Nuclear Physics Mid Term Plan in Italy

LNF – Session

Frascati, December 1st-2nd 2022

Detectors for Gamma Radiation

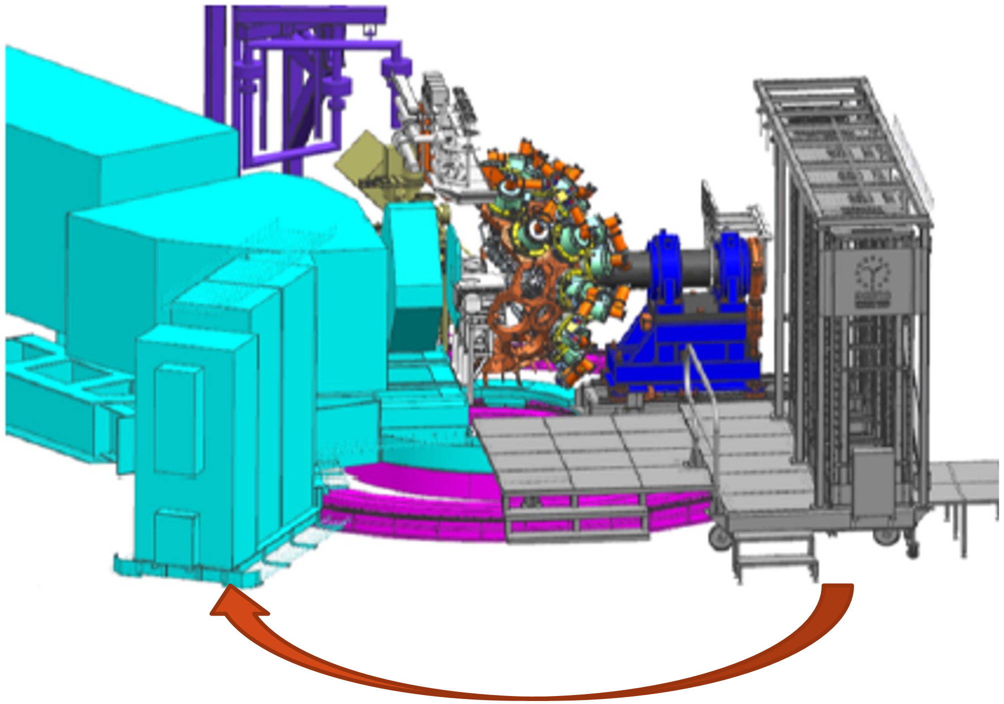
Francesco Sgarbossa

INFN-LNL and University of Padova

Istituto Nazionale di Fisica Nucleare

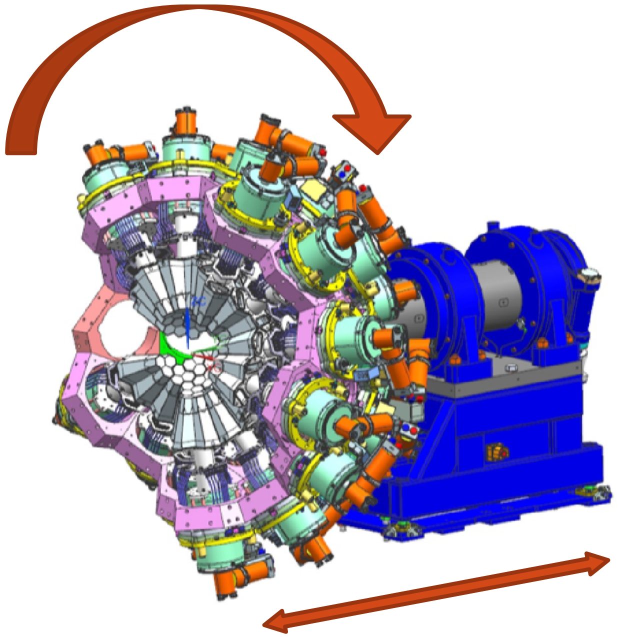
Advance GAmma Tracking Array installation at LNL-INFN

AGATA at LNL in a 2π configuration is the phase 2 of AGATA. At LNL-INFN AGATA couple with PRISMA will consist of up to 27 AGATA triple clusters (ATCs) out of the 30 possible due to the mechanical constrain to get the beam line through.



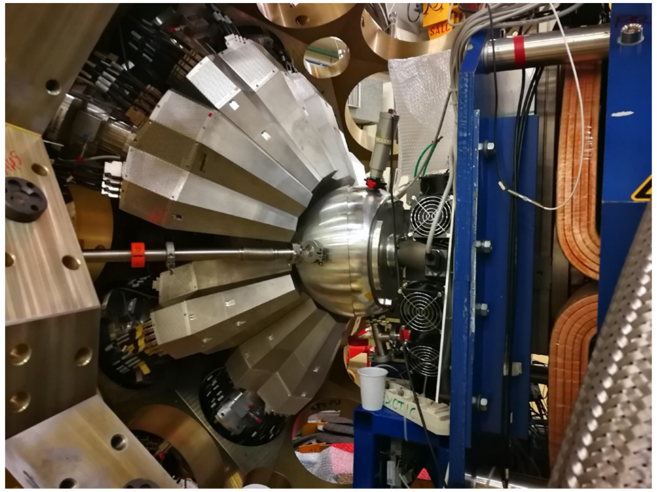
20° - 110°

± 85° along its axis



from 55mm to 750mm

13 ATCs installed close to the reaction chamber



submitted: J.J. Valiente-Dobon et all."Conceptual design of the AGATA 2π array at LNL" NIM

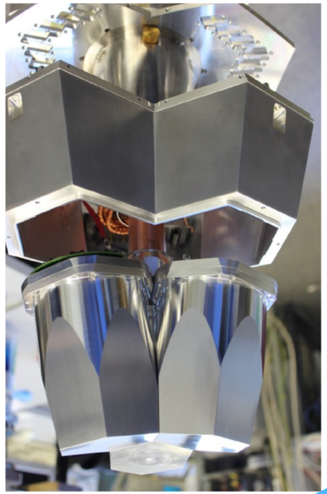
AGATA at LNL-INFN

13 ATCs installed (27 HPGe detector)

n-HPGe encapsulated detector with 36 segments + 1 core

OLD encapsulated HPGe detector standard annealing (few days at 102°C), roughly oneout of three annealed capsules would suffer from leakage current

NEW encapsuleted HPGe detector new annealing method by MIRION: capsules connected to a pumping system during annealing

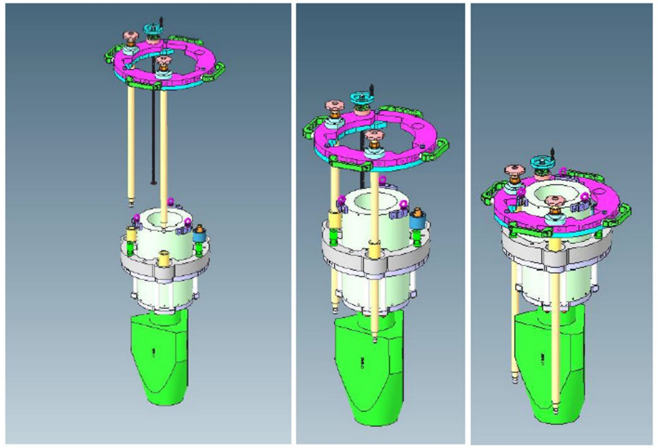


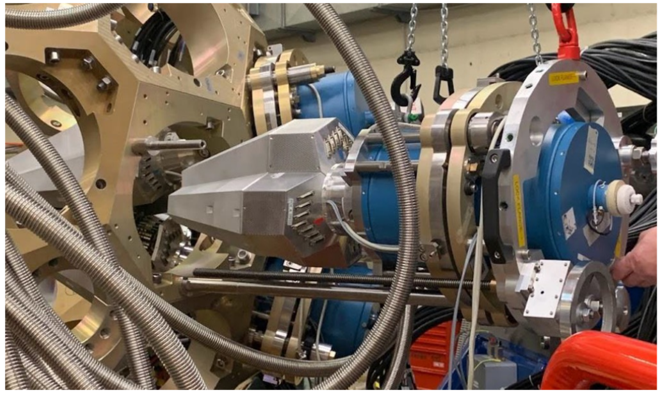
AGATA installation at LNL-INFN

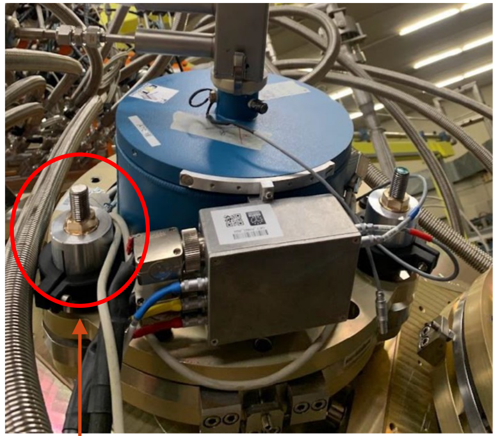
Handling Fixture: mounting the ATC in horizontal way

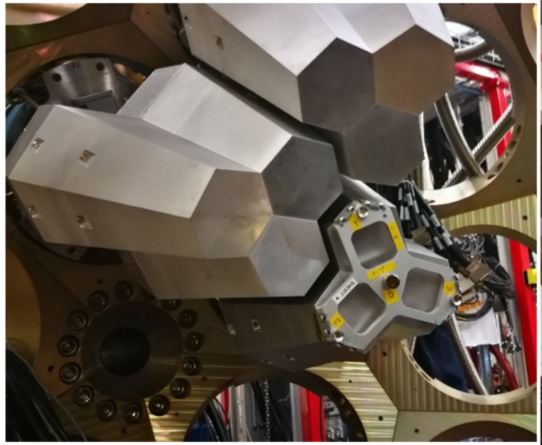
Mechanics upgrade: precise control on the ATC placement

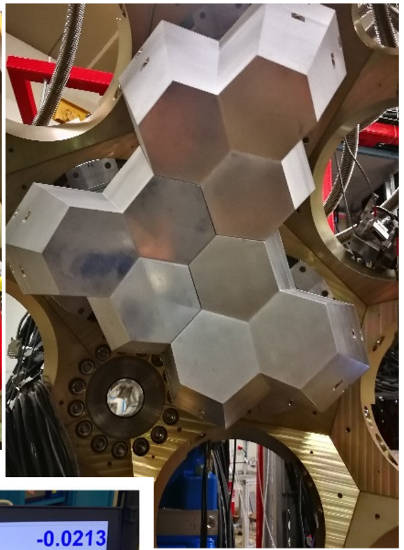
Laser alignment: New laser tool (x,y,z) to align ATC on the AGATA array

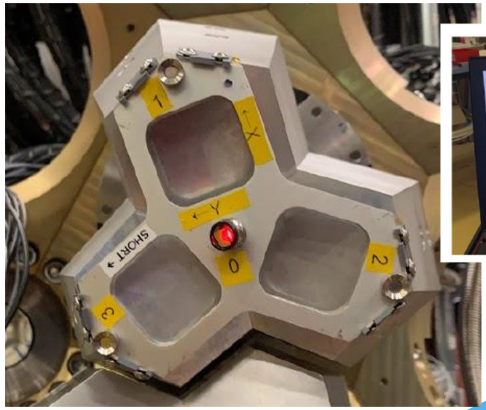


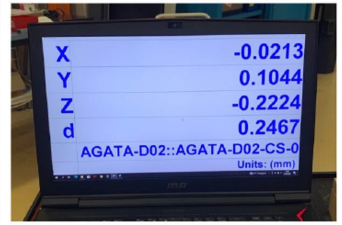












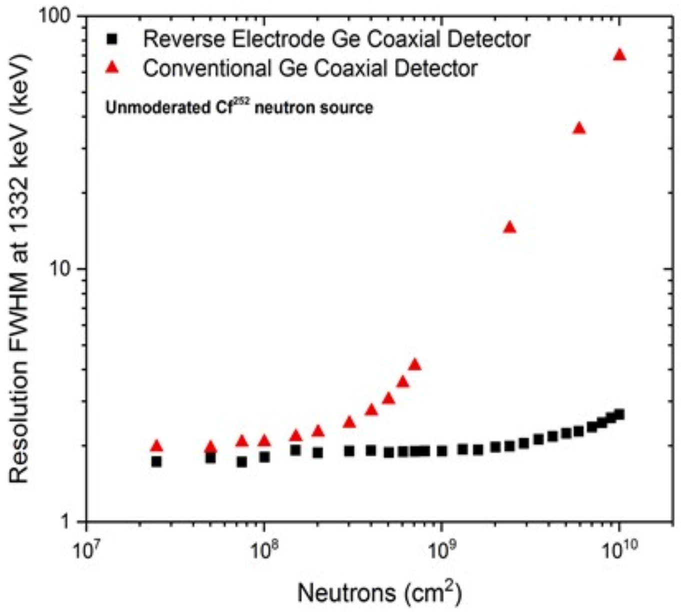
HPGe segmented detector research limits

Limitation on segmented position sensitive n-HPGe detectors: **Li** n **contacts** forms > 0.5 mm junction.

- dead layer where no charge collection occurs [1]
- not stable under annealing treatments for damage recovery [2]
- prevents stable and thin segmentation

Segmentations are currently performed on the p^+ boron side.

- holes are much more subjected to trapping induced by neutron damage -> worse resolution [3]



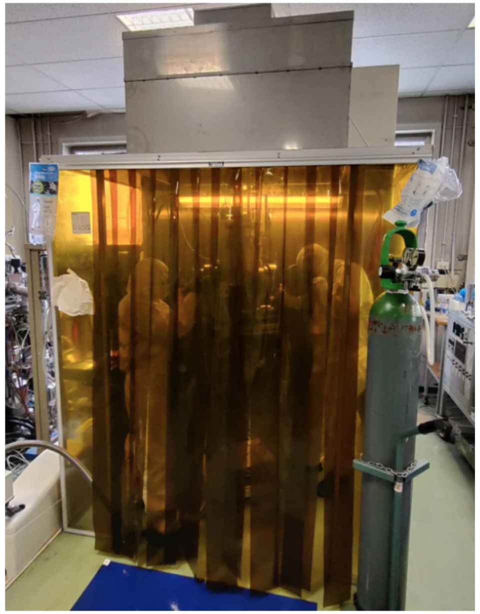
Resolution detrimental effects after neutron radiation exposure in hall (red) and electron (black) colleting non segmented HPGe [4]

1) J. Eberth et al. *Particle and Nuclear Physics* **60** 283 (2008)
2) P. N. Peplowski et al *NIMA* **942** (2019)
3) H. W. Kraner et al. *IEEE Transactions on Nuclear Science* **27**, 1 (1980)
4) R. H. Pehl et al. *IEEE Transactions on Nuclear Science*, **26**, 1 (1979)

N3G: Next Generation Germanium Gamma Ray Detectors

- Fabrication of p-HPGe detector using a new doping technique: **pulsed laser melting** [1]. 200-300 nm junction for n and p side without bulk contamination [2].
- New generation of electronics, DAQ and cryostat for this technology
- Performance and rad-hardness test

CALL CSNV



1. Planar detector prototype (PRONG- INFN)
2. Coaxial geometry upgrade

RETURN TO

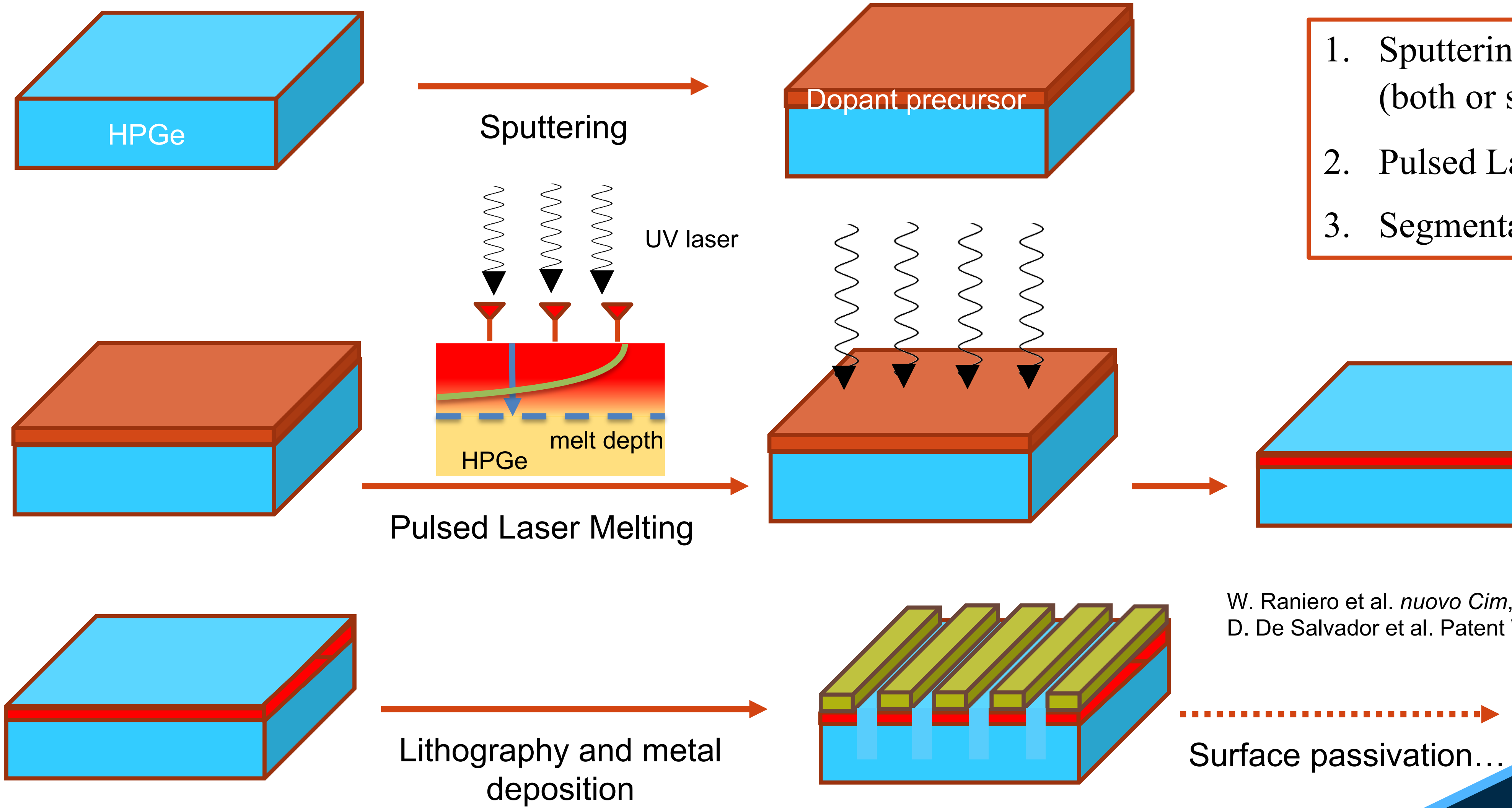
1. International gamma ray community
2. INFN CSN3: new detector
3. Detector repair infrastructure @ LNL

1. n-side segmentation
2. Higher active volume
3. Easy segmentation: 300nm junctions
4. Lower annealing deterioration

1) G. Maggioni et al. *Eur. Phys. J. A*, **54**, 34 (2018)
2) V. Boldrini et al. *J. Phys. D. Appl. Phys.*, **52**, 11 (2019)

N3G approach: from planar to coaxial detector

1. Sputtering precursor deposition (both or single n, p side)
2. Pulsed Laser Melting diffusion
3. Segmentation via lithography

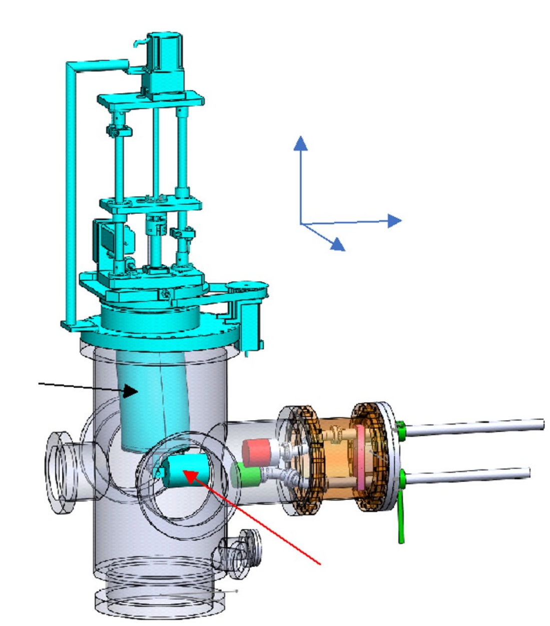


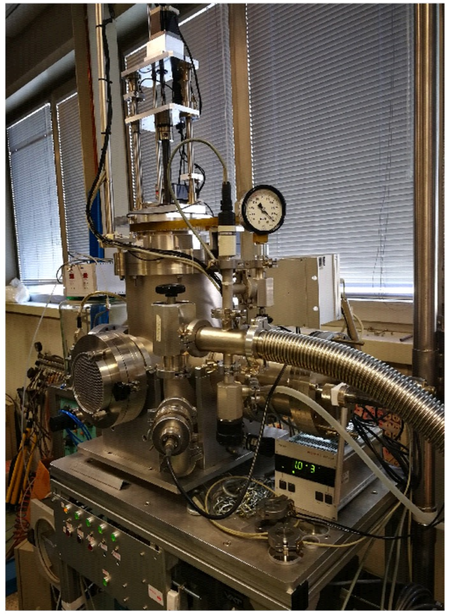
W. Raniero et al. *nuovo Cim*, **44**, 1–5 (2021)
D. De Salvador et al. Patent WO 2021/214028 A1

Fabrication – Dopant deposition

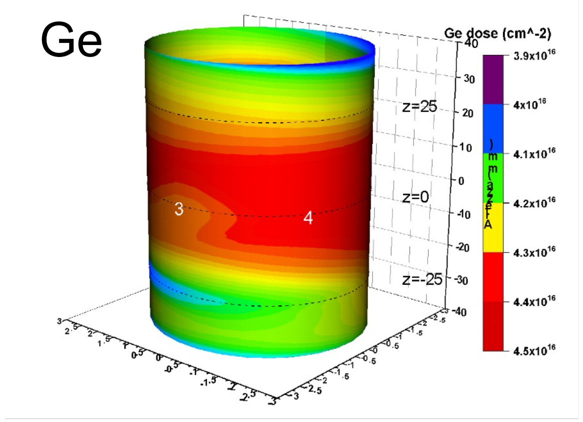
Dopant precursor deposited by sputtering process

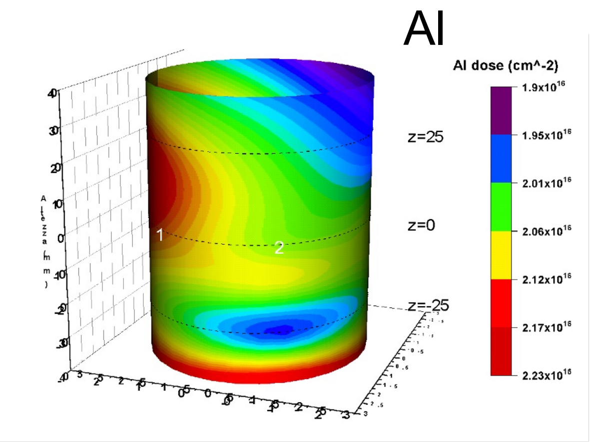
- Coaxial sputtering geometry machine development
- 3D dopant homogeneity



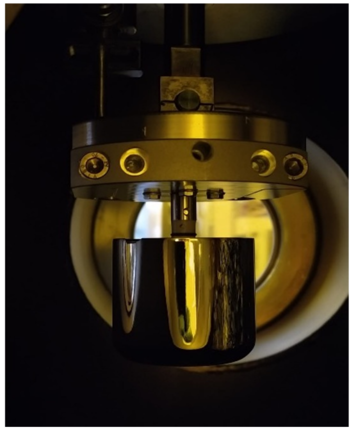


N3G new sputtering chamber @LNL





Homogeneity precursor reconstruction using RBS analysis

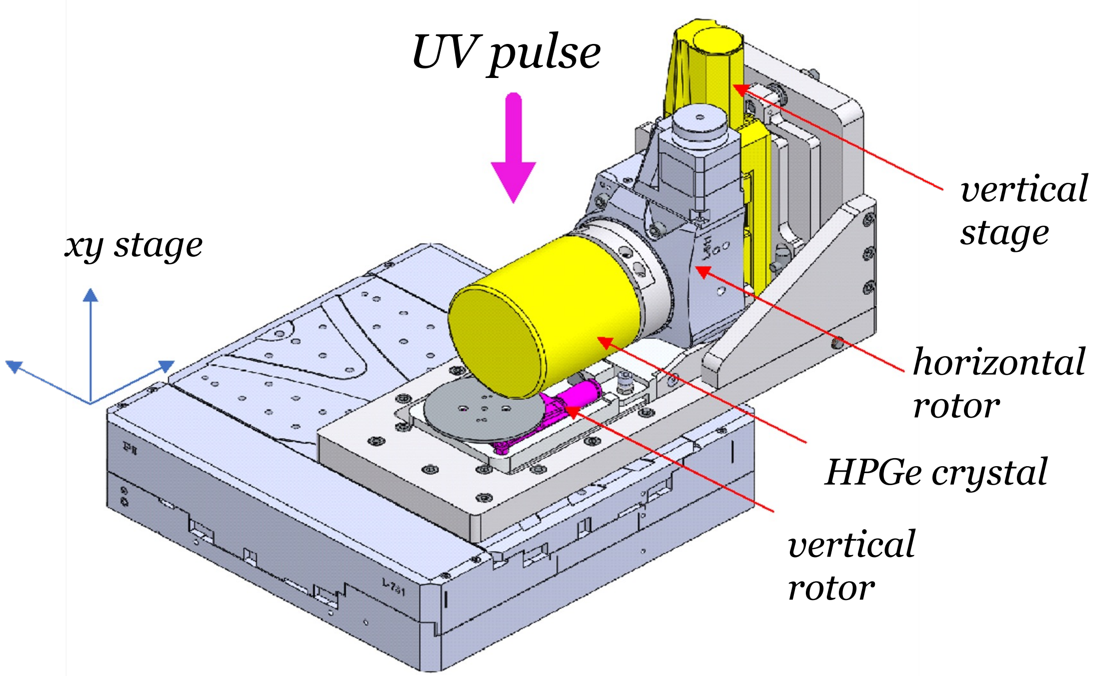


G. Maggioni et al. *Mater. Sci. Semicond. Process.*, **75**, 118–123 (2018)
D. De Salvador et al. Patent WO 2021/214028 A1

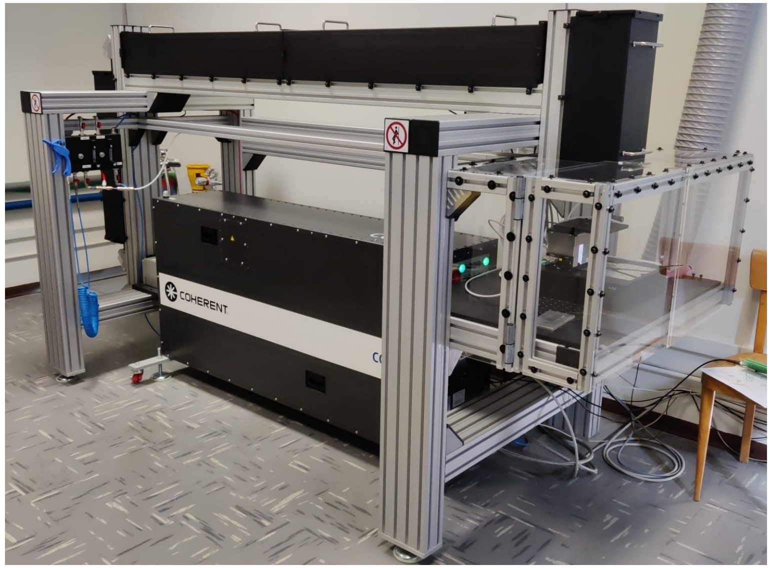
Fabrication – dopant diffusion & junction formation

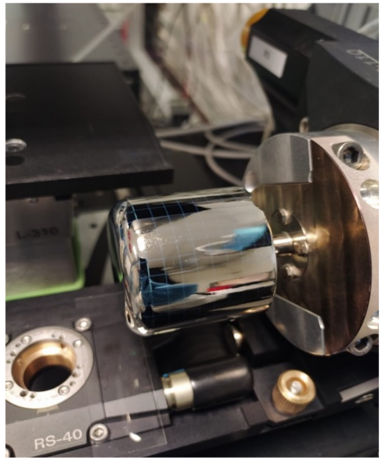
Dopant diffusion by **pulsed laser melting**

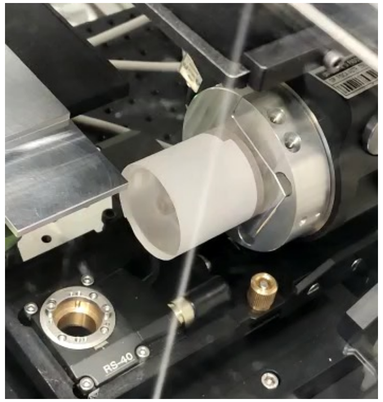
- Huge previous studies (and a patent) on diffusion via PLM
- Coaxial handling system for surfaces exposure to UV laser pulses



Scheme of the laser sample holder







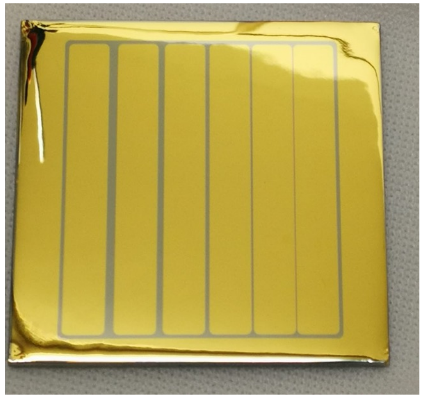
PLM system @ UNIPD

D. De Salvador et al. Patent WO 2021/214028 A1

Fabrication – lithography for segmentation

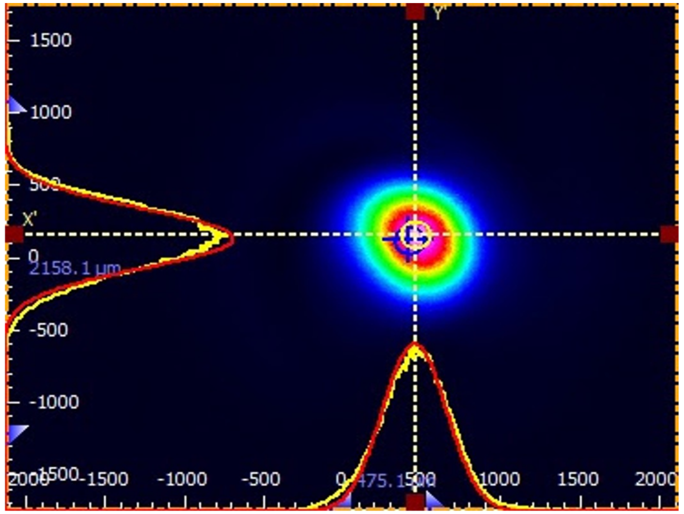
Lithography systems

- Studies using planar HPGe geometry
- Robotic 3D lithography system for coaxial detector segmentation.

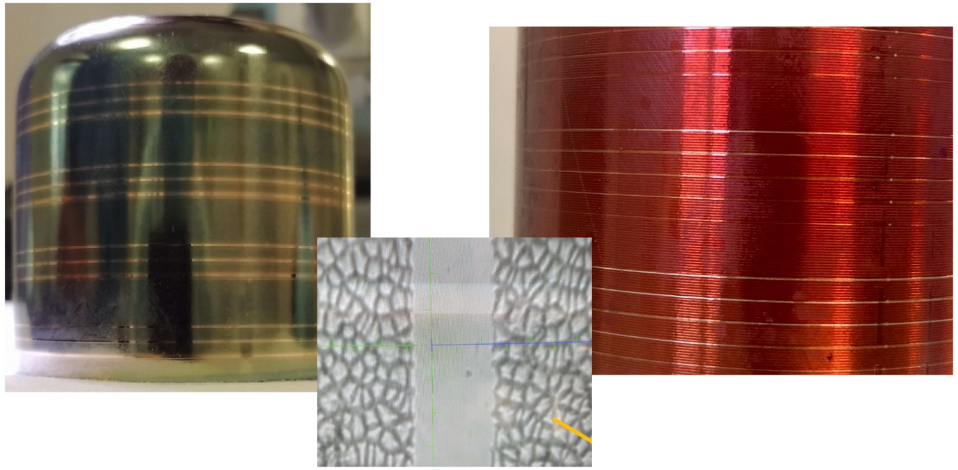


segmented planar detector – variable trench

3D lithography system



Laser for lithography : lateral beam profile



Lithographic tests on coaxial dummy

Detector test: planar results

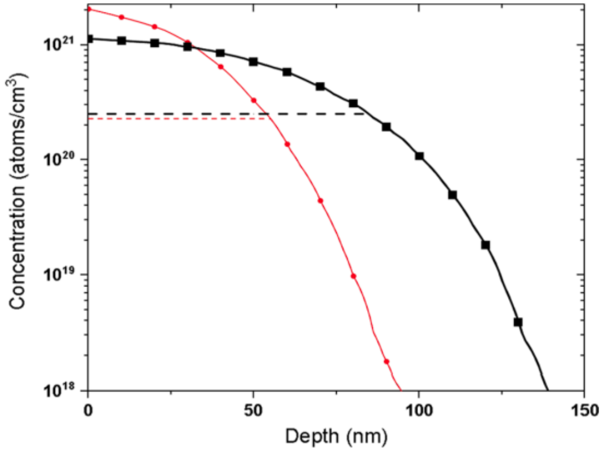

Lab for coaxial detector test @ LNL

PLANAR segmented n side Sb PLM / p side with Al PLM

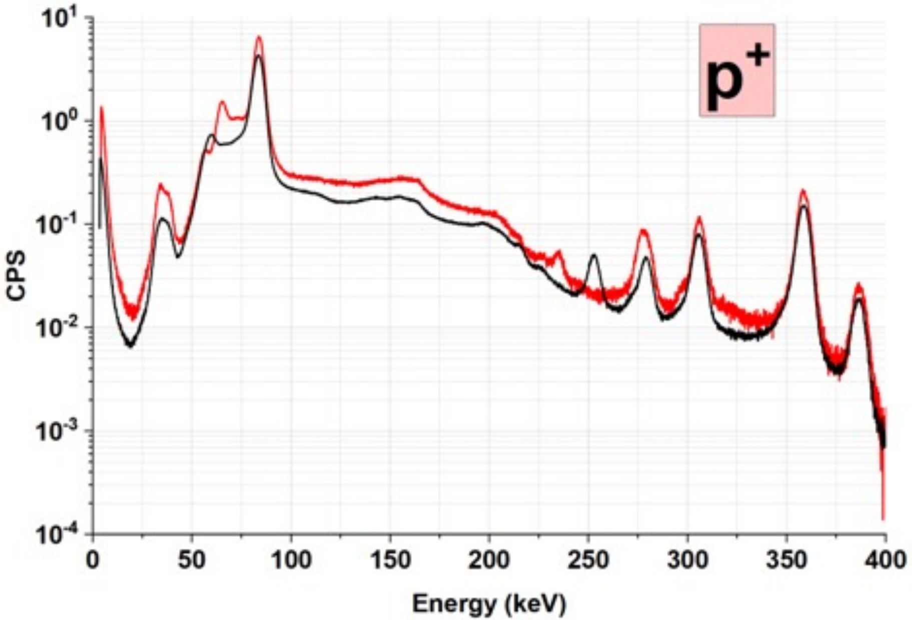
^{133}Ba normalized spectra; before annealing (black data) and after annealing (red data). P+ Al side (without guard ring) and C1 segment Sb (with guard ring). Annealing = 100°C 40h. -15 V polarization.

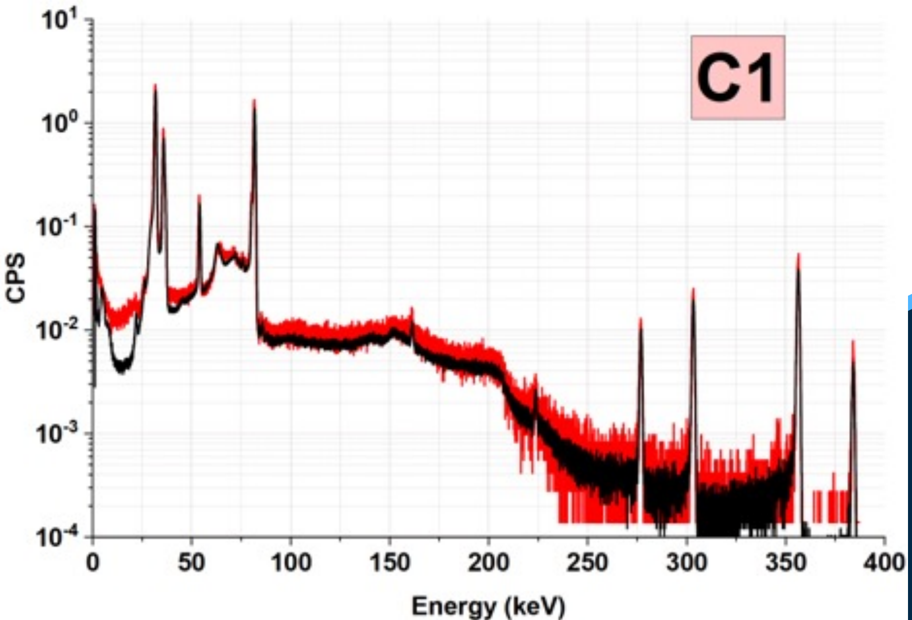
segmented planar detector – Sb n contact

S. Bertoldo et al. *Eur. Phys. J. A*, **57**, 1–10 (2021)



SIMS Sb profile, with electrical activation



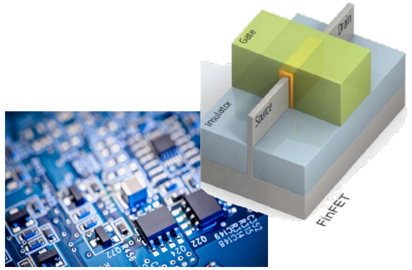


Monolayer doping: the future for detector junction?

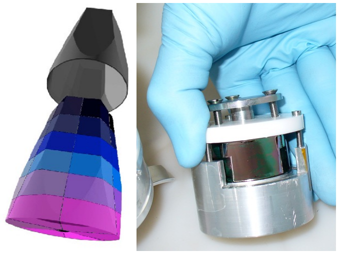
Use of molecular precursor reacting with Ge surface to form a self-limited monolayer [1,2]

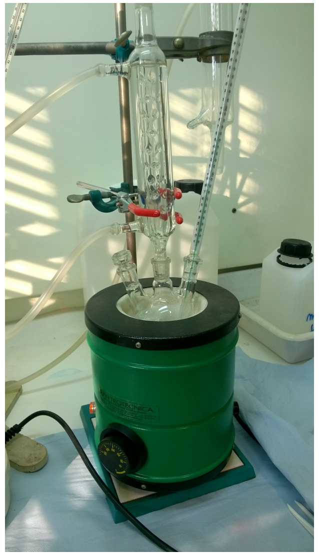
- Extremely controlled amount of dopant
- Coaxial 3D geometry compatible: conformal deposition
- Adsorption process at different temperature
- Compatible with PLM [2,3]

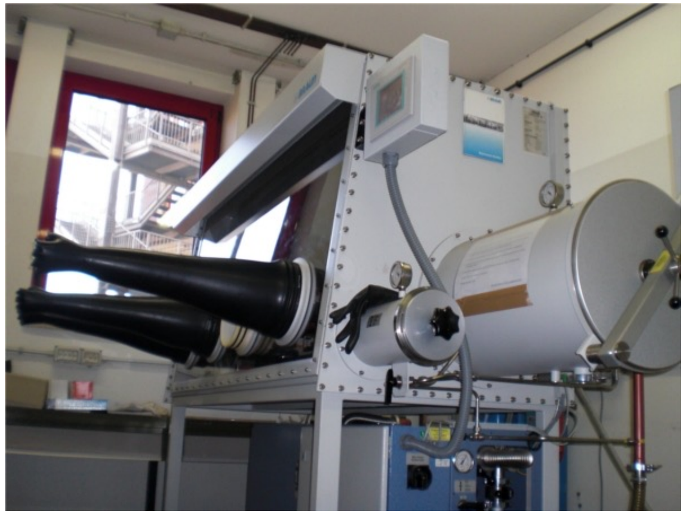
Nanoelectronics



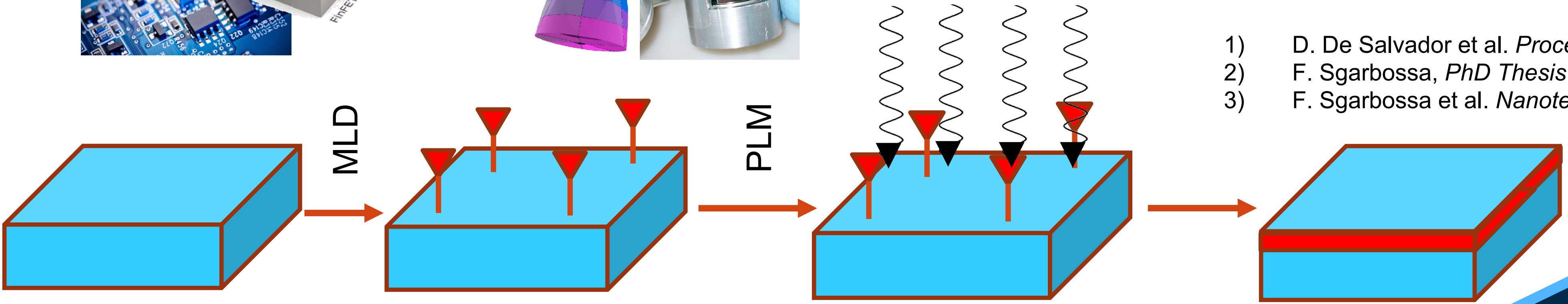
γ-Ray detectors







MLD deposition process @ UNIPD and LNL

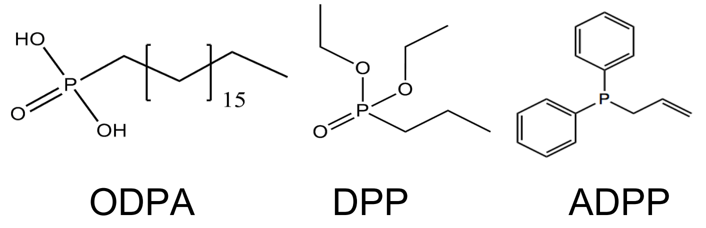


1) D. De Salvador et al. *Proceedings*, **26**, 1, 39 (2019)
2) F. Sgarbossa, *PhD Thesis*, Univ. of Padova (2019)
3) F. Sgarbossa et al. *Nanotechnology*, **29**, 465702 (2018)

Monolayer doping: n type dopant studies

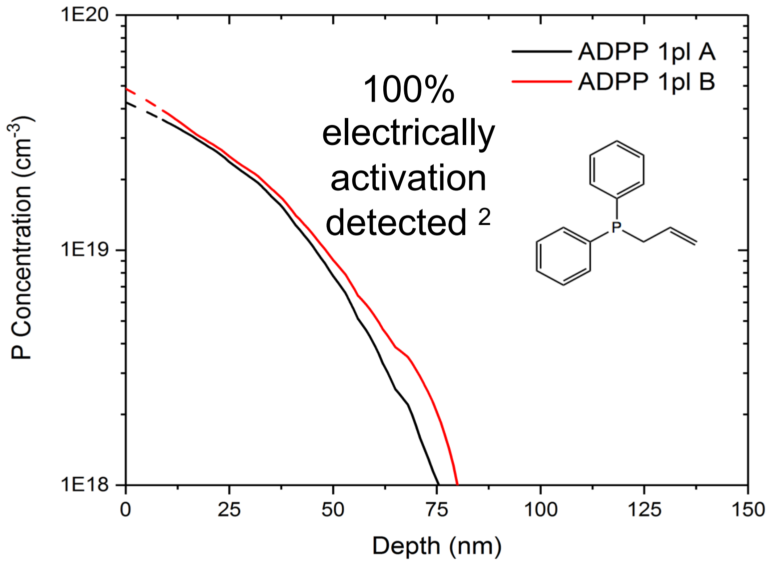
Three different phosphorus molecular precursor studied [1,2]

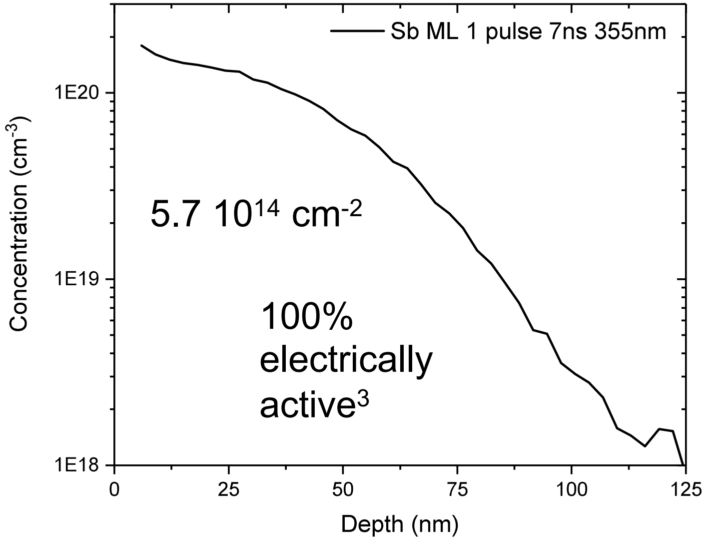
- ADPP found as the best precursor: electrically active after PLM [2]
- PLM treatment guarantee no bulk contamination

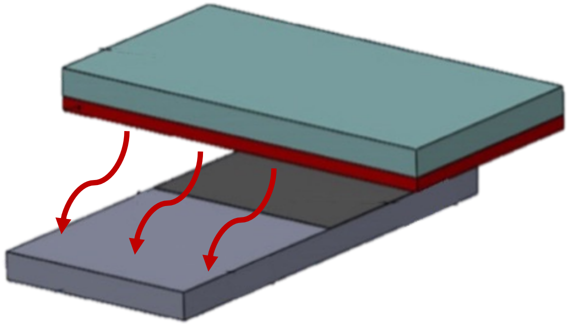


Antimony monolayer formation studied: diffusion via PLM tested [3]

- Sb ML deposition at high temperature could be an issue for contamination



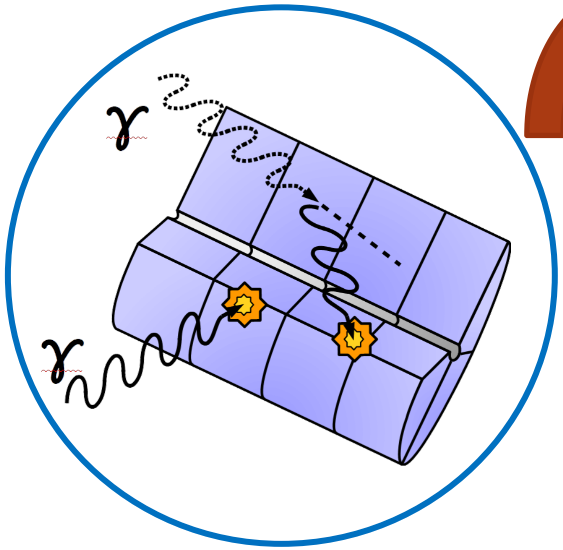


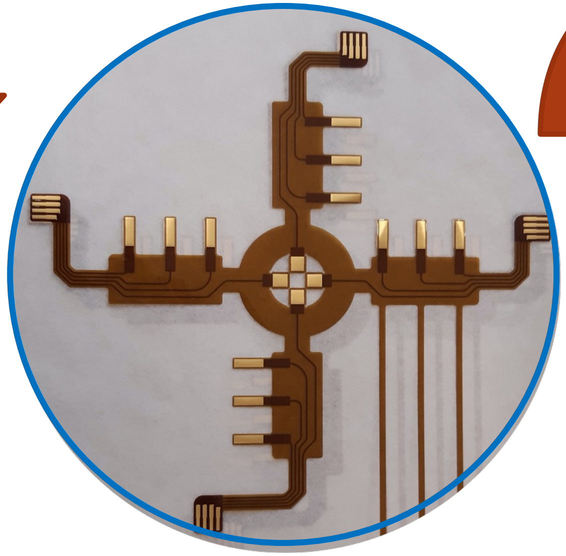


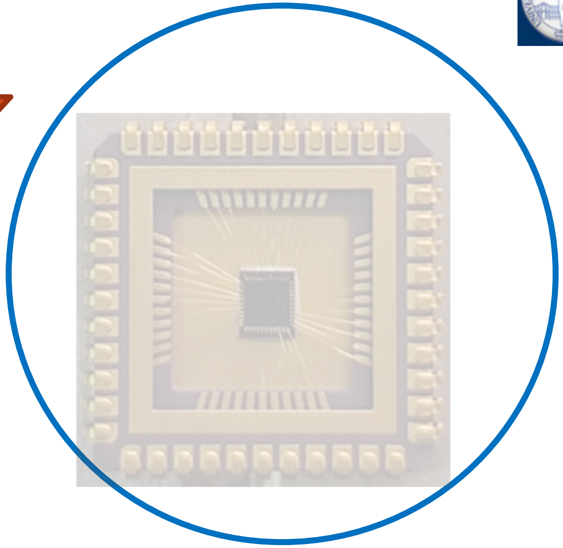
Sb gas monolayer adsorption geometry [3]

1) F. Sgarbossa et al. *Nanotechnology*, **29**, 465702 (2018)
2) F. Sgarbossa et al. *Appl. Surf. Sci.* **541**, 148532 (2021)
3) F. Sgarbossa et al. *Appl. Surf. Sci.* **496**, *143713* (2019)

Front End Electronics for HPGe coaxial & segmented detectors







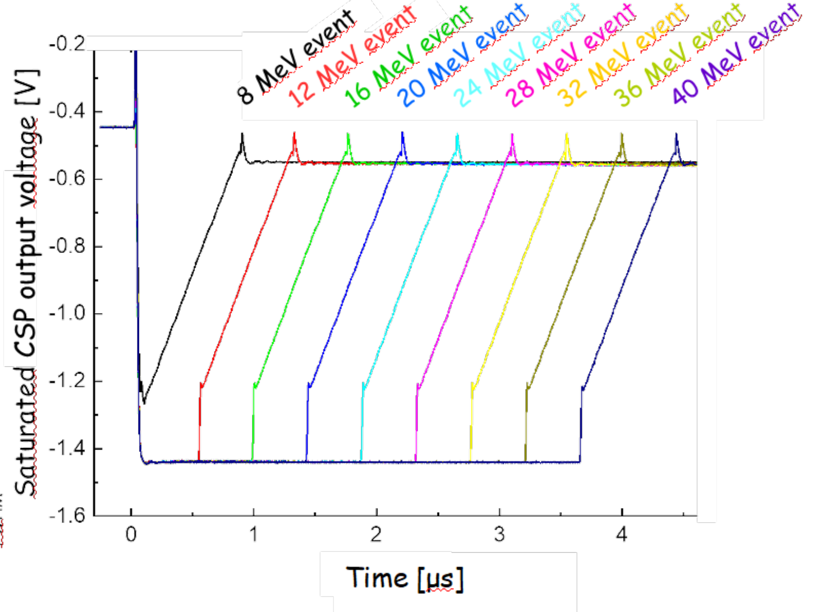
- The external electrodes of the detector are connected to the Charge Sensitive Preamplifier (CSP) through a **flexible PCB** to be wrapped around the detector itself
- The connection system is designed so that **it doesn't scratch and damage** the surface of the electrodes
- With respect to the state-of-the-art HPGe read-out chain, the Charge Sensitive Pre-amplifiers is realized in integrated technology. In such a way it is:

MORE COMPACT **MORE EFFICENT** **LESS POWER CONSUMING**

The ASIC (Applied Specific Integrated Circuits)

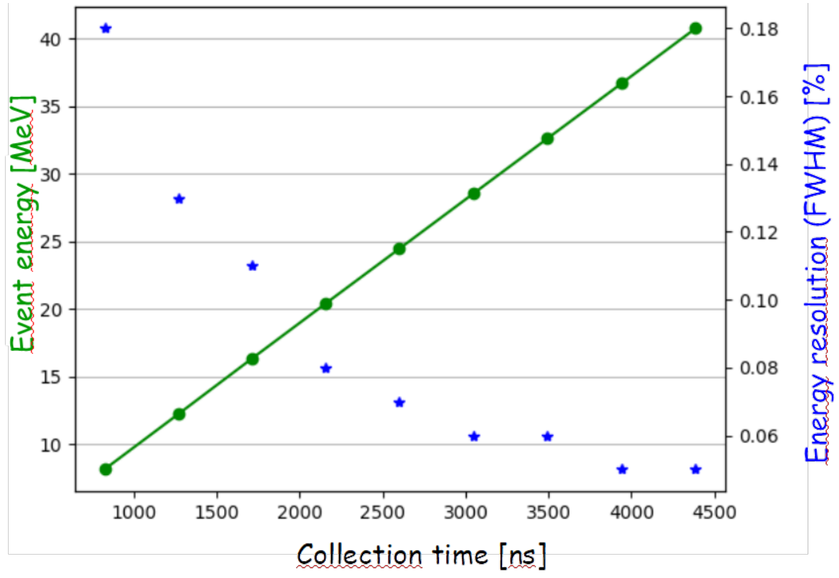
- It is characterized by **6 mW power consumption** and **8 MeV dynamic range**, which can be **extended up to 40 MeV** thanks to an innovative **FAST RESET CIRCUITS**

- It is a **LOW NOISE DEVICE**

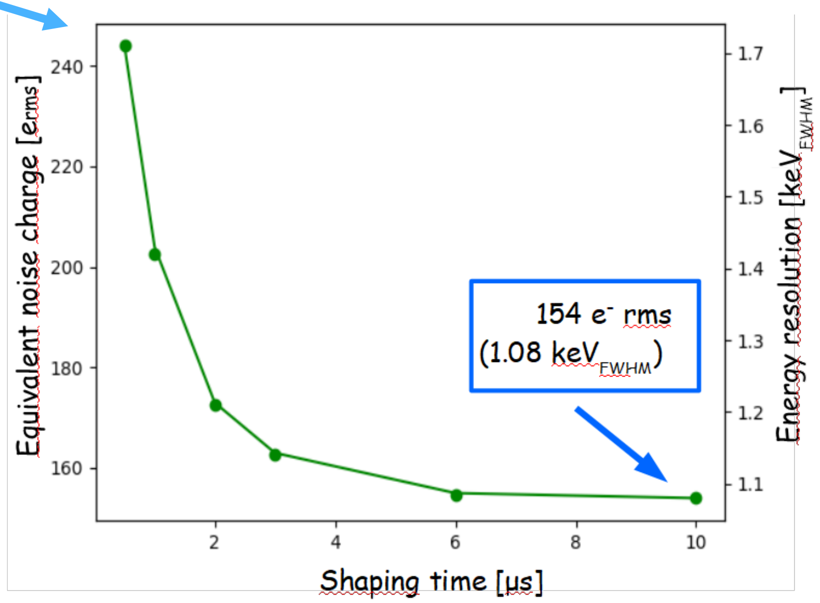


CSP in saturation: the time-duration of this condition is proportional to the incident energy

S. Capra et al. *IEEE Transactions on Nuclear Science*, 69, 7, 1757-1764 (2022)



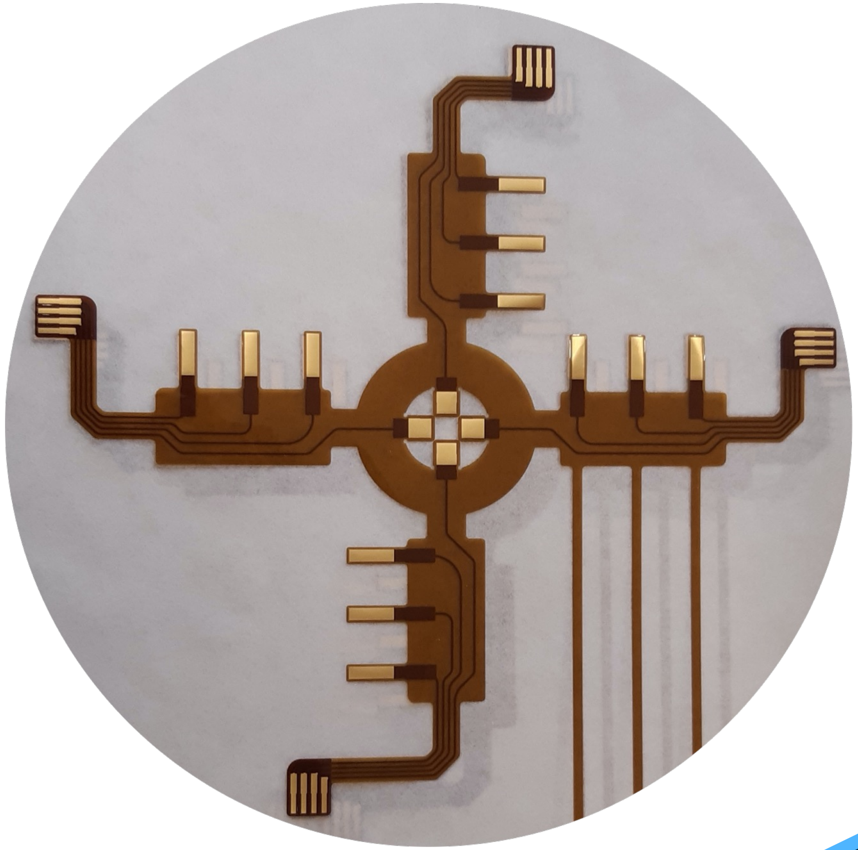
Linearity and energy resolution in fast-reset mode: for events with energy greater than 15 MeV the resolution, expressed as FWHM, is better than 0.11 %



Resolution measurements on 1 MeV simulated events and 15 pF detector capacitance

Challenges

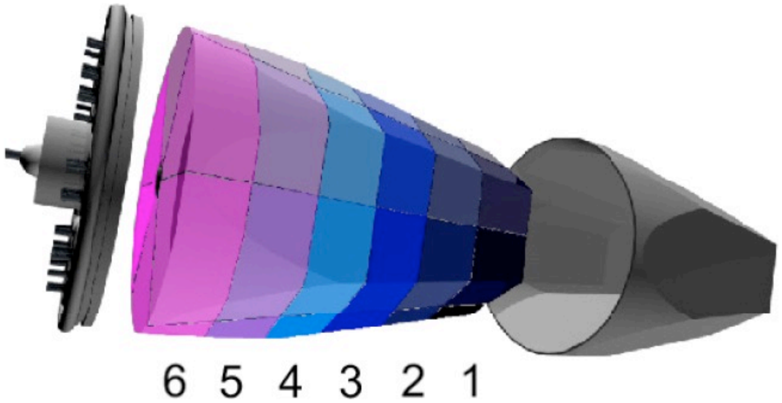
- **Resolution improvements.**
- Direct application in **cryogenic environments.**
  - **Thermal noise reduction.**
  - **No parasitic capacitances** introduced by long cables and connections.
  - Particularly **challenging** because at the state-of-the-art there is no model describing the transistors working behaviors at cryogenic temperature (liquid-nitrogen or liquid argon) to be used in simulations.

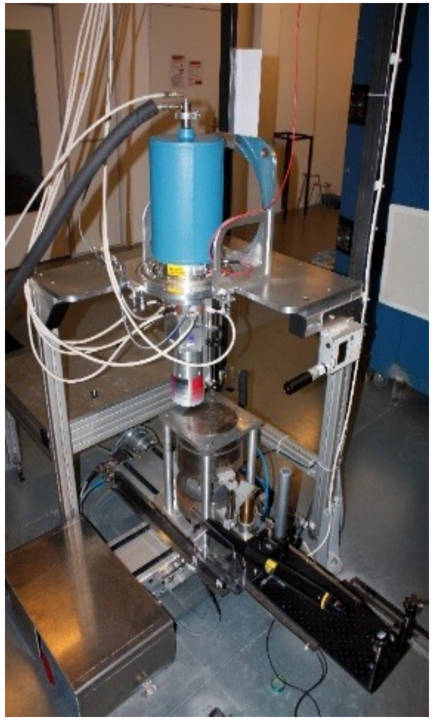


Agata capsule scan: LNL-IPHC collaboration

AGATA DETECTOR

- Encapsulated coaxial N-type detector
- 6x6 segments –> 37 chan. per crystals





IPHC SCANNING TABLE

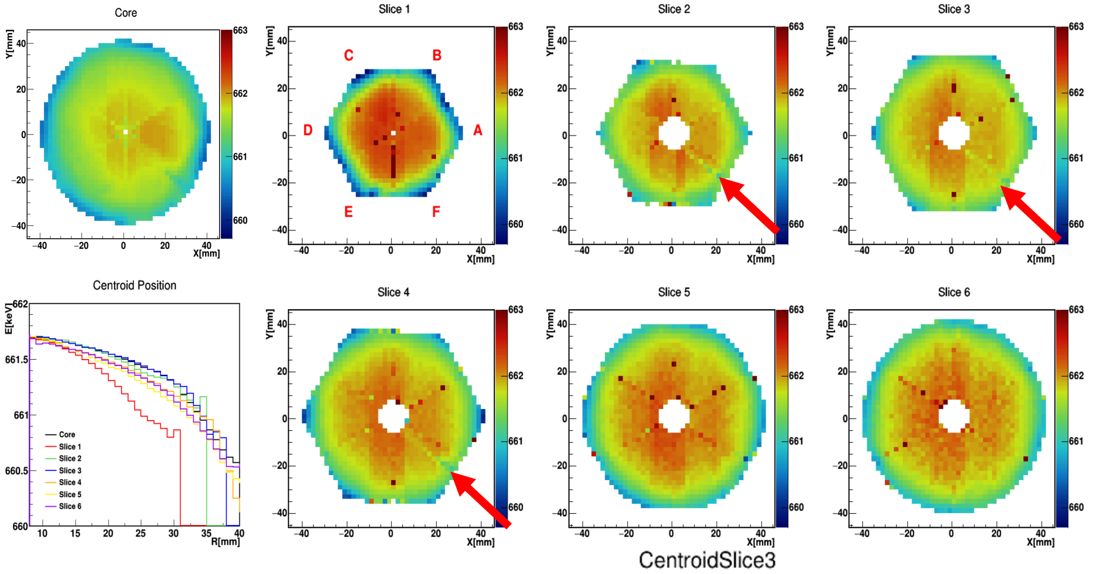
- Encapsulated coaxial N-type detector
- Intense source in a collimator (diam 1 mm, 165 mm) X Y mov. by mm or µm steps
- 14-bit, 100 MHz home made digital electronics (TNT2)
- Labview GUI alternating collimator move, data acquisition and liquid N2 fills

F.C.L. Crespi et al., NIM A 593(3), 440–447 (2008)

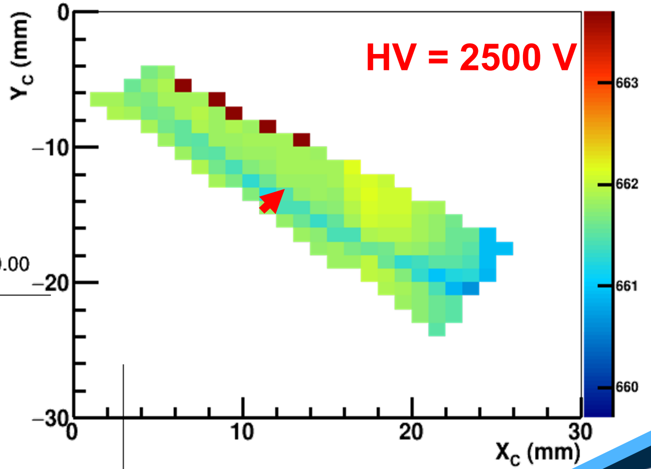
Electron trapping studies

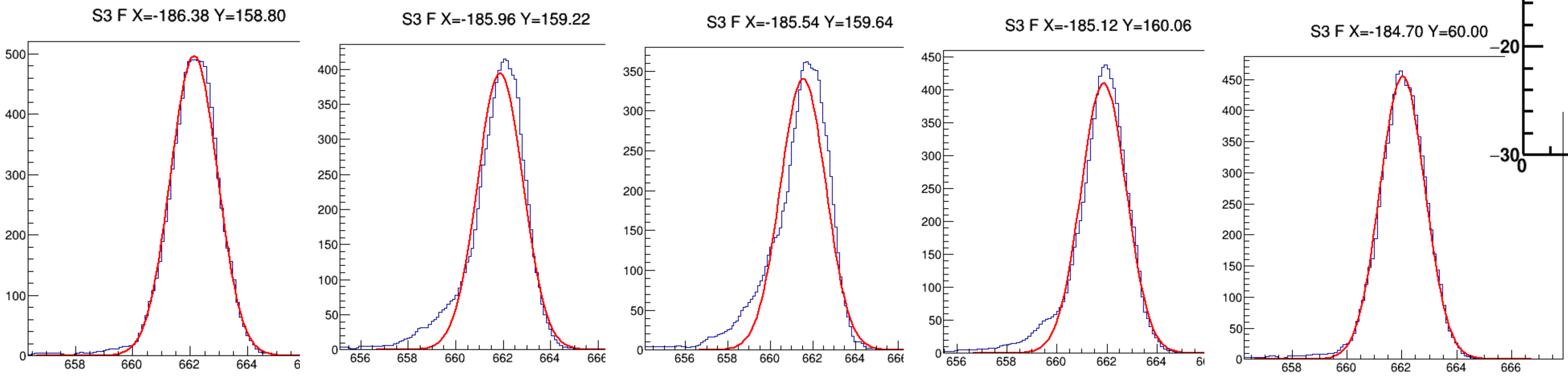
ENERGY PEAK SHIFT

- Detector scanned in vertical position
- ^{137}Cs source (662 keV) used for scanning
- Gamma-ray spectrum collected at each XY position
- Peak shift plotted vs XY/segment slice
- Anomaly observed in slices 2, 3 and 4 (red arrows)



100 µm pitch along the diagonal with 1 mm diam collimator R ~ 15.6 mm





Electron trapping studies

A lot of scans for detailed study of the trapping anomaly but also of the normal electron trapping.

- Geometry of the anomaly - transverse scans
- Trapping half-life - scans using different amplifier shaping time constants
- Collection efficiency - scans vs HV
- Trap depth - scans vs crystal temperature

LNL-IPHC COLLABORATION AND PROSPECTIVES

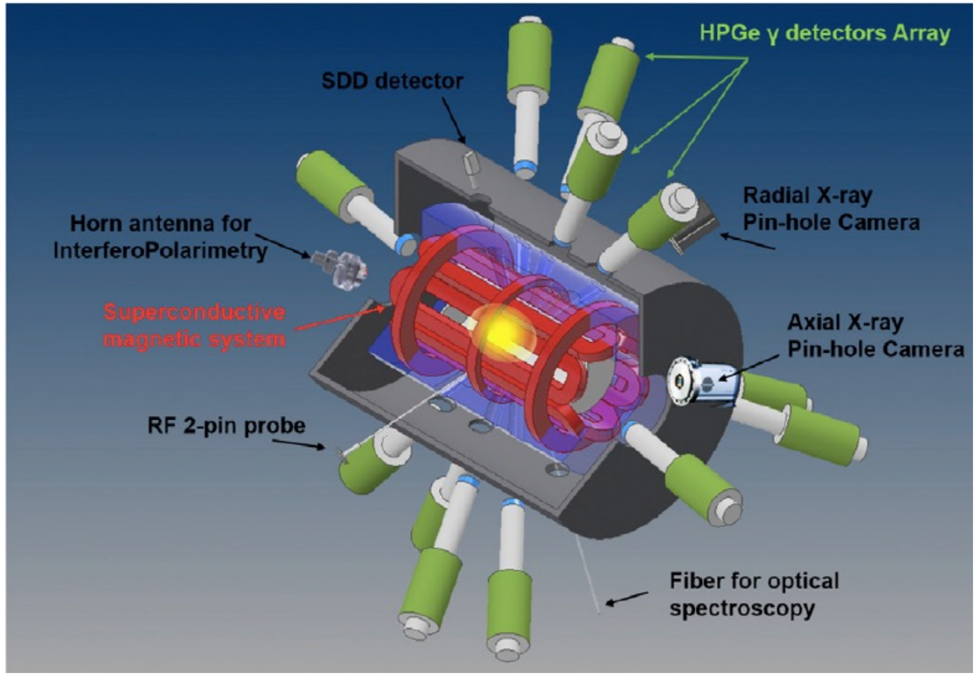
- Scans of passivated surfaces
- Scans of laser implanted contacts with or without segmentation (N3G)
- Scans of any contact/passivated surfaces with or without coating
- Surface/volume exploration with low/high gamma-ray energies (^{241}Am 60 keV, ^{137}Cs 662 keV, ^{152}Eu from 122 to 1408 keV)

IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

INFN Istituto Nazionale di Fisica Nucleare

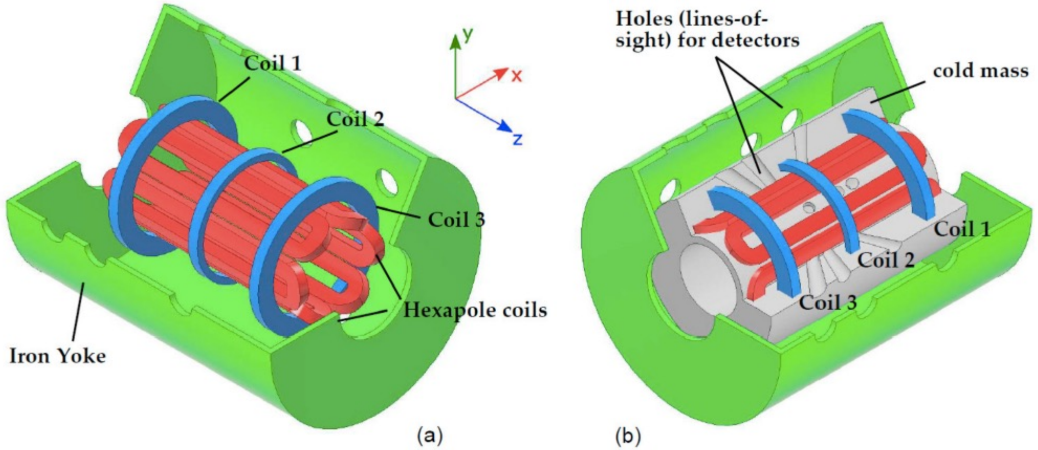
PANDORA (Plasma for Astrophysics, Nuclear Decay Observation and Radiation for Archeometry)

Measure, for the first time in plasma, nuclear beta-decay rates of radionuclides involved in nuclear-astrophysics processes.



Compact magnetic plasma trap has been designed to reach the needed plasma densities, temperatures, and charge-states distributions to emulate stellar-like conditions.

The decay rate of the radionuclides will be measured through the detection of the γ-rays emitted by the excited daughter nuclei following the β-decay.



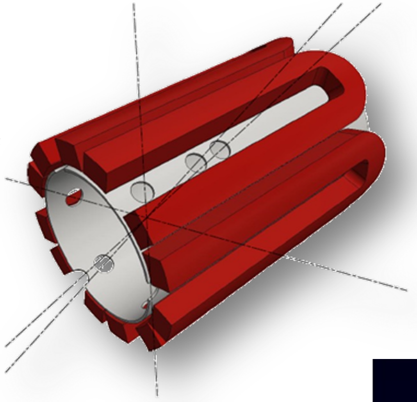
D. Mascali et al. Universe, 8, 80 (2022)

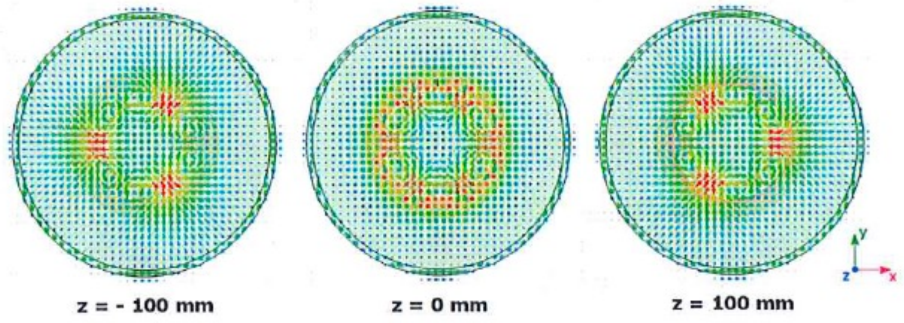
Required Ge array

An array of 14 HPGe detectors placed around the trap will be required to detect the emitted γ-rays.

Main limitations arises from:

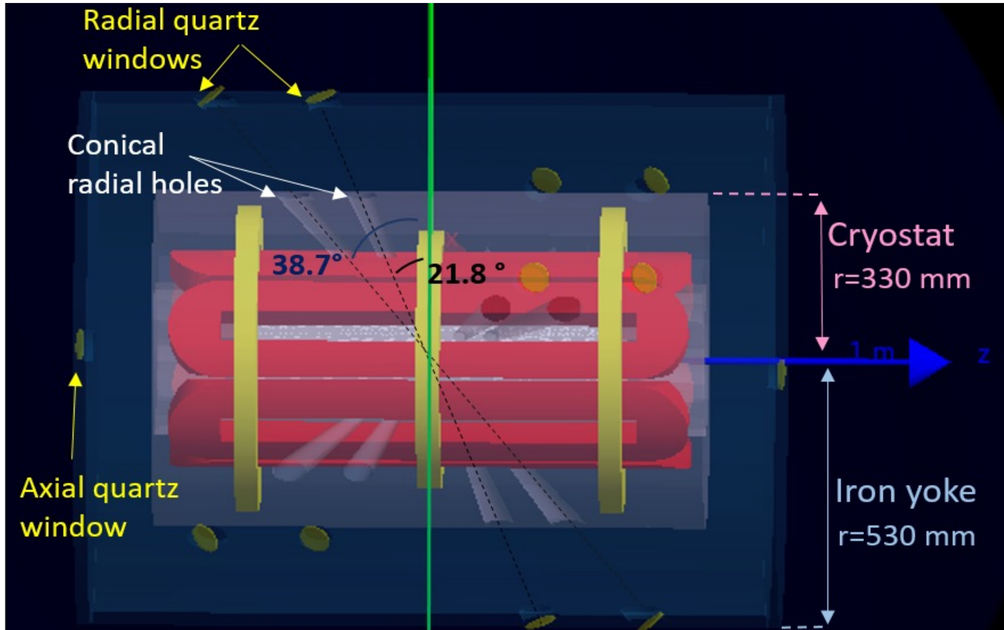
- **Size of coils of the magnetic trap**
- **Magnetic branches:** region of the magnetic trap where the B field lines are more intense – high bremsstrahlung induced gamma and x-rays.





The cryostat structure: holes are created along the conductor hexapole interspaces in order to use it as multi-collimator and suppress the background coming from the magnetic trap.

Iron yoke surrounding the magnetic plasma trap is shown in blue. Quarts windows (in yellow) are placed in correspondence with conical holes.



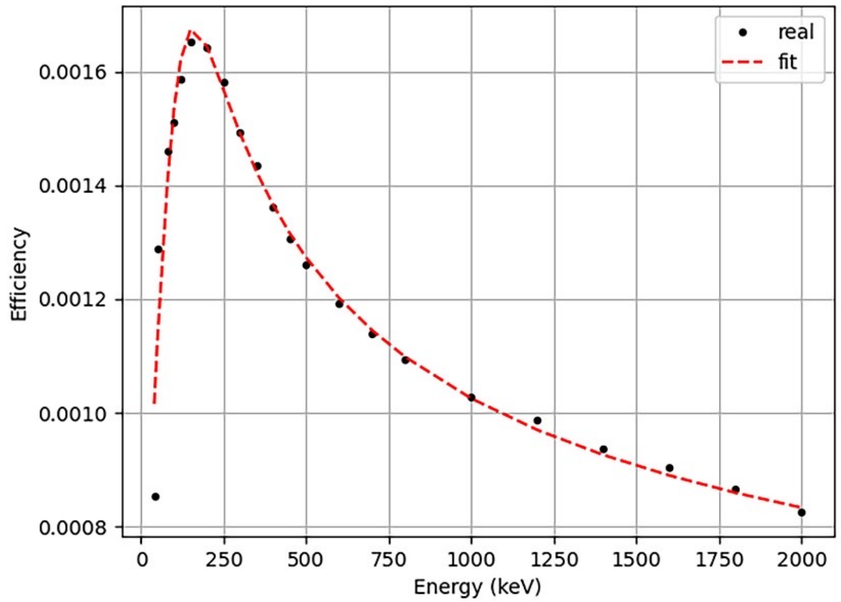
D. Mascali et al. Universe, 8, 80 (2022)
G. Mauro et al. Front. Phys. 10 931953 (2022)

HPGe array for PANDORA

- Photopeak detection efficiency (interplay between detector number and mechanical constraint)
- Signal to noise ratio (high background self-generated inside the trap)

⇒ Harsh experimental conditions (sufficiently fast response from detectors: counting rate of 50kHz on each detector)

- Magnetic field effects on HPGe charge collection (B<200 gauss)



Photopeak detection efficiency vs. gamma-ray Energy

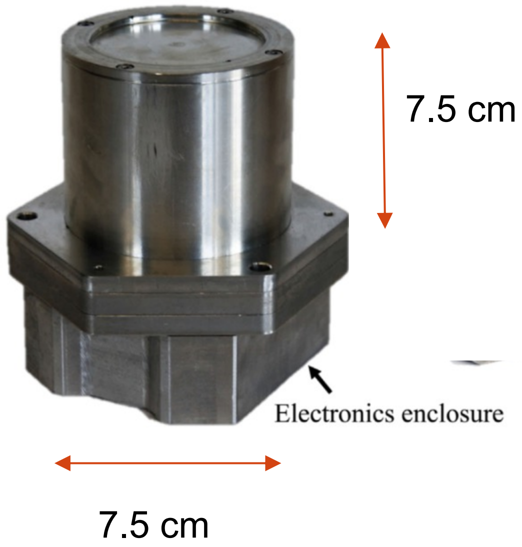
Normal Working conditions will require:

- LN_2 Cooling system for HPGe array is under study
- A new lab to store, repair and perform the maintenance of detectors

E. Naselli et al. *Front. Phys.* 10:935728 (2022)

$LaBr_3$:Ce:Sr + SiPMs

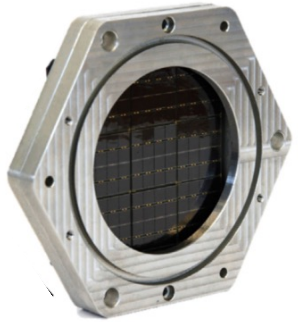
Crystal enclosure

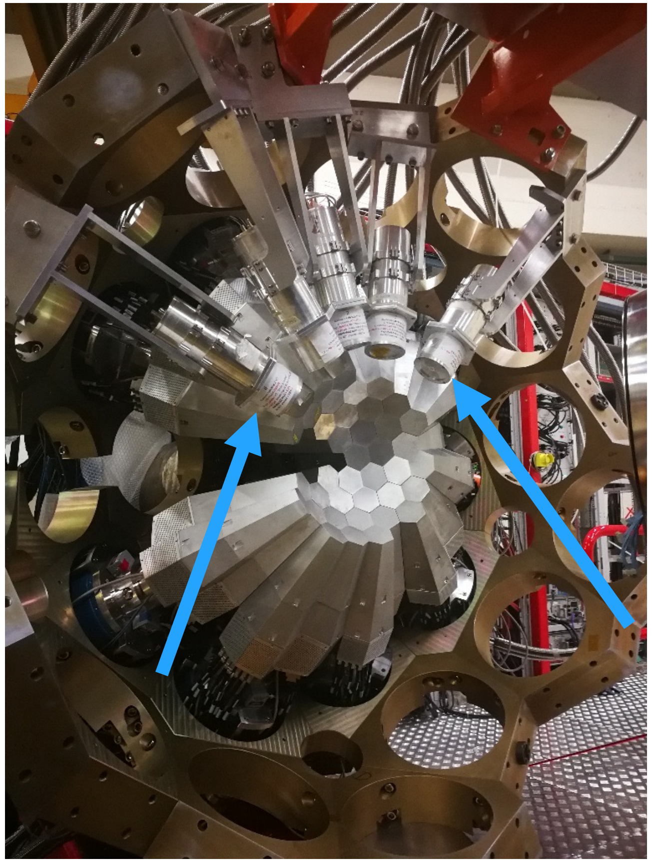


General features:

- The crystal is a $LaBr_3$:Ce:Sr cylinder 7.5 cm high with a diameter of 7.5 cm.
- The detector uses 144 SiPMs and 9 ASICS,
- Each SiPM has 40000 30x30 micron SPADs
- The detector uses a variable gain selected on an event by event basis
- The detector has also an USB based digital embedded DAQ (C++ based)
- The maximum count rate at which the resolution is not degraded is 40kHz

SiPM MATRIX





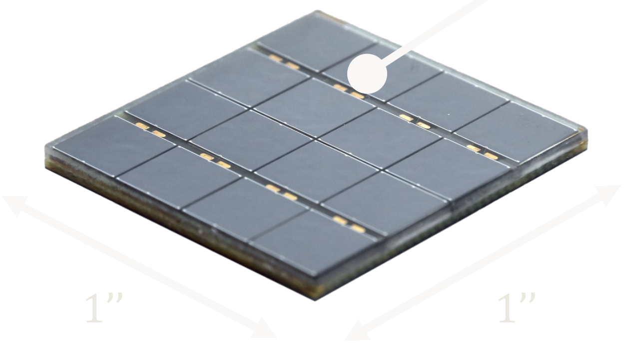
AGATA array at LNL with 5 $LaBr_3$ installed (read from PMT, not SiPMs yet).

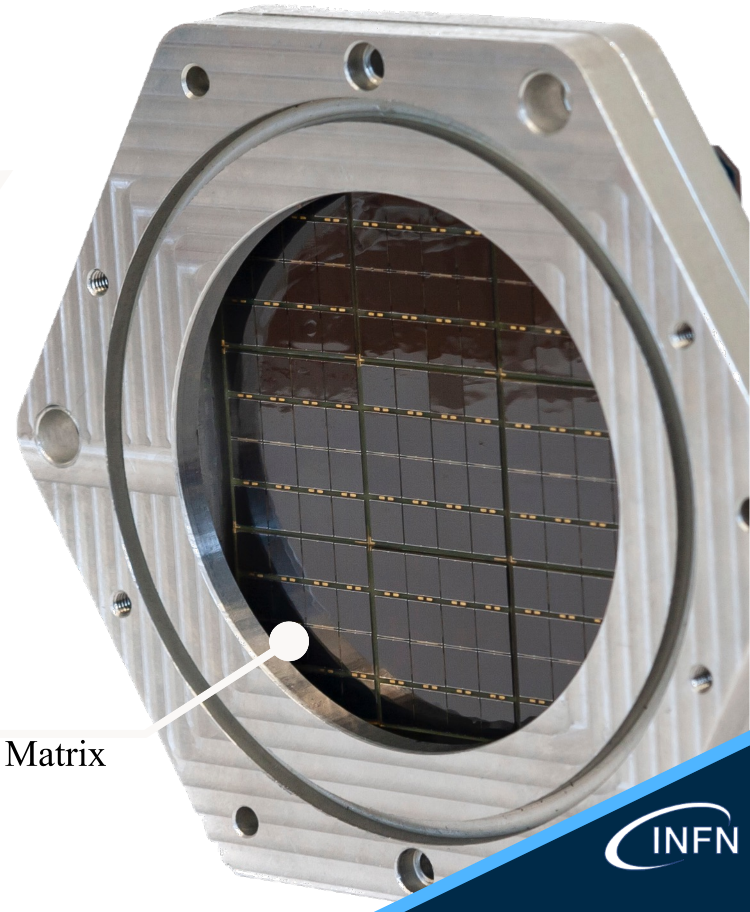
F.Camera[1,3], O.Wieland[3], A.Bracco[1,3] ,F.C.L. Crespi[1,3], S.Leoni[1,3], B.Million[3], C.Fiorini[2,3], M.Agnolin[2,3], G.Borghi[2,3], M.Carminati[2,3], D.Di Vita[2,3], G.Ticchi[2,3]

[1] *Università di Milano, Dipartimento di Fisica, via Celoria 16, 20133 Milano, Italia*
[2] *Politecnico di Milano, Dipartimento di Elettronica, Informazione e Bioingegneria, piazza L. da Vinci 32, 20133 Milano, Italia*
[3] *INFN sez. Milano, via Celoria 16, 20133 Milano, Italia*

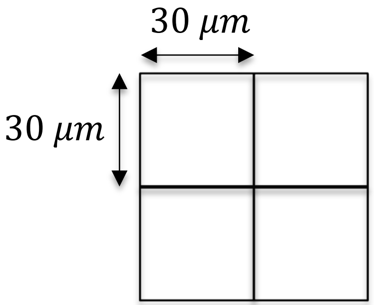
FBK NUV-HD SiPMs custom tile

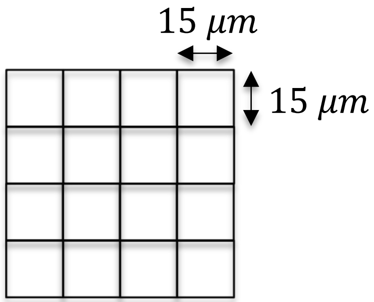
- 1'' x 1'' size, 4-side buttable
- Custom high-reliability connectors
- Temperature sensor under each tile





Two cell options: 30μm and 15μm cells

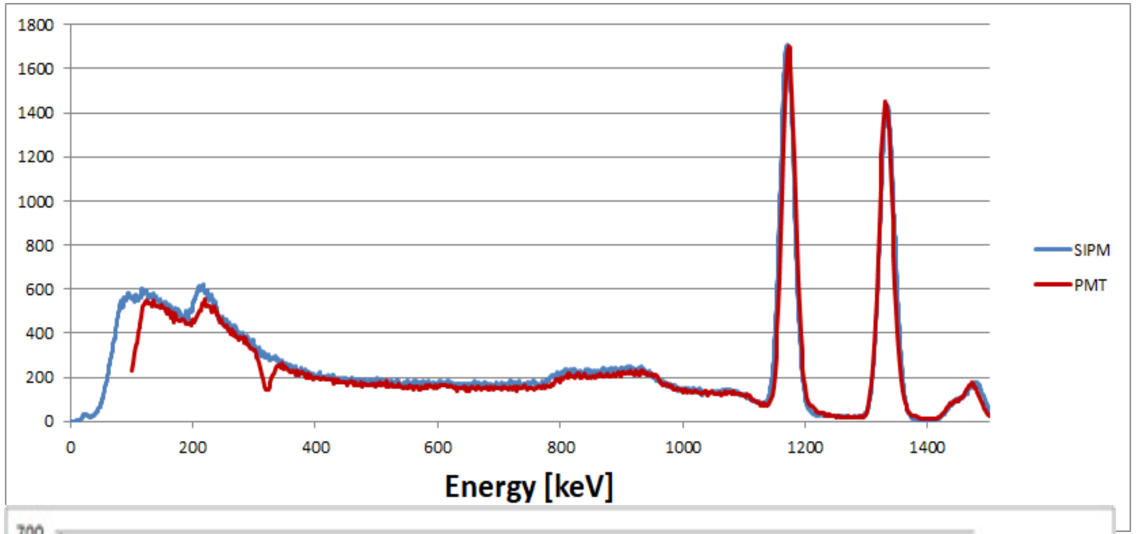


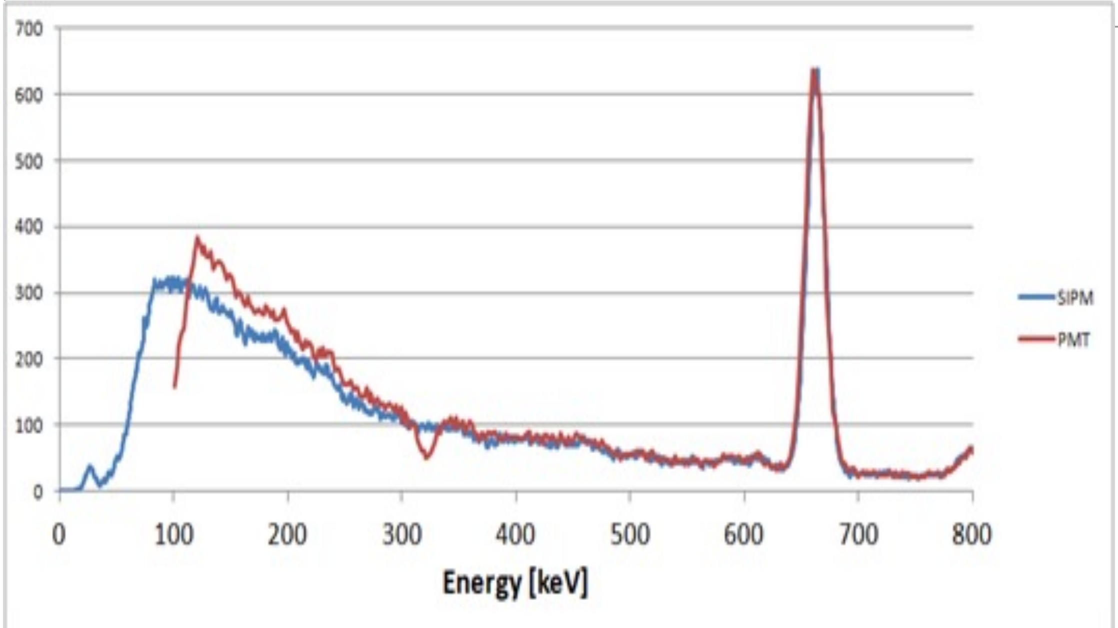


30μm cells:
- 45% PDE (photon detector efficiency)
- 77% FF
- V_{BD} = 26.5V
- 100kHz/mm^2 DCR
- 1% non-linearity at **9MeV**

15μm cells:
- 35% PDE
- 61% FF
- V_{BD} = 31.5V
- 60kHz/mm^2 DCR
- 1% non-linearity at **35MeV**

$LaBr_3$:Ce:Sr + SiPMs Comparison with PMT





$LaBr_3$:Ce:Sr + SiPMs Perspectives

Time performances

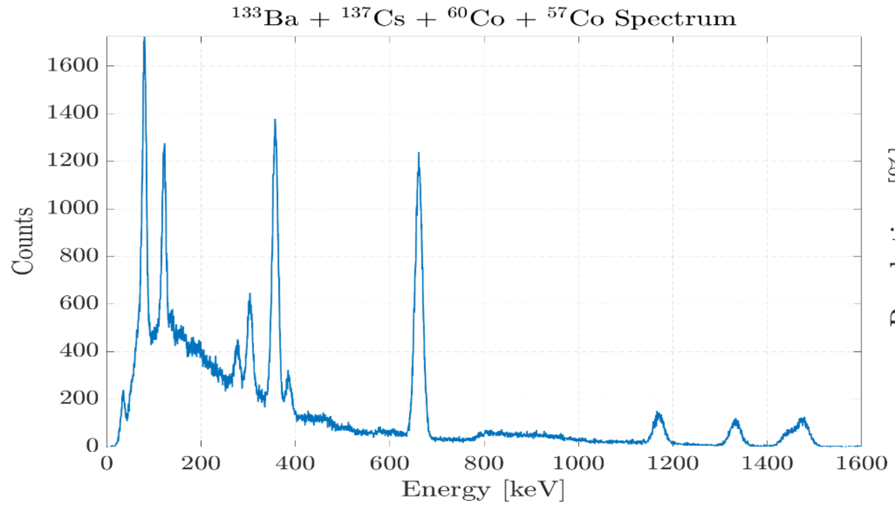
- The used detector has a time resolution of ≈ 2.5 ns
- A new ASIC is going to be developed to improve time performances

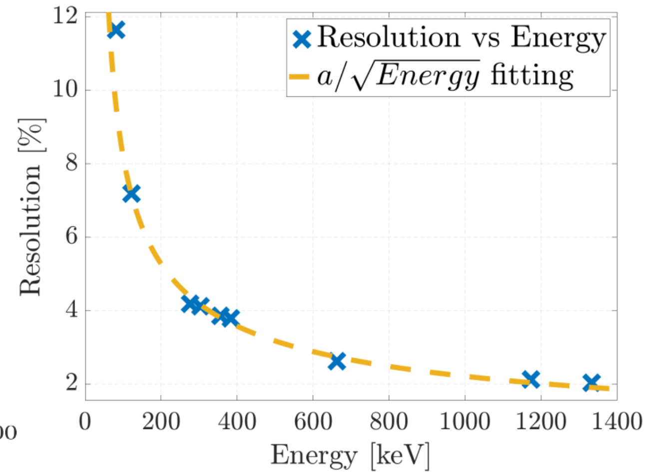
Position Sensitivity

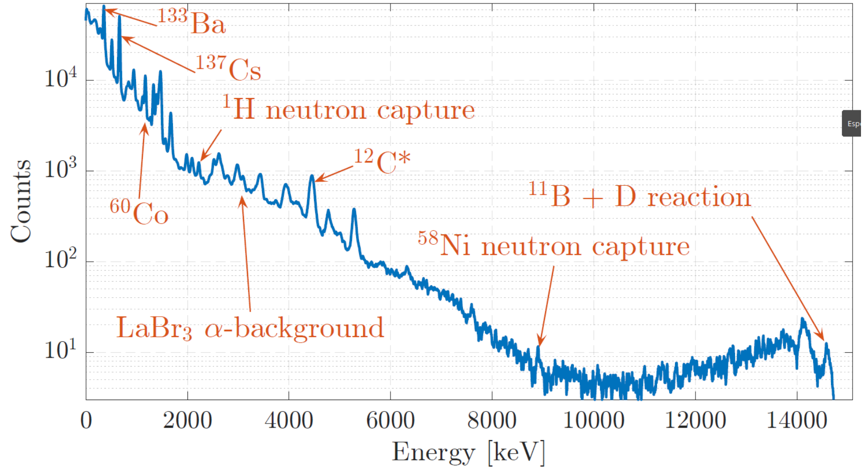
- Doppler Broadening reduction

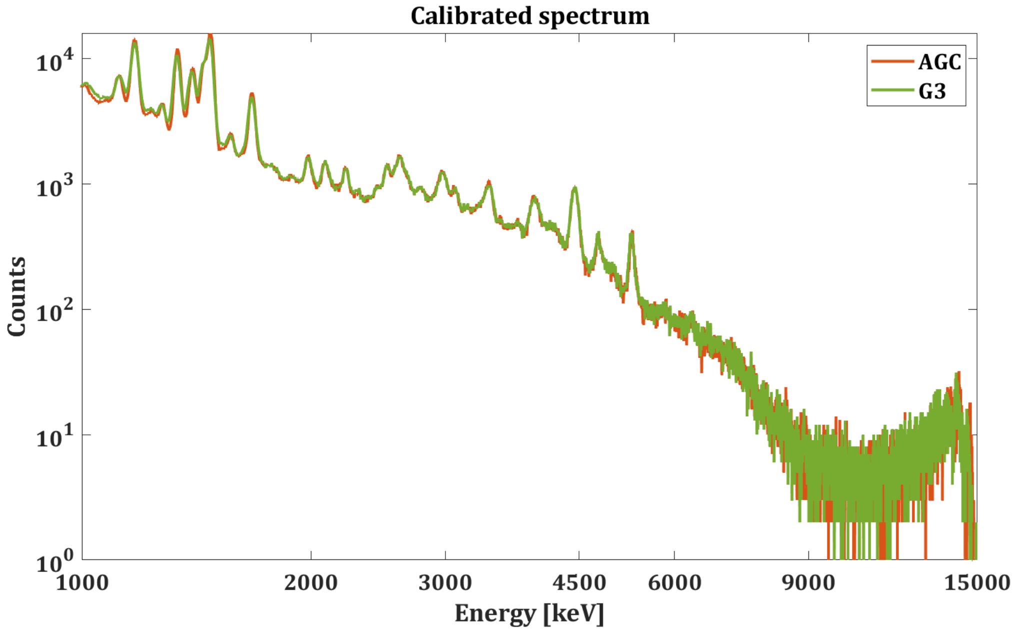
There are no differences between the F.E.P. measured using a PMT and an array of SiPMs

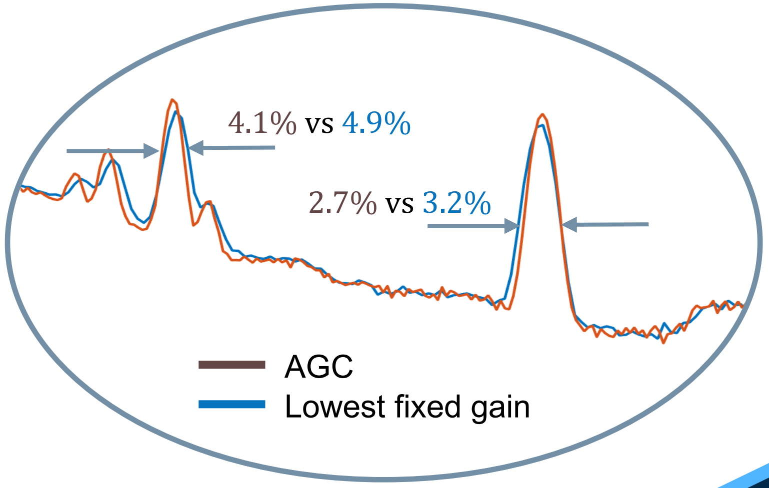
$LaBr_3$:Ce:Sr + SiPMs









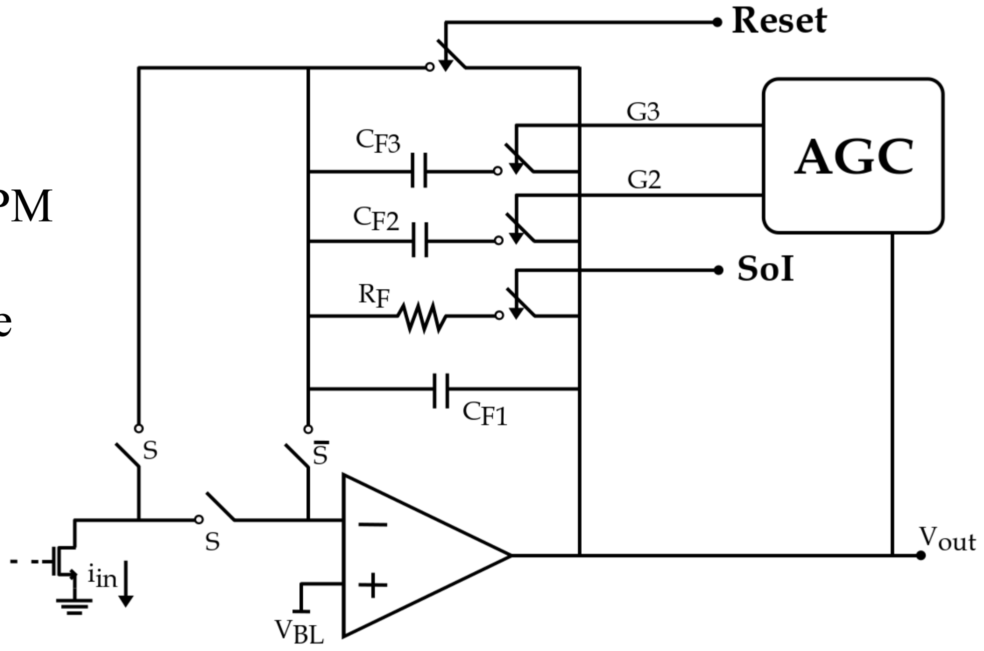


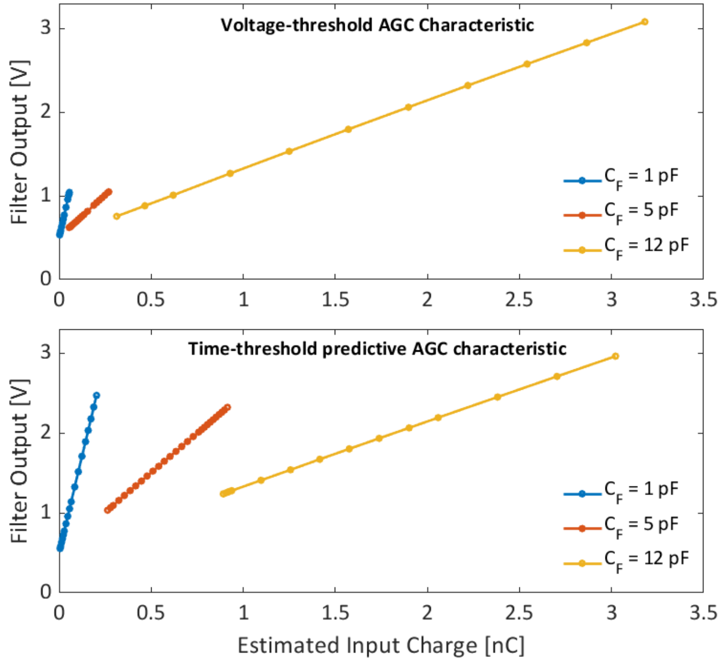
Adaptive gain control (AGV) vs lowest fixed gain

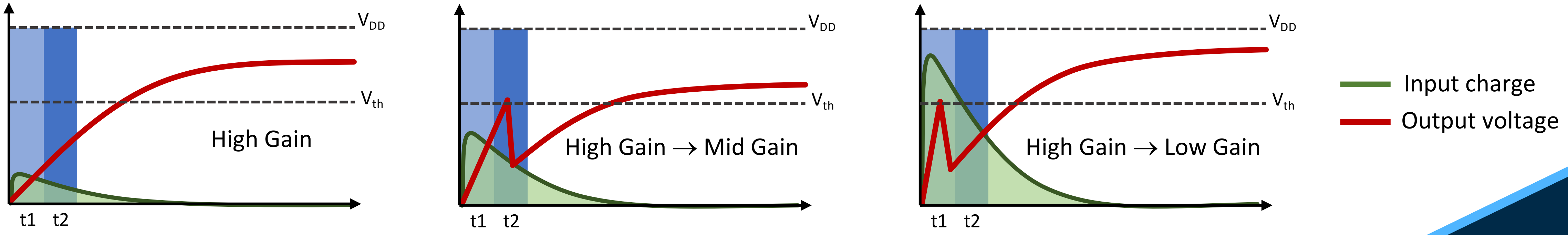
GAMMA ASIC: Adaptive Gain Control (AGC)

GAMMA ASIC:

- 16 channels with AGC
- Stable with >70nF/ch (>24 SiPM 6x6 mm^2 per channel)
- programmable integration time (100ns to 16µs)
- Monolithic readout



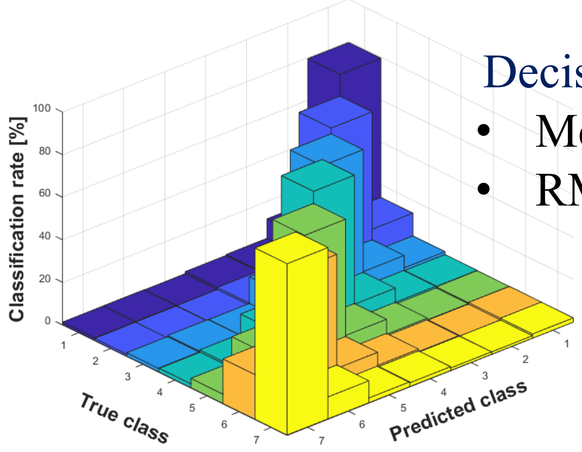




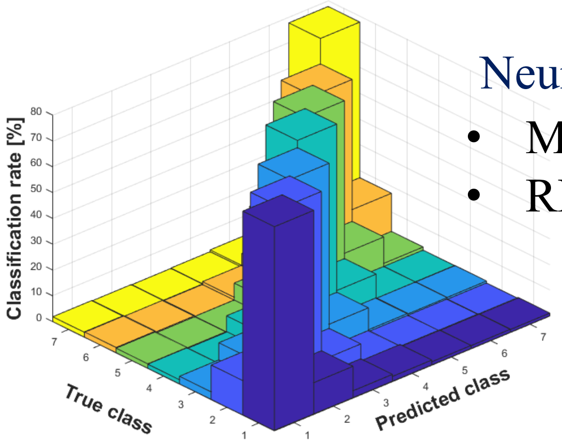
30keV – 30MeV energy dynamic range in a single measurement

Machine learning for position reconstruction (662 keV)

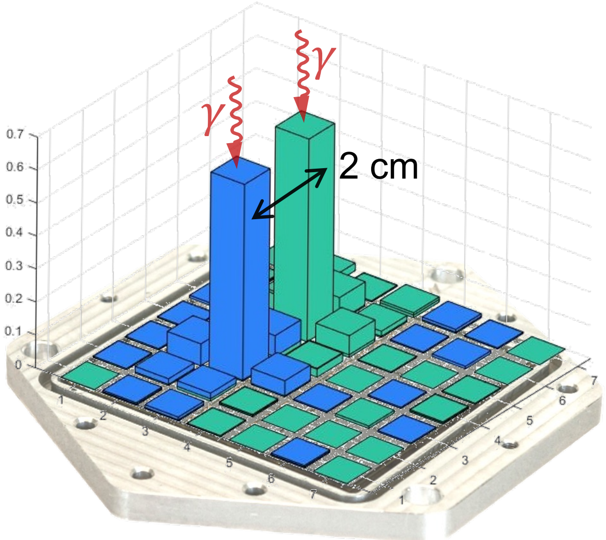
Confusion matrix (x,y)



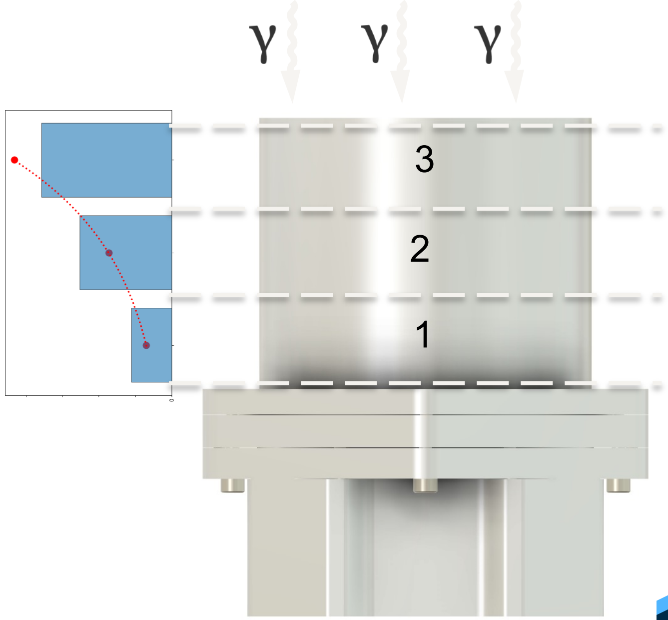
Decision Tree
- Mean error: 0.47 cm
- RMS error: 1.08 cm



Neural Network
- Mean error: 0.42 cm
- RMS error: 1.02 cm

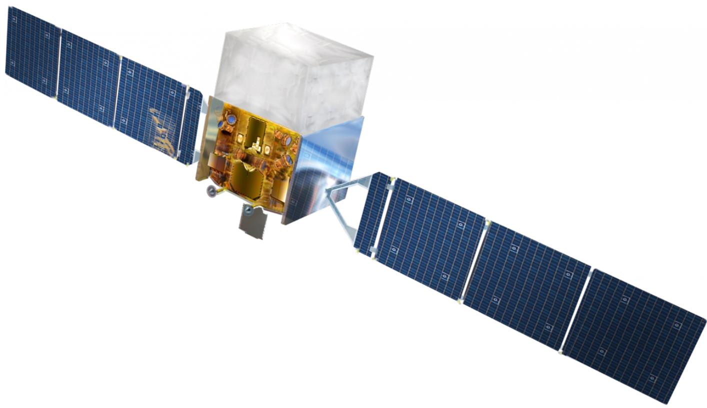


2 cm spaced irradiations



Depth Of Interaction
(z axis)

FERMI-GLAST Large Area Telescope



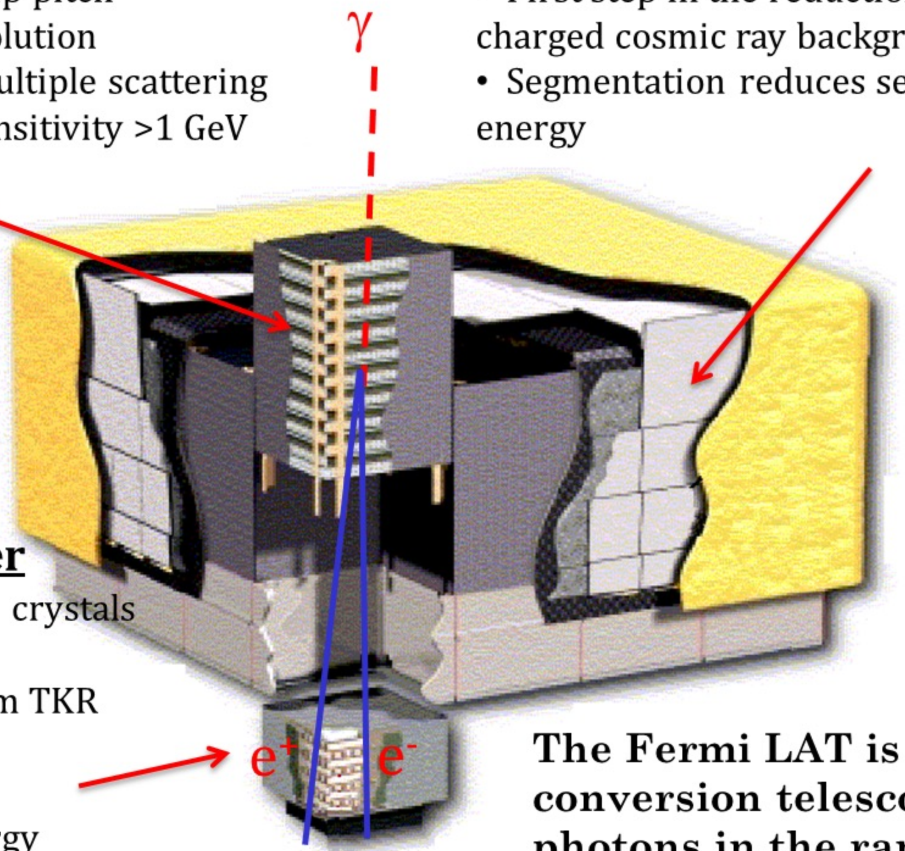
NASA Fermi sat. icon

Precision Si-strip Tracker (TKR)

- Measures incident γ-ray direction
- 18 XY tracking planes: 228 μm strip pitch
- High efficiency. Good position resolution
- 12x 0.03 X_0 front end → reduce multiple scattering
- 4x 0.18X_0 back-end → increase sensitivity >1 GeV

Anticoincidence Detector (ACD)

- 89 scintillator tiles
- First step in the reduction of large charged cosmic ray background
- Segmentation reduces self-veto at high energy

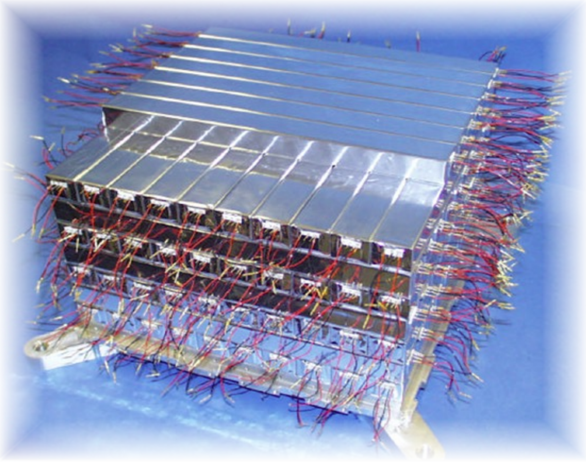


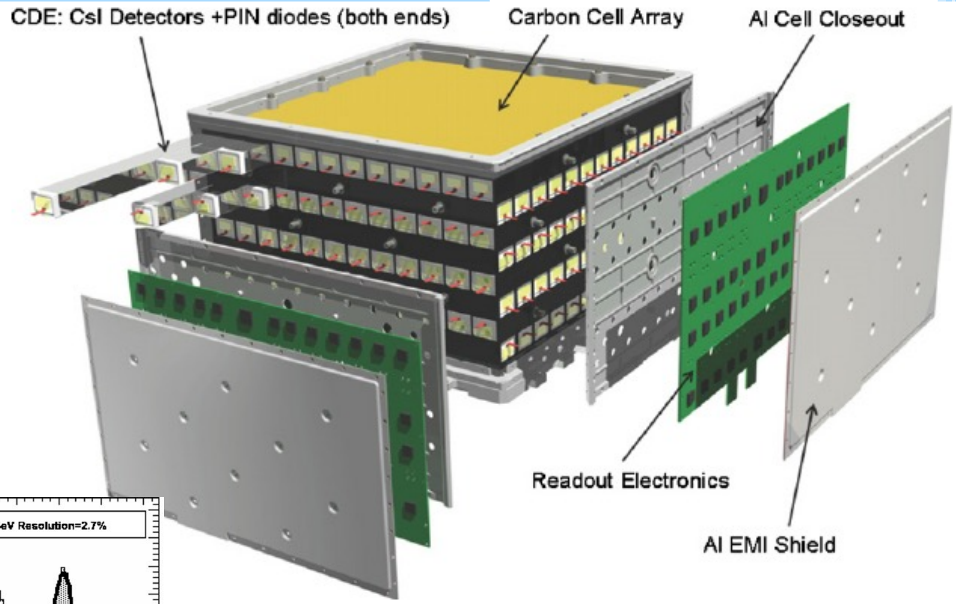
Hodoscopic CsI Calorimeter

- Segmented array of 1536 CsI(Tl) crystals
- 8.6 X_0: shower max contained
  - ~ 200 GeV normal (1.5X_0 from TKR included)
  - ~ 1TeV @ 40° (CAL-only)
- Measures the incident γ-ray energy
- Rejects cosmic-ray background

The Fermi LAT is a pair-conversion telescope for photons in the range from 20MeV up to >300 GeV

GLAST Calorimeter





Modular array

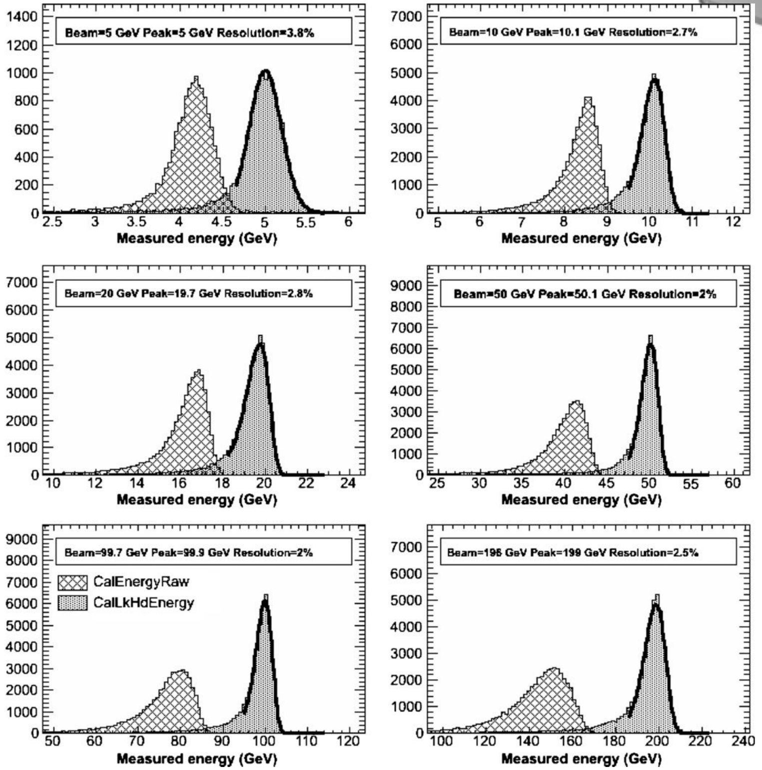
- 4 x 4 CAL modules
- On axis depth = 8.6 R.L.

Each module

- 8 layers of 12 CsI(Tl) crystals
  27 x 20 x 326 mm^3
- Hodoscopic stacking
  Alternating orthogonal layers
- Dual PIN photodiode read-out

Mechanical packaging: Composite cell structure

Electronic boards attached to each side

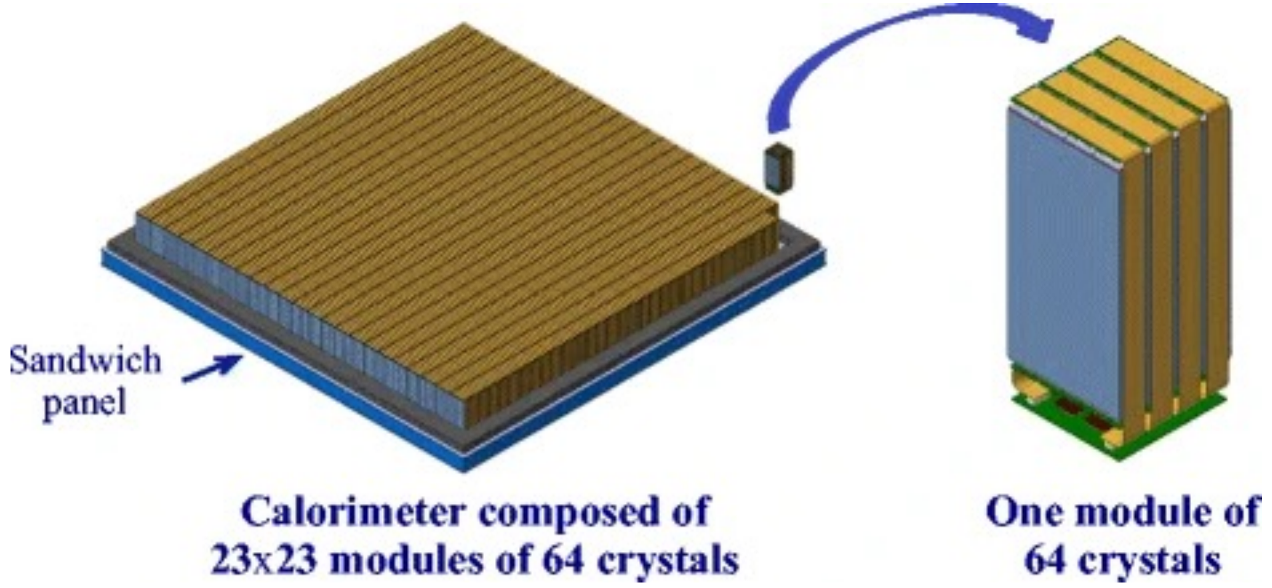


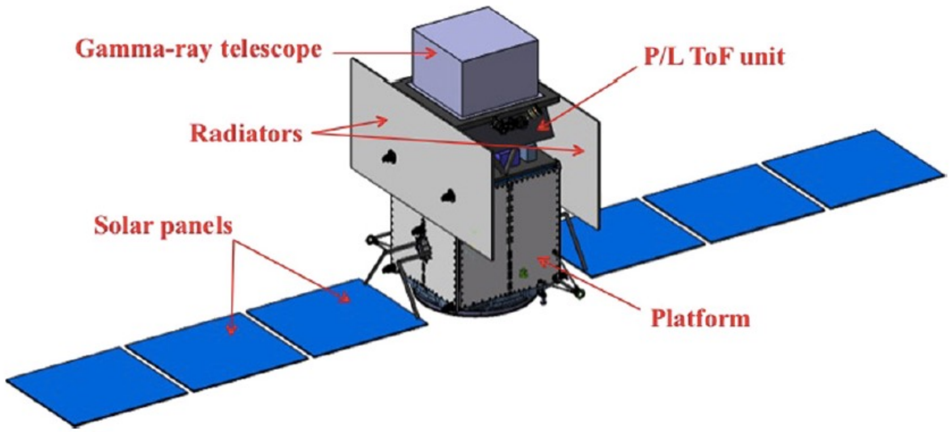
- Energy resolution as a function of electron energy as measured with the LAT calibration unit in CERN beam tests
- Each panel displays a histogram of the total measured energy (hatched peak) and the reconstructed energy (solid peak)
- The beams entered the calibration unit at an angle of 45° to the detector vertical axis

e-ASTROGRAM: calorimeter

Submitted to ESA M7 call

- ASTROGAM proposed to ESA M-class call
  - Compton and pair production gamma-ray detector 0.1 MeV → 10 GeV.
- CAL module
  - Pixelated detector made of 33856 CsI (Tl) scintillator bars of 8 cm length (4.3 rad lenghts) and 5×5 mm^2 cross section, glued at both ends to low-noise Silicon Drift Detectors (SDDs by FBK) or SiPMs.





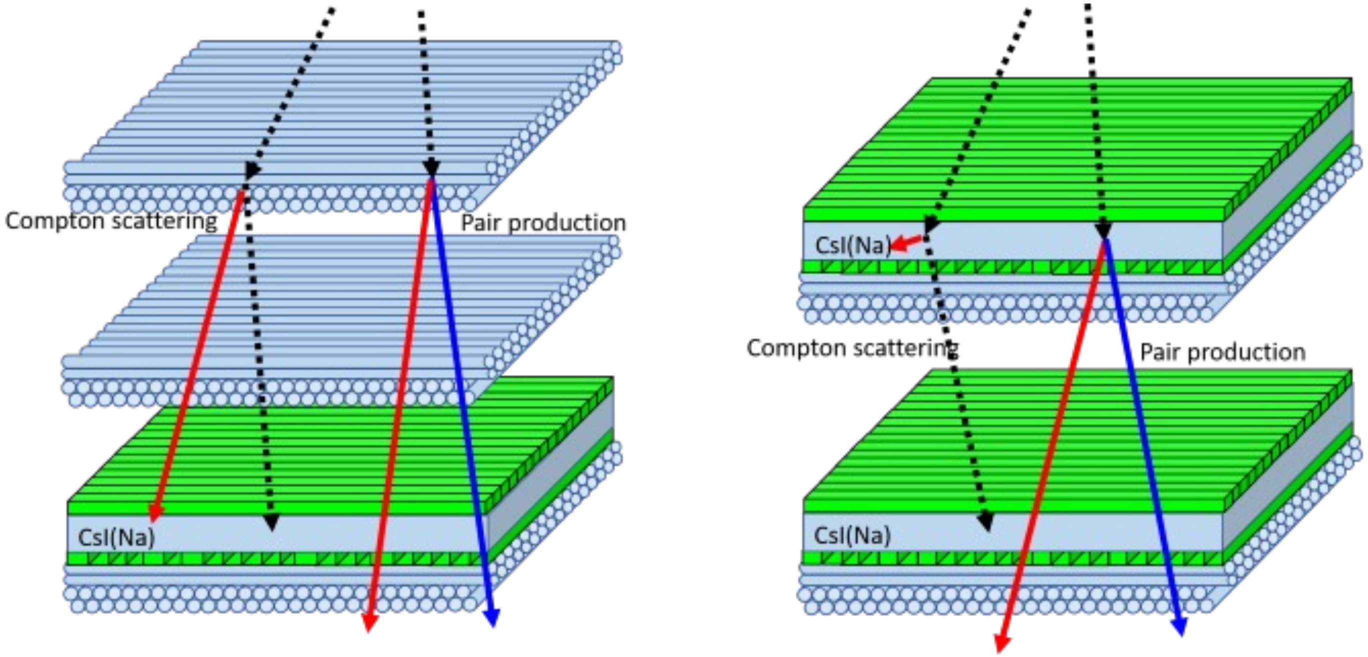
e-ASTROGRAM is a proposed space mission with the purpose of measuring gamma rays from astrophysical sources. It will sample the right energies to explore the highest-energy electromagnetic counterparts of gravitational wave events, localizing possible corresponding gamma-ray burst.

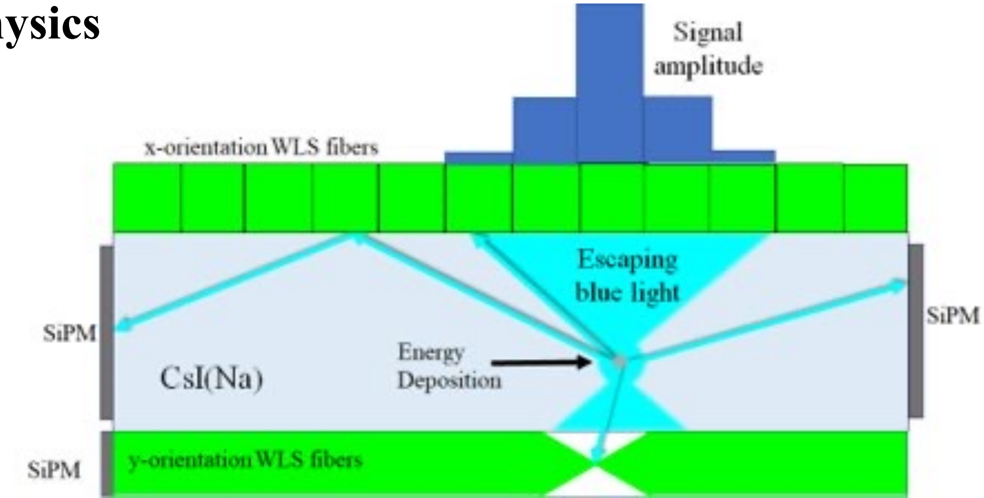
1) Astogram coll, *Exp Astron* 44:25–82 (2017)
2) A. De Angelis et al. *J. Of High Energy Astrophysics*, 19 (2018)
3) Jürgen Knödlseder, *Comptes Rendus Physique,* 17, 663-678 (2016)
4) A. De Angelis et al. arXiv:1611.02232 (2017)

Imaging calorimeter tracker-converter

- Gamma-ray Active tracker-converter based on thin crystal scintillator read-out by external wavelength shifting (WLS) optical fibers

  LYSO or CsI(Na) crystals
- Light tracker based on thin plastic scintillating fibers
- Read-out with SiPM linear array at one (or both) end of the fibers
- Based on the **Advanced Particle-astrophysics Telescope (APT)** proposal



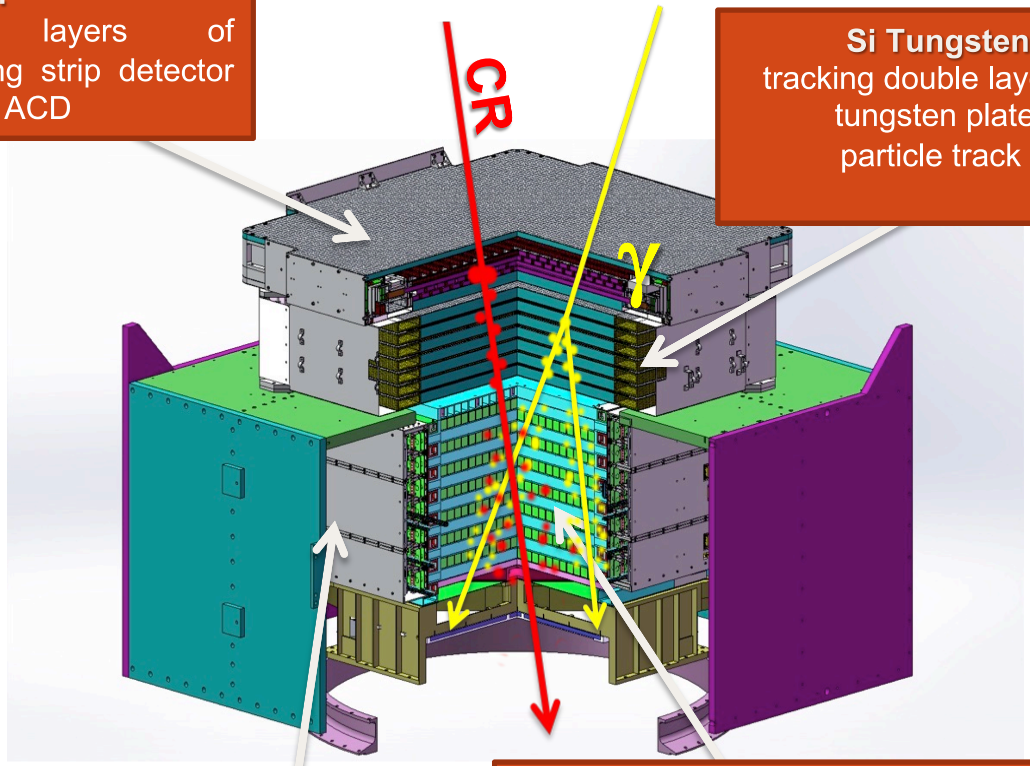


DAMPE project

Dark Matter Particle Explorer dedicated to the indirect detection of dark matter (DM) in space and astrophysical studies.

It was launched to a 500 km Sun-synchronous orbit on Dec. 17th, 2015 from the Jiuquan Satellite Launch Center.

- Si Tungsten Tracker is used as anti-coincidence system for particle bkg rejection for gamma ray detection.
- Photon pair-convert in tungsten plates; energy of positron-electron pairs adsorbed in 14 layer BGO calorimeter (31 rad lengths), read out by PM tubes.



Plastic Scintillator Detector: double layers of scintillating strip detector acting as ACD

Si Tungsten Tracker: 6 tracking double layers + 3 mm tungsten plates. Used for particle track and photon conversion

NUD: it's complementary to the BGO by measuring the thermal neutron shower activity. Made up of boron-doped plastic scintillators

Calorimeter: 308 BGO bars in hodoscopic arrangement (**~32 radiation lengths**). Performs both energy measurements and trigger

Jürgen Knödlseder, *Comptes Rendus Physique,* 17, 663-678 (2016)

DAMPE: photon selection

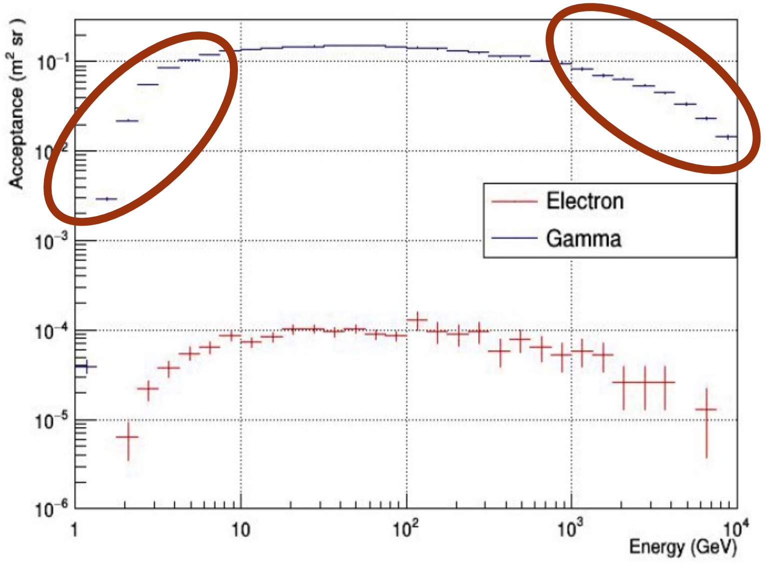
The main background sources are proton and electrons:

- Protons: 10^5 @ E > 100GeV Protons are mainly rejected using the shower profile and the onboard trigger

- Electrons: 10^3 @ E > 100GeV Electrons are mainly rejected using the PSD and 1st layer of STK

Trigger effect

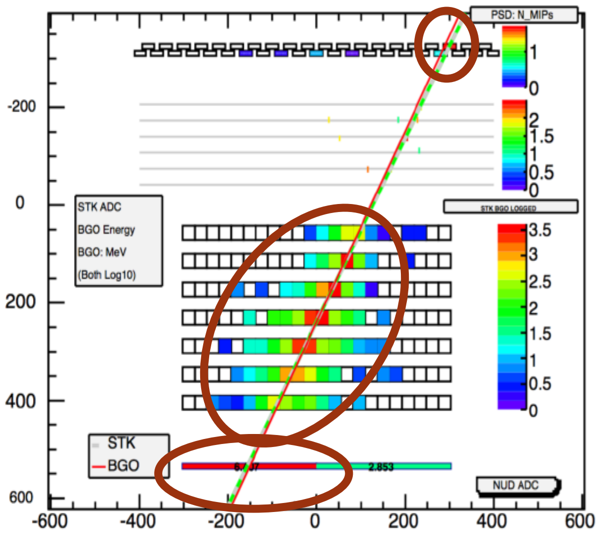
Backscattering effect



Acceptance after the selection criteria applied to reject protons and electrons.

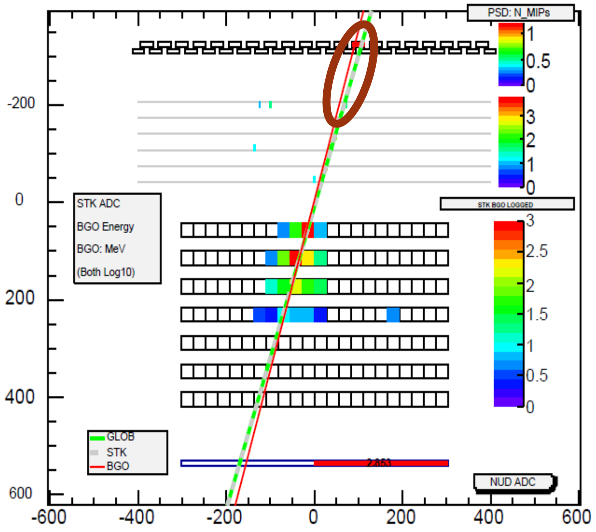
proton

Y [No. 32: 49.132GeV]



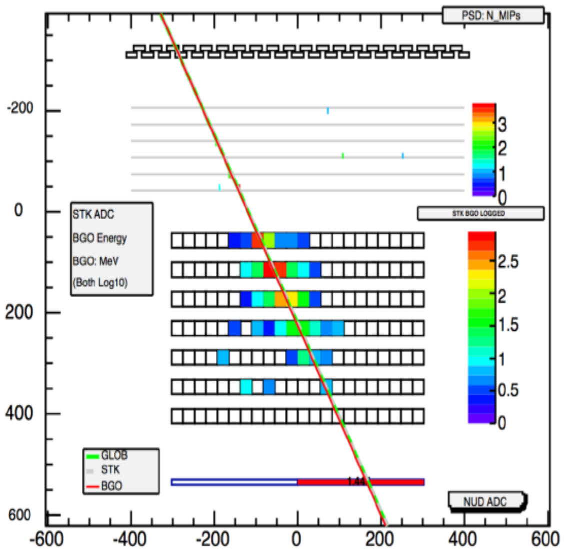
electron

Y [No. 40: 5.034GeV]



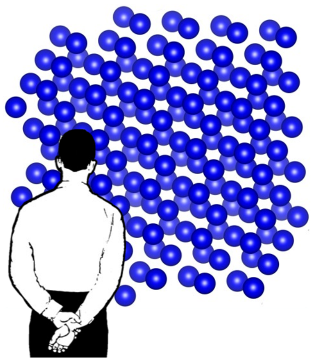
gamma

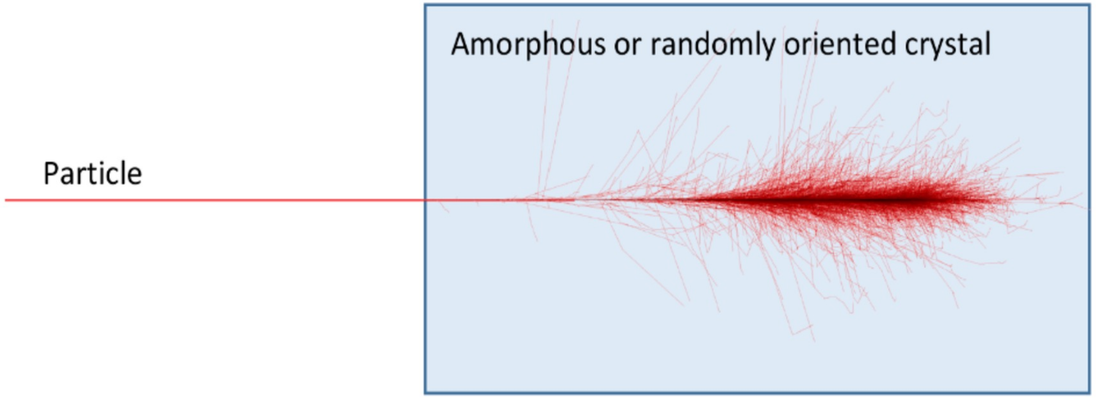
Y [No. 61: 5.559GeV]



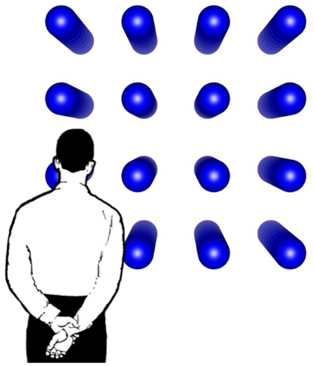
OREO ORiEndted calOrimeter

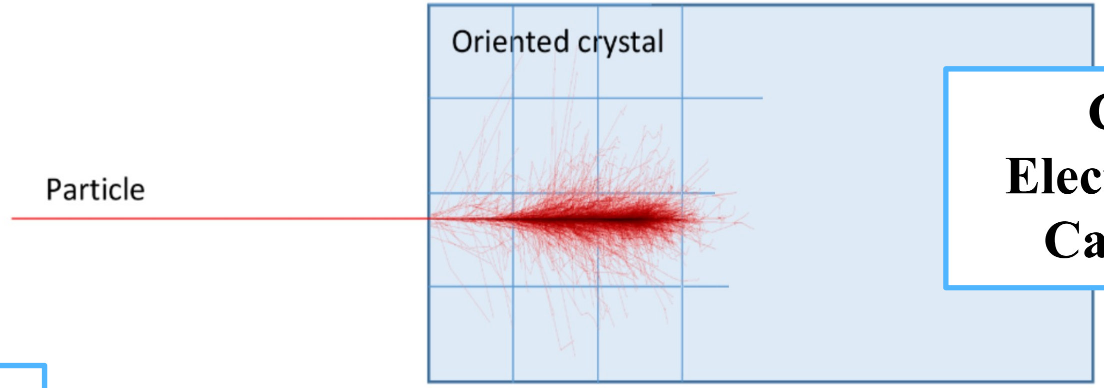
Randomly Oriented Crystals





Axially Oriented Crystals





Compact Electromagnetic Calorimeter!

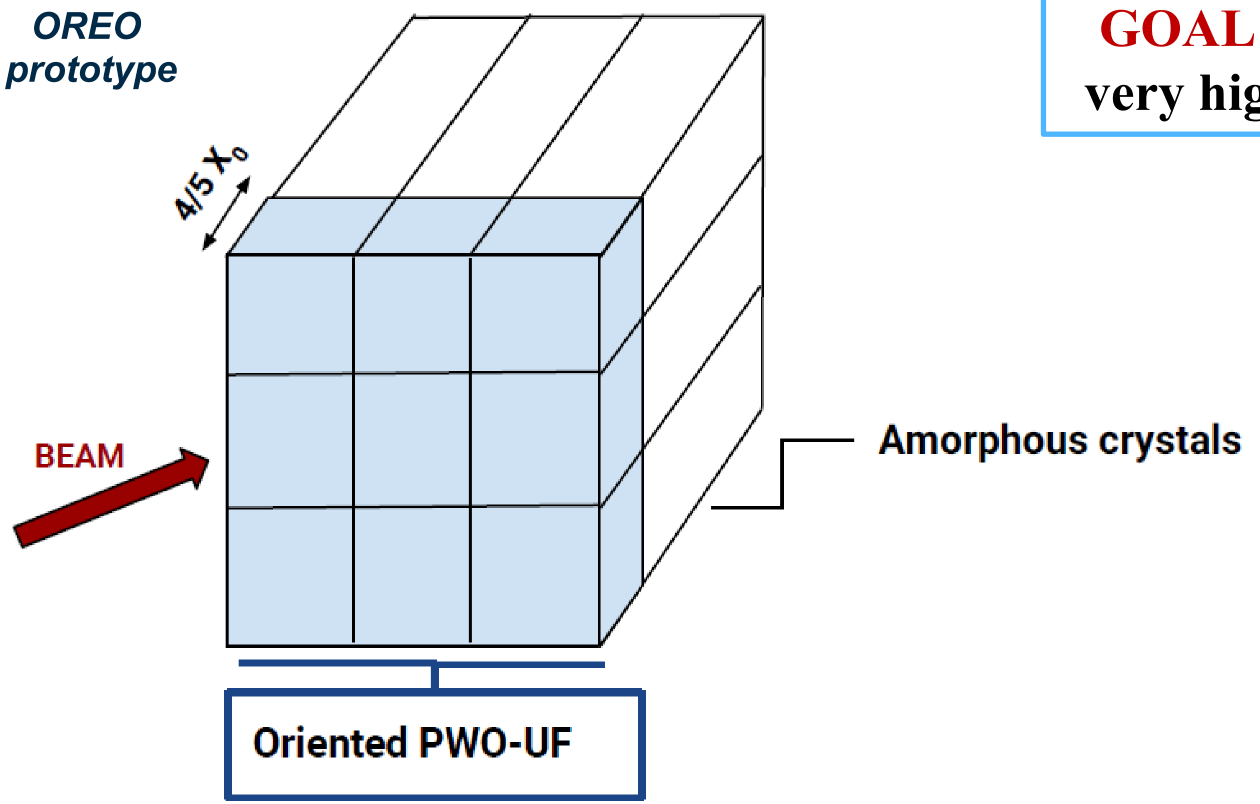
Reduction of the radiation length X_0 in comparison with amorphous media

X_0 reduced from 9 mm to 2 mm in an oriented PbWO4 *scintillator*[1]

1) L. Bandiera, *Phys. Rev. Lett 121 021603 (2018)*

For info: bandiera@fe.infn.it

OREO applications



GOAL: to contain electromagnetic showers initiated by very high energy γ/e in a reduced volume/weight and cost

- ***Radiation length reduction***
  - **X_0 decreases with initial energy increase.**
- ***Angular range:***
  - few mrad up to 0.5°-1° of misalignment between particle direction and crystal axes;
  - Does **NOT** depend on particle energy.

Challenge: Construction of an oriented layer of many crystals

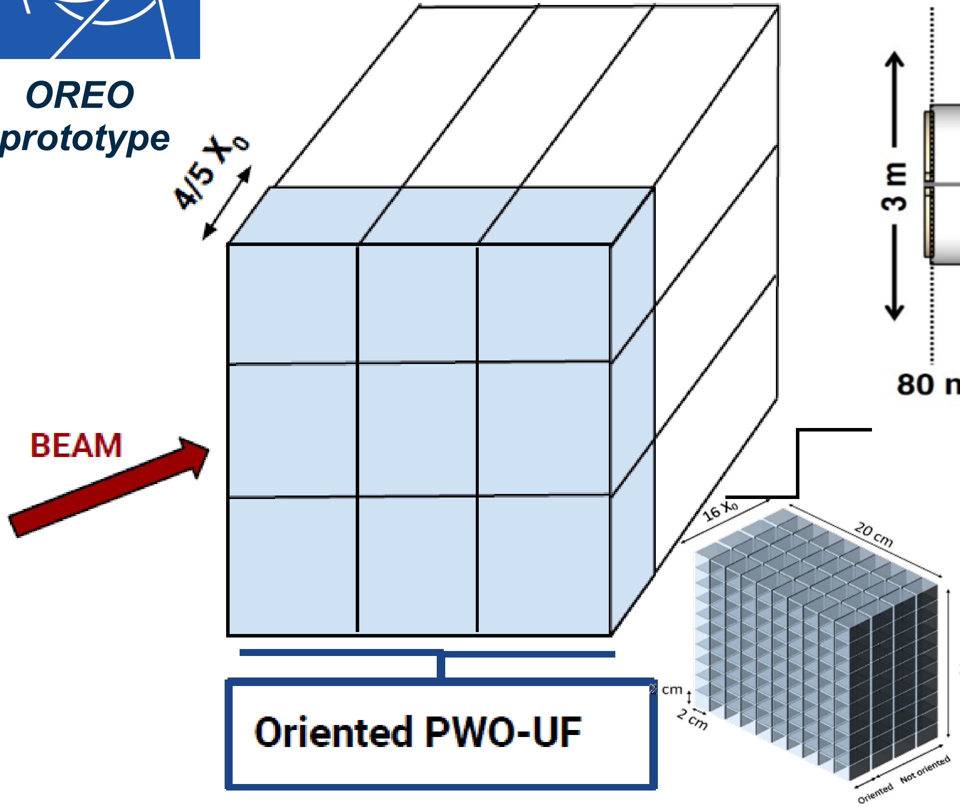
$K_L \to \pi^0 \nu\nu$

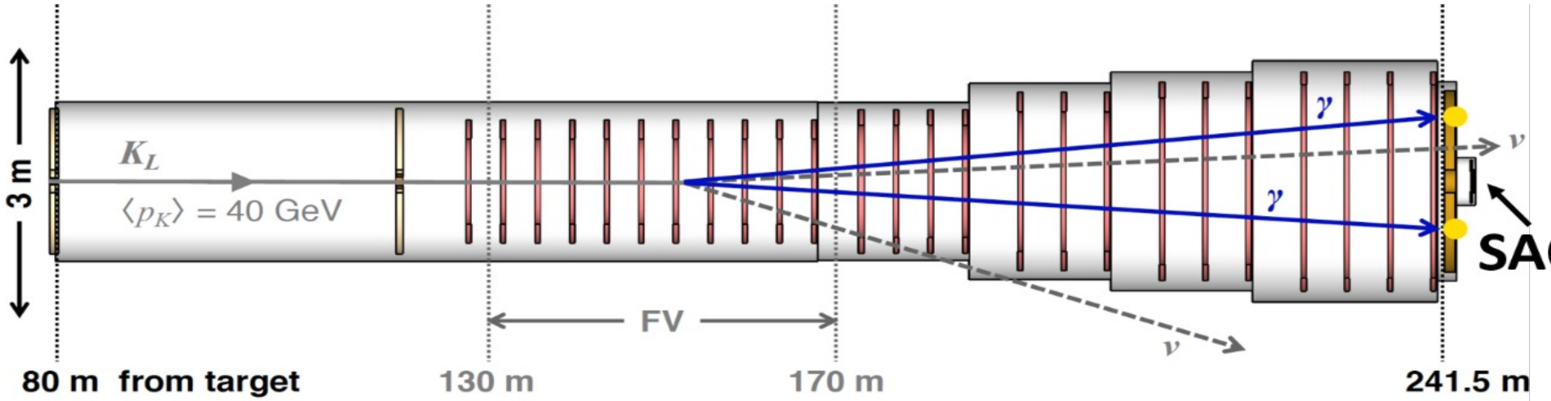
VHE gamma VETO/**Small Angle Calorimeter**

KLEVER is a proposed experiment at CERN SPS to measure $K_L \to \pi_0 \nu\nu$

CERN

OREO prototype





The SAC should:

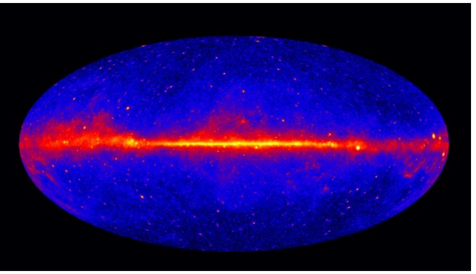
- ✓ **reconstruct the 2 γ of the π^0 coming from $K_L \to \pi^0 \nu\bar{\nu}$** ,while any extra photons must be vetoed with very high efficiency!
- ✓ **insensitivity to more than 500 MHz of neutral hadrons** in the beam.

Challenge:
- Scaling to a large calorimeter
- **The KLEVER SAC ready for 2027!**

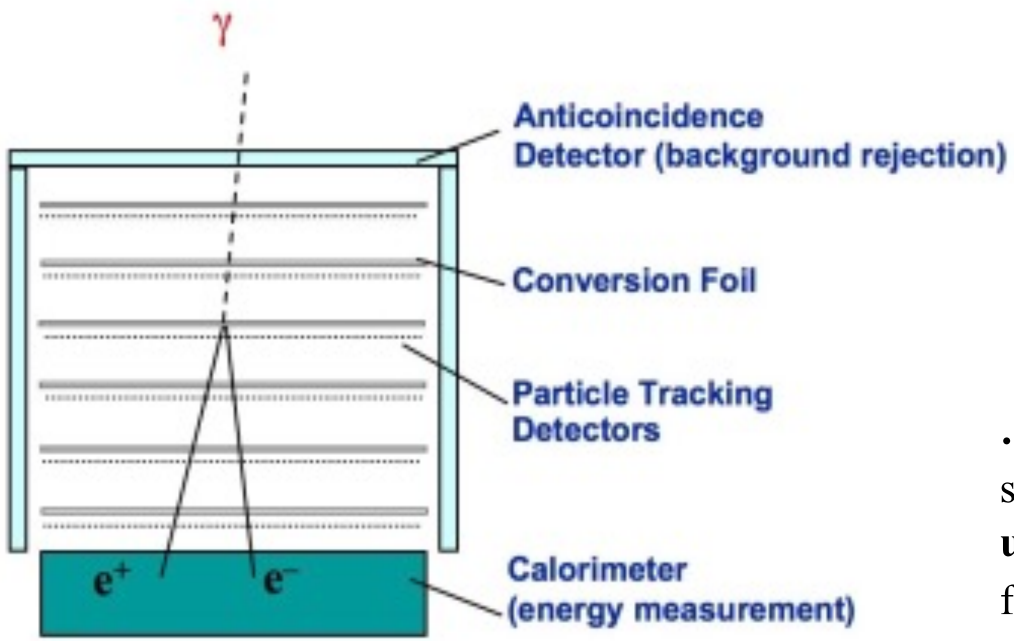
OREO is the best solution for the KLEVER SAC:
- **X_0/λ_{int} (radiation length / nuclear interaction length) as smaller as possible,** minimizing hadronic interaction and discriminating very well electromagnetic signals.
- Excellent time resolution: Ultrafast PWO

For info: Laura Bandiera and Matthew Moulson

Ultra-compact space-borne gamma-ray telescope based on oriented crystal



Take the FERMI-LAT tower as an example…



All of these materials have a crystalline structure and can be oriented along some preferred lattice direction

If we point a telescope towards a gamma-ray source, we could exploit the X_0 reduction in oriented crystals to…

substitute the W amorphous foils with crystalline W:

- ✓ possible reduction of tracker length and thereby of multiple scattering, with an **improvement of the spatial/angular resolution ->** better localization of the source;

use **oriented scintillator crystals in the calorimeter** to:

- ✓ **enhance the sensitivity of the telescope above few GeV, with a reduced volume/weight -> huge cost reduction!**
- ✓ The calorimeter would continue to operate in a standard way in the absence of pointing.

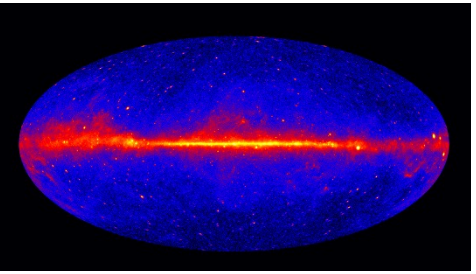
…a variety of possible applications in need of better angular/energy resolution…

search of **dark matter sources** (galactic centre excess, dwarf galaxies); observation of **unidentified Fermi gamma-ray sources**;

follow-up of flaring/transient and **multi-messenger sources**…

For info and new collaborations: Laura Bandiera

Ultra-compact space-borne gamma-ray telescope based on oriented crystal



If we point a telescope towards a gamma-ray source, we could exploit the X_0 reduction in oriented crystals to…

substitute the W amorphous foils with crystalline W:

✓ possible reduction of tracker length and thereby of multiple scattering, with an **improvement of the spatial/angular resolution ->** better localization of the source;

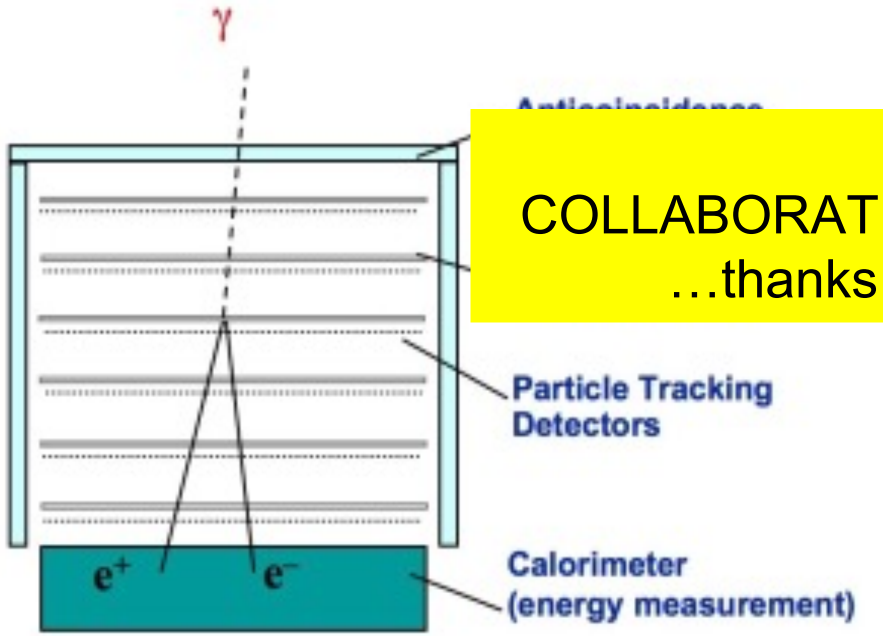
use **oriented scintillator crystals in the calorimeter** to:

…, **with a reduced volume/weight -**

…in a standard way in the absence of pointing.

IDEA AT INITIAL STAGE
COLLABORATION STARTED WITH FERMI-LAT PEOPLE
…thanks to F. Longo, S. Cutini, M. Di Mauro…

Take the FERMI-LAT tower as an example…



…a variety of possible applications in need of better angular/energy resolution…

search of **dark matter sources** (galactic centre excess, dwarf galaxies); observation of **unidentified Fermi gamma-ray sources**;

follow-up of flaring/transient and **multi-messenger sources**…

All of these materials have a crystalline structure and can be oriented along some preferred lattice direction

For info and new collaborations: Laura Bandiera

Thanks for the attention

Walter Raniero	AGATA array
Davide De Salvador	UNIPD & LNL-INFN
Stefano Bertoldo	LNL-INFN
Chiara Carraro	LNL-INFN
Stefano Capra	MI-INFN
Alain Goasduff	LNL-INFN
Gilbert Duchene	IPHC – Uni. STRASBOURG
Franco Camera	MI-INFN & UNIMI
Fabio Gargano	BA-INFN
Mario Nicola Mazziotta	BA-INFN
Domenico Santonocito	LNS-INFN
Laura Bandiera	FE-INFN