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Low-noise low-background Germanium

Towards 60eV FWHM Pulser Resolution in 2.5kg Germanium Point Contact Detectors

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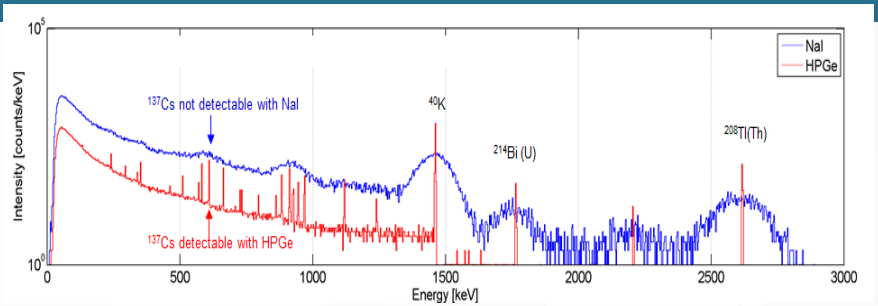
Presentation Summary

- **Germanium Detectors: Advantages and Challenges**
- **Detectors for DM and Neutrino Physics**
- **Experimental Results**
- **Future developments**
- **Conclusions**

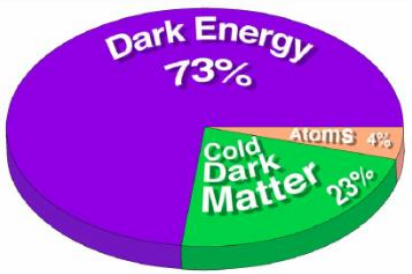
Germanium Detectors: Advantages and Challenges



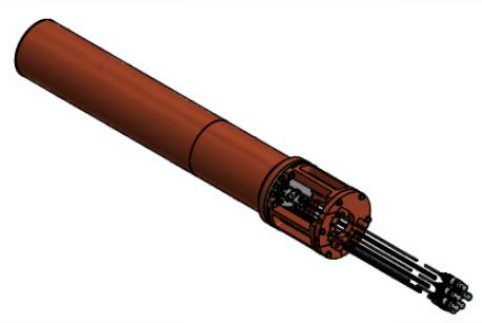
- **HPGe Detectors:**
  - **Best spectroscopic capabilities**
    - Resolution, linearity, crystallographic quality
    - High absorption, possibility to grow large crystals (several kg)
  - **Preferred solution for high resolution spectroscopy**
    - Synchrotron, XAFS, Industrial and medical imaging
    - Nuclear and fundamental physics, Reactor monitoring
- **Challenges:**
  - **Cooling to cryogenic temperatures**
    - LN2 Dewar or Electrical Cooling solutions

							Mobility (cm²/V.s)		Carrier Lifetime (µs)	
	Z	Density (g/cm^3)	Absosption (@140 keV) (cm^{-1})	Resistivity (Ohm.cm)	Band Gap (eV)	Ionisation Energy (eV)	Electrons	Holes	Electrons	Holes
Ge	32	5.32	1.35	50	0.74	2.98	3600	4200	20	20
Si	14	2.33	0.35	10^6	1.16	3.76	2100	1100	20	20
CdTe	48/52	6.06	4	$>10^9$	1.47	4.43	1100	100	1	1
CdTZnTe	48/30/52	6	3.84	$>10^{10}$	1.5	4.64	1050	50-80	3	0.1
GaAs	31/33	5.32	1.35	$>10^8$	1.43	5.2	8500	400	0.25	3

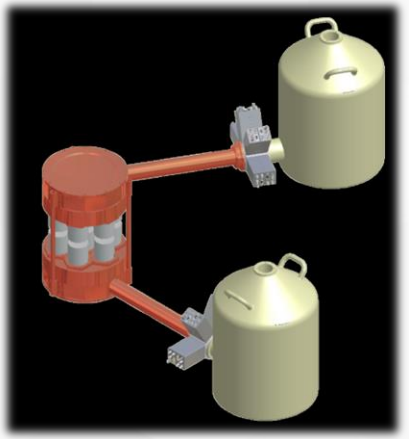
Detectors for DM and Neutrino Physics



- **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
    - Freshly pulled Ge and OFHC Copper parts
    - Underground storage, short manufacturing times
    - Ground transportation



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Detectors for DM and Neutrino Physics

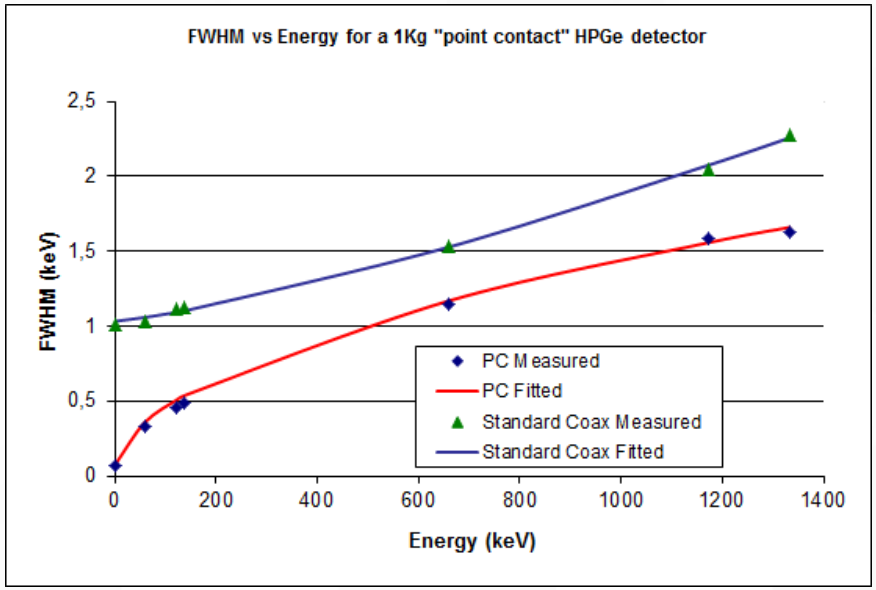
- **Electronic noise (pulser injection):**

$$ENC^2 = \frac{1}{2} e_n^2 C_{in}^2 \frac{A_1}{\tau} + \pi C_{in}^2 A_f A_2 + q I_0 A_3 \tau$$

$$FWHM_{Ge} = 2.35 \cdot \sqrt{F \cdot \varepsilon \cdot E}$$

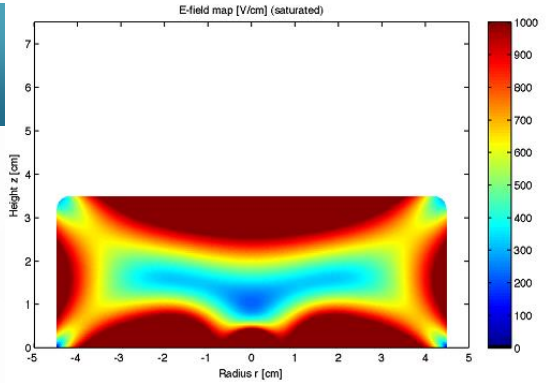
- **Other noise sources:**
  - Room temperature preamp
  - Microphonics
  - Pick-up noise

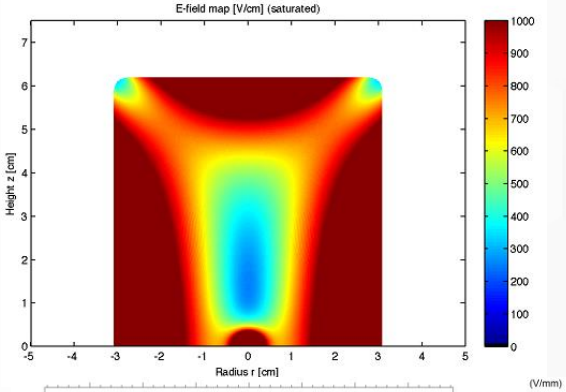
- **Noise reduction techniques**
  - Detector capacitance reduction
  - Leakage current reduction
  - Minimizing stray capacitance
  - Selection of cold preamplifier (FET, ASIC)
  - Bias point optimization
  - Contacting method
  - EMI reduction

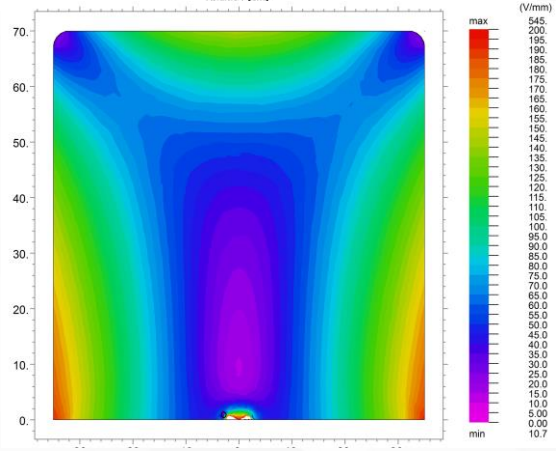


Detectors for DM and Neutrino Physics

- **HPGe crystal**
  - **Selection of large crystals based on simulations**
    - **Current manufactured sizes (among others):**
      - **1.5kg D70 x L70**
      - **1kg D62 × L62**
      - **0.5kg D50 x L50**
  - **Stepwise investigation going on to optimize the crystal capacitance (and thus the overall detector noise performance)**
  - **It's all about a question of tradeoff in the design:**
    - **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 »**







Detectors for DM and Neutrino Physics

Materials used

- **Front end cryogenic electronics**
  - Best available low dielectric loss and low leakage substrate
  - Low electronic and low radioactive background materials
- **Ultra Low Background (ULB) Cryostat**
  - OFHC Copper cryostat or ULB Aluminum
  - Carefully selected and tested low radioactive background materials
  - Underground storage of Cu and Ge to minimize cosmic activation

Other improvements

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

Experimental Results

- New Electrically Cooled Point Contact Detector
  - Applications: Neutrino Physics & Dark Matter search
    - Coherent neutrino-nucleus scattering, requires an energy threshold <300eV
    - Low-mass WIMP searches
    - Neutrinoless Double-Beta Decay
    - Implications on reactor operation monitoring
  - 1.5 kg P-type crystals with Point Contact electrode geometry
  - OFHC Copper cryostats with S-ULB specifications
  - Underground Storage of Cu and Ge parts as well as complete cryostats to minimize activation
  - Fast and reproducible manufacturing

29eV Small Ge detector

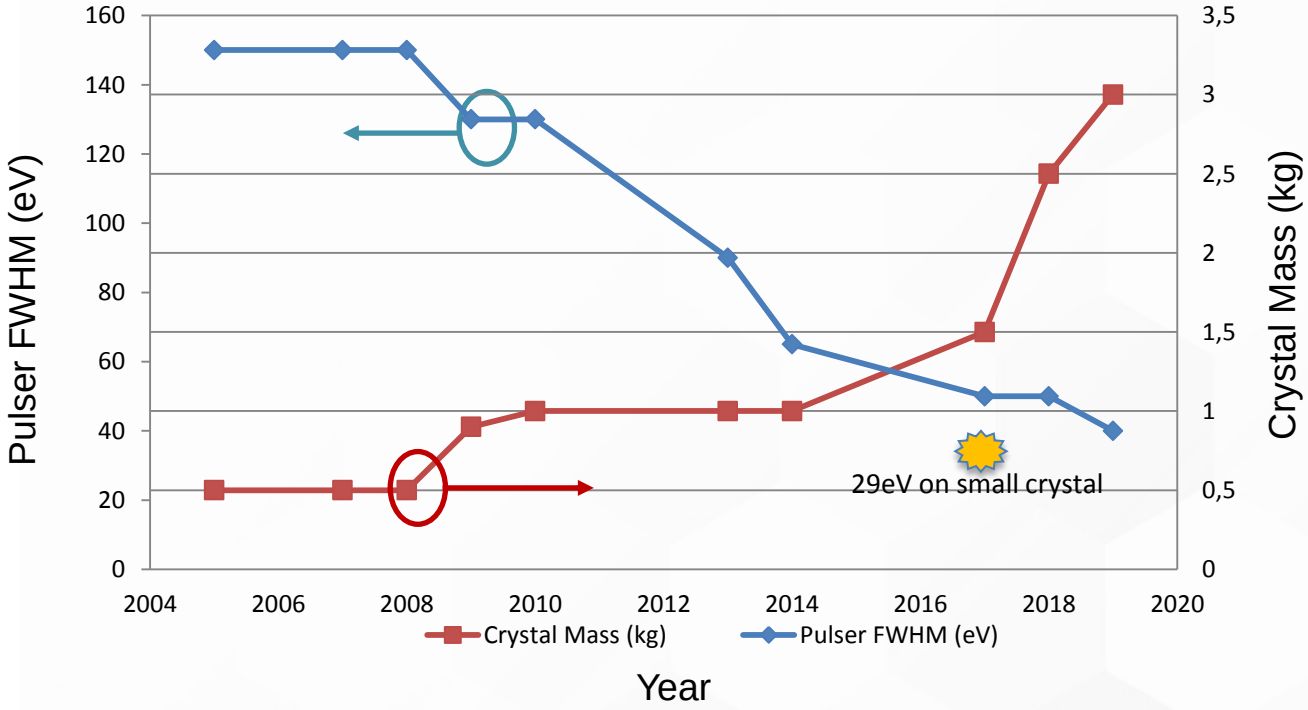
- World Record performance:
  - **50eV FWHM on 1.5kg (150eV noise edge)**
  - **29eV FWHM on small Germanium crystal**

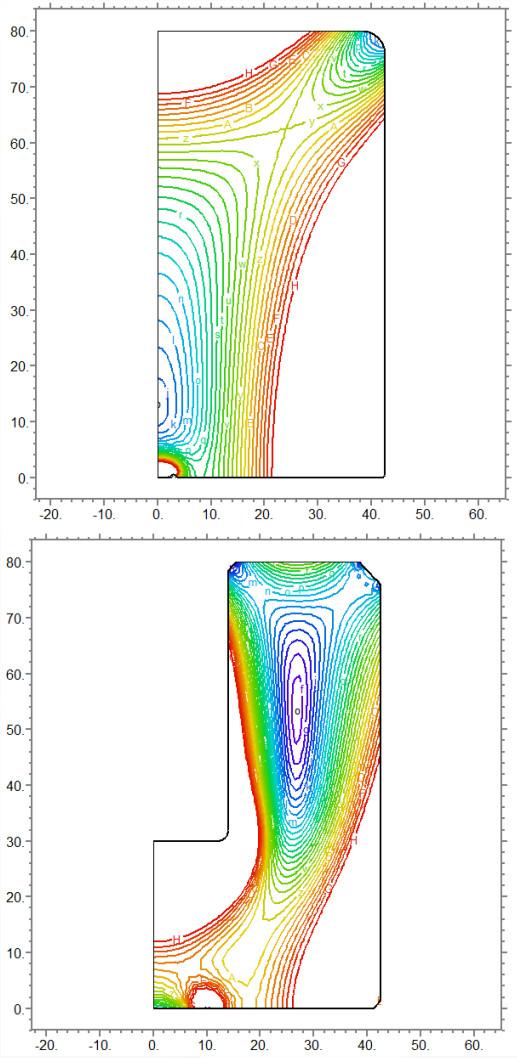
50eV 1.5kg Ge detector

Future Developments

Evolution of Canberra PCGe Detectors

- Crystal size increased from 500g to 1.5kg
- Continuous reduction of electronic noise
- 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





Conclusions

- **Canberra Point Contact Ge Detectors**
  - Continuous improvement process on all levels
  - Well defined selection and benchmarking criteria for all components
  - Proven high reproducibility and reliability of the results
  - Records: - Crystal sizes beyond 2.5 kg
    - Energy resolution down to 50 eV (FWHM with pulser)
    - Complex assemblies of several detectors
  - Deep Underground storage facility available close to Lingolsheim
- **Reliable industrial partner for PCGe Detector design and manufacturing**
  - Large production capability: 3 industrial plants with equipment redundancy and industrial standard
  - Training and long term support of users
  - Installation and operational conditions