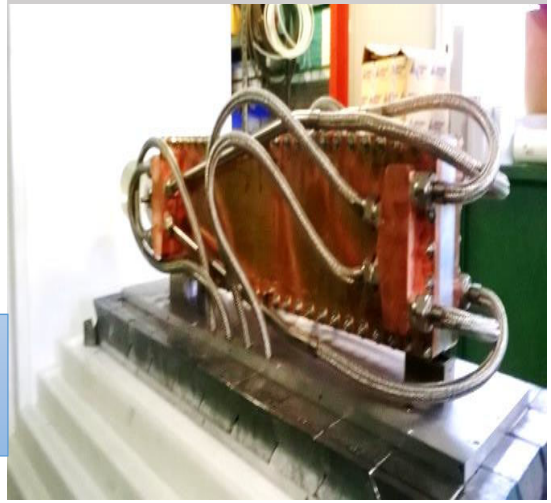
- **2019 To restart cyclotron operation**:
  - → Cyclotron Maitenance and upgrade
    - → Cooling system upgrade
    - → Chopper injection
  - → Building upgrade for final operation
    - → Irradiation bunkers finishing
    - → Final Safety system
    - → Fire brigade authorization



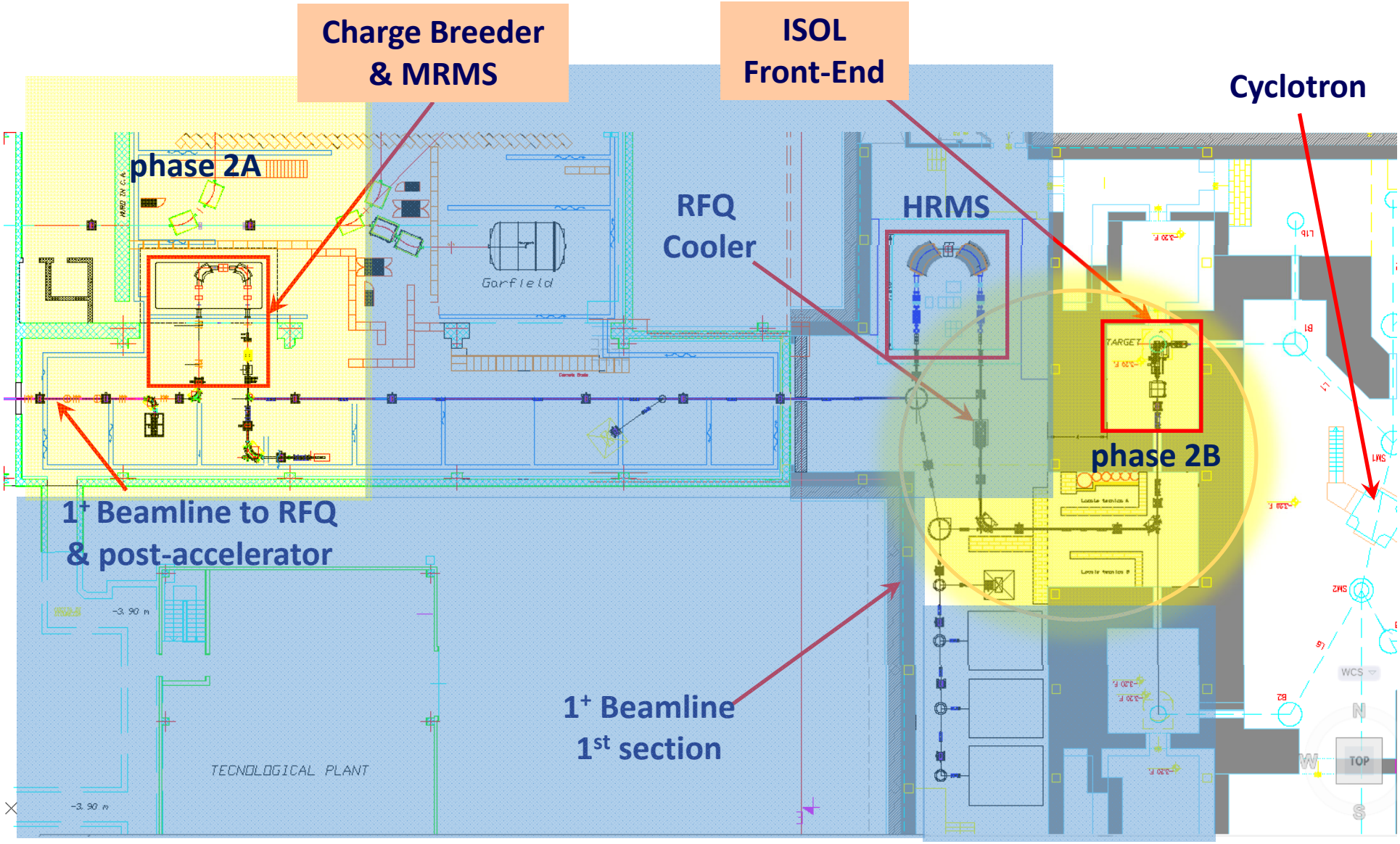


Up to 500 μA current and 70 MeV energy proton beam (35 kW) delivered to the BD
Less than 1% beam loss

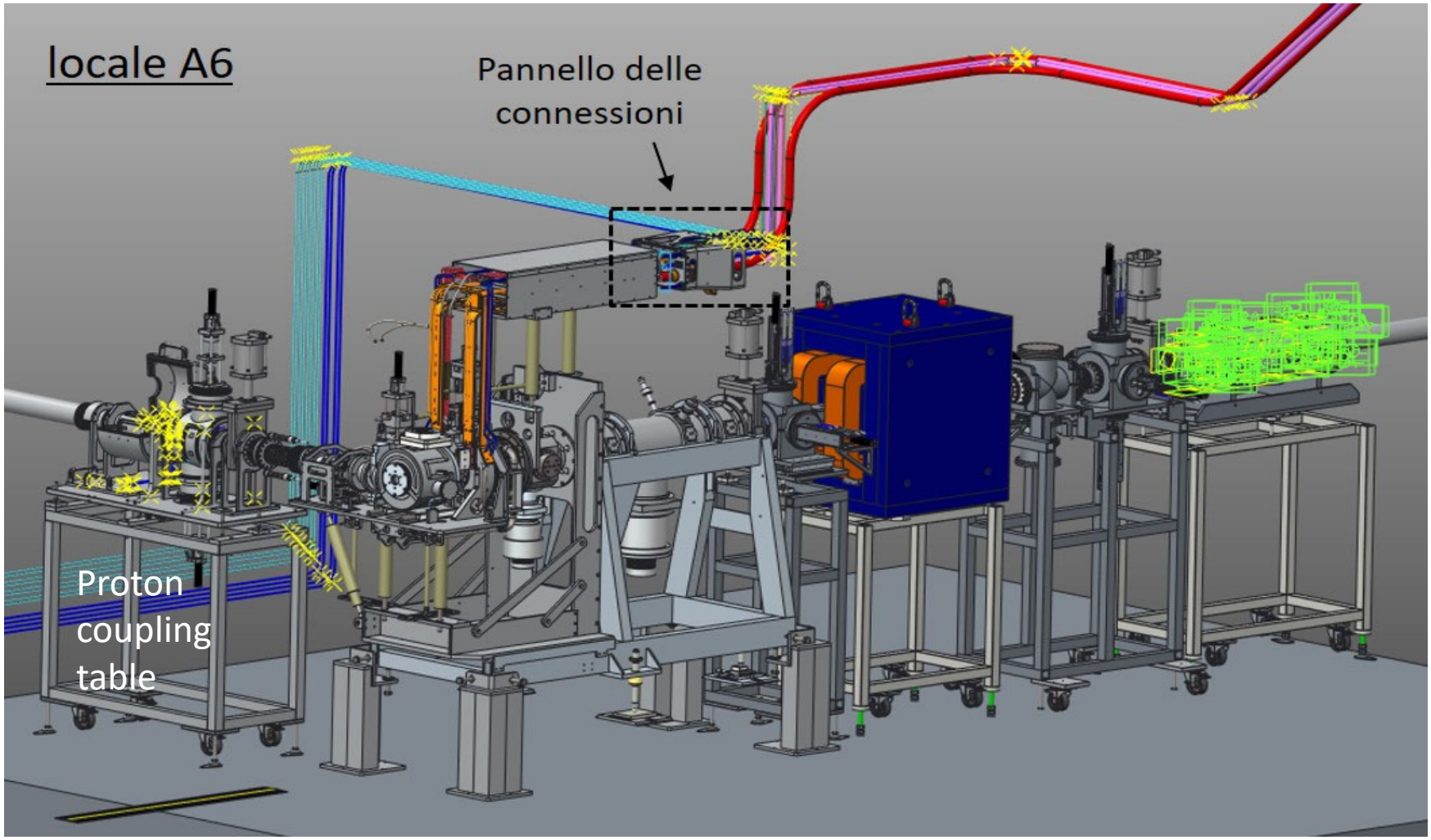
50 kW beam dump



SPES Layout


Charge Breeder
& MRMS
ISOL
Front-End
Cyclotron
phase 2A
RFQ
Cooler
HRMS
phase 2B
1+ Beamline to RFQ
& post-accelerator
1+ Beamline
1st section
TECNOLOGICAL PLANT
Garfield
TARGET

Installation phase 2B
ISOL system

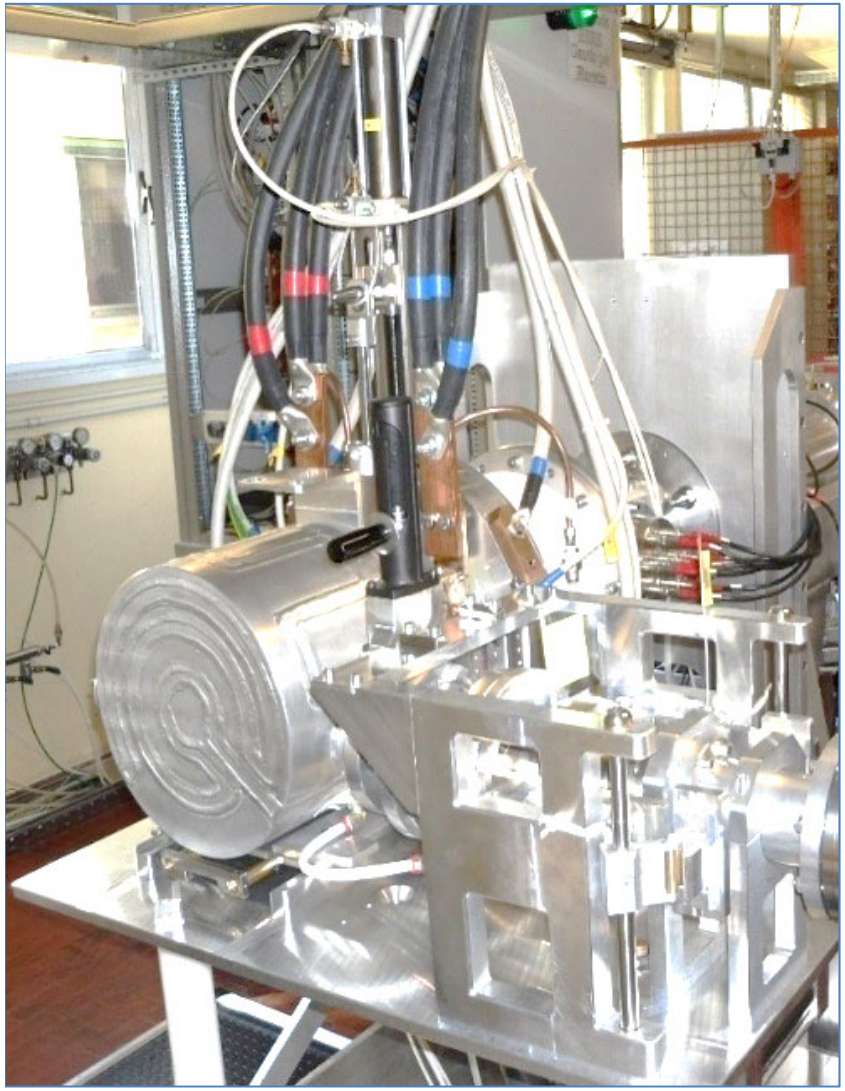


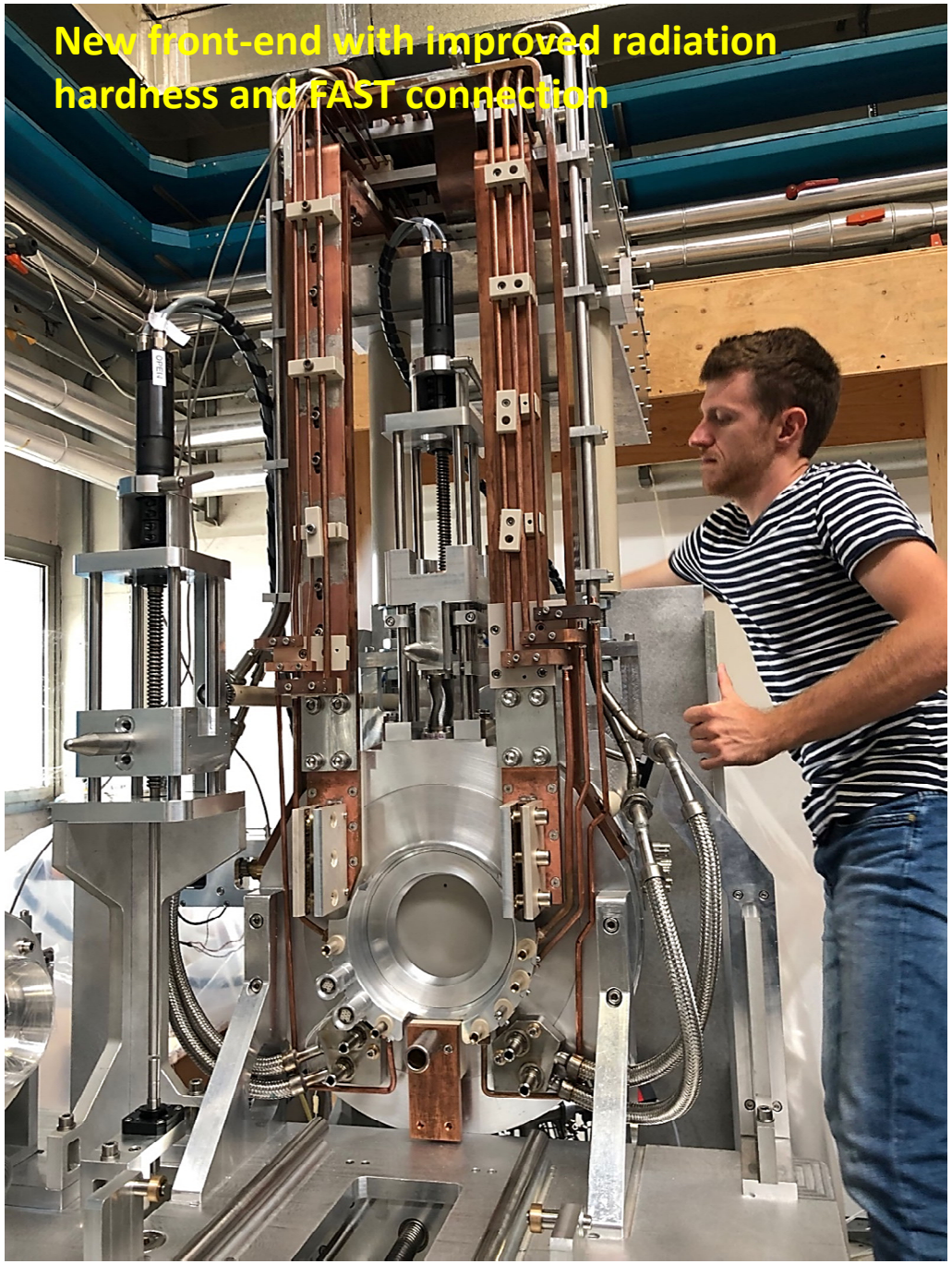
Updated version of ISOL system is under production:

- Radiation hard design (no plastic close to the target)
- Fast coupling-decopling panel board

SPES ISOL front-end

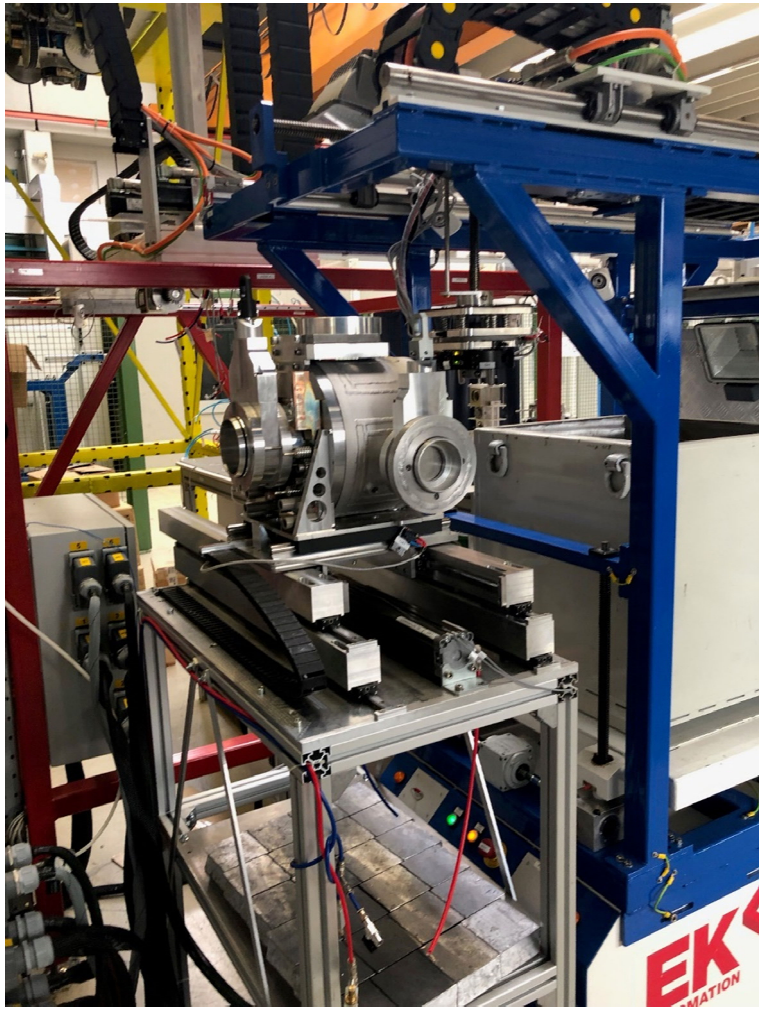
Old ISOL front-end setup





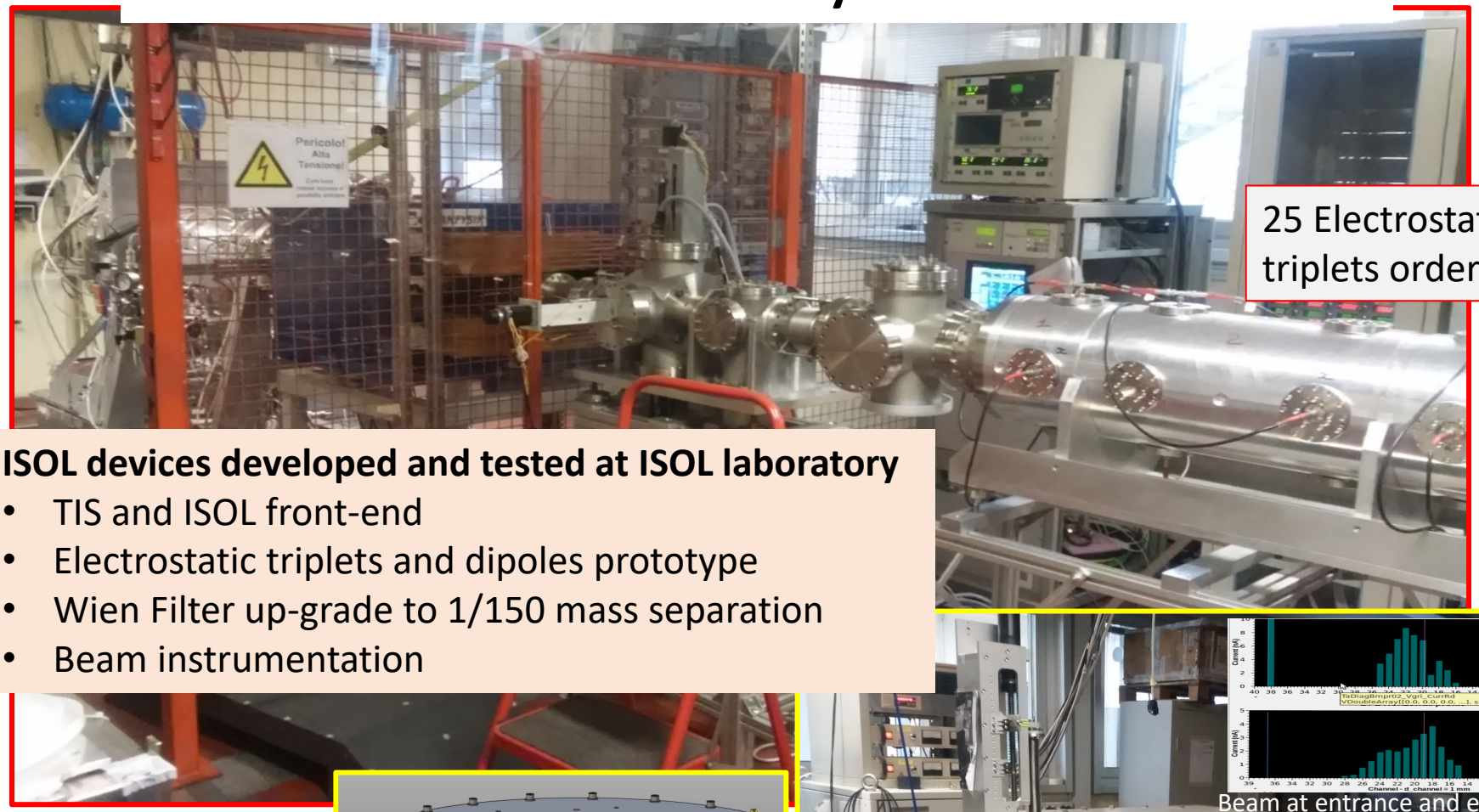
Target handling and storage

Remote handling system



Prototype temporary irradiated target storage

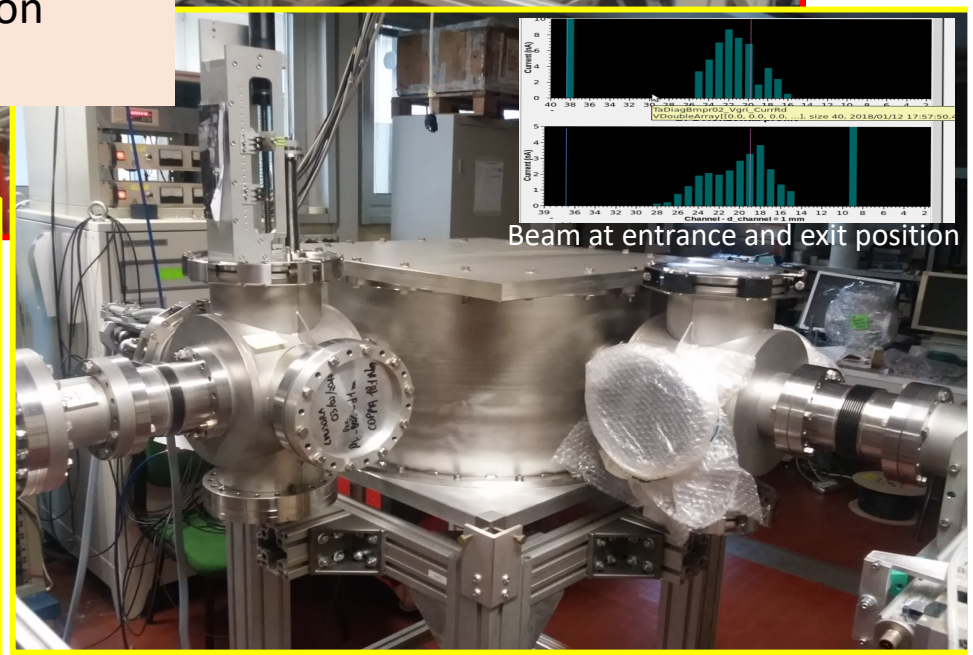
Phase 2B: Installation of ISOL system and 1+ beam line



25 Electrostatic triplets ordered

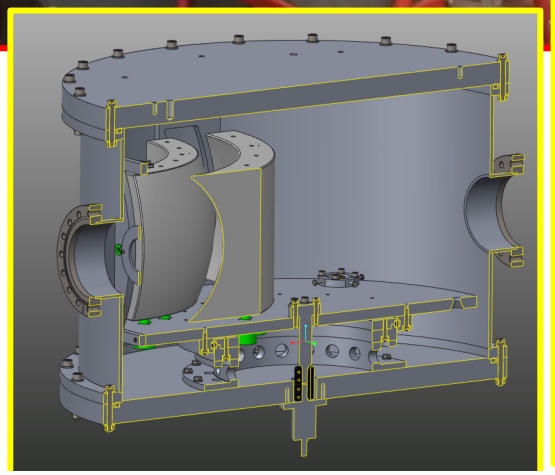
ISOL devices developed and tested at ISOL laboratory

- TIS and ISOL front-end
- Electrostatic triplets and dipoles prototype
- Wien Filter up-grade to 1/150 mass separation
- Beam instrumentation

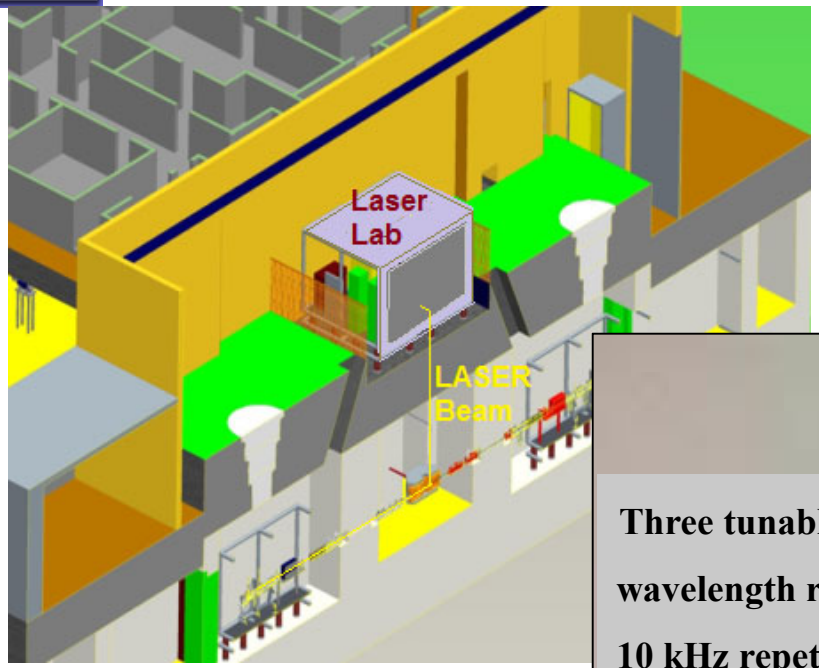


Beam at entrance and exit position

Electrostatic dipole manufactured by LNL Workshop
Steerers produced by INFN-Bologna



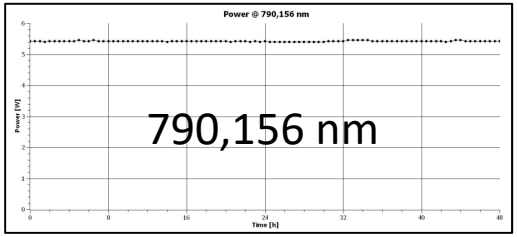
Laser system for selective ionization source

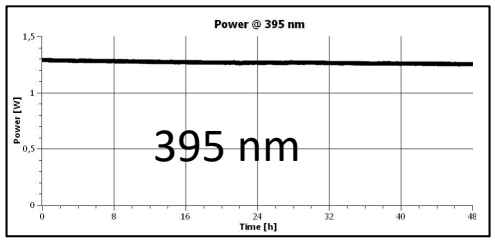


- Laser on delivery(@Sirah)
- FAT (48 h full power) done

  Requirements completely satisfied
- On-line laser lab: building ready (@LNL)
- Temporary services in operation

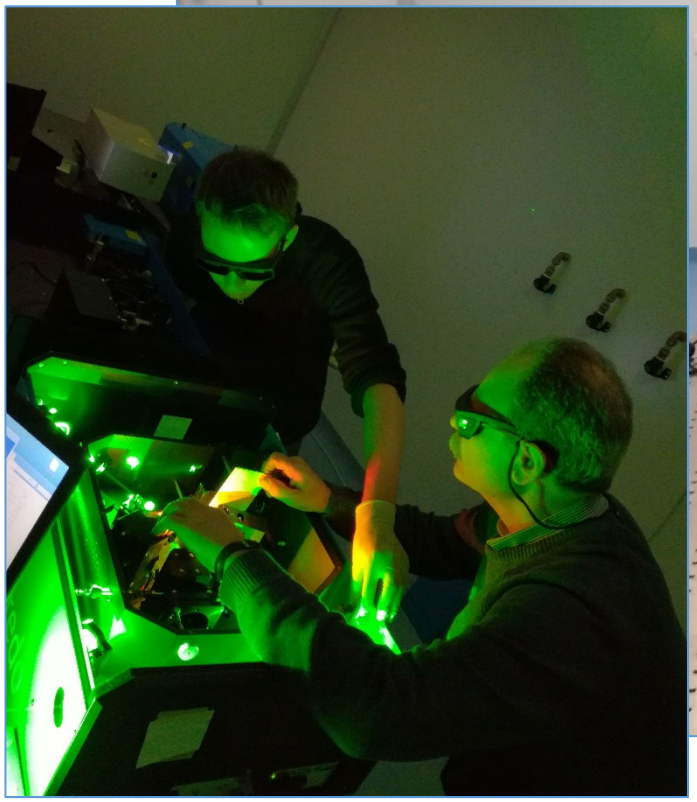
Power stability test over 2 days





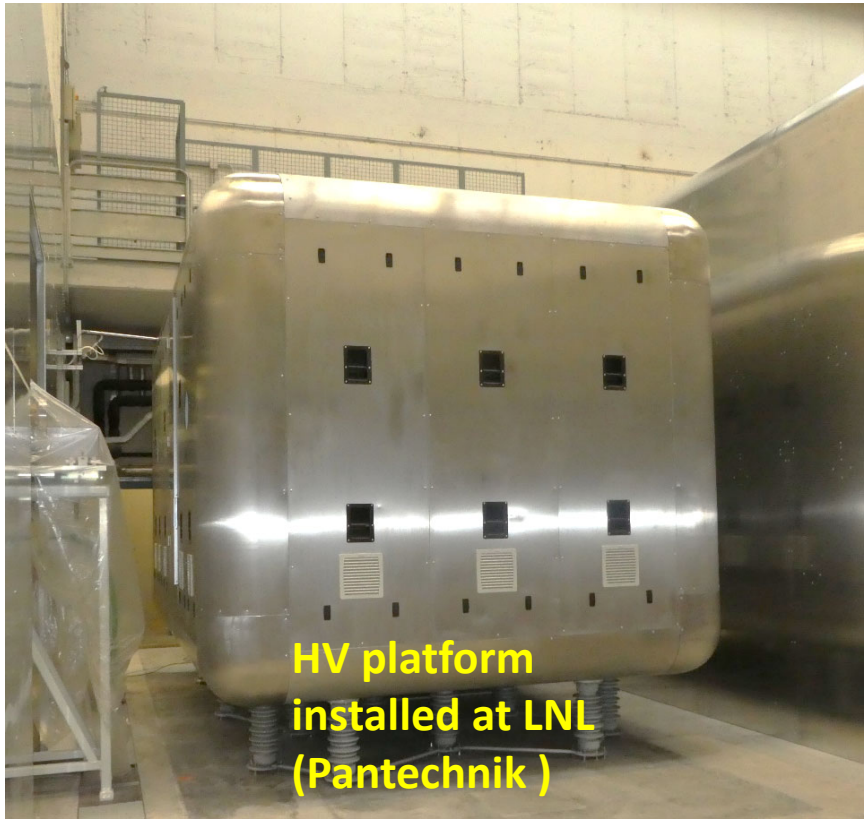
SPES Solid State Laser system (10 kHz rep rate)

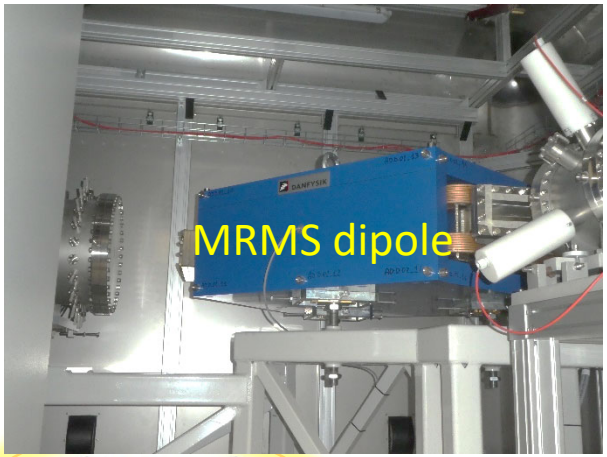
- Laser Laboratory online is operative
- Laser assembled @ LNL under commissioning

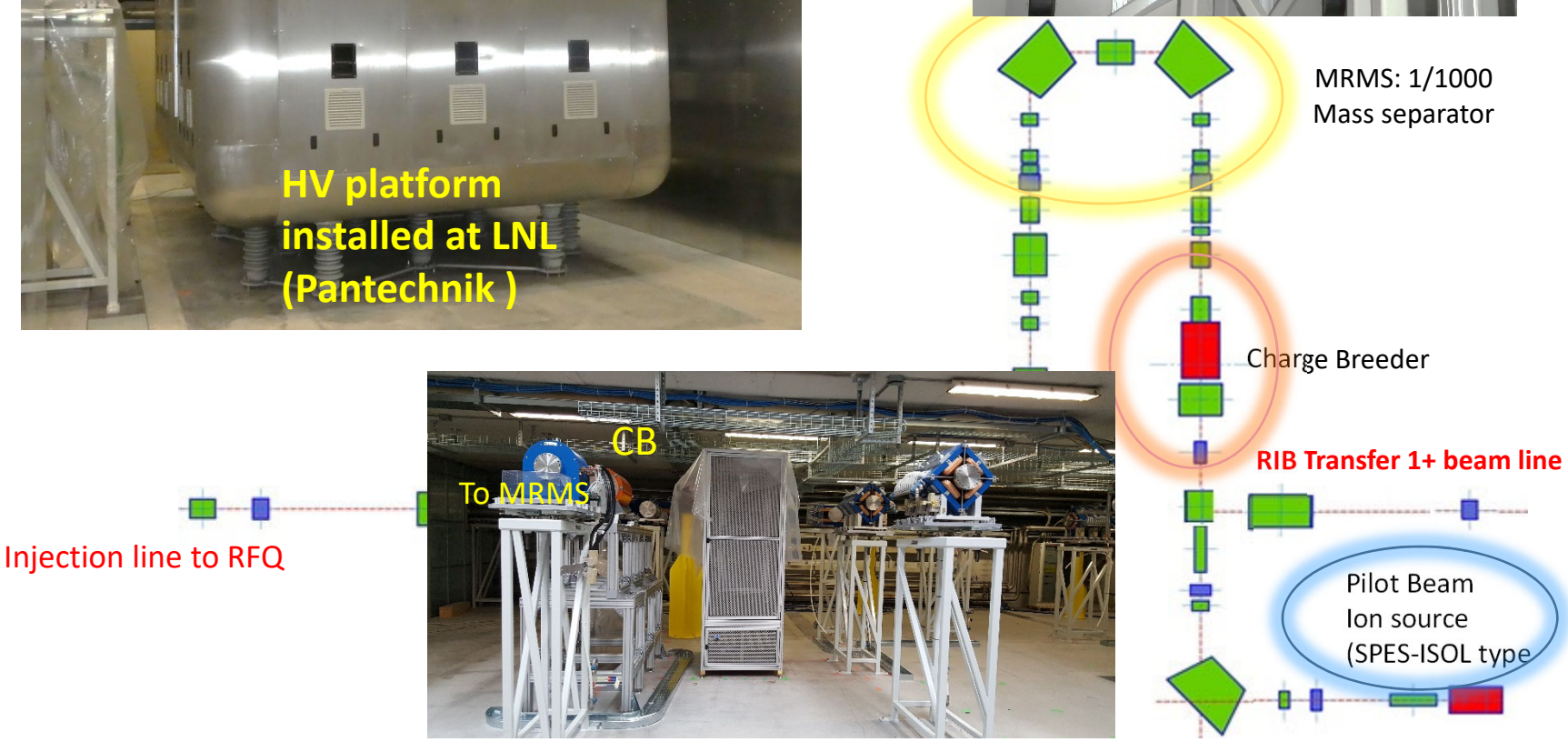


Installation phase 2A: Charge Breeder & n+ beam line

MRMS and HV platform

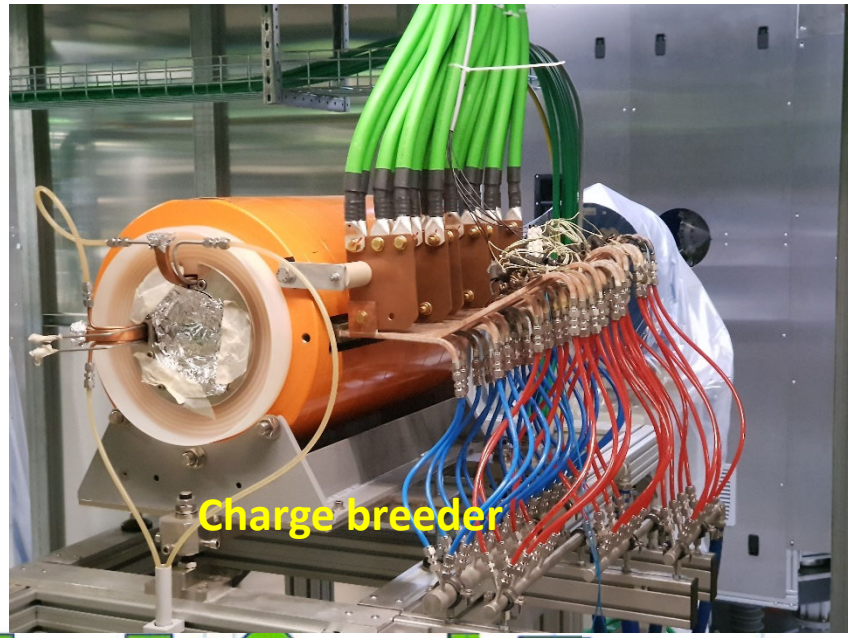


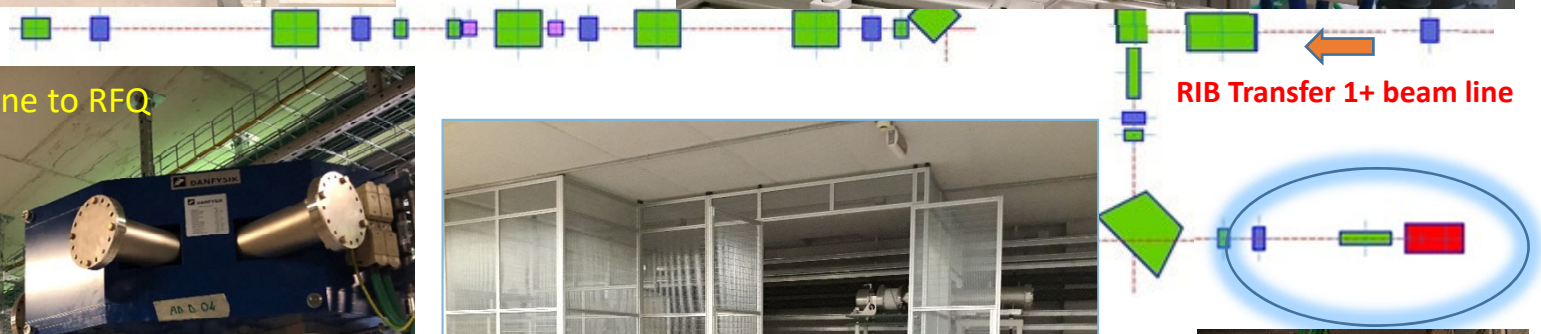


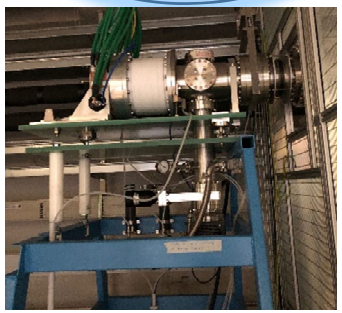


Installation phase 2A: Charge Breeder & n+ beam line

Installation Status on 15th/10/2018



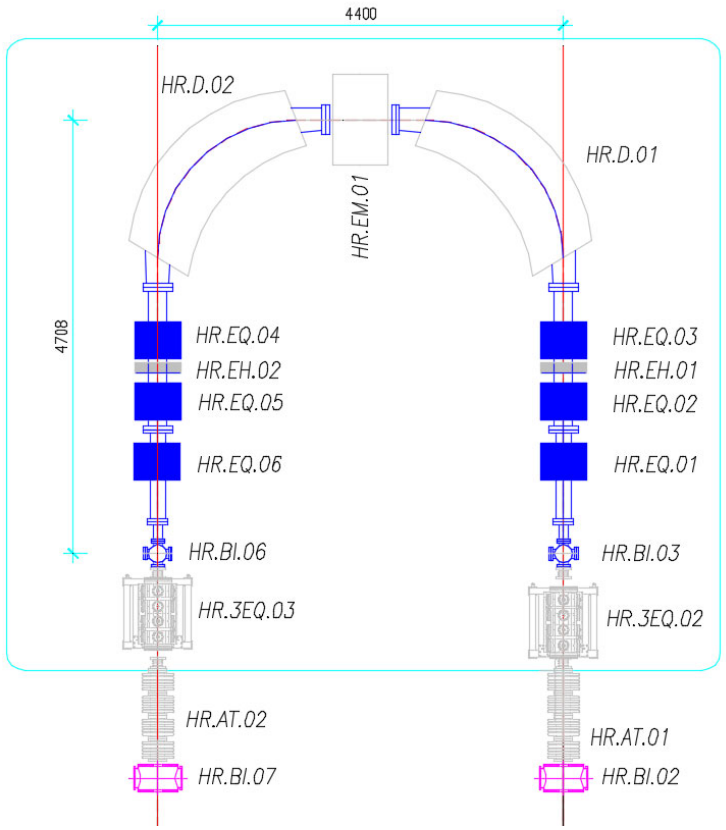




HRMS

- 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 October, 4-5 2018
–Authorization to tender 2019
–Commissioning 2022



Review committee

R. Pardo (ANL-USA, chair)
T. Giles (CERN)
F. Varenne (GANIL)
H. Weick (GSI)

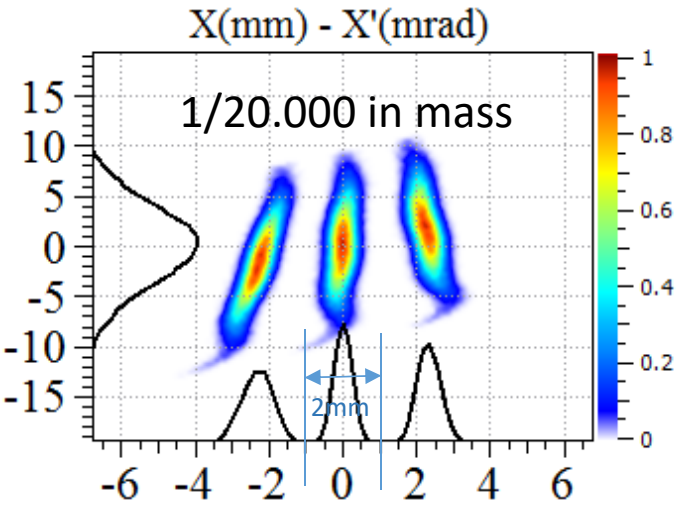


Table 2: Beam Dynamics Parameters

Geometric Emittance	2.7	4 π 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
(collaboration with LPC_Caen)

Installation phase 3: RFQ & RIB transfer line

- Energy 5.7 –> 727.3 keV/A [β=0.0395] (A/q=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)
- Mechanical design and realization, similar to the Spiral2 one, takes advantage of IFMIF technological experience

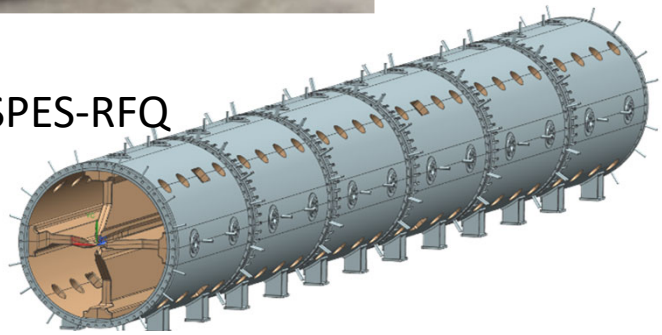
RFQ electrodes dimensional control.

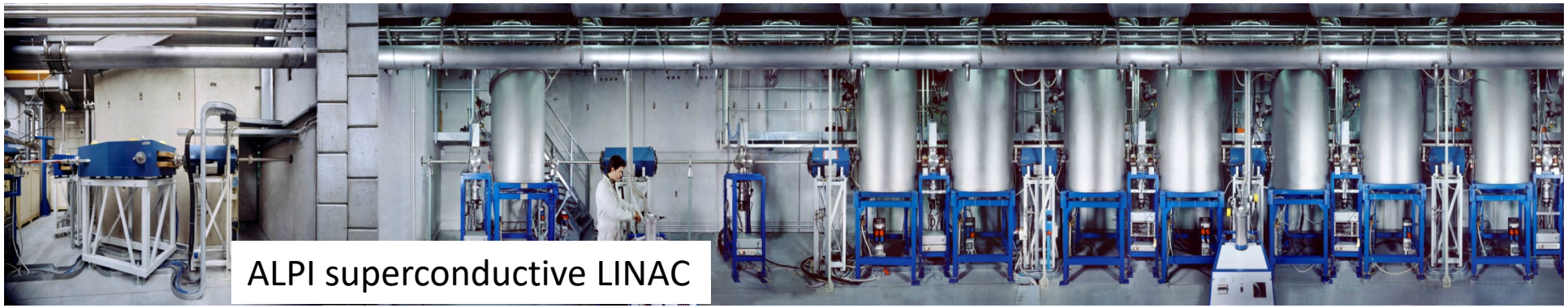
Delivered Full set of 24 electrodes

- Start of tender for 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 Jan 2018
- Completion of all tanks (incl. **Cu deposition**) (sep 2019)
- Assembly and low power testing (jan 2020)
- High power tests start (sept 2020)

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.

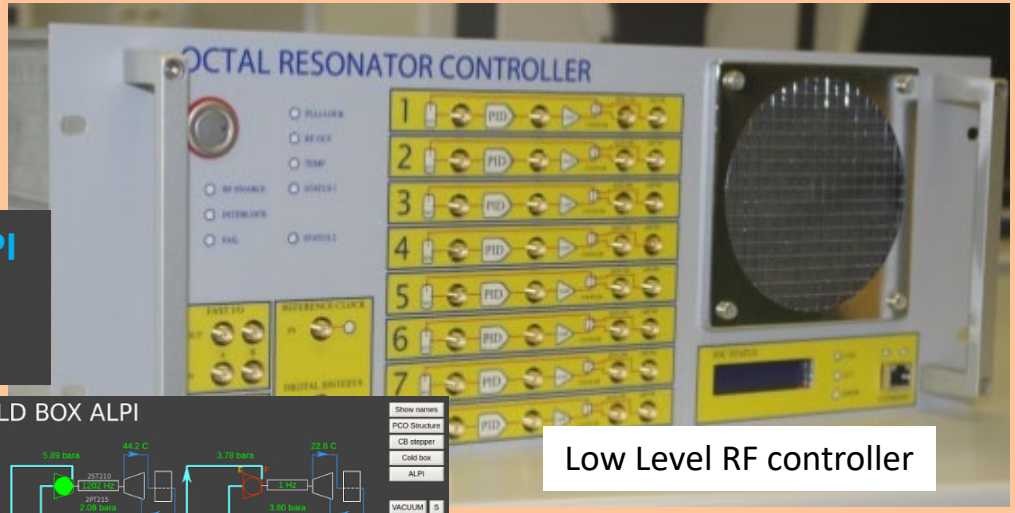
SPES-RFQ





ALPI superconductive LINAC

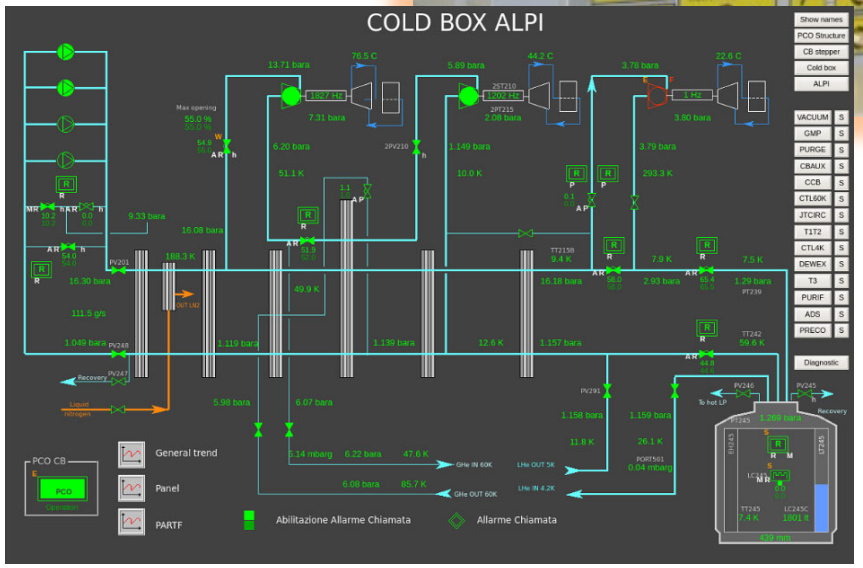
RF development and control



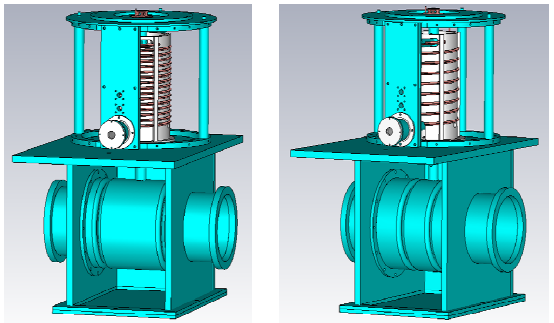
Low Level RF controller

ALPI resonators

Refurbishment of ALPI Cold-Box Control
(CERN-UNICOS)



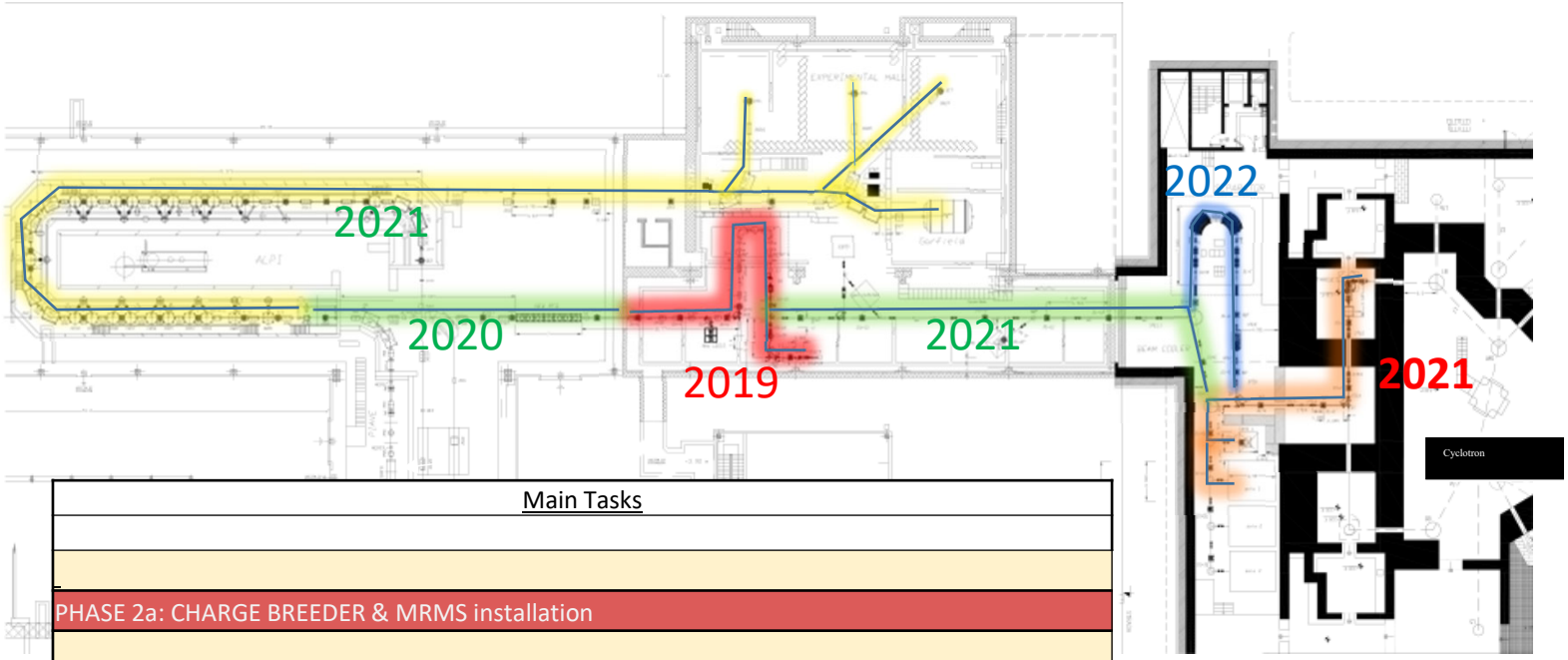
RF Bunchers



5 and 10 MHz structures

EPICS

SPES installation phases



Main Tasks
PHASE 2a: CHARGE BREEDER & MRMS installation
PHASE 2B: ISOL SYSTEM and wien filter
PHASE 2B: 1+ beam line omponents
PHASE 3A: 1+ beam line up to Charge Breeder
PHASE 3B: bunchers & RFQ, ALPI upgrade
PHASE 3A: BEAM COOLER
PHASE 3A: HRMS

Schedule to be revised to accomplish with INFN-BEST contract (work in progress)

Conclusions

- **SPES is in the construction phase**
- **Cyclotron needs maintenance and possibly upgrade (cooling system and injection buncher)**
- **Finishing of infrastructures are planned for 2019**
- **In the next two years the ISOL system will be installed**
- **In 2021 radioactive beams with no-reacceleration will be commissioned**
- **Charge Breeder and MRMS will be in operation by 2019**
- **Reacceleration will be completed at end 2021 using ALPI to reach 10-11 MeV/n**

Thank you for attention

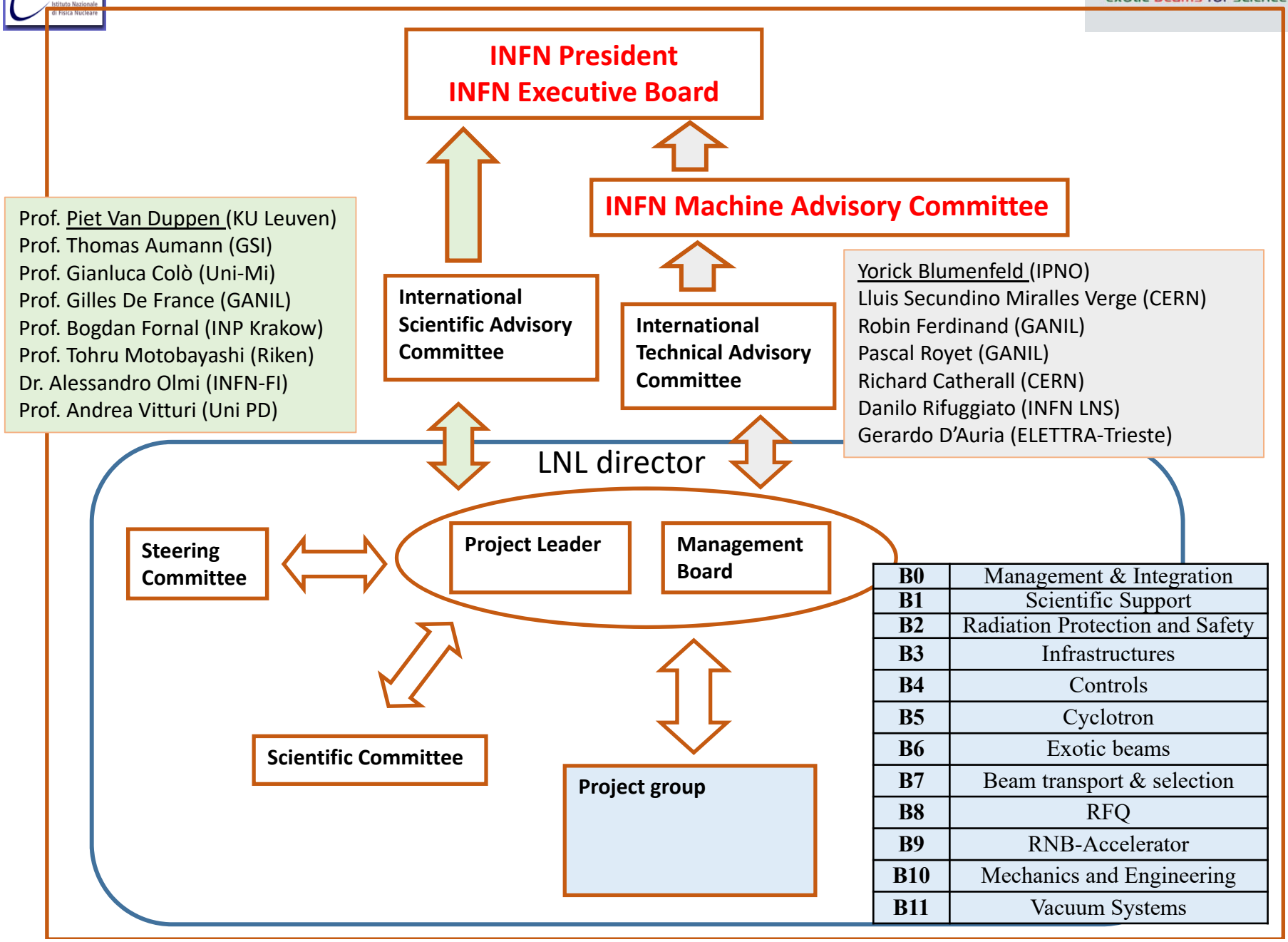
INFN
Istituto Nazionale di Fisica Nucleare

SPES
exotic beams for science

component	Status of SPES components	notes
Cyclotron	• Commissioning completed • New beam lines for Cyclotron are delivered (LARAMED and ISOL2 beam line)	• Maintenance scheduled on 2019
ISOL and RIB production	• ISOL Bunker devices developed and tested at ISOL laboratory. • Laser system delivered (SAT ongoing).	• Installation 2019 - 2020 Commissioning Sept 2020-Mar 2021 • Installation 2018
Charge breeder and MRMS	• Delivery of beam transport components • Installation started (Charge Breeder, 1+ source)	• Installation 2018 • Commissioning 2019 - 2020
HRMS high resolution mass separator	• Physical design ready, integration with beam cooler and beam lines under way • Preliminary dipole design and feasibility check with potential manufacturer done	• Critical Design Review in Oct. 2018 • Authorization to tender March 2019 • Commissioning 2022
Beam Cooler	Collaboration with LPC_Caen for Beam Cooler development (expertise: SHIRaC - SPIRAL2)	• Construction 2019 - 2020 • Installation and Comm. 2021
Normal conductive RFQ	6 modules of RFQ in construction. (24 electrodes delivered)	• Construction 2018-19 • Installation 2020 • Commissioning 2021
1+ Beam line transfer	Electrostatic triplets of quadrupoles ordered Electrostatic dipoles tested Vacuum systems delivered	• Tender for triplets 2018 • Installation 2019 - 2020
Safety	Safety system analysis and design: Bid assigned (PILZ), risk analysis completed Authorization to operate with UCx : process on the way, formal discussion with ISIN ongoing since Jan 2018	• Design completed 2018 • Installation and commissioning 2019 • expected completion ~~June~~ ~~Nov~~ ~~2018~~ ?

Schedule to be revised to accomplish with INFN-BEST contract (work in progress)

SPES Organizzation



Committees members

INFN-Machine Advisory Committee:
A. Variola (INFN-LNF, chair),
M. Vretenar (CERN),
R. Losito (CERN),
R. Bartolini (Diamond Light Source),
G. D'Auria (Elettra ST),
R. Cimino (INFN-LNF),
A. Lombardi (INFN-LNL),
L. Celona (INFN-LNS)
ex officio members
E. Nappi (INFN Executive Board), M. Taiuti (President of INFN-CSN3)

SPES Scientific Advisory Committee
Prof. Piet Van Duppen (KU Leuven - chair)
Prof. Thomas Aumann (GSI)
Prof. Gianluca Colò (Uni-Mi)
Prof. Gilles De France (GANIL)
Prof. Bogdan Fornal (INP Krakow)
Prof. Tohru Motobayashi (Riken)
Dr. Alessandro Olmi (INFN-FI)
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SPES Technical Advisory Committee
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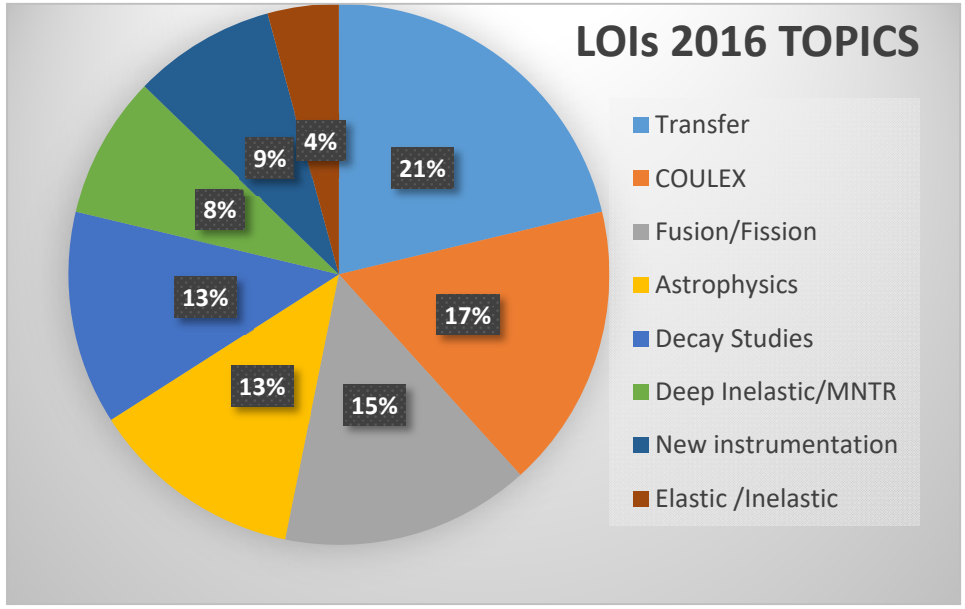
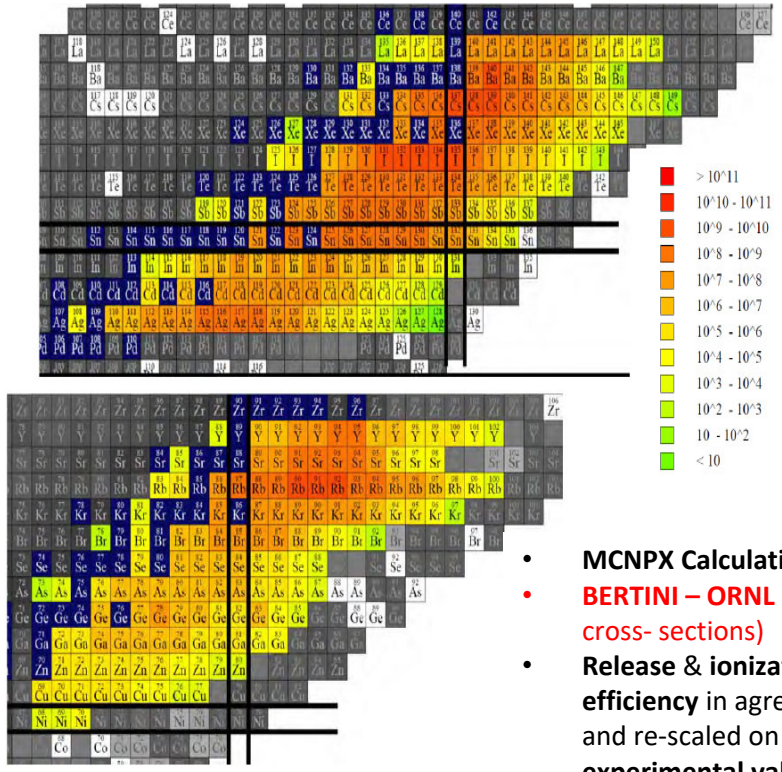
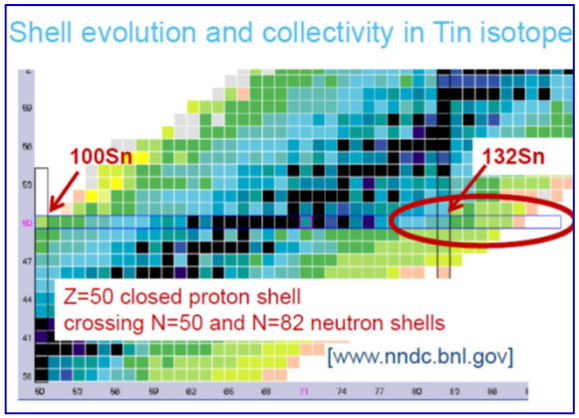
Lluis Secundino Miralles Verge (CERN)
Robin Ferdinand (GANIL)
Pascal Royet (GANIL)
Richard Catherall (CERN)
Danilo Rifuggiato (INFN LNS)
Gerardo D'Auria (ELETTRA-Trieste)

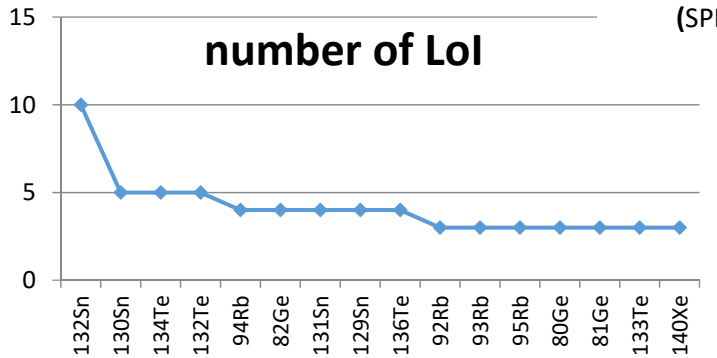
Presented 47 Letters of Intents





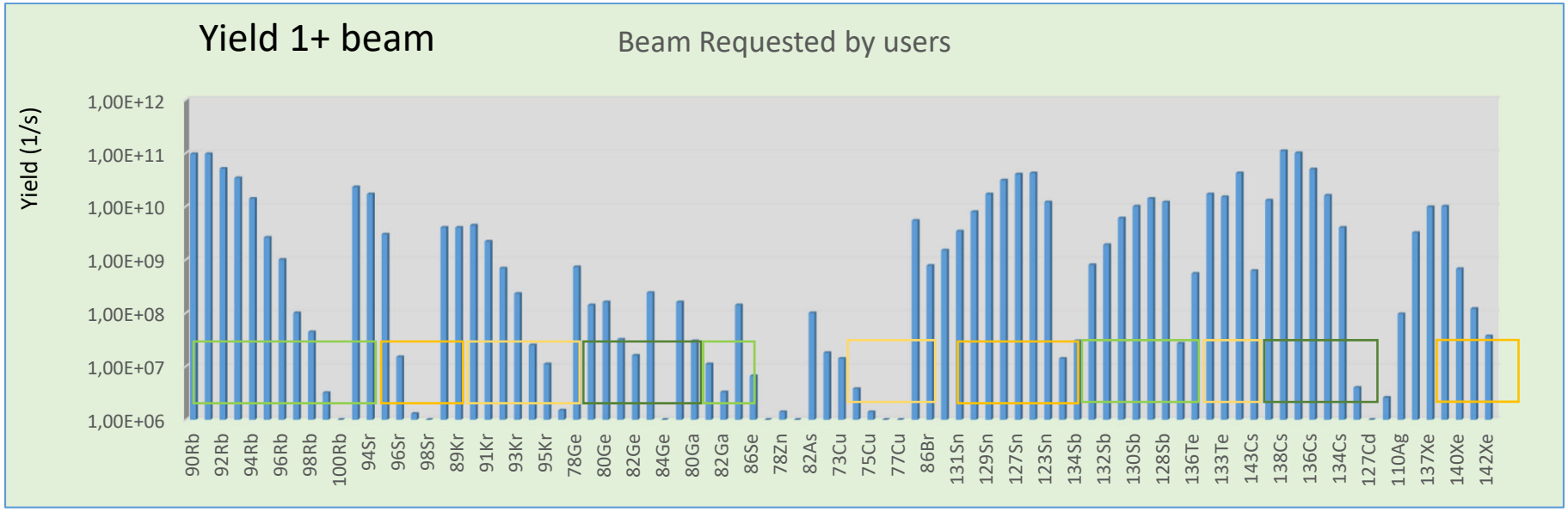
- **MCNPX Calculation**
- **BERTINI – ORNL** (FF cross- sections)
- **Release** & **ionization efficiency** in agreement and re-scaled on **HRIBF experimental values** (SPES **200μA /** HRIBF **5μA**)



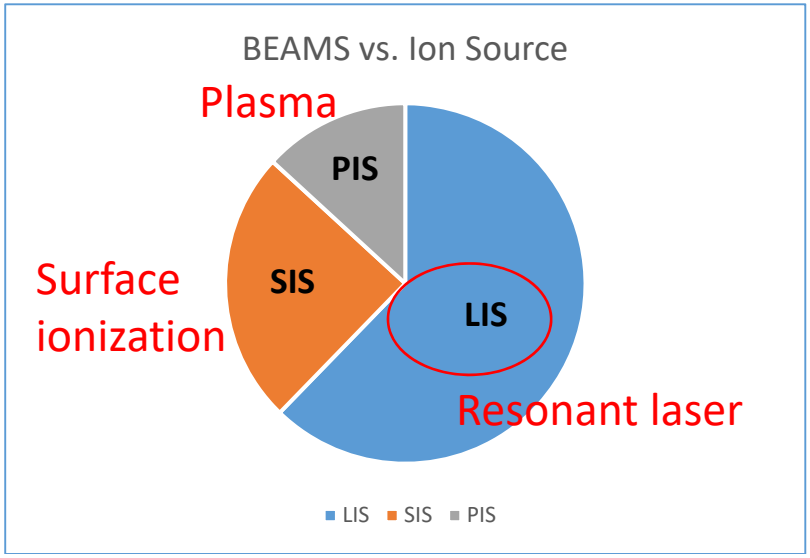


LOI n-rich RIBs

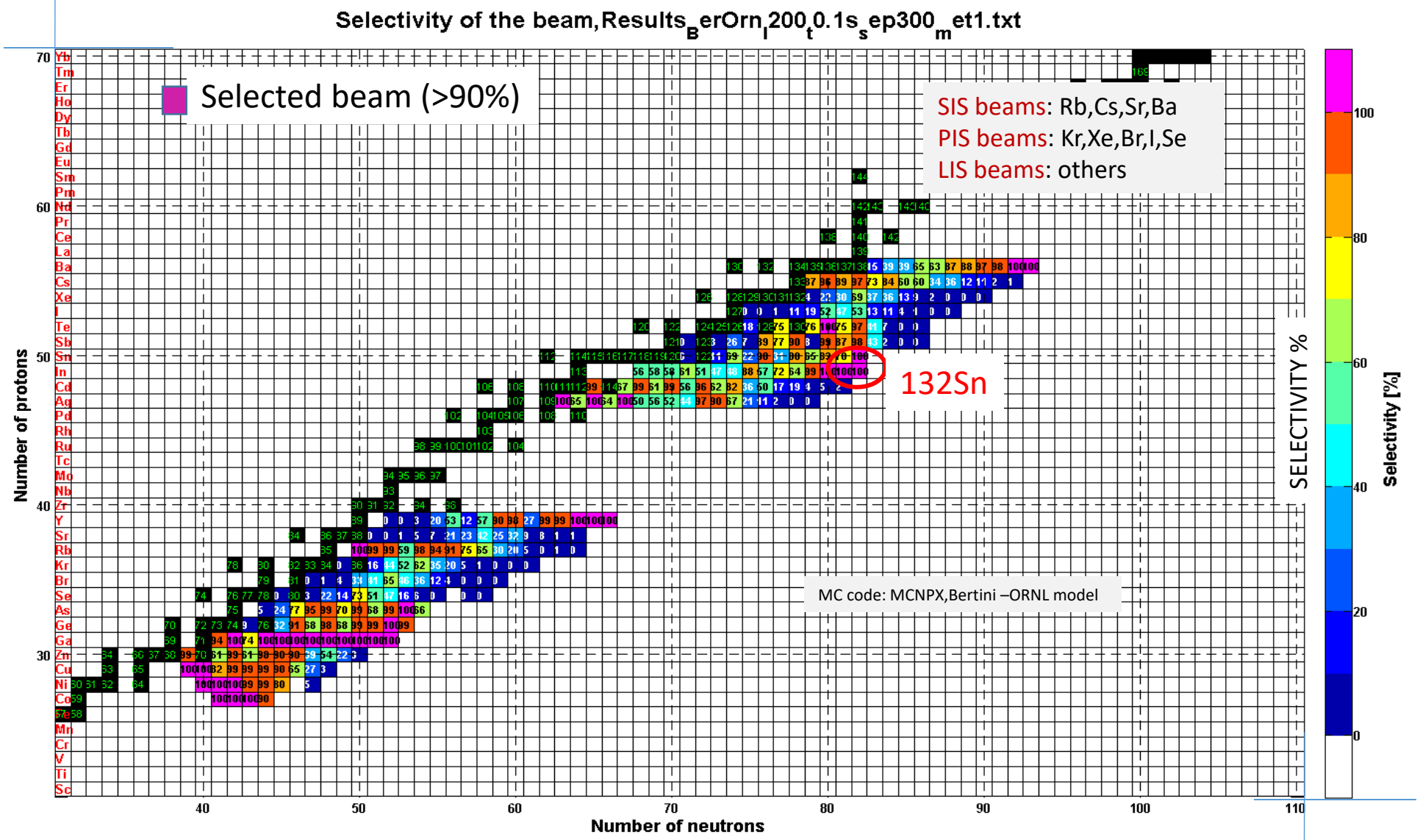
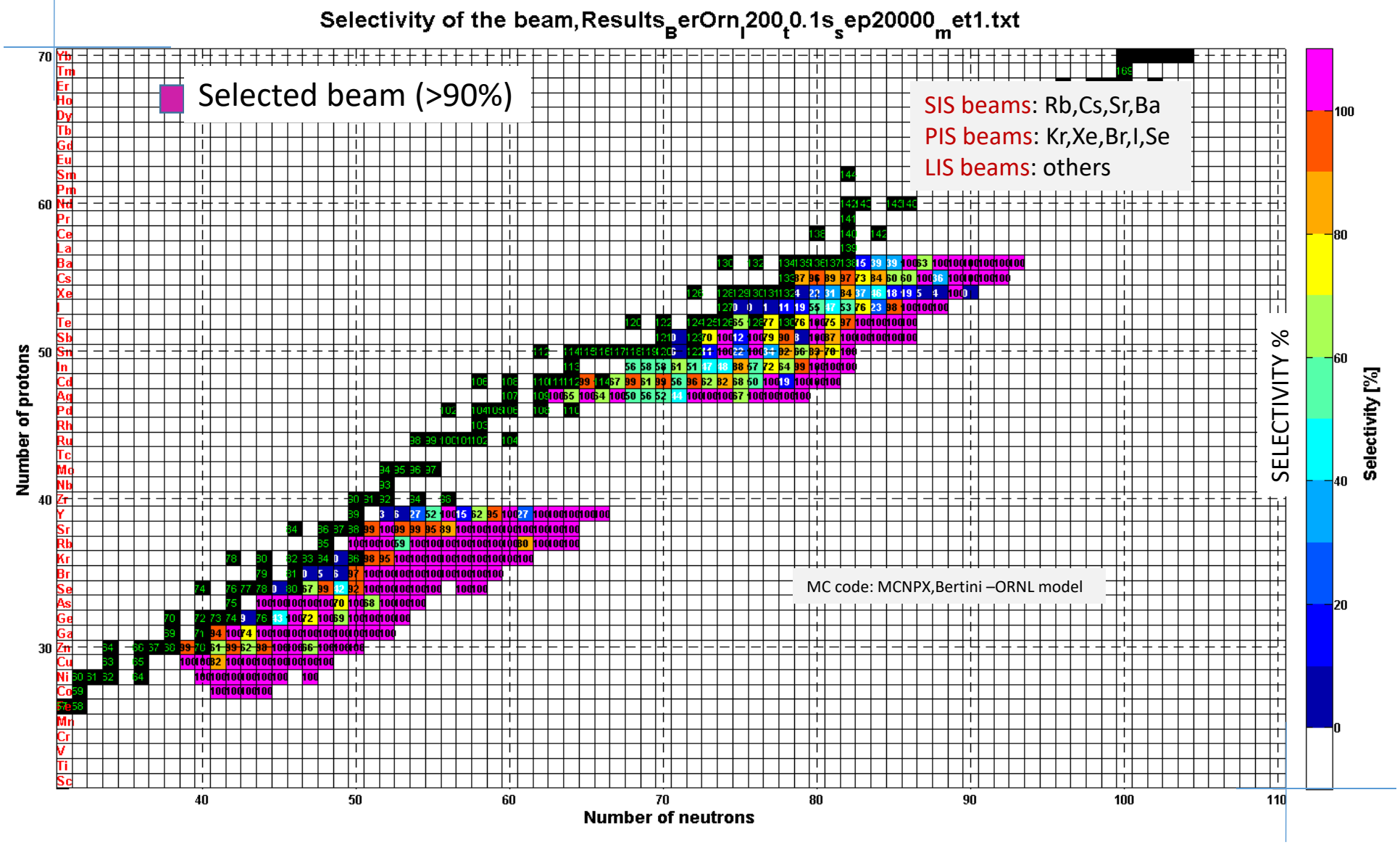
Path toward beam selectivity: **in-target reaction** → ion-source → mass separation



		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	15	→ 82 beams	92%
Benefit with 20.000_HRMS	7	→ 89 beams	100%



Beam Selectivity with LRMS (1/200)



Beam Selectivity with HRMS (1/20.000)