# LAr Scintillation light readout with Silicon Photomultipliers

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# Outline

- Introduction

- SiPMs, a candidate for LAr scintillation light readout?

- Characterization of SiPM at cryogenic temperatures

- Summary and outlook

# GERmanium Detector Array (GERDA)

Is a double beta decay experiment in the underground laboratory LNGS, Italy

- Enriched germanium is serving as source and detector at the same time.

- Extremely long half life $\rightarrow$ extremely low background

- Bare HPGe detectors are operated in LN/LAr

- LAr is:
  $\begin{cases} 1. \text{ cooling liquid} \\ 2. \text{ passive shielding} \\ 3. \text{ scintillator} \end{cases}$

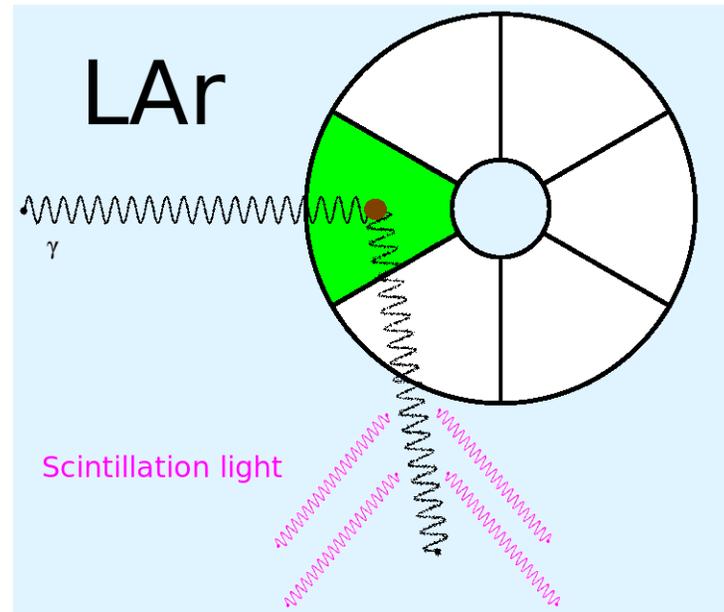Could we use LAr scintillation light to build an active veto in a low background experiment like GERDA?

# GERDA
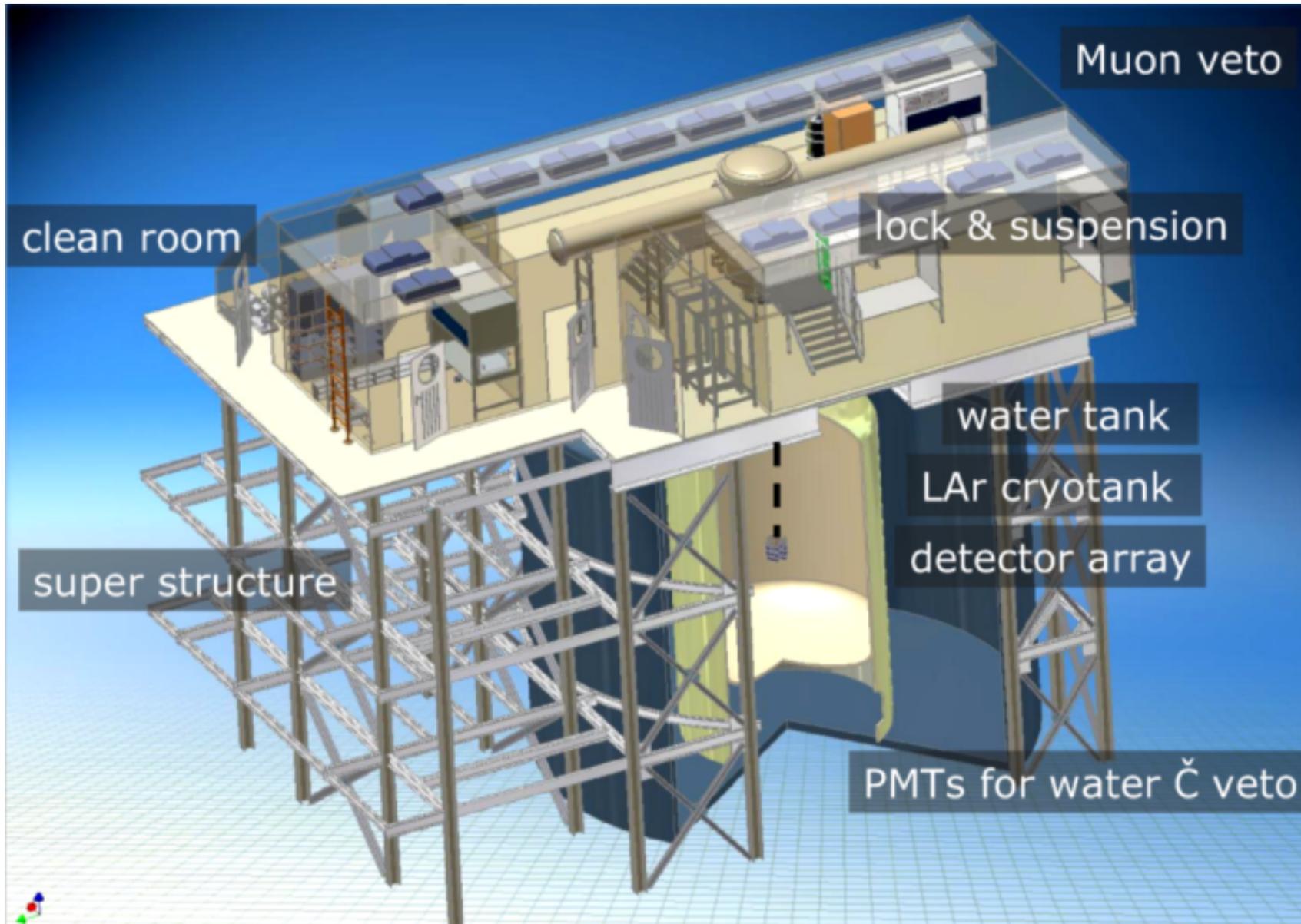
# Motivation of a LAr veto

The $0\nu\beta\beta$ (2n $\rightarrow$ 2p + 2e) decay is a single site event.

Segmented detectors can identify multi site events as background. However if singly Compton scattered gamma escapes detector no identification as background is possible.



$0\nu\beta\beta$ decay Q-value = 2.039MeV. In principal all $\gamma$ sources with a higher energy are dangerous.

$^{208}$Tl e.g. from the decay chain of natural $^{232}$Th emits $\gamma$ with an energy of 2.614MeV.

Detecting scintillation light in LAr from Compton scattered gammas could increase background identification efficiency.

# Heidelberg setup

The GERDA group from MPIK in Heidelberg accomplished background suppression via LAr scintillation light read out with PMTs.(2008JINST 3 P08007)
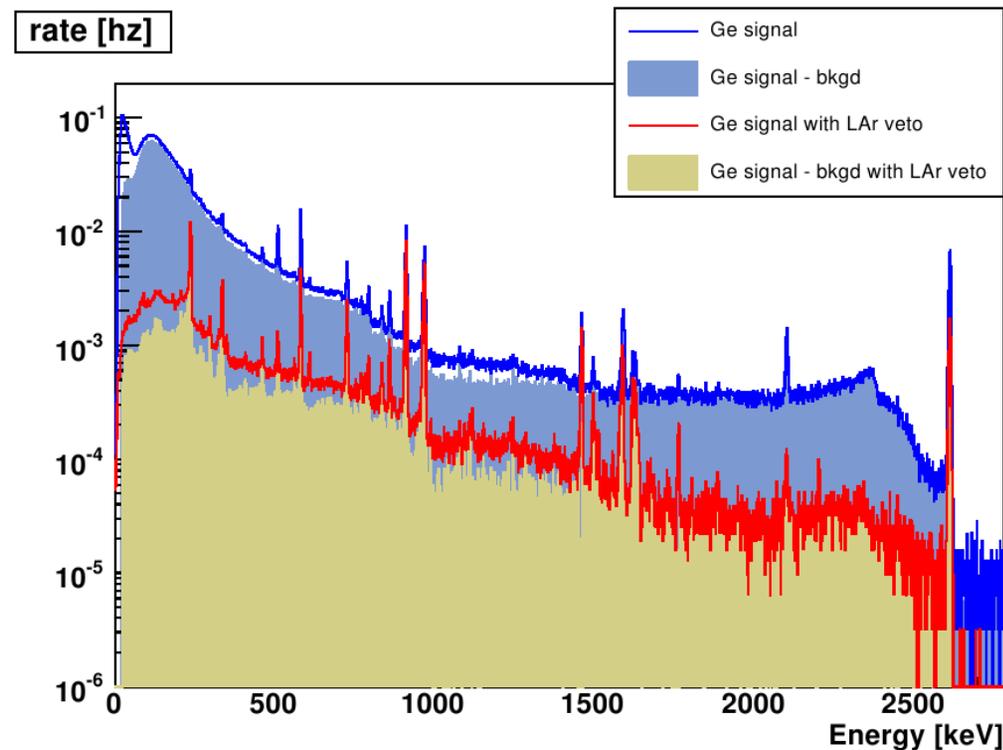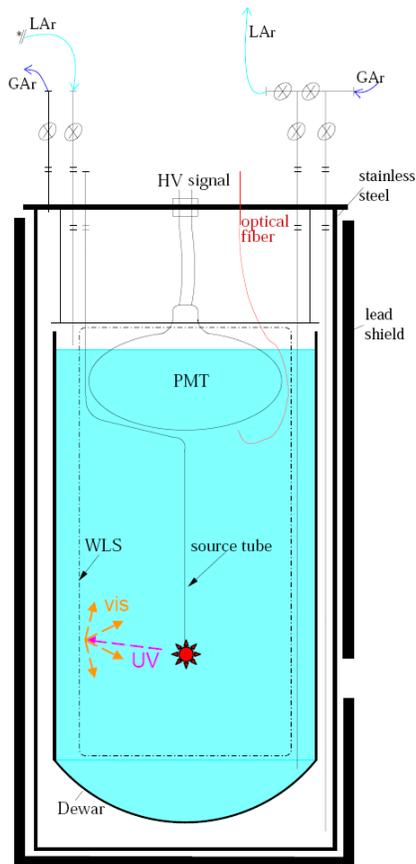


A background suppression of a factor of ten observed by the Heidelberg Group motivated our studies.

# Our goal

PMTs weigh about one kilogram. Their radioactivity is high
$\rightarrow$ Our goal is to replace conventional PMTs by SiPMs

**Si**licon **P**hoto **M**ultiplier characteristics:

- Very small devices (mass of some mg). We expect a much lower radioactivity.

- They do work at cryogenic temperatures

- Do not require HV (HV can lead to problems in Ar atmosphere)

- UV sensitive. Peak is at 400nm

- High photon detection efficiency (PDE) of up to 65%
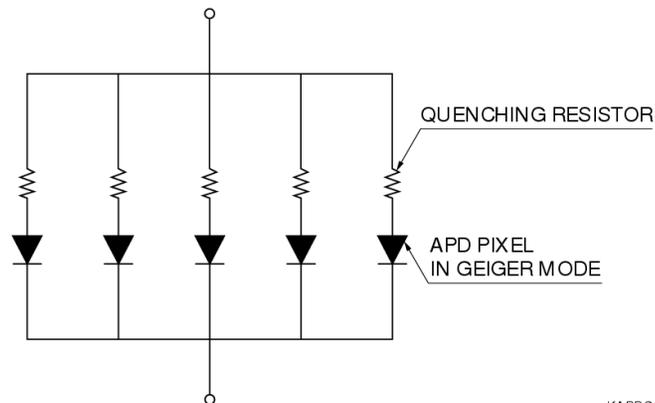
- Relatively cheap

$\Longrightarrow$ excellent candidate for active veto in LAr

# So what is a SiPM?

*Take a couple of APDs in Geiger mode...*
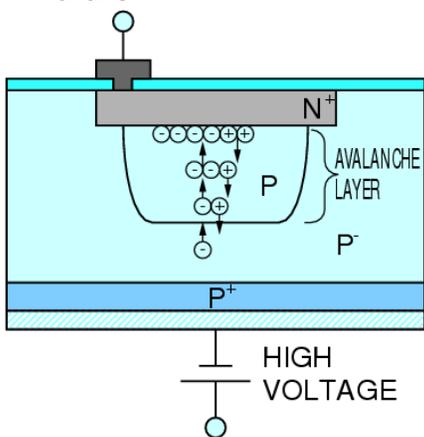


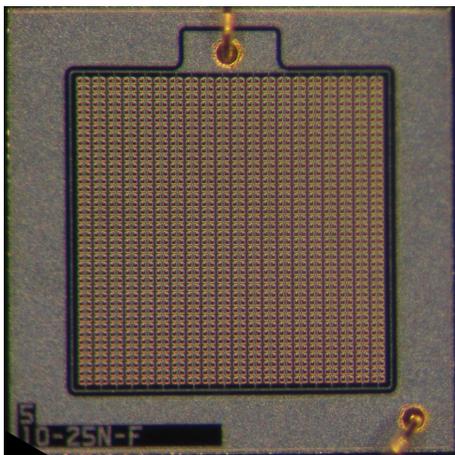*... and arrange them in an array*



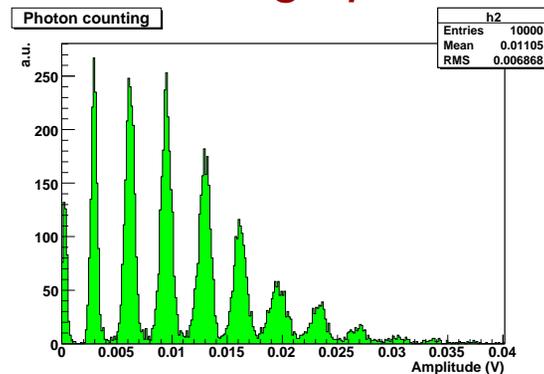*This is what a SiPM chip looks like*



*The number of fired pixels will tell how many photons were detected. Outstanding 1p.e resolution!*

# SiPM properties at cryogenic temperature

- Equipment and experimental setup.

- Pulse shape in LN.

- Gain as a function of temperature and bias.
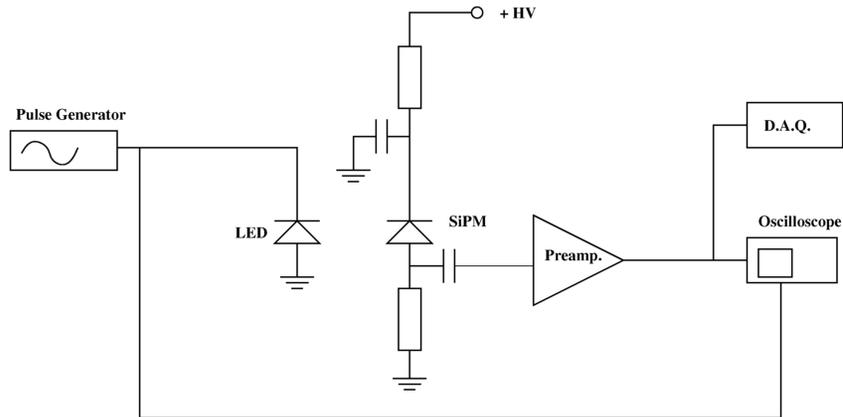
- Dark rate as a function of temperature.

# Hamamatsu's MPPC



We tested three different SiPMs. The following specifications were given by Hamamatsu.

| Number of pixels | 100 | 400 | 1600 |
|---|---|---|---|
| Pixel size | $100\mu$m $\times$ $100\mu$m | $50\mu$m $\times$ $50\mu$m | $25\mu$m $\times$ $25\mu$m |
| PDE at peak value | 65% | 50% | 25% |
| Dark count at RT | 600-1000 kHz | 400-800 kHz | 300 - 600 kHz |
| Gain at RT | $2.75\times10^6$ | $7.5\times10^5$ | $2.4\times10^5$ |

# Setup



- Bias circuit and preamplifier built on one printed circuit board at room temperature
- SiPM is submerged in LN
- coax. cable between the SiPM and the PCB

- Gas tight dewar filled with LN
- LN evaporates slowly
  → temperature increases continuously
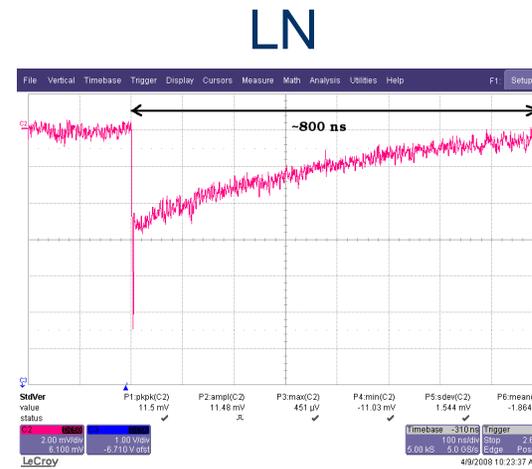- PT100 for temperature readout
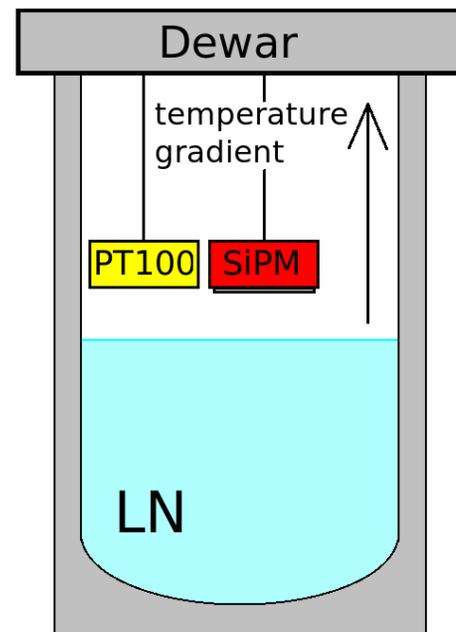
# Pulse shape in LN

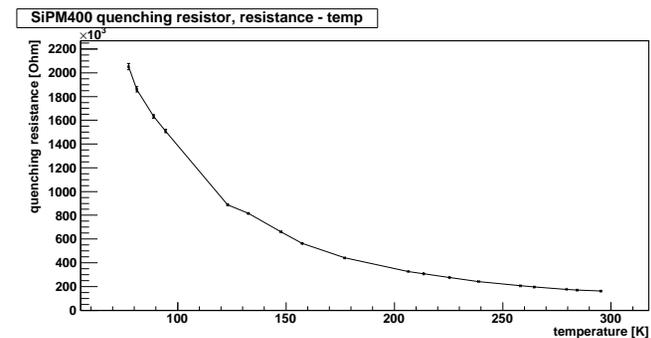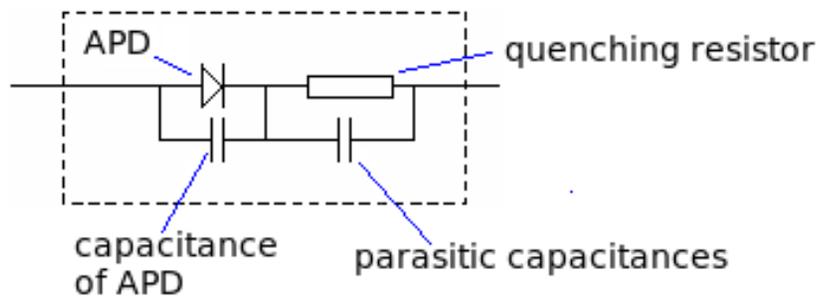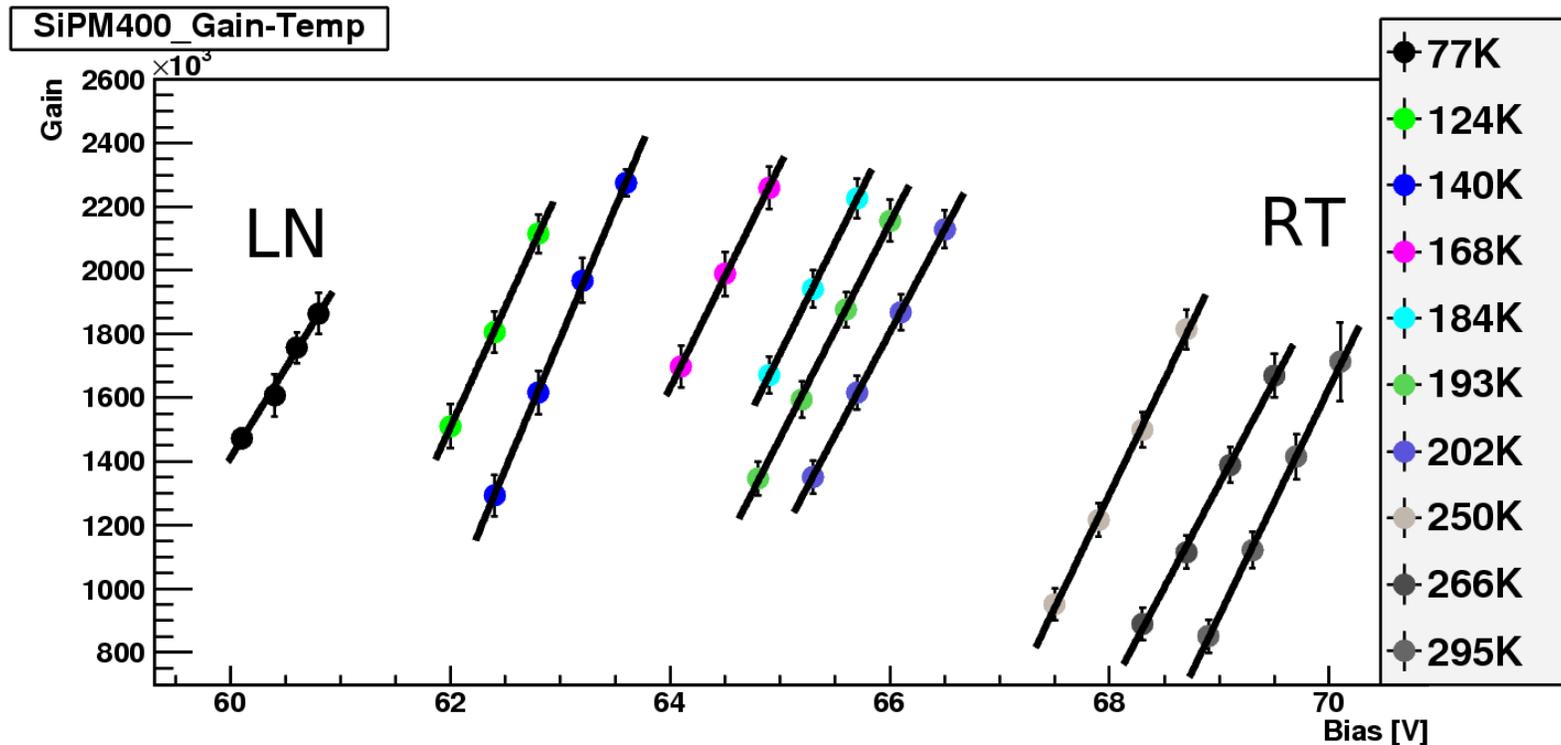The decay time increases at low temperatures by a factor of 6.

RT

LN
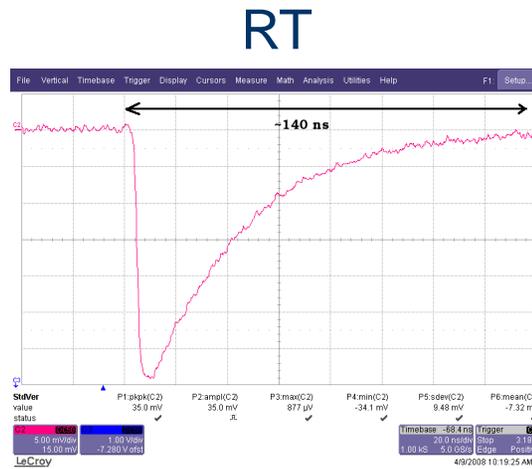




$\tau$ = 45ns

$\tau$ = 440ns

The quenching resistor is temperature dependent.  Slow component from RC-circuit.  Sharp peak from parasitic capacitances.

# Gain v. temperature and bias
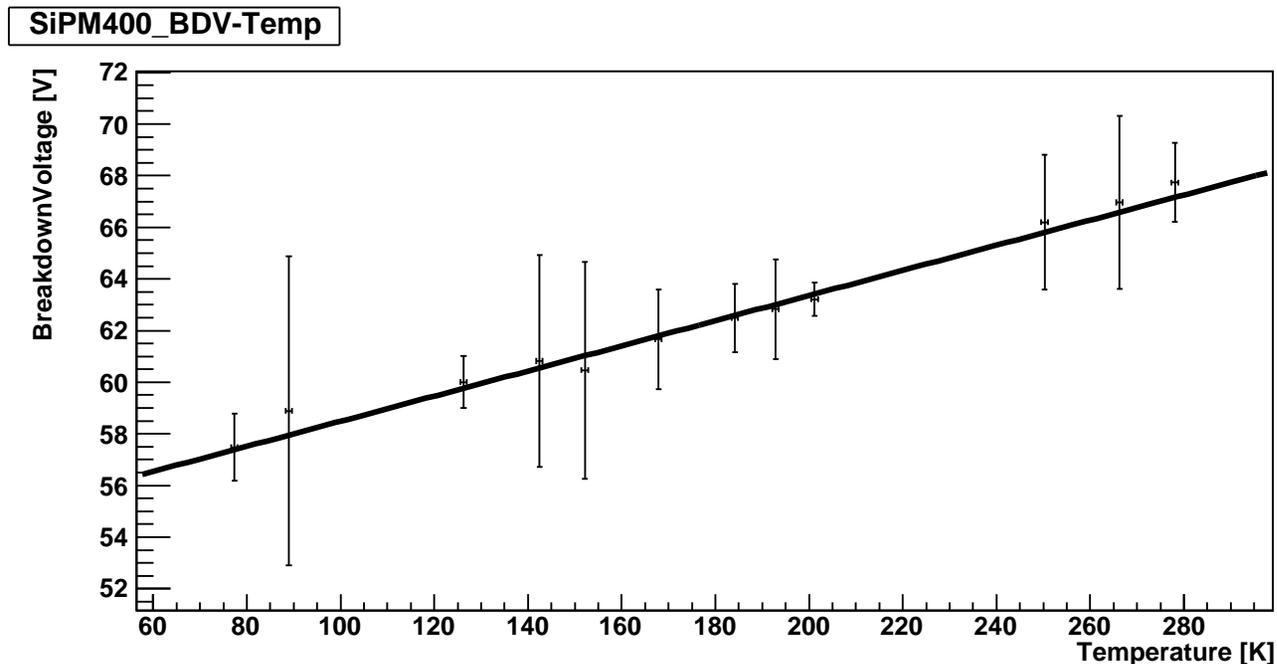
Does the gain drop with decreasing temperatures?



The gain is not a function of the temperature but strongly depends on $V_{\text{bias}}$.
We have to reduce the bias at low temperatures to operate at constant gain.

# Breakdown voltage v. temperature

$$V_{\mathbf{bias}} = V_{\mathbf{bd}} + V_{\mathbf{over}}$$

$V_{\mathrm{bd}}$ is the minimum bias required to operate a SiPM in Geiger mode.
$\mathrm{Gain}(V_{\mathrm{bd}})=0 \rightarrow V_{\mathrm{over}}$ defines the gain.
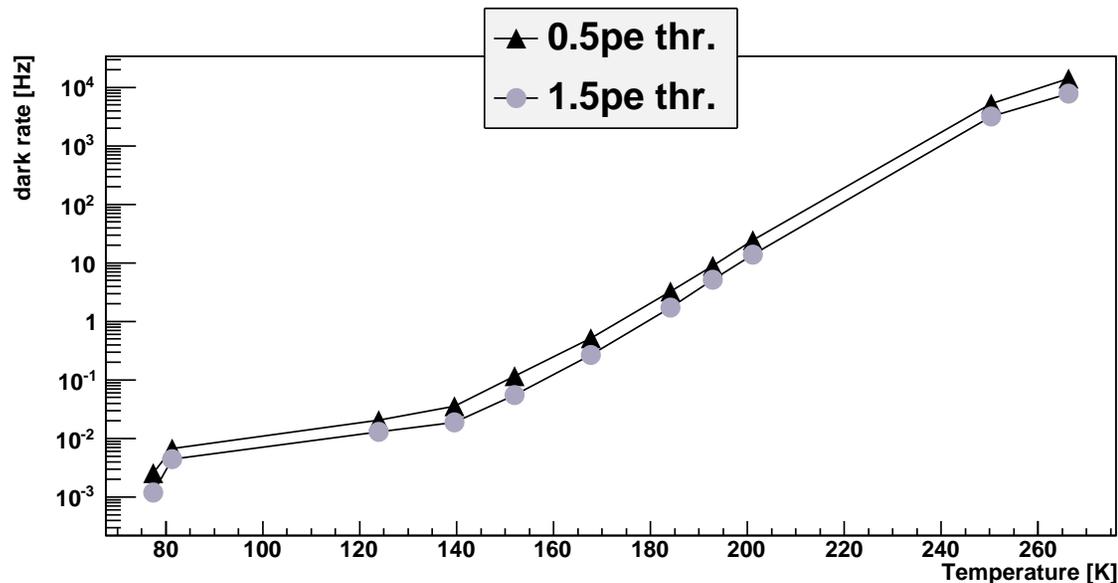


$V_{\mathbf{bd}} = V_{\mathbf{bd}}(\mathbf{T})$
$\rightarrow$ To operate at constant overvoltage we have to reduce the bias.

# Dark rate v. temperature

A nice property of SiPMs is the dark rate reduction at low temperatures.



Up to 6 orders of magnitude reduction in dark rate. $\Longrightarrow$ Excellent candidate for low count rate experiments!

The crosstalk can be derived from the ratio of dark rate with 0.5 and 1.5 p.e threshold. It is not temperature dependant.

# Summary ...

- SiPMs are appropriate detection devices for LAr scintillation light read out

- We know how they work at cryogenic temperatures. By cooling we can reduce the dark counts significantly without any loss of gain.

# ...and outlook

- Proof of principle experiment using SiPMs and WLS-fibre to read out LAr scintillation light has been accomplished. First results look very promising.

- Now we are building an improved setup.

- MC simulations for a GERDA like experiment with LAr veto will be done.

# Thank you for your attention

# Correction curves

There is the problem of nonlinearity as more than one photon can hit the same pixel at once
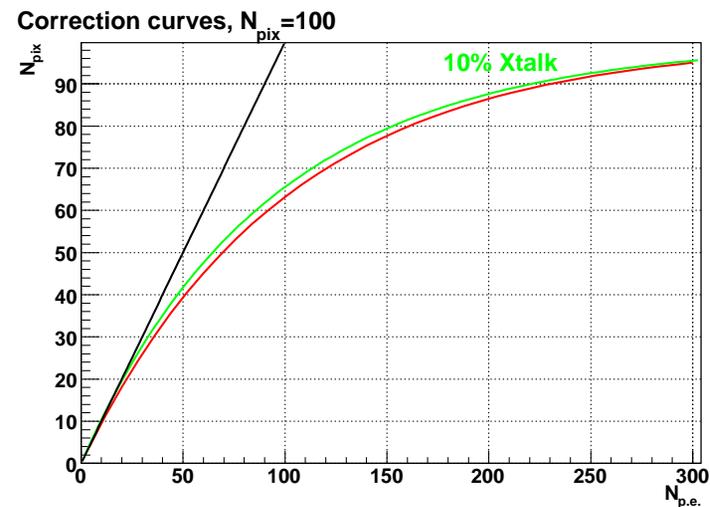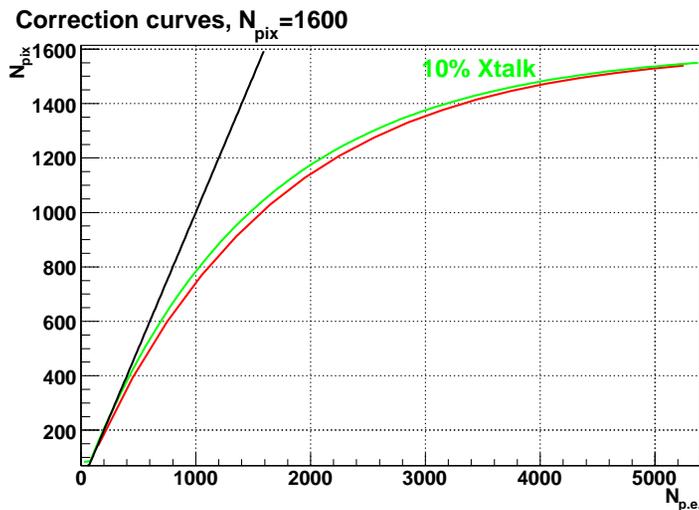
$\rightarrow$ However correction curves exist.

$$N_{fired} = N_{pix}(1 - e^{-N_{pe}/N_{pix}})(1 + p\,e^{-N_{pe}/N_{pix}})$$

$N_{pix}$ number of pixels
$p$ cross talk probability
$N_{pe} = N_{photons} \times Q.E.$

# Photon Detection Efficiency

- APD QE peak 70% is a typical value

- Fill factor is 78.5 , 61.5, 30.8 for the 100, 400, 1600 pixel MPPC's