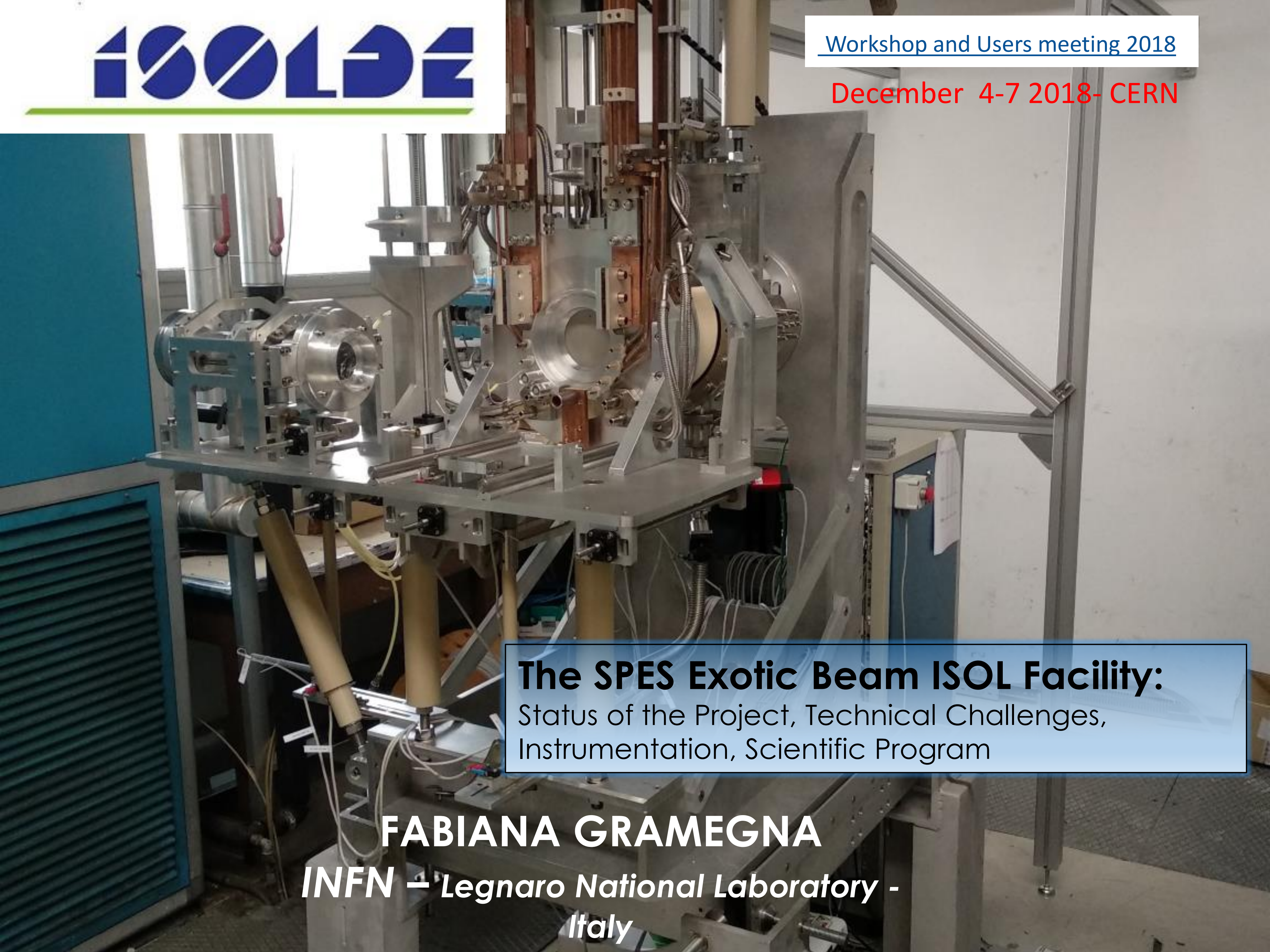


Workshop and Users meeting 2018

December 4-7 2018- CERN

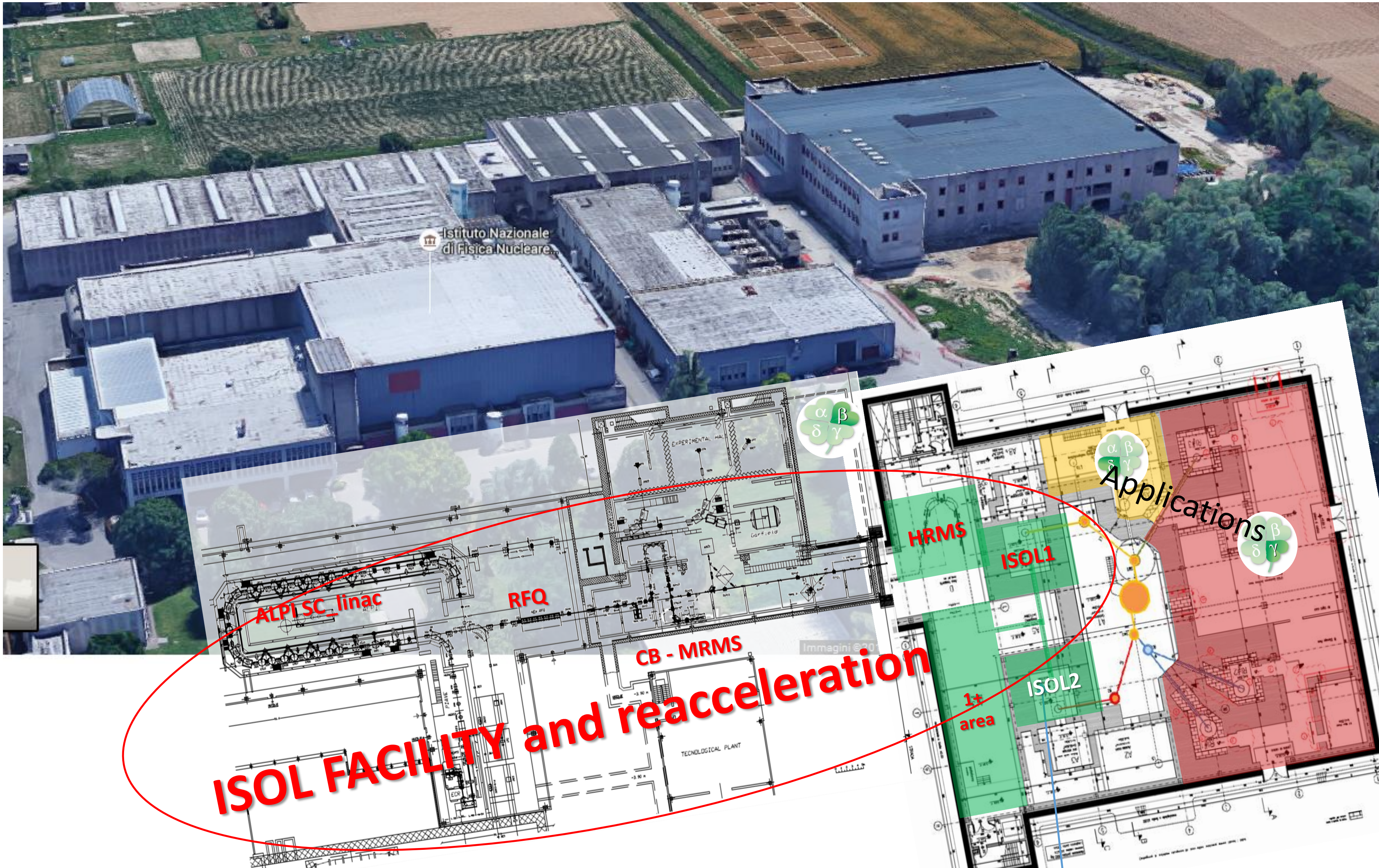
The SPES Exotic Beam ISOL Facility:

Status of the Project, Technical Challenges, Instrumentation, Scientific Program

FABIANA GRAMEGNA

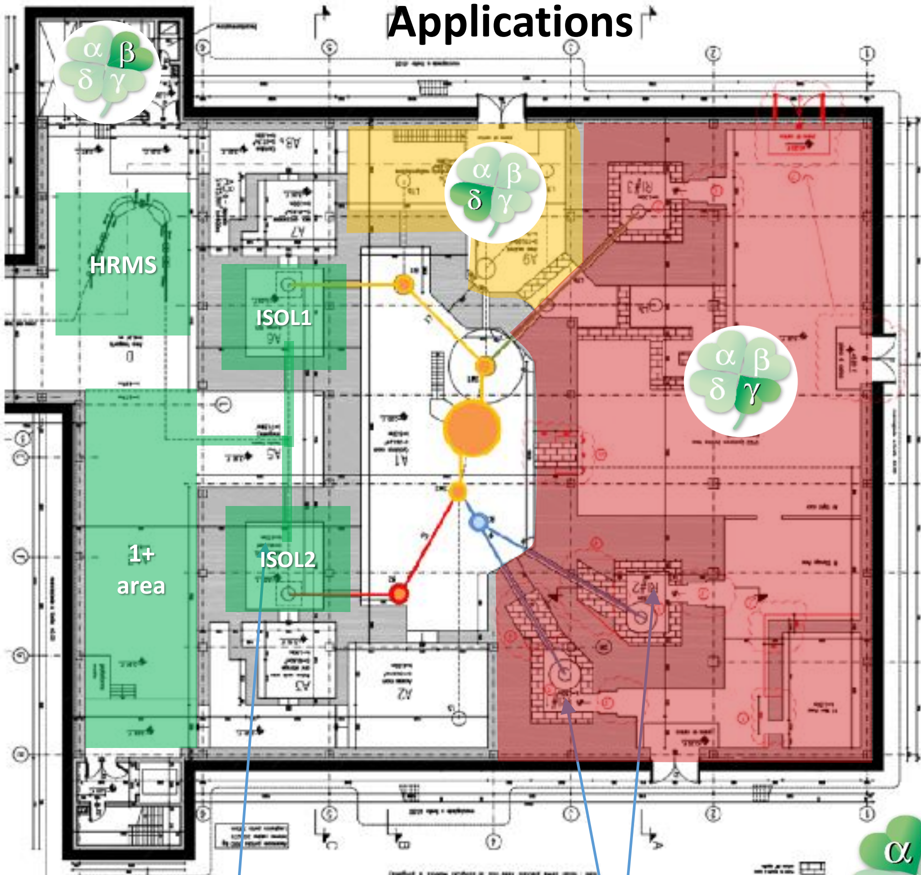
INFN – Legnaro National Laboratory - Italy

SPES infrastructure - layout



SPES project: the phases

Nuclear Applications



ISOL RIBs+ Post-Acc

Nuclear Medicine

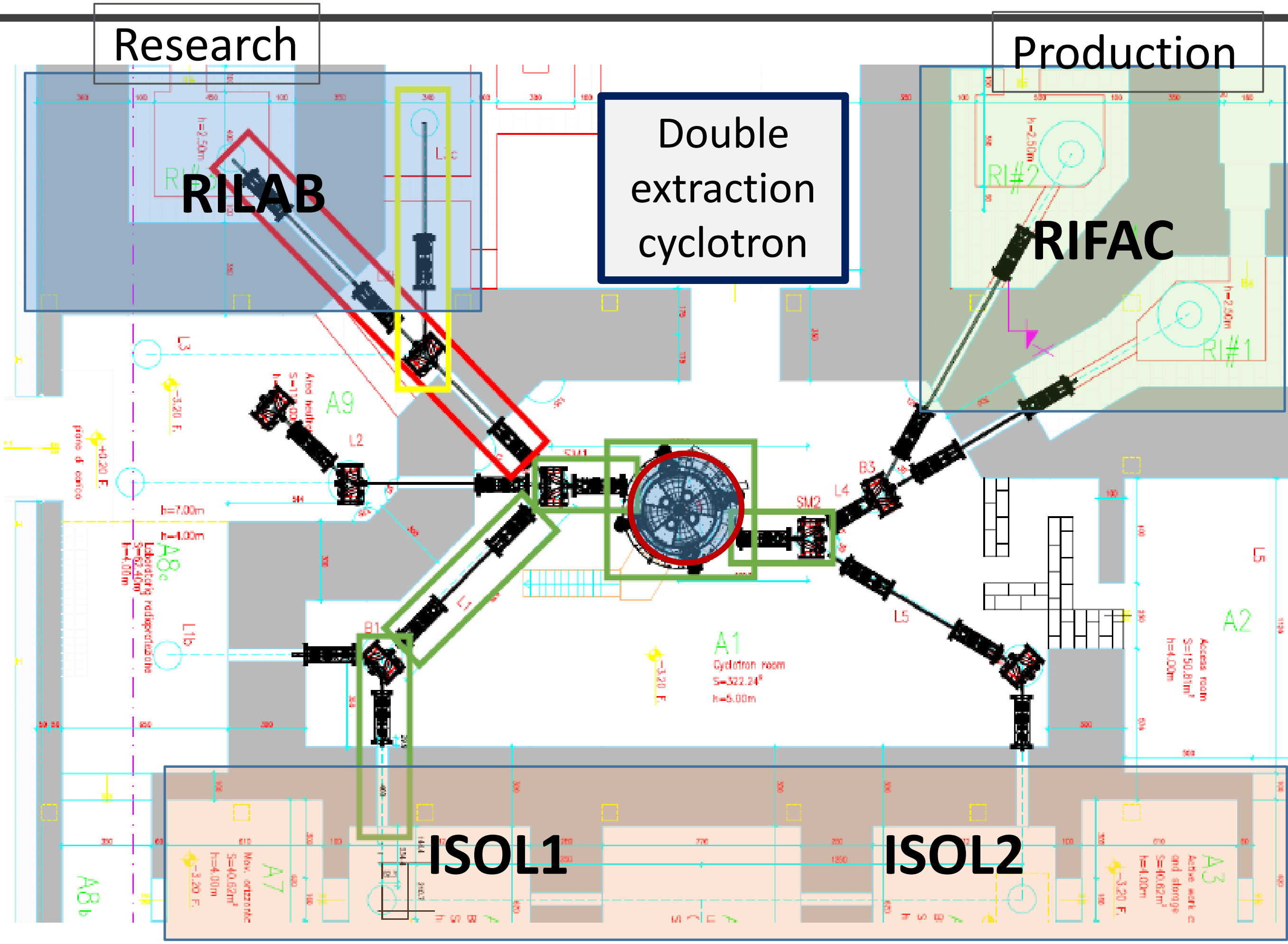
Cyclotron

ISOL RIBs+ Post-Acc.

Nuclear Medicine

Nuclear Applications

SPES-γ Radioisotopes for Nuclear Medicine



- At present installed BL1 → ISOL1
- Partial BL2 → Faraday Cup

LARAMED
- High power beam line BL3b → RILAB–RI#3(up to 500 μA) → all elements at LNL → installation feb/march 2019
- Low power beam line BL3c → RILAB-A9c (up to 100 nA) for cross section measurements → tender beginning 2019

BEST
- BL2 → ISOL2 - ready to be installed within 2019

Production facility operated by INFN and private partner for research and production of radioisotopes
(^{64}Cu, ^{67}Cu, ^{82}Sr, ^{68}Ge, ...)

- 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, ...)

Cyclotron

Nuclear Medicine

SPES-γ Radioisotopes for Nuclear Medicine

LARAMED

Facility under construction

Standard method

- *Compounds* for Radiochemistry Installed
- Plants installed
- Completion of *instrumentation* installation foreseen fall 2019
- Target station for cross section measurement – ready to be installed
- Target Station

Use of the cyclotron proton beam for radioisotope production

Production laboratory in Joint Venture with a private company (signed):

Selected isotopes of medical interest

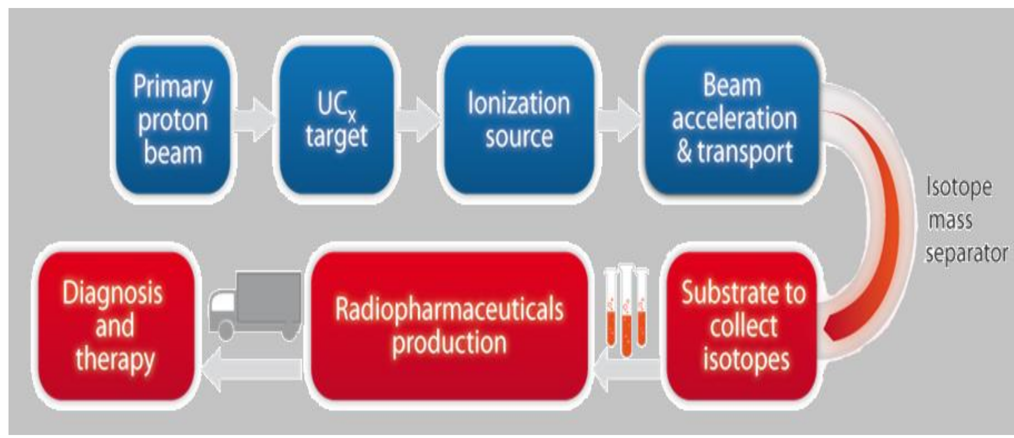
Sr-82/Rb-82 generator

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

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

ISOLPHARM

High specific activity radioPHARMaceuticals production with ISOL technique



HUGE SPECIFIC ACTIVITY

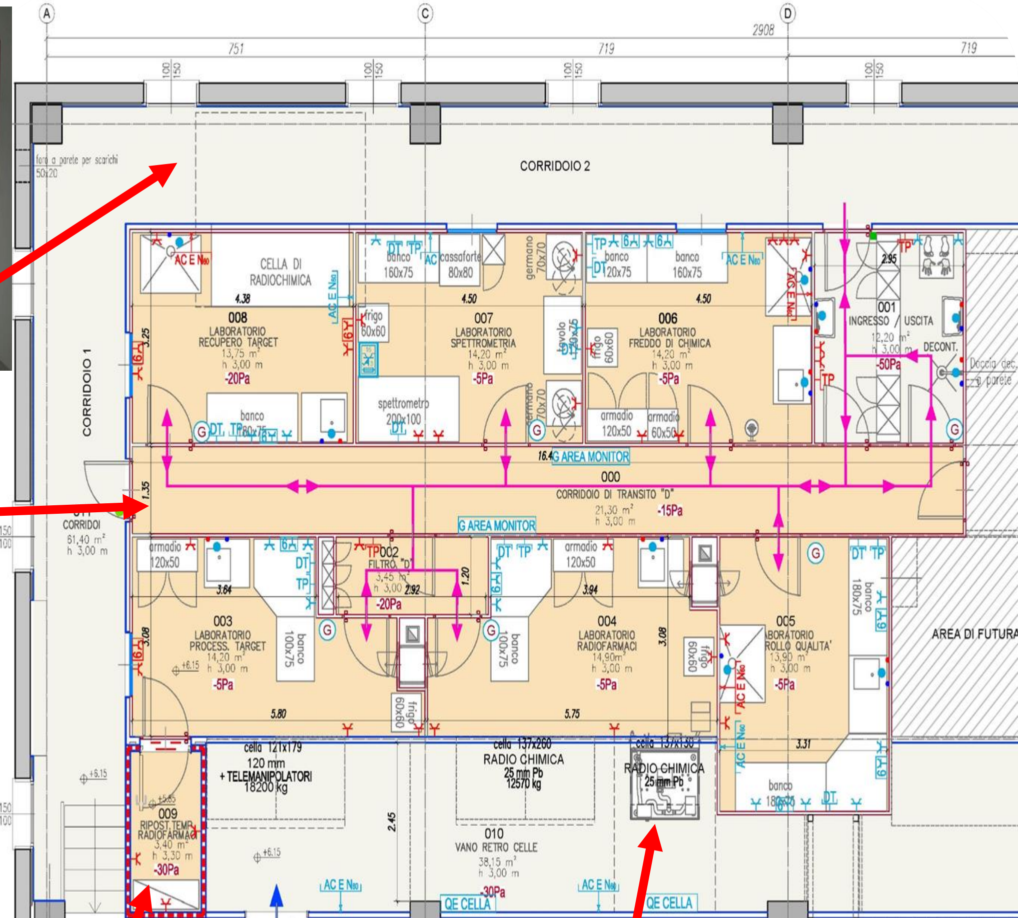
ISOL** technique leads to the production of **radioactive ion beams

(Isolpharm is a international INFN patent)

SPES-γ Radioisotopes for Nuclear Medicine

LARAMED

Target processing & radiochemistry lab
(the so called «Compound»)



SPES-δ: Neutron production at SPES _NEPIR

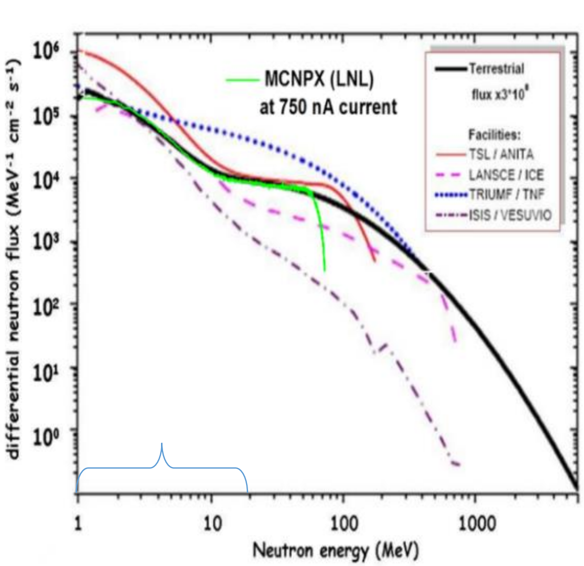
Accelerator based neutron sources have many applications: Nuclear astrophysics, Characterization of nuclear waste, BNCT... The **cyclotron** can also be used as a neutron source

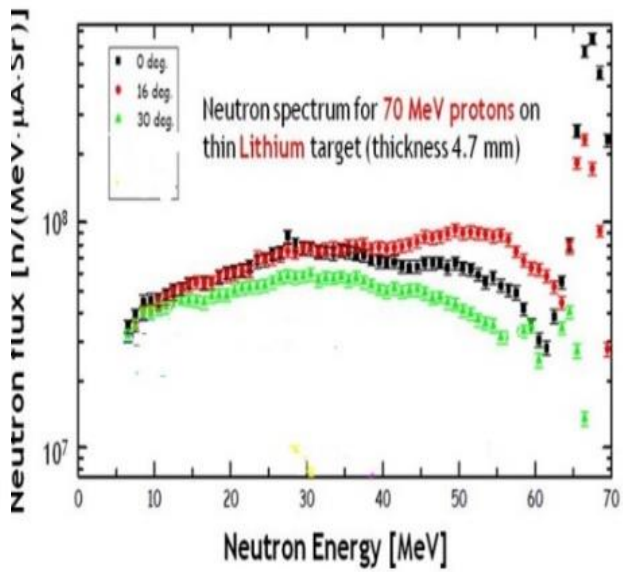
Project at design study level. Partially funded under Ministry of Research and University (collaboration with TIFPA) → SPARE (**Spa**ce **R**adiation Shi**e**lding)

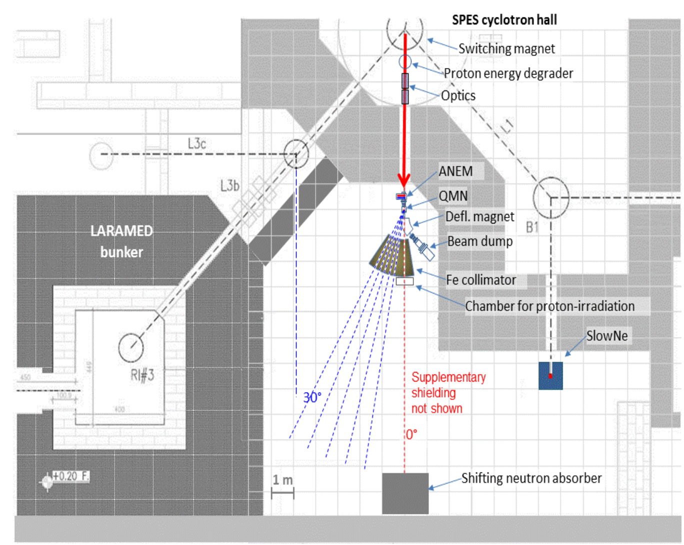
Neutron production by interaction of protons with heavy and light targets

- ❑ Fast neutron production: ~ $6 \cdot 10^{14}\ s^{-1}$
- ❑ Neutron flux Φ_n @ 2.5 m: $5\times10^{8}\ n\ cm^{-2}\ s^{-1}$

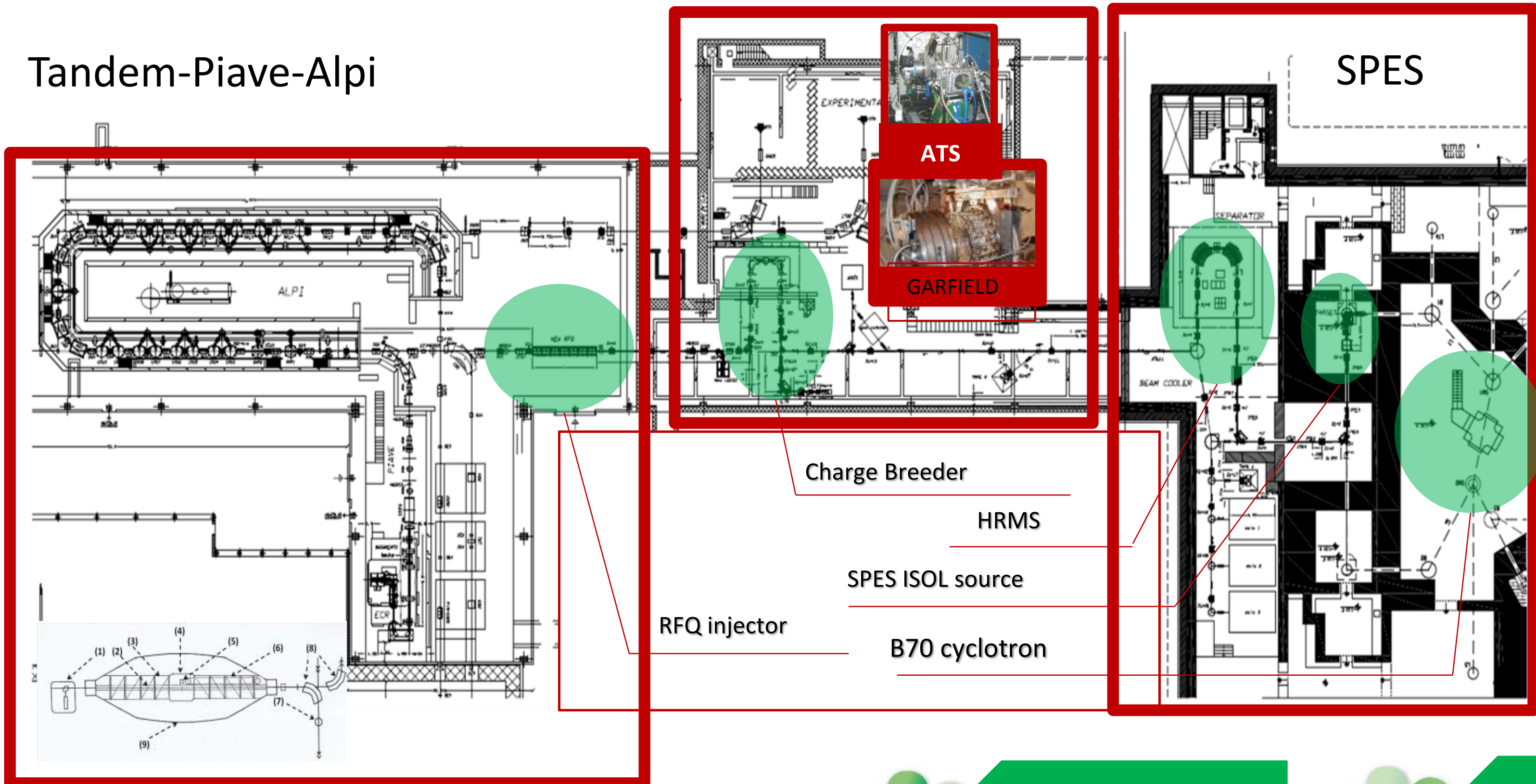
  - ➢ Continuum spectra: SEE: Single Event Effect study
  - ➢ Quasi mono-energetic spectra:







The SPES ISOL RIB project at LNL



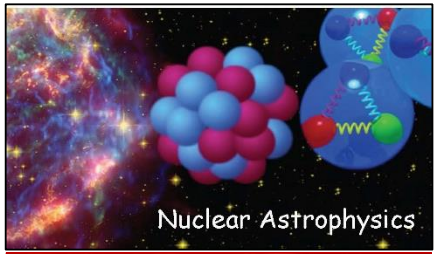
Cyclotron

SOL RIBs+ Post-Acc.

SPES mixing $\psi_{N.P.} = \alpha\,\psi_{SPES\alpha} + \beta\,\psi_{SPES\beta}$

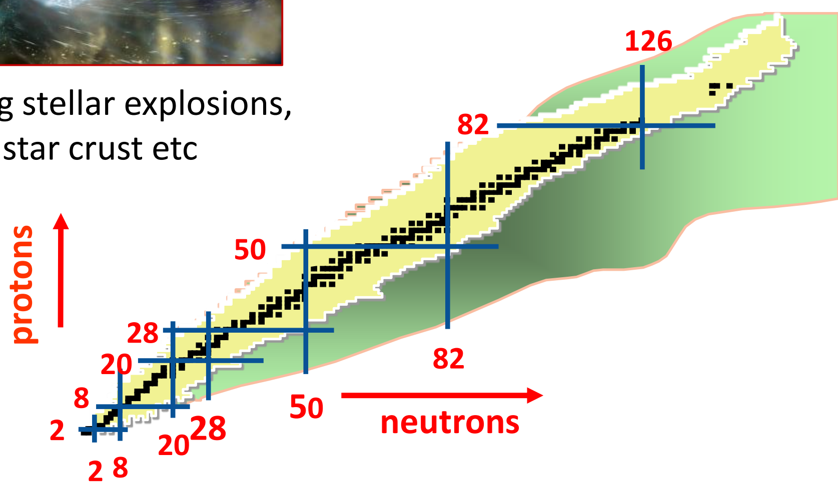
Beyond Isotopes discovery – challenges

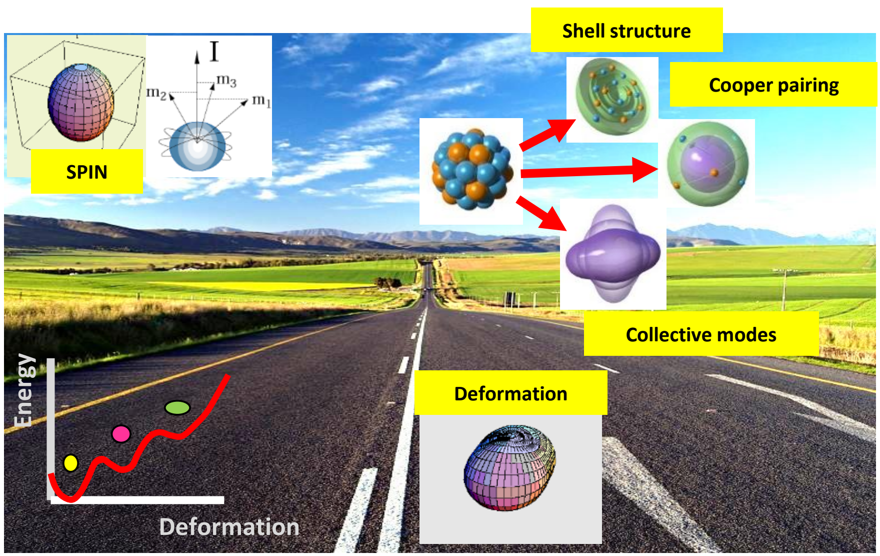
Nuclear Structure & Reaction Dynamics: Long Standing Questions



Powering stellar explosions, neutron star crust etc

- **Which are the limits for existence of nuclei?**
  - Where are the proton and neutron **drip lines** situated?
  - **Where** does the nuclear chart **end**?
- **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** (magic numbers, proton-neutron interaction, shell gap creation and disappearence)?
- **How to explain collective phenomena from individual motion?**
  - What are the **phases** (**NEOS**), relevant degrees of freedom, and symmetries of the nuclear many-body system?
- **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**?



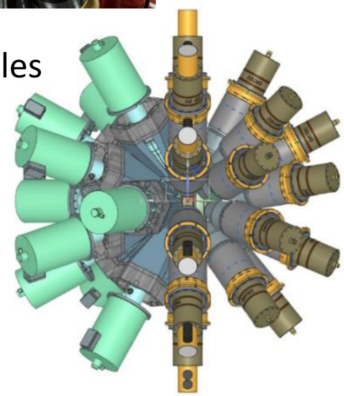


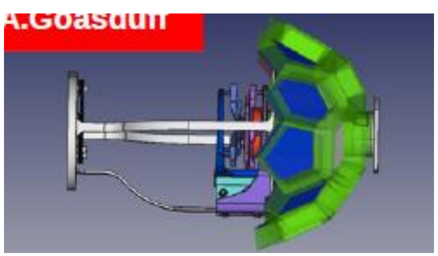
Detector's portfolio: resident setups I

GALILEO

Phase 1:
25 HPGe + 25 BGO + ancillaries
240 ch digital electronics (AGATA)

Phase 2:
30 HPGe + 30 BGO + 10 GTC @ backward angles
Efficiency ~ 7.5%, PT ~ 60%





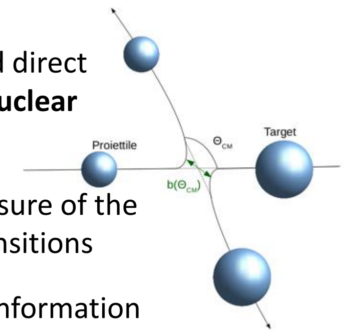
ANCILLARIES

Light charged particle
EUCLIDES, SPIDER; TRACE
Neutron detectors
N-WALL, NEDA
Lifetime measurements)
PLUNGER (from Cologne)
Recoil Detector
RDF (from Kracow)
Fast timing high energy γ-detectors
LaBr3 scintillators

Courtesy of D. Mengoni

Set-up for Coulomb Excitation measurements

COULEX is the most powerful and direct experimental method to study **nuclear collectivity and shapes**:



- **cross-sections** give a direct measure of the **matrix elements** of the e.m. transitions
- **diagonal matrix elements** give information on the **shape**

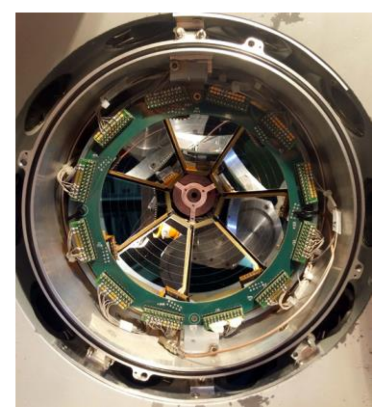
SPIDER: Silicon PIe DEtectoR:

Available @LNL since 2016

- 8 independent sectors, 8 strips + guard ring
- FWHM ~21 keV for α-particles @ ~5.5 MeV
- Modularity: with GALILEO

Cone configuration (7sectors) at backward angles ⟹
$\Delta\Theta = 37.4°$, $\Omega/4\pi = 17.3\%$

Three experiments already performed, one scheduled next year.
7 LoI about Coulex presented for SPES.



Detector's portfolio: resident setups II

PRISMA

Large acceptance magnetic spectrometer

$\Omega \approx 80$ msr;

$B\rho_{max} = 1.2$ Tm

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

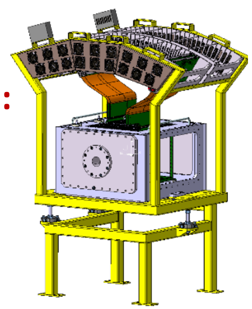
Energy acceptance ~ ±20%

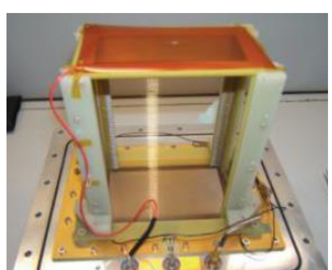
ATS: an ACTIVE TARGET for SPES

Work of P. Gagnant

In synergy with:

1. **ACTAR TPC**
2. **SpecMAT**



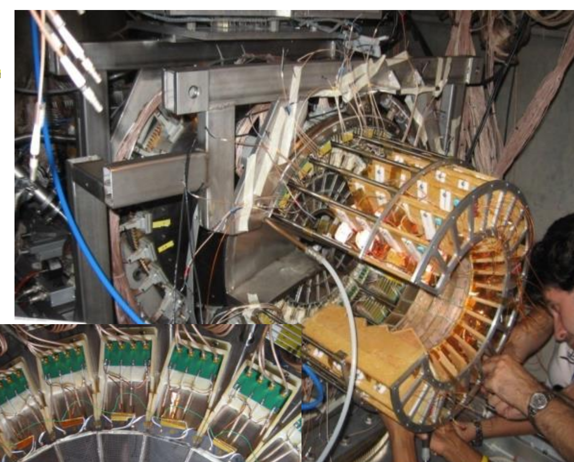


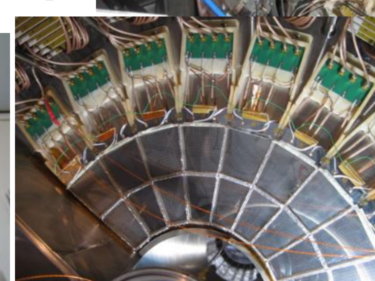
GARFIELD

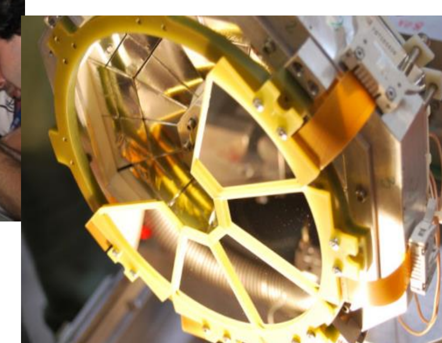
4π array for Light Charged particles and fragments

1) 192 MSGC - CsI(T) telescopes (30°-150°)

2-Rco IC-Si-CsI (5°-18°)

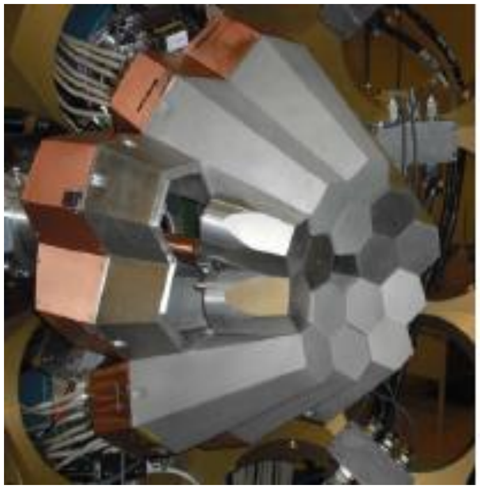


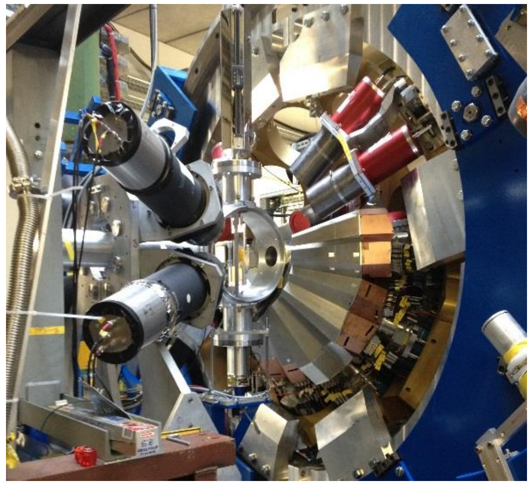




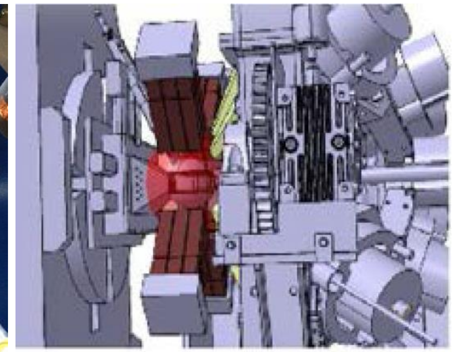
Detector's portfolio: "traveling" setups

AGATA : innovative γ-rays tracking array)

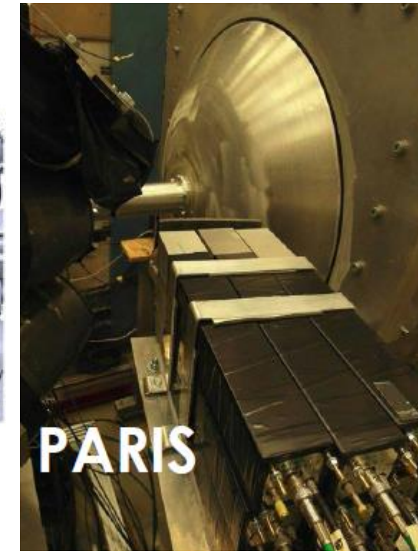




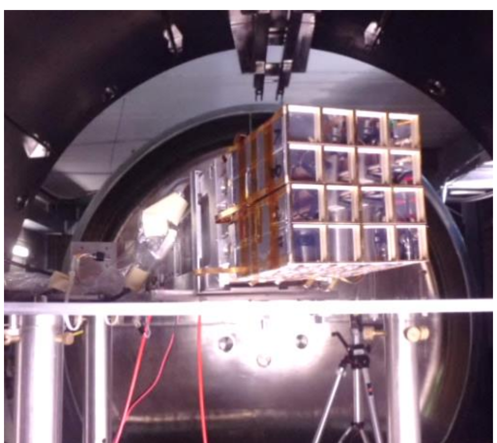
PARIS (High Energy γ-ray Detector Array)

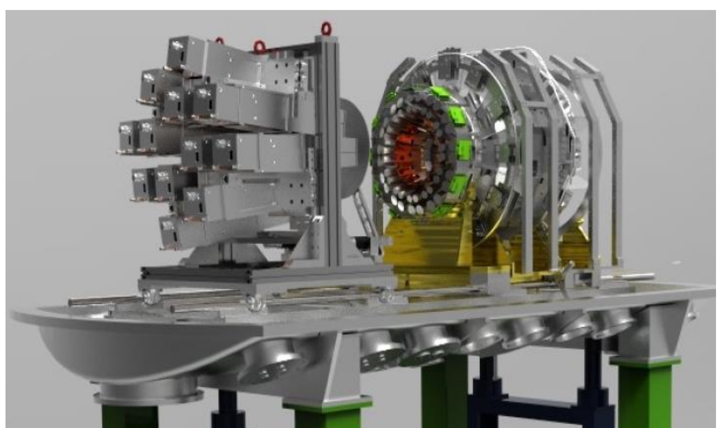


PARIS with AGATA

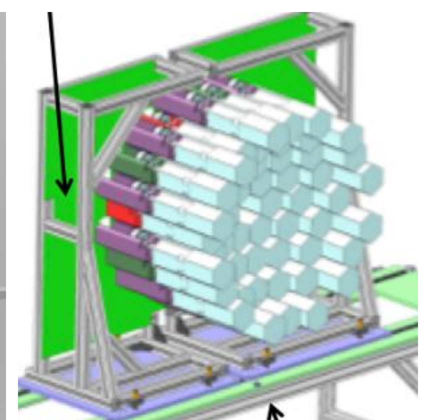


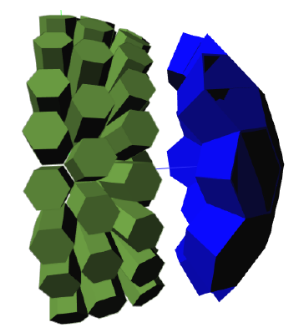
FAZIA: LCP & fragments detection





NEDA (NEutron Detector Array)





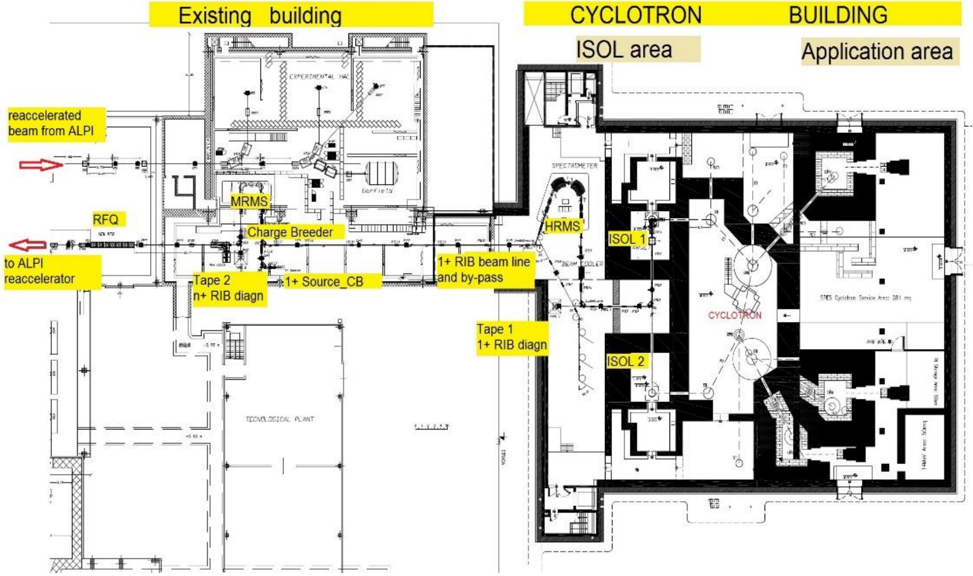
1^+ lines: physics with non post-accelerated beams

Join the LNL USER Committee: http://www.lnl.infn.it/index.php/it/usergrouphome

Technical Advisory Committee of SPES strongly recommended the idea of having installations for **physics with non reaccelerated beams**

A number of LOIs already presented to **2nd SPES International Workshop**

- Could exploit and help characterize first day beams
- Help characterization of beam contaminants
  ➔ useful for post-acceleration
- Gives access to complementary info to in-beam and reaction studies



ACTIONS:

- formation of a Working Group (convener M. Cinausero) to define location and technical needs
- **SPES 1-day workshop** held in Milano (20-21 April 2015): large number of participants

OUTCOME:

- **3 possible experimental areas** are planned, 25 m^2 for each measuring point
- Definition of **beam line elements and beam monitoring**
- Definition of the location of **users control rooms**

3 possible installations:

1- beta-decay Tape Station ★

2- Installation for Laser Spectroscopy

3- multi-purpose for external user equipment

Courtesy of G. Benzoni & M. Cinausero

Detector's portfolio: "low energy" setups

LNL β-decay Tape Station → synergy with RIB characterization

Courtesy of G. Benzoni & T. Marchi

GEANT4 simulations:

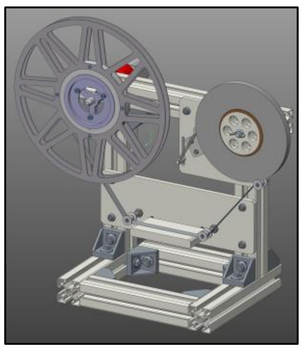
spectrum coming from 10^7 events of the decay $^{33}Si \rightarrow ^{33}P$

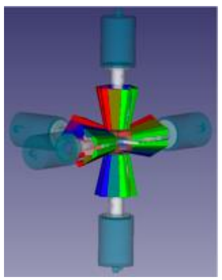
β efficiency ~ 50%

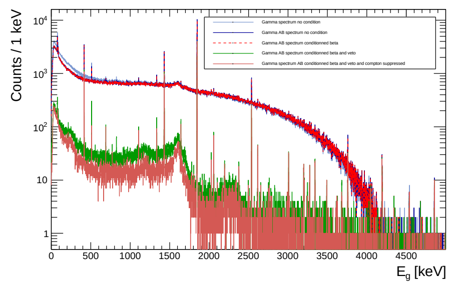
γ efficiency at 1 MeV ~ 9.9%.

P/T reaches 50% (single gamma of 1 MeV)

Veto detector in front of HPGe to reduce bg from e- interacting in crystal

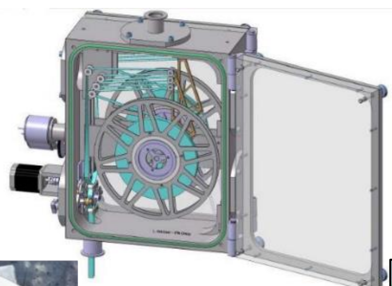


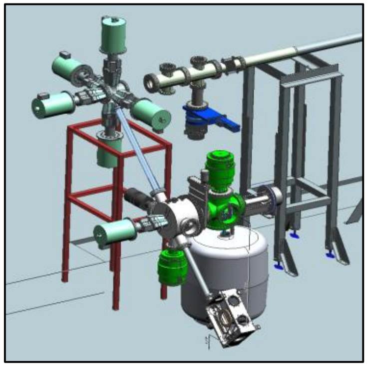


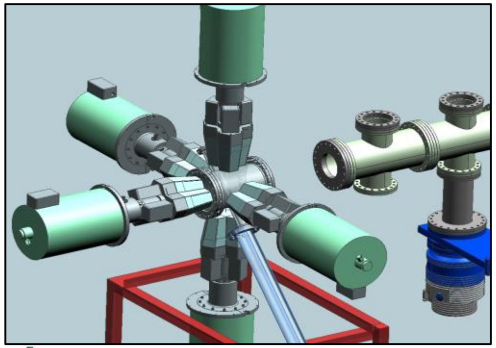


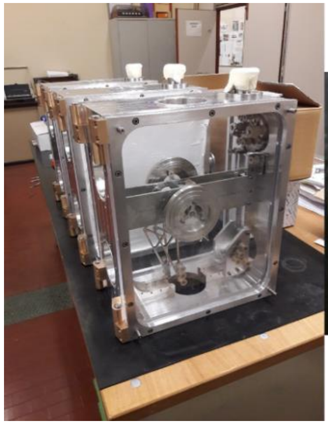
Experimental requirements for a β-TS at an ISOL facility:

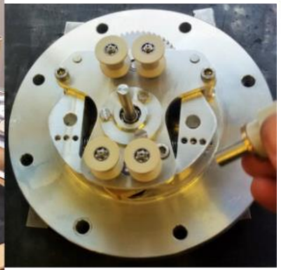
- Very low energy incoming beam (40-60 keV) → no signal coming from implanted nucleus → PASSIVE IMPLANTATION ON MYLAR FOYL
- Possible contaminations (egs isobaric contaminations and/or long-living species produced in the decay chain)→ Need for a fresh implantation point for each single Measurement → MOVING SYSTEM

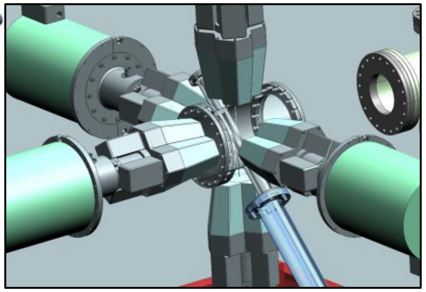


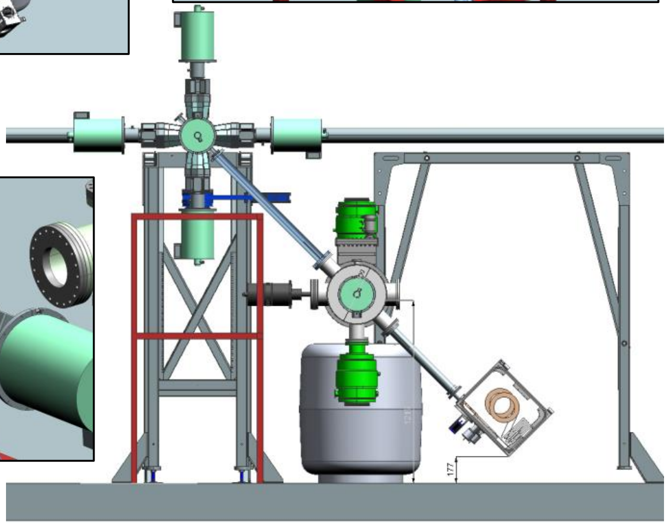










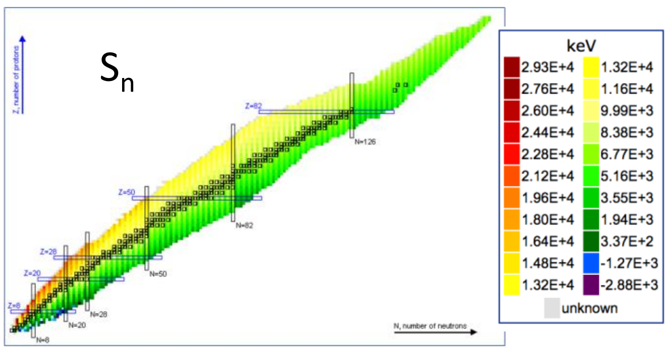


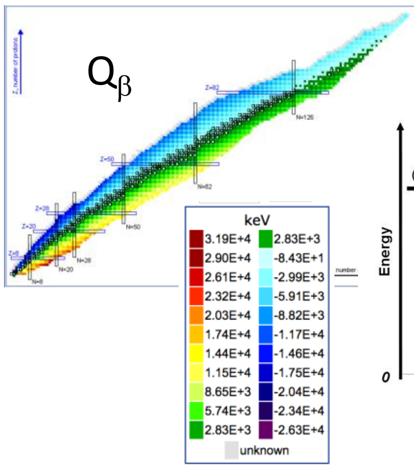
The SPES physics program

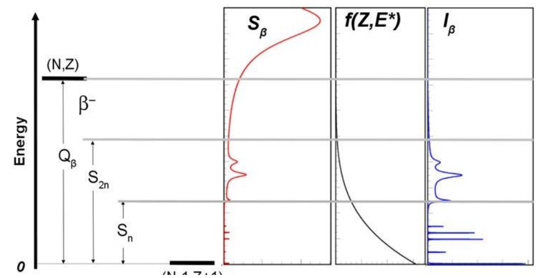
Exotic nuclei: β-decay key features

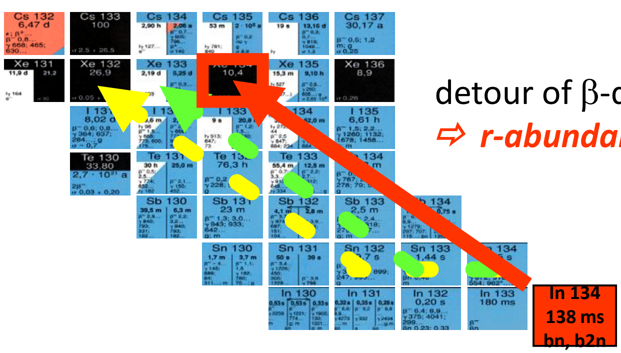
Courtesy of G. Benzoni

- Region in chart of nuclides difficult to access
- Increasing Q_β values (up to 15 MeV)
- Lowering of S_n
- Large range of half-lives ~ 10ms -100 s
- Possible competing modes
  (α decay, cluster decay, delayed fission)



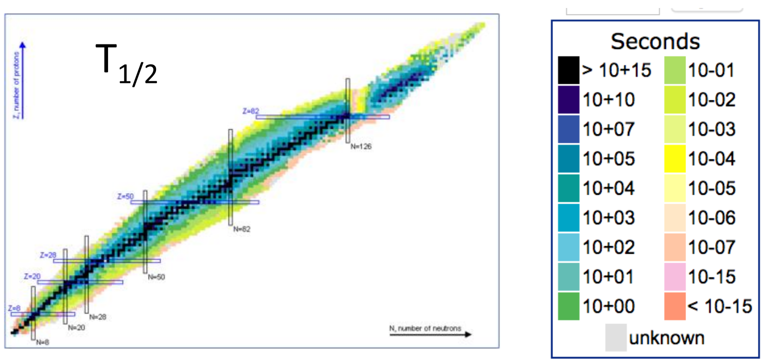






detour of β-decay chains

⇨ ***r-abundance changes***

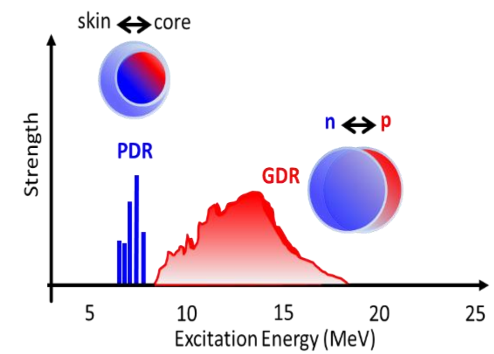


The SPES physics program

1^+ beam program @SPES

PDR populated through β-decay studies in very neutron rich nuclei

- The large Q_β-value window (>12 MeV) allows population at least the PDR.
- The β decay could populate states which are the PDR on the IAS(R) of the mother nucleus



Proof of principle in a recently published paper

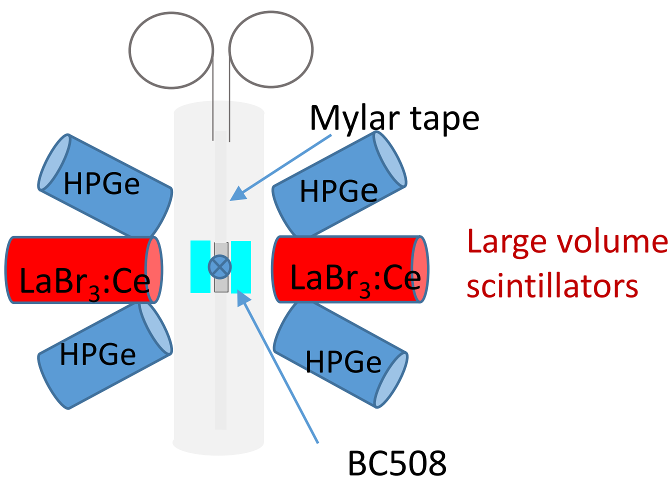
PRL **116,** 132501 (2016) PHYSICAL REVIEW LETTERS week ending 1 APRIL 2016

Investigating the Pygmy Dipole Resonance Using β Decay

M. Scheck,[1,2,*] S. Mishev,[3,4] V. Yu. Ponomarev,[5] R. Chapman,[1,2] L. P. Gaffney,[1,2] E. T. Gregor,[1,2] N. Pietralla,[5] P. Spagnoletti,[1,2] D. Savran,[6] and G. S. Simpson[1,2]

Mother	J^π	Daughter	S_n[keV]	Q_β [keV]	I [pps] @5μA	I [pps] @200μA
^{84}Ga	(0^-)	^{84}Ge	5243	12900	1.01×10^3	4.02×10^4
^{86}Br	(1^-)	^{86}Kr	9857	7626	1.93×10^7	7.73×10^8
^{96}Y	0^-	^{96}Zr	7856	7096	1.12×10^7	4.47×10^8
^{98}Y	(0^-)	^{98}Zr	6415	8824	5.30×10^5	2.12×10^7
^{130}In	$1^{(-)}$	^{136}Sn	7596	10249	1.93×10^4	7.72×10^5
^{136}I	(1^-)	^{136}Xe	8084	6930	2.6×10^8	1.04×10^{10}
^{140}Cs	1^-	^{140}Ba	6428	6220	8.53×10^8	3.4×10^{10}
^{142}Cs	0^-	^{142}Ba	6181	7325	3.35×10^7	1.34×10^9
^{144}Cs	$1^{(-)}$	^{144}Ba	5901	8500	4.35×10^6	1.74×10^8
^{146}Cs	1^-	^{146}Ba	5495	9370	1.12×10^5	4.46×10^6

A. Gottardo et al. – PLB 772 (2017) 779



Example: ^{134}In → ^{134}Sn (Q_β= 14.7 MeV)

$\nu f_{7/2} \rightarrow \pi g_{9/2}$

β decay: $\nu 2f_{7/2} \rightarrow \pi 2f_{7/2}, \pi 2f_{5/2}$;

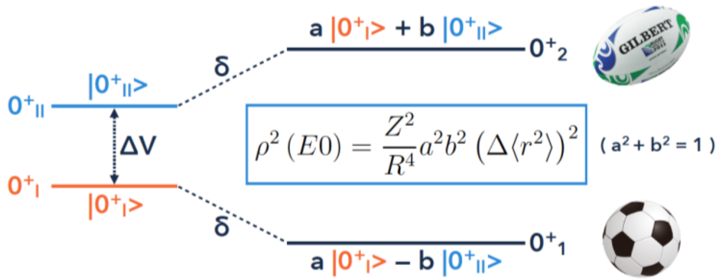
Courtesy of G. Benzoni & D. Mengoni

The SPES physics program

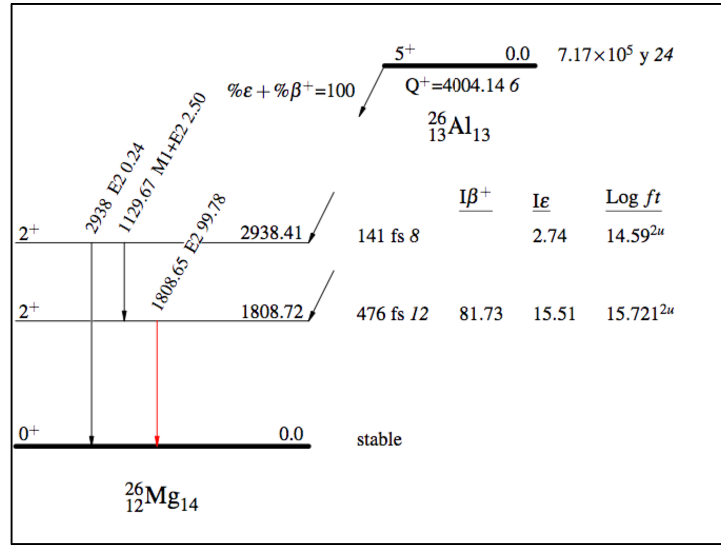
A New Spectrometer for Internal Conversion Electrons @ SPES 1+
(INFN Firenze, INFN Camerino, INFN Milano, LNL)

Electric Monopole Transitions (E0)

- Used for instance to study breathing modes (nuclear compressibility), α-clustering and shape coexistence
- Shape coexistence & E0 transitions, a simplified picture:



Measurement of $\rho^2(E0)$ ($\rho^2(E0) \sim |\langle 0^+_1 || E0 || 0^+_2 \rangle|^2$) ⟹
Shape of excited states and mixing between them



Continuous β-decay background:
it can be acquired as unwanted coincidences with γ - rays or conversion electrons in the β-detector

- **γ-Compton background:**

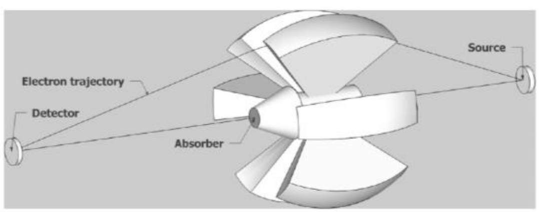
γ-rays can be directly detected in the Si(Li) (only Compton scattering) and indirectly if they are scattered in the materials in the chamber

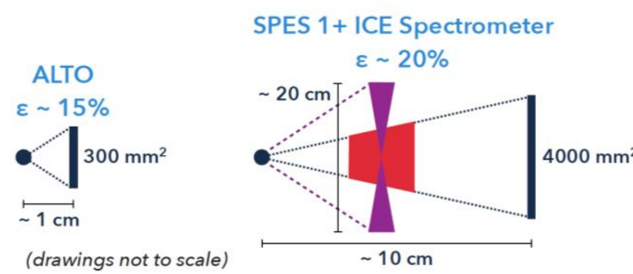
- **e⁻ - backscattering**:

enhanced at high entrance angles (thus higher with a detector just in front of the activity)

Magnetic Transport System

- Central absorber to shield from γ-rays
- Magnetic lenses, composed by permanent magnets, to re-focalize the electrons





Courtesy of G. Benzoni & A. Nannini

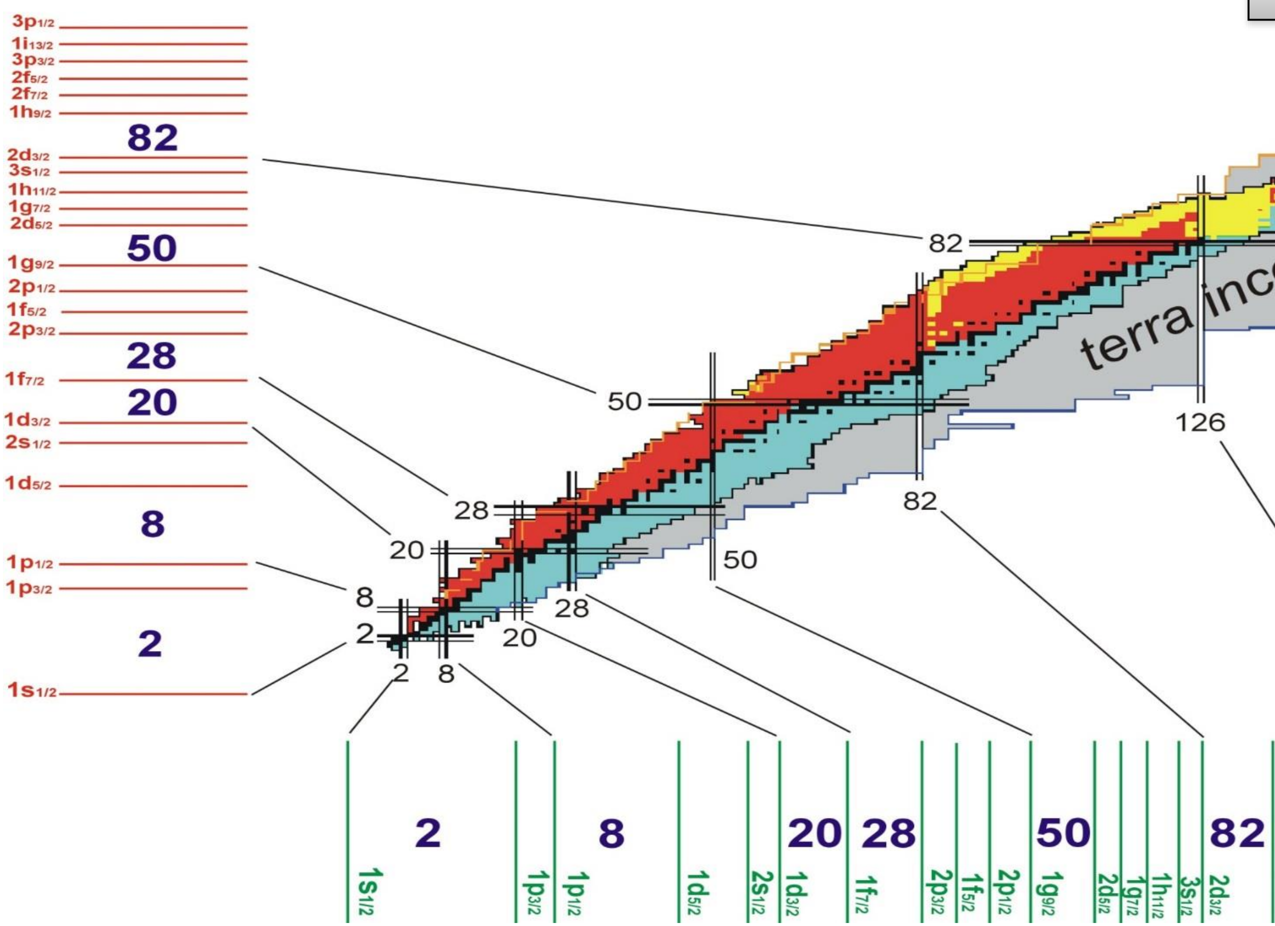
The SPES physics program

“On closed shells in nuclei”

Courtesy of J.J. Valiente

Mayer et al., PR75, 1969 (1949) & Jensen et al., PR75 1766 (1949)

NOBEL 1963



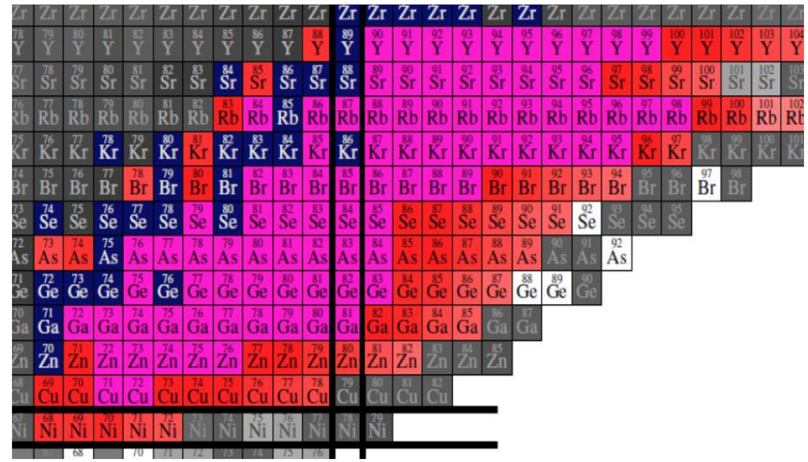
J. Hans D. Jensen
(1907 – 1973)
***PR*75, 1766 (1949)**

Maria Goeppert Mayer
1906 - 1972
***PR*75, 1969 (1949)**

The SPES physics program

"On closed shells in nuclei"

- Study of the **low-lying properties of isotopes near by ^{78}Ni** and **beyond N=50** with the SPES beams.
- **Shell evolution** in the region – NN and NNN interactions, rigidity of the gaps when **going towards ^{78}Ni**
- **Changes due to 3N forces** are amplified in neutron-rich nuclei and will play a crucial role for matter at the extremes.
- Experimentally: Use of **Coulomb excitation, (d,p) and (t,α) reactions** to study the region
- Instrumentation: Sensitive detection systems to be used like: **AGATA, GALILEO, TRACE, DANTE, SPIDER**
- There is no a universal technique to measure the physical properties along an isotopic chain
- Concerns: beam purity > 20%, intensity 10^4-10^5, energy 10MeV/u



^{73}Cu: 1,8 10^5 – ^{75}Cu: 2,8 10^4 – ^{77}Cu: 1,6 10^3

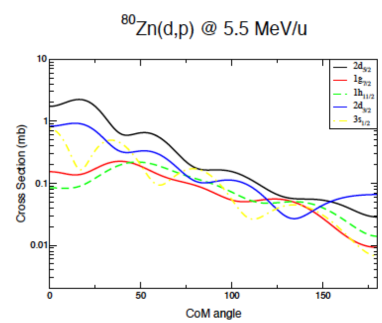
^{74}Zn: 7,0 10^5 – ^{76}Zn: 2,4 10^5 – ^{78}Zn: 2,0 10^4 – ^{80}Zn: 1,0 10^3

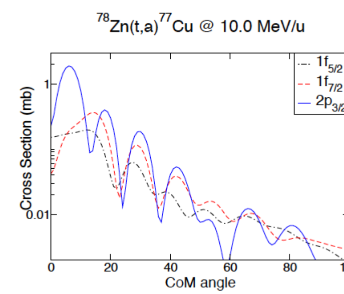
^{81}Ga: 2,2 10^5

^{82}Ge: 2,3 10^5 – ^{84}Ge: 1,3 10^4

^{84}Se: 2,9 10^6 – ^{86}Se: 1,3 10^5 – ^{88}Se: 2,7 10^3

- **Coulomb excitation neutron-rich ^{86,88}Se and ^{84}Ge** – Evolution of deformation quasi-SU(3).
- **Coulomb excitation ^{75,77}Cu**, population of collective states - Infer deformation on the Ni isotopes.
- **(d,p) ^{81}Ga, ^{84}Se, ^{82}Ge, ^{80}Zn** – single particle orbital beyond N=50 $d_{5/2}$, $s_{1/2}$, $d_{3/2}$, $g_{7/2}$ and $h_{11/2}$. Gap stability. Monopole evolution.
- **(t,α)** to selectively populate single proton states in **odd-A ^{73,75,77}Cu** isotopes- $p_{3/2}$, $f_{5/2}$ and $f_{7/2}$. Proton removal from the GS of Zn.





Courtesy of J.J. Valiente

The SPES physics program

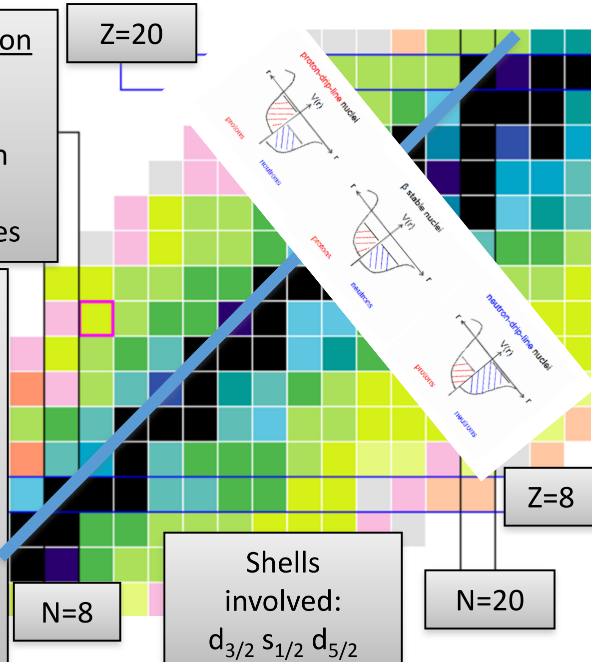
Transfer studies in neutron-deficient nuclei with the neutron detector **NEDA**

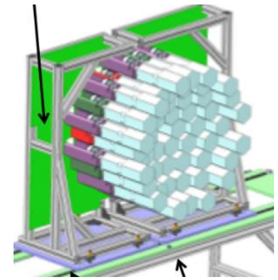
Nuclear structure at the proton drip-line

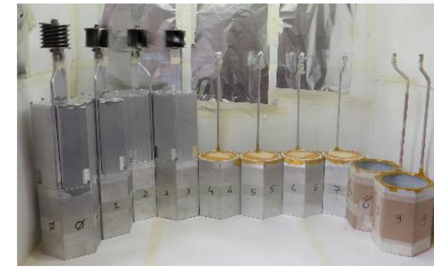
- Shell evolution
- Halo systems and proton emission
- Mirror Energy Differences

Ingredients

- Light neutron deficient beams
- ^{3}He targets/ deuterium
- Neutron detectors
- Gamma-ray arrays
- Particle detector arrays
- Transfer reactions theory
- Theoretically continuum and 3N

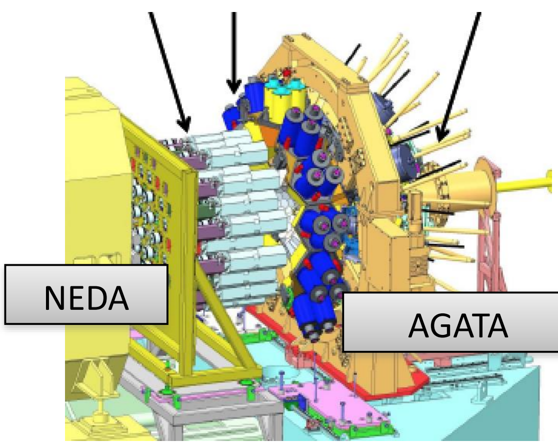






- **Flexible array** – variability of focal positions (experiment dependent)
- **Various physics campaigns** depending on the configuration
- **Neutron multiplicity filter**.
- **Pulse shape discrimination** – online trigger selectivity
- **Off-line implementation** of traditional algorithms and/or Neural Networks
- **Angular resolution**: θ(0.5 m) = ±7° - θ(1 m) = ±4°
- **Timing better than 1 ns**. Same performance digital/analog.
- **Energy resolution** ΔE/E: NEDA 1m – 40%, NEDA 7m – 5%

- Possible proposals with NEDA, AGATA/GALILEO and TRACE-GASPARD to perform with **light SPES beams from 4 to 10 MeV/u**:
  - Transfer reaction, such as (^{3}He,n), (d,n), etc.
  - Fusion evaporation reactions
- Lifetime measurements → target development 3He, d.
- Light neutron-deficent SPES beams → required some developments.



Courtesy of J.J. Valiente

SPES core: the cyclotron

Cyclotron installed at LNL

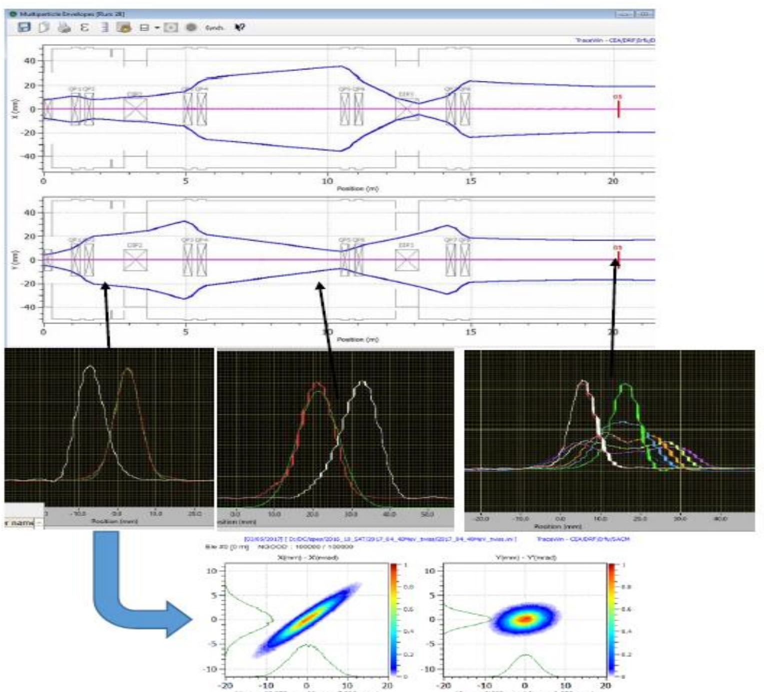
BEST B70
- H^-
- 35-70 MeV
- 0.750 mA
- 2 exits

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, 4^{th} harmonic mode
Ion Source	Multicusp H^- I=15 mA, Axial Injection
Dimensions	Φ=4.5 m, h=1.5 m
Weight	150 tons

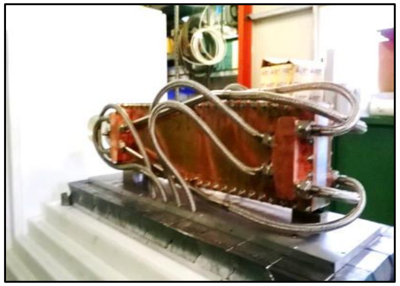
SAT and commissioning completed (2017)
Training of LNL personnel during commissioning completed (December 2017)
Operation (March 2018)

SPES core: the cyclotron

- May 30th 2016 → dual extraction 70 MeV beam – 3 µA
- Sept 9th 2016 → acceleration 70 MeV beam – 500 µA
- Oct Nov 2016 → preliminary endurance test 250 µA, 40 MeV
- End Nov 2016 → source HV transformer broke before completing Site Acceptance Test
- June - July 2017 → endurance test completed
- September 2017 → cyclotron accepted
- October – December 2017→ LNL personnel operation training
- February- March 2018 → LNL cyclotron operation



High power Beam Dump 50kW



Up to **500 µA** current and **70 MeV** energy proton beam (**35 kW**) delivered to the high power Beam Dump
Less than 1% beam loss

Very good Cyclotron vacuum performance
($8x10^{-8}$ mbar with beam ON)

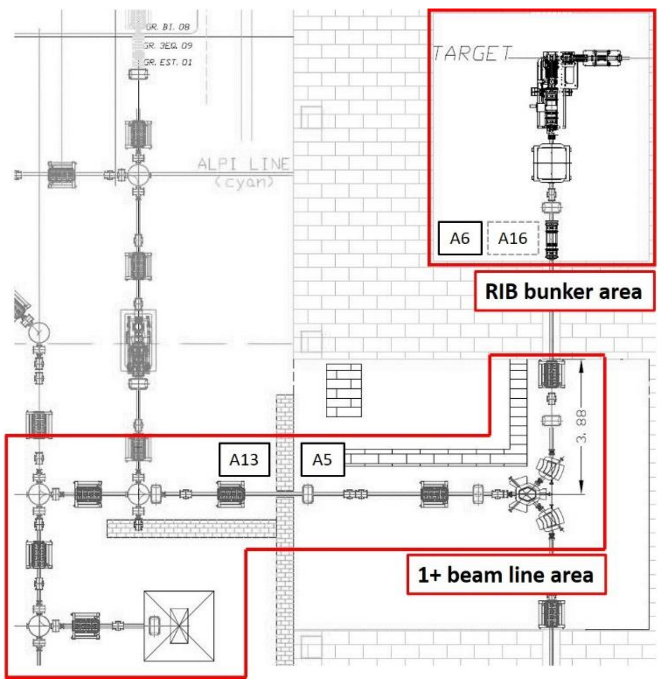
SPES core: the RIB production system

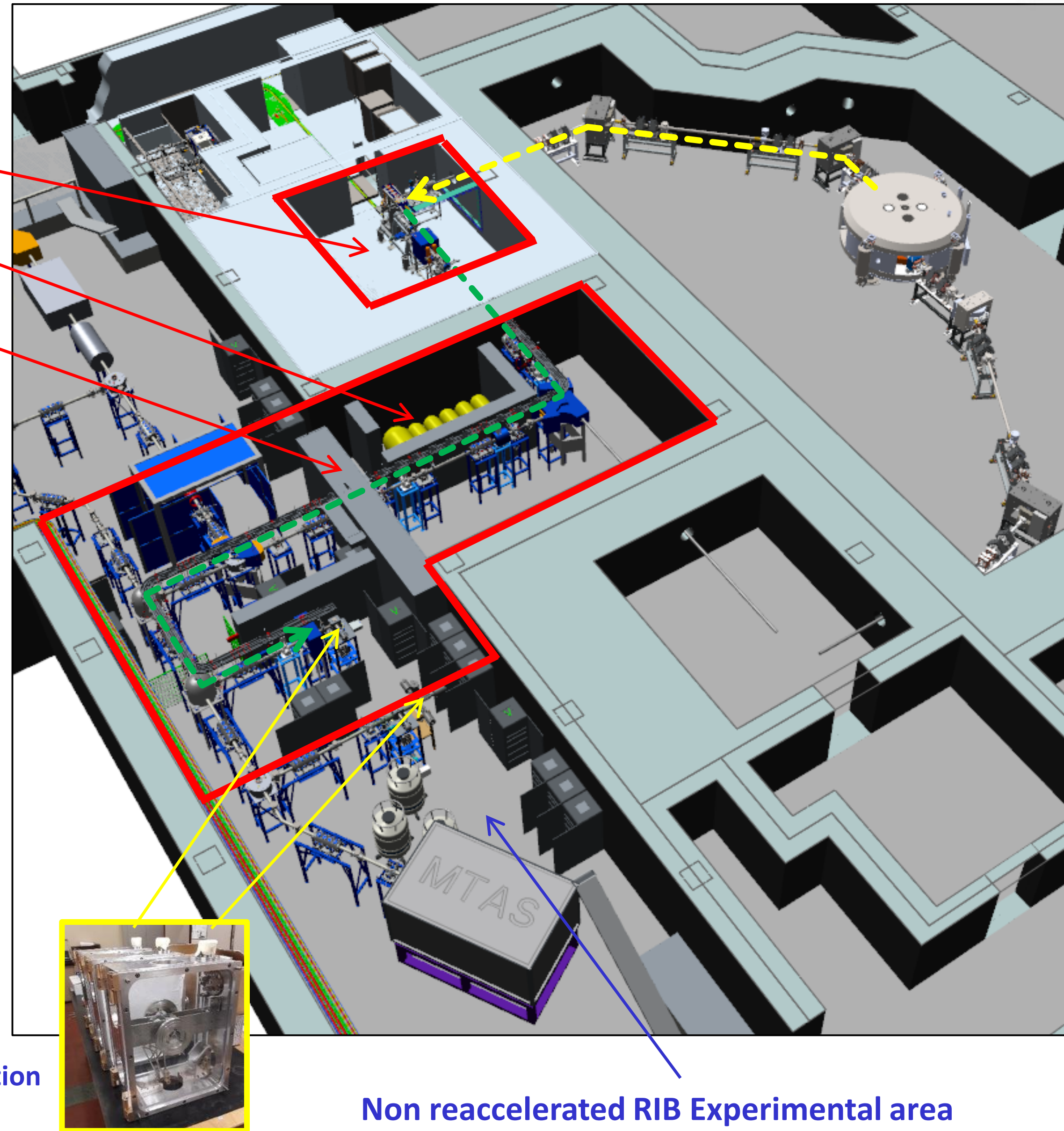
Courtesy of Mattia Manzolaro

RIB bunker

Gas recovery system

1+ beam line

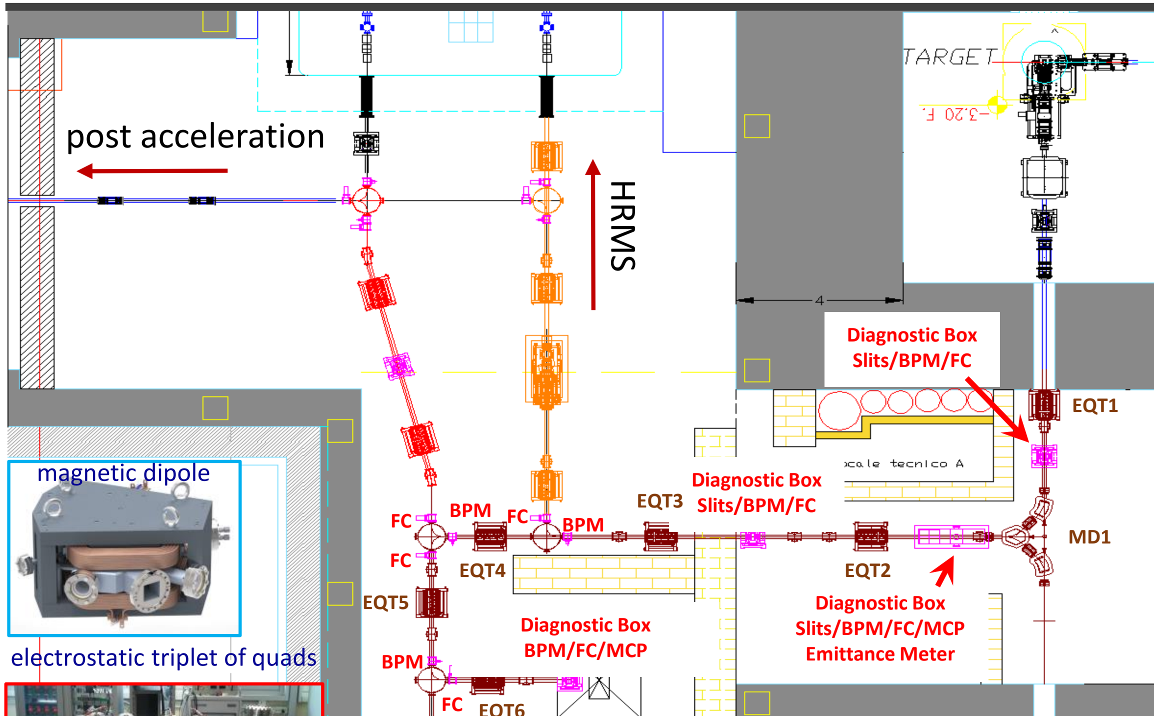


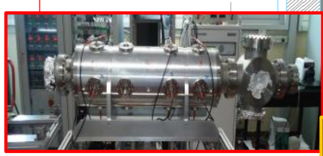


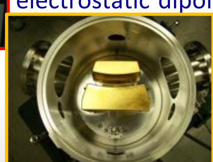
Tape stations for characterization and for β-decay study

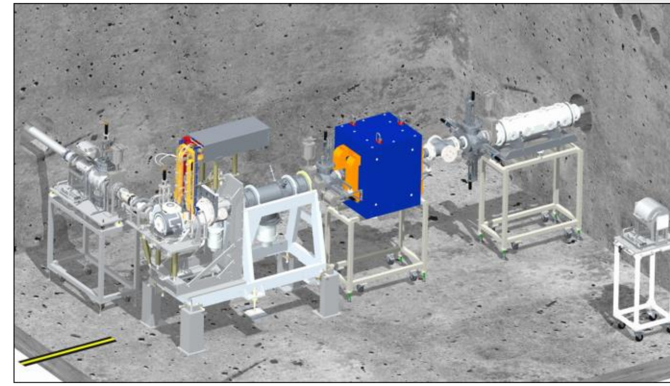
Non reaccelerated RIB Experimental area

The 1^{+} beam line : the beam optics

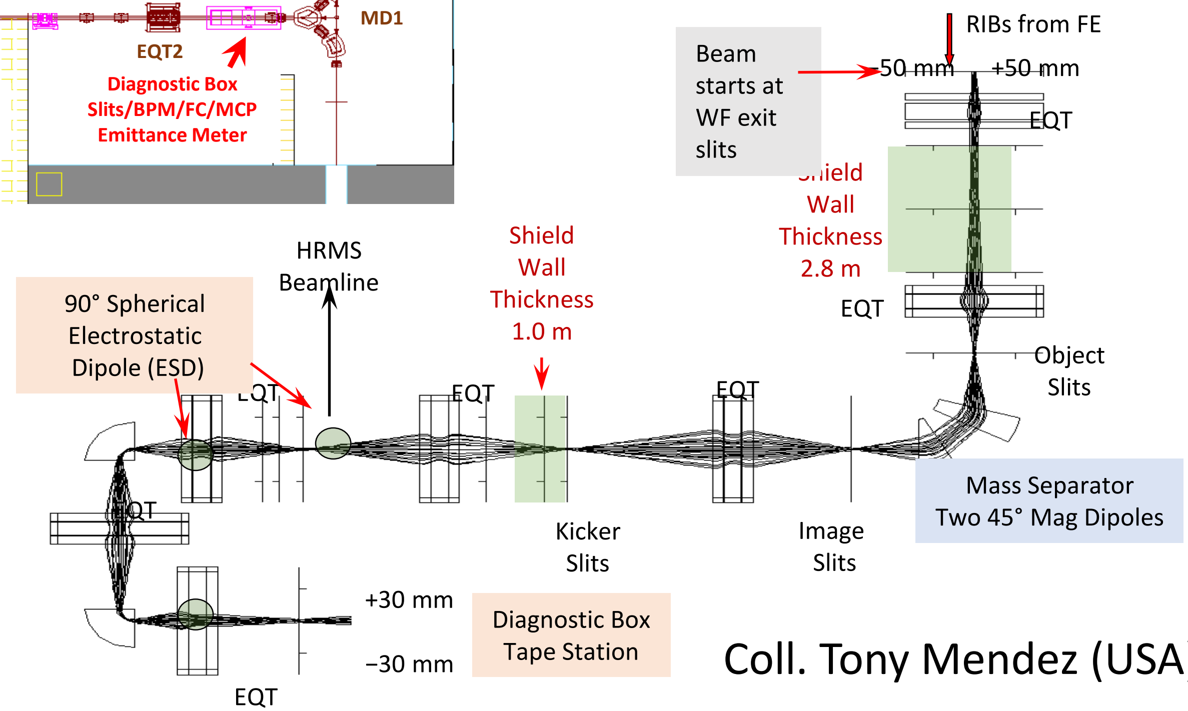








Mass selection **1/300** → ISOL-Wien Filter-LRMS



Coll. Tony Mendez (USA)

SPES core: Radiation Damage Study (SPES-RDS)

An **international** cooperation

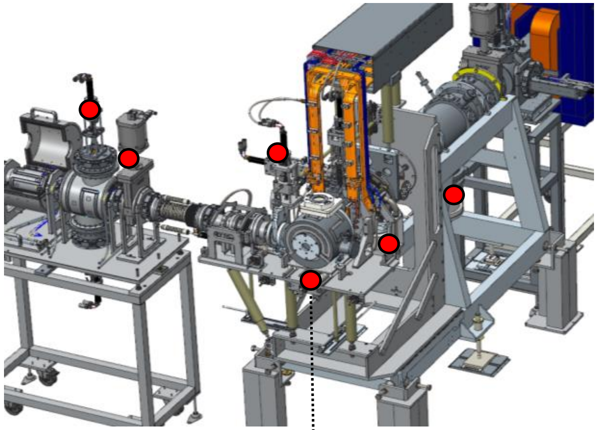
- Department of Mechanical Engineering, **UniBs**
- TRIGA Research Nuclear Reactor LENA, **UniPv**
- European Spallation Source **ESS** ERIC, **Sweden**

EXPERIMENTAL RAD-RESISTANCE of GREASES in NEUTRON FIELDS

STATE OF THE ART: **very scarce literature**

Front End and Target System: advanced nuclearization phase. Target handling systems, Heat resistance tests, Nuclear Safety.

Lubricants in the SPES Front-End

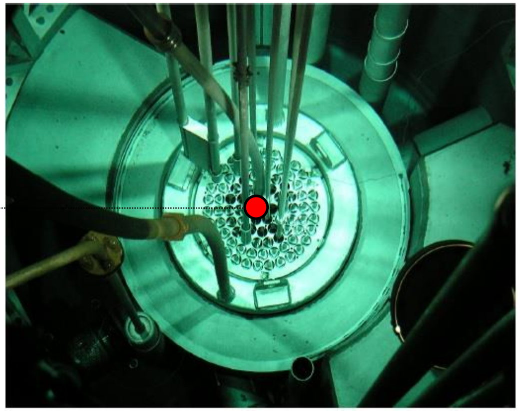


TIS handling
Lubricated bearings
Integrated dose ≈ **30 MGy** in **7 y**
CRITIC COMPONENT

[1]
PRODUCTS SELECTION
✓ 9 products

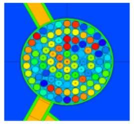
THK SCHAEFFLER MORESCO LUBCON KLÜBER LUBRICATION

[2]
IRRADIATION in REACTOR FACILITY
Neutrons + gamma



Central Thimble irradiation facility
TRIGA MARK II Research Reactor

[3]
DOSIMETRY CALCULATIONS
MCNP5 Monte Carlo

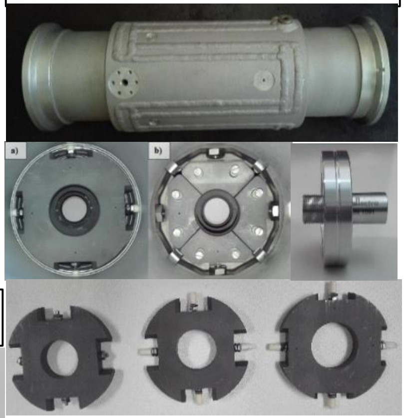


SPES core: The Front-End Construction Status

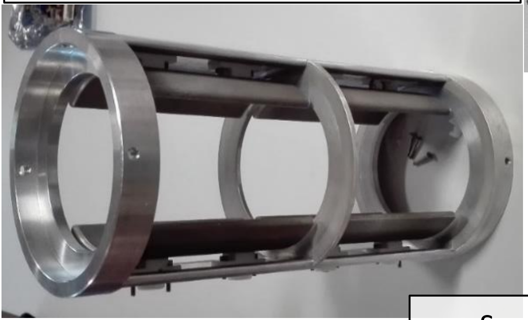
Fast clamps defined (for diagnostic and gate valves)

FE upgrading: the nuclearization phase

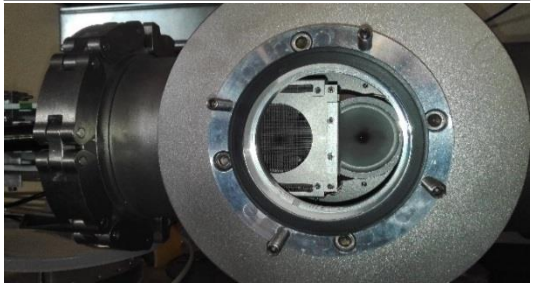
Proton Beam collimator



Steerers: tested successfully



Second diagnostic box: tested successfully (with controls)



Courtesy of Mattia Manzolaro

SPES core: Toward the first SPES RIBs

INFN LN Legnaro — Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro

SPES exotic beams for science

the next two steps of the commissioning phase

1st STEP: 40 MeV, 20 μA → **40 MeV, 20 μA, 10^{12} f/s** → **40 MeV, 200 μA, 10^{13} f/s**

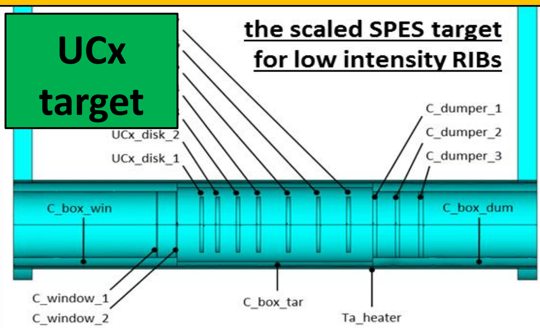
SiC target

SAINT-GOBAIN

First SPES RIB (^{26}Al)

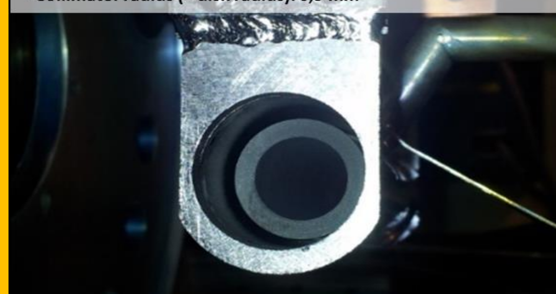
UCx target

the scaled SPES target for low intensity RIBs



Nominal parameters

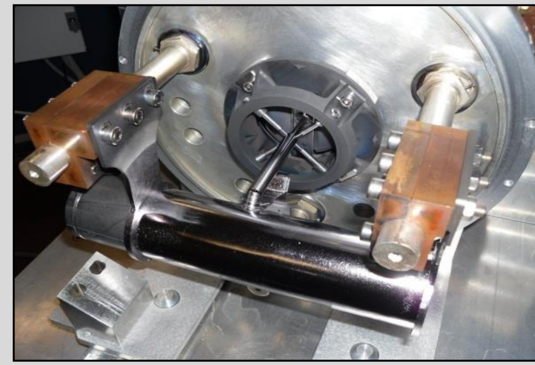
- Target material: UCx (SiC as an alternative)
- Proton beam energy: 40 MeV
- Proton beam intensity: 20 μA
- Proton beam sigma: 5 mm
- Collimator radius (= disk radius): 6,5 mm



first n-rich fission isotopes

UCx target

the full-scale SPES target for high intensity RIBs



Nominal parameters

- Target material: UCx (SiC as an alternative)
- Proton beam energy: 40 MeV
- Proton beam intensity: 200 μA
- Proton beam sigma: 7 mm
- Wobbling radius : 11 mm

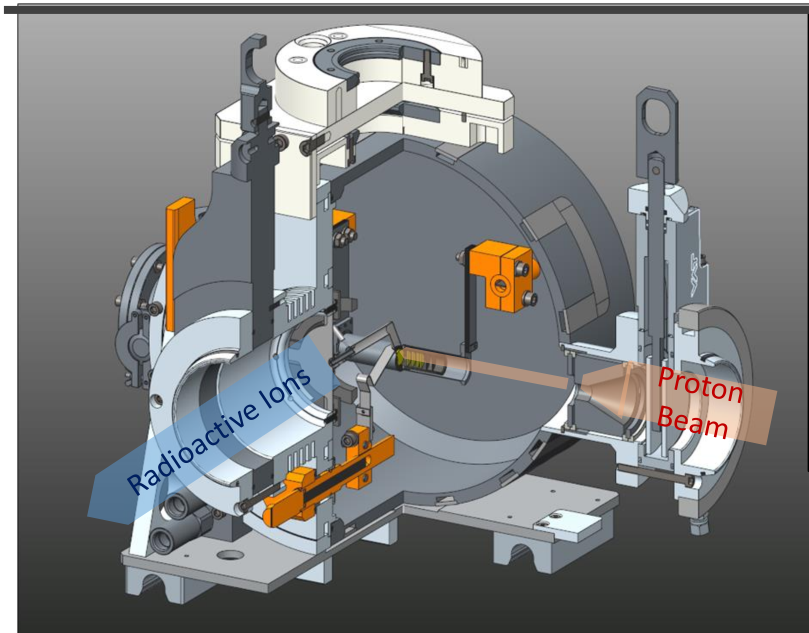
to high proton beam intensities (increase by a factor of 10)

the BEAM INTENSITY depends on → half-life, cross-section, proton flux, diffusion and effusion time, ionization and transport efficiencies

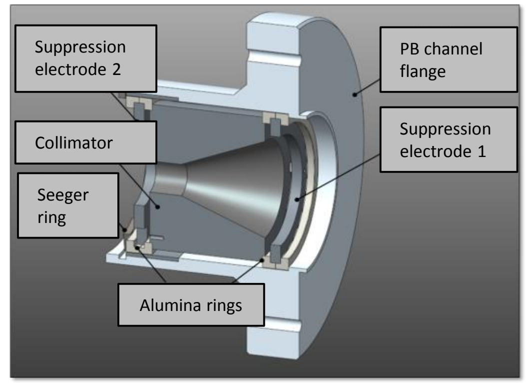
$$Y = \sigma \cdot \Phi_p \cdot N \cdot \varepsilon_d \cdot \varepsilon_e \cdot \varepsilon_i \cdot \varepsilon_t$$

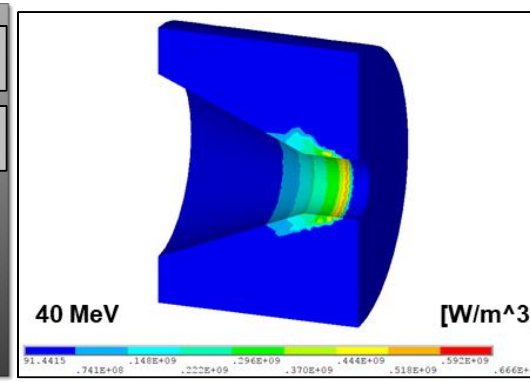
Courtesy of Mattia Manzolaro

SPES core: Development of the SiC - TIS Unit

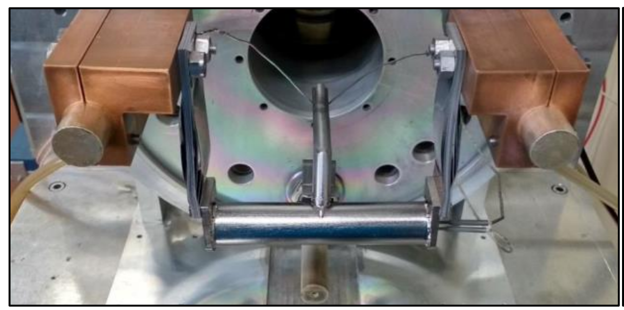


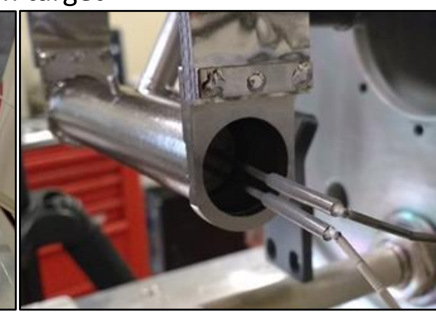
Collimator (required for the 13 mm target)

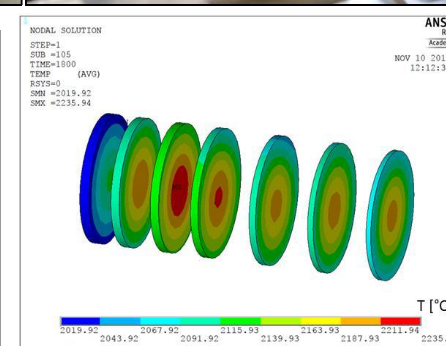




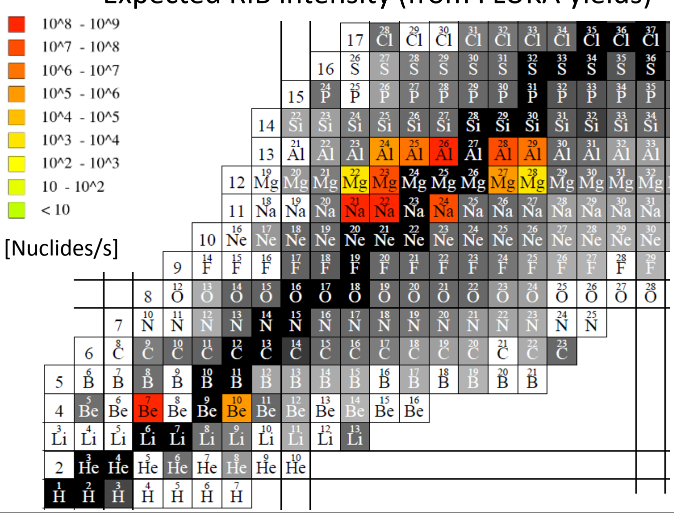
Silicon carbide 13 mm target







Expected RIB intensity (from FLUKA yields)

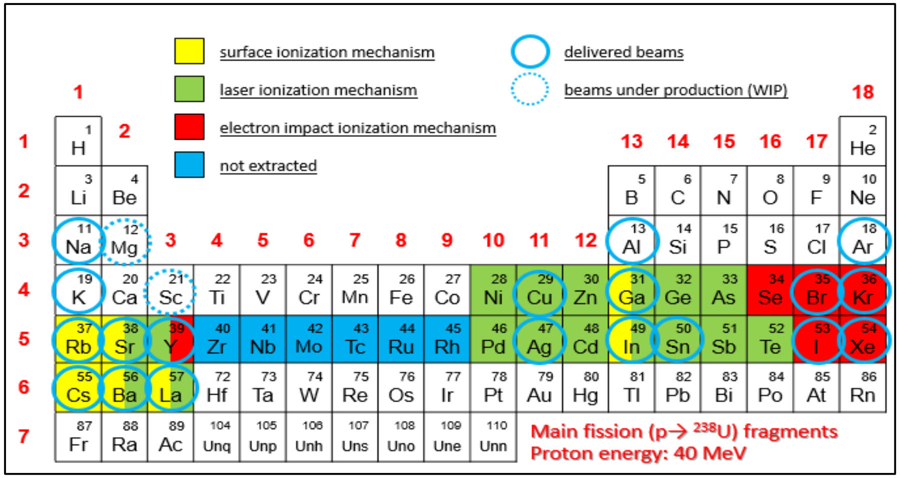


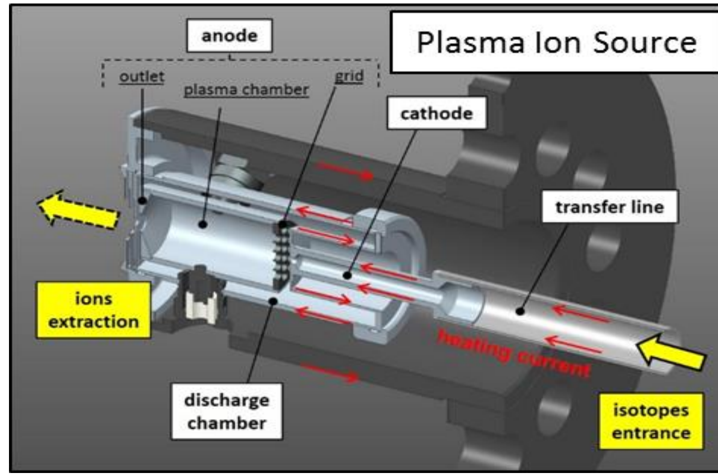
Courtesy of Mattia Manzolaro

SPES core: the Target Ion Source System

WG 1: Off-line beam production @ LNL and characterization of the SPES ion sources

(≈20 different stable beams accelerated so far…)





Al ionization efficiency: influence of the neutrals deposition substrate

Mg ionization efficiency

Al ionization efficiency with PIS

Mass marker with Al(HNO_3)+ Ta oven

Tantalum foil with Al(HNO_3) directly in the transfer line

Graphite foil with Al(HNO_3) directly in the transfer line

SiC foil with Al(HNO_3) directly in the transfer line

Further studies ongoing to implement an alterative technique for the estimation of the ionization efficiency

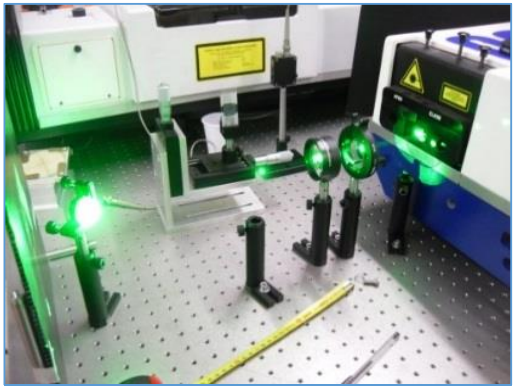
Courtesy of Mattia Manzolaro

SPES core: the Target Ion Source System

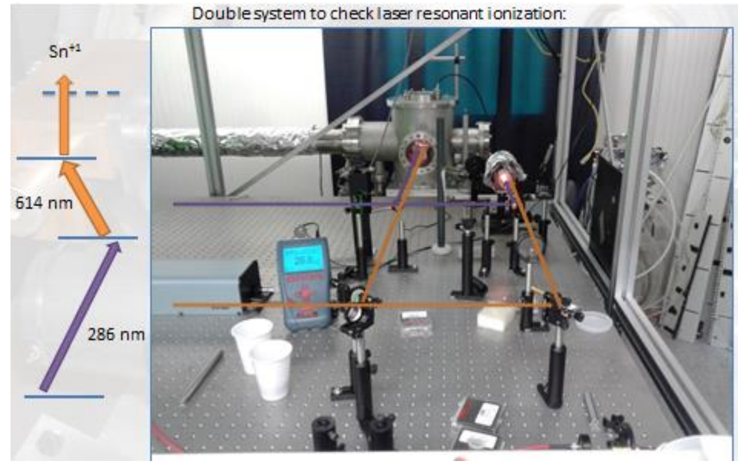
Resonant Laser Source for Selective ionization

LNL OFF-LINE LABORATORY

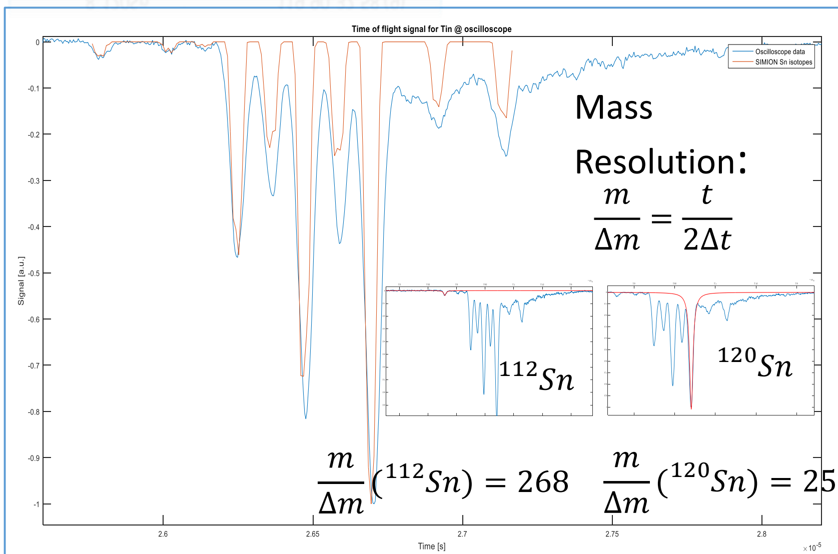
	Isotope	Mass	Abundance
1	112Sn	111,90	0.97 (1)
2	114Sn	113,90	0.66 (1)
3	115Sn	114,90	0.34 (1)
4	116Sn	115,90	14.54 (9)
5	117Sn	116,90	7.68 (7)
6	118Sn	117,90	24.22 (9)
7	119Sn	118,90	8.59 (4)
8	120Sn	119,90	32.58 (9)
9	122Sn	121,90	4.63 (3)
10	124Sn	123,91	5.79 (5)



ToF performances: Tin laser resonant ionization



Simion® simulation (orange) VS ToF acquisition (blue) & ToF mass resolution



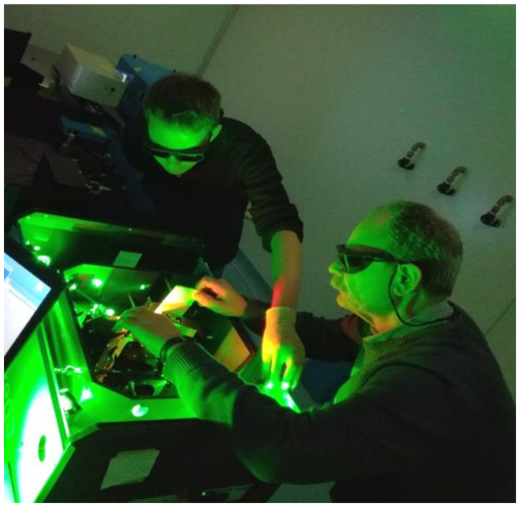
Surface ionization source:
≈ 60 heating-cooling cycles
≈ 380 h (16 days) of operation at 2000-2200°C

Plasma source: optimized to avoid hot-spot and to maximize current
New alignment system
≈ 40 heating-cooling cycles
≈ 160 working hours @ 2000°C

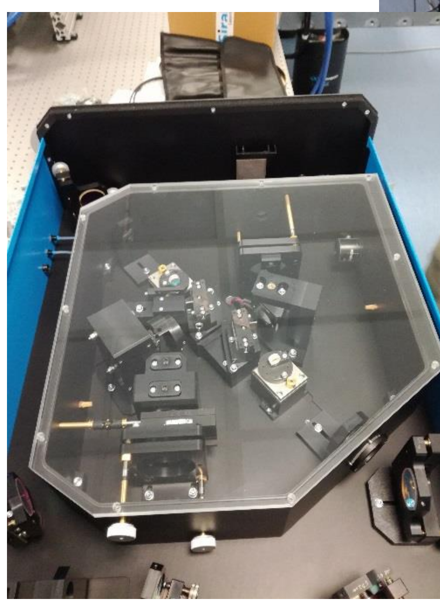
SPES core: the Target Ion Source System

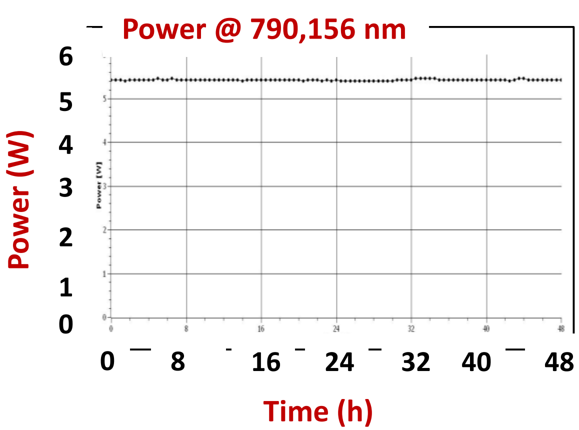
Resonant Laser Source for Selective ionization

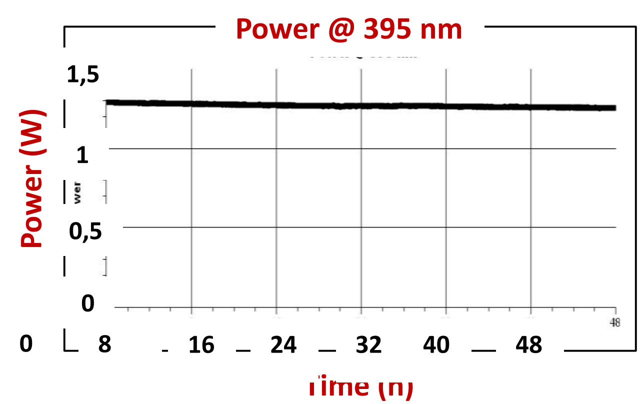
LNL- SPES ON-LINE LASER LABORATORY



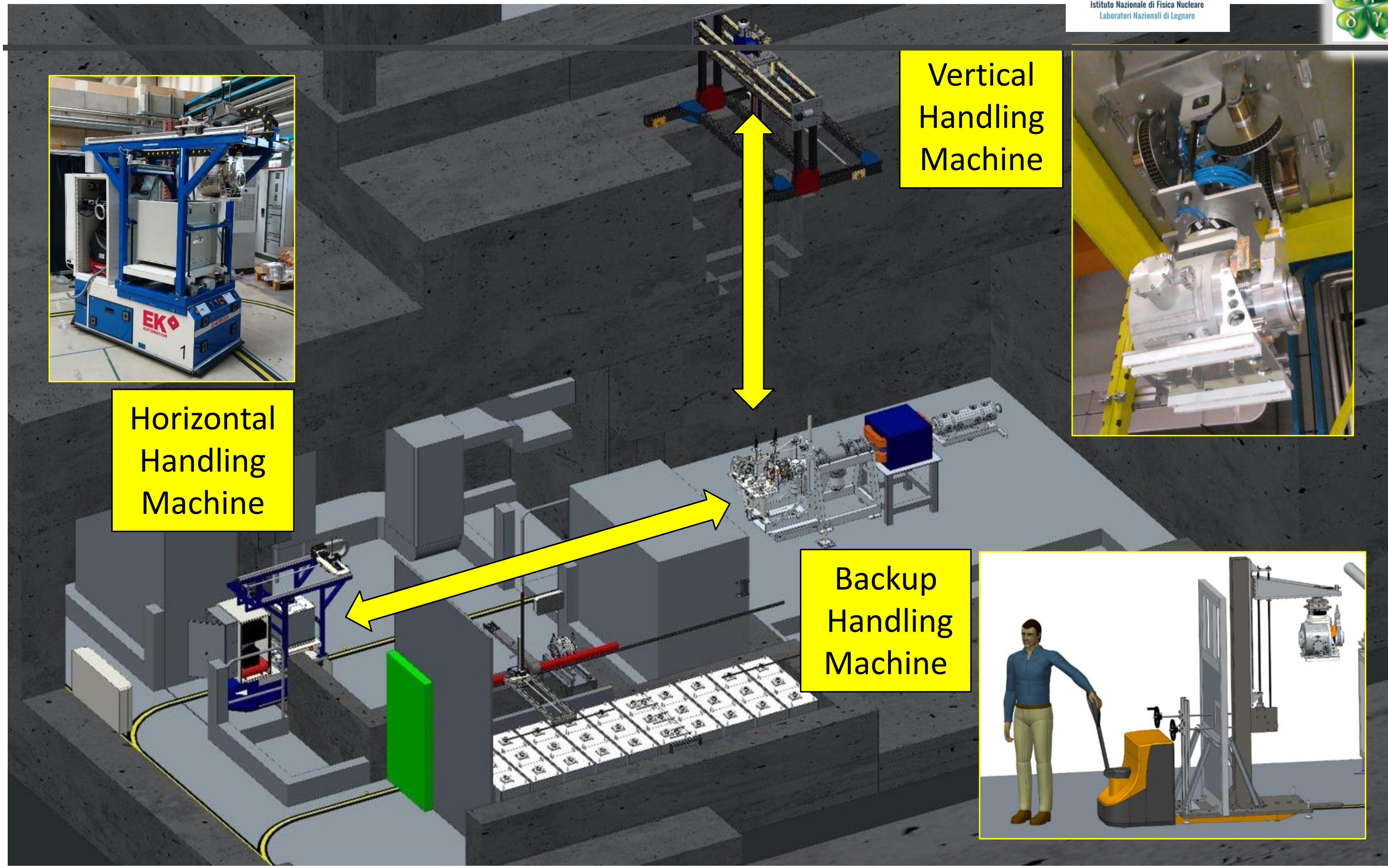
3 independent pump lasers
energizing three tunable
Ti-Sapphire laser systems
(possible generation of higher harmonics)
10 kHz repetition rate
650-980 nm (+ higher harmonics)







SPES core: Horizontal & Vertical handling Machines



Courtesy of Mattia Manzolaro

Beam selection: HRMS+Beam Cooler

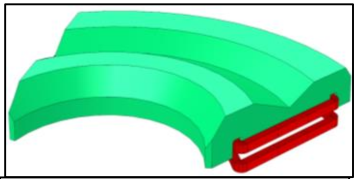
- Physical design ready, integration with beam cooler (coll. With LPC- CAEN) and beam lines under way
- Preliminary dipole design and feasibility check with potential manufacturer done
- Evolution:

– Critical Design Review - 4-5 October 2018:

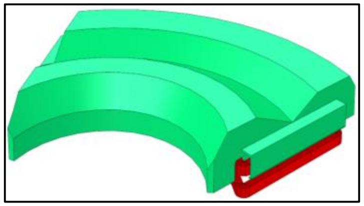
Committee Members: Richard Pardo (ANL), Chair
Timothy Giles (CERN), Helmut Weick (GSI), Franck Varenne (GANIL)

Review Report → upgraded version of the design.

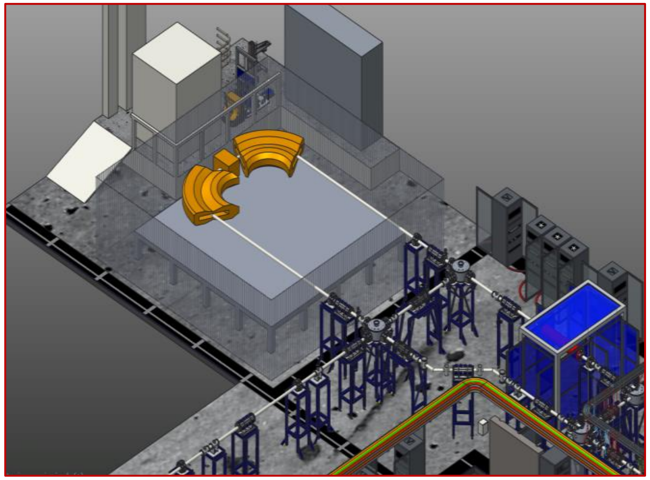
- – Authorization to tender May 2019
- – Commissioning 2022



3D half-model without field clamps



3D half-model with uniform field clamps



1eV energy spread

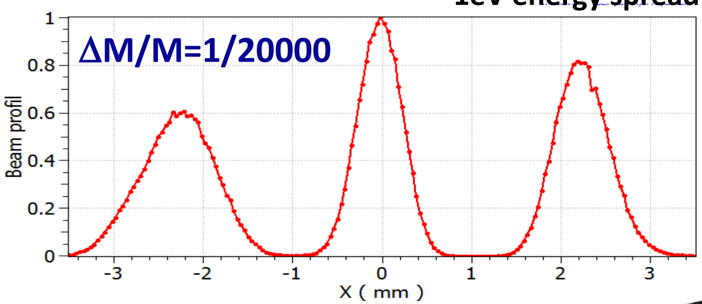


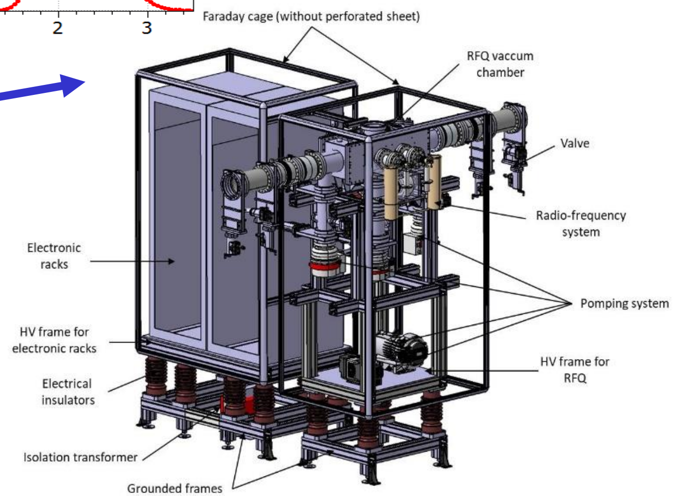
Table 2: Beam Dynamics Parameters		
Geometric Emittance	2.7	4σ mm*mrad
Ion Mass (q=1)	132	amu
Beam Energy	260	KeV
RMS Energy Spread	1	eV
RMS Spot size at image	0.3	mm
Maximum X range	440	mm

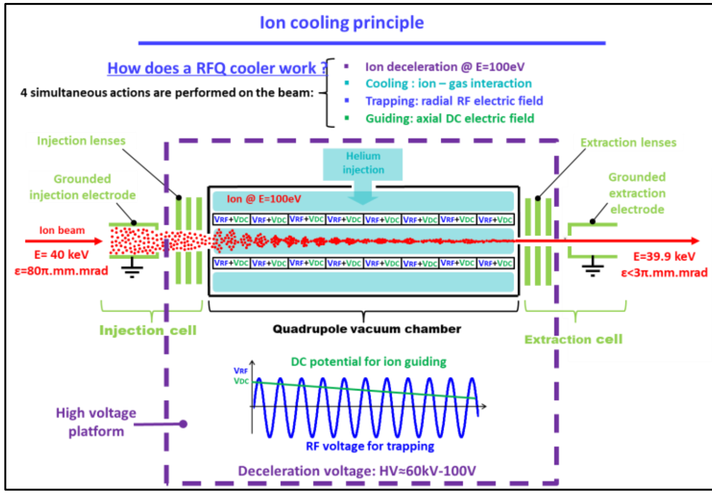
BEAM COOLER

Input requirements:

ΔE= ± 1 eV

Emittance $_{rms,n}$ = 0.68 πmm mrad



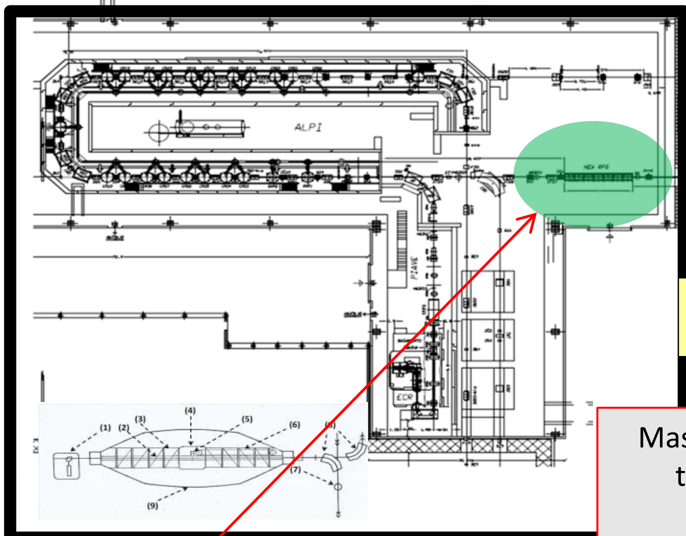


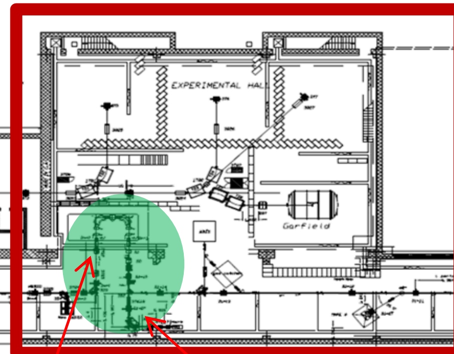
The design of the HRMS is based on assumptions of **beam quality** and thus **relies on a RFQ cooler prior to the HRMS** for preparing the beam (**MOU. LPC- CAEN**)

n$^+$ beam & Reacceleration

May 2018 –April 2019

Tandem-Piave-Alpi upgrade





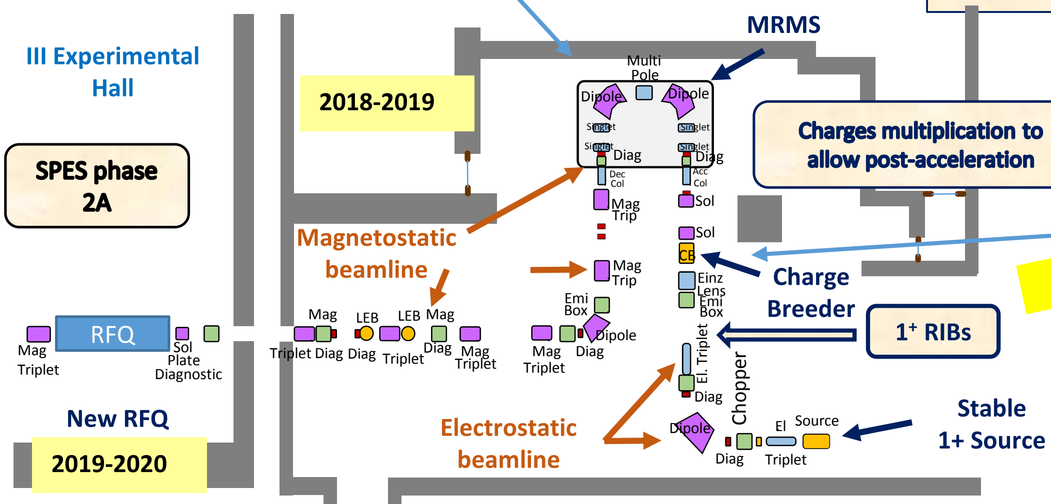
2018-2019

Mass separator to clean the beam from CB contaminants

Contract for experimental activity with LPSC Grenoble on contaminants reduction

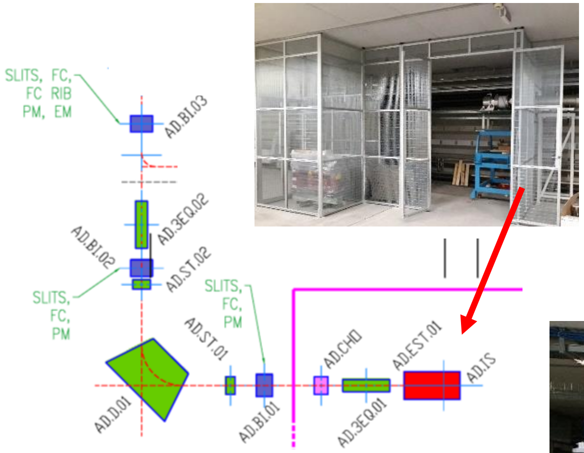
2020

Pre-accelerator RFQ (700 keV/n)

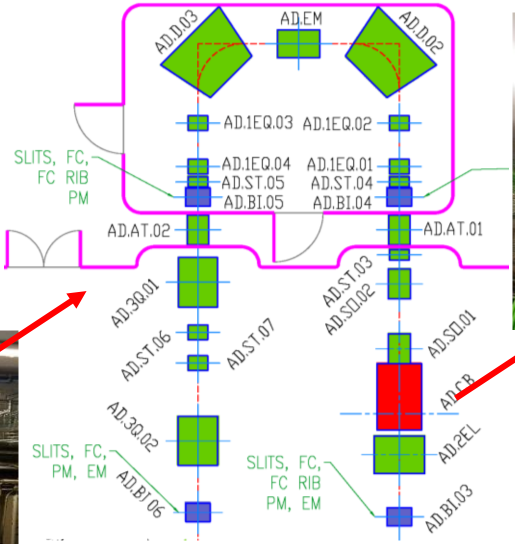


ECR_Charge Breeder from 1$^+$ to n$^+$

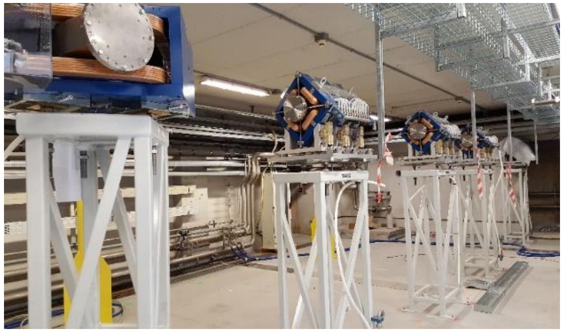
Towards ALPI:
Charge Breeder + MRMS + RFQ



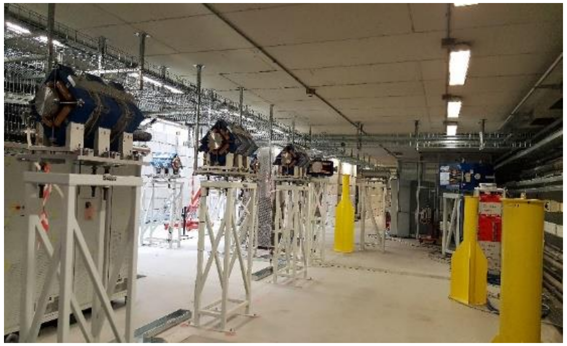
- First operation with SIS (Rb, Cs)
- Some stable isotopes need PIS (Sn, Sb, Te)
- Characterization of the 1+ sources
- Test of beam transport and transmission of the 1+ beam.



CB & Cabling



PIATT-MRMS @ Pantechnik



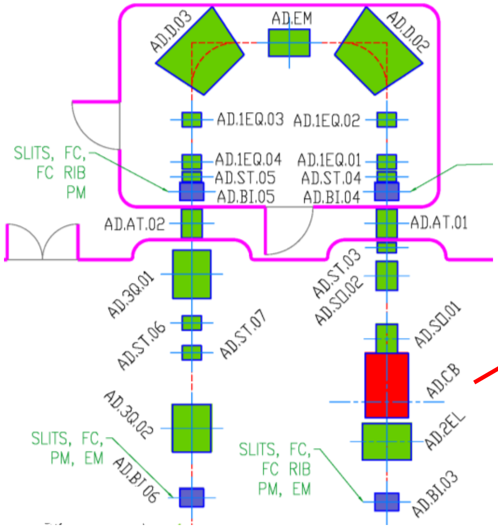
- **Installation in two steps from June 2018**

Make practice with the SPES-CB
Debug software tools (CB and MRMS)
Characterize the MRMS (WPB7)
Verify all the techniques for contaminants reduction for different P_{mw}, f and B.
Test the new aluminum plasma chamber (cont red).
Acquire ε_{rms} of the n+ beam, for different P_{mw}, f and B.

INFN-LPSC: Study for CB contaminants reduction
- plasma chamber
- Materials
- Cleaning & conditioning
- vacuum

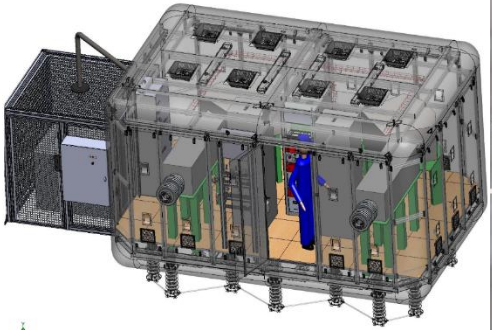
Towards ALPI:
Charge Breeder + MRMS + RFQ


MRMS CAGE INSTALLATION




CB & Cabling


MRMS INSTALLATION


SPES MRMS platform design (A. Galatà)

RFQ: new Injector for ALPI

- Construction of vanes: tender completed in July 2016. Prototype in construction
  - 1st set of 4 electrodes (module 5) was successfully delivered in April 2017
  - 2st set of 4 electrodes (module 4) was brazed in May 2017
- June 2017: Tender for tank construction

RFQ INSTALLATION PLAN

2018

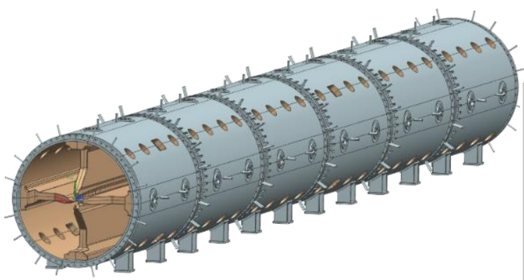
- Tooling for RFQ modules assembly
- Ancillary parts engineering design completion
- All Electrodes & some tanks produced

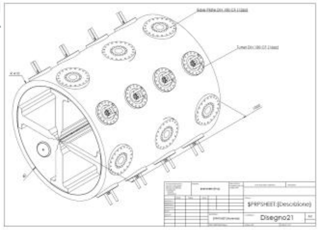
2019

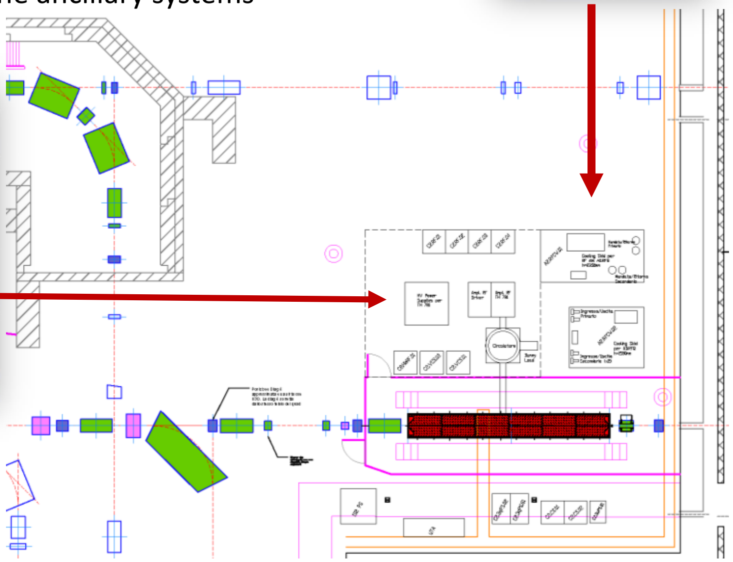
- Completion of the production of the tank
- Production of the tuners
- Copperplating
- Quality Assurance Plan
  - RF testing
  - Mechanical testing
  - Vacuum Test
- Displacement of the ancillary system (RF, cooling skid)
- Upgrade of the RF system

2020

- Installation of the electrical and water plants
- Connection of the RFQ to the ancillary systems

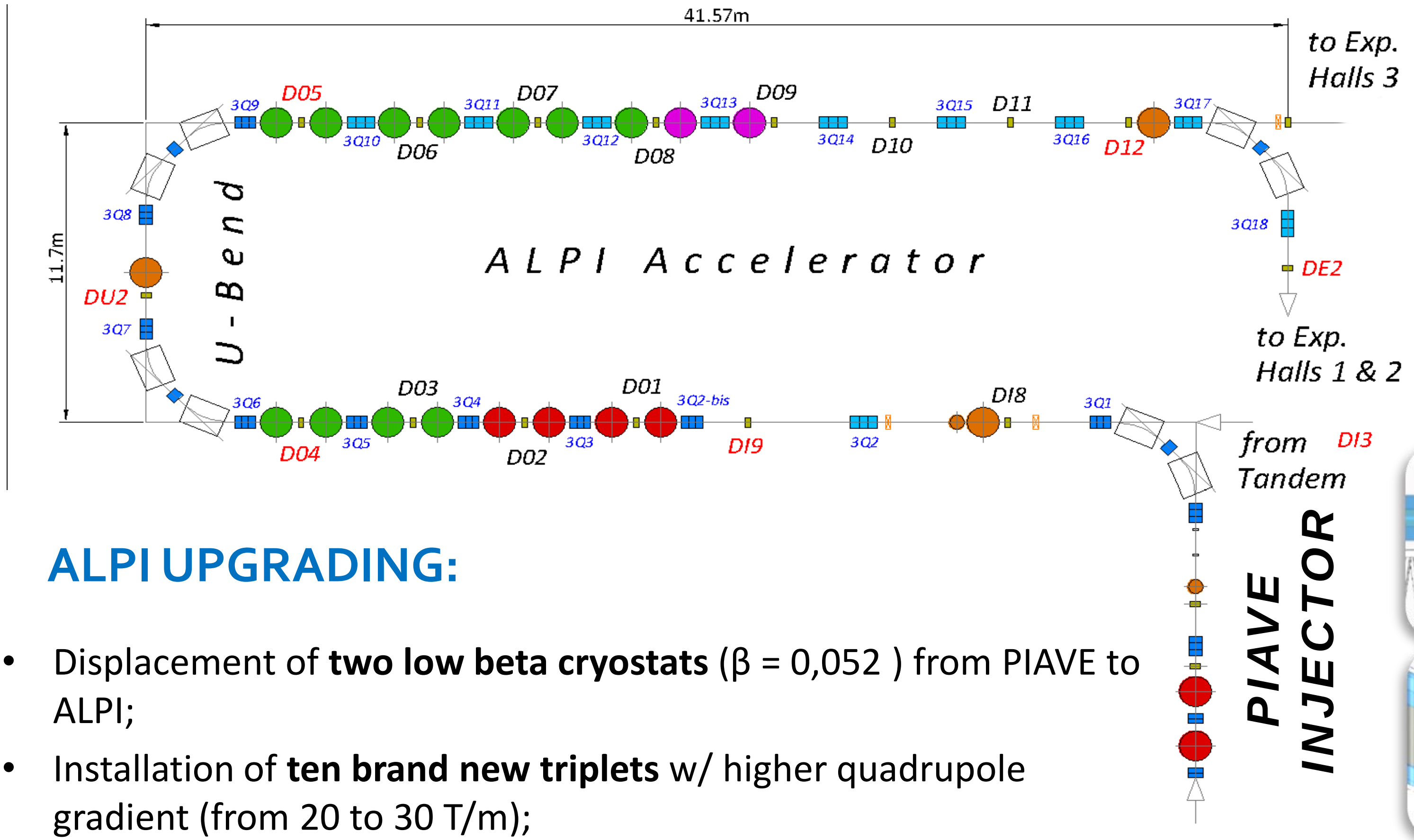


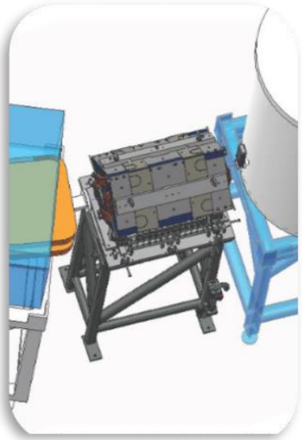


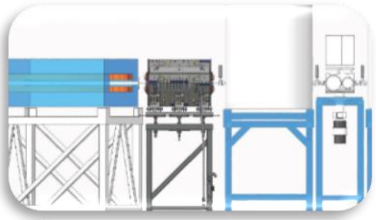


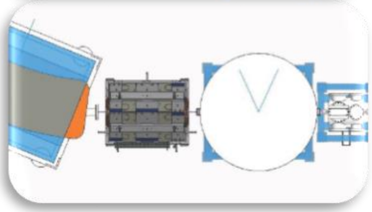
- Energy 5.7 –> 727.3 keV/A [β=0.0395] (A/q=7)
- Beam transmission >93% for A/q=3÷7
- RF power (four vanes) 100 kW (f=80 MHz)
  for up to 1 mA beam (…future high current stable beams)
- Mechanical design and realization, similar to the Spiral2 one, takes advantage of IFMIF technological experience

ALPI: upgraded performances







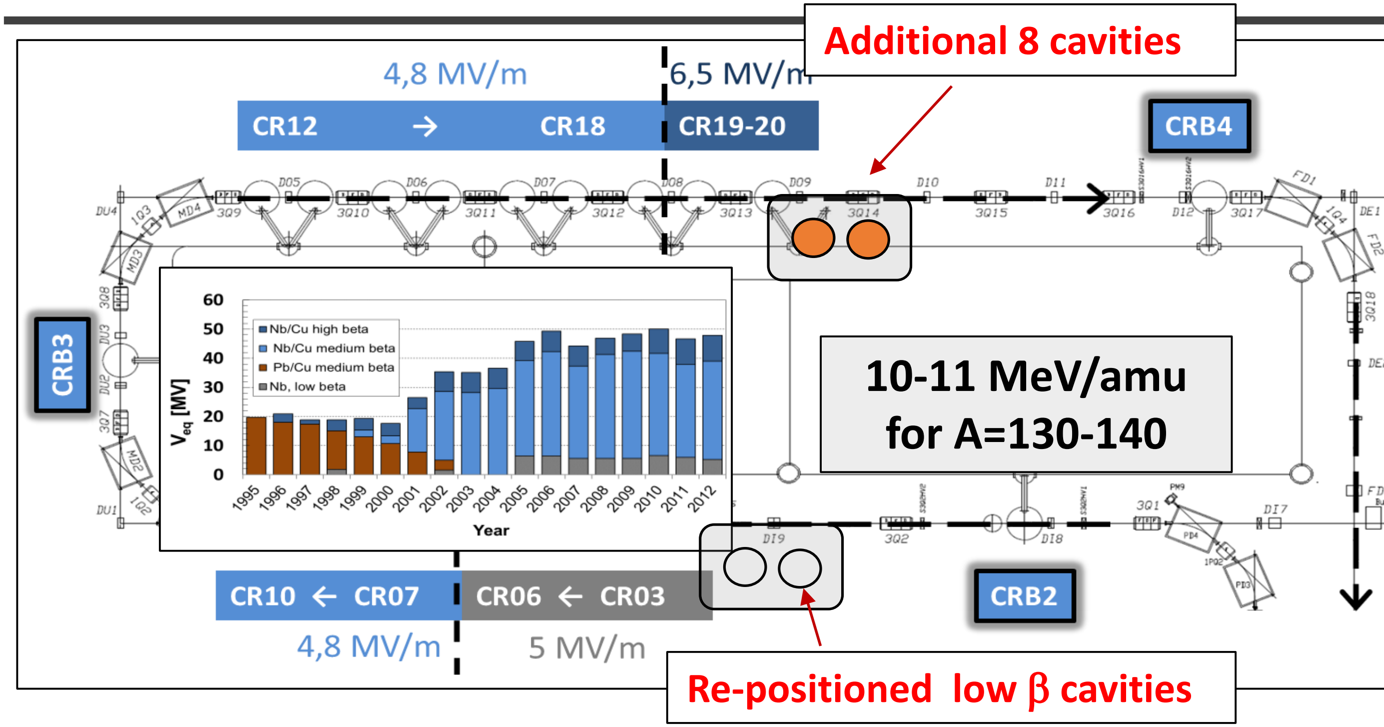


ALPI UPGRADING:

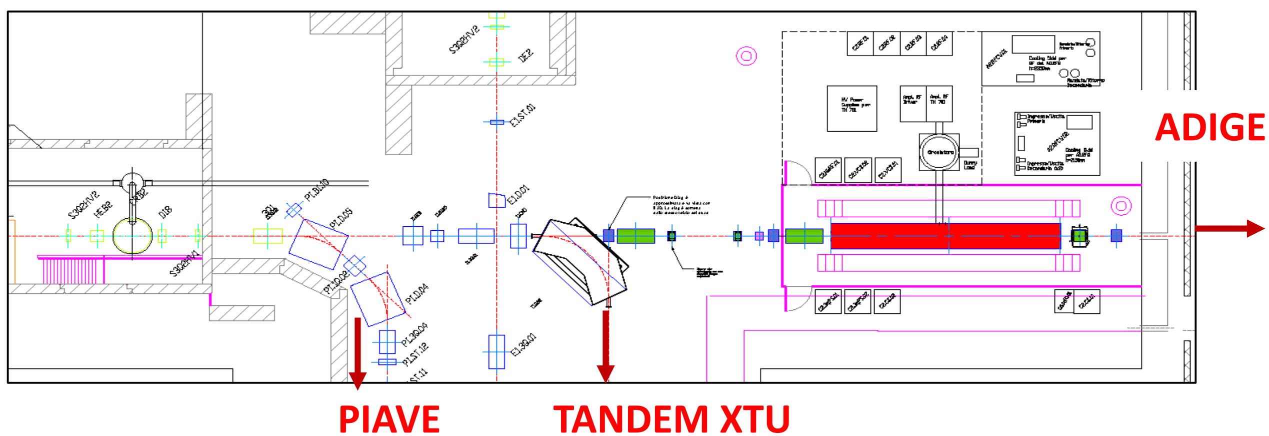
- Displacement of **two low beta cryostats** (β = 0,052) from PIAVE to ALPI;
- Installation of **ten brand new triplets** w/ higher quadrupole gradient (from 20 to 30 T/m);
- **New digital LLRF Controller**;
- Production of **new Diagnostic Boxes** (the new boxes will be installed in a second phase ‘20-’21);
- **Realignment campaign** of the magnetic lenses, cryostats, diagnostic boxes;

May 2018 - Apr.2019

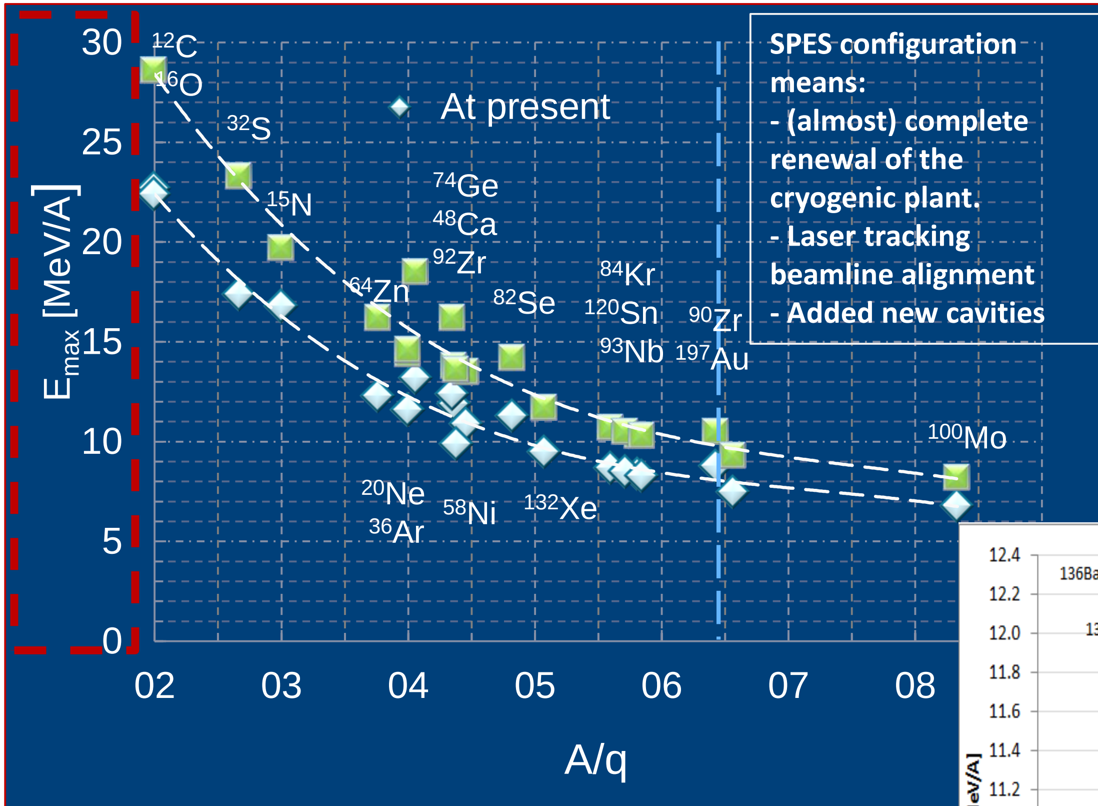
ALPI: upgraded performances



ADIGE – ALPI Matching Section

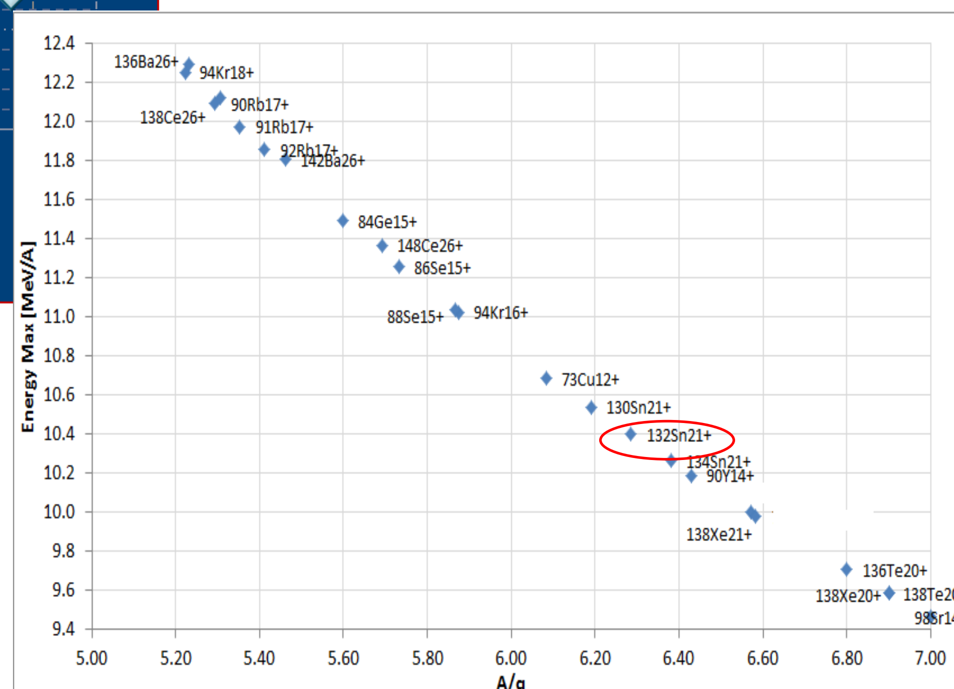


ALPI: upgraded performances



Stable Beam improvement with ALPI upgrading as function of A/q

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



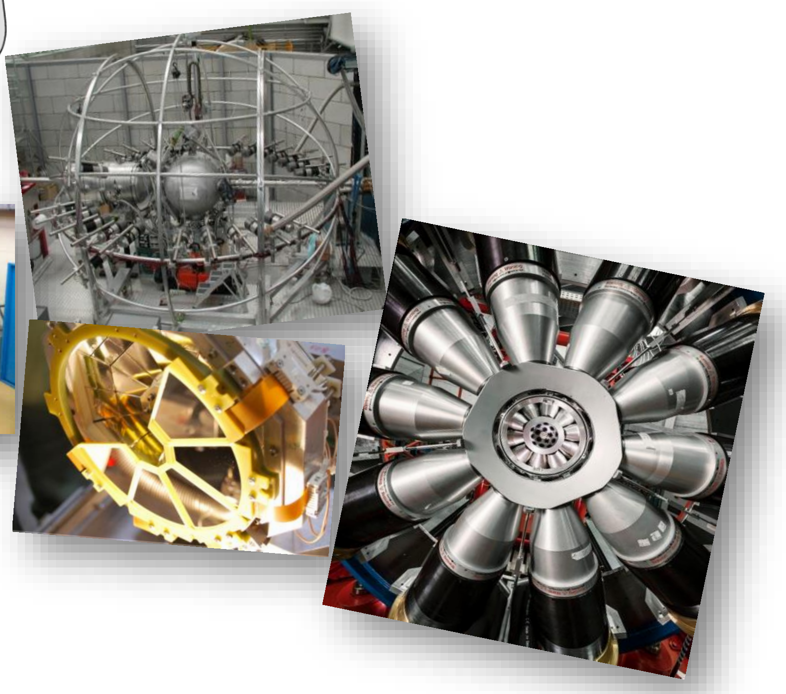
Summary

New and
High Quality Beams

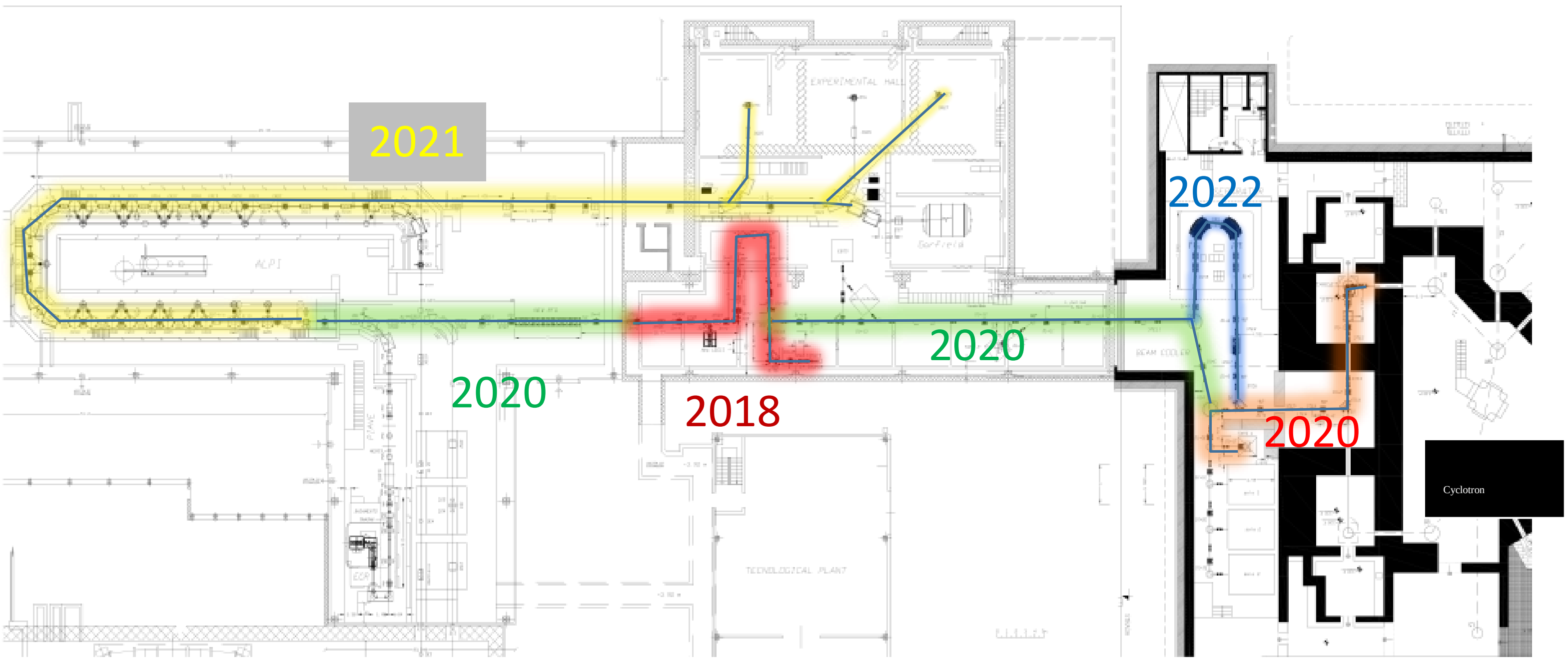
There are big challenges
extending much beyond
the discovery of
new isotopes:

Nuclear Structure
Reaction Dynamics
Nuclear Astrophysics
Nuclear Data

State of the art detectors



SPES INSTALLATION SCHEDULE

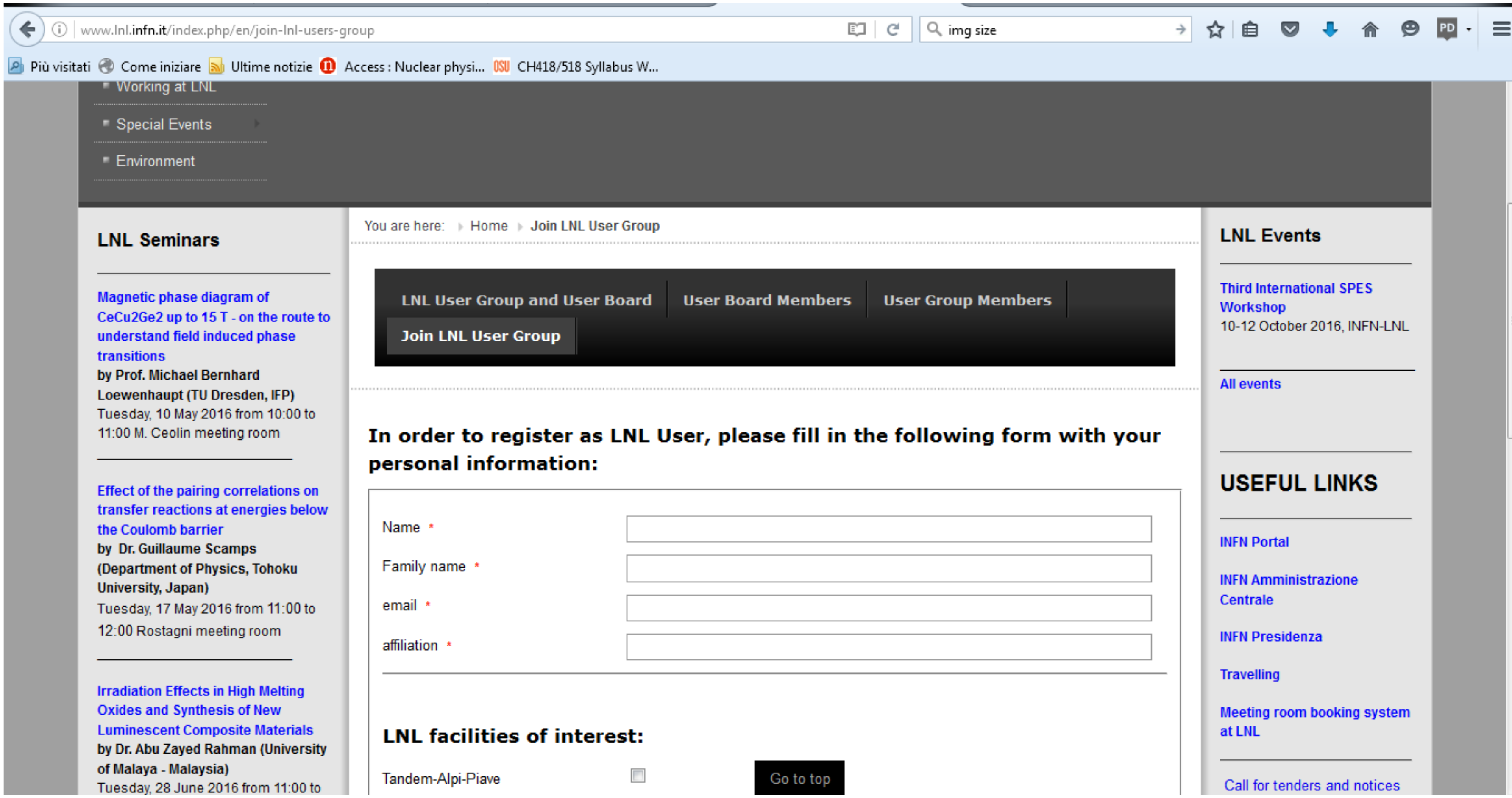


Main Tasks	2017				2018				2019				2020				2021				2022			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
PHASE 2a: CHARGE BREEDER & MRMS installation																								
PHASE 2B: ISOL SYSTEM and wien filter																								
PHASE 2B: 1+ beam line operation																								
PHASE 3A: 1+ beam line up to Charge Breeder																								
PHASE 3B: bunchers & RFQ																								
PHASE 3A: BEAM COOLER																								
PHASE 3A: HRMS																								

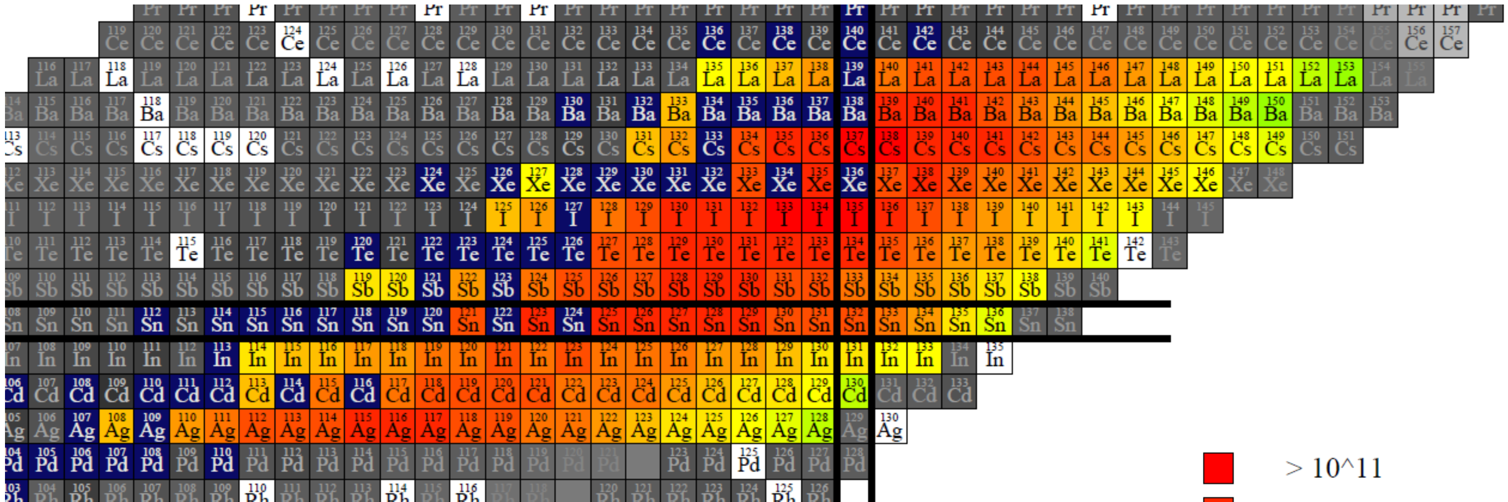
installation **Hardware commissioning** **Beam commissioning**

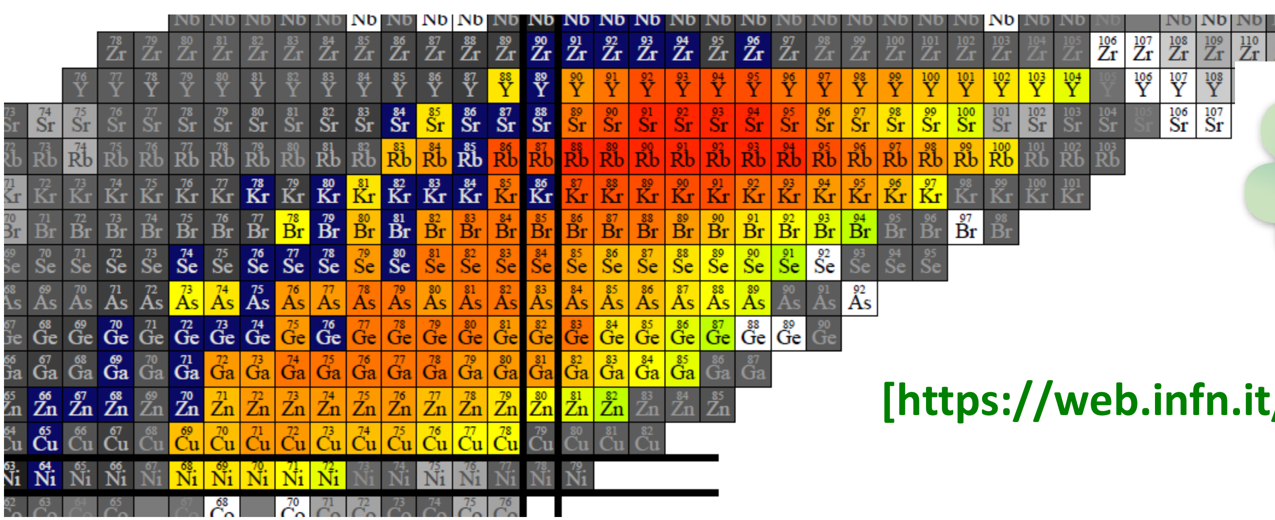
backup

Join LNL User Group



SPES BEAMS (ReA)





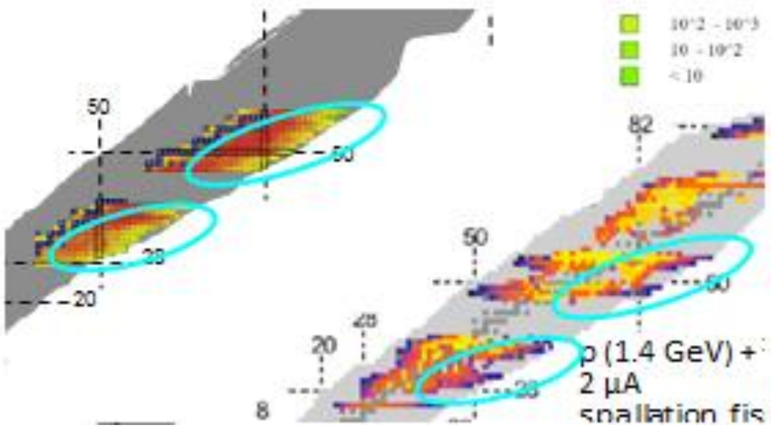
■	> 10^11
■	10^10 - 10^11
■	10^9 - 10^10
■	10^8 - 10^9
■	10^7 - 10^8
■	10^6 - 10^7
■	10^5 - 10^6
■	10^4 - 10^5
■	10^3 - 10^4
■	10^2 - 10^3
■	10 - 10^2
■	< 10

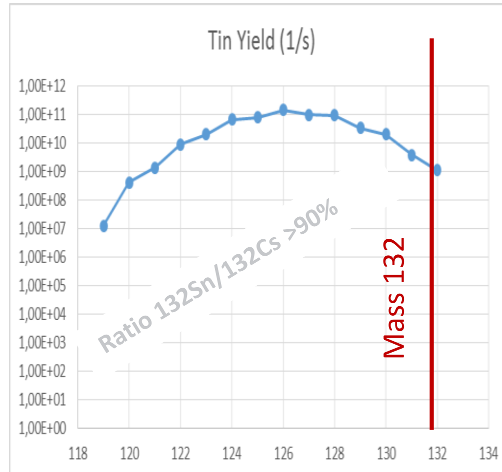
[https://web.infn.it/spes/]

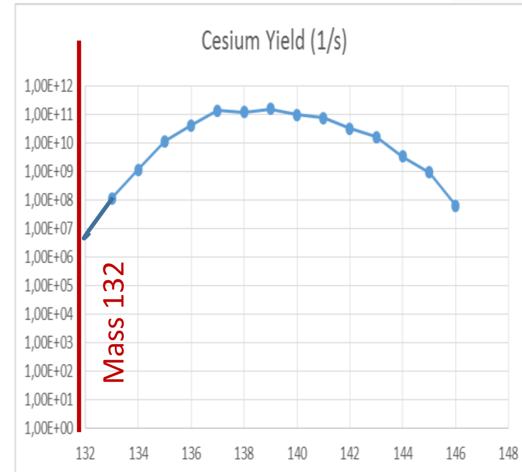
Toward a selected beam: in target reactions

SPES

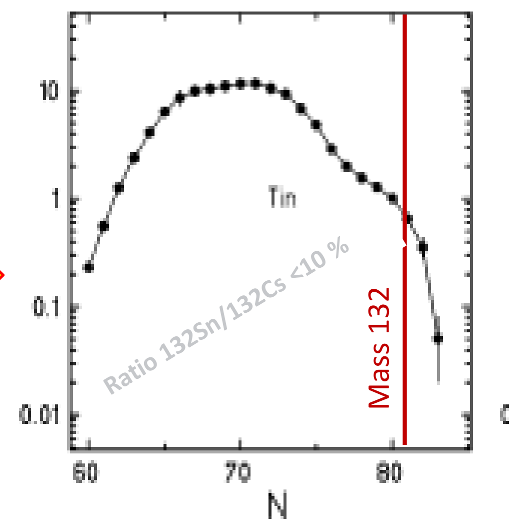
40 MeV protons on 238U

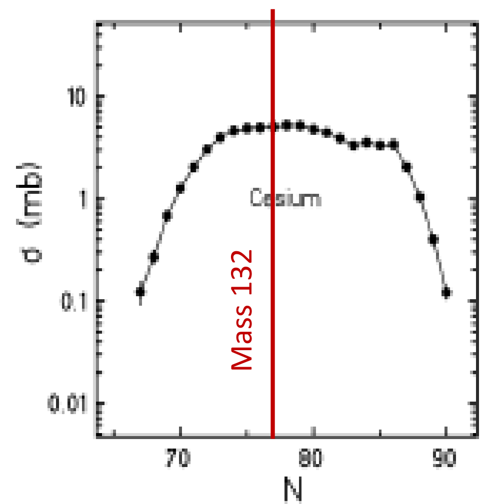






Isolde

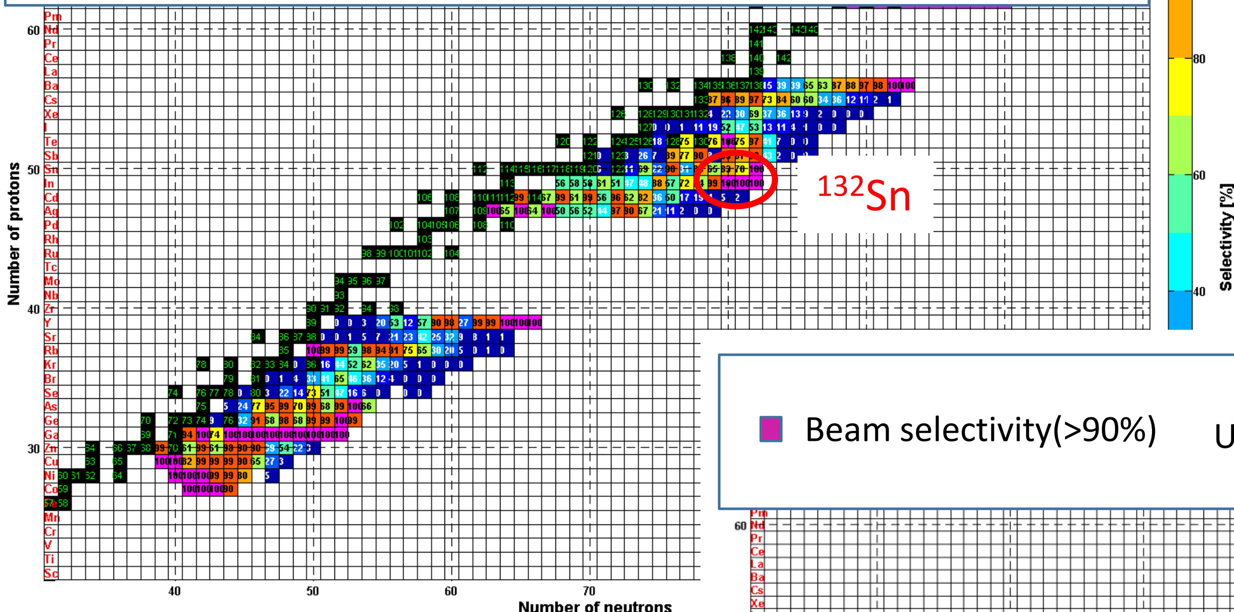




Beam selectivity may be different according to the production reactions and relative rates.

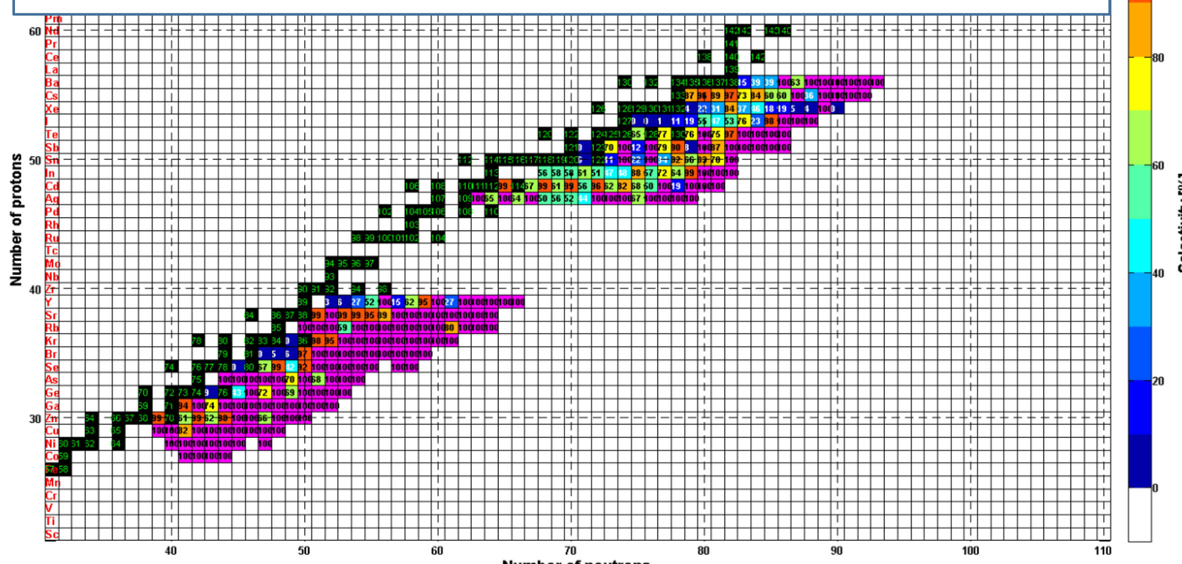
Toward a selected beam: mass resolution

Beam selectivity(>90%) UCx fission **LMR (1/200)**



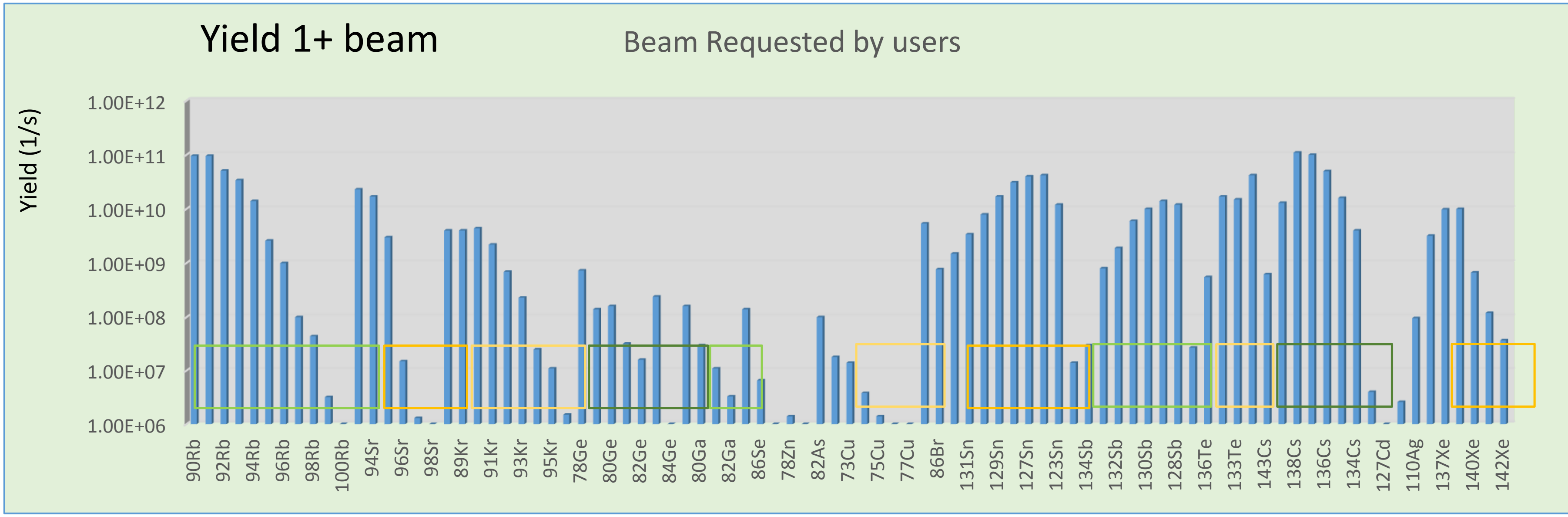
SIS beams: Rb,Cs,Sr,Ba
PIS beams: Kr,Xe,Br,I,Se
LIS beams: others

Beam selectivity(>90%) UCx fission **HRMS (1/20000)**

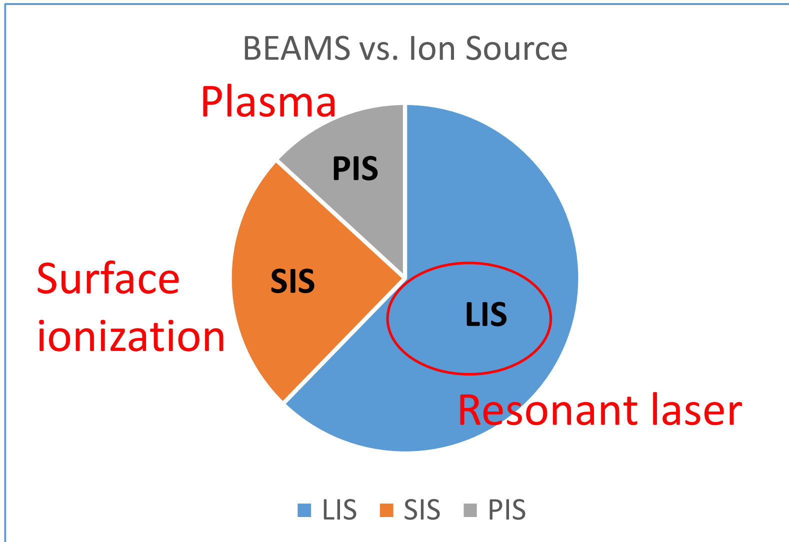


MC code: MCNPX, Bertini –ORNL model

LoI - n-rich RIBs



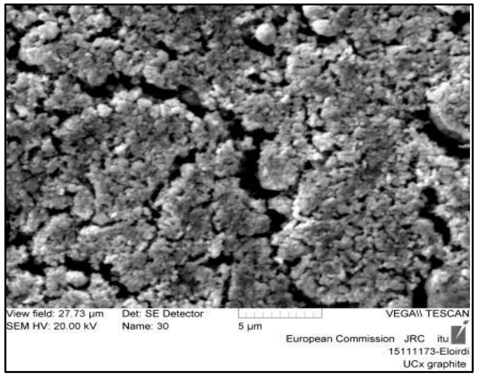
		19 Elements	
Total beams	89		LoI %
Beams with 300_LRMS	47		53%
Benefit with 5.000_HRMS	3	→ 50 beams	56%
Benefit with 10.000_HRMS	17	→ 67 beams	75%
Benefit with 15.000_HRMS	15	→ 82 beams	92%
Benefit with 20.000_HRMS	7	→ 89 beams	100%

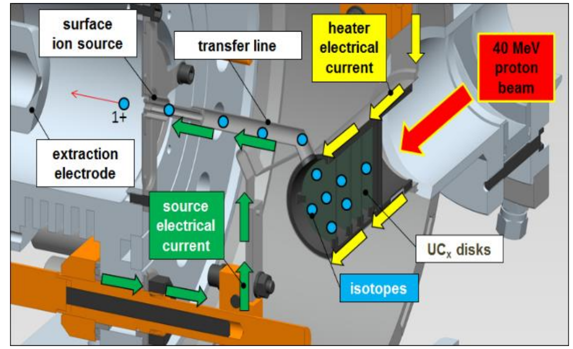


SPES core: the Target Ion Source System

Synthesis of a novel type of UC_x using graphene

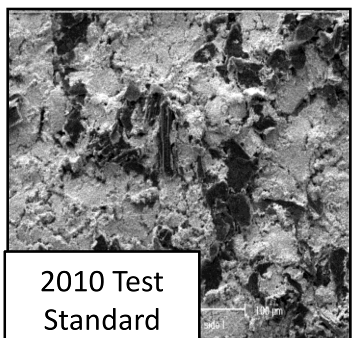
Experiment at JRC-ActUsLab-Karlsruhe: n. AUL-176



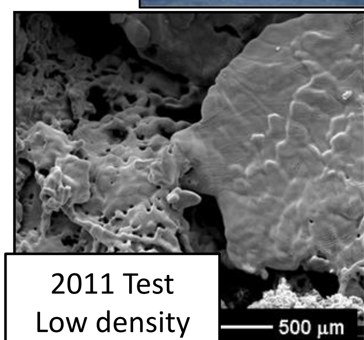


➢On-line testing of the SPES target material and architecture @ **ORNL** (2010-2012)

➢**40 MeV, 50 nA proton beam on a UCx target**



2010 Test Standard UC_X



2011 Test Low density UC_X

	2010	2011
Density (g/cm³)	4.25	2.59
Diameter (mm)	12.50	13.07
Thickness (g/cm²)	0.41	0.41
Calculated porosity (%)	58	75

Production Target

- Characterized by:
- Material of the target (production yield)
- Release time (≈1s for Fast Targets)
- Element Vapour pressure

Ion source target

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

Yield of a nuclear species

$$Y = \sigma \cdot \Phi_p \cdot N \cdot \varepsilon_d \cdot \varepsilon_e \cdot \varepsilon_i \cdot \varepsilon_t$$

It depends on → half-life, cross-section, proton flux, diffusion and effusion time, ionization and transport efficiencies