CUORE and Backgrounds in Undeground Physics

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Outline...

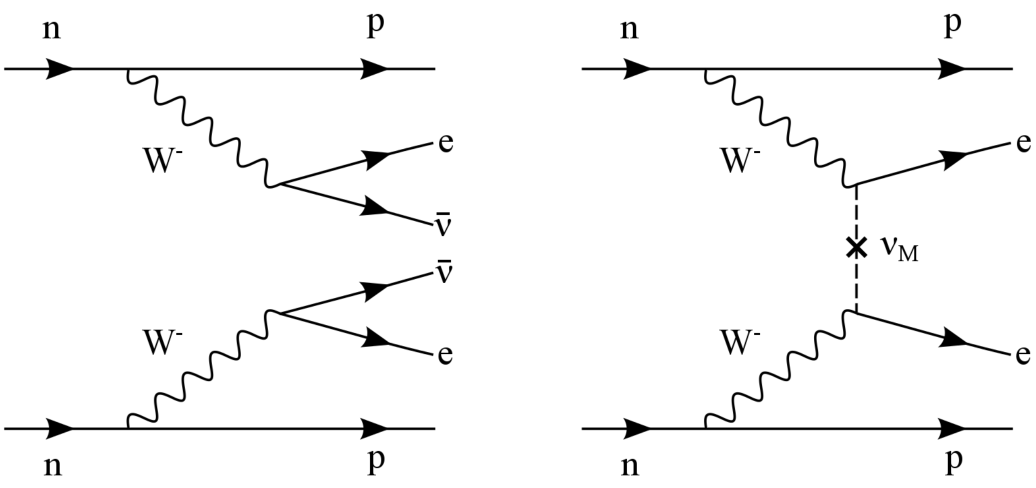
- CUORE
  - Backgrounds and sources
  - Reducing backgrounds
  - Expected backgounds for CUORE/CUPID
- Overview of backgrounds,

  Natural radioactive chains, cosmic rays, etc

CUORE

- Super brief overview,
  - What is 0**νββ**, why is it important,
  - How cuore is trying to measure it,
  - History and results
- Results → backgrounds,
  - Discuss sources
  - Methods of reduction,
  - Expected results from reduction methods

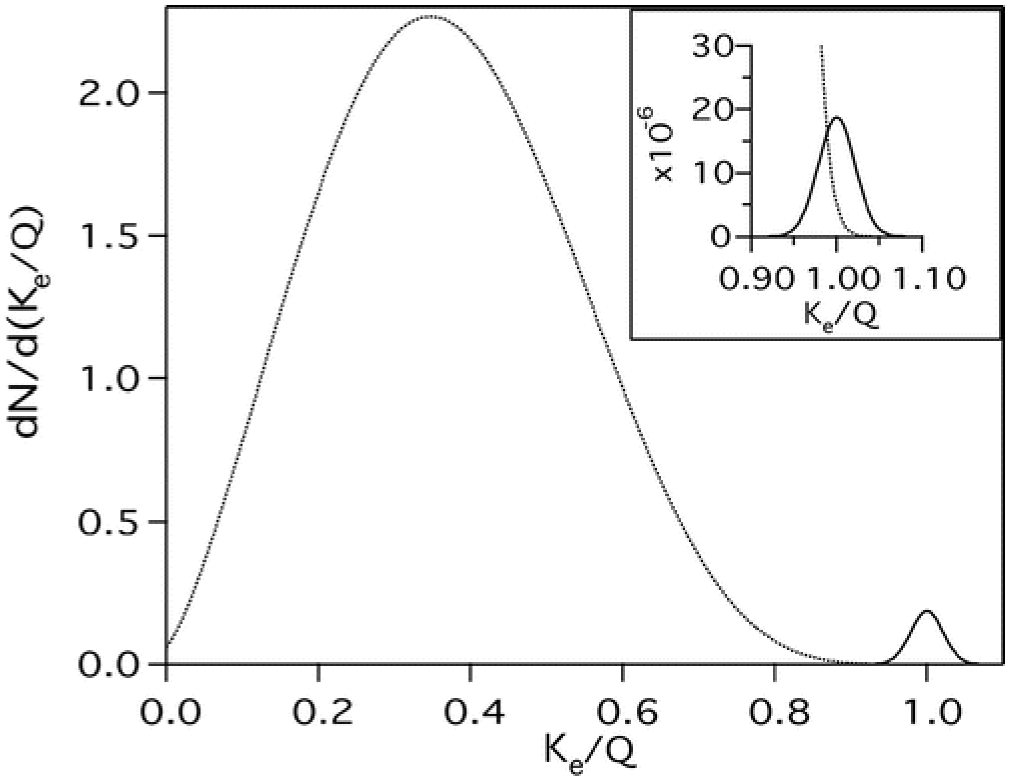
Neutrinoless Double Beta Decay



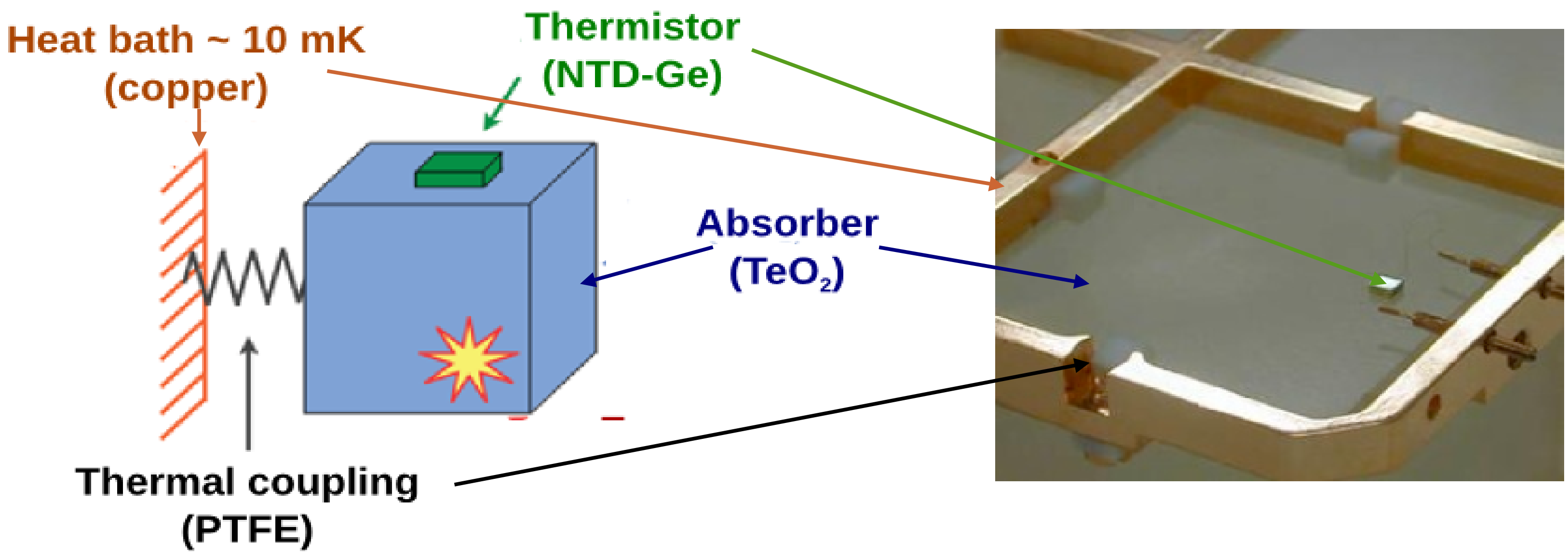
- 2νββ → one of the most rare processes observed
  - Only observable in nuclei whose structure prohibits beta decay
- 0νββ → prohibited by the Standard Model due to lepton number violation
  - Observation → Majorana nature of neutrino! New physics!
- Current limits >10e25 yrs

Search for 0nubb

- Peak at the endpoint of 2νββ spectrum
  - At the Q value
- Needs good energy resolution,
- Very low background

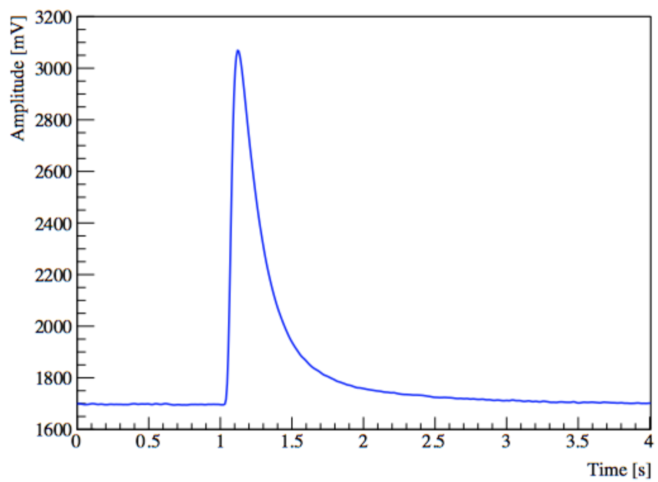


CUORE: Bolometric technique



$$\Delta T = \frac{E}{C(T)}$$

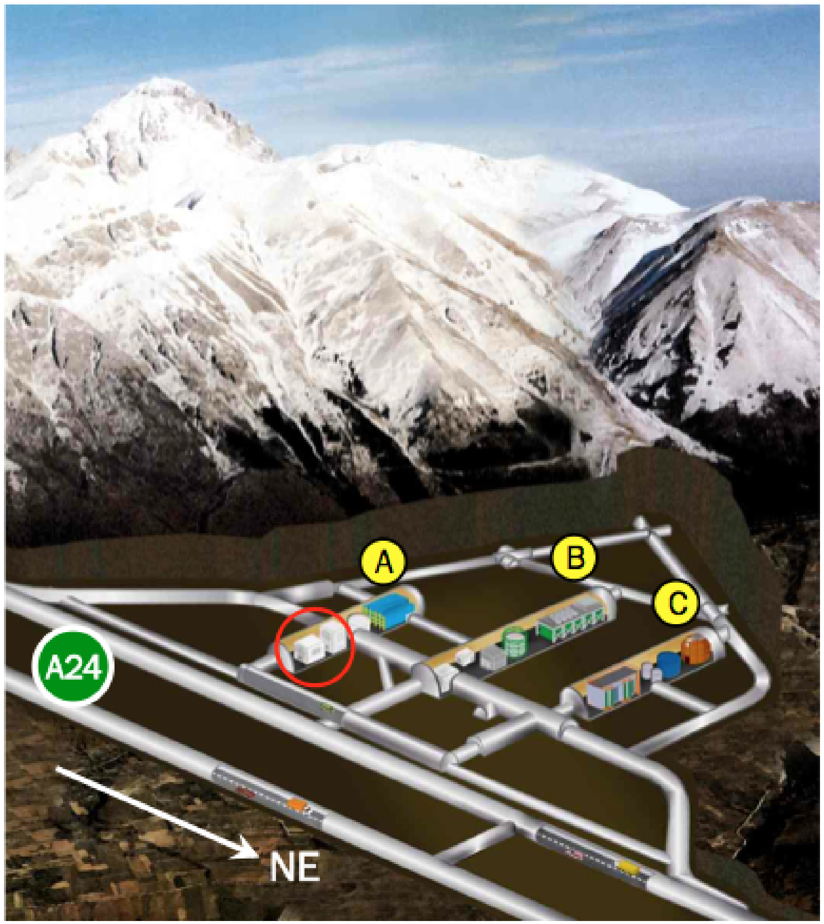
$$\Delta t = \frac{C}{G}$$



Particle energy is converted into phonons
by dielectric and diamagnetic absorbers
whose heat capacity ($C \propto T^3$) is very low at low T.
(At T~10 mK DT ~300 mK @ 1 MeV)

- **Crystal Absorber (TeO_2):** $E \rightarrow \Delta T$
- **Biased T sensor (NTD-Ge):** $\Delta T \rightarrow \Delta V$
- **Thermal link (PTFE+gold wires):** T_0~10 mK

CUORE Underground



Located in the Gran Sasso National Lab, Italy.

In Hall A, (Same hall as CRESST and GERDA)

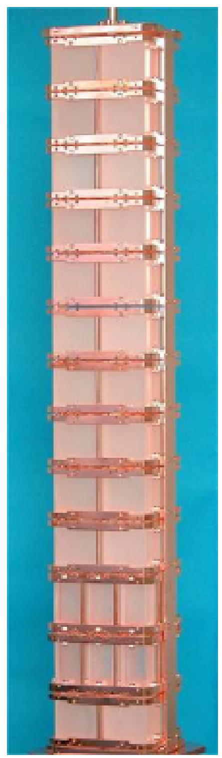
- Average Depth: ~1400m of rock
- Water Equivalent: 3650 m
- Reduces mu flux by a factor of 10^6

CUORE Program

MiDBD
1.8 kg ^{130}Te

1997-2001

Cuoricino
11.3 kg ^{130}Te

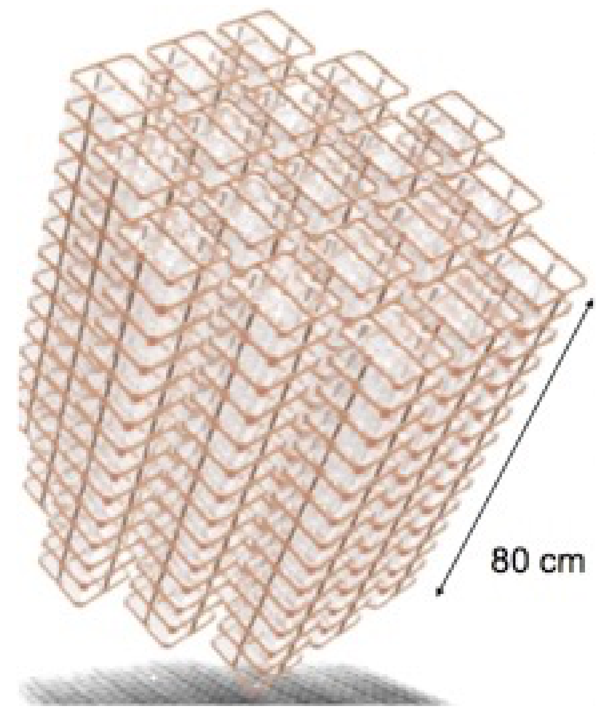


2003-2009

CUORE-0
10.9 kg ^{130}Te

2013-2015

CUORE
209 kg ^{130}Te



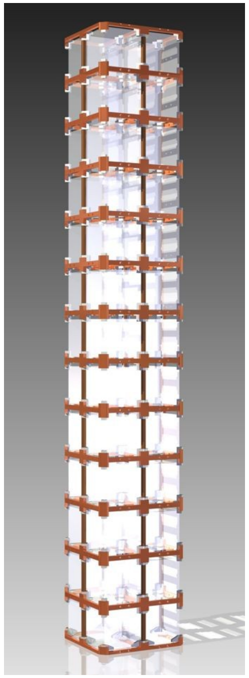
Begin 2016

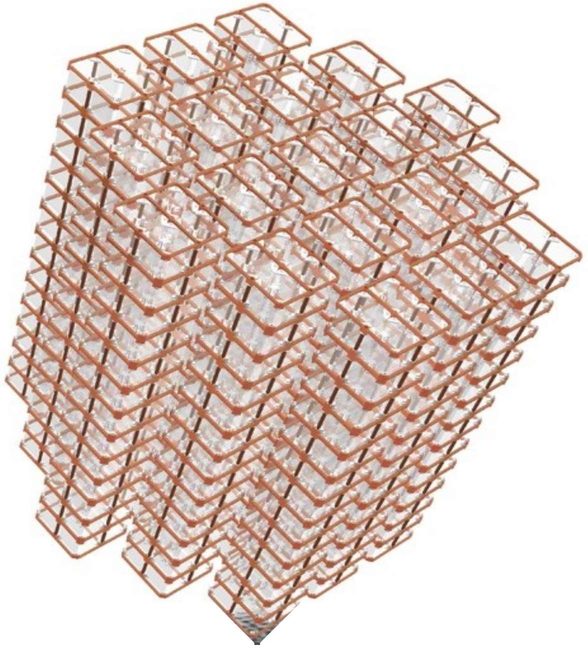
$T_{1/2}^{0\nu} > 2.1 \times 10^{23}$ y → $T_{1/2}^{0\nu} > 2.8 \times 10^{24}$ y → $T_{1/2}^{0\nu} > 4.0 \times 10^{24}$ y

Detectors

CUORE - 0

- One Tower of 52 ^{130}Te Crystals. 5x5x5cm^3 each
- **Total Active Mass**: 39kg TeO_2 (~11kg ^{130}Te)
- **Energy resolution**: 5keV @2615 keV (FWHM)
- **Background**: ~0.06 counts/keV/kg/year



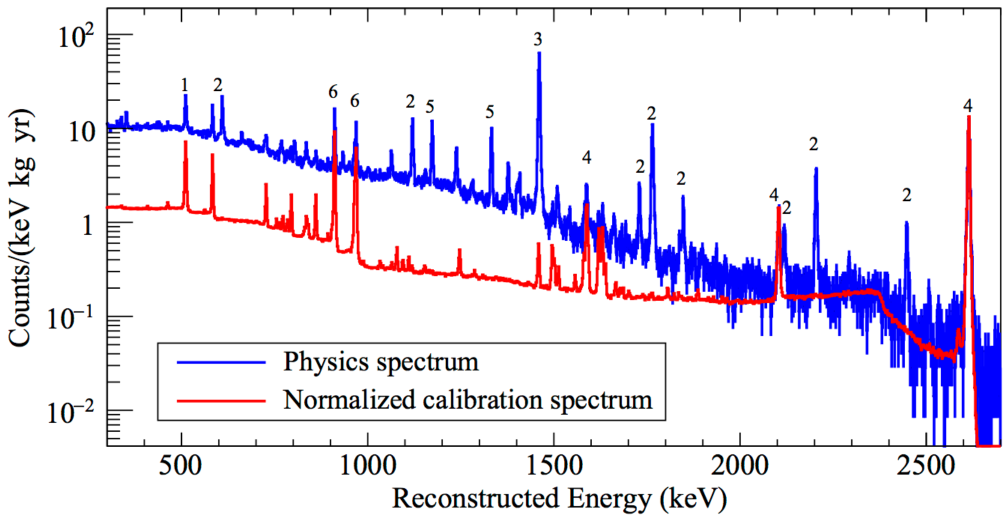


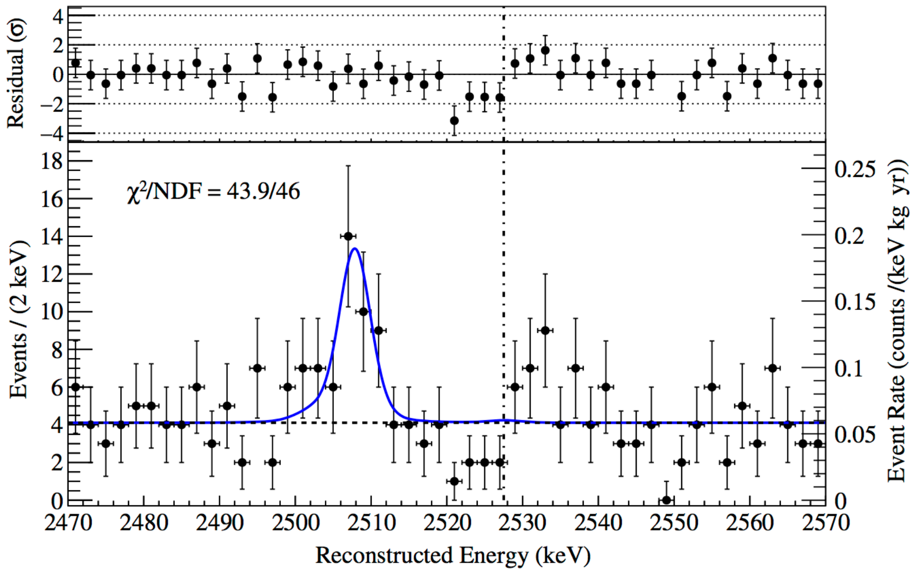
CUORE

- 19 Towers, 988 TeO_2 Crystals. 5x5x5cm each
- **Total Active Mass**: 741kg (~200kg ^{130}Te)
- **Energy resolution**: 5keV @2615 keV (FWHM)
- **Background Aim: 10^{-2}** counts/keV/kg/year

CUORE-0 results

	Cuorecino	CUORE-0
0vbb Half life	2.8×10^{24} yr	2.7×10^{24} yr
Combined with Cuorecino		4.0×10^{24} yr
Resolution	5.8keV	4.9keV
Selection Efficiency	~83%	~81.3%





1. e^+/e^-
2. ^{214}Bi, 3. ^{40}K
4. ^{208}Tl,
5. ^{60}Co, 6. ^{228}Ac

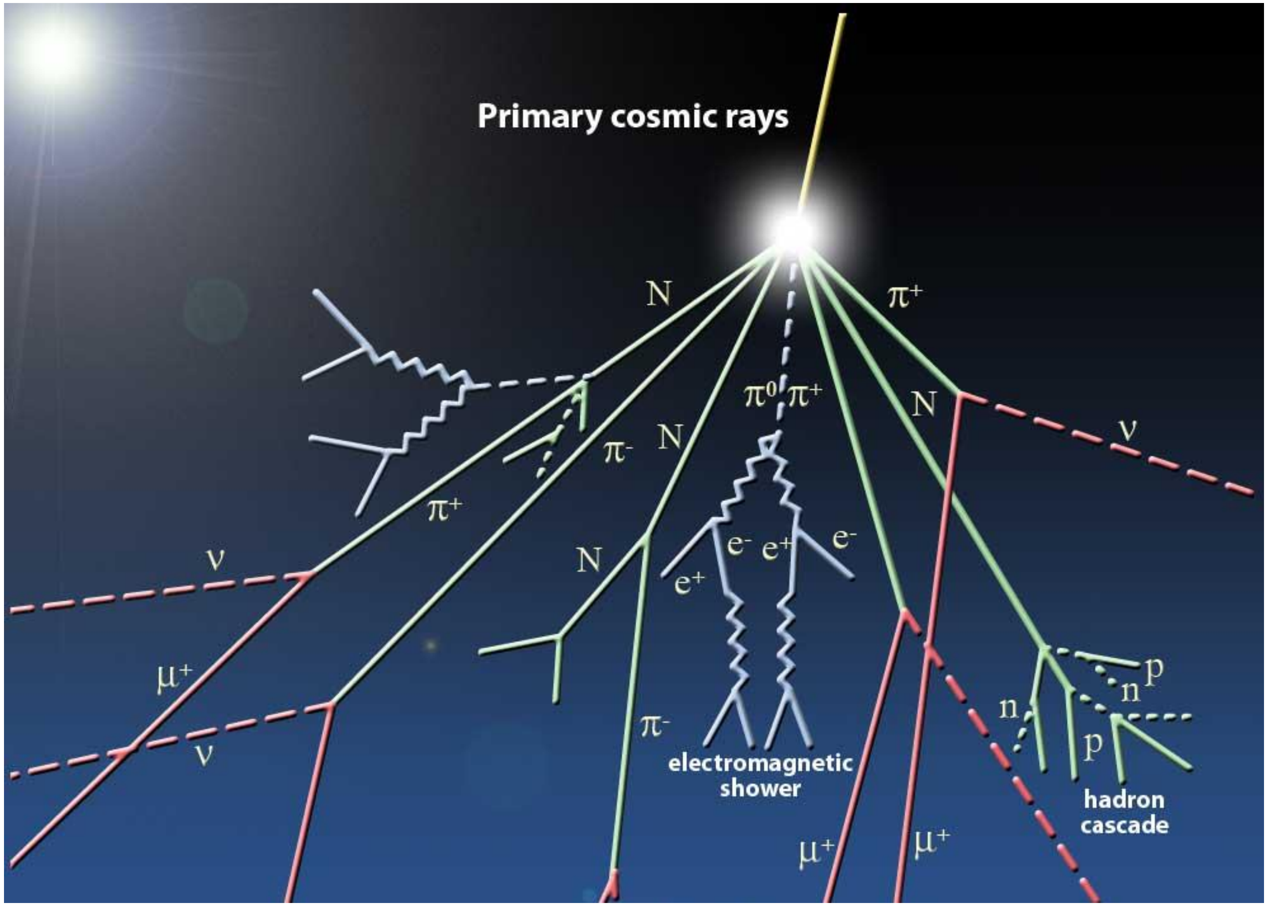
Backgrounds: Overview

- Cosmic Background
- ^{238}U Chain
- ^{232}Th Chain
- ^{40}K
- Intrinsic detector material
- Other radioactive sources

Nuclear fallout material, cosmogenically activated detector and construction material

Cosmic Background

- Cosmic ray primaries and secondaries
- Cosmic muons



Cosmic backgrounds

- Mainly n,p, π, e
- Do not travel far due to higher interaction cross sections
  - Not a problem for underground detector experiments

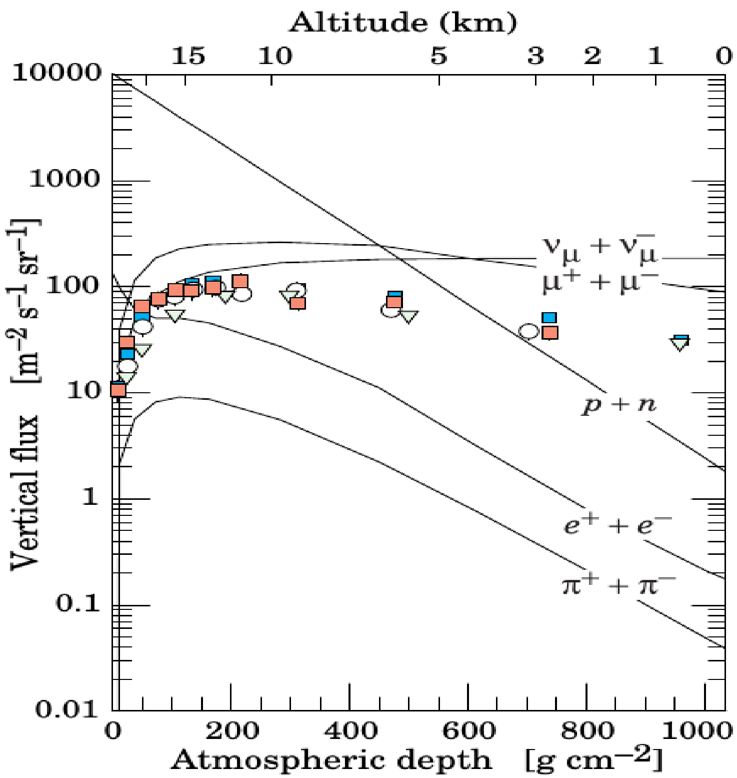


Figure 24.3: Vertical fluxes of cosmic rays in the atmosphere with $E > 1$ GeV estimated from the nucleon flux of Eq. (24.2). The points show measurements of negative muons with $E_\mu > 1$ GeV [32–36].

Cosmic Muon background

- Cosmic rays that hit earth are mostly p and α ~99%,
  - collisions of which produce cascade events producing muons, neutrinos, e, e^+ and γ s
- Muons interact much less, and hence make up most of the cosmic ray products that reach the surface.
- These are mostly produced high in the atmosphere (~15km) with an average energy of 6GeV
- With contributions from pion and kaon decay, the intensity fit is approximately, (for E > 100/Cosθ GeV)

$$\frac{dN_\mu}{dE_\mu d\Omega} \approx \frac{0.14\,E_\mu^{-2.7}}{\mathrm{cm}^2\ \mathrm{s}\ \mathrm{sr}\ \mathrm{GeV}} \left\{ \frac{1}{1+\frac{1.1E_\mu\cos\theta}{115\,\mathrm{GeV}}} + \frac{0.054}{1+\frac{1.1E_\mu\cos\theta}{850\,\mathrm{GeV}}} \right\}$$

- Intensity of muons on the surface ~70 $m^{-2}s^{-1}sr^{-1}$ Or 1 $min^{-1}.cm^{-2}$ for a horizontal detector

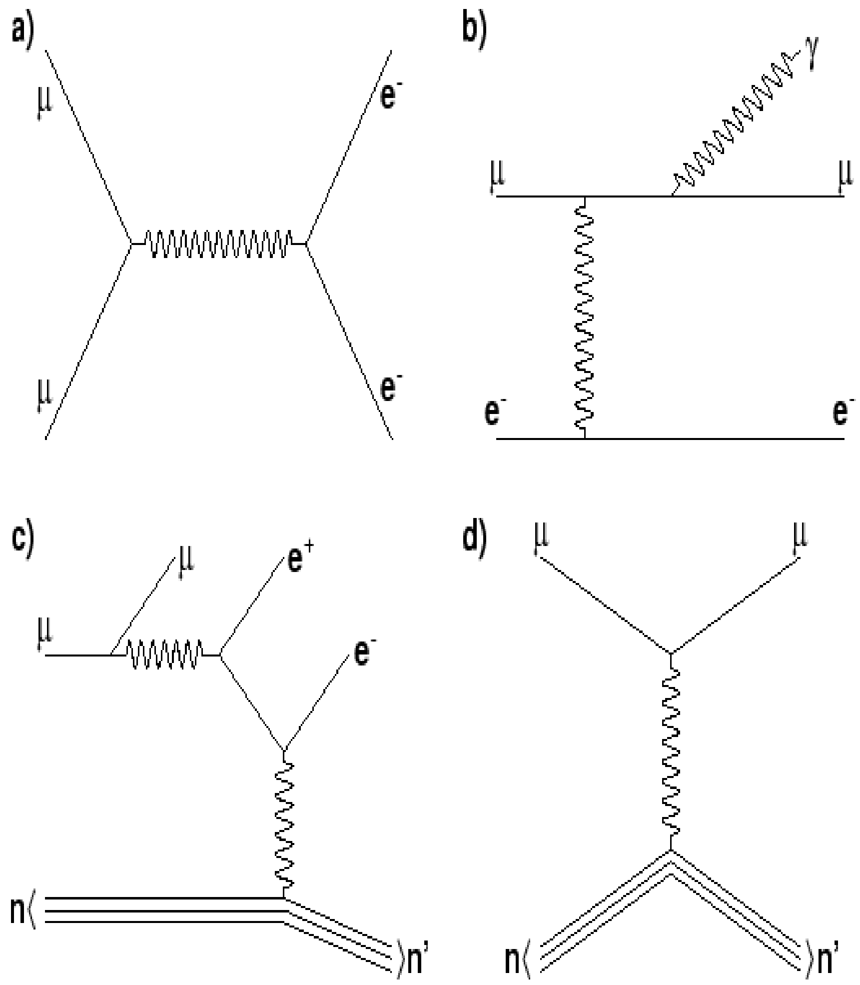
Muon Interactions

- Muons loose energy by bremsstrahlung, pair production and photonuclear interactions,

$$-\frac{dE_\mu}{dX} = a + b\,E_\mu\ ,$$

Table 24.2: Average muon range R and energy loss parameters a and b calculated for standard rock [56] and the total energy loss parameter b for ice. Range is given in km-water-equivalent, or 10^5 g cm^{-2}.

E_μ	R	a	$b_{\rm brems}$	$b_{\rm pair}$	$b_{\rm nucl}$	$\sum b_i$	$\sum b({\rm ice})$
GeV	km.w.e.	MeV g^{-1} cm^2	—	10^{-6} g^{-1} cm^2			—
10	0.05	2.17	0.70	0.70	0.50	1.90	1.66
100	0.41	2.44	1.10	1.53	0.41	3.04	2.51
1000	2.45	2.68	1.44	2.07	0.41	3.92	3.17
10000	6.09	2.93	1.62	2.27	0.46	4.35	3.78



a. Scattering,
b. Bremsstrahlung
c. Pair production
d. Photonuclear interaction

Muons…

- Reduced flux underground, by factor of 10^{-6}
- Still a decent background, 2 counts/year/kg (??)

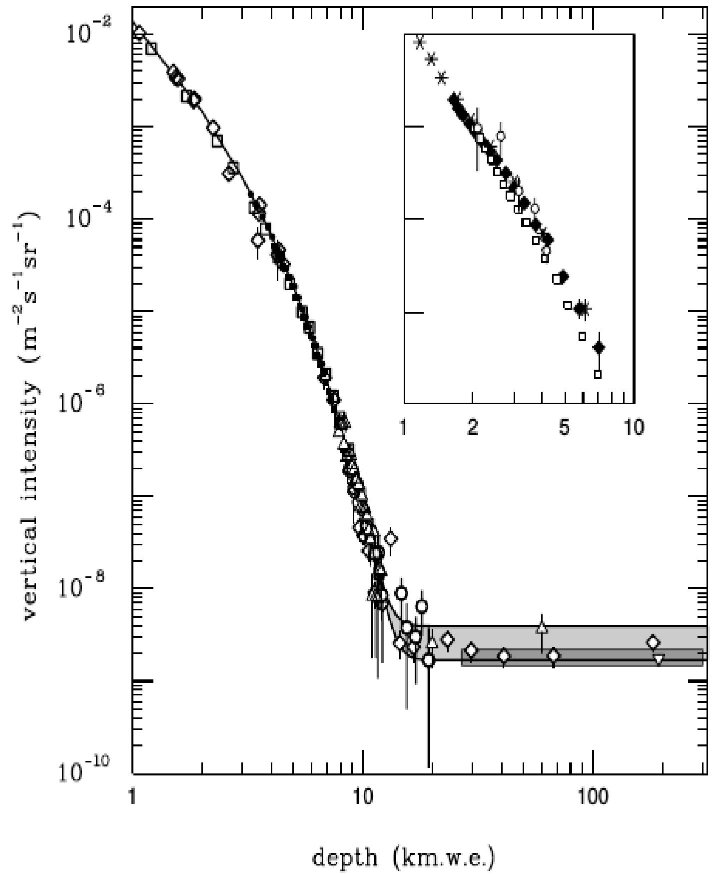
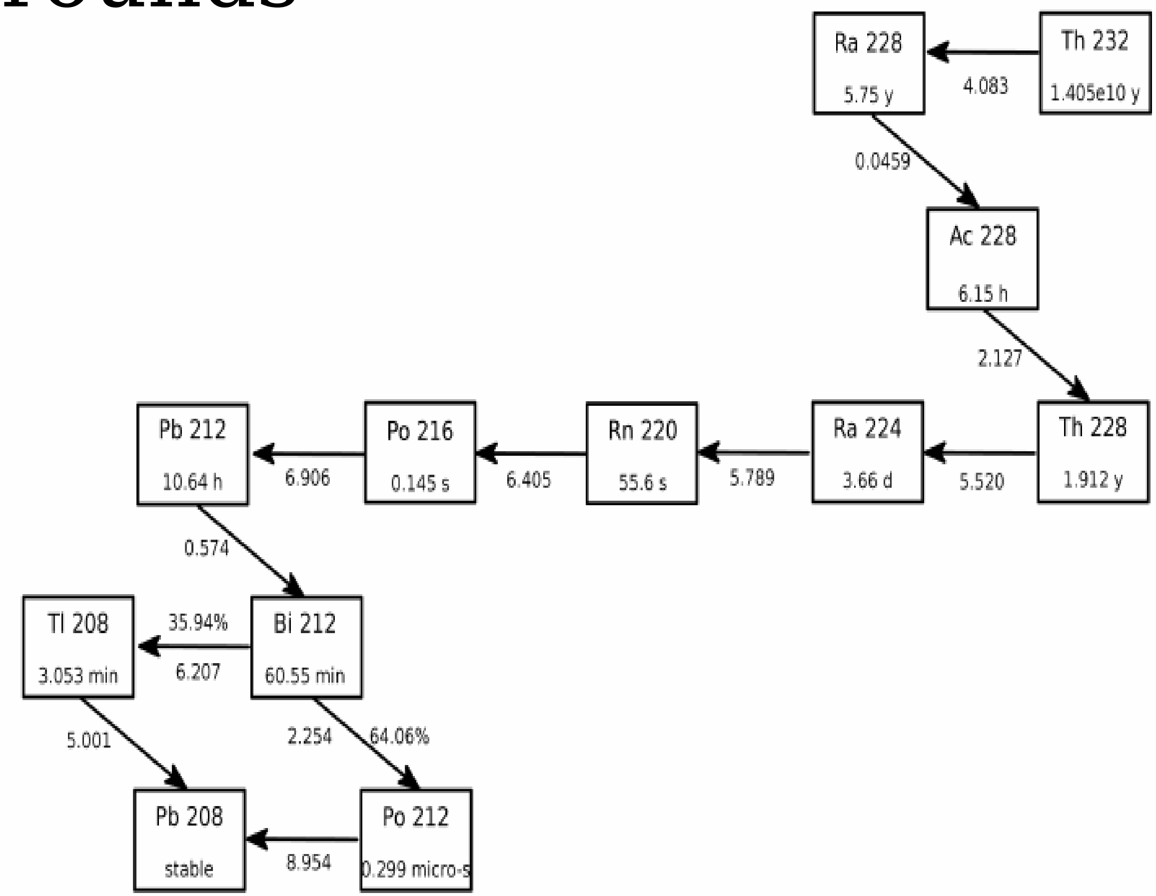


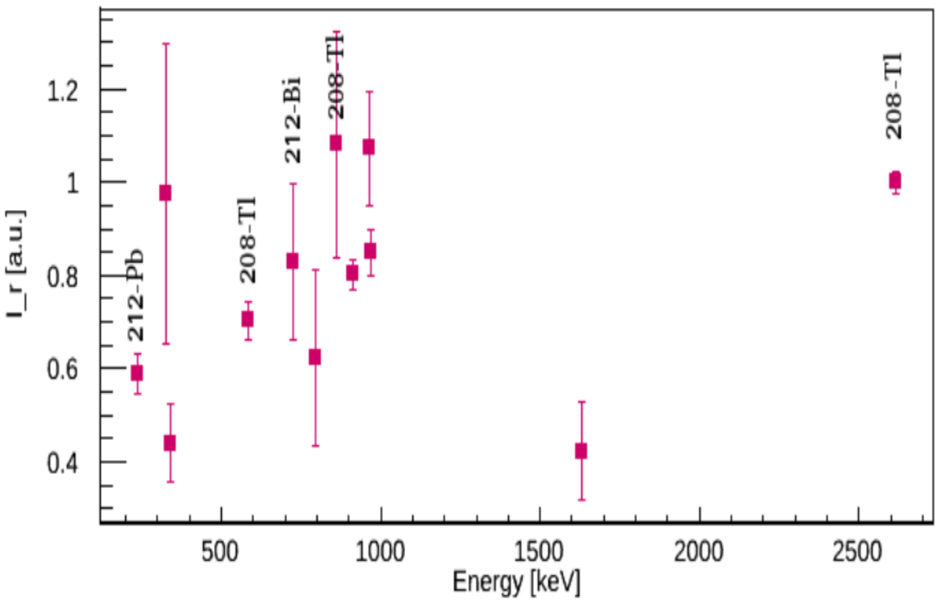
Figure 24.6: Vertical muon intensity vs depth (1 km.w.e. = 10^5 g cm^{-2} of standard rock). The experimental data are from: ◊: the compilations of Crouch [58], □: Baksan [63], ○: LVD [64], •: MACRO [65], ■: Frejus [66], and △: SNO [67]. The shaded area at large depths represents neutrino-induced muons of energy above 2 GeV. The upper line is for horizontal neutrino-induced muons, the lower one for vertically upward muons. Darker shading shows the muon flux measured by the SuperKamiokande experiment. The inset shows the vertical intensity curve for water and ice published in Refs. [59–62].

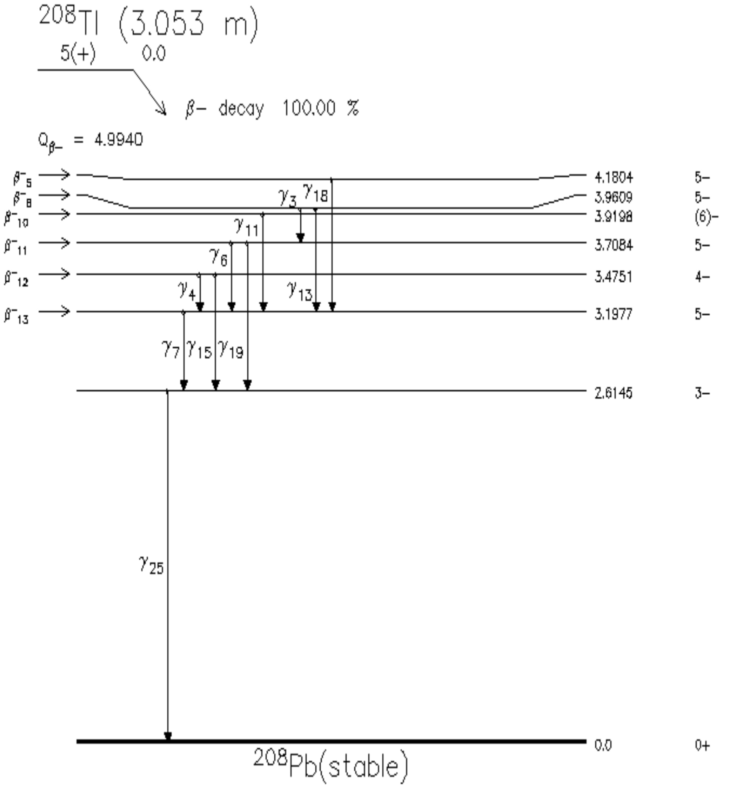
^{232}Th Chain

- One of the two main contributors for backgrounds

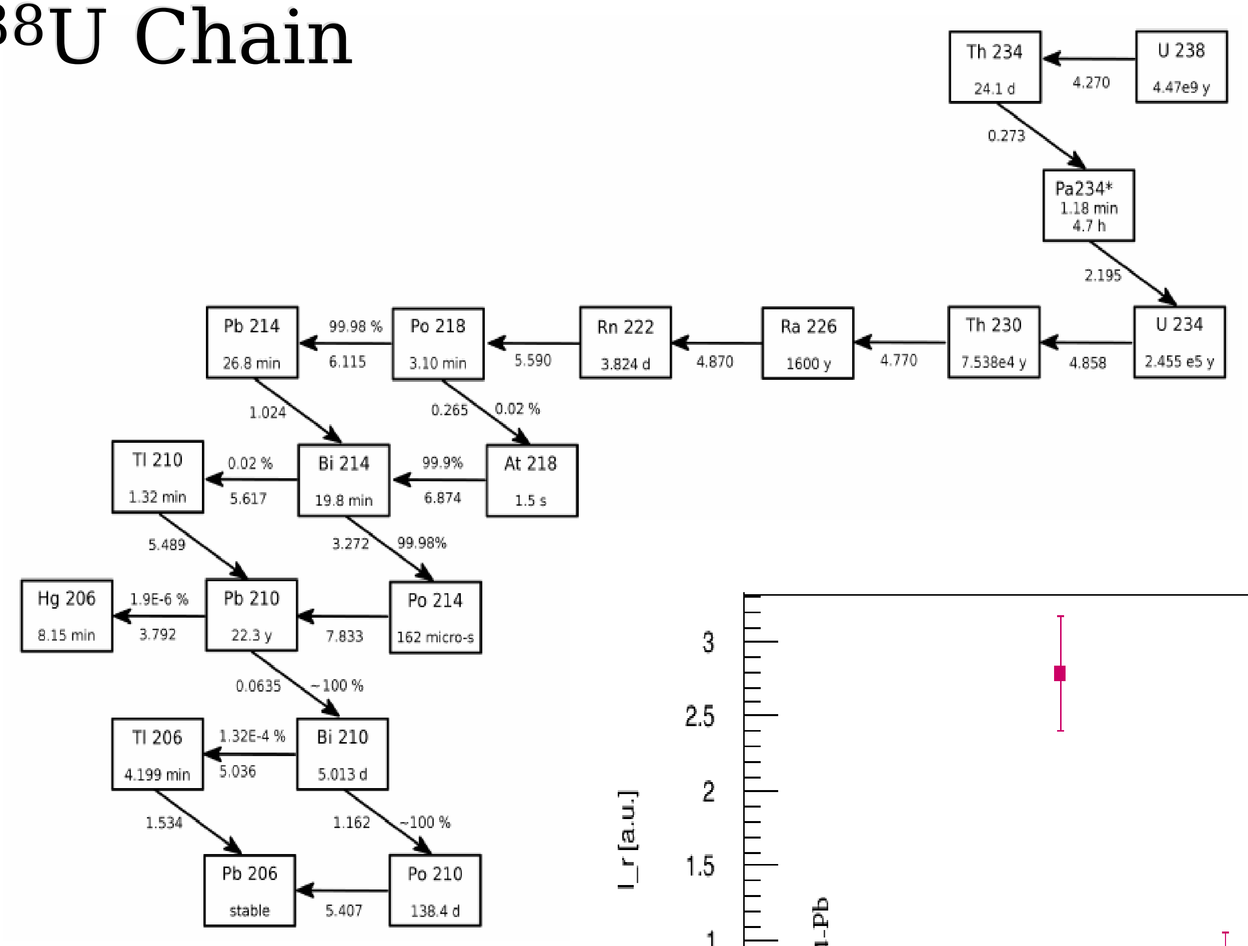


CUORE Background from ^{232}Th

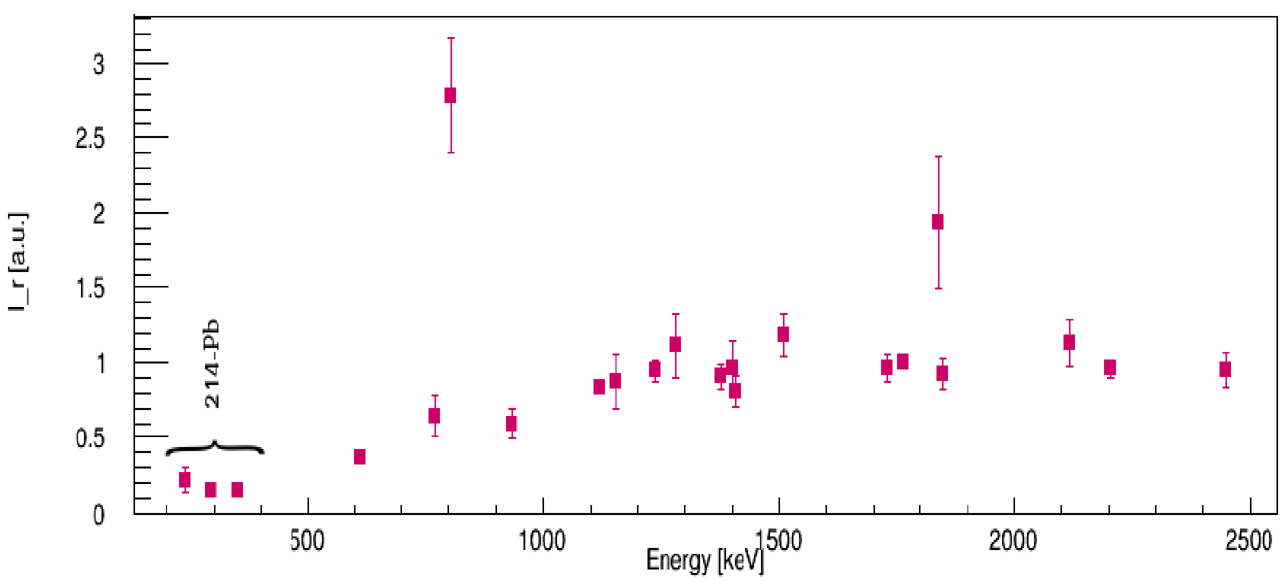




^{238}U Chain



Th 234
24.1 d
U 238
4.47e9 y
4.270
0.273
Pa234*
1.18 min
4.7 h
2.195
U 234
2.455 e5 y
4.858
Th 230
7.538e4 y
4.770
Ra 226
1600 y
4.870
Rn 222
3.824 d
5.590
Po 218
3.10 min
99.98 %
6.115
Pb 214
26.8 min
1.024
0.265
0.02 %
At 218
1.5 s
99.9%
6.874
Bi 214
19.8 min
0.02 %
5.617
Tl 210
1.32 min
5.489
3.272
99.98%
Po 214
162 micro-s
7.833
Pb 210
22.3 y
1.9E-6 %
3.792
Hg 206
8.15 min
0.0635
~100 %
Bi 210
5.013 d
1.32E-4 %
5.036
Tl 206
4.199 min
1.534
1.162
~100 %
Po 210
138.4 d
5.407
Pb 206
stable



I_r [a.u.]
Energy [keV]
214-Pb
0
0.5
1
1.5
2
2.5
3
500
1000
1500
2000
2500

Detector radioactivity

- Intrinsic radioactivity from the detector materials
- Construction materials, Fe, Cu etc

Reducing backgrounds

- Removing the radioactive materials,
  - Using cleaner materials, cleaning
  - Cleaner assembly, construction methods
- Shield
  - External shields,
  - Detector materials as shields
- Tag and veto,
  - External tagging
  - Rejecting events using detector data

Background sources in CUORE

BULK CONTAMINATIONS OF THE CUORE-0 CONSTRUCTION MATERIALS

Component	^{232}Th [Bq/kg]	^{238}U [Bq/kg]	^{40}K [Bq/kg]	Technique
TeO_2 crystals	$<8.4\cdot10^{-7}$	$<6.7\cdot10^{-7}$		bolometric (Th+U) [31]
Glue	$<8.9\cdot10^{-4}$	$<1.0\cdot10^{-2}$	$<47\cdot10^{-3}$	NAA(Th+U)+HPGe(K)
Au bonding wires	$<4.1\cdot10^{-2}$	$<1.2\cdot10^{-2}$		ICP-MS (Th+U)
Si heaters	$<3.3\cdot10^{-4}$	$<2.1\cdot10^{-3}$		NAA (Th+U)
NTD Ge thermistors	$<4.1\cdot10^{-3}$	$<1.2\cdot10^{-2}$		producer spec.(Th+U)
PEN-Cu cables	$<1.0\cdot10^{-3}$	$<1.3\cdot10^{-3}$	$<1.3\cdot10^{-2}$	NAA (Th)+HPGe(U+K)
PTFE supports	$<6.1\cdot10^{-6}$	$<2.2\cdot10^{-5}$		NAA(Th+U)
Cu NOSV	$<2.0\cdot10^{-6}$	$<6.5\cdot10^{-5}$	$7\pm2\cdot10^{-4}$	NAA(Th)+HPGe(U+K)
Cu Outokumpu[a]	$<4.4\cdot10^{-4}$	$<6.7\cdot10^{-4}$	$3\pm1\cdot10^{-3}$	NAA(Th)+HPGe(U+K)
Pb Roman	$<3.3\cdot10^{-5}$	$<4.6\cdot10^{-5}$	$<2.3\cdot10^{-5}$	NAA(Th)+HPGe(U+K)
Pb Ext innermost layer	$<2.6\cdot10^{-4}$	$<7.0\cdot10^{-4}$	$<5.4\cdot10^{-3}$	HPGe

Table 2: 90% C.L. upper limits on bulk contaminations of the various detector components, as obtained from different measurement techniques: bolometric, Neutron Activation Analysis (NAA), Inductively Coupled Plasma Mass Spectrometry (ICP-MS), High Purity Ge diodes γ spectrometry (HPGe).

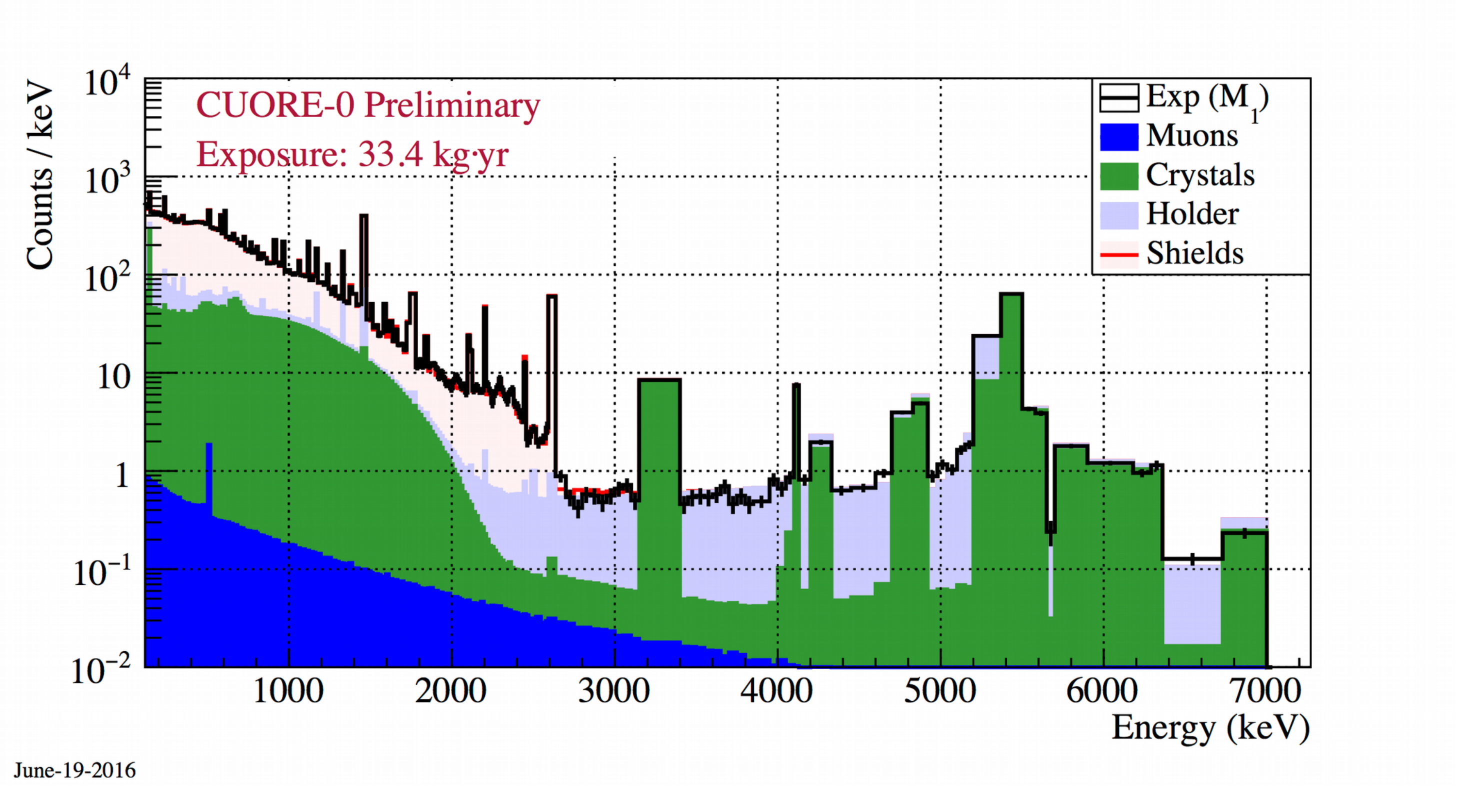
SURFACE CONTAMINATIONS OF THE CUORE-0 CONSTRUCTION MATERIALS

Component	Depth [μm]	^{232}Th [Bq/cm^2]	^{238}U [Bq/cm^2]	^{210}Pb [Bq/cm^2]	Tecnique
TeO_2 crystals	0.01-10	$<2\cdot10^{-9}$	$<9\cdot10^{-9}$	$<1\cdot10^{-6}$	bolometric [31])
Si heaters	0.1-10	$<3\cdot10^{-6}$	$<8\cdot10^{-7}$	$<8\cdot10^{-7}$	bolometric [32]
NTD Ge thermistors	0.1-10	$<8\cdot10^{-6}$	$<5\cdot10^{-6}$	$<4\cdot10^{-5}$	α spectroscopy
PEN-Cu cables	0.1-30	$<4\cdot10^{-6}$	$<5\cdot10^{-6}$	$<3\cdot10^{-5}$	α spectroscopy
PTFE supports	0.1-30	$<1.9\cdot10^{-8}$	$<6.8\cdot10^{-8}$	$<7\cdot10^{-6}$	NAA+bolometric [4]
CuNOSV	0.1-10	$<7\cdot10^{-8}$	$<7\cdot10^{-8}$	$<9\cdot10^{-7}$	bolometric [4]

Table 3: 90% C.L. upper limits for the surface contaminations of the most relevant elements facing the CUORE-0 detector. Different contamination depths are considered (for details refer to [4, 21]).

Background sources in CUORE…

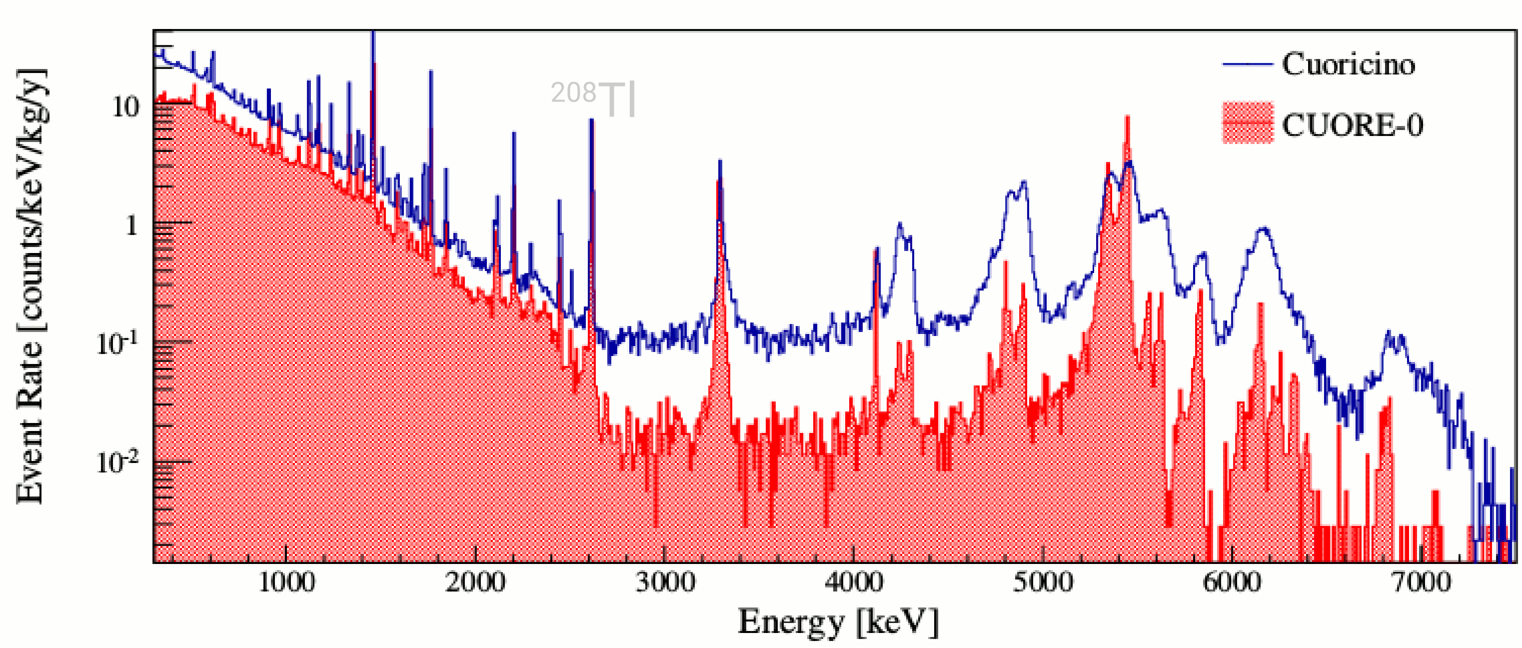
- Breakdown by MC methods and real data…



Cleaning...

- Choosing cleaner construction materials
- Most of the background was due to surface contamination
  - Thourough cleaning methods
  - Assembling in clean room
- Radon free air system
- Lead shields
- Muon veto system

CUORE-0 comparison



Conclusion

- Main background channels for underground physics,
- Go underground,
- Clean and Veto