Beta Decay Spectroscopy at SPES

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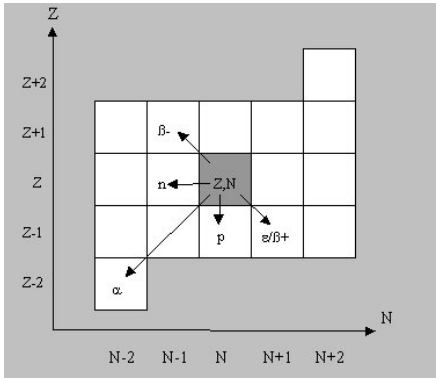
Universita' degli Studi di Milano, Padova, Firenze

Outline:

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

Beta decay: survey of general properties

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

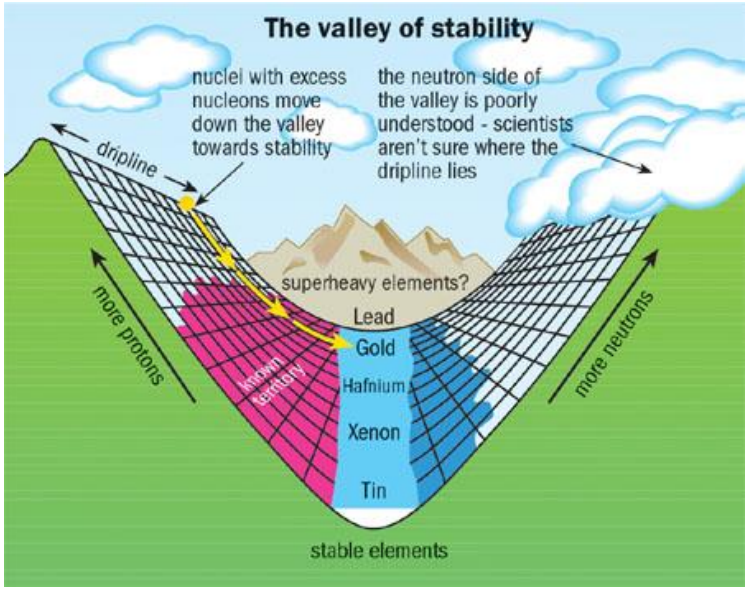


reasons to study beta decay:

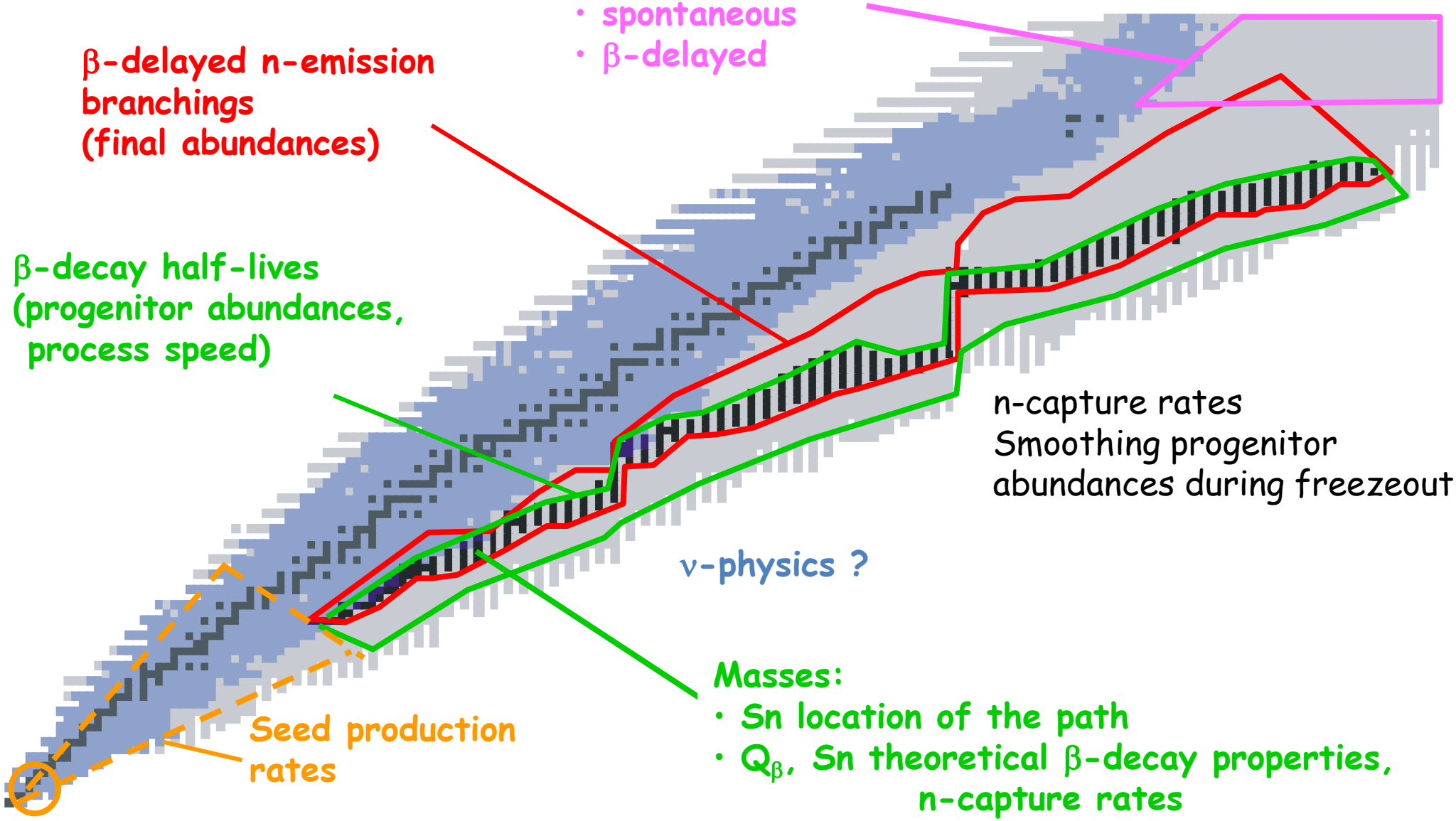
- Access to gross information on the decay, half-life, Pn, branching to other decay modes.
- Input for astrophysics and reactor heat calculation….

……many more…

- 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

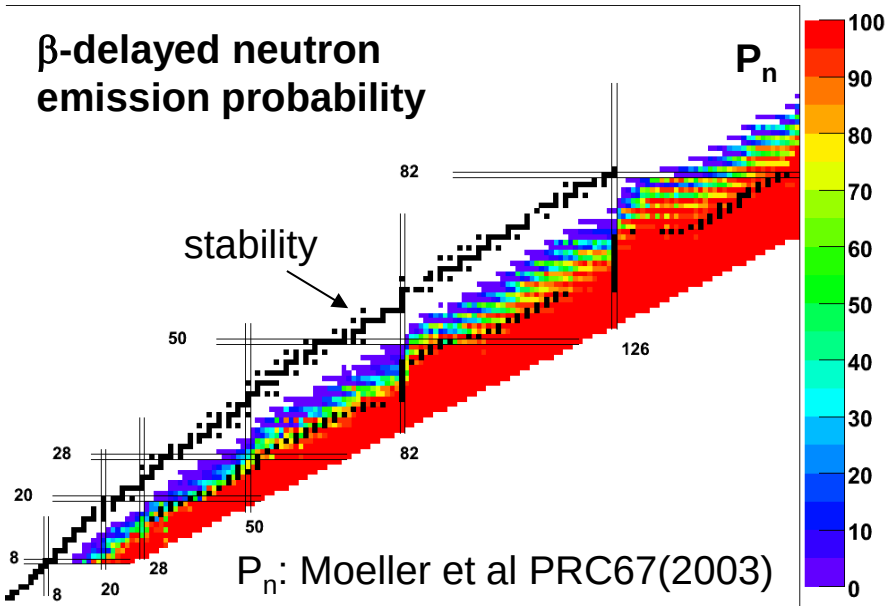


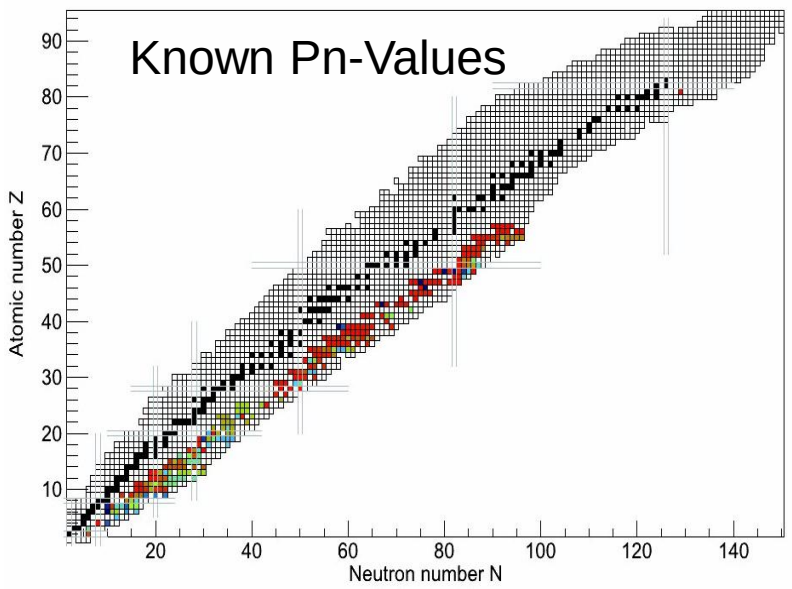
Nuclear physics in the r-process



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.



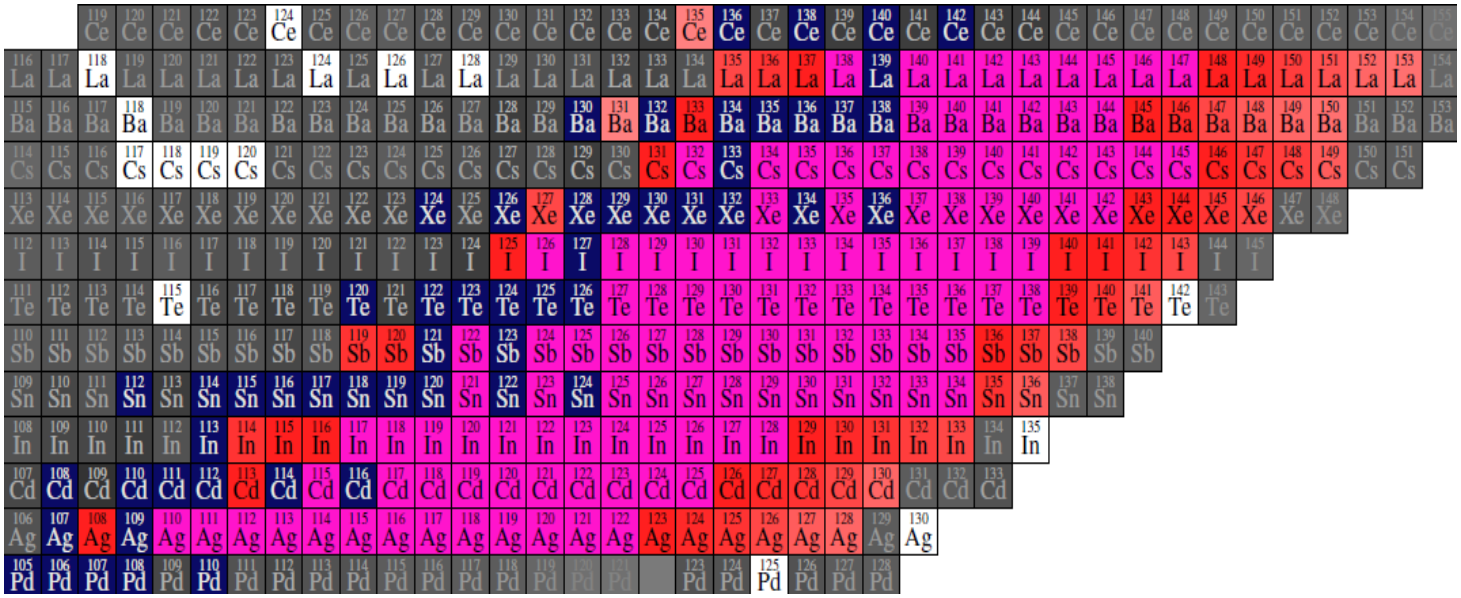


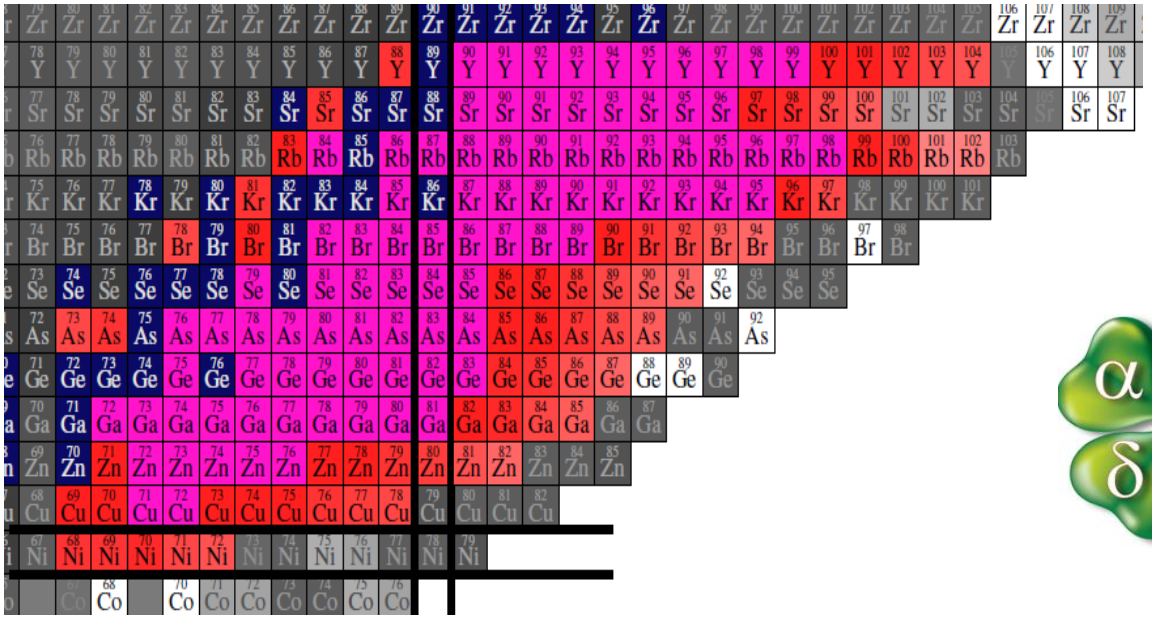
- Practically all NEW nuclei, are expected to be neutron emitters!

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

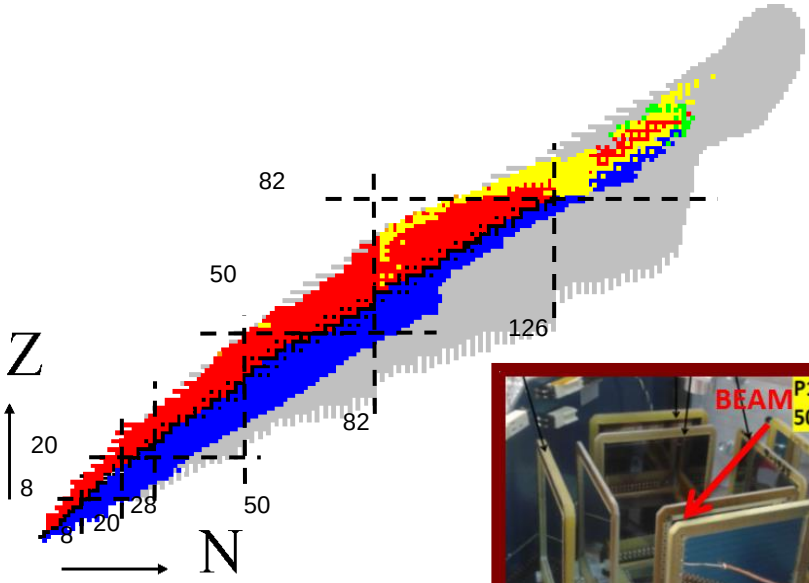
- 10^7-10^9 pps
- 10^6-10^7 pps
- 10^5-10^6 pps
- 10^4-10^5 pps
- 10^3-10^4 pps
- 10 -10^3 pps
- 0 -10 pps

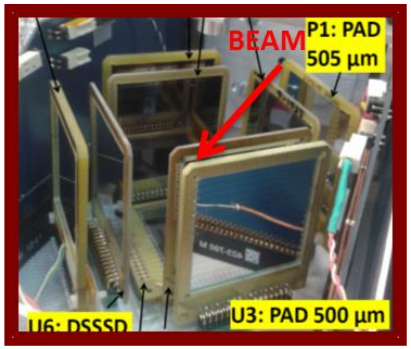
Courtesy of F.Gramegna

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

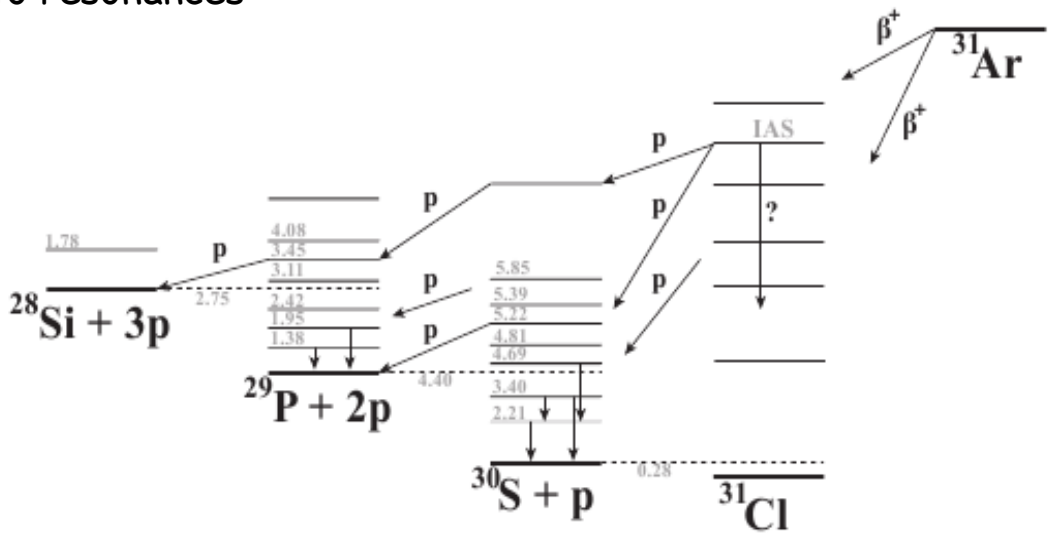
Studies of β-delayed one-two-many-proton emission

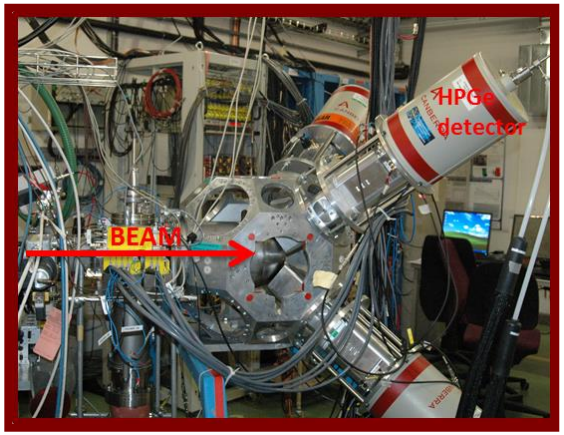
- a number of neutron-deficient isotopes was produced in the rapid proton capture (rp process), which involves very neutron-deficient areas on chart of nuclei.
- Theoretical reconstruction of these processes is hindered by the lack of relevant nuclear data.
- Masses, half-lives, branching ratios, and beta-delayed particle emission probabilities belong to those of special interest.
- these values can be determined from radioactive decay studies.





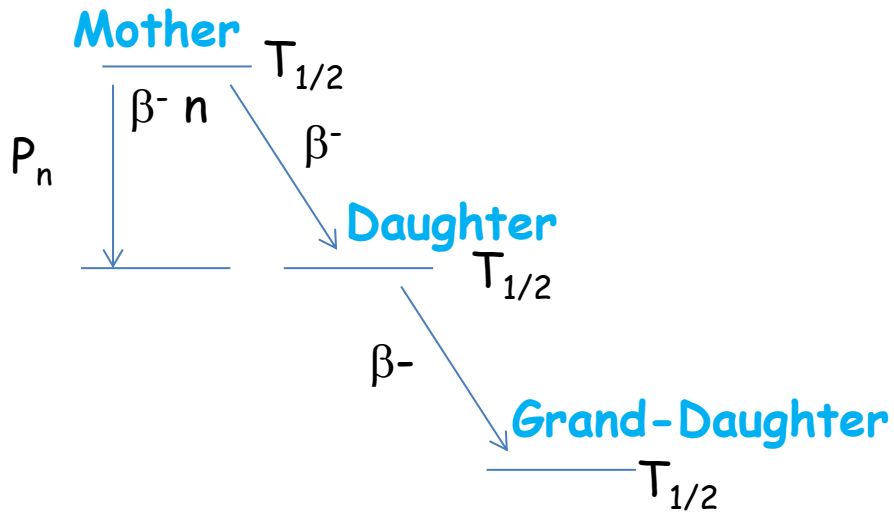
- **β-delayed 1/2/3..-p-decay branch**
- Information on the resonances in particular the ratio between the proton and γ partial widths relevant for astrophysics
- First access to resonances

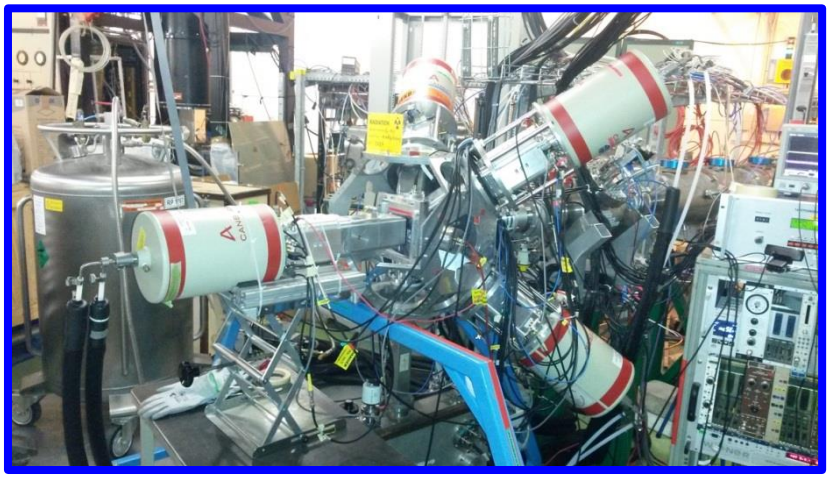


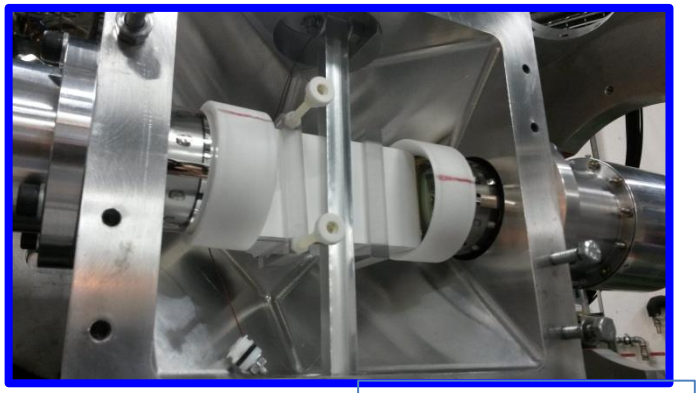


M.Pfutzner et al. Rev. Mod. Phys. 84 (2012) 567

Beta spectroscopy: experimental technique







IDS @ CERN

Basic principle:

- Define nuclear decay
  - ➔ measure HALF-LIFE ($T_{1/2}$)
  - ➔ measure delayed GAMMA EMISSION, spectroscopy of daughter nucleus

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

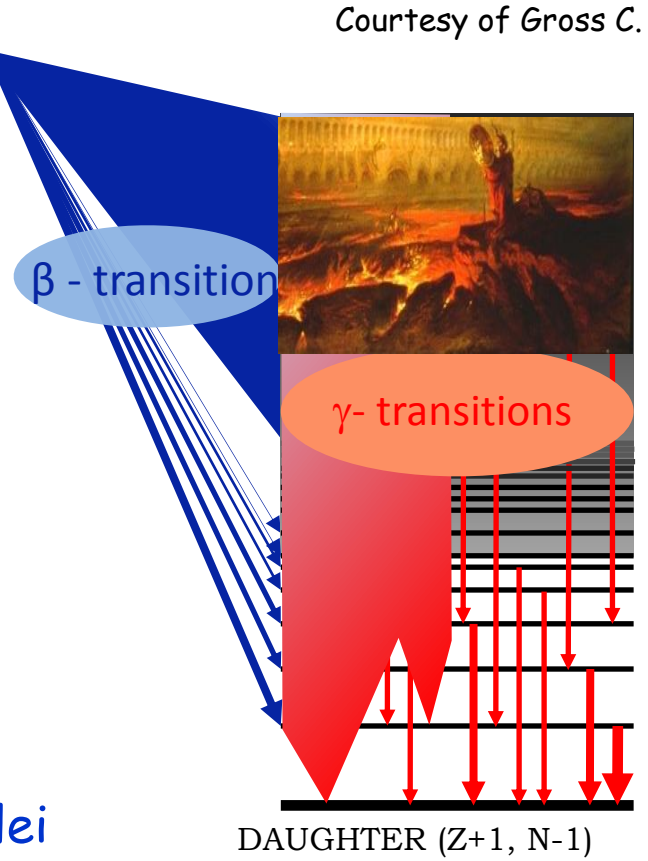
Moving tape system: long and short living radioactivity
COMPACT geometry ➔ high efficiency with few detectors

Beta spectroscopy: true scenario at high Q_β

β-transitions (mostly Gamow-Teller) are feeding highly excited states ➔ Pandemonium effect

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

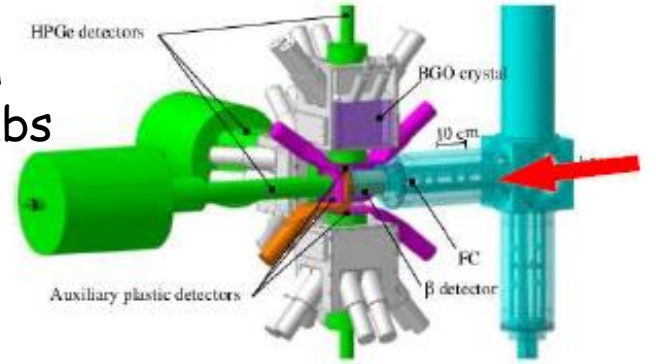
SPES Project

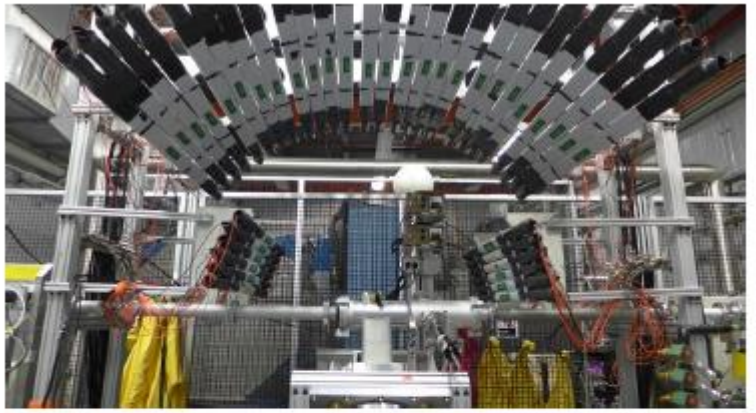
SPES one-day Workshop "Physics at SPES with non re-accelerated beams"

20-21 April 2015 *Milano*
Europe/Rome timezone

* Large positive response: 65 attendees
* Participants from Italy, CERN-Switzerland, Riken-Japan, Oak Ridge-USA, TRIUMF-Canada, Bordeaux-France, Orsay-France, Spain, Greece.
- 18 talks, 5 concerning LOI.

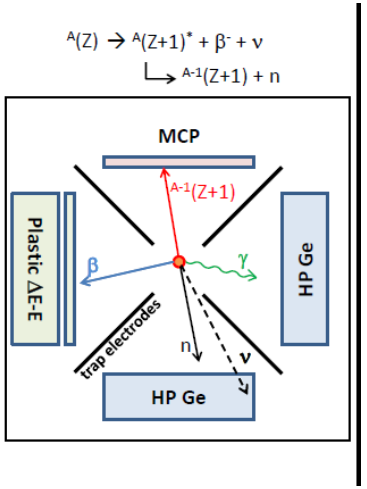
Close collaboration with ALTO and I-Themba Labs to design decay station





VANDLE = Versatile Array of Neutron Detectors for Low Energy

- Nuclear structure - beta strength above S_n
- Nuclear structure - energy "levels"
- Nuclear structure - Gamow-Teller vs forbidden transitions
- Nuclear astrophysics - r-process
- Nuclear energy - neutron energy spectrum



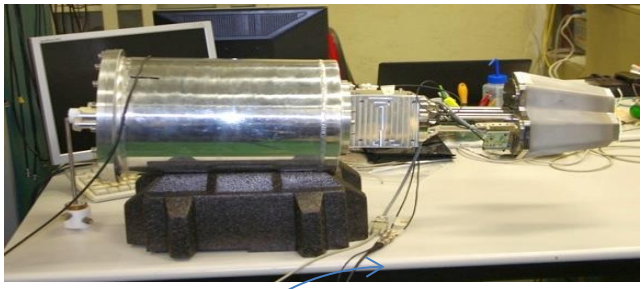
New techniques proposed
Egs. MR-TOF, Pauli Traps

In-house equipment

GASP coaxial HPGe det. Of GALILEO
With new digital electronics:

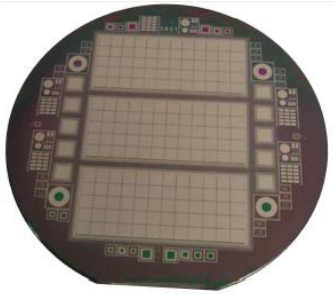
- Preamplifiers
- digital sampling
- Preprocessing
- DAQ

Newly refurbished triple CLUSTER det.

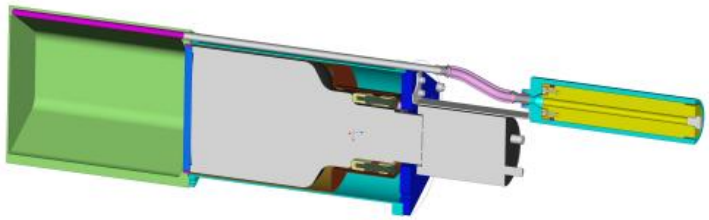


Possible ancillary detectors:

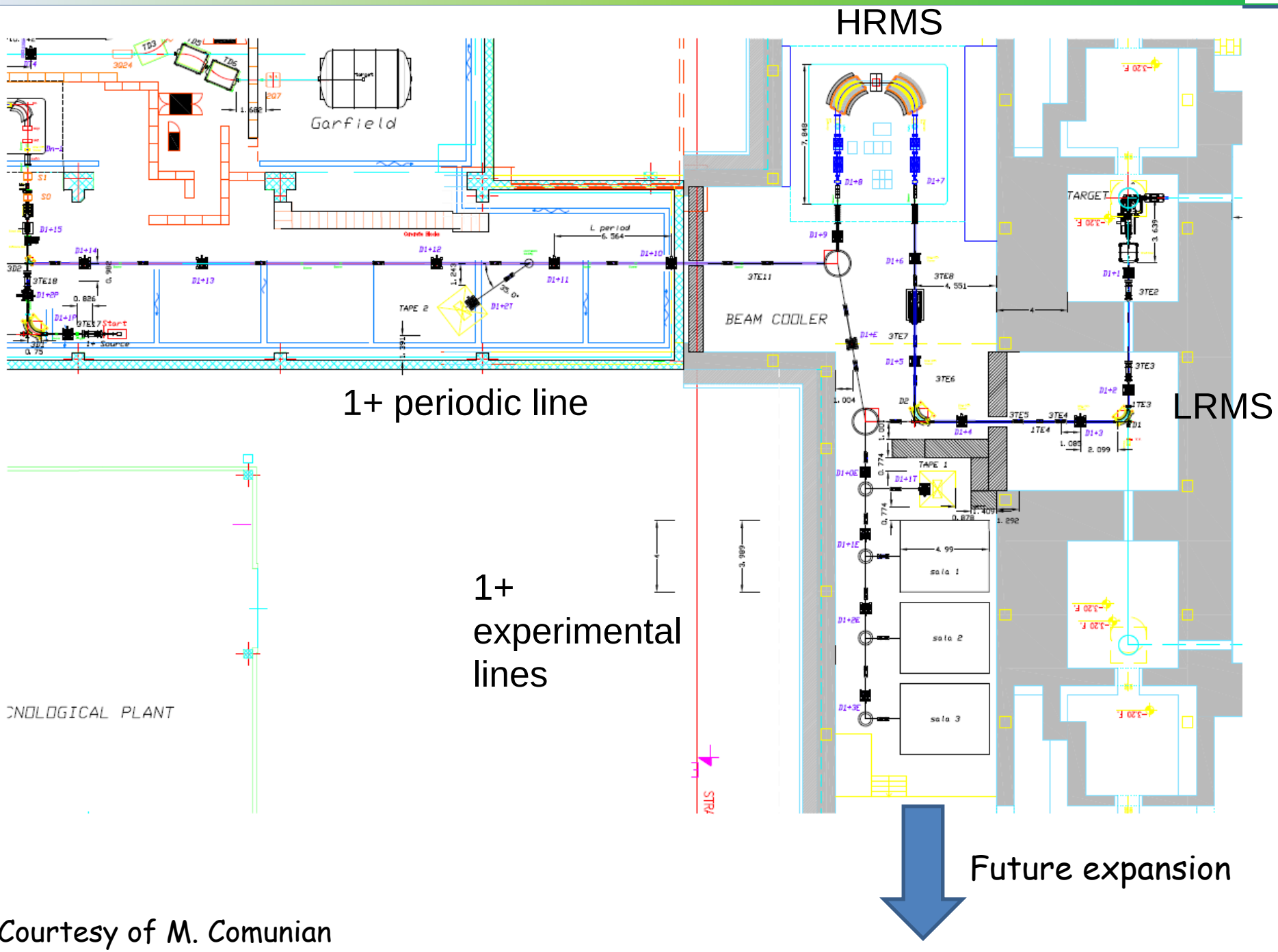
* HPGe Clover/Cluster detectors
* GALILEO coaxial detectors
* Modified NEDA Neutron detectors
* TRACE Silicon detectors
* Fast responding LaBr3:Ce det. for fast time measurements
* Large volume $LaBr_3/BaF_2$ for TAS



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



Experimental area 1+ lines SPES Layout



Courtesy of M. Comunian

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***

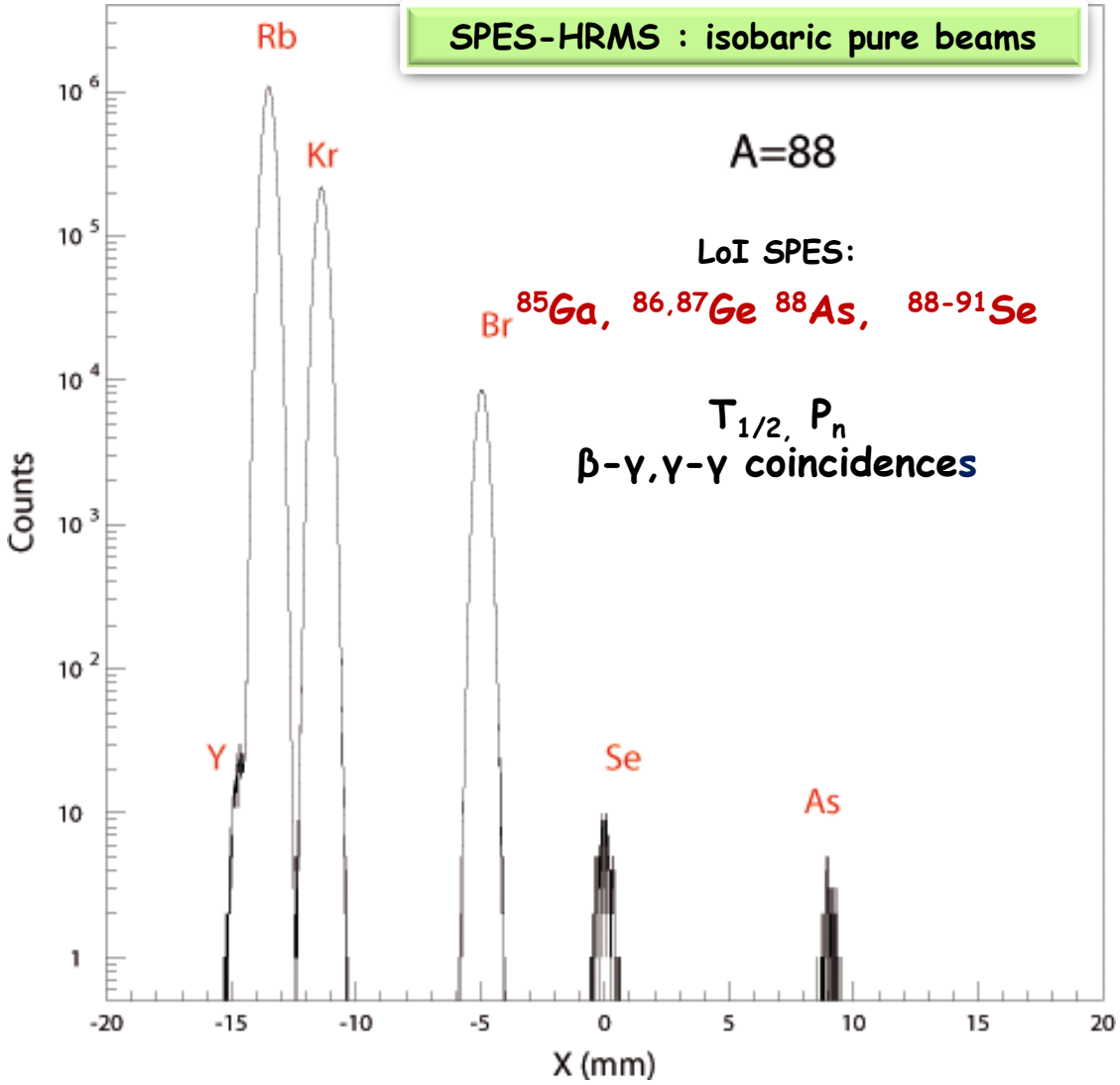
With contribution from:

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

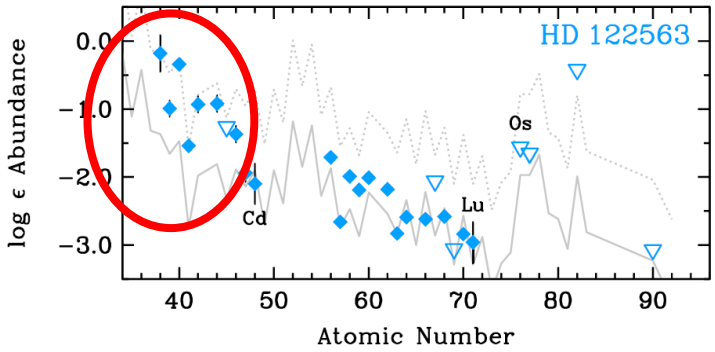
Measurement of the decay characteristics of nuclei around A=90 relevant to r-process nucleosynthesis

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

SPES-HRMS : isobaric pure beams



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.



* investigate the discrete states and the resonances above the neutron separation threshold in neutron-rich nuclei.

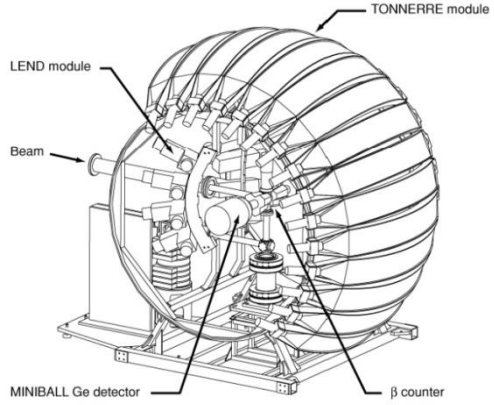
*The states of interest will be populated by beta decay with a high Q value.

* 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.

➔ **direct impact on photoabsorption cross-sections**

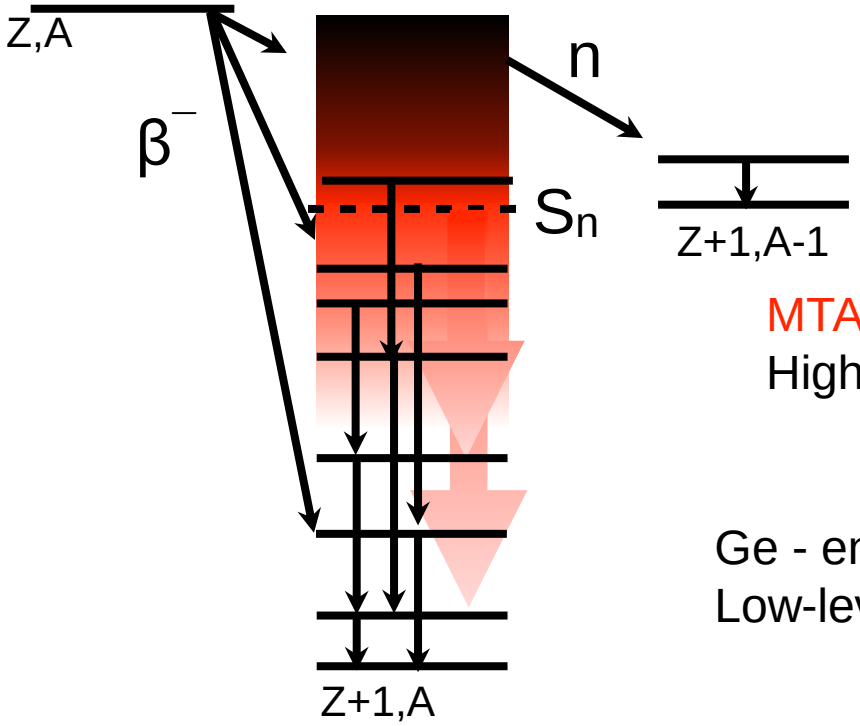
Tonnere, VANDLE neutron arrays

ε: 12 %; σ: 120 keV (1 MeV)



C. Gross (ORNL, USA):

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



VANDLE - energies
3Hen - number

MTAS - energies & number
High level density

Ge - energies & number
Low-level density

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
- Long- assessed techniques to study gamma and neutron decay branches

- Strong correlation with nuclear astrophysics (r-process nucleosynthesis)

- No need for post-acceleration
- Measurements do not require high rates

} **Ideal as 1st day experiments**

- Use in-house equipment and simulations to define better geometry

- 5 LOI from external groups already submitted, 3 of which directly related to astrophysics

Possibility to extend the area with construction of a new building
A document is in preparation and will be circulated to collect LOI
➔ Anyone who is interested is welcome to contribute!