Cryogenic, UV light detectors in the GERDA experiment,

GERDA - Phase II

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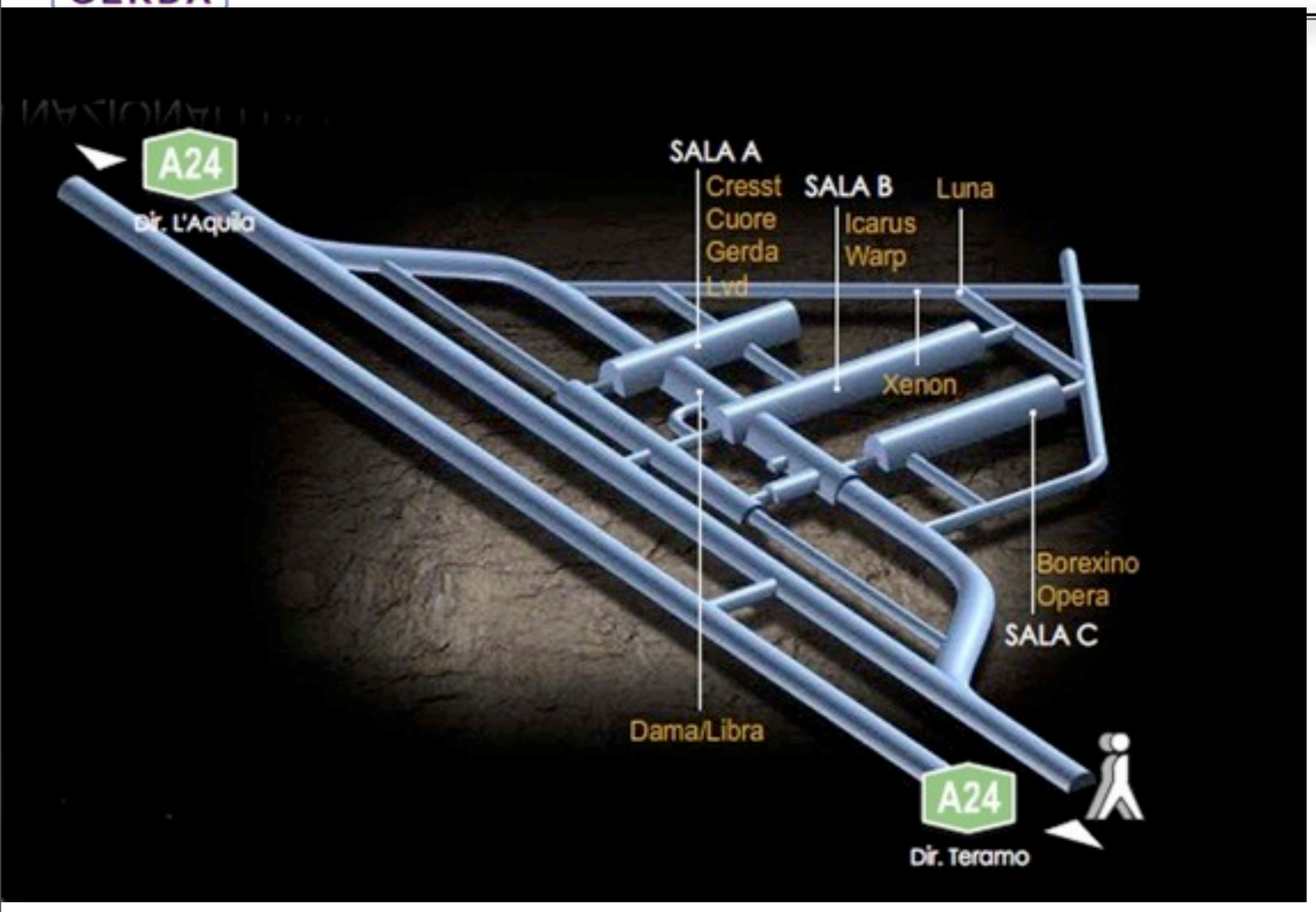
GERDA at Gran Sasso



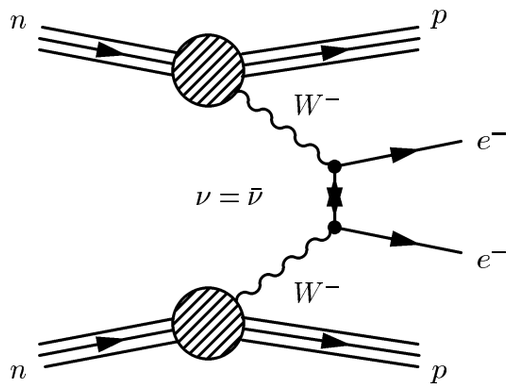
INFN - LNGS underground lab.
3800 m w.e. overburden

Home of many Dark Matter and Double Beta Decay experiments

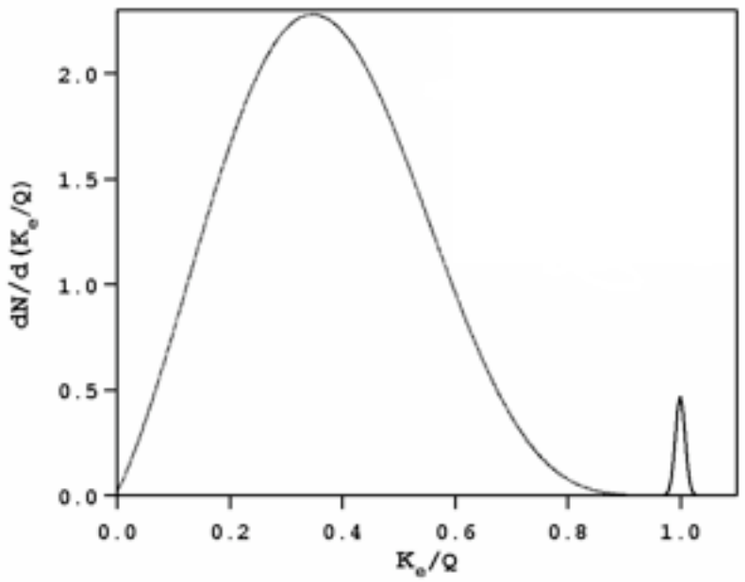
GERDA infrastructure:

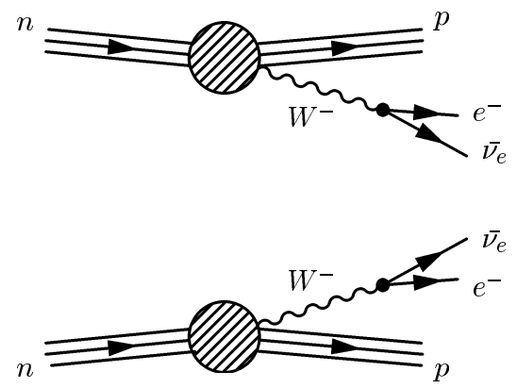
- 590 m^3 water tank,
- 64 m^3 LAr cryostat

0νββ decay



2β decay with 2 neutrinos





2β decay with 0 neutrinos

$(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$

allowed and observed

$(A,Z) \rightarrow (A,Z+2) + 2e^-$

violates lepton number conservation

$$\left(T^{0\nu}_{1/2}\right)^{-1} = F^{0\nu} \cdot \left|\mathcal{M}^{0\nu}\right|^2 \cdot m^2_{\beta\beta}$$

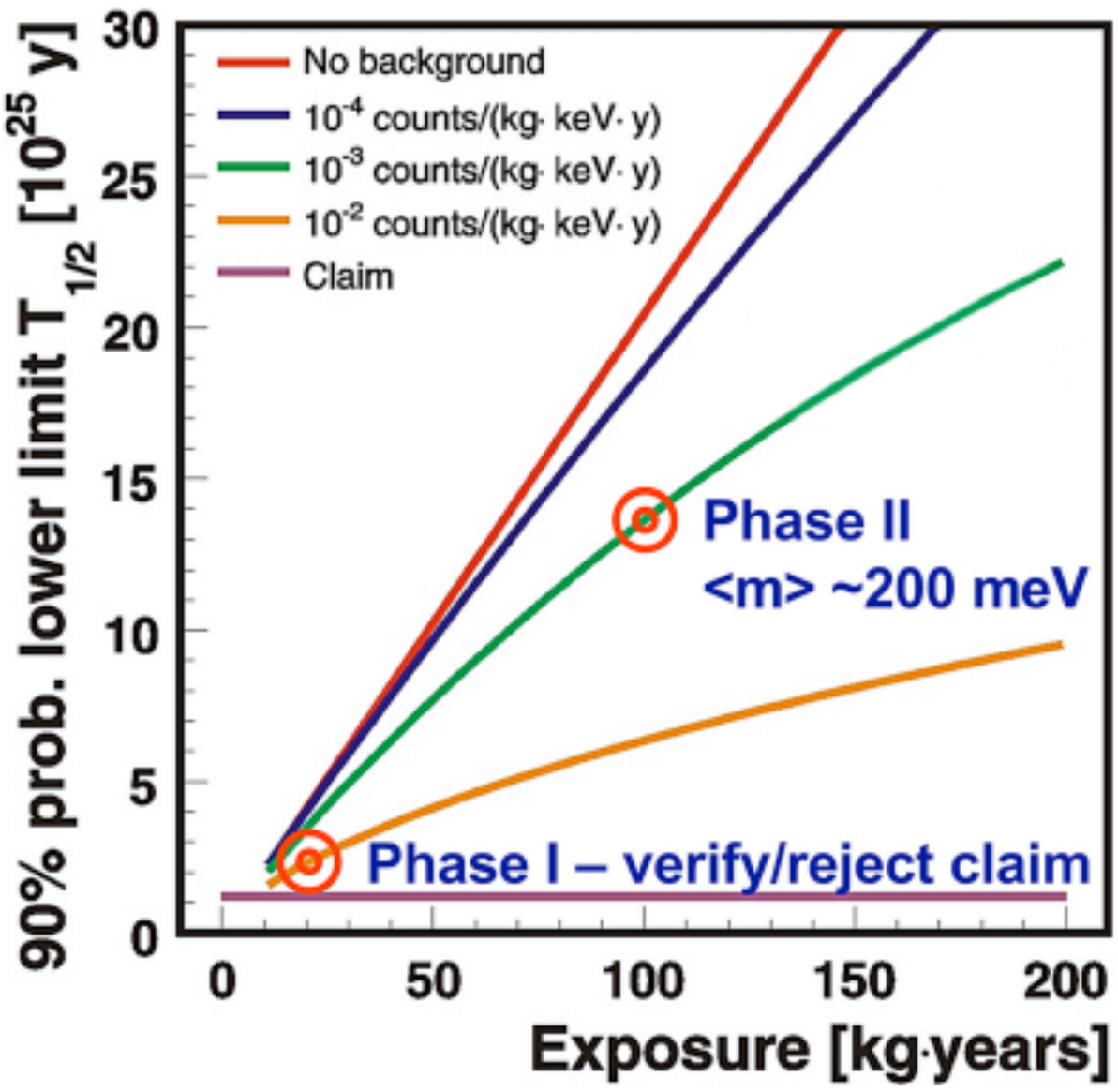
$$\langle m_{\beta\beta} \rangle^2 = \left|\sum_i U^2_{ei} m_{\nu i}\right|^2$$

$M^{0\nu}$ - nuclear matrix element

$F^{0\nu}$ - phase space integral depends on the Q value

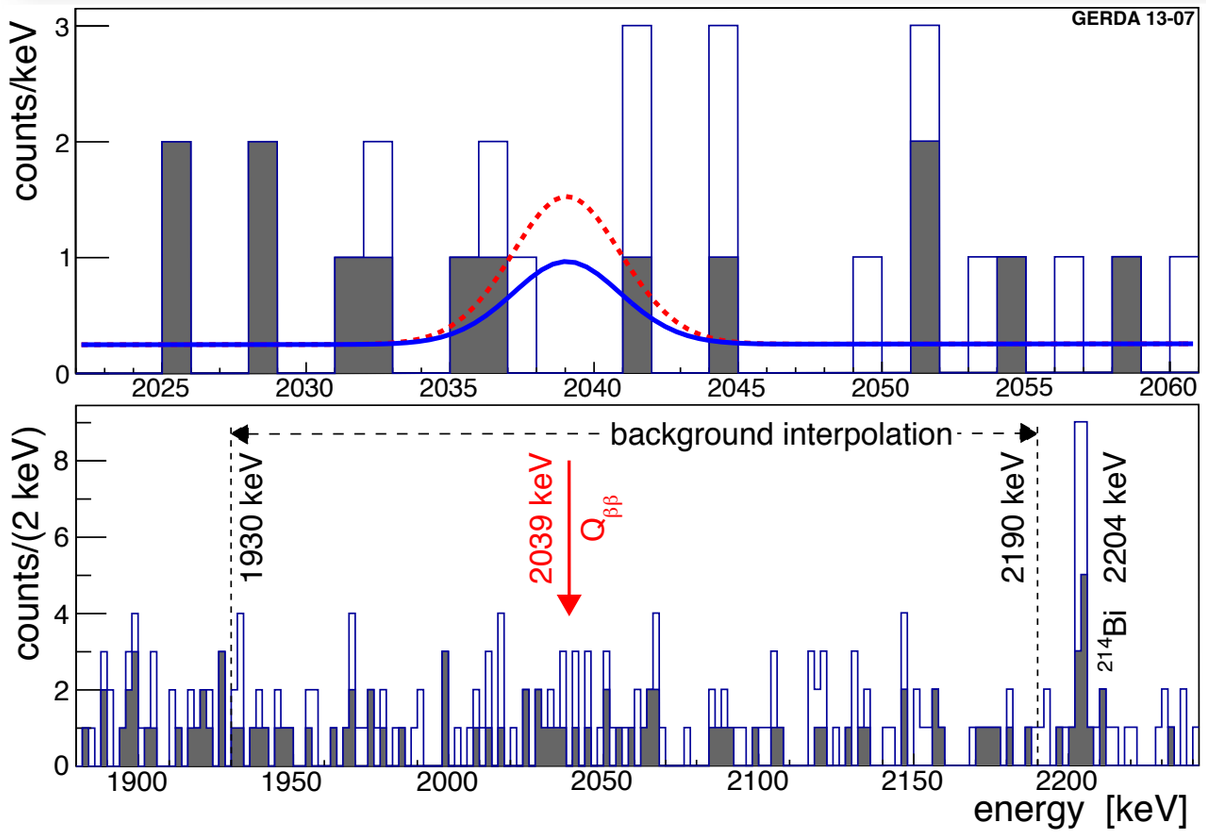
$\langle m_{\beta\beta} \rangle$ - effective neutrino mass

GERDA status



- *Goal of Phase I*: Re-deploy HdM and IGEX detectors (18 kg) in LAr with a background of 0.01 cts/(keV kg yr), scrutinize the claim
- *Status of Phase I*: data taking ended with 21.6 kg · y exposure: from Nov. 2011 to May 2013
- *Goal of Phase II*: background level of 0.001 cts/(keV kg yr) and 100 kg yr exposure
- *Status of Phase II*: under construction: 30 new HPGe detectors (~20 kg) are ready to be deployed

GERDA results



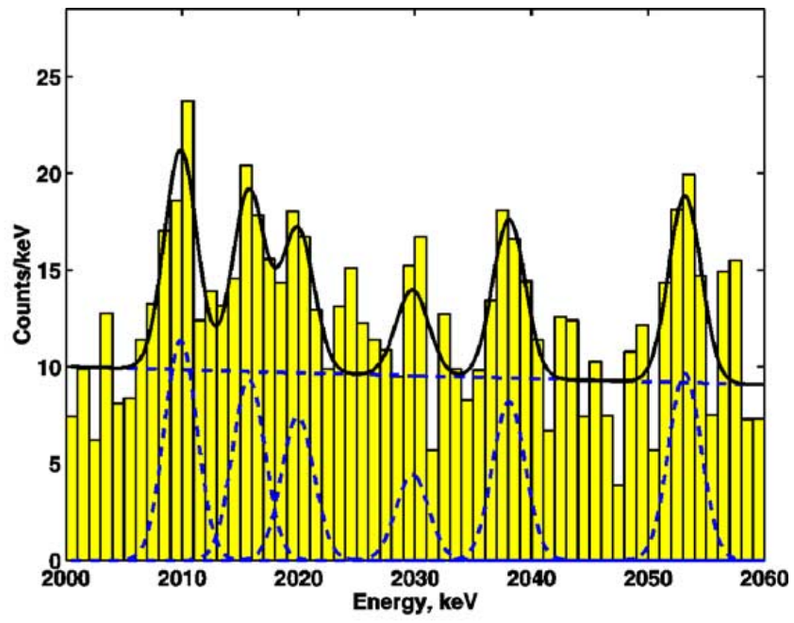
In 2039 ±5 keV we see 7 counts, after PSD only 3 remain:

$T^{0\nu}_{1/2} > 2.1 \times 10^{25}$ yr (90% C.L.)

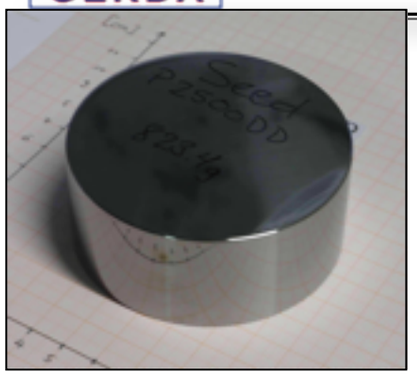
Phys. Rev. Lett. **111**, 122503 (2013)

From *H.V. Klapdor-Kleingrothaus et al. Physics Letters B 586 (2004)* we expect to see 6 signal events

Previous claim discarded



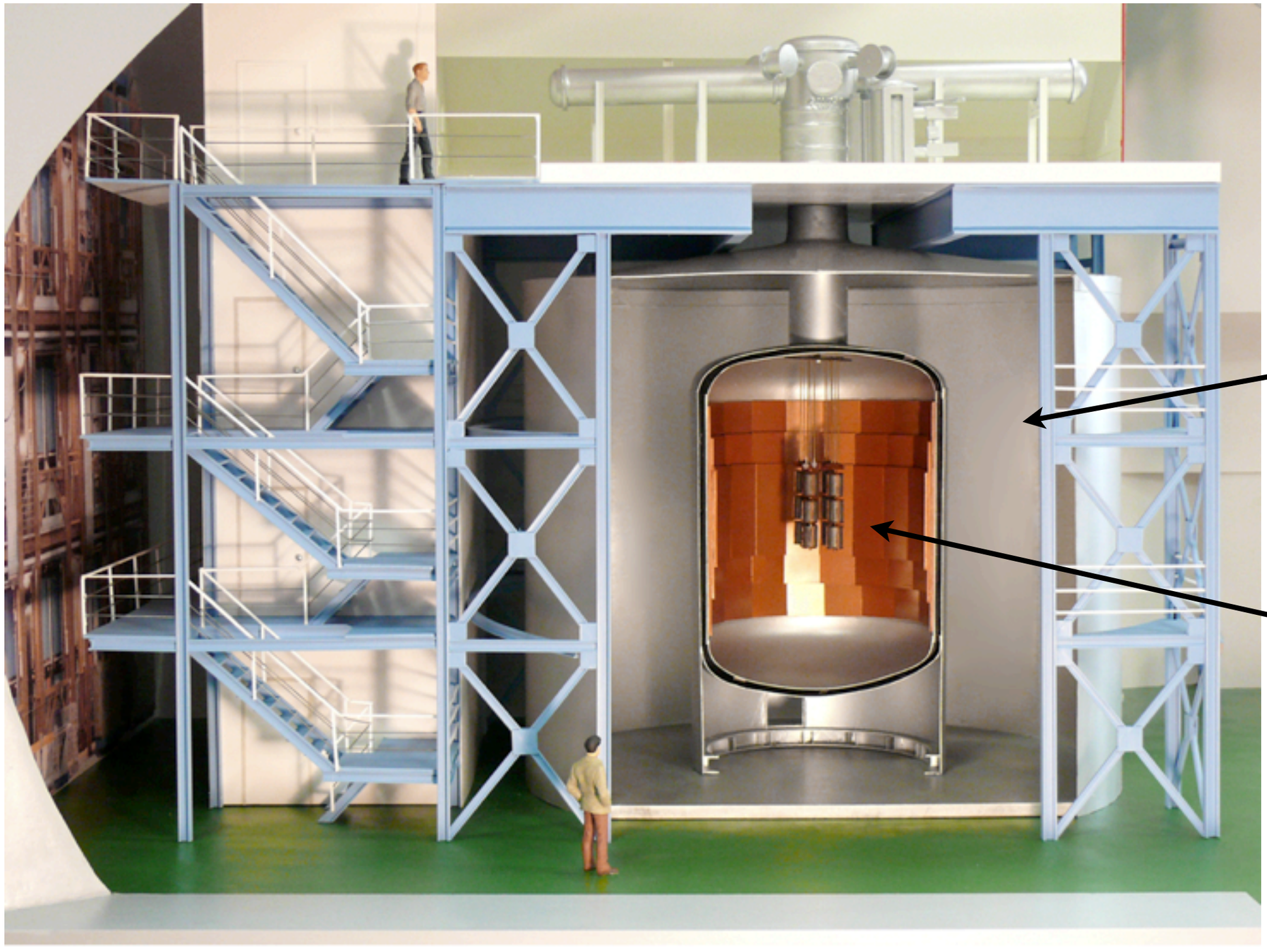
Phase II = Upgrade



$$T_{1/2}^{0\nu} \simeq \sqrt{\frac{M \cdot t}{B \cdot \Delta E}} \quad [yr]$$

- ***More mass:*** From the available 37.5 kg enriched germanium 30 new detectors were produced (~20 kg)
  - 5 of the new BEGe detectors already deployed in Phase I.
- ***Lower background:*** the goal is 10x lower background
  - New detector holders and new FE electronics
  - 'BEGe' detectors for better Pulse Shape Analysis
  - New lock was built to accommodate the LAr veto with PMTs and WLS fibers

Light Detectors in GERDA



Plastic scintillator panels muon veto

Water-Cherenkov muon Veto

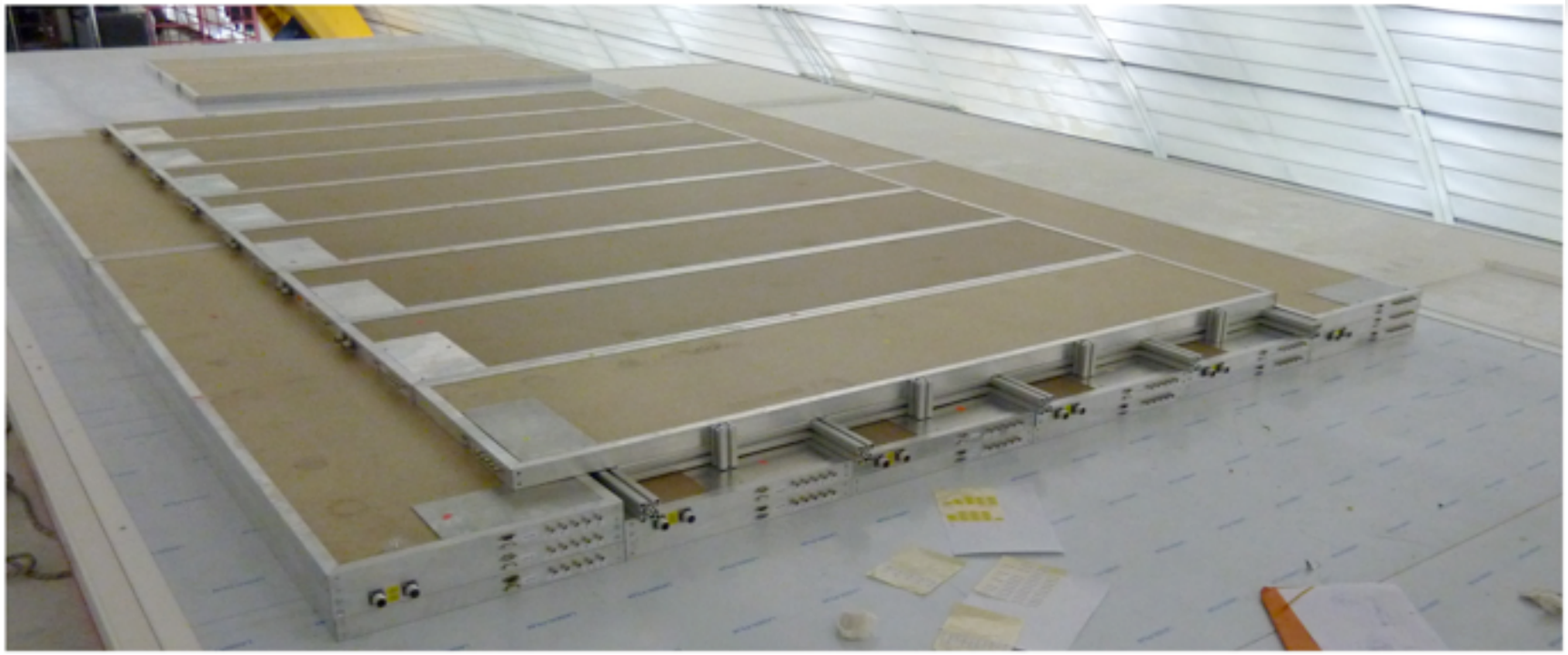
LAr veto

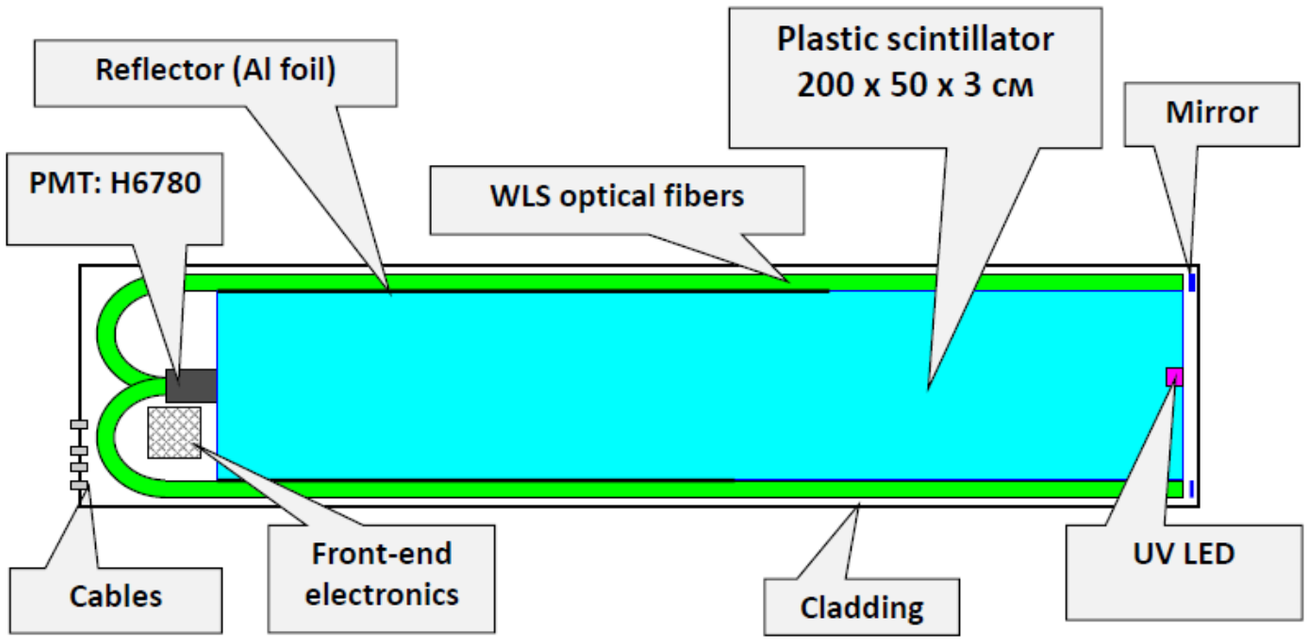
Photo-Sensors in GERDA

- *Plastic scintillator - PMT: 36, PMT-085 / HM-6780*
- *Water-Cherenkov - PMT: 66, 8” ETL 9350KB / ETL 9354KB*
- *LAr-Veto PMTs: 16, 3” Hamamatsu R11065, low background PMTs*
- *LAr-Veto SiPMs: 90, 3x3 mm Ketek, 50µ, 100µ pixel SiPMs*
- *LArGe - PMTs 9, 8”, ETL 9357 cryogenic*
- *+ many spares, many R&D projects*

Total: > 127 PMTs, > 90 SiPMs

Muon veto





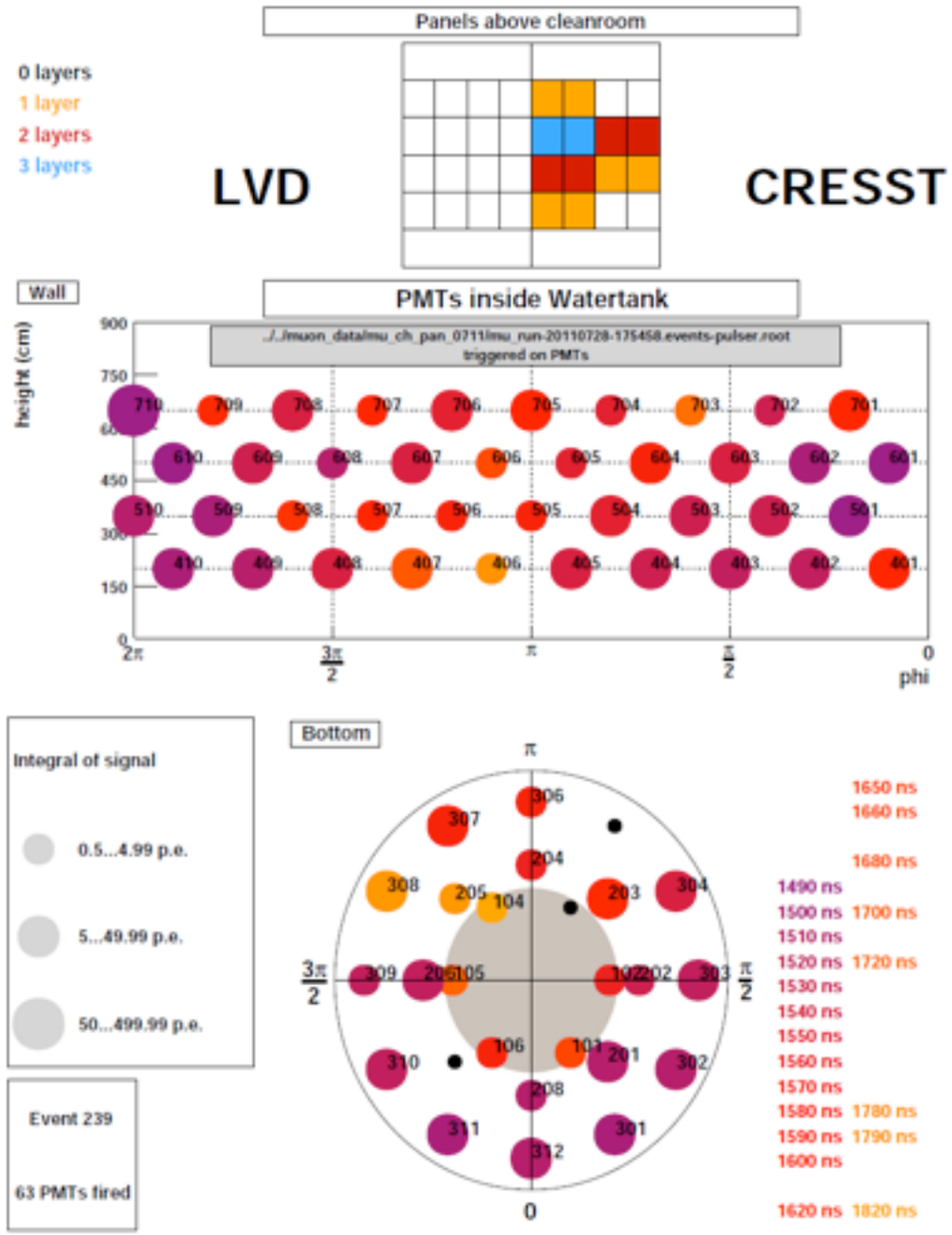
- *200x50x3 cm³ plastic scintillator*
- *PMT: PMT-085 / HM-6780 , 36 piece*
- *36 panels in a 3 layer stack*

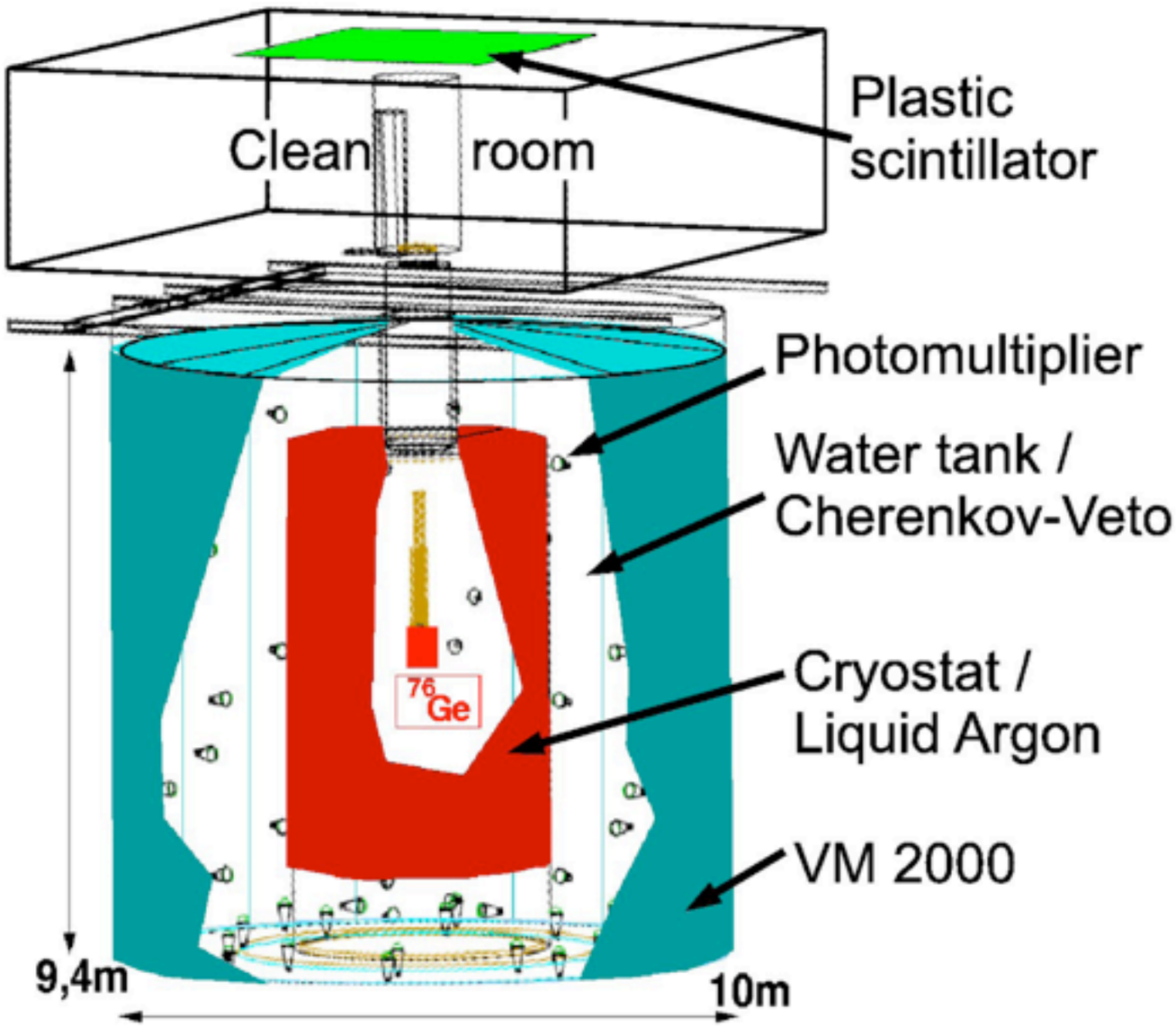
Water-Cherenkov detector

Water-Cherenkov detector

- *PMT: 8” ETL 9350KB / ETL 9354KB*
- *Pressure and water resistant encapsulation*
- *After 5 years they are still working*

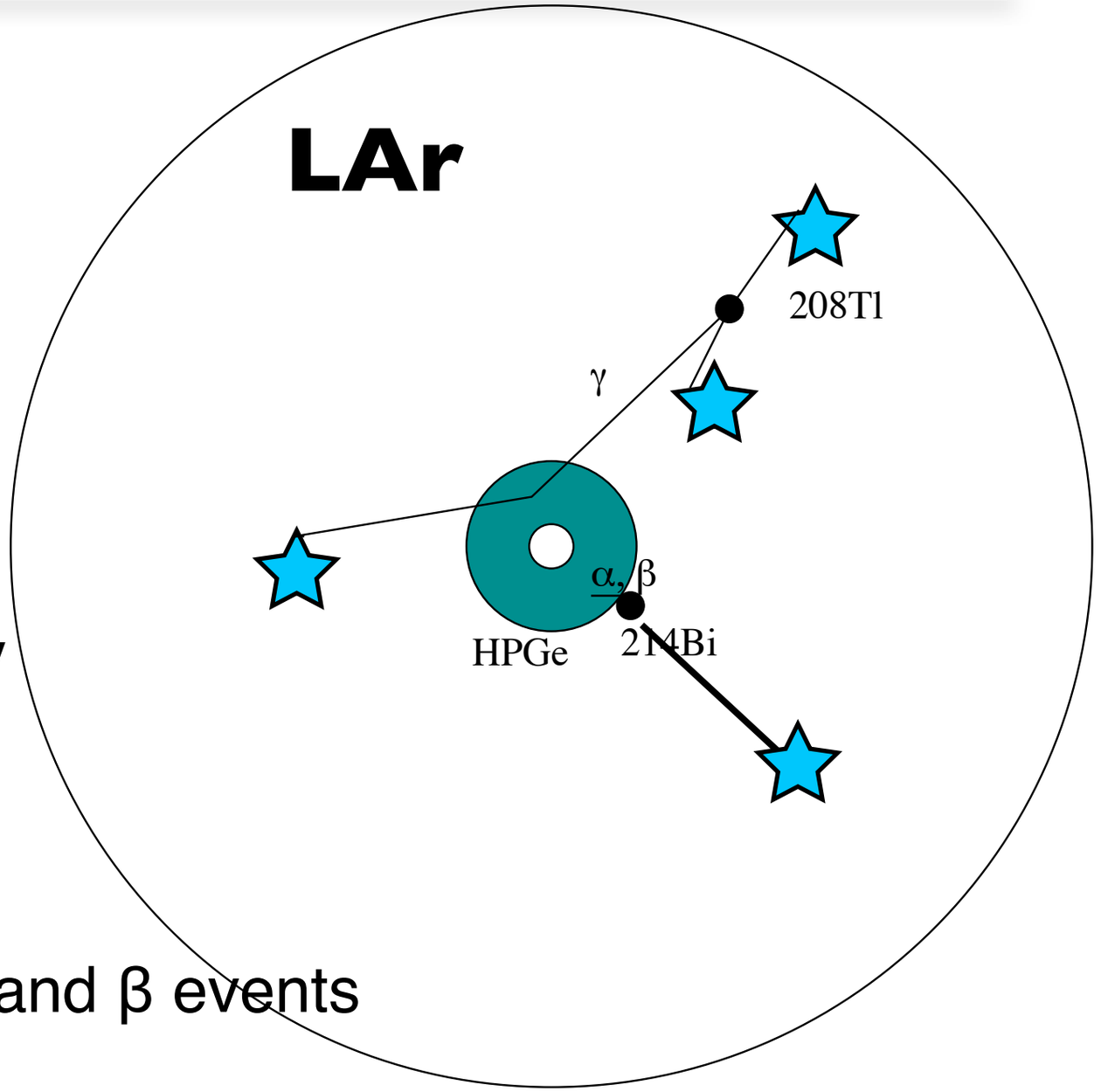
Muon veto - event display





LAr veto - The concept

In the Region of Interest
around 2039 keV



- Nearby ^{208}Tl events can be easily vetoed with very high efficiency
- Veto for ^{214}Bi is less effective
- Does not work well for surface α and β events
  - Veto efficiency in GERDA will strongly depend on the origin of the background

LArGe test facility

lock system

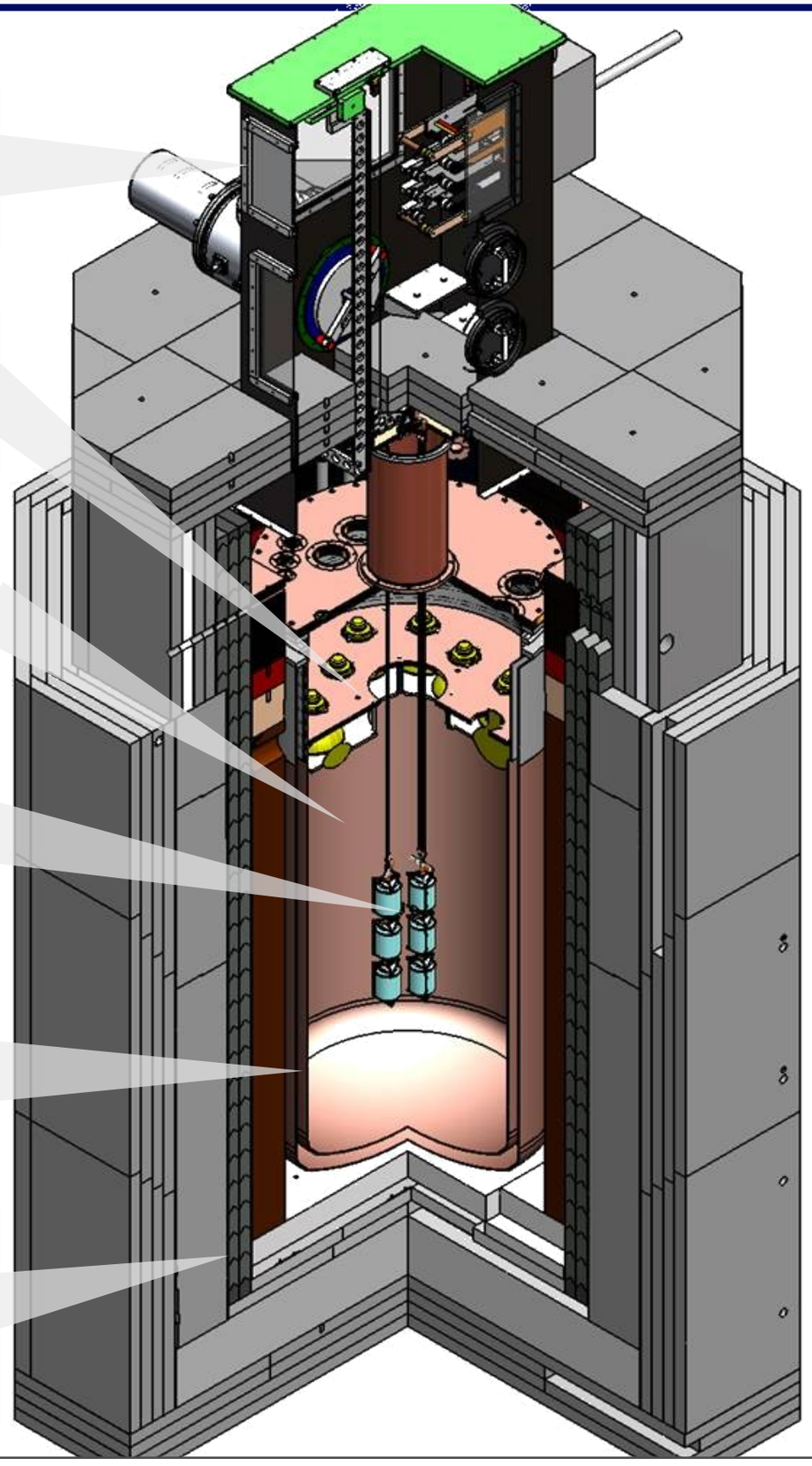
9x 8“ PMTs

reflector foil
& wavelength shifter

bare Ge-detector

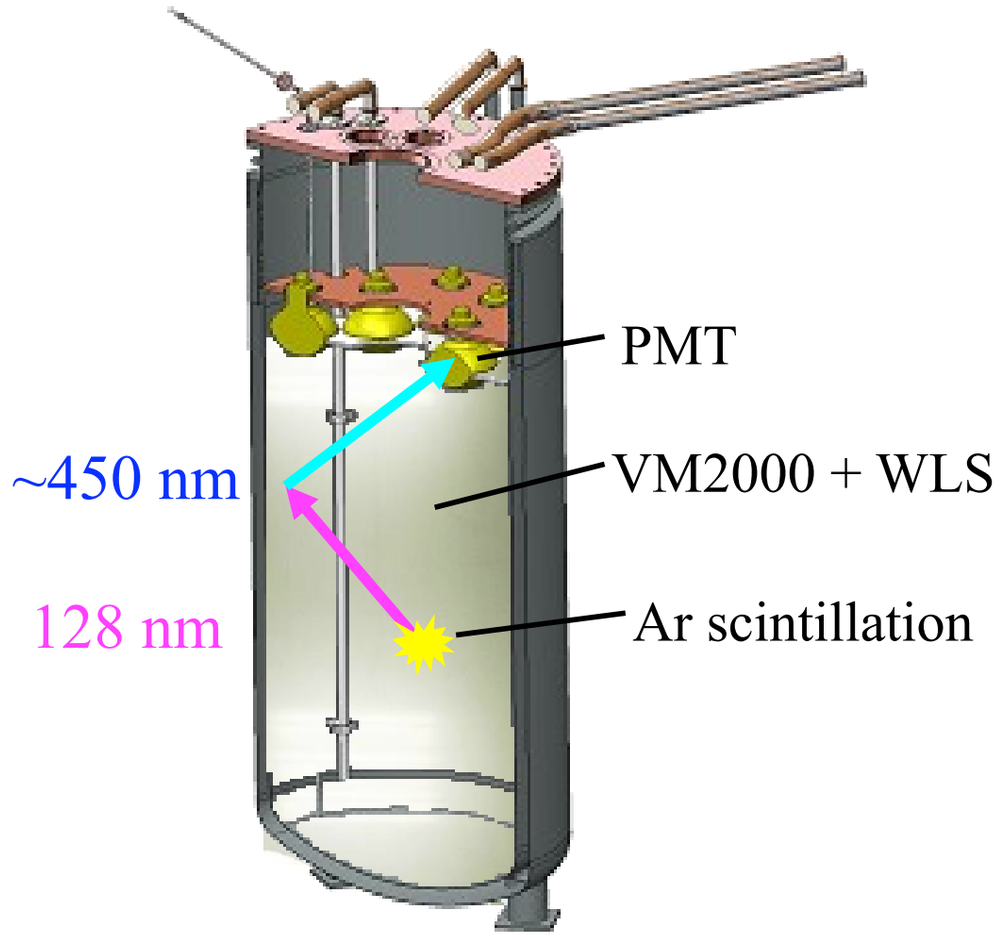
cryostat with LAr
volume 1000 l

Shield (unfinished)
Cu 15 cm, Pb 10 cm,
Steel 23 cm, PE 20 cm



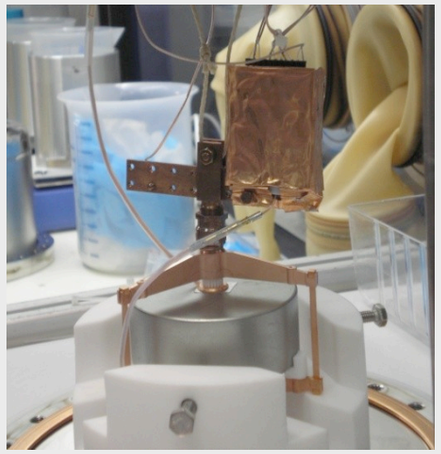
Location:
Germanium detector lab
LNGS @ 3800 m w.e.

http://arxiv.org/abs/1501.05762

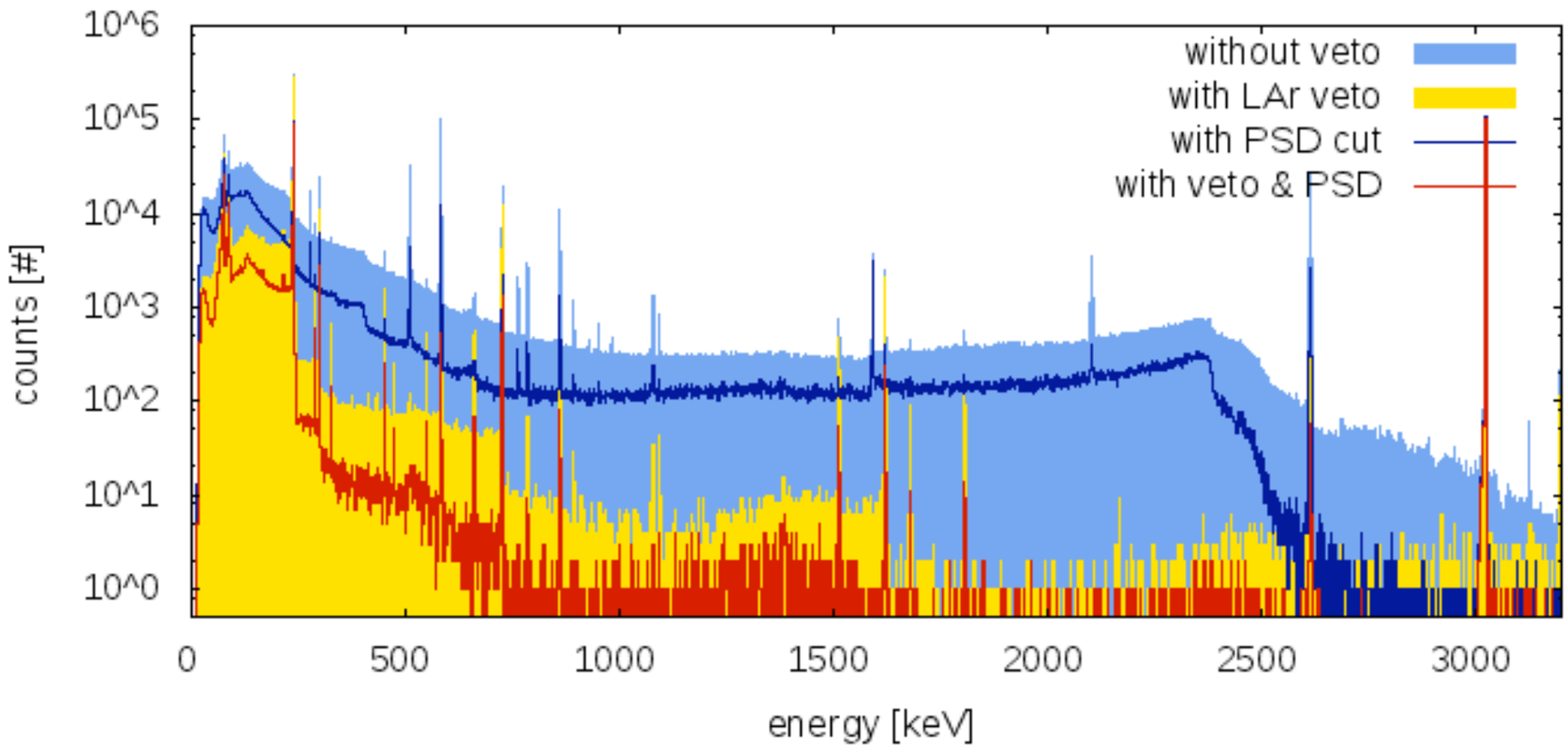


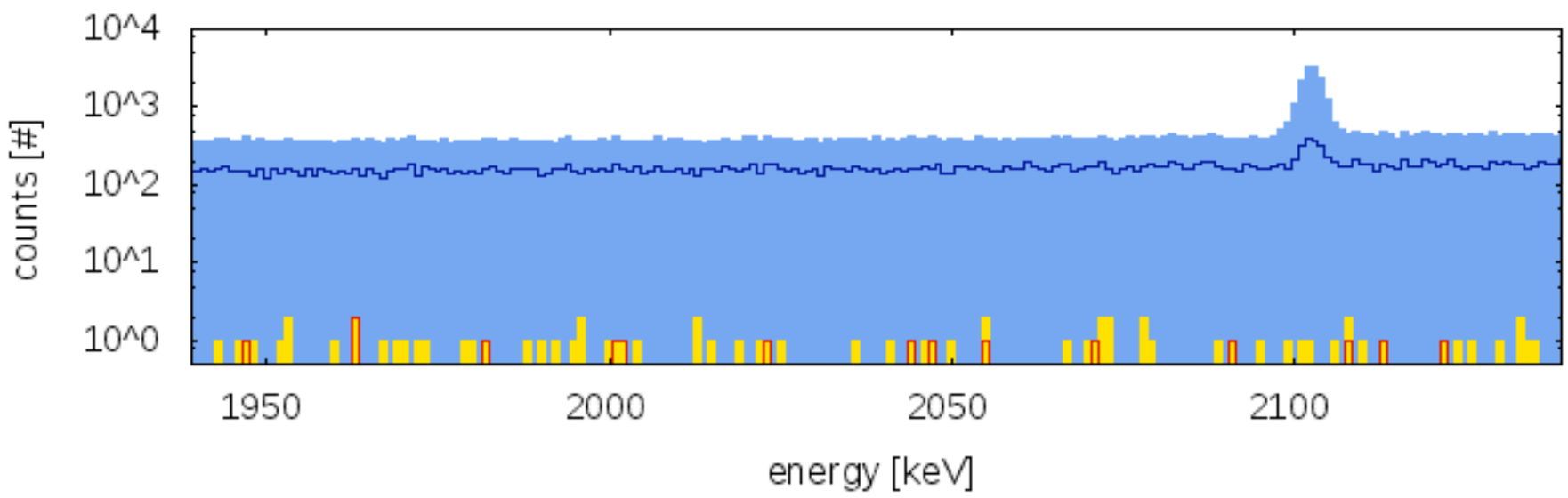
LArGe test facility

- detector: BEGe



- ^{228}Th source
  distance ~7 cm
- DAQ via FADC

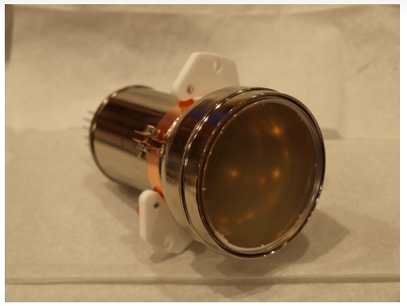




Suppression factors at $Q_{\beta\beta}$ ± 35 keV:

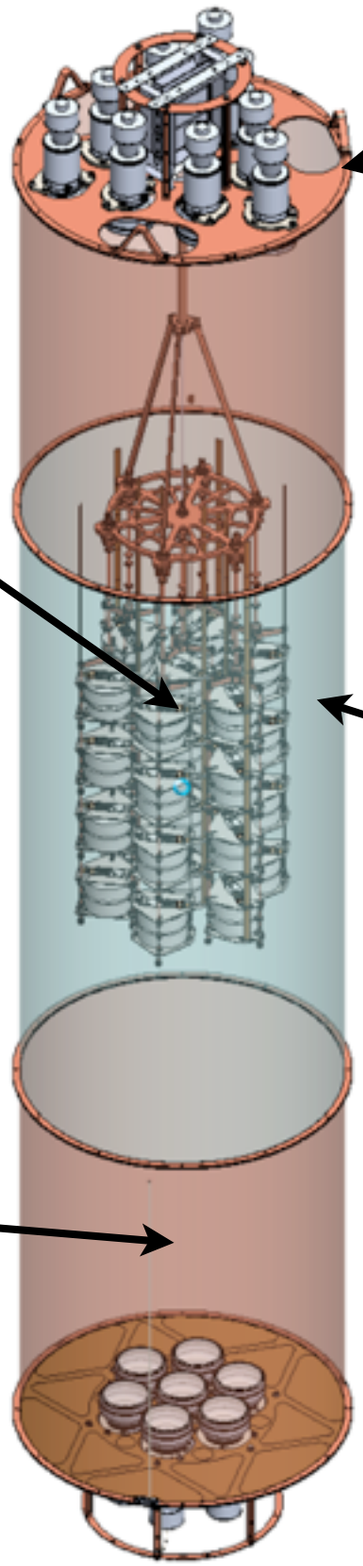
LAr veto	~1200
PSD	~2.4
veto+PSD	~5200

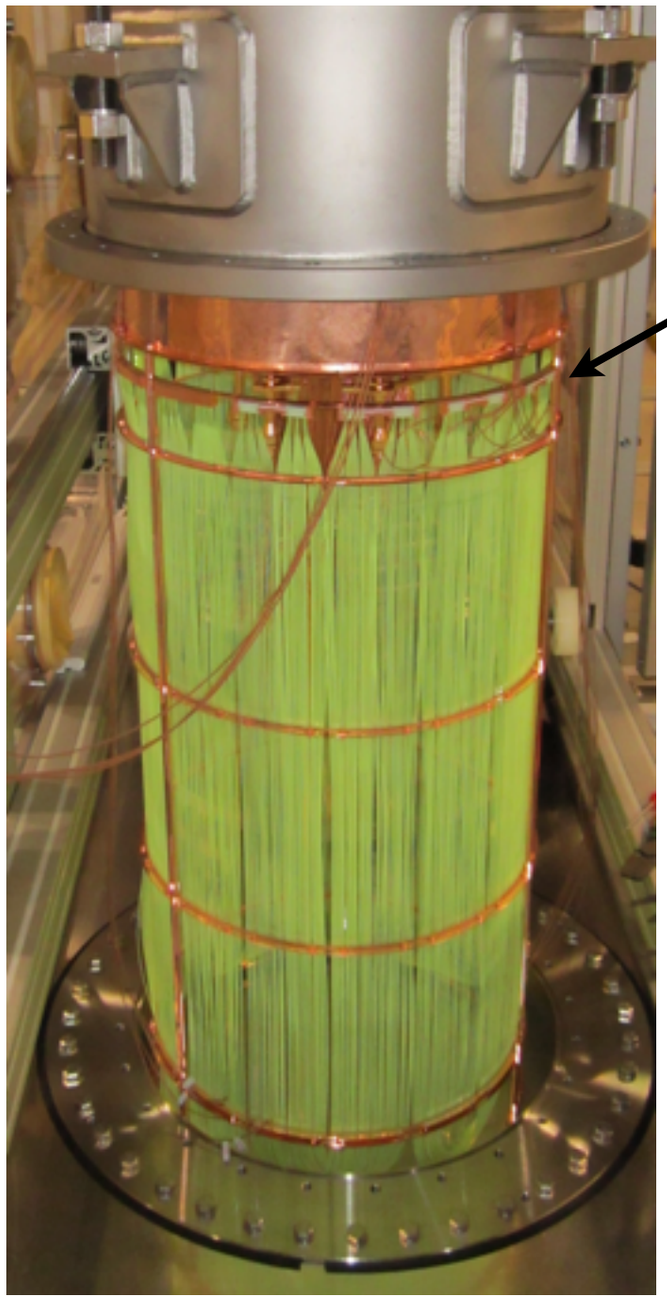
LAr - veto



3” low-background PMT
Hamamatsu R11065-20

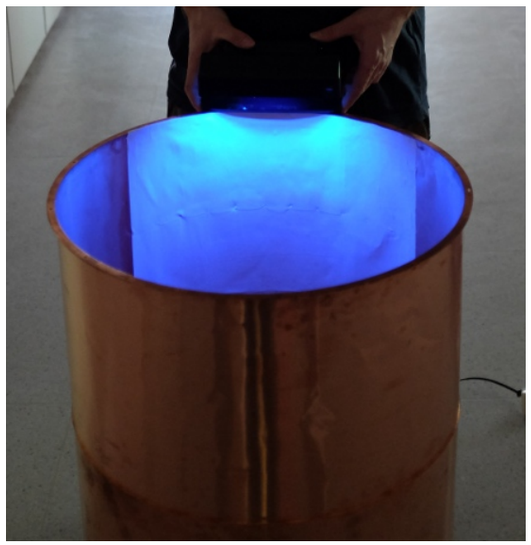
HPGe detector array





SiPMs

Copper “shroud” with Tetratex reflector coated with TPB



Fiber “shroud” 1000 m WLS fiber coated with TPB

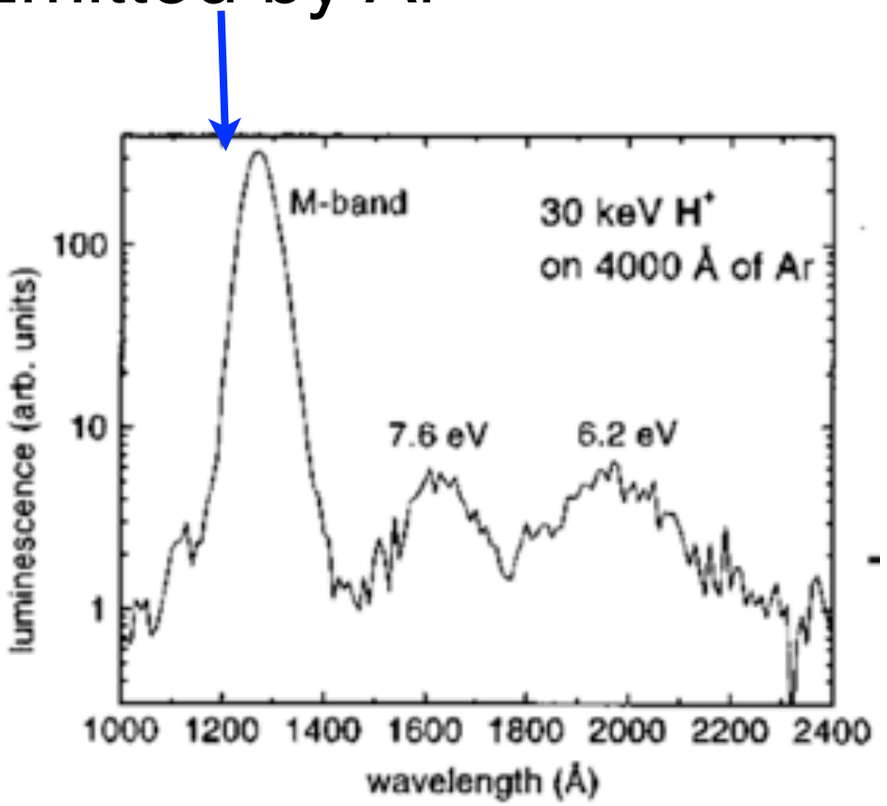
The Wavelength shifter

Tetra-Phenyl-Butadiene (TPB)

128 nm (VUV) → 430 nm → Detected with PMT

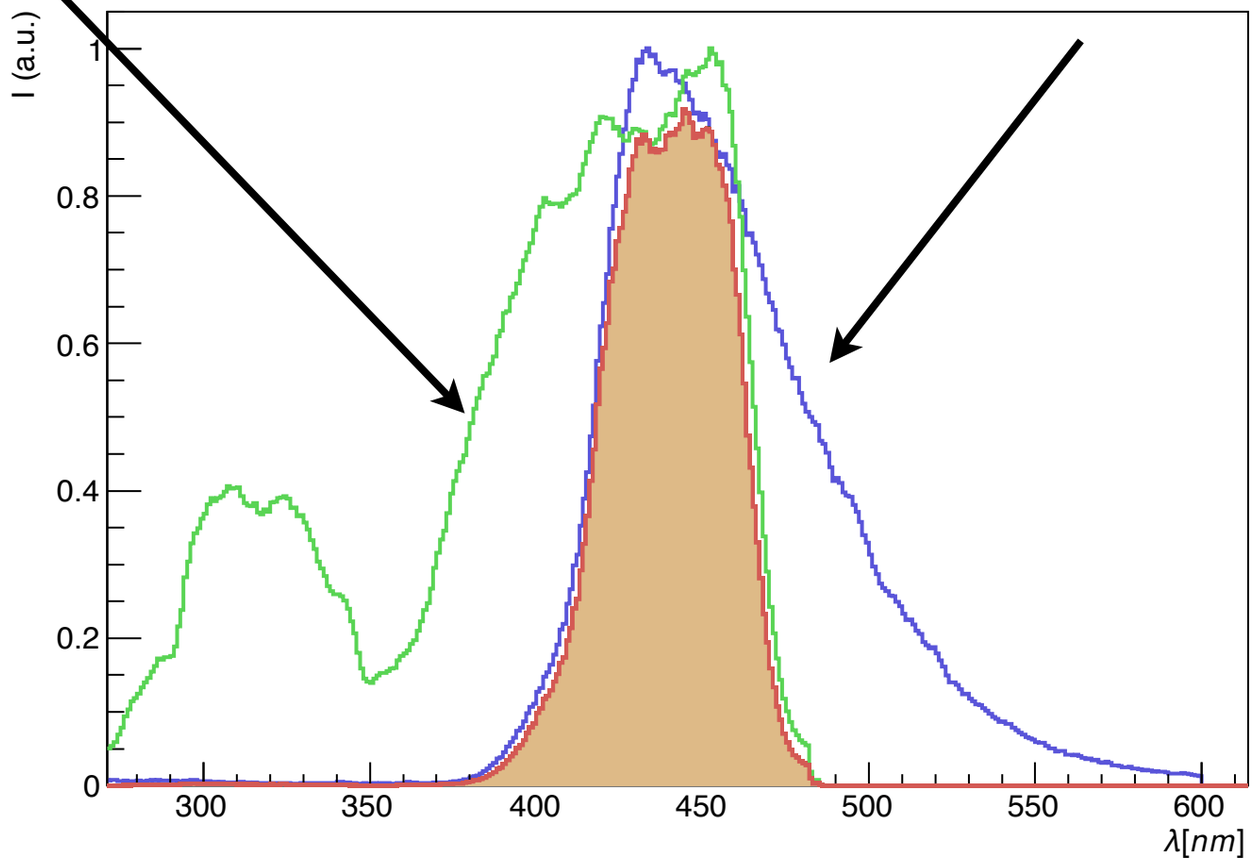
430 nm → Collected with WLS fiber

Emitted by Ar



BCF-91A absorption

TPB - emission spectrum

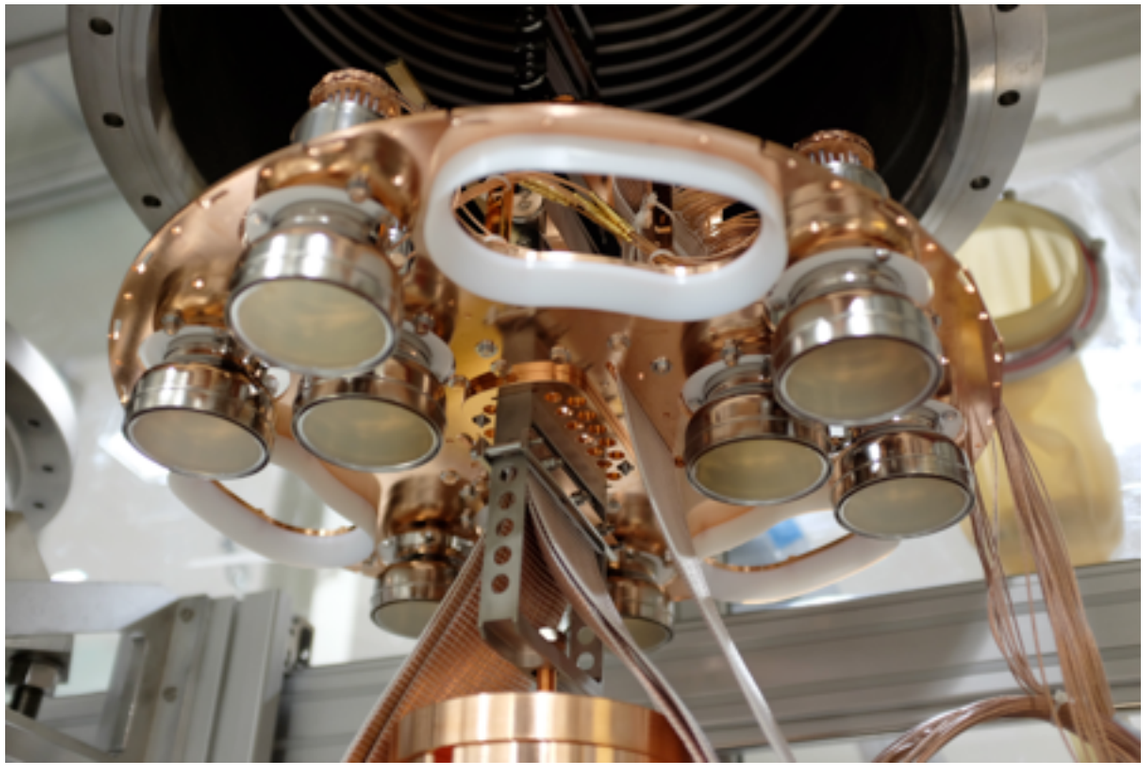


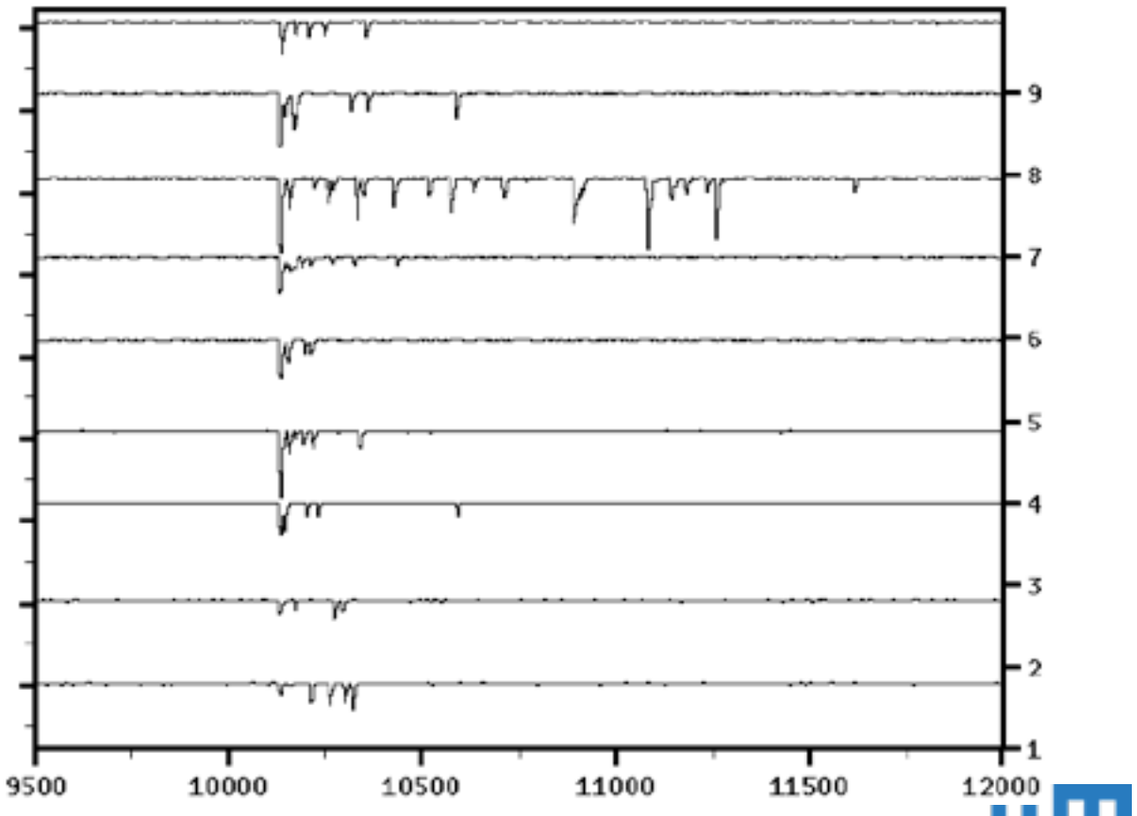
Estimated efficiency ~60%

LAr - veto, PMTs

- *16x 3-inch PMTs are operated in the GERDA cryostat w/ liquid argon to detect 128 nm scintillation light*
- *photocathodes are coated with wavelength shifter (TPB+PST)*
- *use of custom made encapsulated low-background voltage dividers*

Below: 9 PMTs on the top plate of the LAr veto
Right: scintillation signals thereof

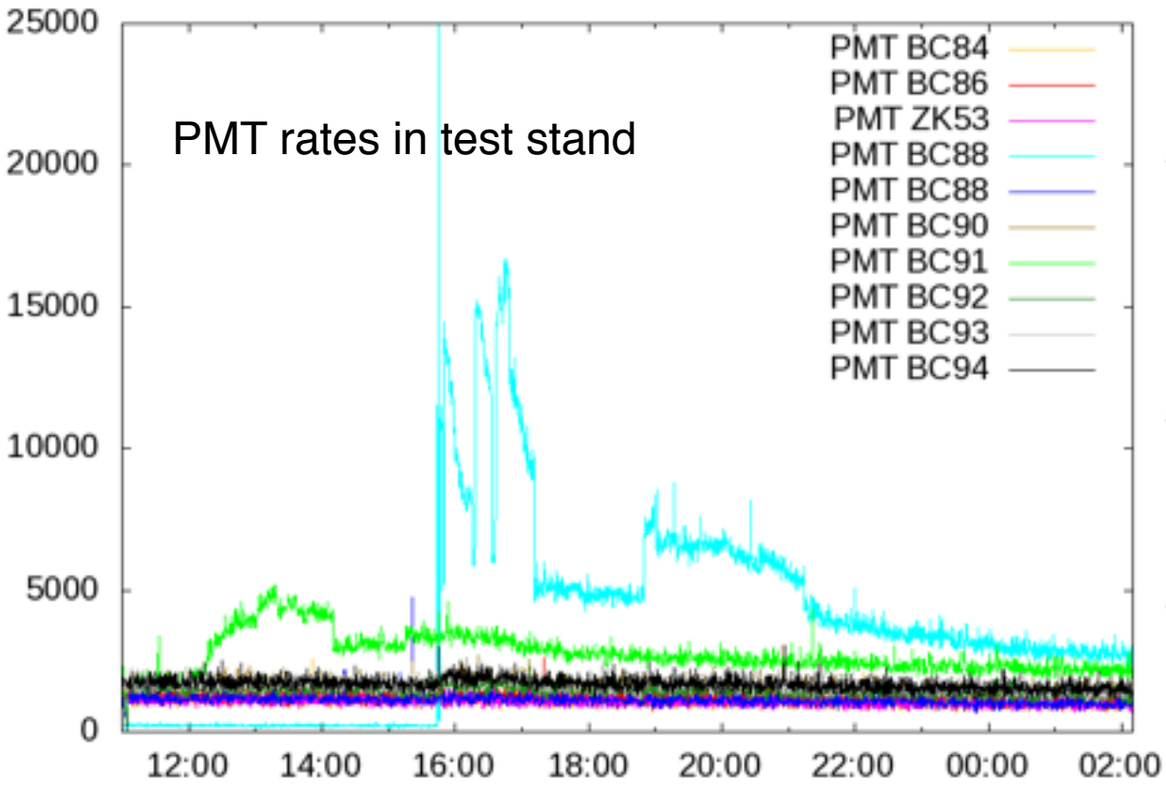


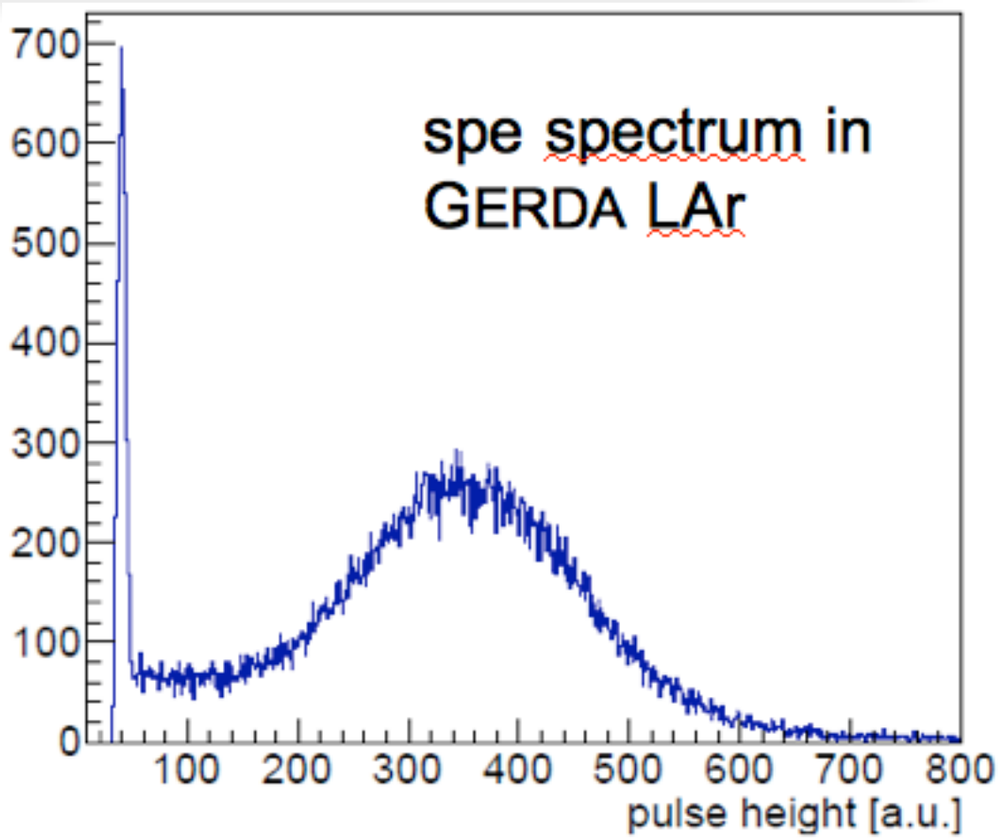


LAr - veto, PMTs

Hamamatsu R11065-20 MOD (3-inch)

- *QE at 420 nm:* *~40%*
- *operation gain:* *2-5·10^{6}*
- *average peak-to-valley:* *4.3*
- *low activity:*
  - *^{228}Th <1.94 mBq/PMT*
  - *^{226}Ra <1.7 mBq/PMT*





- *discovered flashing issue due to discharges inside the PMTs at cryogenic temperature*
- *problem has been greatly improved in close cooperation with manufacturer*
- *~approx. 1/10 PMTs still flashing occasionally*

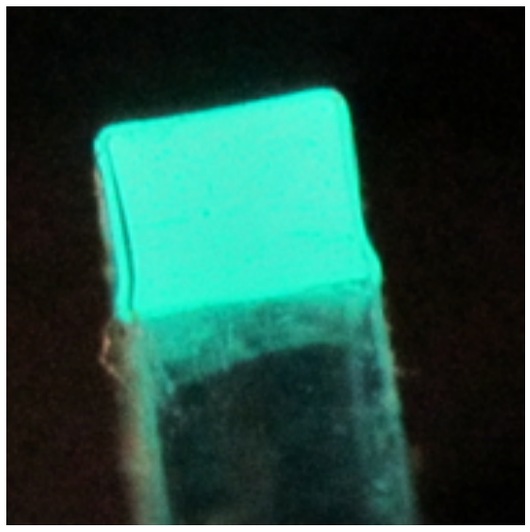
LAr - veto, fibers

Element	*Conc.*	*Activity Bq/kg*	*Background in GERDA cts/(keV kg Yr)*
K	*15 ppb*	*4.6×10^{-4}*	-
Th	*14.3 ppt*	*5.8×10^{-5}*	*3.4×10^{-4}*
U	*3.4 ppt*	*4.2×10^{-5}*	*2.3×10^{-5}*

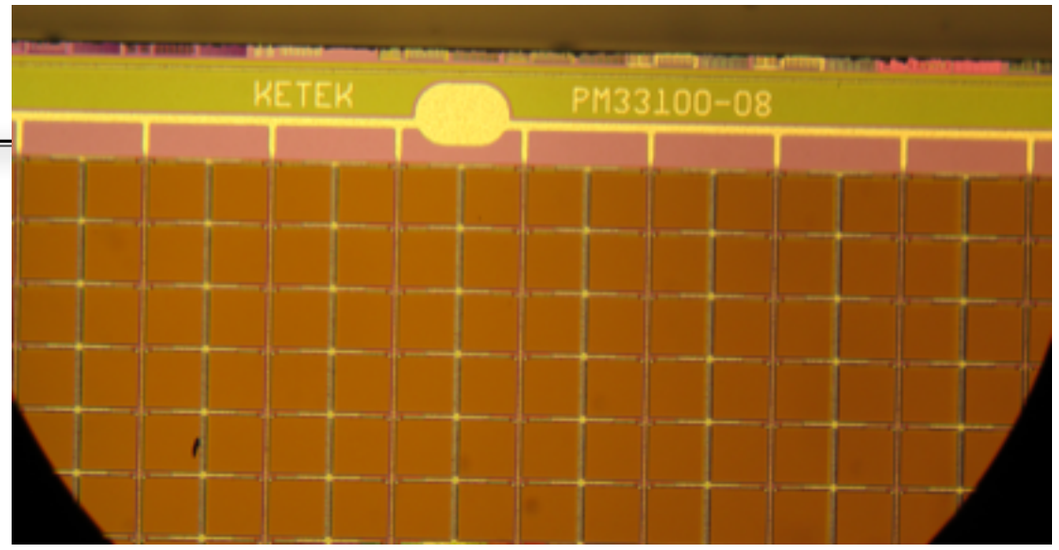
Induced background

ICPMS done at LNGS: WLS fibers

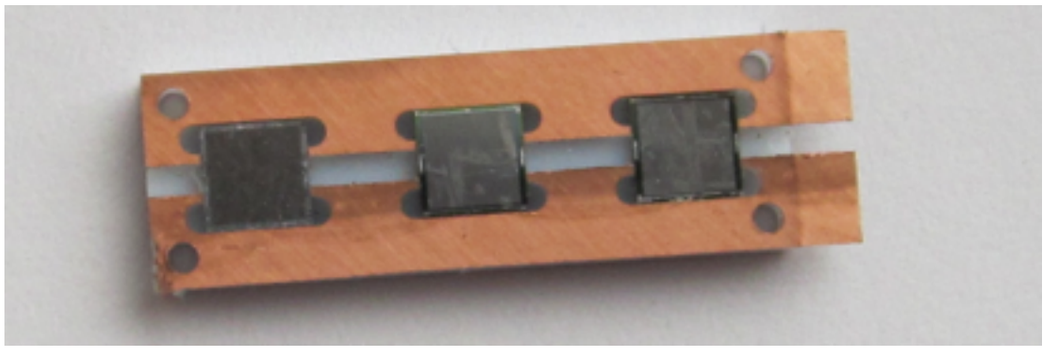
- *BCF-91A, square, multiclad fiber, 7.3 % trapping efficiency*
- *The fiber curtain consists of about 1 kg WLS fiber (4 m^2 photon detector)*
- *Relevant activity: O(>100 μBq)*
- *Compatible with the background goal of GERDA Phase II (10^{-3} cts/(keV kg yr))*

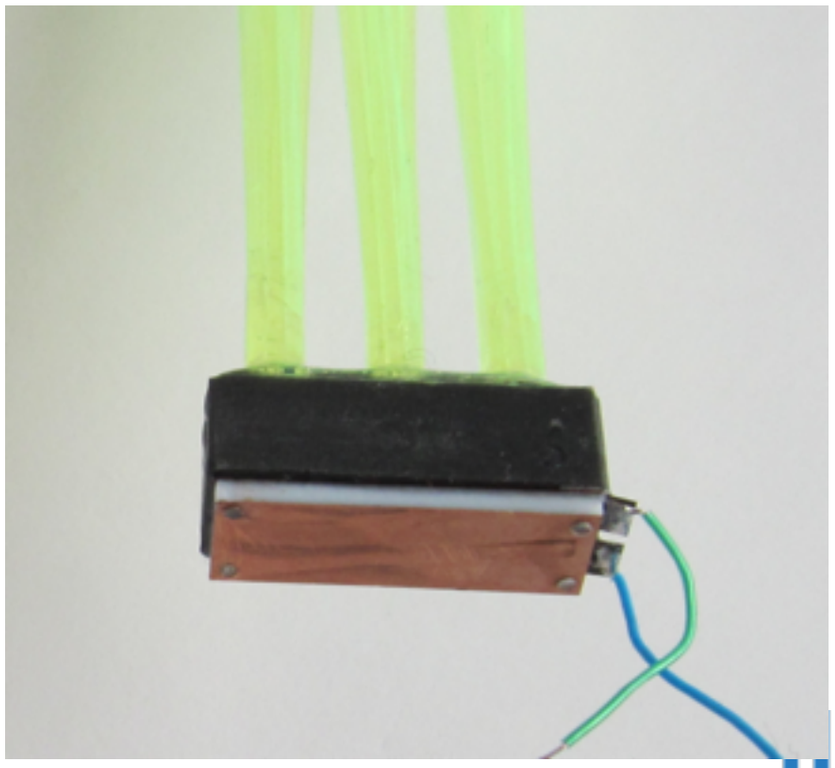


Ketek SiPMs



- *Ketek GmbH the only company to sell SiPMs in die*
- *Self made packaging from radio-pure materials (Cuflon)*
- *3x3 mm², 50 µm and 100 µm pixel size*
- *90 SiPMs to 15 read-out channels*
- *Total sensitive surface in GERDA 8.1 cm²*





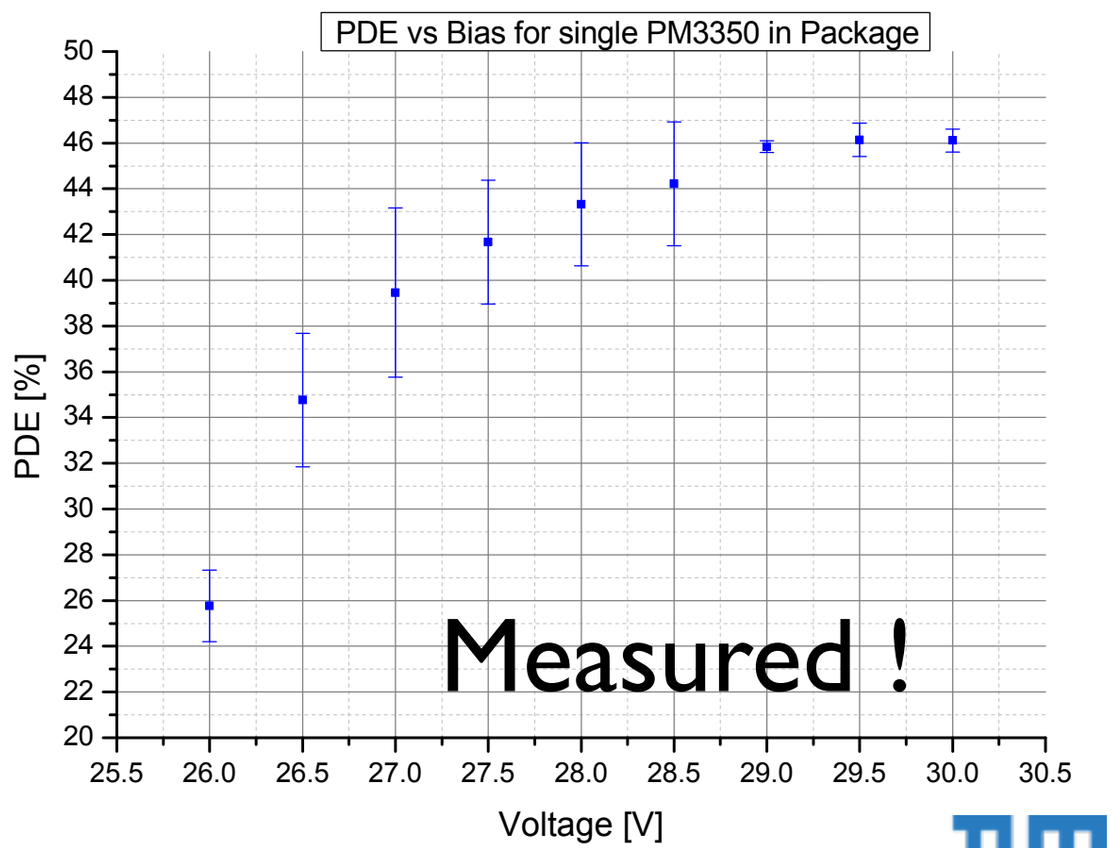
LAr - veto, SiPMs

Element	*Conc.*	*Activity Bq/kg*	*Background in GERDA cts/(keV kg Yr)*
Th	*< 0.25 ppb*	*< 1x10^{-3}*	*~10^{-6}*
U	*< 0.25 ppb*	*< 3x10^{-3}*	*~10^{-7}*

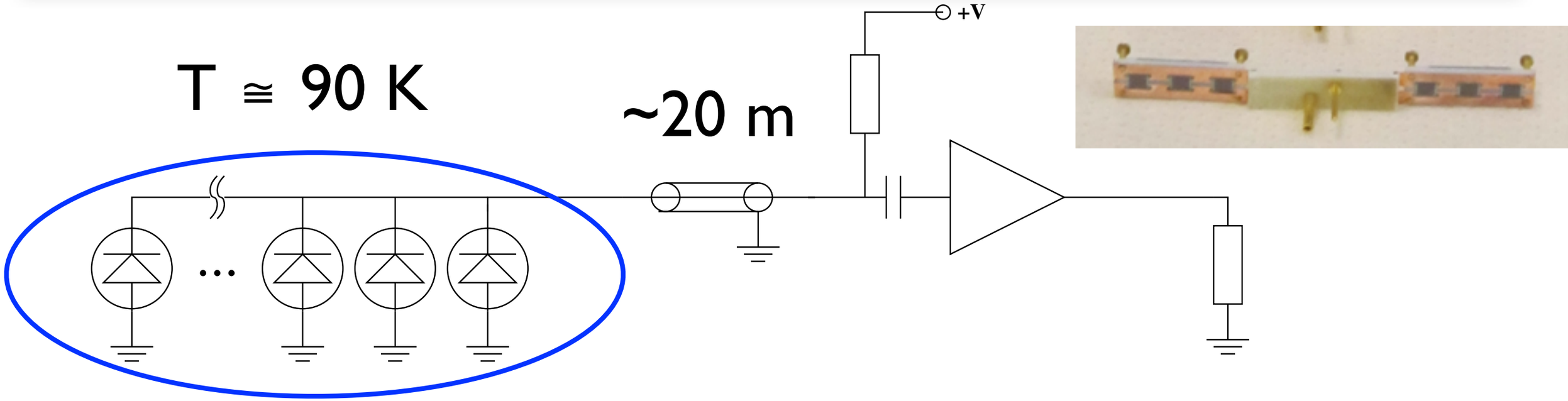
ICPMS done at LNGS: SiPMs

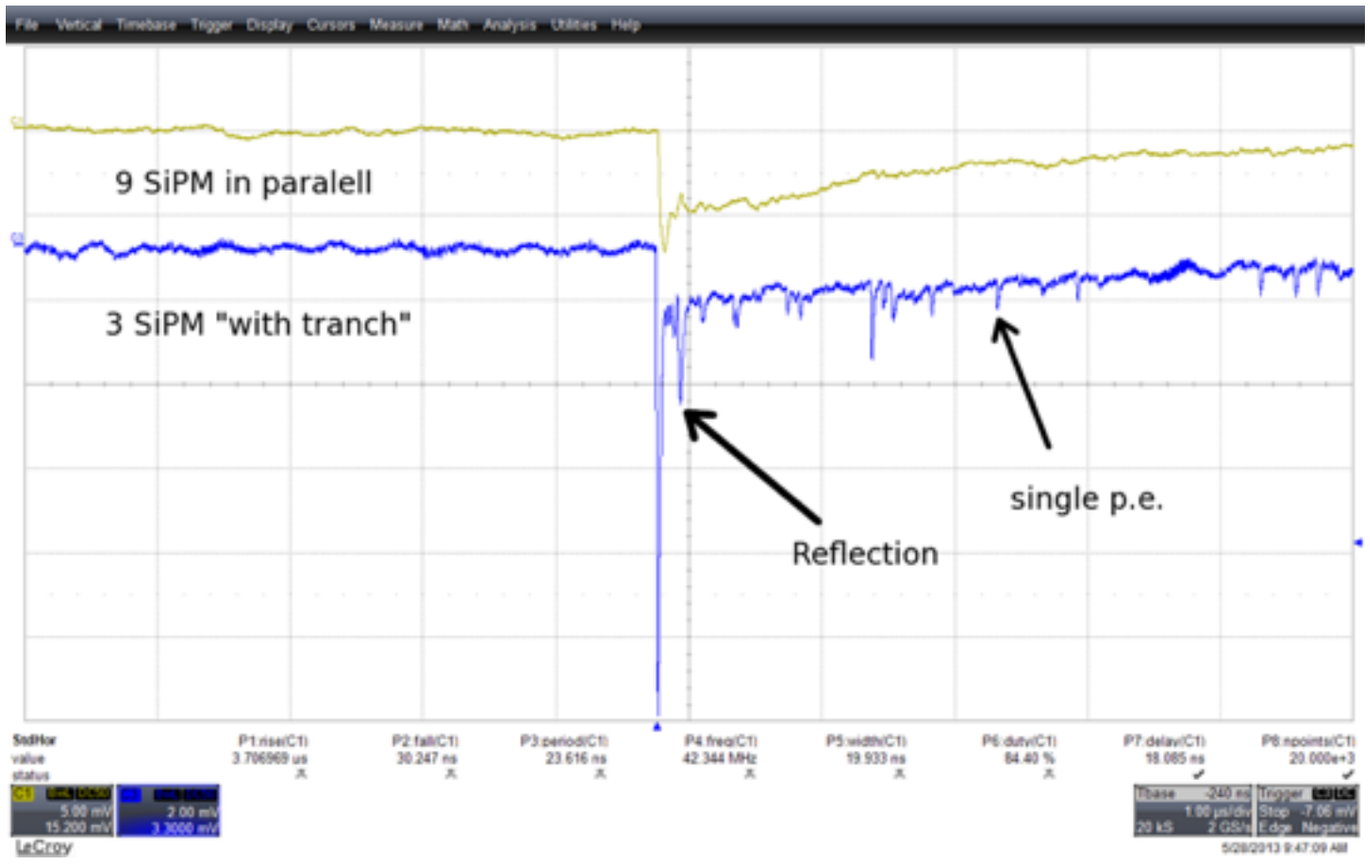
Ketek SiPM in die (3x3 mm, 50µm pixel)

- Good mach for the size of the WLS fiber
- Small & Silicon = Low background
- High QE, Works at cryogenic temperatures
- Relevant activity for GERDA < 10 µBq
- 1 m^2 SiPM would have < 10 mBq activity



SiPM read-out





- How many SiPMs can be connected in parallel ?
- Not limited by the Dark Rate
- Single p.e. resolution preserved ?

Charge Amplifier & SiPM

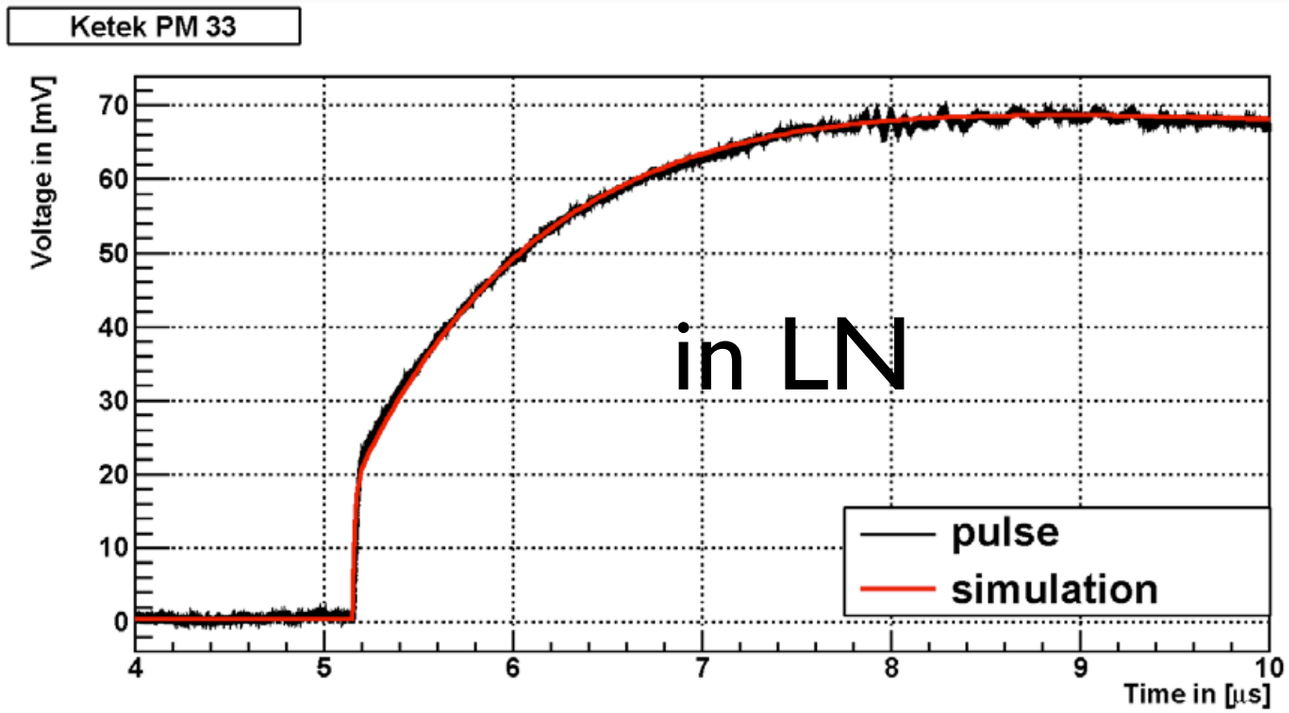
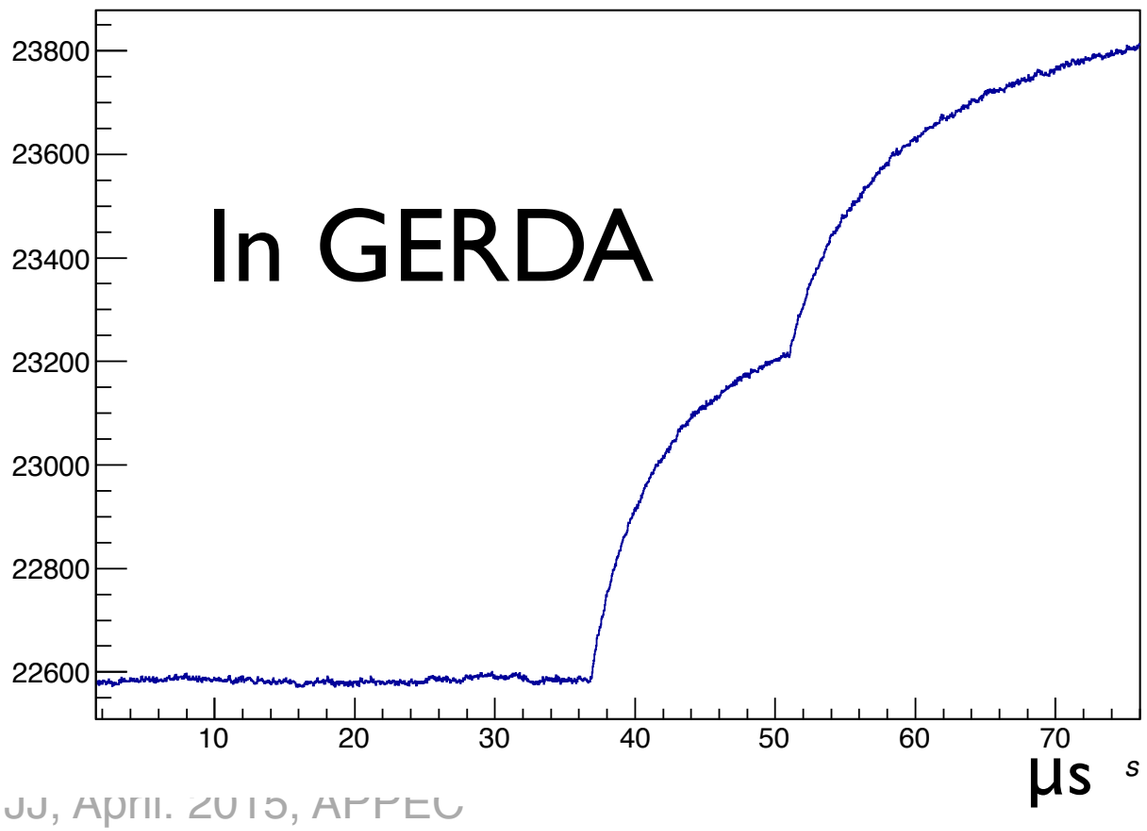
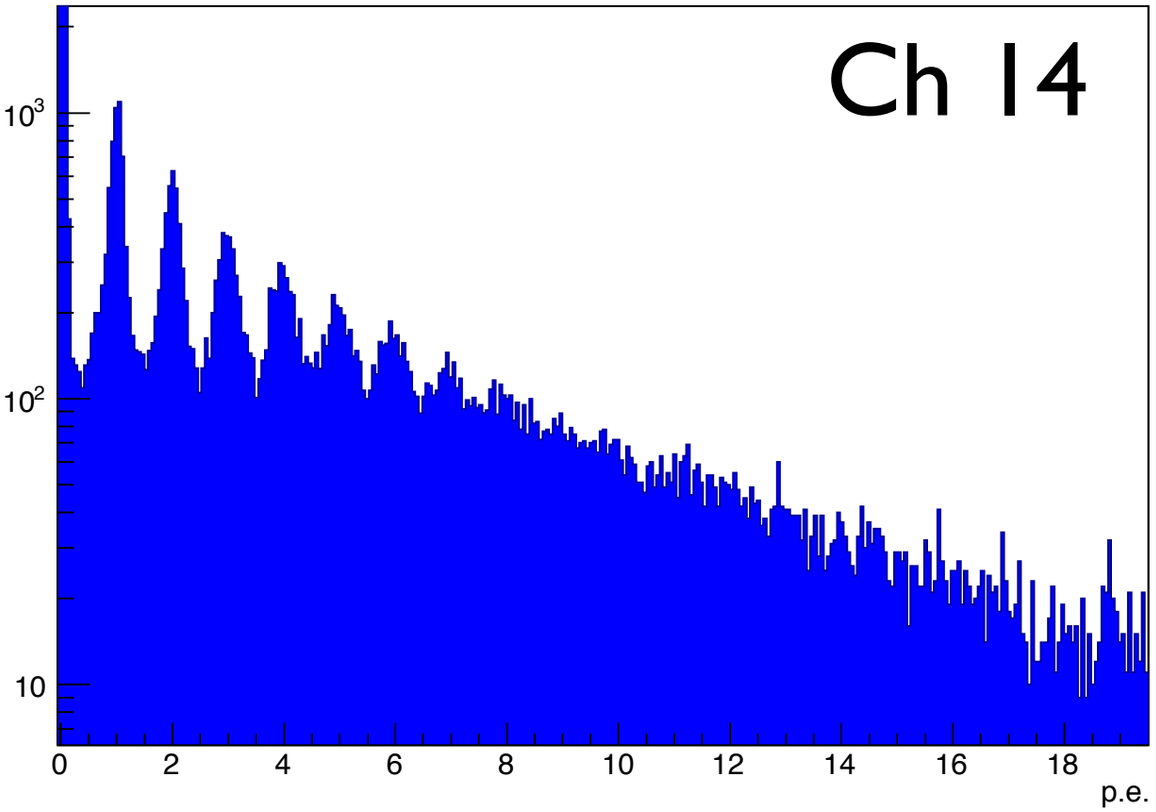


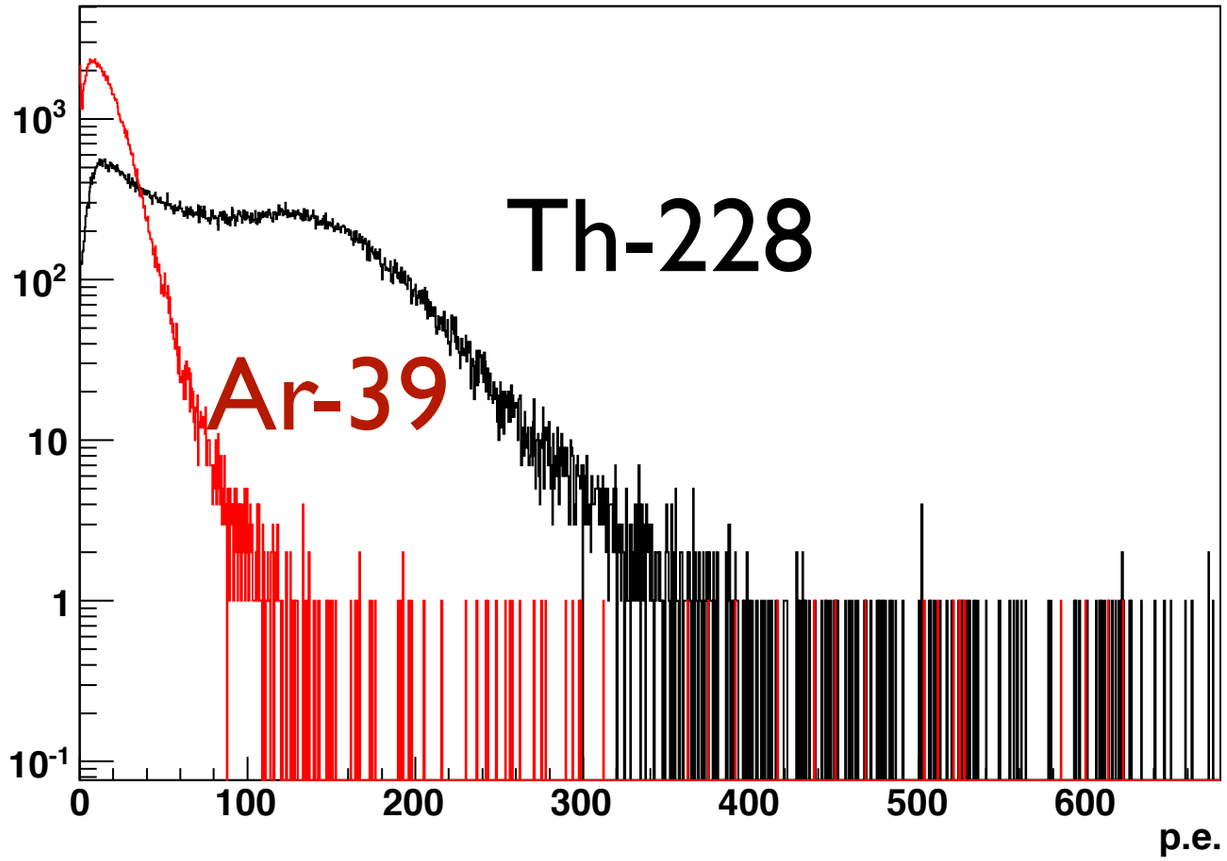
Figure 20: Simulation for Ketek PM 33 SiPM in liquid Nitrogen with charge amplifier



- Fast component - timing at ns level
- Slow component - defined by the quenching resistor
- With CA much better signal to noise ratio
- In GERDA we have to find a p.e. pulse in 5 µs time window
- Signals are digitized with 100 MHz FADC

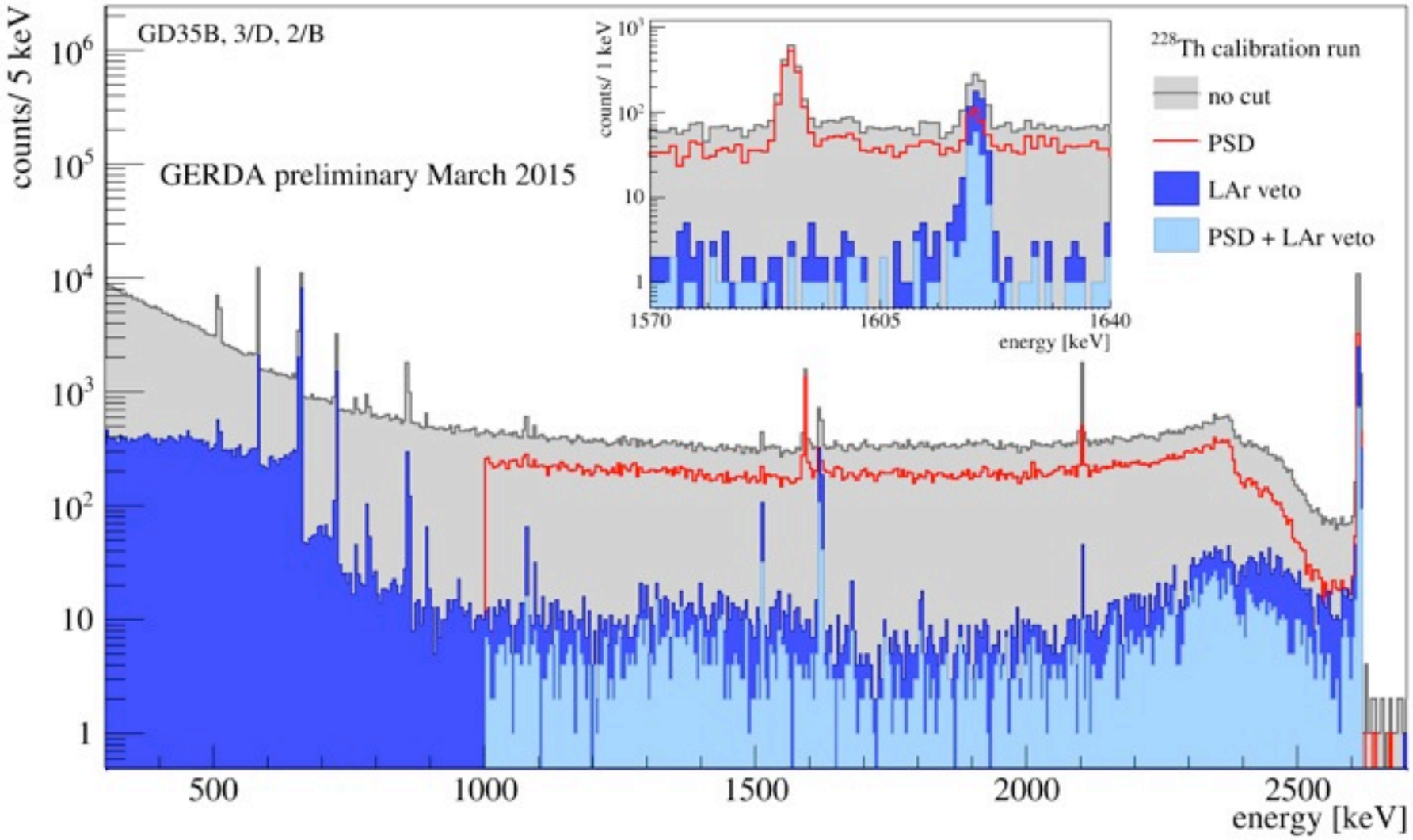
LAr veto commissioning





- *Single channels calibrated and summed up*
- *Light yield fiber-SiPM: 50 - 60 p.e./ MeV*
- *Overall efficiency (fiber + SiPM) ≈ 1 %*
- *Sufficient light for anti Compton-veto*

LAr veto commissioning



- *First commissioning run with LAr-veto turned on*
- *Suppression Factor of 95 achieved with all cuts*
- *Meantime the SF from the fibers is already 3x better*

Summary

- GERDA Phase II is about to start data taking,
  - construction almost finished
- GERDA uses a combination of conventional and novel light detectors:
  - The first experiment with large SiPM array operated at cryogenic temperature
- Our experience will influence the design of the ton-scale experiment