HPGe detector fabrication at CANBERRA

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Ringberg Castle, October 2015



Outline

- ► CANBERRA Lingolsheim overview at a glance
- ► HPGe detectors for dark matter and neutrino physics
 - Crystal design and choice
 - Fighting the noise
 - Materials used
- ▶ Large HPGe detector arrays
- Conclusion



CANBERRA Lingolsheim overview at a glance

Located close to Strasbourg and the largest European scientific instruments and Research Centers

The largest international Labs and Research Institutions are our customers

Prestigious astrophysics and planetology references

► 47 years in the business

Largest germanium detectors ever made

Unique features offered on germanium detectors



5 PhD's and 17 engineers and associates of science

4 Areva experts, strong emphazise on developing talents

area: 2 080 m²

Certified ISO9001, ISO14001, OHSAS18001







CANBERRA Lingolsheim overview at a glance

Key technologies

- HPGe crystal segmentation
- UHV encapsulation
- Electrical cooling
- Ultra low noise
- Ultra low radioactive background
- Large effciency HPGe arrays











CANBERRA's Encapsulated HPGe detectors: a unique vacuum enclosure

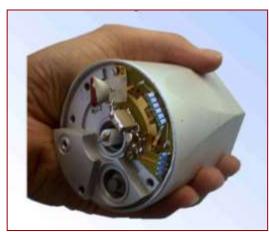
Highlights:

- Reliability
- Easy mounting/exchange
- Compact assembly
- Wide range of shapes
- On-site annealing without pumping



- Nuclear Physics :
 - Euroball Cluster- Miniball Rising
 - Greta / Agata
- Space :
 - Integral (ESA)
 - Mars (NASA)
- Airborne
- Industrial: rough motion applications





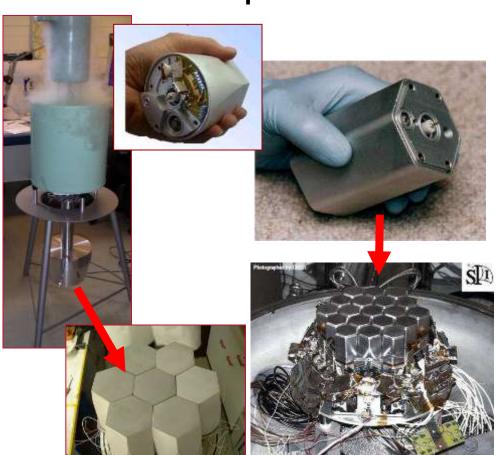
Capsules delivered in many countries

Encapsulation = only solution to address close packing arrays or rough motion application.



CANBERRA's Encapsulated HPGe detectors

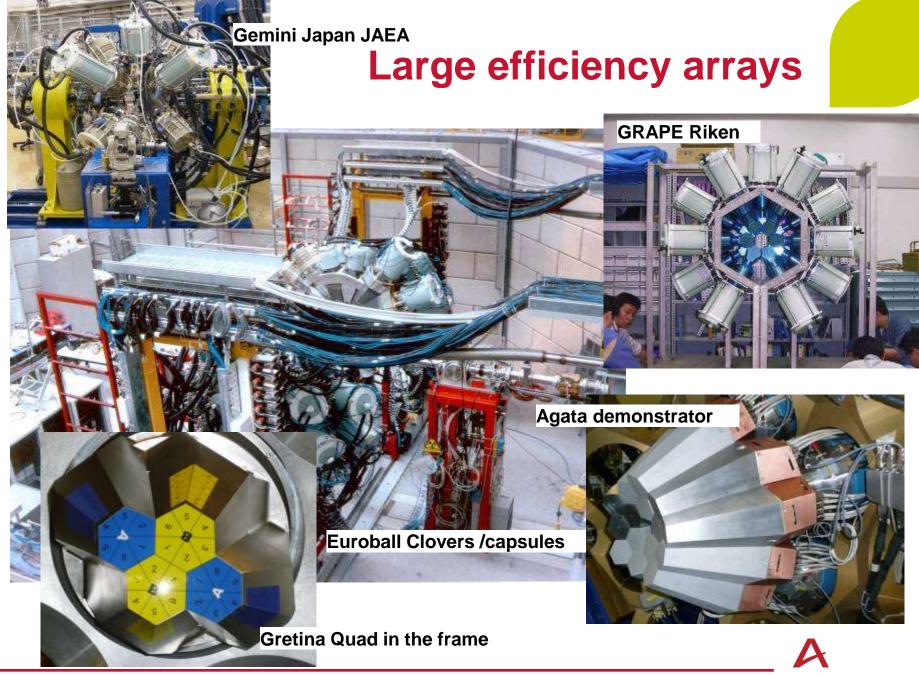
Different encapsulated HPGe detectors:





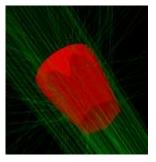




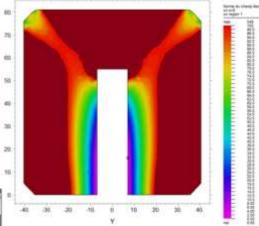


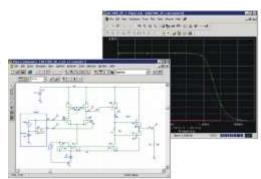
CANBERRA Lingolsheim overview at a glance

- Fields of expertise
 - Semiconductor Process
 - Mechanical Engineering, Vacuum and Cryogenics
 - Thermal simulations
 - Material science
 - Nuclear Physics and Measurement
 - Geant4 Simulations
 - HPGe crystal field simulations
 - Pulse shape simulation and analysis
 - Electronics
 - Circuit design and simulations
 - Noise calculations
 - Signal processing and analysis
- Strong interactions











HPGe detectors for dark matter and neutrino physics

- What are we looking for?
 - Detection of extremely rare events
 - 1 event/year/kg
 - Very low energy interactions
 - Below 1keV for WIMPS
- ▶ What do we need?
 - Large detector mass
 - Increased individual HPGe crystal mass (>1kg/crystal)
 - Array of multiple large HPGe crystals (CDEX, GERDA, MAJORANA)
 - Ultimate energy resolution
 - Ultra low electronic noise (<<100eV pulser FWHM)
 - Ultra low background
 - Highest radio purity materials



Crystal design and choice

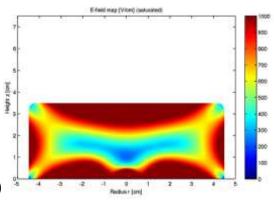
HPGe crystal

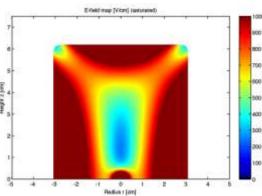
- Selection of large crystals based on simulations
 - Current manufactured sizes (among others):
 - D70 x L70
 - D62 x L62
 - D50 x L50
- Stepwise investigation going on to optimize the crystal capacitance (and thus the overall detector noise performance)





- Detector size (depletion capability vs efficiency)
- Point contact diameter (E-field strength vs PC capacitance)
- Noise contribution (detector capacitance vs FET noise, etc.)
- Record performance vs manufacturing capability
- Process of the crystal with smallest « spot »







Fighting the noise

Electronic noise (pulser injection):

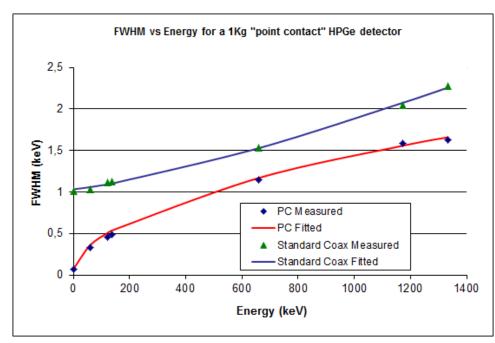
$$ENC^{2} = \frac{1}{2} e_{n}^{2} C_{in}^{2} \frac{A_{1}}{\tau} + \pi C_{in}^{2} A_{f} A_{2} + q I_{0} A_{3} \tau$$
 $FWHM_{Ge} = 2.35 \cdot \sqrt{F \cdot \varepsilon \cdot E}$

Other noise sources:

- Room temperature preamp
- Microphonics
- Pick-up noise

Noise reduction techniques

- Detector capacitance reduction
- Minimizing stray capacitance
- Selection of cold preamplifier (FET, ASIC)
- Bias point optimization
- Contacting method
- EMI reduction

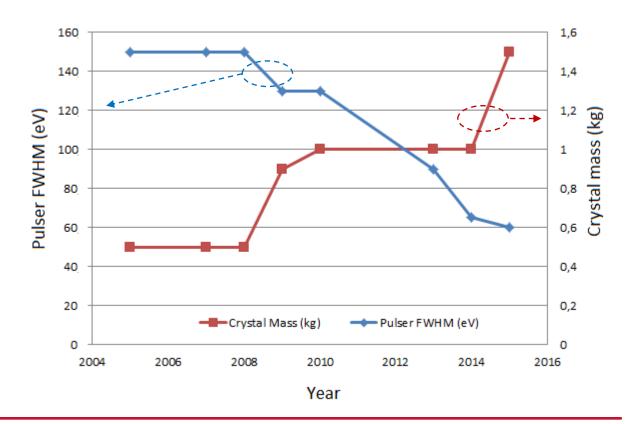




Fighting the noise

Evolution of Canberra PCGe Detectors

- Crystal size increased from 500g to 1.5kg
- Continuous reduction of electronic noise
- Record 60eV FWHM obtained (noise edge 200eV)





Materials Used

Cold Preamplifier

- Best available low dielectric loss and low leakage substrate
- Low electronic and low radioactive background materials

▶ ULB Cryostat

- OFHC Copper cryostat or ULB Aluminium
- Carefully selected and tested low radioactive background materials

Other improvements

- Minimizing Stray capacitance
 - Diode holder
 - Cold PA support
 - Detector contact method
- New improved room temperature preamplifier with better EMI immunity



ULB detectors with ultimate ultra low background material specifications

- CANBERRA ULB BEGe detectors (CP5 cooler):
- Performances of a custom designed BEGe5030 detector
 - Less than 0.09 counts per min :10mn for 1 ct !
 (Measured at Modane Underground Lab, 4500mwe
 15-1500keV,850eV @ 122keV)







Background Data

- ► 600cc coaxial at Modane tunnel is giving an integral background of 223 counts per day [50-3000] keV (source P. Loaiza LSM)
- ▶ 400cc coaxial at Canfranc have a background of 498 counts per day day [50-3000] keV (source I.C. Bandac – LSC)
- ▶ 300cc Well Type at SNO (source I. Lawson SNO TAUP2015) Background run 150 days. Total backgrounds at the level of ~2.5 counts / day in regions of interest, qualifies the detector as ultralow background.

Isotope	Counts per day
238U	1.16
232Th	0.51
228Ac	0.39
235U	0.48
40K	0
210Pb	0

Isotope	Sensitivity for Standard Size Sample	
238U († 226Ra)	0.05 mBq/kg	4 ppt
238U (↓ 226Ra)	0.08 mBq/kg	6 ppt
228Ac	0.2 mBq/kg	49 ppt
232Th	0.4 mBq/kg	98 ppt
235U	0.02 mBq/kg	35 ppt
210Pb	0.15 mBq/kg	12 ppt



Large detector arrays

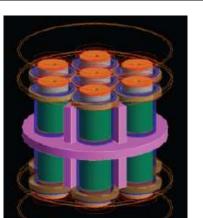
- Example of products: Ultra Low Background
 - 3 x 1kg PCGe encapsulated Array (CDEX)
 - Highly controlled and clean materials
 - Direct dipping in LN2 / Lar
 - Remote room temperature preamplifiers
 - Below 70 eV pulser FWHM for each crystal
 - Best ever achieved Minimum Detectable Activities
 - Building block of a large HPGe Array
 - Ongoing further radiopurity improvements





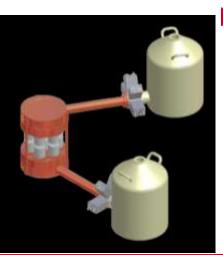


New High Sensitivity Array Detector System



New HPGe array detector for :

- Rare decay measurement (Half-life of 180mTa metastable state)
- Ultra-low radioactivity measurement for 2x ß decay and DM detection
- Resonant Neutrinoless Double Electron Capture (106Cd → 106Pd)
- ► The array consists of a total of 14 HPGe crystals of 70% relative efficiency distributed in 2 independent cryostats.
- Total HPGe mass: 22kg
- The highlights of this unique development:
 - Exhaustive search of materials with lowest achievable level of contamination
 - Simulation work for theoretical approach of the final total background
 - Highest efficiency for samples located on the front and on the side.
 - No compromise on signal to noise ratio
 - Easy local maintenance (access to input stages & detector canisters)



Conclusion

CANBERRA Point Contact Ge Detectors

- Continuous improvement process on all levels
 - Cold and warm preamplifier
 - Crystal structure and holder
 - · Cryostat design and materials used
 - Low background materials
- Well defined selection and benchmarking criteria for all components
- Proven high reproducibility and reliability of the results
- Records: Crystal sizes beyond 1.5 kg
 - Energy resolution down to 60 eV (FWHM with pulser)
 - Complex assemblies of several detectors
- Reliable industrial partner for PCGe Detector design and manufacturing
 - Training and counseling of users
 - Installation and operational conditions

