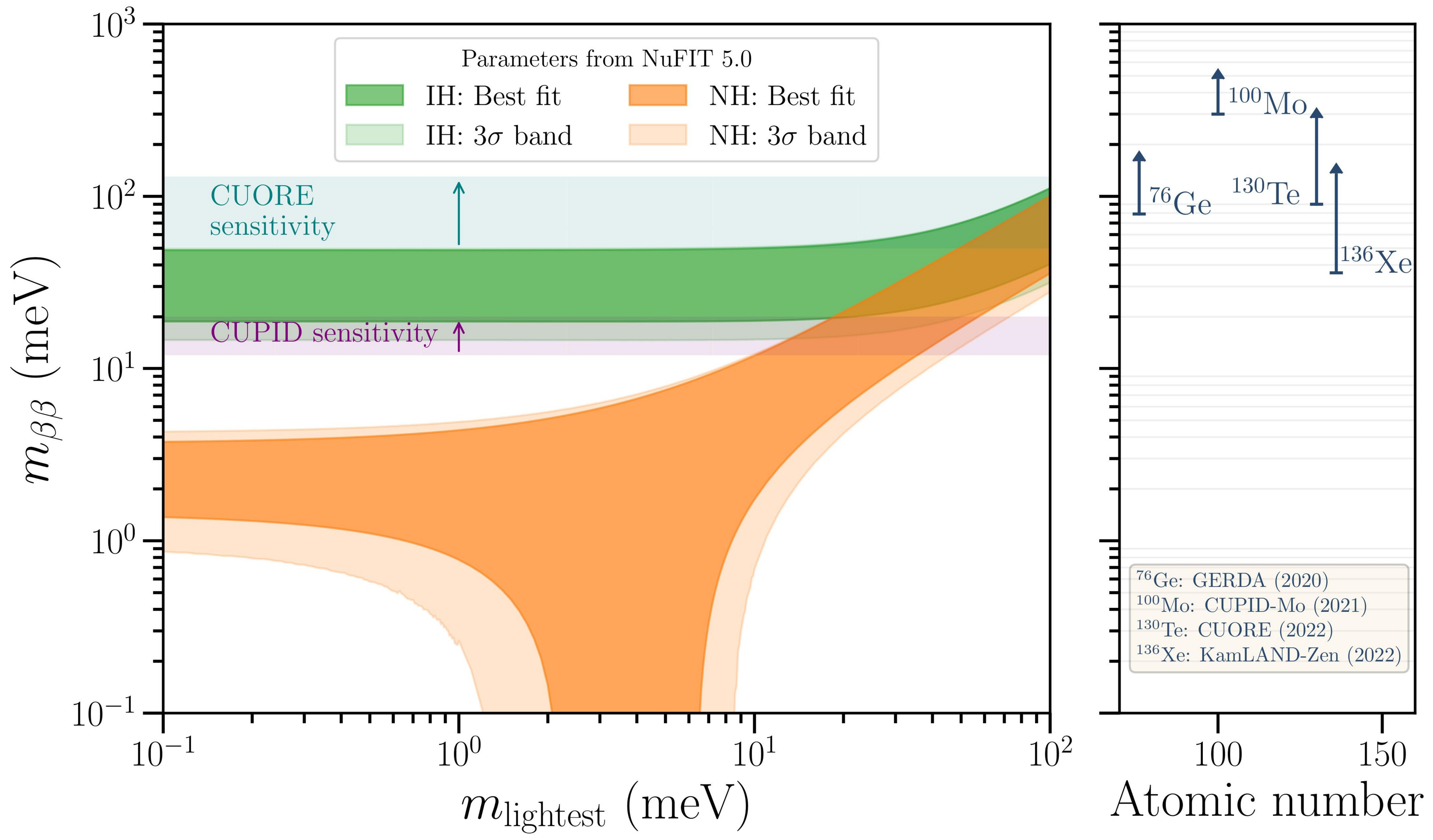
Mitigation of cosmogenic muon-induced backgrounds for CUPID

Jorge Torres (jorge.torresespinosa@yale.edu), for the CUPID collaboration

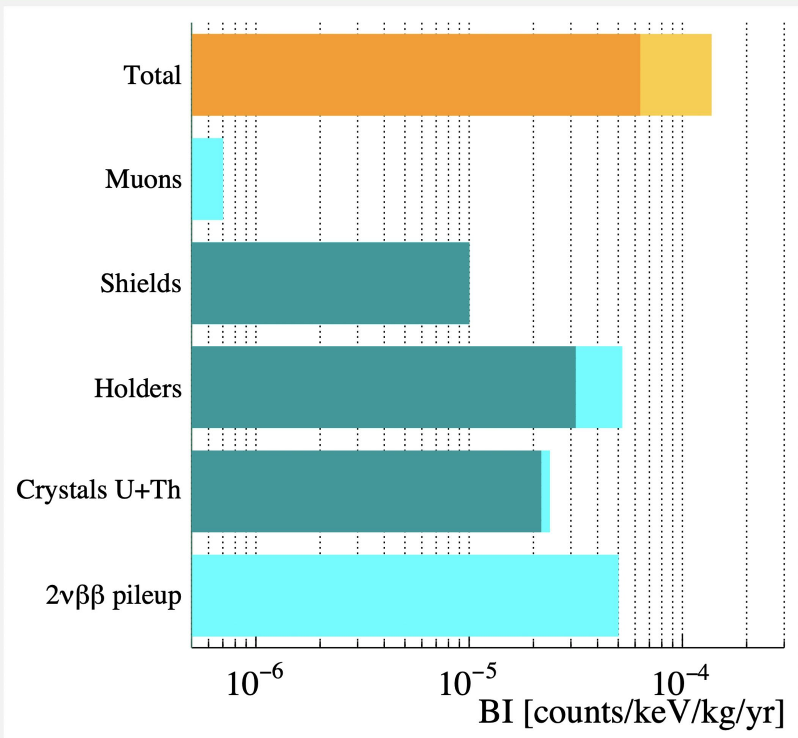
Searching for Neutrinoless Double Beta ($0\nu\beta\beta$) Decay with CUPID

The search for $0\nu\beta\beta$ decay can give us information about the particle-antiparticle nature of neutrinos, as well as information on their mass nature.



The CUORE Upgrade with Particle Identification (**CUPID**) [1], is a next-generation $0\nu\beta\beta$ decay experiment that will use ^{100}Mo as the candidate isotope. With a 3σ discovery sensitivity of 1×10^{27} yr, corresponding to an $m_{\beta\beta}$ range of 12-20 meV, CUPID will be able to probe the full inverted hierarchy region.

Cosmogenic Muons as CUPID Backgrounds

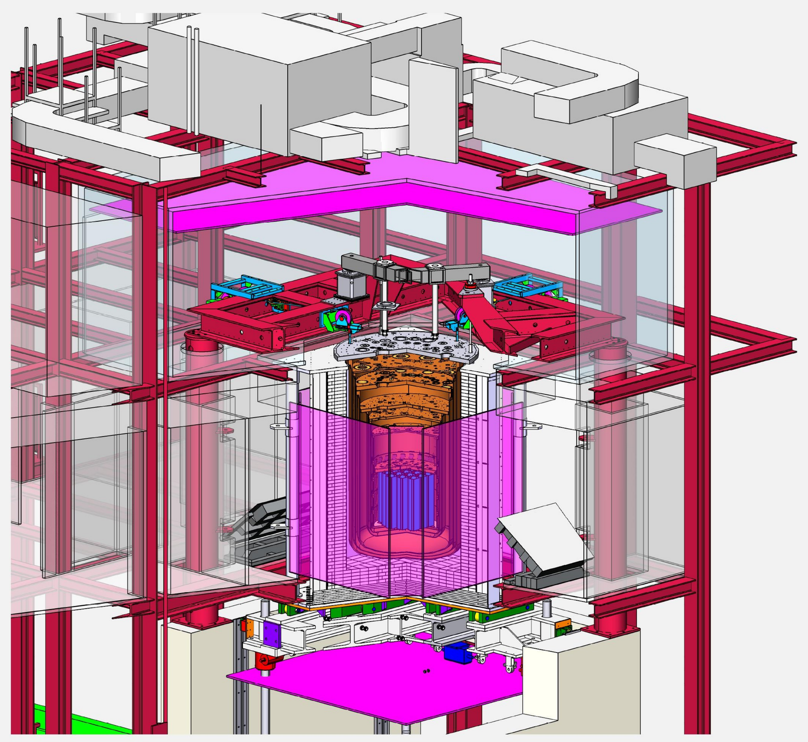


Above: Background Index (B.I.) budget for CUPID.

- In order to achieve its science goal, CUPID's Background Index (B.I.) needs to be $< \mathcal{O}(10^{-4})$ counts/(keV kg yr) [ckky].
- One of those backgrounds are cosmogenic-muon events. They fall into two categories:
  - Direct energy deposition in crystals.
  - Neutrons from muon-induced spallation.
- Muon distribution peaked at $\sim 30°$ from the vertical.

Muon flux at Gran Sasso Lab has been measured [2], yielding a B.I. that exceeds the background budget without any active mitigation.

Muon-veto for CUPID



Above: Proposed muon-veto infrastructure (in fuchsia).

CUPID will have a muon-veto system to mitigate muon-induced backgrounds. The requirements for such system are the following:

- Fit within current CUORE's infrastructure.
- Minimal disruption to CUORE.
- Geometrical coverage efficiency > 99.9%.

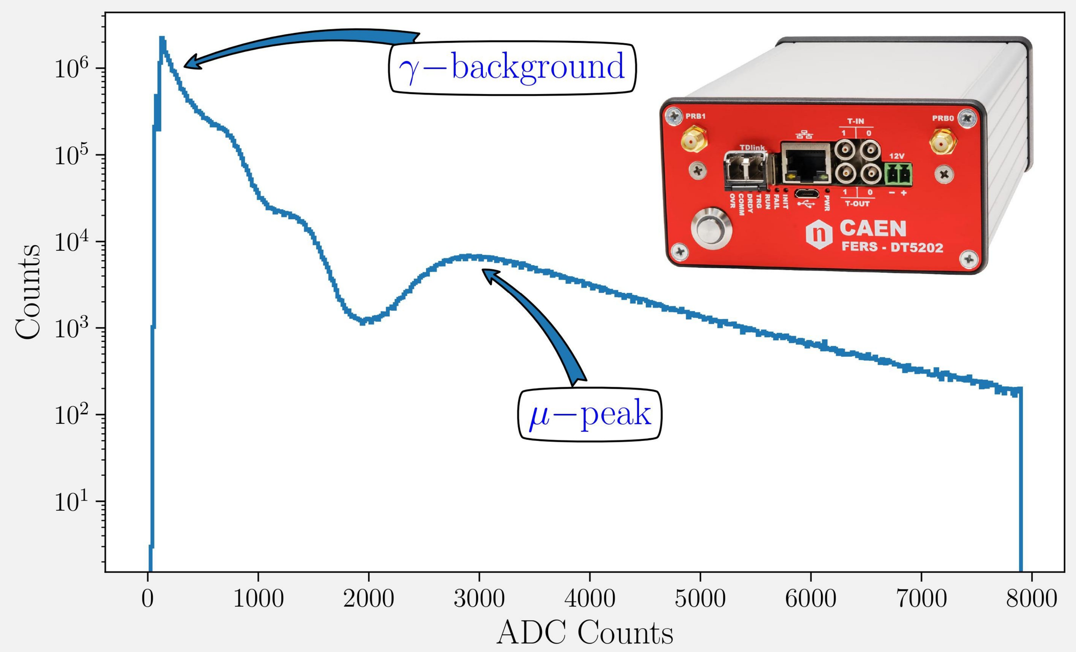
The system will be composed of single modules surrounding the detector, as well as above/below it.

Single Module Design

We require the single modules composing the veto system to satisfy the following:

- Enough light-yield to correctly identify muons vs. gamma events.
- Uniform light collection.
- Dimensions that allow their installation within CUORE's infrastructure.

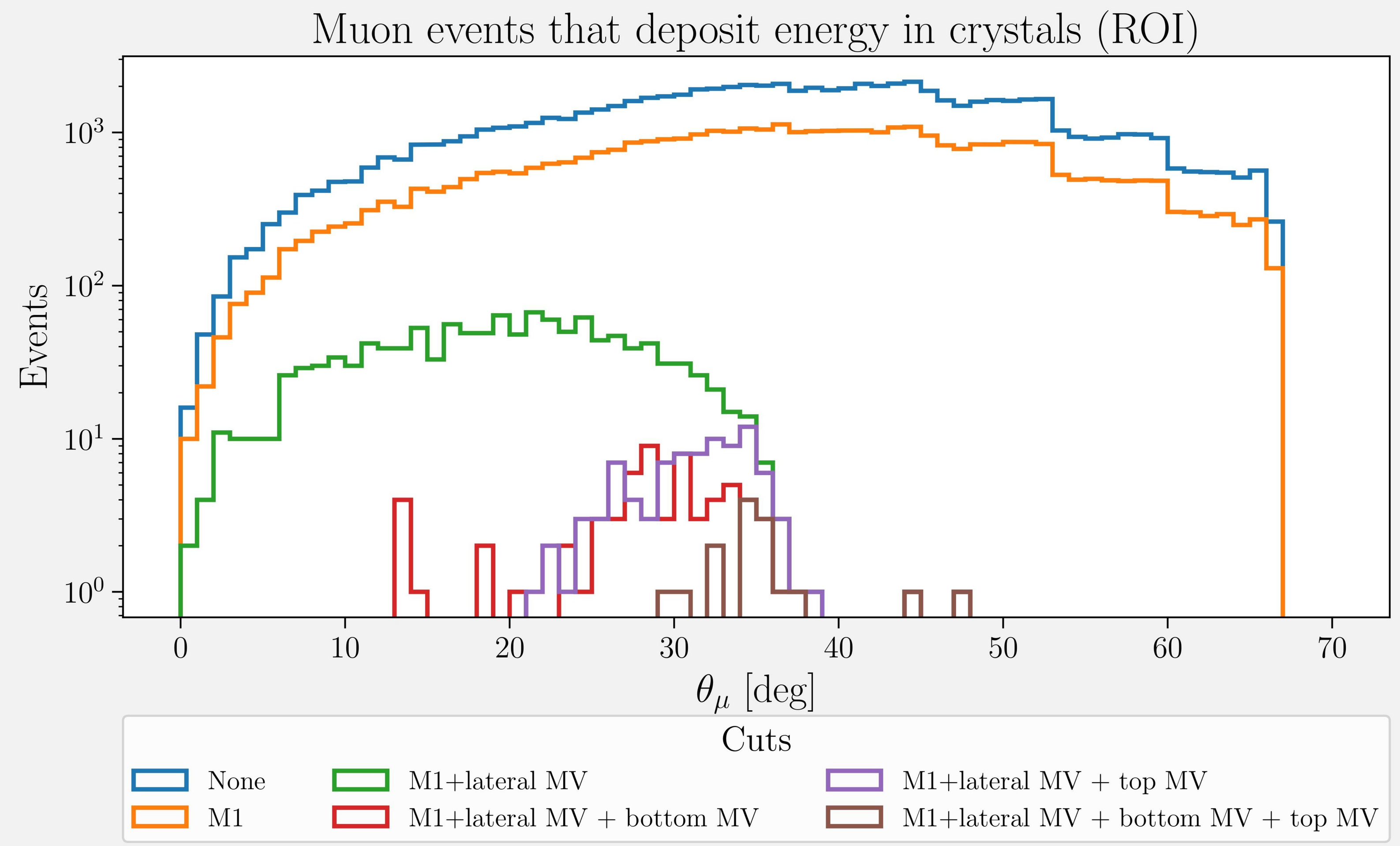
A prototype was built with a wavelength shifting fiber embedded into a 25 cm × 25 cm × 2.54 cm scintillator panel, and coupled to a silicon photomultiplier. Measurements were done at Yale.



Left: Measured spectra as a function of ADC counts, CAEN DT5202 (used for data-taking) embedded in the plot. **Right:** Prototype setup under UV-light.

- Measurements yield a preliminary light collection of ~60 P.E./MeV, which corresponds to a γ/μ discrimination efficiency of > 99.9%
- `Geant4`-based simulation package to optimize prototype currently under development.

Conclusion + Future Work



Above: Simulated events as a function of the muon direction. In different colors we show events that pass different cuts for different geometries. M1 = multiplicity one events.

Configuration (w/M1 cut)	B.I. in ROI [ckky]	Efficiency [%]
Only lateral	3.699×10^{-5}	98.408
Lateral + top	2.734×10^{-6}	99.882
Lateral + bottom	1.983×10^{-6}	99.915
Lateral + bottom + top	4.507×10^{-7}	99.981

- The integration of a muon-veto system is essential for CUPID's physics program.
- The current prototype for the single module achieves the required γ/μ discrimination efficiency.
- Simulations demonstrate that current single module performance + coverage efficiency meet needed background rejection.
- Structural design options are currently under discussion.
- We plan to implement this system in CUORE within the next year.

References:

[1] W. R. Armstrong et al. (CUPID), "CUPID pre-CDR", (2019).
[2] G. Bellini et al. (Borexino), "Cosmogenic Backgrounds in Borexino at 3800 m water-equivalent depth", JCAP **08**, 049 (2013).

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