SPES INSTRUMENTATION

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LNL

III International SPES Workshop

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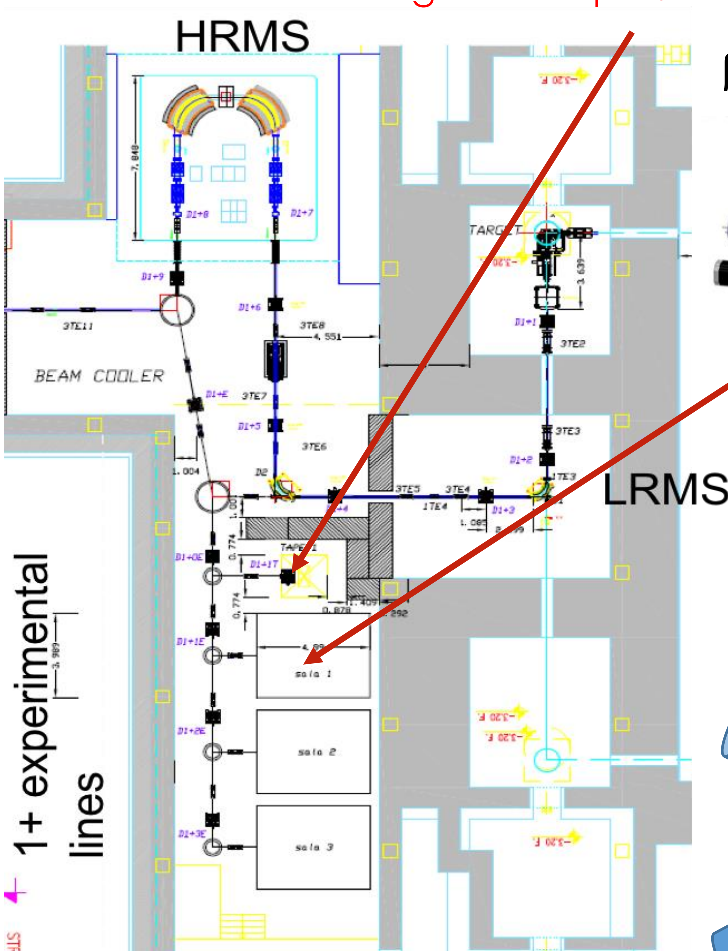
DEFINING THE INSTRUMENTATION

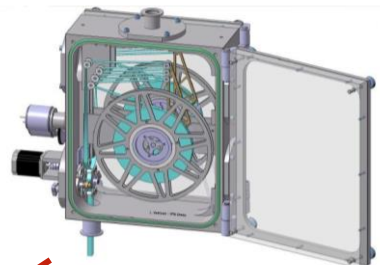
- Physics areas
  - Nuclear structure and «static» properties of nuclei with non re-accelerated beams
  - Nuclear Structure with re-accelerated beams
  - Reaction mechanims with re-accelerated beams (multidetector arrays, spectrometers)
- Detector systems *(disclaimer: not exhaustive!)*
  - Resident detectors: existing, upgrading, developing
  - Travelling detectors: collaborations, timeschedule, upgrading
  - New detectors

LOW ENERGY AREA

Diagnostic Tape Station

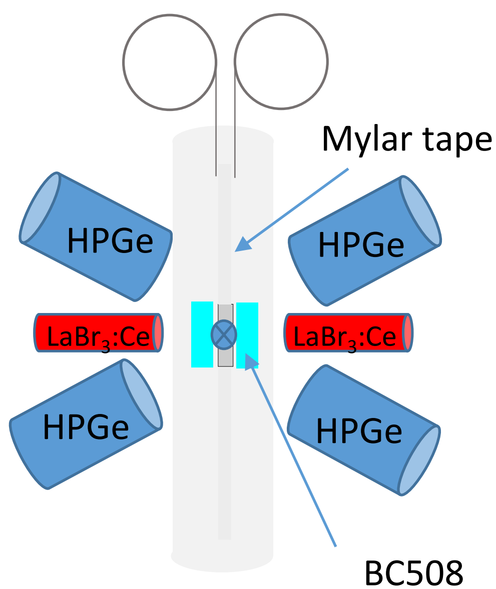


β-Decay Tape Station (β-TS)



Joint collaboration with LNL + INFN-Mi + Orsay (France) + iThembaLabs (South Africa)
For mechanics/electronics/controls

Minimal setup: $T_{1/2}$, P_n, β–γ coincidences
Measured quantities: - Time of β emission
- Energy and Time of γ decay

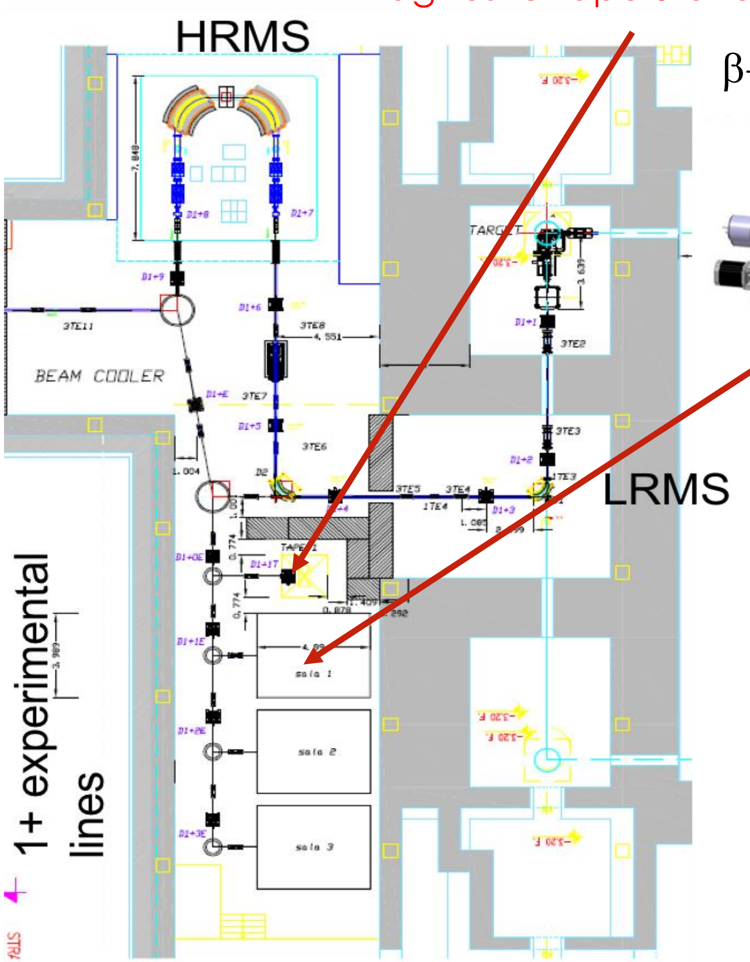


Fast-timing setup: lifetimes in the ns range
β- γ ($LaBr_3$:Ce)-γ (HPGe) coincidences

Courtesy of G. Benzoni (INFN Mi)

LOW ENERGY AREA

Diagnostic Tape Station



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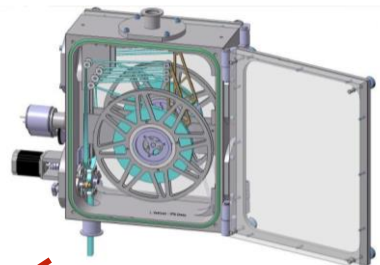

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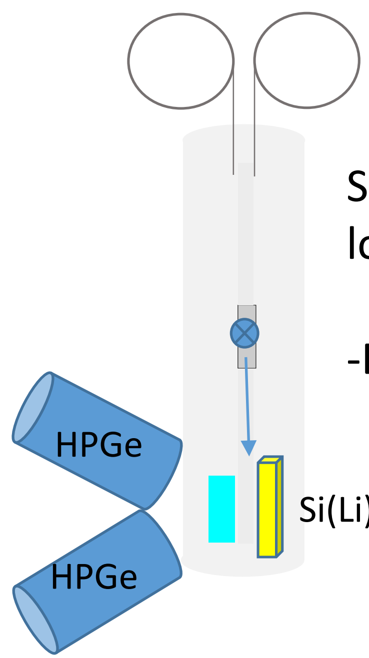
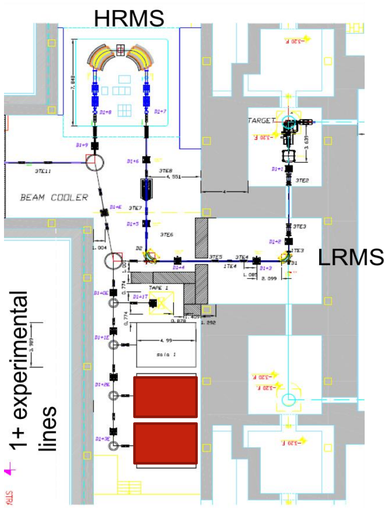


Setup for E0 measurements and long-living activity

-Energy of Conversion electron,

Courtesy of G. Benzoni (INFN Mi)

LOW ENERGY AREA



Complete spectroscopy using TAS

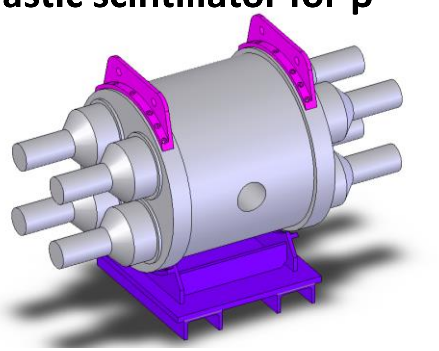
Precious information for:

- Complete spectroscopy ➔ nuclear structure
- Decay heat simulations ➔ nuclear energy

^{136,136m,138}I and ^{140}Xe are decays of highest interest to the NEA (Nuclear Energy Agency (USA)).

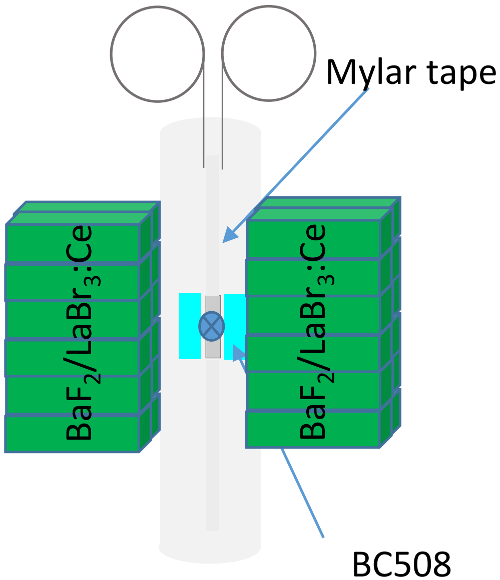
Lucrecia @ ISOLDE

NaI single-crystal 38cm x 38cm
Ge for X-rays
plastic scintillator for β



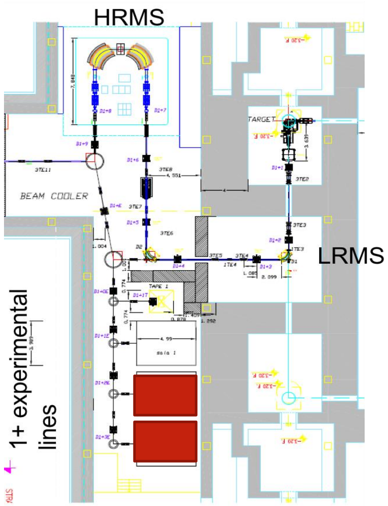
MTAS (ORNL, USA)

19 detectors in full array 70% efficiency at 4 MeV (full energy peak)
Segmented β detectors 70% efficiency



Future development In-house TAS detector: NUSPIN working group

LOW ENERGY AREA



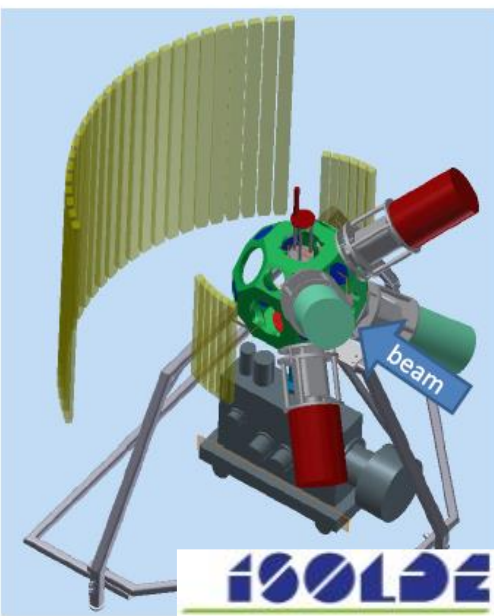
VANDLE →

Versitile Array of Neutron Detectors for Low Energy: Oak Ridge National Laboratory

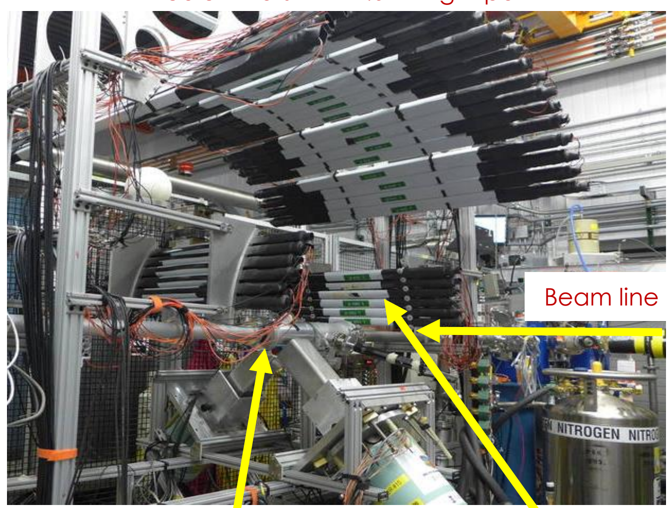
Highly modular array of plastic scintillators

- Scientific goals:

-delayed neutrons and reaction studies.



Medium Bars with 1.0 m flight path



Plastic β-detectors with Si-PMT

Small Bars with 0.5 m flight path

Plastic Bar Sizes:

– Small : 3 x 3 x 60 cm^3

– Medium : 3 x 6 x 120 cm^3

– Large : 5 x 5 x 200 cm^3

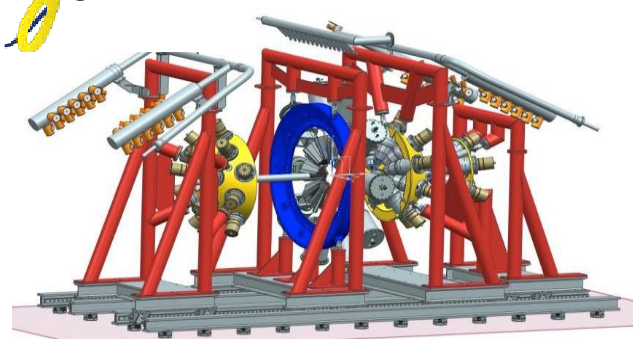
- Neutron Energies Covered:

– Small/Med. : 0.1 - 6 MeV

Large : 1 - 20 MeV

IDS + VANDLE 2015 Campaign

Nuclear Structure with re-accelerated beams: γ-spectrometers: GALILEO



Resident gamma spectrometer at LNL
Commissioning July 2014
First Physics campaign started fall 2015
(25 Detectors + ancillaries)

- 30 GASP detectors (HPGe)
- 10 triple cluster detectors

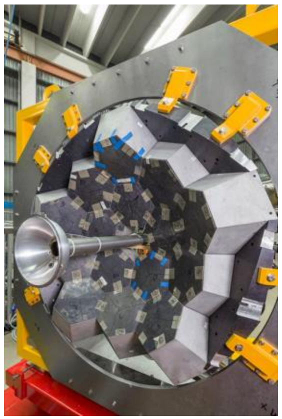
- Takes advantage of the technical developments performed with AGATA:
  - Pre-amplifiers
  - Digital sampling
  - Pre-processing
  - DAQ
- Uses the EUROBALL cluster detectors capsules:
  - Improved efficiency
  - development of a new cluster detector with 3 capsules

Resolution:
FWHM@1332.5 keV < 2.4 keV
Completely digital DAQ:

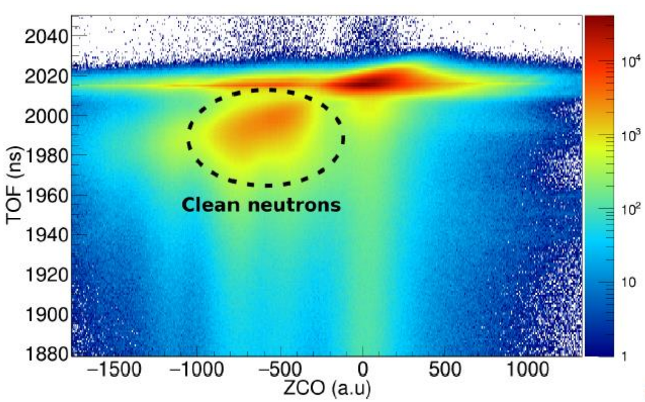
- 4μs rise time, 1μs flat top energy stored
- initial part of the signal taken
- BGO slave of HPGe
- very low noise
- recover time information from the signal
- Efficiency@1332.5 keV 2.4%

Nuclear Structure with re-accelerated beams:
Ancillaries for γ-spectrometers

Coupling GALILEO to neutron detectors

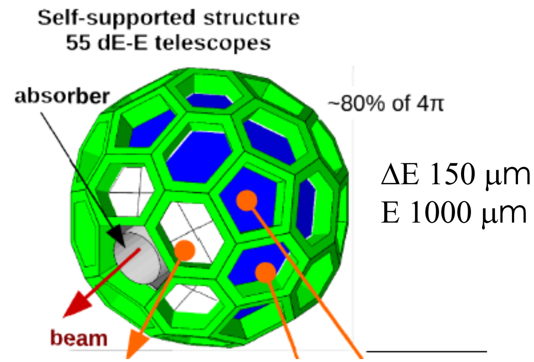


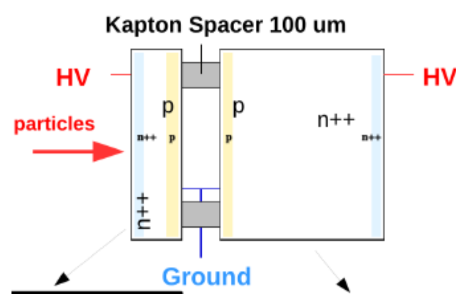
50 (45) BC501A detectors, organic liquid scintillators
Three signals per detector: QVC, TOF, ZCO
Preselected neutron condition provided to the trigger
ε(1n) = 23-27%; advantageous for identification of **2n channel**

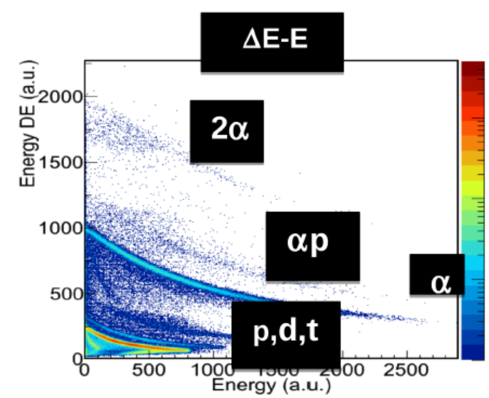


Coupling GALILEO to LCP detectors

EUCLIDES:
4π ΔE–E Si ball (110 detectors)

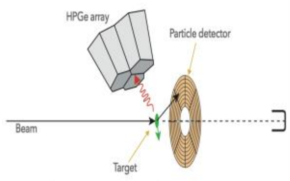






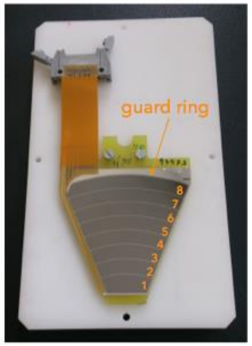
Nuclear Structure with re-accelerated beams:
Ancillaries for γ-spectrometers

SPIDER → Low Energy Coulomb Excitation



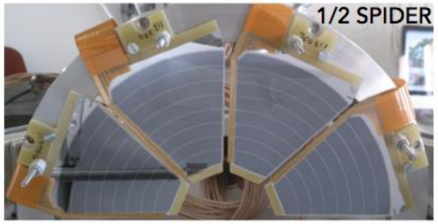
Silicon Pie Detector (SPIDER)
Independent Sectors, 8 strip for each one + guard ring (no cross talk)

Detector thickness ~300 μm, dead layers ~ 50 nm in the junction side and ~ 350 nm in the ohmic side



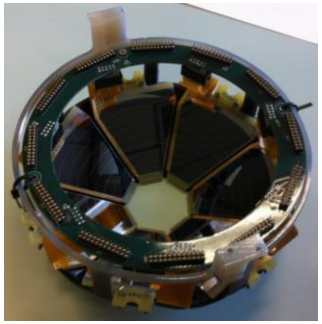
Coupling GALILEO to Fast Timing High Energy γ-ray detectors

Cylindrical $LaBe_3$ 3x3
Energy resolution 3% @661 keV
Time resolution <1ns
Efficiency ≈ 1% @16MeV – 10 crystals placed @ 20 cm



Cone configuration to fit the GALILEO chamber
(7 sectors): 8.5 cm from the target —> $\Delta\Theta = 43°$, $\Omega/4\pi = 18\%$

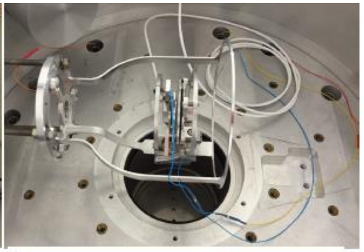
Disc configuration (8 sectors): 5 cm from the target —> $\Delta\Theta = 28.2°$, $\Omega/4\pi = 16.4\%$

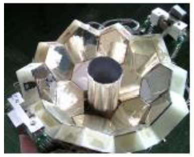


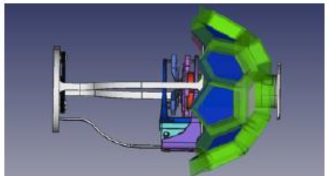
Life time measurements with the Plunger technique

Compact Plunger

Possibility to couple with part of the EUCLIDES detectors
→
Constraints on the Ancillary LPC detectors



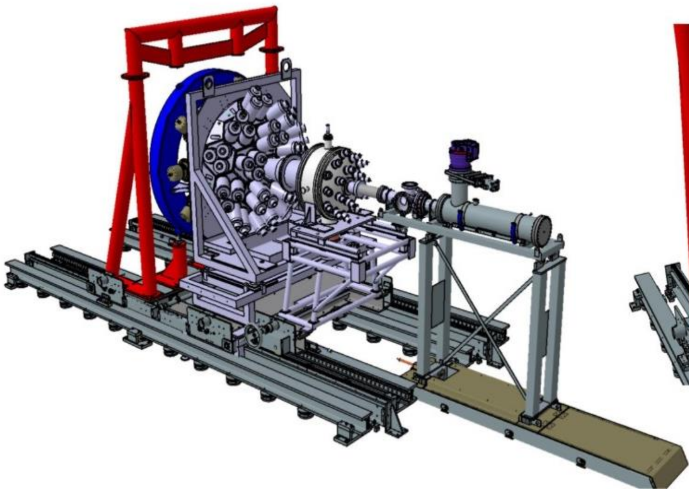




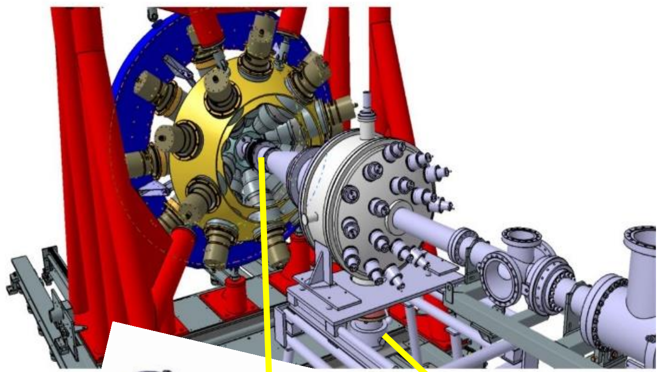
Nuclear Structure with re-accelerated beams:
Ancillaries for γ-spectrometers

Courtesy of P. Bednarczyk (INP PAN Krakow)

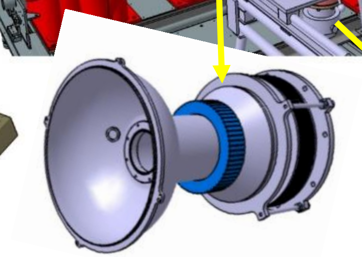
GALILEO 25 HPGe +
NEUTRONWALL+ RFD



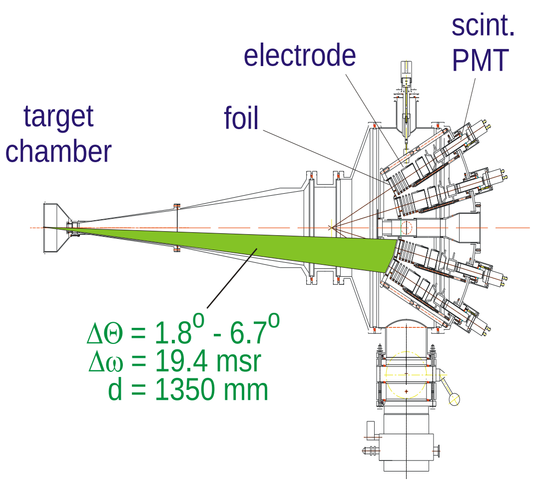
GALILEO 35 HPGe + RFD



RFD vacuum pumping system (10^{-7} Ba)



A connector to the reaction chamber



The RFD DAQ:

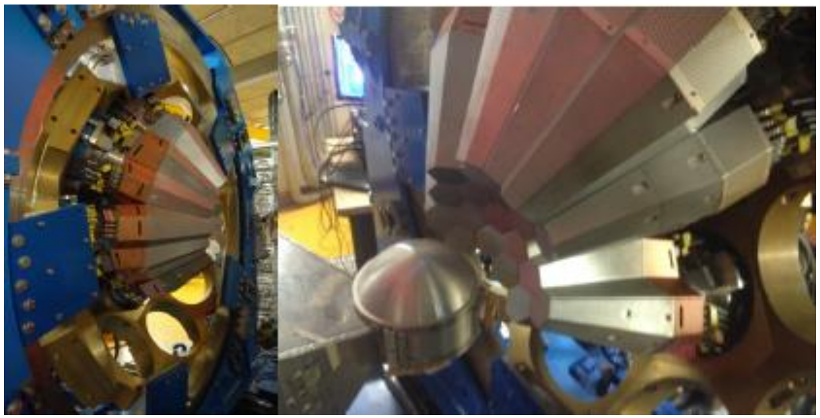
- NIM FEE for γ-recoil-RF trigger.
- 18 VME TDC converters, that measure ToF- the time interval between a beam pulse and a detected recoil.
- A GTS timestamp can be inserted through the AGAVA interface.
- Slow control and setup of the VME modules (converters and CFDs) using Kmax.

RFD - GALILEO :
γ-Recoil ToF measurement in an event-by-event mode

RFD advantages:

- good selection of evaporation residues,
- high efficiency of γ-recoil coincidences: 20 – 50%,
- precise Doppler broadening correction for recoil velocity up to ~7%,
- estimation of a lifetime of highly excited states in the fs range,
- possibility of a coupling to other ancillary particle detectors as NEUTRONWALL and EUCLIDES or the PARIS array

Nuclear Structure with re-accelerated beams:
γ-spectrometers → AGATA (tracking gamma array)



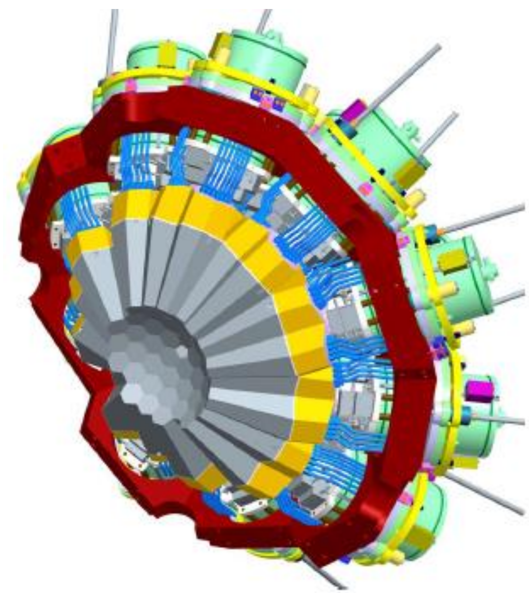
The AGATA Phase 1 (2009-2020)

Phase 1 of AGATA (>1π → 60 Crystals)

MOU ongoing, only 70% achieved,
Decided prolongation until 2020

Triple & Double clusters
Tracking Array

- Upgrade to 32 capsules now installed at GANIL. Installation of the electronic channels ongoing. After summer probably 35 channel available –close to the maximum if spares are kept–. Planning about 45 capsules for 2018.



AGATA 1π

To be used at RIB and High Intensity Stable Beam Facilities

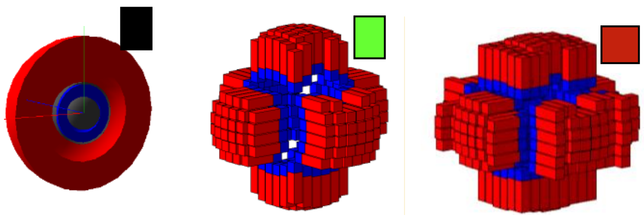
FAIR-HISPEC, SPIRAL2, SPES, GSI, LNL, GANIL,…

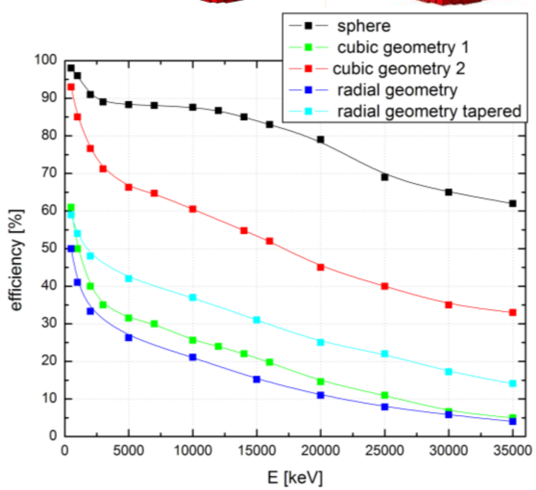
Coupled to Spectrometers, trackers, neutron and LPC arrays…

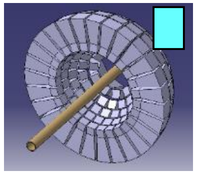
Nuclear Structure with re-accelerated beams:
Ancillaries & γ-spectrometers

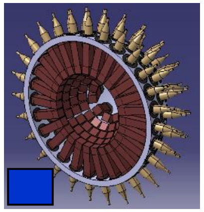
PARIS desing concepts:

Design and build high efficiency detector consisting of 2 shells *(or 1 phoswich shell)* for medium resolution spectroscopy and calorimetry of γ-rays in large energy range



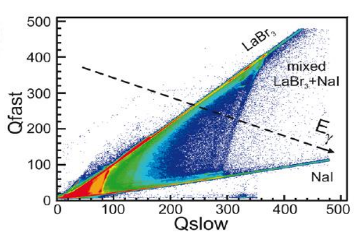


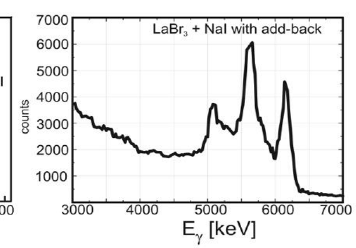




- be modular (to be connected with other detectors: **AGATA**, EXOGAM, **GALILEO**, GASPARD, **NEDA, FAZIA**, ACTAR, HECTOR/**HECTOR+**, EAGLE, ORGAM, CORSET...)
- have high granulation (multiplicity measurement, Doppler correction,...)
- have very high efficiency for high-energy g-rays (5-30 MeV)
- stand high counting-rate (ca. 50MHz)
- have good timing resolution (ca. 500 ps)
- have energy resolution as good as possible (ca. 4%)
- have some position sensitivity
- be transportable (**SPIRAL2/GANIL** will be the primary site, but experimental campaigns are planned also in other facilities:
- **IPN Orsay, HIL Warsaw, CCB Krakow, SPES/LNL,** HIE-ISOLDE, Mumbai,…)

PARIS to be made of clusters:
Cluster = 9 phoswiches
This allows *cubic* or *semi-spherical* geometry with 24 clusters (216 phoswiches)





Nuclear Structure with re-accelerated beams:
Ancillaries & γ-spectrometers

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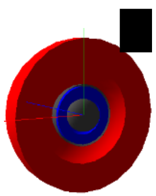
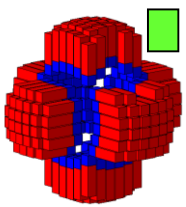
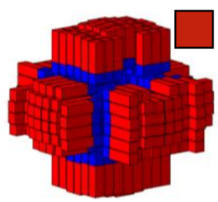
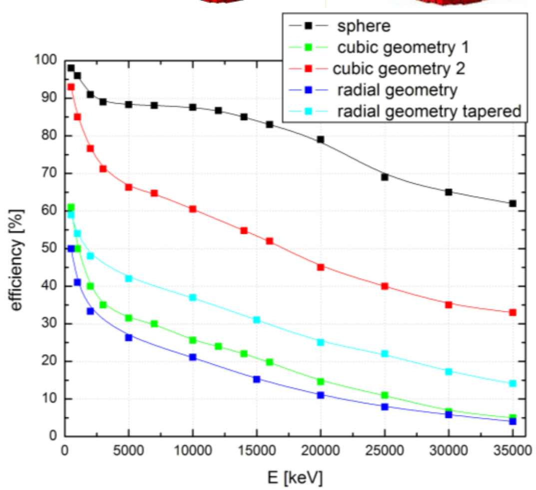
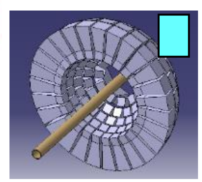
Design and build high efficiency detector consisting of 2 shells *(or 1 phoswich shell)* for medium resolution spectroscopy and calorimetry of γ-rays in large energy range

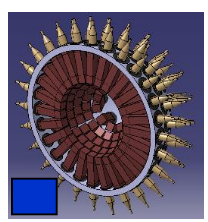












- LaBr3+NaI phoswich is a viable solution for the elements of the PARIS calorimeter, in terms of it meeting the requirements for energy and timing resolution
- Presently we explore the performance of a cluster of 9 phoswich detectors. Source and in-beam testing of this cluster were done recently.
- The next phase will be to complete the PARIS Phase2 (Demonstrator) of 4 clusters, each of 9 phoswich detectors. *(Some delay, due to the delays in delivery time of phoswiches)*
- First PARIS physics experiments are coming in

  FRANCE: AGATA@GANIL and IPN Orsay;

  POLAND: CCB Krakow and HIL Warsaw;

  ITALY: LNL/SPES Legnaro.

Nuclear Structure with re-accelerated beams:
Ancillaries & γ-spectrometers

Study of nuclear collective states, Measurements of the γ-decay from collective states

HECTOR+ Array

- High efficiency portable scintillator detector array
- 8 Large Volume BaF2 Detectors (14 x 17 cm)
- 36 Small Volume BaF2 Detectors
- 10 large Volume LaBr3:Ce detectors (9 x 20 cm)

coupled to HPGe arrays
- AGATA @ LNL Low Lying pygmy and quadrupole states
- AGATA @ LNL isospin mixing in 80Zr
- AGATA @ GSI (pygmy resonance on 64Fe)

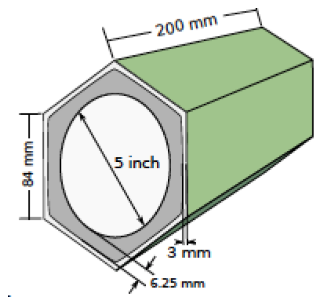
coupled to LAND @ GSI
coupled CACTUS @ OSLO
RIKEN, DEBRECEN.

→ Serpe and TRASMA (BaF_2 clusters) @ Napoli and LNS

AGATA-BaF_2-$LaBr_3$:Ce at LNL

Nuclear Structure with re-accelerated beams:

Neutron Detectors arrays and Development→ NEDA



- Versatile neutron detector to be coupled to γ-ray arrays
- Neutron detection is based on the liquid scintillator EJ301 with good neutron-gamma discrimination capabilities.
- Efficient for neutrons from ~ keV to 10-15 MeV
- Single hexagonal detector FEE fully digital system:
  - 200 MHz and ENOB 11,3
  - Global Trigger System - GTS

- Regular hexagon to tile up a surface
- 20 cm depth detector
- 5" PM Hamamatsu R11833-100HA QE 33%
- PSA liquid EJ301 → 3 liters
- TiO_2 Reflexion paint
- Expasion chamber ΔT =10-50 degrees
- Voltage divider transistorized for large counting rates
- Single to differential converter
- 1mm mu-metal shielding
- Self produced

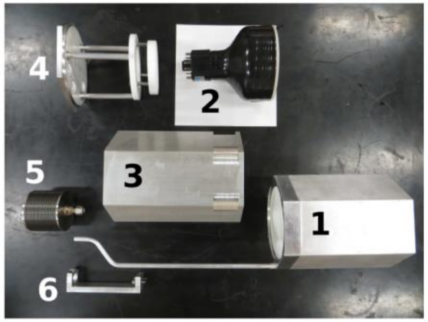
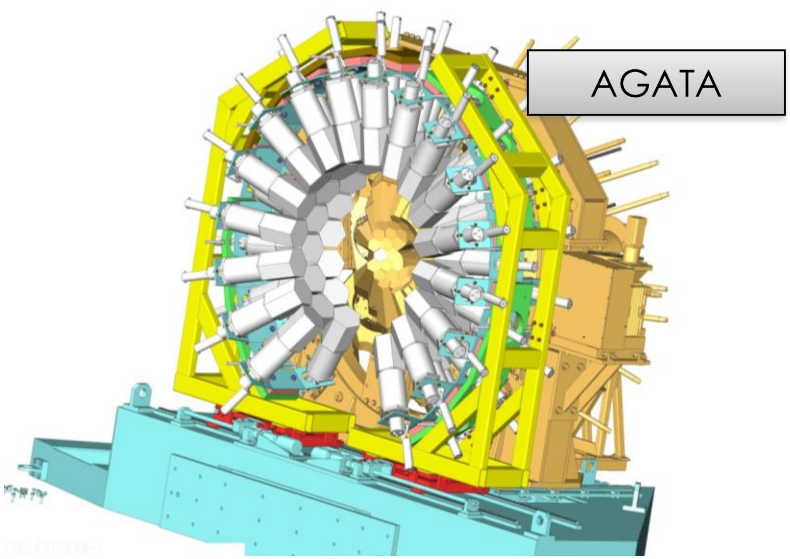


Fig. 1. Elements used for the construction of the NEDA detector: detector cell, with extension pipe (1); PMT (2); PMT housing (3); PMT pusher (4); the bellow (5) and the support for the bellow (6).



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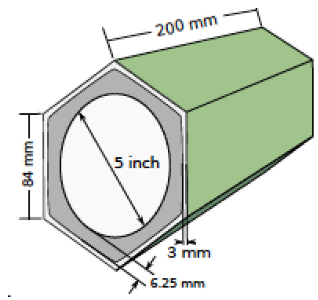
- Self produced



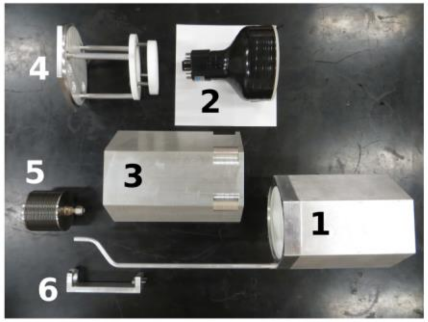
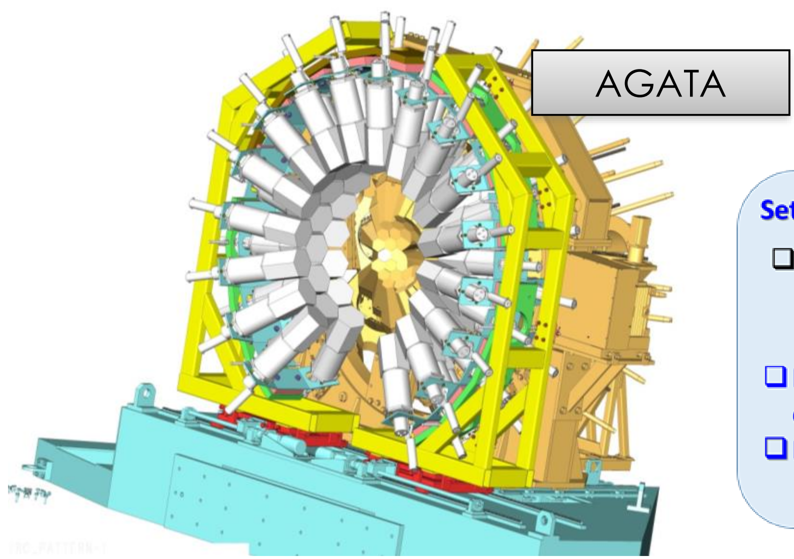


Fig. 1. Elements used for the construction of the NEDA detector: detector cell, with extension pipe (1); PMT (2); PMT housing (3); PMT pusher (4); the bellow (5) and the support for the bellow (6).

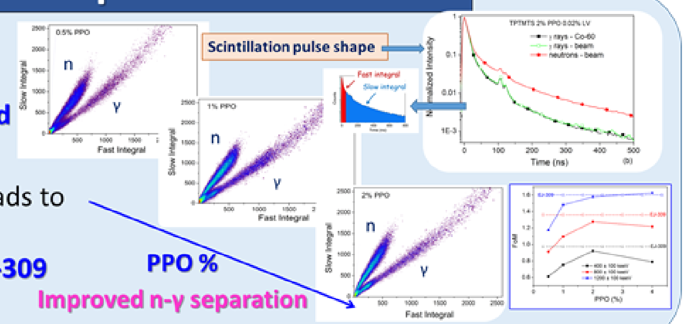


OrIONe

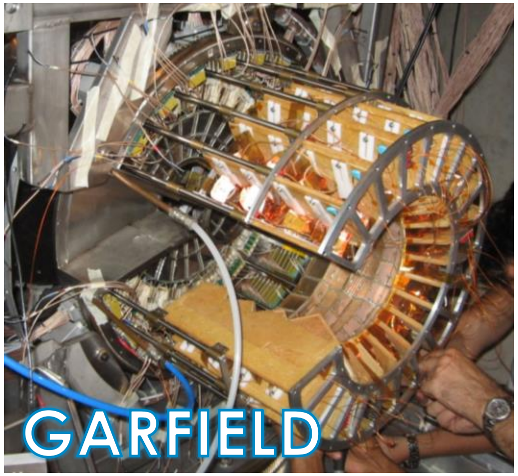
PSD with Liquid Siloxanes

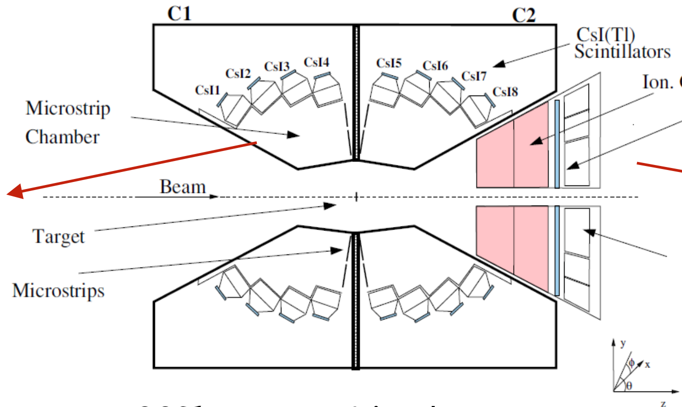
Set-up: CN accelerator (LNL-INFN)

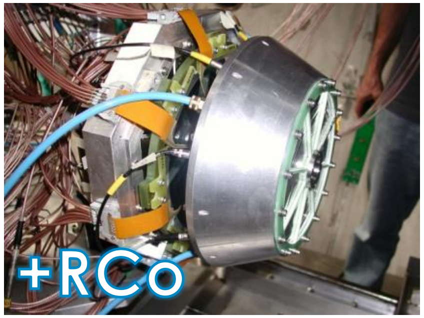
- ❑ 4 MeV pulsed p beam on ^{7}LiF target→pulsed n beam→**Enabled TOF for n-γ separation**
- ❑ **Increase** of primary dye (**PPO**) leads to **optimal n-γ discrimination** [5]
- ❑ **PSD capability comparable to EJ-309**



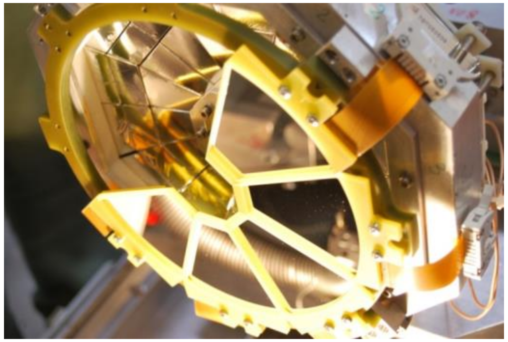
Reaction mechanisms with re-accelerated beams:
Multi –detector arrays → GARFIELD + Ancillaries

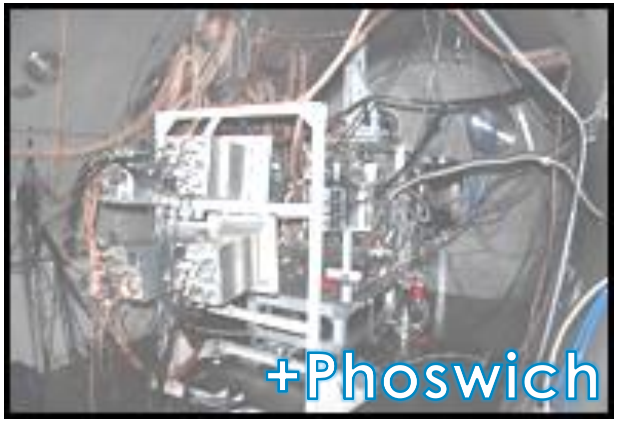


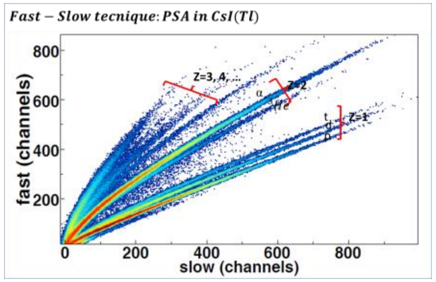


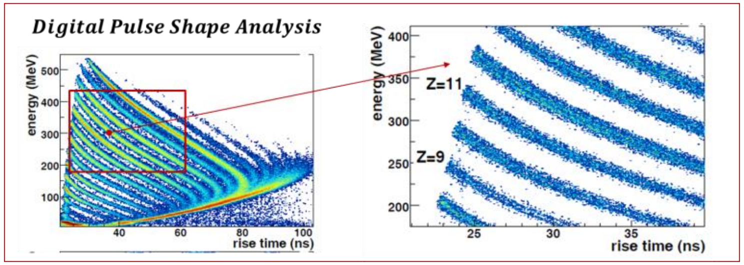


80% geometrical coverage
C1 98°<θ<151° C2 29°<θ<82°
RCO 5°<θ<17° Δθ <1°
Low identification threshold for particle, higly segmented
Identification by ΔE-E and PSA





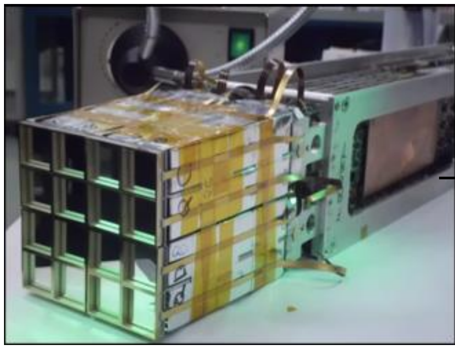




+Gamma array (Hector campaign at LNL)

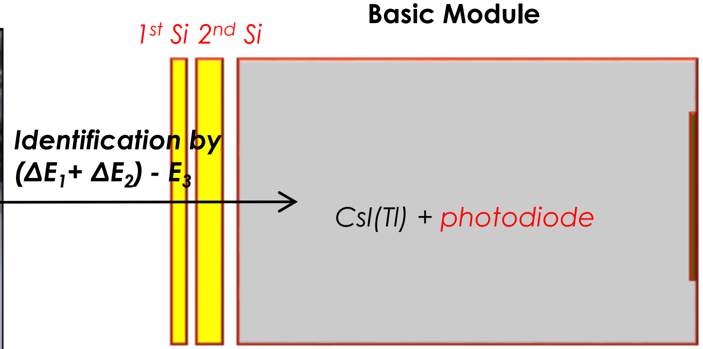
Resident charged particle spectrometer at LNL

Reaction mechanisms with re-accelerated beams: Multi –detector arrays → FAZIA



FAZIA Block with 16 telescopes

Basic Module



1st element: reverse mount 300 μm thick, nTD Silicon of doping uniformity apt to PSA

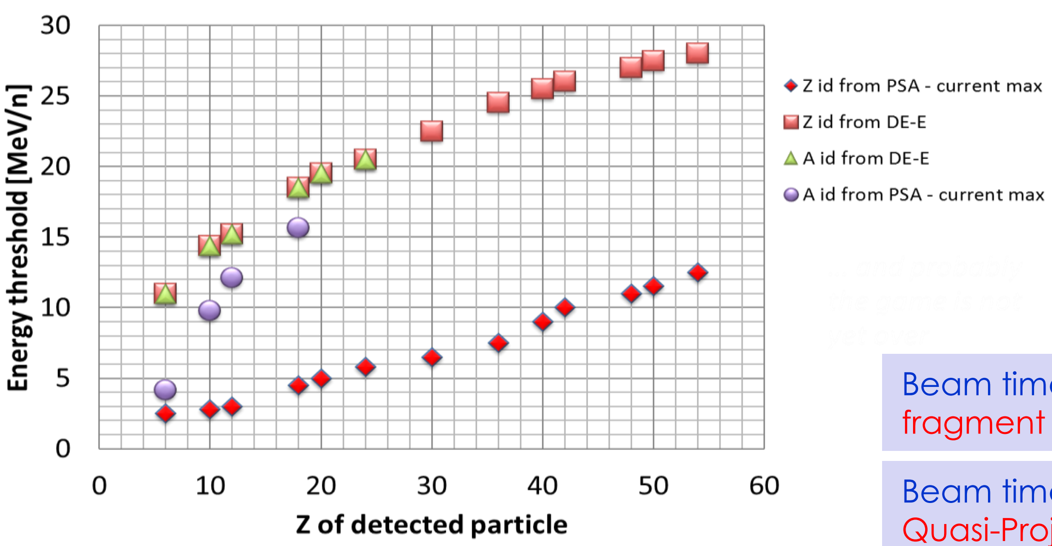
2nd element: reverse mount 500 μm thick, nTD Silicon for redundant PSA

3rd element: 10 cm long CsI(Tl) crystal, coupled to Si-photodiode

First and second Silicon detectors are cut out of a <100> crystal along a properly selected direction in order to avoid channelling.

Total thickness variation of both Silicon detectors < 10 μm

Z and A identification thresholds



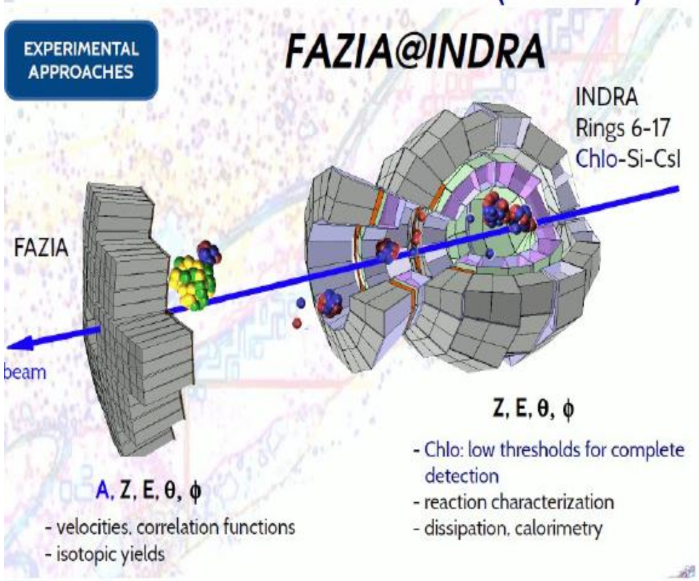
Beam time @ LNS (FALL 2015): Precise measurement of fragment cross section ^{40}Ca+^{48,40}Ca @ 35 AMeV

Beam time @ LNS (June 2015): Role of isospin diffusion on Quasi-Projectile sequential fission ^{84}Kr+^{40,48}Ca@35 AMeV

Reaction mechanisms with re-accelerated beams: Multi –detector arrays → FAZIA

Medium term plans (>2016)

Demonstrator (12 blocks) + INDRA @GANIL



CSS2 will return to operation; stable beams between Ca and Xe (E=40-80MeV/u)

GENERAL PLANNING

- **Experiments INDRA-FAZIA 2017-2019 GANIL**
- **Light unstable beams from LISE (2018-2019 ??)**
- **Experiments with FAZIA at SPES ISOL Facility (2019-2021)**

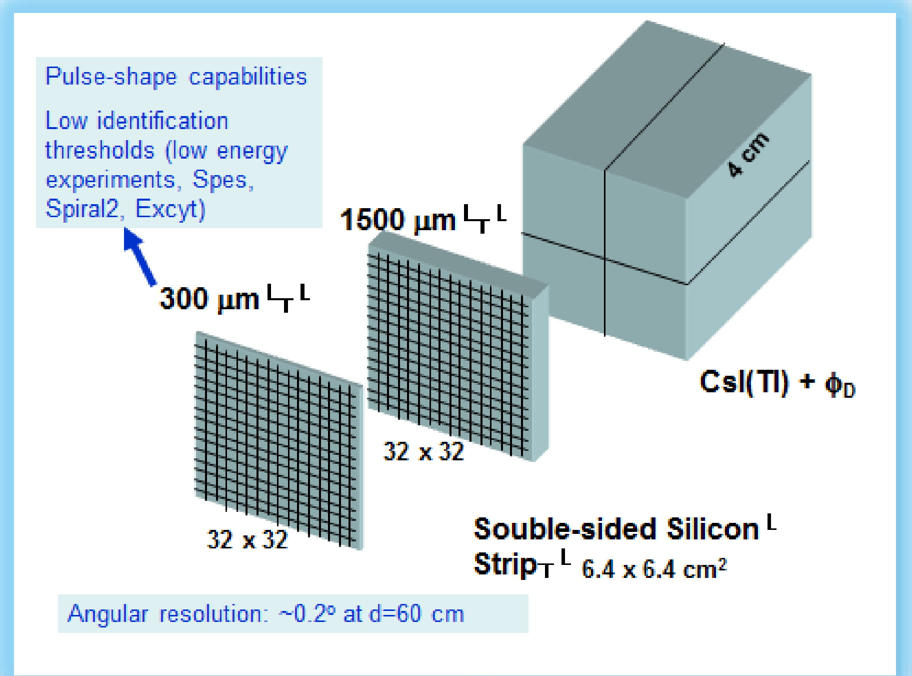
Possible couplings at LNL:
GARFIELD +FAZIA
PARIS (HECTOR+)+FAZIA

The **challenge** for the operation at SPES is the **lowering of the identification threshold** for ions:

- Thin silicon detectors as first stage
- IC first stage

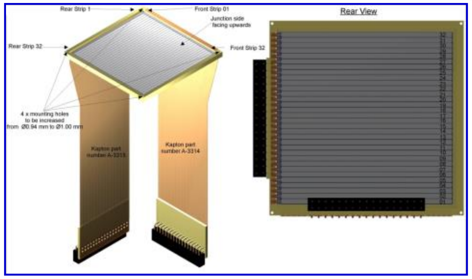
Reaction mechanisms with re-accelerated beams:
Multi –detector arrays

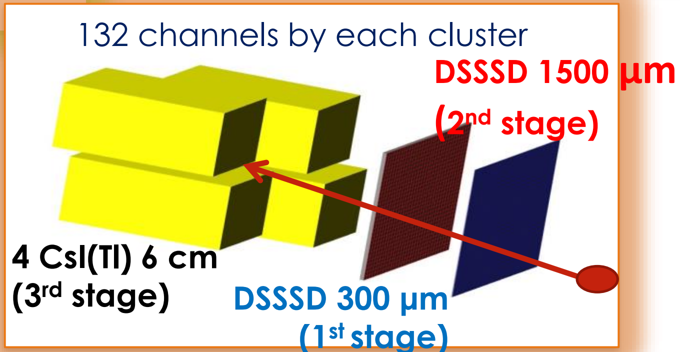
FARCOS: Femtoscope Array for COrrelations and Spectroscopy

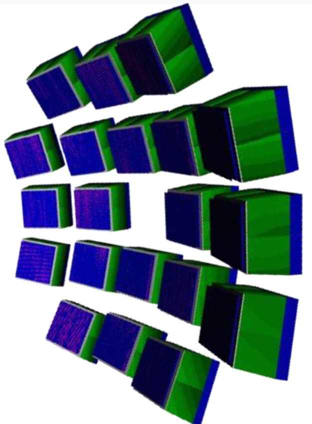


Impact on array features

- Angular resolution ($\delta\theta,\delta\phi<1^{o}$)
- Pulse-shape on first Si layer (Spes, Spiral2,…)
- Flexibility, Modularity: coupling to 4π detectors or spectrometers (transportable)
- Interface to other projects (GANIL, Huelva, MSU)
- Integrated electronics (ASIC,…): internationally based working groups
- Femtoscopy: scientific synergic efforts with other communities (high energy-low energy, dynamics-spectroscopy,…)

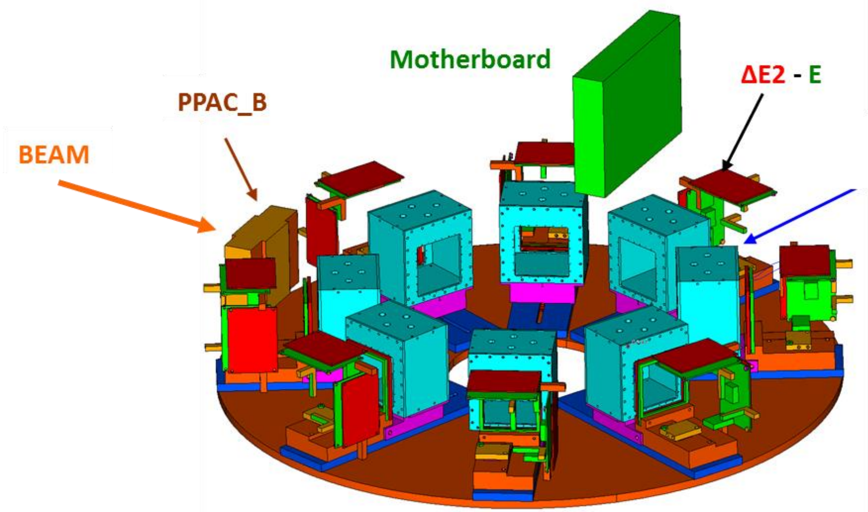




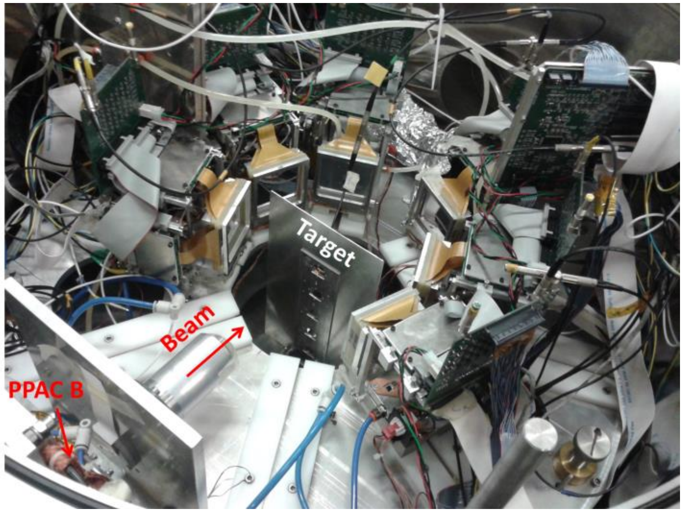


Reaction mechanisms with re-accelerated beams: Multi –detector arrays → EXPADES

a high-granularity, compact, flexible, portable charged-particle detection array for measurements with RIBs



6 EXPADES MODULES IN DSSSD CONFIGURATION AT THE EXOTIC FACILITY (LNL)

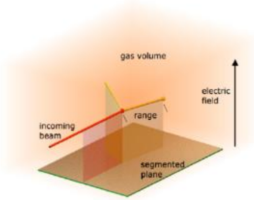


8 Telescopes each one consisting of:
ΔE1 – Ionization Chamber
ΔE2(40 μm) + E (300 μm)
Double Sided Silicon Strip Detectors
64 x 64 mm^2 active area
32 x 32 strips (2 mm) Δθ=1 ° at d=10 cm
For specific measurements also DSSSD (1mm) as E stage

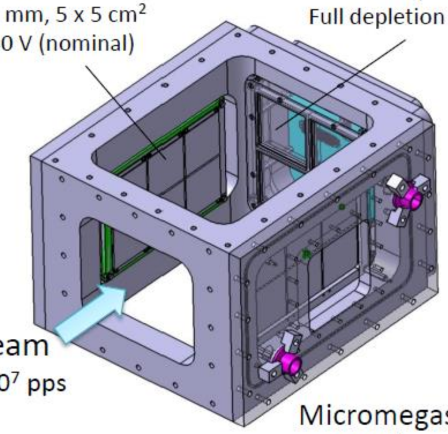
Z identification through ΔE-E
TOF information
Good energy, time and angular resolution
High granularity: coincidence measurements
Coverage: 22% of 4π sr only DSSSDs
5% of 4π sr IC+DSSSD

→ CLAD @ LNS

Reaction mechanisms with re-accelerated beams: Multi –detector arrays → ACTIVE TARGET For SPES

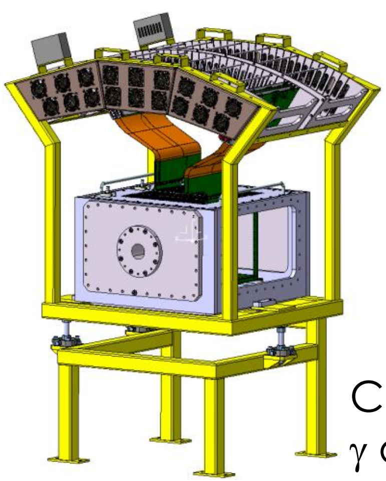


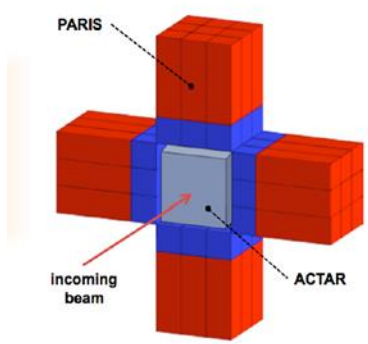
- Gas medium is both target and detection gas
- Segmented detection plane
- Drift times recorded + charge deposition on segments (works as a ***TPC***)
- Auxiliary detectors on the sides of the chamber



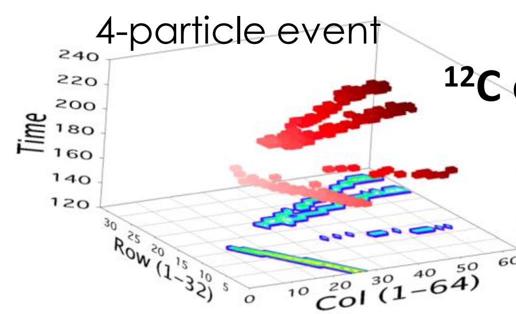
Advantages:

- <u>High efficiency and low detection thresholds</u>
- Wide angular coverage
- Interaction Vertex Reconstruction





Coupling with PARIS-like γ detectors

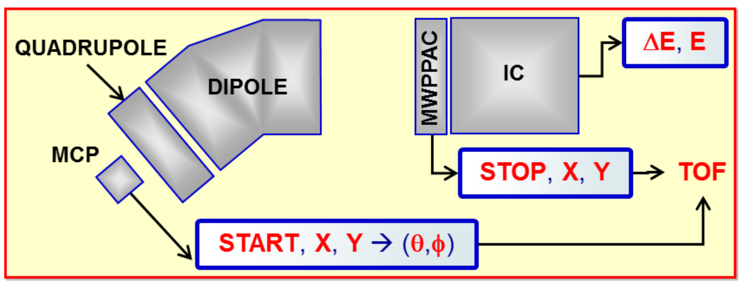


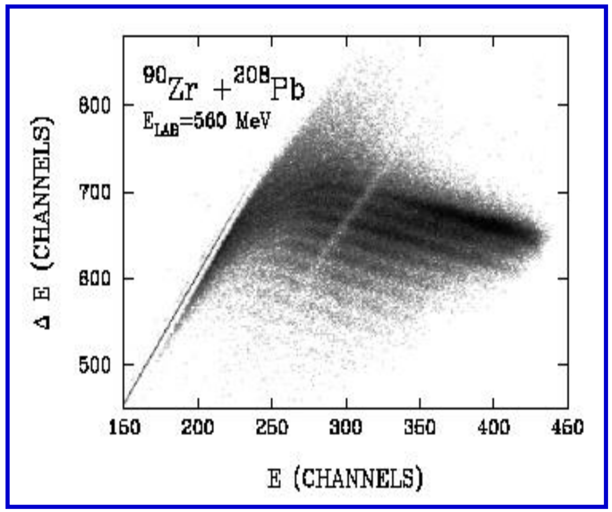
^{12}C on He:C_4H_{10}

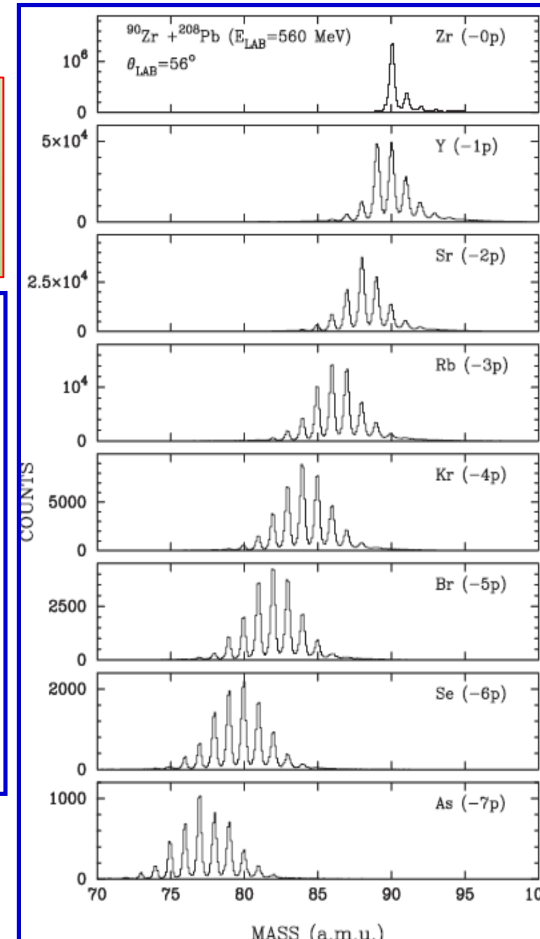
Demonstrator runs with Bacchus Spectrometer at IPN Orsay, June/July 2015

Reaction mechanisms with re-accelerated beams:
Spectrometers → PRISMA

Designed for heavy ion collisions
$\Omega \sim 80$ msr
$B\rho_{max} = 1.2$ Tm
Energy acceptance ~ ±20%







$\Delta A/A \sim 1/20$ $\Delta Z/Z \sim 1/60$

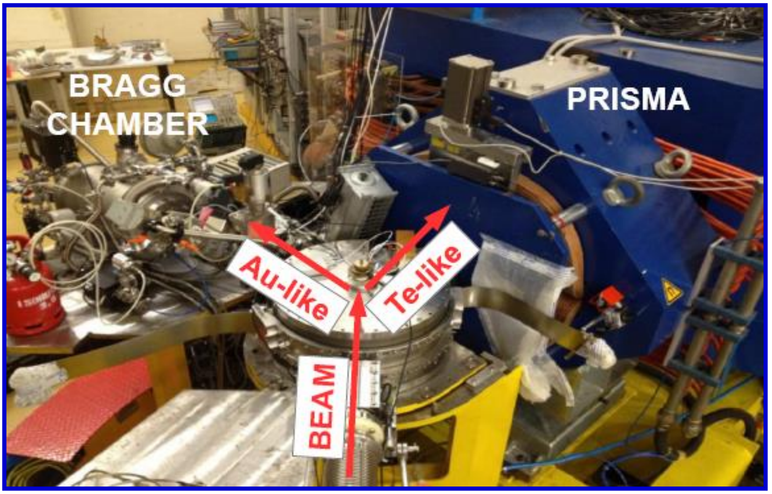
Charge and mass identification in PRISMA allows for precise tagging of species in a wide domain. Coupling with γ-arrays permits accurate structure studies

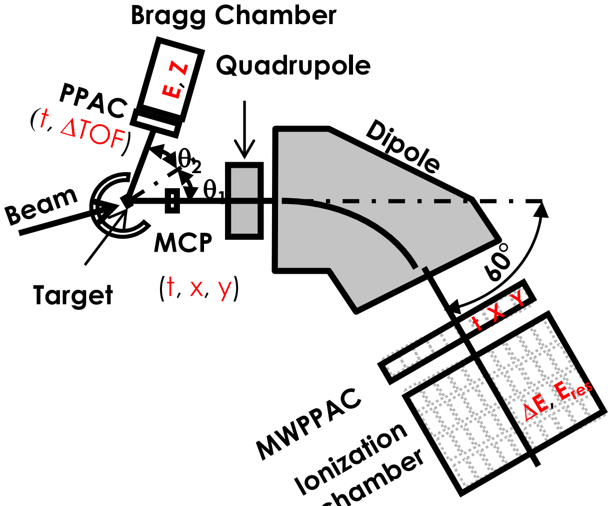
PRISMA + CLARA and PRISMA + AGATA demonstrator campaign at LNL

Reaction mechanisms with re-accelerated beams:

Spectrometers → PRISMA^{++} (PRISMA coupled to a 2nd arm)

Kinematic coincidence measurements



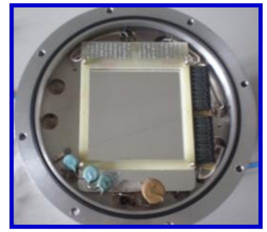


Axial field IC

$d_{cathode\text{-}FG}$ = 32 cm

Gas : CF_4

MWPPAC



$d_{cathode\text{-}anodes}$ = 2 mm

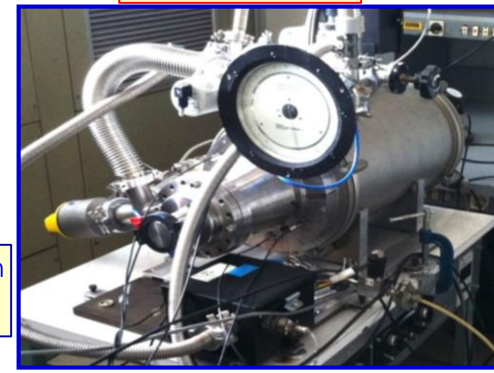
Gas : C_4H_{10}

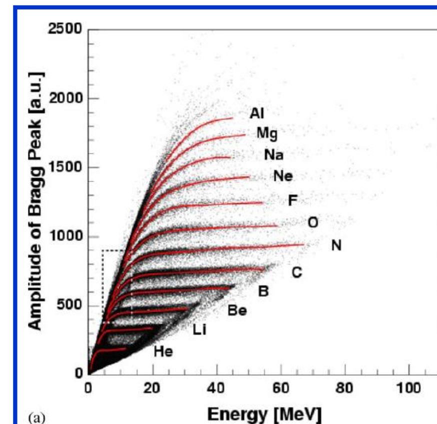
X and Y anode wires

10 μm diameter - 1 mm

delay-line readout → 1ns

Second Arm





PLF or **TLF** in PRISMA (tagging)

x, **y** at the entrance (MCP)

X, **Y** at the FP (MWPPAC)

TOF (MCP-MWPPAC) + **E** (IC) → A_{PLF}

DE, **E** (IC) → Z_{PLF}

TLF or **PLF** in the IC detector

X', **Y'** at KC angle (PPAC) → q_{TLF}, f_{TLF}

DTOF (MCP-PPAC)

E, **Z** (BC)

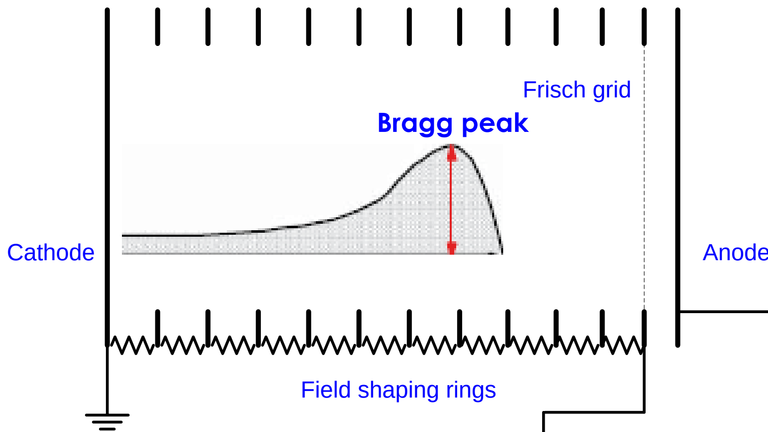
→ **PLF-TLF discrimination**

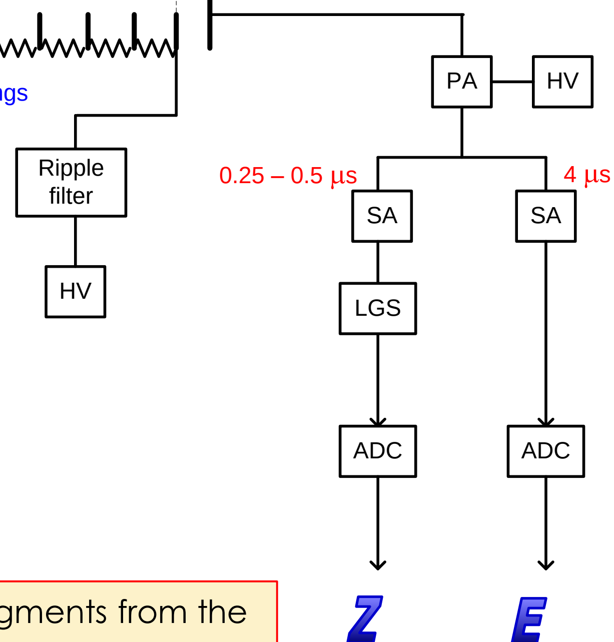
Reaction mechanisms with re-accelerated beams:

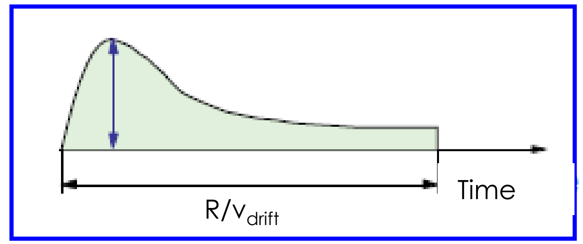
Spectrometers – PRISMA^{++} (PRISMA coupled to a 2nd arm)

Bragg Curve Spectroscopy

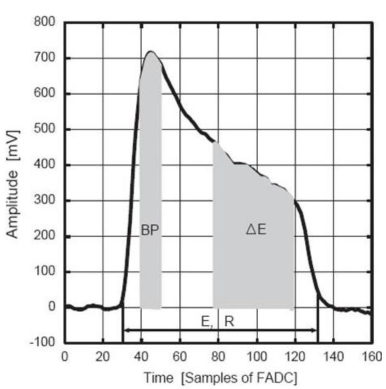
C.R. Gruhn et al., NIM 196 (1982) 33



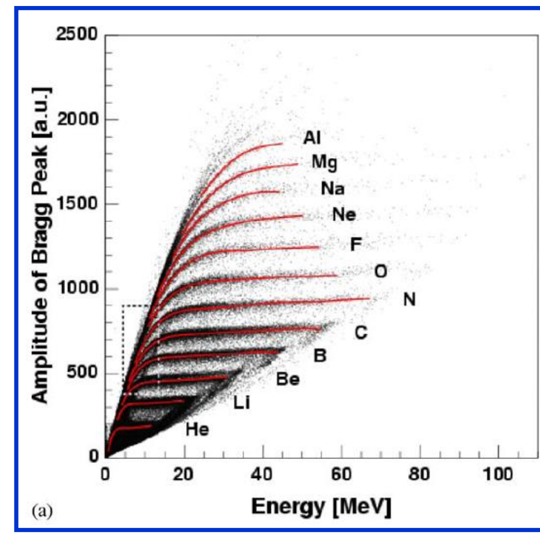




Signal as collected on the anode



Atomic number *Z* of the fragments from the Bragg peak



Energy *E* of the fragments from the integrated charge

SUMMARY AND CONCLUSIONS

G. Casini, LNS November 2012

LOW ENERGY 4 to 12 MeV/u
ISOL Facilities:
Heavy n-rich beams from fissile nuclei
Slightly neutron deficient light- medium mass beams

Main reaction-exit channels

Coulomb Excitation → gamma spectrometry, simple particle array

Direct reactions → gamma spectrometry, segmented particle array

Multinucleon Transfer (MNT) and deep inelastic collisions → spectrometers, HI-detectors, gamma arrays

Fusion reactions → spectrometers, gamma arrays, fission fragment detectors

Impact parameter

- A large variety of instrumentation to be used with RIBs is available
- Development/upgrading of instrumentation is ongoing (italian and international collaboration)
- Starting the preparation of experiments with low energy RIBs
- Needs:
  - Coordinated sinergies between experimental groups
  - Defining strategies for the first day experiments at SPES
  - Beam purification and/or tagging

There's a lot of fun with SPES