
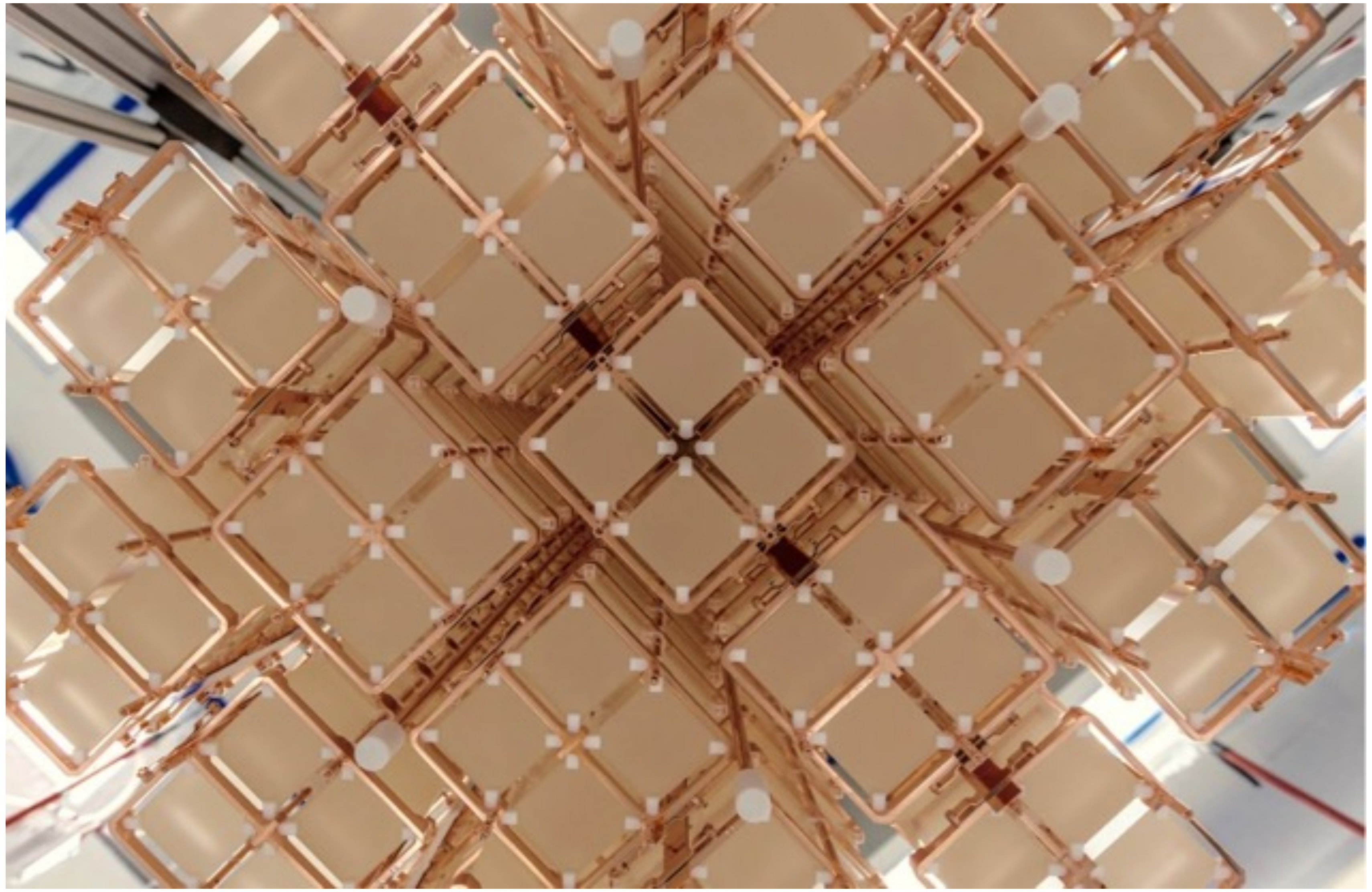
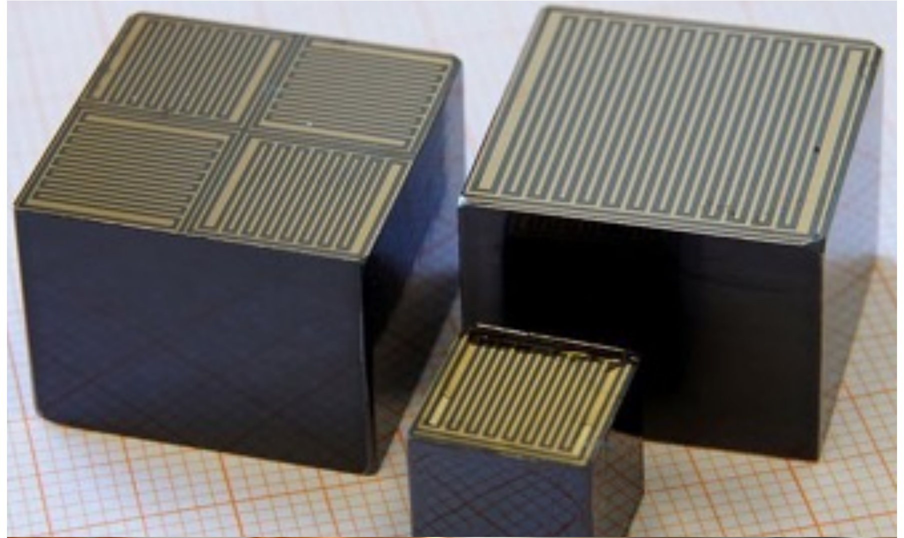
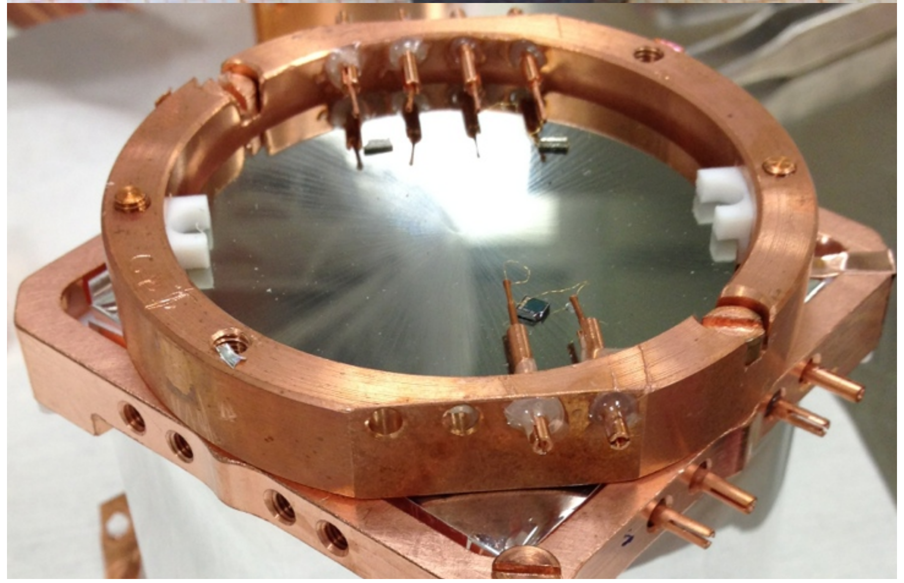

Experimental search of neutrino-less double-beta decay in ^{130}Te

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October 18, 2017 - CNNP 2017 - Catania, Italy

Outline

- Why Tellurium?
- Experimental approaches
  - CUORE
  - CUPID
  - SNO+
  - Cobra
- Conclusions

ββ0ν sensitivity master formula

The number of background events expected along the experiment lifetime is

$$N_B = bkg \cdot \Delta E \cdot M \cdot t_{meas}$$

Two cases are then possible depending on the extent of the background:

$$N_B >> 1 \longrightarrow S^{0\nu}_{1/2} \propto \epsilon \frac{i.a.}{A} \sqrt{\frac{M \cdot t_{meas}}{bkg \cdot \Delta E}}$$

$$N_B < 1 \longrightarrow S^{0\nu}_{1/2} \propto \epsilon \frac{i.a.}{A} M \cdot t_{meas}$$

generally named **"zero background"** condition

N_{nuclei} number of active nuclei in the experiment
t_{meas} measuring time [y]
M detector mass [kg]
ε detector efficiency
i.a. isotopic abundance
A atomic number
ΔE energy resolution [keV]
bkg background [c/keV/y/kg]

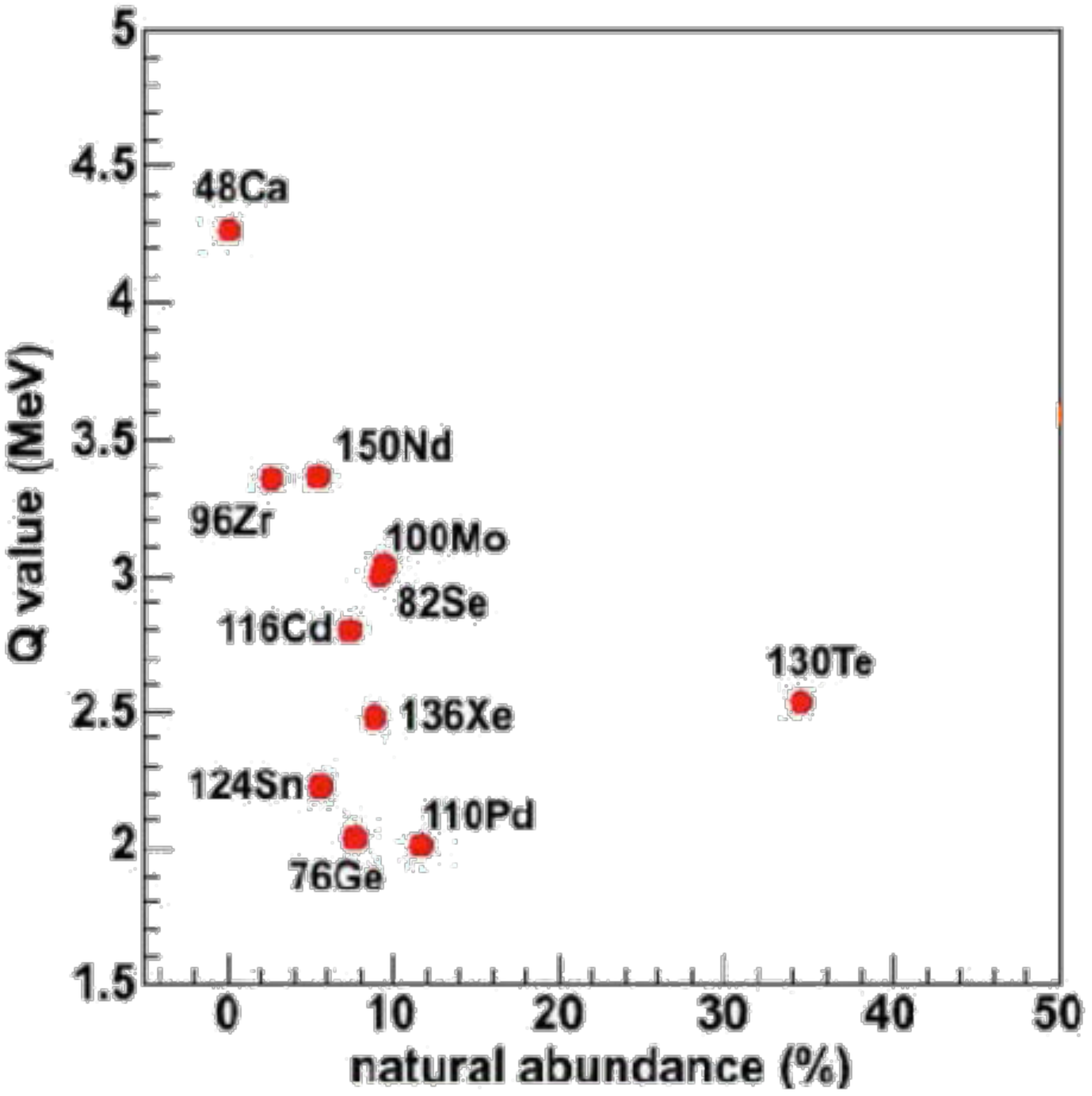
By inserting the proper nuclear factor of merit is then possible to get the sensitivity on the effective neutrino Majorana mass

$$\frac{1}{S^{0\nu}_{1/2}(m_{ee})} \propto \sqrt{S^{0\nu}_{1/2} \cdot G^{0\nu}} |M^{0\nu}|$$

Despite their simplicity these formula's outline the dependence of the sensitivity on the critical experimental parameters: **Mass, Measure Time, Energy resolution, Background and Isotope choice**

Why Tellurium?

Isotope	i.a.(%)	Q [MeV]
^{48}Ca	0.187	4.263
^{76}Ge	7.8	2.039
^{82}Se	9.2	2.998
^{96}Zr	2.8	3.348
^{100}Mo	9.6	3.035
^{116}Cd	7.6	2.813
^{130}Te	34.1	2.527
^{136}Xe	8.9	2.459
^{150}Nd	5.6	3.371



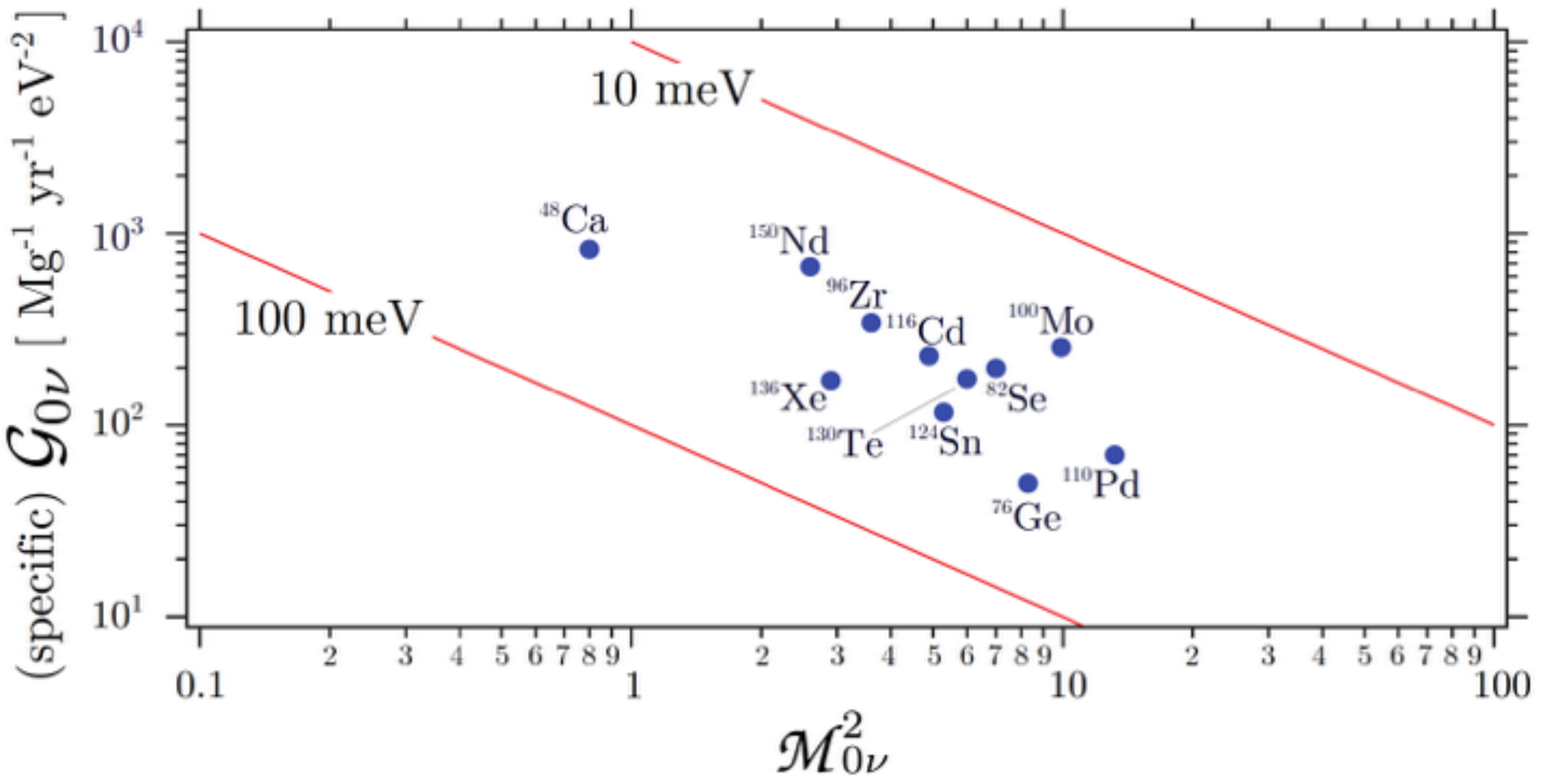
^{130}Te	β− β−	34.08%	2527.51
^{120}Te	β+ /EC,EC/EC	0.09%	1714.81
^{128}Te	β− β−	31.74%	865.87

A preferred isotope?

- Rate master formula $$(T^{0\nu}_{1/2})^{-1} = \mathcal{G}^{0\nu} \cdot |\mathcal{M}^{0\nu}|^2 \cdot |\frac{m_{\beta\beta}}{m_e}|^2$$

$\mathcal{G}^{0\nu}$ ... phase space factor
$\mathcal{M}^{0\nu}$ ... nuclear matrix element
$m_{\beta\beta}$ ... effective neutrino mass
m_e ... electron rest mass

- In principle, isotopes with the best Nuclear Factor of Merit ($\mathcal{G}^{0\nu}*\mathcal{M}^{0\nu\,2}$) should be favoured
- A surprising inverse correlation has been observed between phase space and the square of the nuclear matrix element .
  - dots are the geometric mean of the squared matrix element range limits
  - the phase-space factor is evaluated at g_A=1



No preferred isotope ... within a factor 2-3

A.Robertson, Mod. Phys. Lett. A, Vol. 28, No. 8 (2013) 1350021, arXiv 1301.1323

Experimental approach

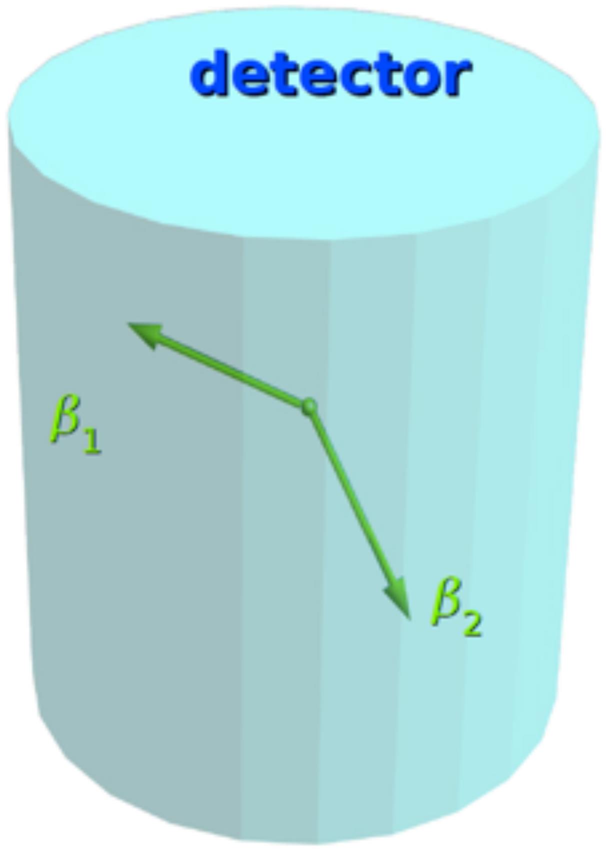
Two main approaches:

- homogeneous (calorimetric or active source)
- inhomogeneous (external-source or passive source)

Calorimeters

Solid-state devices, bolometers, scintillators, gas detectors

+ Very large M possible (~10kg → tons)
+ High efficiency (ε~1)
+ Very high energy resolution (ΔE~0.015% with Ge-diodes, bolometers)
+ Event topology (in gas/liquid Xe detectors or pixellization)
+ Good background levels
- Constraints on detector choice (except for bolometers)
- No or partial particle id

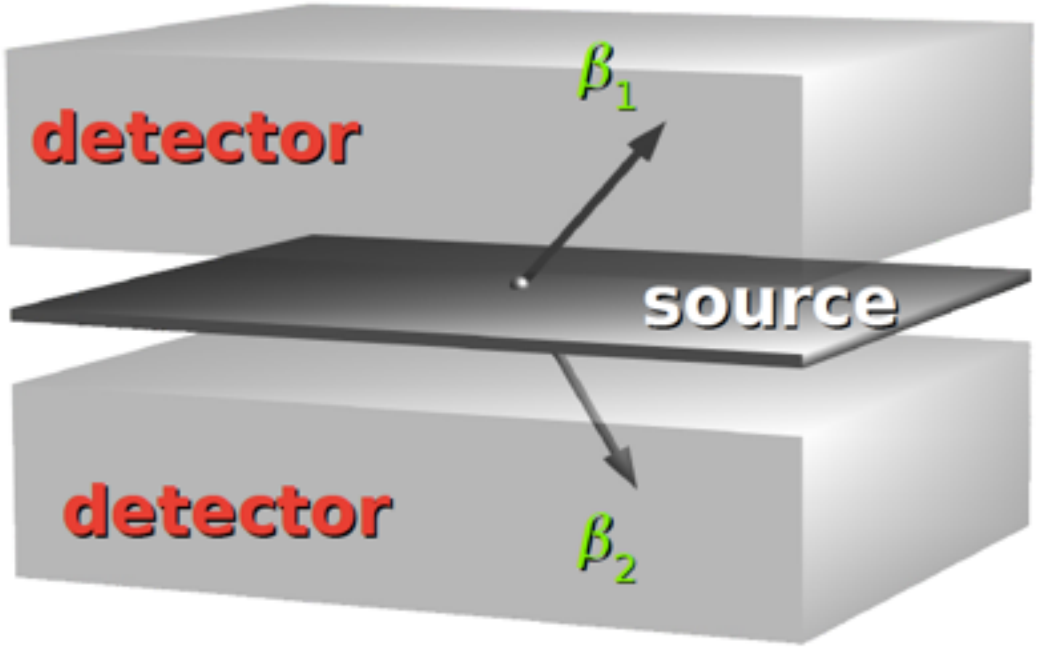


- CUORE/CUPID
- SNO+
- COBRA

External-source detectors

Scintillators, gas TPC, gas DC, magnetic field and TOF

+ Event topology allowing ¨clean bkg¨ (except $2\nu\beta\beta$)
+ Several $\beta\beta$ candidates can be studied with same detector
- Difficult to get large source M
- Difficult to get high efficiency
- Difficult to get good resolution



- NEMO3

Tellurium experiments

Experiment	Technique	Energy resolution	Status	Laboratory	Main information
CUORE	Pure bolometer	High	Running	LNGS	Heat
CUPID	Hybrid bolometer	High	R&D	LNGS	Heat + Light
SNO+	Te loaded scintillator	Low	Construction	SNOLAB	Scintillation + Topology
COBRA	Semiconductor	High	R&D	LNGS	Ionisation + Topology

Geochemical experiments: an historical debate

- O.K.Manuel (Rolla,MO,1991): $T_{1/2}(\beta\beta 2\nu,{}^{130}Te) = 8\times10^{20}$ yr
- T.Kirsten (Heidelberg,1983): $T_{1/2}(\beta\beta 2\nu,{}^{130}Te) = (2.55\pm0.20)\times10^{21}$ yr

CUORE
(Cryogenic Underground Observatory for Rare Events)

Primary goal: search for 0νββ decay in ^{130}Te

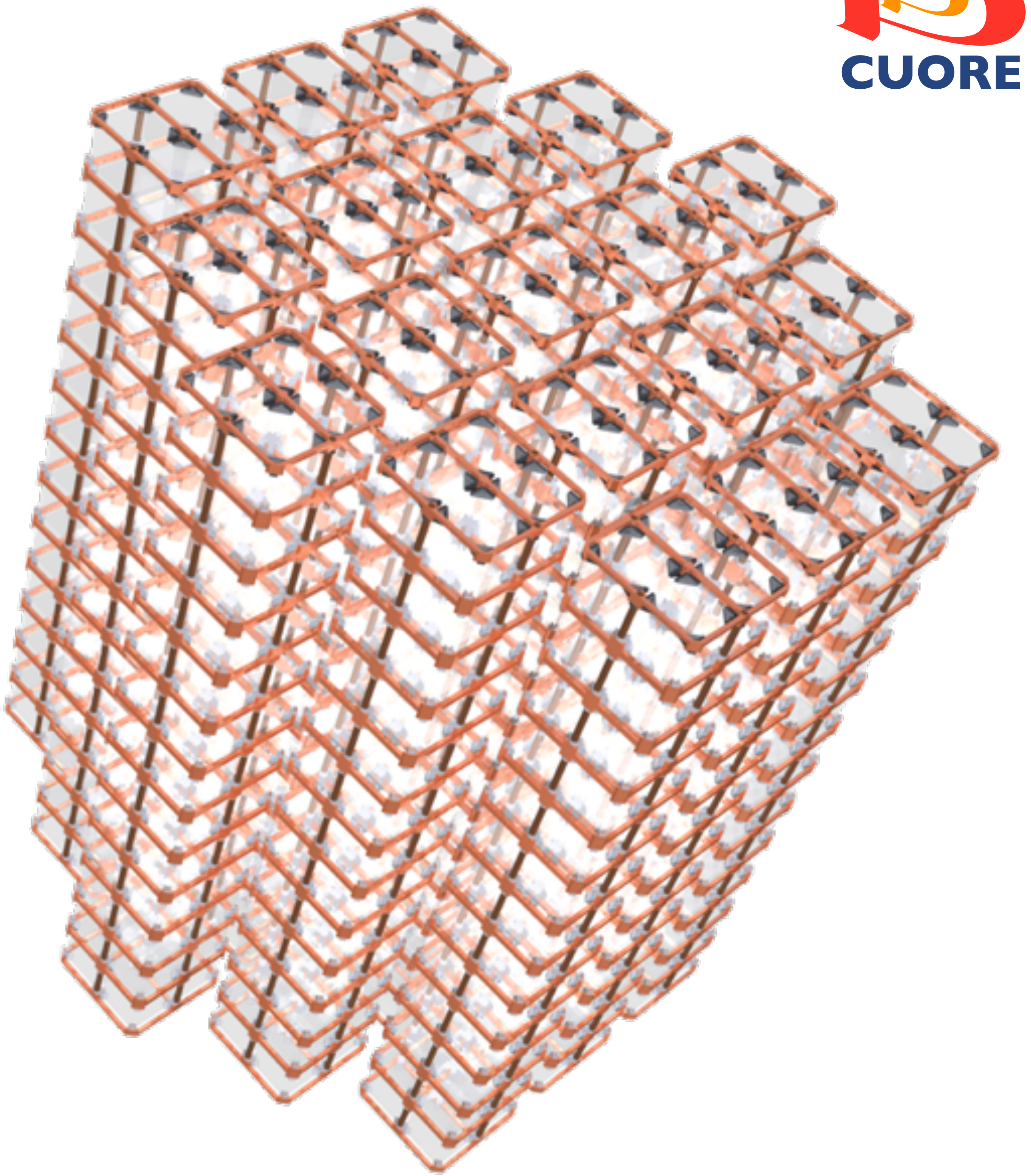
Closely packed array of 988 TeO_2 crystals arranged in 19 towers

^{130}Te:
- large transition energy: $Q_{\beta\beta}$ (^{130}Te) 2527.5 keV
- highest natural isotopic abundance (33.8%)

CUORE design parameters:
- mass of TeO_2: **742 kg** (206 kg of ^{130}Te)
- low background aim: **10^{-2} c/(keV·kg·yr)**
- energy resolution: **5 keV** FWHM in the Region Of Interest (ROI)
- high granularity
- deep underground location
- strict radio-purity controls on materials and assembly

CUORE projected sensitivity (5 years, 90% C.L.):

$T_{1/2} > 9 \times 10^{25}$ yr



See also C.Brofferio talk

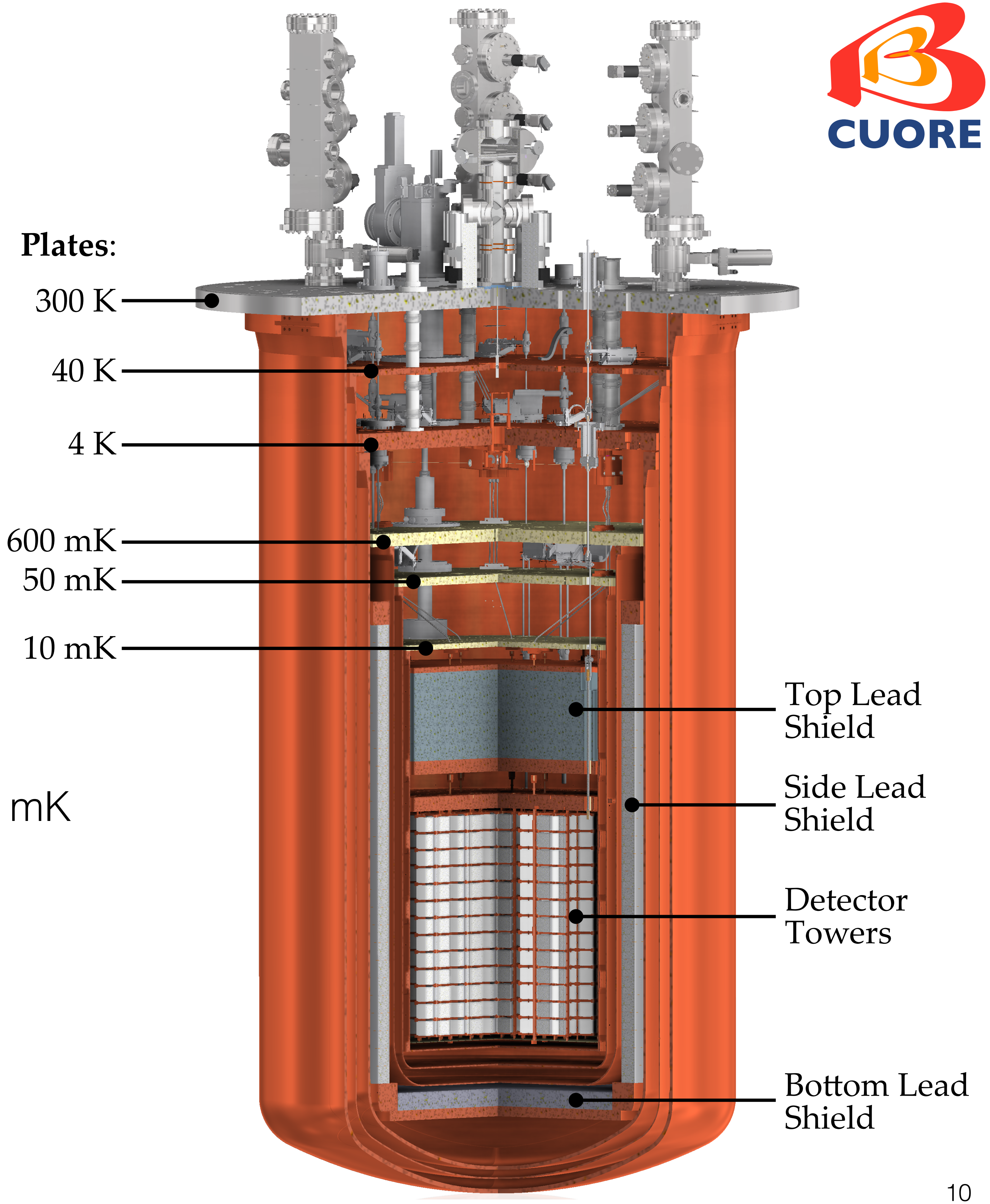
CUORE @ LNGS

1400 m of rock (~3600 m.w.e.) deep

- μ's: ~3 × 10^{-8} / (s·cm^2)
- γ's: ~0.73 / (s·cm^2)
- neutrons: 4 × 10^{-6} n/(s·cm^2) below 10 MeV

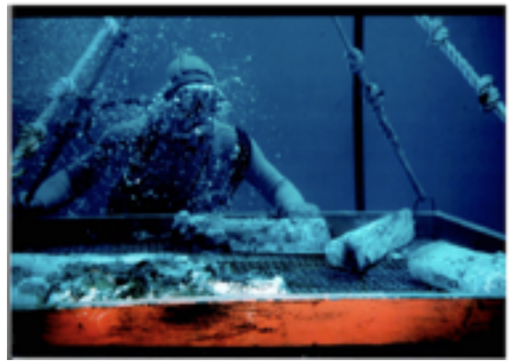
The CUORE cryostat

- Designed to cool down ~1 ton detector to ~10 mK
- Mechanically decoupled for extremely low vibrations
- Low background environment

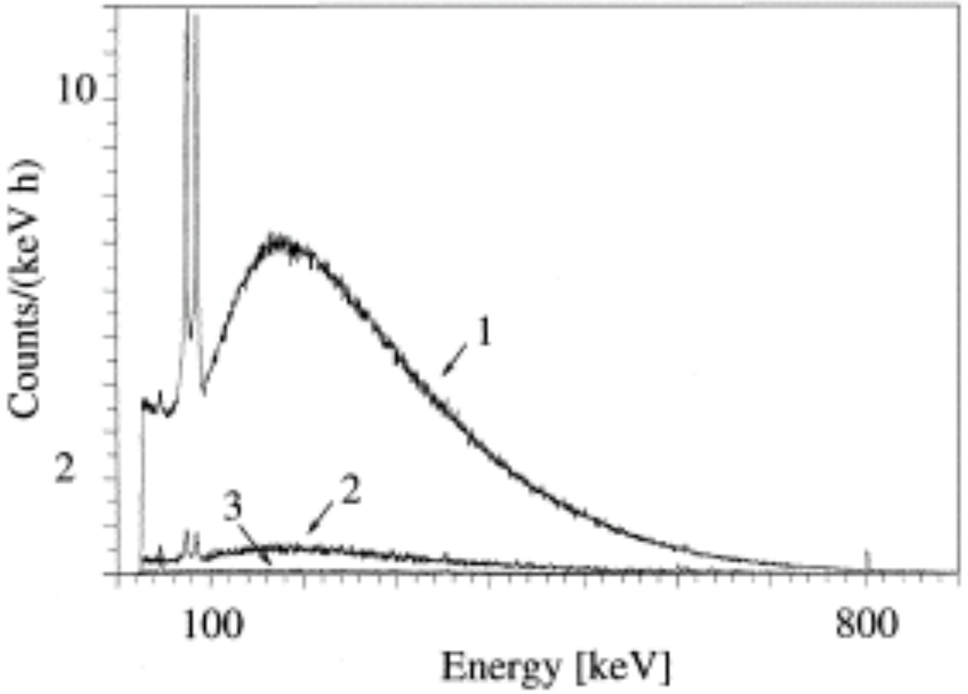


- Cryogen-free cryostat
- Fast Cooling System (^4He gas) down to ~50K
- 5 pulse tubes cryocooler down to ~4K
- Dilution refrigerator down to operating temperature ~10 mK
- Nominal cooling power: 3 μW @ 10mK
- Cryostat total mass ~30 tons
- Mass to be cooled < 4K: ~15 tons
- Mass to be cooled < 50 mK: ~3 tons (Pb, Cu and TeO_2)

Roman lead shielding

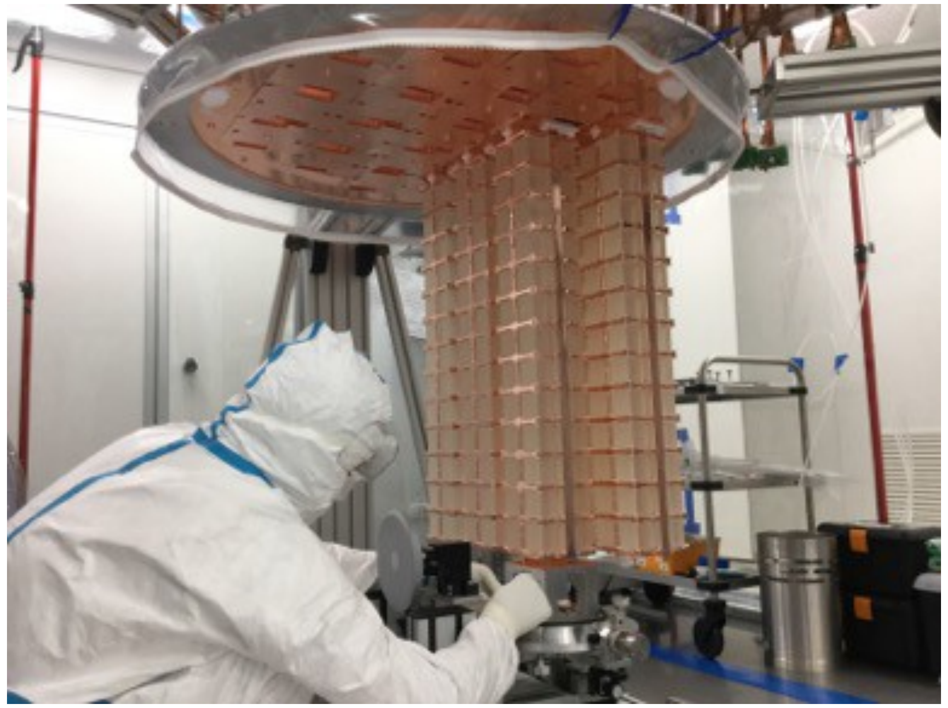


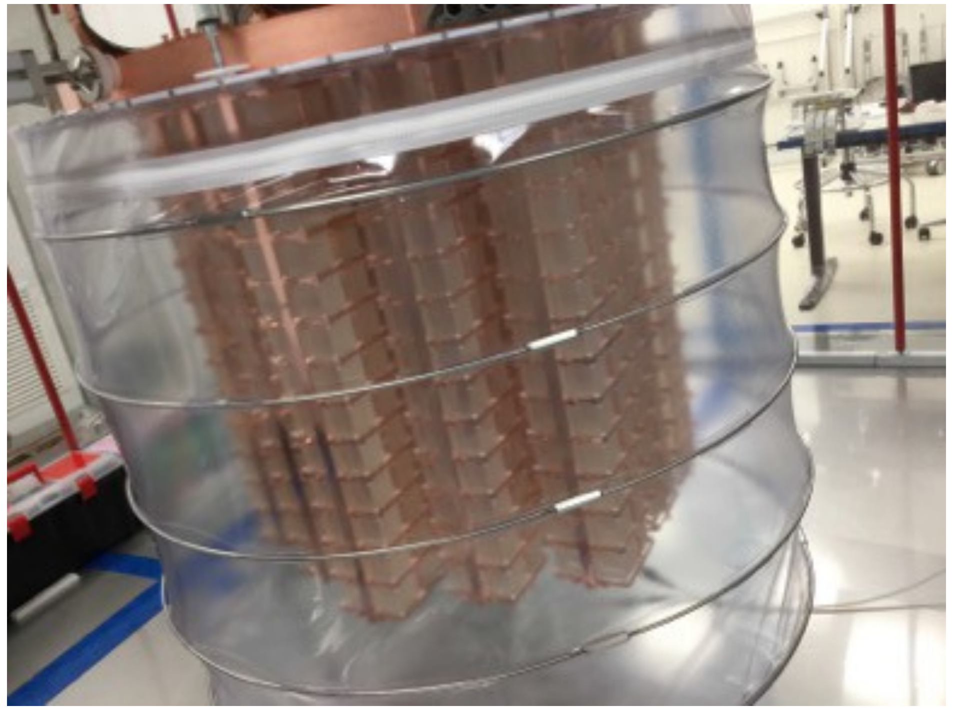
- Lead is an excellent material for shielding but normally it contains ^{210}Pb with 10-1000 Bq/kg (half life ~ 22 y)
- Ingots from a shipwreck found close to Sardinia coast (I sec b.C.)
- Romans extracted the Ag from the Pb (and ^{238}U with it)
  - ^{210}Pb in roman Pb < 4 mBq/kg
- Ancient Roman Pb is extremely precious!
  - agreement with the cultural heritage authorities to preserve the external part of the ingots
  - casting done in N_2 atmosphere with a clean SS mould
  - machining with selected tools and liquids
- Shield 6 cm thick (4.5 tonnes of Pb + 1 tonne of Cu)
  - realized in ring sectors with dovetail design to minimize holes
  - rings interleaved with copper foils to improve thermalization
  - mechanically attached to the still plate but thermalized @ 4K



CUORE construction

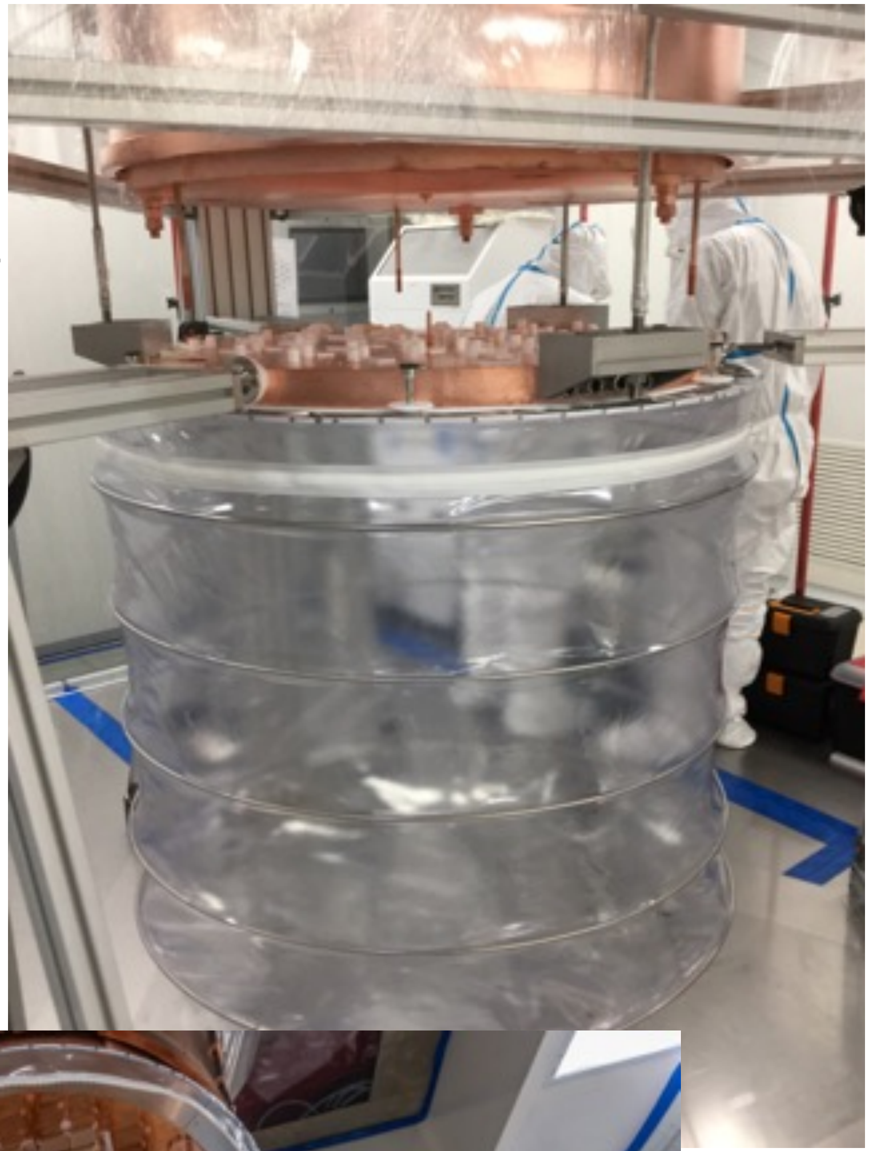
- June 2016: last steps of the CUORE construction process
    - Installation of the front-end electronics (2nd floor)
    - Installation of the DAQ (2nd floor)
    - Detector installation preparation
- August 2016: detector installation
- September-November 2016:
    - Installation of cryostat interfaces
    - Test of readout wires
    - Close-out of the cryostat vessels
    - IVC eventually closed in October 2016
- December 2, 2016: system close-out complete
- December 5, 2016: cool-down start

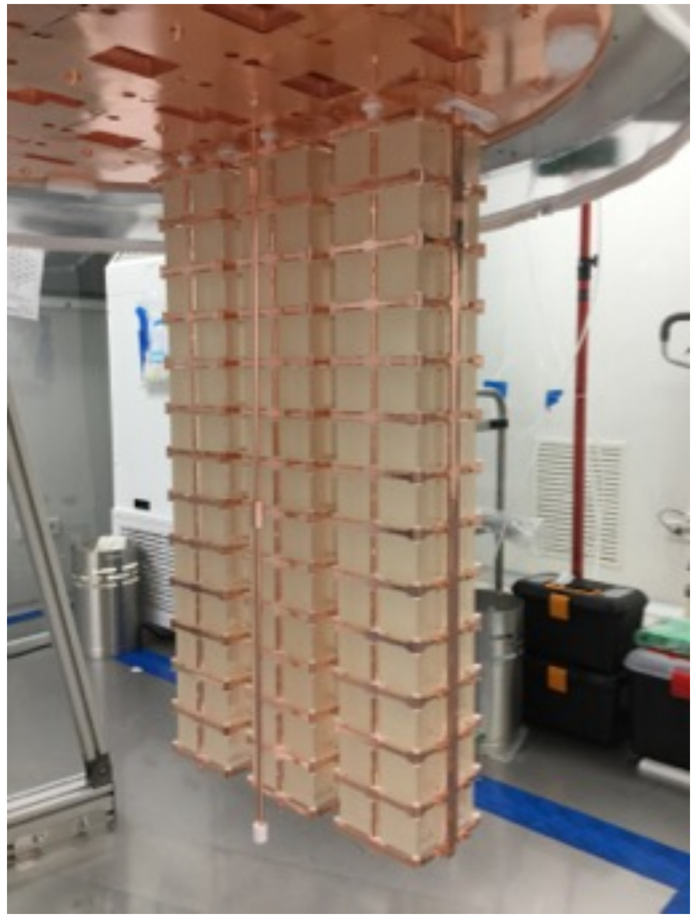




Detector Installation

- The detector installation was the first period in which the detector was exposed to (Rn-free) air
- Custom-made clean room flushed with Rn-free air (Rn concentration <0.1 Bq/m^3)
  - Radon Abatement System
- Detector "protective bag" flushed with nitrogen during installation interruptions
- Strict installation protocol

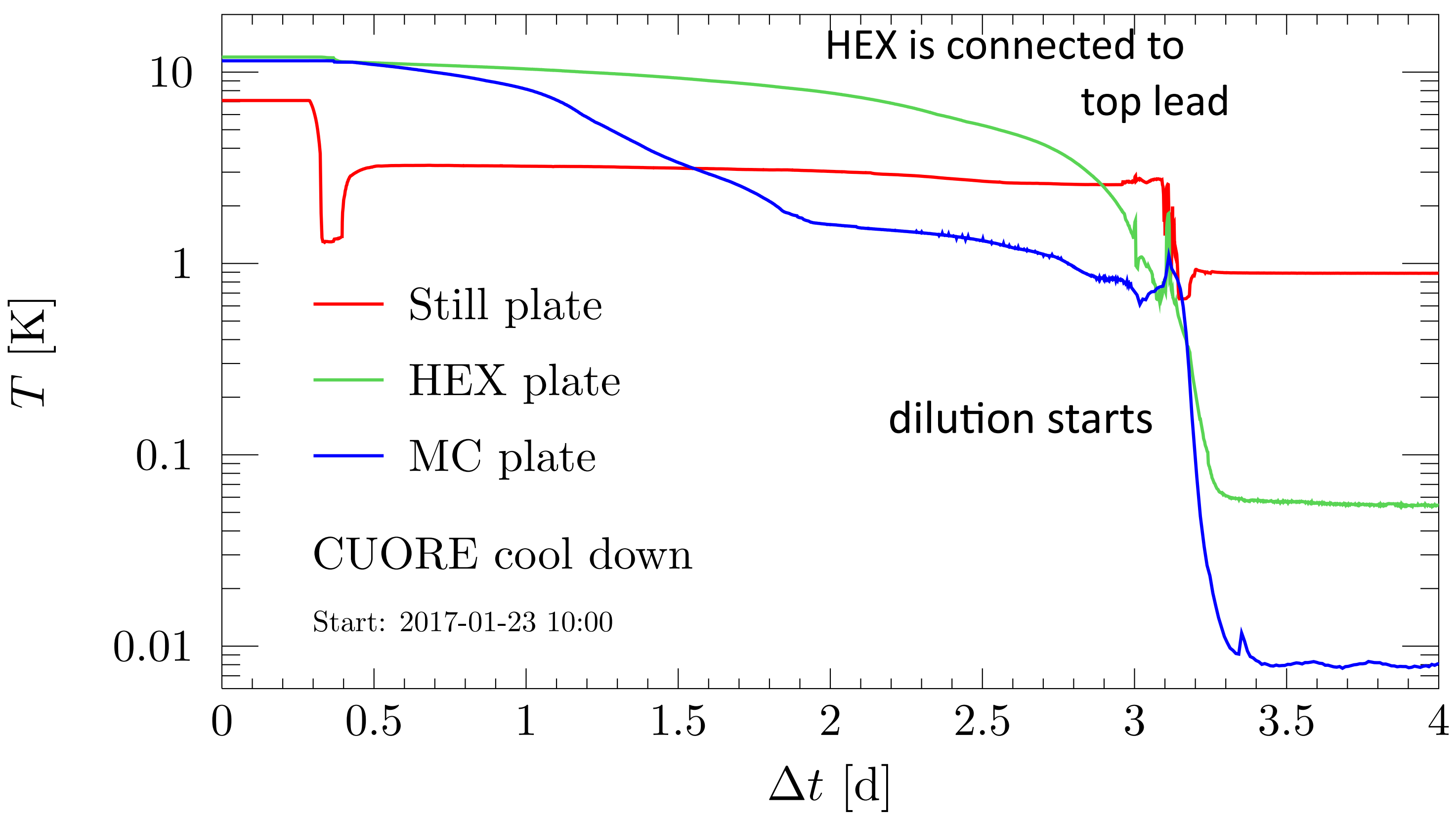




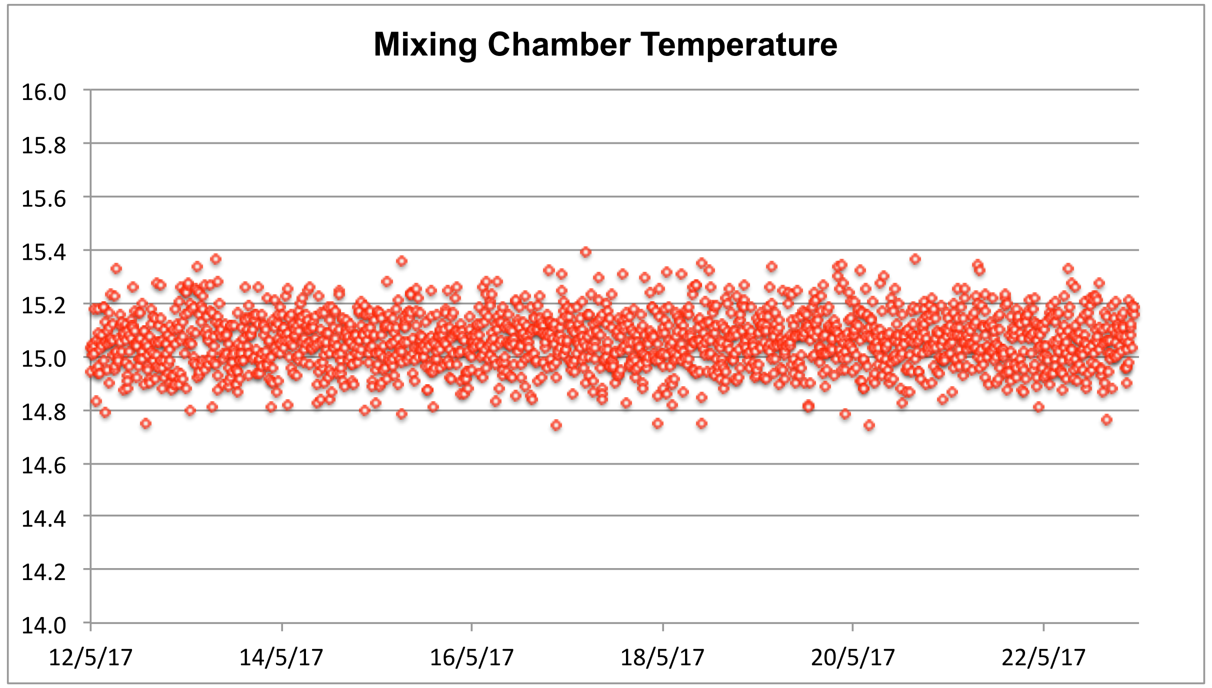
- **Detector installation completed on August 26, 2016**

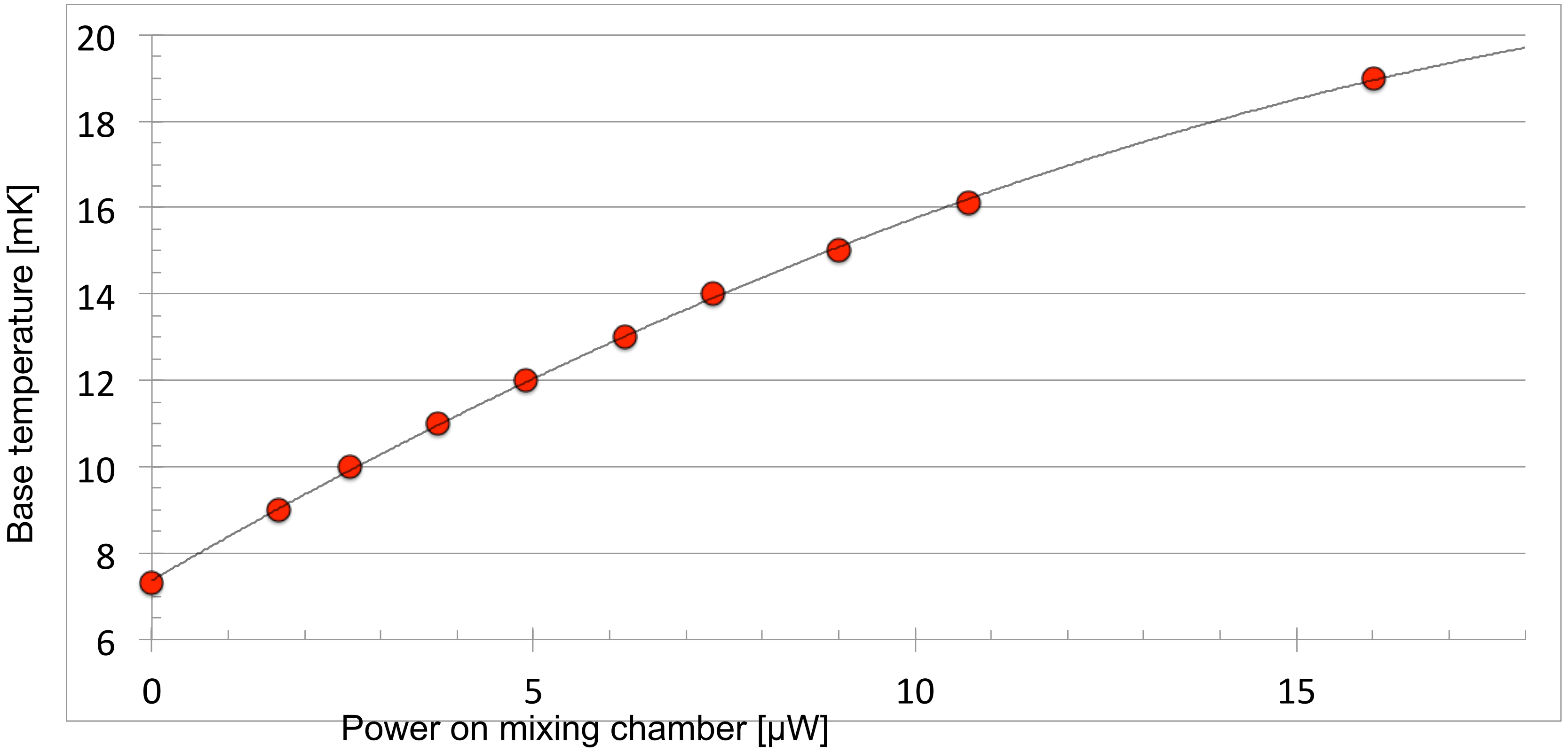
CUORE cooldown

- Reached a stable base temperature of ~7 mK on Jan 27, 2017
- Cooldown to base T: ~ 3 days
- Lowest temperature reached: 6.7 mK
- 984/988 working detectors
- Excellent performance @ full load



- Stable operation





CUORE operation

- Pre-operation (detector commissioning) started in February 2017
- Gradual transition to operation: alternate science runs to technical measurements aiming to achieve better performance and to demonstrate improvements towards the ultimate performance

2017:

Feb-Mar: system optimisation
Apr-May: science runs
Jun-Jul: system optimisation
Aug-Sep: science runs
Oct-Nov: system optimisation

2018:

Science runs

Science runs

- Apr-May 2017 (ds 3018): announced at TAUP 2017
- Aug 2017 (ds 3021): still embargoed

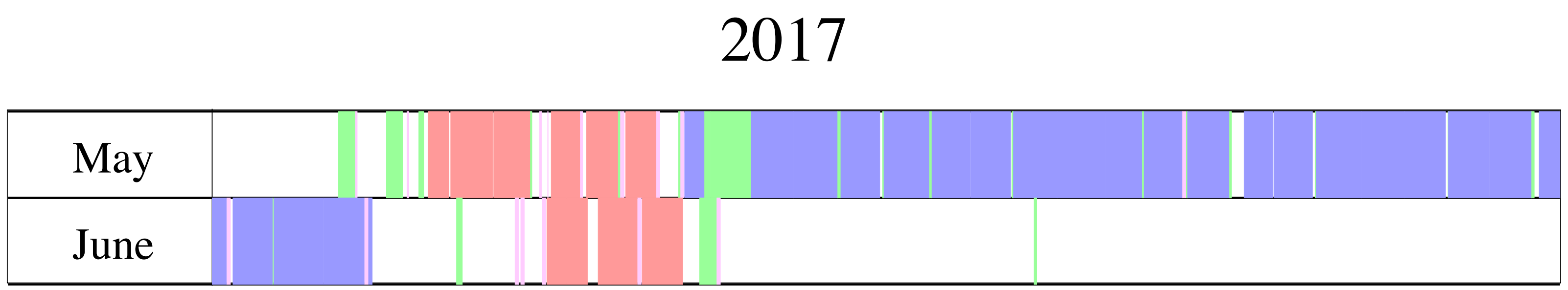
Apr-May 2017 science runs

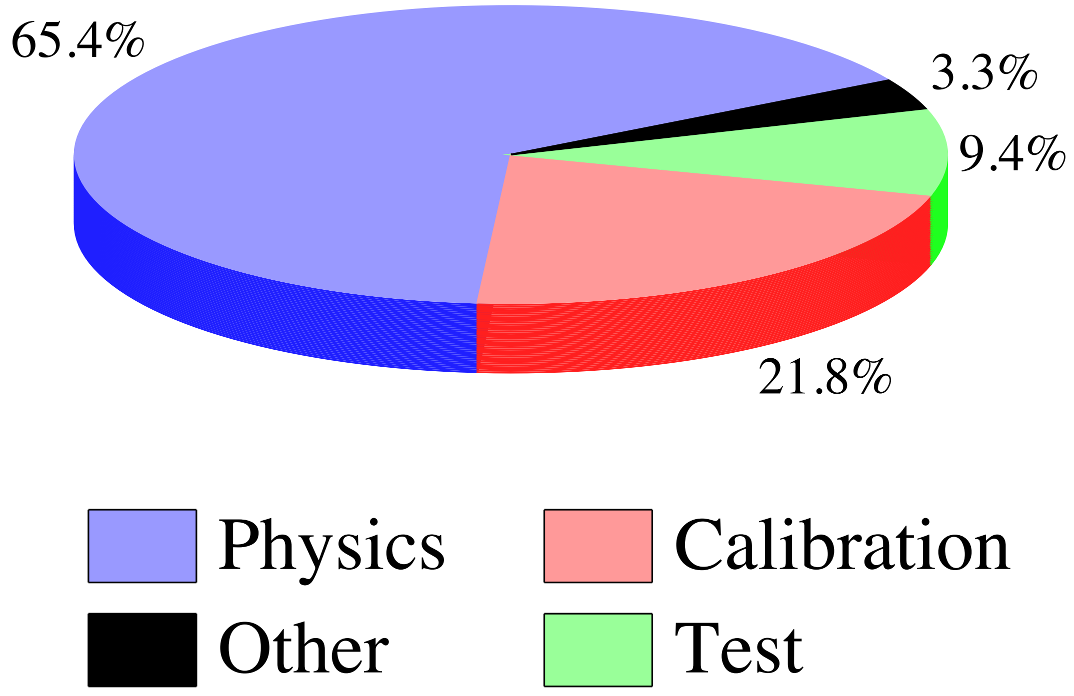
- Science operations started on April 14, 2017
  - **Dataset 1**: very short (identified issue with the thermistor bias on about 1/3 of the channels)
  - Reoptimization of the detector working point
  - **Dataset 2**: 3 weeks of physics data bracketed by 2 calibration periods (May 4 - June 11)
- Operational performance:
  - **984/988 operational channels**
  - Excellent data-taking efficiency when in operations
  - Much improved detector stability, compared to Cuoricino/CUORE-0
  - Calibrations/physics ratio data still to be optimized to maximize 0νββ sensitivity

Acquired statistics for 0vDBD decay search:

- **$^{nat}TeO_2$ exposure: 38.1 kg yr**
- **^{130}Te exposure: 10.6 kg yr**

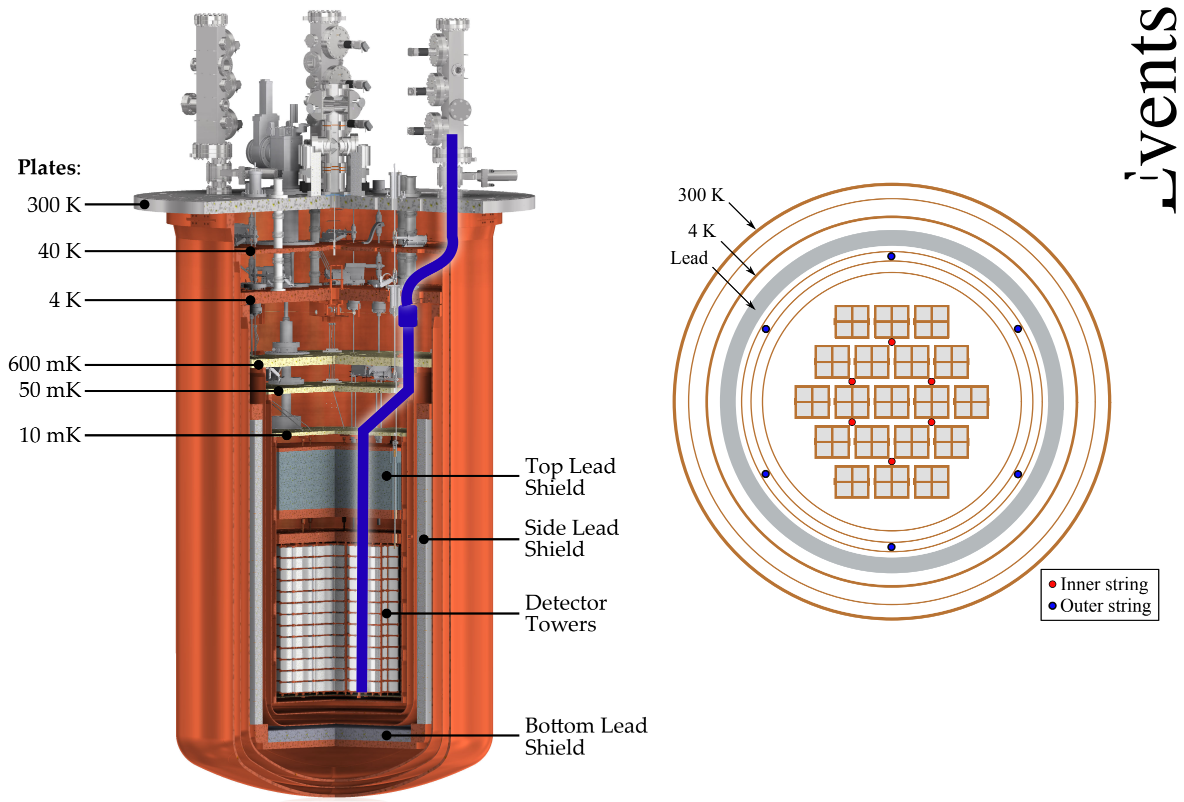
Dataset 2 time breakdown

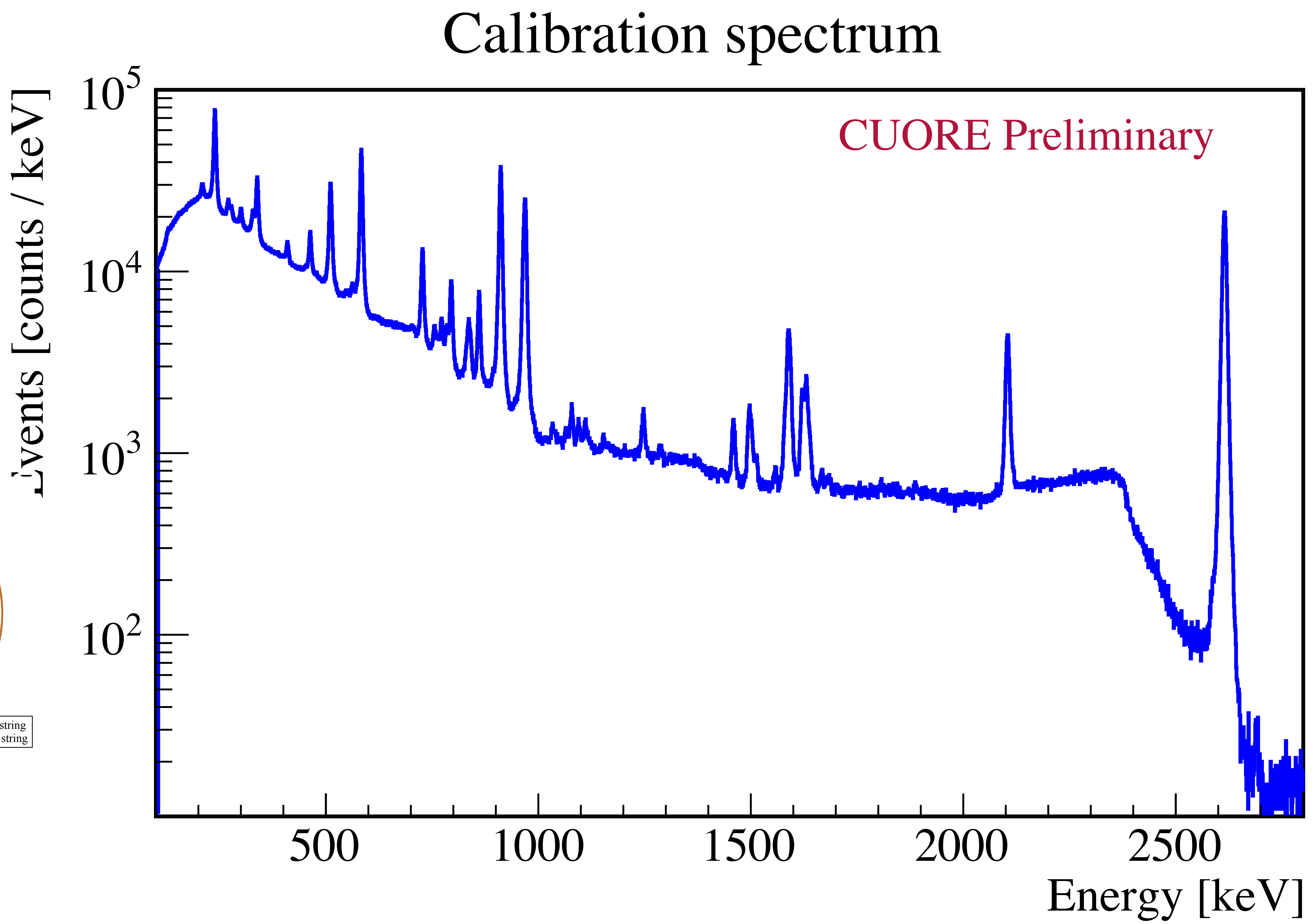




Calibration spectrum

- ^{232}Th sources deployed inside the CUORE detector
- Energy spectrum of all the CUORE detectors

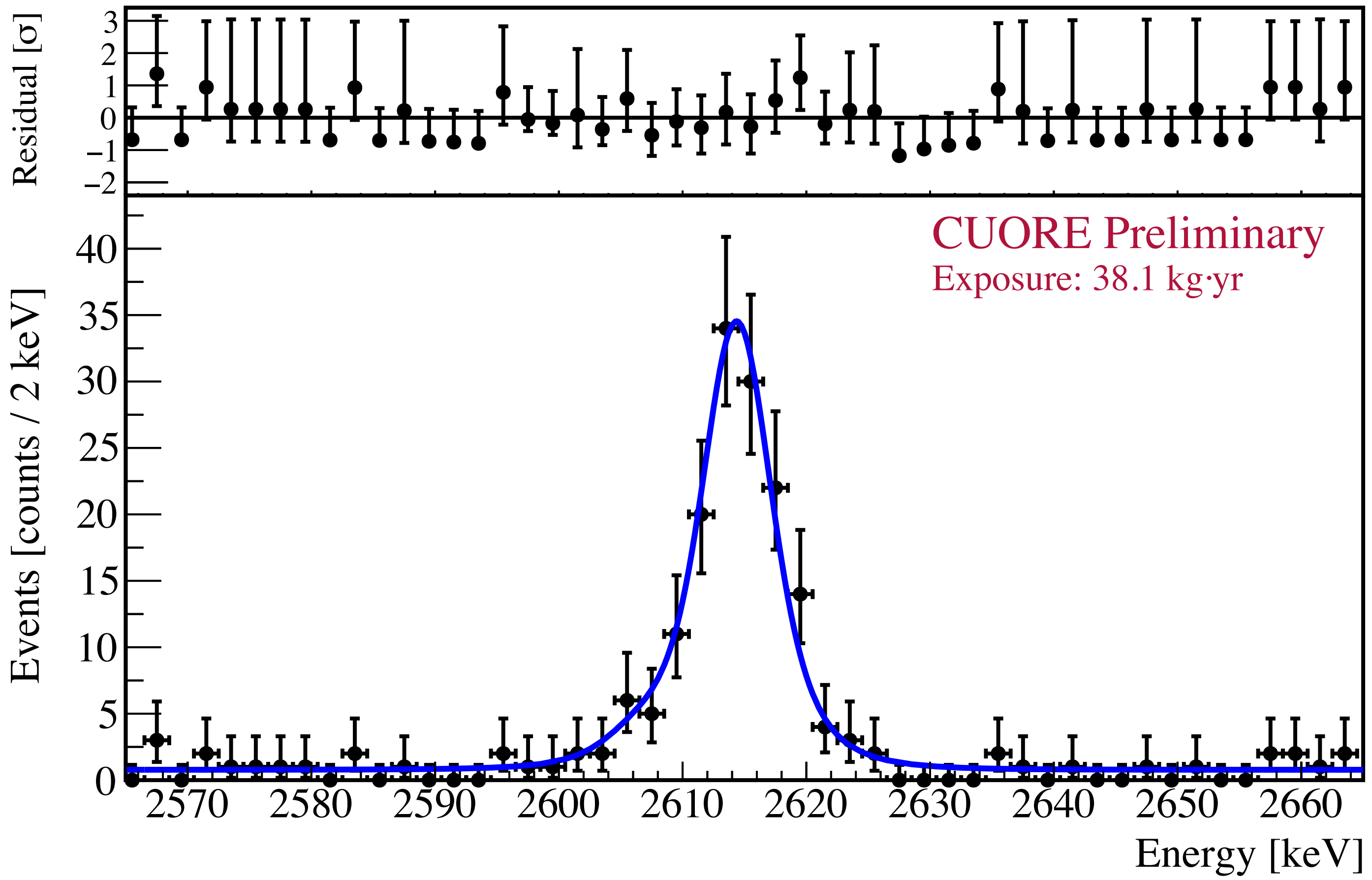


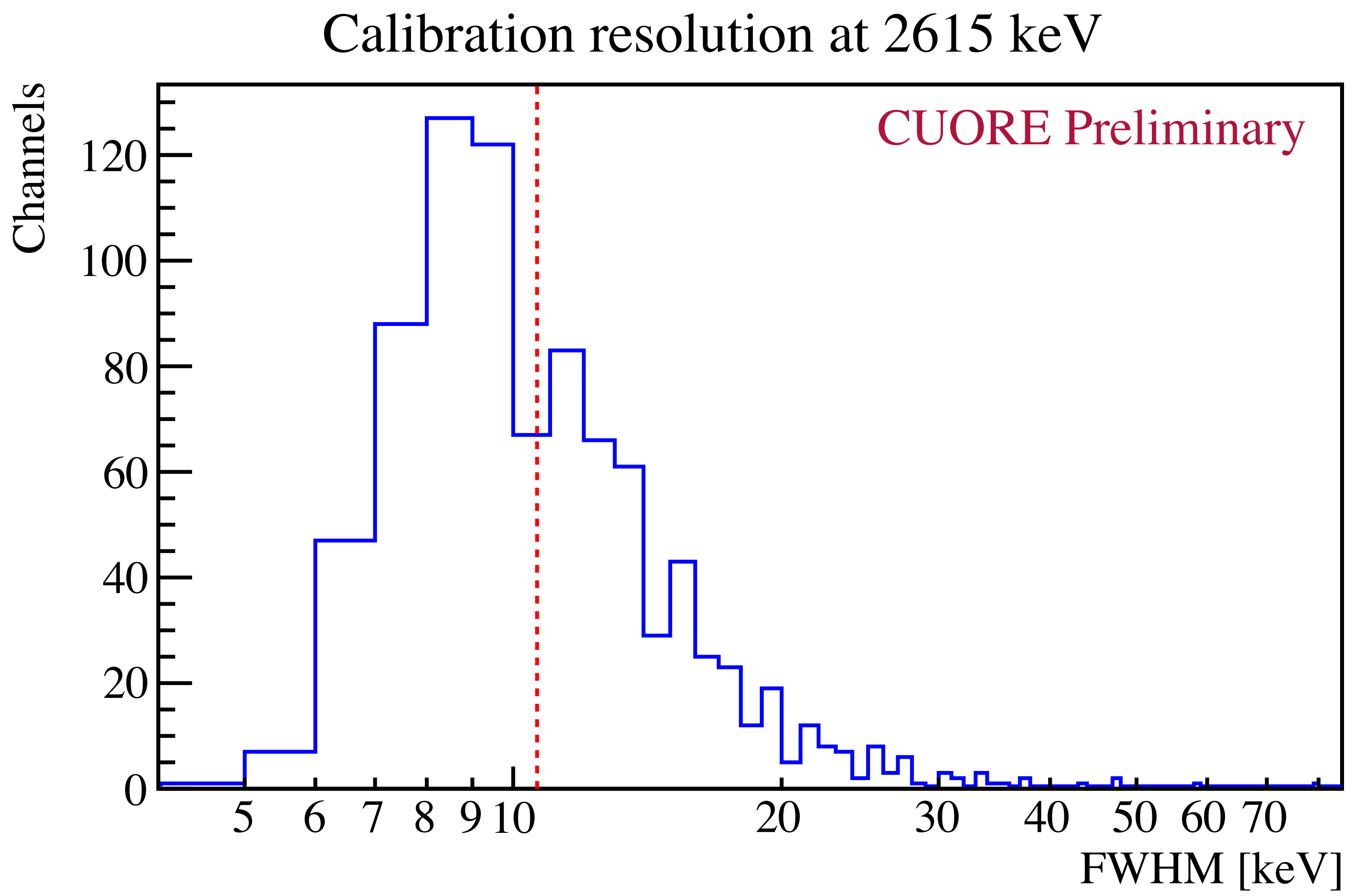


Detector performance: energy resolution

- 899 (90%) best performing channels used for initial analysis; most discarded channels had poor line or pulse shapes, and should be recovered in future runs
- Average (“harmonic mean”) energy resolution in calibration runs: **10.6 keV FWHM @ 2615 keV**

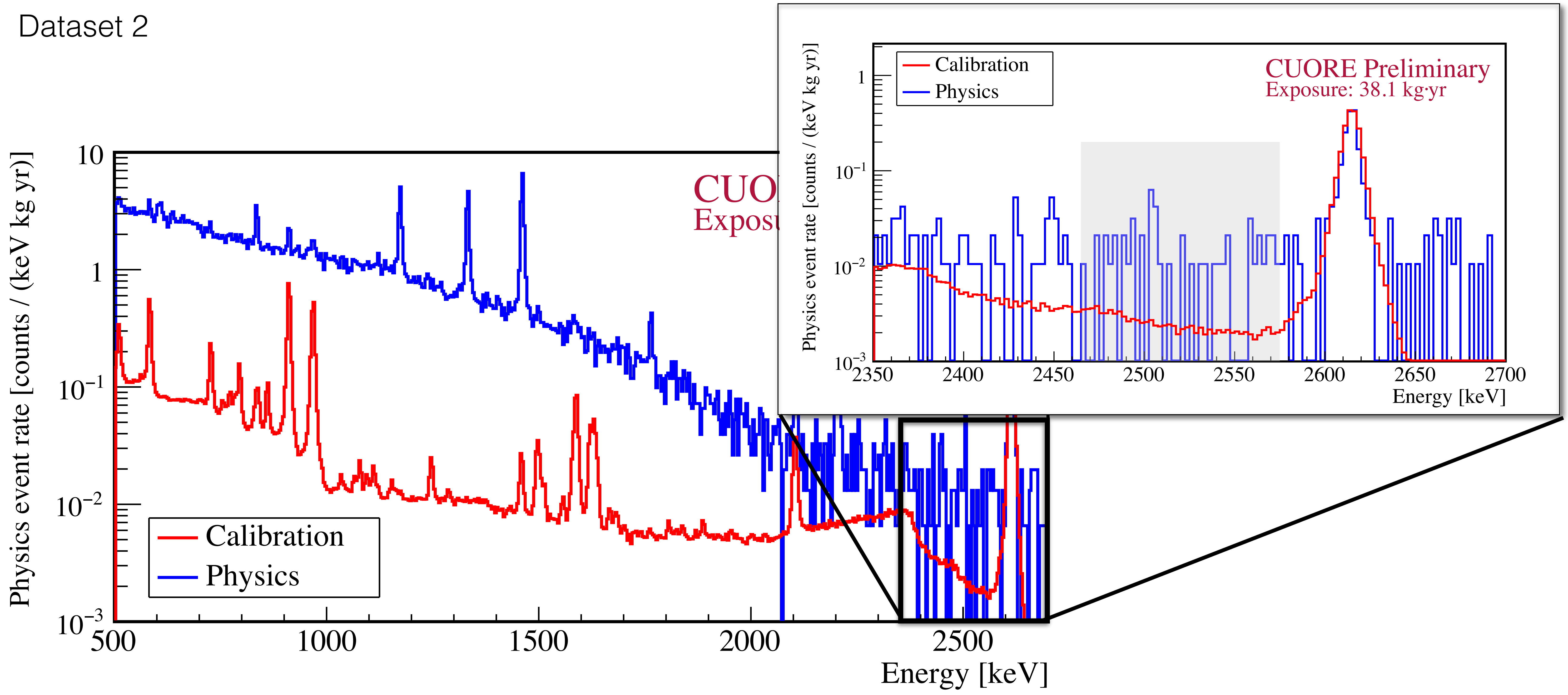
- Significantly better performance in physics data: **(7.9 ± 0.6) keV FWHM @ 2615 keV**





Background spectrum: γ region

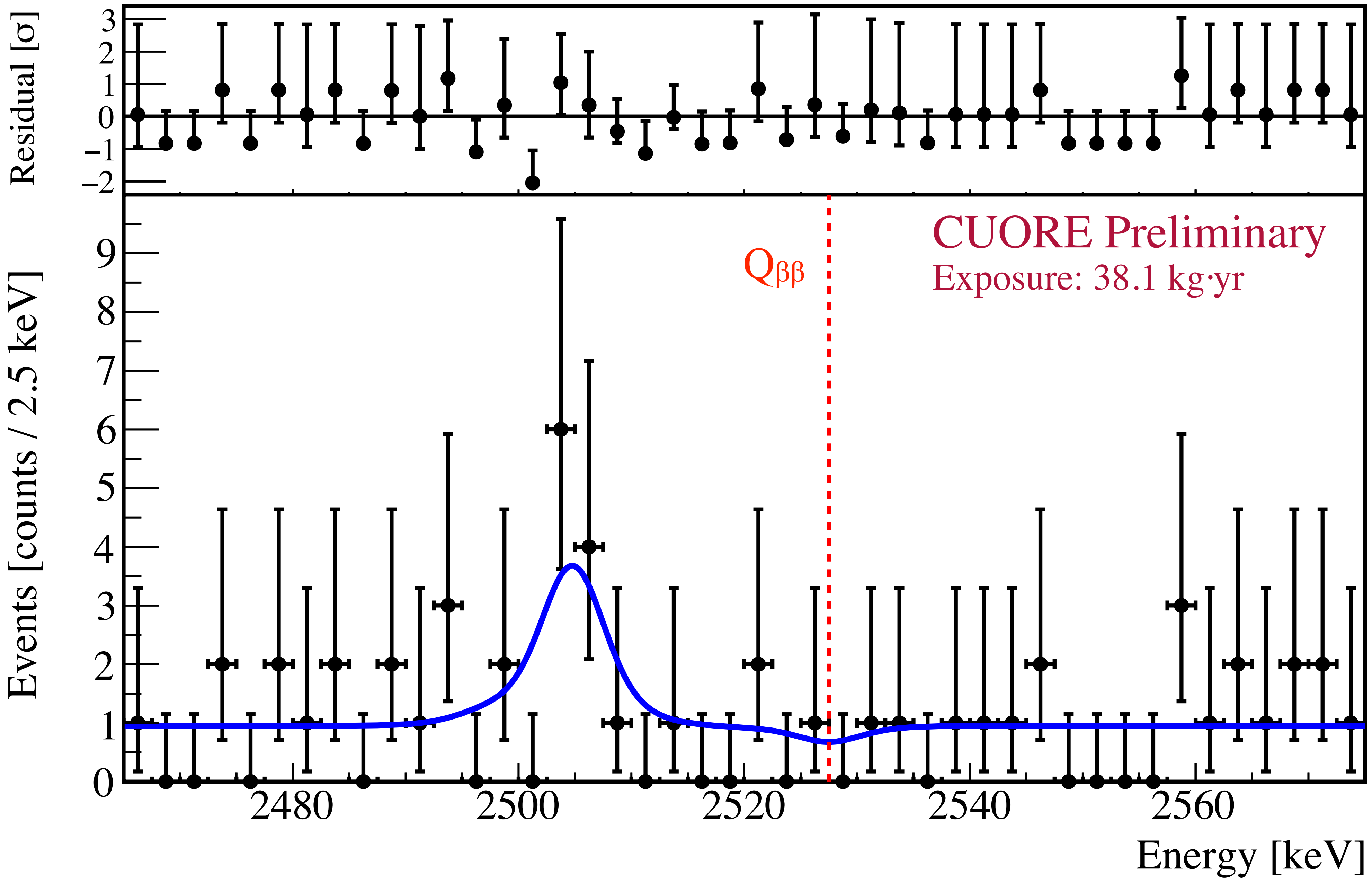
Dataset 2



Fit in the ROI: unblinded spectrum

CUORE

- We determined the yield of $0\nu\beta\beta$ events by performing a simultaneous UEML fit in the energy region 2465-2575 keV
- The fit has 3 components:
  - a posited peak at the Q-value of ^{130}Te
  - a floating peak to account for the ^{60}Co sum gamma line (2505 keV)
  - a constant continuum background, attributed to multi scatter Compton events from ^{208}Tl and surface alpha events



Fit in the ROI: results

CUORE

- Profile likelihood
- Integrated on the physical region

- Region of interest: **2465 to 2575 keV**
- ROI background index: **$(9.8_{-1.5}^{+1.7}) \times 10^{-3}$ c/(keV·kg·yr)**
- Events in the region of interest: **50**
- Best fit for ^{60}Co mean: **(2504.8 ± 1.2) keV**

Efficiencies

Trigger and energy reconstruction	(98.469 ± 0.009) %
Anti-coincidence	(99.3 ± 0.3) %
Pulse shape analysis	(64 ± 3) %
All cuts except containment	**(62.6 ± 3.4) %**
0νββ containment	(88.345 ± 0.085) %
Total 0νββ efficiency	**(55.3 ± 3)%**

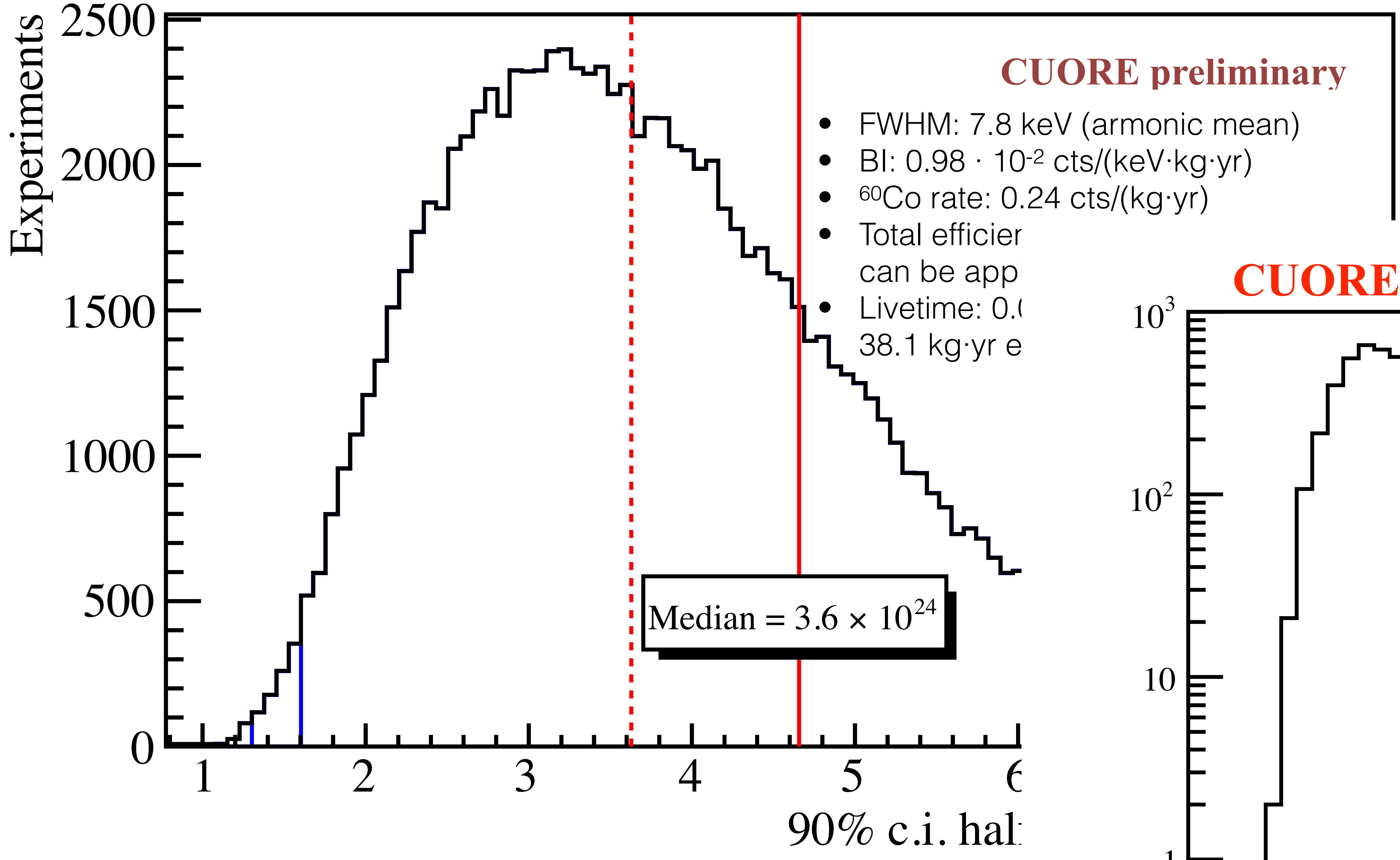
- Best fit decay rate: **$(-0.03_{-0.04}^{+0.07}$ (stat.) ± 0.01 (syst.)$)\times10^{-24}$ / yr**
- Decay rate limit (90% CL, including systematics): **0.15×10^{-24} yr^{-1}**
- Half-life limit (90% CL, including systematics): **4.5×10^{24} yr**
- Median expected sensitivity: **3.6×10^{24} yr (arXiv:1705.10816)**

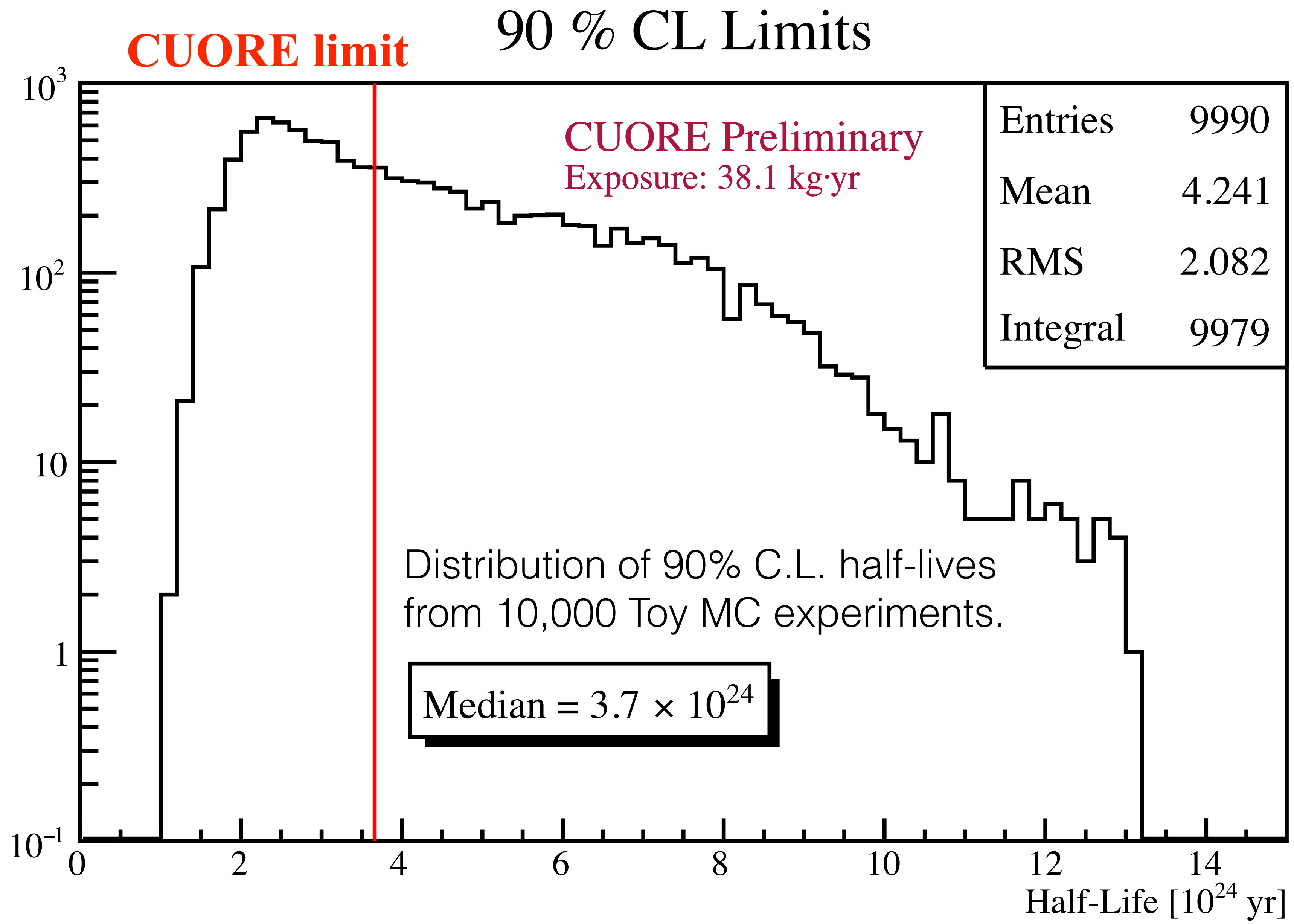
We have also evaluated limits according to "W. Rolke et al., Nucl. Instrum. Meth. A 551, 493-503 (2005)":

- Half-life limit (90% CL, including systematics): 6.1×10^{24} yr
- Decay rate limit (90% CL, including systematics): 0.11×10^{-24} / yr
- Median expected sensitivity: 3.7×10^{24} yr

Fit in the ROI: statistical significance

Exclusion sensitivity





Combination with previous results

- We combined the CUORE result with the existing ^{130}Te
    - 19.75 kg·yr of Cuoricino
    - 9.8 kg·yr of CUORE-0
- The combined 90% C.L. limit is

$T_{0\nu}$ > 6.6 × 10^{24} yr

$m_{\beta\beta}$ < 210–590 meV

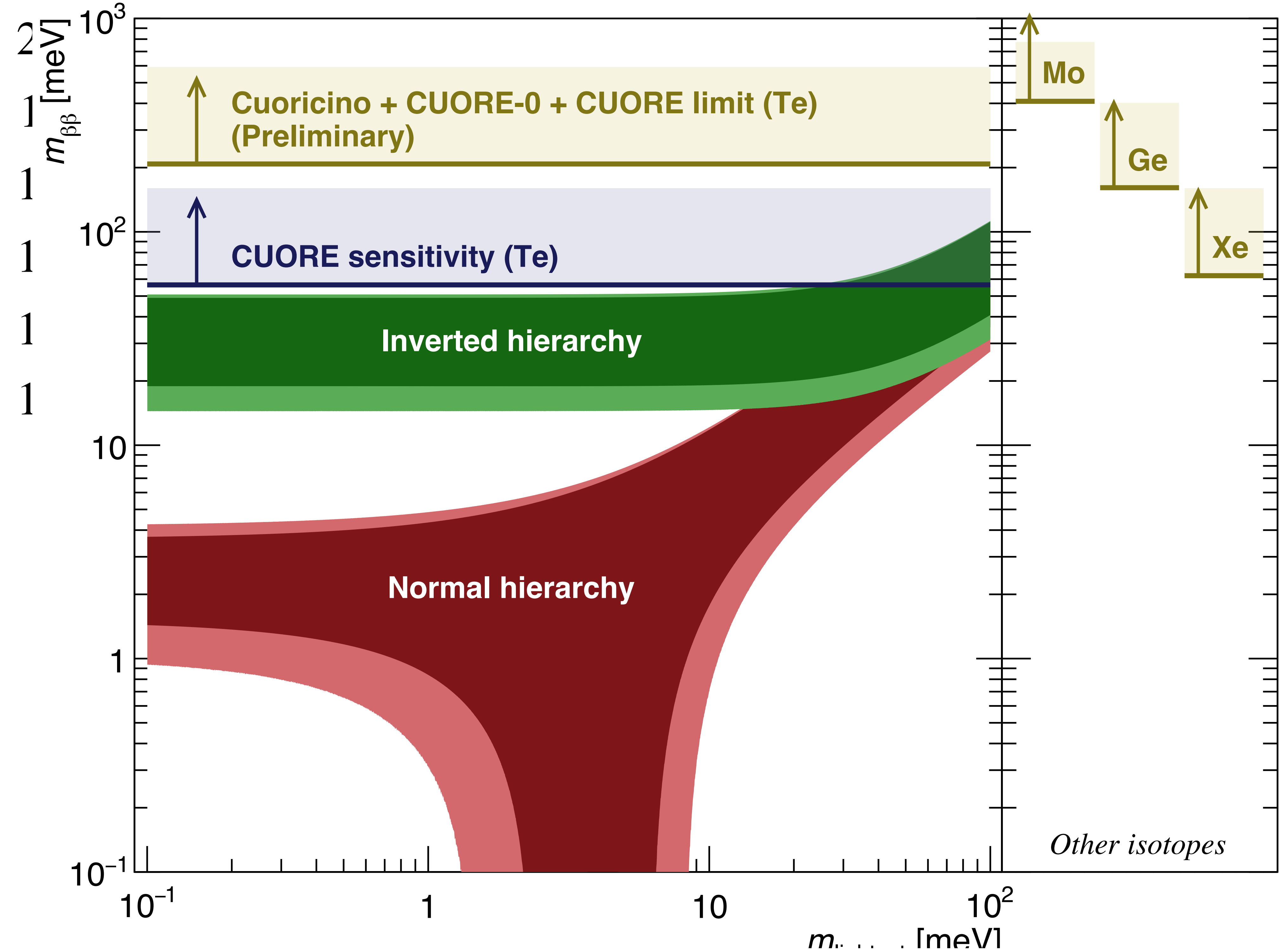
NME:

Phys. Rev. C 91, 034304 (2015)
Phys. Rev. C 87, 045501 (2013)
Phys. Rev. C 91, 024613 (2015)
Nucl. Phys. A 818, 139 (2009)
Phys. Rev. Lett. 105, 252503 (2010)

Experiments:

^{130}Te: 6.5 × 1024 yr from this analysis
^{76}Ge: 5.3 × 1025 yr from Nature 544, 47–52 (2017)
^{136}Xe: 1.1 × 1026 yr from Phys. Rev. Lett. 117, 082503 (2016)
^{100}Mo: 1.1 × 1024 yr from Phys. Rev. D 89, 111101 (2014)
CUORE sensitivity: 9.0 × 10^{25} yr

Combined "Rolke" limit: 8.1×10^{24} yr



Aug 2017 science run

- Total statistics doubled with respect to June 2017
  - All the available data have been fully reprocessed
  - Adopted the usual blinding procedure
  - Data analysis almost complete
  - **Expected release of results: Oct. 23, 2017**
- In the meantime ….

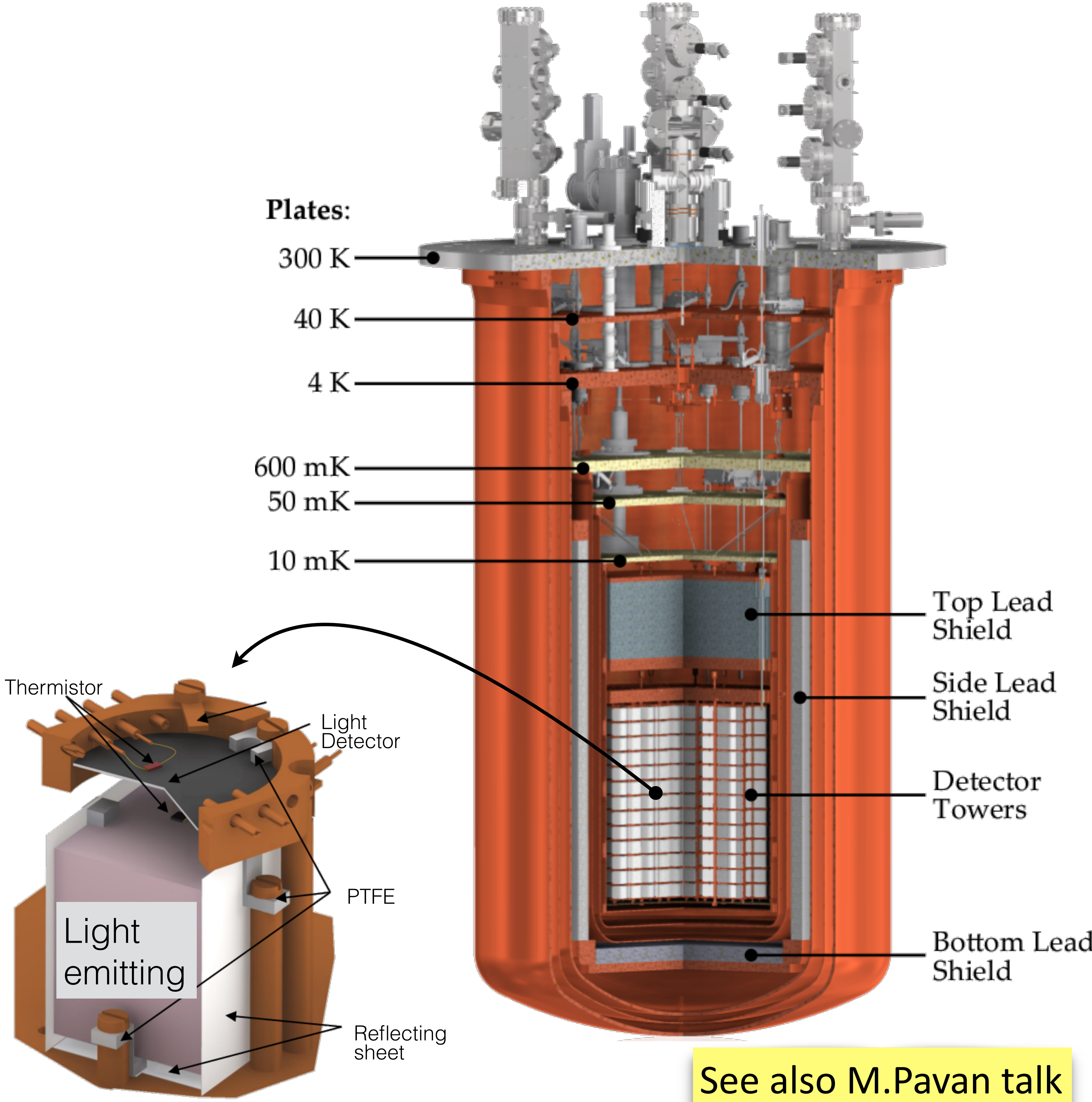
CUPID

CUORE Upgrade with Particle IDentification

- White papers: arXiv:1504.03599, arXiv:1504.03612
- Artusa, D.R. et al. Eur.Phys.J. C74 (2014) 10, 3096, arXiv:1404.4469

- Based on the CUORE design
  - inherits CUORE cryogenics and experience
- Tonne-scale detector with α's rejection
  - **$^{130}TeO_2$: phonons + Cherenkov detector**
- Aims for zero-background measurement
  - BI <0.02 events / (ton-year)
  - 5 keV FWHM resolution

- Half-life sensitivity (2-5)×10^{27} years in 10 years (3σ)
- $m_{\beta\beta}$ sensitivity 6-20 meV (3σ)



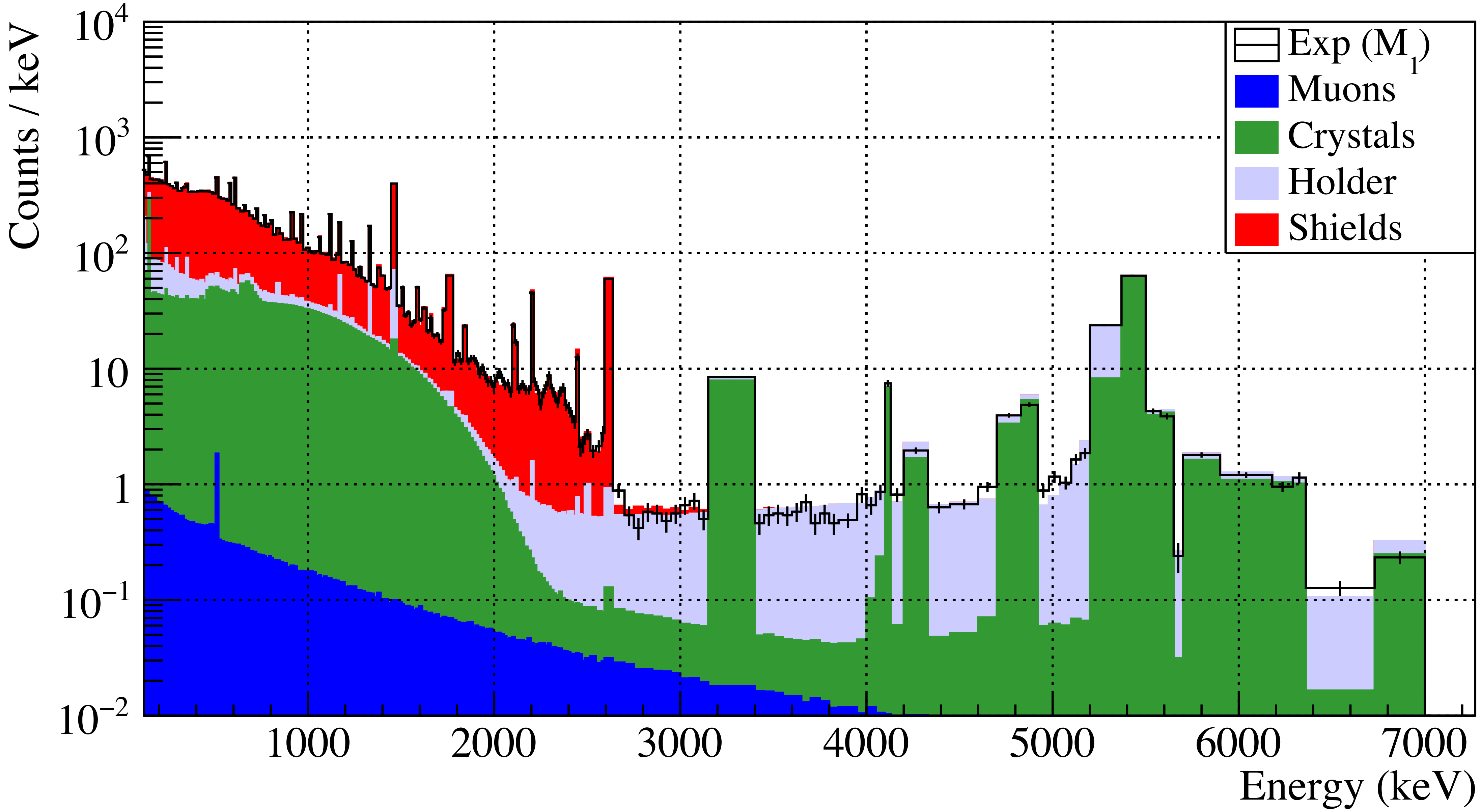
See also M.Pavan talk

CUORE-0 Background Model

- Sources contributing to background reconstruction are fitted to CUORE-0 data
- Radioactive assay of construction materials: fit prior

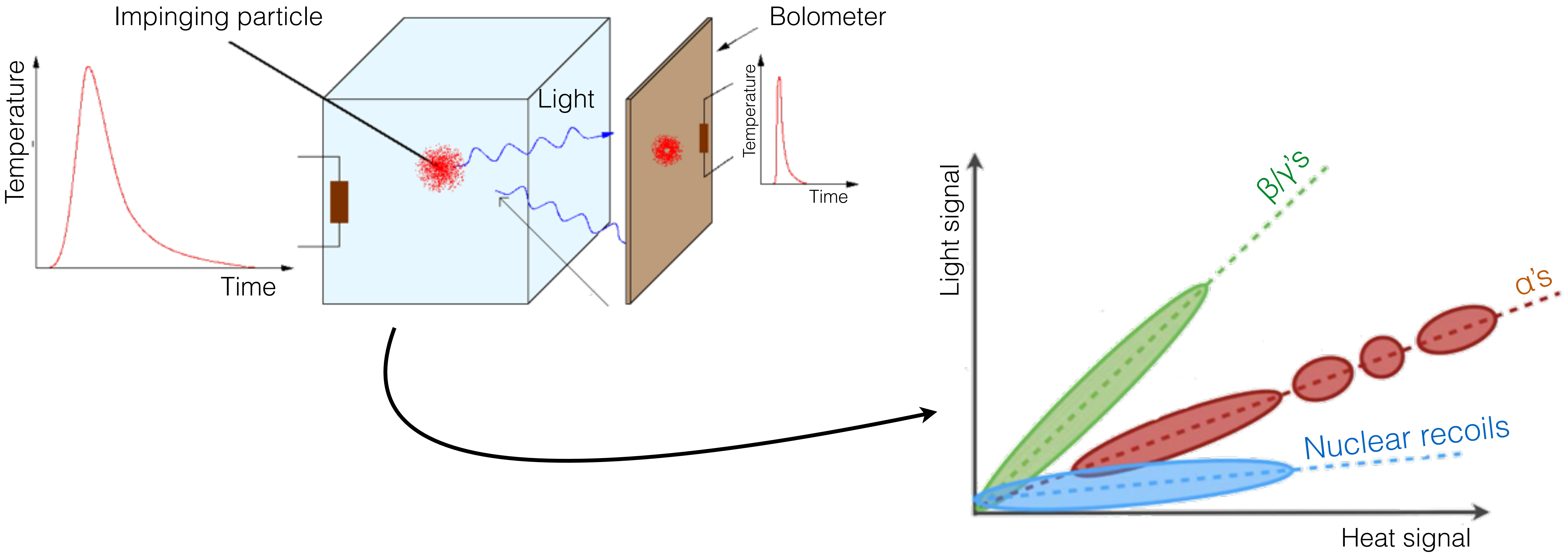
Eur. Phys. J. C (2017) 77: 13

- Dominated by surface contaminations of the detector materials (mainly α's)



CUPID concept: heat + light

- Pure bolometers can't separate α's from β/γ's
- Solution: hybrid detector
  → Simultaneous detection of heat and light (scintillation/Cherenkov)



TeO_2 bolometers with Cherenkov readout

Advantages:

- well known crystal technology
- radio-purity ($<10^{-14}$ g/g)
- cheap isotopic enrichment
- CUORE experinece
- 0.74 ton natural crystals

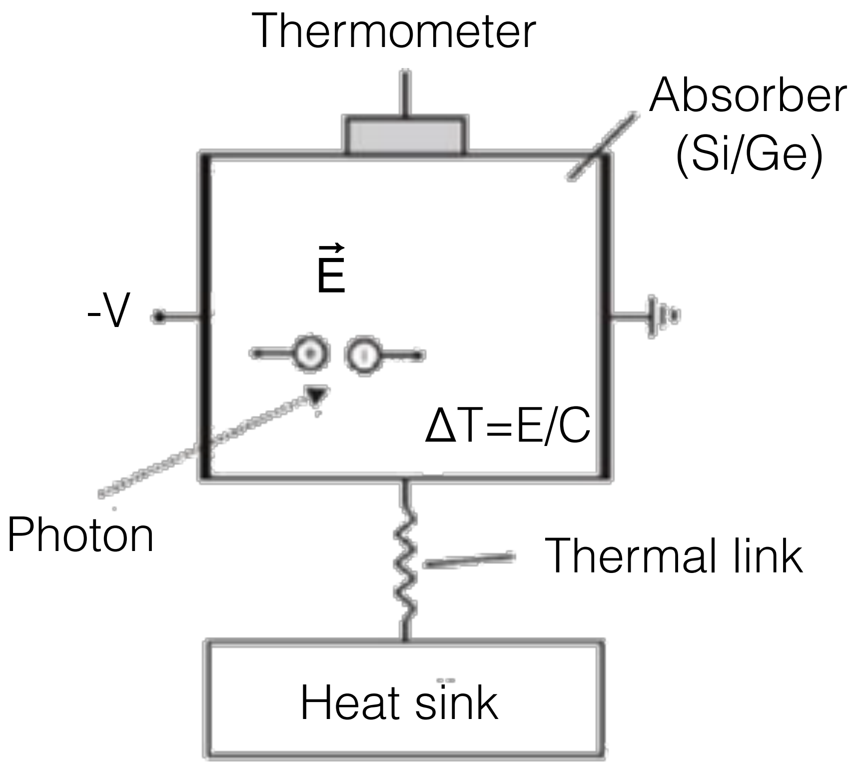
Issues:

- MeV electrons produce few photons
- light collection
- energy thresholds as low as few tens eV
- complex light detectors

- Need to develop extremely performing (low temperature) light detectors
  - Neganov-Luke effect
  - Kinetic Inductance Detectors (KID's)
  - Transition Edge Sensors

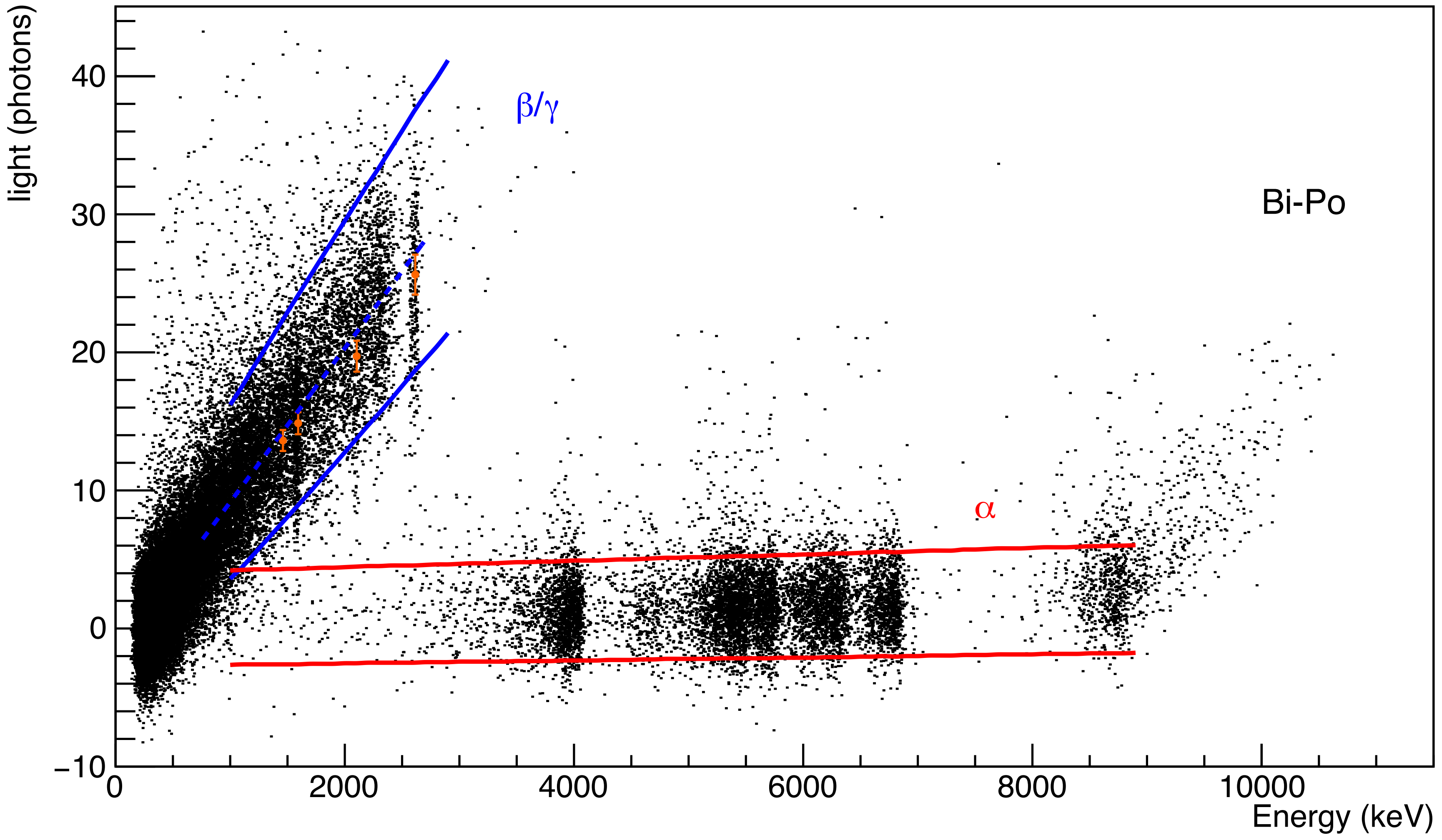
- Dedicated R&D's
  - Very promising results on TeO_2 detectors
  - Next step: large scale arrays (demonstrators)

Neganov-Luke effect



Signal (phonon) amplification through the acceleration of the charge carriers by an applied electric field

L.Gironi et al, Phys. Rev. C 94, 054608 (2016)

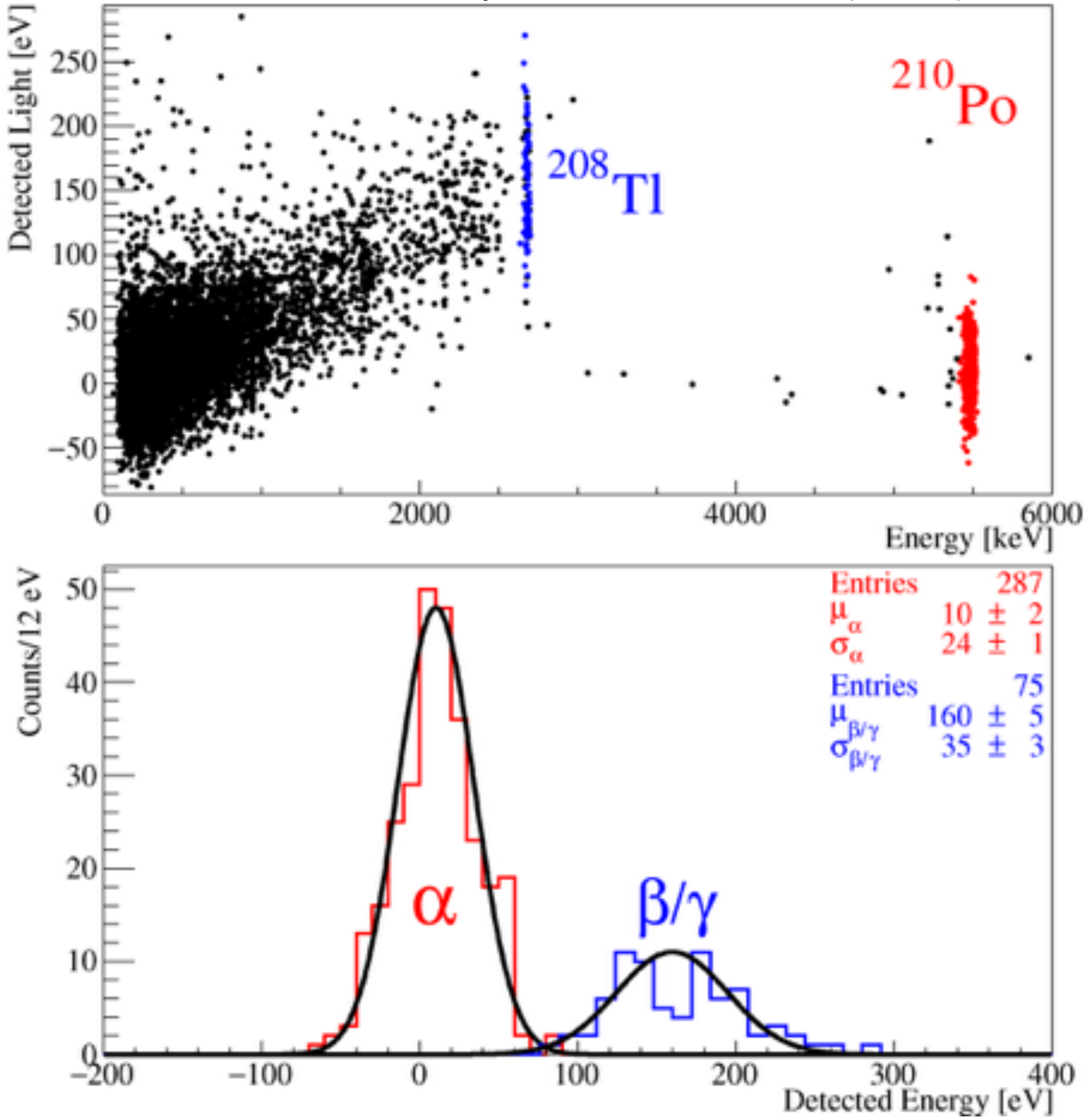


- Si-absorber
- small (1x1x1 cm^3) TeO_2 crystal

Neganov-Luke effect

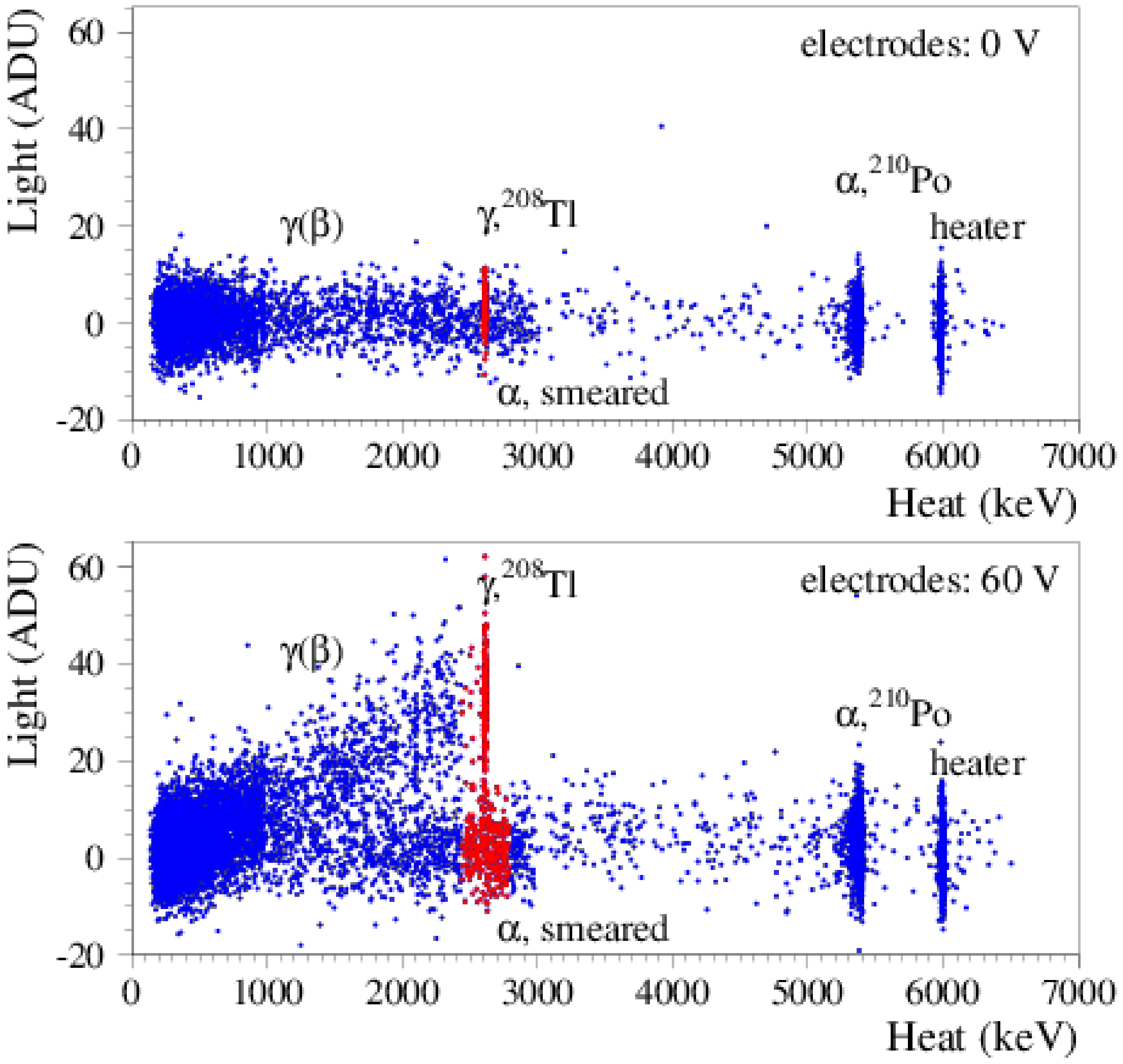
- Ge-absorber
- 92% enriched (36×38×52 mm³) $^{130}TeO_2$ crystal

D.Artusa et al, Physics Letters B 767 (2017) 321



- Ge-absorber
- CUORE-like (5x5x5 cm³) TeO_2 crystal

L.Bergé et al, arXiv:1710.03459



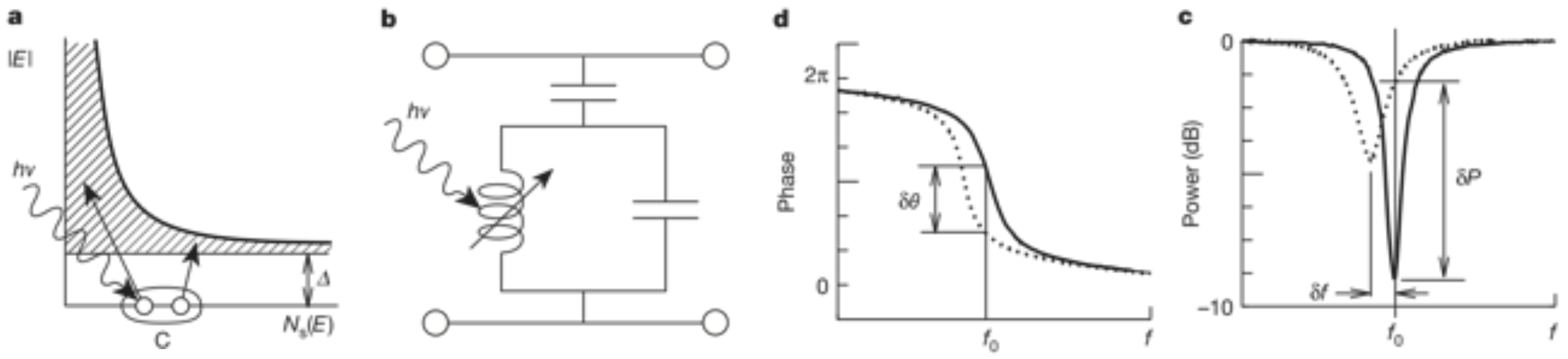
See also:

- J. W. Beeman, et al., Astropart. Phys. 35 (2012) 558
- L. Pattavina, et al., J. Low Temp. Phys. 184 (2016) 286
- K. Scha\¨ffner, et al., Astropart. Phys. 69 (2012) 30
- M. Willers, et al., JINST 10 (2015) P03003
- N.Casali,et al.,Eur. Phys. J. C 75 (12) (2015) 1

KID’s

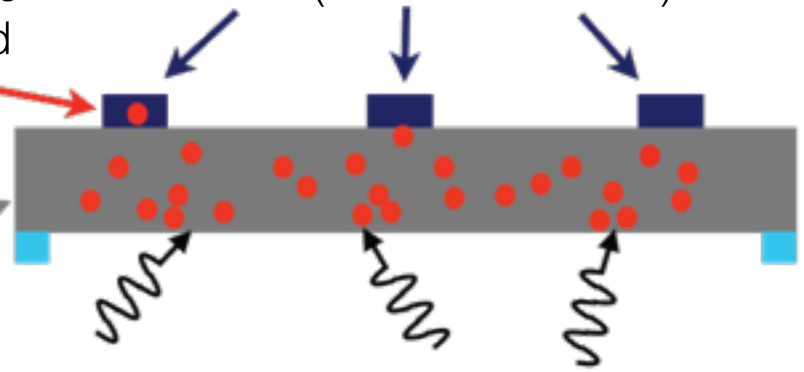
The idea:

- Cooper pairs (cp) in a superconductor act as an inductance (L). Photons or phonons can break cp and change L.
- High quality factor (Q) resonating circuit biased with a microwave (GHz): signal from amplitude and phase shift.



Diffused phonons can be absorbed by the KIDs

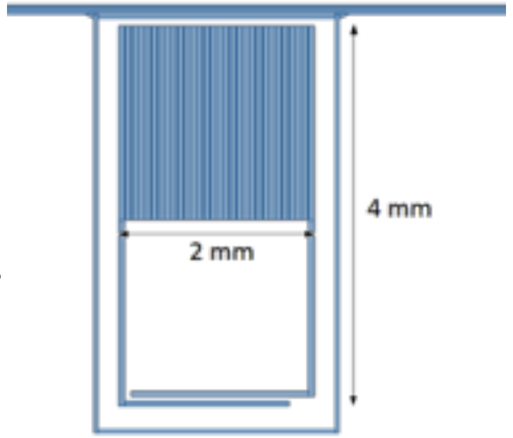
KIDs (~2mm2 x 60-nm)

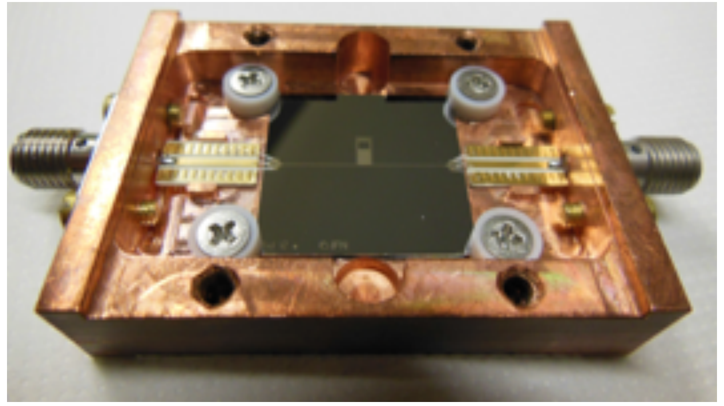


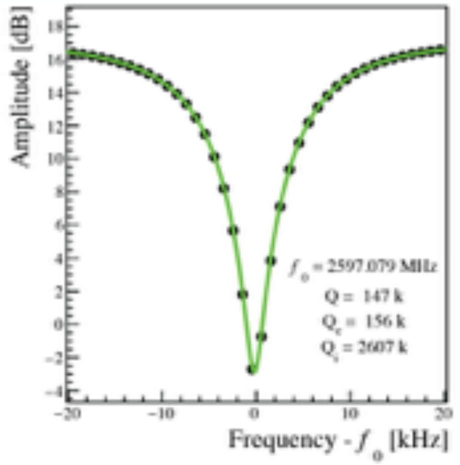
Supports

Substrate of silicon (5x5cm2 x300μm)

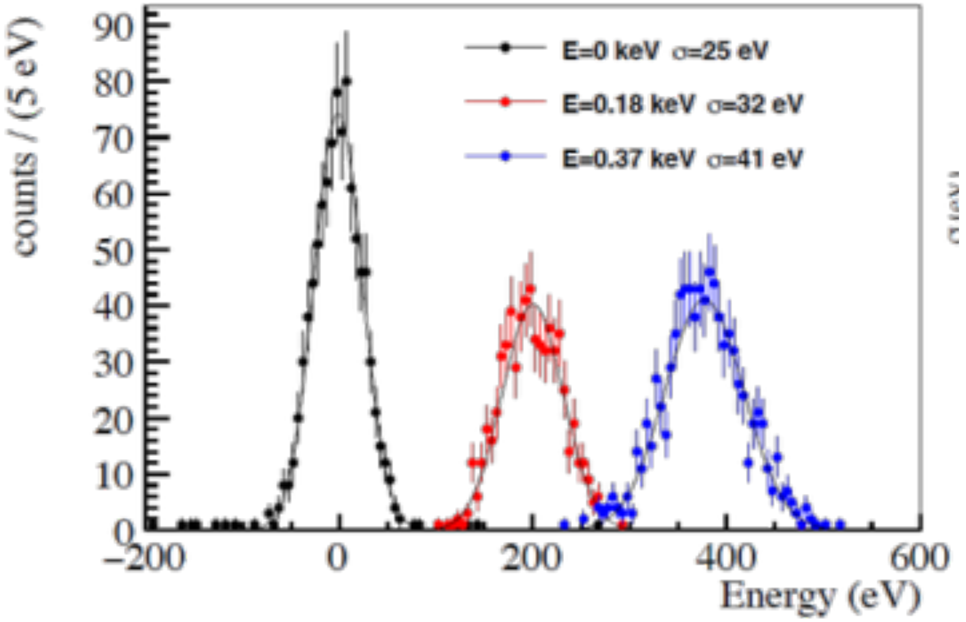
Incident photons convert into athermal phonons

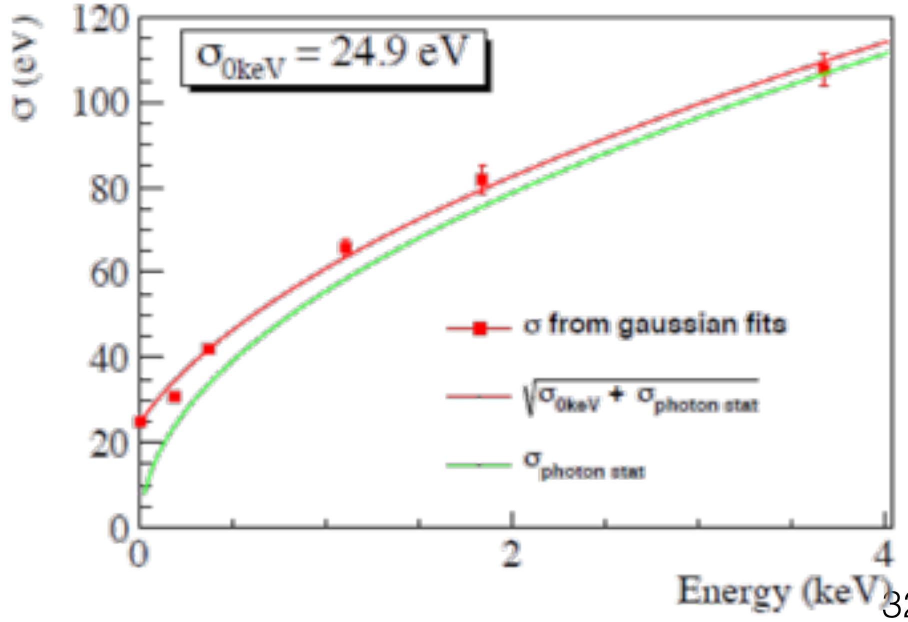






Energy scan w/ optical fibre



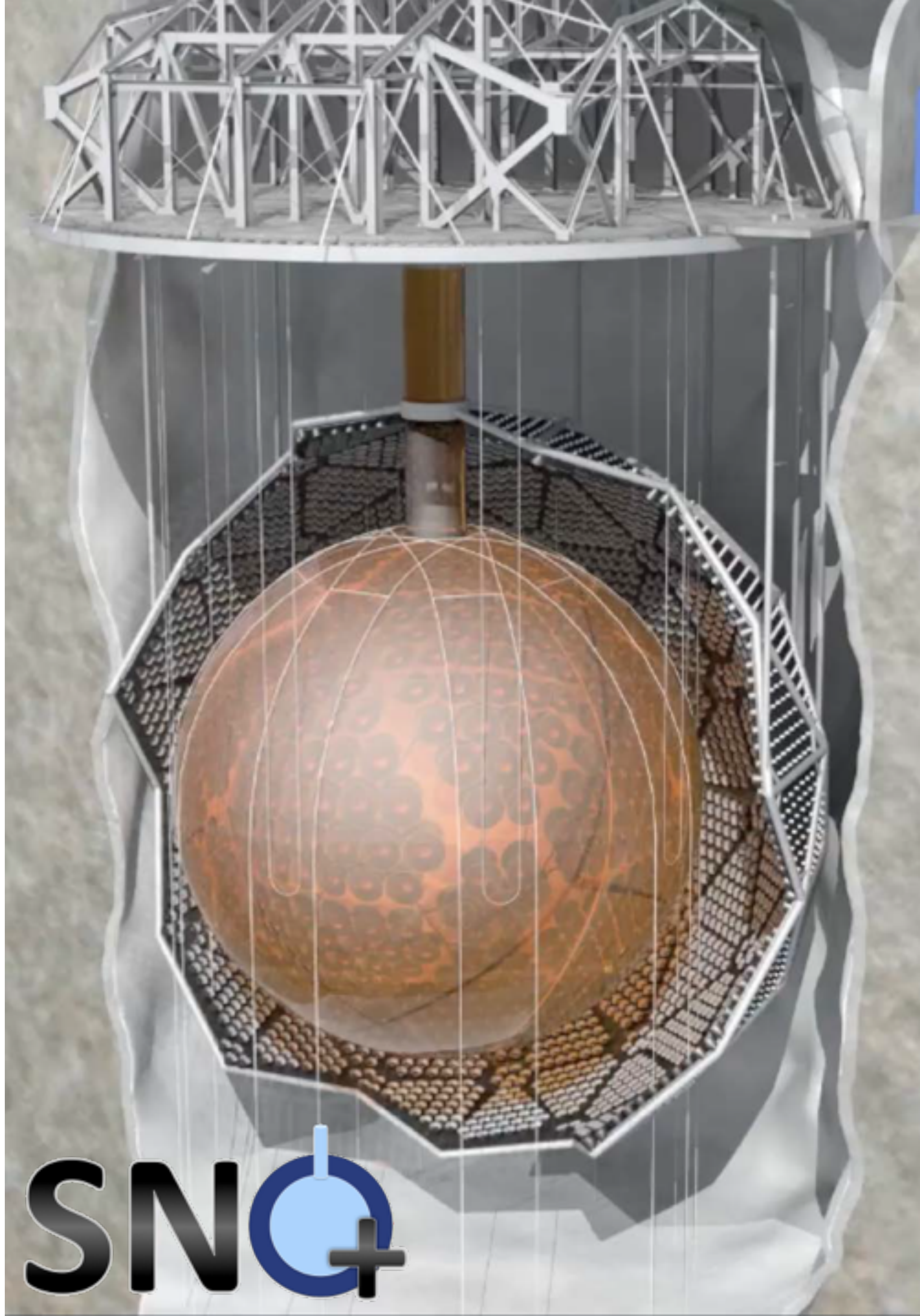


Available results already close to target values

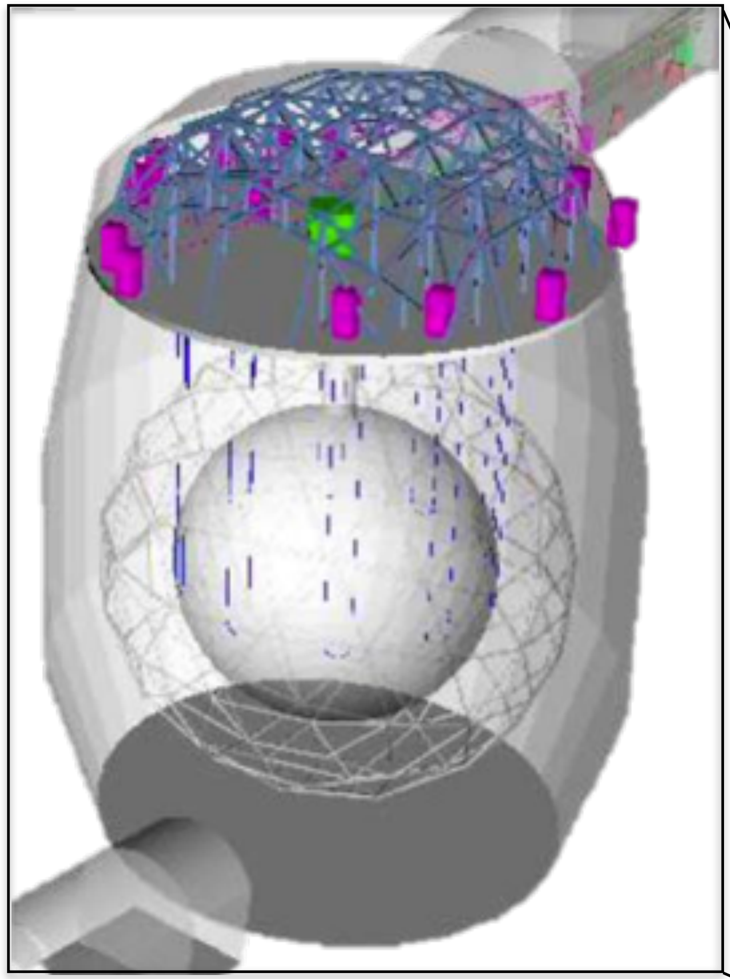
SNO+

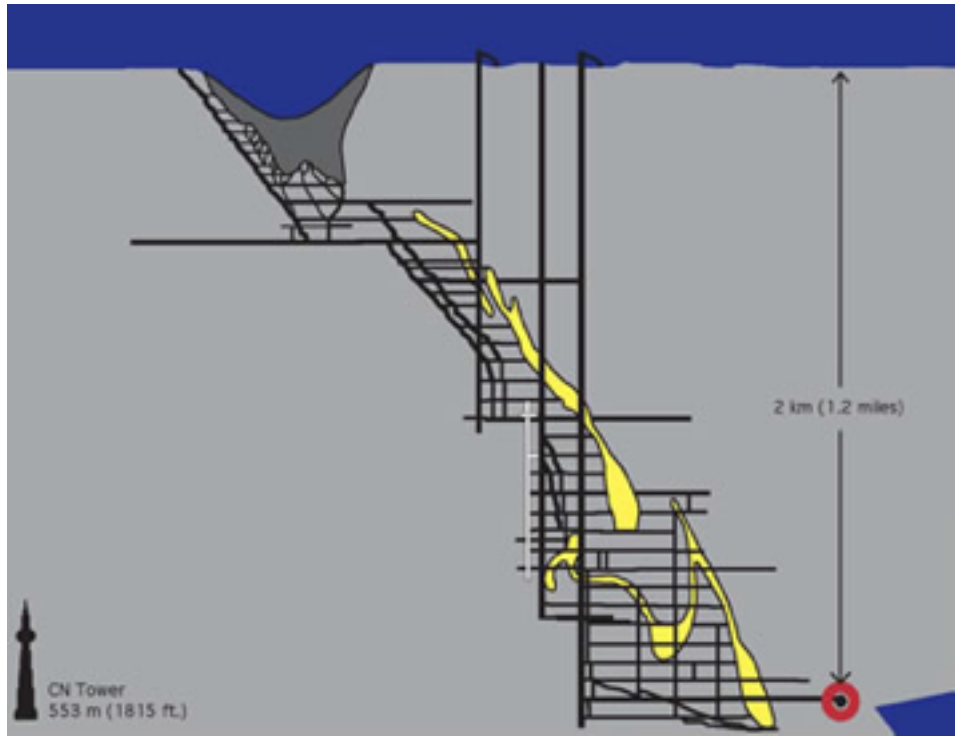
- SNO heavy water replaced by 780 tonnes of liquid scintillator
  - Deck with Upgraded DAQ and calibration system
  - Urylon liner: Rn seal
  - Replaced Hold Up Ropes w/ Hold Down Rope Net
  - New Optical Monitoring System
  - Acrylic Vessel: ø 12 m - 5 cm thick
  - 780 t Liquid scintillator + 3.9 t Tellurium
  - Water shielding: 1700 t inner - 5300 t outer
  - ~9400 PMTs, 50% coverage
  - 2070 m rock overburden @ SNOLAB
  - Stable loading of aqueous $Te(OH)_6$ in SNO+ scintillator with good optical properties achieved by BNL

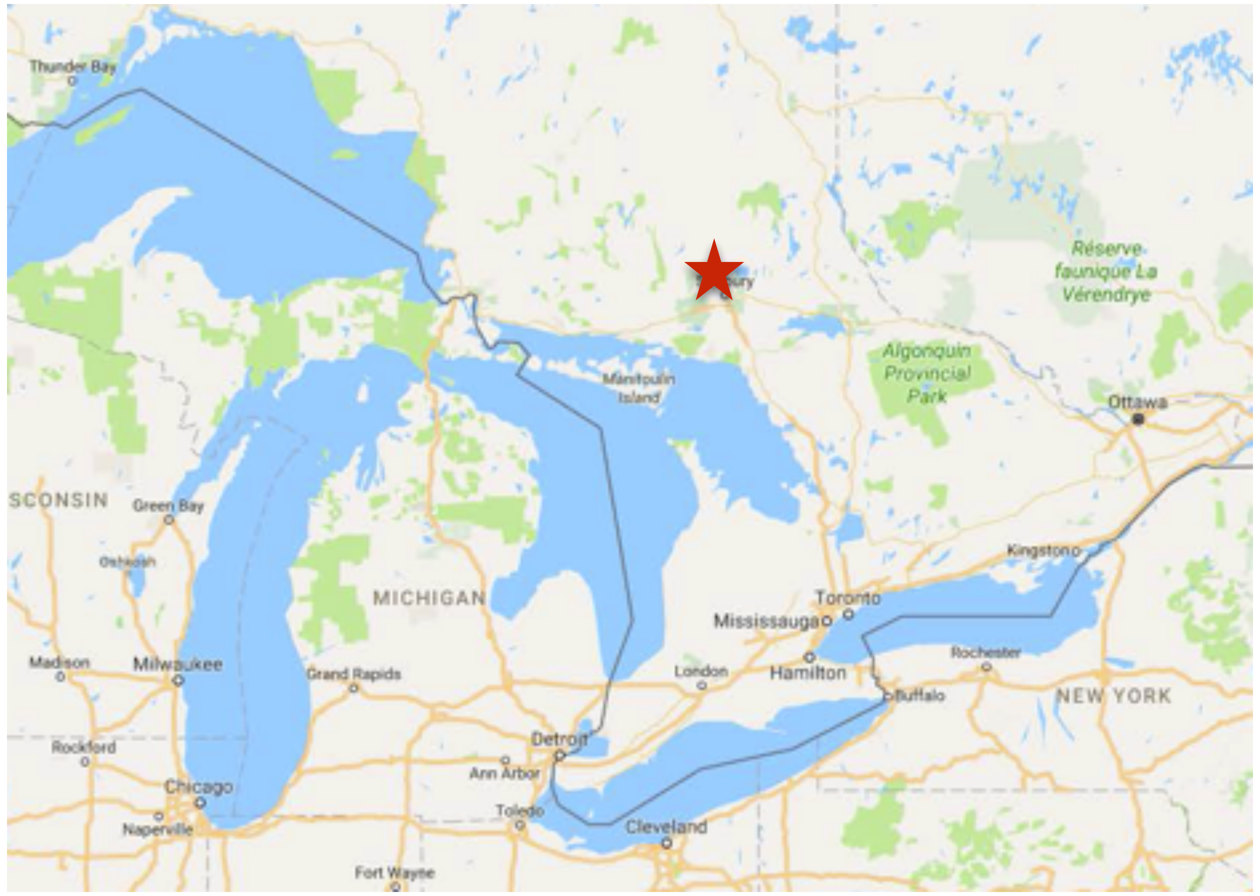
- Detector Commissioned: December 2016 – April 2017



SNO+ @ SNOLAB




2 km (1.2 miles)
CN Tower
553 m (1815 ft.)


Thunder Bay
Réserve faunique La Vérendrye
Algonquin Provincial Park
Ottawa
Manitoulin Island
SCONSIN
Green Bay
Oshkosh
MICHIGAN
Toronto
Mississauga
Kingston
Rochester
Madison
Milwaukee
Grand Rapids
London
Hamilton
Buffalo
NEW YORK
Rockford
Detroit
Ann Arbor
Chicago
Naperville
Toledo
Cleveland
Fort Wayne

SNO+: LAB Plant

- LAB Advantages:
  - Long attenuation length
  - No inherent optical absorption lines
  - High light yield
  - α-β separation decay time

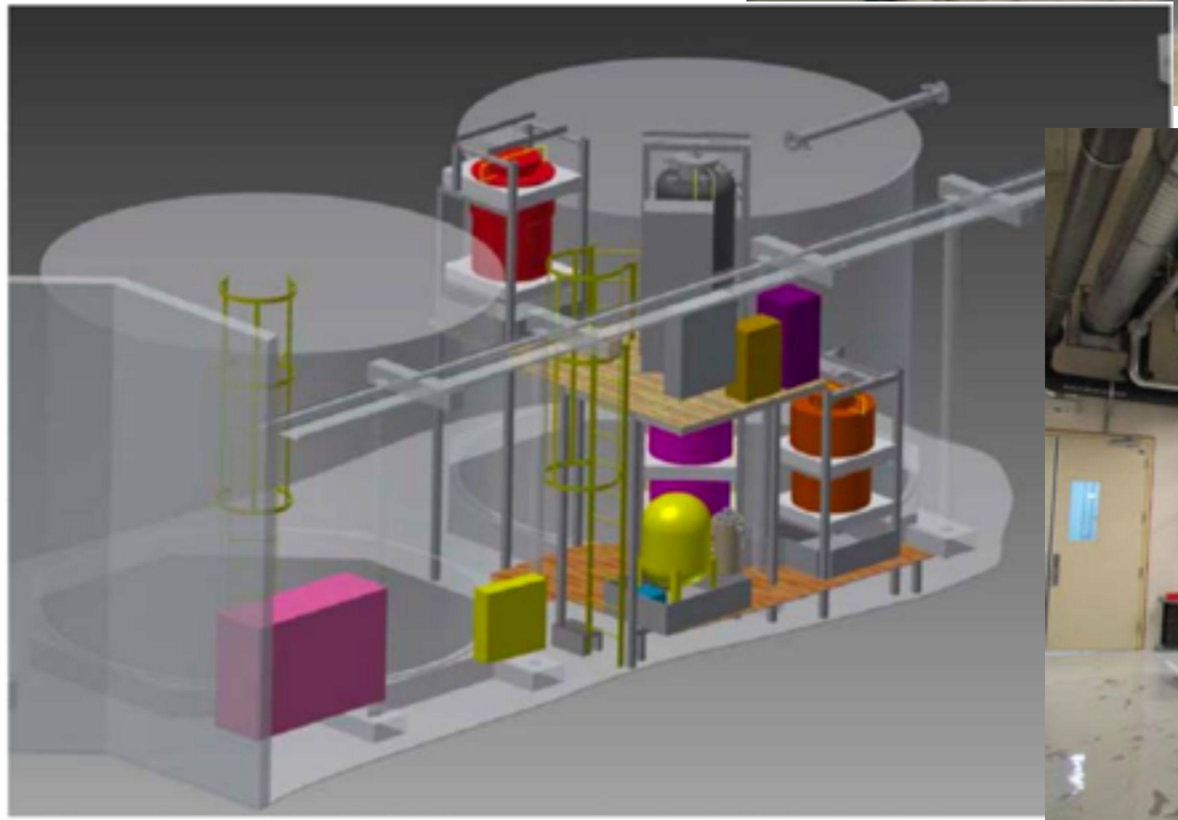
- Multi-stage distillation
- N_2-Steam stripping: Removes Rn, Kr, Ar and O_2
- Water extraction: Removes Ra, K and Bi
- Metal scavengers: Removes Bi, Pb, Ra, Ac, Th (x 800 in single pass)
- Scintillator recirculation (150 LPM) possible during operation

- **Commissioning Ongoing**
- **Filling with Scintillator later 2017**

SNO+: Te storage, purification and loading

- **Concept:**
  - 780 tonne detector and high ^{130}Te isotopic abundance gives large isotope mass
  - 0.3 - 0.5% Te (by weight) in SNO+
    - Phase I is 2.34 – 3.9 tonnes of Te or 800 – 1333 kg of ^{130}Te
  - Percent level loading is feasible
    - 3% Te in SNO+ Phase II would give 8 tonnes of ^{130}Te

- **Purification & Loading**
  - Telluric Acid (TeA) Underground "cooling" since 2015.
  - Purified by multi-pass recrystallization based on solubility of TeA in water based on pH.
  - **Full scale plant now in construction underground**
  - Cocktail: LAB + PPO + Te-ButaneDiol
  - Initial phase: 0.5% Te (~1300 kg ^{130}Te)

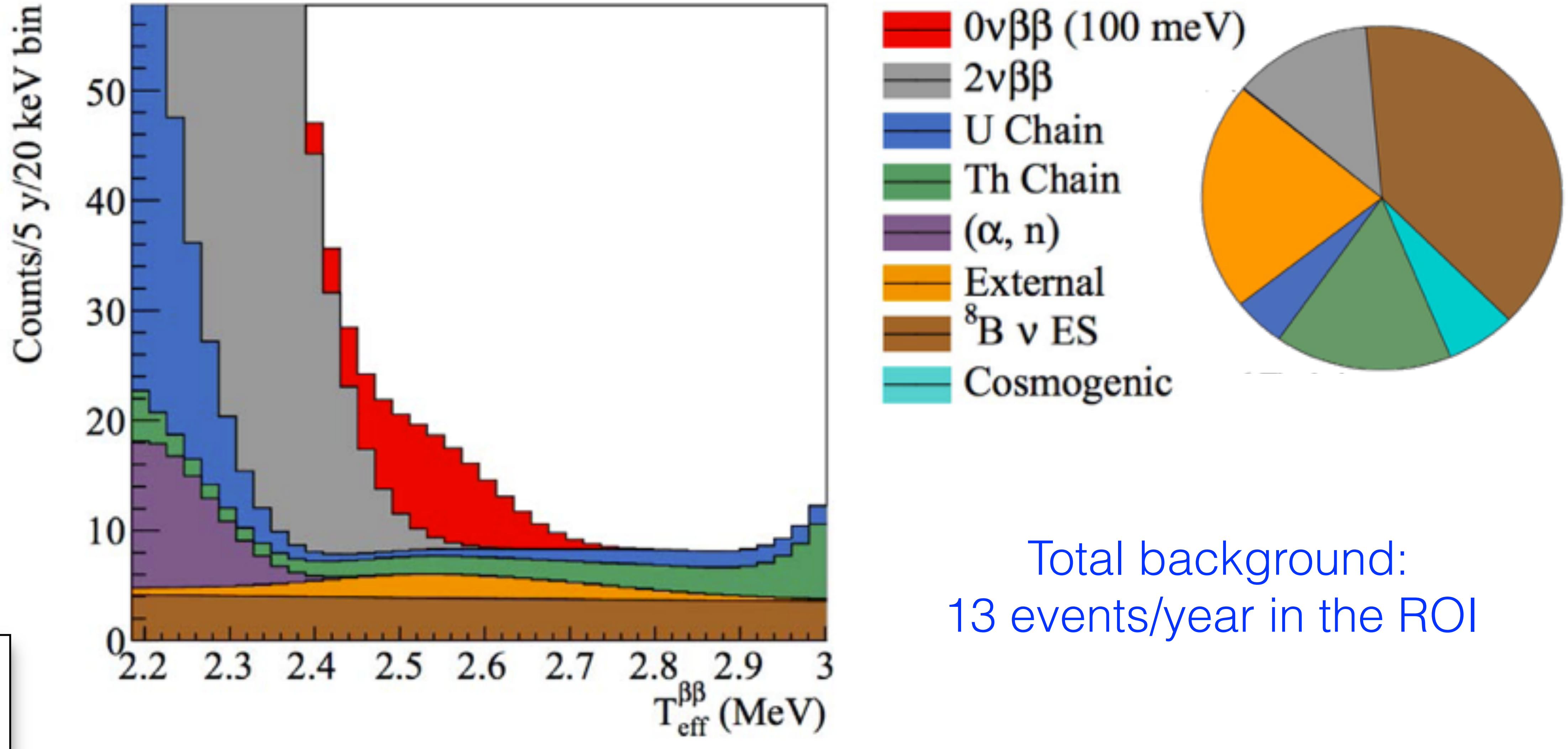


SNO+: phase I

- Scintillator runs
- Measure most background
- Verify detector response models
- Verify purification techniques

- LAB + PPO (2g/L) + bisMSB (15mg/L)
- 0.5% nat. Te (1330 kg 130Te)
- FV = 3.5 m (20%)
- > 99.99% rejection 214BiPo
- 98% rejection 212BiPo
- 390 hits/MeV

5 yr sensitivity with 0.5% loading:
$T_{1/2} > 2 \times 10^{26}$ yr, 90% CL

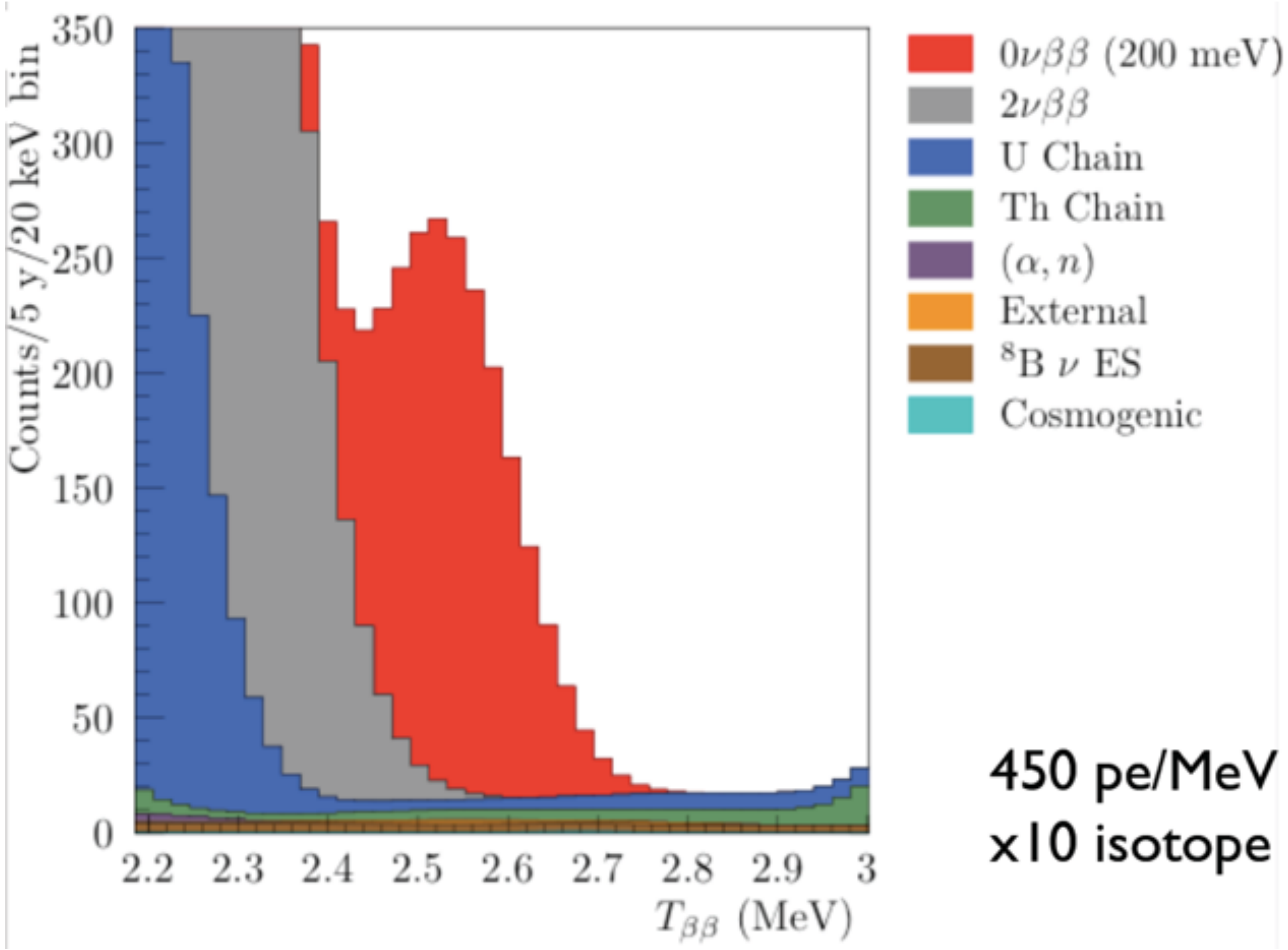


Total background:
13 events/year in the ROI

- SNO+ is filled with light water and taking physics data
- Scintillator process plant is under commission
- Tellurium plant is under construction
- ββ0ν Decay phase will begin in late 2018

SNO+: phase II

- 3% loading of Te (already demonstrated)
- Plug-in replacement of SNO+ PMTs with R5912-HQE's
- Additional wavelength-shifter/loading R&D could further improve this
- Containment bag could reduce amount of isotope, improve cleanliness. Can leverage KamLAND-Zen and BOREXINO knowledge
  - $T_{1/2} > 7 \times 10^{26}$ y (90% CL)
  - 3σ detection for $T_{1/2} > 4 \times 10^{26}$ y

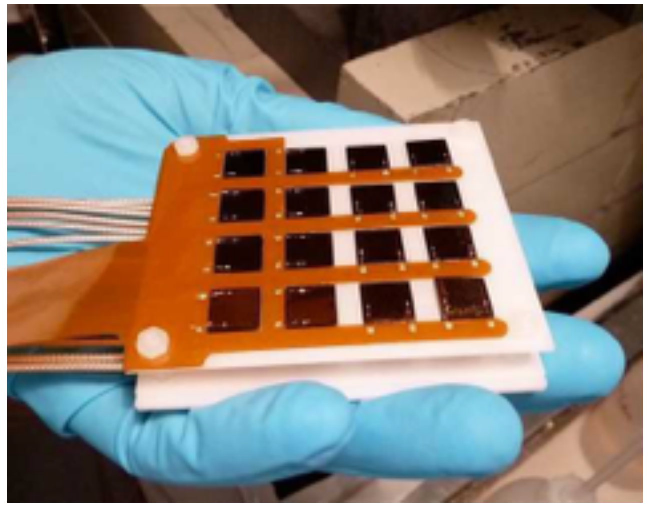


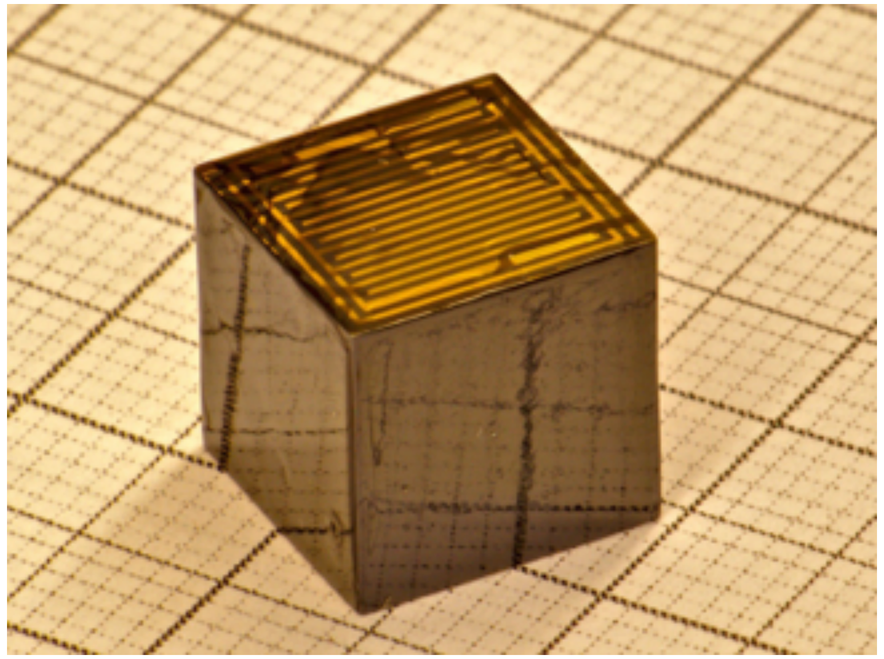
450 pe/MeV
x10 isotope

COBRA (**C**dZnTe **0**ν Double **B**eta **R**esearch **A**pparatus)

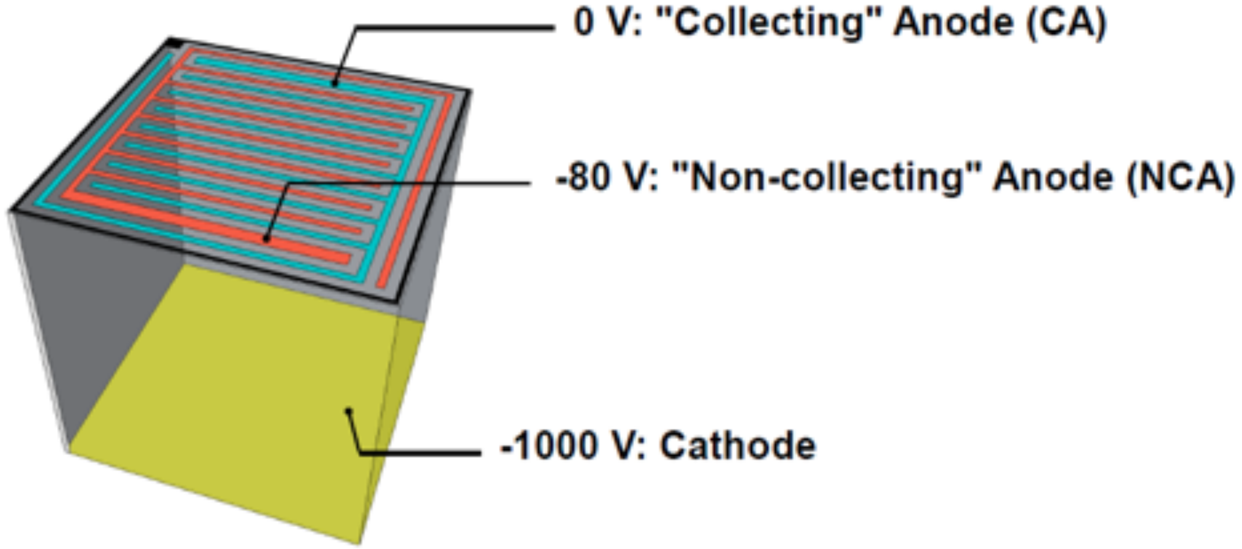
K. Zuber, Phys. Lett. B 519 (2001) 1

- **Next generation double beta-decay experiment in R&D phase**
- **Room temperature semiconductor** with coplanar-grid (CPG) approach
- **CdZnTe Advantages**
  - intrinsic semiconductor at room temperature
  - high density and high atomic number
  - commercially available (several suppliers)
- **Challenges**
  - low mobility lifetime product for holes
  - poor availability of large crystals

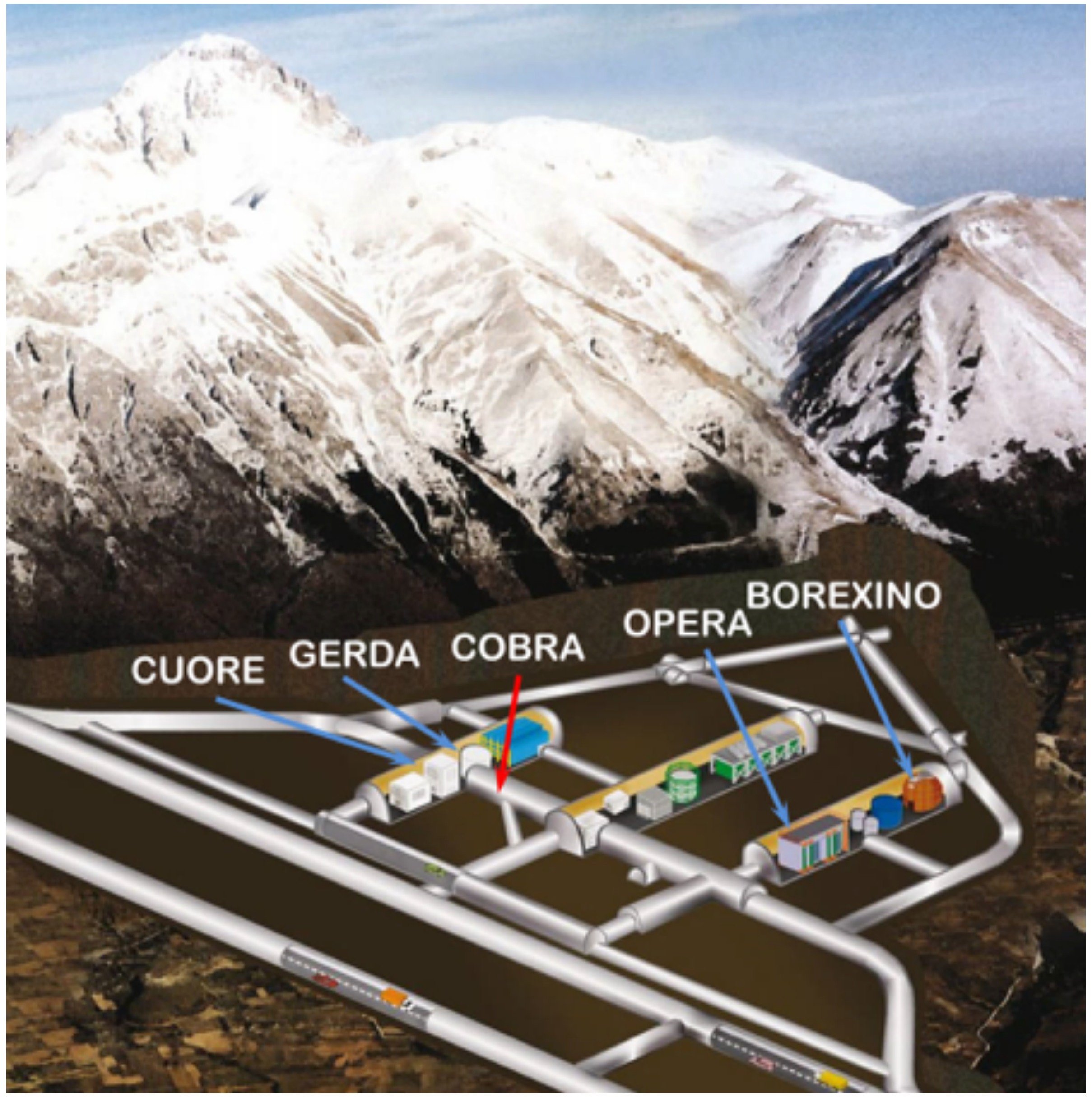


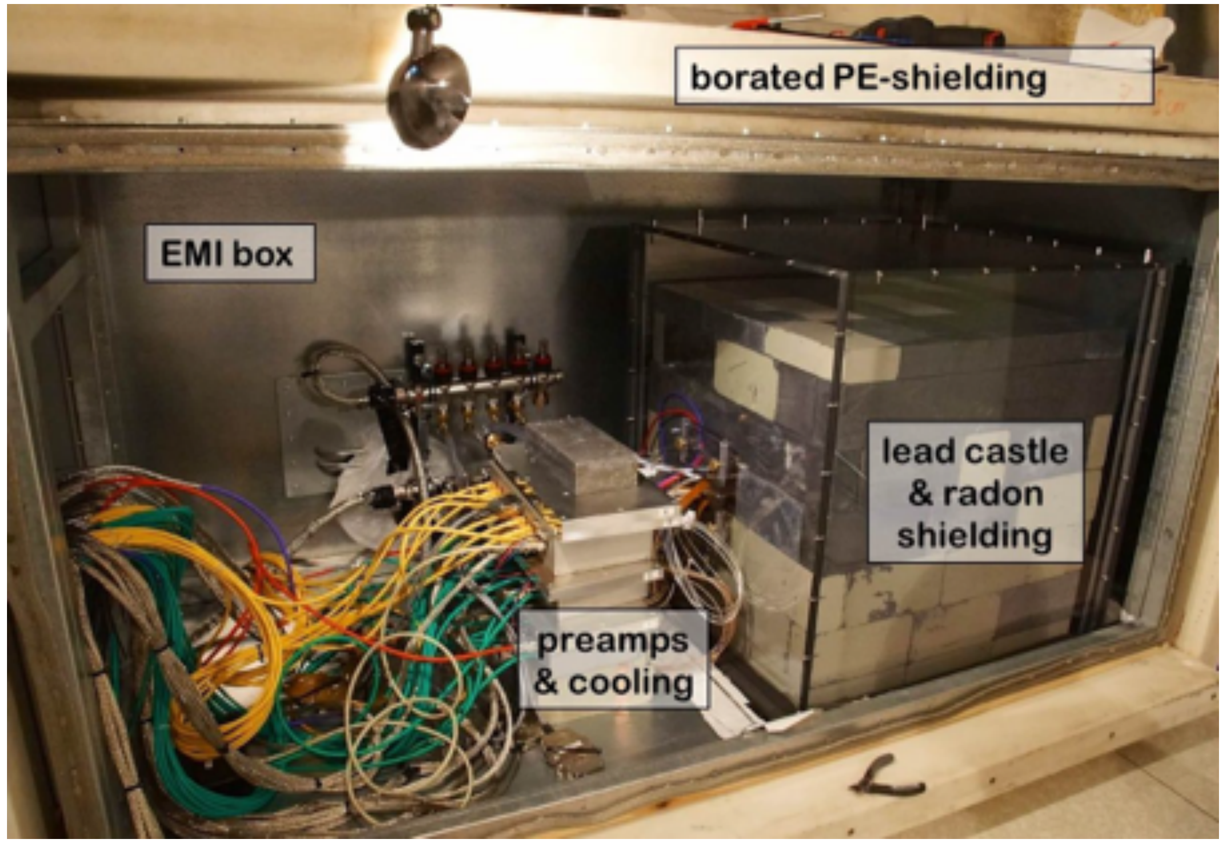


- Search for 0νββ-decay in several isotopes with $T^{0\nu} > 10^{26}$ yr
  - Te-130, Te-128, Zn-70, Cd-114, Cd-116 (two electrons)
  - Zn-64, Cd-106, Cd-108, Te-120 (positron/EC)
- Principle: **detector = source** (high intrinsic detection efficiency)
  - demonstrator at low background facility LNGS built of 4×4×4 1cm side crystals
- Most promising isotopes:
  - ^{116}Cd: Q = 2814 keV → above highest prominent γ-line of nat. decay chains (Tl-208 → Eγ = 2614 keV)
  - ^{130}Te: Q = 2527 keV → high nat. abundance (a = 34.08%)



Underground location: LNGS

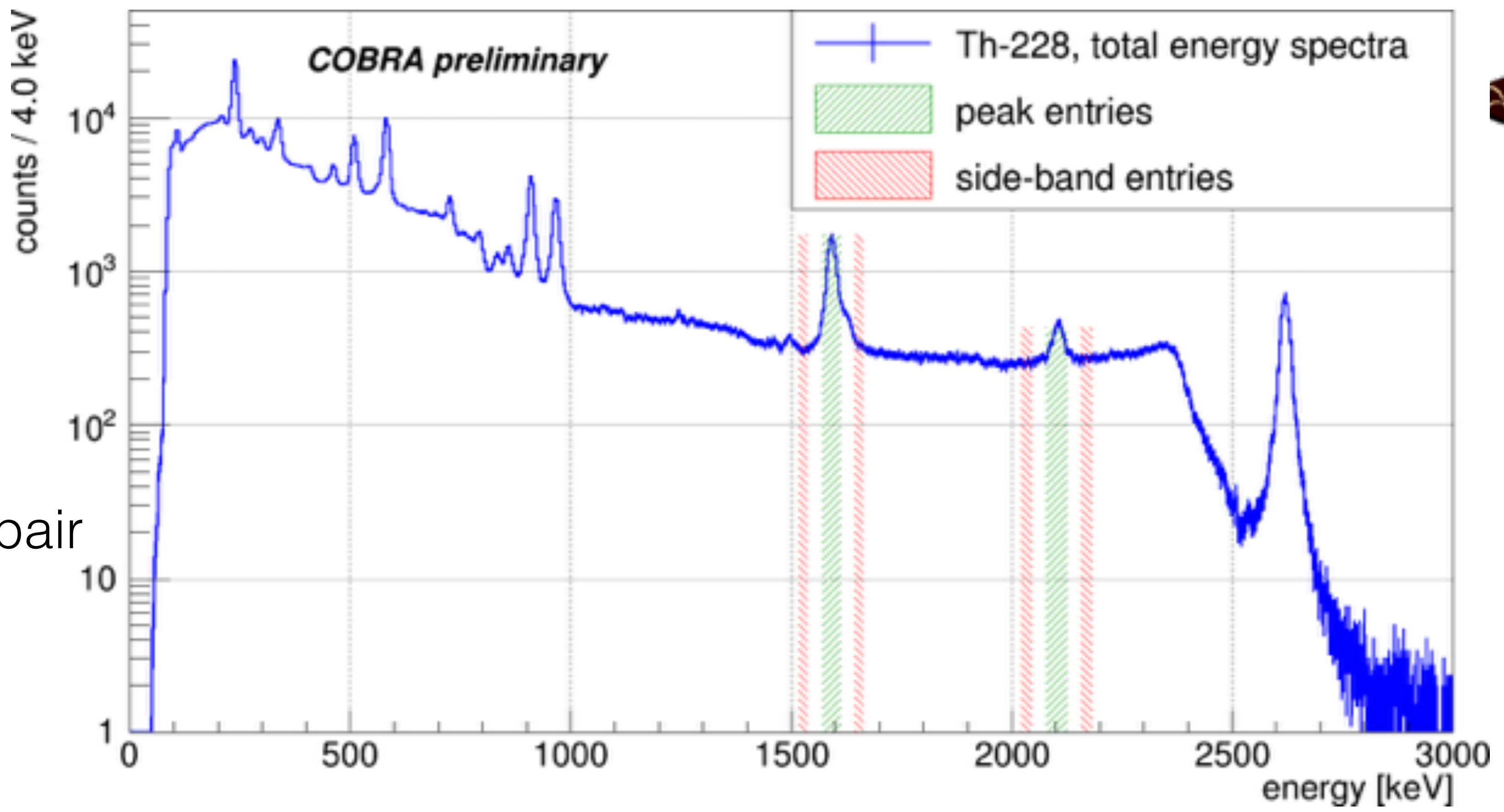




- 1400 m rock coverage (3700 m.w.e.)
- 7 cm boron-loaded polyethylene
- EMI box against electromagnetic interference
- Radon shield and dry N_2-flushing

A working demonstrator

- **On-site detector layer assembly at LNGS**
- **Working data acquisition**
- **Signal reconstruction**



- high energetic ^{228}Th γ-source provides pair creation within CZT crystal
- event topology can be used to optimize selection algorithms

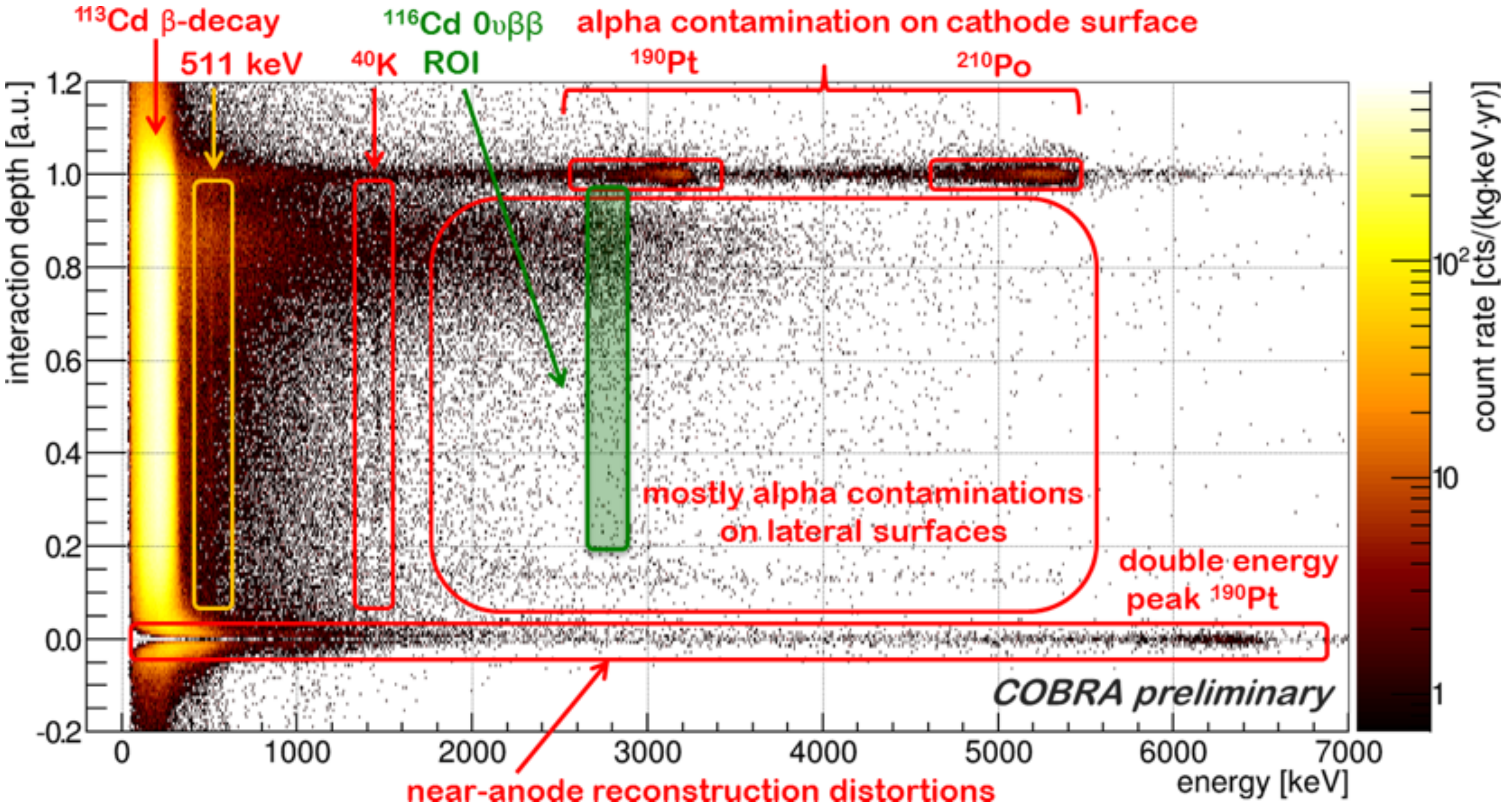
- **CZT contains nine potential double beta isotopes (several decay modes):**
  - **recent peak search** analysis: focus on five β⁻β⁻ g.s. to g.s. transitions
  - achieved Bayesian limits (90% C.L.) of 10^{19}-10^{21} yr (world **best for** ^{114}Cd)

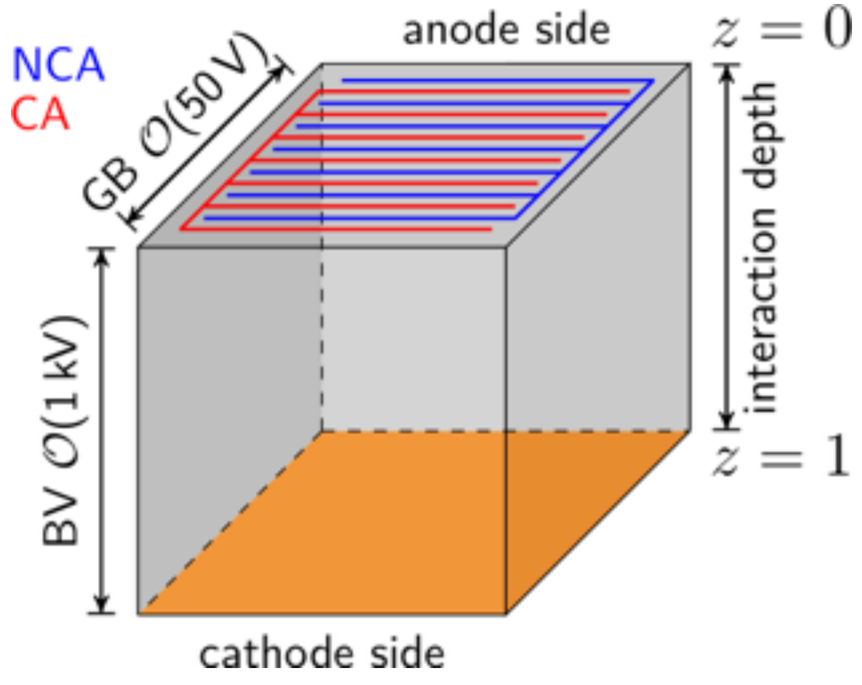
Isotope	Q-value	COBRA'09	COBRA'13	COBRA'15
^{114}Cd	542.3 keV	2.0×10^{20} yr	1.1×10^{21} yr	1.6×10^{21} yr
^{128}Te	865.9 keV	1.7×10^{20} yr	1.4×10^{21} yr	1.9×10^{21} yr
^{70}Zn	998.5 keV	2.2×10^{17} yr	2.6×10^{18} yr	6.8×10^{18} yr
^{130}Te	2527.0 keV	5.9×10^{20} yr	3.9×10^{21} yr	6.1×10^{21} yr
^{116}Cd	2813.5 keV	9.4×10^{19} yr	9.2×10^{20} yr	1.1×10^{21} yr

J. Ebert et al., Results of a search for neutrinoless double beta-decay using the COBRA demonstrator, PhysRevC.94:024603, 2016

Identified background features

- background features identifiable via interaction depth
  - cathode surface at z = 1, CPG anode at z = 0



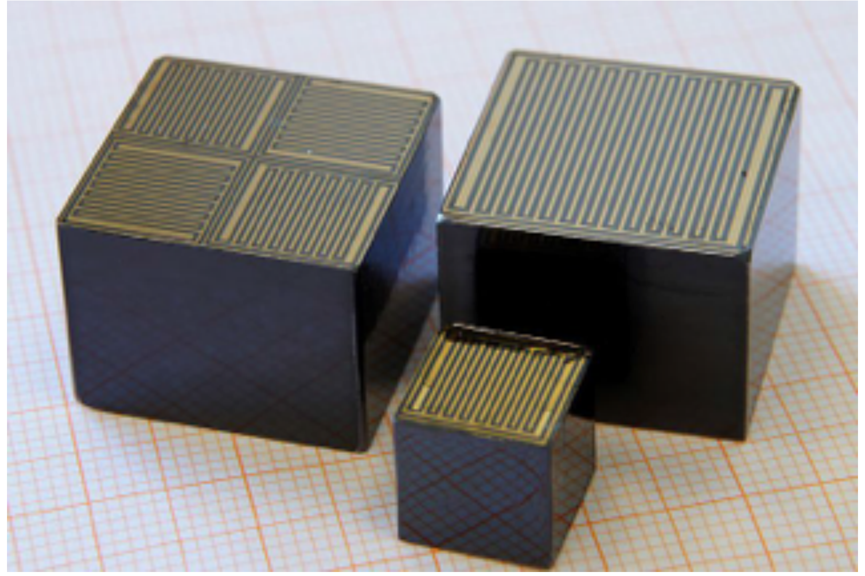


- ^{116}Cd region of interest dominated by α-emitting surface contaminations
- strongest signal caused by homogeneously distributed ^{113}Cd isotopes intrinsic non-unique four-fold forbidden β-decay (sensitive to effective gA)

COBRA prospects

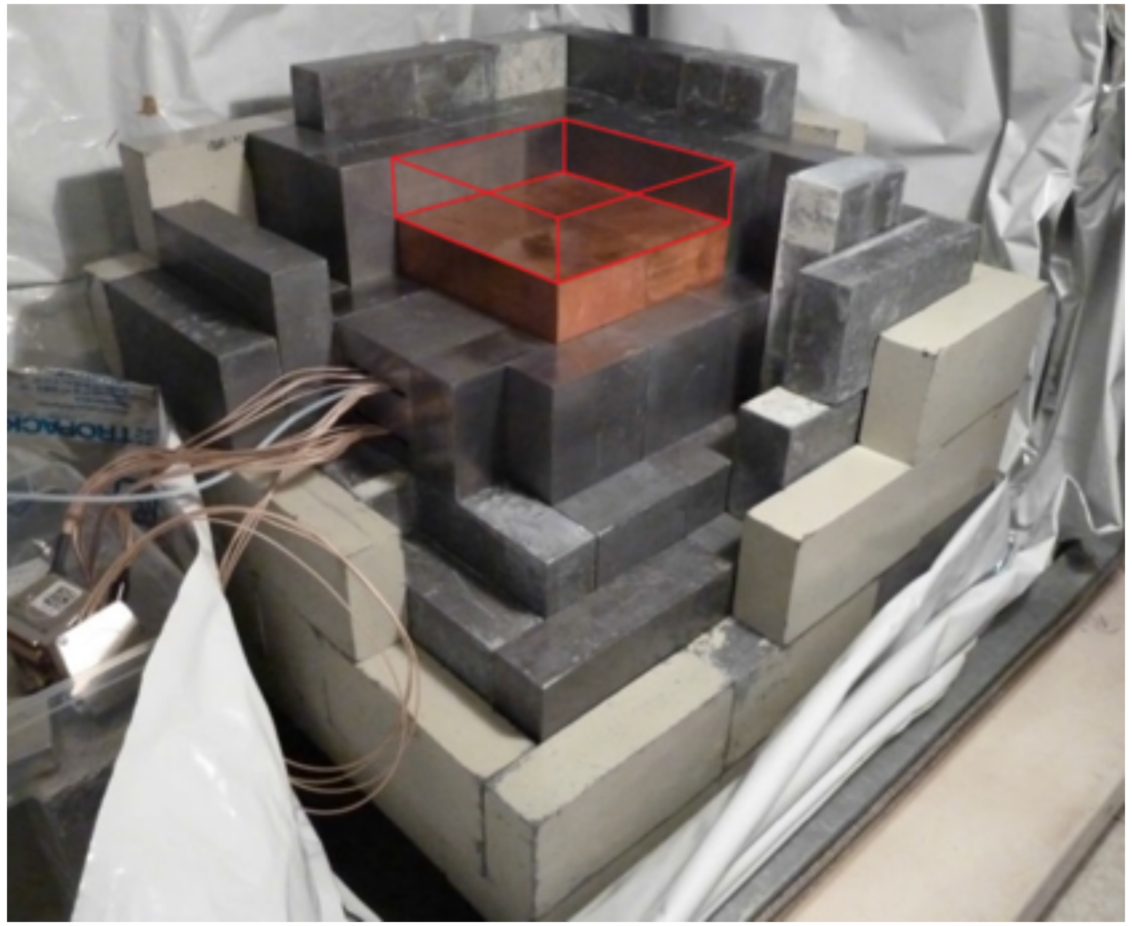
Status

- COBRA is aiming to search for ββ0ν decay with CZT detectors
- long-term operation of 4×4×4 demonstrator array at LNGS
- identification of background components via PSD
- a-suppression of more than 10^3 for instrumented GR detectors



Outlook

- evaluate A/E criterion in terms of efficiency and background rejection capabilities
- ongoing analysis of ^{113}Cd spectral shape to determine effective g_A inside nucleus
- new detector design:
  - switch to larger crystals (2.0×2.0×1.5) cm^3 (36 g per detector)
  - concentrate on quad-CPG approach – hybrid of CPG and pixel detector
- XDEM status
  - adapt shielding of existing demonstrator
  - inish detector characterization (50%)
  - upgrade to COBRA XDEM in early 2018



Conclusions

- CUORE is cold and running since february 2017
- With 3 weeks of physics data CUORE accumulated higher exposure than CUORE-0/ Cuoricino and surpassed their limit.
- Background rates are consistent with the background model
- CUORE successful operation is a technological breakthrough which paves the road to future bolometric developments at tonne-scale
- Promising results with low temperature detectors of Cherenkov light make Tellurium a valid option for CUPID

- SNO+ is filled with light water and taking physics data
  - Scintillator process plant is under commission and Tellurium plant is under construction
  - $\beta\beta0\nu$ phase is anticipated in late 2018

- Based on room temperature CZT detectors COBRA is a very modular and easily scalable
- A COBRA demonstrator with 64 detectors running at LNGS since Nov. 2013

- Interest for Tellurium is strong and making it a very promising candidate for future $\beta\beta0\nu$ experiments