Characterization of Multipixel Avalanche Photodiodes

Hege Austrheim Erdal

Department for Physics and Technology

June 24th, 2009

Outline

Electromagnetic Calorimeters in use today

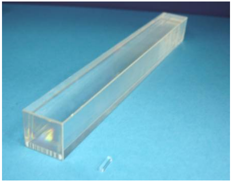
Different photodetectors

Applications for MAPDs

Experimental Setups and Results

Electromagnetic Calorimeters in use today

Crystals



Optical Photons

Photodetectors

- The crystal converts one photon into many photons in the visible light region
- Normally: # photons $\propto$ E deposited in the crystal
- Example: LYSO
  $PbWO_4$ used in PHOS

Example: MAPD

Different Photodetectors

- Photomultipliers Tubes (PMT)
  - High Gain ($G \approx 10^6$)
  - High operating voltage (few kV)

Different Photodetectors

- Photomultipliers Tubes (PMT)
  - High Gain ($G \approx 10^6$)
  - High operating voltage (few kV)
- pin-diode
  - Gain $= 1$

Different Photodetectors

- Photomultipliers Tubes (PMT)
  - High Gain ($G \approx 10^6$)
  - High operating voltage (few kV)

- pin-diode
  - Gain = 1

- Avalanche PhotoDiode (APD)
  - Low Gain
  - Small and insensitive to magnetic field
  - Sensitive to temperature and bias voltage

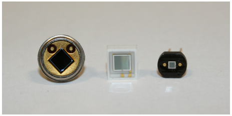
Different Photodetectors

- Photomultipliers Tubes (PMT)
  - High Gain ($G \approx 10^6$)
  - High operating voltage (few kV)

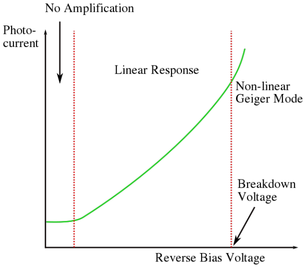
- pin-diode
  - Gain = 1

- Avalanche PhotoDiode (APD)
  - Low Gain
  - Small and insensitive to magnetic field
  - Sensitive to temperature and bias voltage

- MAPD/SiPM/MPPC
  - High Gain ($G \sim 10^5$ - $10^{\ 6}$)
  - Low operating Voltage (< 140V)
  - Small and insensitive to magnetic field

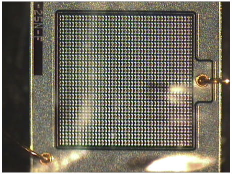


Multipixel Avalanche Photodiode

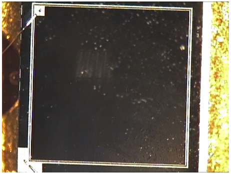


- Pixelated device
- Operated in Geiger Mode, $V_{op} > V_{breakdown}$
- $S_{out} = \#$ pixels fired
- Linear Response when $N_{pixel} >> N_{photons}$
- $E_\gamma \propto S_{out}$
- Gain is sensitive to voltage and temperature change

Pictures taken with a microscope



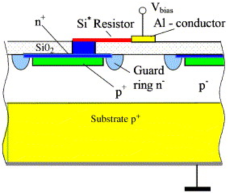
MPPC S10362-11-25C from Hamamatsu, 1x1 mm^2



MAPD from Zecotek, 3x3 mm^2

Multipixel Avalanche Photodiode

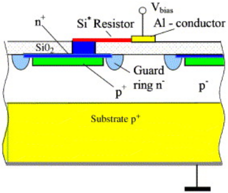
MPPCs/SiPMs



- Depletion region (0.7-0.8 μm) with high electric field between p^+ and n^+ layer
- The pixels are joined together by common aluminum-strips
- The MPPCs/SiPMs have a finite # pixels / mm^2
- Reaches a higher gain than the MAPDs

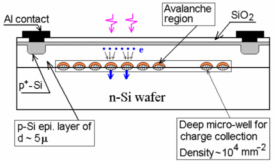
Multipixel Avalanche Photodiode

MPPCs/SiPMs



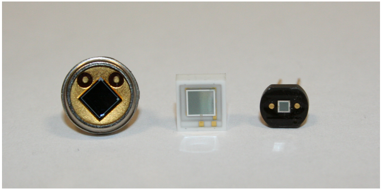
- Depletion region (0.7-0.8 μm) with high electric field between p^+ and n^+ layer
- The pixels are joined together by common aluminum-strips
- The MPPCs/SiPMs have a finite # pixels / mm^2
- Reaches a higher gain than the MAPDs

MAPDs



- Homogeneous entrance window
- Microwells for charge trapping and collection located a few μm below surface
- High Dynamical range
- Relative low gain

Multipixel Avalanche Photodiode



From left: MAPD/MAPD3-A from Dubna and Zecotek, MPPC S10362-33-050C and MPPC S10362-11-025C from Hamamatsu

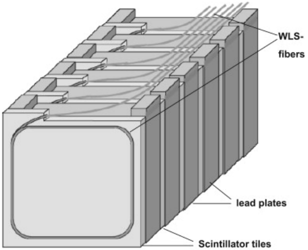
Type	Size	Pixel Density	Gain
MAPD	3x3mm^2	10000/mm^2	$< 10^5$
MAPD3-A	3x3mm^2	15000/mm^2	40000
MPPC S10362-11-025C	3x3mm^2	3600	2.75x10^5
MPPC S10362-33-050C	1x1mm^2	1600	7.5x10^5

Applications for MAPDs

Calorimeters

Example: Projectile Spectator Detector (PSD) at Na61/SHINE (CERN) and CBM at FAIR (GSI)

- Hadronic Calorimeter consisting of 108 modules
- Each module: 60 lead-scintillator tile sandwiches
- Wave Length Shifting fibers → Photodetector
- Testing: MAPDs (Dubna), Readout of full calorimeter: MAPD3-As (Zecotek).



Applications for MAPDs

Positron Emission Tomography

- Is a nuclear medical imaging technique
- Produces a 3D image of biochemical processes in the body
- Detect photon pairs emitted indirectly from a positron emitting nuclei

Applications for MAPDs

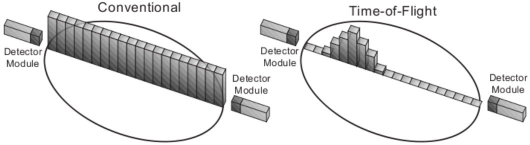
Positron Emission Tomography

- Is a nuclear medical imaging technique
- Produces a 3D image of biochemical processes in the body
- Detect photon pairs emitted indirectly from a positron emitting nuclei

MAPDs are fast devices → Time-of-Flight PET

- uses time-difference in arrival time
- can among other things reduce statistical noise in the image
- $\text{SNR}_{TOF} \cong \sqrt{\frac{D}{\Delta x}}\,\text{SNR}_{conv}, \quad \Delta x = \frac{c \cdot \Delta t}{2}$

  D-size of patient, Δx - uncertainty in position, Δt - uncertainty in time



Motivation

As mentioned, these devices are interesting for different applications due to

- high gain comparable to PMT
- fast, small, compact and insensitive to magnetic field
- relatively inexpensive

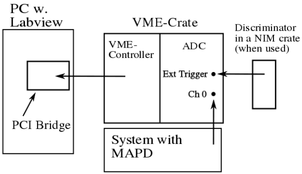
BUT, these devices are new on the market

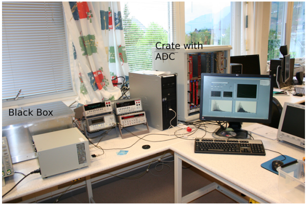
- They are not fully understood yet
- Characteristics change for all samples produced
  → Important to characterize each sample
- There is a growing variety of different detectors
  → Important to gain knowledge on each detector type

The aim of this work has thus been to come up with a setup that makes it easy to characterize each detector with respect to

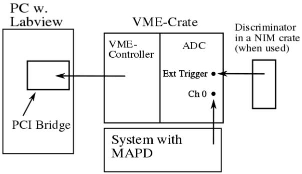
- dark current
- absolute gain
- dark rate

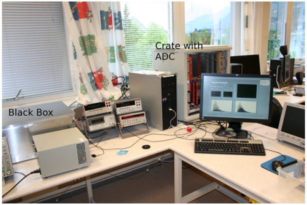
General Setup

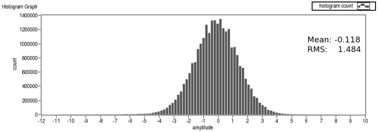




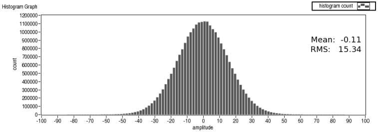
General Setup



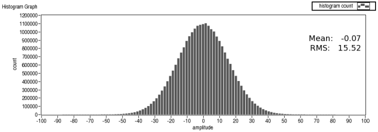




ADC with nothing connected



ADC with preamp connected

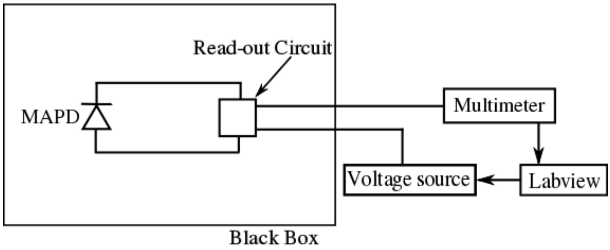


The entire system was connected, here sample 341 is used as an example

The noise was recorded for all detectors used.

Dark Current
Setup

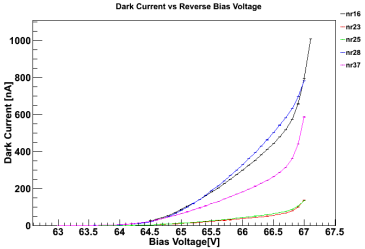
Current that runs through the detector in absence of light



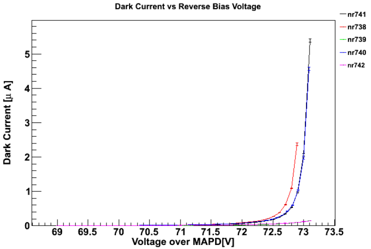
Tested for all four types of detectors

Dark Current

Results



MAPD3-A

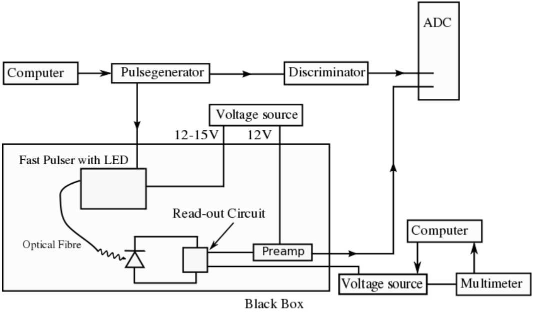


MPPC S10362-11-025C

- The dark current increases rapidly with increasing bias voltage
  $\rightarrow$ Important to set bias voltage not too high
- Internal differences for each detector type
  $\rightarrow$ Important to characterize all samples

Absolute Gain

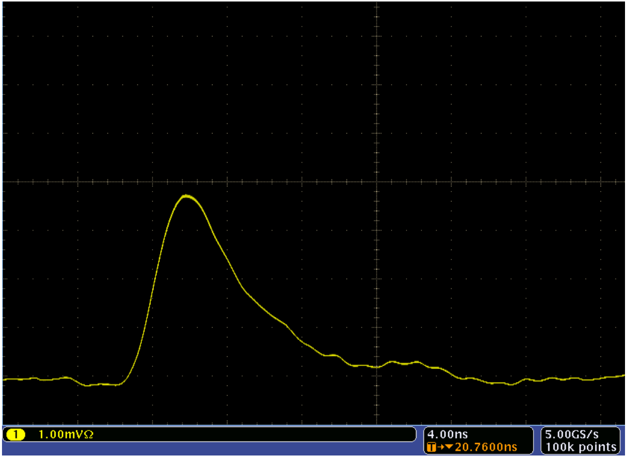
Setup



- Labview Program will integrate signal $\rightarrow$ charge
- Plot single photoelectron spectrum $\rightarrow$ find gain
- Find gain for various bias voltages and temperatures.

Absolute Gain

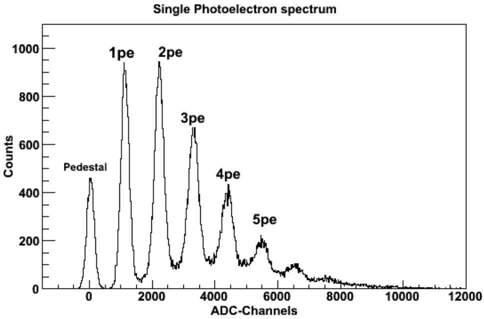
Typical Signal Shapes



MPPC S10362-11-025C, Sample 741. Timescale: 4ns

Absolute Gain

Results



MPPC S10362-11-025C, sample 742

$$Gain = \frac{P_{1pe} - P_{0pe}}{G_{amp} \cdot q_e}$$

P_{1pe} - Position of 1pe peak in charge

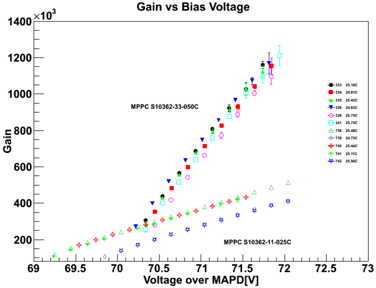
P_{0pe} - Position of pedestal peak in charge

G_{amp} - Gain of preamplifier

q_e - electron charge

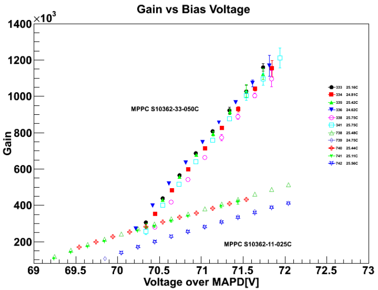
Absolute Gain

Results: Gain versus reverse bias voltage



Absolute Gain

Results: Gain versus reverse bias voltage



A linear fit can be applied to the curves, and use this to extract pixel capacitance, breakdown voltage and the gain dependence on voltage:

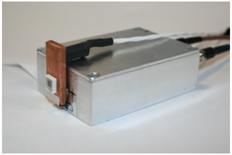
Type	$C_{measured}$	C_{given}	$V_{breakdown}$	$\frac{\%G}{0.1V}$
MPPC S10362-11-025C	23 fF	22 fF	68.3 V, 69.1 V	~ 4.4
MPPC S10362-33-050C	96 fF	89 fF	69.8 V	~ 7

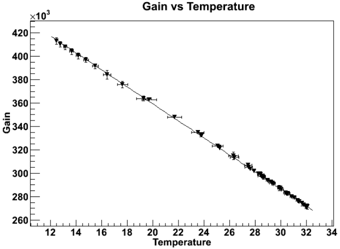
Absolute Gain

Results: Gain versus Temperature

To do these measurements:

- Used a termistor to measure temperature
- Termistor and detector were placed in close contact with a copper-plate

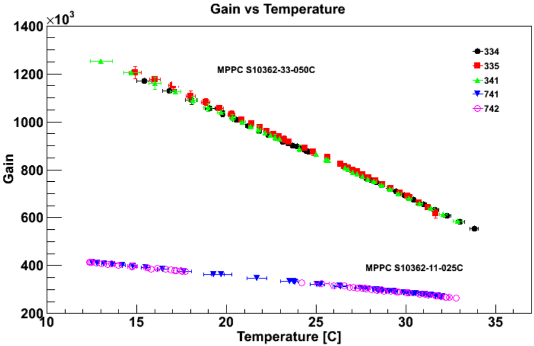




MPPC S10362-11-025C sample 741

Absolute Gain

Results: Gain versus Temperature



For all detectors tested

Gain dependence on temperature when increasing temperature from 24 ^{o}C -25^{o}C:

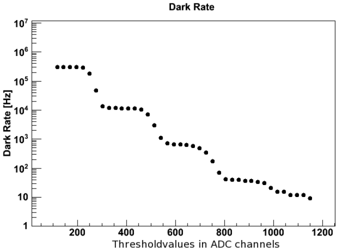
- MPPC S10362-11-025C: $\sim$ 2.2%
- MPPC S10362-33-050C: $\sim$ 3.8%

Dark Rate

Setup

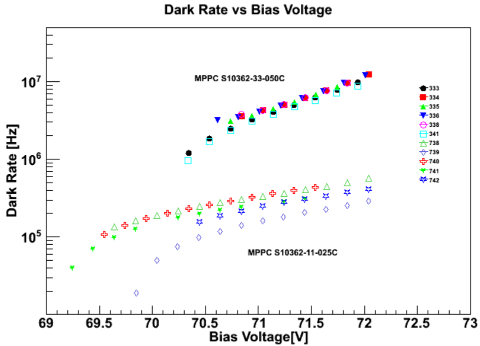
- Same setup as for gain, just turn off pulsegenerator
- Use pulseheight of 1pe from gain measurement, set a threshold to 0.5 of this value
- Count number of pulses exceeding this threshold, plus store pulseheights

→ Can now find frequency as a function of thresholdvalues



Dark Rate

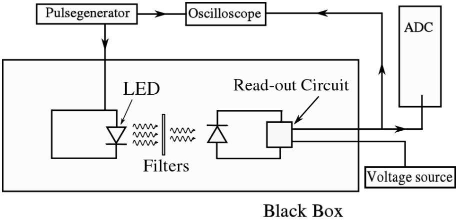
Results



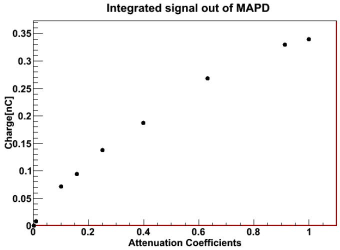
- Some conditions were changed in the Labview program for some of the samples. This lead to:
  - all bins over threshold value were counted as a peak
  - dark rate for low reverse bias voltage had to be taken away (SNR too low)
- For further measurements → average over bins to smooth out signal

Linearity

Done so far



Results for one of the MAPD3-As, have fixed the bias voltage at 66.5V



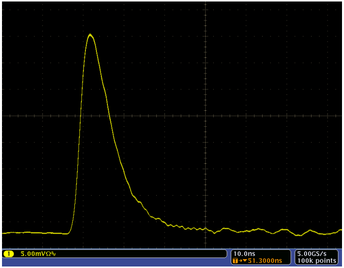
Linearity

What to do next

- The pulse used now has long rise time and are too broad $\rightarrow$ Fast-pulser, this will generate a narrow pulse($\sim$1-3ns)
- The measurements will cover the entire dynamical range of the photodetectors
- Will use a photomultiplier as a reference, or use the filters

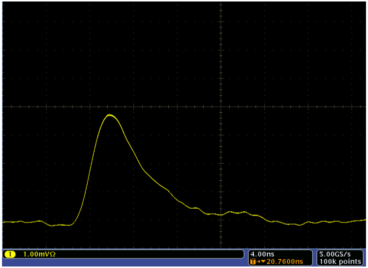
Risetime

- Same setup as for gain, but with high light intensity and without preamplifier



MAPD, Sample 133.
Timescale: 10ns

- Risetime: 2.7 ± 0.2 ns



MPPC S10362-11-025C, Sample 741.
Timescale: 4ns

- Risetime: 2.03 ± 0.15 ns

- Done for all samples used in other experiments
- Width gives information about the charge collection time
  - Depends on the geometry

Conclusion and Outlook

- Various detectors have been characterized with respect to dark current, absolute gain and dark rate.
- A linearity measurement have been done
  - Setup have not been good enough
  - A new setup has been proposed, but not yet tested
- The measurements show the importance of characterizing each individual sample
- Need to do long term stability measurements
- Determine uniformity of the MAPD
- Study crosstalk and afterpulsing effects