Operation and Characterization from Electric Cool Ge Detectors at KSNL

PIRE
GEMADARC

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@

3rd PIRE-GEMADARC Collaboration Meeting (Knoxville, TN) and Ge Technology Workshop

Outline of Talk

- Overview Electro-cooled Ge Detectors.
- Operation & Problems
- Performance: Threshold and background.
- Sensitivity for Low energy physics
- Future Prospects

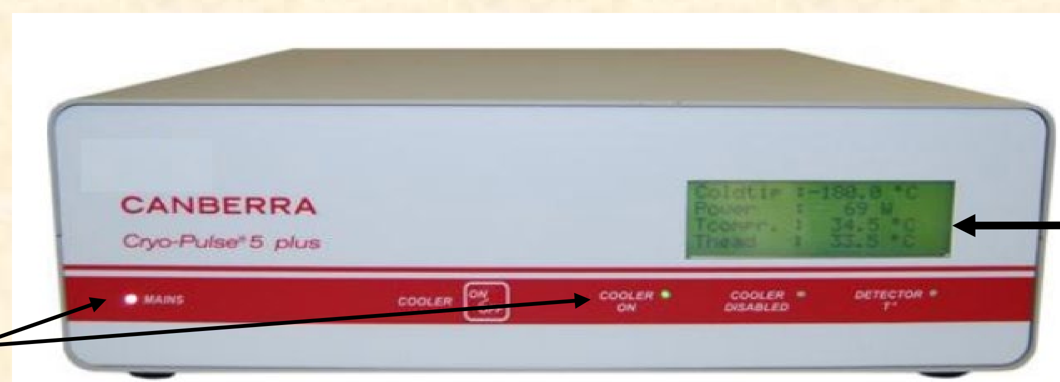
Design of ECGe

Top View

Side View

Cooler **Cold finger** **Detector Capsule** **Air Out** **Air In** **Pre-Amp**

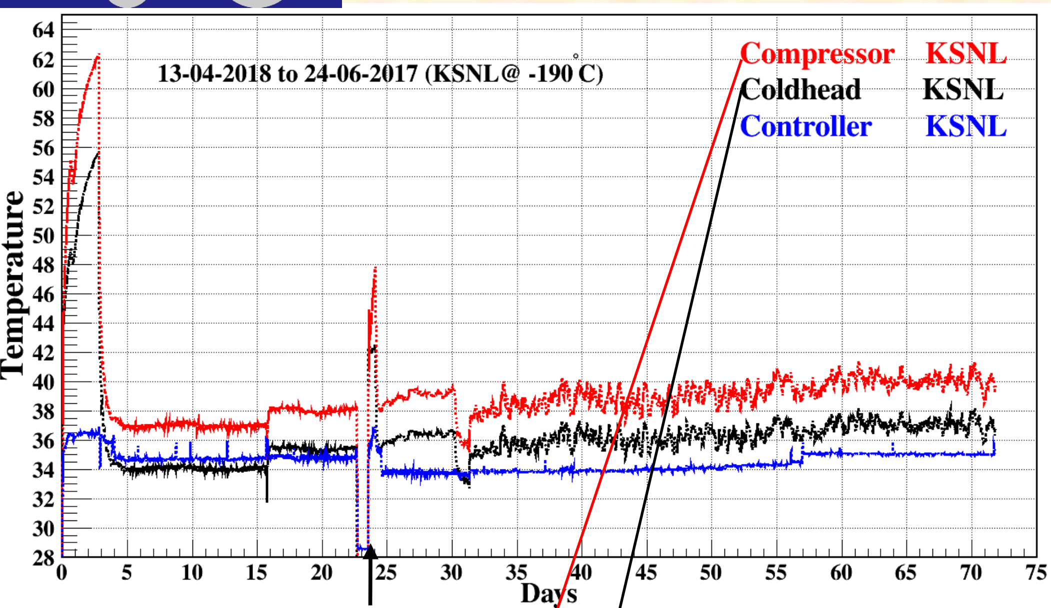
Controller



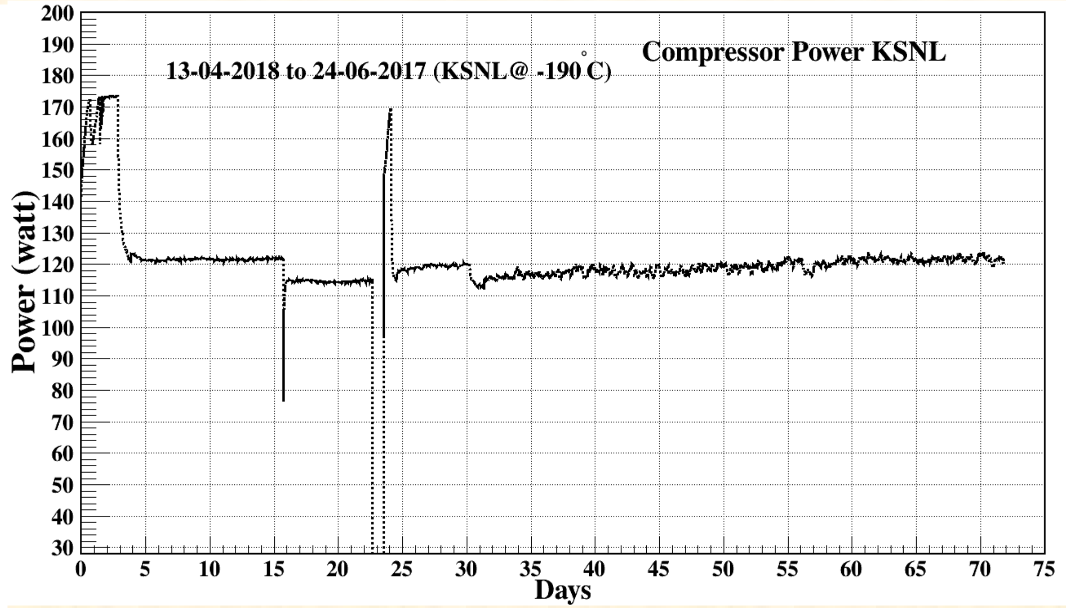
Front Panel Display

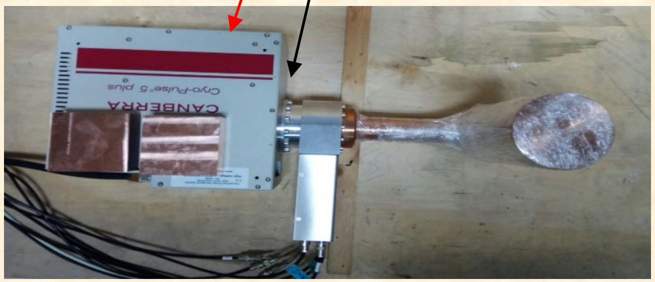
Front Panel LEDs

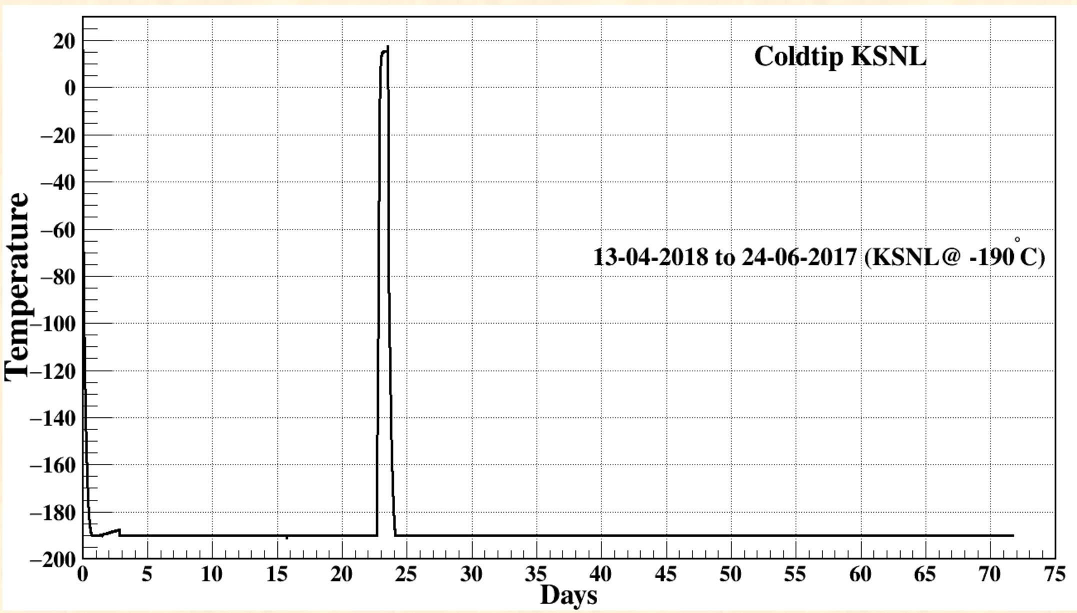
Temperature and Power Profile



Thermal Recycle



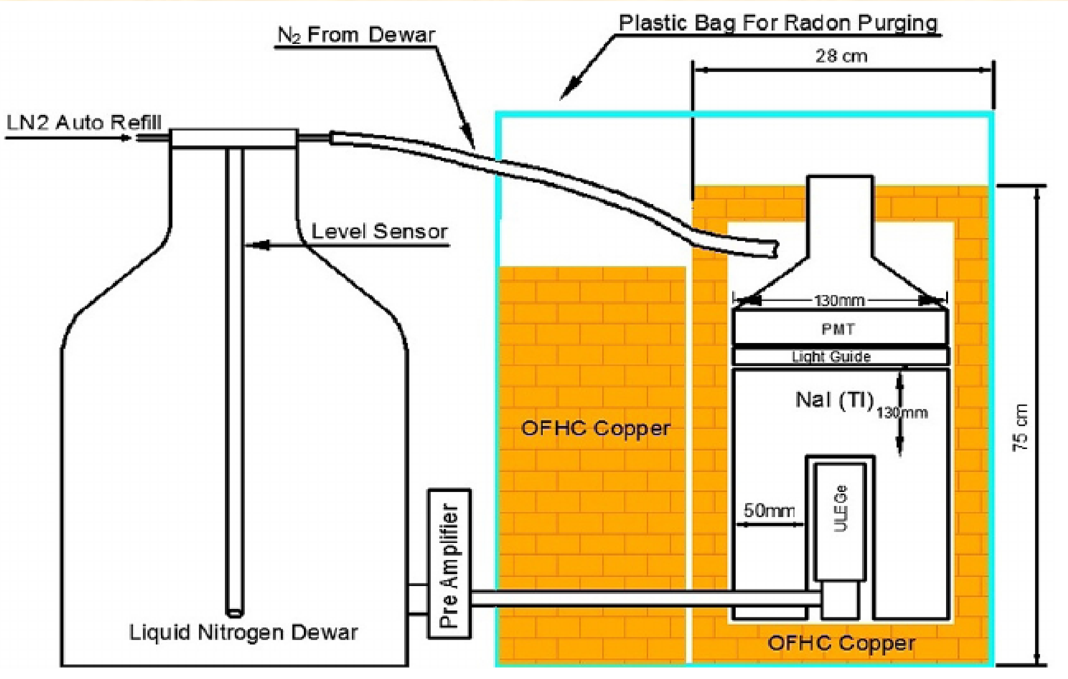


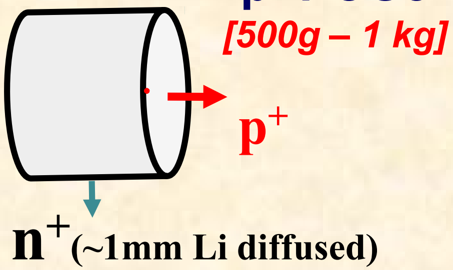


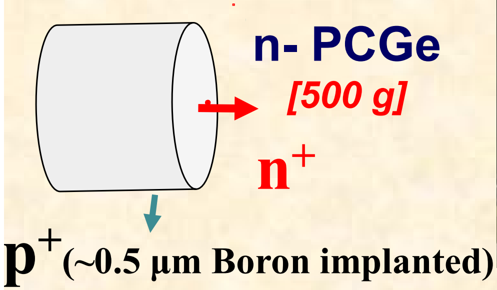
Advantage of Electro-cool Ge detectors

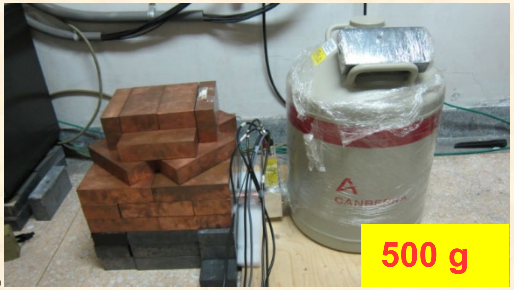
- ☑ **Customize Coldtip temperature for best frontend performance**
- ☑ **Cooling with synchronized negative feedback pumping.**
- ☑ **Less microphonic noise.**
- ☑ **Compact (Portable) Design.**
- ☑ **New JFET and ASIC FE-electronics near point contact.**

Pulsar FWHM and Threshold









	Generation	Mass (g)	Pulsar FWHM (eV_{ee})	Threshold (eV_{ee})
Liquid Nitrogen	G1	500	130	500
	G2	900	100	300
Electro-cool	G3	900	70	200
	G3+	1430	~60	~160

Operation Problems (Difficulties)

☑ **Electro-cooler not powerful enough to cool down after some months -- due to outgassing of internal components.**

Solution: **Necessary to do regular pump down by an external pump to remove residual air.**

☑ **Most performing front-end electronics have:**

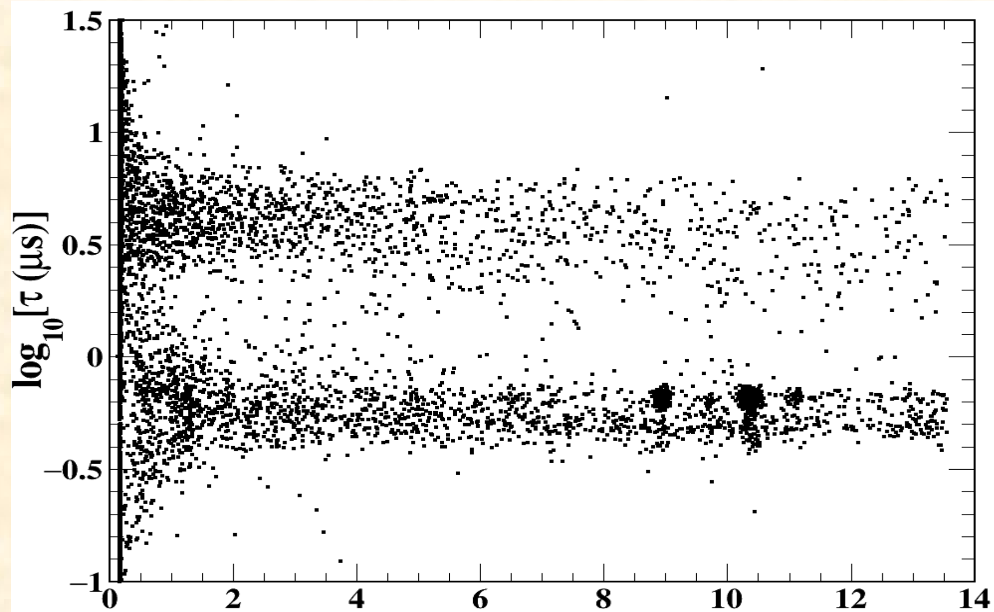
- **higher background (not yet low-background compatible)**
- **High failure rates**

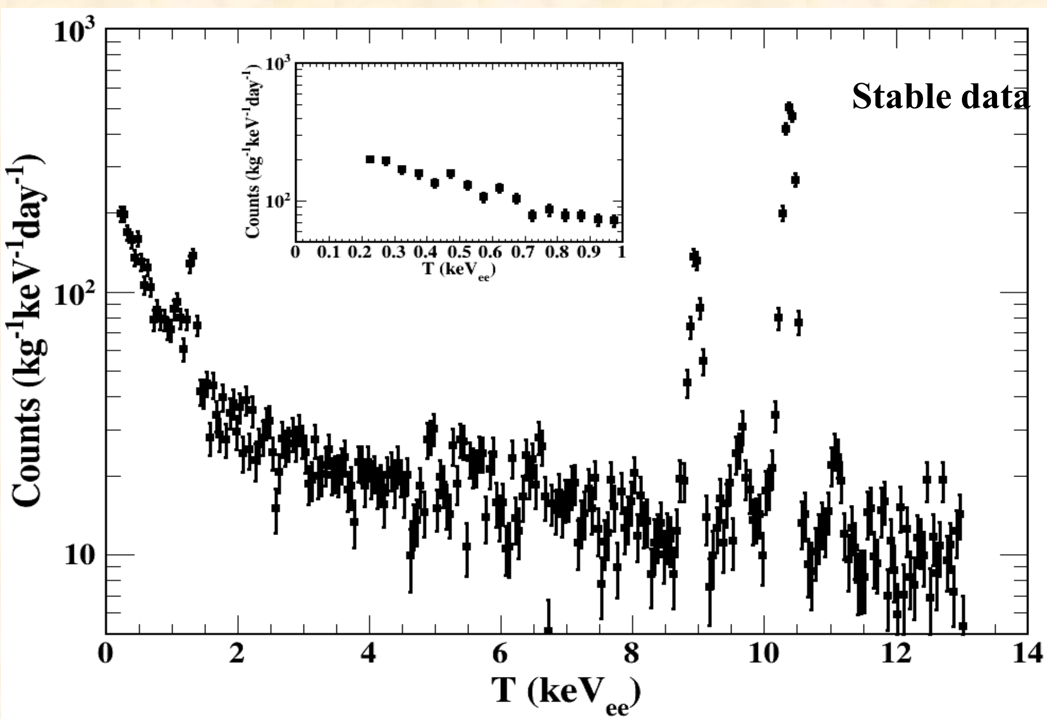
☑ **Repairs & Upgrades take long time than "regular" devices, indicating learning curve from company as well …..**

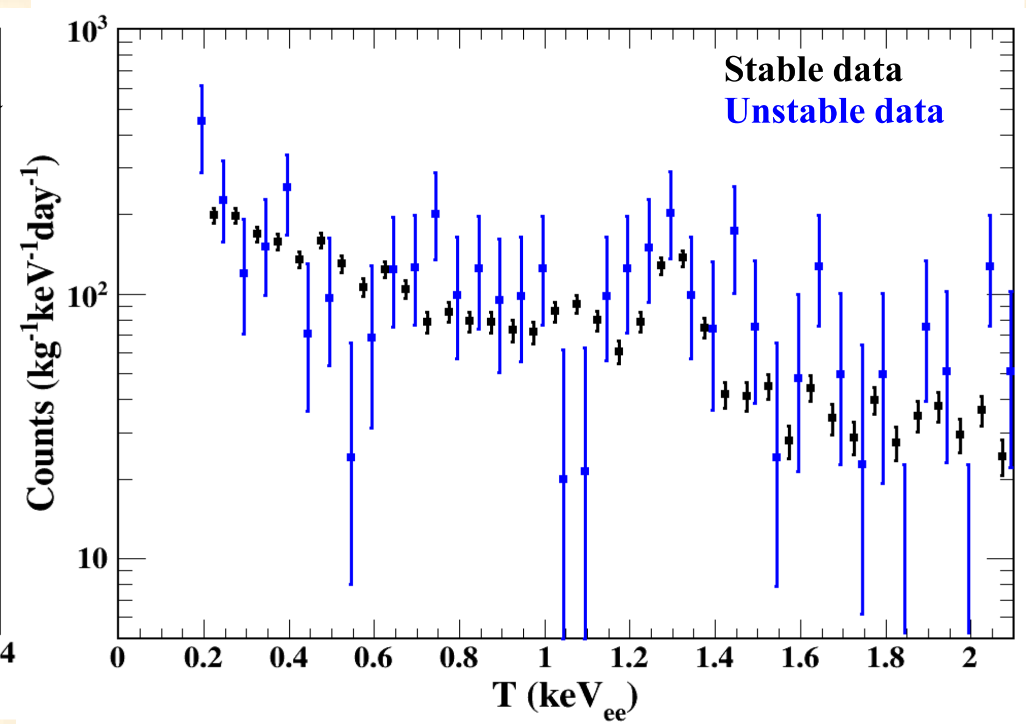
G3+ Generation Detector ..

Germanium detector at -185 C

- Threshold secured 200 eV
- Pulsar FWHM 70 eV
- Clean Surface Bulk band







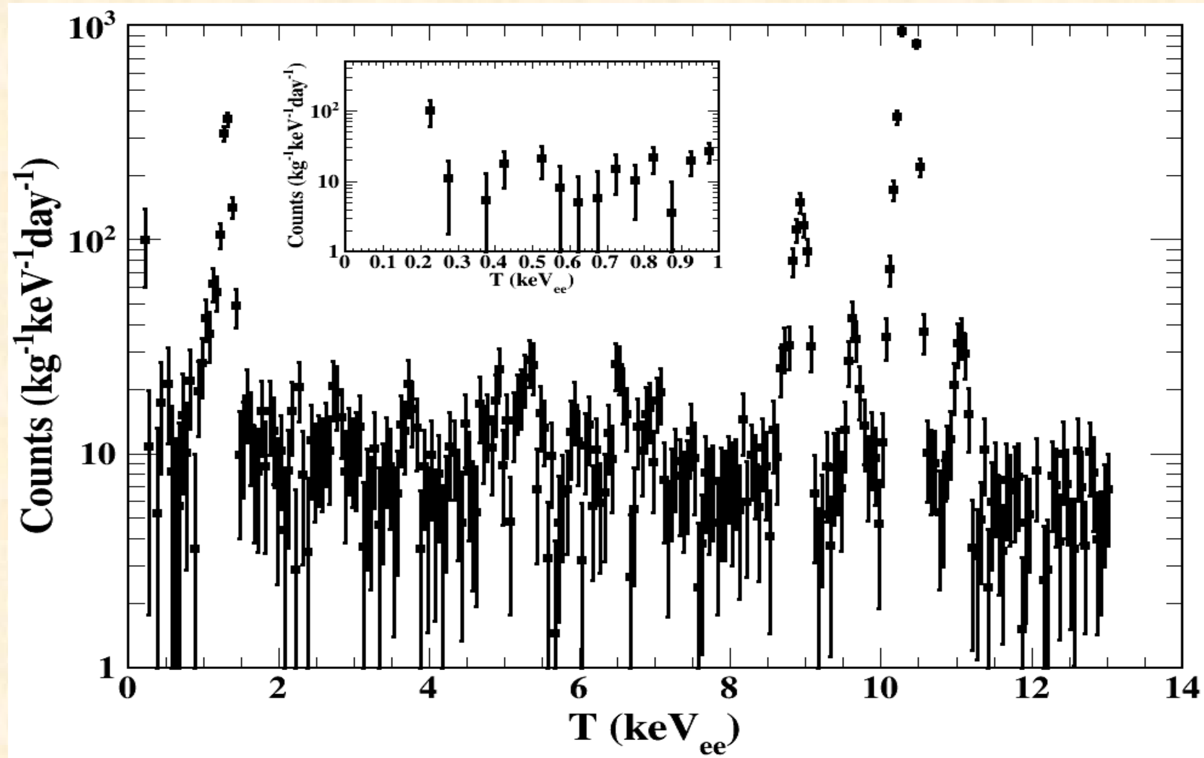
G3 Generation Detector

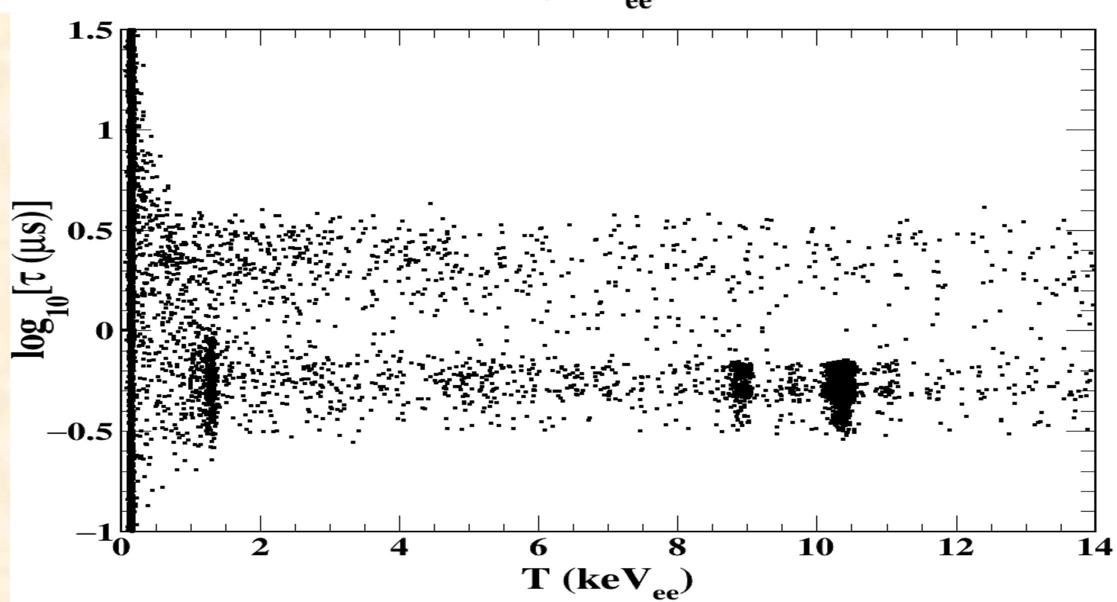
Data collected with G3 detector:

- 30 kgd (-190 C)

Encountered problems:

- 200 eV threshold.
- Pulsar FWHM 70 eV.
- Controlled background.

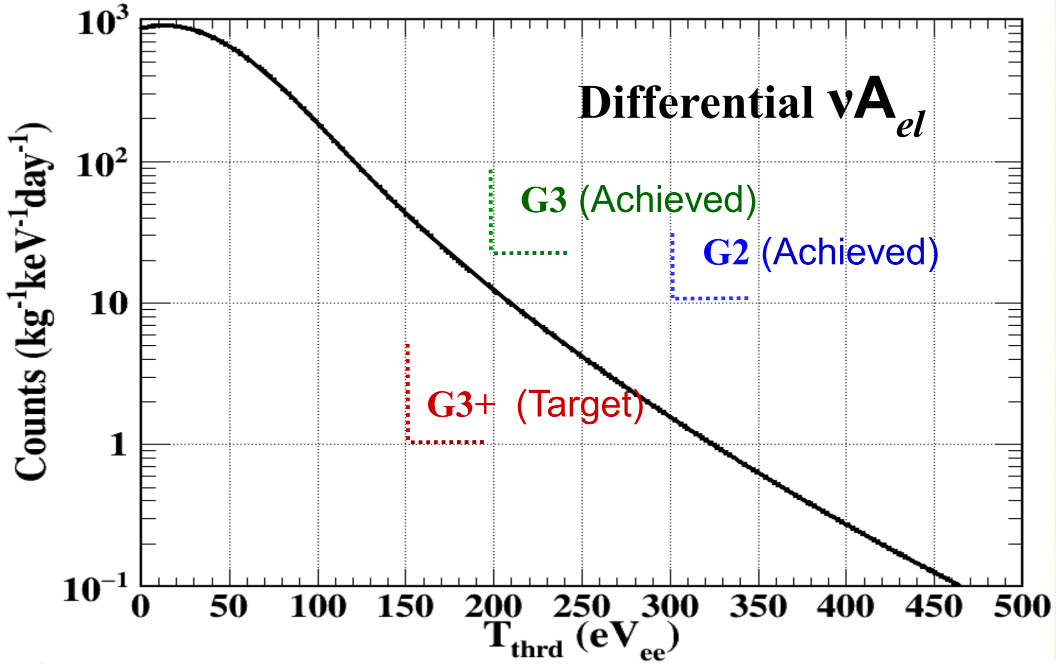


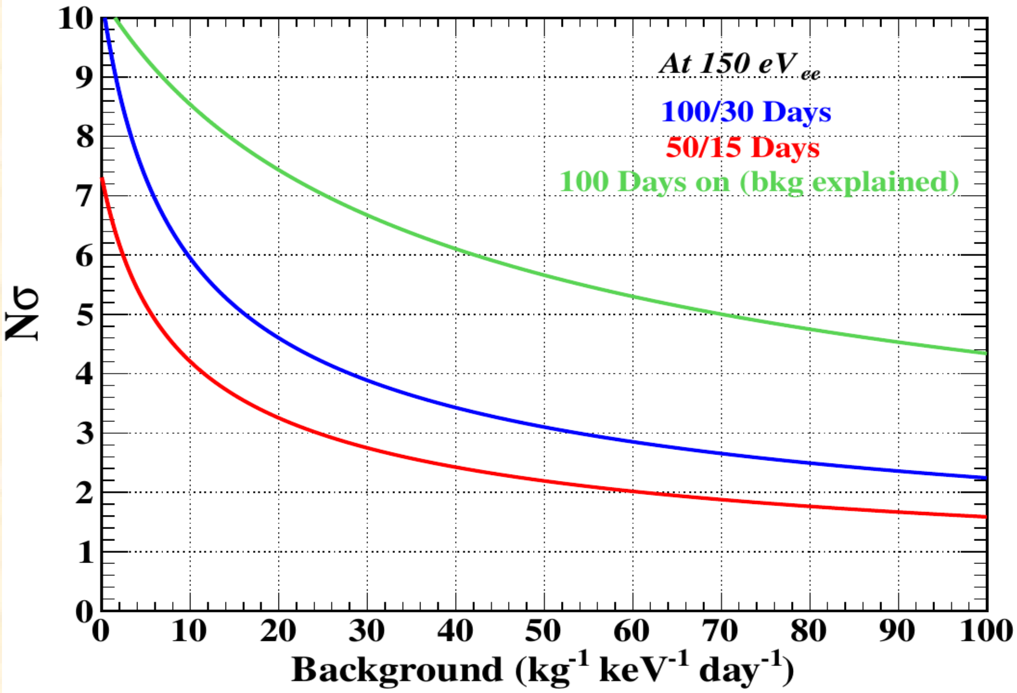


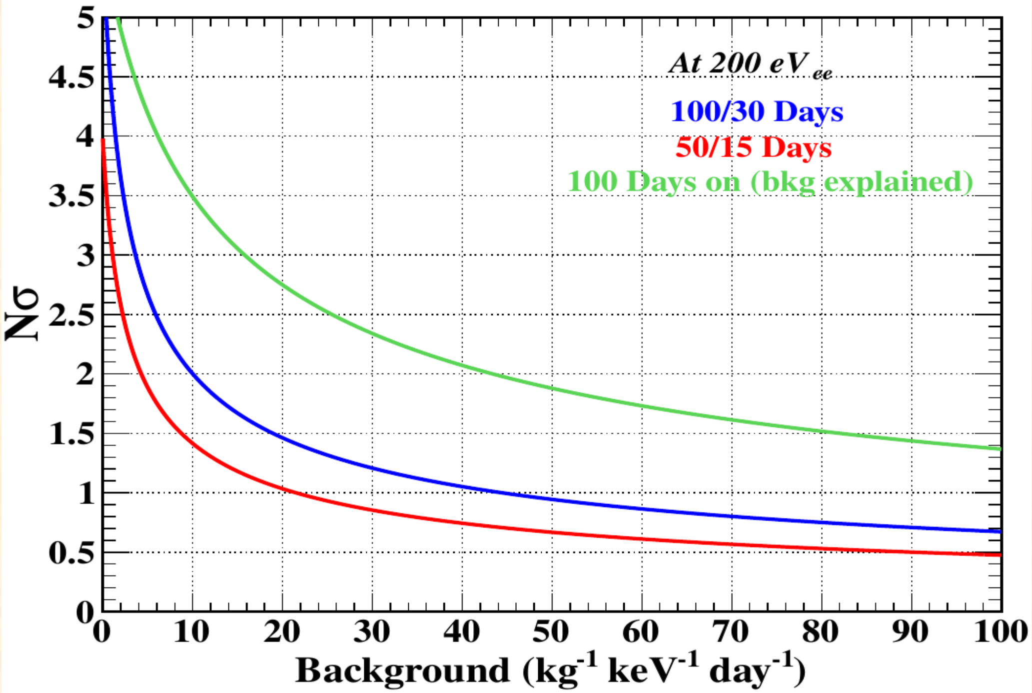
Status to probe νA_{el}

$$\nu + A(Z,N) \rightarrow \nu + A(Z,N)$$

$$\frac{d\sigma_{\nu A_{el}}}{dq^2}(q^2, E_\nu) = \frac{1}{2}\left[\frac{G_F^2}{4\pi}\right]\left[1 - \frac{q^2}{4E_\nu{}^2}\right] \times [\varepsilon Z F_Z(q^2) - N F_N(q^2)]^2$$







THU Ge-activities

Litao Yang (THU)

On behalf of CDEX

The 3rd PIRE-GEMADARC Collaboration Meeting, Dec. 5th, 2018, Knoxville

● The manufacture of HPGe

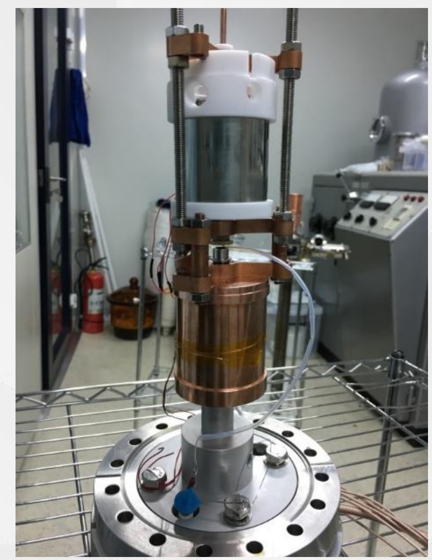
Mechanical Preparation

Lithium Diffusion

Wet Lab

Boron Ion Implant

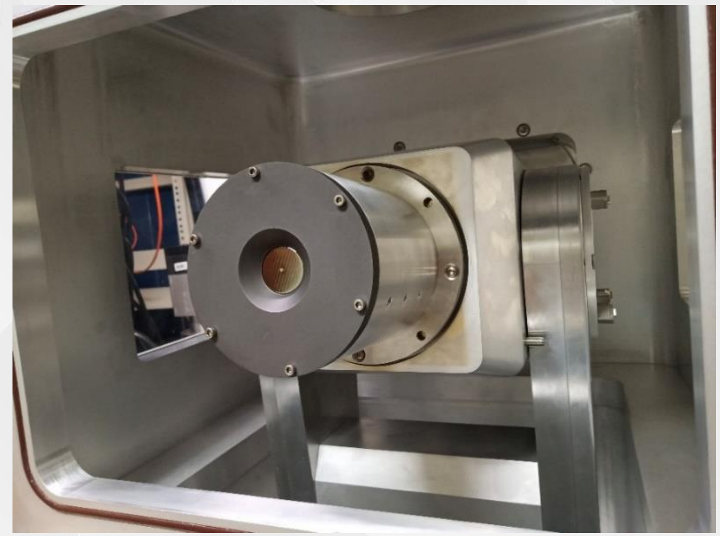
Surface Passivation

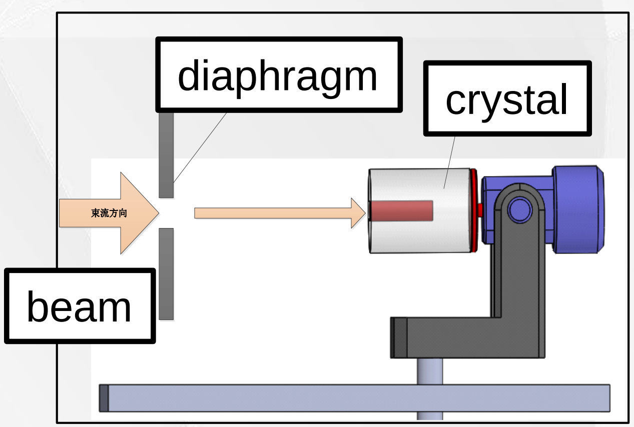


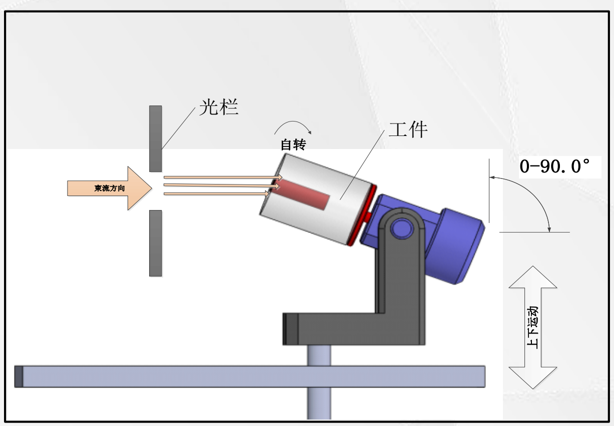
HPGe detector

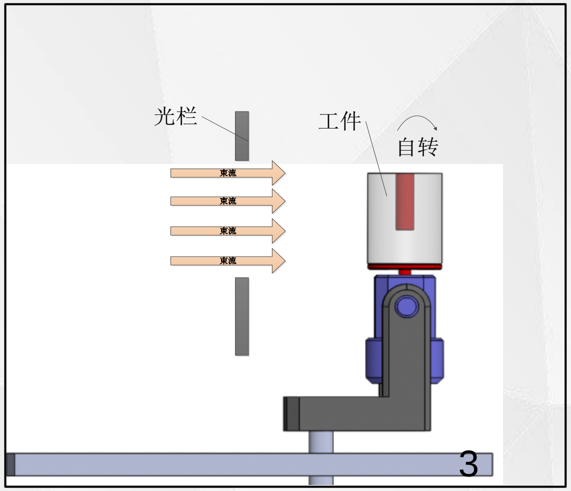
● New Ion Implanter

- ✓ Specially designed for HPGe injection, Max. crystal size: Φ100mmX90mm
- ✓ Injection elements: B, P, Ar









● Laboratory and equipment upgrades

Glove box @ CJPL-I

Fume hood

Water Purifier

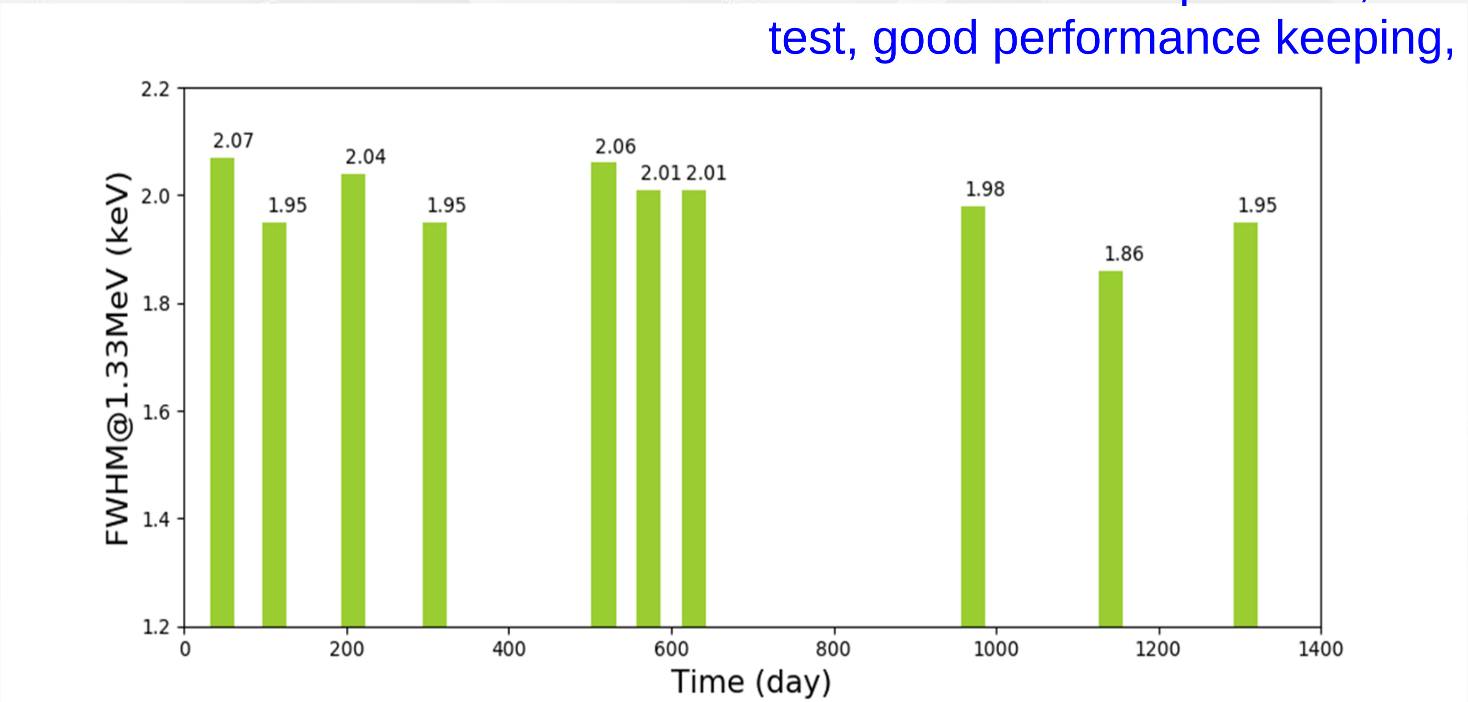
Glove box @ THU

- ✓ First assembly test of the home-made HPGe detector in CJPL-I was completed;
- ✓ A small LN_2 tank was equipped in the glove box@THU, for the test of Bare HPGe in LN_2;

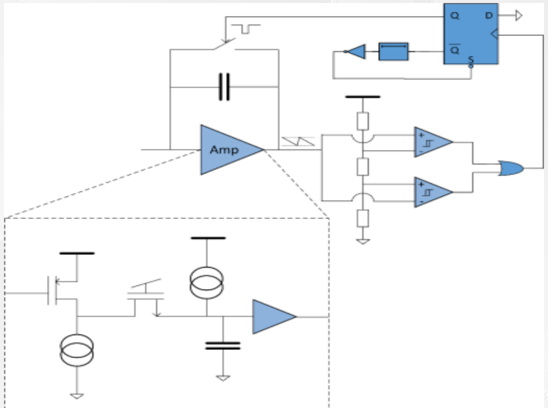
● Long-term stability study

- ✓ Detector: 19#
  - ✓ PPCGe detector, Φ50mm X 50mm
  - ✓ Pre-amplifier: Pulse-reset
- ✓ Latest measure results(2018/10/24):
  - ✓ Leakage current: 16pA
  - ✓ FWHM: 0.72keV@122keV, 1.95keV@1.33MeV

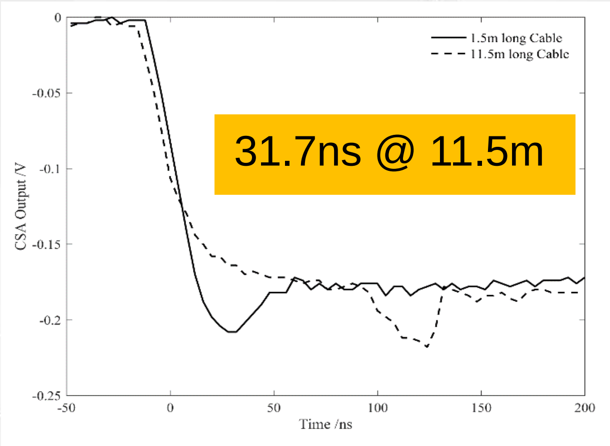
Stored at room temperature, cooled down for test, good performance keeping, >1300 days



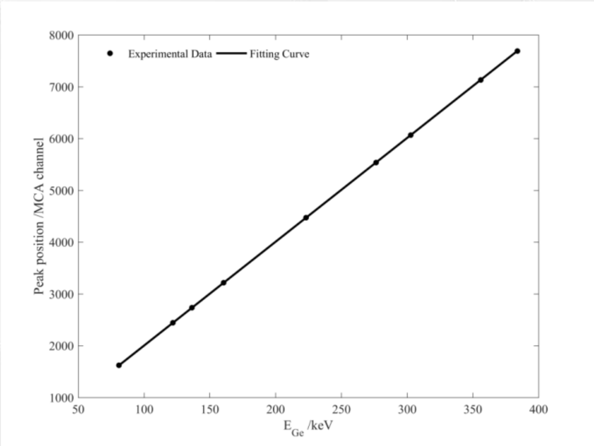
● CMOS Preamplifier ASIC



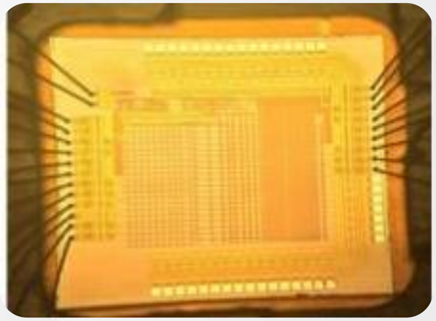
The schematic of the preamplifier with pulse reset



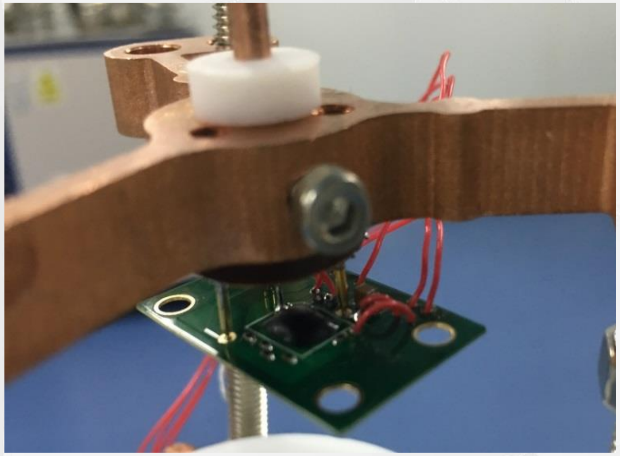
Drive capability > 10m



Linearity test: INL<0.01%



Layout of ASIC preamplifier
3mm x 3mm



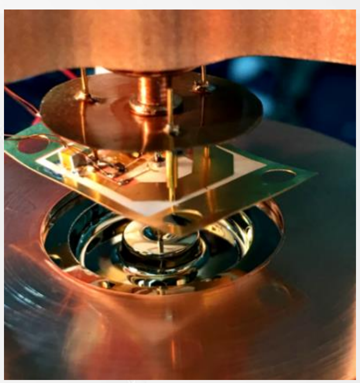
The Readout PCB board

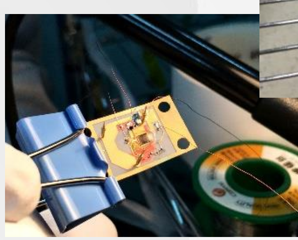
- PCB Material : Rogers 4850
- Tight control on dielectric constant and low loss, close to PTFE
- Utilizing same processing method as standard epoxy/glass (FR4)

● THU-1: ASIC + PPCGe

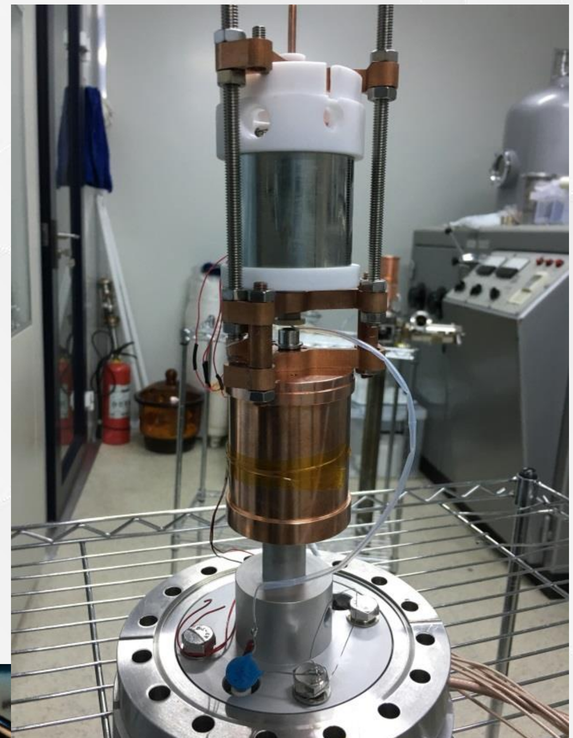
- First 500g home-made PPCGe+ASIC finished testing, energy resolution and energy threshold compared with commercial one.

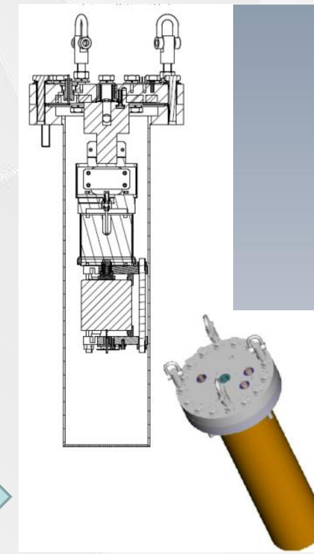
PPC: ϕ50mm x 50mm

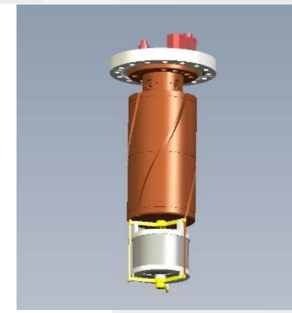




Low noise & low bkg ASIC electronics

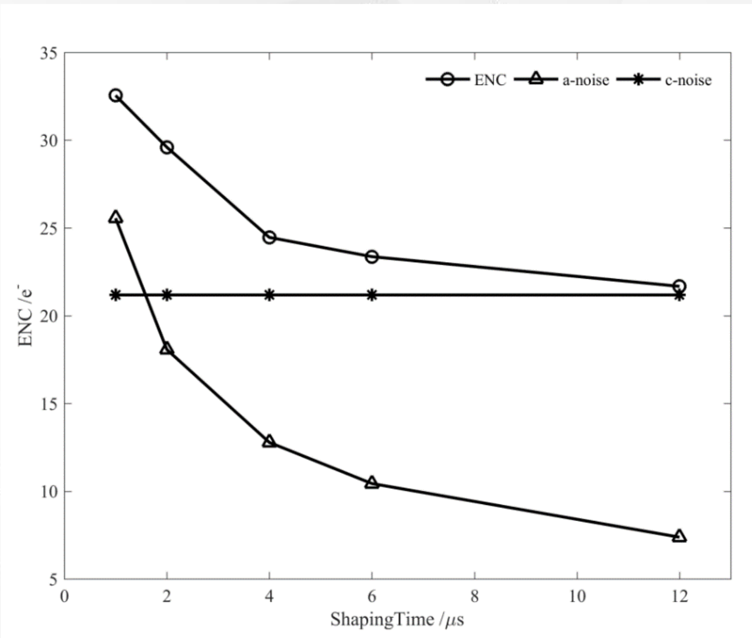






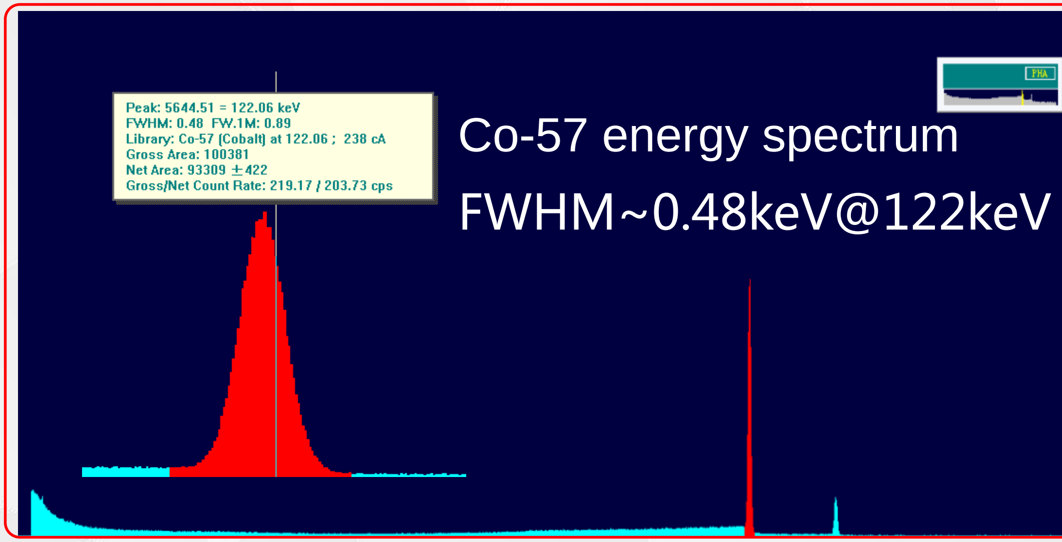
● THU-1 HPGe Detector Performance @ THU

Noise components analysis:
the b-noise is ultra low!



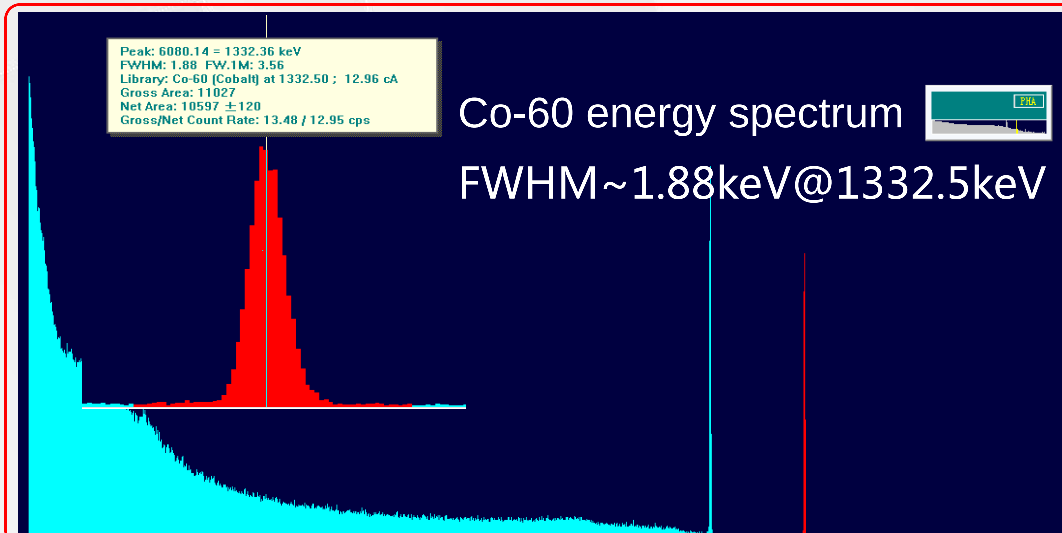
ENC~21.7e

182eV FWHM →152eV FWHM



Co-57 energy spectrum

FWHM~0.48keV@122keV

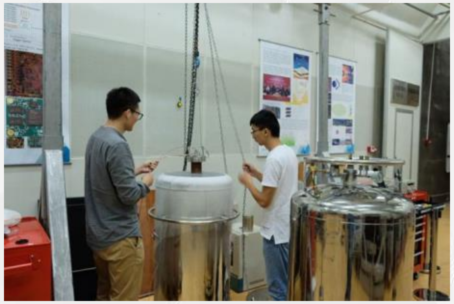


Co-60 energy spectrum

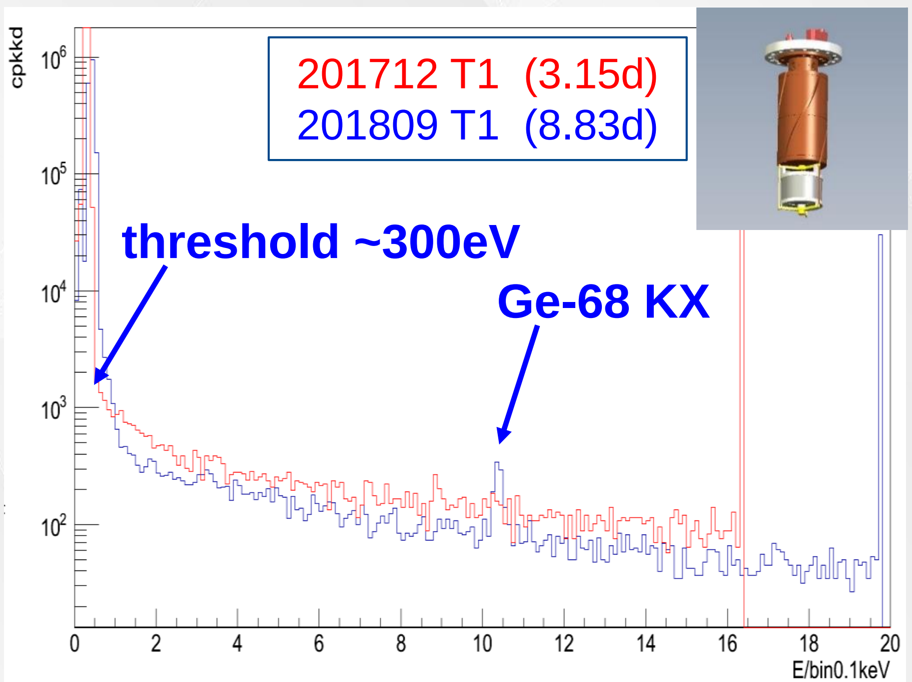
FWHM~1.88keV@1332.5keV

● THU-1 HPGe Detector Performance @ CJPL

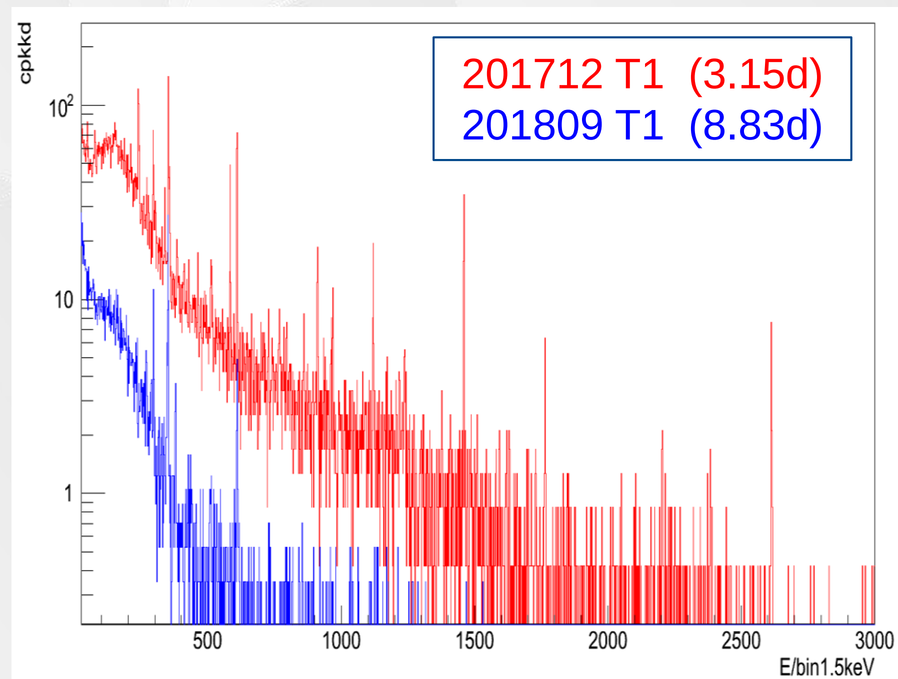
Reset Period ~ 5.7s, Leakage Current ~ 0.043pA.



- ✓ Commercial Ge crystal;
- ✓ Structure machining;
- ✓ Li-drift and B-implanted;
- ✓ Home-made ULB PreAmp;
- ✓ Underground EF-Cu;
- ✓ Underground assemble;
- ✓ Underground testing…



Background spectrum
@low energy region (0~20keV)



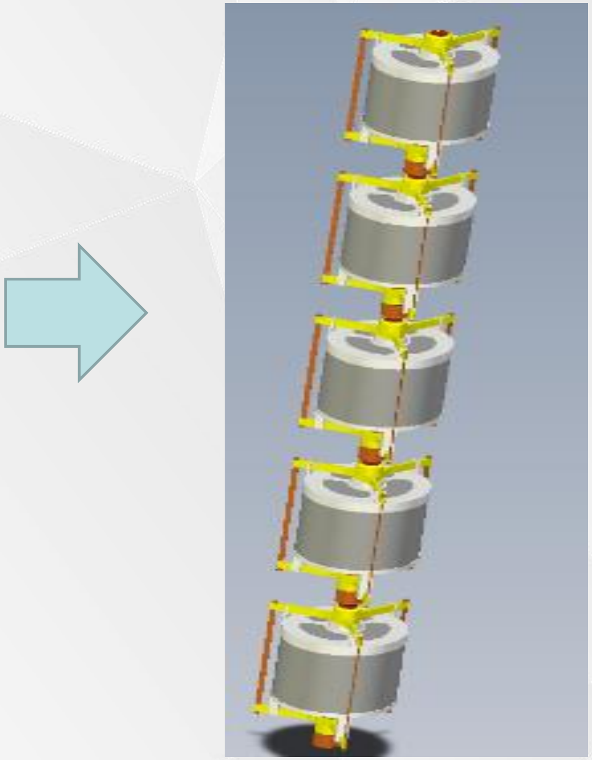
Background spectrum
@high energy region (0~3000keV)

Bare HPGe detectors in LN_2

- Vacuum chamber, structure materials, not conducive to further reduce the radioactive background;
- ASIC-based preamplifiers can work well in liquid nitrogen;

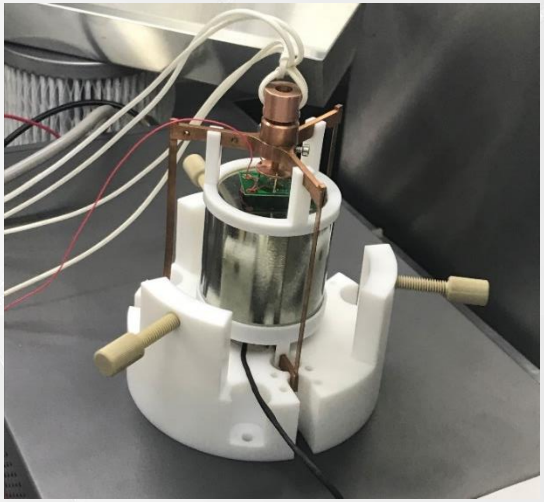
✓ Develop bare HPGe detectors immersed into LN_2!

CDEX-10 detector string layout

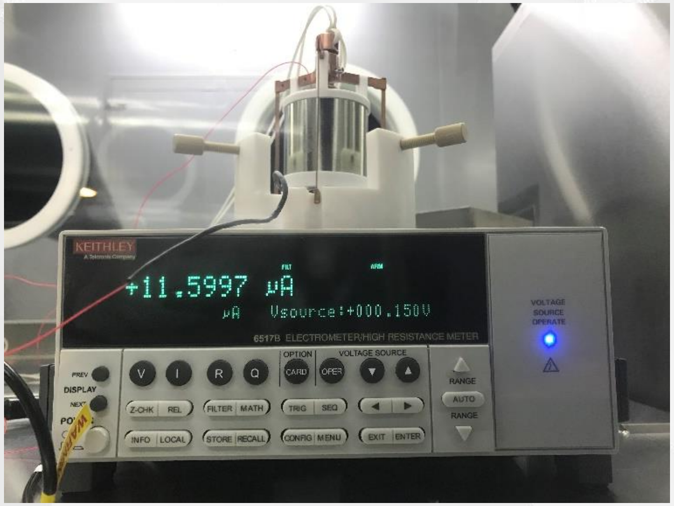


● Bare HPGe detectors in LN_2

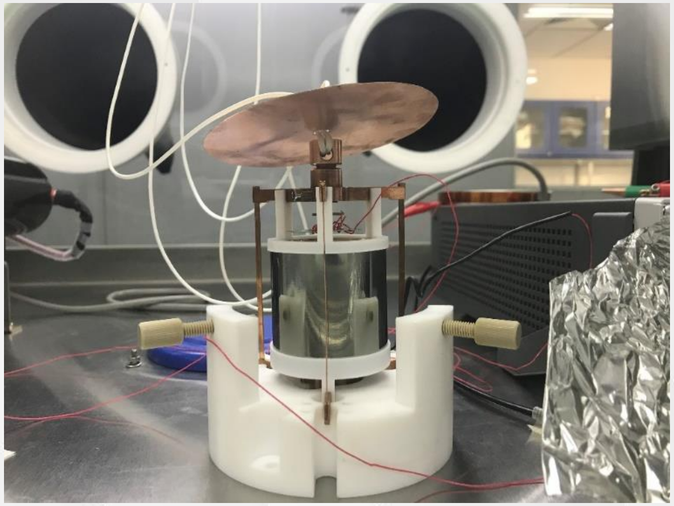
- The leakage current was measured by an electrometer, which also supplied the high voltage at the same time;
- In order to shield infrared radiation, we used a similar design from Gerda. **A copper sheet** is placed above the crystal holder to **block infrared radiation** from the LN_2 tank, lower the leakage current.



Detector structure of test

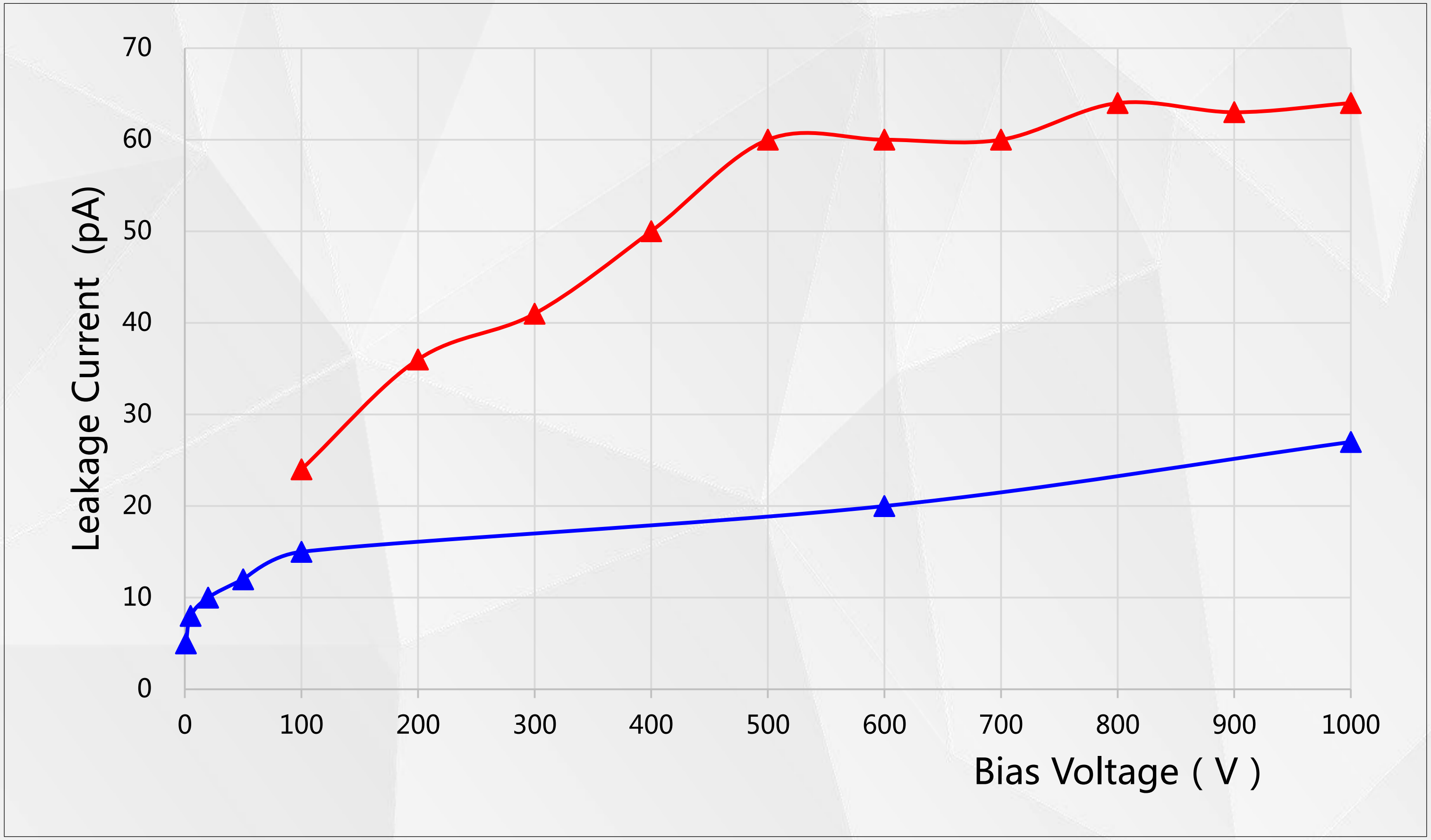


Electrometer
/high resistance meter



Bare HPGe detectors
(with infrared radiation shielding)

Bare HPGe detectors in LN_2

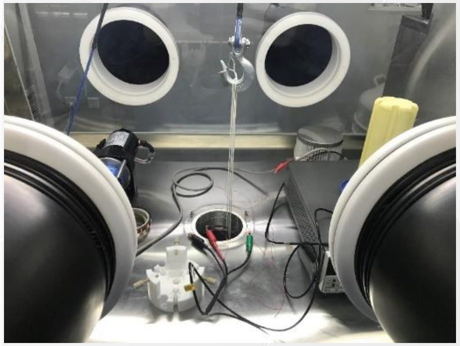


The relationship between Leakage Current & Bias Voltage

Red: for 3 hours, without infrared radiation shielding

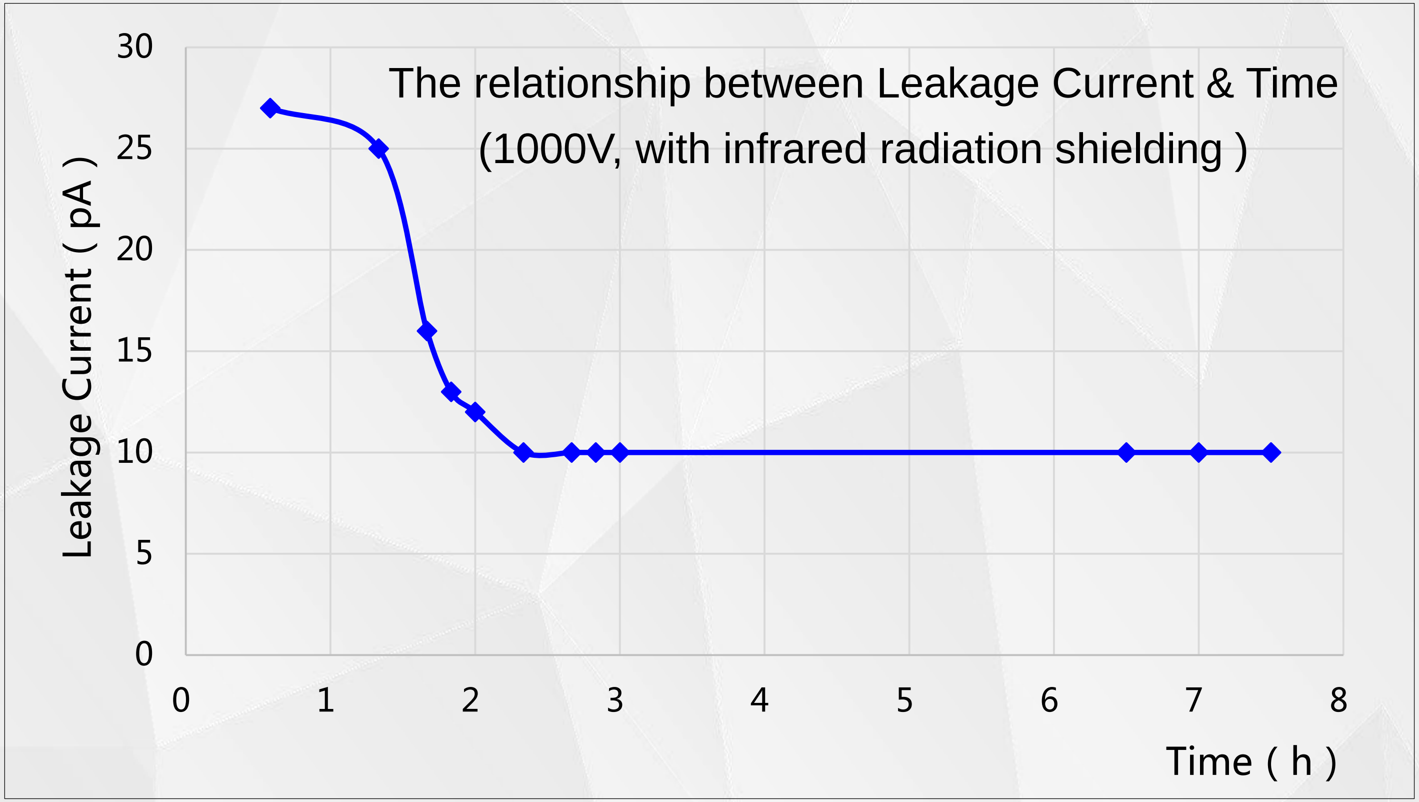
Blue: for 0.5 hours, with infrared radiation shielding

● Bare HPGe detectors in LN_2



Bare HPGe in LN_2

PPC: ϕ50mm x 50mm
Depleted voltage: ~800V

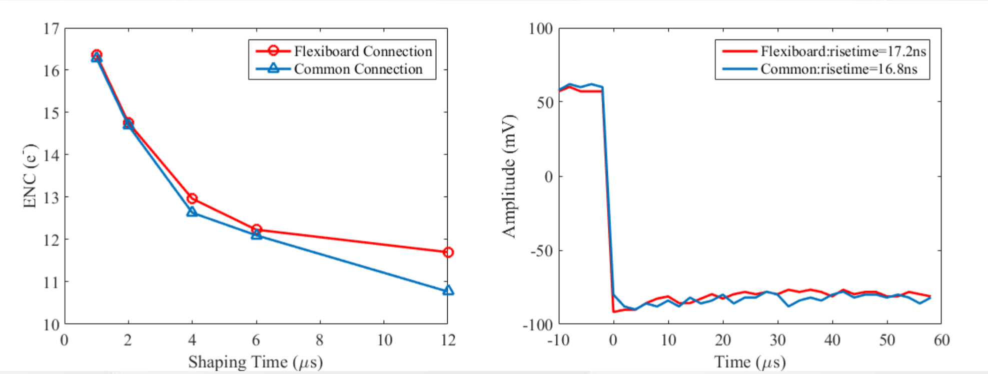


Immerse the detector into liquid nitrogen for about 8 hours, we got a stable leakage current ~10 pA for 1000V bias voltage.

Low background VFE

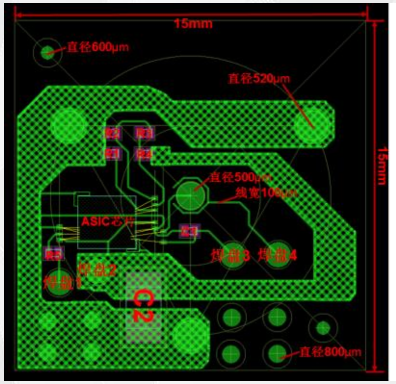
- **Flexible Cable**
  - lower background than coaxial cable
  - now: Kapton
  - next plan: PTFE (more pure, longer)

The ASIC board with 60cm long Flexible cable

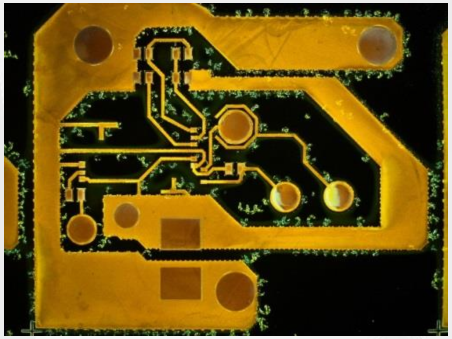


The performances of ASIC Preamplifier with Flexible cable are not degraded.
-noise --risetime

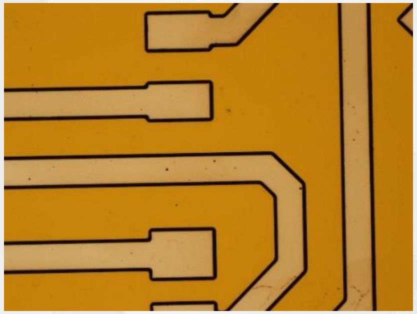
- **Si substrate**
  - The lowest background circuit substrate material
  - Micromachining → low mass
  - The first version of silicon substrate processing is currently completed



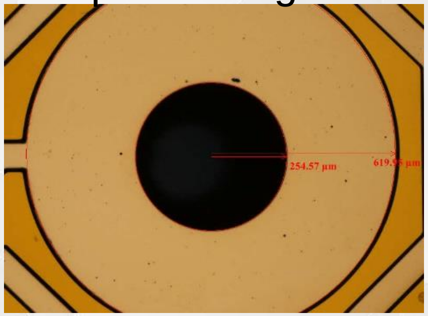
Silicon substrate design



Silicon substrate processing

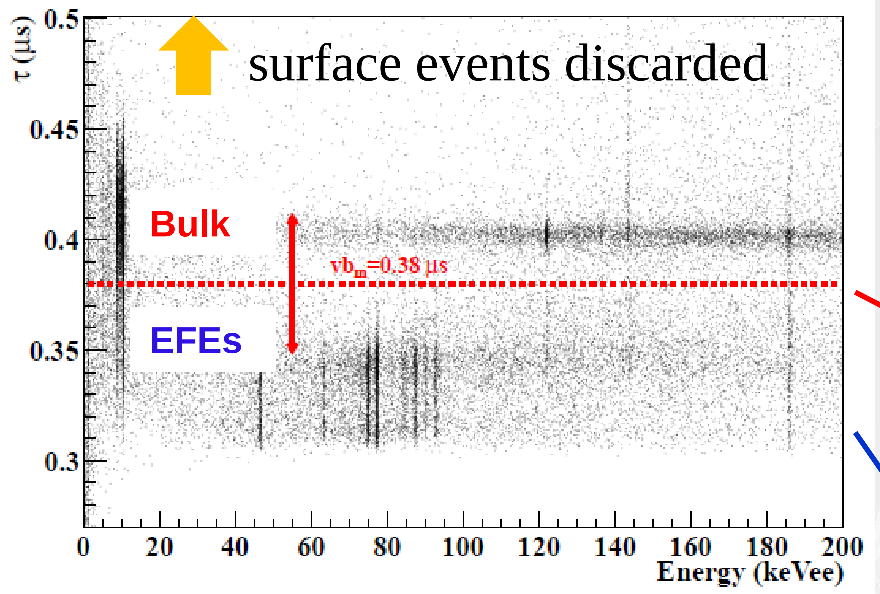


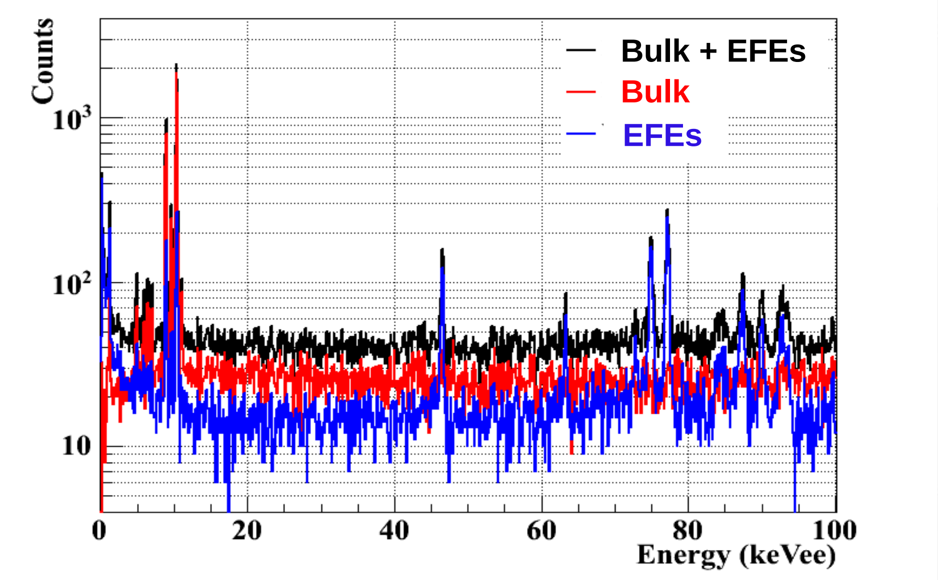
Wiring
(After plating)



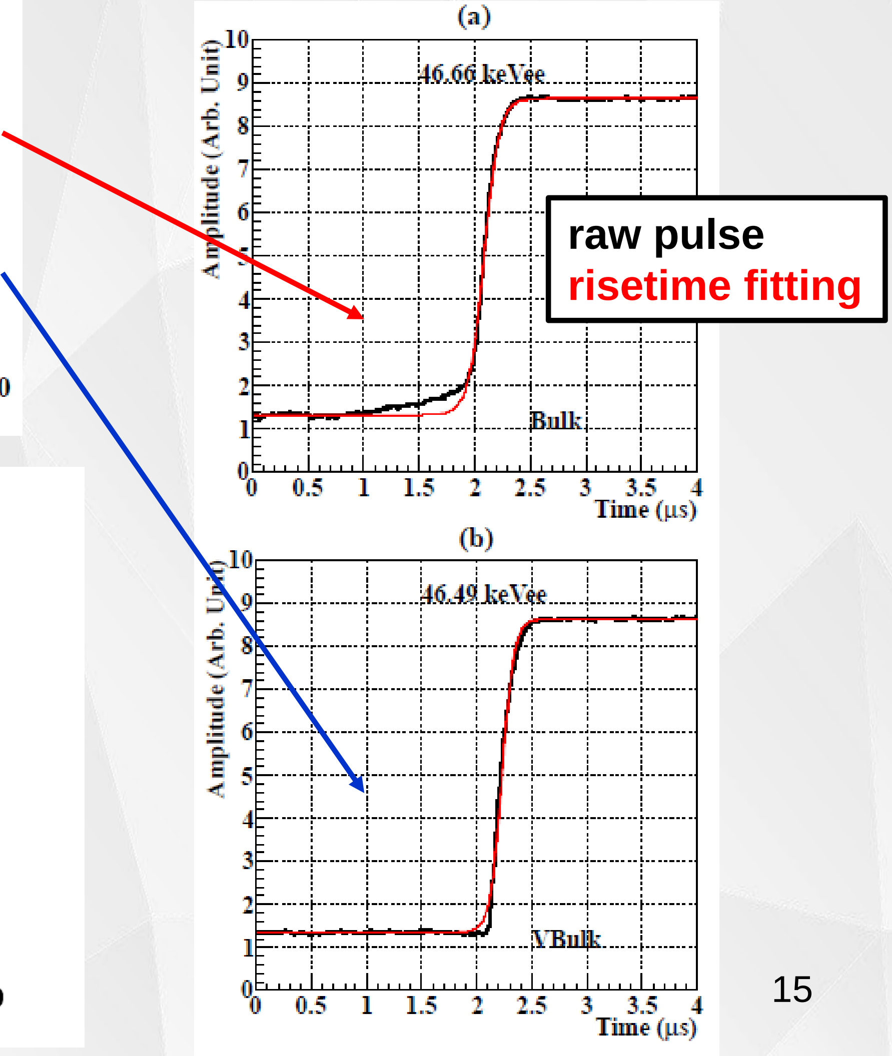
Central through-hole
(After plating)

● EFEs in CDEX-1B/10 background data



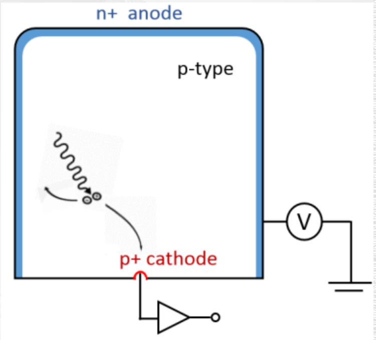


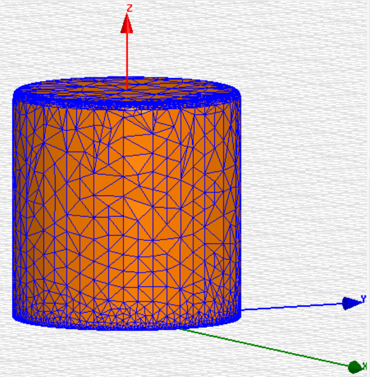
❖ Measured pulses:
- ✓ Top: Bulk event
- ✓ Bottom: EFE



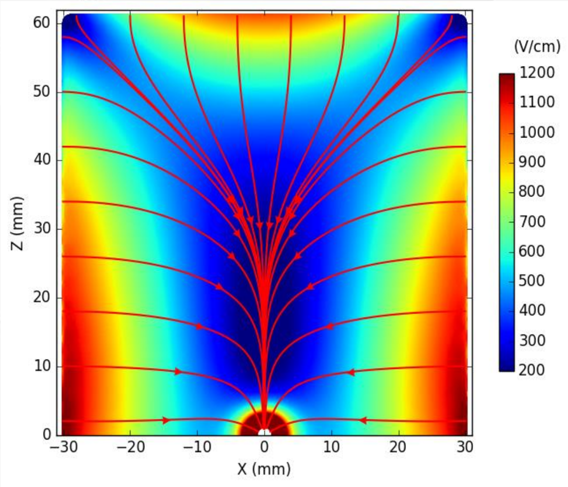
Detector simulation

- **Pulses generated by**
  - ✓Geant4: interaction & energy deposition;
  - ✓ICC package: Induced Charge/Current signal (Shockley-Ramo theorem);
- **P-type Point-Contact (PPCGe) detector:**
  - ✓Small point-like central contact
  - ✓Especially low capacitance (~ 1pF) gives superb energy resolution and low energy threshold

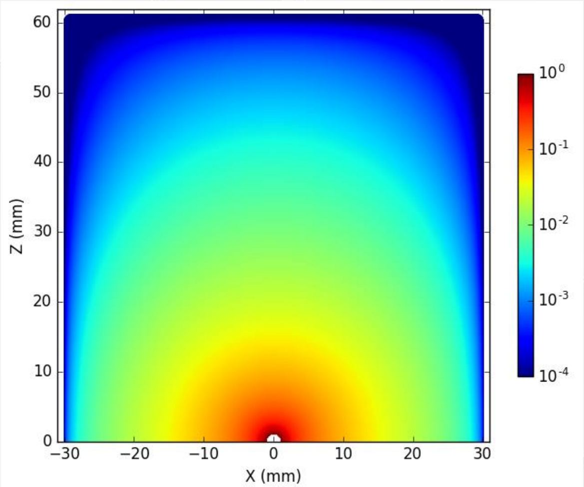




Finite element analysis of E-field (Maxwell)



Electric field



Weighting potential

Impurity concentration:

✓$[-0.5,-0.8]\times 10^{10} cm^{-3}$

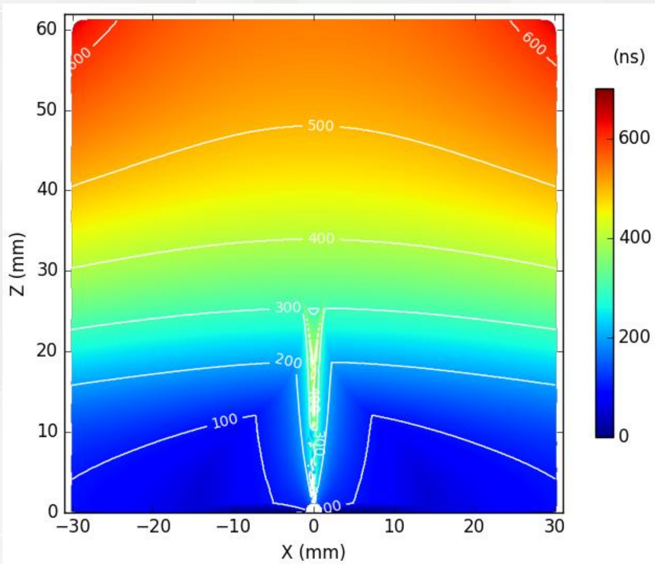
✓no radial gradient

Bias Voltage:

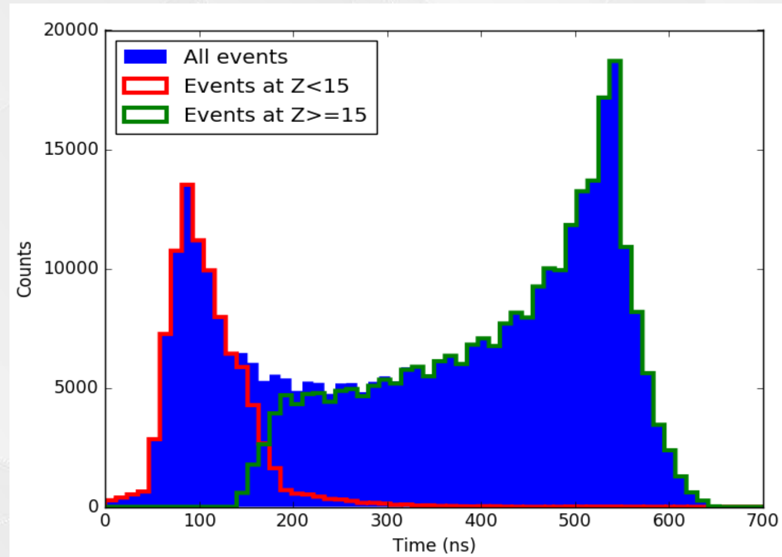
✓+ 3000V

EFEs origin -- detector simulation

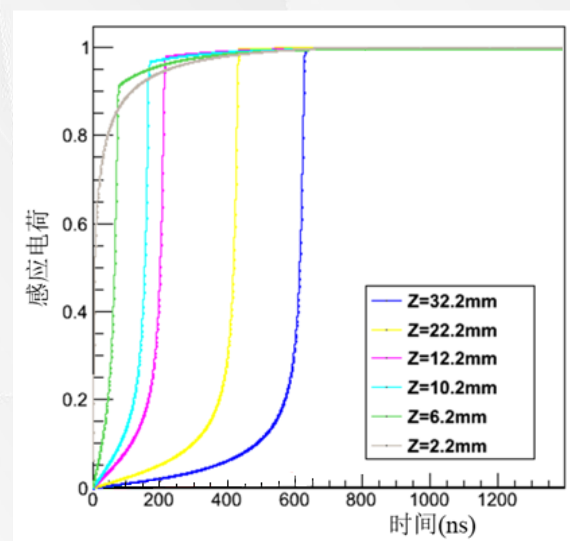
Drift time contour



Drift time distribution

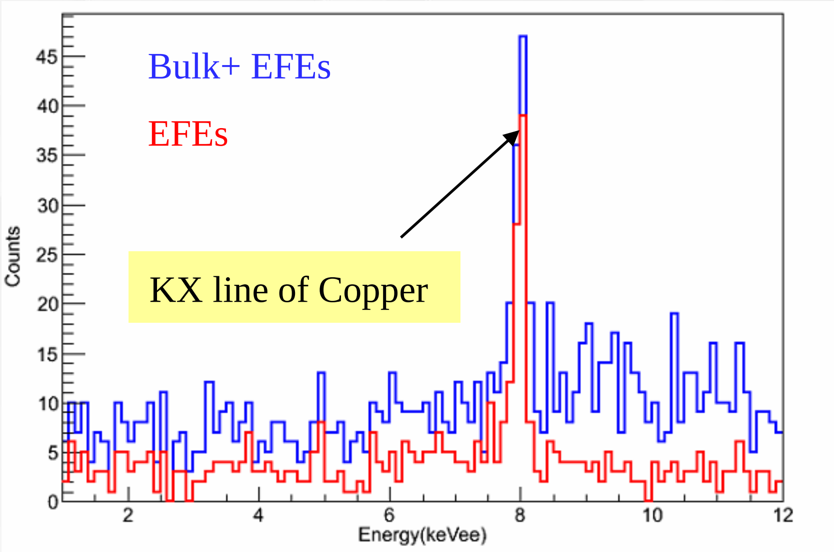


- The very-bulk events mainly arise from the bottom part of the PPC detector
- Very-bulk events discrimination can probably be used for background rejection

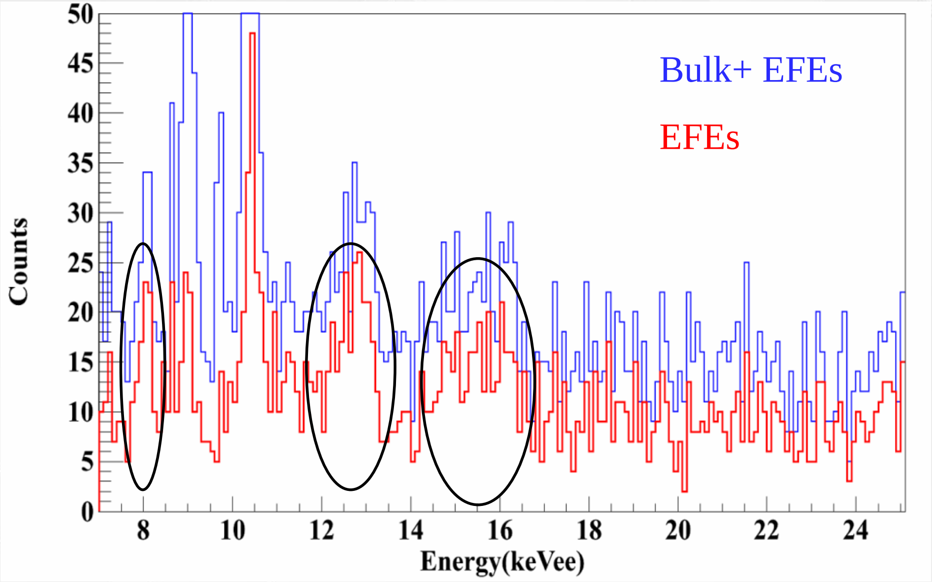


● EFEs origin -- Experimental verification

^{109}Cd gamma source



Background spectrum



- ✓ 8 keV X-rays from Copper was observed in EFEs spectrum of the ^{109}Cd samples;
- ✓ In the background spectrum, there are some clear peaks (12-16keV), which are dominated as EFEs;
- ✓ Experimentally verified that the ultra-fast case comes from the end face of the point electrode where there is no dead layer.

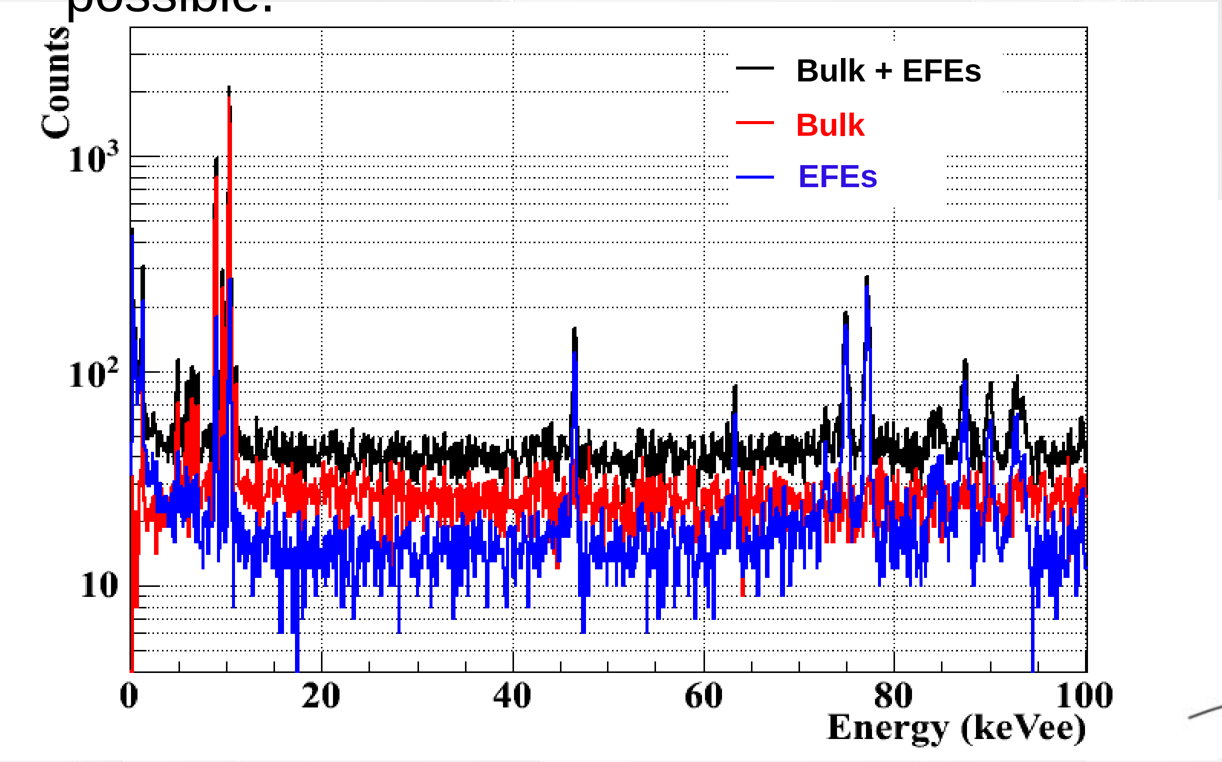
Nuclide	Type	Energy(keV)
Cu	Lα	8.04
Pb	Lβ	12.62
Bi	Lβ	13.01
Th	Lα	12.85
	Lβ	15.62
		16.20
Ra	Lα	12.34
		12.20
	Lβ	14.84
		15.24

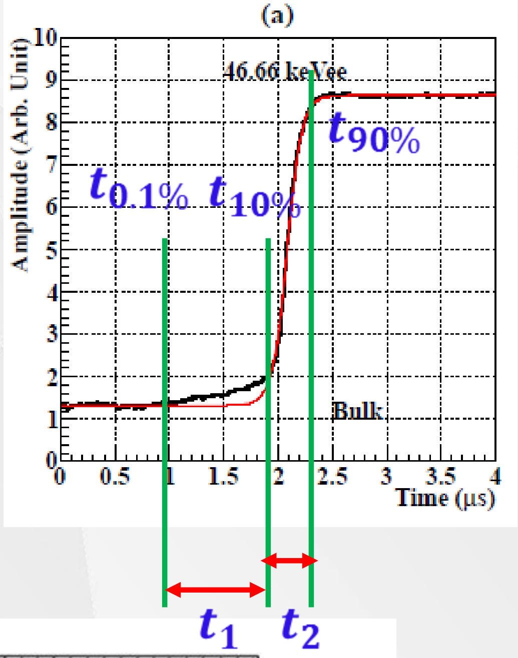
What we learned from EFEs studies? (1)

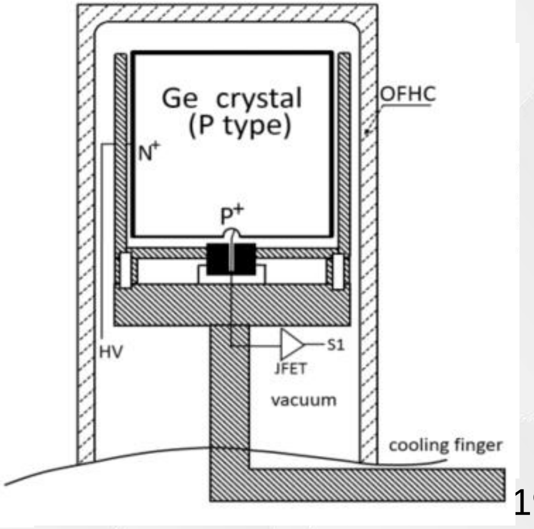
(1) Suppress the background level

Define the drift time: $t_1 = t_{10\%} - t_{0.1\%}$

- Drift time is related to the energy deposited location;
- Possibility of fiducial selection, remove as much as possible while retaining as much fiducial mass as possible.







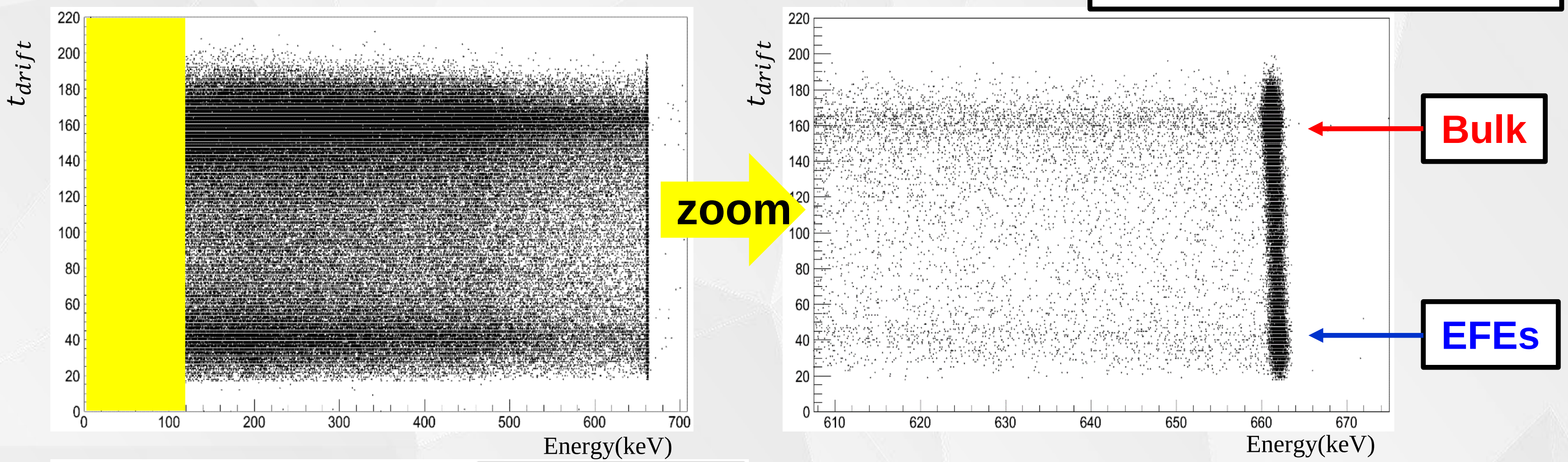
● What we learned from EFEs studies? (2)

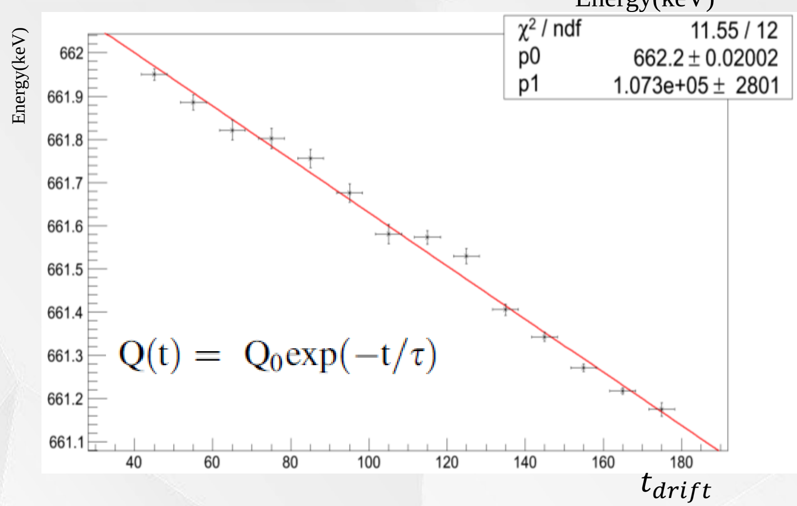
(2) Improve energy resolution

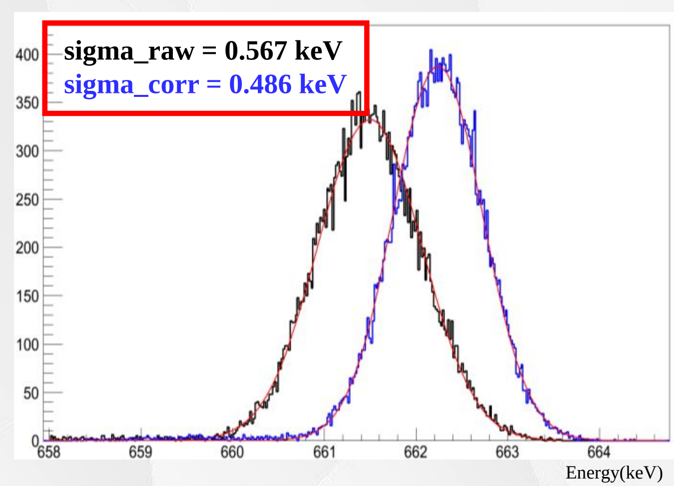
$$Q_{trapping} = Q_0 \cdot \left[1 - exp\left(-\frac{t_{drift}}{\tau}\right)\right]$$

- ✓ Distribution of t_{drift}-E provides information on τ of the carriers;
- ✓ Correct the energy to improve the energy resolution;

Cs-137 calibration data





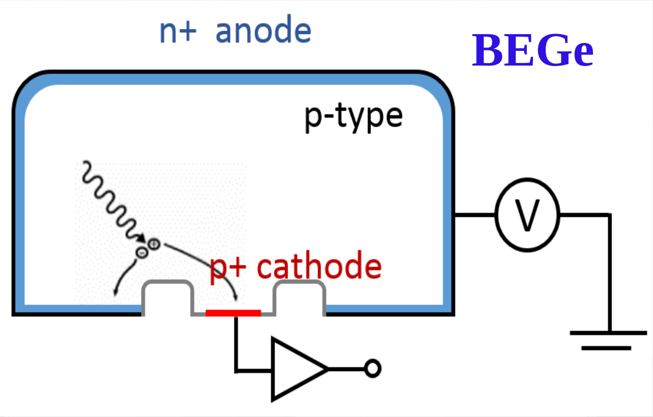


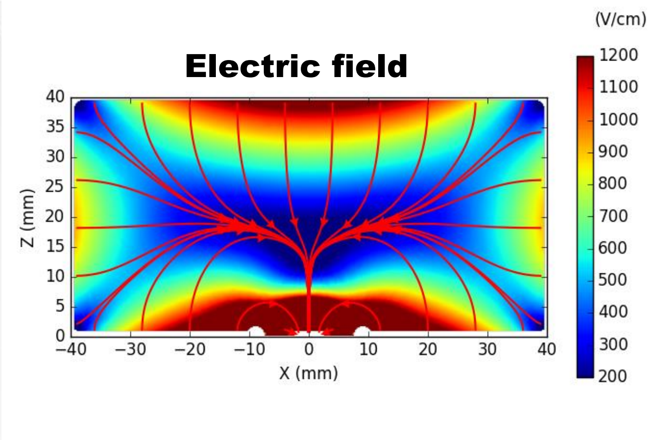
● What we learned from EFEs studies? (3)

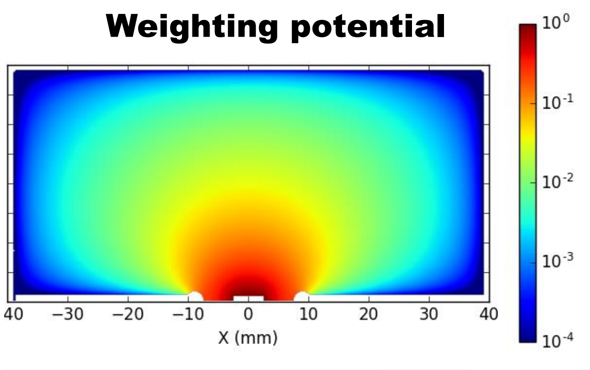
- ❖ n+ anode covers the front, lateral and most of the bottom part, which helps to shield the background events;
- ❖ Optimization of the ratio of diameter to height, short drift time length and uniform distribution results in better energy resolution.

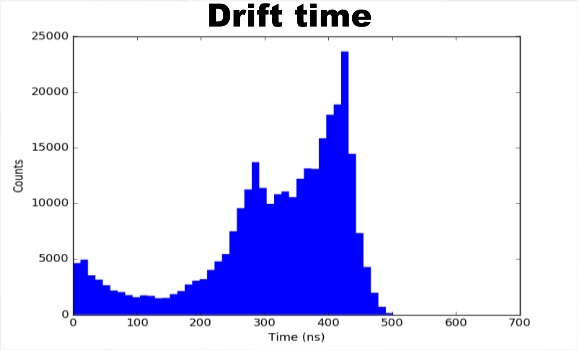
• BEGe detectors with thick window:

- ✓ a planar p-type detector with a relatively small cathode on the bottom side
- ✓ relatively small capacitance (a few pF)
- ✓ smaller EFEs region near the p+ contact









Conclusion

- ✓ Laboratory and equipment upgrades, the entire assembly processes of HPGe were proceeded well and were well-established;
- ✓ First 500g home-made PPCGe+ASIC with threshold of ~300 eV and visible ^{68}Ge X-ray obtained has been achieved;
- ✓ Bare Ge in LN_2 with stable leakage current of ~10 pA under 1K Voltage applied is accomplished;
- ✓ R&D on low background VFE, Si substrate and flexible cables are intensively studied;
- ✓ The study of EFEs can help to better understand the background origins, improve the energy resolution at high energy ranges, optimize detector design on charge collection & bkg reduction.