LATEST RESULTS FROM THE CUORE EXPERIMENT

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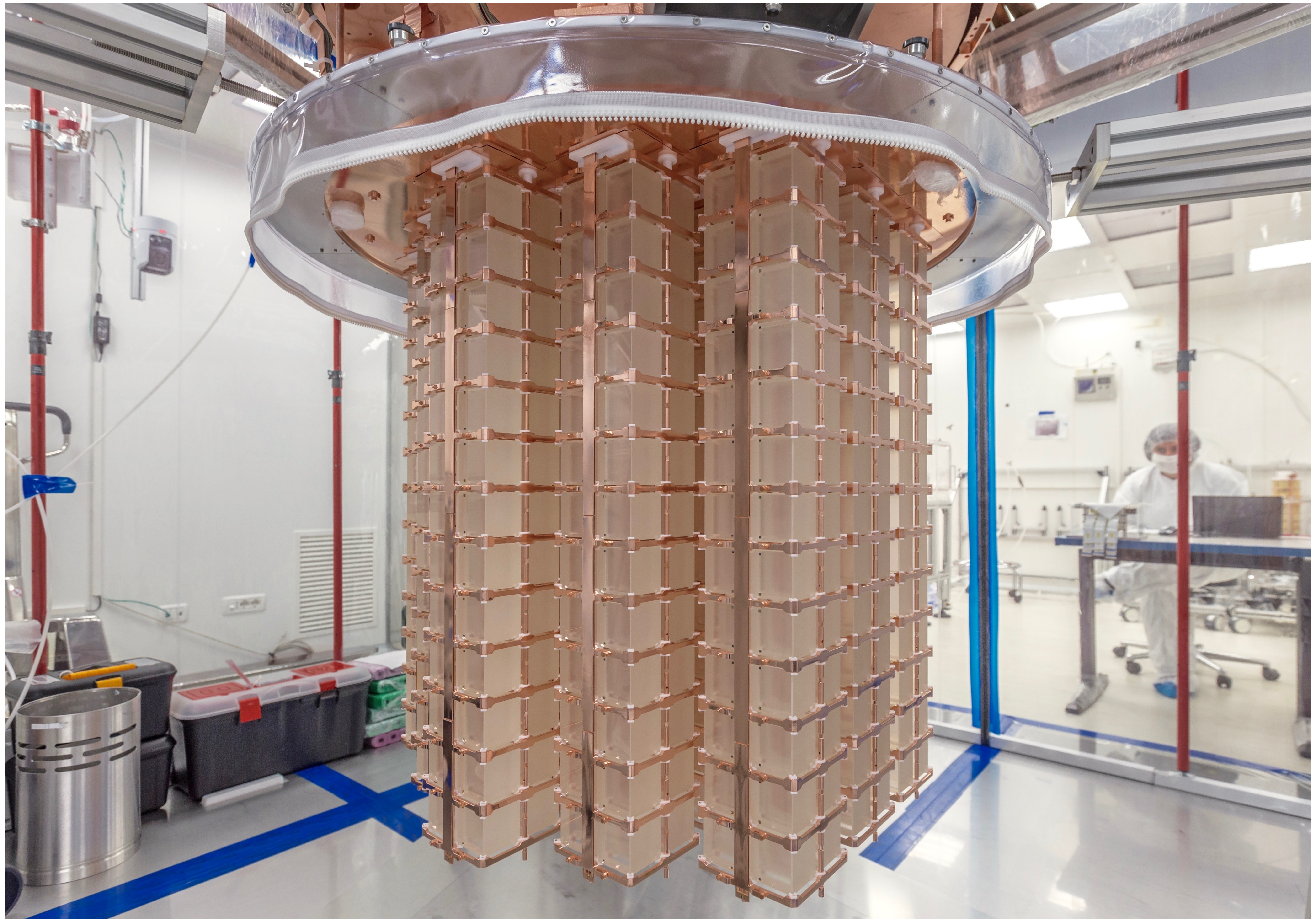
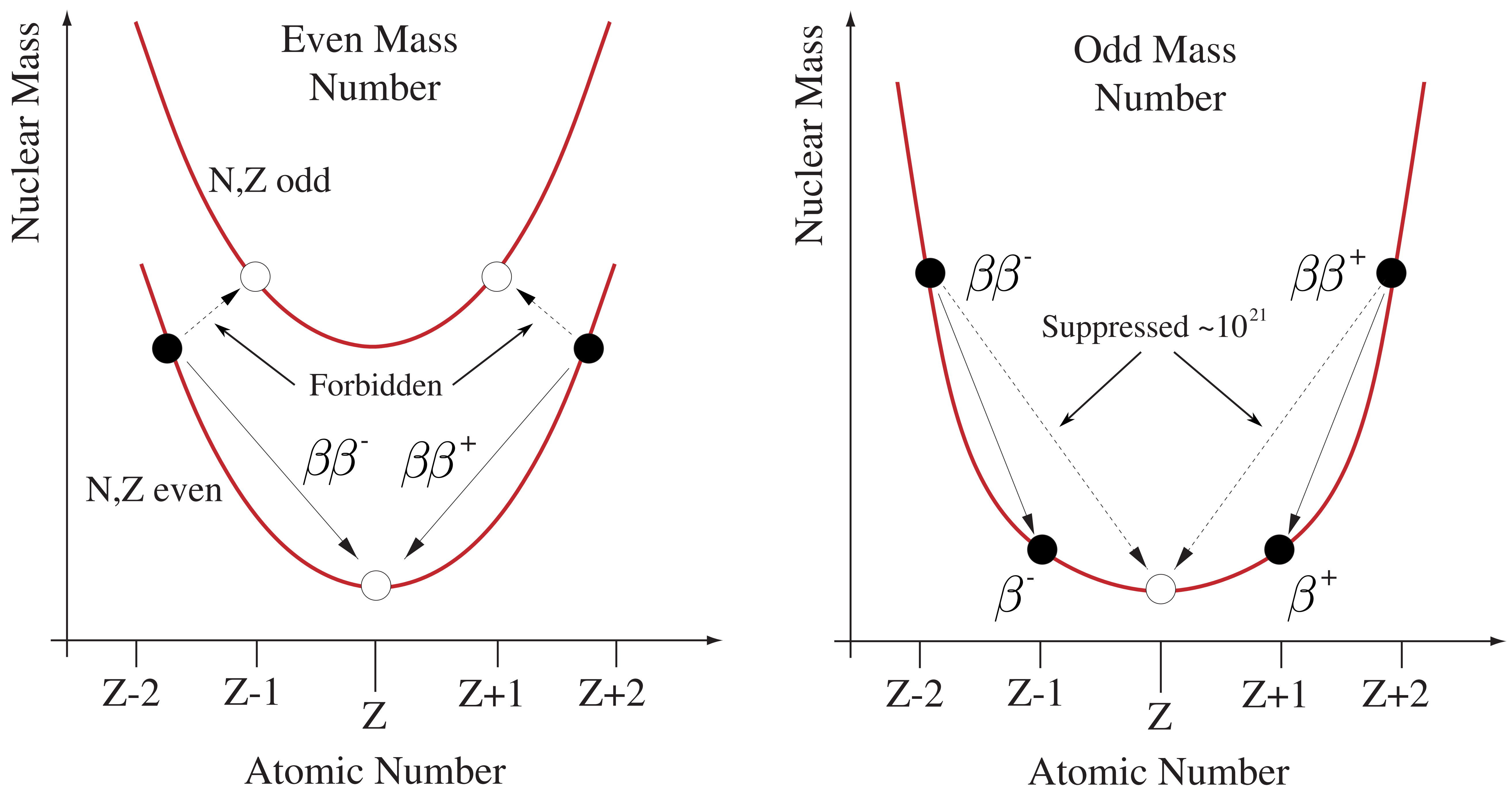
OUTLINE

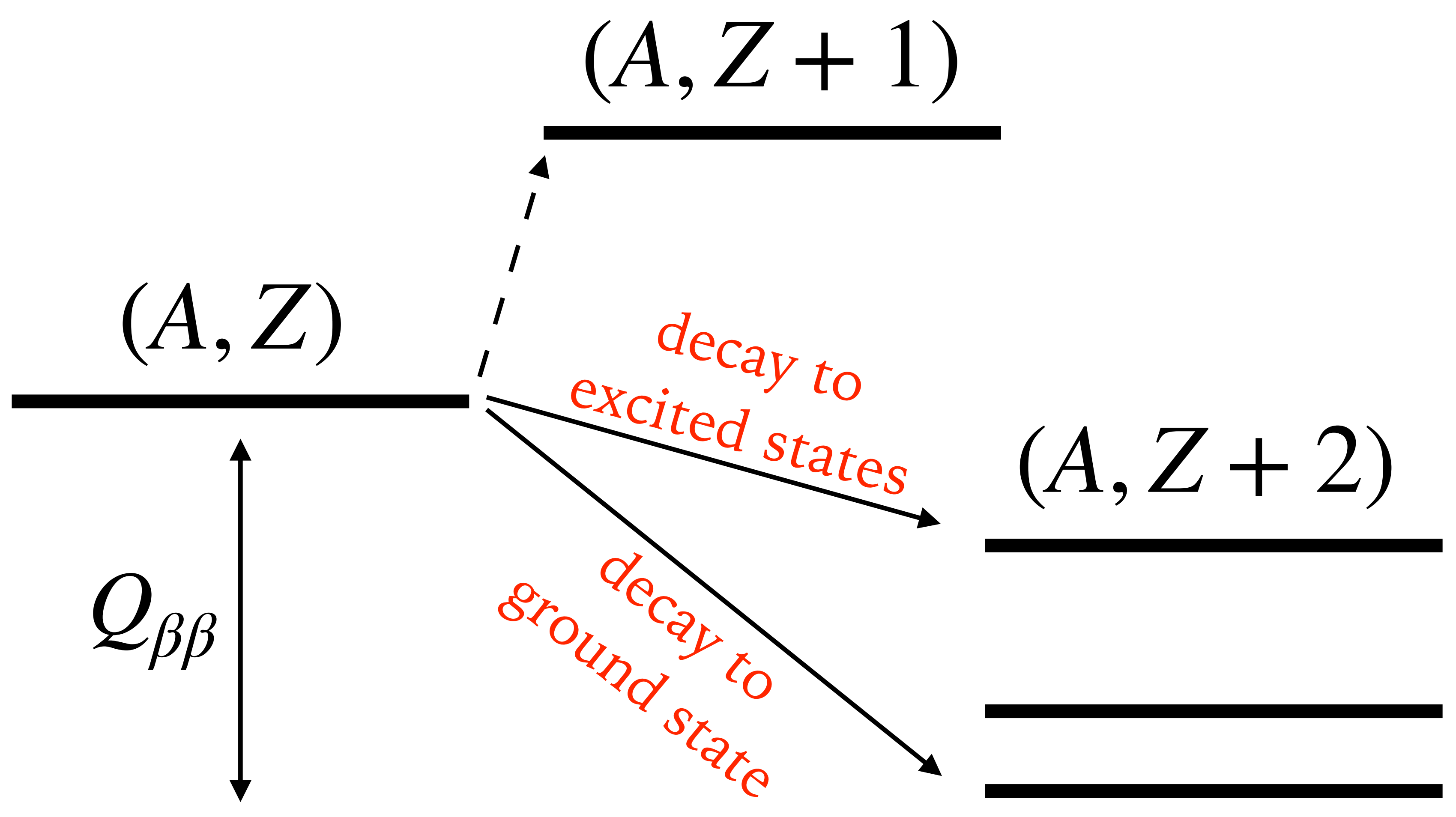
- ➤ Double Beta Decay
- ➤ The CUORE experiment
- ➤ Detector performance
- ➤ $0\nu\beta\beta$ results
- ➤ ^{130}Te half life ($2\nu\beta\beta$)
- ➤ Conclusion



DOUBLE BETA DECAY

$$(A, Z) \longrightarrow (A, Z+2) + X$$



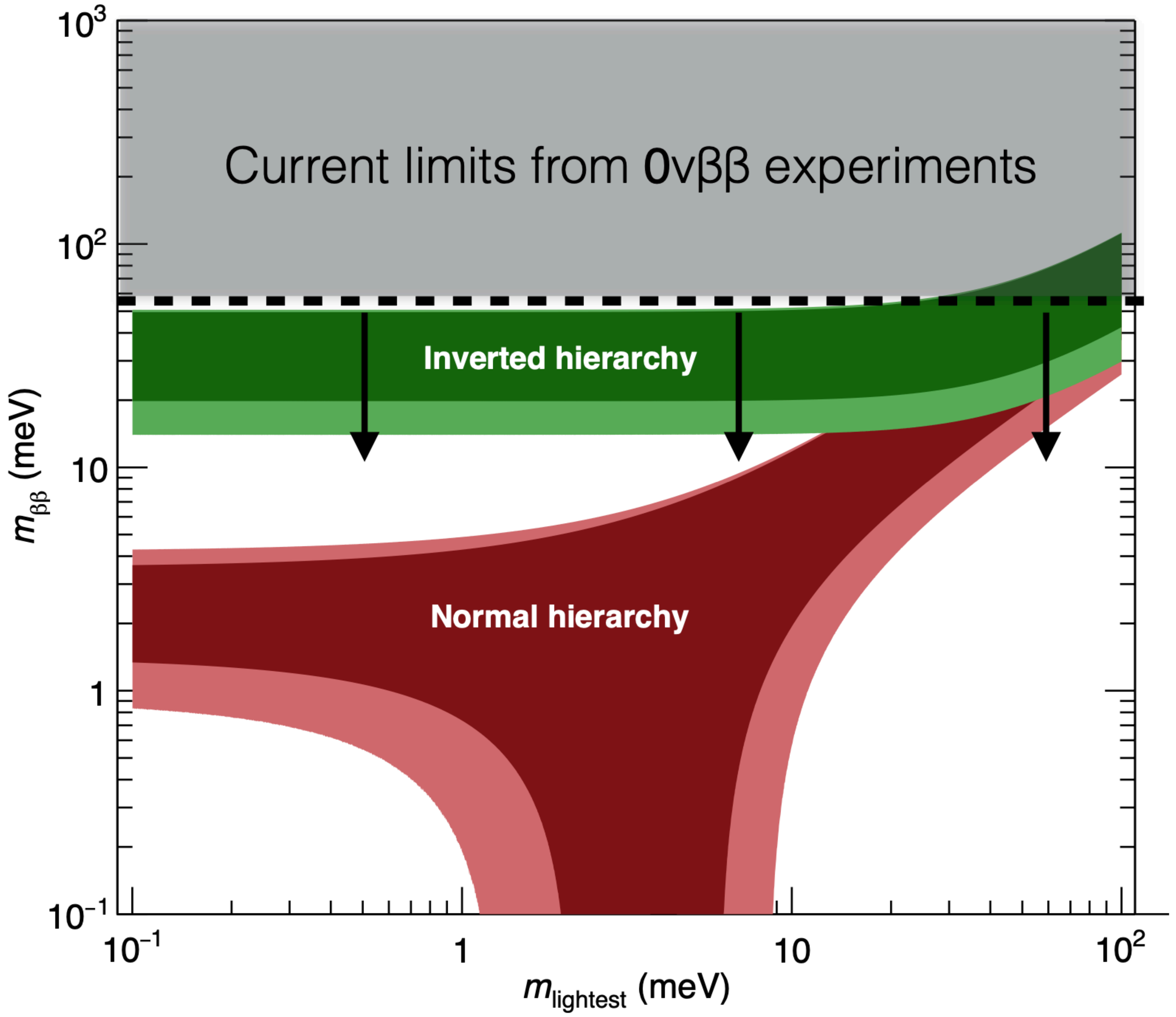


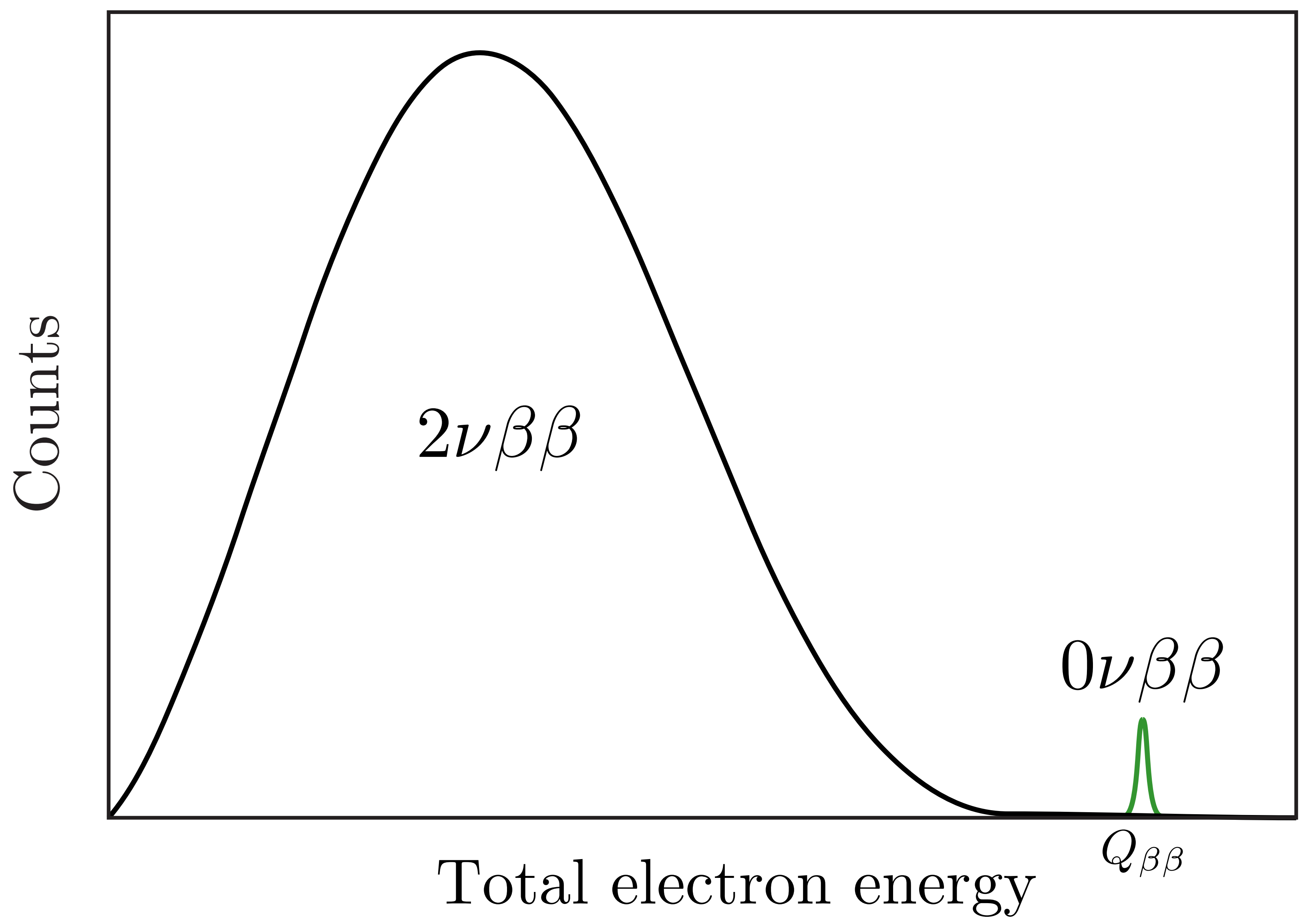
- SM 2nd order weak transition
- even-even nuclei
- half lives 10^{18} - 10^{24} yr

NEUTRINO-LESS DOUBLE BETA DECAY

- Beyond Standard Model process accommodating for Majorana neutrinos
- Lepton Number Violation ($\Delta L = 2$)
- Constraints on neutrino mass hierarchy and scale
- Hints on origin of matter/anti-matter asymmetry
- Experimental signature: peak at $2\nu\beta\beta$ endpoint

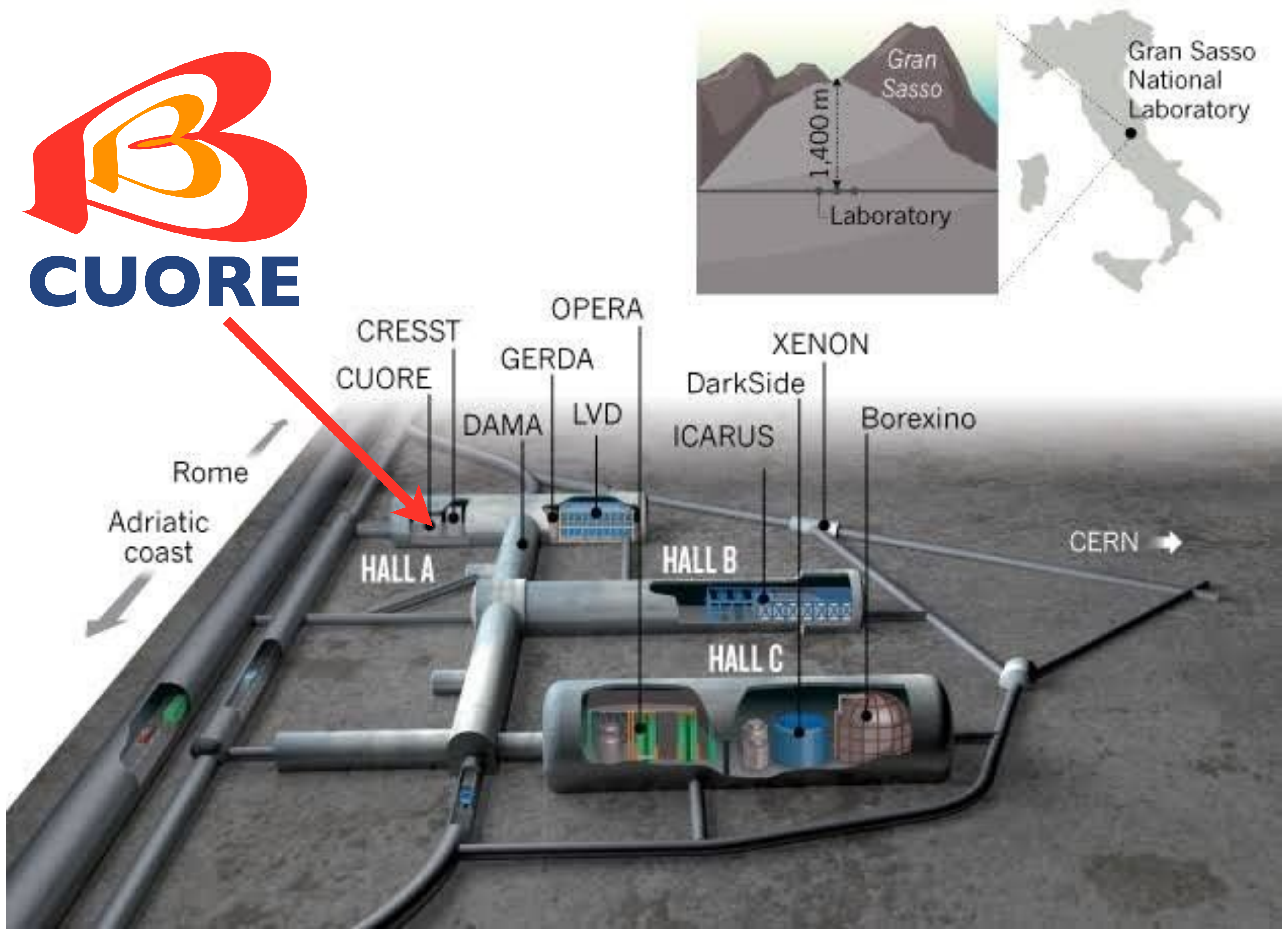
$$\Gamma_{0\nu} = G_{0\nu} |M_{0\nu}|^2 \frac{\langle m_{\beta\beta} \rangle^2}{m_{ee}}$$

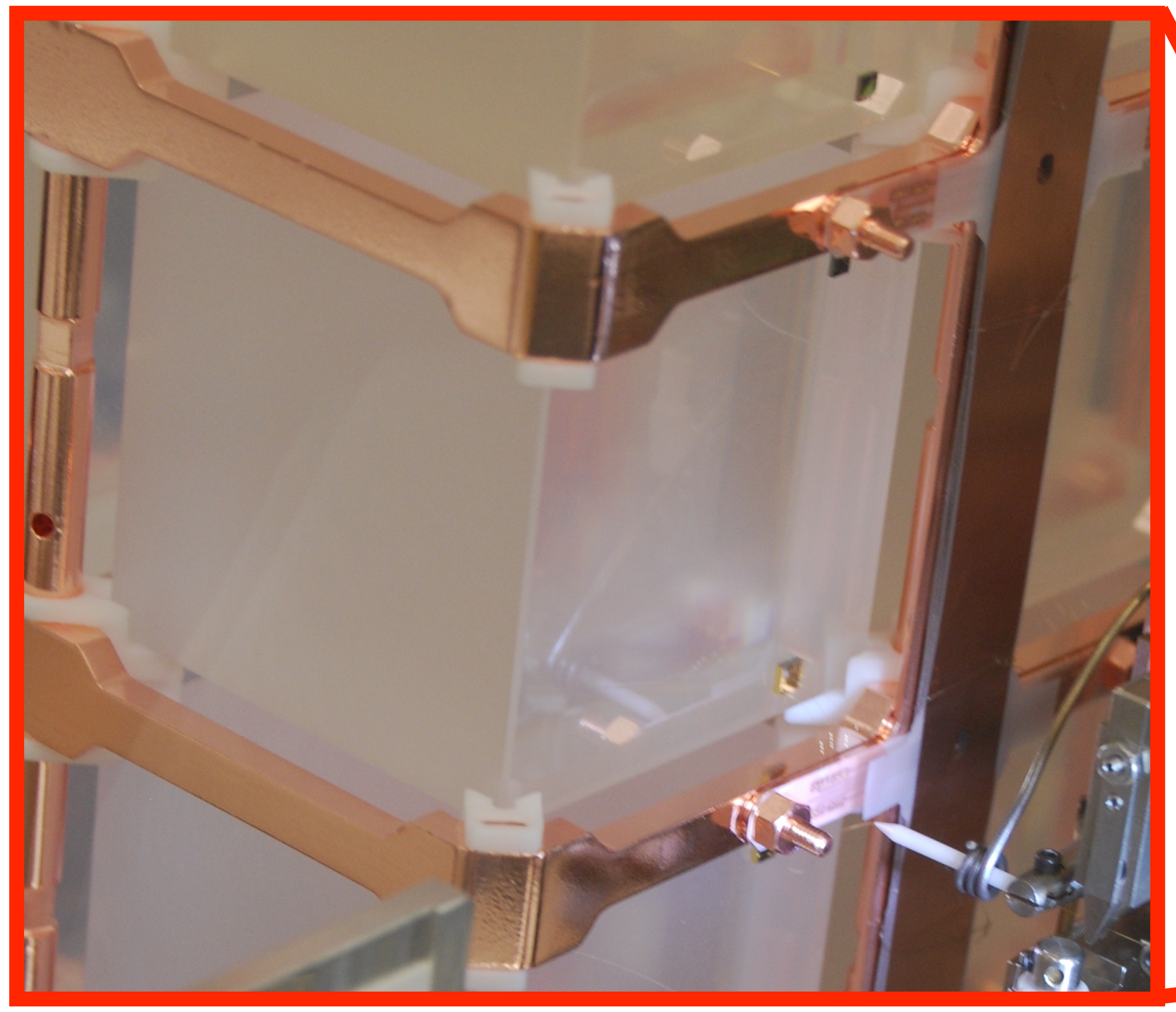


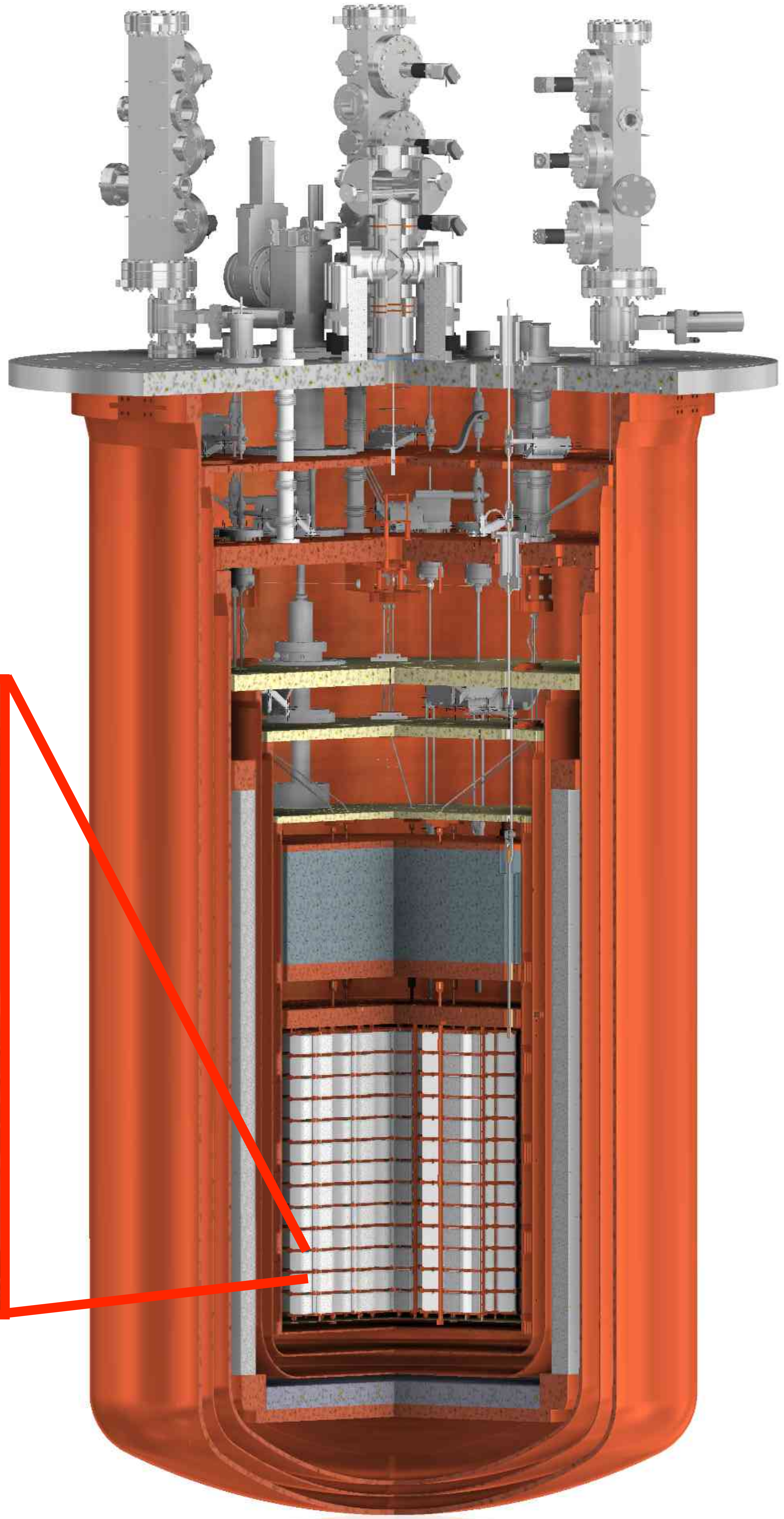


THE CUORE EXPERIMENT

- Cryogenic Underground Observatory for Rare Events
- 988 $^{nat}TeO_2$ crystals at ∼10 mK
- 742 kg TeO_2 , 206 kg ^{130}Te (34% natural isotopic abundance)



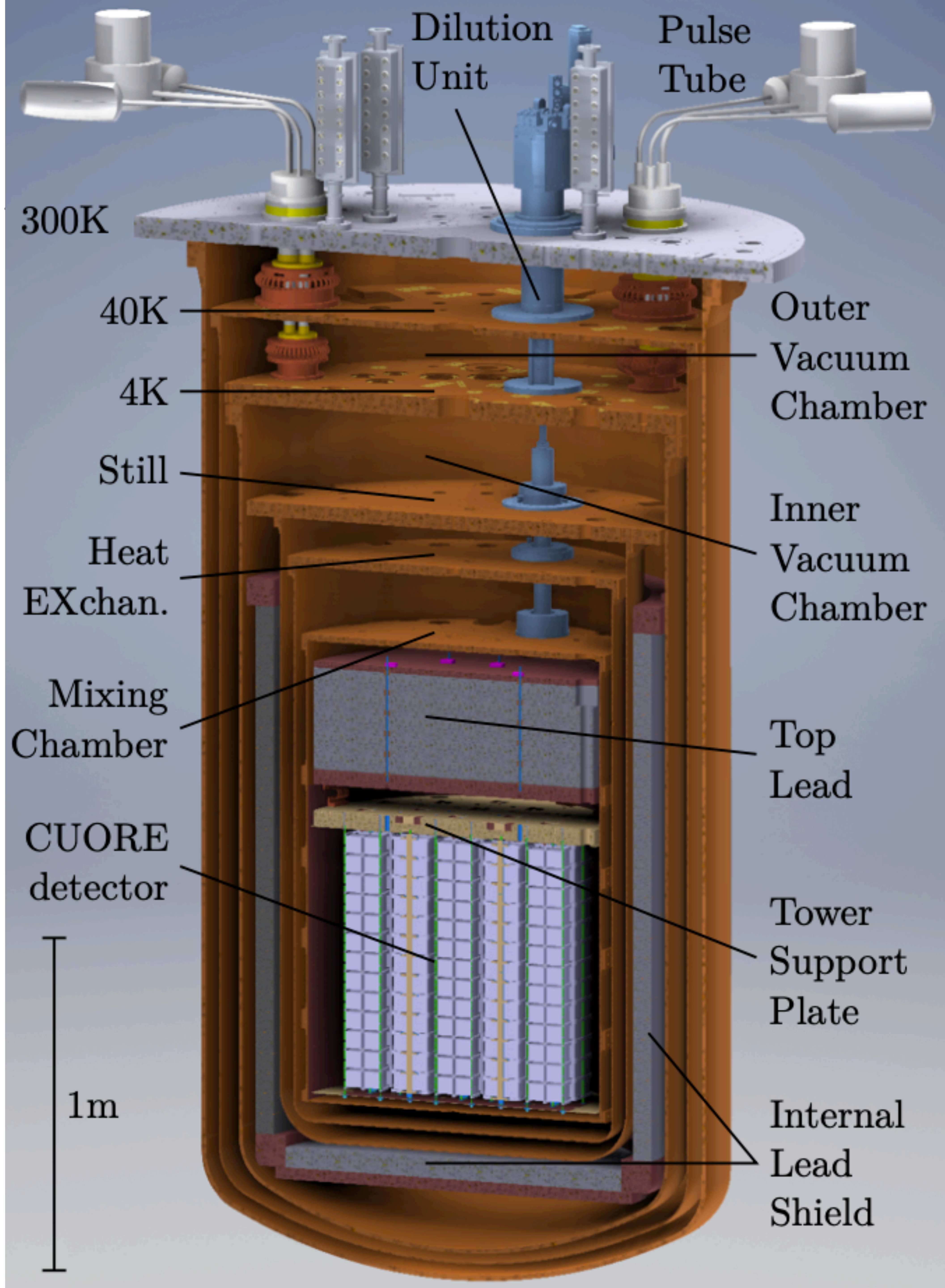




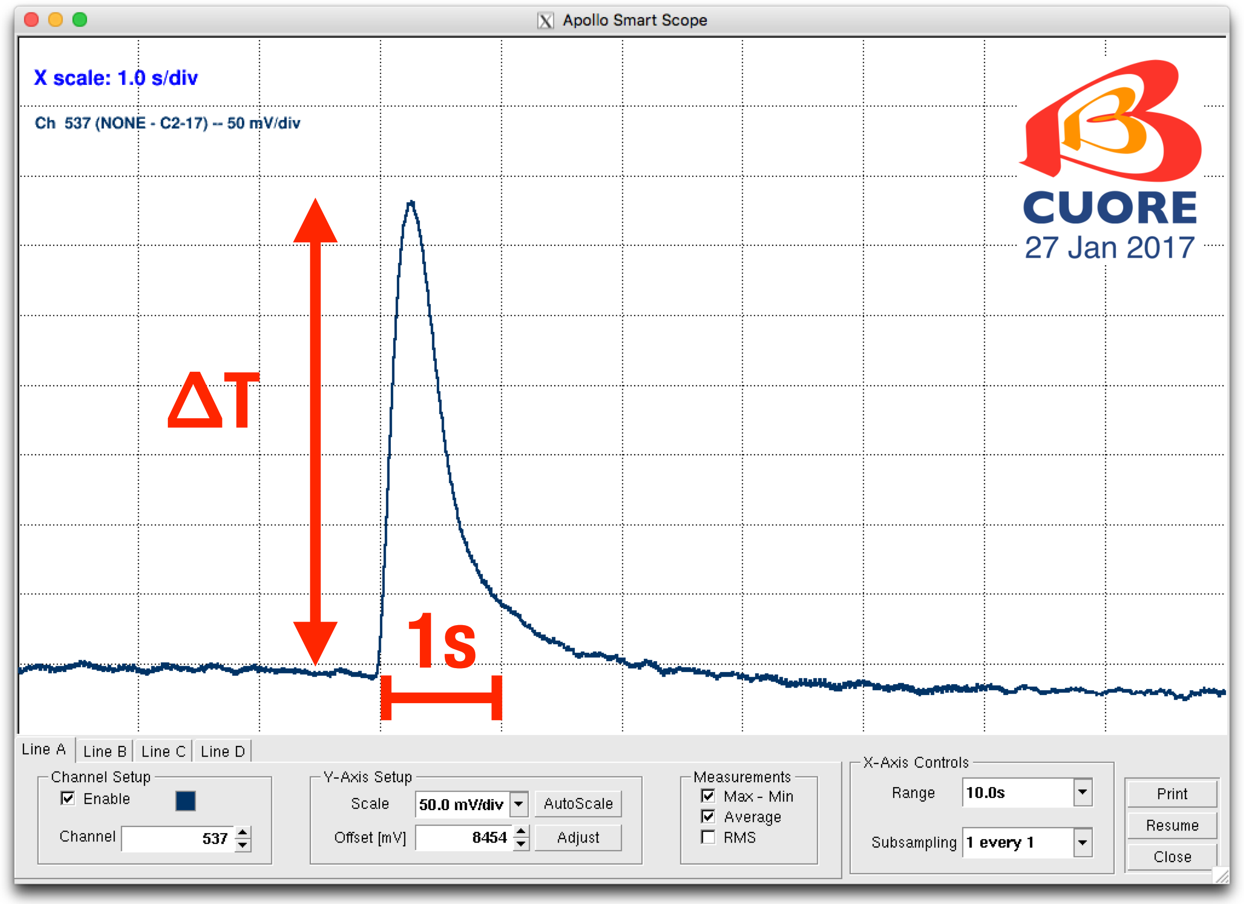
Artusa, D.R. (CUORE Collaboration), Adv. High Energy Phys., 879871, 2015
https://doi.org/10.1155/2015/879871

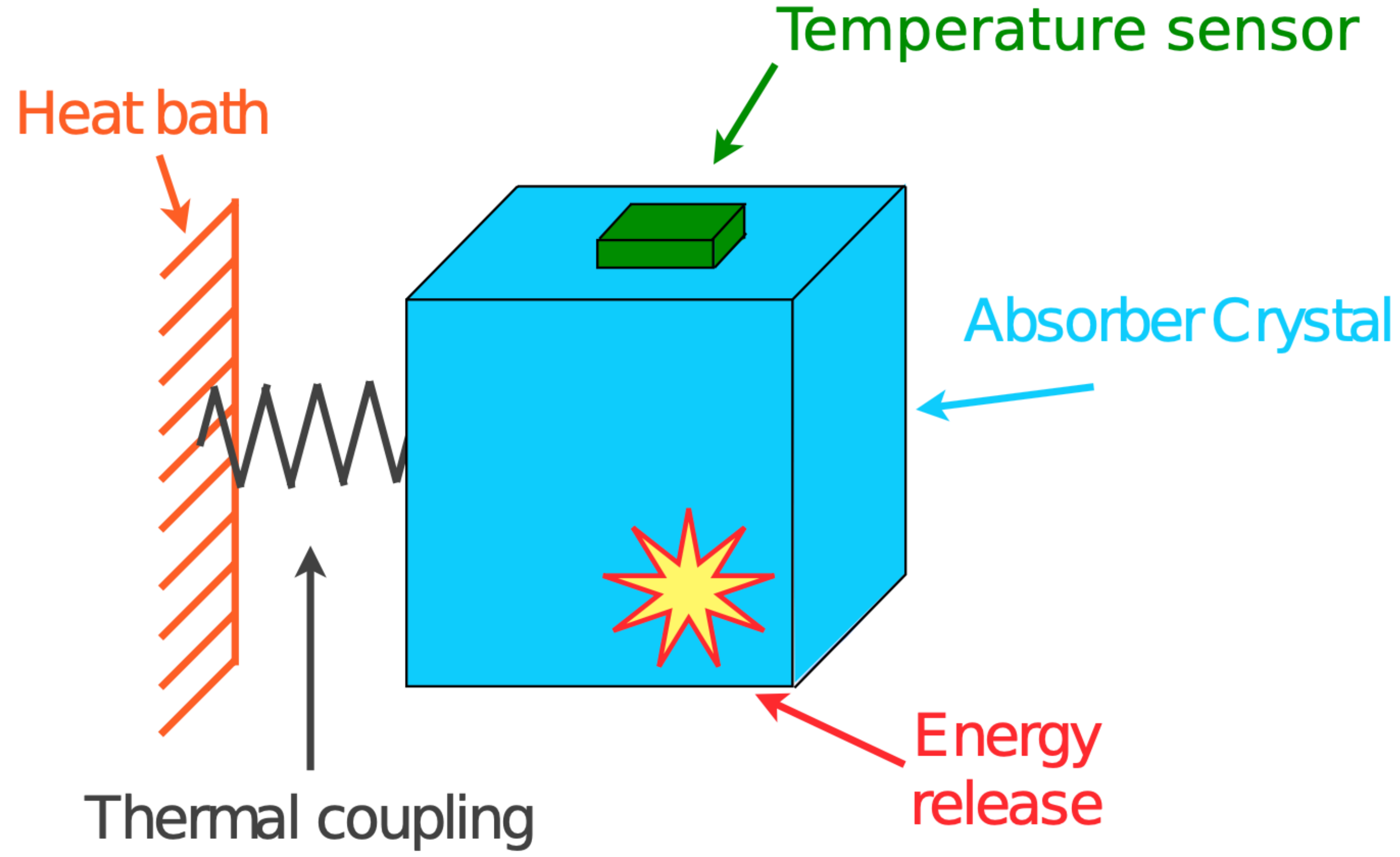
THE CUORE EXPERIMENT

- Custom made dilution refrigerator
  ~ 10 mK base temperature
- 5 pulse tube cryocoolers (no helium bath)
- Nested copper vessels at decreasing temperatures
- Low temperature lead shielding (top)
- Low temperature roman lead shielding (side, bottom)

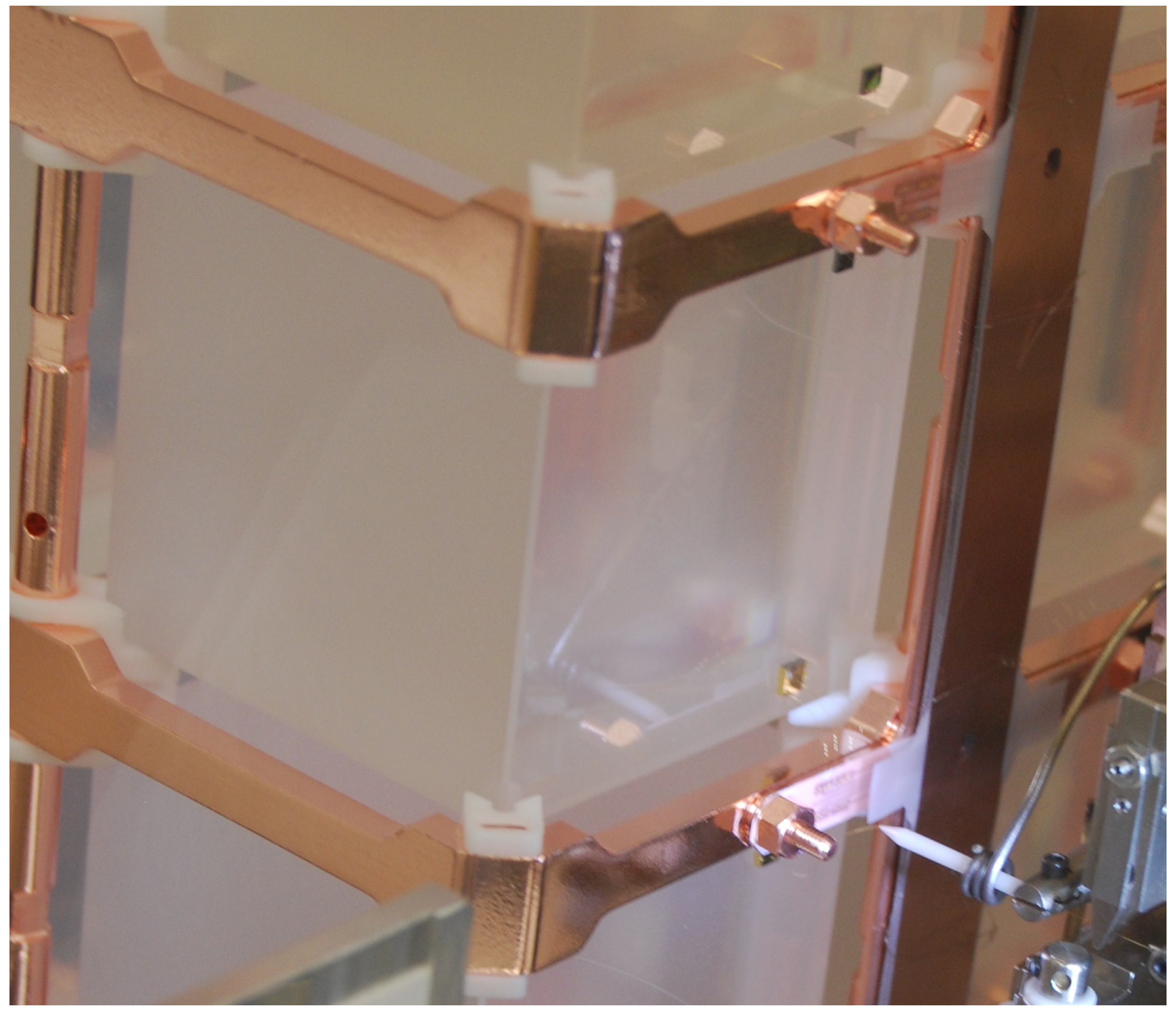


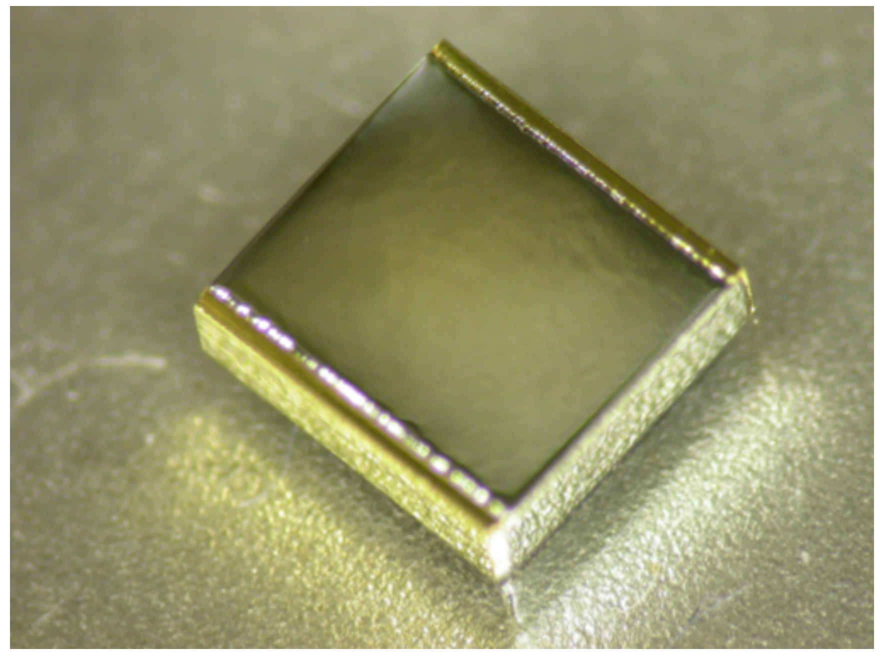
CRYOGENIC BOLOMETERS

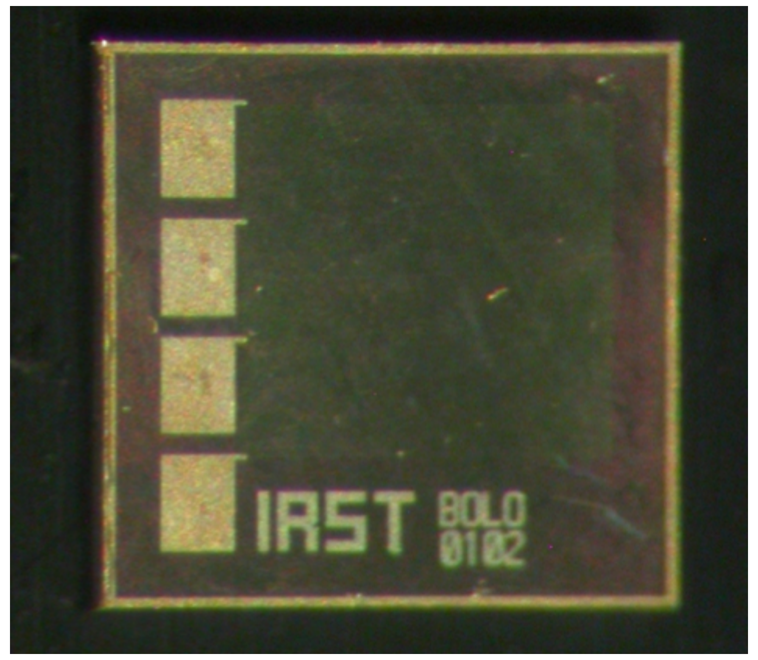




$$\Delta T \sim \frac{\Delta E}{C} \qquad \tau \sim \frac{C}{G}$$





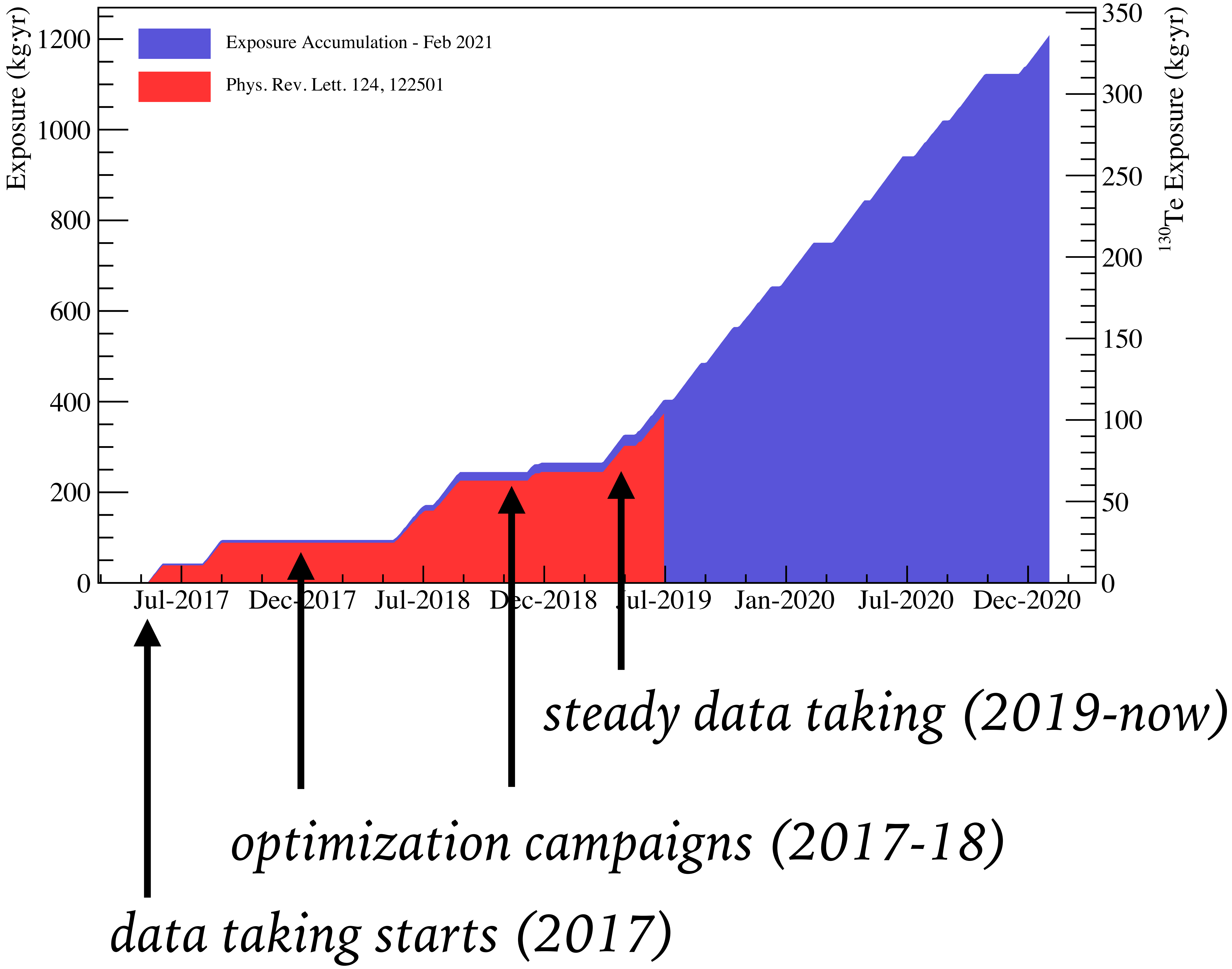


- NTD Ge thermistors biased with constant current
- Si heaters
- weak thermal link to heat bath
- particle interactions heat crystals up
- voltage pulses induced in NTDs

Alduino, C. et al. (CUORE Collaboration), J. Inst. 11(07), P07009, 2016
https://doi.org/10.1088/1748-0221/11/07/p07009

Vignati, M., J. Appl. Phys. 108, 084903, 2010
https://doi.org/10.1063/1.3498808

CUORE DATA TAKING



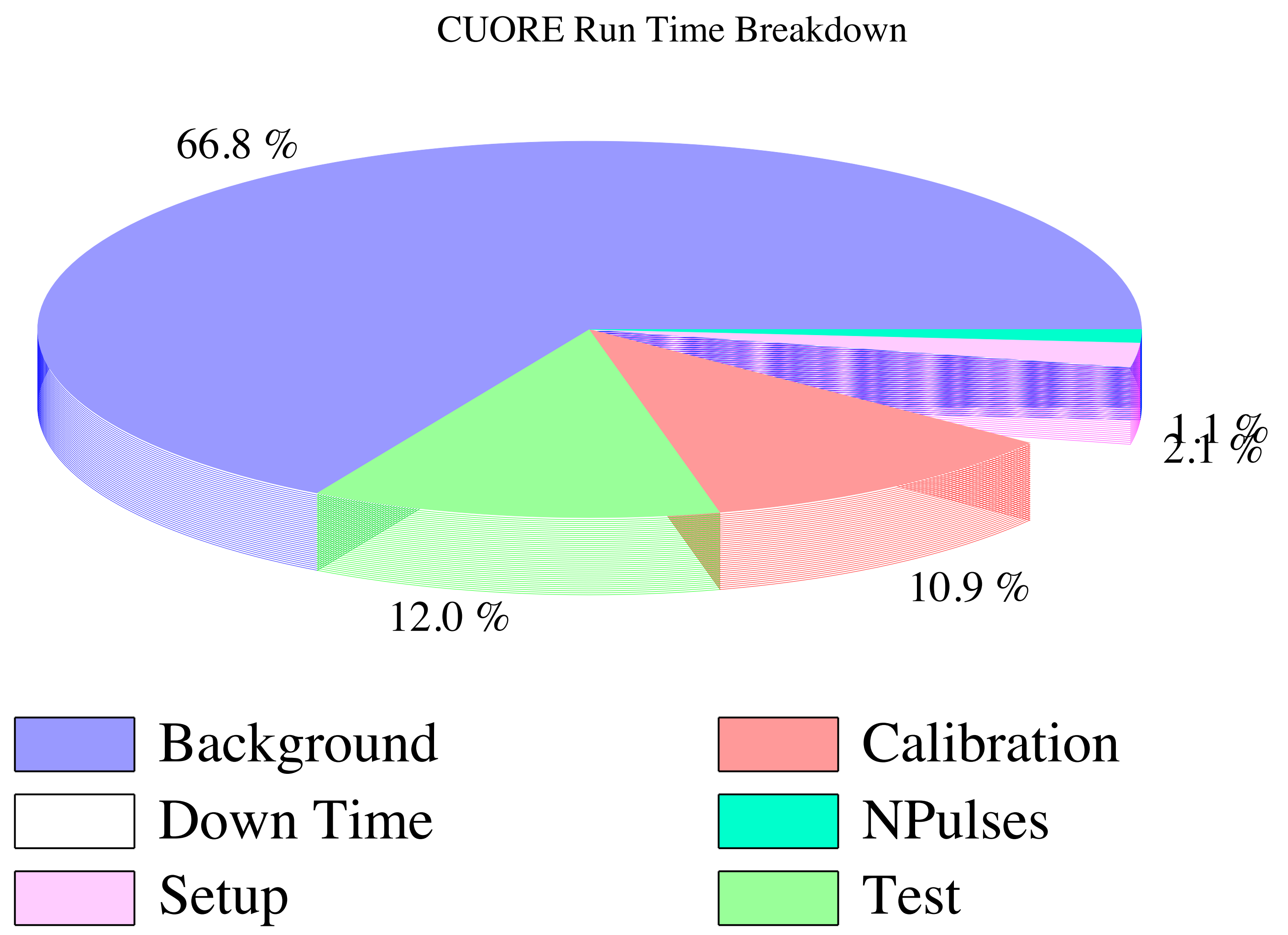
Alduino, C. et al. (CUORE Collaboration), Phys. Rev. Lett. 120, 132501, 2018
https://doi.org/10.1103/PhysRevLett.120.132501

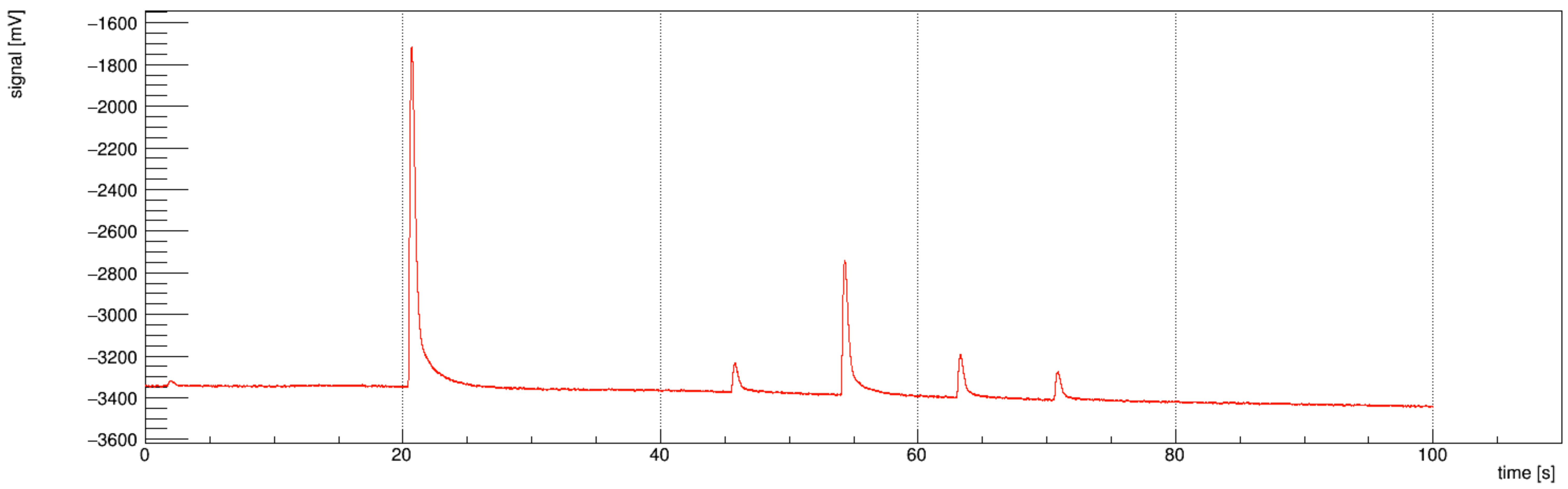
- data taking started in 2017
- optimization campaigns improved understanding and stability of the experiment
- since march 2019 steady data taking with >90% uptime
- reached 1 ton × yr raw exposure
- steadily collecting data at an average rate of ~ 50 kg × yr / month

Adams, D.Q. et al. (CUORE Collaboration), Phys. Rev. Lett. 124, 122501, 2020
https://doi.org/10.1103/PhysRevLett.124.122501

CUORE DATA TAKING

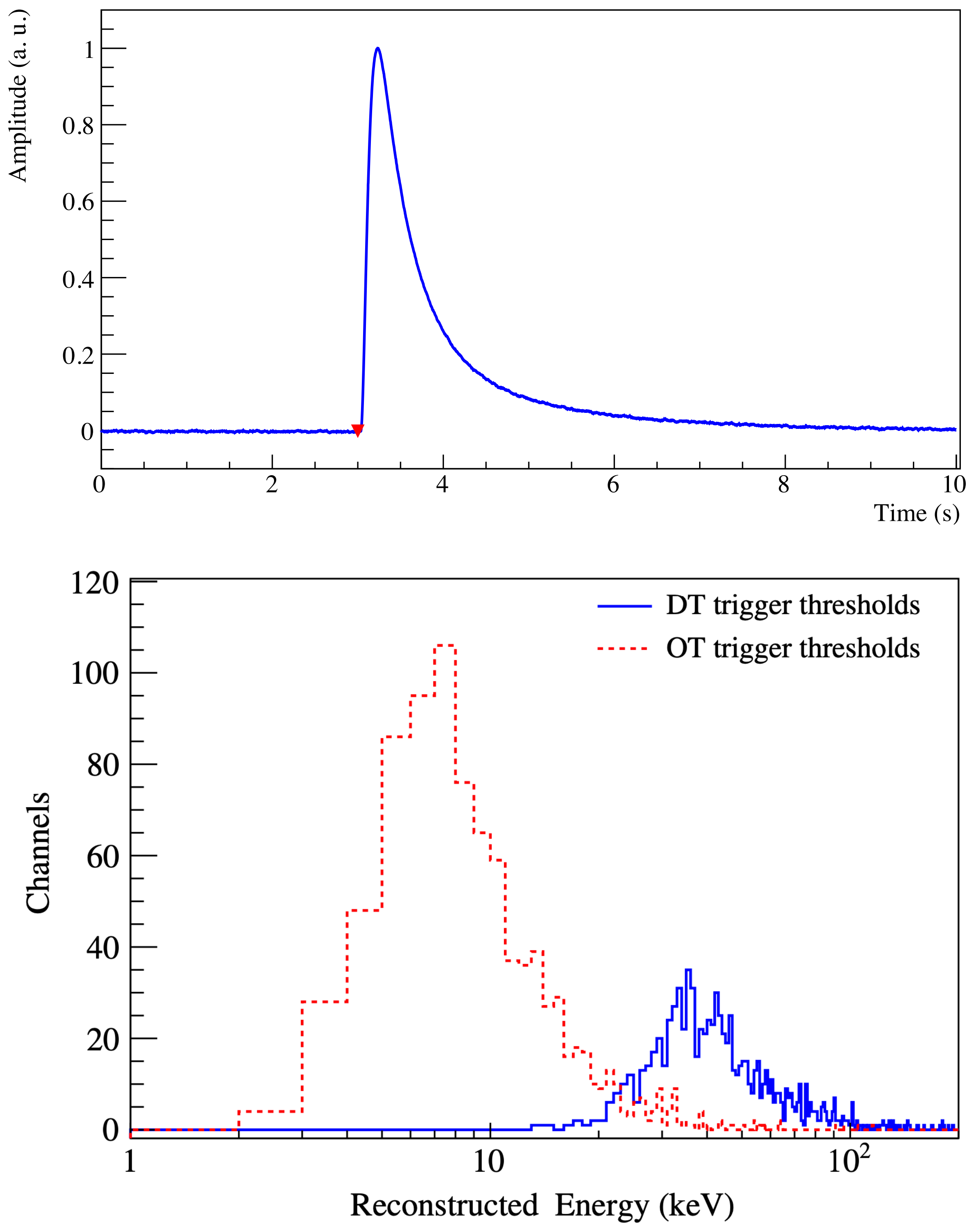
- CUORE "data set": 1 month of background (physics) data taking, few days of calibration before and after
- Voltage output continuously sampled (1 kHz) and stored on disk
- Unstable data taking conditions excluded (e.g. earthquakes)



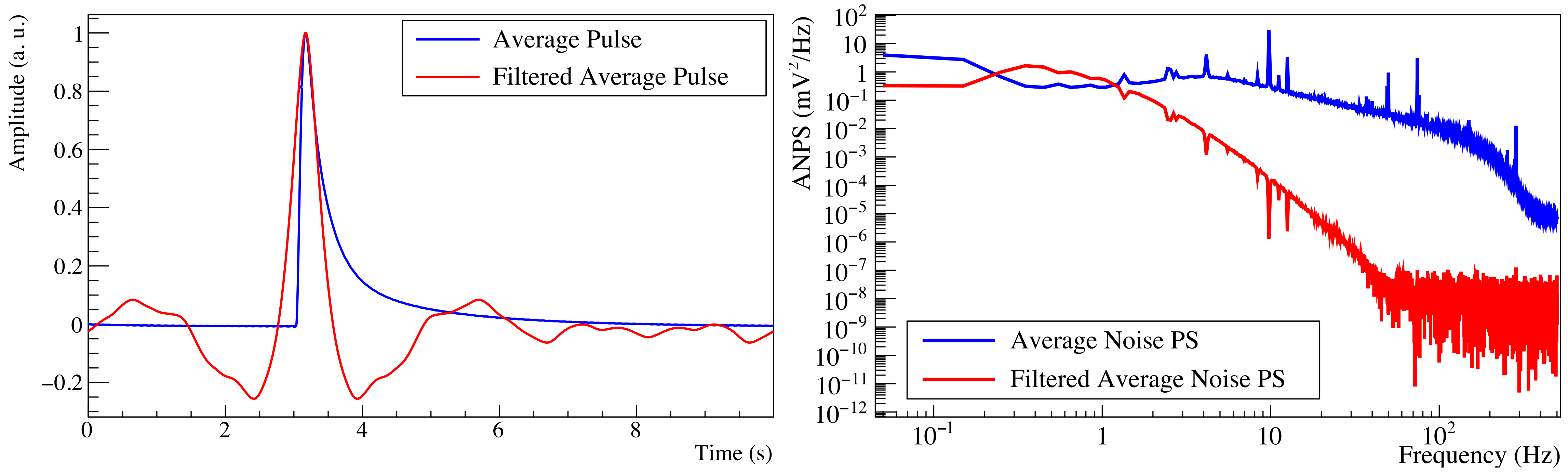


CUORE DATA ANALYSIS

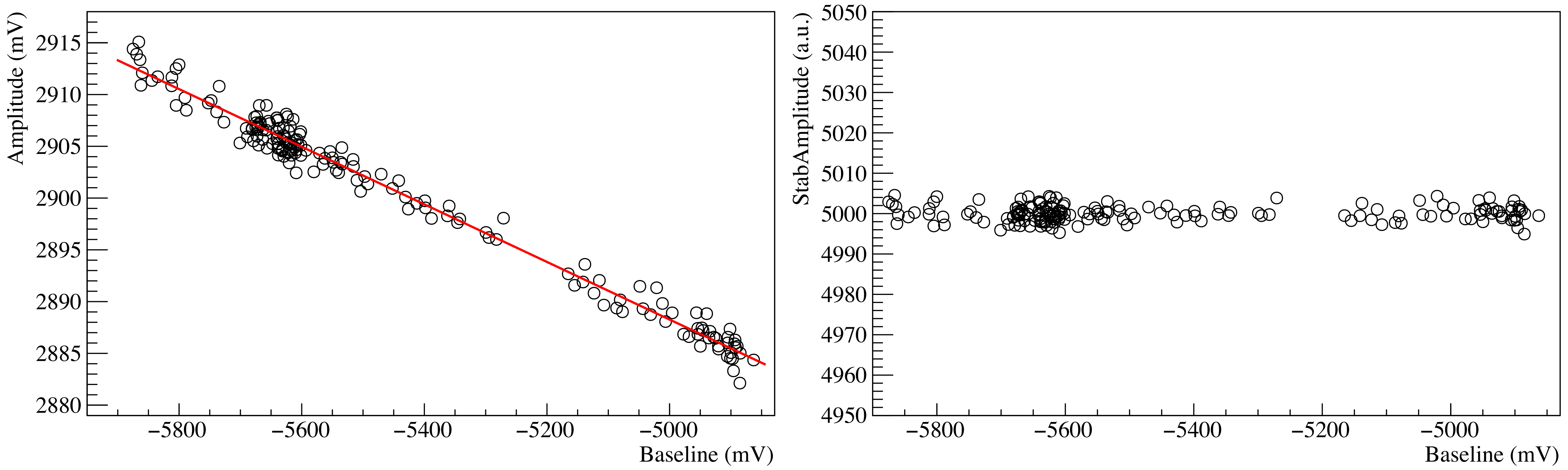
- Trigger
- Optimum Filter
- Gain Correction
- Energy Calibration
- Coincidences
- Pulse Shape
- Blinding



Trigger



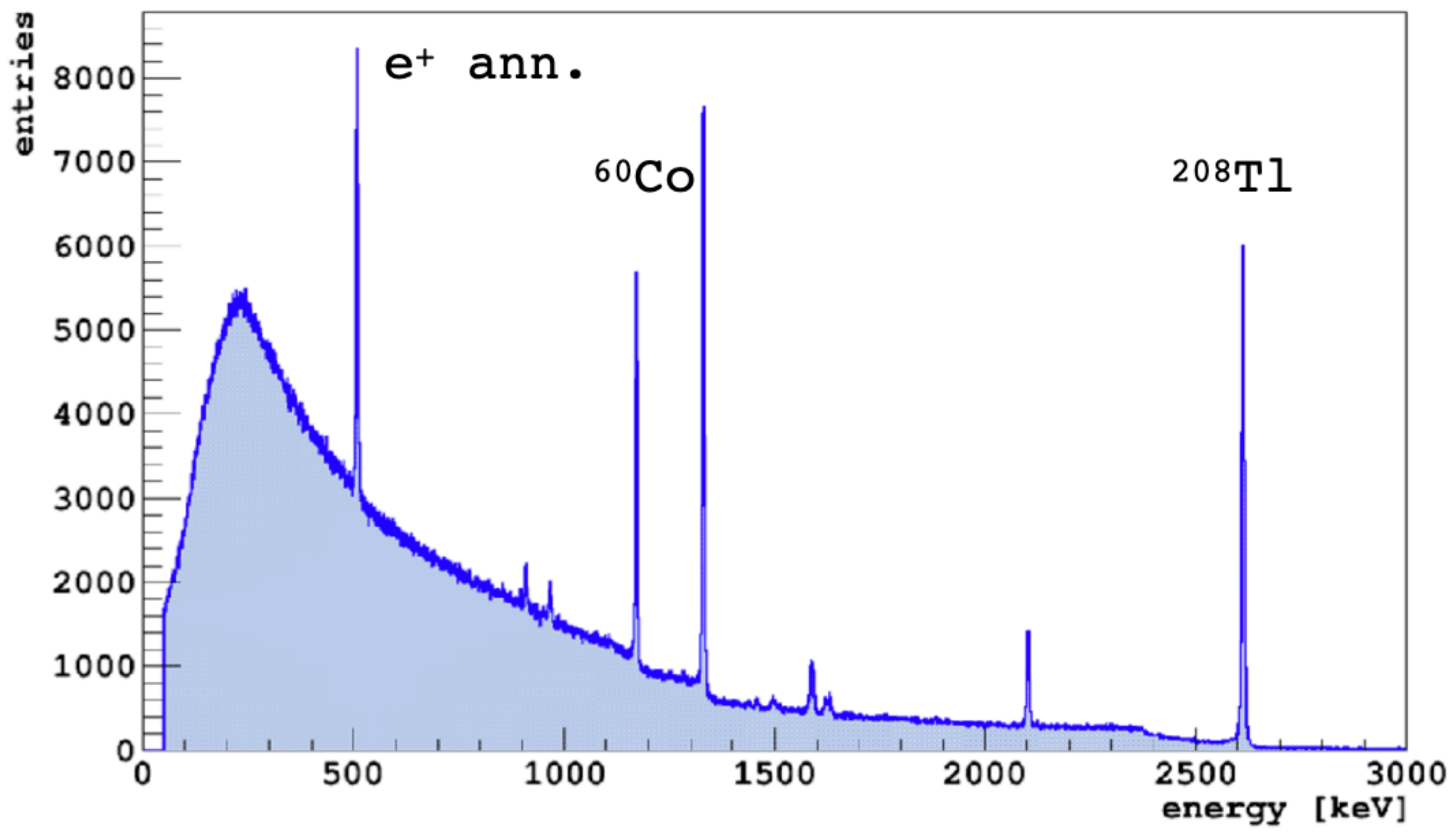
Matched filter maximizes signal-to-noise ratio



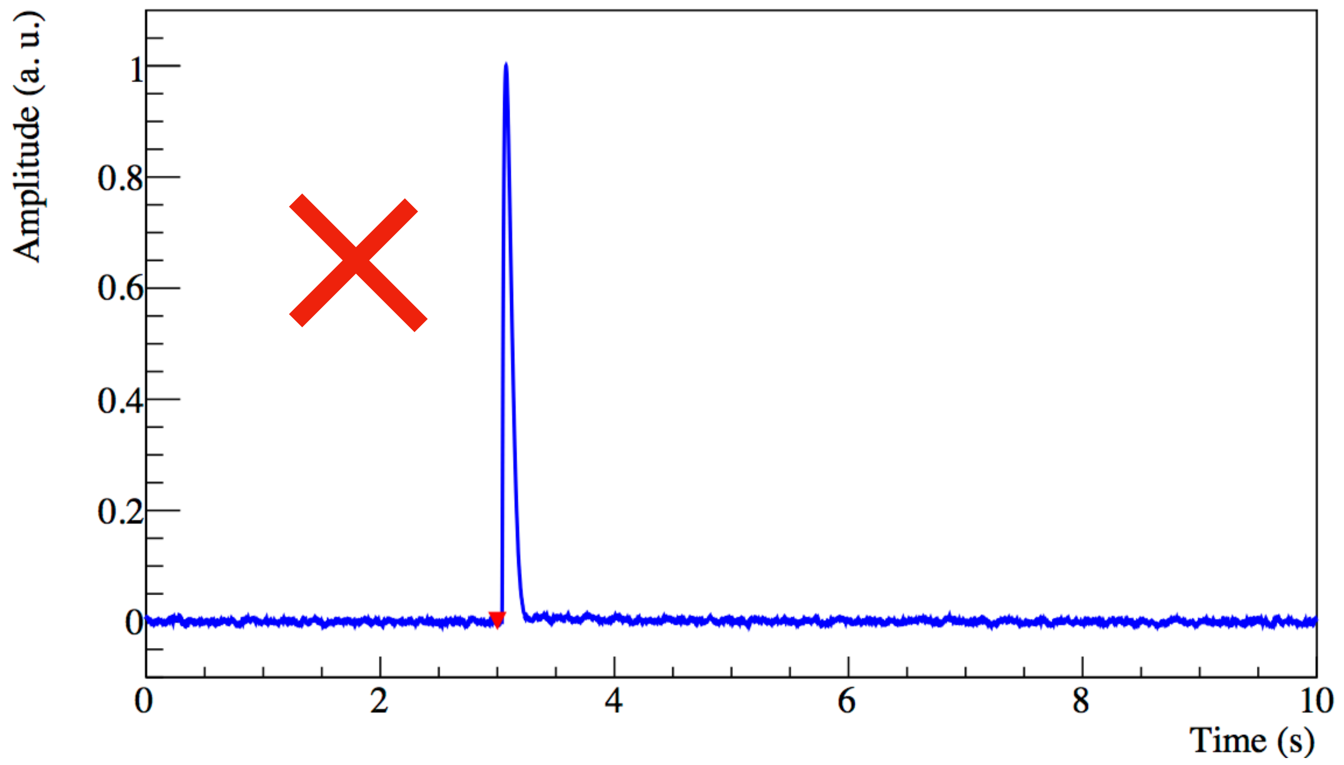
Heater pulses for thermal gain stabilization

CUORE DATA ANALYSIS

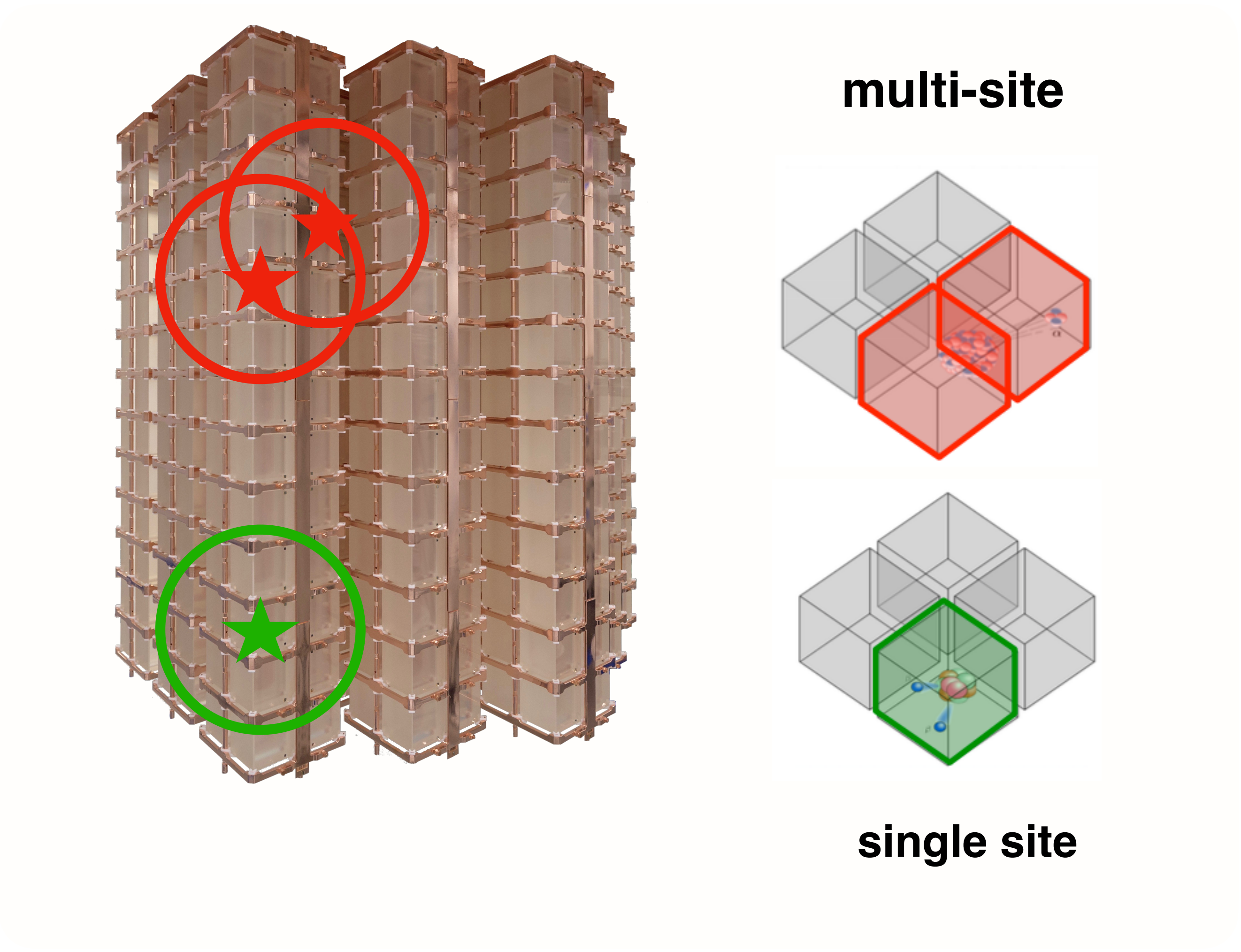
- Trigger
- Optimum Filter
- Gain Correction
- Energy Calibration
- Coincidences
- Pulse Shape
- Blinding

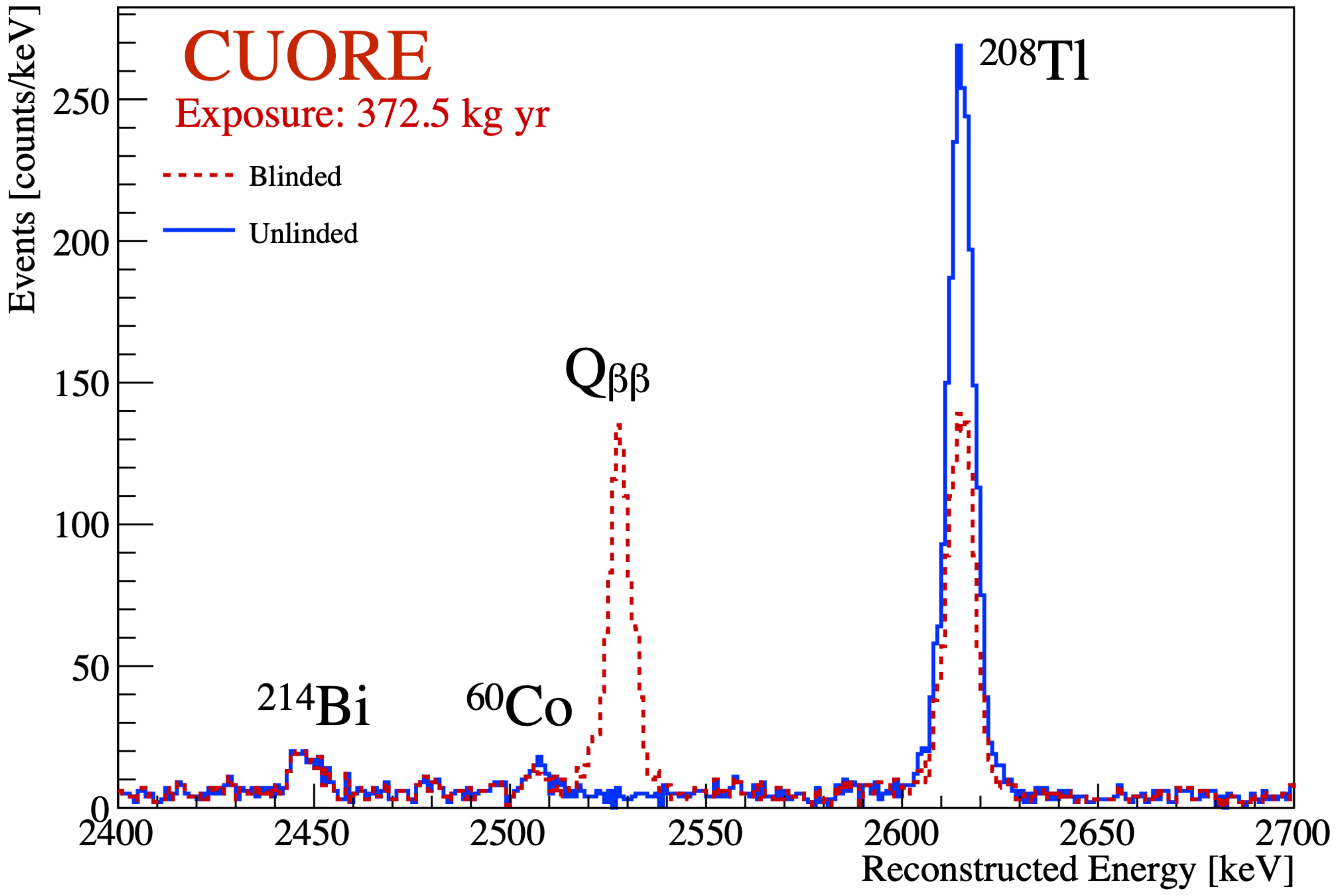


Convert amplitude to energies



Reject spurious events

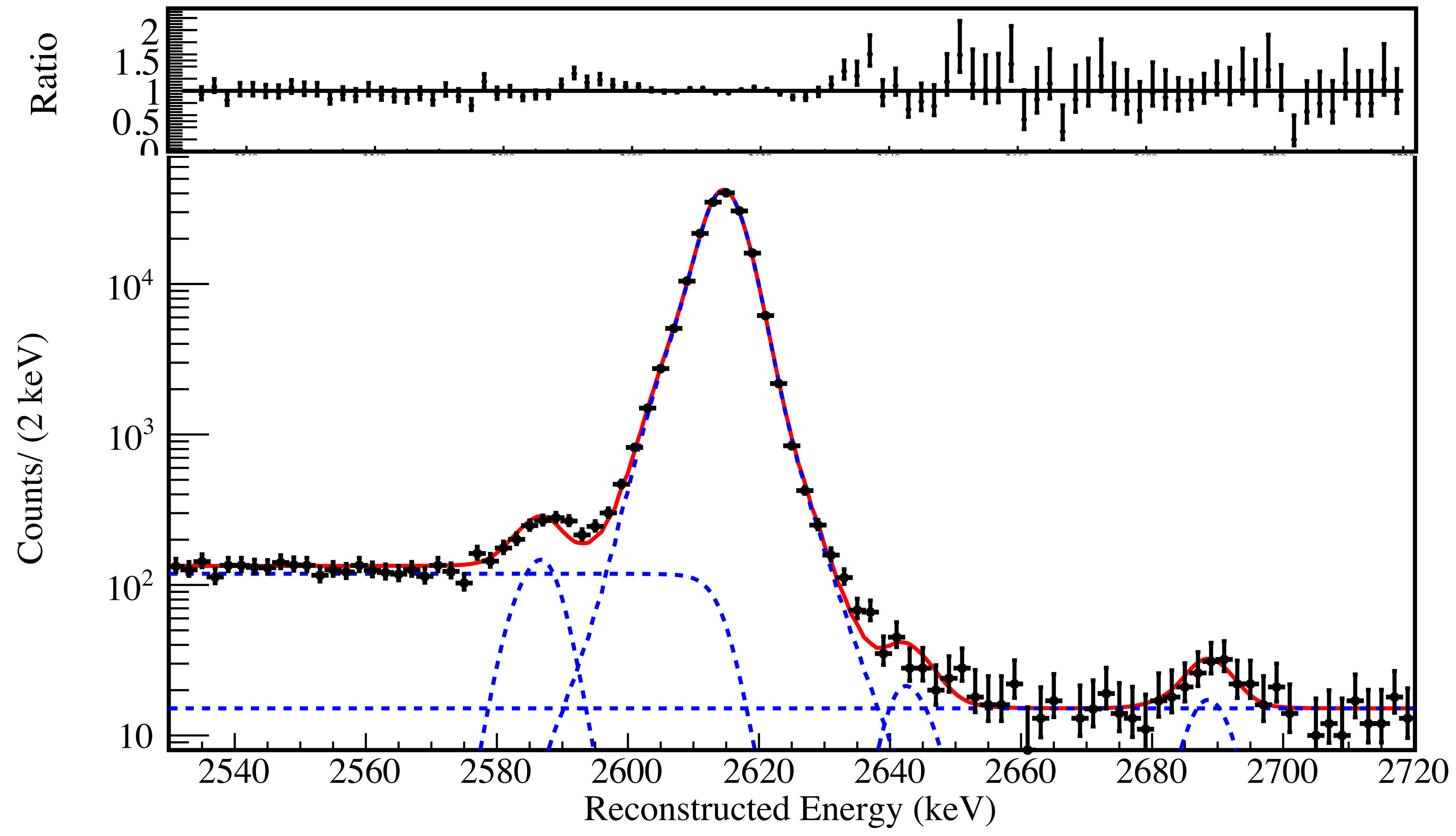


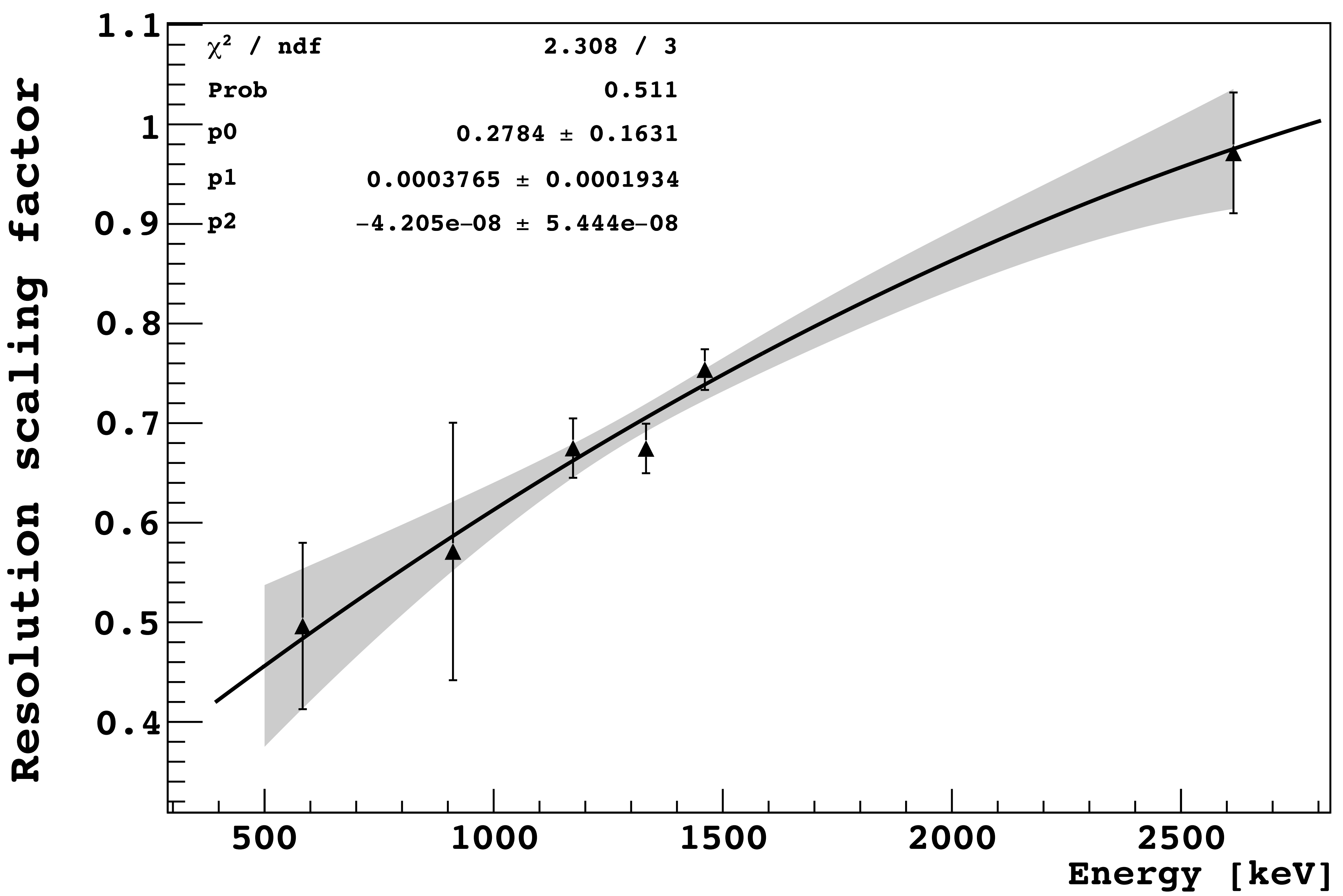


Blinding procedure

NEUTRINOLESS DOUBLE BETA DECAY SEARCH

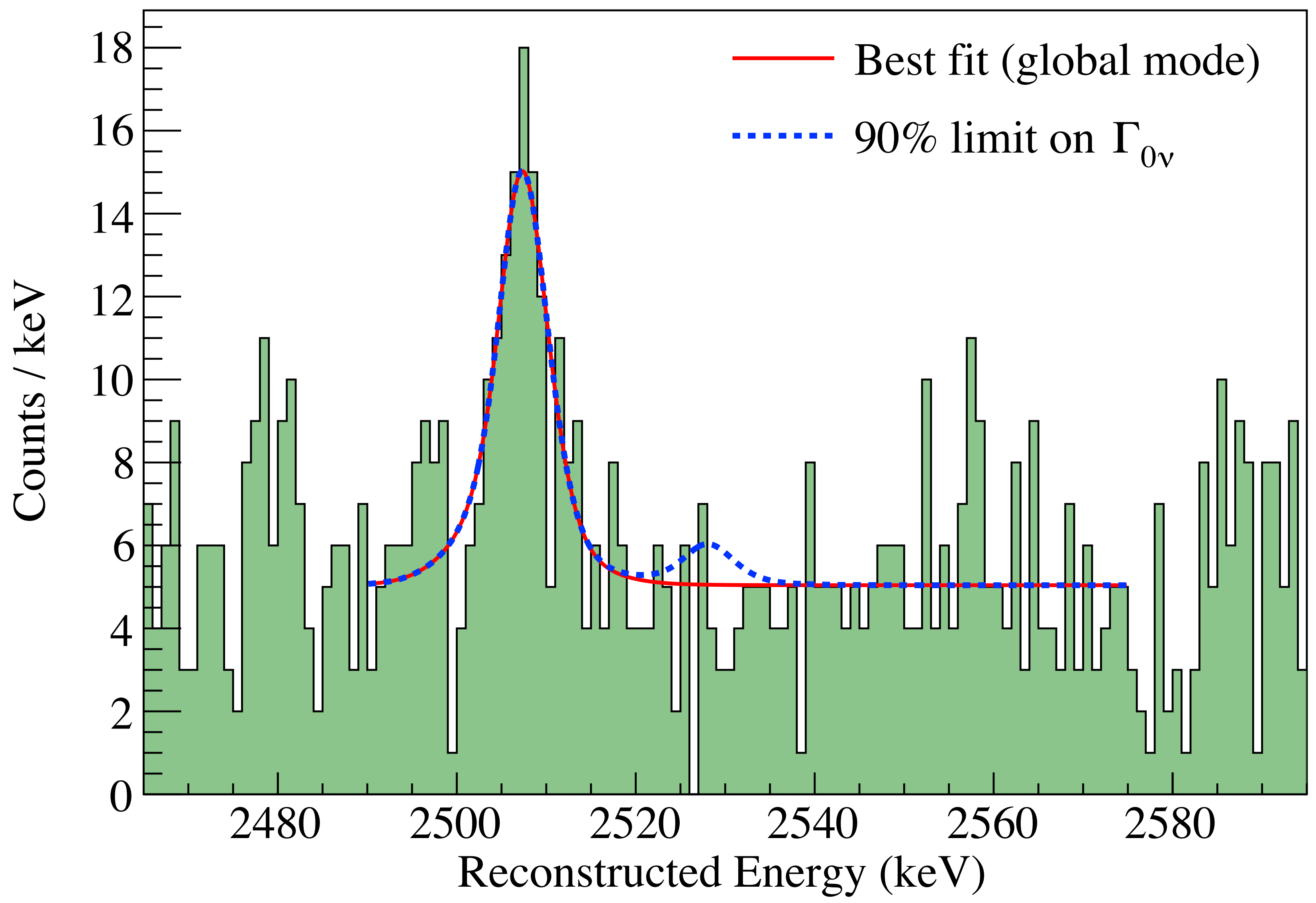
- Total exposure (PRL2020): 372.5 kg × yr $^{nat}TeO_2$
- Model detector response on calibration data for each channel and dataset (sum of 3 gaussians)
- Extrapolate resolution (and energy bias) from physics data
- Containment efficiency from MC simulations $P(\text{single}-\text{site}\,|\,0\nu\beta\beta) = (88.35 \pm 0.09)\,\%$
- Selection efficiency (evaluated from data): trigger, energy reconstruction, pile-up rejection, coincidences, pulse shape $\varepsilon = (87.5 \pm 0.2)\,\%$



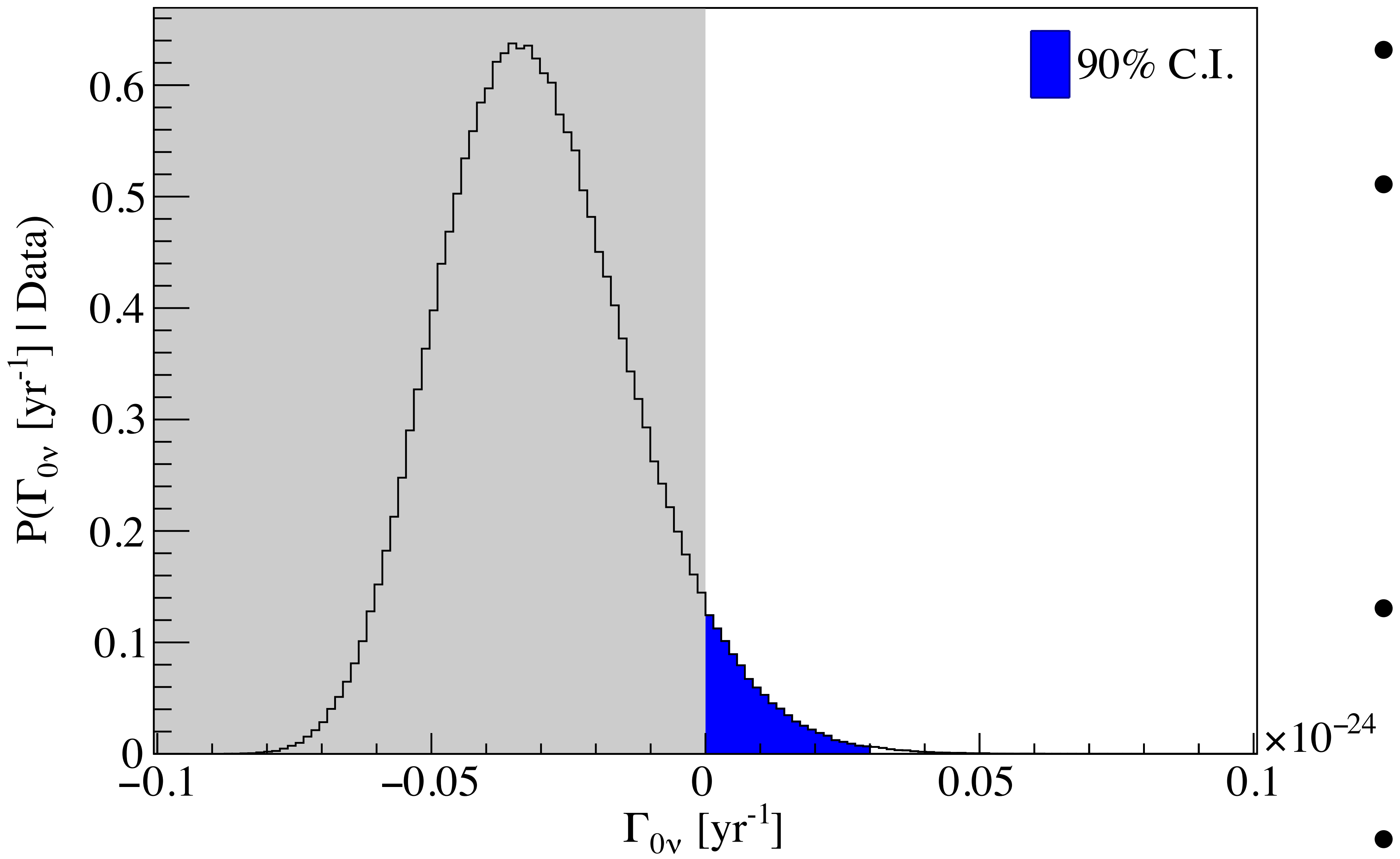


NEUTRINOLESS DOUBLE BETA DECAY (GROUND STATE)

CUORE ROI Spectrum



Posterior for $\Gamma_{0\nu}$



Detector Performance Parameters

Background Index

$$(1.38 \pm 0.07) \times 10^{-2}\ \mathrm{cnts/(keV \cdot kg \cdot yr)}$$

Characteristic FWHM ΔE at $Q_{\beta\beta}$

$$7.0 \pm 0.4\ \mathrm{keV}$$

- No evidence for 0νββ decay

$$T_{1/2}^{0\nu} > 3.2 \times 10^{25}\ \mathrm{yr}\ (90\%\ \mathrm{C.I.})$$

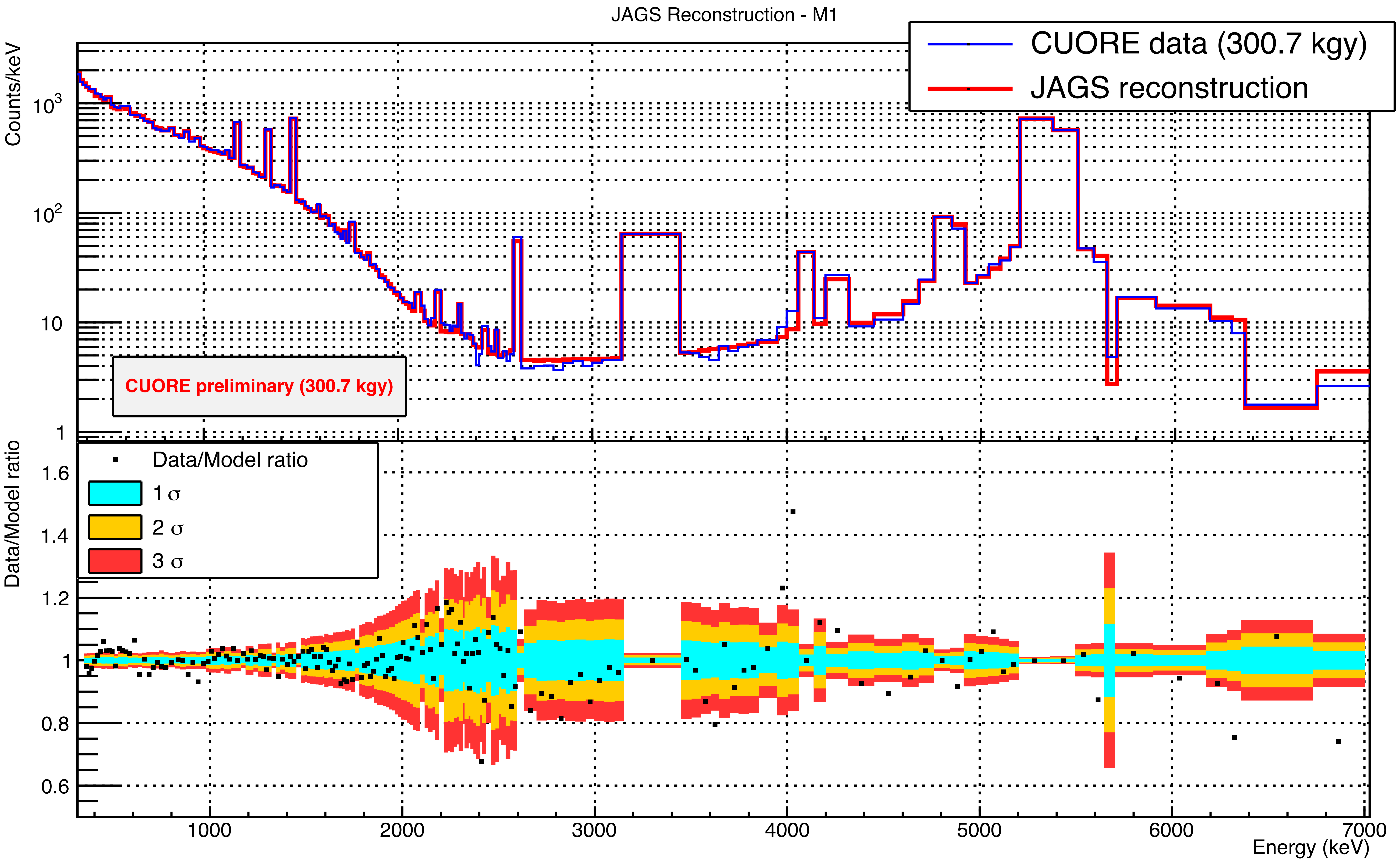
- Interpretation in context of light Majorana neutrino exchange

$$m_{\beta\beta} < 75 - 350\,\mathrm{meV}$$

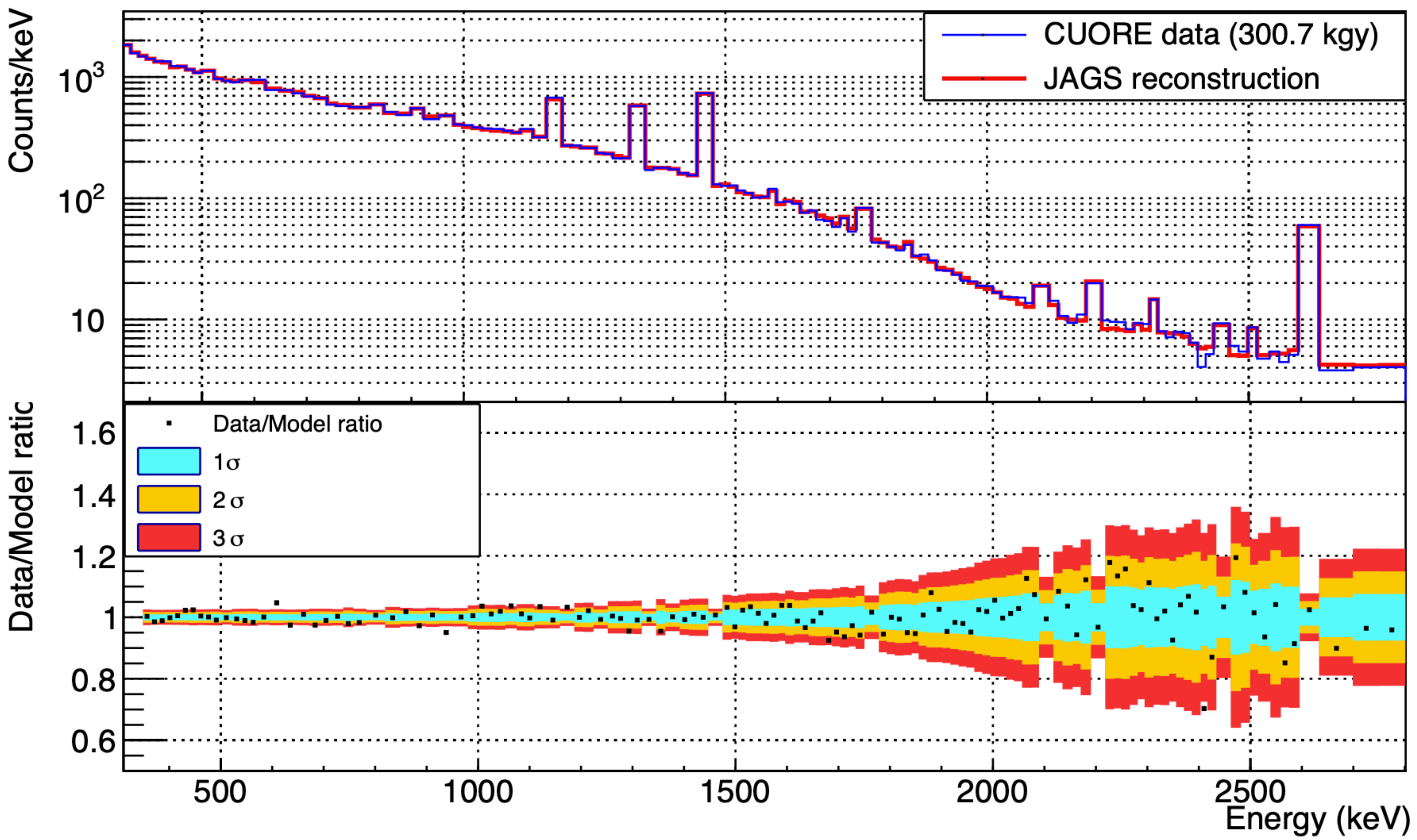
- Unbinned Bayesian fit (BAT)
- Model: flat continuum (BI), posited signal peak (rate), ^{60}Co sum peak (rate, position)
- Uniform prior on physical range (positive rate)
- Systematics: repeat fits with more nuisance parameter, allow negative rates (< 0.4% impact on limit)
- Median 90% C.I. limit setting sensitivity: 1.7×10^{25} yr

Adams, D.Q. et al. (CUORE Collaboration), Phys. Rev. Lett. 124, 122501, 2020
https://doi.org/10.1103/PhysRevLett.124.122501

BACKGROUND MODEL



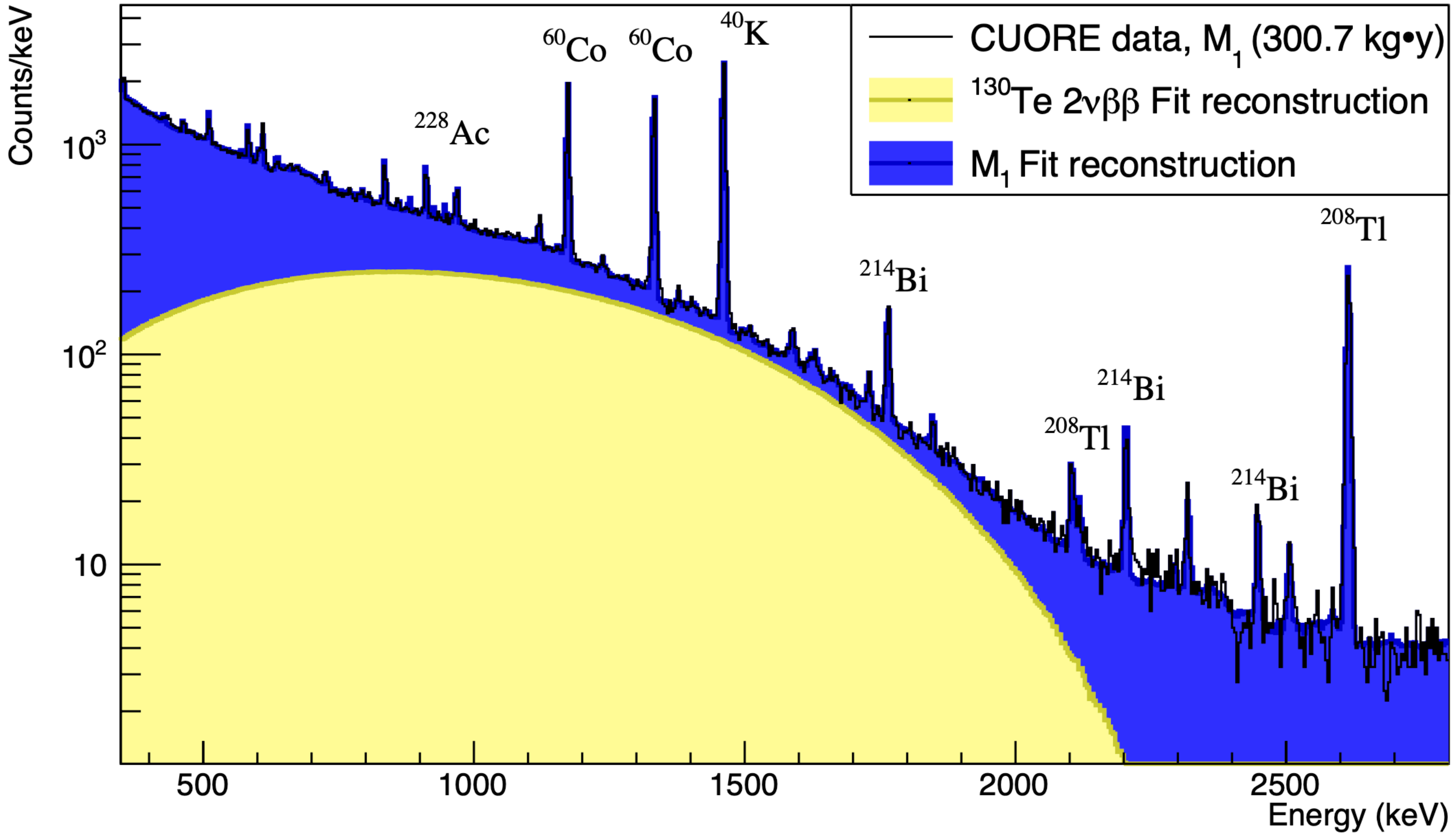
STANDARD MODEL DOUBLE BETA DECAY (GROUND STATE)



- GEANT4 simulation + detector response to produce expected spectra
- 62 simulated sources (bulk, surface, muons)
- use coincidences to constrain source location
- MCMC binned Bayesian fit
- uniform priors (except muons)

Adams, D.Q. et al. (CUORE Collaboration)
https://arxiv.org/abs/2012.11749

STANDARD MODEL DOUBLE BETA DECAY (GROUND STATE)



Systematic uncertainties

- 2νββ model (SSD-HSD)
- energy threshold (300-800 keV)
- geometrical splitting
- ^{90}Sr removal / source list

$$T_{1/2}^{2\nu} = 7.71^{+0.08}_{-0.06}(\text{stat.})^{+0.12}_{-0.15}(\text{syst.}) \times 10^{20}\ \text{yr}$$

Adams, D.Q. et al. (CUORE Collaboration)
https://arxiv.org/abs/2012.11749

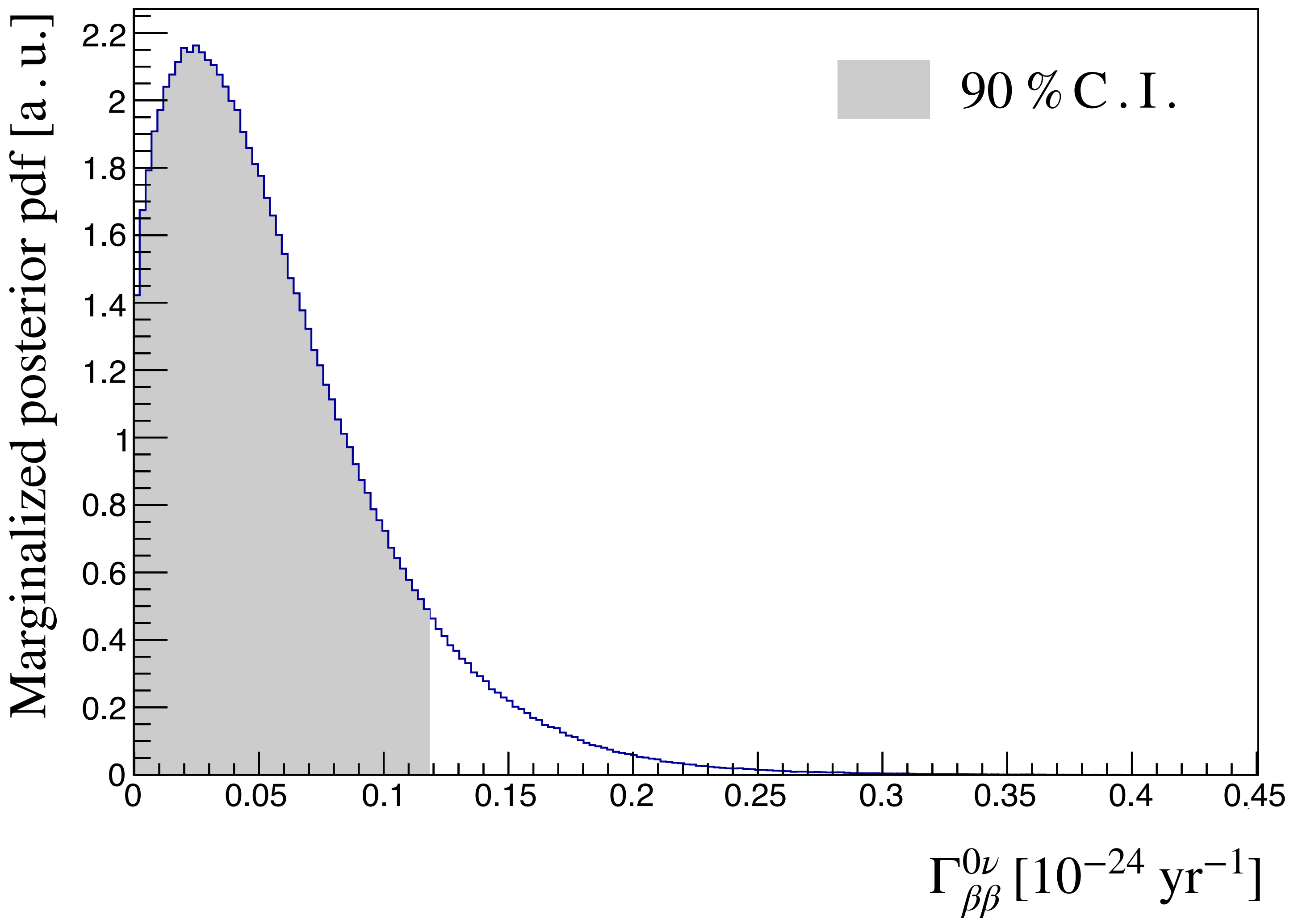
DOUBLE BETA DECAY TO EXCITED STATES

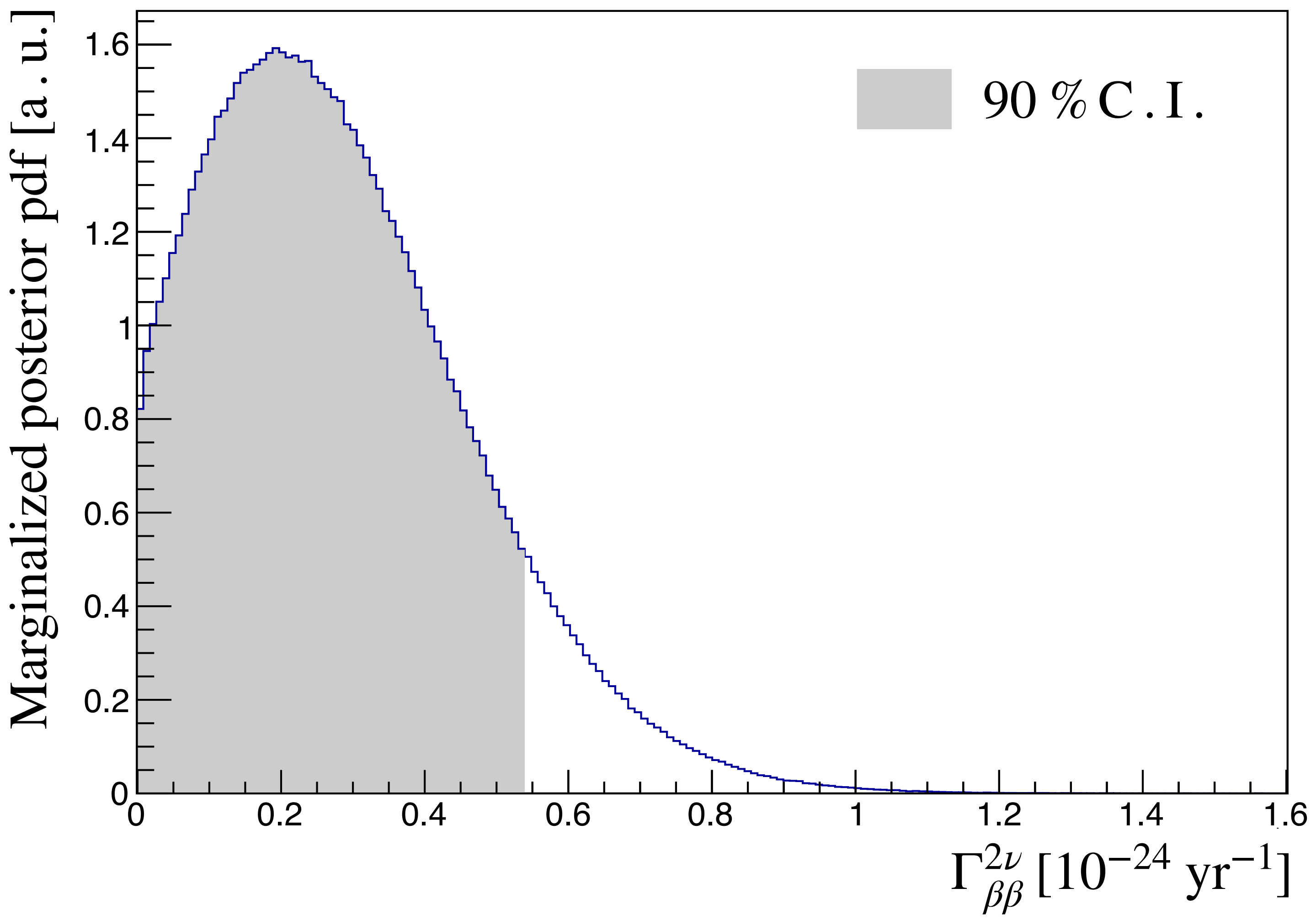
- Fully contained events only (ββ and de-excitation γs all detected)
- Coincident events up to 3 crystals
- Only most sensitive experimental signatures

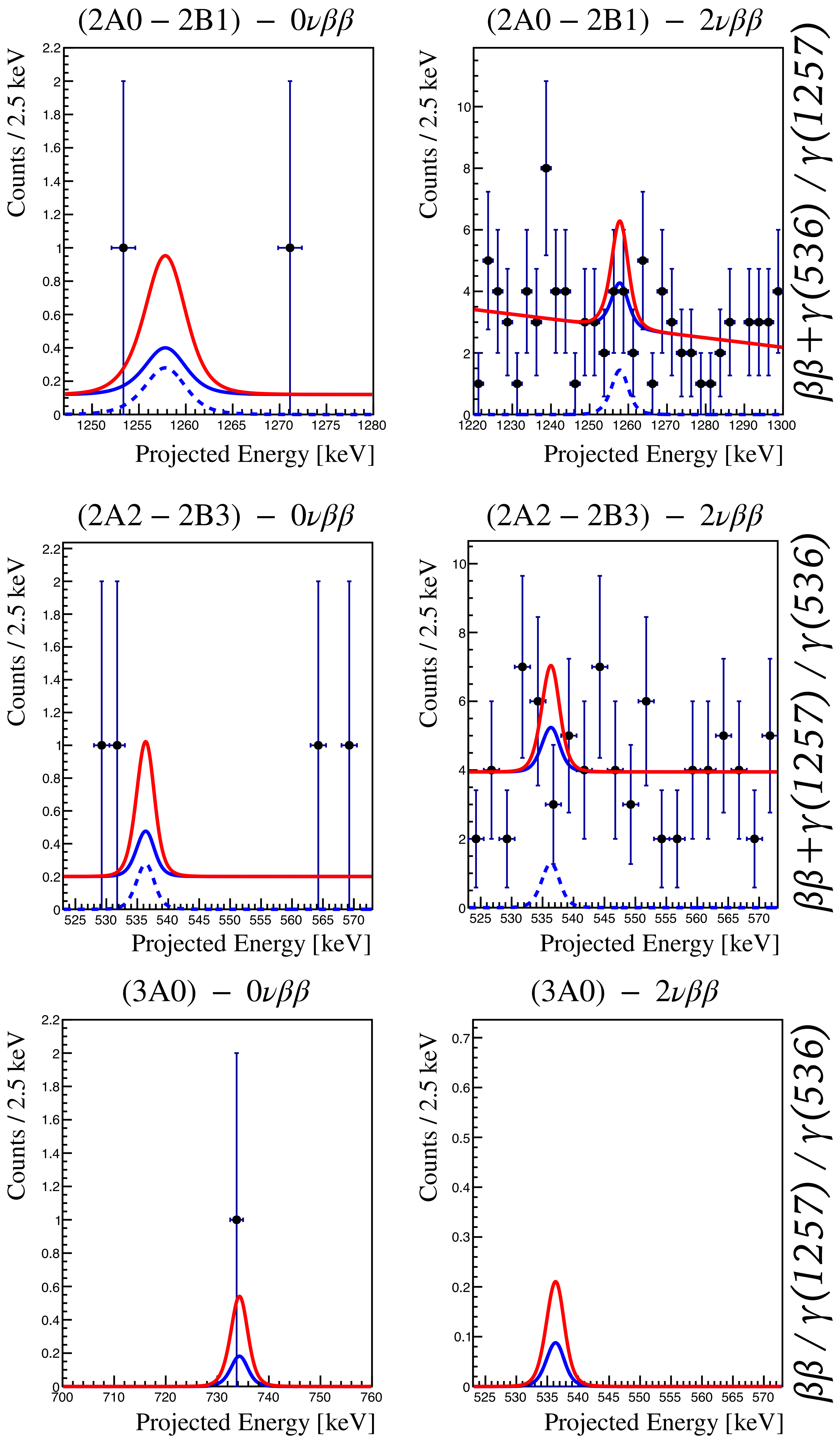
$$T^{0\nu}_{1/2} > 5.9 \times 10^{24}\ \text{yr}\ (90\ \%\ \text{C.I.})$$

$$T^{2\nu}_{1/2} > 1.3 \times 10^{24}\ \text{yr}\ (90\ \%\ \text{C.I.})$$

Adams, D.Q. et al. (CUORE Collaboration)
https://arxiv.org/abs/2101.10702







CONCLUSION

- CUORE demonstrates feasibility of tonne-scale cryogenic calorimeter based experiments
- Physics results about ^{130}Te $0\nu\beta\beta$ and $2\nu\beta\beta$ decay to both ground and excited states released
- Raw exposure of > 1 tonne yr achieved
- Updated results on $0\nu\beta\beta$ and other analyses will be released shortly
- CUORE data taking smoothly underway to collect 5 years live time
- Important feedback for the future CUPID project (CUORE Upgrade with Particle IDentification)

Celi, E. "Double beta decay results from the CUPID-0 experiment" (today, room 1)

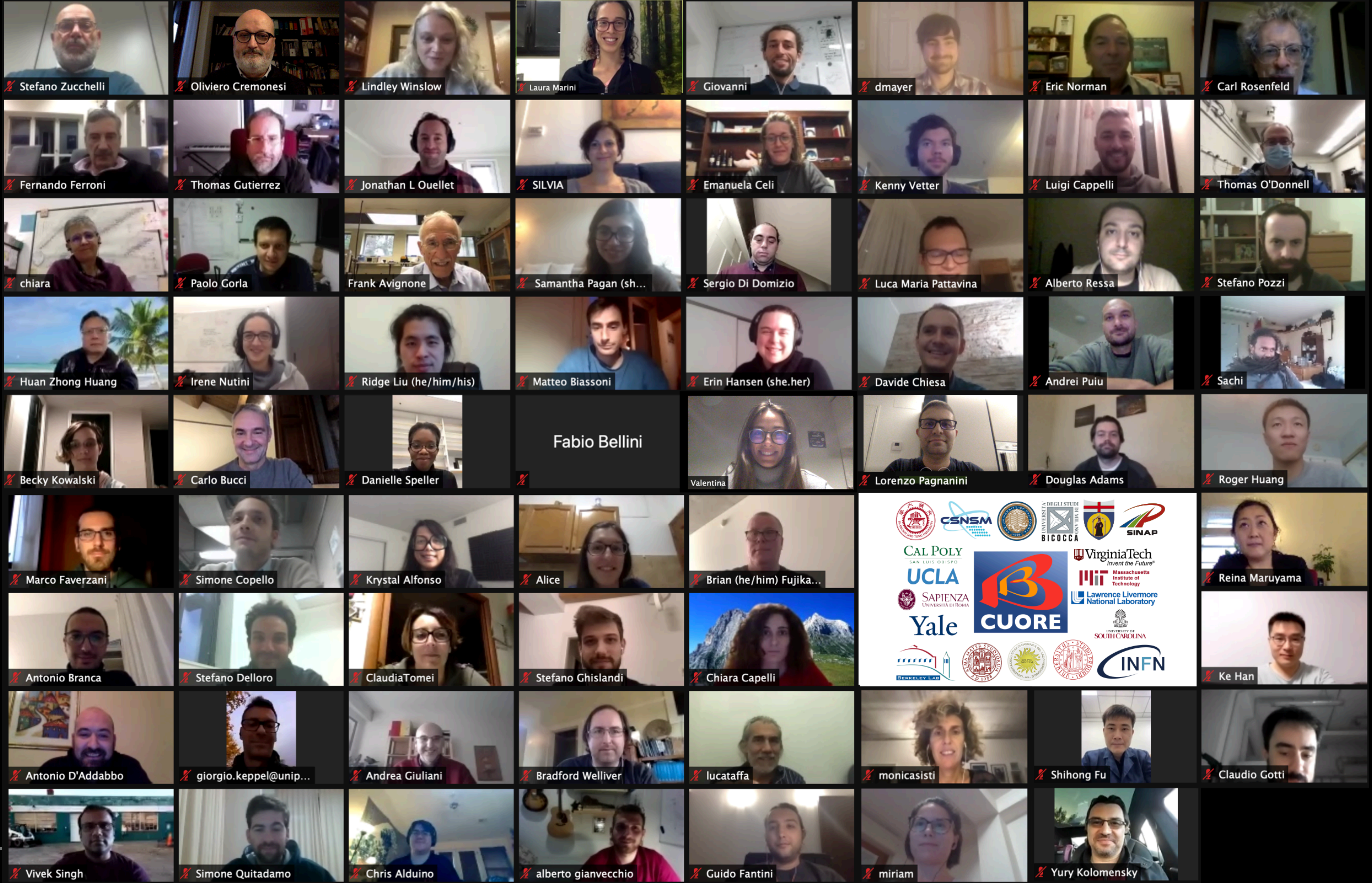
Campani, A. "The search for $0\nu EC\beta+$ of ^{120}Te with CUORE" (today, room 1)

Ressa, A. "Scintillating Li_2MoO4 bolometers for $0\nu\beta\beta$ search" (today, room 1)

Dell'Oro, S. "A novel technique for the study of pile-up events in cryogenic bolometers" (today, room 1)

Giuliani, A, "CUPID: a next generation bolometric neutrino less double beta decay experiment" (24/02, room 1)

Loaiza, P. "The CUPID-Mo experiment for the search of $0\nu\beta\beta$" (24/02, room 1)


Stefano Zucchelli
Oliviero Cremonesi
Lindley Winslow
Laura Marini
Giovanni
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Eric Norman
Carl Rosenfeld
Fernando Ferroni
Thomas Gutierrez
Jonathan L Ouellet
SILVIA
Emanuela Celi
Kenny Vetter
Luigi Cappelli
Thomas O'Donnell
chiara
Paolo Gorla
Frank Avignone
Samantha Pagan (sh…
Sergio Di Domizio
Luca Maria Pattavina
Alberto Ressa
Stefano Pozzi
Huan Zhong Huang
Irene Nutini
Ridge Liu (he/him/his)
Matteo Biassoni
Erin Hansen (she.her)
Davide Chiesa
Andrei Puiu
Sachi
Becky Kowalski
Carlo Bucci
Danielle Speller
Fabio Bellini
Valentina
Lorenzo Pagnanini
Douglas Adams
Roger Huang
Marco Faverzani
Simone Copello
Krystal Alfonso
Alice
Brian (he/him) Fujika…
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Massachusetts Institute of Technology
Lawrence Livermore National Laboratory
CUORE
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BERKELEY LAB
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Simone Quitadamo
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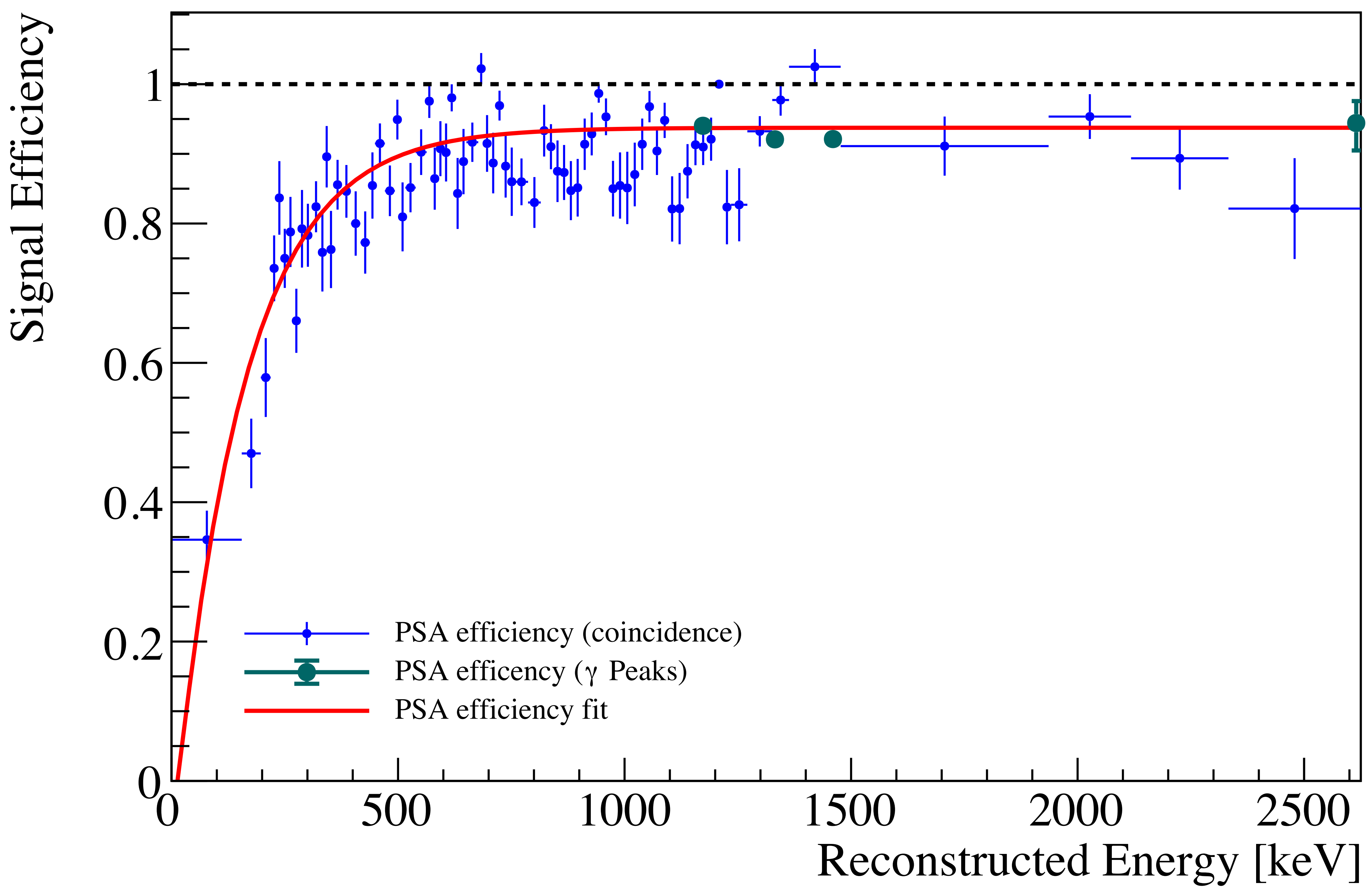
Guido Fantini
miriam
Yury Kolomensky

G.

BACKUP

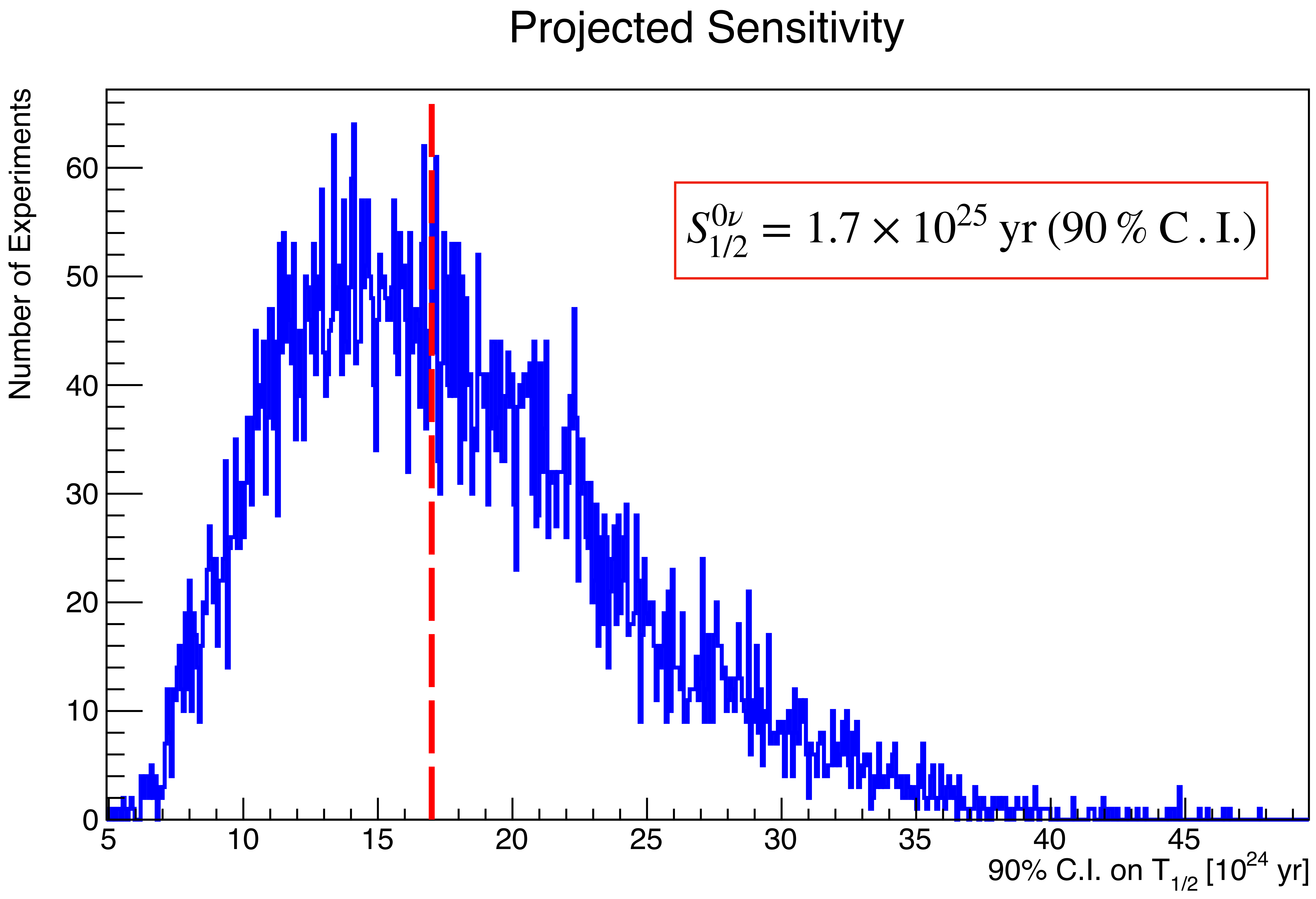
EFFICIENCY EVALUATION



- Selection efficiency evaluated on data
- Trigger, energy reconstruction, pile-up rejection, M1, PSA
- Analysis efficiency dominated by PSA

$$\epsilon = (87.54 \pm 0.17)\,\%$$

NEUTRINOLESS DOUBLE BETA DECAY (GROUND STATE)

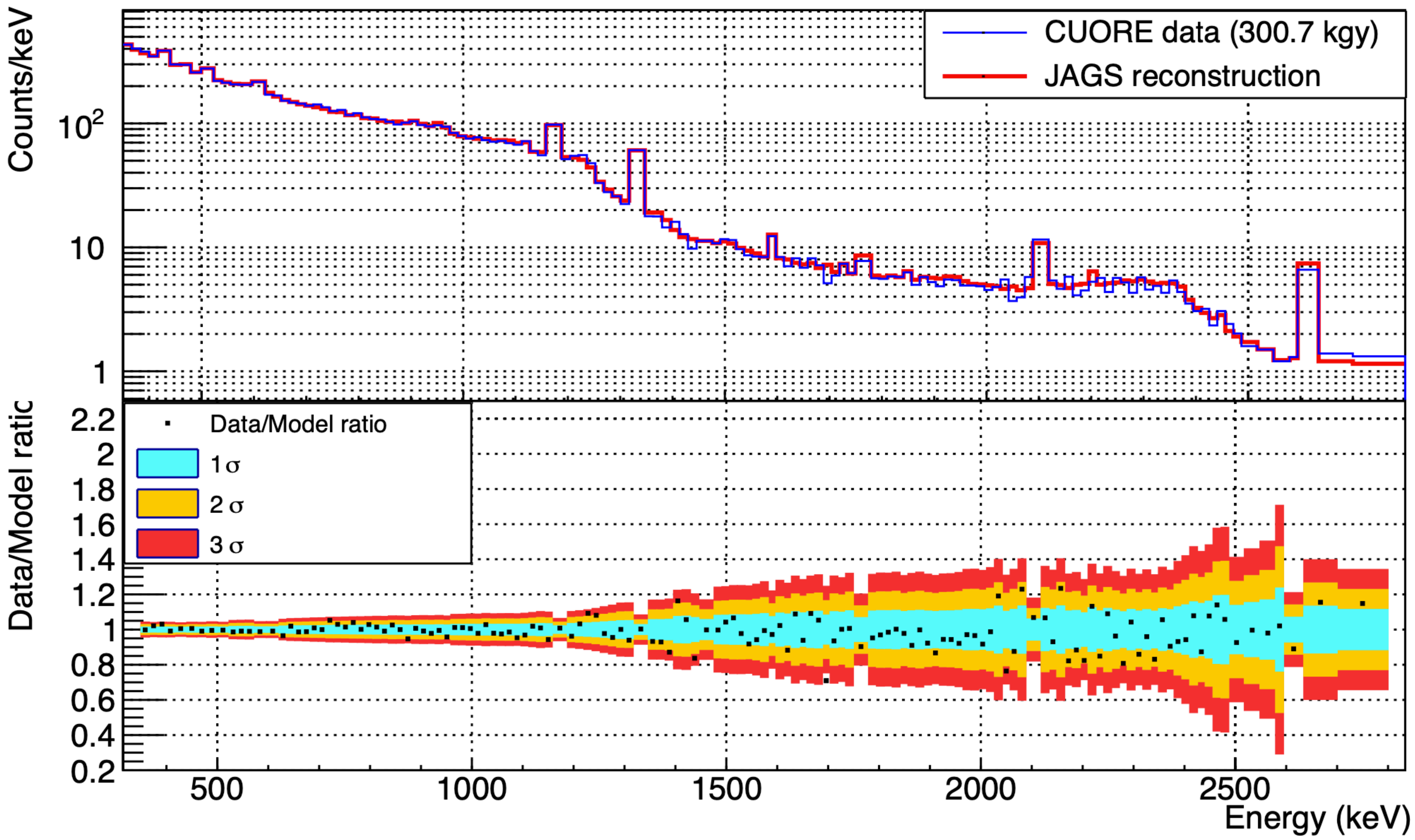


10^4 Toy Monte Carlo pseudo-experiments are generated and fit to extract the median sensitivity

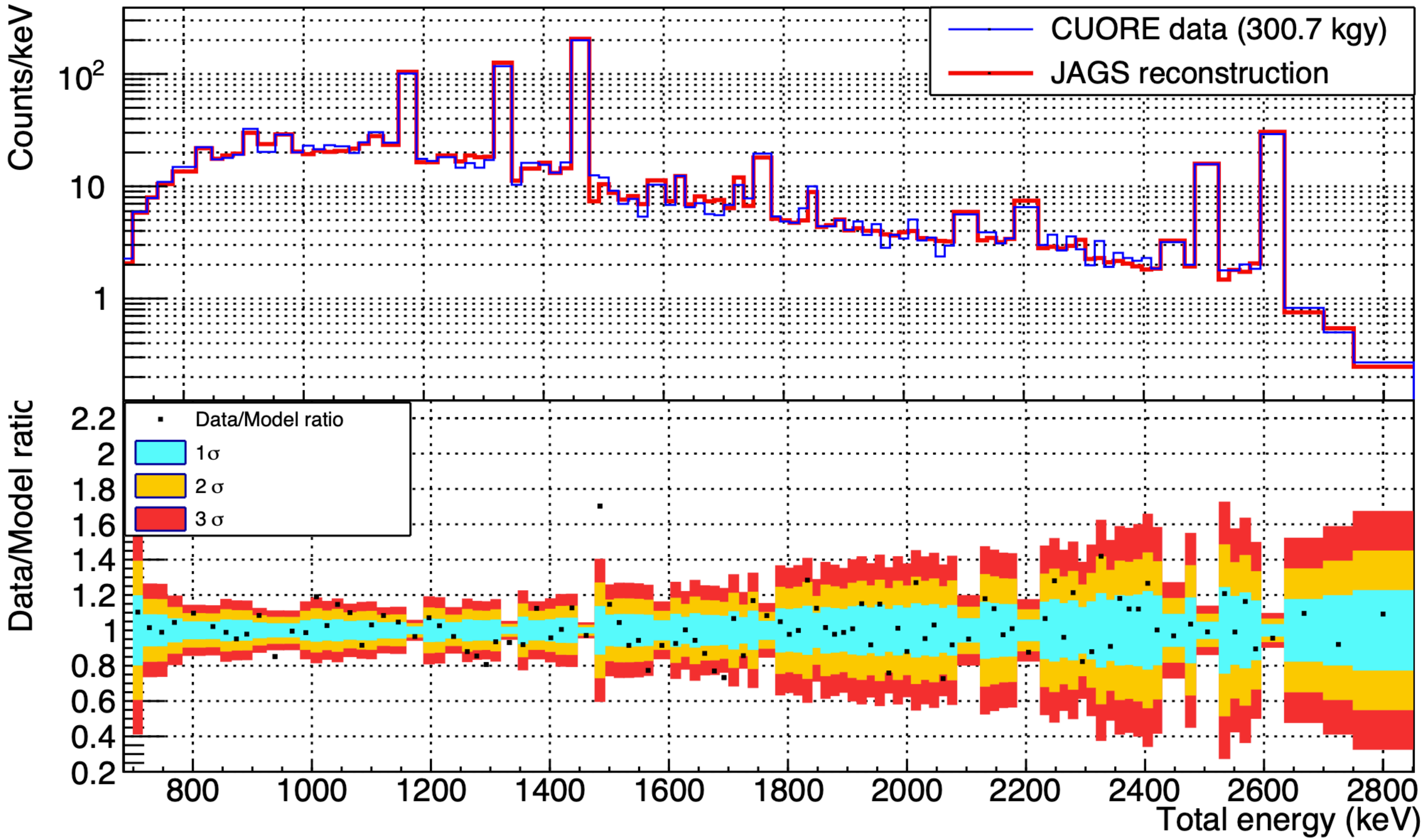
The probability of setting a stronger limit is 3%

Adams, D.Q. et al. (CUORE Collaboration), Phys. Rev. Lett. 124, 122501, 2020
https://doi.org/10.1103/PhysRevLett.124.122501

M2 SPECTRUM FIT (JAGS)



M2-SUM SPECTRUM FIT (JAGS)



EFFECT OF 90SR REMOVAL