The SPES Beta Decay Station, the non-post accelerated area and possible future expansion

G.Benzoni (INFN Mi) A.Saltarelli (UNICAM And INFN Pg), A. Nannini (INFN Fi), M.Rocchini (INFN Fi), N.Marchini (INFN Fi), A. Goasduff (INFN LNL), A.Gottardo (INFN LNL)

A little bit of history

	B-ds and SLICES	1+ AREA: A13 in SPES building
2015	b-DS (beta-decay station) concept presented at INFN for the first time in 2015: presentation and request for fundings at CSN3 within the GAMMA activity • Agreement with ALTO + Ithemba Labs + Oak ridge for designs and scientific activity • SPES One-day workshop "Physics at SPES with non re-accelerated beams", Milano, Apr. 20th-21st	started a working group to define experimental Hall, requirements for infrastructure etcs.
2016	Physics to be studied via β decay in exotic nuclei Third International SPES Workshop (LNL, 10-12 October 2016): collection of LOIs also for decay spectroscopy	Meetings with experts of specific departments: safety, cryogenics, vacuum, radioprotection, etc.
2017	Tape cassette design defined with ALTO Production of 4 tape cassettes	Meetings with experts of specific departments: safety, cryogenics, vacuum, radioprotection, etc. Draft of a TDR started
2018	Low and high-level controllers defined with i-Themba Design of mechanics for b-DS and SLICES set-ups Presentation of the project to INFN18 "4° incontro Nazionale di Fisica Nucleare"	Presentation of a "TDR for the installation of a β- decay station(b-DS) and a Internal Conversion Electrons Spectrometer (ICES) at SPES" to LNL director and INFN management - request for LN2 distribution lines - request for ceiling crane

A little bit of history

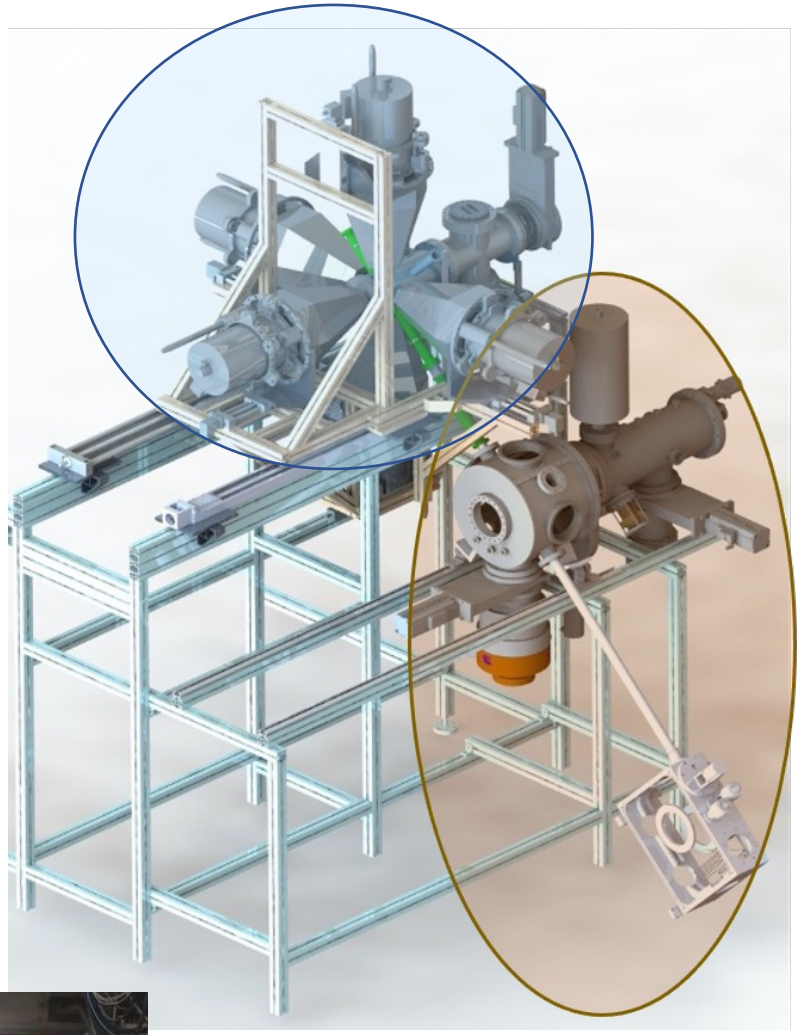
	B-ds and SLICES	1+ AREA: A13 in SPES building
2019	b-Ds and SLICES support structure definition Procurement of components started	
2020	Finalisation of support structure design, procurement of equipment Creation of a full simulation code starting from implantation to gamma spectra	
2021	Equipment ready to be installed, lack of an intermediate hall where to work and perform tests	
2022	Installation of equipment in a temporary area	Definition of a WG to study “Future facilities at LNL” Presentation of final outcome at LNF on Dec. 1st-2nd
2023	Tests in intermediate area waiting for final installation	Revision of requests of infrastructure

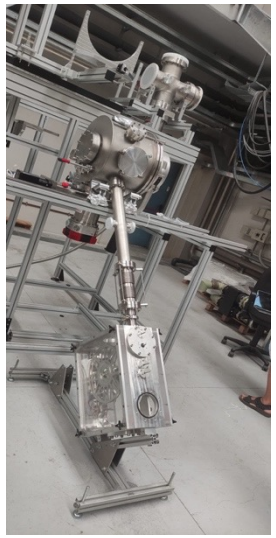
b-DS

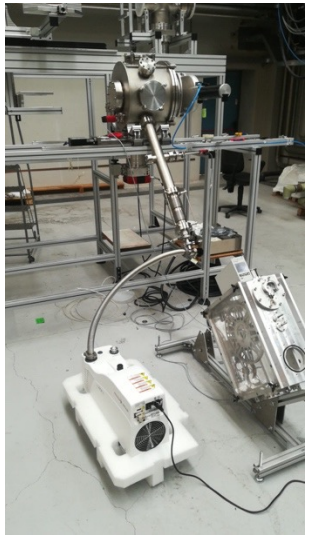
Experimental set-ups under test in intermediate location, waiting for green light for installation

Since end of 2022 sitting in Hall3

Owing to limited services available in area, tests and commissioning are slowly developing and will be finished when system will be put in A13 area

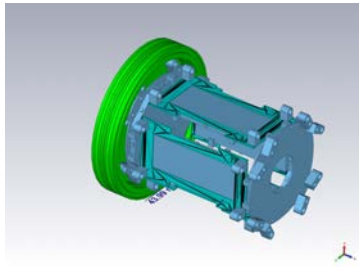


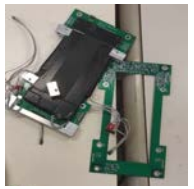


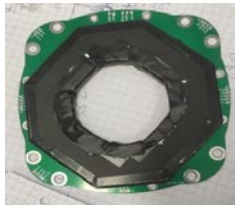


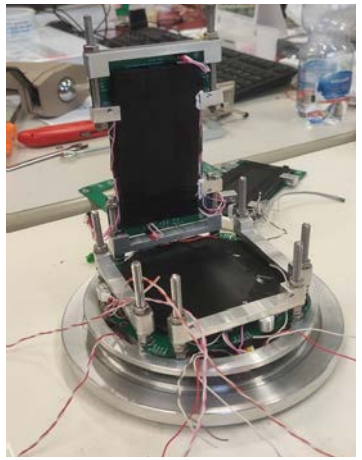
b-DS

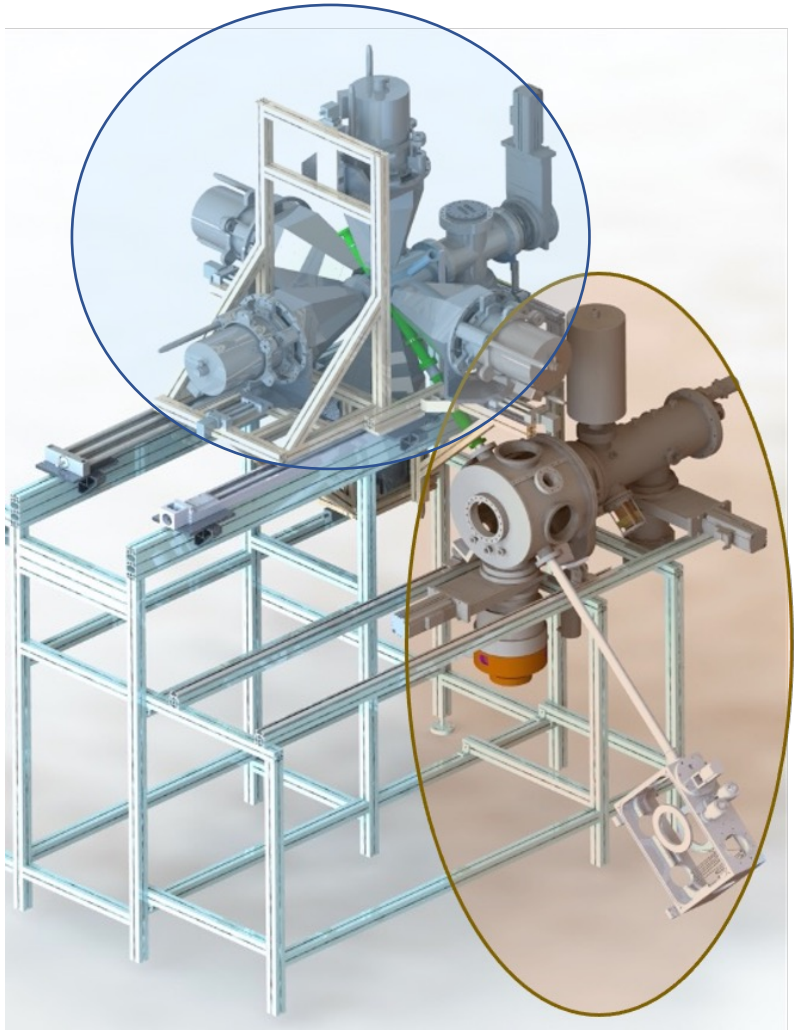
- beta tagging by EJ212 array SiPM readout
- Gamma detection using 5 GTC+AC
- Placed at implantation point
- Served by tape to remove bg.
- Can be complemented
  w/scintillator detectors (LaBr3(Ce))
- $T_{1/2}$, decay scheme, P_n via γ discrimination

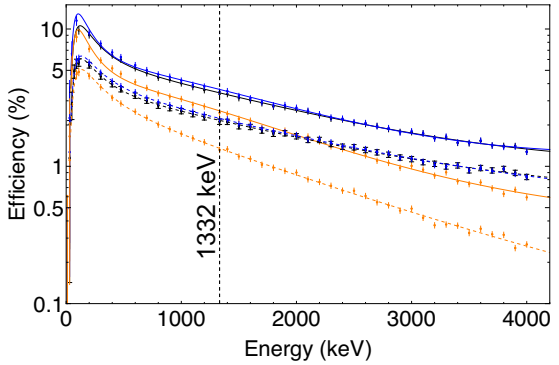


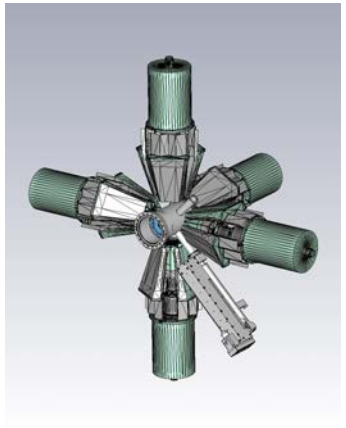


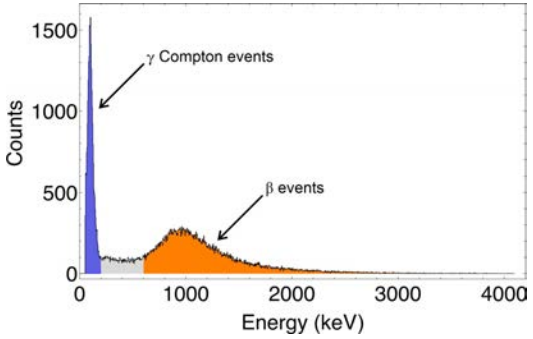






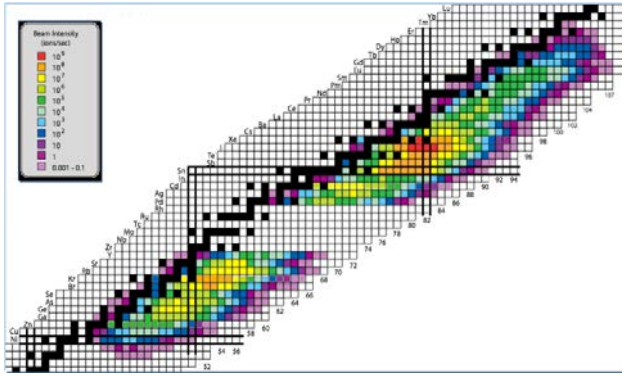






Technical paper under preparation

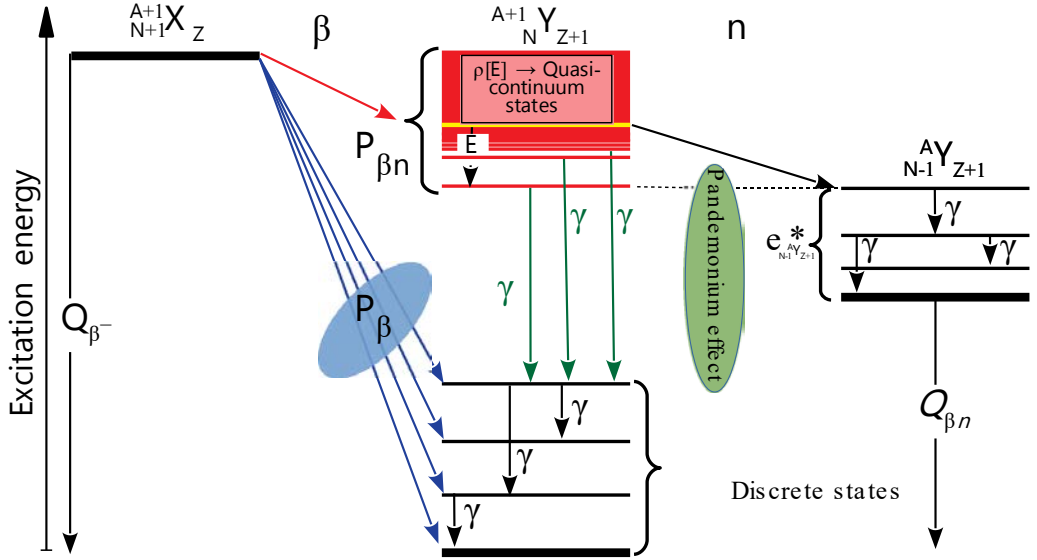
Opportunities with existing/planned equipment



n-rich nuclei ➔ complex decay scheme
neutron-emission channels open up
Short lifetimes
High-Q values, high level densities
Access to exotic decay modes: PDR via β decay
Fundamental questions: CKM unitarity via study of super-allowed decays

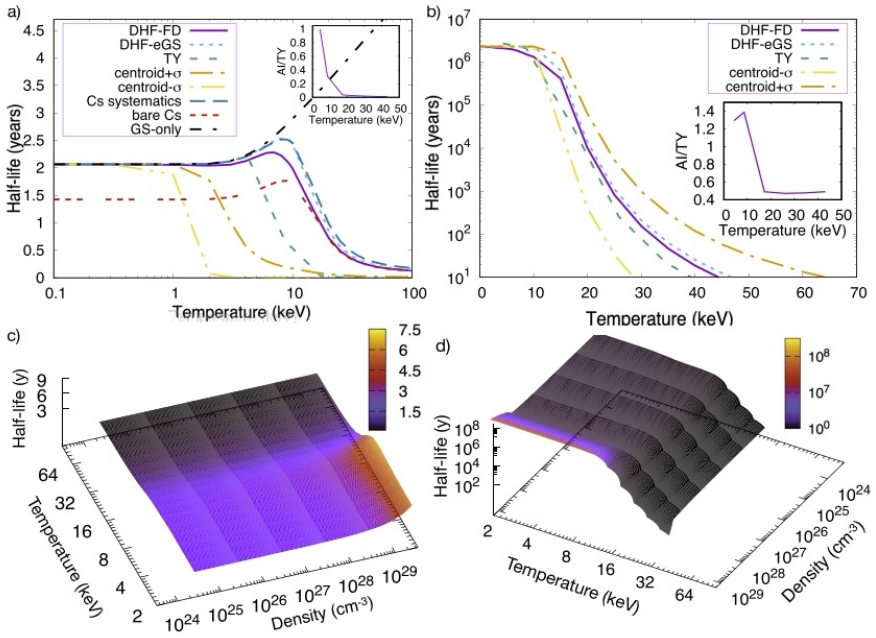
Measurements of direct impact in

- Shell structure evolution
- Evolution of nuclear shapes
- Astrophysical r and s-process modelling
- Modelling and production of radio-isotopes



Parallel theory activity

β-yield measurement and description



Initiative to develop a theory program to calculate, from the β yield, the shape of beta-decay spectra, the rates of the electronic captures (EC) and the subsequent Auger decay.

The inclusion of the nuclear correlations is already planned.

Experimental data on the β yield of the neutron-rich emitters is fundamental to get the transition rates and half-life in the AGB and novae stars.

Courtesy of S.Simonucci, S.Taioli, A.Saltarelli

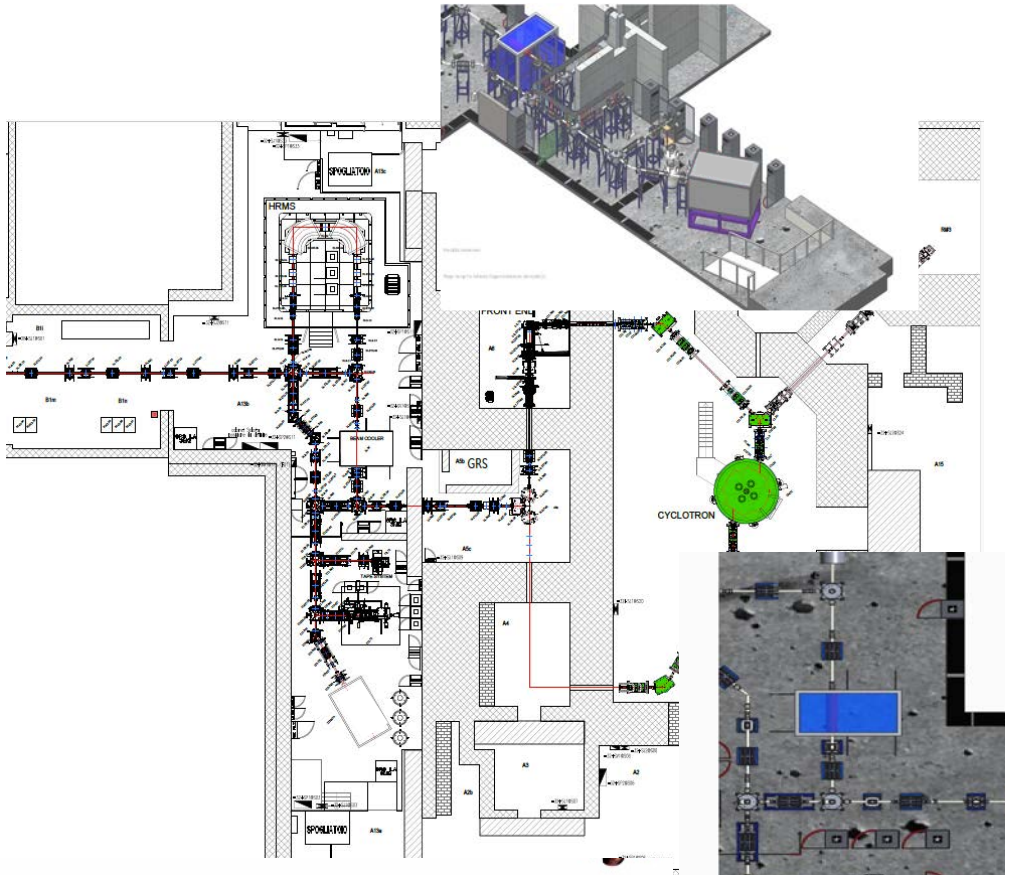
To the experimental areas

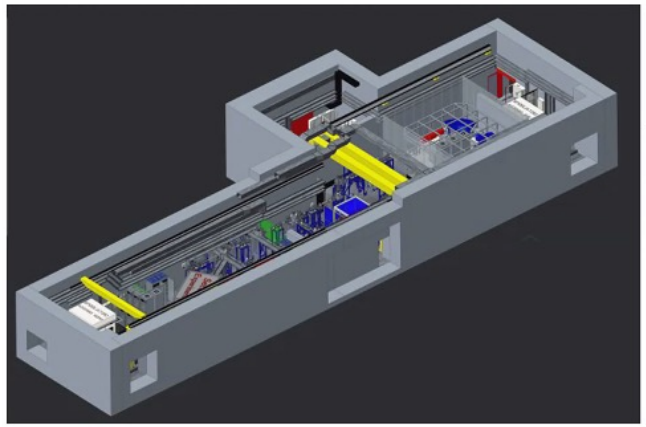
Area A13 in new SPES building dedicated to the installation of experimental set-up using low-energy beams from SPES

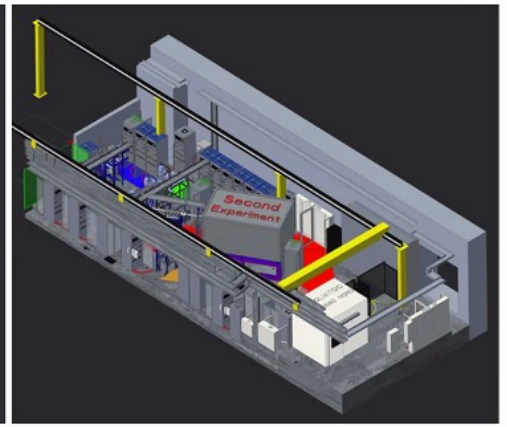
Actual – Present - Layout:

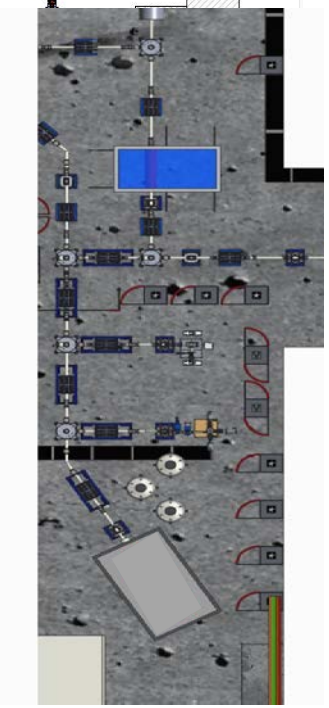
- 3 measuring points,
  - one serving two combined experiments (b-DS and SLICES)
  - Big space foreseen for bulky instrumentation
  - small installations (ISOLFARM)

A13 area: finishing done
Waiting to be equipped and instrumented
On-going: Ceiling crane installation
Still to be defined: LN2 distribution line









Nuclear Physics Mid Term Plan in Italy

LNF – Session

Frascati, December 1st - 2nd 2022

WG: New Facilities @ LNL

Convener1: A.Gottardo[1]
Convener2: G.Benzoni[2] A.Goasduff[1]
Advisor: G.de Angelis[1]

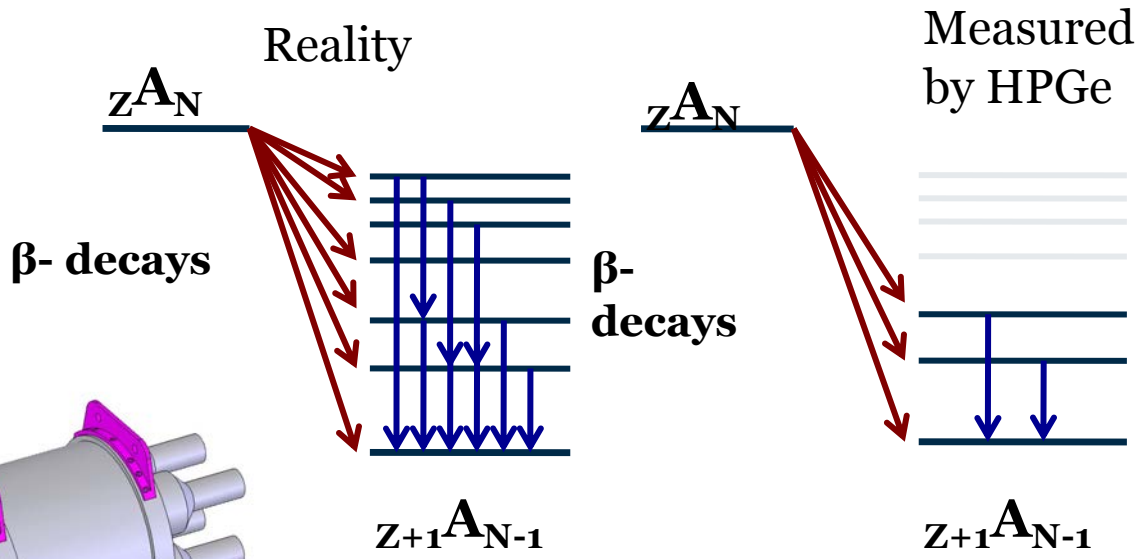
[1]INFN-LNL and [2]INFN Milano

What is missing ?

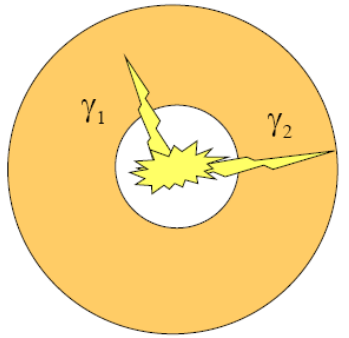
Symbols:
Short/Mid-term (2-5 years)
Long-term (5-10 years)

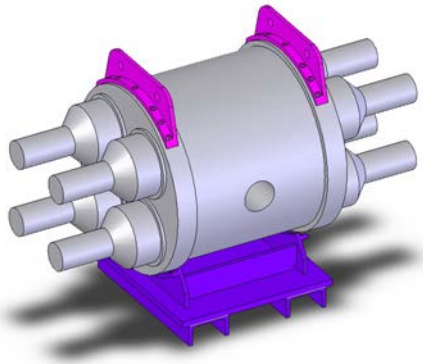
- Determination of ground-state properties
  - Masses
  - Charge distributions
  - Spins and parities
  - Magnetic and electric moments
- Alternative approaches
- Possible new lines :
  - New equipment for b-decay studies: neutron detection arrays; TAS;
  - Collinear Laser Spectroscopy
  - New equipment for mass measurement: MR-TOF-MS

High Q_β: The Pandemonium effect

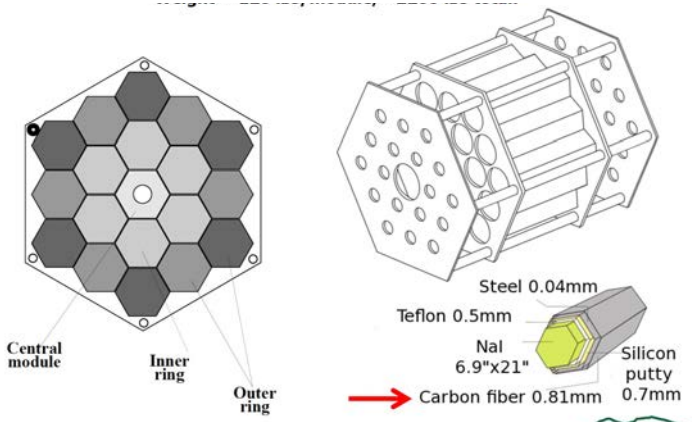


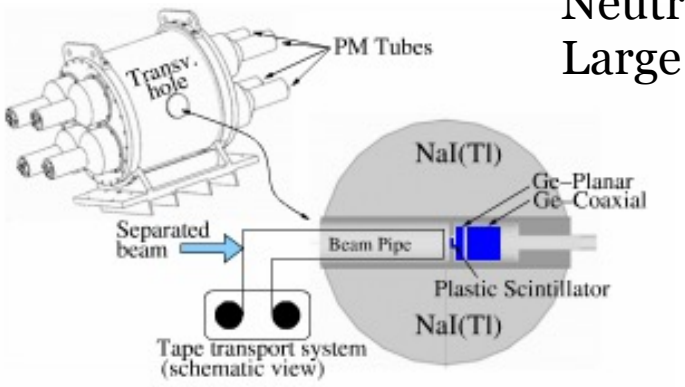
Need for higher efficiency at high energies
➔ large volume scintillators 4π coverage





New scintillator materials
Coupling with different scintillators
Neutron discrimination
Large volume coverage using smaller units

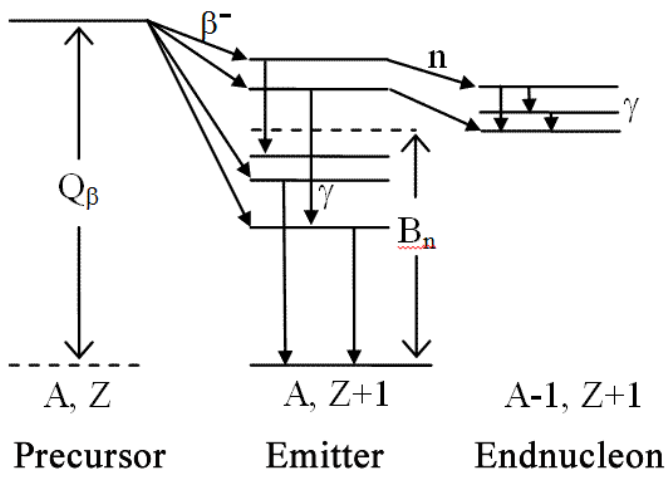




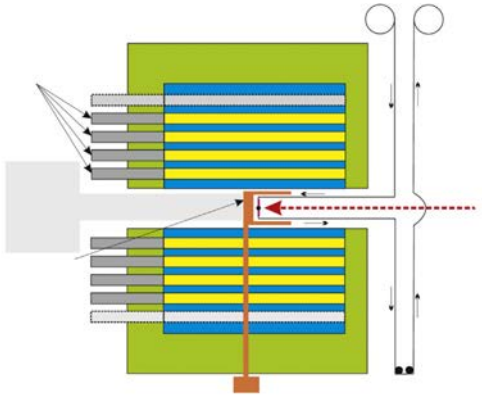
Short/Mid - term

Neutron detection and spectroscopy

Aim : Accessing beta strength above S_n



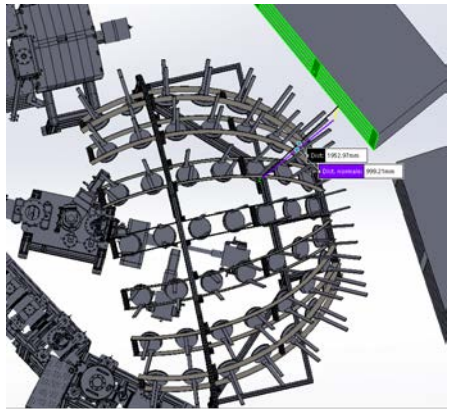
Counting: 3He counters



Example : TETRA@ALTO and BELEN@GSI-FAIR

Destructive detection process (no crosstalk)
No energy threshold
High quasi constant efficiency (~60% up to 1 MeV)
Quasi transparent to γ
No information on energy

Spectroscopy using Time of Flight



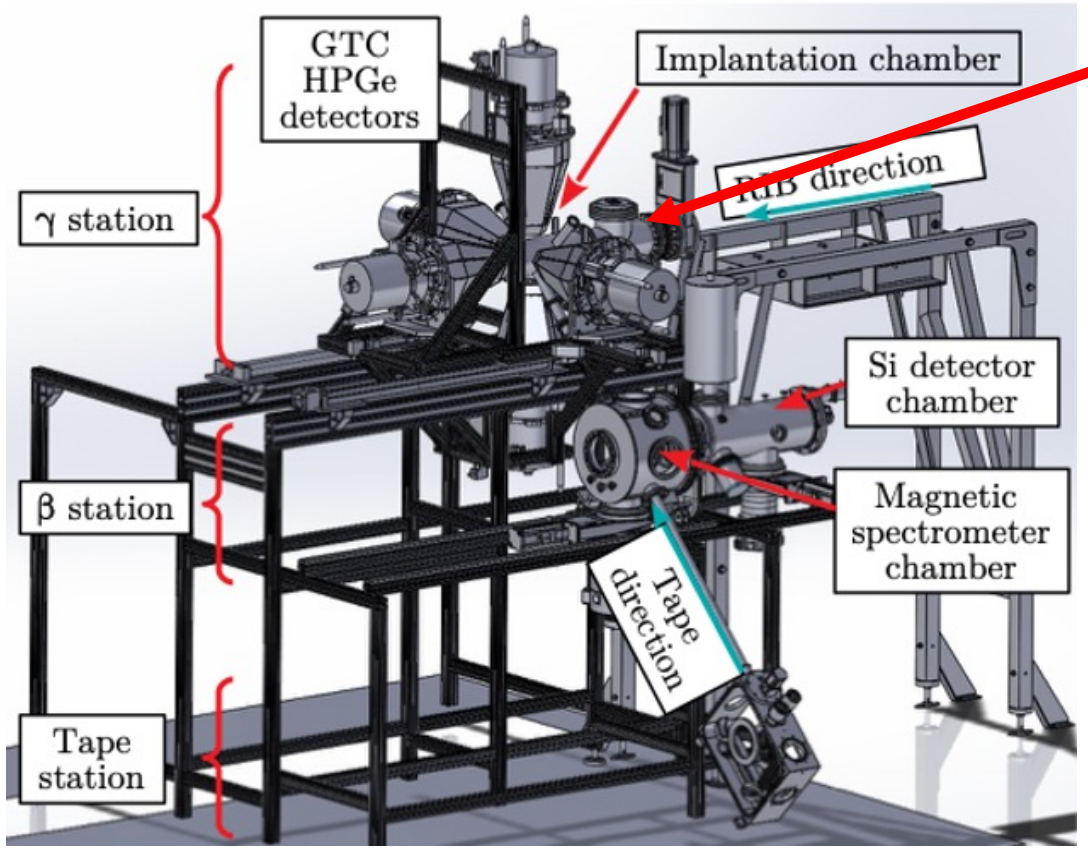
Example : MONSTER detector from Ciemat for FAIR

Energy threshold ~100 keV
Efficiency ~10%

Courtesy of C. Delafosse

Short/Mid - term

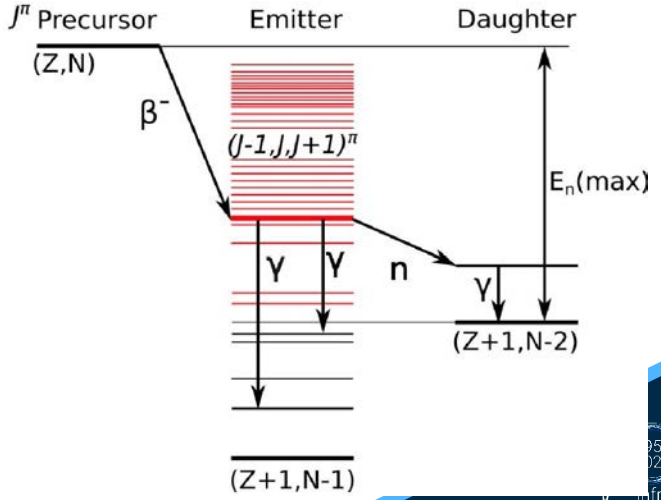
Possible CLYC array for SPES



Instead of the Ge clovers, a 4π array of 3inch CLYC scintillators

- 5% neutron efficiency at 1 MeV
- 10-12% neutron energy resolution
- 20% γ -ray efficiency at 1 MeV
- 4% γ-ray energy resolution at 662 keV

- Possibility to perform β- delayed γ-ray and neutron spectroscopy with the same detectors
- Advantages in 2n emission detection
- Drawback: low efficiency

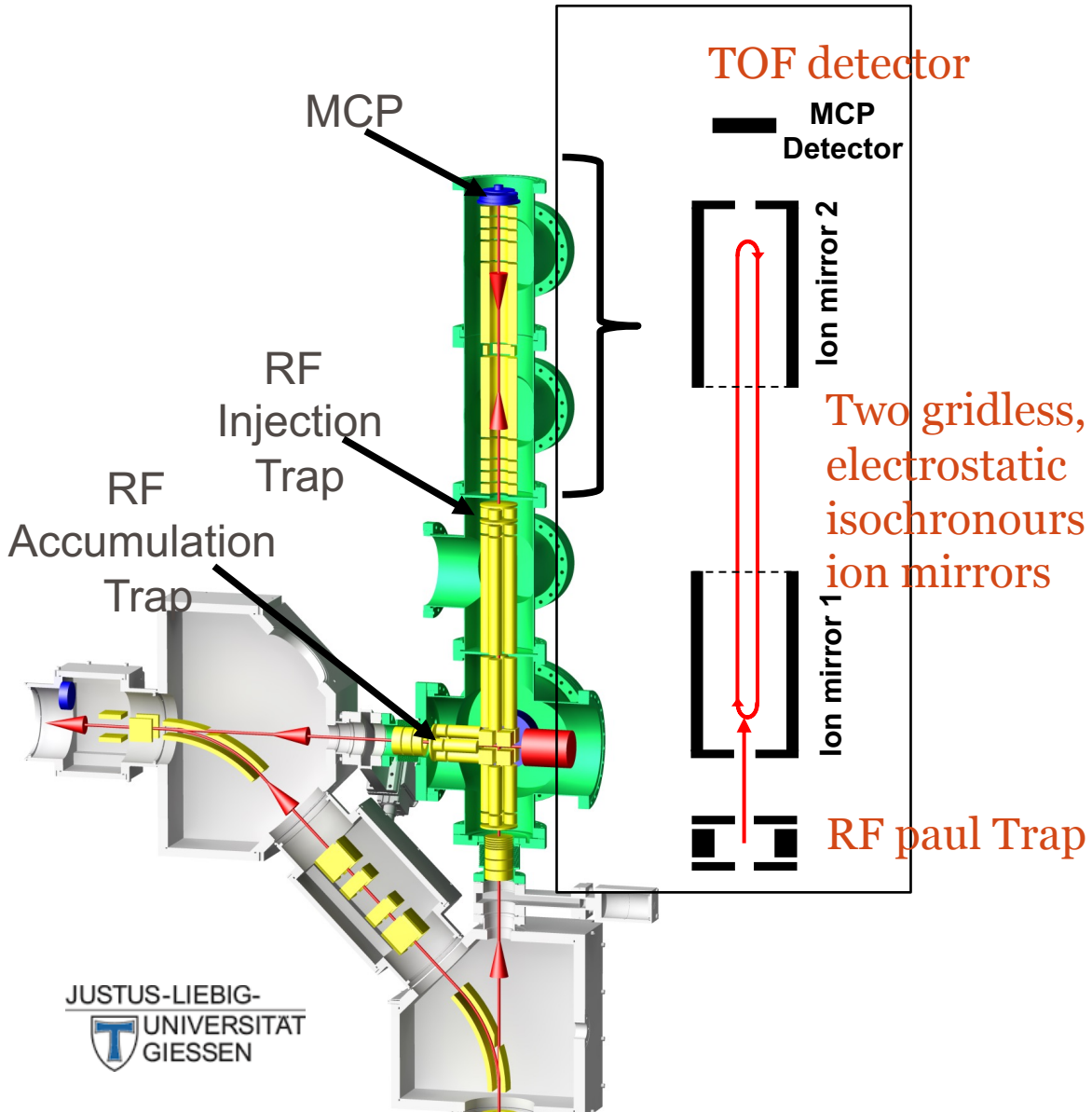


In neutron-rich nuclei (near shell closures):
- High Q-values (> 10 MeV)
- Low neutron separation energies ($\lesssim$ 4 MeV)

β-delayed neutron emission

Multi-Reflection Time-Of-Flight Mass-Separator

Courtesy of T. Dickel



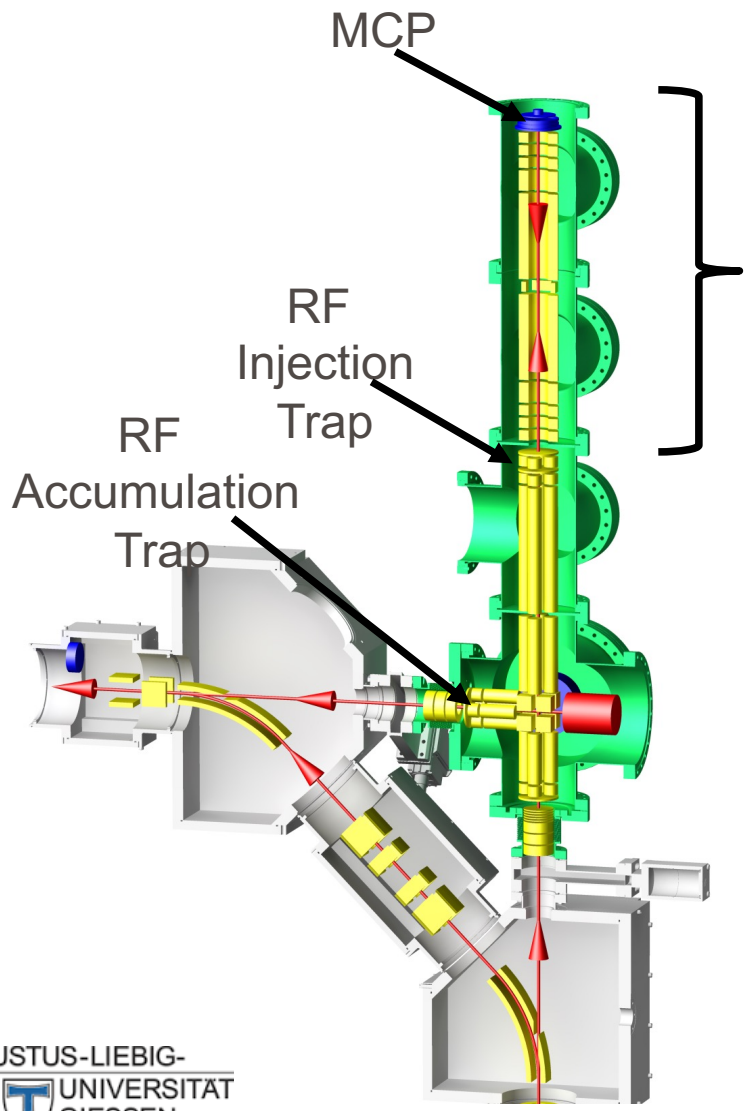
Versatile device

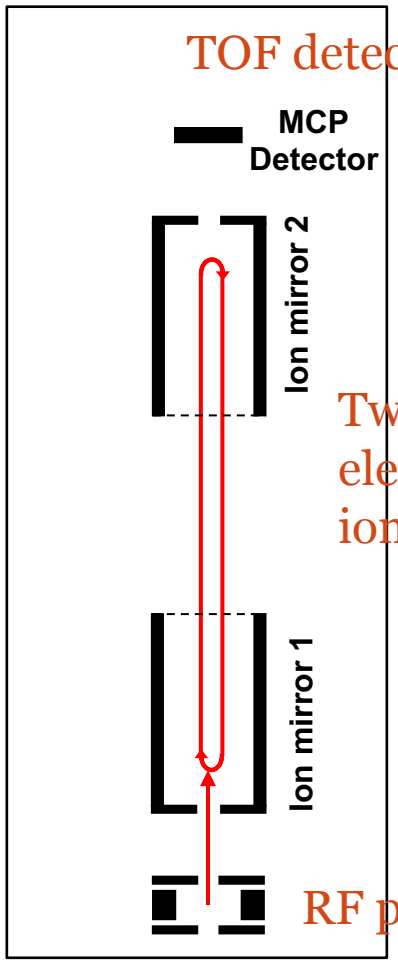
- diagnostic tool to determine the beam composition (broadband mode),
- isobar separator in combination with a nuclear spectroscopy setup (trap-assisted nuclear spectroscopy)
- high-precision mass spectrometer (mass measurements).
- For beam preparation a RFQ cooler and buncher needed

C. Jesch et al., Hyperfine Interact. 235 (2015) 97
M. Yavor et al., Int. J. Mass Spec. 381 (2015) 1-9
T. Dickel et al., J. ASMS 28 (2017) 1079

Multi-Reflection Time-Of-Flight Mass-Separator

Courtesy of T. Dickel





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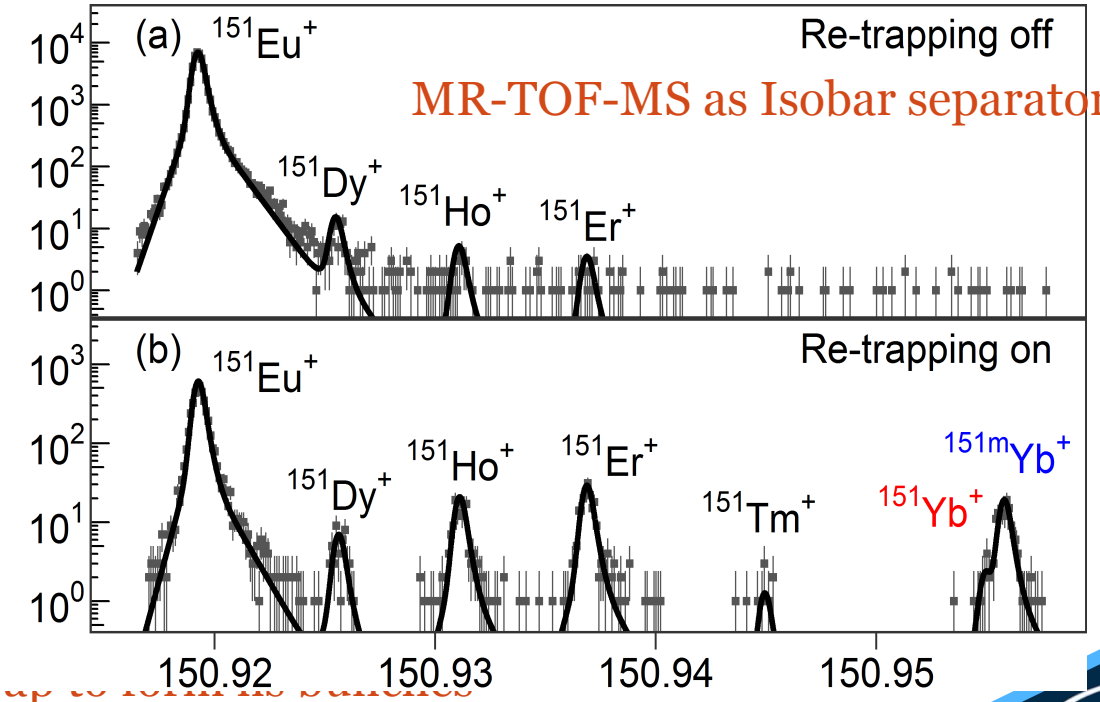
- Mass analyzer
- Mass separation via mass selective re-trapping

MR-TOF-MS as Isobar separator



JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

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Multi-Reflection Time-Of-Flight Mass-Separator

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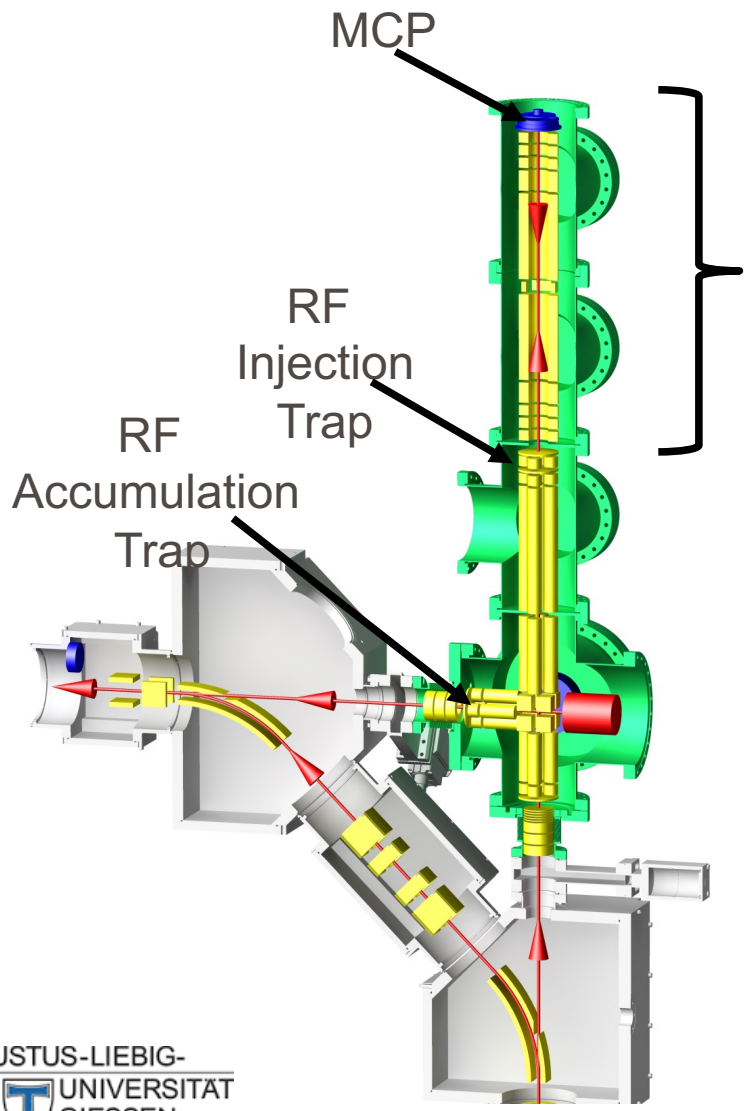
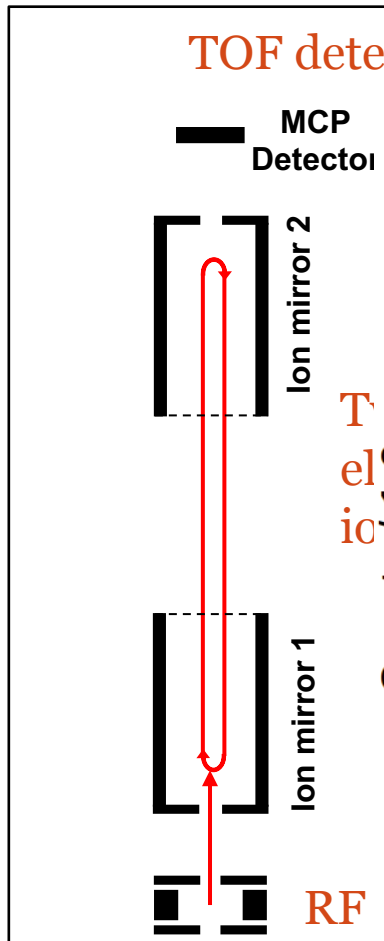
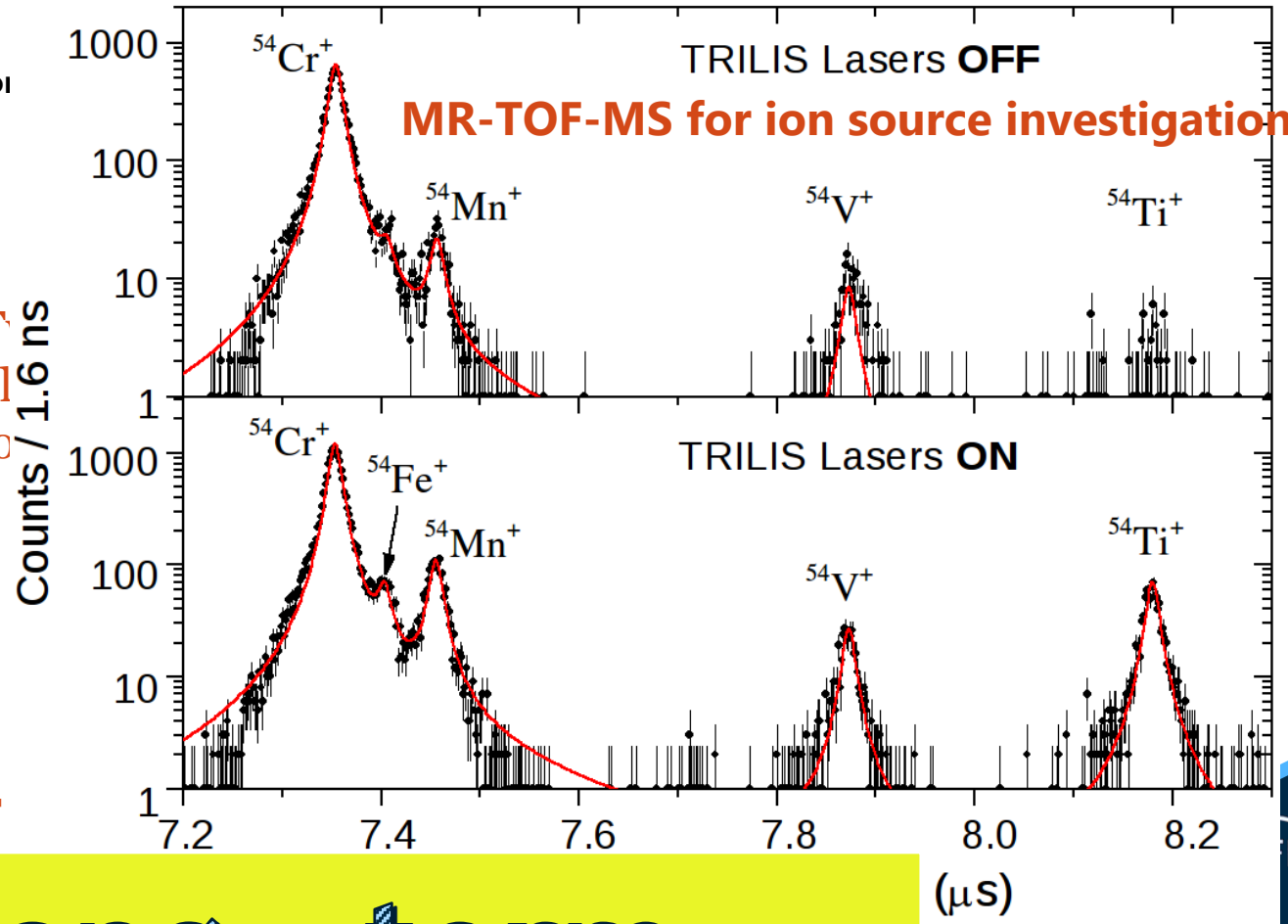




Laser On/OFF validation and tuning



Long - term

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Ultra-purified beam and decay spectroscopy

Beam from magnetic dipole (isobaricallly pure)

Purification setup (double Penning trap, MR-TOF-MS, RI)

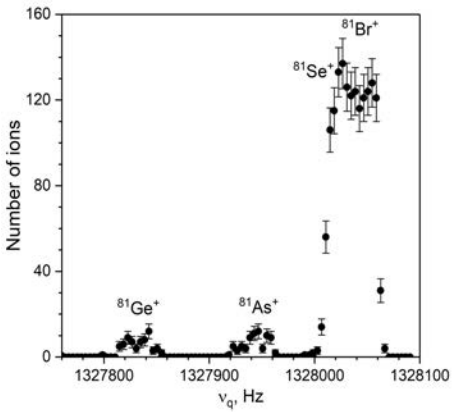
Separation in Z guranteed (can be isomerically purified)

Decay setup

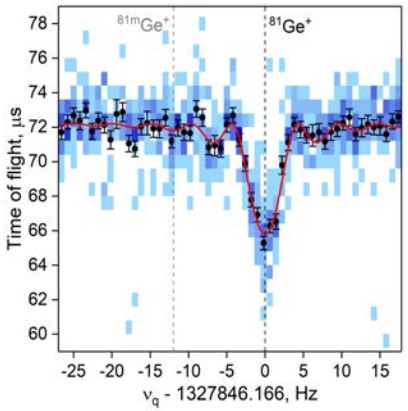
+ Pure beams
+ Better determination of mother nuclei spin and parities
+ Better spin-parity assignment using GT selection rules

- Lower transmission
- Pulsed beam

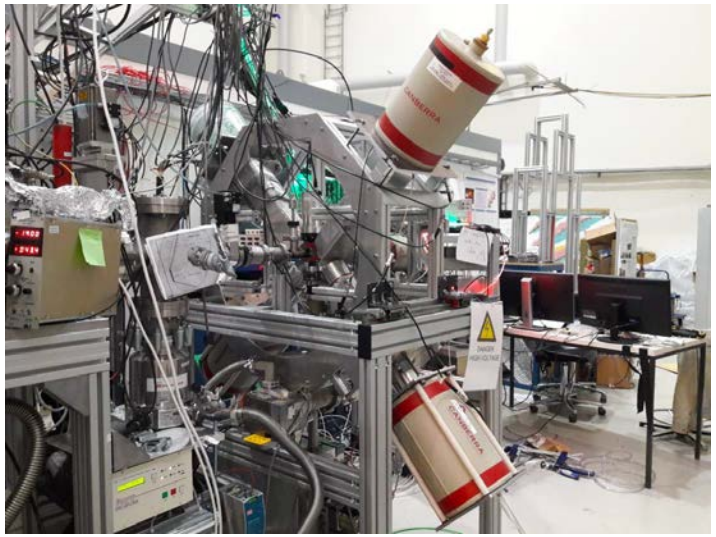
One example : IGISOL at Univ. Of Jyväskylä



Isotopic selection (first trap)



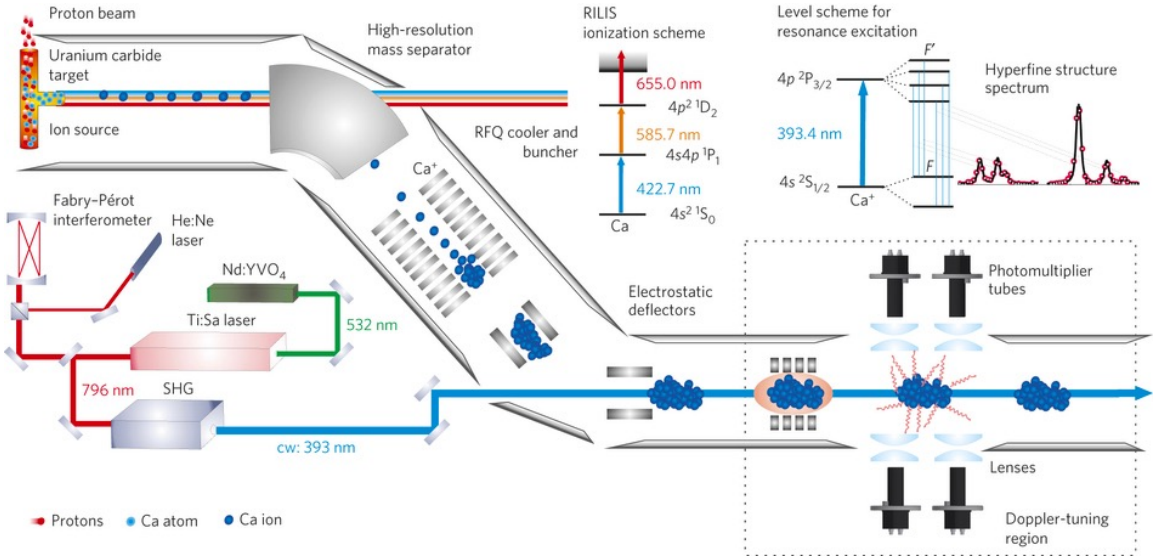
Isomeric selection (second trap)

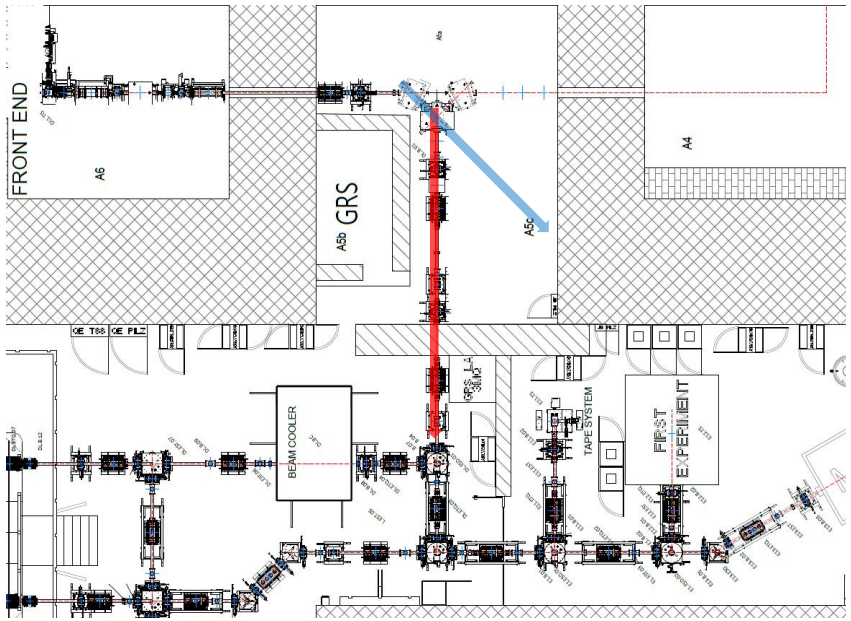


Courtesy of C. Delafosse and M.Block

Collinear Laser Spectroscopy

- Collinear superposition of laser beam on a beam of atoms or ions
- Frequency scanning to excite specific atomic transition
- De-excitation through isotropic photon emission
- Detectors perpendicular to the beam line
- Access to hyperfine structure, spins, charge mean radii
- Optical pumping can allow beta-NMR e β-NQR measurements
- Access to dipole magnetic and quadrupole electric moments





Several option to locate equipment, either close to the dipole or along the beamline before going towards charge breeded

Use of beam purification equipment improves the capabilities

Mid/Long - term

S.L. Kaufman: "High resolution laser spectroscopy in fast beams"; Optics Communications Vol.: 17, No.: 3 (June 1976); P.: 309-312

Courtesy of D. Scarpa

What is missing ?

Short/Mid-term (2-5 years)
Long-term (5-10 years)

- Determination of ground-state properties
  - Masses
  - Charge distributions
  - Spins and parities
  - Magnetic and electric moments
- Alternative approaches
- Possible new lines :
  - New equipment for β-decay studies: **Short/Mid - term**
    - neutron detection arrays; TAS;
  - Collinear Laser Spectroscopy **Mid/Long - term**
  - MR-TOF-MS and trap-assisted spectroscopy **Long - term**

- BONUS: increased beam purifications capabilities

Conclusions: Physics domain with SPES

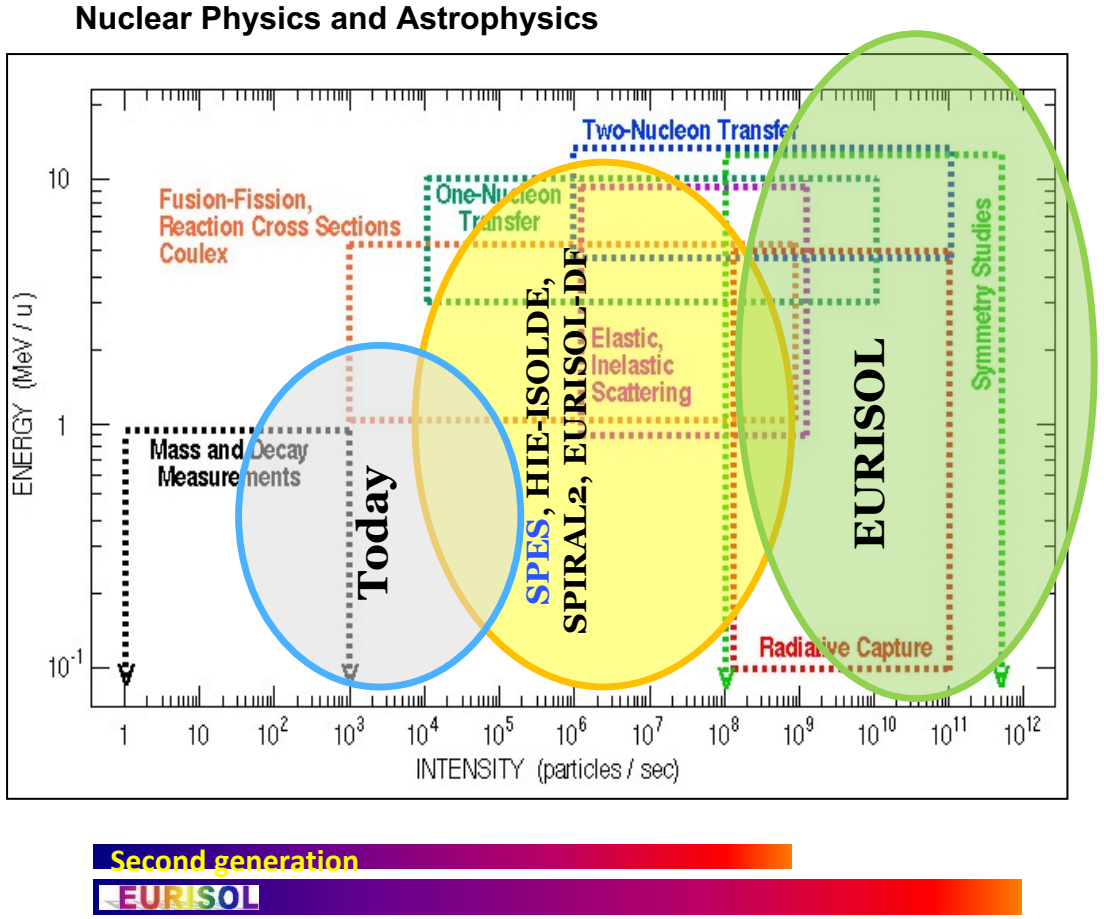
SPES Low-Energy and Post-Accelerated Physics Program, thanks to existing or short-term set-ups, is wide and has an impact in bridging towards next generation radioactive-beams facilities

Short-to-Mid Term opportunities in enlarging the scope of the set-ups are already being developed

Mid-to-Long Term proposed activities will complete the facility and introduce new physics to LNL (ground state properties)

Longer-term projects to be evaluated to enrich further the physics program

However .... Time is running



Conclusions:

- b-DS and SLICES waiting for green light for installation in final area A13
- infrastructure in A13 area is not fully defined and work is still to be finalised

Remarks:

Urgent need to revive community interested in decay studies @ SPES, silently waiting for years

Organisation of a Round Table WS to expand Physics Program, and prepare first proposals

Organisation of a Summer School in Italy with dedicated sessions on decay studies

Capitalise on the exercise of the Mid-Term Plan to foresee possible expansion of the activities

Request for a meeting with new Director, SPES Project Manager, Research and Users Division to set up a realistic timeline and plan for future activities at b-Ds/SLICES and 1+ Area in General