
MIRION
TECHNOLOGIES

MIRION TECHNOLOGIES

Radiation Safety. **Amplified.**

Innovative HPGe detectors for research applications

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Summary

Innovative HPGe detectors for research applications

- **Overview of MIRION Technologies**
- **Key expertise and technologies (MIRION SyD)**
- **Recent HPGe detector developments**

MIRION TECHNOLOGIES

Health Physics (HPD)

Fixed and mobile systems focused on protecting individuals from hazardous radiation exposure, handheld instrumentation, electronic and passive dosimetry for radiation measurement and monitoring

Radiation Monitoring Systems (RMSD)

Fixed and mobile radiation monitoring systems for safety related, area, process, effluent release and fission by-products applications throughout the nuclear plant life cycle

Spectroscopy (SyD) & Services (SvD)

Radiation measurement solutions for laboratory, in vivo, in situ applications & local experts available around the world to provide consulting services and address any nuclear measurement needs

MIRION TECHNOLOGIES

OUR DIVISIONS

Sensing Systems (SSD)

Conduit systems used to pass cables through reactor containment structure & detector systems for plant safety and control

Characterization (ChD)

Specialized camera systems for hazardous environments, as well as NDA systems, Measurements & Expertise for decommissioning and waste management

Dosimetry Services (DSD)

Services providing official dose of record reports for workers exposed to radiation

SyD

Spectroscopy Division (SyD)

MISSION

To create exceptional experiences for our customers at every touchpoint, leading customers to only think of us for every spectroscopy solution.

Product Lines

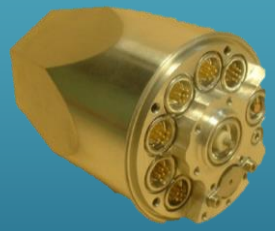
- Gamma Spectroscopy
- Customized Research Detectors
- Alpha Spectroscopy
- Alpha/Beta Counting
- Environmental Monitoring

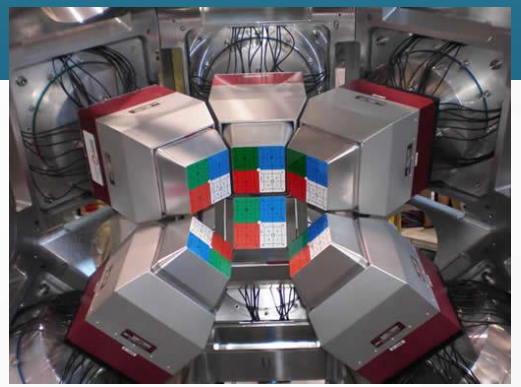
Key Customers

- Nuclear Power and Nuclear Fuel Cycle
- Commercial and State Laboratories
- Federal Governments - Department of Energy, Defense
- Educational and Research Institutions
- Decommissioning and Dismantling through the Characterization division (ChD)
- Nuclear Security/Safeguards
- Industrial, OEM, and Medical

Key expertise and technologies

MIRION SyD



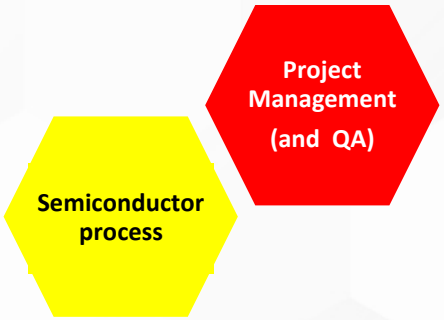


Key expertise and technologies

- Product Development and Project Management
  - Long background in both developing advanced technologies (specialty detectors) and large-scale products (standard detectors)
  - Stage Gate development approach based on technology readiness level (TRL) and technical risk assessment

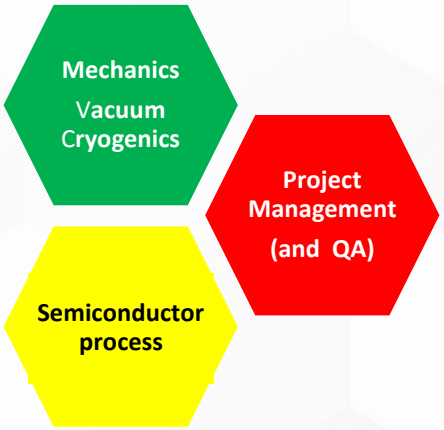
Key expertise and technologies

- Product Development and Project Management
- Semiconductor Process
  - Large know-how and proprietary processes (segmentation, passivation)
  - Driven by modelling
  - Full and redundant set of process equipment for Si, Si(Li) and Ge: shaping, PVD, CVD, implantation, diffusion, outgassing / annealing capabilities
  - Thin layer characterization capability (thickness, stress, reliability, charge carrier life time)
  - Management of clean / radiopure environments



Key expertise and technologies

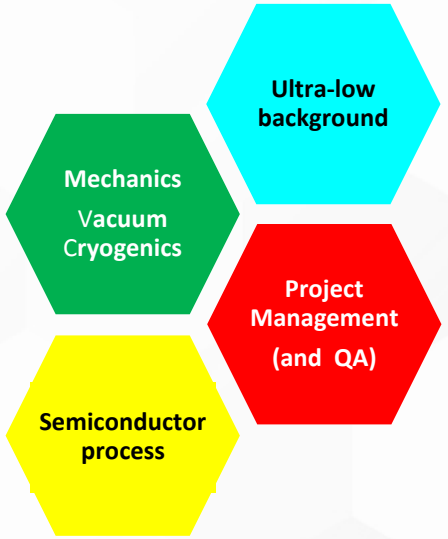
- Product Development and Project Management
- Semiconductor Process
- Mechanics, vacuum and cryogenics
  - Development of low-vibration and long-life cryocoolers for HPGe (> 10y MTTF)



  - Improved thermal balance (necessary for electrical cooling)
  - Proprietary technologies to hold and encapsulated HPGe detectors.
  - Long experience with UHV process

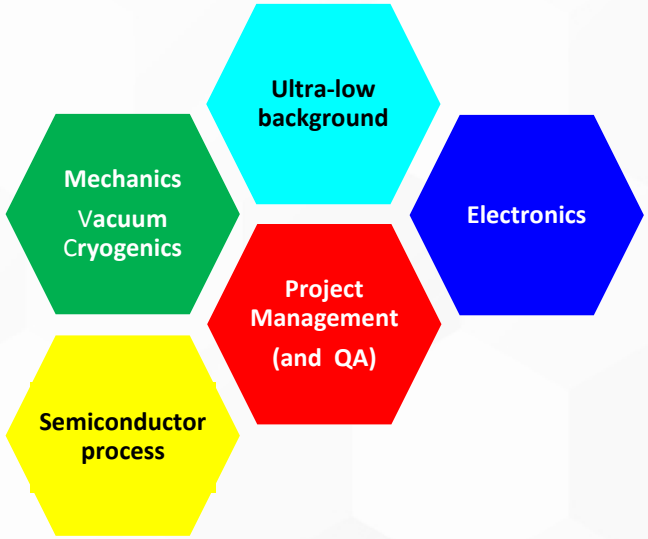
Key expertise and technologies

- Product Development and Project Management
- Semiconductor Process
- Mechanics, vacuum and cryogenics
- Ultra-low background
  - Systematic characterization, traceability and underground storage of radiopure materials
  - Collaboration with international low-background laboratories and experiments (double beta decay, Dark Matter, neutrino scattering)



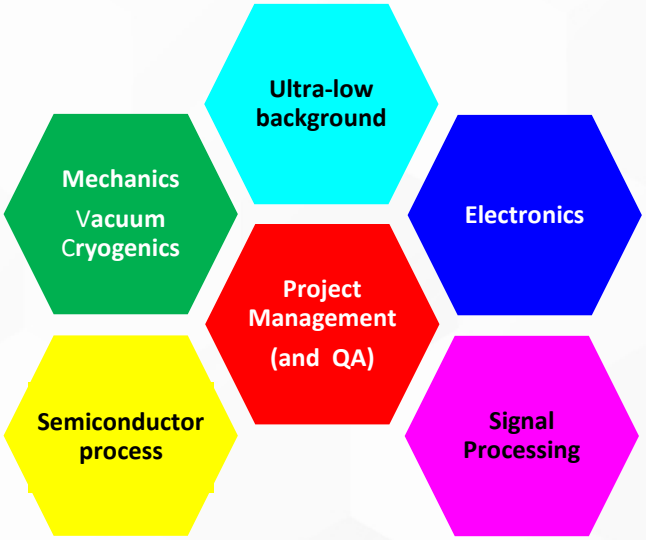
Key expertise and technologies

- Product Development and Project Management
- Semiconductor Process
- Mechanics, vacuum and cryogenics
- Ultra-low background
- Electronics
  - Strong expertise in analog electronics
  - Continuous challenge for low-noise, high count rate, low power, multi-channel and more integrated electronics



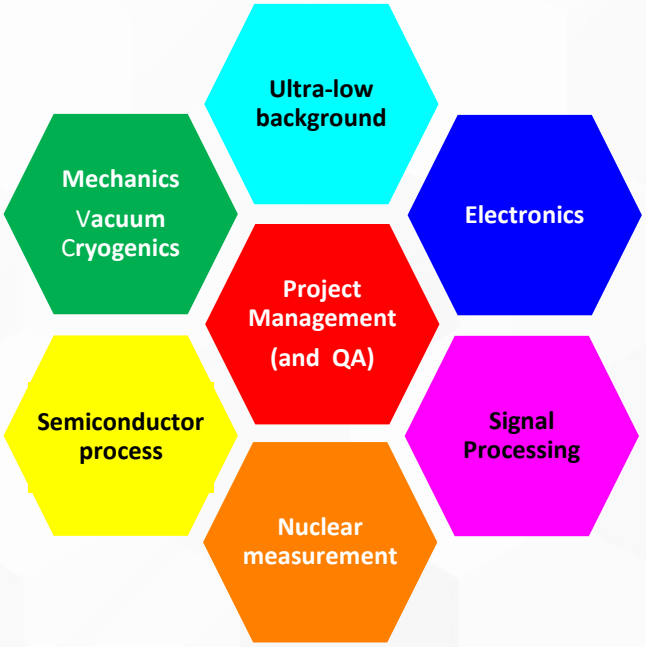
Key expertise and technologies

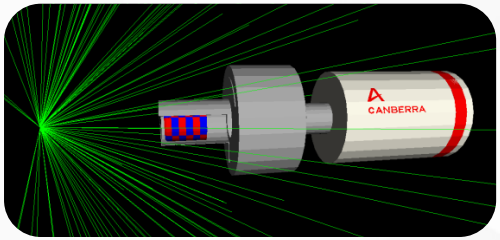
- Project Management
- Semiconductor Process
- Mechanics, vacuum and cryogenics
- Ultra-low background
- Electronics
- Signal Processing
  - Pulse shape analysis techniques transferred from physics to industrial applications
  - Growing know-how with digital acquisition to characterize multichannel detectors



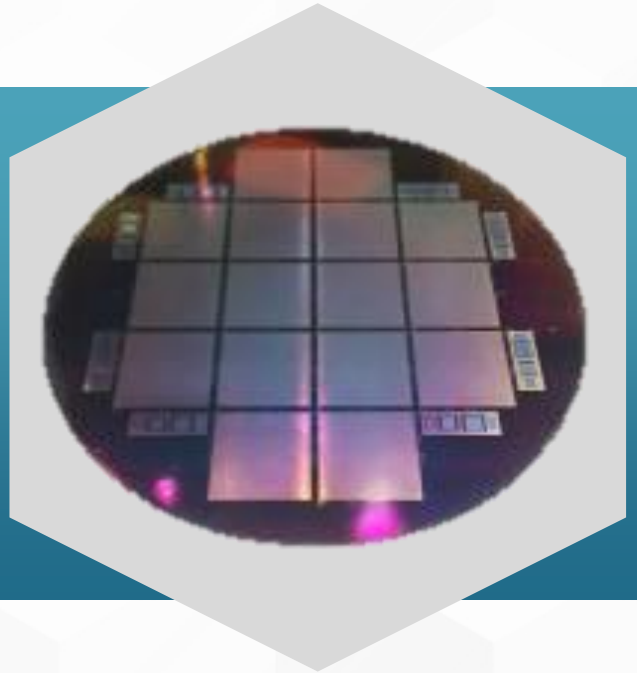
Key expertise and technologies

- Project Management
- Semiconductor Process
- Mechanics, vacuum and cryogenics
- Ultra-low background
- Electronics
- Signal Processing
- Nuclear Measurement (spectroscopy)
  - Alpha, beta, gamma and x-ray spectroscopy is recognised as core competency of MIRION SyD
  - For Lingolsheim, particularly large experience with low background, low noise and multichannel spectroscopy
  - In-depth modelling of detectors during design and characterization phases



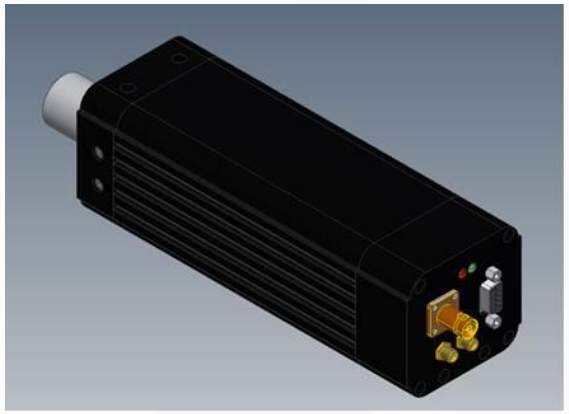


New technologies & Products

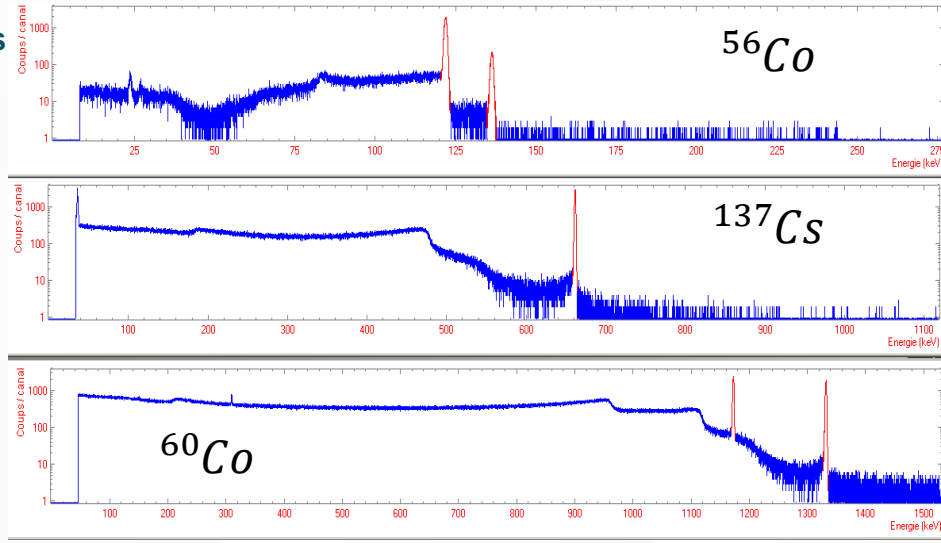


µGe: Miniature Germanium Spectrometer

- **System performance:**
  - **Gamma-ray versions have been manufactured and tested**
    - **Excellent spectroscopy results**
    - **Fast cool-down time**
    - **Low power consumption**
    - **Compact and lightweight footprint**
  - **New paradigm for HPGe detectors**
    - **Opens the way towards new applications**



Parameter	Value
Ge crystal mass	5g (0.1% relative efficiency)
Cool-down time	20 minutes
Energy range	10 keV - 3 MeV
Max. FWHM @ 122 keV	0.8 keV
Max. FWHM @ 662 keV	1.6 keV
Max. FWHM @ 1.33 MeV	2.2 keV
Max. ICR	>100kcps @ 662keV
Detector mass	1.5 kg
Size	∅ 4.8 cm x L 25 cm
Electrical consumption	7 W



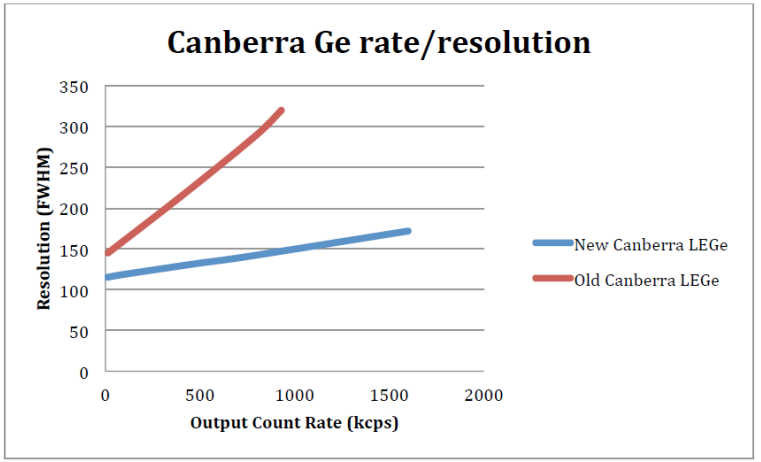
µGe: Miniature Germanium Spectrometer

- **What does the µGe bring to the field?:**
  - **Comparison with the main detector technologies**

Detector technology	Specificity of µGe
HPGe Detectors	Miniaturization Fast availability (cool-down time) Lower cost
Silicon detectors	Superior stopping power above ~30keV Better theoretical resolution at low x-ray energies
RTSD Detectors (CZT, CdTe)	Better efficiency (larger crystals) Better crystallographic properties Superior spectroscopy capabilities
Scintillators (NaI, etc.)	Superior spectroscopy capabilities Linearity Gain stability

Ultimate x-ray Spectroscopy

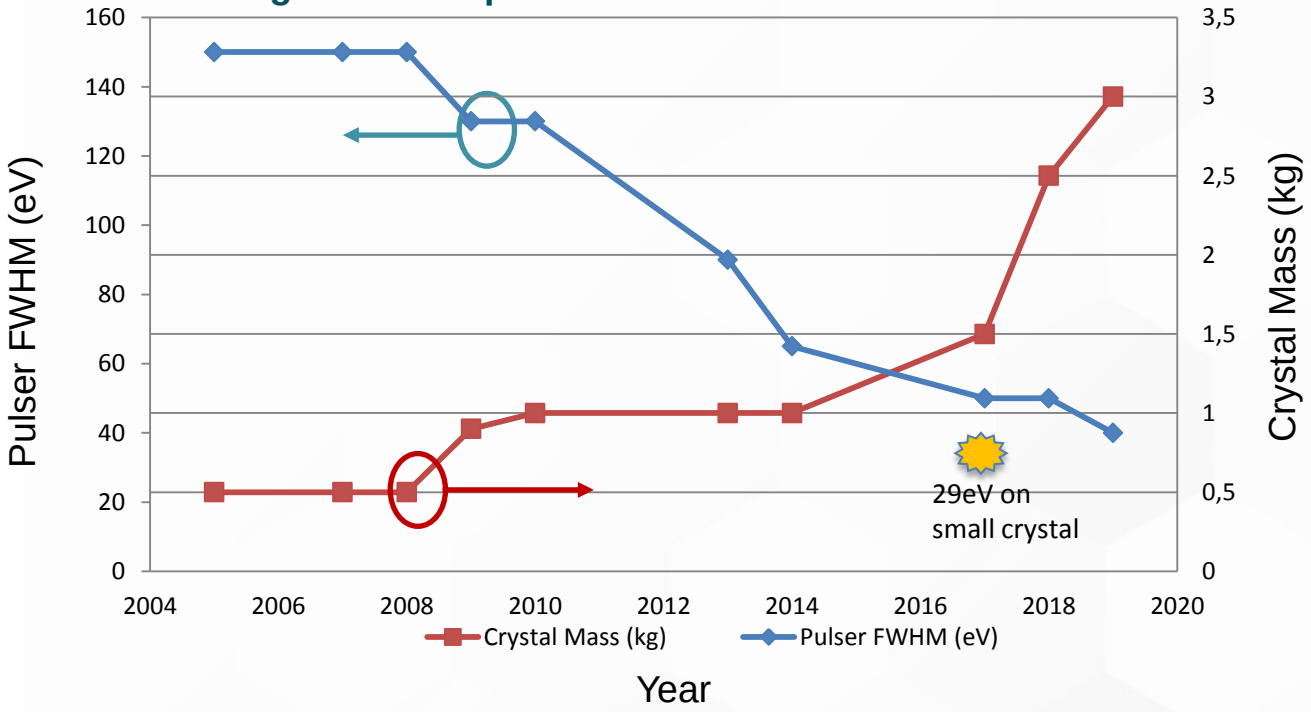
- **Several single and multichannel detectors developed (2016-2018)**
  - **HPGe vs Silicon SDD:**
    - Superior at low energies (better Fano for HPGe)
    - Higher stopping power above ~30keV
  - **State-of-the-art HPGe Detectors:**
    - FWHM close to theoretical limit (105eV @ 6keV)
    - 150eV @ 6keV above 1Mcps
  - **Achieved performance with electrical cooling:**

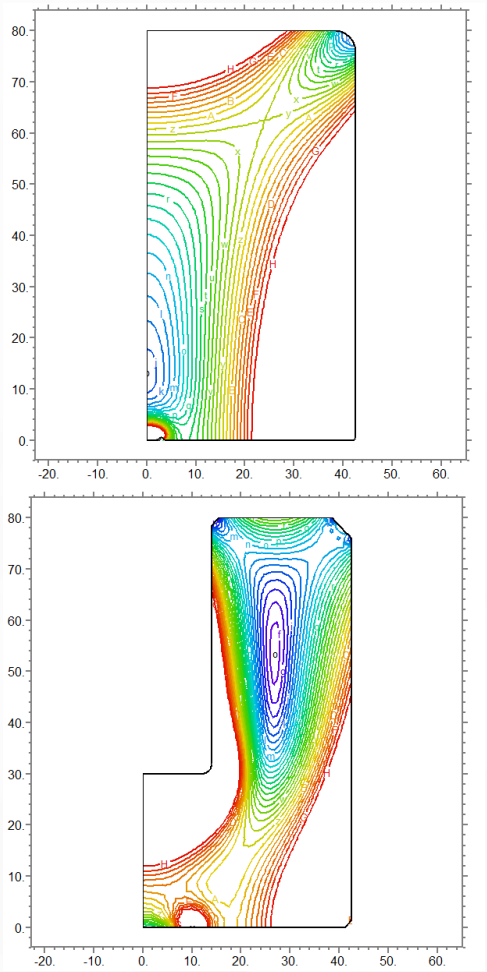


FWHM @ 6keV	Typical	Guaranteed
1kcps 6µs shaping time	< 110 eV	< 130 eV
100kcps 0.5 µs shaping time	< 120 eV	< 145 eV
100kcps 0.1 µs shaping time	< 150 eV	< 170 eV
1Mcps FalconX or Xspress3 mini	< 175 eV	< 190 eV

Low-noise low-background point contact detectors

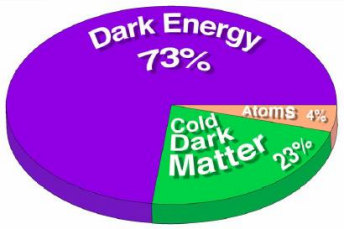
- **Main applications: Dark Matter and neutrino scattering experiments**
- **Continuous improvement of PCGe Detectors**
  - **Crystal size increased from 0.5kg to 1.5kg**
  - **Record 29eV FWHM obtained (noise edge <100eV)**
  - **2.5kg with 50eV FWHM or better in progress (85x80)**
  - **3kg with 40eV possible in the near future**





Specialty - SAGe Point Contact detectors

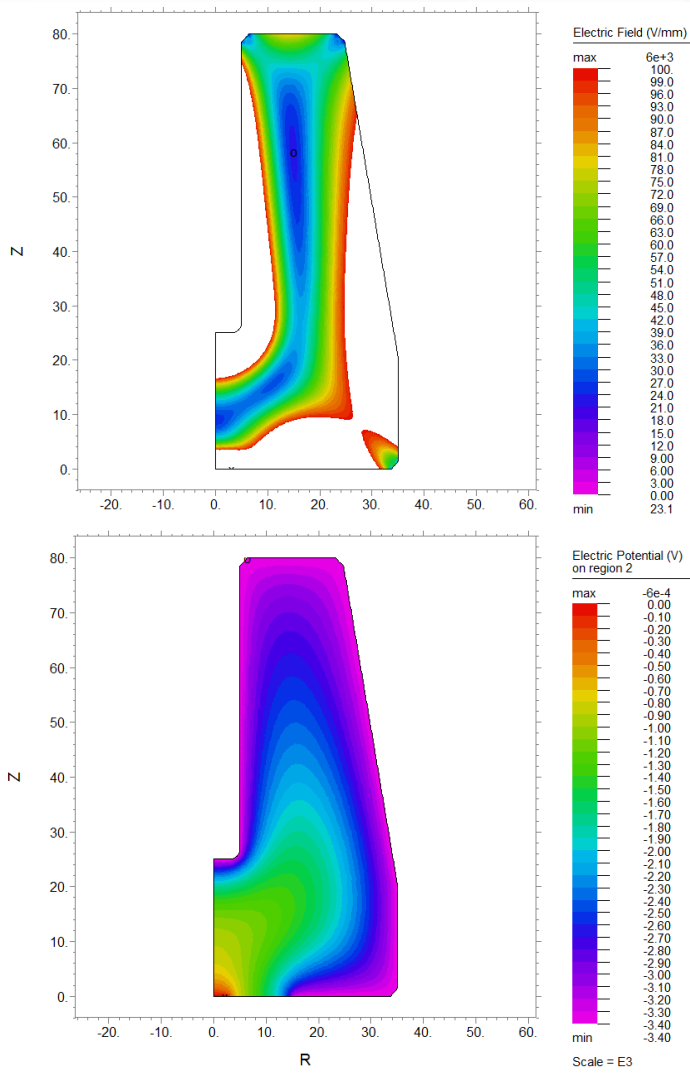
- New Point Contact technology: combine best spectroscopy performance, highest efficiency, lowest background.
  - Applications: Neutrino Physics & Dark Matter search
    - Coherent neutrino-nucleus scattering, requires an energy threshold <100eV
    - Low-mass WIMP searches
    - Improve sensitivities on neutrino magnetic moments
    - Implications on reactor operation monitoring
    - Neutrinoless Double-Beta Decay
  - Experiments: Majorana, Gerda, CDEX, Texono, Edelweiss, CDMS
  - Exemple of a 1.5kg electrically cooled HPGe detector



TEST (pulser)	241Am (60keV)	57Co (122keV)	137Cs (662keV)
50eV	300eV	450eV	1.35keV

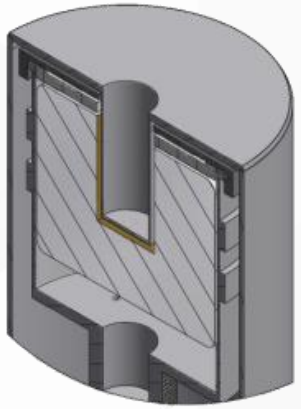
Inverted (point contact) coaxial detector

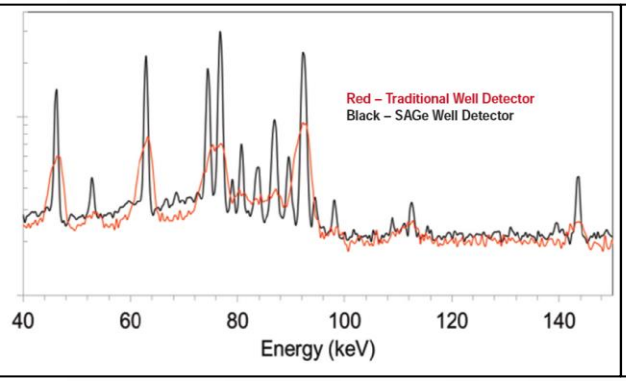
- **Inverted Coaxial detector**
  - Long drift time on purpose for improved position resolution
  - See R.J. Cooper et al., NIM A 665 (2012) 25
- **1st segmented prototype (2012)**
  - For ORNL currently tested in Berkeley
  - N-type crystal
- **2nd segmented prototype (2018)**
  - For University of Liverpool (SIGMA)
  - P-type crystal

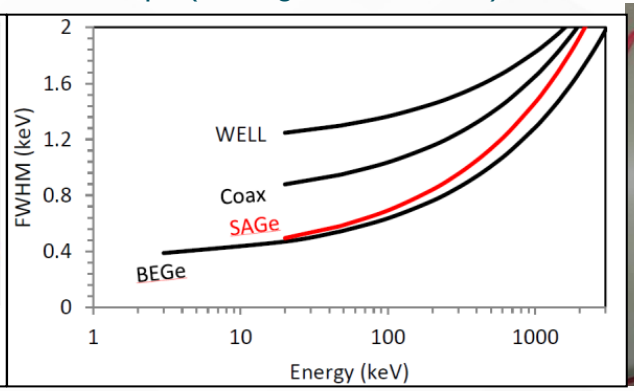


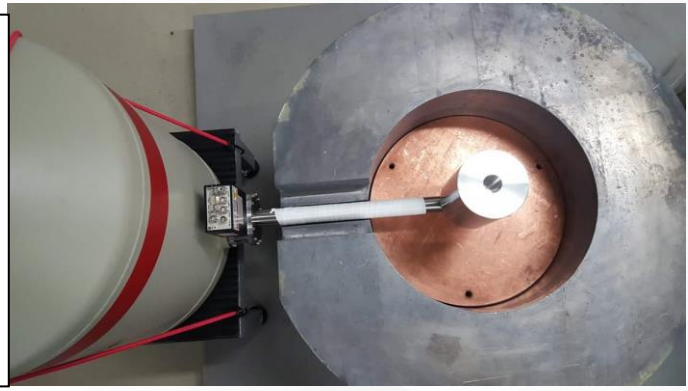
Specialty - SAGeWell in S-ULB cryostat

- The SAGe™ Well Detector combines excellent energy resolution at low and high energies with maximum efficiency for small samples.
- S-ULB SAGeWell detector offer :
  - Active volume > 400cc – well usefull diameter 21mm – active depth 57mm
  - Active volume > 450cc – well usefull diameter 32mm – active depth 52mm
- FWHM performance for S-ULB SAGeWell detectors:
  - At 1.33MeV : < 2.10 keV
  - At 122keV : < 750 eV
  - Measurement conditions:
    - 1000 counts per second
    - Gaussian shaping time 6-12µs (analogue electronics)



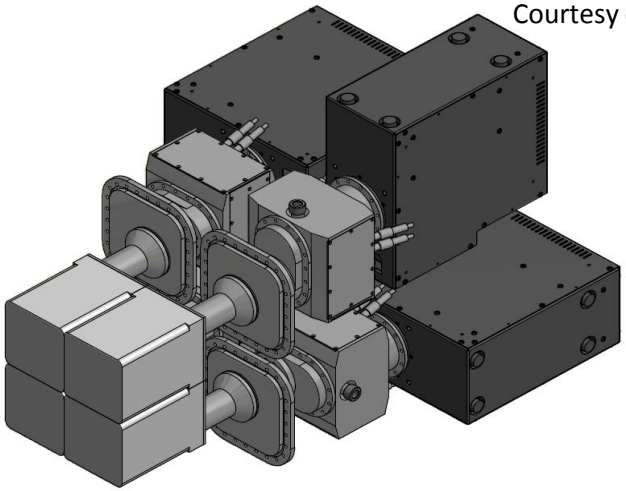






First Electrically cooled Clover Detectors

- COMPEX project: a total of 5 Electrically cooled Clover Detectors
  - For University of Lund (Sweden) to be used at GSI (FAIR Facility)
  - Off-centered cryostat design to form a 23cm x 23cm detection plane for super heavy elements
  - Typical performance of each individual HPGe crystal:
    - FWHM at 60Co : 1.90keV
    - FWHM at 57Co : 800eV
    - Relative efficiency : 28%
  - Total HPGe material weight per clover : 2.6kg

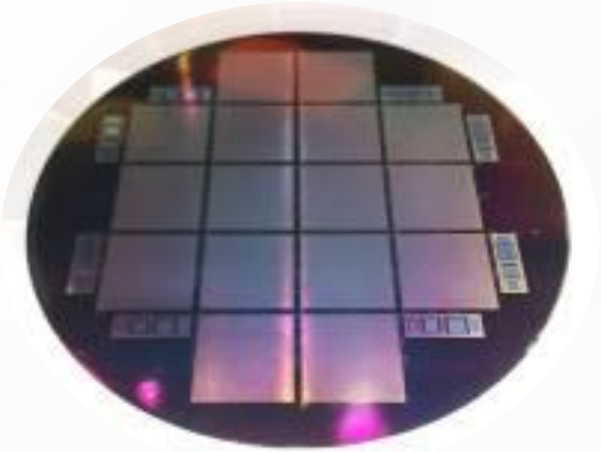


Courtesy of Pr. Rudolph

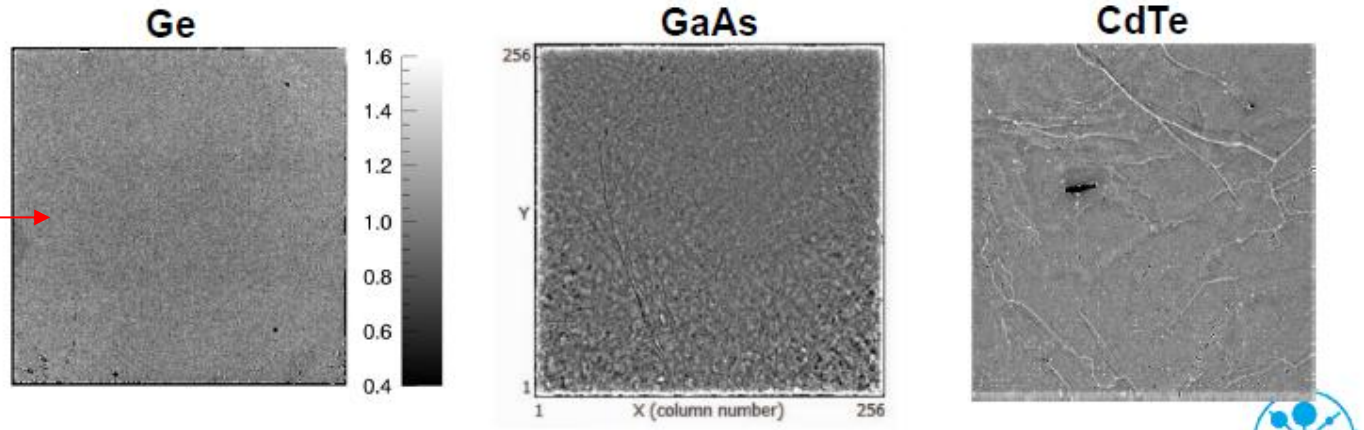
Fine pixel imagers

Developments of HPGe wafers with micrometric pixels

- Wafers are coupled to user ASICS (e.g. Medipix 3)
- Application: imaging or very high count rates
- Down to 55µm; arrays of chips possible
- Advantage of Germanium
  - High efficiency and stopping power
  - High quality & large diameter wafers available



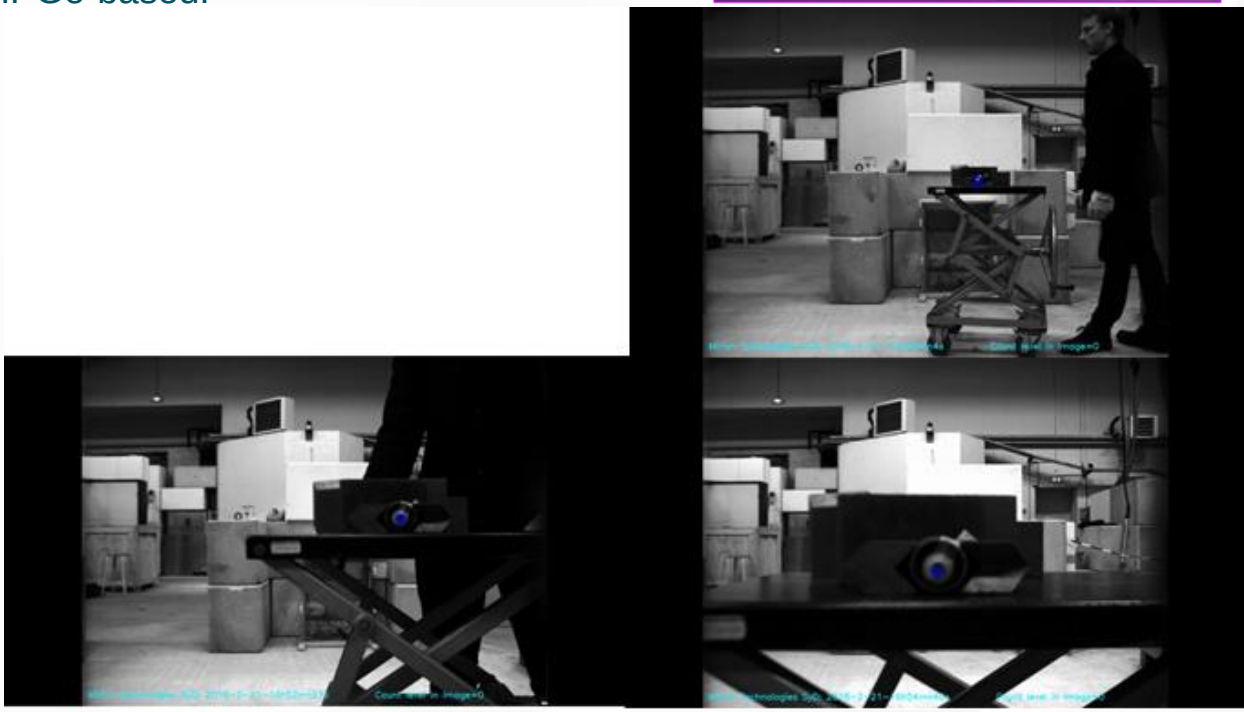
Flat field with much less flaws than other high Z materials



Fine pixel imagers

Existing and future products using fine pixel segmentation:

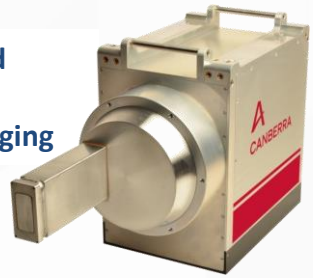
- Ultra-portable gamma imaging systems available
- Existing solutions are based on Si, CdTe or GaAs
- They use Coded Aperture technique for imaging
- Require several minutes to localize a radiation source
- Future generation could be HPGe-based:
  - Live source tracking
  - Ge-grade spectroscopy



Spectro-imagers (Compton cameras)

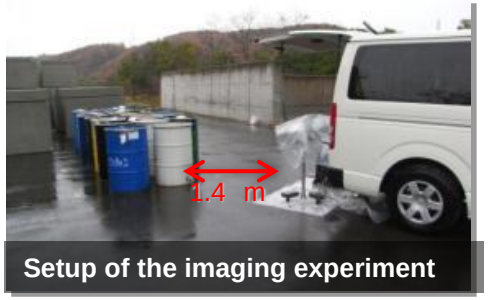
- Mid-term industrial challenge: development of 3rd generation radiation imagers, combining high detection efficiency and hig-resolution spectroscopy

Electricaly-cooled DSSD and pixel detectors for imaging

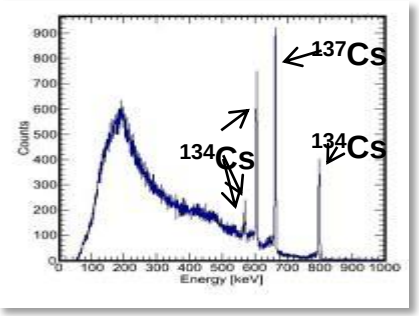


Example of industrial application: waste drum imaging in Fukushima

Courtesy of Dr. Motomura (Riken Kobe)



Setup of the imaging experiment



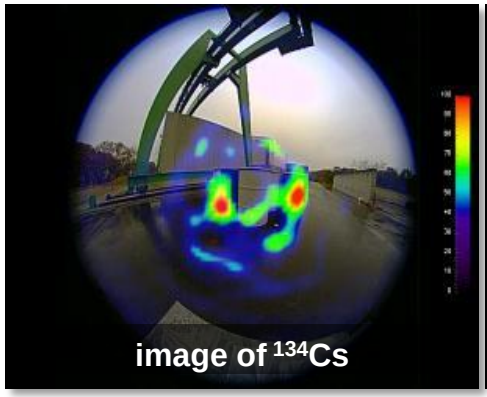


image of ^{134}Cs

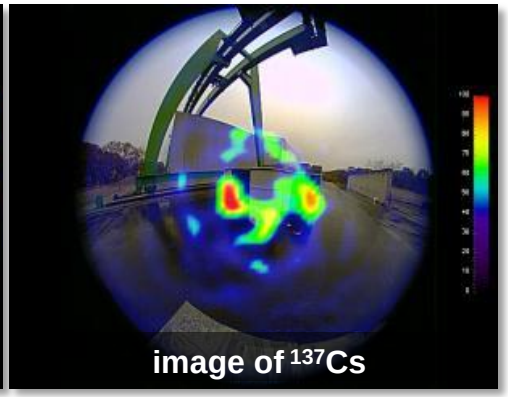


image of ^{137}Cs

Conclusion

Mirion detector solutions are in use for Scientific exploration in the most remote locations on Earth, underground, and in deep space…

Main results recently brought to HPGe detectors:

- **Energy resolution**: noise improvement at low energy (from 100 eV down to a few tens eV)
- **Detection efficiency**: enlarged range of HPGe spectrometer sizes (a few g to several kg)
- **Count rate**: for x-ray spectroscopy, detectors, electronics and signal processing suited for several Mcps without resolution degradation
- **Position sensitivity**: increased segmentation (pixel size of a few tens µm) and introduction of PSA on industrial products
- **Operation**: increased need for electrically cooled detectors, even for scientific applications

MIRION TECHNOLOGIES

Thank You!

THE MIRION TECHNOLOGIES TEAM LOOKS FORWARD TO WORKING WITH YOU.

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