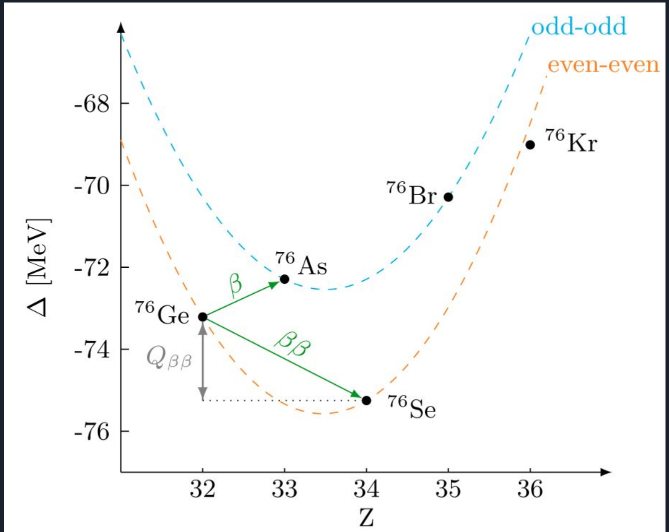
22th SEMINAR ON SOFTWARE FOR NUCLEAR, SUBNUCLEAR AND APPLIED PHYSICS

MANENTI Nicola

UNIVERSITÀ DI PAVIA

INFN
Istituto Nazionale di Fisica Nucleare

Neutrinoless double beta decay (0νββ)



Neutrinoless double-beta decay (0νββ) is a beyond Standard Model process :

1. $\bar{\nu} \equiv \nu$
   → Neutrino Nature as Majorana particle

2. (A, Z) → (A, Z+2) + 2e⁻
   → Leptogenesis (ΔL=2)

3. $T^{0\nu}_{1/2} \propto G^{0\nu} \cdot \left|M^{0\nu}\right|^2 \cdot \left(\frac{m_{\beta\beta}}{m_e}\right)^2$
   → Neutrino mass scaling and ordering

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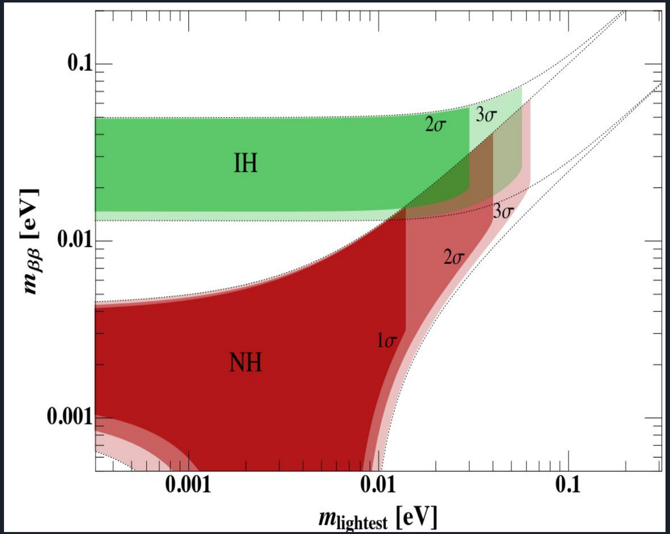

- $G^{0\nu}$ is the phase space factor
- $M^{0\nu}$ is the Nuclear Matrix Element
- $m_{\beta\beta}$ is the Majorana mass

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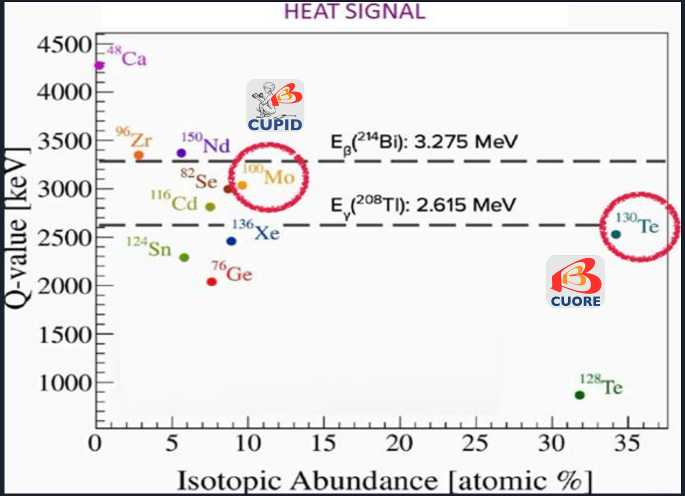
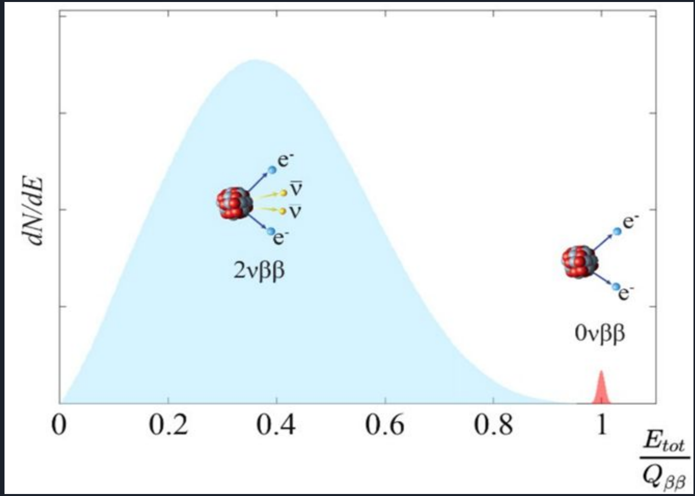
Neutrinoless double beta decay (0νββ)

Only the energy associated to the β particles can be reconstructed

- $Q_{\beta\beta}$ of few MeV
- 2νββ: continuous spectrum till $Q_{\beta\beta}$
- 0νββ: monoenergetic peak at $Q_{\beta\beta}$





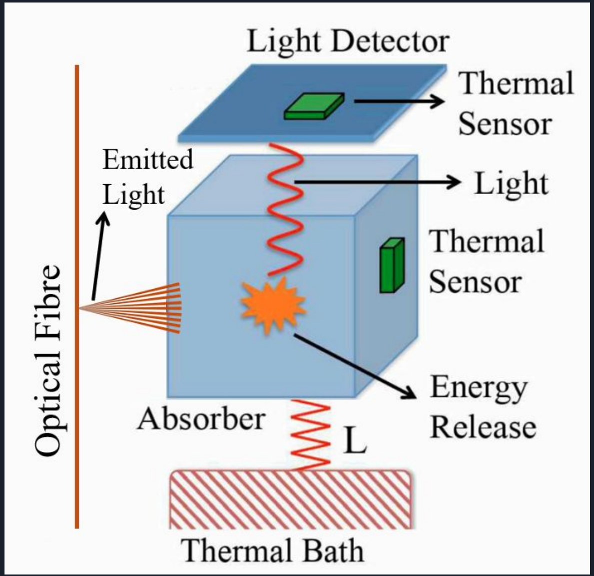
Typical Backgrounds

- End of natural γ-background
- Energy-degraded α particles
- Irreducible 2νββ background

The CUPID experiment

CUORE **U**pgraded with **P**article **ID**entification searches for the 0νββ decay of ^{100}Mo ($Q_{\beta\beta}$ = 3034 keV)

- Underground experiment (LNGS, Italy)
- Cryogenic temperatures *O*(10 mK)
- Bolometric technique
- Double readout of heat and light signal
- ~ 1600 crystals of 280g each



Light Injection System

A system capable to inject light pulses of a given wavelength to be absorbed by a group of LDs.

OUTSIDE THE CRYOSTAT

- **light source**
- **optical fibre with feedthrough**
- **diffusive fibre**

TO BOLOMETERS

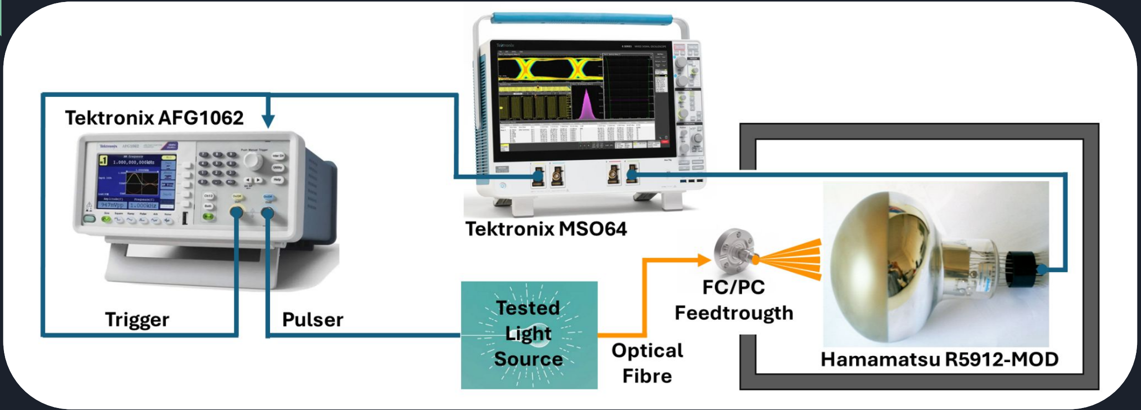
APPLICATIONS

- ➢ Pile-up ID efficiency monitoring
- ➢ LD periodic regeneration
- ➢ LD Stabilisation

REQUIREMENTS

- ➢ Multichannel
- ➢ Wavelength
- ➢ Pulse width
- ➢ Stable pulses
- ➢ Negligible impact on cryogenics
- ➢ Contribution to the background budget as small as possible
- ➢ DAQ interface

Feasibility Test at Pavia



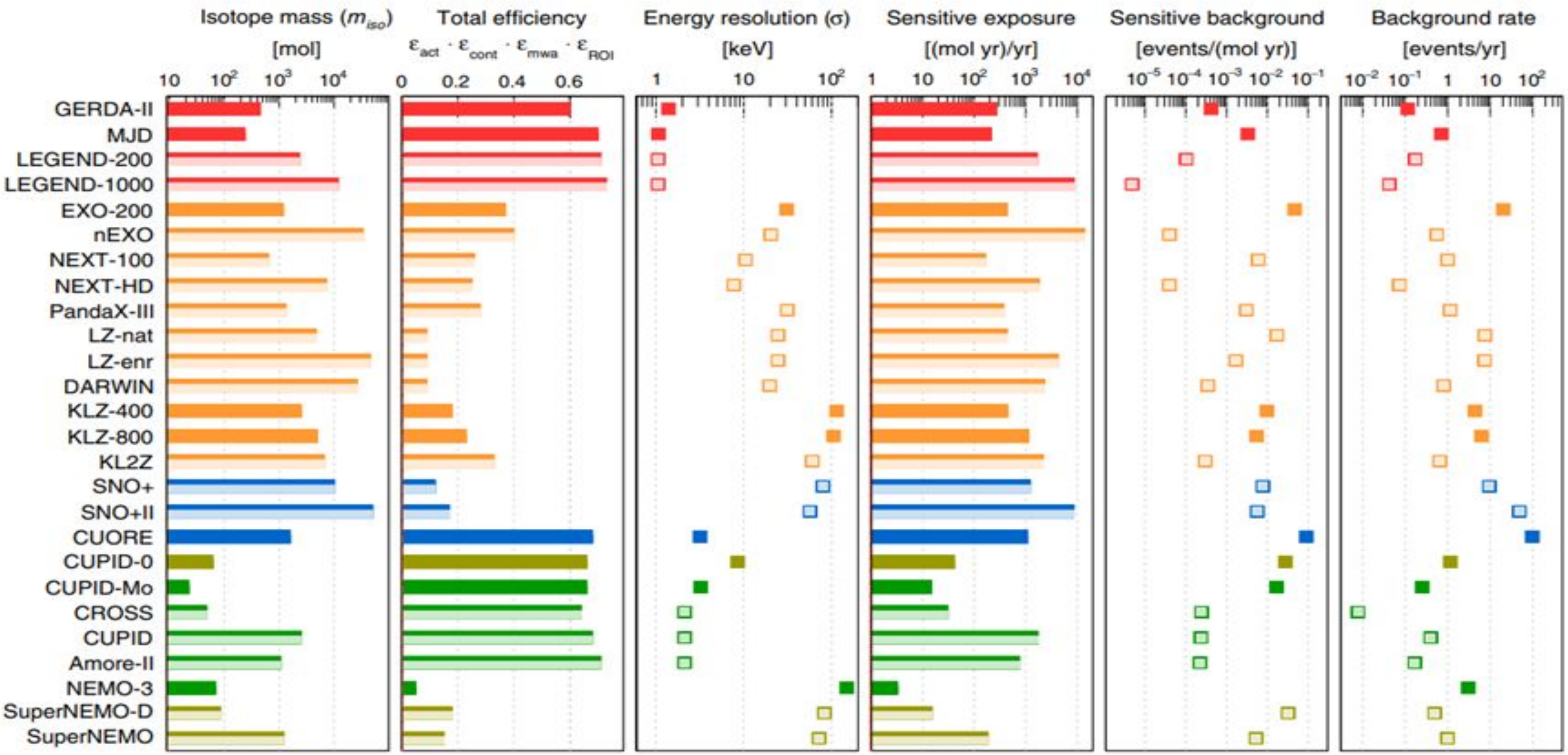
Several test possible with a simple setup:

- ➢ Thermal stress on the optical fibre (from room temperature down to 77K)
- ➢ Light source candidates
- ➢ Pulse generation mechanism
- ➢ Photo statistics

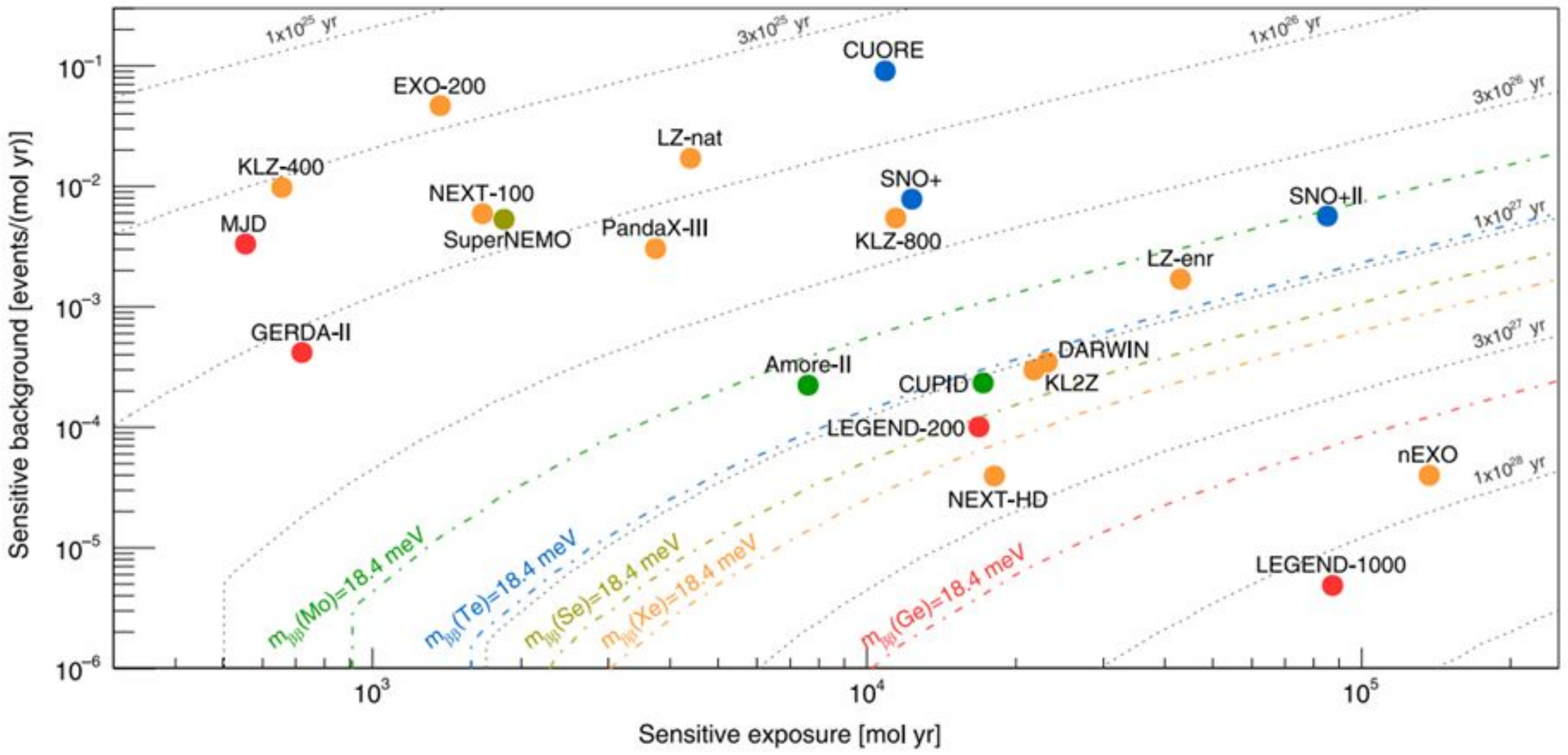
Validation test at LNGS with a single tower (28 crystals)

To Be Continued

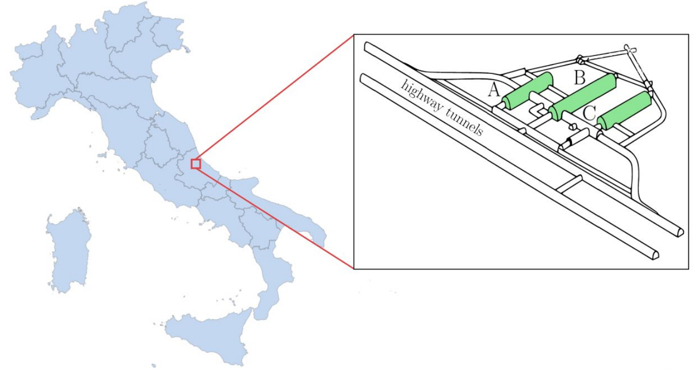
QUESTIONS ?



Isotope mass (m_{iso}) [mol]
Total efficiency $\varepsilon_{act} \cdot \varepsilon_{cont} \cdot \varepsilon_{mwa} \cdot \varepsilon_{ROI}$
Energy resolution (σ) [keV]
Sensitive exposure [(mol yr)/yr]
Sensitive background [events/(mol yr)]
Background rate [events/yr]
GERDA-II
MJD
LEGEND-200
LEGEND-1000
EXO-200
nEXO
NEXT-100
NEXT-HD
PandaX-III
LZ-nat
LZ-enr
DARWIN
KLZ-400
KLZ-800
KL2Z
SNO+
SNO+II
CUORE
CUPID-0
CUPID-Mo
CROSS
CUPID
Amore-II
NEMO-3
SuperNEMO-D
SuperNEMO



Sensitive background [events/(mol yr)]
Sensitive exposure [mol yr]
1x10^25 yr
3x10^25 yr
1x10^26 yr
3x10^26 yr
1x10^27 yr
3x10^27 yr
1x10^28 yr
CUORE
EXO-200
LZ-nat
KLZ-400
SNO+
NEXT-100
SNO+II
MJD
SuperNEMO
PandaX-III
KLZ-800
LZ-enr
GERDA-II
DARWIN
Amore-II
CUPID
KL2Z
LEGEND-200
nEXO
NEXT-HD
LEGEND-1000
mββ(Mo)=18.4 meV
mββ(Te)=18.4 meV
mββ(Se)=18.4 meV
mββ(Xe)=18.4 meV
mββ(Ge)=18.4 meV

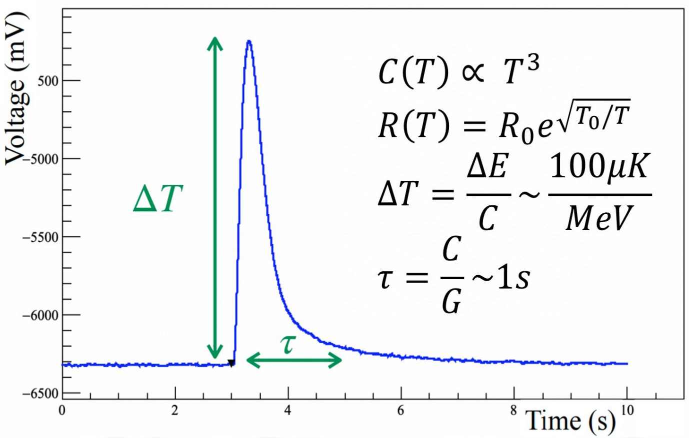


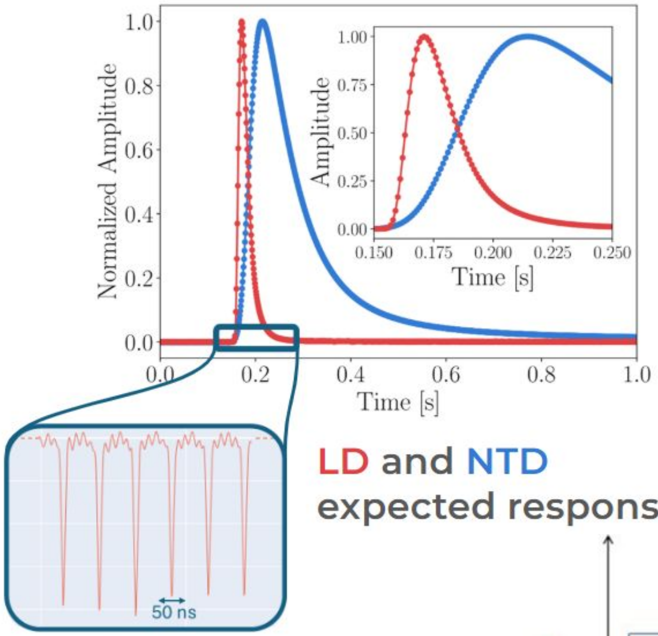
Average depth ~ 3600 m.w.e.

μ flux: 3×10^{-8} μ/s/cm^2

n flux: 4×10^{-6} n/s/cm^2 < 10 MeV

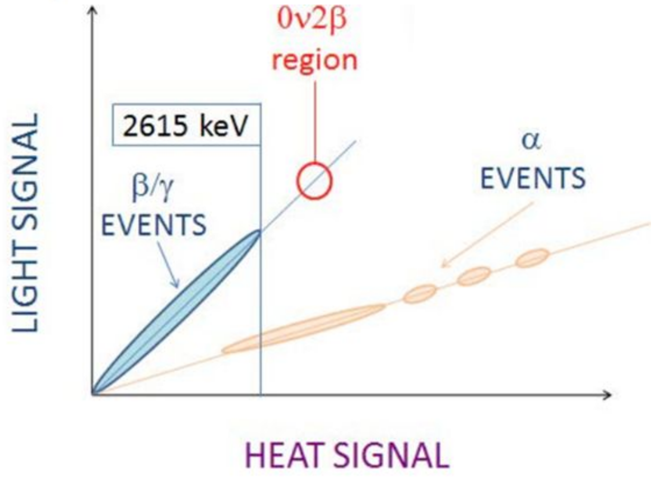
γ flux: ~0.73 γ/s/cm^2 < 3 MeV

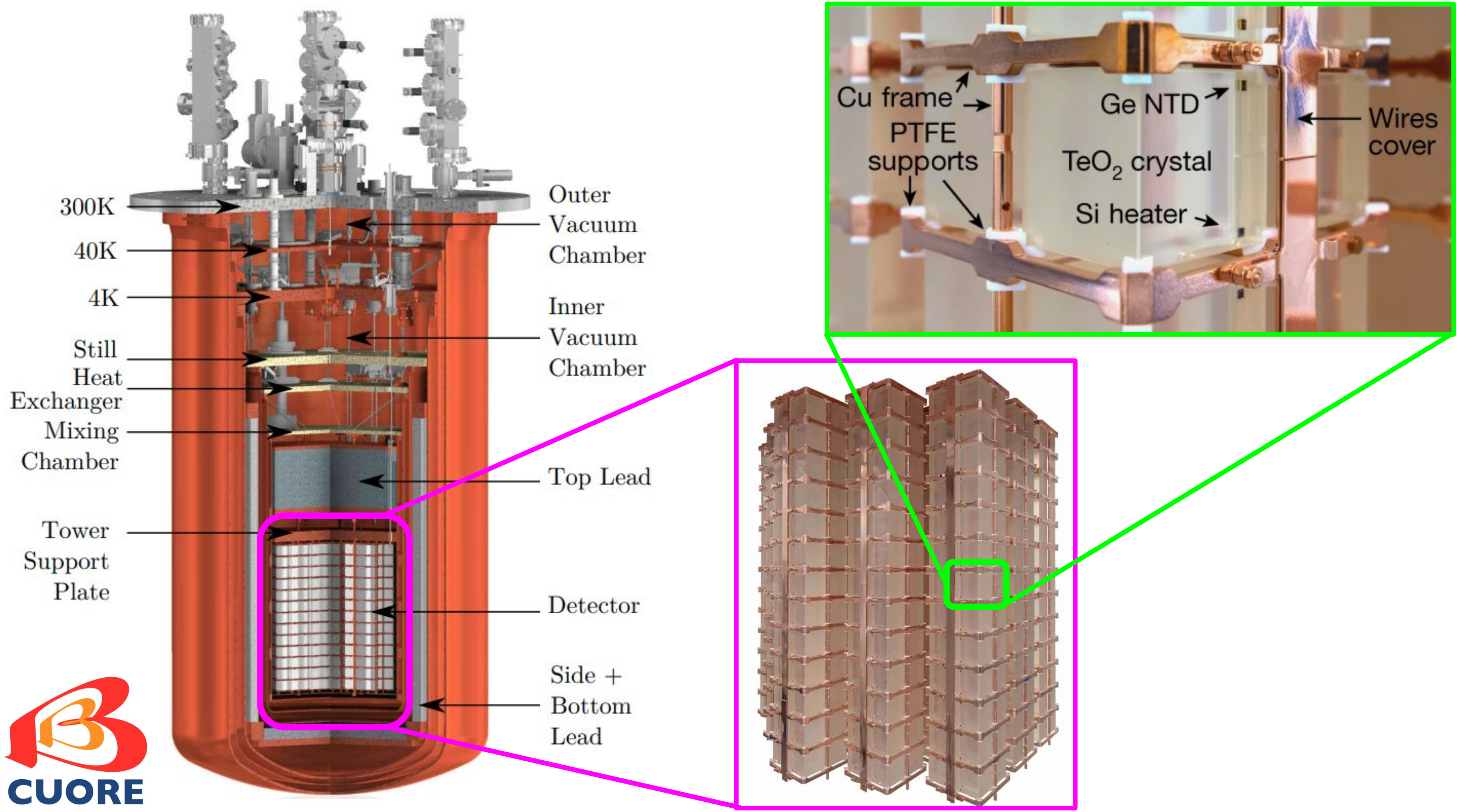




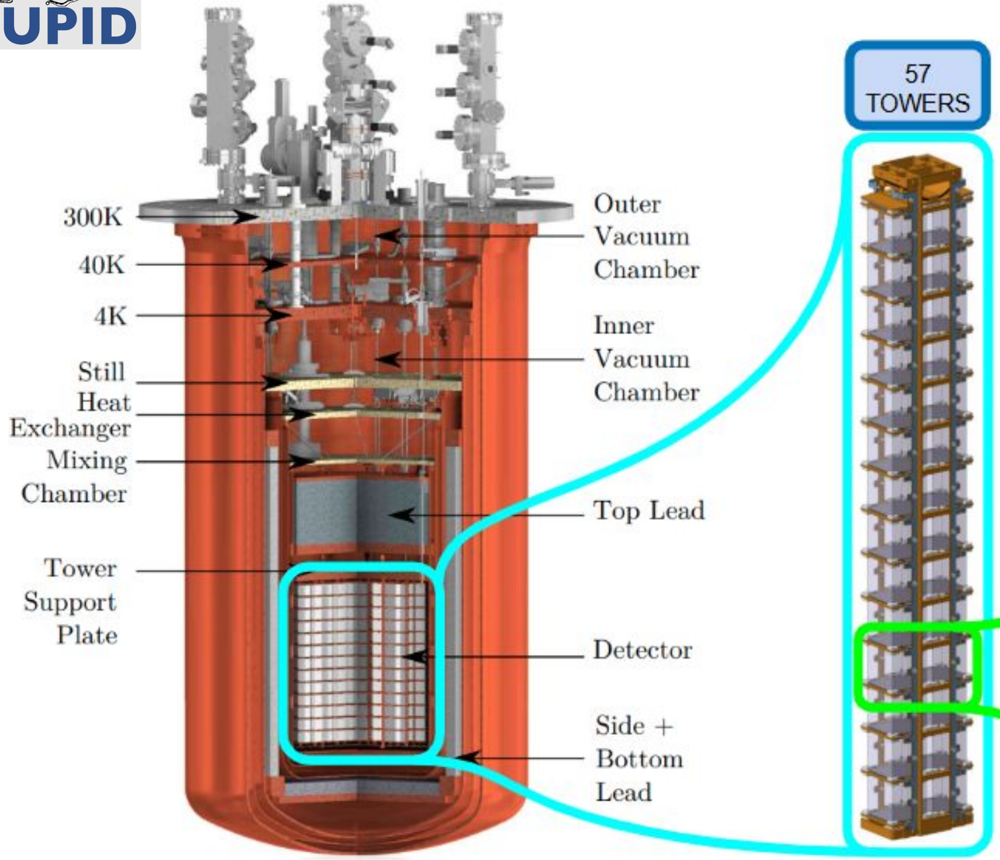
LD and NTD expected response

PMT Train of Pulses




300K
40K
4K
Still
Heat
Exchanger
Mixing
Chamber
Tower
Support
Plate
Outer
Vacuum
Chamber
Inner
Vacuum
Chamber
Top Lead
Detector
Side +
Bottom
Lead
Cu frame
PTFE
supports
Ge NTD
TeO2 crystal
Si heater
Wires
cover
CUORE

- **45×45×45 mm³ $Li_2{}^{100}MoO_4$ crystals:**
  - Single crystal mass: 280 g
- **1596 crystals in the array**
  - 450 kg of $Li_2{}^{100}MoO_4$
  - 95% enrichment in ^{100}Mo: 240 kg of ^{100}Mo
  - 57 towers of 28 crystals each. 14-floors of 2×1 crystal pairs. Gravity assisted design
- **Ge light detectors (LD) with SiO anti-reflective coating.**
  - Top and bottom light detectors for each crystal: 1710 light detectors
  - No reflective foils
- **CUPID performance goal**
  - Energy resolution: 5 keV FWHM
  - Light Yield: 0.3 keV/MeV
  - LD: $\sigma_{baseline}$ ~100 eV for PID
  - Background: 10^{-4} ckky (counts/keV/kg/y)



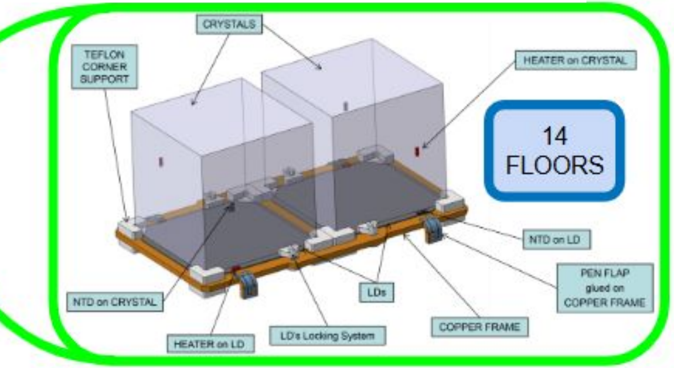
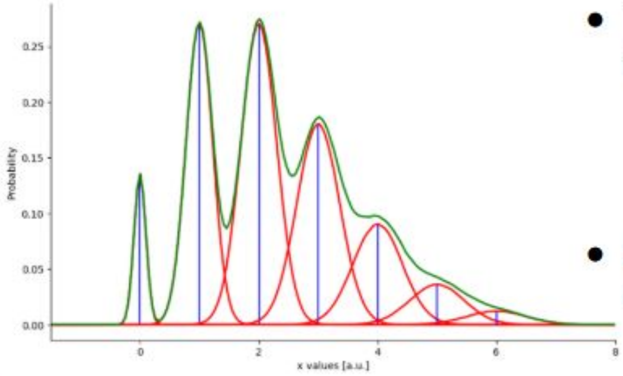


PHOTO STATISTICS

Given Θ as the expected number of photons emitted by the fibre, the observed number of photons (θ) is expected to follow a Poissonian distribution.

$$\frac{[Mean\,(\theta)]^2}{Var\,(\theta)} = \frac{[\Theta]^2}{\Theta}$$

IF the photons have also the same known wavelength, energy calibration can be achieved by measuring the value of Θ



HOWEVER

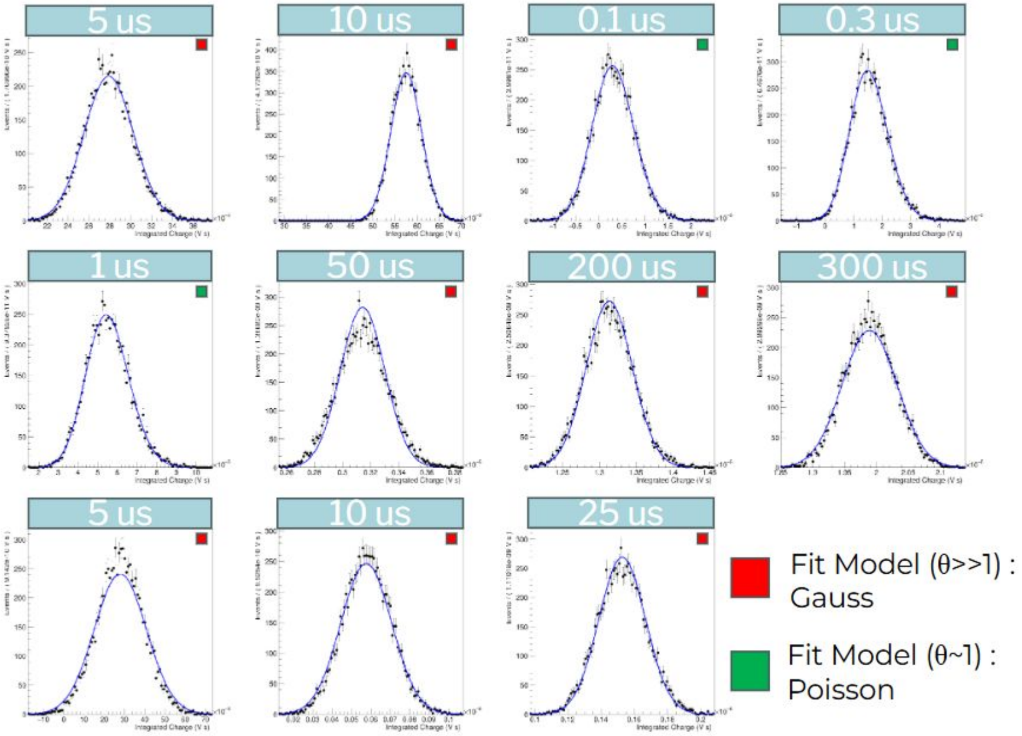
- The real measurable quantity X is proportional to θ through the intrinsic gain (G)

$$\Theta = \frac{Mean\,(X)}{G} \rightarrow \frac{[Mean\,(X)]^2}{Var\,(X)} = \frac{[G\Theta]^2}{G^2\Theta}$$

- Additional shift an smearing in the Poissonian distribution of θ due to the detector response

$$Var\,(\theta) = \sigma^2_{NOISE} + \left(G^2 + \sigma^2_{DET}\right)\Theta$$

SO... the Poissonian term, in the variance, is no longer the only one linear in Θ
➜ the reconstruct value of Θ can be an underestimate



Combined Fit Strategy

To resolve the single contributions to the variance with a fine (Poissonian limit) and gross (Gaussian limit) fit simultaneously.

➜ fine fit: gives access to parameters like σ^2_{NOISE} and G but lacks in probing σ^2_{DET}

➜ gross fit: can reveal $(G^2 + \sigma^2_{DET})$ but lacks in evaluating others