Giovanni Bisoffi, *for the SPES team*

INFN-Laboratori Nazionali di Legnaro

SPES: A BEING BUILT EXOTIC BEAM FACILITY AT INFN-LNL

1. What it is for
2. Design and construction of the new facilities
3. RNB Acceleration with the old ALPI

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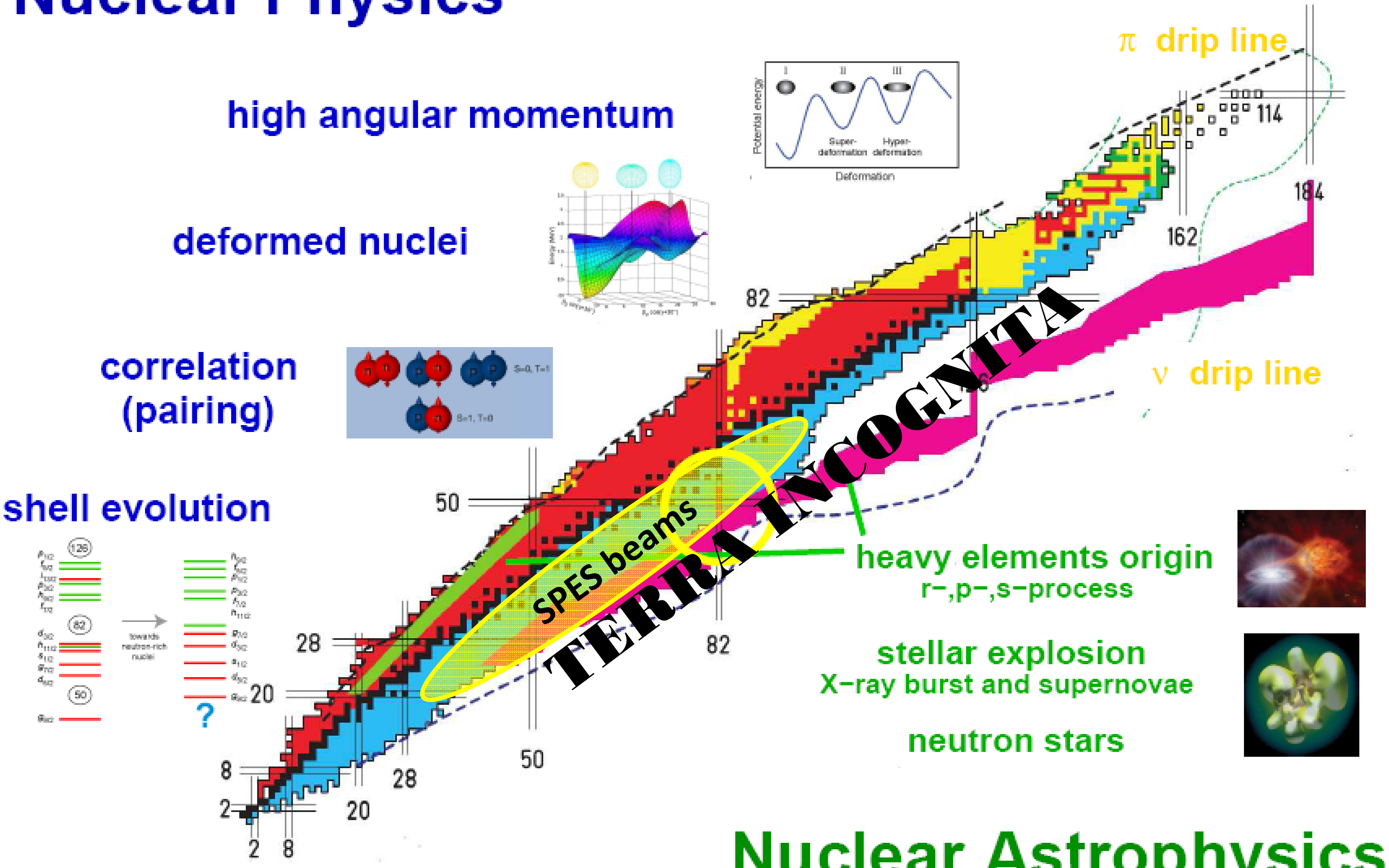
SPES (Selective Production of Exotic Species)

Nuclear Physics

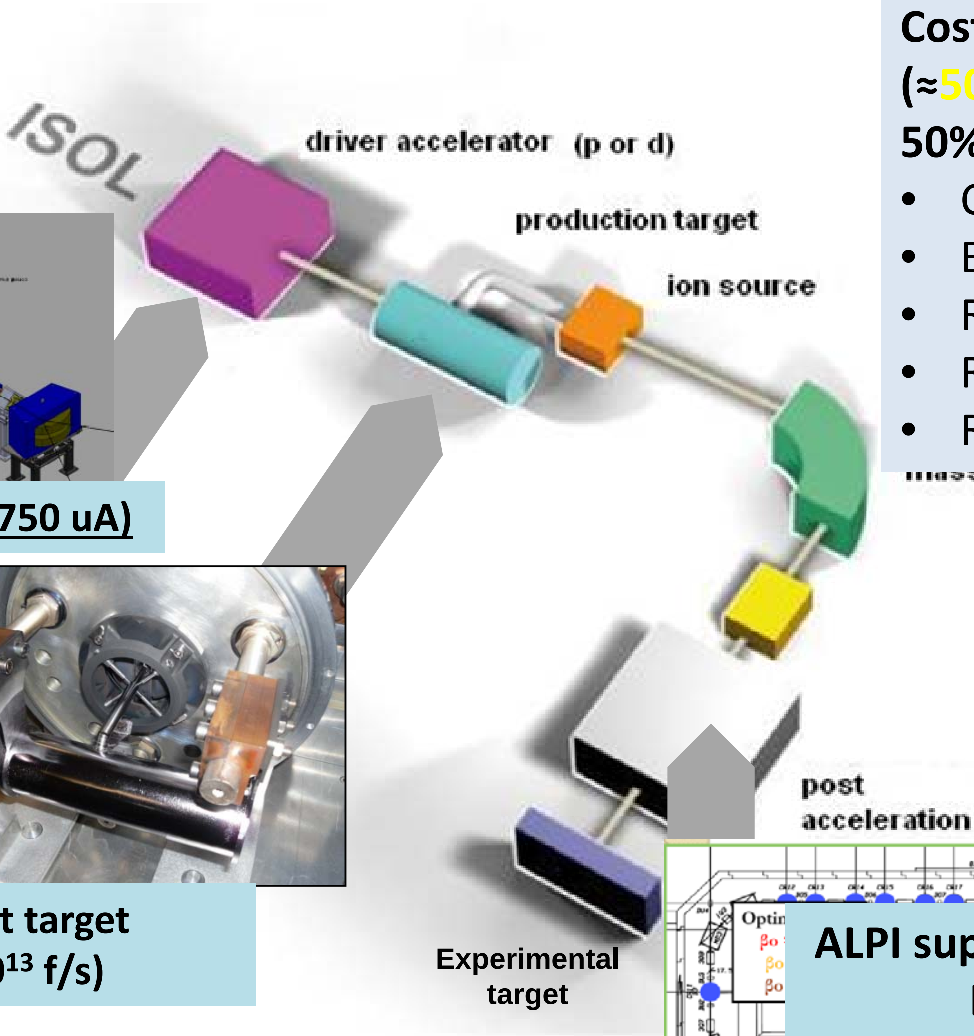


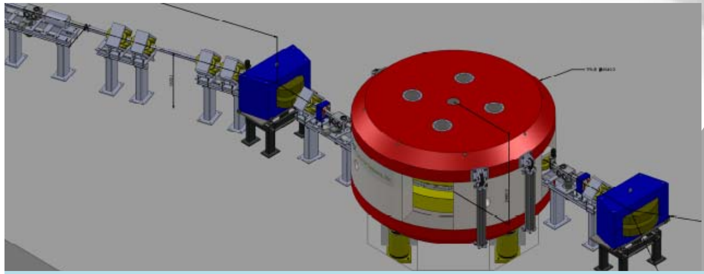
Nuclear Astrophysics

The SPES choice for the ISOL facility

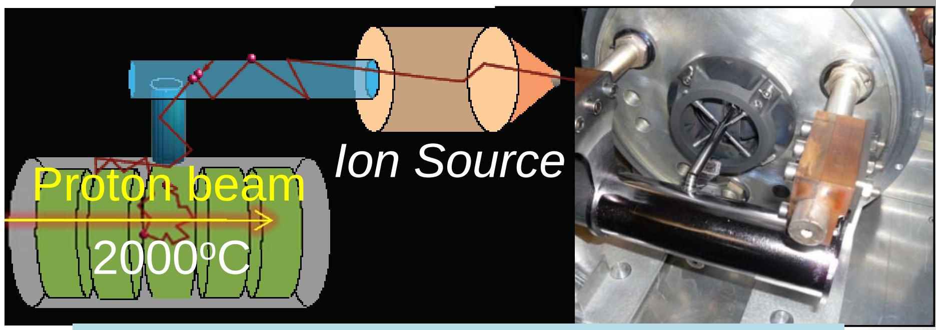
Cost-effective (≈50M€) 50% spent, 50% secured

- Cyclotron 10
- Building 10
- RIB production 5
- RIB transport 15
- Re-acc 10

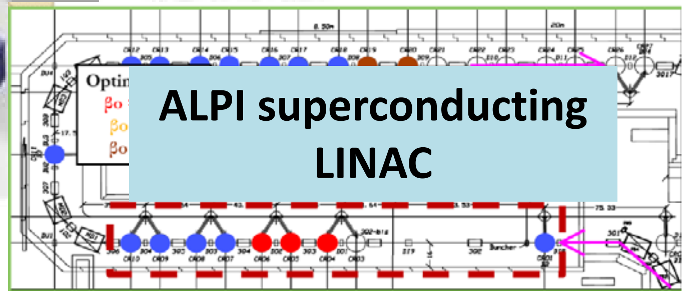




Cyclotron p-driver (30-70 MeV, 750 uA)



NEW CONCEPT: direct target multi-foil UCx (for 10^{13} f/s)

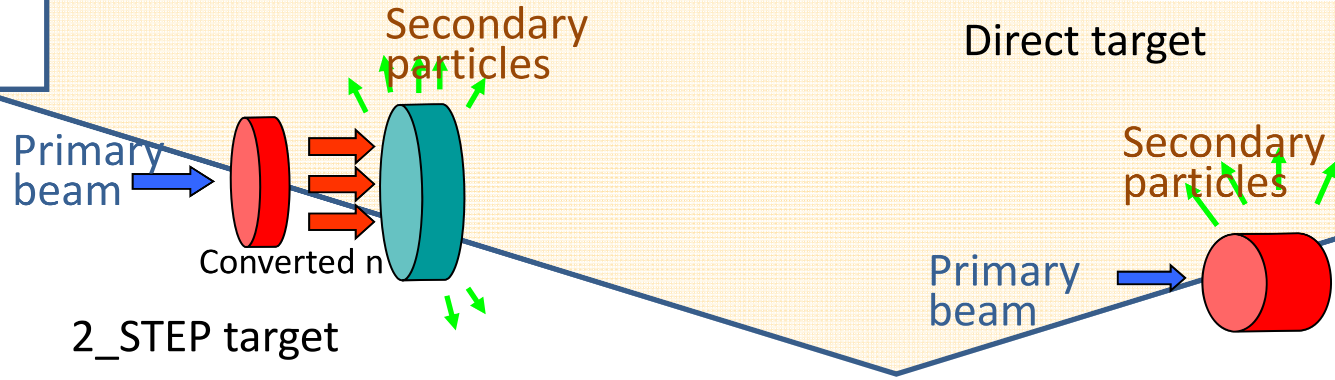


ALPI superconducting LINAC

Beam commissioning expected in **2018**

ISOL Roadmap in EUROPE

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

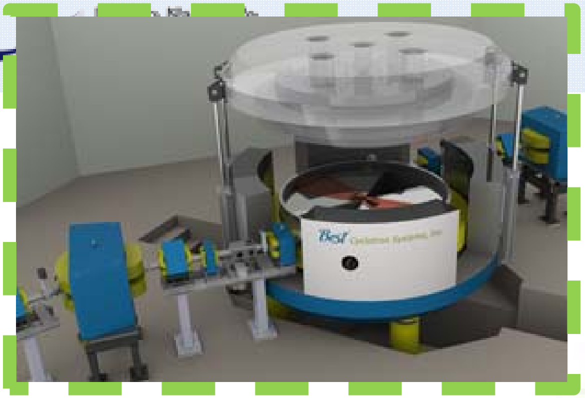


> 10^{15} fission/s
100 MeV/n (A=130)
Mass resolution 1/20000

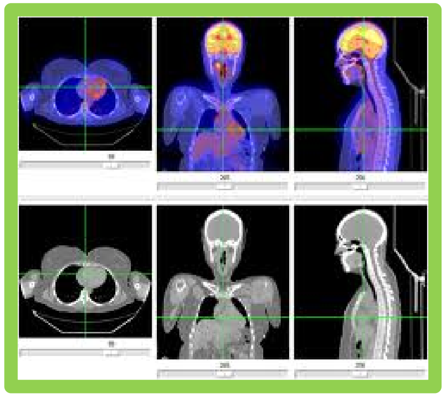
EURISOL

FROM 2025

The four phases of SPES



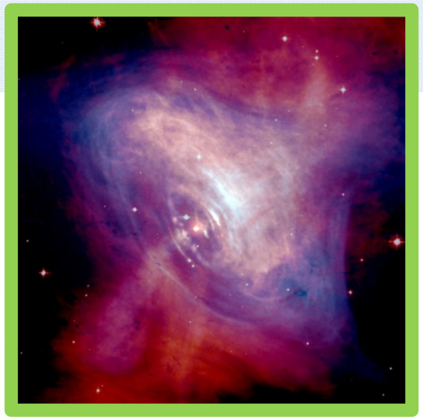
BEST Cyclotron:
- 70 MeV
- 1 mA



LARAMED Project @ LNL

Research and production of RI for medicine:
^{82}Sr, ^{64}Cu-, ^{67}Cu, …

Second generation ISOL facilty



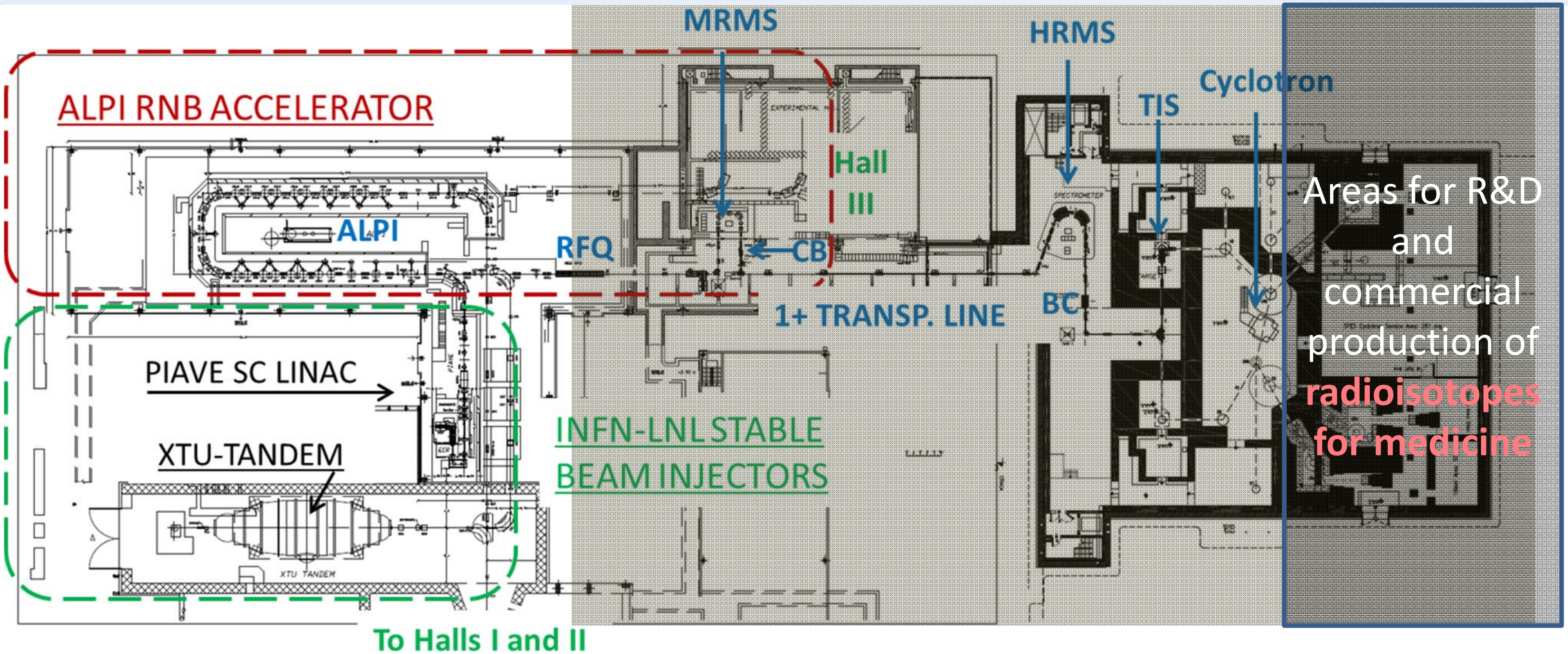
Study of neutron rich nuclei

NEPIR Project @ LNL

Accelerator based neutron source (cosmic spectrum and QMN beams)

1. What it is for
2. Design and construction of the new facilities
3. RNB Acceleration with the old ALPI

LNL Facilities: from stable to exotic

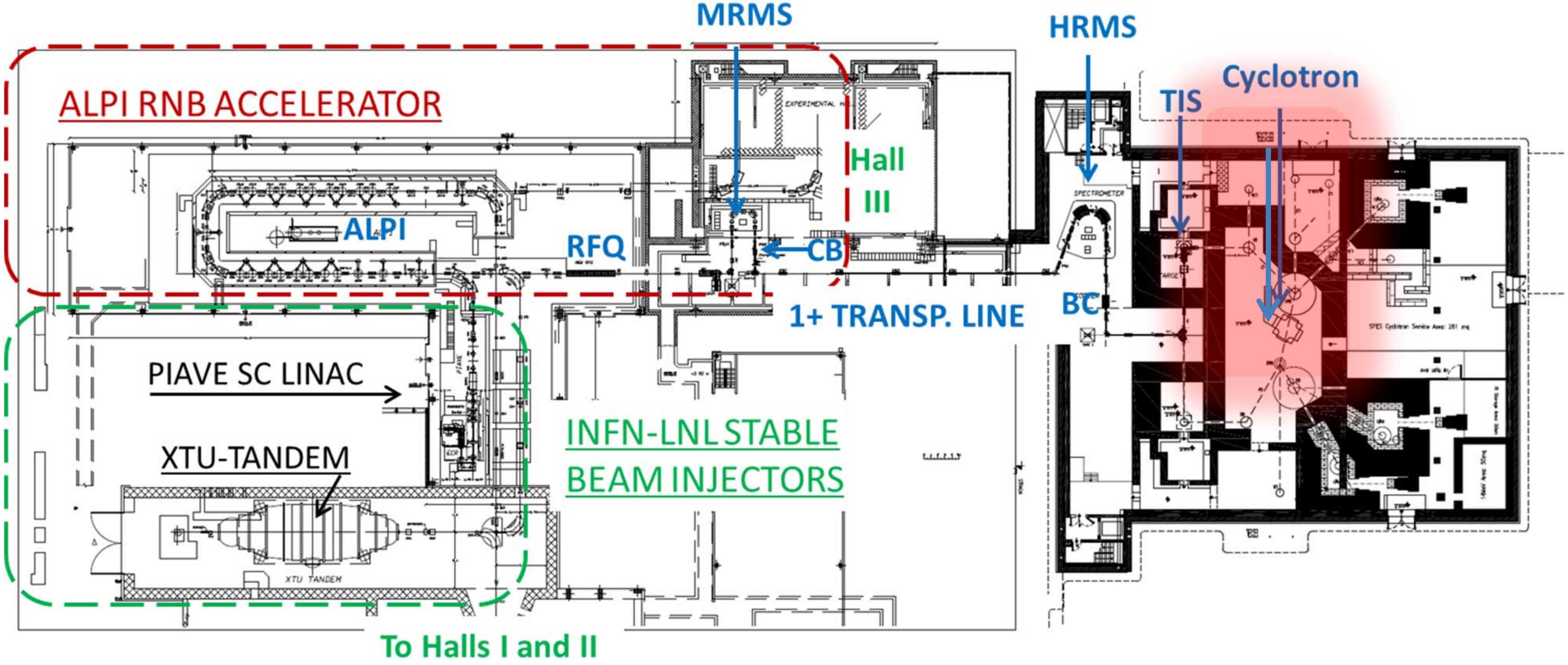


SPES project is rooted on an existing (folded…) SC linac, to be upgraded, but suitable to RNB acceleration.

Start-to-end excursus, **from cycloton to** ALPI

Wide scope aspects: **Safety and Radioprotection**, **Mechanics** (design and integration, new and new+old equipment), **Controls** (new and old integrated), **Vacuum**

SPES Layout

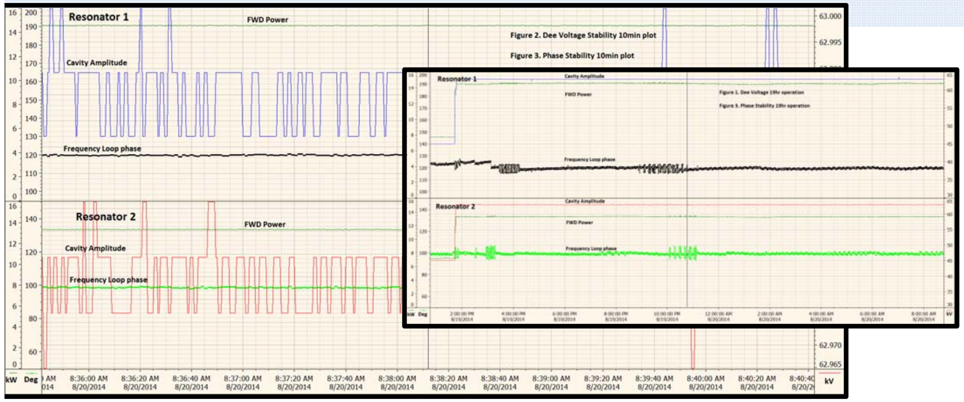


Cyclotron p-driver (30-70 MeV, 700 uA)

Istituto Nazionale di Fisica Nucleare

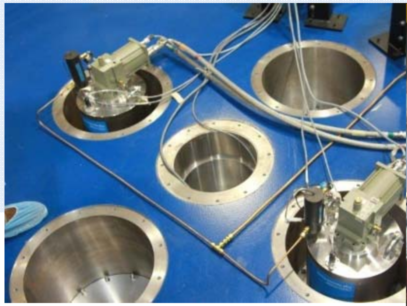
http://www.lnl.infn.it/~gestimp/speslive.jpg

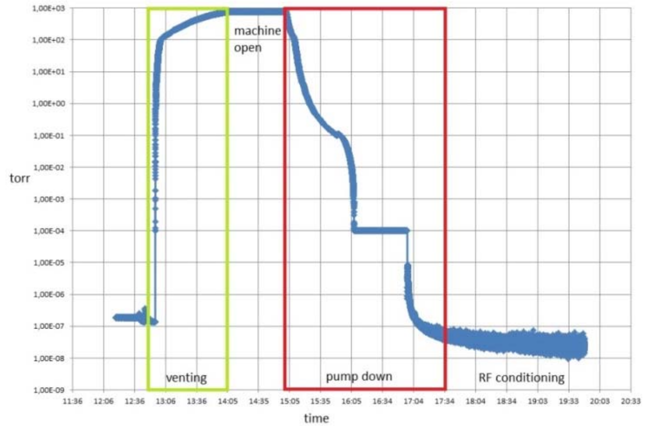
Status July 2014(@BEST Cyclotrons, Ottawa)



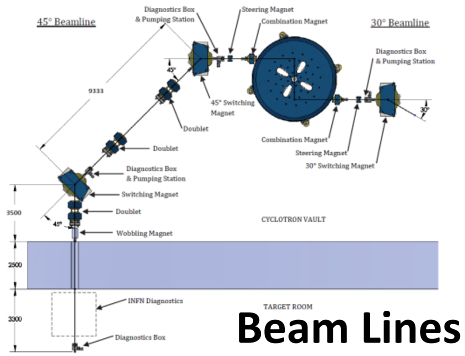
Cavity short and long term stability tests:
$\Delta V \leq 2{,}5 \times 10^{-5}$ (specs: $\leq 5 \times 10^{-4}$; ±0.1 deg)

Source: *6 mA* of H- achieved within acceptance (spec: **10m**A spec, for 800uA extraction)

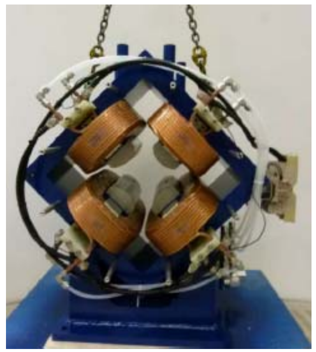




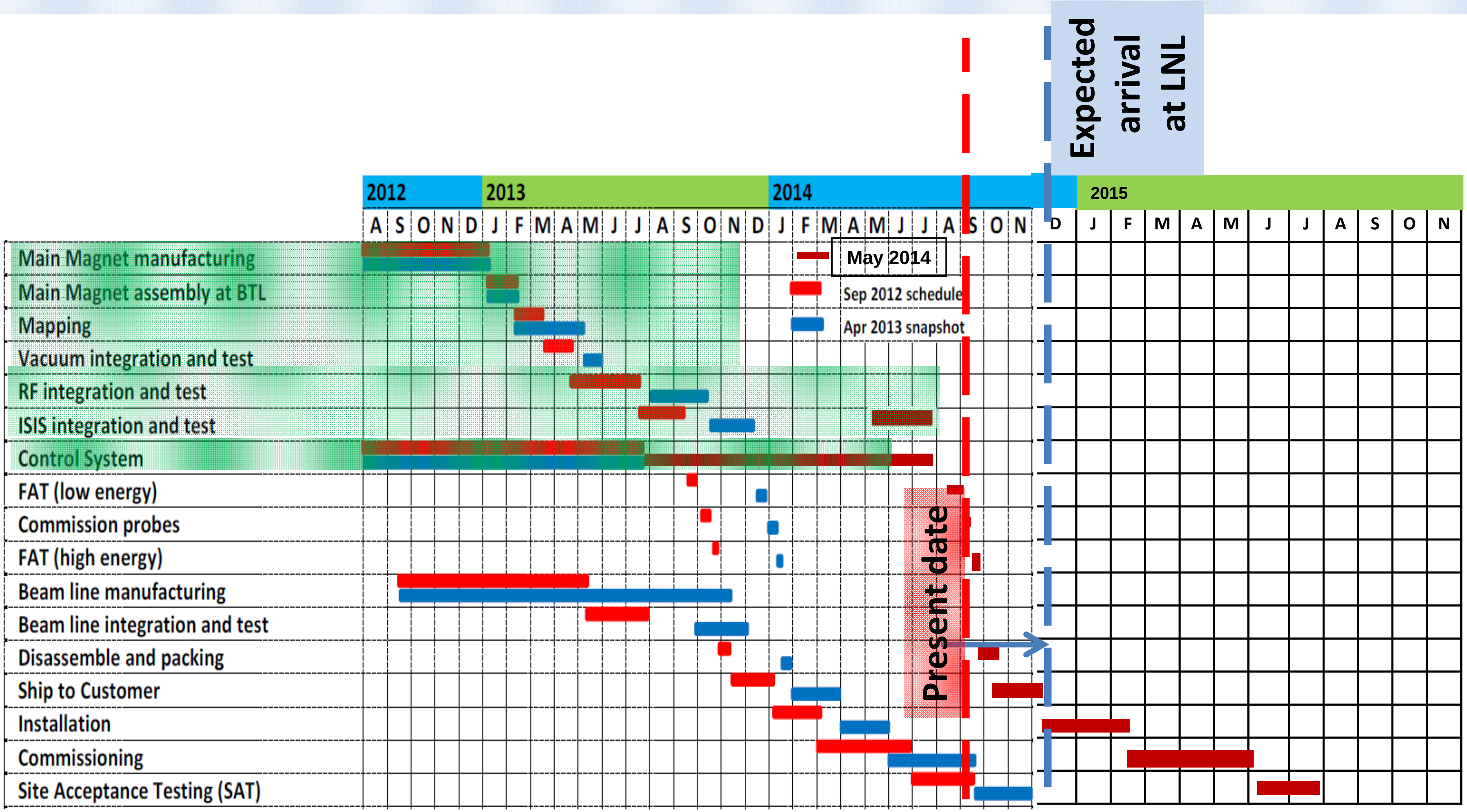
Vacuum: 2,5 hrs from open machine to better than 10^{-8} mbar (*no trim coils and one-piece poles*)



Beam Lines

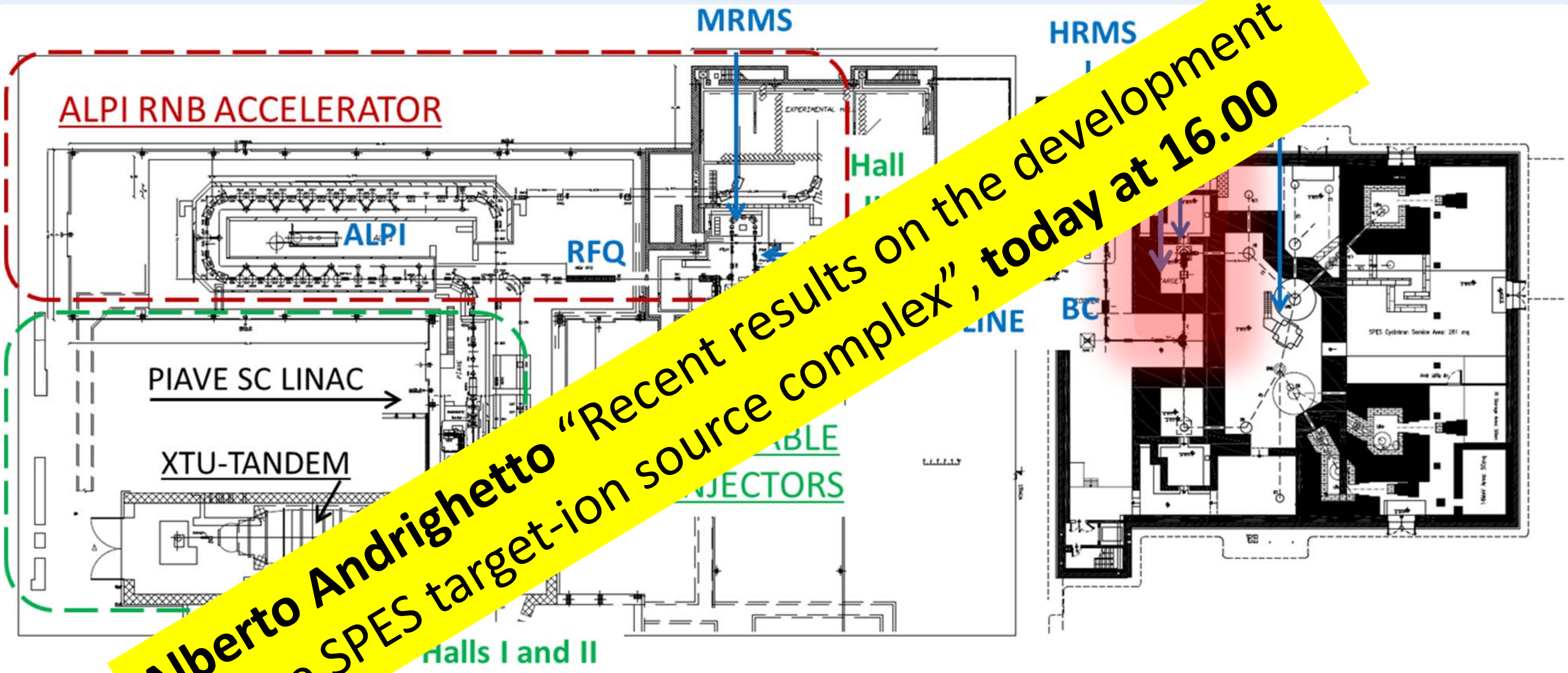


Cyclotron Schedule



Latest official schedule. Might be stretched by 3 more months

SPES Layout



Alberto Andrighetto "Recent results on the development for the SPES target-ion source complex", **today at 16.00**

Target-Ion-Sorce System: **UCx multislice direct** target, associated with **Surface, Plasma and Laser Ion Sources**

SPES safety: main issues

Radioprotection.specific:

- ✓ Radioactive release, in case of accident
- ✓ Activation (cyclotron-beam line, air, water, concrete)
- ✓ Exhausted radioactive gas
- ✓ Temporary storage of irradiated targets
- ✓ Activity build up on selected elements of the RIB-line

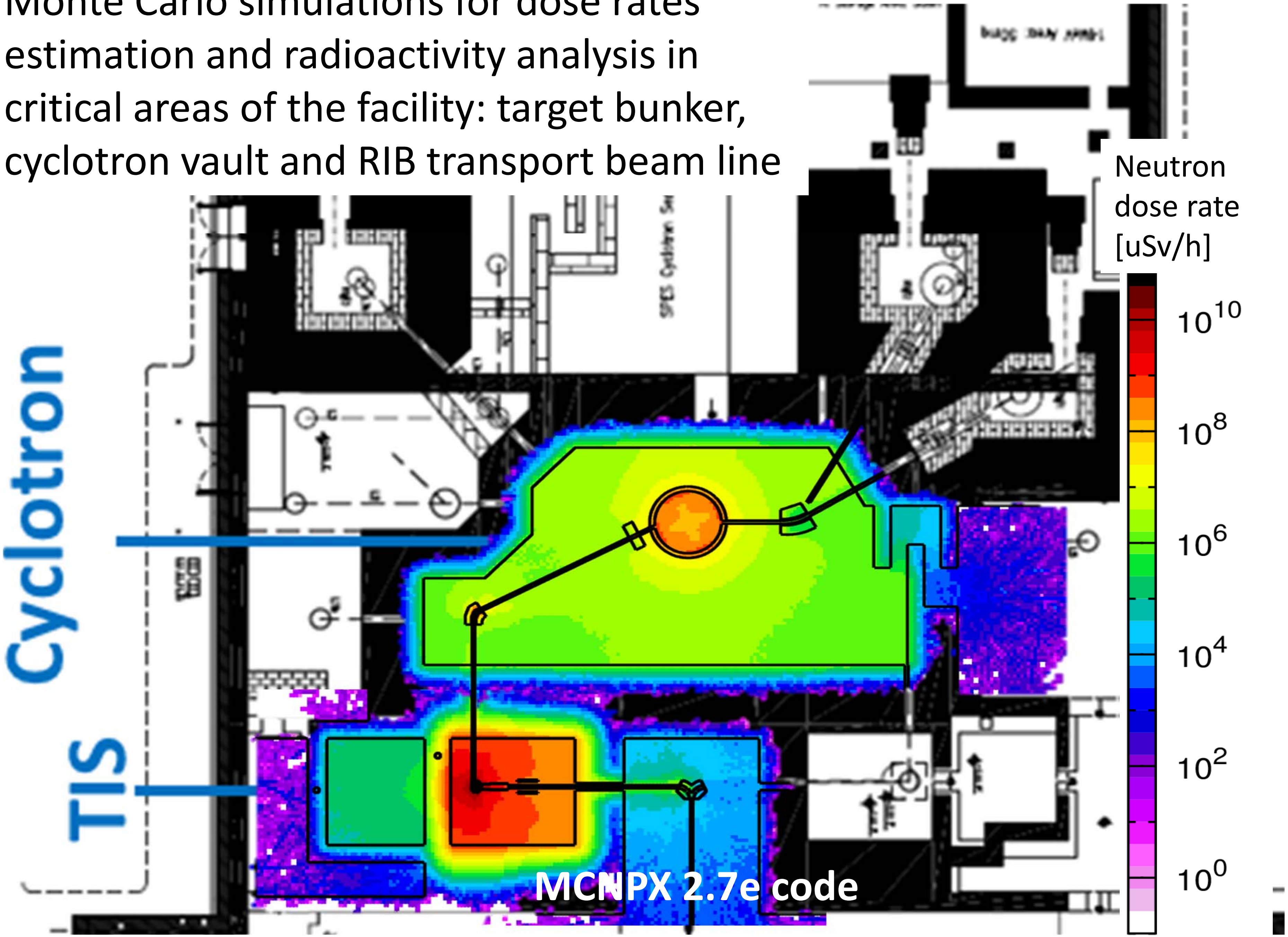
- ✓ Shielding
- ✓ Access Control System

Nuclear Safety Issues:

- TIS cooling system
- Air ventilation and pressure drop plant for target bunker and cyclotron rooms
- ISOL Front End (handling system, interventions, …)
- Vacuum and radioactive gases storage plant; Target Repository

Failure mode, effects and criticality analysis (FMECA) of the above in progress (revision of critical components)

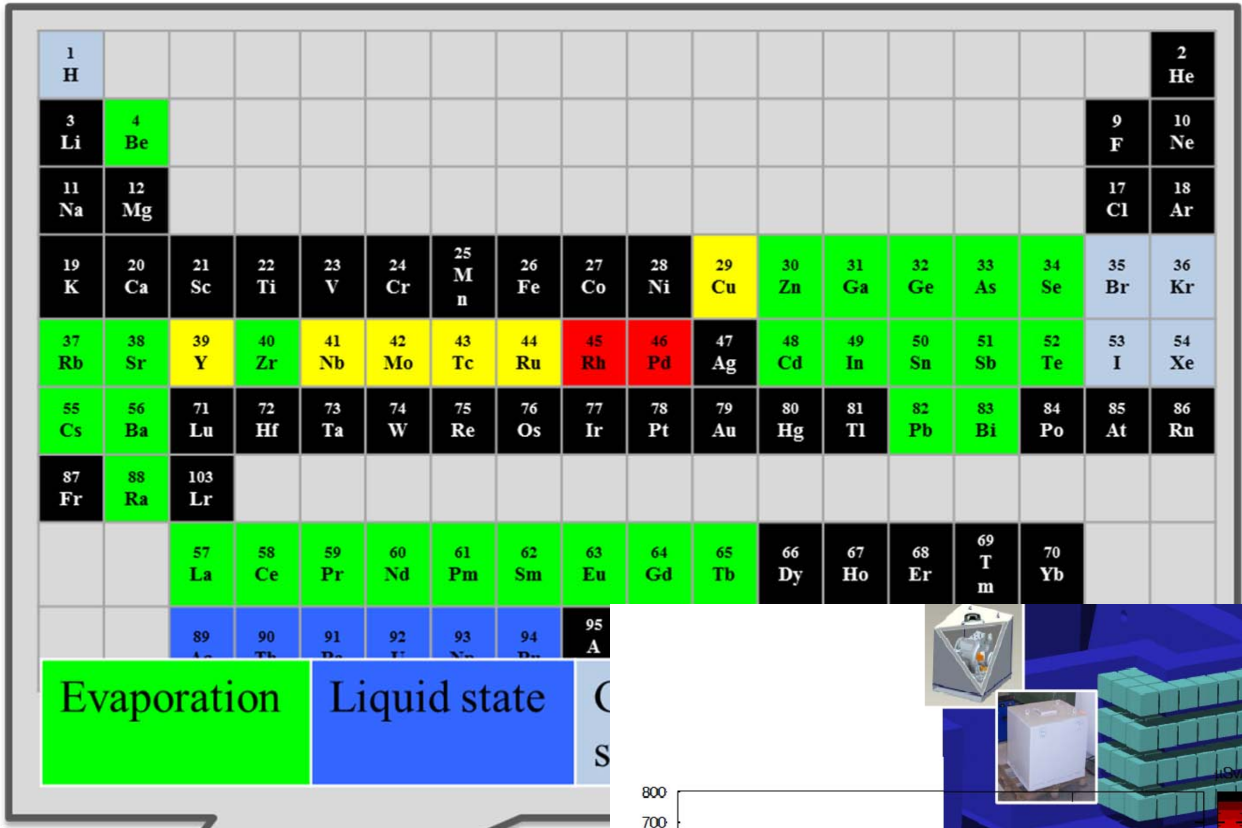
Monte Carlo simulations for dose rates estimation and radioactivity analysis in critical areas of the facility: target bunker, cyclotron vault and RIB transport beam line

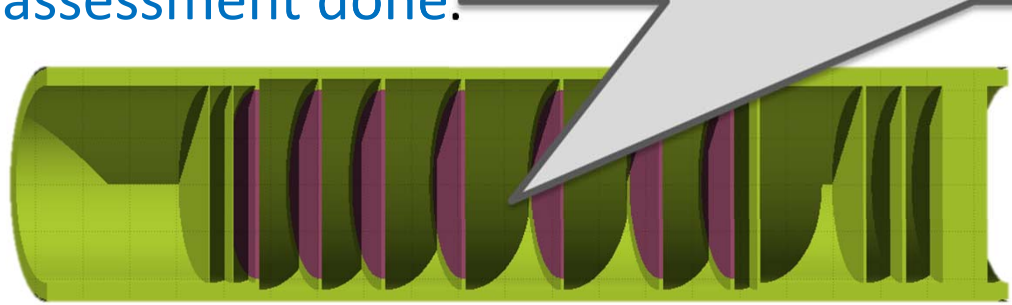


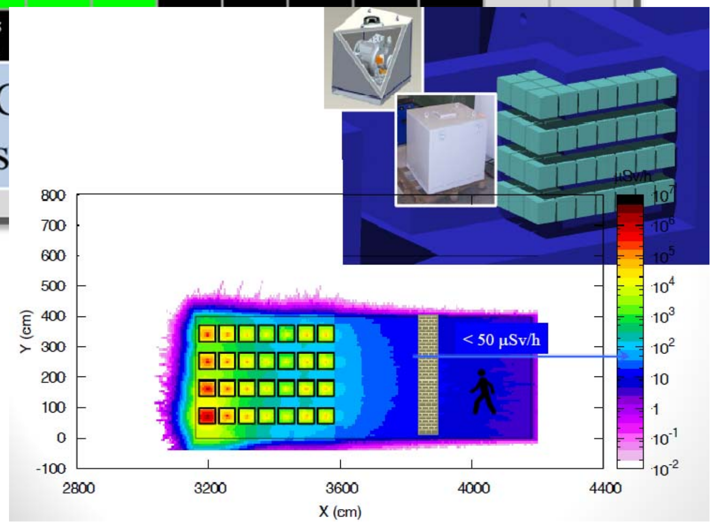
Irradiated target composition

RA elements:

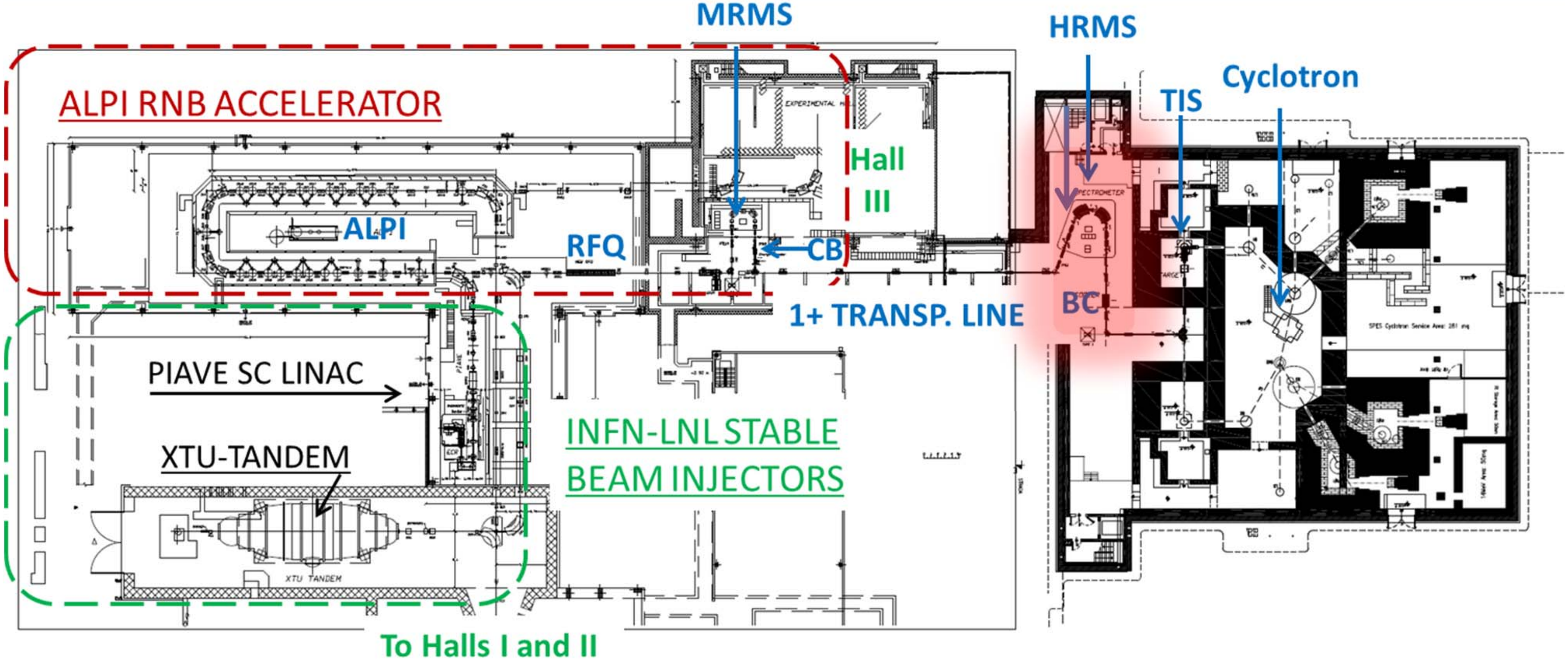
1. Some remain there (storage)
2. Other are released (gas/vapor into gas storage tanks): quantitative assessment done.





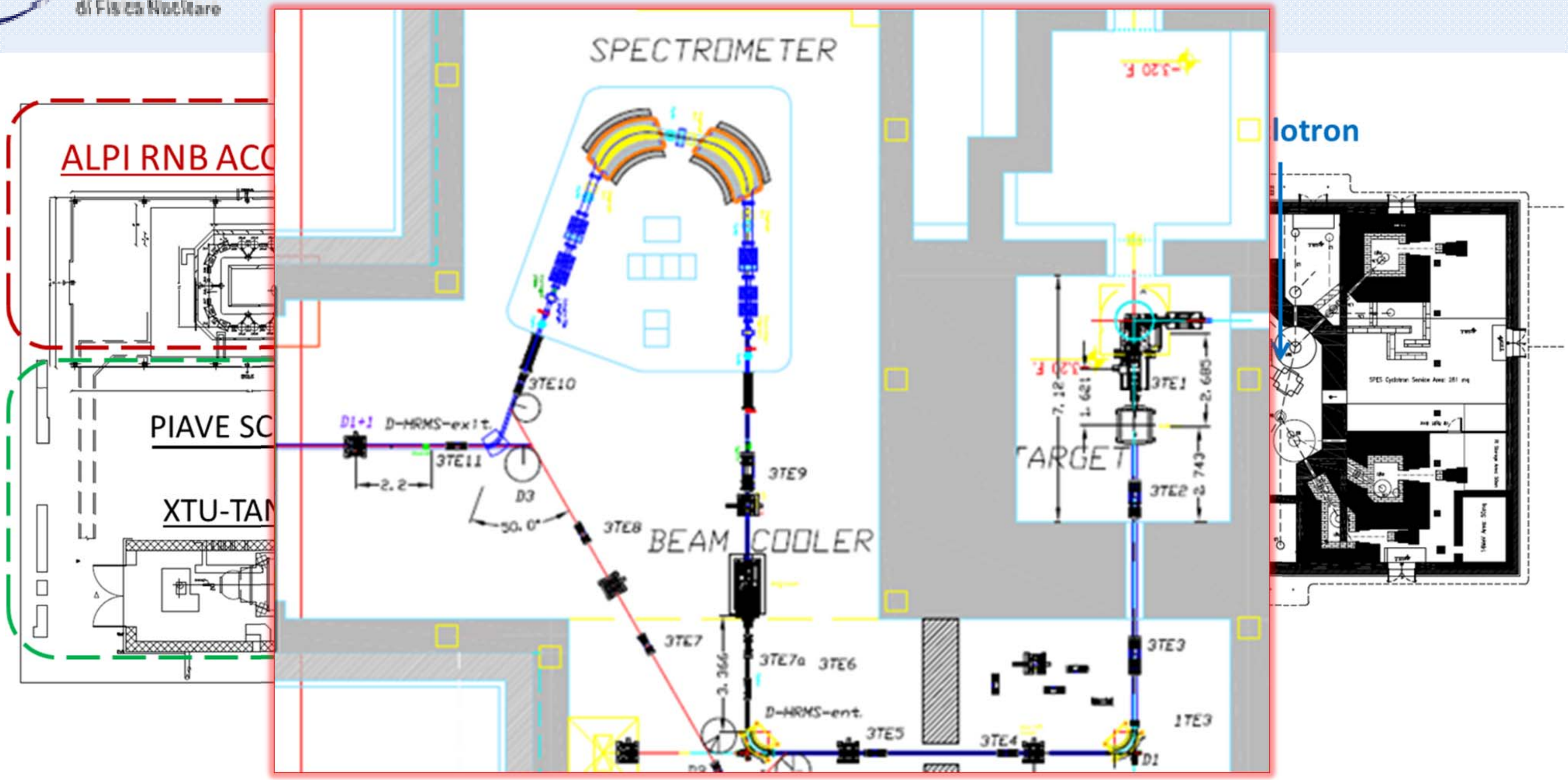


Beam Cooler and HRMS



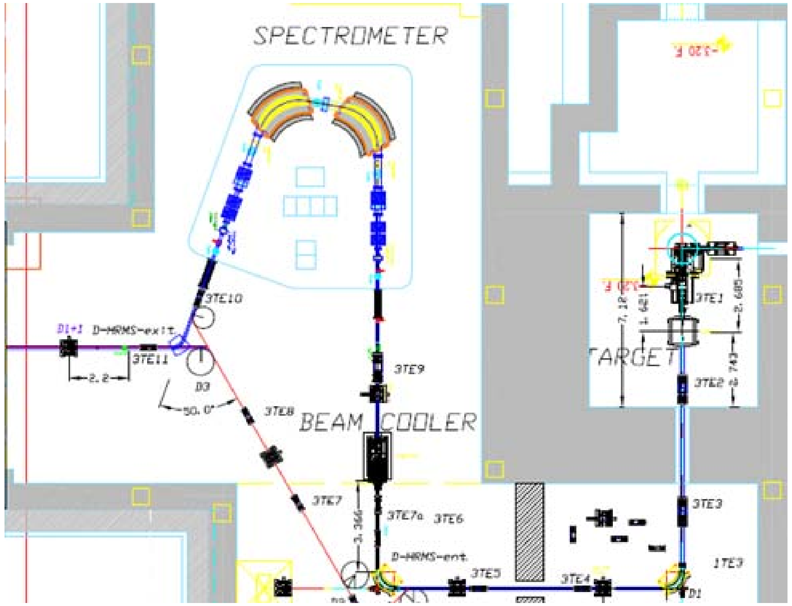
Beam Cooler and HRMS: required to ensure proper mass separation for fission-generated exotic nuclei

Beam Cooler and HRMS

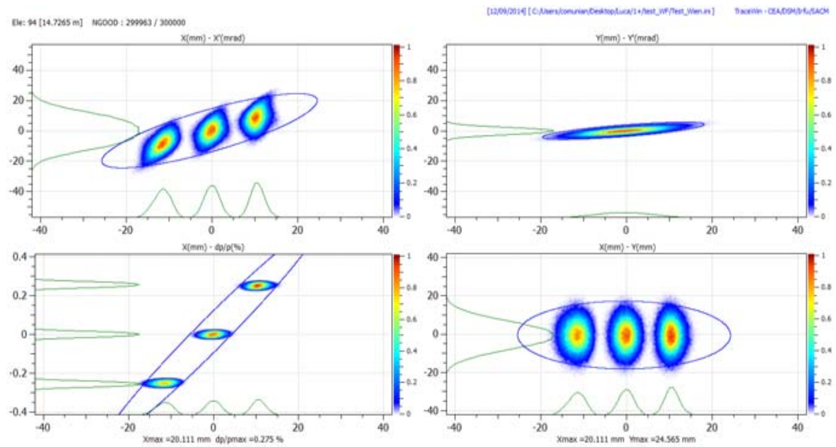


Beam Cooler and HRMS: required to ensure proper mass separation for fission-generated exotic nuclei, plus a by-pass line, plus…

WF + by-pass line

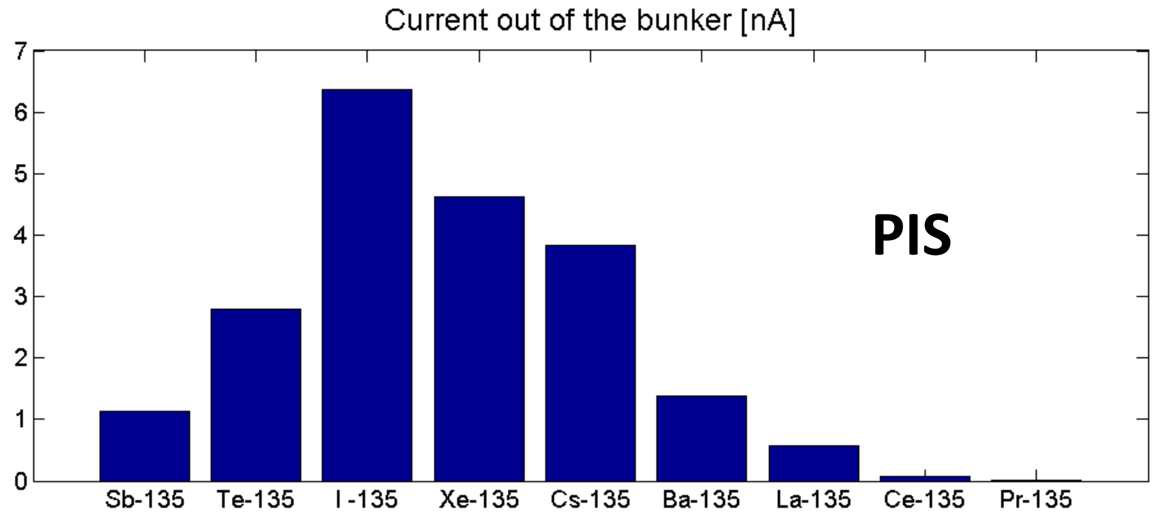


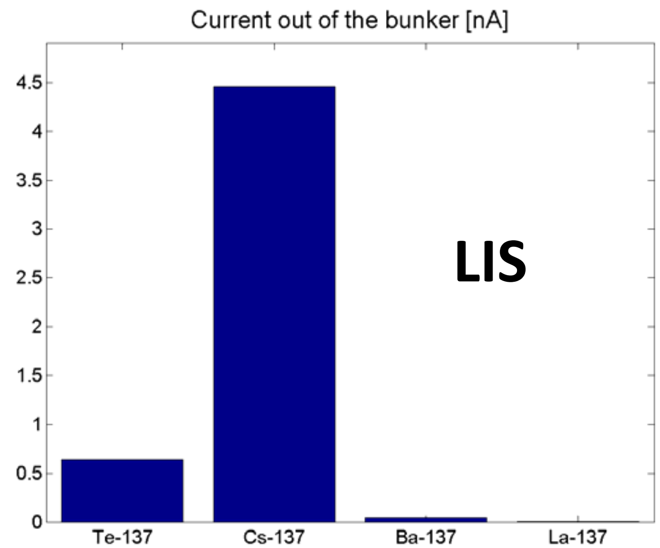
Name	Lenght (m)	Width/Height or diameter(cm)	Magnetic field (kG)	Comments
D29	1.2			
FI3	26.5°			Entrance edge
BN90	0.9425		5.51	R=0.6 m
F03	26.5°			Exit edge
D30	1.25			
QU81	0.2	∅=8	6.76	
D32	0.07			
QU82	0.4	∅=8	-1.7	
D33	0.07			
QU83	0.2	∅=8	1.68	
D34	1.79			



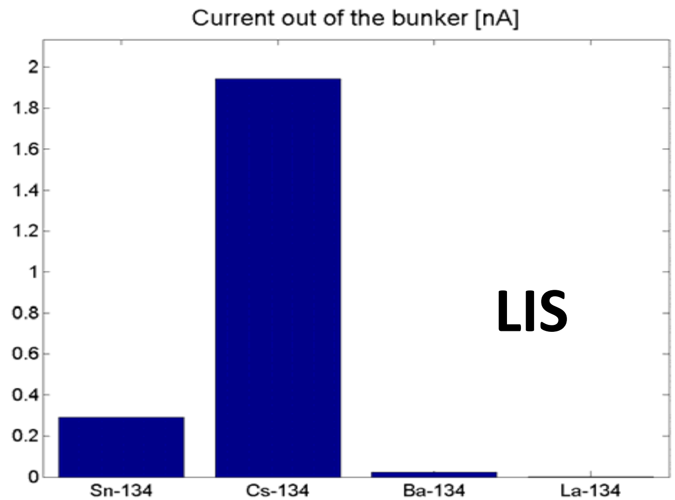
- $\Delta M/M \approx 1/400$ (1° order)
- **$\Delta M/M \approx 1/200$ (2° order)**
- Error study on-going

Beam contaminants to be selected along the beam line



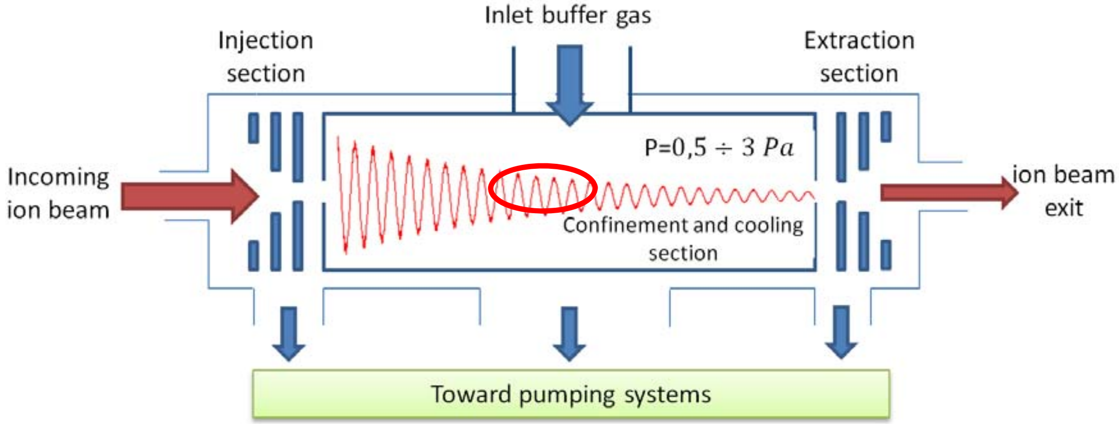


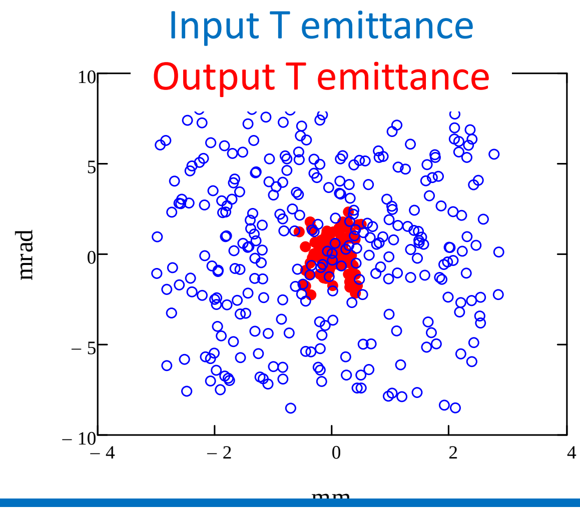
Depending on the desired species and the source type (SIS, LIS, PIS), different **M-resolution** along the beam line are required for **proper RNB selectivity.**



Beam distribution out of the bunker (after the $\Delta M/M \sim 1/70$ WF)

RFQ Beam Cooler

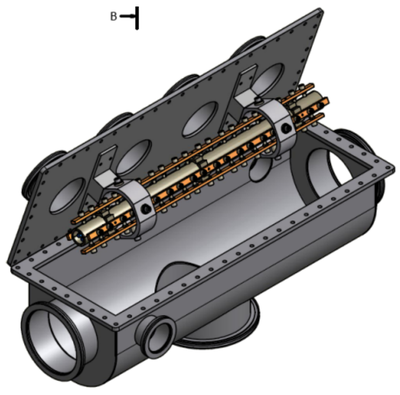




SPES RFQ Beam Cooler parameters

Mass Range	5-200 amu
Transverse Emittance Injected beam	30 π mm mrad @ 40 keV
Emittance Reduction factor	10 (max)
Buffer Gas	He @ 273 K
Beam Intensity	50-100 nA → x10^{11} pps
Energy spread	< 5 eV
RF Voltage range	0.5 – 2.5 kV (1 kV at q=0.25)
RF Frequency range	1 -30 MHz (3.5 – 15 MHz at q=0.25)
RFQ gap radius (ro)	4 mm
RFQ Length (total)	700 mm
Pressure Buffer Gas (He) range	0.1 – 2.5 Pa
Ion energy during the cooling	100 -200 eV

BD and **EM** simulations, **mech.**and **quads** : done
RF system and **HV** tests **in high-P**: will be tested

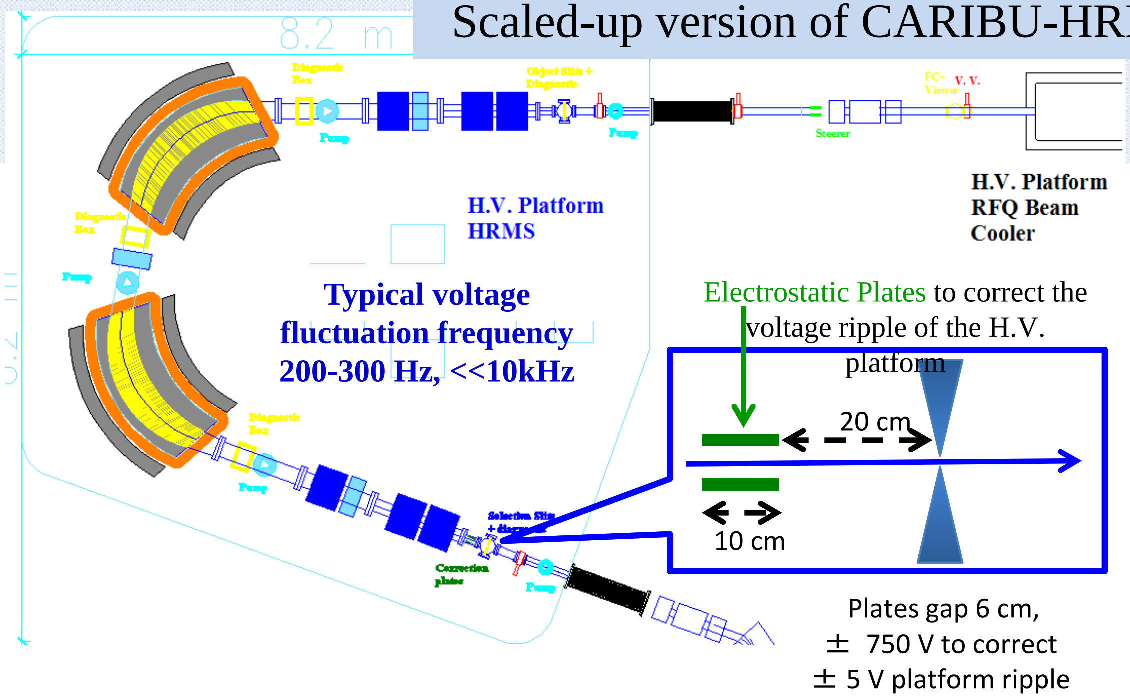


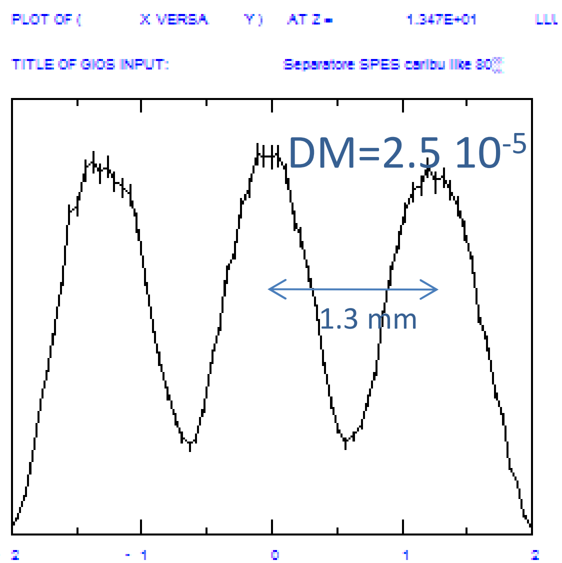
Inj/extr design: Q1/2015

INFN Istituto Nazionale di Fisica Nucleare

HRMS physics design

Scaled-up version of CARIBU-HRMS, ANL (USA)





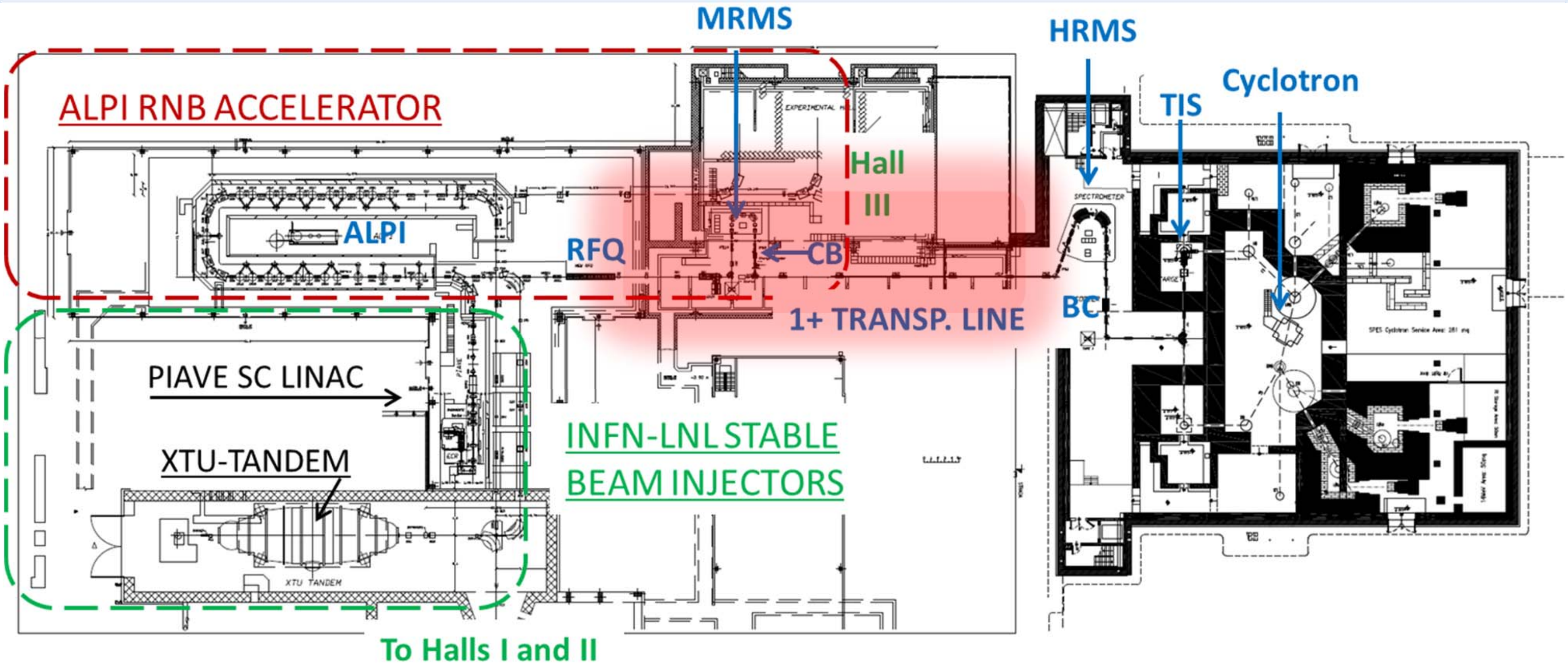
3° order effects analysis (LNS-LNL)

Input parameters:

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

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

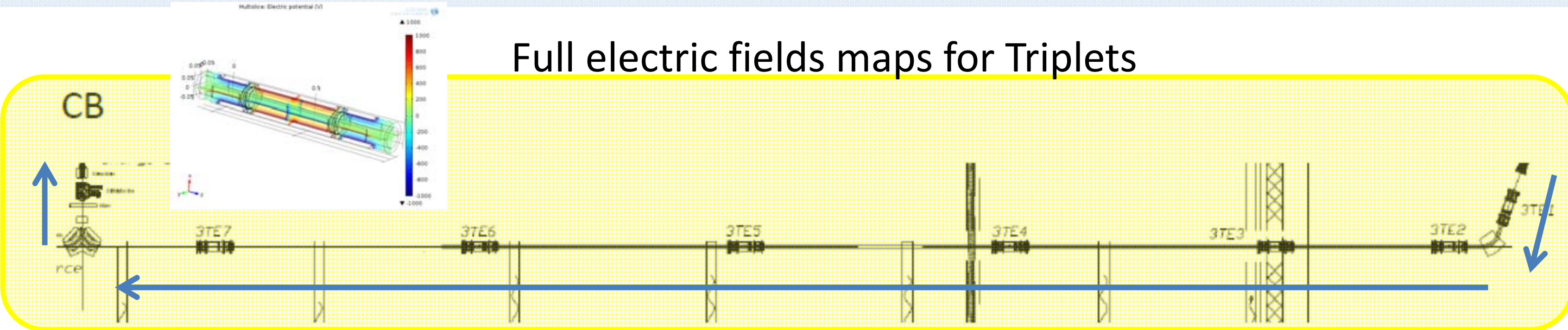
Beam preparation for RNB-acceleration

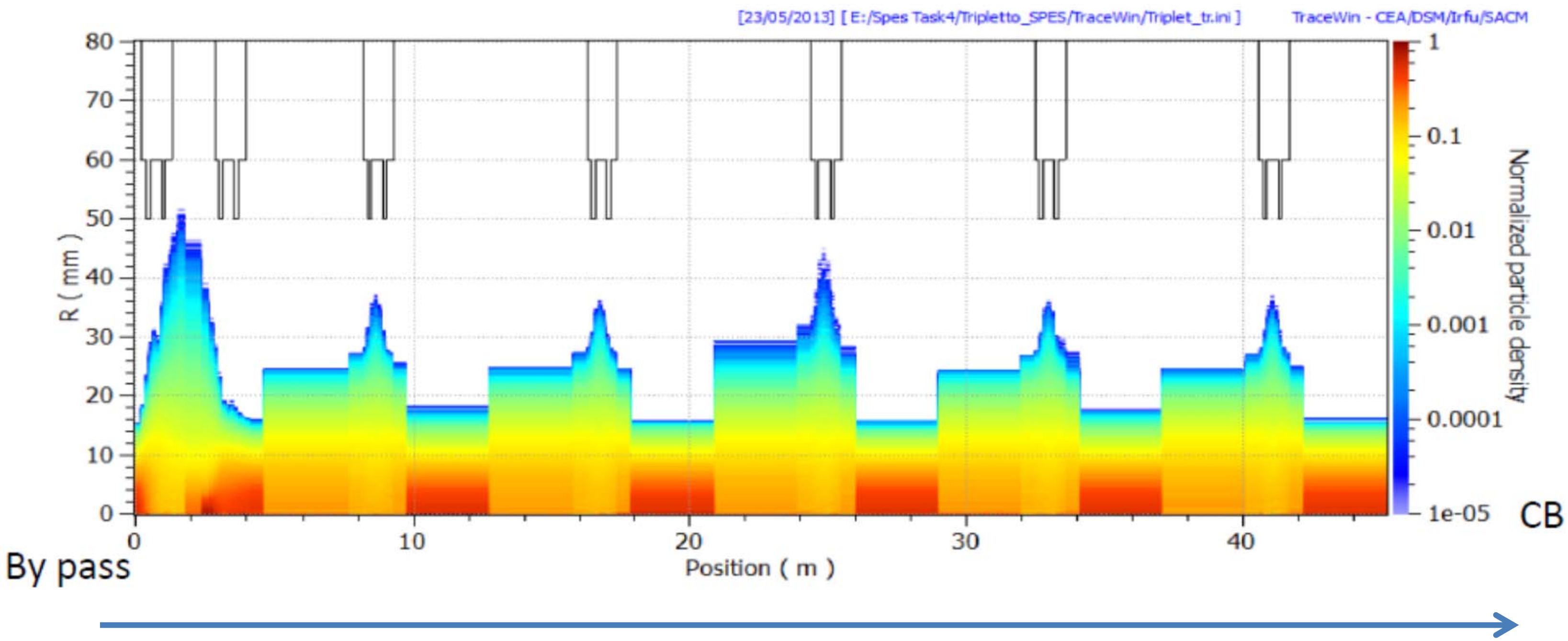


Transport Line to the Charge Breeder: a long line with electrostatic triplets links the new building to the stage of ch. state boosting, mass selection, RFQ injector and ALPI...

Transport line to the Charge Breeder

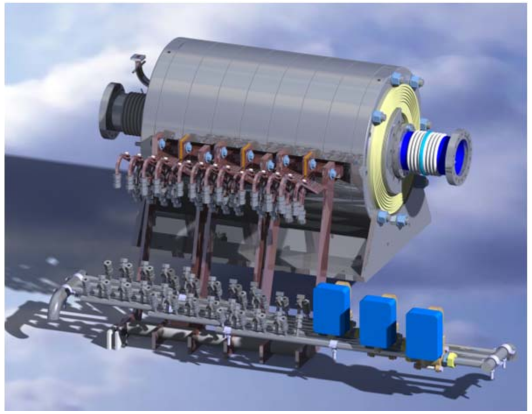
Full electric fields maps for Triplets

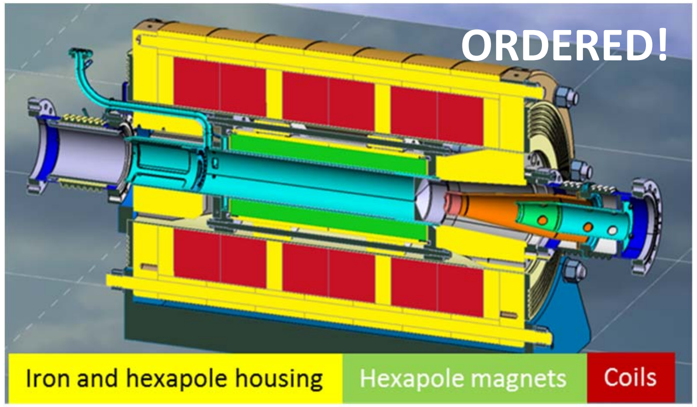


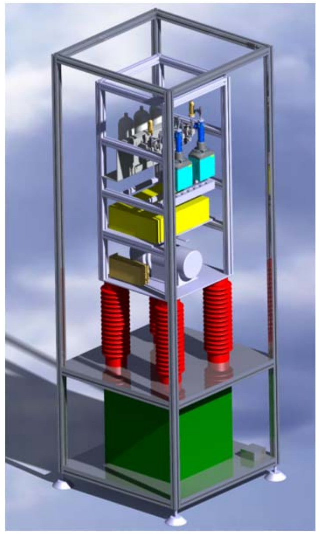


ECR-type Charge Breeder

- Developed by LPSC (linked to LEA-COLLIGA coll.)
- Designed in 2013, approved in June 2014, Delivery: April 2015





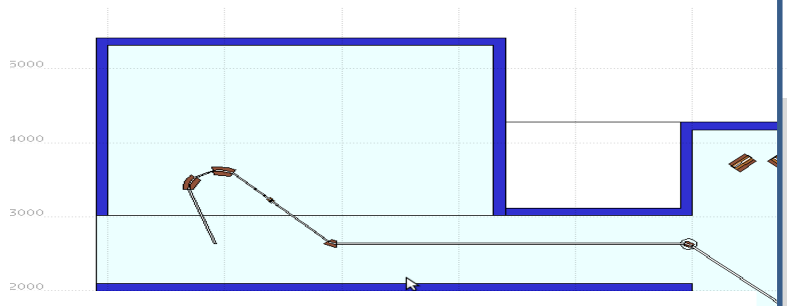


Delta-V bay: to finely adjust CB and 1+ Source Voltages and optimize capture of 1+ beam.

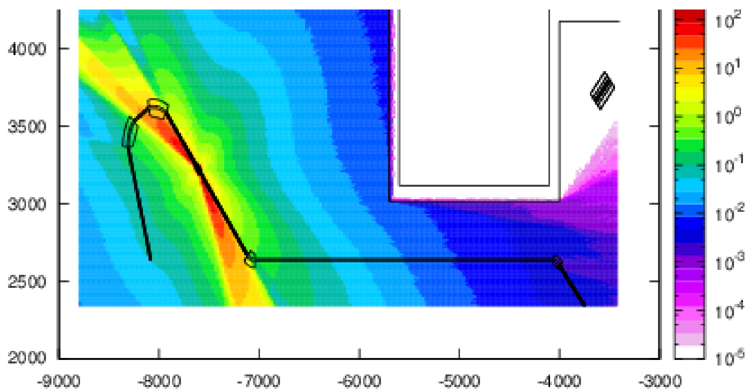
Element	Charge State	Efficiency [%]	CB time [ms]	Global Capture [%]
Ar	8+	16.2	78	75
Xe	20+	10.9	252	80
Rb	17+	7.5	226	55
Sn	21+	6.3	200	-

RIB transport

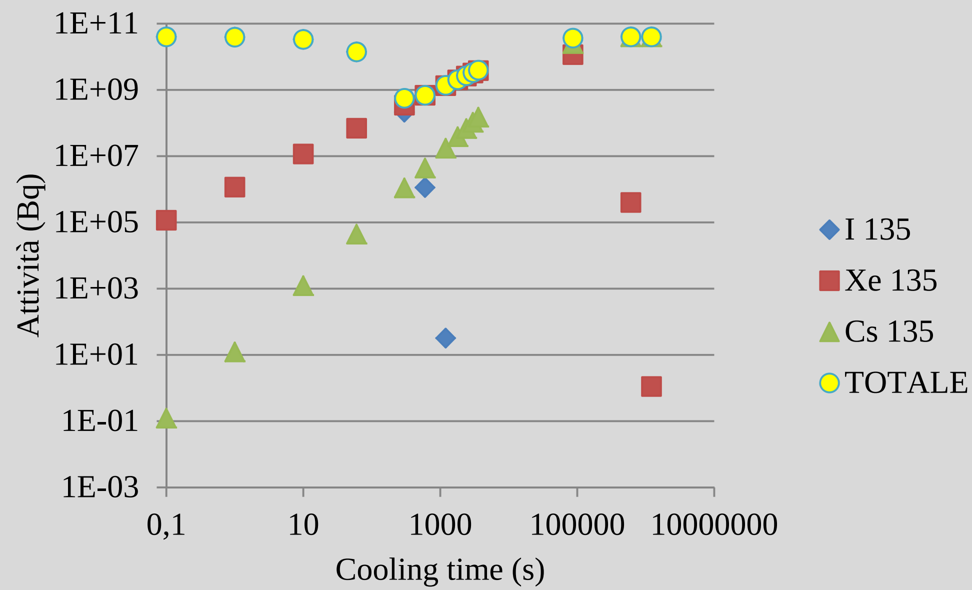
Dose rates evaluation in proximity of the beam line to **avoid overexposure of the accessing personnel**



Dose rate distribution (arb. units) – MC simulations



Radioactivity build up in the charge breeder for selected beams of interest in order to plan **hands-on maintenance**



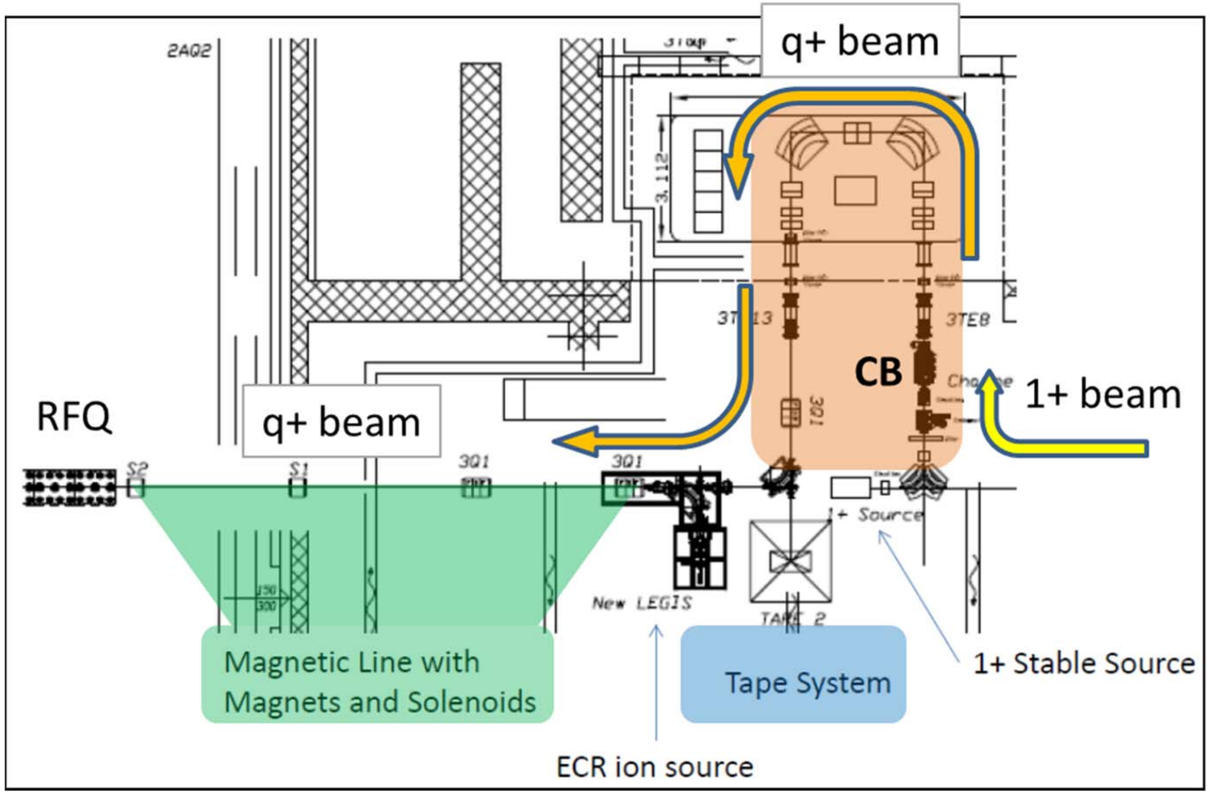
Radioactivity build up – analytical evaluation

Charge Breeder Contaminants

isotope	element	Mass	abundance (%)	M/q														
				1+	2+	3+	4+	5+	6+	7+	8+	10+	11+	12+	13+	14+	15+	16+
12	C	12.000	98.9	12.000	6.000	4.000	3.000	2.400	2.000									
13	C	13.003	1.1	13.003	6.502	4.334	3.251	2.601	2.167									
14	N	14.003	100	14.003	7.002	4.668	3.501	2.801	2.334	2.000								
15	N	15.000	0.366	15.000	7.500	5.000	3.750	3.000	2.500	2.143								
16	O	15.995	99'762	15.995	7.997	5.332	3.999	3.199	2.666	2.285	1.999							
17	O	16.999	0.038	16.999	8.500	5.666	4.250	3.400	2.833	2.428	2.125							
18	O	17.999	0.2	17.999	9.000	6.000	4.500	3.600	3.000	2.571	2.250							
36	Ar	36.968	0.337	36.968	18.484	12.323	9.242	7.394	6.161	5.281	4.621							
40	Ar	39.962	99.6	39.962	19.981	13.321	9.991	7.992	6.660	5.709	4.995							
78	Kr	77.920	0.35									7.792	7.084	6.493	5.994	5.566	5.195	4.870
80	Kr	79.916	2.25									7.992	7.265	6.660	6.147	5.708	5.328	4.995
82	Kr	81.913	11.6									8.191	7.447	6.826	6.301	5.851	5.461	5.120
83	Kr	82.914	11.5									8.291	7.538	6.910	6.378	5.922	5.528	5.182
84	Kr	83.912	57									8.391	7.628	6.993	6.455	5.994	5.594	5.244
86	Kr	85.911	17.3									8.591	7.810	7.159	6.609	6.136	5.727	5.369

Main contaminants of the RNB delivered by the charge breeder are C, N and O: **ΔM/M** of a Medium Resolution Mass Separator (**MRMS**) to separate contaminants **~ 1/1000**.

CB and Medium Resolution Mass Spectrometer, Injection into the RFQ



- A Tape System after the MRMS: RNB identification
- After L-bend: magnetostatic triplets (future stable beam)
- Beam Optics of the MRMS (…)

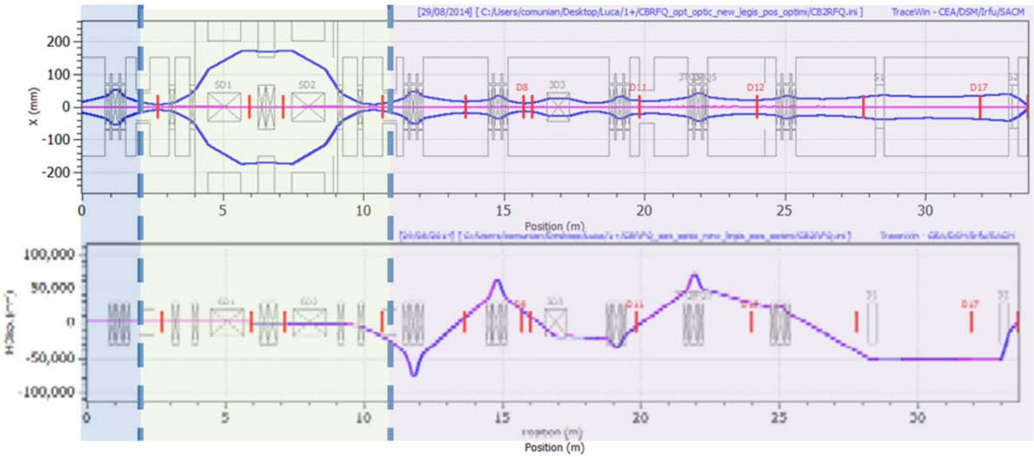
Beam Optics from CB to RFQ

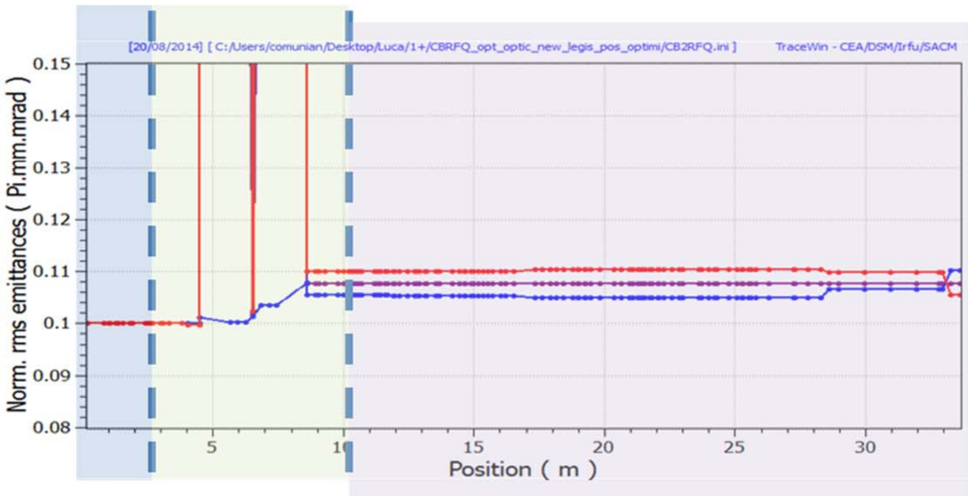
E_x, D_x and $\varepsilon_{(x,y),n}$:

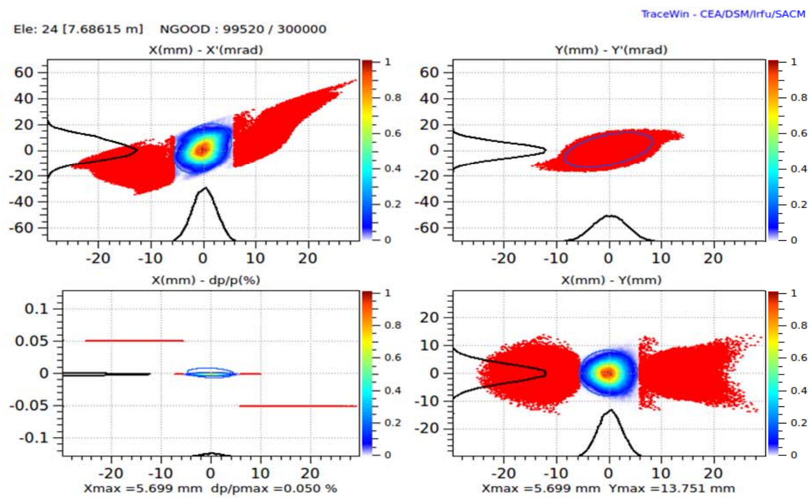
from the CB,

through the MRMS,

to the RFQ



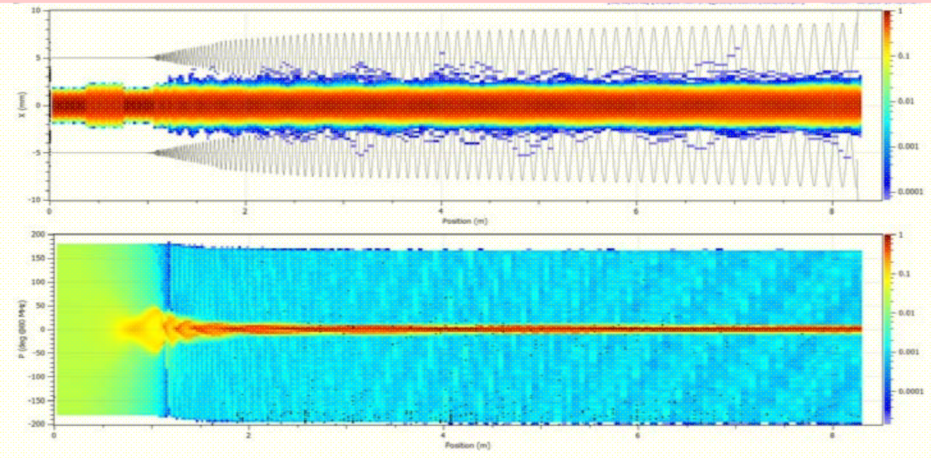


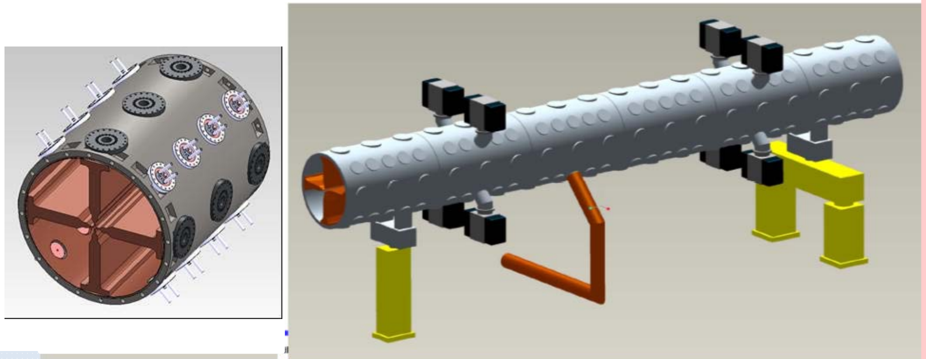


Error study on quad position, angle, gradient; input energy, position
→ 7% beam loss, after the RFQ

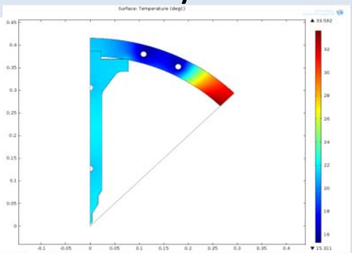
New RFQ Injector for ALPI
(7 m, 7 modules)

- **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)
- **Mechanical design** and realization, similar to the Spiral2 one, takes advantage of IFMIF experience (LNL, INFN_Pd, Bo, To) **for up to 1 mA**

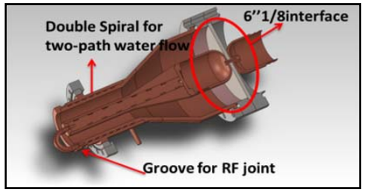




Mechanical layout of the RFQ tank module (≈1 m)

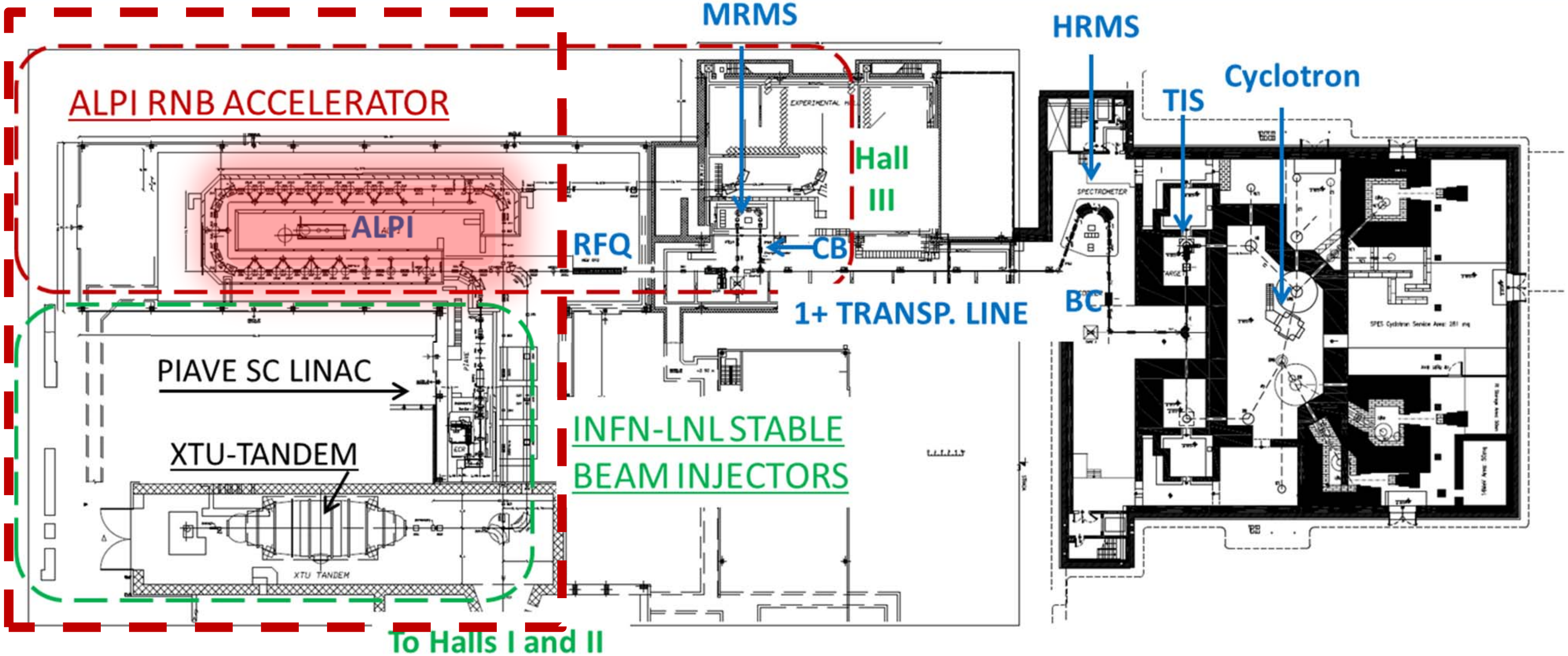


Temperature, Deformation, Heat plots



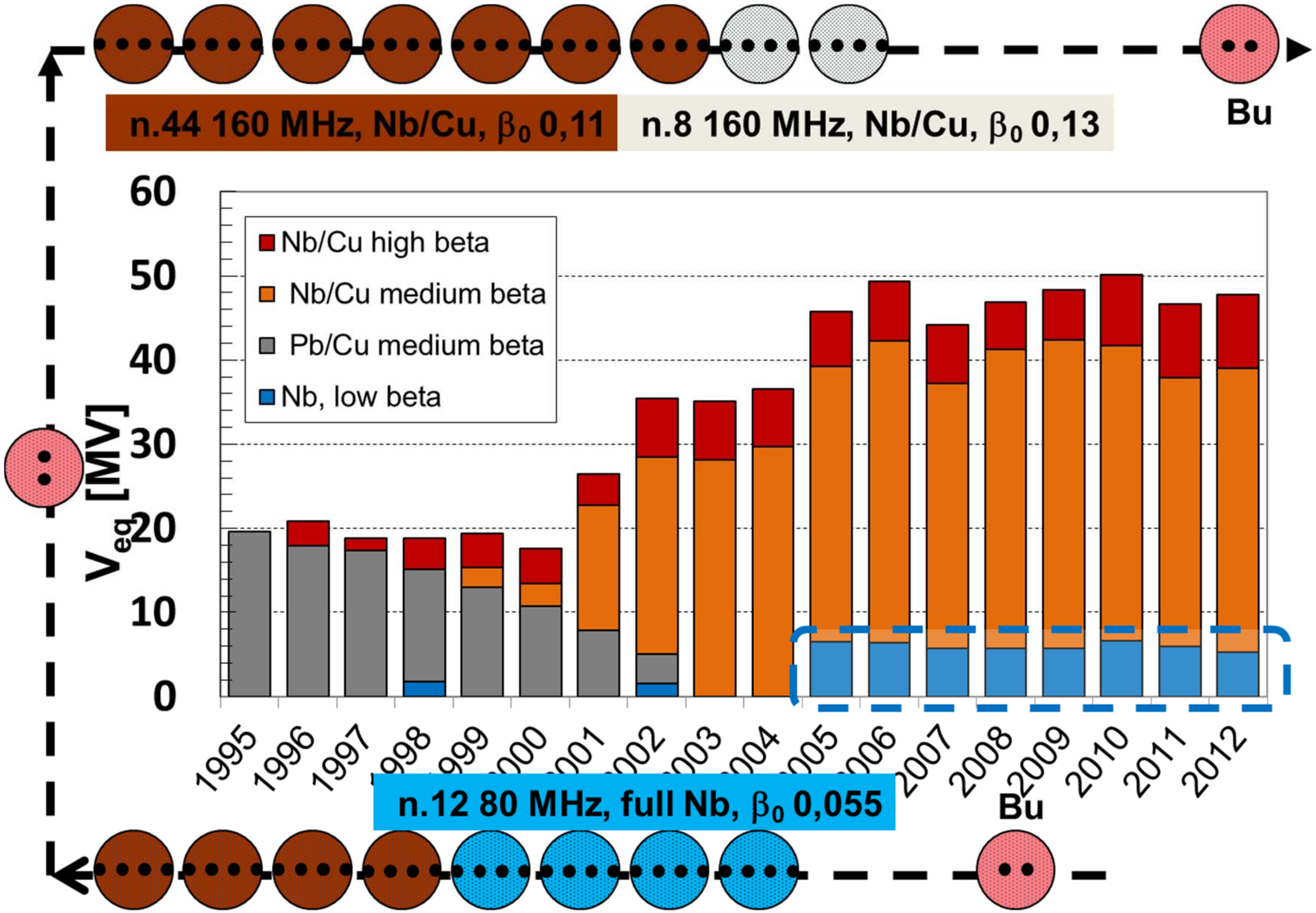
200 kW tertrode **RF amplifier** (175 MHz) available from IFMIF test bench, with f-tuning of the cavity (→ 80 MHz); 200 kW **Power Coupler** developed

ALPI Upgrades for exotic and stable beams

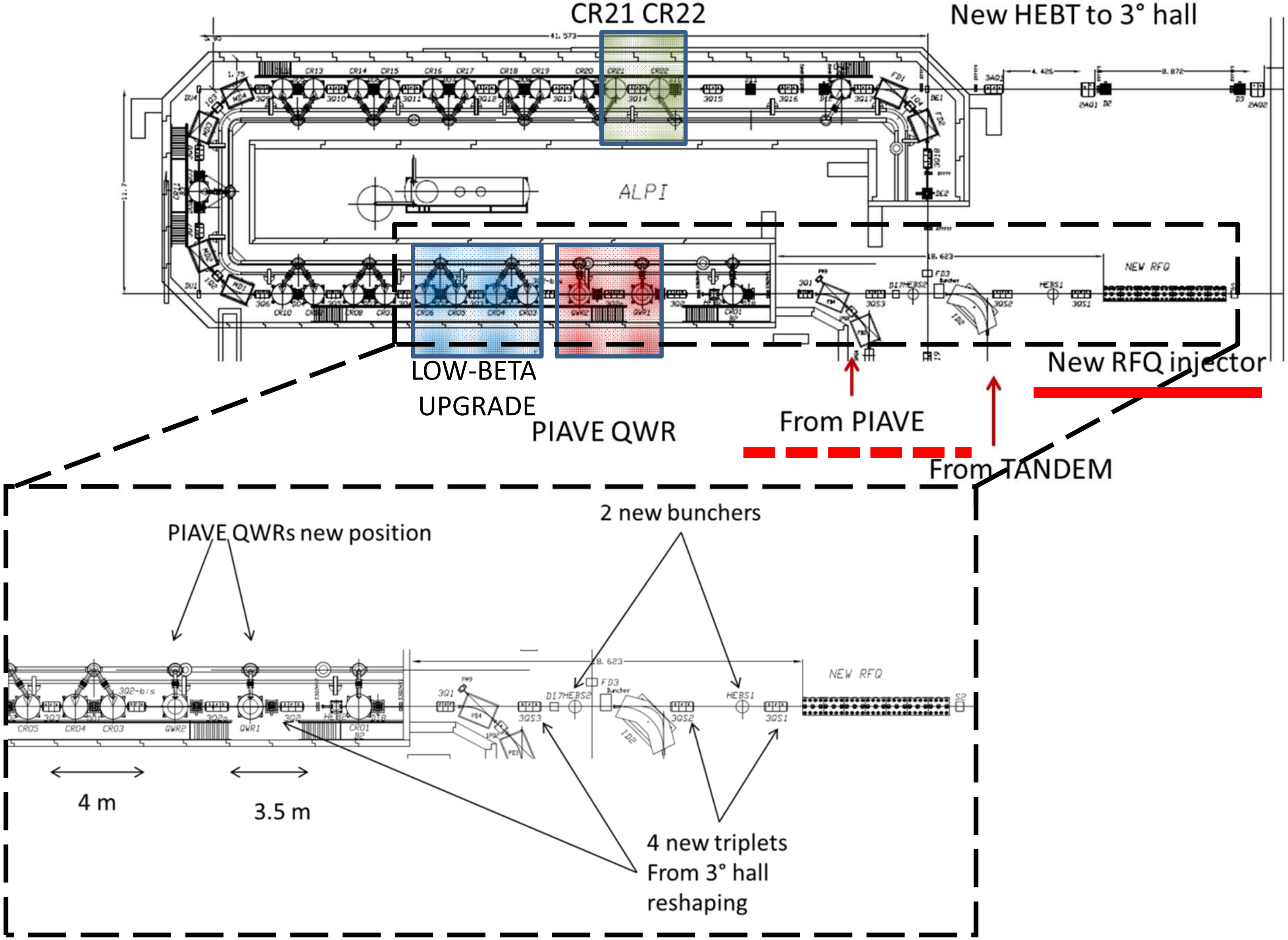


1. higher beam **energies** (more and better working cavities);
2. improved beam transmission (**current**)
3. Improved **reliability** (cryogenics upgrade)

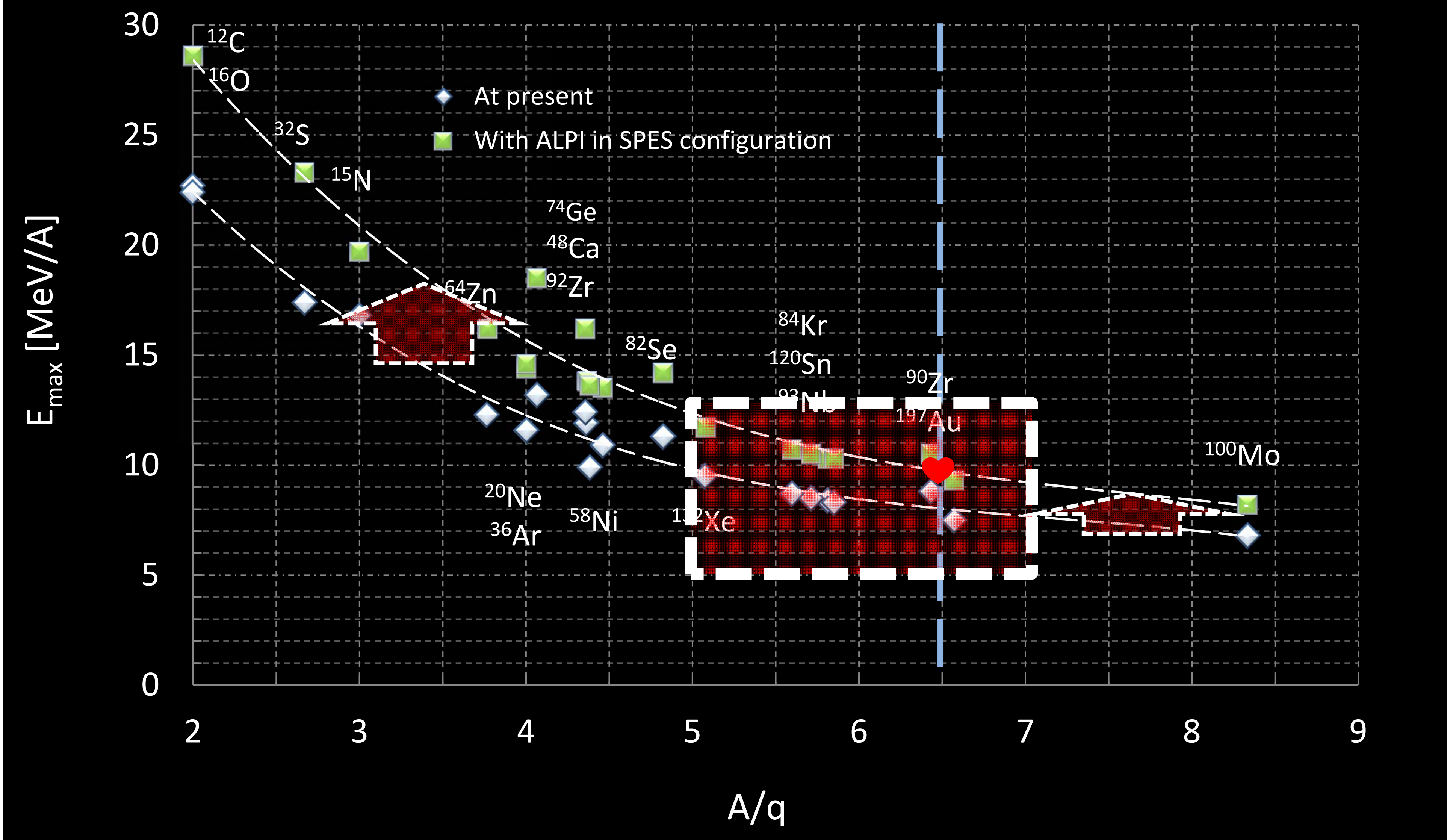
ALPI V_{eq} increase



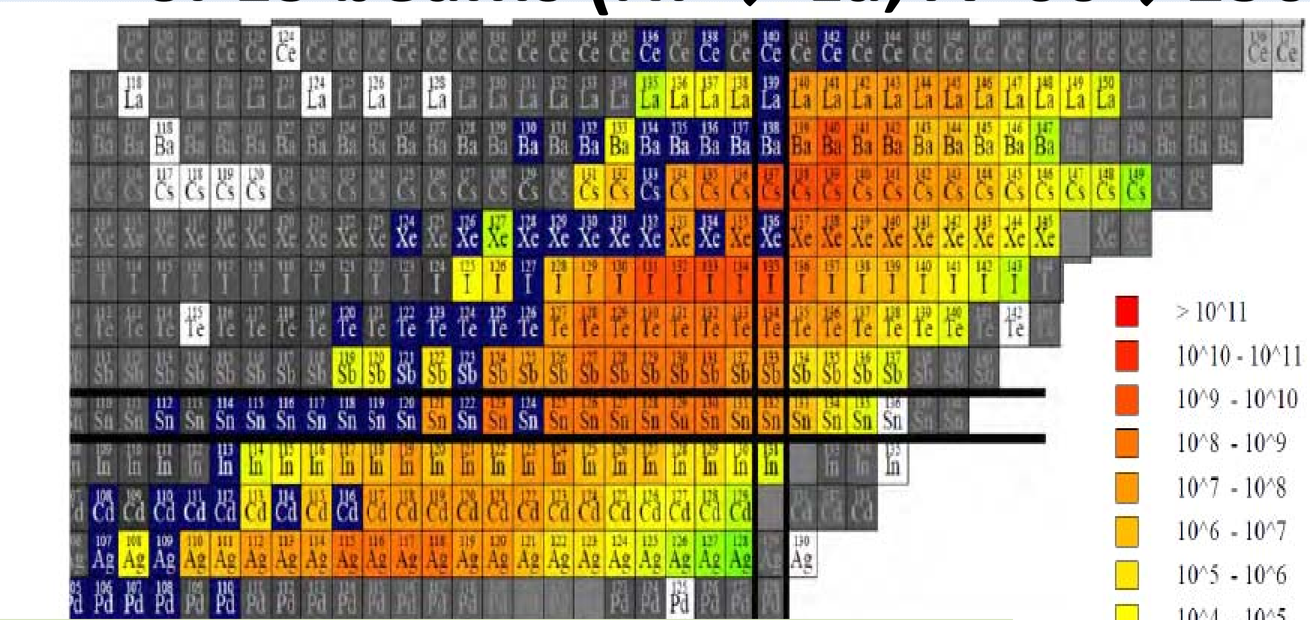
SC Resonator Improvements on ALPI



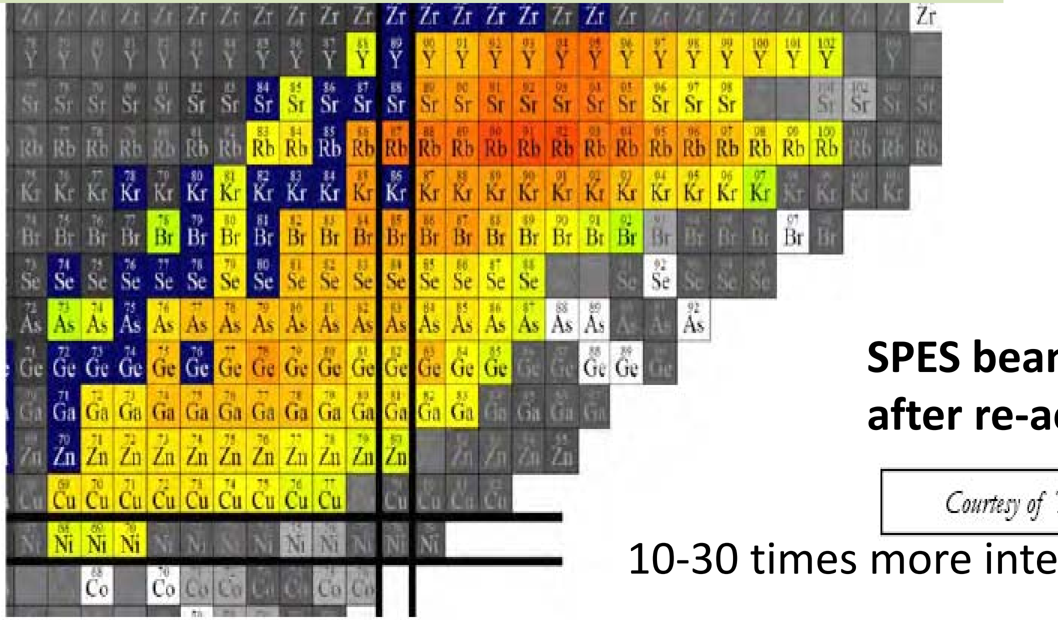
Effect of the E-upgrade on stable beams



SPES beams (Ni → La, A=60→150)



From Zr to Pd not extracted with ISOL due to bad volatility

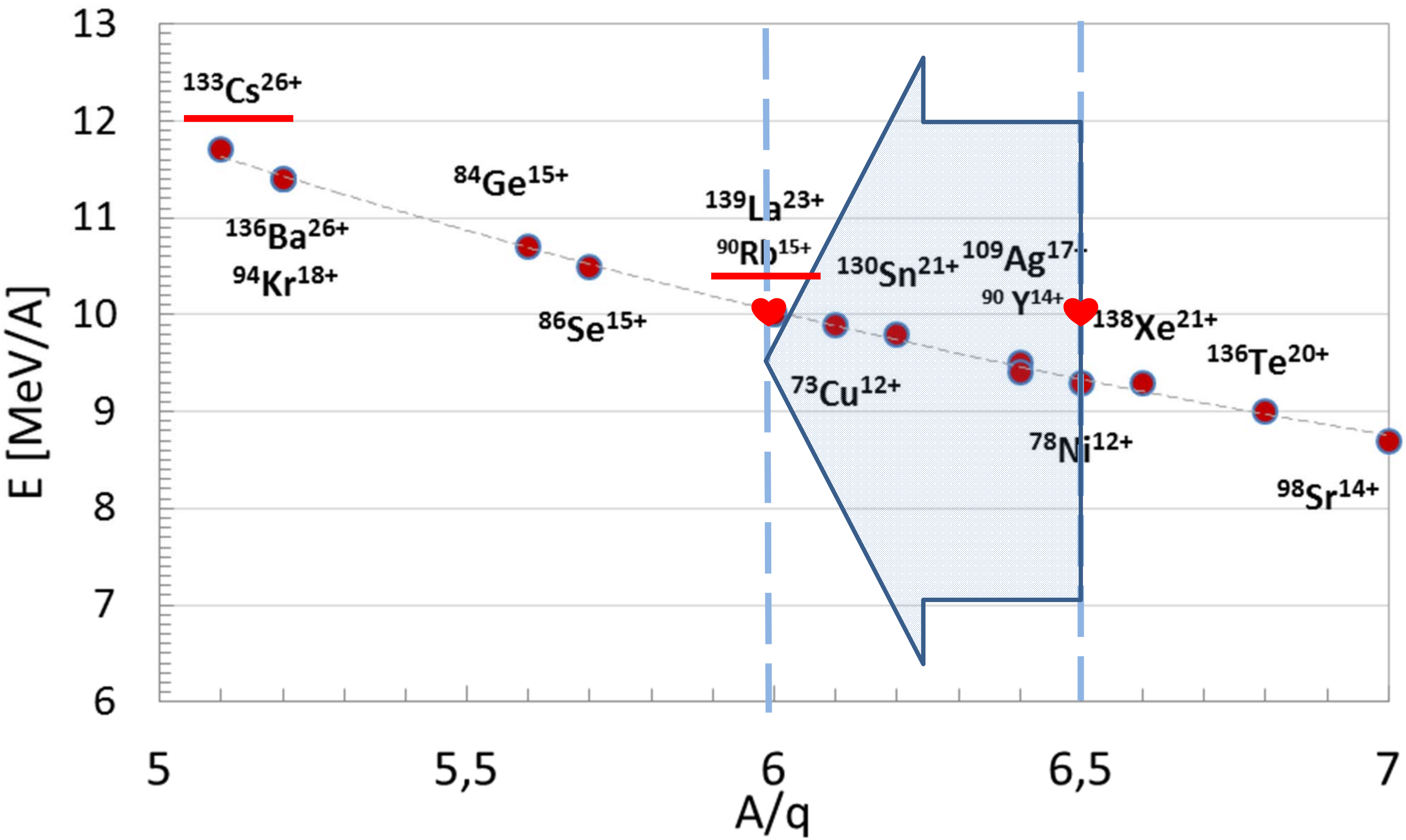


SPES beam intensities (*fission UCx*) after re-acceleration (q+)

Courtesy of T. Marchi

10-30 times more intense before acceleration (1+)

Final Energy of Exotic Beams



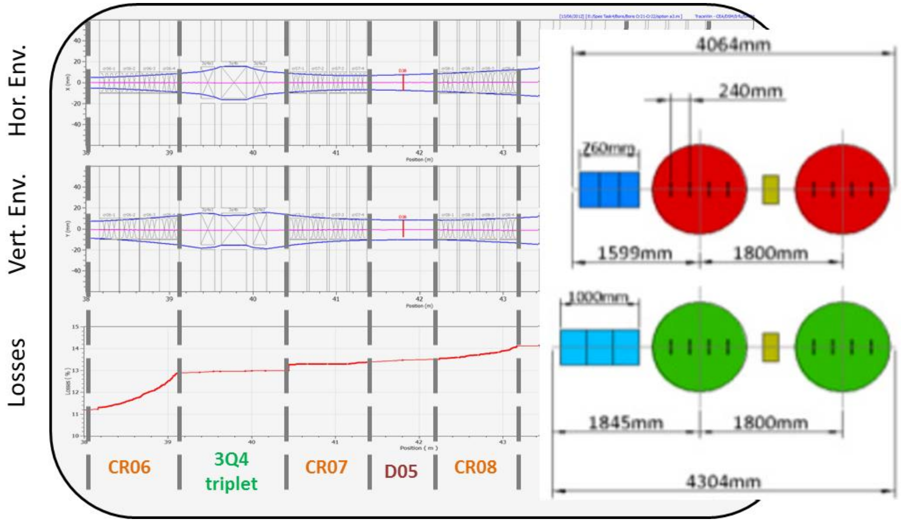
What about beam transmission…?
At present only ≤50% for mid-A beams

ALPI lattice designed for E_a= 3 MV/m (now **4,5÷6,5**) → intrinsic losses (longitudinal phase space)

- *Higher gradient quadrupole triplets*

Imperfect alignment, rough definition of resonator phases, … → additional losses, which can be minimized by:

- *Better linac alignment* (done!) improve beam transmission
- Better resonator controller (digital univ.controller, in R&D)



Laser tracking campaign

Completed in January 2013

Feb 18-24, 2013: commissioning with 95% transmission

Conclusion

- SPES is a national 50 M€ project in the construction phase, 50% funds arrived, 50% are secured
- It will allow n-rich nuclei produced by fission (40 MeV p beam onto a multislice UCx target) to be accelerated to 9-10 MeV/A
- Improvements on ALPI (energy, current, reliability) are required
- «Research and production of radioisotopes for medicine» is an essential partner of Nuclear Science
- Assembly and commissioning is scheduled at present for 2017-2018
- We intend to open shortly 3 positions for young collaborators:
  - ✓ **RF engineer for cyclotron and for SC cavity lab tests (mainly on sputtered cavities)**
  - ✓ **HVAC Enigineer**
  - ✓ **Project Engineer**

EXPRESSIONS OF INTEREST MOSTLY WELCOME!

(bisoffi@lnl.infn.it)

Cyclotron building in progress