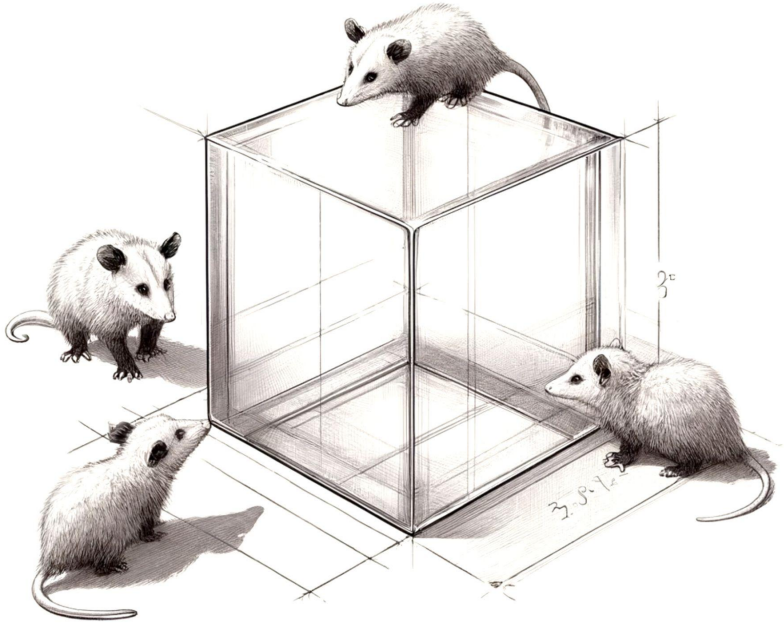
# OPOSSUM

**O**ptimal **P**article identification
**O**f **S**ingle **S**ite events with
**U**nderground **M**KIDs detectors



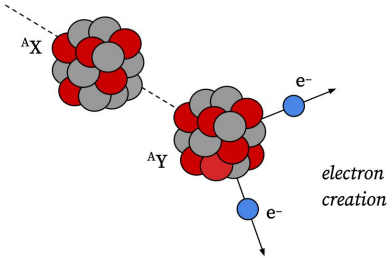
TAUP XICHANG

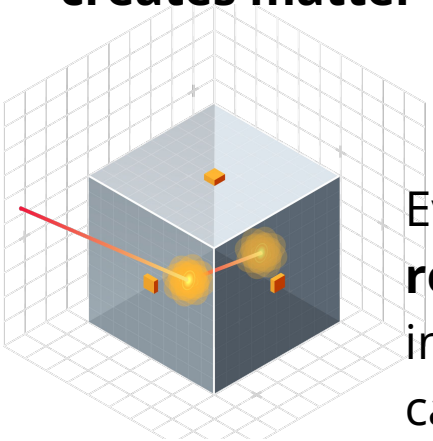
INFN
Istituto Nazionale di Fisica Nucleare

erc
European Research Council
Established by the European Commission

# OPOSSUM in a nutshell

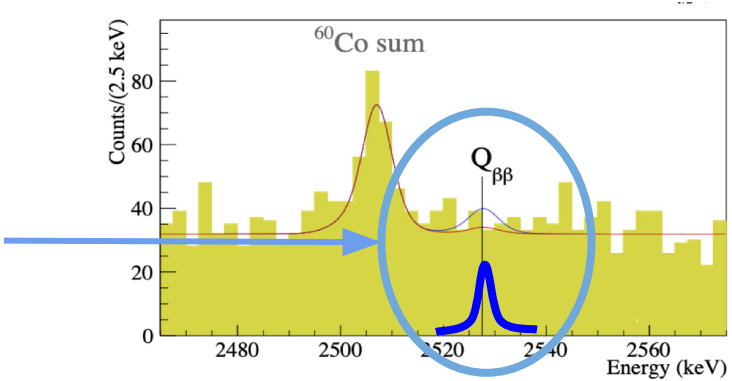
Elimination of all background events in the search for the only **process that creates matter without antimatter.**



Event **topology reconstruction** in low temperature calorimeters.

For the **first** truly **background free** ton-scale experiment in the next 10 years.





European Research Council

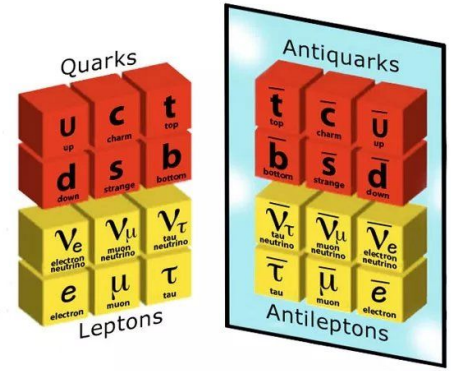
Established by the European Commission

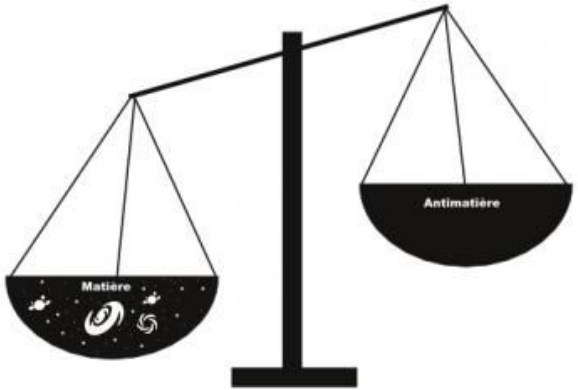
101163231 StG_2024

# Matter-antimatter asymmetry

**Nuclear scale**: Standard Model predicts complete matter/antimatter **symmetry**

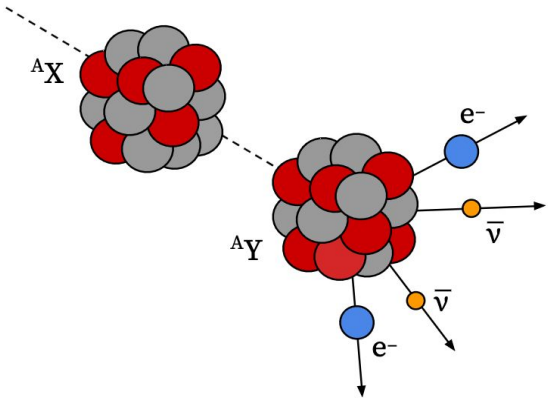
**Universe scale** - matter dominated: SM does not allow the creation of **matter** without antimatter

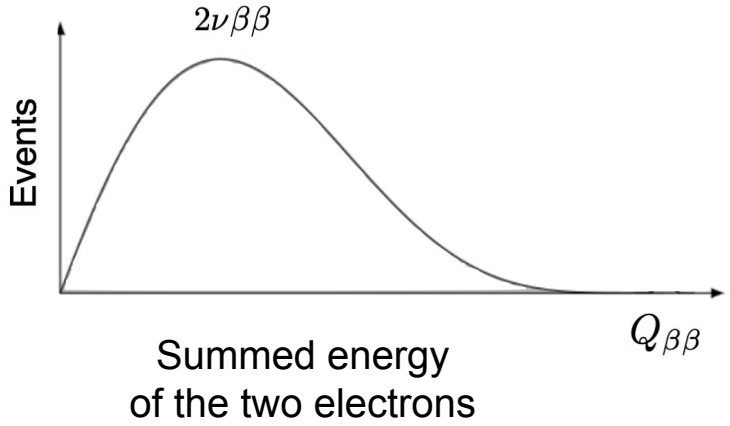



The ultimate probe that can shed light on our understanding of the universe is **Zero Neutrinos Double Beta Decay**

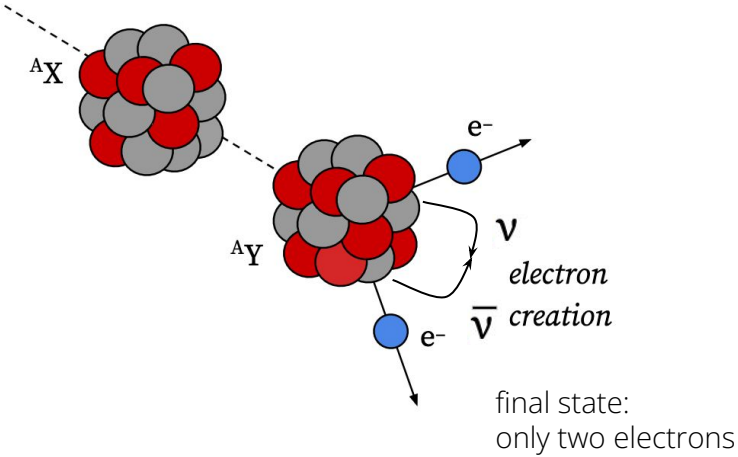
# Two Neutrinos Double Beta Decay

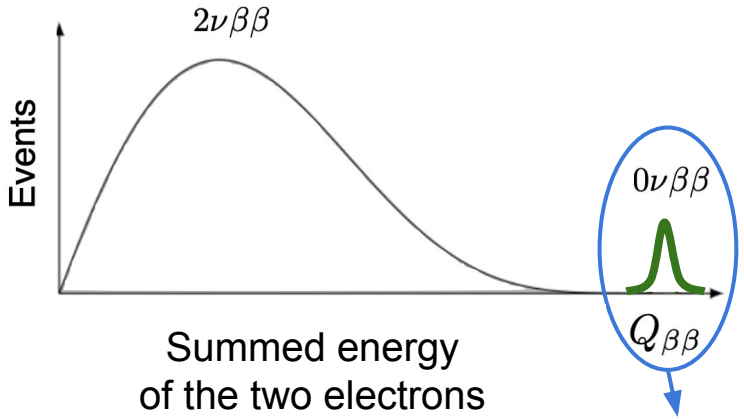



- Two anti-neutrinos and two electrons in the final state
- Observed

# Zero Neutrinos Double Beta Decay




**How to observe 0νββ ?**

- Neutrinos=Antineutrinos (Majorana particles)
- Neutrino mass properties

The only measurable process in which **matter is created**

# 0νββ: the challenge of discovery

**Rarest decay in nature:**

**half-lives > $10^{26}$ -$10^{27}$ y**

Experimental requirements:

- tons*year exposures
- Energy resolution

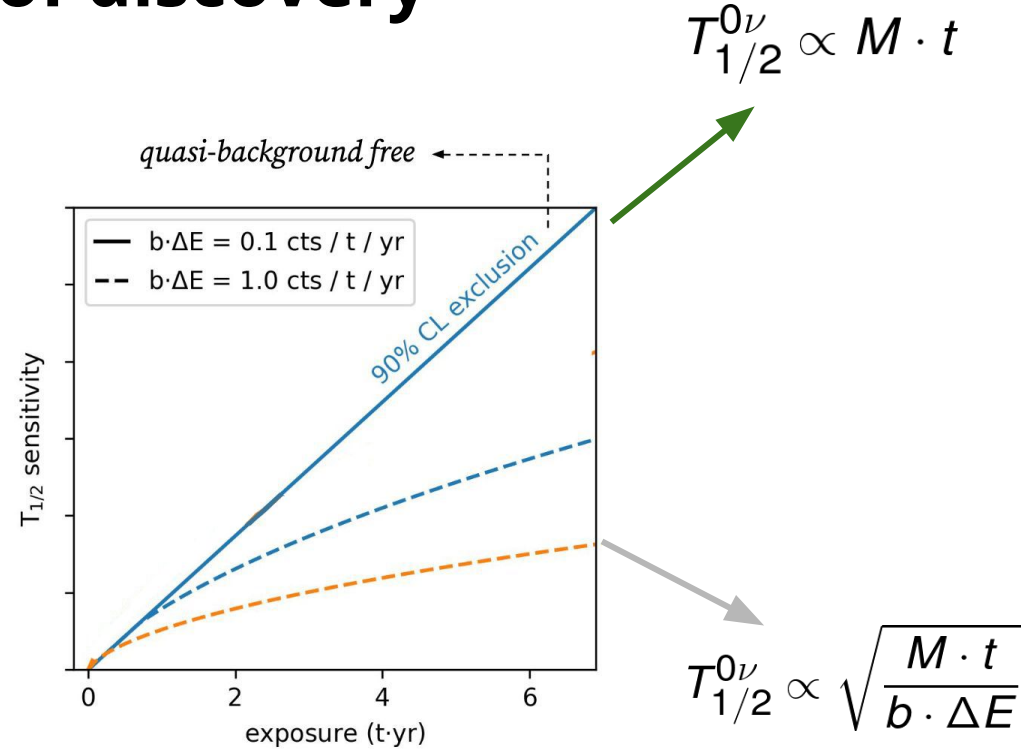
# 0νββ: the challenge of discovery

**Rarest decay in nature:**

**half-lives > $10^{26}$ -$10^{27}$ y**

Experimental requirements:

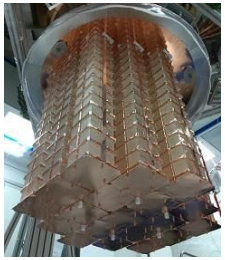
- tons*year exposures
- Energy resolution
- **0 background**



# A world-wide efforts: state of the 0νββ searches

$^{136}$Xe loaded Liquid scintillator

Resolution limited
Enrichment needed
Large exposure



$^{130}TeO_2$ mK-calorimeters

Background limited

34% natural abundance

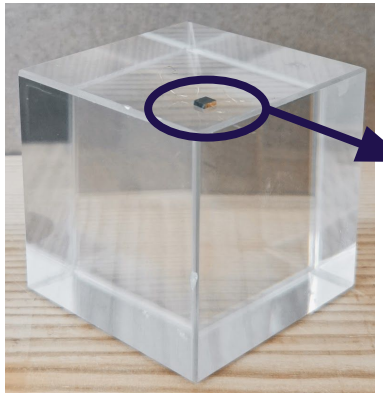
$^{76}$Ge diodes

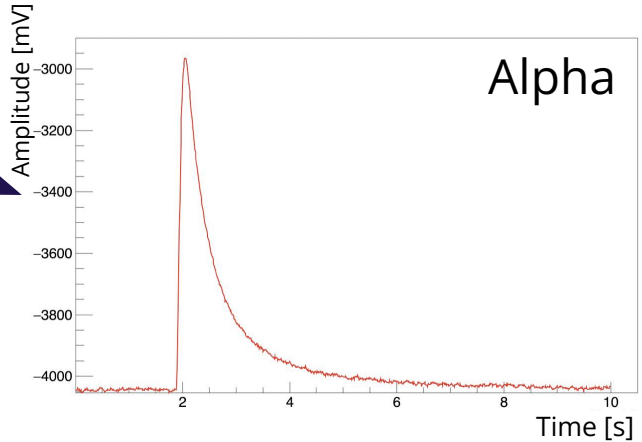
Mono isotopic
Very Expensive Enrichment
High resolution

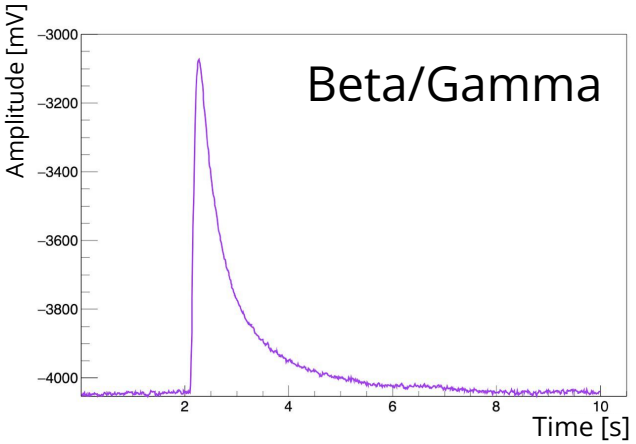
# OPOSSUM

**Innovative detector technology**
**Truly background free**

# $TeO_2$ low temperature calorimeters



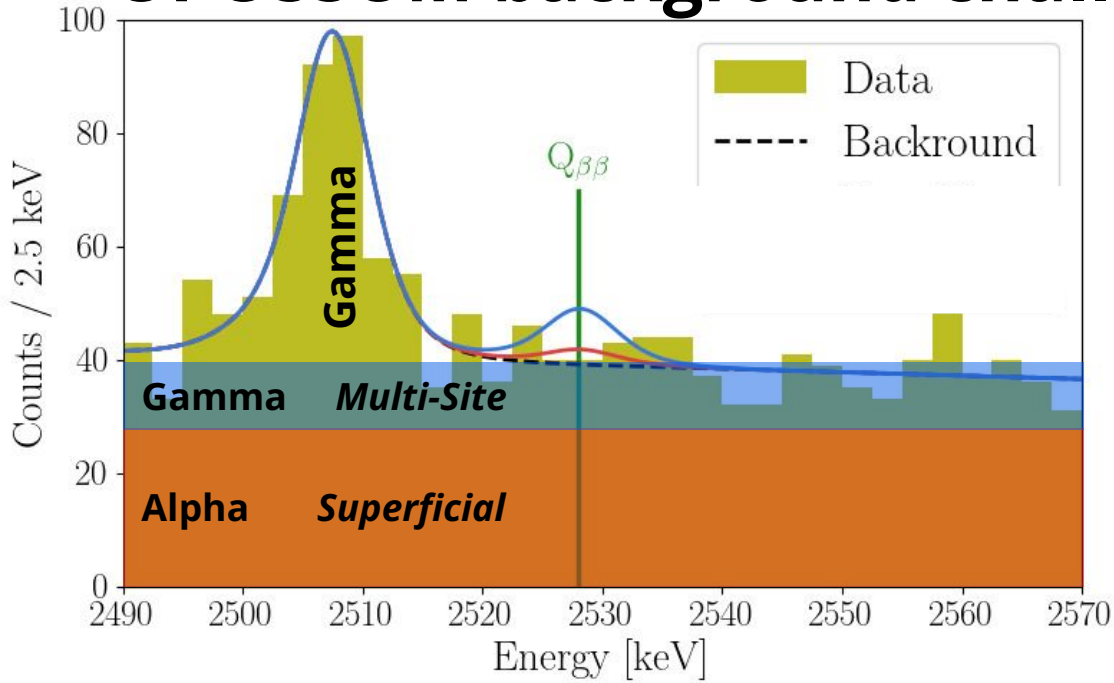



- Thermistor → slow but extremely good **energy resolving** (0.1% FWHM) phonon detector
- **No particle identification** with present technology

⟶ **OPOSSUM** holds the solution for **background-free ton-scale** experiment

# OPOSSUM background challenge

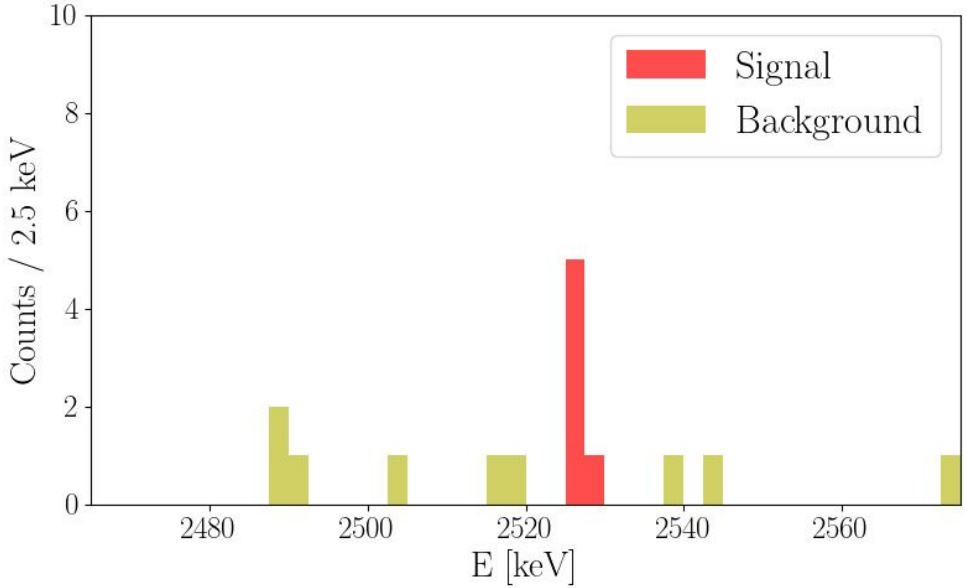



**Alpha** → energy deposited on the **surface** of the TeO2 crystal

**Gamma** → energy deposited in **Multi Site Event unavoidable - until now**

Opossum will eliminate gamma and alpha background through **topological ID**

# OPOSSUM background free



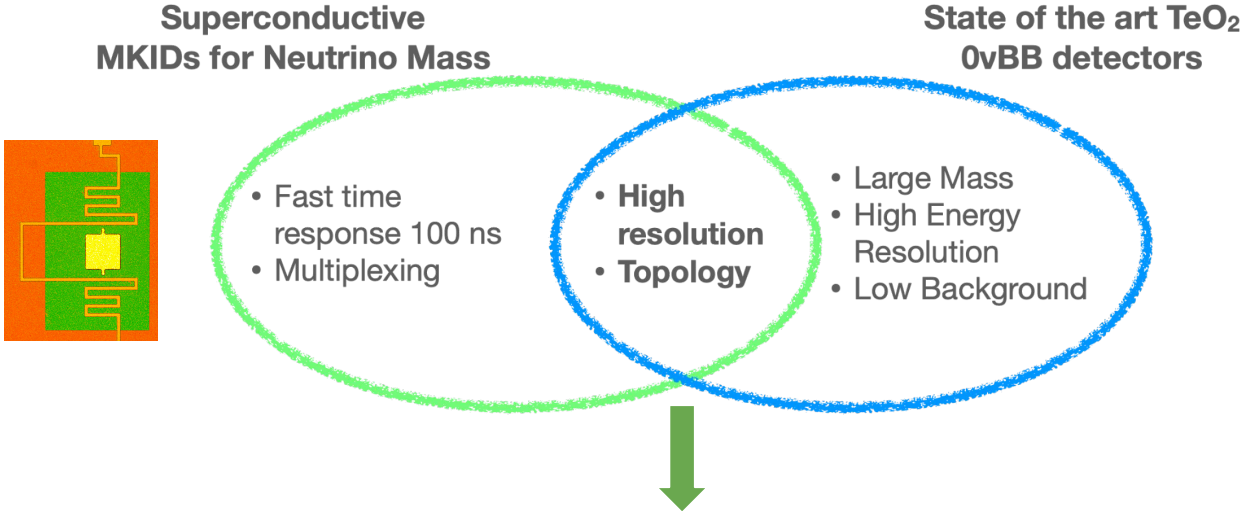

**Alpha** → energy deposited on the **surface** of the TeO2 crystal

**Gamma** → energy deposited in **Multi Site Event unavoidable - until now**

**Neutrinoless Double Beta Decay** → **Single Site Events**

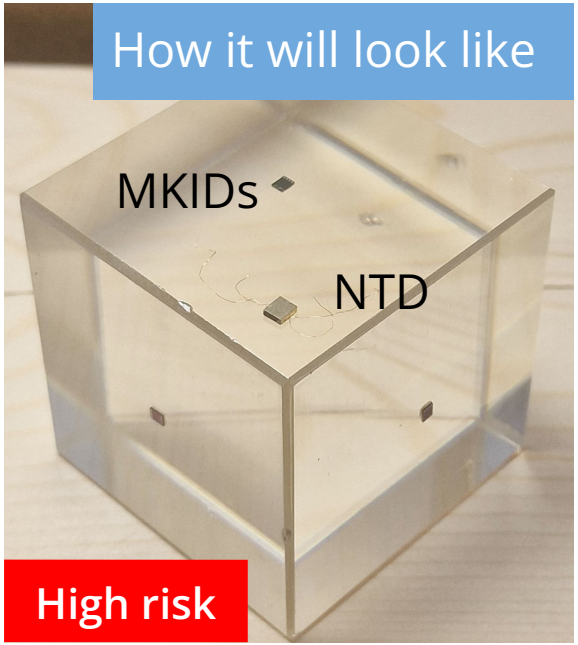
Opossum will **positively tag the 0νββ** events from their topology

# OPOSSUM groundbreaking detectors




**OPOSSUM**

MKIDs-NTD-$TeO_2$
background free detector array

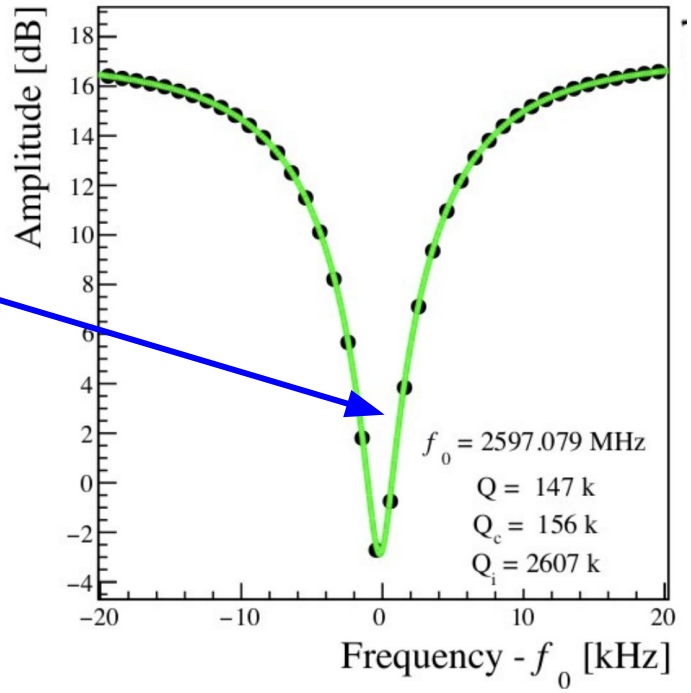



NTD for **high energy resolution**
solid technology

# MKIDs for topology reconstruction

- High Q factor: longer decay time constant, but high energy resolution
- Low Q factor: **Faster time response** of the MKID

$$\tau = \frac{Q}{2\pi f_0}$$




We will **optimise the Q factor** to balance the signal to noise ratio and the time response for the topology reconstruction

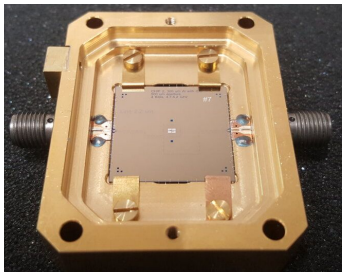
# Microwave Kinetic Inductance Detectors - MKIDs

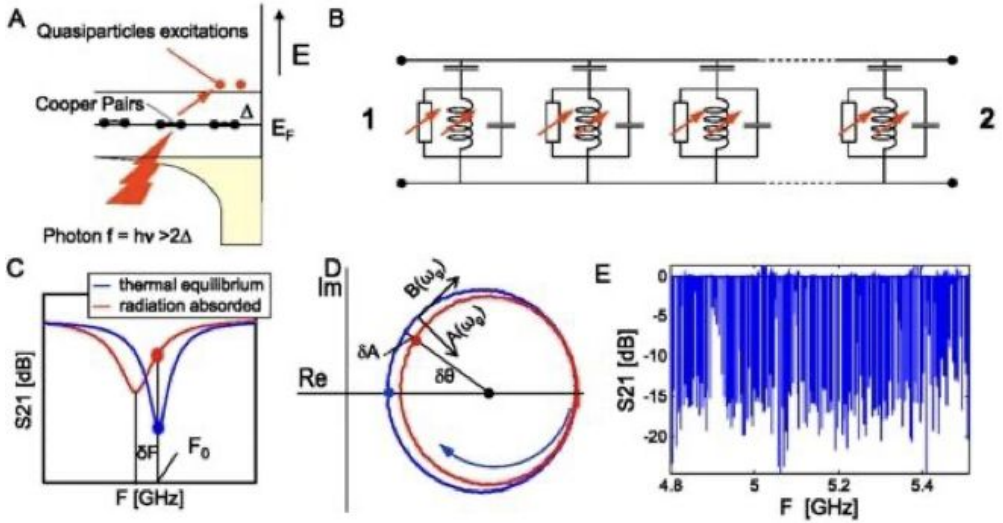
**LC** superconductive circuits

Cooper pairs as a mean of detection

**Sensitive to fast-high energy phonons**

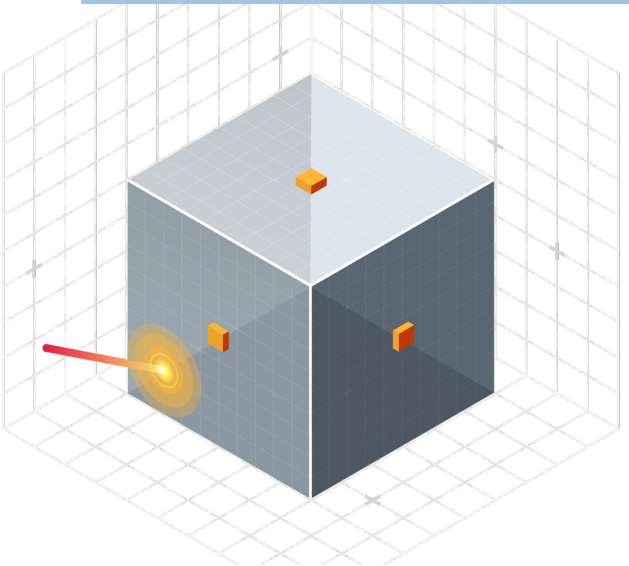
Each MKID can be read out with an RF signal sent along a common line

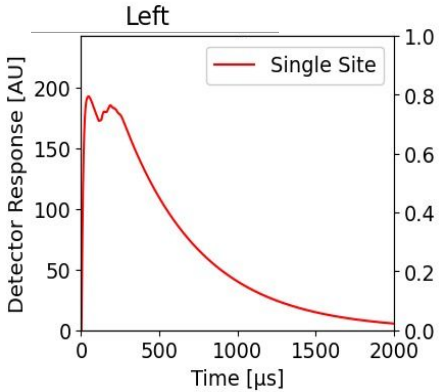


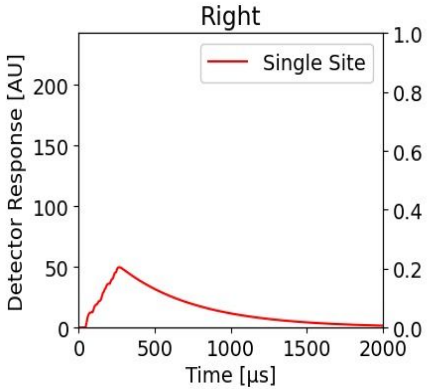


# OPOSSUM revolutionary detection technique

6 MKIDs on each $TeO_2$ crystal for topological reconstruction





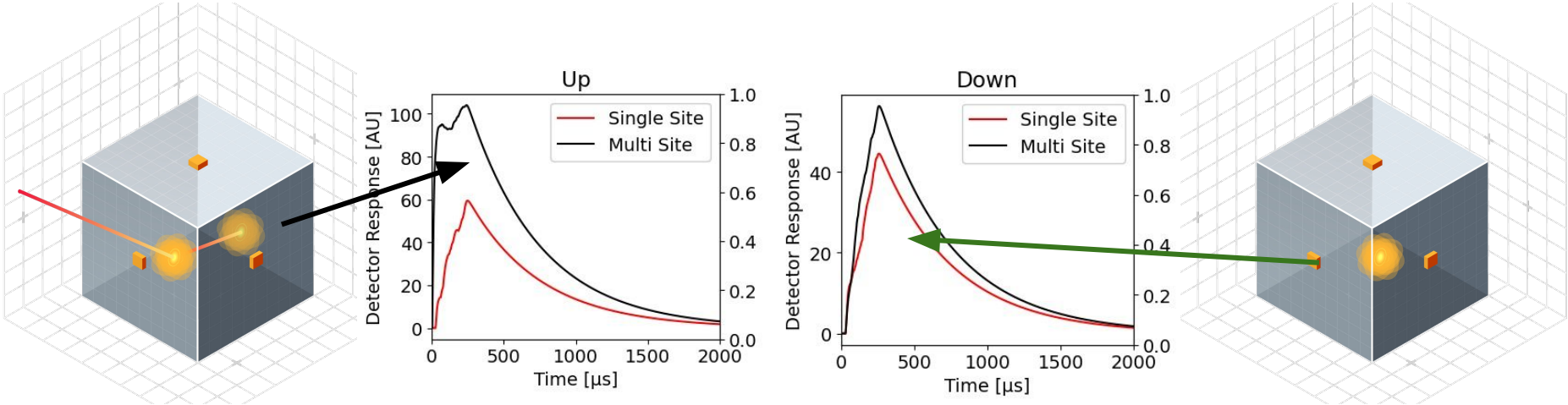




- 3σ (99.97%) rejection rate of alpha surface events

Simulated phonon signals in MKIDs on $TeO_2$

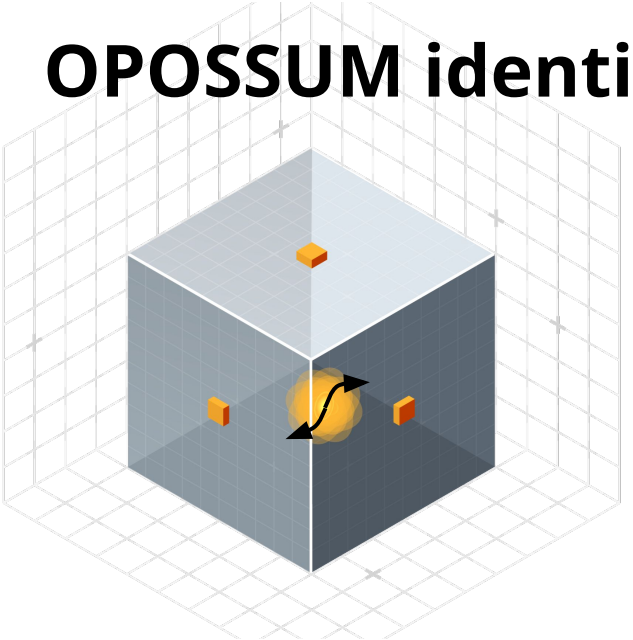
# OPOSSUM pioneers the topological ID

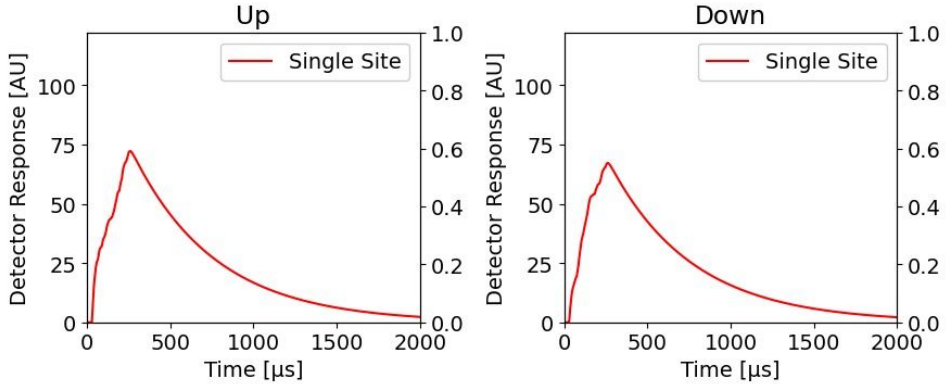
Tagging of Multi Site Events with MKIDs

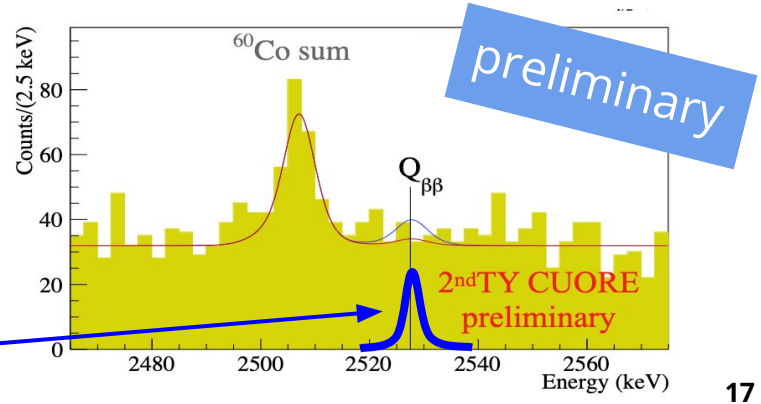



- 3σ (99.97%) rejection rate of alpha surface events
- 2σ (95%) tag and rejection gamma

# OPOSSUM identifies the 0νββ events






**OPOSSUM** will positively identify the Single Site Events

Background reduction of two orders of magnitude -> **sensitivity increase of more than an order of magnitude**

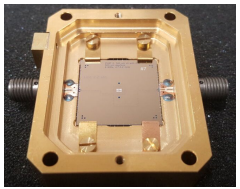
**OPOSSUM has discovery potential!**

# OPOSSUM's plan

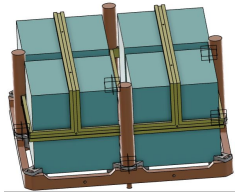
**OPOSSUM final array**
10 kg test

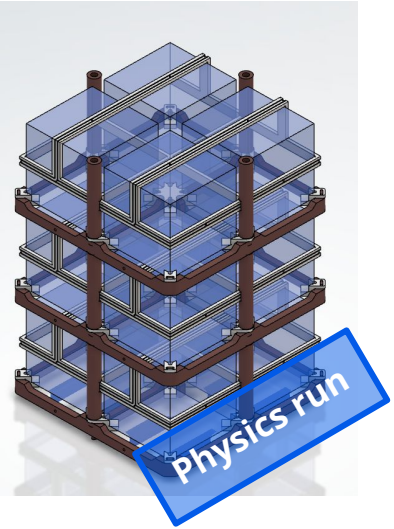
RF and cryo setup

MKID Deposition **on $TeO_2$**

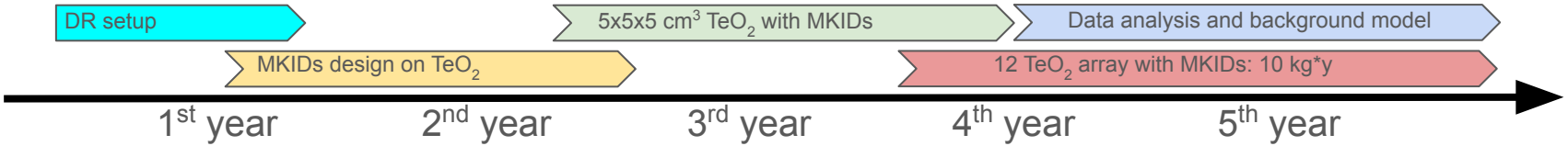


4x$TeO_2$ + MKIDs






## $TeO_2$ CUORE crystals already available

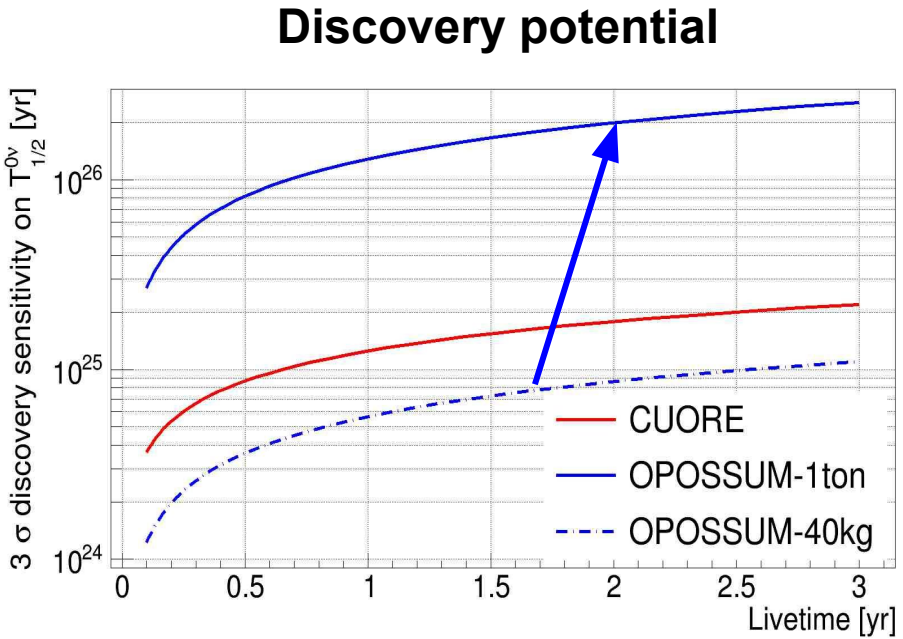


# OPOSSUM next development

Increase the sensitivity of current experiments by more than an order of magnitude

No enrichment needed
Technology more easily to implement on existing experiments

**Phased approach**: OPOSSUM 40 kg will be the next step



If you are interested in the topic, both hardware and software development and you feel like spending some time at LNGS

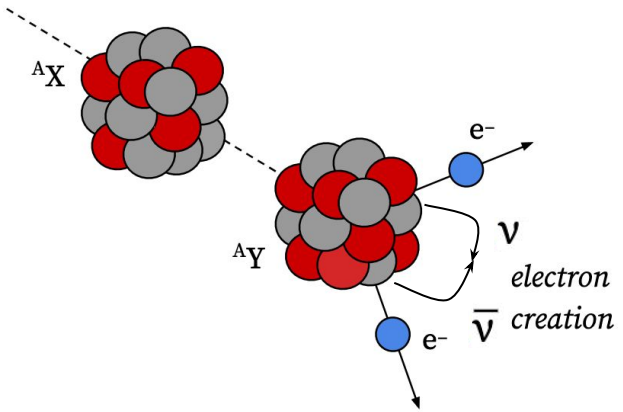
drop us a message:
andrei.puiu@lngs.infn.it

# We are hiring

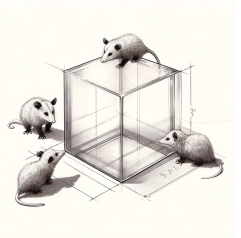
# OPOSSUM physics reach

The 10 kg-scale OPOSSUM demonstrator is just the starting point!

**Opossum is the key to opening an unexplored experimental avenue for the observation of 0νββ, a fundamental process of nature**




We just started developing the first superconductor film on TeO2 crystals



# Backup slides