SPES Project

Selective Production of Exotic Species

Gianfranco Prete LNL-INFN
On behalf of the SPES Collaboration

Nuclear Structure Physics with Advanced Gamma–Detector Arrays (NSP13)
10-12 June 2013
Palazzo del Bo', Padova, Italy

SPES project strategy

- SPES is a research project for **nuclear physics and astrophysics,** with applications to :

  - production of radionuclides of medical interest;

  - production of neutrons for industrial research

- **SPES will develop an up-to-date ISOL facility exploiting the existing ALPI superconductive linac at LNL to re-accelerate neutron-rich radioactive ion beams (RIBs).**

The SPES four phases

Exotic nuclei

Phase α :
production of Neutron-rich nuclei by proton-induced U fission at rate 10^{13} f/s

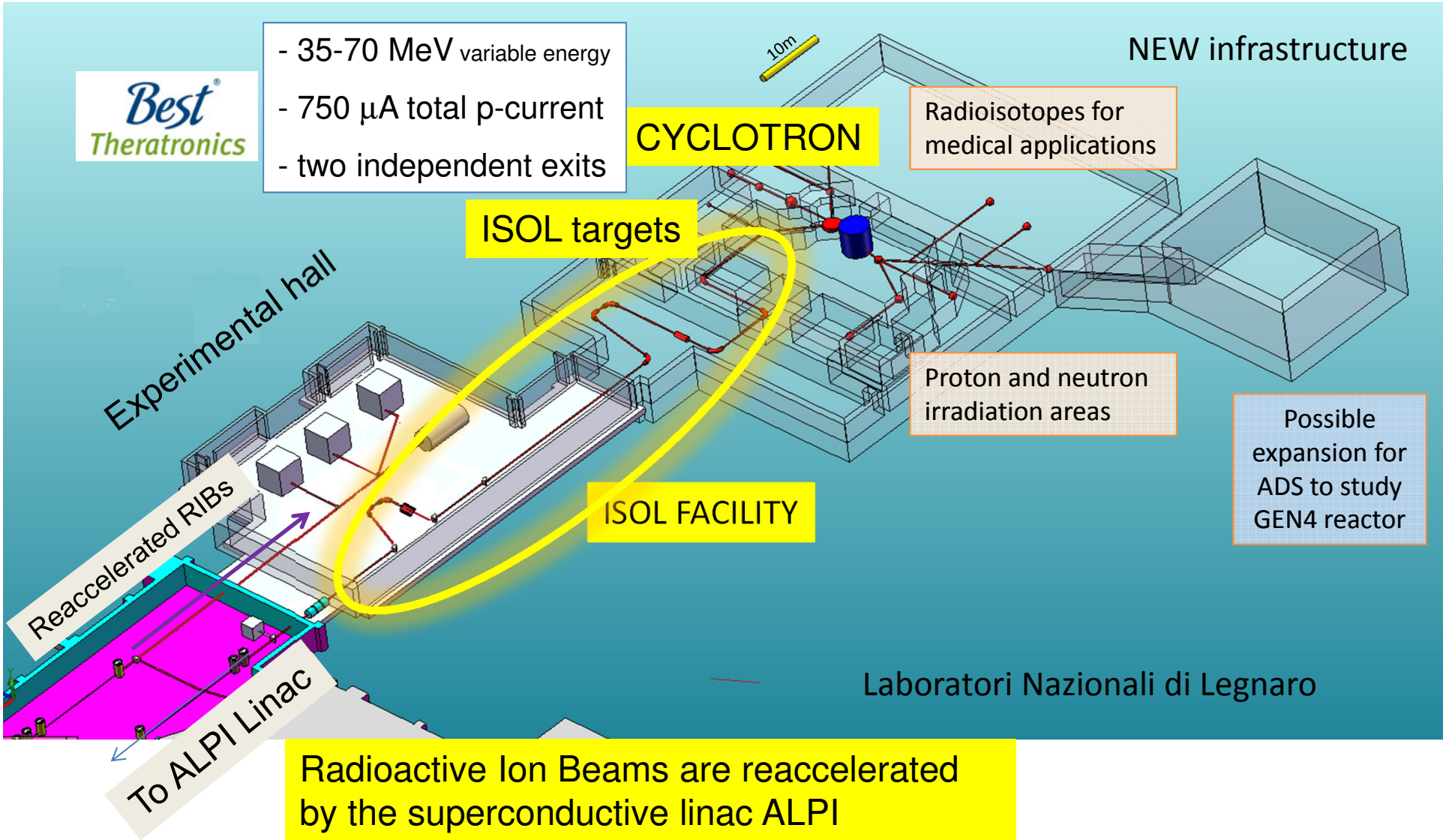
Phase β:
transport, selection and reacceleration up to $\geq$10 MeV/u of RIBs

Applications

Phase γ:
Proton and neutron facility for applied physics

Phase δ:
Radioisotope production & Medical applications

SPES layout



Radioactive Ion Beams are reaccelerated by the superconductive linac ALPI

SPES Project planning

The project planning has been remodulated according to several constraints:

- Building construction
- Cyclotron construction
- Expected financial resources

First reaccelerated beam on target is expected for 2017

SPES alpha: completely financed (19.3 Meuro)

Buildings and infrastructures
Cyclotron proton driver
ISOL Target prototype with surface and plasma sources

SPES-beta: partially financed

ISOL Target with Laser Source
Radioactive Ion Beam Transport
High resolution mass selection (HRMS and Beam Cooler)
Charge Breeder
RFQ for pre-acceleration
Superconducting ALPI accelerator upgrade
Safety and control systems

The first year of SPES-beta has been financed by Ministry of Research with 5.6 Meuro within the call “Premium projects 2011”.
Additional funding under evaluation for “Premium projects 2012”.

SPES-γ : cyclotron neutron facility

Union for Compact Accelerator-based Neutron Sources

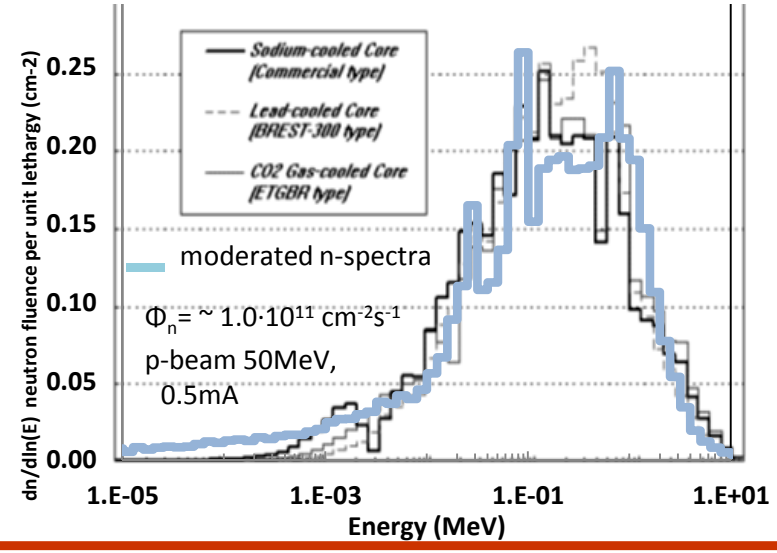
UCANS

Integral neutron production at SPES Cyclotron

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

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

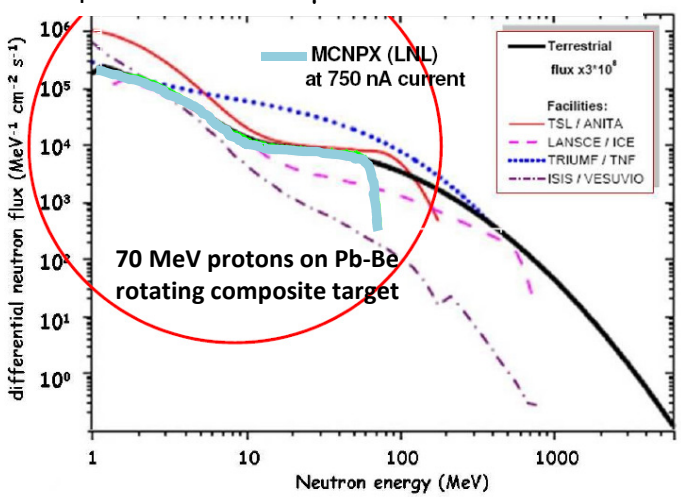
Simulation of fast reactor spectra



Single Event Effect facility

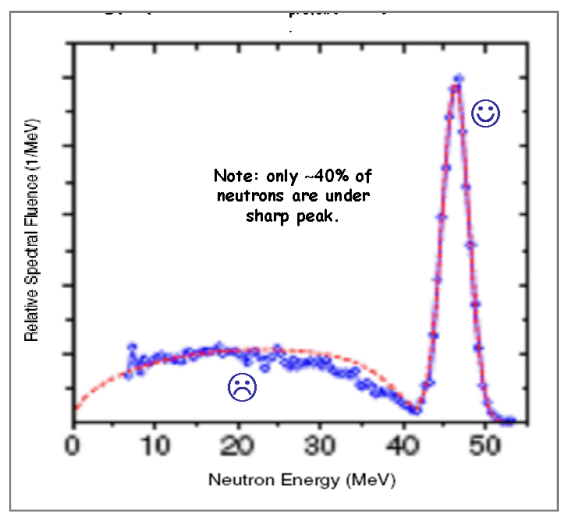
Simulate terrestrial neutron flux (* 3 10^8)

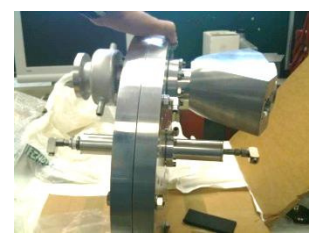
p-beam: 70MeV 3μA



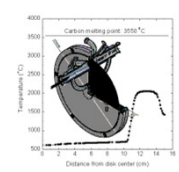
Quasi mono energetic n-spectra

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



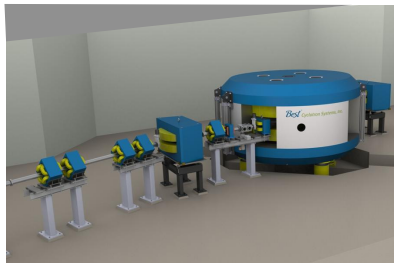


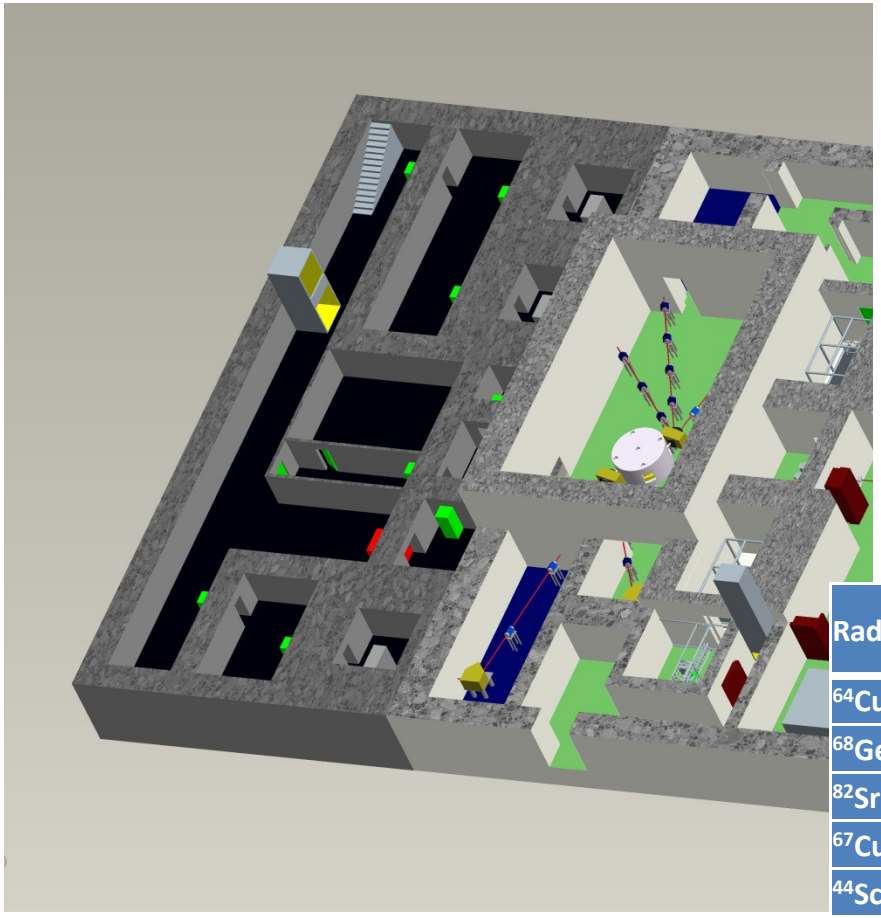
Rotating target prototype



SPES-δ : LARAMED project radionuclides for medicine

SPES cyclotron is similar to the ARRONAX one. It is well suited to produce innovative radioisotopes for medicine.





Aim is the production of

- innovative radiopharmaceutical (e.g. Sr-82, I-124 Cu-64/Cu-67)
- traditional radiopharmaceutical with new approaches (Tc-99m)

Partnership with industry is under discussion

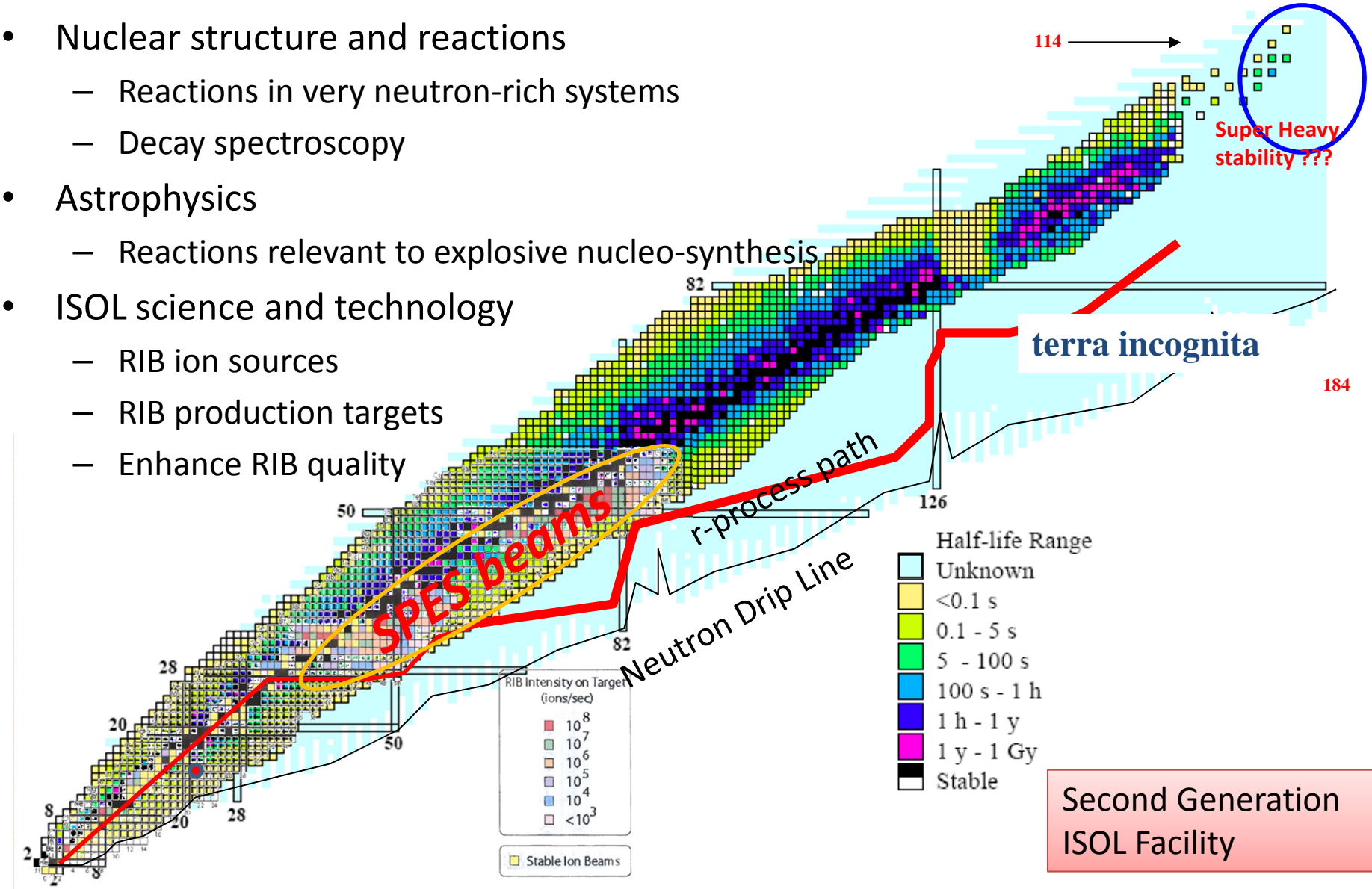
LARAMED is under evaluation for dedicated funding by Italian Ministry of Research in the framework of the call "Progetti Premiali 2012"

Radionuclide	Target nucleus	Nuclear Reaction	Cross section (mbarns)	Needed energy (MeV)
^{64}Cu	Ni	^{64}Ni(p,n)	≈ 675	15
^{68}Ge	Ga	^{69}Ga(p,2n)	≈ 550	30
^{82}Sr	RbCl	^{nat}Rb(p,4n)	≈ 98	70
^{67}Cu	ZnO	^{68}Zn(p,2p)	≈ 10	70
^{44}Sc	Ca	^{44}Ca(p,n)	≈ 700	12
^{47}Sc	Ti	^{48}Ti(p,2p)	≈ 20	70

SPES α–β : Selective Production of Exotic Species

Production of Radioactive Beams by Uranium fission

- Nuclear structure and reactions
  - Reactions in very neutron-rich systems
  - Decay spectroscopy
- Astrophysics
  - Reactions relevant to explosive nucleo-synthesis
- ISOL science and technology
  - RIB ion sources
  - RIB production targets
  - Enhance RIB quality



Second Generation ISOL Facility

ISOL Roadmap in EUROPE

Second generation 2014-2025	10^{13-14} fission/s 10 MeV/n (A=130)	Effective Mass resolution 1/20000

GANIL spiral2 laboratoire commun CEA/DSM CNRS/IN2P3

HESOLDE

SPES exotic beams for science

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

EURISOL

FROM 2025

First generation ISOL facilities in EUROPE	Effective Mass resolution 1/4000	RIBs AMeV	Reaccelerator
IGISOL Jyvaskyla	Gas catcher (New ISOL technique)		No reacc.
ALTO Orsay	Photo-fission on UCx target **(5 10^{11} f/s, n-rich beams)**		No reacc.
CRC Louvain-la-Neuve	^{6}He, ^{7}Be, ^{10}C, ^{11}C, ^{13}N, ^{15}O, ^{18}Ne, ^{19}Ne, ^{35}Ar	0.2 - 10	CYCLONE110
EXCYT LNS_Catania	^{8,9}Li, ^{20,21}Na	2 - 7	TANDEM
SPIRAL_1 GANIL	**HI fragmentation on graphite, about 50 beams**	**2 - 20**	**CIME _cyclotron**
ISOLDE CERN	**1.4GeV proton induced spallation Fission. (UCx target, 4 10^{12} f/s, neutron-rich beams)**	**2 - 3**	**REX_linac**

Letters of Intent for SPES

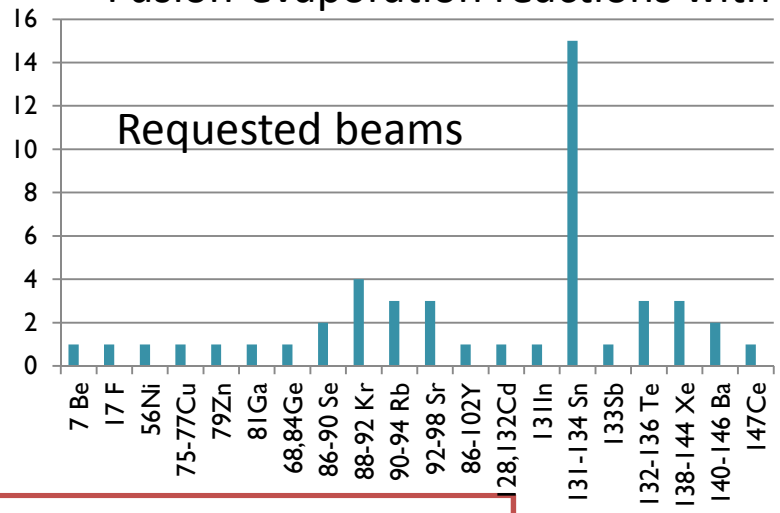
SPES2010 Workshop
(LNL- November 15th-17th, 2010)

24 LoI's for reaccelerated exotic beams

- Transfer reactions with RIBs
- Coulomb excitation with RIBs
- Collective excitations of exotic nuclei (DDR, Pygmy resonances)
- Effects of isospin in neutron-rich nuclei
- Fusion-evaporation reactions with RIBs

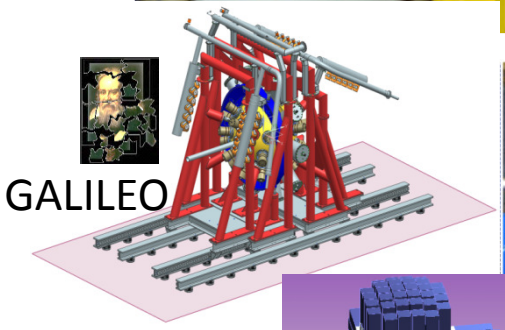
International collaborations:

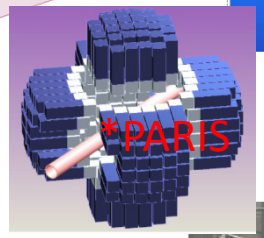
Italy
Bulgaria
Hungary
France
Poland
Spain
Great Britain
Turkey
USA
Slovakia
Romania
Croazia
Russia
India
Germany
Canada

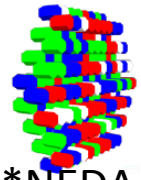


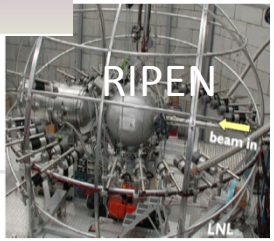
Definition of First Day Experiments:
- ❖ Scientific priorities
- ❖ Instrumentation development
- ❖ RIB production

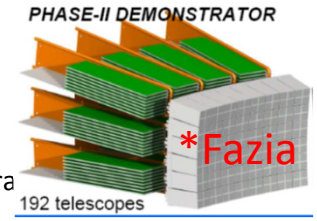
http://web2.infn.it/spes/

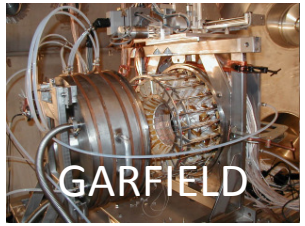








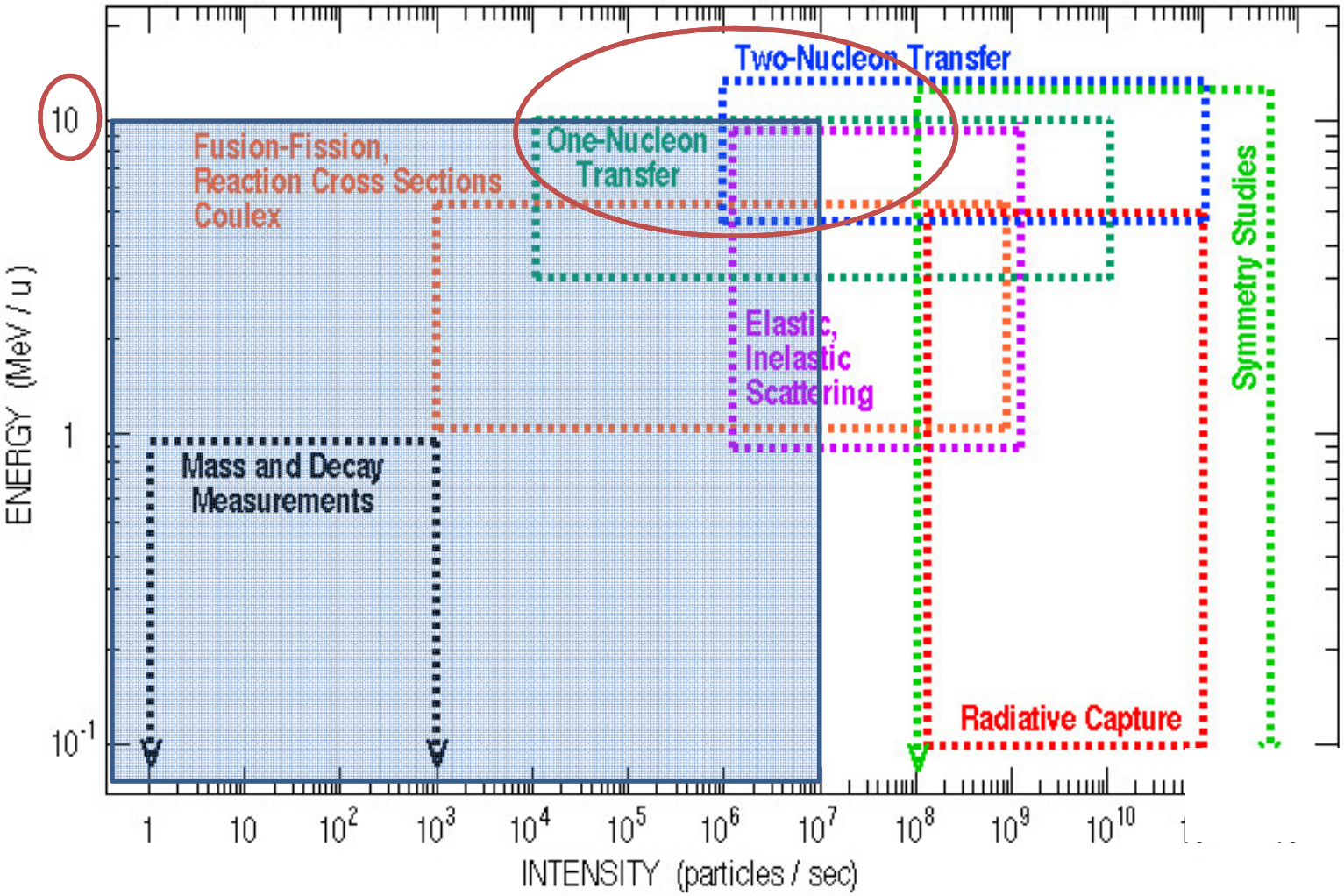




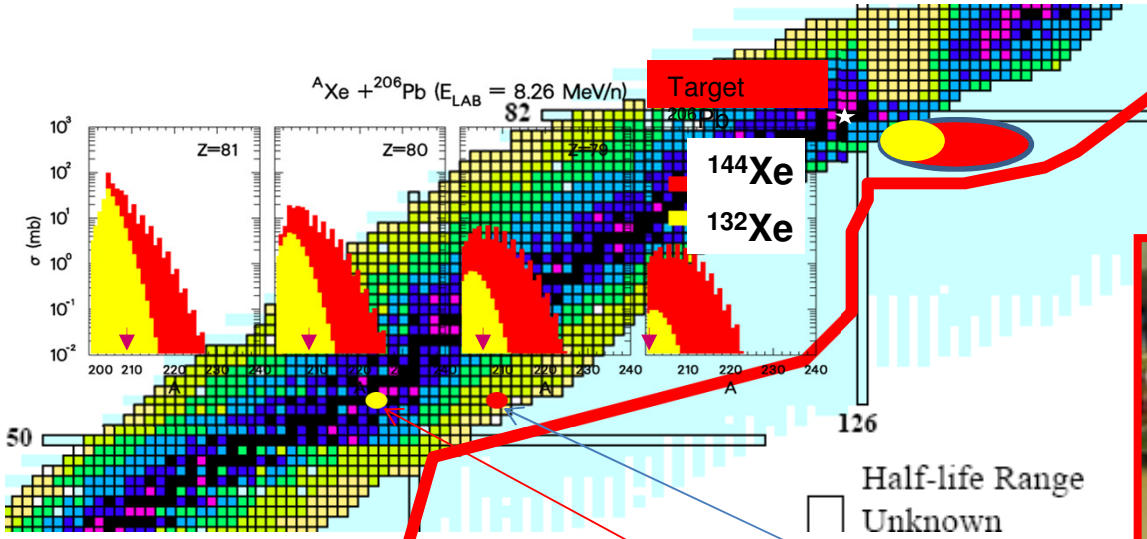
*SPES-SPIRAL2 or european collabora
** part of Chimera installed at SPES

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



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



Coupled channel calculations (Grazing). curtesy G. Pollarolo

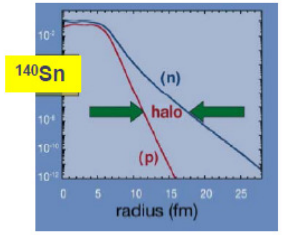
Beam: ^{132}Xe ^{144}Xe

-Multinucleon transfer
- Nuclear superfluidity (pair transfer)
- Elastic and inelastic scattering
- Near and sub-barrier fusion

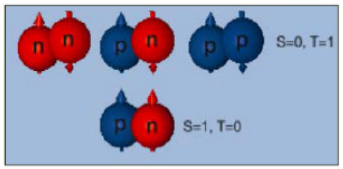
Do the degrees of freedom and the corresponding matrix elements tested with stable beams hold with RIBs ?

Do the form factors for one and two particle transfer and their strength need to be modified with RIBs ?

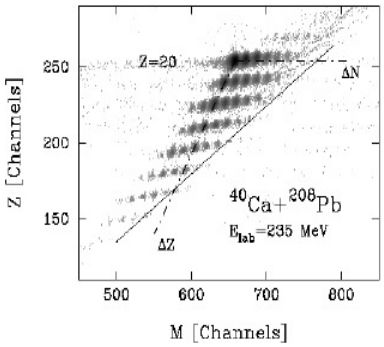
modification of nn correlations (neutron rich nuclei)



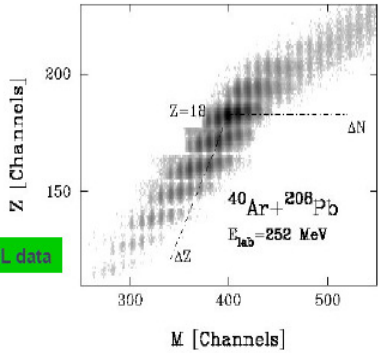
neutron-proton correlations (proton rich nuclei)



Multinucleon transfer reactions : from neutron poor to neutron rich nuclei



LNL data



GALILEO gamma array
Coupling to ancillary Detectors

Study of weak reaction channels & SPES beams

- **High efficiency**
- **High resolving power**

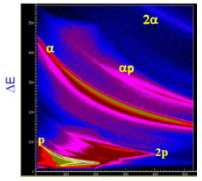
- High spin states
- Collectivity and shell model
- Isospin symmetries
- Isospin mixing in N=Z nuclei
- Spectroscopy at the dripline
- Shell stability and evolution in neutron rich nuclei
- Symmetries at the critical point
- Rotational damping

Wide range of nuclear spectroscopy studies

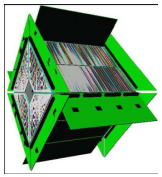
Light charged particle detectors

- ❑ **EUCLIDES**
- ❑ **TRACE**
- ❑ **LUSIA**

TRACE_highly segmented LCP detector.
(reduce double hitting, position information)

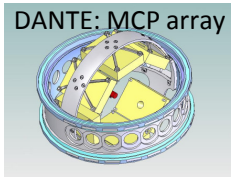


DE-E ISIS



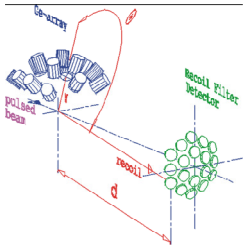
Neutrondetectors

- ❑ **n–Ring**
- ❑ **N–Wall**
- ❑ **NEDA**



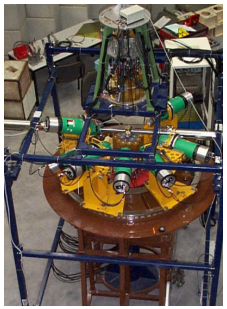
Binary reaction products detection

- ❑ **DANTE**



Recoil detectors

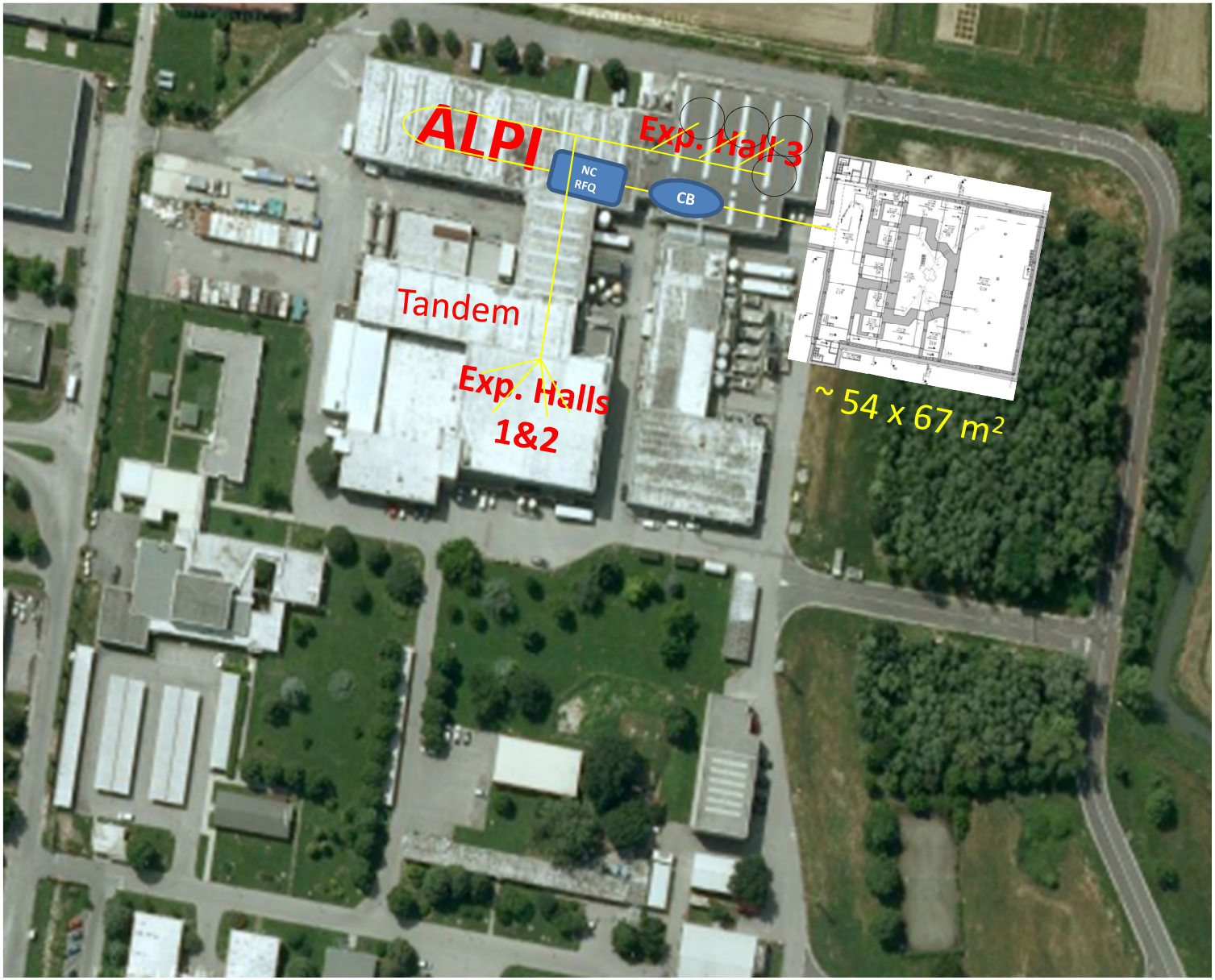
- ❑ **RFD**



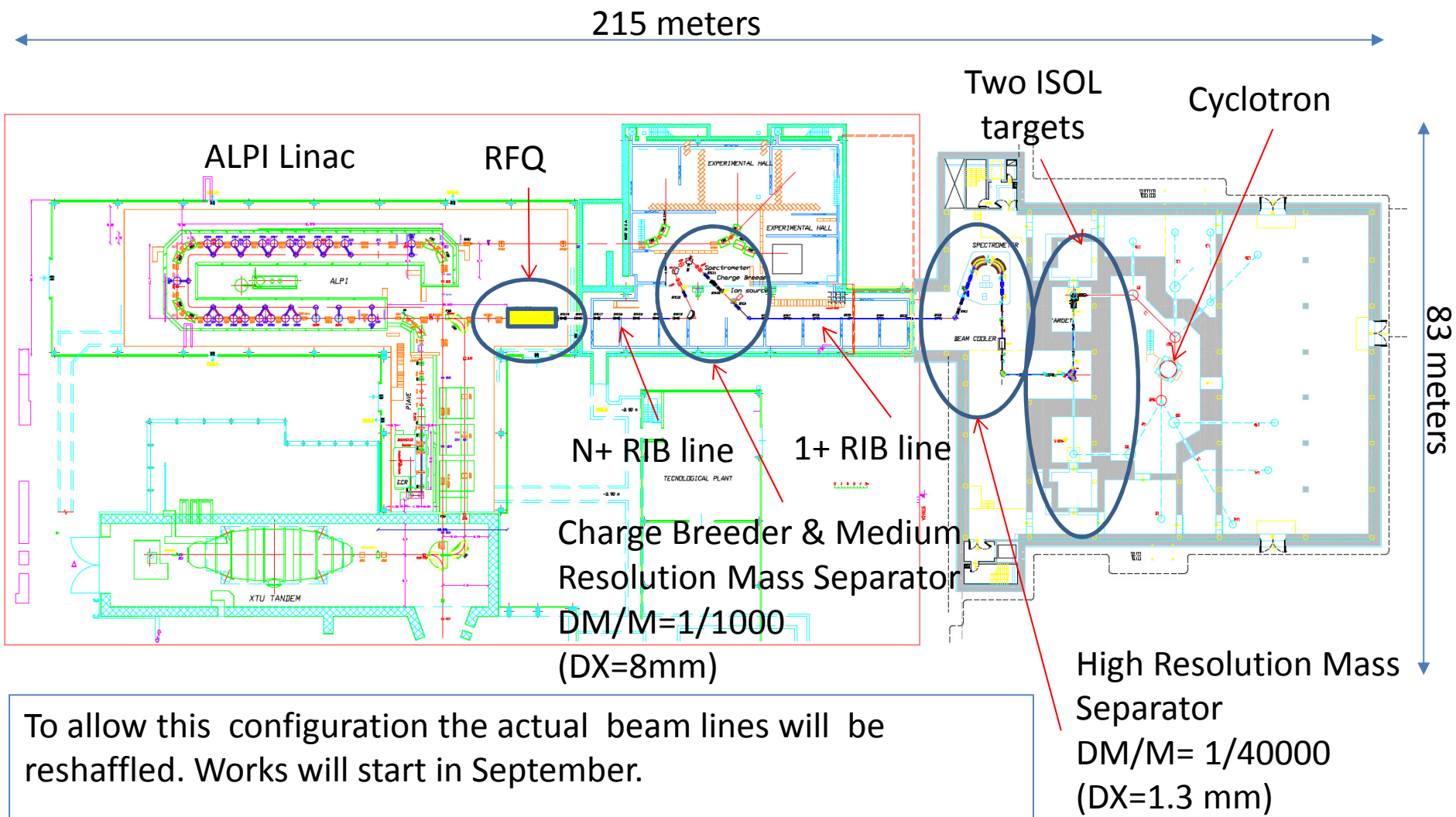
High–energy gamma–rays detectors

- ❑ **HECTOR**

SPES Facility Layout



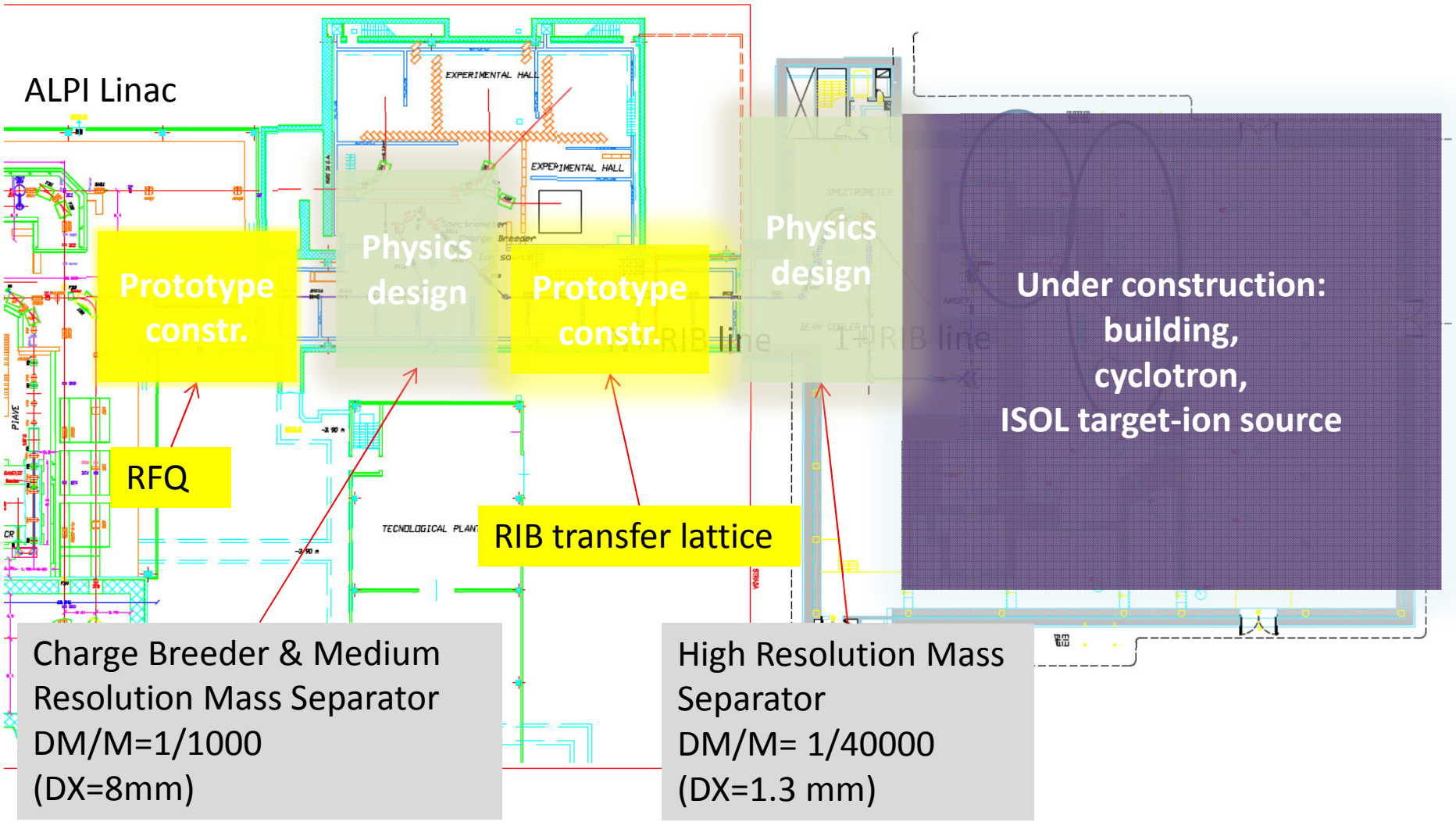
ALPI and SPES LAYOUT



To allow this configuration the actual beam lines will be reshaffled. Works will start in September.

Four experimental areas will be available in experimental hall 3. RIBs can be transported in the other two halls too .

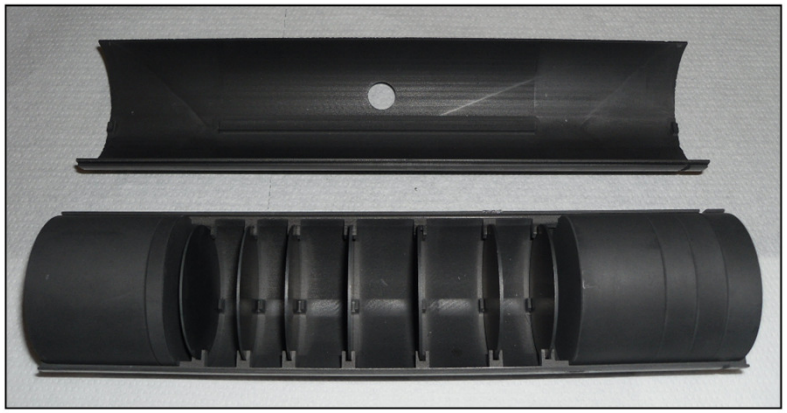
ALPI and SPES LAYOUT

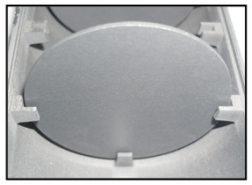


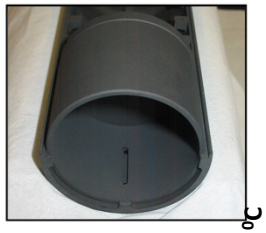
NEW DIRECT TARGET CONCEPT to operate with 10kW proton beam

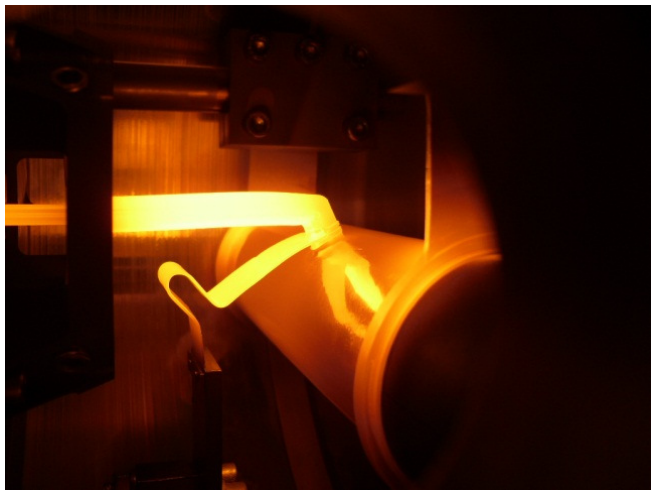
The SPES choice: optimize the Direct Target design and material production to reach 10^{13} fissions/s

UCx= 7 disks, 4 cm dia, 1.3 mm (~30g total)
In target proton beam = 200 µA 40MeV

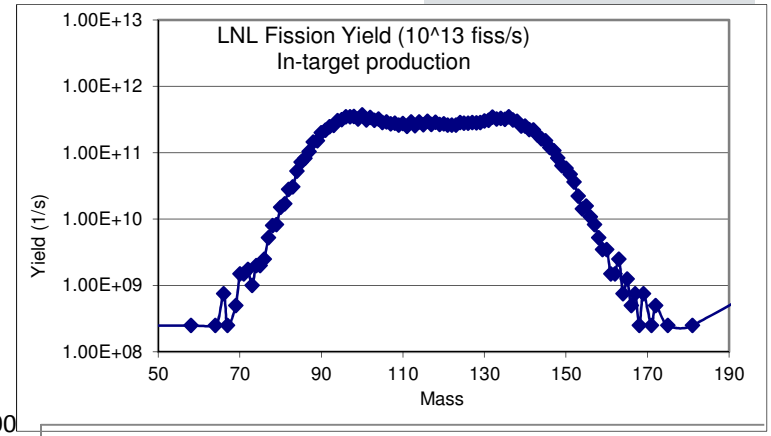


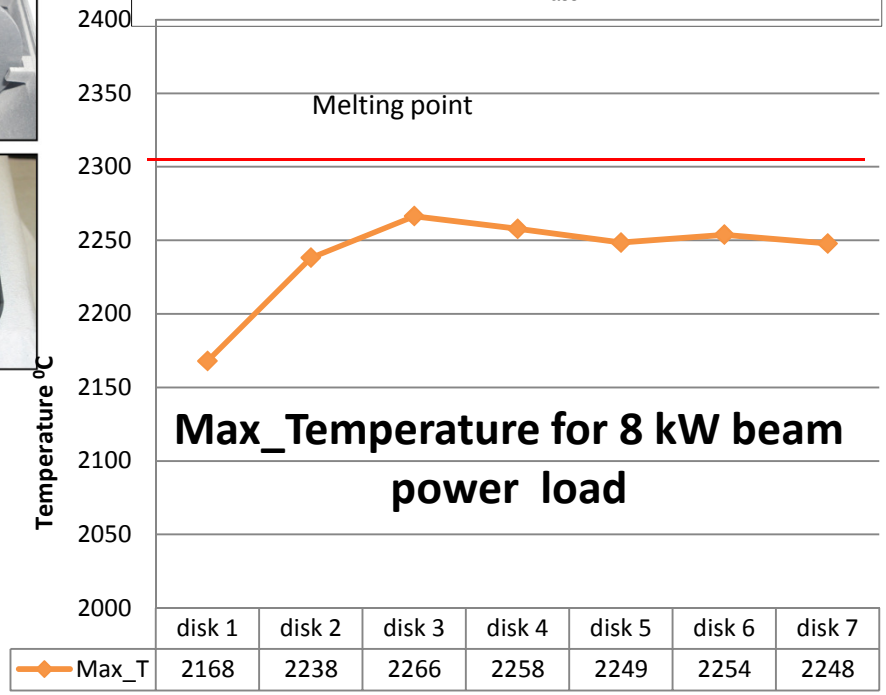






Target under operation at 2000°C

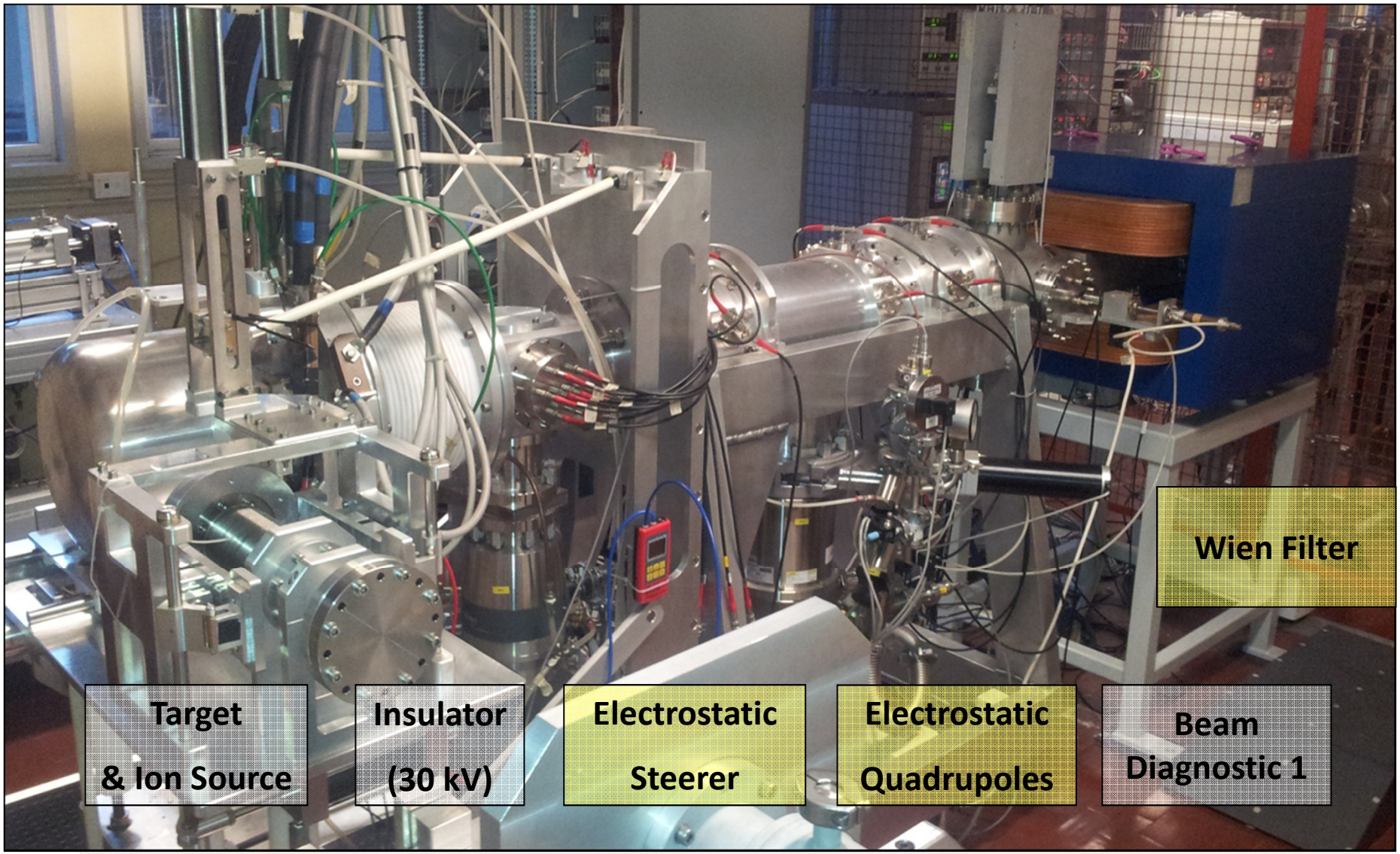




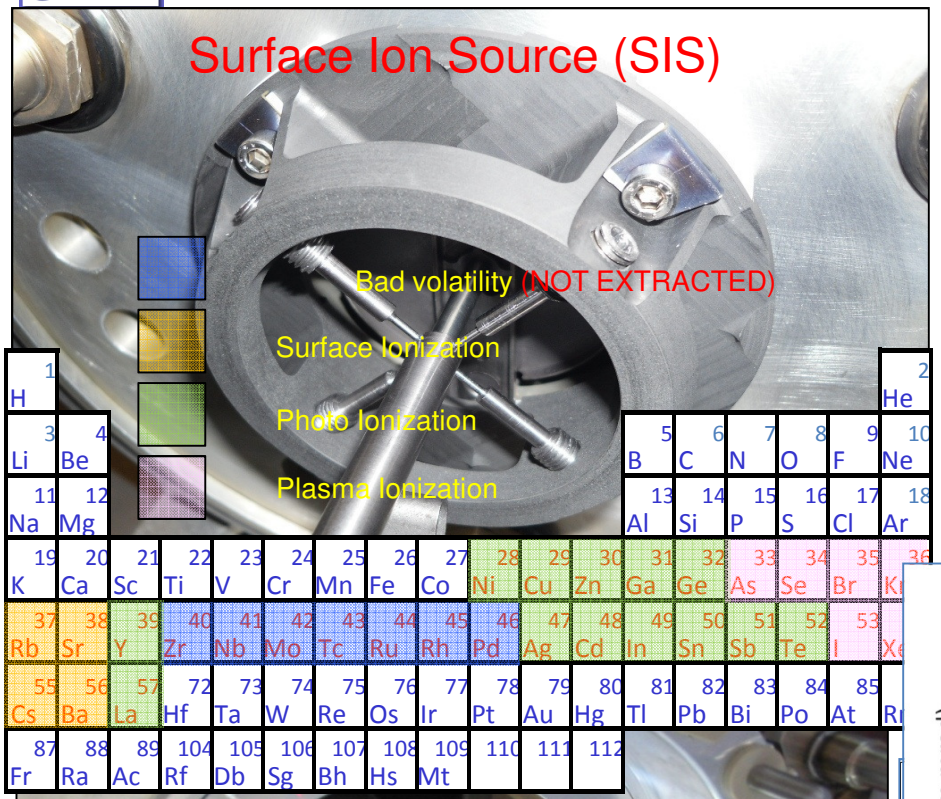
Collaboration: LNL, ENEA-Bologna, Padova University (Eng, Chem)

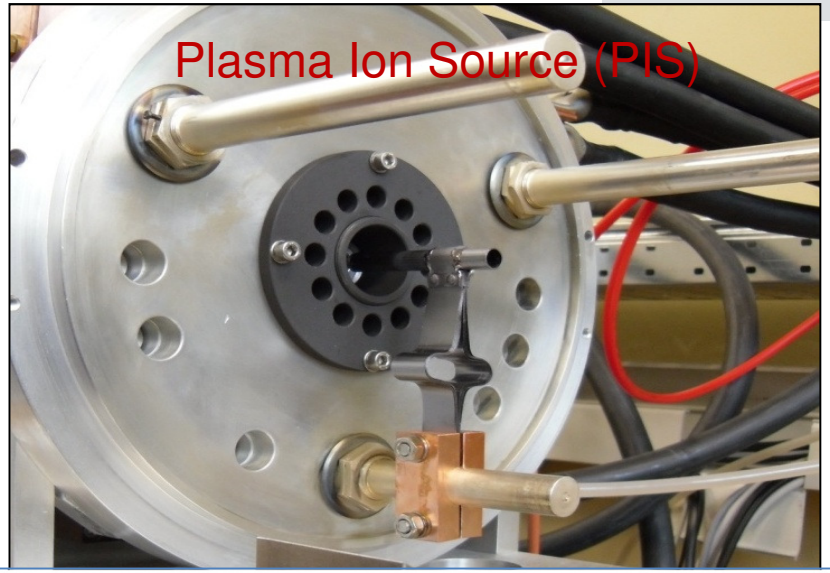
The SPES off-line Front end

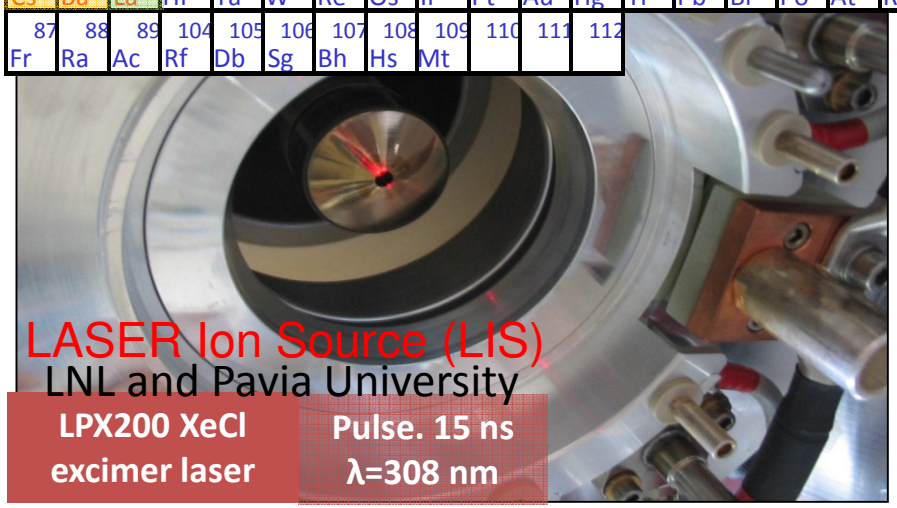
(working since 2010)

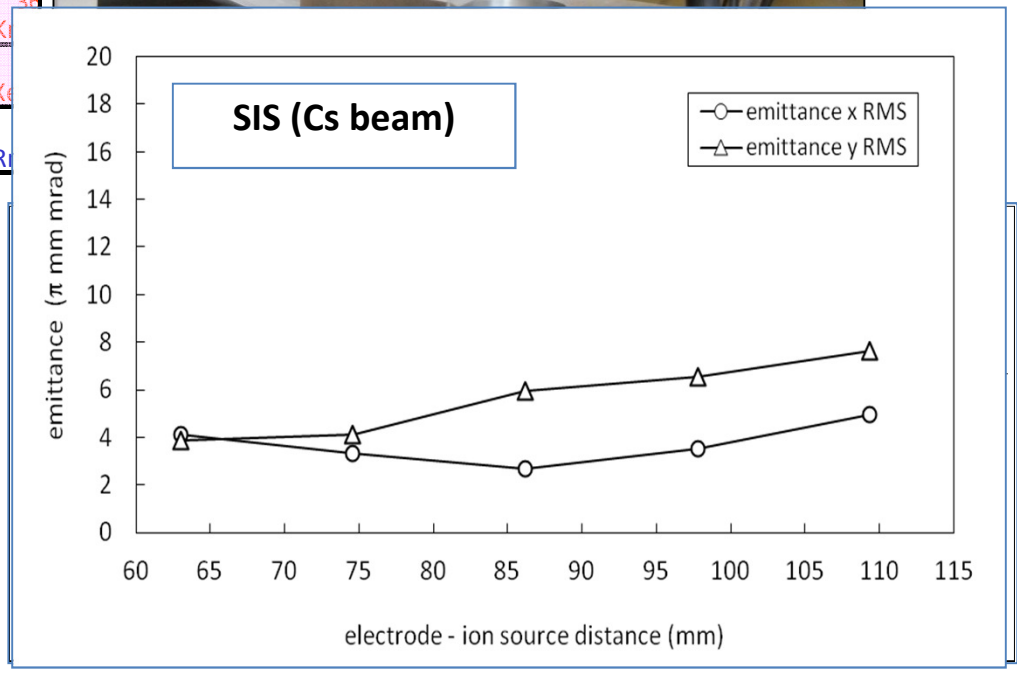


The SPES Ion Sources





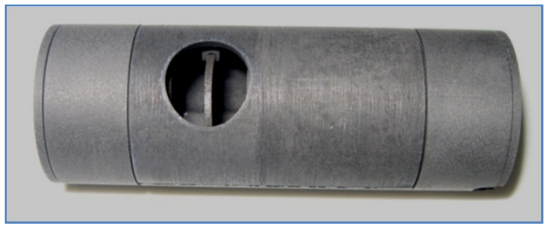


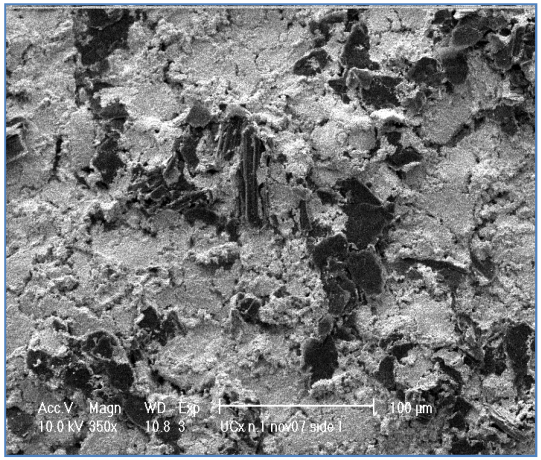


Target material production (ENSAR_ActiLab)

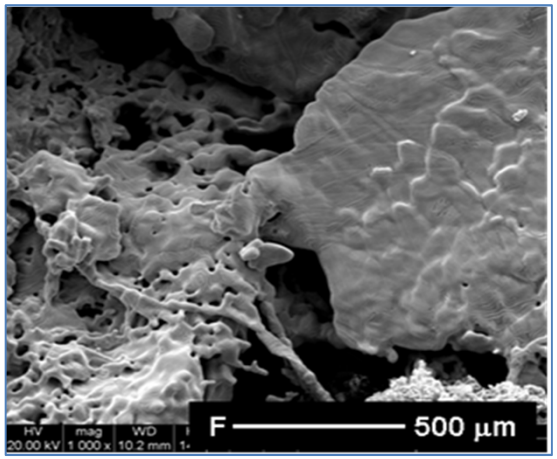
Study of the target porosimetry and isotopes production yield

2010 Test
Standard UC_x

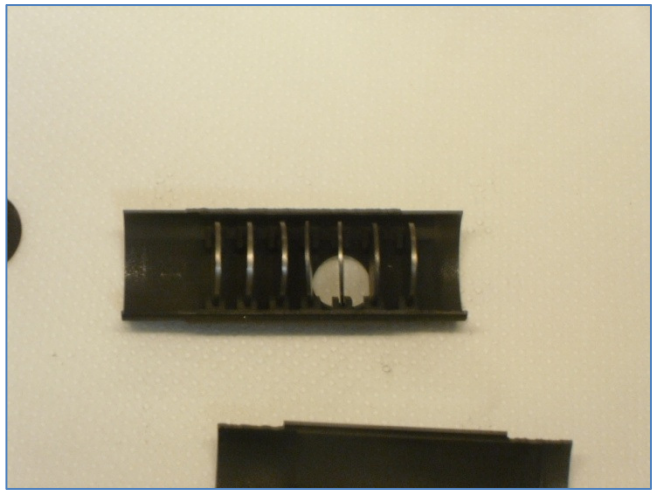




2011 Test
Low density UC_x



2012 Test
Medium density UC_x



	2010	2011	2012
Density (g/cm^3)	4.25	2.59	6.38
Diameter (mm)	12.50	13.07	12.91
Thickness (g/cm^2)	0.41	0.41	0.41
Calculated porosity (%)	58	75	37

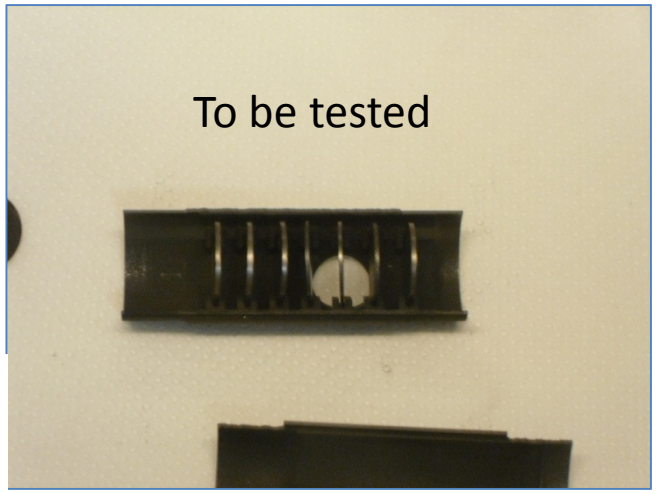
WP 02

UCx Target in-beam test

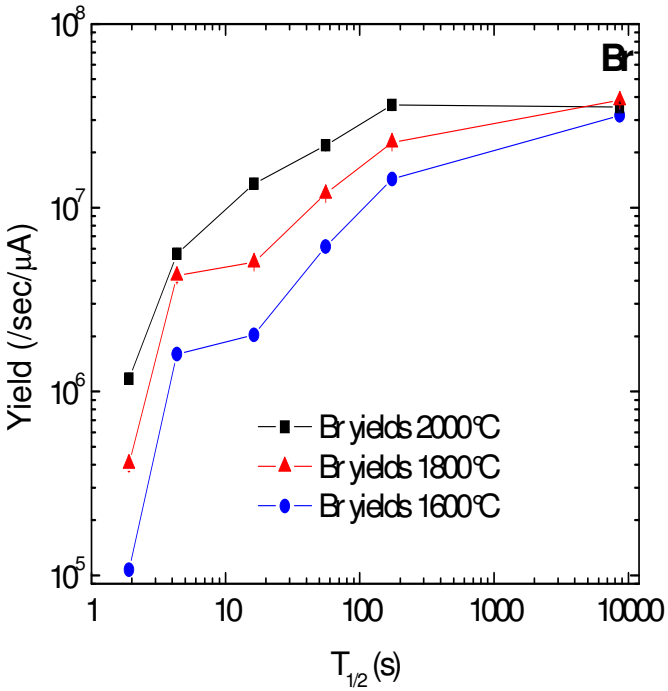
2010 Test
Standard UC_x

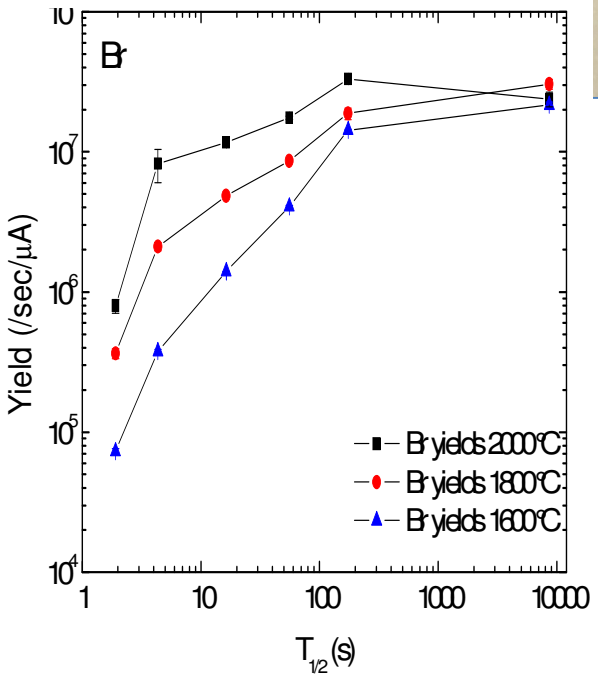
2011 Test
Low density UC_x

2012 Test
Medium density UC_x



ORNL experiments 40 MeV, 50 nA protons, plasma ion source





- Targets tested at 3 different T: 2000°C, 1800°C and 1600°C
- 20 elements, about 80 isotopes collected
- Yield vs. half-life characterization

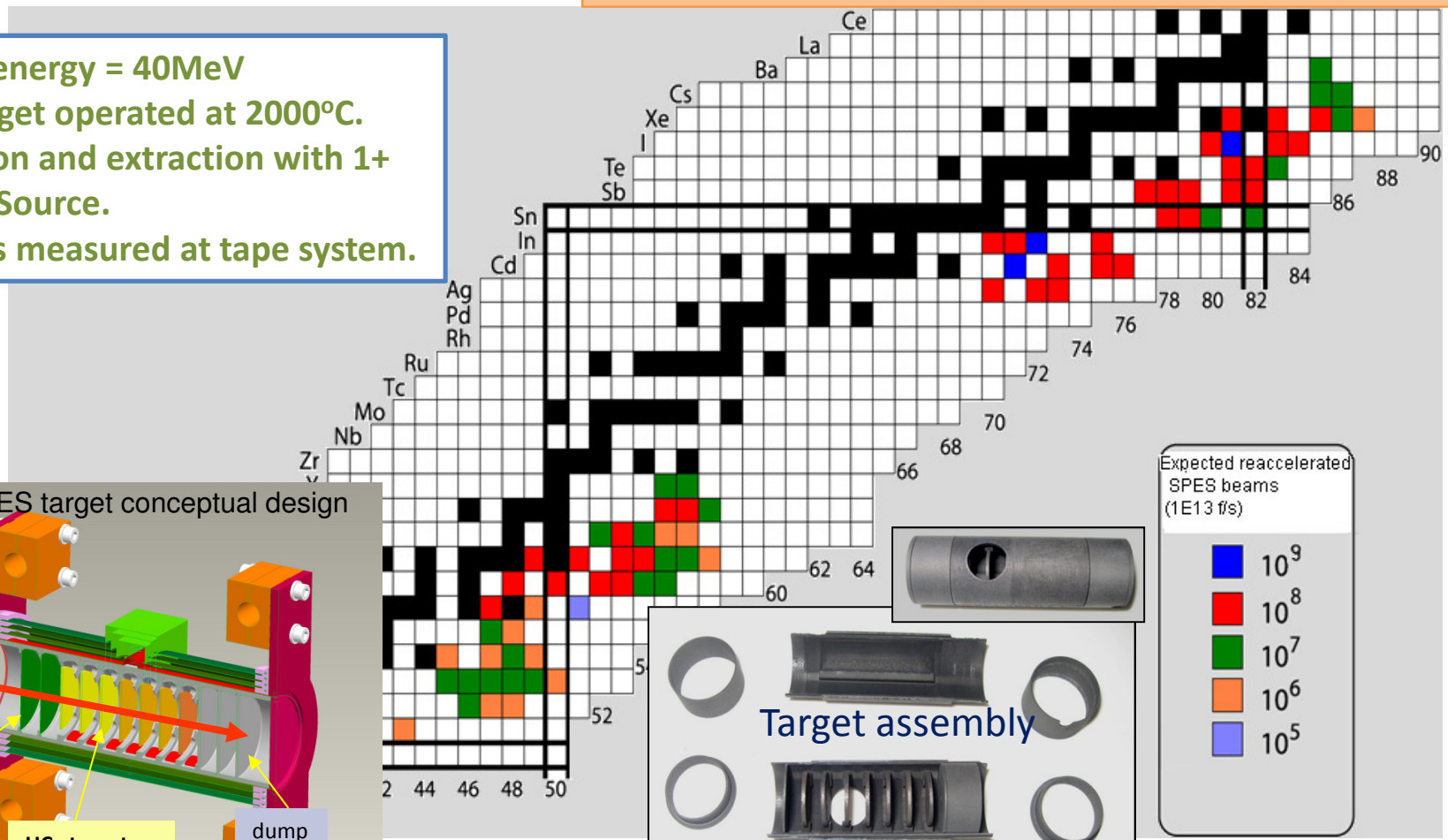
SPES Target
On-line Test experiment at HRIBF

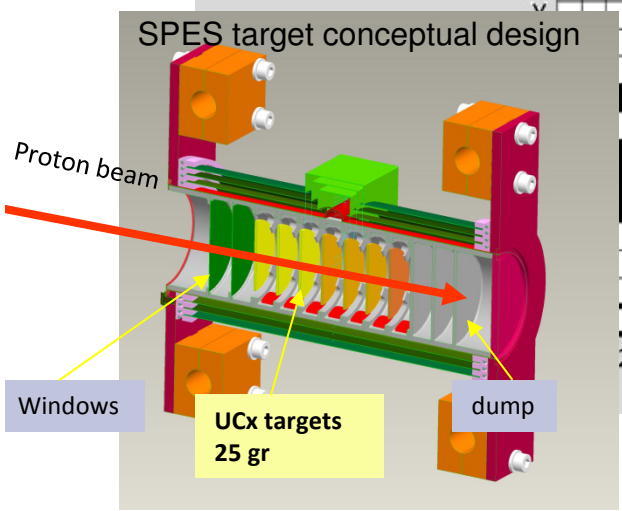
Eur. Phys. J. A (2011) 47: 32 DOI: 10.1140/epja/i2011-11032-5

Neutron-rich isotope production using the uranium carbide multi-foil SPES target prototype

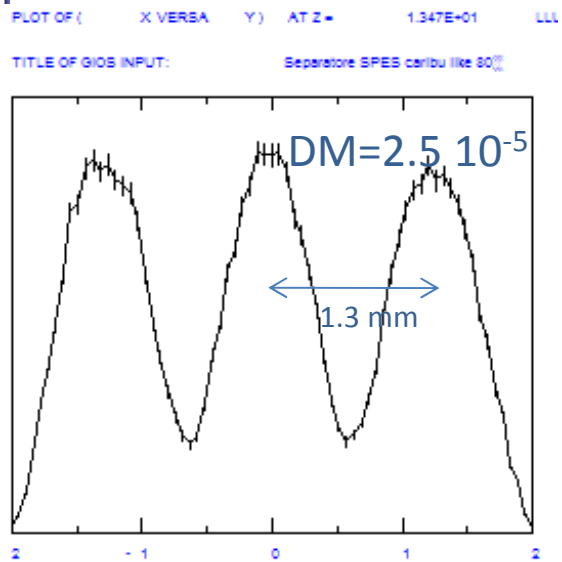
Proton energy = 40MeV
ISOL target operated at 2000°C.
Ionization and extraction with 1+
Plasma Source.
Isotopes measured at tape system.

Expected beam on target
Data scaled to: 200 microA proton current 2-5% transport efficiency





HRMS physics design



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

3° order effects analysis (LNS-LNL)

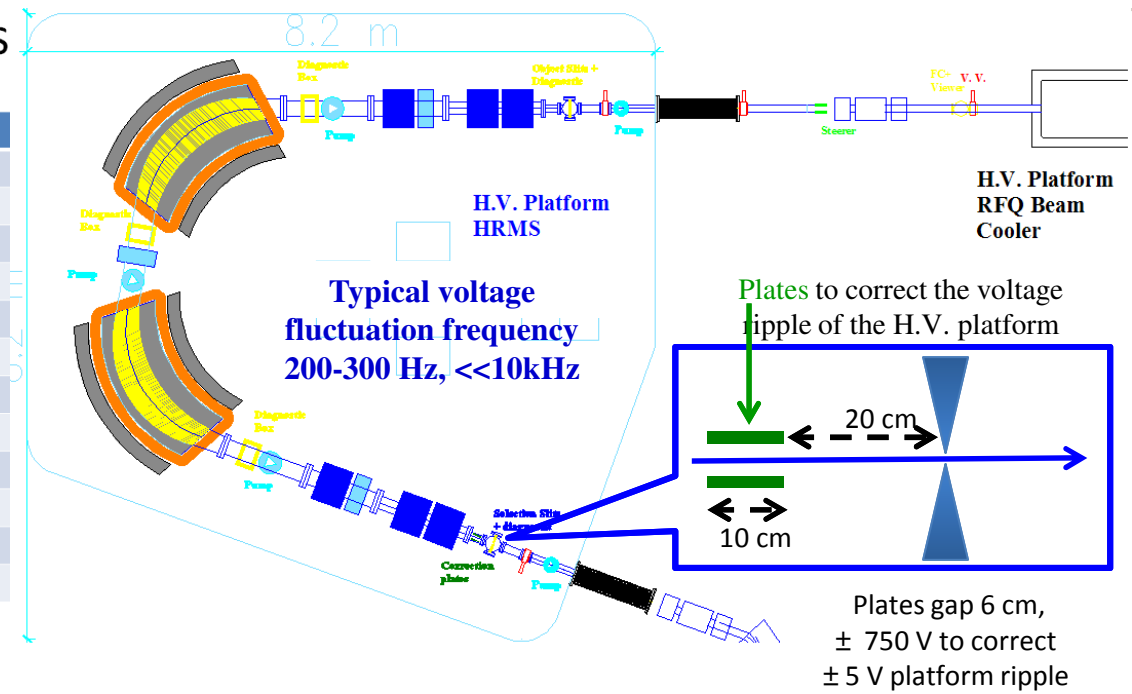
Input parameters:

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

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

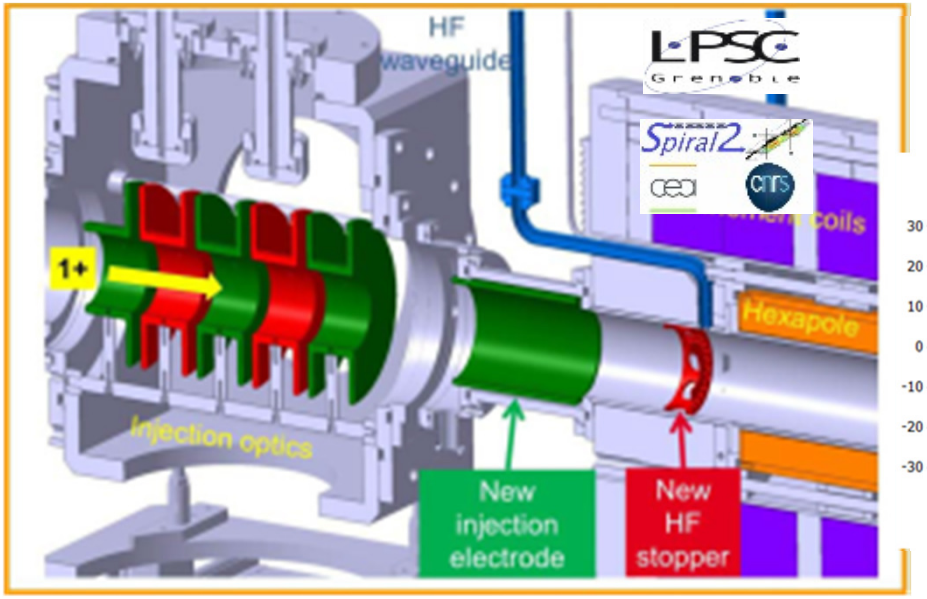
SPES RFQ Beam Cooler parameters

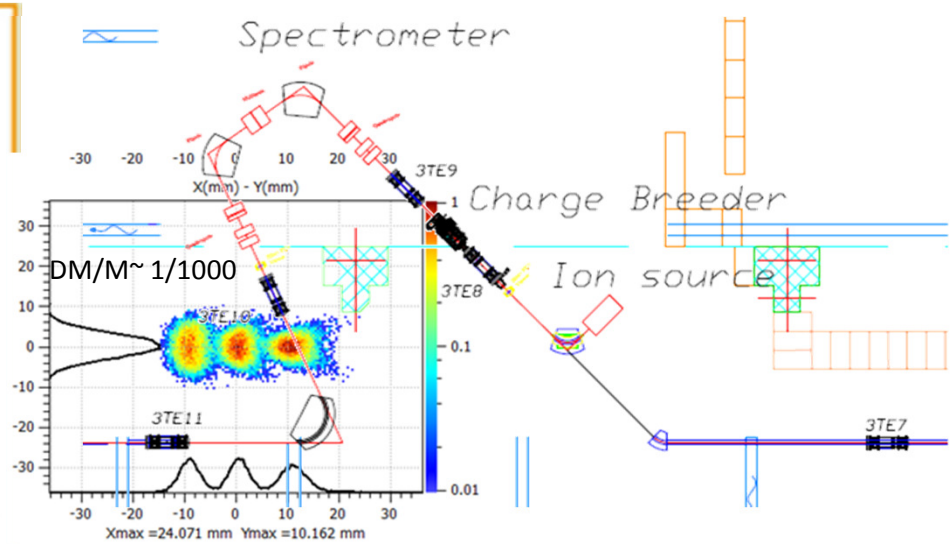
Mass Range	5-200 amu
Transverse Emittance Injected beam	30 π mm mrad @ 40 keV
Emittance Reduction factor	10 (max)
Buffer Gas	He @ 273 K
Beam Intensity	50-100 nA → x10^{11} pps
Energy spread	< 5 eV
RF Voltage range	0.5 – 2.5 kV (1 kV at q=0.25)
RF Frequency range	1 -30 MHz (3.5 – 15 MHz at q=0.25)
RFQ 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



Charge Breeder

- CB based on ECR technique
- Developed by LSPC in the framework of LEA collaboration
- Design 2013, construction 2014



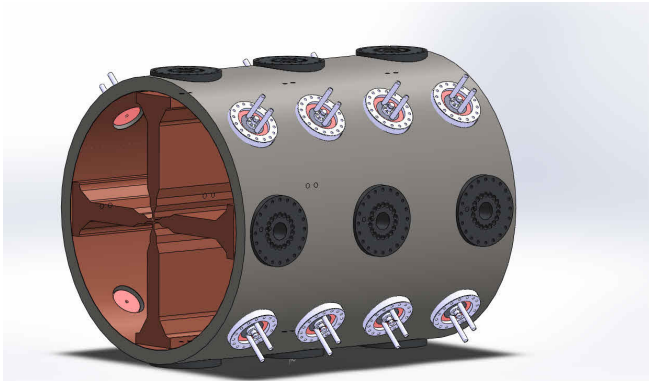


Charge Breeder and Medium Resolution Mass Separator

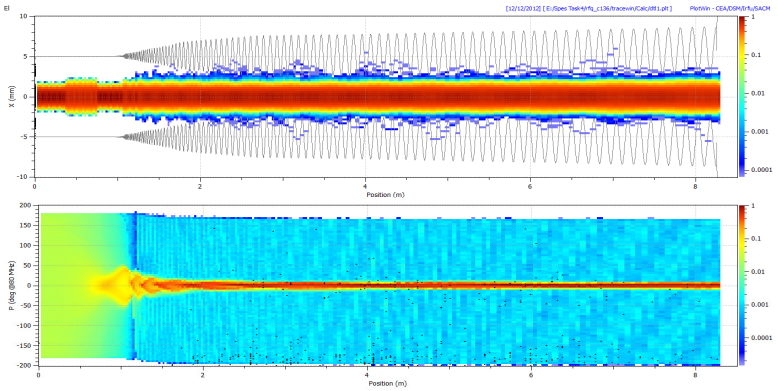
Element	Charge State	Efficiency [%]	CB time [ms]	Global Capture [%]
Ar	8+	16.2	78	75
Xe	20+	10.9	252	80
Rb	17+	7.5	226	55
Sn	21+	6.3	200	-

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).



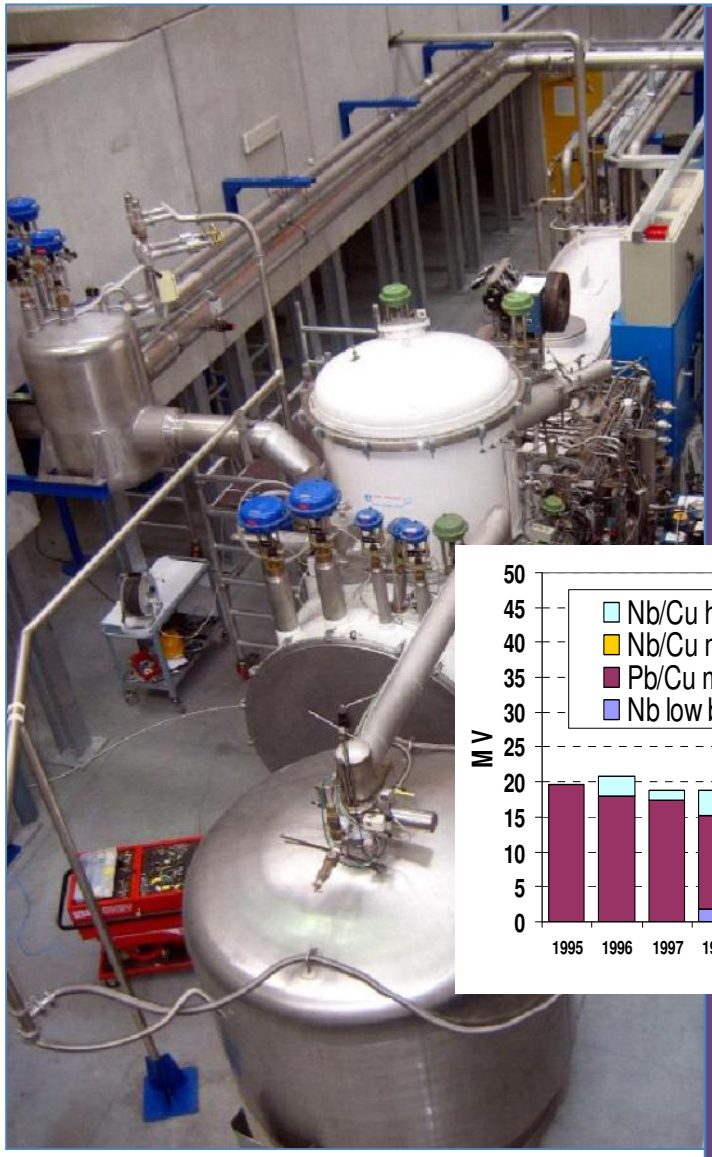
Mechanical layout of the RFQ tank module of about 1 meter.



First prototype construction: end 2013

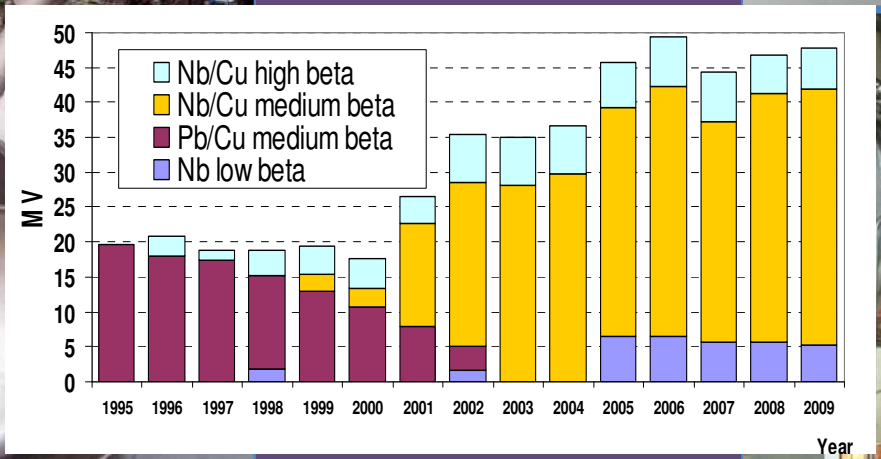
Parameter (units)	Design Value
Operational mode	CW
Frequency (MHz)	80.00
Injection Energy (keV/u)	5.7 (β=0.0035)
Output Energy (keV/u)	727 (β=0.0395)
Accelerated beam current (μA)	100
Charge states of accelerated ions (Q/A)	7 – 3
Inter-vane voltage V (kV, A/q=7)	63.8 – 85.84
Vane length L (m)	6.95
Average 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)

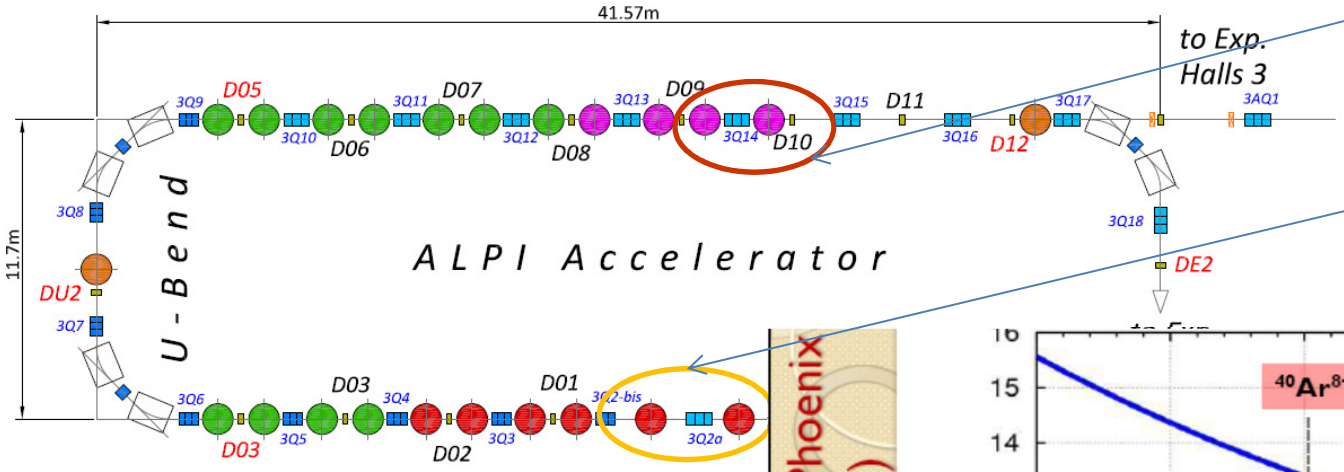
Upgraded ALPI layout

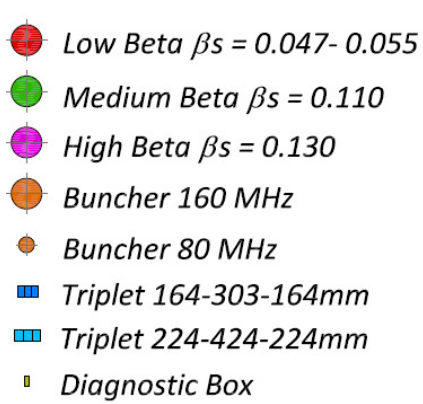
- All Cavities from CR03 to CR07 at 4.5 MV/m.
- Medium beta CR07 to CR18 at 4.5 MV/m.
- High beta 6.5 MV/m for CR19-CR22.
- **Final Energy of 10 MeV/A (A/q=7)**

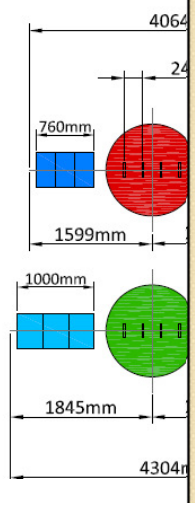
- **Increase energy**
- **Optimize transfer efficiency**

Additional cryostats: Increase total Energy

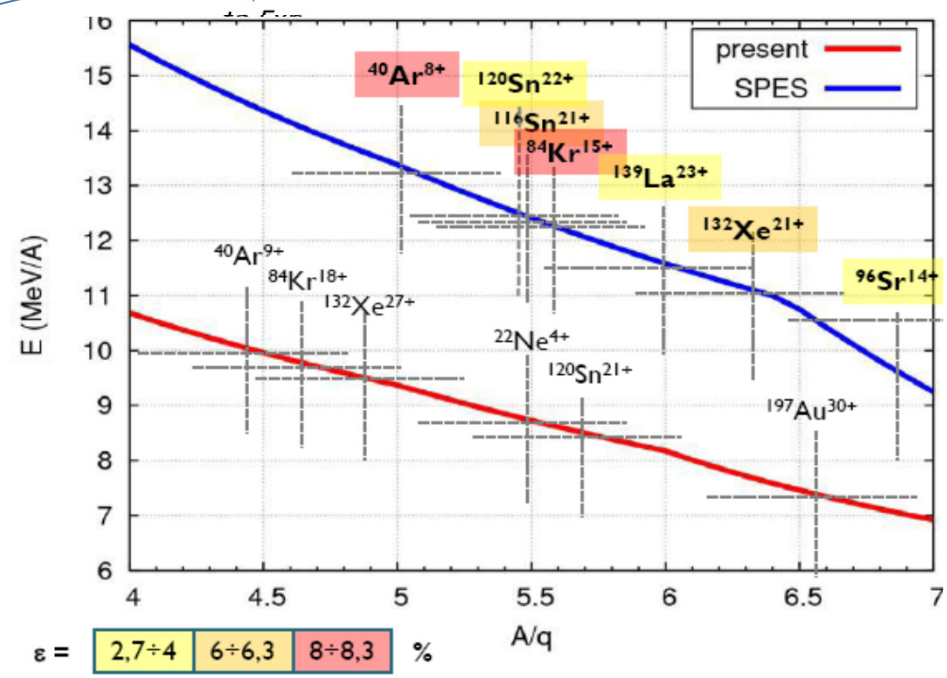
Cryostats relocated from PIAVE: reduce losses from 40% to 20%





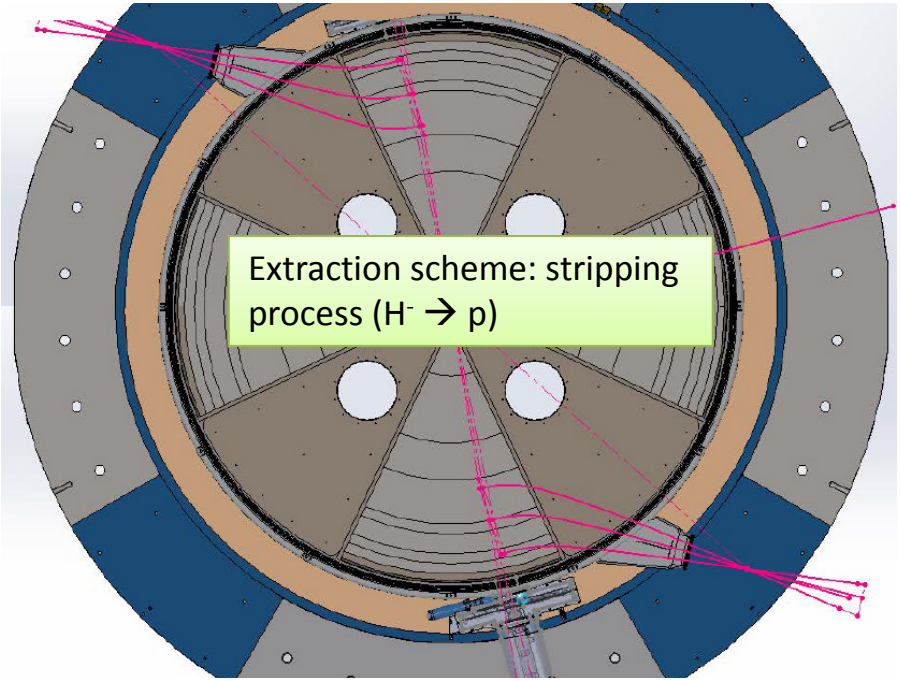


SPES Final Performance (Phoenix charge- bred beams)



70 MeV p Cyclotron

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 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

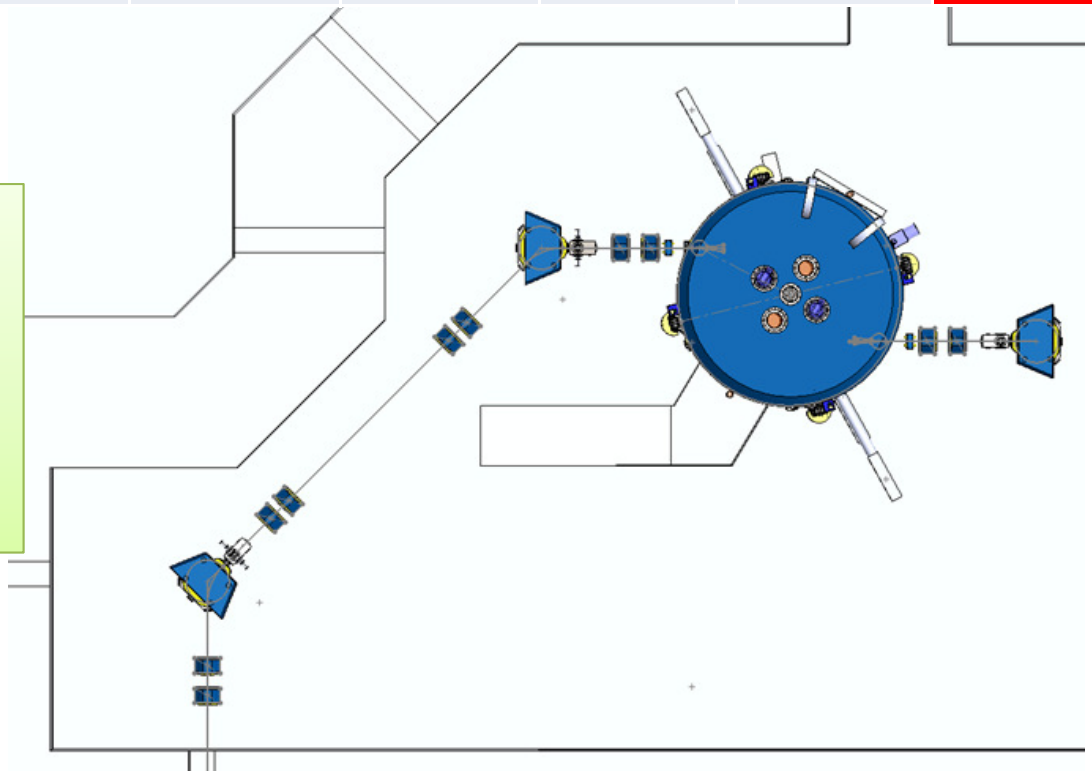


Cyclotron Schedule (2013-2014)

	2013		2014		
	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
- High power beam transport line (SPES target)



SPES Schedule May 2013

	2012	2013	2014	2015	2016	2017
Authorization to operate and safety	UCx 5µA	Full	UCx auth	orization		
ISOL Target-Ion Sources development						
ISOL Targets construction and installation						
Building Construction	Executive project					
Cyclotron Construction & commissioning	in	schedule				
RFQ development and Alpi up-grade						
Design of RIB transport & selection (HRMS, Charge Breeder, Beam Cooler)						
Construction and Installation of RIBs transfer lines and spectrometer						
Complete commissioning and first exotic beam						

Current status and overview

- Letters of Intent: under discussion to select first-day-exp.
- ISOL Target and Ion Source: working in off-line laboratory.
- Layout for beam transfer and pre-acceleration: defined.
- Authorizations ready for cyclotron operation.
- Contract for cyclotron: signed November ‘10, final design accepted (June ’11), cyclotron under machining.
- Building: financed (June ‘12), ground braking started.
- Phase β partially financed (July ‘12)

SPES building site

June 4, 2013

Work in progress !!