LAr based anti-compton veto with Silicon Photomultipliers

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Outline

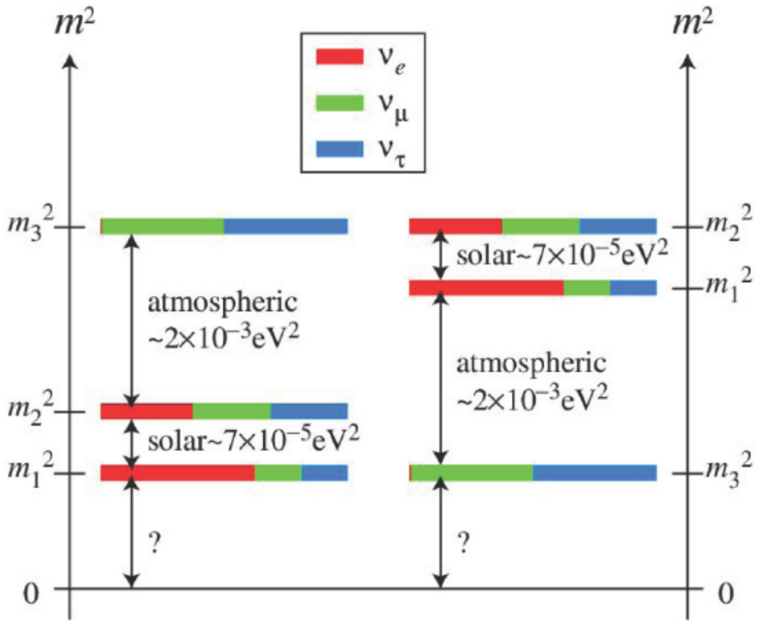
- Introduction ($0\nu\beta\beta$ and the GERDA Experiment)
- SiPMs, a candidate for LAr veto
- Experimental Setup
- Results

Neutrino properties

ν-oscillations observed $\rightarrow m_\nu > 0$

Still many open questions:

- m_ν = ?
- $\nu = \overline{\nu}$?
- normal or inverted hierarchy ($m_3 > m_2$) ?
- θ_{13}=?
- CP violating phase?

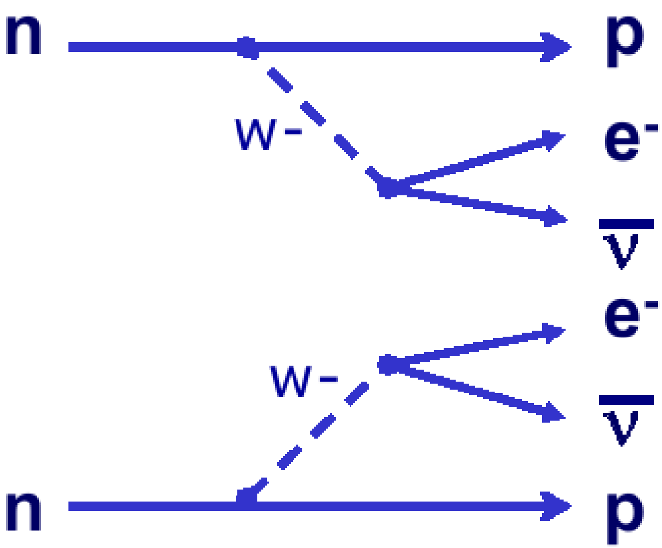


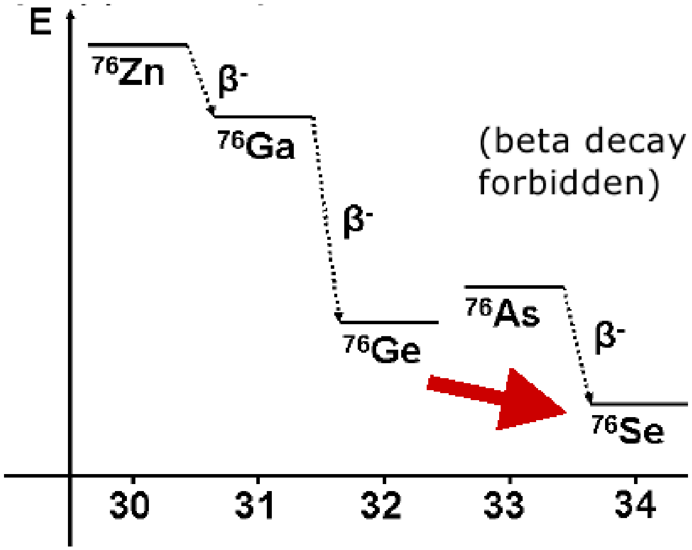
normal hierarchy $m_3 > m_2$ or inverted hierarchy $m_3 < m_2$

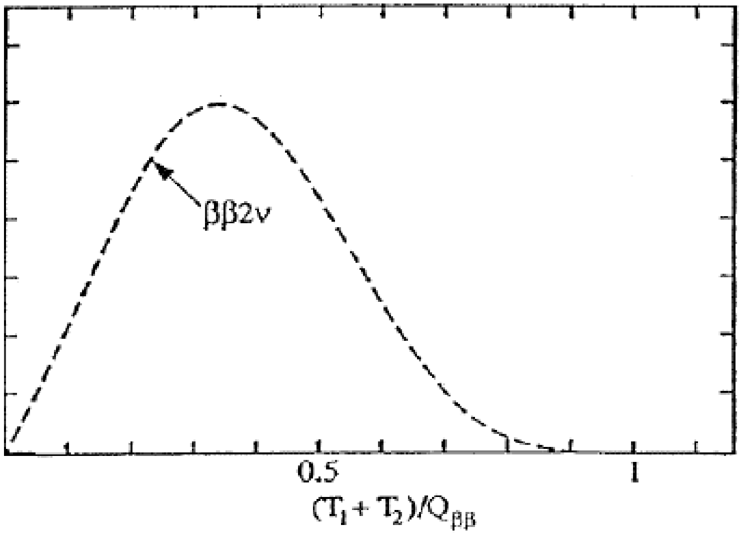
The neutrinoless double beta-decay could answer the first three questions.

Neutrino accompanied Double beta-decay

- (A,Z) $\rightarrow$ (A,Z+2) + 2e^- +2$\overline{\nu}_e$
- $2\nu\beta\beta$ could be observed in $\sim$ 35 isotopes.
- $T^{2\nu\beta\beta} \sim 10^{11} \times$ age of the universe (Ge^{76}).

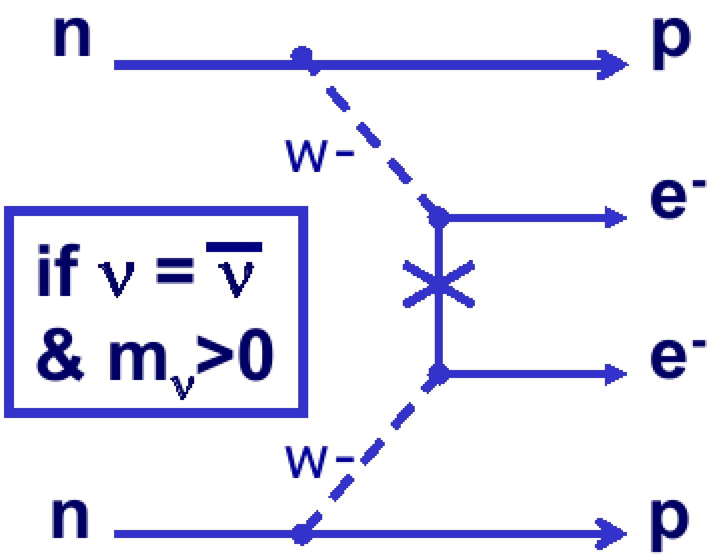




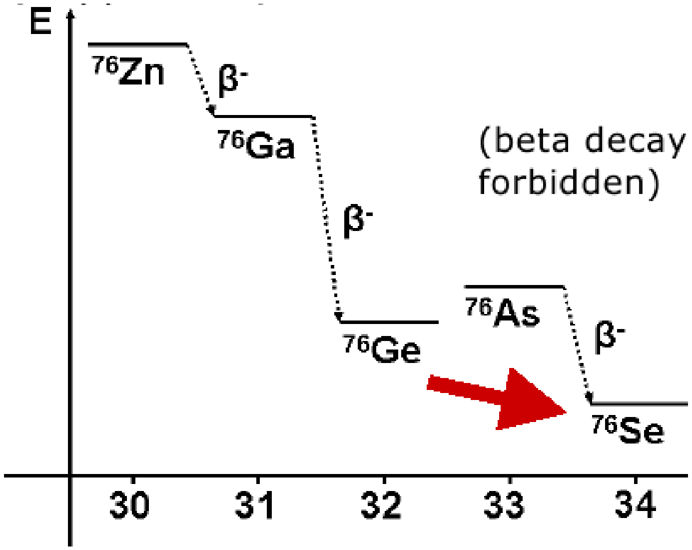


Neutrinoless double beta-decay ($0\nu\beta\beta$)

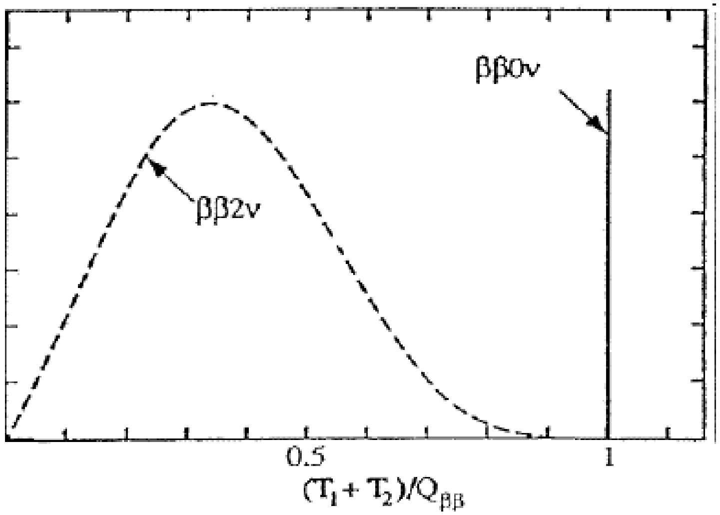
- (A,Z) $\rightarrow$ (A,Z+2) + 2e^-
- Leptonnumber violation ΔL = 2
- $T^{0\nu\beta\beta} \gtrsim 10^{15} \times$ age of the universe.



if $\nu = \overline{\nu}$
& $m_\nu > 0$



(beta decay forbidden)



How to search for 0$\nu\beta\beta$

- Get a material that can $\beta\beta$-decay.
- Measure sum of the deposited energy of both created electrons in the detector.
- Search for an energy peak at the Q-value.

The Gerda group uses germanium as target material.

Why germanium?

Sensitivity on $T^{0\nu\beta\beta} \propto \epsilon \cdot \sqrt{\frac{M}{\sigma \cdot b}}$.

Challenge	germanium advantage
high signal efficiency ϵ	source = detector $\longrightarrow$ high efficiency
good energy resolution σ	better tahn 0.25% !
low background rate b	ultrapure material
large target mass M	existing detectors from old experiments
background discrimination	segmentation, pulse shape analysis

☹need enrichment

☹$Q_{\beta\beta}$=2039keV (<2614keV)

GERmanium Detector Array (GERDA)

Is a double beta decay experiment based on enriched germanium
Biggest challenge is to reduce the background

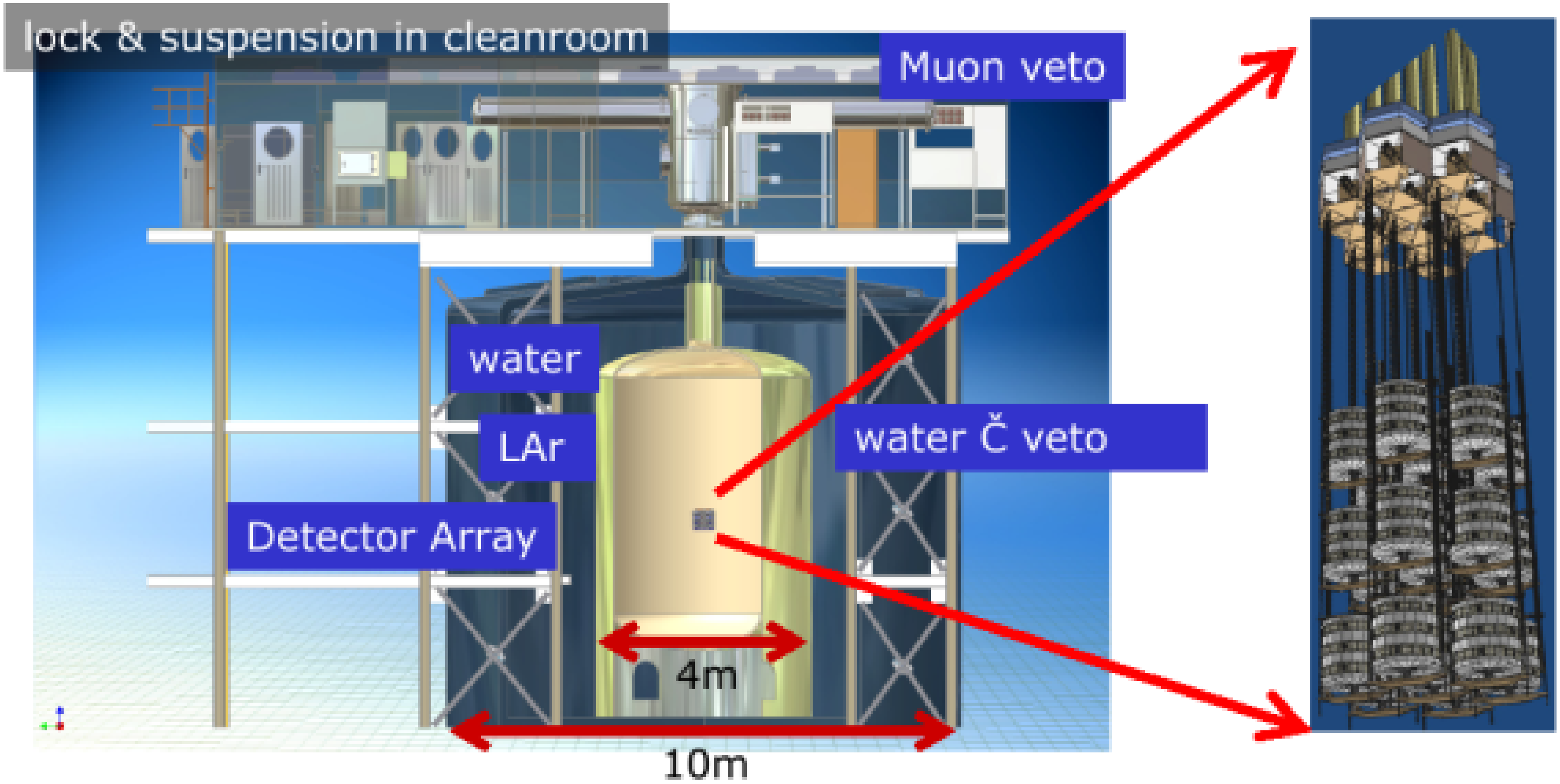
Passive BG reduction

- only usage of radio-pure materials
- shielding against external radioactivity

Active BG reduction

- active vetoing of muons with a Water-Cerenkov veto
- detector coincidence
- pulse shape analysis
- detector segmentation
- LAr-anti-compton-veto

GERDA


lock & suspension in cleanroom
Muon veto
water
LAr
water Č veto
Detector Array
4m
10m

Operation in liquid argon

GERDA's main design feature: Bare germanium detectors are operated in LAr

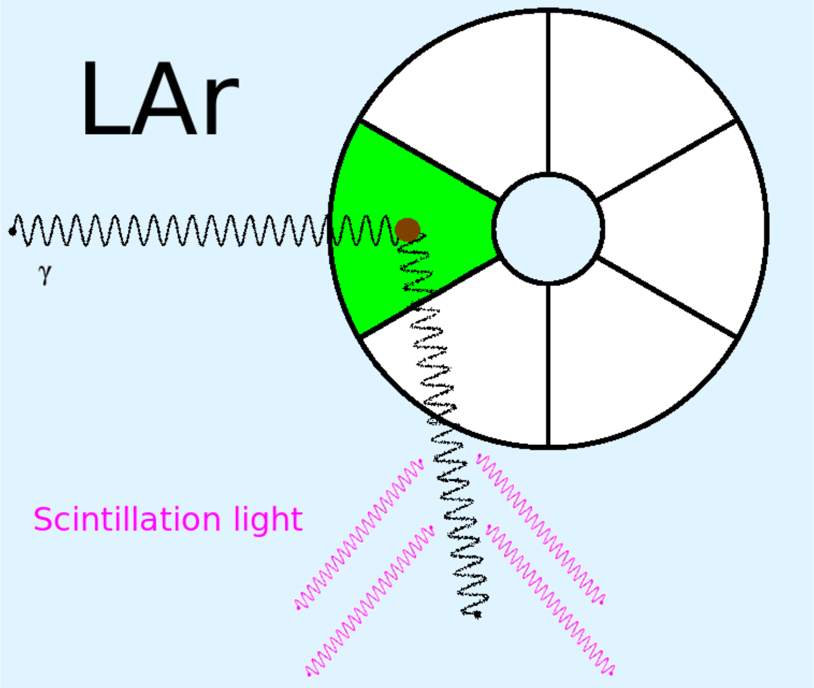
- LAr is: $\left\{ \begin{array}{l} \text{1. cooling liquid} \\ \text{2. passive shielding} \\ \text{3. scintillator} \end{array} \right.$

Use LAr scintillation light for an active veto in a later phase!

Motivation of a LAr veto

$0\nu\beta\beta$ decay is a local event.

Segmented detectors can identify multi-site events as background. If singly Compton scattered gamma escapes detector $\rightarrow$ no identification as background is possible.

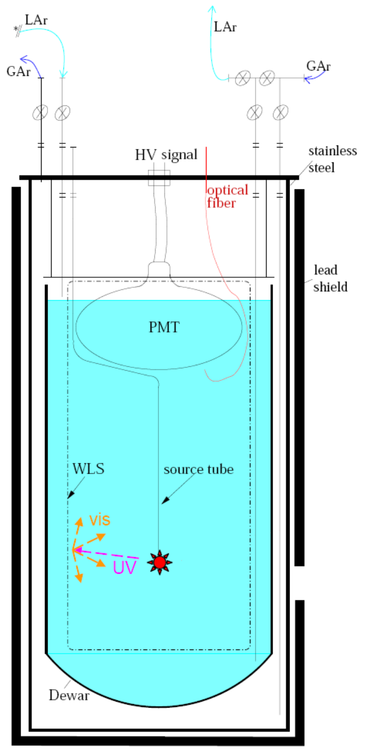


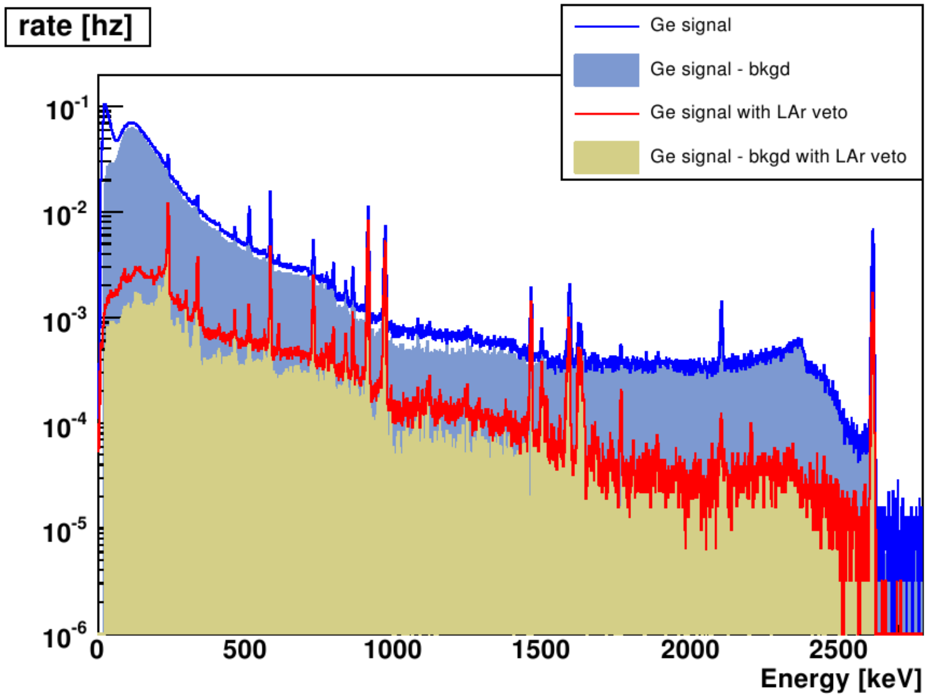
$0\nu\beta\beta$ decay Q-value = 2.039MeV. All γ with a higher energy are dangerous.

Detecting scintillation light in LAr from Compton scattered gammas could identify these events.

Heidelberg setup

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





The background suppression observed by the Heidelberg Group motivated our studies.

Our goal

PMTs: 1kg, high radioactivity
→ Our goal: replace PMTs by SiPMs

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

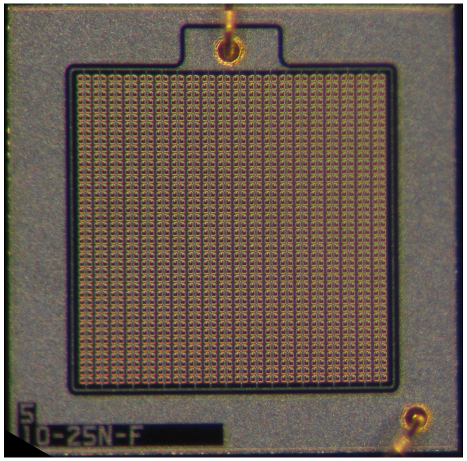
- very small photosensors (some mg), we expect much lower radioactivity
- work at cryogenic temperatures
- do not require HV (HV leads to problems in Ar atmosphere)
- high photon detection efficiency (PDE)
- relatively cheap

⟹ excellent candidate for active veto in LAr

So what is a SiPM?

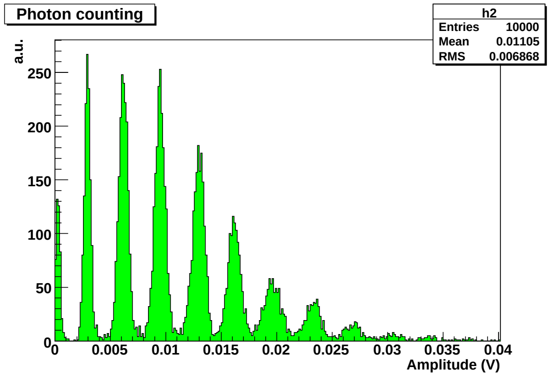
This is what a SiPM chip looks like

Array of avalanche photodiodes (APD) in Geiger mode.
APD sees one or more photons → fire



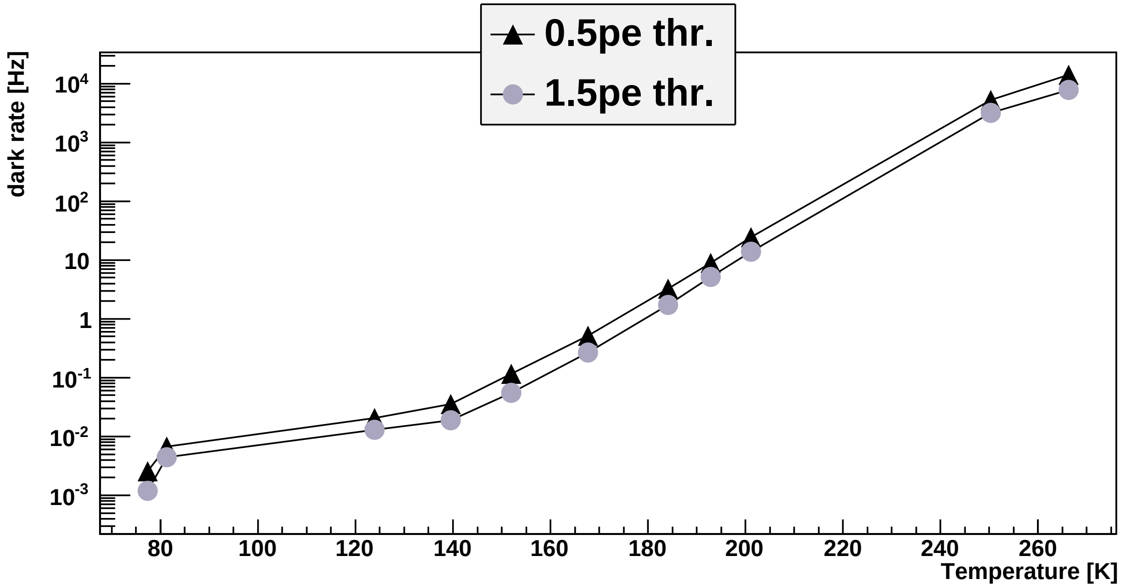
Single photon resolution!

Every pixel is an APD.
Number of fired pixels will tell how many photons were detected.



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!

Problems

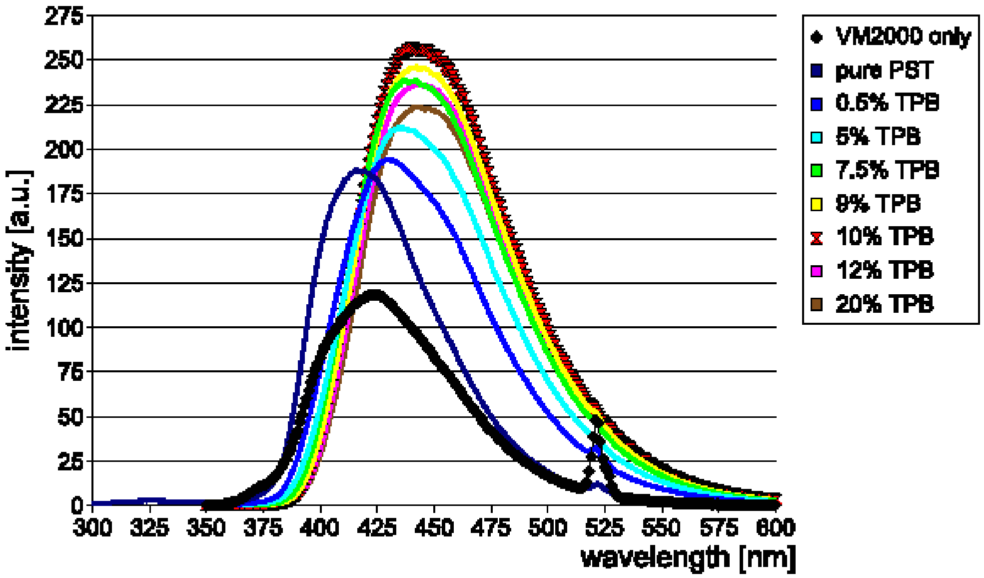
1. Argon scintillates in the VUV (128nm). SiPM peak sensitivty is at 400nm.
→ Shift the light from UV to visible range

2. SiPMs are very small (1mm × 1mm).
→ Increase the effective surface.

Mirror foil (VM2000) (Problem 1)

Keep the light in the experiment by covering everything with VM2000 foil (95 % reflectivity).

Coat the foil with a flourescent dye (TPB). The dye shifts the scintillation light towards the visible range.

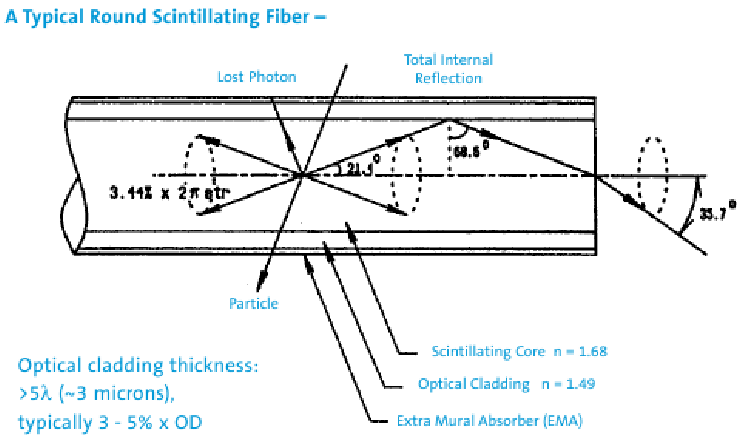


Match emitted light with wavelength you need. Problem 1 √

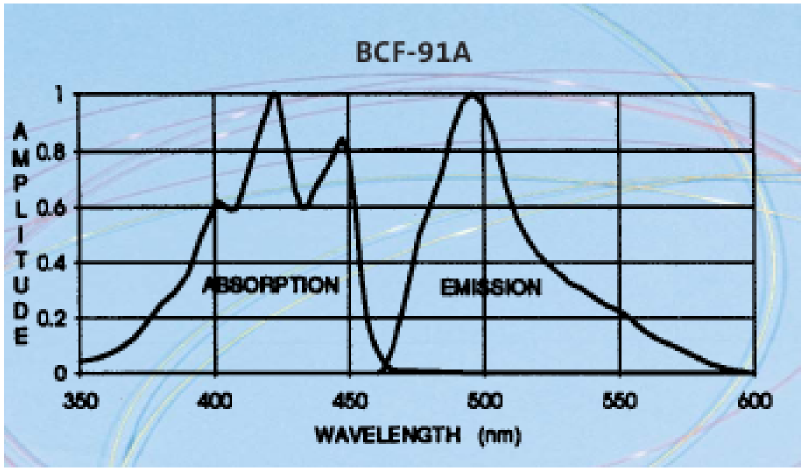
Optical light guide (Problem 2)

Couple SiPMs to a wave length shifting (WLS) light guide. Problem 2 $\surd$

Light gets trapped in the light guide and is guided to the SiPMs.

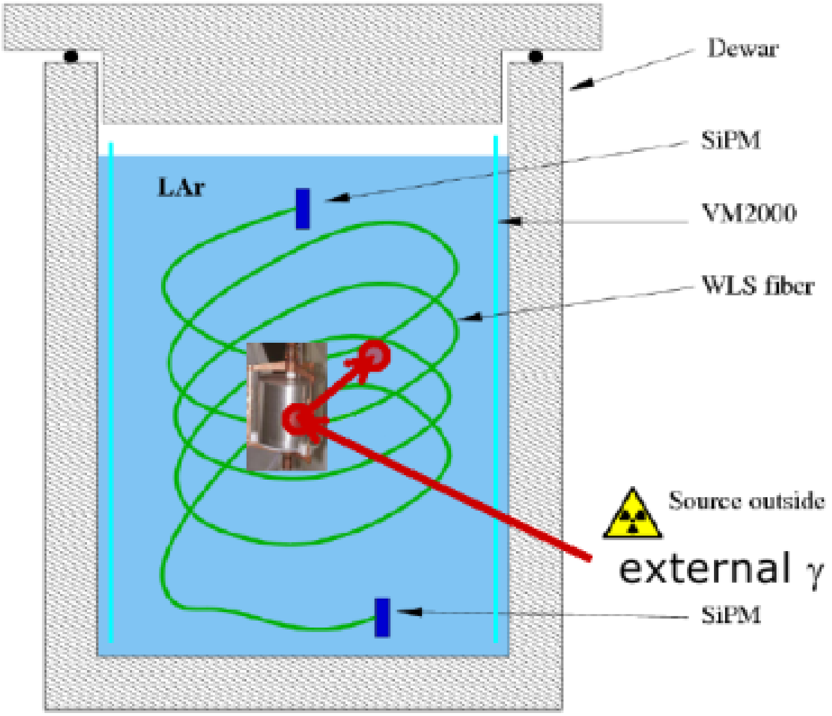


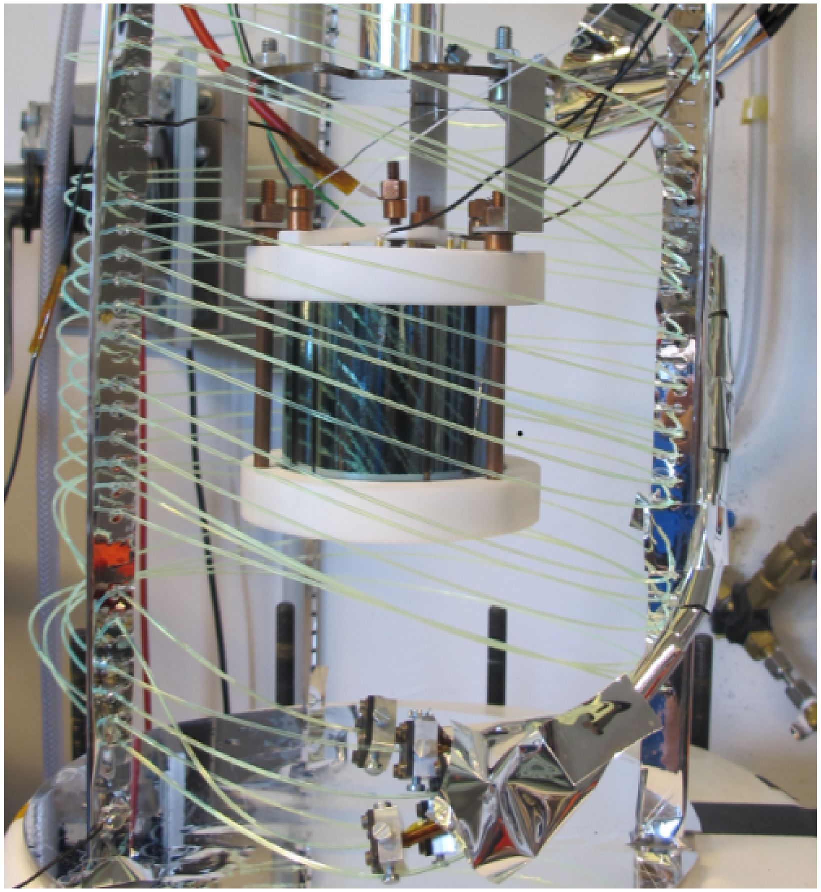
The light guide is made of a flourescent material. ”Shifts” incident light to longer wavelengths.



Match dye emission with light guide absorption.

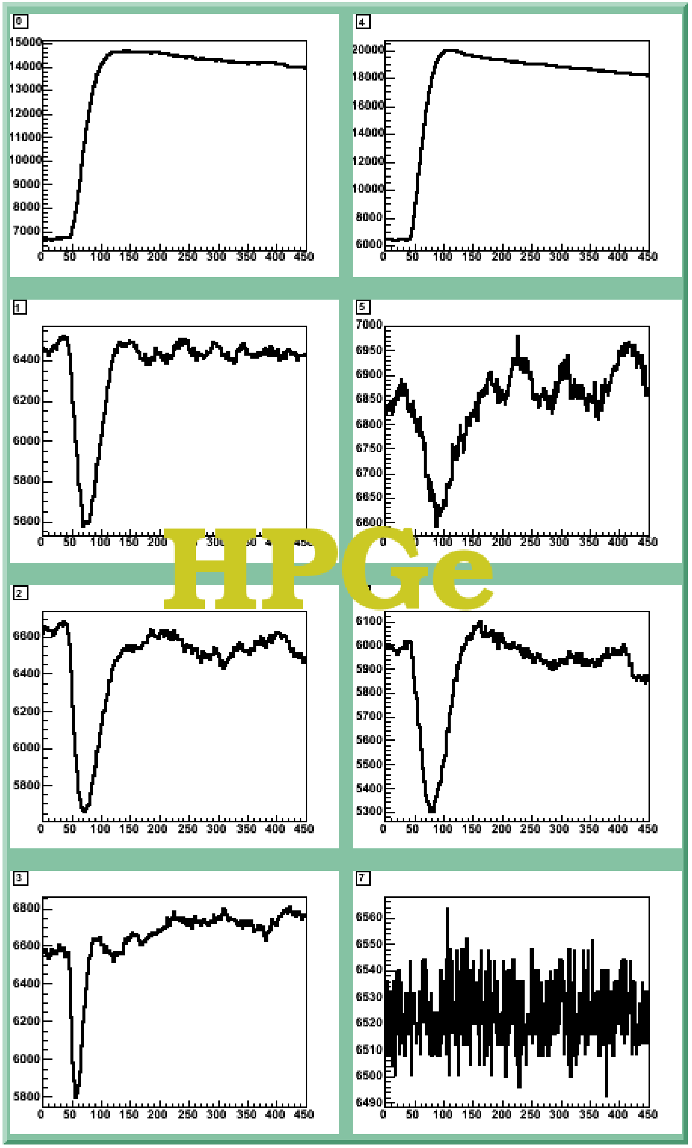
Experimental Setup

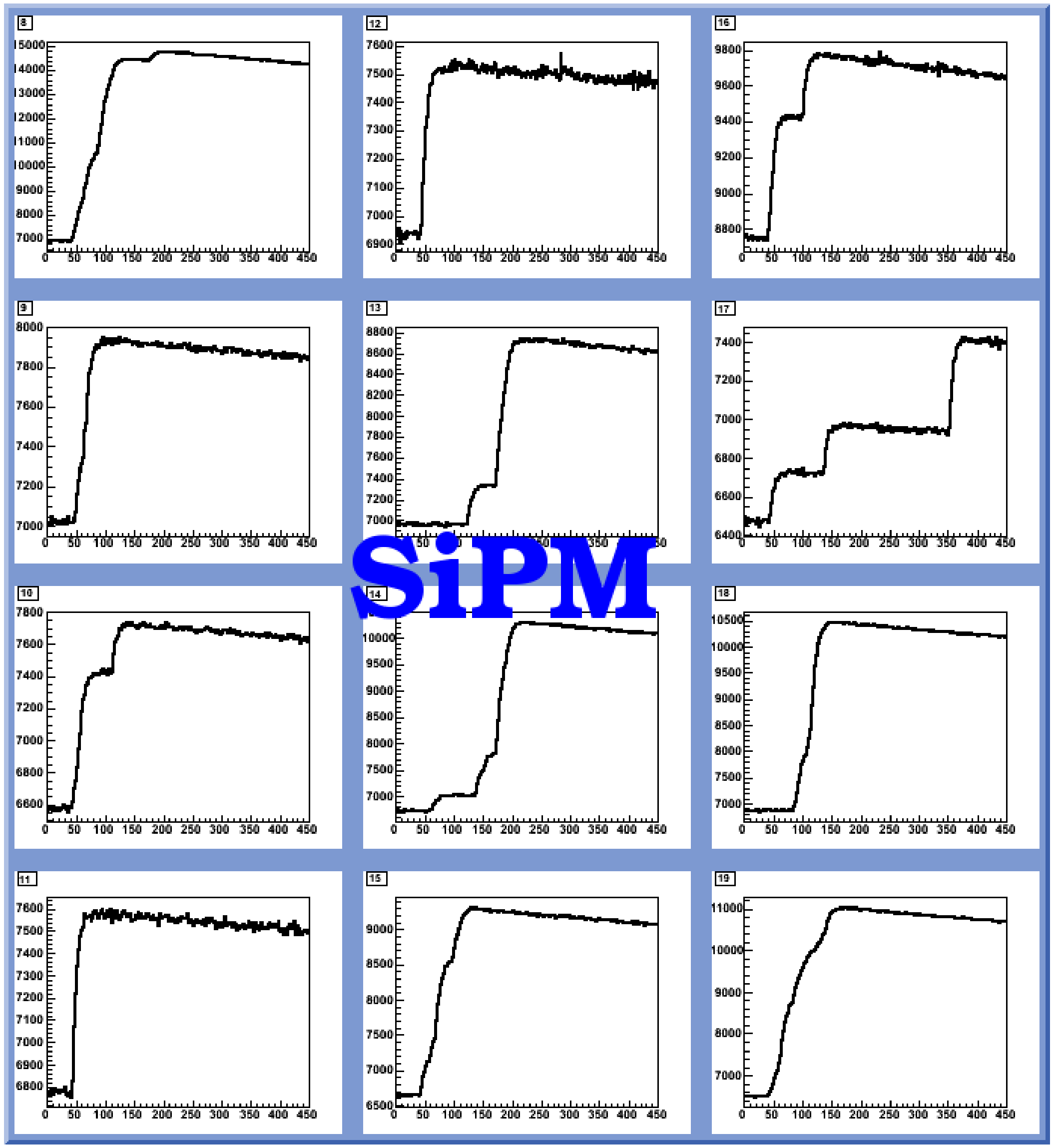




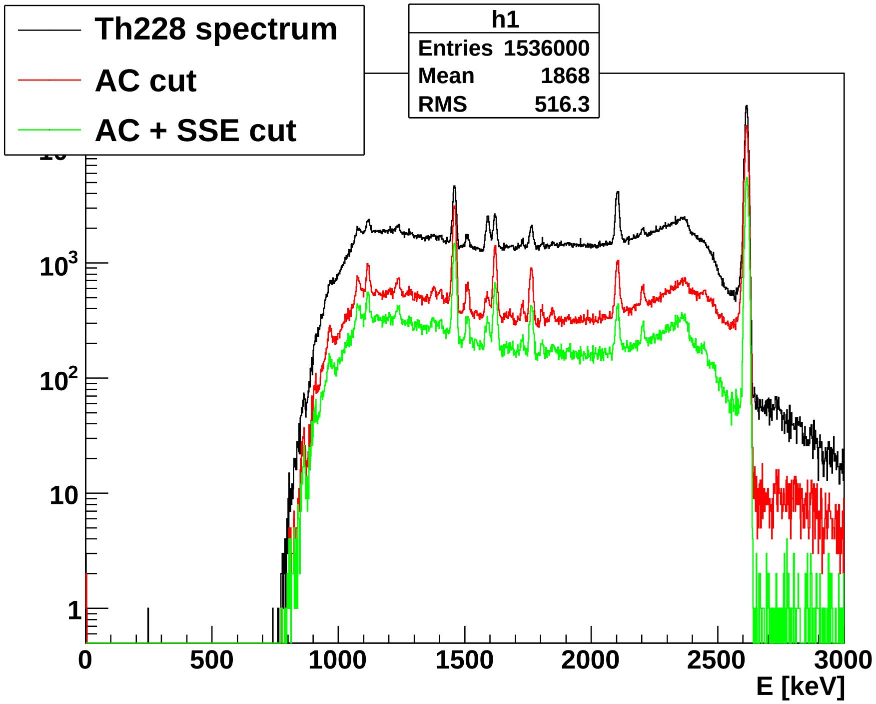
6×2.5m light guide. 12 SiPMs. ∼15l active volume.
High Purity Germanium detector. 6-fold segmented in ϕ.

Results


HPGe
0
4
1
5
2
3
7
0 50 100 150 200 250 300 350 400 450


SiPM
8
12
16
9
13
17
10
14
18
11
15
19
0 50 100 150 200 250 300 350 400 450

Results



in the ROI (2039 ± 56)keV

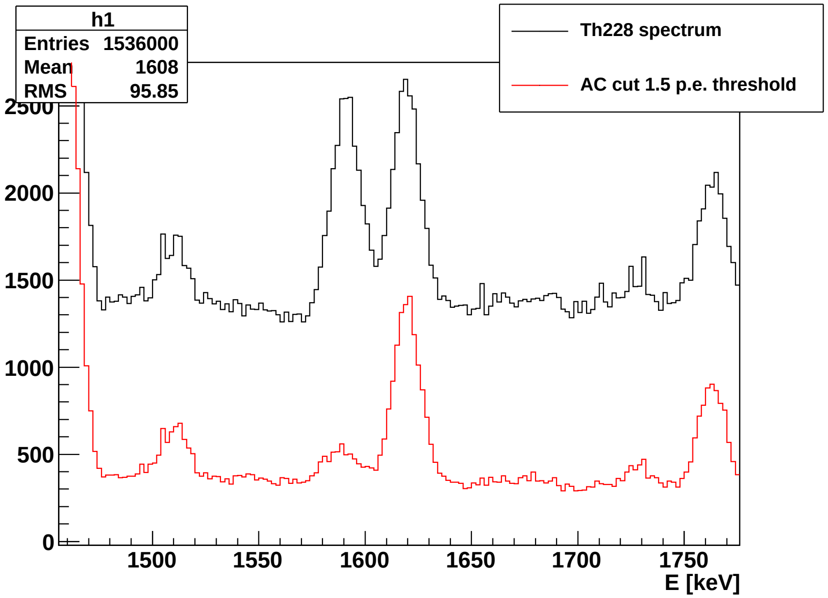
- LAr-anti-compton-veto (AC) with 0.5 photon threshold SF = 5.2
- AC-veto + single-segment-cut (SSE) SF = 10.6

Full absorption peaks are not supressed.

Results

Double escape peak (DEP): 2.6MeV-$\gamma \rightarrow$ 1.6MeV-γ + e^- + e^+
1.6MeV-γ absorbed, e^+ anihilates $\rightarrow$ both 511keV-γ escape.

Excellent DEP suppression !!!



Summary ...

- GERDA and $0\nu\beta\beta$ could teach us a lot about neutrinos
- For high sensitivity on $0\nu\beta\beta$ we need low background → Use LAr-AC-veto to supress background.
- SiPMs are appropriate detection devices for a LAr-AC-veto
- A supression of a factor 5 has been achieved with a small test setup.

...and outlook

- Go into pulse shapes. Potential to increase veto efficiency?
- Monte Carlo simulations

Thank you for your attention

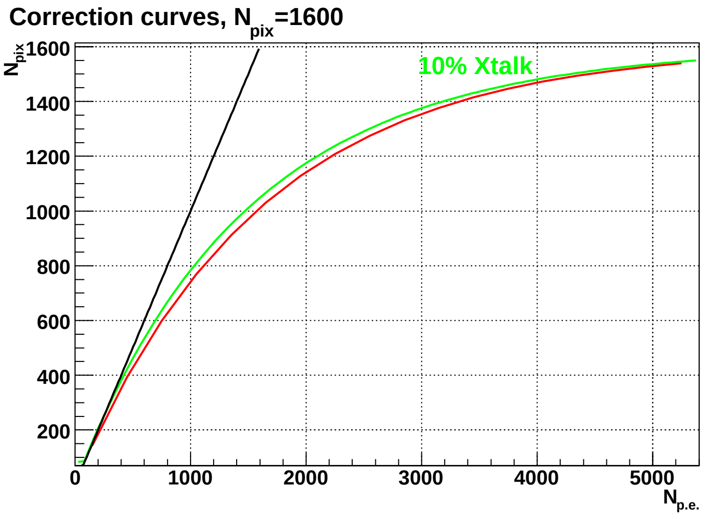
Backup-slides

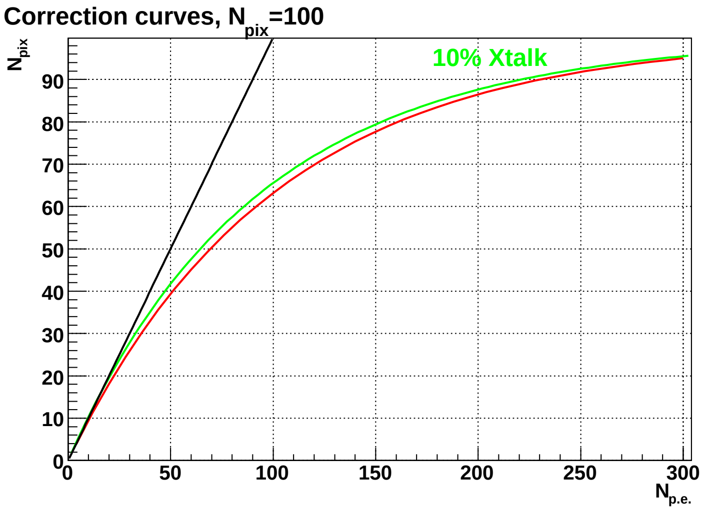
Correction curves

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

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

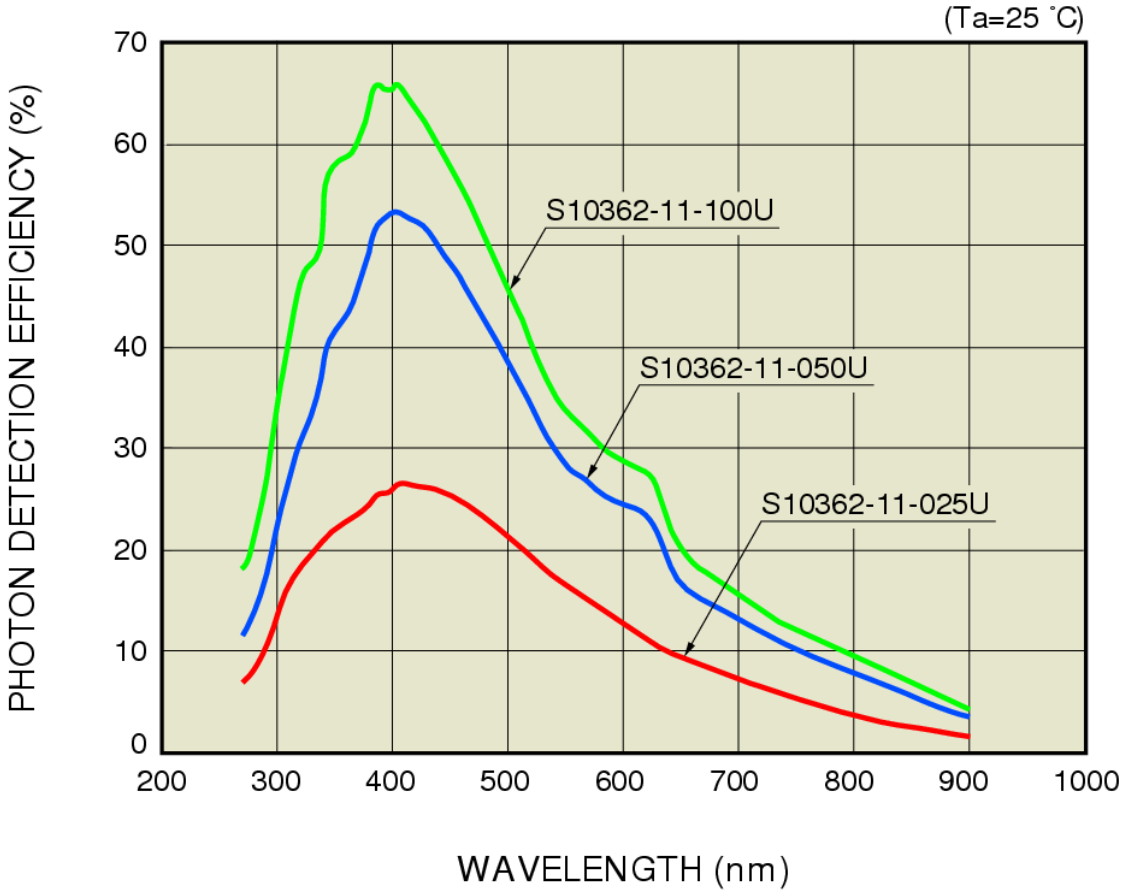
N_{pix} number of pixels
p cross talk probability
$N_{pe} = N_{photons} \times Q.E.$


Correction curves, N_{pix}=1600


Correction curves, N_{pix}=100

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

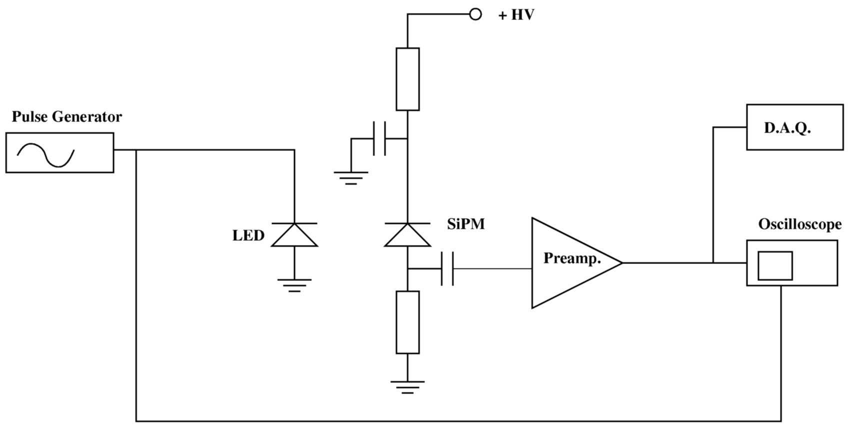


Hamamatsu's MPPC

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

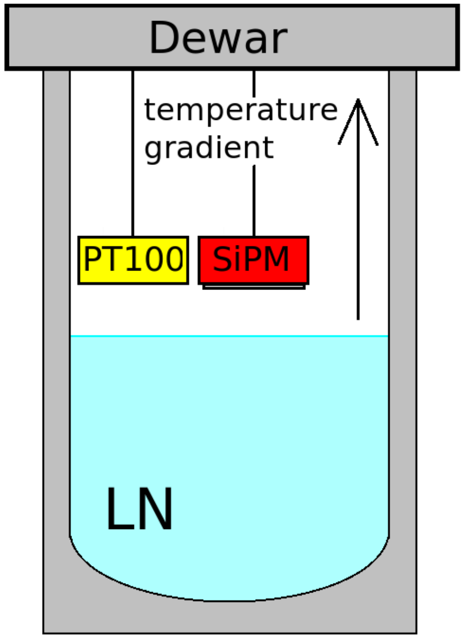
Number of pixels	100	400	1600
Pixel size	100μm $\times$ 100μm	50μm $\times$ 50μm	25μm $\times$ 25μm
PDE at peak value	65%	50%	25%
Dark count at RT	600-1000 kHz	400-800 kHz	300 - 600 kHz
Gain at RT	2.75×10^6	7.5×10^5	2.4×10^5

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

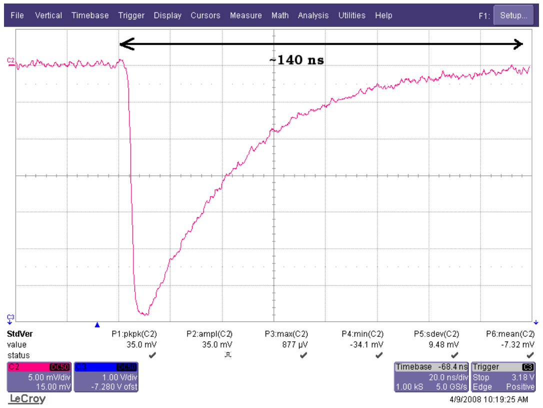
- Gas tight dewar filled with LN
- LN evaporates slowly
  → temperature increases continuously
- PT100 for temperature readout



Pulse shape in LN

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

RT

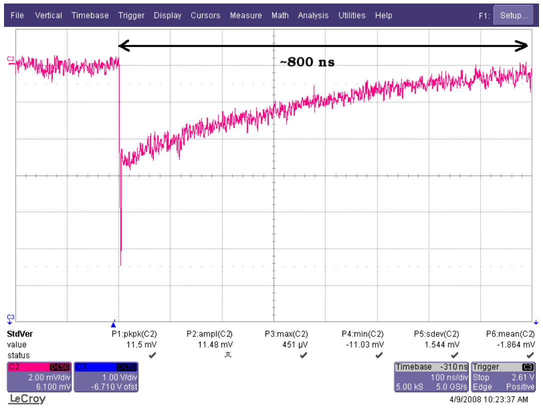


StdVer	P1:pkpk(C2)	P2:ampl(C2)	P3:max(C2)	P4:min(C2)	P5:sdev(C2)	P6:mean(C2)
value	35.0 mV	35.0 mV	877 µV	-34.1 mV	9.48 mV	-7.32 mV
status	✓	⎍	✓	✓	✓	✓

C2 DC50: 5.00 mV/div, 15.00 mV
C3 DC50: 1.00 V/div, -7.280 V ofst
Timebase -68.4 ns: 20.0 ns/div, 1.00 kS, 5.0 GS/s
Trigger C3: Stop 3.18 V, Edge Positive
4/9/2008 10:19:25 AM

τ = 45ns

LN



StdVer	P1:pkpk(C2)	P2:ampl(C2)	P3:max(C2)	P4:min(C2)	P5:sdev(C2)	P6:mean(C2)
value	11.5 mV	11.48 mV	451 µV	-11.03 mV	1.544 mV	-1.864 mV
status	✓	⎍	✓	✓	✓	✓

C2 DC50: 2.00 mV/div, 6.100 mV
C3 DC50: 1.00 V/div, -6.710 V ofst
Timebase -310 ns: 100 ns/div, 5.00 kS, 5.0 GS/s
Trigger C3: Stop 2.61 V, Edge Positive
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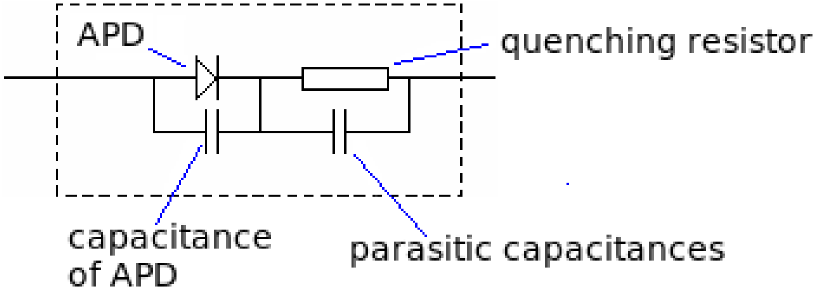
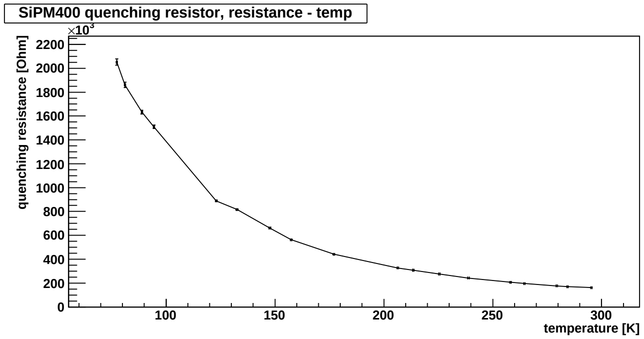
τ = 440ns

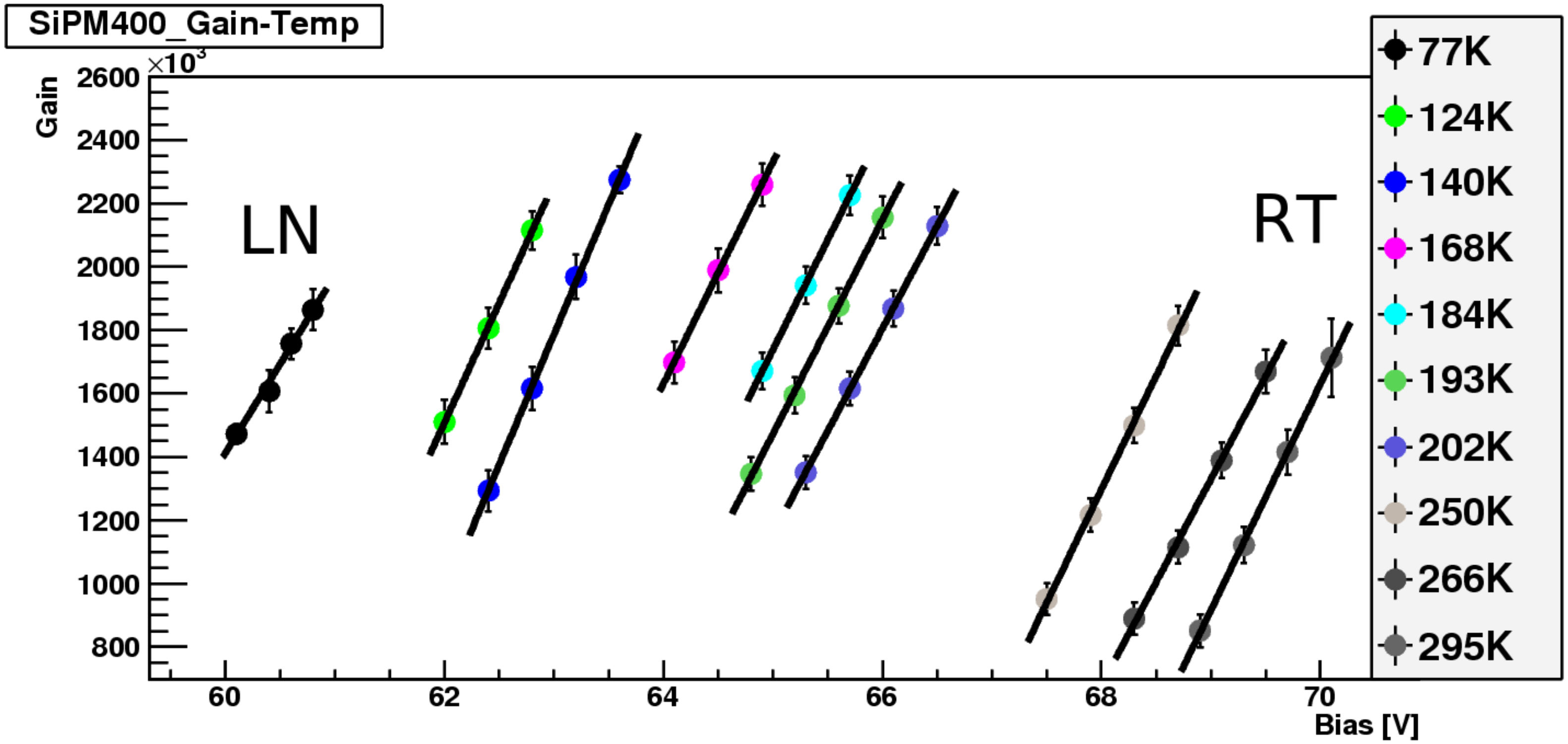
The quenching resistor is temperature dependent. Slow component from RC-circuit. Sharp peak from parasitic capacitances.





Gain v. temperature and bias

Does the gain drop with decreasing temperatures?

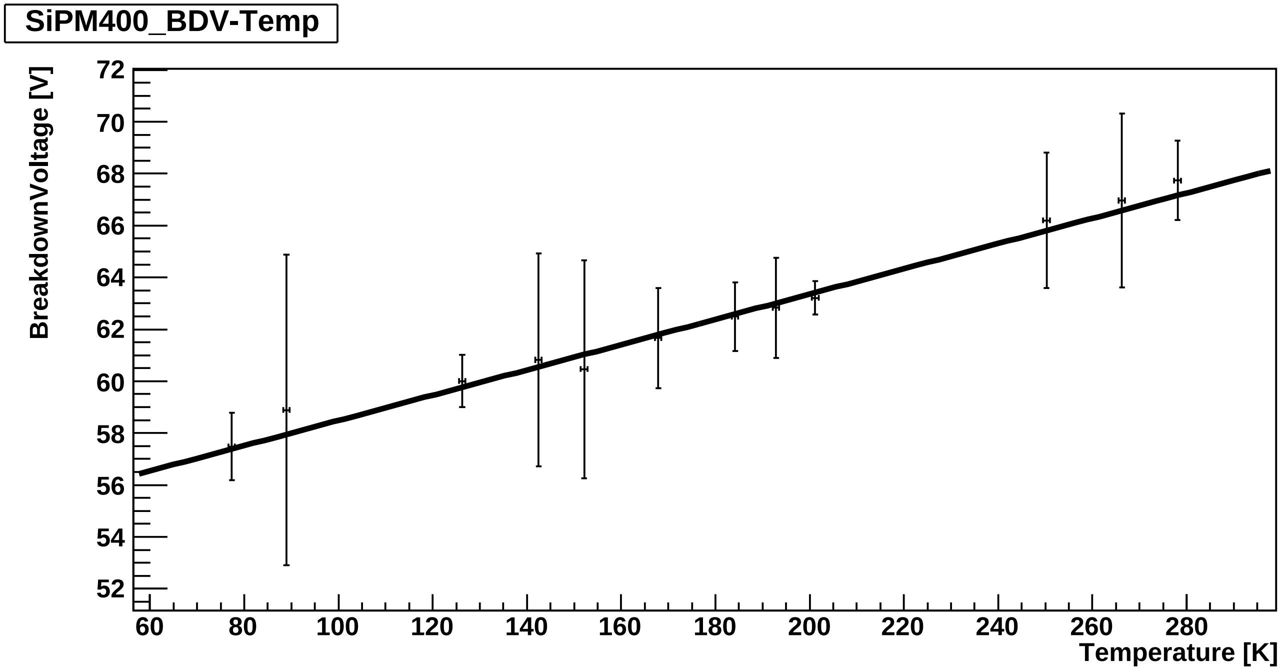


The gain is not a function of the temperature but strongly depends on V_{bias}.
We have to reduce the bias at low temperatures to operate at constant gain.

Breakdown voltage v. temperature

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

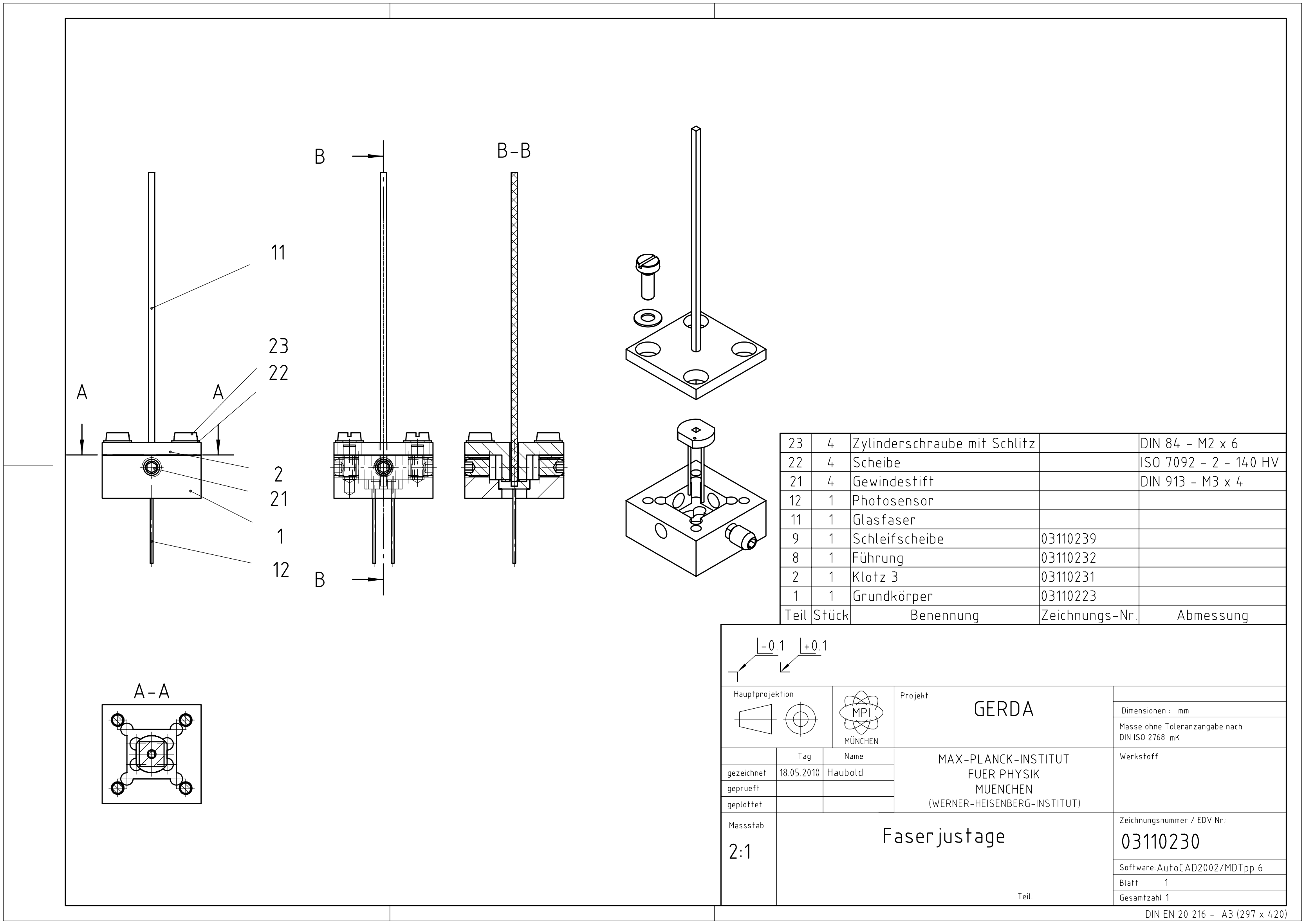
V_{bd} is the minimum bias required to operate a SiPM in Geiger mode.
Gain(V_{bd})=0 $\rightarrow$ V_{over} defines the gain.



$V_{\mathbf{bd}} = V_{\mathbf{bd}}$(T)

$\rightarrow$ To operate at constant overvoltage we have to reduce the bias.

coupling



Teil	Stück	Benennung	Zeichnungs-Nr.	Abmessung
23	4	Zylinderschraube mit Schlitz		DIN 84 - M2 x 6
22	4	Scheibe		ISO 7092 - 2 - 140 HV
21	4	Gewindestift		DIN 913 - M3 x 4
12	1	Photosensor		
11	1	Glasfaser		
9	1	Schleifscheibe	03110239	
8	1	Führung	03110232	
2	1	Klotz 3	03110231	
1	1	Grundkörper	03110223	

Hauptprojektion

MPI
MÜNCHEN

Projekt
GERDA

Dimensionen : mm
Masse ohne Toleranzangabe nach
DIN ISO 2768 mK

	Tag	Name
gezeichnet	18.05.2010	Haubold
geprueft		
geplottet		

MAX-PLANCK-INSTITUT
FUER PHYSIK
MUENCHEN
(WERNER-HEISENBERG-INSTITUT)

Werkstoff

Massstab
2:1

Faserjustage

Teil:

Zeichnungsnummer / EDV Nr.:
03110230

Software: AutoCAD2002/MDTpp 6
Blatt 1
Gesamtzahl 1

DIN EN 20 216 - A3 (297 x 420)