SPES Project

Gianfranco Prete
SPES Project leader

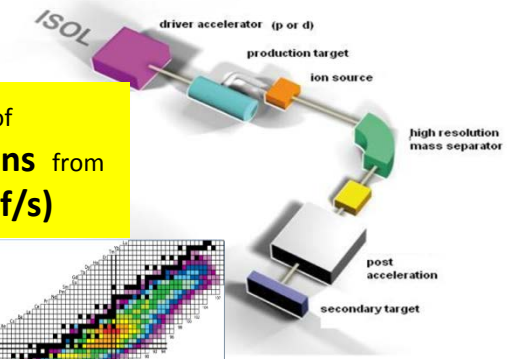
SPES Strategy

BEST Cyclotron installation & commissioning:

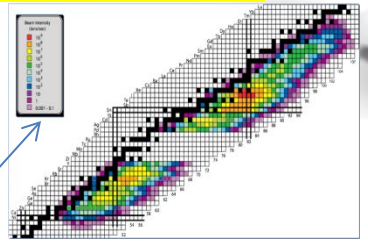
- 70 MeV proton beam
- 750 μA

Funded

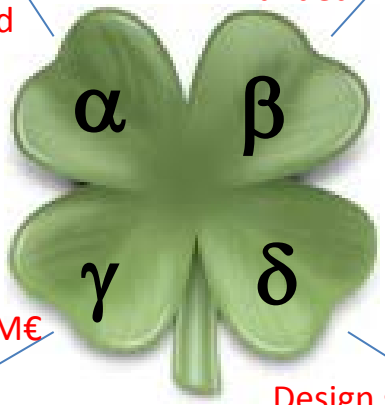
Second generation ISOL facility
Toward EURISOL



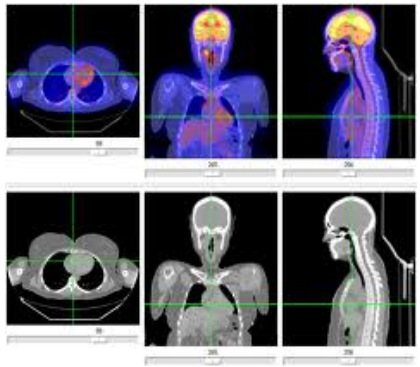
Production & re-acceleration of **exotic beams. Neutron–rich ions** from **p-induced Fission** on **UCx (10^{13} f/s)**



Funded



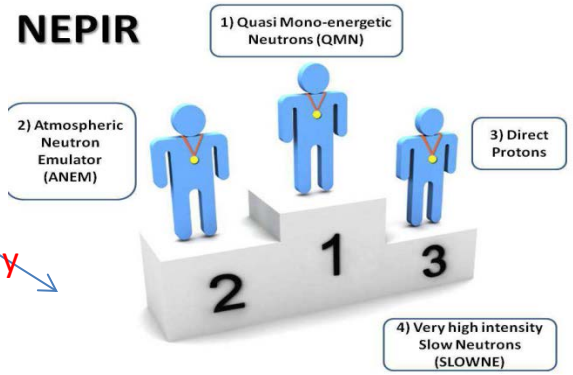
LARAMED



Partially funded 6.8 M€

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

NEPIR



Design study

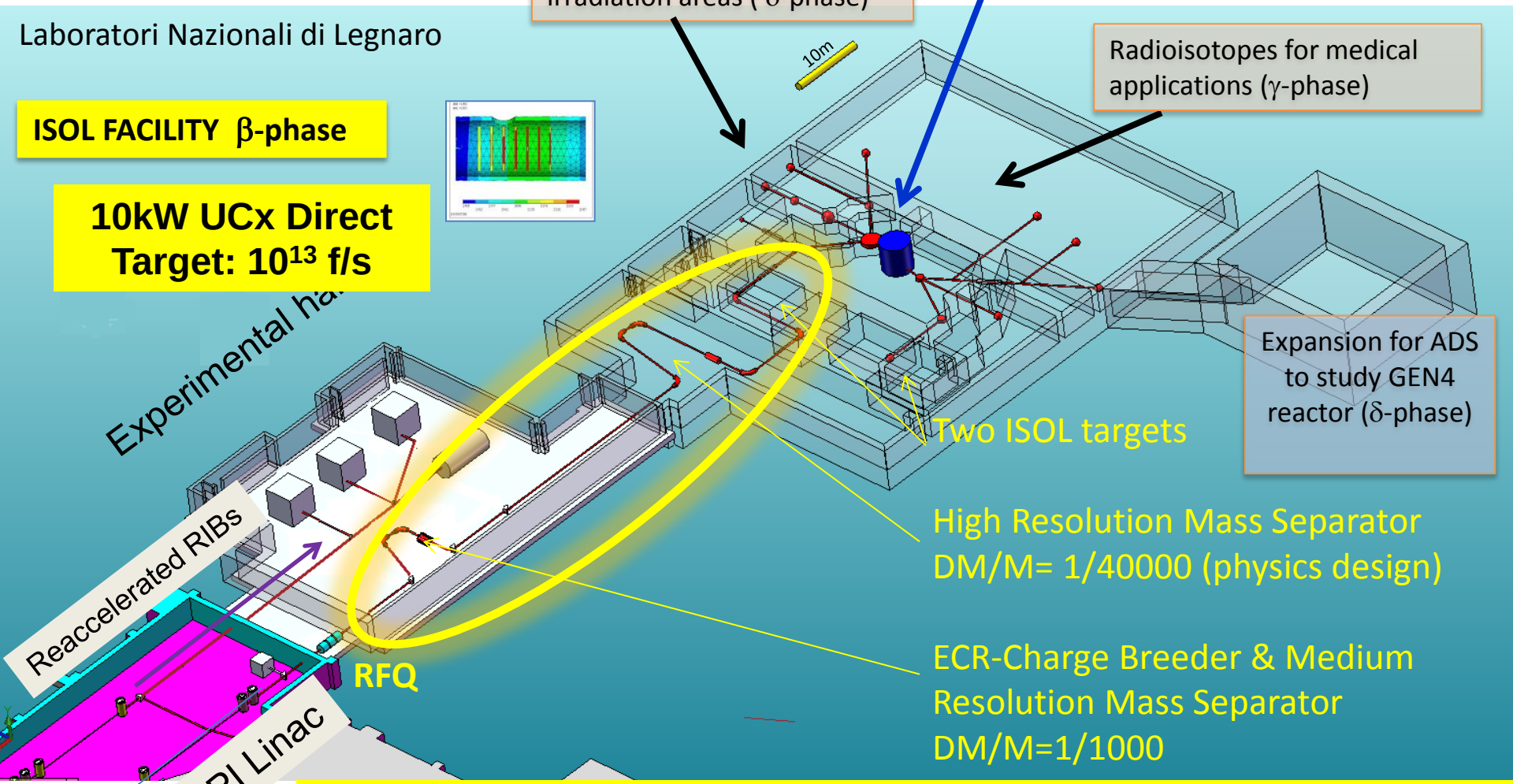
Accelerator based neutron source (**Proton and Neutron Facility for Applied Physics**)

SPES layout

Laboratori Nazionali di Legnaro

ISOL FACILITY β-phase

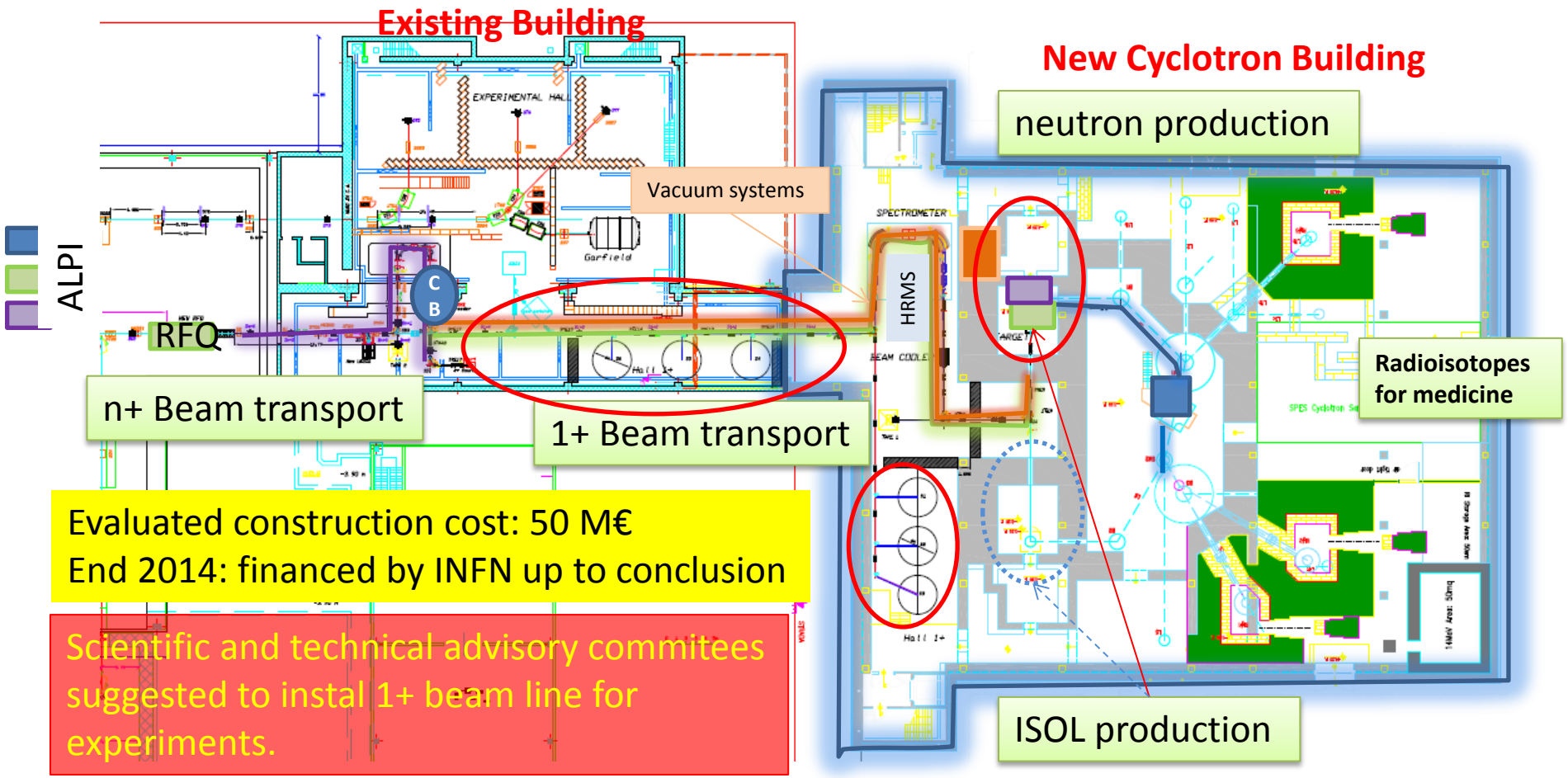
10kW UCx Direct Target: 10^{13} f/s



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

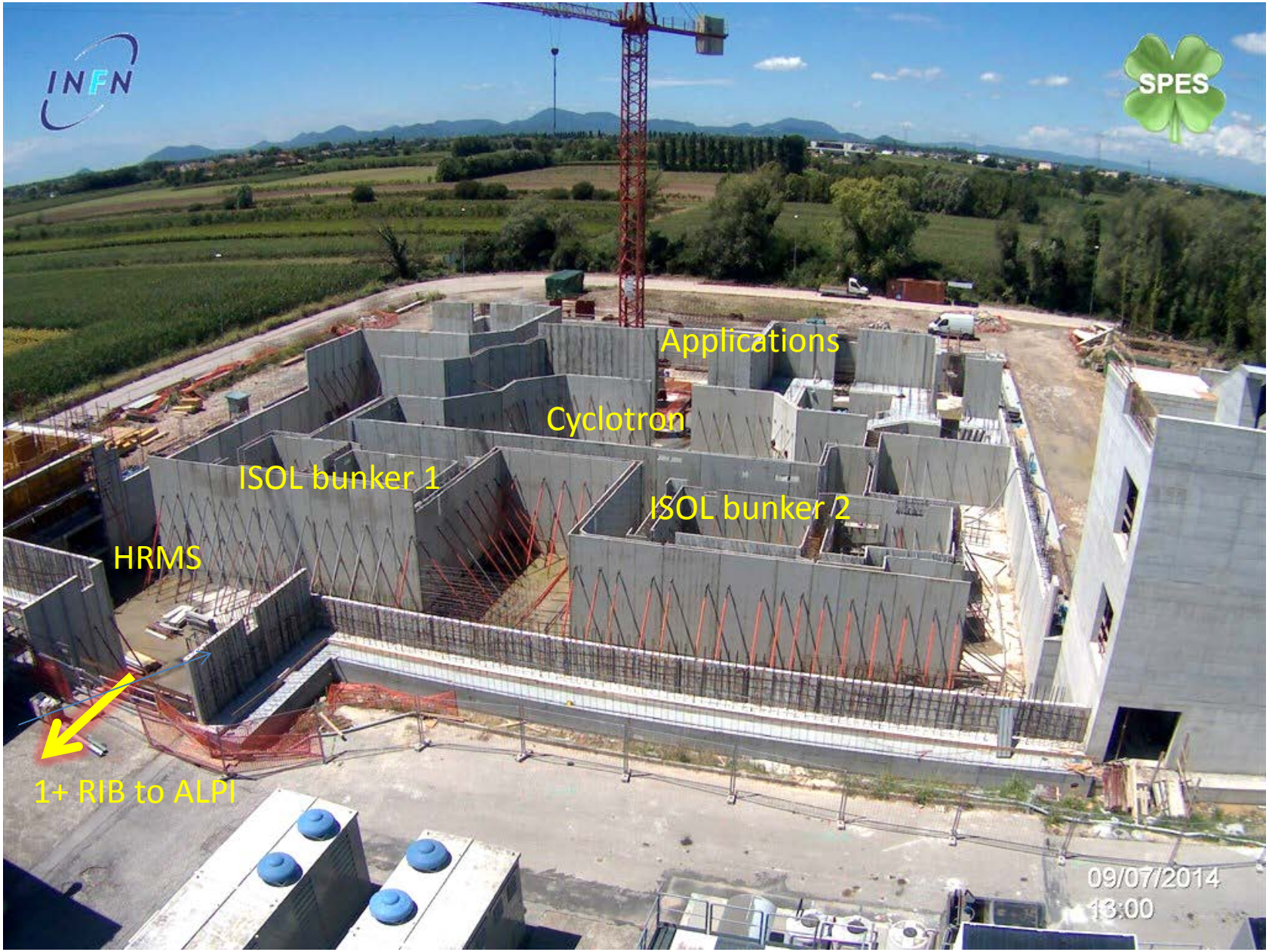
MAIN TENDERS

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

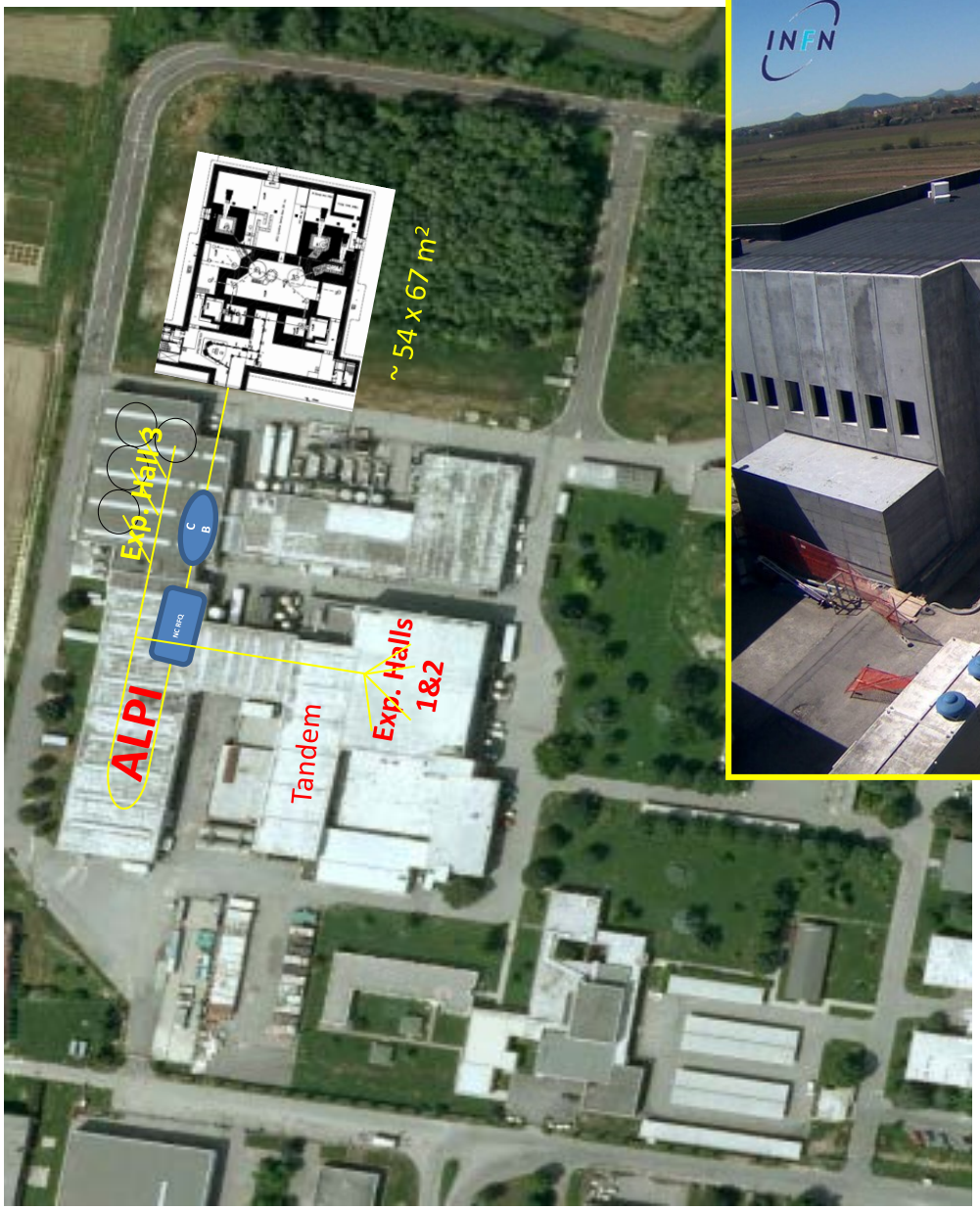


Evaluated construction cost: 50 M€
End 2014: financed by INFN up to conclusion

Scientific and technical advisory commitees suggested to instal 1+ beam line for experiments.


INFN
SPES
Applications
Cyclotron
ISOL bunker 1
ISOL bunker 2
HRMS
1+ RIB to ALPI
09/07/2014
13:00

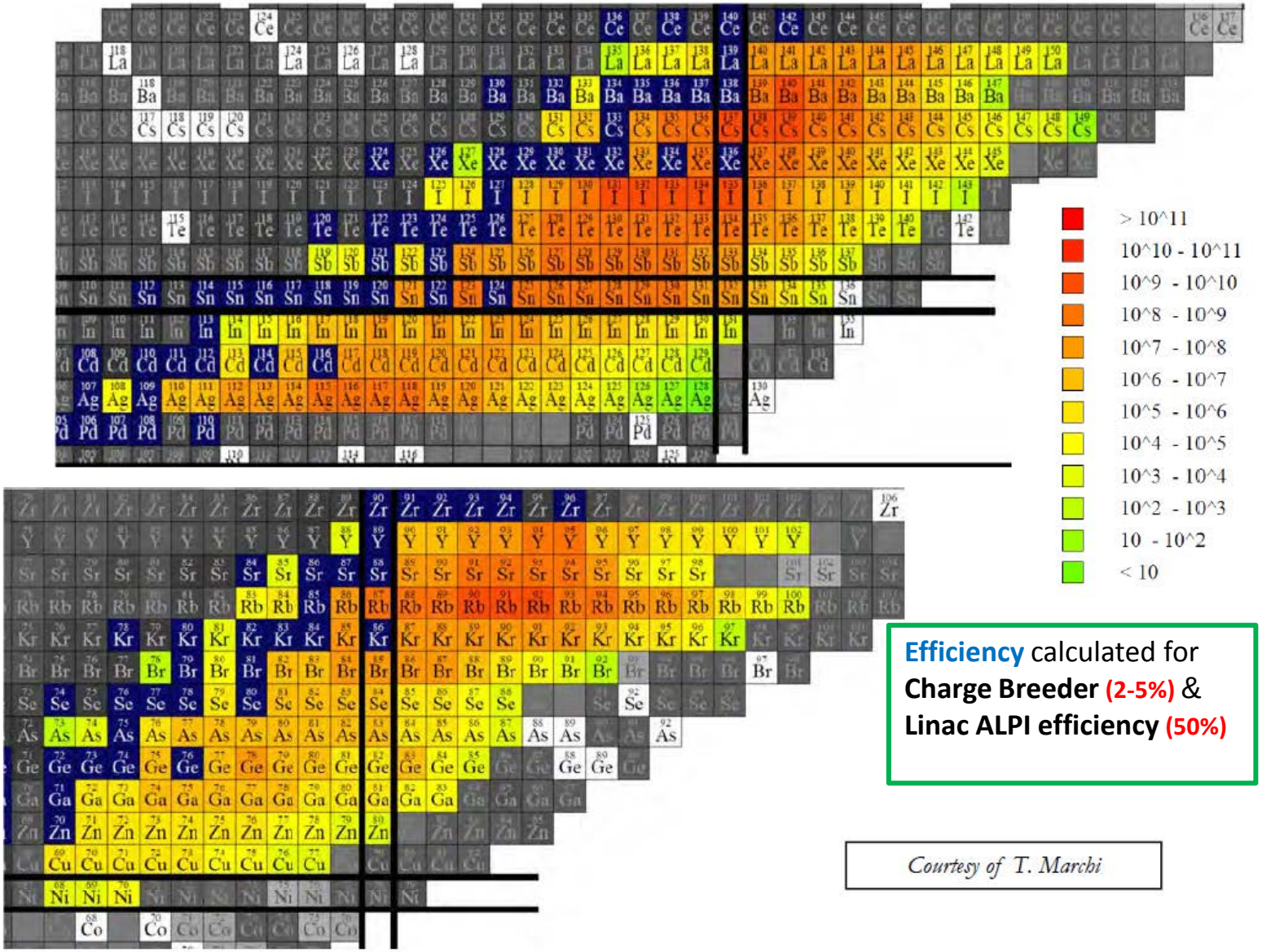
SPES Facility Layout



New infrastructure for:

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

Preparing the Scientific Activities :
SPES beam intensities after re-acceleration (q^+)

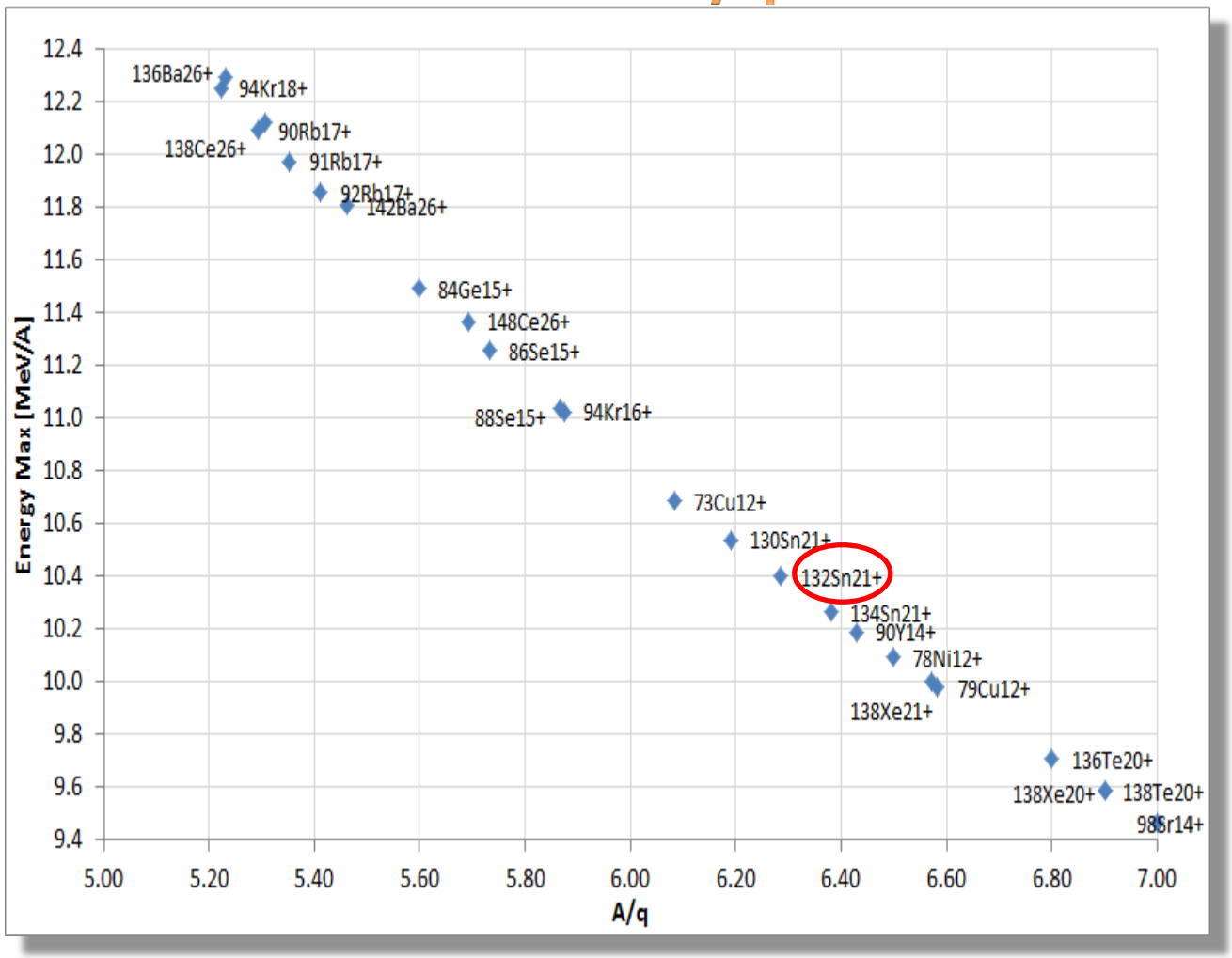


Efficiency calculated for **Charge Breeder (2-5%)** & **Linac ALPI efficiency (50%)**

Courtesy of T. Marchi

https://web.infn.it/spes/images/NEW_SITE/PDF/SPES_Beam_Tables

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

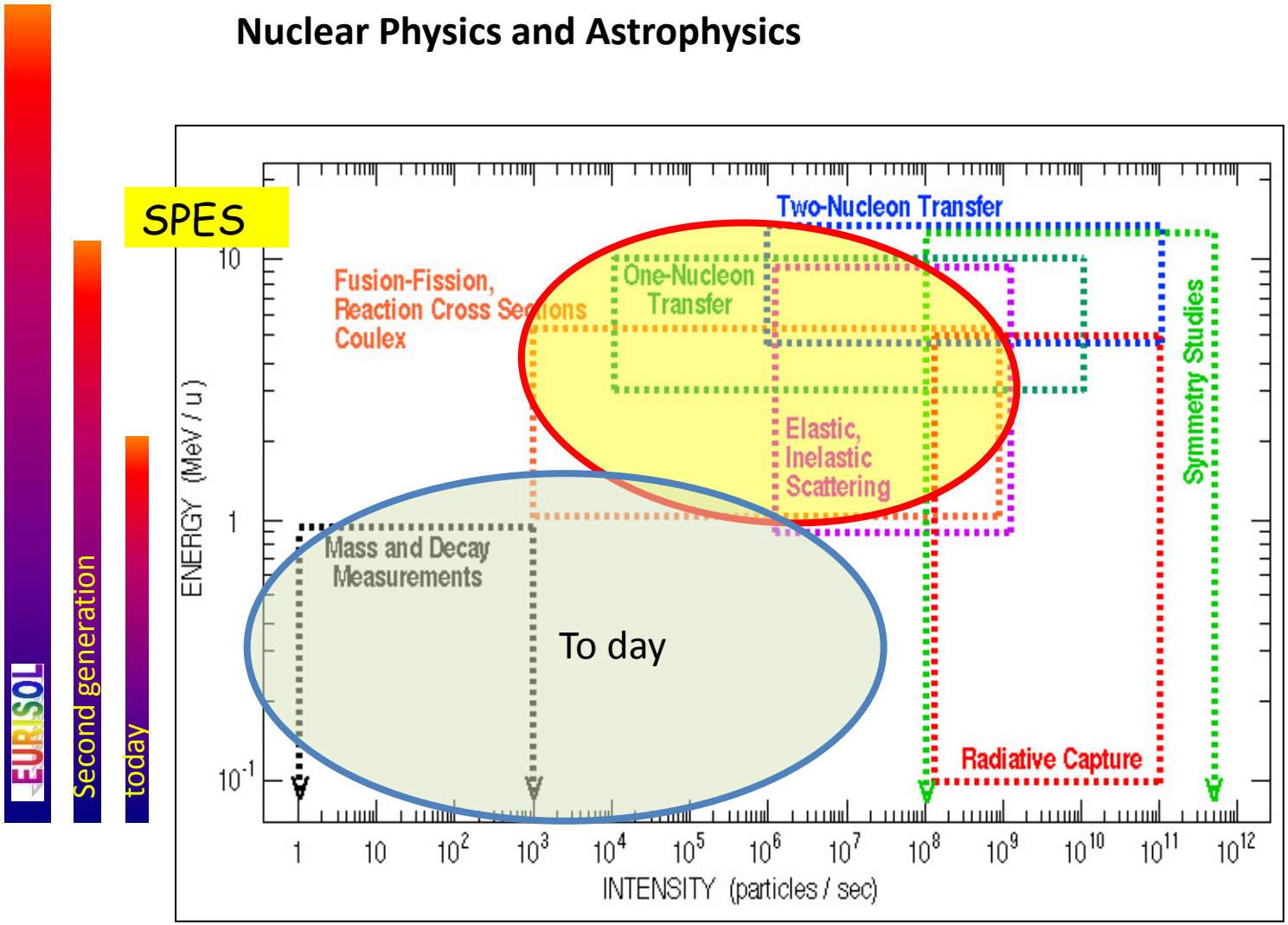


Preliminary results from alpi performances with 2 cavities as margin, Low Beta=5 MV/m, Medium Beta=4.3 MV/m, High Beta=5.5 MV/m

(M. Comunian)

Physics Domain with RIB

Nuclear Physics and Astrophysics



today

Second generation

EURISOL

Experiments at SPES

Exploiting the ALPI superconductive LINAC to supply beams at 10A MeV

First beams with Surface ion source → Rb, Cs

Low current on target (5 microA)

low energy experiments without reacceleration

transfer reactions

gamma spectroscopy

new instrumentation

TIME LINE

1) **Driver Commissioning**
   - **2015:** Delivery of infrastructure
   - **2015-2016:** First sub-systems

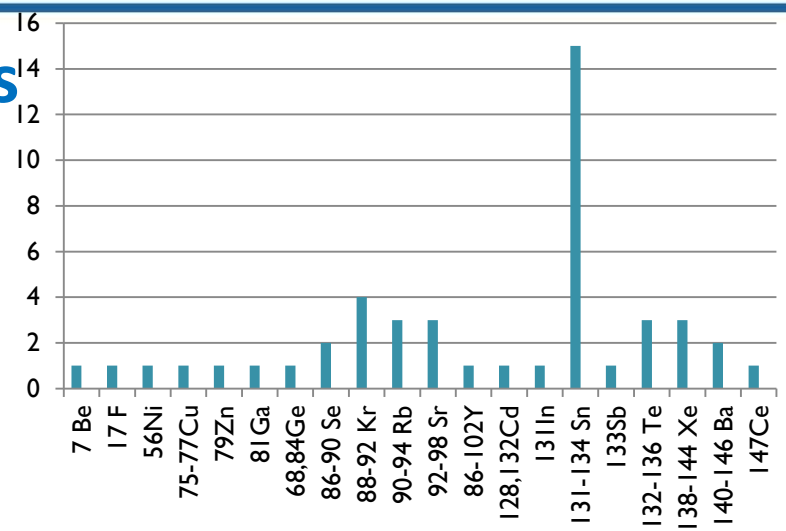
2) **RIB Operational-> : 40 MeV on target**
   - **2017** I = 5 µA, SiC (13 mm); low energy
   - **2018** I > 5 µ A, UCx – SiC (40 mm); low energy
   - **2019** I= 150 µ A, UCx (40 mm); reacceleration

iCal export More Europe/Rome English Login

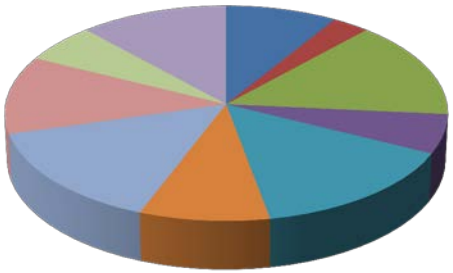
Second SPES International Workshop

26-28 May 2014 *INFN Laboratori Nazionali di Legnaro*
Europe/Rome timezone

Presented 37 Letters of Intents

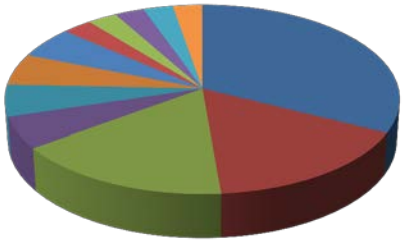


SPES LOIs Topics



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

SPES LOIs Spokespersons

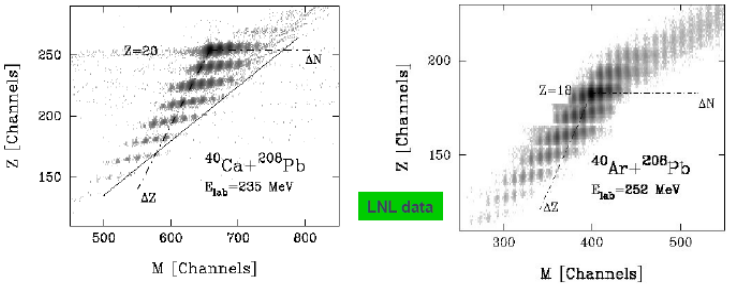


- Italy
- France
- Poland
- Russia
- USA
- Belgium
- Croatia
- Norway
- Bulgaria
- Spain
- Russia
- China

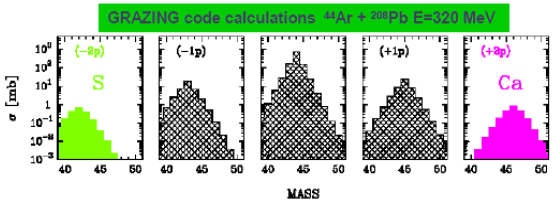
Multinucleon Transfer Reactions

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

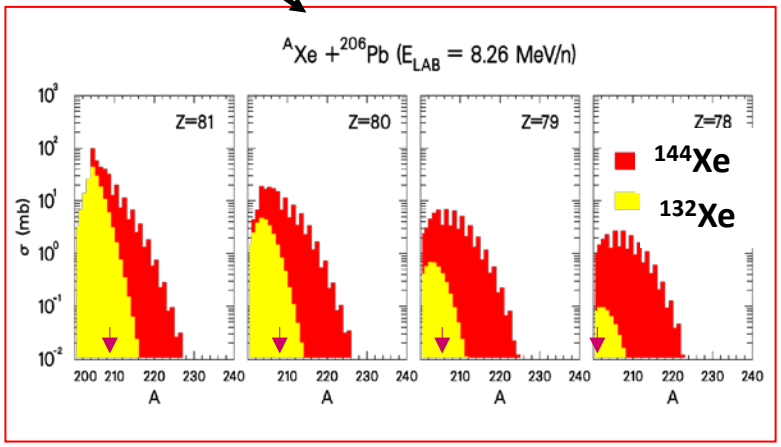
Multinucleon transfer reactions : from neutron poor to neutron rich nuclei



with (moderately n-rich) heavy ions one can populate (nn), (pp) and (np) channels with comparable strength



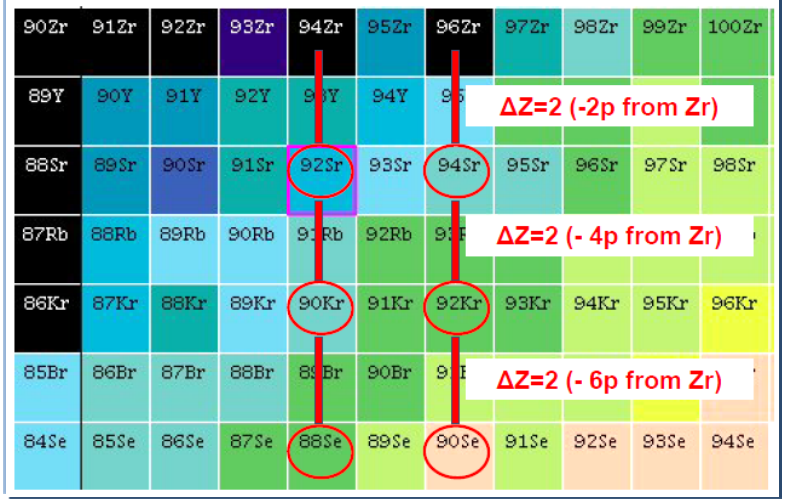
It is clear that while with **^{40}Ca beams** most of the **transfer flux** feeds **neutron pick-up & proton stripping,** with the **most neutron rich ^{40}Ar** the **neutron stripping & proton pick-up channels** start to have a **significant yield. With even more neutron rich** beams the **yields** in the **stripping & pick-up** directions (both for **neutrons and protons)** become **comparable.**



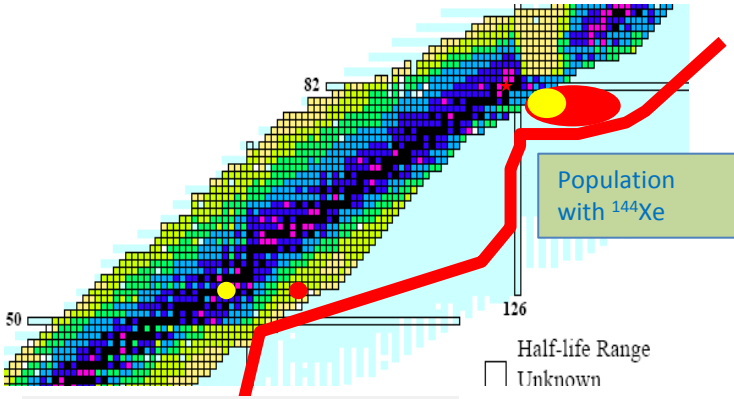
Coupled channel calculations (Grazing). G. Pollarolo

Target ^{206}Pb

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



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

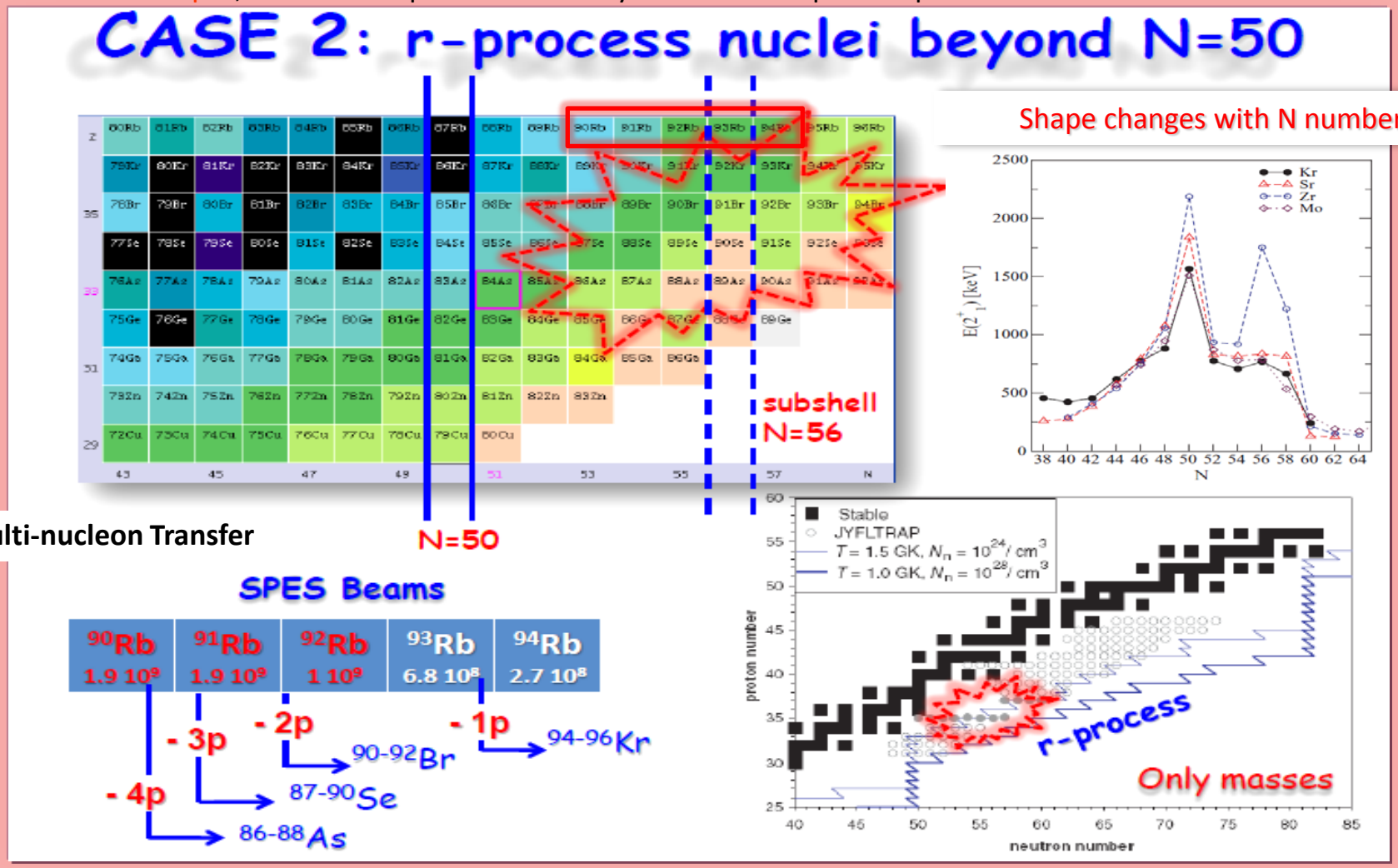


Beam
^{132}Xe ^{144}Xe

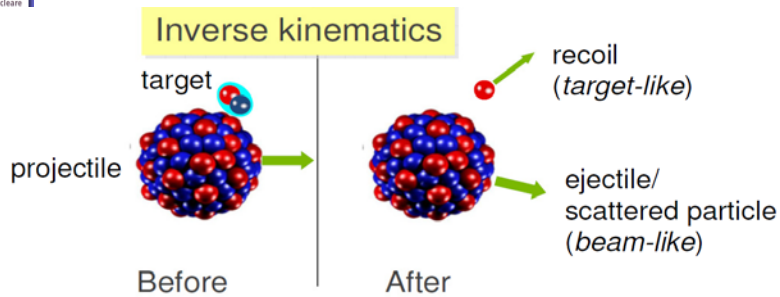
r-process nuclei:
β-decay and isomer spectroscopy

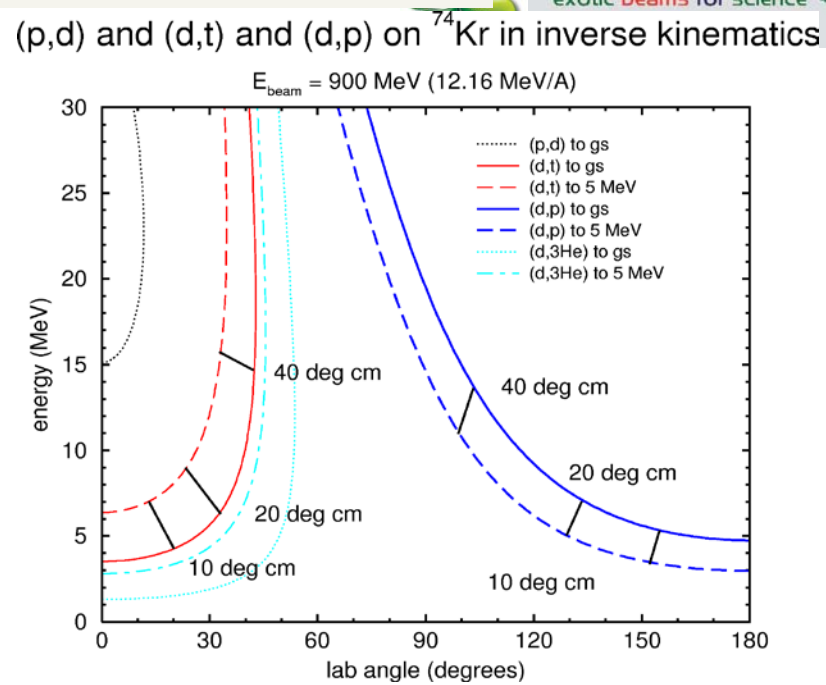
Importance of nuclear deformation for r-process:
Experimental cases @SPES – **S. Leoni et al. INFN_Uni Milan (I) – INP Kracow (Pl)**

An important region which can be accessed is the neutron-rich region beyond the shell closure at N=50, in particular the Ge-Br isotopes, which are expected to be very close to the r-process path



Inelastic scattering, transfer reactions





With transfer we can probe:

- occupancy of single-particle (shell model) orbitals in the original nucleus A ground state
  or distribution of s.p. strength in all final states of A–1 or A+1 nucleus that is, can add a nucleon to the original nucleus, e.g. by (d,p)
- identify the angular momentum of the transferred nucleon
- hence, identify the s.p. level energies in A–1 or A+1 nuclei produced from even-even nuclei
- identify the s.p. purity of coupled states in A–1 or A+1 nuclei produced from odd nuclei

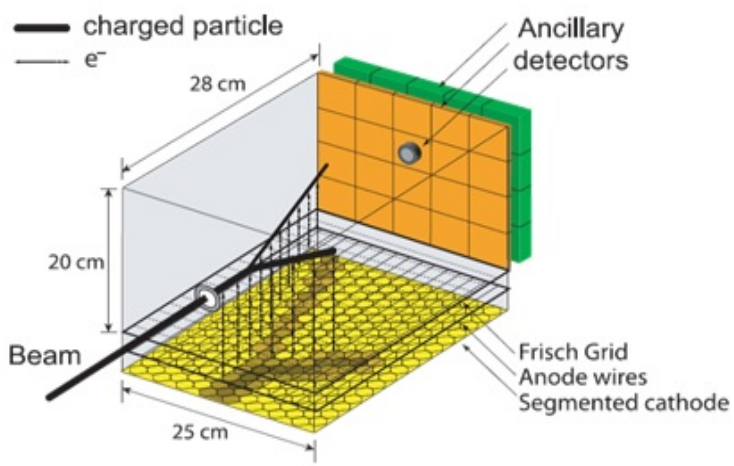
and the scattered particle is detected, with most yield being at small centre-of-mass angles

Time-Projection Chamber (TPC)

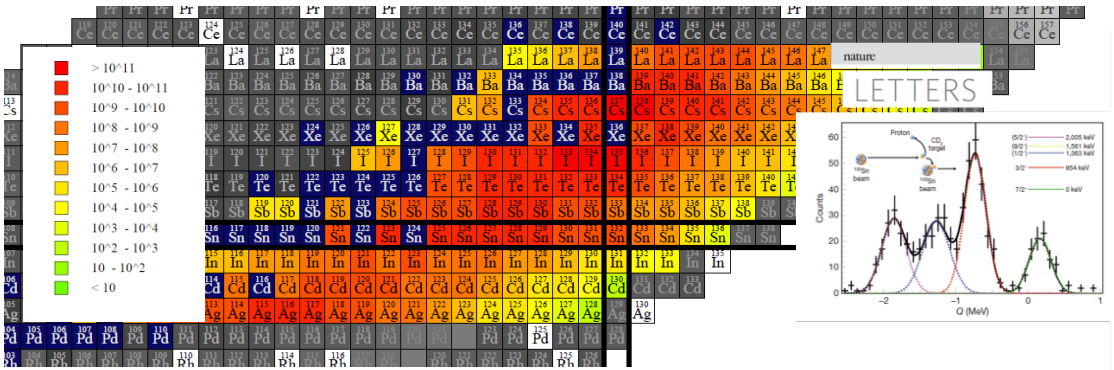
detection gas is the target

- Large target thickness and still good resolution
- Low detection threshold
- Large solid angle and High efficiency

- Electrons, produced by ionization, drift to an amplification zone
- Signals collected on a segmented "pad" plane⇒2D-image of the track
- 3rd dimension from the drift time of the electrons



In particular: Shell Structure in the vicinity of ^{132}Sn with an active target



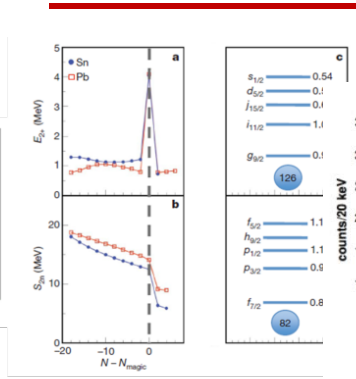


Figure B1.1 - 2. (left) Q-value spectrum for the ^{132}Sn(d,p)^{133}Sn reaction at 54° in the center of mass reference frame. (right) Comparison between Sn and Pb "signs" of magicity: two neutron separation energies (a) and first 2⁺ state energies (b) as a function of the number of neutrons beyond the shell closure. (c) and (d) represent the single particle states above the magic numbers N=126 and N=82 respectively. The numbers on the right are the measured spectroscopic factors. Adapted from [16].

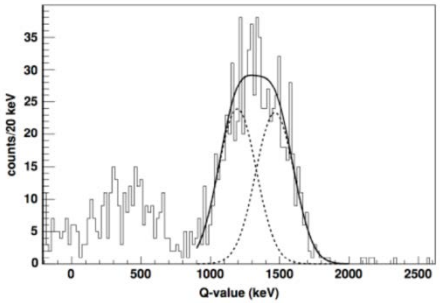


Figure B1.1 - 5. Q-value spectrum for the ^{82}Ga(d,p)^{83}Ge at 4 AMeV on CD_2 target as measured in [22]

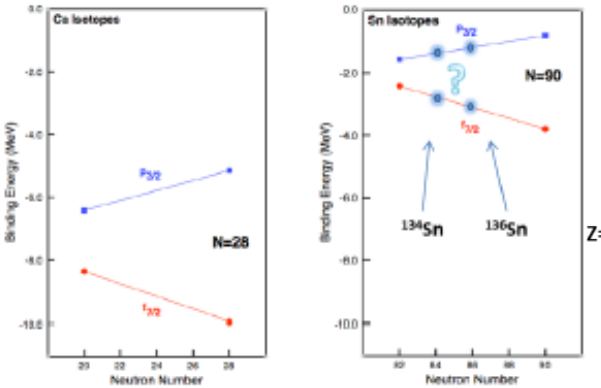
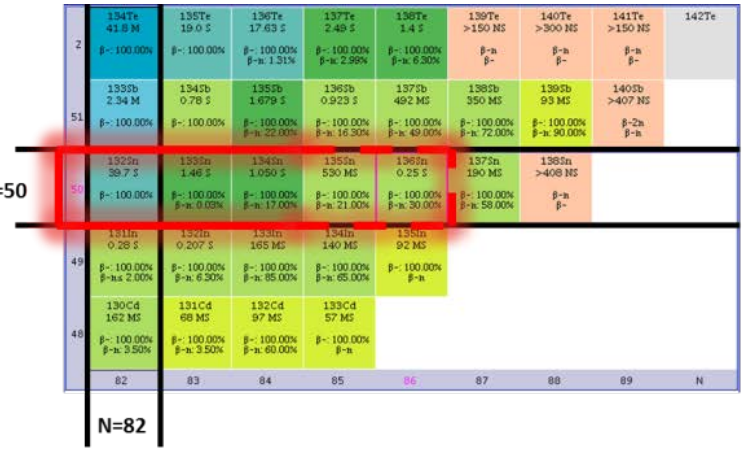


Fig.1 Analogy between f7/2 and p3/2 evolution of binding energies in the known Ca isotopes to what could be expected for the Sn isotopes approaching N=90. Figure adapted from[13].



Expected beam intensities @ 10 AMeV	SPES 1st day (5 μA p beam)	SPES full power (200 μA p beam)
^{132}Sn	7.8 10^5	3.1 10^7
^{133}Sn	7.0 10^4	2.8 10^6
^{134}Sn	1.2 10^4	4.9 10^5
^{135}Sn	1.6 10^2	6.2 10^3
^{136}Sn	-	0.9 10^2

T. Marchi , R. Raabe, MagicTin EU-MSCA proposal – Approved

SPES at low current

In preparation for this SPES activity:
Commissioning experiment with <u>low-intensity</u> ^{120}Sn beam at ALPI energies (!10^6pps)

SPES Project

SPES one-day Workshop "Physics at SPES with non re-accelerated beams"

20-21 April 2015 *Milano*
Europe/Rome timezone

Outcome 1-day Workshop on the Physics at SPES with non re-accelerated beams", Milano on April 20th-21st 2015.

* Good response: 65 registered participants coming from:
Italy, CERN, Riken-Japan, Oak Ridge-USA, TRIUMF-Canada, Bordeaux-France, Orsay-France, Giessen-Germany, Spain, Greece.

18 oral presentations, some based on LOI presented in May 2014

- **Beta decay spectroscopy of fission fragments**
- **Beta decay studies using the gamma Total Absorption Technique**
- **Neutron Decay Spectroscopy**
- **Trap assisted measurements**

Instrumentation

Tape station surrounded by beta-detectors and a number of ancillary detectors:
high-resolution HPGE detectors in a closely packed configuration allow for detailed decay studies, while the addition of neutron detectors allow to firmly establish the beta-delayed neutron branch.
Traps coupled to laser spectroscopy, spin polarization, beta-NMR.
Multi Reflection TOF for high precision mass measurement.

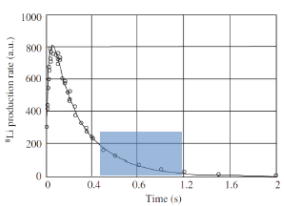
SPES Instrumentation

Diagnostics for SPES:
2 tape stations
to characterize the RiB

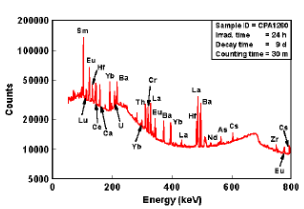
Beta decay station as a permanent and flexible setup
- Tape station + β detector
- Coupling to HPGe, LaBr3, neutron detectors etc…

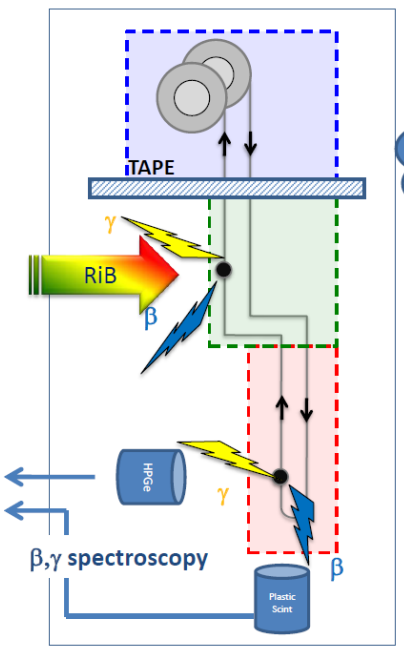
1.The tape station(s) for SPES

Beam characterization:
- Release Curve



- Beam Composition and Isotopic Yields





The tape station is the "eyes and ears" of an ISOL facility.
Tim Giles, seminar on ISOLDE diagnostic tools, LNL May 2014

Requirements:
1-Reliability
2-Lasting operability
3-Ease of use

Moving the tape, the residual activity due to the long lived isotopes is minimized.

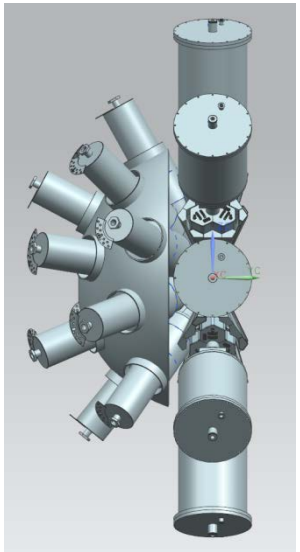
The GALILEO project

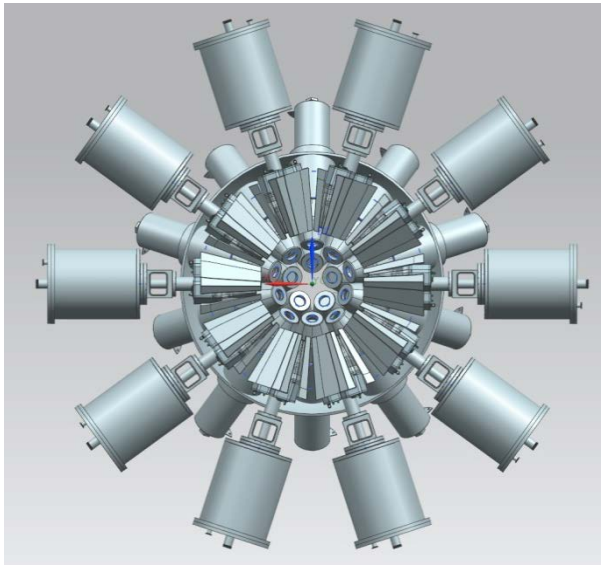
GALILEO – a new gamma–ray array spectroscopy

- takes advantage of the developments made for AGATA
  - preamplifiers
  - digital sampling
  - preprocessing
  - DAQ

- uses the EUROBALL cluster detectors capsules
  - improved efficiency
  - development of a new cluster detector with 3 capsules

- **Phase 1: 40 GASP detectors**





e_{ph}~8% P/T~50%

Detector configuration

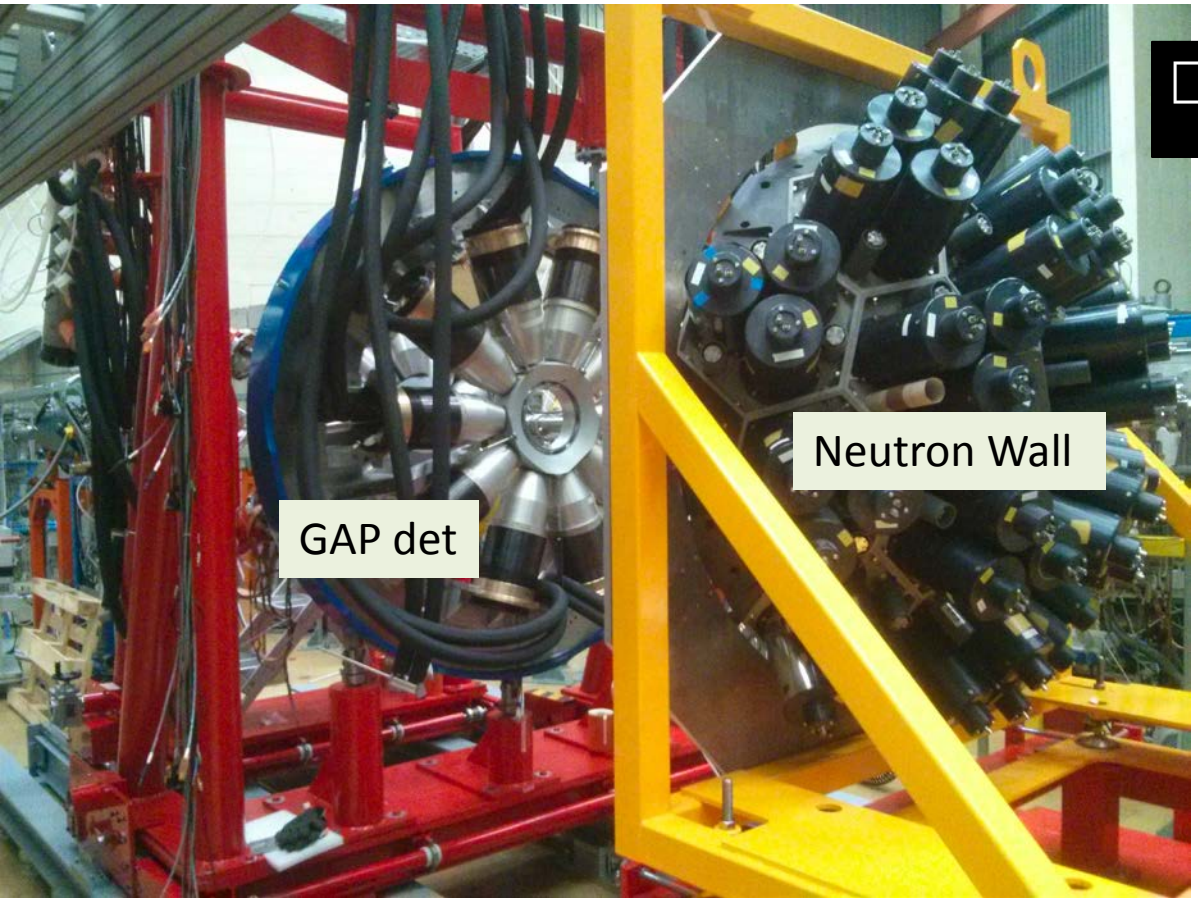
- 30 GASP detectors @ 22.5cm

5	5	5	5	5	5
29º	51º	59º	121º	129º	131º

- 10 triple cluster detectors @ 24 cm

90º

GALILEO installation at LNL



Installed: 25 GASP detectors
Neutron Wall (from NeutronWall Collaboration)
EUCLIDES light particle detector array
Commissioning concluded, ready for run.
10 proposals submitted to LNL-PAC (June,30)

Present stable beam campaign

- Shape coexistence
- N~Z T=0 coherent pairing
- Isospin symmetry breaking
- Octupolar deformation

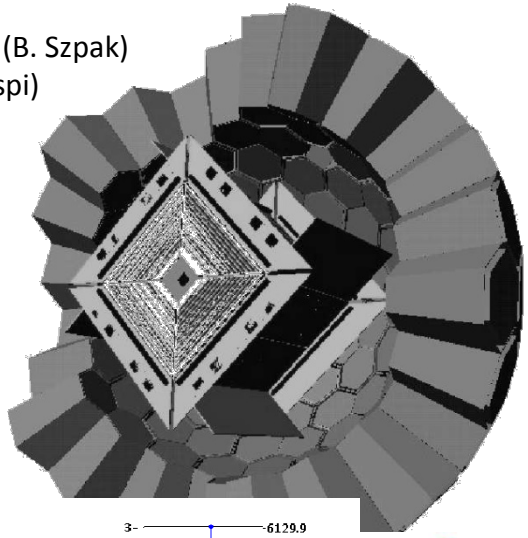
Future RIB campaign

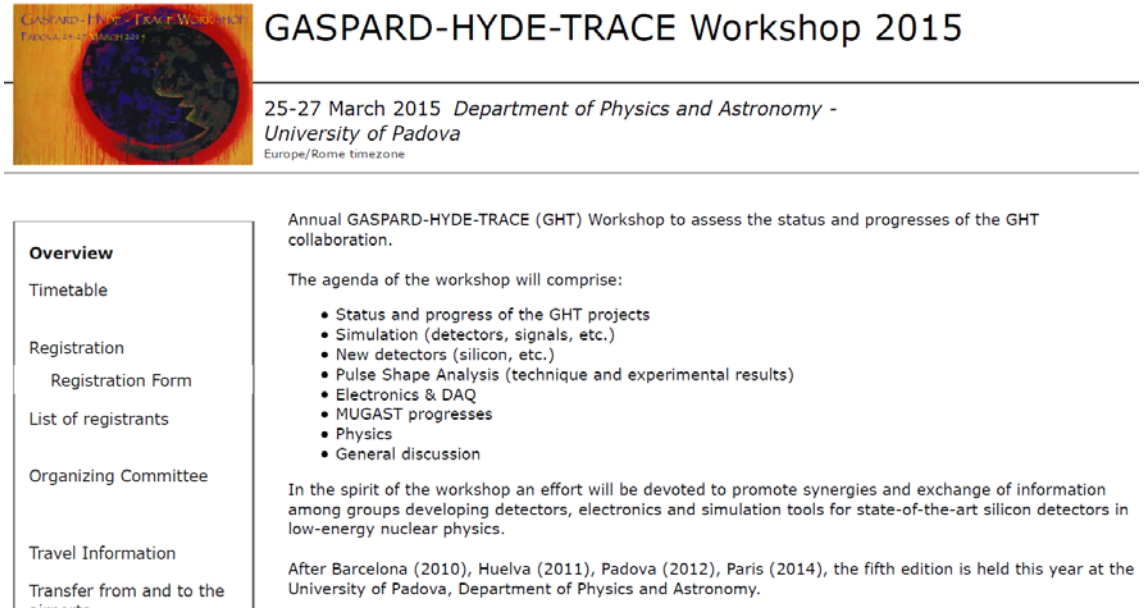
- Shape evolution around Ni and Sn via direct reaction and Coulex
- Shape deformation
- High Energy excitation
- Astrophysics

Gamma spectroscopy with Galileo and ancillaries

Letters of Intent 2nd SPES workshop, 2014

- Exploring the Z=32 triaxiality corridor towards N=50 via safe Coulex (M.Zielinska)
- Spectroscopy studies around 78Ni and beyond N = 50 via transfer and Coulomb excitation reactions. (J.J. Valiente-Dobon, A. Gadea, R. Orlandi, E. Clement)
- Nuclear magicity at Z 50 N 82. Neutron capture cross section via the surrogate method. (D.Mengoni, G.deAngelis)
- Transfer reaction measurements for r-process nucleosynthesis (S.D.Pain)
- Structure of Sb nuclei around 132Sn as a testing ground for realistic shell model interactions. (B. Szpak)
- Low-lying dipole excitation via nuclear probes in exotic nuclei. (E.Lanza, D.Mengoni, F.C.L.Crespi)
- Search for Exotic-Octupole deformation effects in n-rich Ce-Xe-Ba Nuclei. (E.Sahin)
- Coulomb Excitation measurements of Radioactive Ions: N82 and Z50 (B.Melon)
- Shape coexistence in Kr isotopes towards N=60 (V.Modamio)
- The Onset of deformation in the n-rich Y isotopes. (M.Kmiecik)





GASPARD-HYDE-TRACE Workshop 2015

25-27 March 2015 *Department of Physics and Astronomy - University of Padova*
Europe/Rome timezone

Overview
Timetable
Registration
Registration Form
List of registrants
Organizing Committee
Travel Information
Transfer from and to the

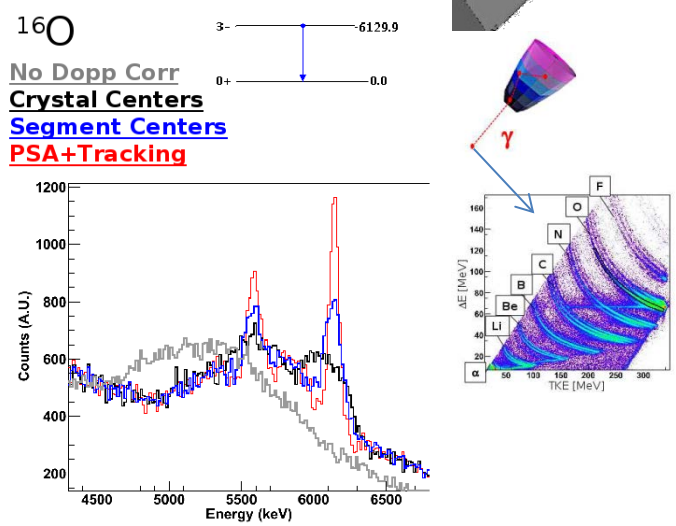
Annual GASPARD-HYDE-TRACE (GHT) Workshop to assess the status and progresses of the GHT collaboration.

The agenda of the workshop will comprise:

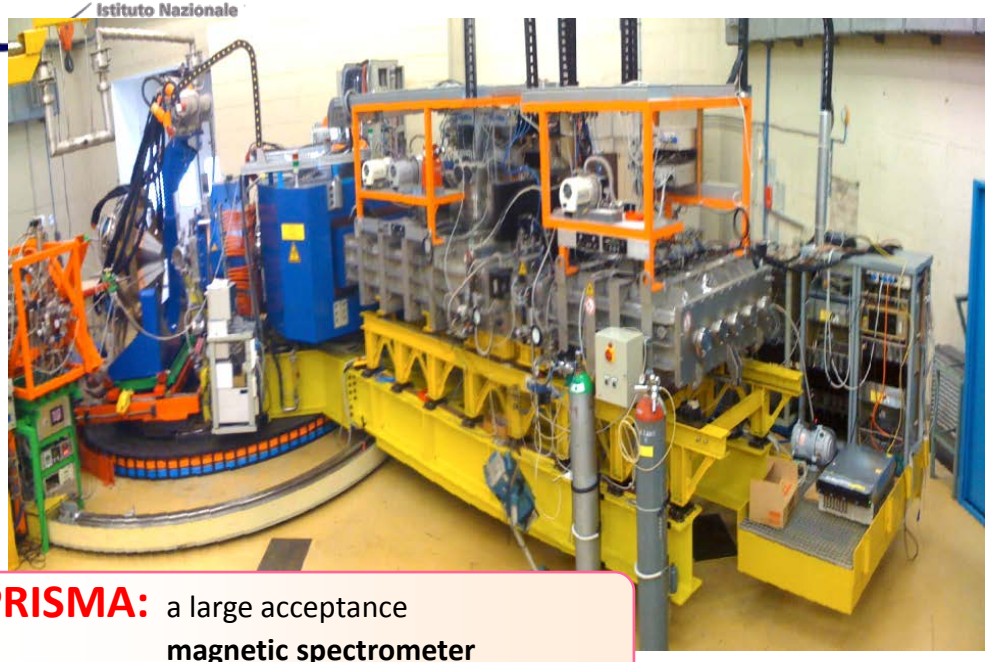
- Status and progress of the GHT projects
- Simulation (detectors, signals, etc.)
- New detectors (silicon, etc.)
- Pulse Shape Analysis (technique and experimental results)
- Electronics & DAQ
- MUGAST progresses
- Physics
- General discussion

In the spirit of the workshop an effort will be devoted to promote synergies and exchange of information among groups developing detectors, electronics and simulation tools for state-of-the-art silicon detectors in low-energy nuclear physics.

After Barcelona (2010), Huelva (2011), Padova (2012), Paris (2014), the fifth edition is held this year at the University of Padova, Department of Physics and Astronomy.



SPES Instrumentation



PRISMA: a large acceptance **magnetic spectrometer**

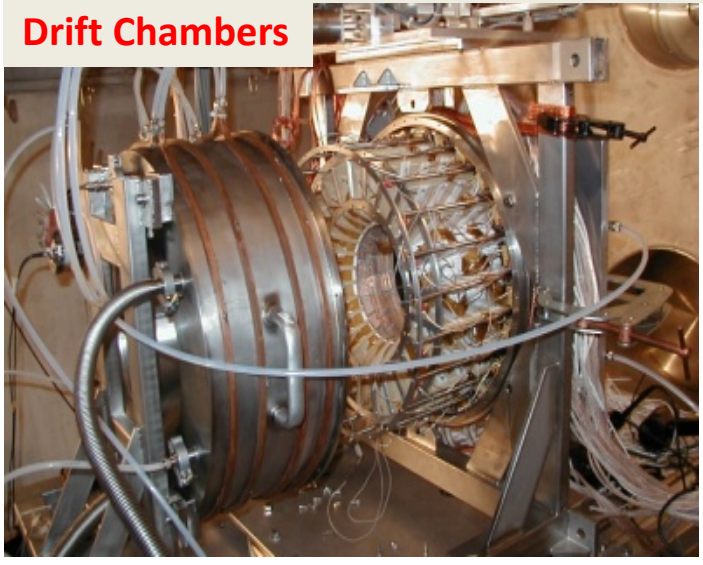
$\Omega \approx 80$ msr; $B\rho_{max} = 1.2$ Tm

$\Delta A/A \sim 1/200$

Energy acceptance ~ ±20%

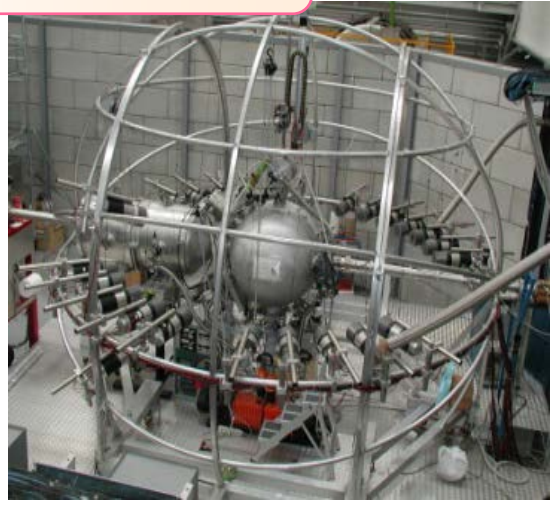
GARFIELD 4π -LCP & Fragments

Drift Chambers

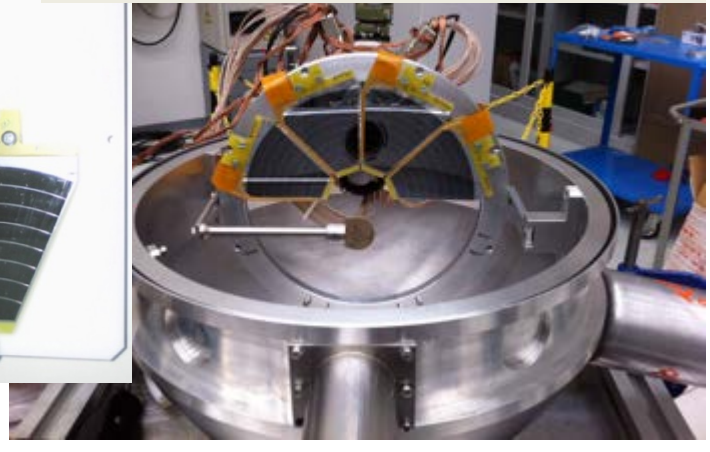


RIPEN

Neutron Array

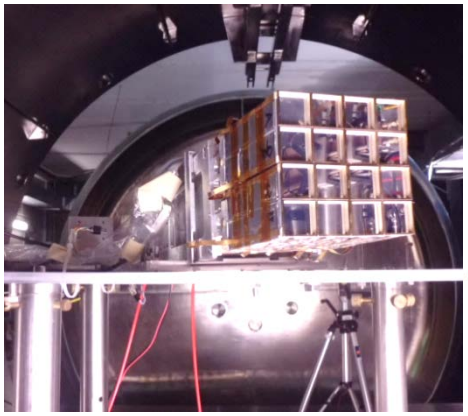


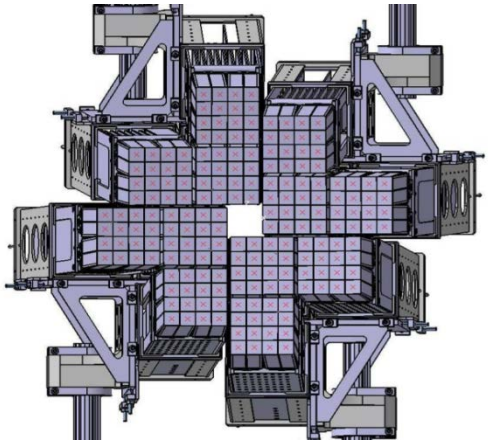
SPIDER LCP Si-strip detector



SPES Instrumentation

FAZIA: LCP & fragments detection





AGATA : innovative γ-rays tracking array)

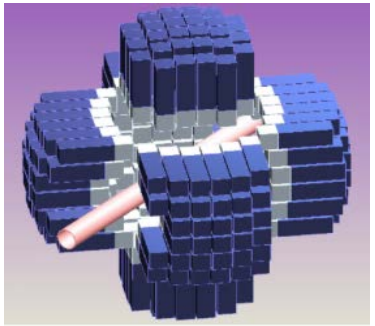
COMPLEMENTARY Activity (LNL-LNS)

- **Tagging & Tracking**
- **New Ancillary detectors developements**
- **Training & experiment preparation**

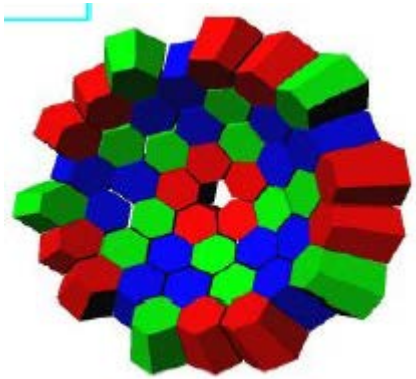
International Collaborations:

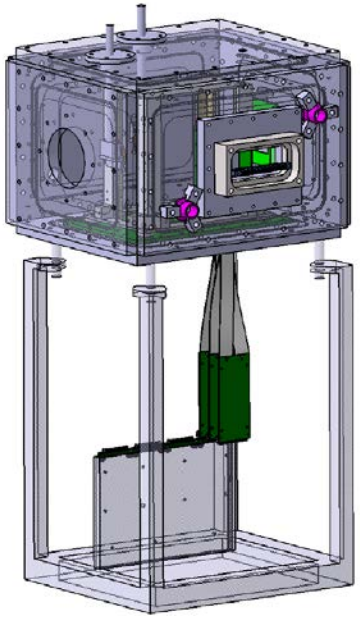
itinerant detectors

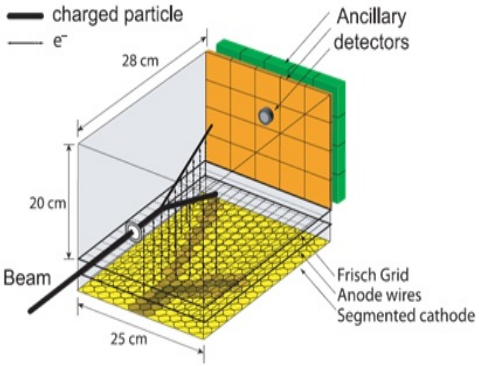
PARIS (High Energy γ-ray Detector Array)



NEDA (NEutron Detector Array)







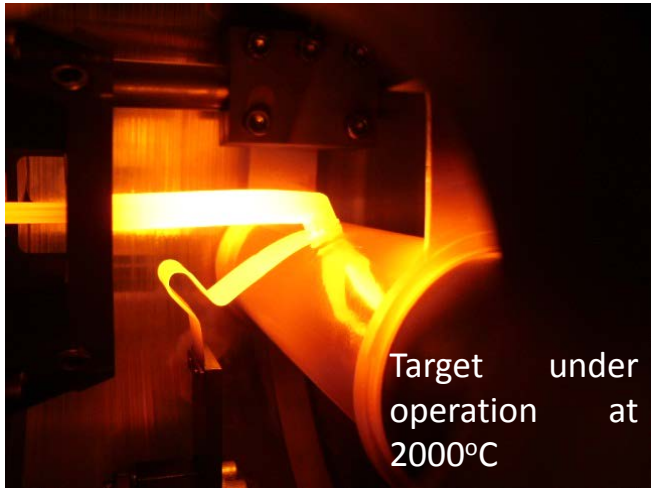
ACTAR :(Active Target Detector)

Technical highlights: the production target

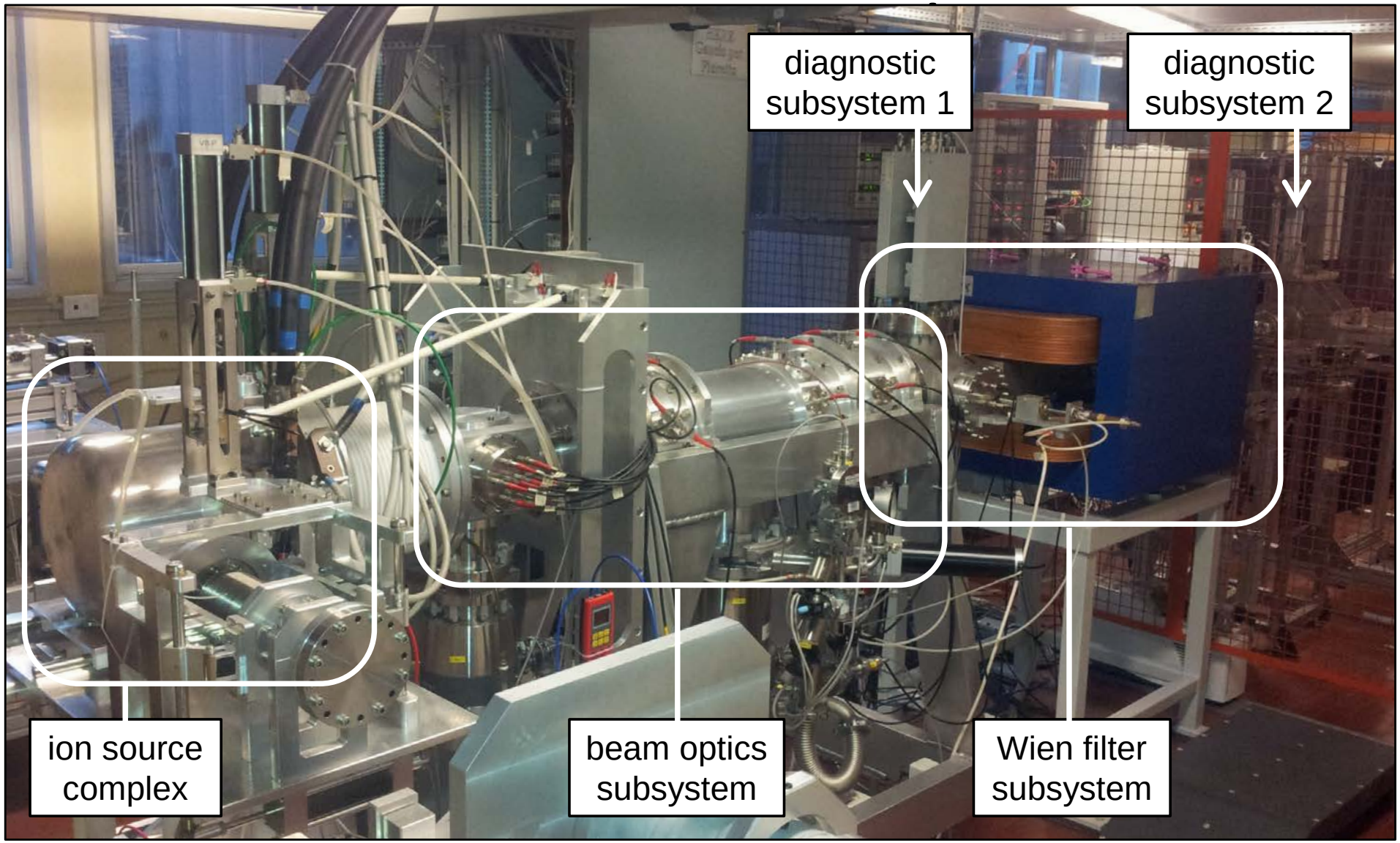
SPES DIRECT TARGET CONCEPT to operate with **8 kW** proton beam

(A. Andrighetto et al.)

- Direct Target carefully designed to reach **10^{13} fissions/s** with **8 kW** proton beam (thermo-mechanical considerations);
- **In beam power test** performed at **iThemba labs** on May 2014 (SiC target, 4 kW p beam, 1200° C);
- Prototype under operation.
- Fully developed **front-end** following ISOLDE design;

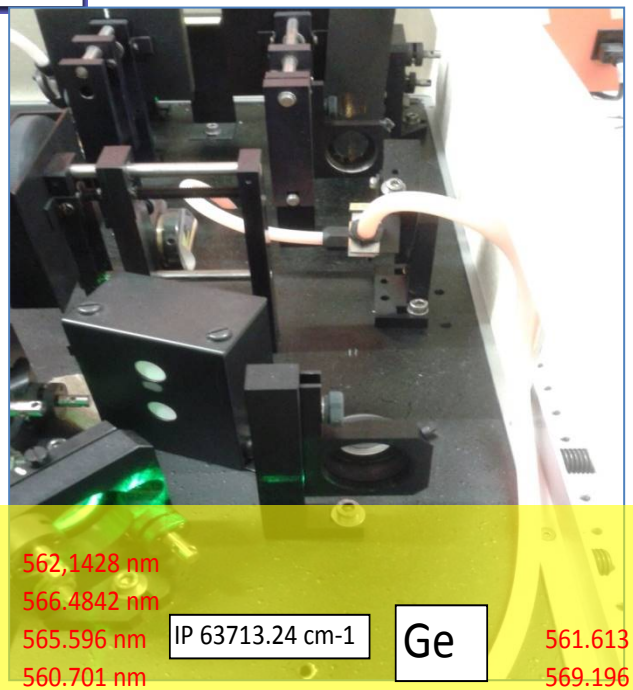


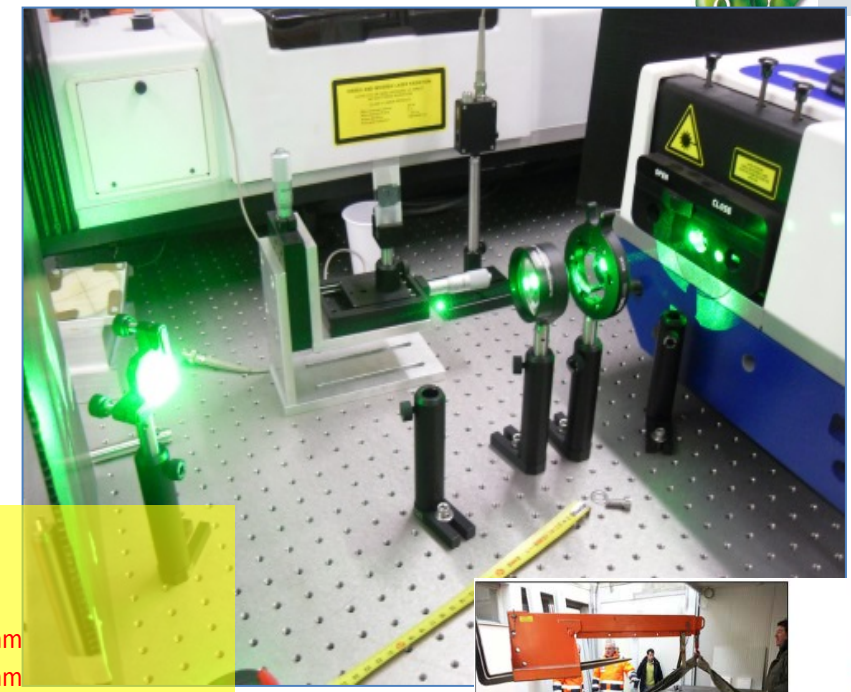
SPES ISOL system

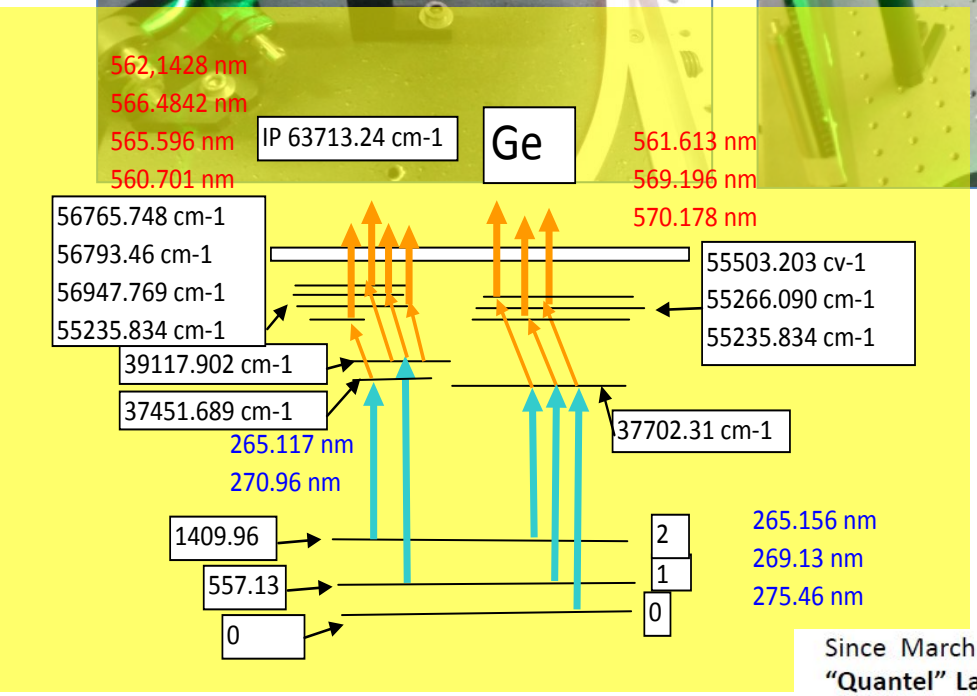


System under operation for source commissioning. Updated version, under construction.

SPES new LASER Laboratory @ LNL

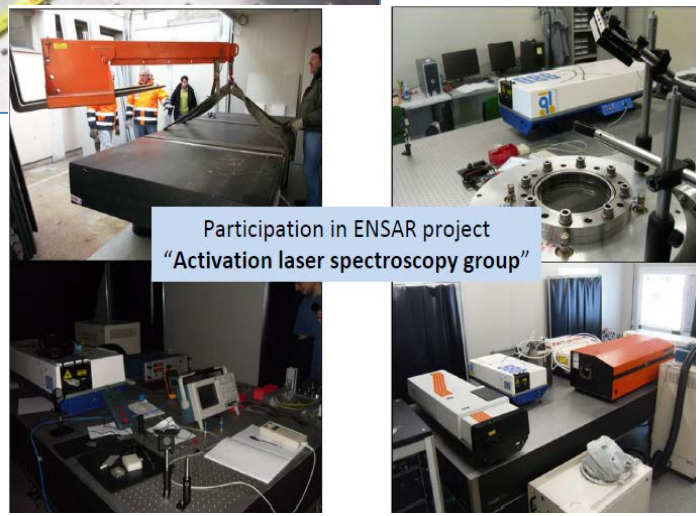






D. Scarpa

A tunable dye laser system ready for atomic spectroscopy study



Participation in ENSAR project
"Activation laser spectroscopy group"

Since March 2013 a new laser laboratory is operational at LNL. At present a **Nd:YAG "Quantel" Laser** is used for ablation studies; the **new all solid state tunable laser** system for the SPES project will be tested .

Cyclotron Site Test at BEST Company (Ottawa)

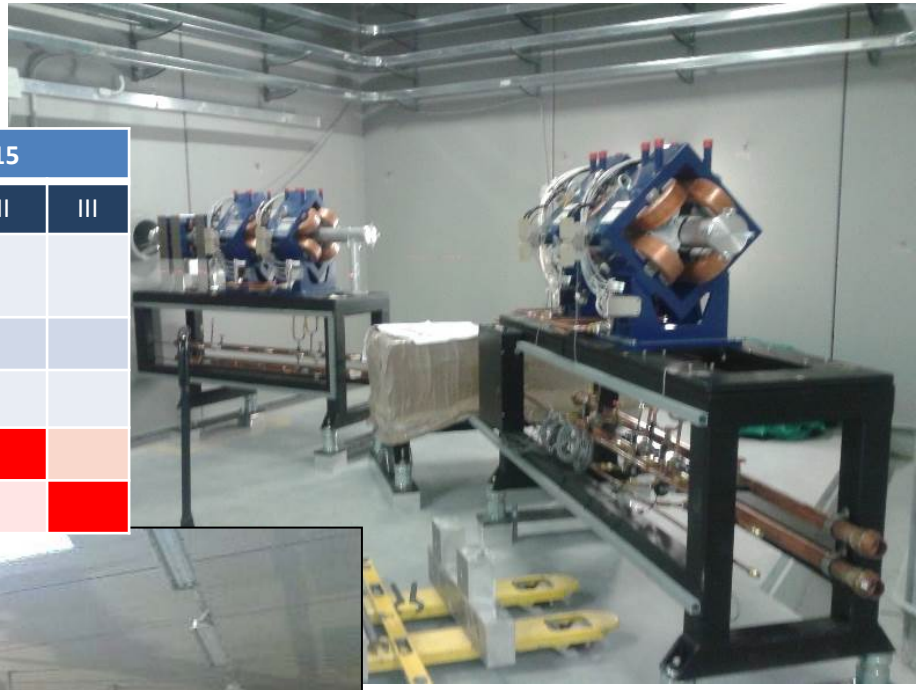
November 2014 Factory Acceptance Test

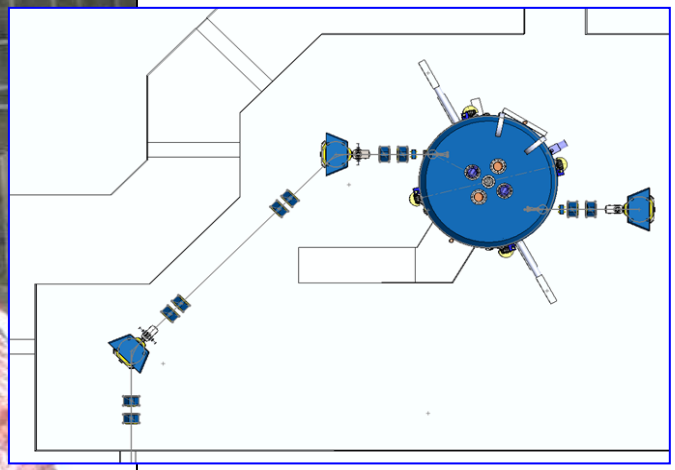
Cyclotron assembled and operated with 700 µA at 1MeV

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

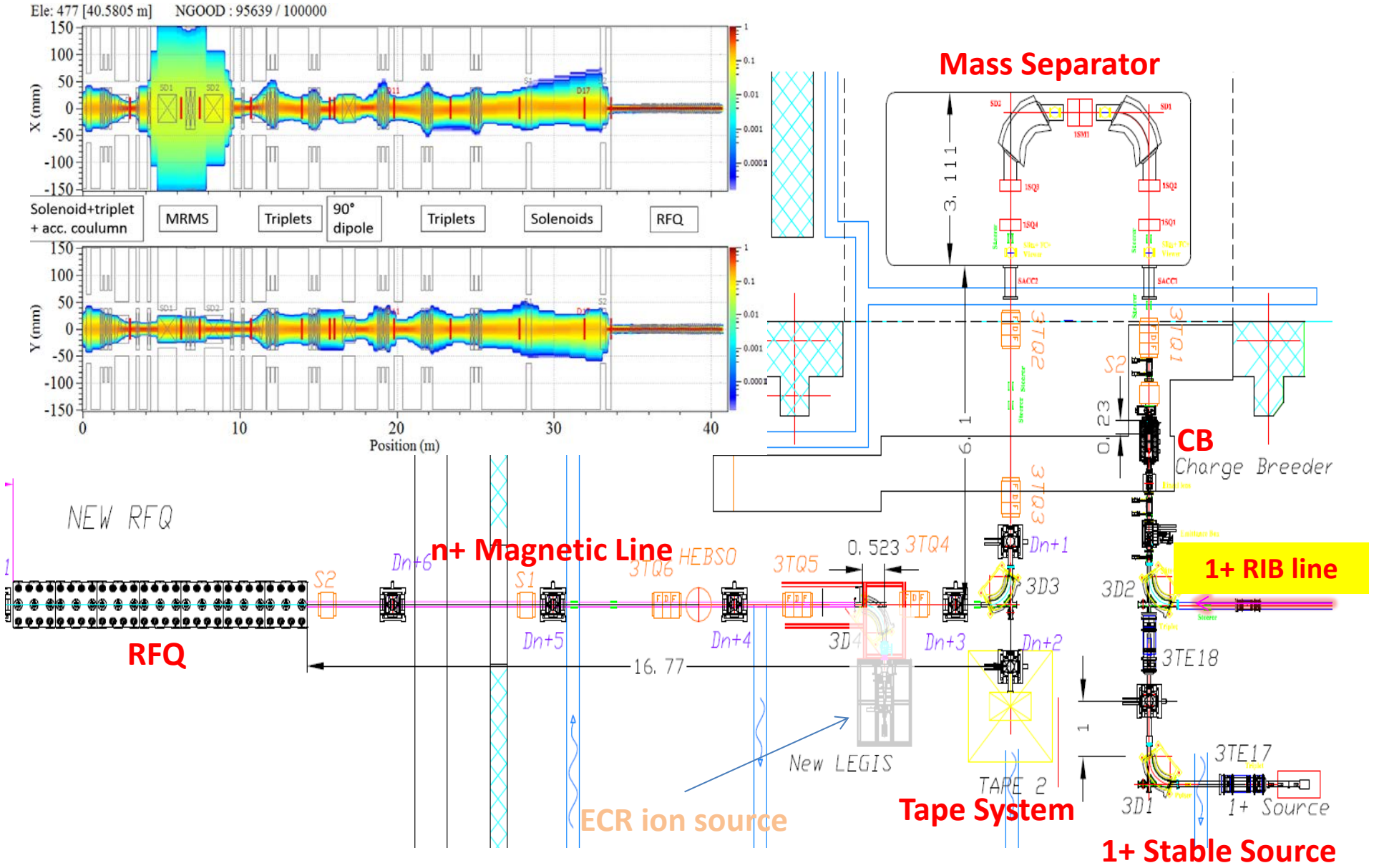
SPES: Cyclotron Schedule (2013-2015)

	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										





Transport Line to SPES RFQ

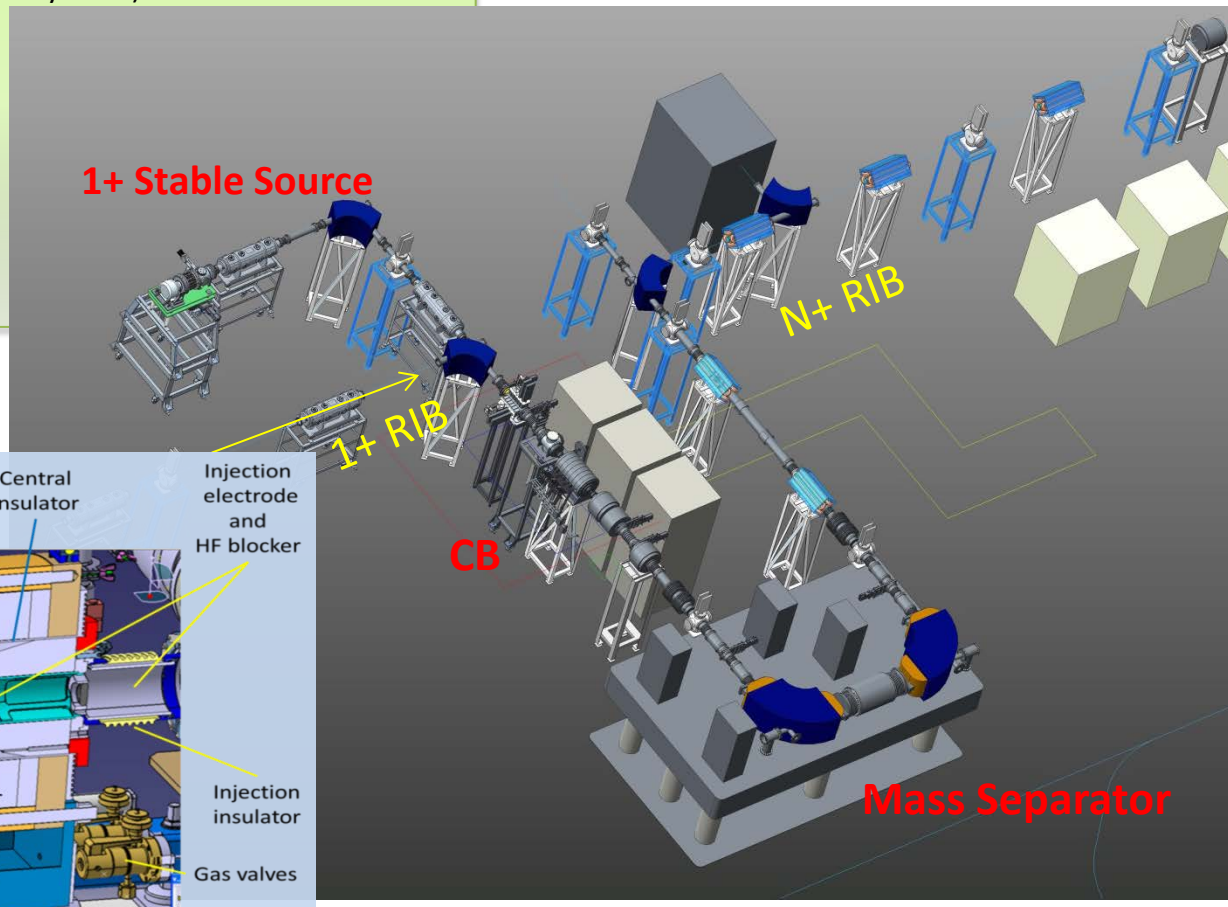


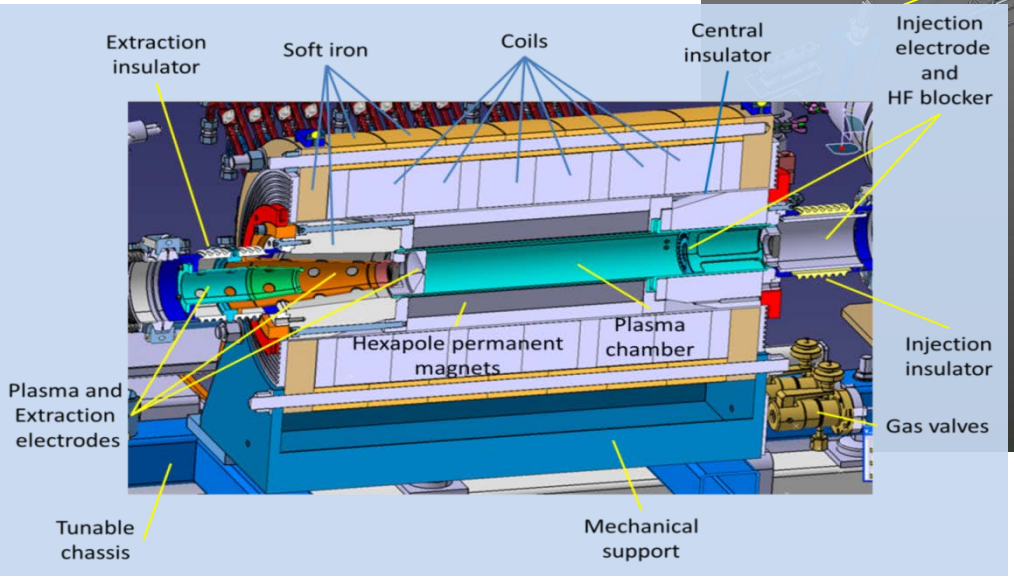
Exotic Beam reacceleration

Collaboration with LPSC (Grenoble) for the SPES Charge Breeder

The development of an Upgraded PHOENIX booster is Part of a MoU in the frame of the European Associated Laboratories (LEA-Colliga) with GANIL.
(In exchange: development of SPIRAL2 n-converter by INFN)
Project and construction by LPSC_Grenoble

- 2010 Preliminary measurements
- 2011 Conceptual design and schedule
- 2012 Design
- 2013 Agreement definition
- 2014 Construction
- 2015 Commissioning



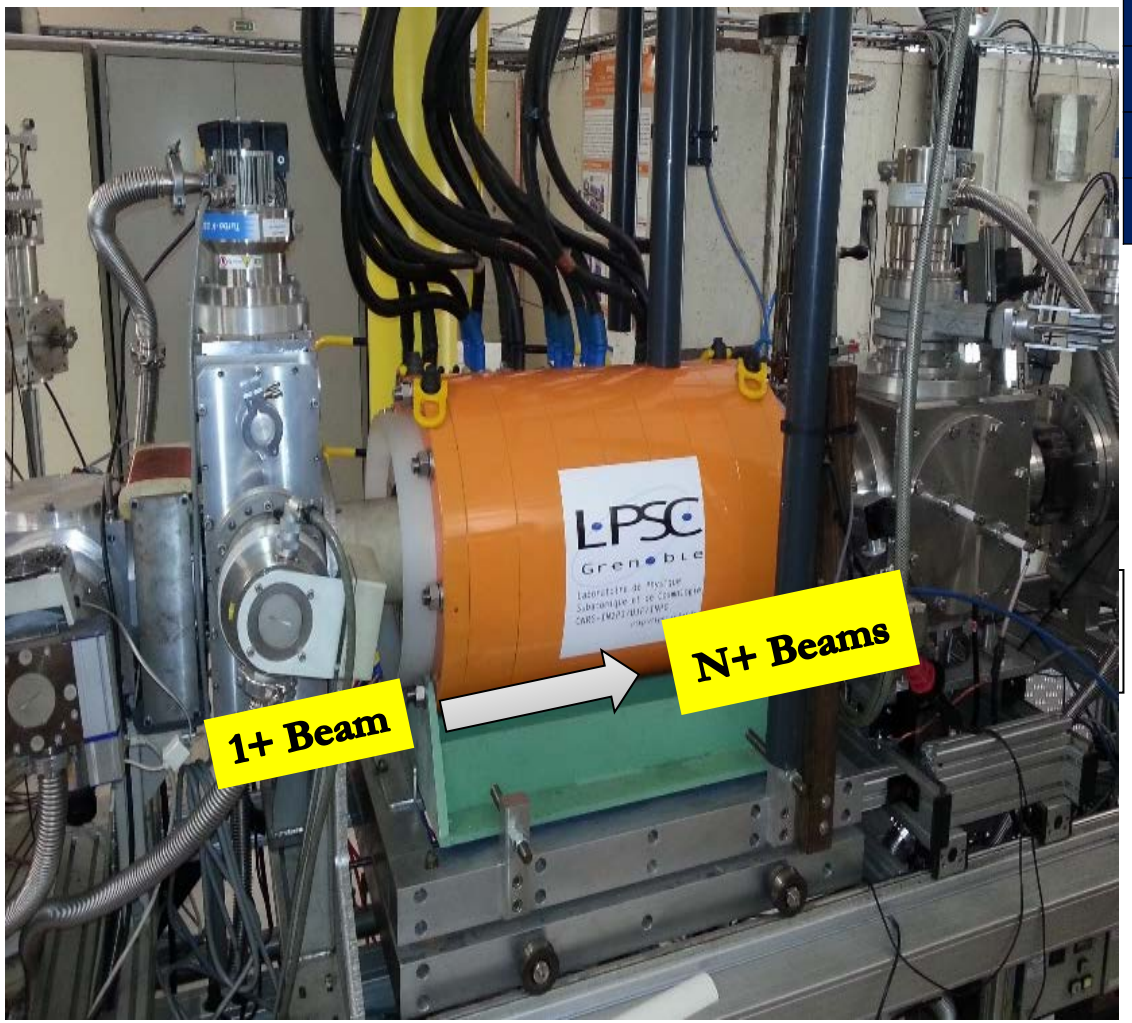


Validation of the SPES-CB

LPSC-Grenoble April 4th, 2015

Charge Breeder Beams:

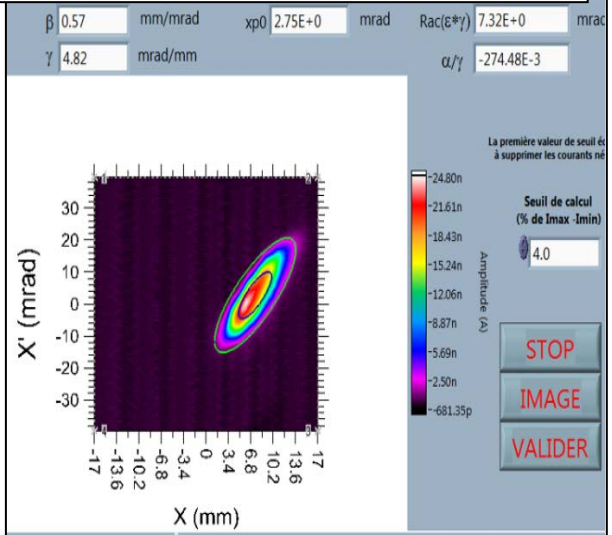
✓Global capture up to 90% !



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

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

- Ar^{8+}:
  - ✓$\varepsilon_{norm,rms}$ ~ 0,03*π*mm*mrad (96%)
  - ✓Efficiency ~ 15%
  - ✓τ_{CB} ~ 80 ms



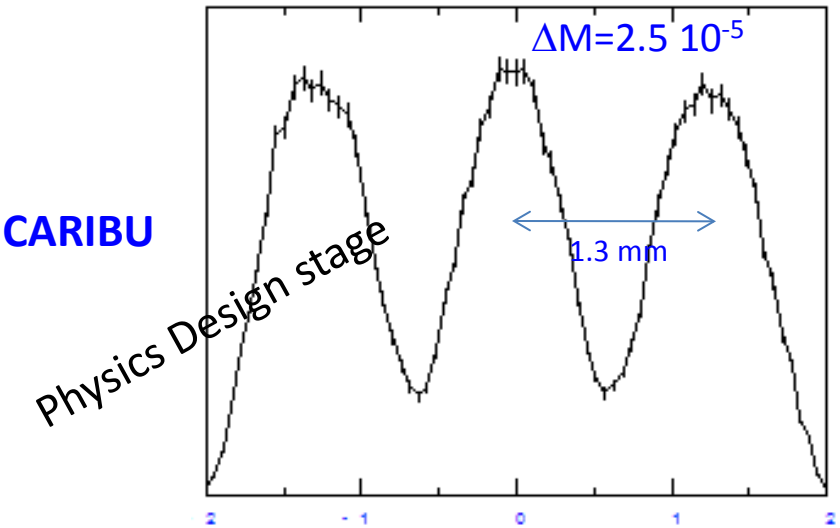
High Resolution Mass Separator & Beam Cooler

L.Calabretta, M.Comunian, A.Russo, L.Bellan

Approaching Mass resolution: 1/40000 !

Synergies with LNS
Collaboration SPES – CENBG Bordeaux

Scaled-up version of the separator designed for CARIBU
Mass resolution: 1/40000

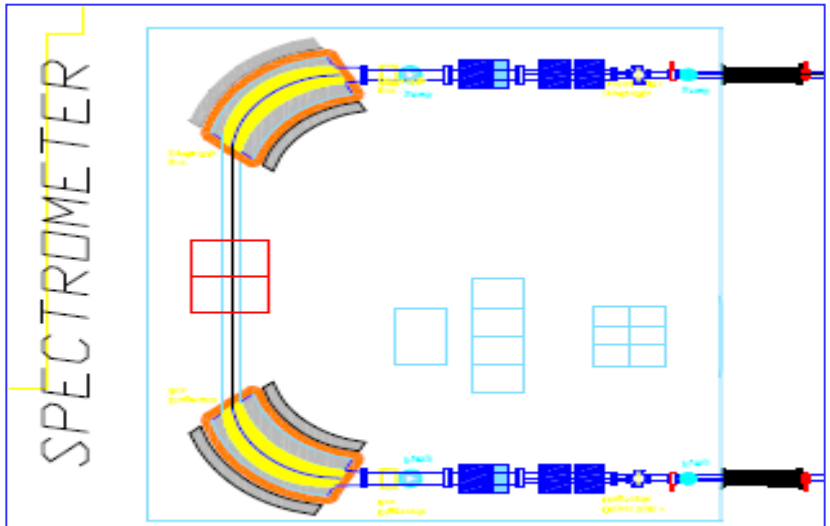


High Resolution Mass Separator

Beam Cooler to match the HRMS input requirements

COOLBEAM experiment financed by INFN-CSN5, 2012→2015
Collaboration: LNL-LNS, Milan

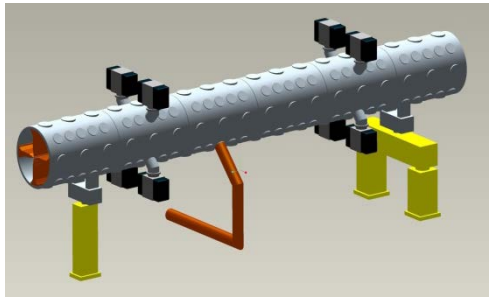
M.Maggiore



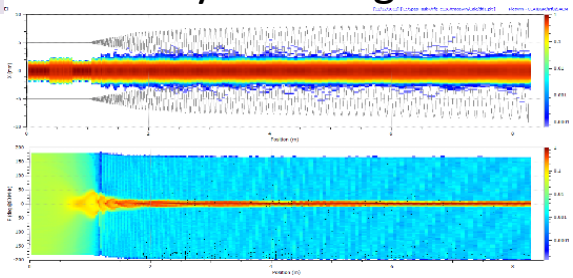
New study with EXCYT dipoles

Exotic Beam reacceleration: room temperature RFQ

Mechanical layout of the **RFQ**



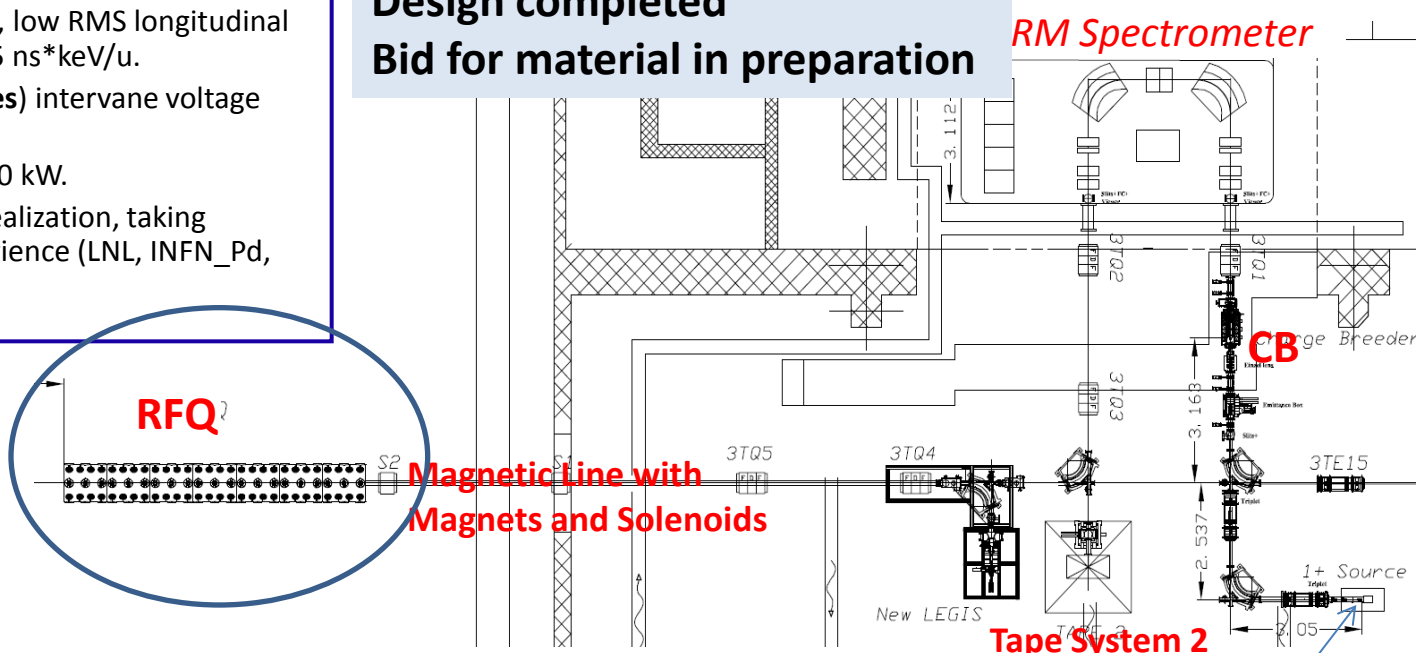
Physics design



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).

Design completed
Bid for material in preparation



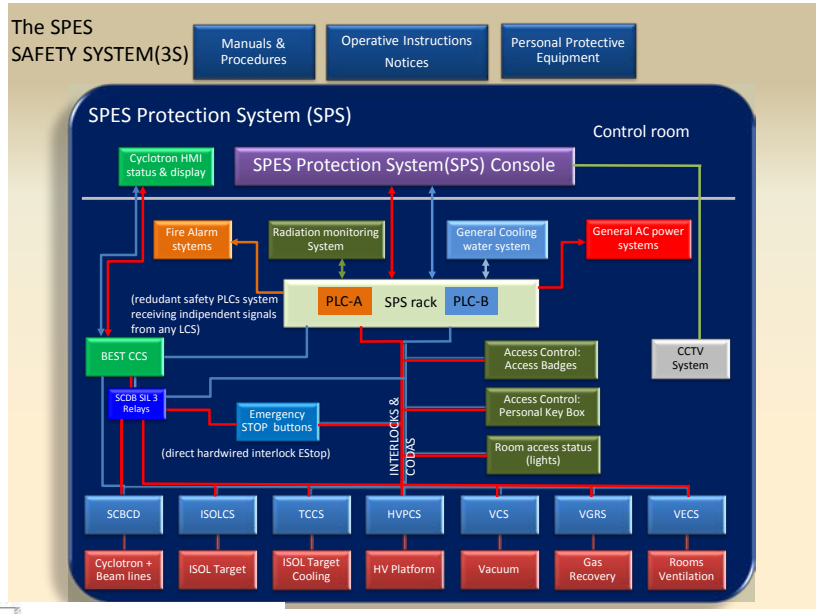
E. Fagotti, A. Pisent

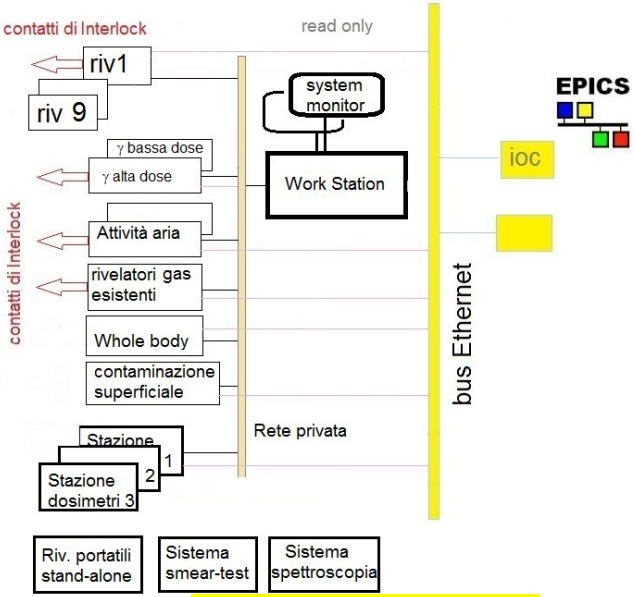
SPES safety system

A SIL3 safety system is under development
Simplified system ready in October for cyclotron test

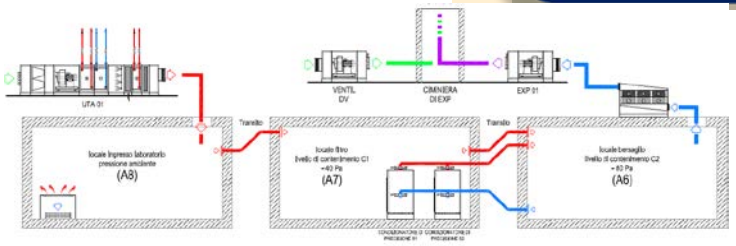
Cyclotron and beam lines

ISOL target

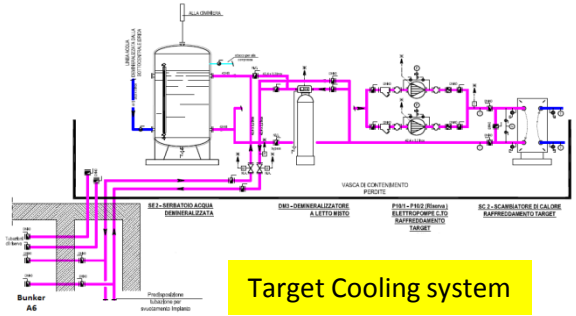




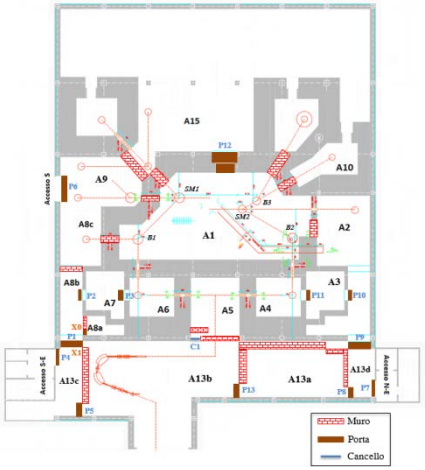
Radiologic survey system



ventilation



Target Cooling system



Access Control System

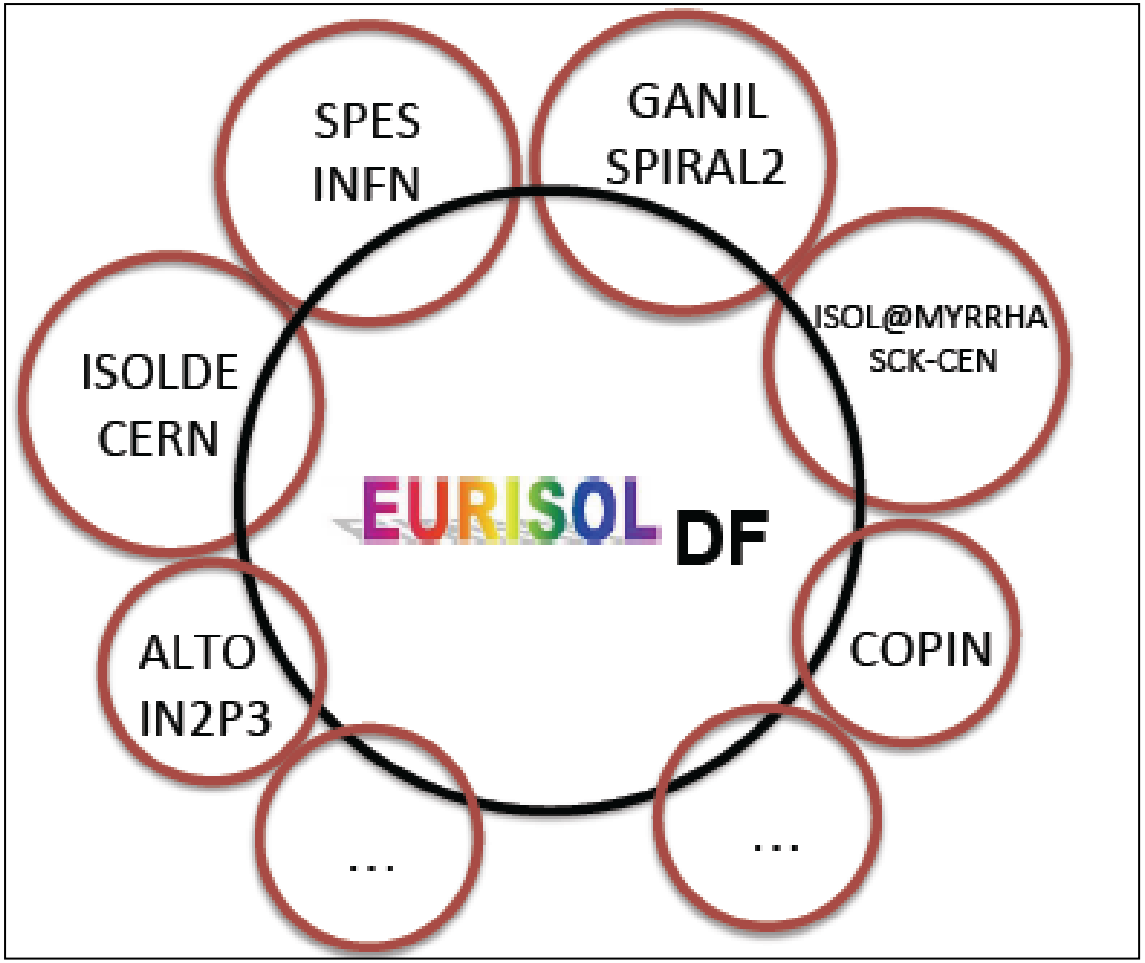
SPES general planning

	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								

An opportunity for the European nuclear physics community

A distribute laboratory for radioactive beams:

- ❑ More exotic beams available
- ❑ Coordination of competences to face technologic challengis of EURISOL
- ❑ Joint effort to manage the activity at European level
- ❑ SPES fully support the initiative



TANKS for ATTENTION