Status of the SPES project

Selective Production of Exotic Species

Gianfranco Prete LNL-INFN
On behalf of the SPES Collaboration

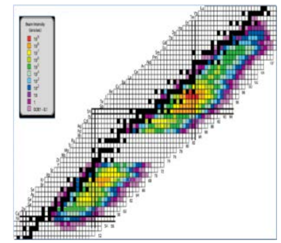
V Seminario Nazionale Rivelatori Innovativi - SNRI2016

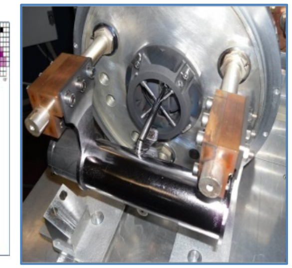
Padova / LNL 24-28 October 2016

SPES Strategy

Second generation ISOL facility toward EURISOL

Neutron–rich ions by **p-induced Fission** on **UCx (10^{13} f/s)**



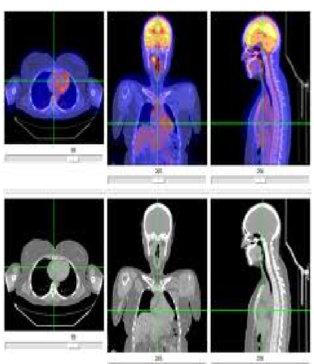


Cyclotron

ISOL RIBs+ Post-Acc.

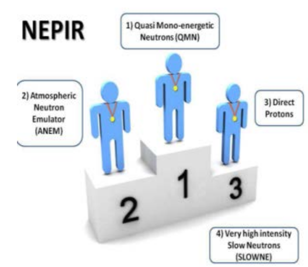
Nuclear Medicine

Nuclear Applications



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

LARAMED



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

Design study

The Nuclide Chart

Which are the limits for existence of nuclei?

- Where are the proton and neutron **drip lines** situated?

How does the nuclear force depend on varying proton-to-neutron ratios?

- What is the **isospin dependence** of the **spin-orbit force**?
- Which is the **shell evolution** moving **far from stability?**

How to explain collective phenomena from individual motion?

How are complex nuclei built from their basic constituents?

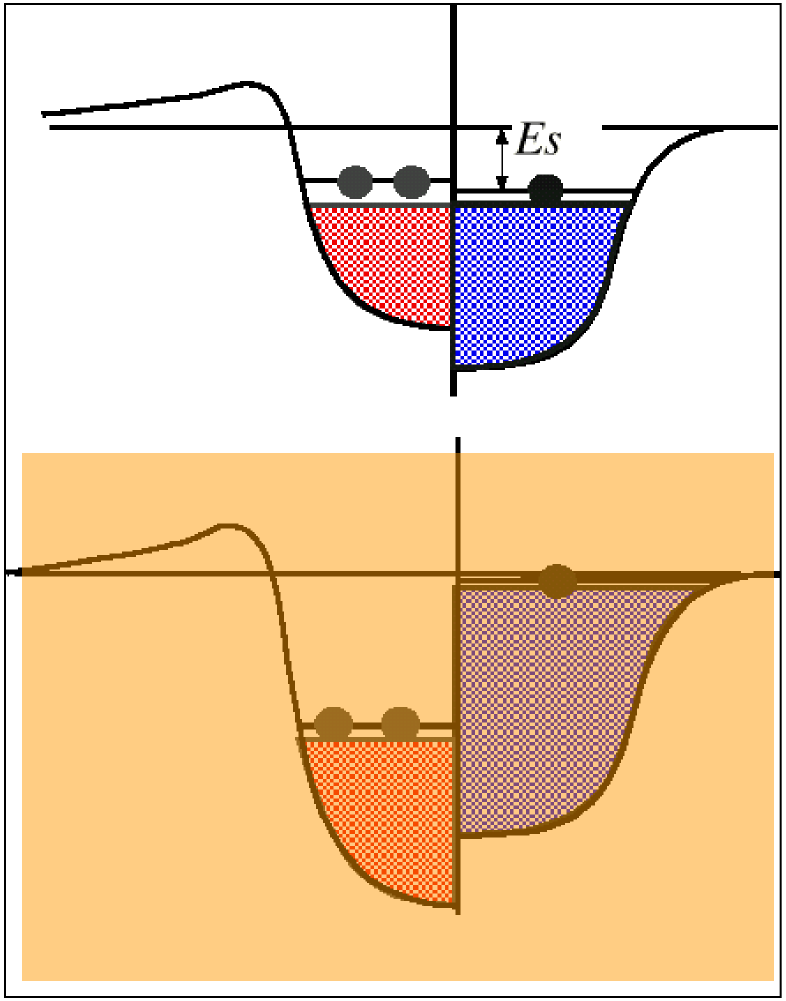
- What is the **effective nucleon-nucleon interaction**?
- How does QCD constrain its parameters?

Which are the nuclei relevant for astrophysical processes and what are their properties?

- What is the **origin** of the **heavy elements**

Qualitative Difference Near the Neutron-Dripline

protons neutrons



Stable nuclei:

N/Z ≈ 1 - 1.5, $S_p \approx S_n \approx$ 6 - 8 MeV

- Homogeneously mixed protons and neutrons
- Good mean-field description
- Good "single-particle" picture (magic numbers)
- Large gaps between major shells
- Empirical shell-model interactions

Very neutron-rich nuclei:

N/Z ≈ 2 - 2.5, S_n << 1 MeV

- Diffuseness of neutron distribution (neutron skins & halos)
- More states near the Fermi surface
- Breakdown of the single-particle description
- Redefinition or disappearance of magic numbers
- Unknown shell-model interactions

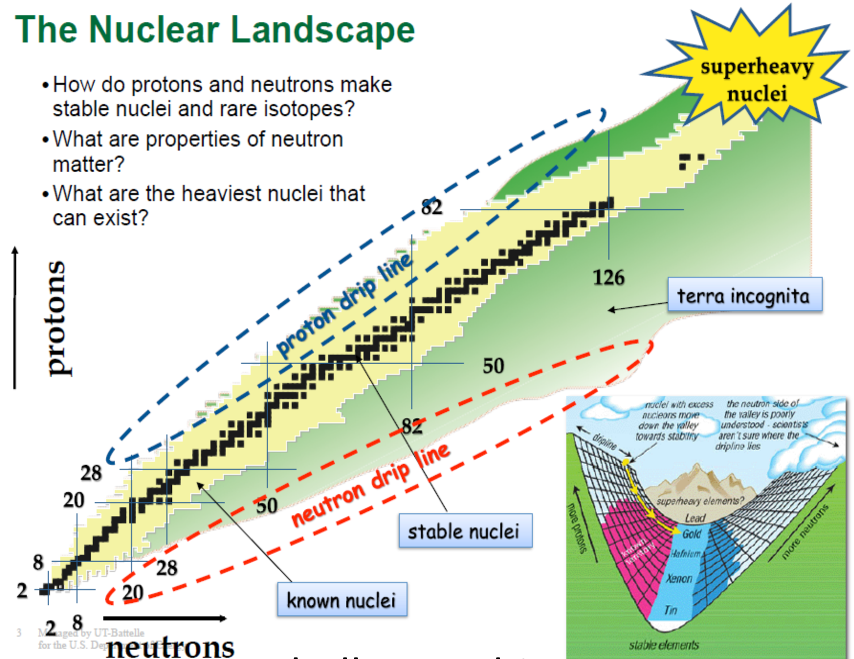
Physics @SPES

Moving away from the stability valley → Exotic Nuclei & Limit of Nuclear Existence

The Open Questions:

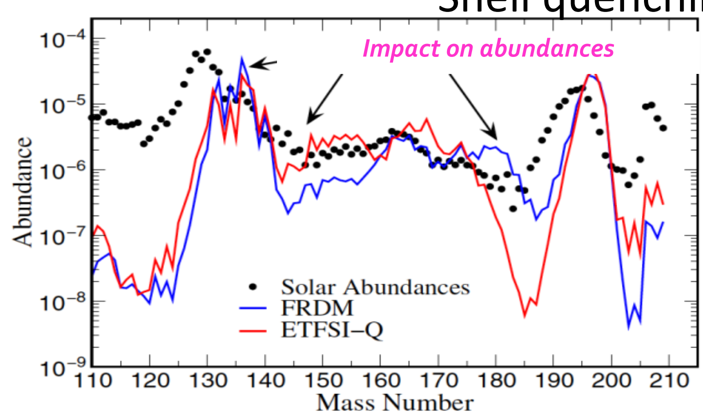
1. Shell Evolution & interactions
2. Symmetries (isospin mixing T=0, T≠0 in N=Z nuclei)
3. Order & Chaos Transition
4. Collective States: Part-Vib-Coupling, Pygmy & Giant Resonances
5. β–decay & r-process
6. Isospin effects on structure & reaction dynamics

Stable Nuclei = 300
Nuclei observed = 3000
Nuclei expected = 6000

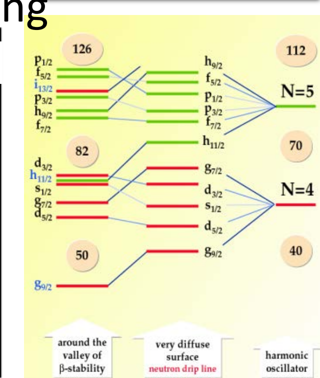


The Experimental tecniques:

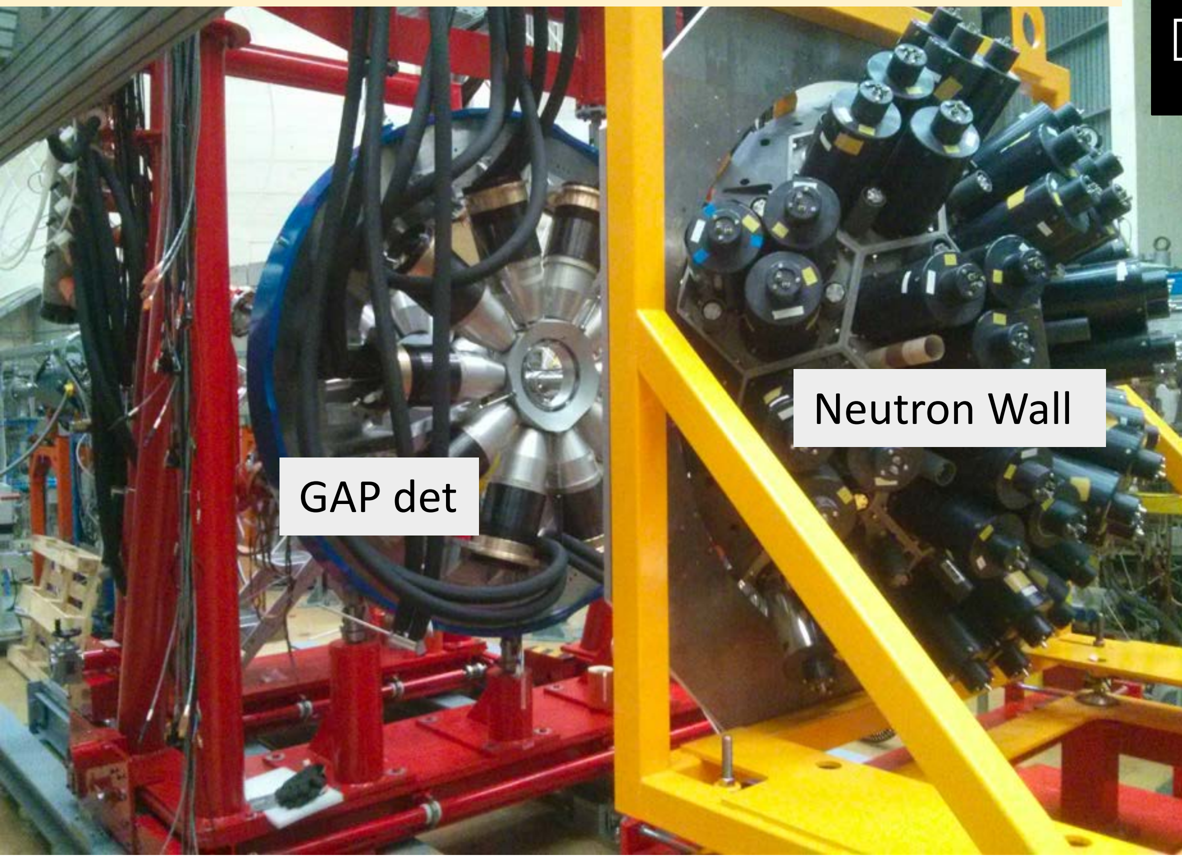
- Coulomb Excitation
- Transfer Reactions
- Decay Spectroscopy
- Reaction Studies



Shell quenching



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 2015)

□ 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

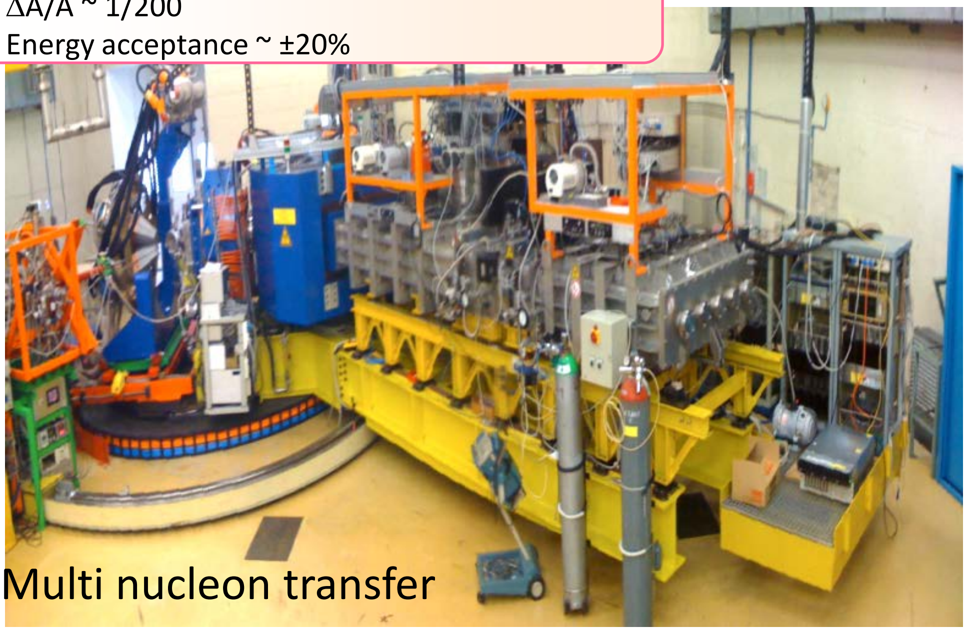
Instrumentation@SPES

PRISMA: a large acceptance **magnetic spectrometer**

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

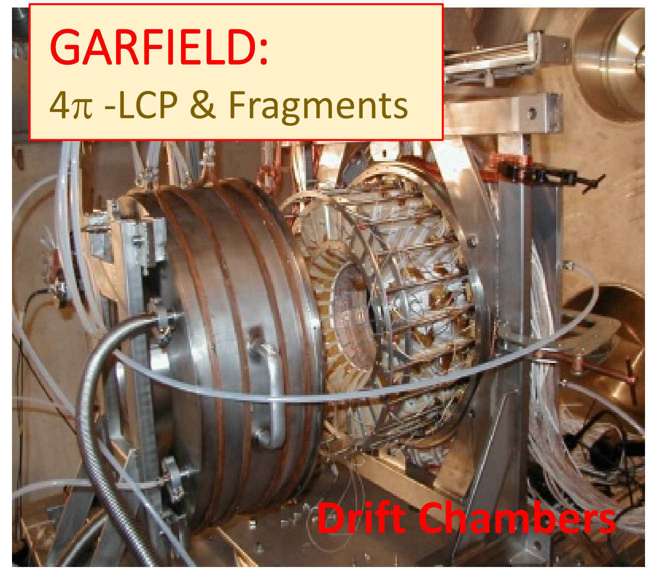
$\Delta A/A \sim 1/200$

Energy acceptance ~ ±20%



Multi nucleon transfer

GARFIELD: 4π -LCP & Fragments



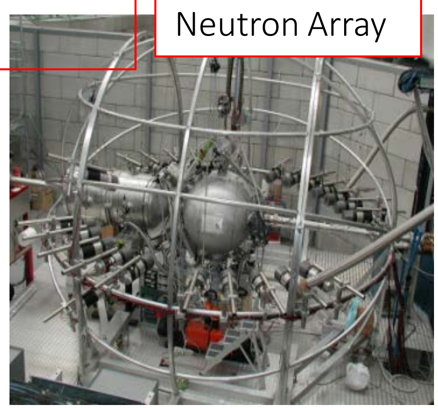
Reaction mechanism

SPIDER: ring silicon detector

Coulomb exitation

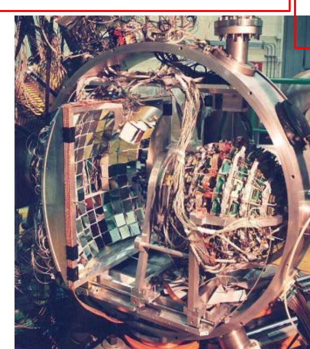
RIPEN

Neutron Array



8πLP: Si+CsI

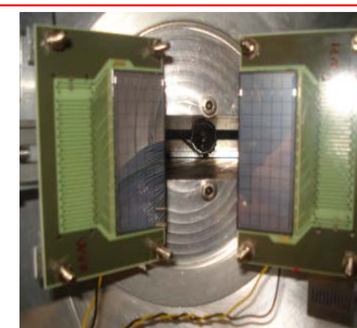
LCP array



TRACE: (gamma Ancillary)

pixeled Si-Si LCP detector

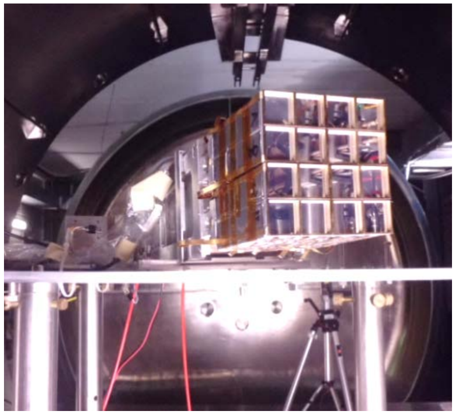
Transfer and binary reactions

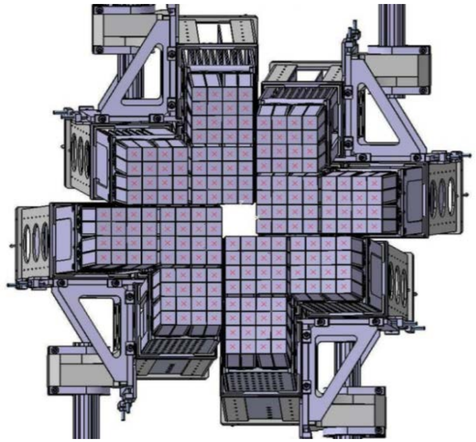


Instrumentation@SPES

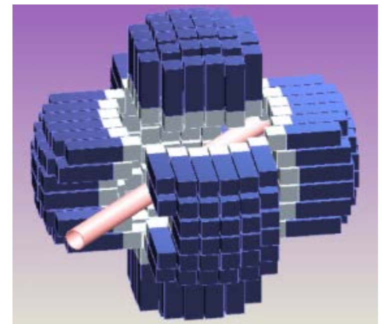
International Collaborations:
itinerant detectors

FAZIA: LCP & fragments detection

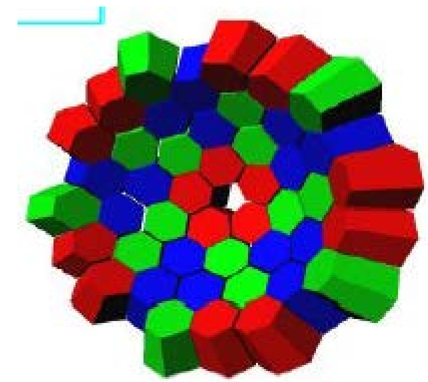




PARIS (High Energy γ-ray Detector Array)

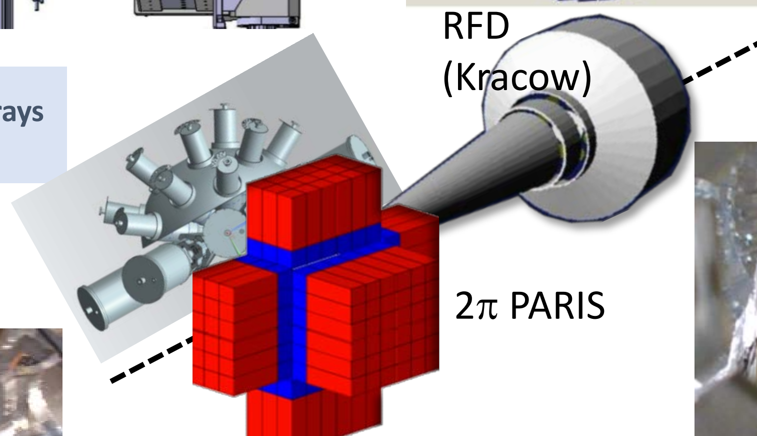


NEDA (NEutron Detector Array)



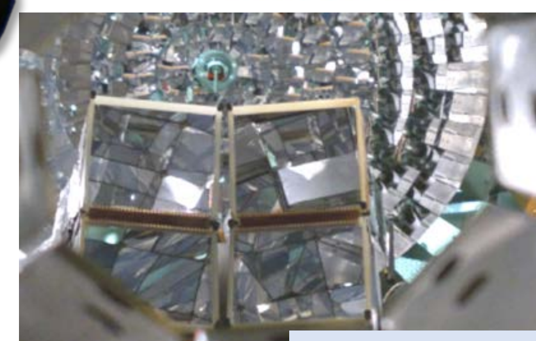
AGATA : innovative γ-rays tracking array)

RFD (Kracow)

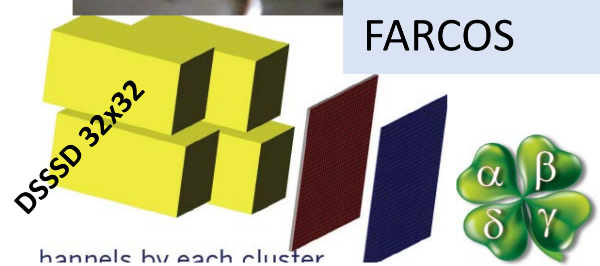


2π PARIS

GALILEO +nWall



FARCOS

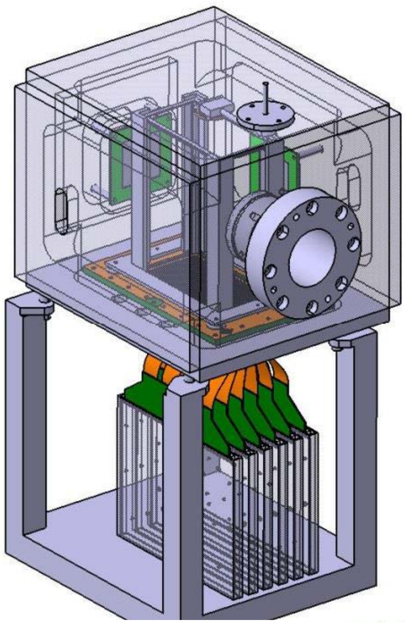


hannels by each cluster

Instrumentation@SPES

ACTAR : **Active Target Detector** for inelastic scattering and transfer reactions

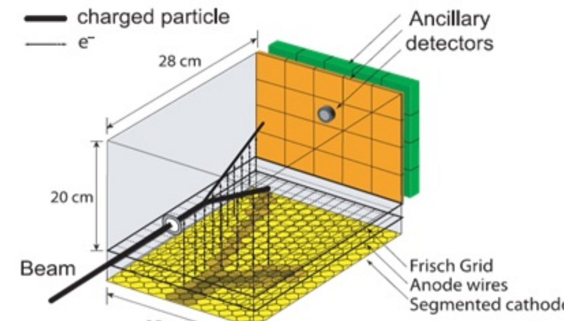
Starting activity with ACTAR collaboration: ENSAR2 GDS network and PRIN Italian national project (T. Marchi KU Leuven – contact person)



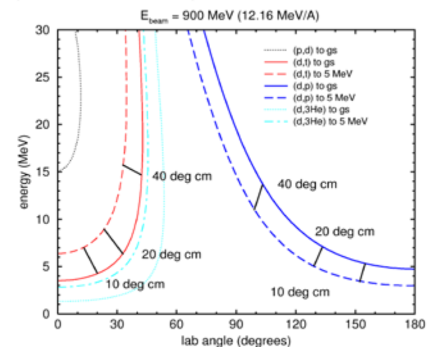
ATS @ SPES within the NUCL-EX collaboration (LNL, Bologna, Fi, Pd, Mi, Na) + LNS_Stream

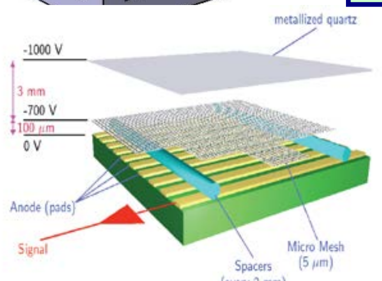
With transfer we can probe:

- occupancy of single-particle (shell model) orbitals in the original nucleus A ground state
- 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

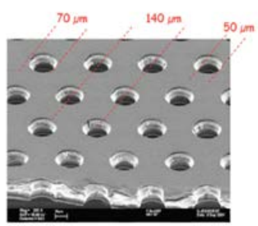


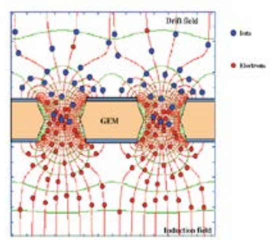
(p,d) and (d,t) and (d,p) on ^{74}Kr in inverse kinematics





Micro-megas technology for the amplification region : low cost 5€/cm





Gas Electron Multipliers: GEM

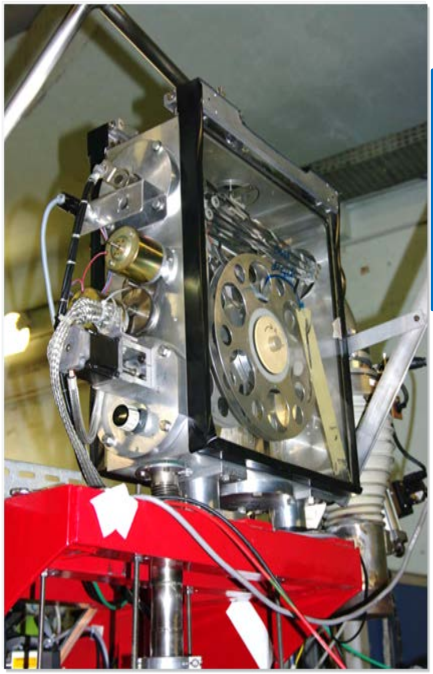
The **ACTAR TPC** collaboration is actually composed by:
Centre d'Etudes Nucleaires de Bordeaux Gradignan (CENBG), France
Grand Accelerateur National d'Ions Lourds (GANIL), France
Institut de Physique Nucleaire d'Orsay (IPNO), France
Institut de Recherche sur les lois Fondamentales de l'Univers (IRFU), France
University of Leuven (KUL), Belgium
Universidade de Santiago de Compostela (USC), Santiago, Spain

Courtesy of R. Raabe & G.F. Grinyer

Instrumentation@SPES: Tape system

Collaboration ALTO-INFN-iThembaLabs

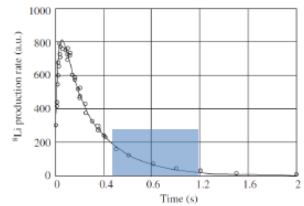
Tape station based on Orsay design



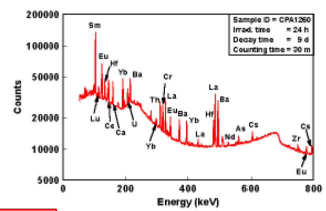
Diagnostics for SPES:
tape stations
to characterize RIBs

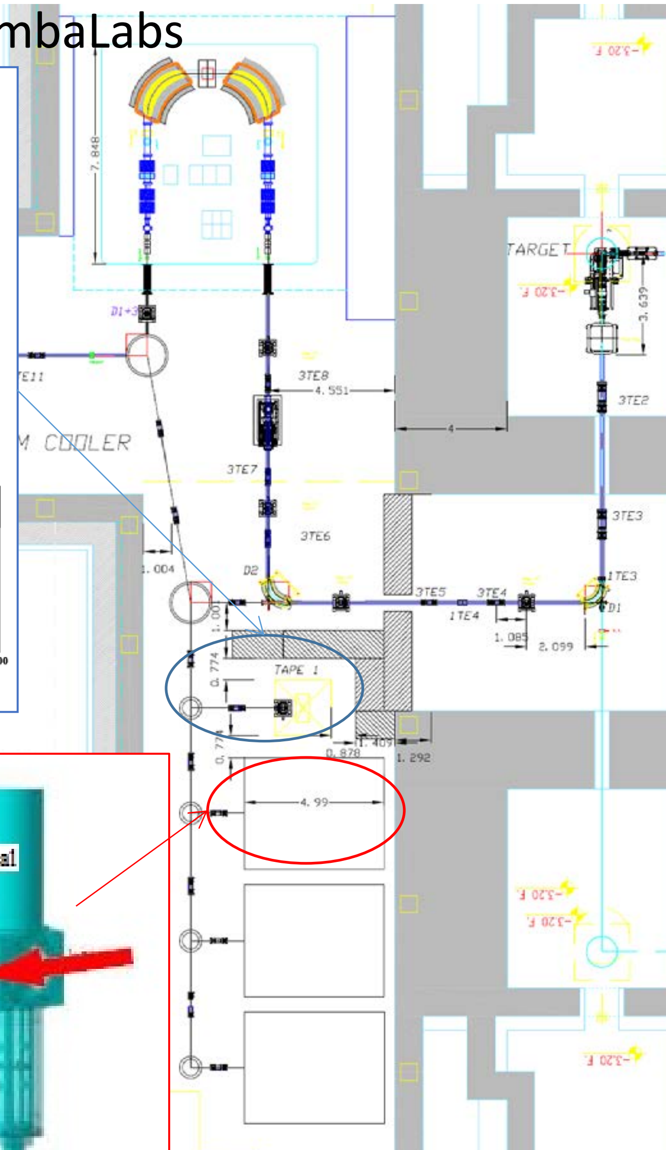
Beam characterization:

- Release Curve

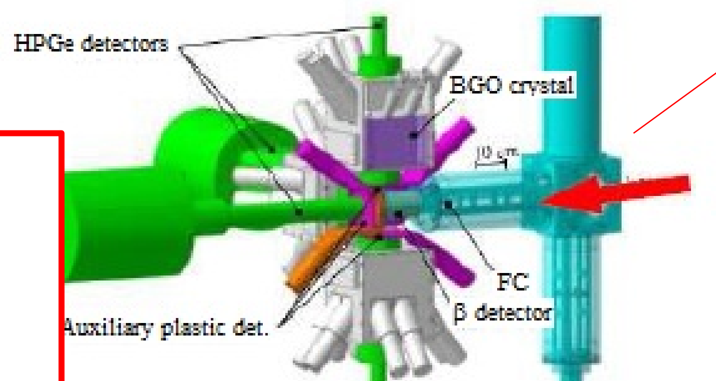


- Beam Composition and Isotopic Yields





β_decay experiments



Beta decay station as a permanent and flexible setup

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

Group leader: Giovanna Benzoni INFN-Mi

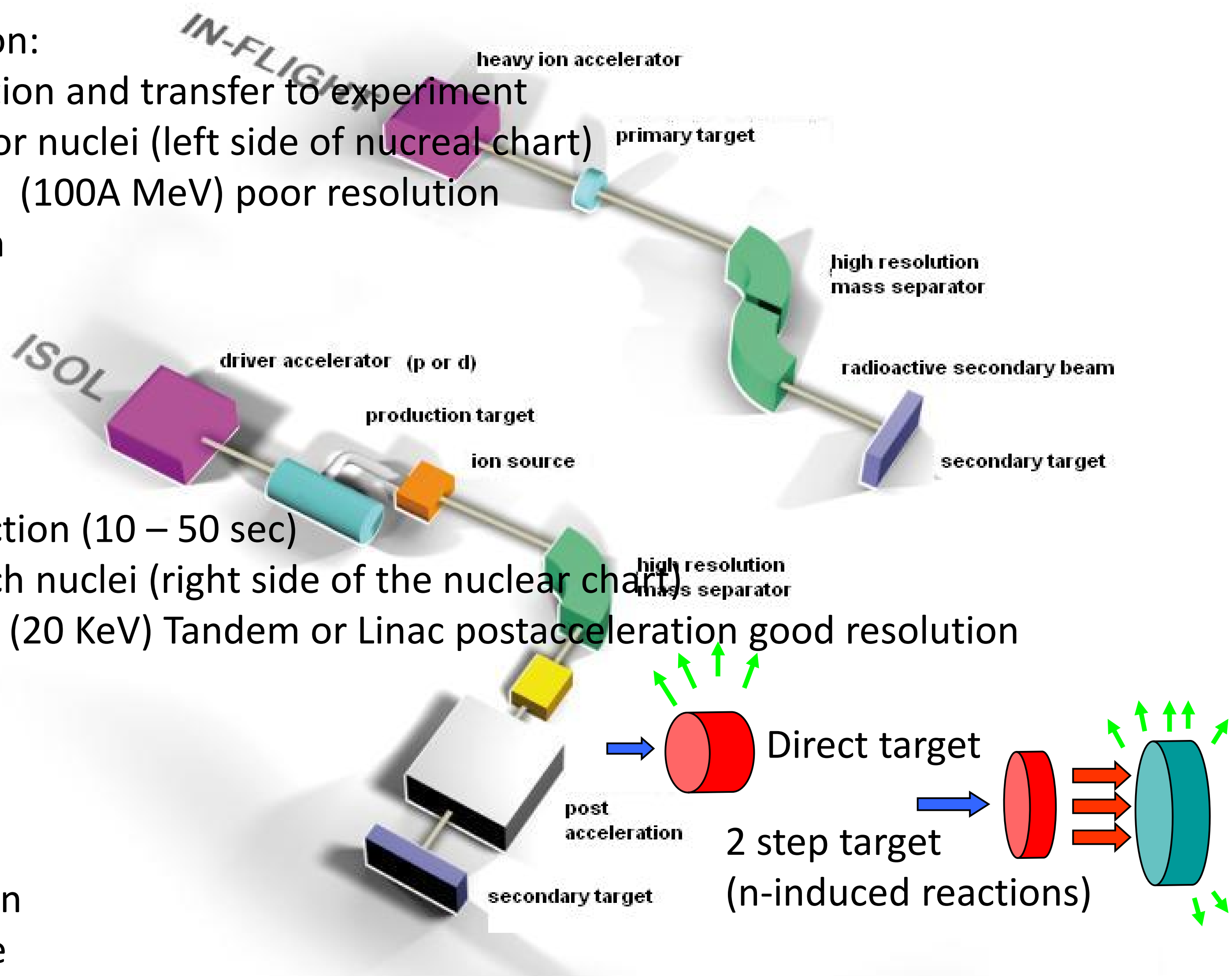
Radioactive Ion Beam production methods

Fragmentation reaction:

- fast production and transfer to experiment
- neutron-poor nuclei (left side of nucreal chart)
- High energy (100A MeV) poor resolution
- mixed beam

Fission reaction:

- slow extraction (10 – 50 sec)
- neutron-rich nuclei (right side of the nuclear chart)
- low energy (20 KeV) Tandem or Linac postacceleration good resolution

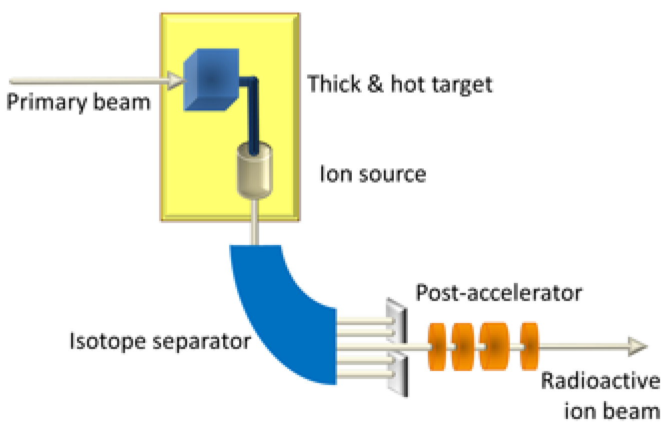


Nuclear Physics European Coordination Committee

How we can produce beams of radioactive elements ?

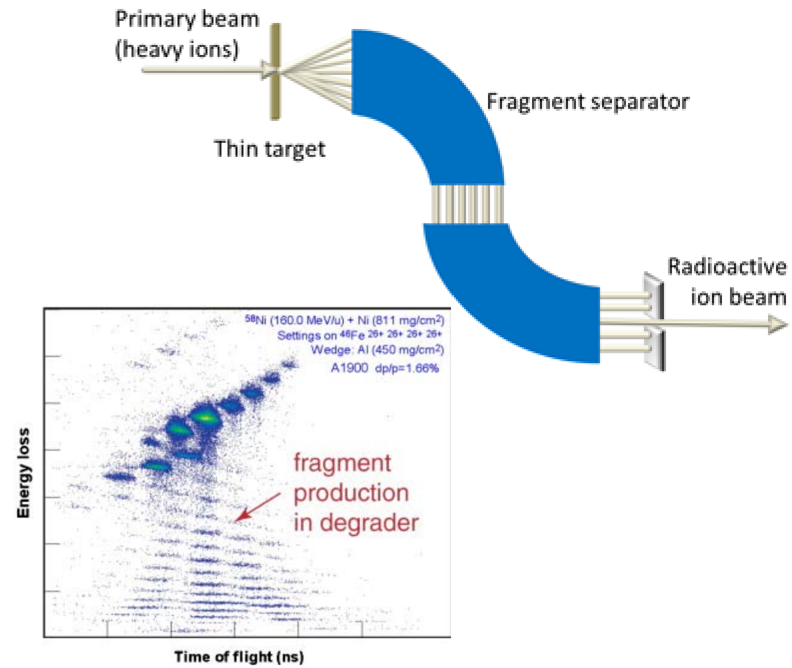
The Isotope Separator On Line (ISOL) method

The exotic nuclei are produced by spallation, fission or fragmentation reactions of a light projectile with a thick target. The reaction products diffuse out of the target through the transfer line towards the ion source, where they are ionized, and subsequently extracted, separated on-line and (in some cases) reaccelerated. Although the energies are low, the intensity of these secondary beams is very high.

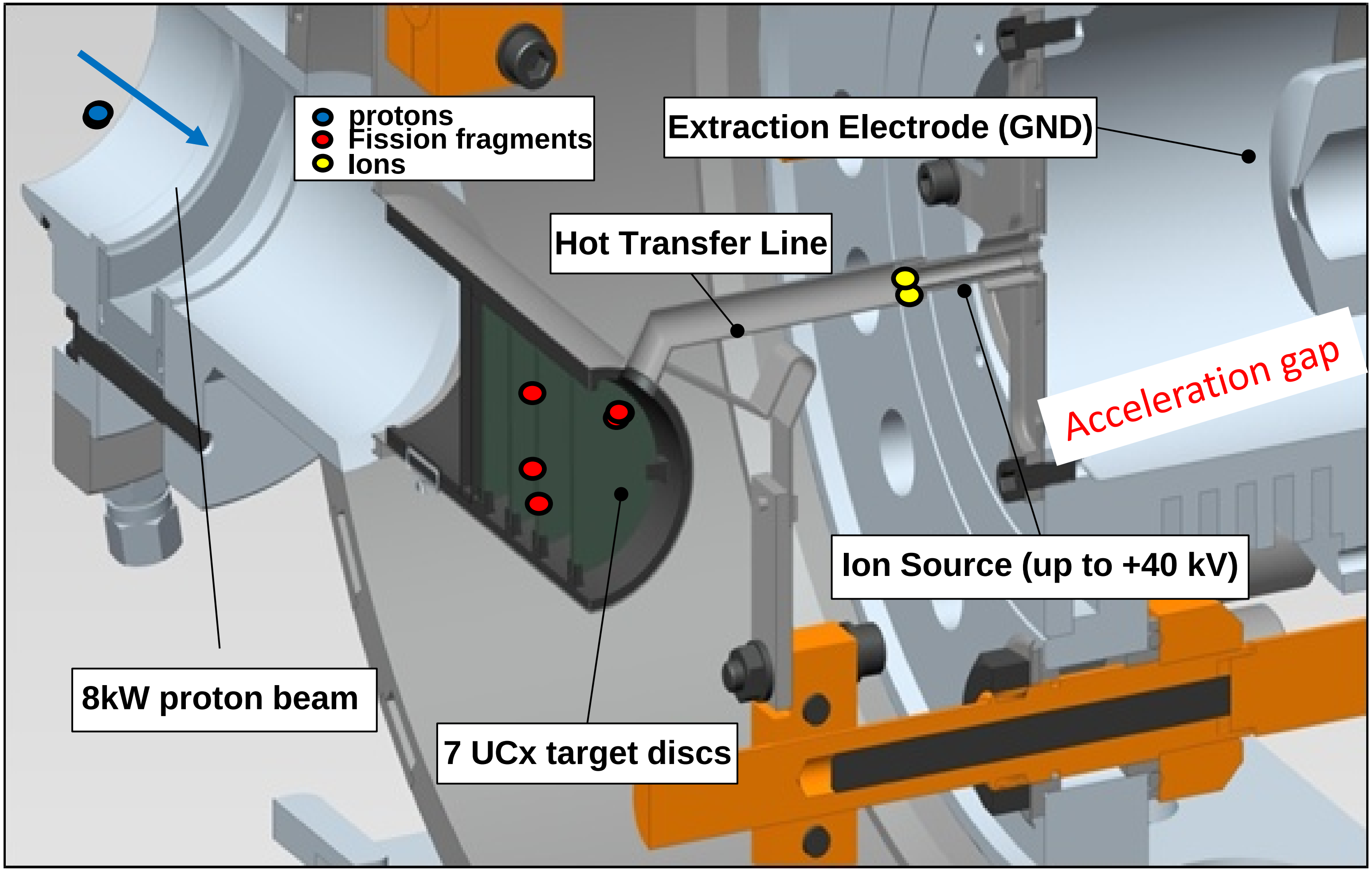


- **The in-flight method**

The exotic nuclei are produced by the fragmentation of a high-energetic, heavy projectile on a thin target. The reaction products, emerging with beam-like velocities, are then separated in-flight. Secondary beams with high energy are produced, but their intensity is low.

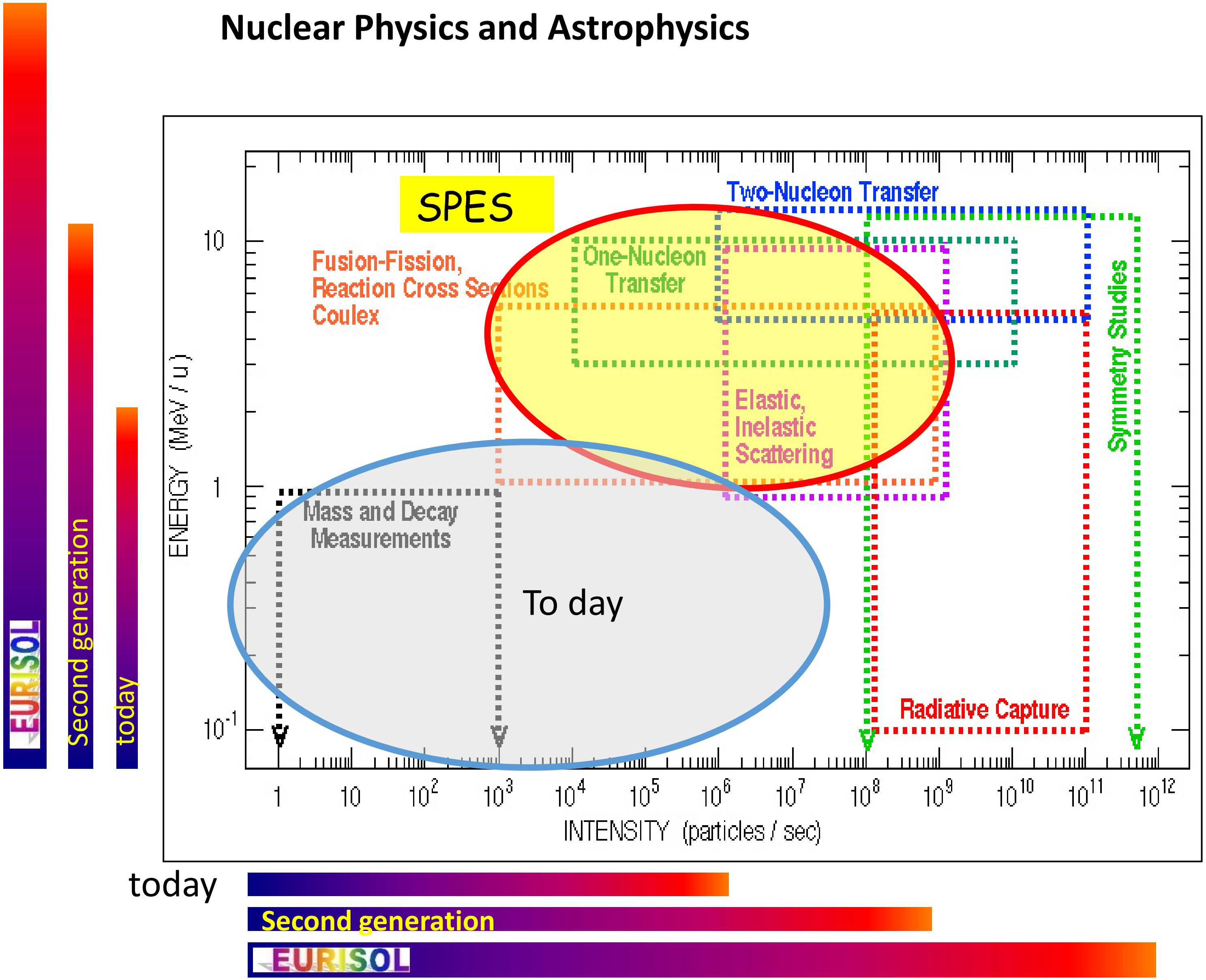


The SPES TIS complex



Physics Domain with RIB

Nuclear Physics and Astrophysics



SPES Framework

SPES@LNL: an international resource for NUCLEAR PHYSICS

NATIONAL SPES collaborations

- Accelerator Technologies & Mechanics
INFN Section and Univ. of Milano, Bologna, LNS, LNL, Pavia, Trento and Palermo

- Physics Programs & Detectors
INFN Sections of Bari, Bologna, Catania, Firenze, Milano, LNL, LNS, Padova, Perugia, Trento, Napoli

INTERNATIONAL collaborations

on

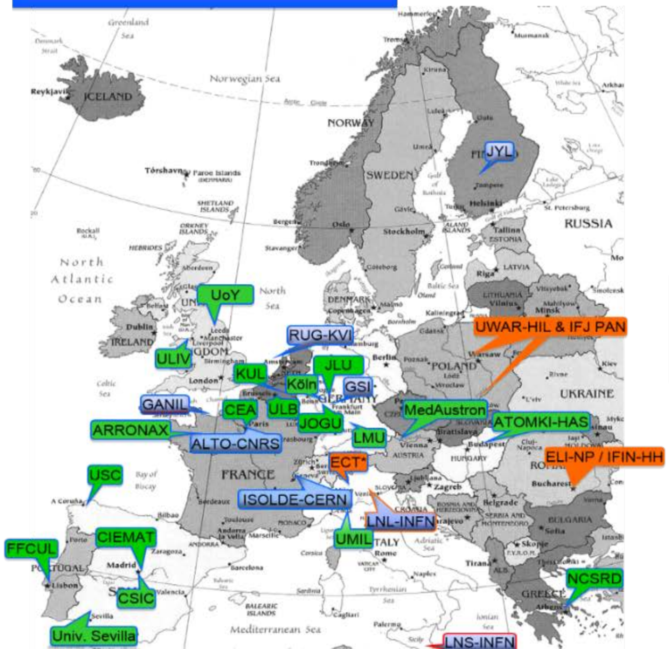
Nuclear Physics & Astrophysics,
Modern Detectors &
Accelerator Technologies

International Laboratories

LIA CollAGAIN (ALTO-GANIL-INFN)
LIA POLITA (INFN – COPIN)
LIA COPIGAL (COPIN – GANIL-ALTO)

- ISOLDE CERN & SPES
- MoU INFN & iTHEMBA & HRIBF ORNL
- Ongoing collaborations with RIKEN, MSU-FRIBS, RISP-KOREA, BARC, NEW DEHLI, DUBNA, ...
- International collaboration on Innovative Itinerant Detectors
AGATA, FAZIA, PARIS, NEDA, GASPARD, ACTAR/GDS

FP8 ENSAR2 **Partners**



7 ⇒ 10 TNA Facilities

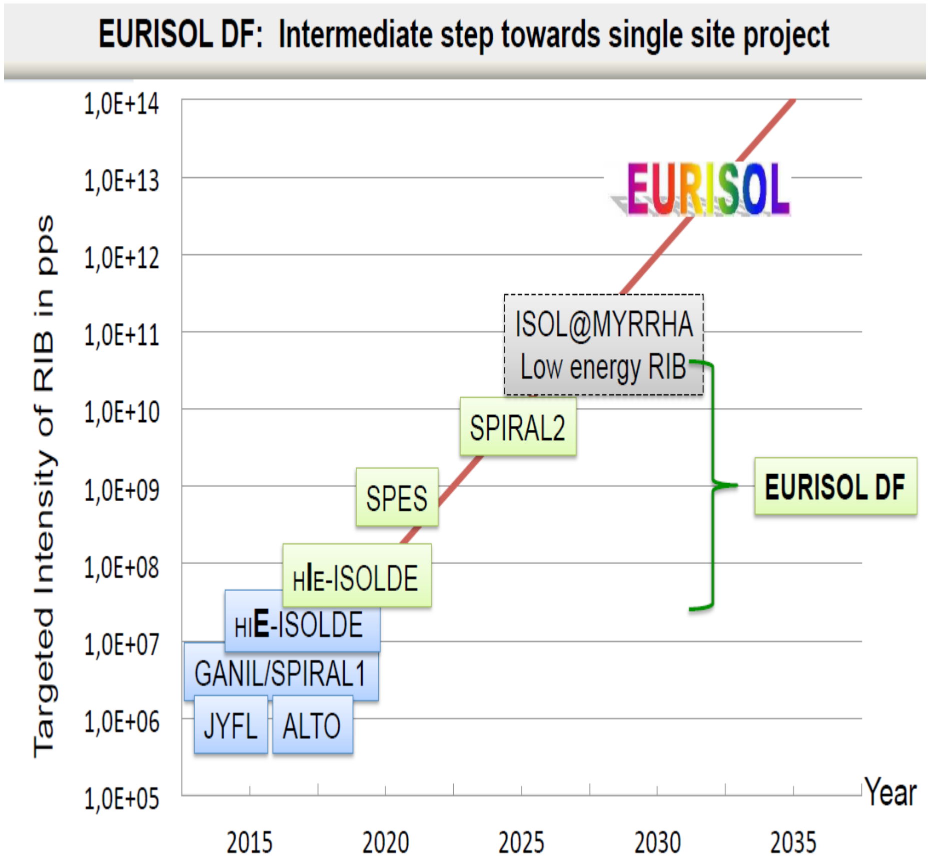
30 ⇒ 30 beneficiaries
15 countries

Community: 2700-3000 scientists and highly qualified engineers

Close collaboration with infrastructures outside Europe:
Canada: TRIUMF
China: IMP Lanzhou
Japan: RIKEN & RCNP
Russia: Dubna/JINR
South Africa: iThemba
United States: NSCL & ANL

EURISOL Distributed Facility (DF) Initiative

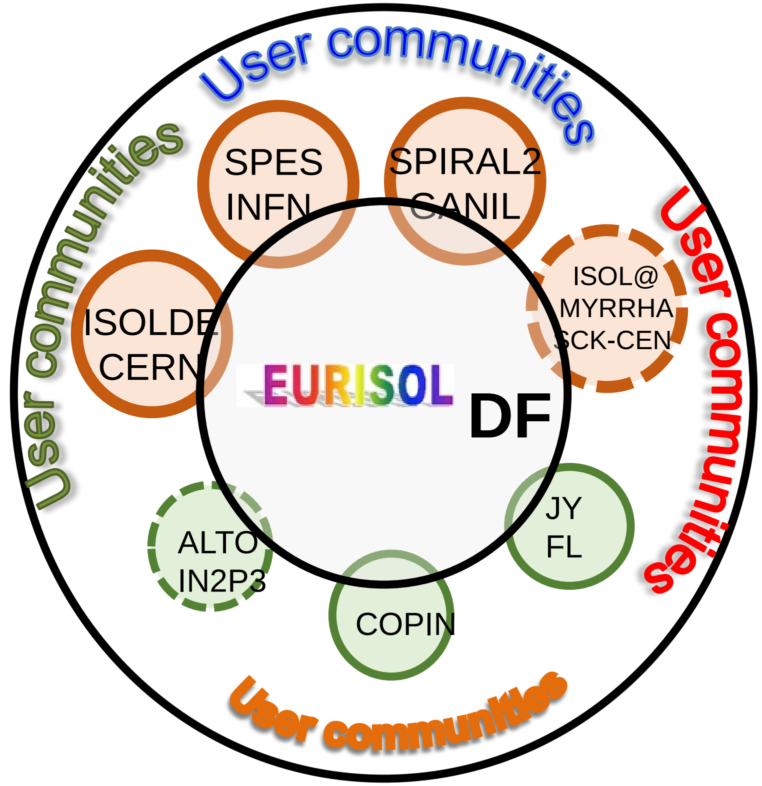
Project to be submitted for the 2018 update of the ESFRI roadmap



Complementarities: Instrumentation eg. AGATA, FAZIA, GASPARD, PARIS

Challenges: High-power targets & sources, purification of RIB

EURISOL DF

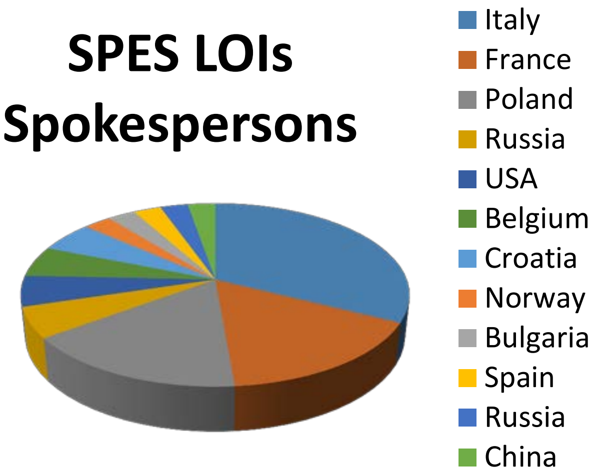


- A **distribute laboratory** for radioactive beams:
- **More exotic beams** available
- **Coordination of competences** to face EURISOL technologic challenges
- **Joint effort** to manage the activity at European level

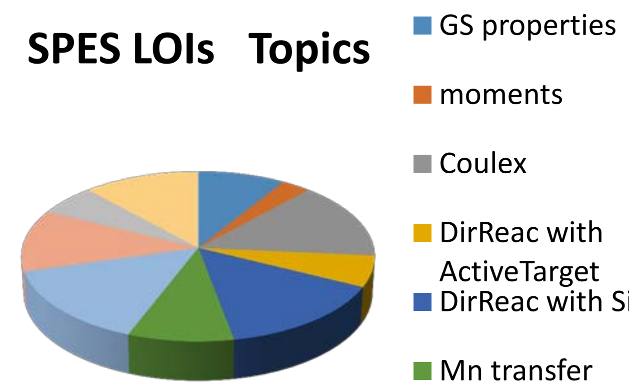
SPES2010 Workshop
(LNL- November 15th-17th, 2010)
24 LoI's for reaccelerated exotic beams

Presented 37 Letters of Intents

SPES LOIs Spokespersons



SPES LOIs Topics

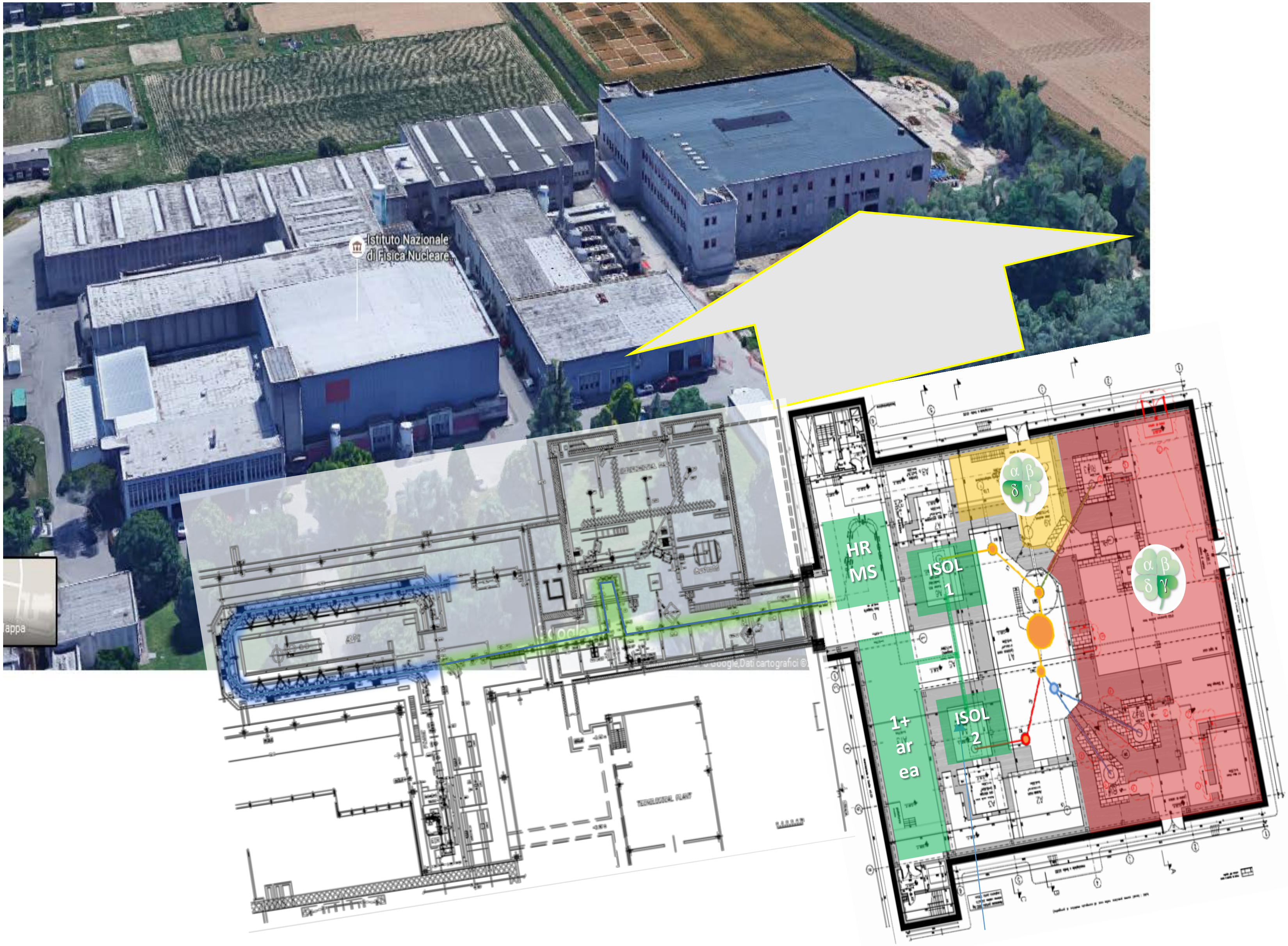


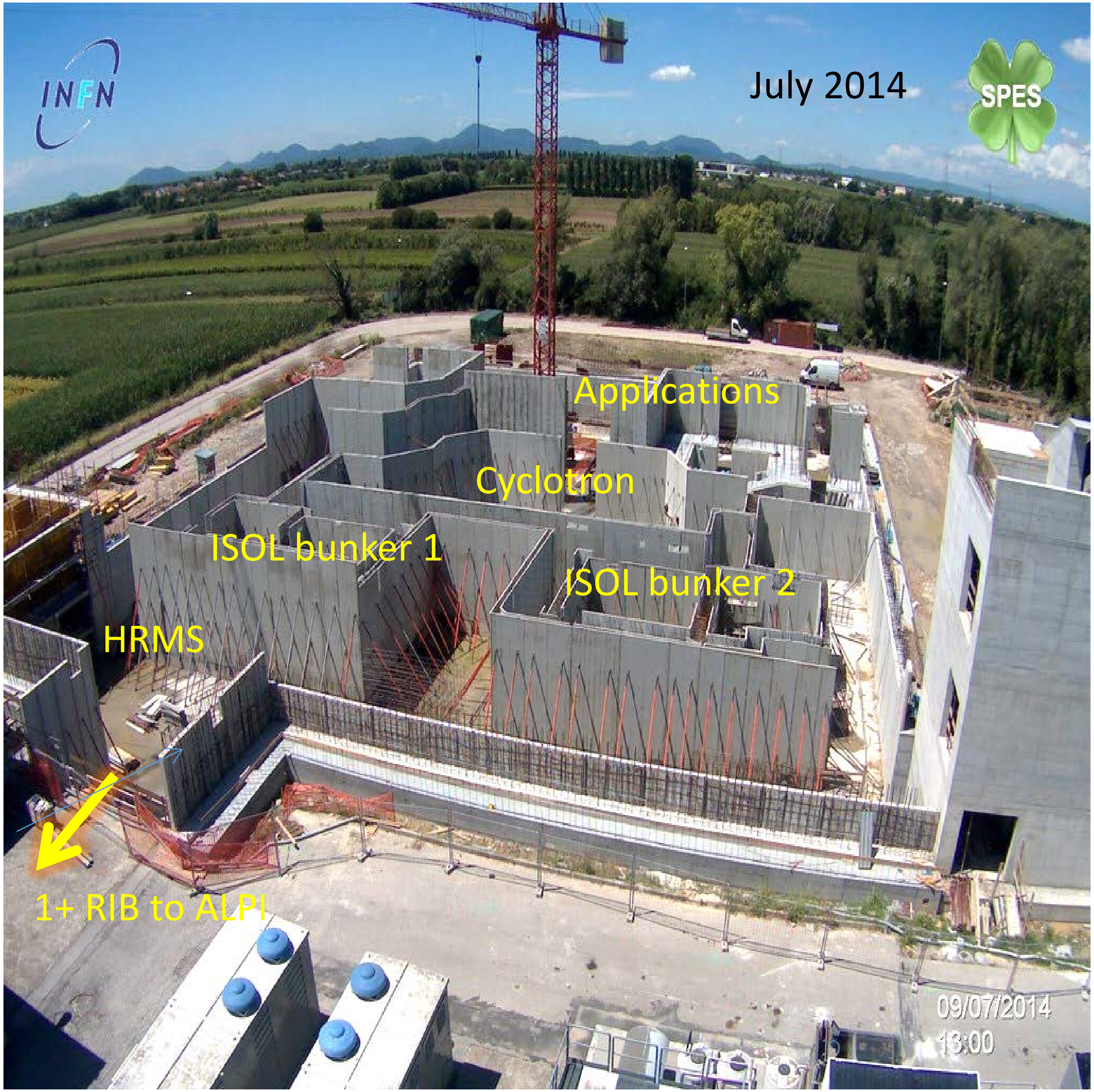
Confermata la competitività del progetto e l'interesse della comunità internazionale

Presented 47 Letters of Intents

INFN-Laboratori Nazionali di Legnaro

SPES infrastructure - layout





SPES building

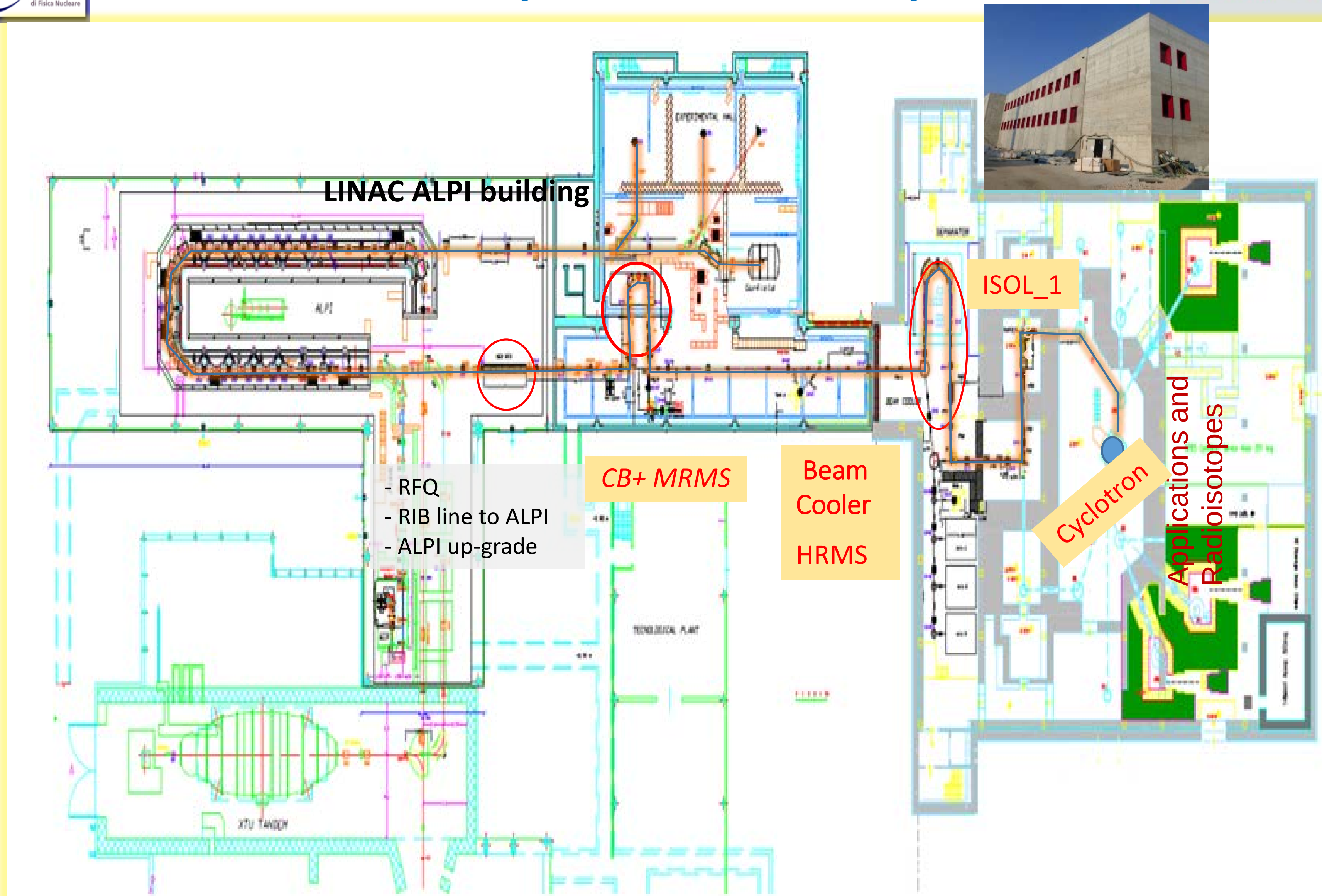
50x60 m^2
-3 to +11 m height
24.000 m^3 of concrete
1.150 tons iron

3-4 m shielding wall thick

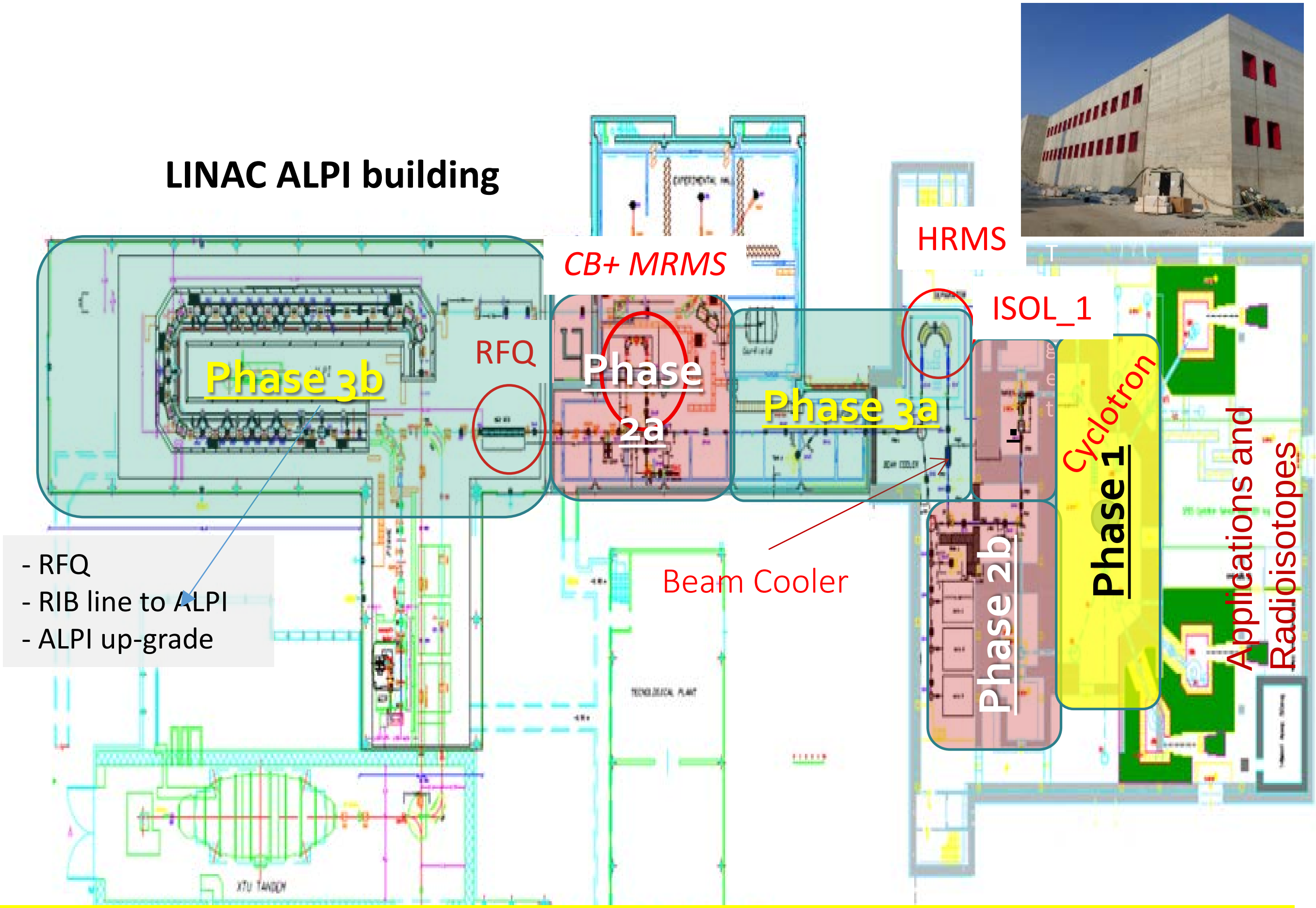
The SPES building 2016

Tanks to G. Fiorentini

SPES layout: ISOL facility



SPES layout: ISOL facility installation phases



- **Phase 1. 2016** - Building + First operation with the cyclotron NOW!
- **Phase 2. 2017-18** - From C.B. to RFQ + SPES target, LRMS, 1+ Beam Lines
- **Phase 3. 2019 – 20 -** HRMS-BeamCooler + RFQ to ALPI

Breaking News:
May 30th 2016 → dual extraction 70 MeV beam – 3 μA
Sept 9th 2016 → acceleration 70 MeV beam – 500 μA
End Oct 2016 → expected to complete Site Acceptance Test

Cyclotron highlights

SPES exotic beams for science

Main Parameters

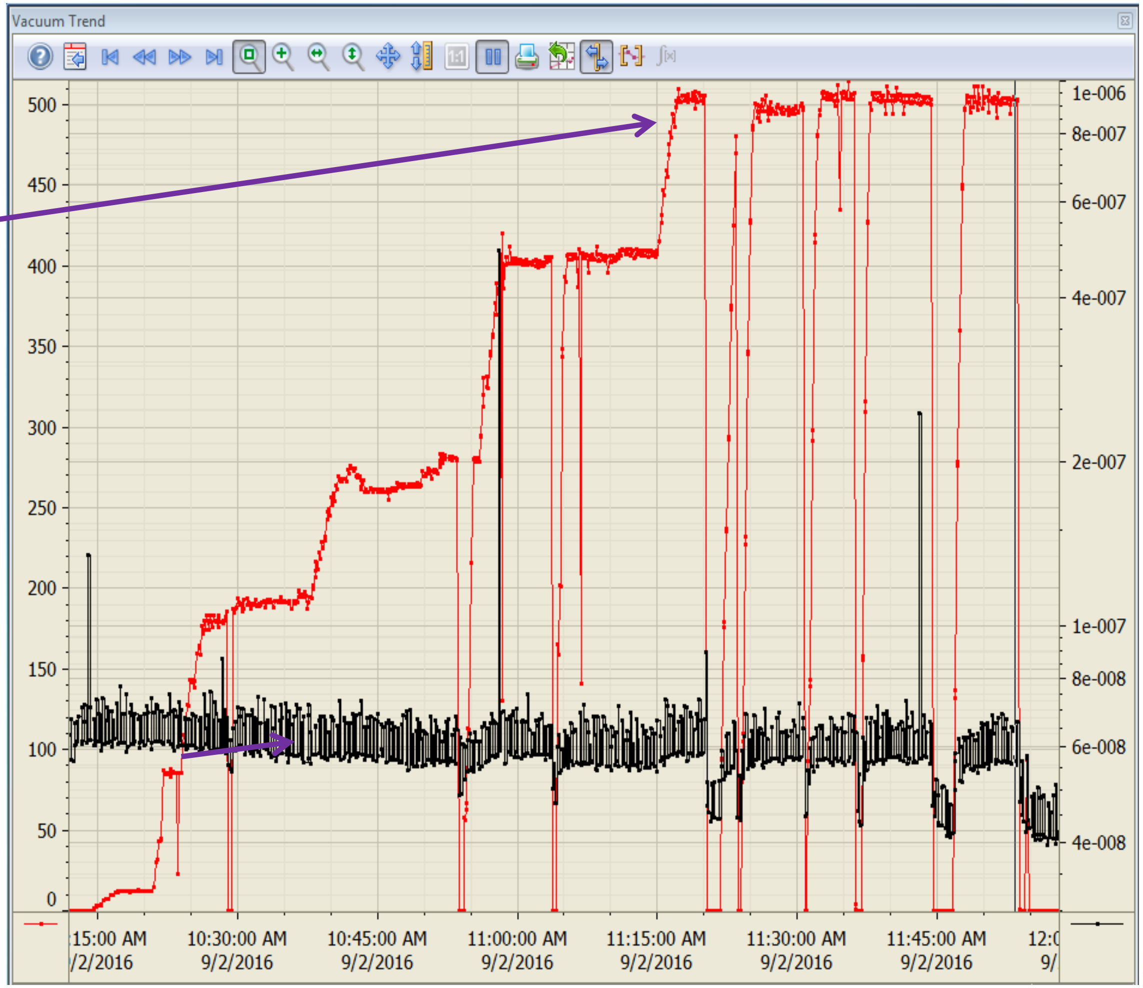
Accelerator Type	Cyclotron AVF 4 sectors
Particle	**Protons (H^- accelerated)**
Energy	**Variable within 30-70 MeV**
Max Current Accelerated	**750 μA** (52 kW max beam power)
Available Beams	**2 beams at the same energy** (upgrade to different energies)
Max Magnetic Field	1.6 Tesla
RF frequency	56 MHz,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

May 12, 2015

52kW beam dump

E.Boratto, F.Pasquato

Beam test on 50kW INFN target



500µA

70 MeV

$6x10^{-8}$ Torr

Best Cyclotron Systems, Inc.

healthcare for everyone TeamBest Your True Partner

See A.Lombardi presentation

ISOL system and diagnostics

ISOL system and Radioactive Beam production
Wien Filter for first mass selection
Beam transport
Remote target handling

ISOL system with Direct target & H^+ Cyclotron

INFN-LNL-223 (2008)

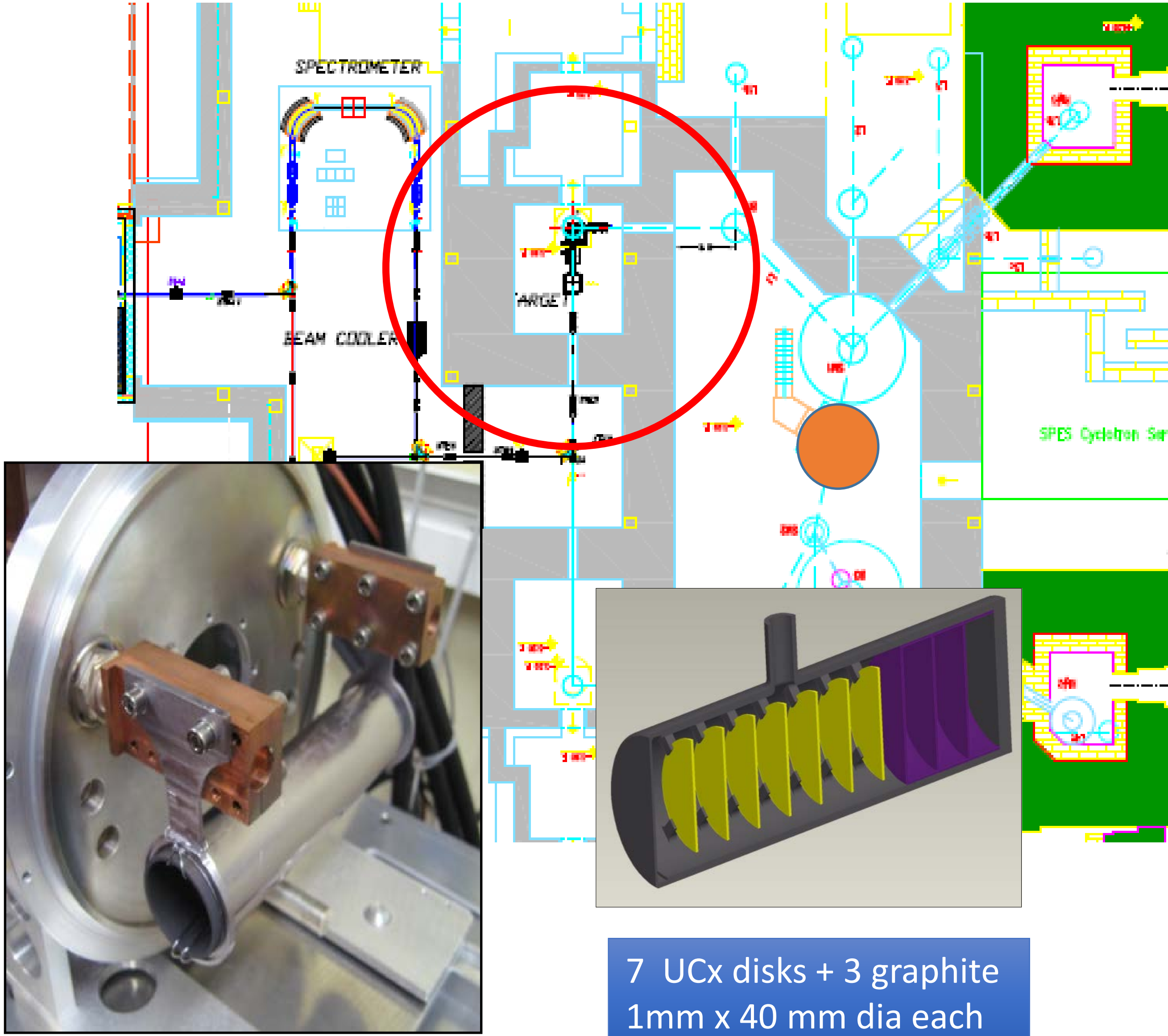
NEW concept developed for the Direct Target: **Multi-foil UCx** designed to sustain 10kW beam power to reach **10^{13} f/s**

The ISOL front-end design follows the ISOLDE system.

A proton beam of 40 MeV, 0.2mA will produce up to **10^{13} f/s** in the UCx target (~ 30 g).

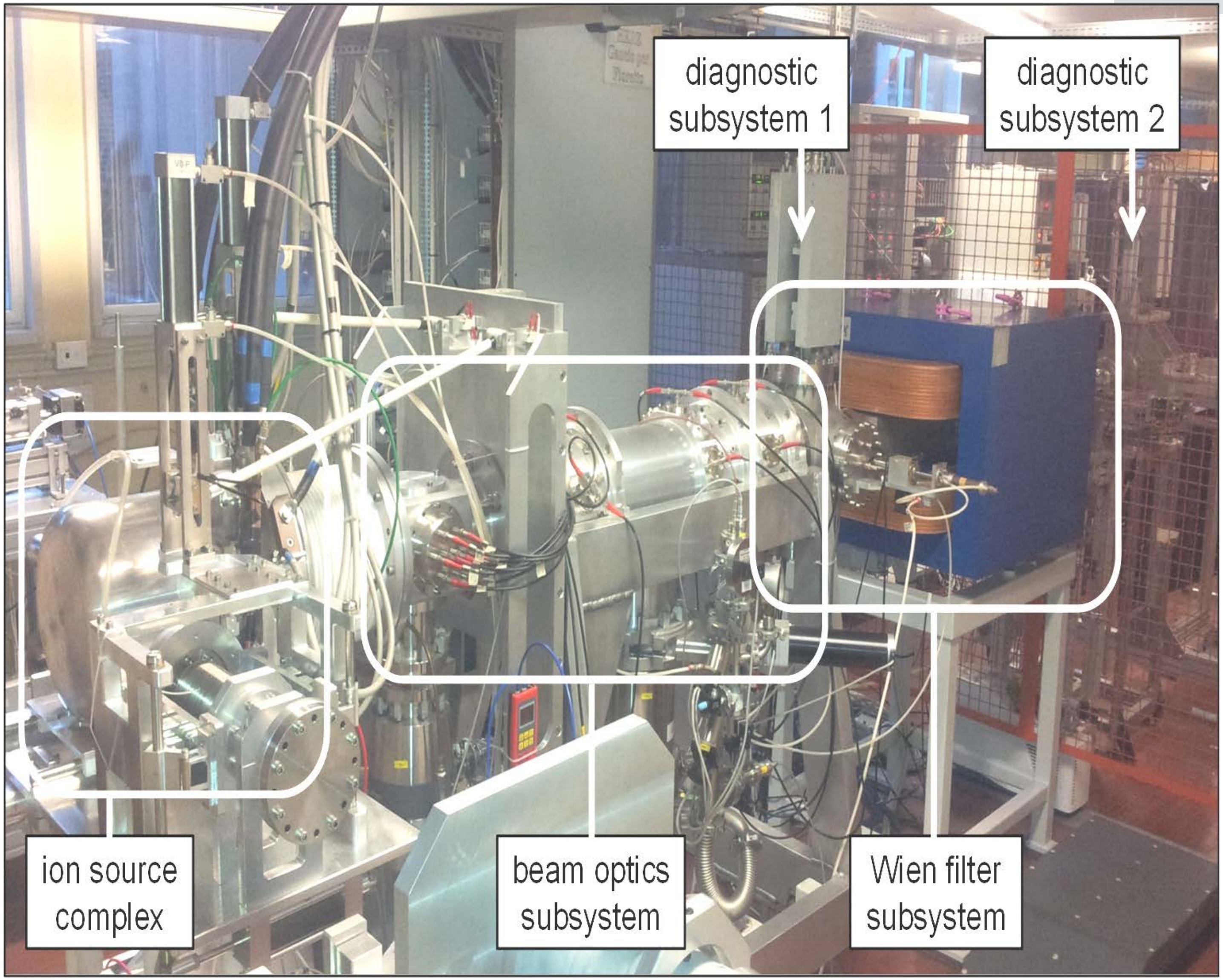
The cyclotron accelerates H+ and will produce 2 proton beams, feeding 2 targets at the same time.

Evaluated cost ~ **50 M€**



7 UCx disks + 3 graphite
1mm x 40 mm dia each

SPES_ISOL Front-End



System under operation for ion sources commissioning.
Updated version under construction (radiation hardness improved).

See A.Andrighetto presentation

Effusion-diffusion effect on isotopes release

1-step: p 40 MeV 200µA on multi-slice direct target (60gr UCx)

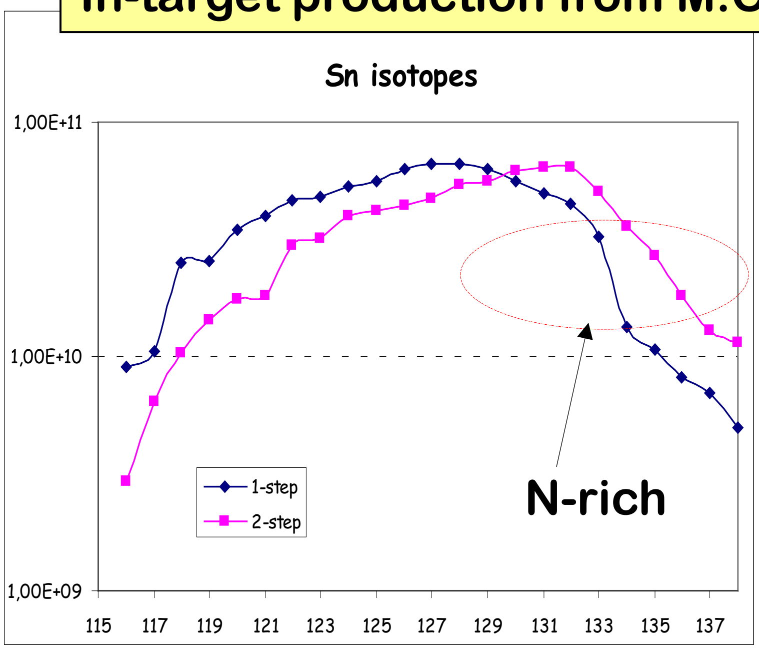
2-step: d 40 MeV 2mA on thick ^{12}C neutron converter + UCx target (800 gr)

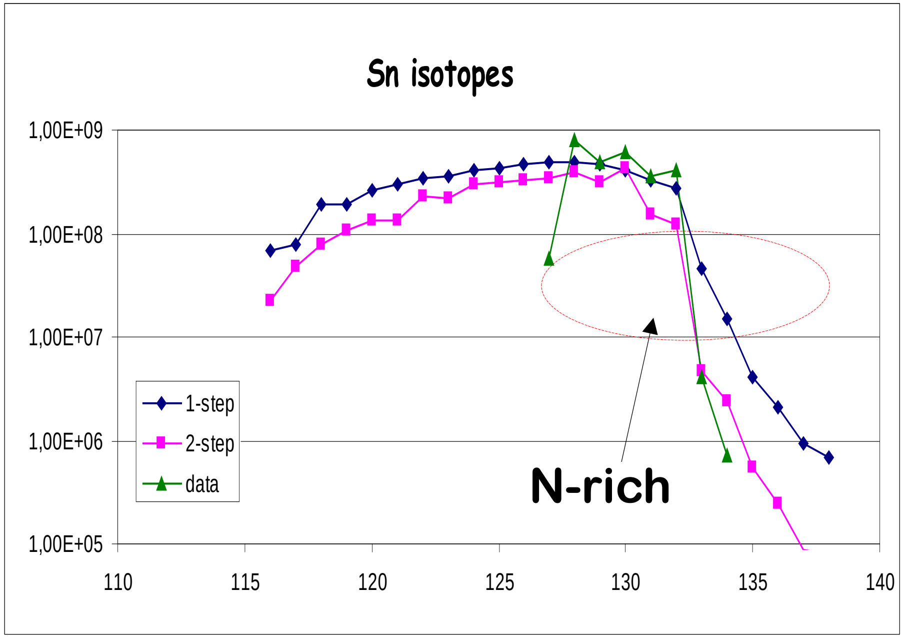
10^{13} f/s

Release times considered:
1-step 2 s
2-step 40 s

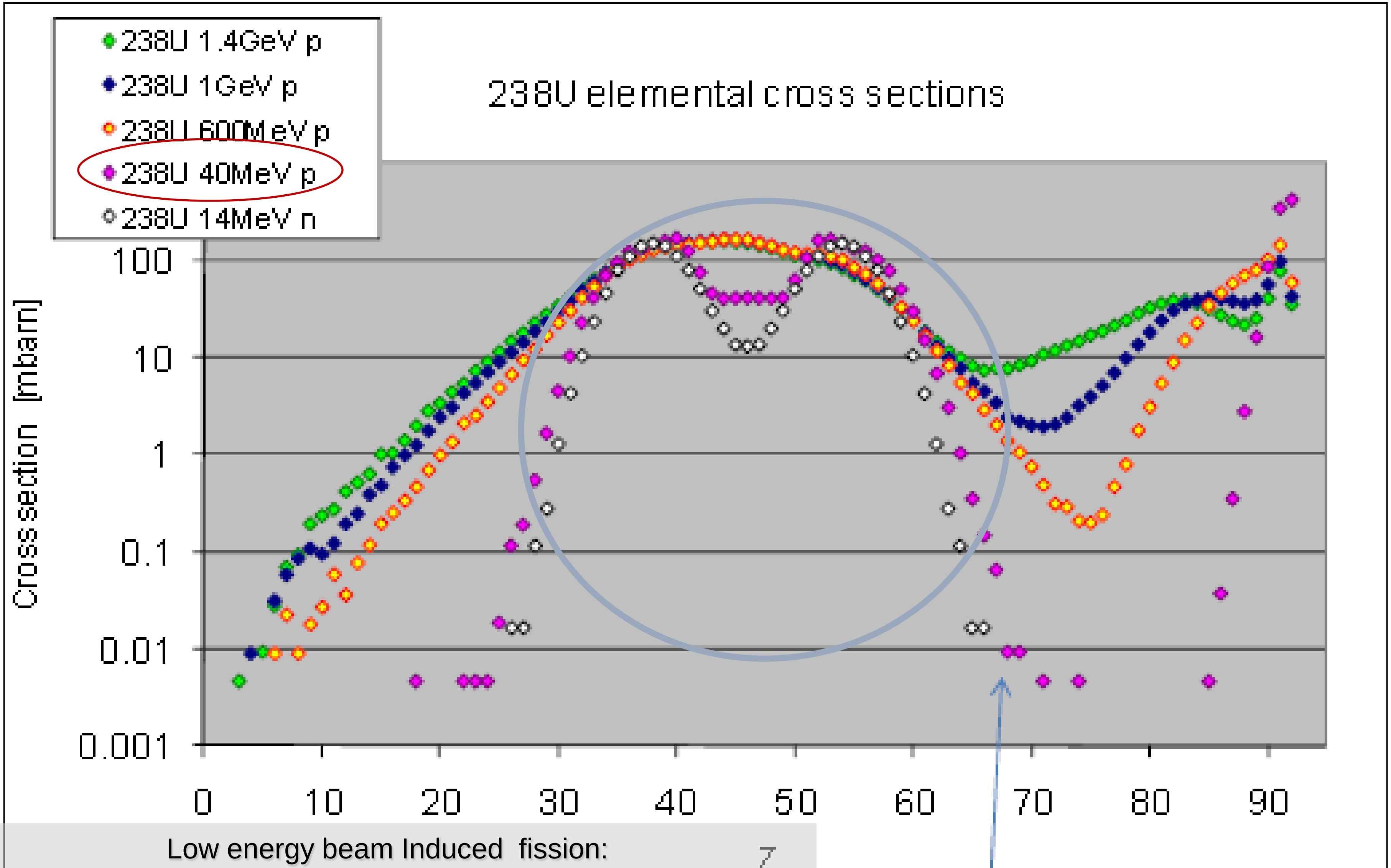
Intensities evaluated considering emission, ionization and acceleration efficiencies

In-target production from M.C.





In target production

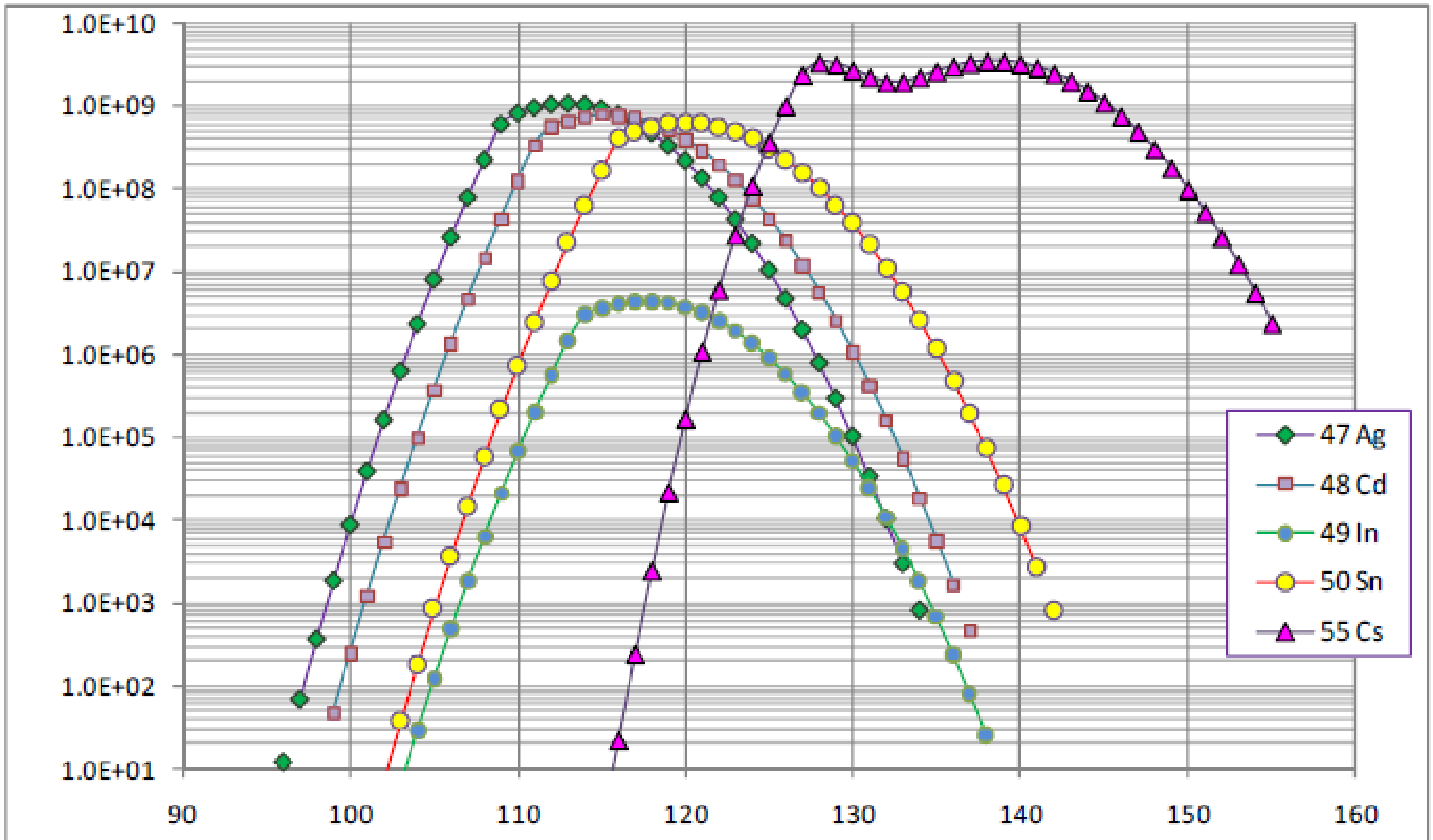


Low energy beam Induced fission:
Pure Fission Region:
- No spallation spectra;
- No alpha emitters

Mass separation : (ISOLDE UCx 50 g/cm2 target S&T X-sections, no decay losses)

RILIS ionized Ag and Sn vs. Cs in a hot *Nb-cavity*

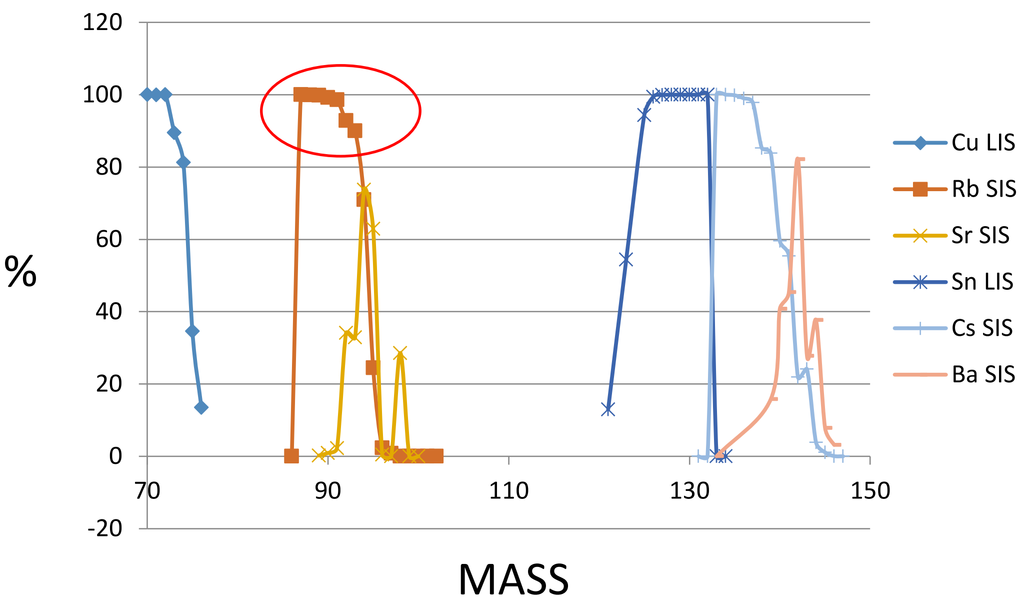
HRS standard operations: HRS tuning while handling low intensity "invisible RIBs" is very challenging (not included in this simulation)



Ion source sectivity

exotic beams for science

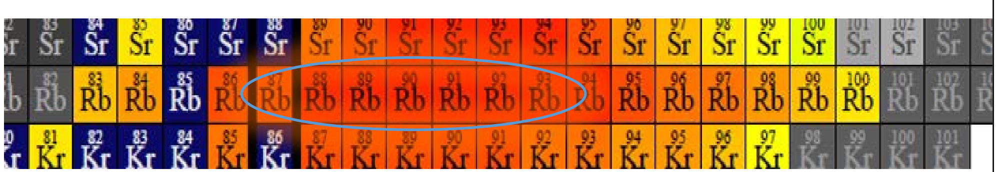
Evaluated beam selectivity with mass selection 1/200

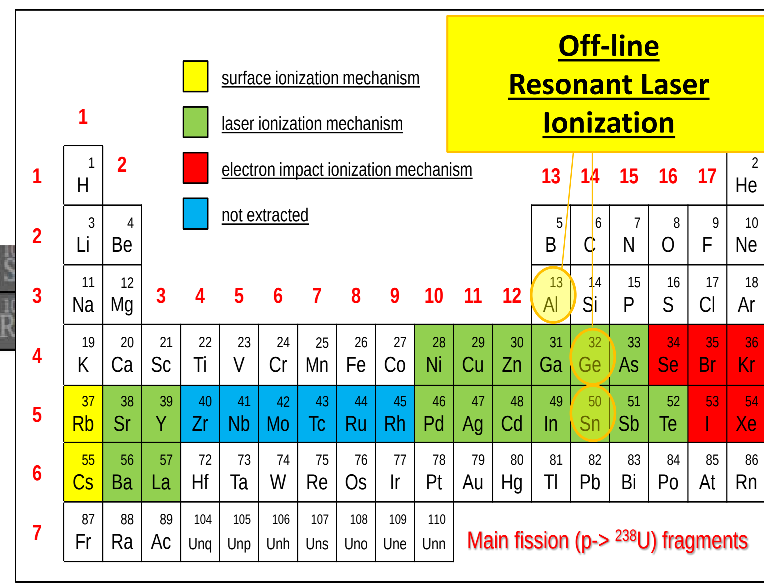


- Characterized by:
  - Ionization efficiency
  - Emittance
- The **SELECTIVITY** of the source depends on the ionization efficiency of each element.

Ion sources

Surface Ionization
Resonant Laser
Plasma ionization





Possible first n-rich beam: Rb

M.Manzolaro, D.Scarpa

Target materials production and tests

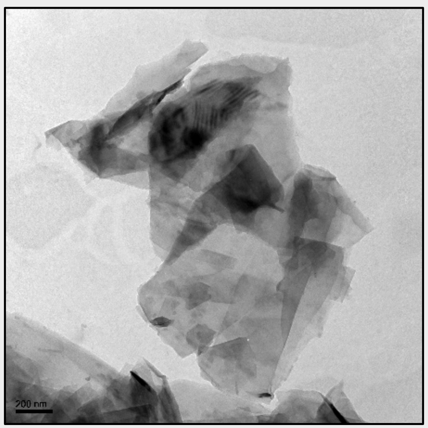
Synthesis of a novel type of UC_x using graphene

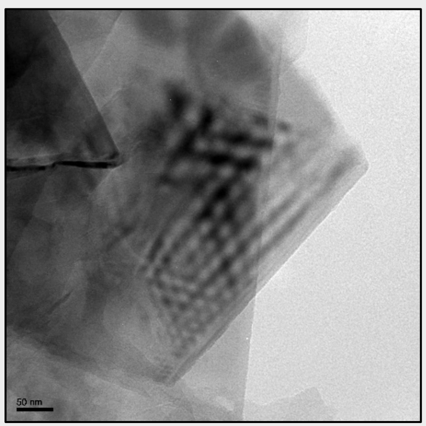
Experiment submitted & accepted at Karlsruhe: n. AUL-176 "Study of the use of Reduced Graphene Oxide as source of carbon for UCx-Graphene nanocomposites production"

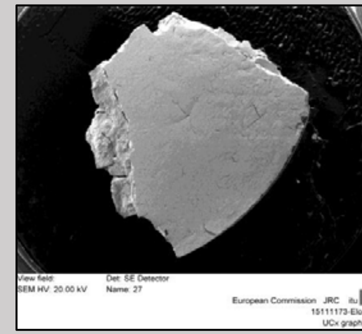
Final phase (Nov-Dec 2015, JRC-ITU Karlsruhe, ActusLab)

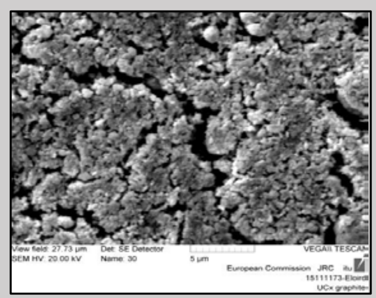
<u>Production of uranium carbide using graphite or graphene as carbon sources</u>

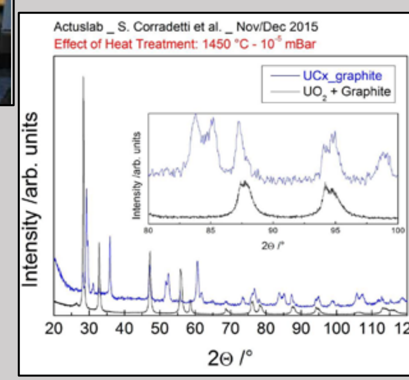
$$UO_2 + 6C \rightarrow UC_2 + 2C + 2CO$$



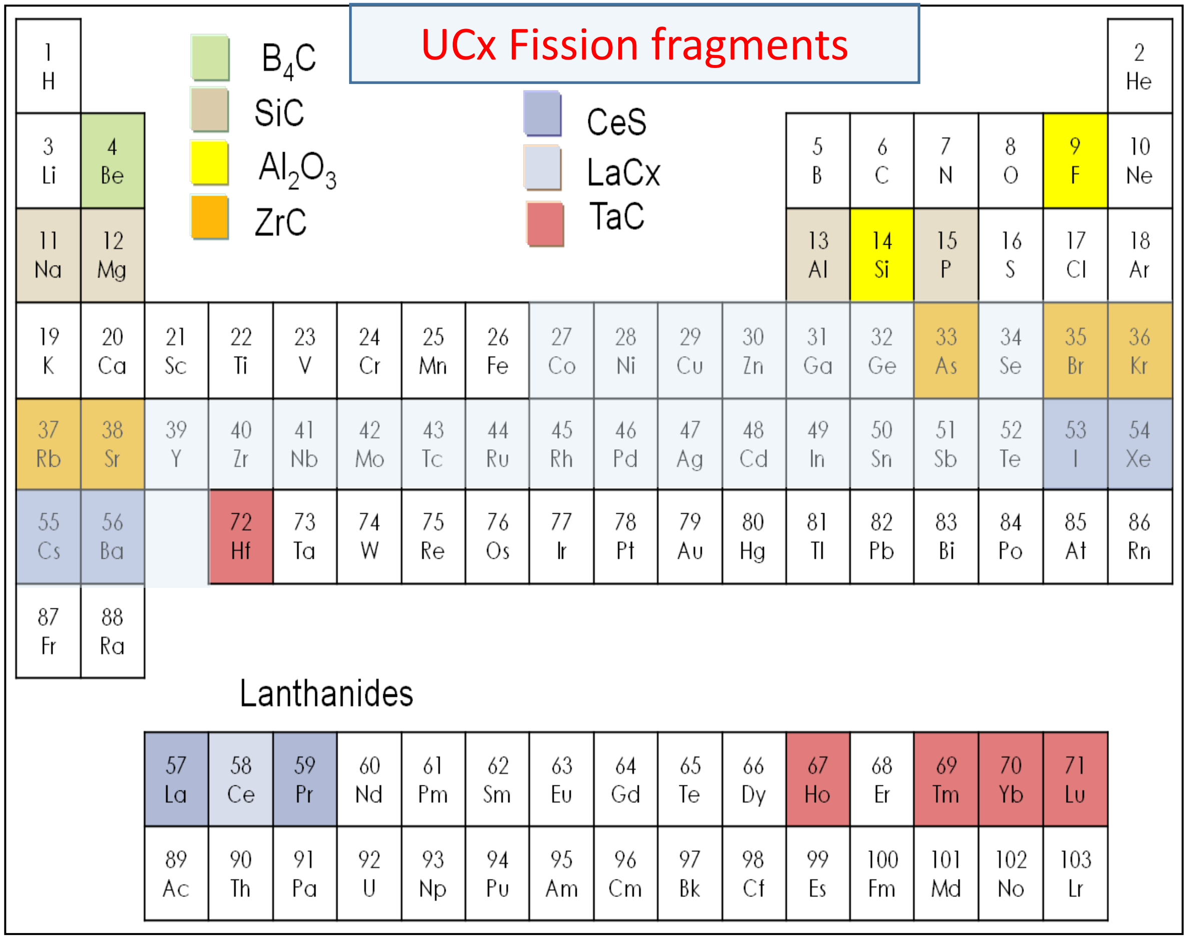






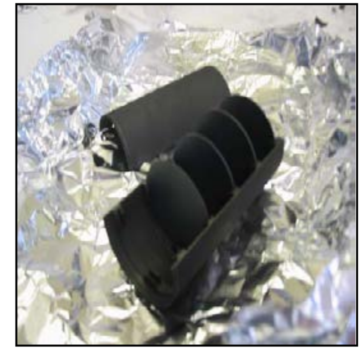


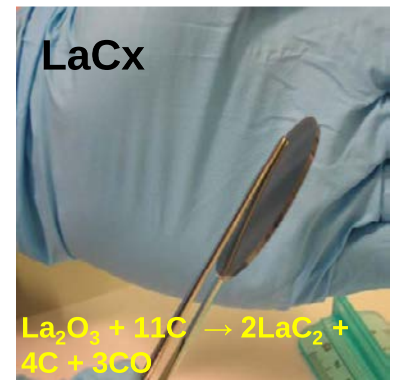
ISOL system: target material development

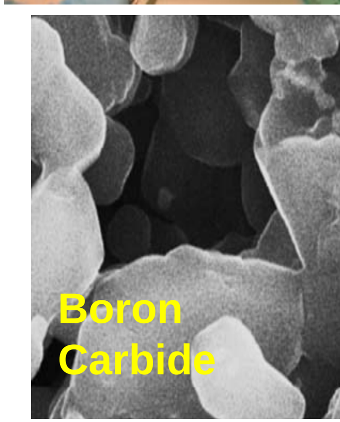


- 7 Be*
- 10 Be*
- 21 Na*
- 22 Na*
- 22 Mg*
- 23 Mg*
- 24 Al*
- 25 Al*
- 26 Al*
- 29 P*

SiC (Saint Gobain)

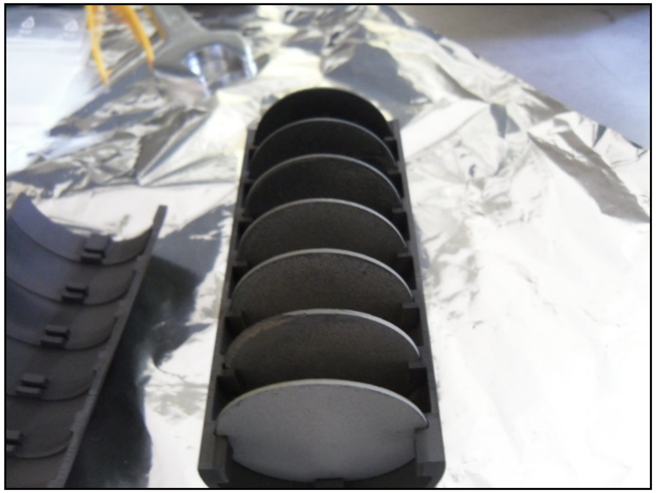


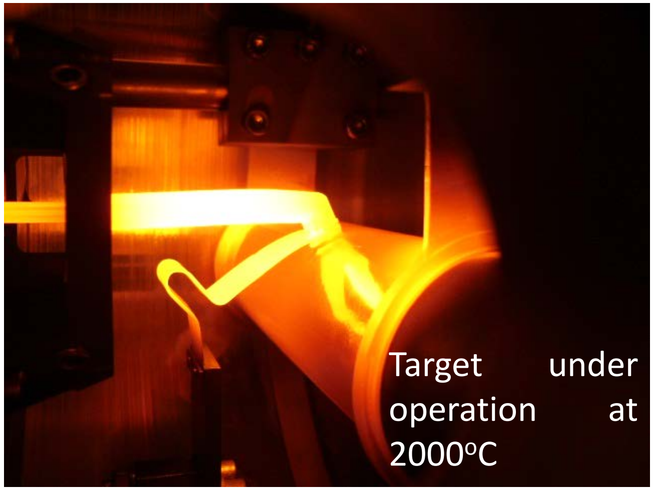




S.Corradetti

SPES Target ion source system



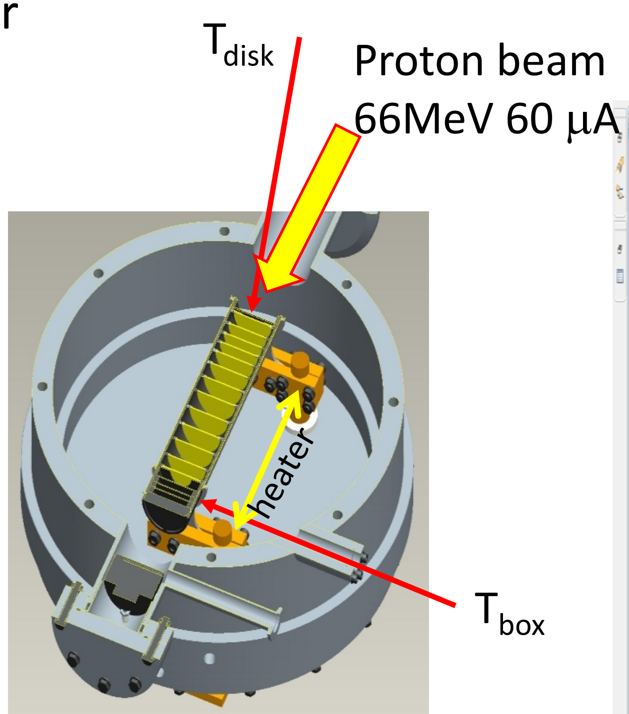


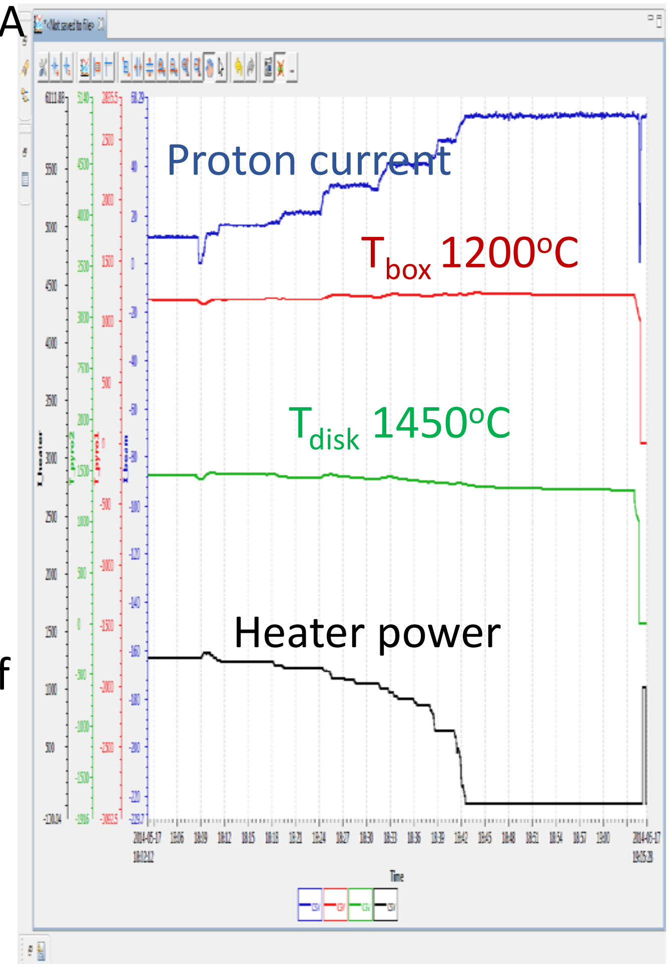
SPES target: iThemba_LABS test

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)



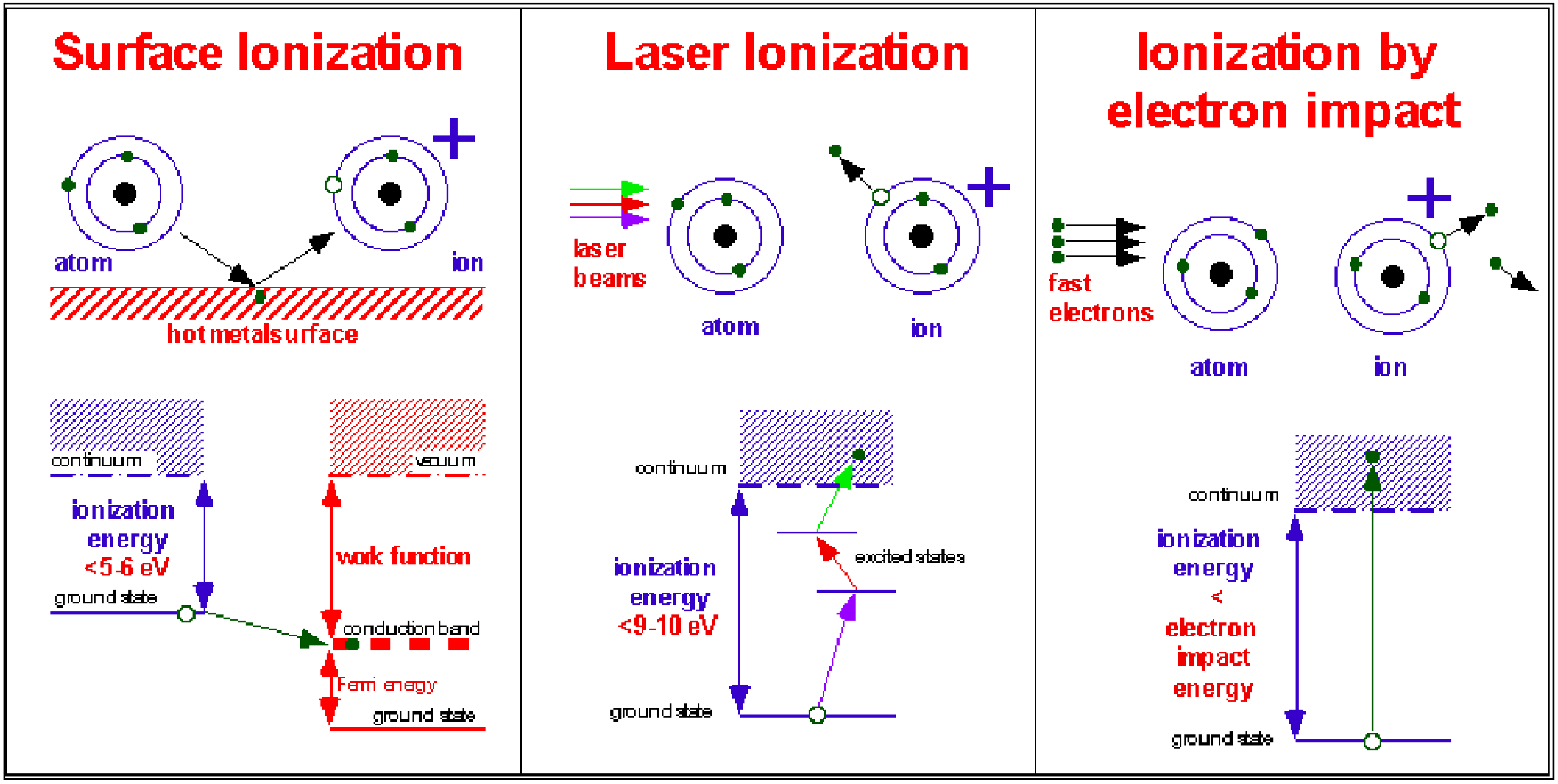


Tanks to Rob, Lowry and all the iThemba_Labs Cyclotron staff

iThemba_Labs, May 17th, 2014

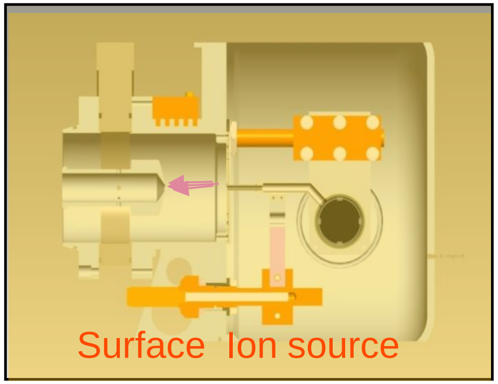
Ionization Schemes

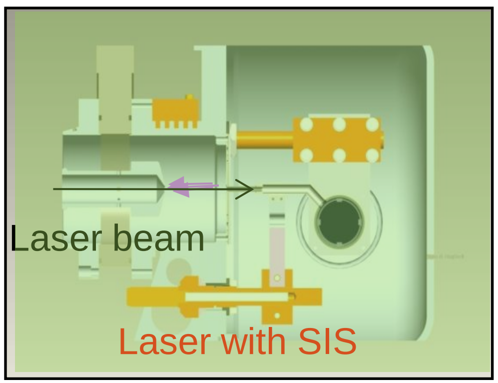
- Induced by surfaces impact
- Induced by photons
- Induced by electron collisions

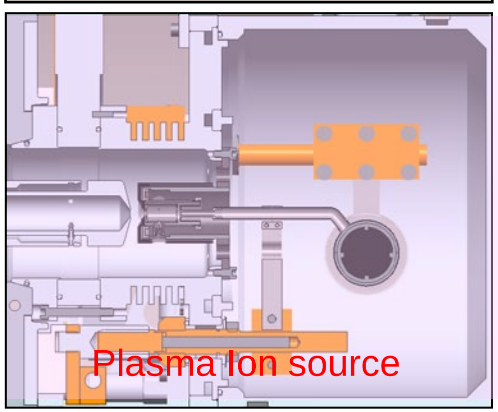


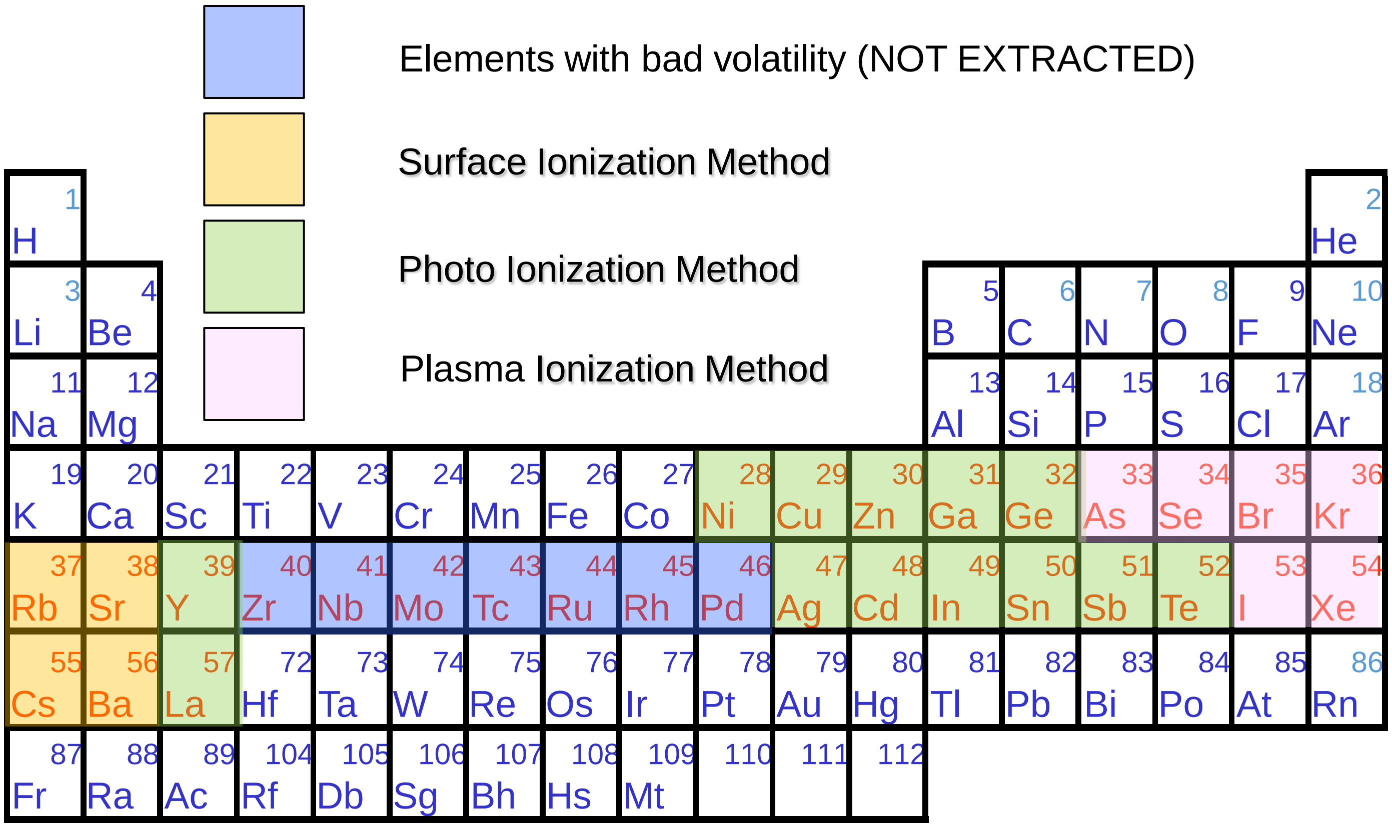
WP1: IONIZATION methods for n-rich RIB's

(3 methods, 2 Ion sources)



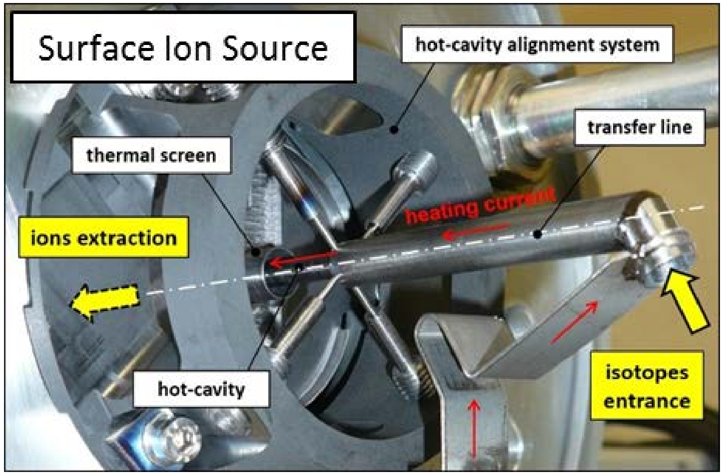


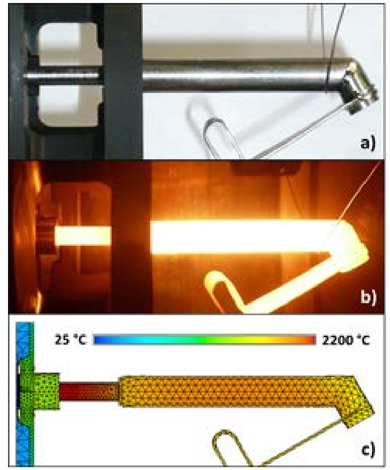




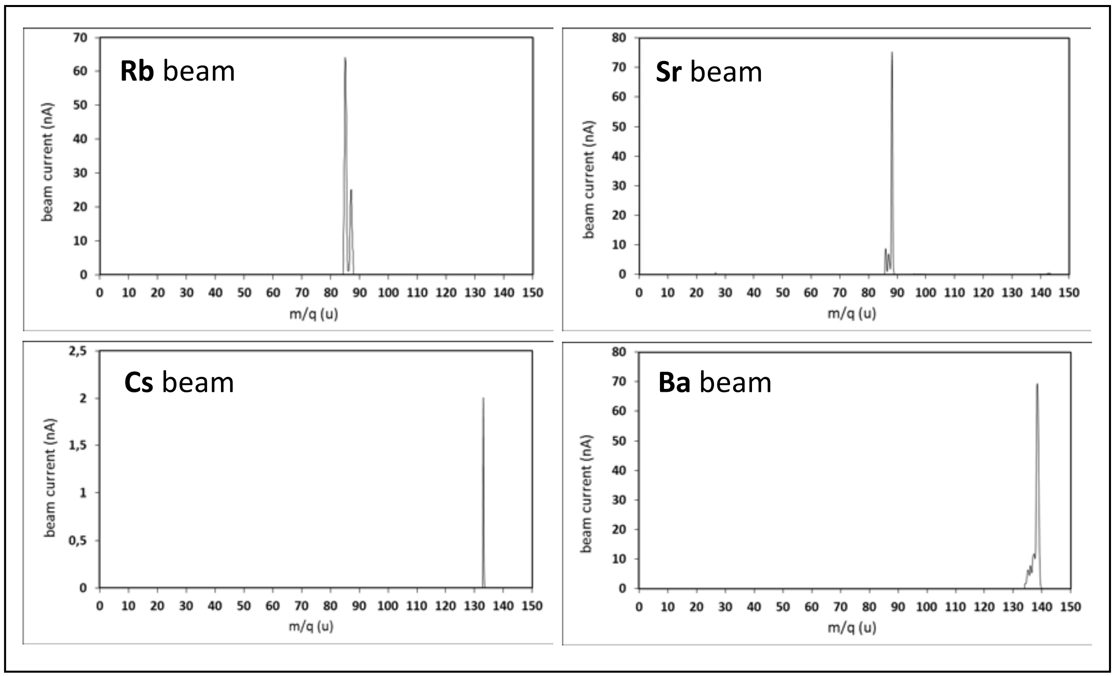
Main fission (p-> ^{238}U) fragments

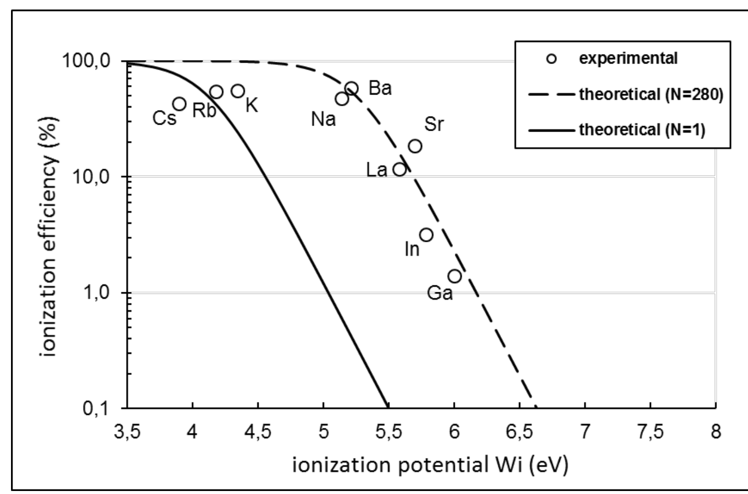
Characterization of the SPES Surface Ion Source



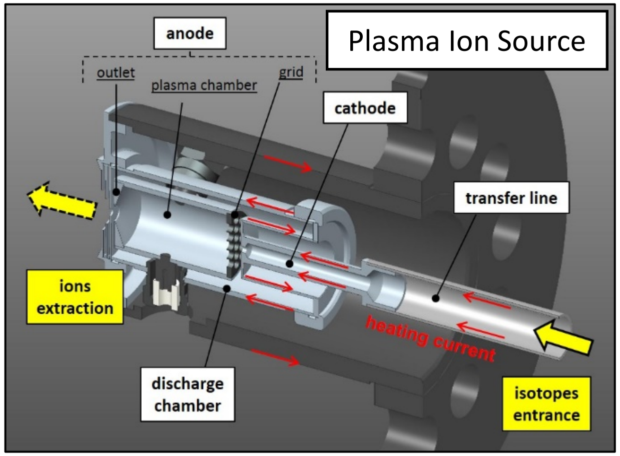


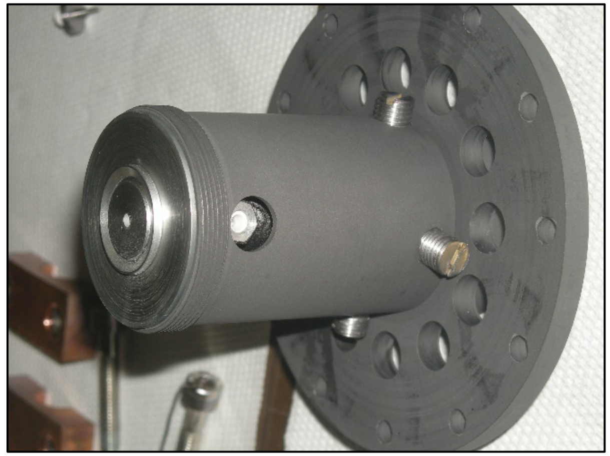
beam	ion. eff. (%)	hot-cavity temp. (°C)	hot-cavity material
Na	47,6	2200	Ta
K	55,4	2200	Ta
Ga	1,4	2200	Ta
Rb	54,5	2200	Ta
Sr	18,5	2200	Ta
In	3,2	2200	Ta
Cs	43,2	2200	Ta
Ba	58,8	2200	Ta
La	20,1	2200	Ta

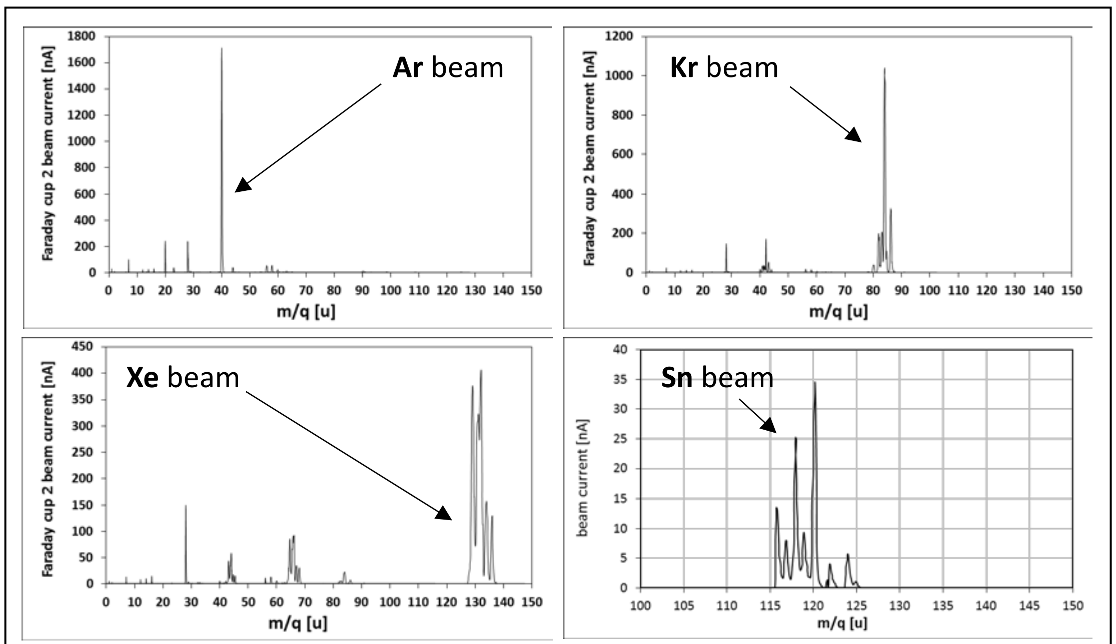




Characterization of the SPES Plasma Ion Source







beam	ion. eff. (%)	injection mode	cathode temp. (°C)
Ar	6	gas tube	2200
Br	WIP	oven	2200
Kr	8,5	gas tube	2200
Y	very low	oven	2300
Sn	10	oven	2200
I	19	oven	2200
Xe	11	gas tube	2200

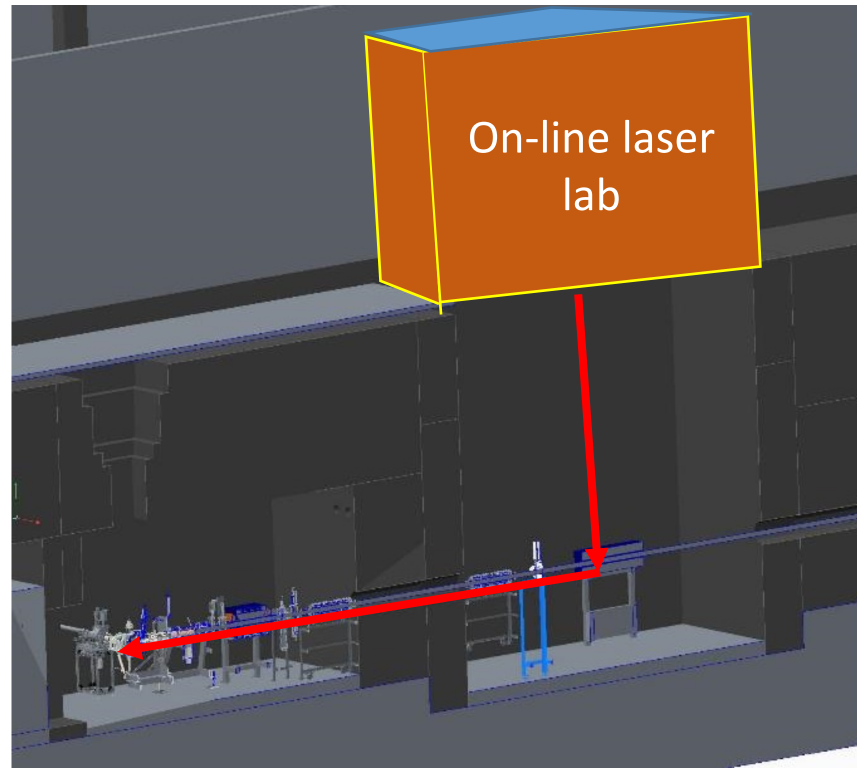
Development of the RIB apparatus: resonant laser ionization

Offline: Spectroscopy

- 3 Dye Laser @ 10 Hz rep. rate

Online (SS laser): RIB prod.

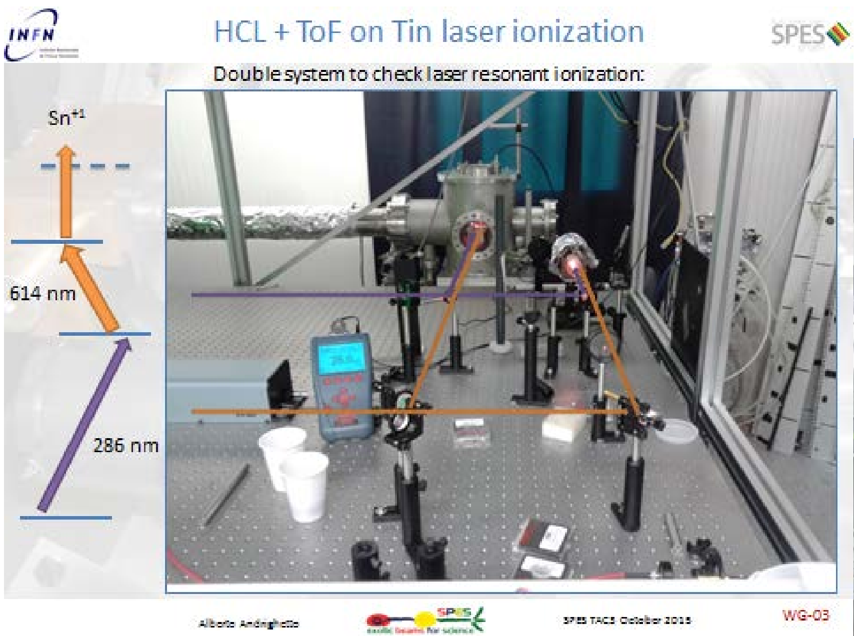
- 3 TiSa Laser @ 10 kHz rep. rate



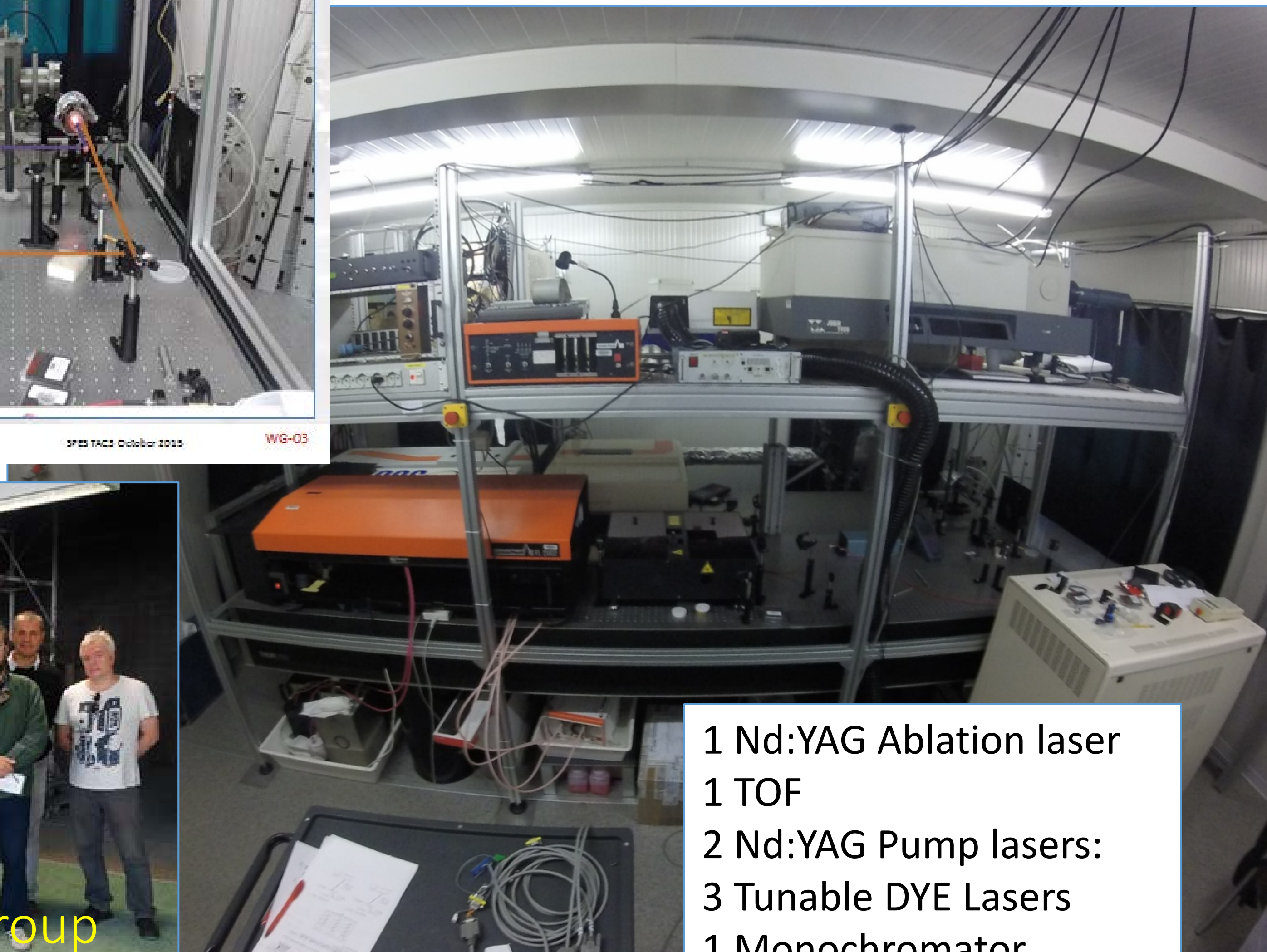
Diagnostic tools:
- Monochromator
- HCL
- ToF Mass Spectrometer

Diagnostic tools:
- Λ-meter
- Alignments System
- Ion-Beam

Off-line Laser Laboratory



Ready for test since 2014…



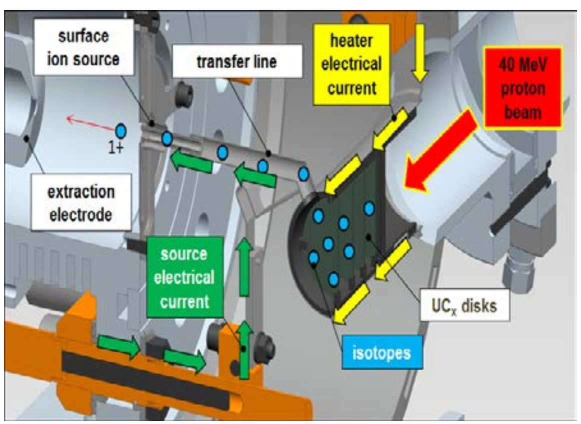
1 Nd:YAG Ablation laser
1 TOF
2 Nd:YAG Pump lasers:
3 Tunable DYE Lasers
1 Monochromator
8 HCL

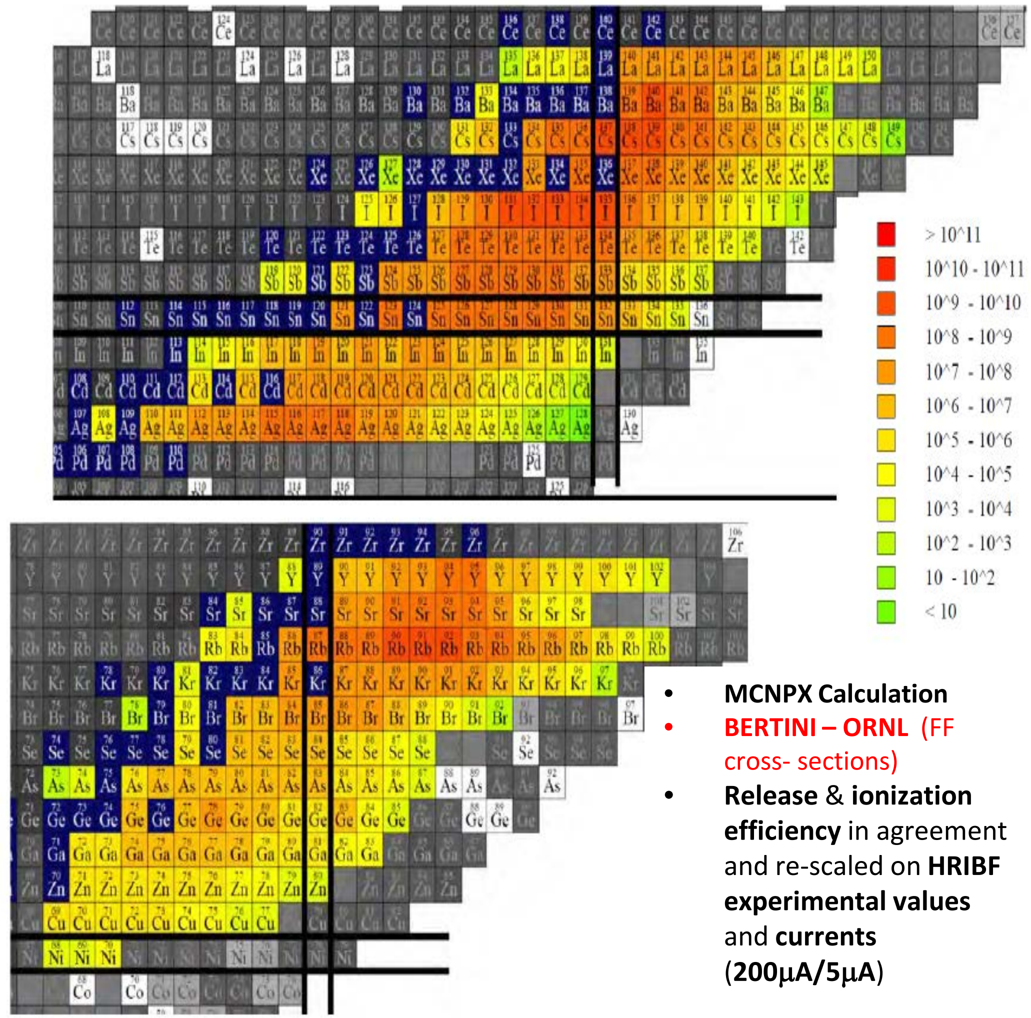
ISOL system: target material development

UCx target for neutron-rich ion production

Expected intensity for reaccelerated beams (10^{13} f/s)

Production Target





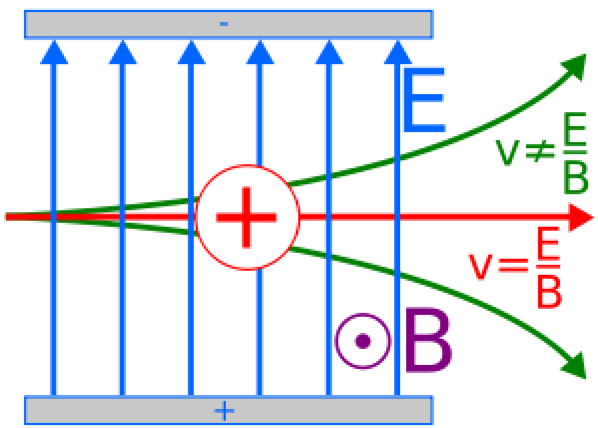
- **MCNPX Calculation**
- **BERTINI – ORNL** (FF cross- sections)
- **Release** & **ionization efficiency** in agreement and re-scaled on **HRIBF experimental values** and **currents** (**200μA/5μA**)

https://web.infn.it/spes/index.php/news/spes-beam-tables

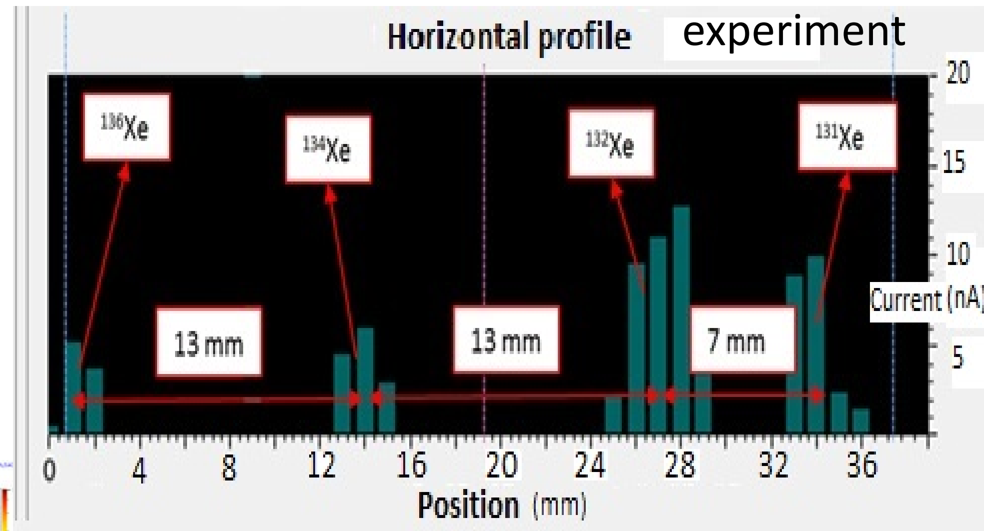
T. Marchi

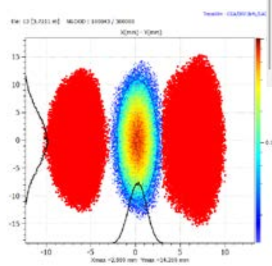
Wien Filter optimization

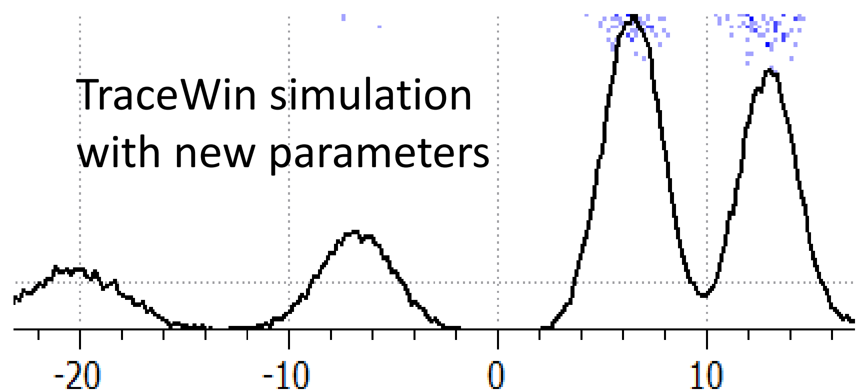
Improved mass selection from 1/70 to more than 1/100
new design of electric and magnetic fields (A.Monetti PhD thesis)



Plasma source, Xe @ 40 kV extraction







RESULTS

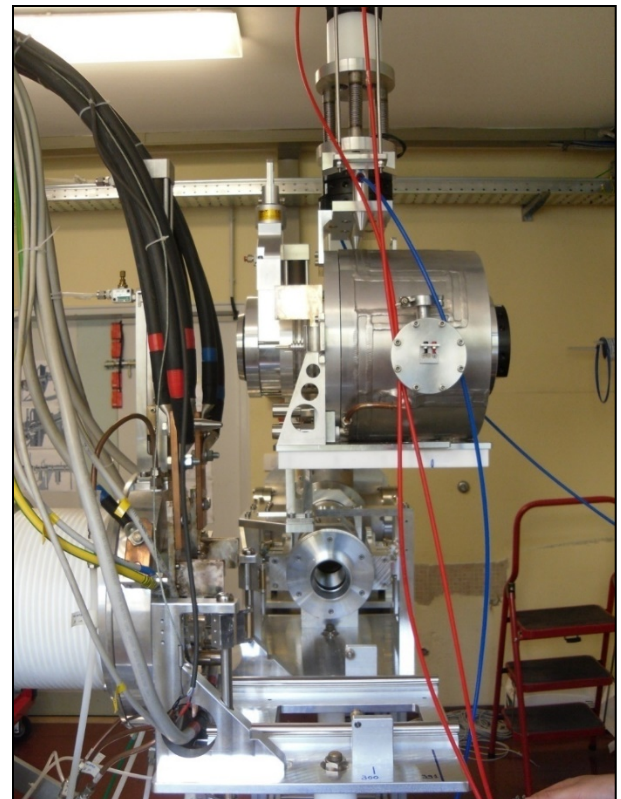
Beam size: 6 mm

M_{150} particle lost: 0.04%

“Unwanted” particles: 0.08% (M_{149})

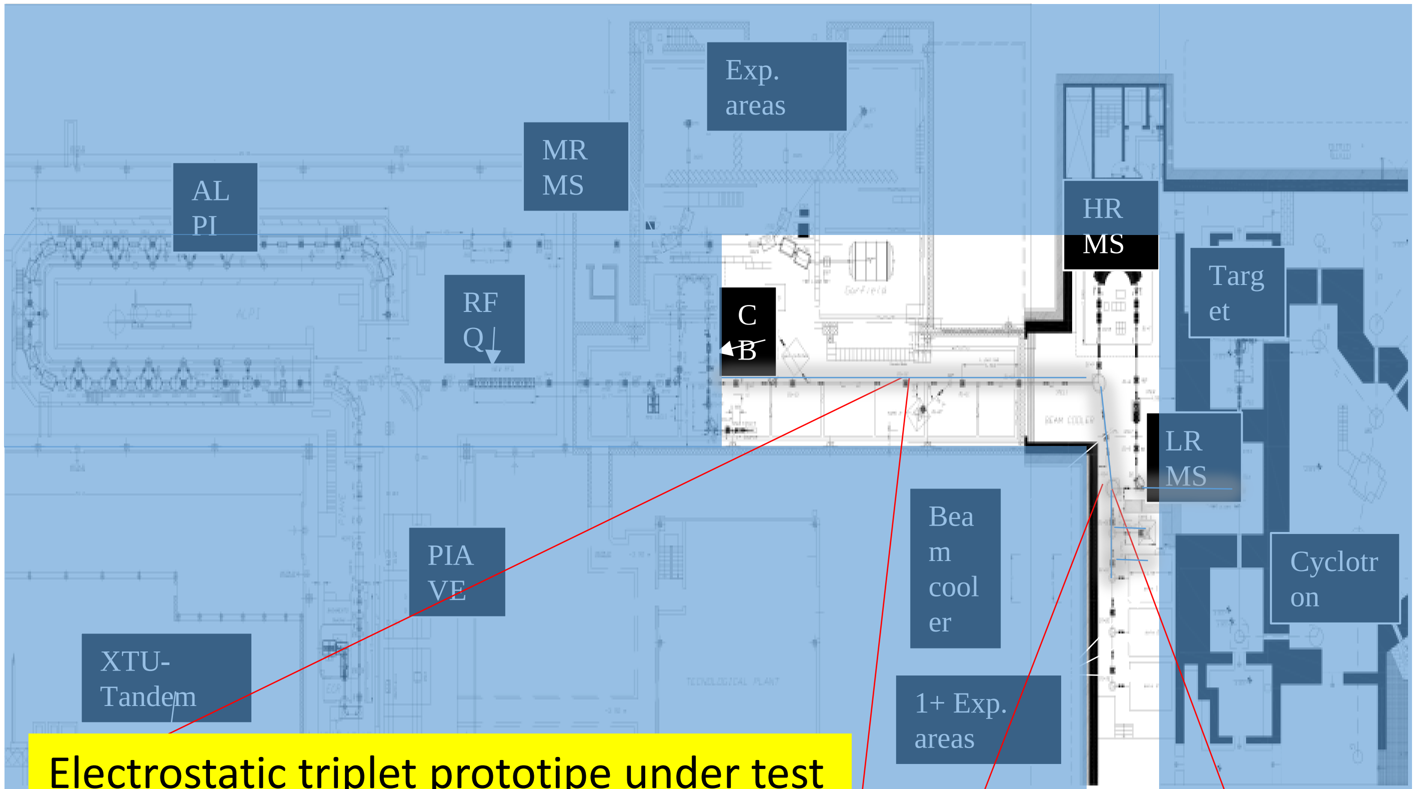
AGV test at LNL

- Simulation software Siemens in Tia Portal
- Movement test in automatic mode
- Experimental tests with 3 transponder

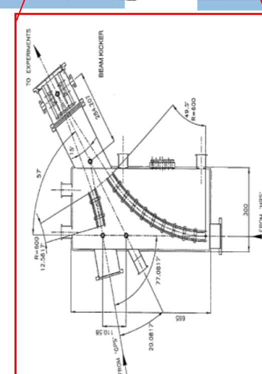


Phase 3: Beam transport and mass selection

1+ beam transport and selection



Electrostatic triplet prototipe under test



Electrostatic dipoles under development

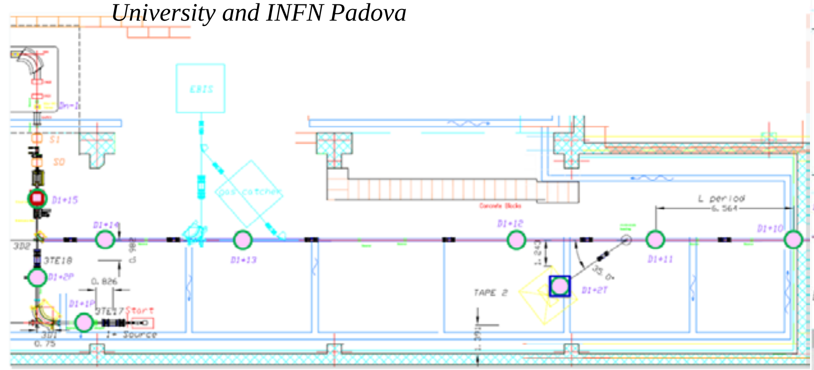
Collaboration with Tony Mendez (ORNL-HRIBF)

Report of the working group "Diagnostica SPES"

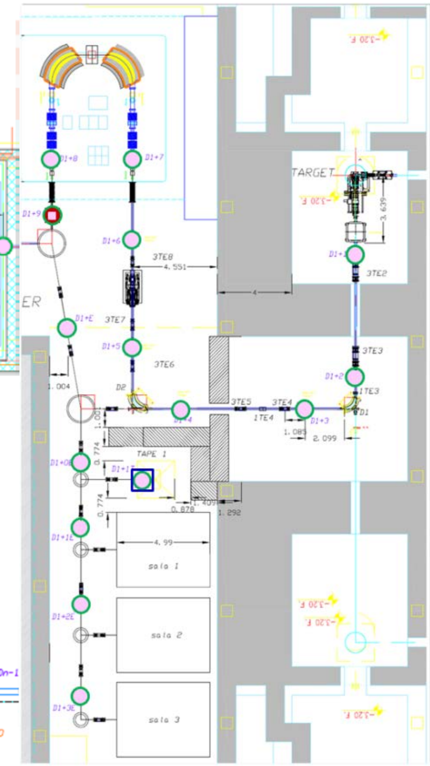
E. Fioretto, R. Cherubini, M. Poggi
INFN - Laboratori Nazionali di Legnaro

G. Collazuol, D. Fabris, D. Mengoni, G. Montagnoli
University and INFN Padova

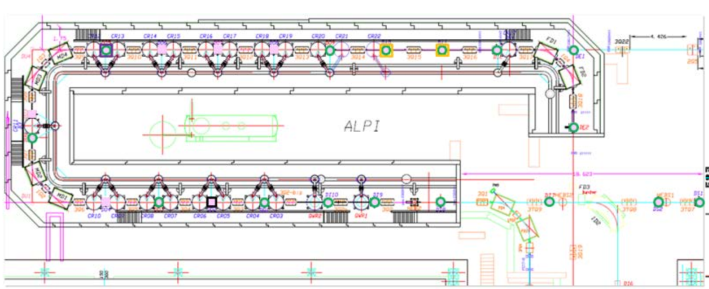
Beam profile Monitor 58
Beam Current Monitor 50
Beam Emitance Meter 3
Tape Station 2
Energy, timing (Si, MCP)

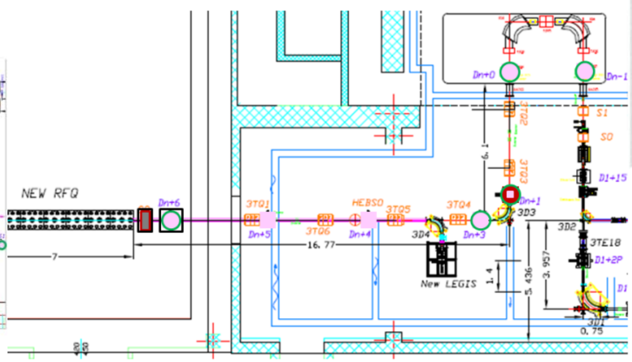


- 9 Beam Profile Monitors (BPM)
- 1 Beam Emittance Meter (BEM)
- 9 Beam Current Monitors
- 1 Tape station



- 15 Beam Profile Monitors (BPM)
- 1 Beam Emittance Meter (BEM)
- 15 Beam Current Monitors
- 1 Tape station





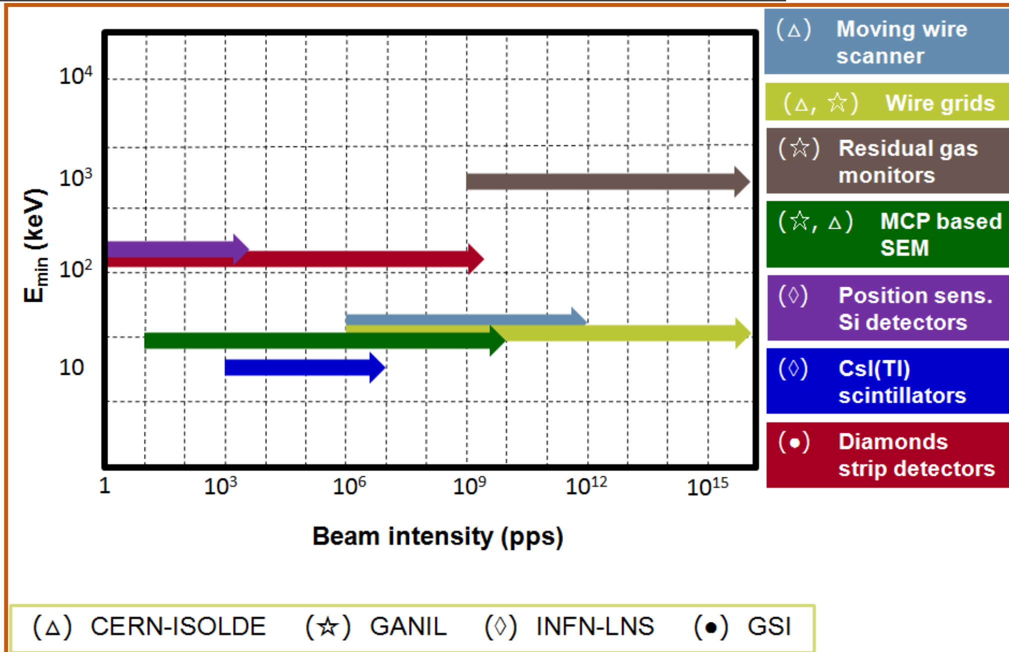
- 27 Beam Profile Monitors (BPM)
- 21 Beam Current Monitors
- 1 MCP detector (Timing)
- 1 Si detector (Timing)
- 2 Fast FC for E meas. by TOF

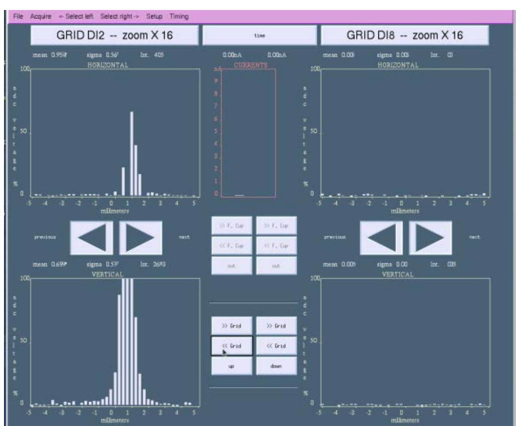
- 7 Beam Profile Monitors (BPM)
- 1 Beam Emittance Meter (BEM)
- 5 Beam Current Monitors
- 1 Diagnostic plate (temporary)
- 2 MCP (Timing)

https://docs.infn.it/share/page/site/spes/document-details?nodeRef=workspace://SpacesStore/425679b4-6360-4271-bd46-fdc66724e244

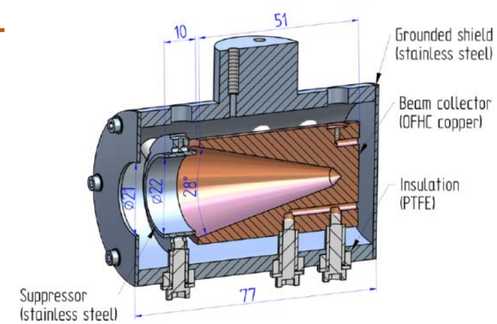
Phase 2: Low energy, low intensity beam monitors

MCP & grid beam monitor (LNL)





Horizontal and vertical profiles of a ^{40}Ca beam (charge state 9^+) at current of about 10 fA (10^4 pps).

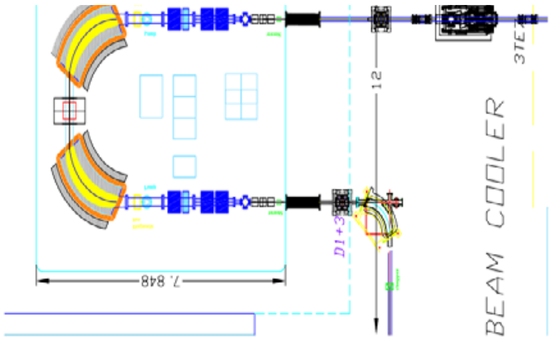


A FC prototype for measuring intensities of the order of the fA has been designed for the USR facility at GSI and tested at LNS.

https://docs.infn.it/share/page/site/spes/document-details?nodeRef=workspace://SpacesStore/425679b4-6360-4271-bd46-fdc66724e244

Phase 3: High Resolution Mass Separation

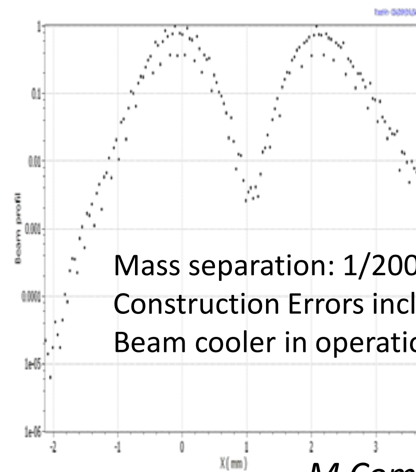
Collaboration: LNS, LNL, CENBG Bordeaux
Physics design: 1/40000



ΔE= ± 1 eV
Emittance $_{rms,n}$ = 0.68 πmm mrad

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%

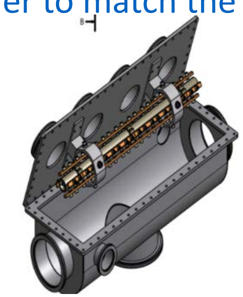
^{132}Sn beam in simulations

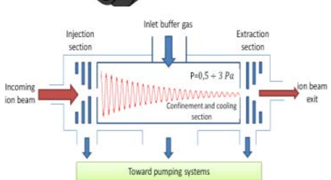


Mass separation: 1/20000
Construction Errors included
Beam cooler in operation

M.Comunian

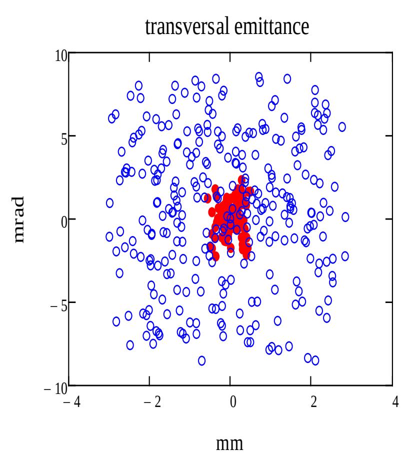
Beam Cooler to match the HRMS input requirements





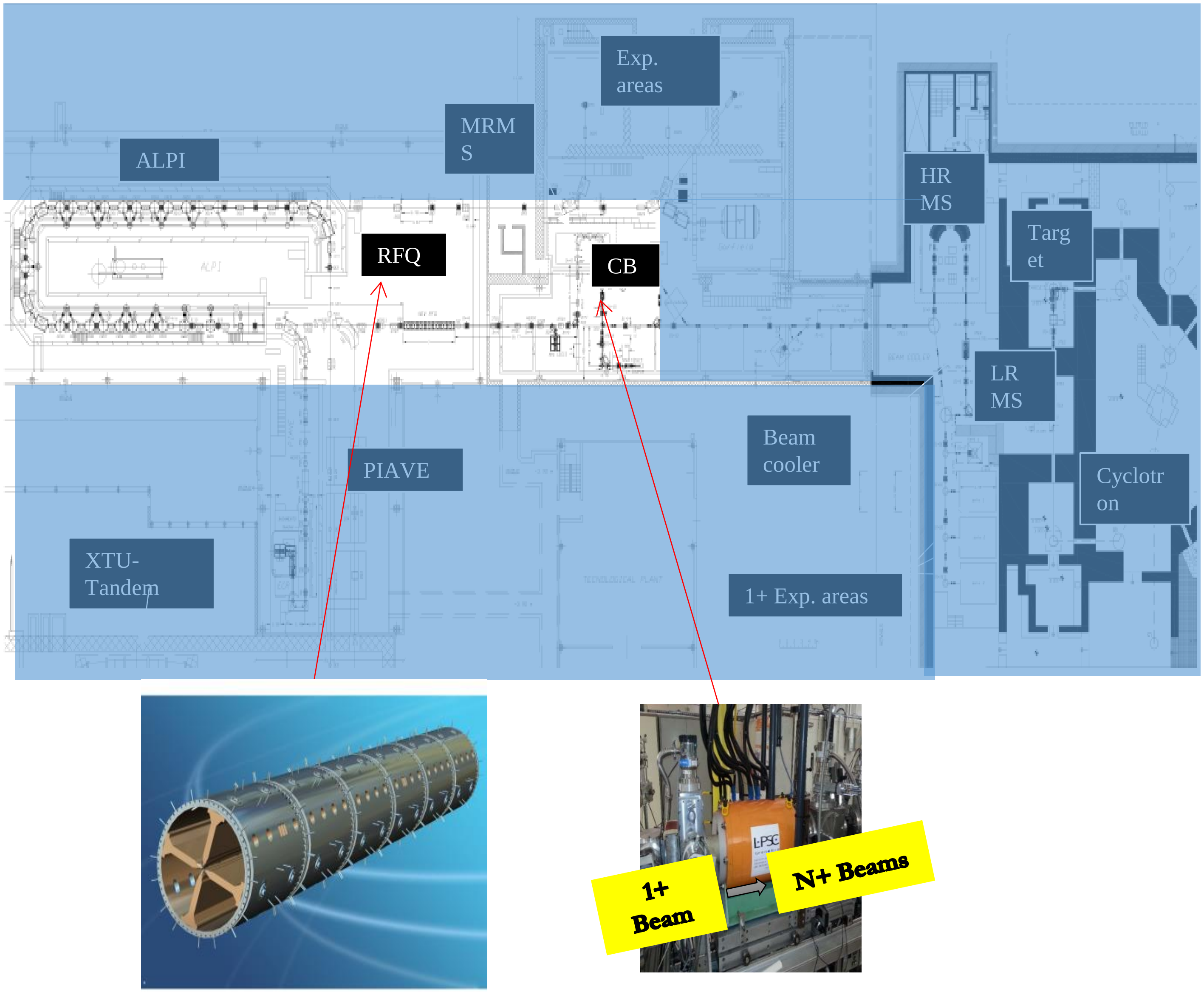
M.Maggiore

Collaboration with LPC_Caen for BC development (SPIRAL2)

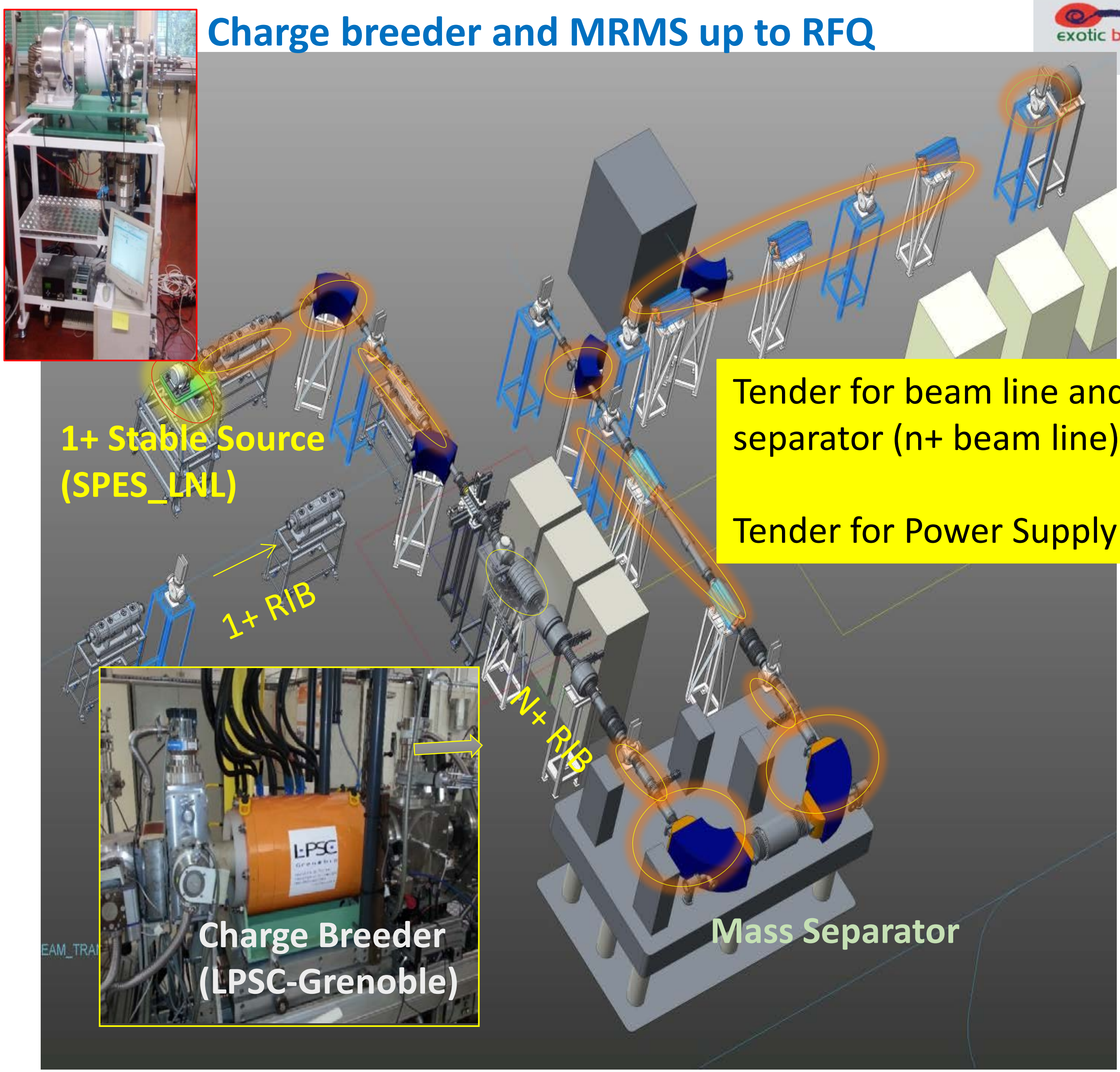


Input T emittance
Output T emittance

Beam transport and reacceleration



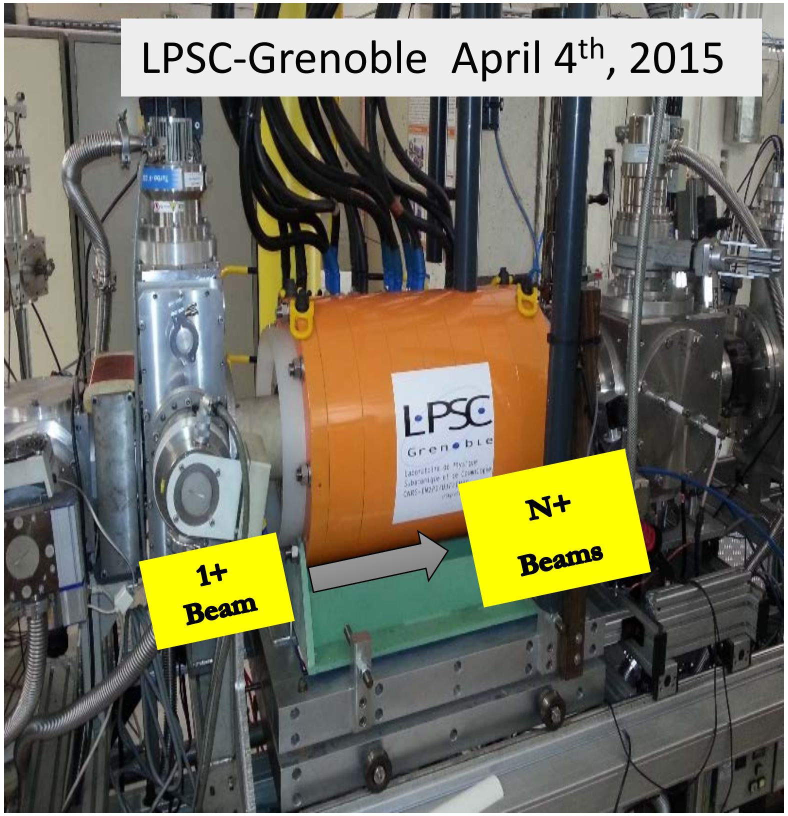
Phase 2: Exotic Beam reacceleration: Charge breeder and MRMS up to RFQ



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

Tender for Power Supply: 0.7M€

Phase 2: Validation of the SPES-Charge Breeder



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

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

A.Galatà

Development at LPSC (Grenoble). Upgraded PHOENIX booster as Part of a MoU in the frame of the European Associated Laboratories (LEA-Colliga)

- 2015 Commissioning at LPSC
- 2015 Delivery to LNL
- 2016-17 Installation and test

M.Manzolaro

Assembly of 1+Source Front-End

SPES production, similar to ISOL source

Phase 3: the SPES-RFQ

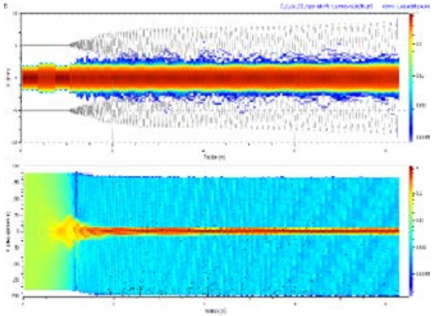
Synergies with IFMIF project

Design completed
Construction started (electrodes 1,3 M€)
Additional study to finalize RF

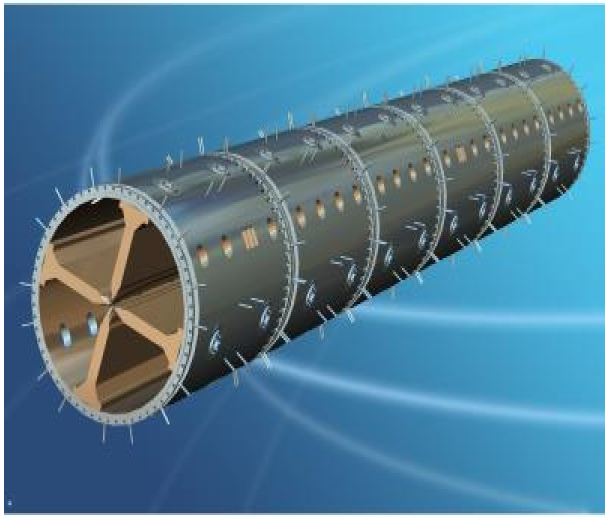
Production sequence & Scheduling
Appoved by TAC

- Schedule : Dec 2015 to Sept 2019
  - Electrodes call for tender : dec 2015
  - Electrode production : sept 2016
  - Completion of 24 electrodes : sept 2018
  - Tank call for tender : march 2016
  - Tanks Completion : dec 2018
  - Assembly and low power testing : june 2019
  - High power tests : sept 2019

High power RF
Coupler 200kW 100%
duty cycle

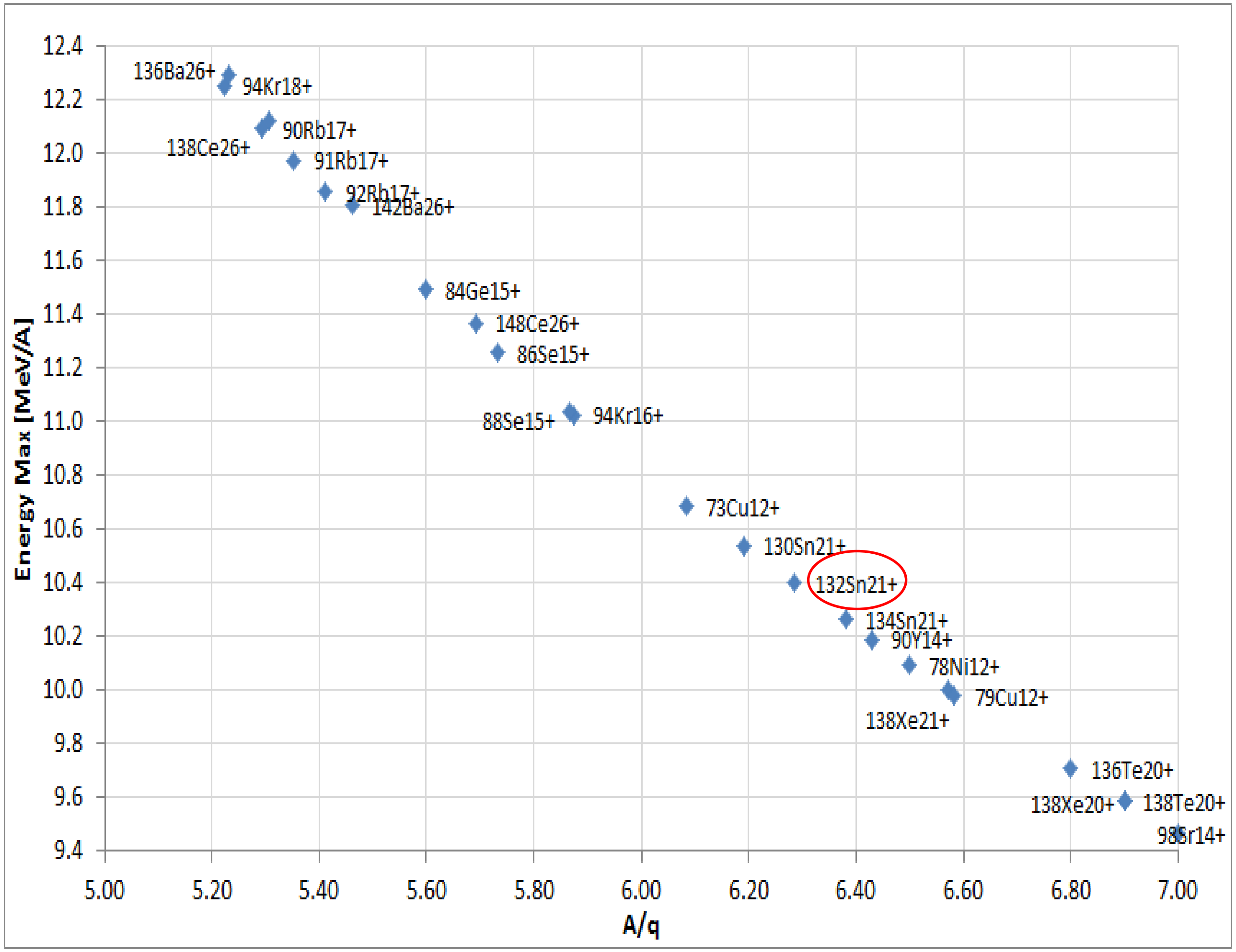


Physics design



A.Palmieri, A.Pisent

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

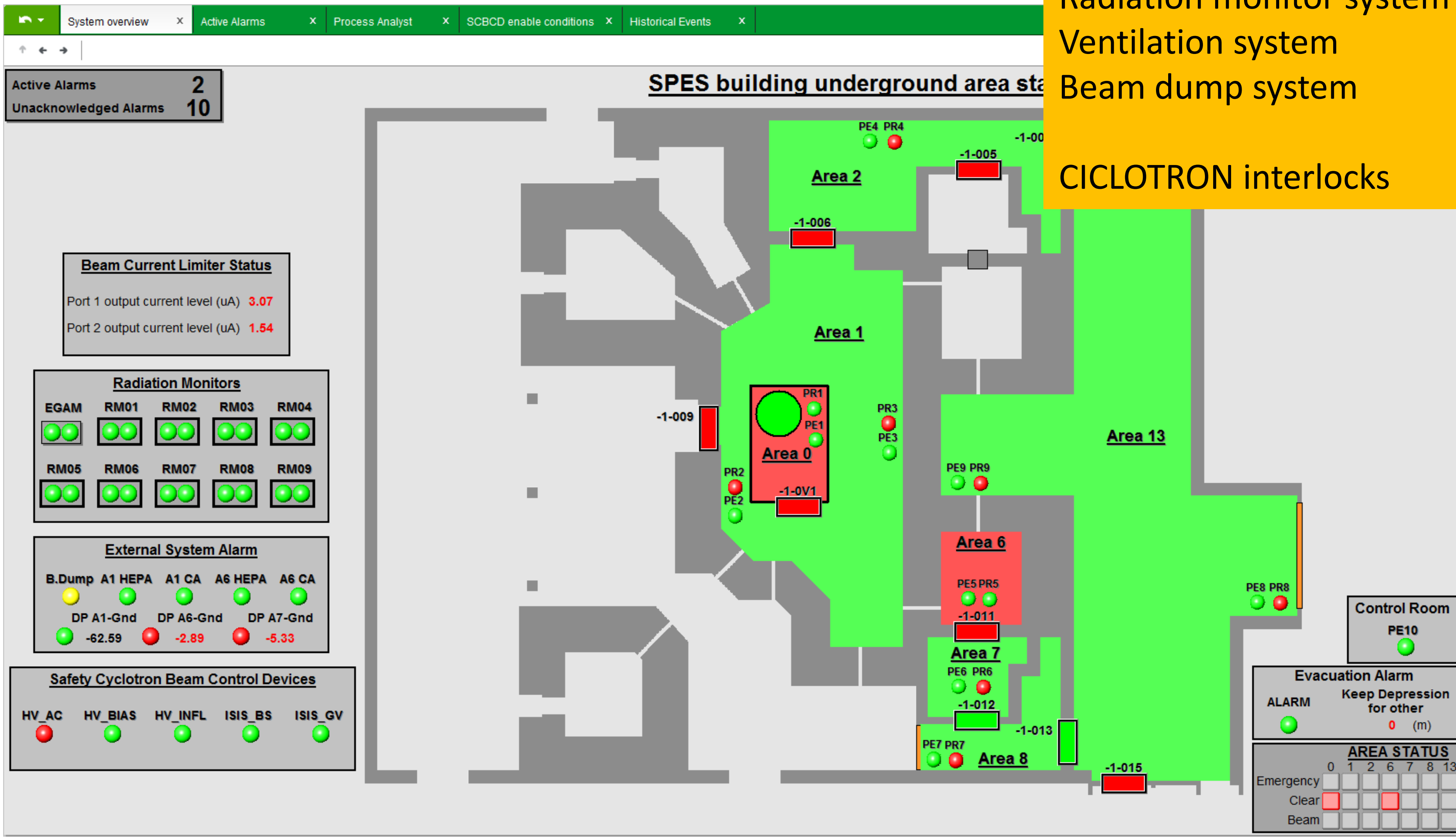


(M. Comunian)

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

SAT Safety System

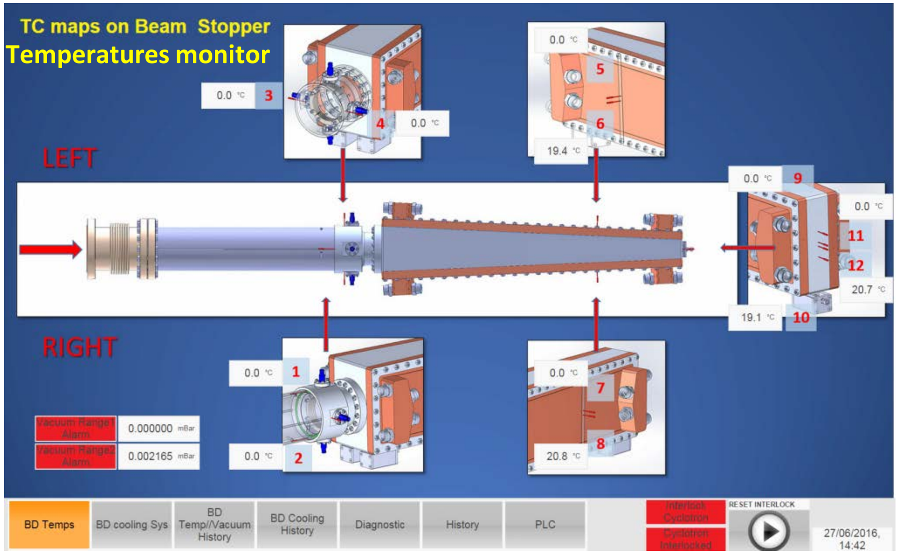
Temporary system for cyclotron SAT

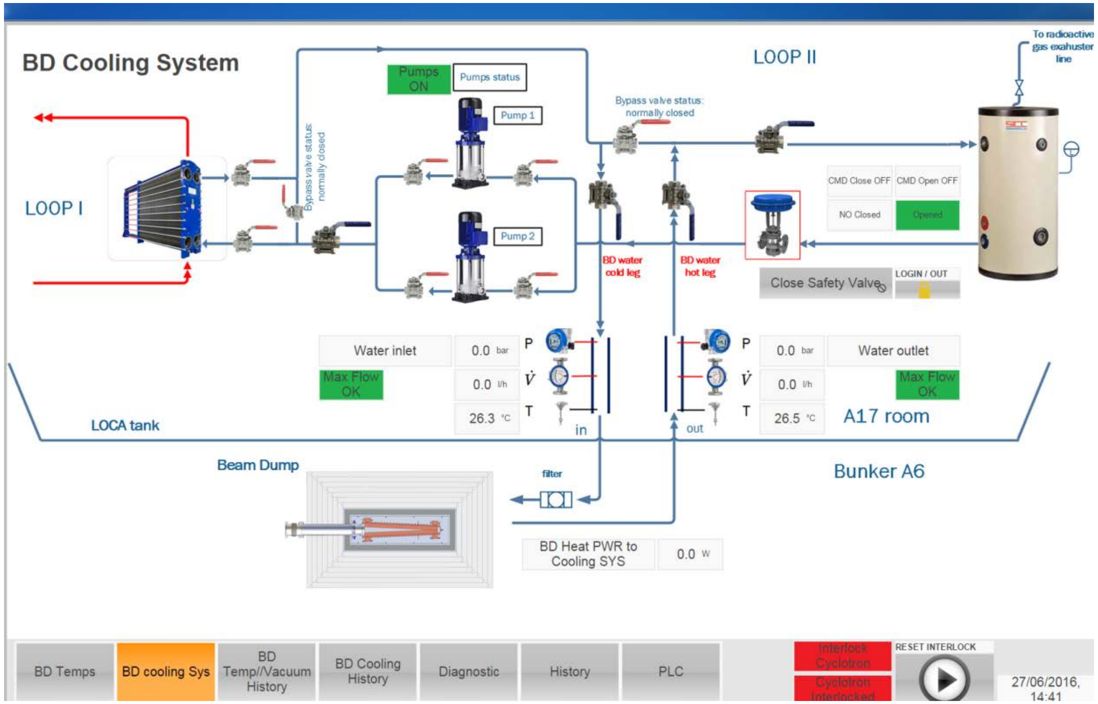


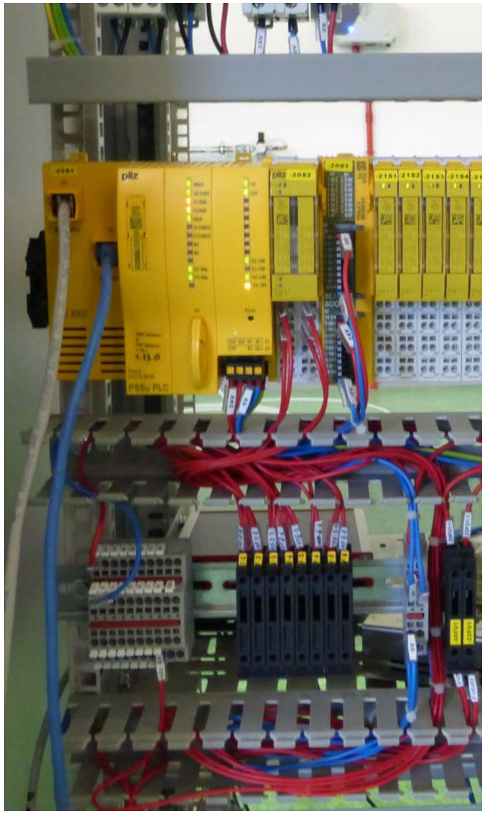
Access control system
Radiation monitor system
Ventilation system
Beam dump system

CICLOTRON interlocks

BEAM DUMP control and SAFETY system







PILZ SIL3 PLC

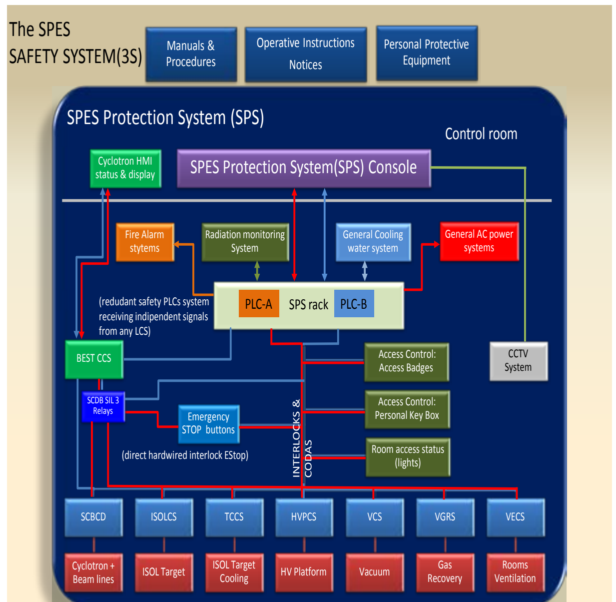
SPES safety system

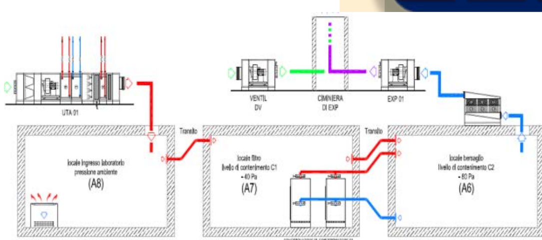
A SIL3 safety system is under development (assigned to PILZ)

A simplified system is in operation for cyclotron test

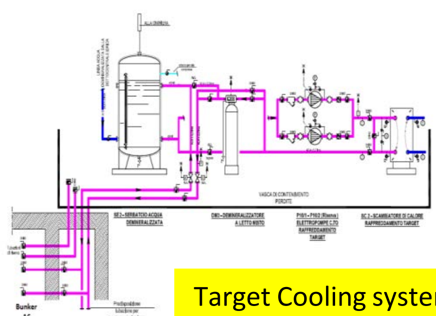
Cyclotron and beam lines

ISOL target

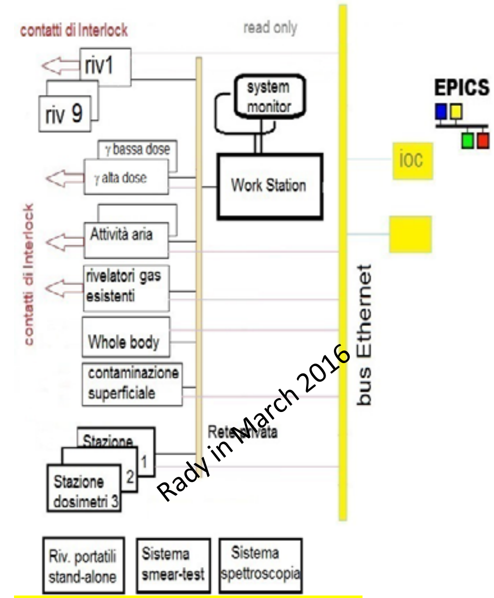




ventilation



Target Cooling system



Rady in March 2016

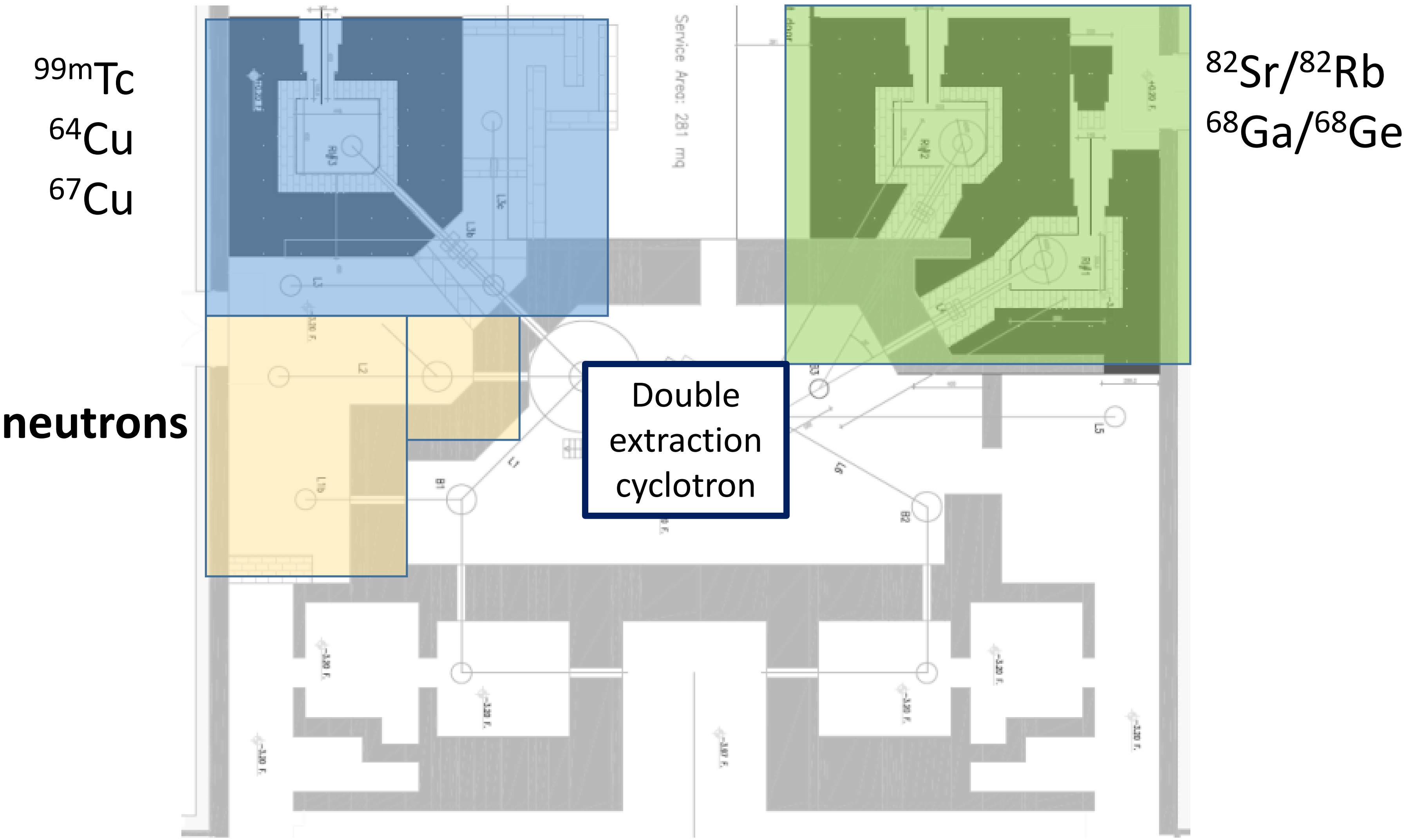
Radiologic survey system

Access Control System

SPES applications

Radioisotope Laboratory

Radioisotope Factory



SPES-γ : cyclotron neutron facility

Union for Compact Accelerator-based Neutron Sources

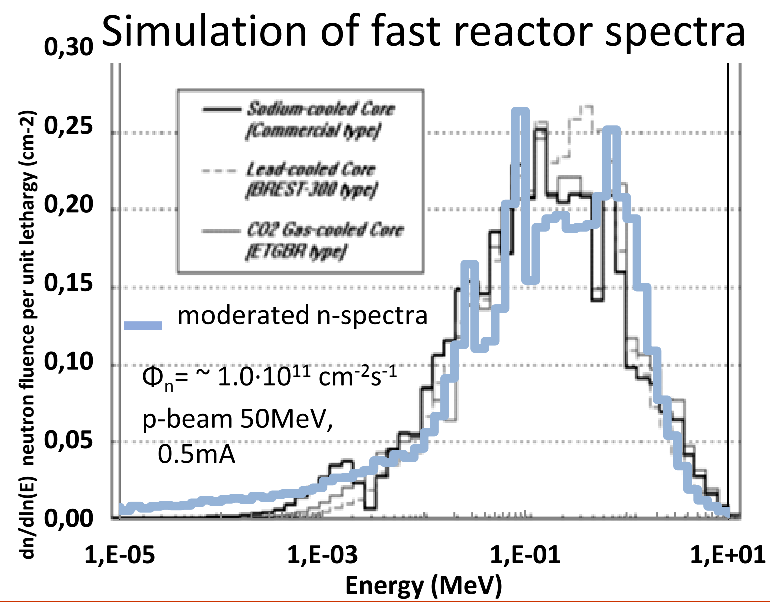
UCANS

Integral neutron production at SPES Cyclotron

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

Energy region (MeV)	Sn (n/s) $\sim 6\cdot10^{14}$ s^{-1}	**Φ_n @ 2.5 m (n cm^{-2} s^{-1})**	**Φ_n @ 1 cm (n cm^{-2} s^{-1})**
1 < E < 10	$\sim 5\cdot10^{14}$ s^{-1}	5×10^{8}	3×10^{13}
10 < E < 50	$\sim 1\cdot10^{14}$ s^{-1}	1×10^{8}	6×10^{12}

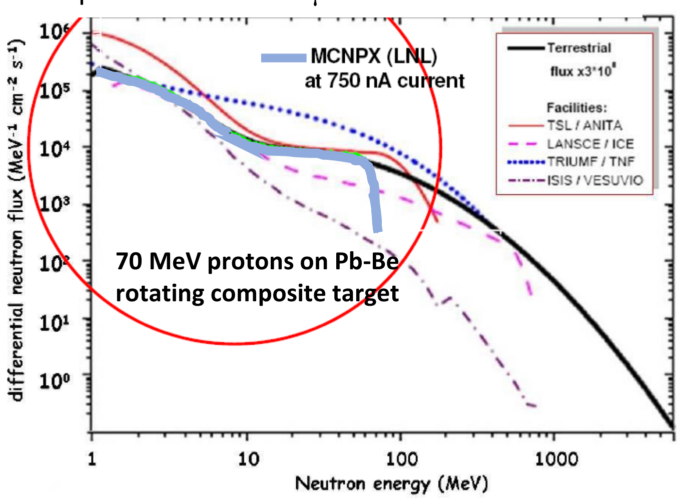
Simulation of fast reactor spectra



Single Event Effect facility

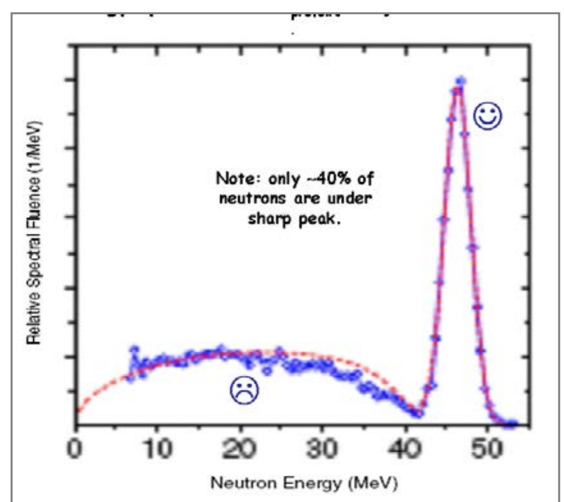
Simulate terrestrial neutron flux (* 3 10^{8})

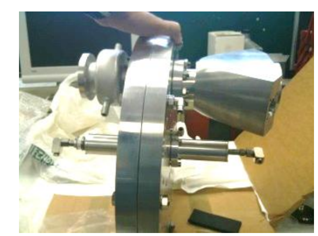
p-beam: 70MeV 3μA



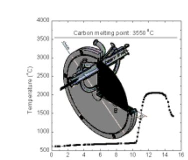
Quasi mono energetic n-spectra

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





Rotating target prototype



Initiatives for accelerator driven neutron sources

INFN Istituto Nazionale di Fisica Nucleare — agenzia spaziale italiana — Centro Fermi, Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi

Progetto Premiale 2016

SPARE: **Space Radiation** Shielding

Settore di afferenza:
AEROSPAZIO

HORIZON 2020 –
Work Programme 2016 - 2017
European Research Infrastructures
H2020-INFRADEV-2016-2017
RIA- Design study

The aim of this activity is to support the conceptual and technical design for new research infrastructures offering neutrons and to path the way to avoid a possible gap in neutron capacity for science and industry in Europe.

UCANS

UCANS-V, May 12-15, 2015 - Laboratori Nazionali di Legnaro, Pd, Italy
UCANS-VI October 25-28, 2016 @ Xian, China

Union for Compact Accelerator-driven Neutron Sources
The Union for Compact Accelerator-driven Neutron Sources (UCANS) was formed in 2009 to support the ongoing development of small accelerator based neutron sources around the world, and to promote the exchange of information on emerging science and novel applications relevant to long-pulsed and/or medium-flux neutron sources.

LARAMED Products & activities

Some radionuclides of interest for nuclear medicine. They can be produced by means of the SPES cyclotron

Radioisotope	Half-life
Fe-52	8.3 h
Cu-64	12.7 h
Cu-67	2.58 d
Sr-82	25.4 d
Ge-68	270.8 d
I-124	4.18 d
Ac-225	10 d

LARAMED is also a gym for science and technology

- APOTEMA (gr V)
- TECNOSP (gr V)
- COME (gr III)
- ISOLPHARM

SPES γ: Radioisotope Production & research

LARAMED

Funded with 6.8 Meuro

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

1. Joint Research lab of INFN, CNR, Universities and external companies:
   - ✓ Cross Section measurements through target activation
   - ✓ High power targets tests
   - ✓ Radio-isotope/radio-pharmaceutical Production test facility . ^{99m}Tc, ^{64}Cu, ^{67}Cu, ^{82}Sr…

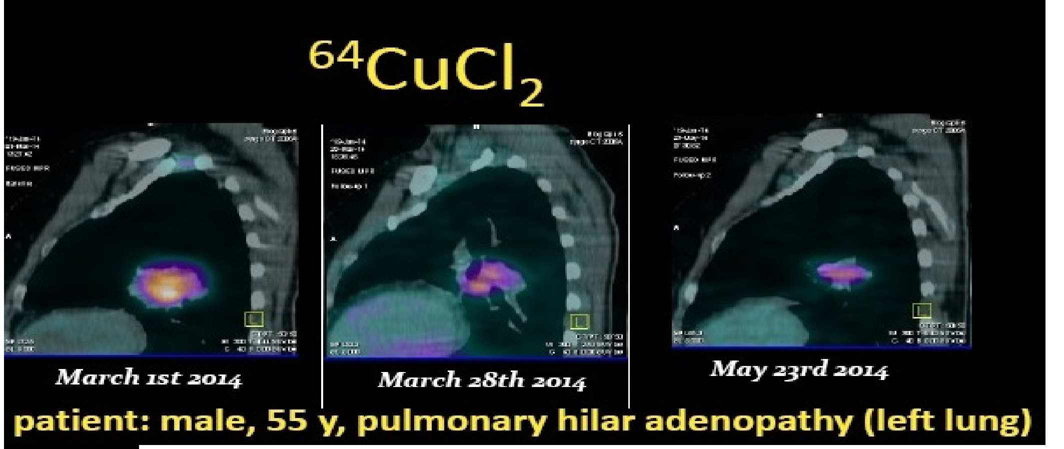
2. Production laboratory in Joint Venture with external companies:
   - ✓ Selected isotopes of medical interest

Sr-82/Rb-82 generator
(T1/2: 25.6 d EC 100% **/ 1.3 min** photons 511keV, 776keV)

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

STATUS:

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

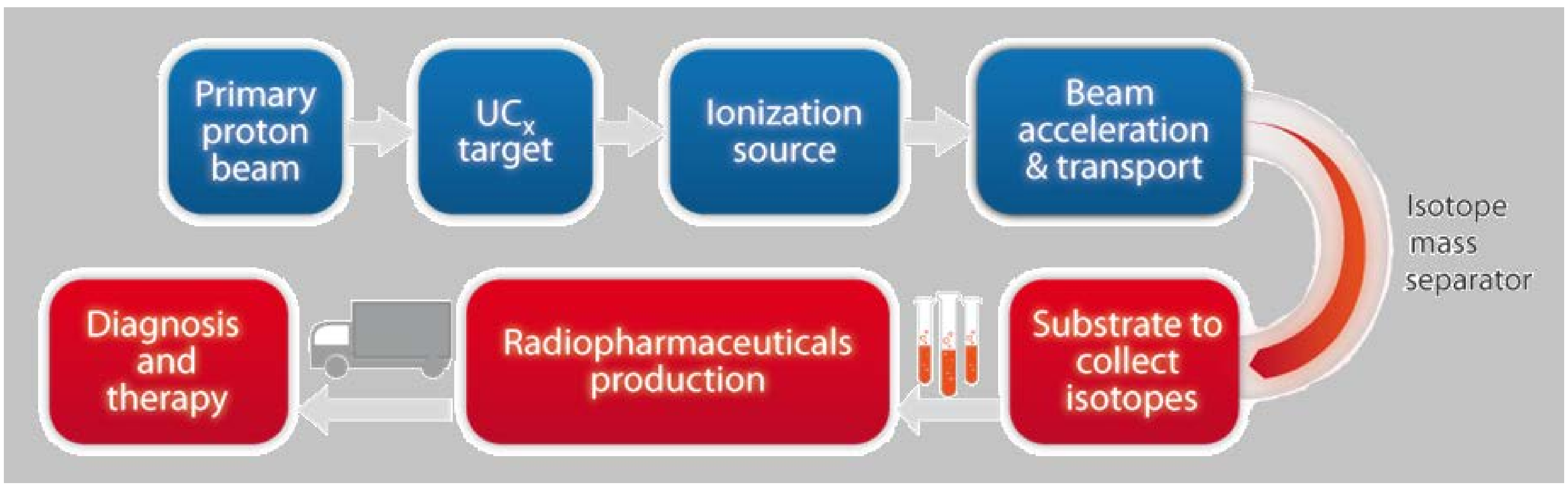


ISOLPHARM

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

ISOL PHARM

High specific activity radio**PHARM**aceuticals production with **ISOL** technique



⟶ **HUGE SPECIFIC ACTIVITY**

ISOL** technique leads to the production of **radioactive ion beams

(Isolpharm is a international INFN patent)

Specific activity: ISOL *vs* others

The **specific activity** is a measure of the **activity per mass** and is usually expressed in units of GBq/mg or Ci/mg.

↓

Essential for the radioisotope conjugation to *in-vivo* carriers for targeted drug delivery

Radiopharmaceutical	Targeted organs	Half-life	Specific Activity (GBq/mg)	
			ISOLPHARM technique production	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	Prostate, 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

Radiopharmaceutical	Targeted organs	Half-life	Specific Activity (GBq/mg)	
			ISOLPHARM technique production	^{235}U fission
^{133}Xe	Lung and liver	5.25 d	**≥ 6920**	≥ 3

After 2 days of irradiation: 4.1E+15 atoms of ^{89}Sr = 18 mCi (patient dose: 4 mCi every 6 months).

SPES CYCLOTRON
load work per year

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.

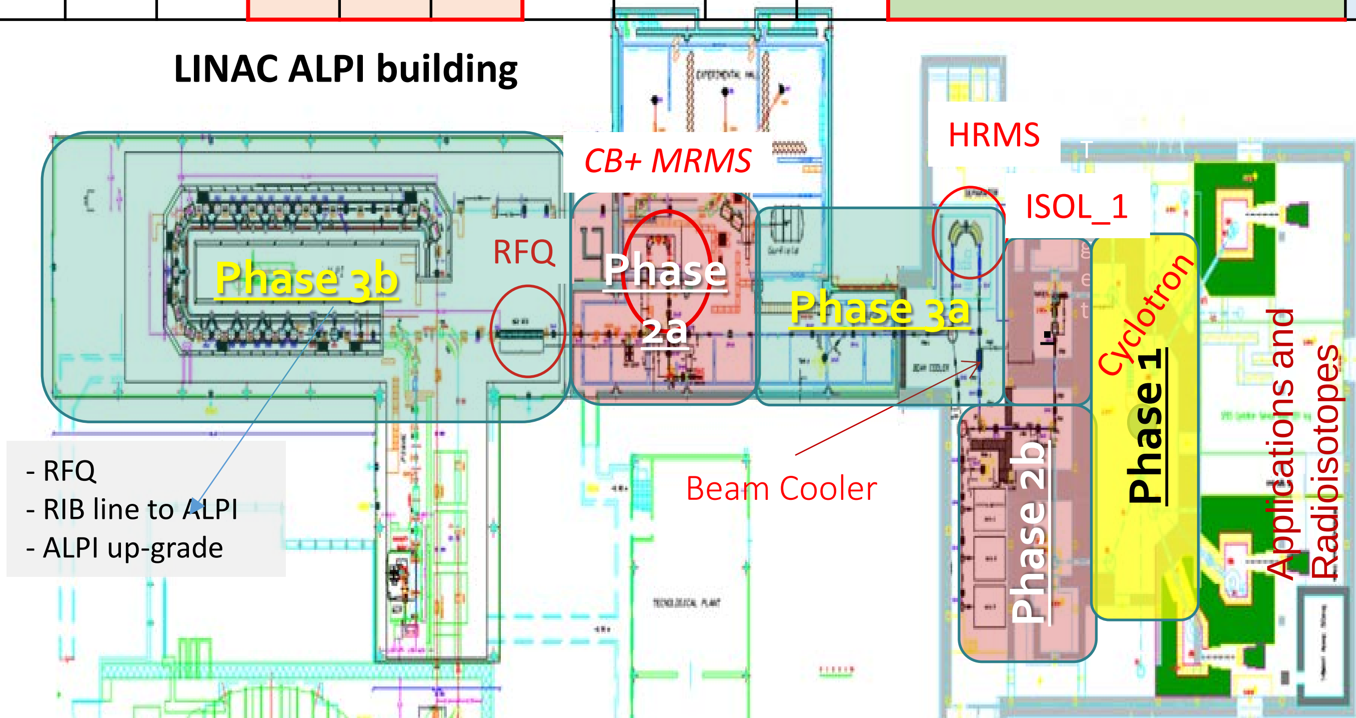
Expected Beam on target:
10600 hours per year

Beam sharing

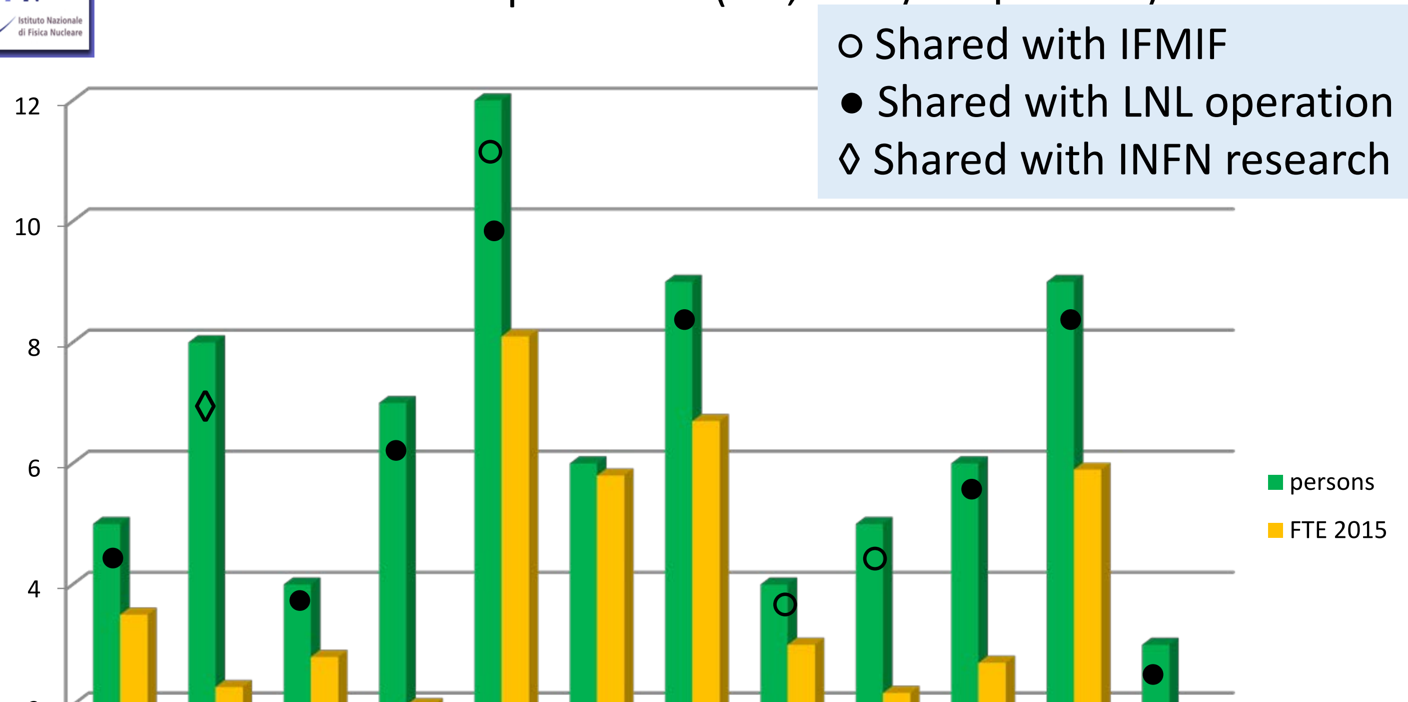
	Proton beam	N.rs of SHIFTS	Beam on target: Total 10600 hours
ISOL 1	300μA 40MeV	10	2800
Irradiation 1	500 μA 70MeV	9	2500
Irradiation 2	500 μA 70MeV	10	2800
ISOL 2	300 μA 40MeV	9	2500
Maintanance		7	7x14x24= 2350
Cyclotron Operation		19	19x12x24= 5462 esperiment 19X2x24= 912 beam preparation

SPES installation timing

2017				2018				2019				2020				2021			
Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	FASE 2A: INSTALLATION					FASE 2A: HW COMM	FASE 2A: BEAM COMM												
								FASE 3A: INSTALLATION					FASE 3A: HW COMM		FASE 3A: BEAM COMM				
			FASE 2B: INSTALLATION					FASE 2B: HW COMM	FASE 2B: BEAM COMM										
										FASE 3B: INSTALLATION					FASE 3B: HW COMM	FASE 3B: BEAM COMM			



SPES personnel (46,2 FTE/ 78 persons)



	persons	FTE
SPES	78	46
STAFF TI	40	15
TD, fellowship	38	31
SPES ≥50%	49	38
STAFF TI ≥50%	17	10
TD, fellow >50%	32	28

Conclusions

- The SPES project is financed by INFN up to the completion
- The Cyclotron is completely installed & under test
- The Site Acceptance Tests are undergoing
- ISOL:
    - The ISOL system will be installed in 2017
    - First radioactive beam in 2019 (no reacceleration)
    - Re-accelerated beams: end 2020 - 2021
- Applications:
    - A program for study and production of radioisotopes for medical use is started
    - A neutron facility for fast neutrons is under design