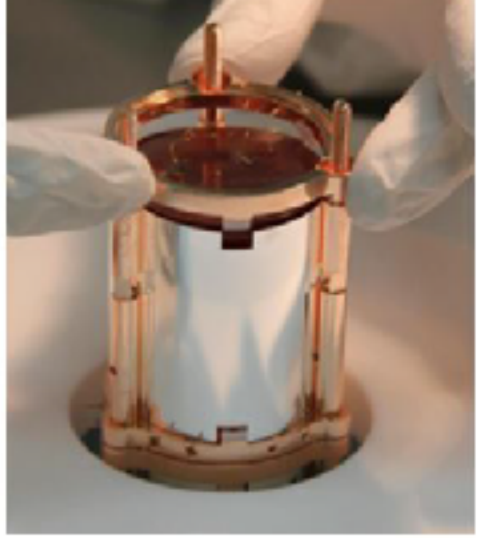
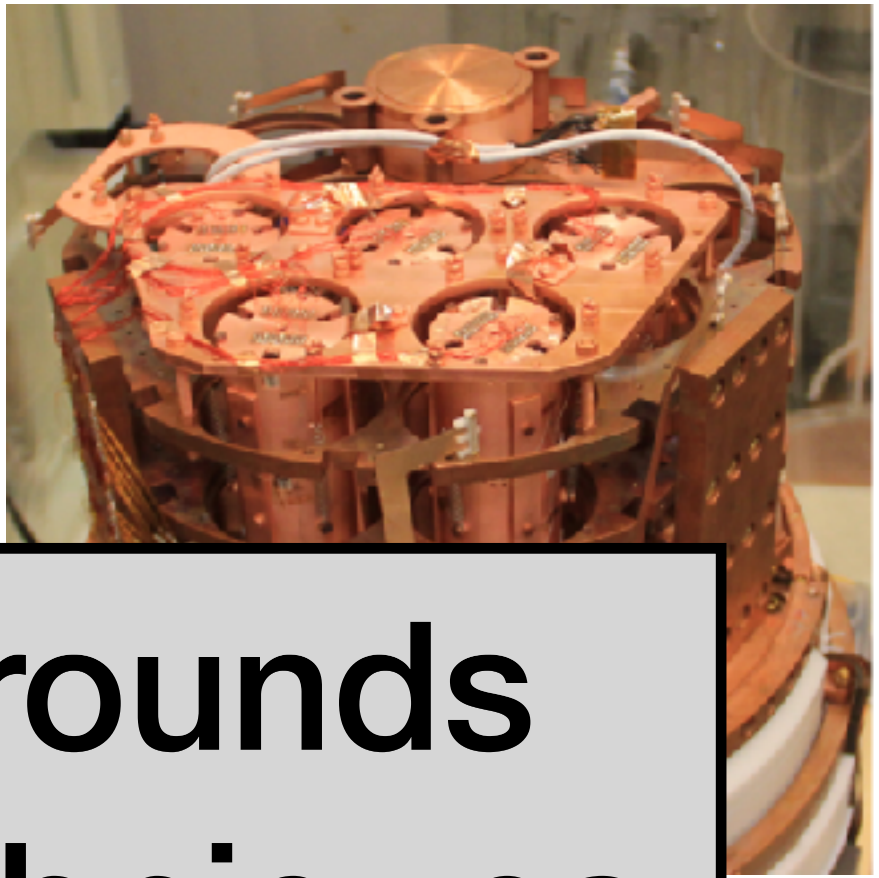
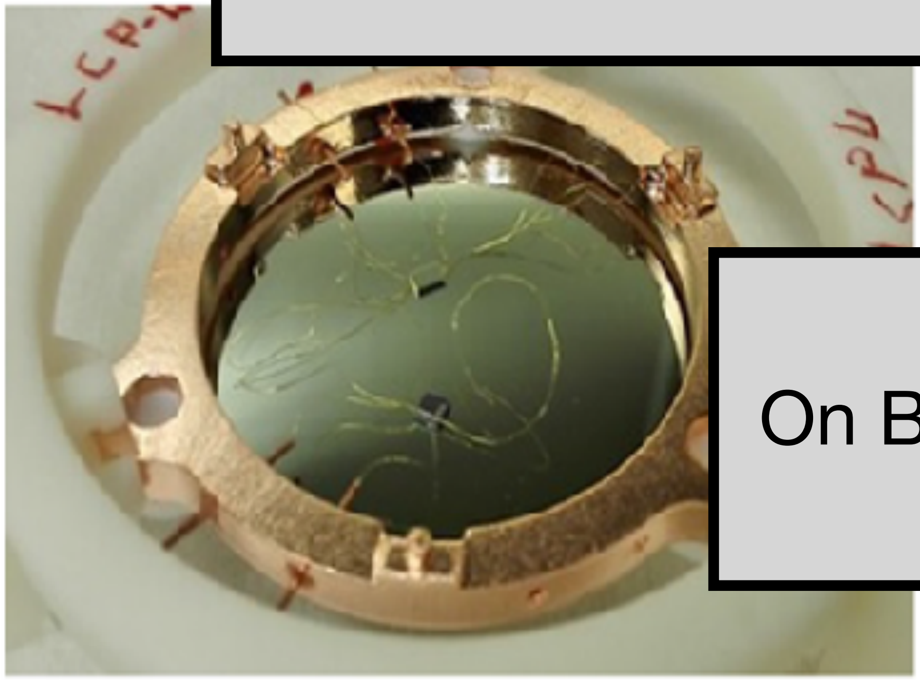




Projected Backgrounds and Mitigation Techniques for the CUPID Experiment



Samantha Pagan
On Behalf of the CUPID Collaboration
Yale University

CUORE and CUPID Talks at DNP2020

CUORE Talks

FG.00004: Studying CUORE Pulses with Principal Component Analysis Roger Huang(University of California, Berkeley)
FG.00006: Analysis Techniques for Background Reduction and Event Identification in the Search for Neutrinoless Double Beta Decay with CUORE Pranava Teja Surukuchi (Yale University)
KG.00005: Searching for Neutrinoless Double Beta Decay in CUORE using Multi-Site events Sachinthya Wagaarachchi (University of California, Berkeley)
KM.00001: Neutrinoless double beta decay and the search for neutrino mass Erin Hansen (Department of Physics, UC Berkeley)
SK.00009: Noise Correlation with Acoustic Signals in CUORE Kenneth Vetter (University of California, Berkeley)

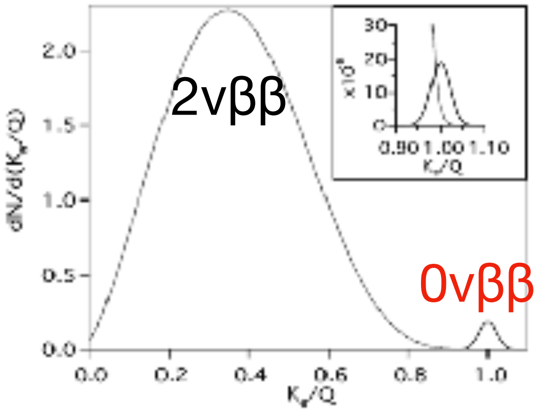
CUPID Talks

FG.00003: Mock data production for pileup rejection studies in CUPID Mattia Beretta
FG.00005: Projected Backgrounds and Mitigation Techniques for the CUPID Experiment Samantha Pagan (Yale University)
KG.00003: A detailed background model for the CUPID-Mo `$0 \nu \beta \beta$` experiment Toby Dixon (University of California, Berkeley)
KN.00007: Performance and optimization of transition-edge sensor based photon detectors for CUPID Vivek Singh (University of California, Berkeley)
LM.00003: New Results in the search for `$0\nu\beta\beta$` decay in `$^{100}$`Mo from CUPID-Mo Bradford Welliver (Lawrence Berkeley National Laboratory)

CUORE to CUPID

Neutrinoless double beta decay searches

$$(A,Z) \rightarrow (A,Z+2) + 2e^- \cancel{+ 2\bar{\nu}_e}$$



Annu. Rev. Nucl. Part. Sci. 2002.52:115-151

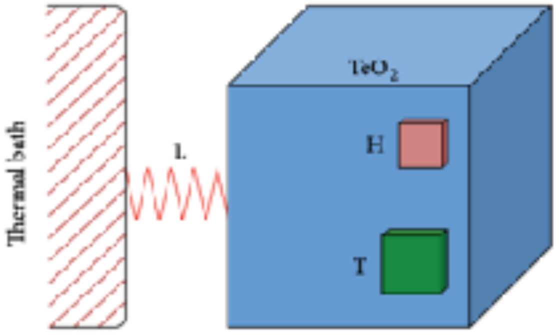
CUORE: The Cryogenic Underground Observatory for Rare Events

Source/detector material: ^{130}Te

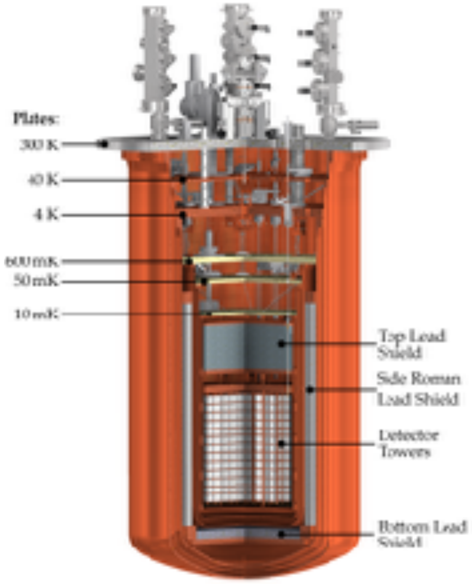
Signal: Peak at 2528 keV

Bolometers: Low temperature Calorimeters

CUORE Cryostat operating at ~10mk



Bolometer



CUORE Cryostat

CUPID: CUORE Upgrade with Particle IDentification

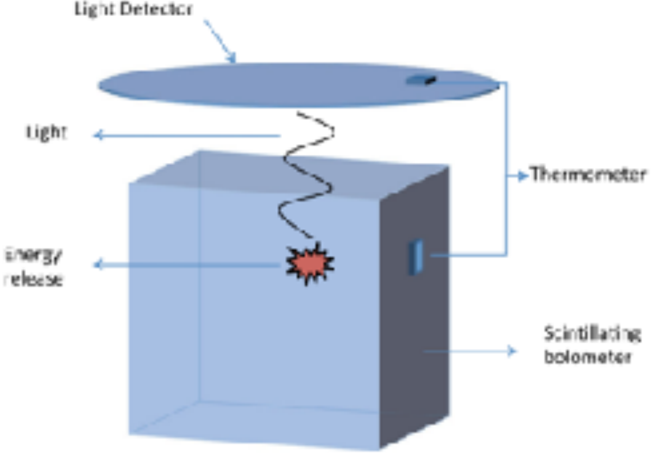
Source/Detector Material Proposed: ^{100}Mo, and other possible sources

Signal: Peak at 3035 KeV for ^{100}Mo

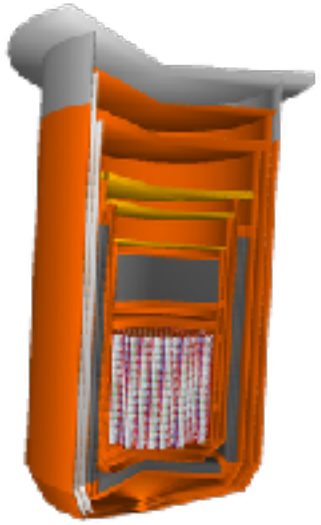
Scintillating Bolometers

CUORE Cryostat operating at ~10mk

Light detector



Scintillating bolometer



CUPID Cryostat

Other demonstrators: Cuoricino, CUORE-0, CUPID-0, CUPID-Mo

Sensitivity from CUORE to CUPID

Current CUORE Sensitivity: $m_{\beta\beta}$ of **75-350 MeV** [arXiv:1912.10966]

CUORE Background:10^{-2} counts/keV/kg/yr

CUPID Baseline Sensitivity Prediction : $m_{\beta\beta}$ of **10-17 MeV**

CUPID Baseline Background: 10^{-4} cts/keV/kg/yr

time

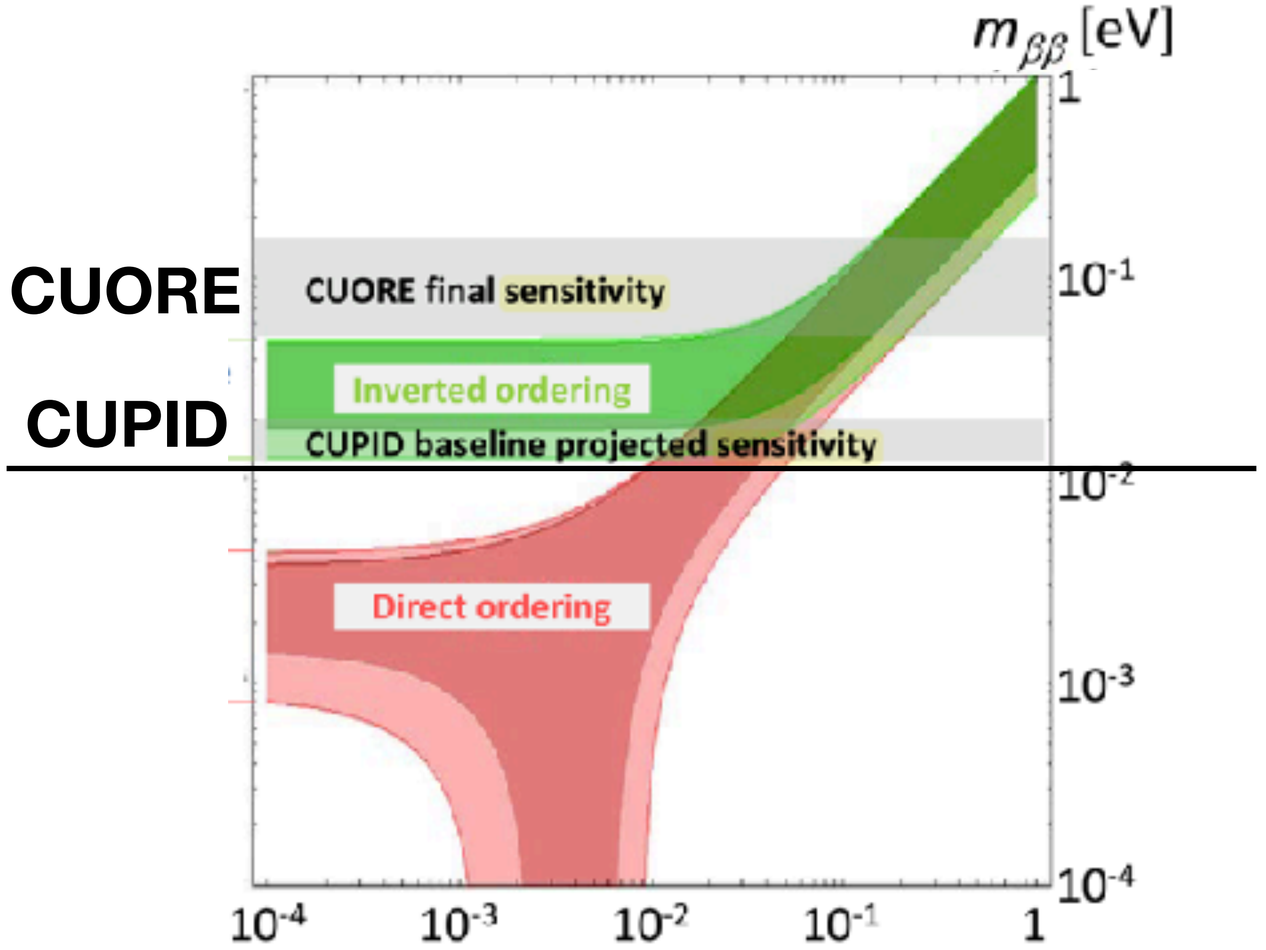
mass

$$s \propto a_I \sqrt{\frac{mt}{B\Delta E}}$$

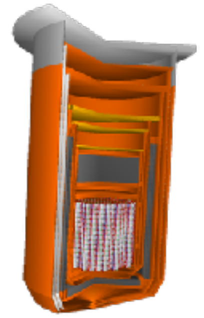
Isotopic abundance

Backgrounds

Energy Resolution

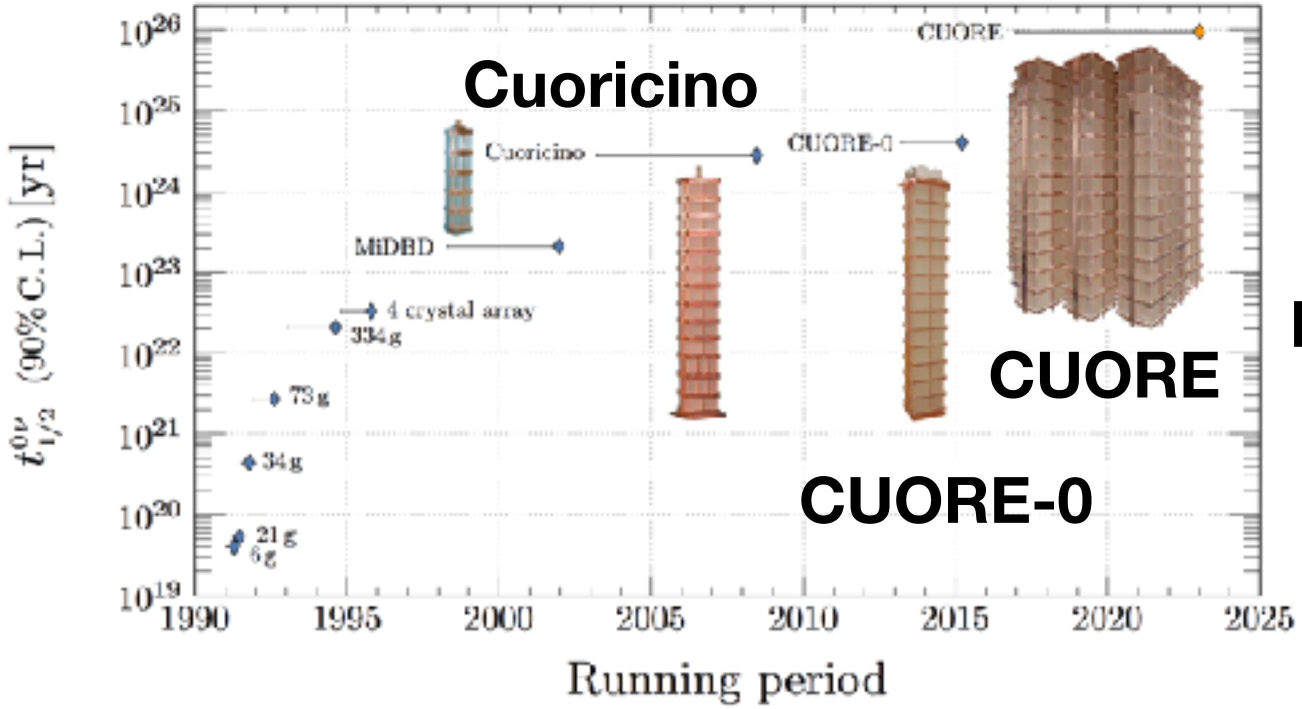


Lightest neutrino mass [eV]



CUPID Baseline

250 kg of ^{100}Mo



Predicted CUPID Backgrounds

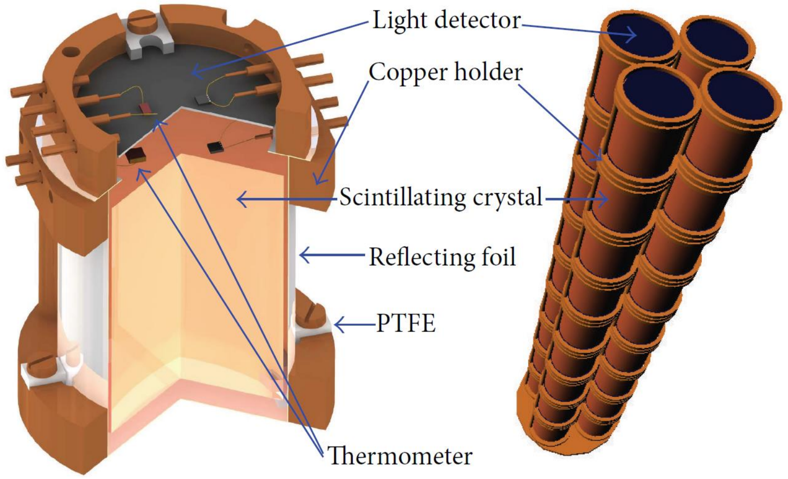
Near sources: Crystals, copper holders, reflecting foil

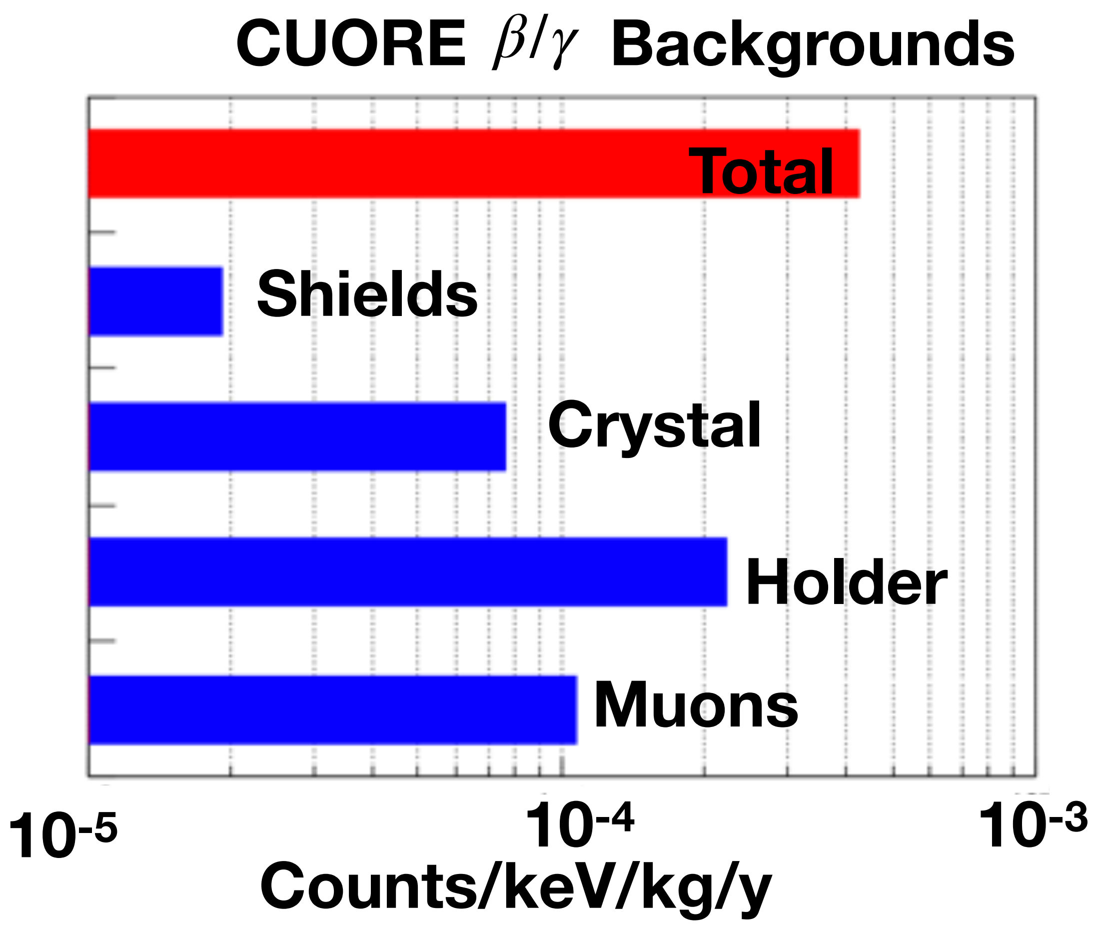
2vββ, crystal impurities, decays in ^{238}U and ^{232}Th chains

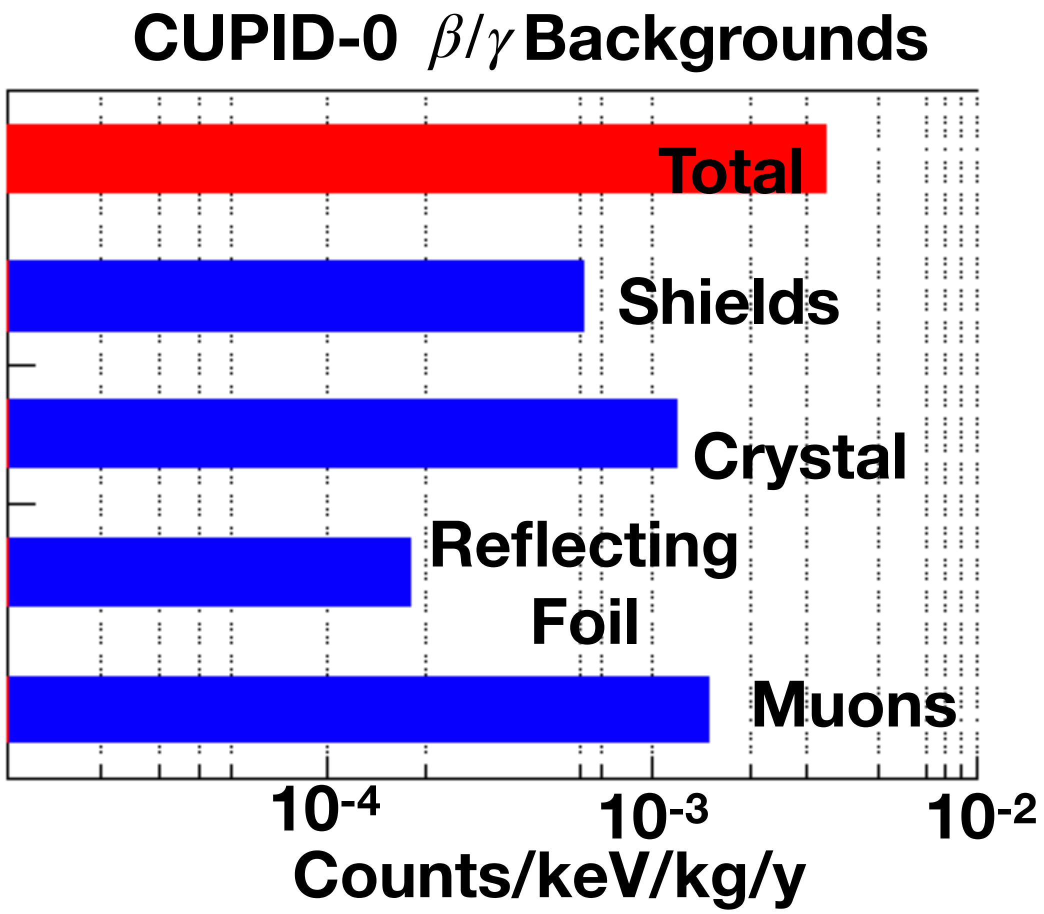
Far Sources: Shields, Cryostat

Decays in ^{238}U and ^{232}Th chains

Externals Sources: Environmental muons, γs, and neutrons







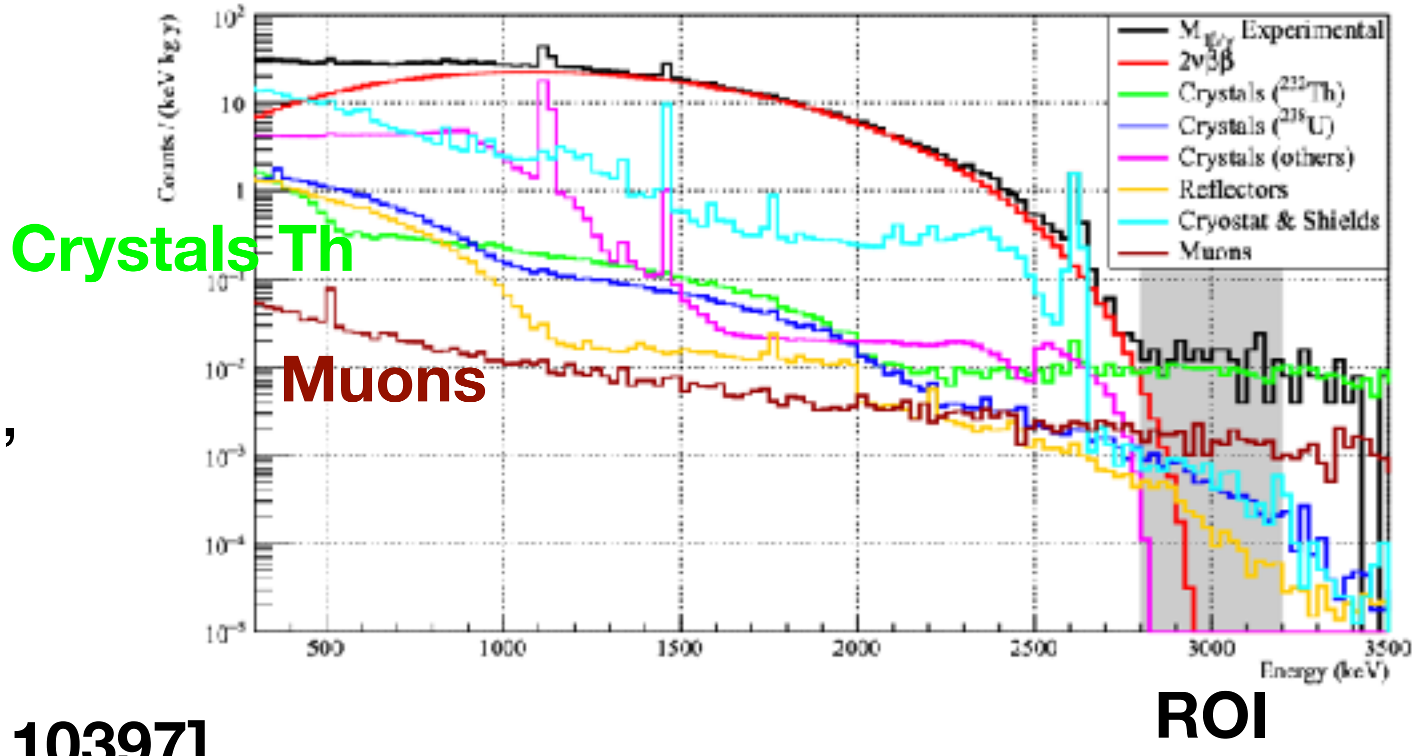
β and γ background counts in the ^{100}Mo regions of interest for CUORE (Left) and CUPID-0 (right)

Background Model for CUPID-0

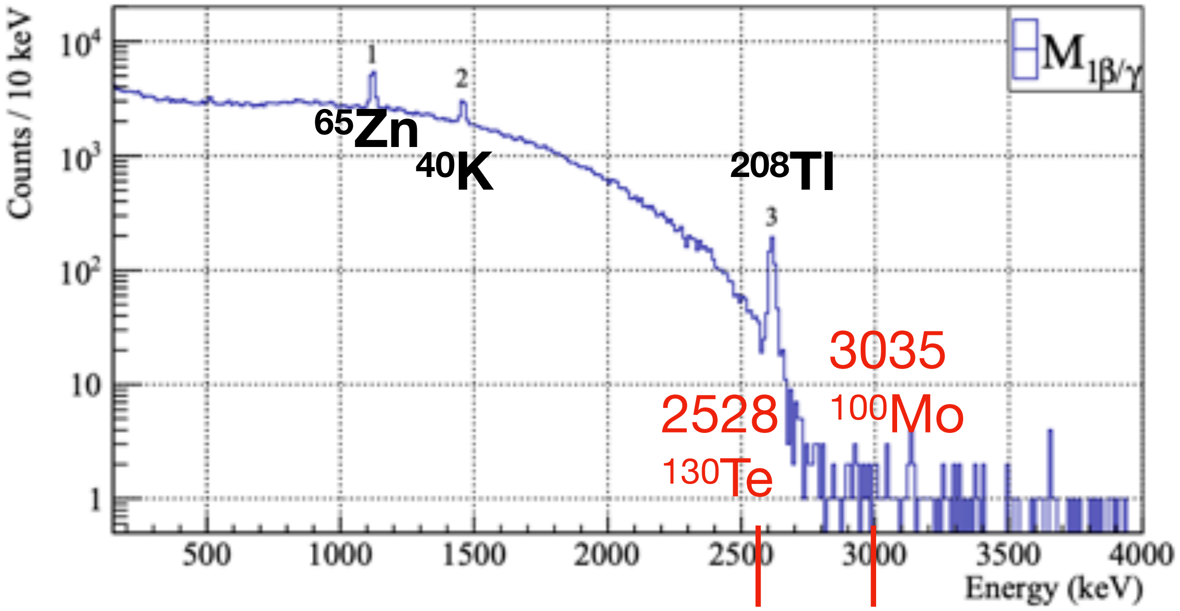
In operations since June 2017

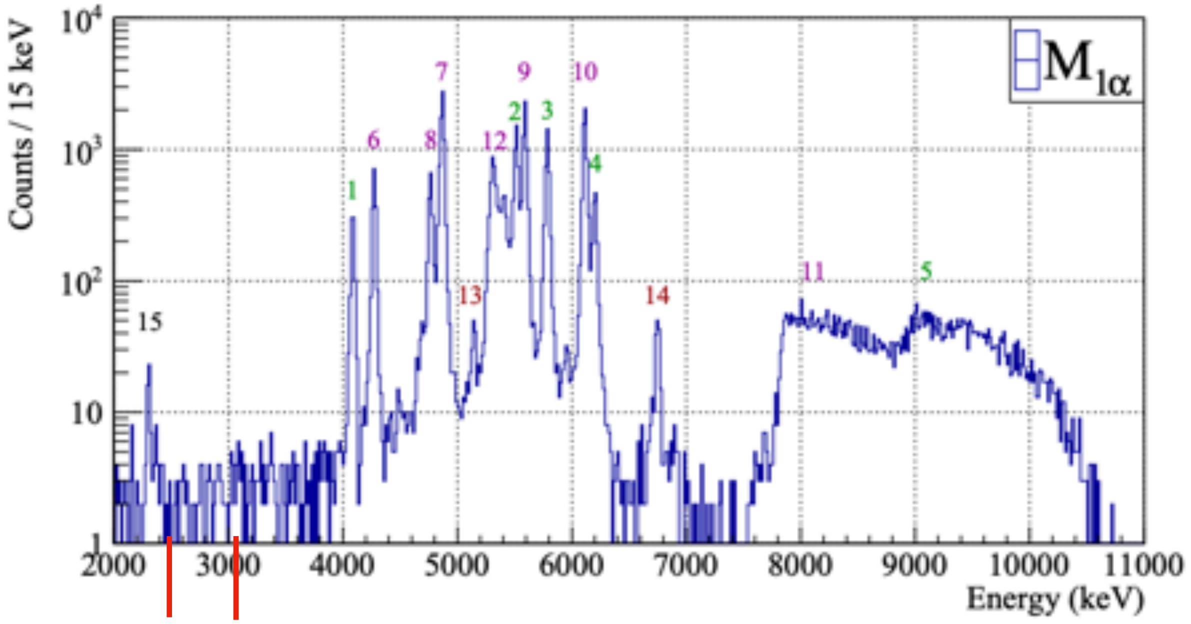
9.95 kg years

Zn^{82}Se scintillating calorimeters, Q value ^{82}Se Q-value 2997 keV compared to 3035 of ^{100}Mo



CUPID-0 2019 Spectrum [arxiv:1904.10397]





(1) ^{232}Th, (2) ^{228}Th, (3) ^{224}Ra, (4) ^{212}Bi, (5) ^{212}Bi + ^{212}Po, (6) ^{238}U, (7) ^{234}U + ^{226}Ra, (8) ^{230}Th, (9) ^{222}Rn, (10) ^{218}Po, (11) ^{214}Bi + ^{214}Po, (12) ^{210}Po, (13) ^{231}Pa, (14) ^{211}Bi, (15) ^{147}Sm

KG.00003: A detailed background model for the CUPID-Mo (Toby Dixon)

Background spectrum of Multiplicity 1 events

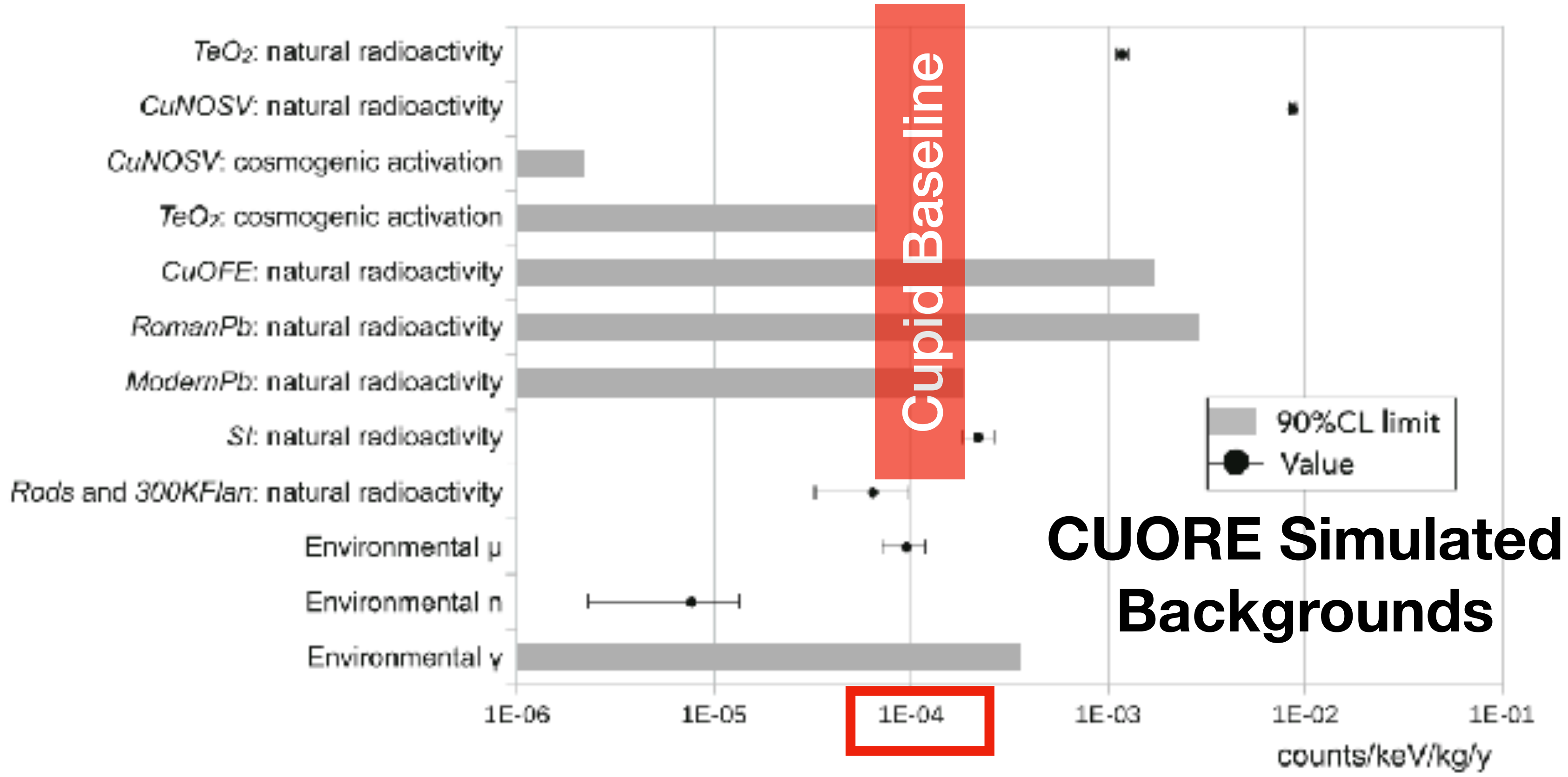
Background Mitigation Techniques

Passive Techniques

Shielding

Reducing radioactivity of materials

Creating a low radioactivity environment



CUORE Simulated Backgrounds

Active Techniques

Particle ID: Scintillating Bolometers—> Readout heat and light signals

Discriminate between α and β/γ events by pulse shape analysis

Time Veto and data analysis

Discrimination of $2\nu\beta\beta$ background, β/γ decays by their signature

Muon tagger, identification of muons tracks in data

FG.00003: Mock data production for pileup rejection studies in CUPID (M. Beretta)

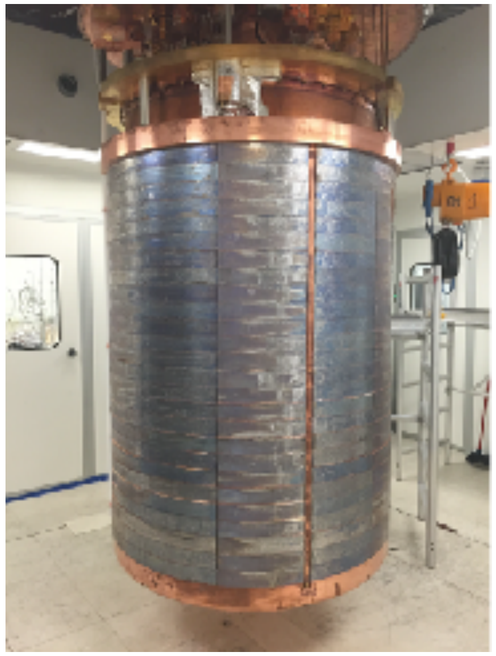
Passive Background Mitigation Techniques

Shielding

~1300 m rock overburden at LNGS

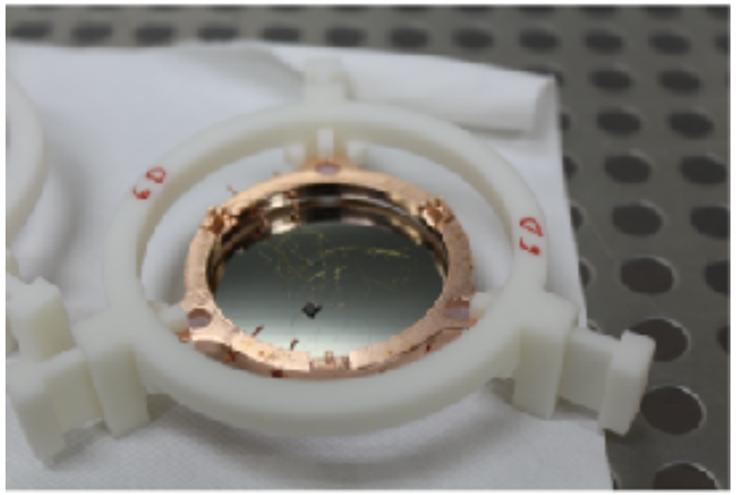
Ancient lead shielding around crystal

Copper shielding



Lead Shielding: Photograph courtesy of the CUORE collaboration

CUPID-0 Light Detector



Radio Purity of Materials and the Environment

Crystal fabrication and purification techniques

Surface cleaning

Underground storage of materials to avoid cosmogenic activation

Radon Abatement

Radio-purity Assessments

Clean Rooms, nitrogen filled gloveboxes

Construction of a CUORE tower in a Glovebox

Active Mitigation Techniques: Particle Identification Scintillating Bolometers

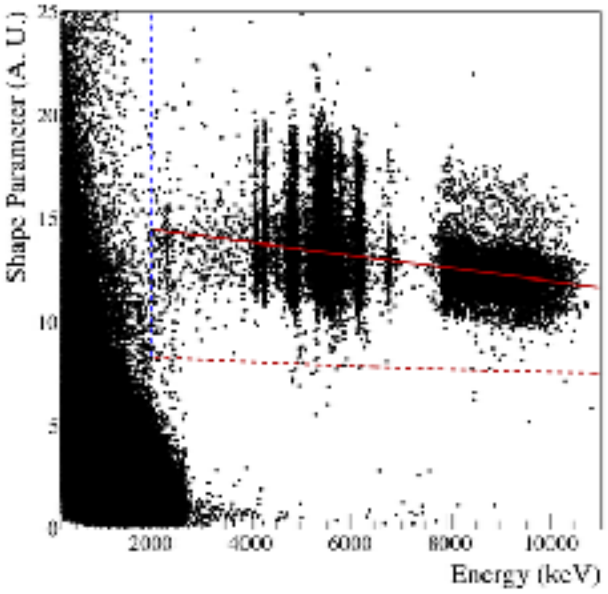
Scintillating Calorimeters give both a **heat and light signal**

CUPID-0 has demonstrated this technique for discriminating between α and β/γ events based on the pulse shape analysis

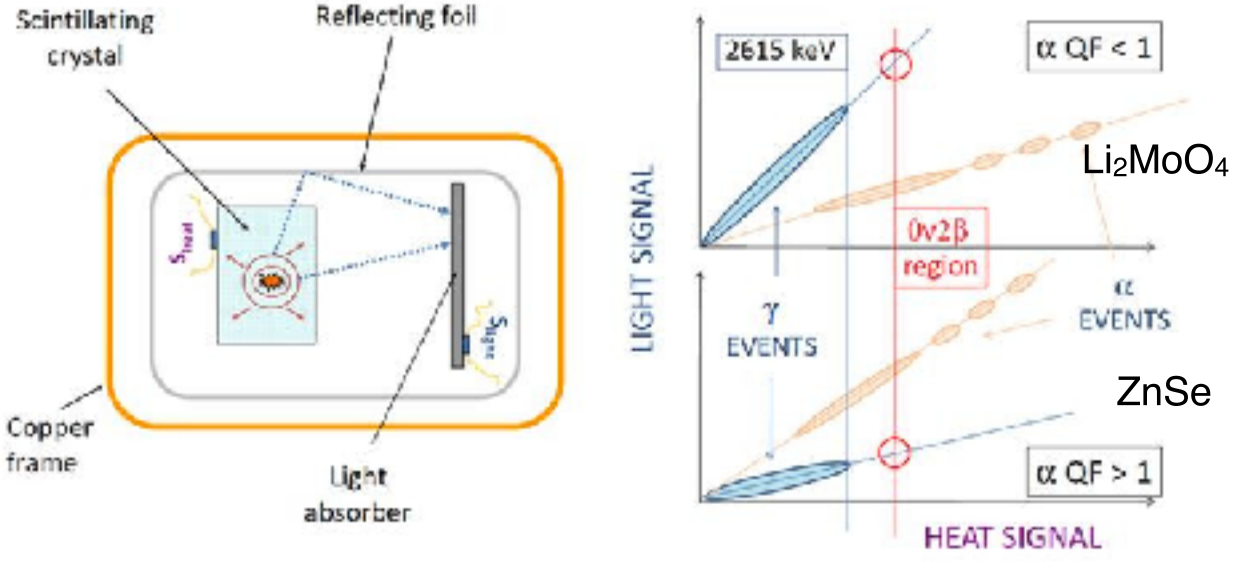
α Rejection rate of 99.9% in CUPID-Mo

Heat and light signal could also help discriminate between 2νββ signal

KN.00007: Performance and optimization of transition-edge sensor based photon detectors for CUPID (V. Singh)



Shape parameters of light pulses in CUPID-0 data to distinguish α and β/γ event



Particle Identification using the heat and light signals from a scintillating bolometer

Active Mitigation Techniques: Muon Tagging

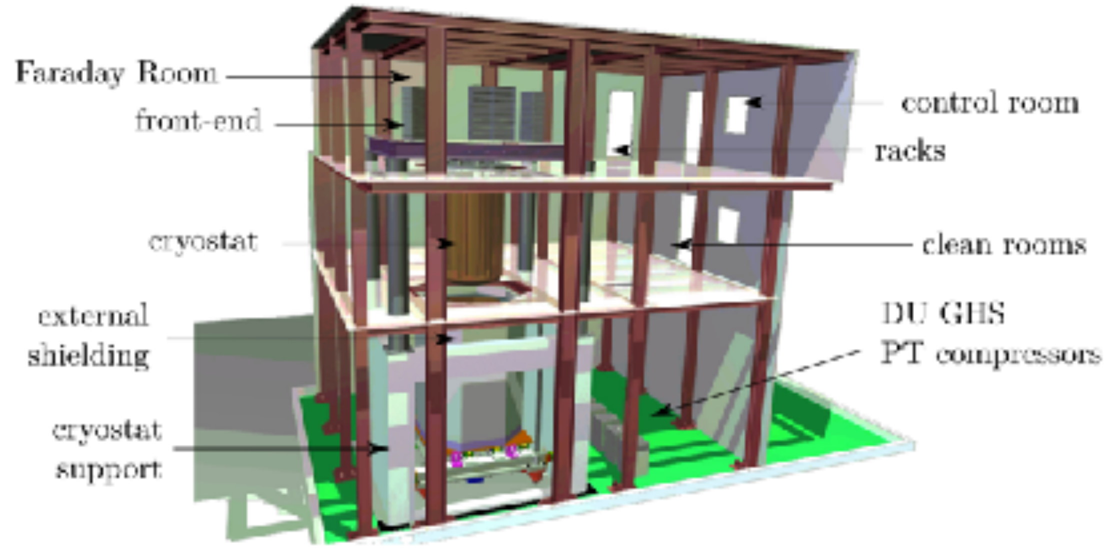
Cosmogenic muons become CUPID’s **most significant background** after upgrades

Predicted Muon Rate: is ~ 10–4 counts/(keV·kg·yr), which is **~1.8 muon/hours in the CUPID crystals, 7 muons/hour in lead shield**

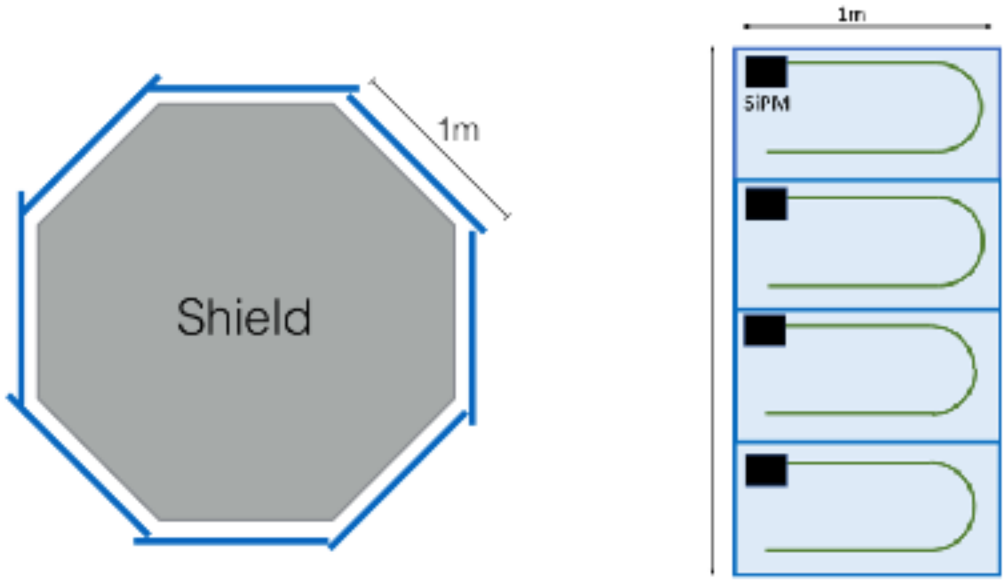
Limited space between external shielding and the surrounding environment

Goal: 99% Efficiency

Exploring modular designs of plastic scintillator panels with wavelength shifting fibers, and Silicon Photomultipliers (SiPMs) as detectors



CUORE and CUPID Hut



Preliminary design ideas for the muon tagger

Muon Veto Simulations and Prototyping

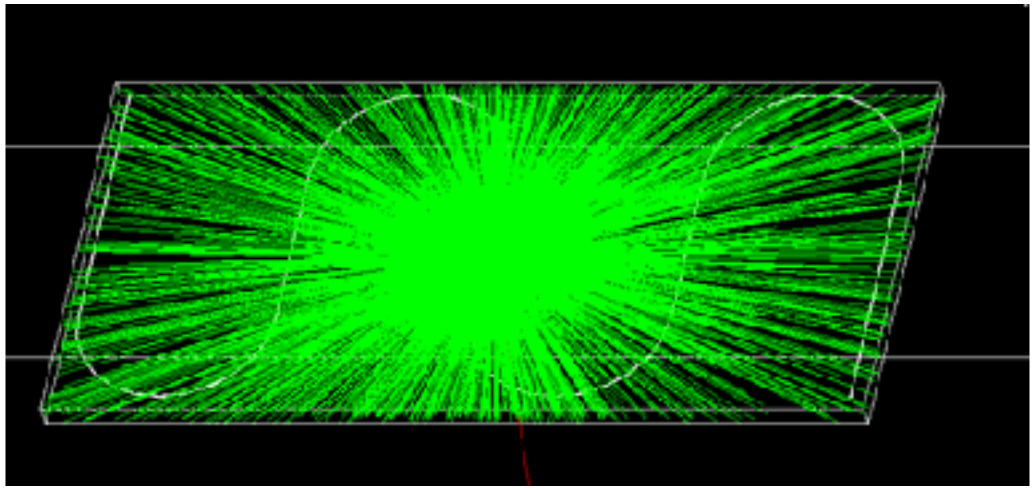
Monte Carlo simulations in Geant4 of various panels designs and geometry

Panel width, wavelength shifting fiber coverage and design, reflective material

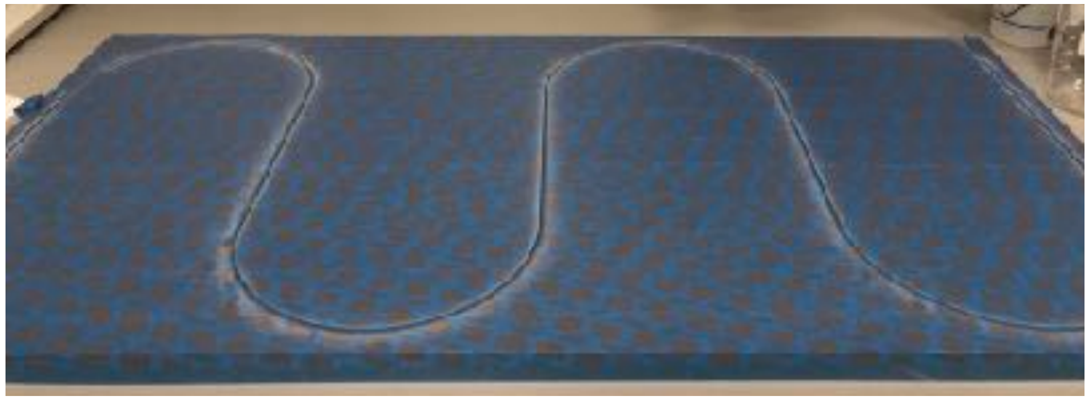
Studies of overall light yield, uniformity, efficiency

Discrimination between cosmogenic muon and radioactive backgrounds

Concurrent prototyping and testing efforts

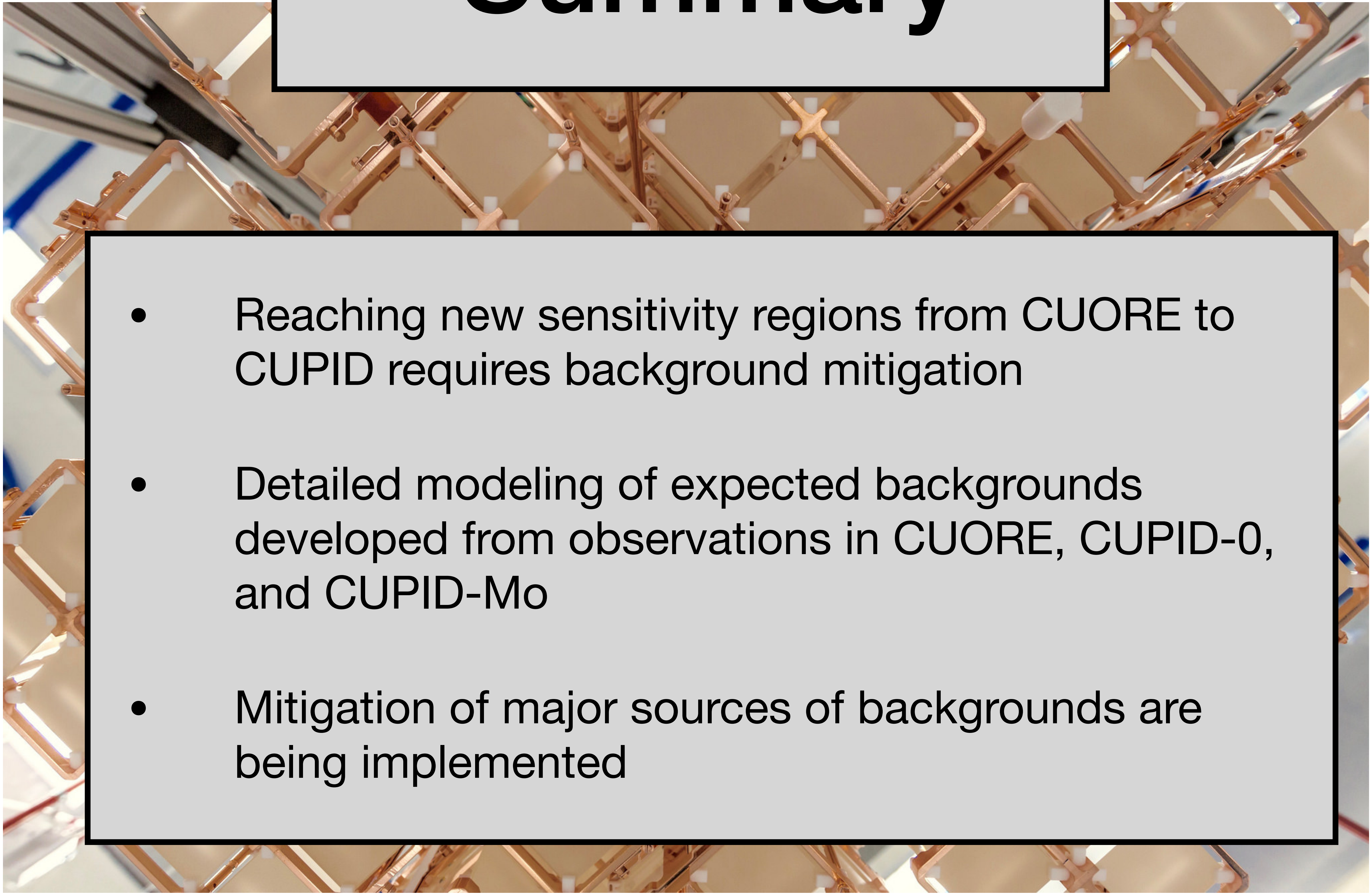


Geant4 simulation of a muon hitting a muon veto panel



Prototype of a muon veto panel

Summary



- Reaching new sensitivity regions from CUORE to CUPID requires background mitigation
- Detailed modeling of expected backgrounds developed from observations in CUORE, CUPID-0, and CUPID-Mo
- Mitigation of major sources of backgrounds are being implemented

CUPID Collaboration

CUPID pre-CDR: arXiv:1907.09376

INFN Sezione di Milano Bicocca and University of Milano Bicocca, Italy
INFN Sezione di Roma and Sapienza University of Rome, Italy
INFN Sezione di Roma and Gran Sasso Science Institute, Italy
INFN Laboratori Nazionali del Gran Sasso, Italy
INFN Sezione di Bologna and University of Bologna, Italy
INFN Laboratori Nazionali di Frascati, Italy
INFN Laboratori Nazionali di Legnaro, Italy
INFN Sezione di Padova, Italy
INFN Sezione di Genova and University of Genova, Italy
CSNSM Orsay, France
CEA Saclay, France
IPNL Lyon, France
LAL Orsay, France
SIMAP Grenoble, France
Universidad de Zaragoza, Spain
Argonne National Laboratory, USA
Lawrence Berkeley National Laboratory and University of California, Berkeley, USA
Cal Poly, San Luis Obispo, USA
Johns Hopkins University, USA
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