Production of Radioactive Ion Beams at Legnaro

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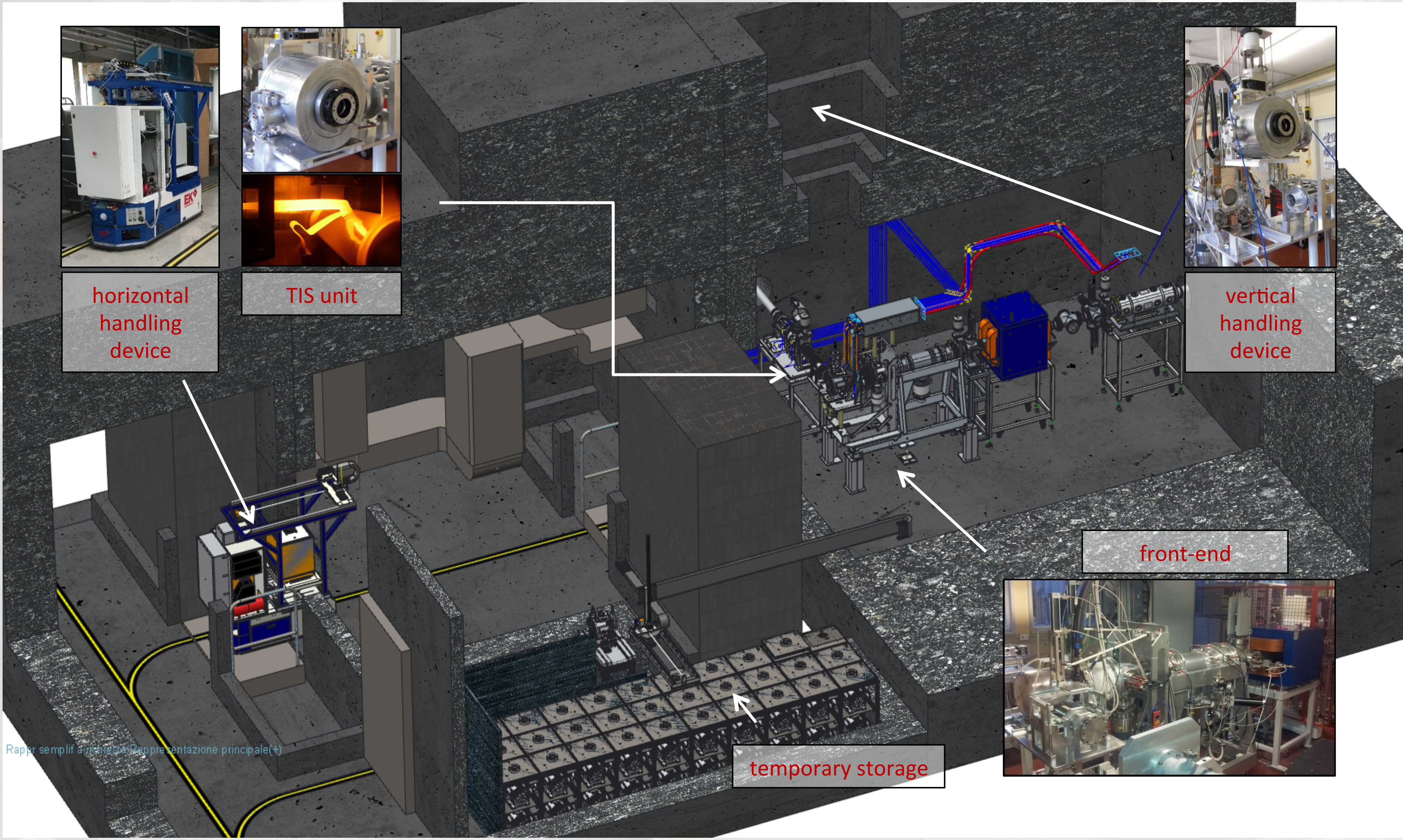
Talk Overview

-The SPES RIB Source

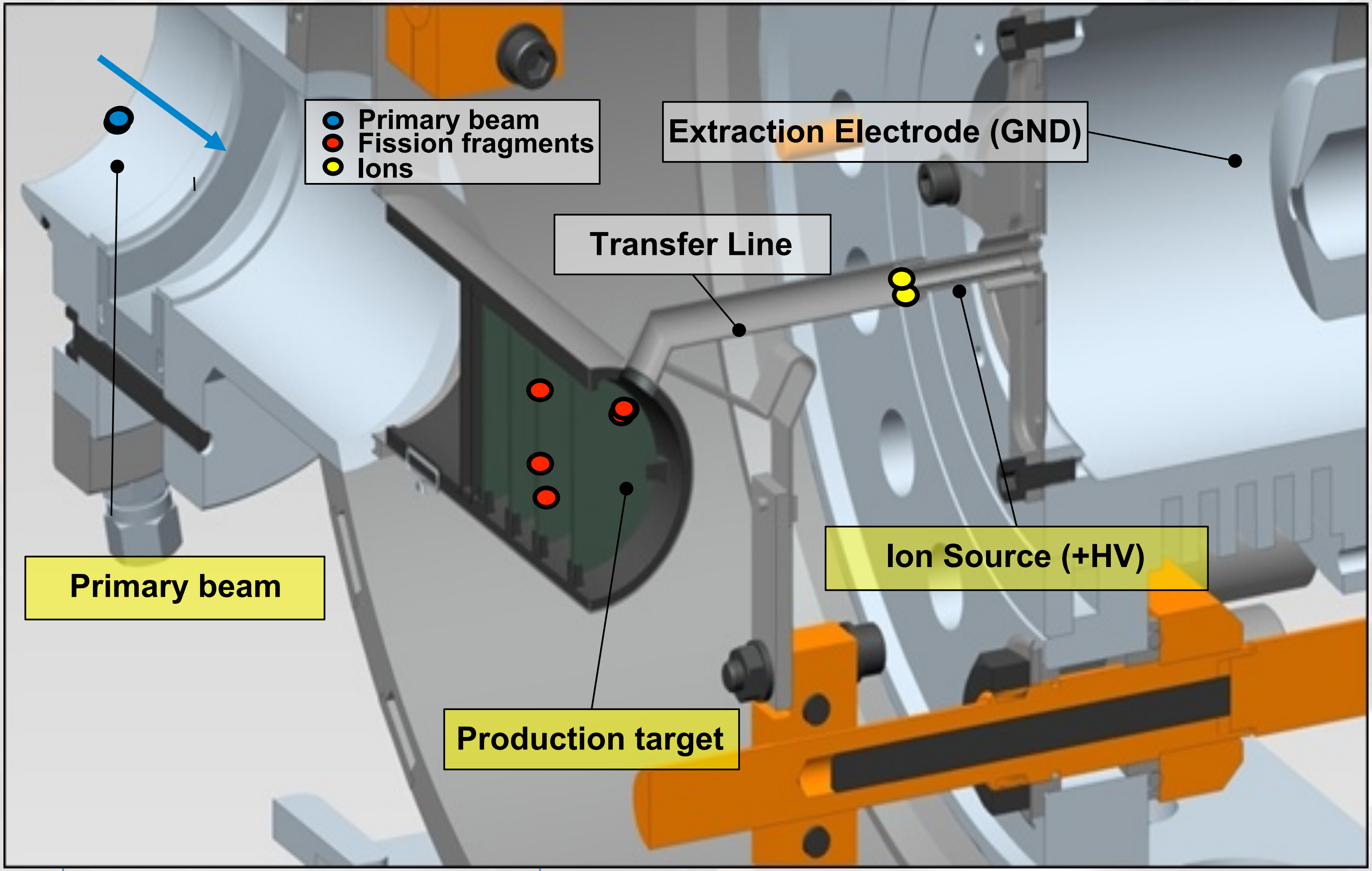
- The RIB +1 line.

- Possible first RIB’s @ SPES.

The RIB source complex



The SPES TIS UNIT



Driver vs. Target

Isotopes vs. Ion Source

Production Target: material requirements

Target materials have to meet some specific mandatory requirements:

- They have to be solid -> Safety requirement
- They have to be refractory (the higher the reachable temperature the better the release) -> ISOL requirement

In addition

- Their emissivity value should be high (higher emissivity means better thermal radiative exchange.)
- They should be easy to produce/purchase

Target concepts: state of art

UC_x target (Operation temperature: 2200°C)

Target R&D and state of art: | Nuclear reactions studied | Designed | Tested |

SiC target (Operation temperature: 1800°C)

Target R&D and state of art: | Nuclear reactions studied | Designed | Tested |

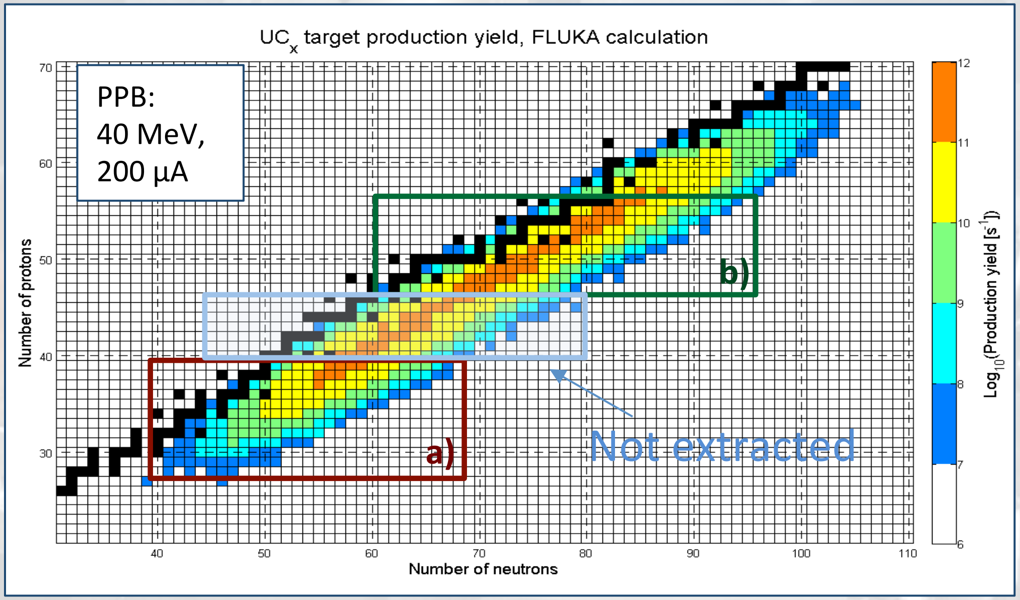
ZrGe target (Operation temperature: 1800°C)

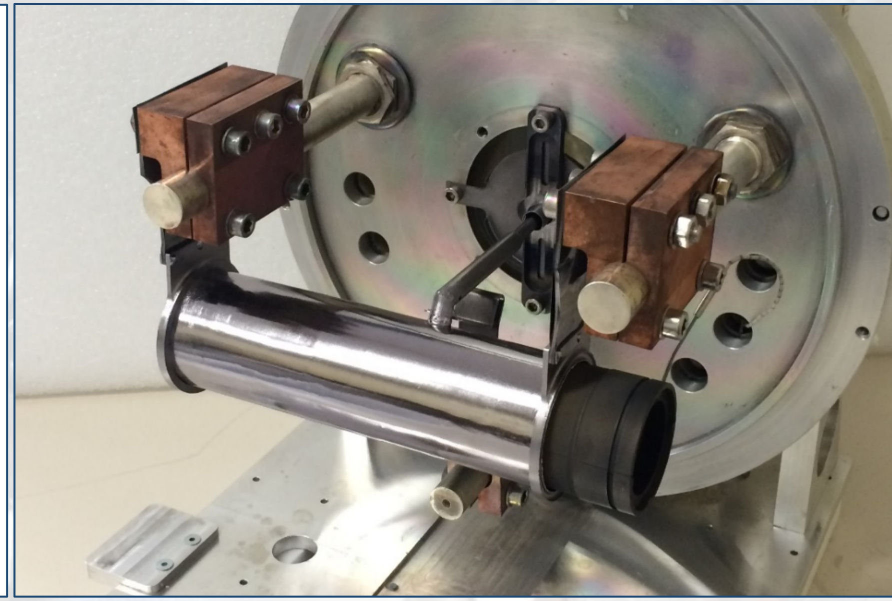
Target R&D and state of art: | Nuclear reactions studied | Designed | Tested |

TiC target (Operation temperature: 2000°C)

Target R&D and state of art: | Nuclear reactions studied | Designed | Tested |

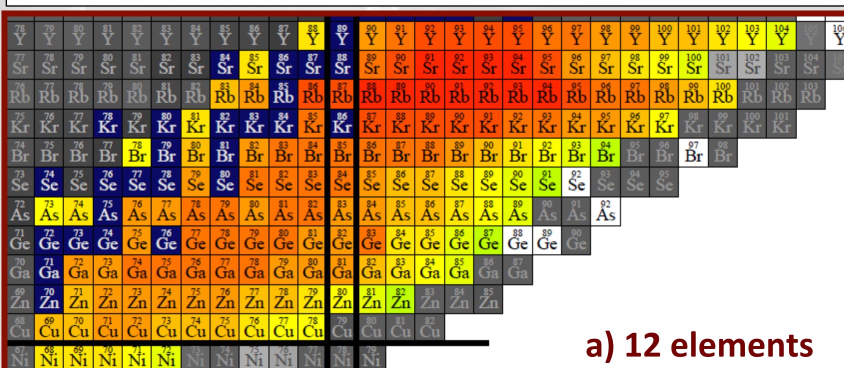
Isotope production: UC_x target

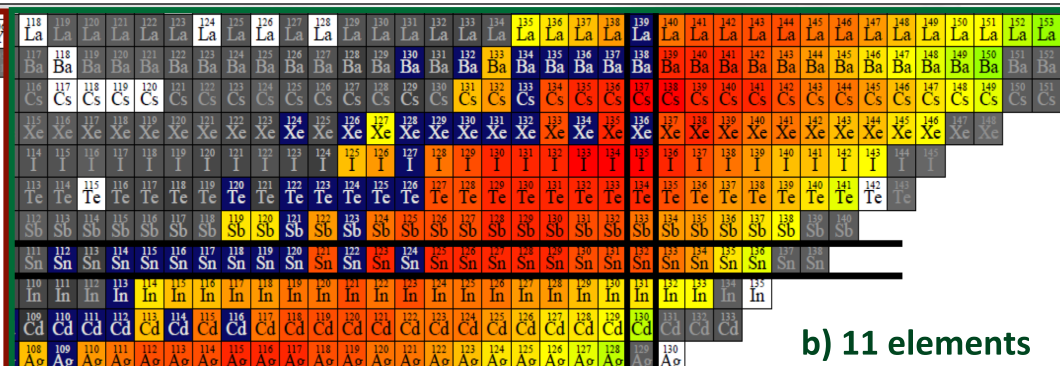




> 10^11	10^9 - 10^10	10^7 - 10^8	10^5 - 10^6	10^3 - 10^4	10 - 10^2
10^10 - 10^11	10^8 - 10^9	10^6 - 10^7	10^4 - 10^5	10^2 - 10^3	< 10

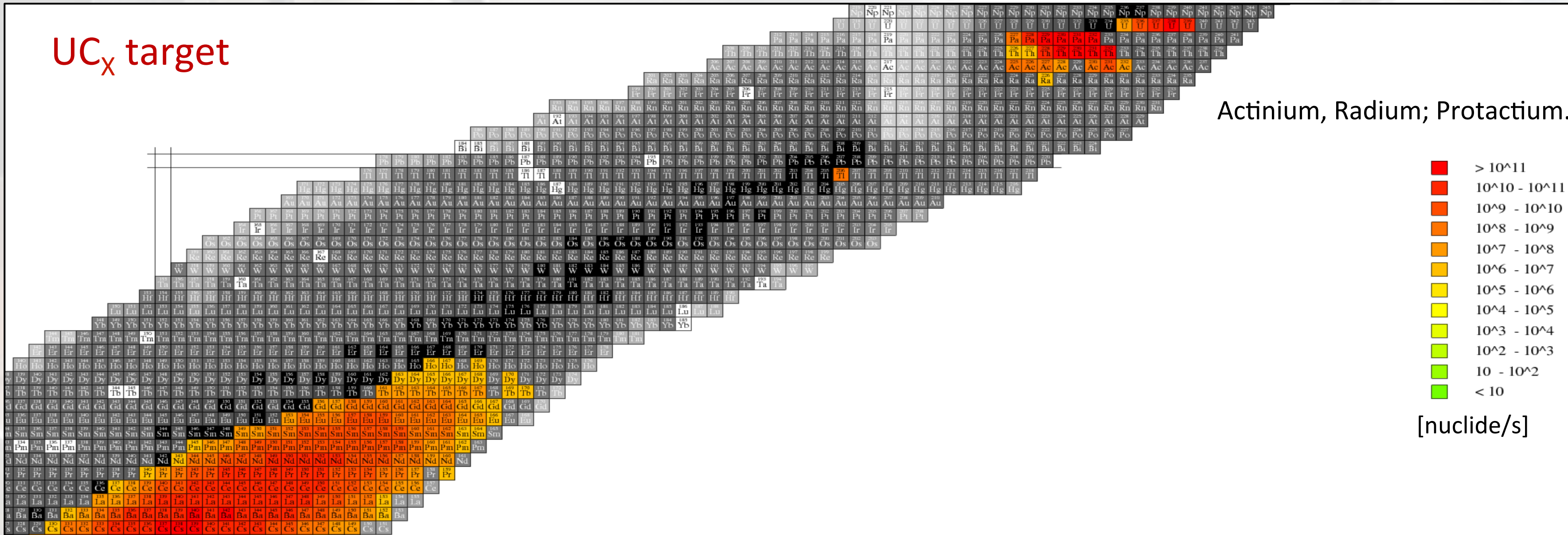
[nuclide/s]

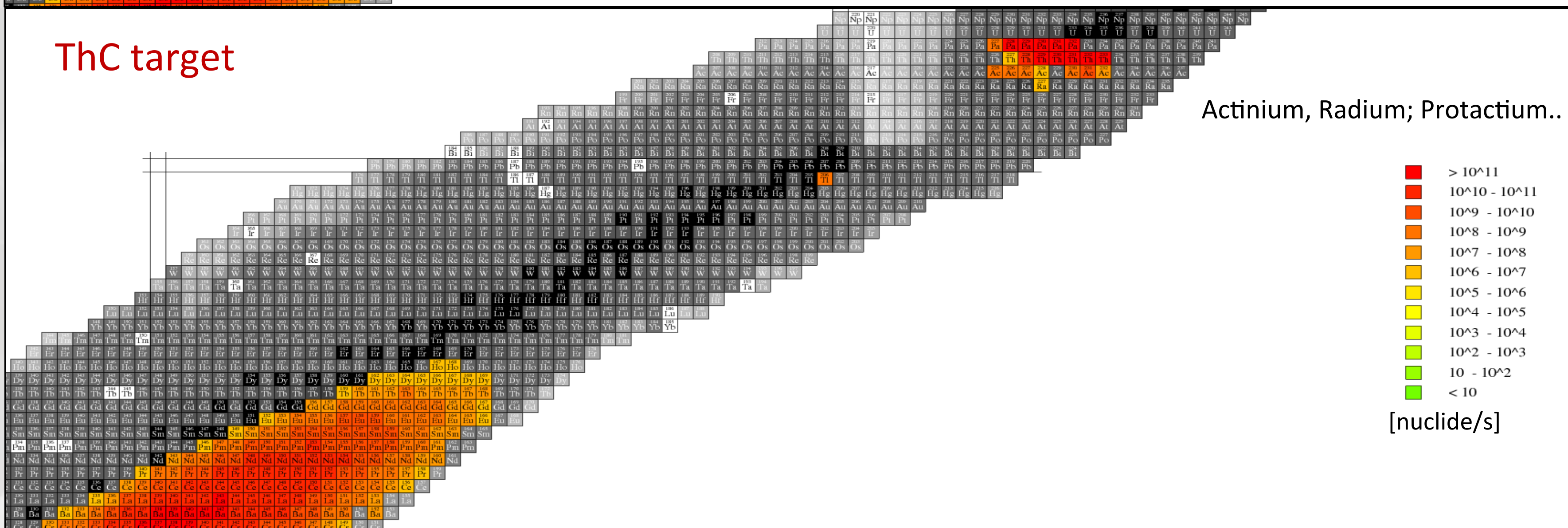




FLUKA& MCNPX calculations experimentally validated @ ORNL

Comparison 40 MeV p-> UC_x v.s. ThC (Fluka)



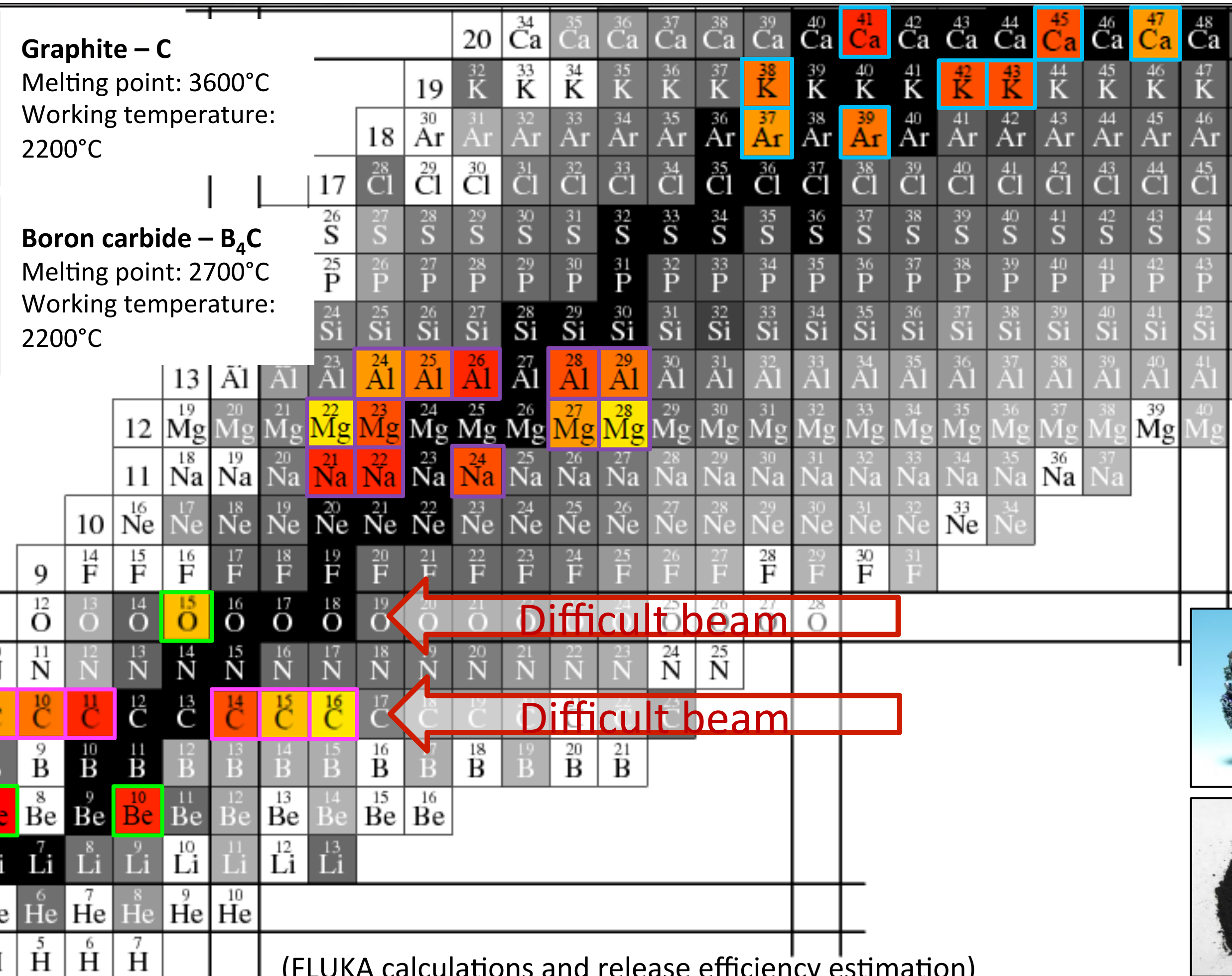


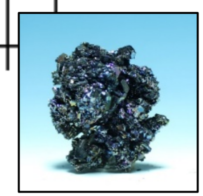
SPES beams (light): non fissile targets

C/B_4C target — ZrO_2/HfO_2/CeO_2 target — SiC target — TiC target

Graphite – C
Melting point: 3600°C
Working temperature: 2200°C

Boron carbide – B_4C
Melting point: 2700°C
Working temperature: 2200°C





Silicon carbide – SiC
Melting point: 2700 °C
Working temperature: 2200°C

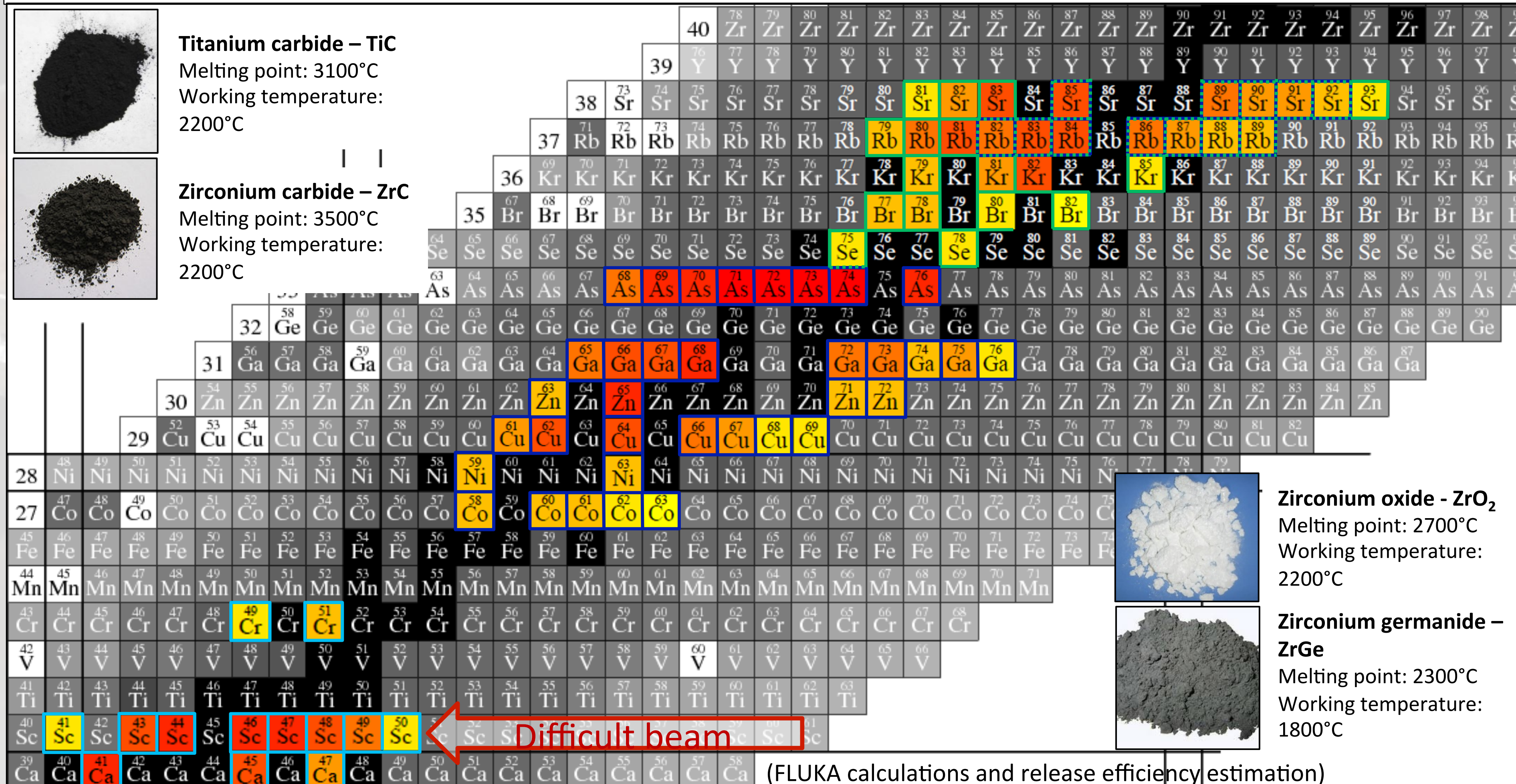
Titanium carbide – TiC
Melting point: 3100°C
Working temperature: 2200°C

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

[nuclide/s]

SPES beams (medium): non fissile targets

TiC target — ZrGe target — ZrC/ZrO_2 target



Titanium carbide – TiC
Melting point: 3100°C
Working temperature: 2200°C

Zirconium carbide – ZrC
Melting point: 3500°C
Working temperature: 2200°C

Zirconium oxide - ZrO_2
Melting point: 2700°C
Working temperature: 2200°C

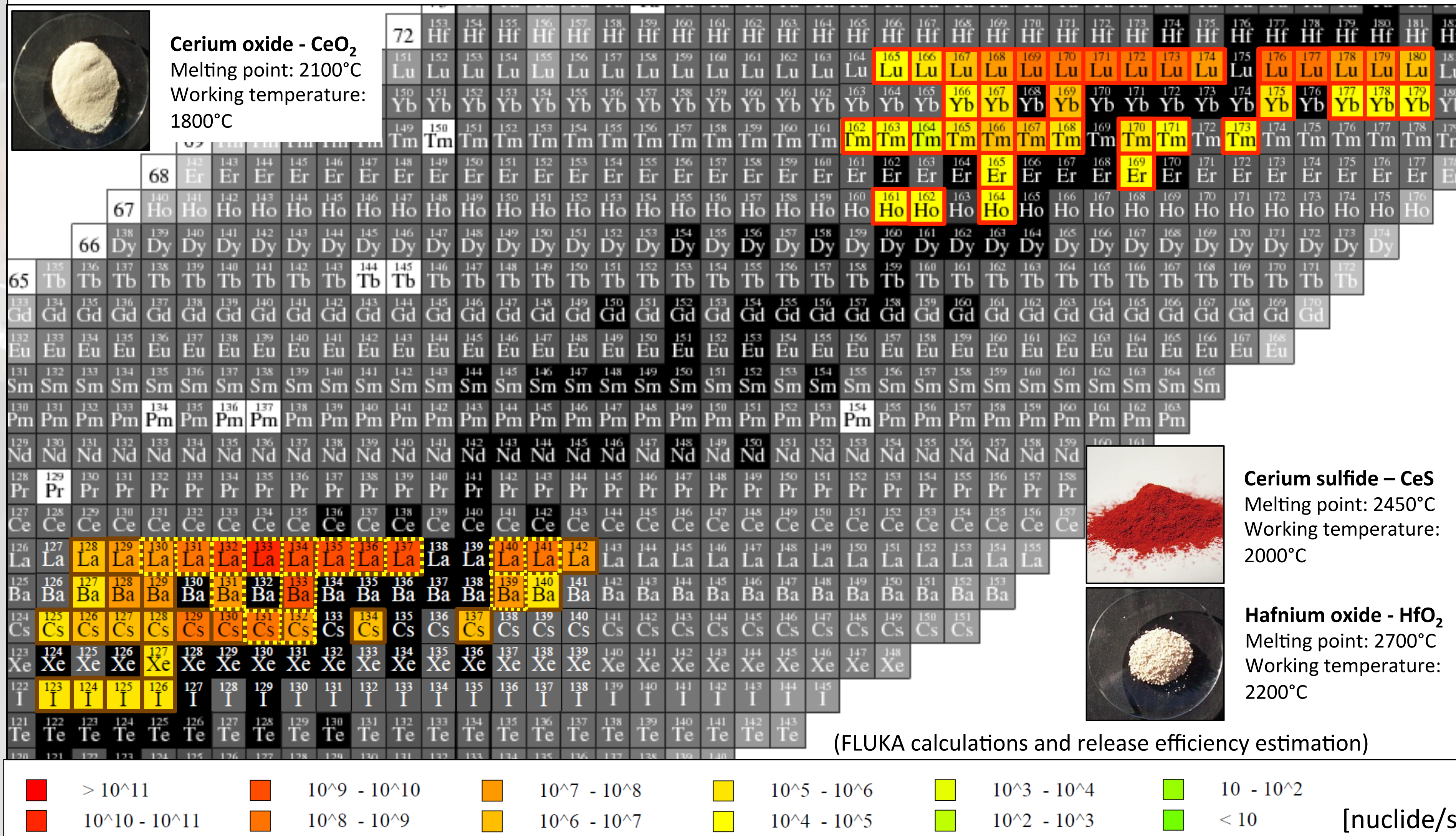
Zirconium germanide – ZrGe
Melting point: 2300°C
Working temperature: 1800°C

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

[nuclide/s]

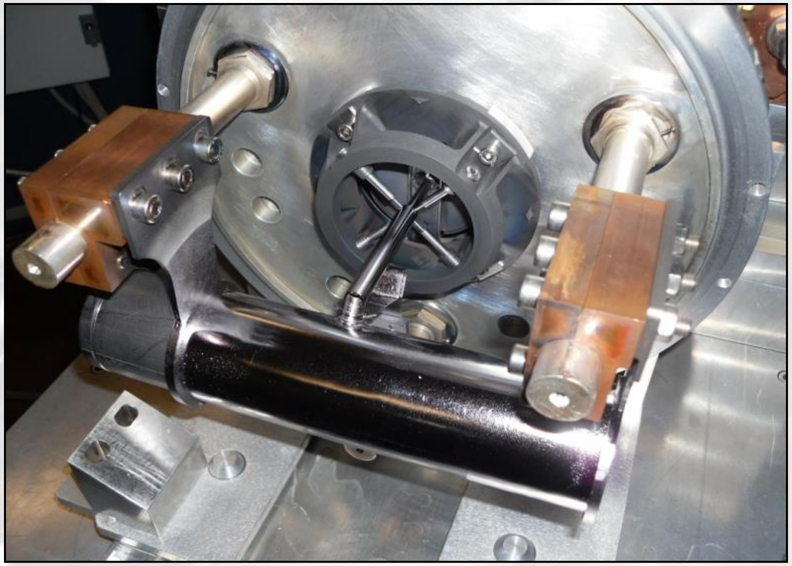
SPES beams (heavy): non fissile targets

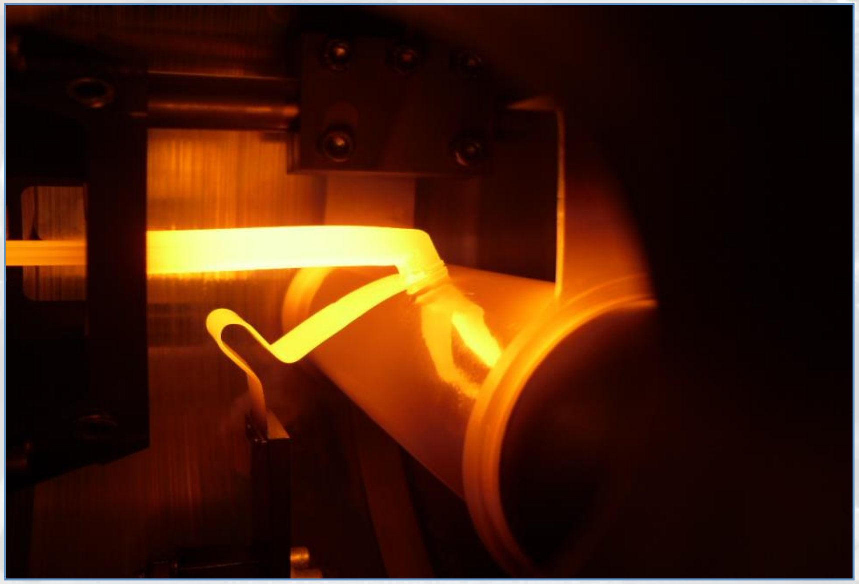
CeO_2 target — CeS target — HfO_2 target

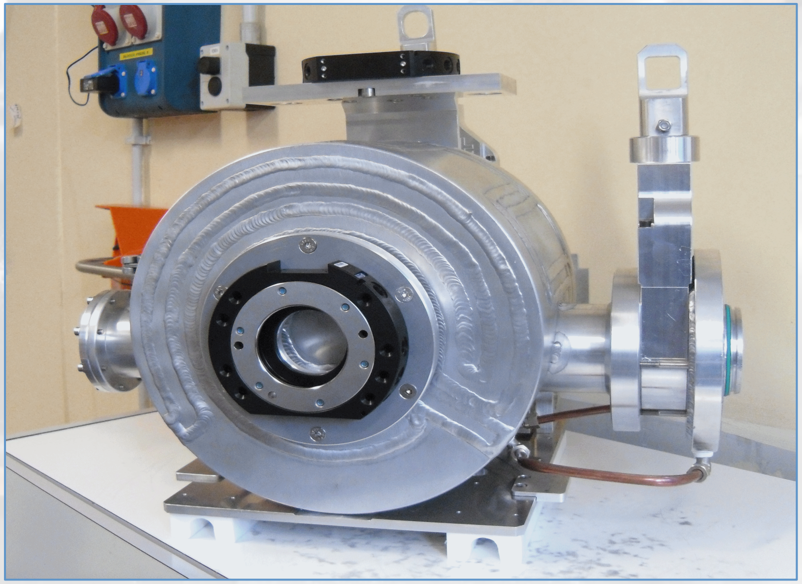


(FLUKA calculations and release efficiency estimation)

The TIS Unit

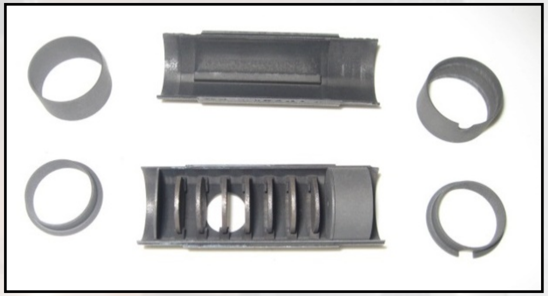
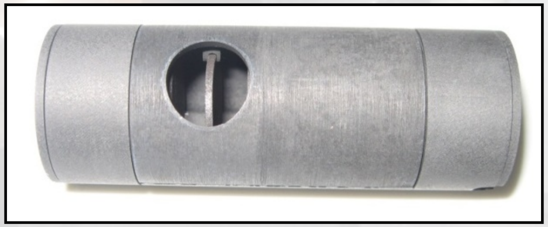


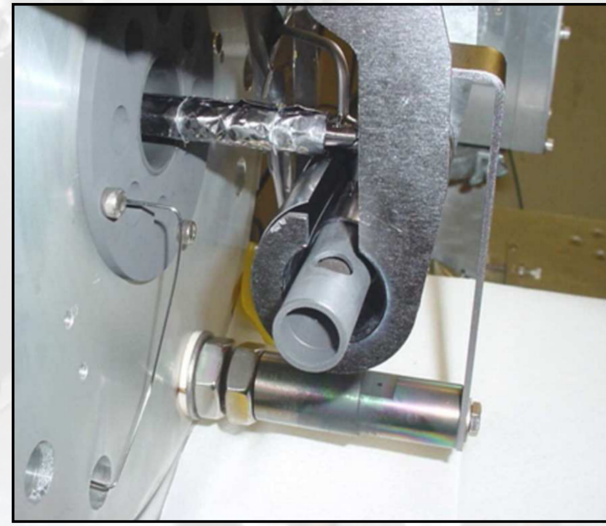


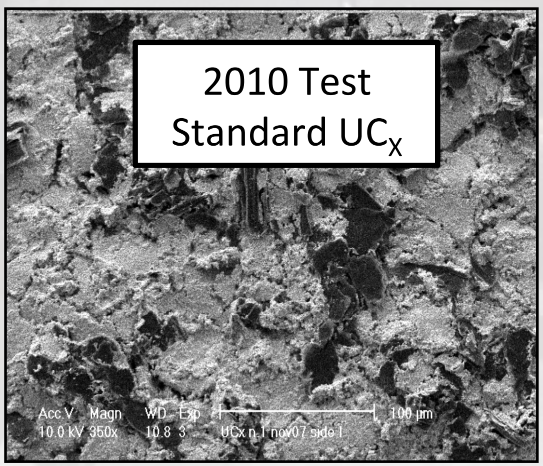


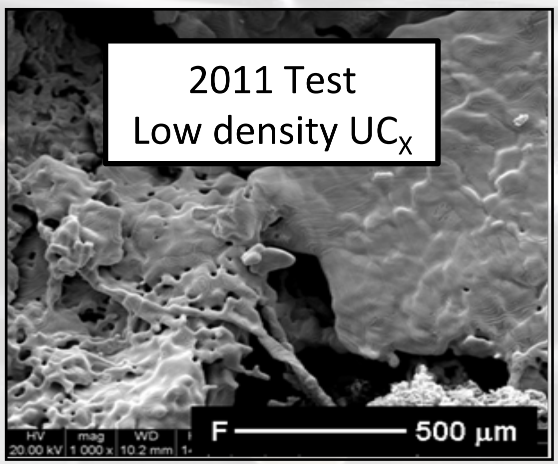
Target material and UCx production

- On-line testing of the SPES target material and architecture @ ORNL (2010-2012)
- 40 MeV, 50 nA proton beam on a UCx target



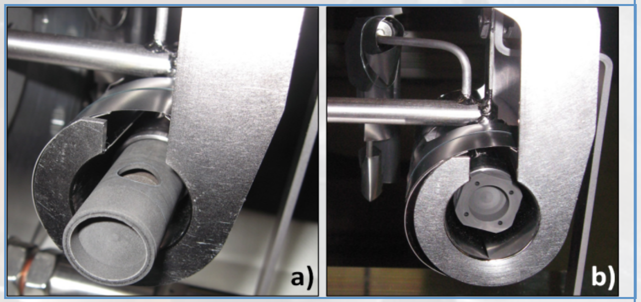


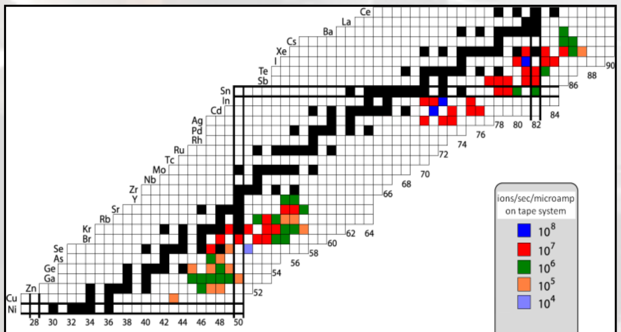
	2010	2011
Density (g/cm³)	4.25	2.59
Diameter (mm)	12.50	13.07
Thickness (g/cm²)	0.41	0.41
Calculated porosity (%)	58	75

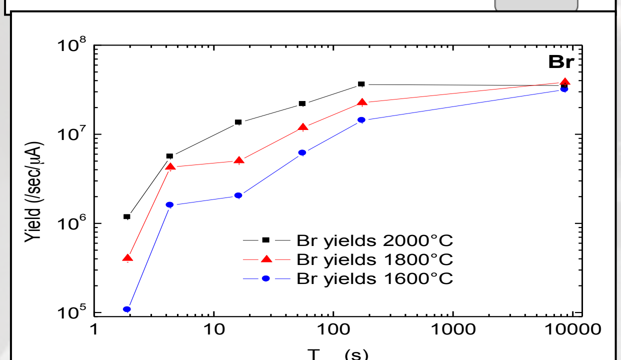
Experimental Yield with UCx target

Irradiation by 40 MeV, 50 nA proton beam, ionization with plasma ion source

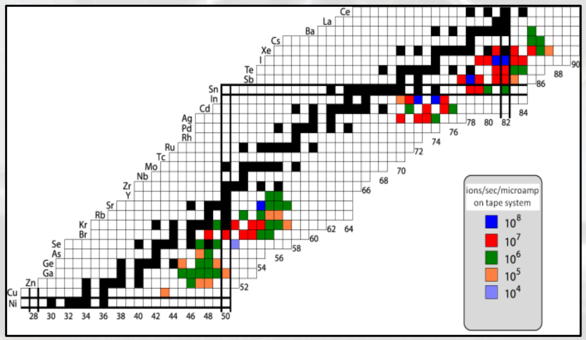
2010 Test
Standard UC_X

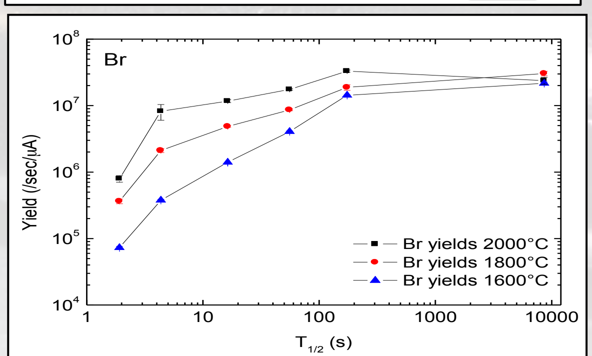






2011 Test
Low density UC_X





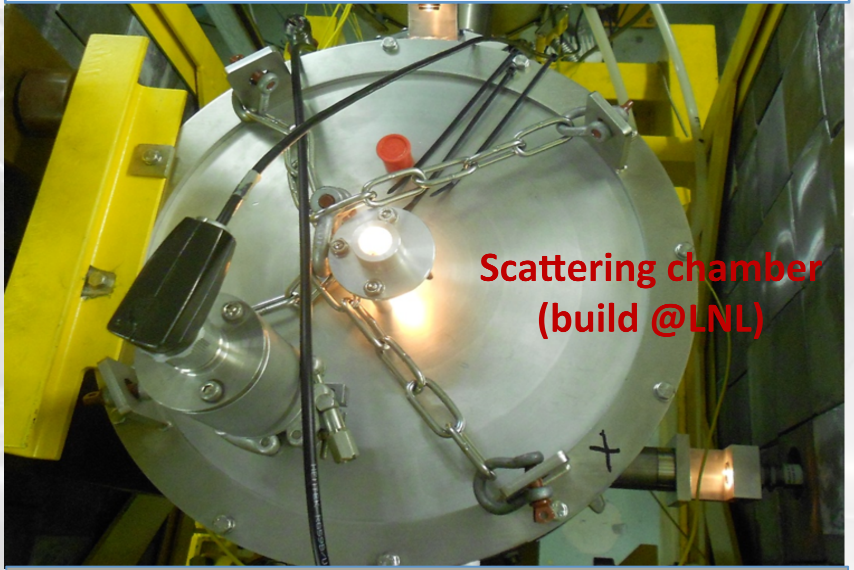
Isotope	$T_{1/2}$ (s)	Yield(ions/s·µA)	ΔYield (ions/s·µA)	ΔYield/Yield
^{72}Cu	6.60	$2.19 \cdot 10^5$	$4.30 \cdot 10^3$	0.01963
^{78}Zn	1.47	$1.22 \cdot 10^5$	$3.62 \cdot 10^3$	0.02967
^{79g}Ge	19.00	$1.31 \cdot 10^6$	$4.05 \cdot 10^4$	0.03092
^{81}As	34.00	$7.15 \cdot 10^5$	$1.59 \cdot 10^4$	0.02224
^{81}Ga	1.22	$2.20 \cdot 10^5$	$6.55 \cdot 10^3$	0.02977
^{83g}Se	22.40 m	$3.30 \cdot 10^6$	$3.23 \cdot 10^4$	0.00979
^{87}Kr	1.27 h	$1.09 \cdot 10^7$	$1.04 \cdot 10^6$	0.09541
^{88}Br	16.30	$1.15 \cdot 10^7$	$2.31 \cdot 10^5$	0.02009
^{90}Br	1.91	$9.94 \cdot 10^5$	$4.01 \cdot 10^4$	[illegible]
^{92}Kr	1.84	$1.55 \cdot 10^6$	$2.42 \cdot 10^4$	[illegible]
^{93}Rb	5.80	$3.25 \cdot 10^5$	$1.03 \cdot 10^4$	0.03169
^{93}Sr	7.45 m	$1.10 \cdot 10^7$	$1.12 \cdot 10^5$	0.01018
^{94}Sr	1.23 m	$6.30 \cdot 10^6$	$1.91 \cdot 10^5$	0.03032
^{95}Y	10.30 m	$2.05 \cdot 10^6$	$6.66 \cdot 10^4$	0.03249
^{119}Ag	2.10	$2.96 \cdot 10^7$	[illegible]	0.00834
^{120g}Ag	1.23	$1.52 \cdot 10^7$	$4.32 \cdot 10^5$	0.02842
^{120m}In	47.30	$4.23 \cdot 10^7$	$1.02 \cdot 10^6$	0.02411
^{121}Ag	0.78	$5.53 \cdot 10^6$	$1.44 \cdot 10^5$	0.02604
^{123m}Cd	1.82	$1.08 \cdot 10^7$	$1.60 \cdot 10^5$	0.01481
^{123g}In	5.98	[illegible]	$2.03 \cdot 10^6$	0.01664
^{124}Cd	1.29	$8.24 \cdot 10^6$	$1.63 \cdot 10^5$	0.01978
^{132}Sn	[illegible]	$2.14 \cdot 10^6$	$2.80 \cdot 10^4$	0.01308
^{133m}I	9.00	$1.04 \cdot 10^7$	$1.54 \cdot 10^5$	0.01481
^{133}Sb	2.50 m	$9.77 \cdot 10^6$	$3.72 \cdot 10^5$	0.03808
^{134g}I	52.50 m	$1.40 \cdot 10^8$	$2.77 \cdot 10^7$	0.19786
^{134}Te	41.80 m	$4.90 \cdot 10^7$	$7.70 \cdot 10^6$	0.15714
^{137}Xe	3.83 m	$4.58 \cdot 10^7$	$2.88 \cdot 10^6$	0.06288
^{140}Cs	1.06 m	$1.44 \cdot 10^6$	$4.85 \cdot 10^4$	0.03368
^{141}Ba	18.30 m	$2.48 \cdot 10^6$	$3.24 \cdot 10^5$	0.13065

20 elements, about 80 isotopes collected

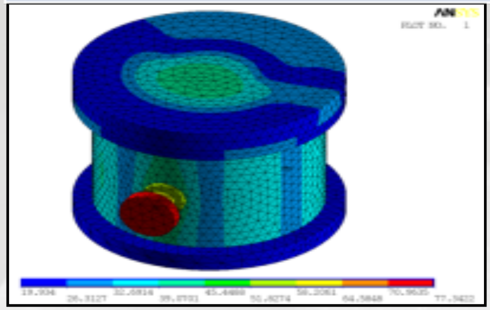
4) Full scale (40 mm.) SiC @ Ithemba, p=66 MeV, 60 microA for thermal dissipation studies

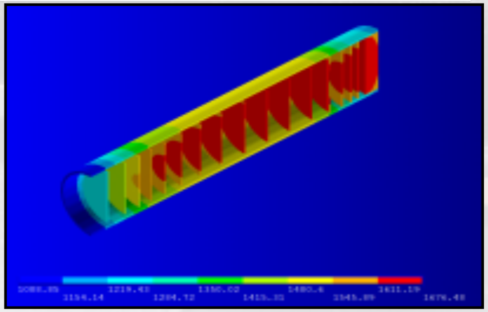
- On-line testing of the SPES target architecture @ iThemba (May 2014)

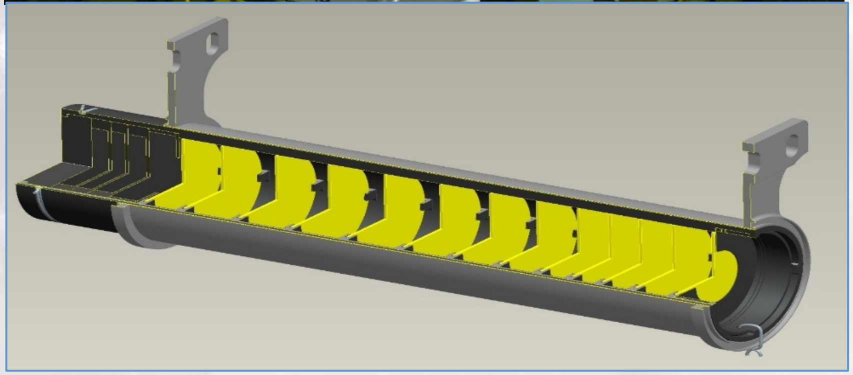
iThemba LABS: funded to build an RIB target/ion-source like SPES



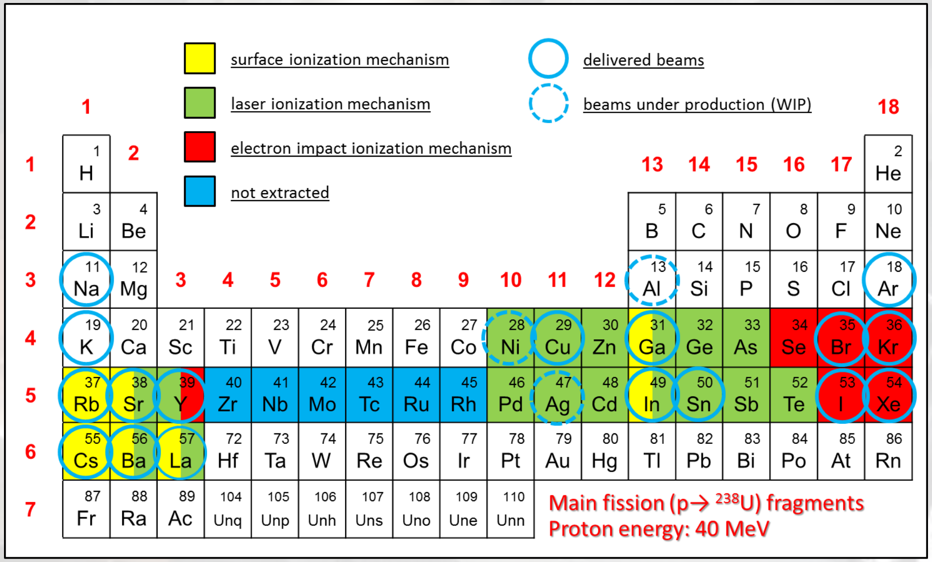
Measure [°C]	Estimated by FEM model [°C]
1° disk: 1365 ± 30°C	1390
Box: 1230 ± 25°C	1267
Dump on chamber: 728°C ± 10°C	750

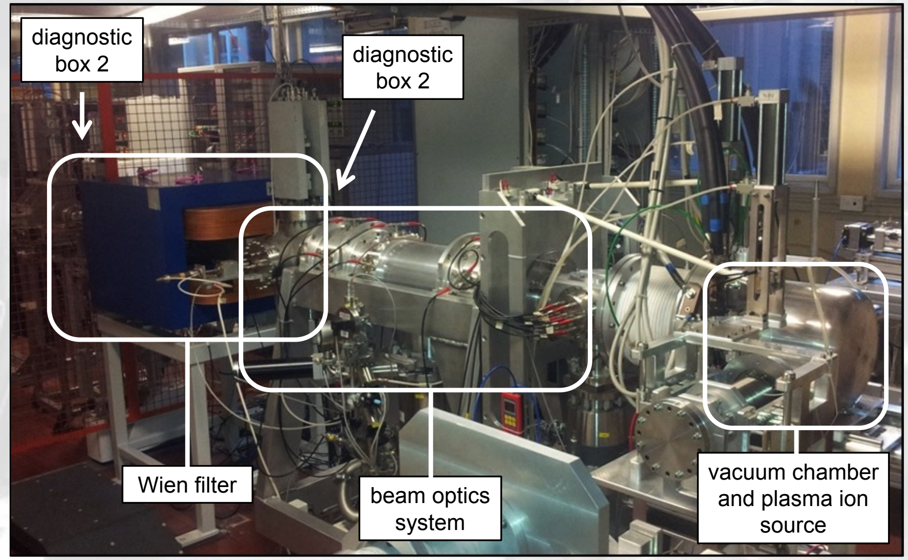


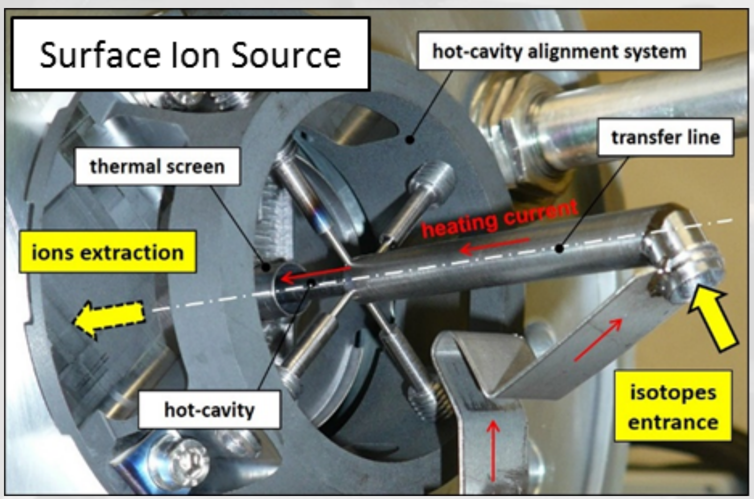


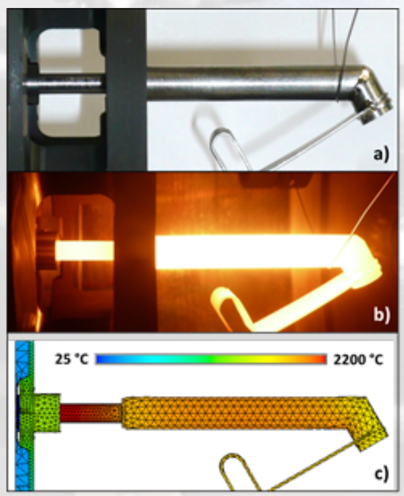


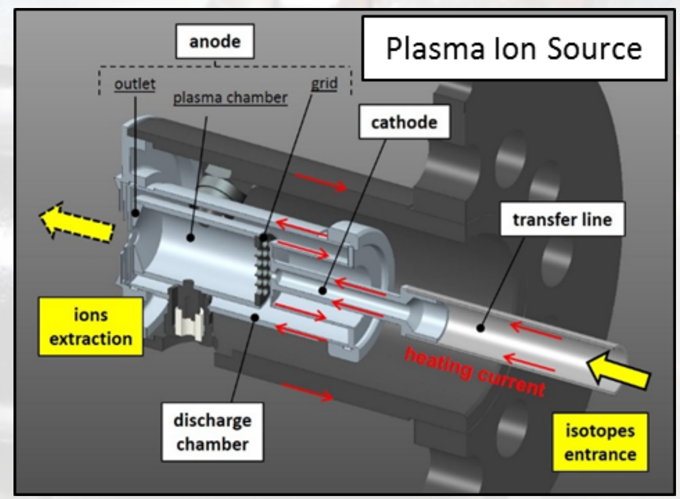
Characterization of the SPES ion sources
(17 different stable beams accelerated so far… + 2 under development)



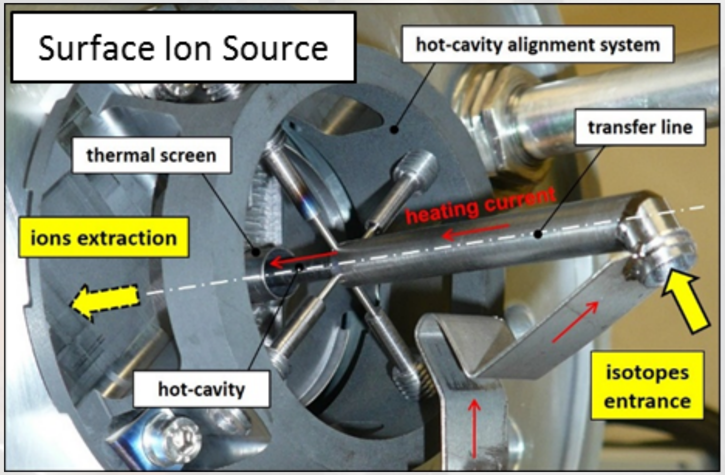


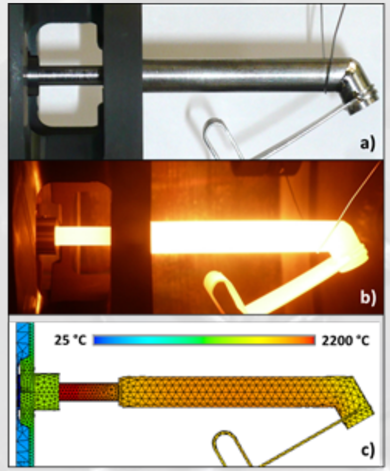




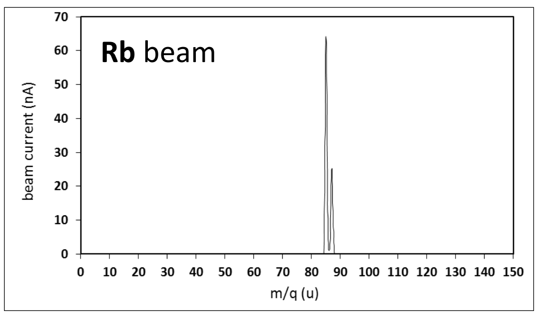


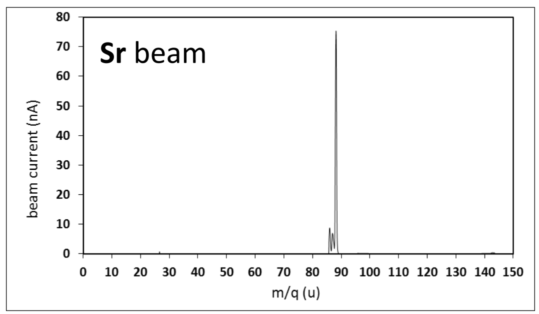
Characterization of the SPES Surface Ion Source

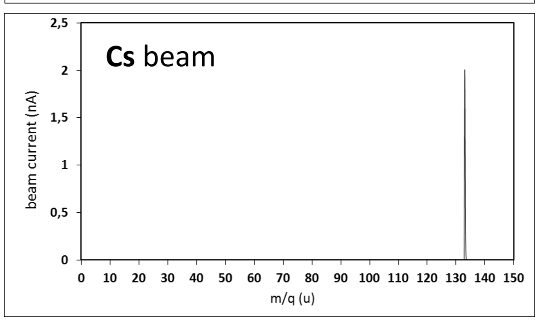


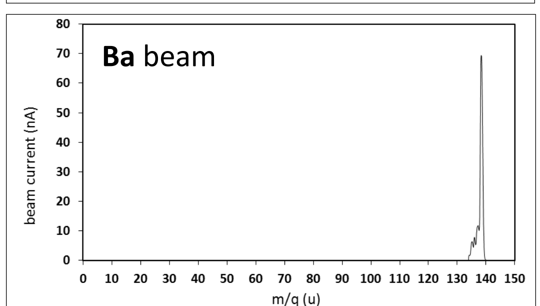


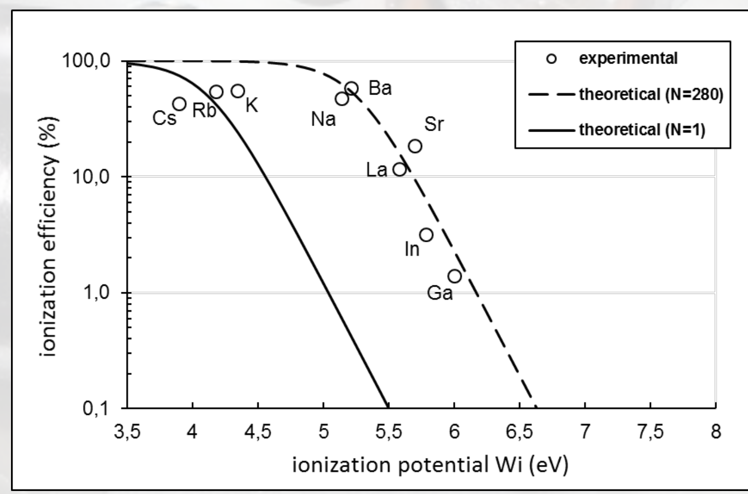
beam	ion. eff. (%)	hot-cavity temp. (°C)	hot-cavity material
Na	47,6	2200	Ta
K	55,4	2200	Ta
Ga	1,4	2200	Ta
Rb	54,5	2200	Ta
Sr	18,5	2200	Ta
In	3,2	2200	Ta
Cs	43,2	2200	Ta
Ba	58,8	2200	Ta
La	20,1	2200	Ta



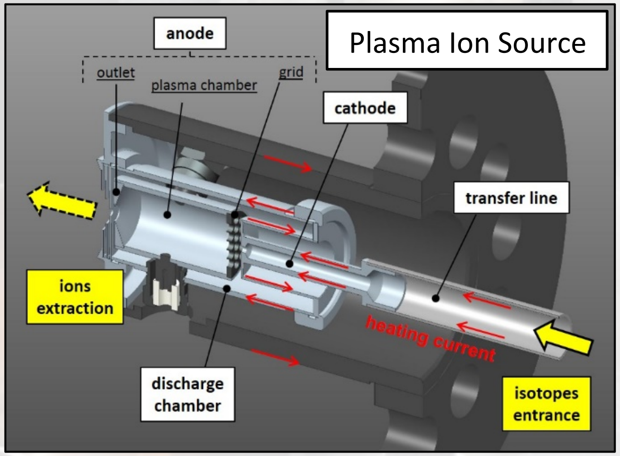


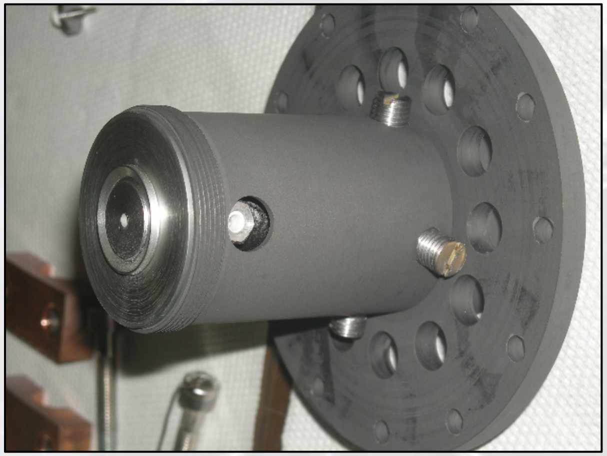


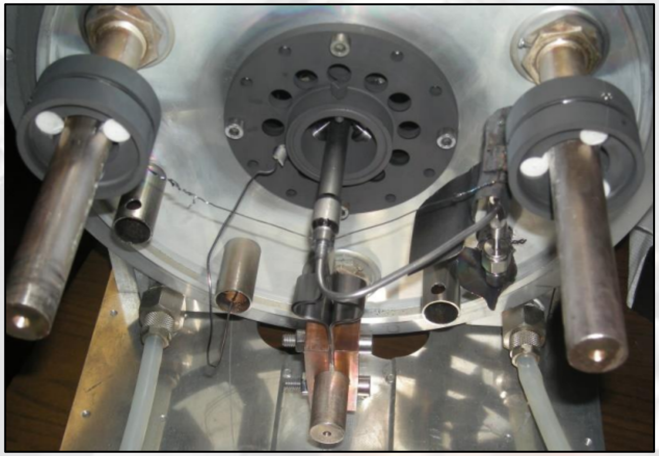


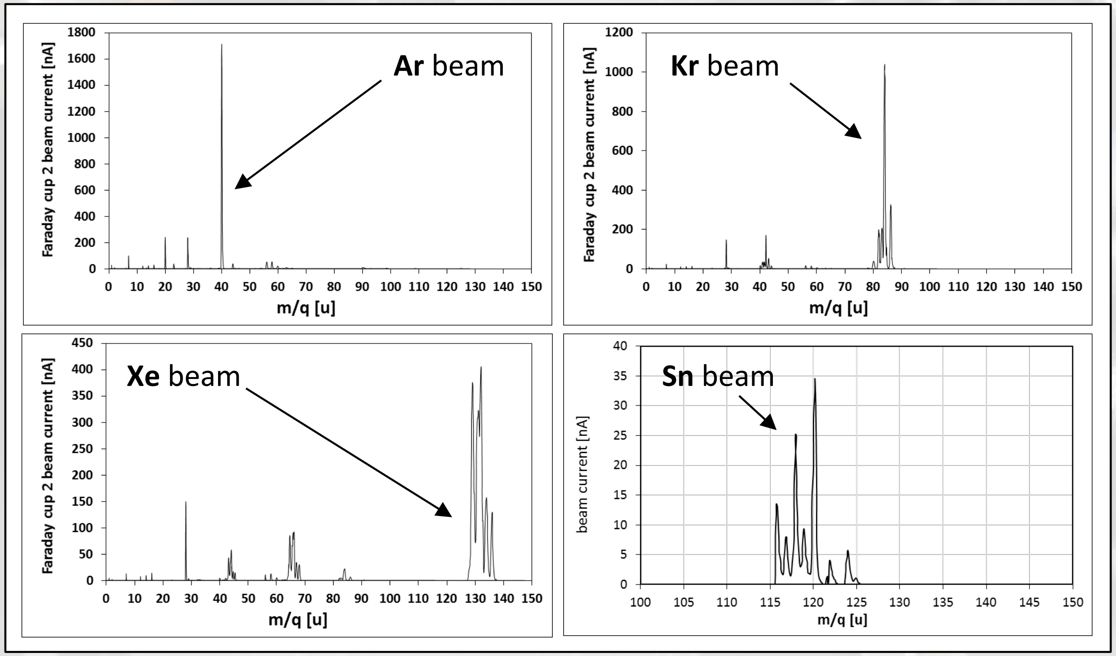


Characterization of the SPES Plasma Ion Source









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

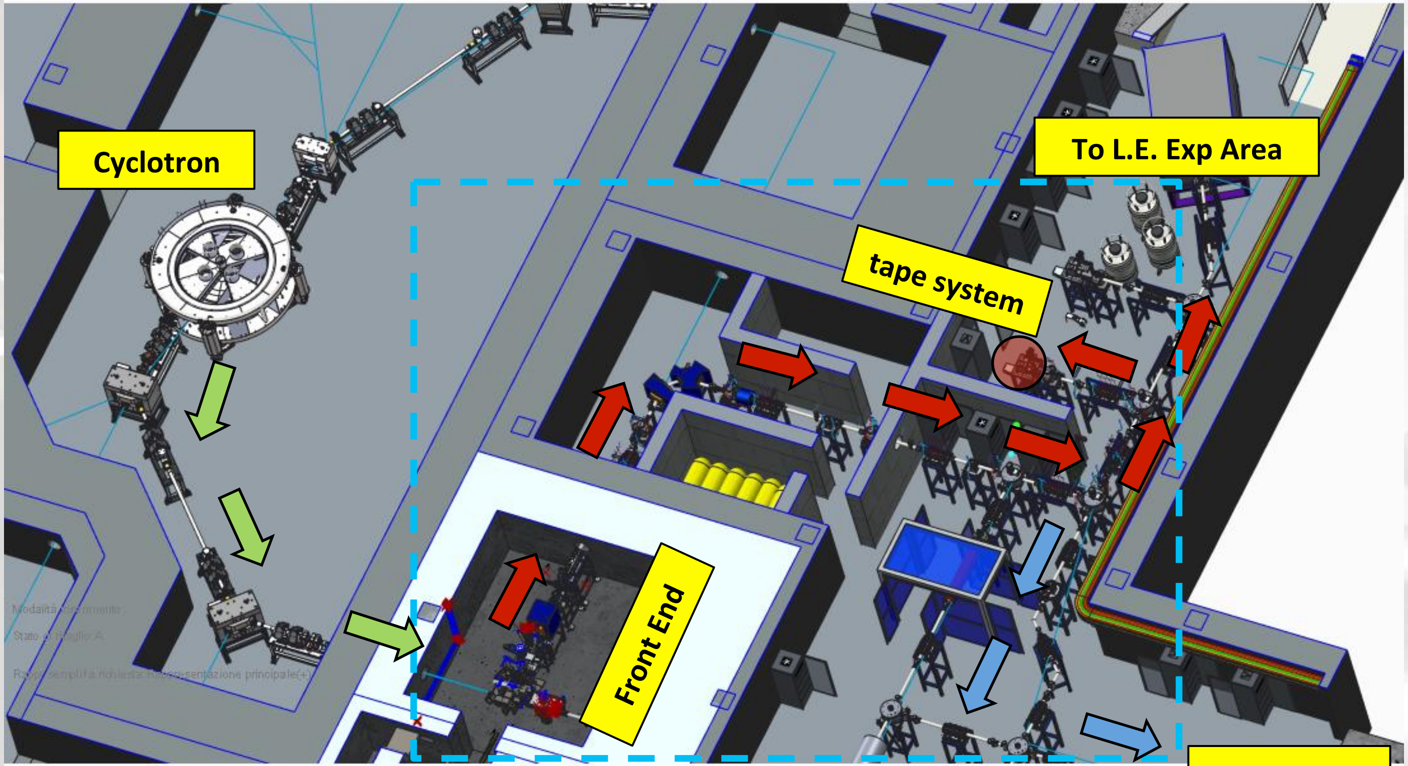
The RIB +1 line

(First Low Energy RIB at SPES)

Alberto Andrighetto

The 1+a beam line operation: The general layout

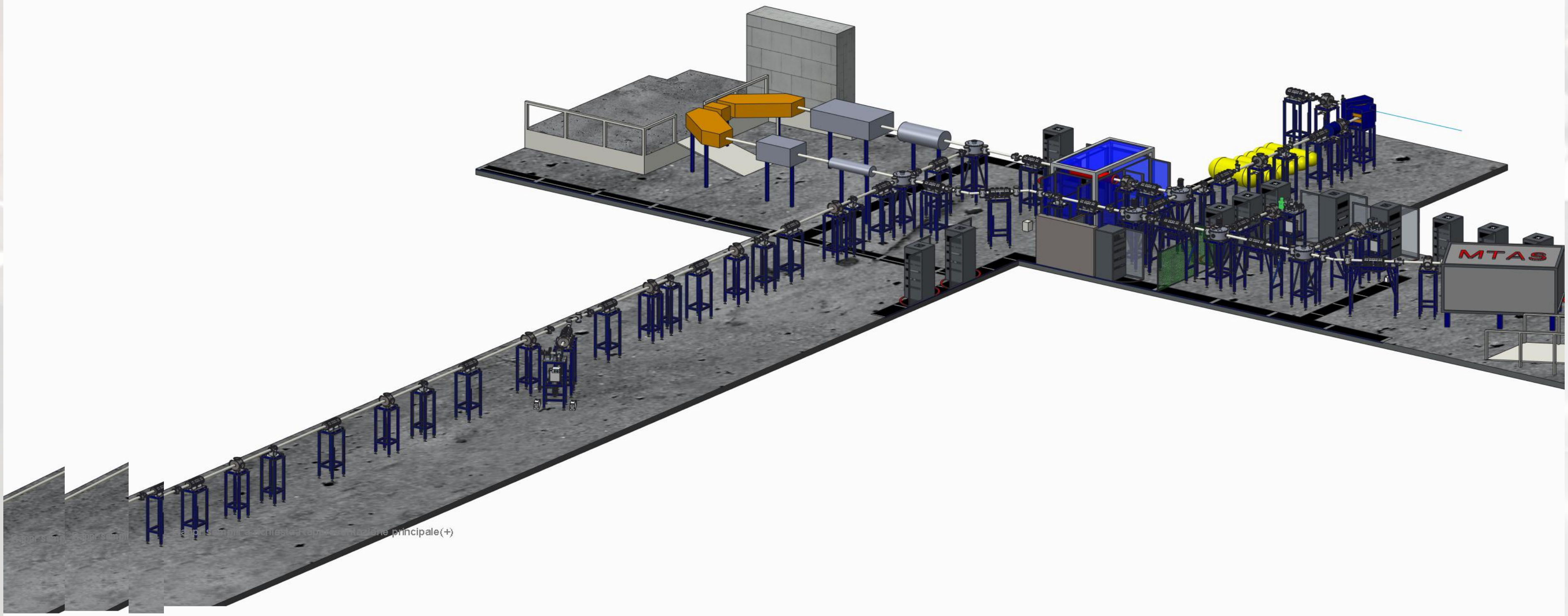
1+ beam line from **TIS** to **tape system**



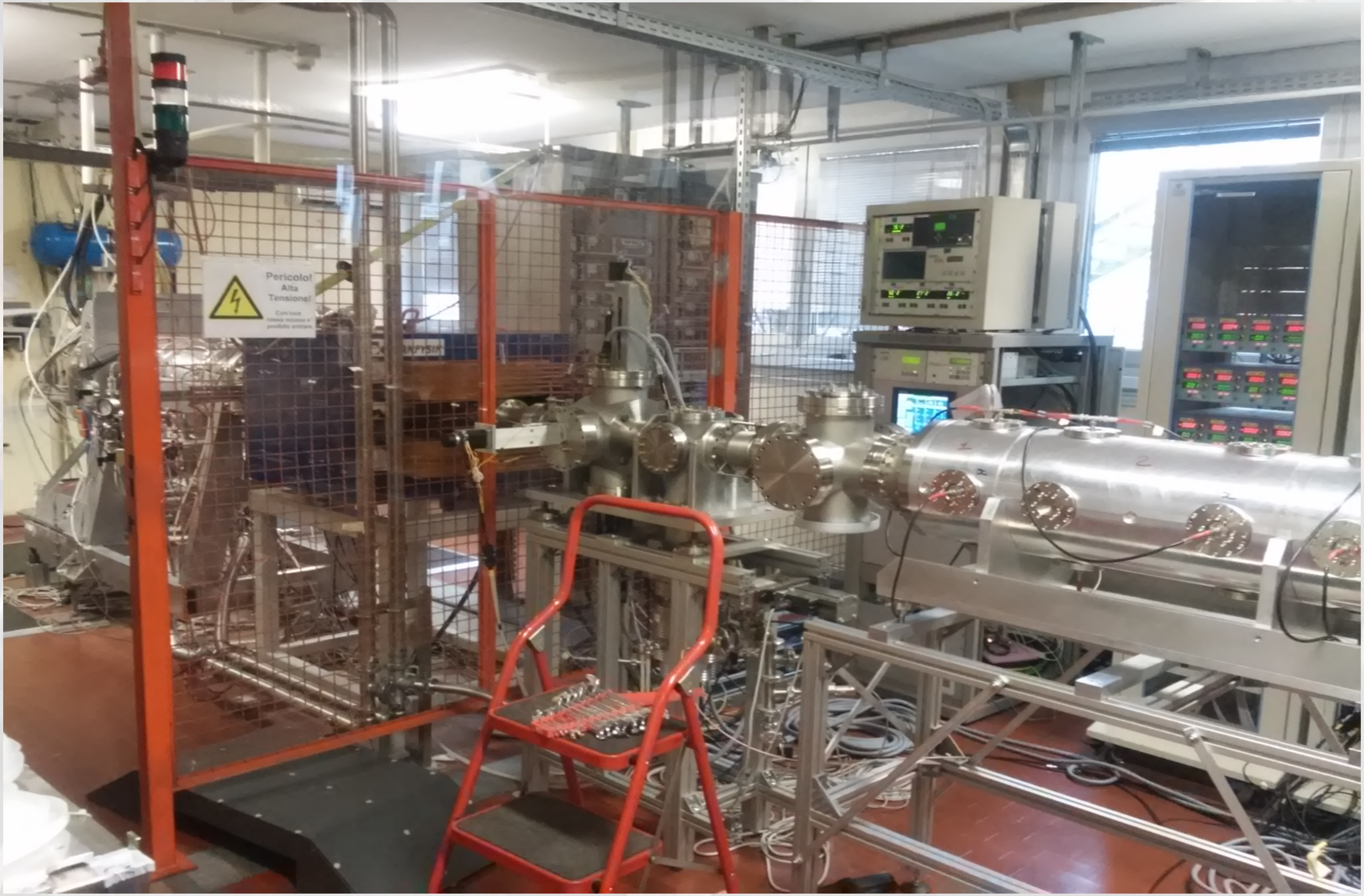
STEP1:
Low Energy, Low Intensity Beam for first experimental studies

STEP2:
ALPI Beam for 'High' Energy experimental studies

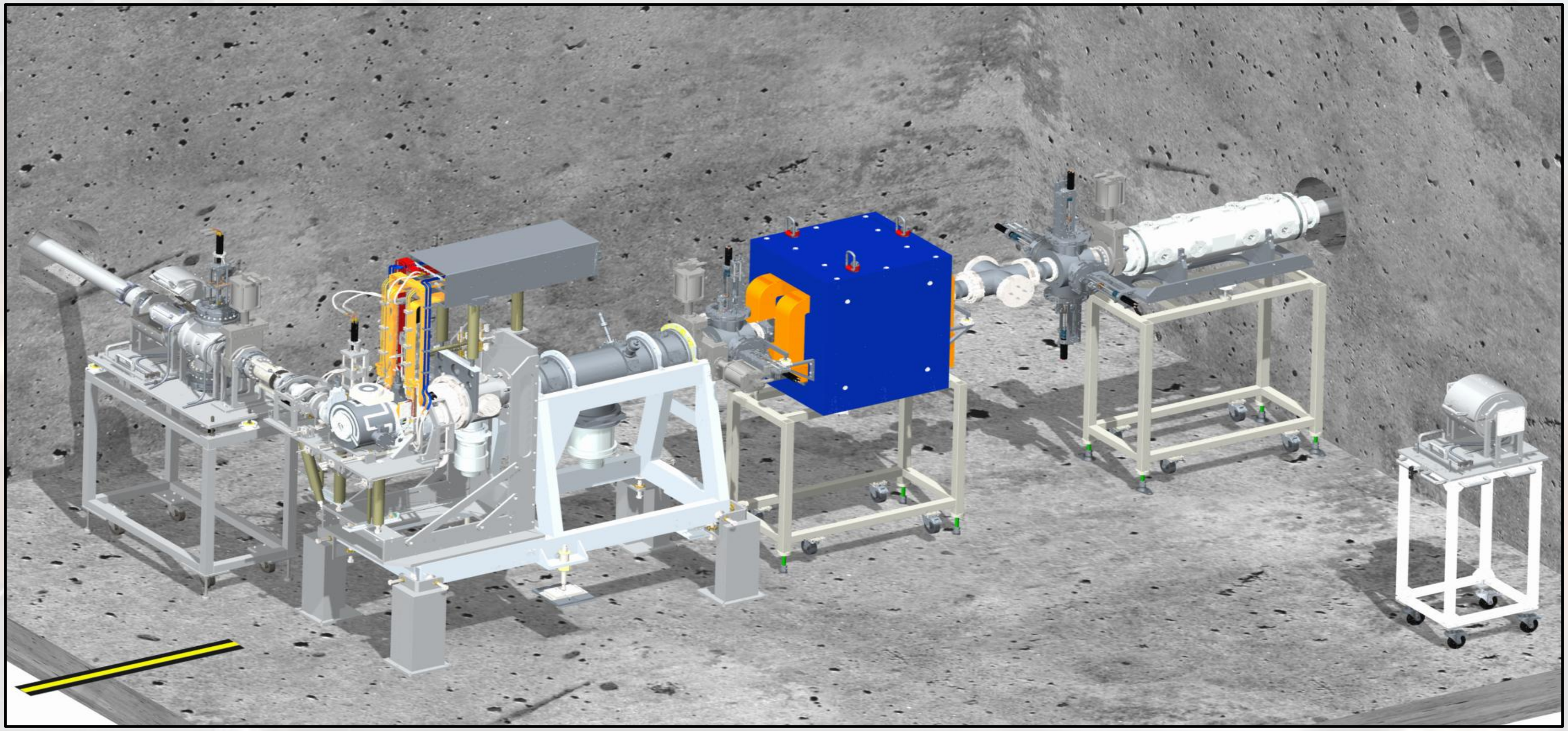
The 1+ beam line: the construction phases (2-3)



RIB Bunker set-up



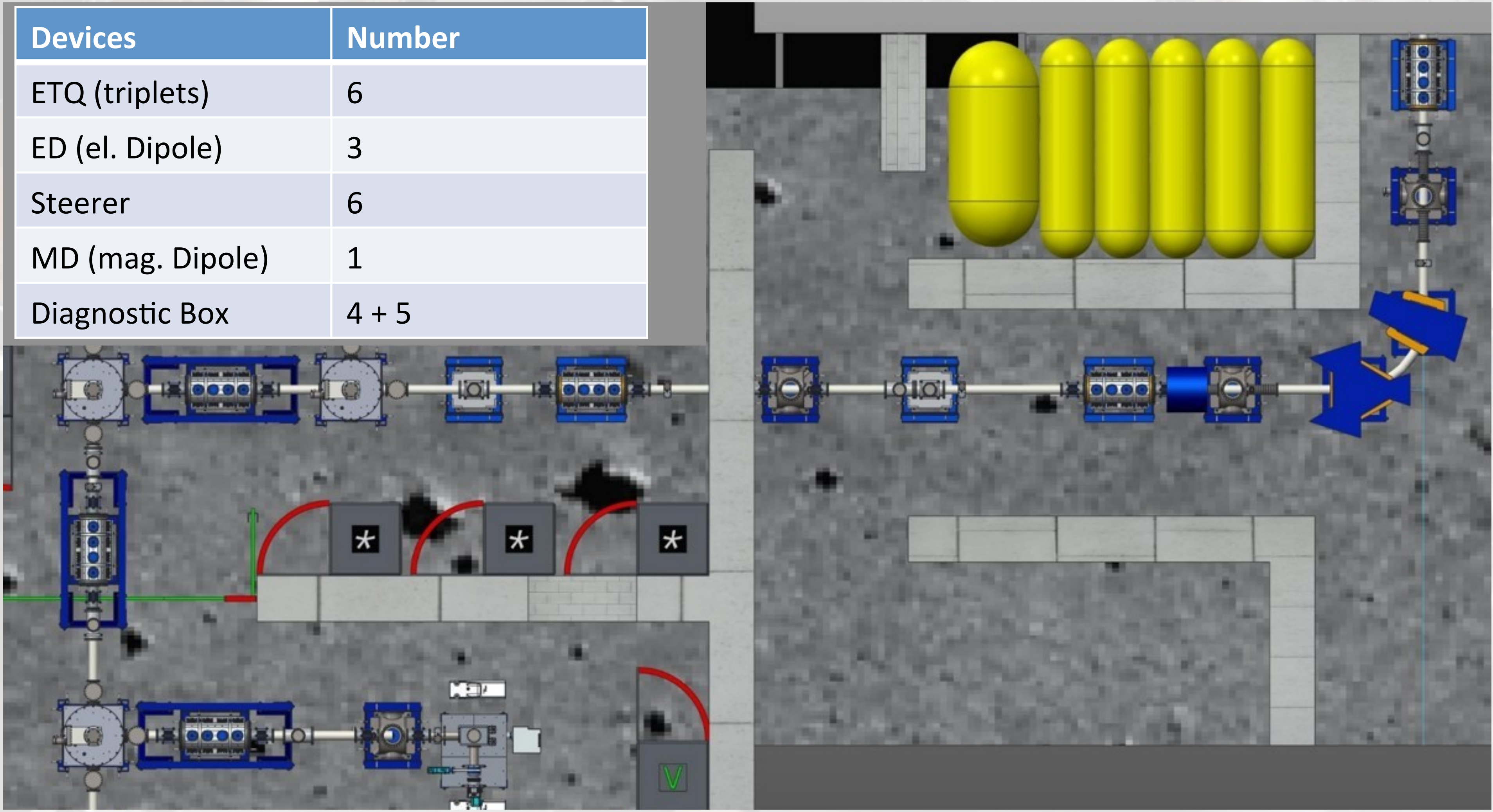
RIB Bunkers: Layout



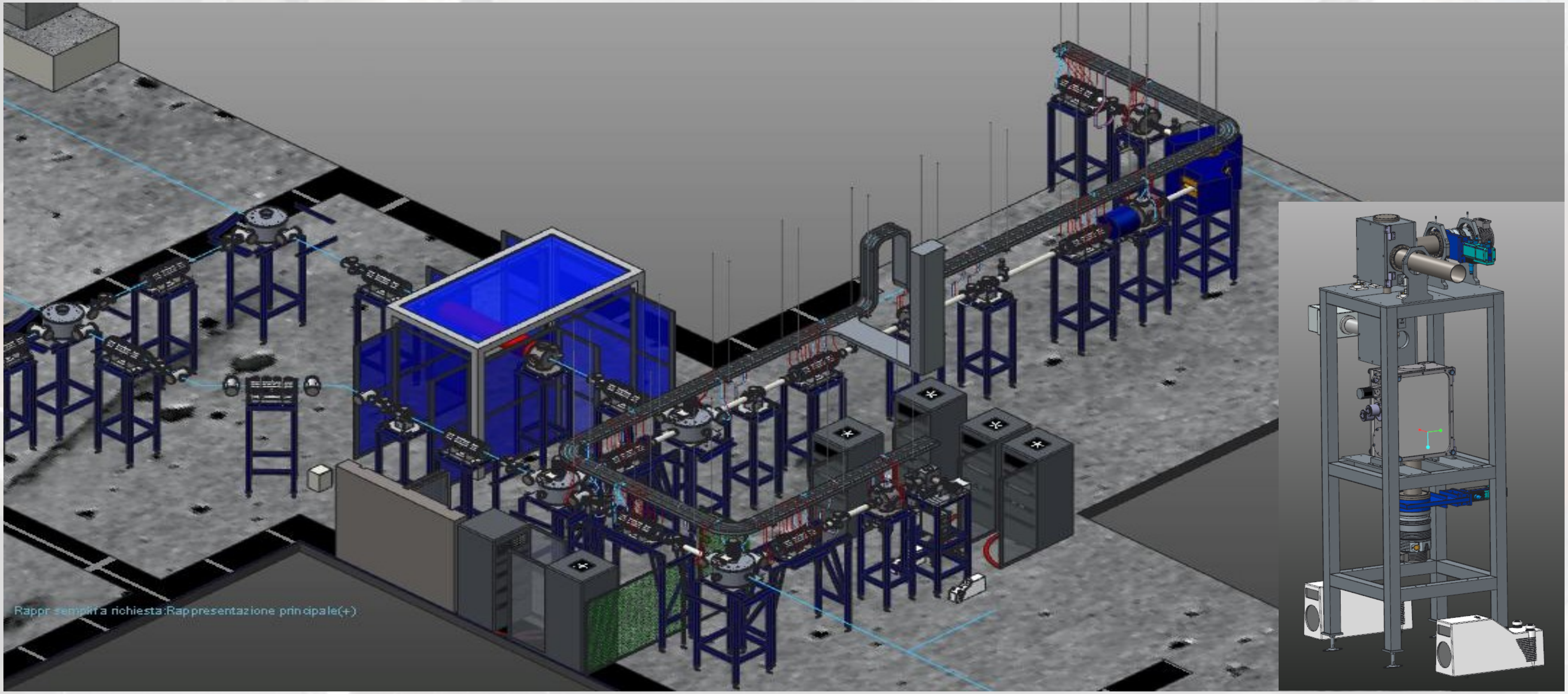
subsystem name	design status	construction status	delivery date estimation
protonic front-end	90%	20%	September 2018
radioactive font-end (removable)	90%	60%	July 2018
radioactive font-end (fixed)	90%	90%	done
diagnostic box 1	100%	80%	March 2018
Wien filter (electrostatic)	100%	90%	March 2018
Wien filter (magnetic)	100%	tender	Dec 2018
steerer box	100%	80%	March 2018
diagnostic box 2	100%	70%	March 2018
quadrupole triplet	100%	90%	March 2018

1+A beam line operation: Devices to TS

Devices	Number
ETQ (triplets)	6
ED (el. Dipole)	3
Steerer	6
MD (mag. Dipole)	1
Diagnostic Box	4 + 5



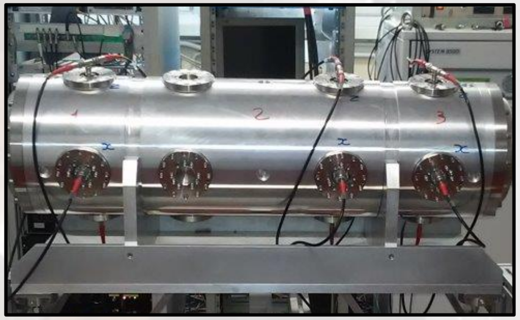
1+ A beam line operation: Layout



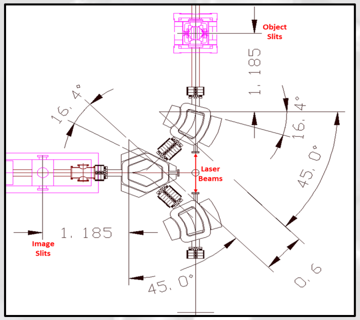
subsystem name	design status	construction status	delivery date estimation
Quadrupole triplets	100%	tender	November 2018
Electrostatic Dipole (prot)	100%	50%	January ‘18; Nov. 18 for others
Frames	80%	tender	July 2018
Diagnostic box (no detector)	10%	0%	Dec 2018
Magnet Dipole	100 %	tender	Dec 2018
Steerer box (prot)	100%	10%	done, End ‘18 for others
Tape System	70%	30% (?)	Dec 2018

1+ beam line operation: devices

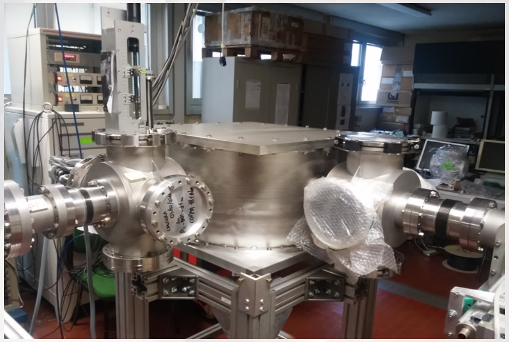
<u>electrostatic triplet of quads</u>
Prototype tested; Purchase Tender launched



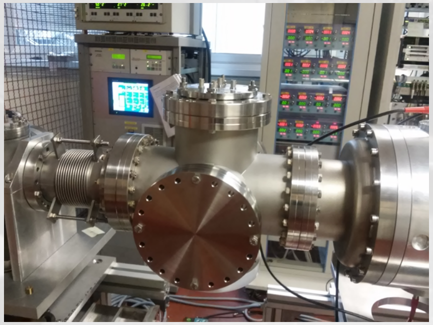
<u>magnetic dipole</u>
documentation ready for the Purchase Tenders



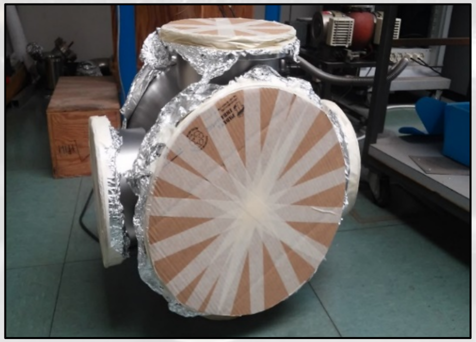
<u>electrostatic dipole</u>
Prototype tested; internal production start



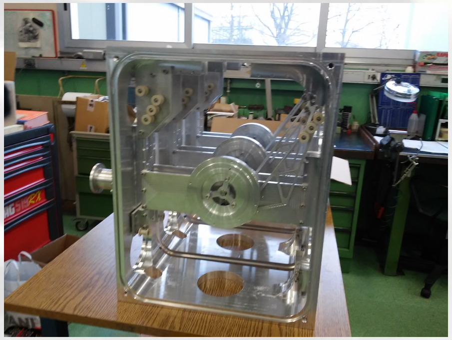
<u>electrostatic steerers</u>
Prototype tested; internal production start



<u>diagnostic box</u>
documentation ready for the call for Tenders



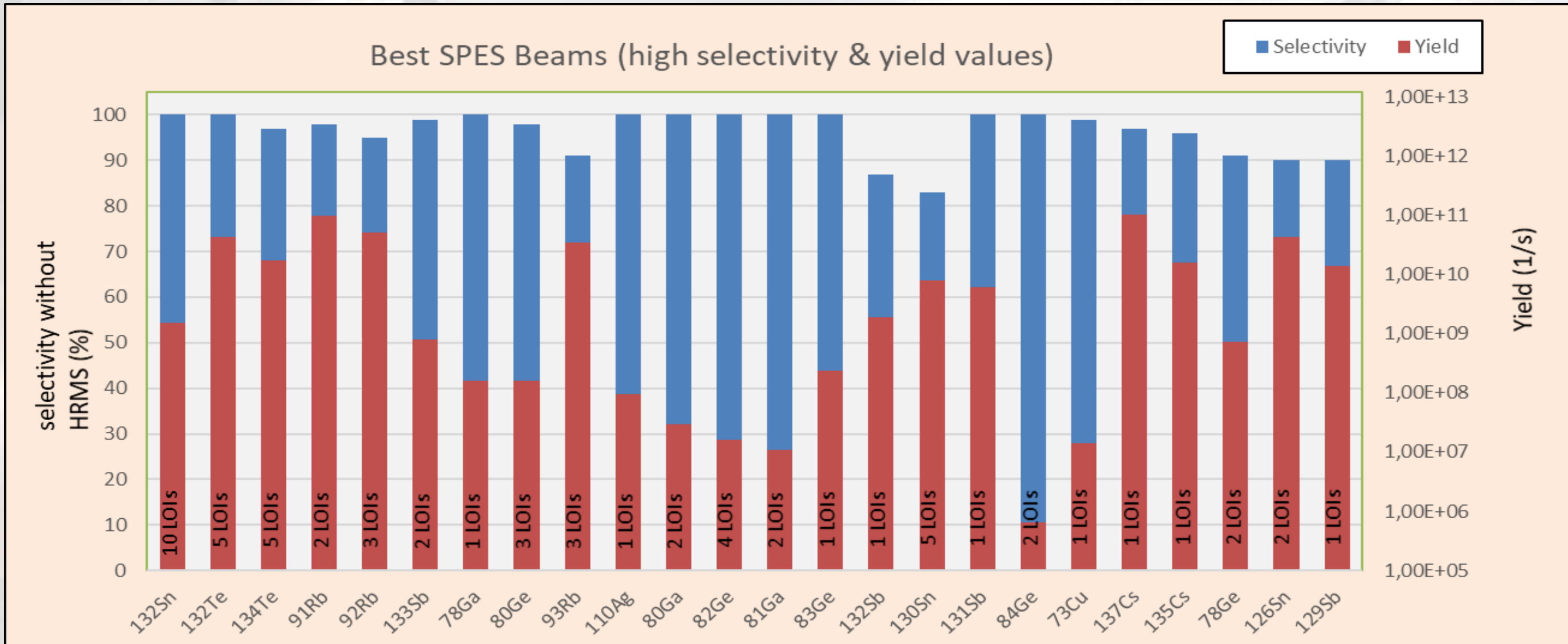
<u>tape system</u>
In construction (4 devices)



Possible first SPES RIBs

(first physics experimental campaign)

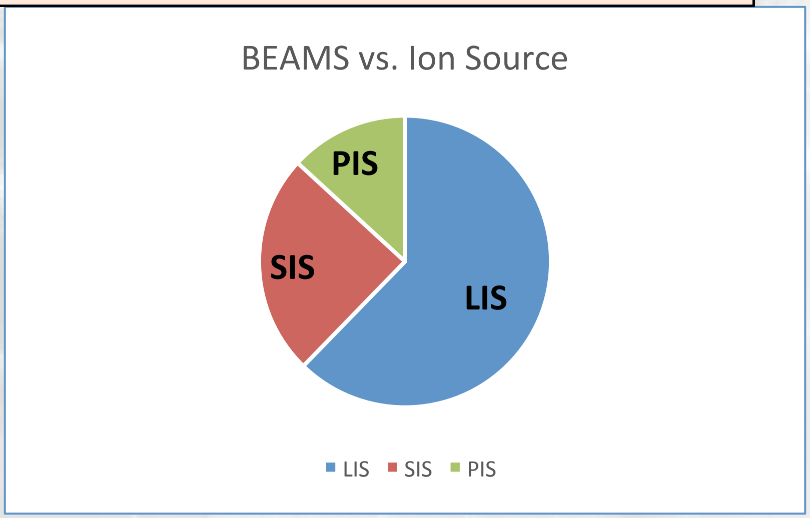
LOI users requirements



Total Beams:	89			

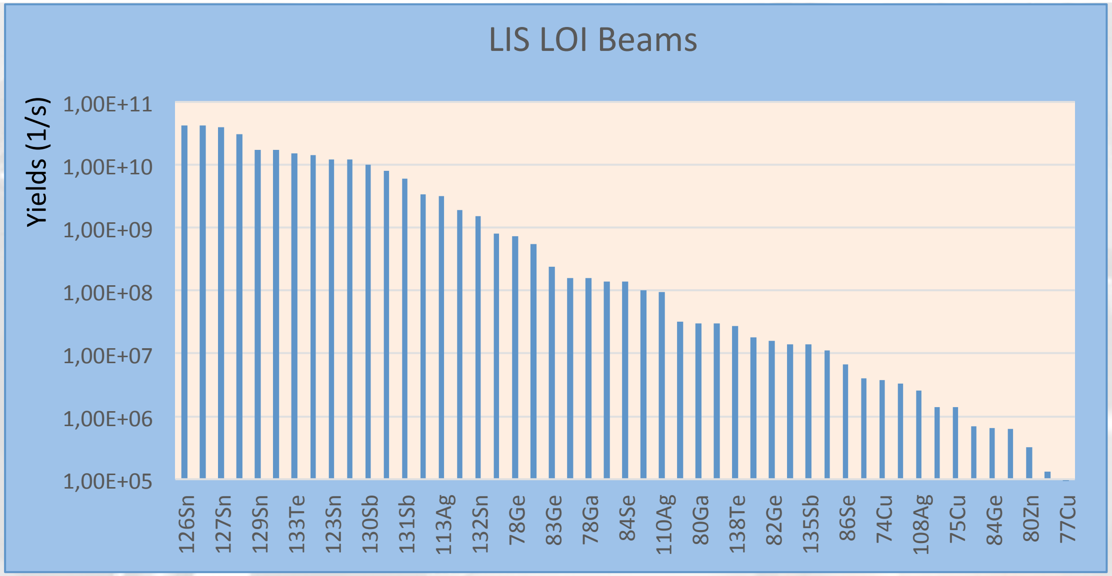
19 Elements

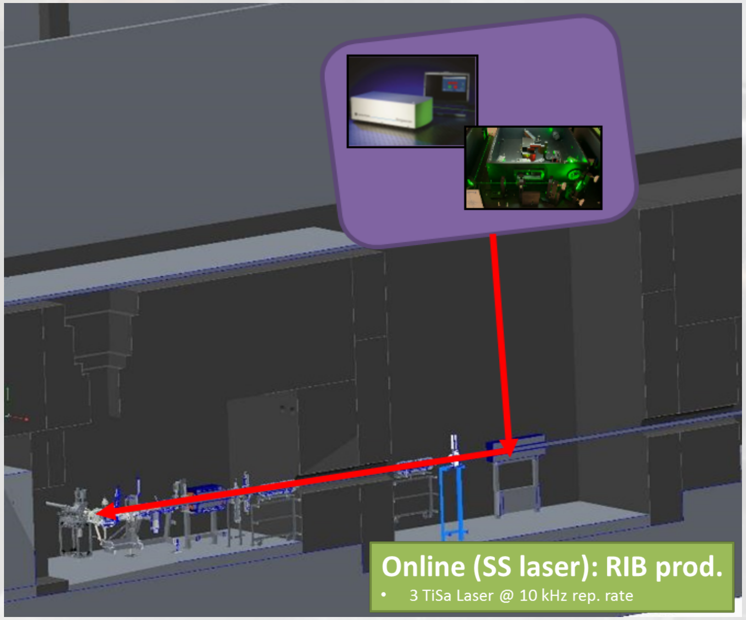
Beam with LMR:	47	(95 LOI)		53% (56%)
Benefit with 5000 HMR :	3	(3 LOI)	-> 50 beams (98 LOI)	56% (58%)
Benefit with 10000 HMR :	17	(31 LOI)	-> 67 beams (129 LOI)	75% (77%)
Benefit with 15000 HMR :	15	(25 LOI)	-> 82 beams (154 LOI)	92% (92%)
Benefit with 20000 HMR :	7	(10 LOI)		

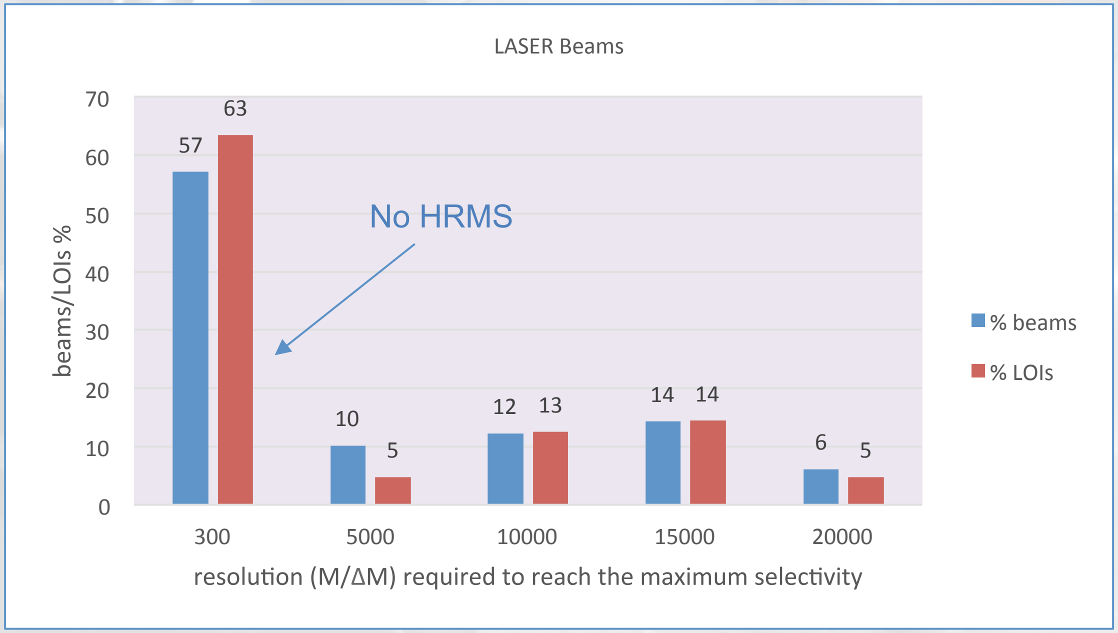


LIS Beams

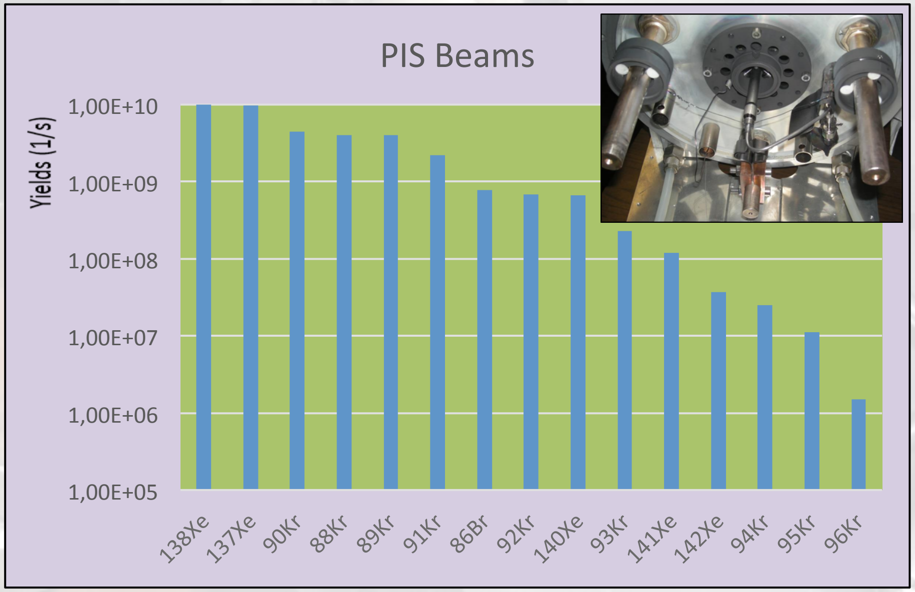

Offline: Spectroscopy
• 3 Dye Laser @ 10 Hz rep. rate

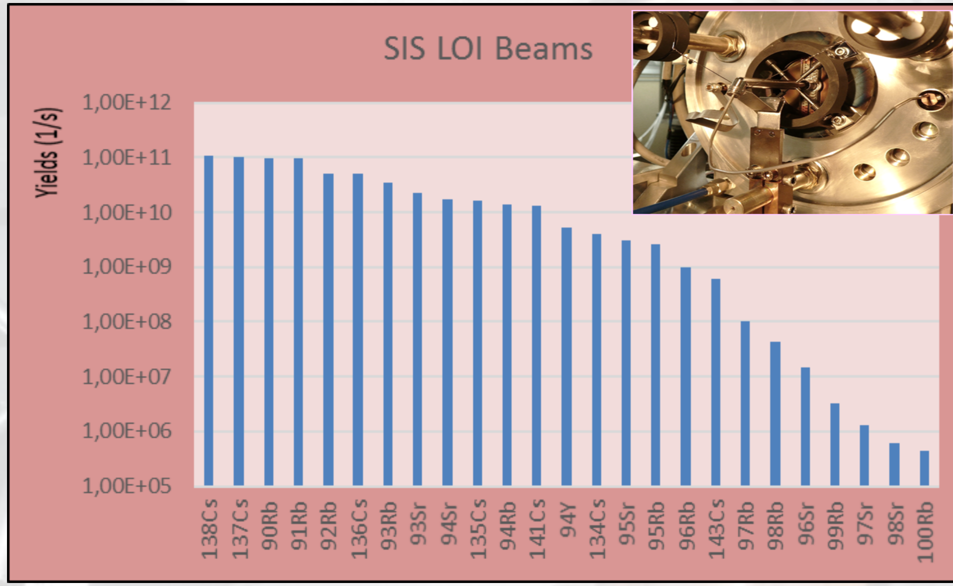

LIS LOI Beams
Yields (1/s)
1,00E+11
1,00E+10
1,00E+09
1,00E+08
1,00E+07
1,00E+06
1,00E+05
126Sn
127Sn
129Sn
133Te
123Sn
130Sb
131Sb
113Ag
132Sn
78Ge
83Ge
78Ga
84Se
110Ag
80Ga
138Te
82Ge
135Sb
86Se
74Cu
108Ag
75Cu
84Ge
80Zn
77Cu

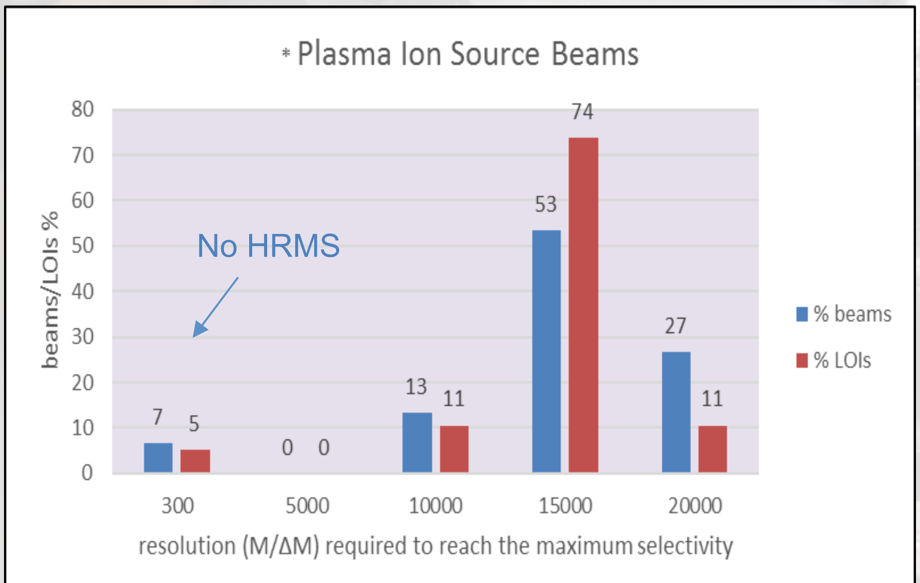

Online (SS laser): RIB prod.
• 3 TiSa Laser @ 10 kHz rep. rate

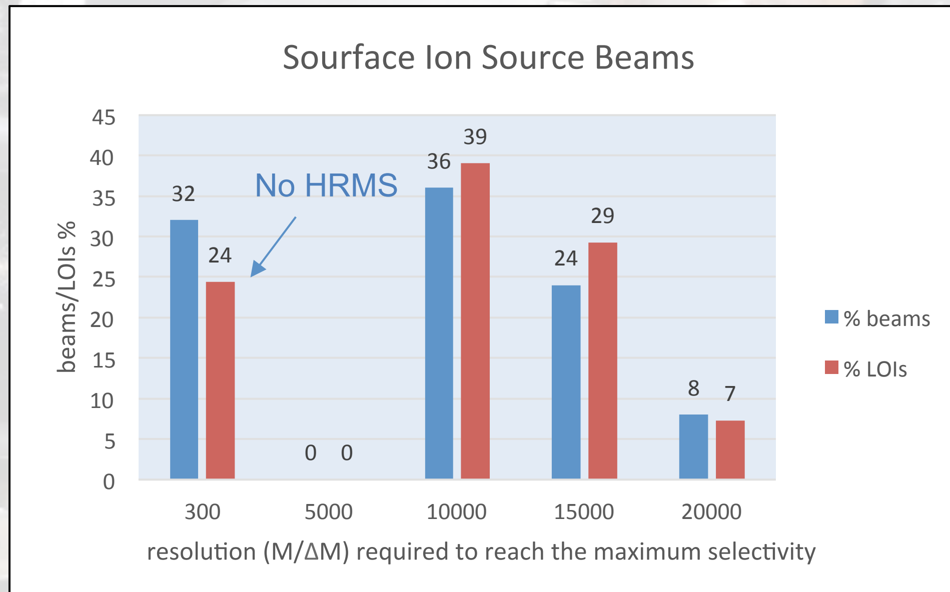

LASER Beams
beams/LOIs %
70
60
50
40
30
20
10
0
57
63
10
5
12
13
14
14
6
5
No HRMS
300
5000
10000
15000
20000
resolution (M/ΔM) required to reach the maximum selectivity
% beams
% LOIs

SIS & PIS Beams



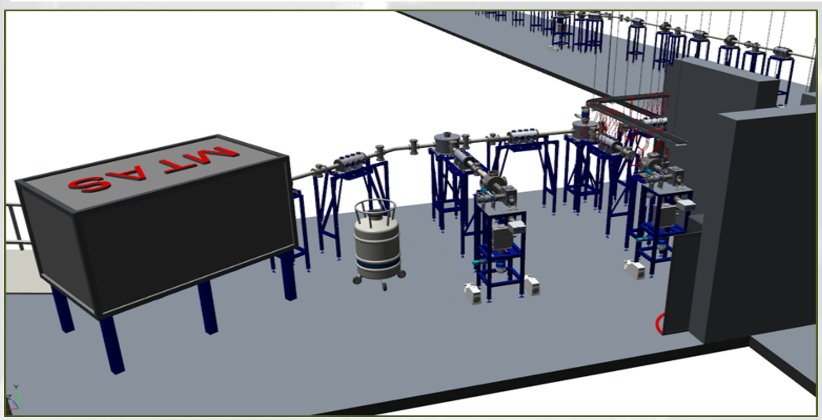


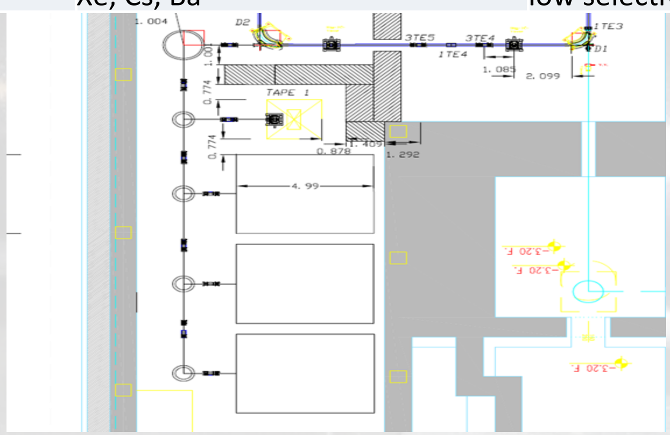


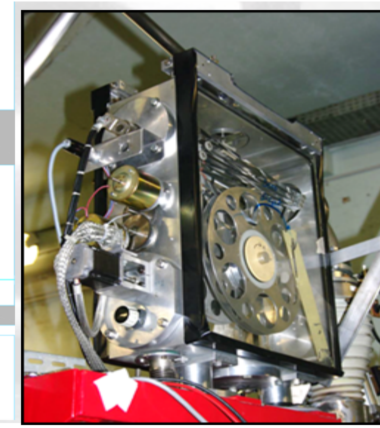


LOIs & UCx target: RIBs Low Energy (overview)

nucl. sy.	yield (pps) @ 20 μA	selectivity (%)	ion source type	main contaminants (if sel. < 60%)	notes	LOI reference
123 Sn	1.28E+09	12	LIS	In	low selectivity beam	38
121 Sn	2.02E+08	6.6	LIS	In	low selectivity beam	38
83 Ge	2.47E+07	100	LIS	-	selective beam	27
82 As	1.07E+07	71	LIS	-	selective beam	27
110 Ag	9.60E+06	100	LIS	-	selective beam	38
80 Ga	3.05E+06	100	LIS	-	selective beam	27
134 Sn	2.49E+06	3	LIS	In, Cs, Ba	low selectivity beam	10
84 As	1.86E+06	69	LIS	-	selective beam	27
82 Ga	3.29E+05	100	LIS	-	selective beam	10; 27
108 Ag	2.58E+05	38	LIS	Rb, Sr, In	low selectivity beam	38
84 Ge	6.61E+04	100	LIS	-	selective beam	10; 27
83 Ga	6.06E+04	100	LIS	-	selective beam	10; 27
96 Rb	9.89E+07	31	SIS	Sr	easy beam	37
147 Cs	4.91E+04	1.7	SIS	Ba	easy beam	10
100 Rb	4.49E+04	1.2	SIS	Sr	easy beam	10
86 Br	7.73E+07	42	PIS	As, Se, Kr	low selectivity beam	44
139 I	5.94E+06	1.5	PIS	Xe, Cs, Ba	low selectivity beam	10
140 I	9.17E+05	0.1	PIS	Xe, Cs, Ba	low selectivity beam	10
141 I	1.40E+05	0.1	PIS	Xe, Cs, Ba	low selectivity beam	10







Conclusions

Goals: beam delivery & RIB Source Commissioning

User requirements vs Project Construction Phases

Third International SPES Workshop

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

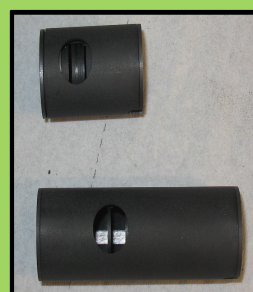
Europe/Rome timezone

- selettività
- 1 - Bednarczyk
- 2 - Morelli
- 3 - Chipps
- 4 - Marchi
- 5 - Kozulin
- 6 - Kurtukian
- 7 - Corradi
- 8 - Pirrone
- 9 - Stahl
- 10 - Rykaczewski
- 11 - Fioretto
- 12 - Stefanini
- 13 - Zhang
- 14 - Szilner
- 15 - Modamio
- 16 - Casini
- 17 - Nannini
- 18 - Valiente
- 19 - Piantelli
- 20 - Melon
- 21 - Goasduff
- 22 - Crespi
- 23 - Valiente
- 24 - LaCognata
- 25 - Mengoni
- 26 - Gottardo
- 27 - Gottardo
- 28 - Pain
- 29 - Trippella
- 30 - Iskra
- 31 - Leoni
- 32 - Leoni
- 33 - Leoni
- 34 - Hadynska
- 35 - Testov
- 36 - Pierroutsakou
- 37 - Nannini
- 38 - Cristallo
- 39 - Verney
- 40 - Benzoni
- 41 - Benzoni
- 42 - Vardaci
- 43 - Assie
- 44 - Crespi
- 45 - Raabe

within the end of 2019

40 MeV, 20 μA

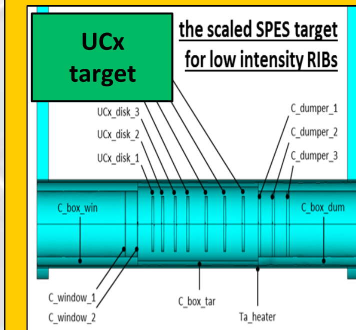
SiC target

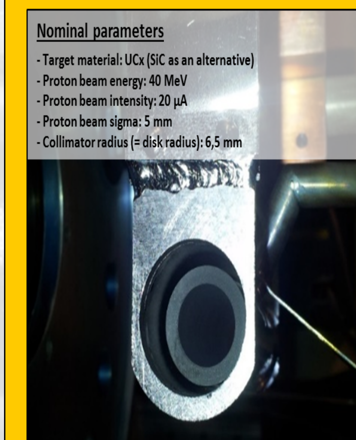


First SPES RIB (^{26}Al)

40 MeV, 20 μA, 10^{12} f/s

UCx target — the scaled SPES target for low intensity RIBs

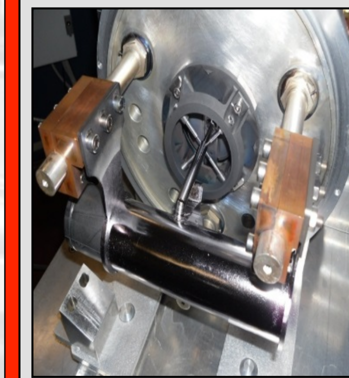




first n-rich fission isotopes

40 MeV, 200 μA, 10^{13} f/s

UCx target — the full-scale SPES target for high intensity RIBs



Nominal parameters

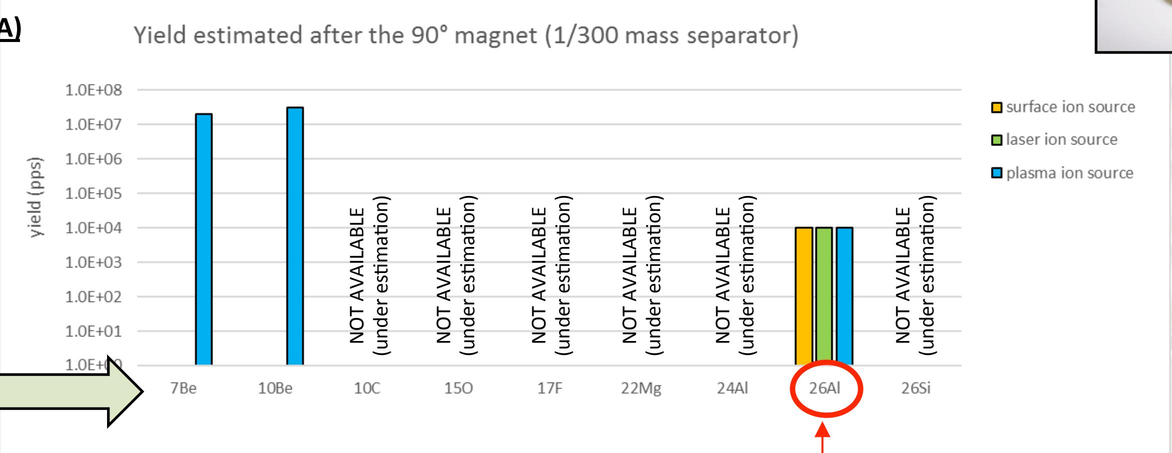
- Target material: UCx (SiC as an alternative)
- Proton beam energy: 40 MeV
- Proton beam intensity: 200 μA
- Proton beam sigma: 7 mm
Wobbling radius : 11 mm

The ‘demonstrative’ (first) beam:

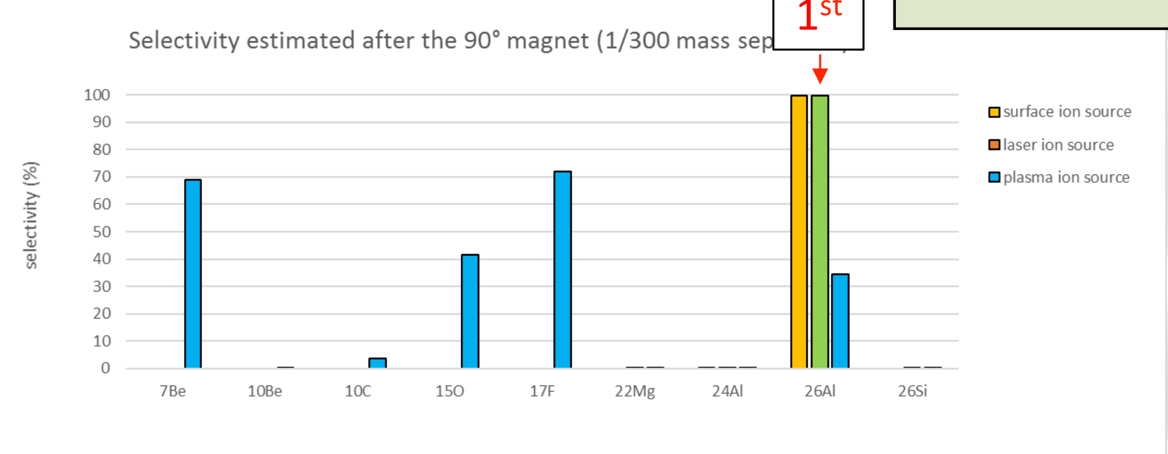
1st SPES RIB (26Al)

A scaled SiC target
(40 MeV protons up to 20 μA)
will be used for the first SPES RIBs

SiC target beams requested by LOIs



1st



> High yields

> High selectivity
(even without HRMS)

- **Low energy**
- **Different IS**

^{26}Al

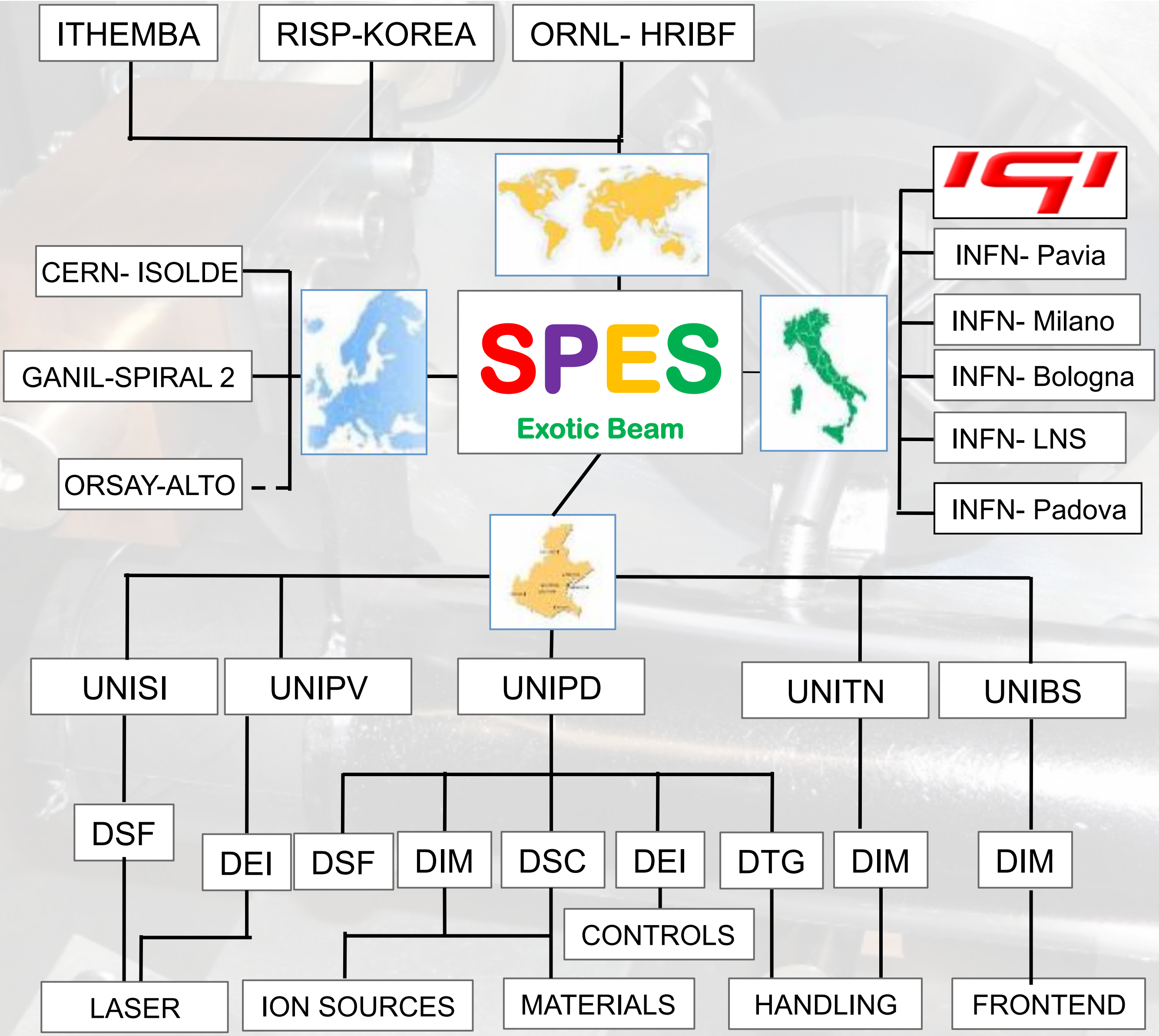
1^{st} SPES RIB

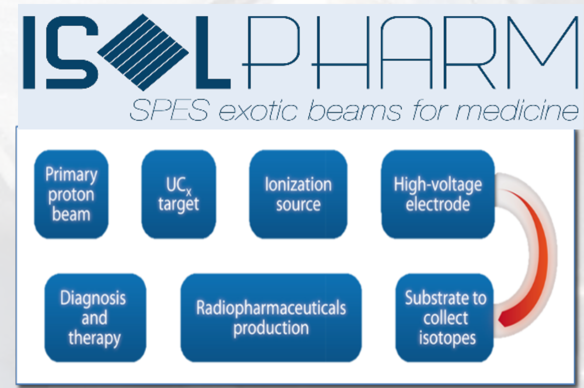
preparatory beam for the post-acc. phase
(requested by LOIs)

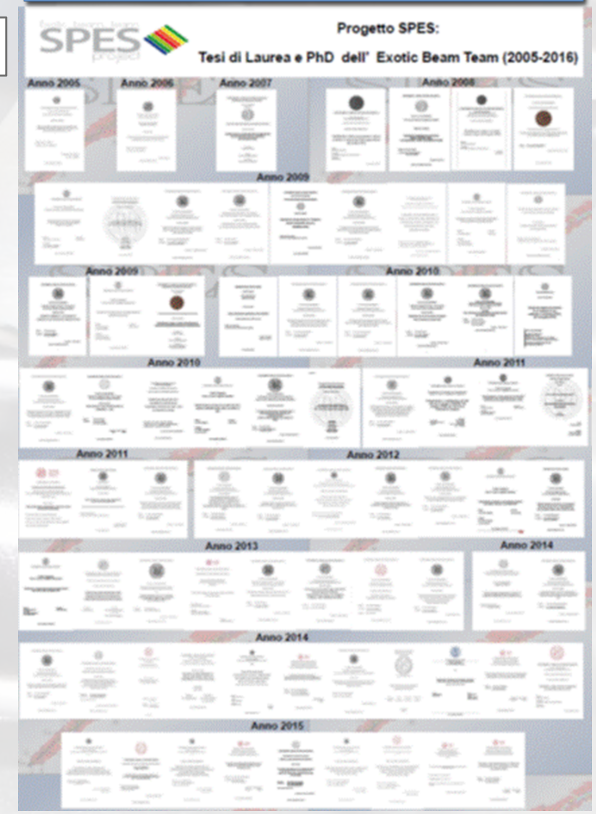
LOI	beams
L. Morelli	7Be, 10Be
J.J. Valiente	10C, 17F, 20Na, 22Mg, 24Al, 26Si
M. La Cognata	26Al
M. Assié	7Be, 26Si, 15O

High energy LOI beams with dedicated targets (no UCx)

The collaboration network for SPES-RIB







Conclusion