CHEP Joint International Workshop: Detector Development for High Energy Physics and Various Applications & 7th Luminescence Materials Workshop
11. Feb. 2025 – 14. Feb. 2025, Jeongseon, High-1 Resort
The Center for High Energy Physics, Kyungpook National University

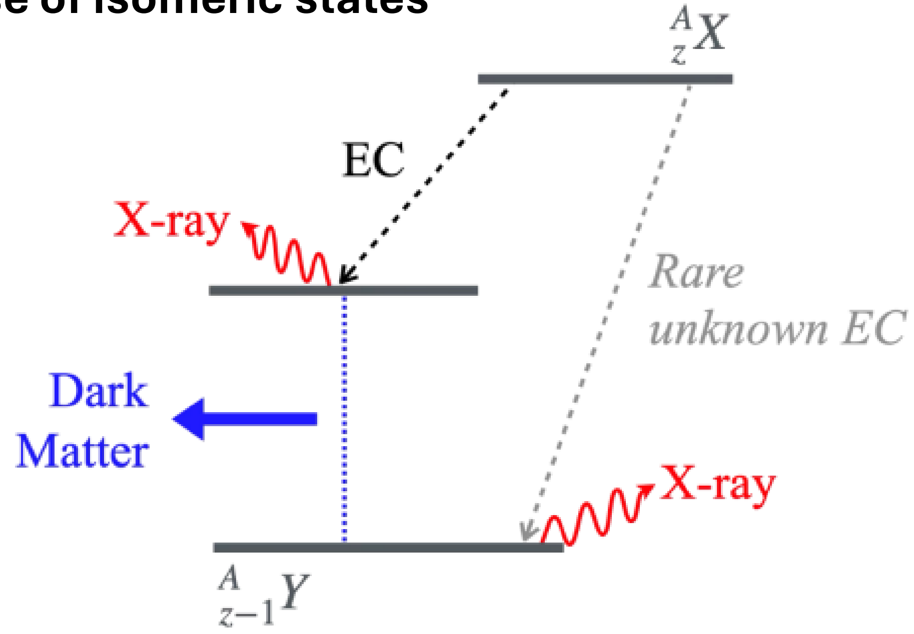
Prospects for the Global Rare Anomalous Nuclear Decay Experiment (GRANDE)

On behalf of the GRANDE Collaboration

Presented by: Nguyen Thanh Luan
The Center for High Energy Physics (CHEP), Kyungpook National University

Dark Matter Search with Radioactive sources

- ❑ Axion-like particle or dark photon searches with M1 and E1, E2 transitions of nuclear decay
- ❑ Decay process: Coupling is proportional to ε^2 not ε^4 (Accelerator, Reactor)
- ❑ Tabletop-scale experiment (much lower cost)
- ❑ Source-detector technique (radioactive doping in fast scintillator)
- ❑ Time-delayed coincidence method to eliminate backgrounds in the case of isomeric states



- ❑ Low mass only (typically << 1 MeV due to detector costs)
- ❑ Activity limitations
- ❑ 4π veto
- ❑ Need for a “zero-background” experiment (Underground lab)

GRANDE:

- ❑ Underground experiment at the Yemi Underground Lab with low-background shielding
- ❑ Radioactive source embedded in a crystal scintillator ($CeBr_3$: fast, high light yield, low background)
- ❑ 4π VETO with BGO
- ❑ Aim for a zero-background condition
- ❑ Measurement of Rare EC process, rare beta, and alpha decay with isomer gamma emission

Invisible Axion Search in ^{139}La $M1$ Transition

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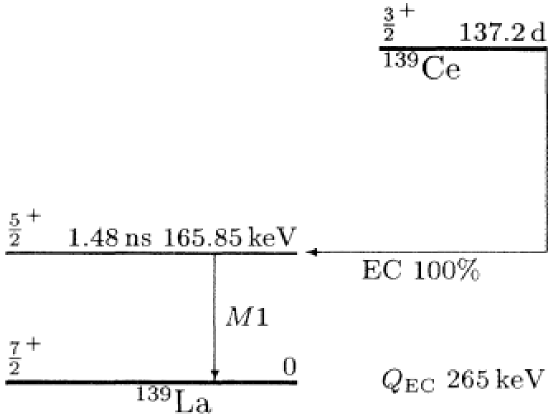
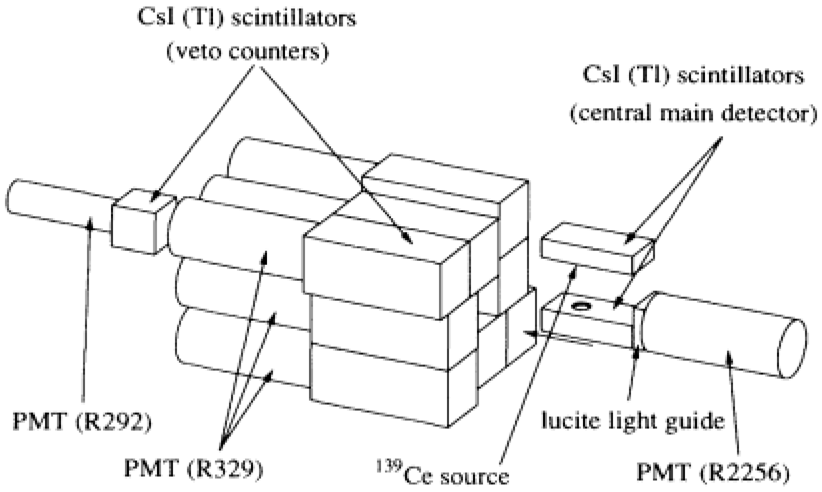
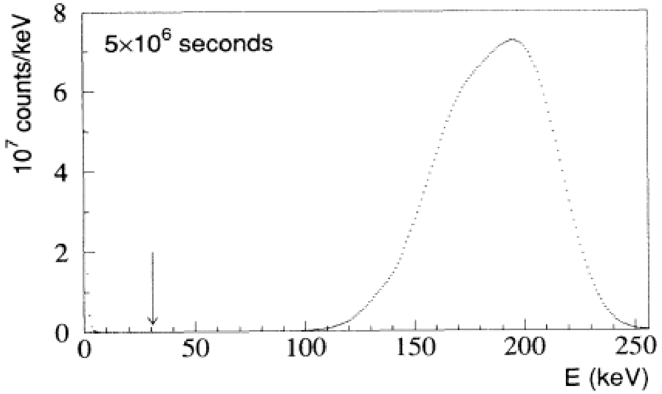
(Received 8 July 1993)

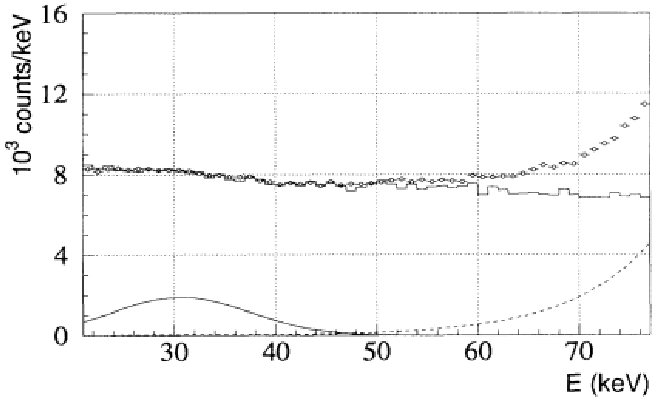
A search for invisible axions is carried out by looking for invisible $M1$ transitions in ^{139}La$(5/2^+ \rightarrow 7/2^+)$ with a transition energy of 166 keV. A limit to the branching ratio of axion emission to that of γ emission is obtained to be $\Gamma_a/\Gamma_\gamma < 1.21 \times 10^{-6}$ at the 95% confidence level. Hadronic axions heavier than 26.7 keV are excluded by this upper limit. It is also concluded that the branching ratio of the second forbidden electron capture decay of ^{139}Ce into the ground state of ^{139}La$(7/2^+)$ is less than 9.7×10^{-7} at the 95% confidence level.

PACS numbers: 14.80.Gt, 23.20.Lv, 24.80.–x, 27.60.+j









$$\Gamma_a/\Gamma_\gamma < 1.21 \times 10^{-6} \text{ at the 95\%}$$

GRANDE 1st brick!

Constraints for Rare Electron-Capture Decays Mimicking Detection of Dark-Matter Particles in Nuclear Transitions

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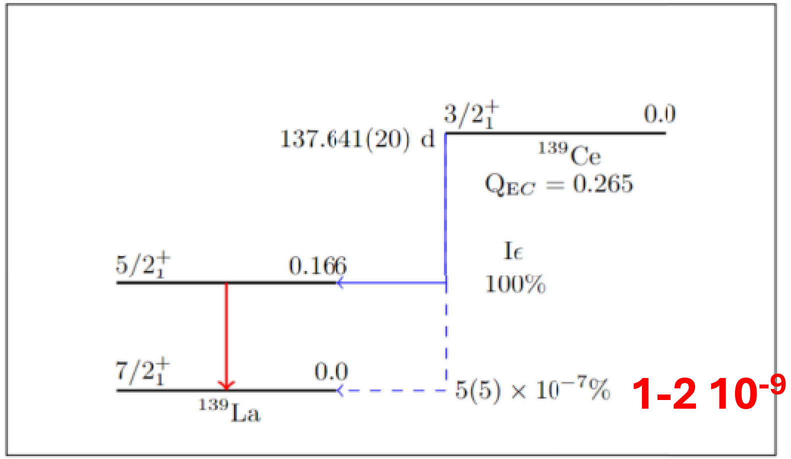
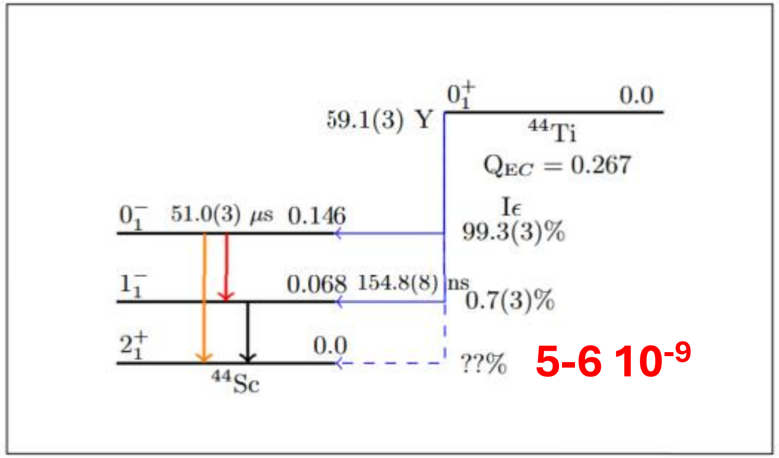
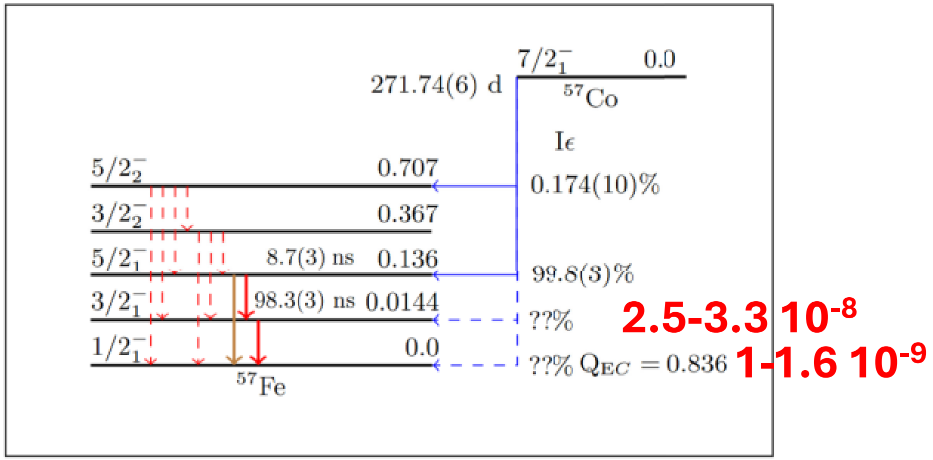
(Received 30 May 2024; revised 24 September 2024; accepted 5 November 2024; published 2 December 2024)

We give for the first time theoretical estimates of unknown rare electron-capture (EC) decay branchings of ^{44}Ti, ^{57}Co, and ^{139}Ce, relevant for searches of (exotic) dark-matter particles. The nuclear-structure calculations have been done exploiting the nuclear shell model with well-established Hamiltonians and an advanced theory of β decay. In the absence of experimental measurements of these rare branches, these estimates are of utmost importance for terrestrial searches of dark-matter particles, such as axionic dark matter in the form of axionlike particles, anapole dark matter, and dark photons in nuclear transitions. Predictions are made for EC-decay rates of second-forbidden unique and second-forbidden nonunique EC transitions that can potentially mimic dark-matter-particle detection in dedicated underground experiments designed to observe the absence of the corresponding nuclear electromagnetic transitions.

DOI: 10.1103/PhysRevLett.133.232501








PHYSICAL REVIEW LETTERS 133, 232501 (2024)

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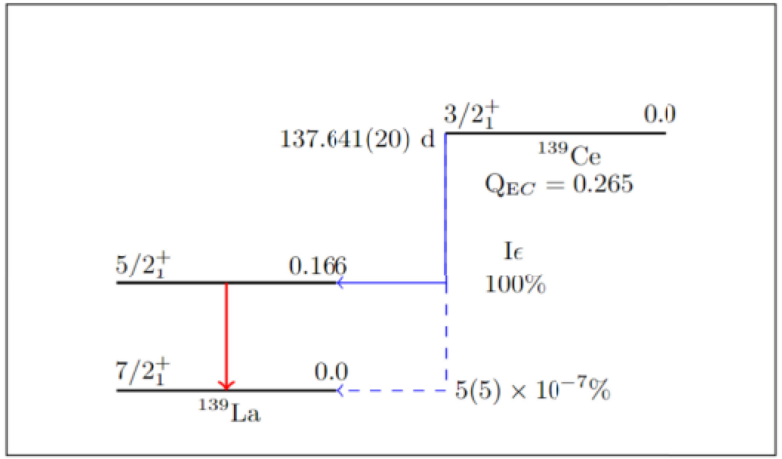
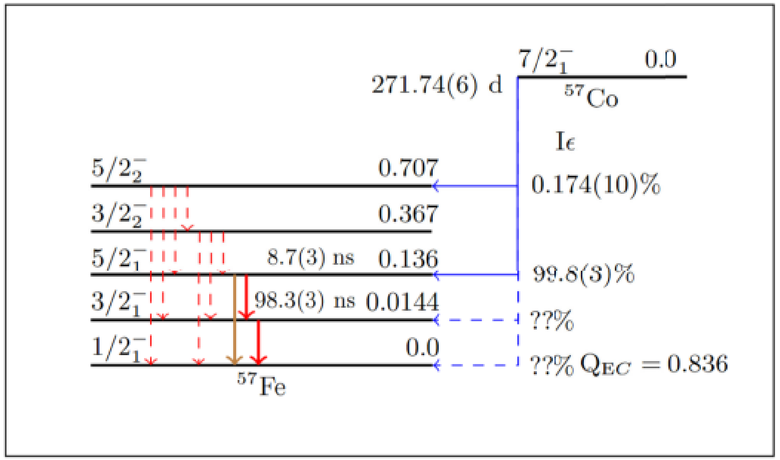
Major possibilities for dark matter particle searches through EC transitions

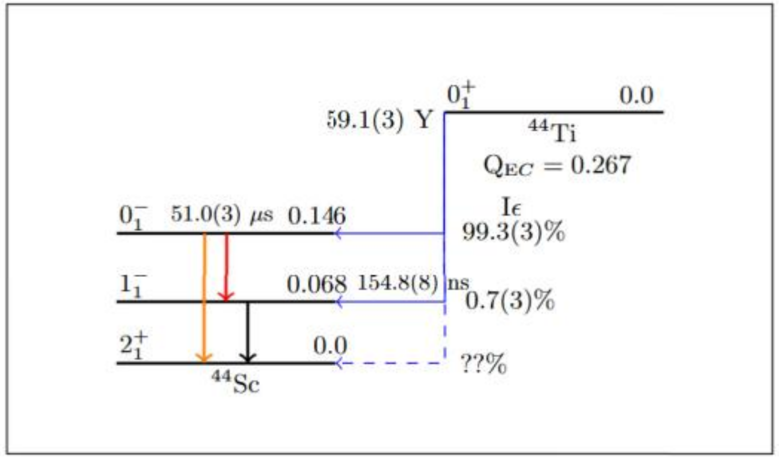


#1
M1 $5/2^+_1 \rightarrow 7/2^+_1$: 165.86 keV
K_α X-ray: ~33 keV



#1
M1 $5/2^-_1 \rightarrow 3/2^-_1$: 122.06 keV
M1 $3/2^-_1 \rightarrow 1/2^-_1$: 14.4 keV
K X-ray: ~6 keV

#2
E2 $5/2^-_1 \rightarrow 1/2^-_1$: 136.47 keV
K X-ray: ~6 keV



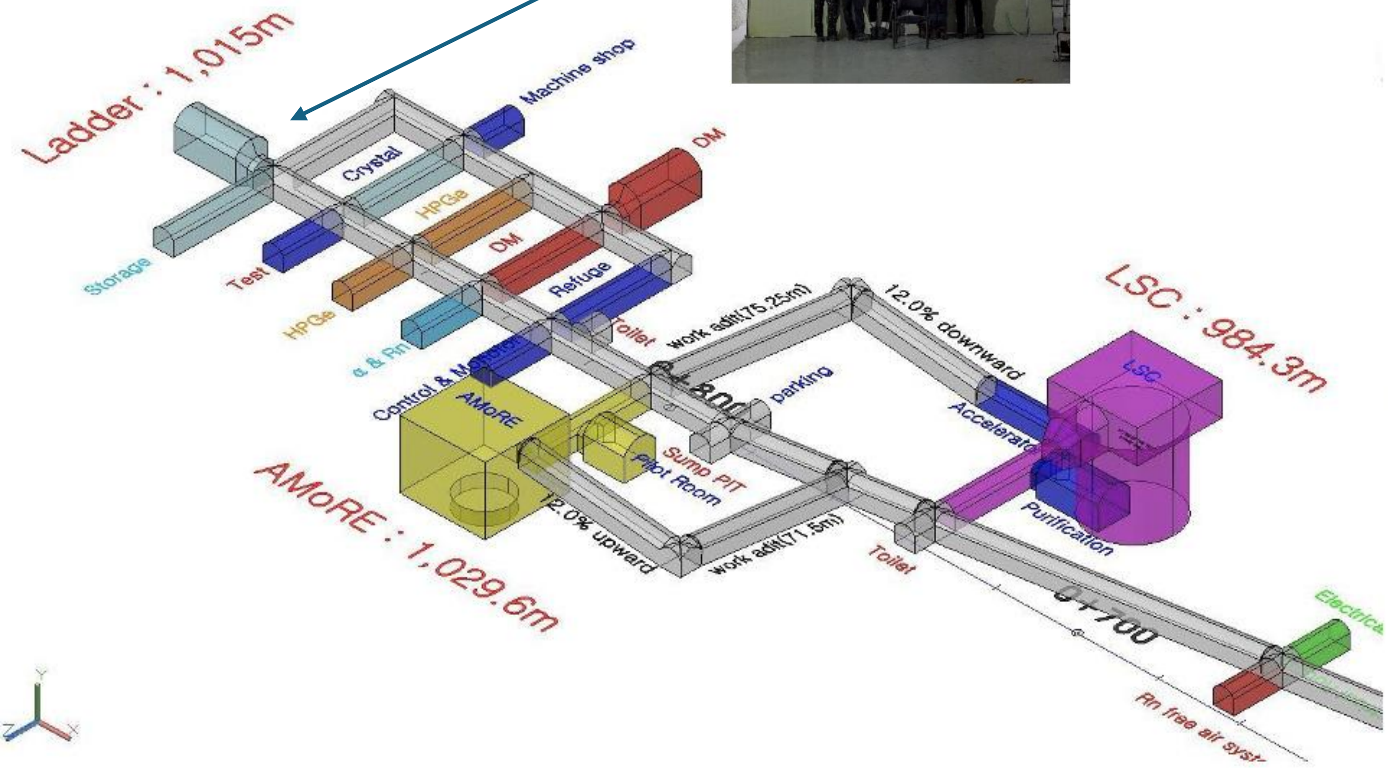
#1
M1 $0^-_1 \rightarrow 1^-_1$: 78.33 keV
E1 $1^-_1 \rightarrow 2^+_1$: 67.87 keV
K_α X-ray: 4 keV

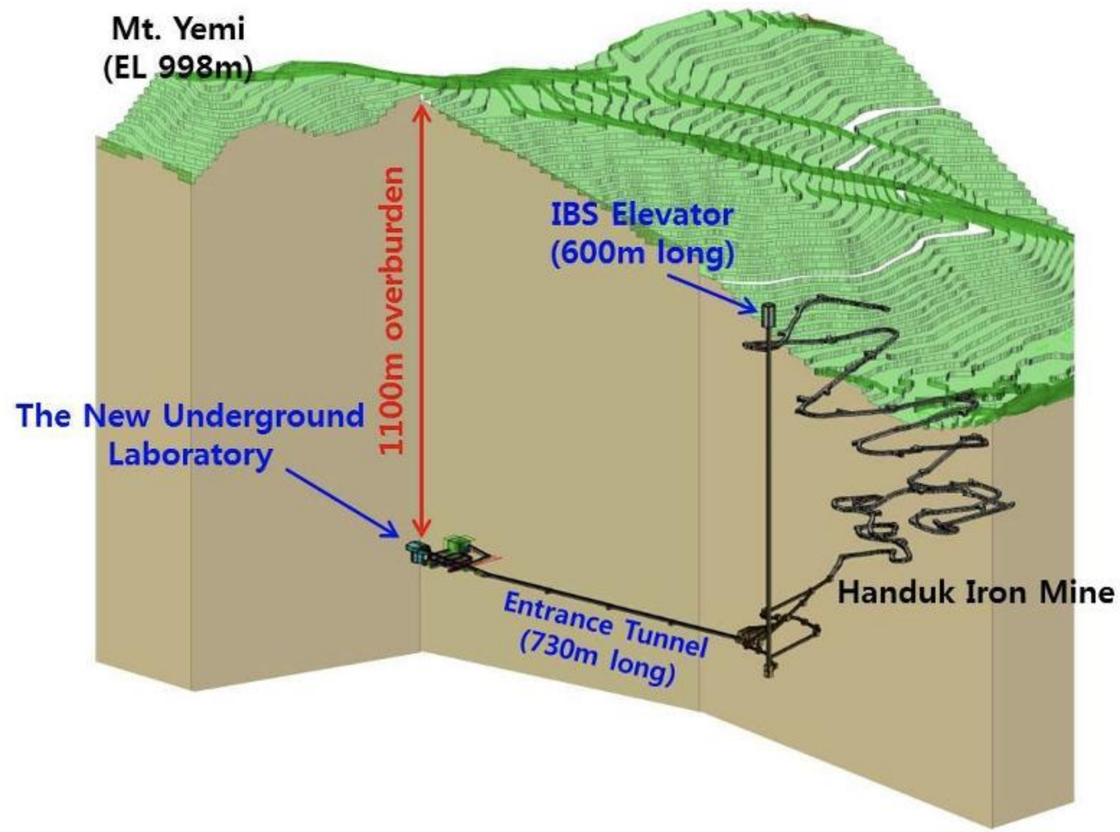
#2
M2 $0^-_1 \rightarrow 2^+_1$: 146.212 keV
K_α X-ray: 4 keV

Yemi Underground Lab (Center for Underground Physics, IBS)

GRANDE 2nd brick!

GRANDE ROOM



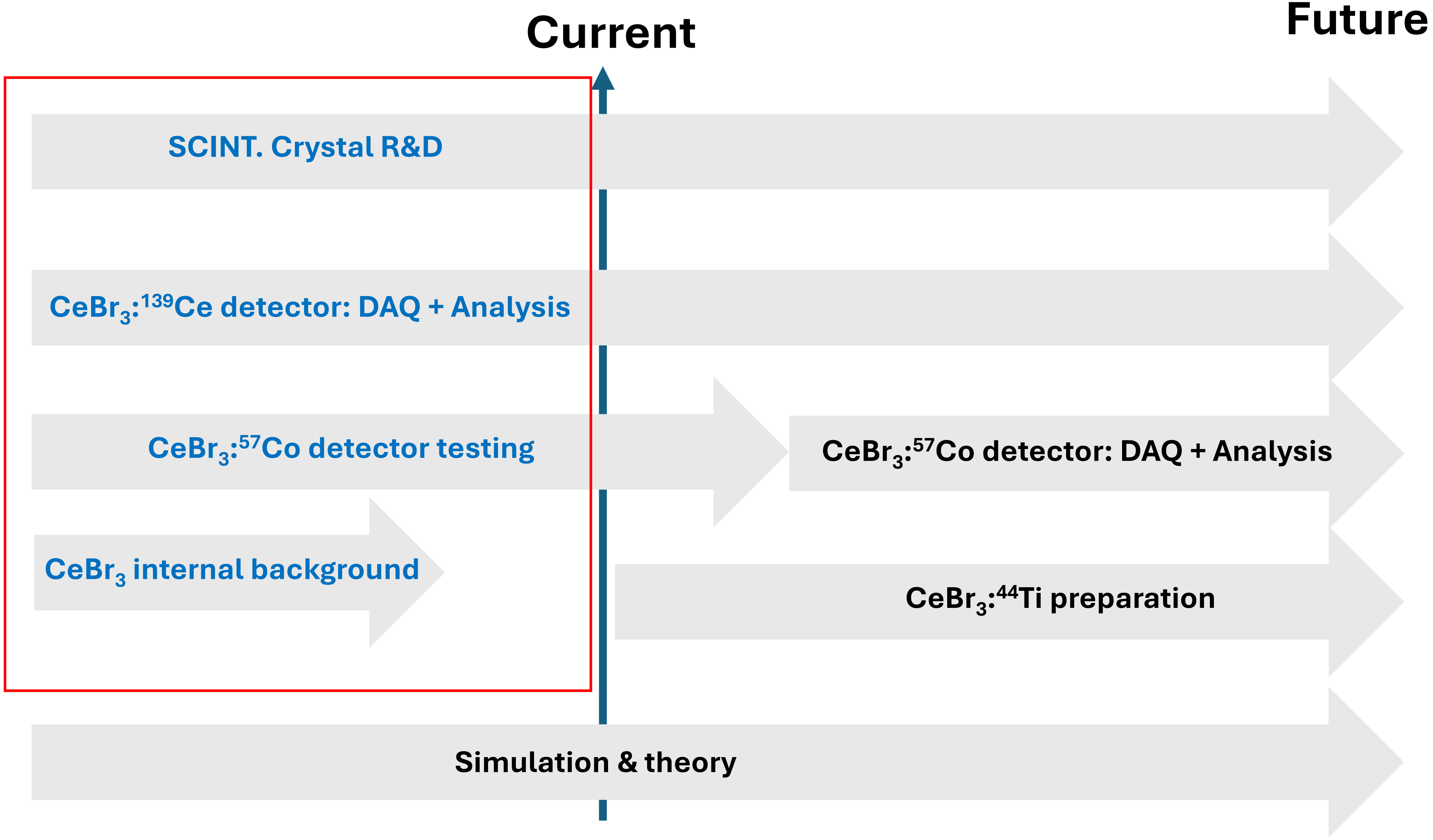


GRANDE 3rd brick!

The GRANDE Collaboration

- Kyungpook National University, KOREA
- Center for Underground Physics, KOREA
- University of Jyväskylä, Finland
- University of the Aegean, Greece
- Nakhon Pathom Rajabhat University, Thailand
- University of Chiangmai, Thailand

GRANDE Track



Source-as-Detector Experiment

Table-top experiment

$CeBr_3$ advantages : Fast decay time, high light yield, good energy resolution

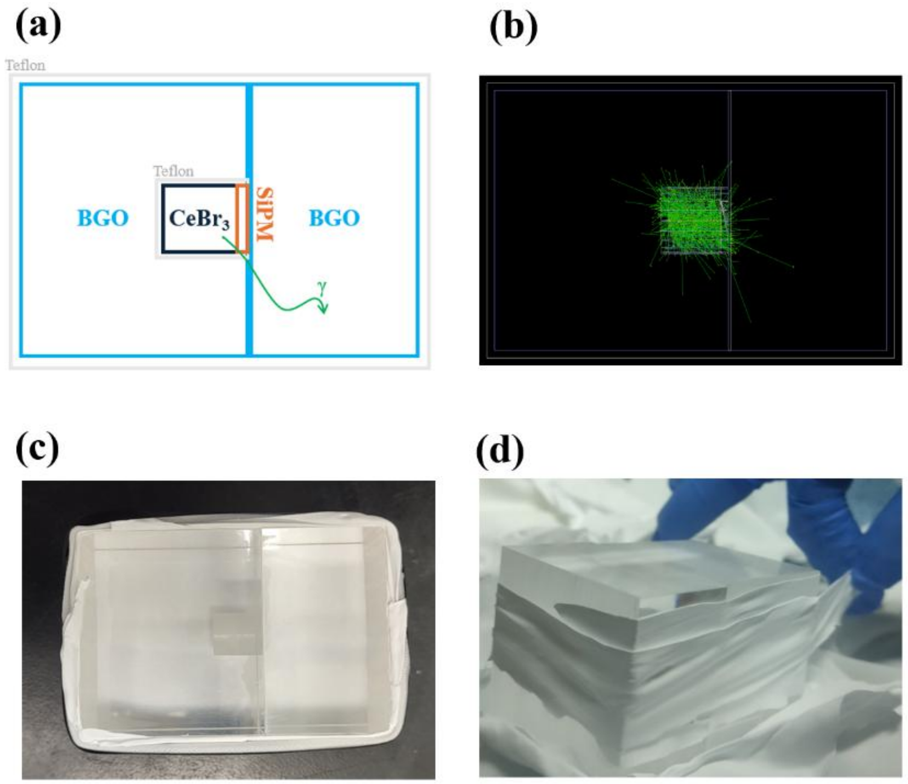
Disadvantages : very hygroscopic, internal background

$CeBr_3$:^{139}Ce

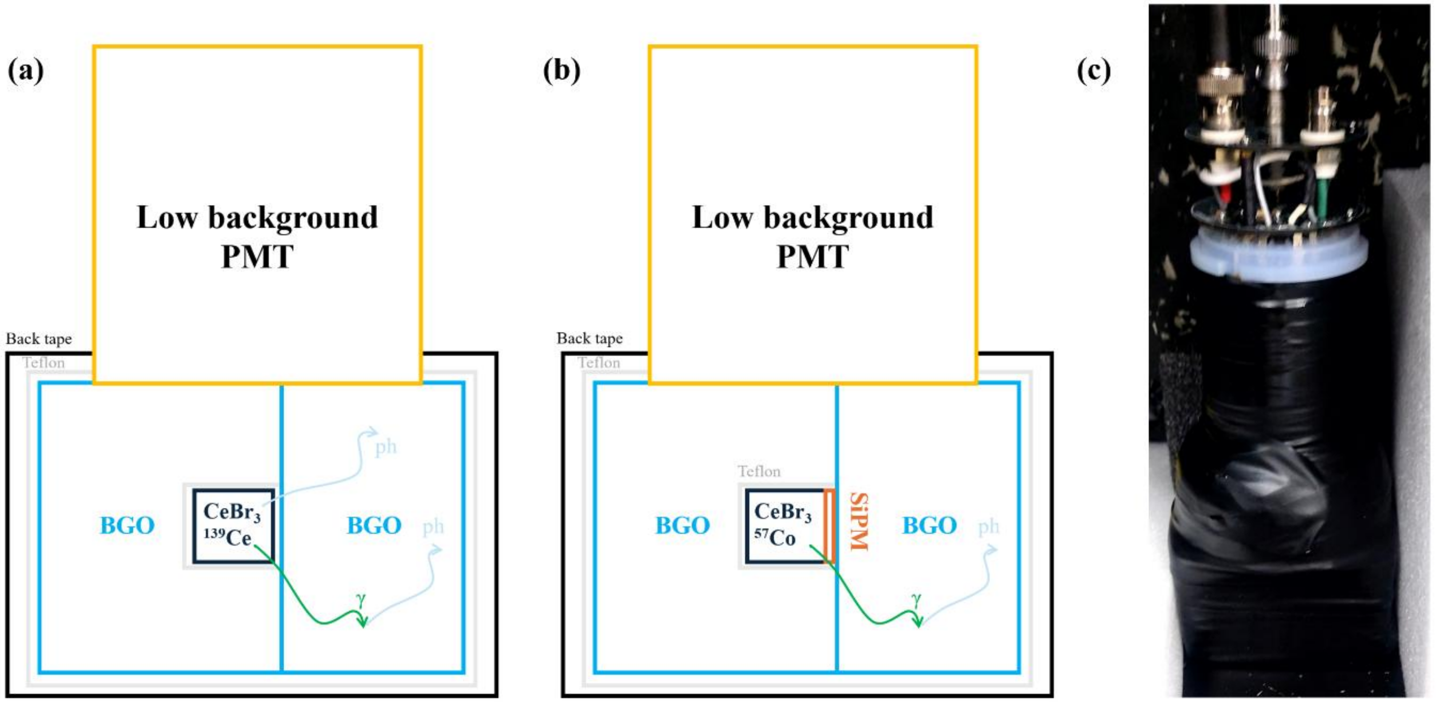
$CeBr_3$:^{57}Co

$CeBr_3$:^{44}Ti

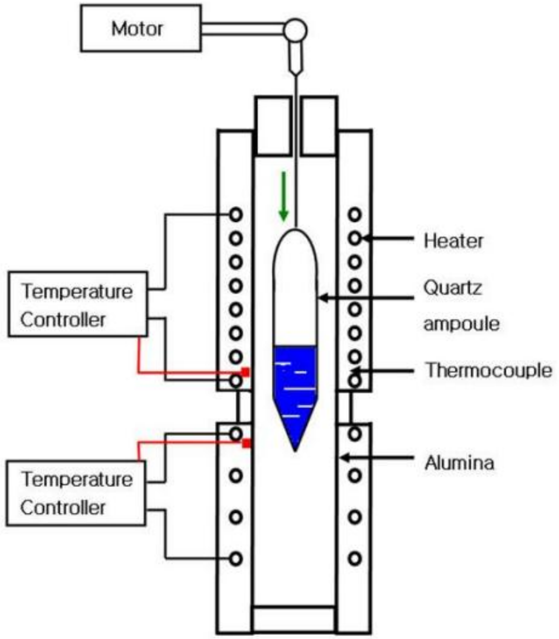
BGO veto

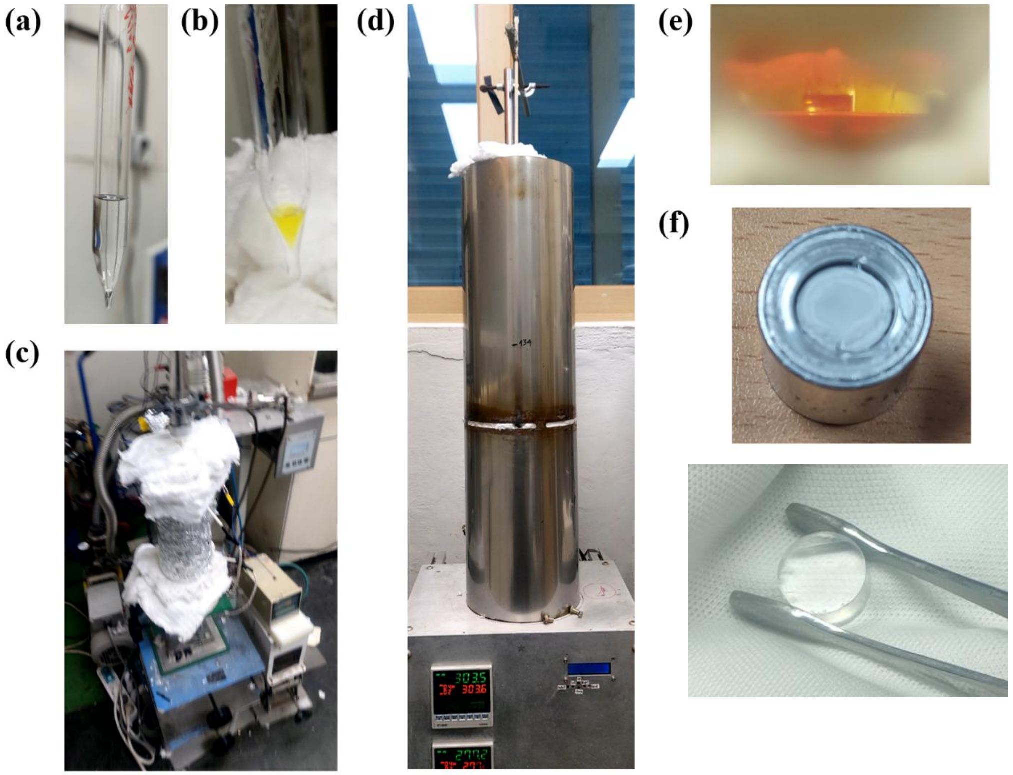


Detector schematic

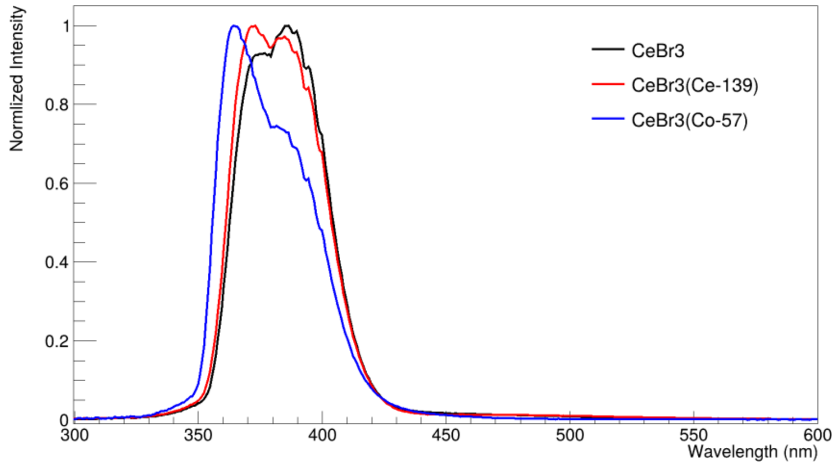


Crystal growth using the Bridgman method





X-ray luminescence

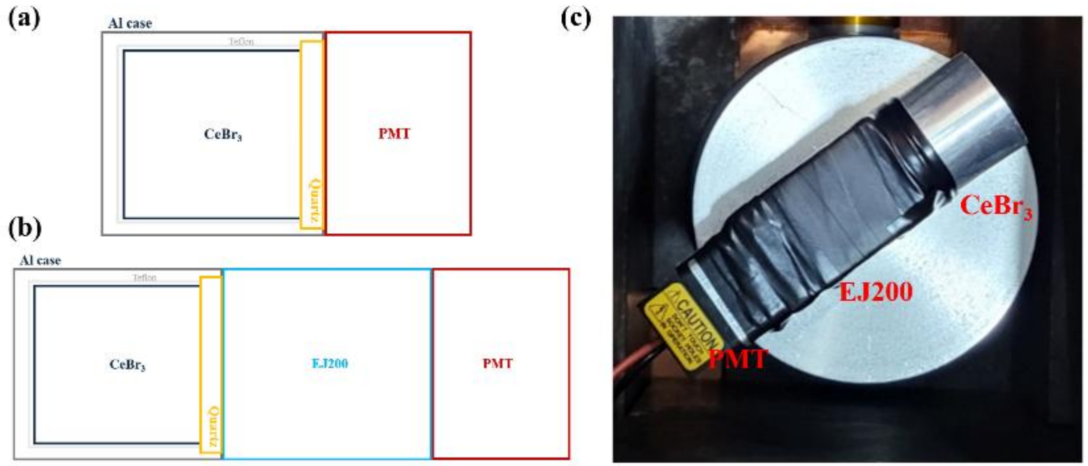


Targets:

- ❑ Crack-free
- ❑ High radioactive
- ❑ Low internal background
- ❑ High light yield
- ❑ Size handle

Pure $CeBr_3$ internal background @ Yemi

Suitable for double beta decay search



PHYSICAL REVIEW C **105**, 045801 (2022)

Constraints on partial half-lives of ^{136}Ce and ^{138}Ce double electron captures

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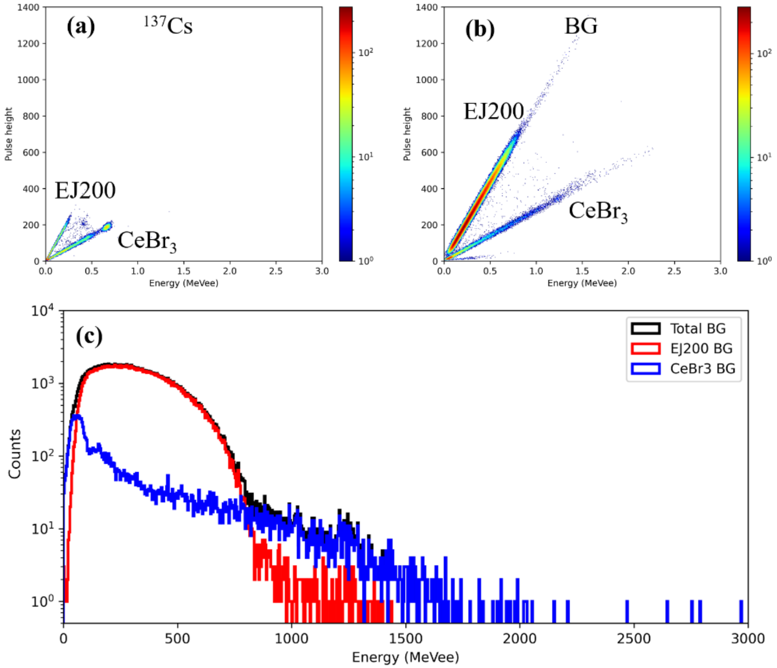
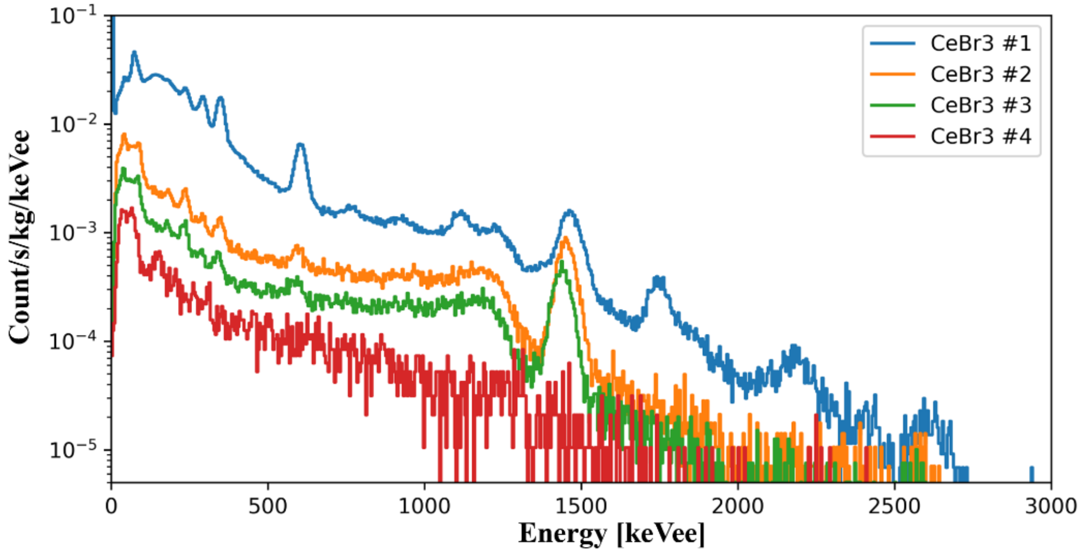
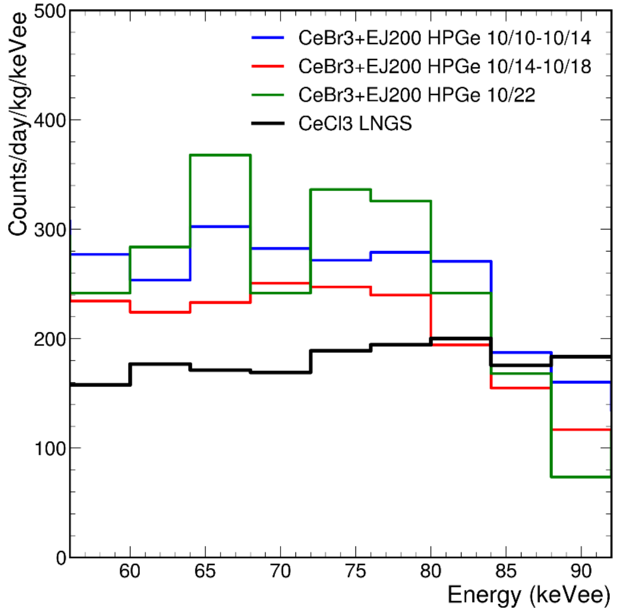
The γ-ray emissions from a radiopure cerium-bromide crystal with a mass of 4381 g were measured for a total of 497.4 d by means of high-resolution γ-ray spectrometry in the HADES underground laboratory at a depth of 500 m.w.e. A search for $0/2\nu\epsilon\epsilon$ and $0/2\nu\epsilon\beta^+$ double beta decay transitions of ^{136}Ce and ^{138}Ce was performed using Bayesian analysis techniques. No signals were observed for a total of 35 investigated decay modes. 90% credibility limits were set in the order of 10^{18}–10^{19} yr. Existing constraints from a cerium oxide powder measurement were tested with a different cerium compound and half-life limits could be improved for most of the decay modes. The most likely accessible decay mode of the ^{136}Ce $2\nu\epsilon\epsilon$ transition into the 0_1^+ state of ^{136}Ba results in a new best 90% credibility limit of 5.0×10^{18} yr.

DOI: 10.1103/PhysRevC.105.045801

Good background condition @ Yemi



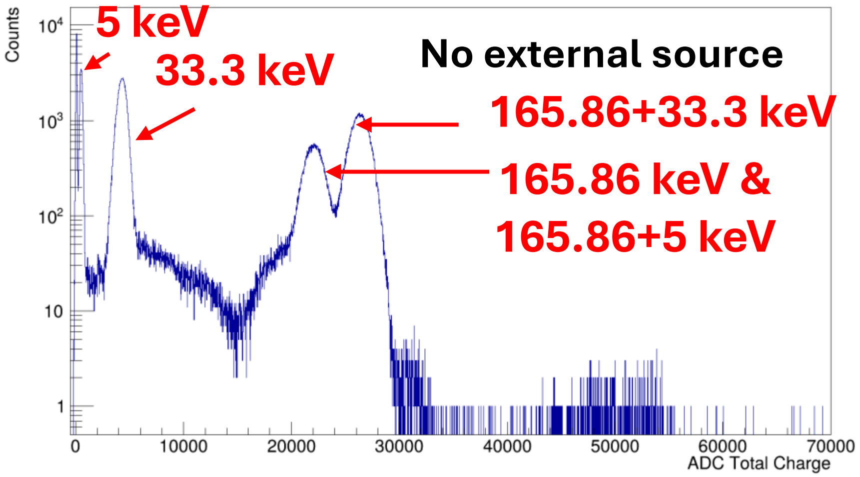


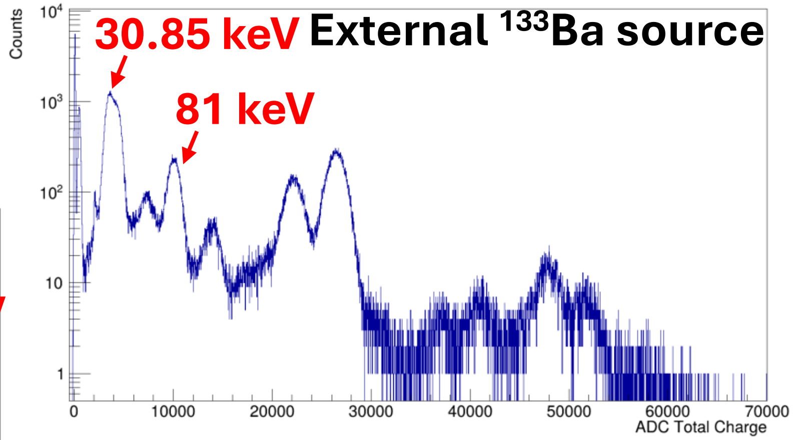


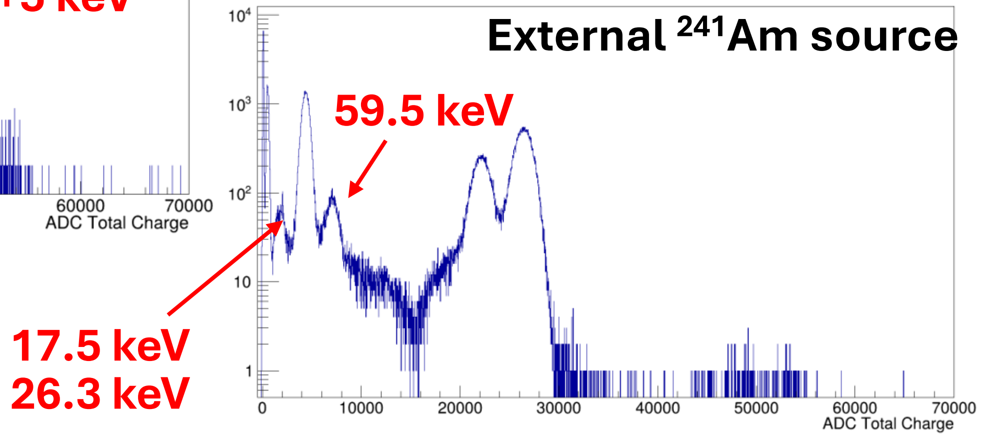
With help of E.K. Lee (IBS)

The Gran Sasso National Laboratory (LNGS) of the INFN (Italy)
P Belli et al., J. Phys. G: Nucl. Part. Phys. 38 (2011) 015103 (15pp)

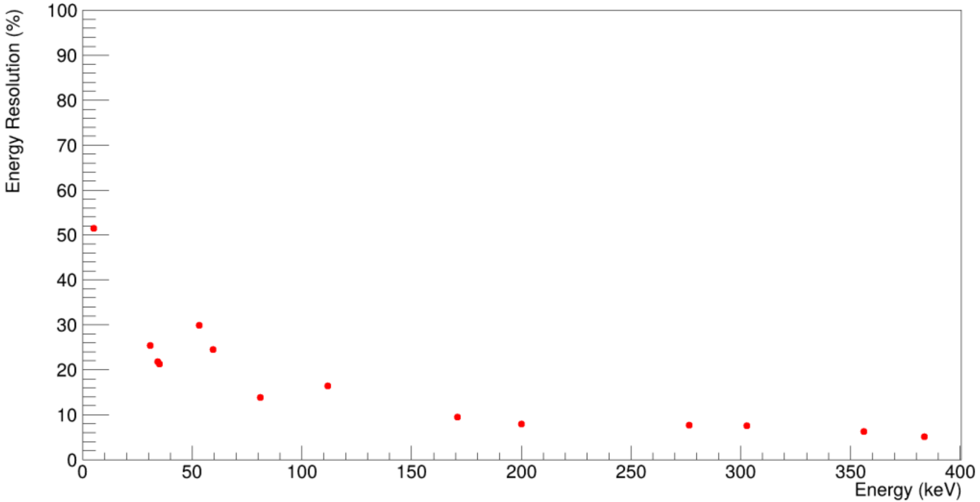
$CeBr_3$:^{139}Ce

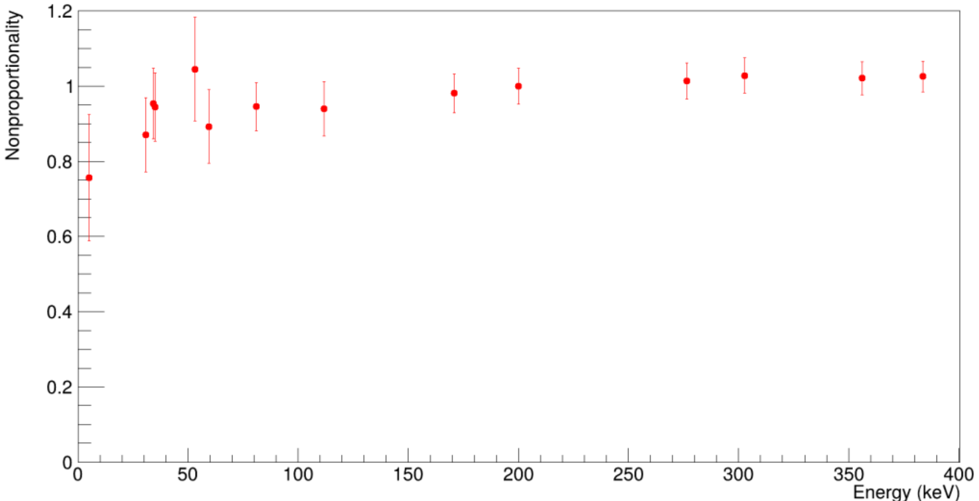




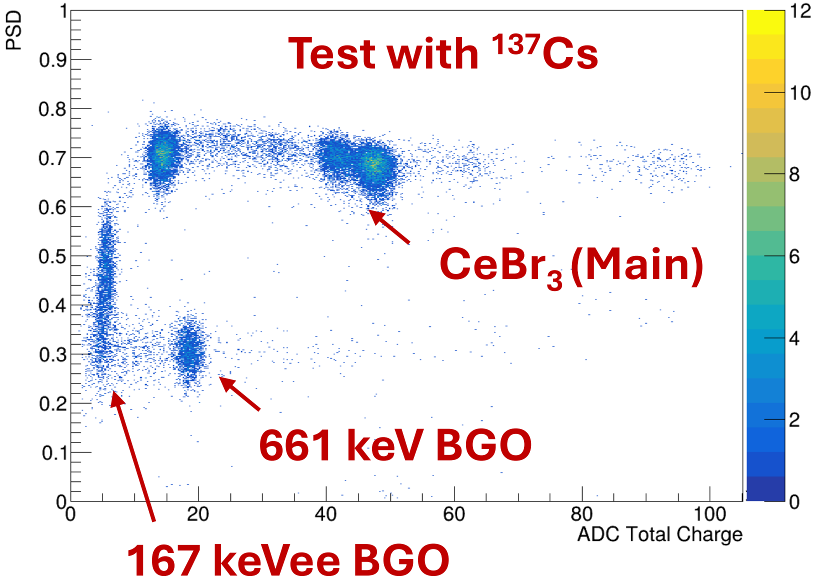


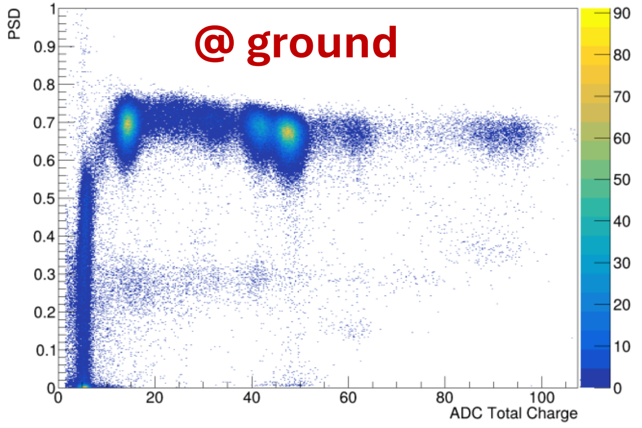
Isotope	Energy (keV)
^{139}Ce	5
	34.21504
	170.86
	200.075
^{241}Am	59.5
^{133}Ba	30.85
	35.1
	53.15
	81
	111.85
	276.4
	302.85
	356.02
	383.85

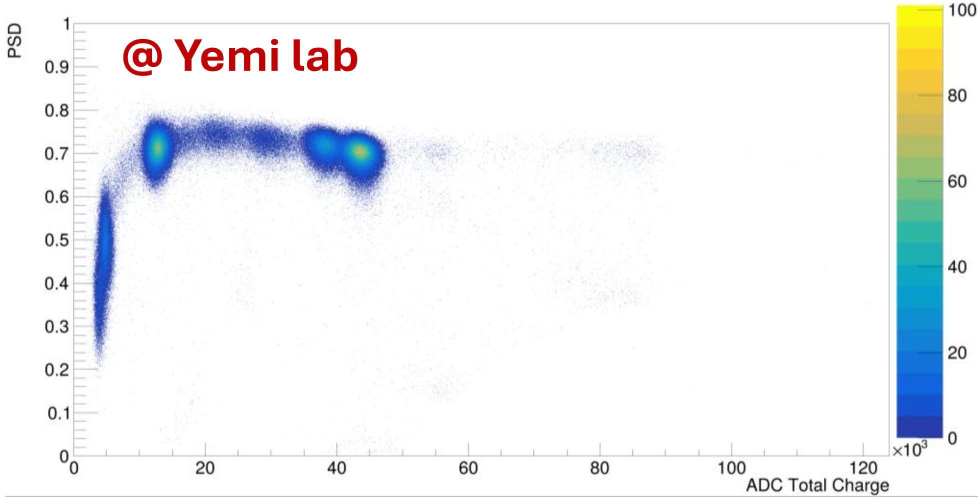




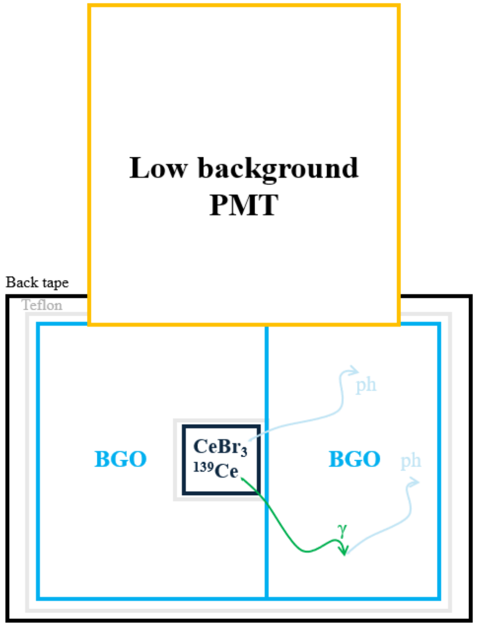
$CeBr_3$:^{139}Ce + BGO veto

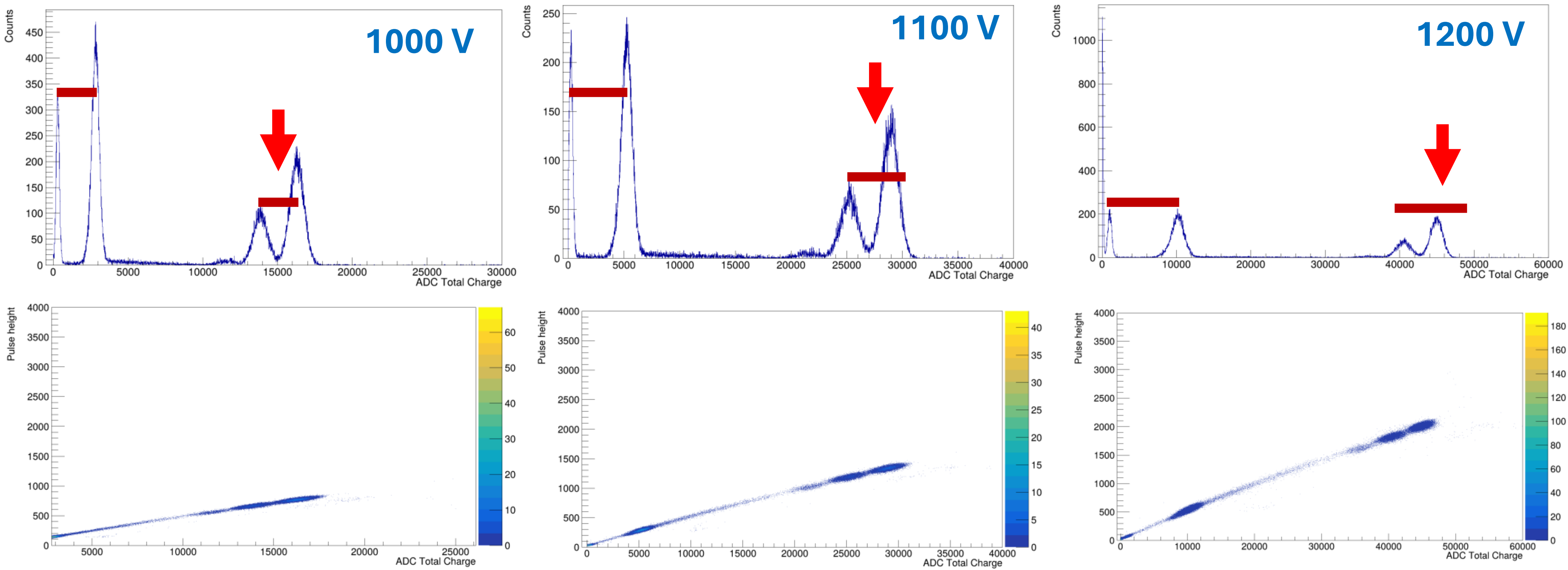






R12669 – SEL (Hamamatsu Photonics) low BG PMT gain effect





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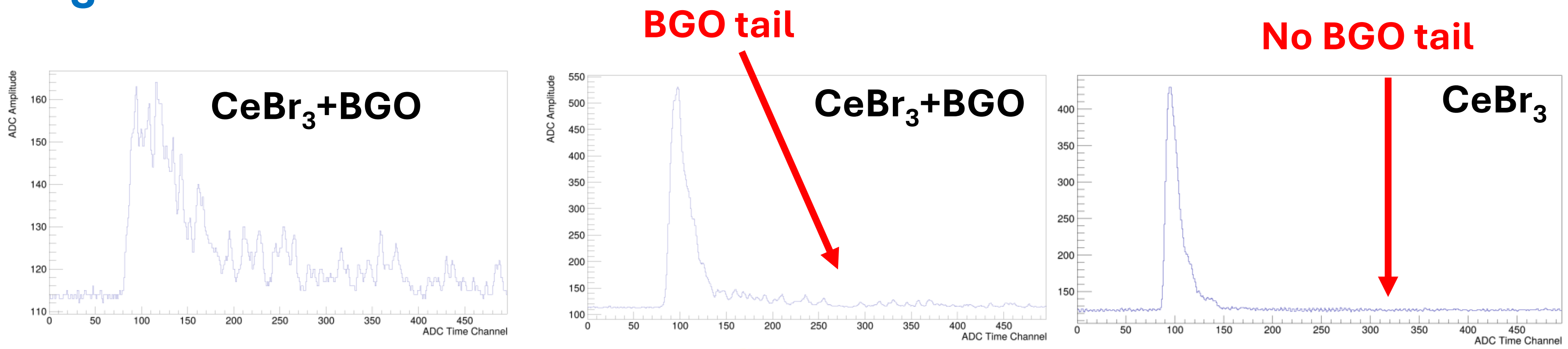
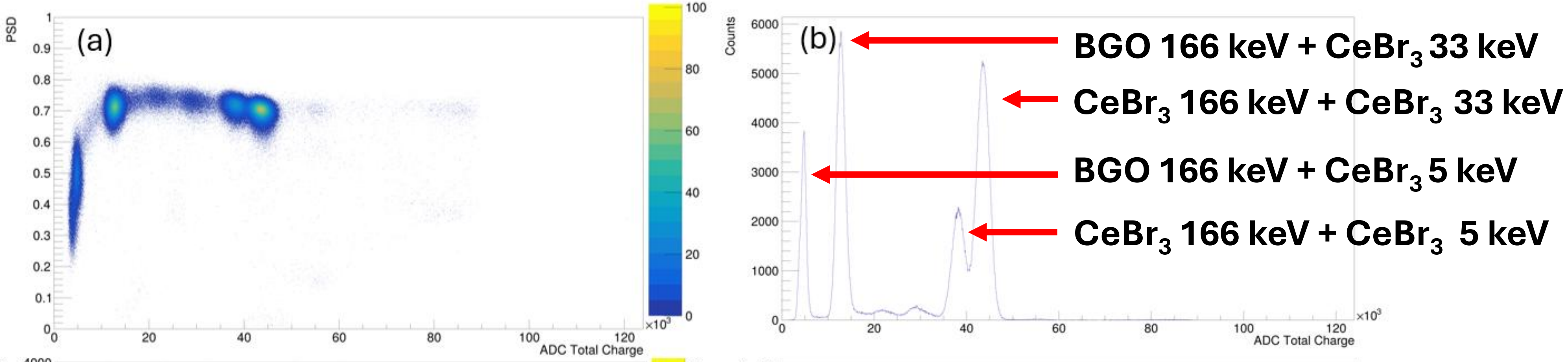
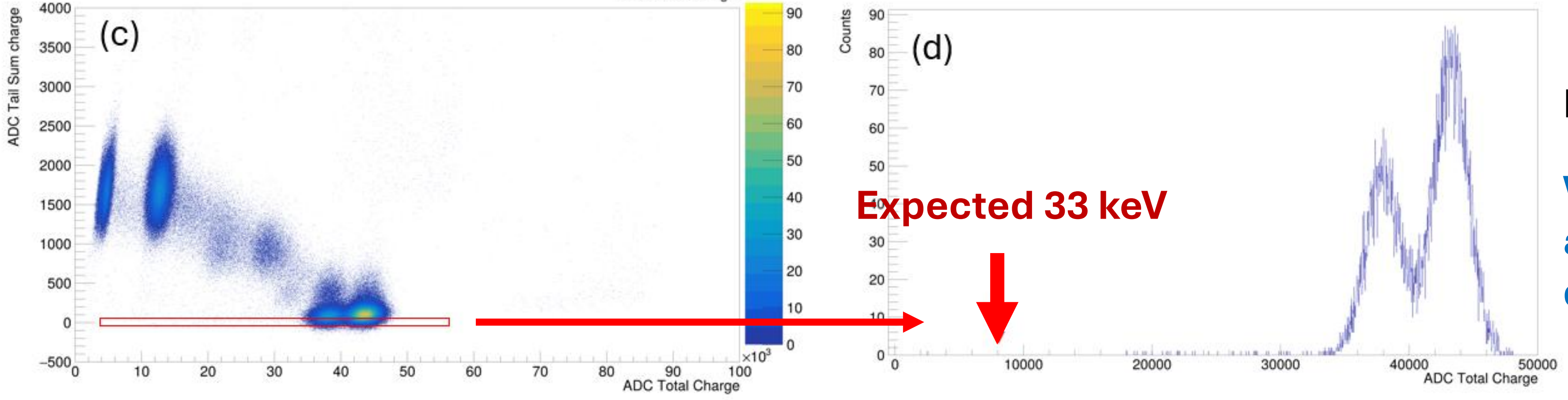


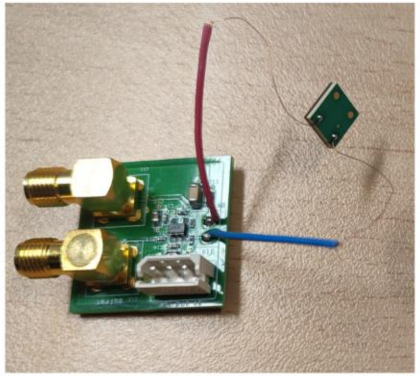


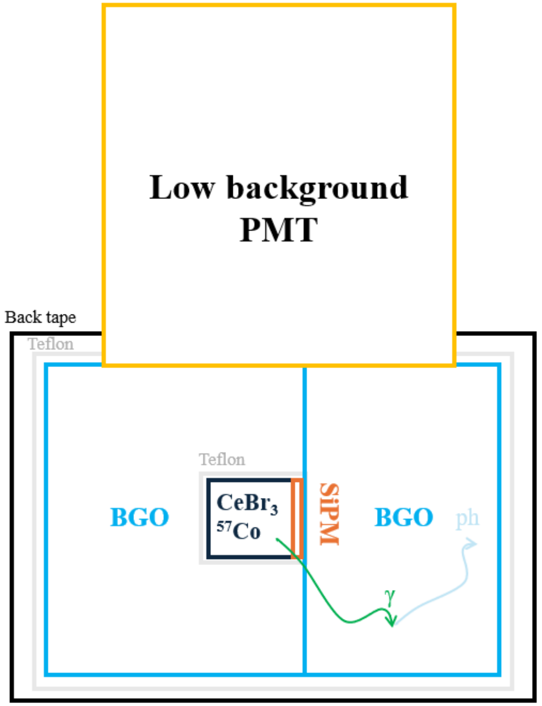


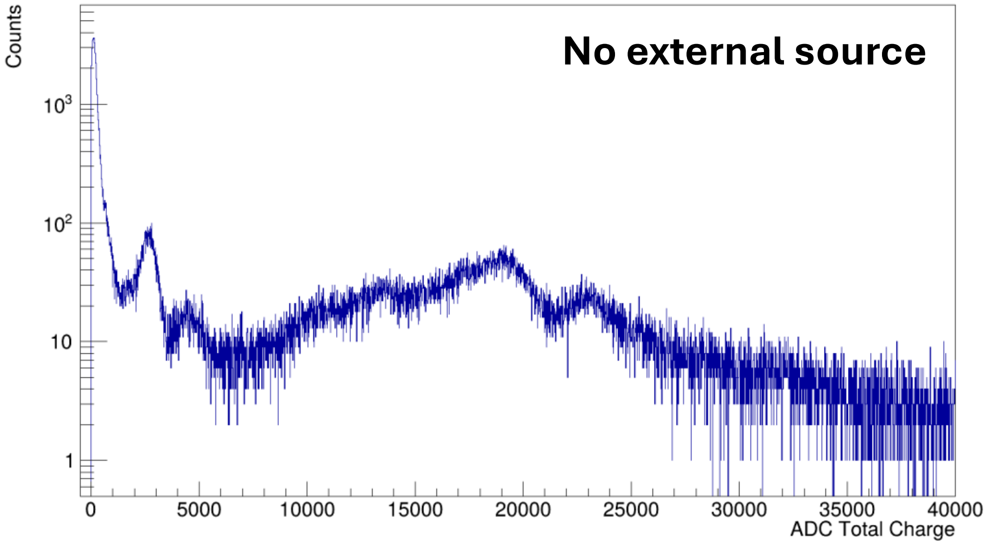
Data rate ~20 kHz

We have reached 10^{-6} and aim to collect more data to reach 10^{-9}.

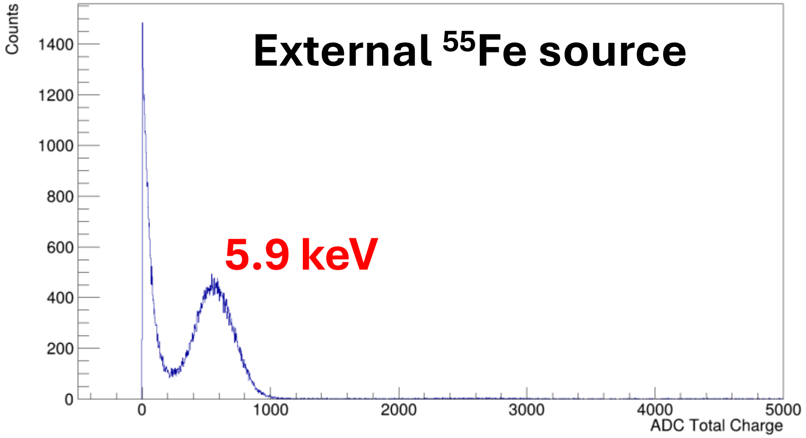
$CeBr_3$:^{57}Co

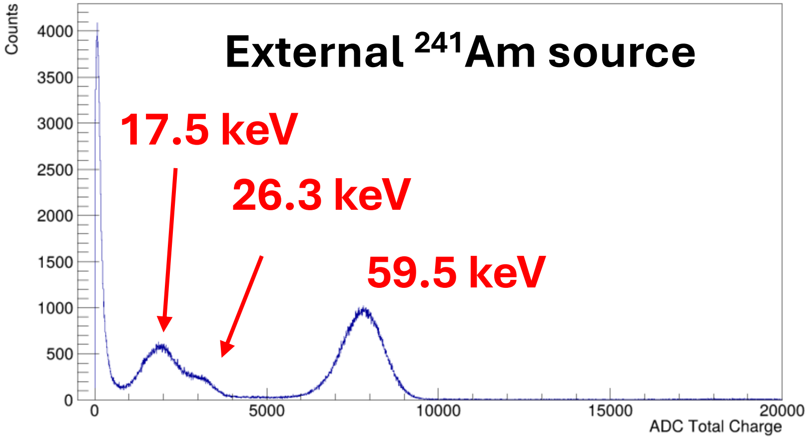


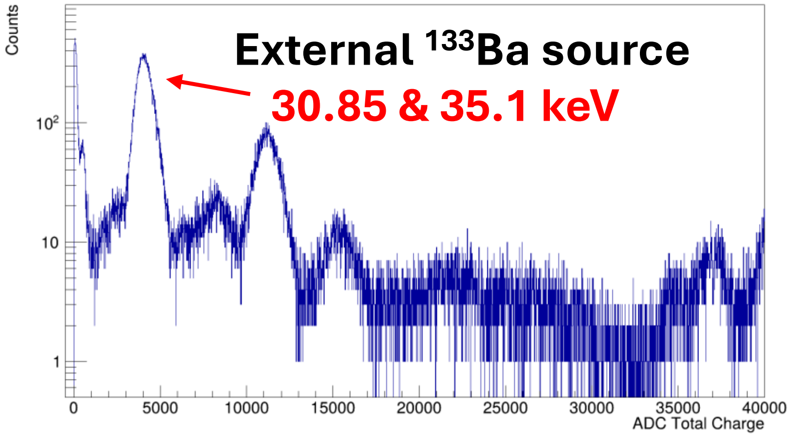




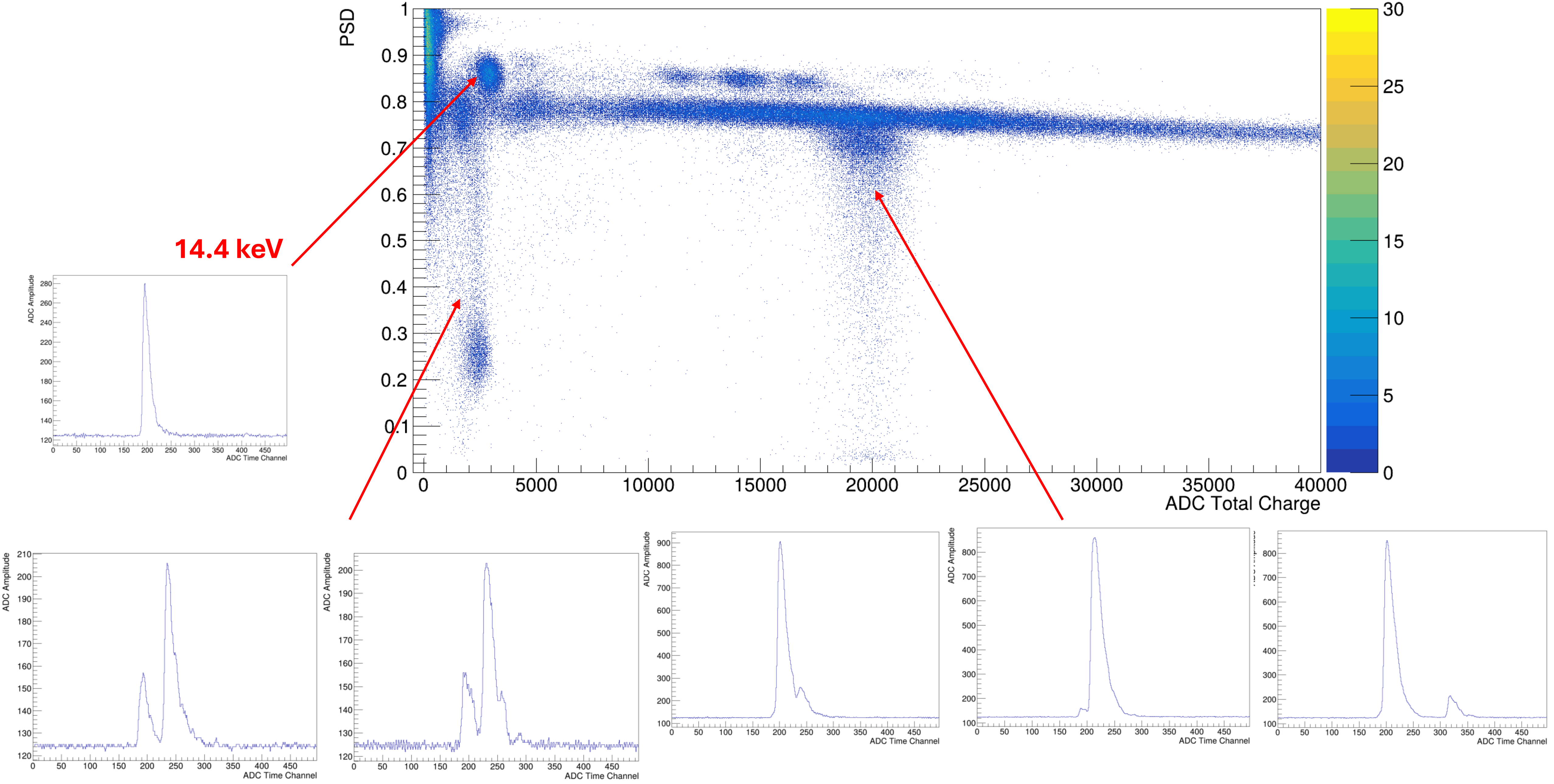
- $CeBr_3$:^{57}Co crystal can reach the 6 keV range
- ^{57}Co activity in CeBr3:^{57}Co needs to be increased



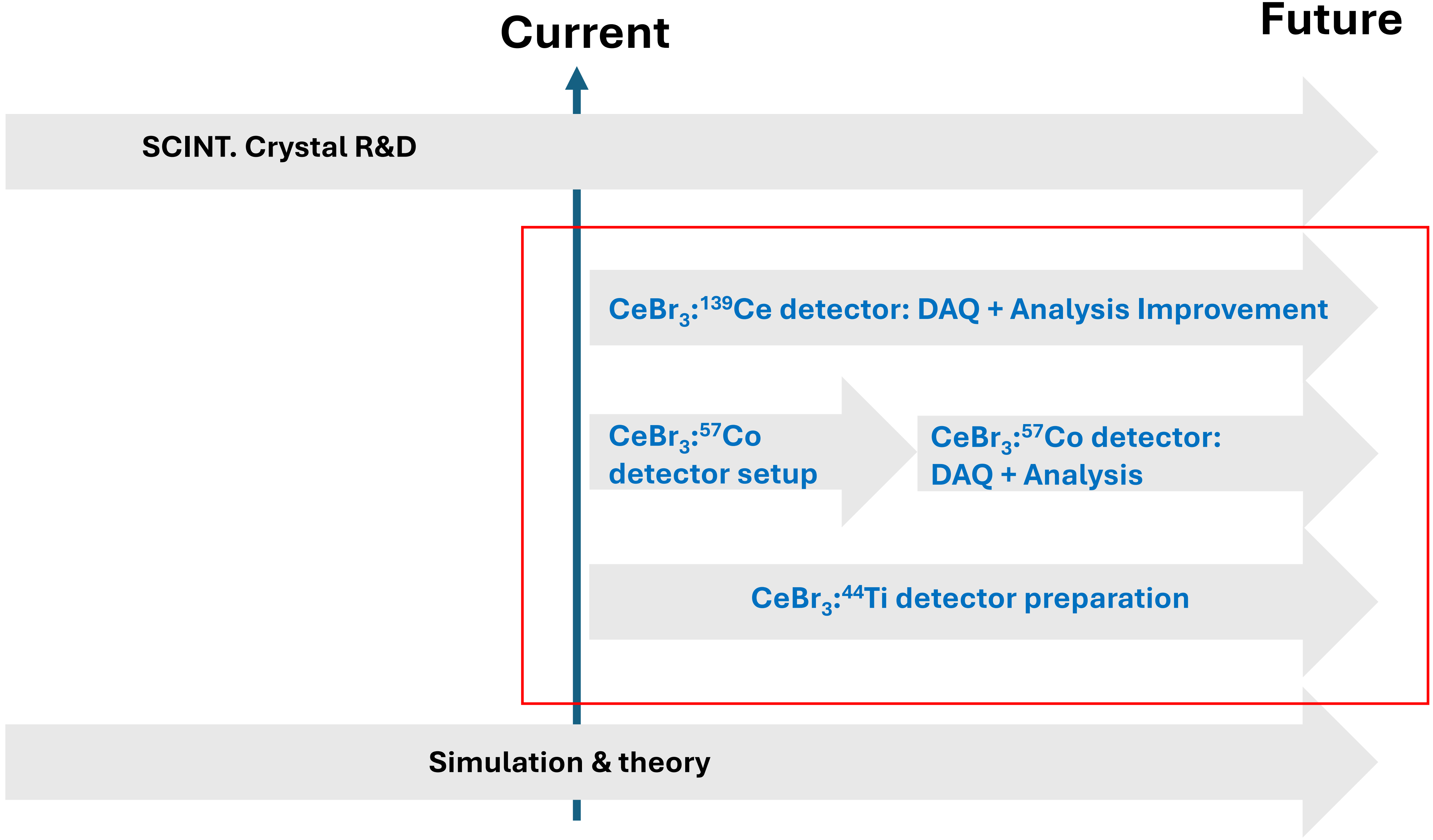




$CeBr_3$:^{57}Co cascade decay



GRANDE Track



GRANDE

- ❑Dark Matter Search with Radioactive sources
- ❑Measurement of Rare EC process, rare beta, and alpha decay with isomer gamma emission

The challenges (We are in R&D)

- ❑ High-quality scintillator development
- ❑ Radioactive source
- ❑ Detector fabrication improvement
- ❑ Data acquisition improvement
- ❑ Data analysis development
- ❑ Simulation and theoretical modeling

Welcome new ideas and contributions

Welcome to GRANDE Collaboration!

Thank you for your listening!