SPES Project

Selective Production of Exotic Species

Gianfranco Prete LNL-INFN
On behalf of the SPES Collaboration

ABNP 2014
Workshop on Accelerator based Neutron Production
April 14th-15th, 2014
Laboratori Nazionali di Legnaro (Padova), Italy

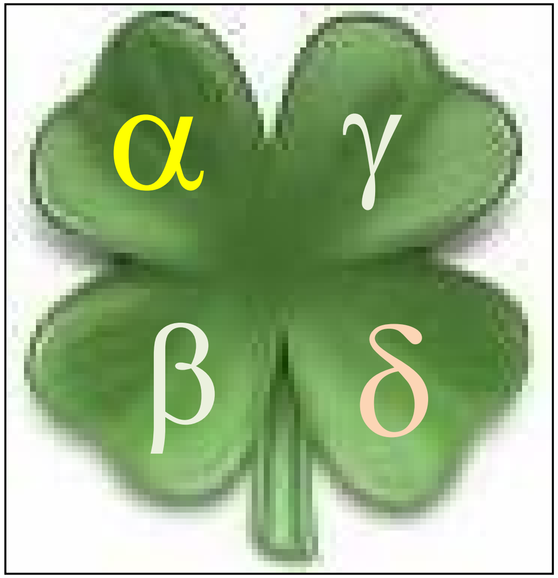
SPES project strategy

- **Develop a Neutron Rich ISOL facility delivering Radioactive Ion Beams at 10A MeV using the LNL linear accelerator ALPI as re-accelerator .**
- Make use of a Direct ISOL Target based on UCx and able to reach 10^{13} Fission/s (fission is the main reaction mechanism to produce n-rich isotopes).
- Develop an applied physics facility based on the technology and the components of the ISOL facility. Applications in medicine and neutron production.

Exotic nuclei

Production **ISOL facility** for Neutron rich nuclei by U fission 10^{13} f/s

Reacceleration high purity beam
Reacceleration up to ≥10 MeV/u



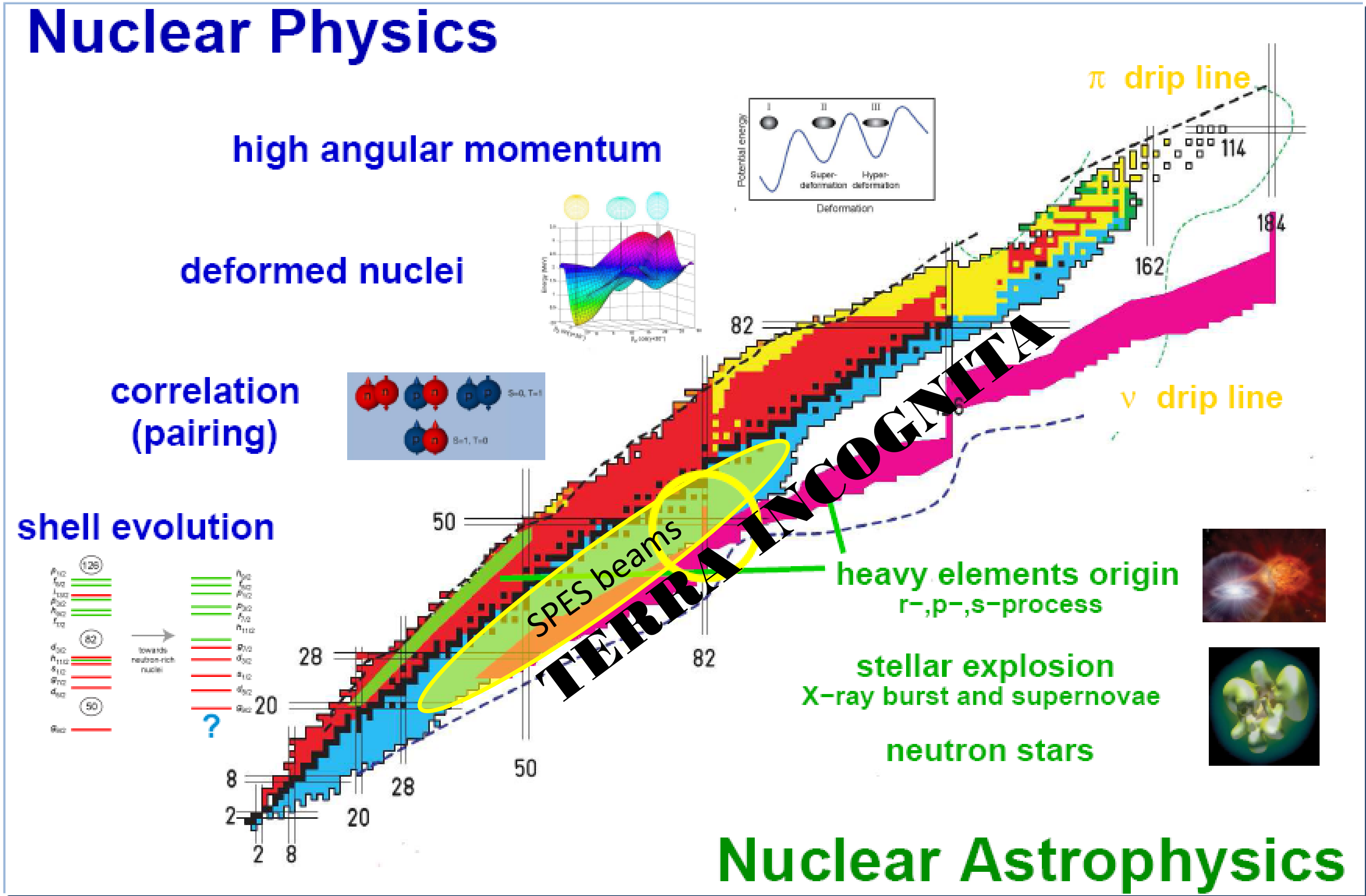
Applications

Radioisotope produduction & Medical applications (**LARAMED**, partially funded)

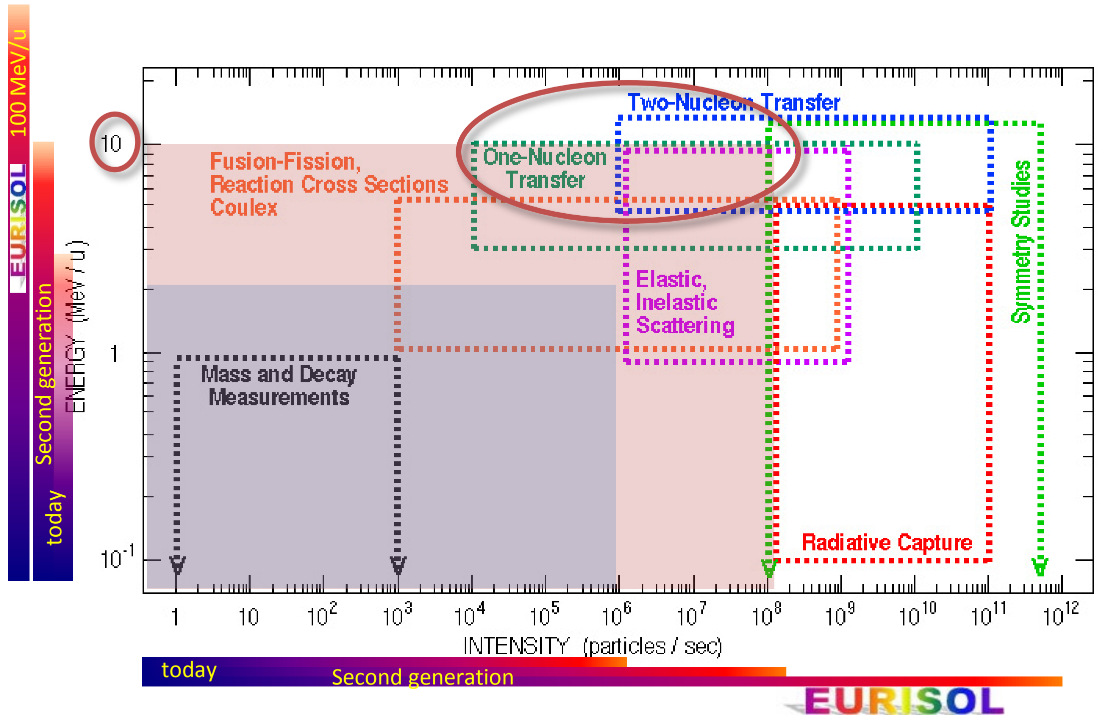
Proton and neutron facility for applied physics (**NEPIR**, preliminary design)

SPES

Selective Production of Exotic Species



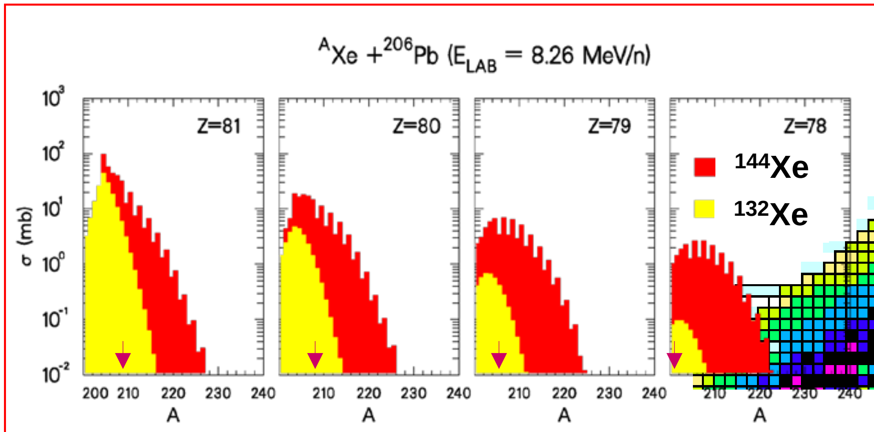
Neutron-rich radioactive beams and transfer reactions: a tool to investigate nuclei far from stability

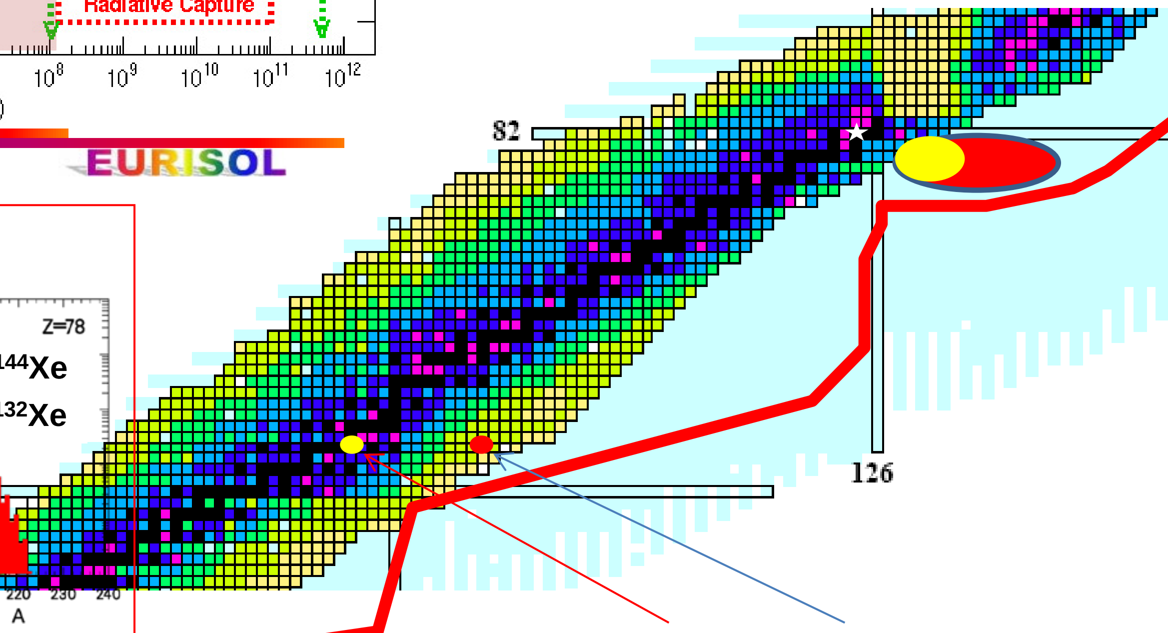


SPES: 10^{13}fission/s

E/A= 10AMeV, A=130

Target ^{206}Pb





Beam: ^{132}Xe ^{144}Xe

Coupled channel calculations (Grazing). G. Pollarolo

SPES scientific and technical collaboration

Second Generation ISOL facilities

European ISOL Roadmap toward

EURISOL

NATIONAL LEVEL

SPES Collaboration:
Acc.Techologies & Mechanics
(Mi, Bo, LNS, LNL, Pv, Tn, Pa)
Physics Programs & Detectors
(Ba, Bo, Ct, Fi, Mi, LNL, LNS, Pd, Tn, Na)

INTERNATIONAL LEVEL

EUROPE

LEA Colliga → France-Italy
(SPES, SPIRAL2,ALTO,EXCYT,FRIB, Coll. on Det.)

ISOLDE (CERN)→SPES (Italy)
(Radioprotection and nuclear safety ; Charge Breeding , Laser Ion Sources (RILIS), Target development and material characterization, Spectrometers and mass selectors , superconducting cavities)

LEA (in preparation)→ **Poland-Italy**

International collaboration on **Innovative Itinerant Detectors &** on **experimental proposals** to keep a **qualified** & **competitive level**
AGATA, FAZIA, PARIS, NEDA, GASPARD
Italy → France, England, Spain, Poland, Romania, Bulgaria, Turkey, Germany, Croatia, Sweden, Finland, Denmark.

WORLD

ORNL, iTHEMBA-Labs
ELI_np
RISP-KOREA

RIKEN, MSU-FRIBS, BARC, NEW DEHLI, DUBNA, MOSCA

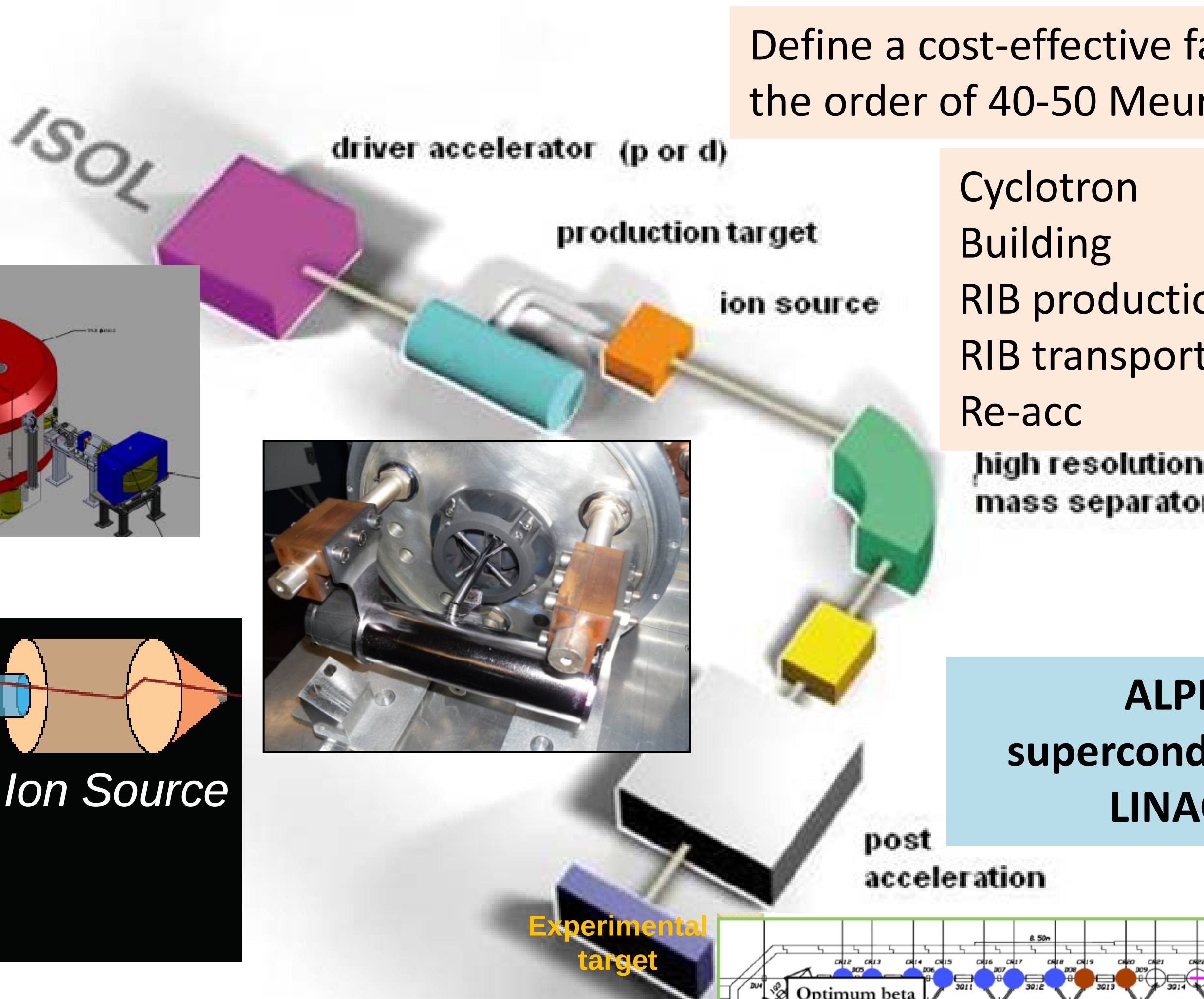
The SPES choice for the ISOL facility

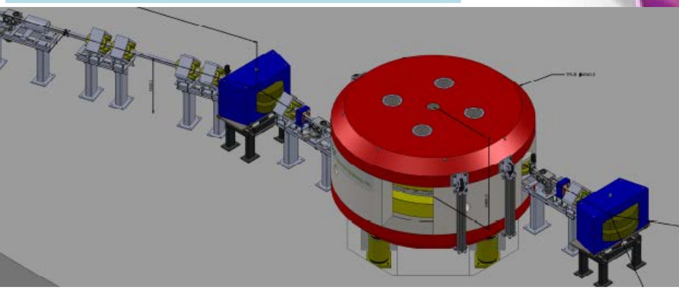
Proton driver: 70MeV
0.75 mA 2 exit ports

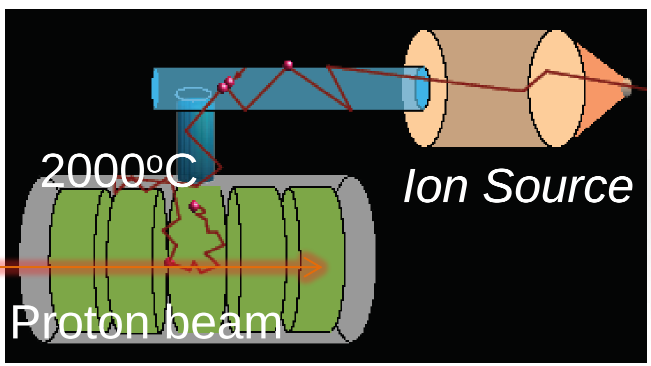
'Commercial' cyclotron

Define a cost-effective facility in the order of 40-50 Meuro

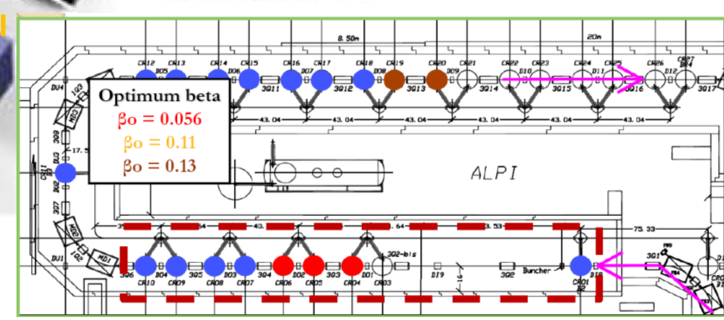
Cyclotron	10
Building	10
RIB production	5
RIB transport	15
Re-acc	10





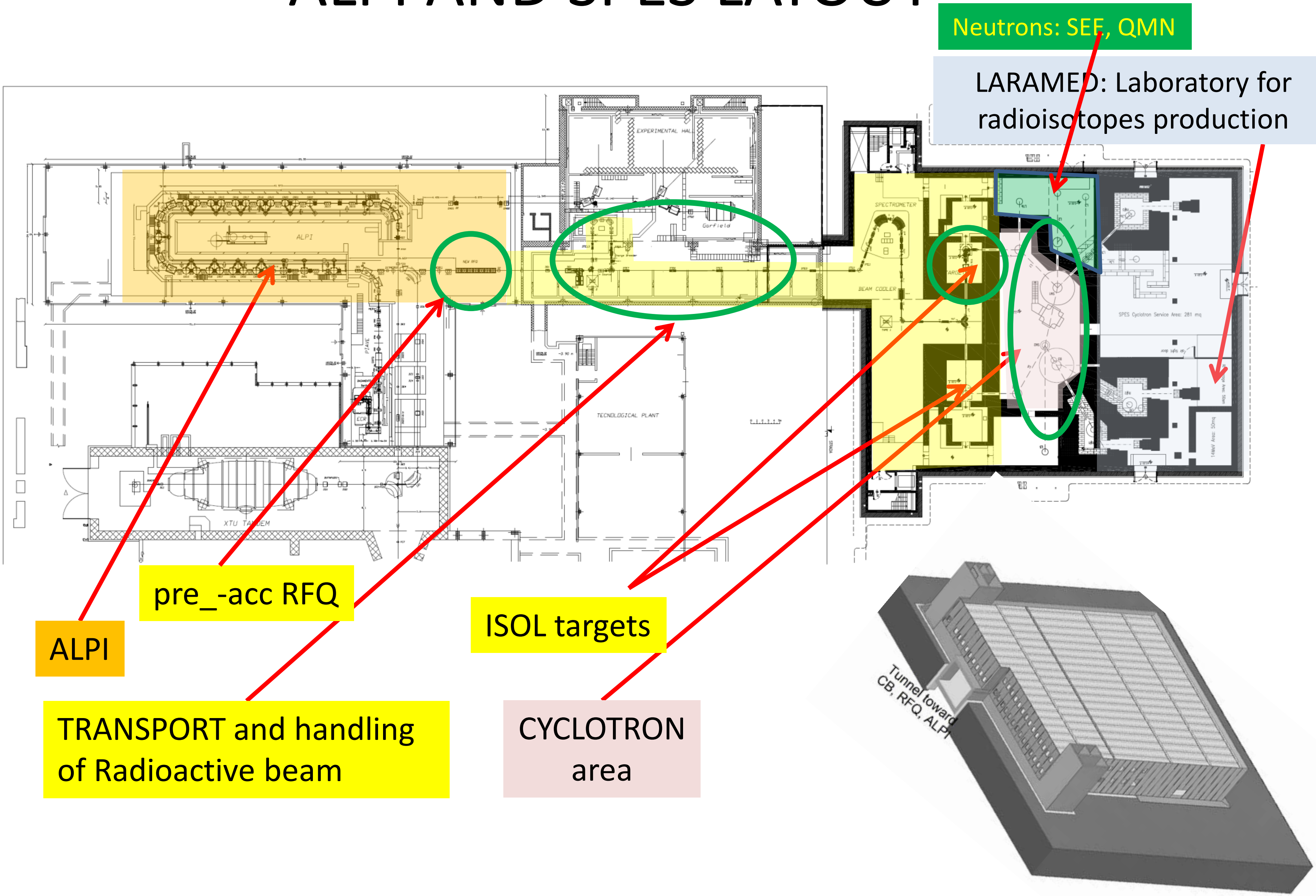


ALPI superconductive LINAC



NEW CONCEPT for direct target:
Multi-foil UCx designed to reach 10^{13} f/s

ALPI AND SPES LAYOUT

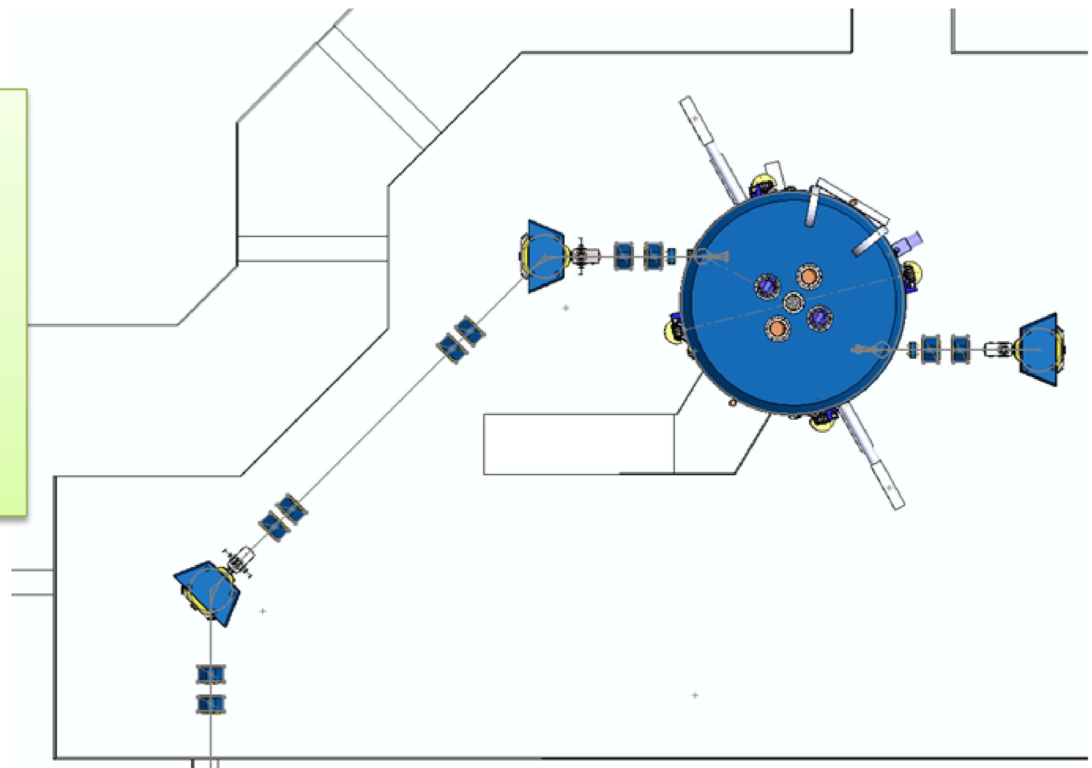


Cyclotron Schedule (2013-2014)

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

The Contract with BEST Theratronics provides for:

- Cyclotron
- Two exit channels
- High power beam transport line (up to SPES target)



Resonator tuned at: $f_o = 56.199600 MHz$

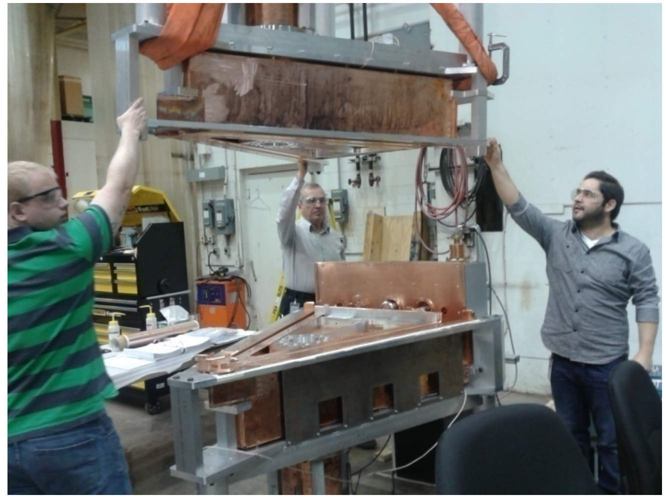
Input reflection coef: $S_{11} = -65 dB$ (average value -56dB)

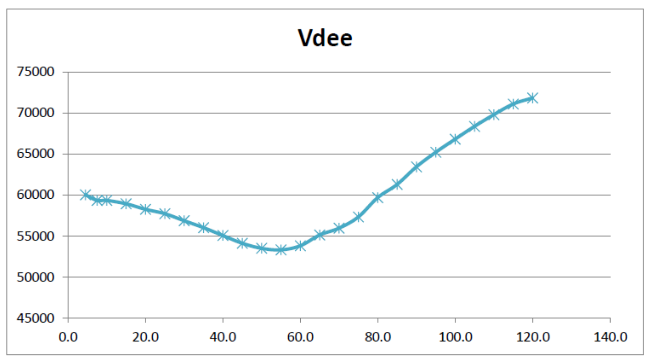
Quality factor loaded: $Q_l = 3156$ unloaded value expected to be approximate 6300.

$\Delta f_{coarse} = 30.8 kHz/mm$ 161mm

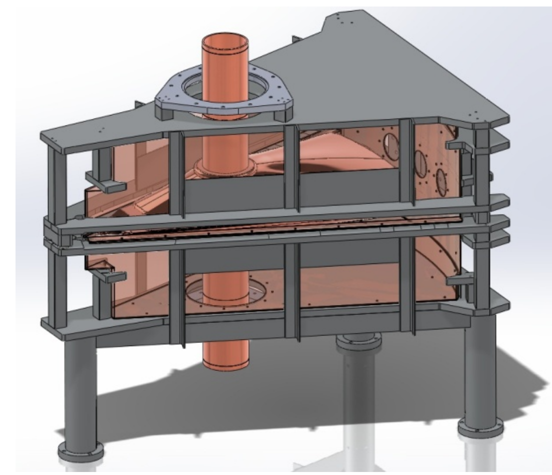
$\Delta f_{fine} = 30.0 kHz/mm$ ±10mm

The main magnet ready for the rf resonators





The D voltage distribution

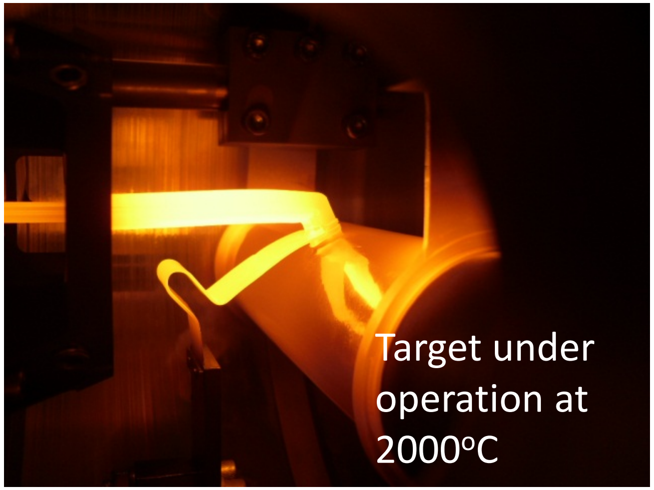


The first rf resonator successfully tested inside the test stand

Technical highlights

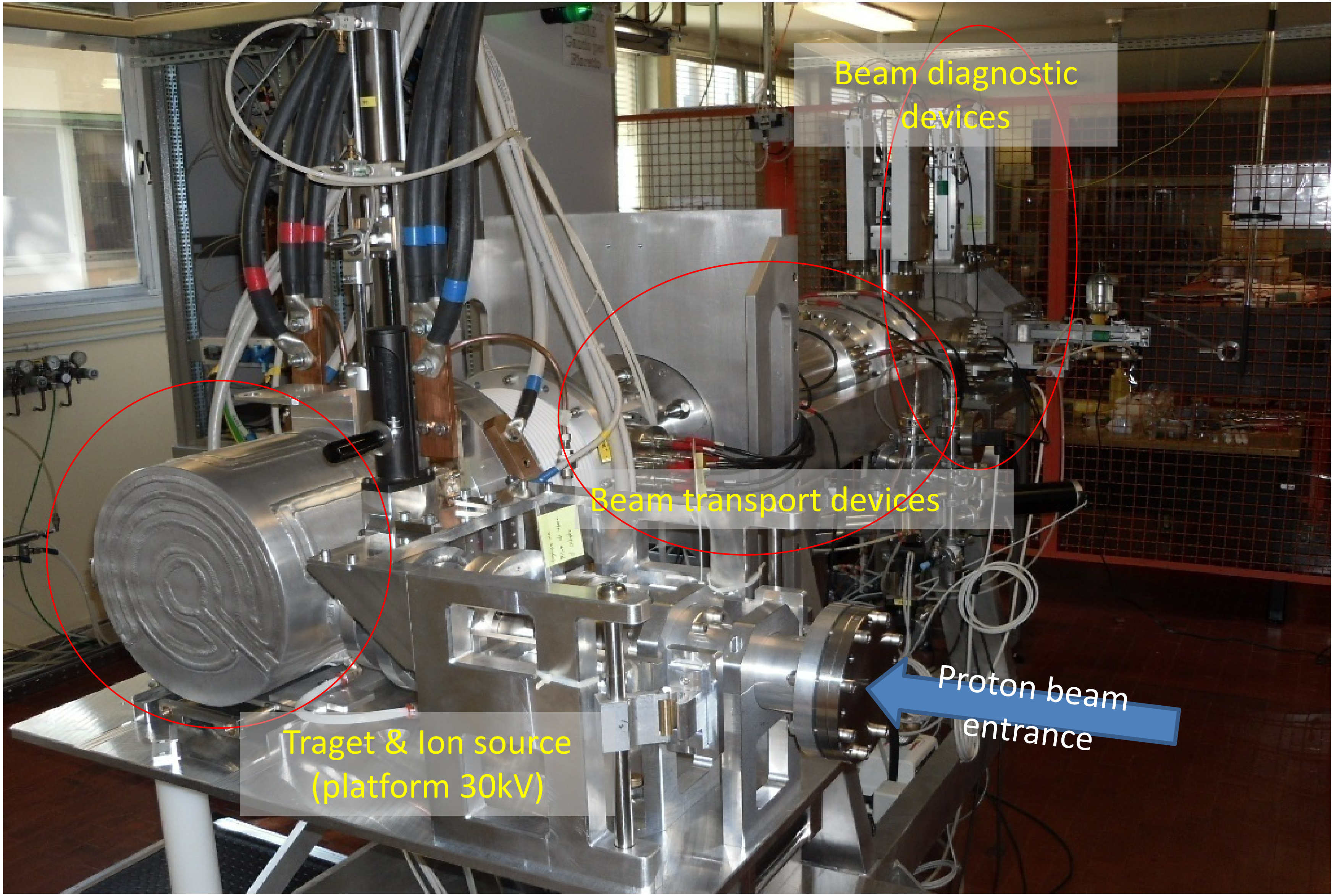
SPES DIRECT TARGET CONCEPT to operate with 8 kW proton beam

- Direct Target carefully designed to reach 10^{13} fissions/s with 8 kW proton beam. (Thermo-mechanical considerations)
- Prototype under operation.
- Fully developed front-end following ISOLDE design.
- **In beam test scheduled at iThemba labs. (May 2014, power test with proton beam)**



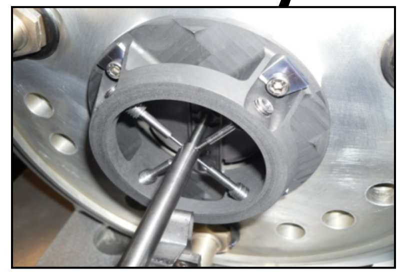
WP03: Ionization measurements

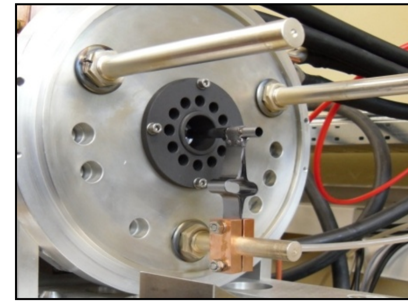
Front end running since June '10



Technical highlights

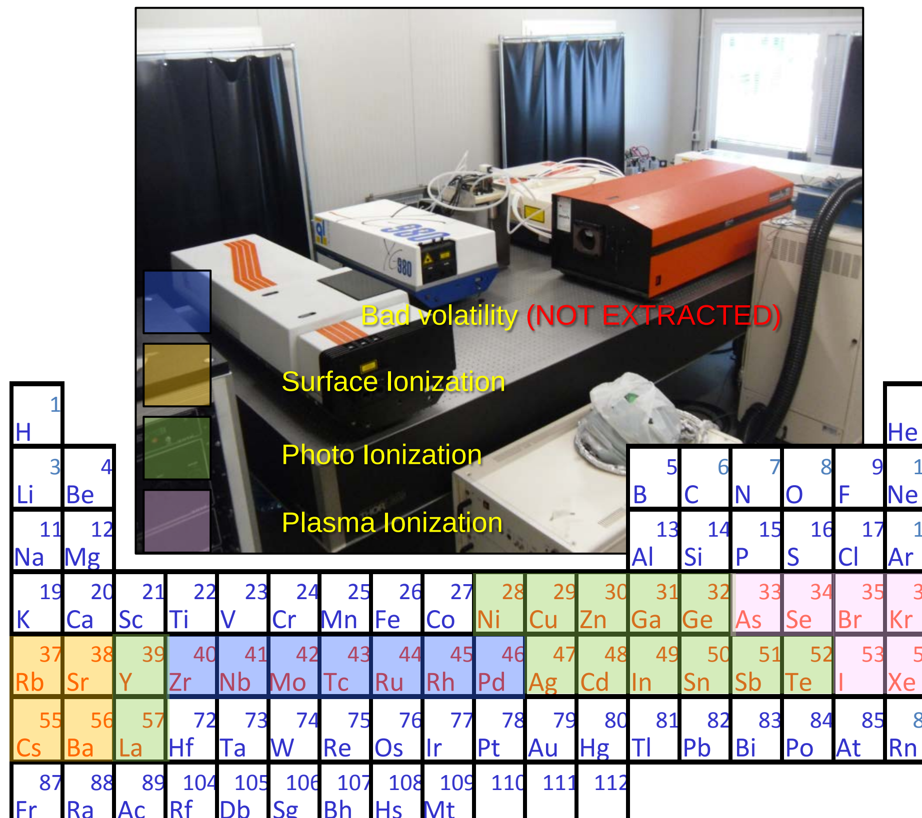
Ion sources and Laser laboratory





Development of ion sources able to ionize the full set of produced isotopes. Pointing to SELECTIVE ionization.

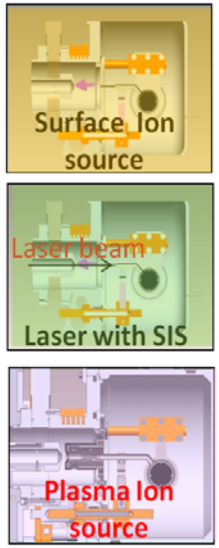
- Surface ionization and plasma ion source was developed and are under laboratory test and characterization.
- A new laser laboratory was settled at LNL to develop the resonant laser ionization ion source. Work in collaboration with Pavia University, participation to ENSAR2 JRA.

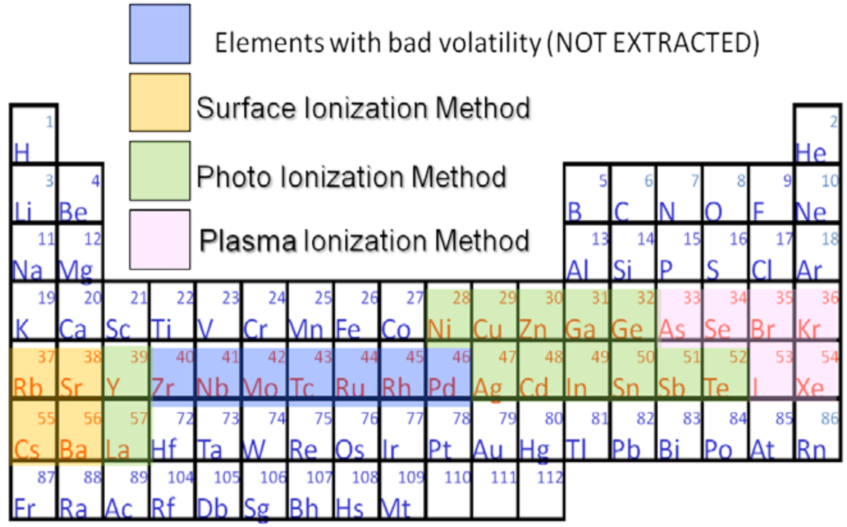


SPES: Target materials & Ionization Methods

UCx target

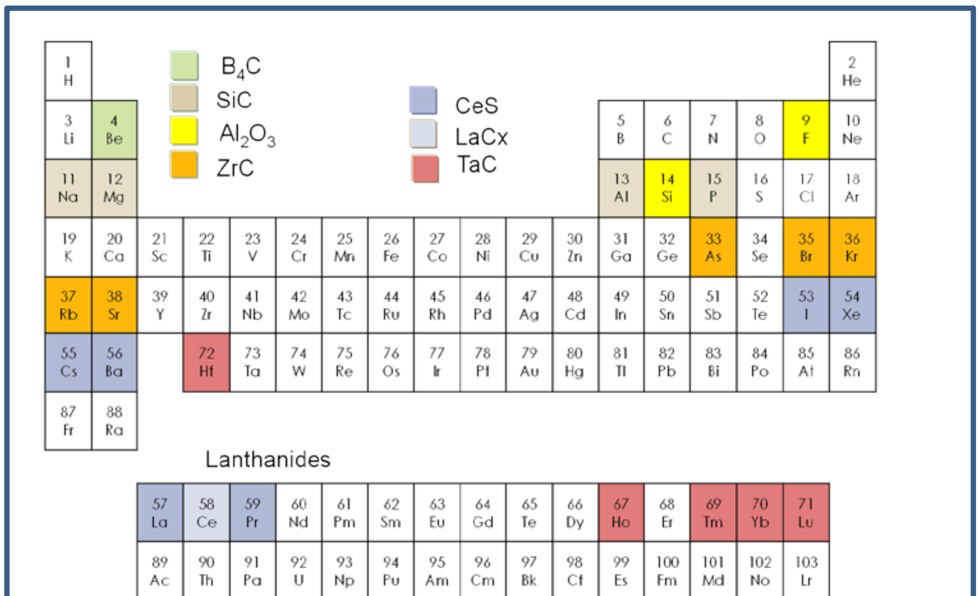
Proton induced reactions





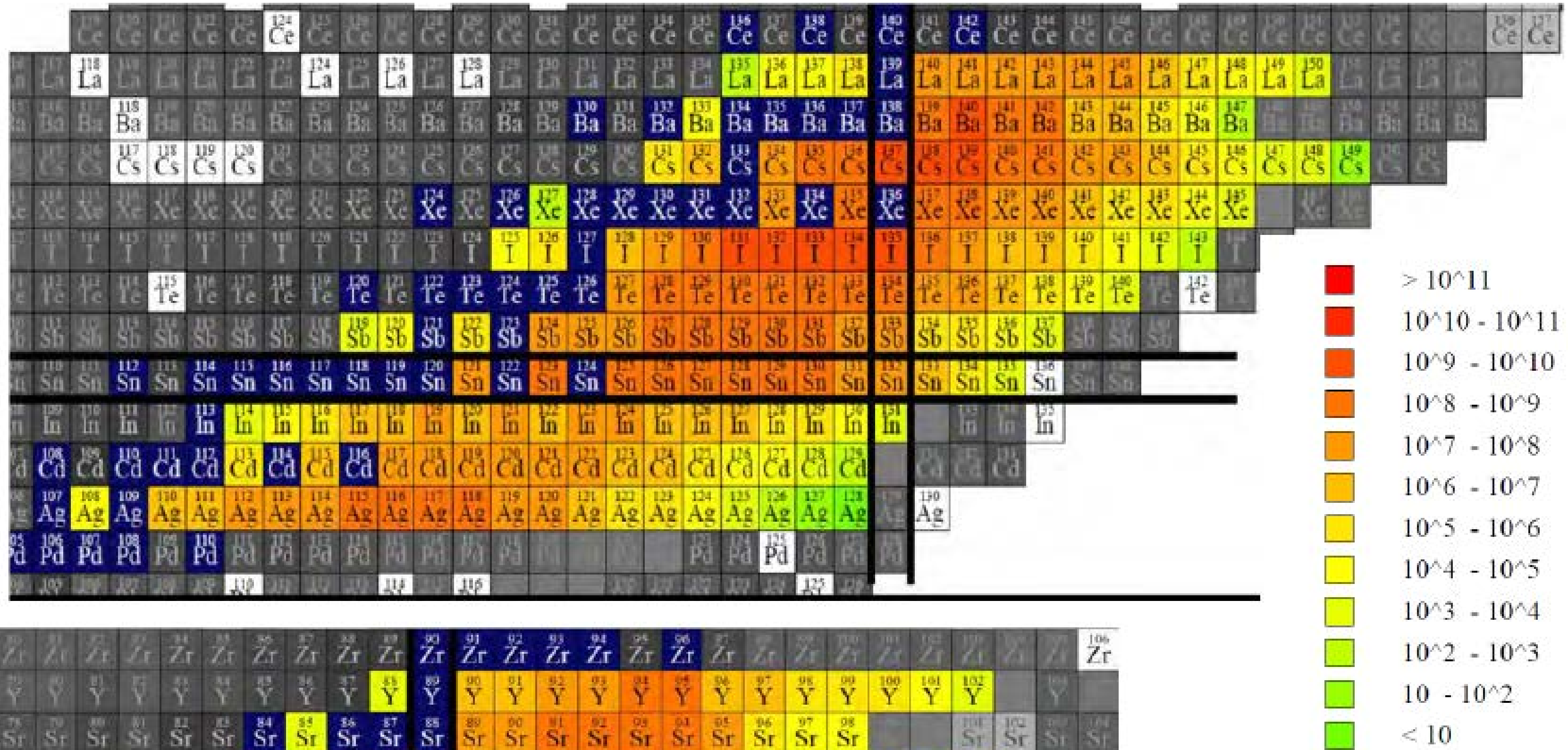
Main fission (p-> ^{238}U) fragments

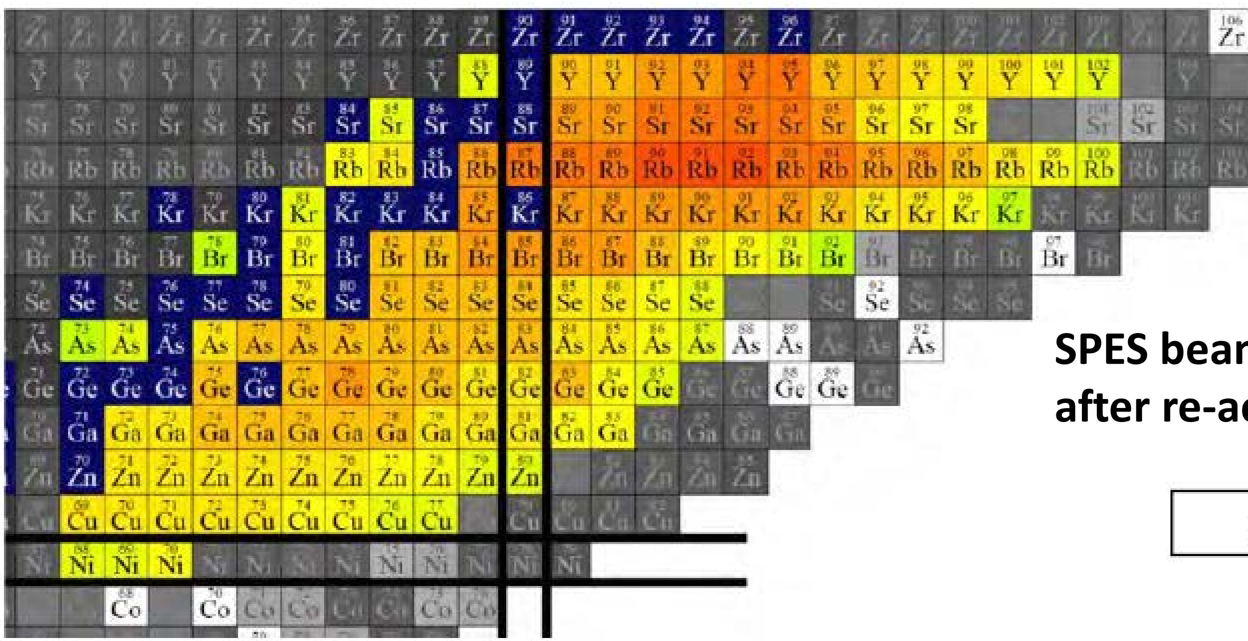
Other target materials



7	Be*
10	Be*
21	Na*
22	Na*
22	Mg*
23	Mg*
24	Al*
25	Al*
26	Al*
29	P*

The target materials we are developing for the SPES ISOL facility, will allow to produce a variety of beams both in the neutron-rich and the neutron-poor area

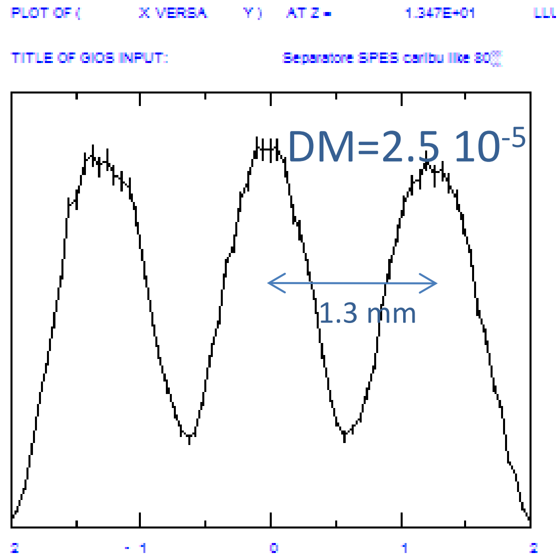




SPES beam intensities (*fission UCx*) after re-acceleration (q+)

Courtesy of T. Marchi

HRMS physics design



A scaled-up version of the separator designed by Cary Davids for CARIBU, Argonne

3° order effects analysis (LNS-LNL)

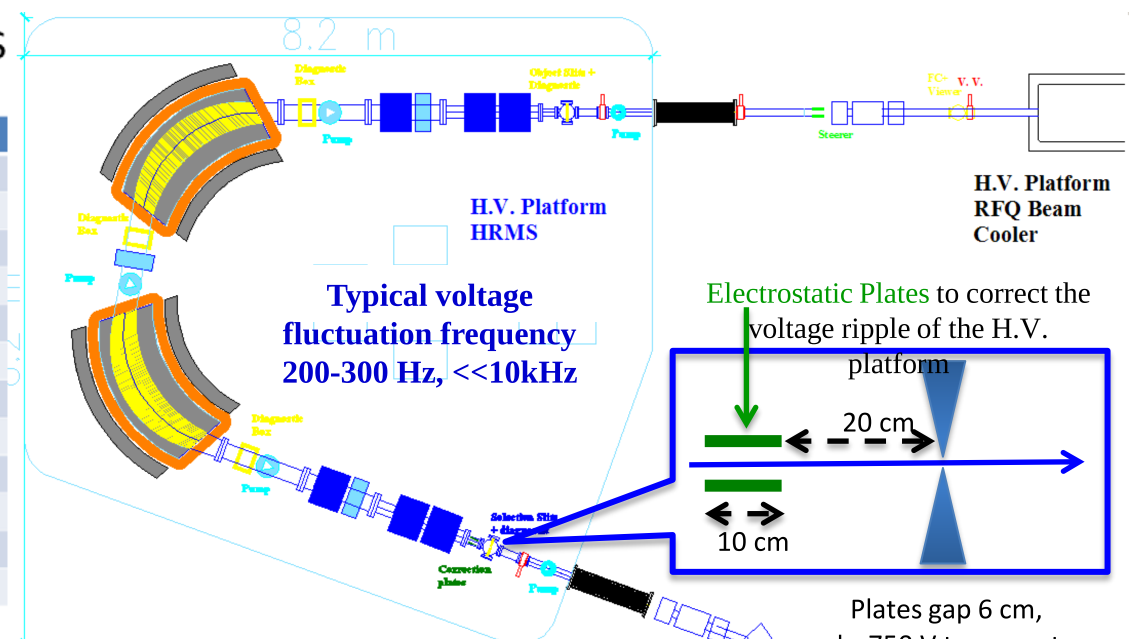
Input parameters:

- Energy= 260 KeV
- $\Delta\theta$=4 mrad
- **ΔE= ± 1.3 eV**
- **Emittance=3π mm mrad**

Mass resolution: 1/40000 (eng. design: 1/25000)

SPES RFQ Beam Cooler parameters

Mass Range	5-200 amu
Transverse Emittance Injected beam	30 π mm mrad @ 40 keV
Emittance Reduction factor	10 (max)
Buffer Gas	He @ 273 K
Beam Intensity	50-100 nA → $x10^{11}$ pps
Energy spread	< 5 eV
RF Voltage range	0.5 – 2.5 kV (1 kV at q=0.25)
RF Frequency range	1 -30 MHz (3.5 – 15 MHz at q=0.25)
RFQ gap radius (ro)	4 mm
RFQ Length (total)	700 mm
Pressure Buffer Gas (He) range	0.1 – 2.5 Pa
Ion energy during the cooling	100 -200 eV

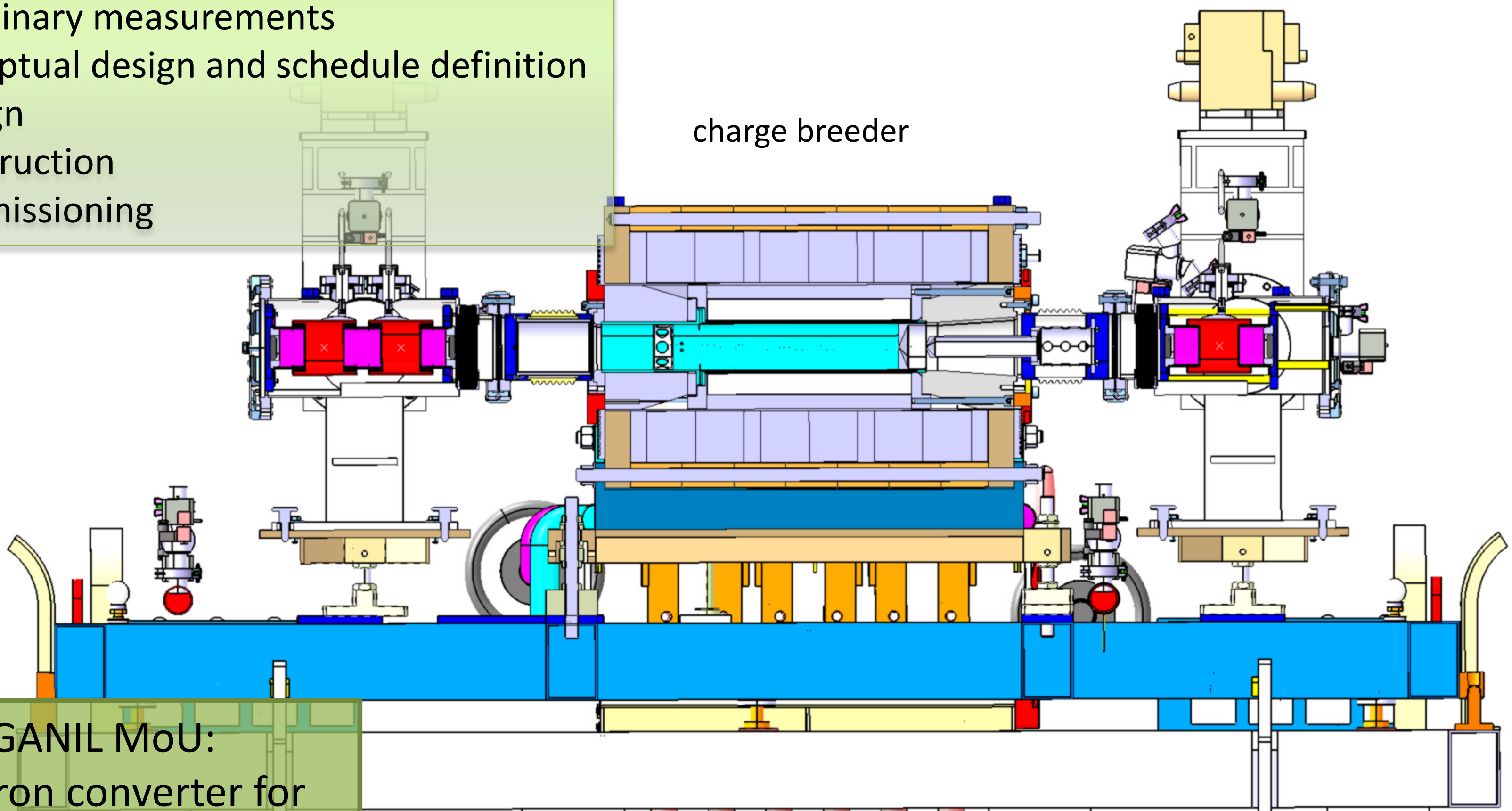


Plates gap 6 cm,
± 750 V to correct
± 5 V platform ripple

ECR Charge Breeder

Development of an upgraded POHENIX booster
Part of MoU GANIL_SPIRAL2 – INFN_SPES

2010 Preliminary measurements
2011 Conceptual design and schedule definition
2012 Design
2014 Construction
2015 Commissioning



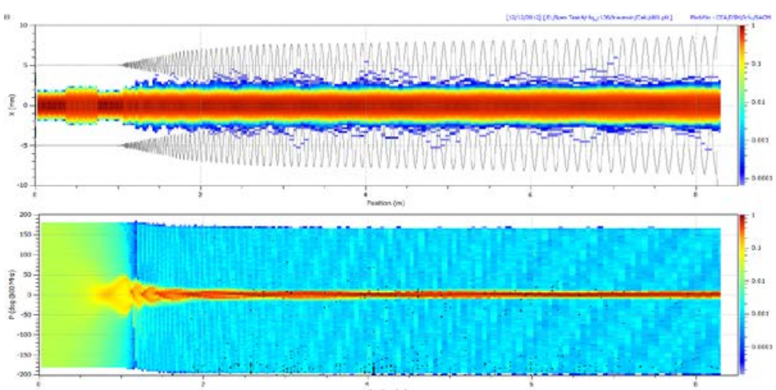
Thierry Lamy, LPSC -

INFN-GANIL MoU:
INFN: neutron converter for SPIRAL2
LPSC: Charge Breeder for SPES

NEW RFQ injector for ALPI

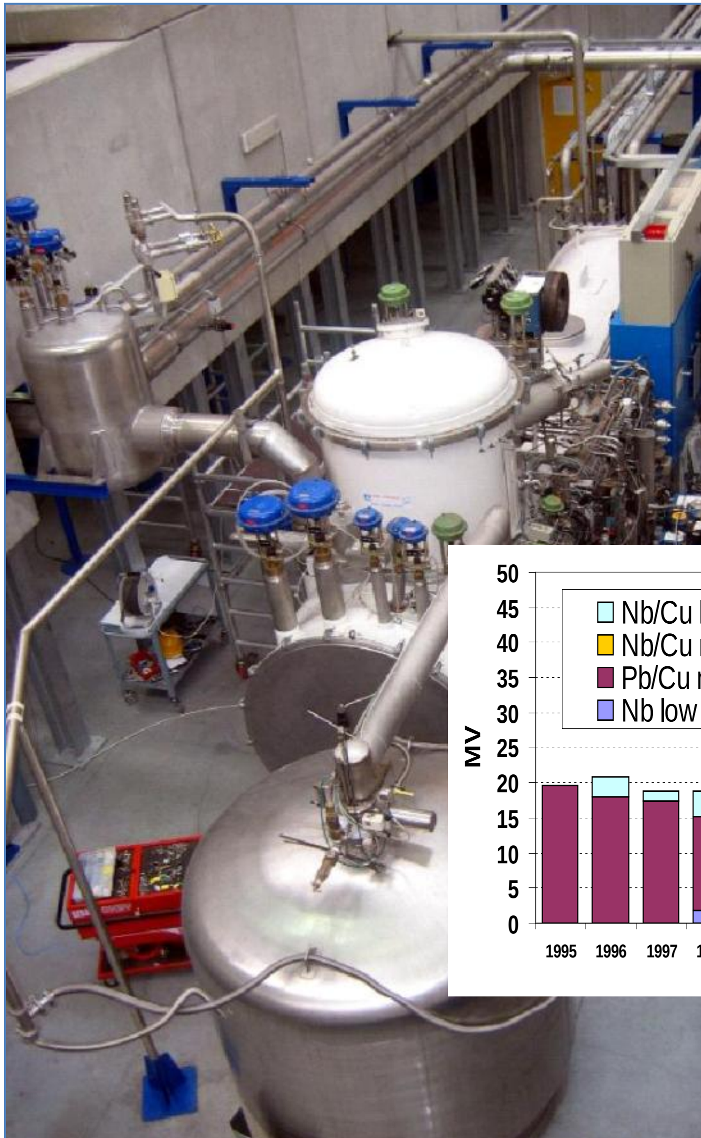
- Energy 5.7 –> 727.3 [β=0.0395] KeV/A (A/q=7)
- Beam transmission >95%, low RMS longitudinal emittance at output: 0.15 ns*keV/u.
- Length 695 cm (7 modules) intervane voltage 63.8 – 85.8 kV
- RF power (four vanes) 100 kW.
- Mechanical design and realization, taking advantage of IFMIF experience (LNL,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

Mechanical layout of the RFQ tank module of about 1 meter.



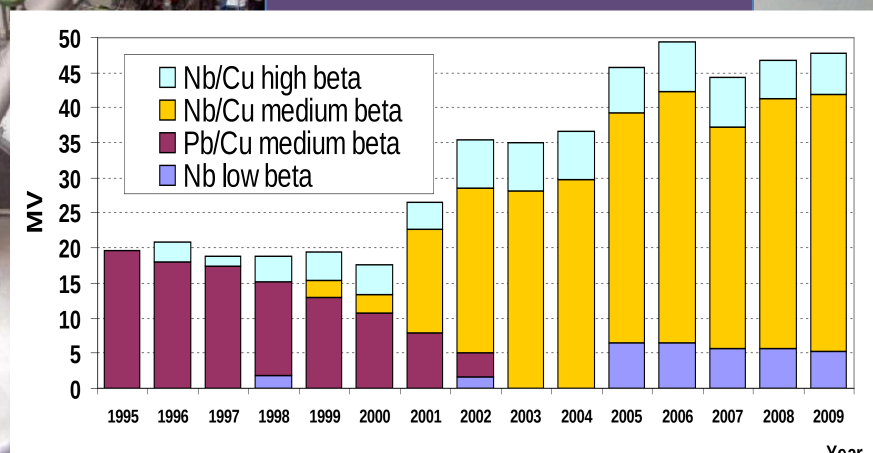
Parameter (units)	Design Value
Operational mode	CW
Frequency (MHz)	80.00
Injection Energy (keV/u)	5.7 (β=0.0035)
Output Energy (keV/u)	727 (β=0.0395)
Accelerated beam current (μA)	100
Charge states of accelerated ions (Q/A)	7 – 3
Inter-vane voltage V (kV, A/q=7)	63.8 – 85.84
Vane length L (m)	6.95
Average radius R_0 (mm)	5.33 – 6.788
Synchronous phase (deg.)	-90 – -20
Focusing strength B	4.7 – 4
Peak field (Kilpatrick units)	1.74
Transmission (%)	95
Output Long. RMS emittance (mmmrad) / (keVns/u)/(keVdeg/u)	0.055 / 0.15 / 4.35

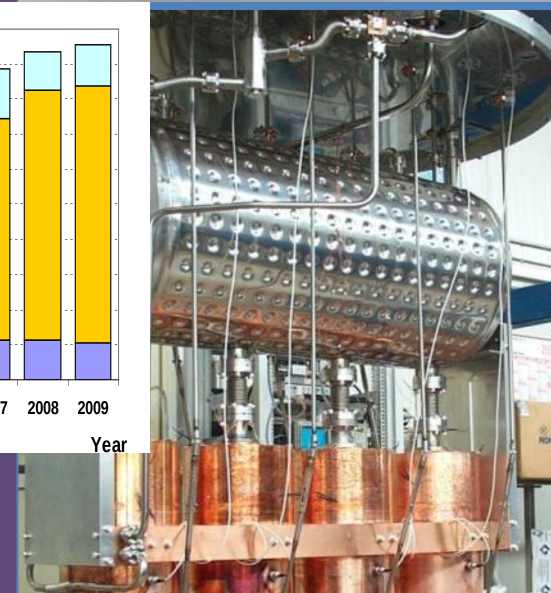
The ALPI Superconductive-Linac



Superconductive linac based on QW resonators (since 1995)

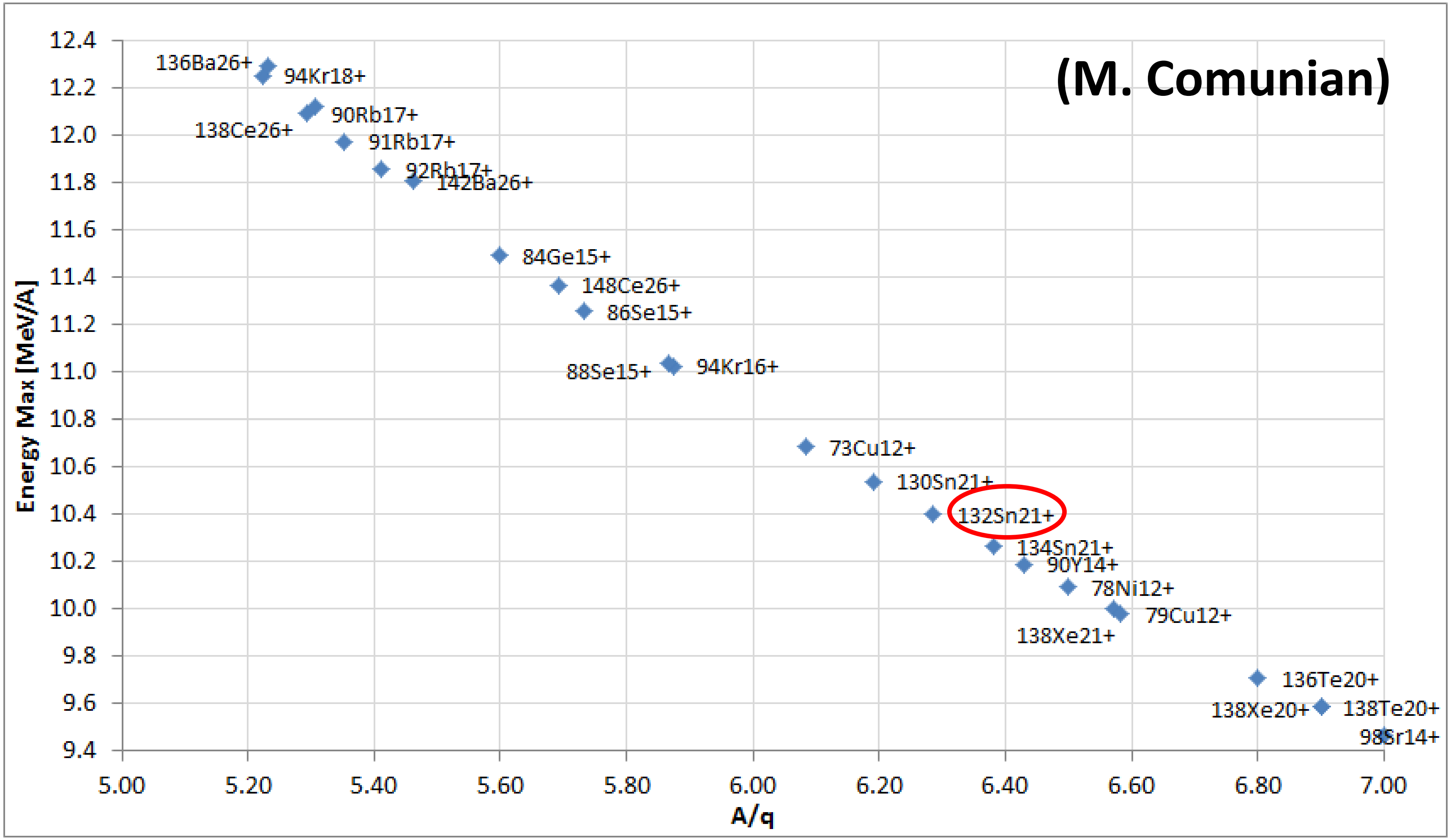
Up graded to Veq ~ 50 MV





Pb/Cu to Nb/Cu spattered cavities (or bulk Nb cavities)

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



Preliminary results from alpi performances with 2 cavities as margin, Low Beta=5 MV/m, Medium Beta=4.3 MV/m, High Beta=5.5 MV/m

SPES CYCLOTRON
load work

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

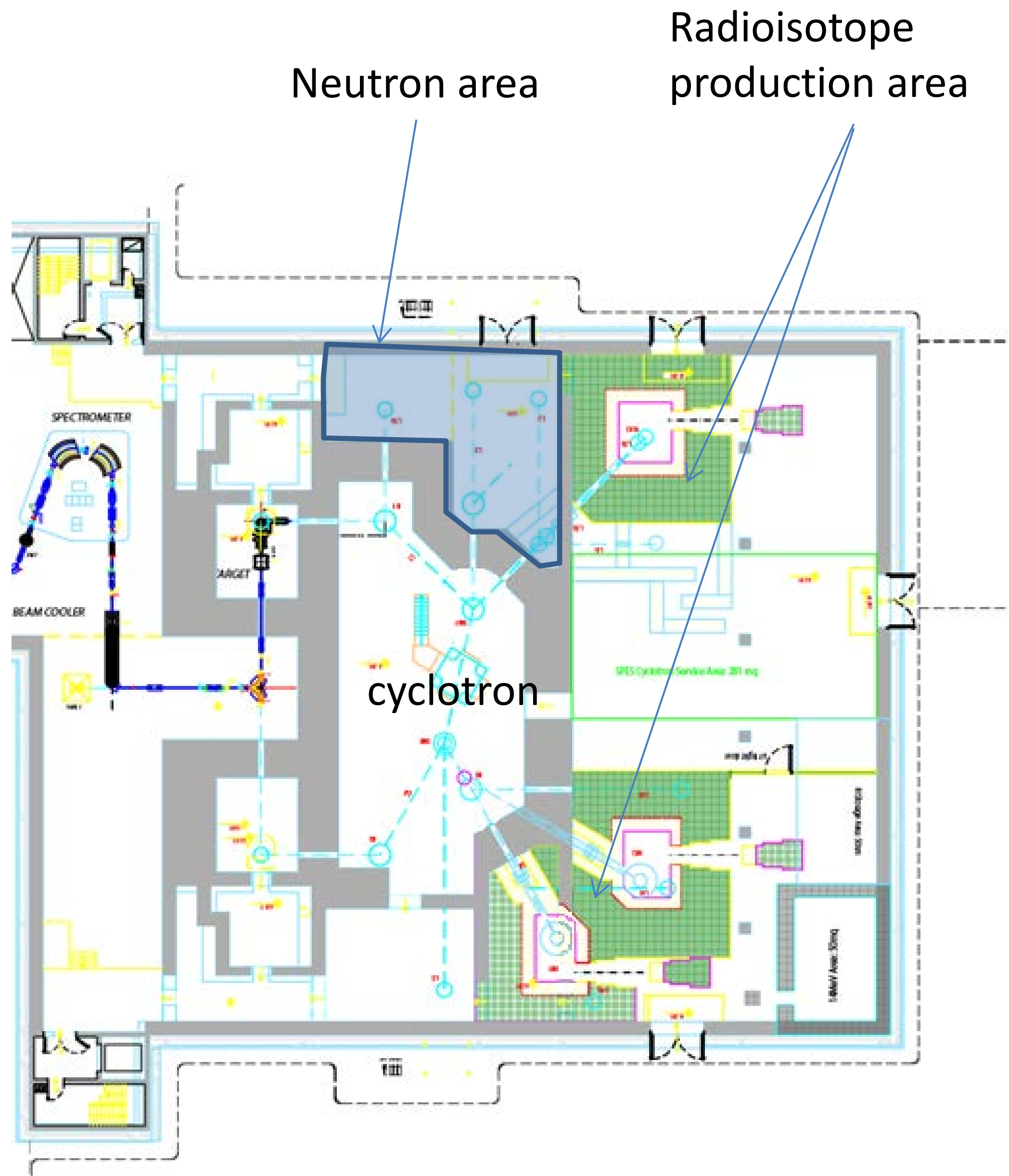
Beam on target →280 hours per shift

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

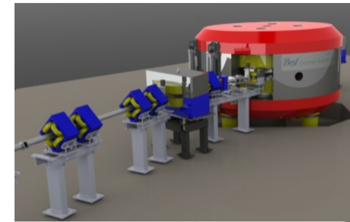
7 shifts for cyclotron maintenance

Expected Beam on target:
10600 hours per year

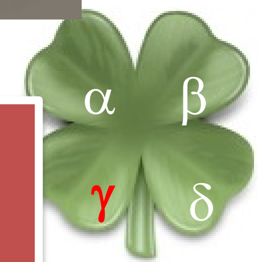
Over 5000 hours/year of proton beam available for applications



LARAMED project
production of radionuclides



radioisotopes production



Preliminary study

Leadership:
A.Duatti

- Among applications, production of radionuclides of medical interest is particularly interesting.
- Aim is the production of
  I. innovative radiopharmaceuticals (e.g. Sr-82, Cu-64, Cu-67)
  II. traditional radiopharmaceutical with new approaches (Tc-99m)
- The model is the ARRONAX center in France at Nantes, where a similar cyclotron is in operation.
- By exploting the cyclotron and its building, a center for medical radioisotopes can be built, with a cost of 10-30 Meuros depending on the number of production lines.
- Partnership with industry is under discussion

Production of radioisotopes of medical interest at different proton 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-268	271 d				

SPES-γ : cyclotron neutron facility

Union for Compact Accelerator-based Neutron Sources

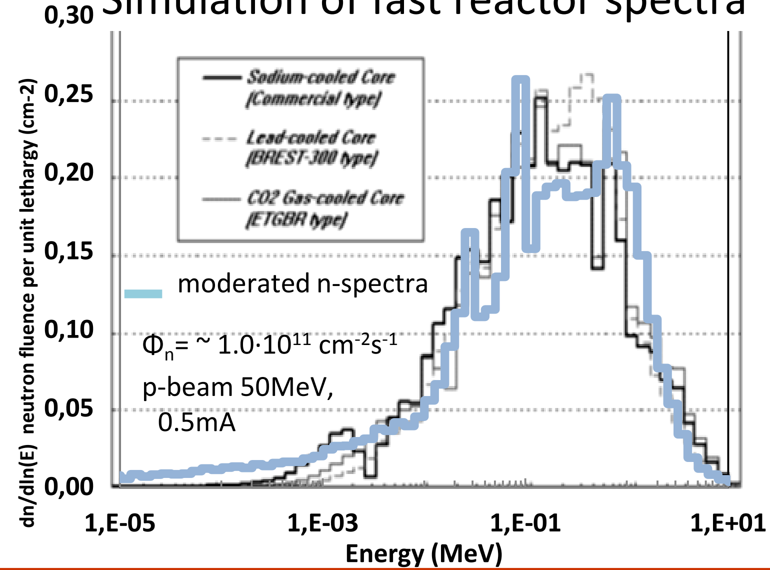
UCANS

Integral neutron production at SPES Cyclotron

Proton beam= 70 MeV, 500 μA Target = W 5mm

Energy region (MeV)	Sn (n/s) $\sim 6{\cdot}10^{14}\ s^{-1}$	Φ_n @ 2.5 m ($n\ cm^{-2}\ s^{-1}$)	Φ_n @ 1 cm ($n\ cm^{-2}\ s^{-1}$)
1 < E < 10	$\sim 5{\cdot}10^{14}\ s^{-1}$	5×10^{8}	3×10^{13}
10 < E < 50	$\sim 1{\cdot}10^{14}\ s^{-1}$	1×10^{8}	6×10^{12}

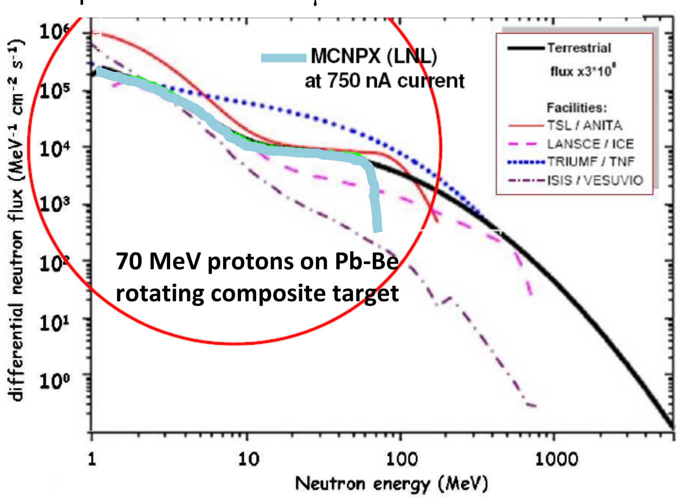
Simulation of fast reactor spectra



Single Event Effect facility

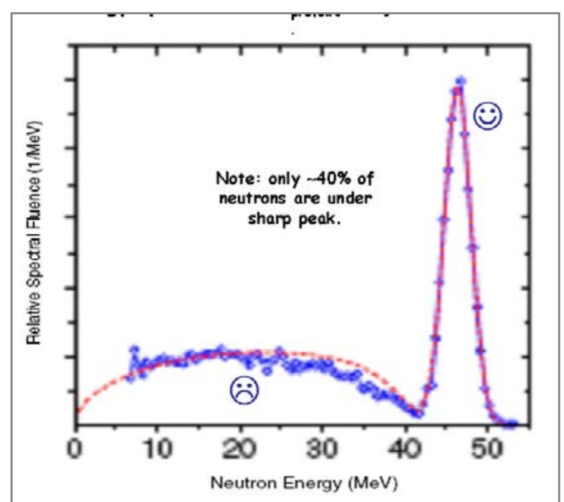
Simulate terrestrial neutron flux (* 3 10^{8})

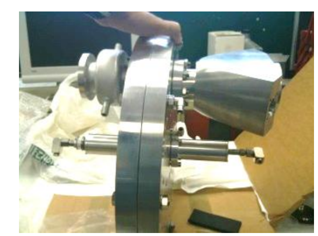
p-beam: 70MeV 3μA



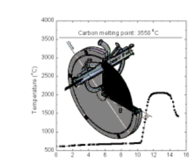
Quasi mono energetic n-spectra

3 10^{5} $n\ cm^{-2}s^{-1}$ p-beam: 70MeV 50μA





Rotating target prototype



SPES Schedule January 2014

	2012	2013	2014	2015	2016	2017
Authorization to operate and safety	UCx 5μA	Full UCx authorization				
ISOL Target-Ion Sources development						
ISOL Targets construction and installation						
Building Construction	Executive project	raw building construction				
Cyclotron Construction & commissioning						
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						
Complete commissioning and first exotic beam						

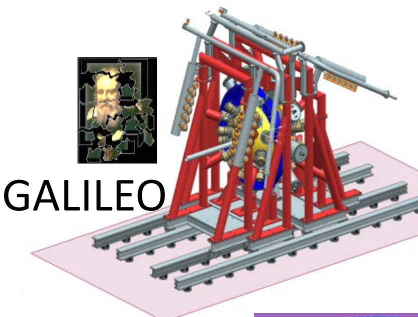
In definizione Programma preliminare .
Ancora ufficiosamente aperta la fase di raccolta delle LoI.
Oltre 60 interventi programmati

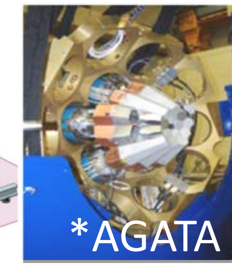
SPES2010 Workshop
(LNL- November 15th-17th, 2010)
24 LoI's for reaccelerated exotic beams

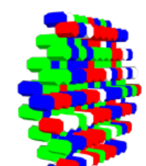
n. 10 Status Reports
n. 36 LOIs

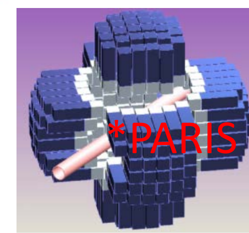
From:
Spagna, Francia, Norvegia, Svezia, Germania, Belgio, Italia, Polonia, Bulgaria, Russia, USA, etc

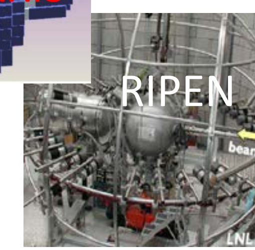
Covering:
Beta decay, nuclear moments, Coulex, Transfer, nulti-nucleon transfer, Fusion- evaporation, etc.

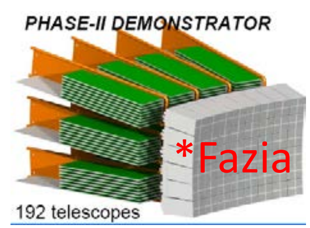


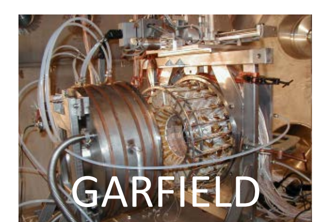












SPES: Work in progress