SPES project

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INFN Laboratori Nazionali di Legnaro

SPES project goals

- **Second generation ISOL facility for nuclear physics: Production & re-acceleration** of **exotic beams**. **Neutron–rich ions** from p-induced Fission on **UCx (10^{13} f/s), 10 MeV/amu**

- Research and Production of **Radio-Isotopes for Nuclear Medicine**

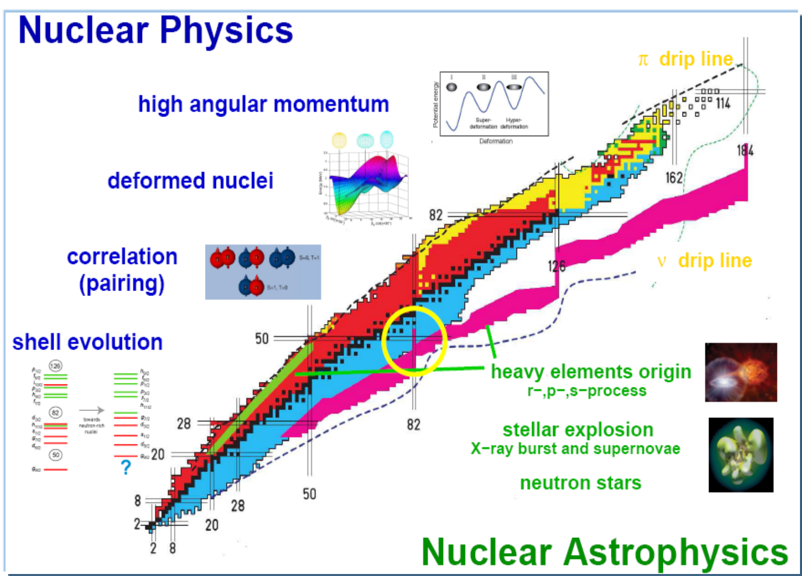
- Accelerator-based neutron source (**Proton and Neutron Facility for Applied Physics**)

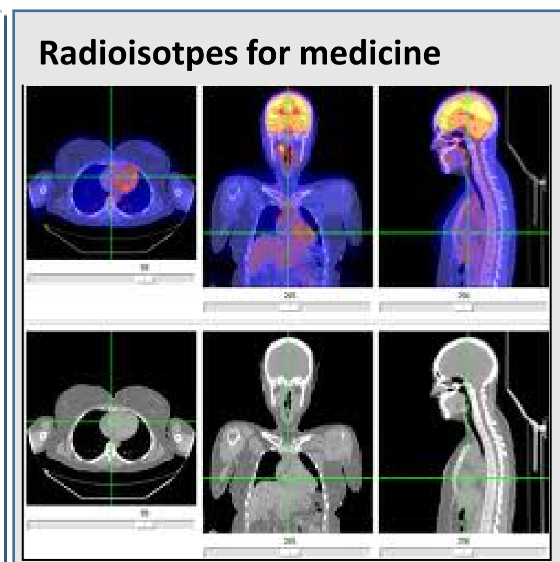
α β δ γ **Cyclotron**

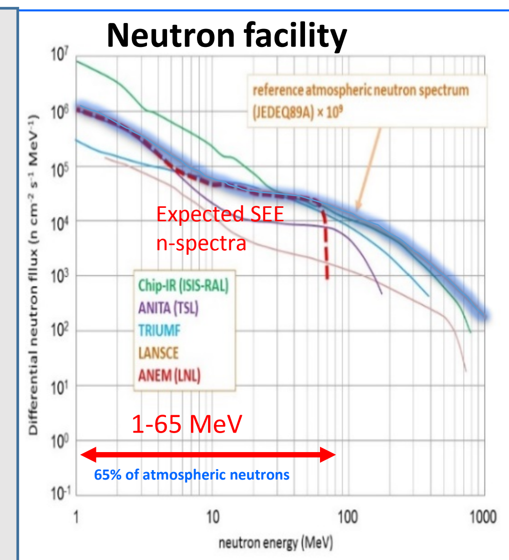
α β δ γ **ISOL RIBs+ Post-Acc.**

α β δ γ **Nuclear Medicine**

α β δ γ **Nuclear Applications**

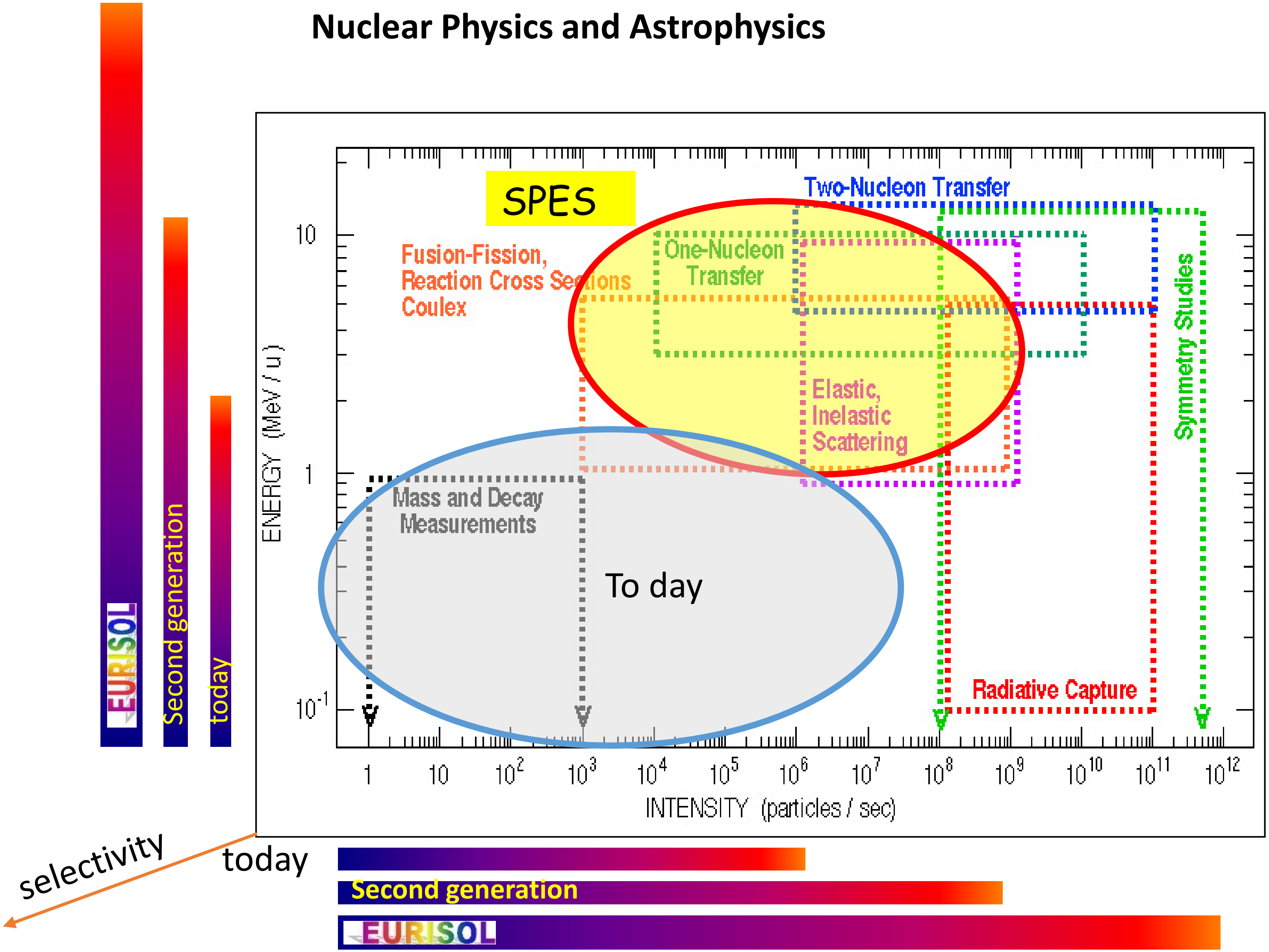






Physics Domain with RIB

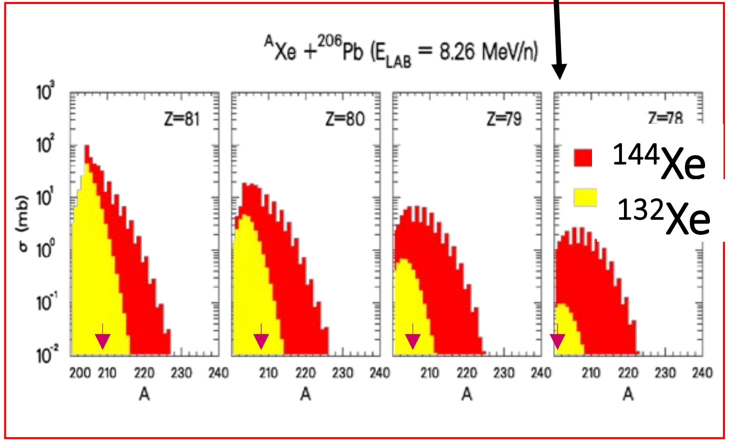
Nuclear Physics and Astrophysics



Neutron-rich Radioactive Beams & Transfer Reactions:
a tool to investigate nuclei far from stability

Two-nucleon & Multi-pair Transfer Reactions are quite complicated processes

- The pairing correlations strongly affect (and enhance) the **two-particle Transfer Reactions** → it is, however, not obvious the quantitative connection.
- orders of magnitude more complex in the case of **multi-particle (or multi-pair) transfers** → they cannot be treated as a ***genuine* direct process**.



Coupled channel calculations (Grazing). G. Pollarolo

Target ^{206}Pb

Some proposed beams for SPES : ^{92,94}Sr, ^{90,92}Kr, ^{88,90}Se

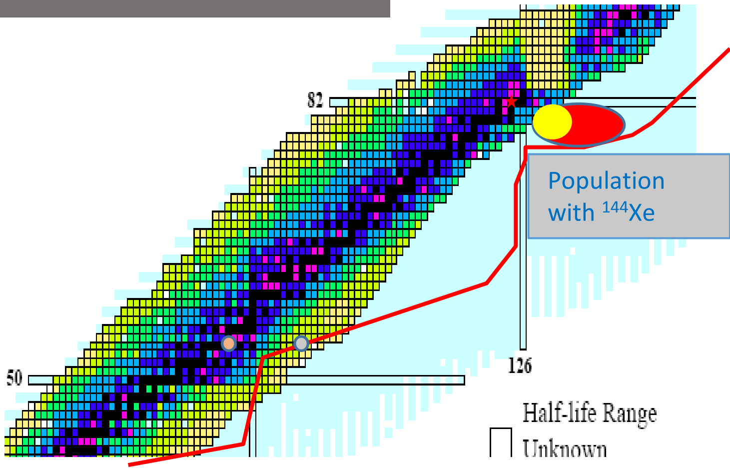
90Zr	91Zr	92Zr	93Zr	94Zr	95Zr	96Zr	97Zr	98Zr	99Zr	100Zr
89Y	90Y	91Y	92Y	9 Y	94Y	9				
88Sr	89Sr	90Sr	91Sr	92Sr	93Sr	94Sr	95Sr	96Sr	97Sr	98Sr
87Rb	88Rb	89Rb	90Rb	9 Rb	92Rb	9				
86Kr	87Kr	88Kr	89Kr	90Kr	91Kr	92Kr	93Kr	94Kr	95Kr	96Kr
85Br	86Br	87Br	88Br	8 Br	90Br	9				
84Se	85Se	86Se	87Se	88Se	89Se	90Se	91Se	92Se	93Se	94Se

ΔZ=2 (-2p from Zr)

ΔZ=2 (- 4p from Zr)

ΔZ=2 (- 6p from Zr)

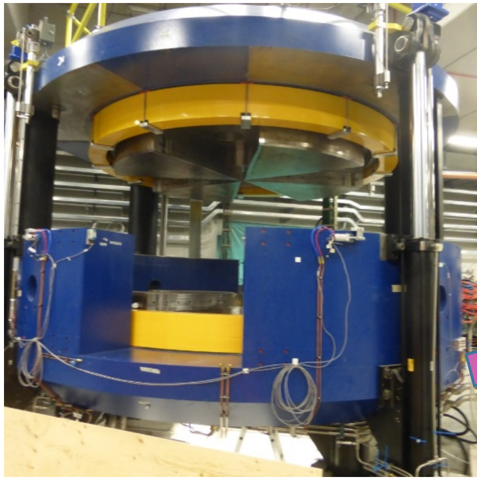
Study of **NN correlations** with neutron-rich nuclei → **pairing force →** modified with neutron/proton excess



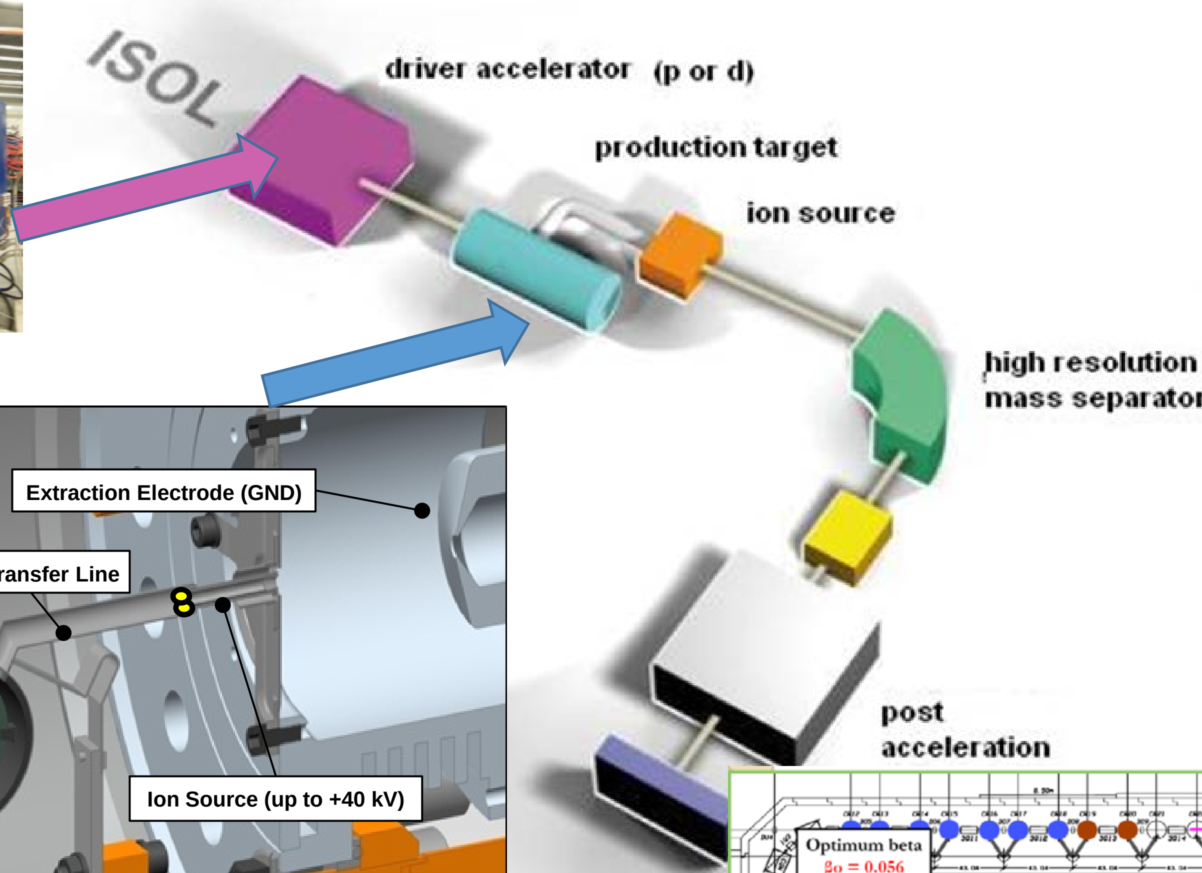
Population with ^{144}Xe

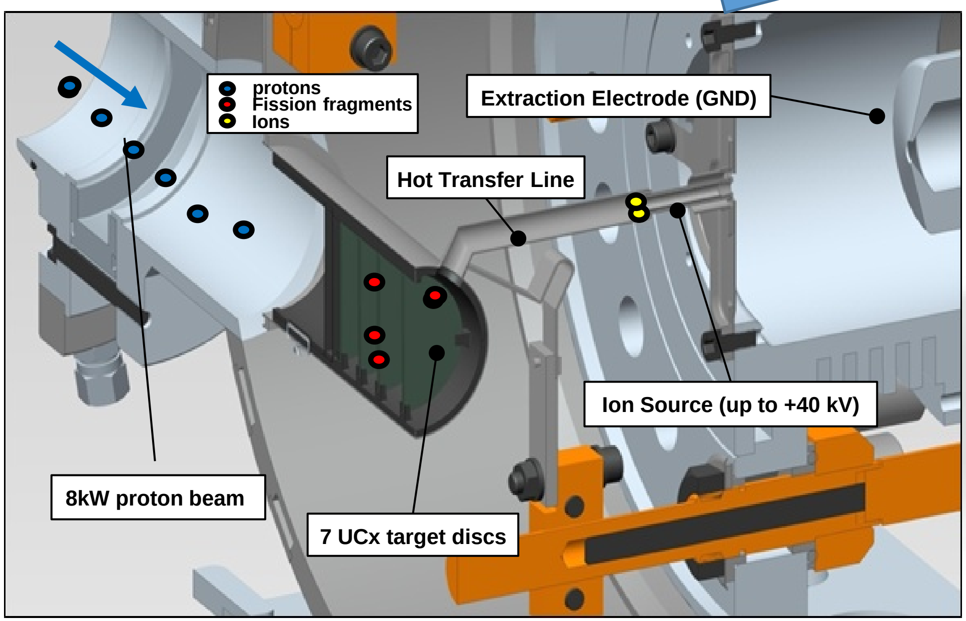
Beams ^{132}Xe ^{144}Xe

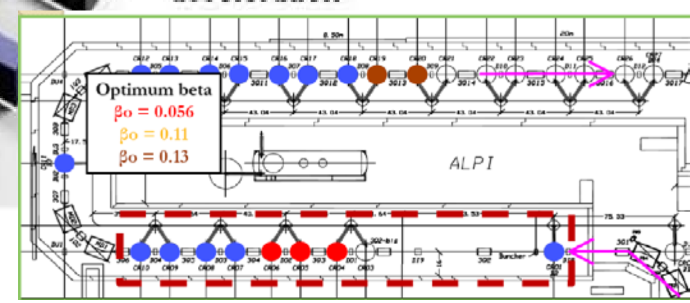
The SPES ISOL complex



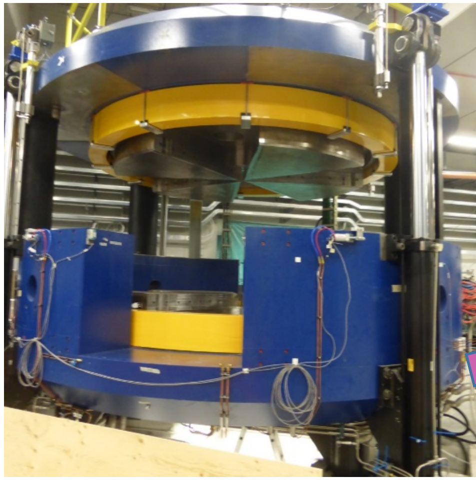
35-70 MeV cyclotron

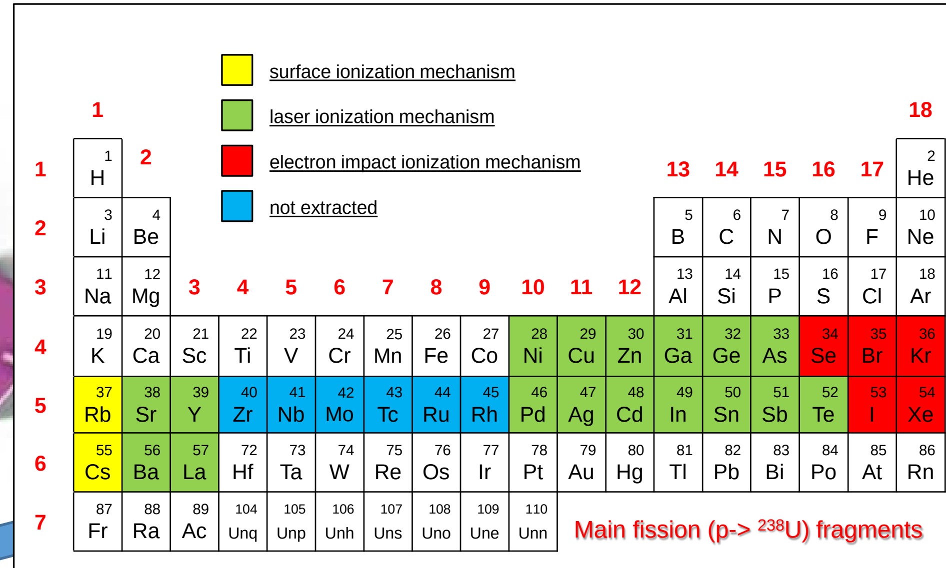


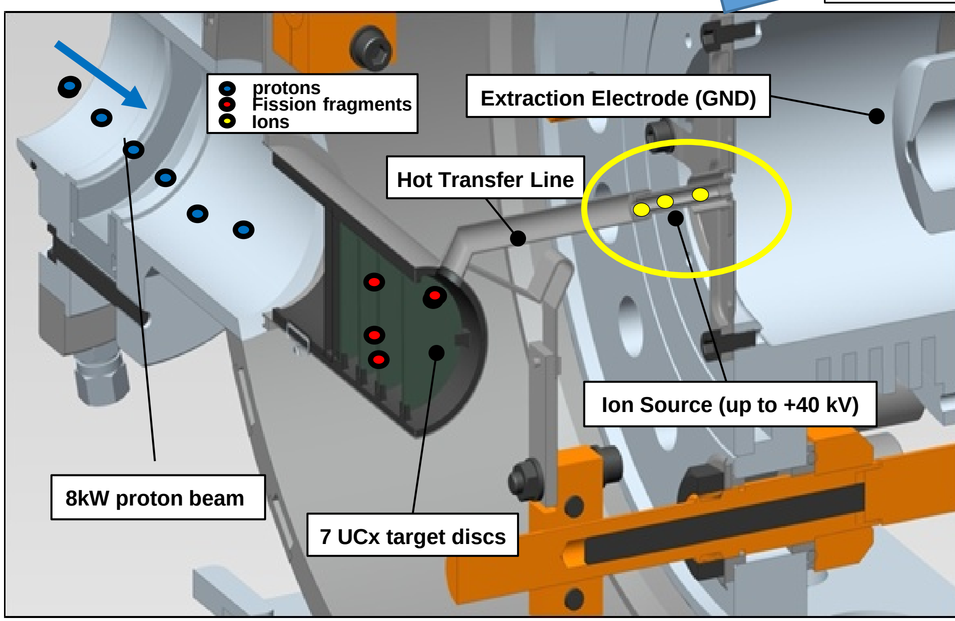


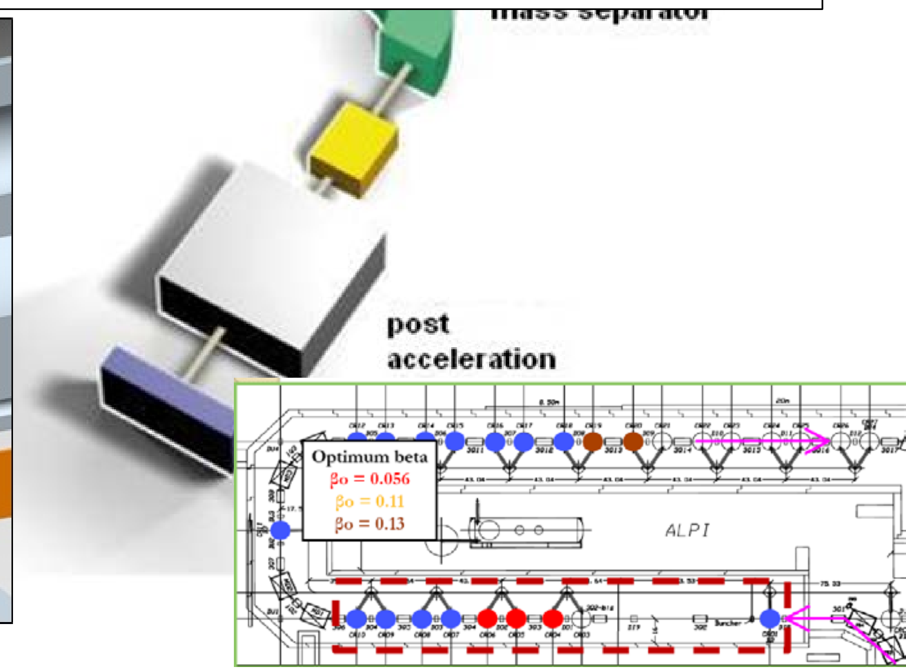


The SPES ISOL complex

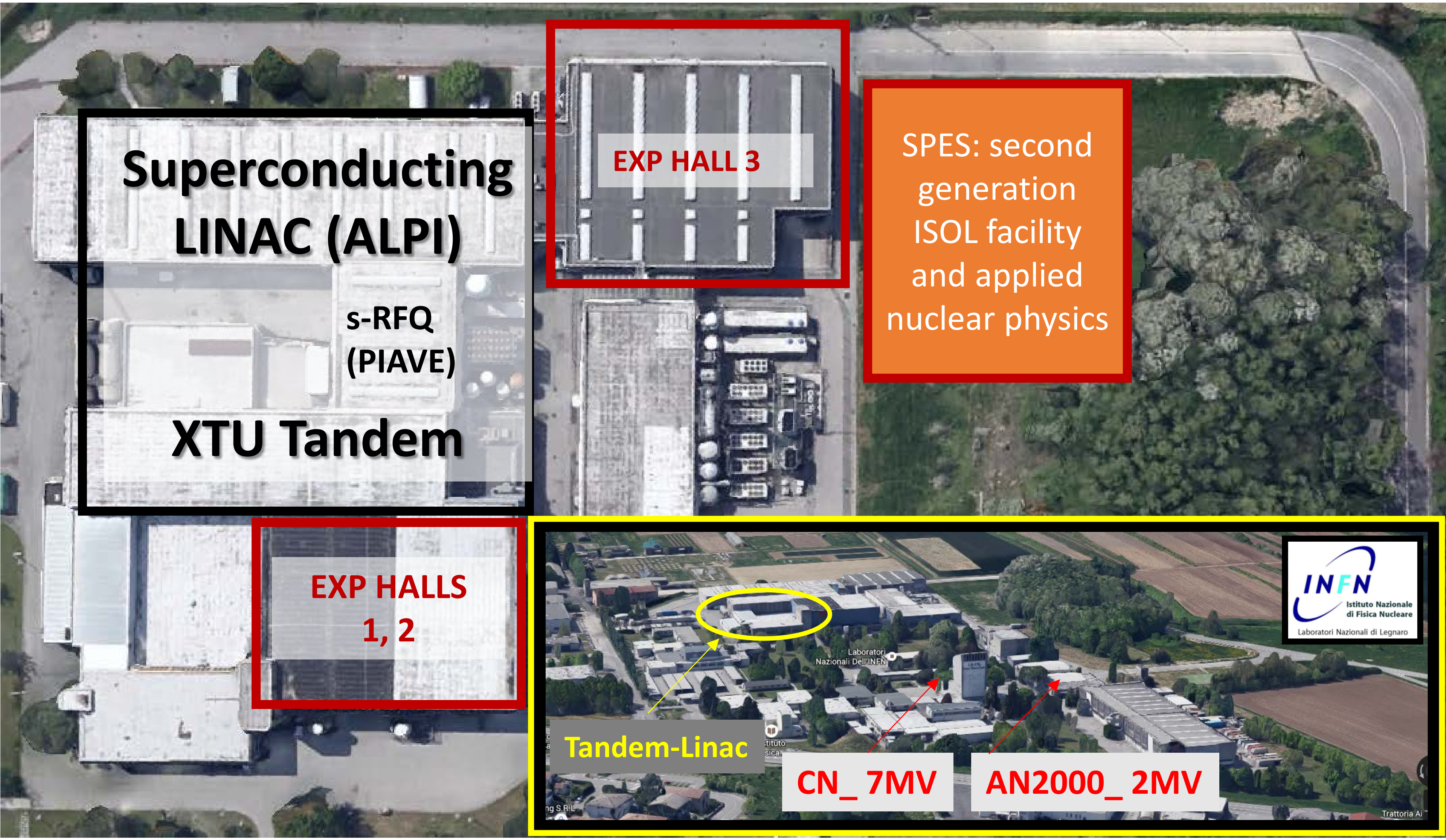








Operating facilities at LNL



SPES infrastructure - layout

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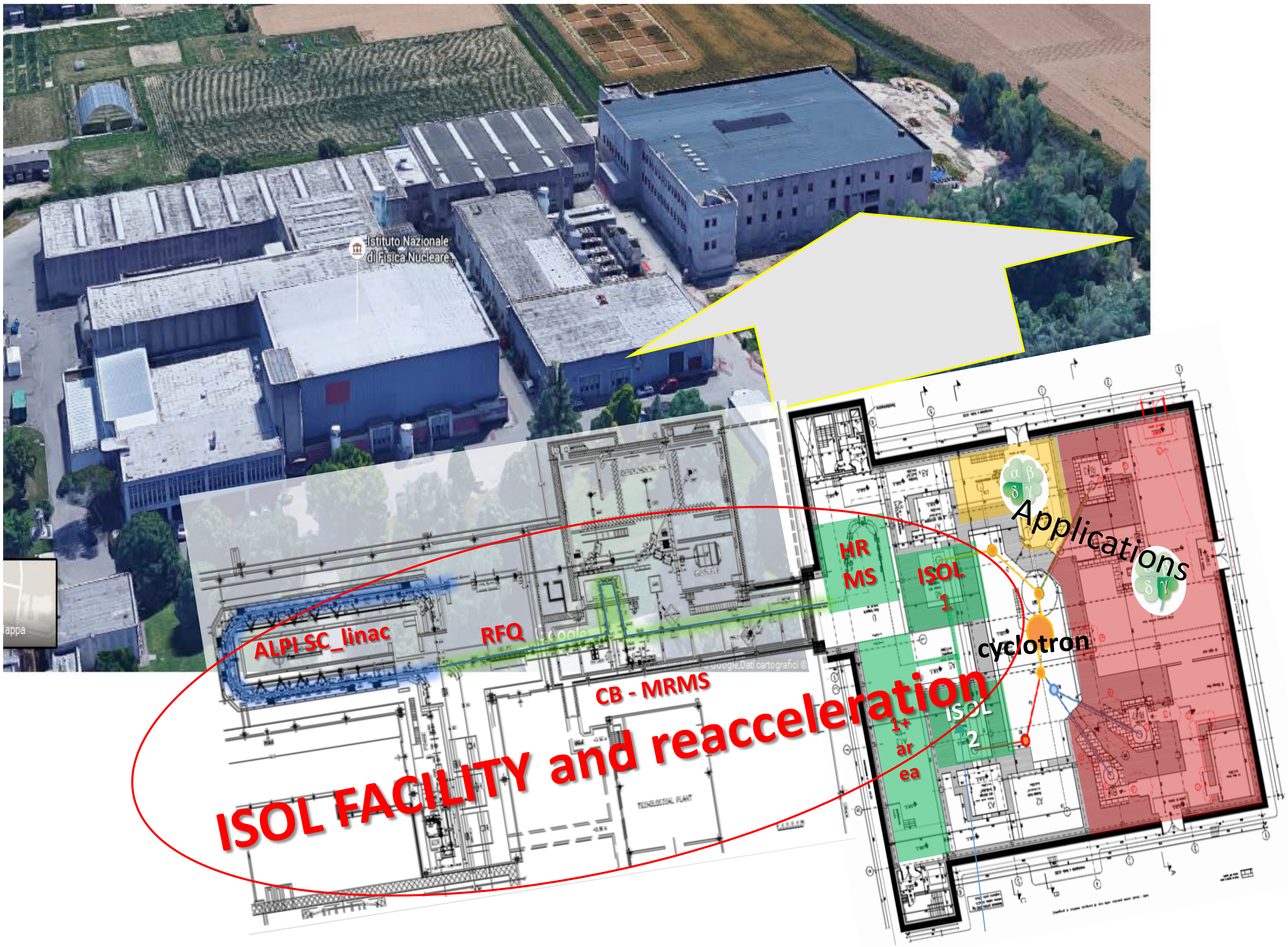


SPES main components

Cyclotron

«commercial» proton cyclotron (BEST)
35-70 MeV
750 microA shared on two exits

ISOL system

10kW Direct target
UCx 10^{13} f/s for n-rich RIBs
2 target stations

Irradiation bunkers

3 irradiation bunkers for medical radio-isotopes production and study

RIB selection and transfer

200 - 20.000 mass selection
Beam cooler, High resolution mass selection
Charge Breeder (ECR), Medium resolution mass selection

Neutron production

Neutron production area

Laboratories and infrastructures

ISOL target labs.
Compound for Medical radioisotopes treatement

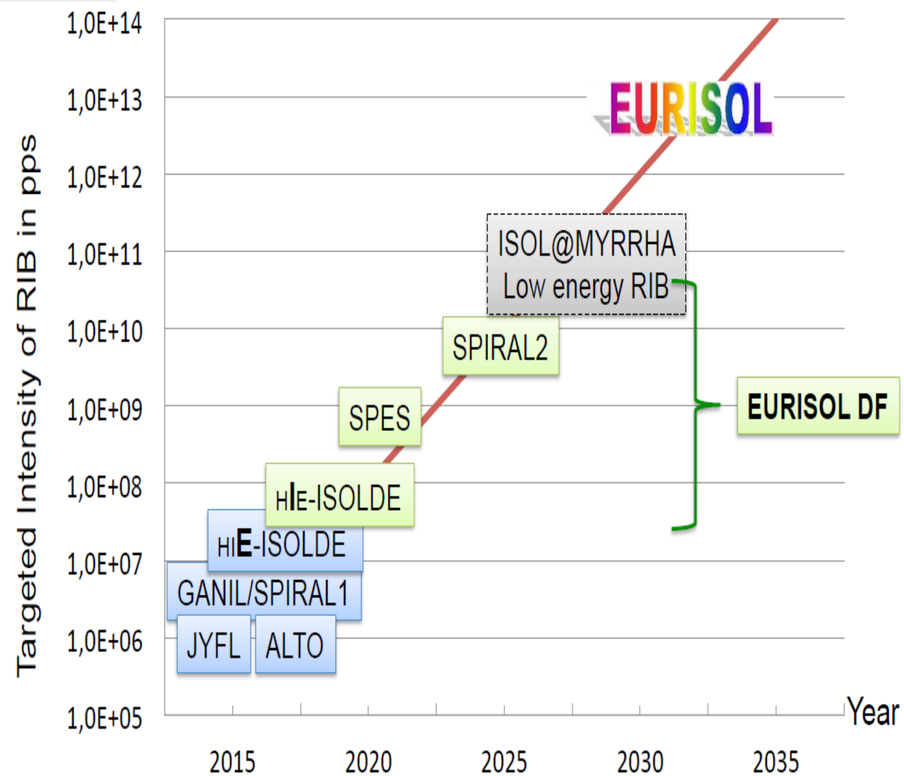
RIB re-acceleration

Normal conductive RFQ
Superconductive LINAC

EURISOL Distributed Facility (DF) Initiative

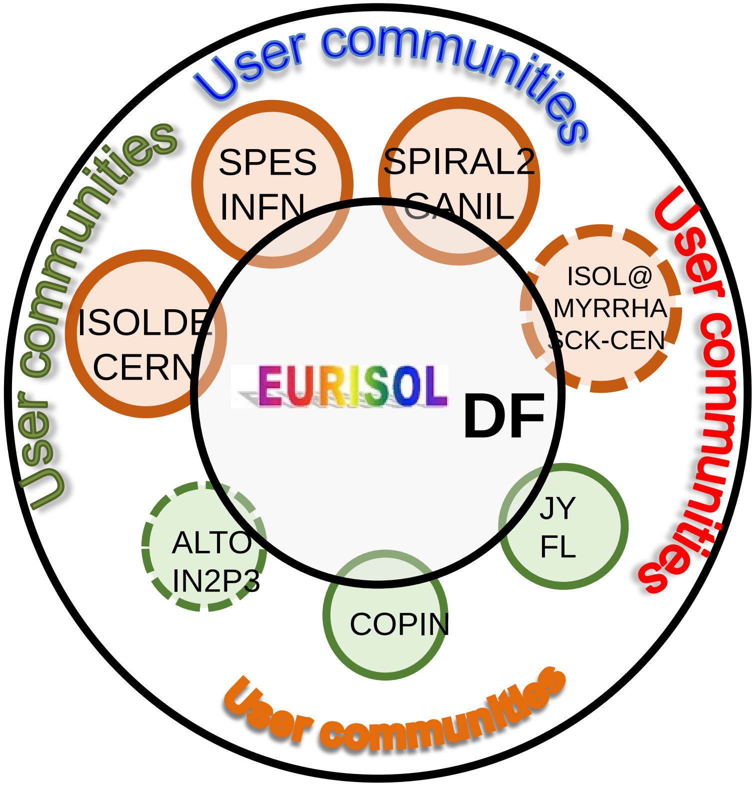
Project to be submitted for the 2020 update of the ESFRI roadmap

EURISOL DF: Intermediate step towards single site project



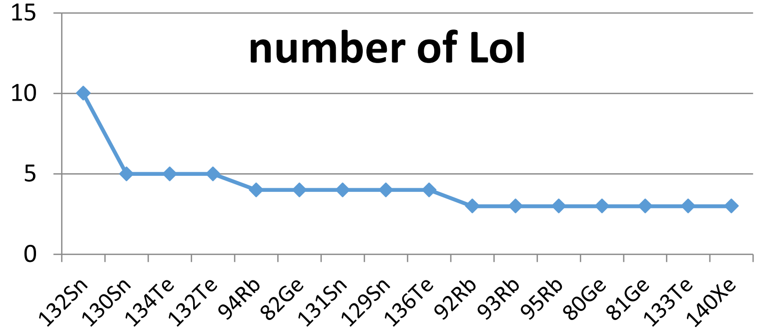
Complementarities: Instrumentation eg. AGATA, FAZIA, GASPARD, PARIS
Challenges: High-power targets & sources, purification of RIB

EURISOL DF



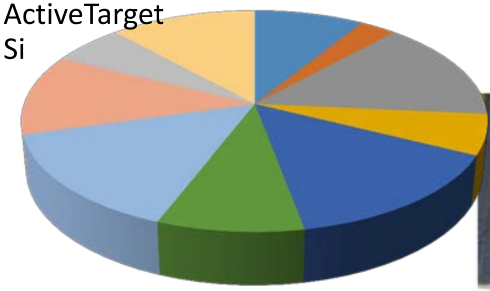
- A **distribute laboratory** for radioactive beams:
- **More exotic beams** available
- **Coordination of competences** to face EURISOL technologic challenges
- **Joint effort** to manage the activity at European level

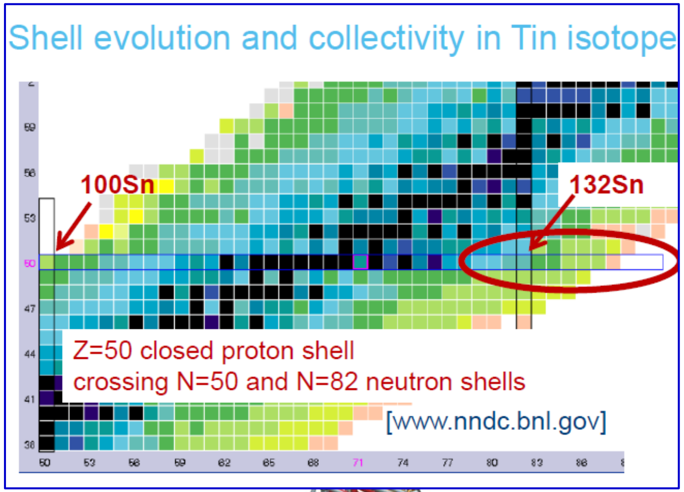
Presented 47 Letters of Intents

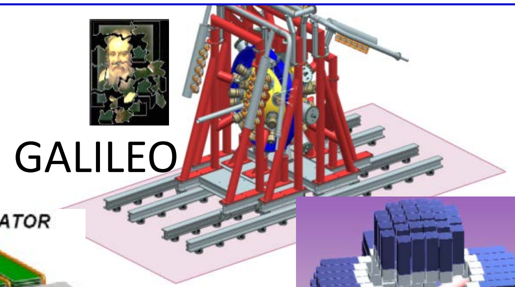


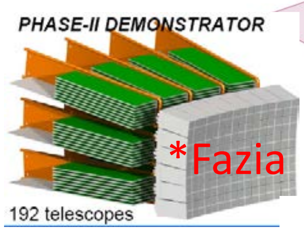
SPES LOIs Topics

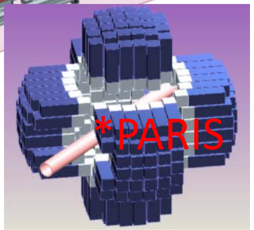
- GS properties
- moments
- Coulex
- DirReac with ActiveTarget
- DirReac with Si
- Mn transfer
- Collective ex
- Fusion
- Super Heavy
- Dymanics

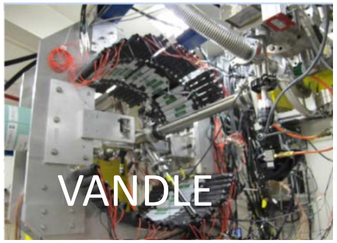


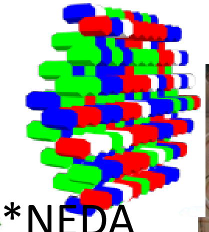


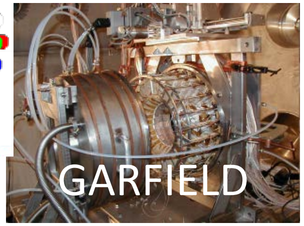












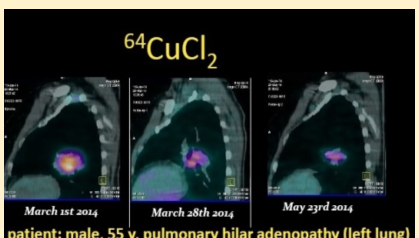
SPES γ: Radioisotope Production & research

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

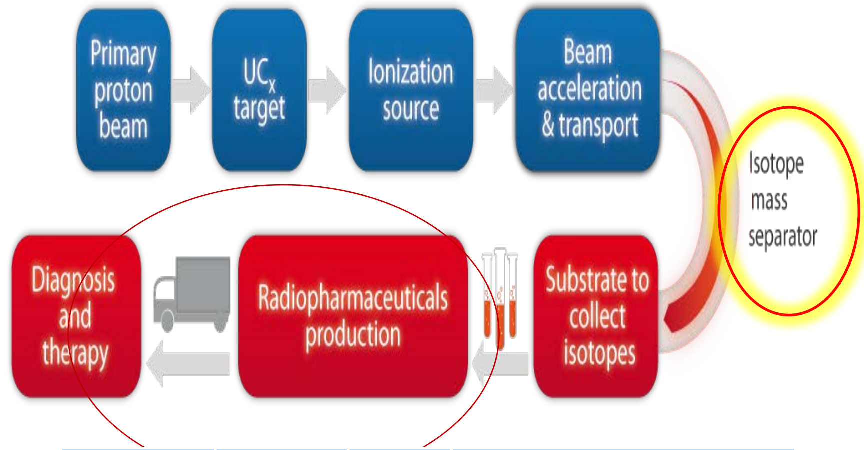
ARRONAX (Nantes) – SPES collaboration:
Isotopes and high-Power target developments

A.Duatti

ISOLPHARMA*

* INFN Patent

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



Radiopharmaceutical	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).

Collaboration with Pd_University (Pharmacy) and hospitals for preliminary test

A.Andrighetto

NEPIR: Neutron production at SPES

Integral neutron production at SPES Cyclotron Proton beam= 70 MeV, 500 μA Target = W 5mm			
Energy region (MeV)	Sn (n/s) $\sim 6\cdot10^{14}\ s^{-1}$	Φ_n @ 2.5 m (n cm^{-2} s^{-1})	Φ_n @ 1 cm (n cm^{-2} s^{-1})
1 < E < 10	$\sim 5\cdot10^{14}\ s^{-1}$	5×10^{8}	3×10^{13}
10 < E < 60	$\sim 1\cdot10^{14}\ s^{-1}$	1×10^{8}	$6x10^{12}$

Continuum and Quasi Mono Energetic fast neutron spectra

- Cross section data for basic science and astrophisics
- Oncology studies
- Calibration of radiation instrumentation
- Radiation protection studies (shielding-benchmarks)
- Radiation hardness studies

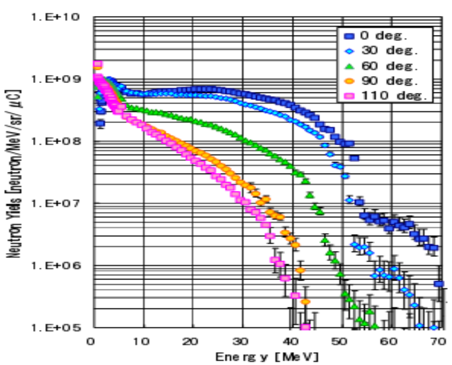


Figure 4: Thick target yield for C(p,xn) at 70 MeV

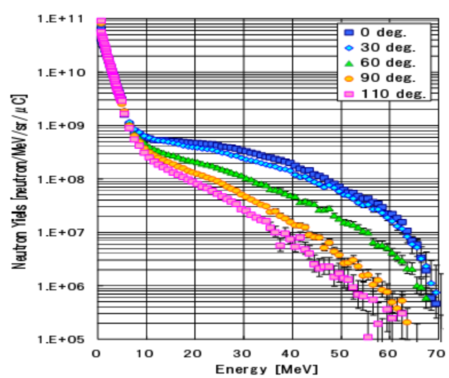
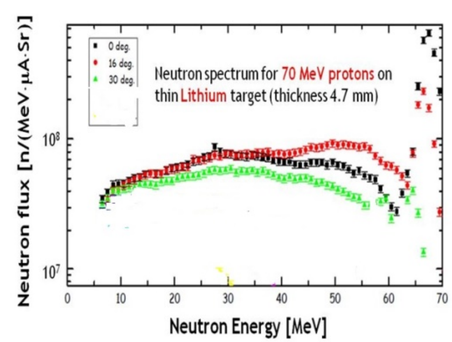
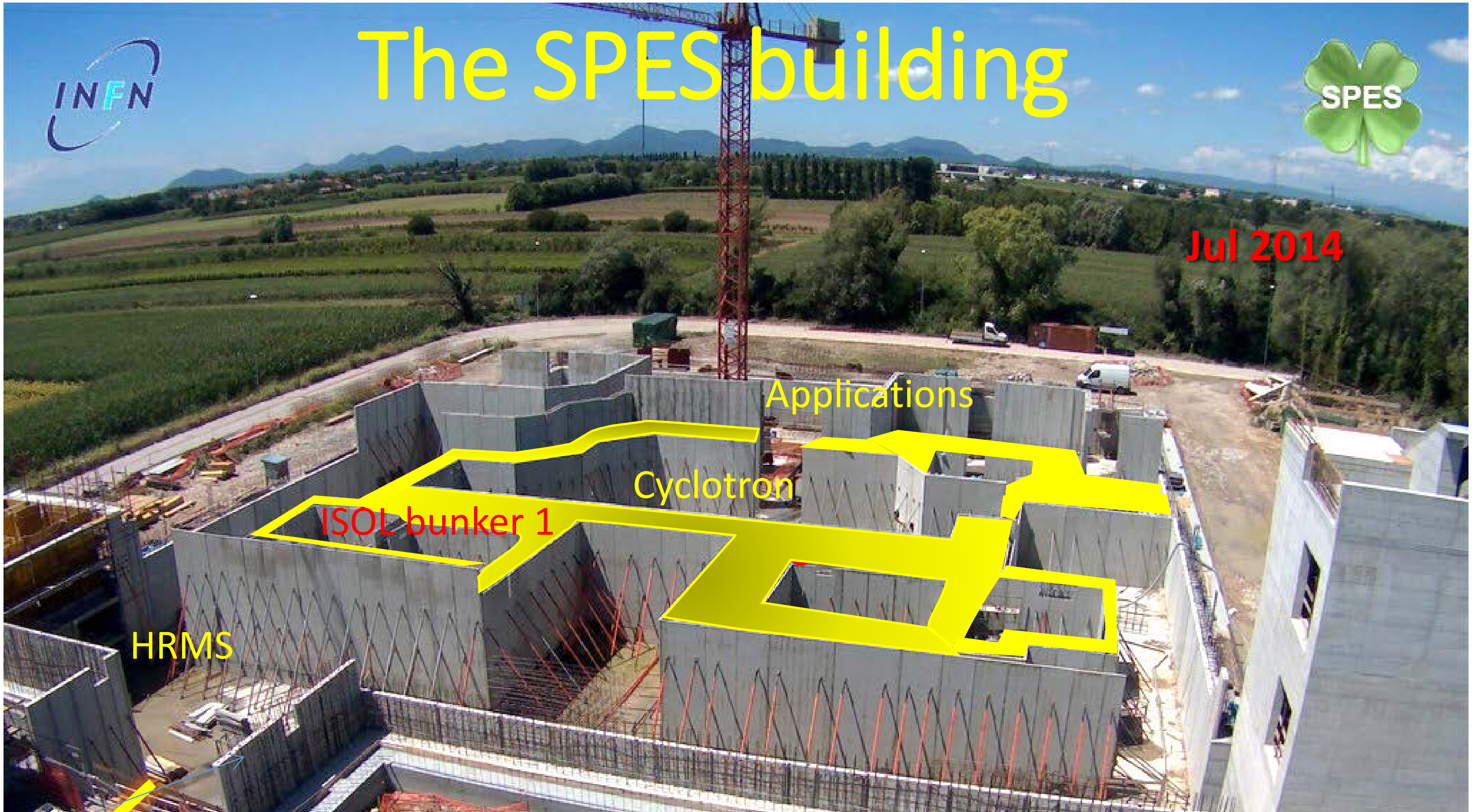


Figure 14: Thick target yield for W(p,xn) at 70 MeV



Project at design level

The SPES building



50 x 60 m^2
-3 to +11 m height
24.000 m^3 of concrete
1.150 tons iron

3-4 m thick shielding walls

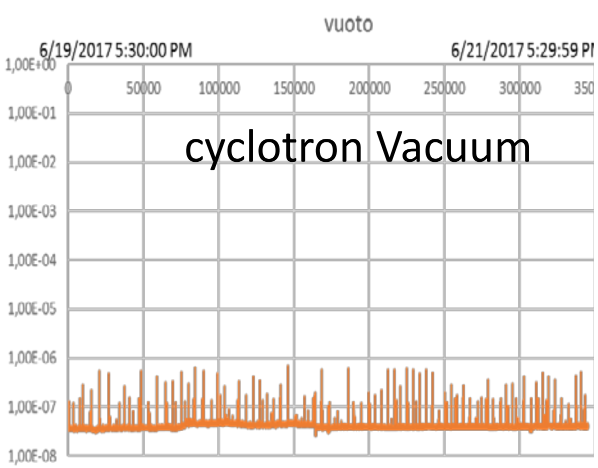
The SPES building 2016

Cyclotron and beam lines

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

Cyclotron commissioning

- 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
- End Nov 2016 → source HV transformer brakes before to complete Site Acceptance Test
- June - July 2017 → endurance test completed



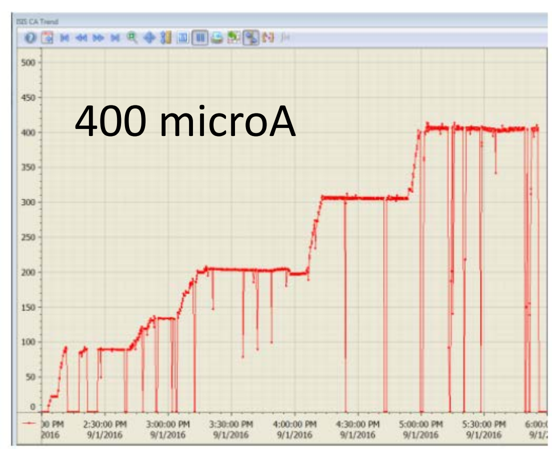
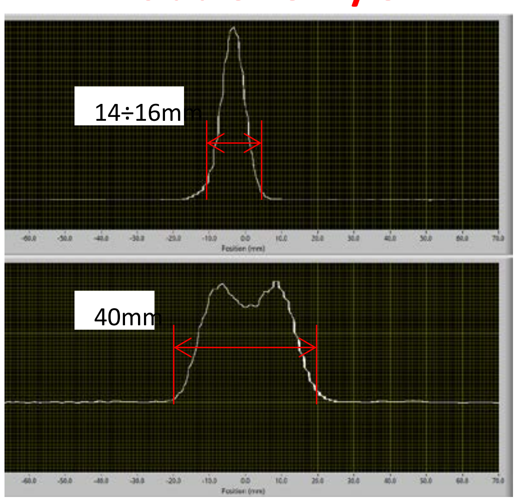


Figure 7: Beam current on target ramp-up (µA), versus time.

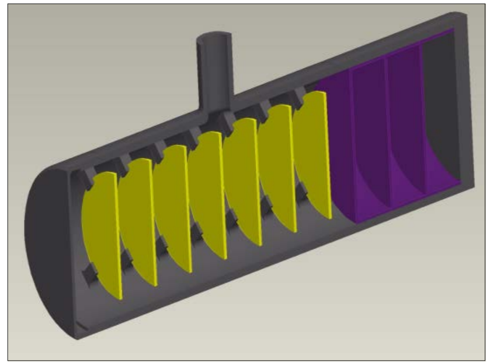
Wobbler OFF/ON

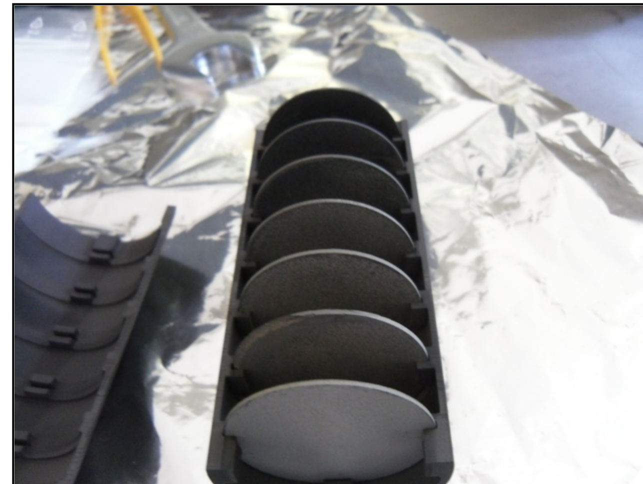


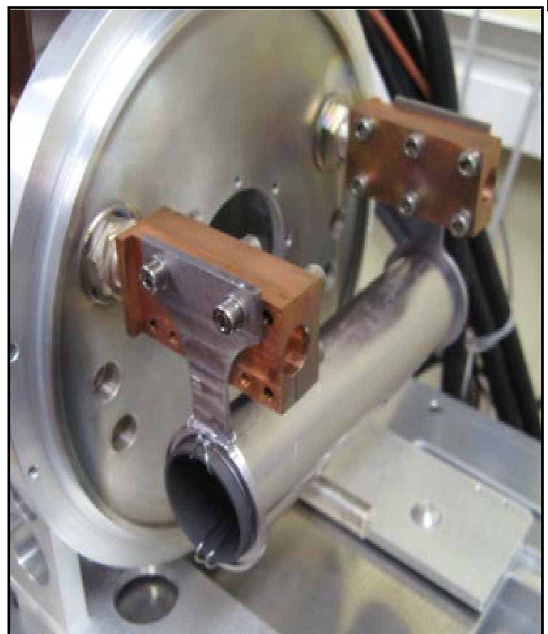
SPES Target ion-source system

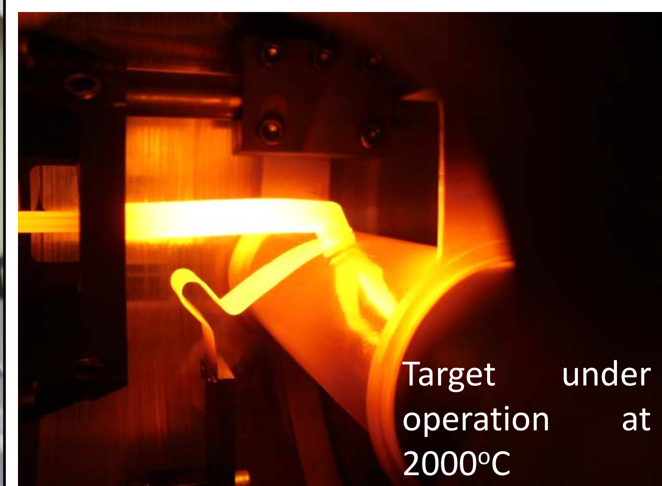
Main component of the ISOL system

NEW concept developed for the SPES Direct Target: **Multi-foil UCx** designed to sustain 10kW beam power to reach **10^{13} f/s**

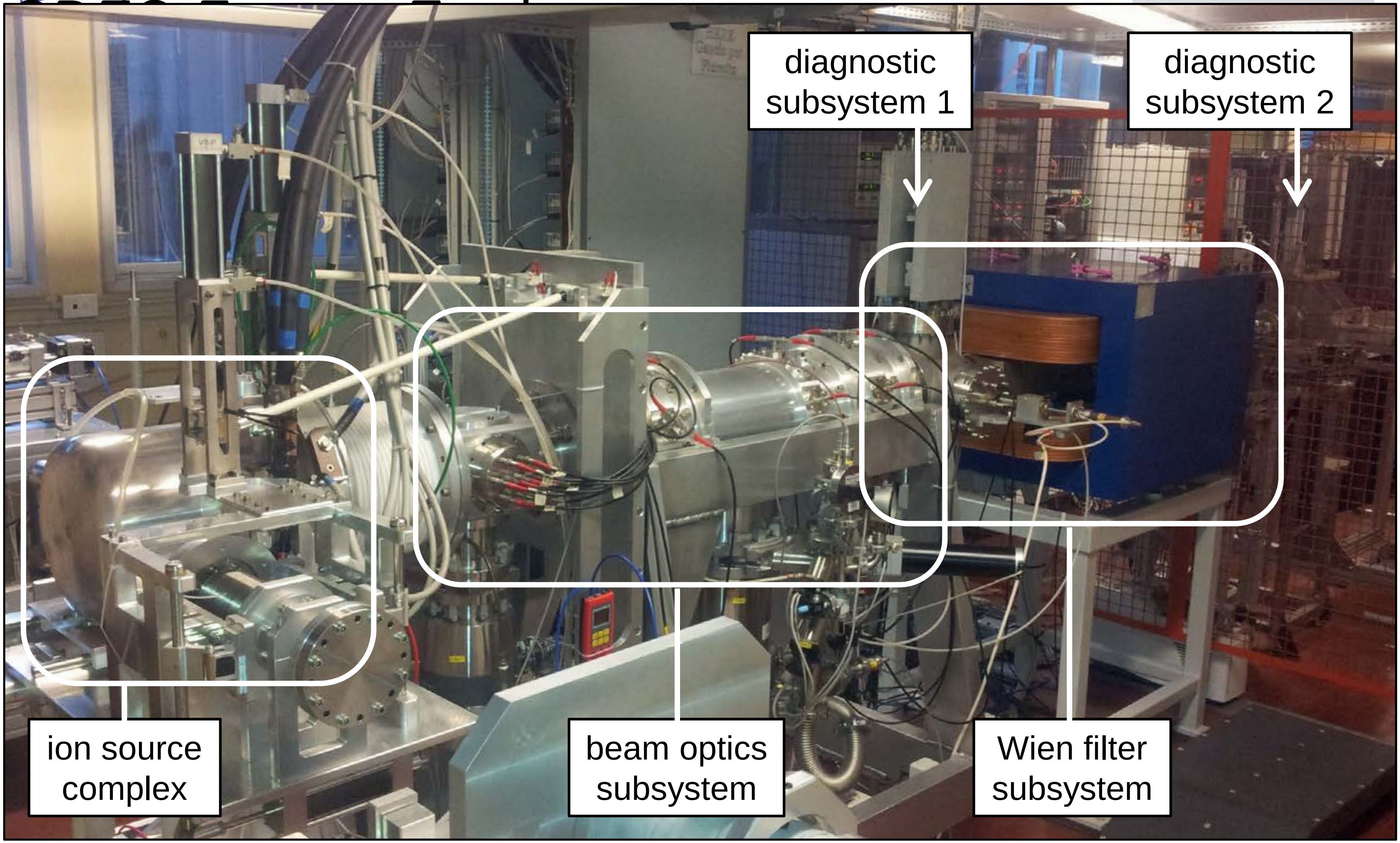








SPES ISOL system



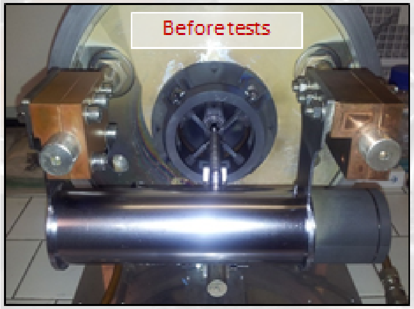
System under operation for source commissioning.
Final version updated for radiation hardness is under construction.

ISOL system developments

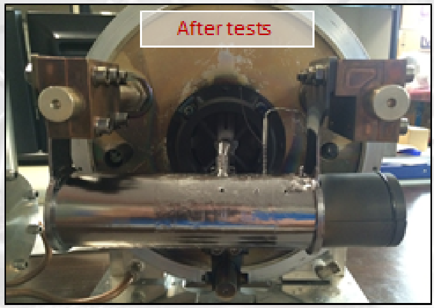
TIS unit endurance test:

Tests at high temperature with Joule heating thermal load (1300A target heater, 350A line):
heating power ≈ 12 kW > primary proton beam thermal load (≈10 kW)

Before tests



After tests



- ≈ 415 testing hours at high temperature -> ≈ 220 hours at maximum power (12kW)
- 79 heating cycles sustained -> 9 with current ramps of 1 s from 0 A to 1300A (!) to 350A (!)

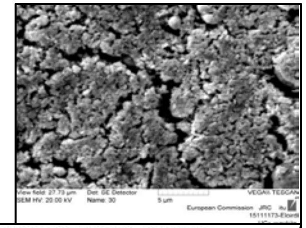
TIS UNIT STILL OPERATIVE !!

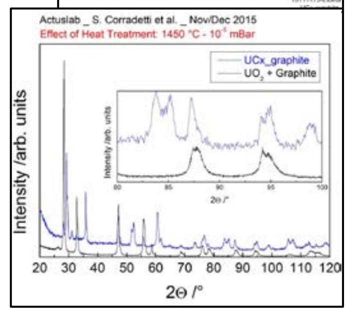
SPES TAC3 October 2015

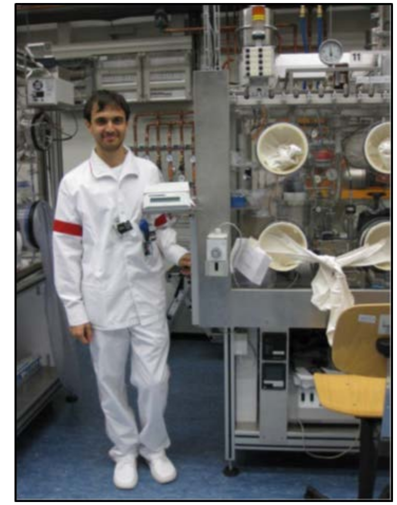
WG-01

Synthesis of a novel type of UC_x using graphene

Experiment at JRC-ActUsLab-Karlsruhe: n. AUL-176



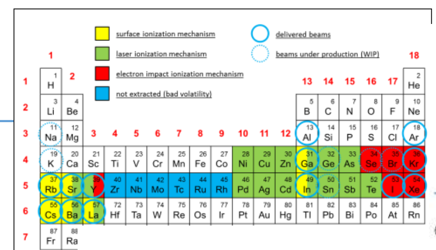




Surface ionization source:
≈ 60 heating-cooling cycles
≈ 380 h (16 days) of operation at 2000-2200°C

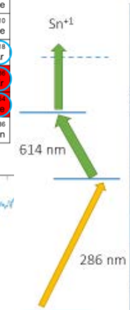
Plasma source: optimized to avoid hot-spot and to maximize current New alignment system
≈ 40 heating-cooling cycles
≈ 160 working hours @ 2000°C

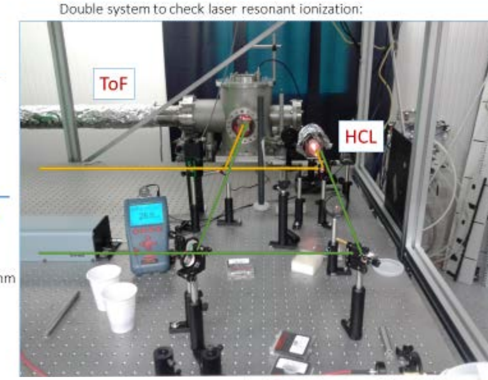
Laser Source



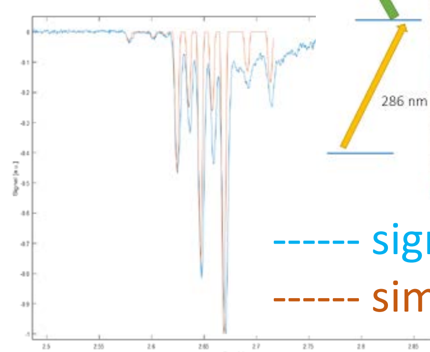
HCL + ToF on Tin laser ionization

Double system to check laser resonant ionization:





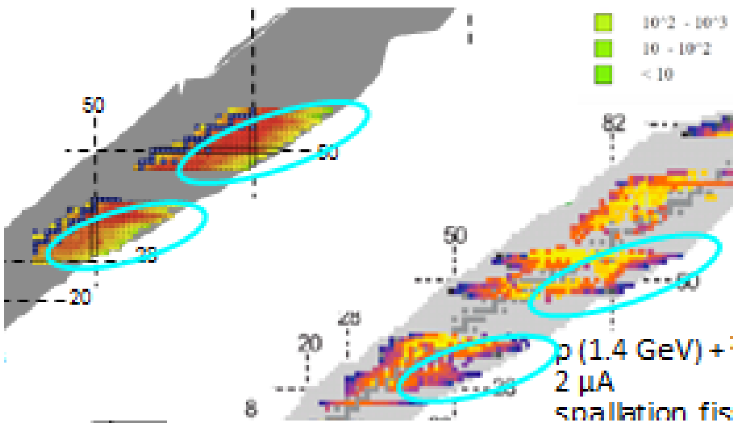
WG-03

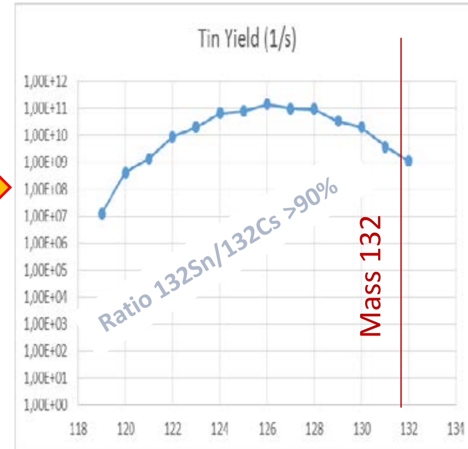


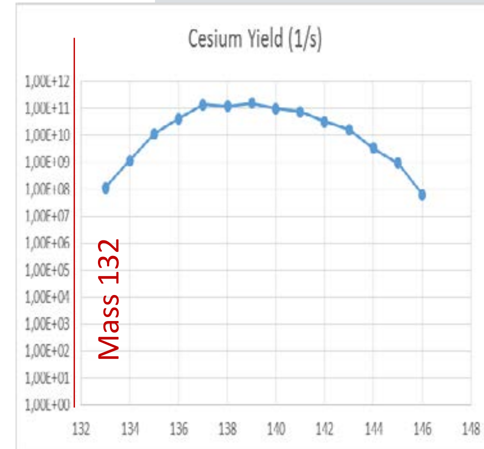
------ signal
------ simulation

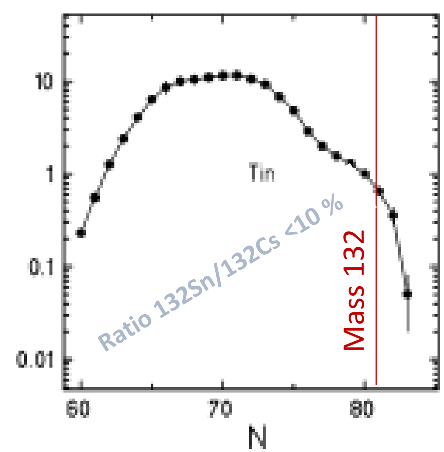
Isotopes spectra (Isolde vs SPES)

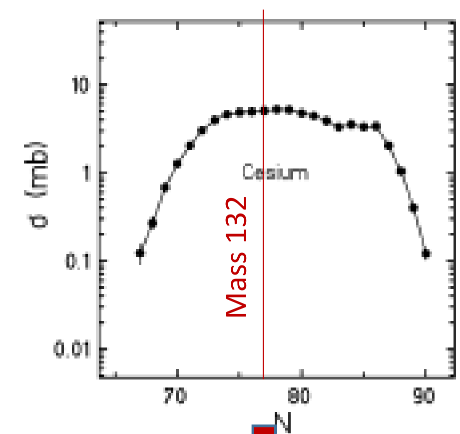
40 MeV protons on 238U





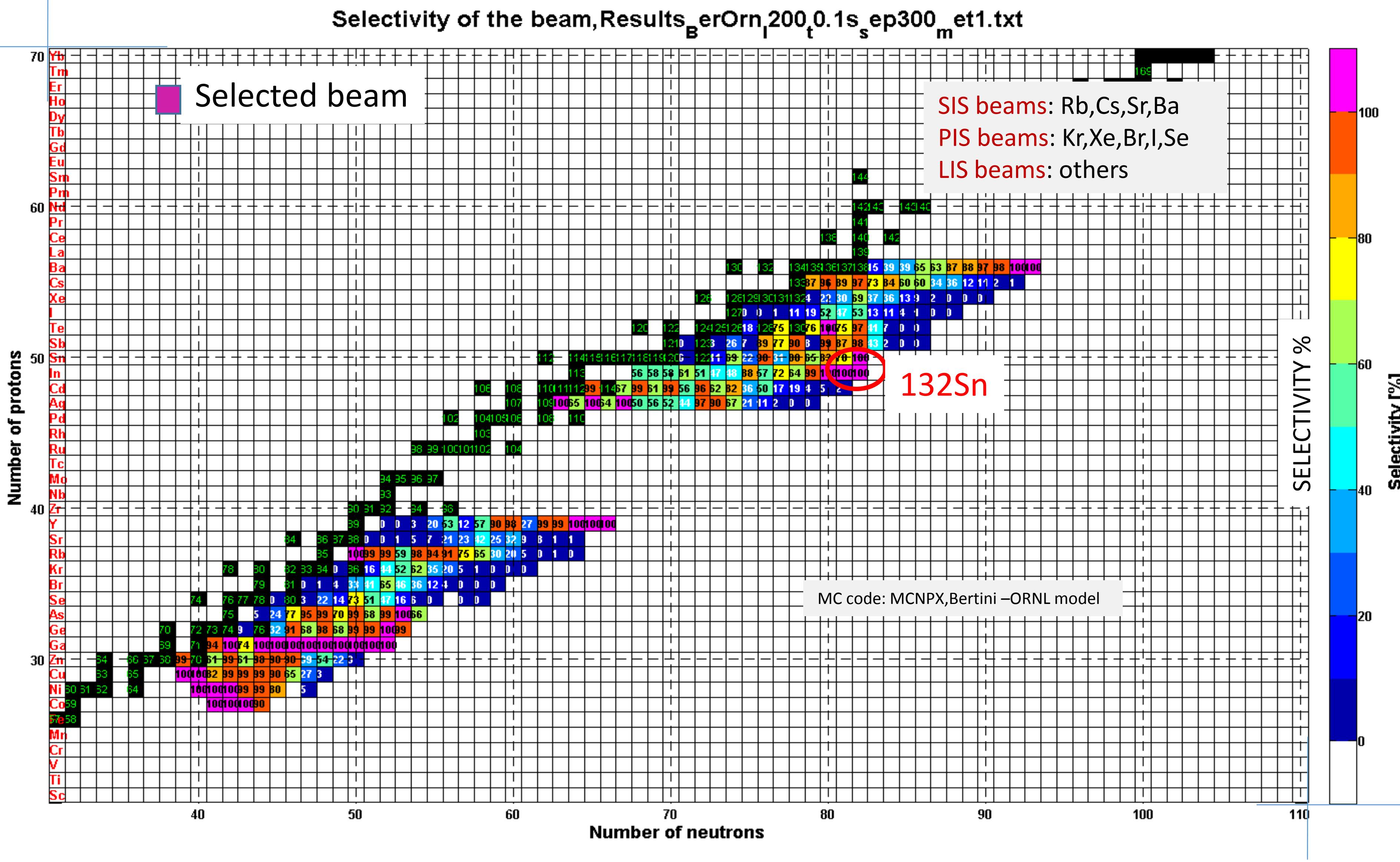




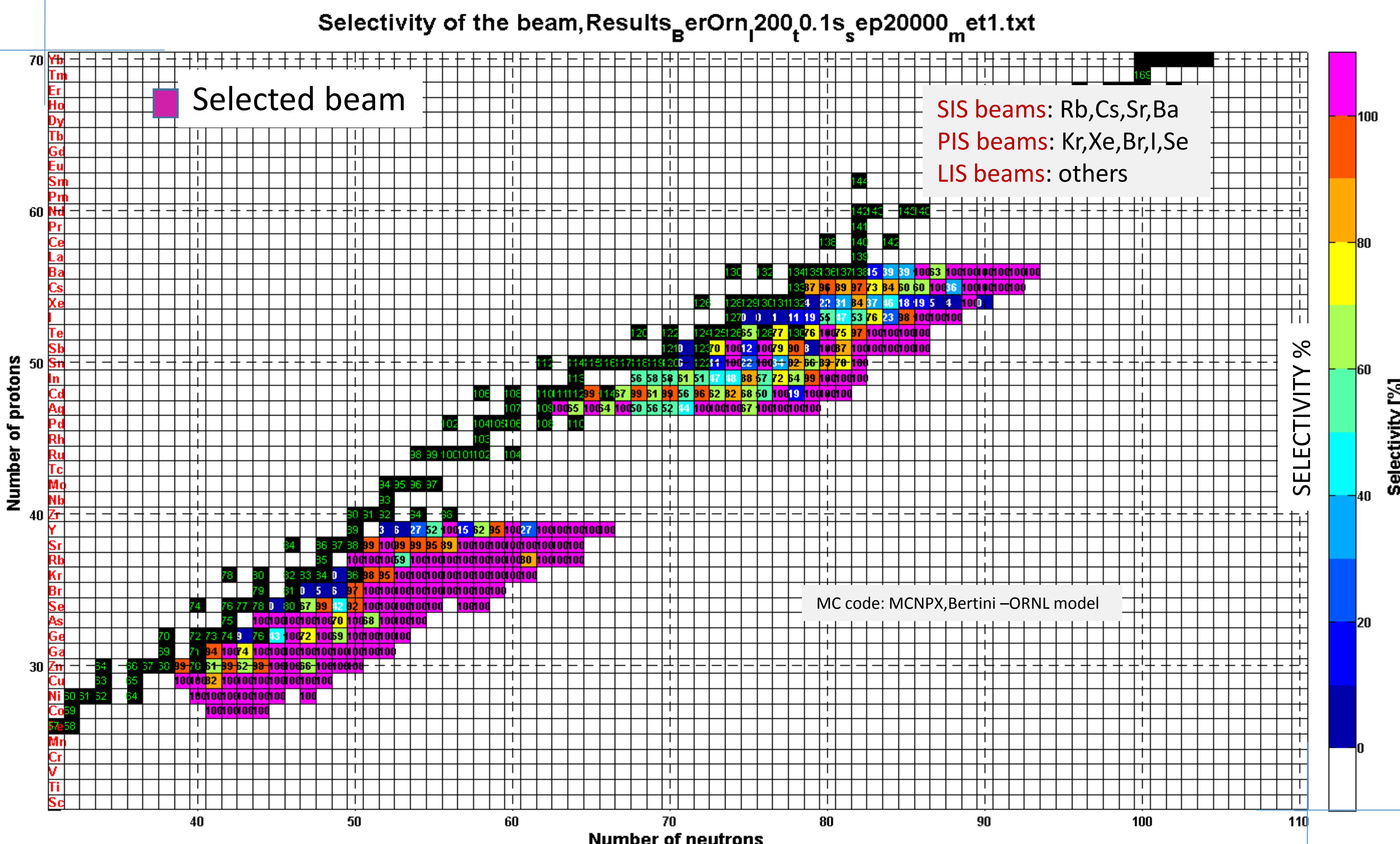


The Isotopes spectra width is crucial for beam selectivity

Beam Selectivity with LRMS (1/200)

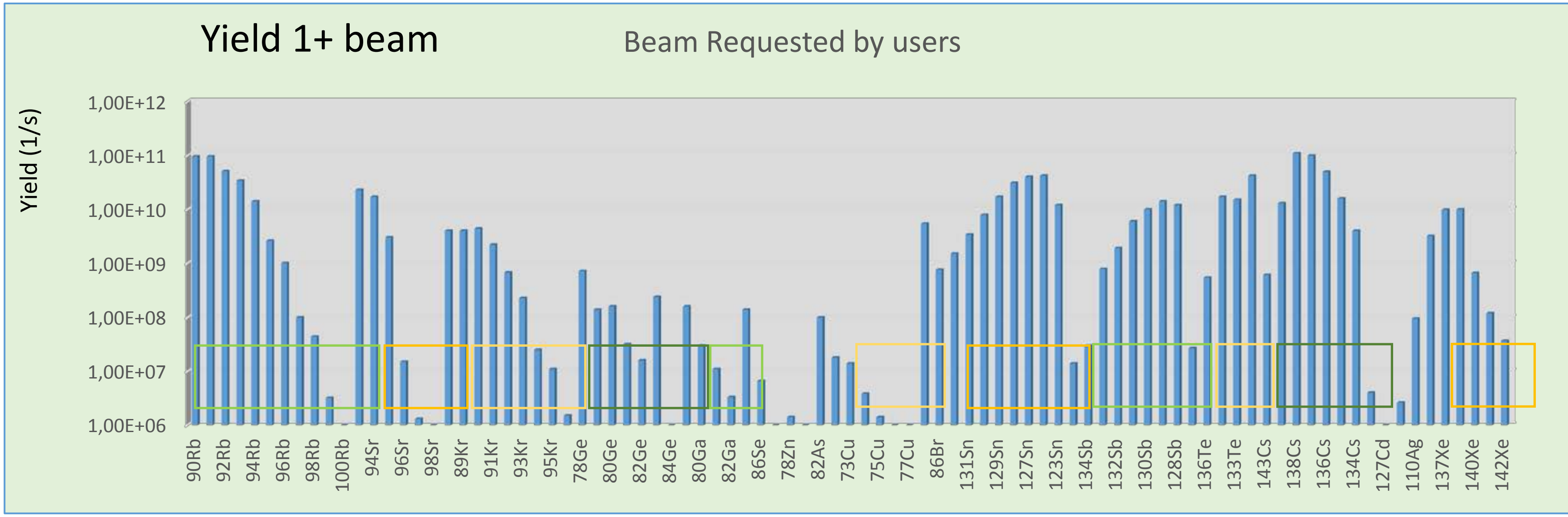


Beam Selectivity with HRMS (1/20.000)

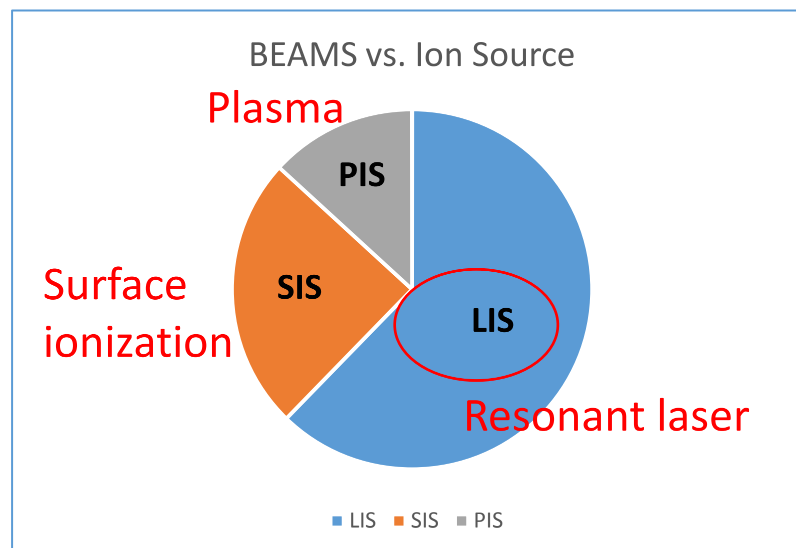


LOI n-rich Ribs…

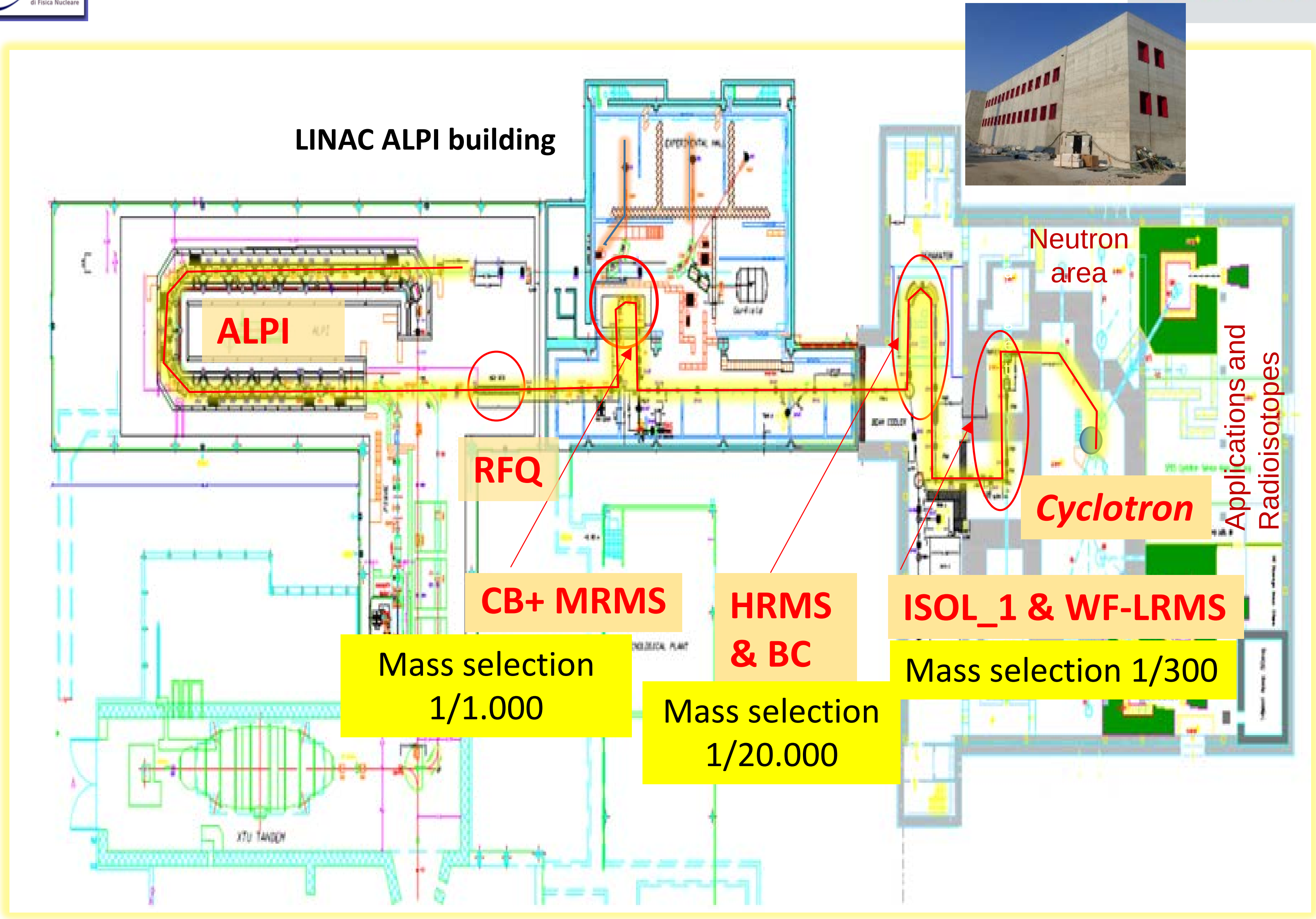
Path toward beam selectivity: **in-target reaction** → ion-source → mass separation



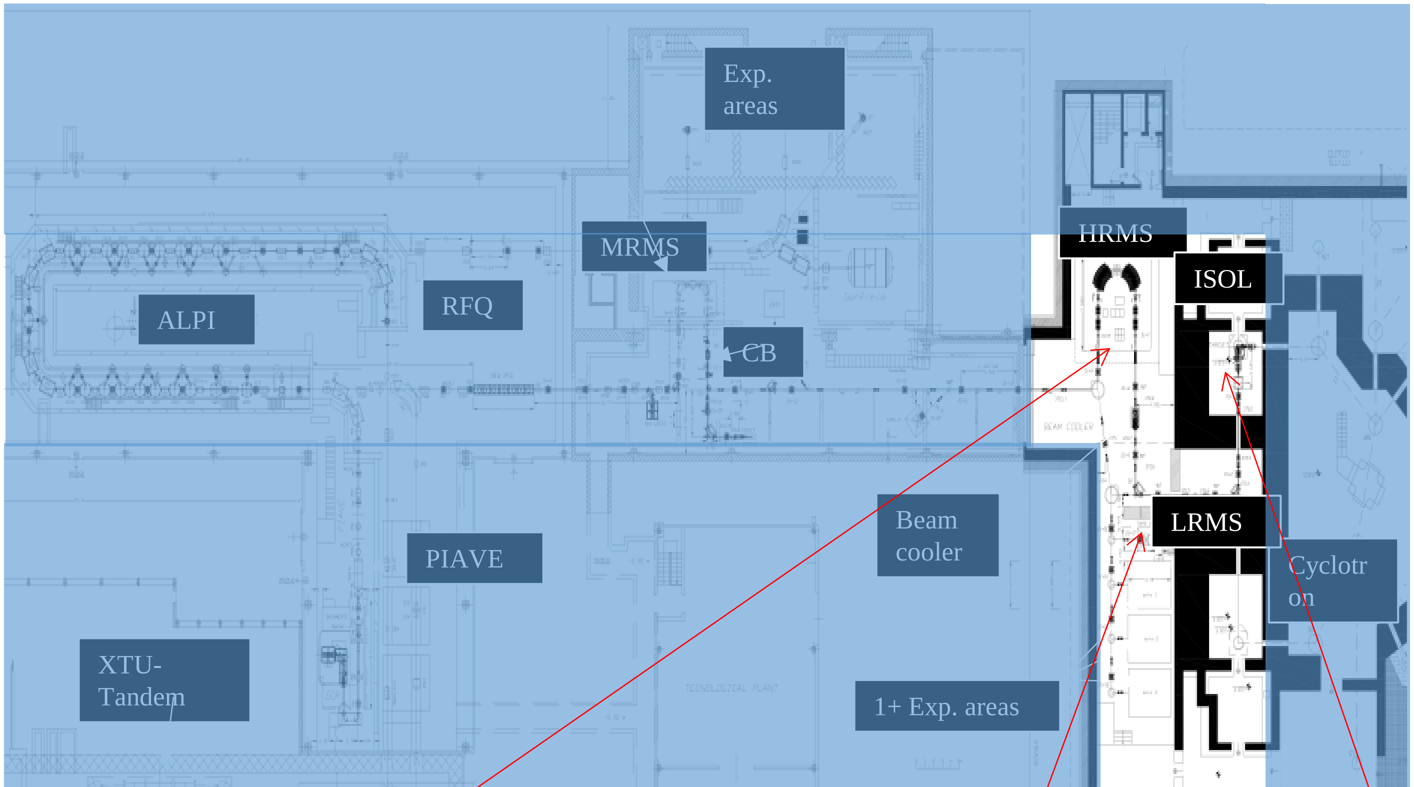
		19 Elements	
Total beams	89		LOI %
Beams with 200_LRMS	47		53%
Benefit with 5.000_HRMS	3	→ 50 beams	56%
Benefit with 10.000_HRMS	17	→ 67 beams	75%
Benefit with 15.000_HRMS	25	→ 82 beams	92%
Benefit with 20.000_HRMS	7	→ 89 beams	100%

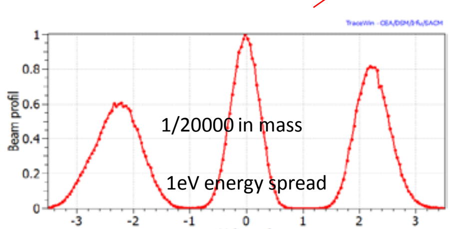


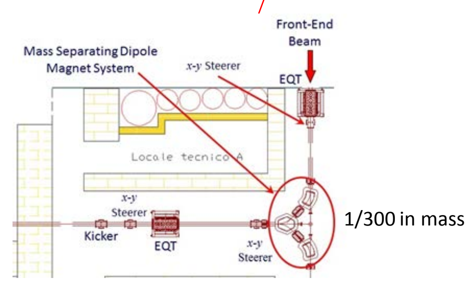
SPES layout: ISOL facility

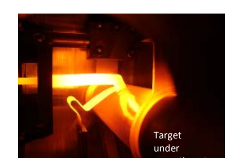


1+ Beam production and transport



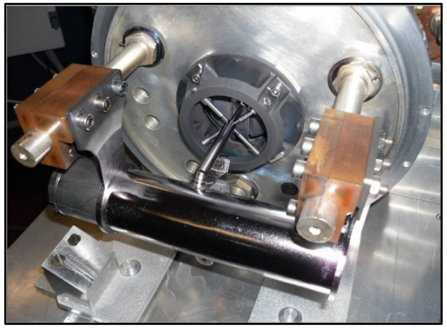


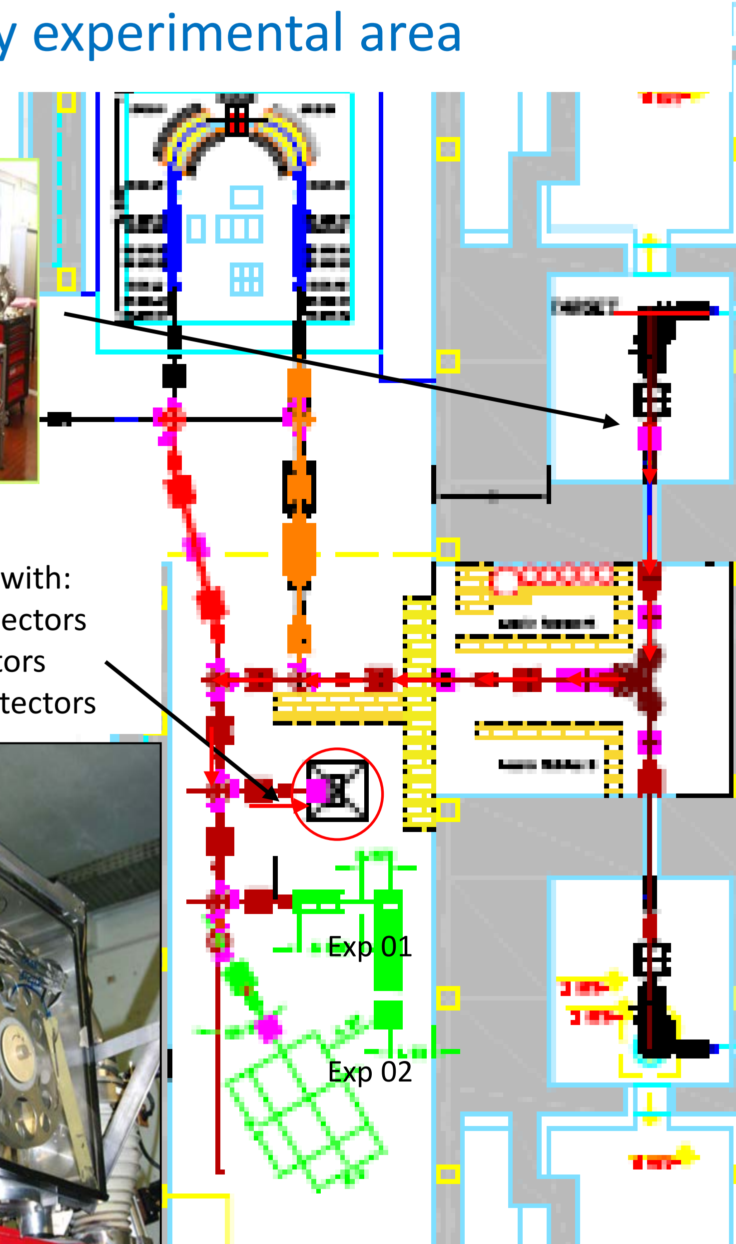




ISOL production and SPES Low Energy experimental area

Front end and Target – Ion Source unit





Collaboration ALTO-INFN-iThembaLabs

Tape station based on Orsay design (BEDO)

tape station with:
- gamma detectors
- beta detectors
- neutron detectors

Beta decay station as a permanent and flexible setup

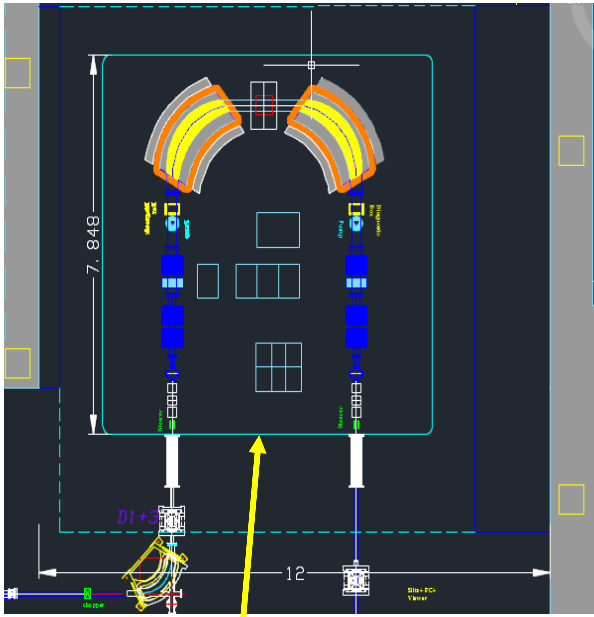
- Tape station + β detector
- Coupling to HPGe, LaBr3, neutron detectors etc…

G. Benzoni (INFN Mi) contact person
Collaboration with:
CENBG Bordeaux (PIPERADE_Trap assisted spectroscopy)*
ORNL (MTAS_Total absorption spectr., VANDALE_neutron array)**

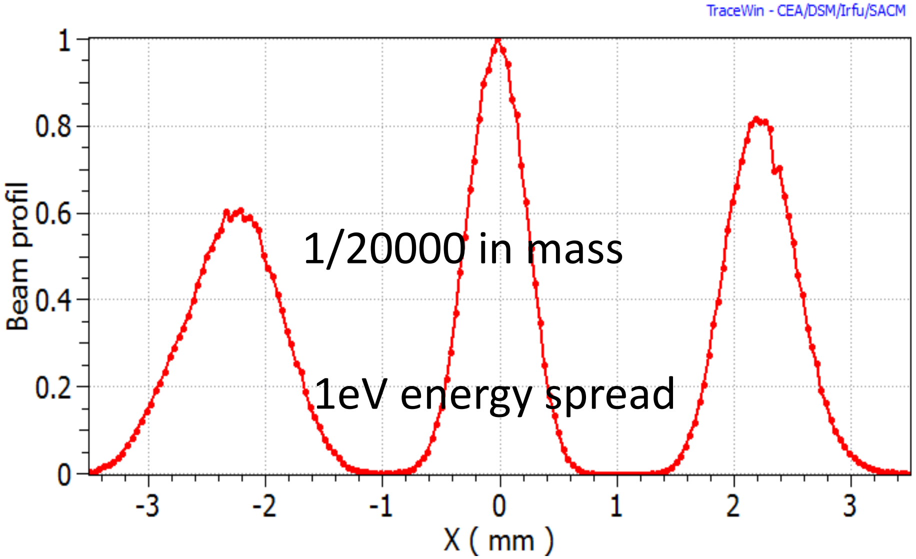
* S.Grevy
** Rykaczewski

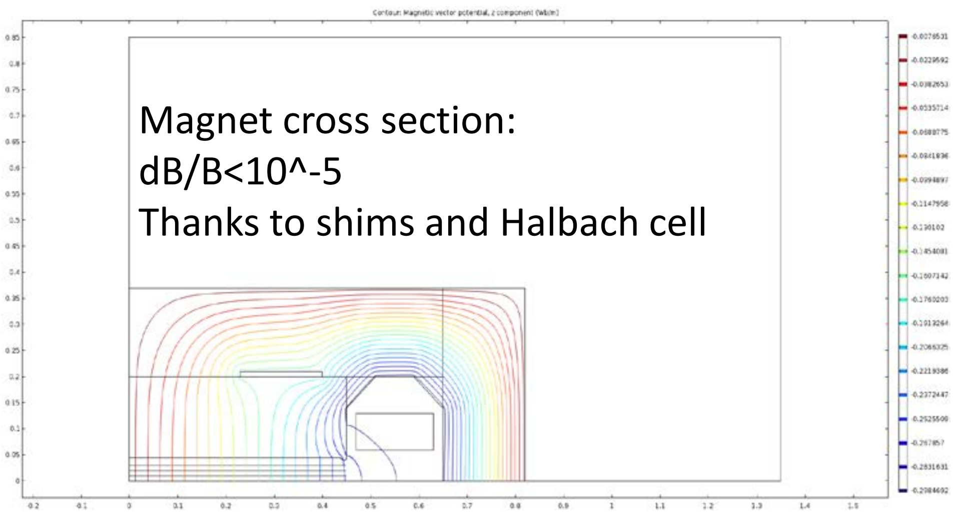
HRMS

- 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 in April 2018
  - Authorization to tender October 2018
  - Commissioning 2021



220 kV platform





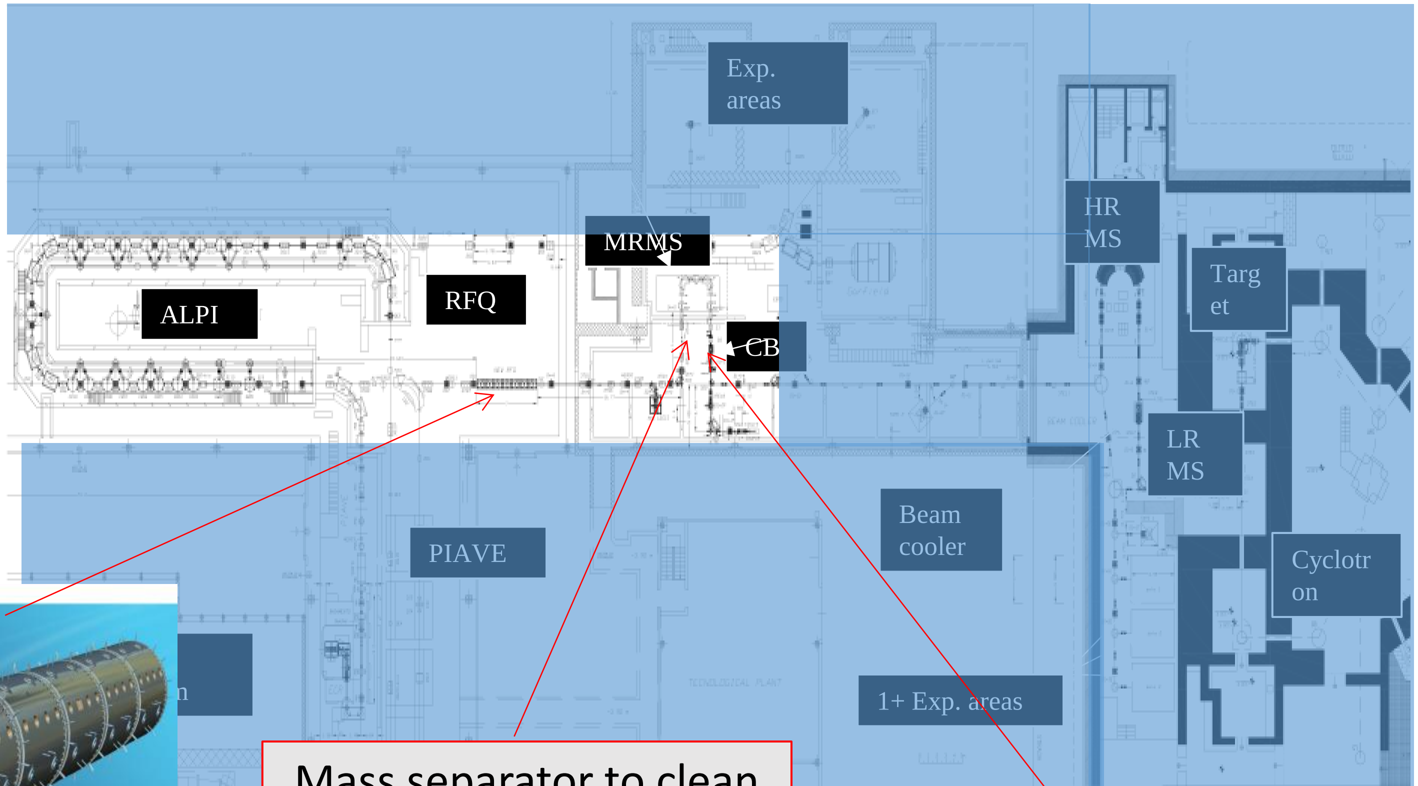
Input requirements:

ΔE= ± 1 eV

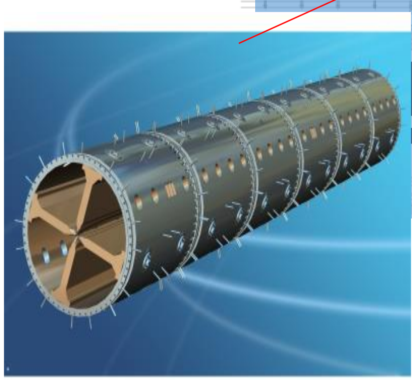
Emittance $_{rms,n}$ = 0.68 πmm mrad

Collaboration with LPC_Caen for Beam Cooler development (expertise: SCIRaC - SPIRAL2)

n+ Beam transport and reacceleration



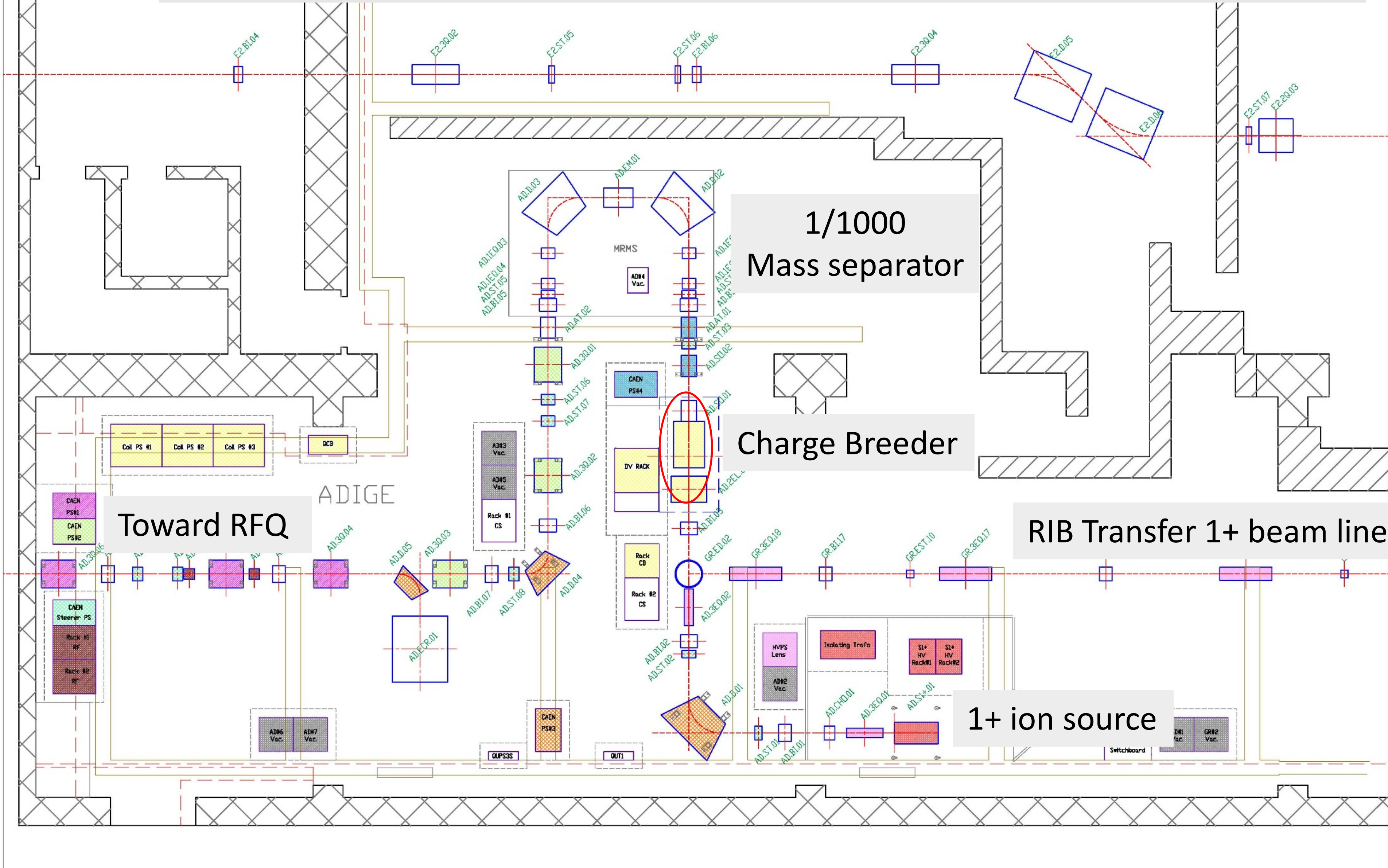
Mass separator to clean the beam from CB contaminants



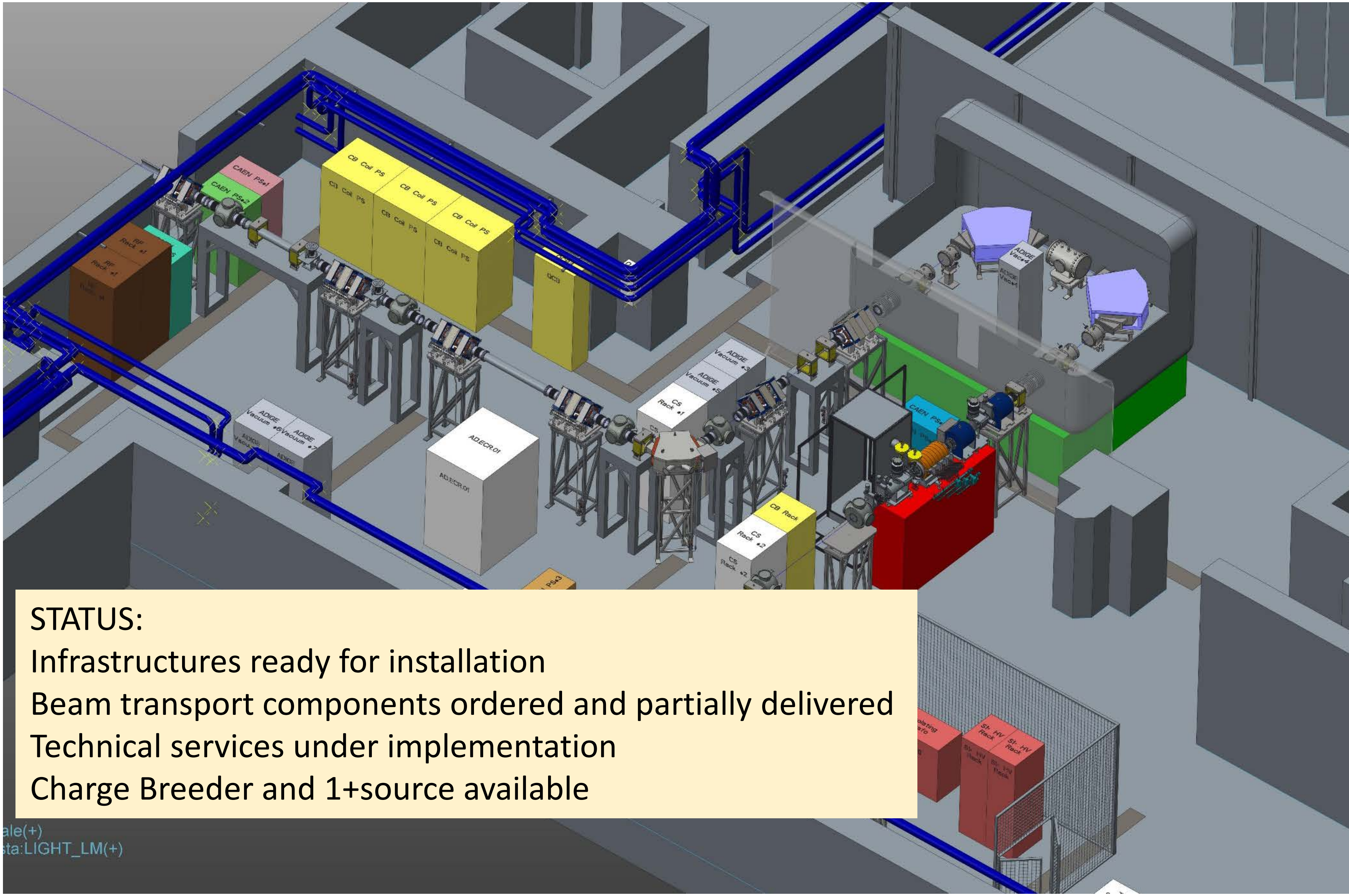
Pre-accelerator
RFQ (700 keV/n)

ECR_Charge Breeder
from 1+ to n+

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



C.Roncolato



STATUS:

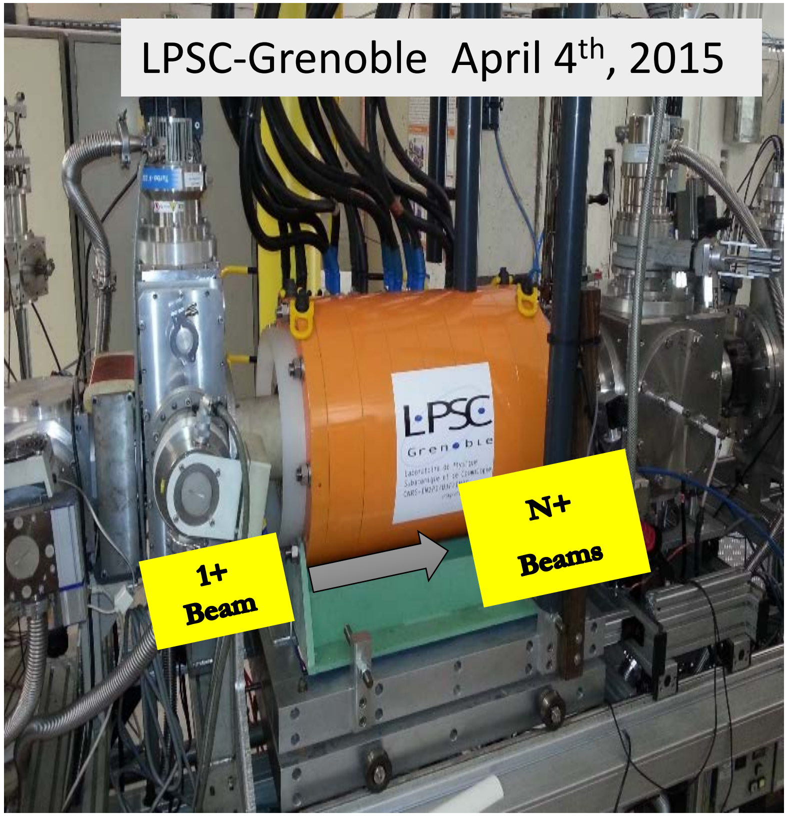
Infrastructures ready for installation

Beam transport components ordered and partially delivered

Technical services under implementation

Charge Breeder and 1+source available

Phase 2: Validation of the SPES-Charge Breeder

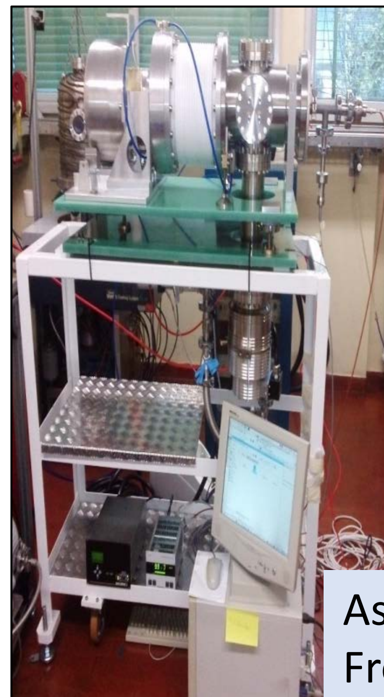


		EFFICIENCY* [%]		
ION	**Q**	**SPES req**	**Best LPSC**	**SPES-CB**
Cs	26	≥ 5	8,6	11,7
Xe	20	≥ 10	10,9	11,2
Rb	19	≥ 5	6,5	7,8
Ar	8	≥ 10	16,2	15,2

**results obtained for the same 1+ injected current*

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

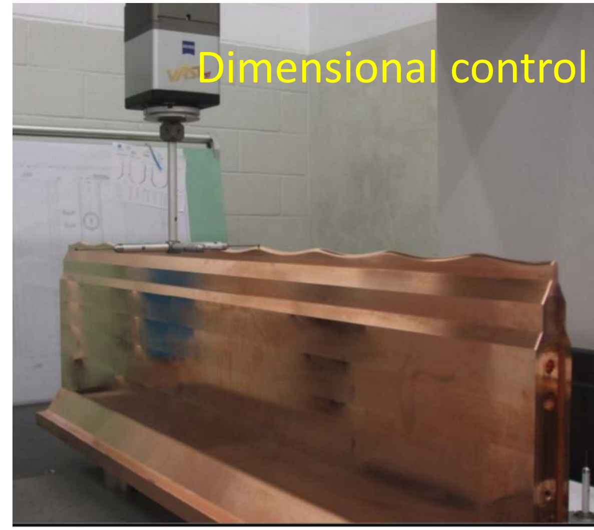


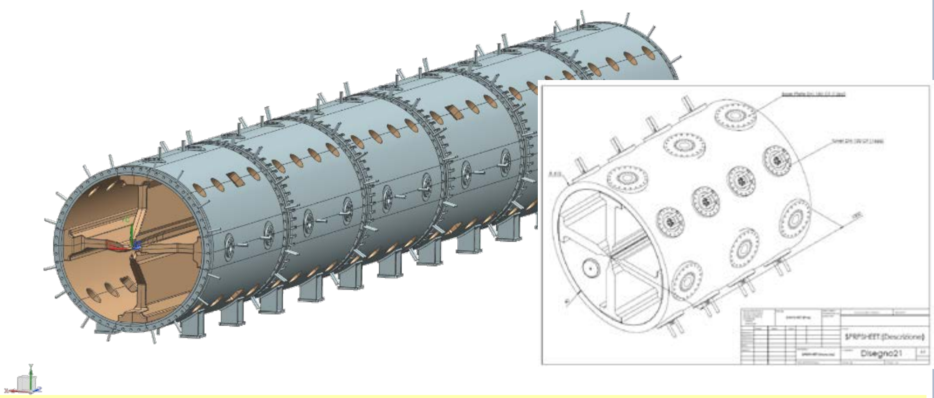
Assembly of 1+Source Front-End

SPES production, similar to ISOL source

Exotic Beam RFQ Injector for ALPI

- Construction of vanes: tender completed in July 2016. Prototype in construction
  - 1st set of 4 electrodes (module 5) was successfuly delivered in April 2017
  - 2st set of 4 electrodes (module 4) was brazed in May 2017
- June 2017: Tender for tank construction





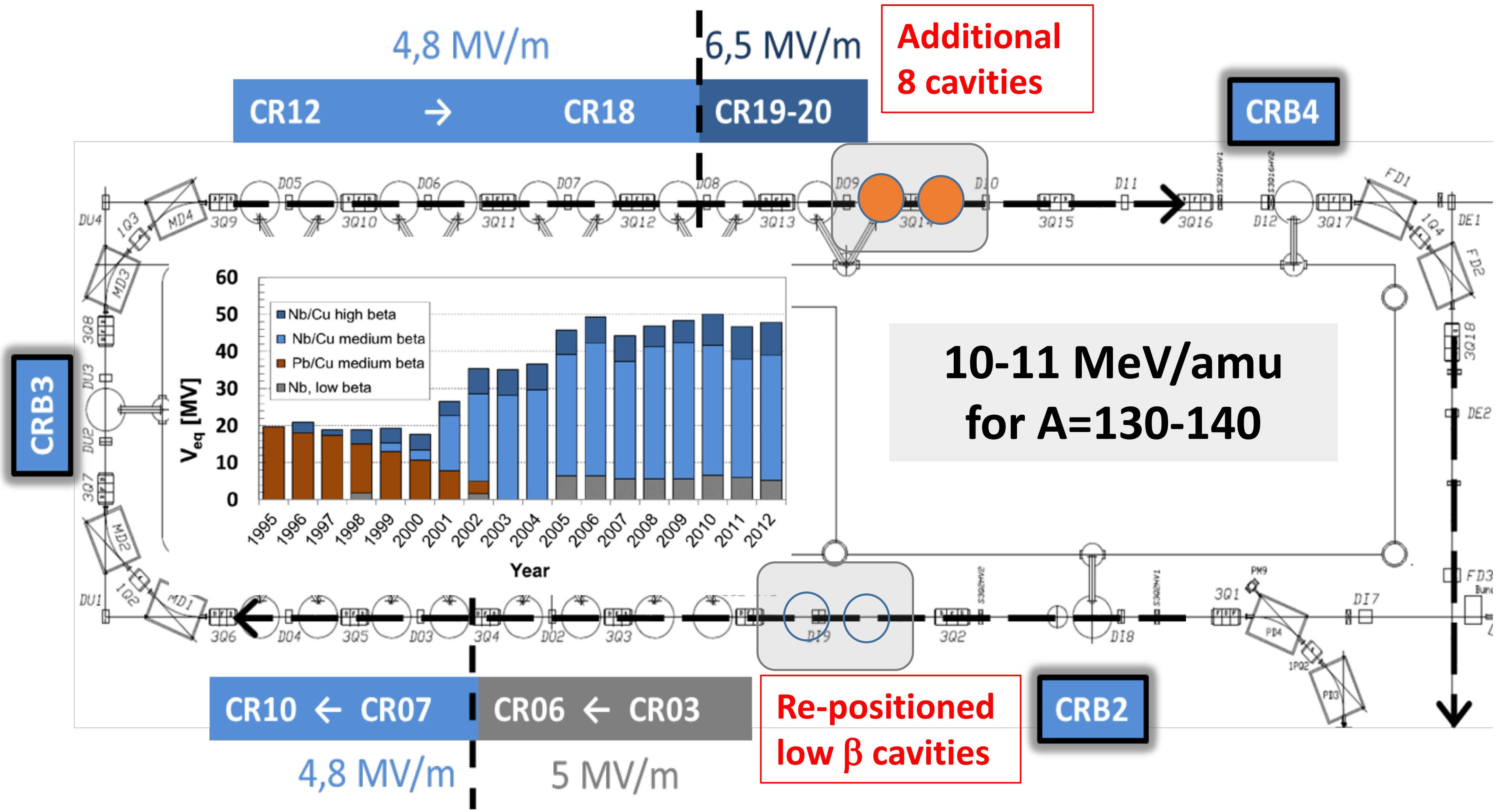
- Energy 5.7 –> 727.3 keV/A [β=0.0395] (A/q=7)
- Beam transmission >93% for A/q=3÷7
- RF power (four vanes) 100 kW (f=80 MHz)
  for up to 1 mA beam (…future high current stable beams)
- Mechanical design and realization, similar to the Spiral2 one, takes advantage of IFMIF technological experience

IFMIF synergy

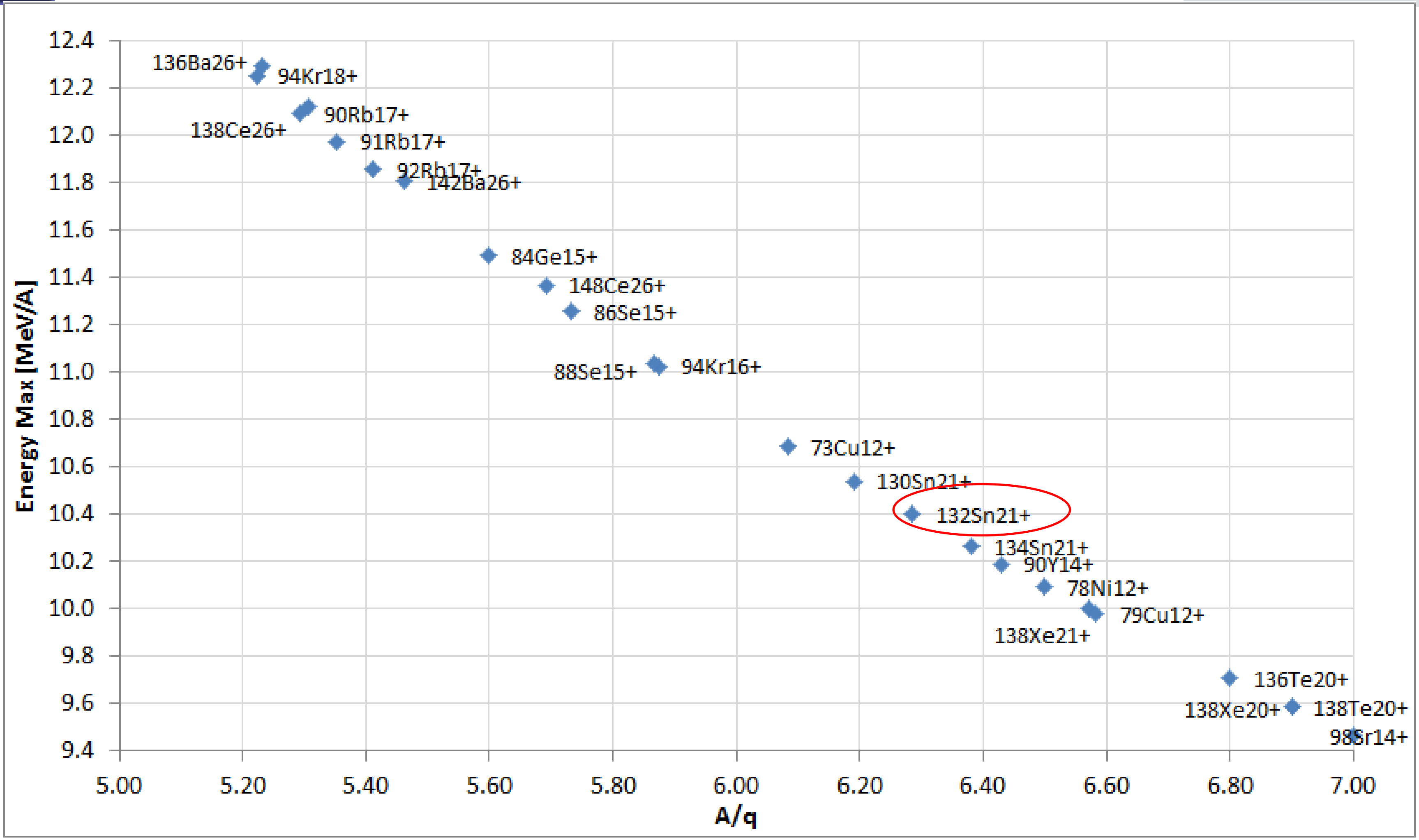
200 kW **RF amplifier** (175 MHz→ 80 MHz tuning required);

200 kW **Power Coupler**

Matching into ALPI SC linac

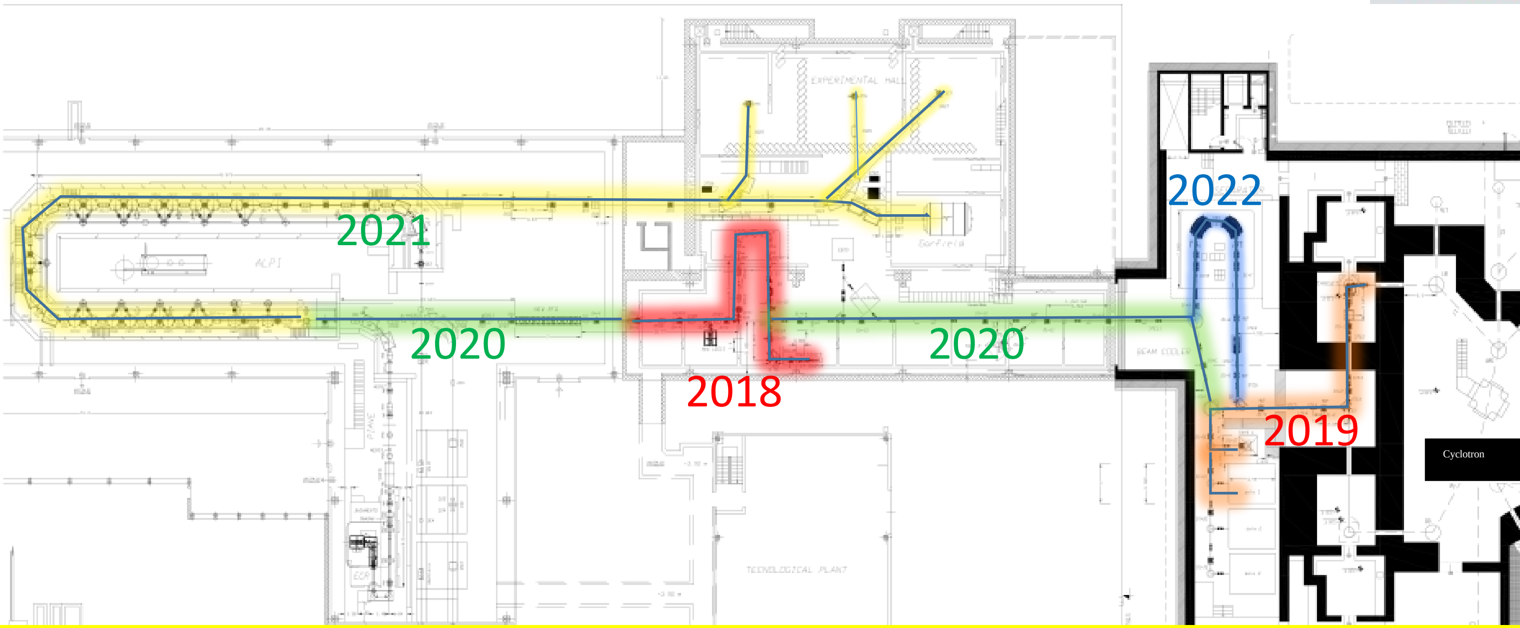


Expected SPES reaccelerated beams



Energy from SPES Post-Accelerator as function of A/q

Installation phases



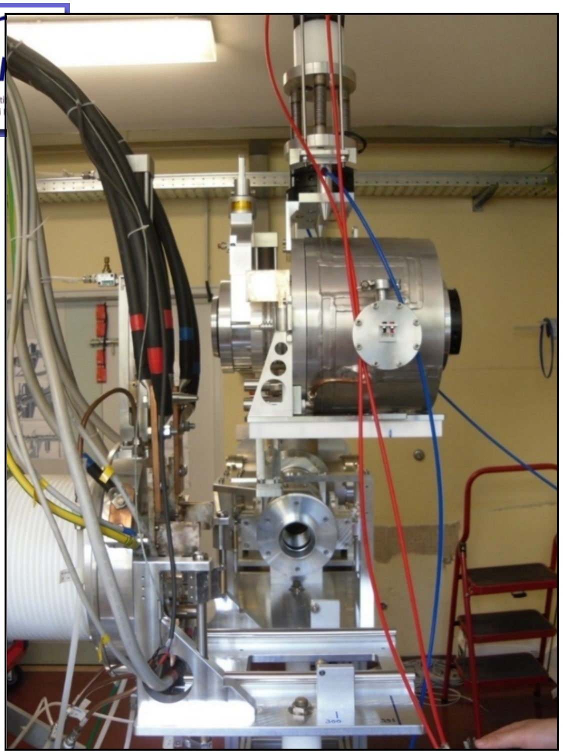
- ✓ installation of Charge Breeder and related mass separator: ready in 2018
- ✓ installation of ISOL and 1+ beam line up to the tape station: ready in 2019
- ✓ Installation of RFQ and 1+ beam line up to Charge Breeder: ready in 2020
- ✓ Reaccelerated beams: ready in 2021
- ✓ High resolution mass selection: ready in 2022

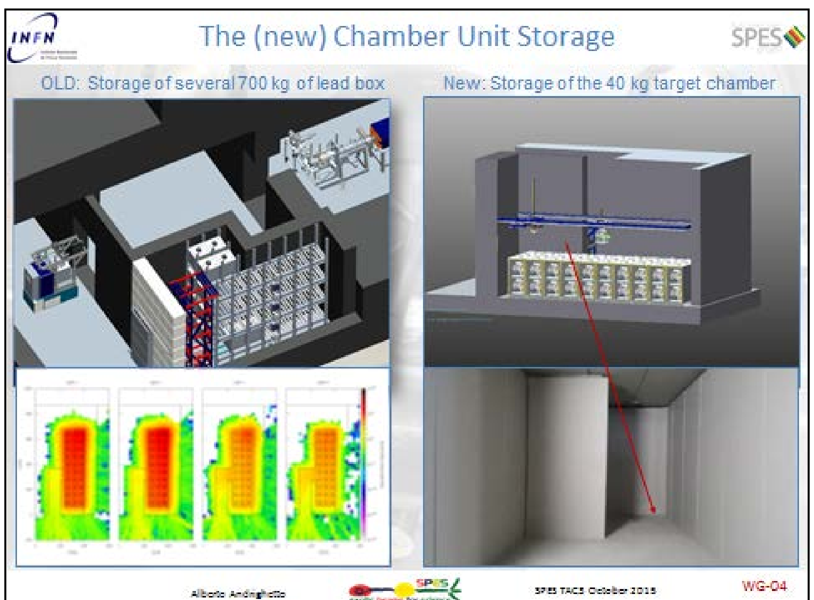
Conclusions

- SPES is in the construction phase
- Infrastructures and Cyclotron are completed
- In the next two years the ISOL system and the Charge Breeder will be installed
- In 2019 radioactive beams with no-reacceleration will be available
- Reacceleration will be completed in 2021 using ALPI to reach 10-11 MeV/n

AGV **test** at LNL

- Movement test in automatic mode
- Experimental tests with 3 transponder





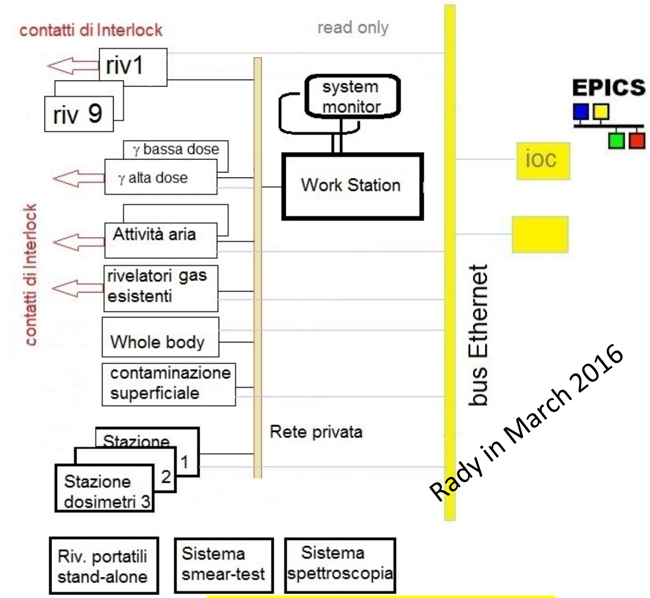
SPES safety system

A SIL3 safety system is under development

Cyclotron and beam lines

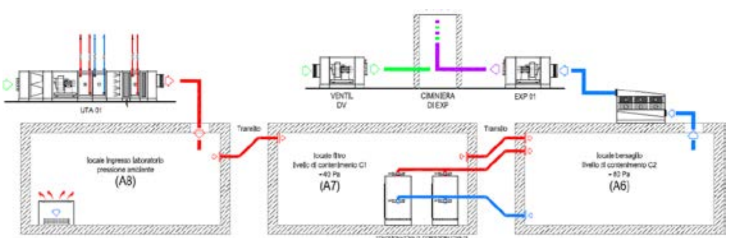
ISOL target

SPES safety system (PILZ)

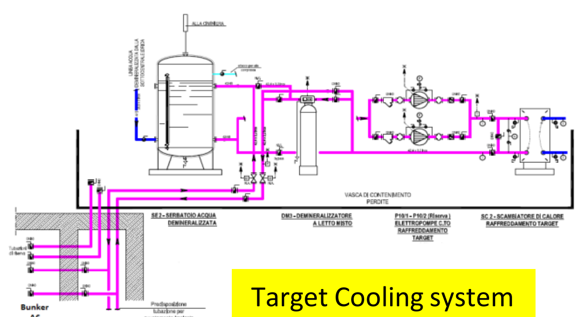


Radiologic survey system

Access Control System



ventilation



Target Cooling system

WP_B2