Background with mild shield: paper layout

23/09/2025 – BULLKID-DM Meeting – Online

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Low-energy spectrum of the BULLKID detector array operated with mild shied

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We present the operation with mild shield in a surface lab of BULLKID, a detector for searches of light Dark Matter and precision measurements of the coherent and elastic neutrino-nucleus scattering. The detector consists of an array of 60 cubic silicon particle absorbers of 0.34 g each, sensed by cryogenic kinetic inductance detectors. The data presented focuses on 15 elements of the array, with two central units used to evaluate background and with their surrounding elements used as veto. The low energy spectrum resulting from an exposure of 290 hours to ambient backgrounds, obtained without radiation shields, is flat at the level of $(6.8 \pm 0.4\,\mathrm{stat.} \pm 0.2\,\mathrm{syst.}) \times 10^4$ counts / keV kg days down to the energy threshold of 200 ± 16 eV. The high energy spectrum agrees with Geant4 simulations and displays the typical particle-induced X-ray emission of lead, further validating the calibration procedure.

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1. INTRODUCTION
2. EXPERIMENTAL SETUP
3. DATA ANALISYS AND RESULTS
4. COMPARISON WITH OTHER EXPERIMENTS
5. CONCLUSION AND PERSPECTIVES

APPENDIX A: CLUSTER EVENT SELECTION
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Shield and detector setup

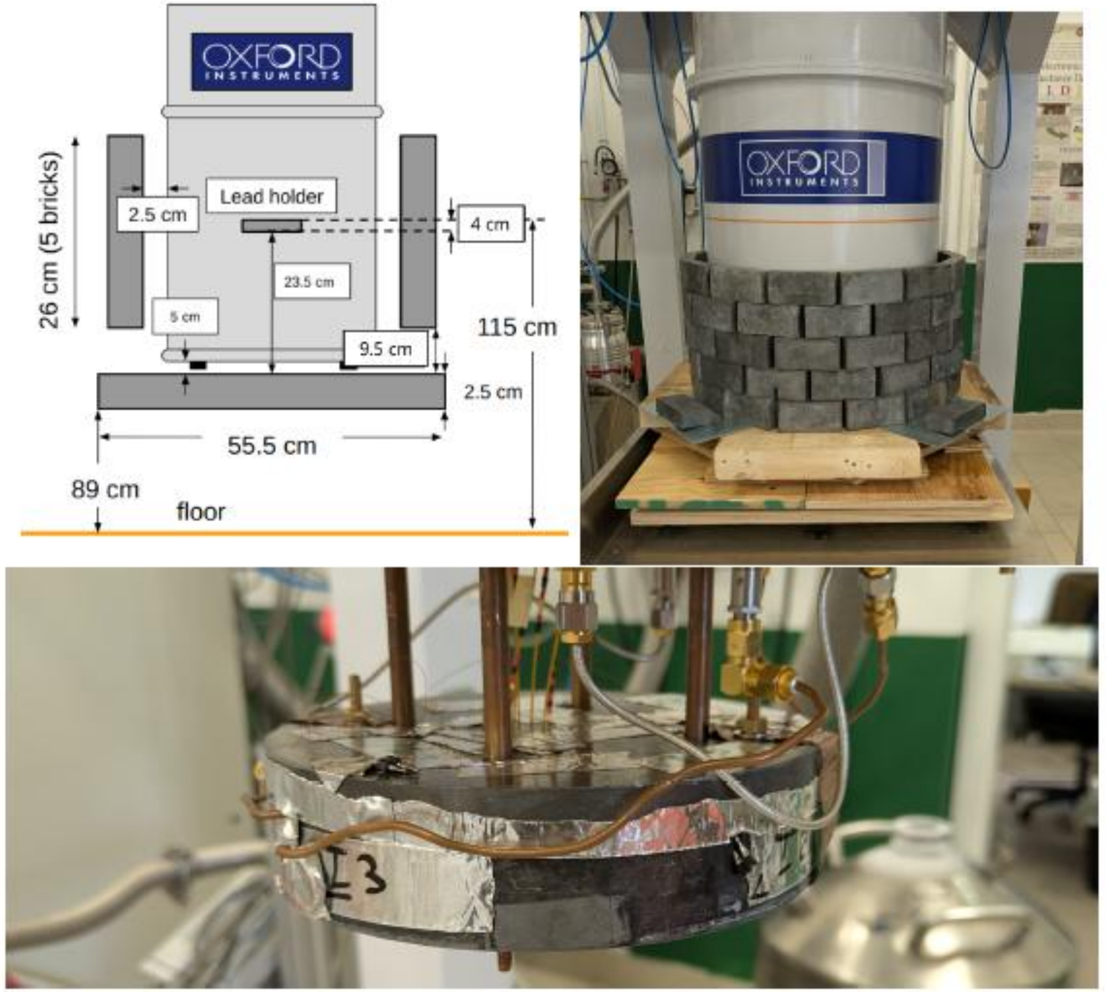


Figure 1. **Top left:** Schematic representation of the shielding deployed around the BULLKID detector, in the form of an outer lead castle and an inner lead case. **Top right:** The external lead castle surrounding the external dewar of the cryostat. The castle is supported by wood planks to center it as much as possible around the actual position of the array used to acquire background. Under the cylindrical castle more bricks are arranged as a square covering the bottom side of the dewar (unseen in the picture). **Bottom:** The lead case surrounding the detector covers the full solid angle, increasing the shielding with little added weight.

Device used and KID map

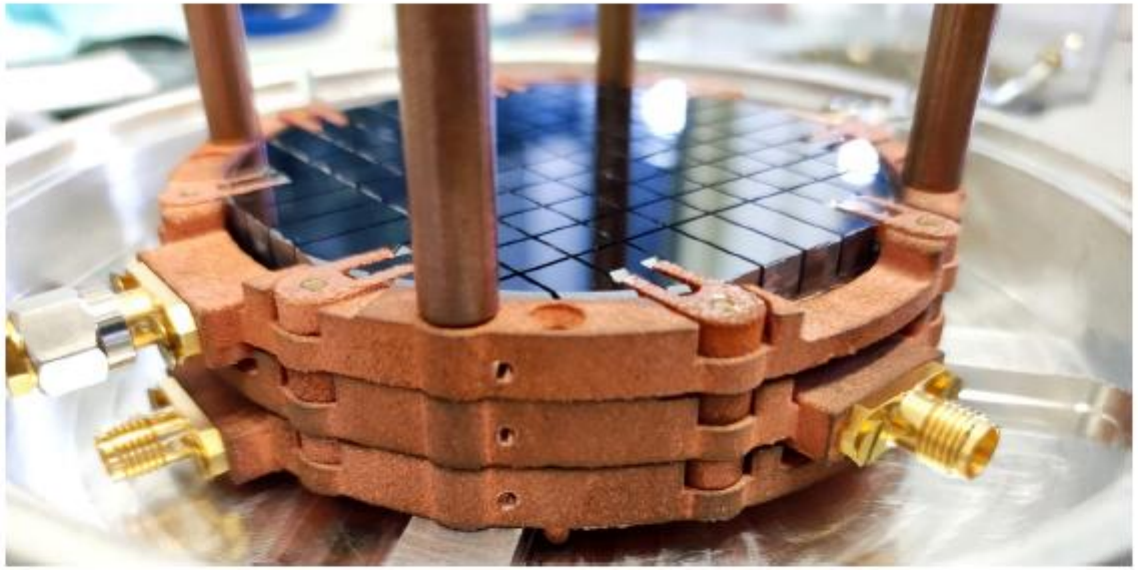
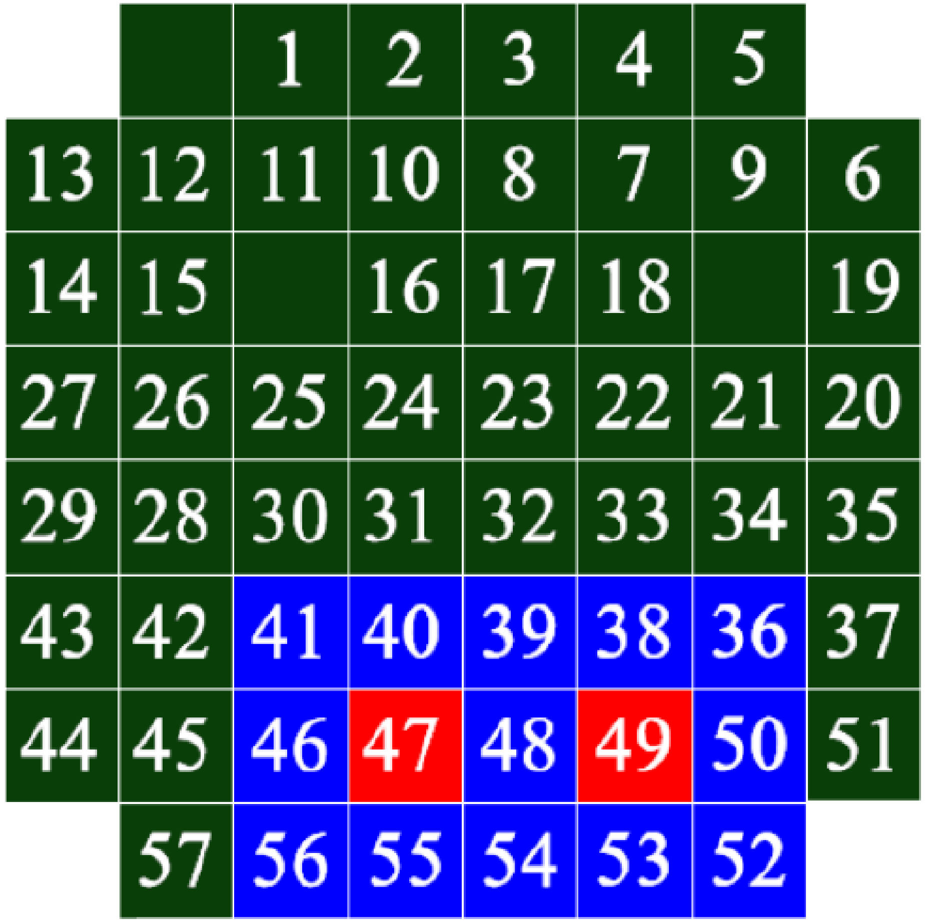


Figure 2. **Top:** Stack of 3 BULLKID wafers as a proof of concept to scale the active mass of the detector. For the data acquisition and analysis described in this work only the top wafer has been used; **Bottom:** Map of the array used for the characterization of the background with lead shield. The master KIDs (red) trigger whole cluster, with the side units (blue) being acquired in coincidence to veto events. The resonators are numbered in order of increasing resonant frequency.



Stability of the detector response

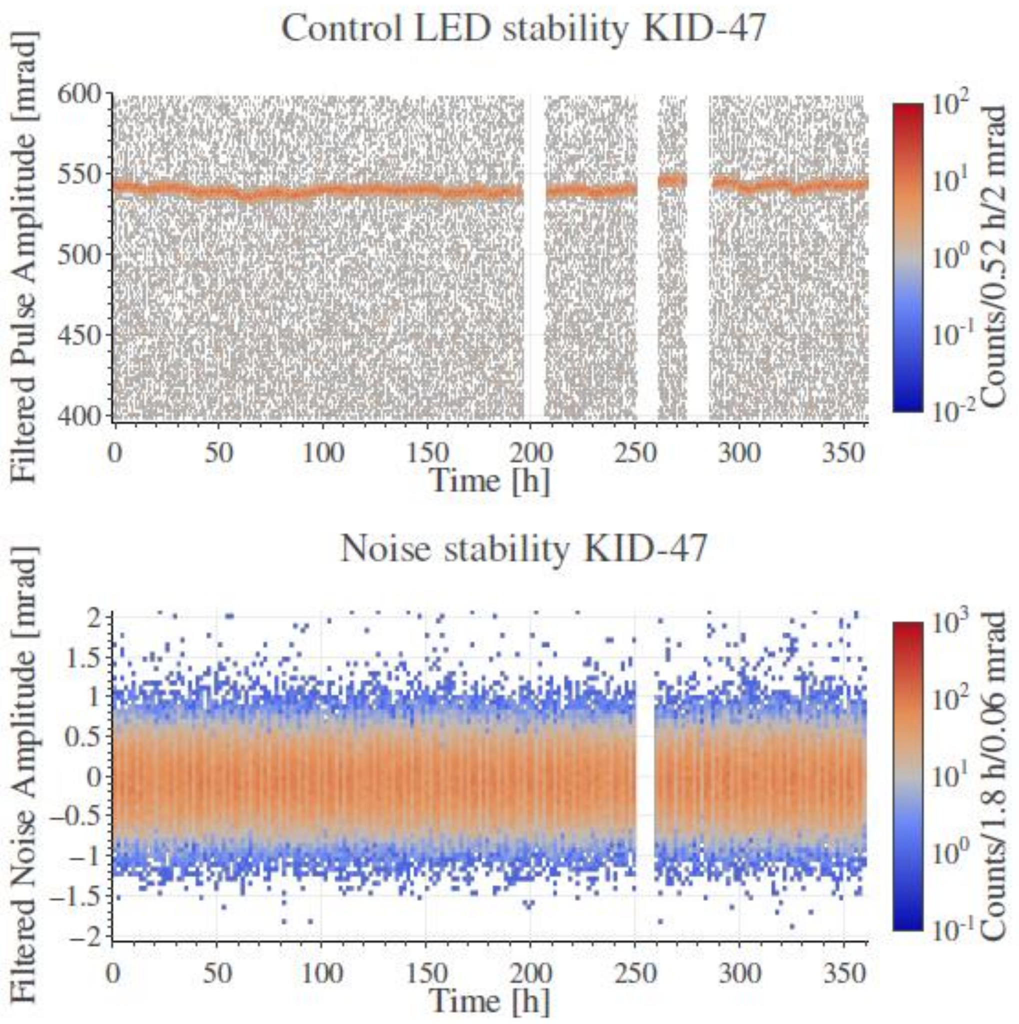


Figure 3. Top: Distribution of noise samples after applying the matched filter during the whole duration of the data taking for KID-47. The RMS is 0.38 mrad and corresponds to 33 eV after calibration. Bottom: Distribution of KID-47 pulse response to the phonon leakage produced by energy depositions on the adjacent die of KID-48. Three distinct intervals in which the signal was not detected have been removed from the analysis.

Individual and combined low energy background

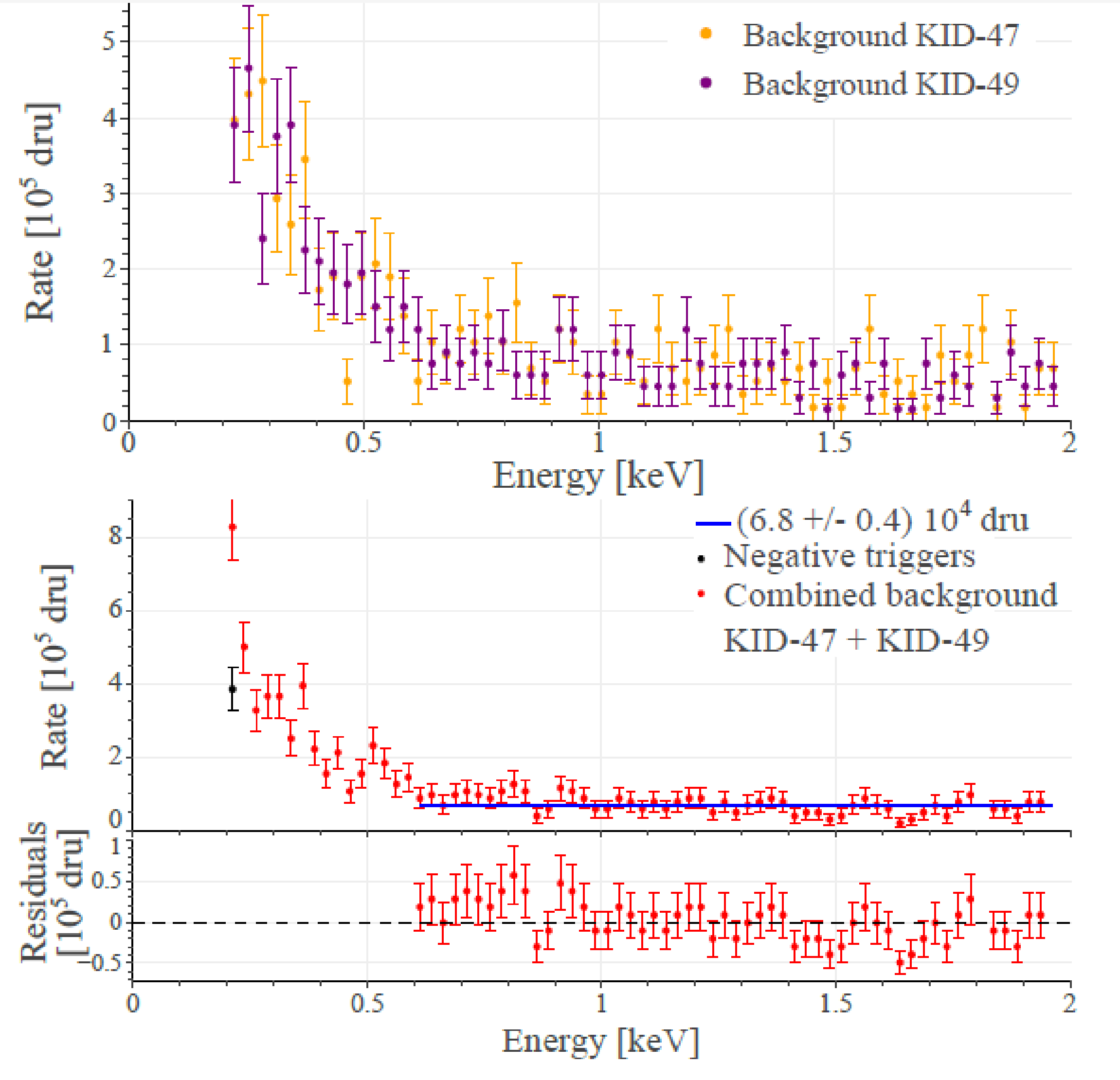


Figure 4. **Top:** Energy spectrum after 290 h of exposure for the dice sensed by KID-47 (orange) and KID-49 (purple). After applying the event selection based on the pulse shape and on the Ω variable and correcting for the efficiencies, the two spectra fully overlap. **Bottom:** Combined energy spectrum of the two master dice for a total exposure of 580 h $\times$ 0.34 g (red datapoints). The energy spectrum is flat down to approximately 0.6 keV, to a level of $(6.8 \pm 0.4) \cdot 10^4$ DRU compatible with Geant4 simulations. The region between 0.6 keV and the threshold of 0.2 keV, defined as the last bin with a non-negligible contribution of noise false positives (black), displays a progressive increase in the counting rate up to a maximum of $5 \cdot 10^5$ DRU at threshold.

Combined high energy background and XRF

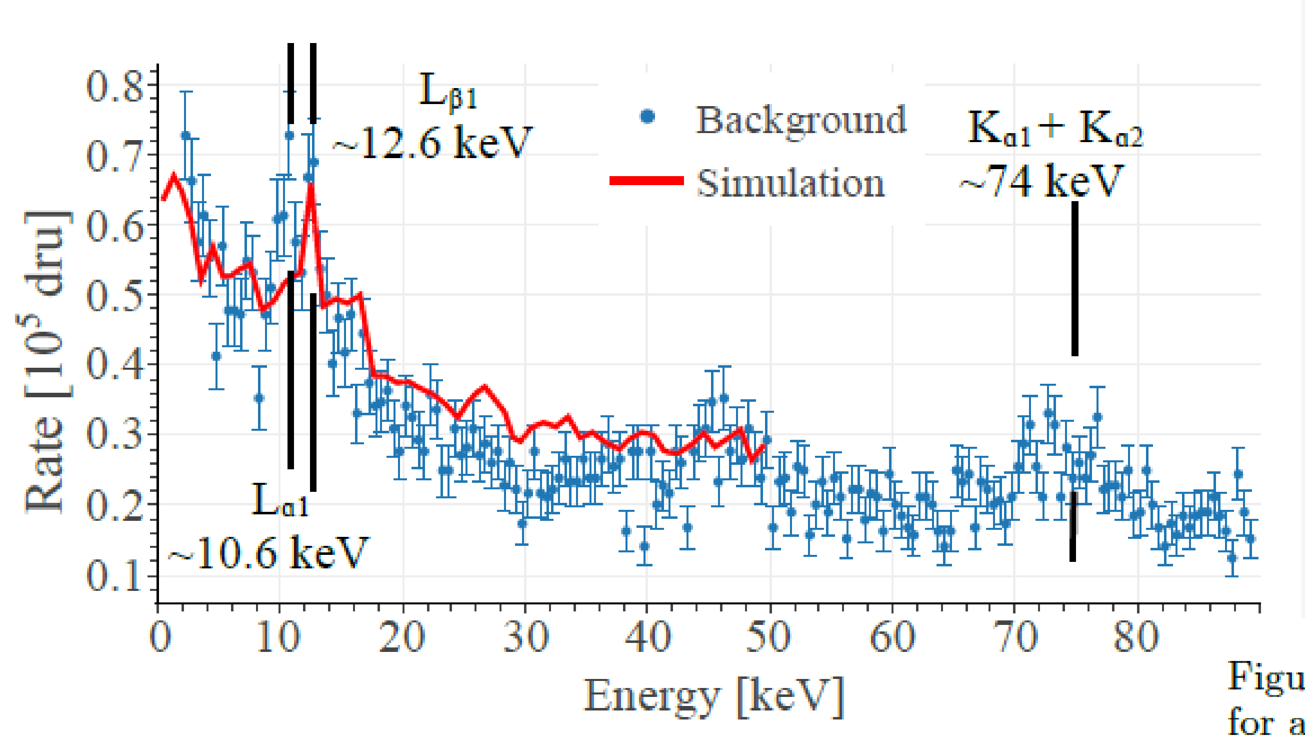


Figure 5. Combined energy spectrum of the two master dice for a total exposure of 580 h × 0.34 g, from 3 keV to 90 keV (blue data points). The particle-induced X-ray emission of lead at 10.6, 12.6 and 74 keV are highlighted in black. The measured high energy background is overall compatible with the Geant4 simulation (red line), however the X-ray lines are not completely reconstructed suggesting that further improvements on the background model are necessary.

COMPARISON WITH OTHER EXPERIMENTS

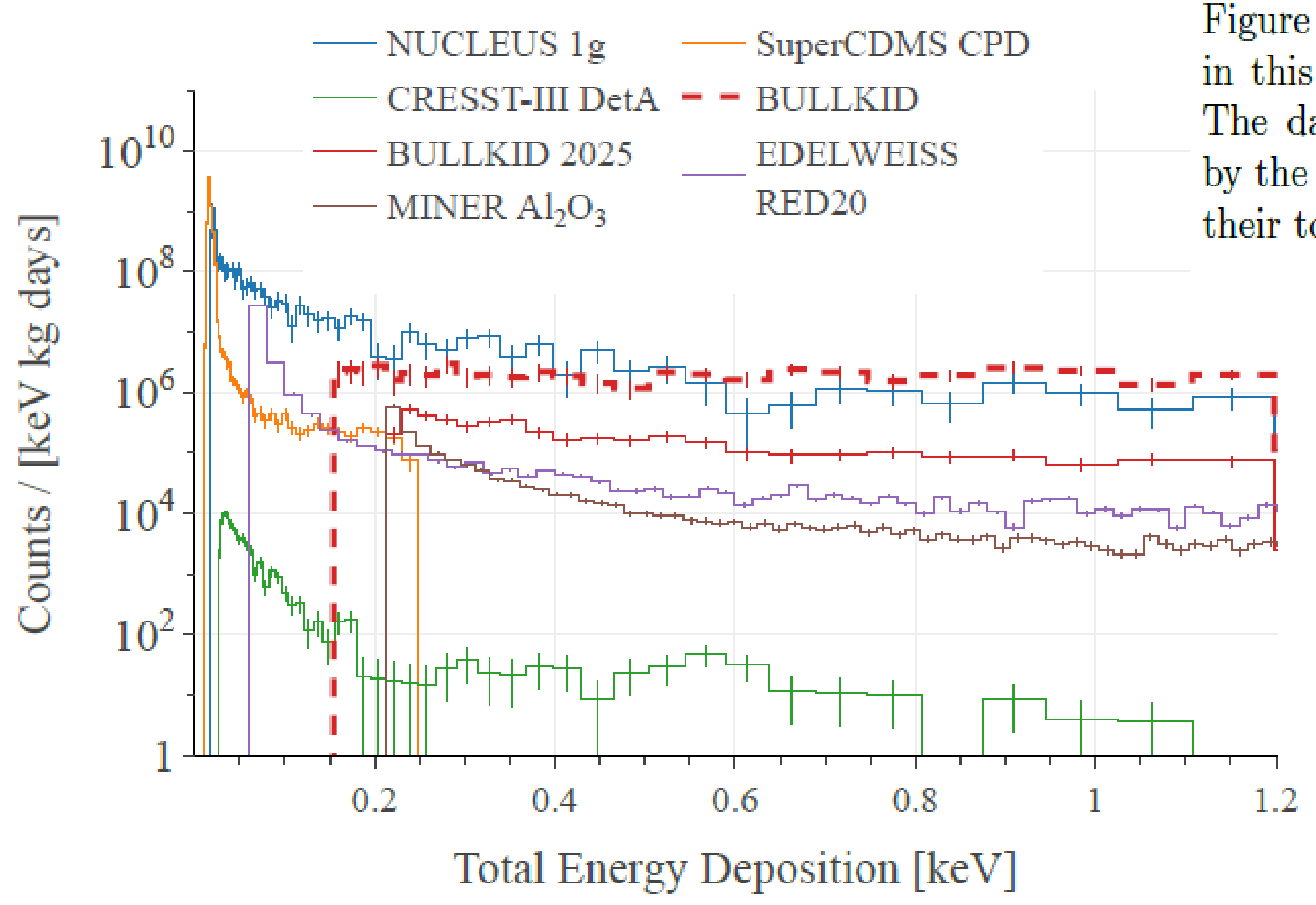
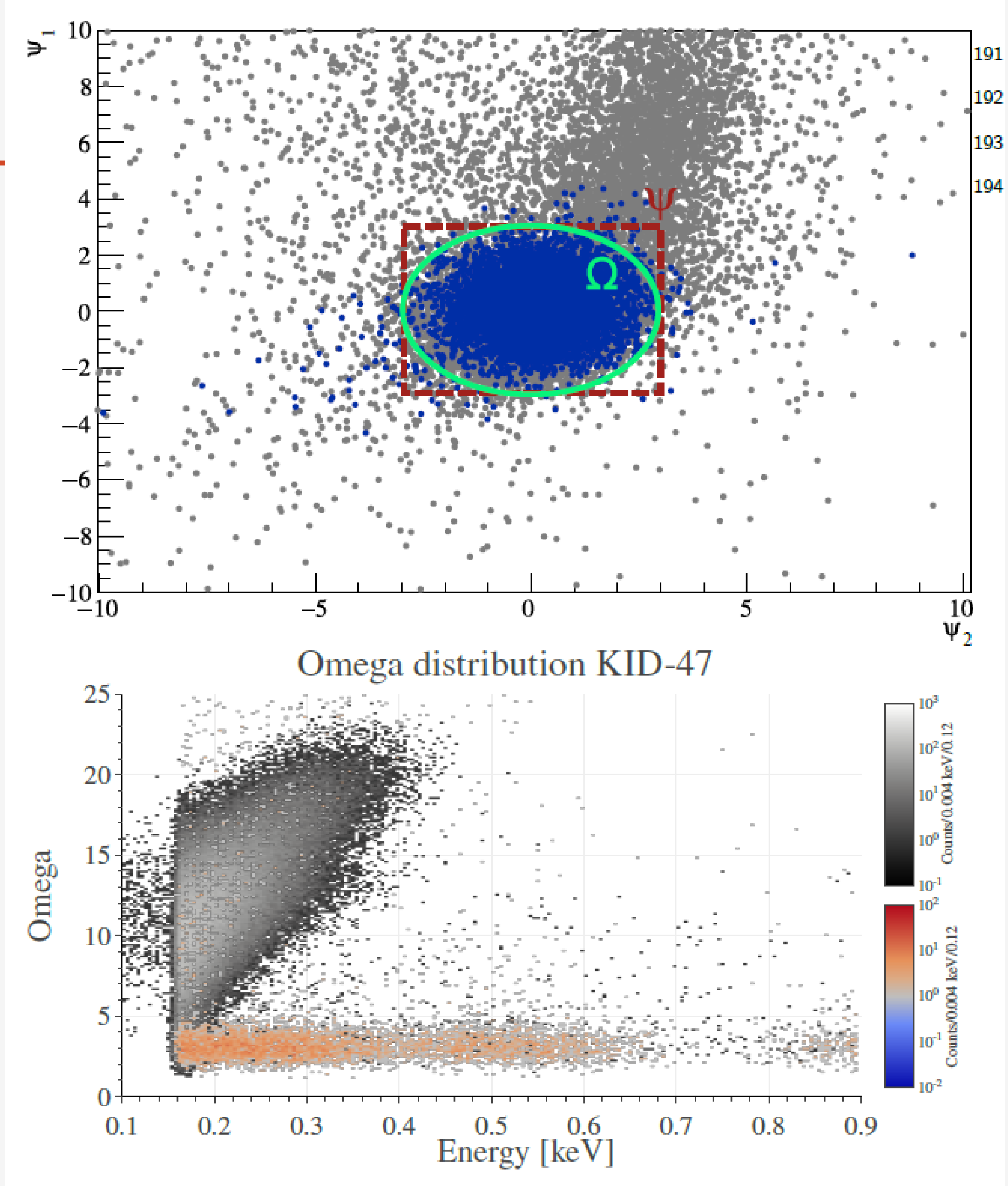


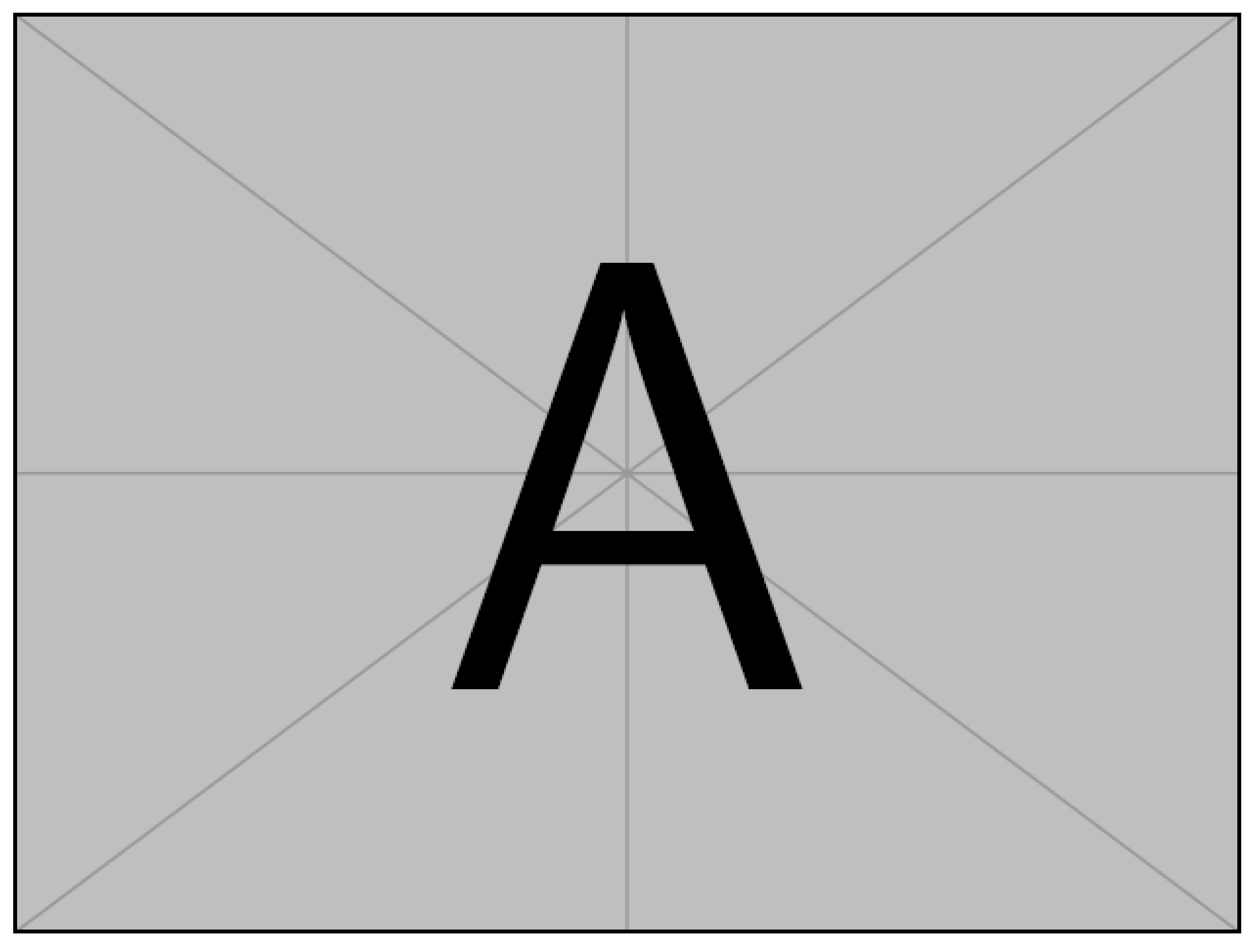
Figure 9. Comparison of the BULLKID's spectrum presented in this work with other experiments of the field (see text). The data are taken from the public repository maintained by the organizers of the EXCESS workshop and plotted with their tool (See Ref. 15 in Ref. [3]).

Appendix A: EVENT SELECTION

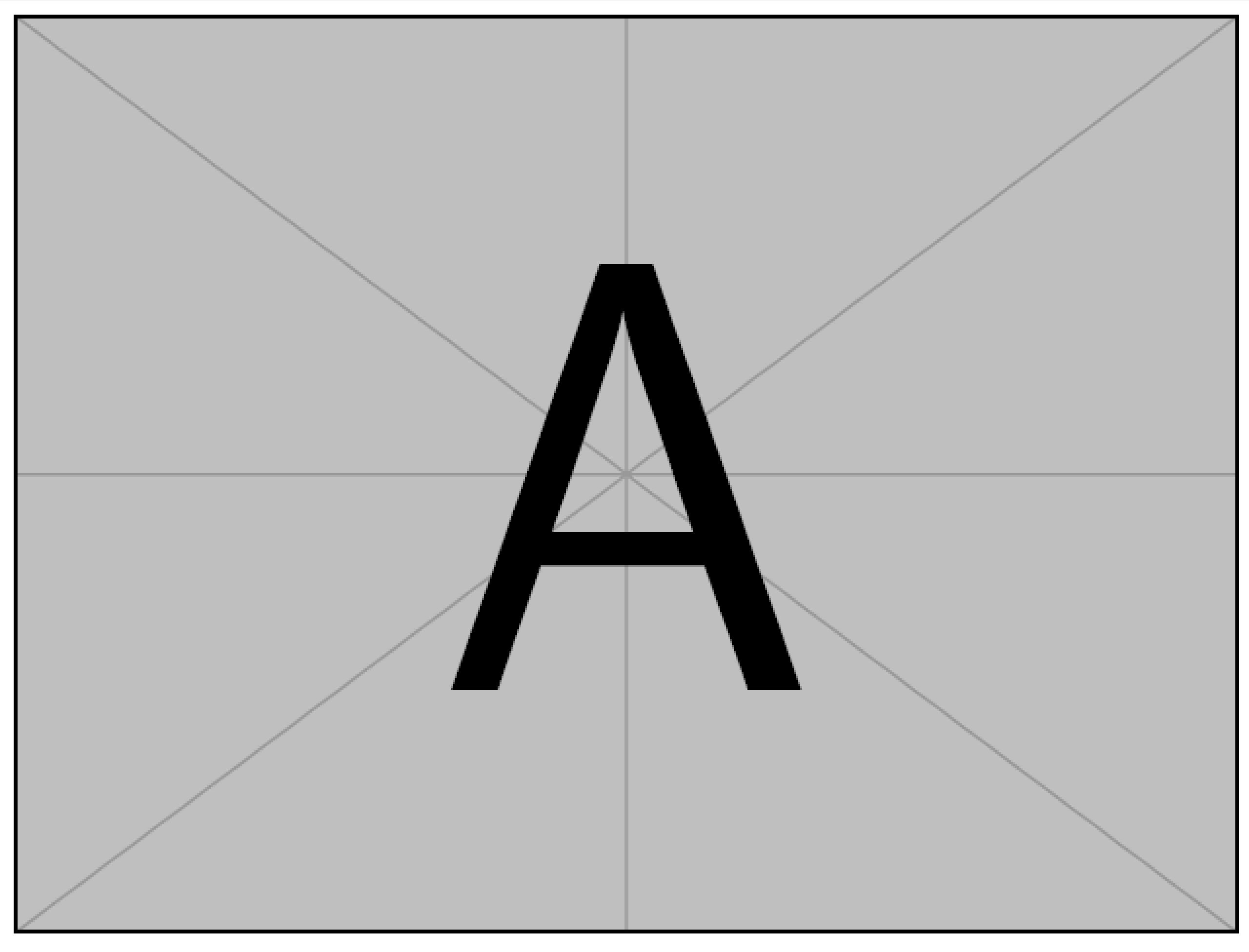
Figure 7. **Top:** 2-dimensional parameter space defined by the variables ψ_1 and ψ_2 for KID-47. The blue points represents LED events known to be shining on the correct die, while the gray points are unwanted background to be rejected. The red rectangle represents the event selection achieved by independently requiring $|\psi_1| < 3$ and $|\psi_2| < 3$, achieving high efficiency at the cost of moderate rejection power. The event selection achievable by the condition $\Omega < 3$, represented as a green circle, achieves a higher rejection of the background while retaining a comparable efficiency on the LED events; **Bottom:** Distribution of the Ω variable computed for KID-47 for LED events (red-blue colorscale) and 1 h of background events (gray colorscale). The variable allows for good separation down to approximately 200 eV.



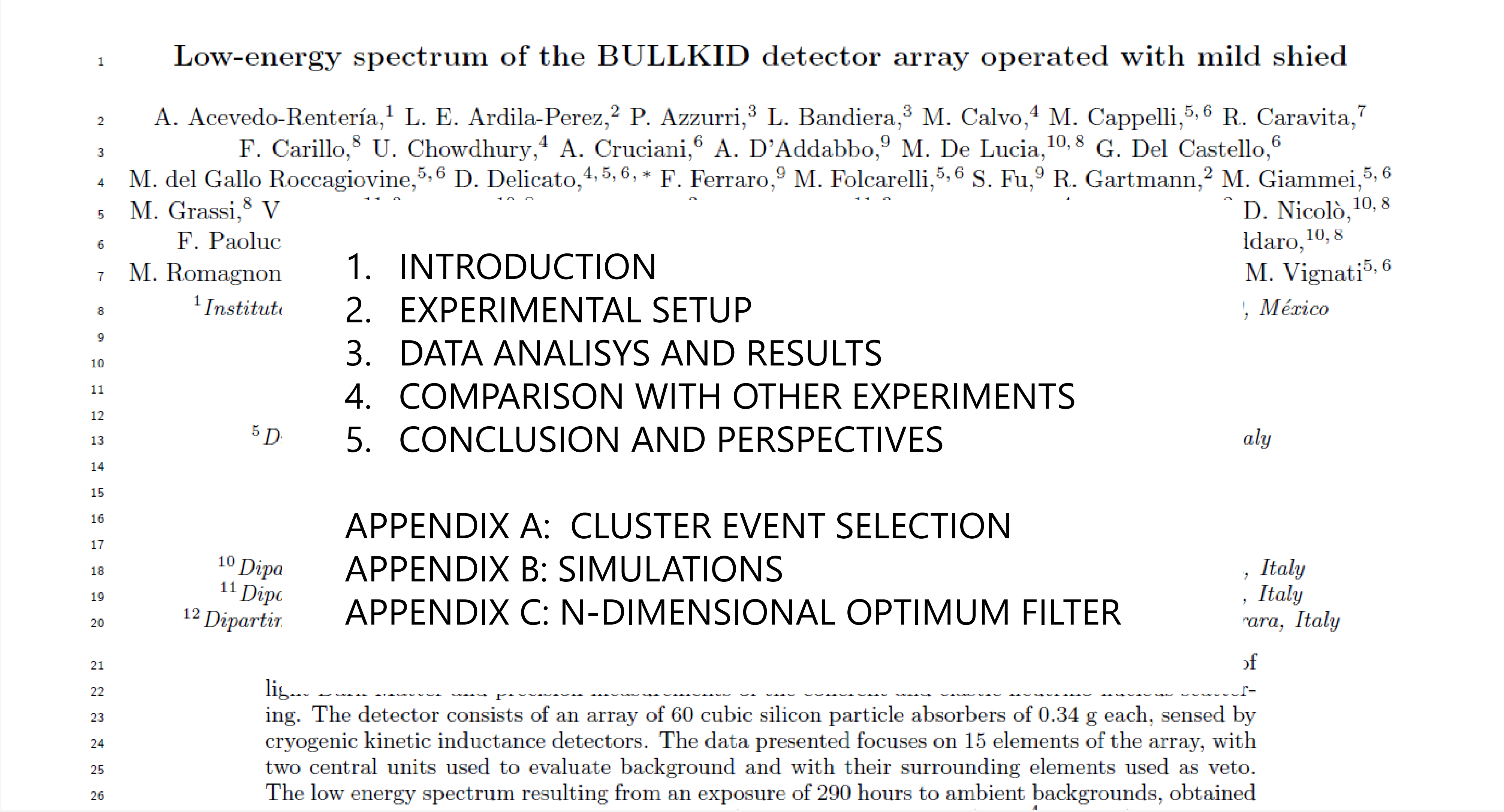
Appendix B: SIMULATIONS



Appendix C: N-DIMENSIONAL OPTIMUM FILTER and THE NEGATIVE TRIGGER SPECTRA



Thank you for your attention



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