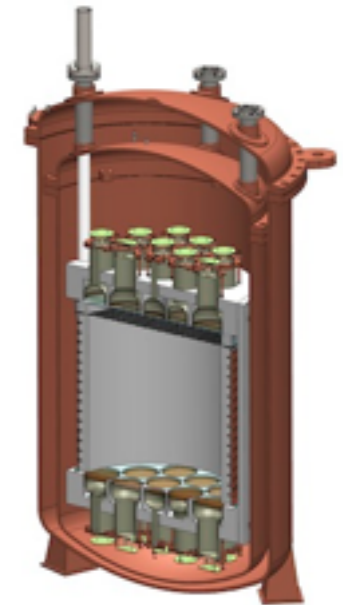
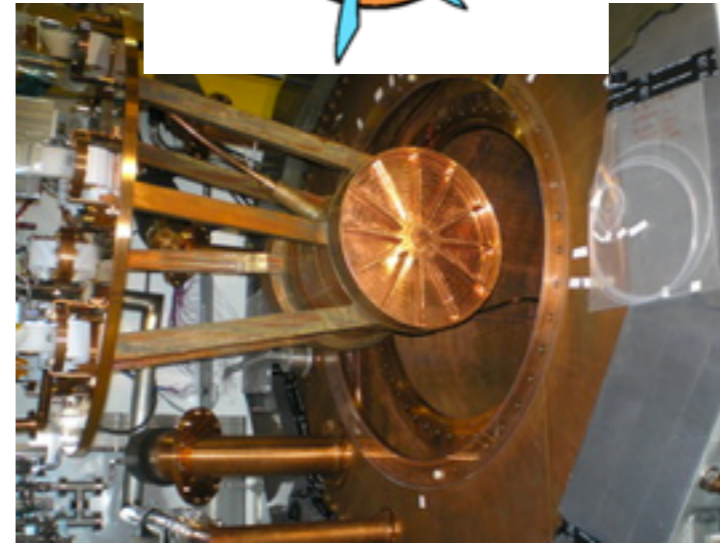


LAr scintillation light read-out with SiPMs and WLS fibers in GERDA

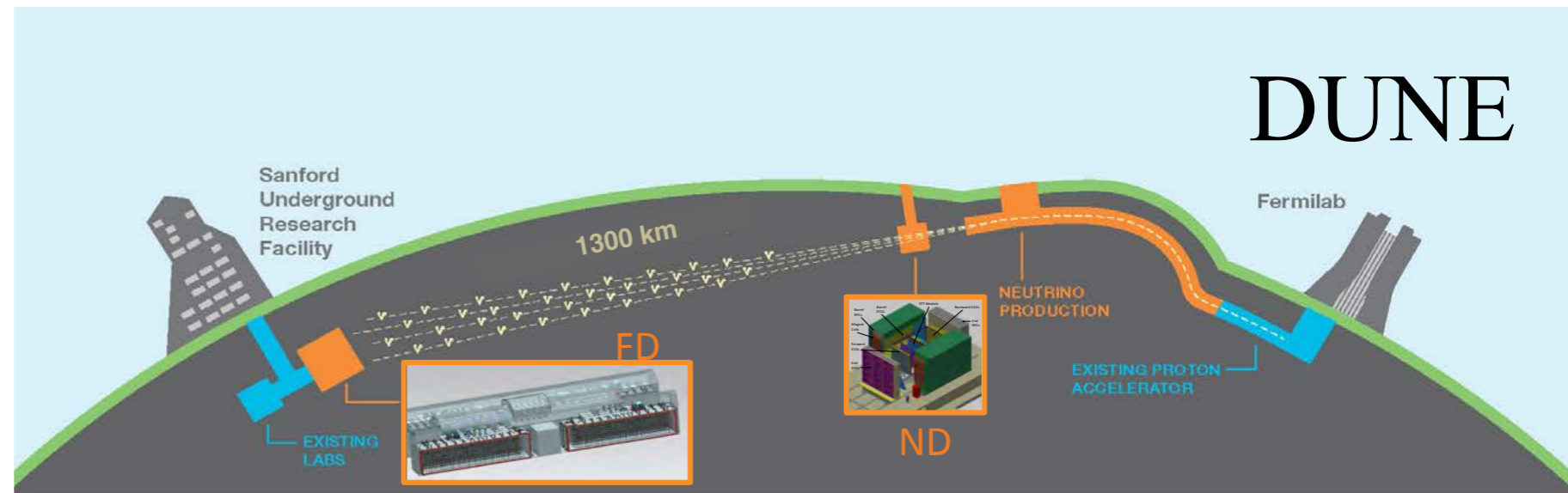
*József, Janicskó Csáthy
Technische Universität München*

Cryo-liquid experiments

- Noble liquids used as detection medium for $0\nu 2\beta$, dark matter and in HEP experiments
- The search for suitable light detector is a significant part of the R&D
- Problems all experiments share:
 - VUV light
 - low temperature
 - radiopurity



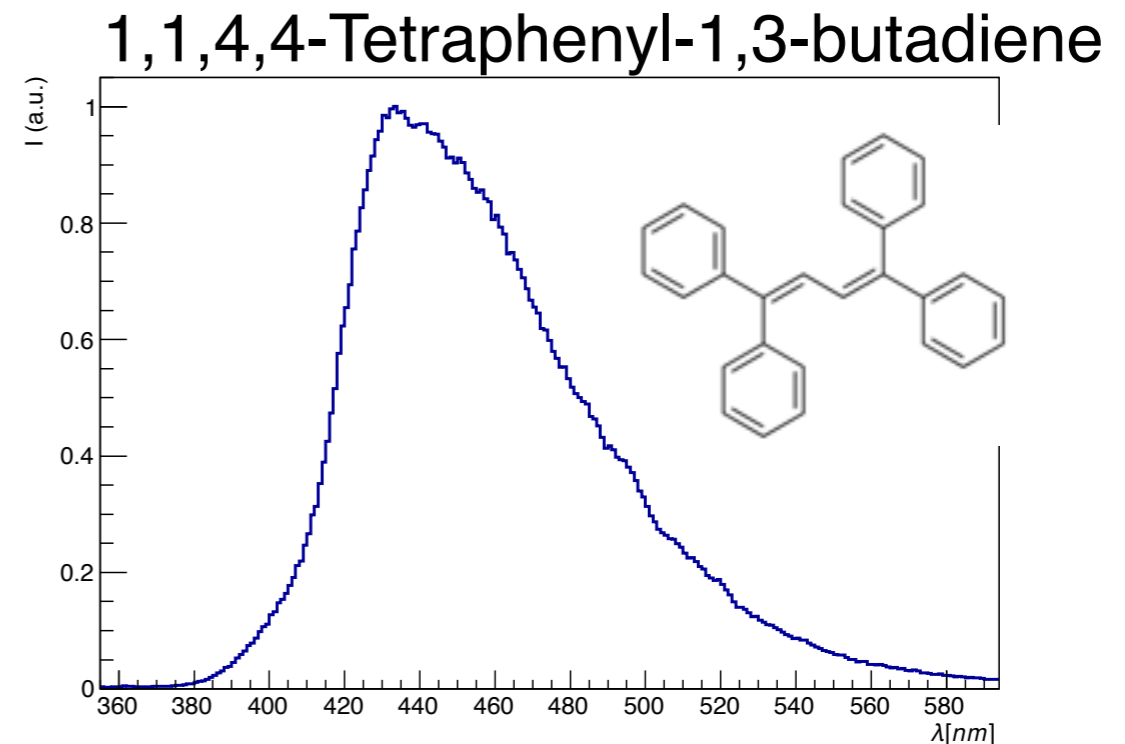
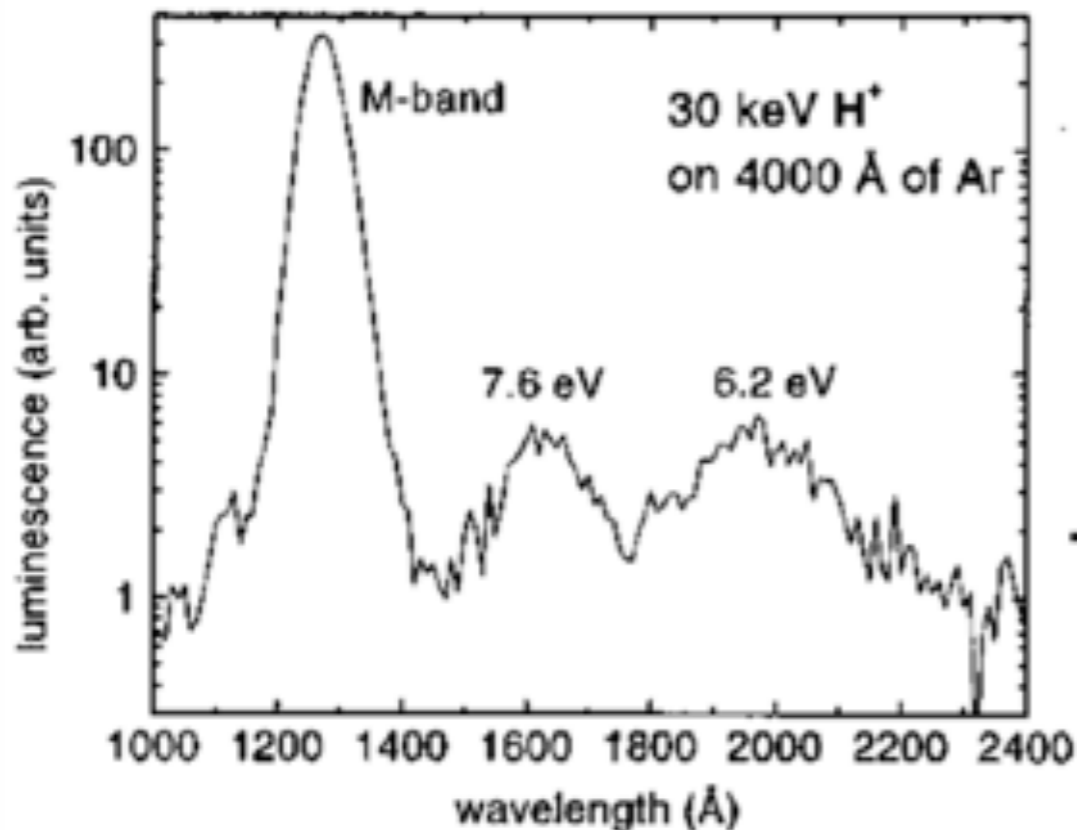
DarkSide-50



Noble - liquid scintillators

	A	ρ [kg/l]	T [K]	X_0 [cm]	λ [nm]
He	4	0.125	4	756	80
Ne	20	1.2	27	24	80
Ar	40	1.39	87	14	128
Kr	84	2.41	120	4.5	148
Xe	131	2.94	165	2.9	170

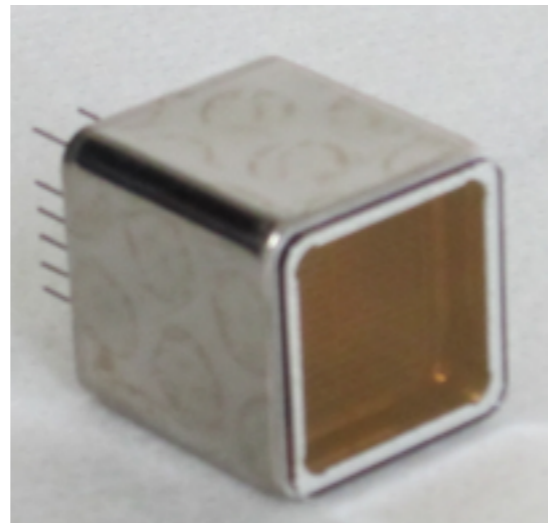
- wavelength from 80 to 170 nm
- LAr is the cheapest and LXe is the heaviest target
- direct detection down to 120 nm possible
- scintillation light converted to visible with TPB



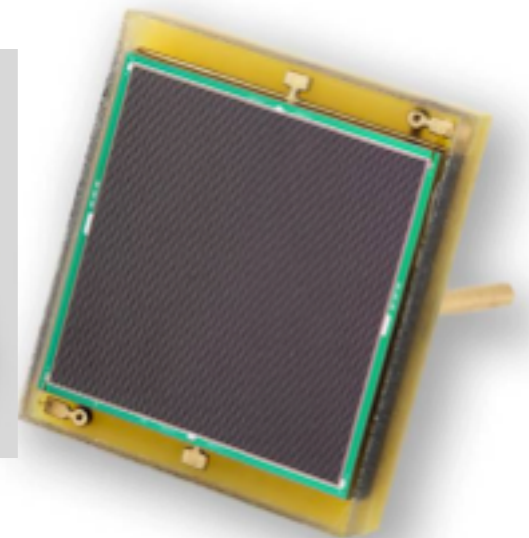
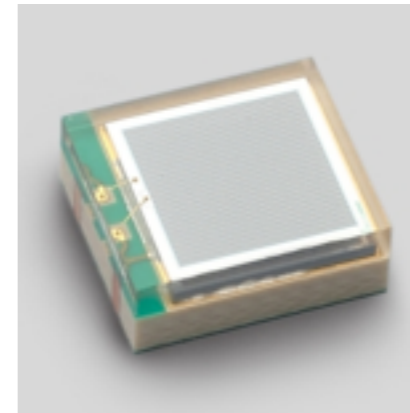
Detectors for LAr temperature



R11065-XX



R8520-XXX

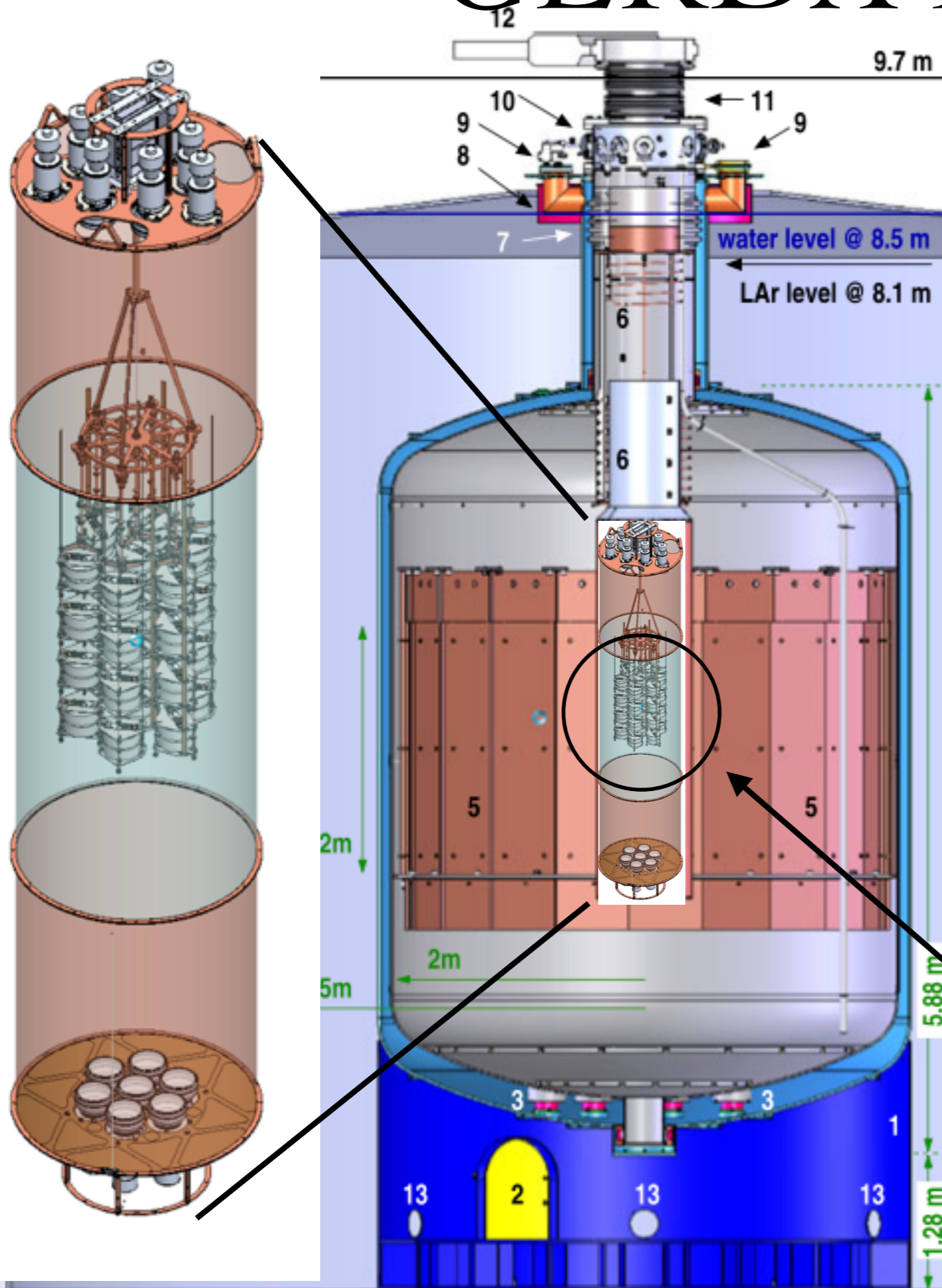


SiPMs

- 8" PMTs Hamamatsu and ETL
- Metal housing PMT's from Hamamatsu
 - 3" and 1" version are used practically by all low background experiments
- SiPMs from several manufacturers
 - The only experiment with large SiPM arrays in LAr is GERDA

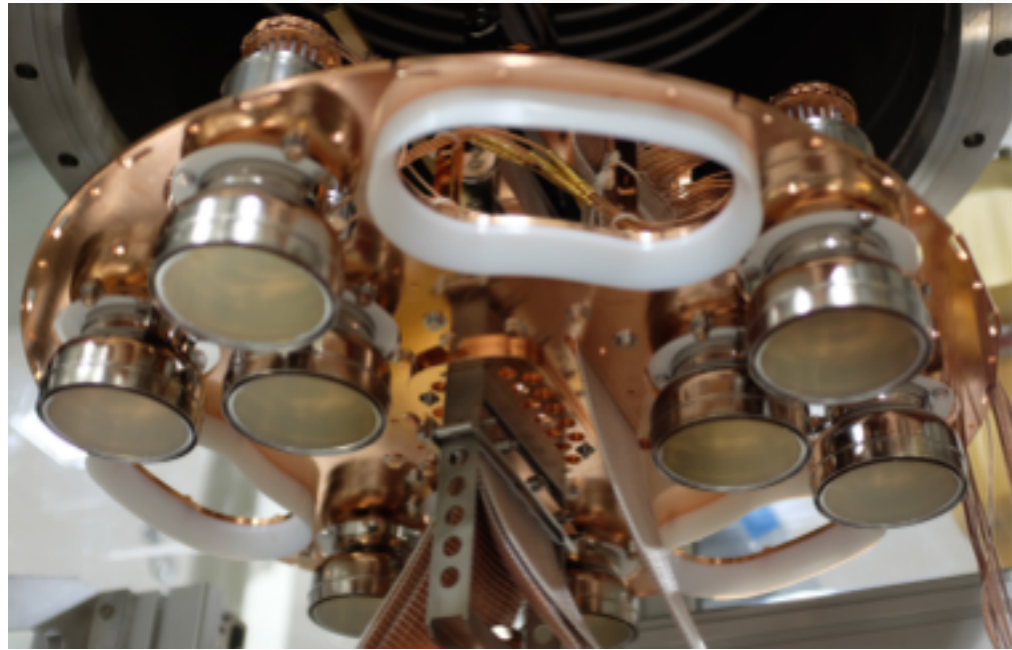


GERDA LAr veto

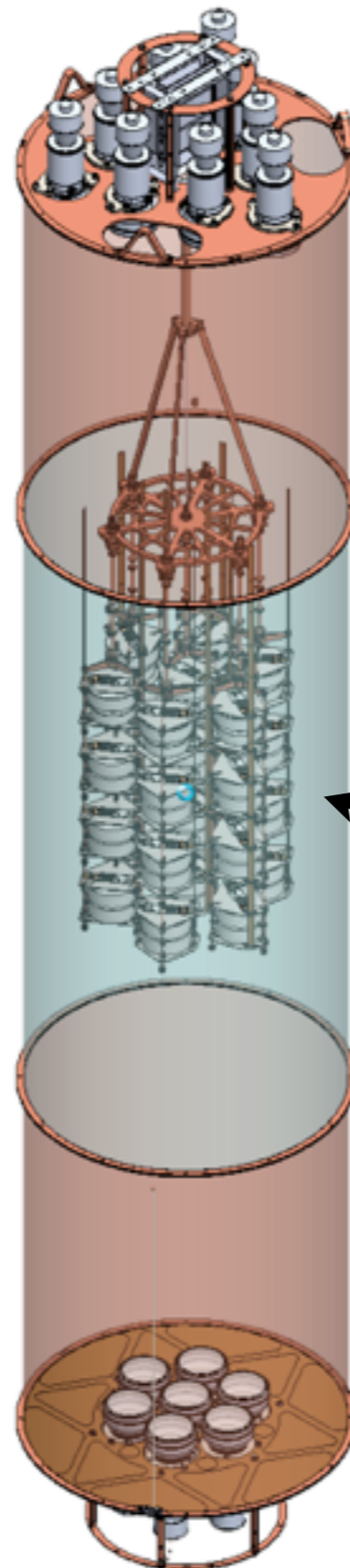
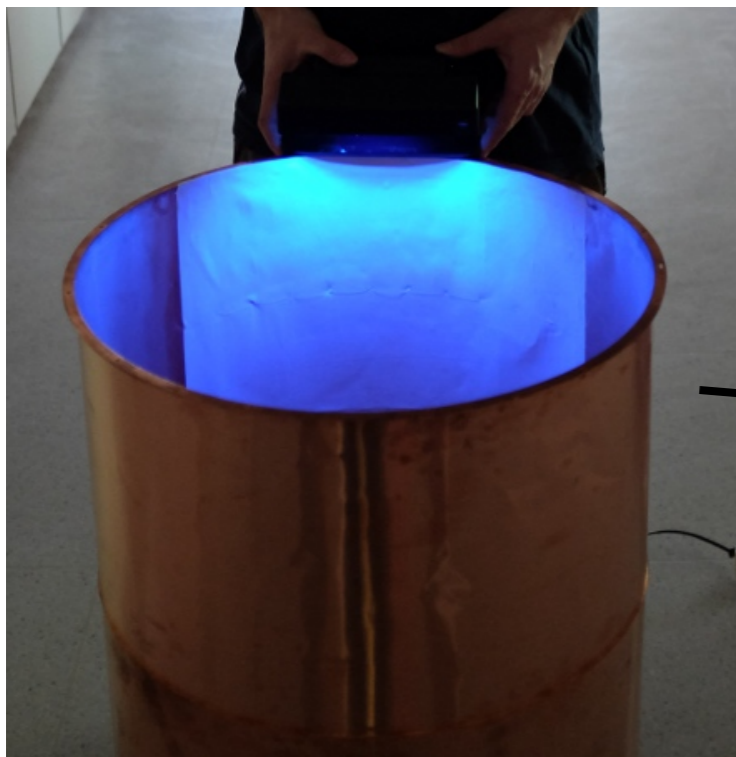


- “Deployed together with the HPGe detectors
- Limited in diameter and length
- Number of electronic channels is limited
- Can be replaced/repaired with each cooling cycle
- Operational since Nov.2014
- In $\Phi=1\text{m}$ around the HPGe array allowed activity $<100 \mu\text{Bq}$

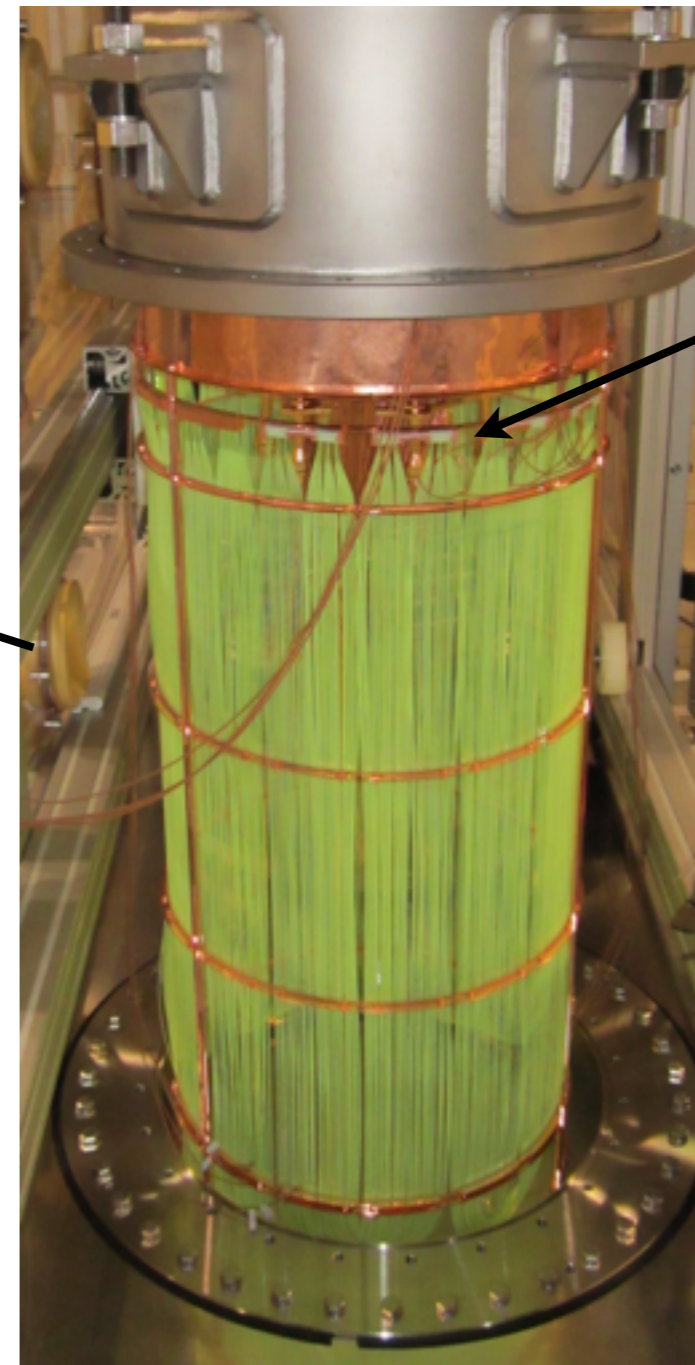
LAr - veto



Copper "shroud" with Tetratex reflector coated with TPB



3" low-background PMT Hamamatsu R11065-20



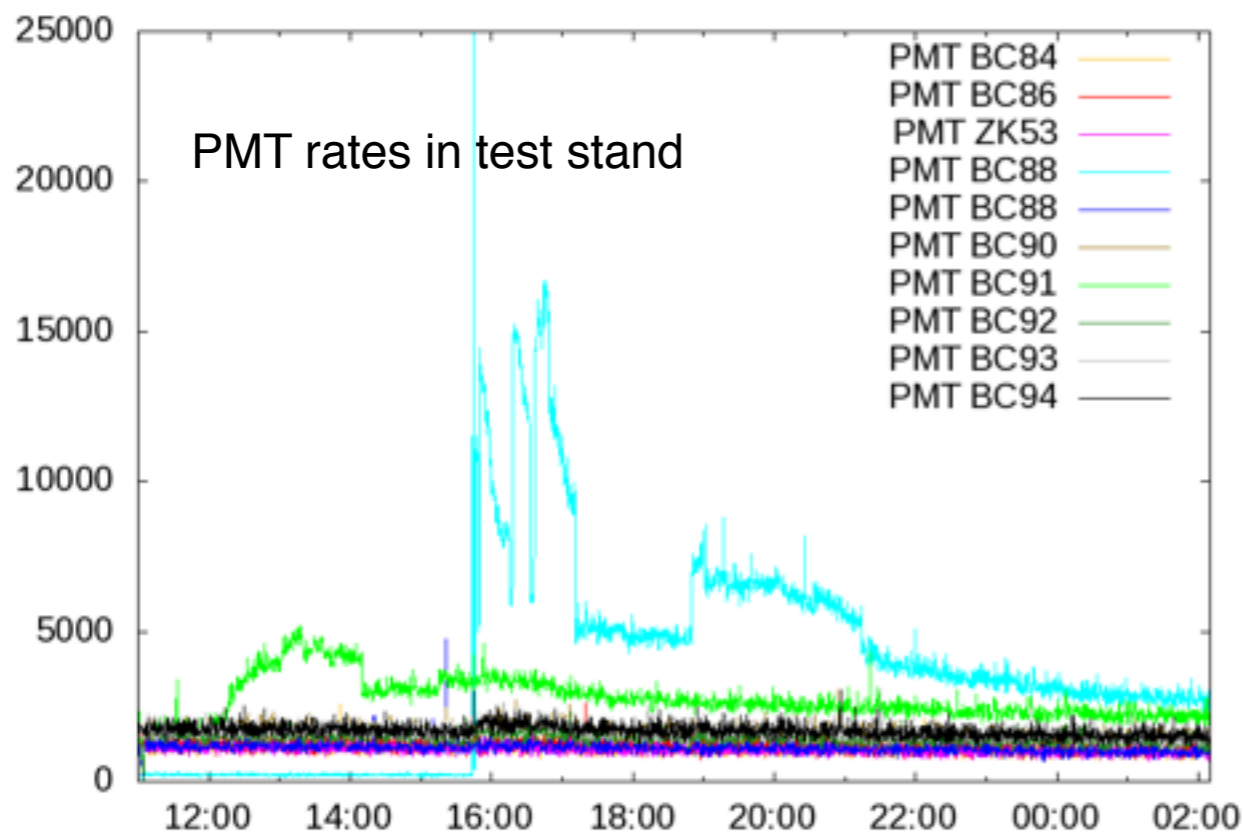
SiPMs

Fiber "shroud" 800 m WLS fibre coated with TPB

LAr - veto, PMTs

Hamamatsu R11065-20 MOD (3-inch)

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

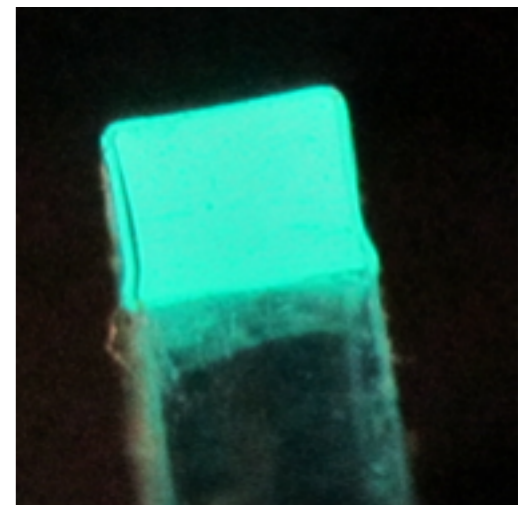


- *discovered flashing issue due to discharges inside the PMTs at cryogenic temperature*
- *problem has been greatly improved in close cooperation with manufacturer*
- *~approx. 1/10 PMTs still flashing occasionally*

LAr-veto, Fibers



- ~800 m BCF-91A square WLS fiber, total surface: ~3 m²
- coated with TPB, vacuum deposition
- Total activity of the fibers ~80 μBq
- Low background SiPMs packaging done at TUM, SiPMs in die from Ketek GmbH.



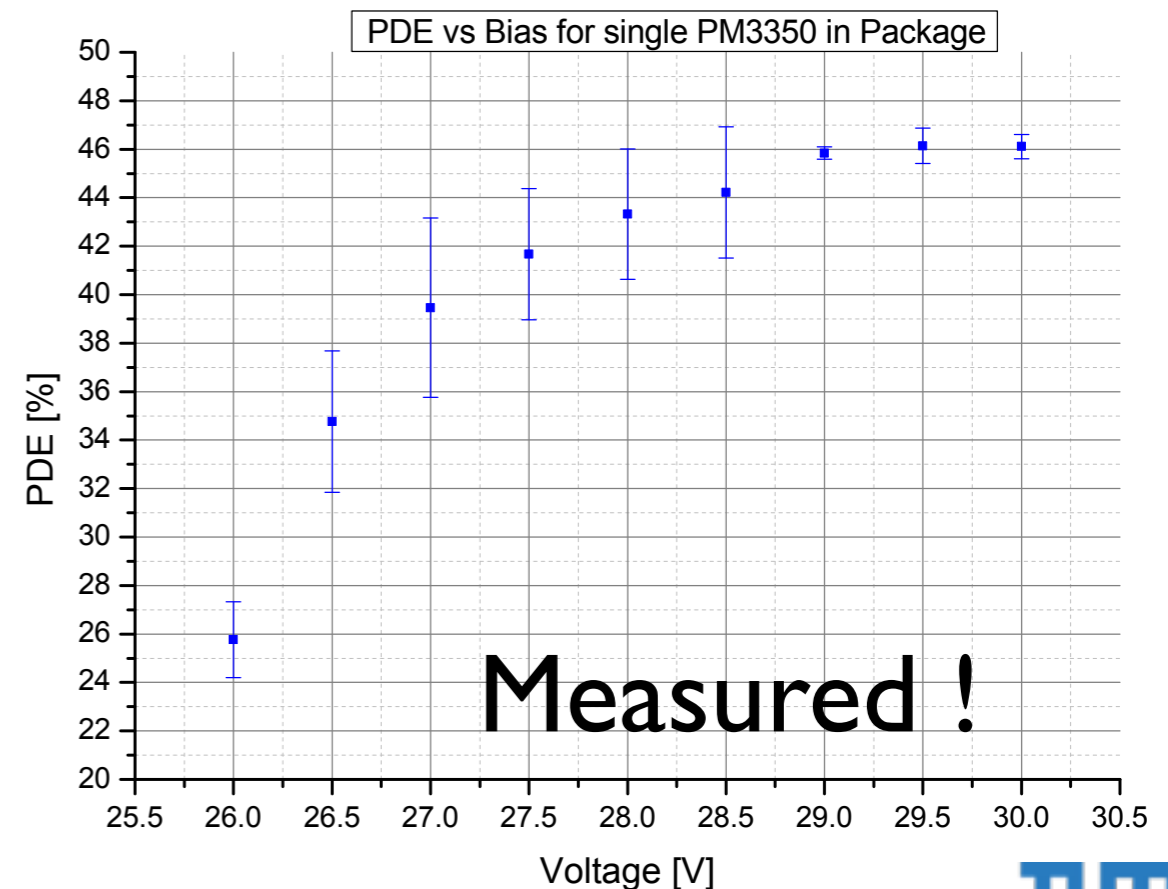
LAr - veto, SiPMs

<i>Element</i>	<i>Conc.</i>	<i>Activity Bq/kg</i>	<i>Activity Bq/piece</i>	<i>Background in GERDA</i>
<i>Th</i>	$< 0.25 \text{ ppb}$	$< 1 \times 10^{-3}$	$< 2 \times 10^{-8}$	$\sim 10^{-6}$
<i>U</i>	$< 0.25 \text{ ppb}$	$< 3 \times 10^{-3}$	$< 6 \times 10^{-8}$	$\sim 10^{-7}$

ICPMS done at LNGS: SiPMs

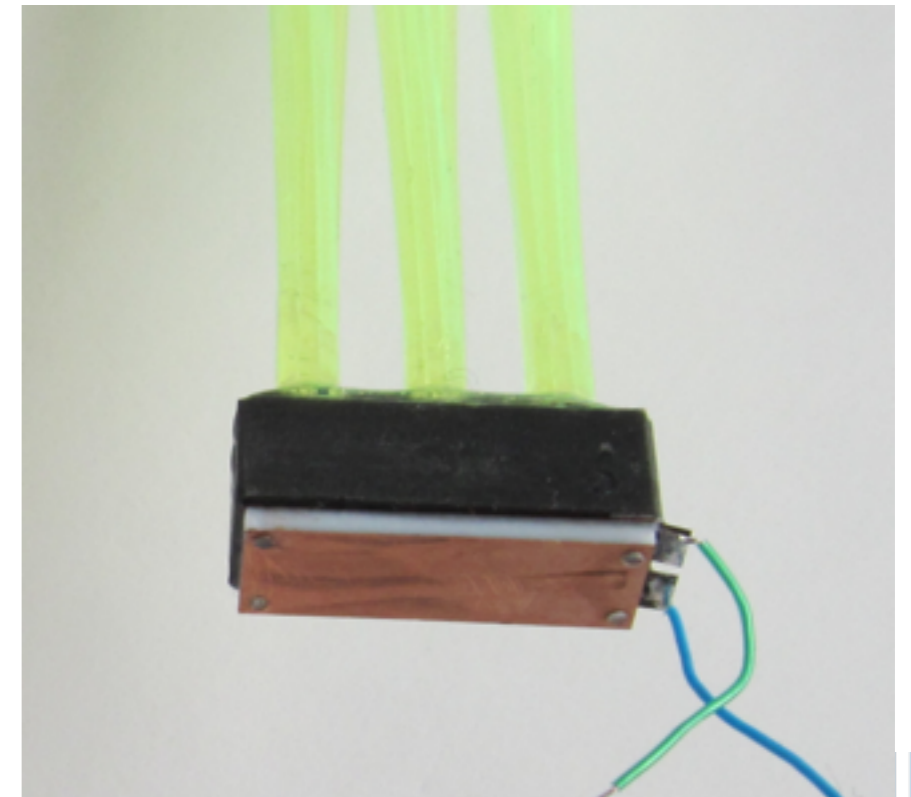
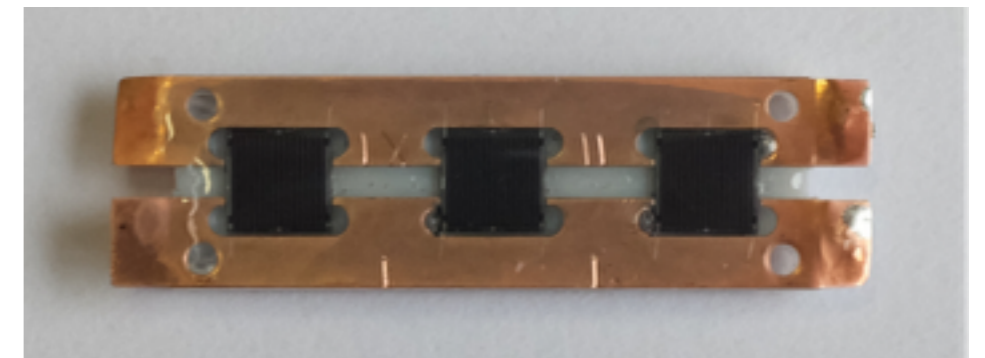
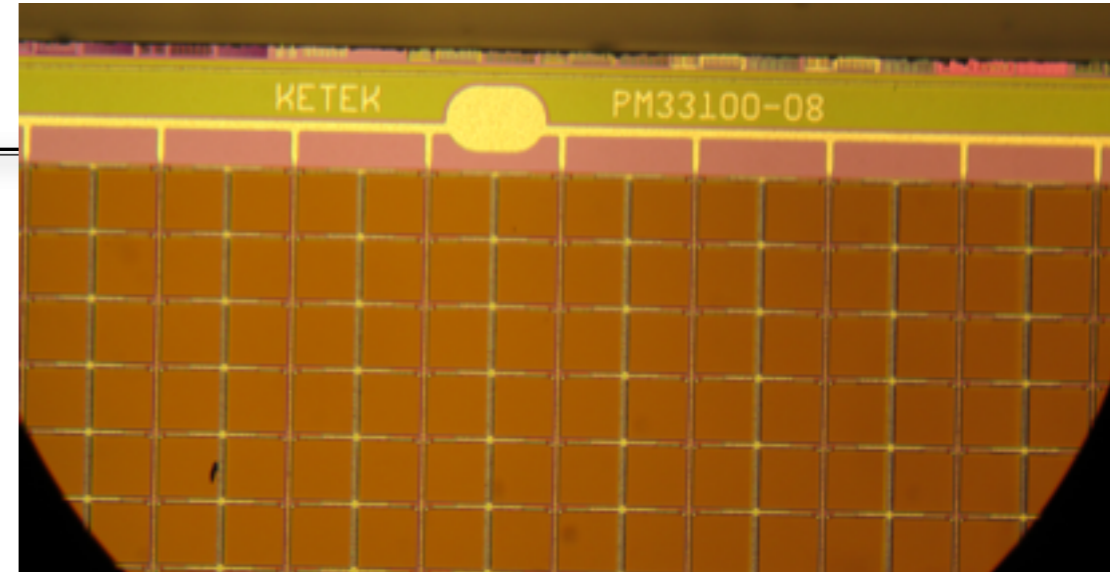
Ketek SiPM in die (3x3 mm, 50 μ m pixel)

- Good match for the size of the WLS fiber
- Small & Silicon = Low background
- High QE, Works at cryogenic temperatures
- Relevant activity for GERDA $< 10 \mu\text{Bq}$
- $1 \text{ m}^2 \text{ SiPM}$ would have $< 10 \text{ mBq}$ activity

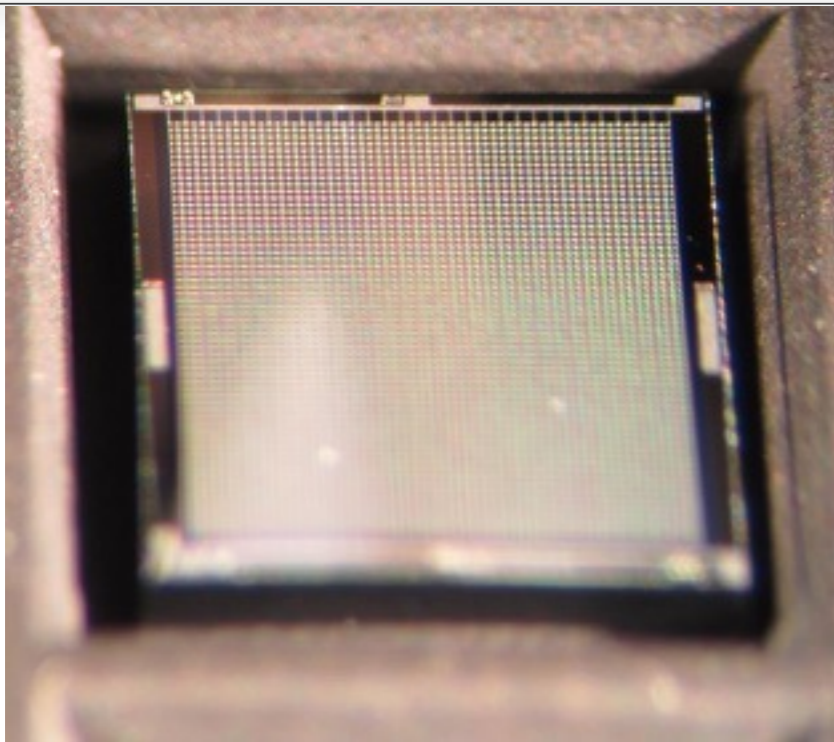


Ketek SiPMs

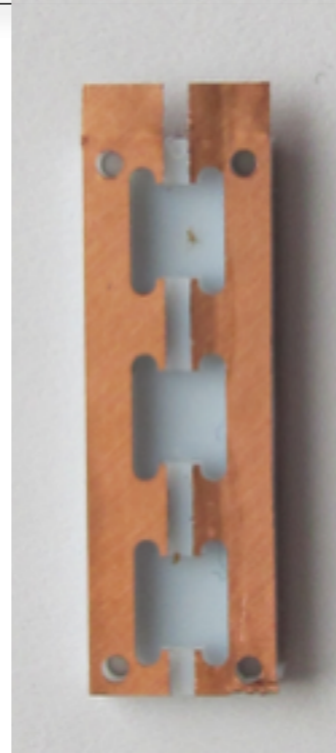
- Radio-purity of the SiPM is given by the packaging ...
- Ketek GmbH the only company to sell SiPMs in die
- Self made packaging from radio-pure materials (Cuflon)
- $3 \times 3 \text{ mm}^2$, $50 \mu\text{m}$ and $100 \mu\text{m}$ pixel size
- 90 SiPMs to 15 read-out channels
- Total sensitive surface in GERDA 8.1 cm^2



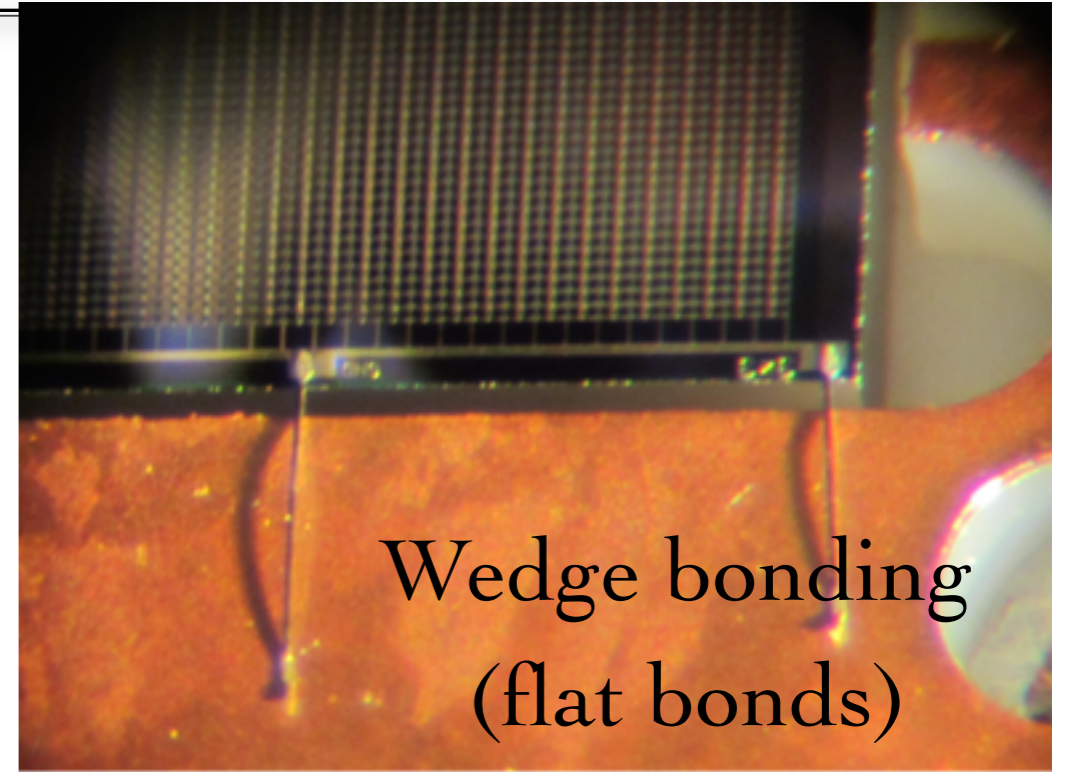
SiPM packaging



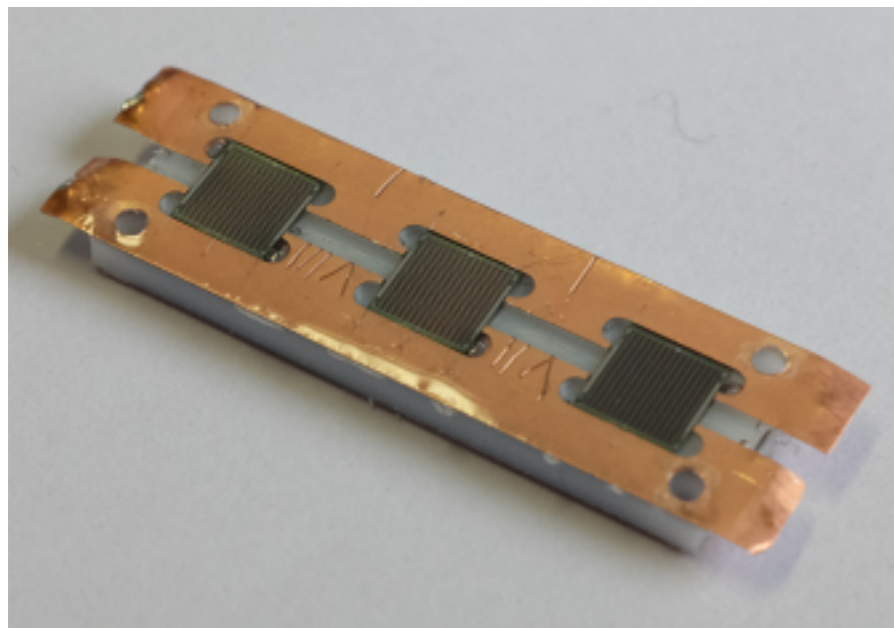
Chips in waffle package



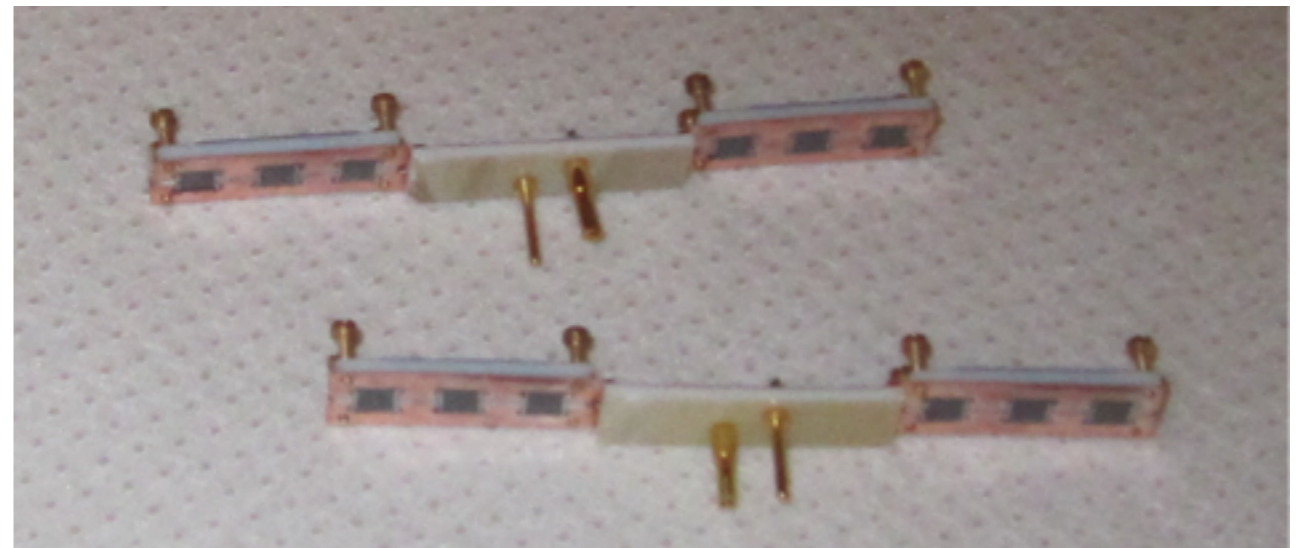
Cuflon PCB



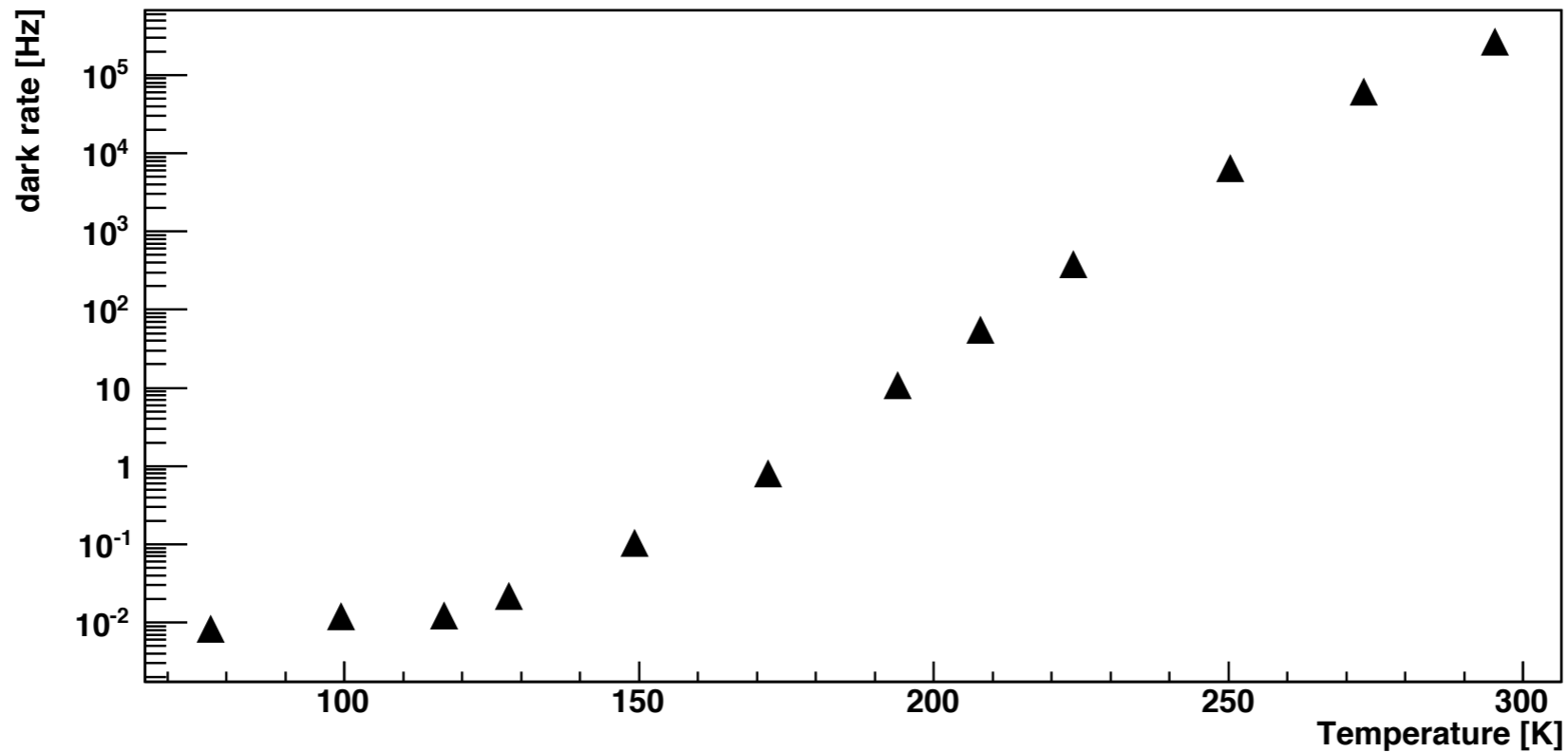
Arrays of 6 SiPM



transparent epoxy

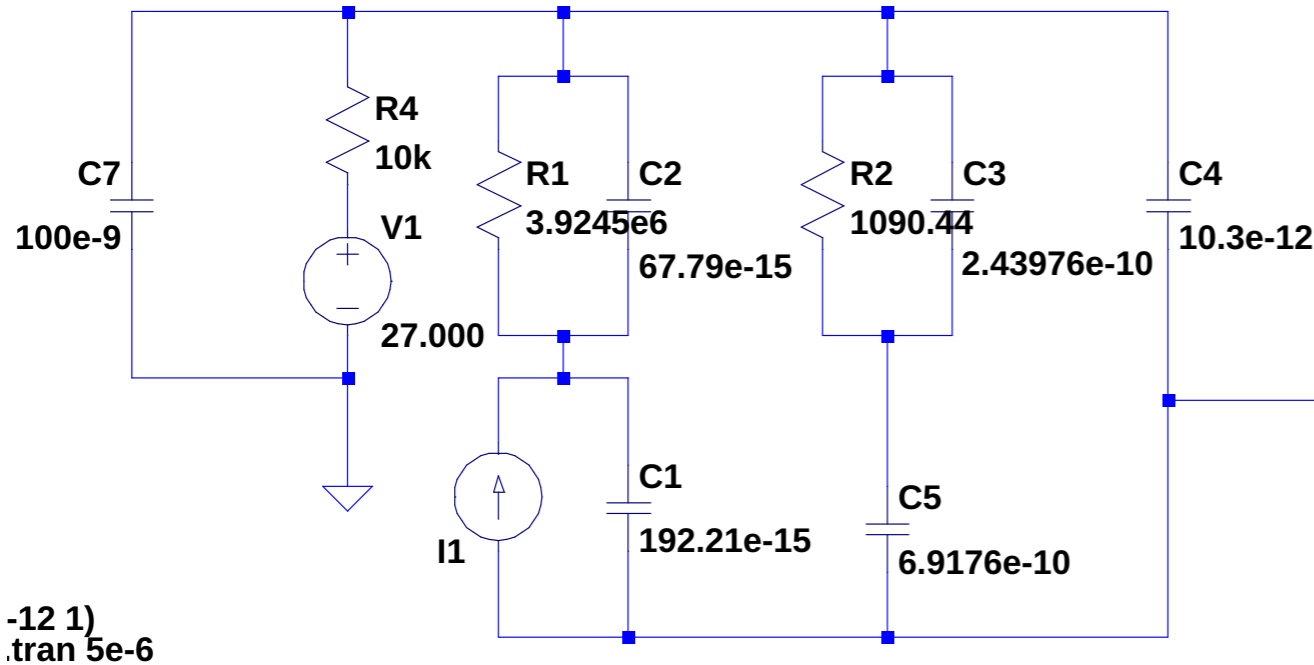


SiPM Dark Rate

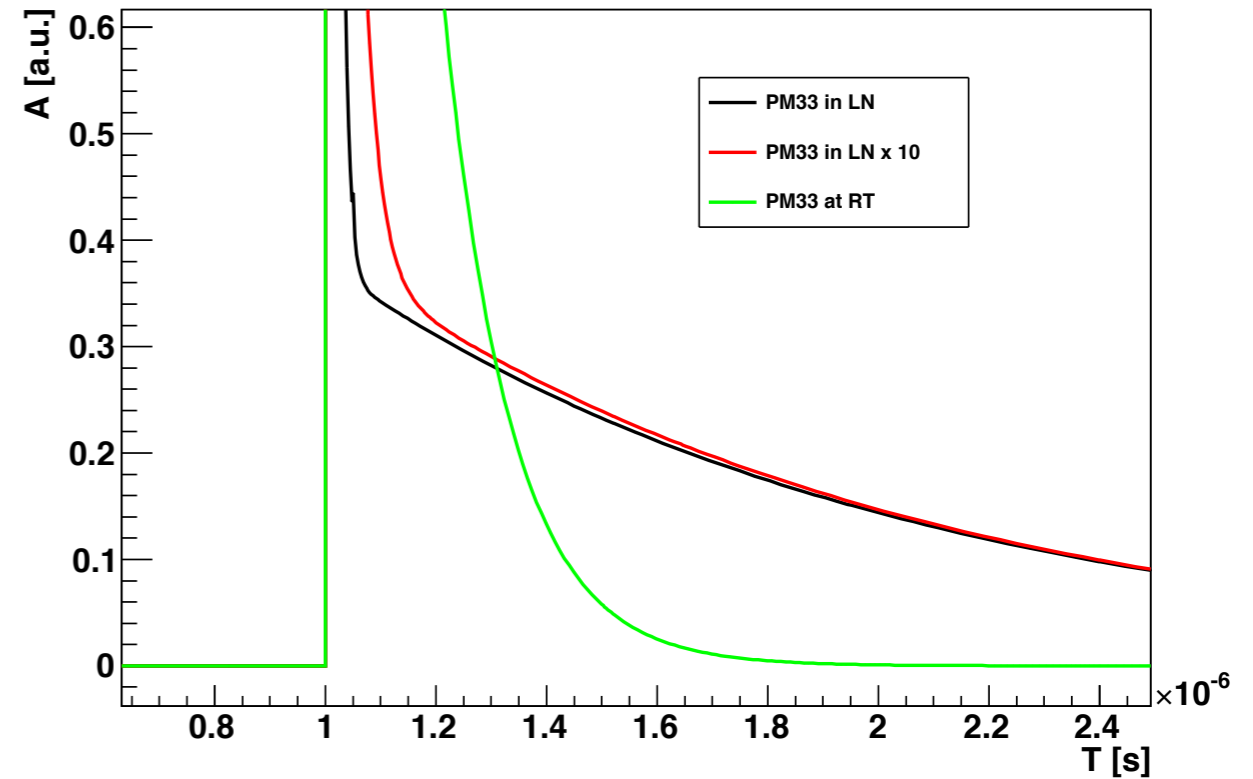
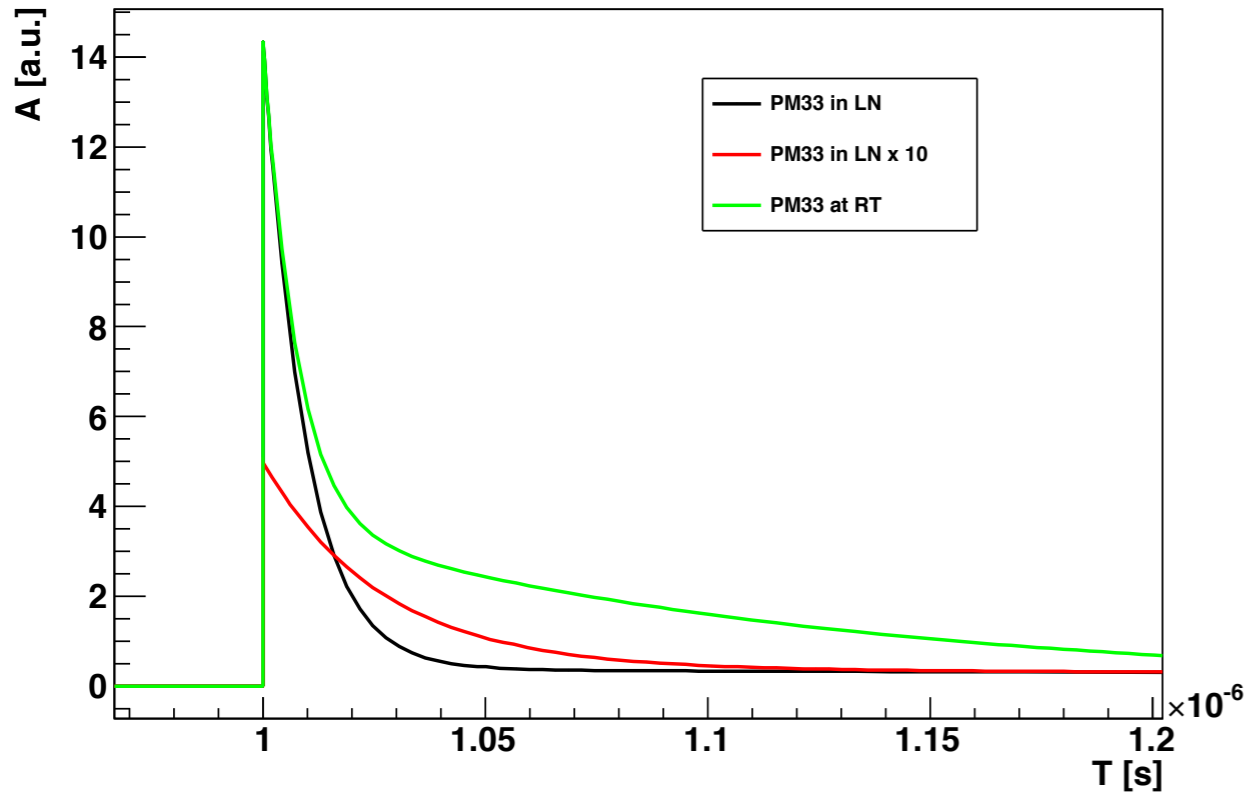


- Measured with Hamamatsu MPPC 50 μm pixel 10⁻² Hz/mm² in **LN**
- Ketek 3x3 mm, 50 μm , ~ 1 Hz = 10⁻¹ Hz/mm²
- 100 cm² SiPM array would have ~ 1 kHz DR in **LAr**
 - In **LXe** the DR is 10 kHz or 100 kHz ?
- How does the DR depend on SiPM design, production process, wafer quality?
 - ➔ Systematic study needed

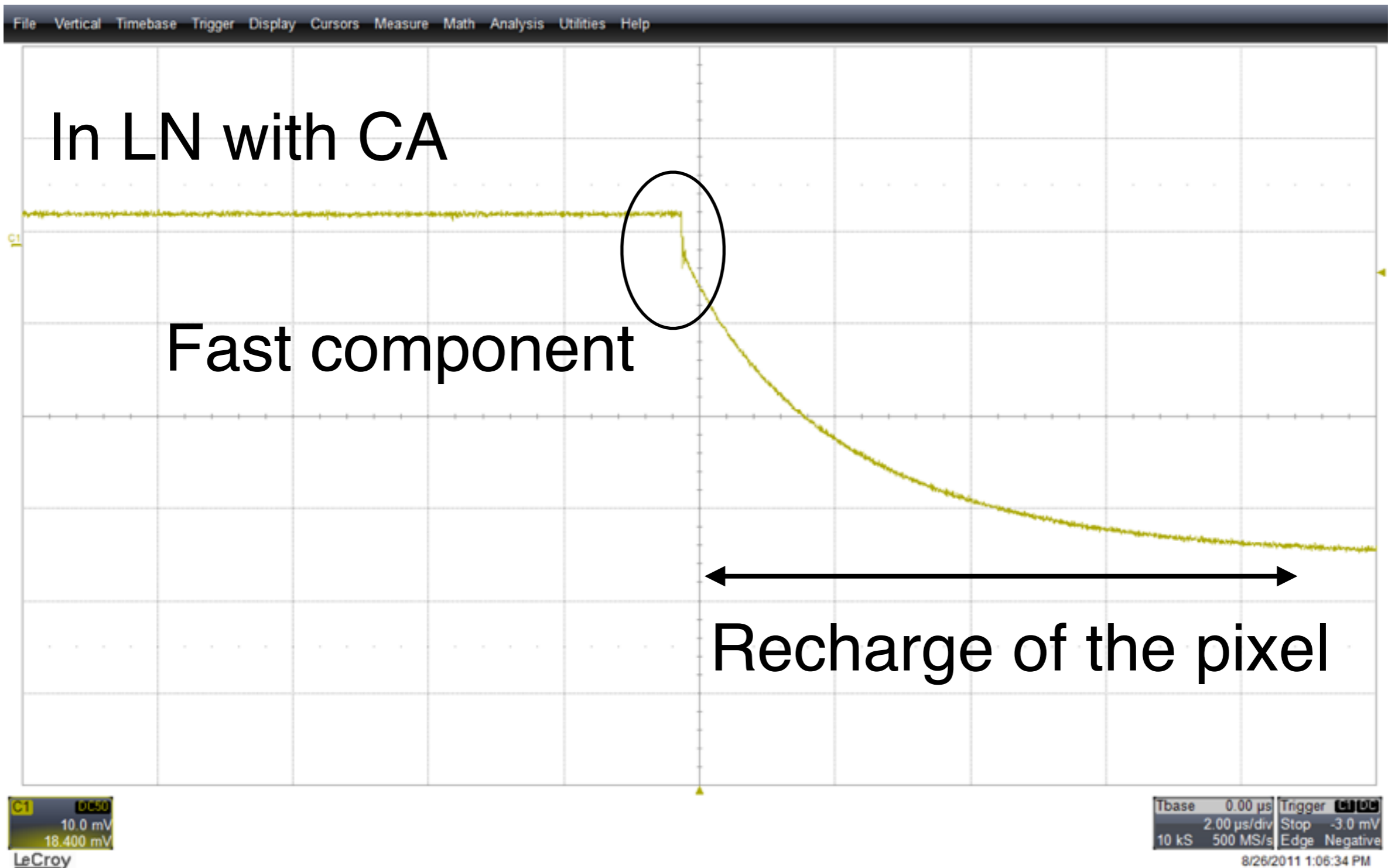
Spice model of the SiPM



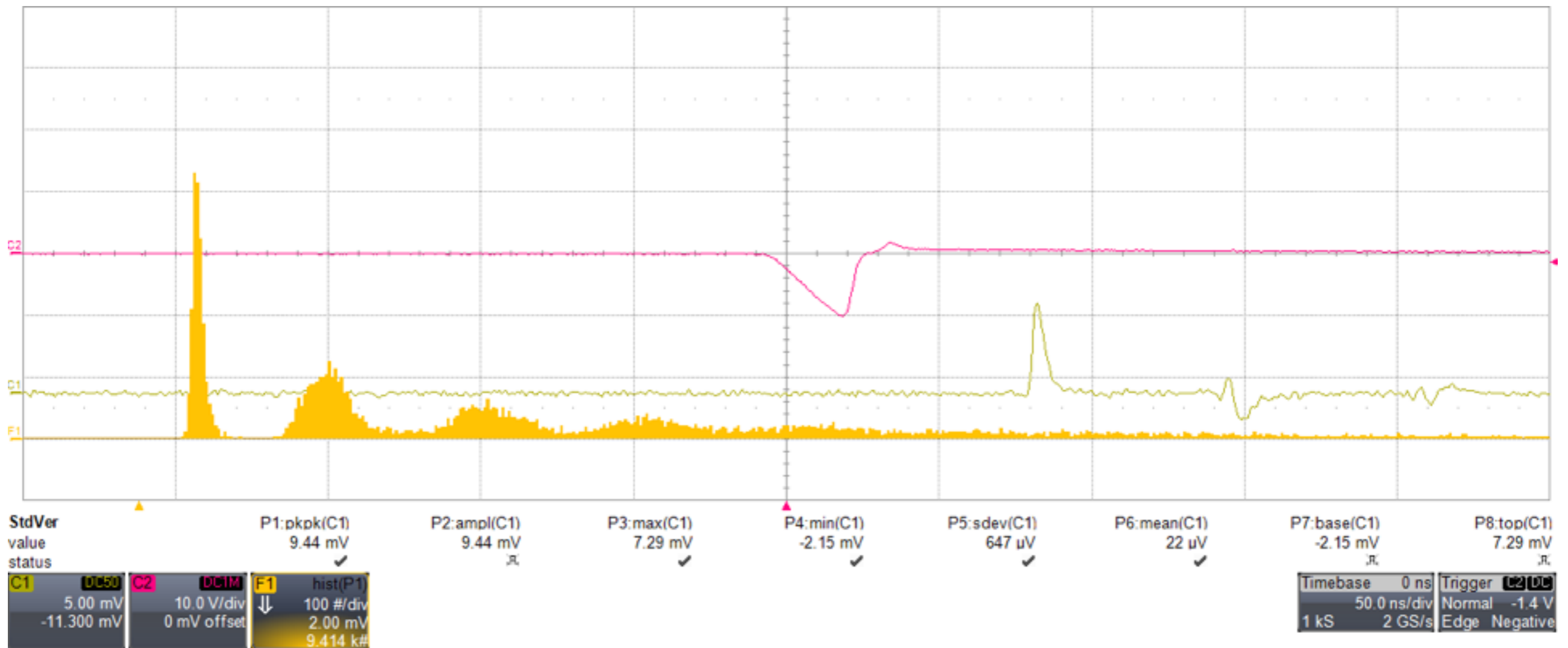
- See for example: NIM A 572 (2007) 416–418
- Model tuned for Ketek SiPMs in LN
- Quenching resistor $\sim 10x$ larger in LN



Ketek SiPM: Charge integral

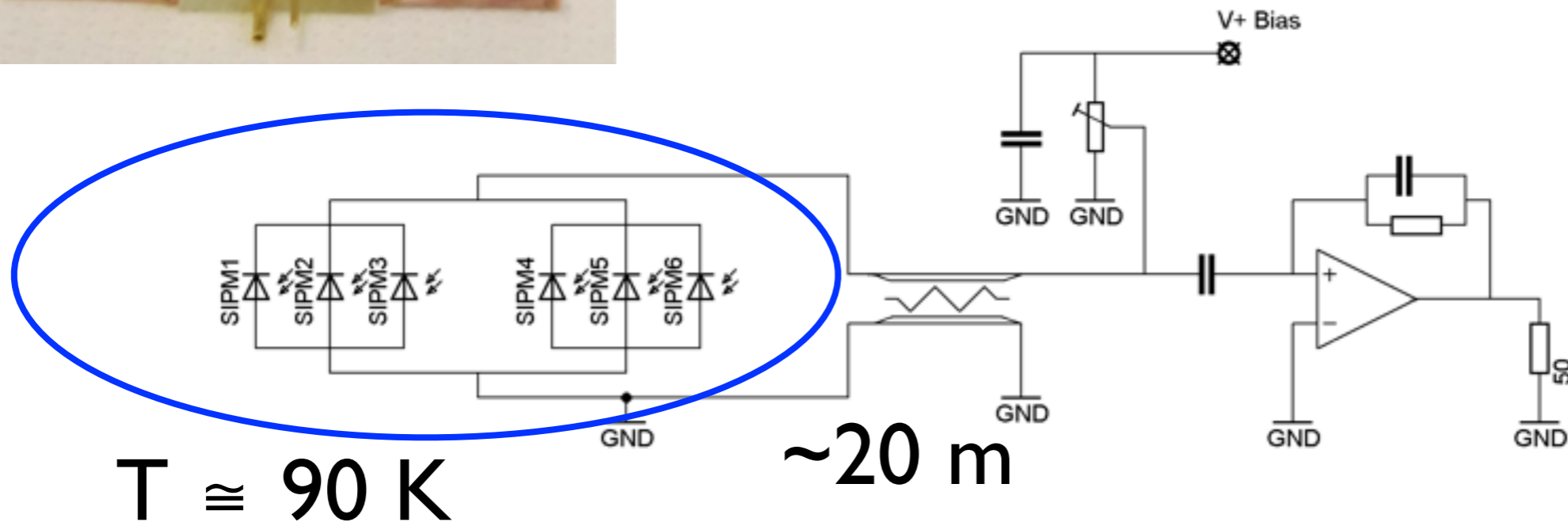
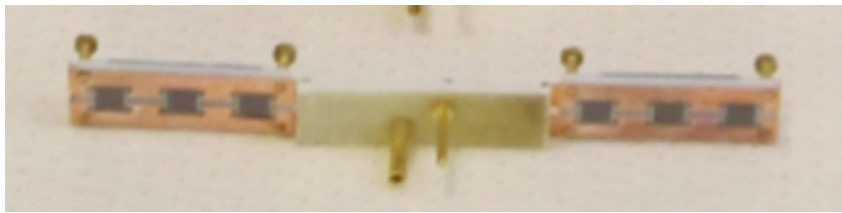


Ketek 100 μm SiPM: Fast pulse



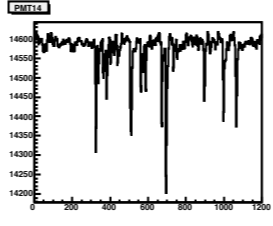
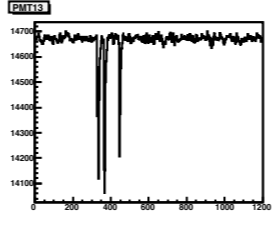
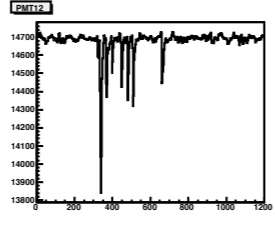
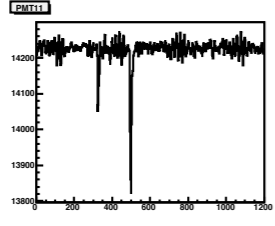
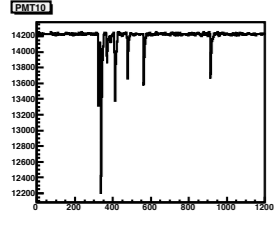
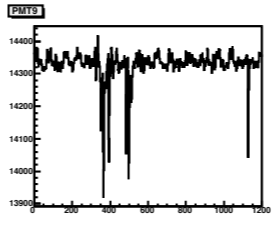
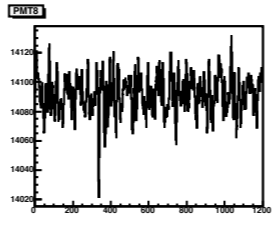
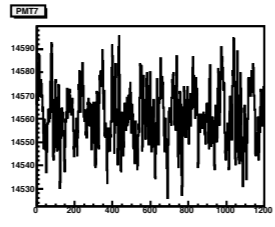
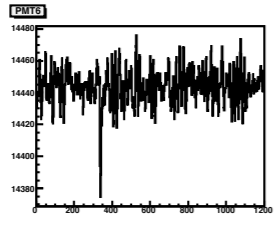
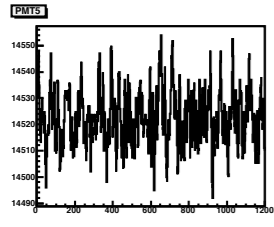
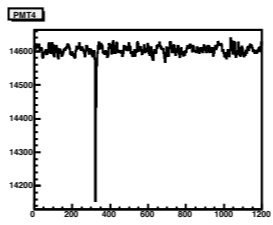
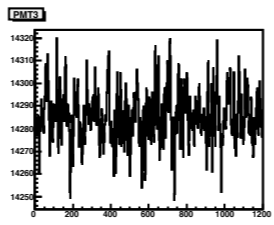
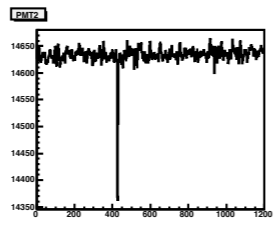
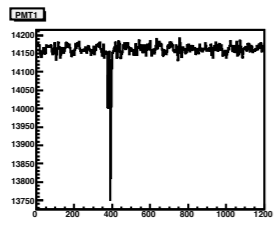
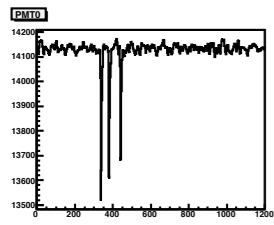
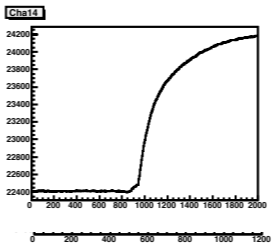
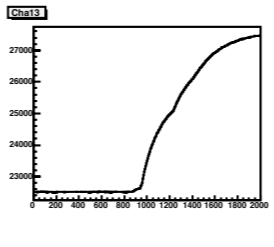
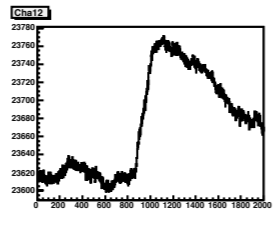
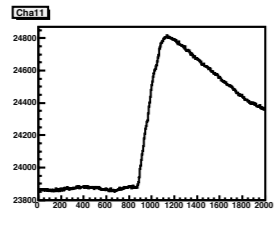
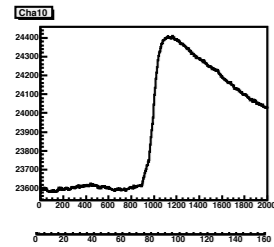
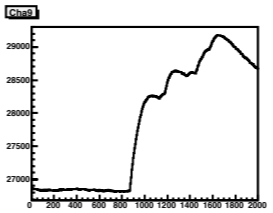
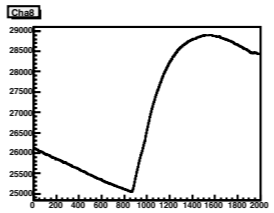
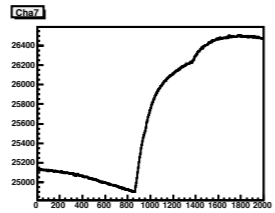
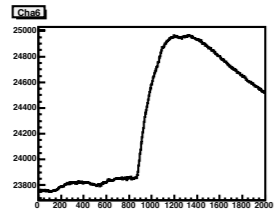
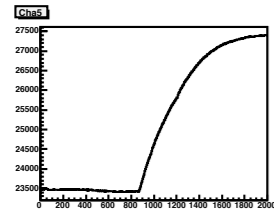
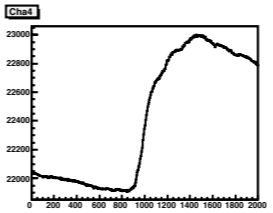
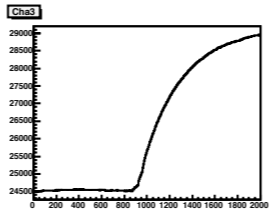
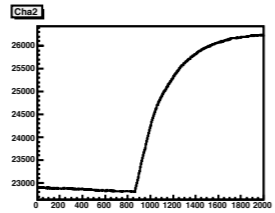
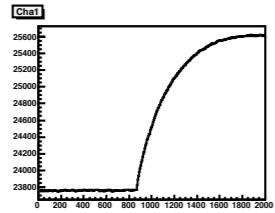
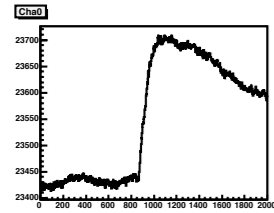
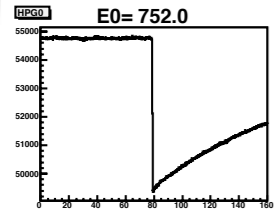
- Fast component: low gain
- Depends on the pixel size (capacity), here 100 μm .
- Single photon (pixel) resolution preserved

GERDA SiPM read-out



- 6, $3 \times 3 \text{ mm}^2$ SiPM in paralel: no electronics in LAr!
- 20 m, 50Ω cable to the amplifier \implies no fast pulses
- Read-out from the 'high voltage' side \implies signal and bias is the same cable
- Aiming to detect 1 p.e. in $5 \mu\text{s}$

LAr - veto

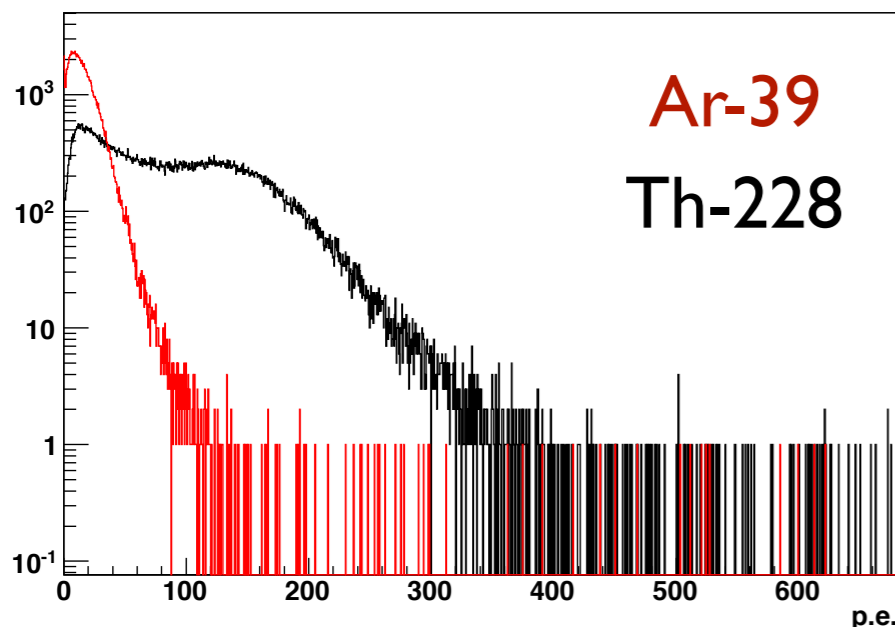
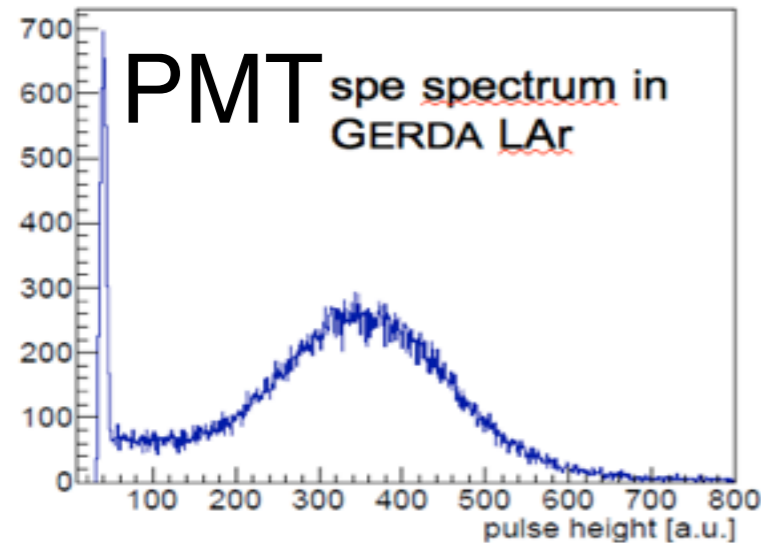
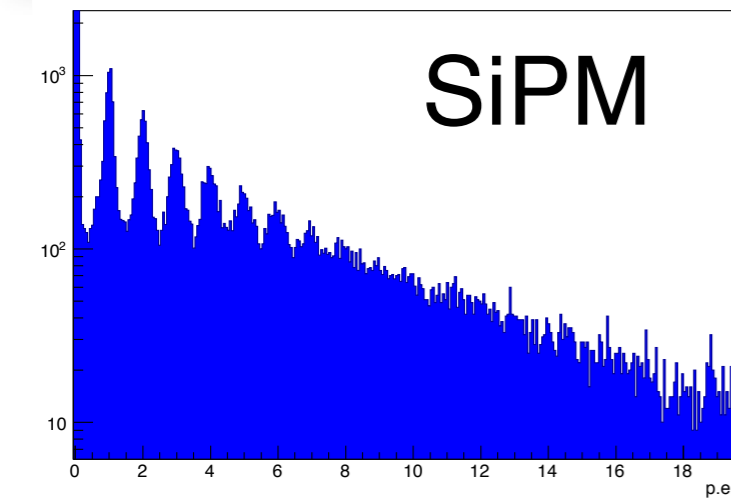


HPGe - channel
160 μ s - traces

15- SiPM channels
80 μ s - traces
80 ns resolution

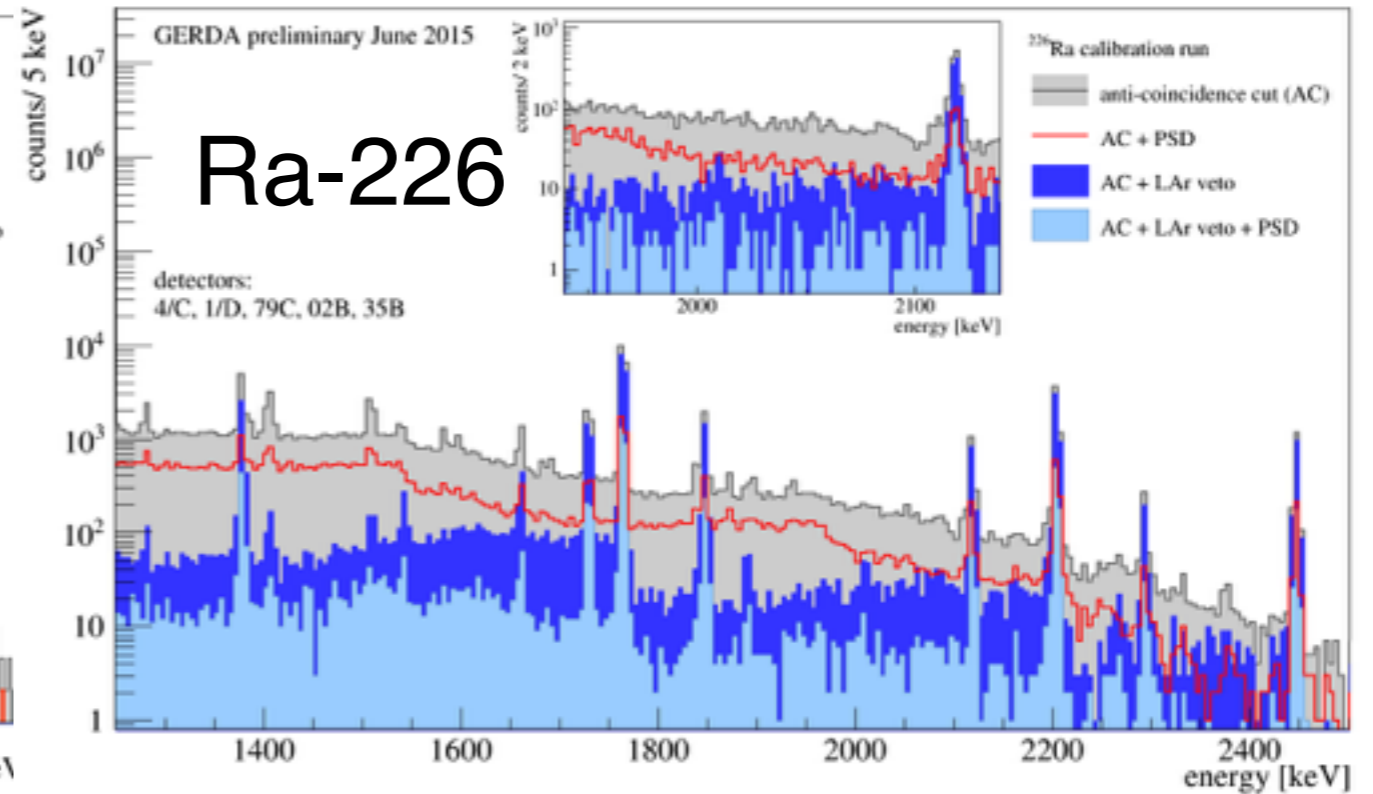
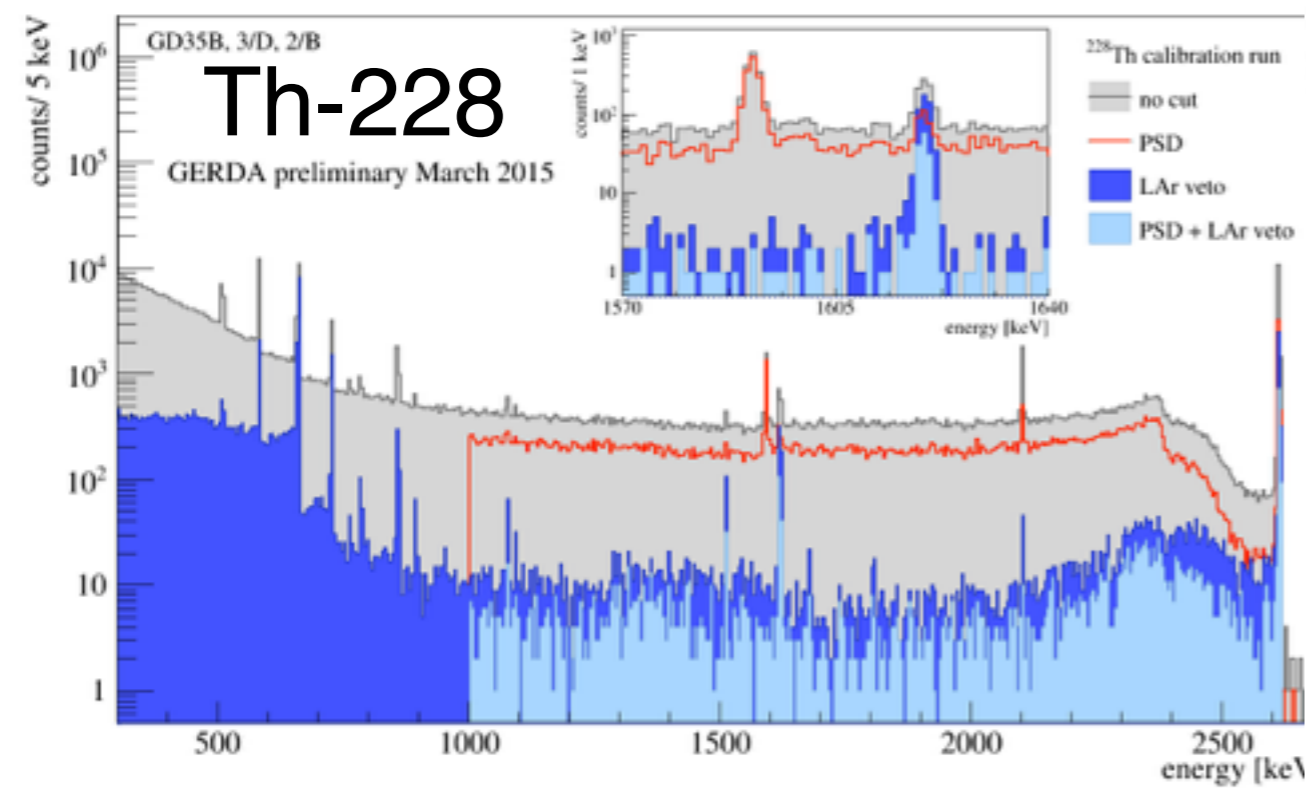
16 - PMT channels
12 μ s traces
10 ns resolution

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 ²²⁸Th source
- Count rate dominated by ³⁹Ar
- LAr -veto Suppression Factor tested with one detector string with ²²⁸Th and ²²⁶Ra sources

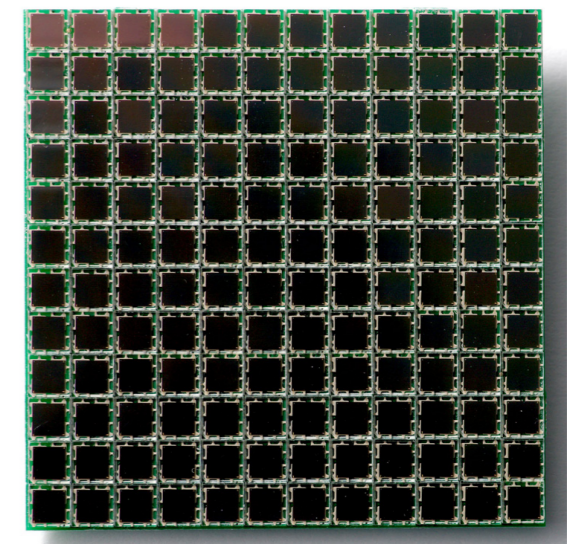
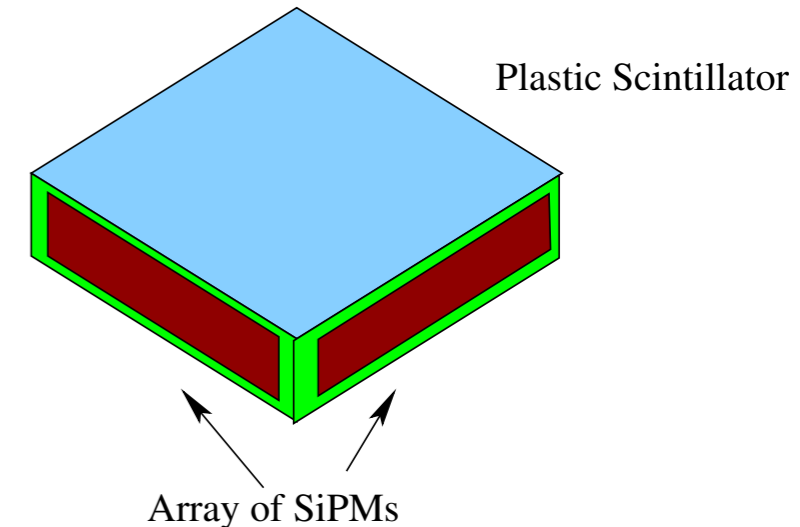
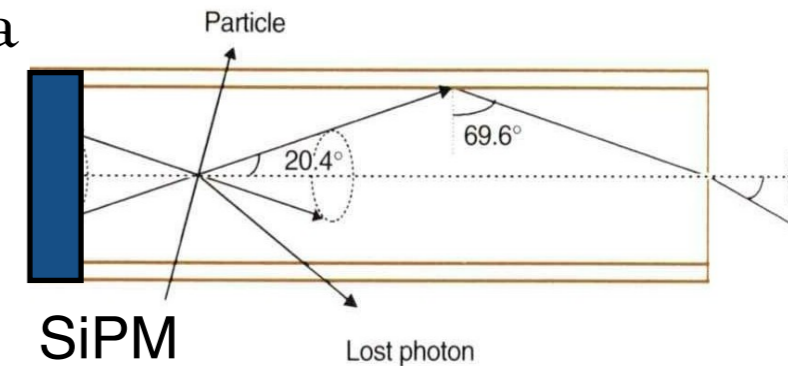
LAr veto commissioning



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%

Future of light detectors

- WLS fibers with SiPM read-out: continuation of the Gerda concept
 - Max. 14% trapping efficiency, total efficiency up to ~5%
- 2D WLS 'fiber': WLS plates with SiPMs on the edges
 - trapping efficiency up to 30% possible at
 - 10% overall detection efficiency
 - combination of large SiPM array + WLS technology, surface increases $\sim(\text{Nb. of SiPMs})^2$
- Highest possible p.d.e. \Rightarrow large SiPM array
 - 40 - 60 % p.d.e. possible
 - Pure Si detector = lowest possible background
 - Need to develop ASIC to reduce number of channels
 - Low background packaging at industrial scale



Conclusions

- UV sensitive, low temperature photosensor are a common problem of many experiments
- For future low background experiments PMTs are not an option
- GERDA operates (probably) the largest SiPM array in cryo-liquid
 - With SiPM + WLS fibers the design goal achieved: background & performance OK
- Future of light detection in noble liquids : SiPMs