Pile-up rejection for AMoRE-II

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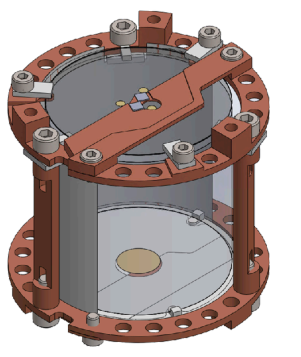
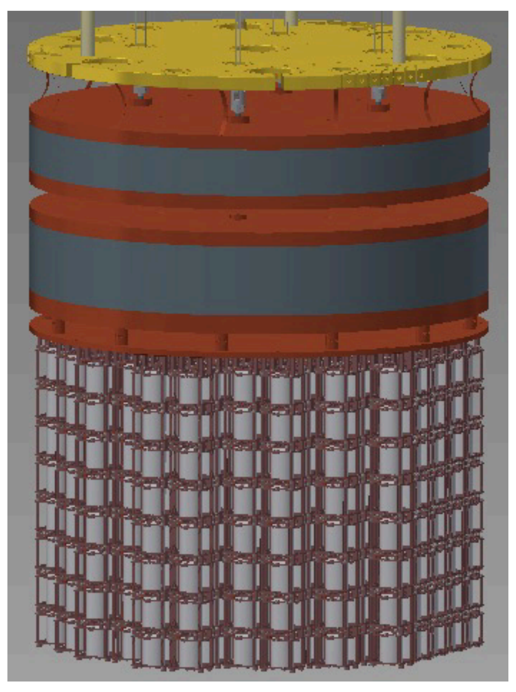
AMoRE: 0vDBD search

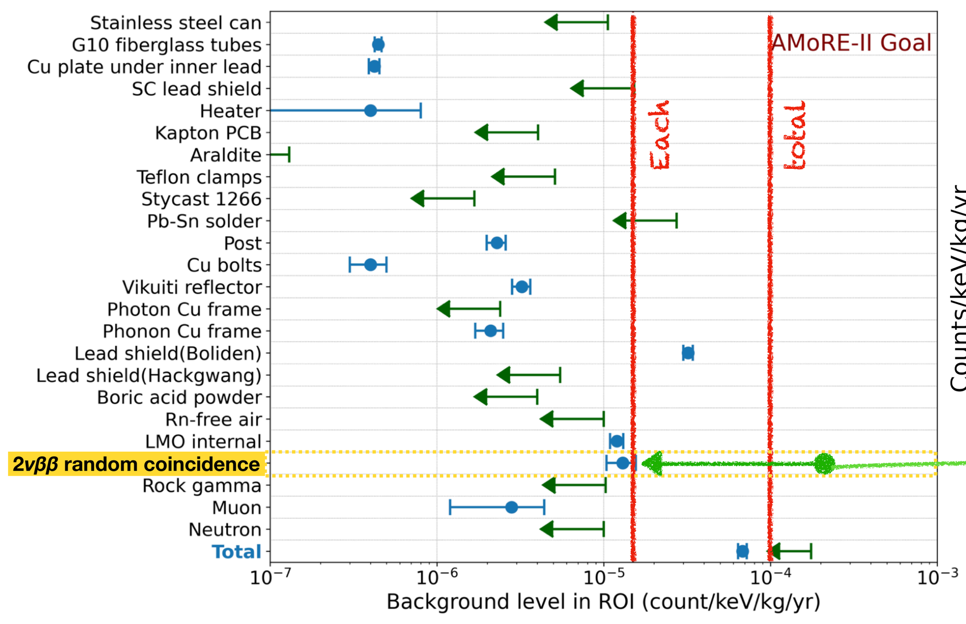


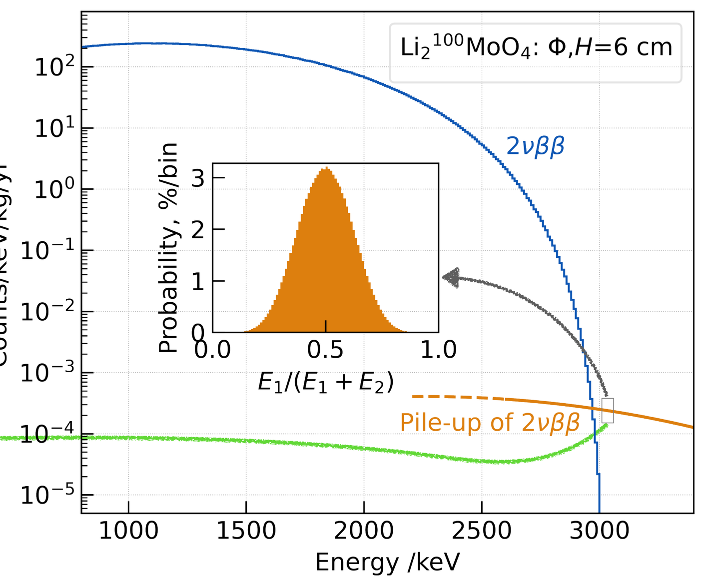


- Mo-100 enriched scintillation crystal.
- Cryogenic detector technique (MMC).
- AMoRE-II using 157 kg of Li_2MoO_4.
  - Being prepared at 1000 m underground in Yemilab [1].
  - 5+ years running: mass·time exposure > 500 kg·year.
  - Energy resolution ~ 10 keV FWHM at $Q_{\beta\beta}$=3034 keV.
  - Background level ≪ 2×10^{-4} count/keV/kg/year (ckky).
  - Half-life sensitivity ~ 4×10^{26} years at 90% CL.

Pile-up background

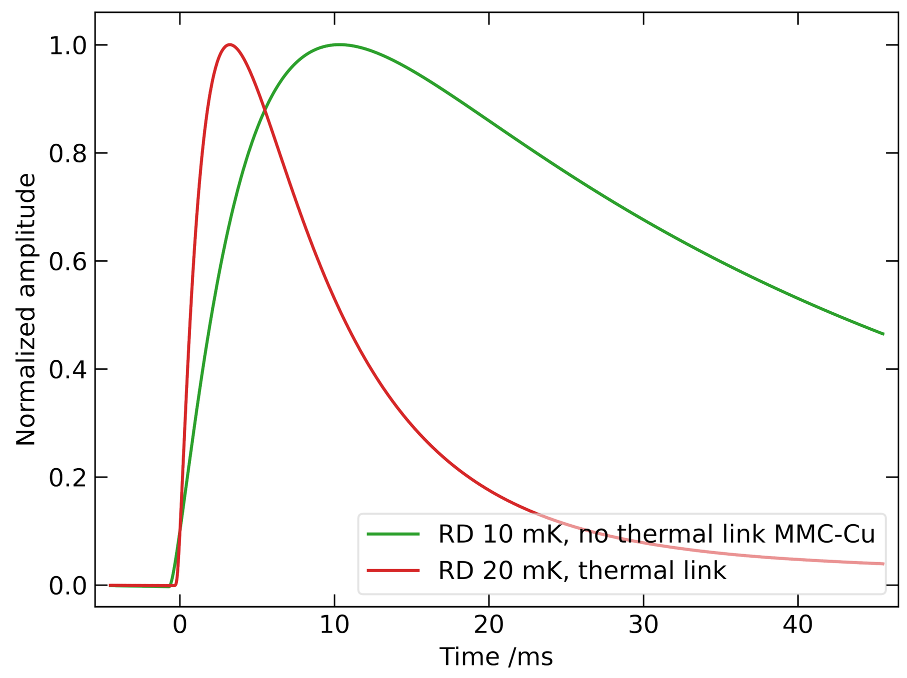
- Preference for a larger-size crystal detector to reduce the number of detector channels (~€$₩).
- Random coincidence of two signals in a detector crystal volume.
- Expecting the largest contribution from two 2vDBD signals.
- Rate scales with the crystal size (internal~volume, external~area) and coincidence *t* window.
  - For Li_2MoO_4 with Φ/H=6 cm and a 500 μs coincidence time window (*Δt*): pile-up background rate at ROI ~ 2.2×10^{-4} ckky [4].
- Rejection at the analysis level is required with $\varepsilon_{rejection}$≳90%.

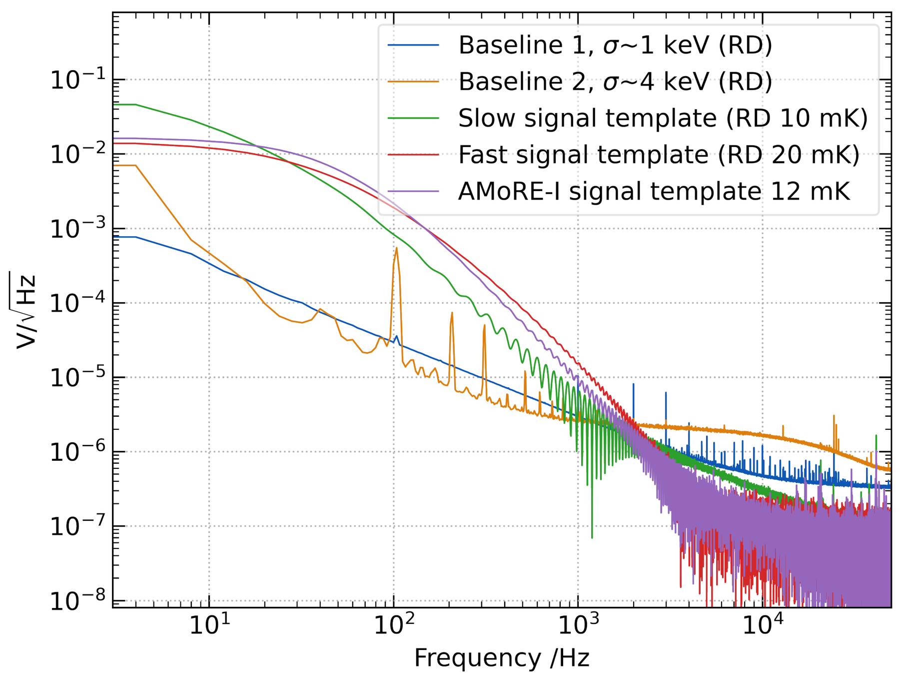




Signal and noise characteristics affects pile-up rate

- A faster signal and higher signal/noise preferred for less pile-up rate [2].
- Signal parameters such as size and speed (rise-/decay-time) can be tuned with: 1. temperature, 2. crystal surface condition, 3. thermal link between sensor (MMC) and Cu frame [3].
- Baseline r.m.s. can be controlled to be as small as a few keV level.

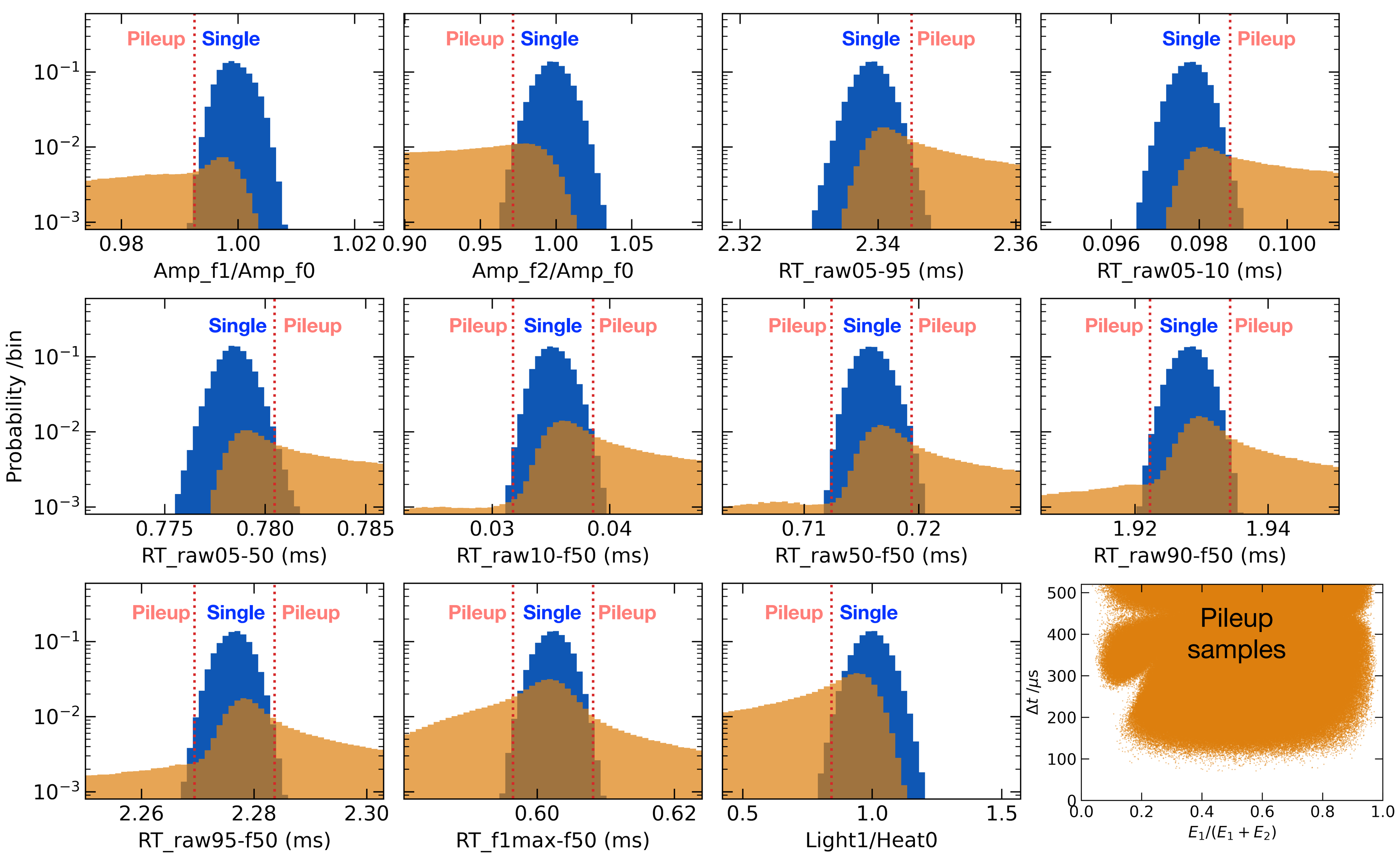


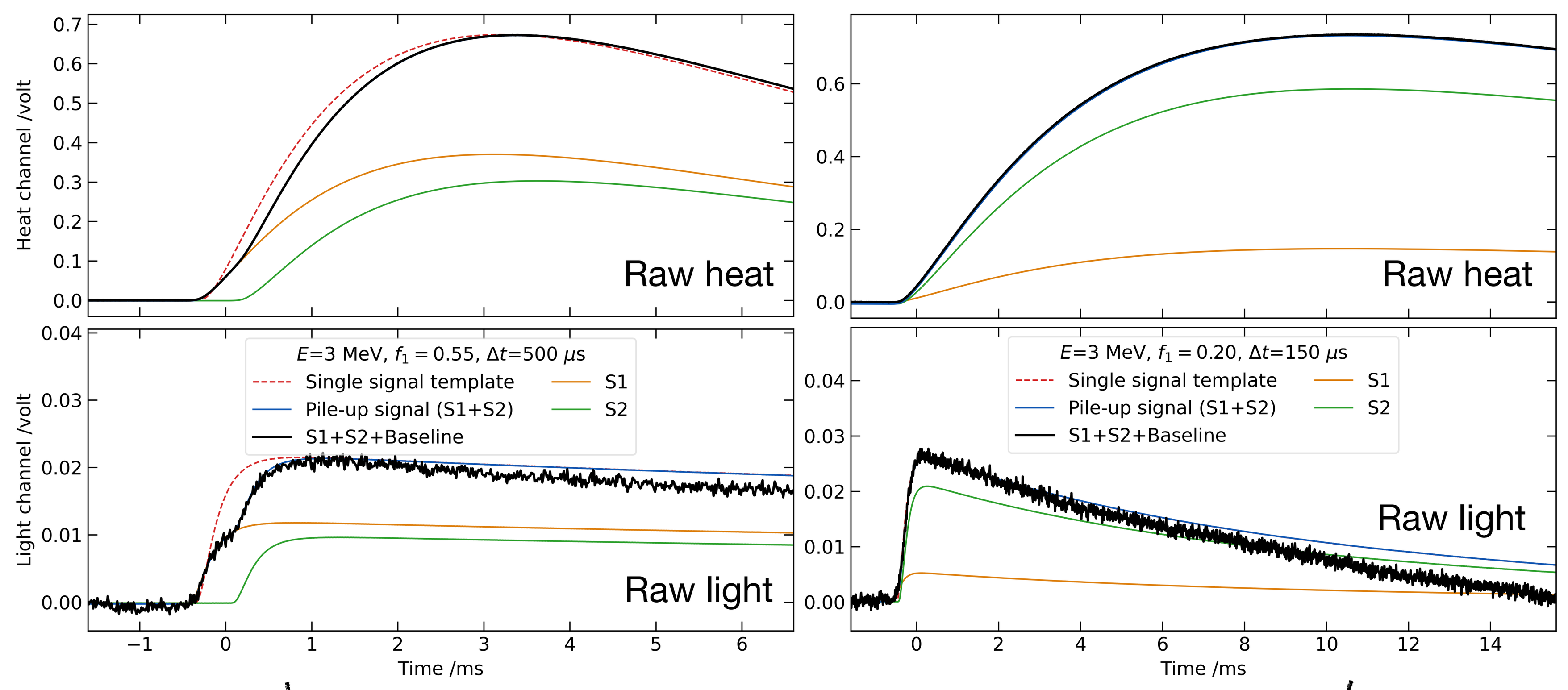


Pile-up simulation and analysis

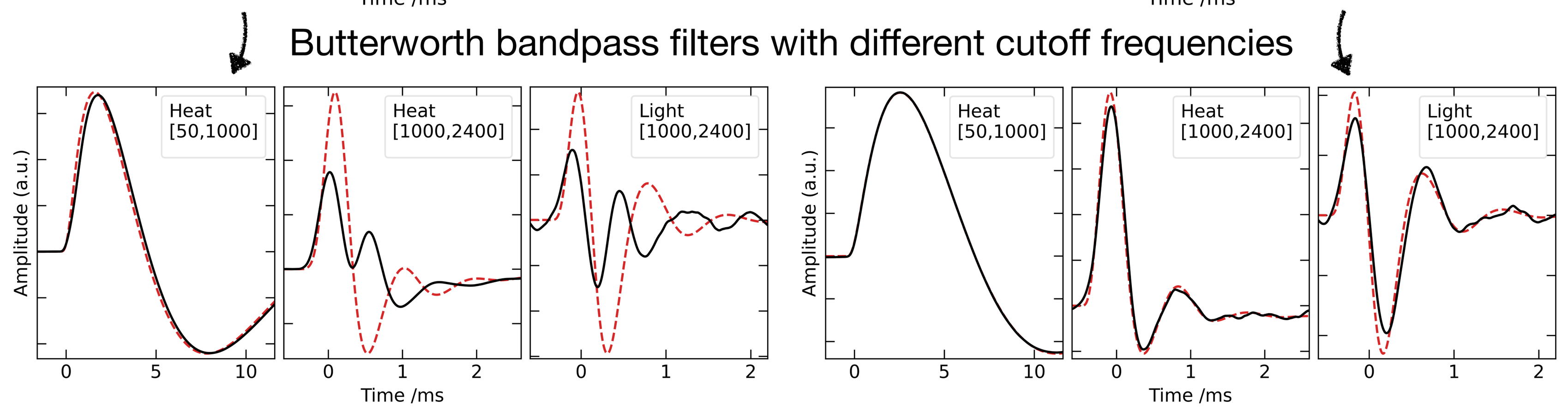
- Signal templates of Li_2MoO_4 detectors from R&D data:
  1. Fast signal: rise-time ~ 1.9 ms, 10-90%, (Diffused surface / 20 mK / MMC thermal link to Cu-frame ❍)
  2. Slow signal: rise-time ~ 5.8 ms, 10-90%, (Diffused surface / 10 mK / MMC thermal link to Cu-frame ✕)
- Noise (baseline): randomly sampled from real data.
- Analysis utilizing a machine learning method: gradient boosting [5].

Selected parameters for discrimination and training/evaluation data samples



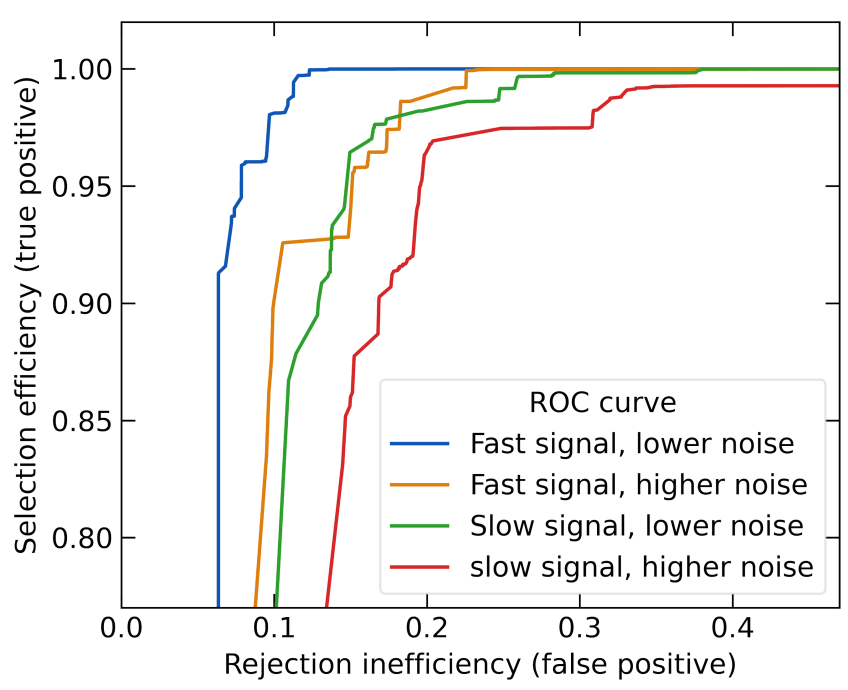


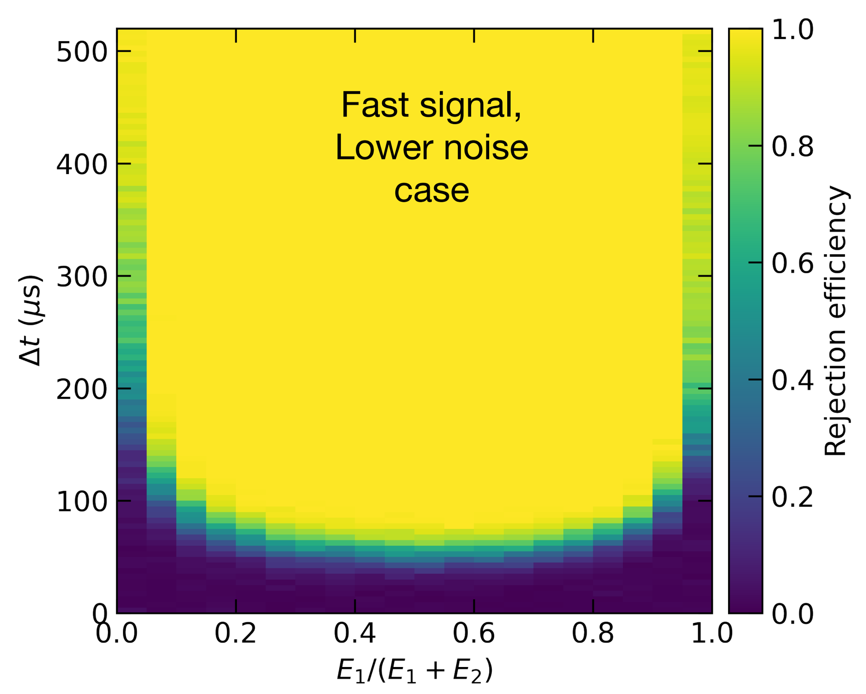
Butterworth bandpass filters with different cutoff frequencies



Result and Discussion

- Rejection efficiency for the pile-up of 2vDBD signals at ROI in 500 μs:
  - Better than 90% with faster signals on lower noise baselines.
  - Close to 80% with slower signals on higher noise baselines.
  - Selection efficiency for the single signal event > 95%.
- Pile-up rate by 2vDBD at ROI can be suppressed down to (2–4)×10^{-5} ckky.
- Studying the possibility for further improvements, not only for pile-up discrimination but also for more general event type classification.



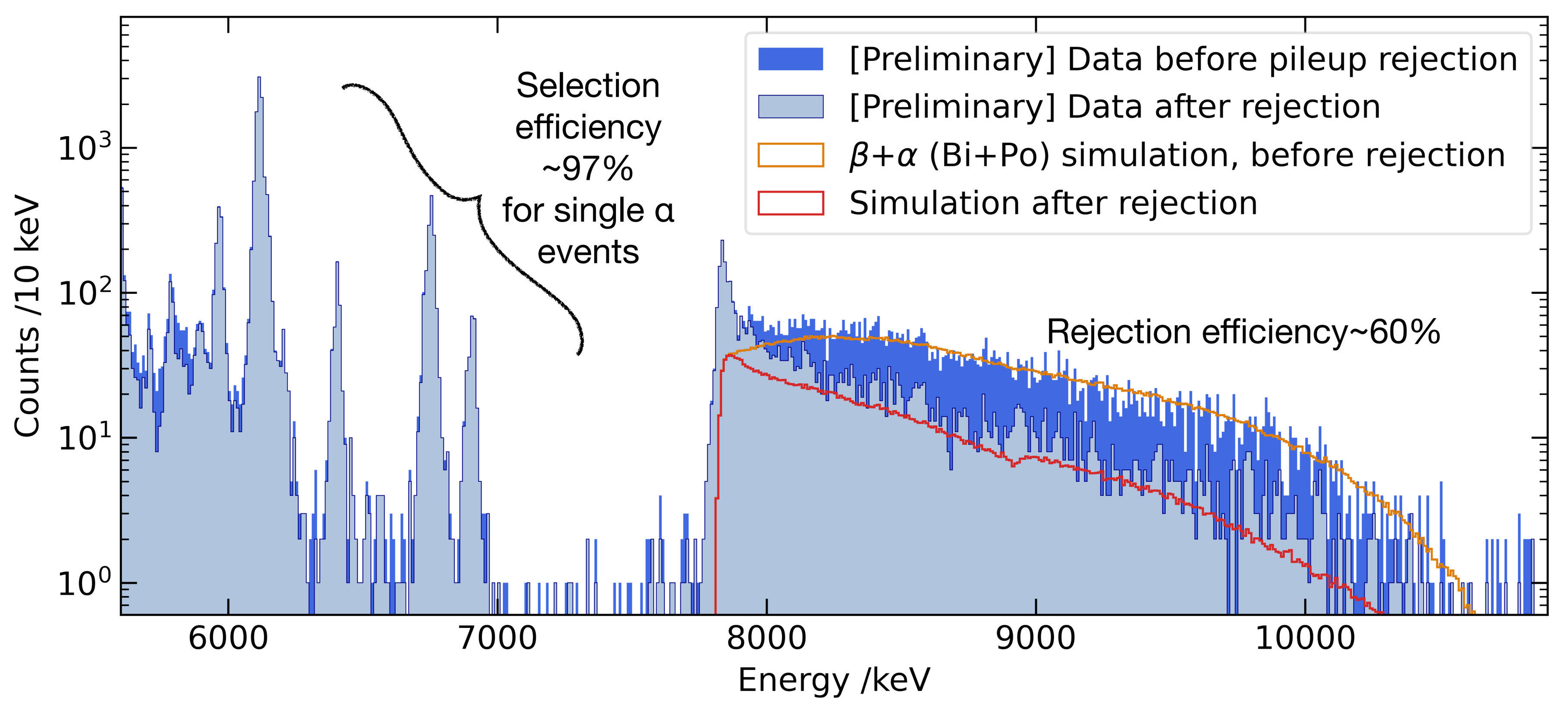


Validation using real data: Bi-Po β-α decay

- A $CaMoO_4$ crystal detector with a high U/Th contamination in AMoRE-I [6].

$$^{214}\mathrm{Bi} \xrightarrow[Q=3.27\ \mathrm{MeV}]{\beta-\mathrm{decay}} {}^{214}\mathrm{Po}\ (T_{1/2}=164\ \mu s) \xrightarrow[Q=7.83\ \mathrm{MeV}]{\alpha-\mathrm{decay}} \cdots$$ Some can be discriminated.

$$^{212}\mathrm{Bi} \xrightarrow[Q=1.88\ \mathrm{MeV}]{\beta-\mathrm{decay}} {}^{212}\mathrm{Po}\ (T_{1/2}=299\ \mathrm{ns}) \xrightarrow[Q=8.95\ \mathrm{MeV}]{\alpha-\mathrm{decay}} \cdots$$ Expecting no rejection at all!



References: [1] K.S. Park et al, DOI:10.3389/fphy.2024.1323991. [2] G.B. Kim et al, DOI:10.1016/j.astropartphys.2017.02.009. [3] S.C. Kim et al, DOI:10.1088/1748-0221/17/07/P07034. [4] C. Augier et al, DOI:10.1103/PhysRevLett.131.162501. [5] T. Chen and C. Guestrin, DOI:10.1145/2939672.2939785. [6] V. Alenkov et al, DOI:10.1140/epjc/s10052-022-11104-3.