LAr Scintillation light readout with Silicon Photomultipliers

Allen Caldwell, Béla Majorovits, Xiang Liu,
József Janicskó Csathy, *Hossein Aghaei-Khozani

March 17, 2010

Outline

- Introduction
- SiPMs, a candidate for LAr scintillation light readout?
- Characterization of SiPM at cryogenic temperatures
- Summary and outlook

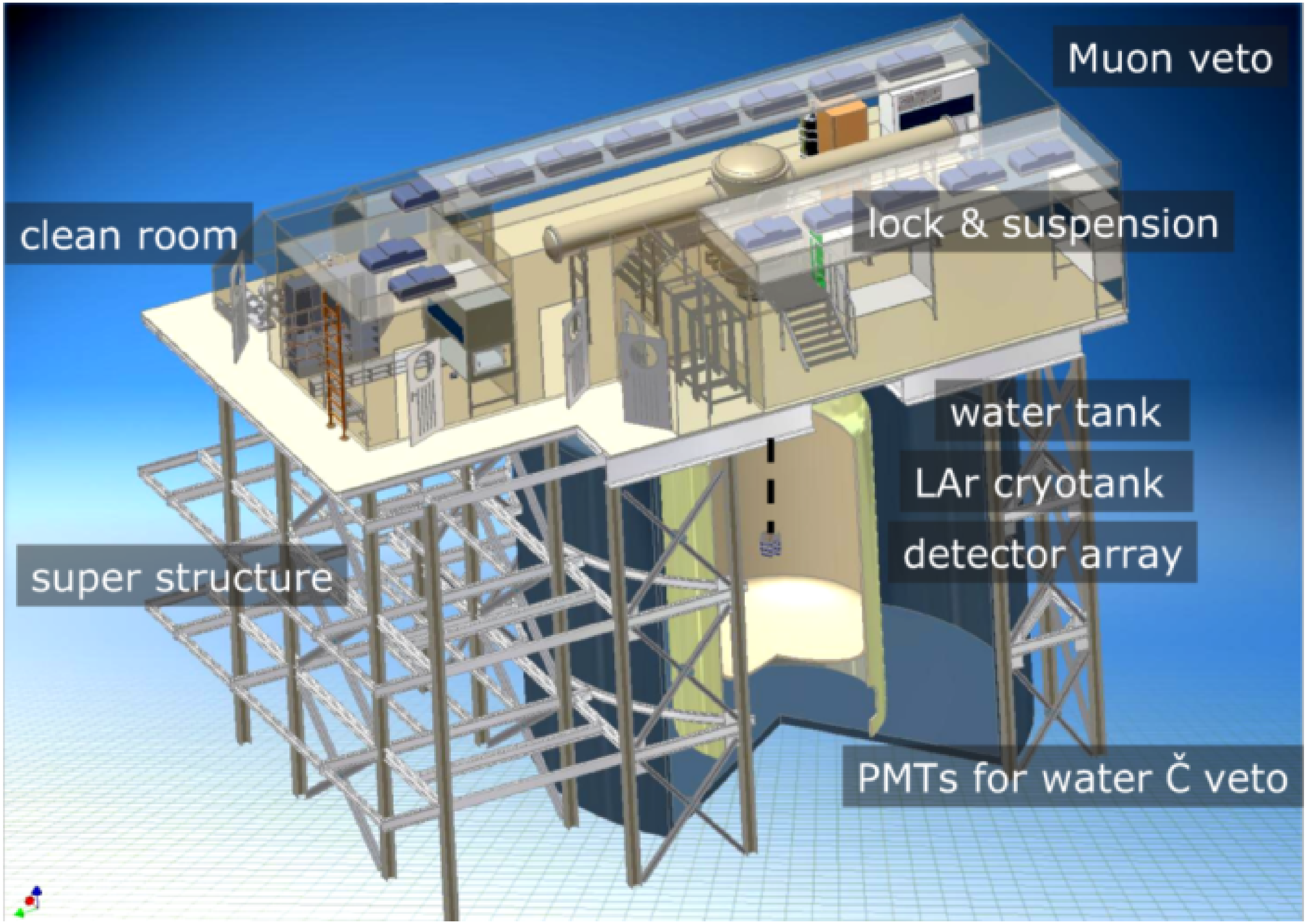
GERmanium Detector Array (GERDA)

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

- Enriched germanium is servng 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: $\left\{ \begin{array}{l} 1.\ \text{cooling liquid} \\ 2.\ \text{passive shielding} \\ 3.\ \text{scintillator} \end{array} \right.$

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

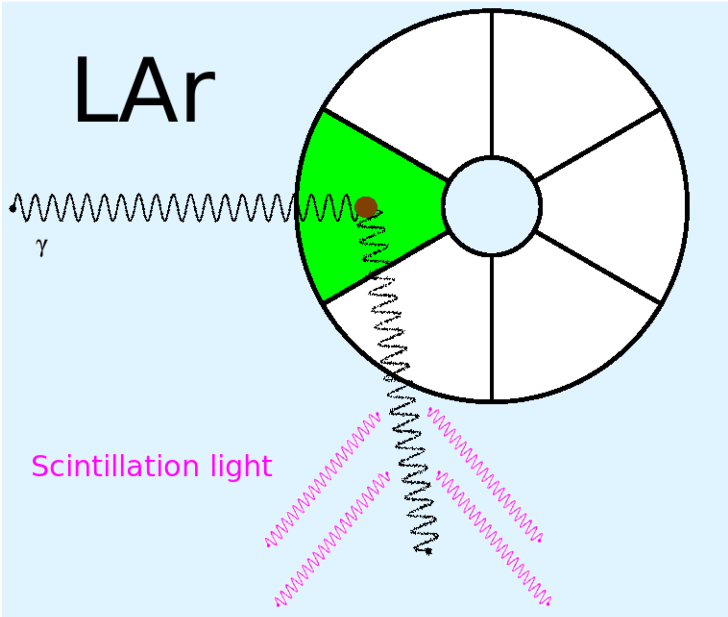
GERDA


Muon veto
clean room
lock & suspension
water tank
LAr cryotank
detector array
super structure
PMTs for water Č veto

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.

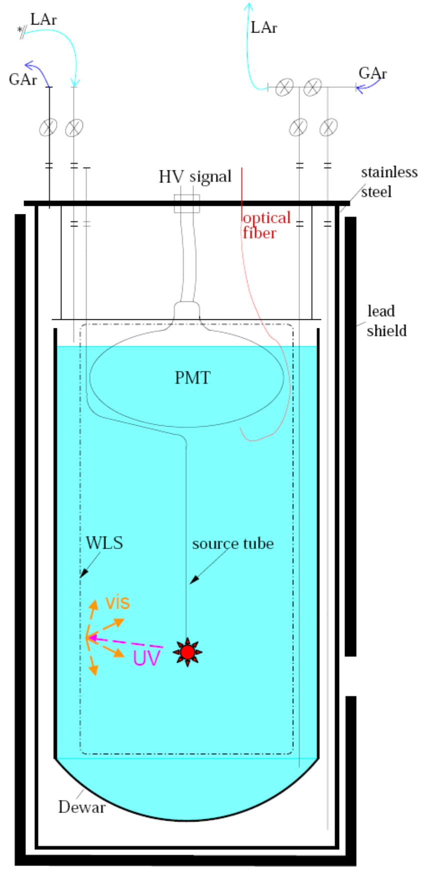


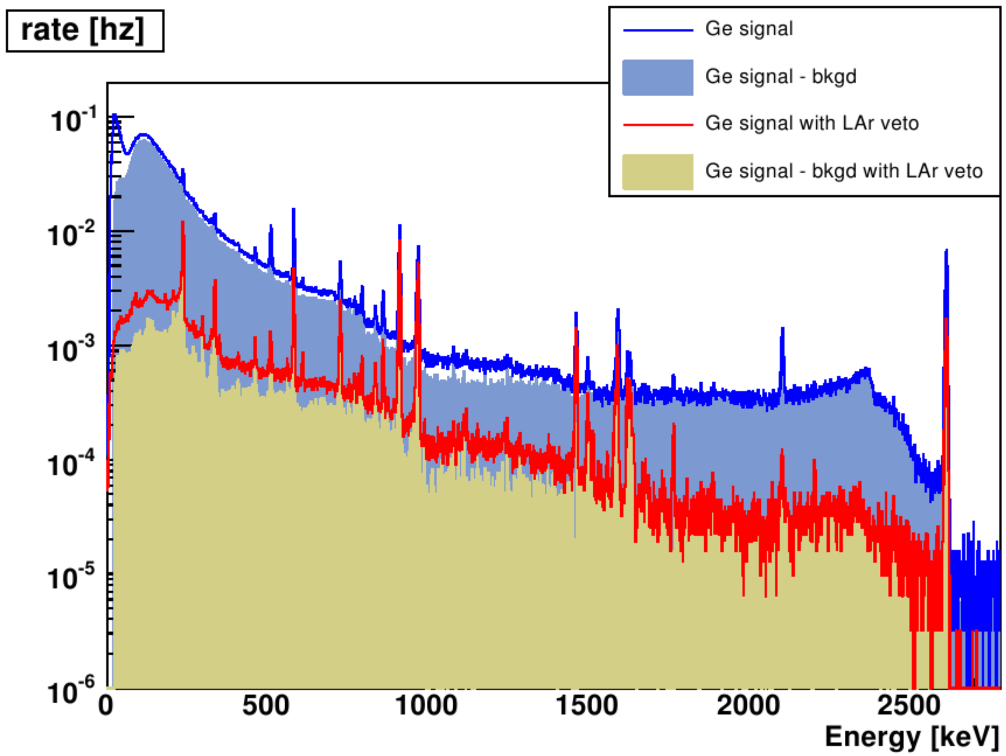
$0\nu\beta\beta$ decay Q-value = 2.039MeV. In principal all γ sources with a higher energy are dangerous.
$^{208}\mathrm{Tl}$ e.g. from the decay chain of natural $^{232}\mathrm{Th}$ emits γ with an energy of 2.614MeV.

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

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
$\longrightarrow$ Our goal is to replace conventional PMTs by SiPMs

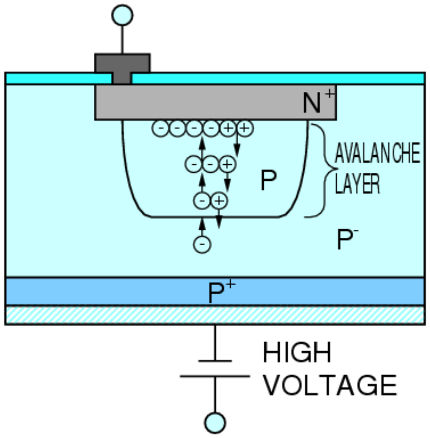
Silicon **P**hoto **M**ultiplier characteristics:

- 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

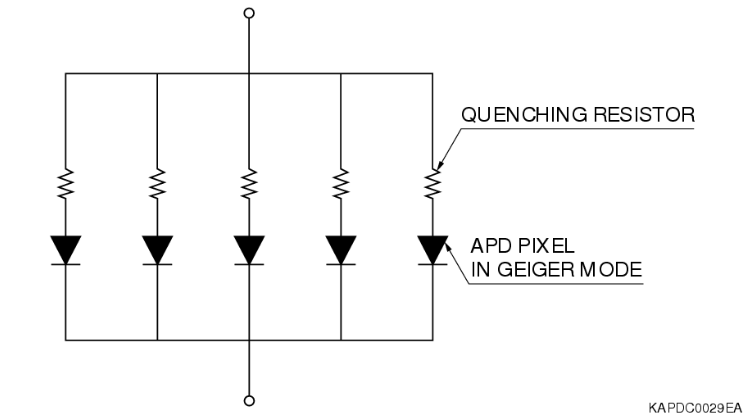
$\Longrightarrow$ excellent candidate for active veto in LAr

So what is a SiPM?

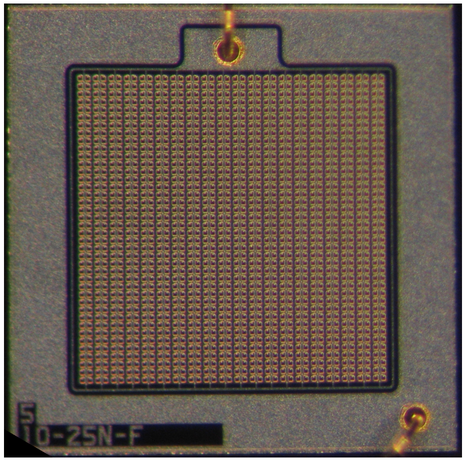
Take a couple of APDs in Geiger mode...



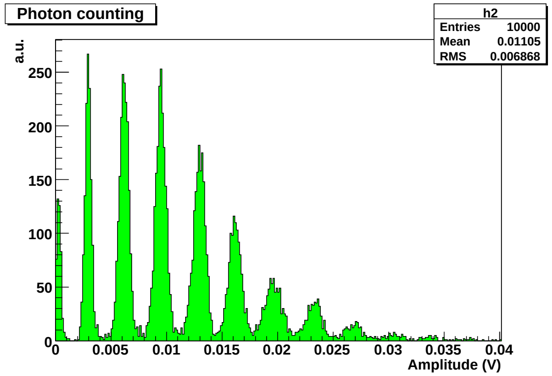
... and arrange them in an array



This is what a SiPM chip looks like



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



Definition of some important SiPM parameters

Dark rate

The firing rate of a SiPM when not illuminated. This is typically due to thermal pulses and their afterpulses.

Gain

The gain is the charge amplification of a SiPM.

$$\text{Gain} = \frac{\text{charge output of the SiPM}}{\text{elemental charge}}$$

Breakdown voltage

The V_{bd} is the minimum bias required to operate a SiPM in Geiger mode. The Gain at V_{bd} is zero, by definition.

We therefore operate at $V_{\mathrm{bias}}=V_{\mathrm{bd}}+V_{\mathrm{over}}$

Quenching resistor

Quenching resistor extinguishes the avalanche discharge of a SiPM by decreasing the voltage in the highfield region below V_{bd}. Without quenching the discharge would not come to an end.

SiPM properties at cryogenic temperature

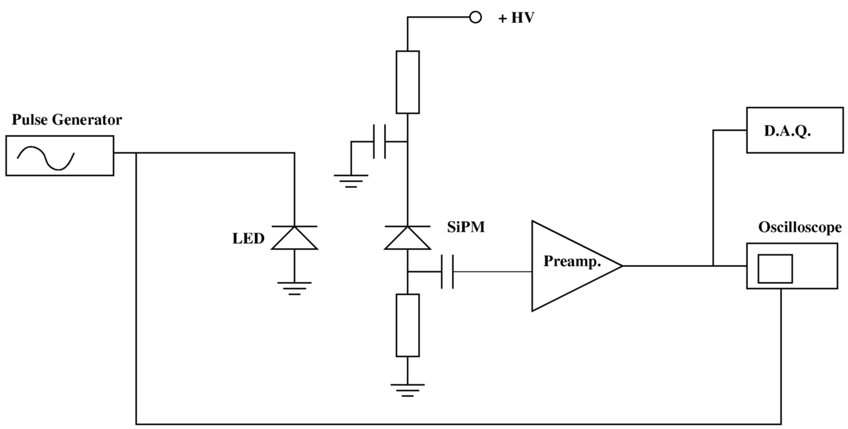
- Equipment and experimental setup.
- Pulse shape in LN.
- Gain as a function of temperature and bias.
- Dark rate as a function of temperature.

Hamamatsu's MPPC

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

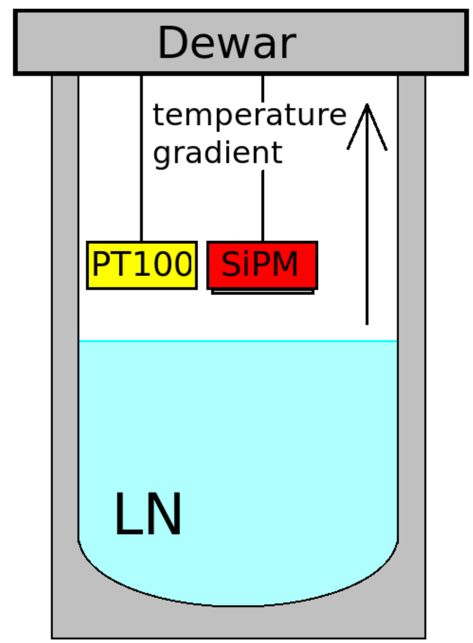
Number of pixels	100	400	1600
Pixel size	100μm $\times$ 100μm	50μm $\times$ 50μm	25μm $\times$ 25μm
PDE at peak value	65%	50%	25%
Dark count at RT	600-1000 kHz	400-800 kHz	300 - 600 kHz
Gain at RT	2.75×10^6	7.5×10^5	2.4×10^5

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

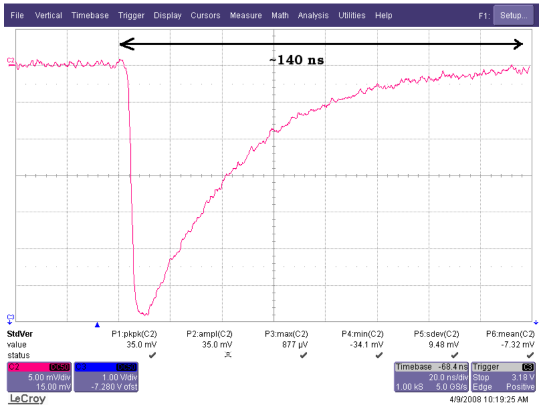
- Gas tight dewar filled with LN
- LN evaporates slowly
  $\longrightarrow$ temperature increases continuously
- PT100 for temperature readout



Pulse shape in LN

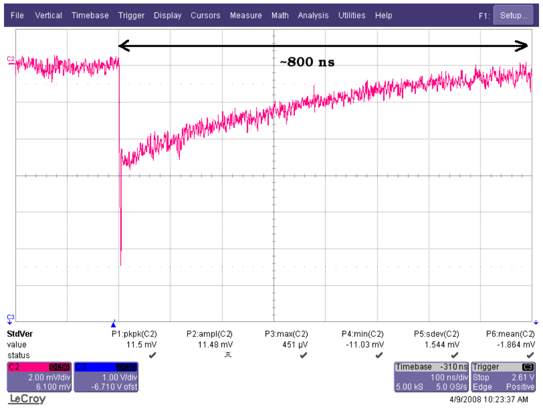
The decay time increases at low temperatures by a factor of 6.

RT



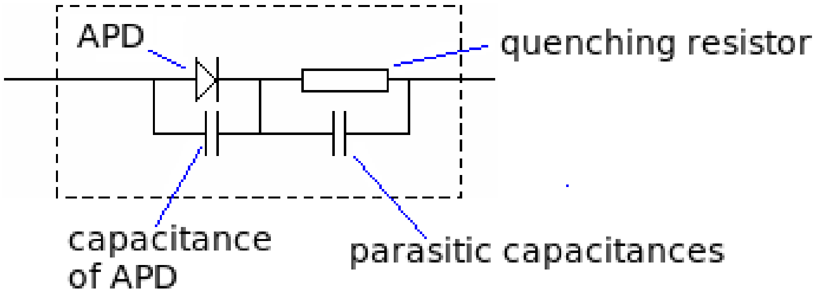
τ = 45ns

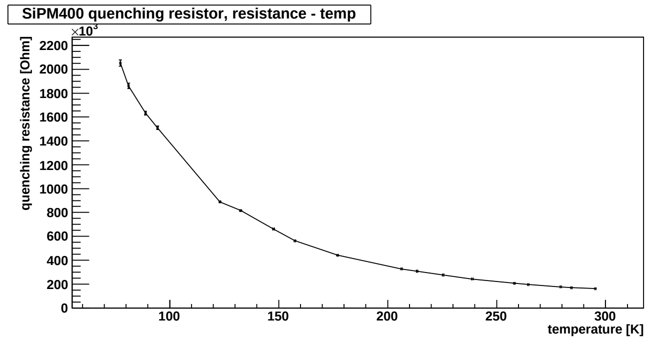
LN



τ = 440ns

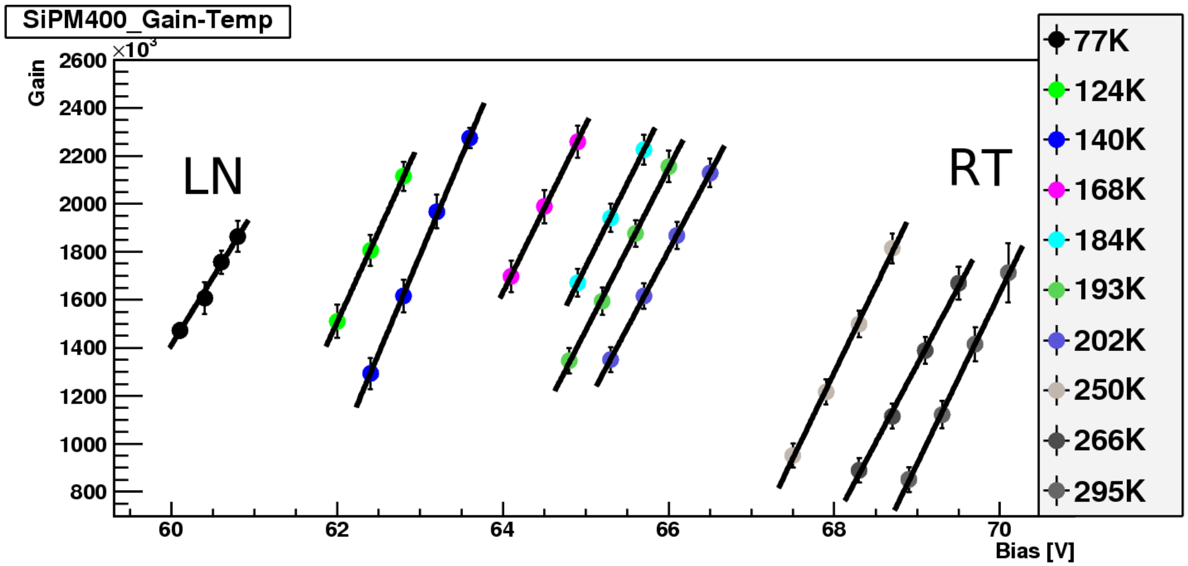
The quenching resistor is temperature dependent. Slow component from RC-circuit. Sharp peak from parasitic capacitances.





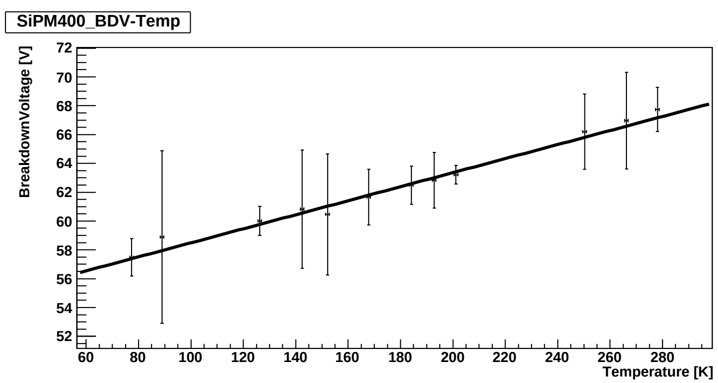
Gain v. temperature and bias

Does the gain change at LN temperature?



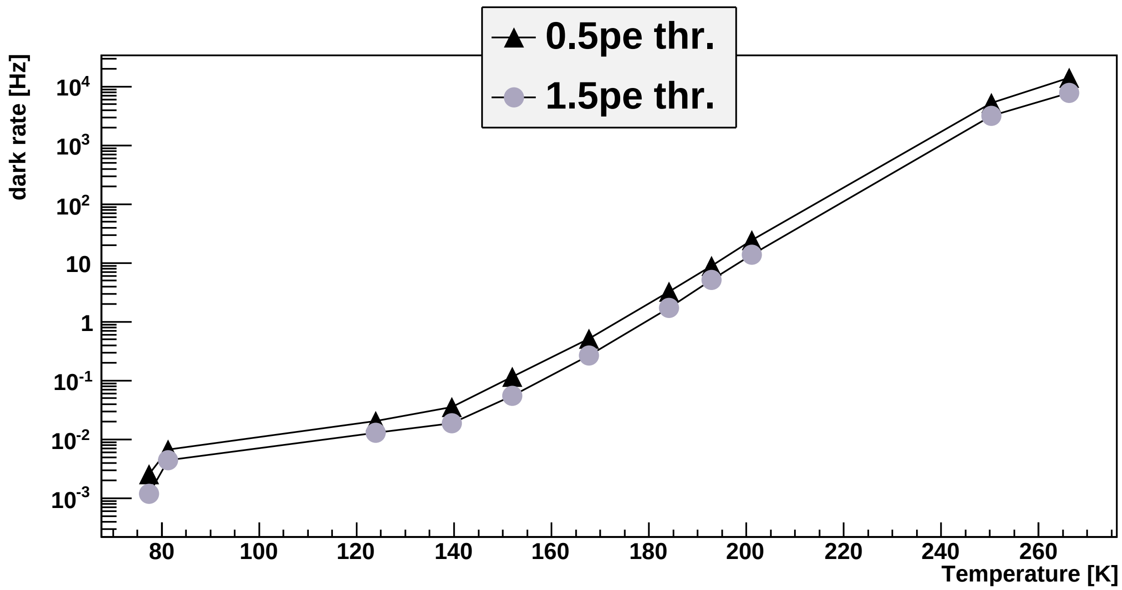
The gain is not a function of the temperature. But the gain strongly depends on V_{over}.

$V_{\mathbf{bd}}$ = $V_{\mathbf{bd}}$**(T)** $\longrightarrow$ To operate at constant overvoltage one has to adjust 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 texperiment 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.

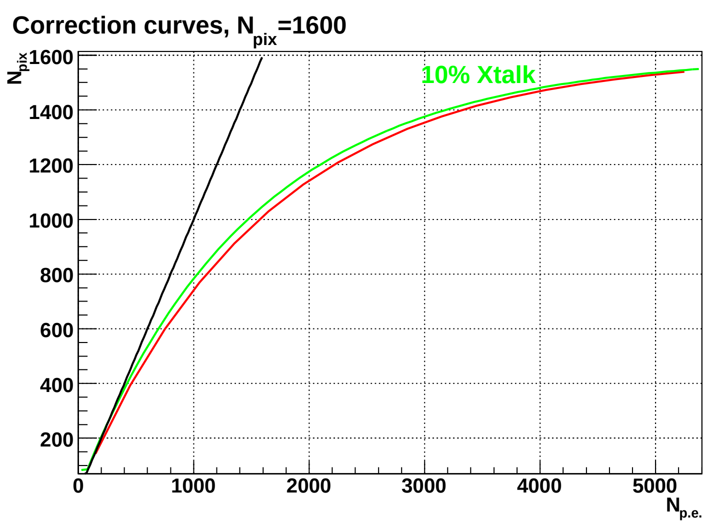
Thank you for your attention

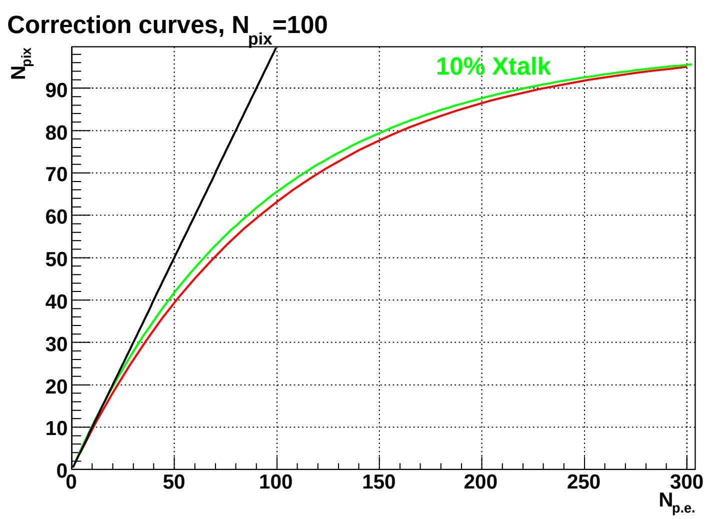
Correction curves

There is the problem of nonlinearity as more than one photon can hit the same pixel at once
$\longrightarrow$ 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