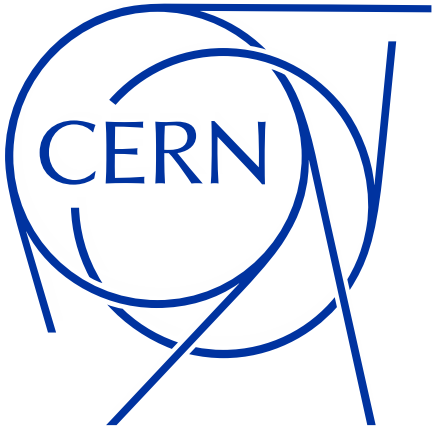


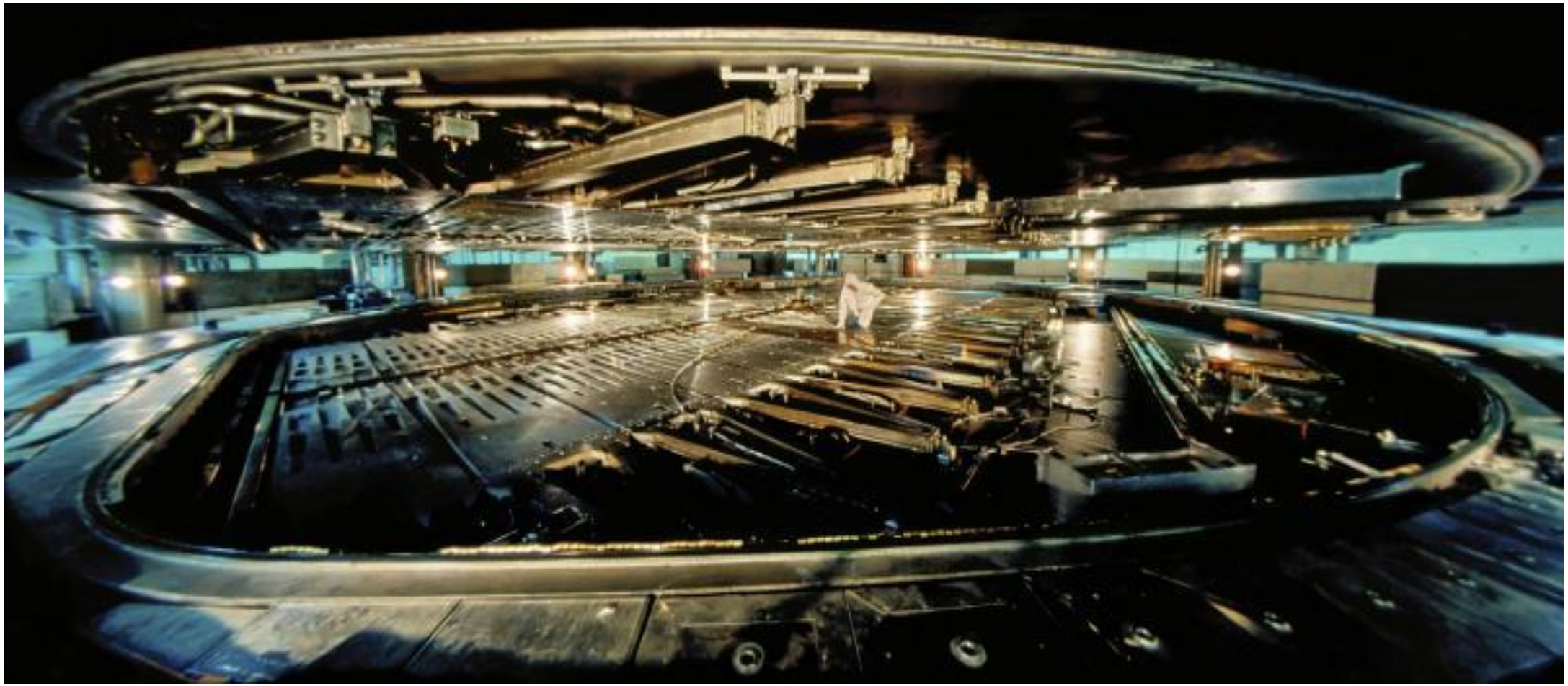
ARIES: A High-Efficiency, High-Granularity Beta-Tagging Scintillator Array with Ultra-Fast Timing for Decay Spectroscopy

Victoria Vedia **victoria.vedia@cern.ch**

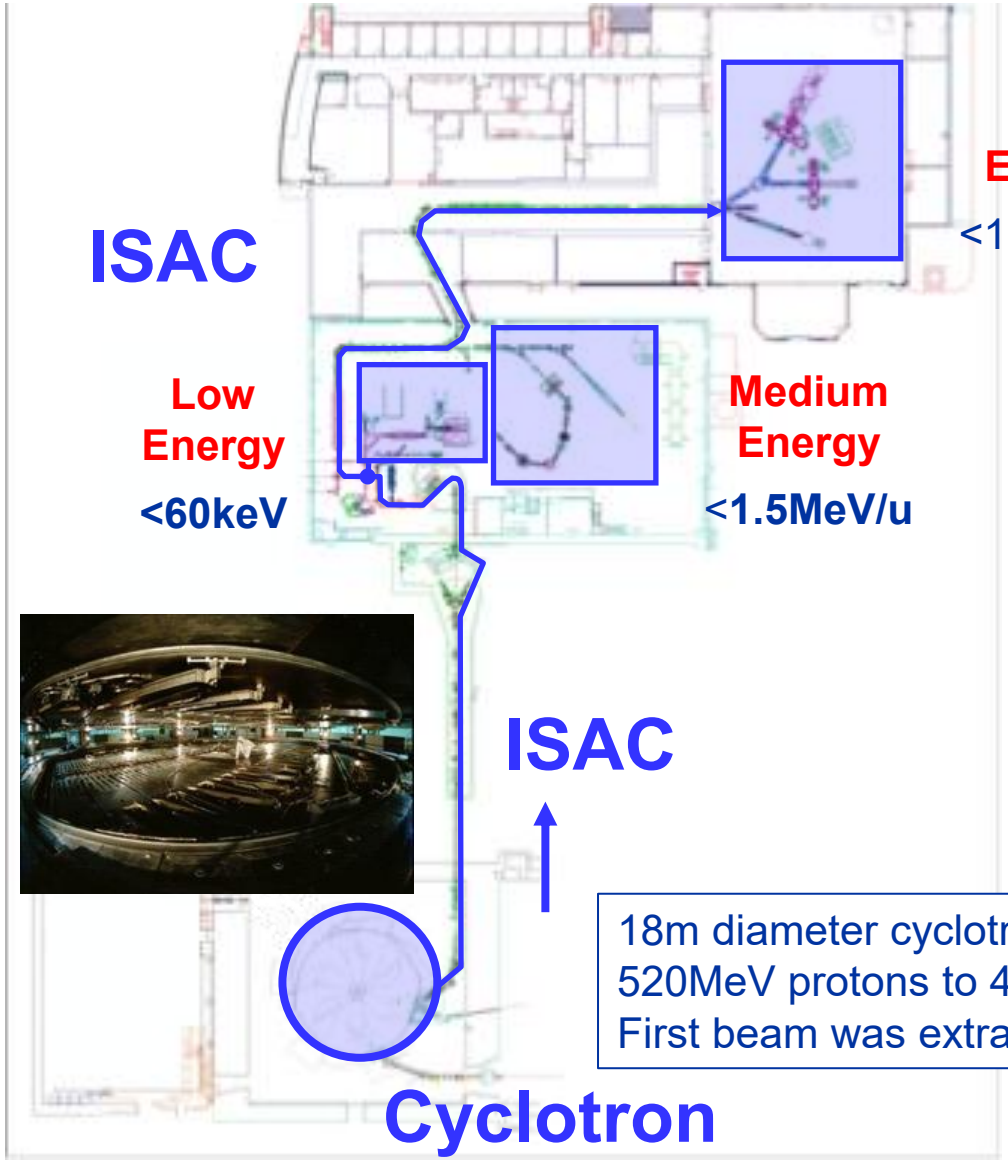
25th of Sep 2025

TRIUMF: Canada's National Laboratory for Accelerator-based Science

Cyclotron with **18m** of diameter, **520 MeV** proton beam

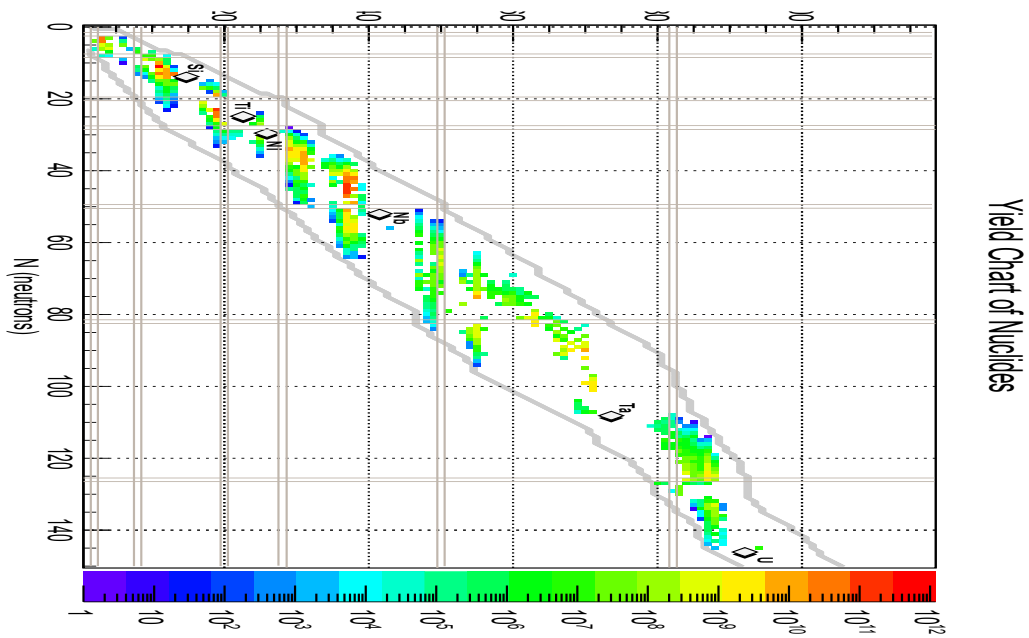


TRIUMF-ISAC:Isotope Separator and ACcelerator



520MeV p^+ at 100μA on ISOL target

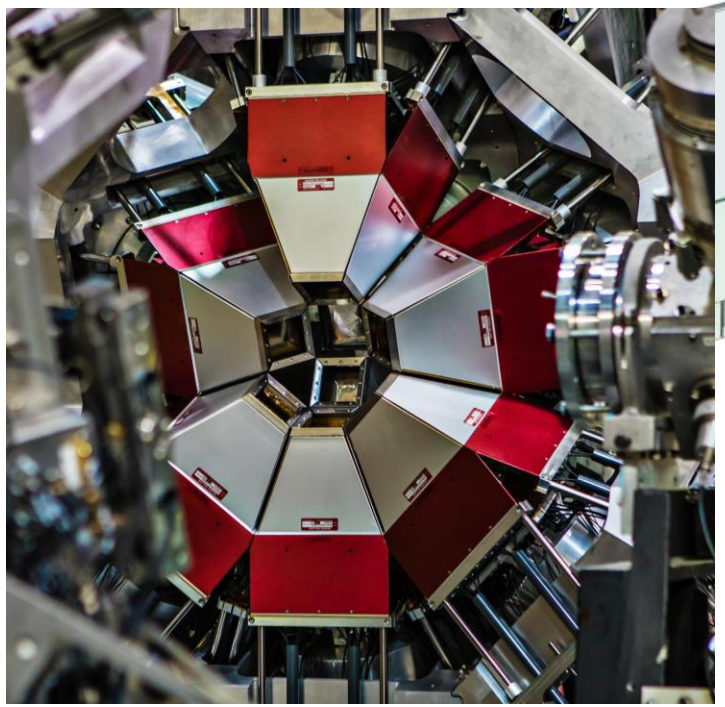
Targets: SiC, TiC, NiO, Nb, ZrC, Ta, TaC, ThO, UO, UCx
Ion sources: Surface, TRILIS, FEBIAD, IG-LIS

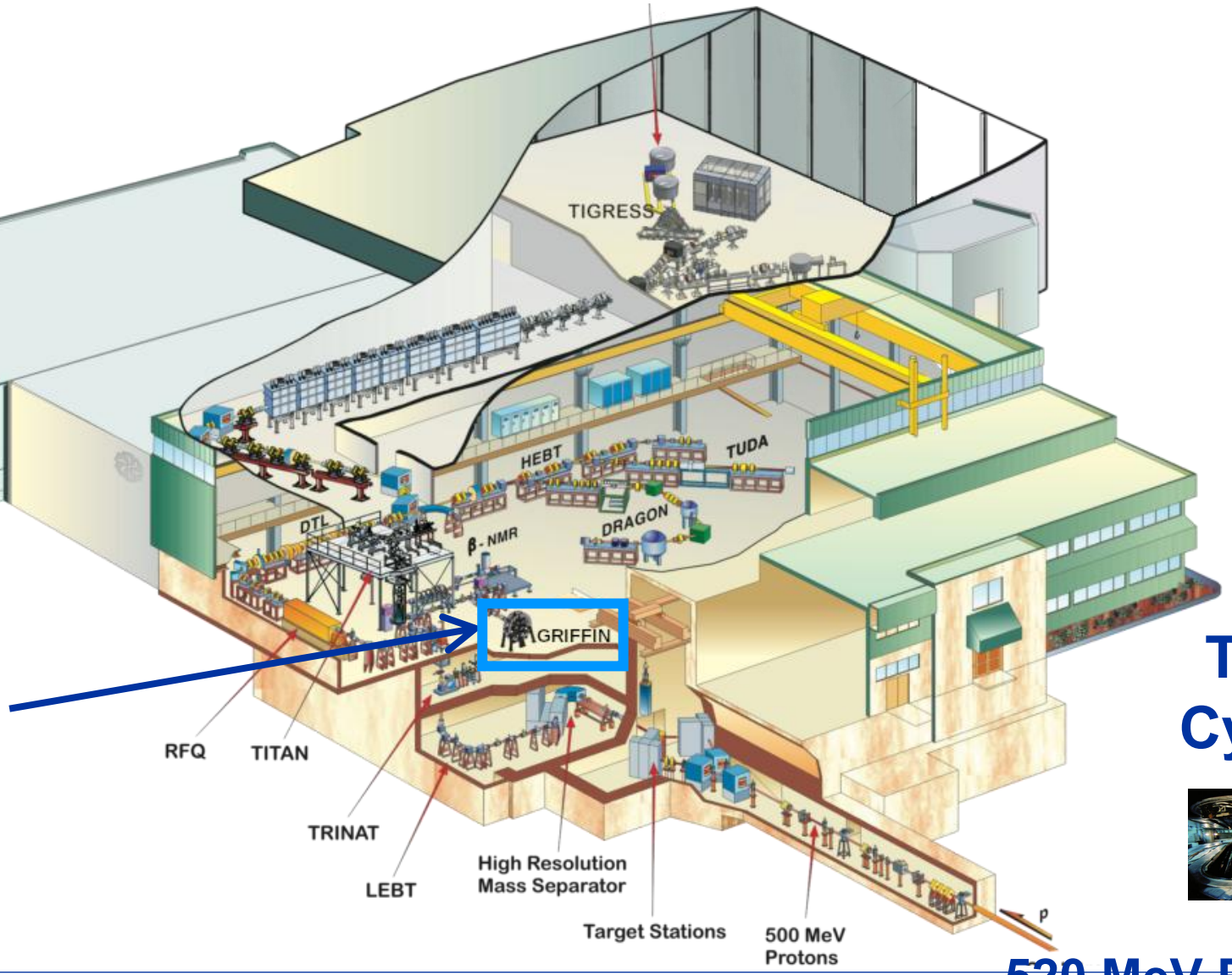


18m diameter cyclotron producing 520MeV protons to 4 beamlines.
First beam was extracted in 1974.

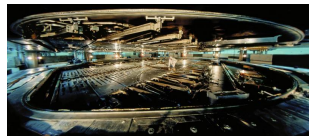
β Decay Studies and γ-Ray Spectroscopy at ISAC

GRIFFIN



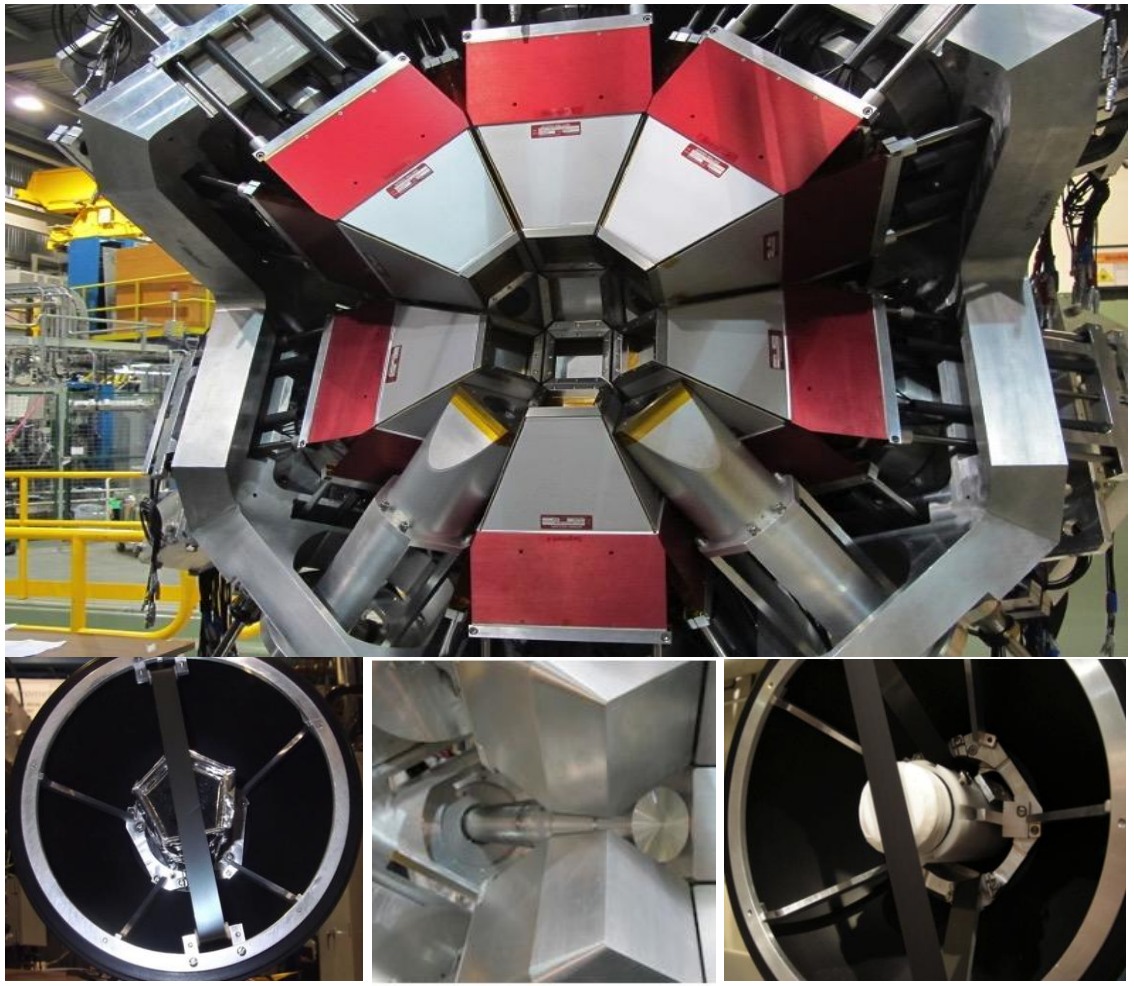


TRIUMF Cyclotron



520 MeV Protons

GRIFFIN Experimental Setup



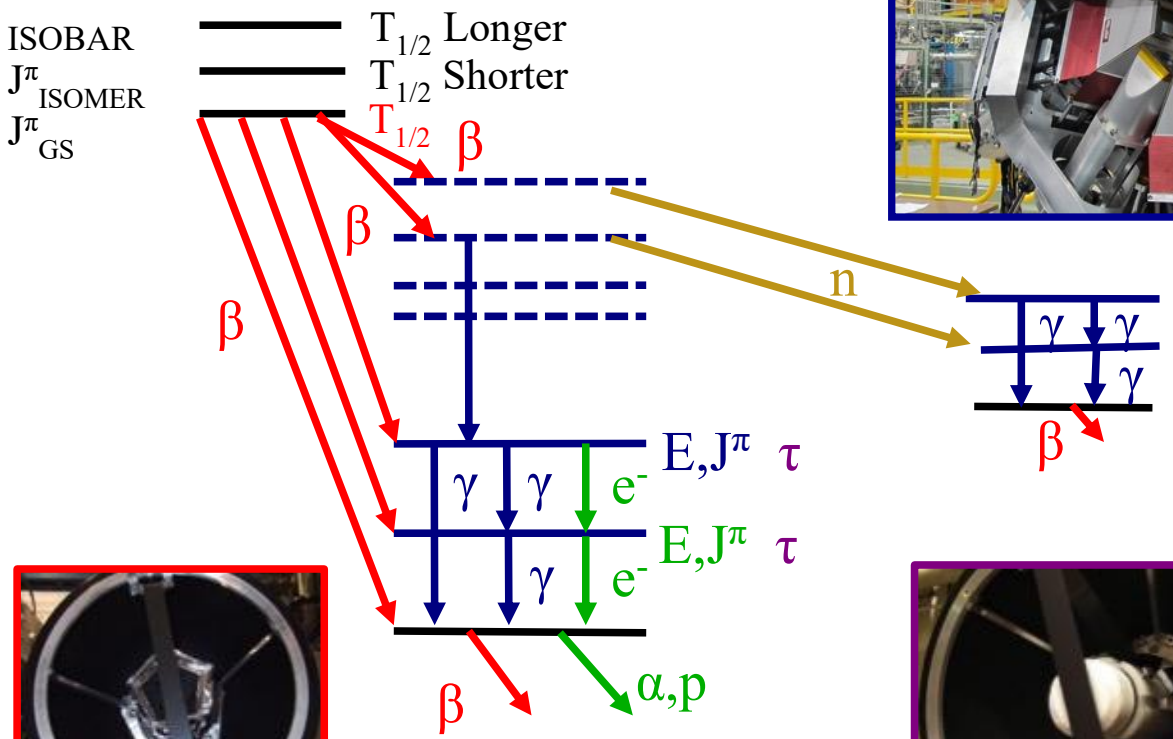
SCEPTAR LaBr$_3$(Ce) ZDS

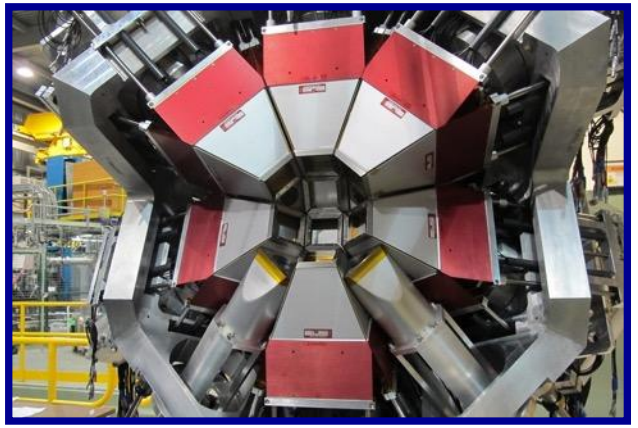
- **16 BGO Suppressed HPGe clovers**
  - 15% efficiency at 1332 keV
  - **4032** crystals pairs at **51 unique angles** for γ-γ angular correlation studies
- **β tagging scintillators**
  - SCEPTAR and ZDS
- **8 BGO Suppressed LaBr$_3$(Ce)**
  - Lifetime measurements via Ultra Fast Timing techniques $\gamma\gamma$(t)

Complete Set of Ancillary Detectors at GRIFFIN

Fast, in-vacuum tape system

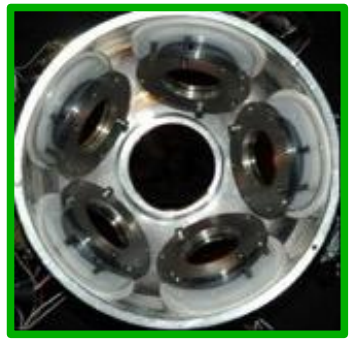
Enhances decay of interest





HPGe: 16 Compton-suppressed Clovers

Detect gamma rays and determines branching ratios, multipolarities and mixing ratios



PACES: 5 Cooled Si(Li)s

Detects Internal Conversion Electrons and alphas/protons

$LaBr_3$: 8 Compton-suppressed $LaBr_3$

Fast-timing of photons to measure level lifetimes

DESCANT Neutron array

Detects neutrons to measure beta delayed neutron branching ratios

SCEPTAR: 10+10 plastic scintillators

Detects beta decays and determines branching ratios

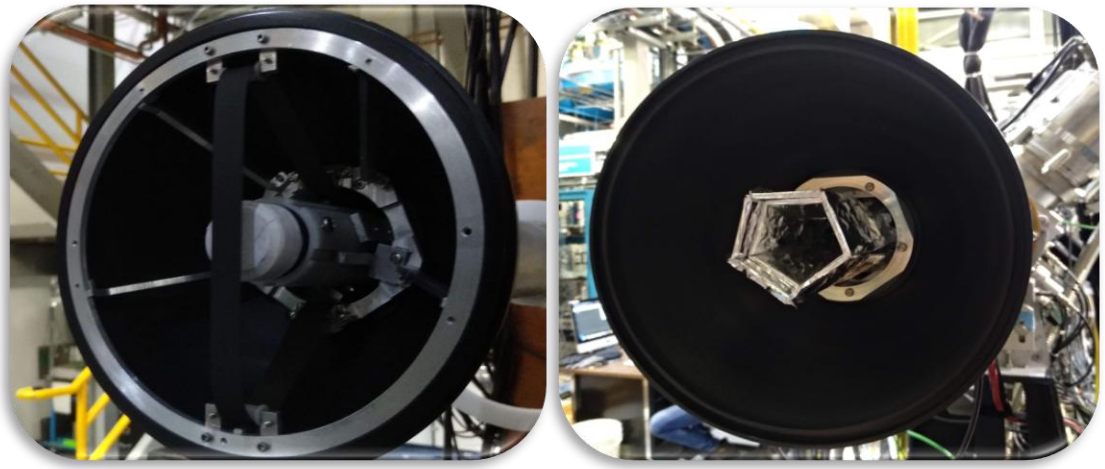
Zero-Degree Fast scintillator

Fast-timing signal for betas

The ARIES Detector

Motivation

- **Main ancillary** detector at GRIFFIN -> Design for GRIFFIN geometry
- **ARIES** : Good features of ZDS and SCEPTAR + New capabilities - Drawbacks
- **Leverage Technologies** (Flex circuit, Al coating by Magneton Sputtering, Mux Circuit)



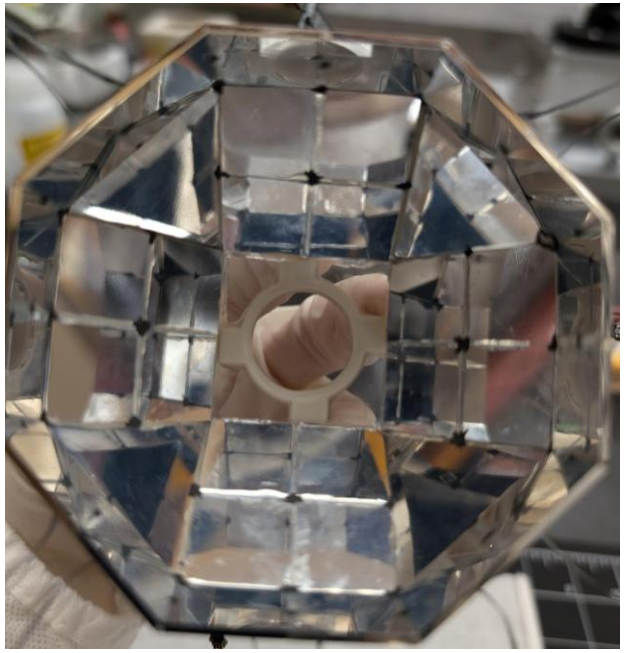
ZDS and SCEPTAR features

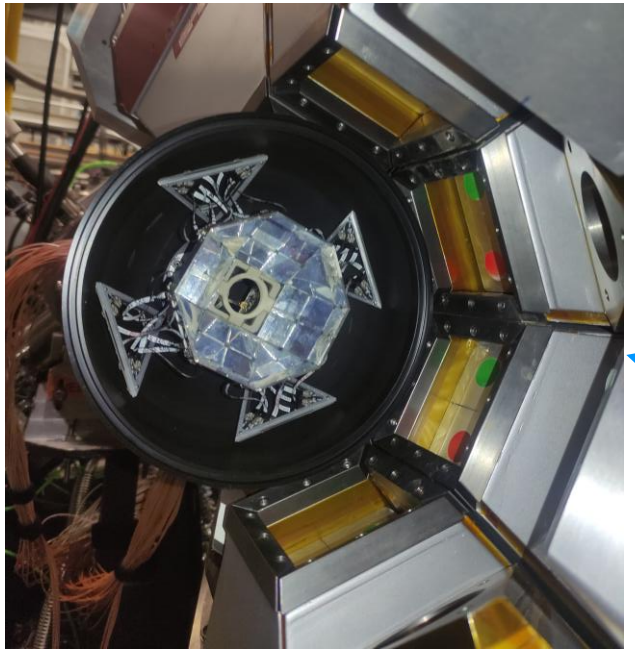
Combine **β-detection** efficiency **80%**
Fast-Tming capabilities ->ZDS

Improved ARIES features

β-detection efficiency : **91.5%**
US (upstream):43.5% and DS 48% downstream
βγγ(t) timing x2 eff. increase over ZDS

ARIES Matches GRIFFIN Geometry 1:1





76 channels in two self-supporting halves of a rhombicuboctahedron

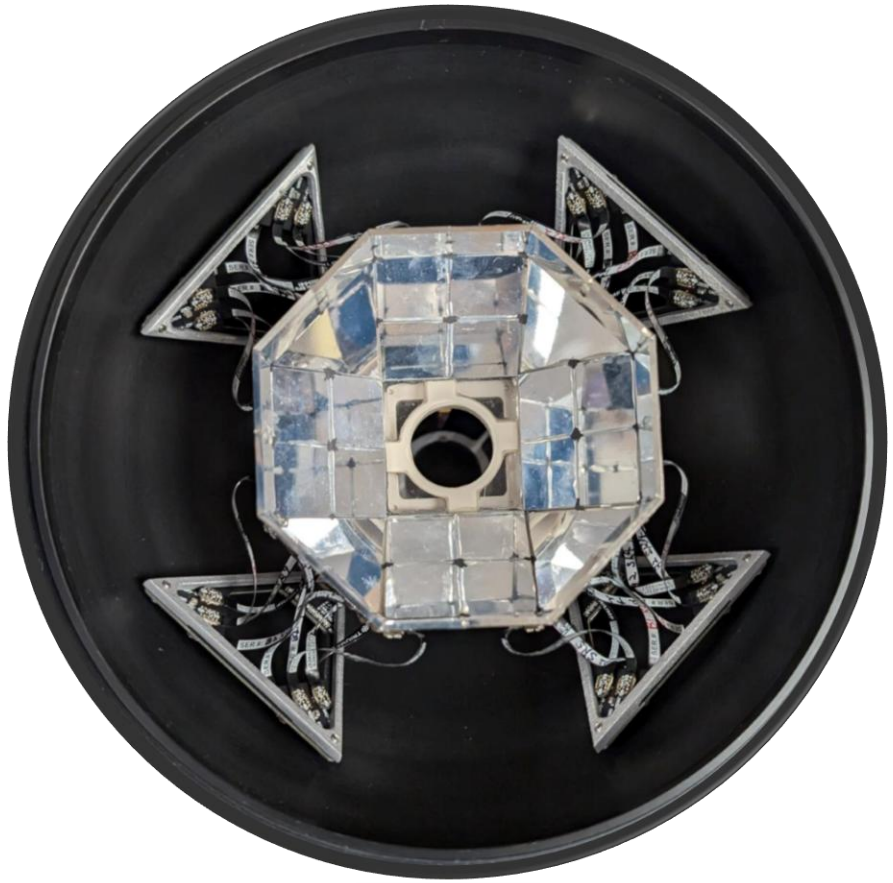
- 1 paddle for each **HPGe** crystal
- 8 triangles for each **$LaBr_3$**(Ce)
- 4 paddles downstream (**ZDS)**

36 (US)+**40** (DS)= **76**

ARIES Detector

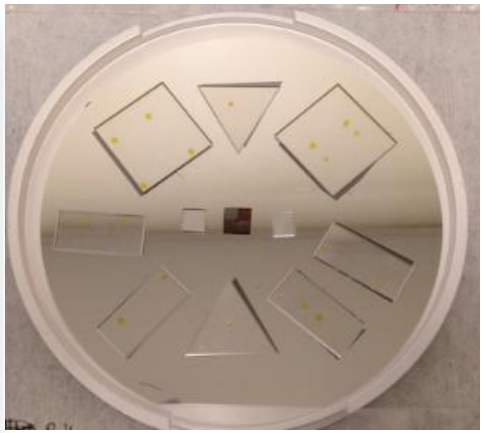
New Capabilities

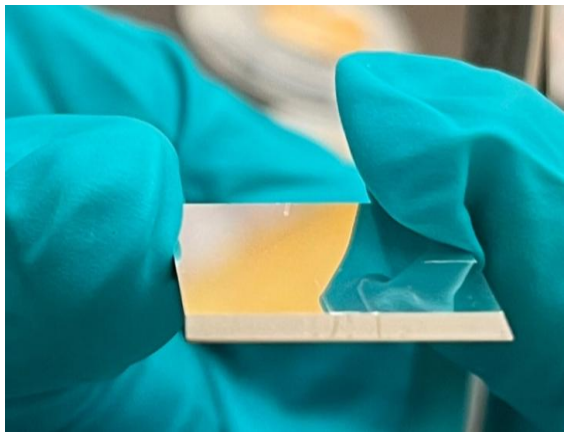
- β–γ angular correlations >114 unique angles
- High granularity and low γ-ray attenuation
- Superior count-rate capability ~20MBq
- Ultra Fast Timing $\beta\gamma\gamma(t)$ statistic x2
- Easy and economical to be replaced
- Background reduction (vetoing HPGe signals from punch-through e^-)

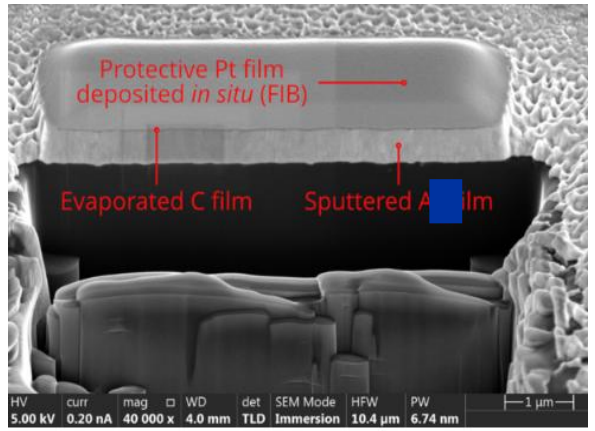


ARIES Scintillators

- **76 Paddles:**
  - Ultra Fast **BC-418** plastic scintillator of **1.5 mm** thickness
  - **390 nm** Wavelength of max emission
  - Rise time of **500 ps** and Decay time of **1.4 ns**
- **Ultra thin Reflective Coating**: **< 300 nm** of Aluminum by **MSD** (Magnetron Sputtering Deposition) leaving a window for the SiPM coupling. Characterized by Profilometry analysis
- **Self supported structure :** To minimize **γ-ray attenuation**, and maximize solid-angle coverage (source-to-tile distance of 38 mm)

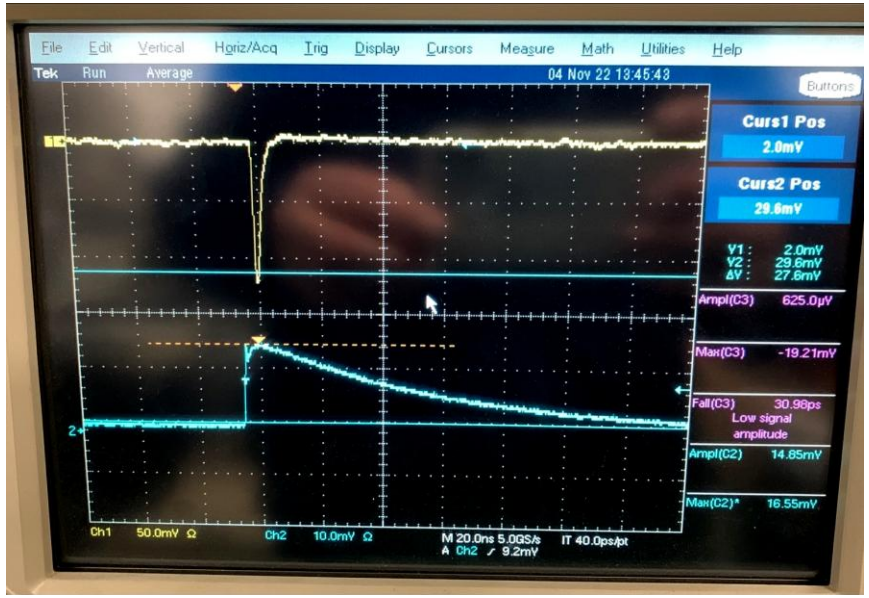


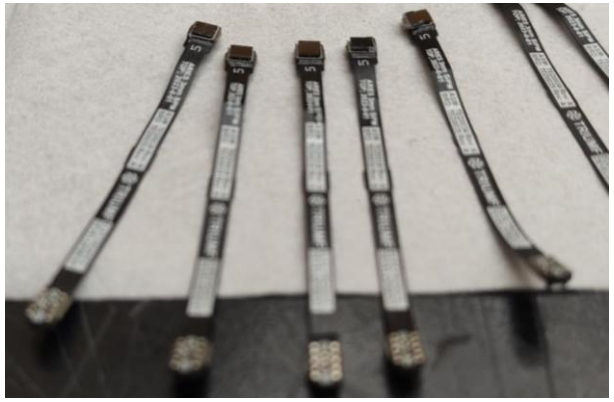


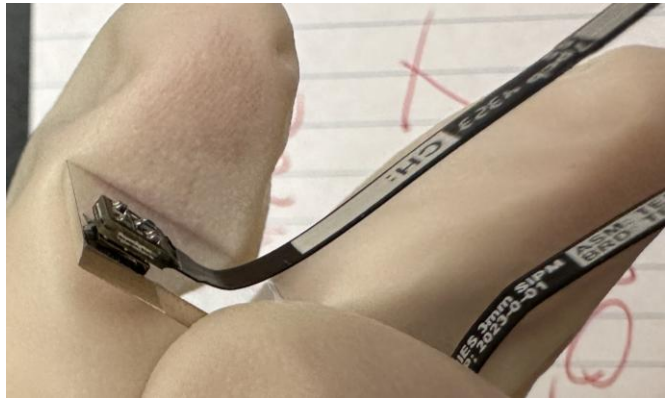


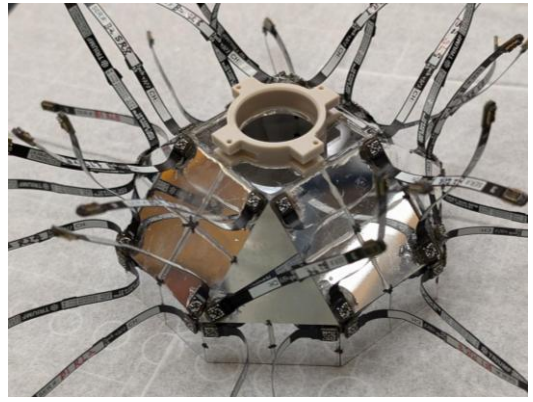
ARIES Electronics

- **Light readout**: Ultra-Fast, High-gain SiPM (J-Series) of
  - 3x3 $mm^{2,}$ Fill Factor of 75% and 5,676 microcells
  - 110 ps of rise time
  - 2 outputs SO (Energy) and FO (Timing)
- **Detachable Tentacles:**
  - Flexible printed circuit boards of ~50μm thickness
  - Cemented to the plastic Scintillators (Optical Cement)
- **Minimal γ-ray attenuation:** All electronic boards and supporting structures occupy the shadow zones



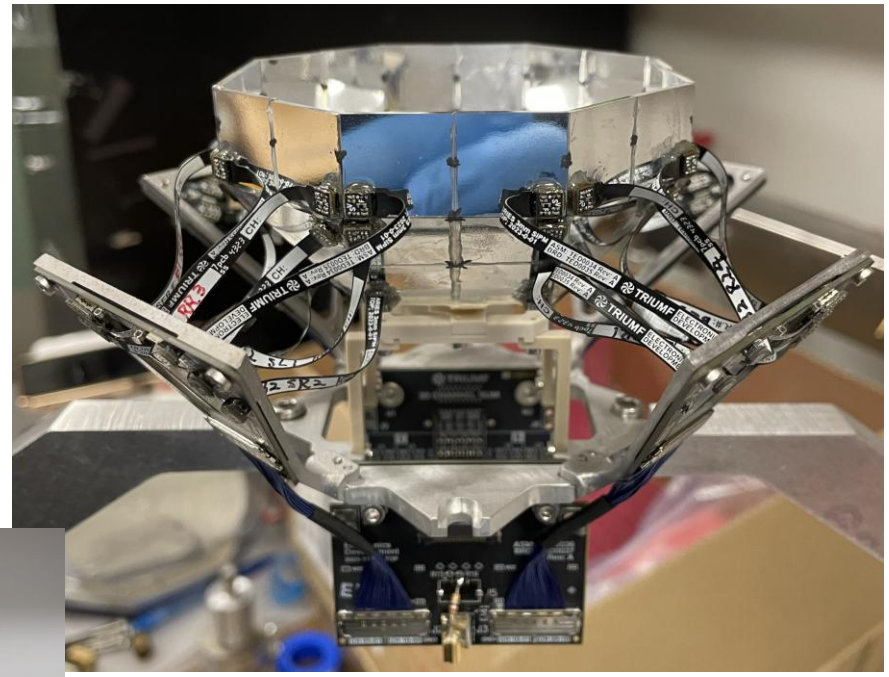


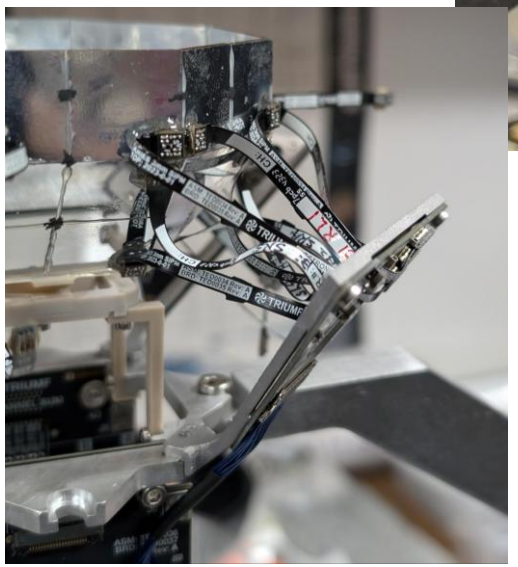


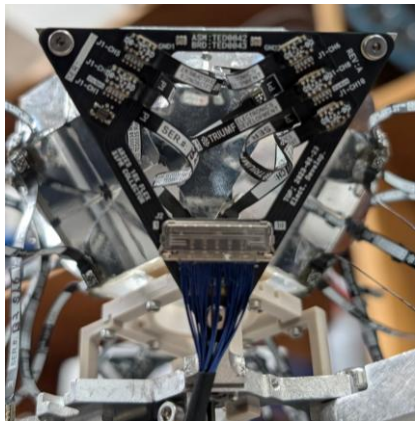


ARIES Electronics

- **Triangular Rigid Boards:**
  - Four collector boards per hemisphere, 10ch each,
- **Summing Amplifier**
  - Multiplexing Fast Outputs (FO), 4 FO for Fast Timing
- **Two Motherboards**
  - Two motherboards per hemisphere.
  - 76 energy signals (SO)
  - 4 ultra-fast-timing signals (FO)

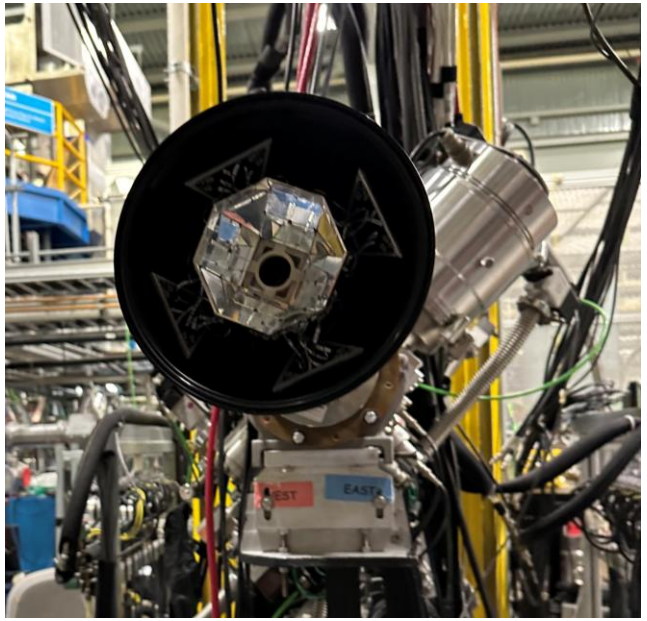


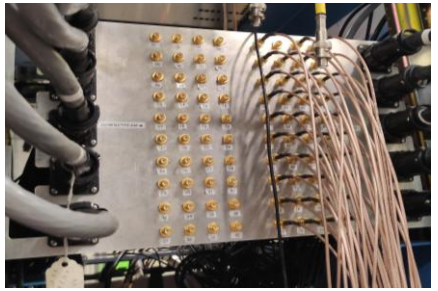


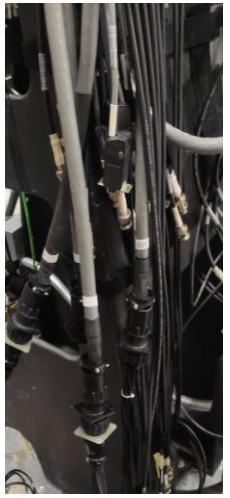


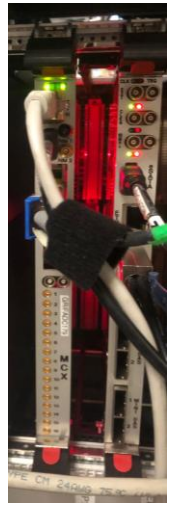
Installed on the GRIFFIN beam line

- **Data acquisition with the GRIFFIN DAQ** custom made DAQ
  - CSA Rear Transition Card (RTC)
  - ADC GRIF16
  - **High data through-put** *>300MB/s total*
  - **High accountability** (Deadtime, pile-up, event tracing)
- **Installation of Setup components:**
  - Signals Patch Panels (Beam line and GRIFFIN shack)
  - 16xRG-174 cables for Signals (SO) and Power
  - LMR-400 cables for Fast Signals (FO)
  - CAEN VME unit for Voltage Supply
  - ic





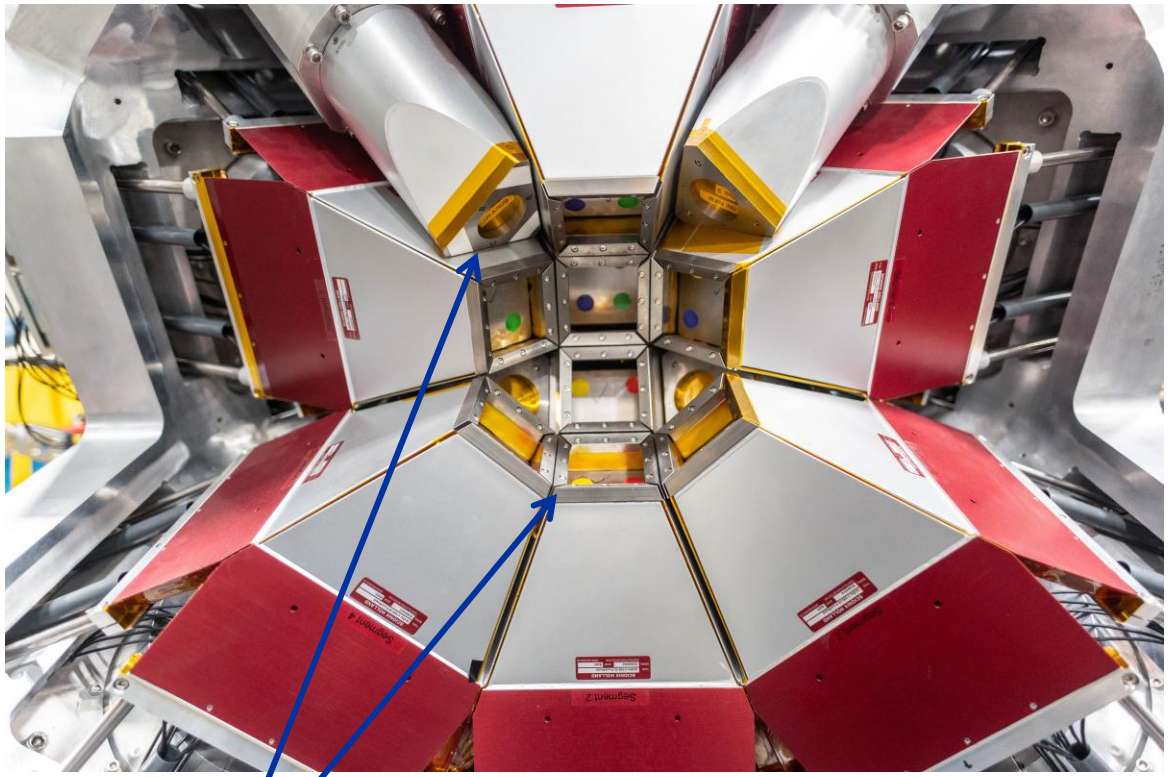




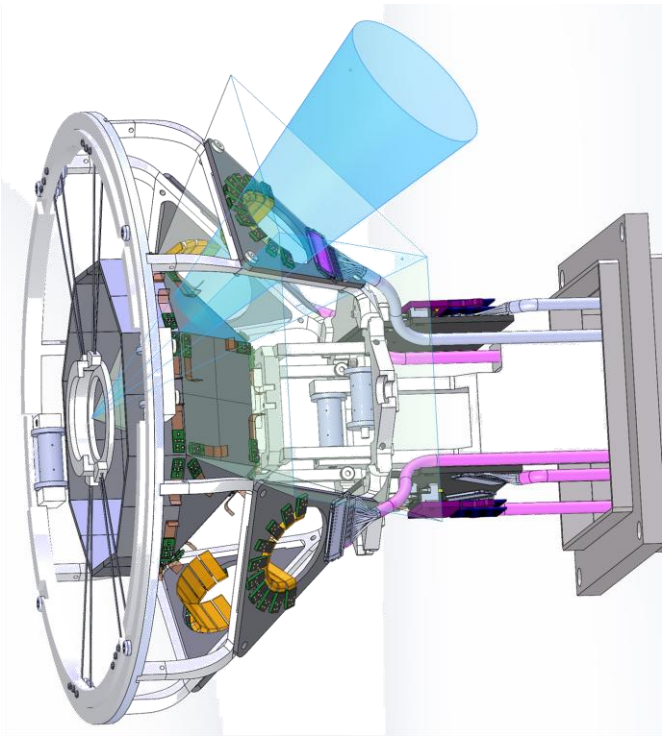
ARIES Detector

- **Minimal γ-ray attenuation:**

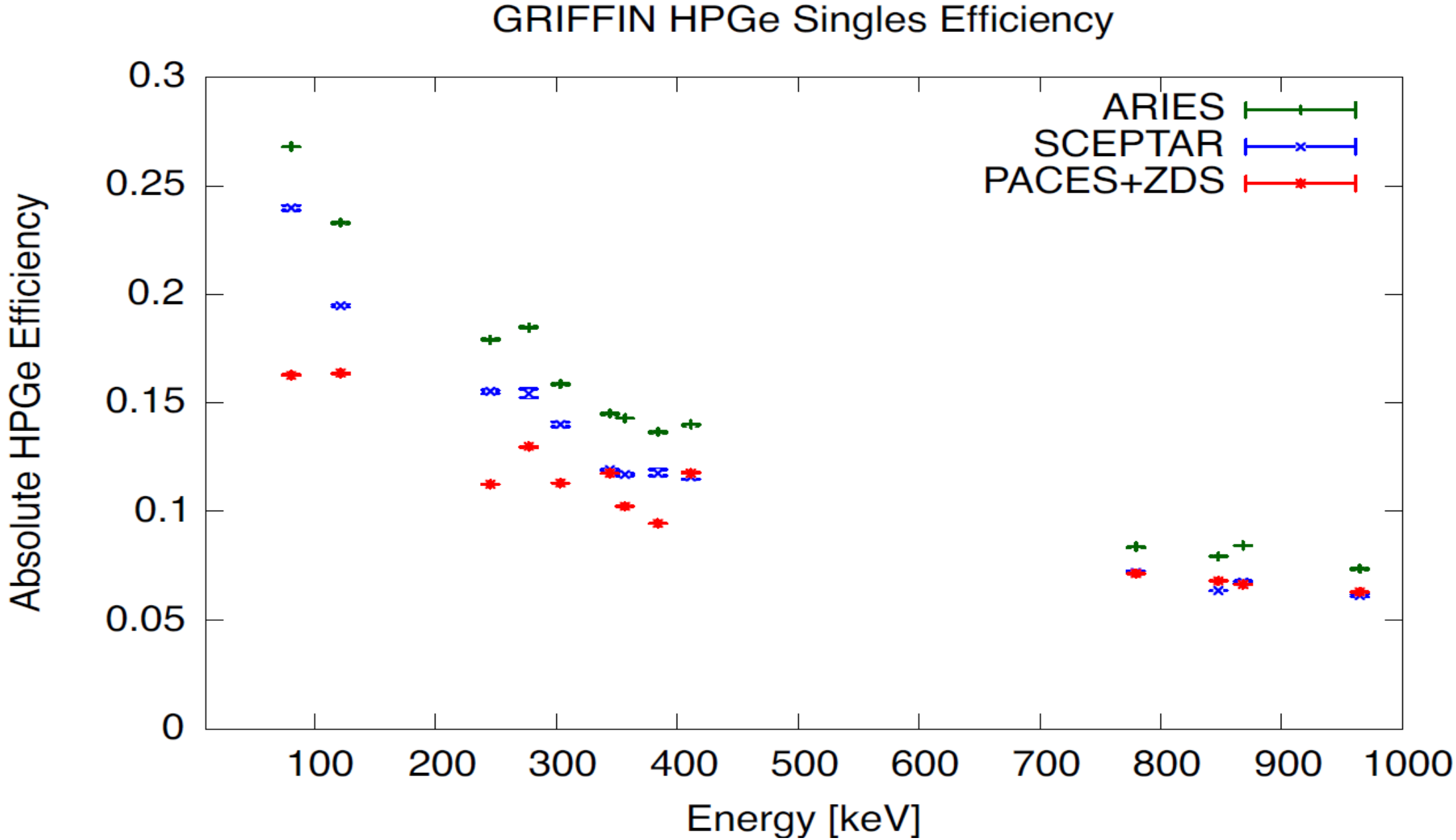
  All electronic boards and supporting structures occupy the shadow zones of the hevimet of the the BGO suppression shields. No components are blocking the either the HPGe nor the $LaBr_3$(Ce).



Shadow zone of hevimet: γ-rays are not measured

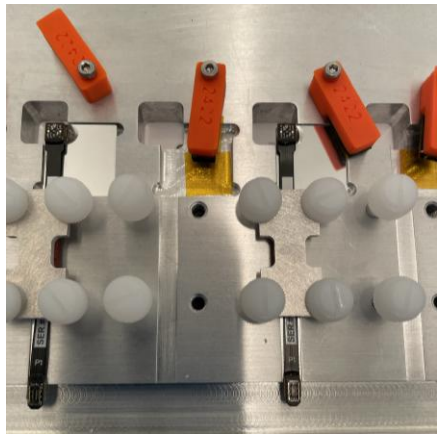


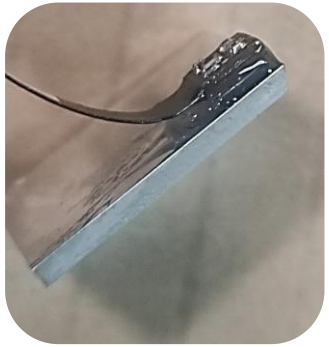
Blue cone indicates the solid angle coverage of $LaBr_3$(Ce)


GRIFFIN HPGe Singles Efficiency
Absolute HPGe Efficiency
Energy [keV]
ARIES
SCEPTAR
PACES+ZDS
0.3
0.25
0.2
0.15
0.1
0.05
0
100
200
300
400
500
600
700
800
900
1000

Construction of ARIES

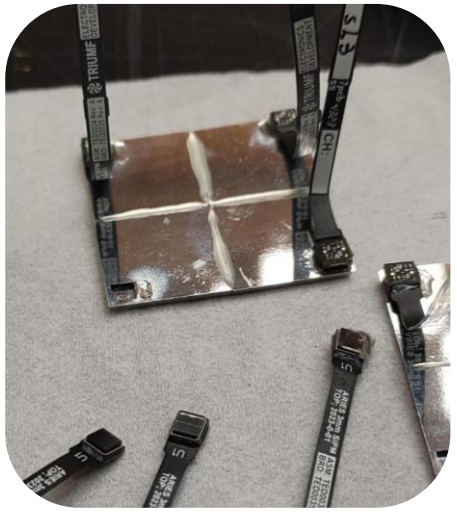
1 Coupling of individual tiles with tentacles



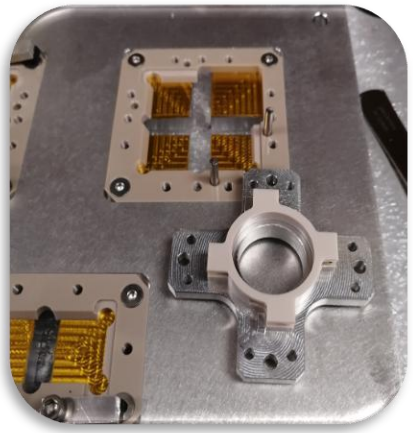


2 Gluing of the composite tiles

Squares 32x32mm
Rectangles 32x15mm

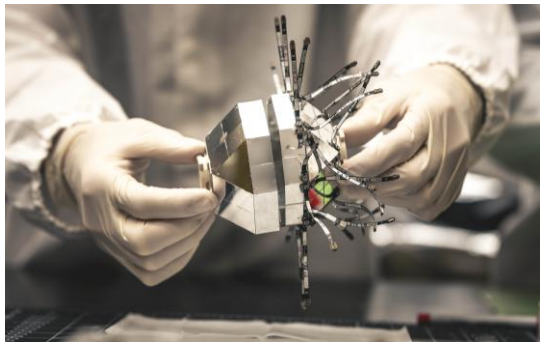


3 Gluing of the coupling ring

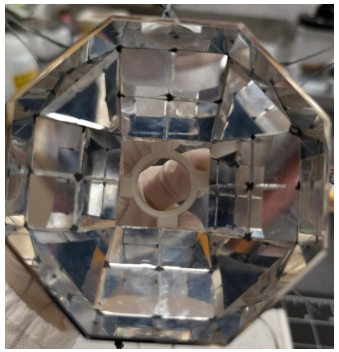


3 Assembly of the full Hemisphere

4 Unmolding the Hemisphere



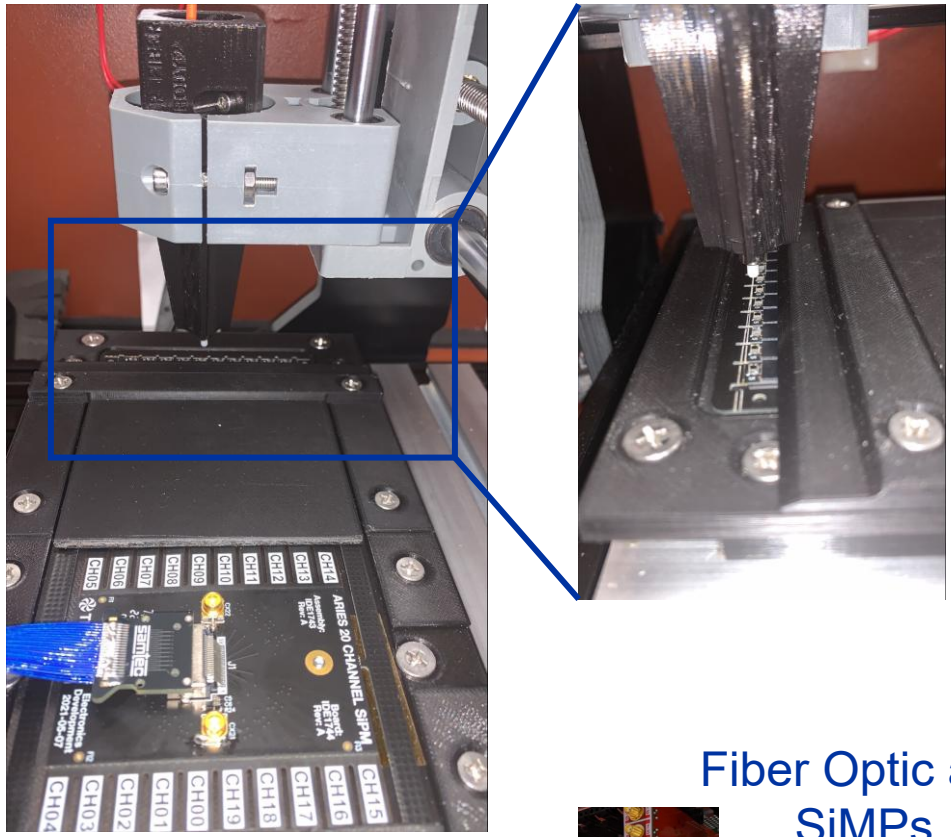
5 Adding conductive paint



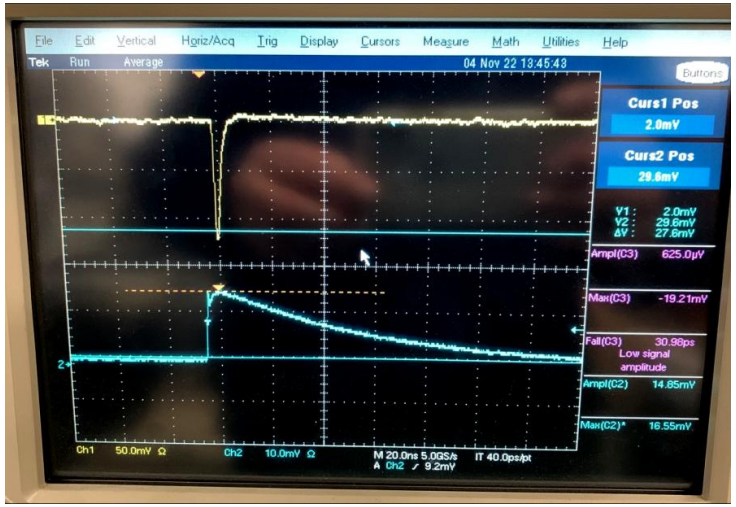
Electronics of the ARIES Detector

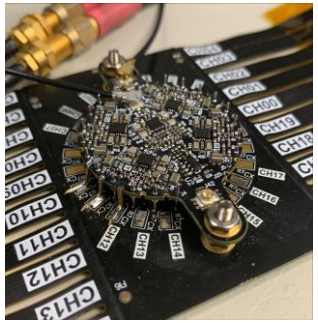
1. Systematic Test of every Ch channel

Testing of the Electronics: Laser box and at the GRIFFIN beam line



2. Test of the Summing Amplifier for FO



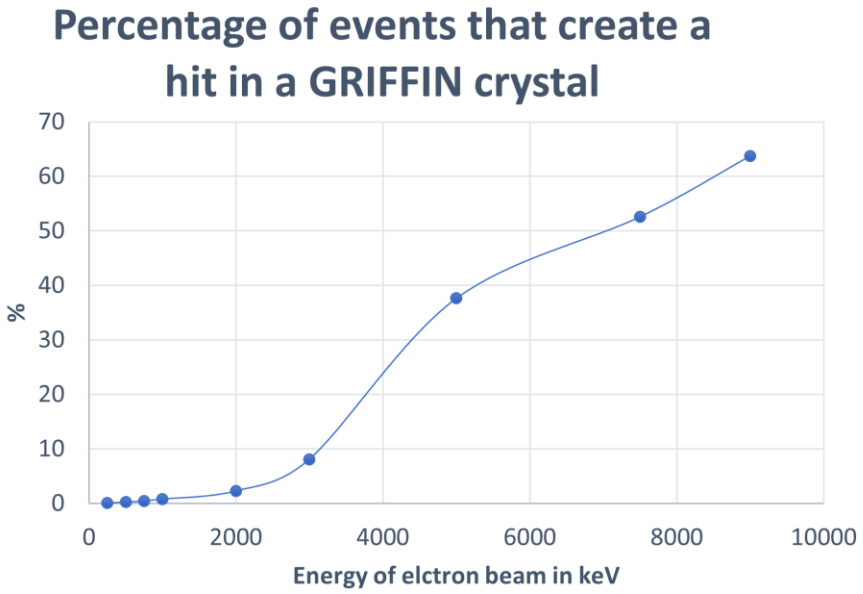


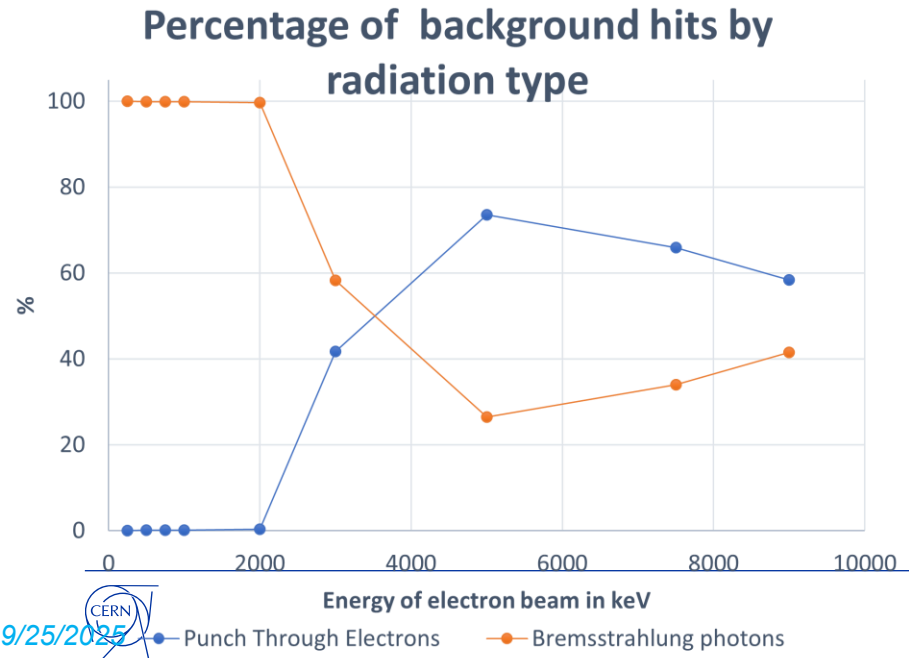
Laser box with circuit board

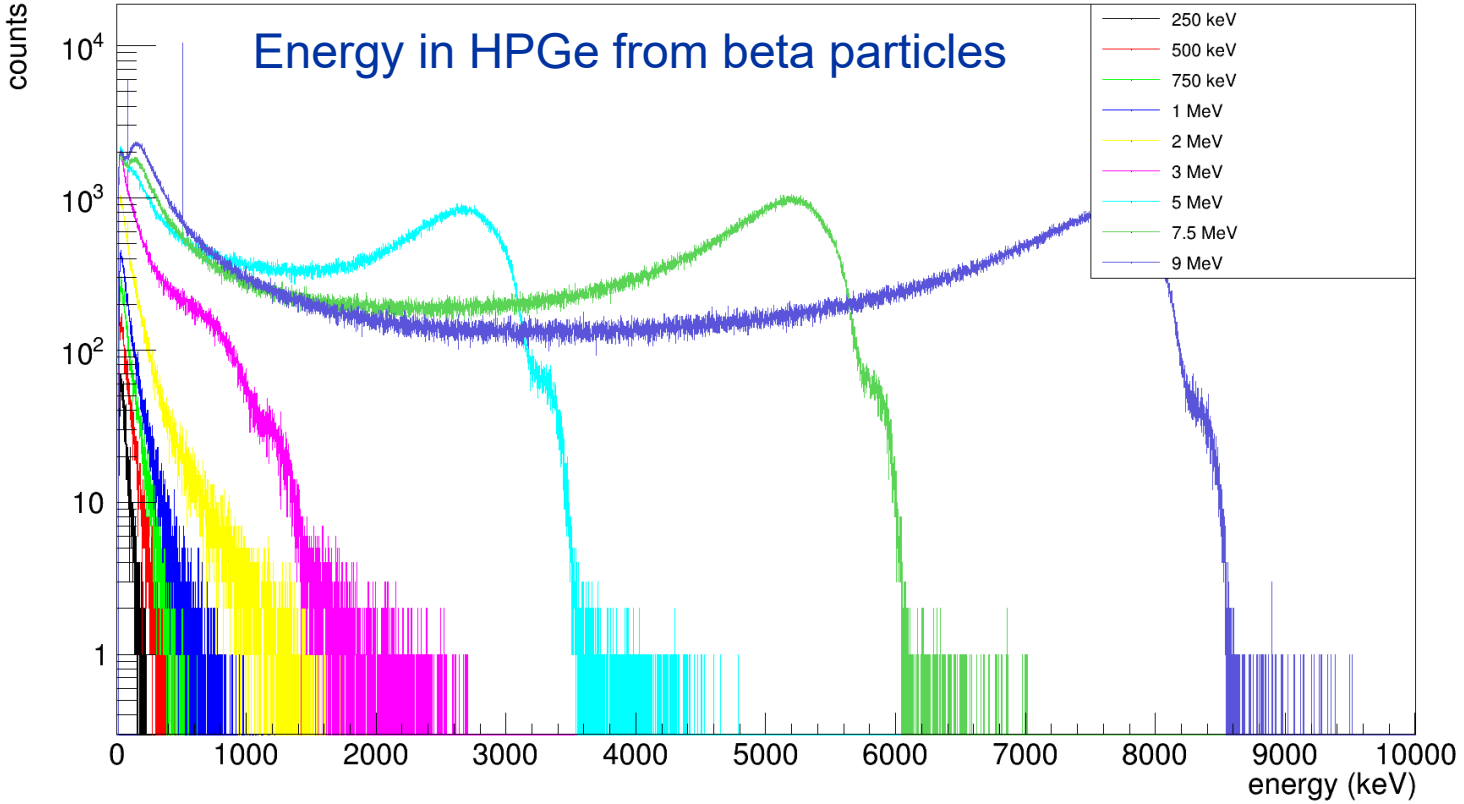
Fiber Optic and SiMPs

CSA RTC

Bremsstrahlung veto with ARIES



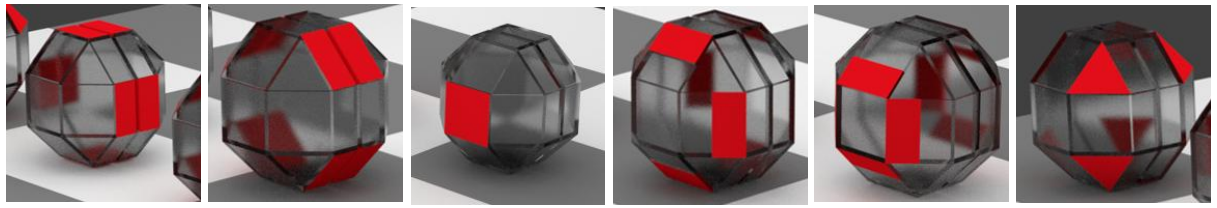




Background is from Bremsstrahlung radiation only below 2MeV, but only a few percentage of such low-energy beta particles produce a background in HPGe.

Punch-through of beta particles into HPGe only possible above 2MeV, but quickly dominate and become a significant source of background.

Bremsstrahlung veto with ARIES



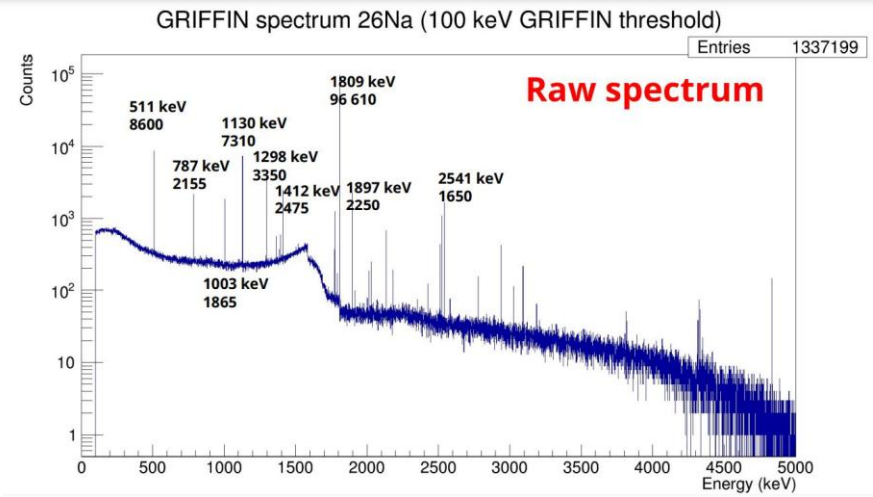
6 distinct ARIES tile types/locations investigated in GEANT4 simulations.

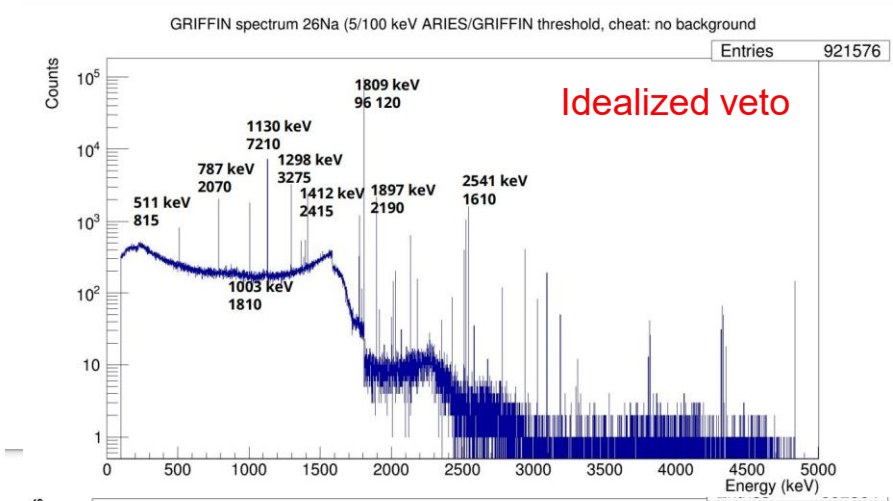
GEANT4 simulated ^{26}Na decay spectra on the right;
"Idealized veto" removes background events in the GEANT4 simulation based on primary particle type,
"Angle veto" uses an algorithm in the data sorting based on relative ARIES-HPGe angles. 30 degrees is used for ^{26}Na which vetos 2-4 HPGe crystals.

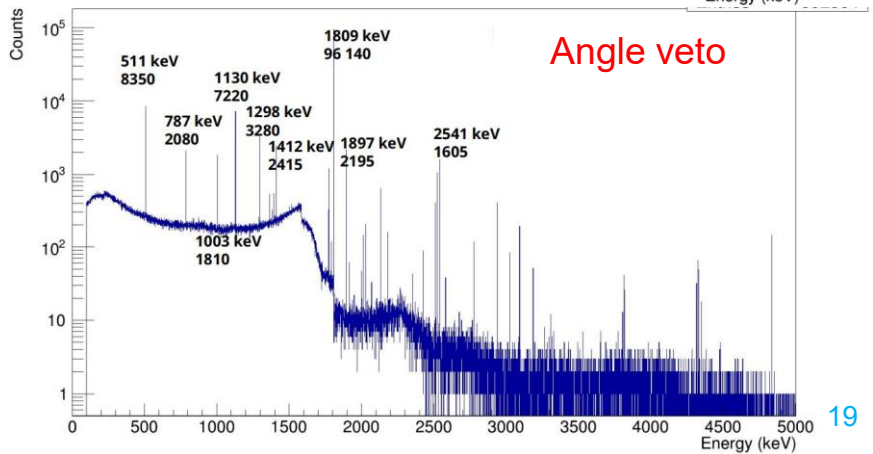
The "Angle veto" removes 82% of the events removed by the "Idealized veto" for ^{26}Na decay spectrum. Eff_{HPGe}=28.1%@100keV

The 20mm DELRIN absorber removes 80% of the events removed by the "Idealized veto", but causes a reduction in low-energy gamma-ray efficiency. Eff_{HPGe}=19.5%@100keV

The most effective choice of angle to veto has a *Q*-value dependence and can be chosen on an experiment by experiment basis.



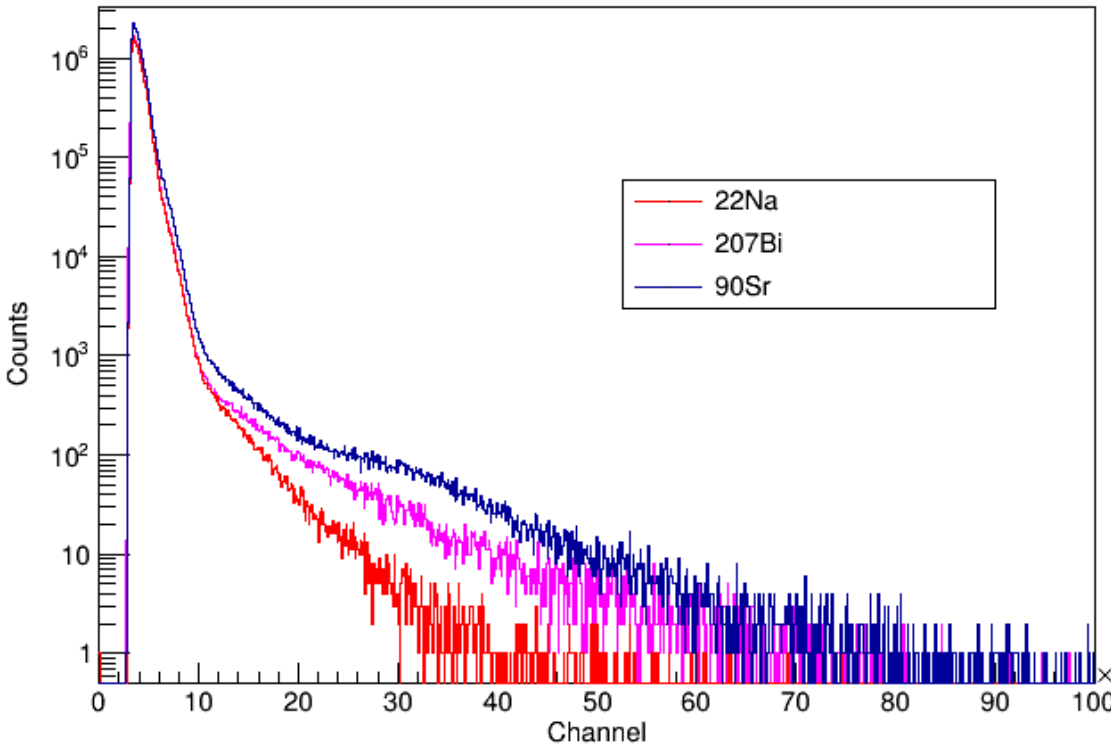




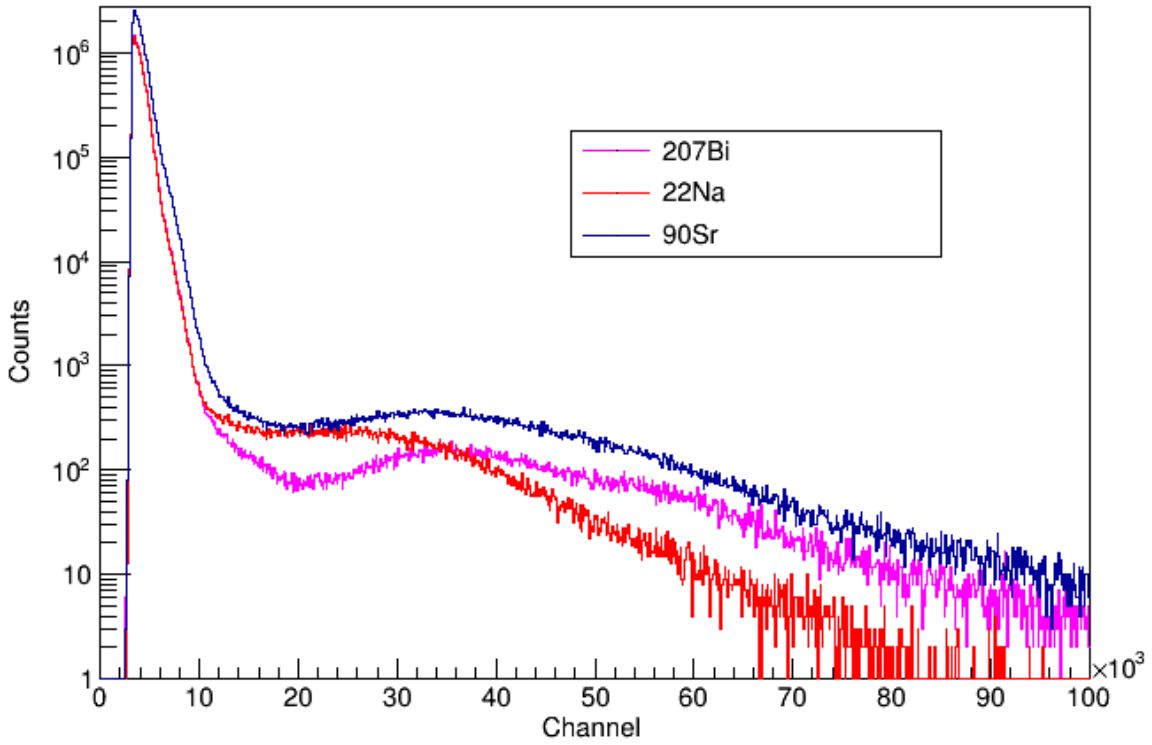
Energy of ARIES Detector

Square Tile of BC422Q (0.5%) 16x16 mm and polished 90º edges

1x1 mm optical window

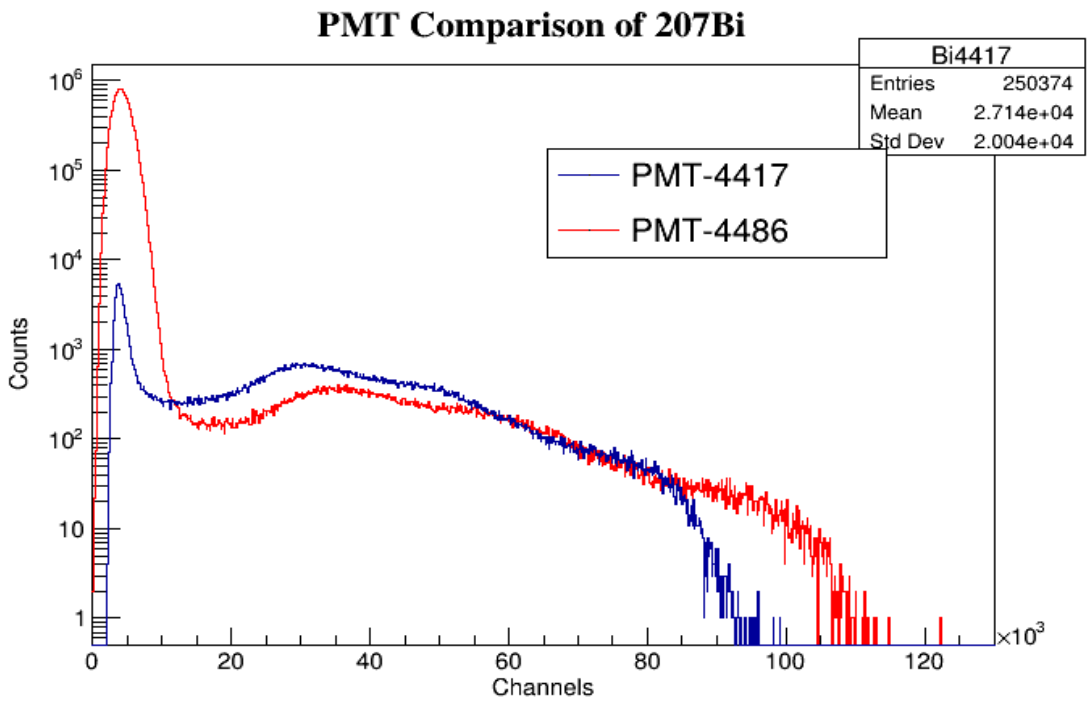


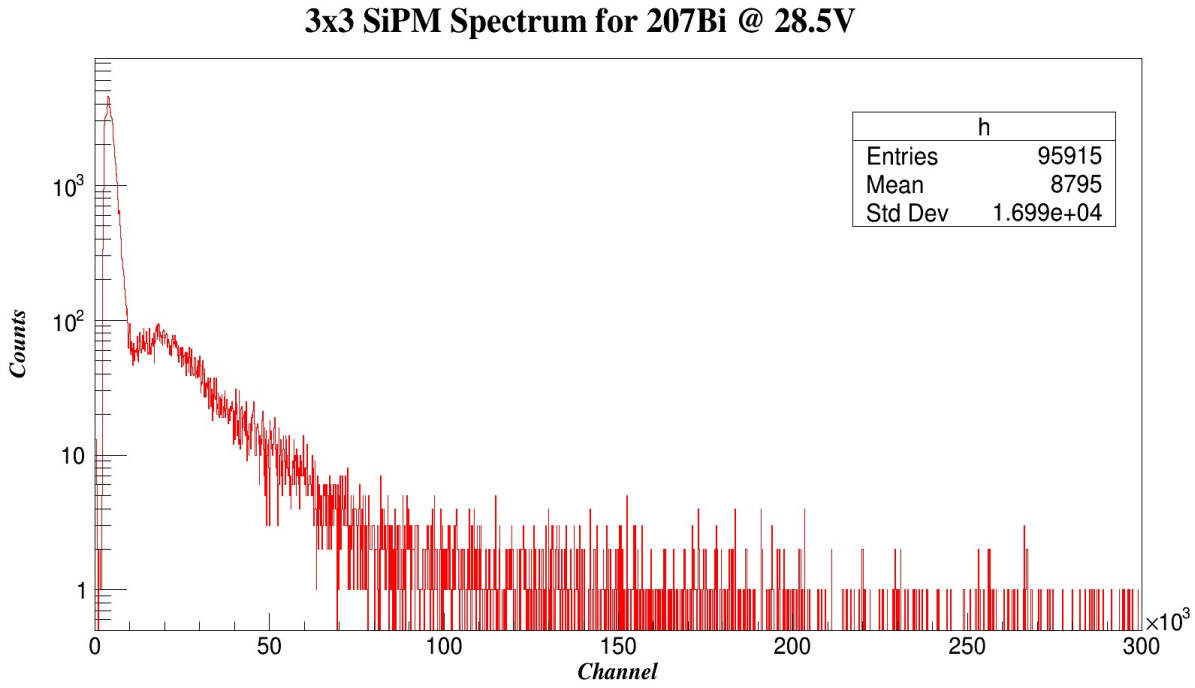
3x3 mm optical window



Energy of ARIES Detector

Square Tile of BC422Q (0.5%) 16x16 mm and polished 90º edges





ARIES Detector

Physics opportunities

- Lifetime measurements with $LaBr_3(Ce)$ coincidences
- β-γ angular correlations
- Spin polarized beams to GRIFFIN
- Compton polarimetry from β-γ (order of magnitude higher efficiency than γ–γ)
- Internal Pair Formation (IPF) detection and identification
- Potential for lifetime measurements of 0^+ beta particle internal conversion

Development of analysis Techniques

- **β-γ angular correlations**. To date only γ–γ angular correlations exist
- **β-Compton polarimetry**. (order of magnitude higher efficiency than γ–γ)
- **Bremsstrahlung and Punch-through veto**

The ARIES Detector

Summary

- State-of-the-art **β-tagging array** and main ancillary detector of **GRIFFIN** facility
- **High-efficiency** and **Ultra-fast** β-particles detector with 1:1 GRIFFIN geometry
- β–γ angular correlations >114 unique angles
- Ultra-fast beta coincidence timing signal from >91% solid angle coverage.
- Lifetime Measurements down to the few ps range

Thank you!

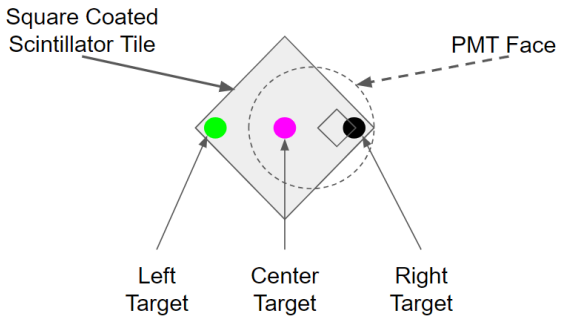
Victoria Vedia, A. B. Garnsworthy, R. Umashankar, D. Chemutai, A. Grimes, L. Mantle, G. Pasquino, M. Qiu, K. Raymond, H. Robertson, S. Rodríguez, J. Rodríguez, W. Royer, M. Spinazze, L. Tomlin and M. Winokan.
D. Bishop, M. Constable (Electronics design), S. Georges (Mechanical design)

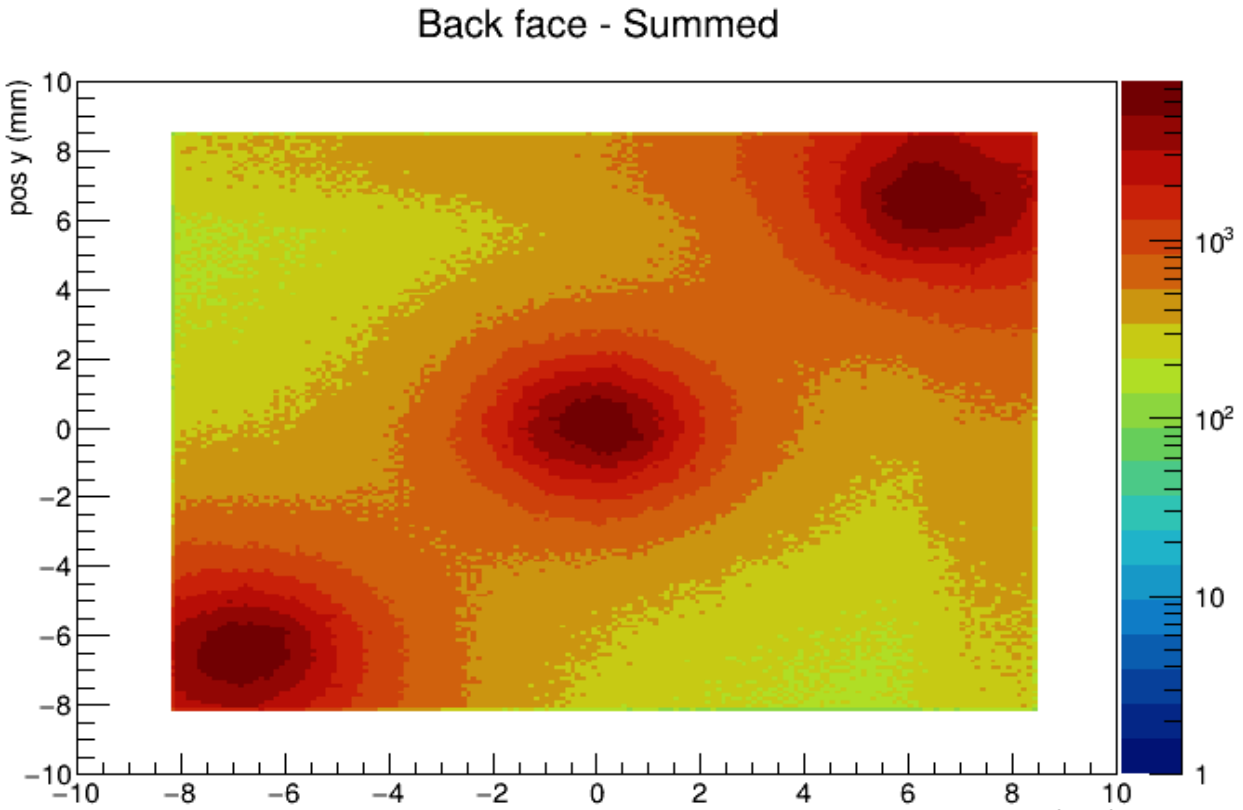
home.cern

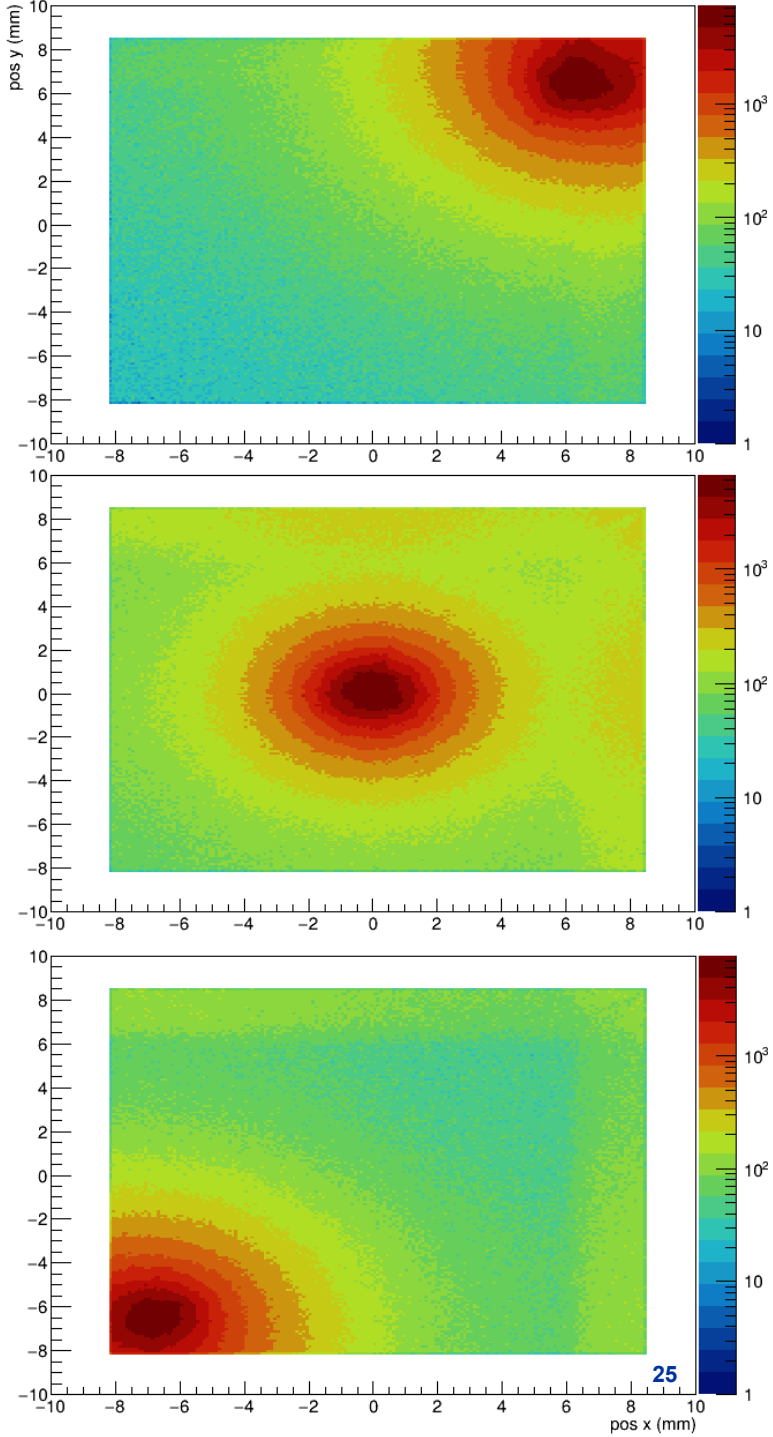
Special Thanks to: Adam Garnsworthy, Rashmi Umashankar, Miles Constable, Shaun Georges and the ARIES team

Light collection as a function of position in the tile

- Comparing with empirical tests



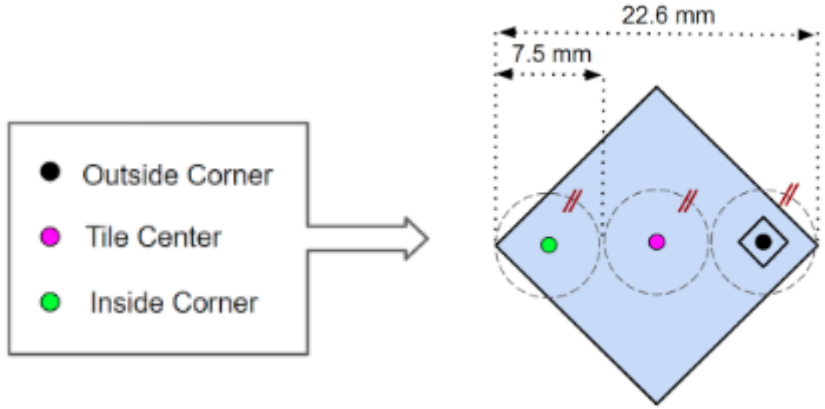




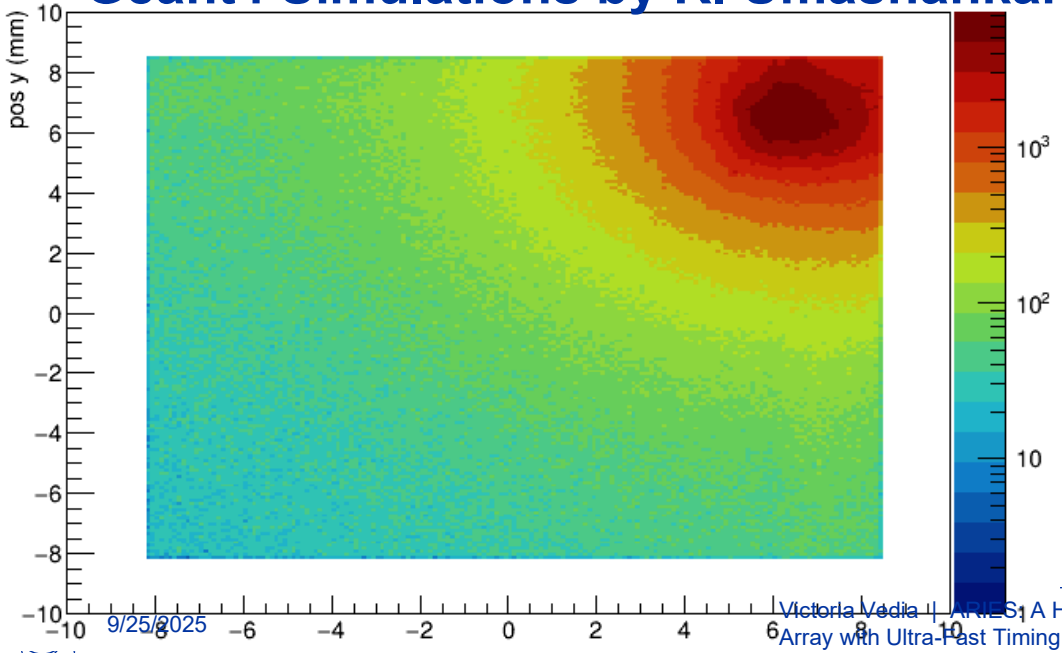
Geant4 Simulations by R. Umashankar

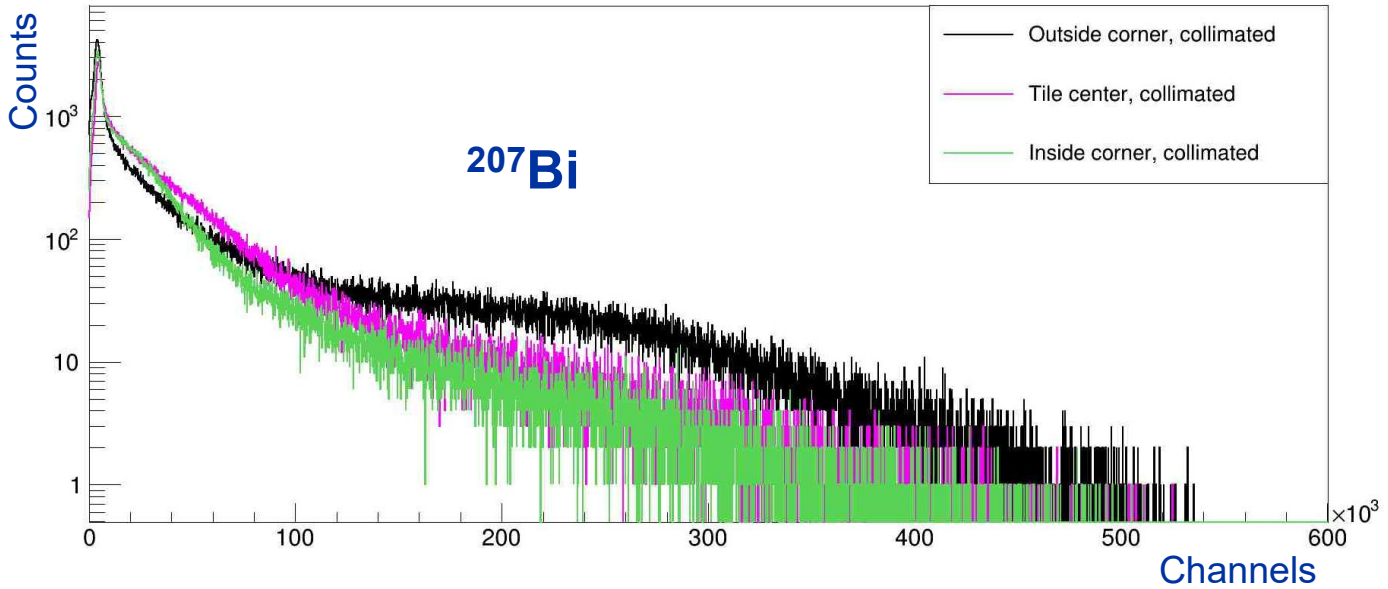
Light collection as a function of position in the tile

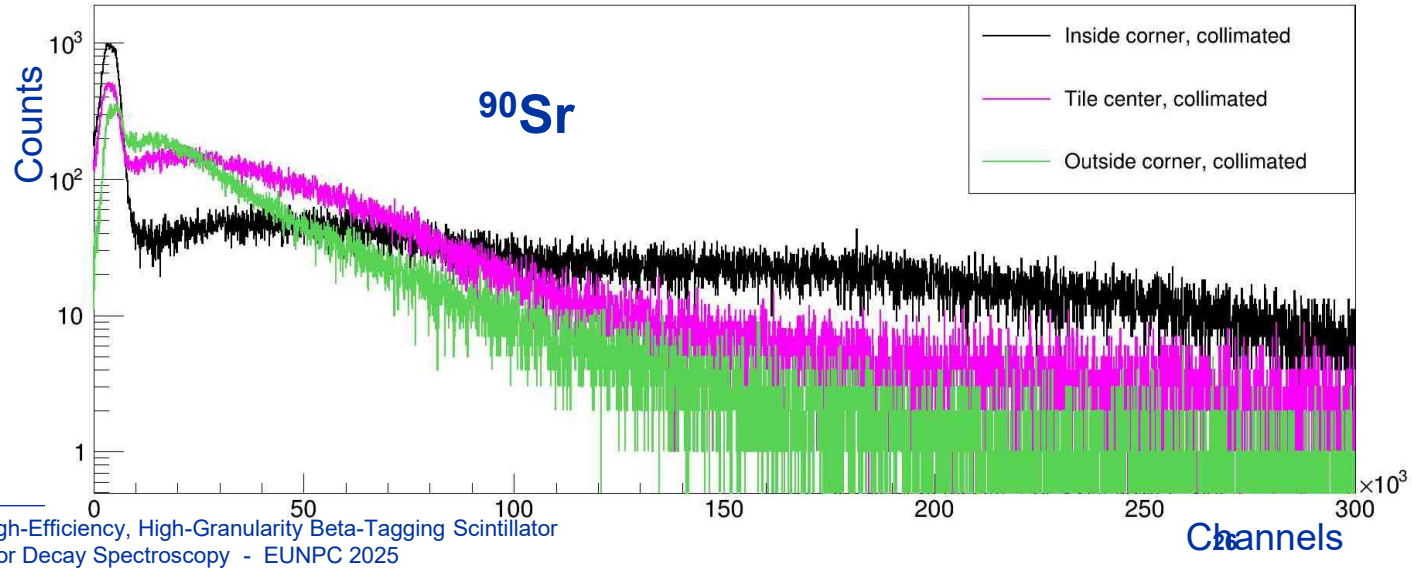
Plots and figure courtesy of A. Grimes



Geant4 Simulations by R. Umashankar







ARIES Detector: Scintillator Material

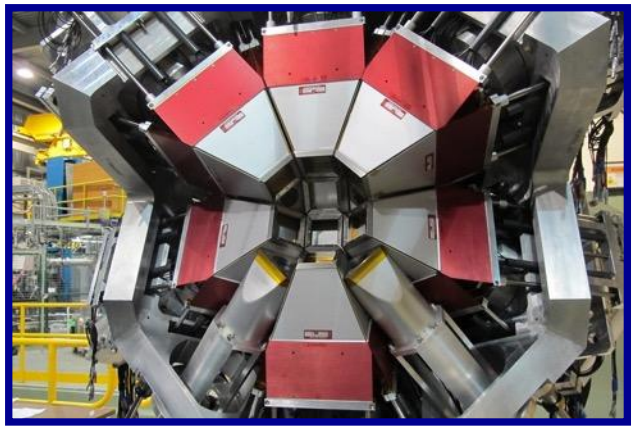
- **EJ-228 (BC-418)**
  - Higher Photon Yield: A factor of 3.5 more scintillation photons produced
  - Ultra Fast Timing response: Excellent for lifetime measurements (Ultra Fast Timing)
  - Same structural properties (Softening point, Temperature range, Vacuum-compatible)
  - Lower energy threshold limit, give access to lower energy Q-values

Scintillator	BC-422Q (0.5%)	BC-418	BC-404	$LaBr_3(Ce)$
Photon Yield ph/MeV	2 900	10 200	10 400	63 000
Wavelength of max emission(nm)	370	390	408	380
PDE of SiPM (%)	32	38	40	---
Rise Time (ns)	0,1	0,5	0,7	5
Decay Time (ns)	1,6	1,4	1,8	16
Pulse Width (ns)	0,4	1.2	2.2	
Ancillary Detector	ZDS	ARIES	SCEPTAR	$LaBr_3(Ce)$

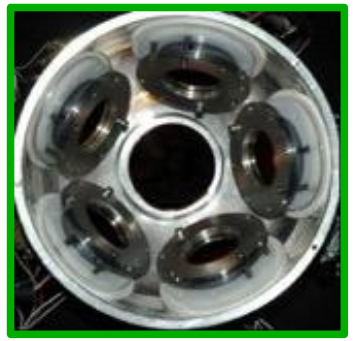
https://eljentechnology.com/products/plastic-scintillators

https://www.onsemi.com/pdf/datasheet/microc-series-j.pdf

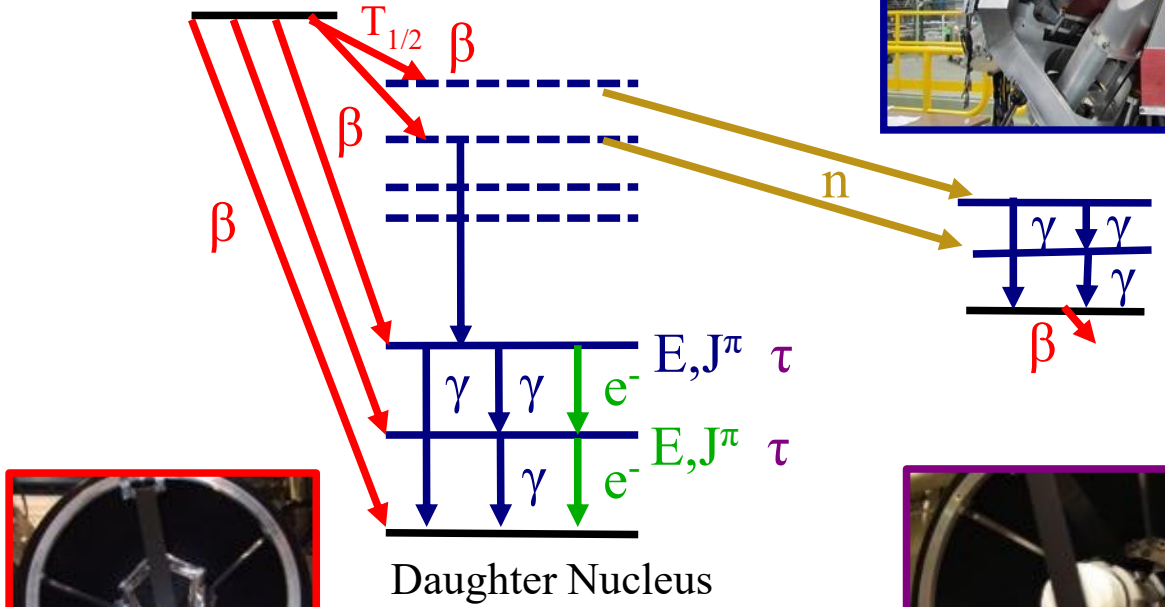
β-decay Spectrometers



HPGe: *Detect gamma rays and determines branching ratios, multipolarities and mixing ratios*



Cooled Si(Li)s
Detects Internal Conversion Electrons and alphas/protons



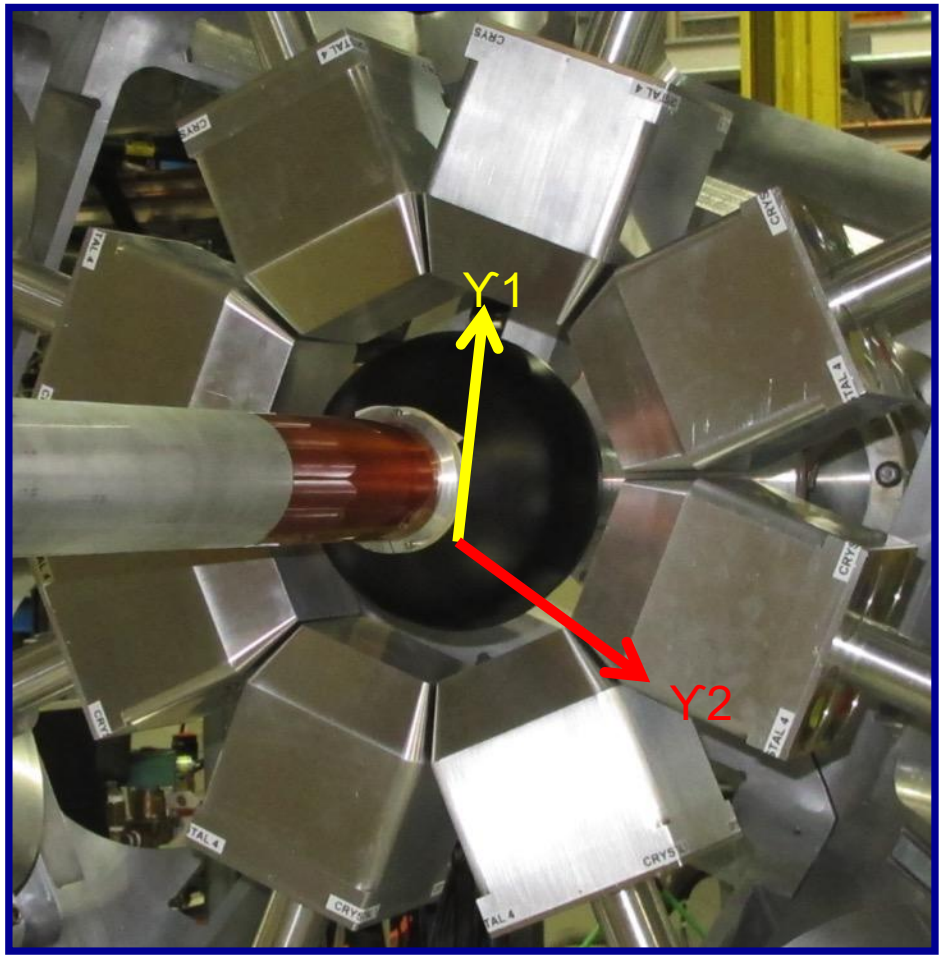
$LaBr_3$: *Fast-timing level lifetimes*

Plastic scintillators
Beta decays and branching ratios

Fast scintillator
Fast-timing signal for betas

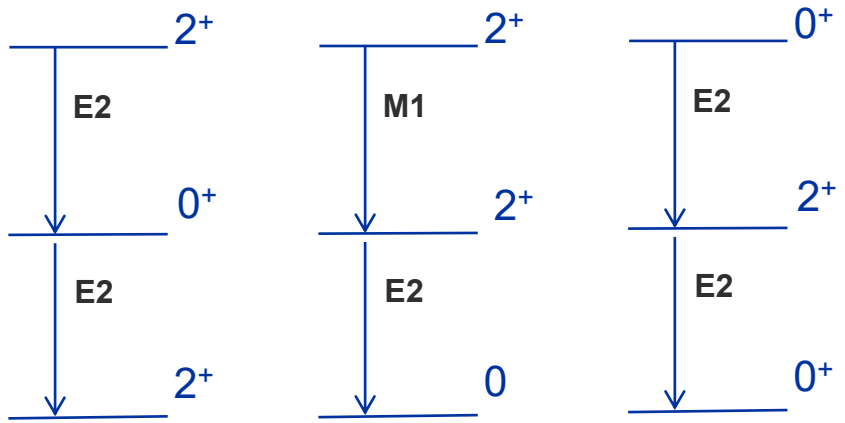
Neutron array
For beta-delayed neutron emission

Gamma-Gamma Angular Correlations



1. Cascade of 2 γ-rays. Spatial distribution
2. First γ-ray define the orientation
3. Intensity of the 2nd γ-ray at different angles.
4. GRIFFIN has 4096 pairs of crystals at 52 different angles.

$\gamma\gamma$ angular correlations with low intensity beams

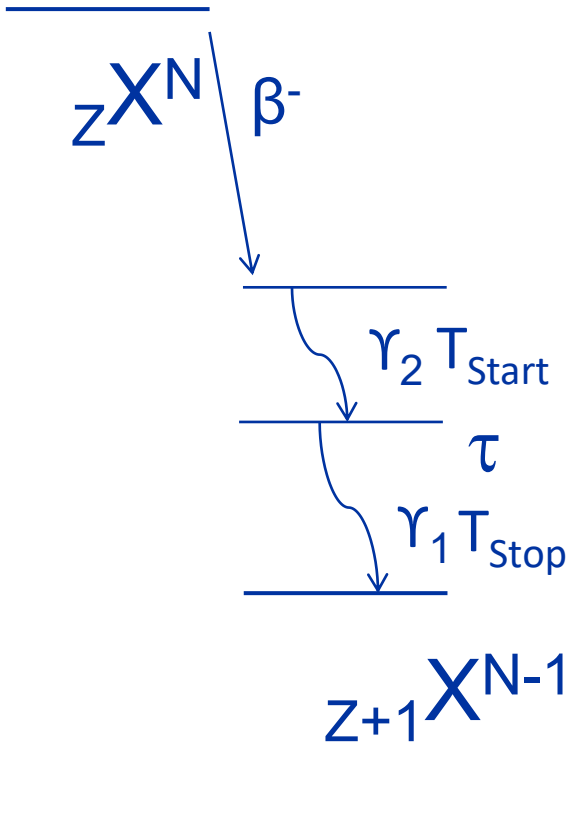


γ–γ angular correlation analysis techniques with GRIFFIN

J.K. Smith, *et al.,* NIM A 922, 47 (2019).

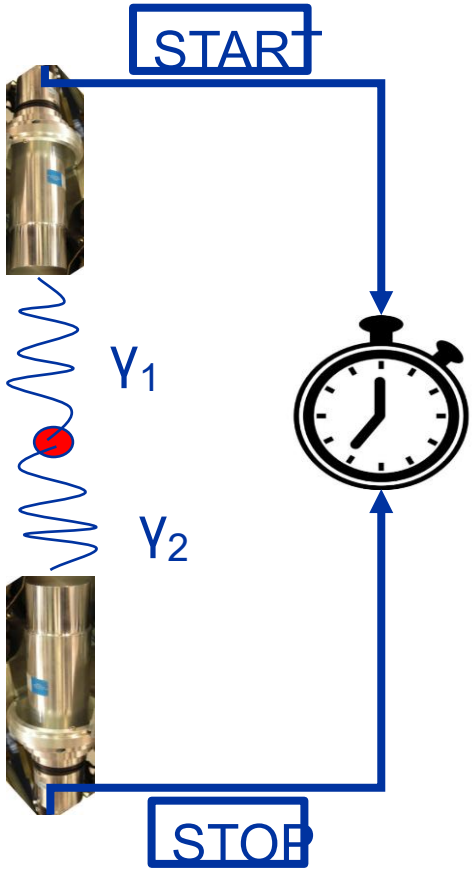
Lifetime Measurementsz

Transition rates



$$B(\lambda L; J_i \to J_f) = \frac{\hbar L\left((2L+1)!!\right)^2}{8\pi(L+1)}\left(\frac{E_\gamma}{\hbar c}\right)^{-(2L+1)}\frac{\mathrm{BR}}{\tau}$$

- Transition strengths sensitive probe into the nuclear structure
- Direct information on the matrix element connecting the initial and final state
- Information about collectivity and deformation



Lifetime Measurements

Transition rates

$$B\left(\lambda L; J_i \rightarrow J_f\right) = \frac{\hbar L\left((2L+1)!!\right)^2}{8\pi(L+1)}\left(\frac{E_\gamma}{\hbar c}\right)^{-(2L+1)}\frac{\mathrm{BR}}{\tau}$$

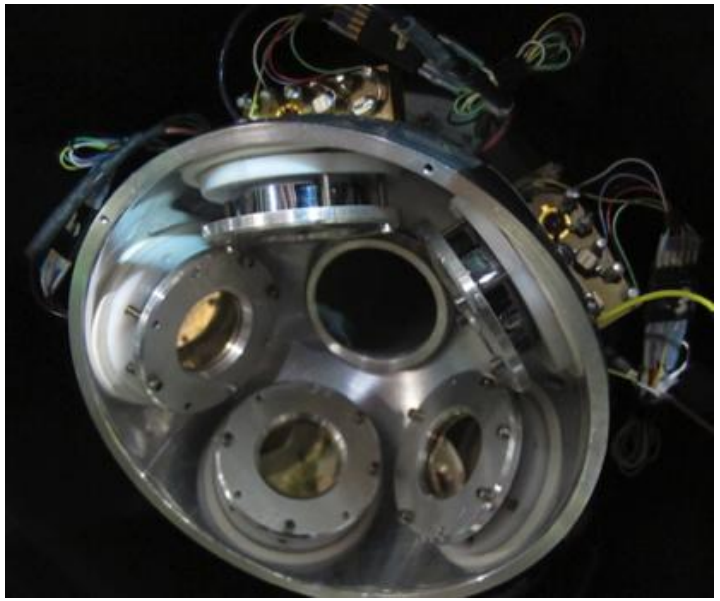
Energy: GRIFFIN clovers (HPGe detectors)

Branching ratio: High precision using GRIFFIN

γ-ray angular momentum (L): Angular correlations.

Lifetimes: Fast Timing array in GRIFFIN

Conversion Electron Spectroscopy



PACES Array

Si(Li)-Ln2 cooled

2 keV resolution for electrons
20 keV threshold
Gamma-electrons coincidences

J. Park *et al.*, PRC 96, 014315 (2016).