SPES Project

Il progetto SPES: una facility per la fisica dei fasci esotici e applicazioni in medicina nucleare

Gianfranco Prete
SPES Project leader

SPES Strategy

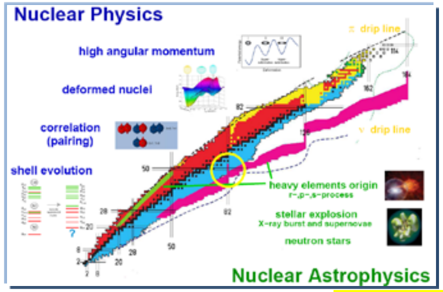
BEST Cyclotron installation & commissioning:

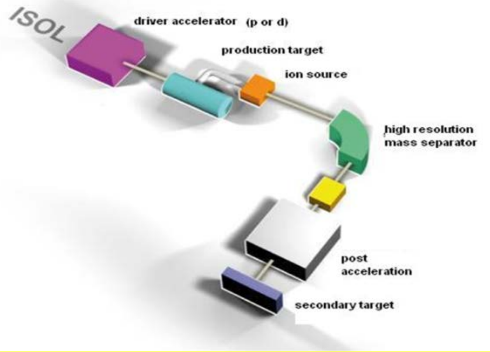
- 70 MeV proton beam
- 750 μA

Funded

Second generation ISOL facility

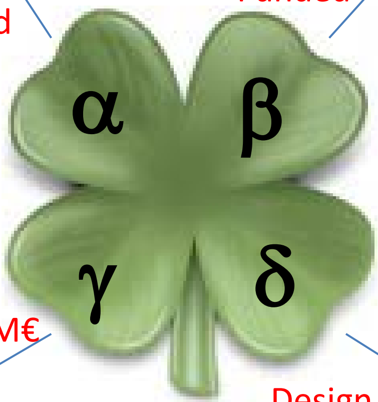
Toward EURISOL

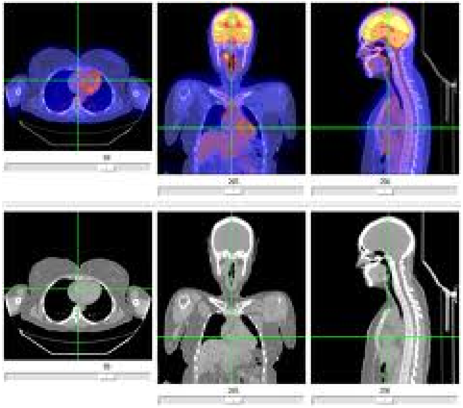




Funded

Production & re-acceleration of **exotic beams. Neutron–rich ions** from p-induced Fission on **UCx (10^{13} f/s)**



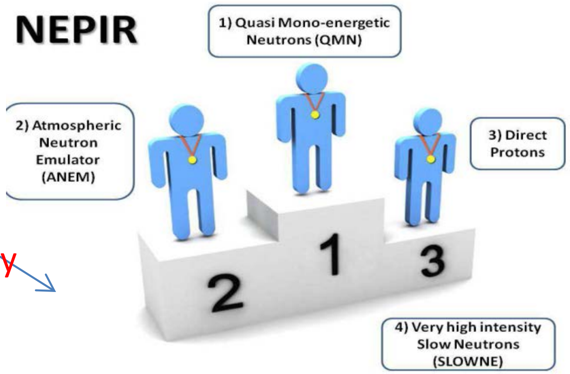


LARAMED

Partially funded 6.8 M€

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

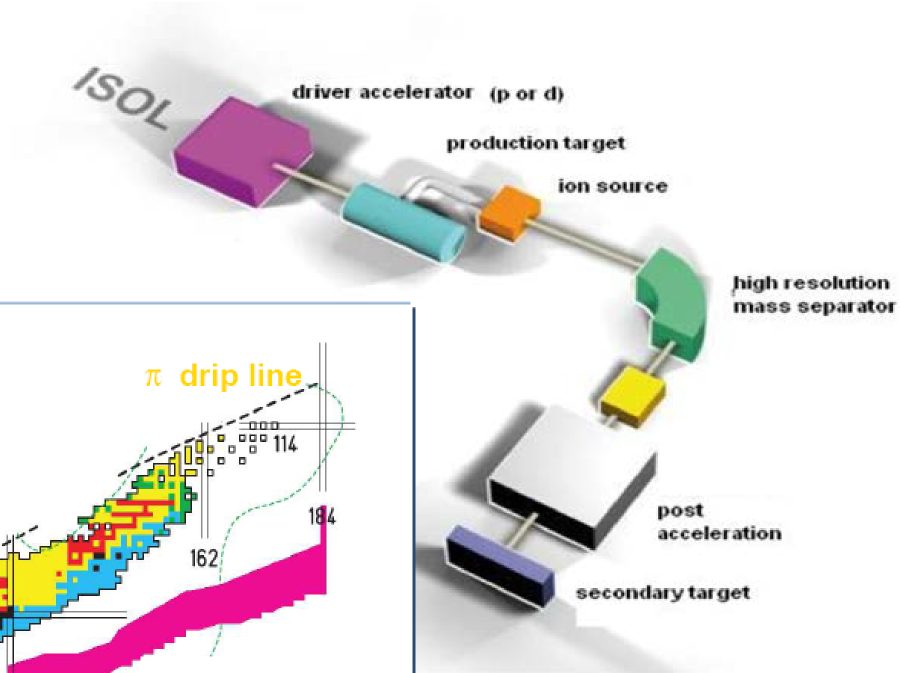
NEPIR

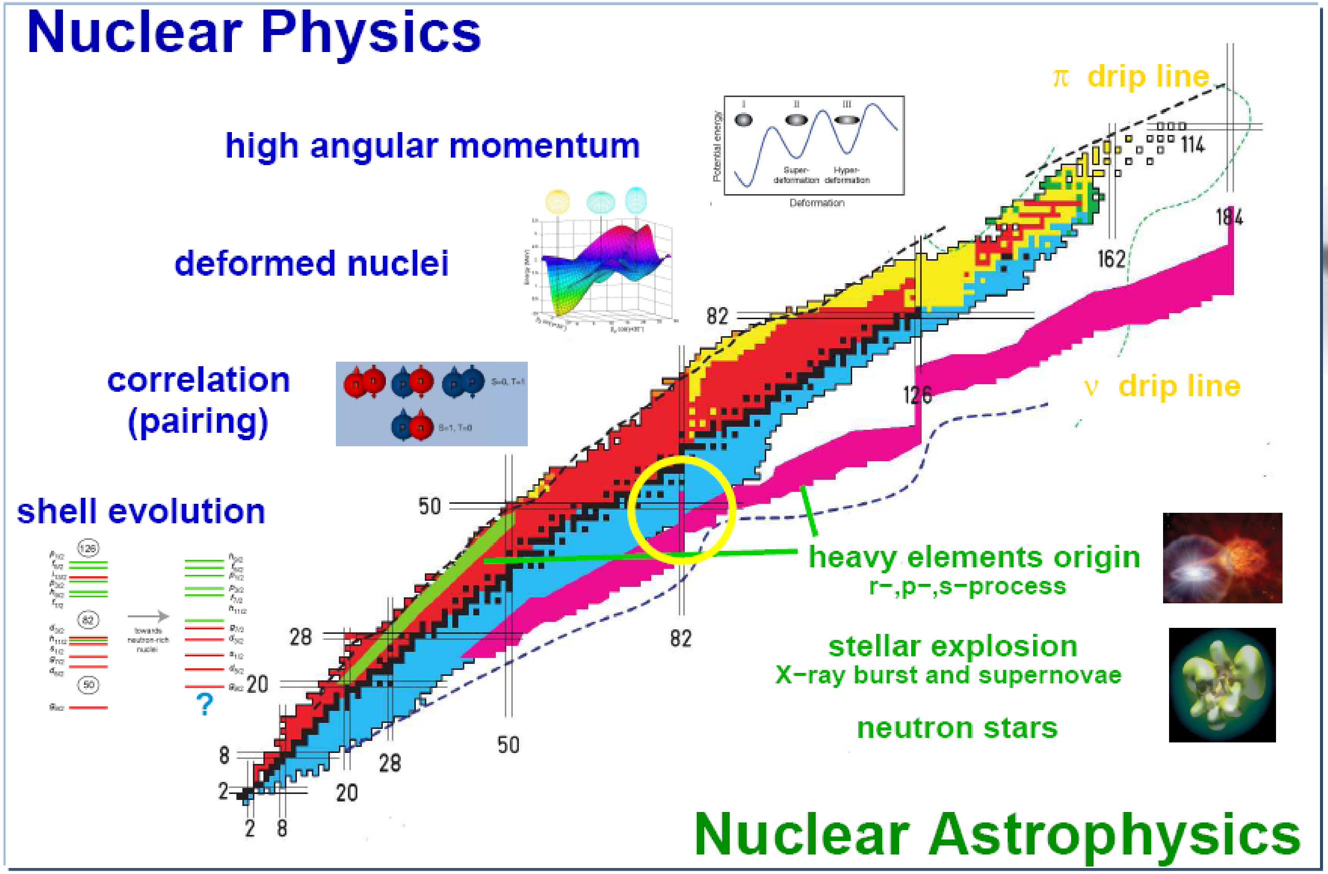


Design study

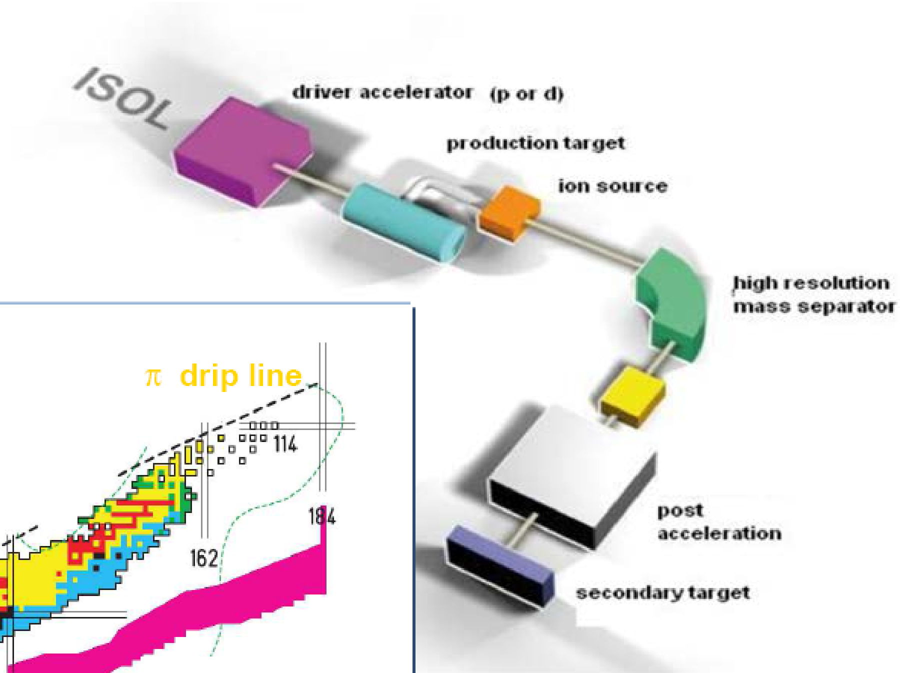
Accelerator based neutron source (**Proton and Neutron Facility for Applied Physics**)

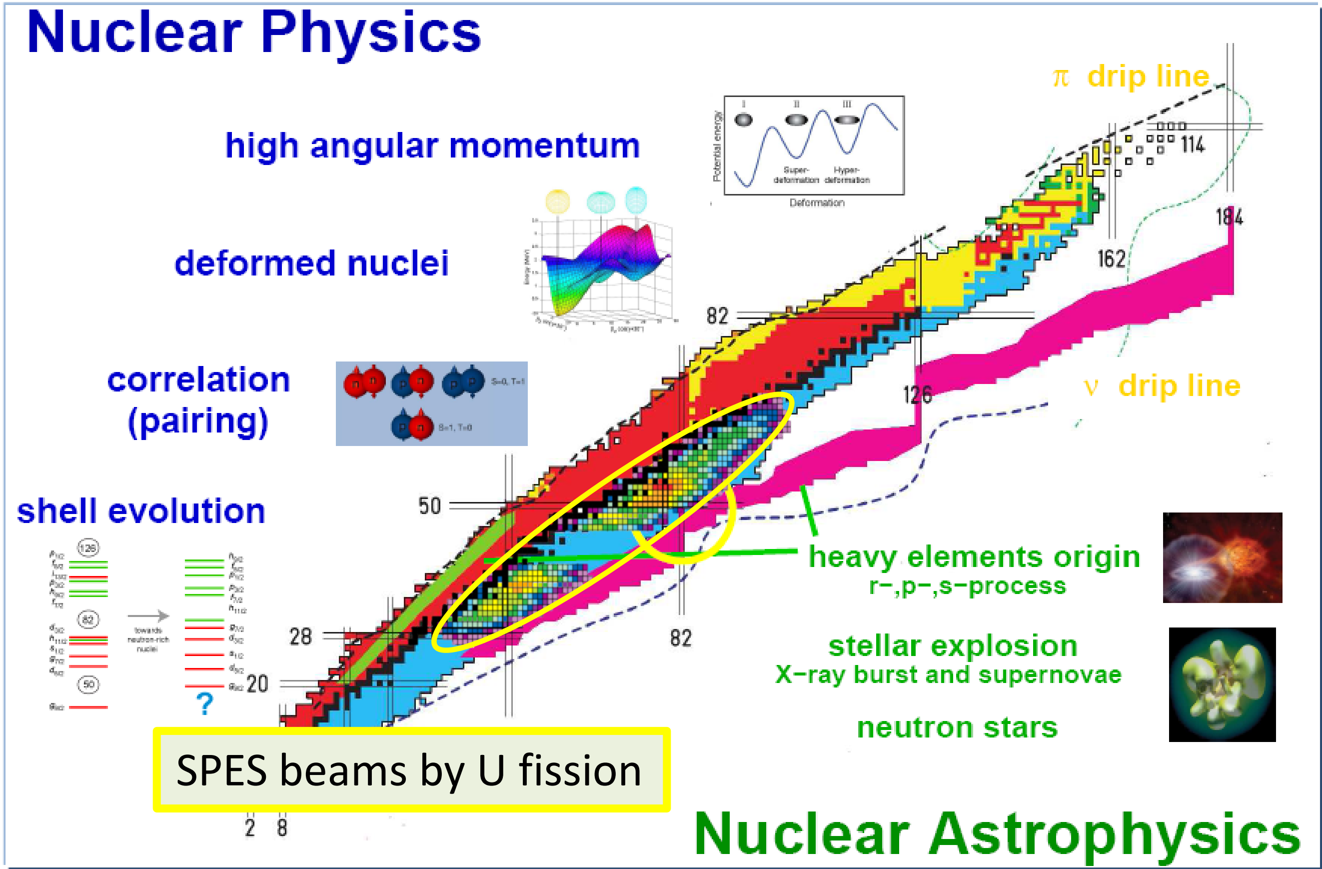
ISOL technique and Nuclear Physics





ISOL technique and Nuclear Physics

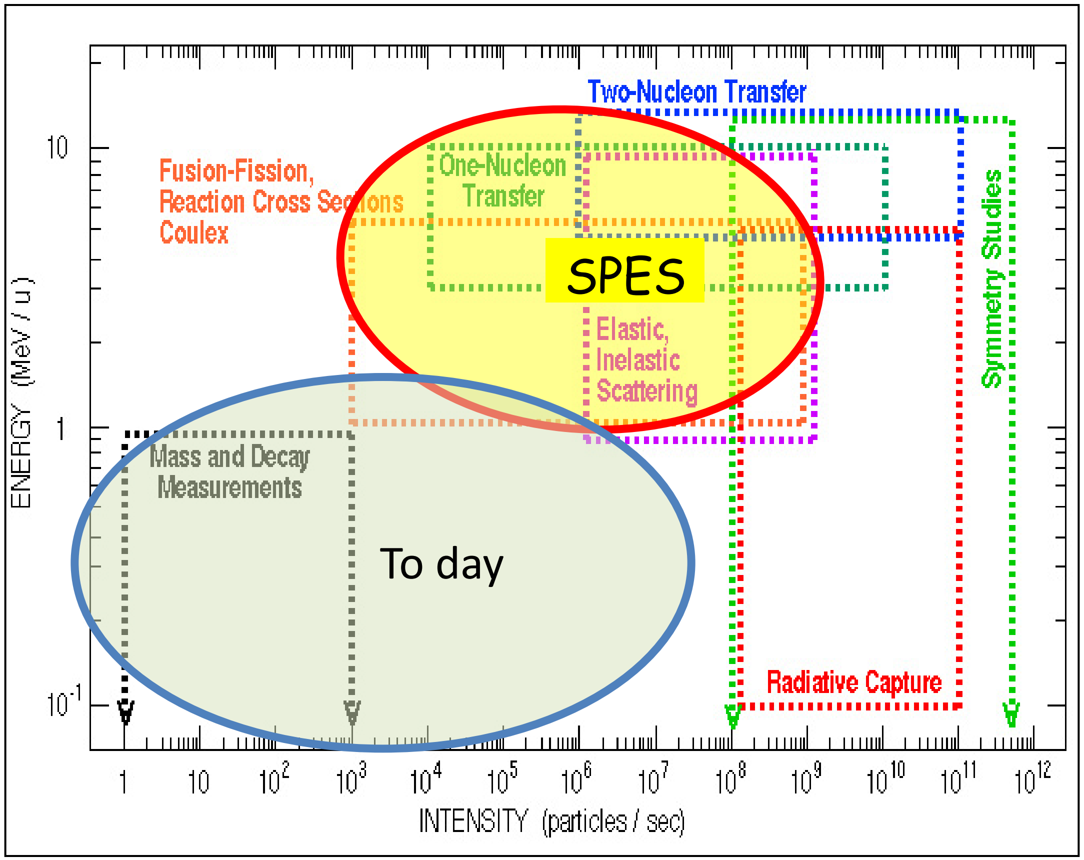




Physics Domain with RIB

Nuclear Physics and Astrophysics

- **Coulomb Excitation**
- **Decay Spectroscopy**
- ***Transfer Reactions***
- ***Reaction Studies***



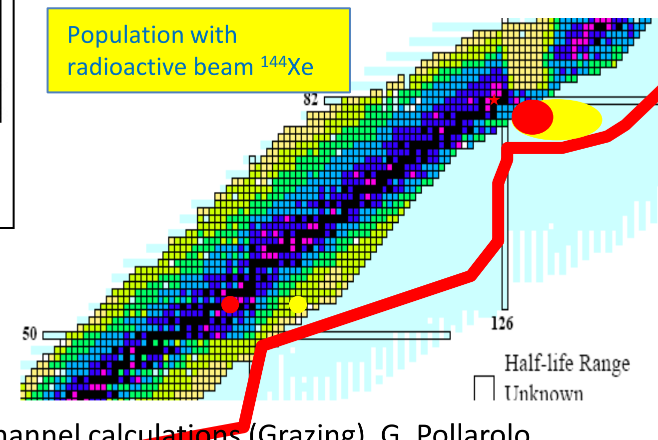
EURISOL
Second generation
today

today
Second generation
EURISOL

More n-rich produced
New class of fenomena

$^{n}Xe + ^{206}Pb\ E_{lab}=8.3MeV/n$

Population with radioactive beam ^{144}Xe



Coupled channel calculations (Grazing). G. Pollarolo

ISOL Roadmap in EUROPE

2016-2025 Generation 2

10^{13-14} fission/s
10 MeV/n (A=130)

Effective Mass separation 1/20000

GANIL spiral2 — laboratoire commun CEA/DSM CNRS/IN2P3

ISOLDE

SPES — exotic beams for science

New beams for the Nuclear Physics community

DEVELOPMENT OF CRITICAL TECHNOLOGY TO BUILD EURISOL

FROM 2025

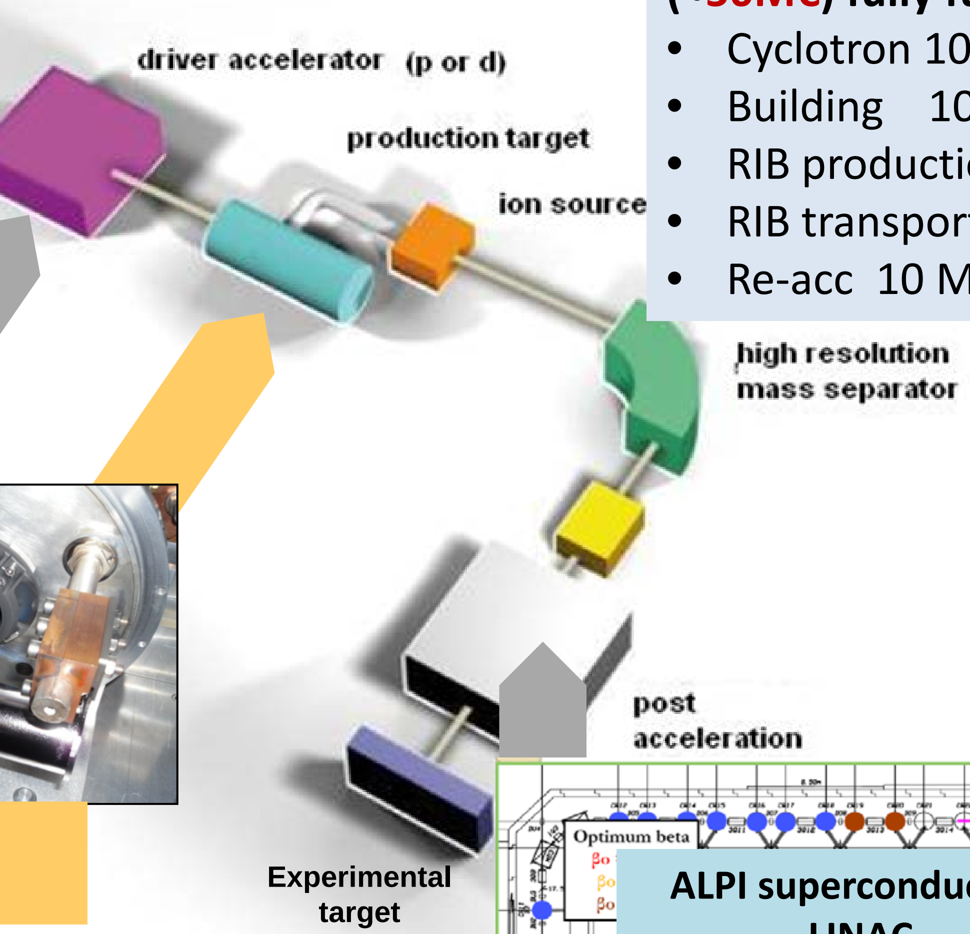
EURISOL

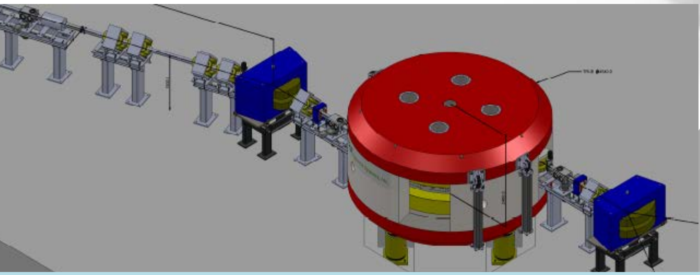
> 10^{15} fission/s
100 MeV/n (A=130)
Mass separation 1/20000

The SPES choice for the ISOL facility

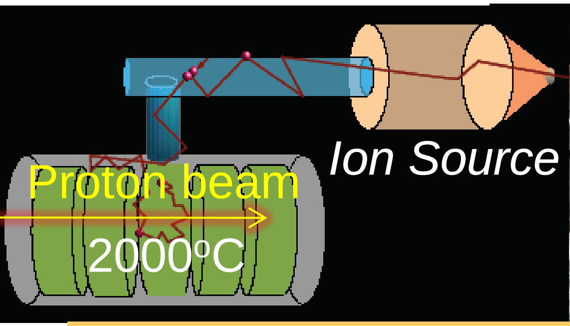
Cost-effective project (≈50M€) fully funded

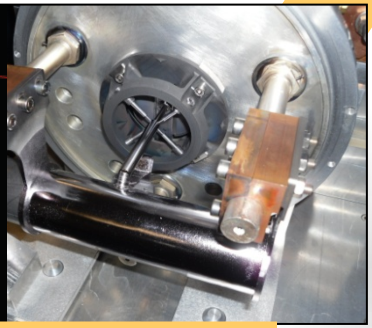
- Cyclotron 10 M€
- Building 10 M€
- RIB production 5 M€
- RIB transport 15 M€
- Re-acc 10 M€



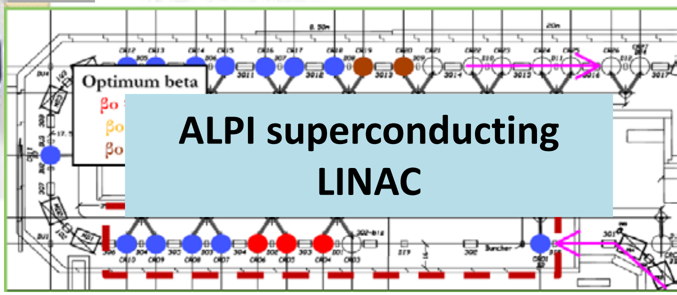


Cyclotron p-driver (30-70 MeV, 750 uA)





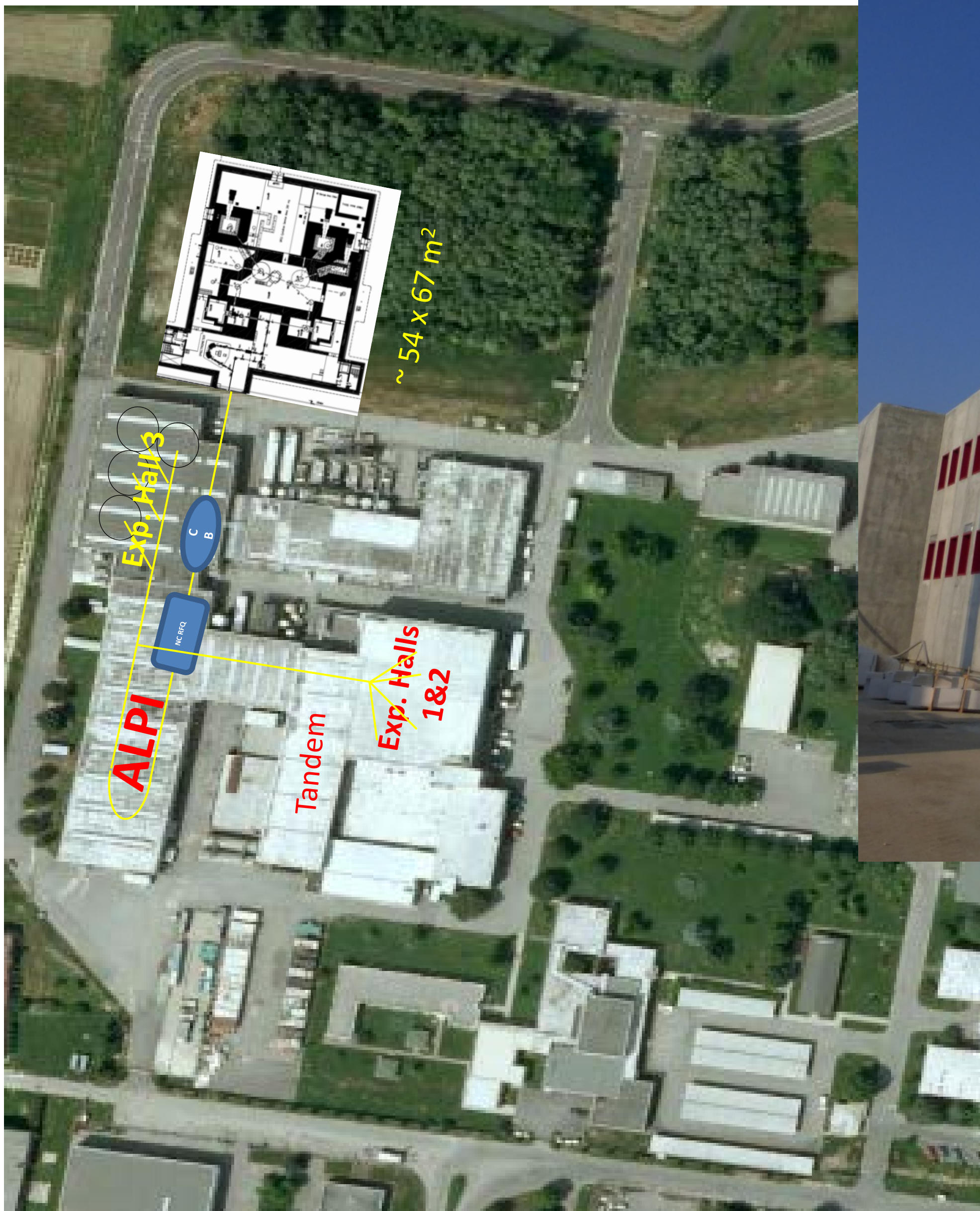
NEW CONCEPT: direct target multi-foil UCx (for 10^{13} f/s)



ALPI superconducting LINAC

Beam commissioning expected in **2019**

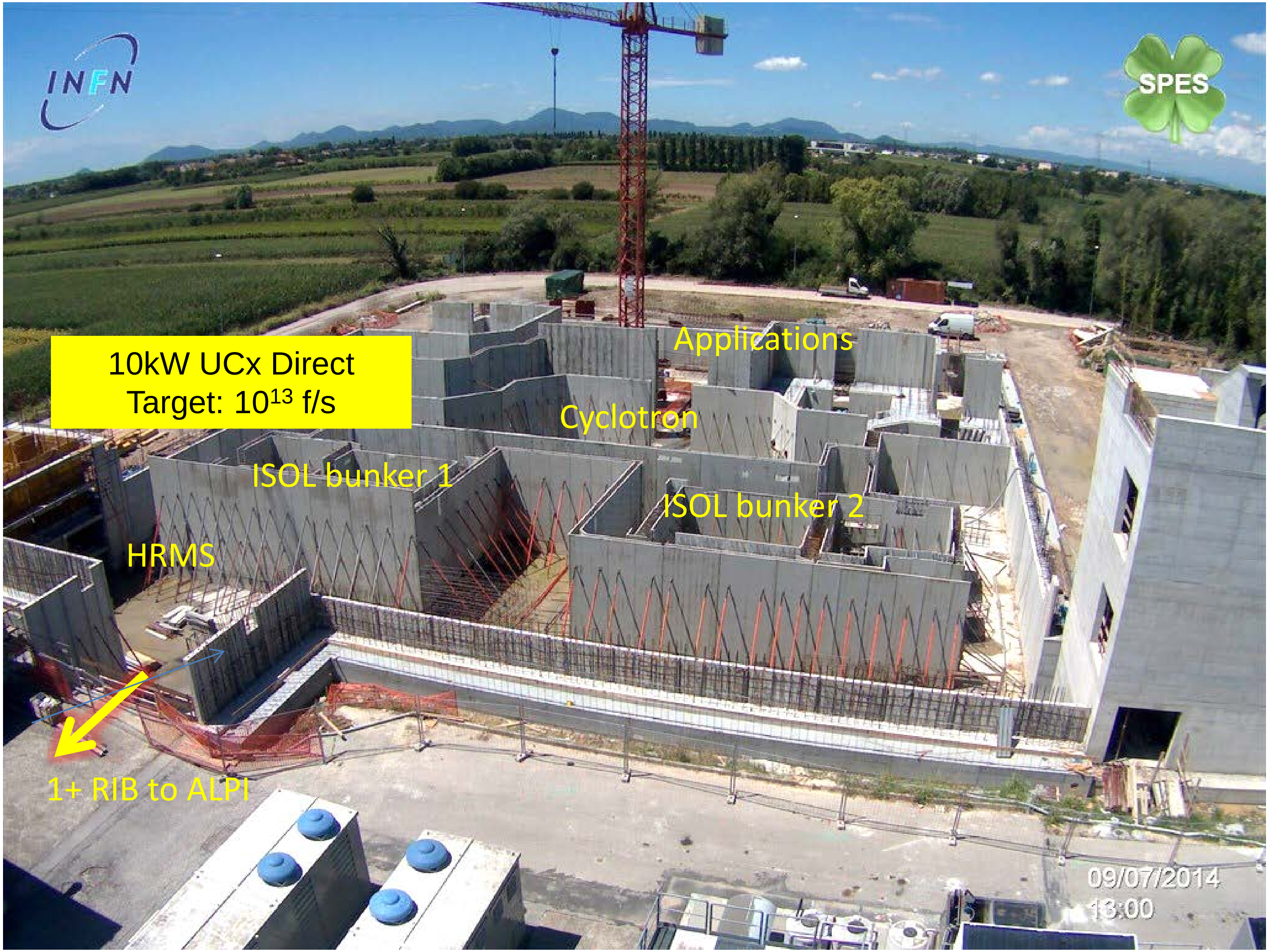
SPES Facility Layout



New infrastructure for:

- cyclotron
- RIB (Radioactive Ion Beam)
- application facility

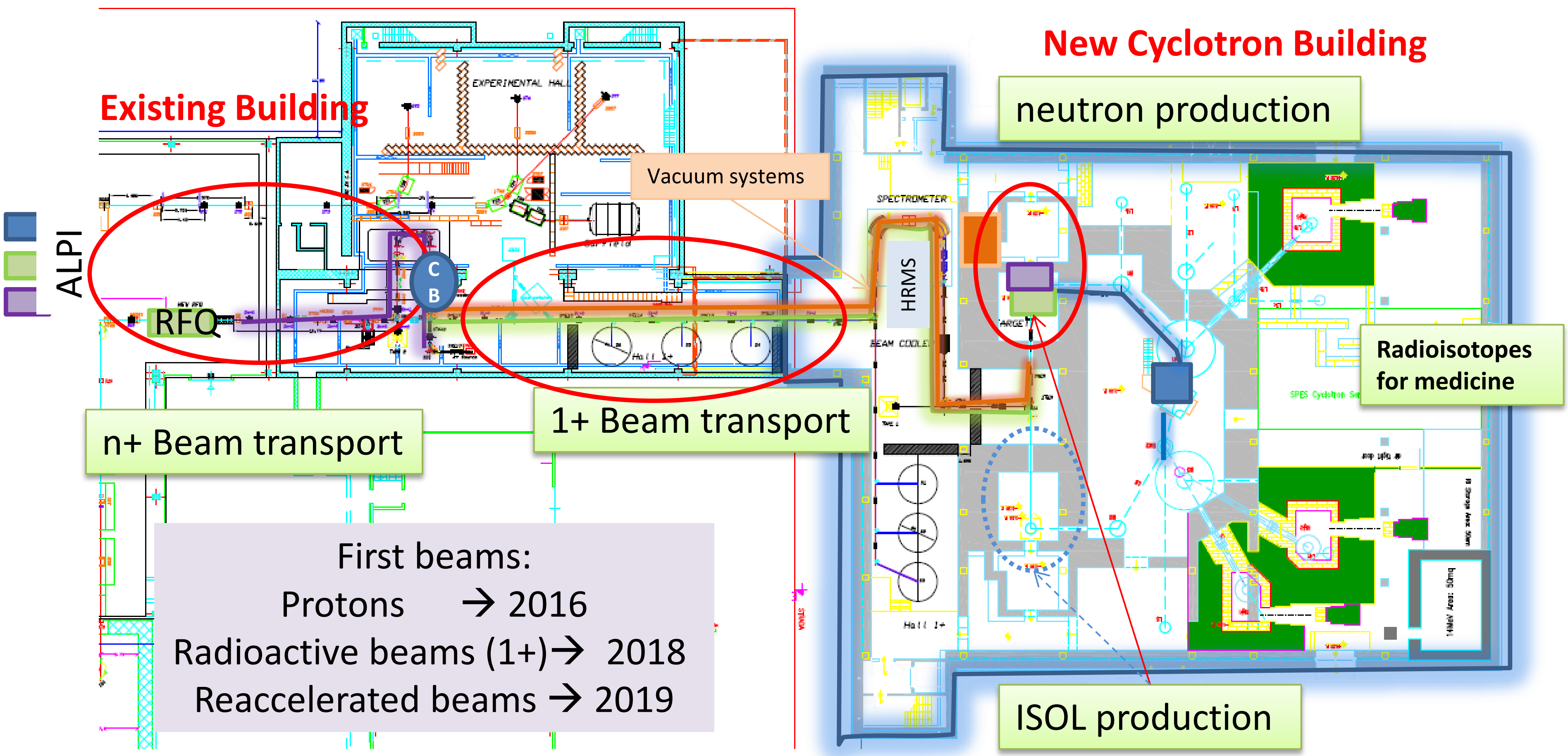
https://www.youtube.com/watch?v=gOcJFW4I6_Q



INFN
SPES
10kW UCx Direct
Target: 10^13 f/s
Applications
Cyclotron
ISOL bunker 1
ISOL bunker 2
HRMS
1+ RIB to ALPI
09/07/2014
13:00

Construction phase: MAIN TENDERS

- **2010-2012**: ISOL target, Cyclotron and Building
- **2013-2014**: Laser source, Charge Breeder and n+ beam transport
- **2015**: 1+ beam line safety
- **2016**: Vacuum systems, RFQ and installation
- **2017**: High Resolution Mass Separator



First beams:
Protons → 2016
Radioactive beams (1+) → 2018
Reaccelerated beams → 2019

SPES: Cyclotron Schedule (2013-2015)

	2013		2014			2015		
	II	III	I	II	III	I	II	III
Final Assembly and Testing								
Factory Commissioning								
Disassembly and Shipping								
Installation at LNL								
Commissioning at LNL								

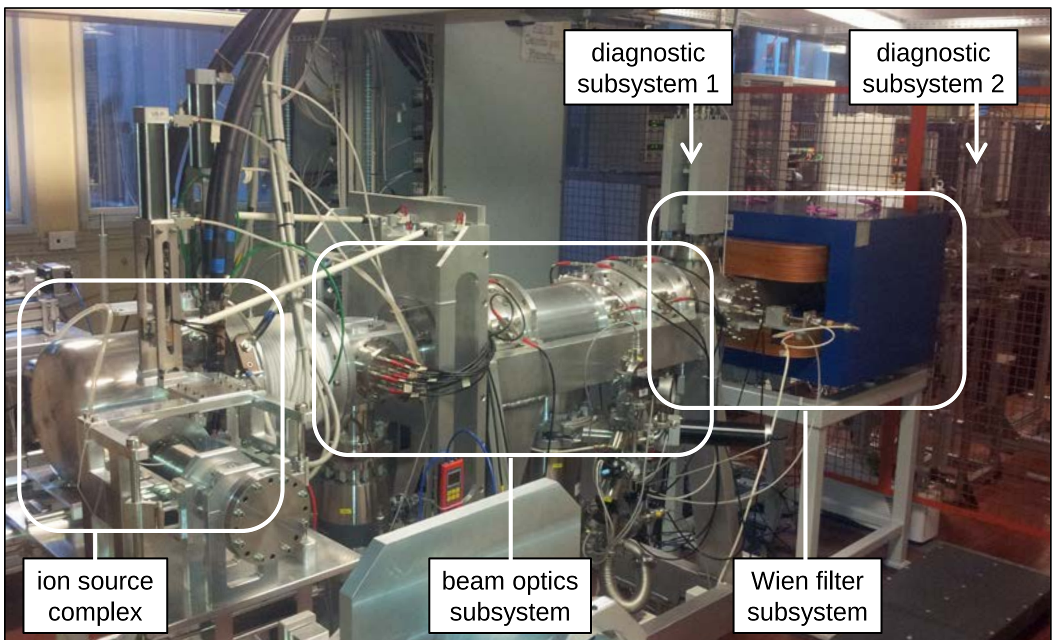
Main Parameters

Accelerator Type	Cyclotron AVF 4 sectors
Particle	**Protons (H^- accelerated)**
Energy	**Variable within 30-70 MeV**
Max Current Accelerated	**750 µA** (52 kW max beam power)
Available Beams	**2 beams at the same energy** (upgrade to different energies)
Max Magnetic Field	1.6 Tesla
RF frequency	56 MHz, 4th harmonic mode
Ion Source	Multicusp H^- I=15 mA, Axial Injection
Dimensions	Φ=4.5 m, h=1.5 m
Weight	150 tons

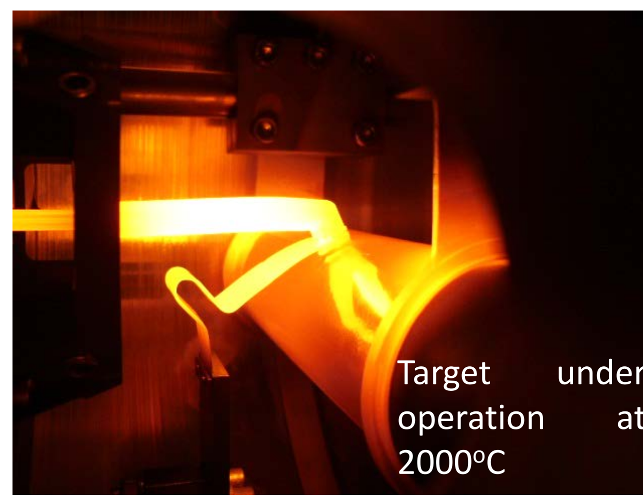
Technical highlights:
the ISOL production target

SPES DIRECT TARGET CONCEPT to operate with **8 kW** proton beam

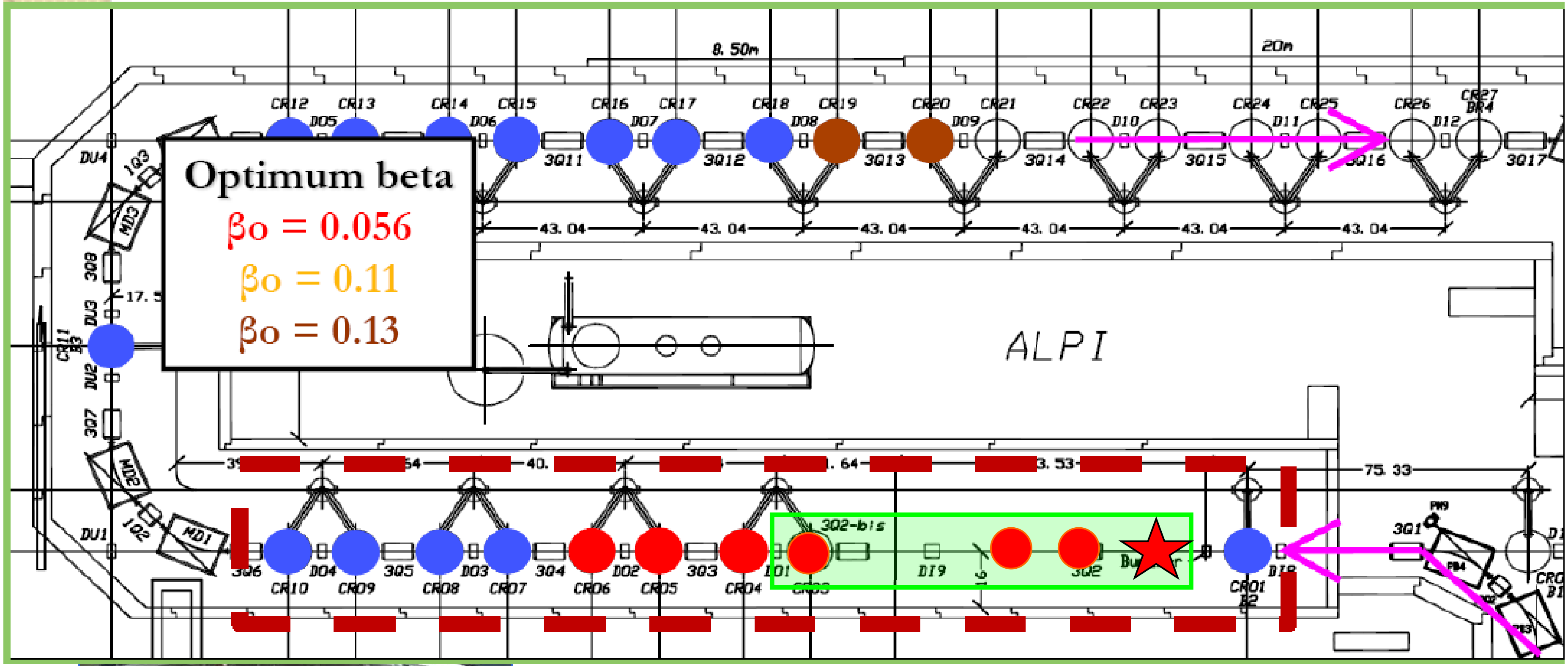
- Direct Target carefully designed to reach **10^{13} fissions/s** with **8 kW** proton beam (thermo-mechanical considerations);
- **High power in beam test succesfully** performed at **iThemba labs (South Africa)** on May 2014;
- Prototype under operation.
- Fully developed **front-end** following ISOLDE design



UCx target completely developed



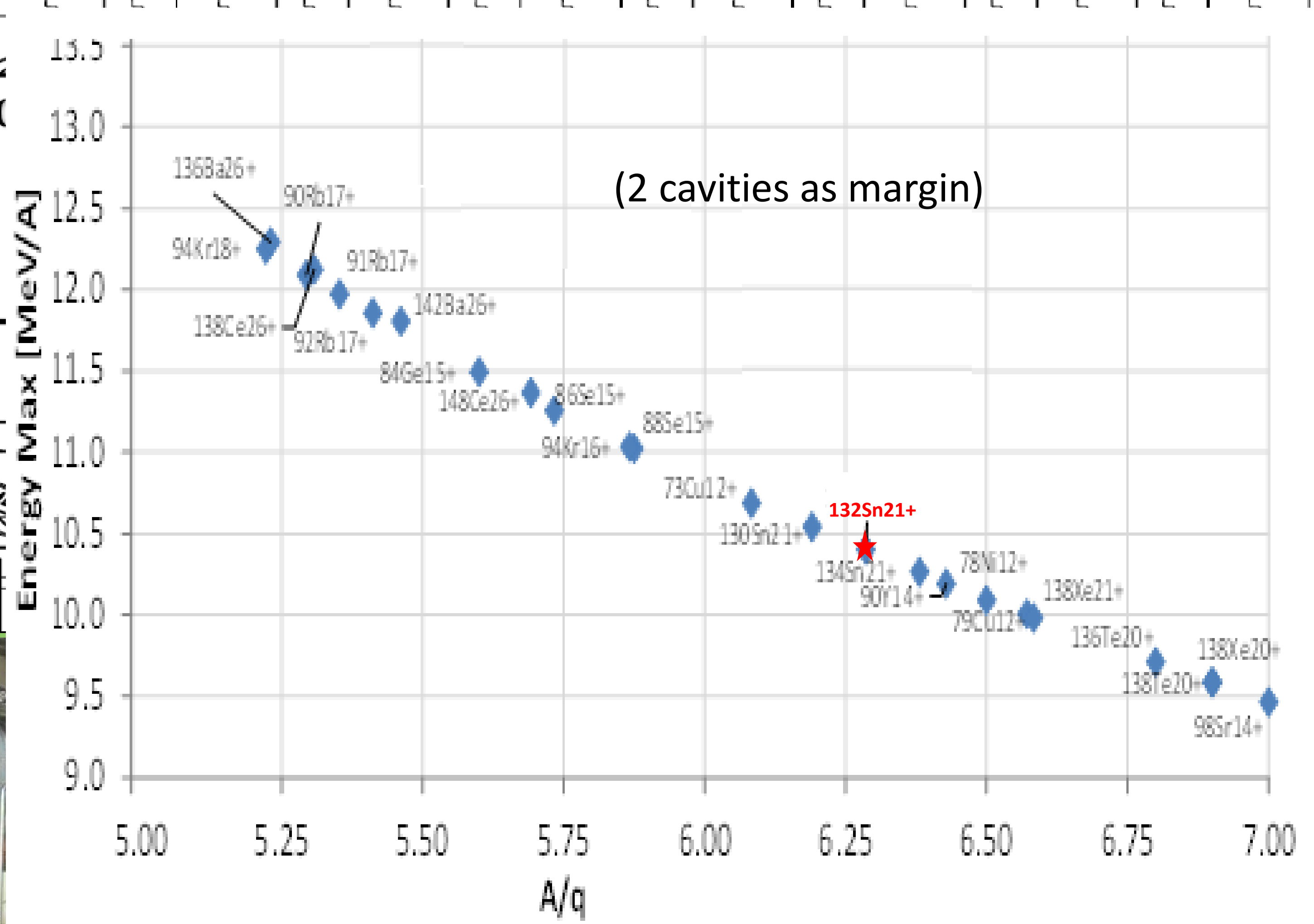
ALPI superconductive linac



Superconducting linac based on Quarter Wave Resonators

ALPI upgrade:
Upgrade LowBeta RF power
2 additional LowBeta Cryostats (CR1, CR2)
New buncher
New magnetic lenses (from 20 to 30 T/m)

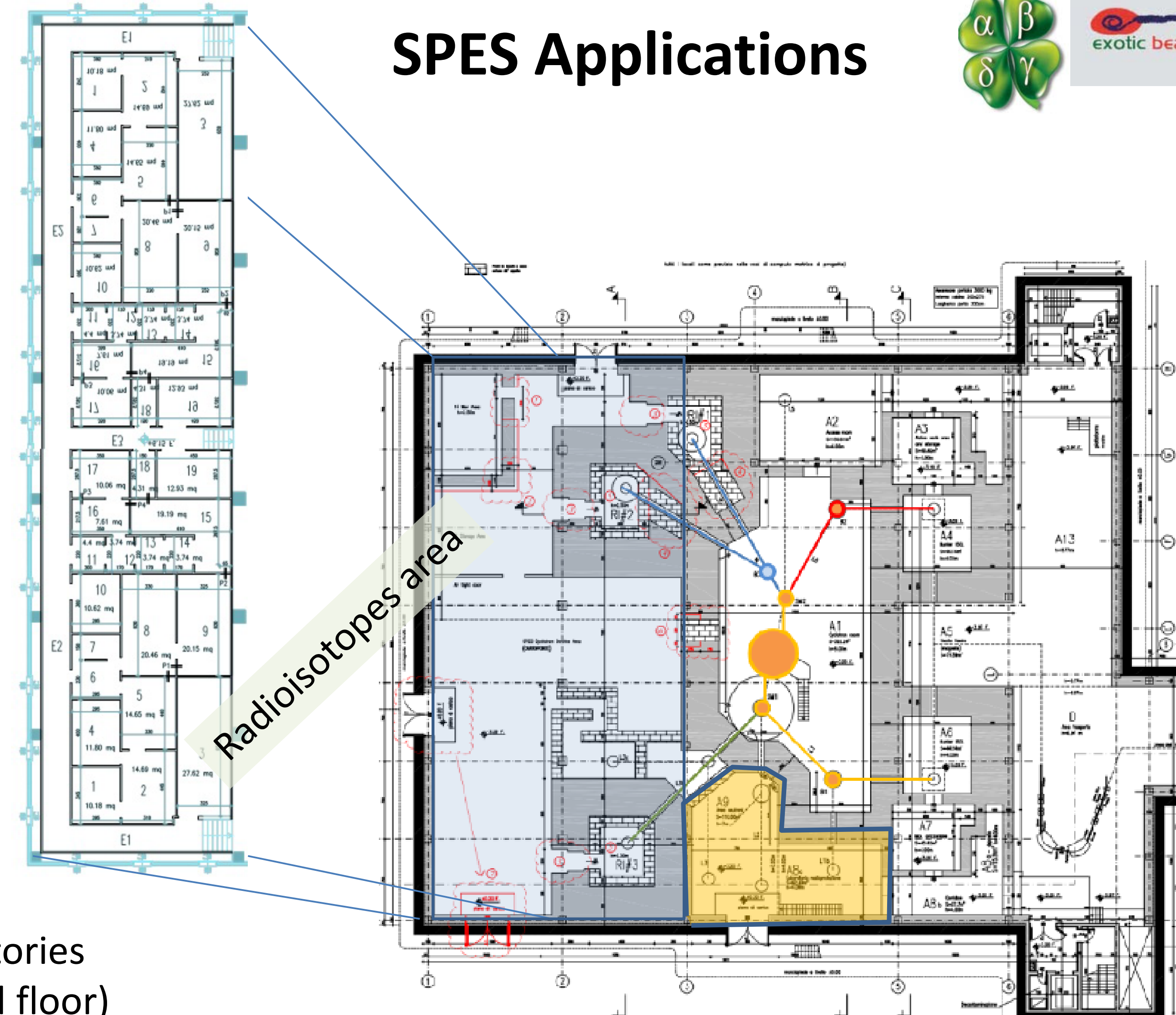
ALPI superconductive linac



ators

New buncher
New magnetic lenses (from 20 to 30 T/m)

SPES Applications



Laboratories
(second floor)

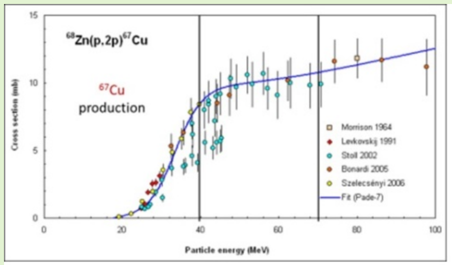
Neutron area

SPES γ: Radio-isotopes for medicine

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

^{64,67}Cu: radioisotopes under evaluation (R&D)

^{82}Sr: generator for ^{82}Rb (Commercial interest)



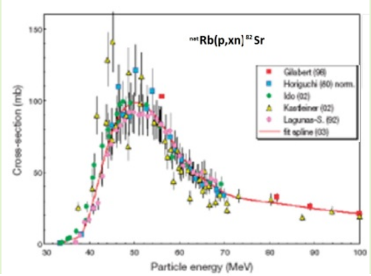


Table 7 – List of Isotopes Produced by Proton Accelerators of Various Energies

30 MeV		45 MeV		70 MeV	
Isotope	Half-Life	Isotope	Half-Life	Isotope	Half-Life
Cu-64	12.7 h	Zn-62	9.2 h	Fe-52	8.3 h
Y-86	14.6 h	Co-55	17.5 h	Xe-122	20.1 h
Cu-67 *	2.58 d	Hg-195m	41.6 h	Mg-28	21 h
Sc-47	3.35 d	Bi-206	6.2 d	Ba-128	2.43 d
I-124	4.2 d			Cu-67 *	2.58 d
Tc-96	4.28 d			Ru-97	2.79 d
Xe-127	36.4 d			Sn-117m	13.6 d
Y-88	106.7 d			Sr-82	25.4 d
Ge-68	271 d				

Effect of cancer **treatment with ^{64}Cu** produced with proton beam at cyclotrons. Better result expected with **^{67}Cu.**

$^{64}CuCl_2$

patient: male, 55 y, pulmonary hilar adenopathy (left lung)

LARAMED Project

Funded with 6.8 Meuro

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

- Measurement of cross section through targets activation
- High power targets tests
- Radioisotopes/radiopharmaceuticals Production test facility (^{99m}Tc, ^{64}Cu, ^{67}Cu, ^{82}Sr, ...)

STATUS:

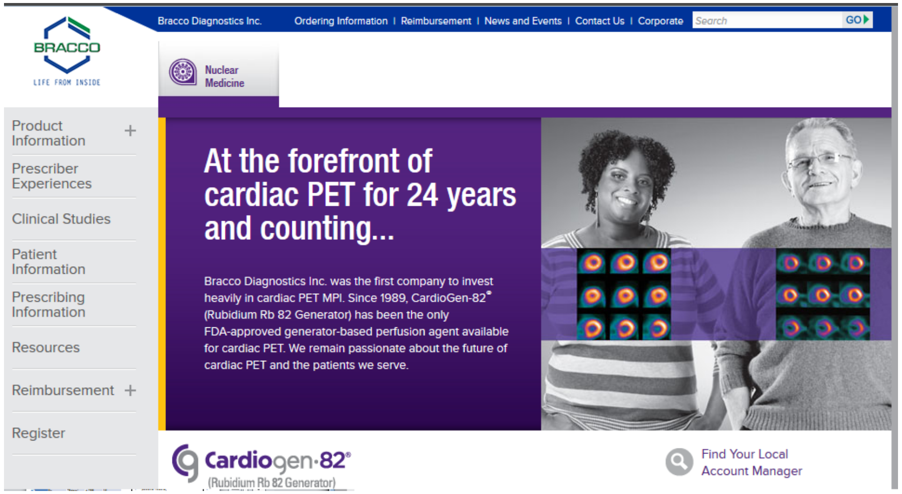
- Building and infrastructures underer development
- Design of radiochemistry labs
- Design of beam line and target management
- Contract with company for radioisotopes production to be finalized

Production laboratory in joint venture with external companies:

Selected isotopes of medical interest

Sr-82/Rb-82 generator

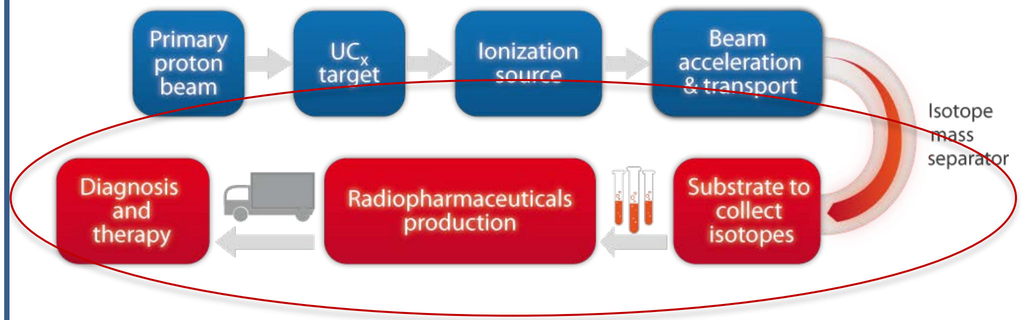
$T_{1/2}$: 25.6 d EC 100% **/ 1.3 min** photons 511keV, 776keV



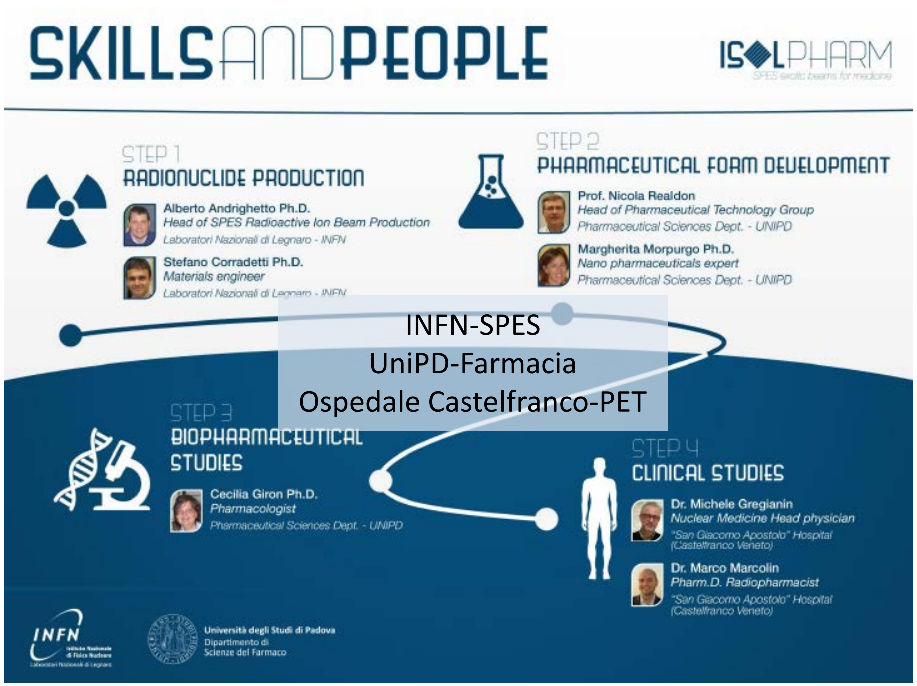
ISOLPHARMA*

* Patent pending

Use of ISOL technique: Direct isotope on-line separation



A suitable substrate is used to collect the radioisotope of interest. A Sodium Chloride substrate is suggested in order to obtain a biocompatible formulation.



HIGH Specific Activity and Purity

Radiopharmaceutical	Targeted organs	Half-life	Specific Activity (GBq/mg) SPES production	Specific Activity (GBq/mg) Neutron capture reaction
^{89}Sr-$SrCl_2$	Bone	50.5 d	≥ 597	≥ 0,004
^{90}Y-YCl_3	Liver and endocrine system	64.1 h	≥ 9480	≥ 0,8
^{125}I-NaI	Prostat, brain, lung, pancreas, liver	59.4 d	≥ 552	≥ 6
^{131}I-NaI	Thyroid	8.02 d	≥ 3911	≥ 0,7
^{75}Se-H_2SeO_3	Liver	119.6 d	≥ 323	≥ 3,7

After 2 days of irradiation:

- 4.1E+15 atoms of ^{89}Sr collected
- 18 mCi= 4 doses

(patient dose: 4 mCi every 6 months).

About 100 patients may be treated every year. Allow the production of radiopharmaceutical on a regional scale.

Alternative way to 99mTc

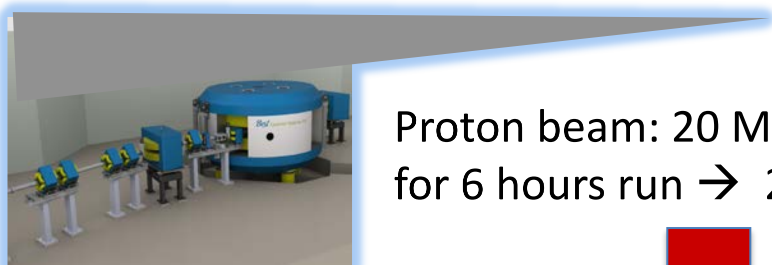
Standard production in Nuclear Reactor by fission of U-235 induced by thermal neutrons using Highly Enriched Uranium (HEU) targets → Mo-99/Tc-99m generator

40 million scans /year world wide

HEU strategic material → possible lack of production. IAEA asks for alternatives

APOTEMA experiment: Direct production

100Mo(p,2n) → 99Tc, 99mTc



Proton beam: 20 MeV, 200 μA for 6 hours run → 270 GBq/day

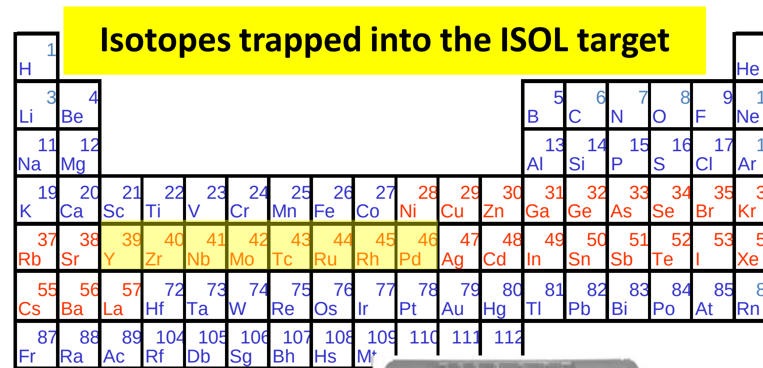
- Define best way for production (purification)
- Development of high power target s

Needs Padova hospital: 150 GBq/day

Use of exausted ISOL targets for alternative way of 99mTc production:

extraction of trapped elements

INFN-LNL-237 (2012)
ISBN 978-88-7337-016-1



UCx Target conditioned following standard chemical procedures

Regional production of Mo-99 1150 GBq_3day /week (needs of Veneto)

Mo-Tc 99m generator

Useful as strategic production

(Today not commercially competitive)

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)** **~ $6\cdot10^{14}$ s^{-1}**	**Φ_n @ 2.5 m** **(n cm^{-2} s^{-1})**	**Φ_n @ 1 cm** **(n cm^{-2} s^{-1})**
1 < E < 10	~ $5\cdot10^{14}$ s^{-1}	5×10^{8}	3×10^{13}
10 < E < 50	~ $1\cdot10^{14}$ 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

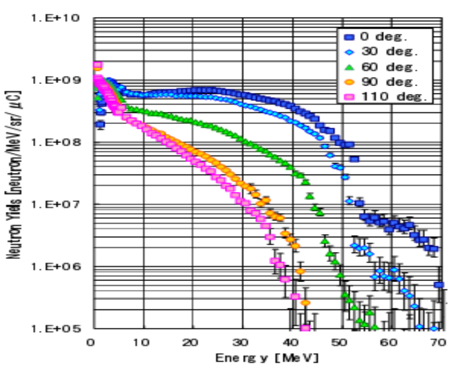


Figure 4: Thick target yield for C(p,xn) at 70 MeV

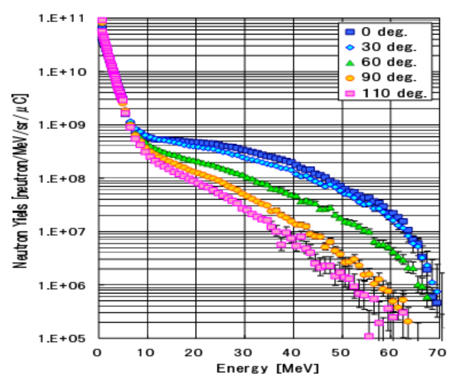
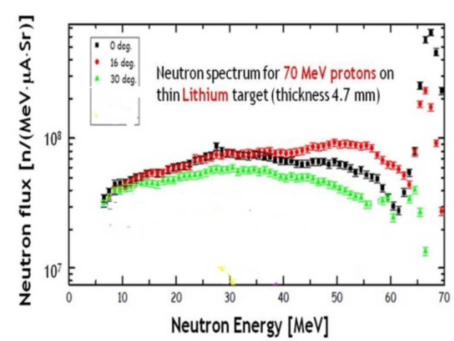
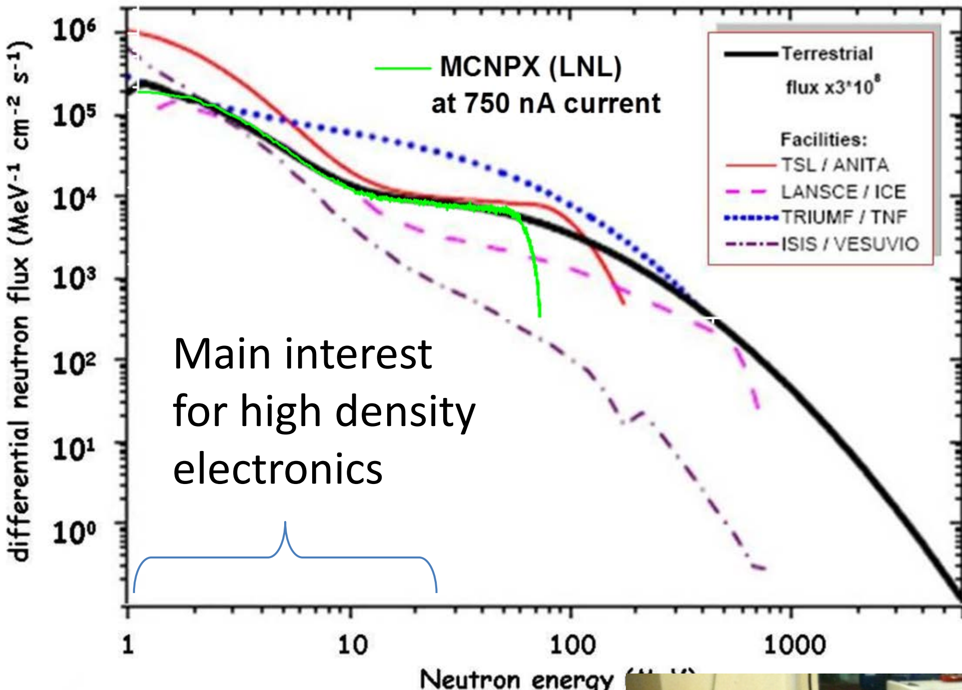


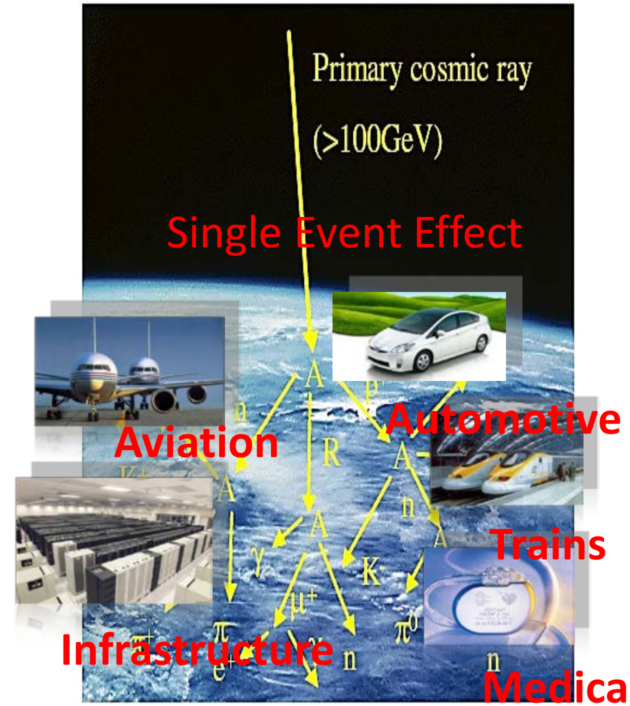
Figure 14: Thick target yield for W(p,xn) at 70 MeV



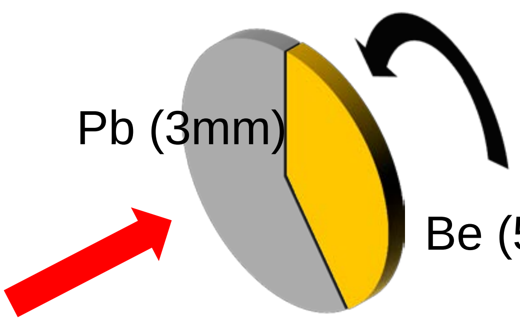
ANEM

simulated fast neutron atmospheric spectrum (PbBe variant)

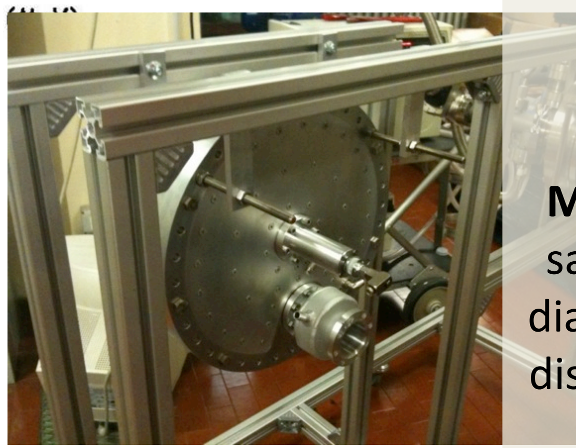




NEUTRON FLUX:
F~10^8 (n/s/cm^2/MeV) at 3m
Amplification factor 3 x 10^8
Ep=70MeV, 0.750μA
Pb-Be Composite target

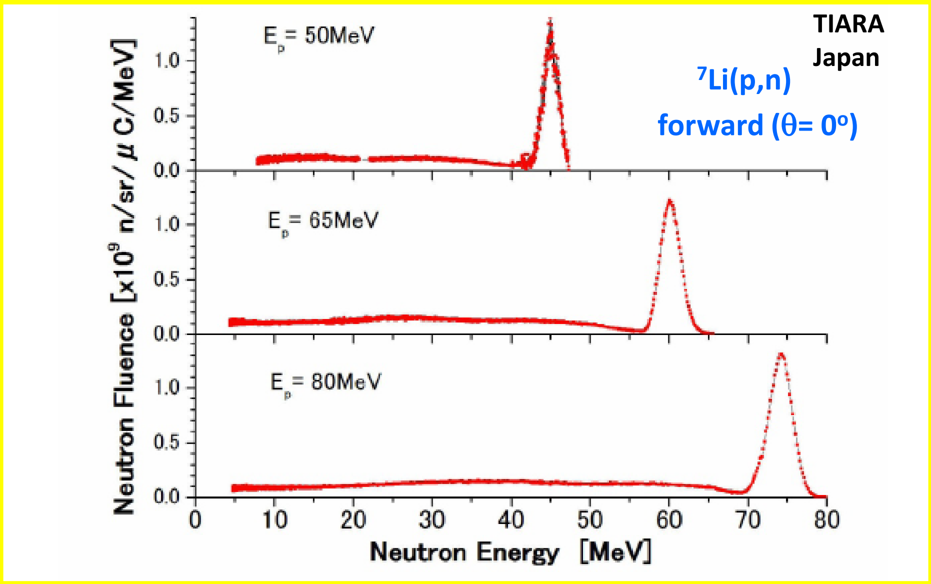


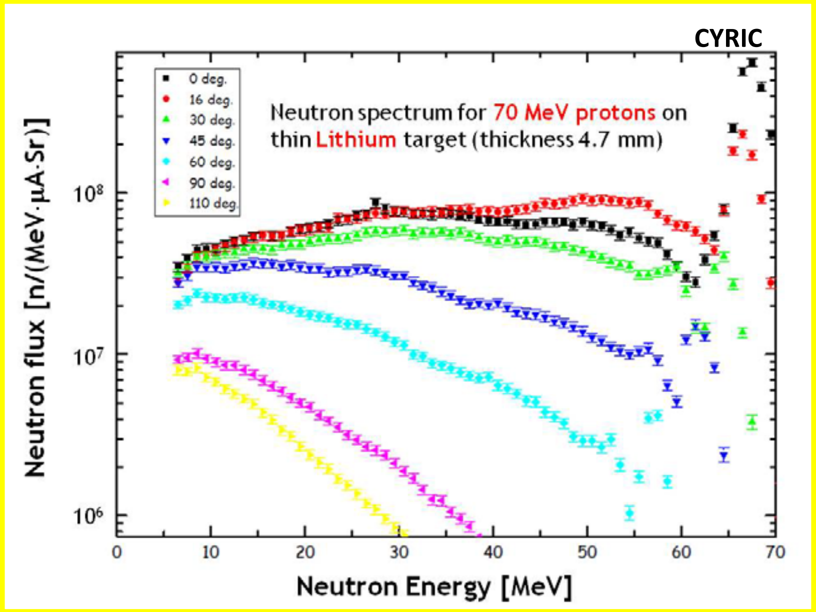
70 MeV protons



Medium size device irradiation: same flux on a beam spot of 1m diameter can be obtained at 10 m distance increasing the current by a factor 10 (~ 10 microA)

Quasi mono-energetic neutrons (QMN) from thin (millimetric) Li and Be targets (*)

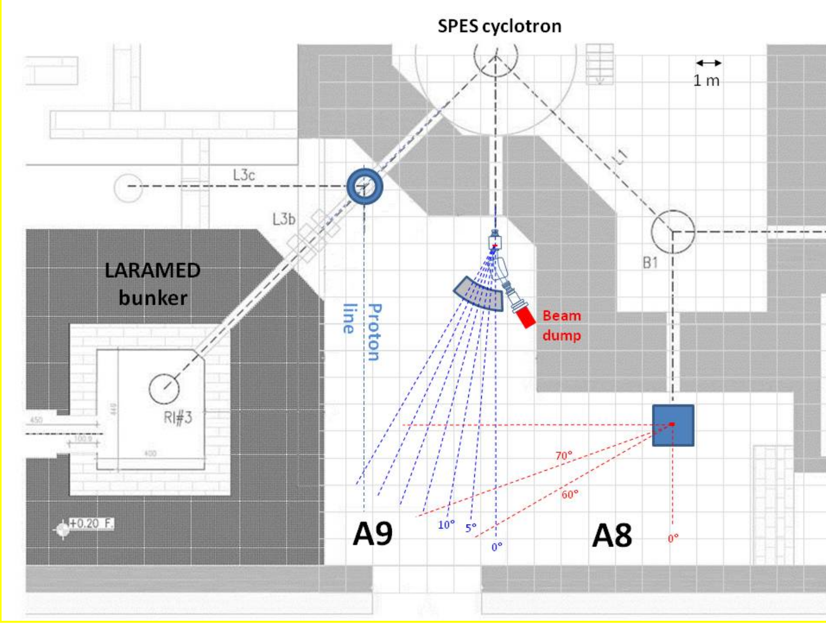




(*) the protons emerging from the target are magnetically deflected towards a beam dump.

Corrected Energy spectral fluence at 0°

$$\phi_0^{corr}(E) = \phi_0(E) - A\phi_\theta(E)$$



EURADOS European Radiation Dosimetry Group

Report 2013-02
Braunschweig, May 2013

Warning for needs of QMN in Europe

CONCLUSIONS

- The SPES project is financed by INFN up to the completion

- The cyclotron is under installation

- The proton beam is expected to be extracted in September 2015 for the Site Acceptance Test

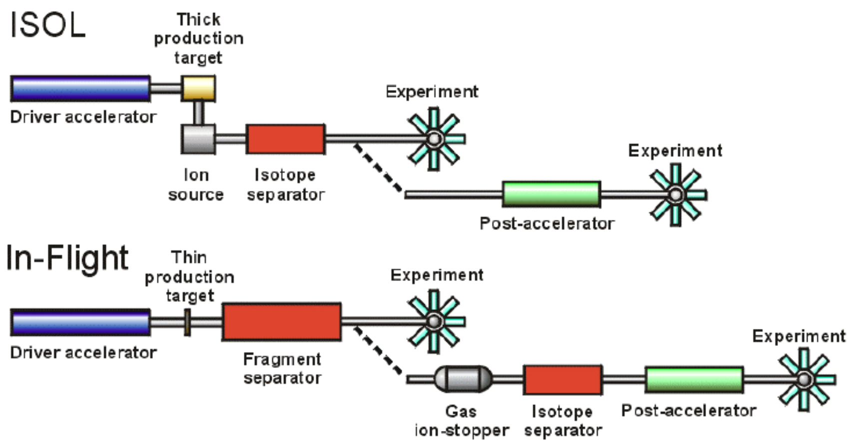
- ISOL:
  - The ISOL sistem will be installed in 2016

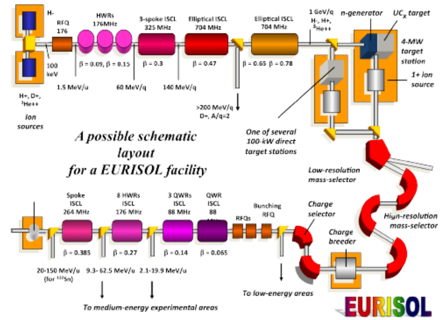
  - First radioactive beam in 2018 (no reacceleration)

- Applications:
  - A program for study and production of radioisotopes for medical use is started
  - First beams available for medicine and neutrons in 2016

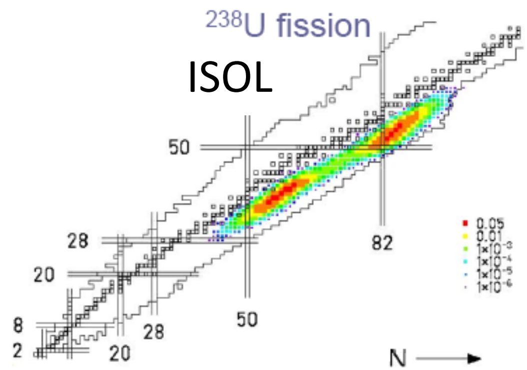
  - A neutron facility for fast neutrons is under design

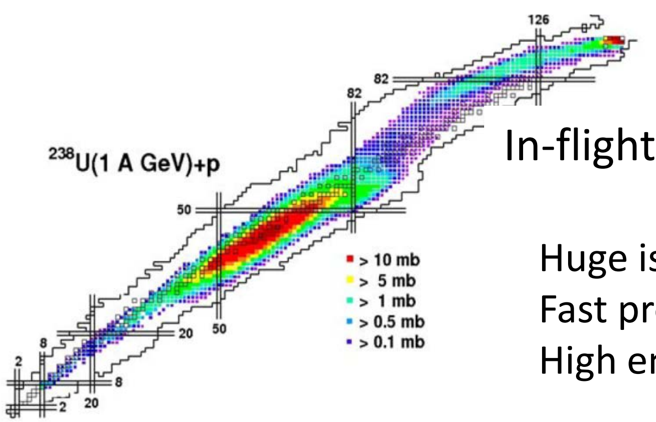
Methods of RIB production and post-acceleration.



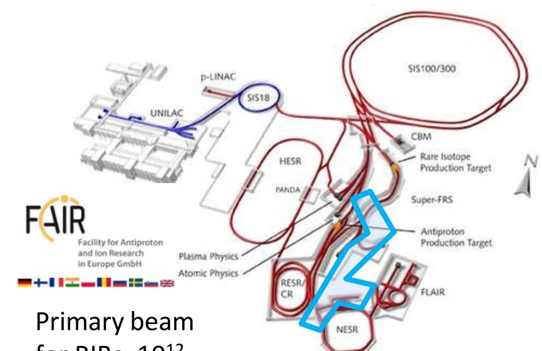


Quite selected Neutron Rich beams.
Slow production process
Selected energy (up to 10A MeV)





Huge isotopes production
Fast production process
High energy (100A MeV)



Primary beam for RIBs: 10^{12} pps of $^{238}U^{28+}$ at 1.5-2 GeV/u, NuPECC

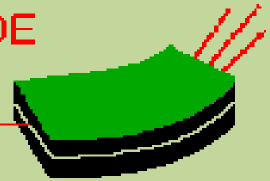
ISOL Roadmap in EUROPE

TODAY Generation 1

SPIRAL – GANIL

Light ions (up to A=90, Proton rich)

ISOLDE
CERN



10^{12} fission/s
2 MeV/n (A=130)

Effective Mass separation1/4000

INFN LNS - EXCYT

Light ions (up to A=10)

2016-2025 Generation 2

$10^{13\text{-}14}$ fission/s
10 MeV/n (A=130)

Effective Mass separation 1/20000

GANIL spiral2 laboratoire commun CEA/DSM CNRS/IN2P3

HIE-ISOLDE

SPES exotic beams for science

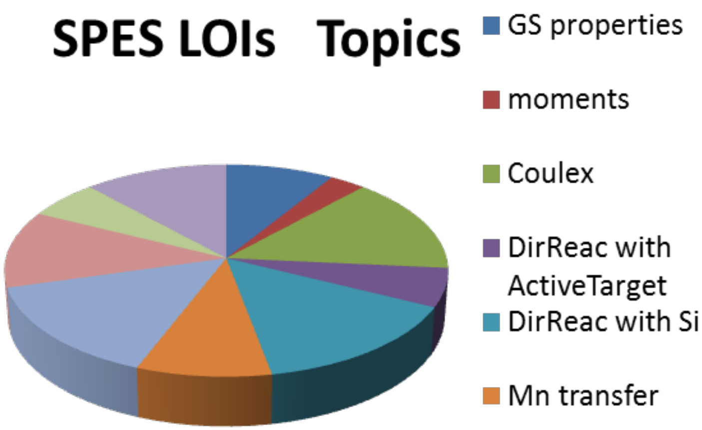
FROM 2025

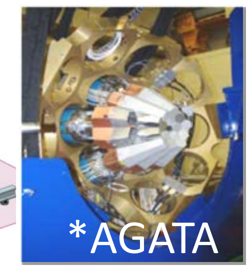
EURISOL

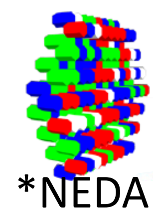
> 10^{15} fission/s
100 MeV/n (A=130)
Mass separation 1/20000

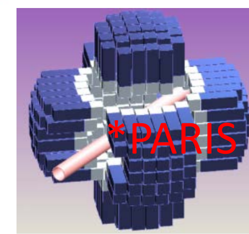
Presented 37 Letters of Intents

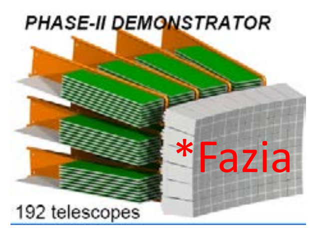
SPES LOIs Topics

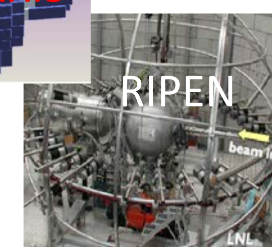




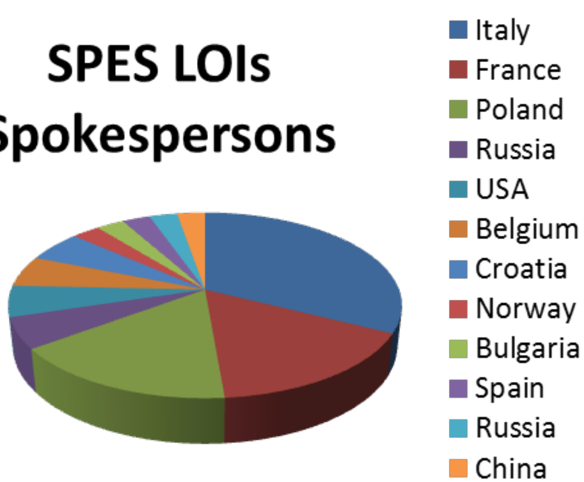


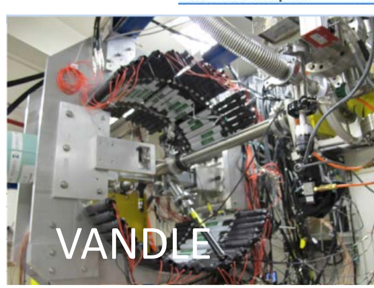


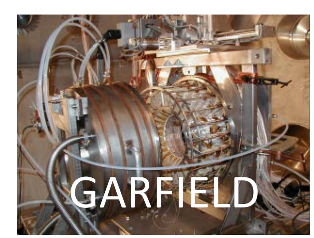




SPES LOIs Spokespersons







SPES exotic beams for science

SPES one-day workshop "Nuclear Astrophysics at SPES"

12-13 November 2015 *Teatro di Corte della Reggia di Caserta, Caserta*

Europe/Rome timezone

SPES one-day Workshop: Physics at SPES with non re-accelerated beams
Milano - *April 20-21, 2015*

Second SPES International Workshop
INFN Laboratori Nazionali di Legnaro - *May 26-28, 2014*

SPES one-day Workshop: Collective Excitations of Exotic Nuclei
Università degli Studi di Milano - *December 9-10, 2013*

SPES one-day Workshop: Isospin on reaction mechanism with RIBs
INFN Laboratori Nazionali del Sud - *October 8-9, 2013*

SPES one-day Workshop: Coulomb excitation with RIBs
INFN Firenze - *September 27-28, 2012*

EURORIB'12 - European Radioactive Ion Beam Conference 2012
Hotel Alexander Palace, Abano Terme (PD), Italy - *May 20-25, 2012*

SPES one-day Workshop: Transfer reactions with RIBs
INFN Napoli - *April 20, 2012*

First SPES School on Experimental Techniques with Radioactive Beams
INFN Laboratori Nazionali del Sud - *November 8-11, 2011*

SPES2010 International Workshop
INFN Laboratori Nazionali di Legnaro - *November 15-17, 2010*

Incontro Tecnico SPES - EXCYT
INFN Laboratori Nazionali del Sud - *November 30-December 2, 2009*

First SPES Physics Workshop
INFN Laboratori Nazionali di Legnaro - *October 29-30, 2008*

Following the success of the previous editions of the "SPES one-day Workshop", we are pleased to announce a new event to be held in the Royal Palace of Caserta on November 12-13, 2015.

This event will be focused on Nuclear Astrophysics at SPES.

The workshop is promoted by the SPES Study Group.

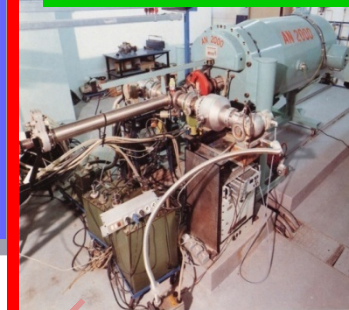
SPES general planning

	2012	2013	2014	2015	2016	2017	2018	2019
Authorization to operate and safety	UCx 5microA							
ISOL Target-Ion Sources development								
ISOL Targets construction and installation								
ISOL on-line commissioning								
Building Construction	Executive project	raw building construction						
Cyclotron Construction & commissioning				Cyclotron at LNL				
RFQ development and Alpi up-grade								
Design of RIB transport & selection (HRMS, Charge Breeder, Beam Cooler)								
Construction and Installation of RIBs transfer lines , CB and spectrometers								
Stepwise commissioning and first exotic beam (2018), HRMS in 2019								

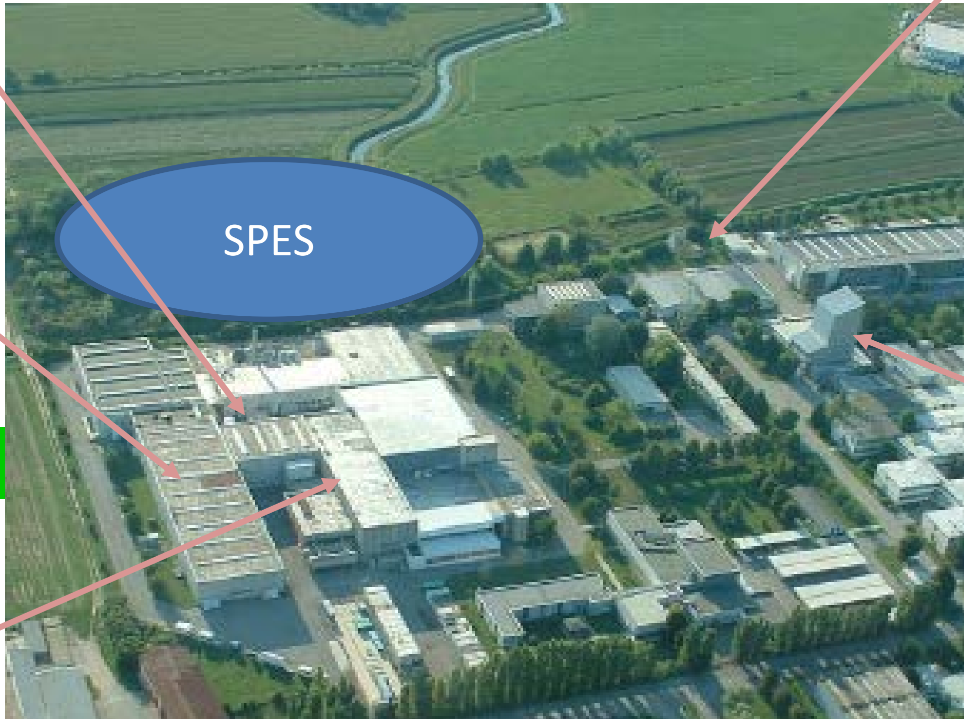
Laboratori Nazionali di Legnaro: site for SPES facility

PIAVE Heavy Ion Injector

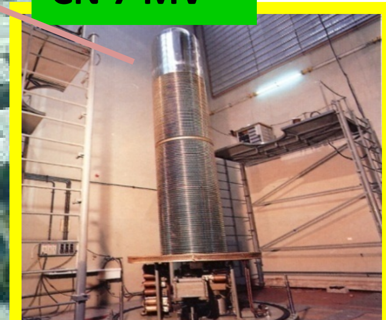
AN2000 2 MV



ALPI Linac 48 MVeq

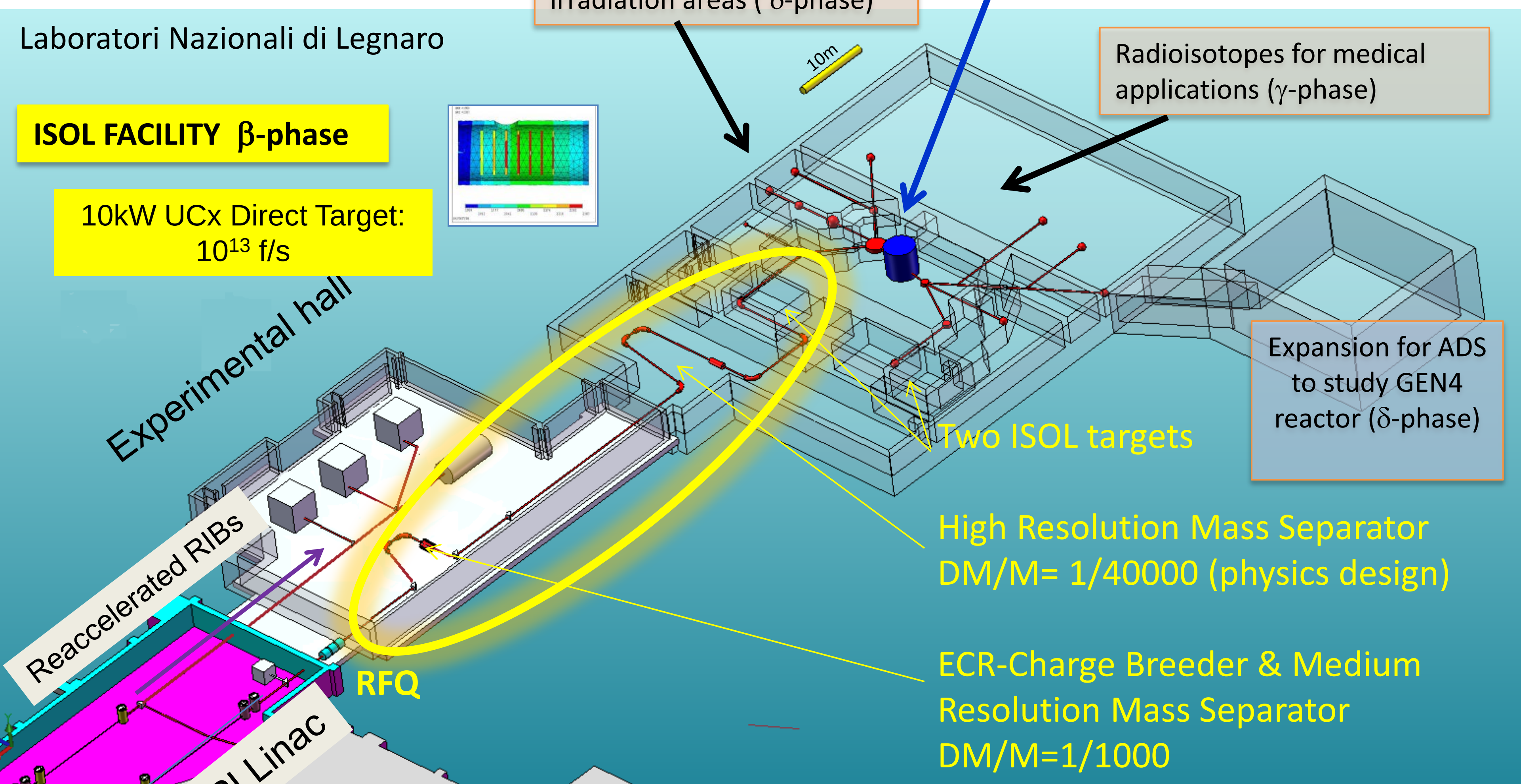


CN 7 MV



Tandem XTU 15 MV

SPES layout



Radioactive Ion Beams are reaccelerated by the superconductive linac ALPI. A normal conductive RFQ placed before ALPI will match the input acceptance beam parameters.

The goal of SPES

- **S**elective **P**roduction of **E**xotic **S**pecies

production of re-accelerated neutron-rich exotic beams
10^{13} fission/s in-target production, and re-acceleration at 10*A MeV (A=132)

- Optimized use of the two exits high current proton driver

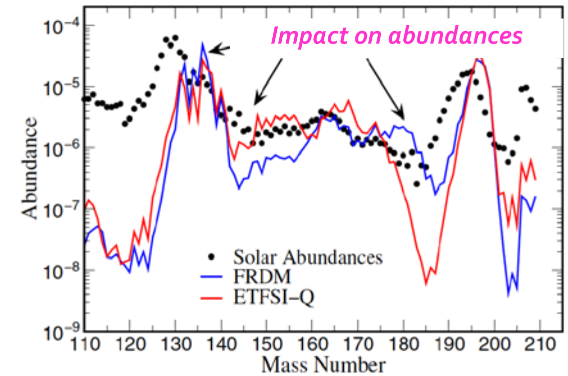
Radioisotope production & Medical applications
innovative radiopharmaceuticals (e.g. Sr-82, Cu- 64, Cu-67)

Fast neutron production & material applications: Atmospheric neutron spectra, QMN
Single Event Effect, neutron capture cross sections

The Scientific Program

MOVING AWAY FROM THE **STABILITY VALLEY**:

EXOTIC NUCLEI & **LIMIT** of **NUCLEAR EXISTENCE**



The open questions:

- ❑ Limit of Nuclear Existence ?
- ❑ Robustness of Magic Numbers ?
- ❑ Validity of Quantum Numbers (Isospin, K, …) ?
- ❑ Change in Structure due to n-excess ?
- ❑ β-decay and r-process path location ?

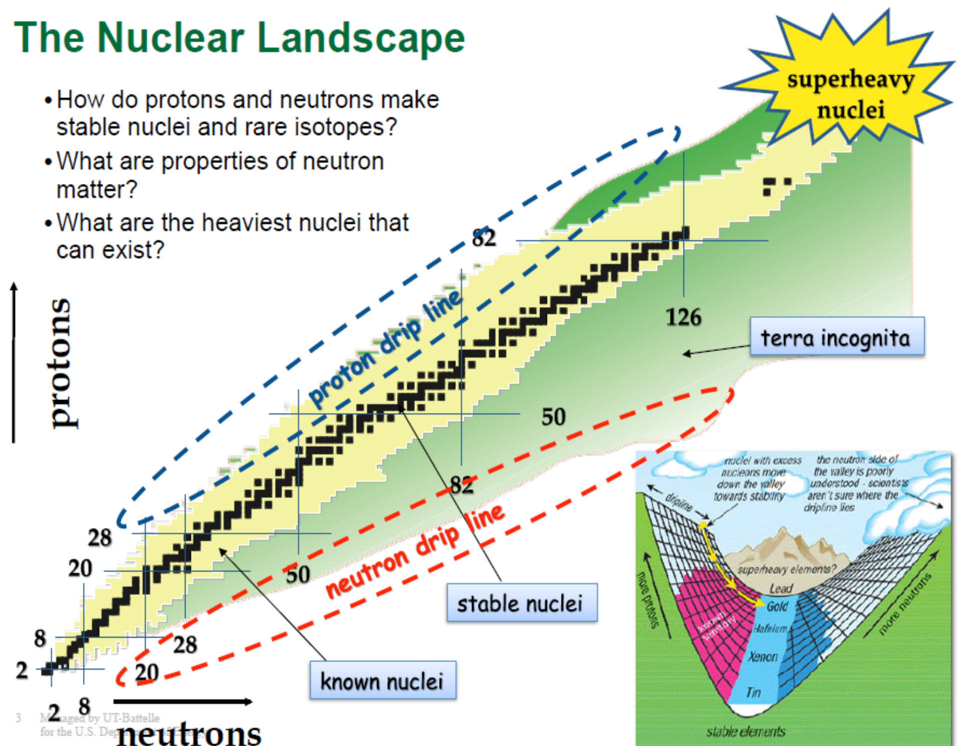
1. Shell Evolution & interactions
2. Symmetries (isospin mixing T=0, T≠0 in N=Z nuclei)
3. Order & Chaos Transition
4. Collective States: Part-Vib-Coupling, Pygmy & Giant Resonances
5. β–decay & r-process
6. Isospin effects on structure & reaction dynamics

The Experimental tecniques:

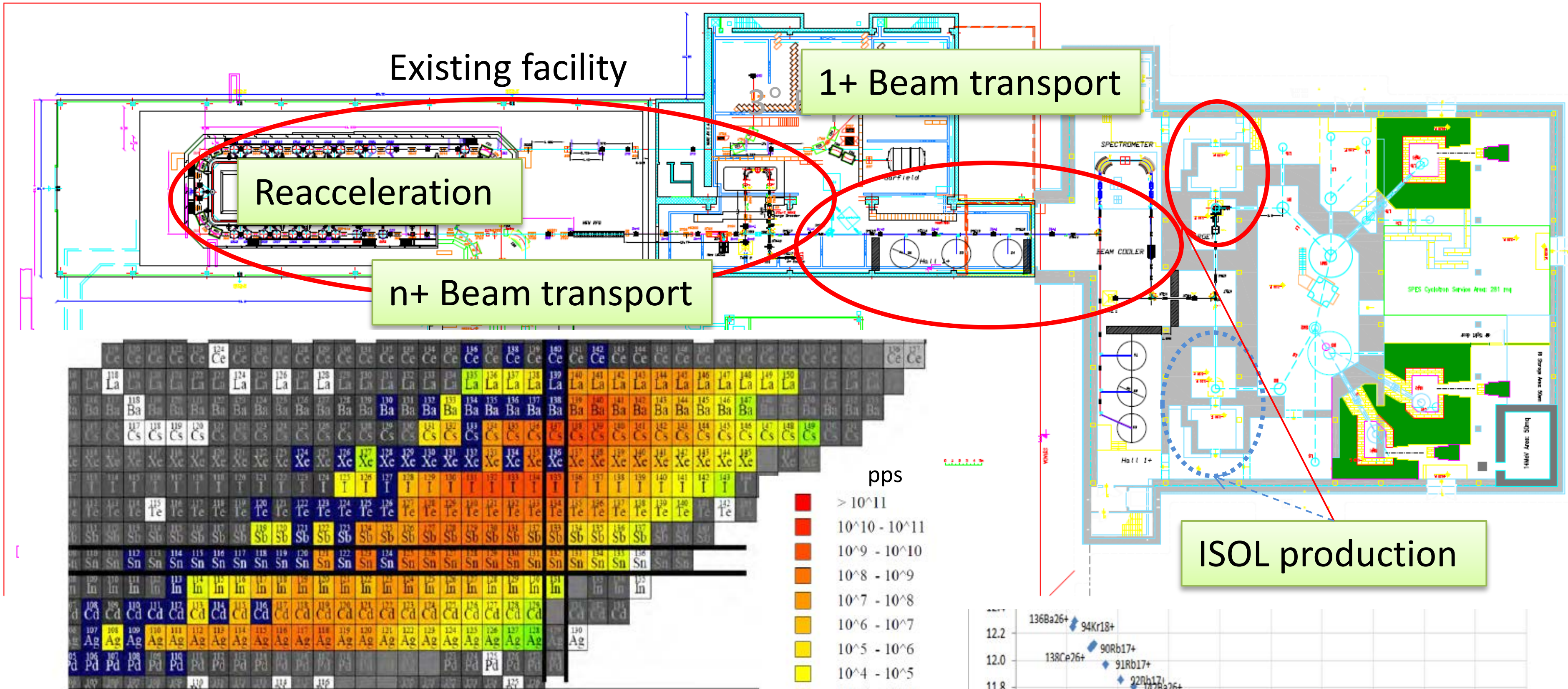
- Coulomb Excitation
- Transfer Reactions
- Decay Spectroscopy
- Reaction Studies

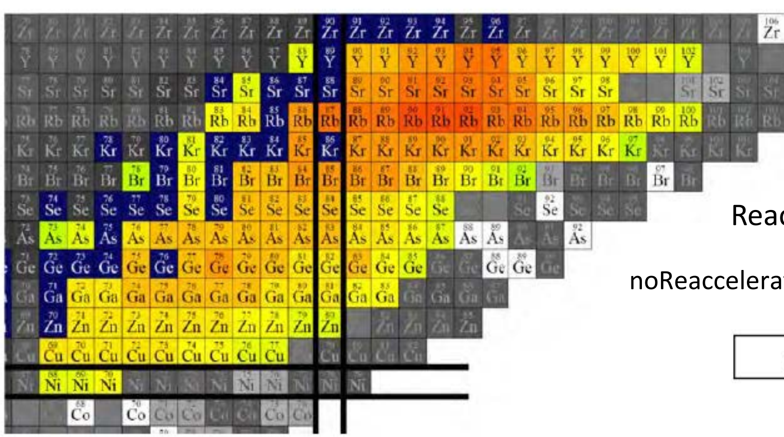
The Nuclear Landscape

- How do protons and neutrons make stable nuclei and rare isotopes?
- What are properties of neutron matter?
- What are the heaviest nuclei that can exist?



ISOL FACILITY

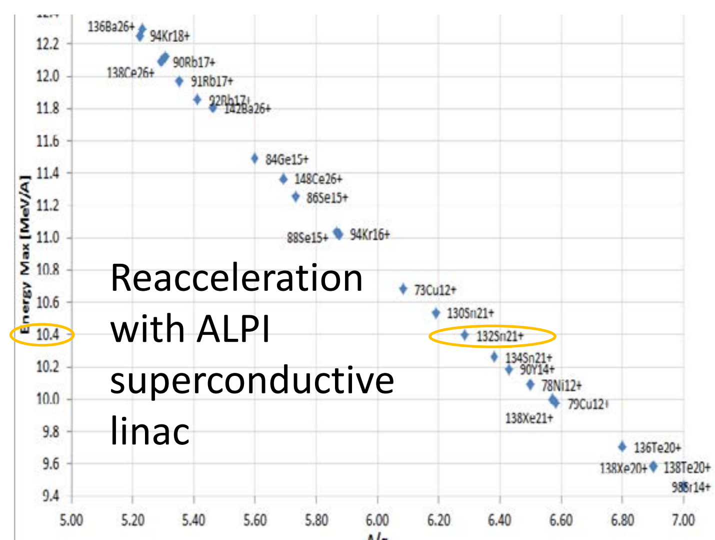




Reaccelerated beams

noReaccelerated beam rates: x10 - x50

Courtesy of T. Marchi



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:
10600 hours per year**

More than 5000 hours/year of proton beam available for applications

Beam sharing

	Proton beam	N.rs of SHIFTS	Beam on target: Total 10600 hours
ISOL 1	300μA 40MeV	10	2800
Irradiation 1	500 μA 70MeV	9	2500
Irradiation 2	500 μA 70MeV	10	2800
ISOL 2	300 μA 40MeV	9	2500
Maintanance		7	7x14x24= 2350
Cyclotron Operation		19	19x12x24= 5462 esperiment 19X2x24= 912 beam preparation

SPES: Target Power test @ iThemba Lab

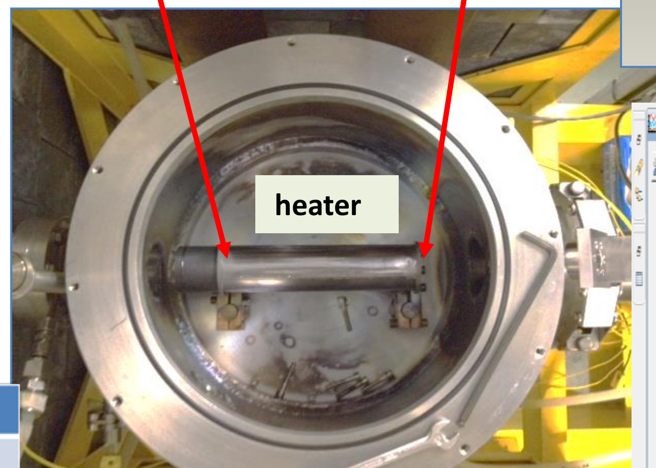
May 15, 2014

SPES target **in-beam power test** (SiC target)

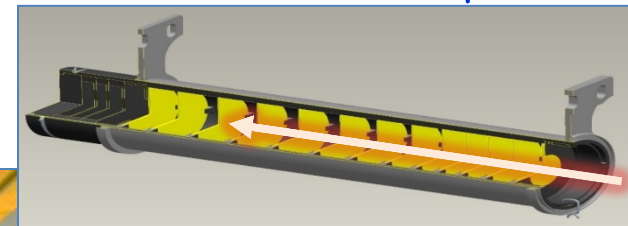
Heater power compensated by proton beam.

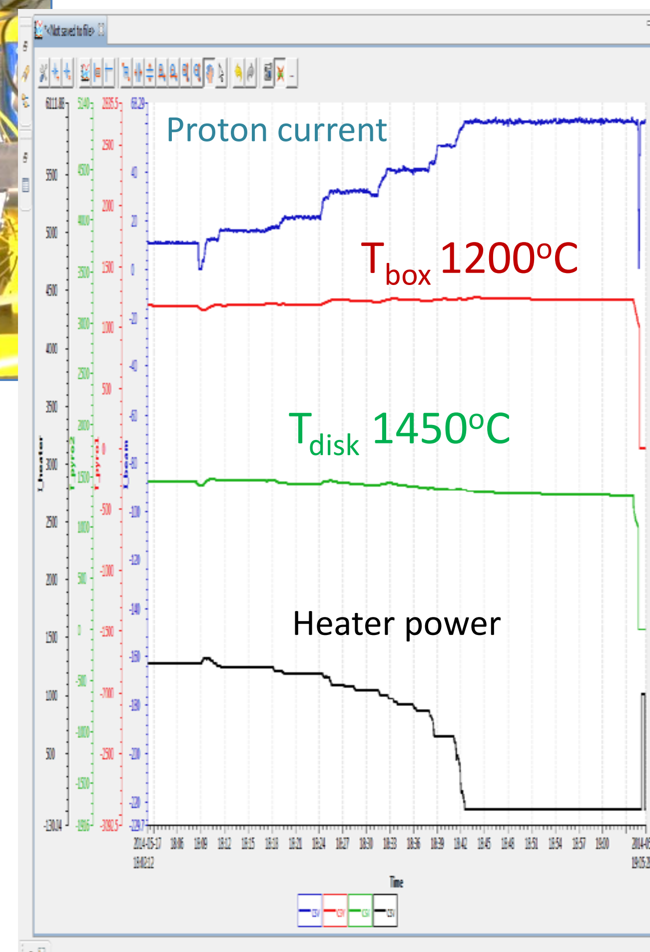
- Up to **4 kW proton** beam in target.
- **Stable temperatures**
- **Stable vacuum** (3 10^{-5} mbar)

T_{box} T_{disk}



Proton beam 66MeV 60 µA





Measure [°C]	Estimated by FEM model [°C]
1° disk: 1365 ± 30°C	1390
Box: 1230 ± 25°C	1267
Dump on chamber: 728°C ± 10°C	750

Thanks to Rob, Lowry and all the **iThemba_Labs Cyclotron** staff

Why 1/20000? An example

Ref case: $^{132}\boldsymbol{Sn}$ produced by LIS

Zoom of the nuclide chart

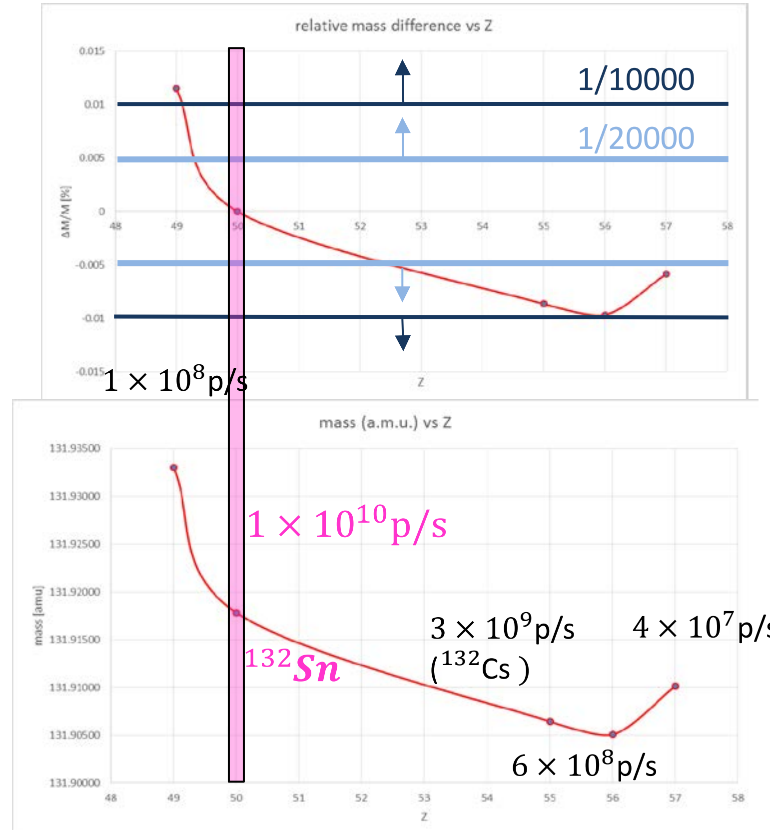
Z\A	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143
42	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	0.00E+00	0.00E+00	0.00E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	0.00E+00	0.00E+00	0.00E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	0.00E+00	0.00E+00	0.00E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	0.00E+00	0.00E+00	0.00E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	0.00E+00	0.00E+00	0.00E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	3.60E+09	2.52E+09	4.20E+09	3.85E+09	4.19E+09	2.98E+09	2.52E+09	1.72E+09	1.26E+09	3.03E+08	1.73E+08	9.94E+07	2.31E+07	1.93E+06	1.96E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	9.96E+09	1.84E+10	1.29E+10	2.10E+10	1.57E+10	2.36E+10	1.85E+10	2.42E+10	2.03E+10	2.43E+10	1.63E+10	1.30E+10	2.60E+09	2.52E+09	1.25E+09	2.09E+08	2.79E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	0.00E+00	3.15E+06	1.95E+07	2.23E+07	1.24E+08	1.88E+08	5.05E+08	7.47E+08	1.40E+09	2.06E+09	3.75E+09	3.15E+09	7.56E+09	8.11E+09	1.29E+10	1.31E+10	1.87E+10	1.16E+10	1.44E+10	1.10E+10	1.33E+10	7.76E+09	1.13E+10
56	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E+06	1.51E+06	1.66E+07	6.34E+07	1.01E+08	2.93E+08	3.98E+08	5.74E+08	1.05E+09	2.01E+09	2.14E+09	4.07E+09	4.33E+09	6.79E+09	4.82E+09	6.24E+09	4.48E+09	6.78E+09	3.08E+09
57	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.77E+06	1.13E+07	3.62E+07	4.22E+07	1.33E+08	2.09E+08	4.46E+08	5.68E+08	1.03E+09	1.40E+09	2.23E+09	1.66E+09	2.41E+09	1.96E+09	2.32E+09
58	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

HRMS selected species

1/200 selected species

WF selected species

Nominal beam



If mass separation is 1/10000, we can separate just one isobar from the nominal beam. Instead, a separation in mass of over 1/20000 ensures a “clean selection”, in particular versus ^{132}Cs.

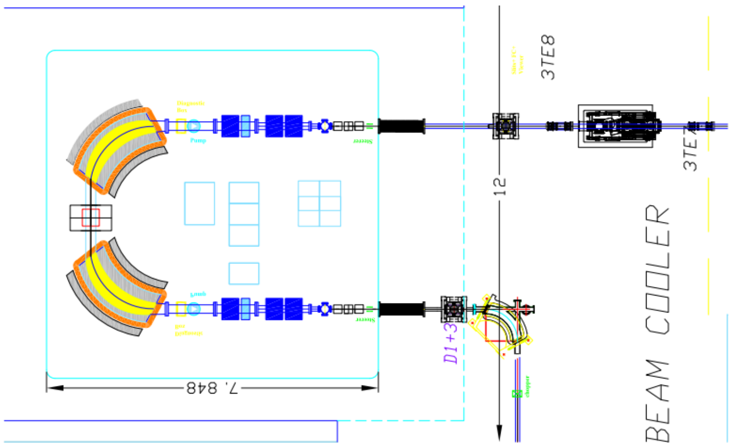
High Resolution Mass Separation

Mainly based on CARIBU-HRMS design, ANL (USA)

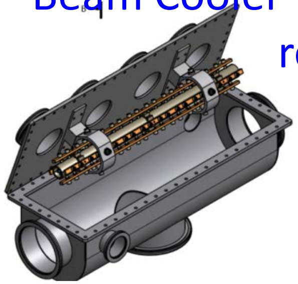
^{132}Sn beam in simulations

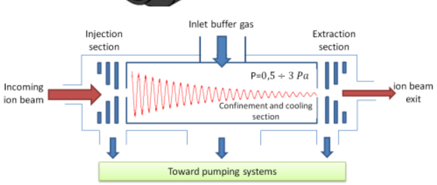
Multitracking effects analysis (LNS-LNL)
Input parameters:
- Energy= 260 KeV (-220 kV HV platform)
- **ΔE= ± 1 eV**
- **Emittance rms = 0.68 πmm mrad**
- Mass resolution (design): 1/40000

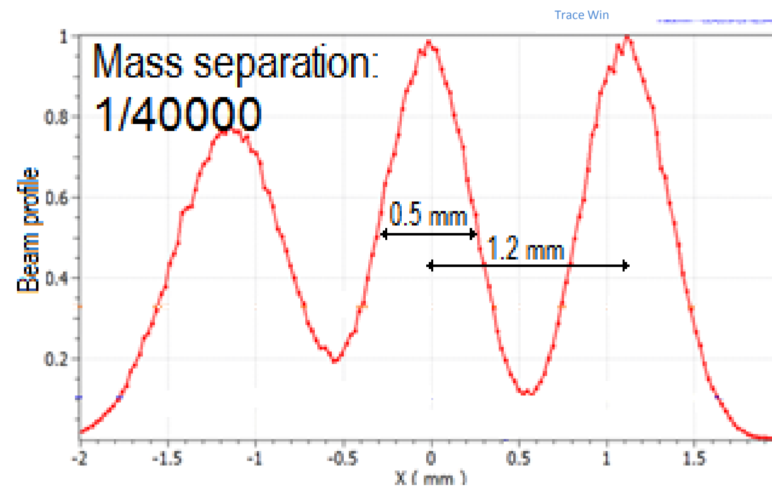
} **By Beam Cooler**



Beam Cooler to match the HRMS input requirements

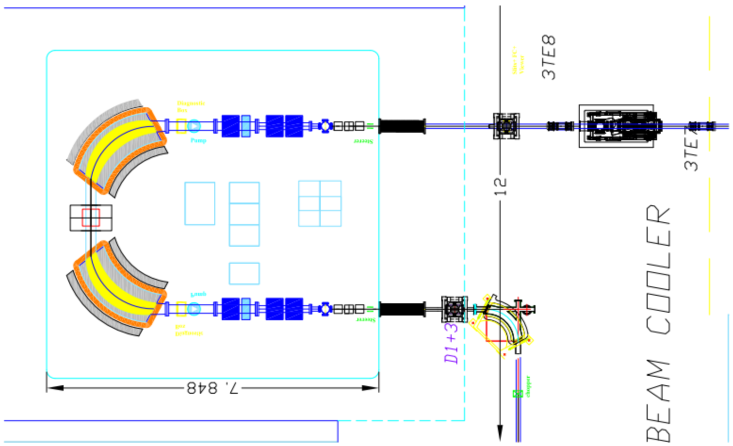






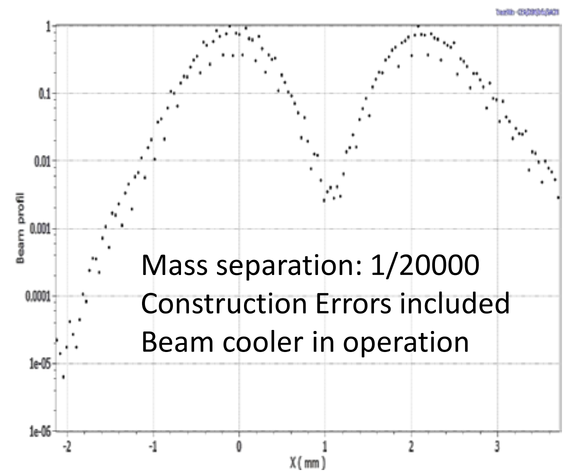
LNL – LNS collaboration

High Resolution Mass Separation

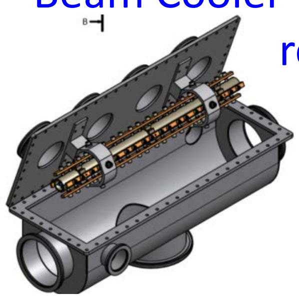


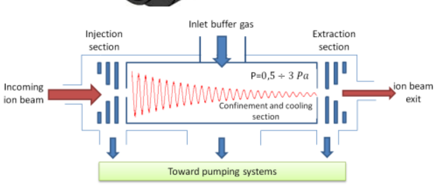
^{132}Sn beam in simulations

Type	Max range
Misalignment (x,y) (*no effect on R*)	0.5 mm
Tilt (xy,yz,xz)	0.1°
Field error	0.05%
All errors	0.25 mm, 0.05°, 0.025%



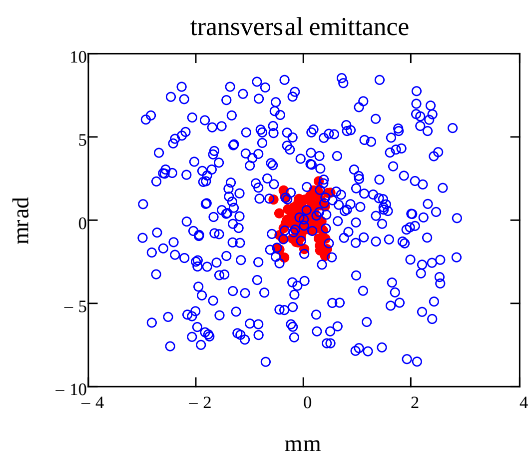
Beam Cooler to match the HRMS input requirements





COOLBEAM experiment financed by INFN-CSN5, 2012→2015

Collaboration: LNL-LNS - Milan



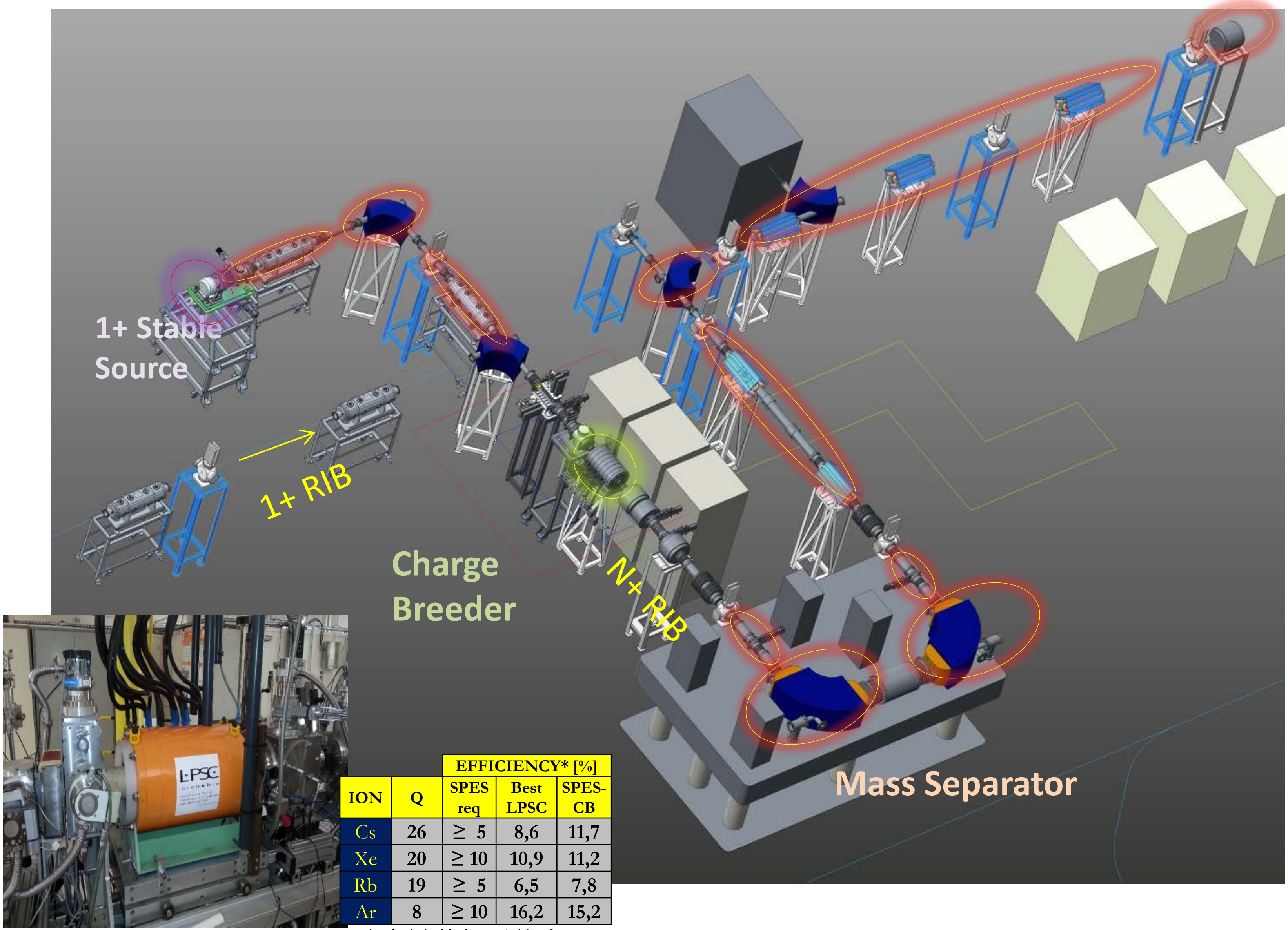
Input T emittance

Output T emittance

M.Maggiore

Exotic Beam reacceleration

Tender for beam line and mass separator (n+ beam line): 1.5M€



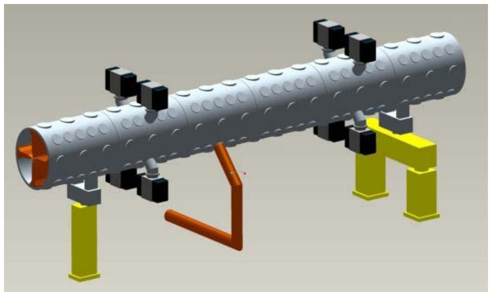
ION	Q	EFFICIENCY* [%] SPES req	Best LPSC	SPES-CB
Cs	26	≥ 5	8,6	11,7
Xe	20	≥ 10	10,9	11,2
Rb	19	≥ 5	6,5	7,8
Ar	8	≥ 10	16,2	15,2

*results obtained for the same 1+ injected current

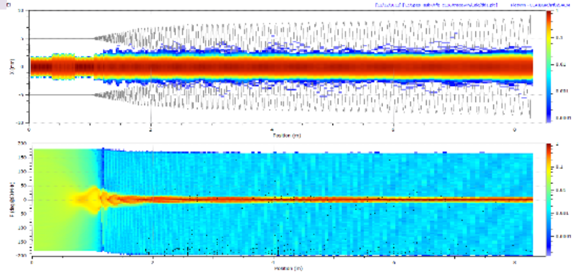
Exotic Beam reacceleration: room temperature RFQ

SPES exotic beams for science

Mechanical layout of the **RFQ**

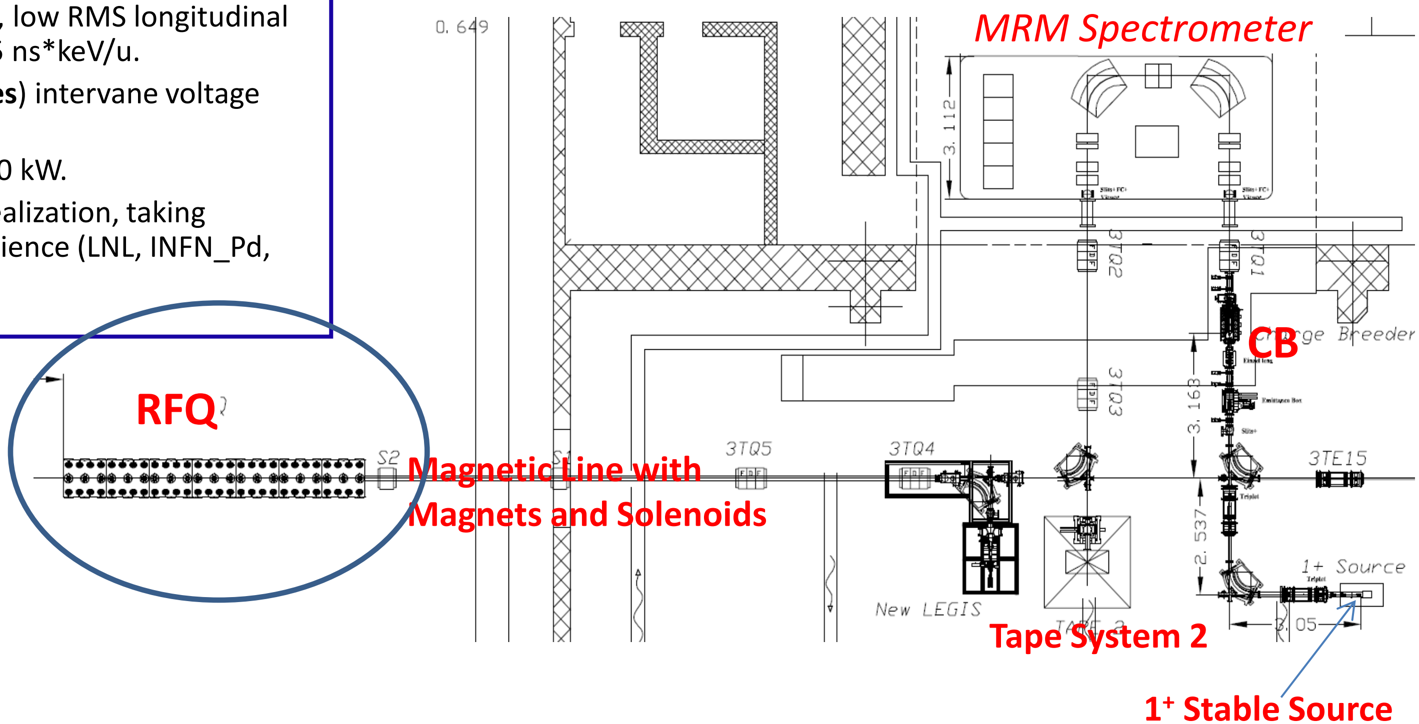


Physics design



High power RF Coupler 200kW 100% duty cycle

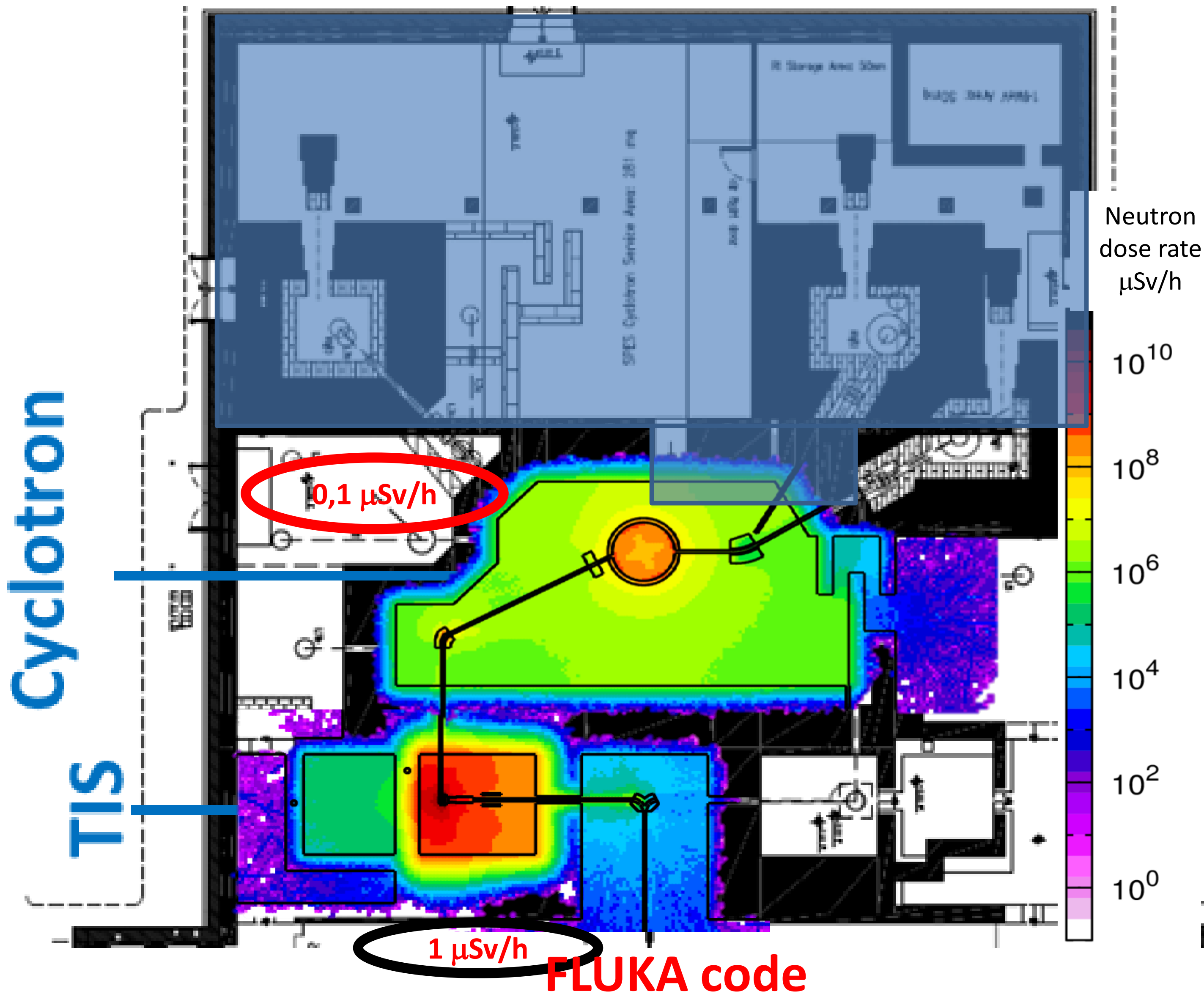
- Energy 5.7 → 727.3 [β=0.0395] KeV/A (A/q=7)
- Frequency 80 MHz
- Beam transmission >95%, low RMS longitudinal emittance at output: 0.15 ns*keV/u.
- Length 695 cm (**7 modules**) intervane voltage 63.8 – 85.8 kV
- RF power (four vanes) 100 kW.
- Mechanical design and realization, taking advantage of IFMIF experience (LNL, INFN_Pd, Bo, To).



E. Fagotti, A. Pisent

Layout and shielding results

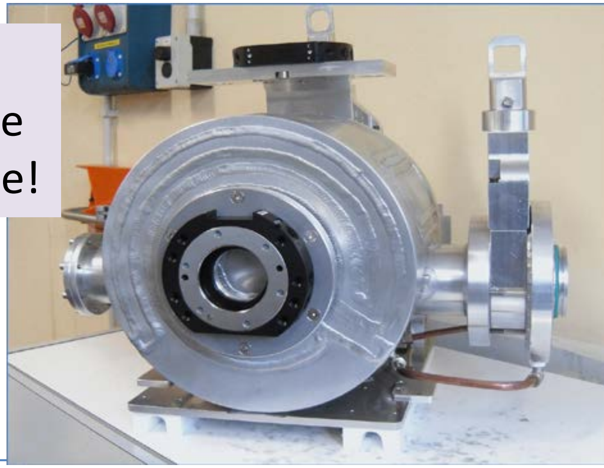
Monte Carlo simulations for dose rates estimation and radioactivity analysis in critical areas of the facility: target bunker, cyclotron vault and RIB transport beam line

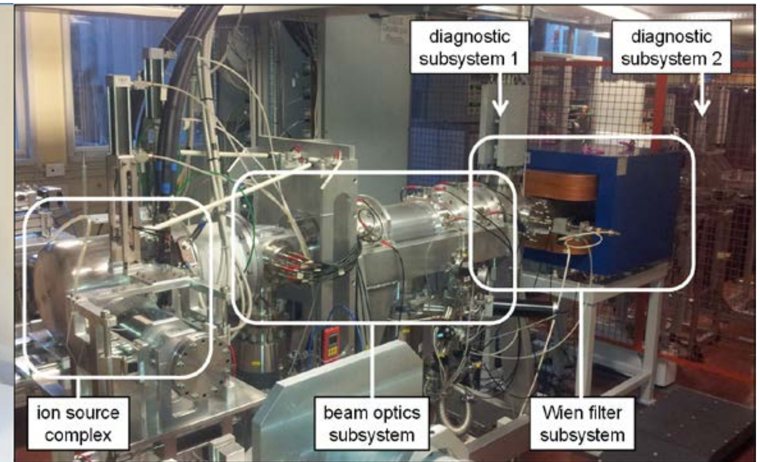


Radioactivity: The critical points

1) Neutron activation

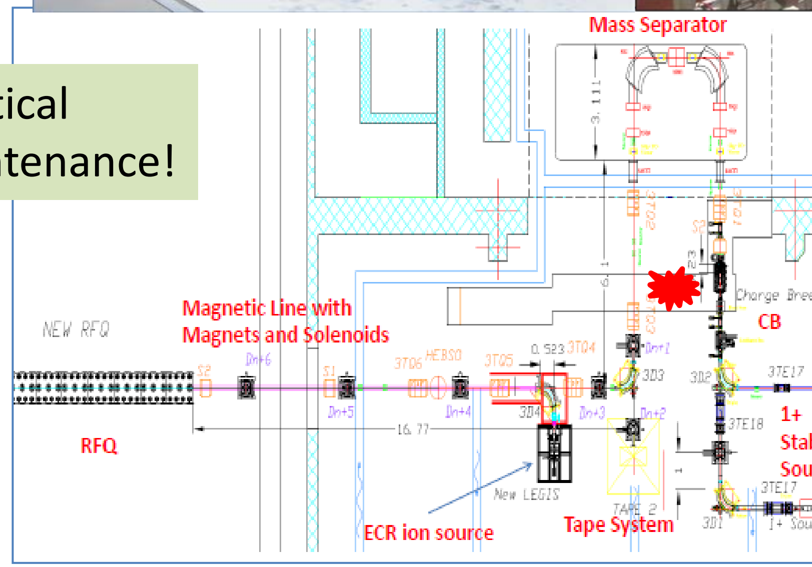
Critical
for damage
and storage!

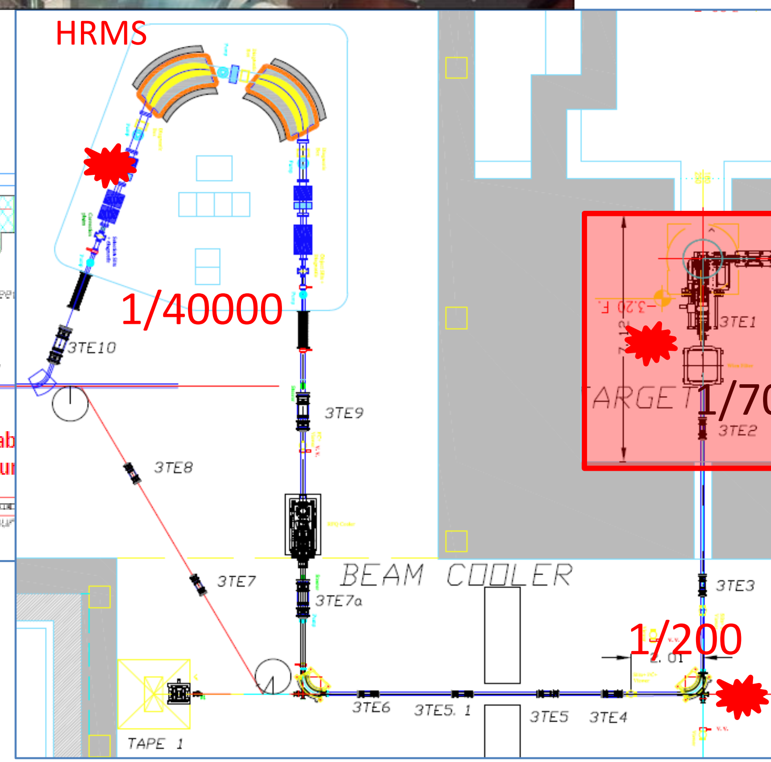


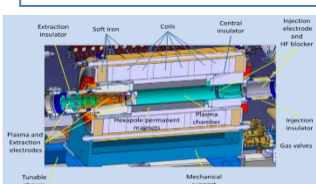


2) Radioactive beam hot-spot

Critical
for maintenance!

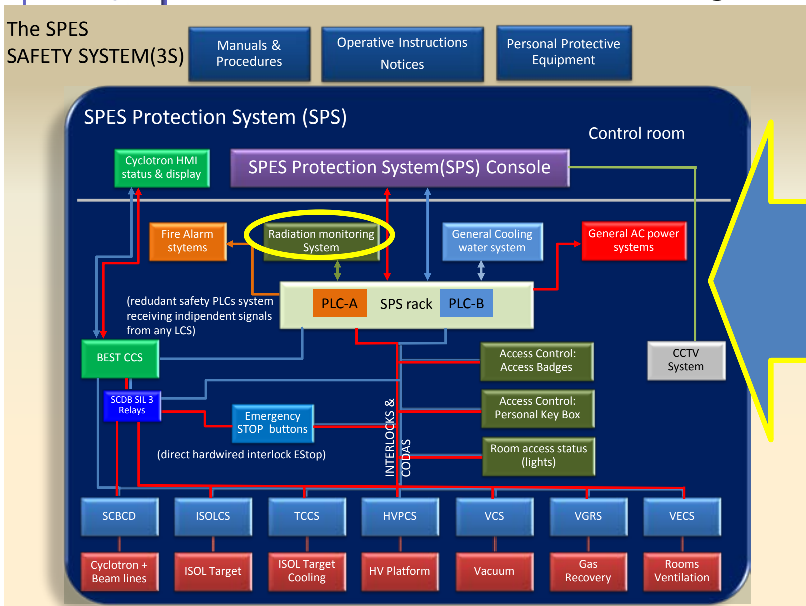


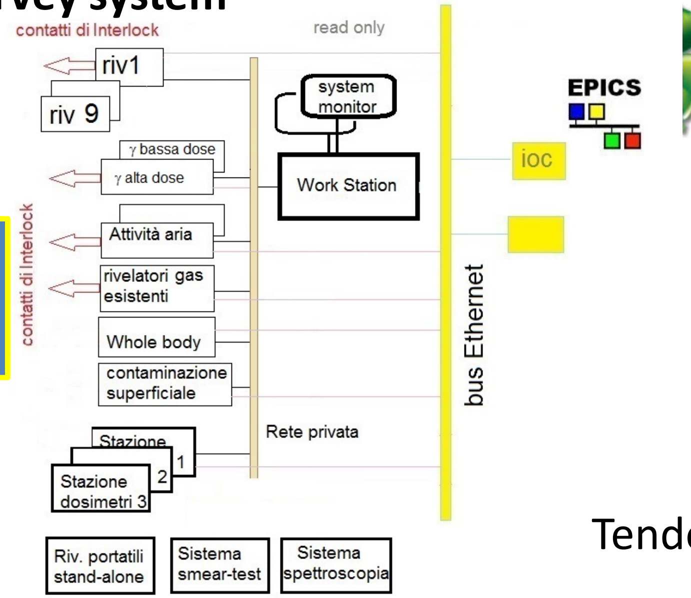




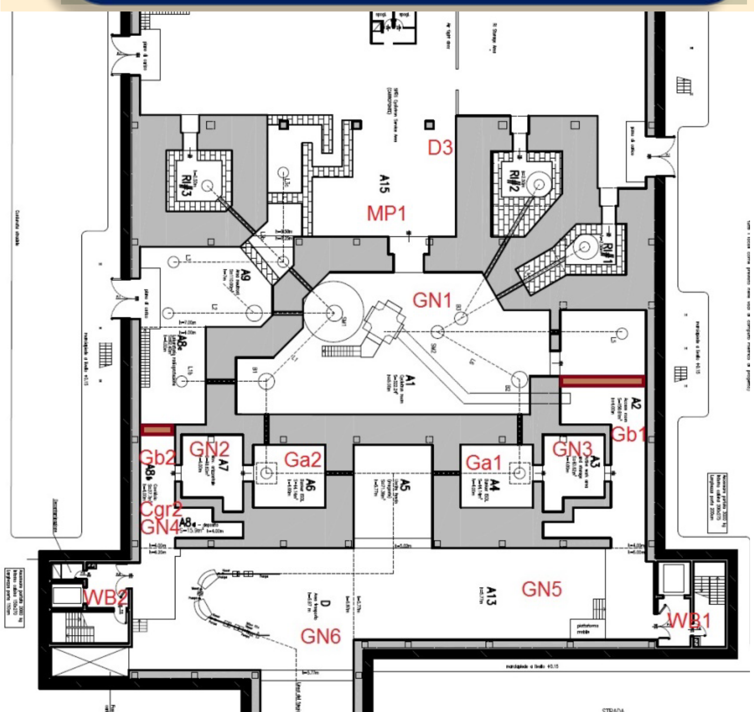
Charge Breeder:
Loss of 90% of
radioactive beam

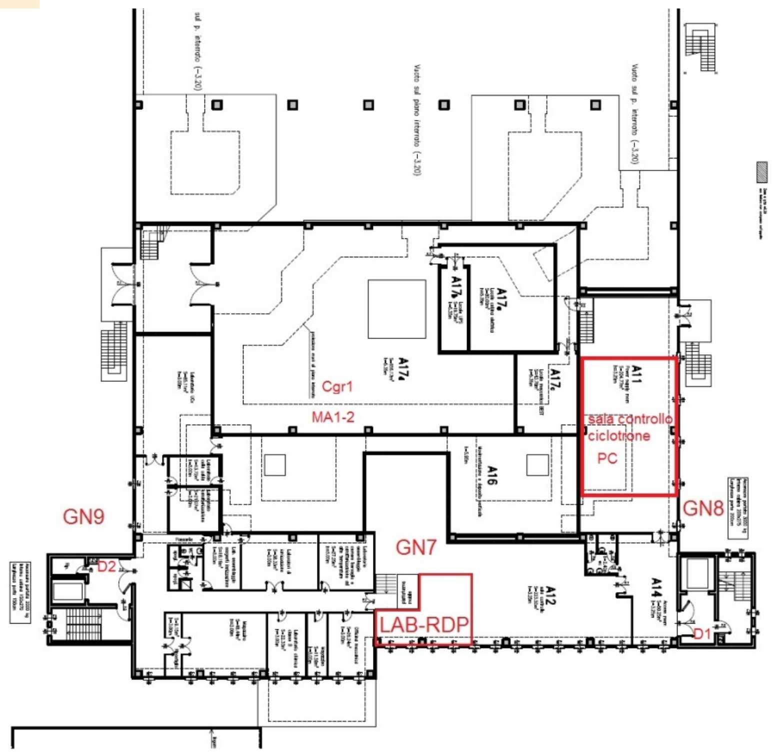
Radiologic survey system



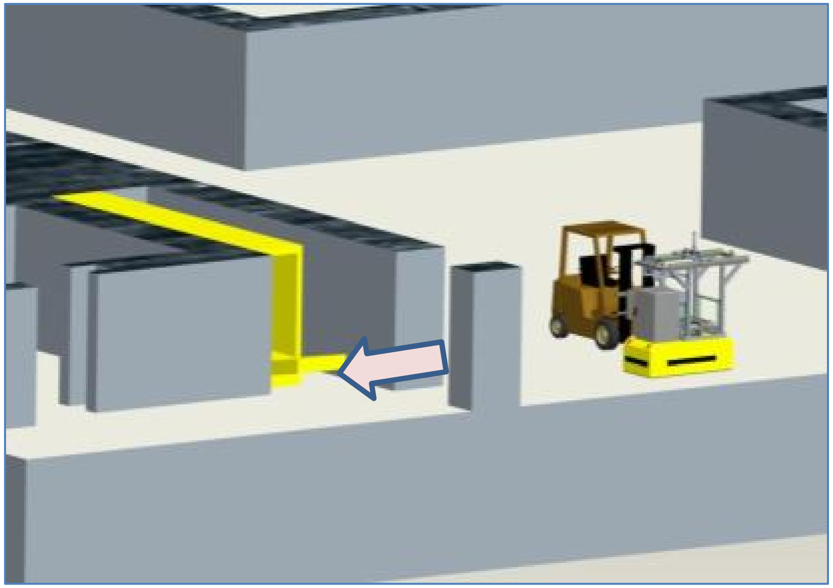


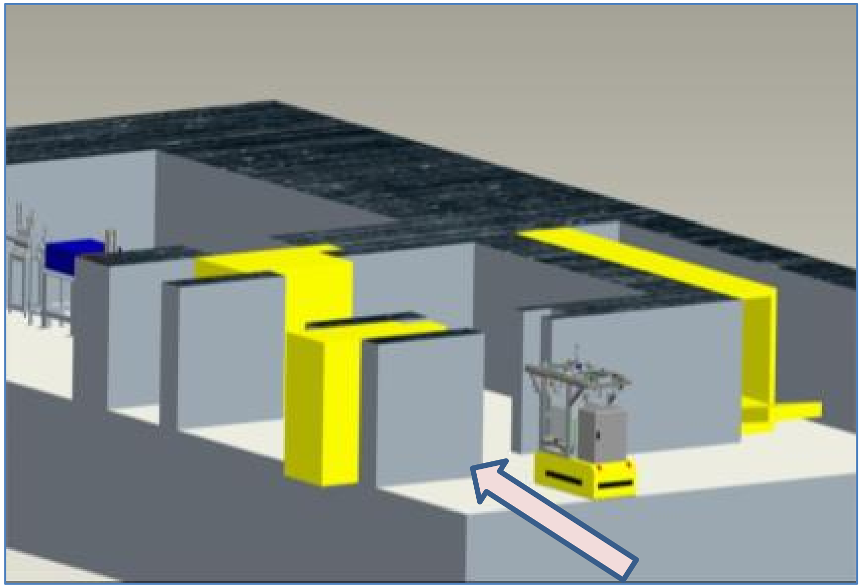
Tender for 1.2 Meuro

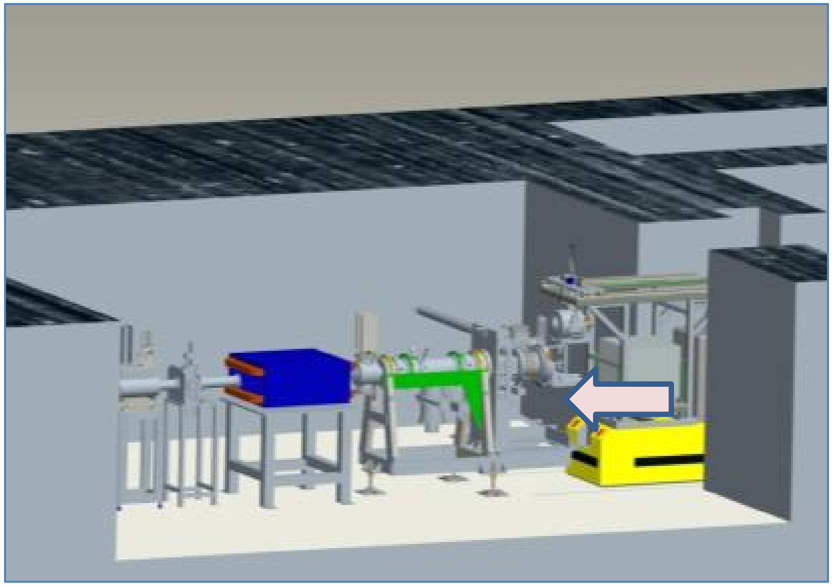


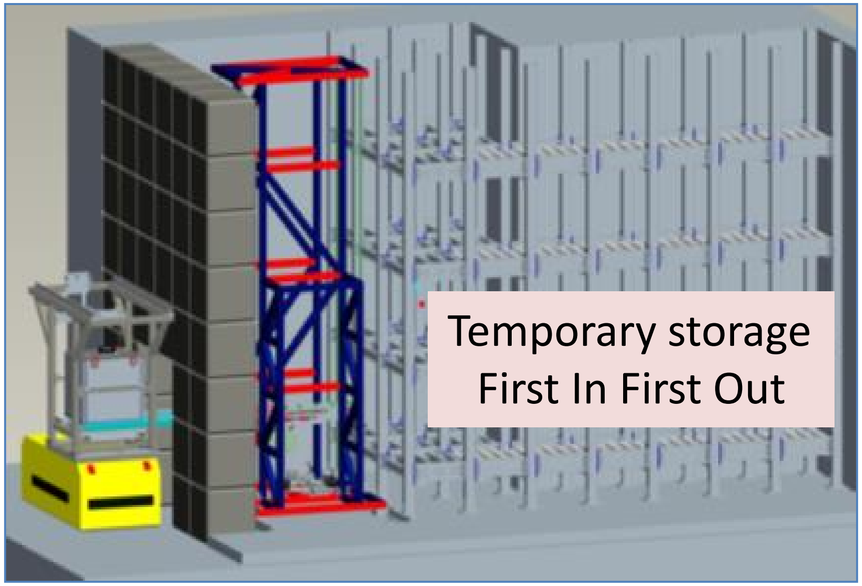


SPES Horizontal Handling system



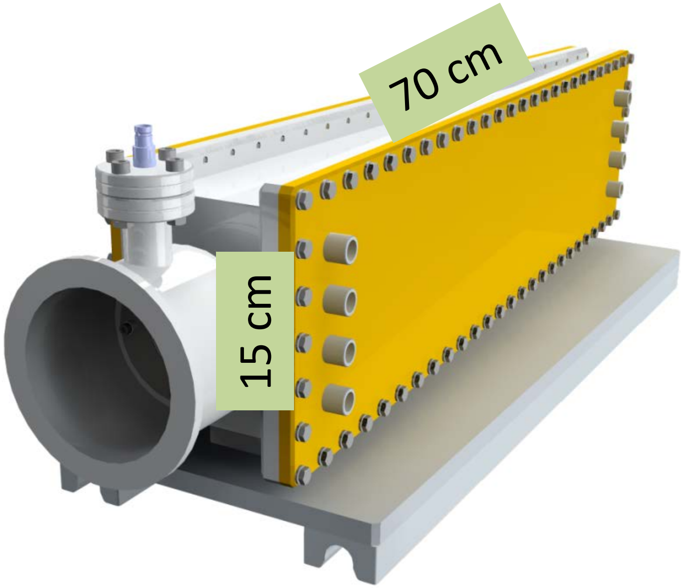




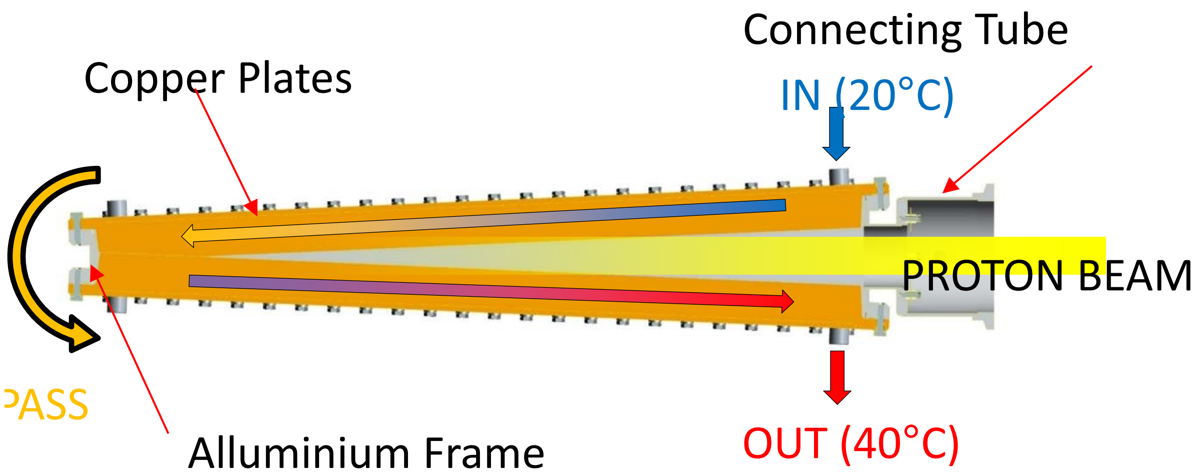


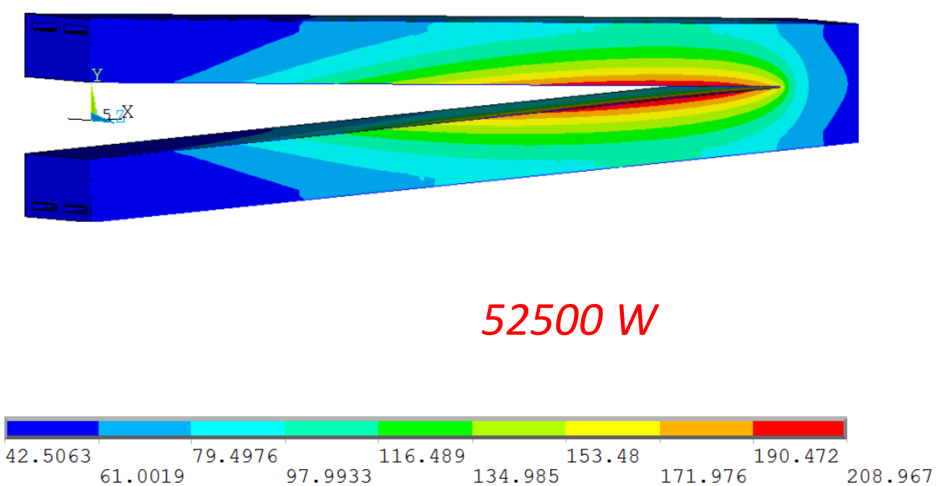
WG-04

High Power Beam Dump



50 = kW proton beam (≈ 100 W/cm³ at 150ºC)





Cooling system:

Flow	*0,16 l/s*
Velocity	*1,25 m/s*
ΔT	*20 °C*

Input thermal power:

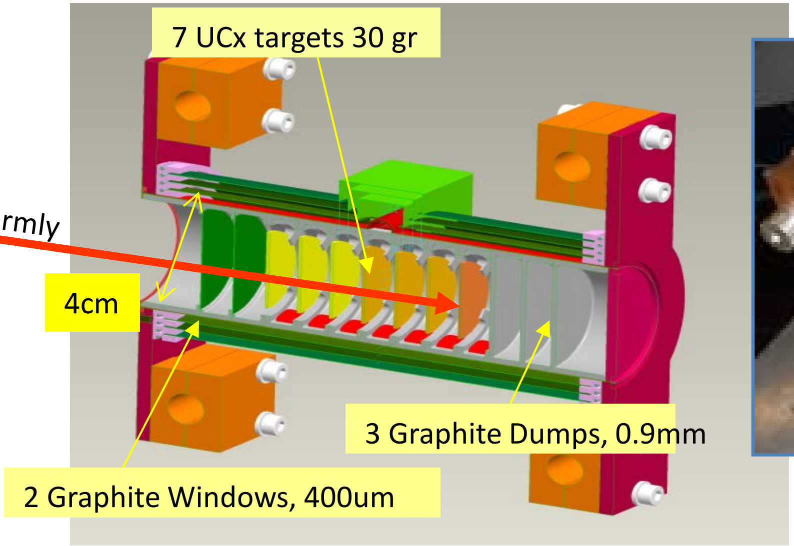
Energy	70 MeV
Current	750 μA
Power	52500 W

High power target at SPES

Cooling by irradiation

ISOL target
operation temp: 2000°C
10 kW (1kW/cm^3)
Multi disks, thick target

See Andrighetto talk



Cooling by micro channels

LENOS target
operation temp: 150°C
3 kW (3kW/cm^2, 300 kW cm^3)
Single element, 100μmthin target

See Mastinu talk