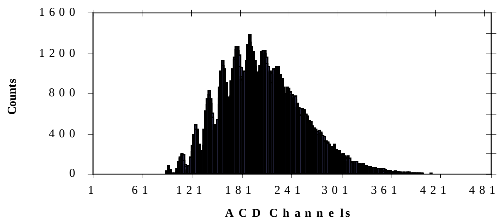
Solid state PMT (MRS, SiPM)

Victor Rykalin



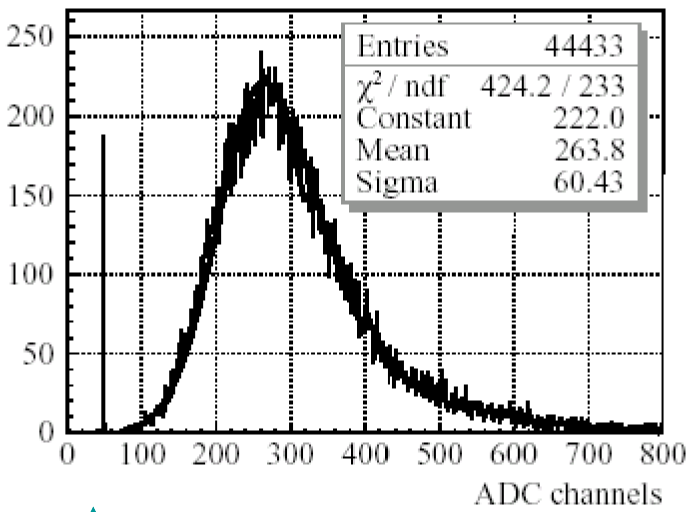
Frascati , 21 October , 2004

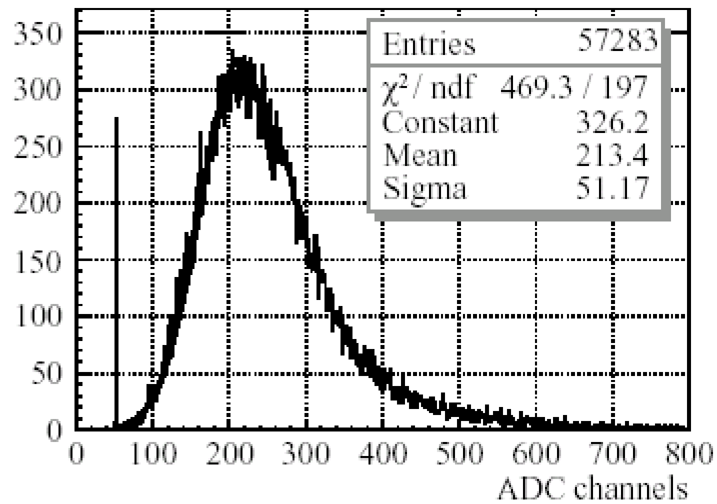
Limited Geiger mode APD

- SiPM Silicon PMT
- MRS Metal Resistive Semiconductor
- Originally started from the same technology V. Golovin, Patent of Russia # 1644708.
- Currently SiPM - MEPHI Moscow (are not available on market)
- Currently MRS - CPTA Moscow (available on the market

What we are talking about ?

560 nm





MRS

XP2020

What we are talking about ? or where we are ?

Device	HAMAMATSU APD	MRS or SiPM	VLPC	PMT
Input sig. from MIP (photons)	60	60	60	60
Photo Electrons (500 nm)	48	**7**	48	**7-10**
Gain	400 ?	10E(6)	10E(5)	10E(6)
APD output Charge (fC)	3	1152	768	1152
S/N$_{\text{(room T)}}$	~ 5.5 Est. ~ 3 real ~ 8.1 (10°C)	~ 8 meas.*	>10 (9°K) meas.**	> 10 meas.***

*** B. Dolgoshein An Advanced Study of Silicon PM ICFA IB 2002**

****A. Bross et all. Fermilab FN 0733 2003**

***** Rykalin V. NICADD presentation http://nicadd.niu.edu 2002**

Basics

1 PRINCIPLE OF OPERATION

One μ–cell of a photodiode designed in mesa-technology is shown schematically in Fig.1. Each of 1 mm^2 diodes produced in this technology contains 1370 such cells connected electrically to each other and to common readout by means of Al metallization lines. Photosensitive area composes approximately 60% of the total area. Doping concentrations are such that a high local electric field, exceeding breakdown voltage, is reached in the photosensitive layer at relatively low reverse bias voltages (45-48 V). Each photoelectron, which is created by incident photon or by the leakage current and reaches multiplication zone, initializes an avalanche creating up to $\sim 10^6$ secondary electrons.

The avalanche is locally quenched by a film resistor formed on the surface of each pixel from the n-side, therefore the pulse amplitude from each μ-cell does not depend on the amount of initial charges. Quasi-linearity of the device is reached when it detects light uniformly distributed over the whole area, in this case the total pulse-hight is determined by the amount of fired μ-cells, and the dynamic range - by the total amount of cells on the detector area (typically $\sim 10^4/mm^2$). In mesa-technology pixels are optically isolated due to deep inter-pixel etching and metallization. Each cell has its own film resistor connected to common Al grid. This layout gives the following advantages:

- optical separation reduces probability of photo-ionization, i.e. secondary avalanche ignition in adjacent pixels by UV photons emitted from a primary avalanche,
- resistor values are under better control,
- avalanche process in one cell does not influence sensitivity of the others,
- localized quenching by individual film resistors reduces total dead time, which in this case is defined by a single pixel and does not depend on the total amount of fired pixels.

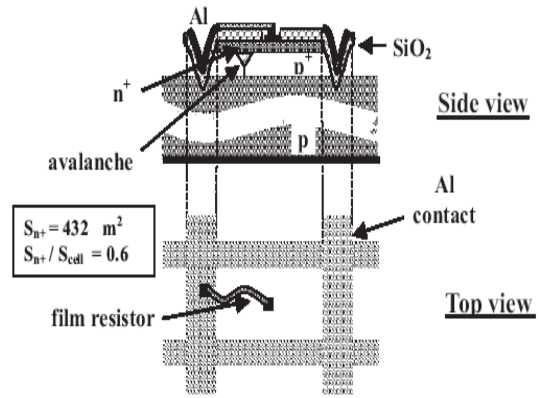
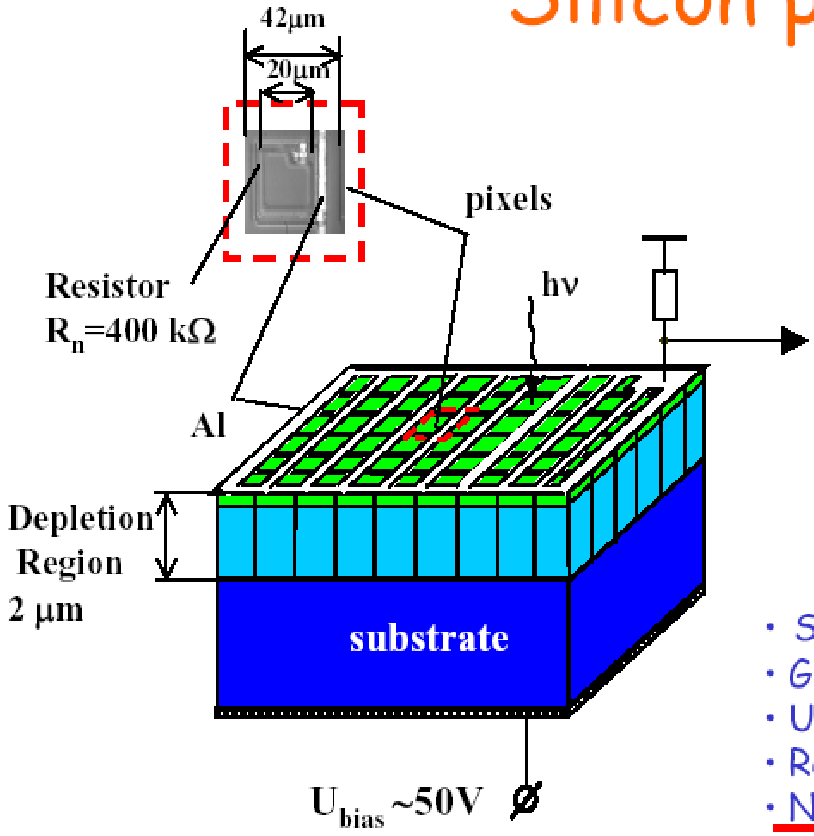
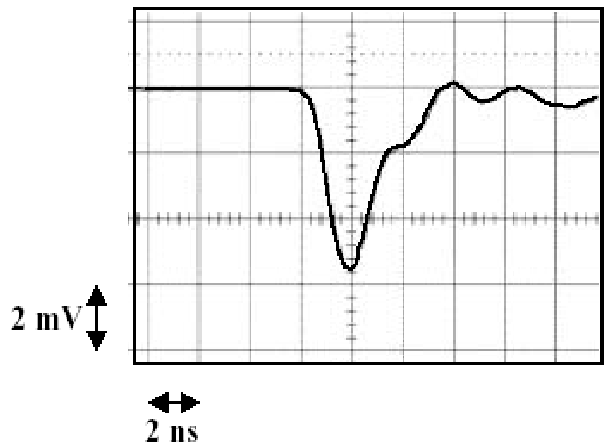


Figure 1. Schematic view of one MRS APD$_G$ μ-cell.

MRS

Silicon photomultiplier (SiPM)

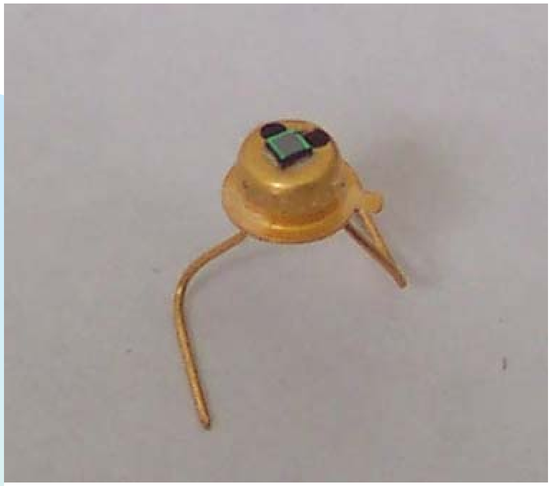


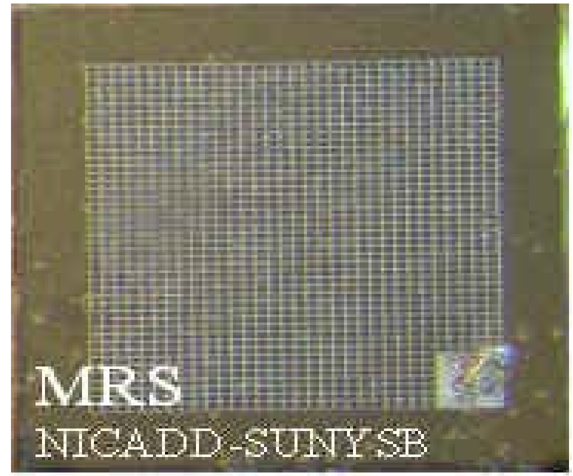


SiPM main features:

- Sensitive size 1x1mm^2 on chip 1.5x1.5 mm^2
- Gain $2 \cdot 10^6$
- U_{bias}~50V
- Recovery time ~ 100 ns/pixel
- Number of pixels: 576
- Nuclear counter effect: negligible (due to Geiger mode
- Insensitive to magnetic field
- Dynamic range ~10^3/mm^2

For further details see:
«Advanced study of SiPM»
http://www.slac.stanford.edu/pubs/icfa/fall01.html





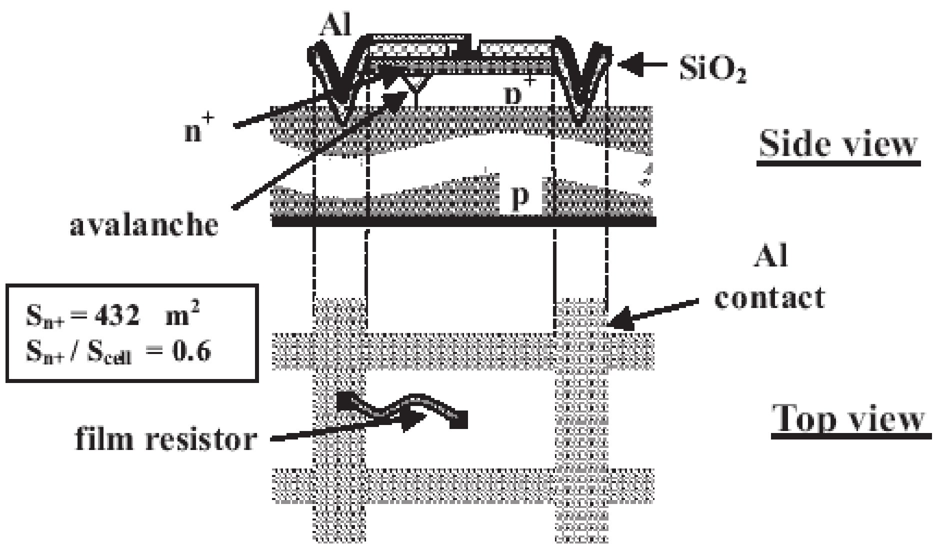


Figure 1. Schematic view of one MRS APD$_G$ μ-cell.

General introduction

- Spectral response range 420-1000 nm
- Peak sensitivity wavelength 670 nm (MRS)

ε (670 nm)	23 %	Photon detection efficiency $\varepsilon = QE \cdot \varepsilon_{geom}$
Operating voltage	45-65 Volts	
Dark current	~ 2 µA	
Capacitance	~25 pF	
Gain	$\sim 5 \cdot 10^6$	
Time response	~ 1-2 ns	
Time resolution	< 300 ps	
Price (~100000)	expect ~ $10/ch	
Price (1-5)	really ~ $ 80/ch	

LED measurements

The apparatus schematic in Fig. 6 was used to carry out the LED measurements. In order to simulate the scintillating cell output, a blue (max in ~ 450nm) LED was used. The LED was positioned in such way that the majority of the emitted light was across to KURARAY Y-11, 1mm, round, WLS fiber of ~1m long, ensuring that blue light doesn't reach the photodetector directly.

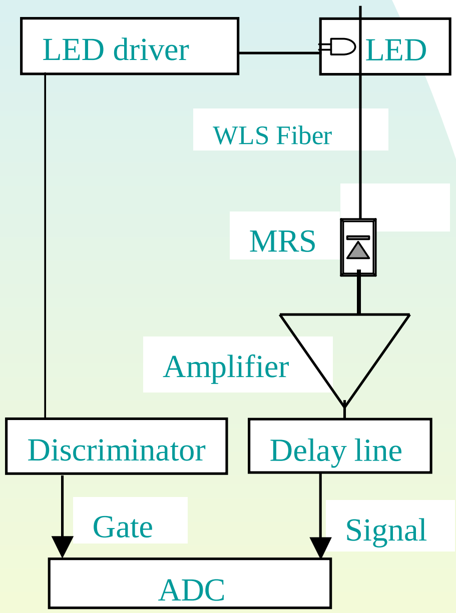


Fig. 6. Apparatus schematics used for LED measurements

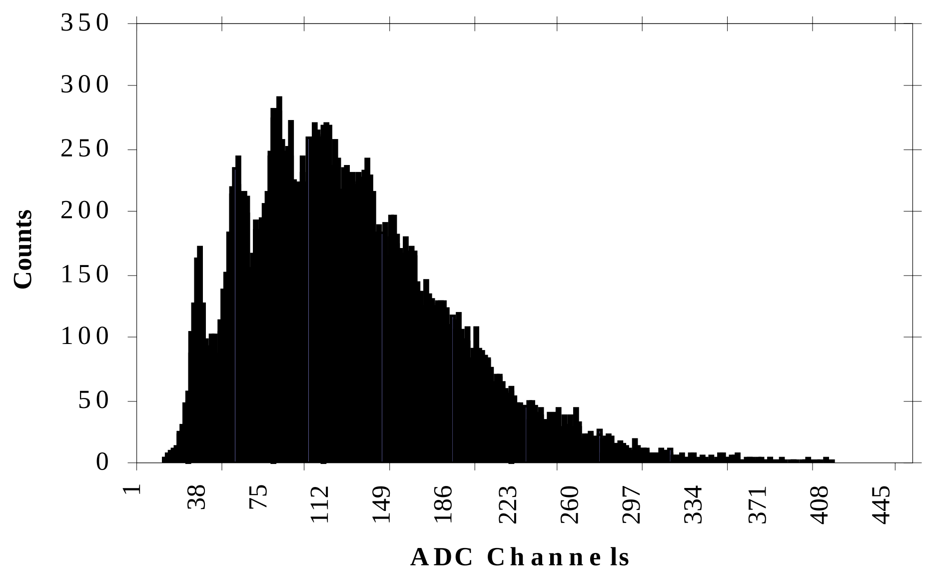
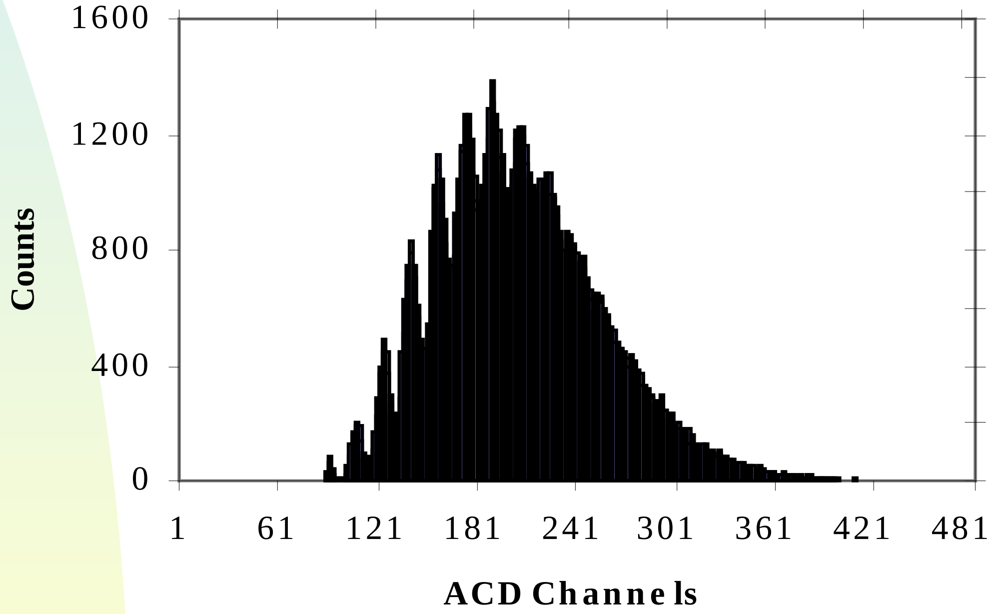


Fig. 7. MRS response to LED Signal. MRS was at 52.0V, gate of ~50ns used. Pedestal was in channel 38.

Amplitude distribution (LED) !

- Clear single-electron separation(with preamplif)
- 1 PE ~ 2-3 mV (50 Ohm load)



MRS response to scintillating strip signal from cosmic rays

The test was performed using scintillating strip with cosmic rays as the source of Minimum Ionizing Particles (MIPs). The strip used was made from extruded scintillator with co-extruded hole along the strip, 1m long, 5cm wide and 5mm thick. 1.5m long KURARAY Y-11, 1.0mm outer diameter, round, multiclad, WLS fiber with mirrored end, was embedded and glued, with 0.15m of fiber from the edge of the strip to the MRS. MRS was biased at 52.0V, gate of ~50ns and double-coincidence trigger of equal area were used. Fig. 8 shows the apparatus schematics used for cosmic measurements. Fig. 9 shows the cosmic ray signal with the MRS. Using calibration data from the LED measurements for 1PE, we estimate the signal level at 17PE .

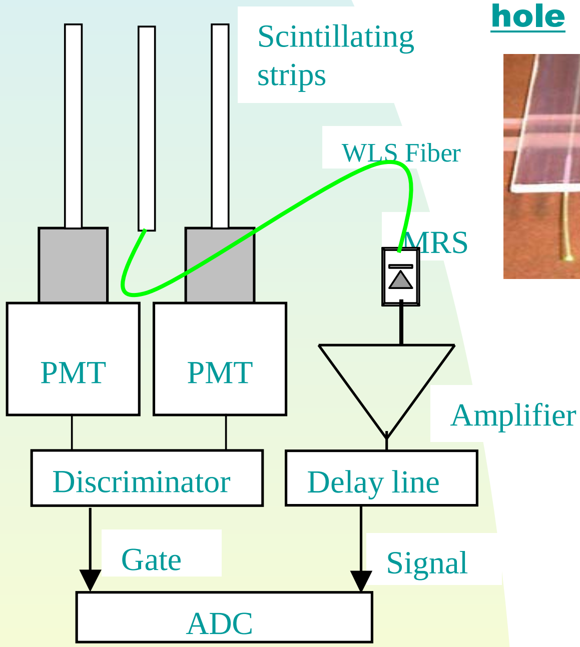
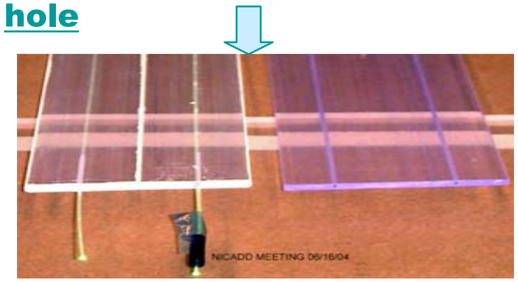


Fig. 8. Apparatus schematics used for cosmic measurements.

Extruded FNAL-NICADD scintillator, with co-extruded hole



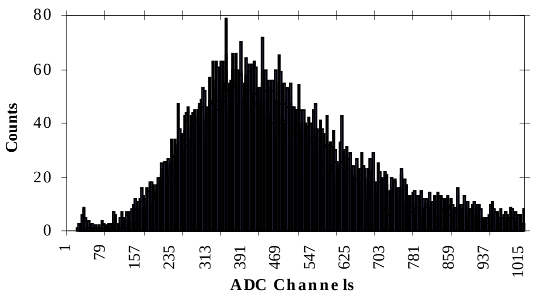
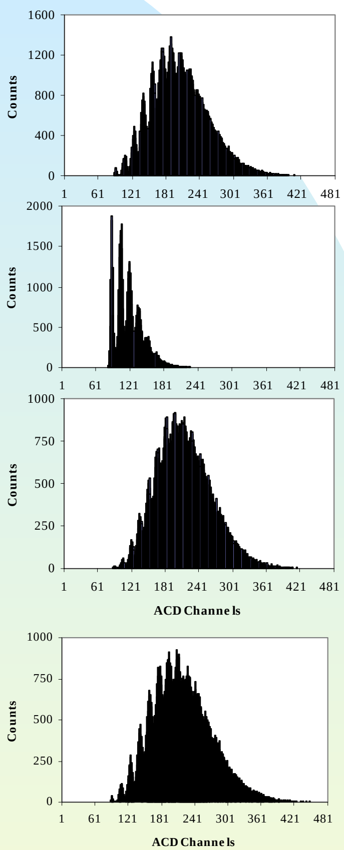
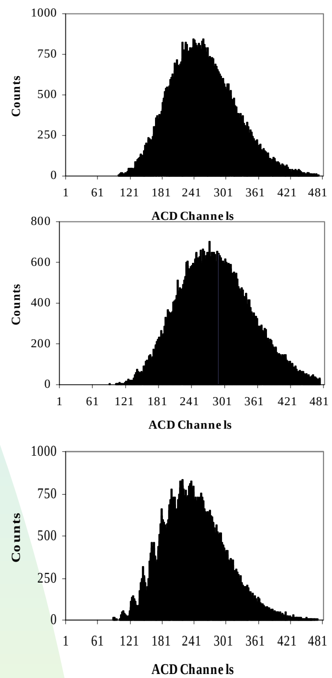
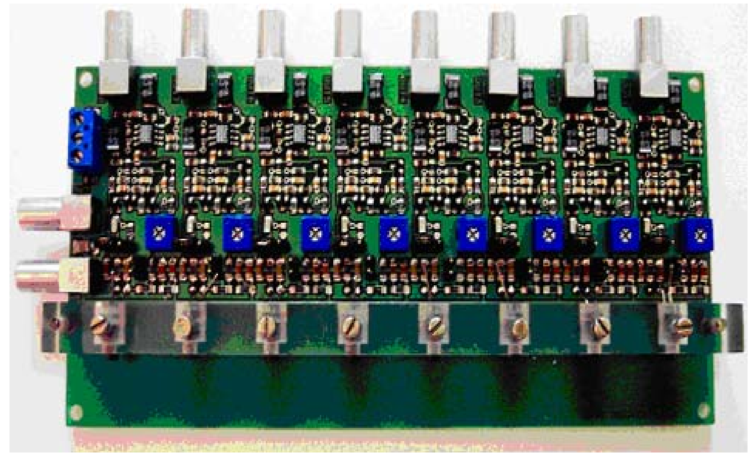


Fig. 9. MRS response to scintillating strip signal from cosmic rays. MRS was at 52.0V, gate of ~50ns used. Pedestal was in channel 38. Get 17PE.

Tested PC board + MRS

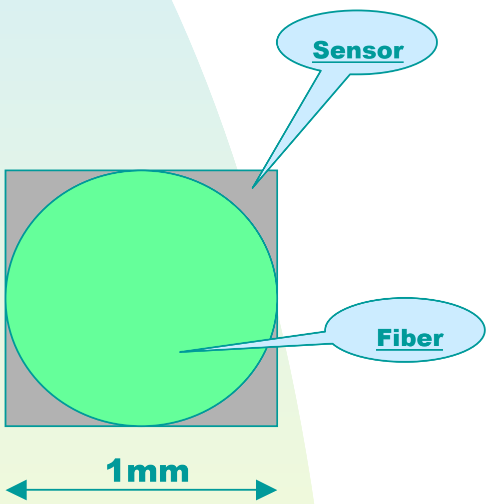






Linearity range of MRS

From Fig11. The deviation from linearity of the level of up to 5 % starts at ~2200 photons(~550 PE in MRS response), and the deviation of the level of 10% with light intensity up to ~3000 photons (~770PE).



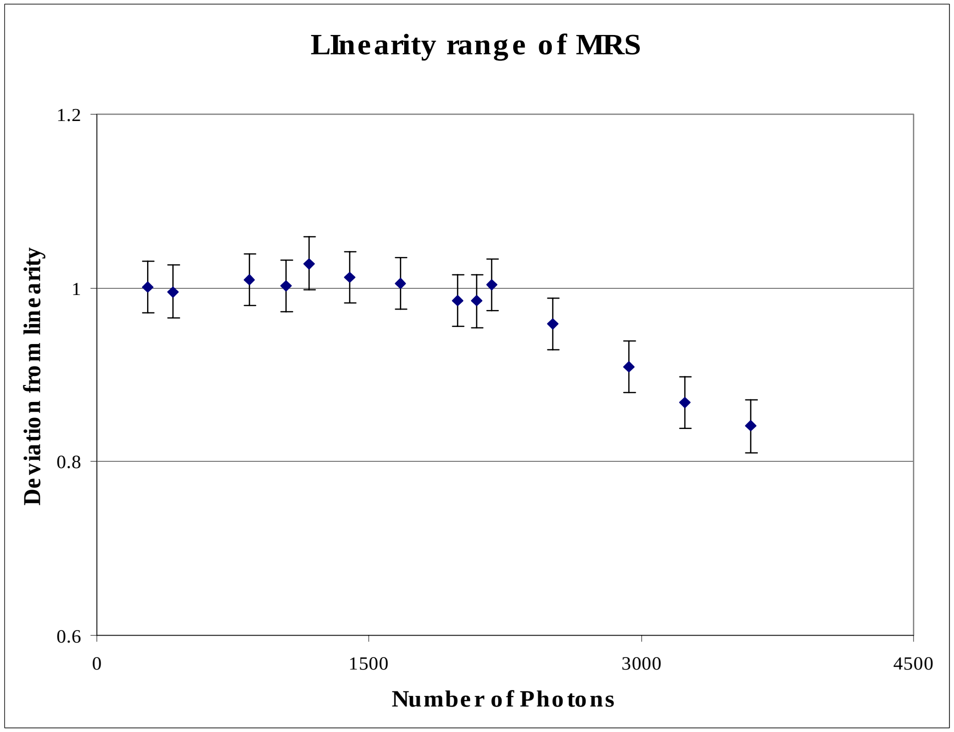
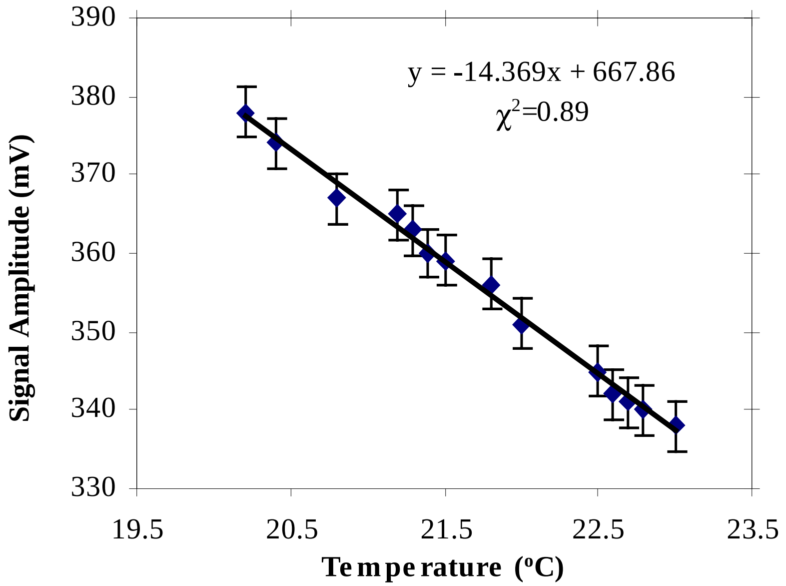


Fig. 18. Linearity range of MRS.

Impact of the temperature

- S/N can be improved with decrease of T



Noise behavior!

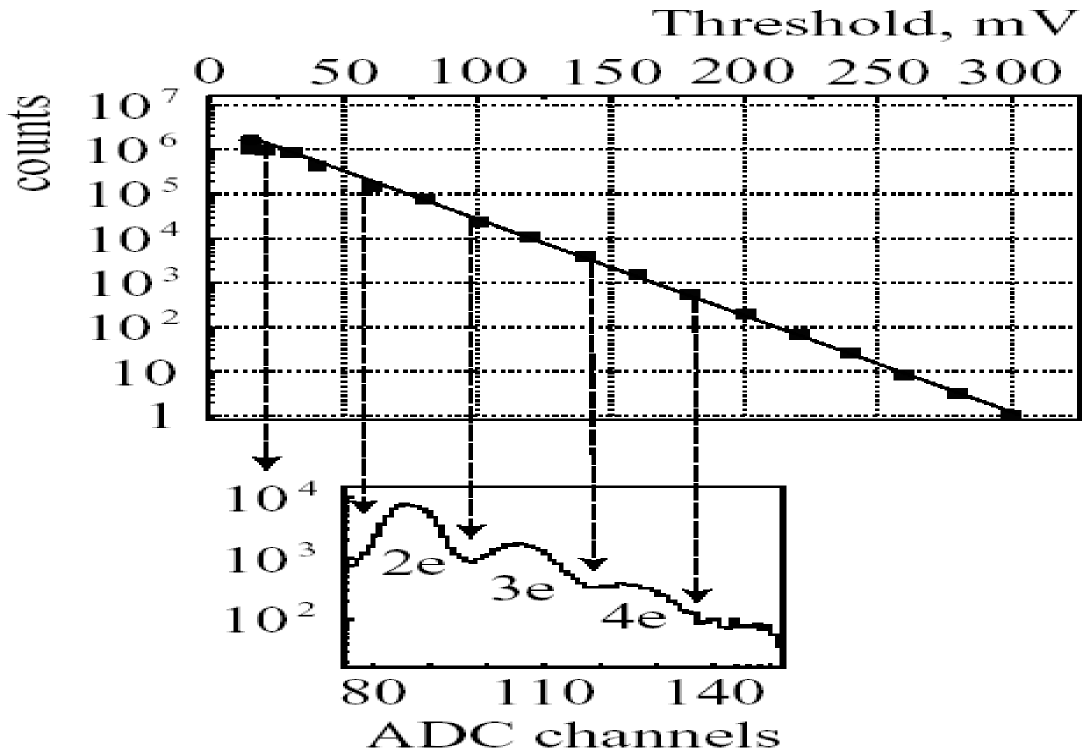
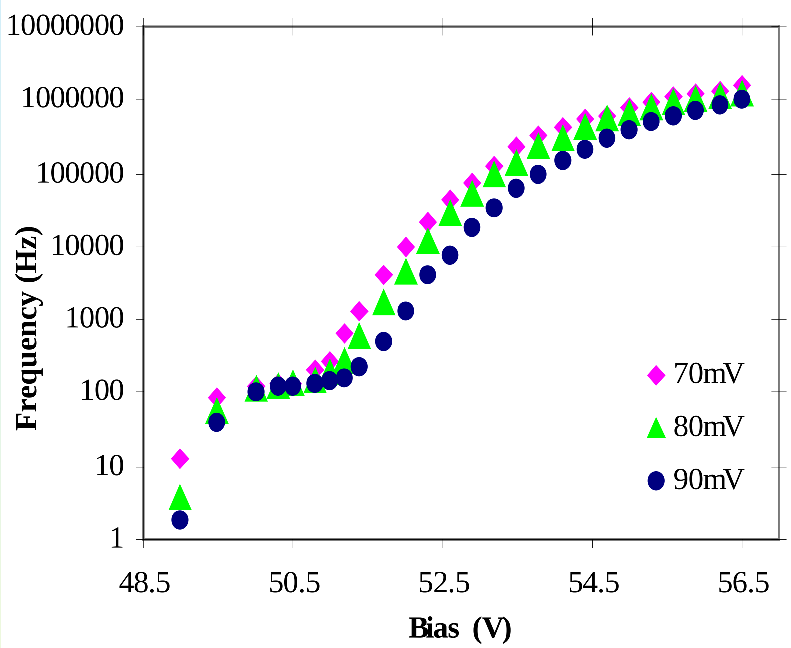
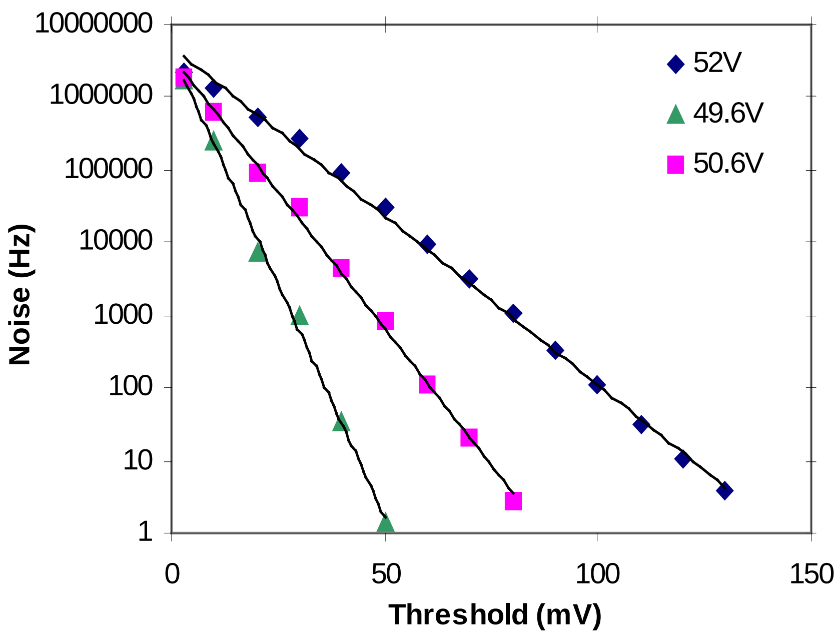


Fig. 5. Noise spectrum of APDg (above), and corresponding self-triggering amplitude spectrum (below).

Noise dependences

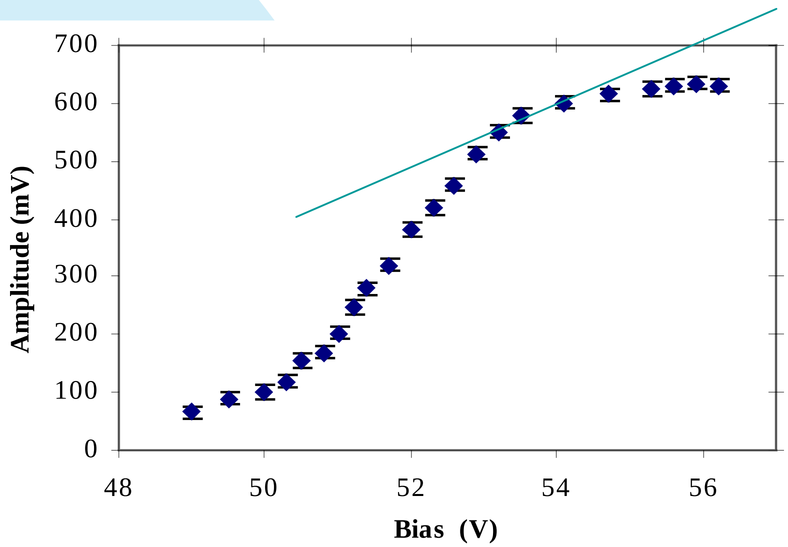


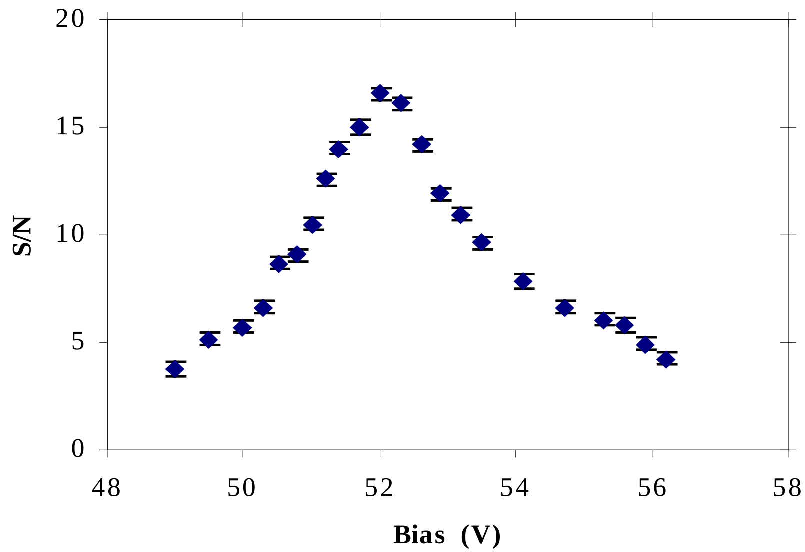
Signal dependence on bias voltage at different thresholds (~150Hz signal from LED is supplied to MRS).



Noise dependence on the threshold for different bias voltages. At 52V - 1PE ~ 30V.

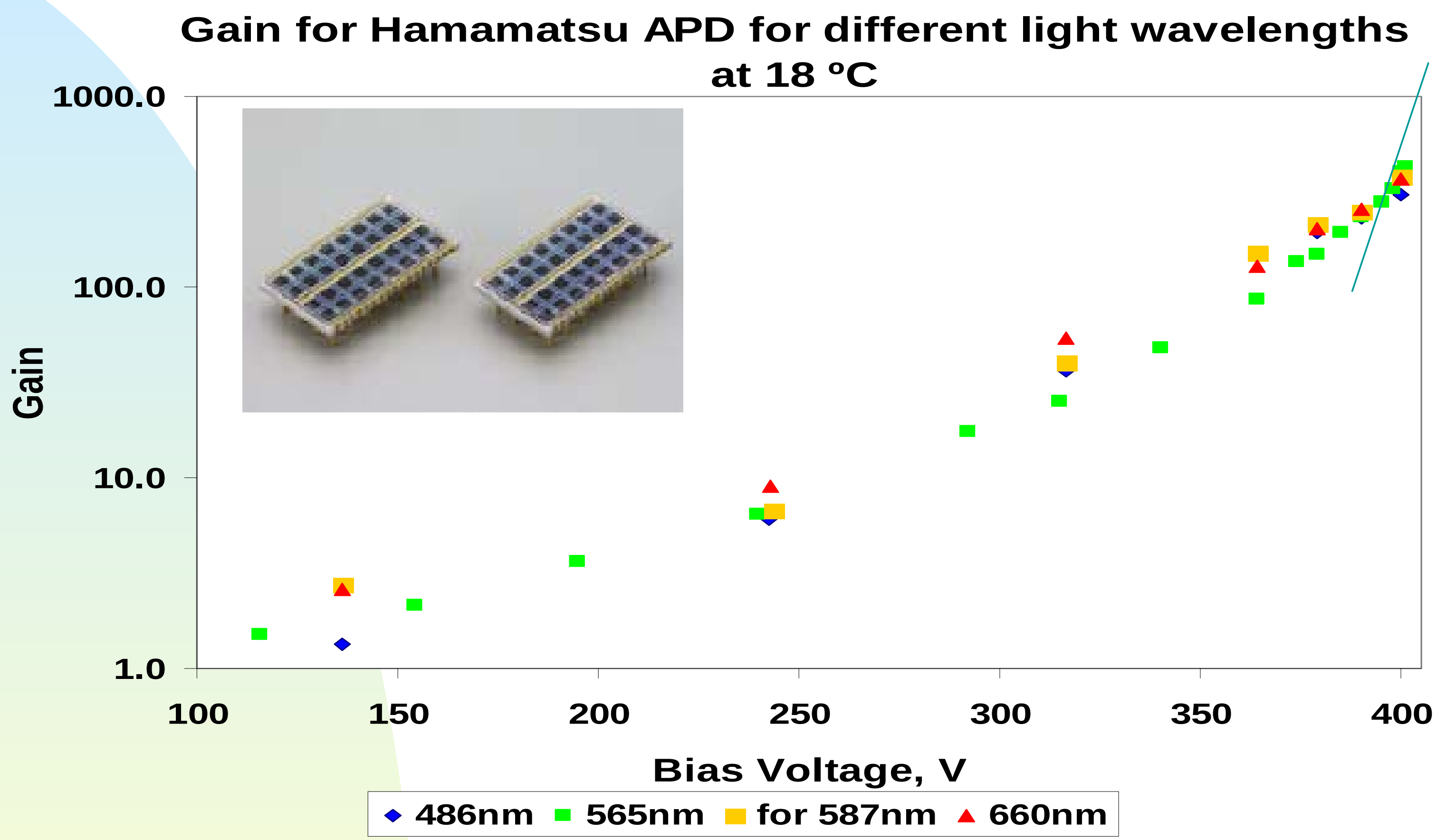
Working point





Working range ~ 1.5 volts

Just for comparison purposes



MRS scan

The dependence of the output from MRS on the fiber alignment with the sensor was measured. Scans with fiber moving along, away and angled to the sensor were conducted

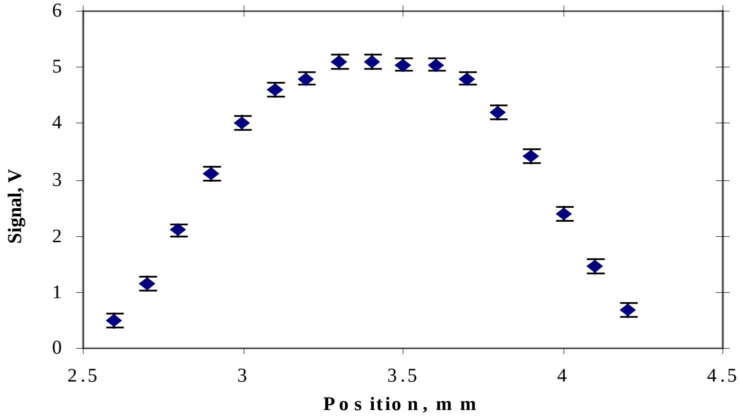


Fig. 10. Output signal amplitude versus position of the fiber along the MRS sensor.

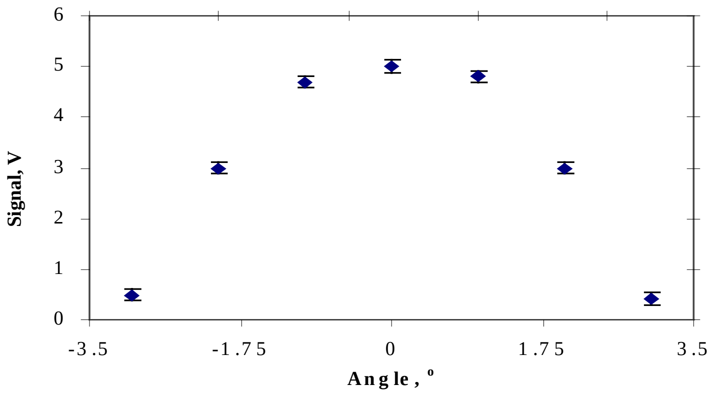


Fig. 11. Output signal amplitude versus angle of the 0.5mm fiber to the MRS sensor surface.

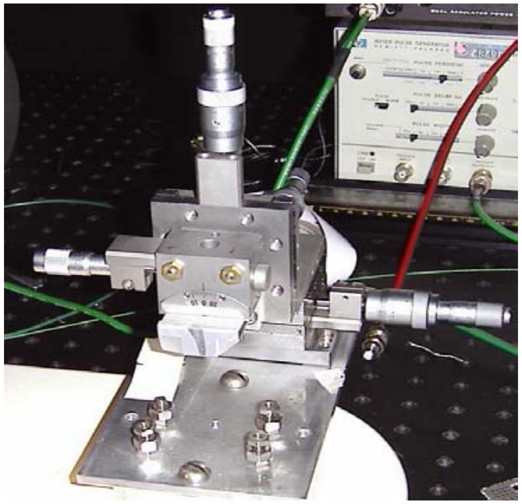


Fig. 12. 462 series XYZ-M used

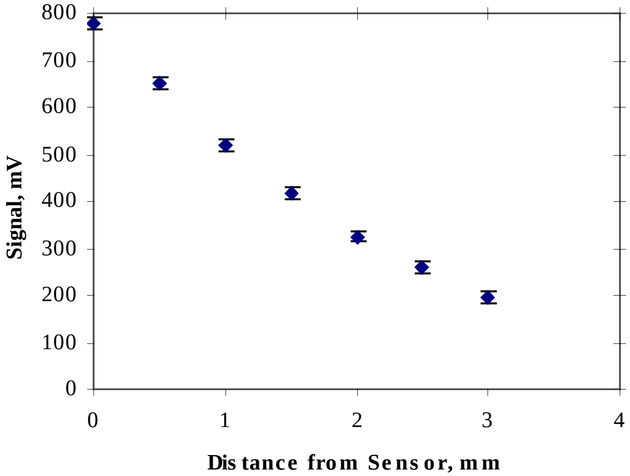


Fig. 12. Output signal amplitude versus fiber distance from the sensor.

Irradiation Effects

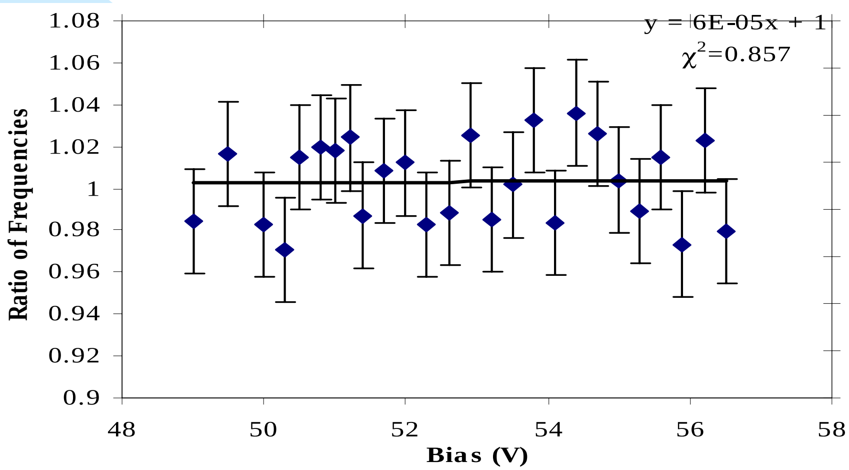


Fig. 15. Ratio of frequencies.

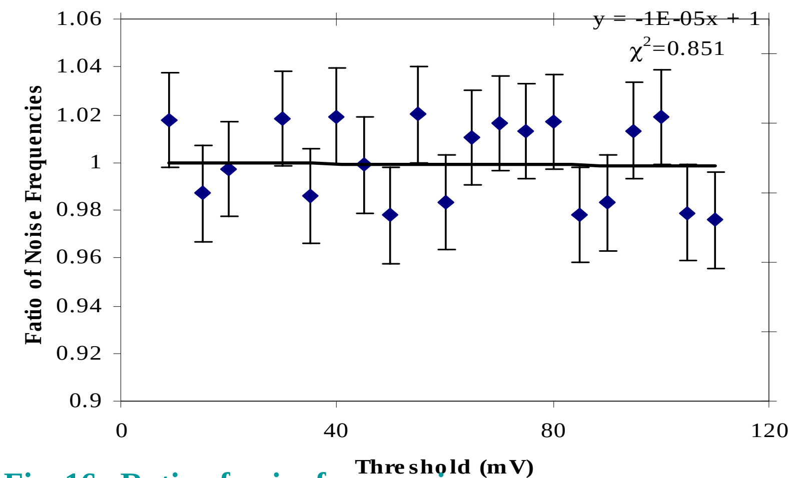
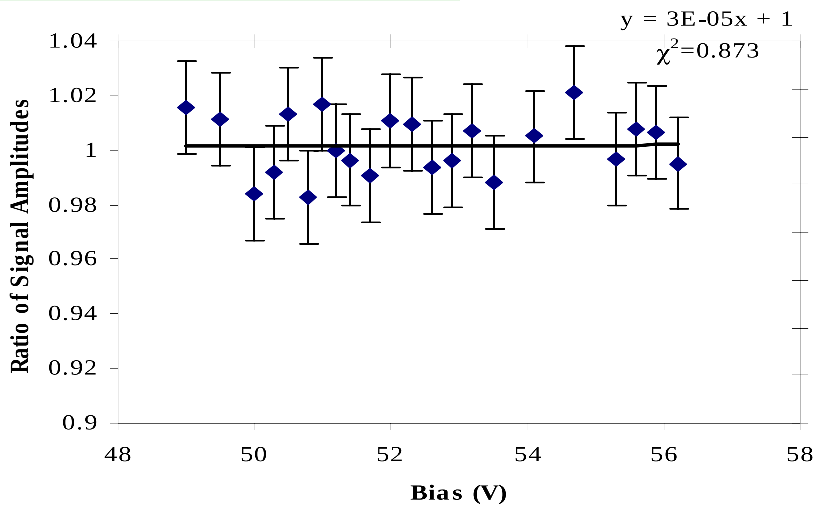


Fig. 16. Ratio of noise frequencies.



A separate study was undertaken to observe changes in the MRS sensor response after its irradiation with a dose of 1Mrad using gamma rays. The following parameters of the sensor :noise, amplification, signal detection,and bias voltage range for the sensor, were measured before and after the irradiation.

Within error bars , all the ratios are very close to 1.

Fig. 17. Ratio of signal Amplitudes.

Summary

1. Measurements performed using cosmic rays with 5mm thick extruded scintillator, allow clear distinction of the MIP signal. Clear PE separation can be seen from the LED measurements.

2. The device operates in the linear mode , up to 2000 of photons.

3. Noise studies indicate that single-electron noise dominates and placing the threshold at the 1PE level allows reducing noise by about 2500 times (at chosen working point).

4. The tilt of the fiber from the normal to the sensor surface of 1 degree results in only 4% loss of the output. On the other hand, an air gap of 0.5 mm between fiber and the sensor decreases the output by ~17 %

5. Tested sensors are well suited to use with scintillator tiles.

References used

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