Beta Decay Spectroscopy at SPES

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Outline:

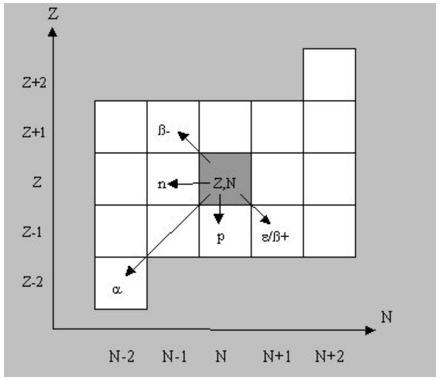
- Beta decay and n-rich nuclei
- decay station and ancillaries
- LOI presented

SPES
exotic beams for science

INFN
Istituto Nazionale
di Fisica Nucleare

Beta decay: survey of general properties

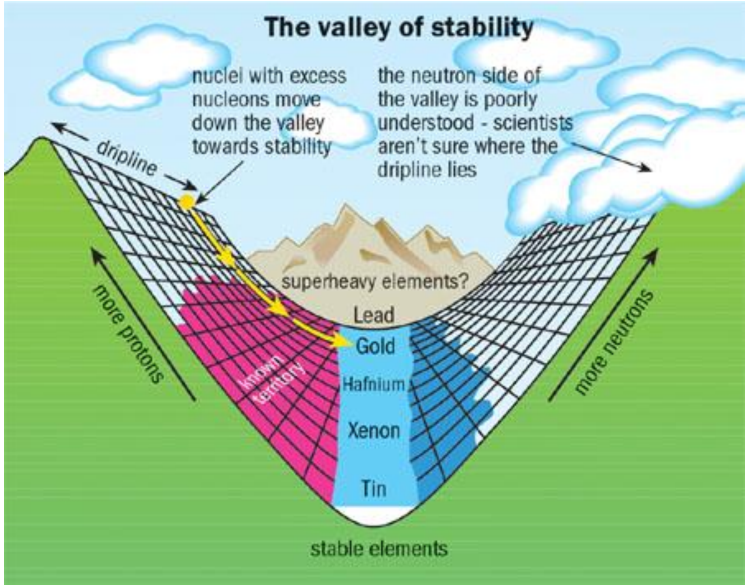
- β^- decay is the most common type of radioactive decay
  - β^- decay
  - β^+ decay
  - Electron capture (EC)



reasons to study beta decay:

- Access to gross information on the decay, Half-life, Pn etc.
- First information on excited states far from stability
- Spin assignment owing to selection rules
- Access to non-yrast states
- Definition of shapes
- Connection to mass measurements
- Input for astrophysics and reactor heat calculation….

……many more…



Exotic nuclei → exotic properties

* Changes in magic numbers

* Many new effects arising at small changes in nuclear configuration:
- deformations
- change in levels sequence
- collectivity
- isomerism and loss of isomerism
- monopole drift
- proton core excitations
- proton intruder isomers

…

Shell model calculations need to include a large valence space to describe all effects

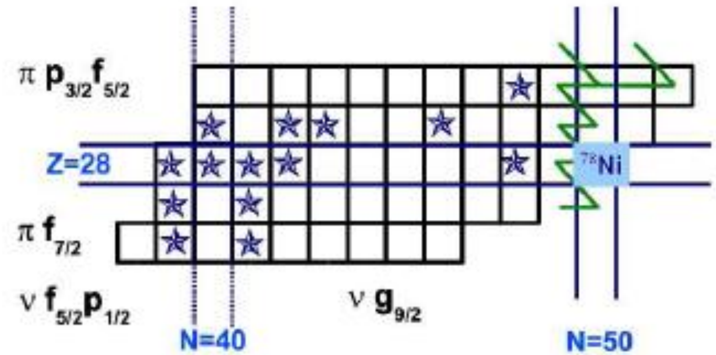
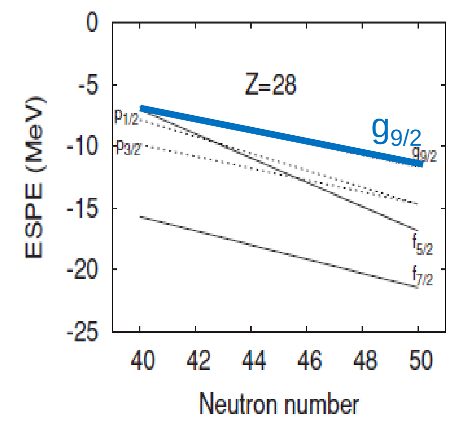


Fig. 1. Fragment of the chart of nuclei around ^{68}Ni and ^{78}Ni with selected known microsecond isomers observed using ^{86}Kr fragmentation [7, 10, 11, 30].

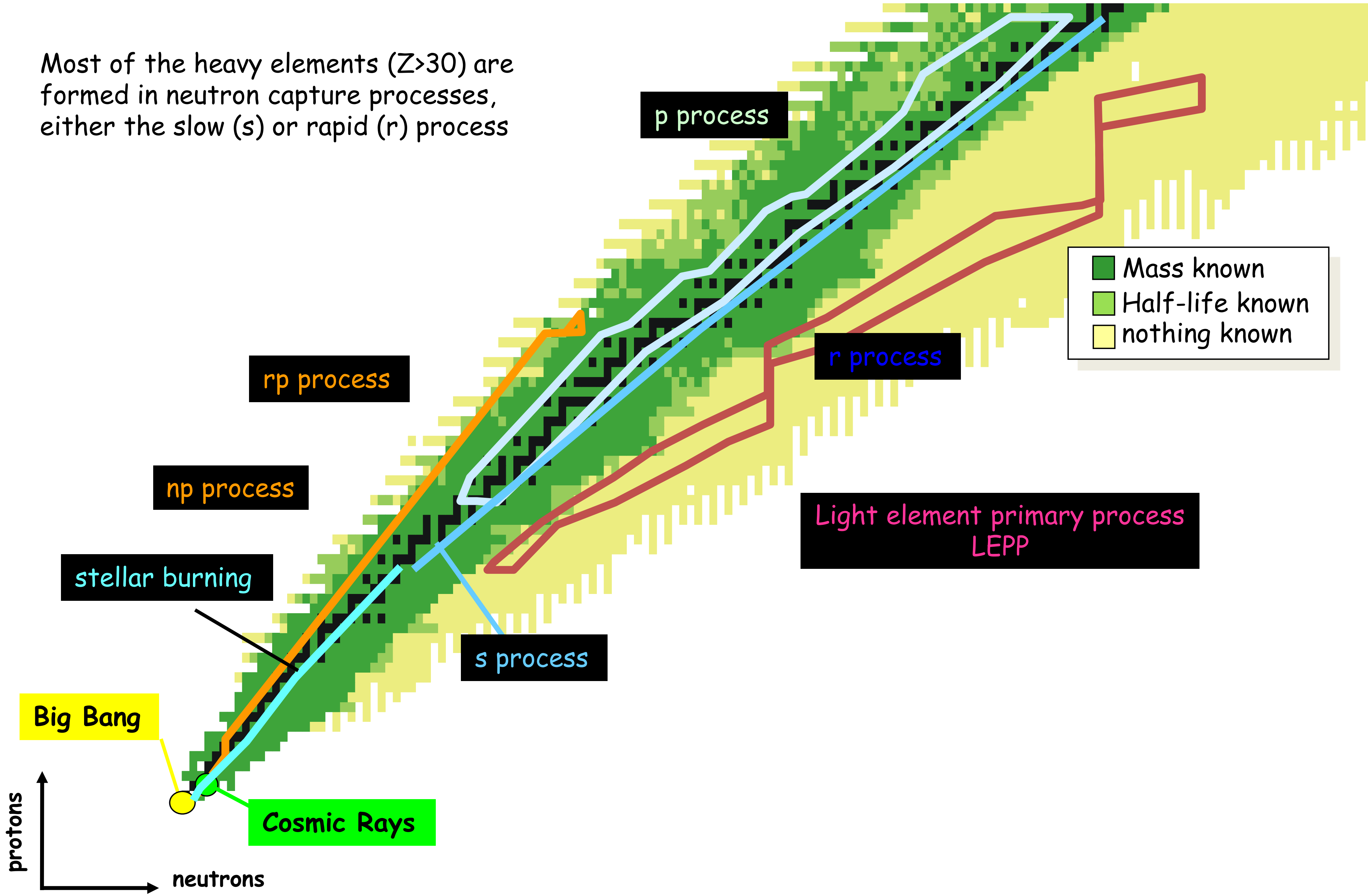


N=40 sub-shell closure

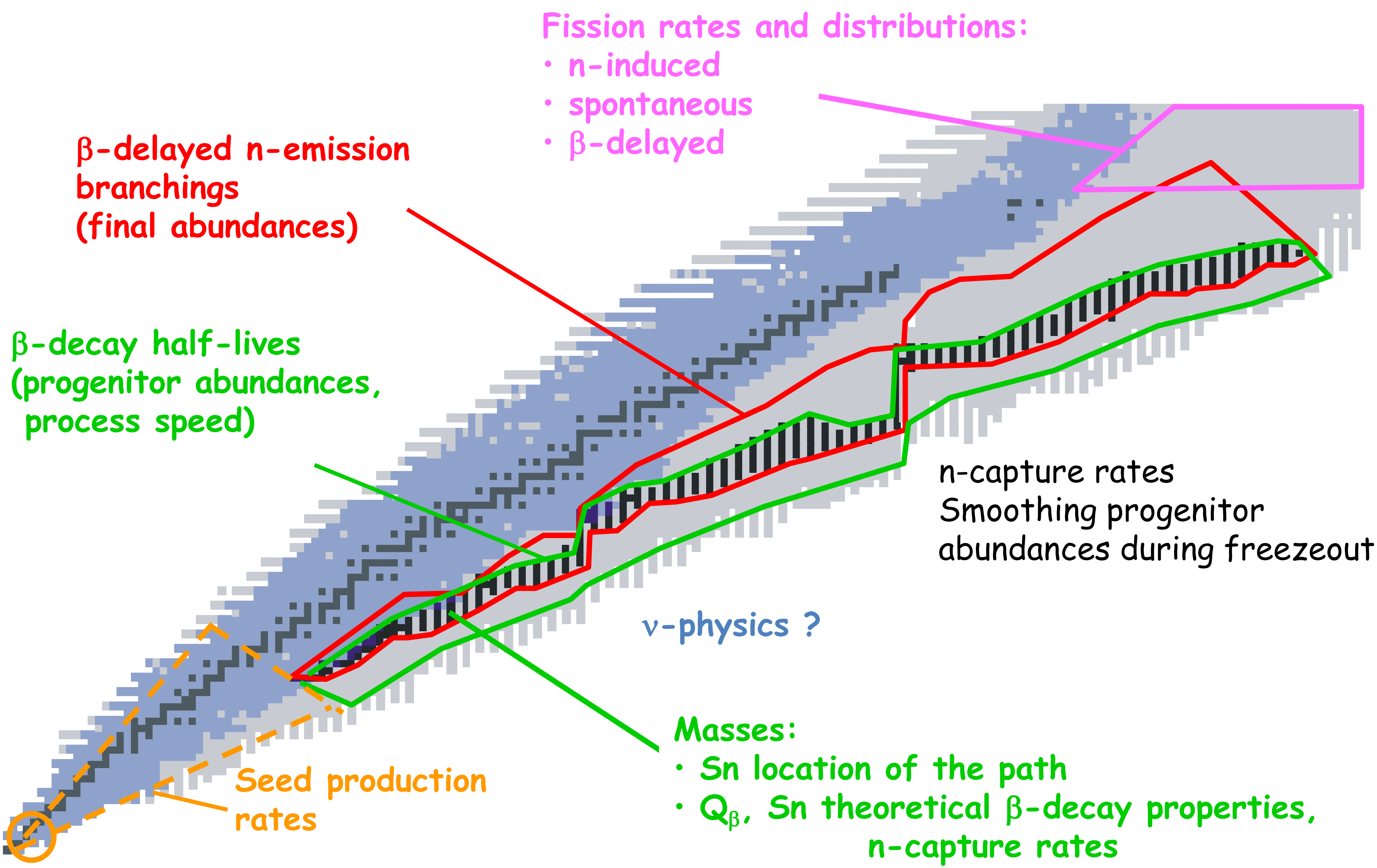
K.Sieja and F. Nowacki, PRC 81, 061303 R (2010)
R. Grzywacz et al., Eur. Phys. J. 25, 89 (2005).

Nucleosynthesis

Most of the heavy elements (Z>30) are formed in neutron capture processes, either the slow (s) or rapid (r) process

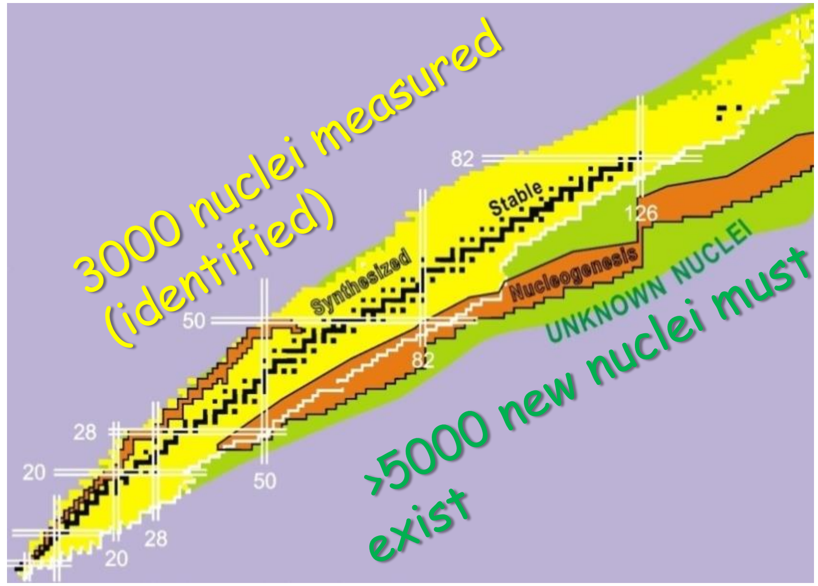


Nuclear physics in the r-process

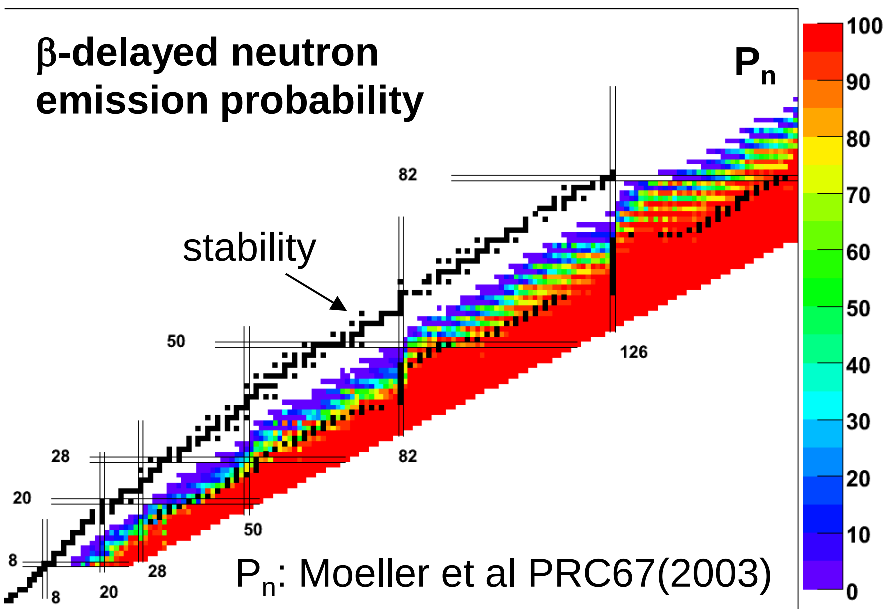


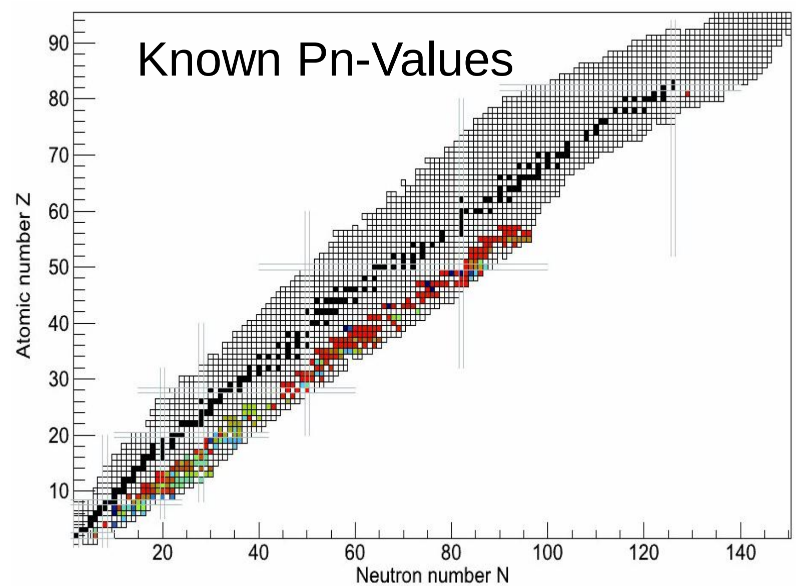
Beta-delayed neutron emission

The knowledge we have on nuclear structure and dynamics is based on about 3000 nuclei, whereas still more than 5000 new nuclei must exist.



Almost all these new nuclei are expected to be neutron emitters, and hence, an understanding of this property and the involved technique becomes of pivotal impotance for NS and future studies.

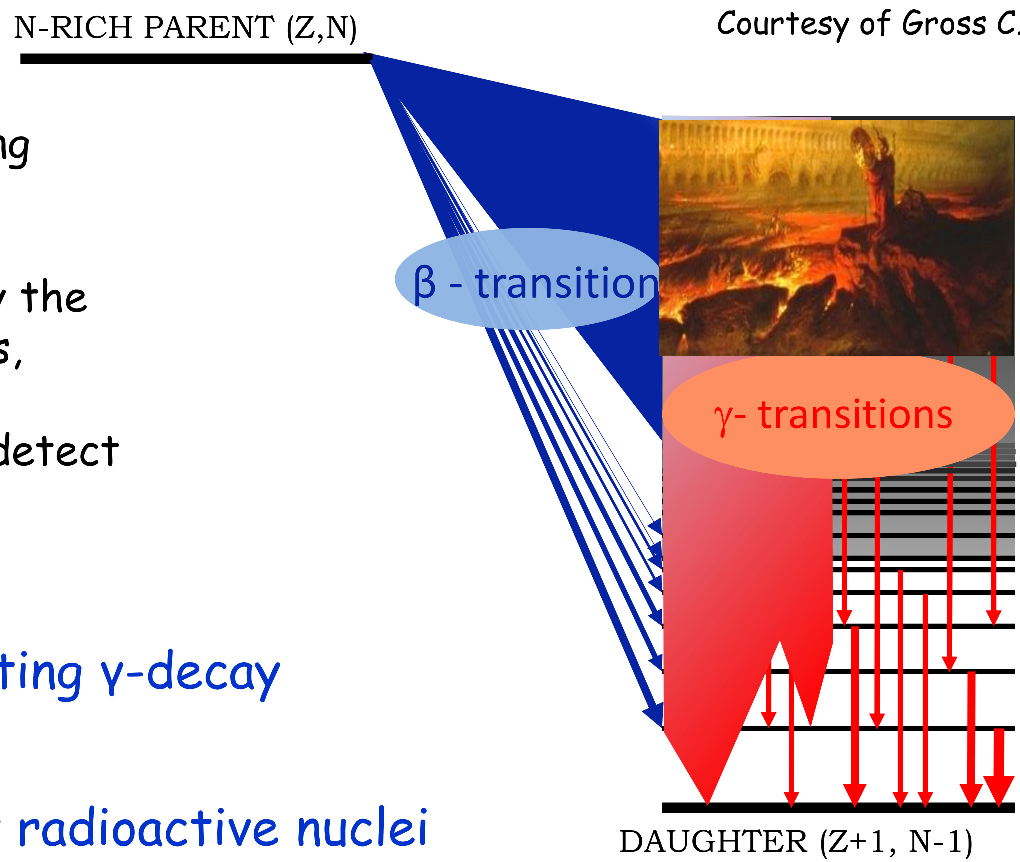




• Practically all NEW nuclei, are expected to be neutron emitters!

Beta spectroscopy: true scenario

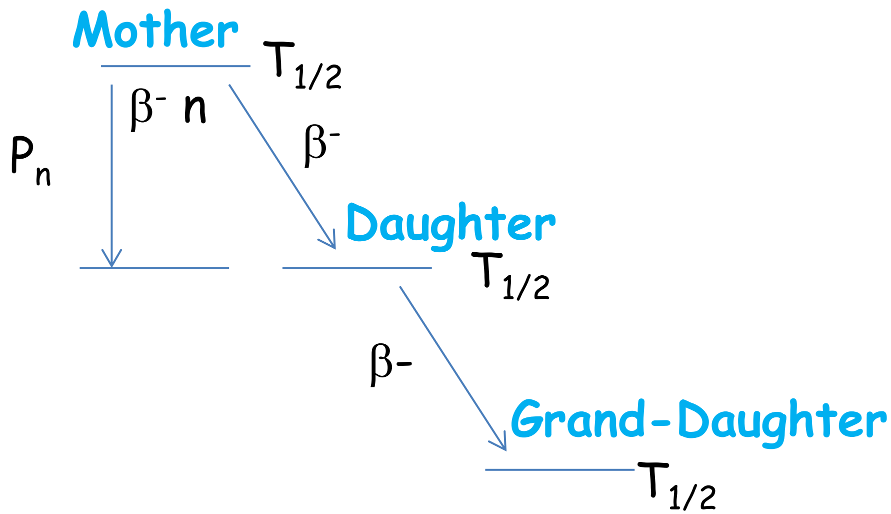
- β-transitions (mostly Gamow-Teller) are feeding highly excited states,
- these many, weak β-transitions are followed by the cascades of γ-transitions in the daughter nucleus,
- these weak γ-transitions are very difficult to detect with radiation detectors with low efficiency

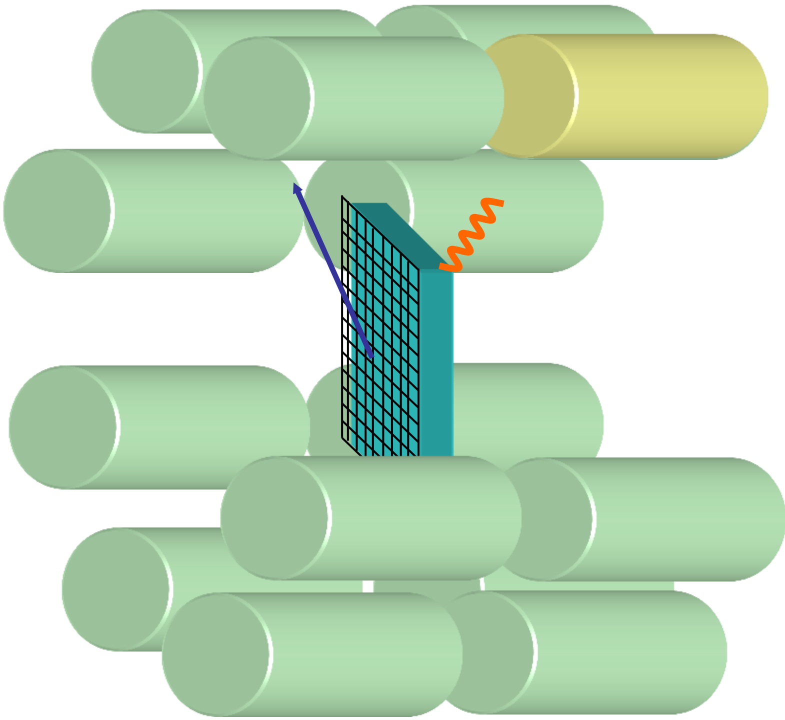


- to determine a true β-feeding and resulting γ-decay patterns (nuclear structure),
- to determine a “decay heat” released by radioactive nuclei produced in nuclear fuels at power reactors,

Total absorption γ-spectroscopy, TAS measurements

Beta spectroscopy: experimental technique





Basic principle:

- Detect Mother nucleus implantation
- Correlate succeeding beta emission
  - ➔ measure HALF-LIFE ($T_{1/2}$)
  - ➔ measure delayed GAMMA EMISSION, spectroscopy of daughter nucleus

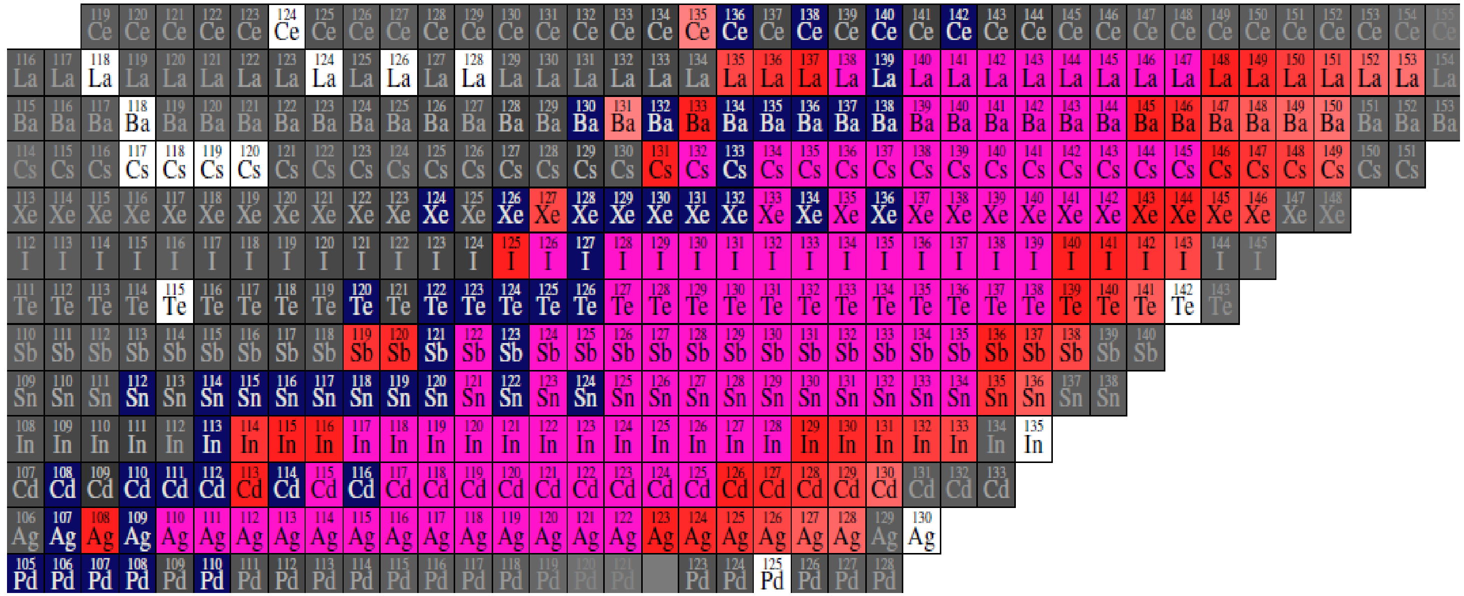
Tape system + Plastic/Si surrounded by HPGe + additional detectors (LaBr3, Neutron det.) or Total Absorption Spectrometer

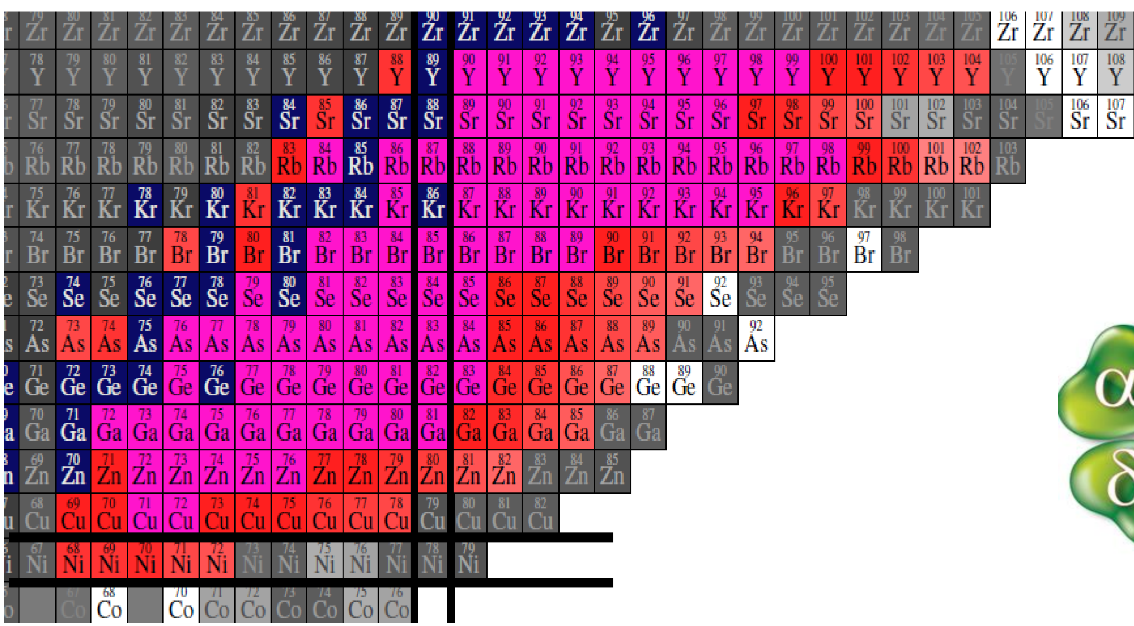
Moving tape system: long and short living radioactivity…2 possible measuring points

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)





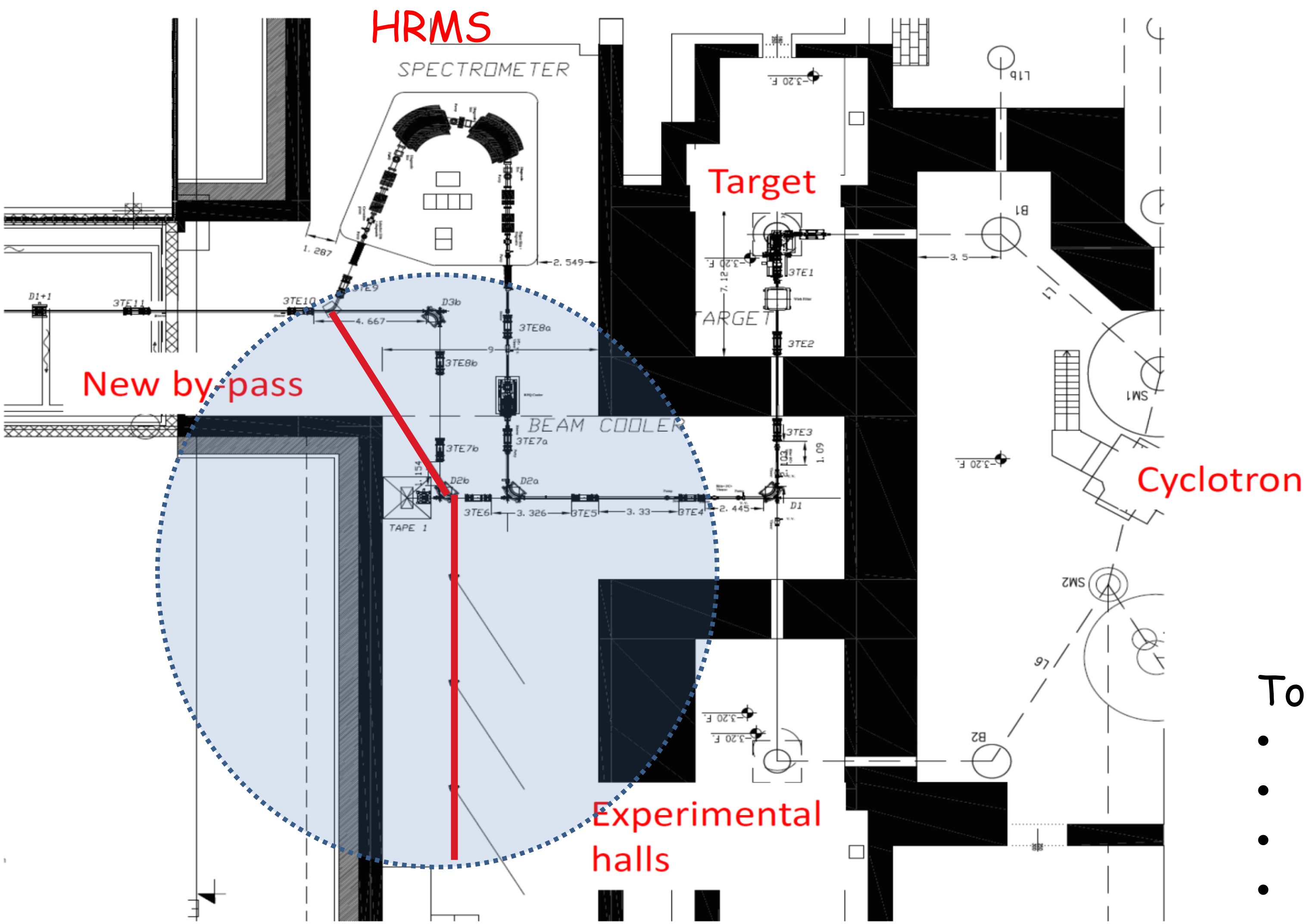
SPES beams after Ion Source

- 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

Courtesy of F.Gramegna

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

New experimental halls



To be defined:

- Shielding
- Access to area
- LN2 lines
- Separation of different exp. areas

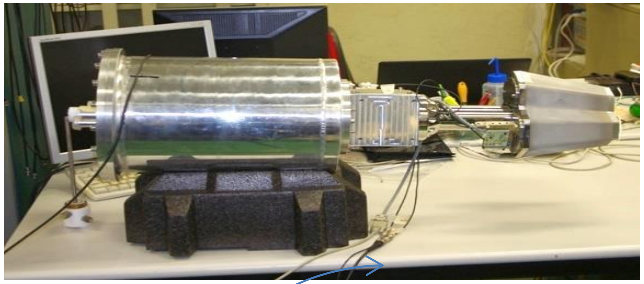
Courtesy of M. Comunian

In-house equipment

GASP coaxial HPGe det.
With new AGATA-like electronics:

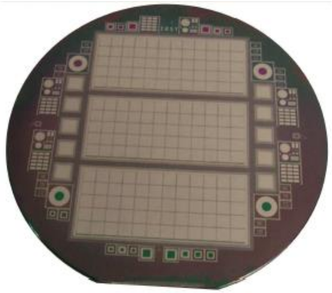
- Preamplifiers
- digital sampling
- Preprocessing
- DAQ

Newly refurbished triple CLUSTER det.

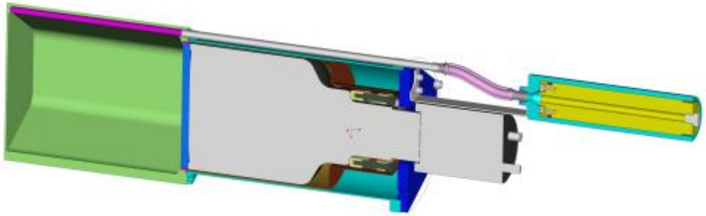


Possible ancillary detectors:

* HPGe Clover/Cluster detectors
* GALILEO coaxial detectors
* Modified NEDA Neutron detectors
* TRACE Silicon detectors
* Fast responding LaBr3 det. For fast time measurements
* Large volume $LaBr_3/BaF_2$ for TAS



- 200 μm thin dets: ~2 nA (10 V FD)
- 1.5 mm thick dets: ~50÷500 nA (200 V FD)



Beta decay spectroscopy at SPES

Activities already proposed via LOIs

C. Gross (ORNL, USA): ***Nuclear Structure of neutron-rich nuclei determined through beta decay spectroscopy of fission fragments***

T. Kurtukian-Nieto (CENBG and University of Bordeaux, France): ***Measurement of the decay characteristics of nuclei around A=90 relevant to r-process nucleosynthesis***

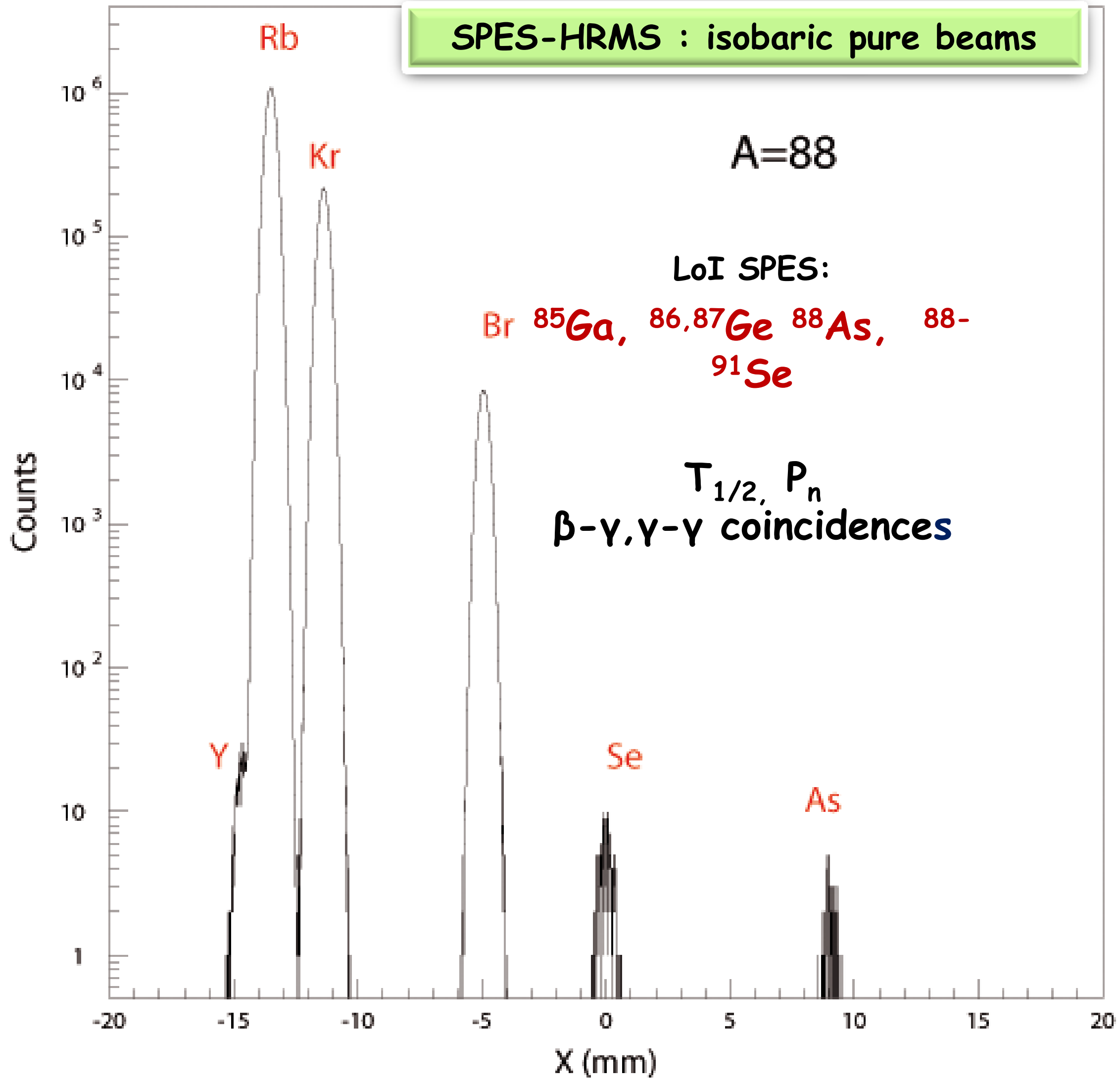
Gottardo (IPN, Orsay, France): ***Neutron Decay Spectroscopy at SPES***

With contribution from:

B. Rubio (IFIC, Valencia, Spain): ***Beta decay studies using the gamma Total Absorption Technique at present and future facilities: A personal point of view***

Overproduction of stable Sr, Y, and Zr in some UMP, compared to the SS r-process

SPES-HRMS : isobaric pure beams



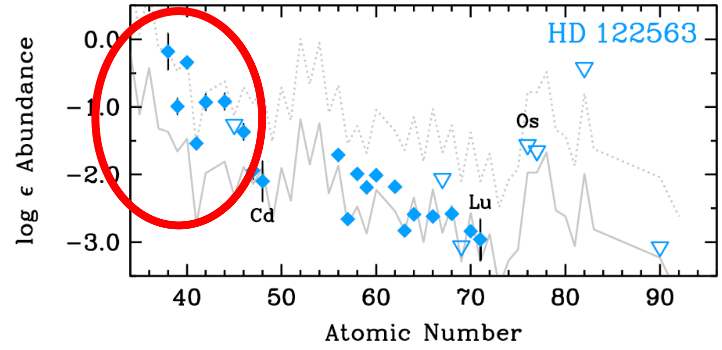
LoI SPES:

Br ^{85}Ga, ^{86,87}Ge ^{88}As, $^{88-91}$Se

$T_{1/2}$, P_n

β-γ,γ-γ coincidences

If a N = 56 "ladder" the β decay of ^{88}Ge, ^{89}As, and ^{90}Se would immediately translate into an enhanced production of Sr, Y, Zr.



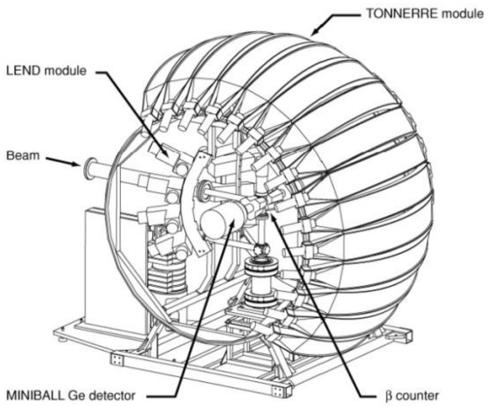
A. Gottardo :
A Letter of Intent for Neutron-Decay Spectroscopy at SPES

* investigate the discrete states and the resonances above the neutron separation threshold in neutron-rich nuclei.
The states of interest will be populated by beta decay with a high Q value.

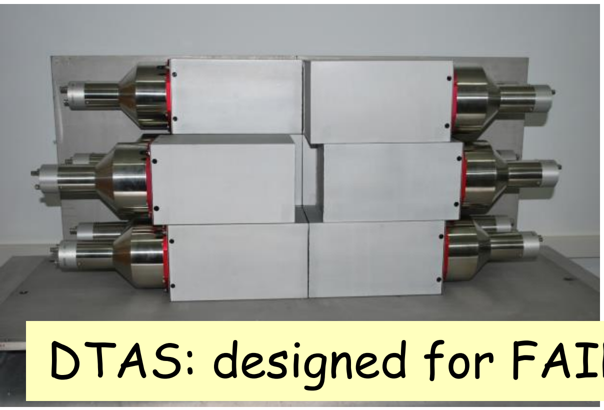
* population of collective resonant states at high excitation energy (>9 MeV).
The decays with sufficiently high Q values (> 10 MeV) could populate the Pygmy Dipole Resonance in selected physics cases, where the spin and parity of the mother nucleus do not disfavor the population of such states in the daughter nucleus.
The spin and parity of the decaying nucleus will also determine the component of the PDR which could be excited.
In some cases, there could be a direct excitation of ground-state dipole-excited modes (for example 1- states in even-even nuclei)
of the daughter isotope, while in other cases a population of the PDR built on the isobaric analog state (IAS) is more favorable.

Tonnere, VANDLE neutron arrays

ε: 12 %; σ: 120 keV (1 MeV)

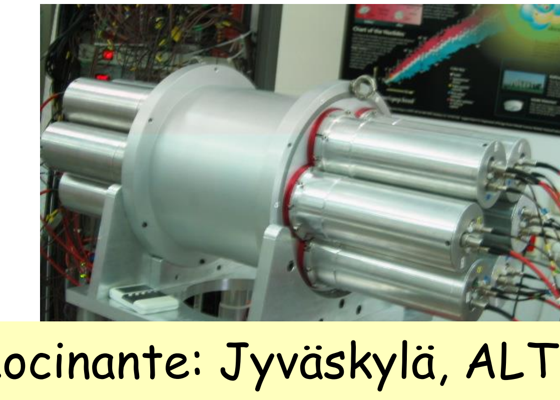


B. Rubio **TAS measurements**



DTAS: designed for FAIR

Lucrecia: Isolde, permanent



Rocinante: Jyväskylä, ALTO.

(Similar efforts at USA)

TAS is an essential tool for precise measurements of beta-decay strength functions B(GT)

The technique is well known and can be applied to any Isol facility provided
Isotopic and isobaric separation exists.

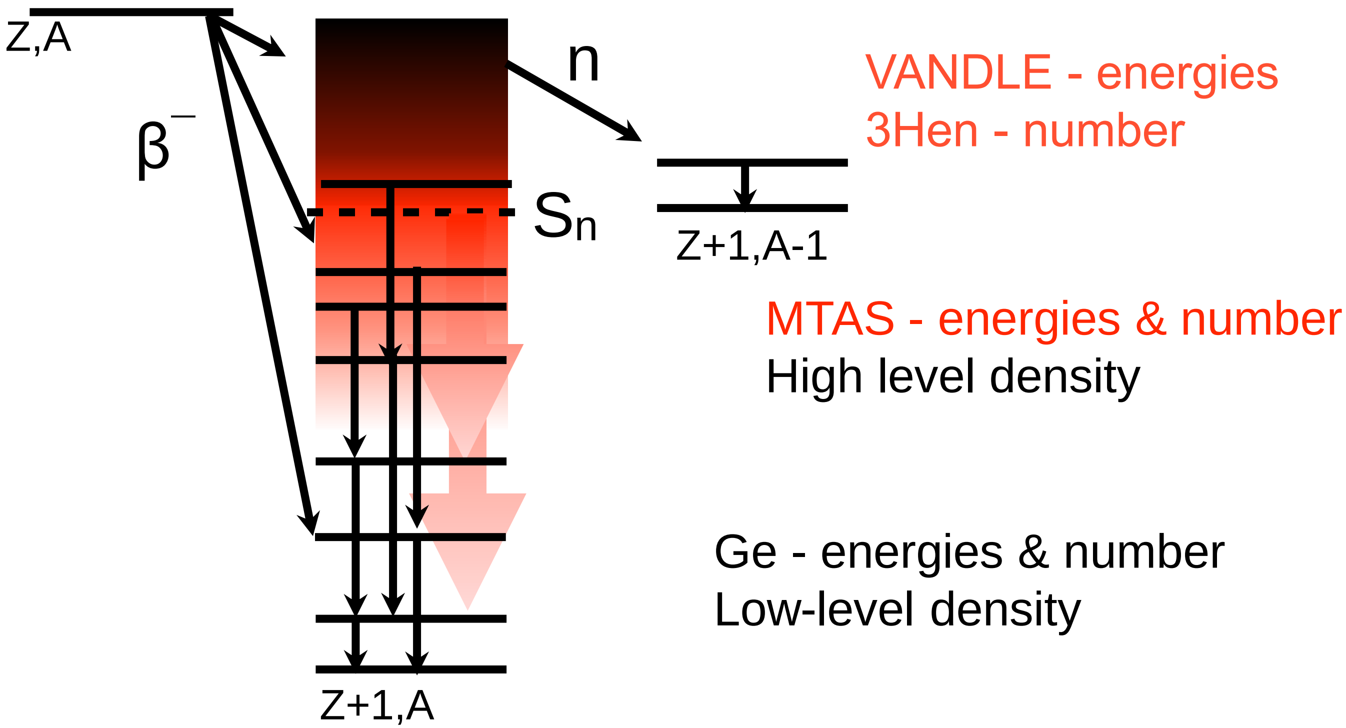
Experiments are proposed at the European Isol facilities (Jyväskylä, Isolde and ALTO)

LoI´s at Spiral II and RIKEN.

This workshop is timely and appropriated to study the opportunities at SPES

C. Gross (ORNL, USA):

Nuclear Structure of neutron-rich nuclei determined through beta decay spectroscopy of fission fragments



Beams from SPES will be of high purity thanks to the 70 MeV production energy and the high resolution mass analysis. **These beams will enable a world class decay spectroscopy program and a collaboration with researchers from the former HRIBF can bring modern state-of-the-art detector systems** for beta decay experiments and beam production techniques to SPES. The exotic isotopes to be studied will impact r-process simulations, nuclear structure theory, and nuclear energy applications

Conclusions:

Beta decay studies in exotic nuclei:

- A good tool to access first info on nuclei
- Strong correlation with nuclear astrophysics (nucleosynthesis)
- Long- assessed techniques to study gamma and neutron decay branches

- No need for post-acceleration
- Already identified suitable area and collaborations are being defined

- Try to use in-house equipment

- 3 LOI from external groups already submitted (withou setup definition)

- ➔ support from community

- Experimental areas to be defined, with possibility of other set-ups for egs. Mass measurements

- Commissioning with **5** μA proton current on UCx → authorization already got to operate.

- HRMS required for most cases. To define which can run wothout

SPES Beams & Priorities

1. Use of higher currents on different carbides → SiC & B_4C
2. A/q between 4 & 7 (Charge Breeder – RFQ- present ALPI Configuration) → upgrading forseen as second priority depending on user requests
3. Accelerated beams currents safe vaues > 10^4 pps
4. All isotopes are easily obtained with PIS – but strong contamination which has to be evaluated for each requested ion → needs of *experimental tagging*
5. Cs and Rb are contaminants which are always present when using SIS and LIS. They can be eliminated by the Wien filter for isotopes far from their masses.
6. HRMS at present not in the budget → its employement is necessary in some cases (PIS source) but → reduction of RIB intensity → its use depend on *specific request* of user/experiment
7. Only few elements available at the beginning with LIS → need of development for each element → *specific request* to the target groups (Andrighetto)