LAr scintillation light read-out with SiPMs and WLS fibers in GERDA

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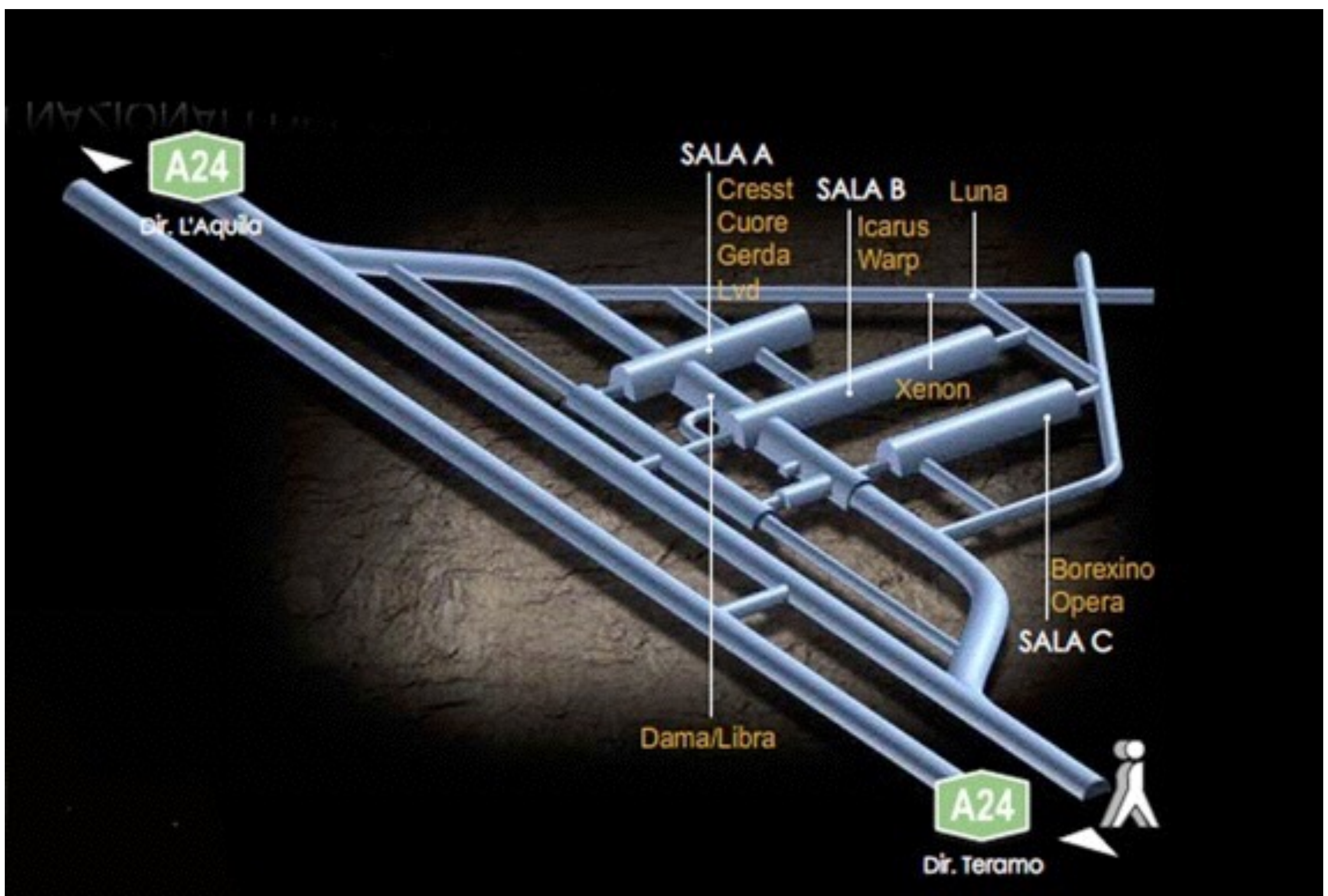
GERDA at Gran Sasso

- The GERDA experiment (GERmanium Detector Array) is built for the search of $0\nu\beta\beta$ decay in ^{76}Ge
- is located at INFN - LNGS underground lab. with 3800 m w.e. overburden



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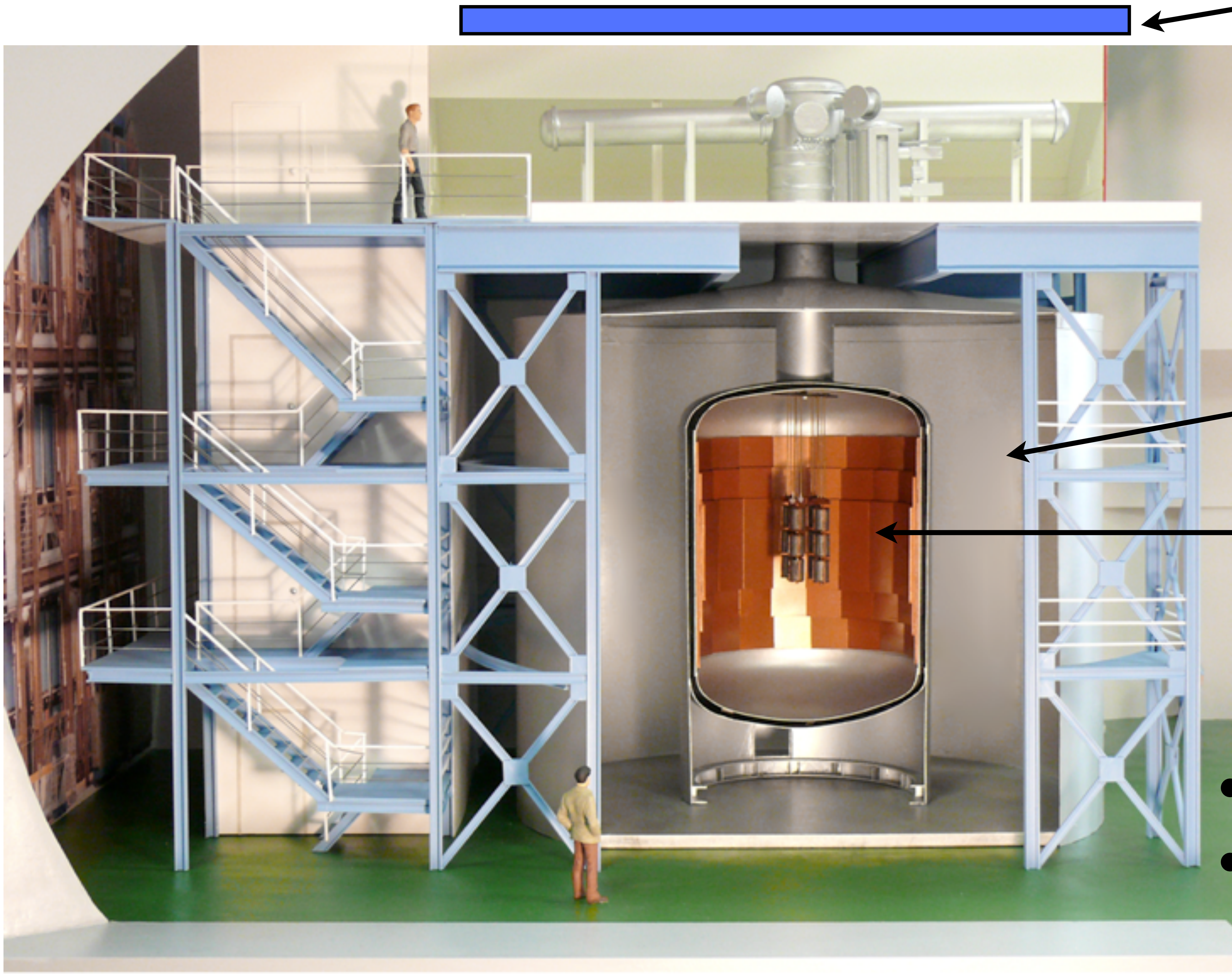
GERDA



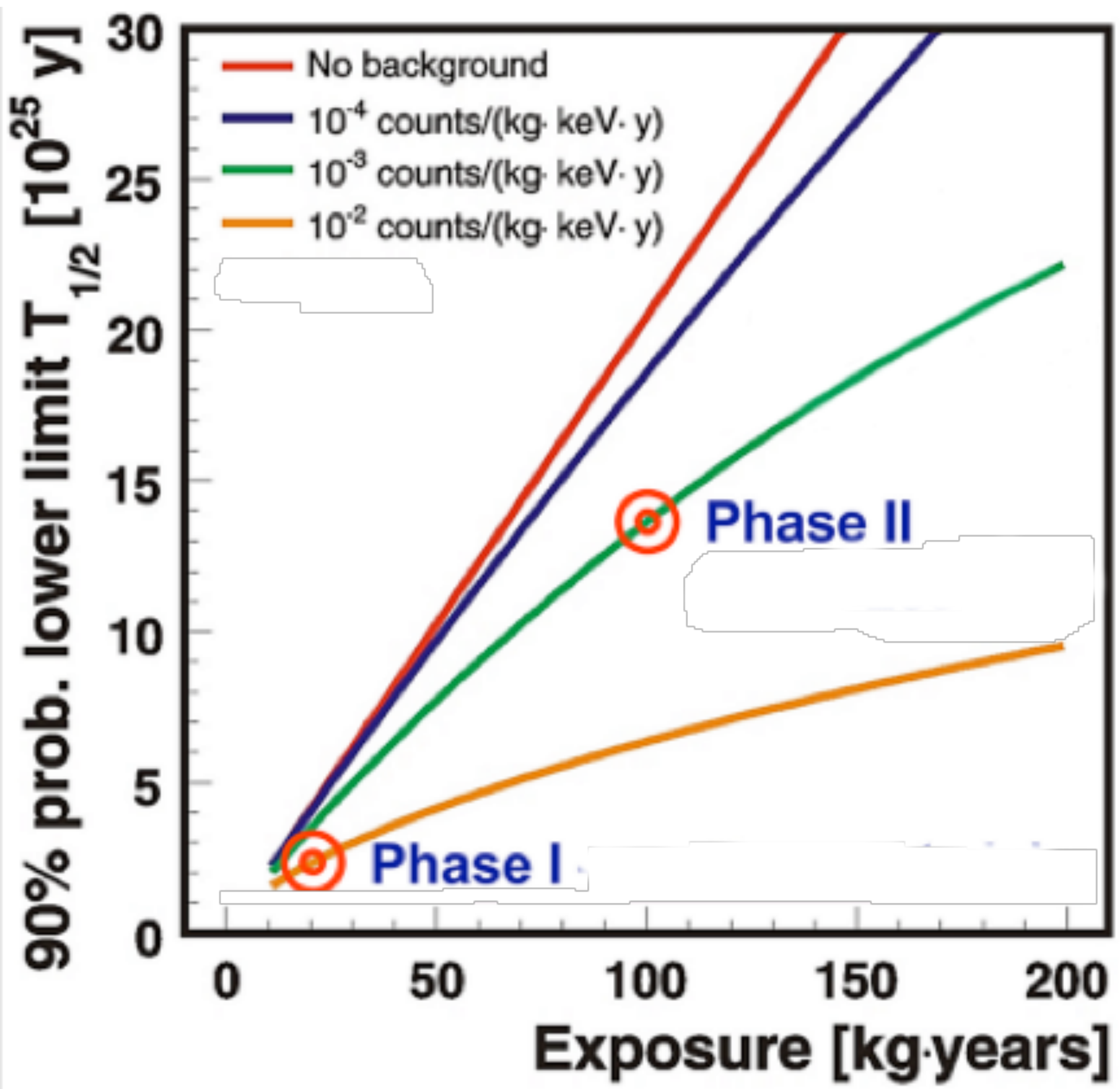
Plastic scintillator panels muon veto

Water-Cherenkov muon Veto

LAr veto

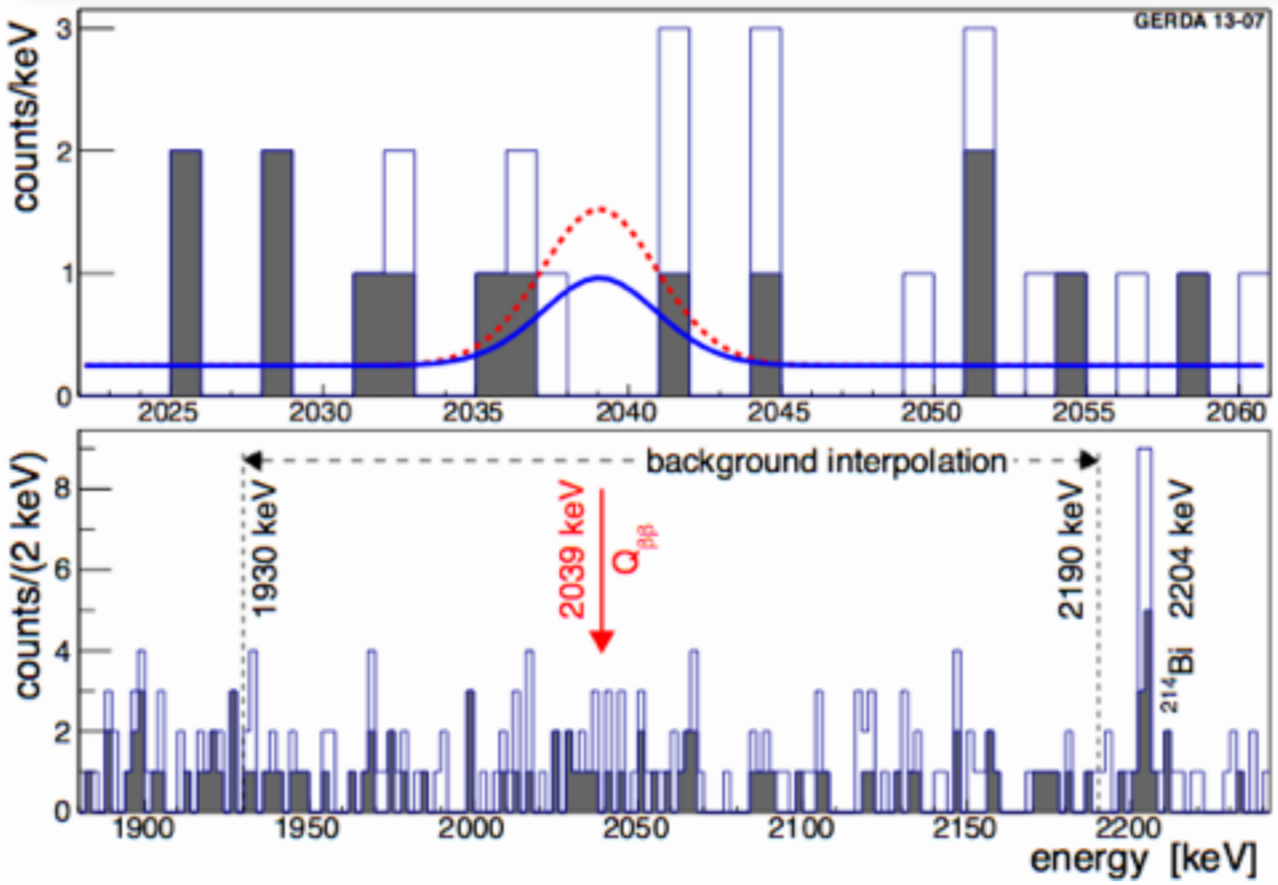
- 590 m^3 water tank,
- 64 m^3 LAr cryostat

GERDA status



- *Status of Phase I*: data taking ended with 21.6 kg · yr exposure: from Nov. 2011 to May 2013
- *Result of Phase I:* $T^{0\nu}_{1/2} > 2.1 \times 10^{25}$ yr
- *Goal of Phase II*: background level of 0.001 cts/(keV kg yr) and 100 kg yr exposure
- *Phase II strategy to reduce background:* LAr scintillation light readout + pulse shape discrimination
- *Phase II status:* is in commissioning phase right now

GERDA Phase I results

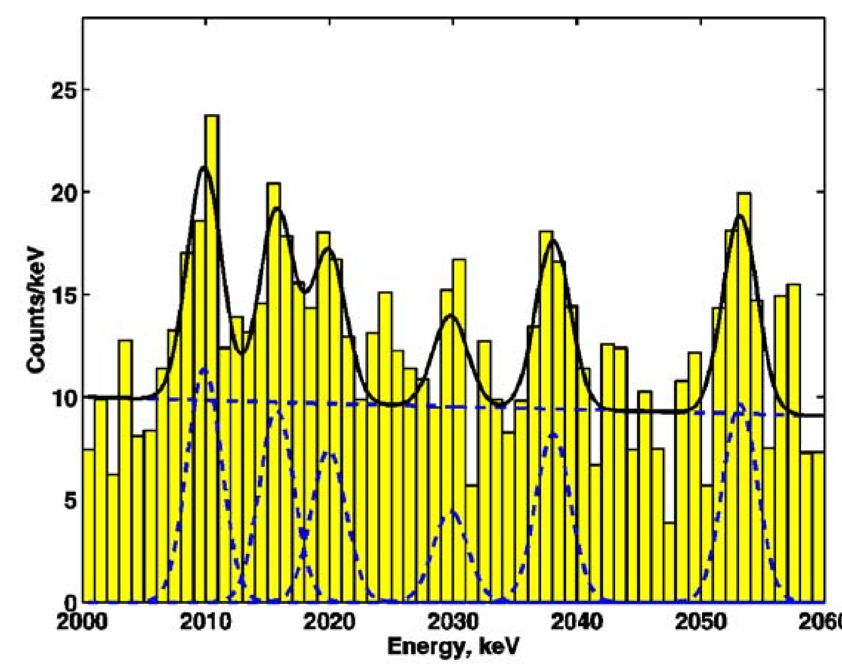


In 2039 ±5 keV we see 7 counts, after PSD only 3 remain:

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

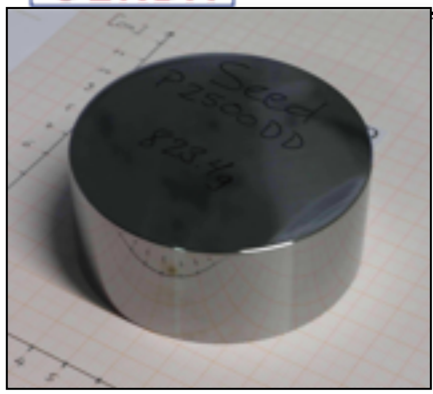
Phys. Rev. Lett. **111**, 122503 (2013)

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



Previous claim discarded

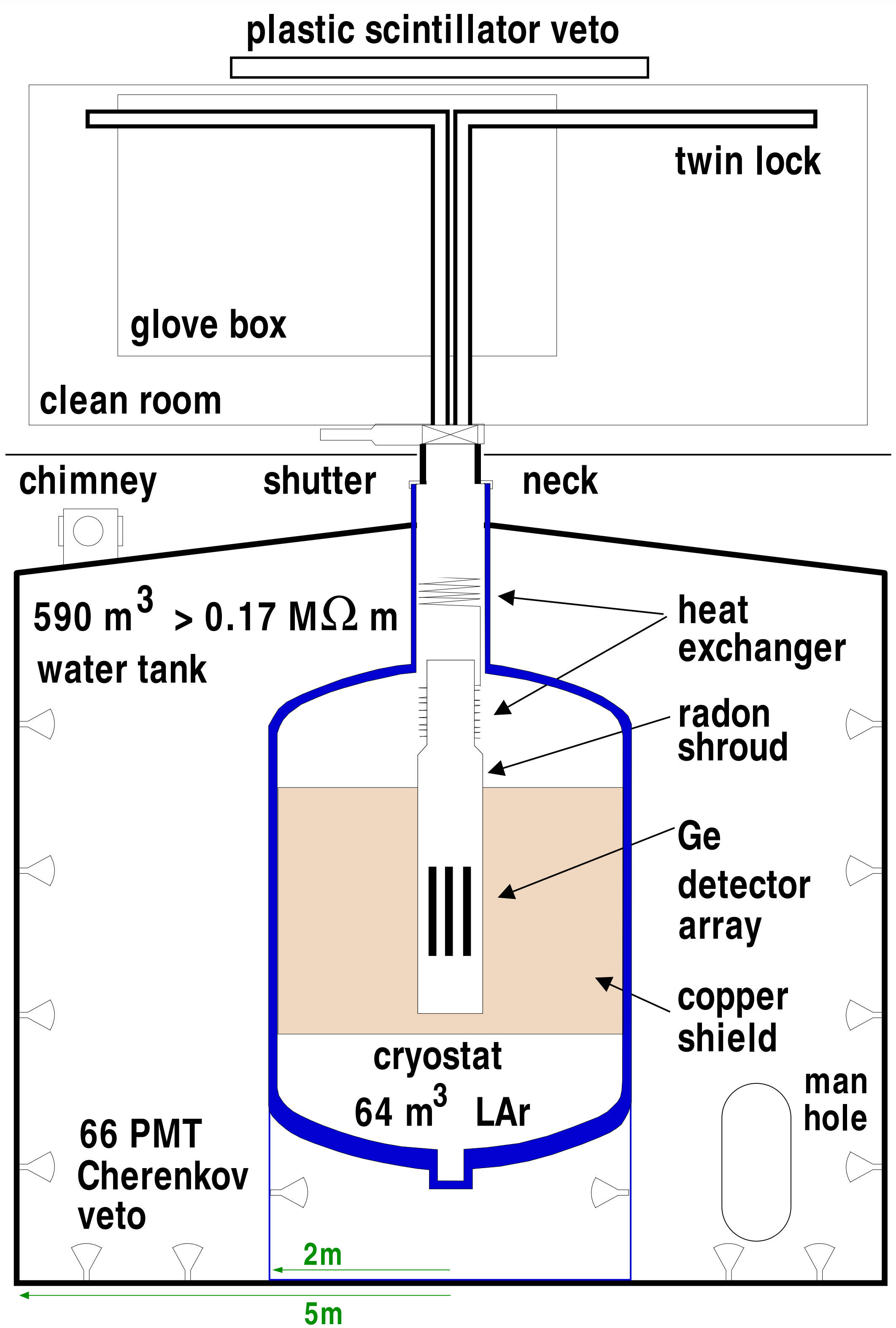
Phase II - Upgrade



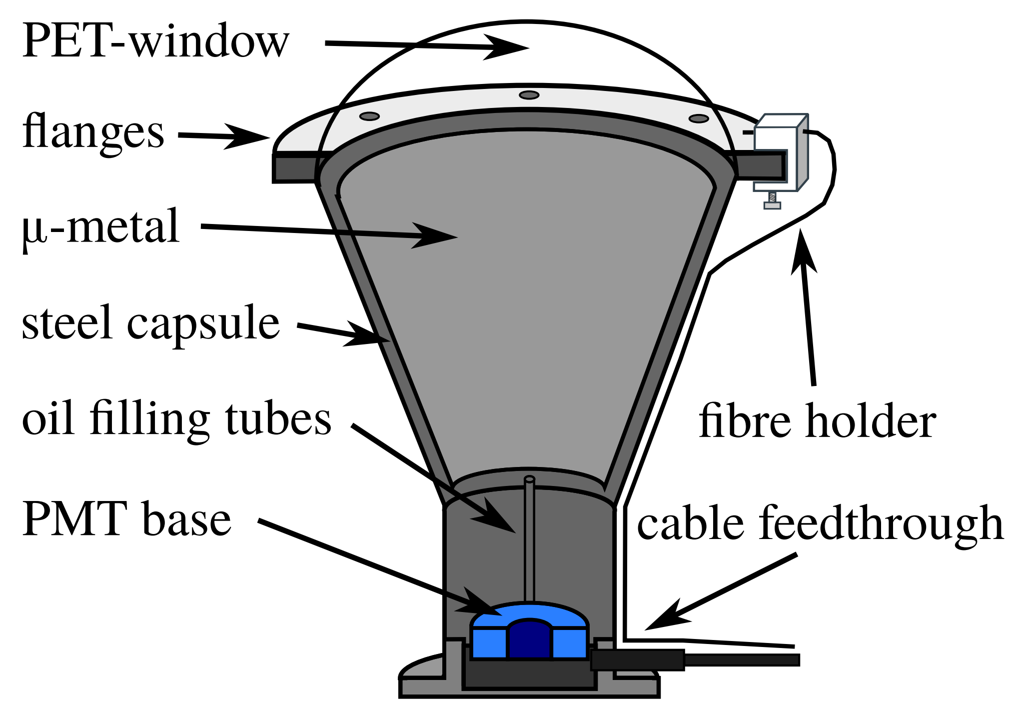
$$T_{1/2}^{0\nu} \simeq \sqrt{\frac{M \cdot t}{B \cdot \Delta E}} \;\; [yr]$$

- ***More mass:*** From the available 37.5 kg enriched germanium 30 new detectors were produced (~20 kg)
- ***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

Muon veto

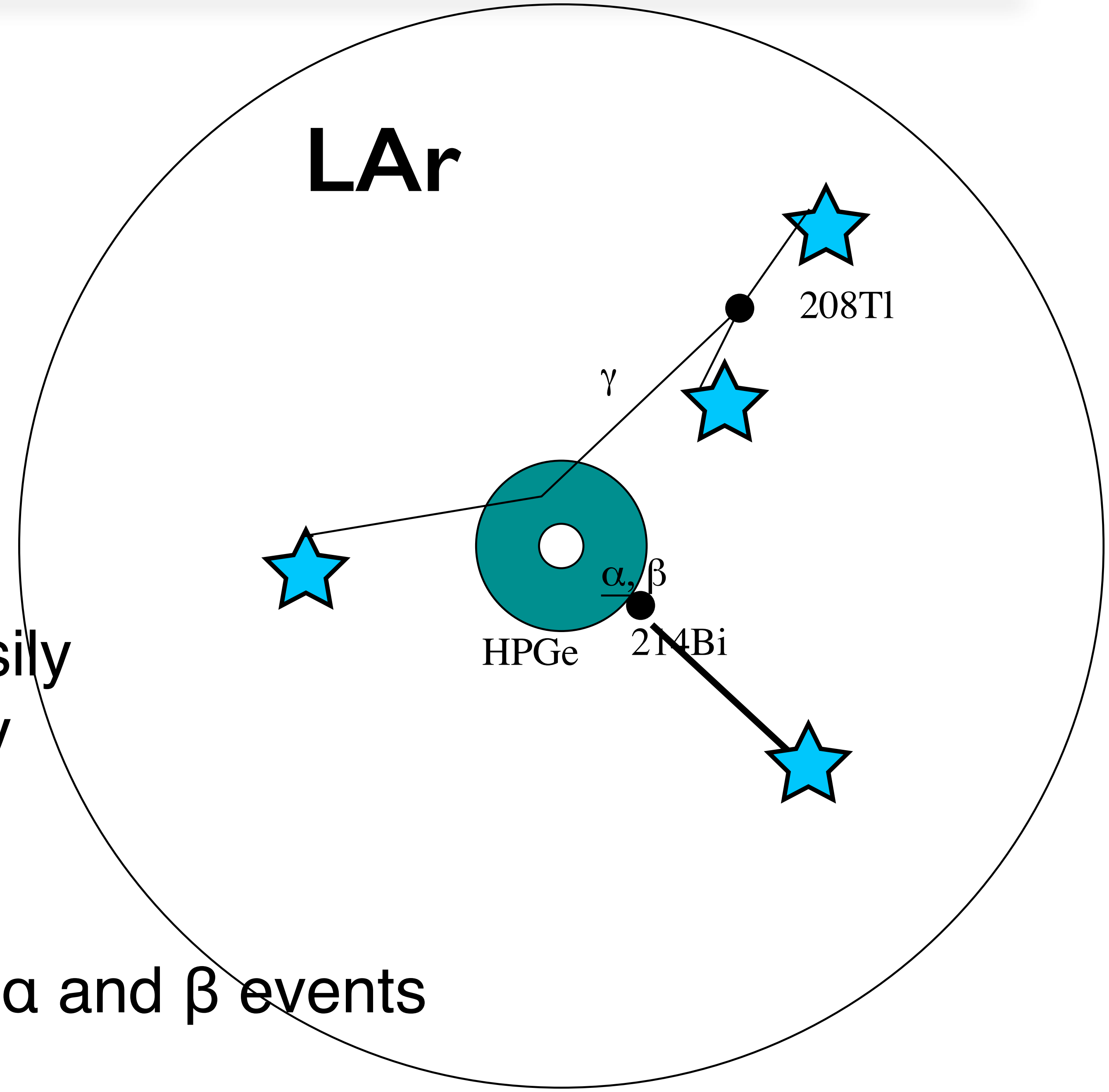


- 66, 8” PMTs in a ~600 m³ water tank



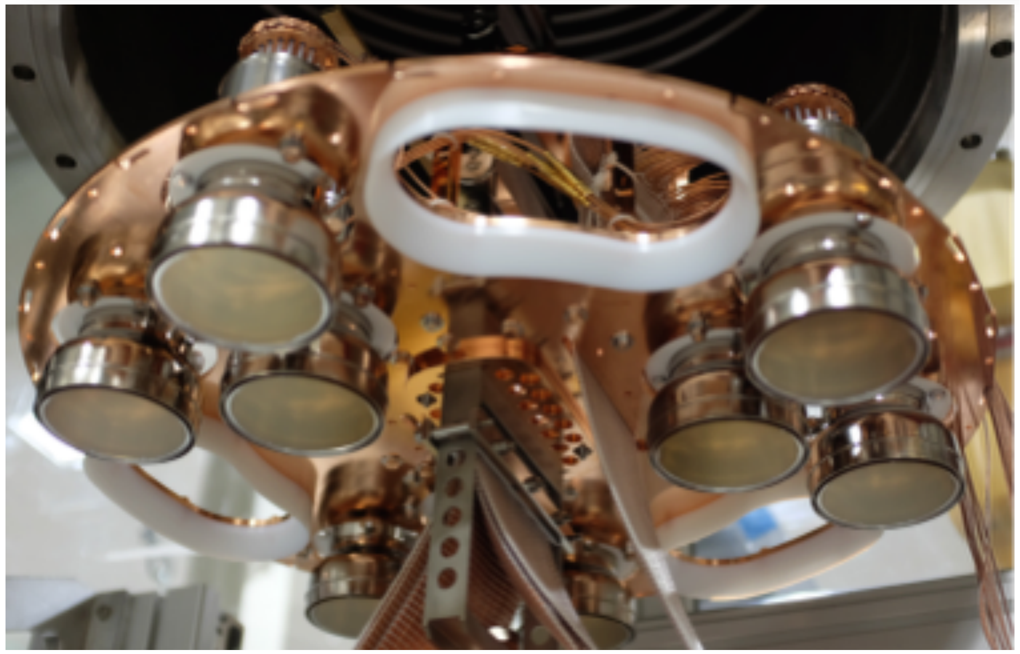
LAr veto - The concept

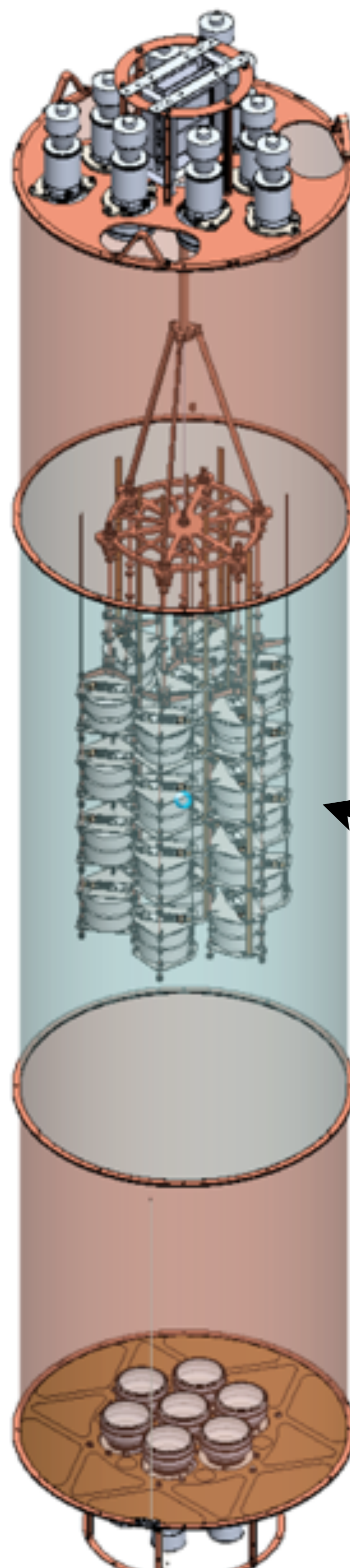
In the Region of Interest around 2039 keV



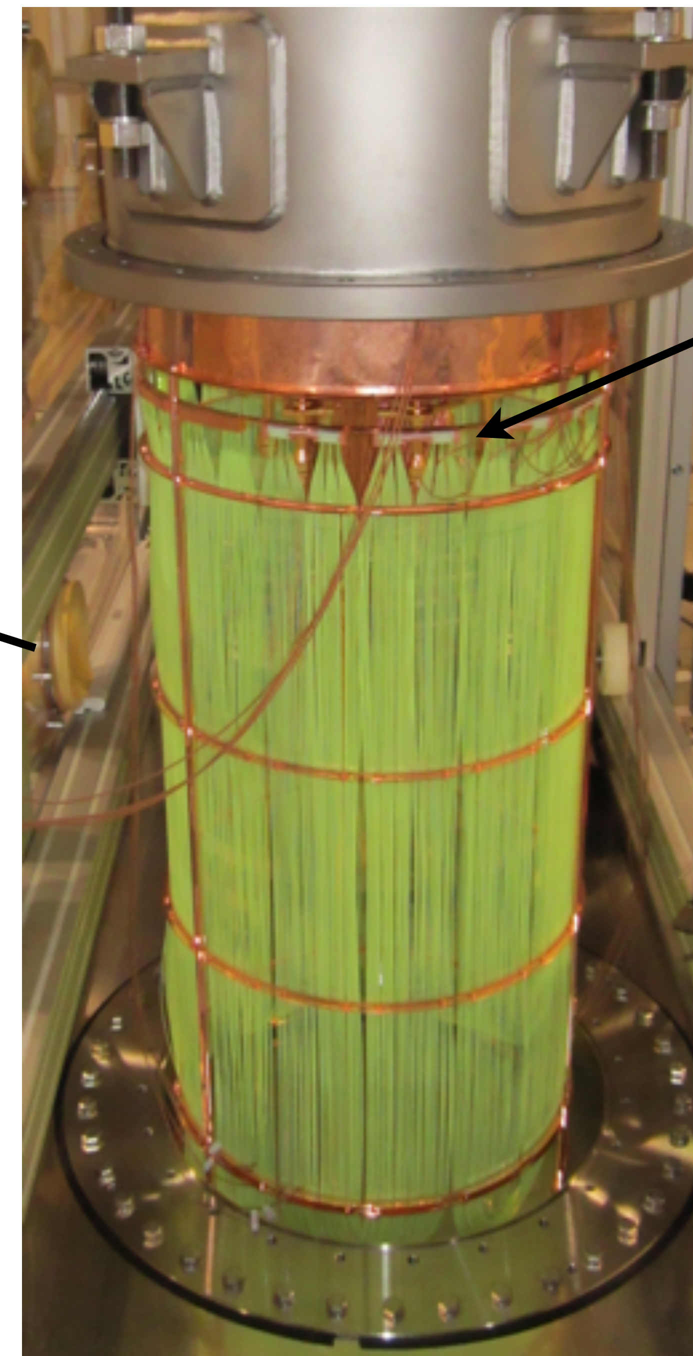
- Nearby ^{208}Tl events can be easily vetoed with very high efficiency
- Veto for ^{214}Bi is less effective
- Does not work well for surface α and β events
  - Veto efficiency in GERDA will strongly depend on the origin of the background

LAr - veto





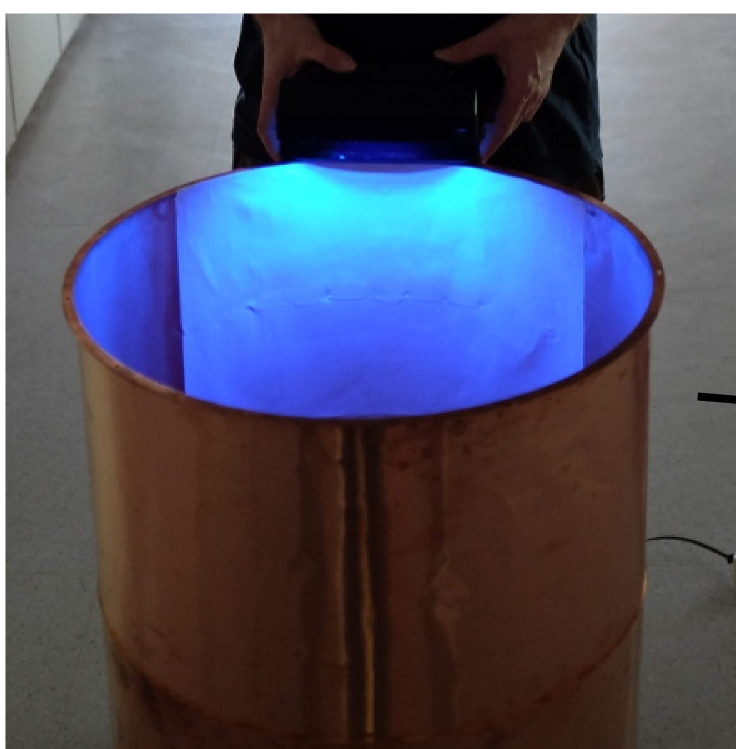
3" low-background PMT
Hamamatsu R11065-20



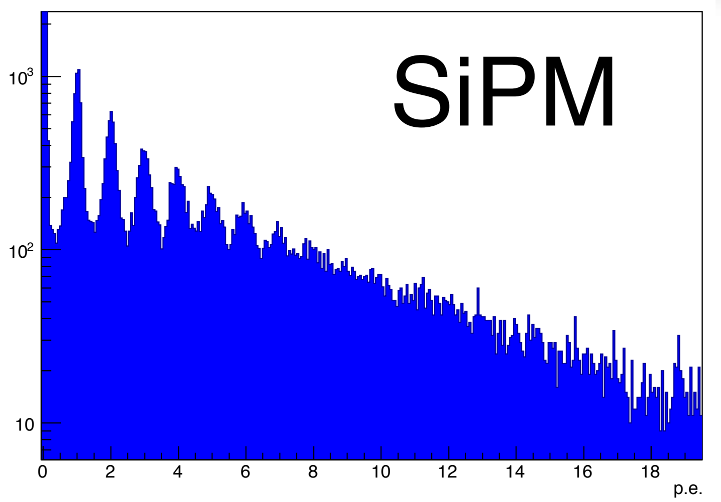
SiPMs

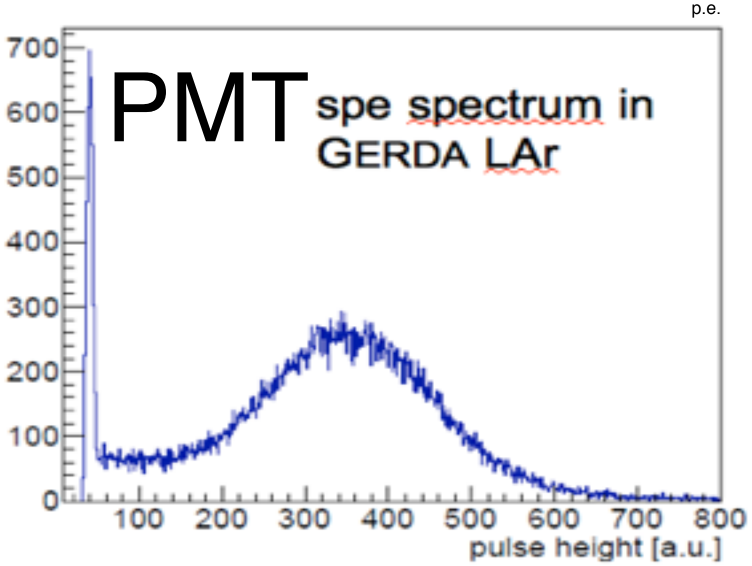
Fiber "shroud"
800 m WLS
fibre coated
with TPB

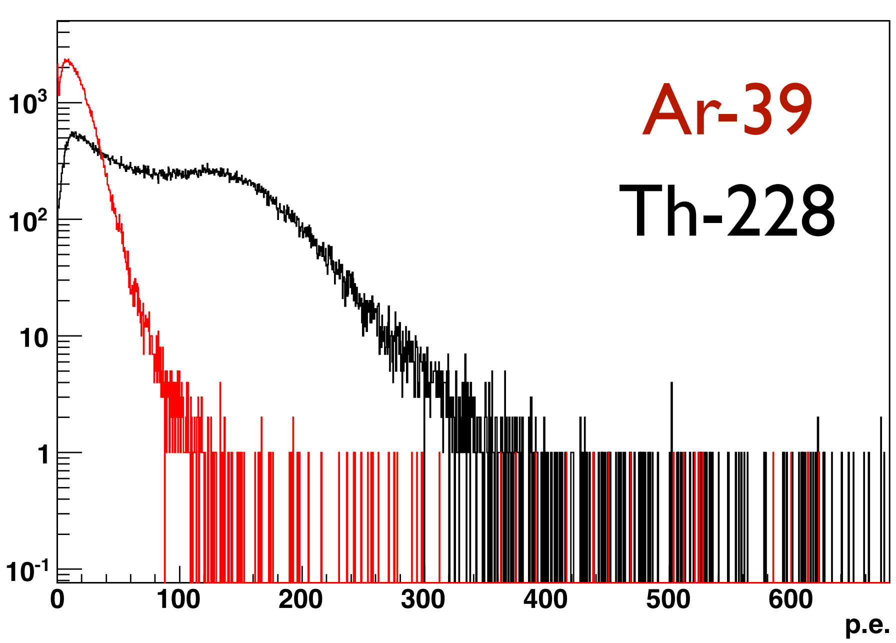
Copper "shroud" with
Tetratex reflector coated
with TPB



LAr veto commissioning

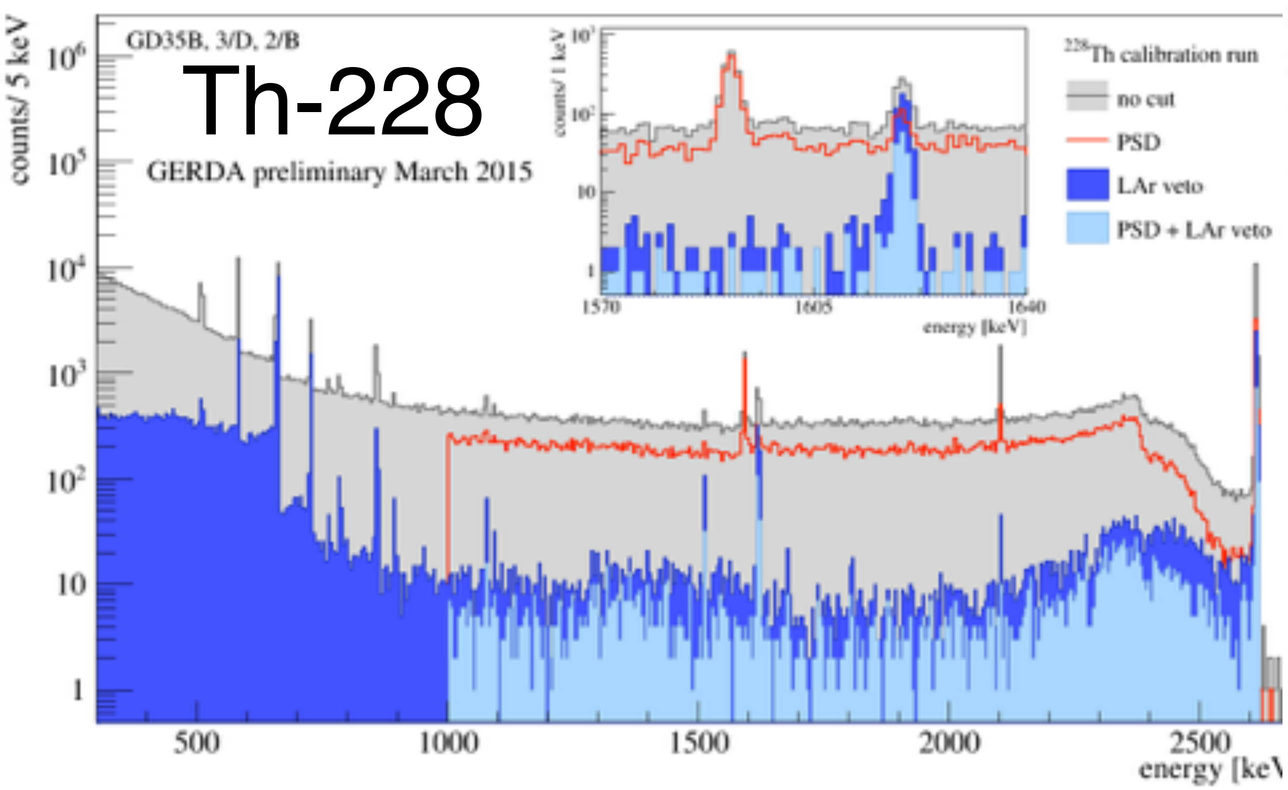


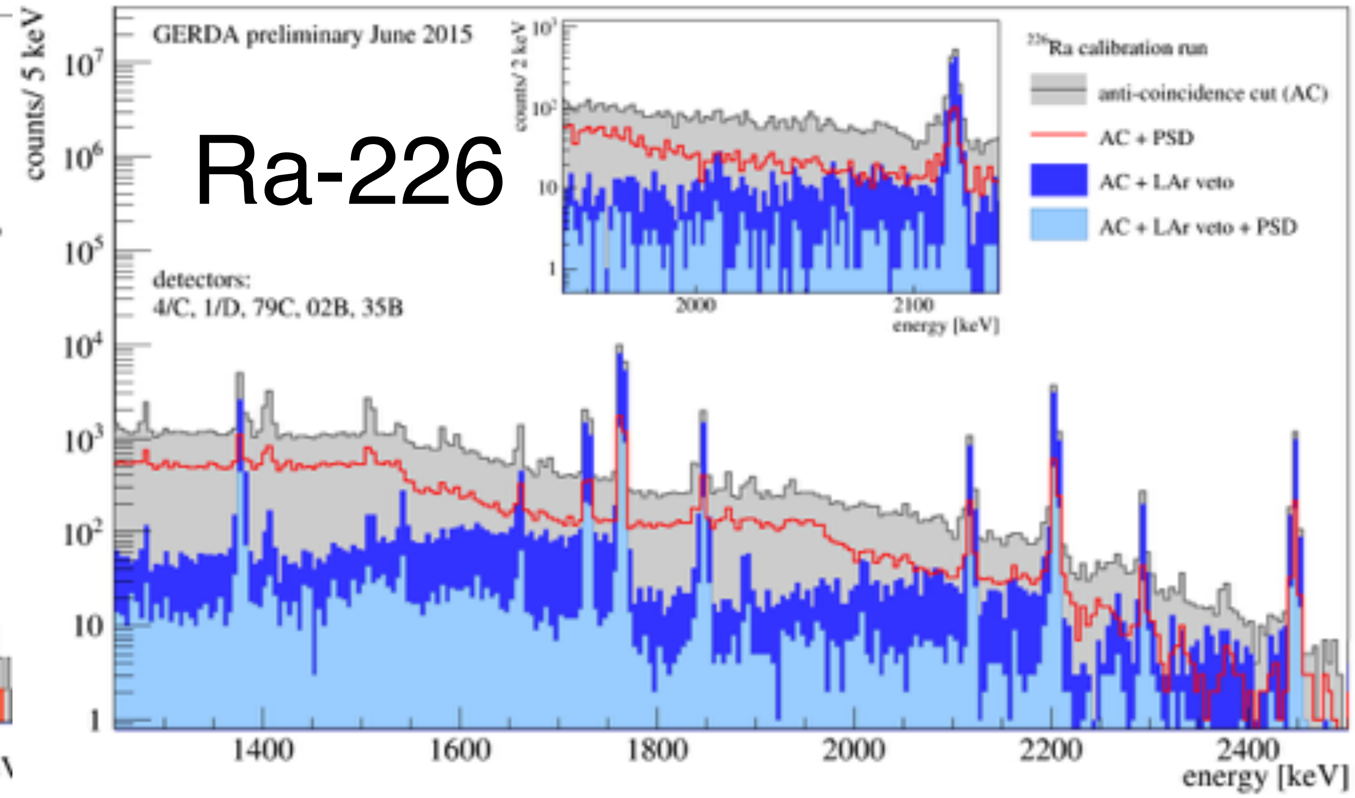




- "Photo-electron" peaks recognisable in the amplitude spectrum - in both SiPMs and PMTs spectra
- Veto on one photo-electron in any channel
- After single channels calibrated and summed up: light yield: 50 - 60 p.e./MeV - with ^{228}Th source
- Count rate dominated by ^{39}Ar
- LAr -veto Suppression Factor tested with one detector string with ^{228}Th and ^{226}Ra sources

LAr veto commissioning





Suppression of:	Ge Anti-Coincidence	LAr-veto	PSD	LAr + PSD	Acceptance
^{228}Th	1.26 ± 0.01	97.9 ± 3.7	2.19 ± 0.01	344.6 ± 24.5	86.8%
^{226}Ra	1.26 ± 0.01	5.7 ± 0.2	2.98 ± 0.06	29.4 ± 2.5	89.9%

More on SiPMs

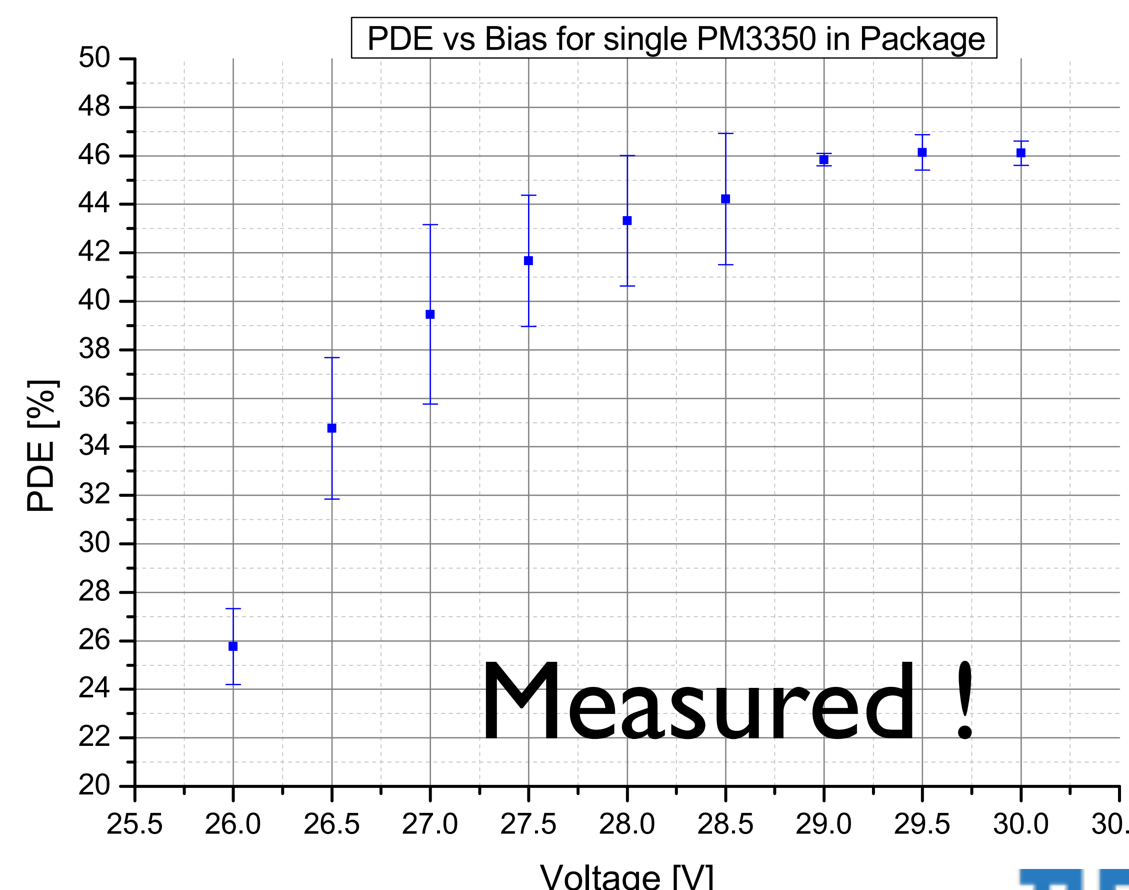
LAr - veto, SiPMs

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



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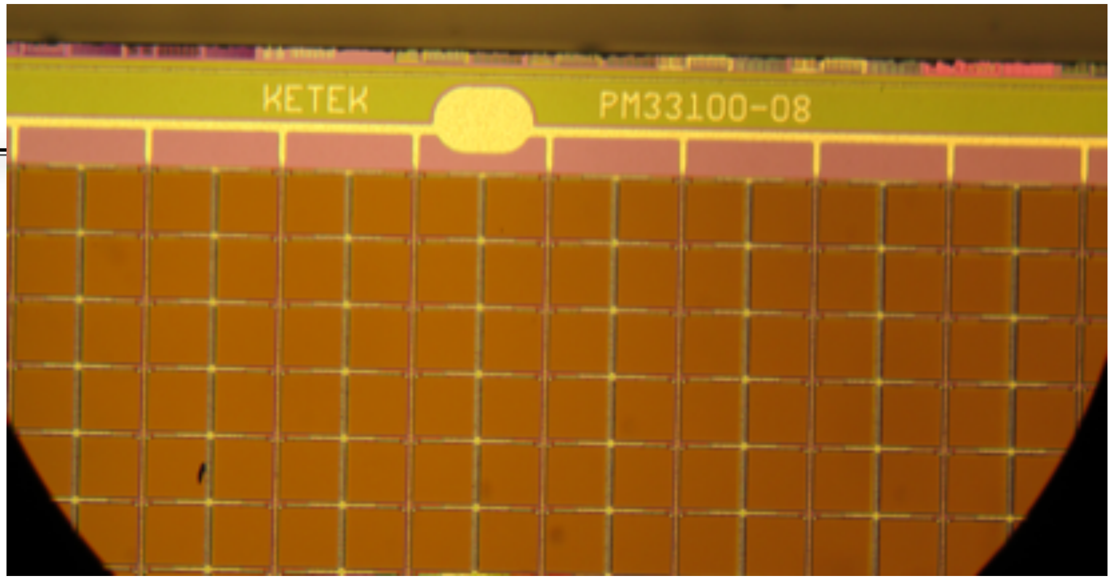
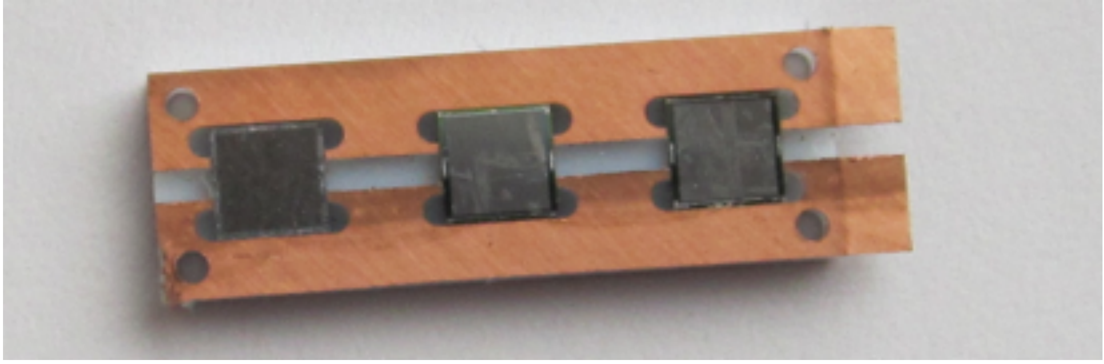
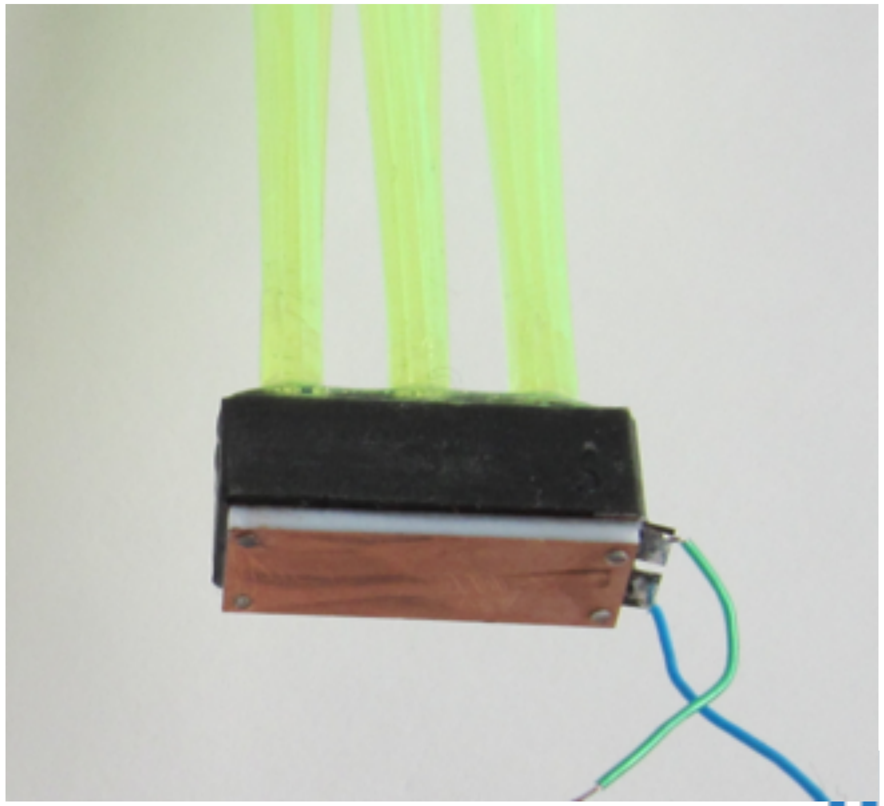
Ketek SiPMs

- *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*







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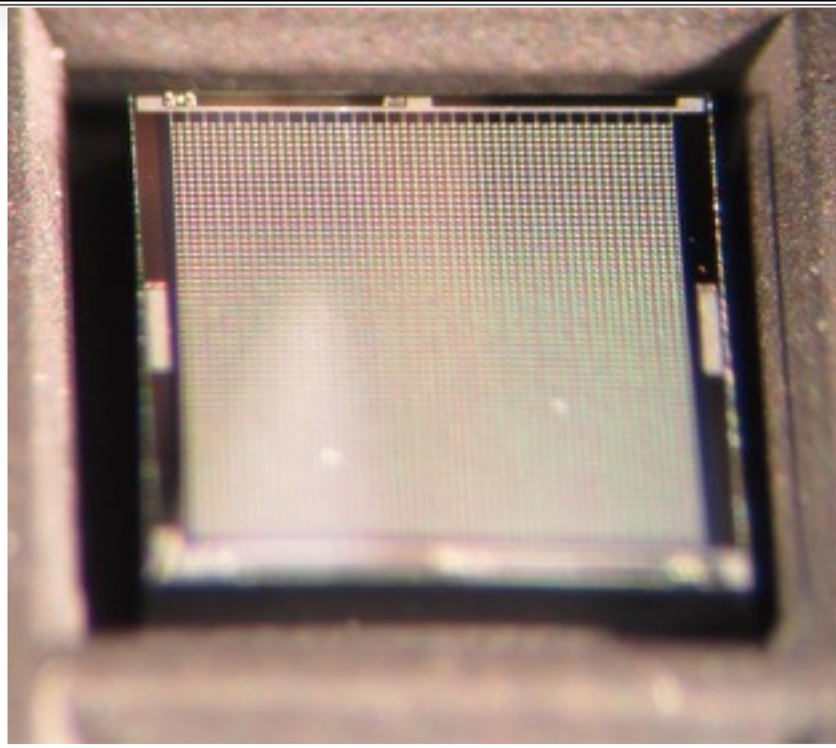
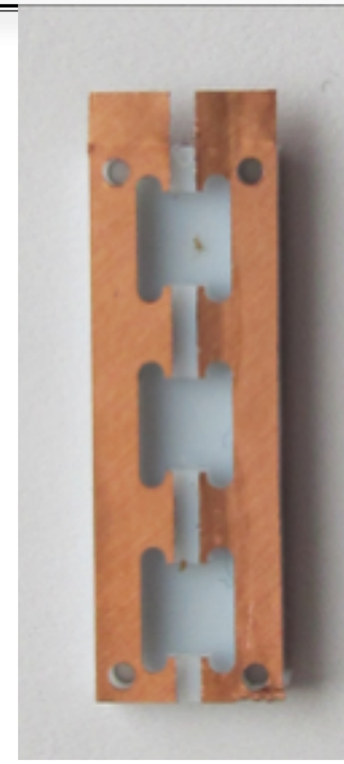
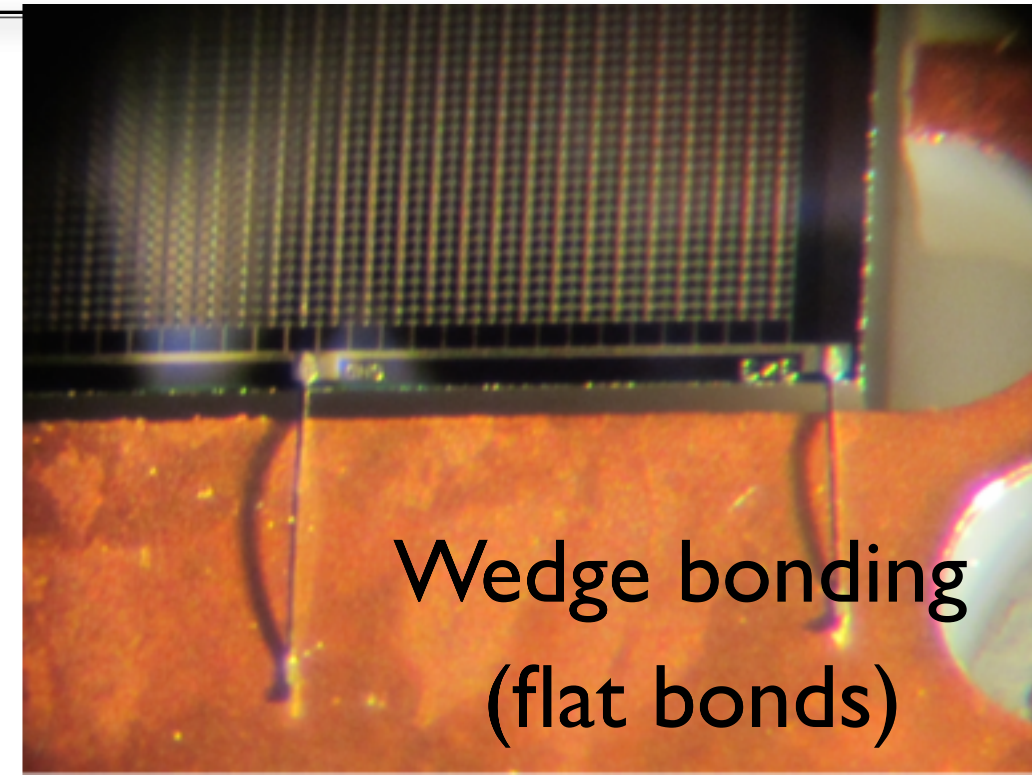
SiPM packaging



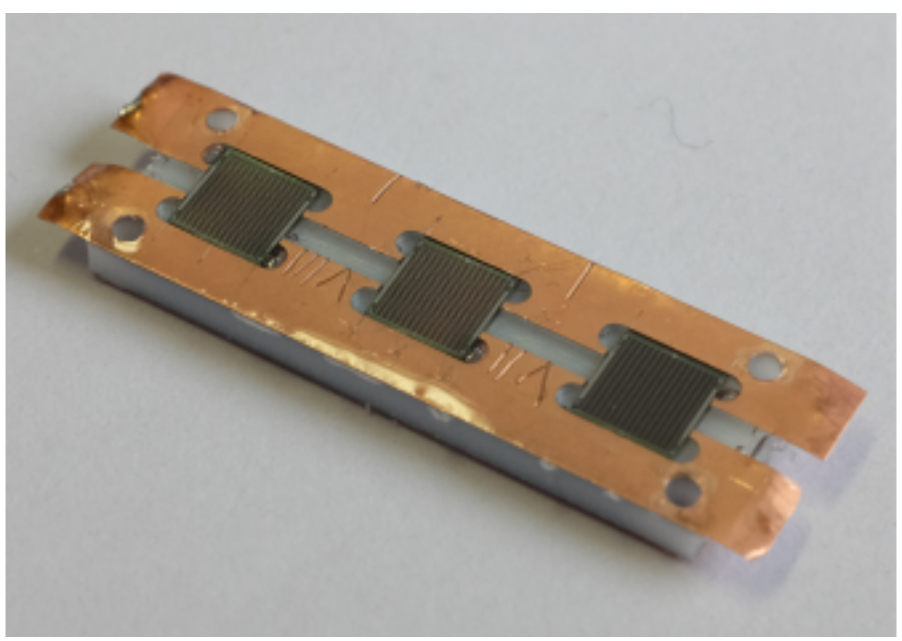
Chips in waffle package



Cuflon PCB

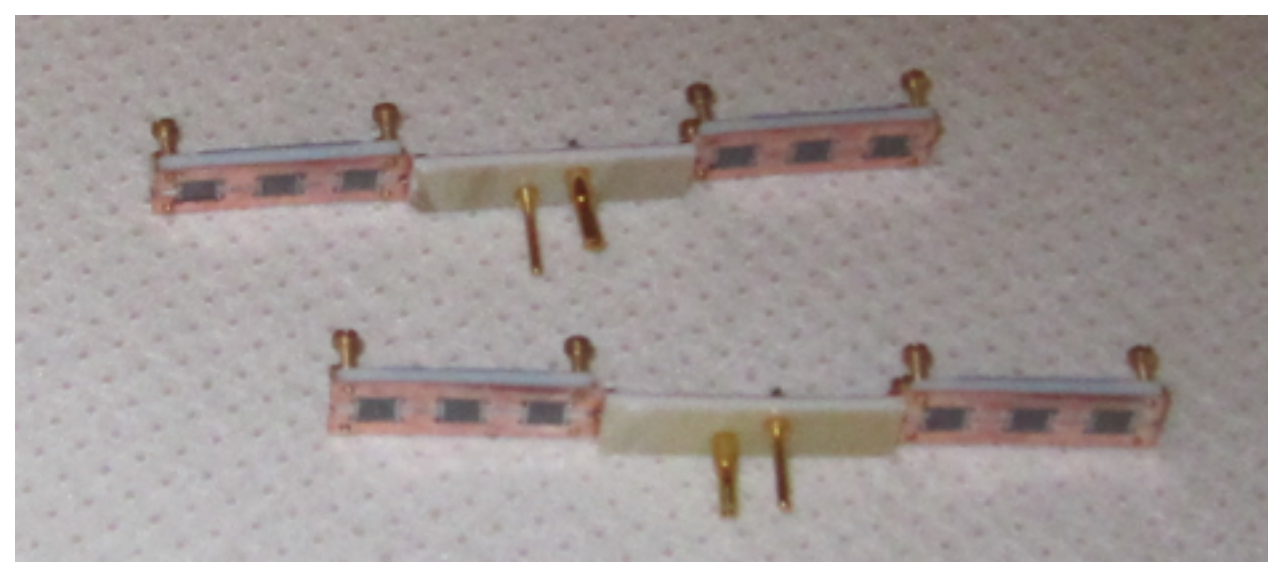


Wedge bonding
(flat bonds)



transparent epoxy

Arrays of 6 SiPM

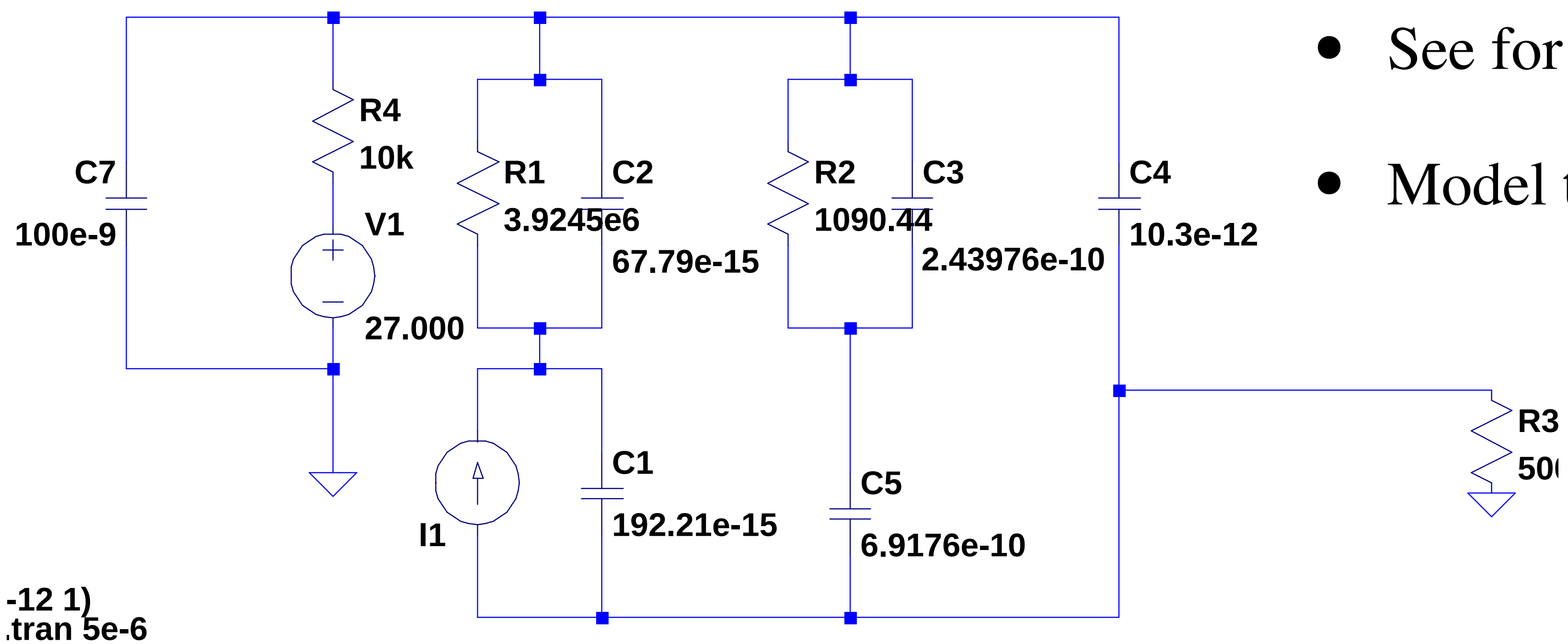


On SiPM packaging

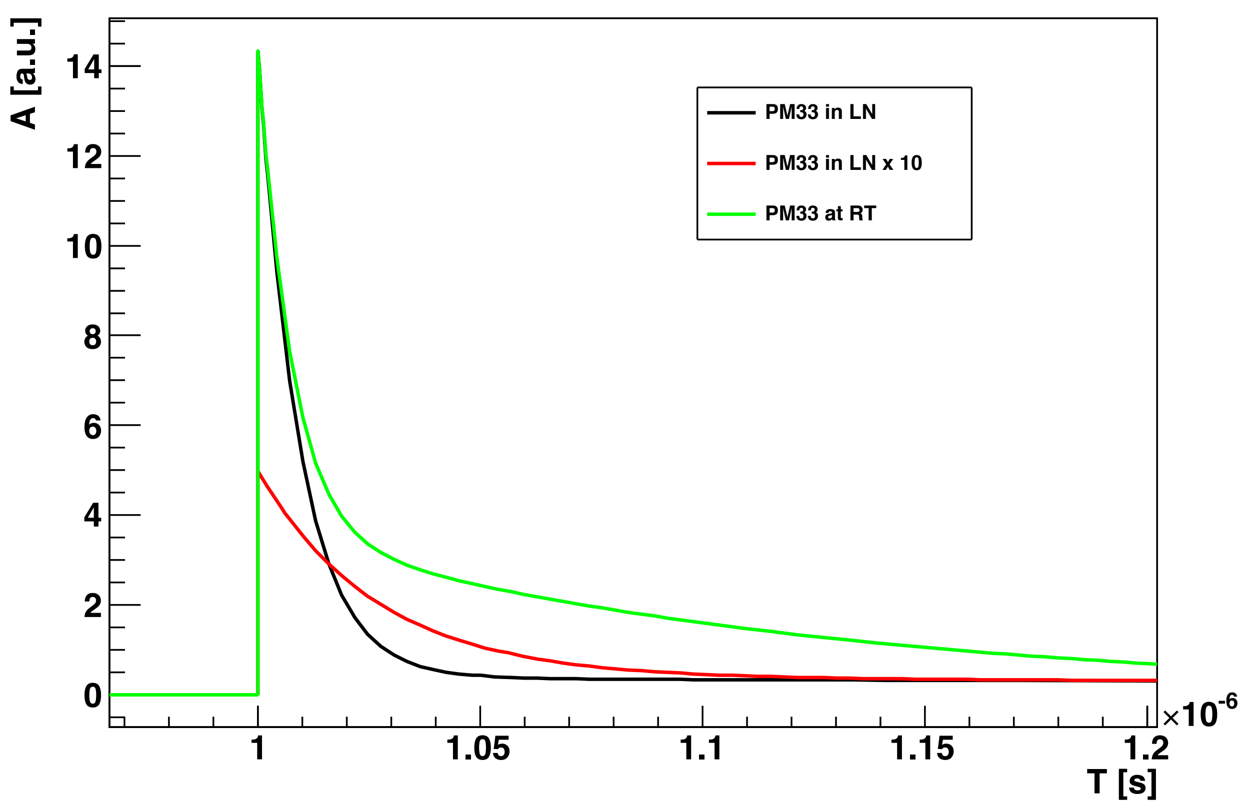
Why bare chips or self made packaging ?

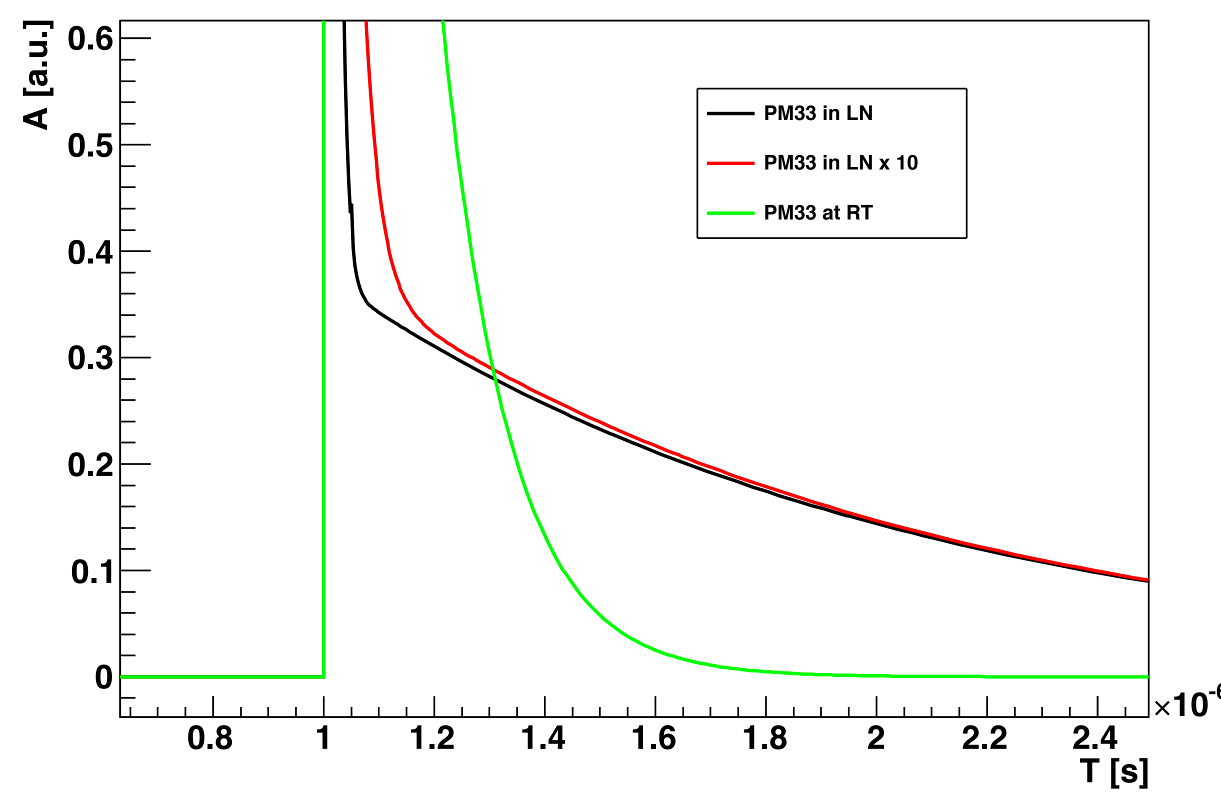
- SiPMs small and made of pure Si - major advantage over PMTs
  - allowed materials for low background experiments: silicon, synthetic quartz, electrolytic copper, some plastics
- Bare chips sensitive down to 160 nm (SiO_2 cutoff)
  - direct detection of VUV light might be possible
  - in the future we could have MgF_2 coating (sensitivity down to 120 nm)
- Integration problem: front-end (ASIC) should be close to the chip while maintaining radiopurity - one substrate for all
  - connectors & cables our biggest problems

Spice model of the SiPM

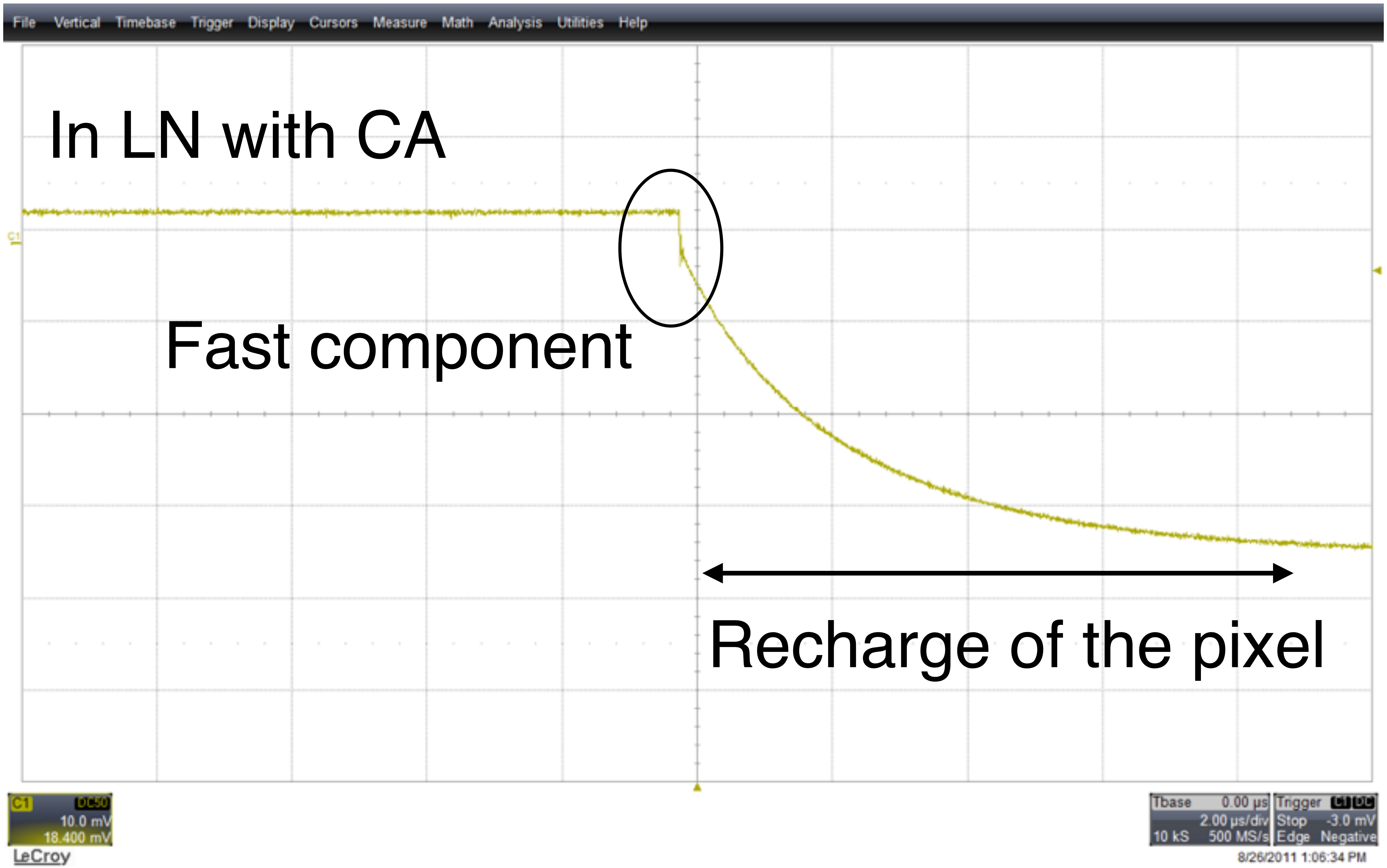


- See for example: NIM A 572 (2007) 416–418
- Model tuned for Ketek SiPMs in LN

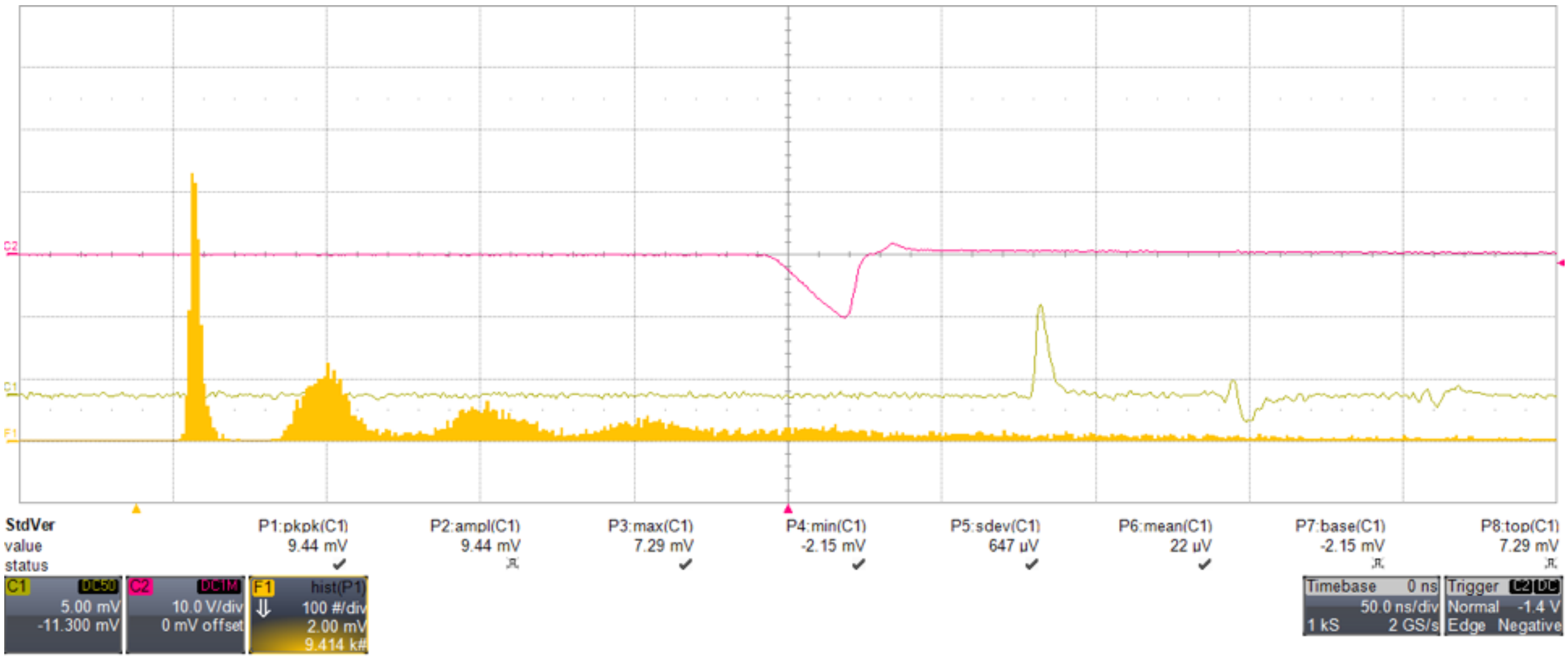




Ketek SiPM: Charge integral

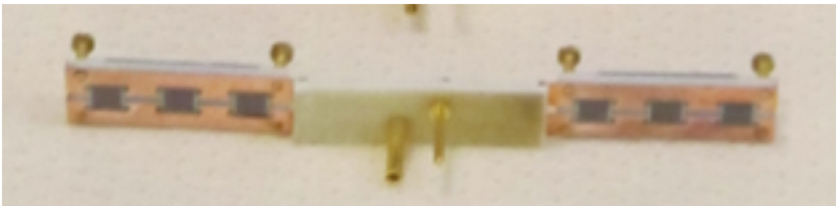


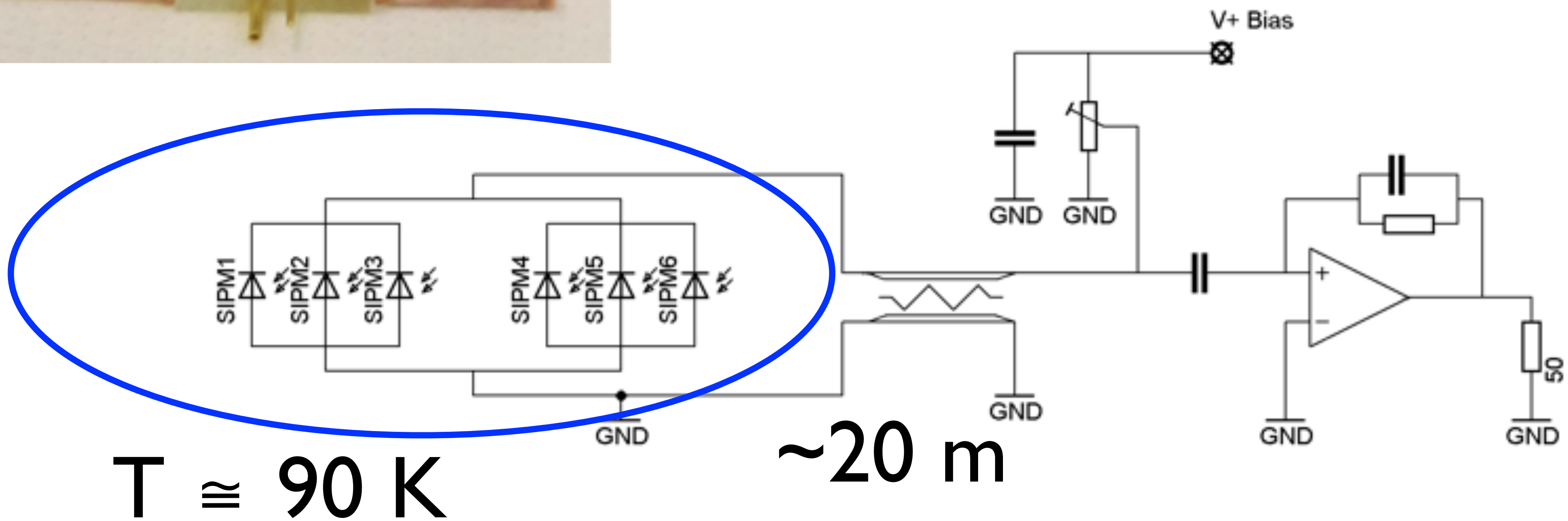
Ketek 100 µm SiPM: Fast pulse



- Fast component: low gain
- Depends on the pixel size (capacity), here 100 µm.
- Single photon (pixel) resolution preserved

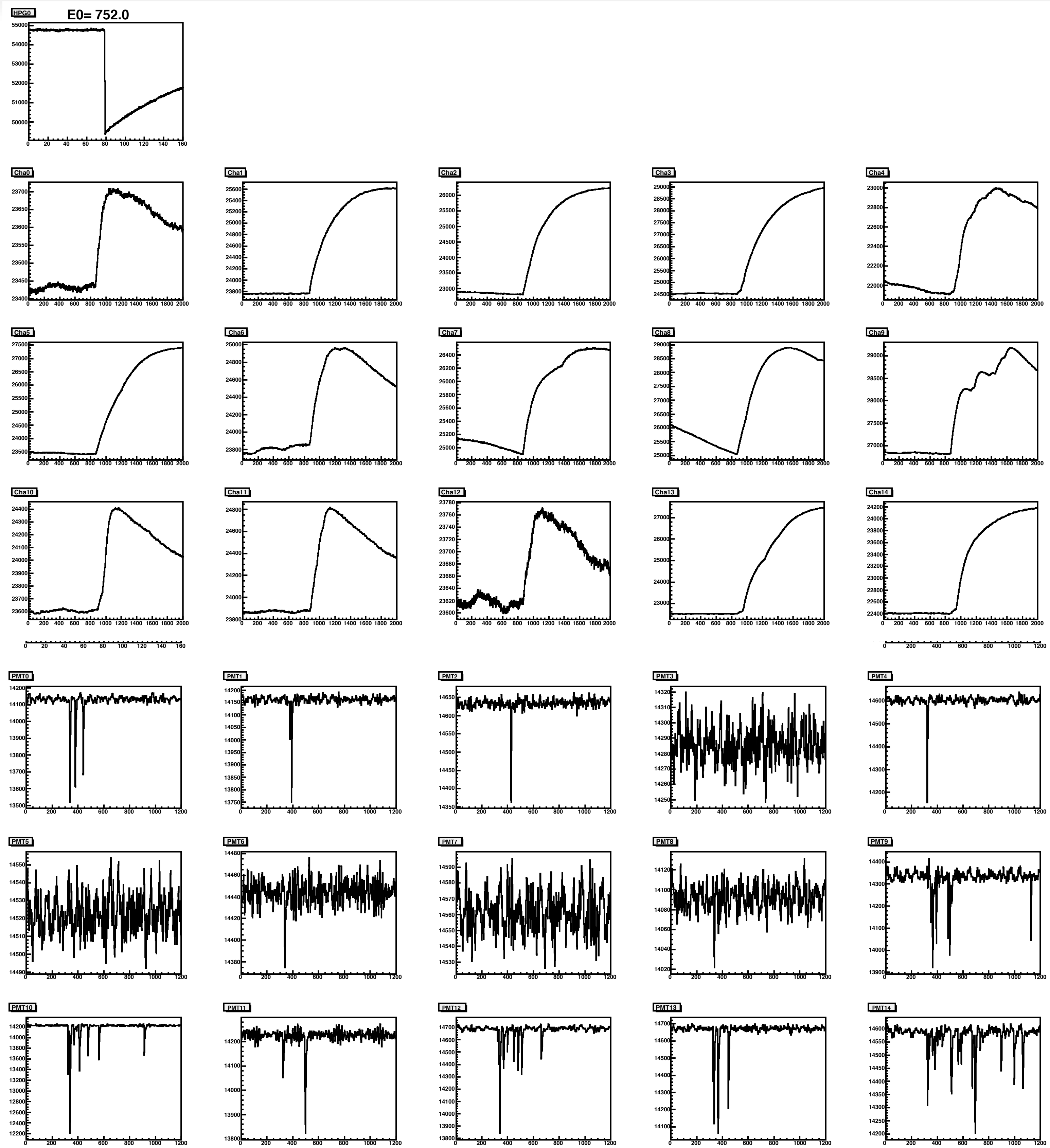
GERDA SiPM read-out





- 6, 3x3 mm² SiPM in paralel: no electronics in LAr!
- 20 m, 50 Ω cable to the amplifier
- Read-out from the 'high voltage' side

LAr - veto

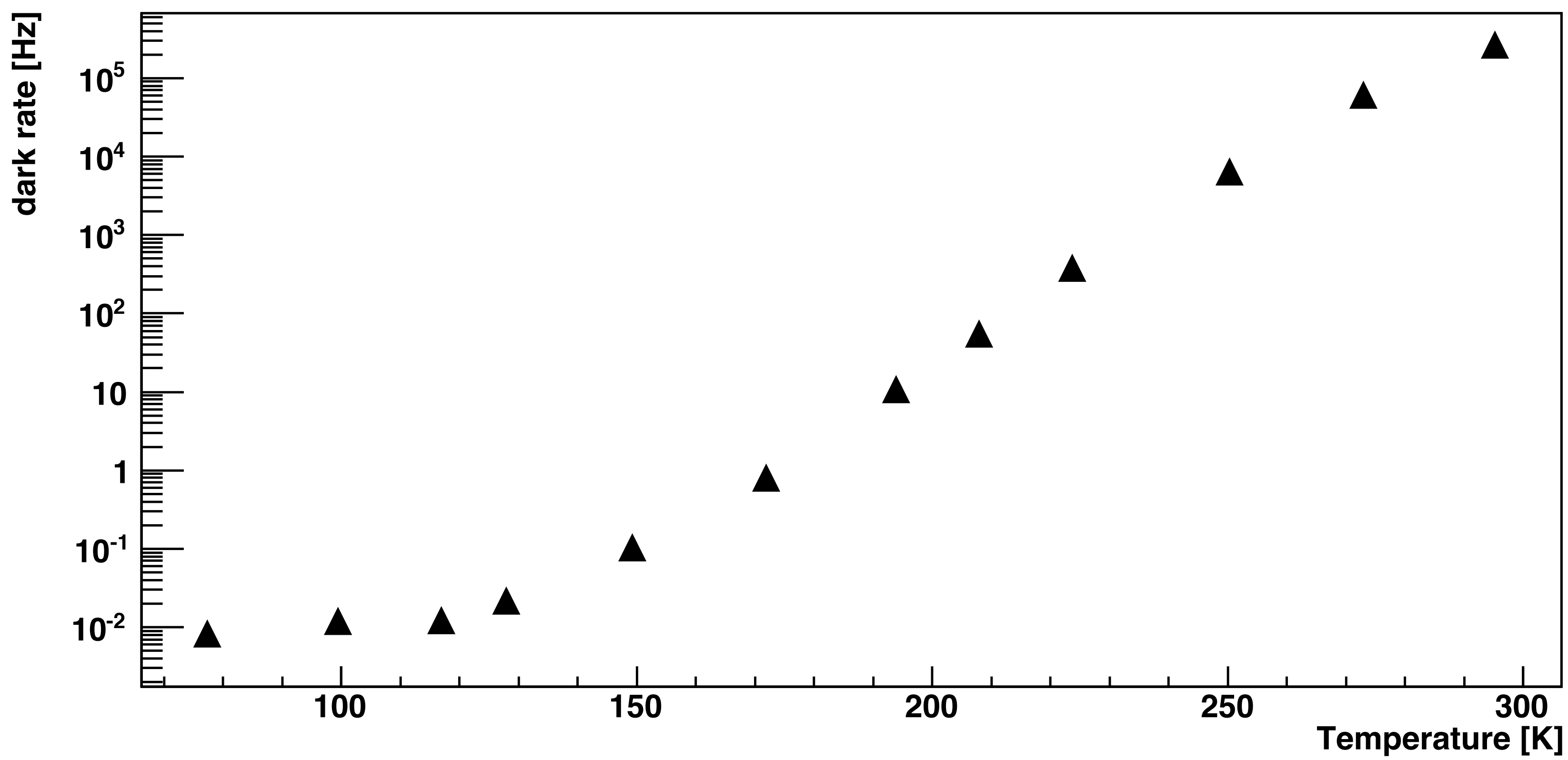


HPGe - channel
160 µs - traces

15- SiPM channels
80 µs - traces
80 ns resolution

16 - PMT channels
12 µs traces
10 ns resolution

SiPM Dark Rate



- Measured with Hamamatsu MPPC 50 µm pixel 10^{-2} Hz/mm^2 in **LN**
- Ketek 3x3 mm, 50 µm, ~ 1 Hz = 10^{-1} Hz/mm^2
- 100 cm^2 SiPM array would have ~1 kHz DR in **LAr**
    - In **LXe** the DR is 10 kHz or 100 kHz ?
- How does the DR depend on SiPM design, production process, wafer quality?

➡ Systematic study needed

Future ...

Demand:

- Gerda - like - 200 kg HPGe experiment (maybe 1 ton experiment ?)
  - probably the same technology as GERDA

Other Cryo-liquid experiments:

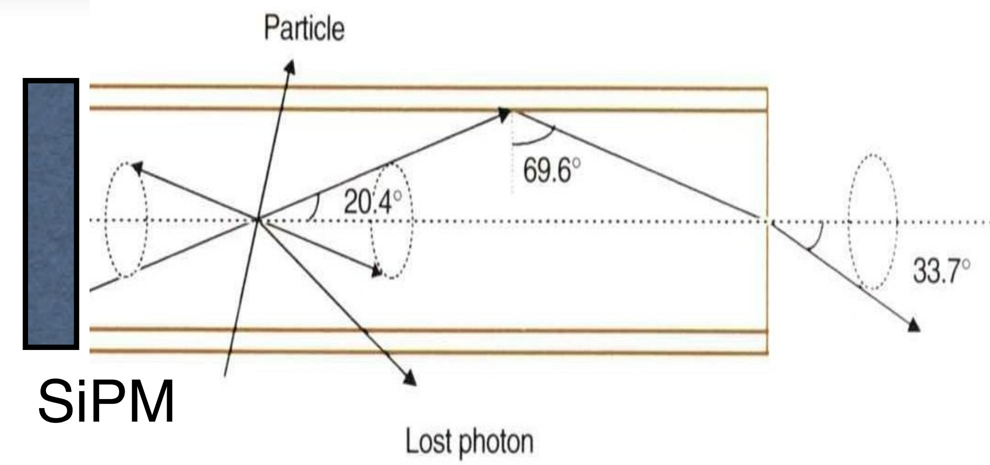
- Xe - double beta decay (nEXO), dark matter Xe-TPC. (Xe-1t, LZ)
- Ar - dark matter: Ar-TPC, HEP: DUNE

Offer:

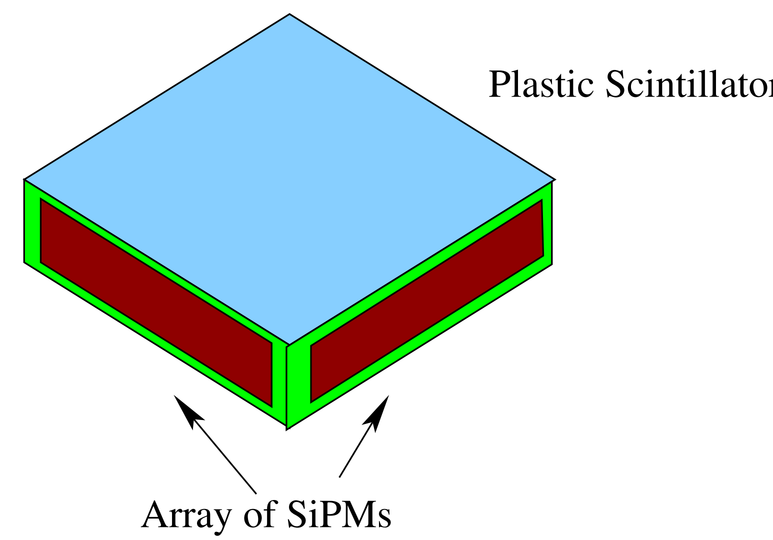
- PMTs still have reliability problems in LAr
- Low background experiments will have to phase out PMTs
- SiPMs are OK but too small

Possible technology

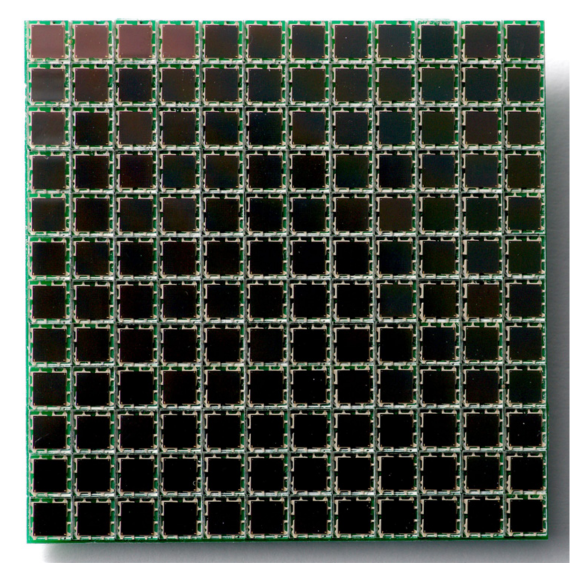
- Instrument tons of LAr with WLS fibers or scintillator bars - with SiPM read-out
    - Max. 14% trapping efficiency, total efficiency ~5% for a narrow wavelength



- 2D WLS ‘fiber’: WLS plates with SiPMs on the edges
    - trapping efficiency up to 30% possible at the right wavelength, 10% det. eff.



- Highest possible p.d.e. ⇒ large SiPM array
    - 40 - 60 % p.d.e.



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ASIC for large SiPM array

- Sum up the signal from 10÷100 cm^2 SiPM without adding up the capacity. (“amplifier” with ~100 inputs and 1 output channel)
- drive 50 Ω line (analog signal preferred)
- Should work at LN temperature
- available in ‘die’ (radiopurity requirement)
- ~mW power consumption, single rail power line (derived from SiPM bias)
- integrated bias circuit for ~100 SiPMs: equalise gain between SiPMs, current limit, shut down broken SiPM

We don’t need !

- signal rise time better than 10 ns
- dynamic range > 1000 / channel