IWM-EC 2018

International Workshop on Multi facets of Eos and Clustering

22nd - 25th May 2018
Catania, Italy

The SPES Exotic Beam ISOL Facility:

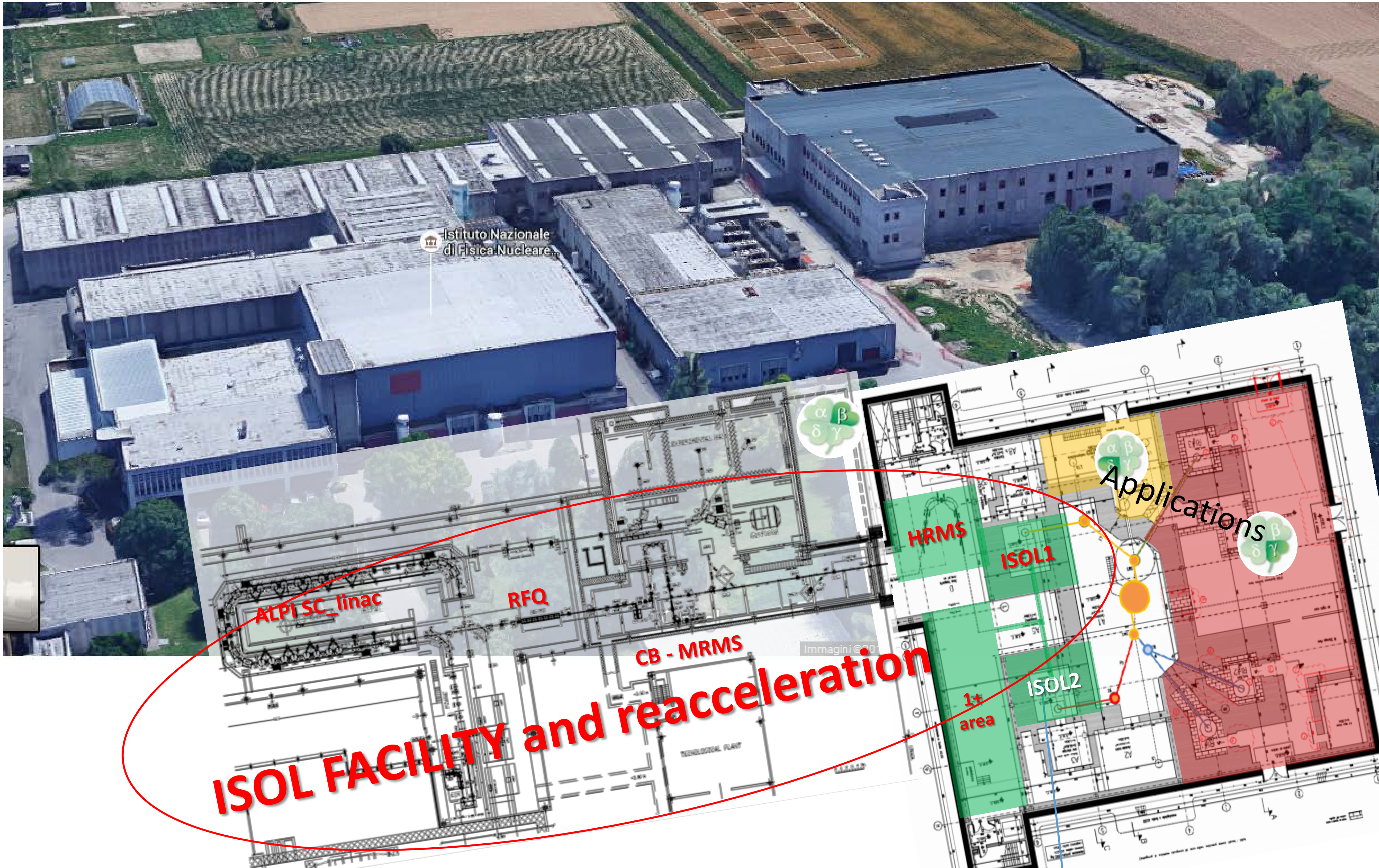
Status of the Project, Technical Challenges, Instrumentation, Scientific Program

FABIANA GRAMEGNA

INFN – Legnaro National Laboratory - Italy

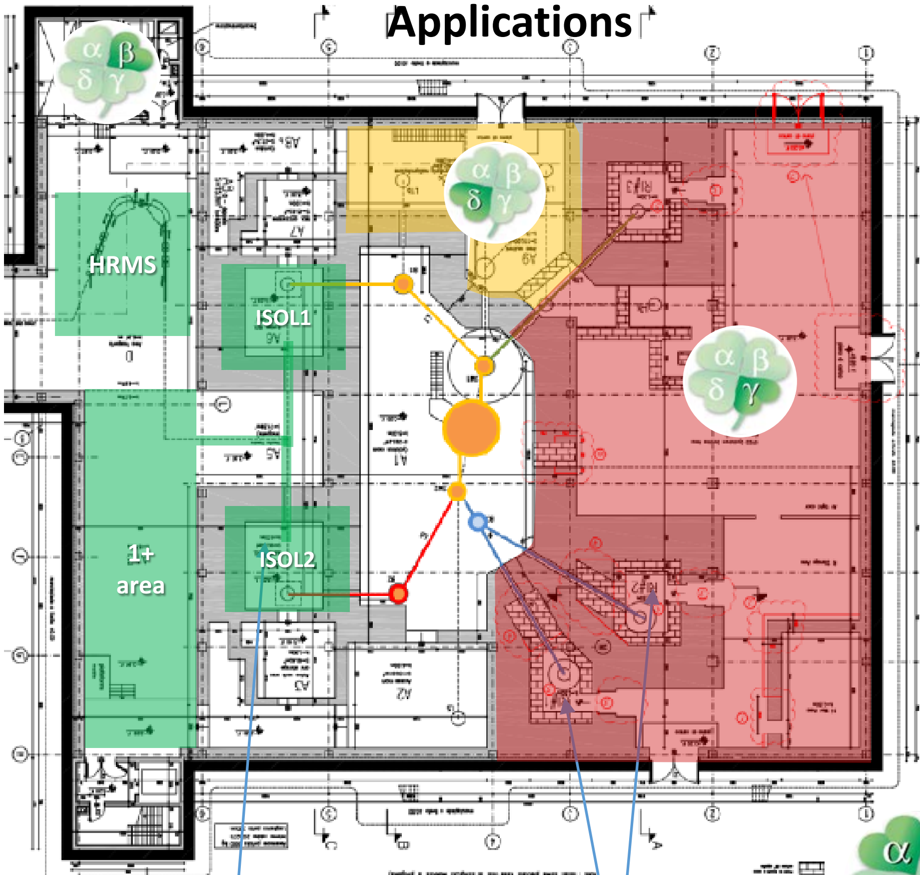
22-25 May 2018

SPES infrastructure - layout



SPES project: the phases

Nuclear Applications



ISOL RIBs+ Post-Acc

Nuclear Medicine

- Cyclotron
- ISOL RIBs+ Post-Acc.
- Nuclear Medicine
- Nuclear Applications

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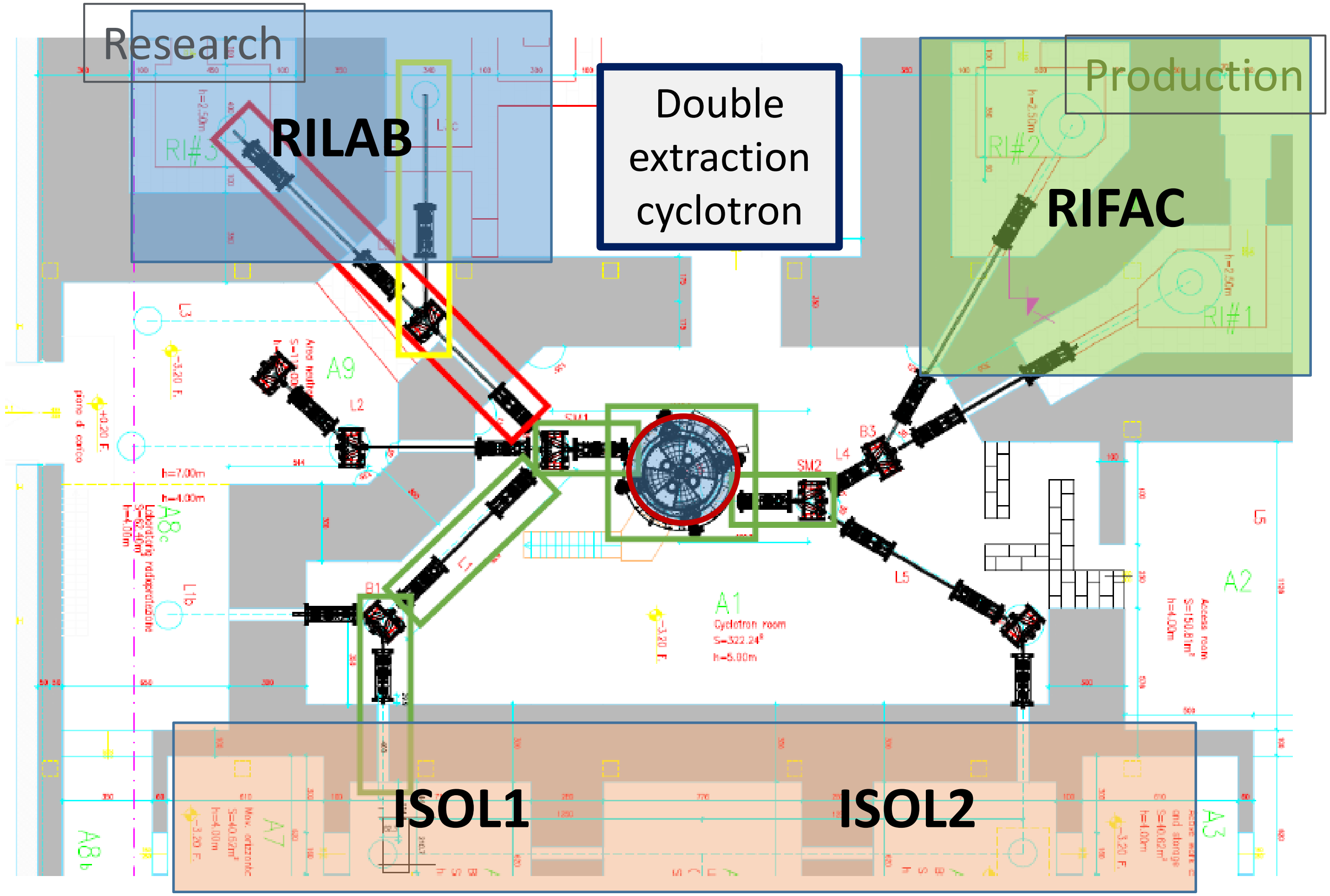
SPES-γ Radioisotopes for Nuclear Medicine

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

SPES exotic beams for science



Actual Installation: Cyclotron and BL1, BL2 lines

LARAMED (high power beam: 30-70 MeV, 10uA): beamline BL3b under construction and supplied by BEST Theratronics Installation expected in November 2018

LARAMED (low power: 30-70 MeV, 200 nA): beamline BL3c under design, tender in September 2018

- 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

Production facility operated by INFN and private partner for research and production of radioisotopes

(^{64}Cu, ^{67}Cu, ^{82}Sr, ^{68}Ge, ...)

SPES-γ Radioisotopes for Nuclear Medicine

LARAMED

Facility under construction
Standard method

- *Compounds* for Radiochemistry Installed
- Plants installed

Use of the cyclotron proton beam for radioisotope production

Production laboratory in Joint Venture with a private company (under signature):
Selected isotopes of medical interest

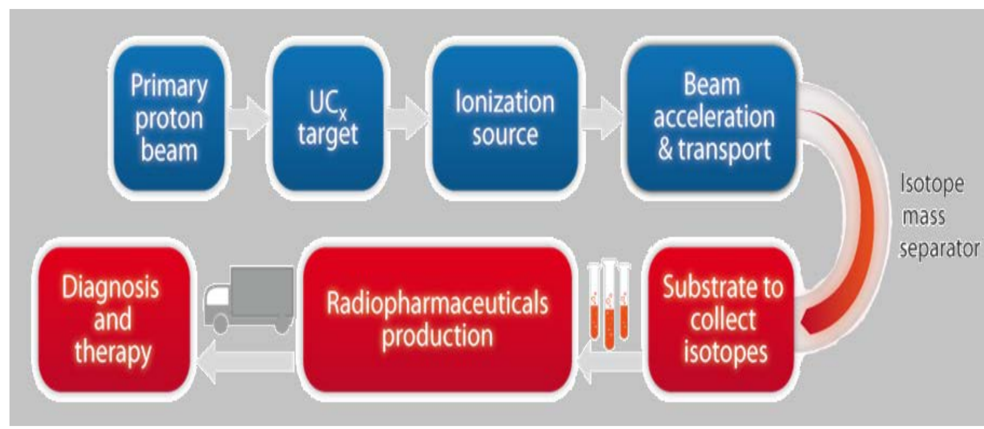
Sr-82/Rb-82 generator

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-δ: Neutron production at SPES _NEPIR

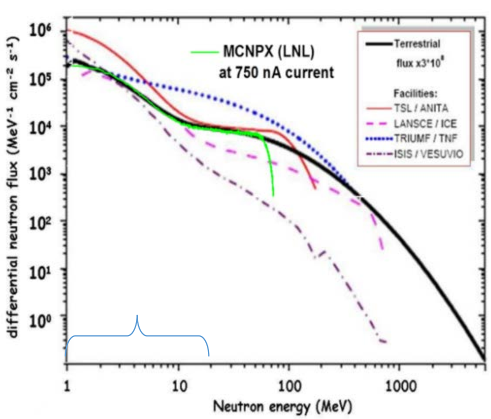
Accelerator based neutron sources have many applications: Nuclear astrophysics, Characterization of nuclear waste, BNCT... The **cyclotron** can also be used as a neutron source

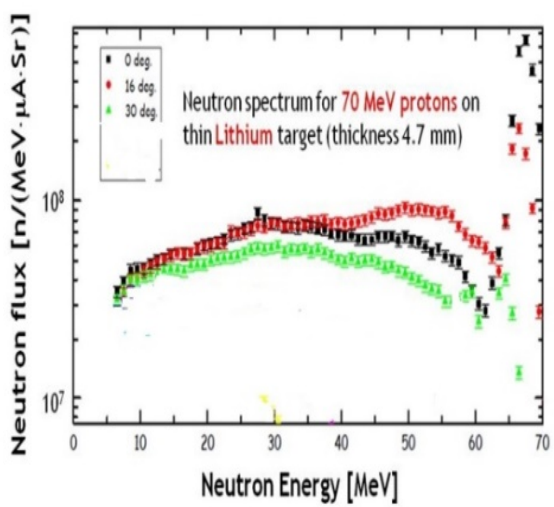
Project at design study level. Partially funded under Ministry of Research and University (collaboration with TIFPA) → SPARE (**Spa**ce **R**adiation Shi**e**lding)

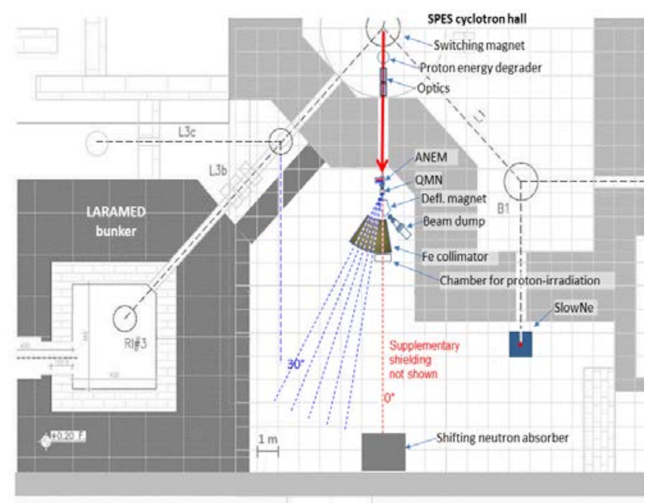
Neutron production by interaction of protons with heavy and light targets

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

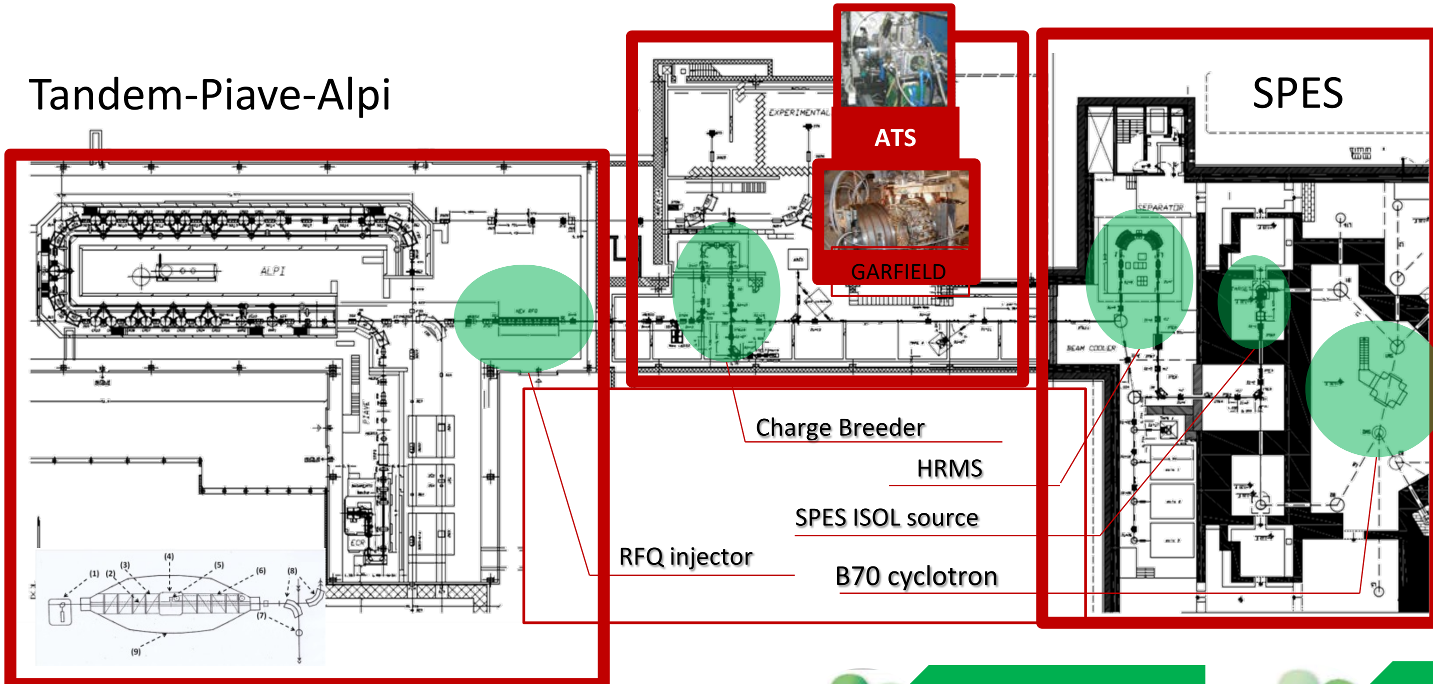
  - Continuum spectra: SEE: Single Event Effect study
  - Quasi mono-energetic spectra:







The SPES ISOL RIB project at LNL



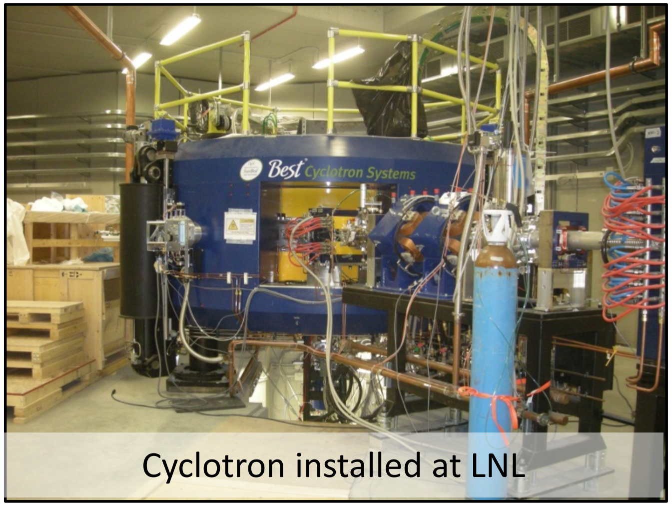
Cyclotron

ISOL RIBs+ Post-Acc.

SPES mixing

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

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)

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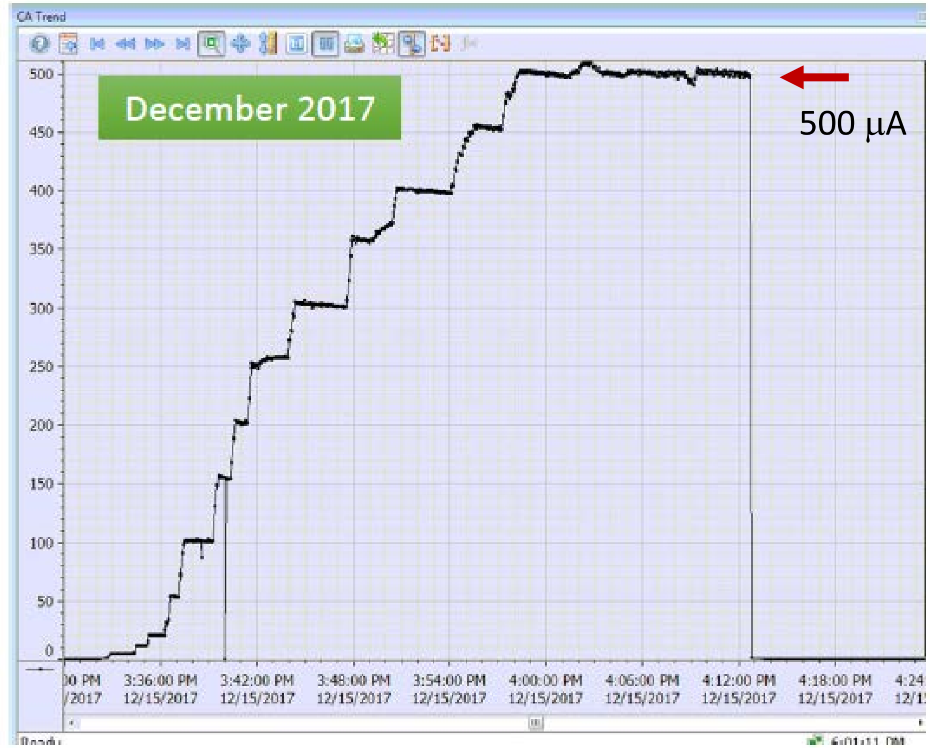
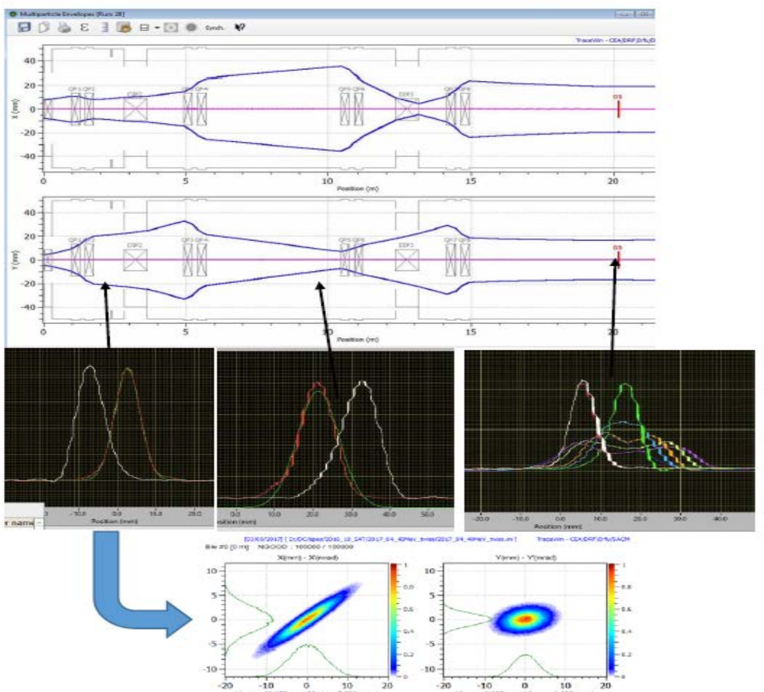
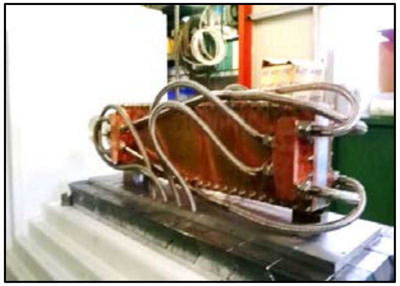
SPES core: the cyclotron

- 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

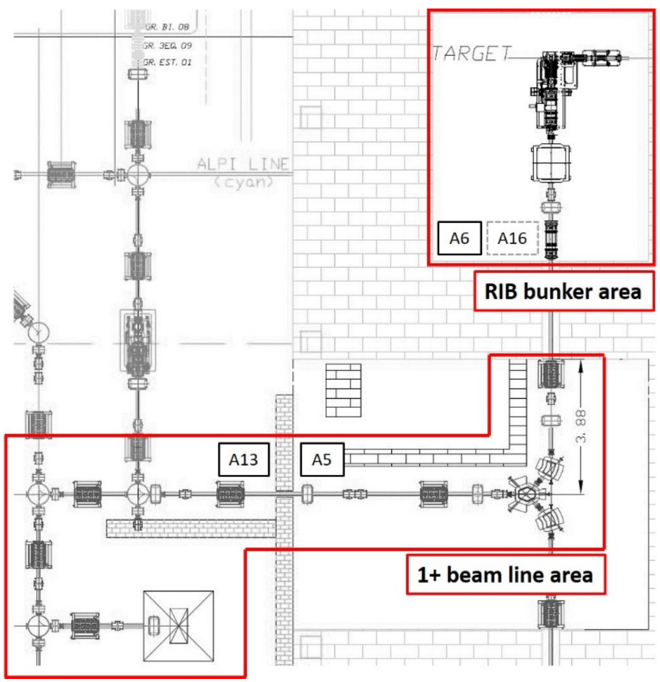
Very good Cyclotron vacuum performance
($8x10^{-8}$ mbar with beam ON)

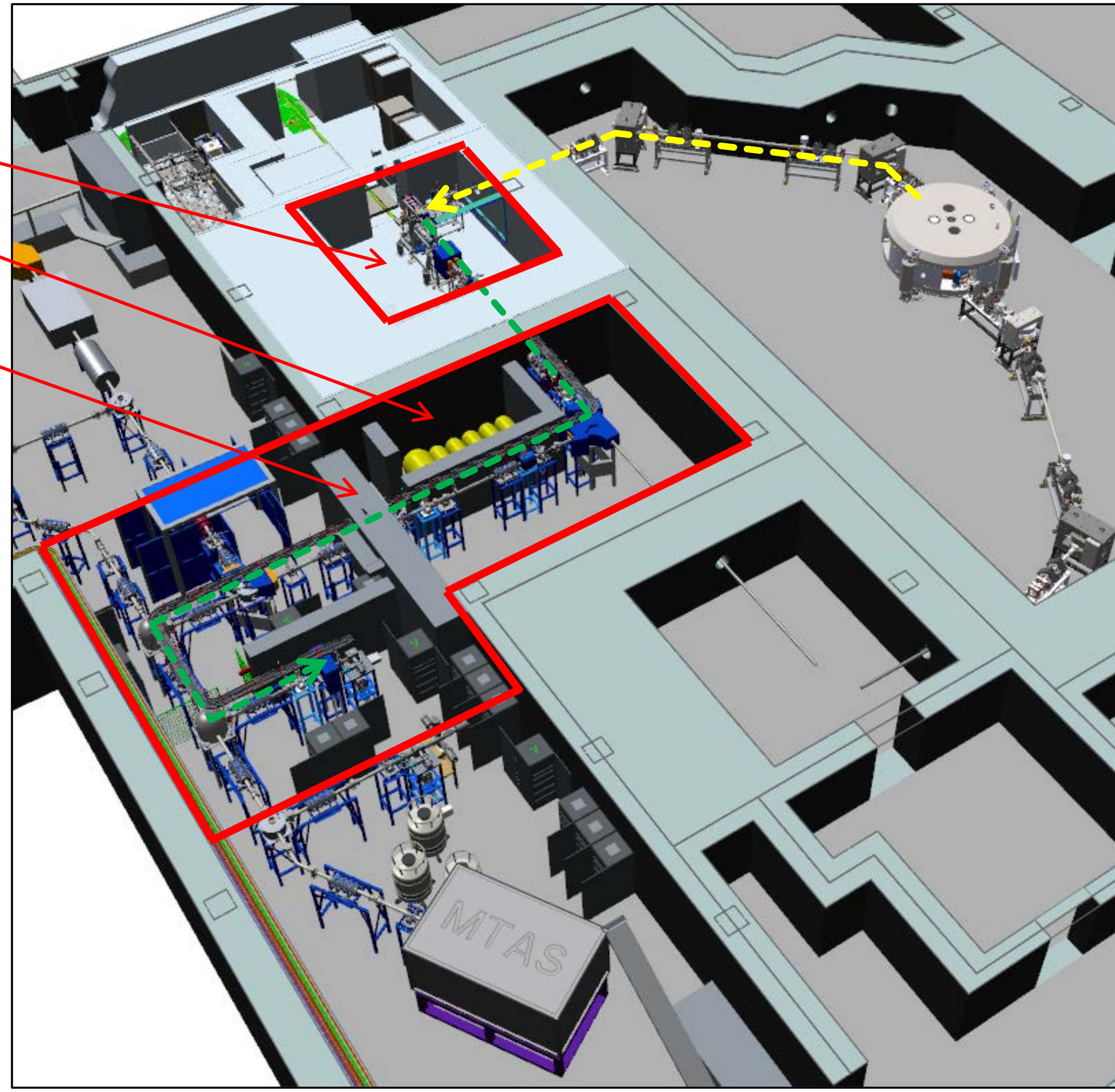
SPES core: the RIB production system

RIB bunker

Gas recovery system

1+ beam line





Courtesy of Mattia Manzolaro

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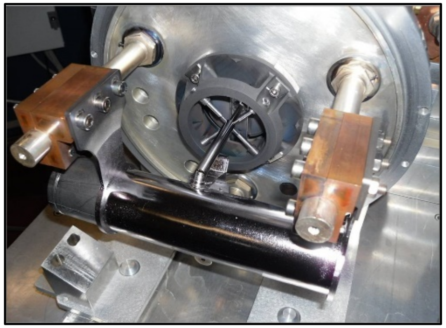
SPES Low Energy experimental area

Front end and Target – Ion Source unit



tape stations:

- RIB diagnostic
- β-decay studies

Tape station for beam diagnostic & characterization based on Orsay design (BEDO)

3 Beta decay stations under construction:

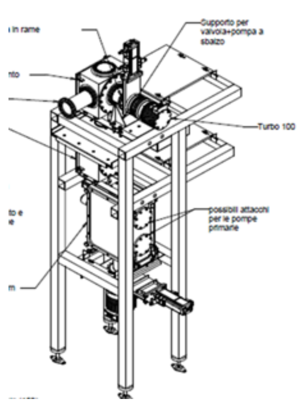
- 2 Tape stations + β detectors + HPGe for RIB characterization (*T. Marchi & F. Gramegna*)
- 1 Tape station dedicated to Physics: Coupling to a larger number of HPGe, β detectors LaBr3, neutron detectors etc…(*G. Benzoni (INFN Mi) contact person*)

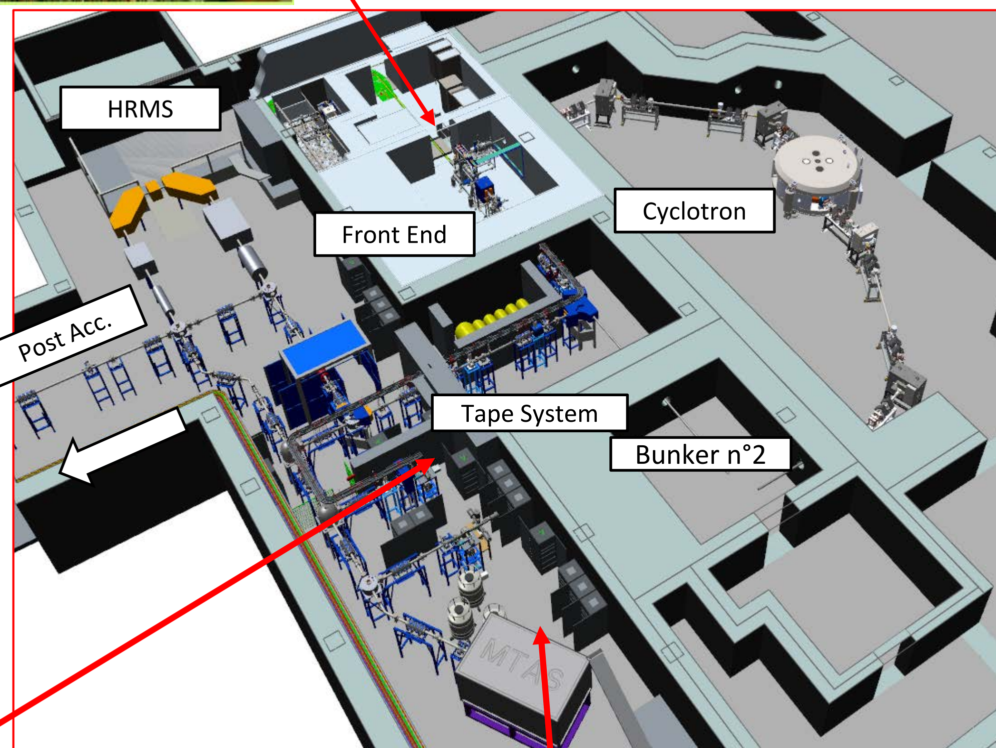
LOW ENERGY RIB AREA:

Collaboration with:

ORNL (MTAS_Total absorption spectrometer, VANDLE_neutron array) Rykaczewski

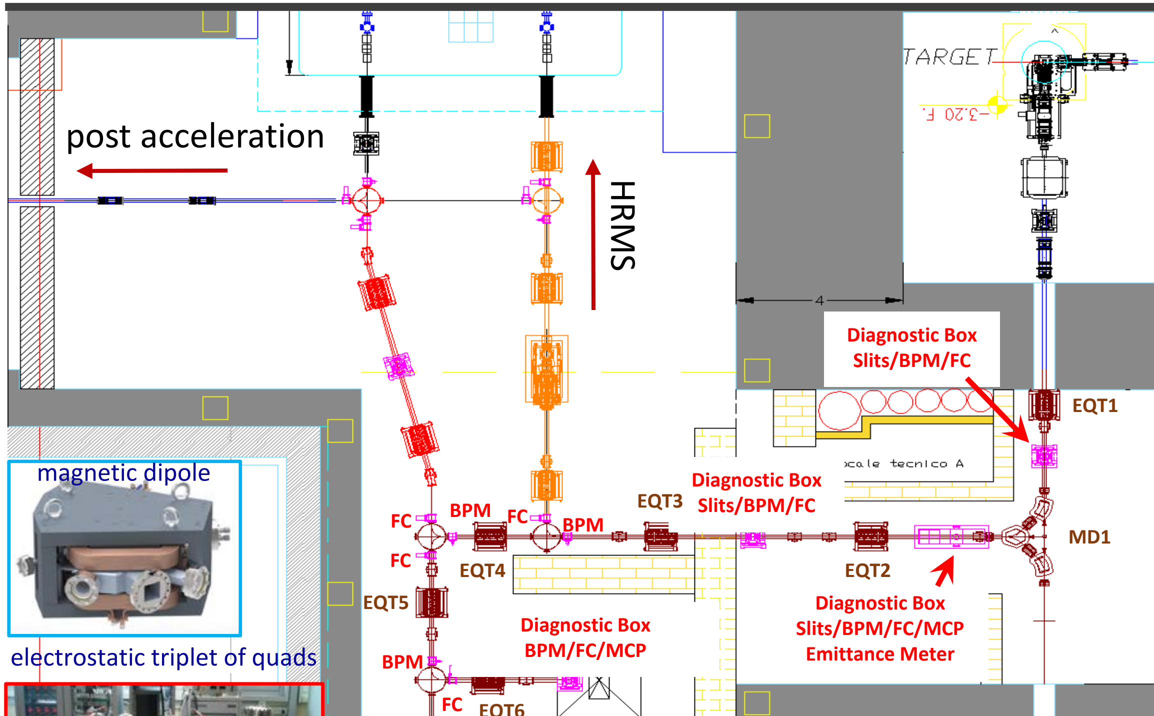
SPES international workshop 2016



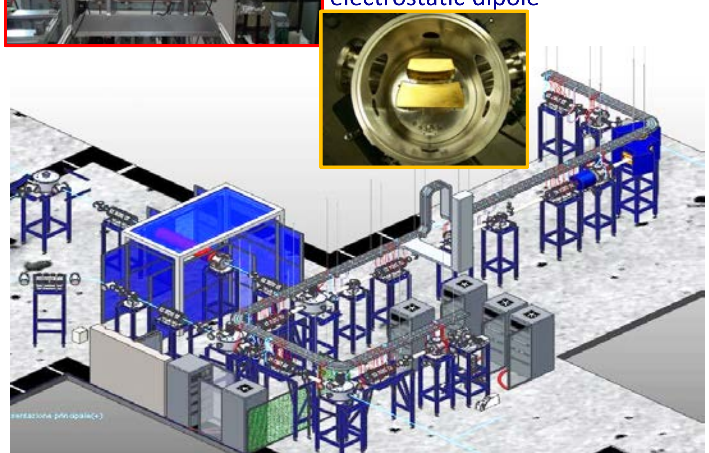


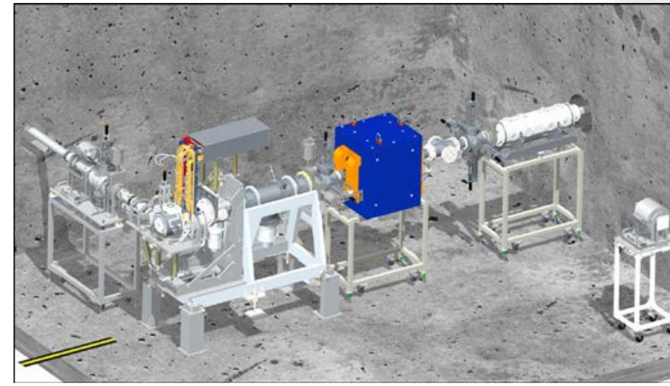
Non reaccelerated RIB Experimental area

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

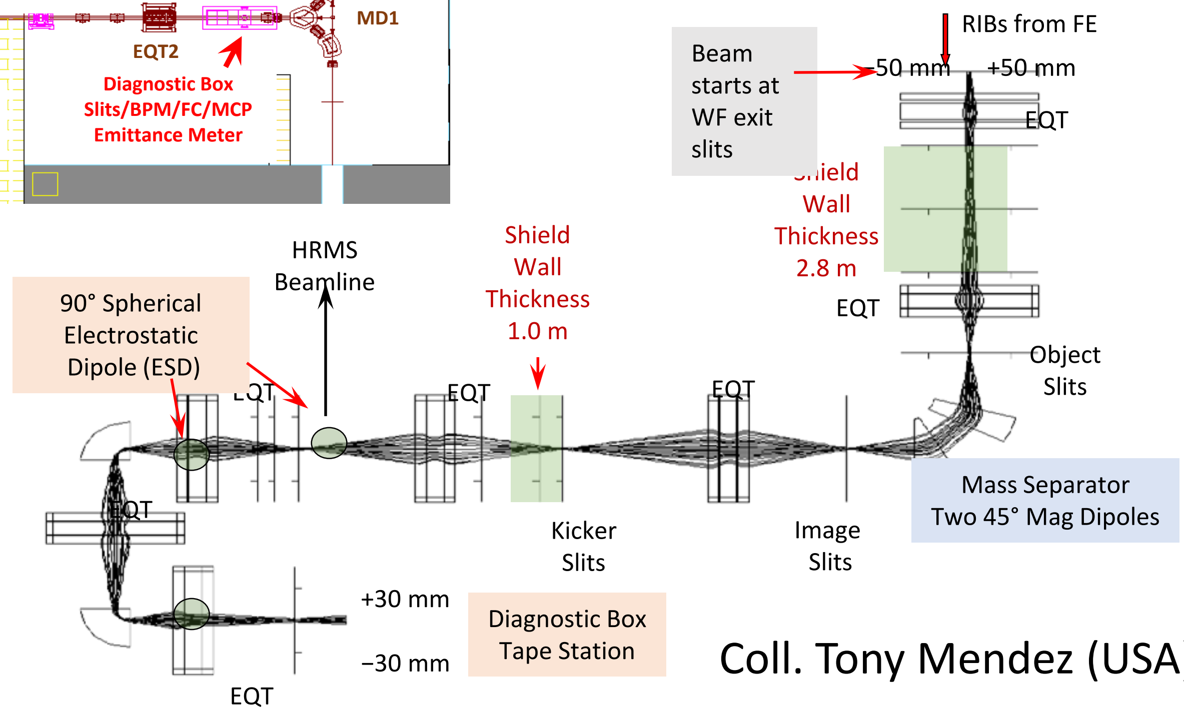


electrostatic dipole





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



Coll. Tony Mendez (USA)

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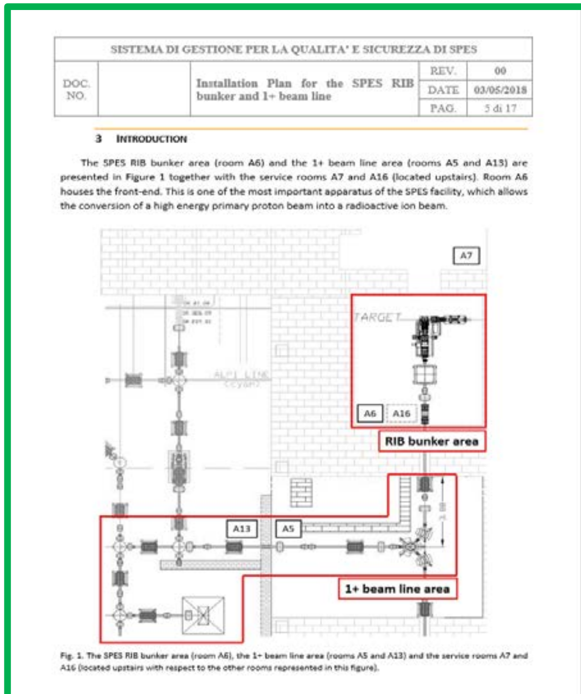
SPES core: the RIB production system

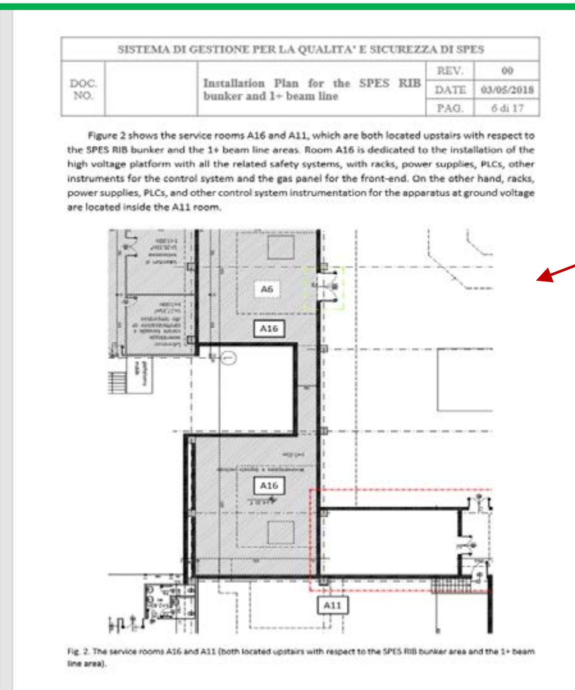


SISTEMA DI GESTIONE PER LA QUALITA' E SICUREZZA DI SPES				
DOC. NO.		Installation Plan for the SPES RIB bunker and 1+ beam line	REV.	00
			DATE	03/05/2018
			PAG.	5 di 17

3 INTRODUCTION

The SPES RIB bunker area (room A6) and the 1+ beam line area (rooms A5 and A13) are presented in Figure 1 together with the service rooms A7 and A16 (located upstairs). Room A6 houses the front-end. This is one of the most important apparatus of the SPES facility, which allows the conversion of a high energy primary proton beam into a radioactive ion beam.

Fig. 1. The SPES RIB bunker area (room A6), the 1+ beam line area (rooms A5 and A13) and the service rooms A7 and A16 (located upstairs with respect to the other rooms represented in this figure).



SISTEMA DI GESTIONE PER LA QUALITA' E SICUREZZA DI SPES				
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			DATE	03/05/2018
			PAG.	6 di 17

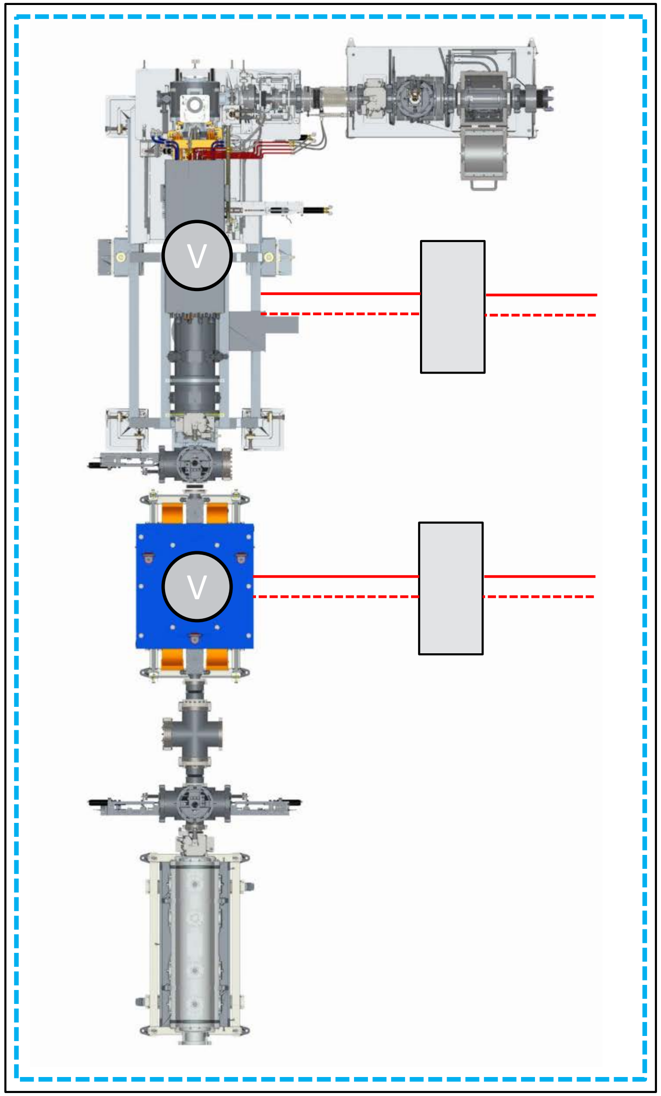
Figure 2 shows the service rooms A16 and A11, which are both located upstairs with respect to the SPES RIB bunker and the 1+ beam line areas. Room A16 is dedicated to the installation of the high voltage platform with all the related safety systems, with racks, power supplies, PLCs, other instruments for the control system and the gas panel for the front-end. On the other hand, racks, power supplies, PLCs, and other control system instrumentation for the apparatus at ground voltage are located inside the A11 room.

Fig. 2. The service rooms A16 and A11 (both located upstairs with respect to the SPES RIB bunker area and the 1+ beam line area).

INSTALLATION document ready

COMMISSIONING document & OPERATION document under development

SPES core: Installation plan schematic overview



- Removing the Beam Dump and stocking in reserved area
- Cleaning, painting, sealing and general preparation of the experimental rooms
- Installation of the main plants with cables and pipes at specific hubs
- Mechanical installation of the main parts of the machine / beam line
- Installation of the vacuum system
- Installation of the cabling and piping systems between the hubs and the machine / beam line
- Installation of the control system

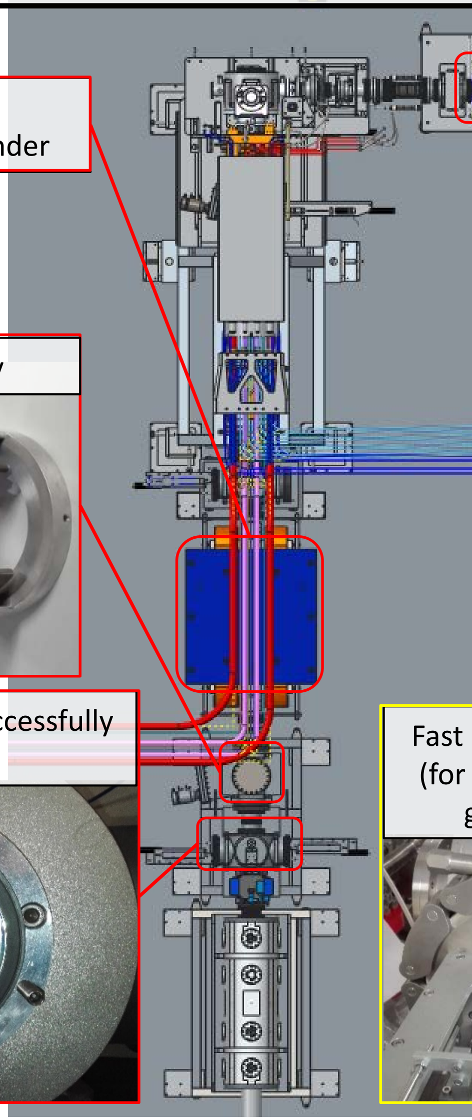
… for both the **RIB bunker area** and the **1+ beam line area**

Courtesy of Mattia Manzolaro

SPES core: The Front-End Construction Status

Most of the 3D design has been completed. Few missing details will be completed within May 2018

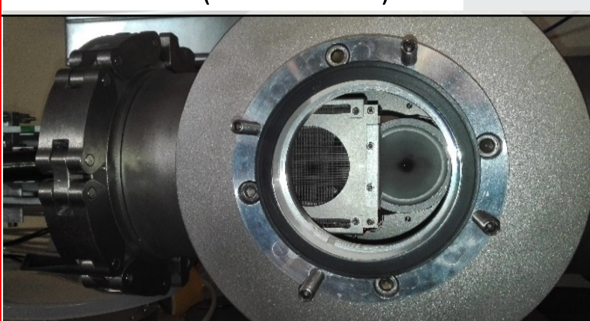
FE upgrading: the nuclearization phase



Specifications of the Wien Filter magnetic part written for the tender

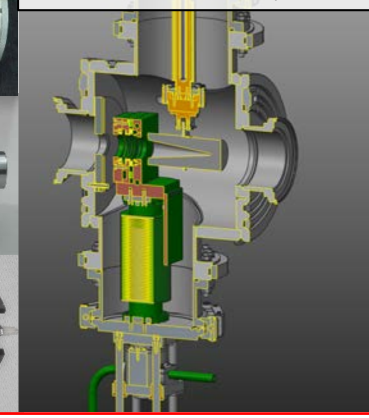
Steerers: tested successfully

Second diagnostic box: tested successfully (with controls)



Proton Beam collimator box

Proton Beam Diagnostic box (green to be constructed)



Fast clamps defined (for diagnostic and gate valves)

Defined and bought helicoflex of proton beam line

Courtesy of Mattia Manzolaro

SPES core: Radiation Damage Study (SPES-RDS)

An **international** cooperation

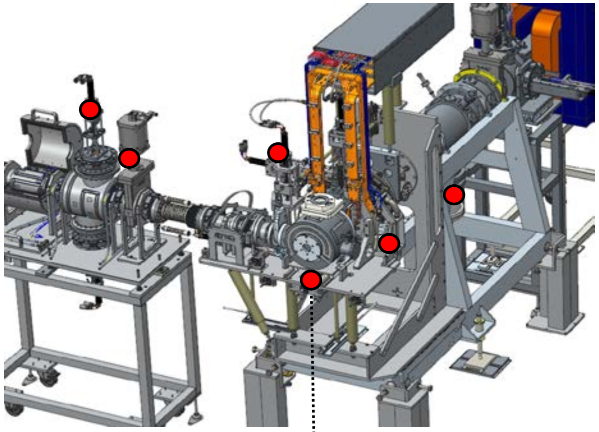
- Department of Mechanical Engineering, **UniBs**
- TRIGA Research Nuclear Reactor LENA, **UniPv**
- European Spallation Source **ESS** ERIC, **Sweden**

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.

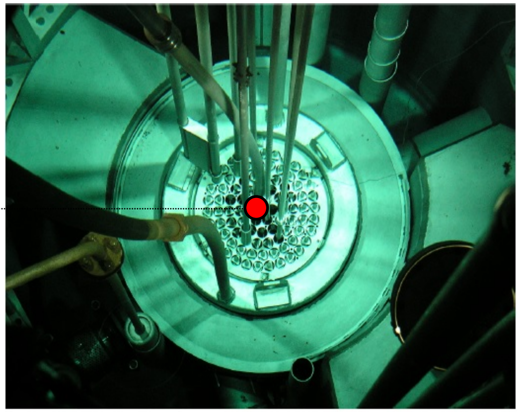
Lubricants in the SPES Front-End



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

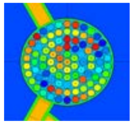
[1]
PRODUCTS SELECTION
✓ 9 products

[2]
IRRADIATION in REACTOR FACILITY
Neutrons + gamma



Central Thimble irradiation facility
TRIGA MARK II Research Reactor

[3]
DOSIMETRY CALCULATIONS
MCNP5 Monte Carlo



SPES core: Toward the first SPES RIBs

40 MeV, 20 μA

SiC target

SAINT-GOBAIN

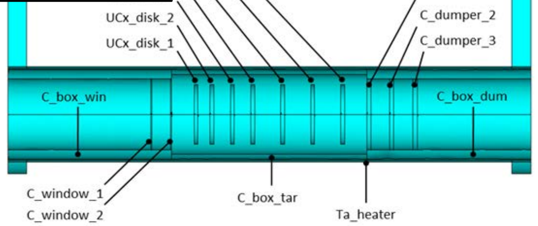
First SPES RIB (^{26}Al)

the next two steps of the commissioning phase

40 MeV, 20 μA, 10^{12} f/s

UCx target

the scaled SPES target for low intensity RIBs



Nominal parameters

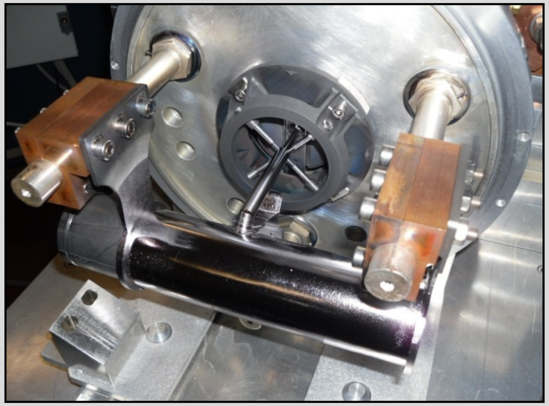
- Target material: UCx (SiC as an alternative)
- Proton beam energy: 40 MeV
- Proton beam intensity: 20 μA
- Proton beam sigma: 5 mm
- Collimator radius (= disk radius): 6,5 mm

first n-rich fission isotopes

40 MeV, 200 μA, 10^{13} f/s

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)

Courtesy of Mattia Manzolaro

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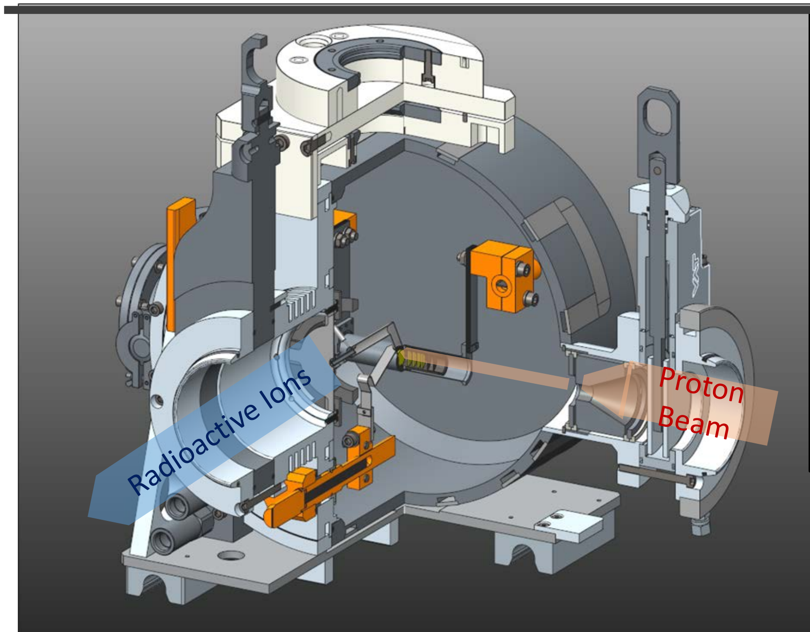
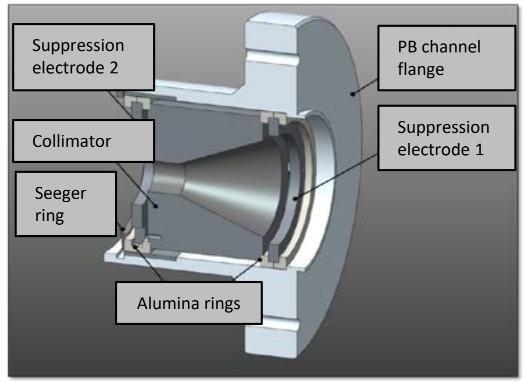
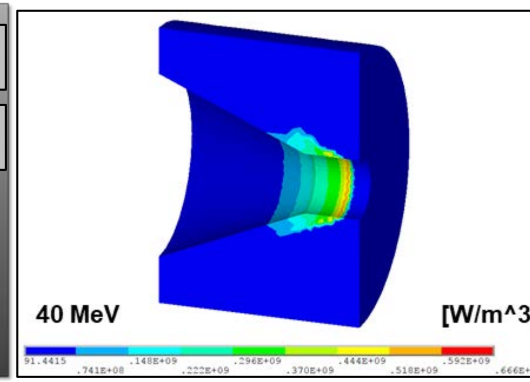
SPES core: Development of the SiC Target - Ion Source Unit

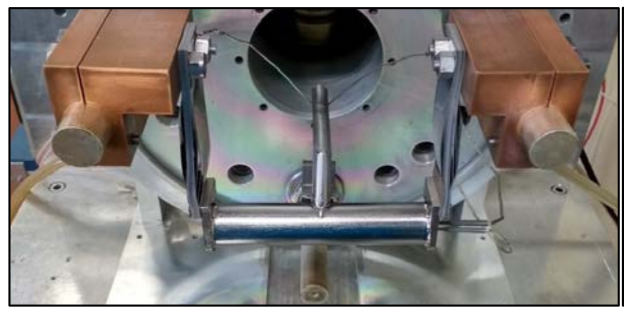


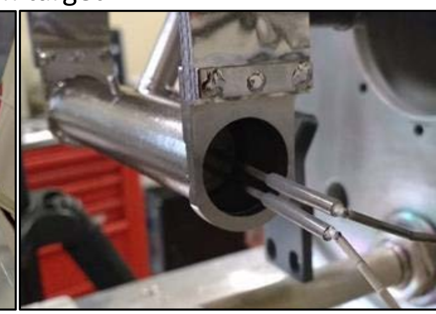
Collimator (required for the 13 mm target)

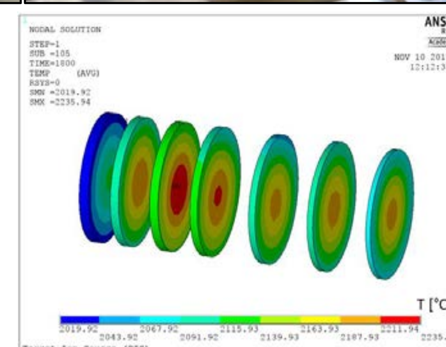




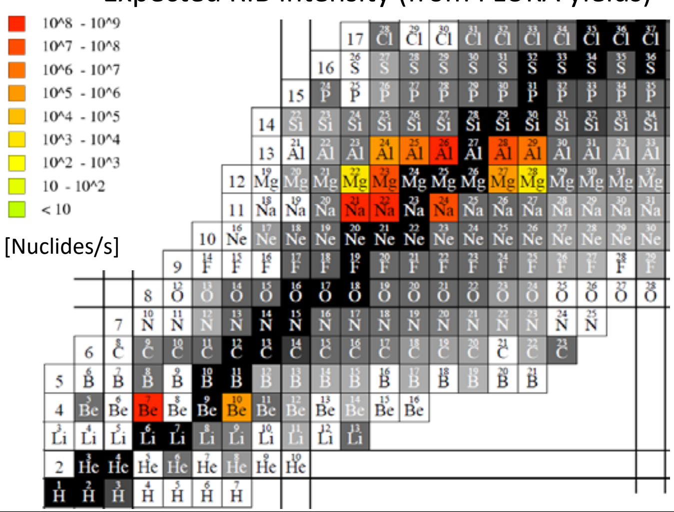
Silicon carbide 13 mm target







Expected RIB intensity (from FLUKA yields)

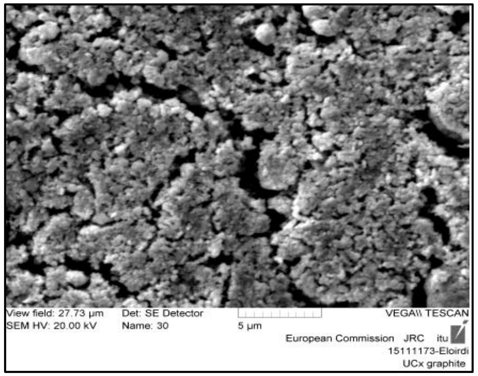


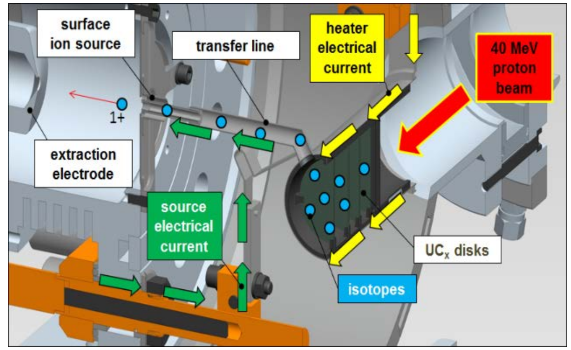
Courtesy of Mattia Manzolaro

SPES core: the Target Ion Source System

Synthesis of a novel type of UC_x using graphene

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





Production Target

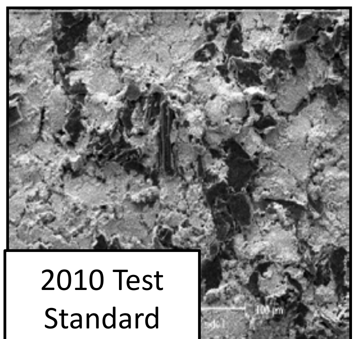
- Characterized by:
- Material of the target (production yield)
- Release time (≈1s for Fast Targets)
- Element Vapour pressure

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

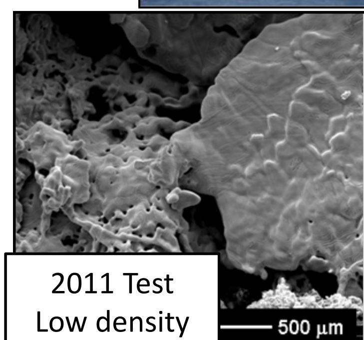
➢**40 MeV, 50 nA proton beam on a UCx target**

Ion source target

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



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

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

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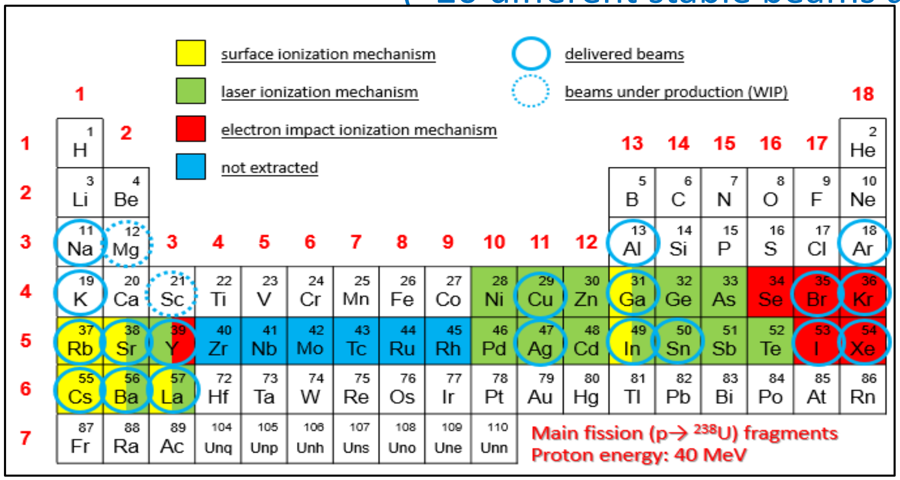
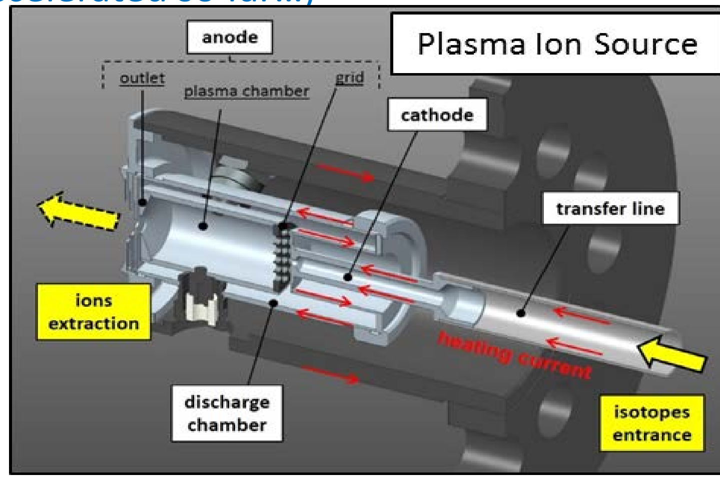
SPES core: the Target Ion Source System

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

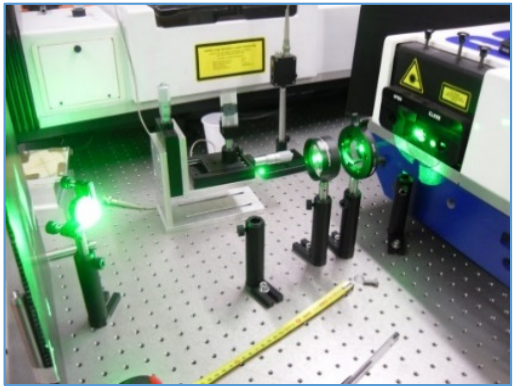
IWM-EC 2018

SPES core: the Target Ion Source System

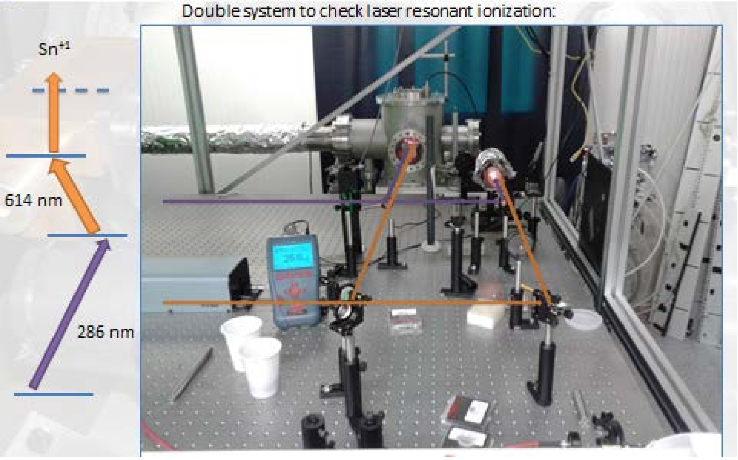
Resonant Laser Source for Selective ionization

LNL OFF-LINE LABORATORY

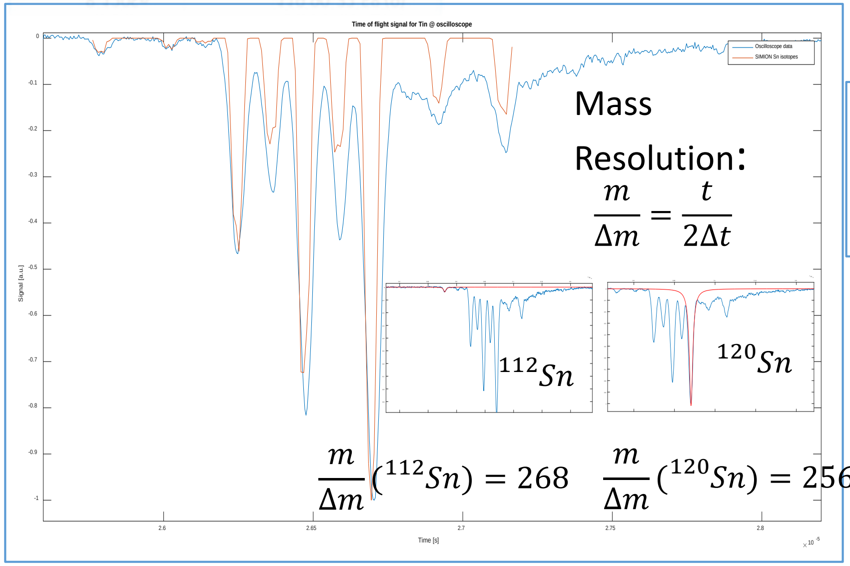
	Isotope	Mass	Abundance
1	112Sn	111,90	0.97 (1)
2	114Sn	113,90	0.66 (1)
3	115Sn	114,90	0.34 (1)
4	116Sn	115,90	14.54 (9)
5	117Sn	116,90	7.68 (7)
6	118Sn	117,90	24.22 (9)
7	119Sn	118,90	8.59 (4)
8	120Sn	119,90	32.58 (9)
9	122Sn	121,90	4.63 (3)
10	124Sn	123,91	5.79 (5)



ToF performances: Tin laser resonant ionization

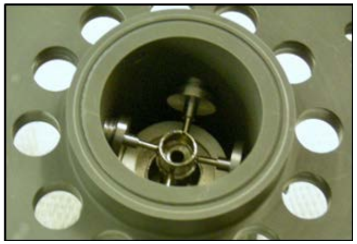


Simion® simulation VS ToF acquisition & ToF mass resolution



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

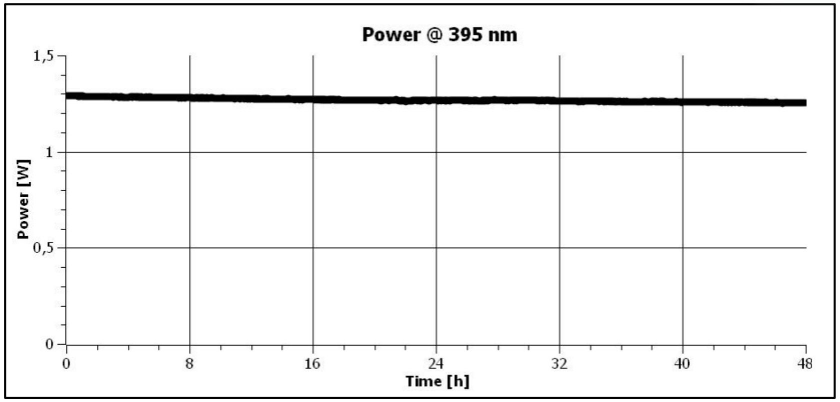
Plasma source: optimized to avoid hot-spot and to maximize current
New alignment system
≈ 40 heating-cooling cycles
≈ 160 working hours @ 2000°C

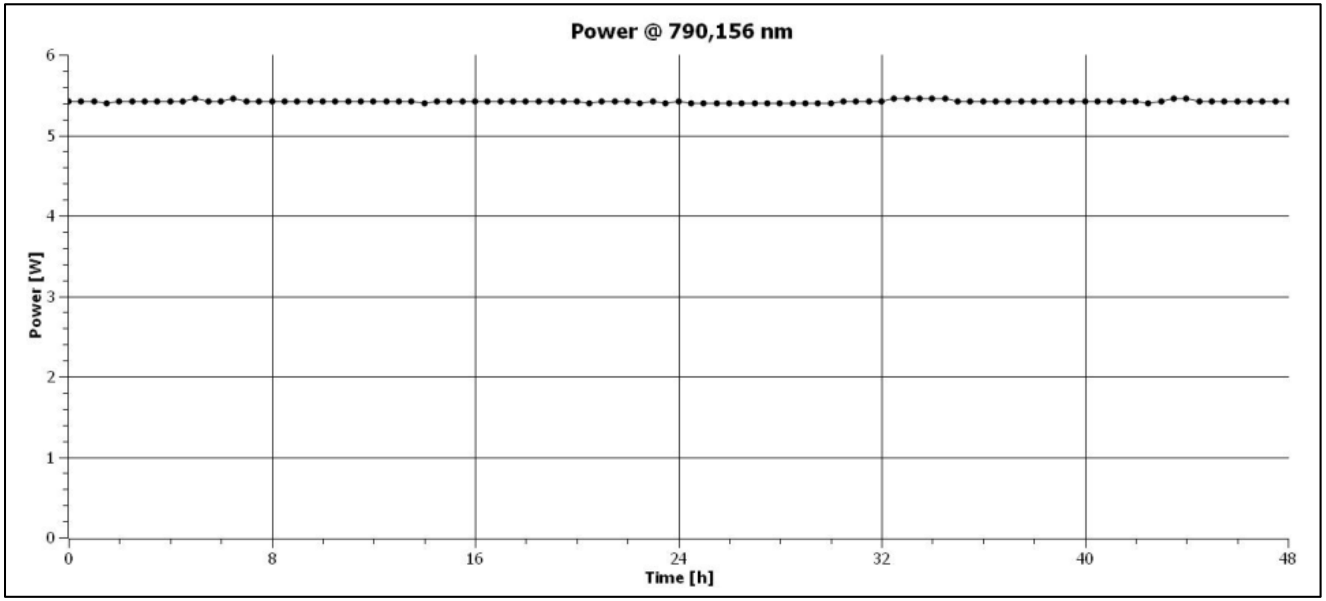


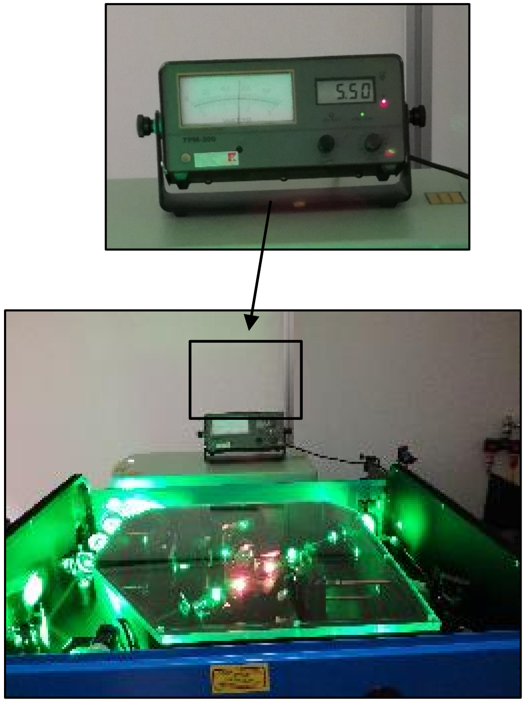
IWM-EC 2018

New SS Laser System for on-line operation (10 kHz rep rate)

- **First prototype ready (@Sirah)**
- **Requirements completely satisfied**
- **FAT (48 h full power) done and OK**
- **Other two line in production (@Sirah)**
- **On-line laser lab on preparation (@LNL)**

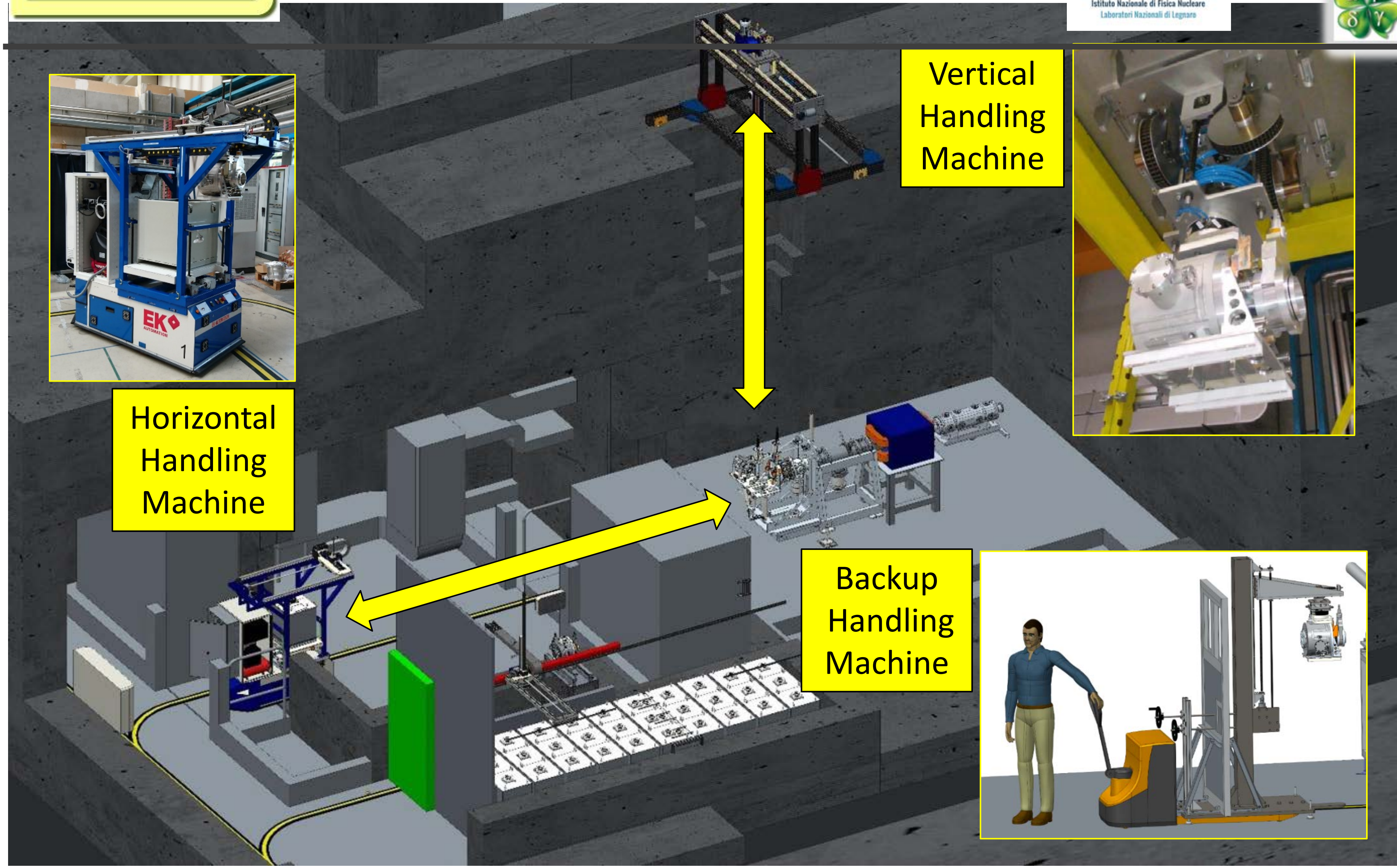






Courtesy of Mattia Manzolaro

SPES core: Horizontal & Vertical handling Machines



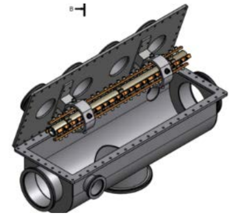
Courtesy of Mattia Manzolaro

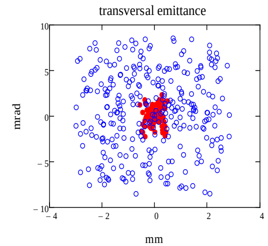
IWM-EC 2018

Beam selection: HRMS

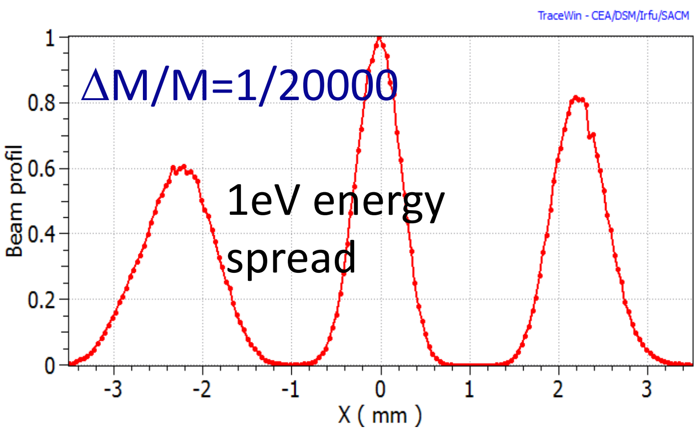
- Physical design ready, integration with beam cooler (coll. With LPC- CAEN) and beam lines under way
- Preliminary dipole design and feasibility check with potential manufacturer done
- Evolution:
  - Critical Design Review in 4-5 October 2018
  - Authorization to tender February 2019
  - Commissioning 2022

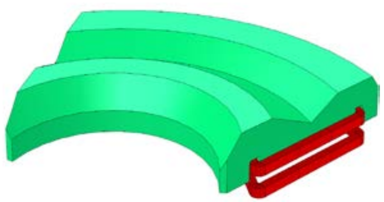
BEAM COOLER



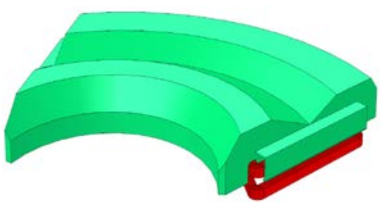


Input T emittance
Output T emittance

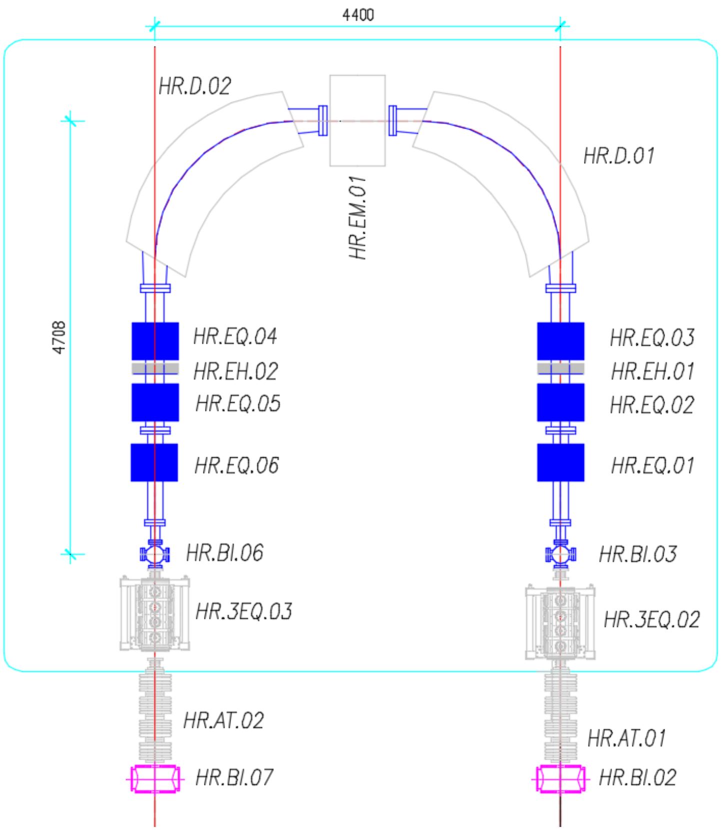




3D half-model without field clamps



3D half-model with uniform field clamps



Input requirements:

ΔE= ± 1 eV

Emittance $_{rms,n}$ = 0.68 πmm mrad

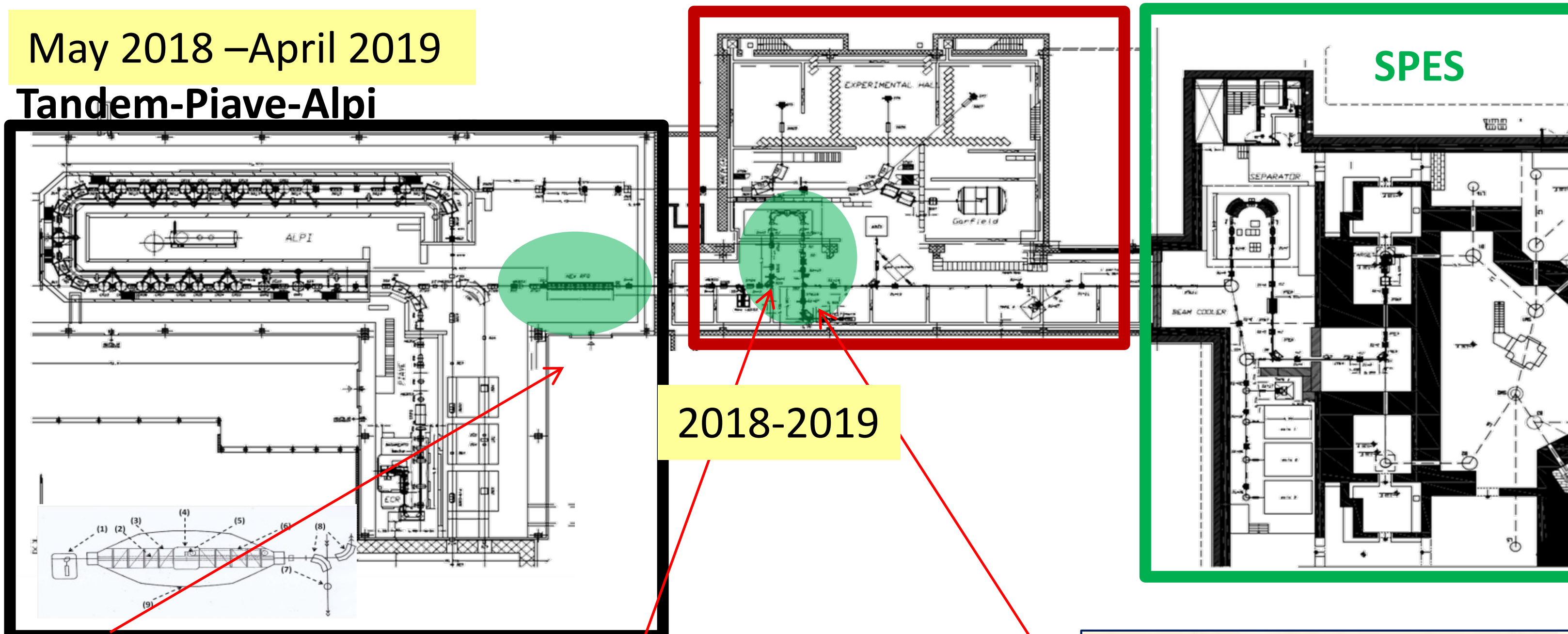
Table 2: Beam Dynamics Parameters

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

n^{+} beam & Reacceleration

May 2018 –April 2019

Tandem-Piave-Alpi

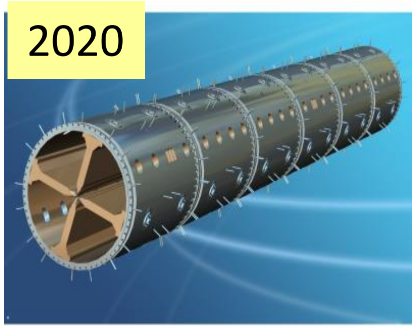


2018-2019

Mass separator to clean the beam from CB contaminants

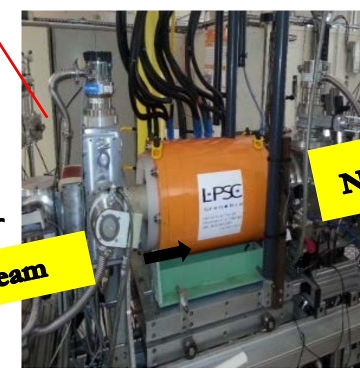
Contract for experimental activity with LPSC Grenoble on contaminants reduction sent to INFN for signature

2020



Pre-accelerator RFQ (700 keV/n)

ECR_Charge Breeder from 1^{+} to n^{+}



N+ Beams

1+ Beam

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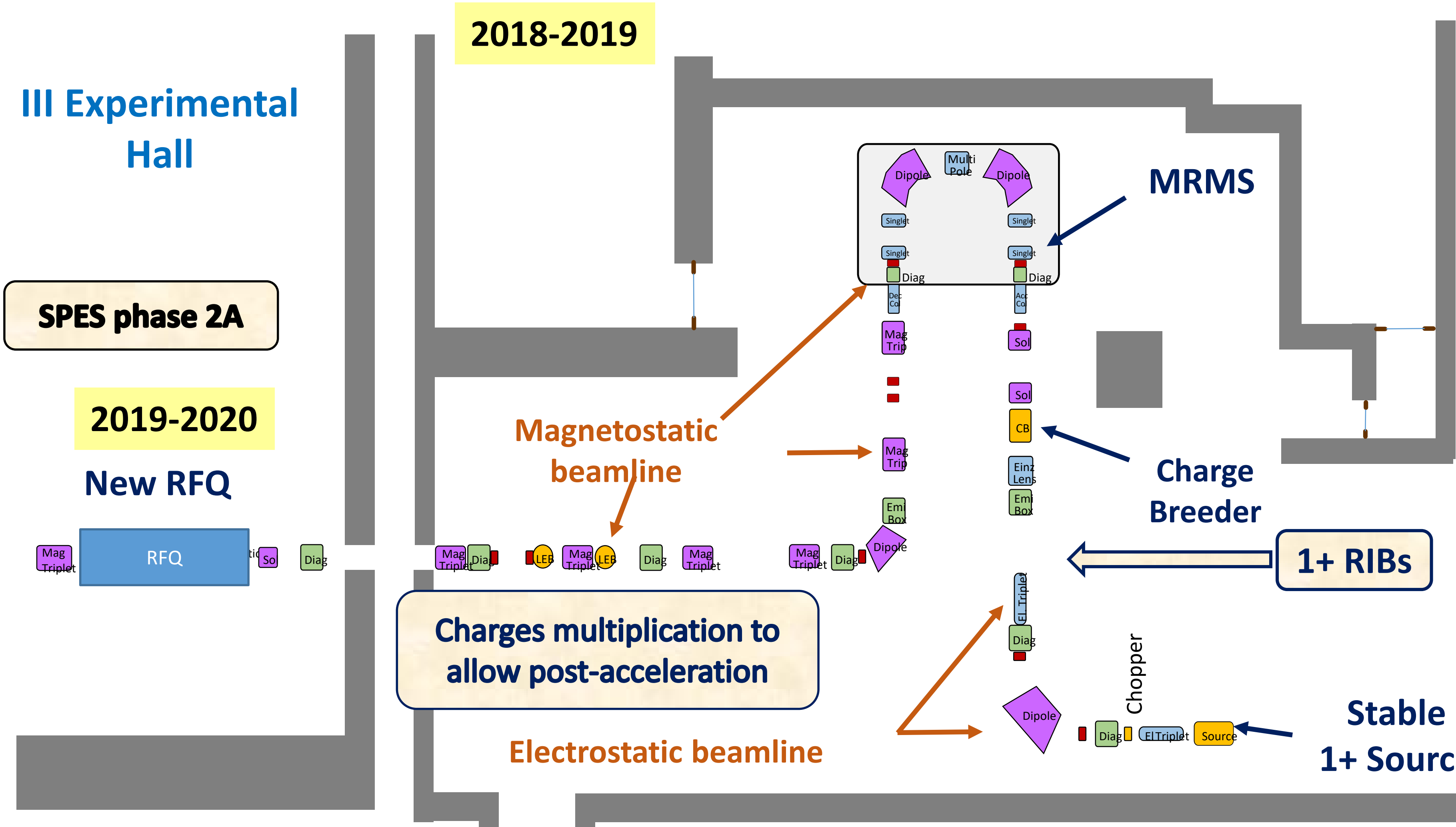
Towards ALPI: ADIGE→

Charge Breeder + MRMS + RFQ



Charges multiplication to allow post-acceleration

- **Beginning of the operations with the N+ beam line (first part) in June 2018).**
- **Break in Autumn 2019 to allow the installation of the line up to the RFQ.**

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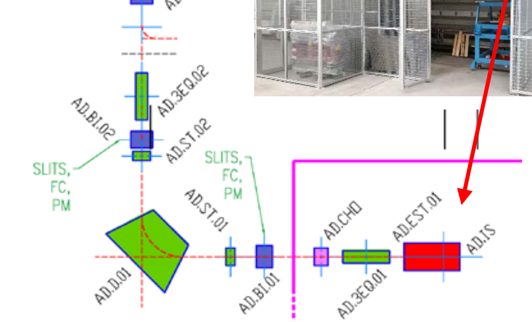
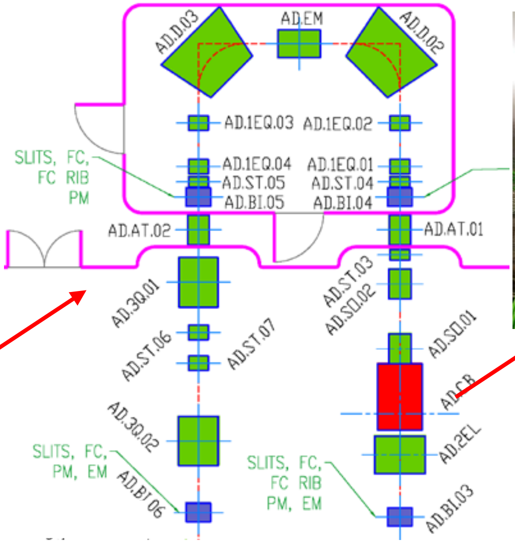
Towards ALPI:
Charge Breeder + MRMS + RFQ

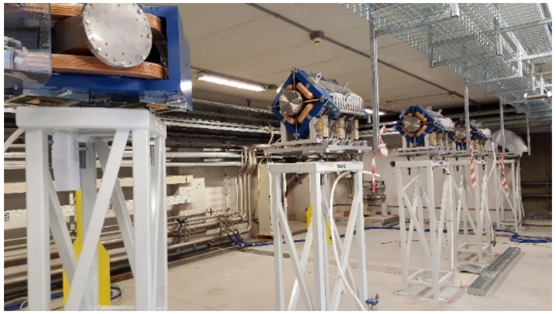


- First operation with SIS (Rb, Cs)
- Some stable isotopes need PIS (Sn, Sb, Te)
- Characterization of the 1+ sources
- Test of beam transport and transmission of the 1+ beam.



CB & Cabling

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.



PIATT-MRMS @ Pantechnik

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

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

In autumn 2018 a gradual commissioning of the MRMS will be performed

IWM-EC 2018

RFQ: new Injector for ALPI

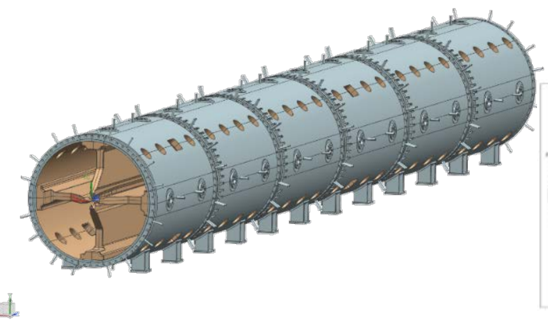
- Construction of vanes: tender completed in July 2016. Prototype in construction
  - 1st set of 4 electrodes (module 5) was successfully delivered in April 2017
  - 2st set of 4 electrodes (module 4) was brazed in May 2017
- June 2017: Tender for tank construction

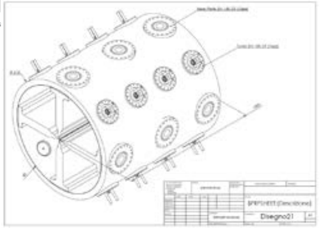
RFQ INSTALLATION PLAN

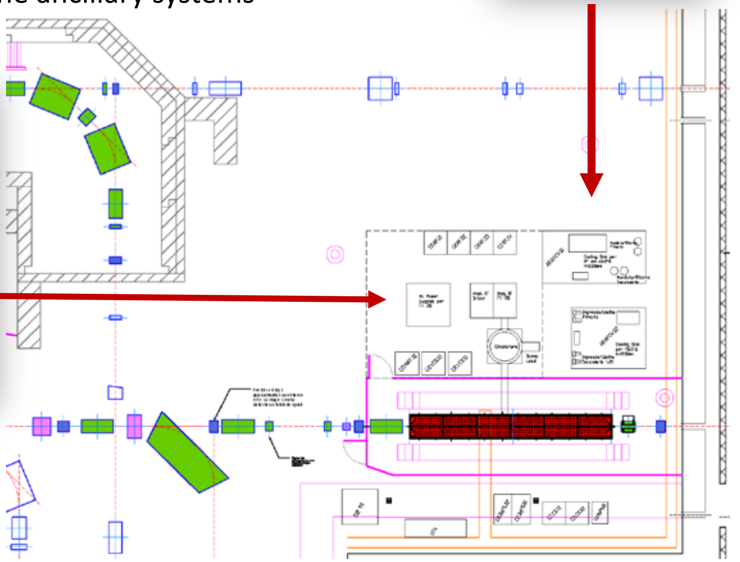
2018
- Tooling for RFQ modules assembly
- Ancillary parts engineering design completion
- All Electrodes & some tanks produced

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



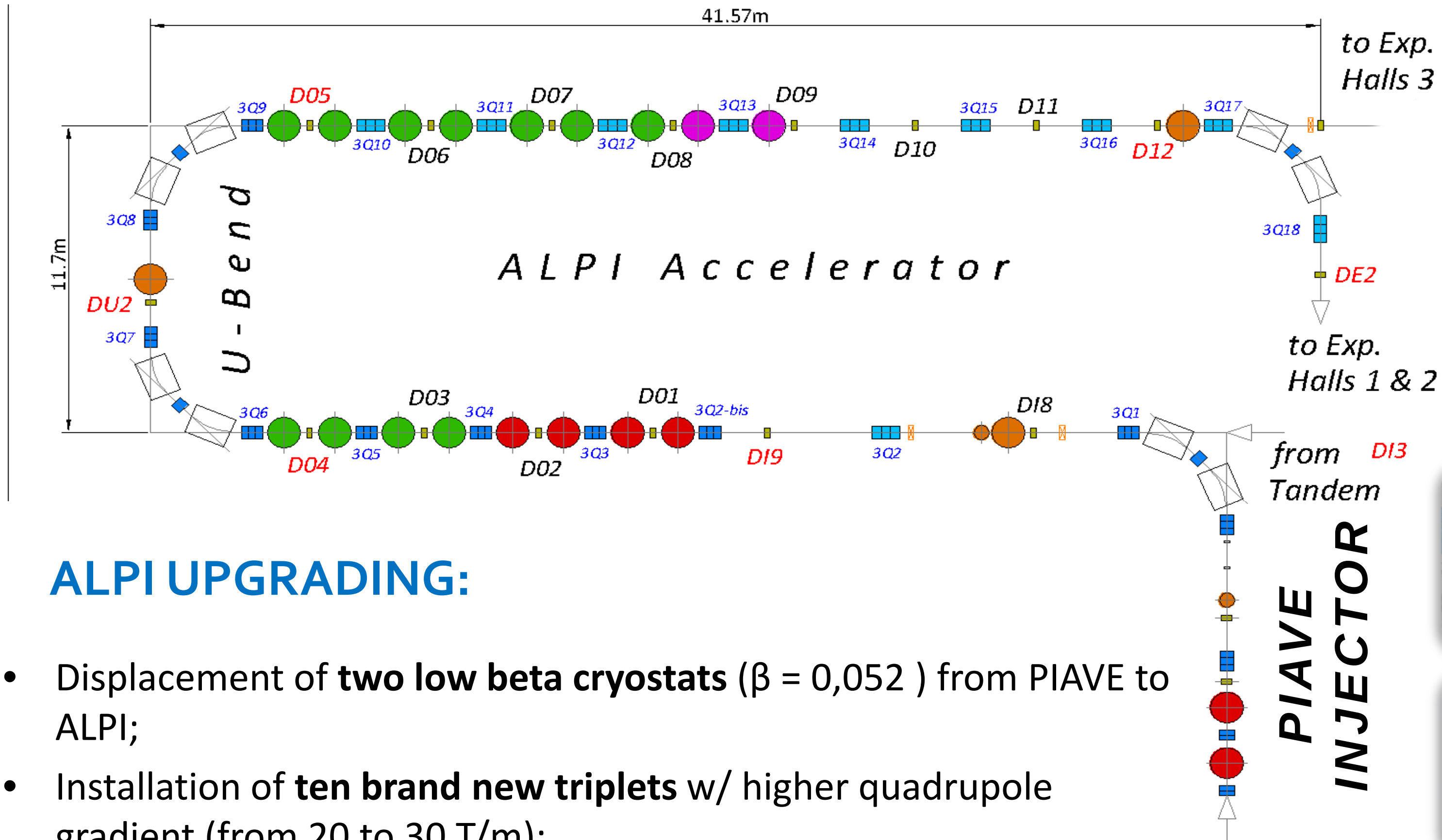


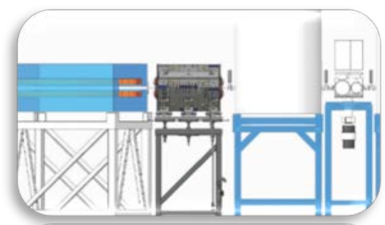


- Energy 5.7 –> 727.3 keV/A [β=0.0395] (A/q=7)
- Beam transmission >93% for A/q=3÷7
- RF power (four vanes) 100 kW (f=80 MHz)
  for up to 1 mA beam (…future high current stable beams)
- Mechanical design and realization, similar to the Spiral2 one, takes advantage of IFMIF technological experience

IWM-EC 2018

ALPI: upgraded performances



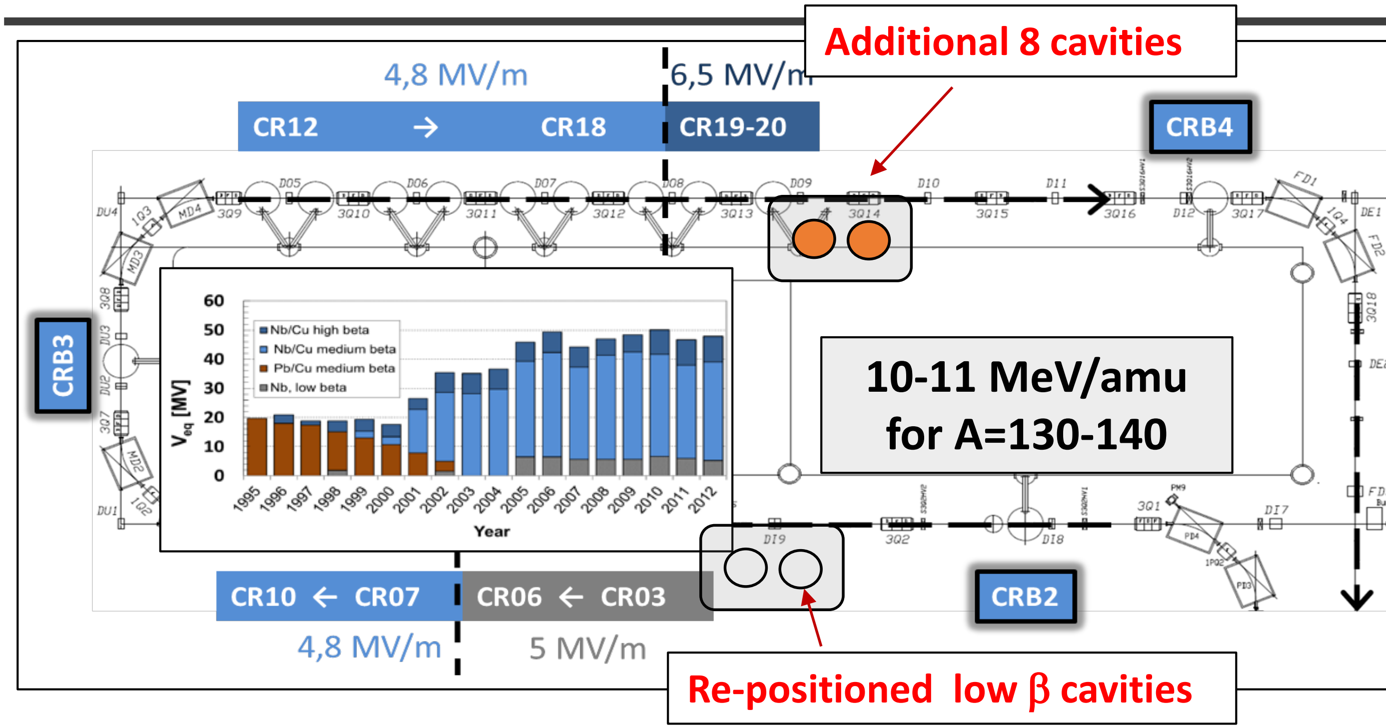


ALPI UPGRADING:

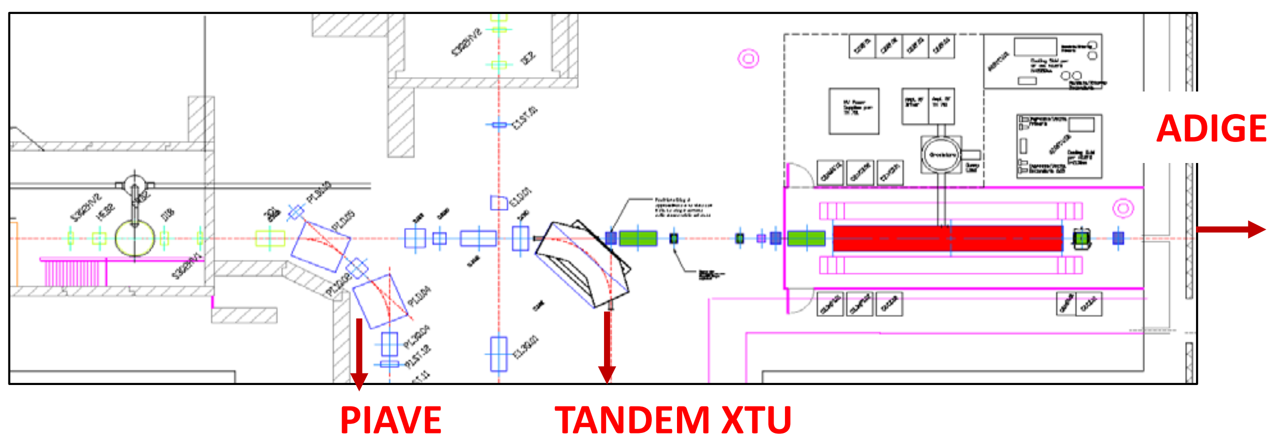
- Displacement of **two low beta cryostats** (β = 0,052) from PIAVE to ALPI;
- Installation of **ten brand new triplets** w/ higher quadrupole gradient (from 20 to 30 T/m);
- **New digital LLRF Controller**;
- Production of **new Diagnostic Boxes** (the new boxes will be installed in a second phase '20-'21);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

May 2018 - Apr.2019

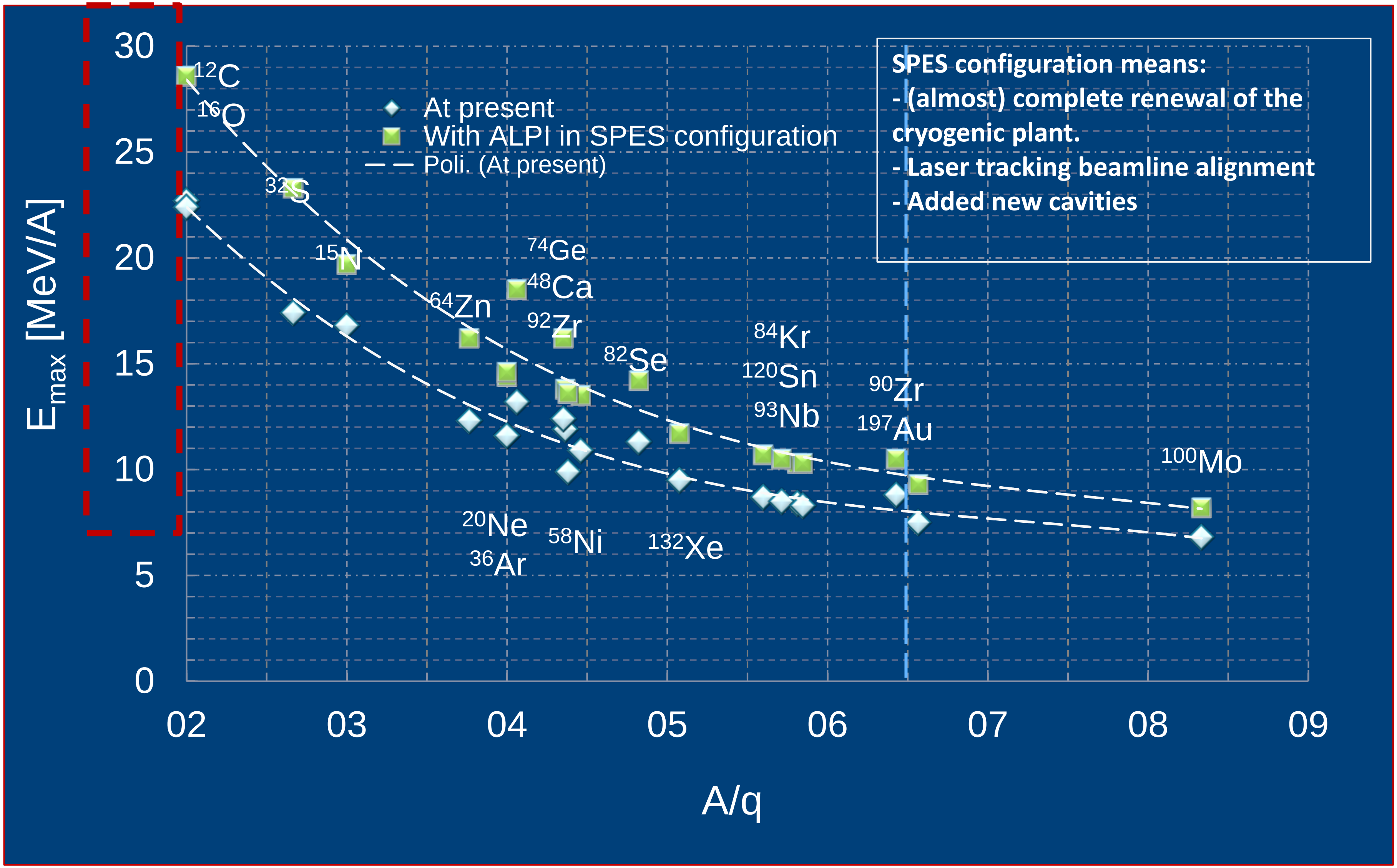
ALPI: upgraded performances



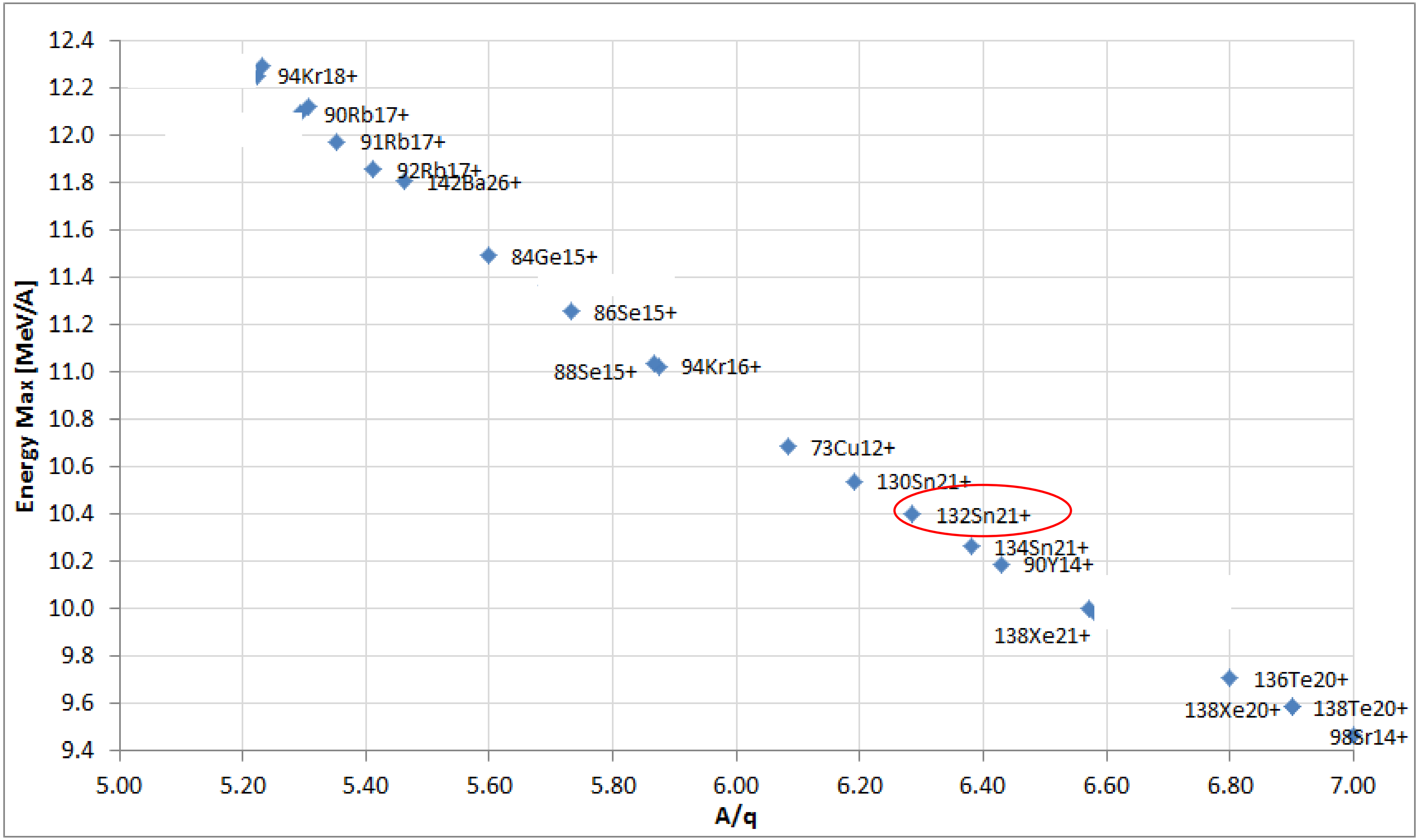
ADIGE – ALPI Matching Section



ALPI: upgraded performances



ALPI: upgraded performances



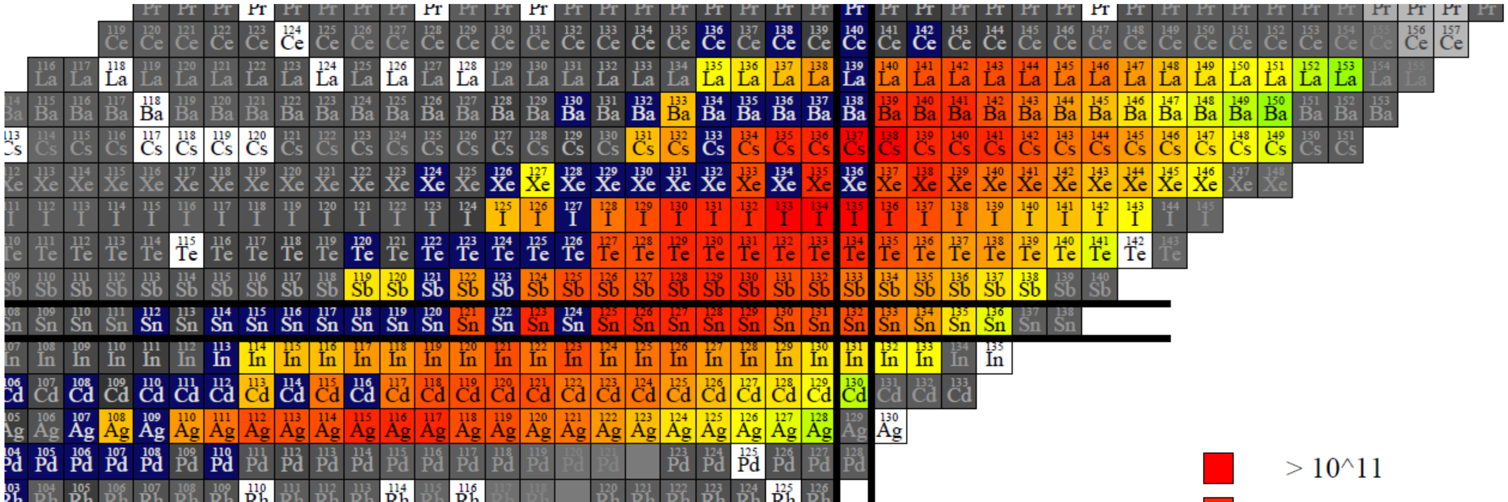
Energy from SPES Post-Accelerator as function of A/q

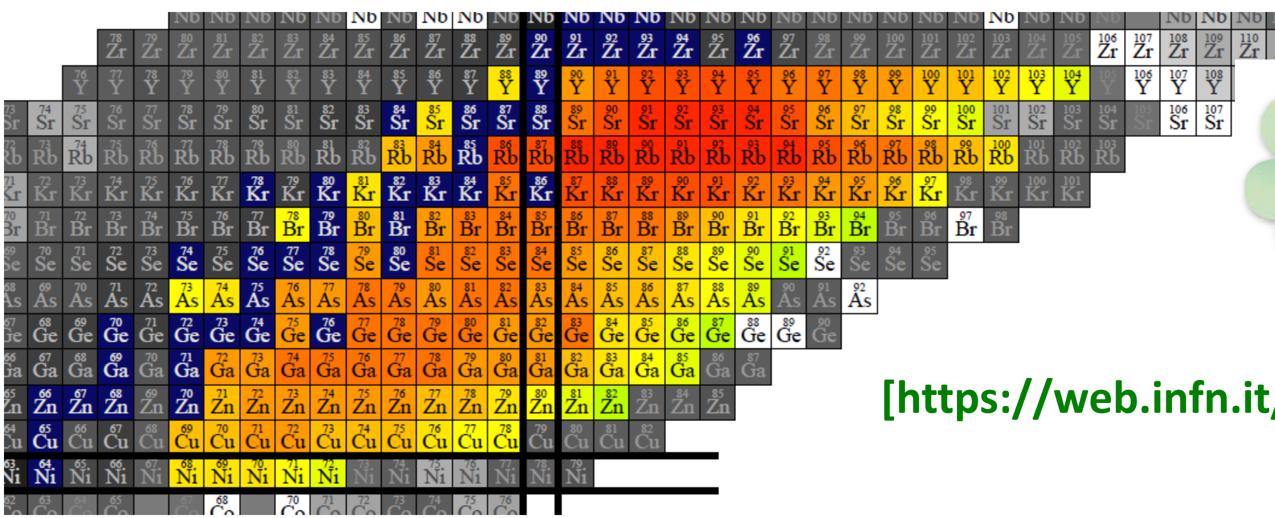
IWM-EC 2018

SPES BEAMS (ReA)

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

SPES exotic beams for science





- > 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/]

IWM-EC 2018

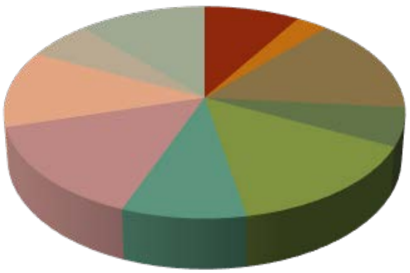
Physics at SPES

Third International SPES Workshop

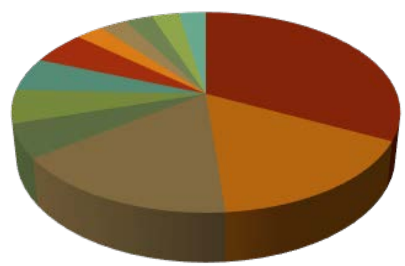
10-12 October 2016 *INFN Laboratori Nazionali di Legnaro*

Europe/Rome timezone

SPES LOIs Topics



SPES LOIs Spokespersons



The **SAC was impressed** with the **number of LOI's** and the **broad scientific spectrum** proposed to be studied with the SPES Radioactive Ion Beams (RIB). The SAC **appreciates the progress of the SPES project**

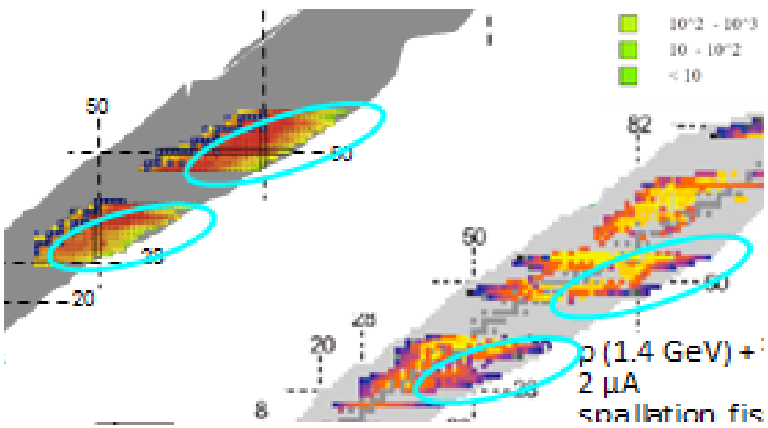
One Day Workshops

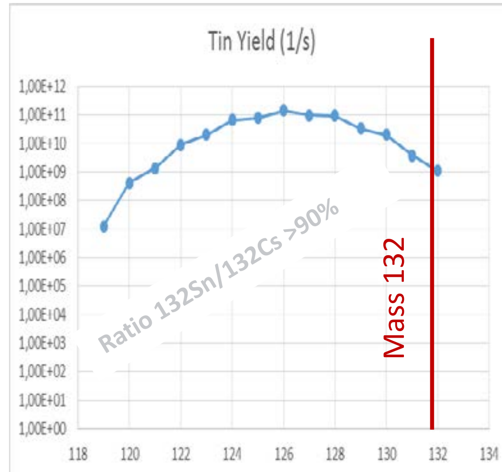
Napoli (2012): Transfer Reactions
Firenze (2012): Coulomb Excitation
Catania (2013): Isospin in Reaction Mechanisms with RIBs
Milano (2013): Collective Excitations of Exotic Nuclei
Legnaro (2014): Fusion-evaporation Reactions with RIBs
Milano (2015): Physics at SPES with non re-accelerated beams
Caserta (2015): Nuclear Astrophysics at SPES

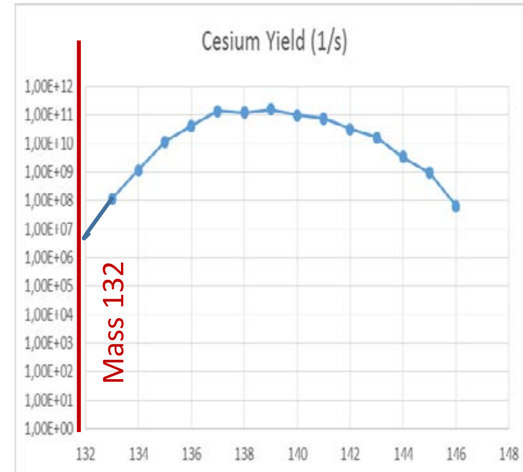
Toward a selected beam: in target reactions

SPES

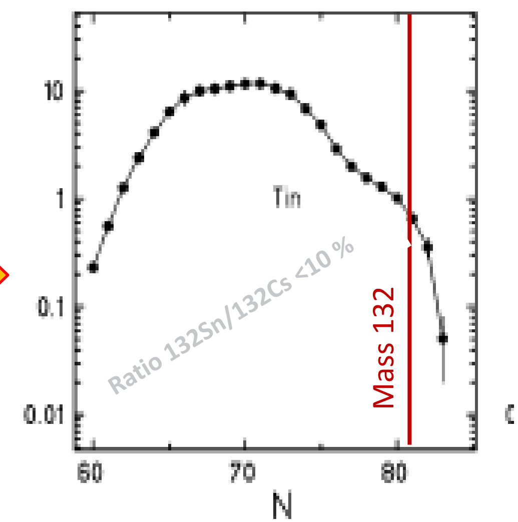
40 MeV protons on 238U

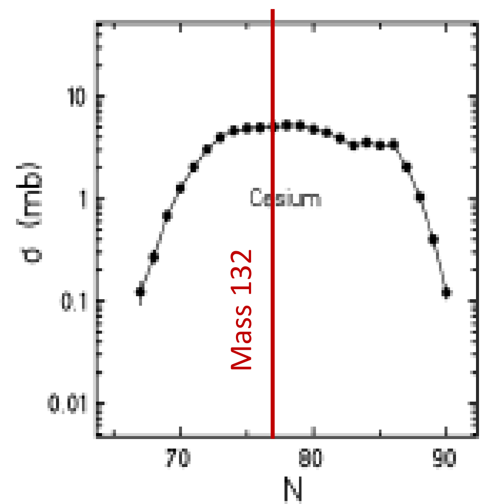






Isolde





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

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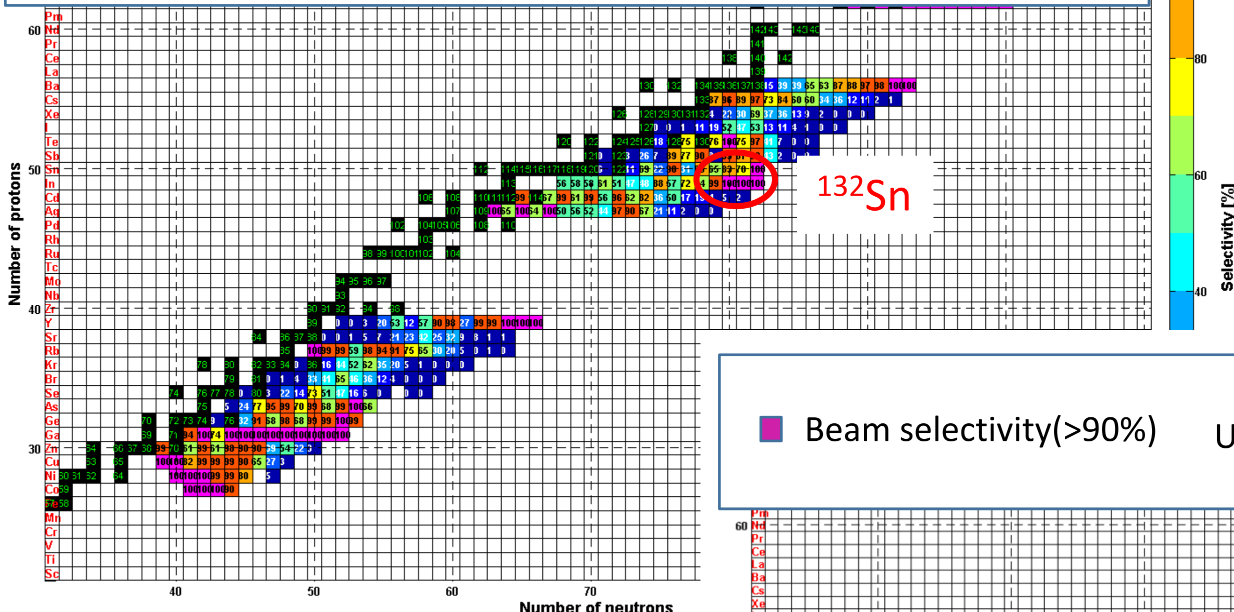
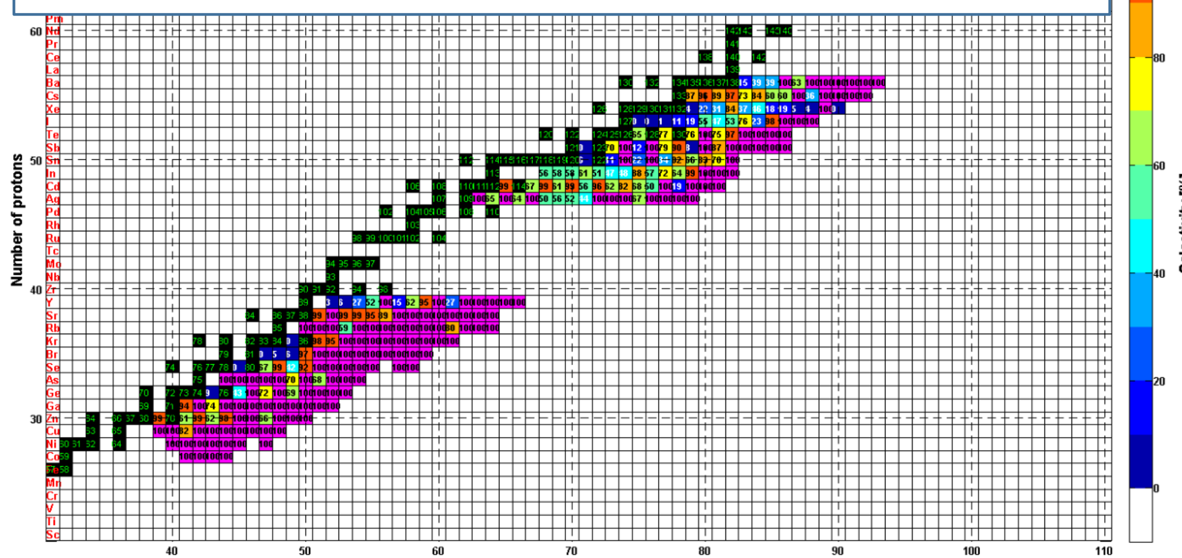
Toward a selected beam: mass resolution

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



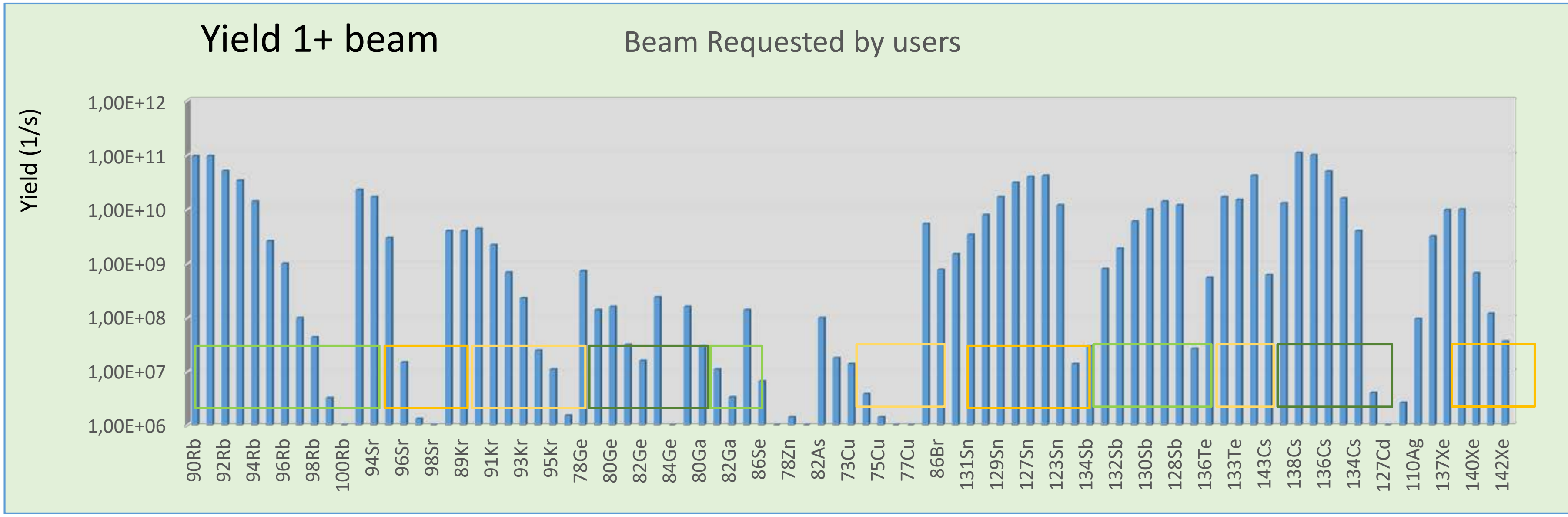
SIS beams: Rb,Cs,Sr,Ba
PIS beams: Kr,Xe,Br,I,Se
LIS beams: others

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

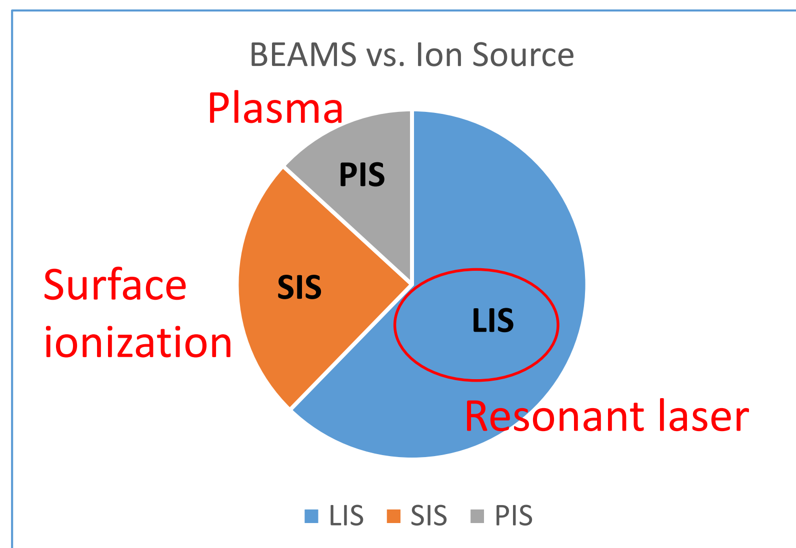


MC code: MCNPX, Bertini –ORNL model

LoI - n-rich RIBs



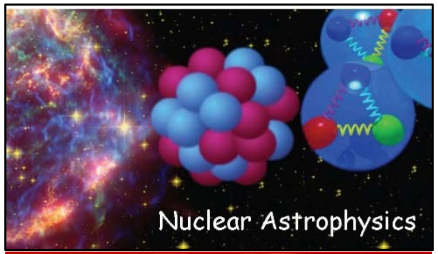
		19 Elements	
Total beams	89		LoI %
Beams with 300_LRMS	47		53%
Benefit with 5.000_HRMS	3	→ 50 beams	56%
Benefit with 10.000_HRMS	17	→ 67 beams	75%
Benefit with 15.000_HRMS	15	→ 82 beams	92%
Benefit with 20.000_HRMS	7	→ 89 beams	100%



IWM-EC 2018

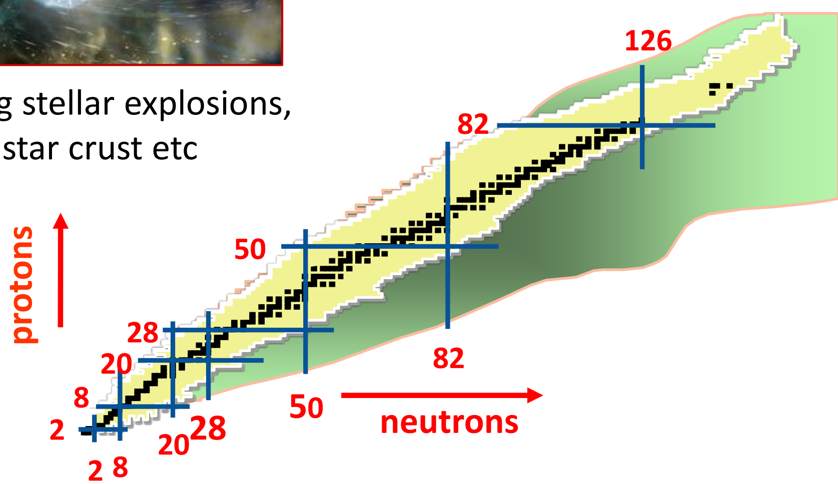
Beyond Isotopes discovery – challenges

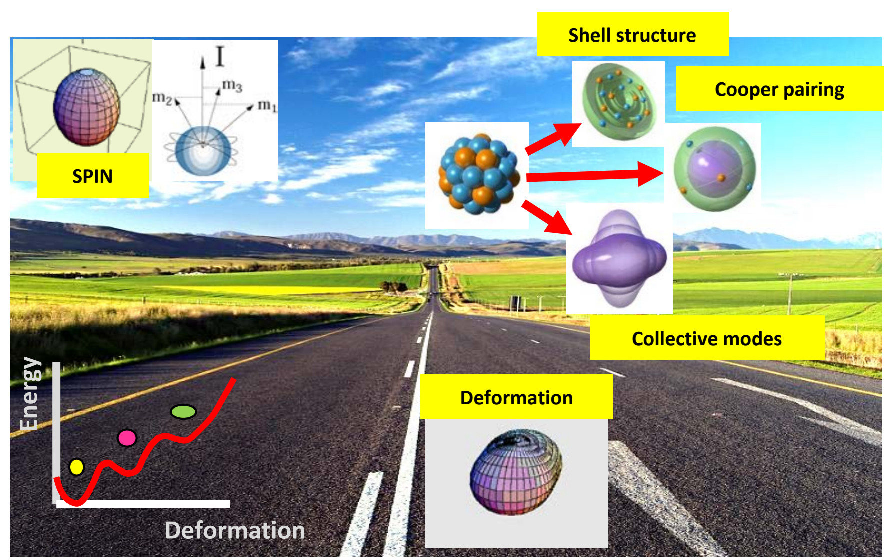
Nuclear Structure & Reaction Dynamics:
Long Standing Questions



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**?





Beyond Isotopes discovery – challenges

Nuclear Structure

- Shell evolution
- G.s. & E.s. properties (masses, radii, deformation, …)
- Decay properties
- Collectivity
- Ab-initio models

Reaction Dynamics

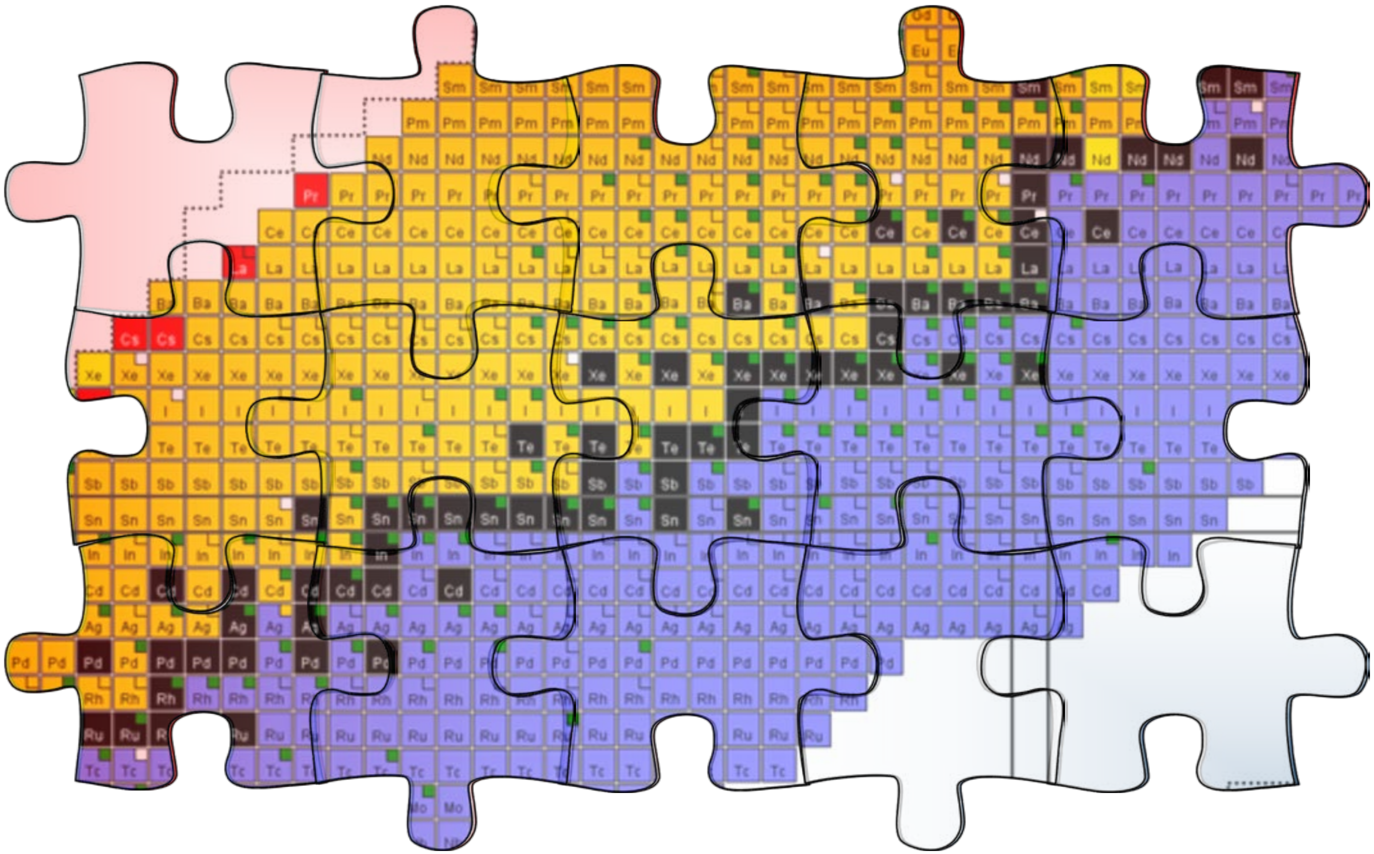
- Characterize the mechanisms that drive nuclear reactions and describe reaction dynamics
- Study the interplay between structure and reactions (e.g. clusters)

Nuclear Astrophysics and Applications

- Provide Nuclear Data (cross sections, lifetimes …)

IWM-EC 2018

Beyond Isotopes discovery

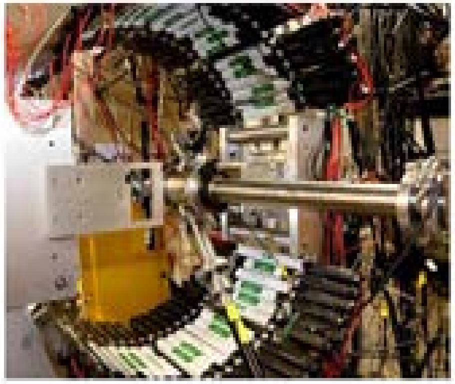


Understanding the physics driven by the <u>nuclear force</u>
within the many-body nuclear system,
probing
<u>fundamental symmetries and interactions</u>

Detector's portfolio: "low energy" setups

(ORNL collaboration)

MTAS
Total abs. γ-Spectr.

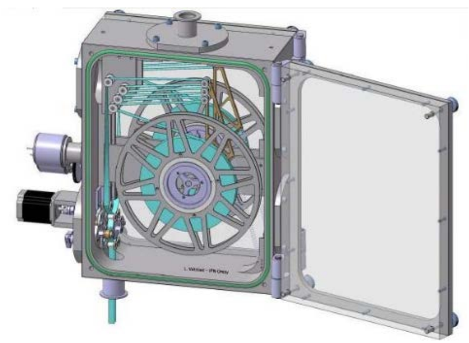


VANDLE
Neutron array

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

β-decay Tape Station



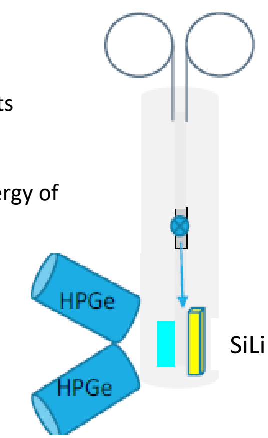
Flexible and modular

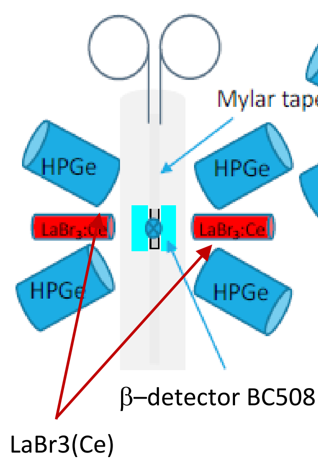
Minimal SETUP to extract T1/2, Pn, β–γ coincidences. Measured quantities:
- Time of β emission
- Energy & Time of γ emission

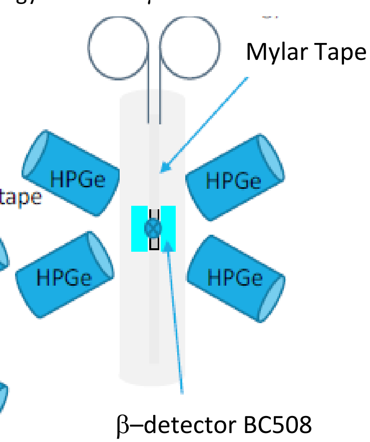
Fast timing SETUP: lifetime measurements in the ns range β–γ (LaBr3.Ce) γ (HPGe)coincidences

SETUP for E0 measurements and long-living activity

Additional information: Energy of Conversion electron







Detector's portfolio: resident setups I

PRISMA

Large acceptance magnetic spectrometer

$\Omega \approx 80$ msr;

$B\rho_{max} = 1.2$ Tm

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

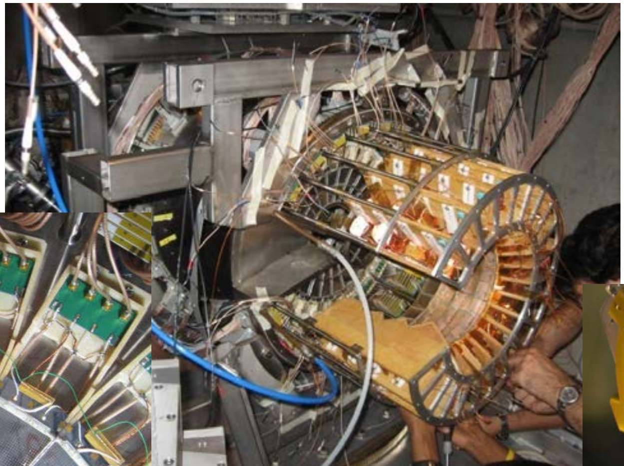
Energy acceptance ~ ±20%

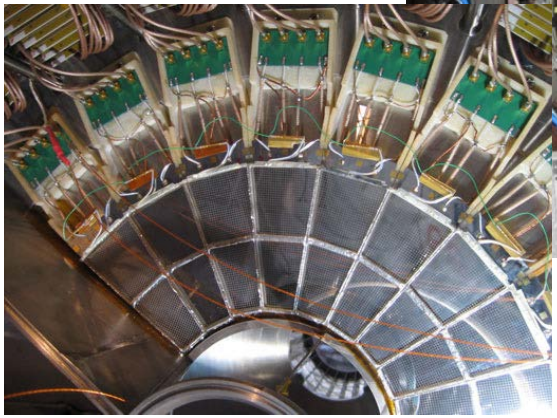
GARFIELD

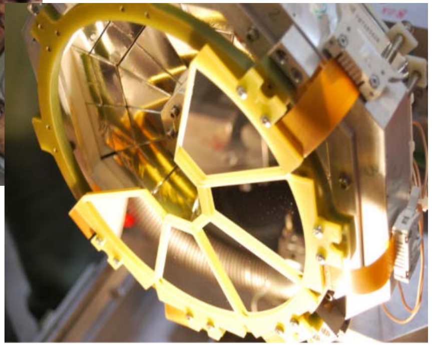
4π array for Light Charged particles and fragments

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

2-Rco IC-Si-CsI (5°-18°)





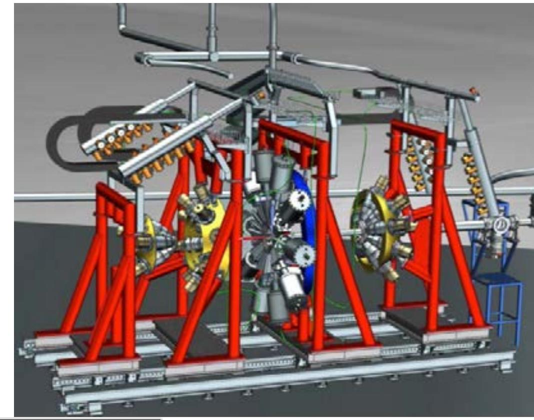


Detector’s portfolio: resident setups II

GALILEO

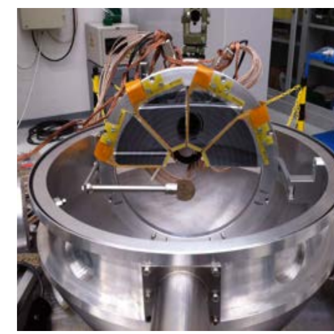
Phase 1:
25 HPGe + 25 BGO + ancillaries
240 ch digital electronics (AGATA)

Phase 2:
30 HPGe + 30 BGO + 10 TC



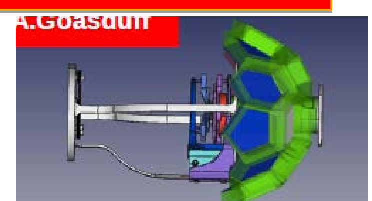
Study of weak reaction channels stable beams

- High efficiency
- High resolving power



- Light charged particle detectors
  EUCLIDES, SPIDER, TRACE
- Neutron detector
  N–Wall
- Lifetime measurements
  Plunger from Cologne
- Recoil detectors
  RFD
- Fast timing High–energy gamma–rays detector
  LaBr3 detectors

Commissioned dets
Commissioning phase
To be commissioned



Courtesy of D. Mengoni

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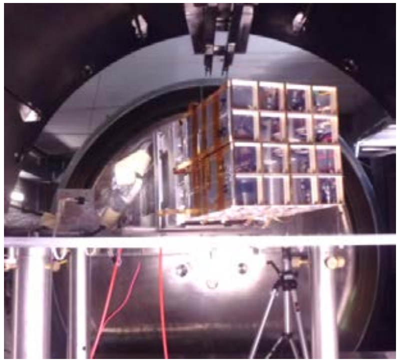
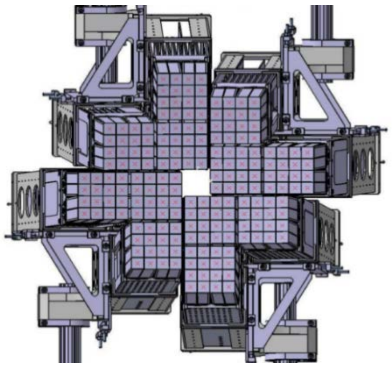
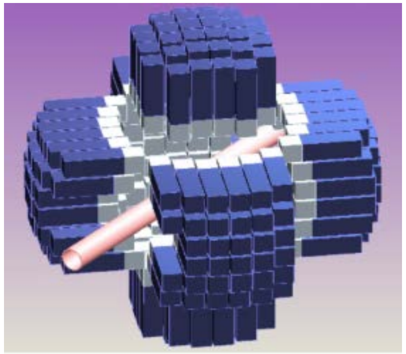
Detector’s portfolio: “traveling” setups

FAZIA: **LCP & fragments detection**

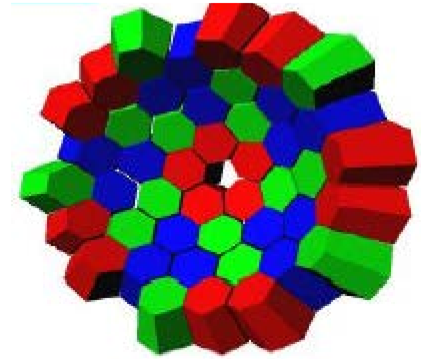


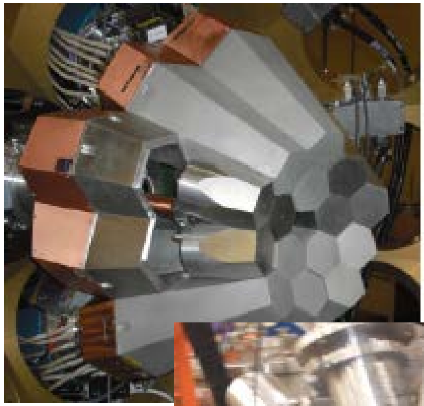


PARIS **(High Energy γ-ray Detector Array)**

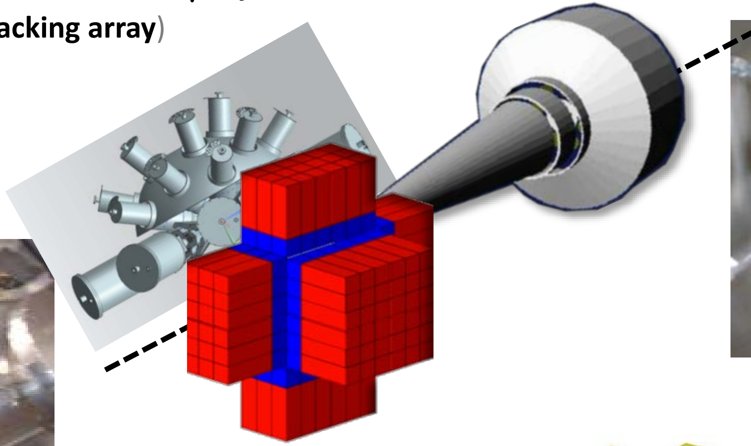


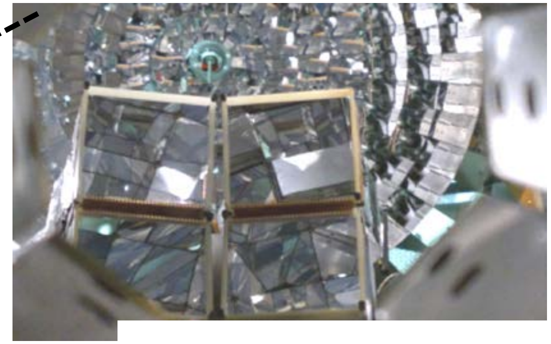
NEDA **(NEutron Detector Array)**



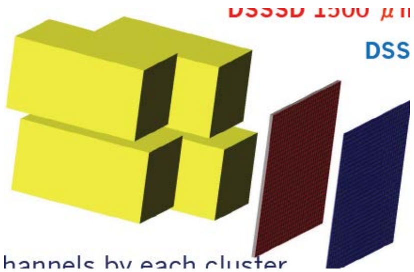


AGATA **: innovative γ-rays tracking array)**





FARCOS: LPC correlator



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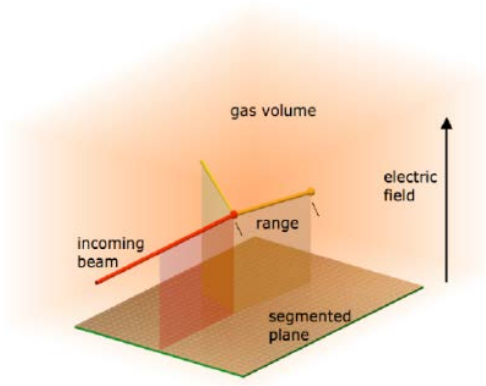
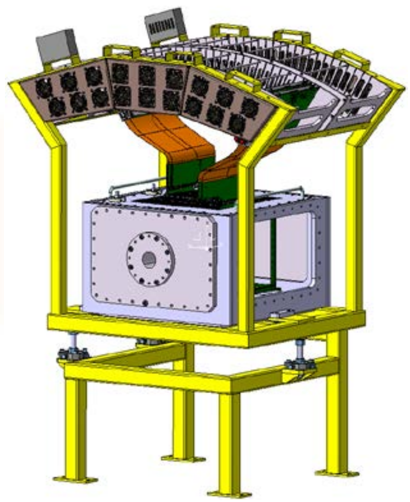
Active Target For SPES

In synergy with:
1. ACTAR TPC
2. SpecMAT

European Research Council
Established by the European Commission

T. Marchi – KU Leuven/LNL





Work of P. Gangnant

- Gas Medium is both target and detection gas
- Segmented detection plane
- Drift time recorded + charge deposition on segments (TPC)
- Auxiliary detectors on the sides of the chamber

Advantages:
- High efficiency and low detection thresholds
- Wide anglular coverage
- Interaction vertex reconstruction
- Exploit the low intense RIBS

Some Physics Cases:
Elastic/Inelastic Scattering, Resonant reactions, Direct reactions,Giant Resonances, Decay studies.

Two letters of intent for SPES endorsed by the SAC:
- **B. Fernandez Dominguez et al, Direct Reactions with exotic nuclei in the r-process using an active target**
- **R. Raabe, T. Marchi et al, Shell Structure in the vicinity of ^{132}Sn with an active target**

LoI @ PAC LNL- Demonstrator tests @LNL

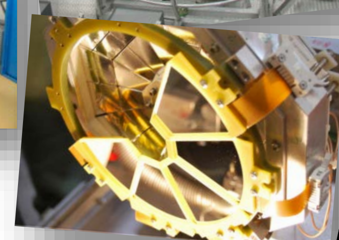
Summary

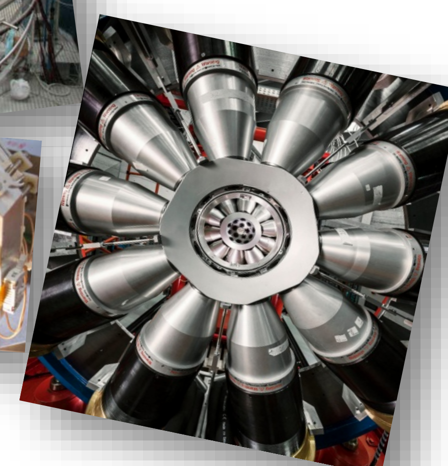
New and
High Quality Beams

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

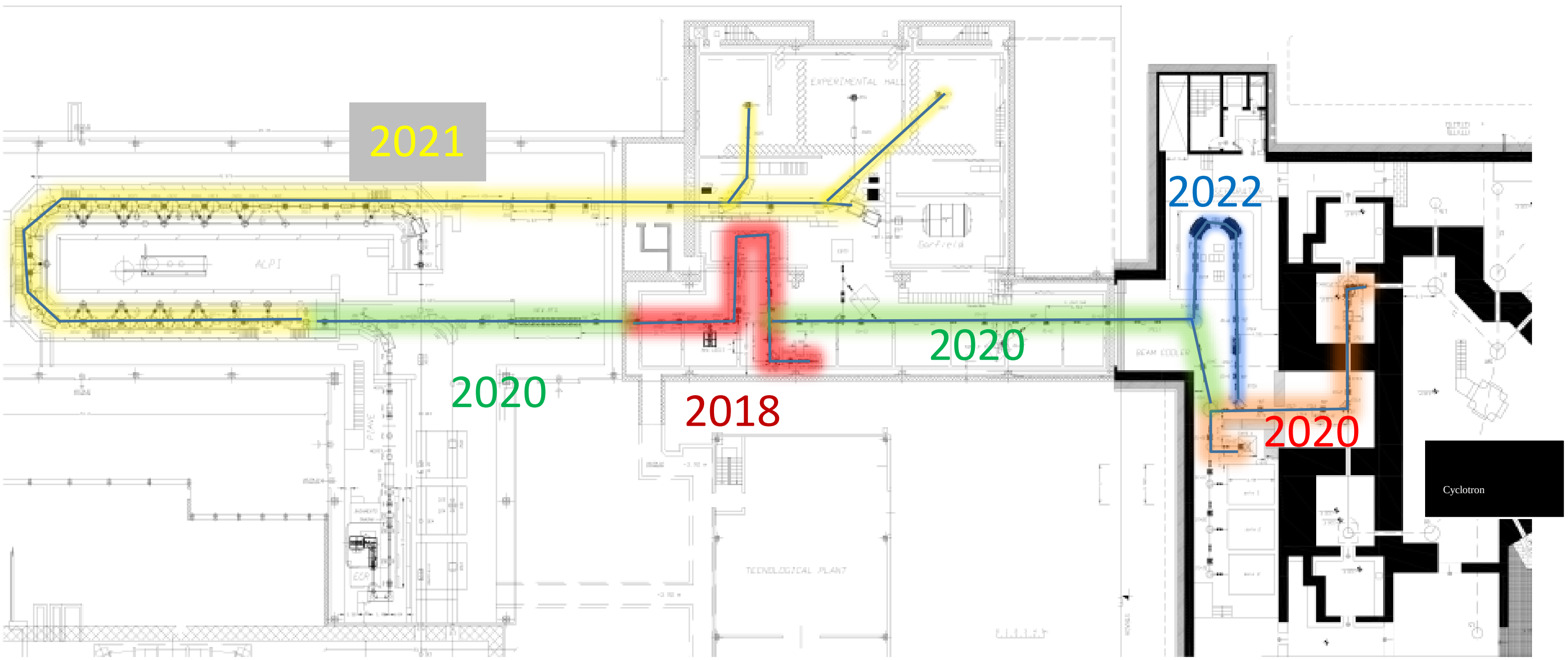




SPES INSTALLATION SCHEDULE

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

SPES exotic beams for science



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																								

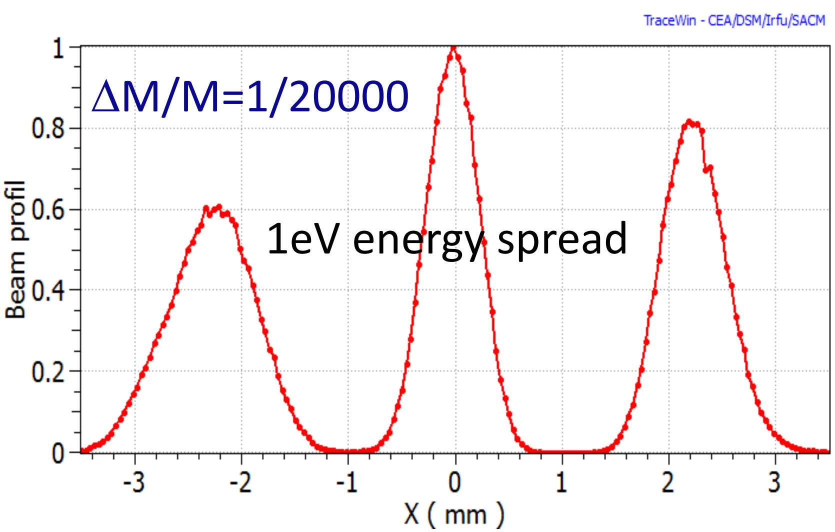
installation **Hardware commissioning** **Beam commissioning**

backup

component	Status of SPES components	notes
Cyclotron	• Commissioning completed • New beam line for Cyclotron is on the way to be delivered (LARAMED beam line)	
ISOL and RIB production	• ISOL Bunker devices developed and tested at ISOL laboratory. • Laser system under delivery (FAT completed).	• Installation 2018 - 2019 Commissioning March-Sept 2020 • Installation 2018
Charge breeder and MRMS	• Delivery of beam transport components • Installation started (Charge Breeder, 1+ source)	• Installation 2018 • Commissioning 2018 - 2019
HRMS high resolution mass separator	• Physical design ready, integration with beam cooler and beam lines under way • Preliminary dipole design and feasibility check with potential manufacturer done	• Critical Design Review in October 2018 • Authorization to tender March 2019 • Commissioning 2022
Beam Cooler	Collaboration with LPC_Caen for Beam Cooler development (expertise: SHIRaC - SPIRAL2)	• Construction 2018 - 2019 • Installation and Comm. 2020
Normal conductive RFQ	6 modules of RFQ in construction. (24 electrodes delivered)	• Construction 2018-19 • Installation 2019-2020
1+ Beam line transfer	Electrostatic triplets of quadrupoles ordered Electrostatic dipoles tested Vacuum systems delivered	• Tender for triplets 2018 • Installation 2019 - 2020
Safety	Safety system analysis and design: Bid assigned (PILZ), risk analysis completed Authorization to operate with UCx : process on the way, formal discussion with ISPRA ongoing	• Design completed 2018 • Installation and commissioning 2019 • waiting for additional questions, expected completion June 2018

Beam selection: HRMS

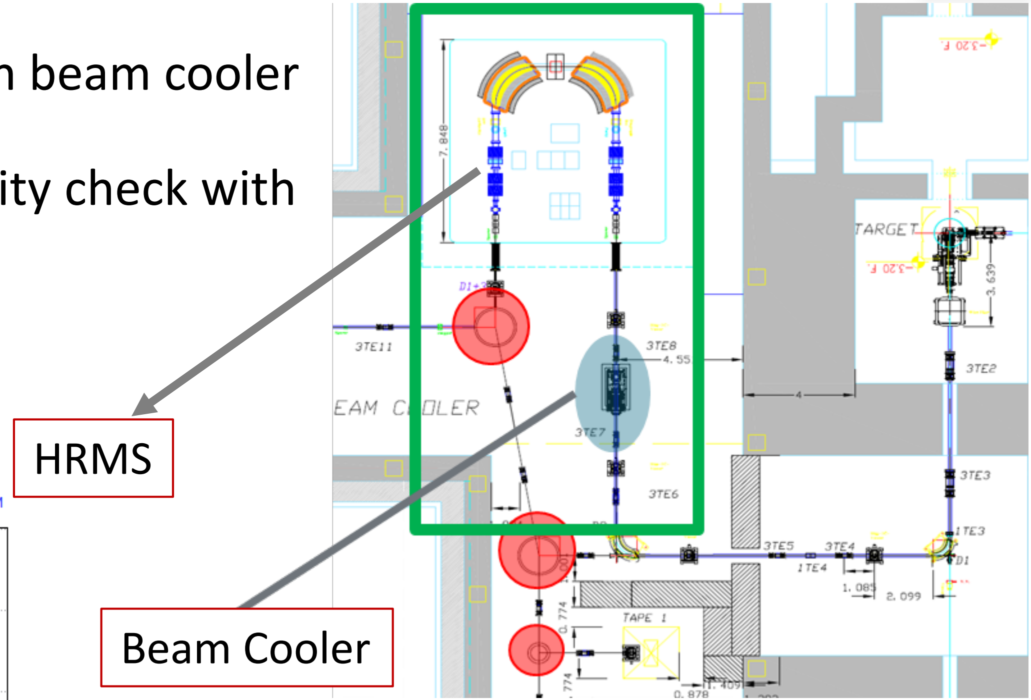
- Physical design ready, integration with beam cooler and beam lines under way
- Preliminary dipole design and feasibility check with potential manufacturer done
- Evolution:
  - Critical Design Review in April 2018
  - Authorization to tender October 2018
  - Commissioning 2021

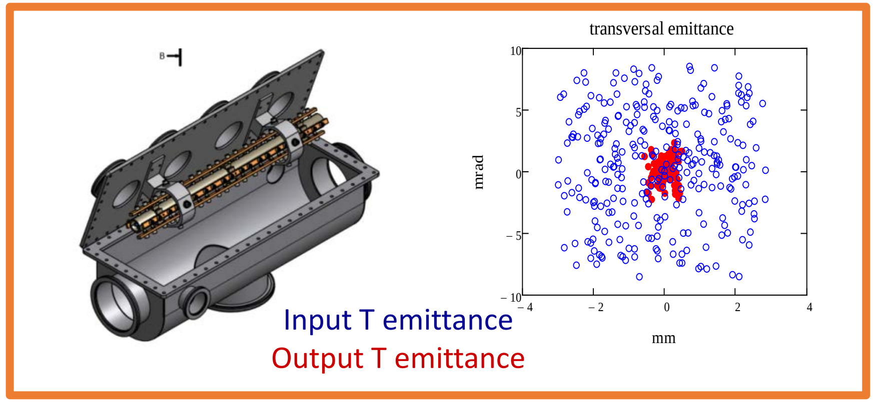


Input requirements:

$\Delta E = \pm 1$ eV

Emittance $_{rms,n}$ = 0.68 πmm mrad





Collaboration with LPC_Caen for Beam Cooler developement (expertise: SCIRaC - SPIRAL2)

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Contemporary alchemy

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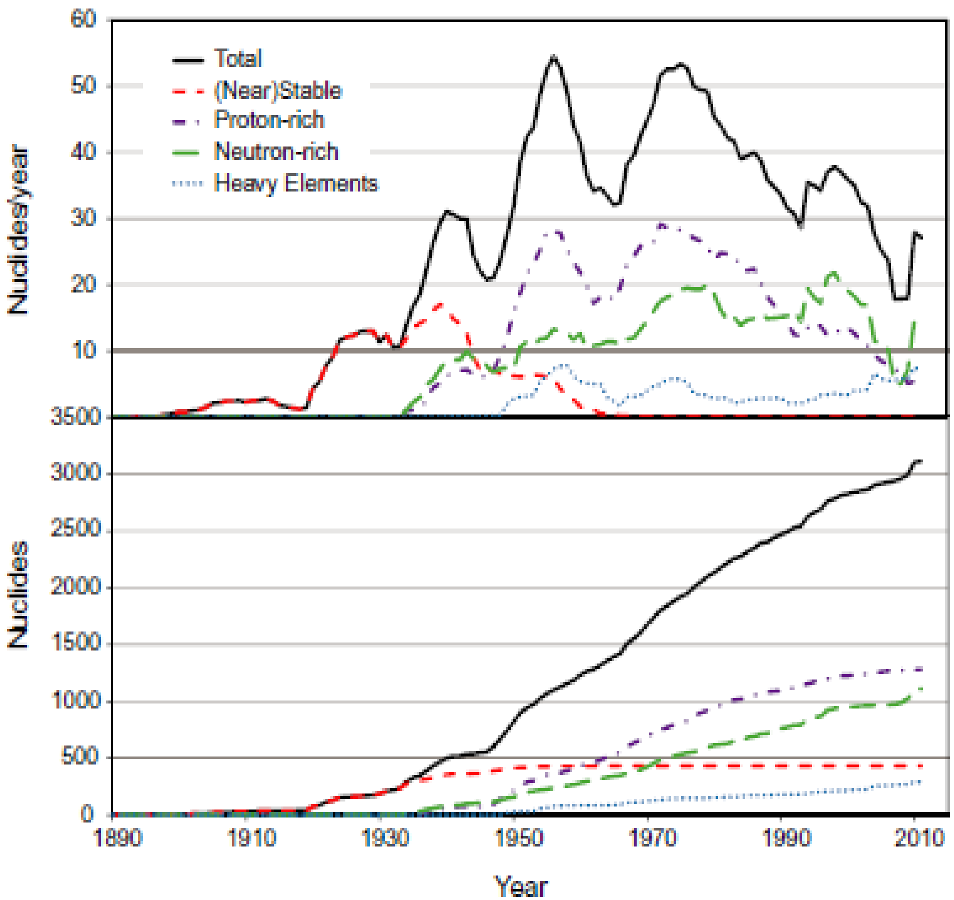
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

SPES exotic beams for science

Rep. Prog. Phys. **76** (2013) 056301



IOP Publishing Reports on Progress in Physics
Rep. Prog. Phys. **76** (2013) 056301 (14pp) doi:10.1088/0034-4885/76/5/056301

Current status and future potential of nuclide discoveries

M Thoennessen

Fusion-Evaporation reactions with Heavy Ions.
Increasing energy and intensities

High energy light beams:
target fragmentation/fission. (ISOL)

High energy heavy beams:
projectile fragmentation/fission. (In-flight)

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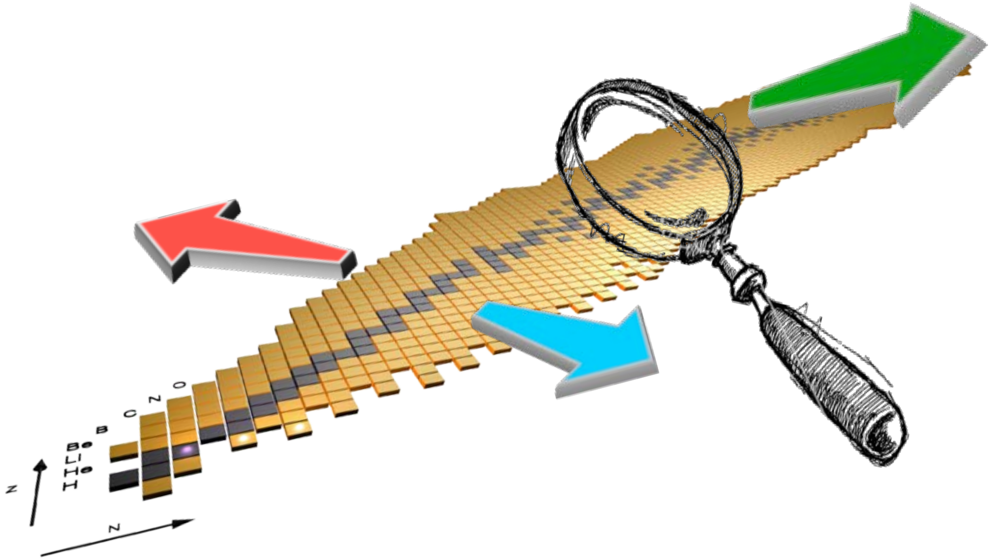
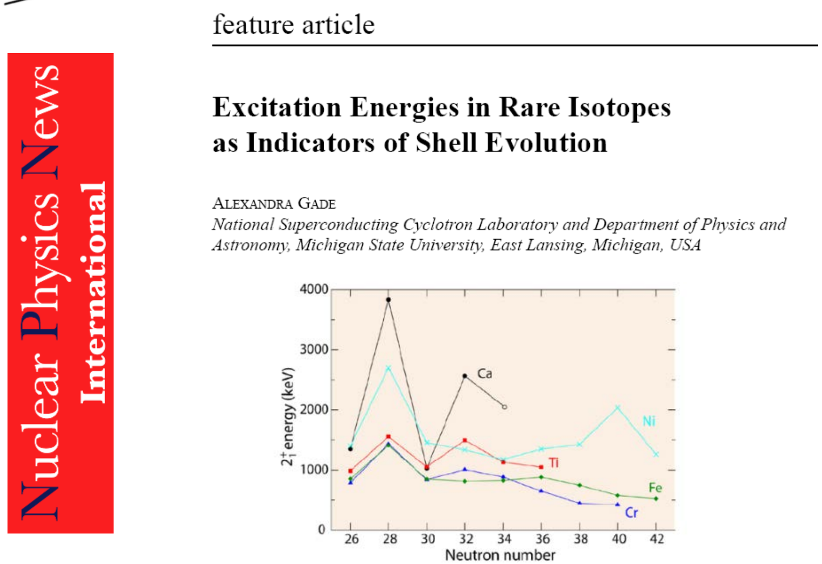
Beyond Isotopes discovery



Nuclear Physics will focus on Radioactive ion beams to:

- **Explore** and locate the extremes of nuclear existence
- **Discover** exotic properties of nuclei (shapes, structure evolution)
- **Explain** the role of isospin in complex systems (nEOS, E_{sym})

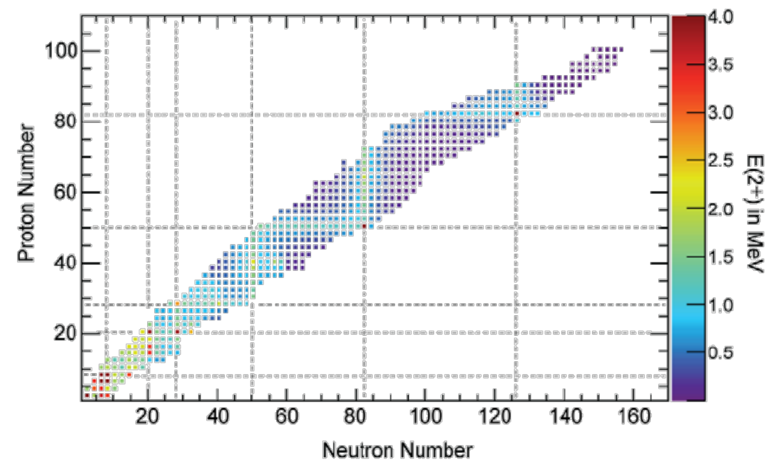


Nuclear Physics News International

feature article

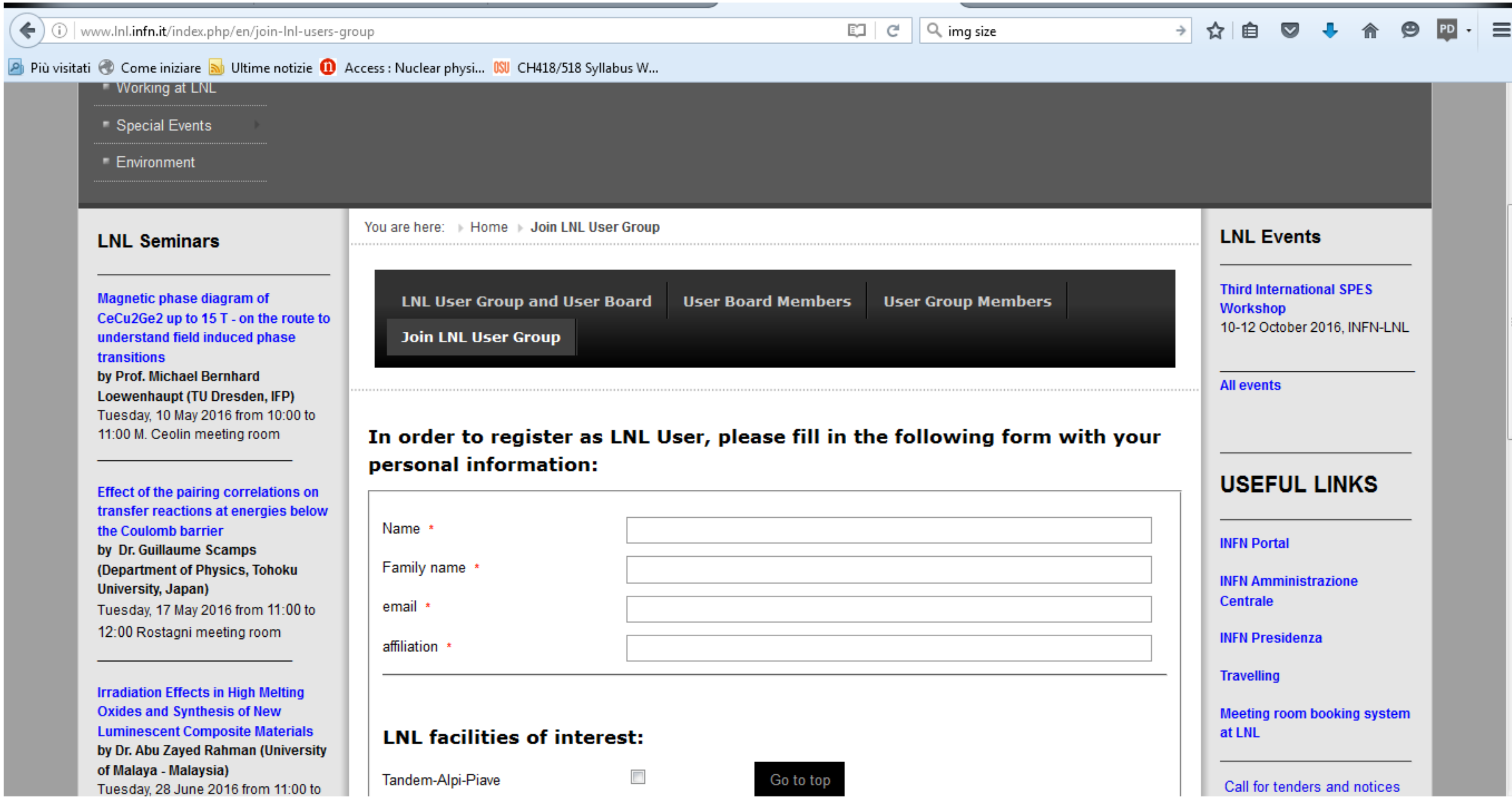
Excitation Energies in Rare Isotopes as Indicators of Shell Evolution

Alexandra Gade
National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA

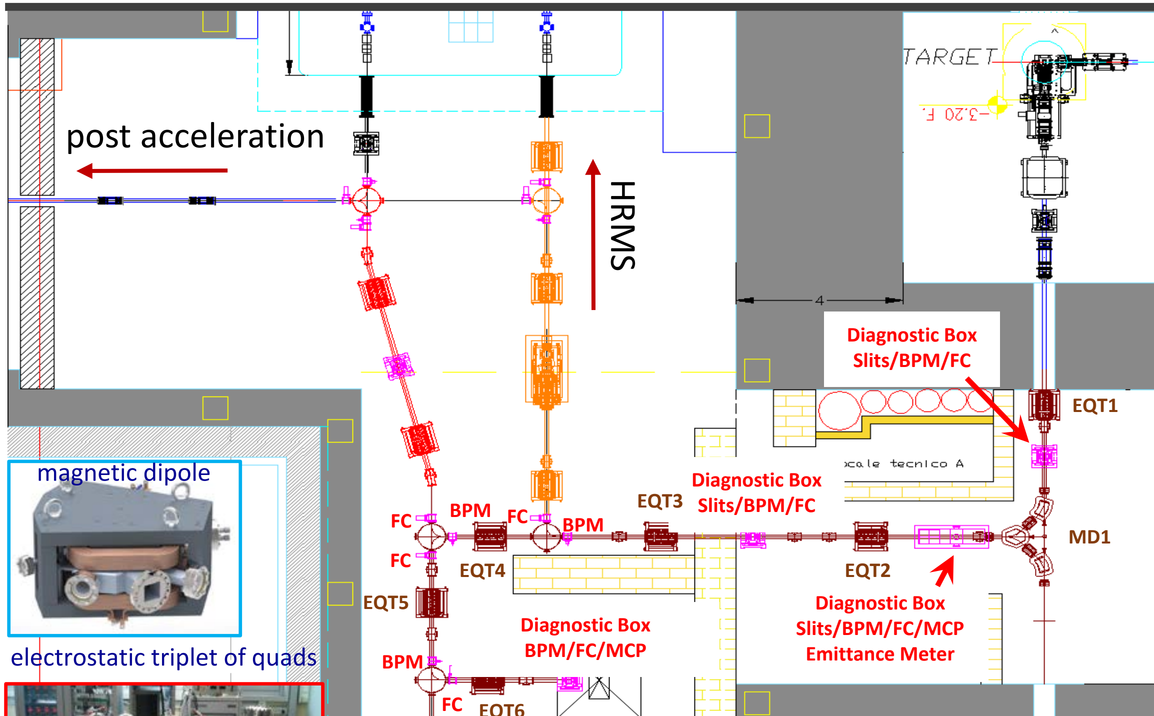


[A. Gade, Nucl Phys News 23-4 (2013) 10]

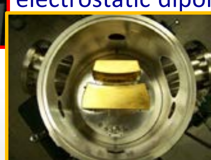
Join LNL User Group

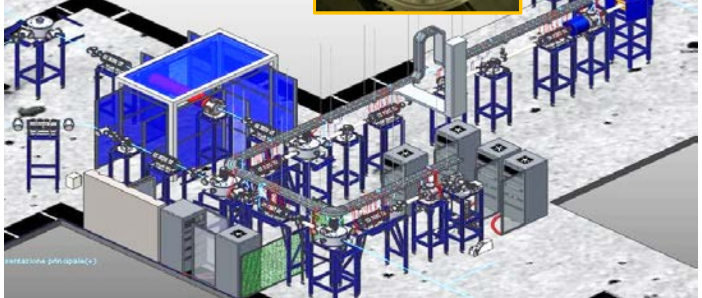


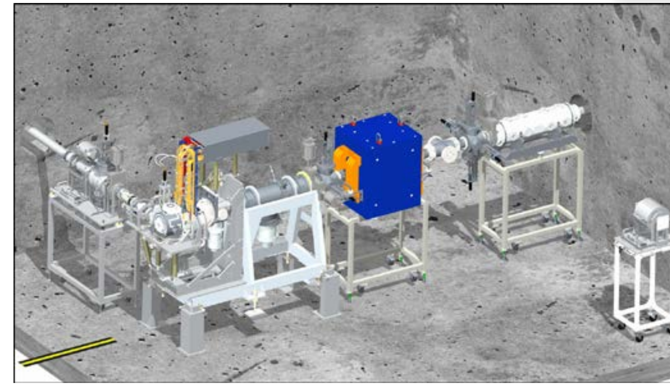
The 1+ beam line : the beam optics



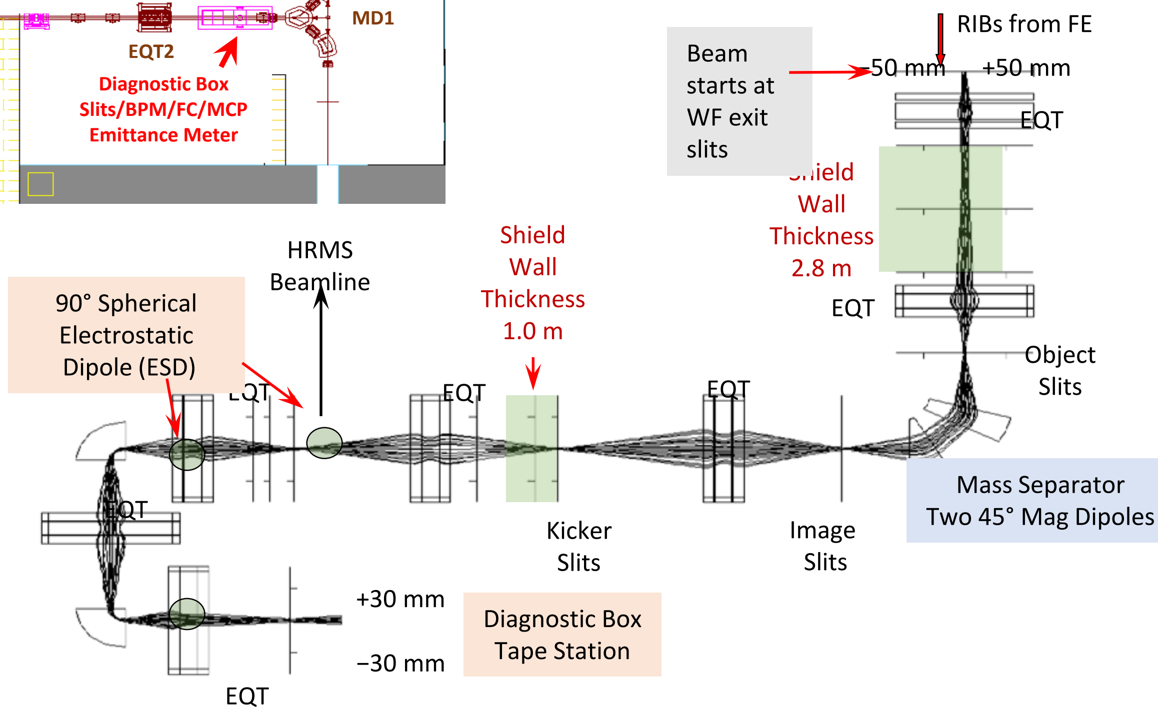
electrostatic dipole



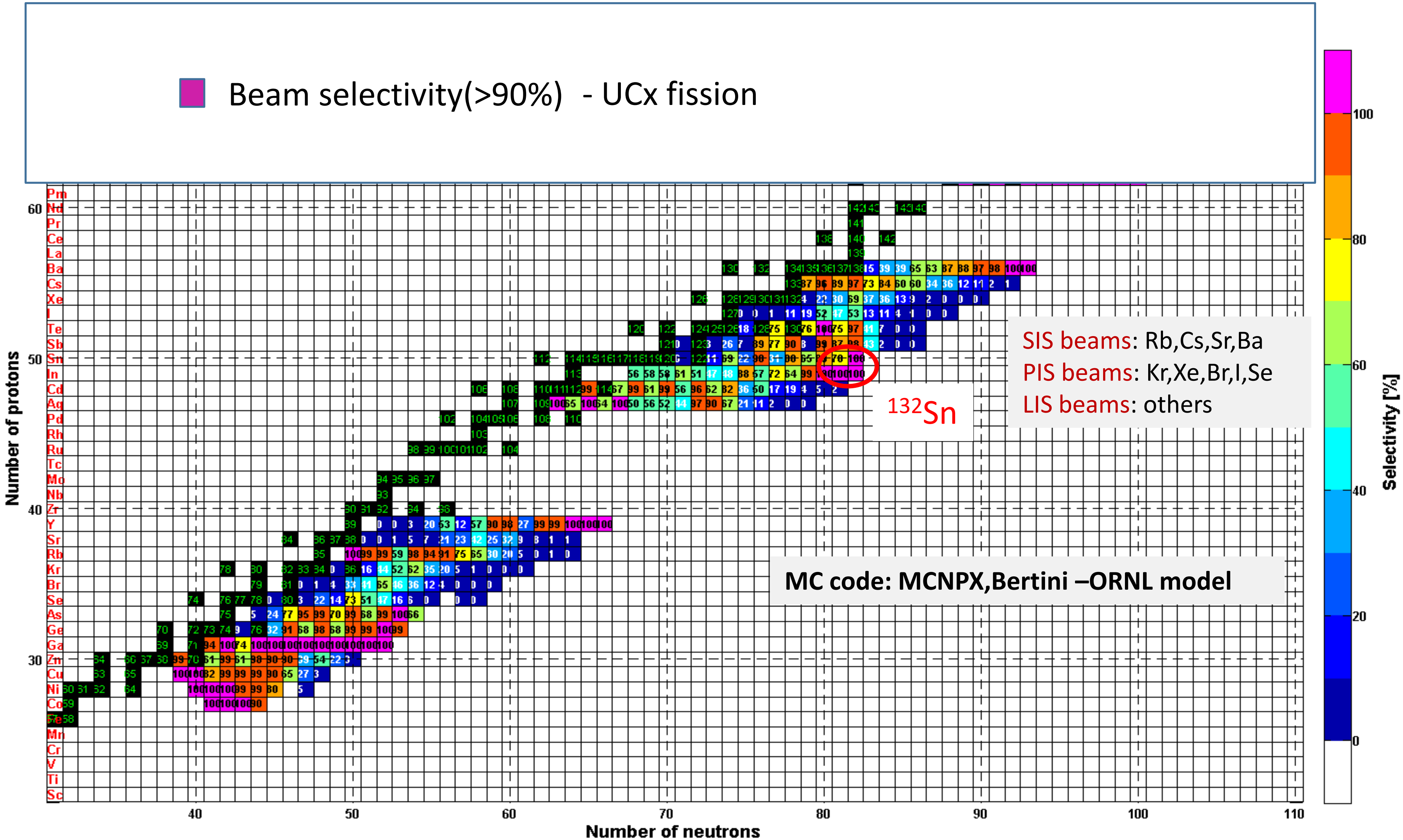




Mass selection **1/300** → ISOL-Wien Filter-LRMS

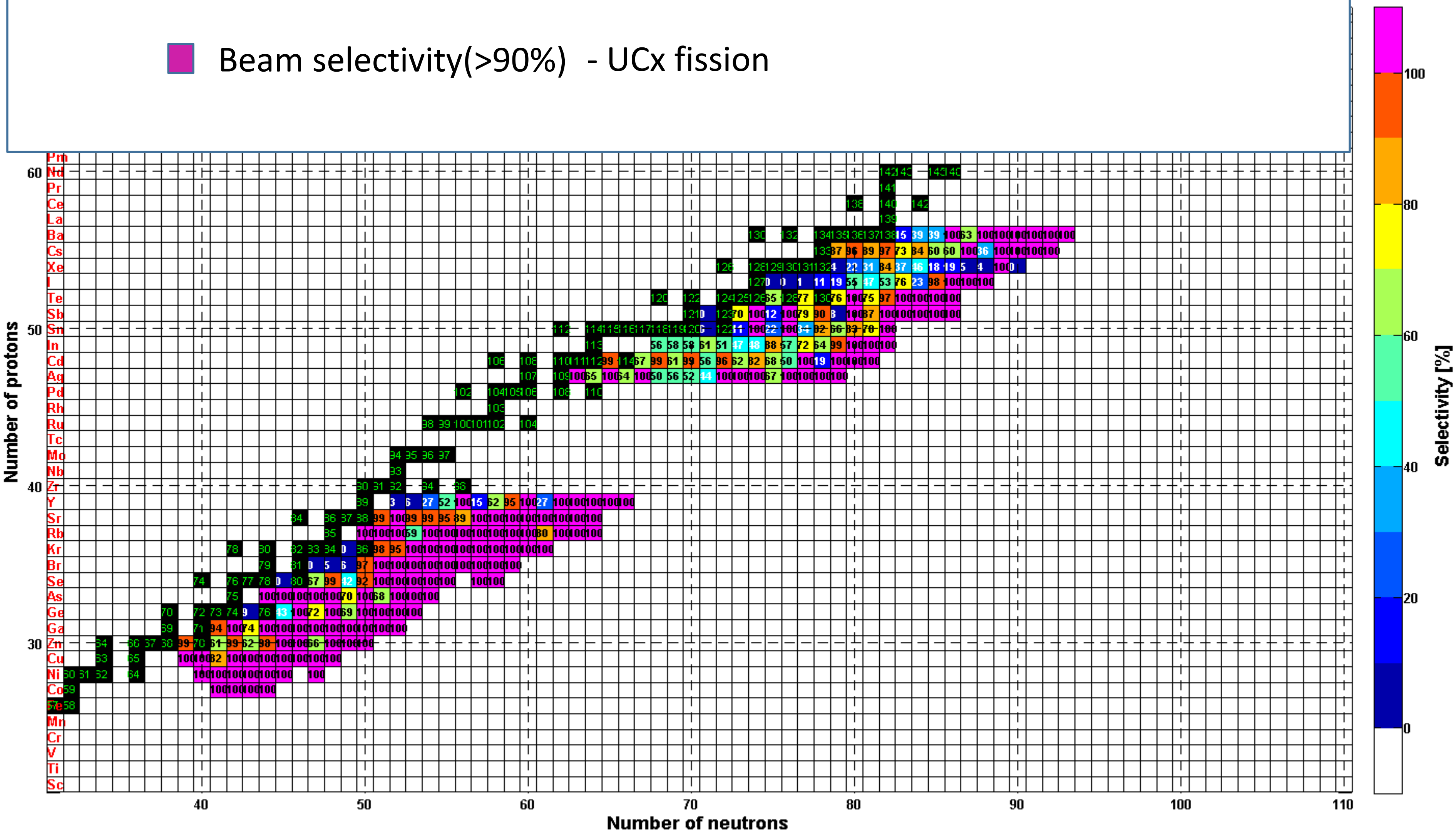


Toward a selected beam: LMR (1/200)



Toward a selected beam: HRMS (1/20000)

■ Beam selectivity(>90%) - UCx fission



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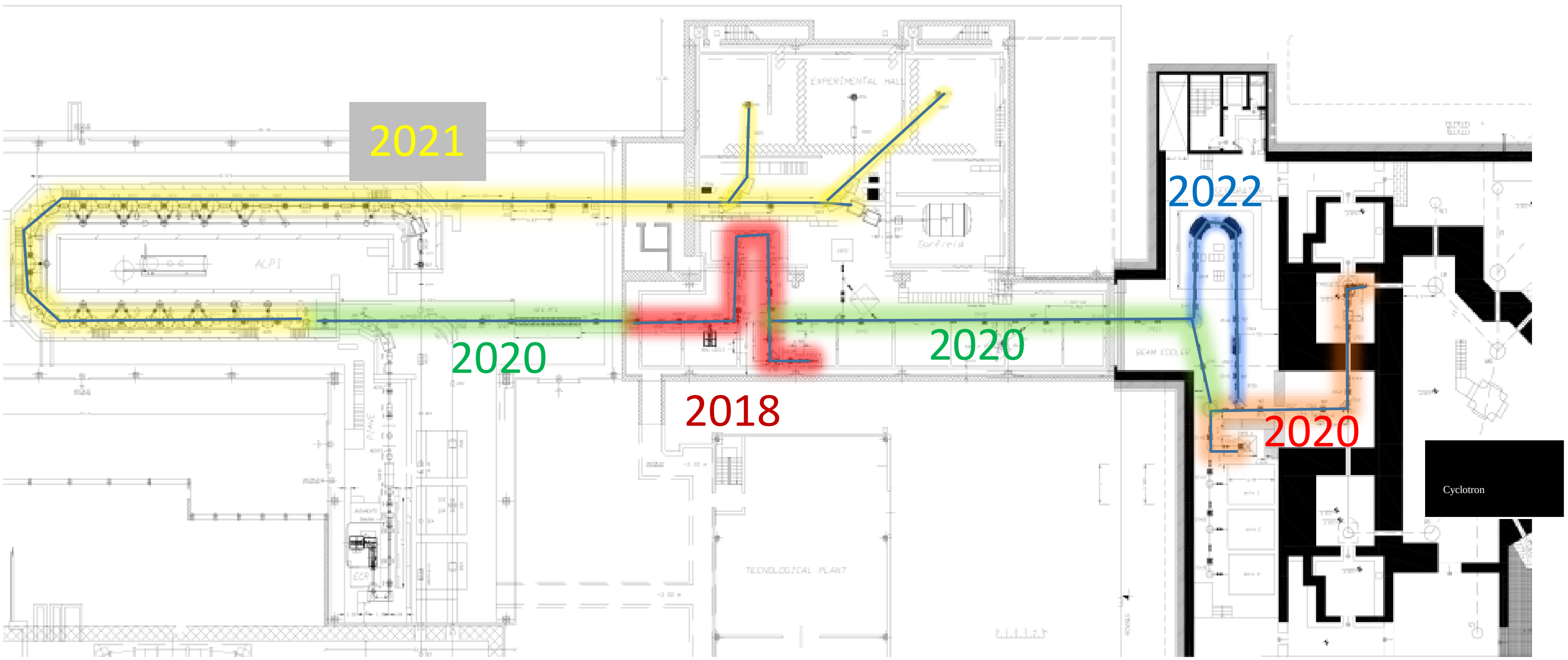
SPES SCHEDULE



- ✓ installation of Charge Breeder and related mass separator: ready in **2018**
- ✓ installation of ISOL and 1+ beam line up to the tape station: ready in **2019**
- ✓ **Low energy RIBs in 2020 (commissioning) and fall 2020 (users)**
- ✓ Installation of **RFQ** and 1+ beam line up to Charge Breeder: ready in **2020**
- ✓ Reaccelerated beams: ready in **2021**
- ✓ High resolution mass selection: ready in **2022**