Optical Injection System feasibility study for CUPID

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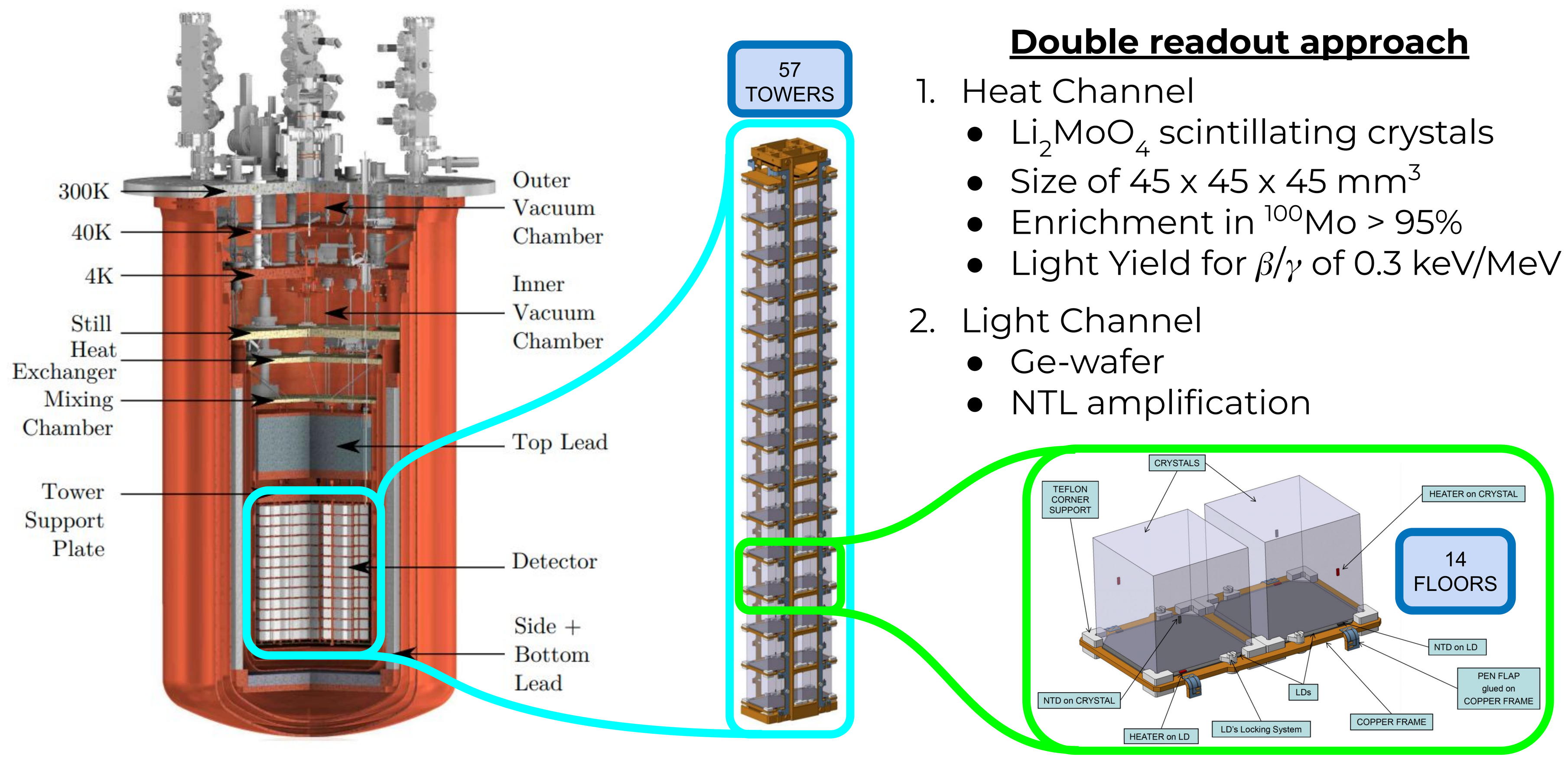
1. THE CUPID EXPERIMENT

CUORE **U**pgraded with **P**article **ID**entification is a next-generation experiment, whose main search is the 0νββ decay of ^{100}Mo ($Q_{\beta\beta}$ = 3034 keV)

- Underground experiment (LNGS, Italy)
- Bolometric technique
- Double readout of heat and light signal
- 1596 crystals of 280g each

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

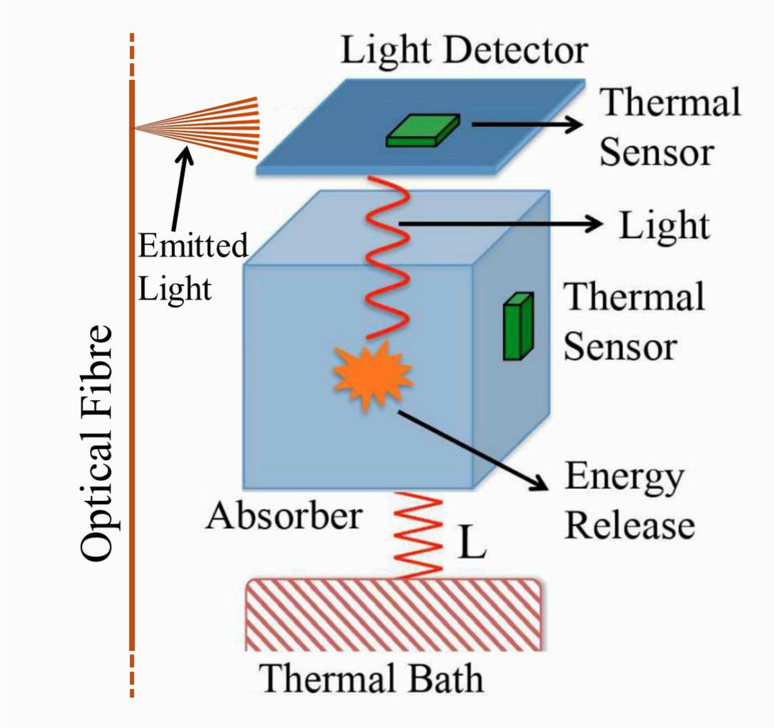


Double readout approach

1. Heat Channel
   - Li_2MoO_4 scintillating crystals
   - Size of 45 x 45 x 45 mm^3
   - Enrichment in ^{100}Mo > 95%
   - Light Yield for β/γ of 0.3 keV/MeV
2. Light Channel
   - Ge-wafer
   - NTL amplification

2. THE 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

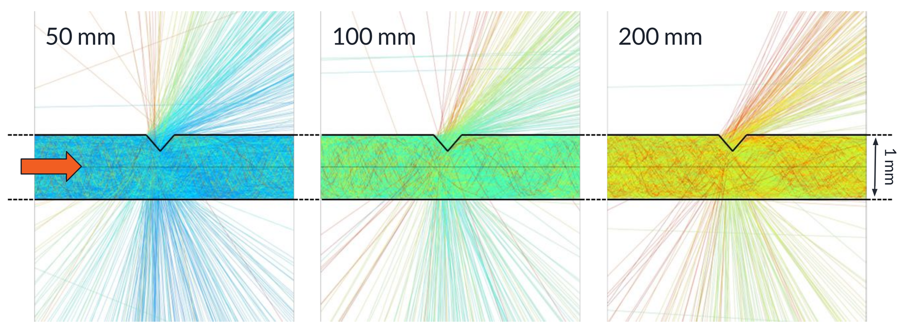
optical fibre with feedthrough

diffusive fibre

TO BOLOMETERS

Applications

- ➤ Pile-up ID efficiency monitoring
- ➤ LD periodic regeneration
- ➤ LD stabilisation
- ➤ Energy calibration (?)



Requirements

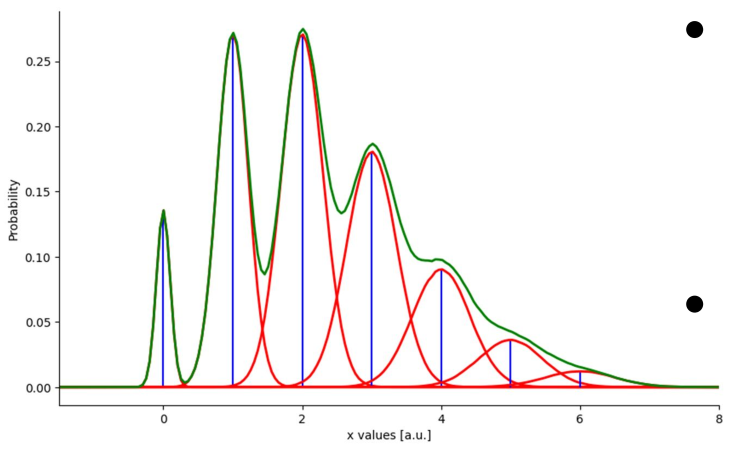
- ➤ Multichannel
- ➤ Wavelength
- ➤ Pulse width
- ➤ Stable pulses
- ➤ Negligible impact on cryogenics
- ➤ Contribution to the background budget as small as possible
- ➤ DAQ interface

3. PHOTON STATISTICS

Given Θ as the expected number of monoenergetic 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 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)

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

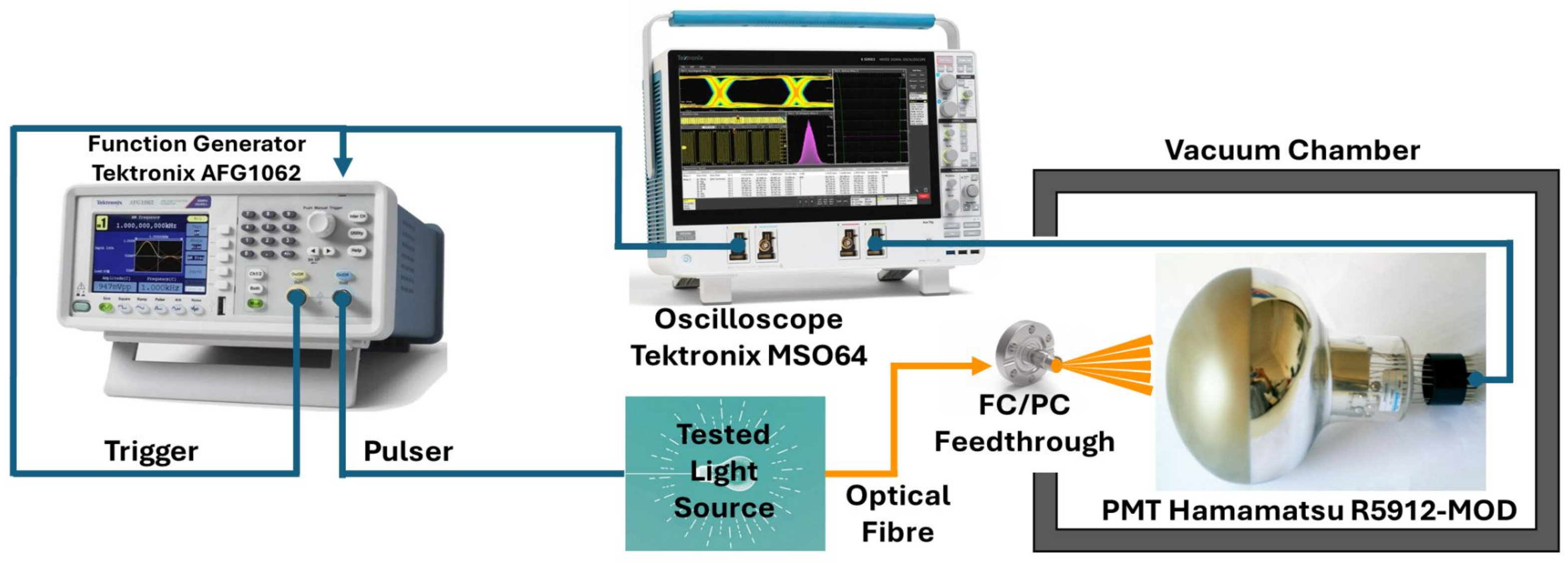
- Additional shift an smearing in the Poissonian distribution of θ due to the detector response

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

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

4. TEST WITH PMT IN PAVIA

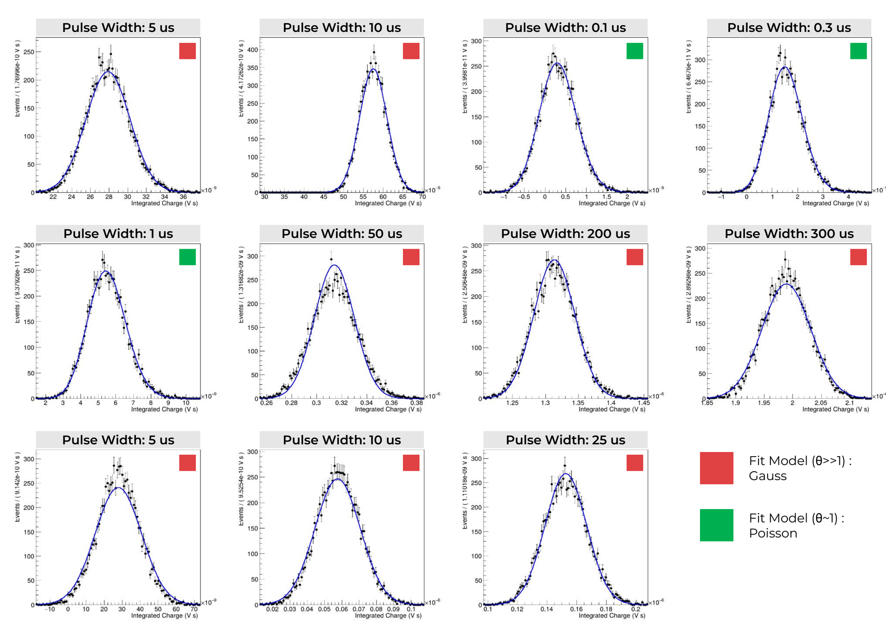
Dedicated setup in Pavia with a Photomultiplier tube as light detector:
→ the gain of the PMT can be measured separately



Several tests are possible with a simple setup:

- thermal stress on the optical fibre (from room temperature down to 77K)
- light source candidates
- pulse generation mechanism
- photon statistics

supported by a wide range of literature on this topics.



Combined Fit Strategy

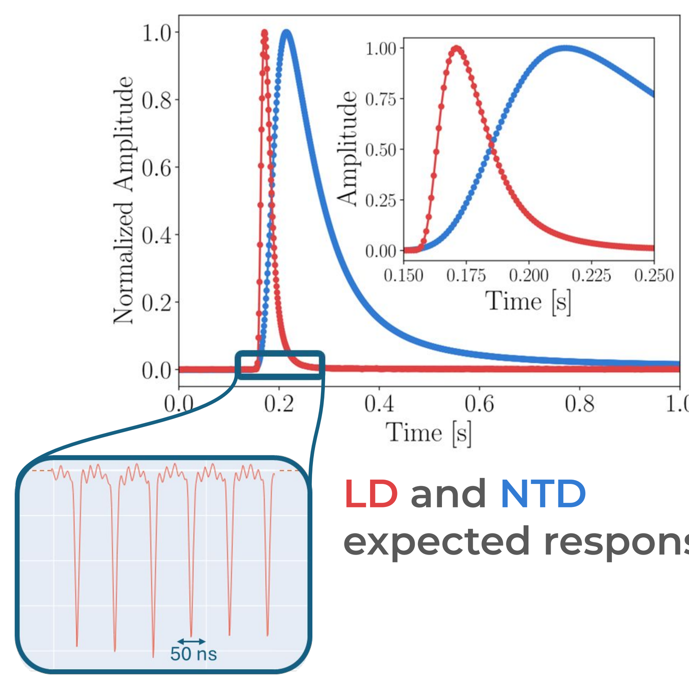
To resolve the single contributions to the variance with a fine (Poissonian limit) and gross (Gaussian limit) fit simultaneously.

→ fine fit: gives access to parameters like σ^2_{NOISE} and G. Not conclusive in probing σ^2_{DET}.

→ gross fit: can reveal $(G^2 + \sigma^2_{DET})$ but lacks in evaluating others. Needed to probe higher order contribution to the variance.

Train of Pulses

The pulse width and the pulse area, i.e. Θ, are not necessary linear.
→ constructing a longer pulse by sub sequencing identical pulses can correct such deviation
→ the detector is blind to the single pulses and see the train as a whole



LD and NTD expected response

PMT Train of Pulses

Works in progress

- notches on the fiber to direct the light onto the detectors
- constraints on the materials requirements for the system
- thermal stress on the optical fibre (down to 77K)
  → near-future validation with the test of a single CUPID tower

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