Threshold Gas Čerenkov Detectors Using Avalanche Photodiodes

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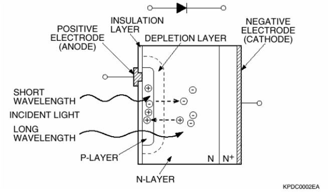
Introduction

This talk

Avalanche photodiode based photon detection to replace PMTs for gas Čerenkov should ...

- the magnetic fields be too high
- the rates be too large during high luminosity running

Avalanche Photodiodes (APDs)



- Gain 100 - 1000.
- Similar to regular photodiodes
- Reverse bias voltages 50 200V
- Photoelectrons produce avalanche of charge due to rev. bias

Characteristics

- Fast signals
- Very sensitive to voltage and temperature changes
- Typically have small sensitive surface areas.

	PMT	APD	Photodiode
Quantum Eff.	0.30	0.35	1.0
Gain	10^6	10^3	1
Collection Eff.	0.95	1.0	1.0

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2. APD detectors could provide the fast particle identification to match high rate capabilities of GEMs.
3. Fast signals provide great opportunity to exploit faster waveform digitizers and FPGA based waveform discrimination.

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- APD performance is not effected by magnetic fields

Question

With a smaller gain, can we still detect a Čerenkov signal with an APD?

PMT vs APD

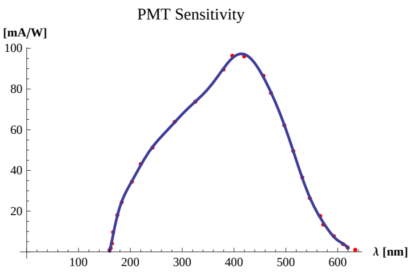


Figure: Sensitivity Data and interpolated function, $S(\lambda)$ used for PMT calculations. Data was extracted from Photonis

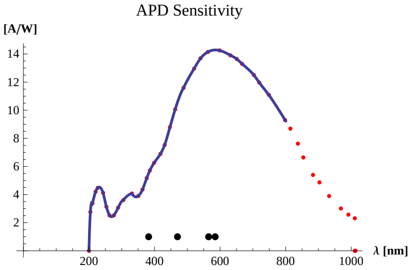


Figure: APD sensitivity from Hamamatsu. The black dots mark the wavelengths of our LED measurements.

PMT Comparison Measurements

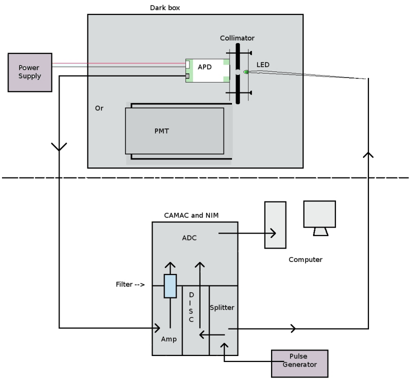
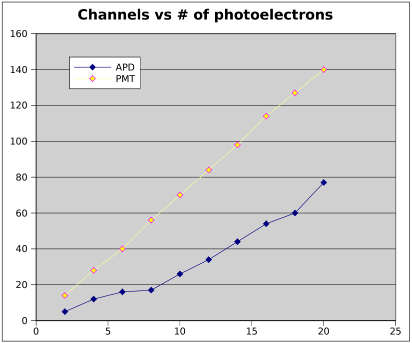


Figure: Dark box setup used to measure APD performance in comparison to a PMT

Procedure

1. Using a calibrated PMT and a very small, 0.5mm diameter, light collimator we set the LED pulser to produce about 100 photons.
2. Swapping out the PMT with the APD, we measured the signal with the same light pulse settings.
3. Repeated for many different PMT mean p.e. values in order to check light collimation.
4. Also used 4 different LED colors.

Results



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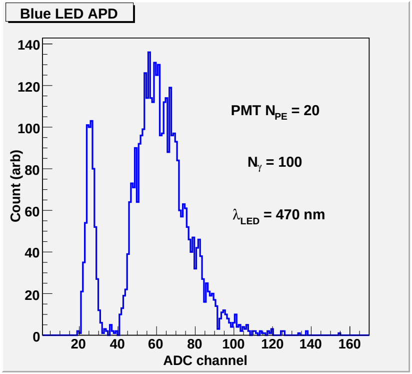


Figure: APD response for our setup with about 100 photons

Number of photoelectrons

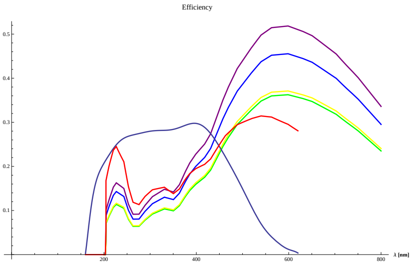


Figure: Shown is the PMT Quantum Efficiency (blue) and APD's efficiency (red)

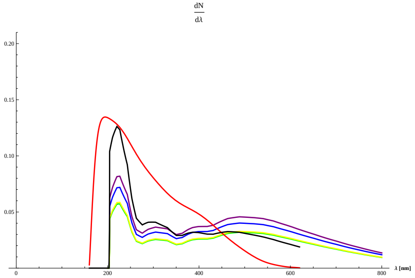


Figure: The PMT integrand (red) and APD "QE" integrand (black) and APD naive efficiencies (with colors corresponding to those of the LEDs used).

Number of photons	Number of PMT P.E.	Number of APD P.E.
125	25	17

High Background Tests at Jlab

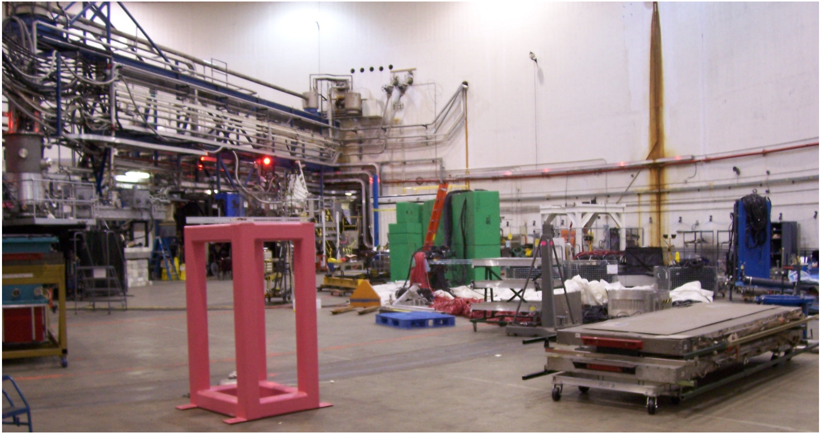
Goals of Tests

- *Can APD survive in a harsh radiation environment?*
- Just turning it on while in the Hall.
- In a quiet environment we now expect a signal, but can a Čerenkov signal be expected in a high radiation environment? (assuming most light is collected on sensitive surface of APD)
- Flashing an LED while running at a high luminosity.

Secondary Goal

- *Can we actually collect the light and see a Čerenkov signal?*
- Requires additional detectors.

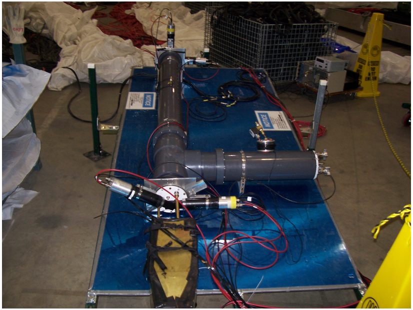
Setup in Hall A



- Sitting unshielded at 90°at perimeter of the hall.
- During Prex, beam energy   1 GeV, and very high luminosity
- Prototype detector tube, with spherical mirror, scintillators in front and back.

During Prex Highest Luminosity Running

Both APDs died a while after being turned on at high luminosities.



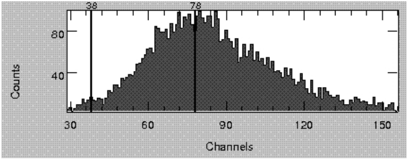


Figure: APD's ADC spectrum for a LED pulsing at 10Hz in Hall A, with 50uA on the thick Pb target.

Tests after show that the APDs are still good. The module's electronics were fried.

What we have learned

- Čerenkov light can be detected with clean separation
- APD can operate in a high background environment
- APD module electronics do not survive survive in high radiation environment

Current and future work

- Upgrade to VME64x DAQ and flash ADCs
- Design APD electronics
- Finish prototype detector and detect Čerenkov signal

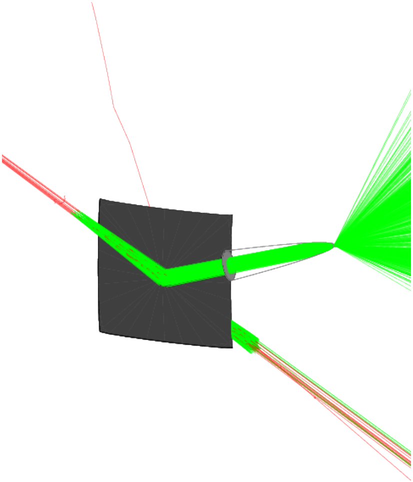
Thank you!

Backup Slides

Čerenkov Radiator Thresholds

Particle	Cherenkov Radiator Gas	Momentum Threshold
Electron	N2	20.965
Muon	N2	4334.89
PiPlus	N2	5726.21
KPlus	N2	20254.3
Electron	CO2	17.0503
Muon	CO2	3525.47
PiPlus	CO2	4657.
KPlus	CO2	16472.4
Electron	C4F10	9.32603
Muon	C4F10	1928.33
PiPlus	C4F10	2547.24
KPlus	C4F10	9009.89

Simulation



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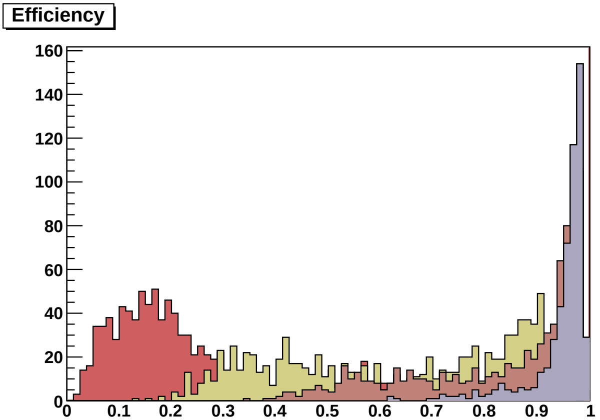
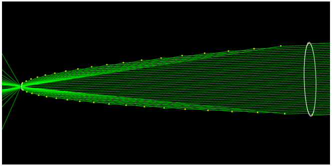
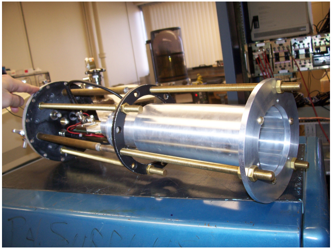
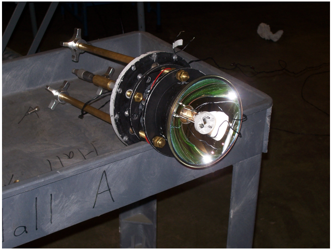


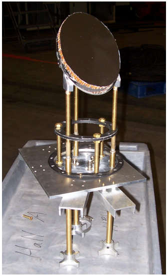
Figure: Optical collection efficiency results from GEANT4 simulation of 1000 electrons for a 5*mm* (gray), 3*mm*(gray), 2*mm*(yellow) and 1*mm* (red) APD. The efficiency decreases as with the APD size but drops off dramatically from 3*mm* to 2*mm*.

Prototype PMT









APD

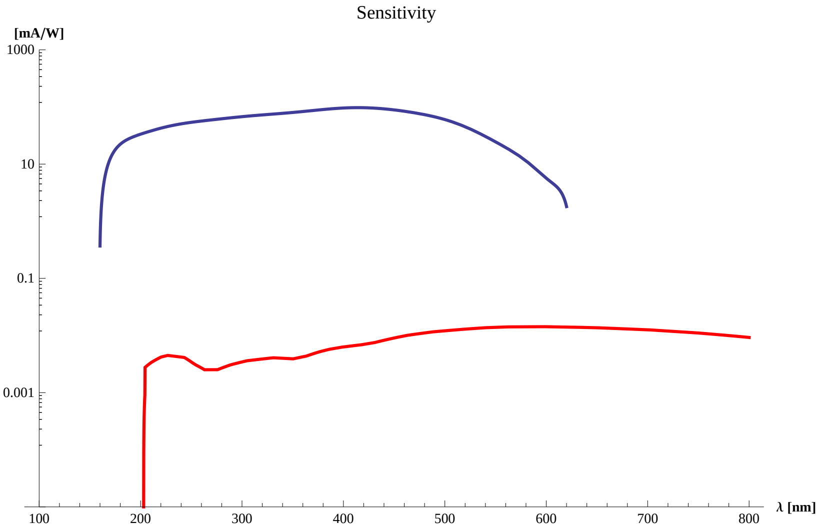

Sensitivity
[mA/W]
1000
10
0.1
0.001
100
200
300
400
500
600
700
800
λ [nm]

Figure: d

The number of photoelectrons can be calculated by integration of the equation

$$\frac{d^2N}{dLd\lambda} = \frac{2\pi\alpha}{\lambda^2}(1 - \frac{1}{n^2\beta^2})E(\lambda)R(\lambda) \quad (1)$$

where $E(\lambda)$ is the (quantum) efficiency of the photon detector and $R(\lambda)$ takes into account the reflectivity and collection efficiency of the optical system. Setting $R(\lambda) = 1$

$$QE(\lambda) = \frac{1240.824S(\lambda)}{\lambda} \quad (2)$$