

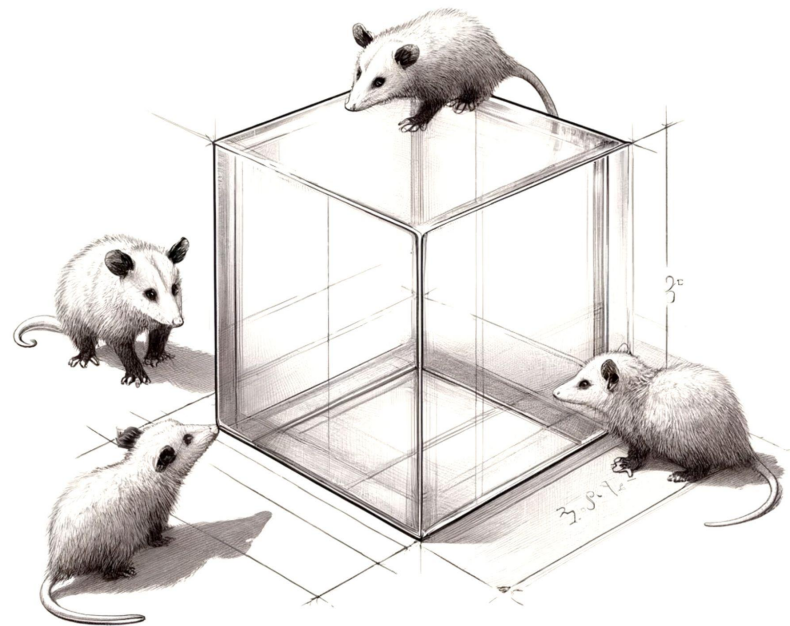
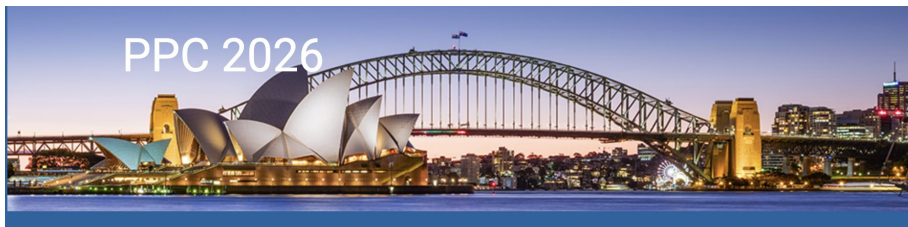
# OPOSSUM

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

Event Topology Discrimination  
in  $\text{TeO}_2$  Cryogenic Calorimeters

Andrei Puiu

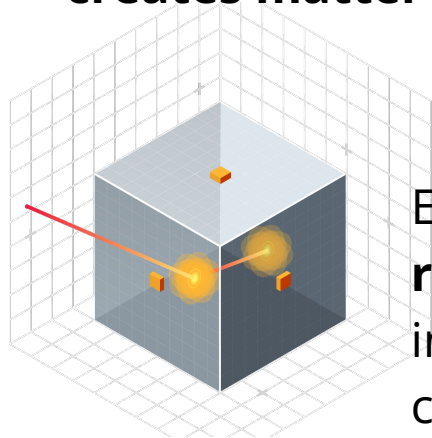
INFN - Laboratori Nazionali del Gran Sasso



European Research Council  
Established by the European Commission

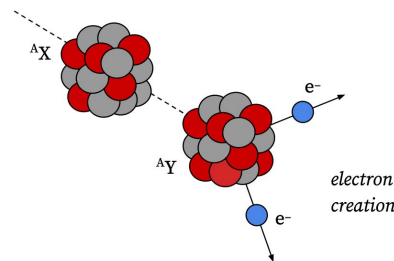
# OPOSSUM in a nutshell

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



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

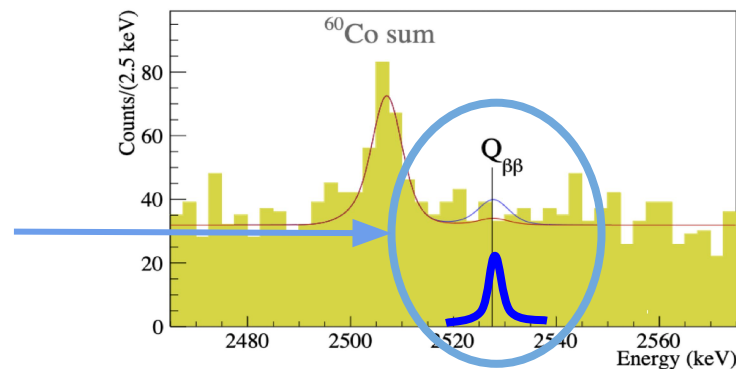
For the **first** truly **background free** ton-scale experiment in the next 10 years.



European Research Council

Established by the European Commission

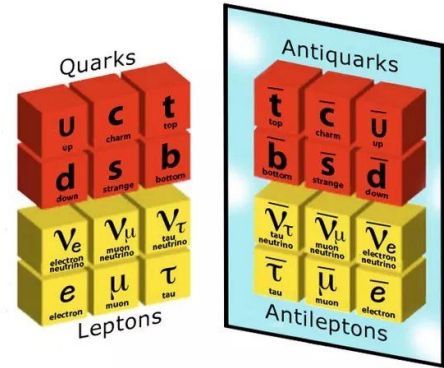
101163231 StG\_2024



# Matter-antimatter asymmetry

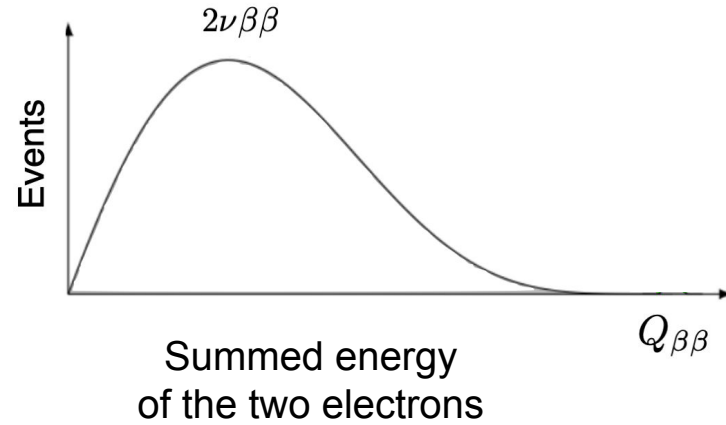
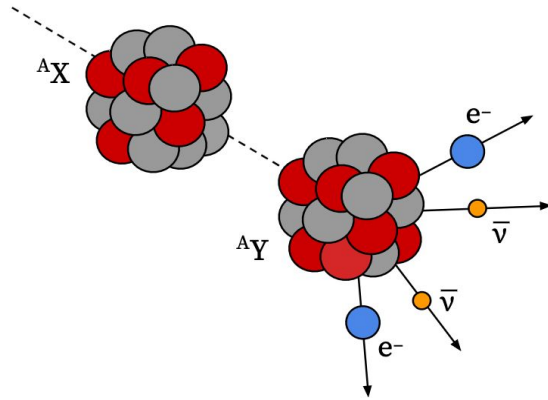
**Nuclear scale:** Standard Model predicts complete matter/antimatter **symmetry**

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



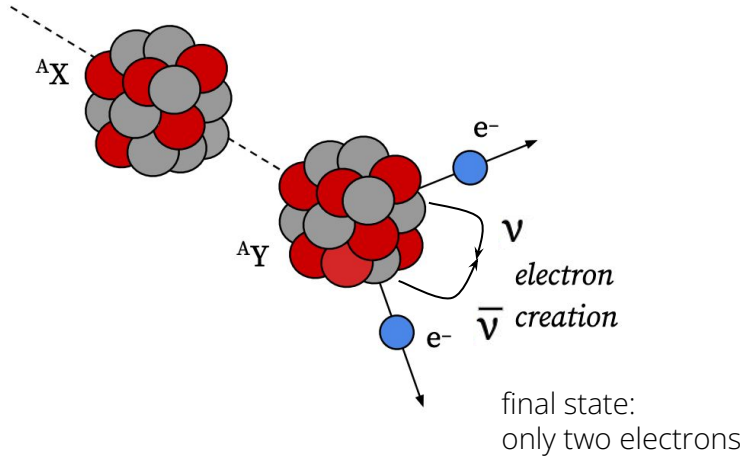
The ultimate probe that can shed light on our understanding of the universe is **Zero Neutrinos Double Beta Decay**

# Two Neutrinos Double Beta Decay

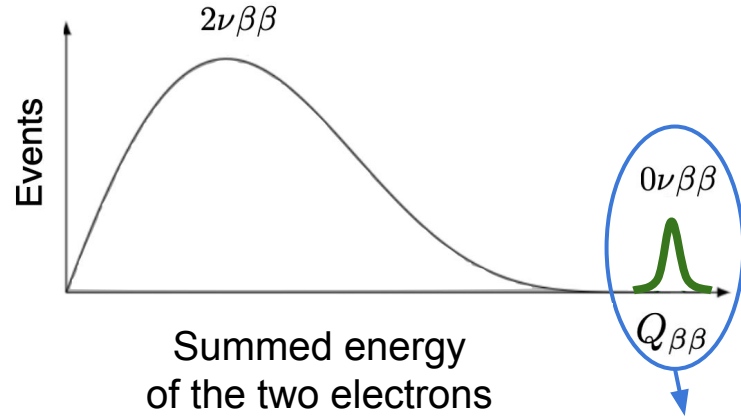


- Two anti-neutrinos and two electrons in the final state
- Observed

# Zero Neutrinos Double Beta Decay



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



**How to observe  $0\nu\beta\beta$  ?**

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

# $0\nu\beta\beta$ : the challenge of discovery

Rarest decay in nature:

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

Experimental requirements:

- tons\*year exposures
- Energy resolution

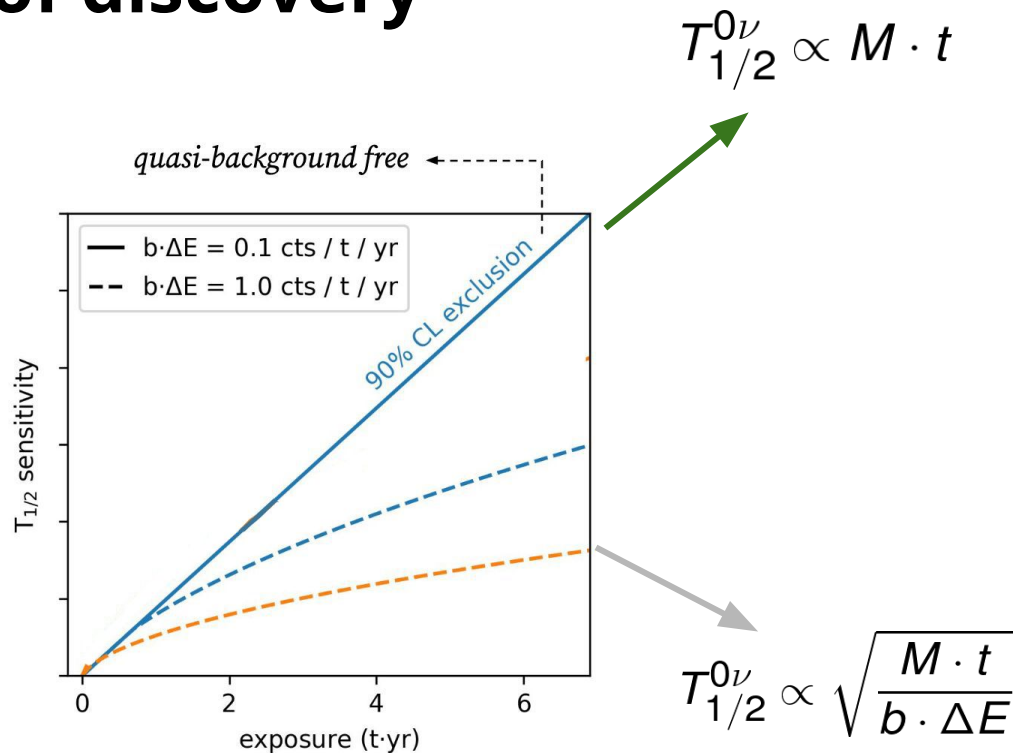
# $0\nu\beta\beta$ : the challenge of discovery

Rarest decay in nature:

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

Experimental requirements:

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

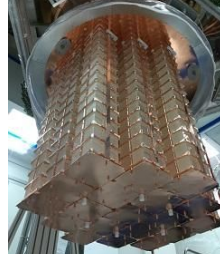


# A world-wide efforts: state of the $0\nu\beta\beta$ searches



$^{136}\text{Xe}$  loaded Liquid scintillator

Resolution limited  
Enrichment needed  
Large exposure



$^{130}\text{TeO}_2$  mK-calorimeters

Background limited  
34% natural abundance



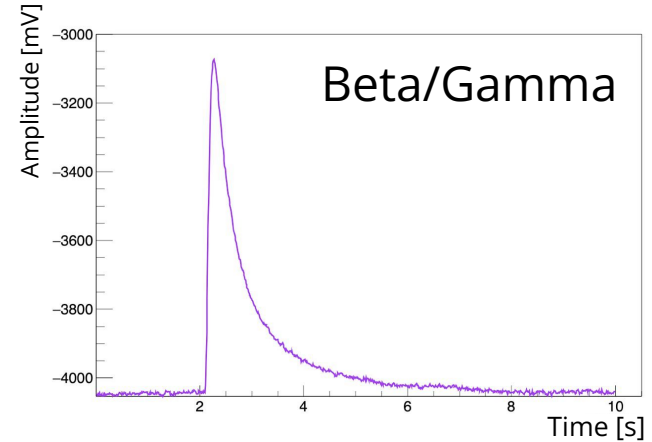
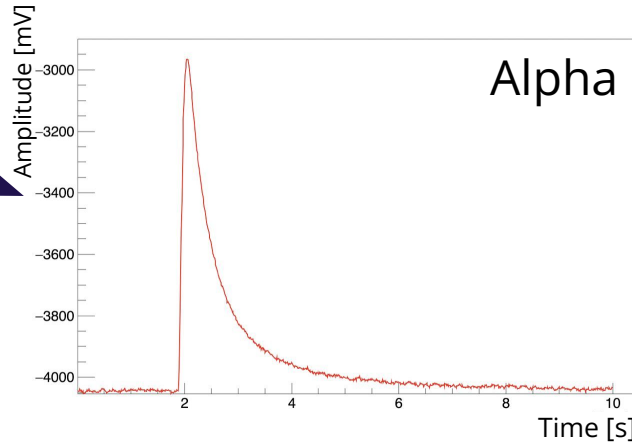
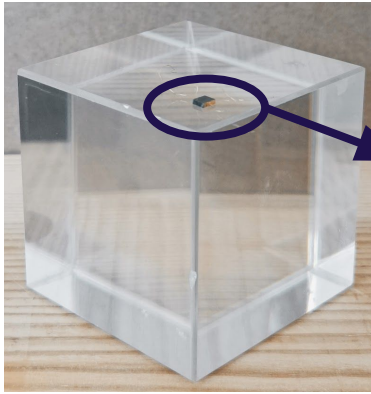
$^{76}\text{Ge}$  diodes

Mono isotopic  
Very Expensive Enrichment  
High resolution

**OPOSSUM**

Innovative detector technology  
Truly background free

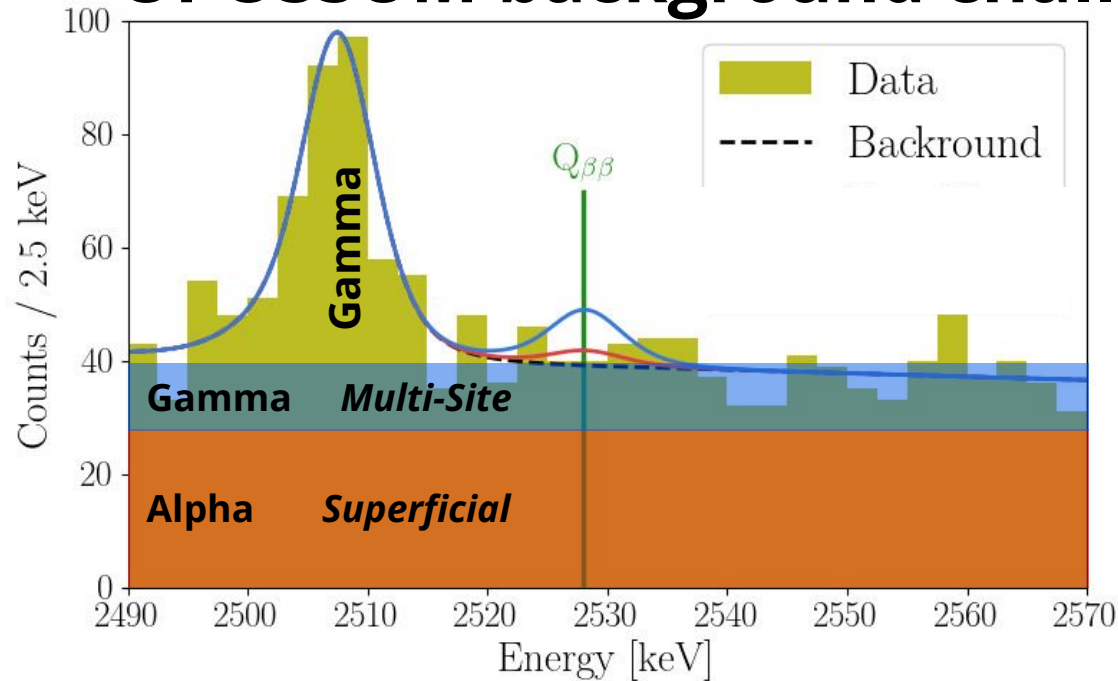
# TeO<sub>2</sub> low temperature calorimeters



- 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

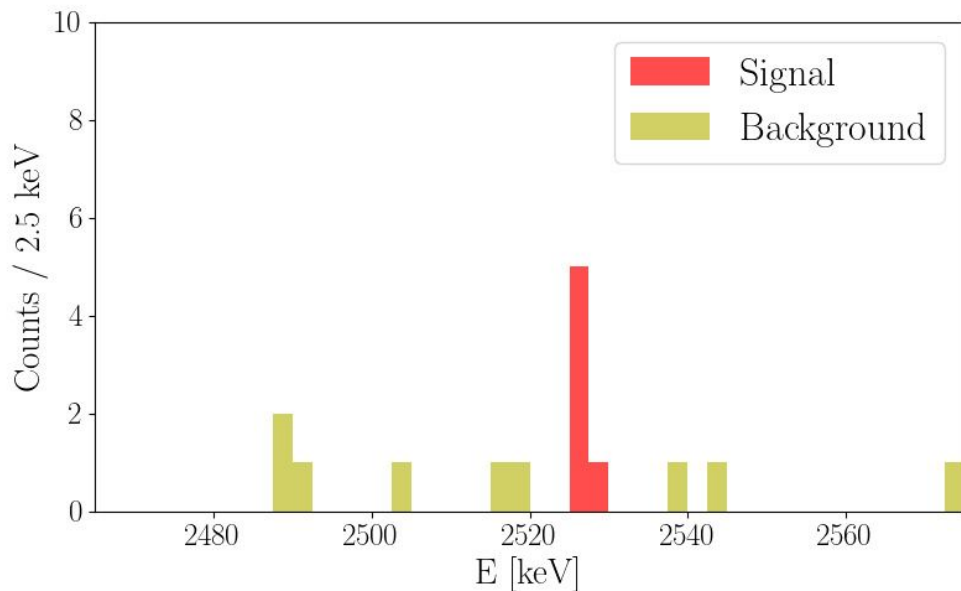


**Alpha** → energy deposited on the **surface** of the TeO<sub>2</sub> crystal

**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 TeO<sub>2</sub> crystal

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

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

Opossum will **positively tag the  $0\nu\beta\beta$**  events from their topology

# OPOSSUM groundbreaking detectors

Superconductive  
MKIDs for Neutrino Mass

- Fast time response 100 ns
- Multiplexing

State of the art  $\text{TeO}_2$   
0vBB detectors

- **High resolution**
- **Topology**
- Large Mass
- High Energy Resolution
- Low Background

**OPOSSUM**

MKIDs-NTD- $\text{TeO}_2$   
background free detector array

How it will look like

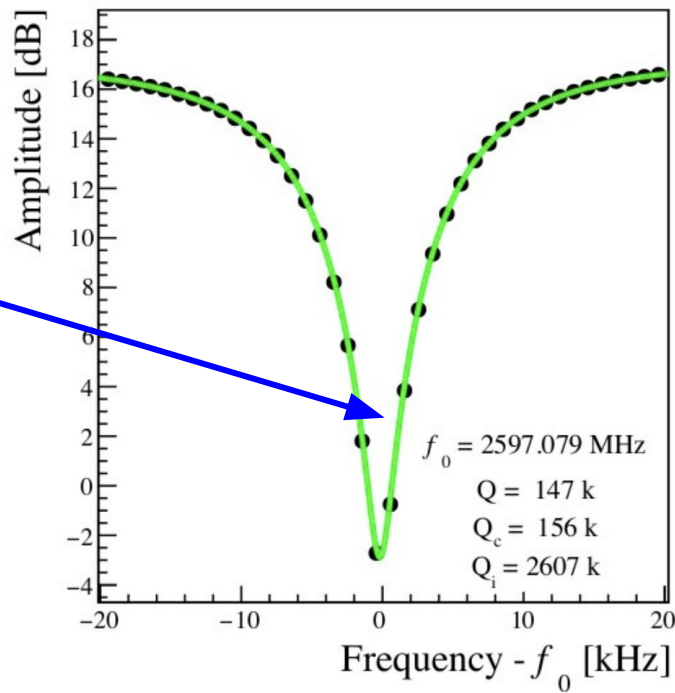


NTD for **high energy resolution**  
solid technology

# 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

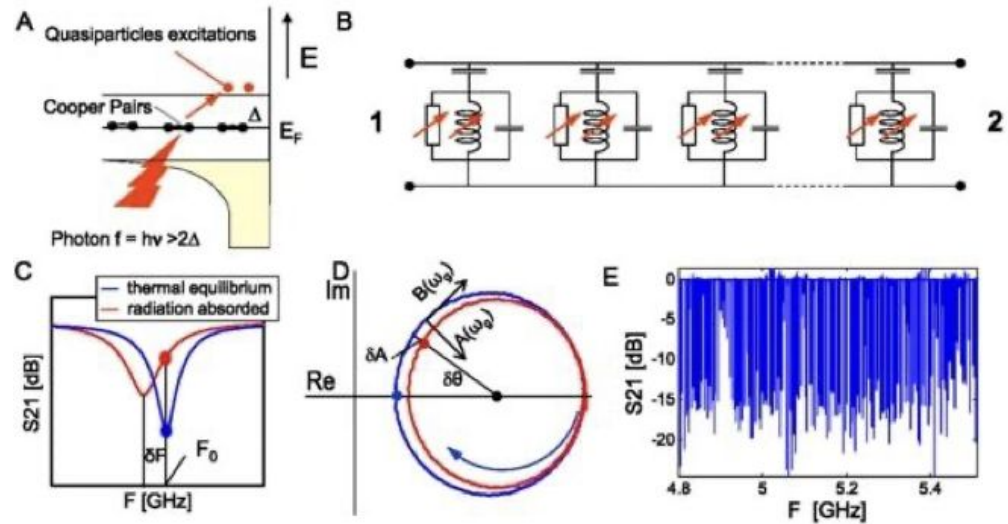
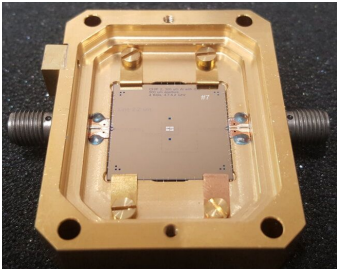
# Microwave Kinetic Inductance Detectors - MKIDs

LC superconductive circuits

Cooper pairs as a mean of detection

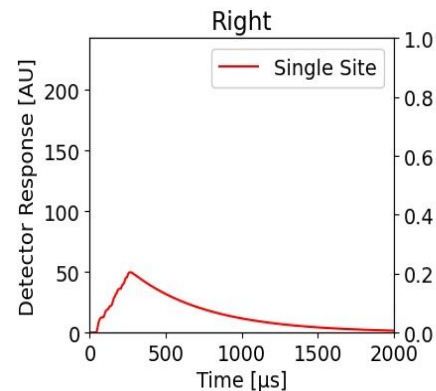
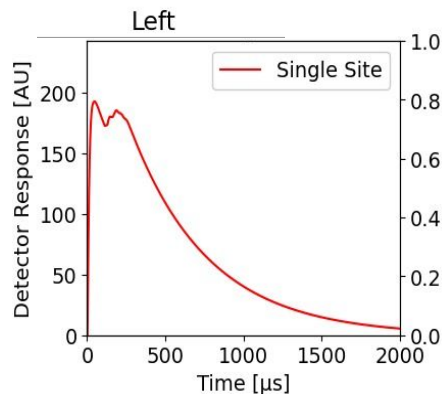
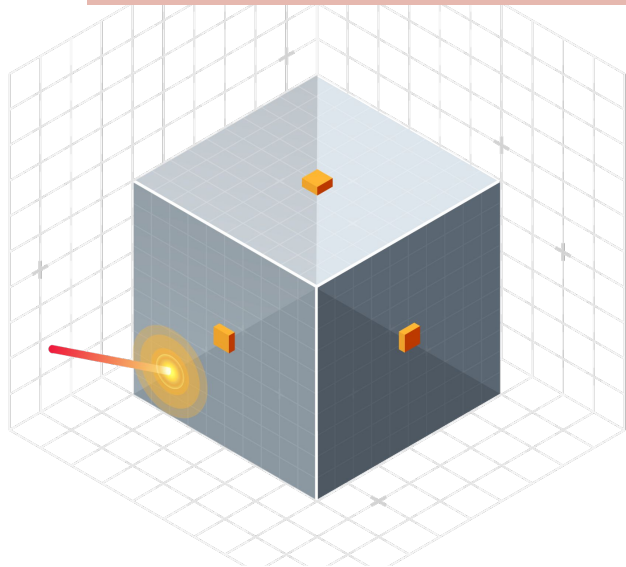
**Sensitive to fast-high energy phonons**

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



# OPOSSUM revolutionary detection technique

6 MKIDs on each  $\text{TeO}_2$  crystal for topological reconstruction

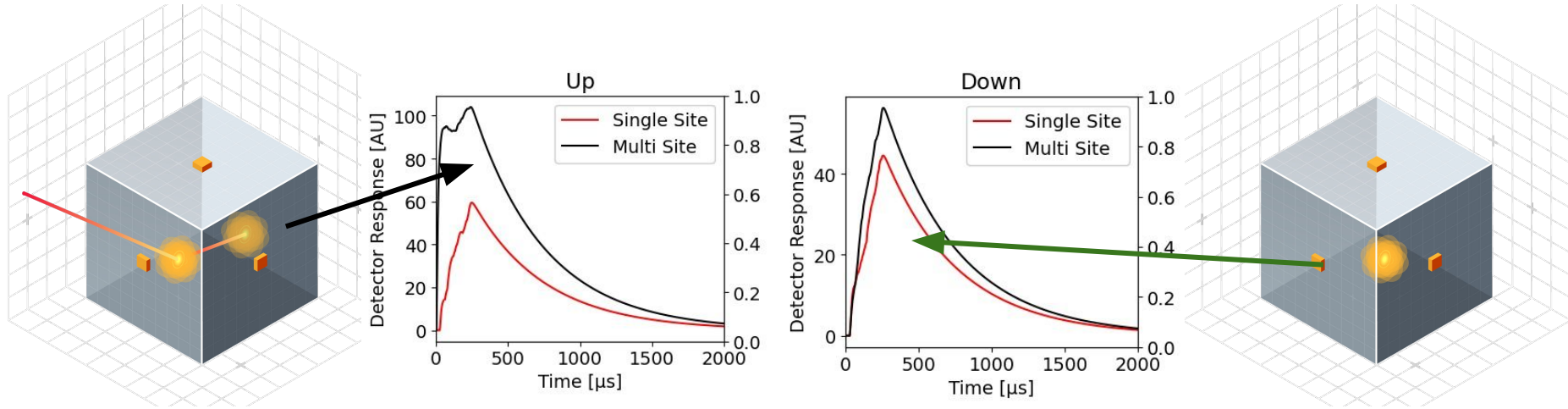


Simulated phonon signals  
in MKIDs on  $\text{TeO}_2$

- $3\sigma$  (99.97%) rejection rate of alpha surface events

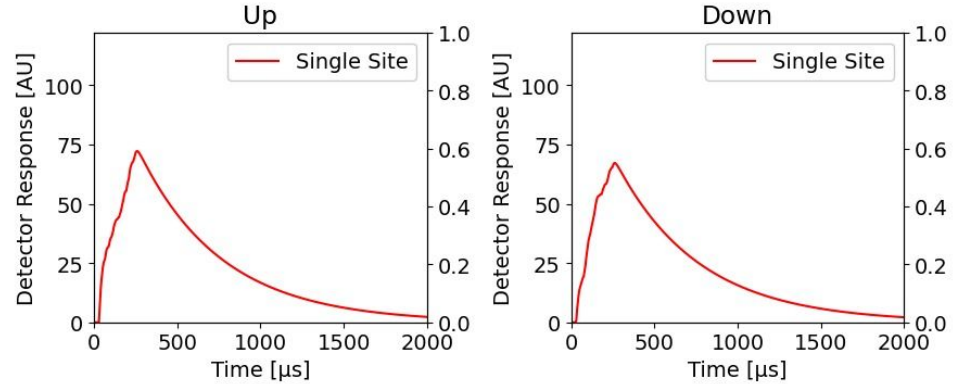
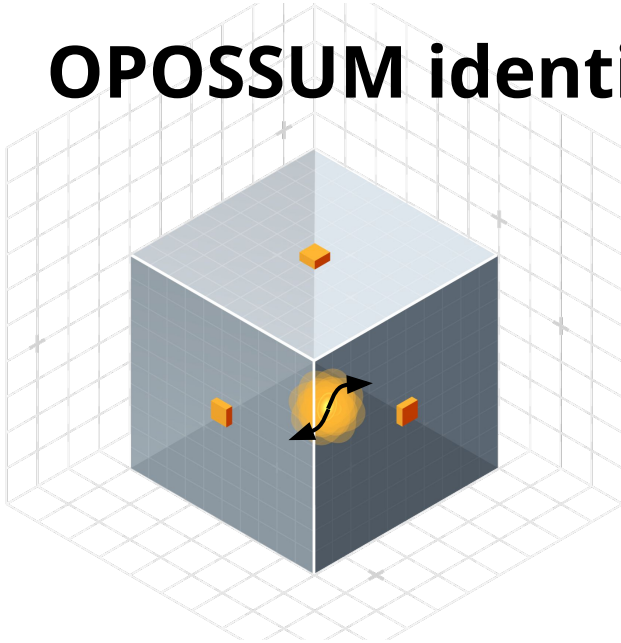
# OPOSSUM pioneers the topological ID

## Tagging of Multi Site Events with MKIDs



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

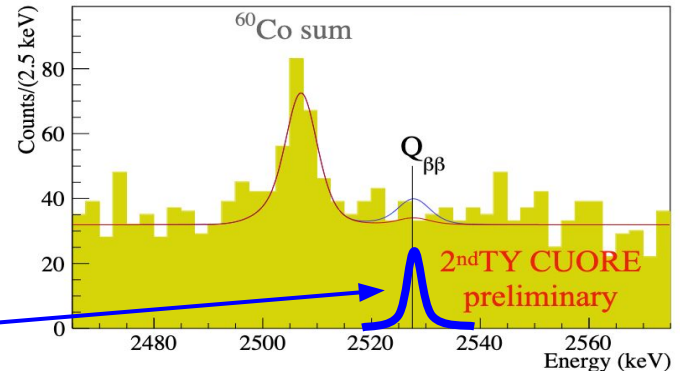
# OPOSSUM identifies the $0\nu\beta\beta$ events



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

Background reduction of two orders  
of magnitude  $\rightarrow$  **sensitivity increase of more than an  
order of magnitude**

**OPOSSUM has discovery potential!**

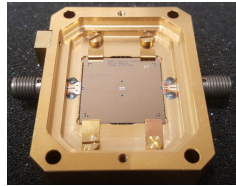


# OPOSSUM's plan

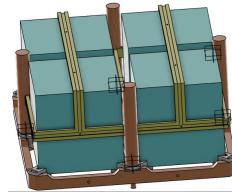
RF and cryo setup



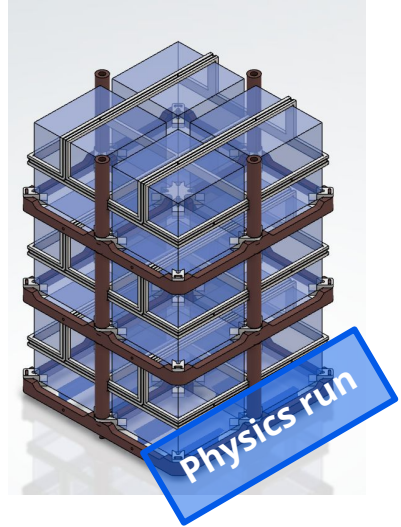
MKID  
Deposition  
on  $\text{TeO}_2$



$4 \times \text{TeO}_2$   
+  
MKIDs



**OPOSSUM**  
final array  
10 kg test



**$\text{TeO}_2$  CUORE crystals already available**

DR setup

MKIDs design on  $\text{TeO}_2$

$5 \times 5 \times 5 \text{ cm}^3 \text{ TeO}_2$  with MKIDs

Data analysis and background model

12  $\text{TeO}_2$  array with MKIDs: 10 kg\*y

1<sup>st</sup> year

2<sup>nd</sup> year

3<sup>rd</sup> year

4<sup>th</sup> year

5<sup>th</sup> year

# OPOSSUM's test facility at LNGS



*LETI* underground dilution refrigerator

- 8 mK base temperature, 300  $\mu$ W @100 mK
- RF readout lines (4-8 GHz and 0.2-3 GHz HEMT amplifier @ 4 K)
- 3 DC SQUIDS

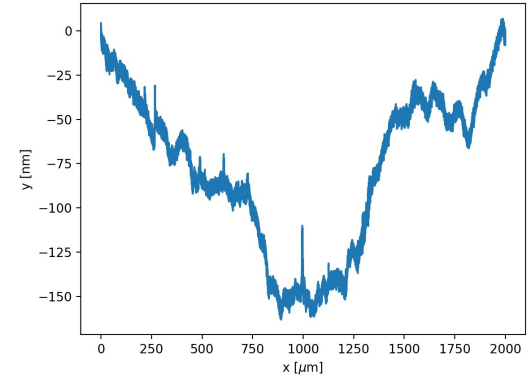
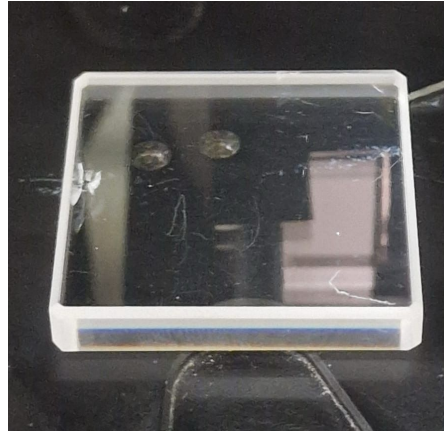
Two-stage spring decoupling stage  
Possibility to mount external shielding



# The challenge of Tellurium dioxide

Surface treatment before thin film deposition non-trivial

- New polishing techniques are being developed
- 100 nm could be acceptable
- Deposition tests ongoing

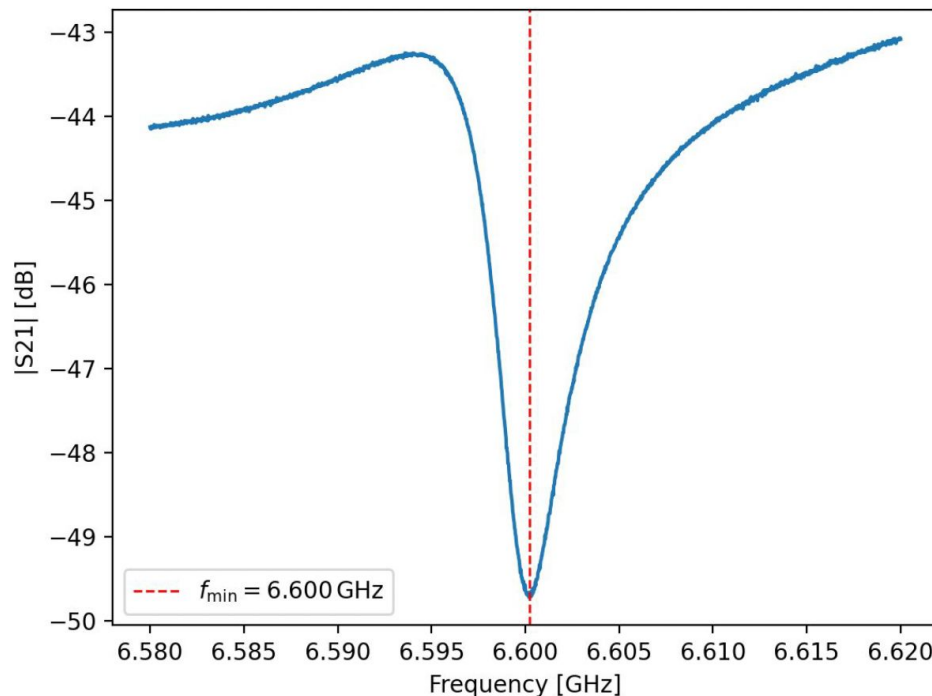


# OPOSSUM's first steps

First resonator design on  
Si-substrate

Tested at LNGS underground  
(IETI dilution refrigerator)

Characterization setup ready to  
start studying MKIDs on TeO<sub>2</sub>  
substrate

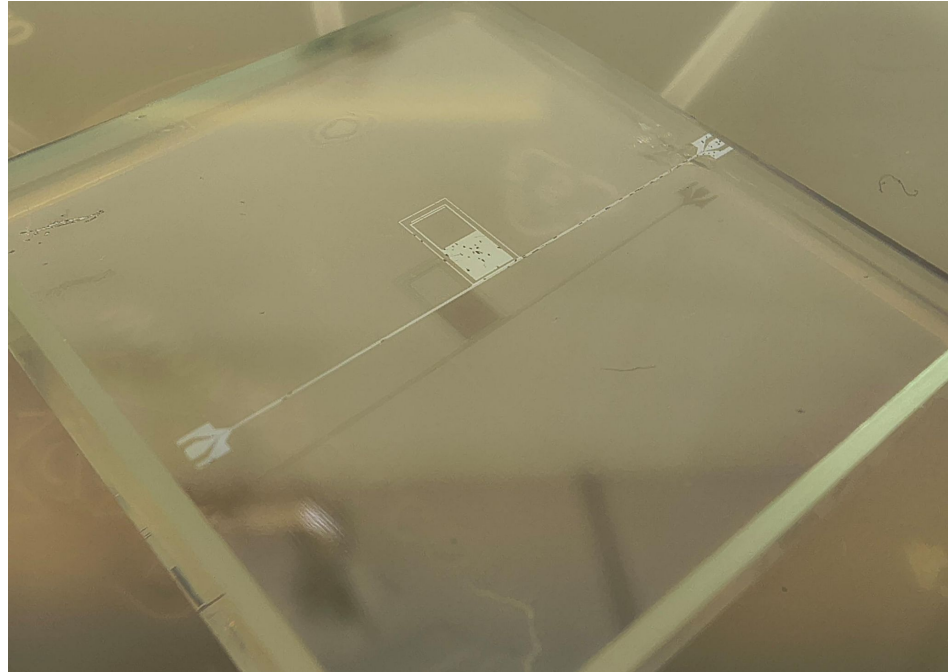


# OPOSSUM's first TE02 deposition

In collaboration with INRiM  
(Istituto Nazionale di Ricerche  
Metrologiche - Torino)

we have produced the first  
Al-film on TeO<sub>2</sub> crystal

To be tested at 10 mK at LNGS  
in September



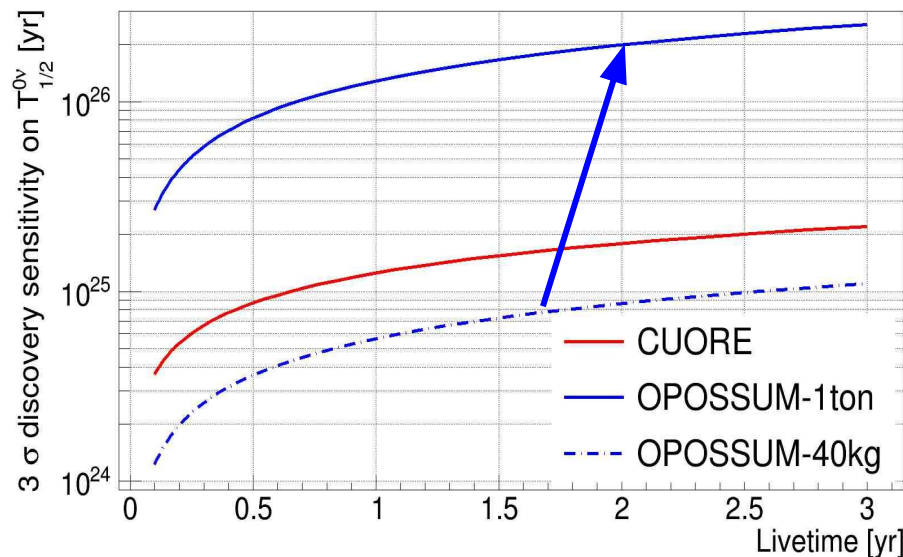
# OPOSSUM next development

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

## Discovery potential



If you are interested in collaborating with the  
OPOSSUM team, drop us a message:

[andrei.puiu@lngs.infn.it](mailto:andrei.puiu@lngs.infn.it)

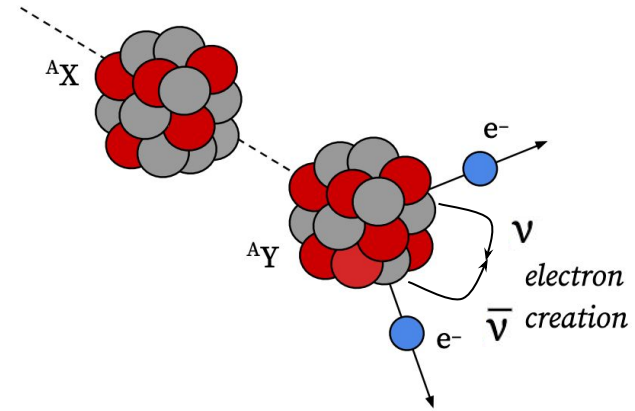
**We are hiring**



# 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  $0\nu\beta\beta$ , a fundamental process of nature



We just started developing the first superconductor film on TeO<sub>2</sub> crystals

