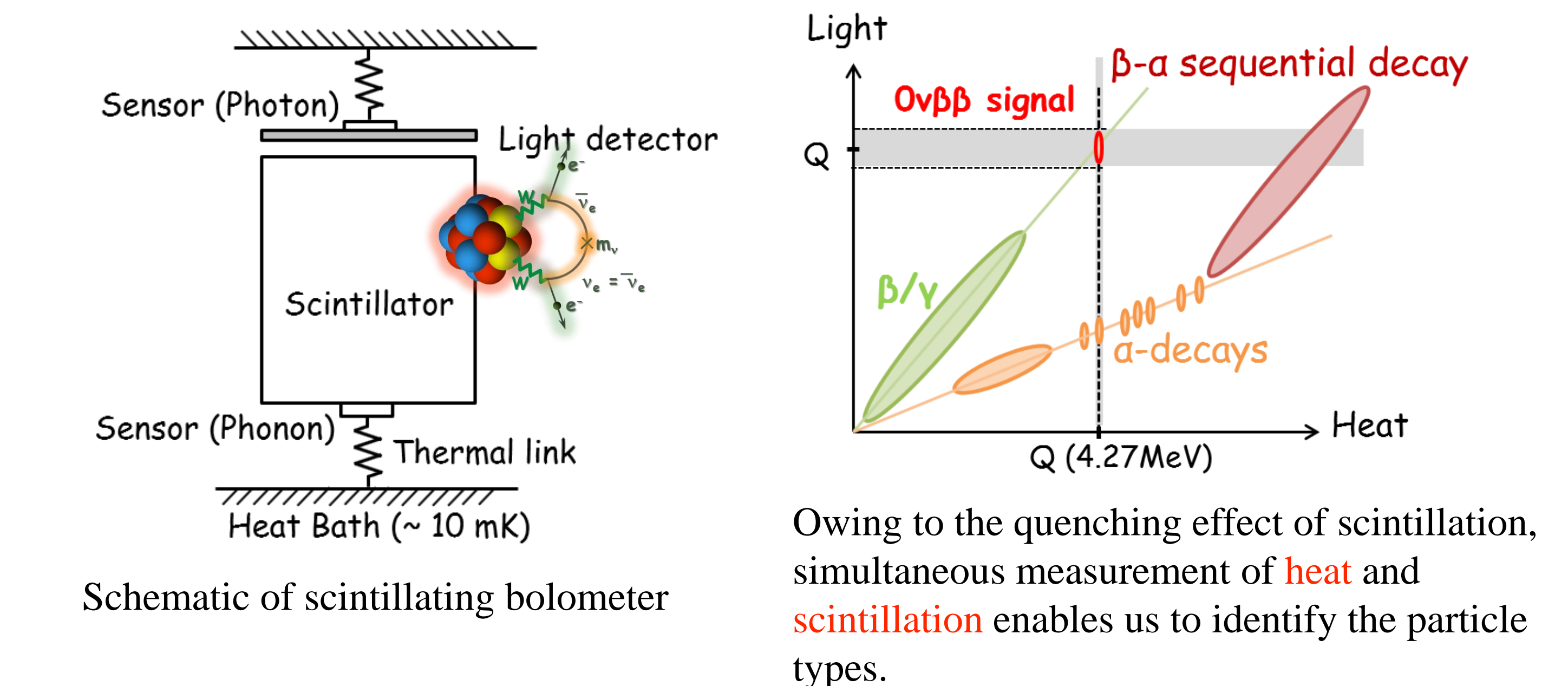


I. Motivation for Development

•The CANDLES experiment is a project to search for neutrino-less double beta decay($0\nu\beta\beta$) of ^{48}Ca with CaF_2 scintillators.

•In order to realize the high energy resolution and low background measurement in the next step, CANDLES is studying the scintillating bolometer technique.



•Some CANDLES group members began collaborative study with Korean group (part of AMoRE collaborators) since 2017 to study the low temperature properties of CaF_2 (pure) and CaF_2 (Eu).

II. Application of CaF_2 (pure) and MMC

•We firstly demonstrated simultaneous measurement of heat and scintillation by CaF_2 (pure) .
•We used contaminated CaF_2 crystal for this R&D including ~30mBq of ^{226}Ra .

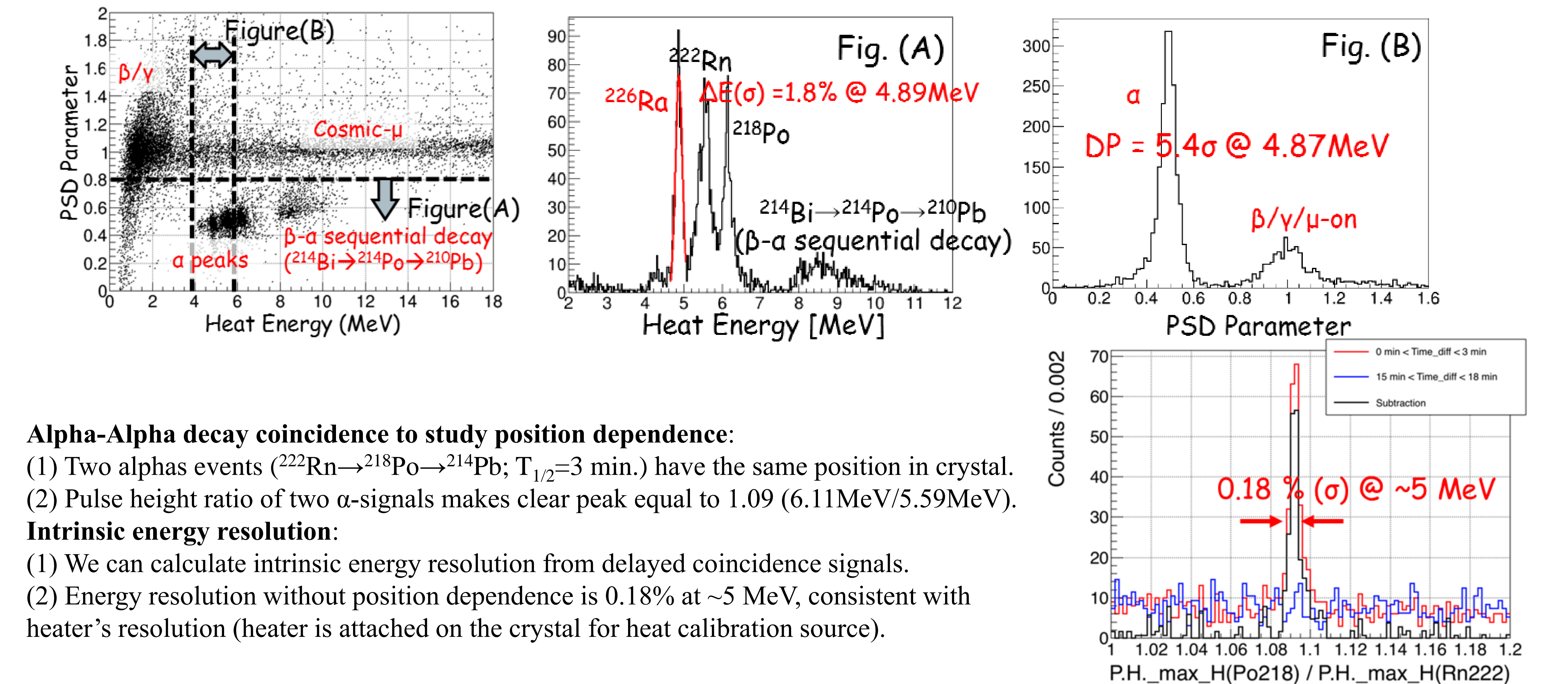
Phonon signal's energy resolution:

•Energy resolution is $1.84 \pm 0.07 \%$ at 4.87 MeV.

Performance of particle ID:

•PSD parameter are defined by using light/heat ratio and rise time of light signal.

• α events are discriminated due to the quenching effect of alpha events. (DP = 5.41 around 4.87 MeV)



Alpha-Alpha decay coincidence to study position dependence:

(1) Two alphas events ($^{222}\text{Rn} \rightarrow ^{218}\text{Po} \rightarrow ^{214}\text{Pb}$; $T_{1/2}=3$ min.) have the same position in crystal.
(2) Pulse height ratio of two α -signals makes clear peak equal to 1.09 (6.11MeV/5.59MeV).

Intrinsic energy resolution:

(1) We can calculate intrinsic energy resolution from delayed coincidence signals.

(2) Energy resolution without position dependence is 0.18% at ~5 MeV, consistent with heater's resolution (heater is attached on the crystal for heat calibration source).

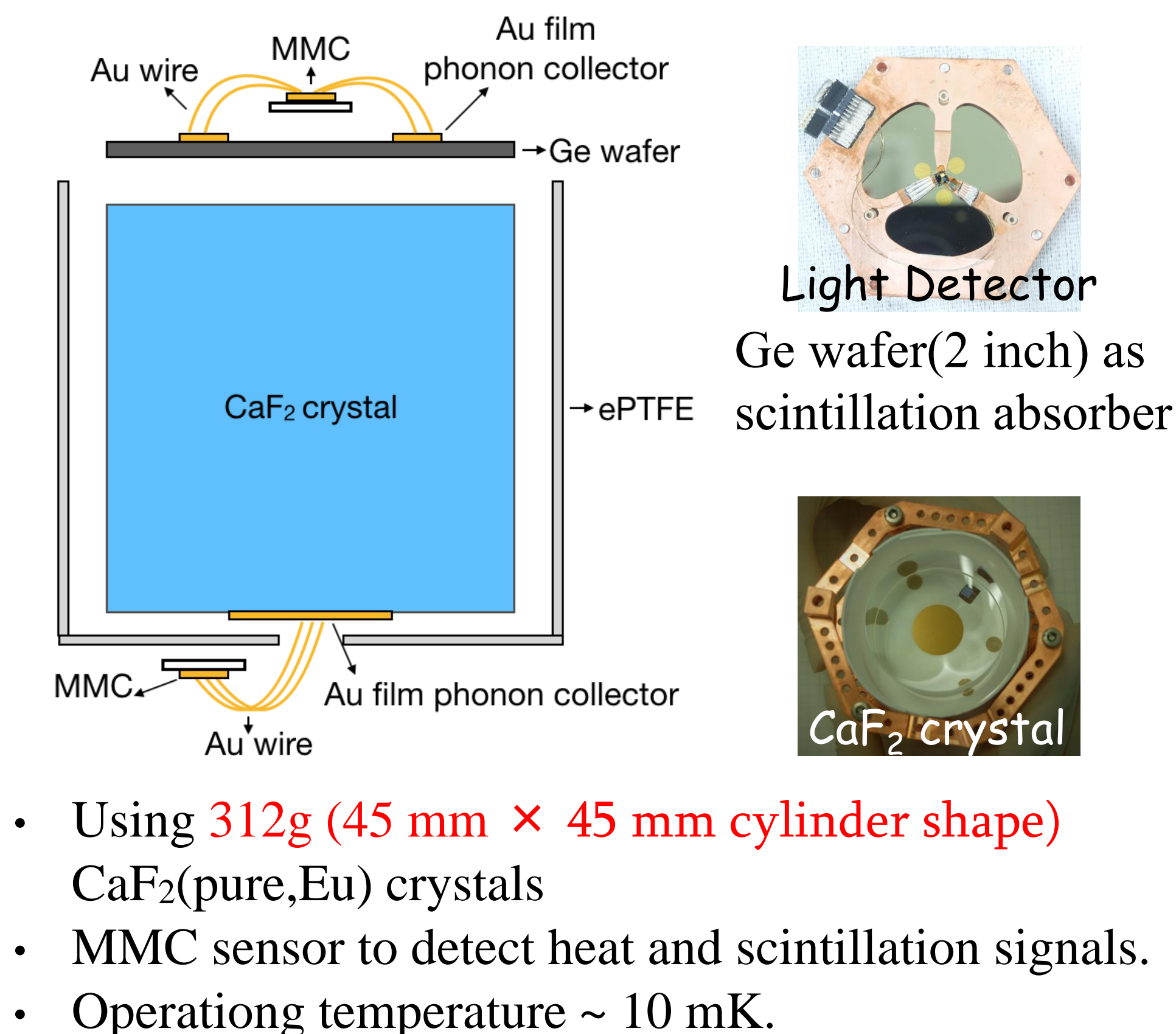
1 Department of Physics, Osaka University, Japan.

2 Research Center of Nuclear Physics, Osaka University, Japan.

3 Korea Research Institute of Standards and Science, Korea.

4 Center for Underground Physics, Institute for Basic Science, Korea.

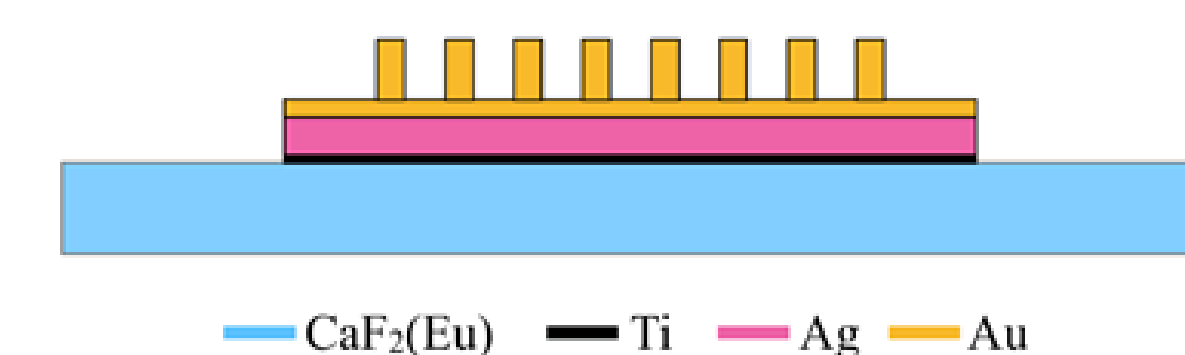
Detector Setup for CaF_2 Bolometers



III. Application of CaF_2 (Eu) and MMC

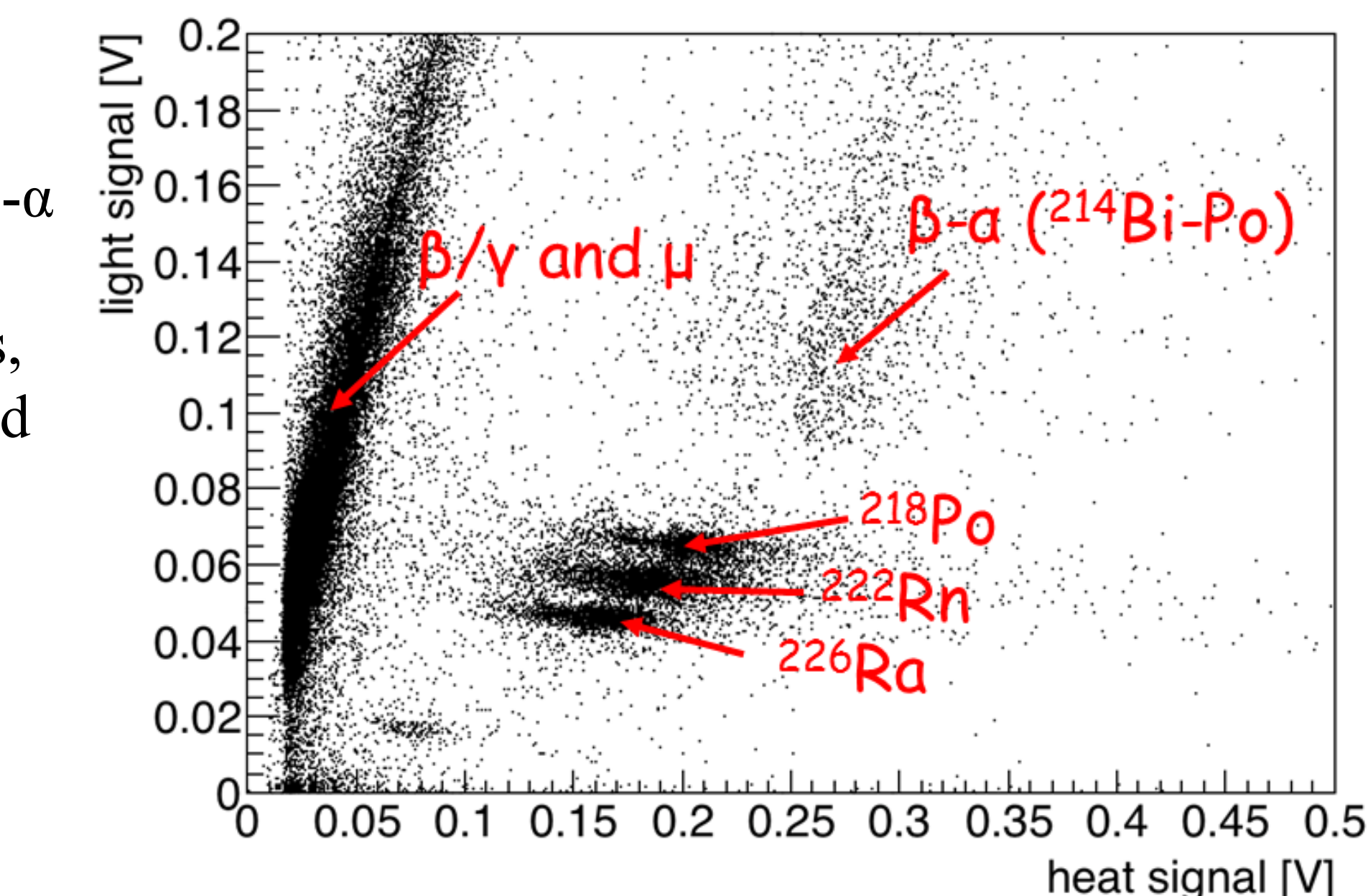
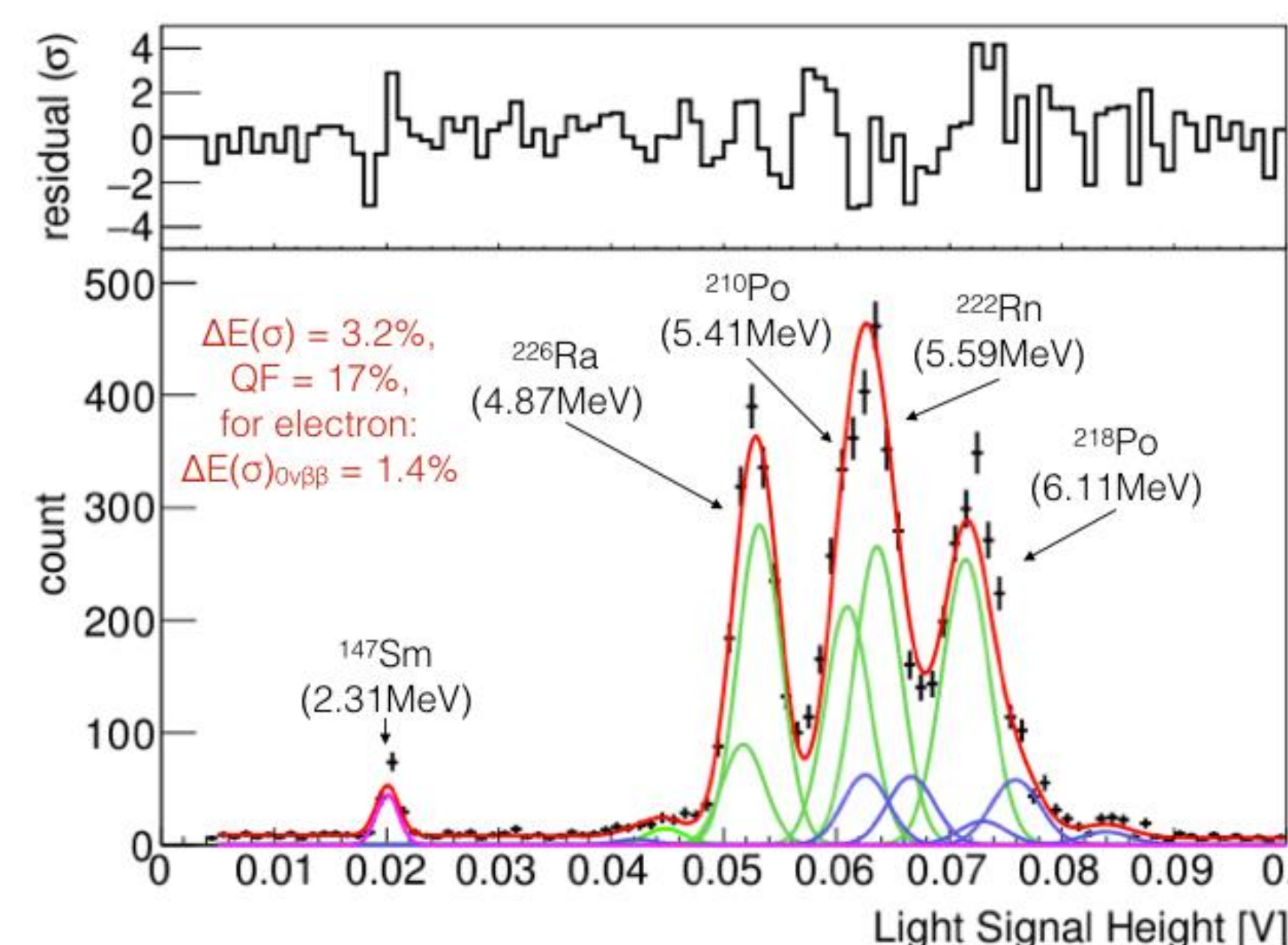
Multi layer film phonon collector:

absorb phonon faster and reflect scintillation efficiently (>99.9%).



Simultaneous measurement of heat and scintillation light:

(1) Clear observation of β/γ band, α groups and β - α sequential decay of ^{214}Po .
(2) Alpha groups are mainly from Uranium series, confirmed by decay time of ^{222}Rn - ^{218}Po - ^{214}Pb and energy.
(3) Much different from the case of CaF_2 (pure)



Good energy resolution of scintillation light signal:

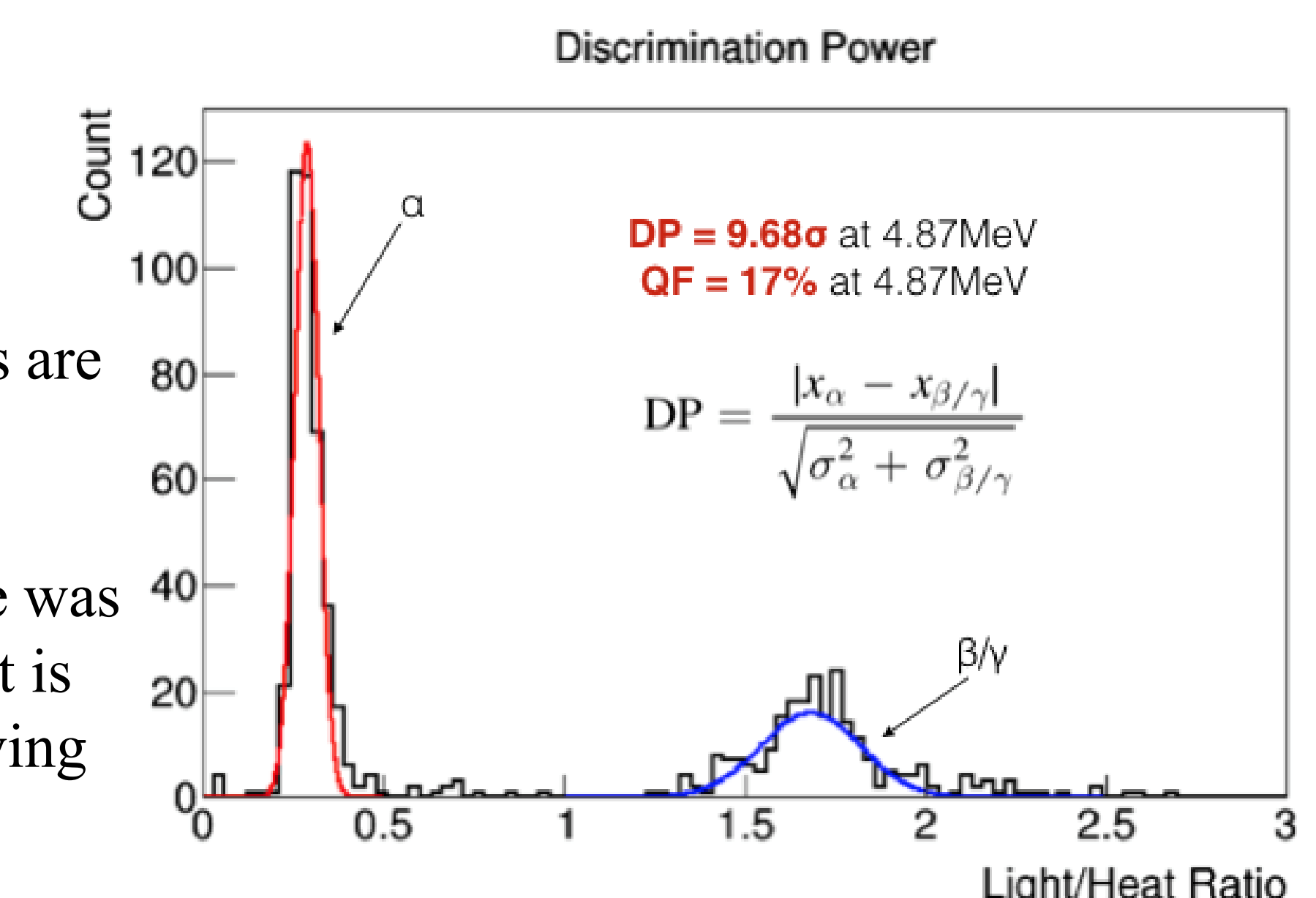
(1) Alpha groups are used to evaluate light signal's resolution.
(2) Best fit: assume background candidates to fit alpha groups.

Green: Uranium series;
Blue: Thorium series;
Pink: impurities from doping.

Discrimination power of β/γ and α :

(1) Heat signal almost without quenching.
(2) Same heat signal's beta/gamma and alpha events are separated by 10 sigma.

Instead of heat capacity, a strong position dependence was found to make energy resolution worse. We predict it is from paramagnetic ion Eu^{2+} 's spin and we are studying the spin-lattice interaction.



Light signals of α -ray events are widely distributed.

Reason(not confirmed yet)

- CaF_2 (pure) crystal has a conduction band at 8~10 eV in addition to 4~5 eV [Ref.].
- Large amount of VUV light (120 ~ 160 nm) may be emitted in the case of α -particles, having a large energy loss density. In the CaF_2 crystal, the attenuation length of VUV light is about 5 mm, so VUV is detected only in the event near the LD.

[Reference] J. Birth et al., Phys. Rev. B41.3291

