SPES: Steps toward the Physics cases

Providing the SPES Users information about beams, currents & contaminations

F.G. & Jose Javier Valiente
SPES Scientific Support

1st Meeting of the Technical Advisory Committee
22-23 January 2014

SPES for USERS

- One can register as a **SPES User** to have updated news
  - https://web2.infn.it/spes/

- A **new call** for **LOIs** has been launched @ the end of 2013
  - DEAD LINE March 14th 2014

- The Second **International Workshop** will be held:
- **26-29 May 2014 @LNL**

1st Meeting of the Technical Advisory Committee
22-23 January 2014

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Evaluation of the RIB production & trasportation

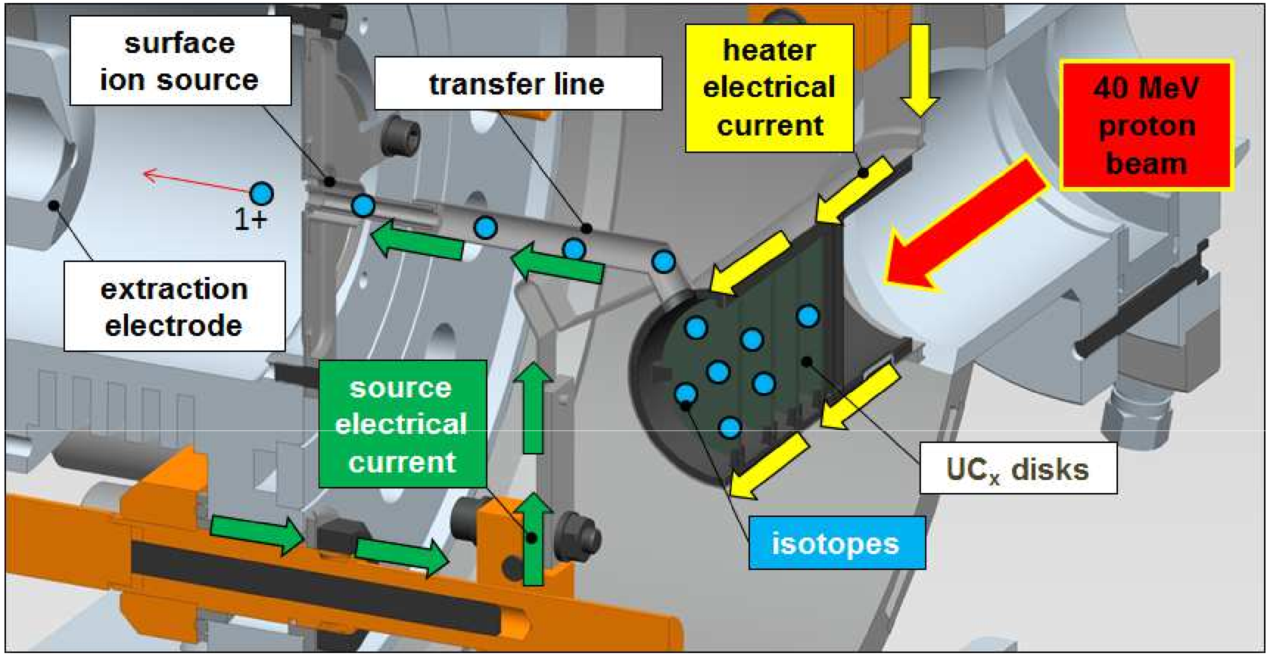
SPES exotic beams for science

- Evaluation of the induced radioactivity in SPES (safety, radioprotection & risk evaluations) → BERTINI –RAL (FF cross sections)
- Evaluation of the RIBs intensities @ 1+ (low energy physics) & after the LINAC_ALPI re-acceleration (user experimental target (**UET**)) – BERTINI – ORNL (FF cross sections)
- Evaluation of beam purity & contaminants @ the user UET and along the accelerator transport line

Where do we start from → common interest to evaluate radioactivity/contamination & RIB production but with different aim:

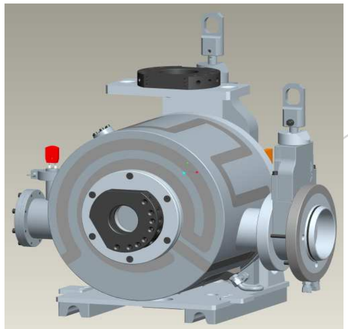
1. ***Radioprotection & safety Purposes:*** evaluation of the **worst cases** → maximization of currents to evaluate hot spots & beam line contaminations → used **OVERESTIMATION**
2. ***RIB productions evaluation*** & ***user info*** → to be used more Realistic numbers

Target – Ion source SPES complex



The Target – Ion source system is placed in an Aluminium chamber
The main part of the radioactivity (95% estimated) does not exit the chamber

The chamber is replaced after 2 weeks of irradiation and 2 weeks of cooling by a remote controlled machine



See later A. Andrighetto talk

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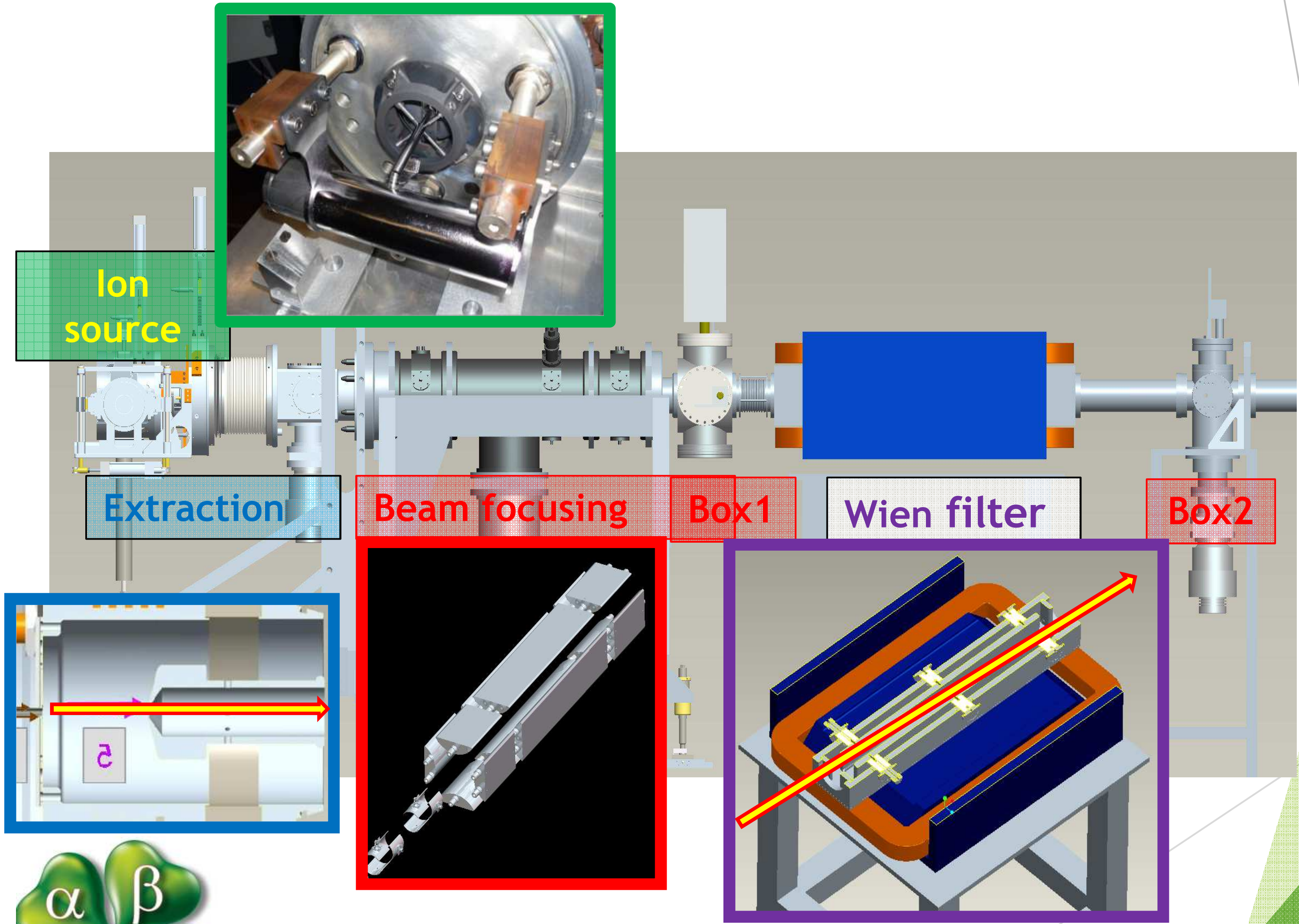
The Front-End

SPES exotic beams for science



See later A. Andrighetto talk

... towards the transport line ... vs ALPI

SPES: Target materials & Ionization Methods

exotic beams for science

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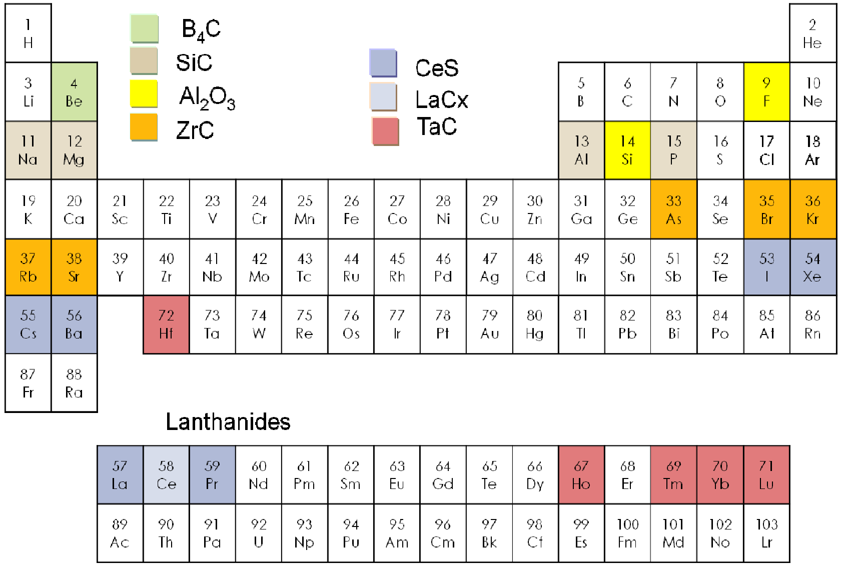
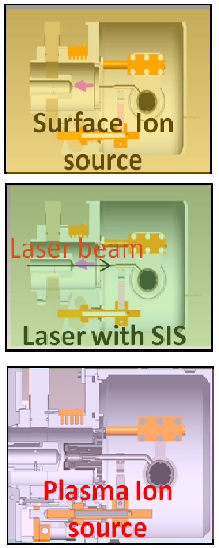
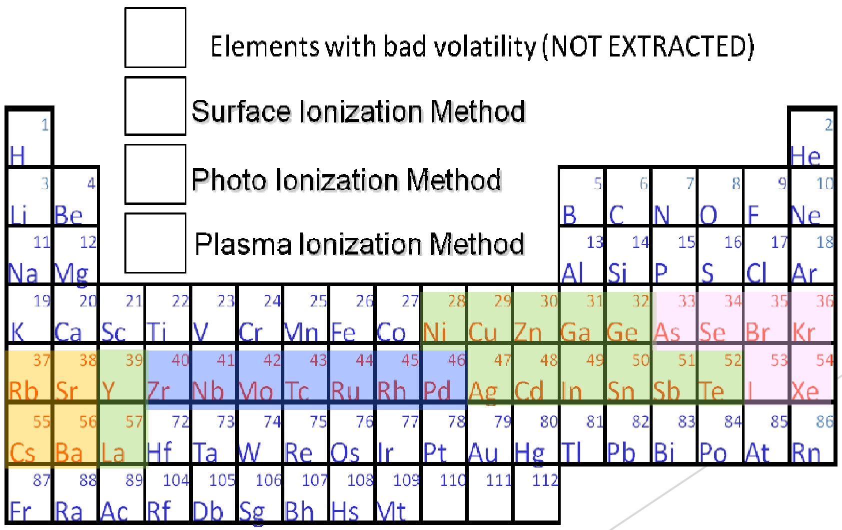
The target materials we are developing for the SPES ISOL facility will allow to produce a variety of beams both in the neutron-poor and the neutron-rich area



UCx





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

See later A. Andrighetto talk

Production target

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

Ion source target

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

Yield of a nuclear species

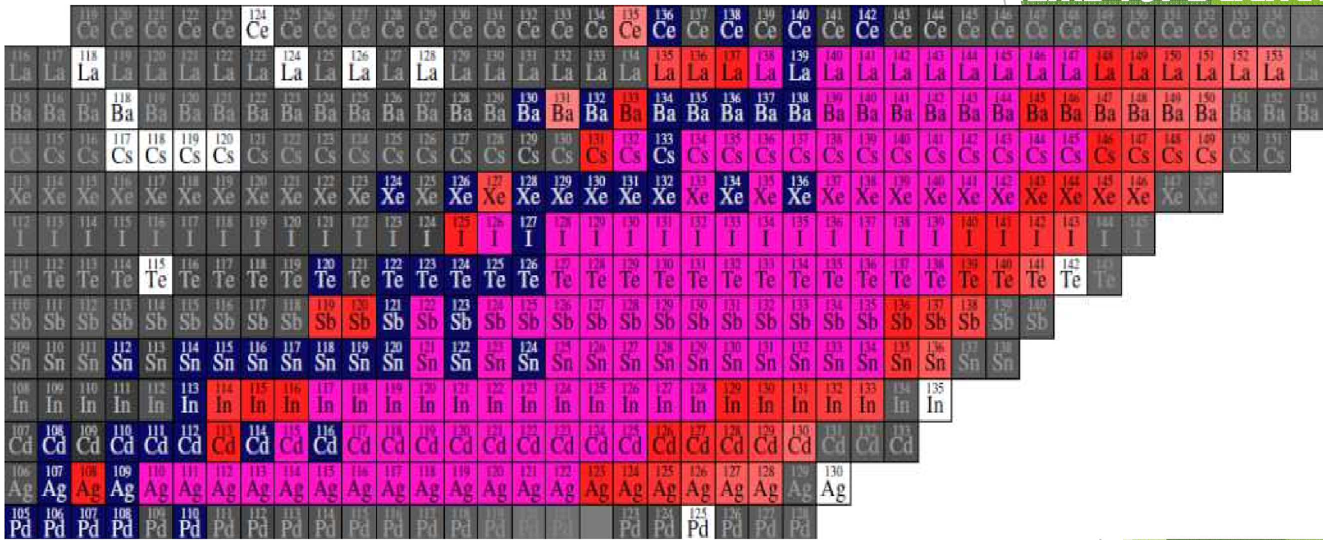
$$\boxed{Y = \sigma \cdot \Phi_p \cdot N \cdot \varepsilon_d \cdot \varepsilon_e \cdot \varepsilon_i \cdot \varepsilon_t}$$

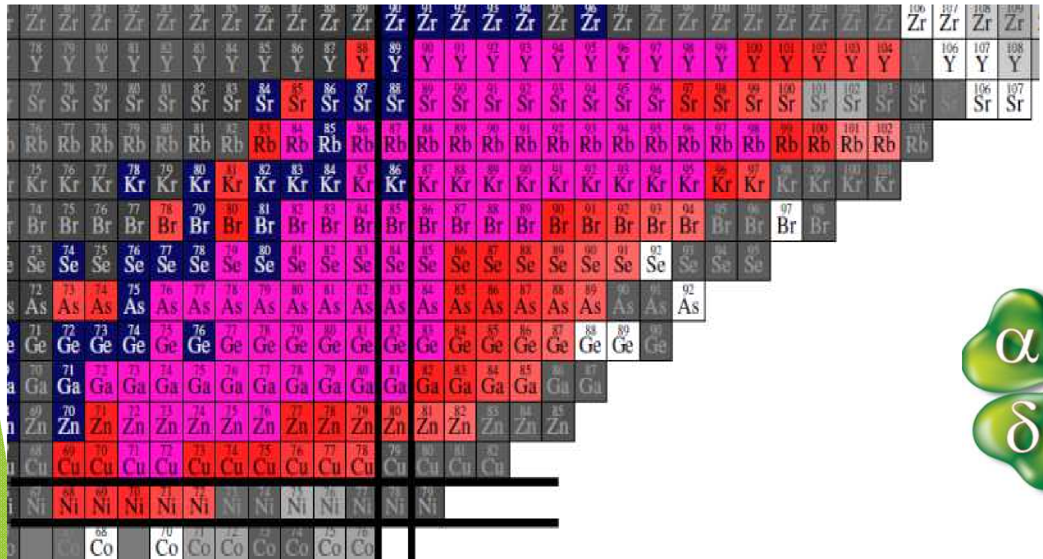
It depends on → half-life, cross-section, proton flux, diffusion and effusion time, ionization and transport efficiencies

SPES beam intensities after the Ion-Source (1^+)

Calculated with **MCNPX**
Considered the **release** and **ionization efficiency** in agreement and re-scaled on **HRIBF experimental values** and **currents** (200μA/5μA)

BERTINI – ORNL (FF cross sections)





SPES beams after Ion Source

- 10^7-10^9 pps
- 10^6-10^7 pps
- 10^5-10^6 pps
- 10^4-10^5 pps
- 10^3-10^4 pps
- 10 -10^3 pps
- 0 -10 pps

https://web2.infn.it/spes/index.php/characteristics/spes-beams-7037/spesbeamstable

SPES beam intensities after re-acceleration (q^+)

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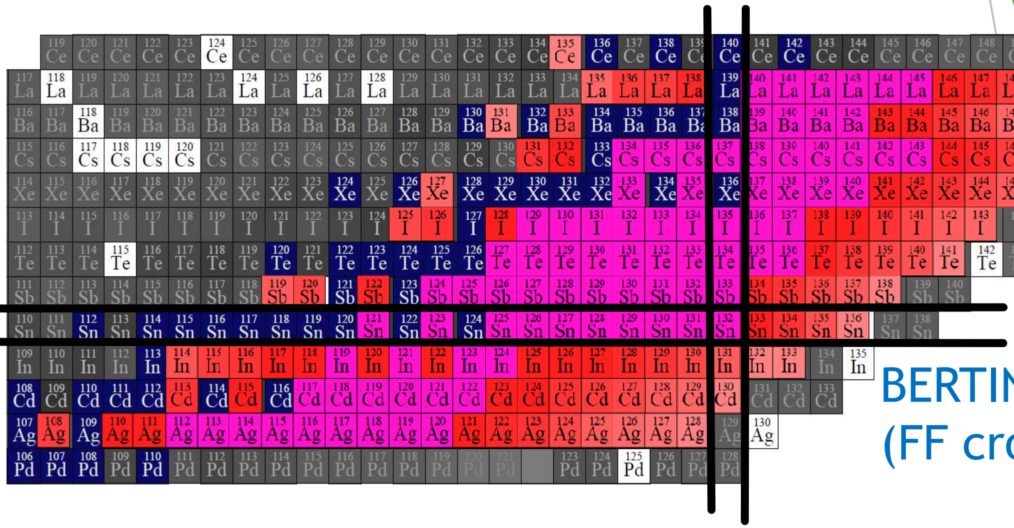
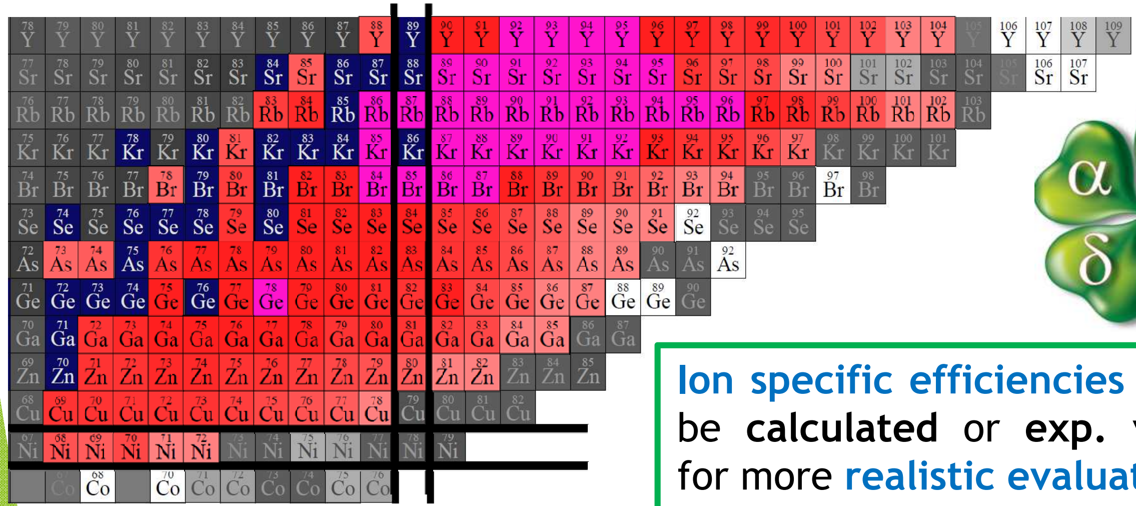
SPES exotic beams for science

Calculated with **MCNPX**
Considered the **release** and **ionization efficiency** in agreement and re-scaled on **HRIBF experimental values** and **currents** (200μA/5μA)

Average efficiencies calculated for **Charge Breeder (2-5%)** & **Linac ALPI efficiency (50%)**



BERTINI – ORNL
(FF cross sections)



SPES re-accelerated beams

- 10^7-10^9 pps
- 10^6-10^7 pps
- 10^5-10^6 pps
- 10^4-10^5 pps
- 10^3-10^4 pps
- 10 -10^3 pps
- 0 -10 pps

Ion specific efficiencies have to be **calculated** or **exp. verified** for more **realistic evaluation**

https://web2.infn.it/spes/index.php/characteristics/spes-beams-7037/spesbeamstable

Light ions @ SPES →

Still to be correctly evaluated for SPES (work in progress)

SPES - First period UCx 5μA Intensity – then SiC/B_4C Higher Intensity (100-200 μA)

Isotope	A	Z	N	Life time	Yields (HRIBF)	Q+	Production Target
Be*	7	4	3	4.60E+06	2.E+07 **	3	B_4C target – oxides LIS-FEBIAD
Be*	10	4	6		3.E+07 **	3	B_4C target – oxides
F *	17	9	8	6.48E+01	2.E+07 **	5	HfO_2, ZrO_2 target
F *	18	9	9	6.58E+03	2.E+06 **		Al_2O_3 target FEBIAD
Na*	21	11	10	2.25E+01		5	Al_2O_3 – SiC - CeS target SIS
Na*	22	11	11	2.60E+00		5	Al_2O_3 – SiC - CeS target
Mg*	22	12	10	3.86E+00		9	Al_2O_3 – SiC - CeS target LIS-FEBIAD
Mg*	23	12	11	1.13E+01		9	Al_2O_3 – SiC - CeS target
Al*	24	13	11	2.05E+00		7	SiC , CeS, Nb_5Si_3 targe SIS +LIS
Al*	25	13	12	7.18E+00	1E+04 **	7	SiC , CeS, Nb_5Si_3 target
Al*	26	13	13	6.35E+00	1E+04 **	7	SiC, CeS, Nb_5Si_3 target
Si*	26	14	12	2.21E+00	1E+03 **		Al_2O_3 – CeS target FEBIAD
Si*	27	14	13	4.16E+00	1E+03 **		Al_2O_3 – CeS target
P*	29	15	14	4.10E+00			SiC, CeS target FEBIAD
Cl*	34	17	17	1.53E+00	5E+03 **		Ce_2S_3 e CeO_2 target – (hygrosc.)

** available beams intensities at HRIBF with Ep=40-50MeV and Direct ISOL targets. @SPES at least a factor 10 improvement it is expected.

https://web2.infn.it/spes/index.php/characteristics/spes-beams-7037/spesbeamstable

Evaluation of the induced radioactivity in SPES

- Aim → Final Report
- Prepared under coordination of **Jose Javier Valiente Dobon** & **F.G.**
- <u>Verified by</u>: **Demetre Zafiropoulos** & **Gianfranco Prete**
- <u>Final Approval</u>: **Gianfranco Prete** **(SPES coordinator)**

- Method → group coordinated by **J.J. Valiente**

  Beam production → **A. Monetti** (MNCNPX + Mathematica)

  Beam transportation → **M. Comunian**

  Radioprotection Issues → **L. Sarchiapone**

  Radioactivity in the Pumping system → **A. Porcellato**

  General Considerations

  Risk Analysis

Framework of the calculations (Mathlab)

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A. Monetti – SPES Target group

exotic beams for science

PARAMETERS

Release Time

T_0 Isotopic Production

Isotopes $T_{1/2}$

Source Efficiency

Extraction Efficiency

WF Separation

WF Efficiency

INPUT

Mass & Charge of the element
(RIB & contaminants)

Source type
(SIS, LIS, PIS)

Temperature
(in case of SIS or LIS)

OUTPUT

Production @ Release Time

FC1 Current Values
(after 1^+ ionization)

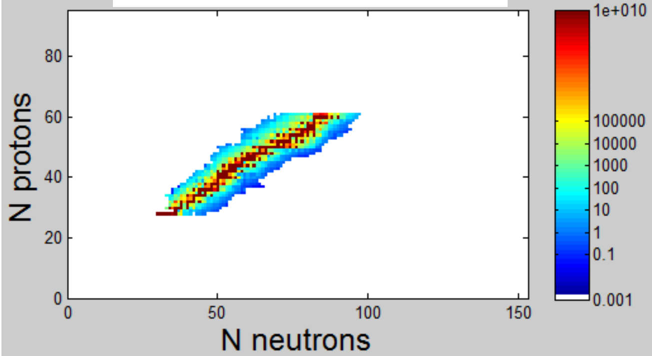
Current Values in FC2 (after Wien Filter) & Current Values @ the experimental area

Beam purity/contamination

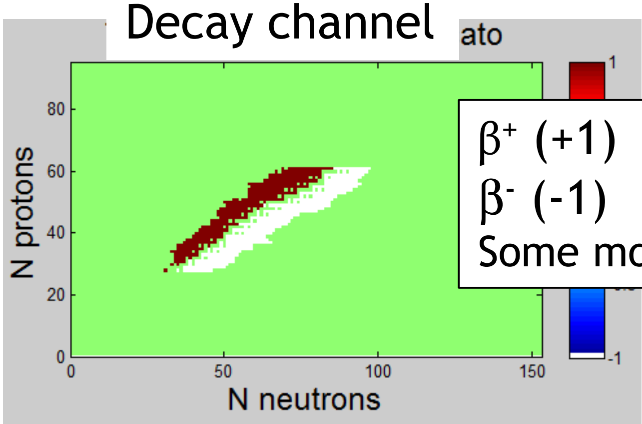
The IDEA : INPUT - OUTPUT & RESULTS:

A. Monetti - SPES target group

Life Times (s)

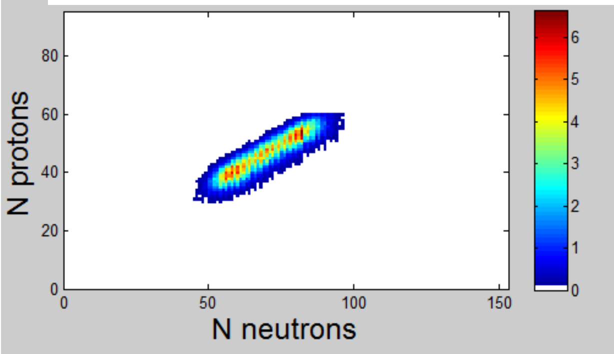


Decay channel

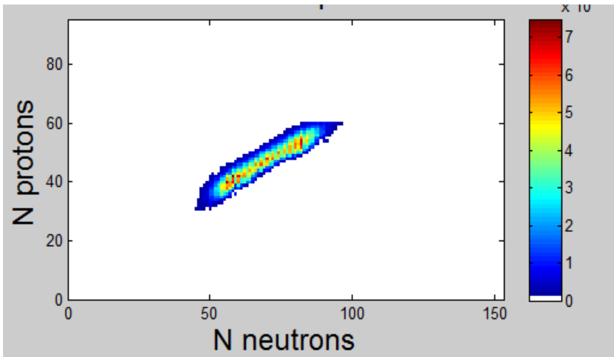


β^+ (+1) stable (0)
β^- (-1)
Some more to be added

T_0 (in target)production

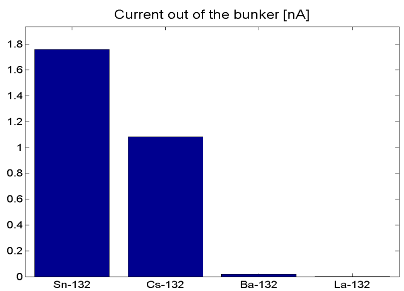


Production after the release time



Worst case
Fast Release
$T_{release}$=1s

Input data to the transport system



All elements can exit the source

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Beam proposed for Radioactivity Evaluations

SPES exotic beams for science

The test cases in term of **radioprotection** and **safety** have been chosen according to:

1. Highest half life of contaminant isotopes
2. Highest beam currents after the Target Bunker

- ^{90}Rb – Contaminant ^{90}Sr half life 28 years
- ^{135}I – Contaminant ^{135}Cs half life $2 \cdot 10^6$ years
- ^{137}Te – Contaminants ^{137}Cs half life 30 years
- ^{94}Kr – High current
- ^{138}Xe – High current
- ^{132}Sn, ^{134}Sn – Highly requested

Surface Ion Source (SIS) is only used to ionize the element of the first group (Rb, Cs) → good selectivity

Laser Ion Source (LIS) is used to ionize most of the elements produced in the target

Plasma Ion Source (PIS) is used for the elements with high ionization energy → low selectivity, bad emissivity

See later D. Zafiropoulos talk

Some examples: the ^{90}Rb, ^{94}Kr cases

SPES exotic beams for science

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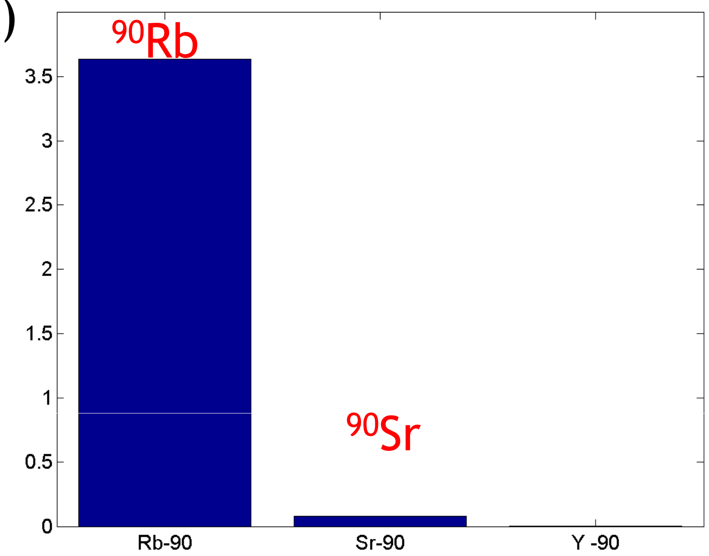
Prod.Intensities: **3.14 *10^{10} p/s**
After $T_{release}$=1s → **3.22*10^{10} p/s**

Expected @ 1^{+} → 9.62 *10^{10} p/s
Expected @ User → 1.92 *10^{9}p/s

^{90}Rb $T_{1/2}$= 158 s
^{90}Sn $T_{1/2}$= 98 y
SIS source – T=1999°C

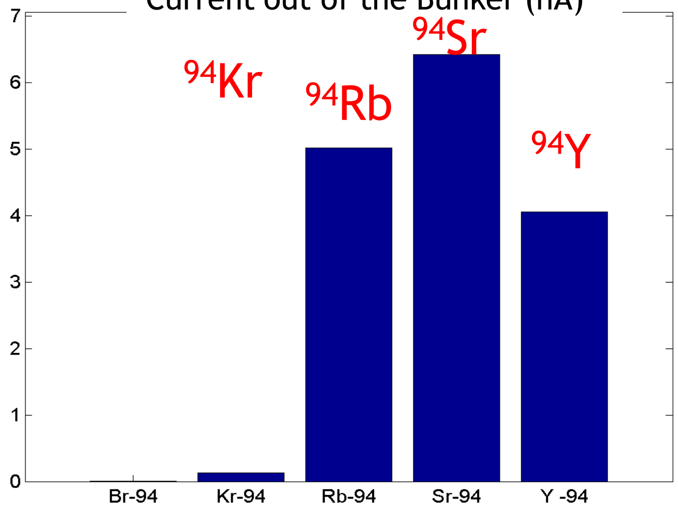


Prod.Intensities: **3.30 *10^{10} p/s**
After $T_{release}$=1s → **1.65*10^{9} p/s**

Expected @ 1^{+} → 2.49 *10^{7} p/s
Expected @ User → 4.99 *10^{5}p/s

^{94}Kr $T_{1/2}$= 0.2 s

PIS source – bad selectivity



Only WF selection considered at present

See later M. Comunian talk

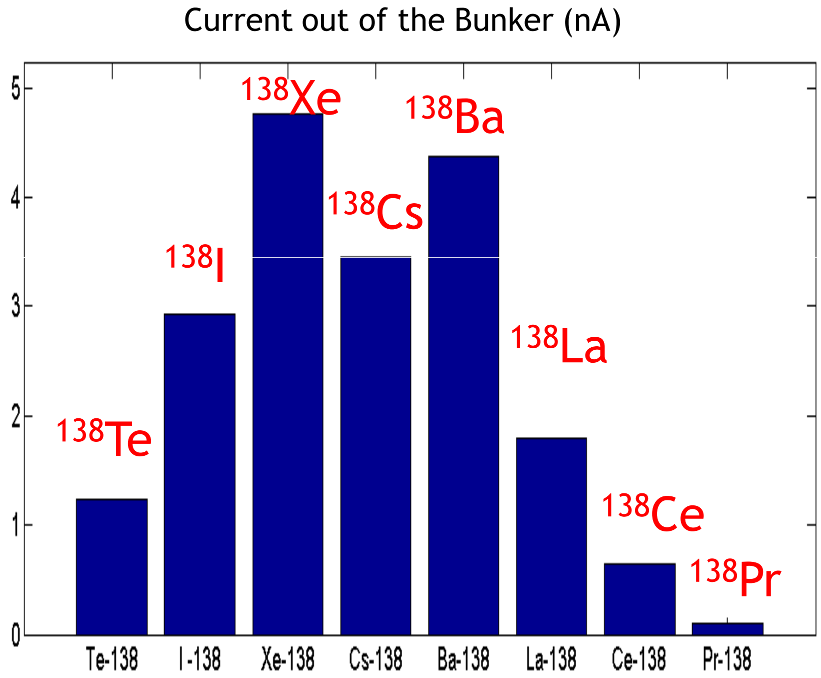
Some examples: the ^{138}Xe case

Prod.Intensities: **5.73 *10^{10} p/s**
After $T_{release}$=1s → **6.11*10^{10} p/s**

Expected @ 1^{+} → 1.01 *10^{10} p/s
Expected @ User → 2.08 *10^{8}p/s

^{135}I $T_{1/2}$= 14.08 m

PIS source →
low selectivity



Only WF selection considered at present

See later *M. Comunian talk*

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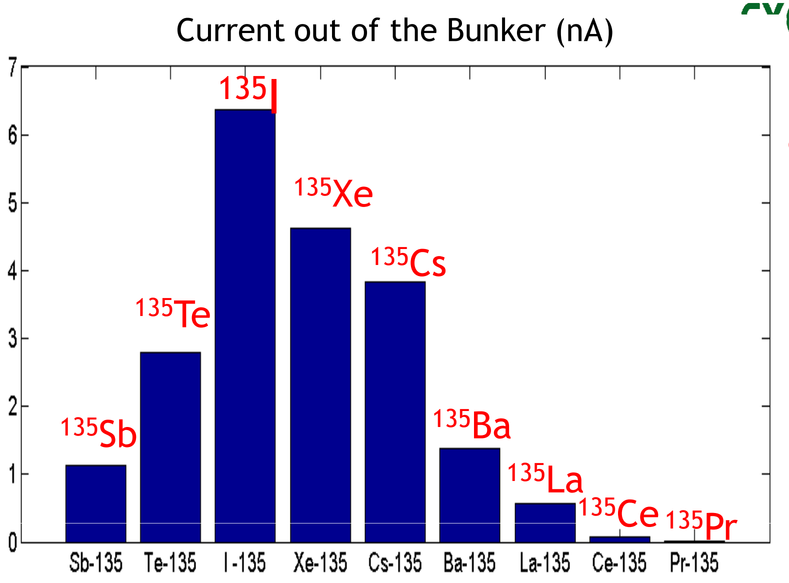
^{135}I, ^{137}Te cases

Prod.Intensities: **8.07 *10^{10} p/s**
After $T_{release}$=1s → **8.19*10^{10} p/s**

Expected @ 1$^+$ → 1.73 *10^{11} p/s
Expected @ User → 3.46 *10^{9}p/s

^{135}I $T_{1/2}$= 6.5 h
PIS source →
low selectivity

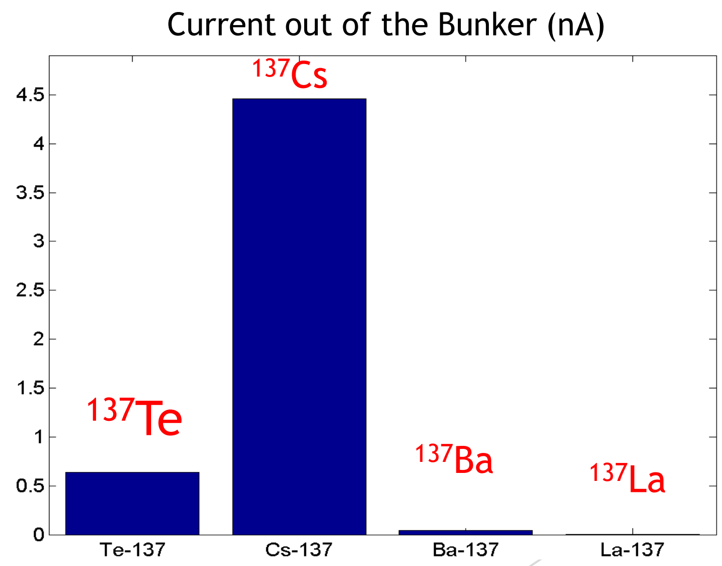


Prod.Intensities: **2.16 *10^{10} p/s**
After $T_{release}$=1s → **1.63*10^{9} p/s**

Expected @ 1$^+$ → 8.39 *10^{7} p/s
Expected @ User → 1.68 *10^{6}p/s

^{137}Te $T_{1/2}$= 2.49 s
^{137}Cs $T_{1/2}$= 30.2 y

LIS source



Only WF selection considered at present

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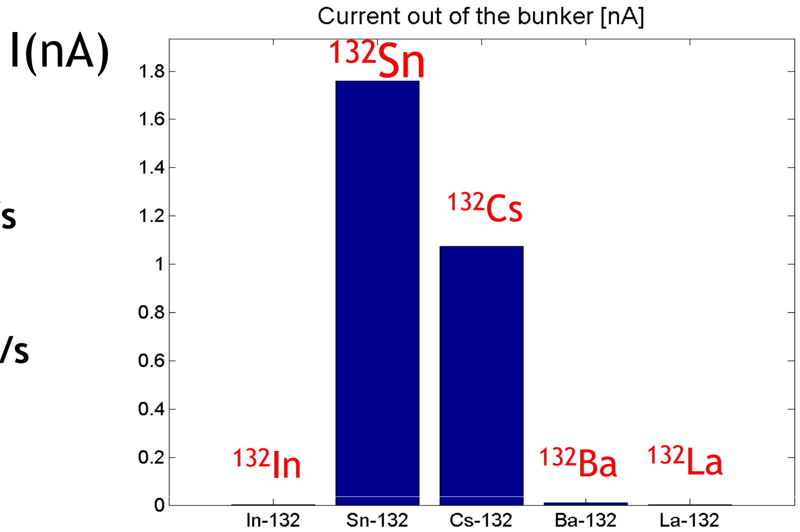
^{132}Sn, ^{134}Sn cases

Prod.Intensities: **3.84 $*10^{10}$ p/s**
After $T_{release}$=1s → **4.52$*10^{10}$ p/s**

Expected @ 1^{+} → 1,56 **$*10^{9}$ p/s**
Expected @ User → 3,11 **$*10^{7}$p/s**

^{132}Sn $T_{1/2}$= 39.7 s



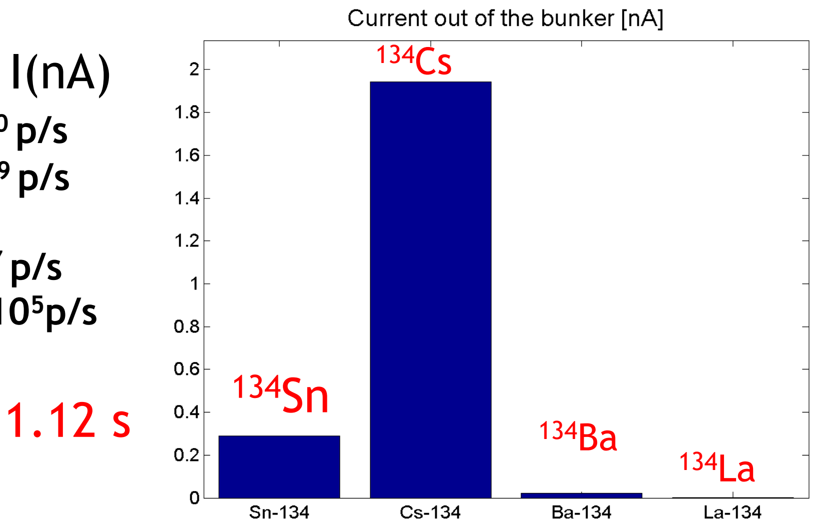
Only WF selection considered at present

See later M. Comunian talk

Prod.Intensities: **1.45 $*10^{10}$ p/s**
After $T_{release}$=1s → **7.47$*10^{9}$ p/s**

Expected @ 1^{+} → 2.49 **$*10^{7}$ p/s**
Expected @ User → 4,99 **$*10^{5}$p/s**

^{134}Sn $T_{1/2}$= 1.12 s



LIS source T=1500 °C

Beams Table →
User Information for next LoIs

More cases are needed to give a realistic prediction to USERS according to:

1. Beam currents after the first selection (W.F. + 90° dipole magnet $\Delta M/M=1/150$)
2. Beam currents after the second selection (C.B + $\Delta M/M=1/1000$)
3. Contaminants as a function of the kind of isotope (nuclear chart region, Relative yields & life time, Source system, Magnetic Separators.
4. Evaluation of HRMS selectivity & efficiency for the selected Ion

From the previous LoIs (2010):

- ^{132}Sn, ^{134}Sn – Highly requested
- Rb, Cs first day isotopes (low current operation)
- Light isotopes (high current operation with different Carbides)
- Cu, Zn isotopes (see next)
- Kr, Se, Ge, Y

FIRST DAY BEAMS @ SPES
No HRMS & Beam Cooler

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SPES exotic beams for science

Some examples which are under consideration:

- **Using the LIS →**
- **Zn beams** (mass range **72-80**) re-accelerated Beam Intesities from 10^5 to 10^3 pps
- **Ga beams** (mass range **79-83**) re-accelerated Beam Intensities from 10^6 to 10^4 pps

Direct Reaction Measurement in inverse kinematics in the N=50 region (for example ^{81}Ga+d → ^{80}Zn+ p; ^{79}Zn+d → ^{80}Ga + He),
Important to study the ***Neutron Shell Closure effects****. Important for* ***astrophysics****: characterization of excited level of importance for the* ***r-process****.*

- **^{75}Cu beam** , **Coulomb Excitation** → to study the **Tensor Force nature of the Nuclear interaction**. This nucleus has **4 neutron less** and **1 proton** more than the **double magic ^{78}Ni**.

Studying the region around ***^{78}Ni*** *is of paramount importance especially for the r-process → important "waiting point".*

Some more important cases: Coulomb excitation of **^{98}Sr e ^{97,99}Rb** (deformation region: proton occupy the fp shell and neutrons the gds).

Some more cases can be studied even at low selectivity using specific **"event tagging"** systems (under study) → Downstream Ionization Chambers (up to (<10^4 - 10^5 pps) or MCP_tof_systems etc.

- Verification of contaminants through Characterization Stations (see later)
- Studying & application of Purification Methodes (see HRIBF & ISOLDE)

Learning from others: Purification methods @ HRIBF

Contamination information

2. Recent HRIBF Development - Isobarically Pure ^{132}Sn Beams Now Available

Recent measurements have shown that isobarically pure beams of Sn isotopes can be delivered to experiments at the HRIBF. The Sn atoms are produced via proton-induced fission in a uranium carbide target and transported to an electron-beam-plasma (EBP) ion source. In the presence of sulfur vapors, the SnS molecule forms and is ionized and extracted from the EBP ion source as SnS^+, which is then converted to Sn^- in the Cs-vapor charge-exchange cell and delivered to the tandem electrostatic accelerator. The Sn beams produced in this manner are pure (>99%) with no detectable contamination from Sb and Te isotopes. When Sn isotopes are extracted from the ion source as Sn^+ ions, they comprise a small fraction of the total beam delivered to the experiment (e.g. for A=132, the beam composition is Te - 87%, Sb - 12%, and Sn - 1%).

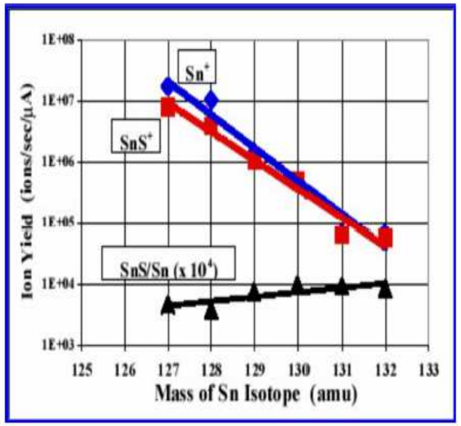


Fig. 2-1 - Positive-ion yields for Sn isotopes from a UC target at UNISOR.

RIB Injector Operations and Development

During this reporting period, we delivered the following neutron rich beams to the Recoil Mass Spectrometer (RMS) in Robinson Hall using the uranium-carbide-target-electron-beam-plasma ion source:

Isotope	Intensity (ions per second)	Contaminant Intensity (ions per second)	Energy (MeV)	Charge State
^{78}Ge	4.5×10^5	1.1×10^6	174.5	11
^{80}Ge	1.8×10^5	1.6×10^6	179	11
^{134}Te	1.7×10^6	7.2×10^5	396	16
^{134}Te	3.9×10^5	1.6×10^5	530	14/26
^{134}Te	1.8×10^5	7.5×10^4	560	15/28
^{136}Te	2.5×10^5	2.5×10^5	396	16
^{138}Te	not observed	1.9×10^6	396	16

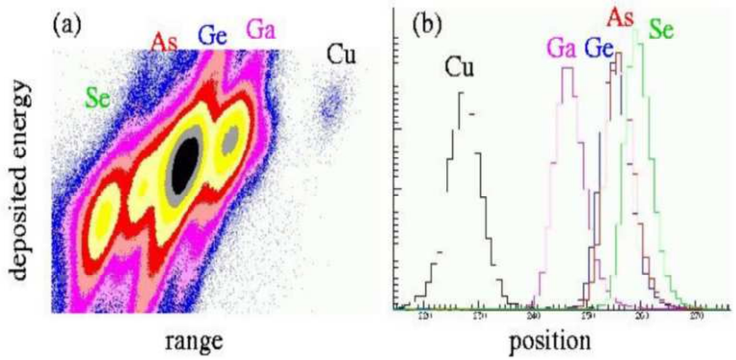
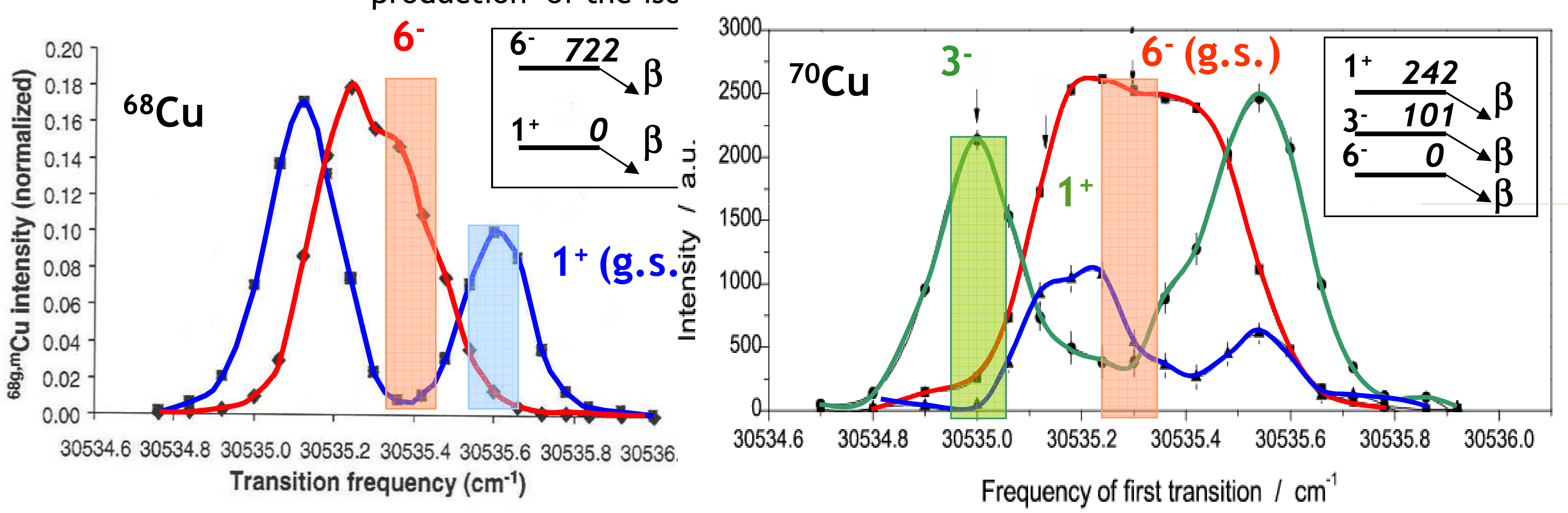


Figure 4-2: (a) Ion chamber range vs. deposited energy used to identify Z for the A=78 mass. measurement. (b) Position measurement in the MCP where position has been determined element by element. Peaks are normalized to the same area, and do not represent the actual relative intensities.

Importance of tagging system

Learning from others: Isomeric beams @ ISOLDE

- technique based on in-source laser spectroscopy (U. Köster et al., NIM B160, 528 (2000), L. Weissman et al., PRC 65, 024315 (2000))
- set the **laser frequency** to select and maximize the production of the isomer of interest



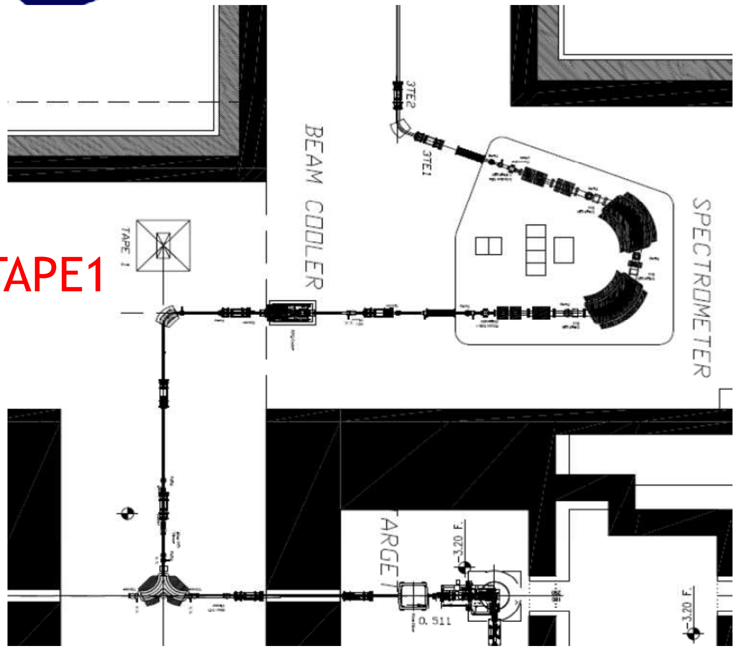
γ-Spectroscopy with Cu isomer beams: I. Stefanescu et al. PRL **98**, 122701 (2007), E. Rapisarda et al. PRC **84**, 064323 (2011)

The resonant laser-ionization technique employed in this work proved to be a very efficient and selective method for producing neutron-rich Cu beams, as no isobaric contaminants other than Ga were present in the beams. The amount of Ga isobar in each of the beams of interest was determined.

Scientific program:

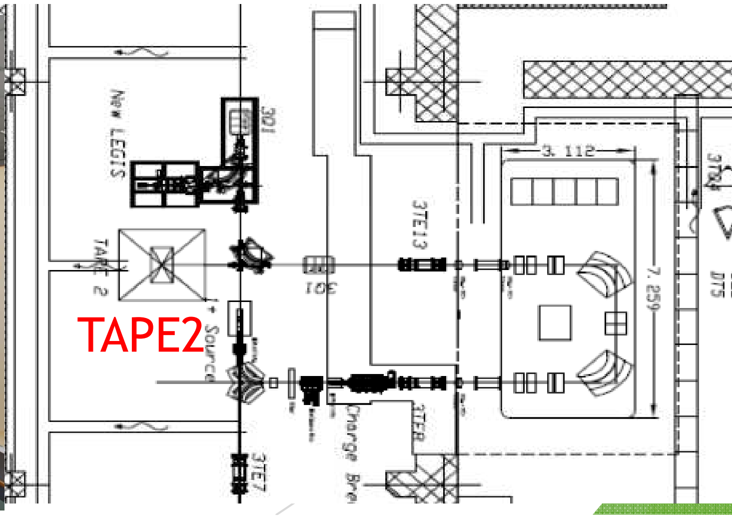
Characterizarion & β-decay study

TAPE1



- ▶Some **Tape Station systems** for radioisotopes identification are under development @ SPES.
- ▶The tape system can be associated to the target-source system comprehensive of the first selection stage, allowing the measurement and the characterization of the implanted radio-isotopes even down to low intensities.
- ▶The irradiated zone is transferred in front of the Ge-detectors for γ-ray counting, while a new implantation can take place over a new region of the tape.

One of these stations is foreseen to be implemented for β-decay studies with non accelerated beams



TAPE2

BEAMS Table → User Information for LoI

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- Reformulate a TABLE to provide **more complete** info to users with the prediction of :
  - RIB Currents (low, medium & high proton current on UCx and other targets like B_4C and SiC) → new simulations → scaling for efficiencies considering more specific parameters (efficiencies, life times, decay chains) for every isotope
  - possible contaminants and relative predicted yields → **GEANT4/FLUKA + MathLab upgraded framework**
  - Comparison with previous facilities (**ISOLDE, HRIBF, ALTO, iTHEMBA**) → literature search, collaborations

i.e. specific Charge Breeder efficiencies

Mass Range			ION	Q	Efficiency [%]	Year Data Source	(M/q)_min	(M/q)_max
		138	Xe	20+ (21+)	10,9 (6,2)	2012 (2005)	6.57	6.90
130	132	134	Sn	21+	6	2005	6.19	6.38
		98	Sr	14+	3.5	2005	7	7
		94	Kr	16+(18+)	12(8,5)	2013	5.22	5.88
90	………..	99	Y	14+	3.3	2002	6.43	7.07
74	………..	80	Zn	10+	2.8	2002	7.40	8.00
	81	82	Ga	11+	2	2002	7.36	7.45
90	91	92	Rb	17+	7.50	2013	5.29	5.41
		34	Ar	8+(9+)	16,2(11,5)	2012 (2013)	3.78	4.25

… & … Source Ionization efficiencies …

especially → Laser ionization efficiencies … etc.

See later M. Comunian talk

See later A. Andrighetto talk

1st Meeting of the Technical Advisory Committee
22-23 January 2014

INFN
Istituto Nazionale
di Fisica Nucleare

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THANK YOU

See later P. Favaron talk

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