Indigenous Development of SiPM, Instrumentation, Characterization and Application

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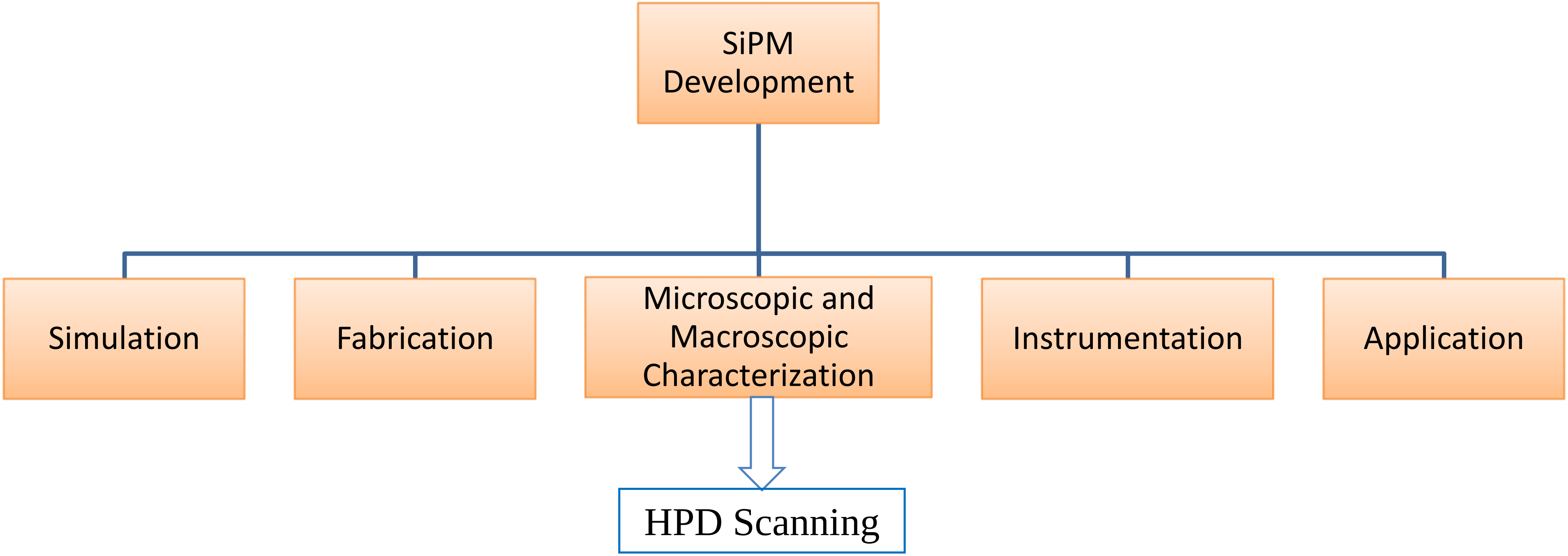
Overview



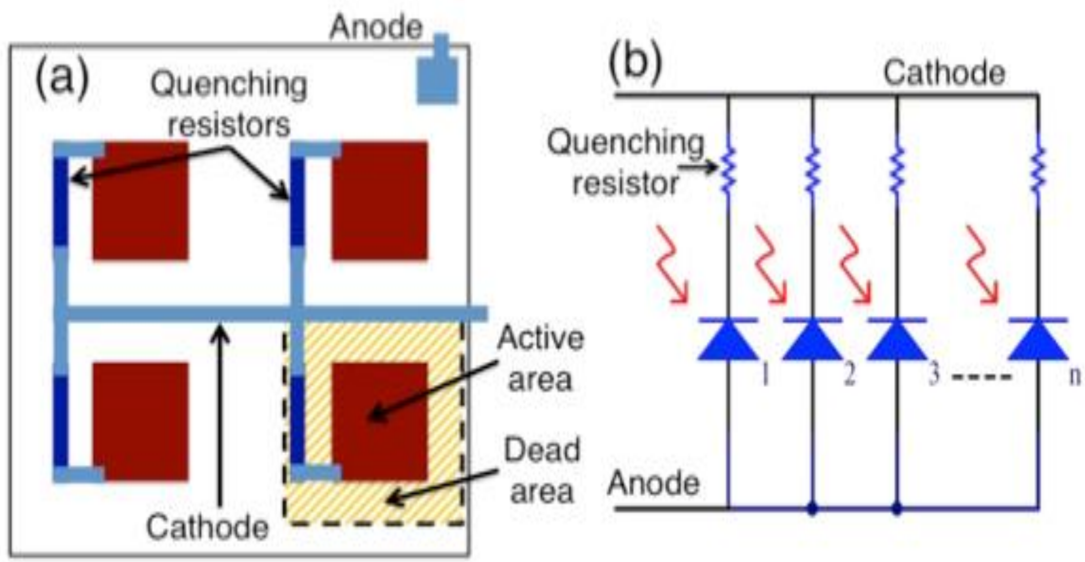
SiPM Development
Simulation
Fabrication
Microscopic and Macroscopic Characterization
Instrumentation
Application
HPD Scanning

Silicon Photo-Multiplier (SiPM) – A Novel Photo Detector

- SiPM is a 2-D array of Avalanche Photo-Diodes (APD)
- APDs in the SiPM are biased in the *Geiger mode* are resistively coupled together to form a two Pin device
- Features very high gain ~10^5 , fast response ~100 ps, immunity to magnetic field ..

10 µm – 30 µm

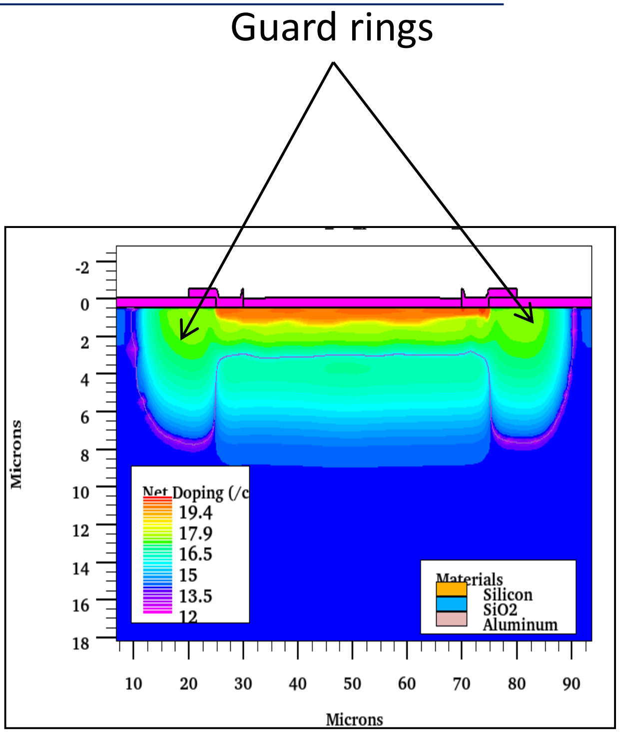
10 µm – 50 µm



P. Buzhan, B. Dolgoshein et.al, Nuclear Instruments and Methods in Physics Research Section A, vol. 567, no. 1, pp. 78 - 82, 2006.

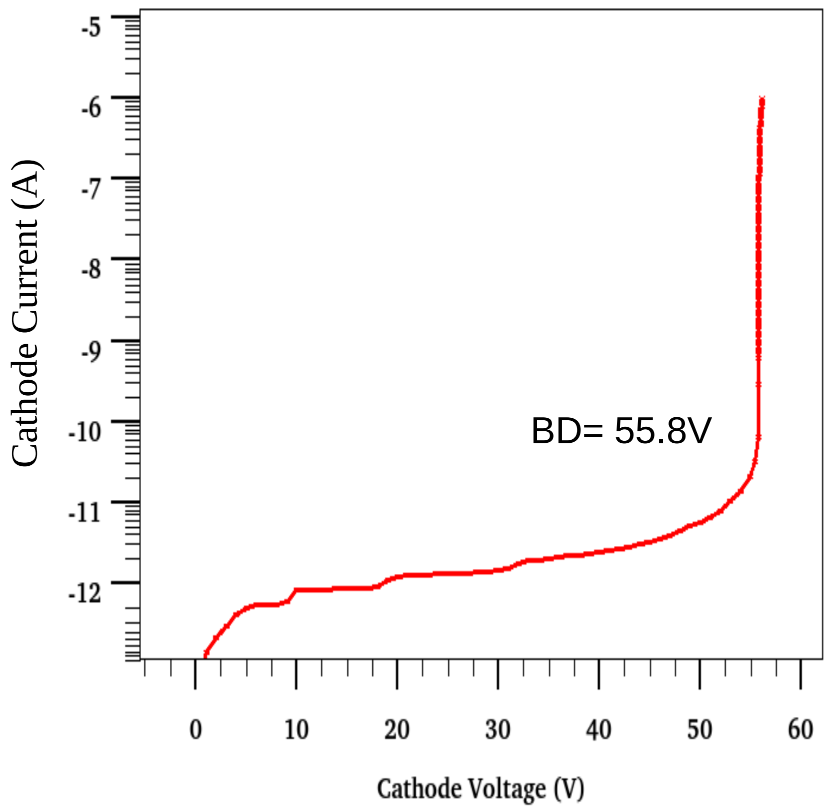
Process Simulations: Structure

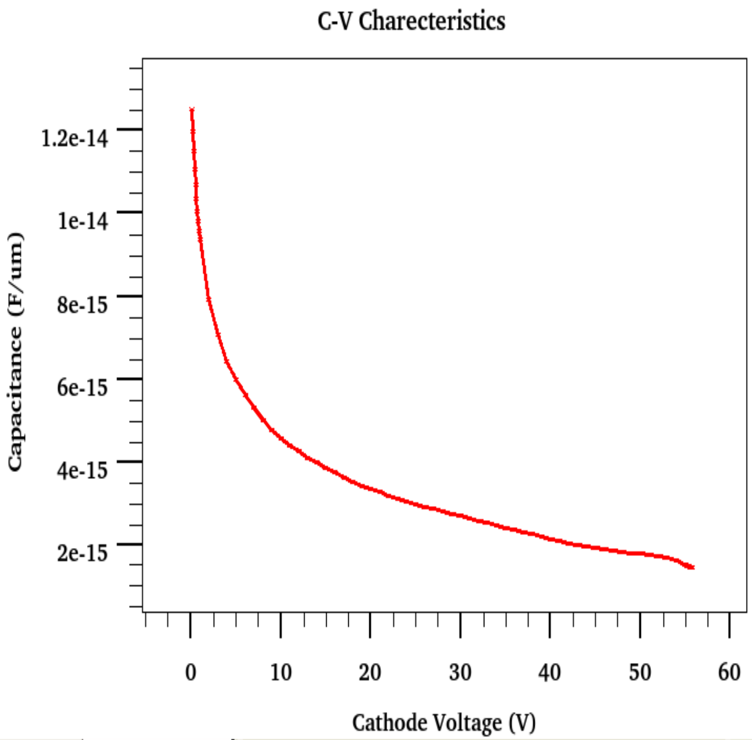
- Process parameters and imperfections are considered
- Guard rings have been designed and included in the structure to prevent edge-breakdown.
- Ion implantation has been simulated with monte-carlo engine with crystal damage model.
- All thermal cycles including oxide growth thermal cycle has been included.
- All electrical as well as opto-electrical characterization performed.



Structure for process level simulations

Process Level Structure: I-V and C-V characteristics

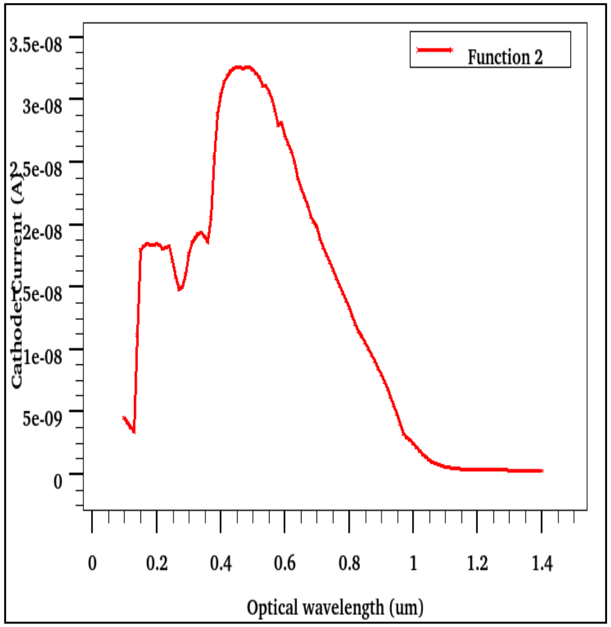




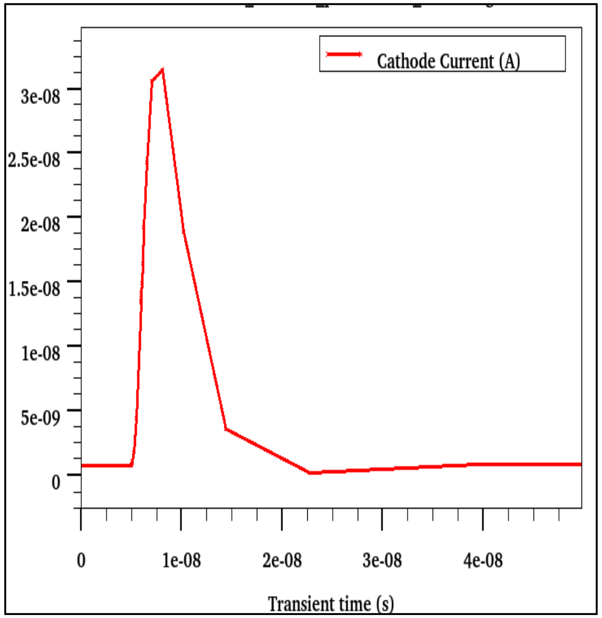
I-V characteristics

C-V characteristic

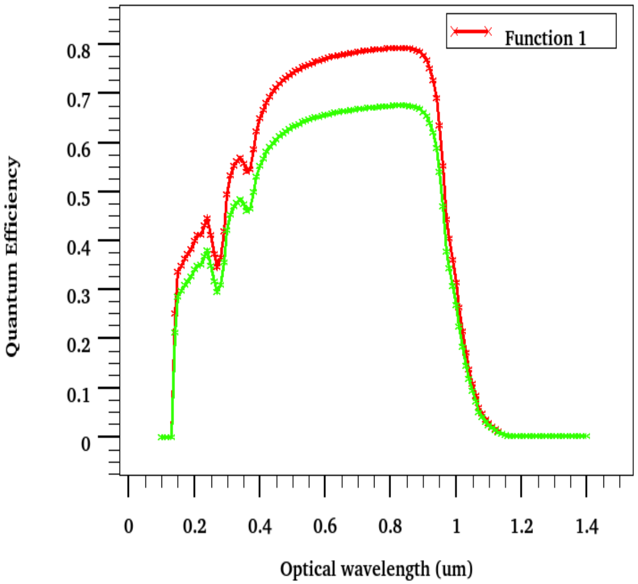
Process Level Structure: Optical Simulations



Spectral response



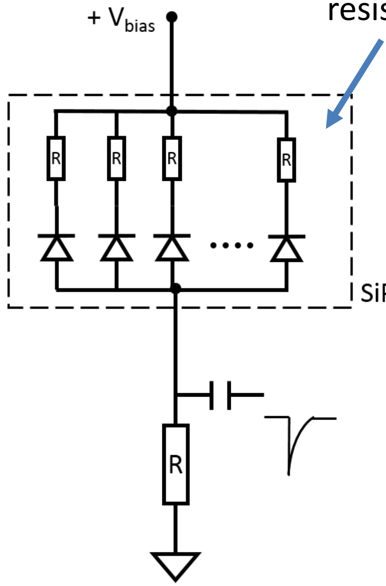
Transient response



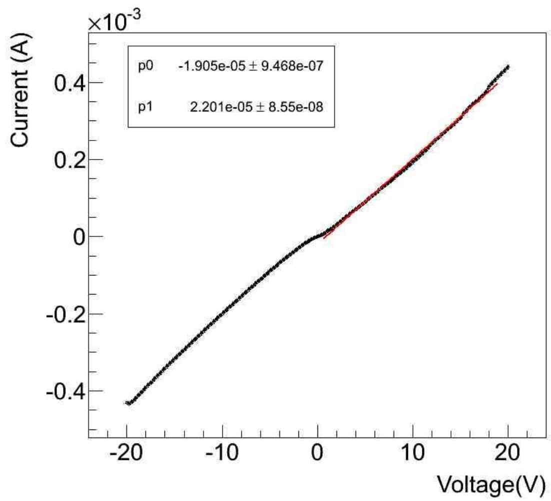
ARC effect

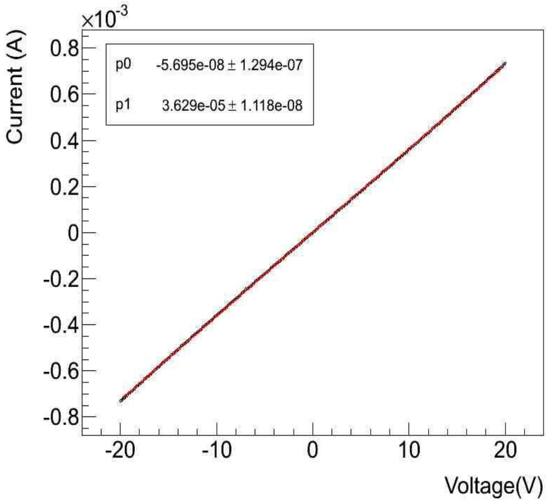
Fabrication of Micro-resistors

- The quenching resistor is important for proper device operation.
- Fabrication of resistors is vital first step towards fabrication of SiPM
- The SiPM's are large array detectors and therefore value of the resistance across the wafer should be uniform
- Typically is the last step in the process and hence requires very low thermal budget.
- Hot wire CVD (HWCVD) chosen because:
  - Low temperature process (substrate ~ 300 – 400 °C)
  - In-situ boron doping (Implanter step is avoided)

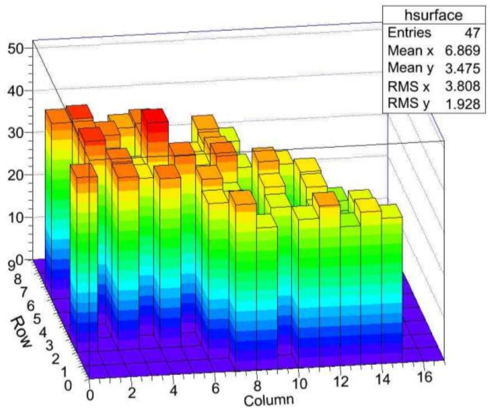


Measurements

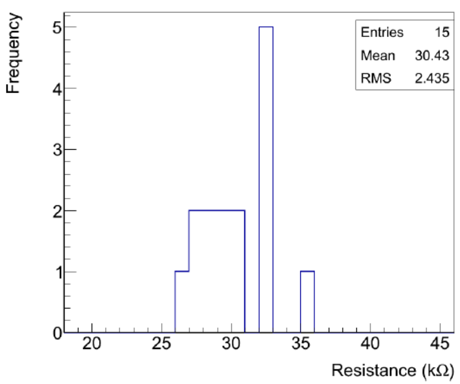




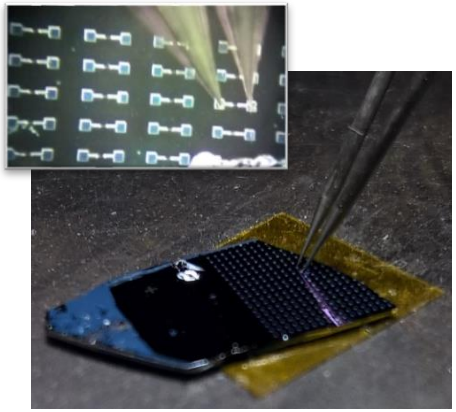
Same resistor before and after annealing



Few resistors, after annealing cycle



Characterization

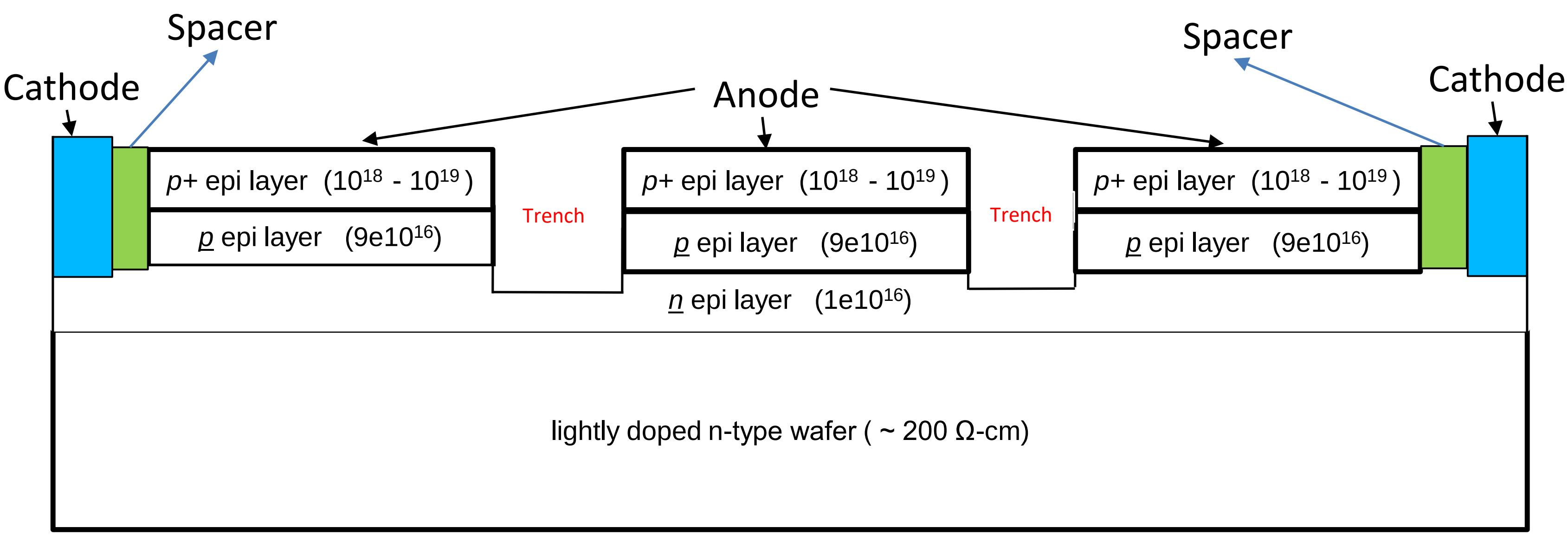


Overall 8% variation is seen across the sample.

Some variation can be attributed to film non-uniformity and can be improved.

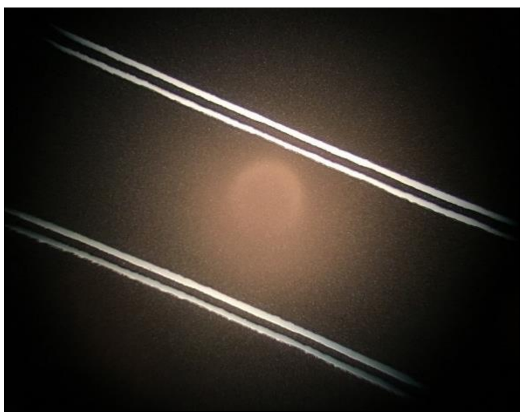
Fabrication of Deep Trenches

- As a parallel approach, fabrication of the SiPM is envisaged with multiple epitaxilly grown doped silicon layers.
- In this case, trenches are required to provide electrical as well as optical isolation
- Proposed SiPM structure with trenches

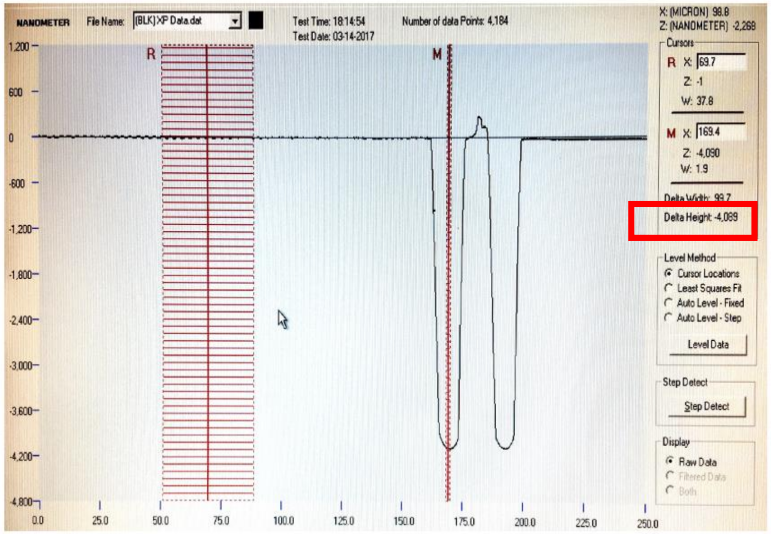


Trench fabrication: Results

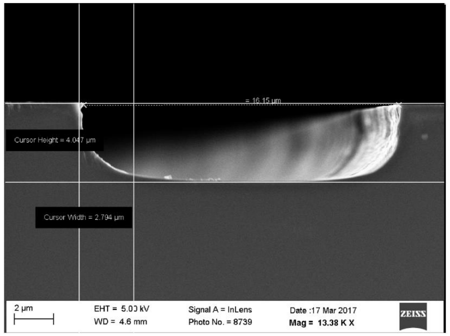
- Bosch like process:
  - Process with CHF3 for small etch and polymerization on side walls
  - Process with SF6 + O2 for deep etching



Optical Microscope Image



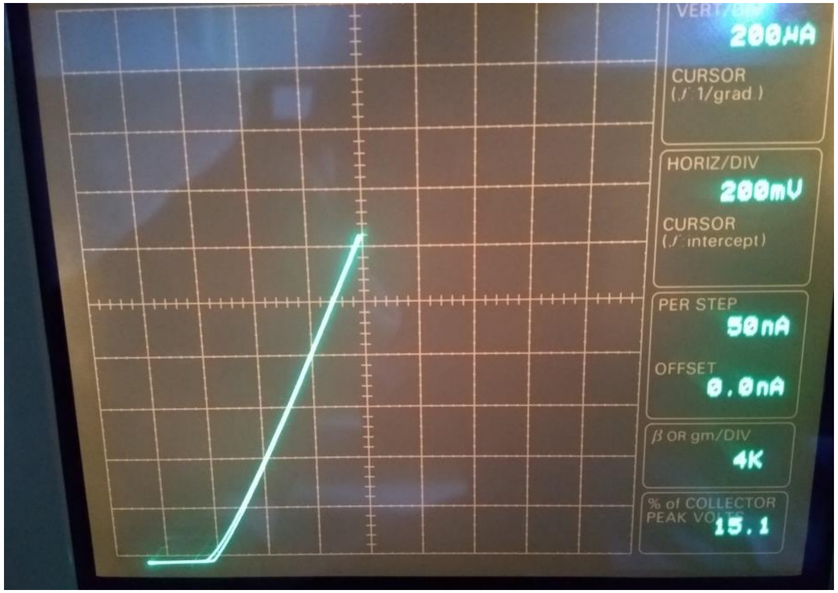
Profilometer Measurement

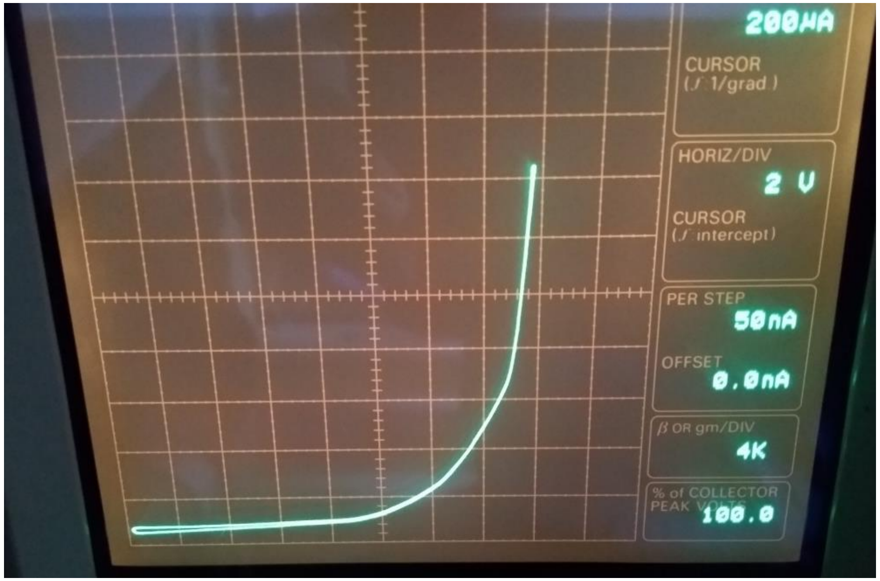


Electron Microscope Image

Final SiPM fabrication at BEL

- The process for device fabrication has been optimized for BEL foundry
- BEL has taken up the fabrication of the device their internal funds
- First wafer (prototype) is finished with the fabrication cycle and now in final stage of packaging
- Devices from first wafer will be shipped to TIFR in next 15 days for proper tests



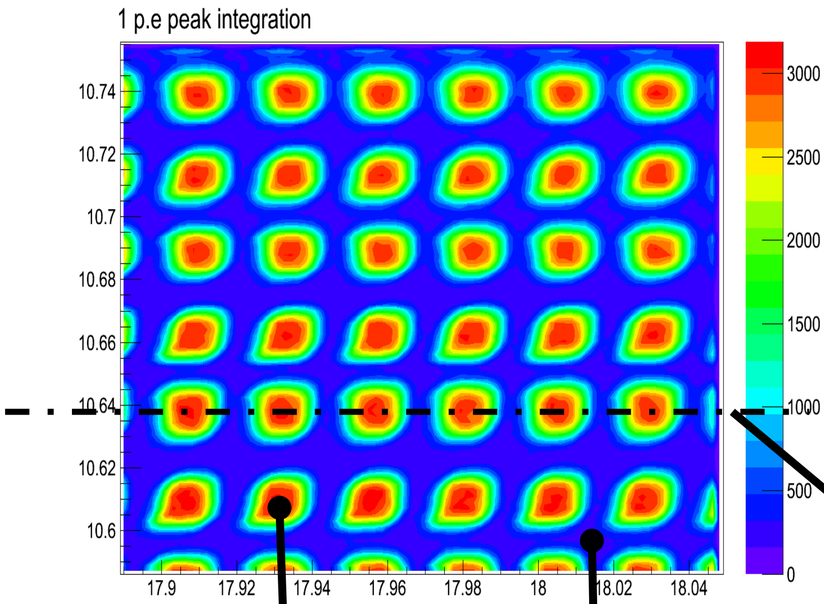


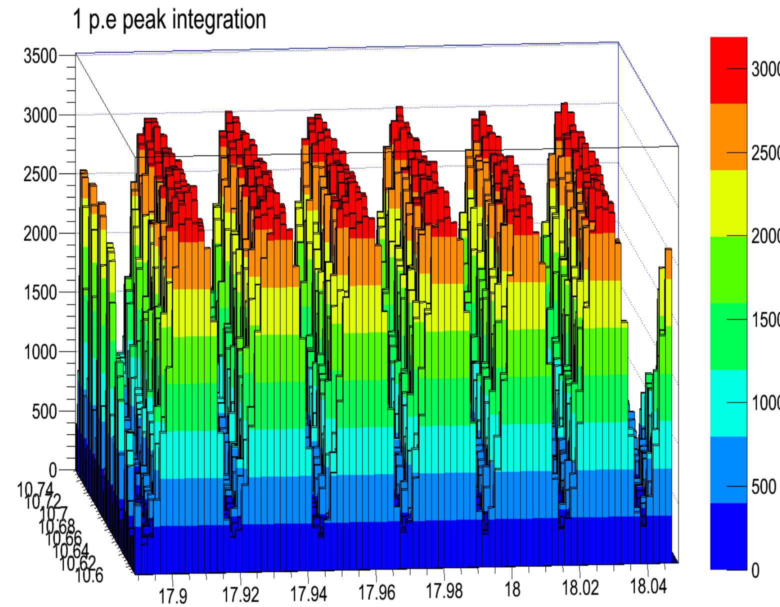
Characterization of SiPM

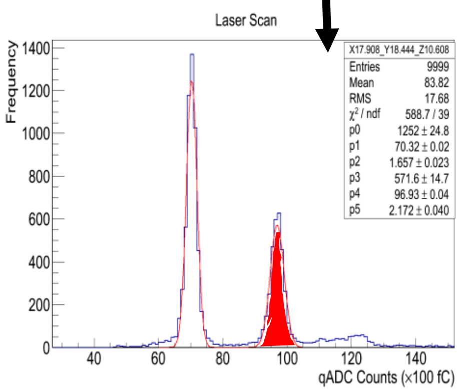
- Many characterization facilities have been setup to thoroughly test the SiPM
  - I-V measurement
  - Dark response measurement
  - LED/LASER response measurement
- In SiPM access to signal of individual diode is not possible
- Therefore, such characterization gives macroscopic properties of the device

"A Micron Resolution Optical Scanner for Characterization of Silicon Detectors" , R. A. Shukla, S. R. Dugad, C. S. Garde, A. V. Gopal, S. K. Gupta, and S. S. Prabhu, Review of Scientific Instruments 85, 023301 (2014); doi: 10.1063/1.4863880.

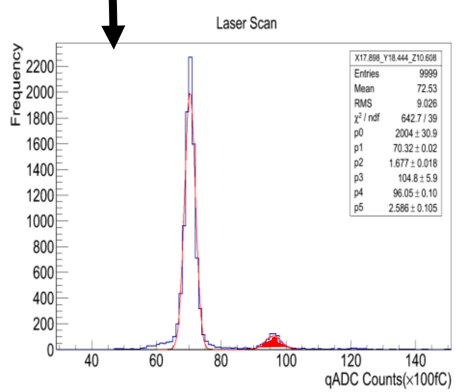
RESULTS : 2-D plots (1 p.e peak integration)



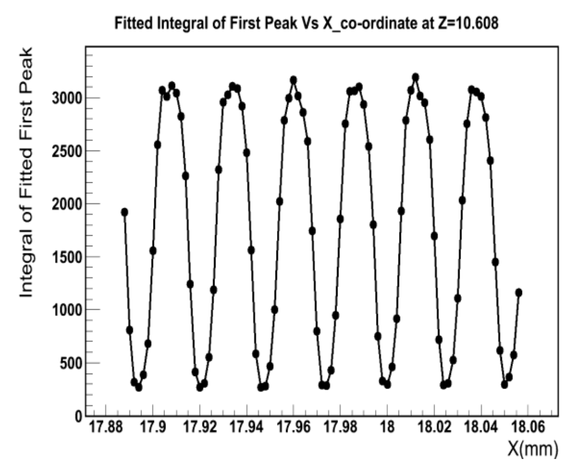




A typical histogram from



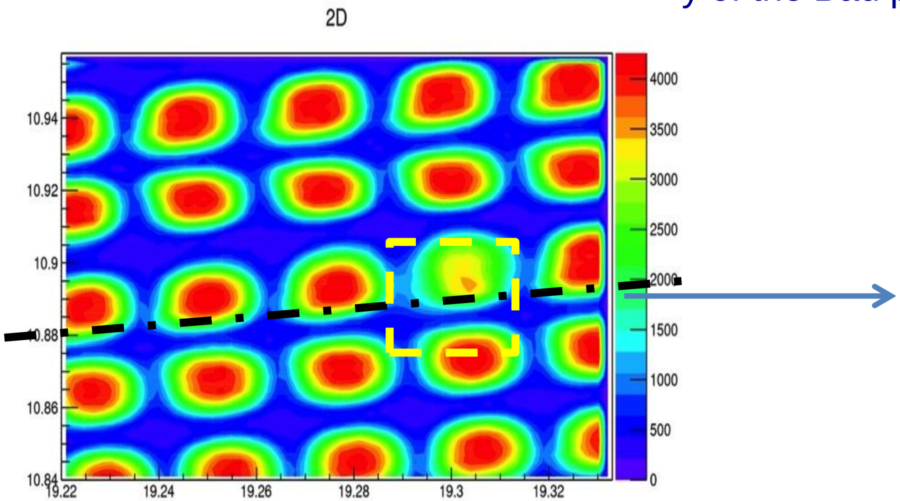
A typical histogram from

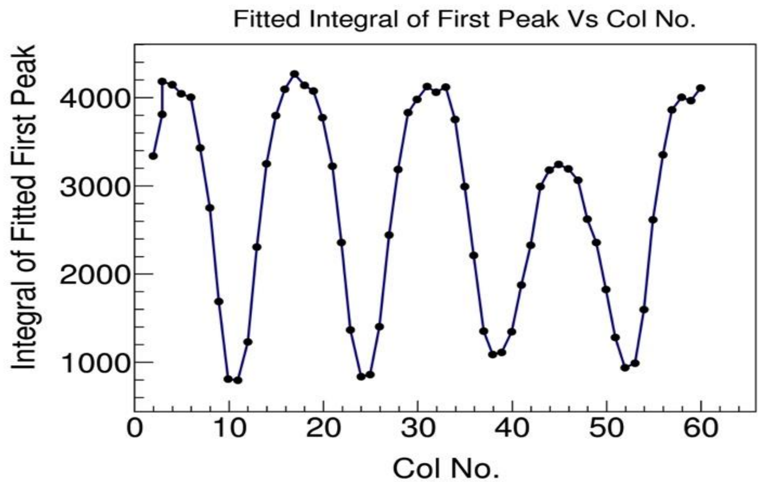


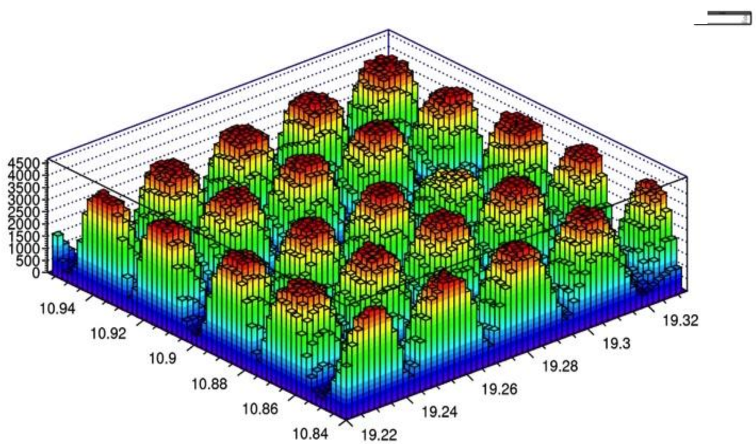
The contrast in number of events (integration) in 1 p.e events between active and dead region demonstrates excellent sensitivity of our instrument !!

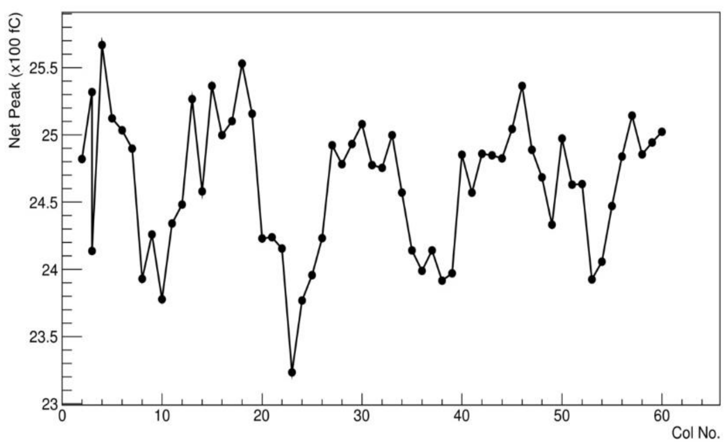
Scan indicating less sensitive pixel

- Usefulness of the was immediately proven when we found a pixel with considerably low gain
- One more scan was taken near the bad pixel to confirm the results and for more investigation
- More investigation shows that the sensitivity of the Bad pixel is low by ~25%

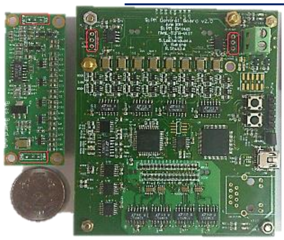


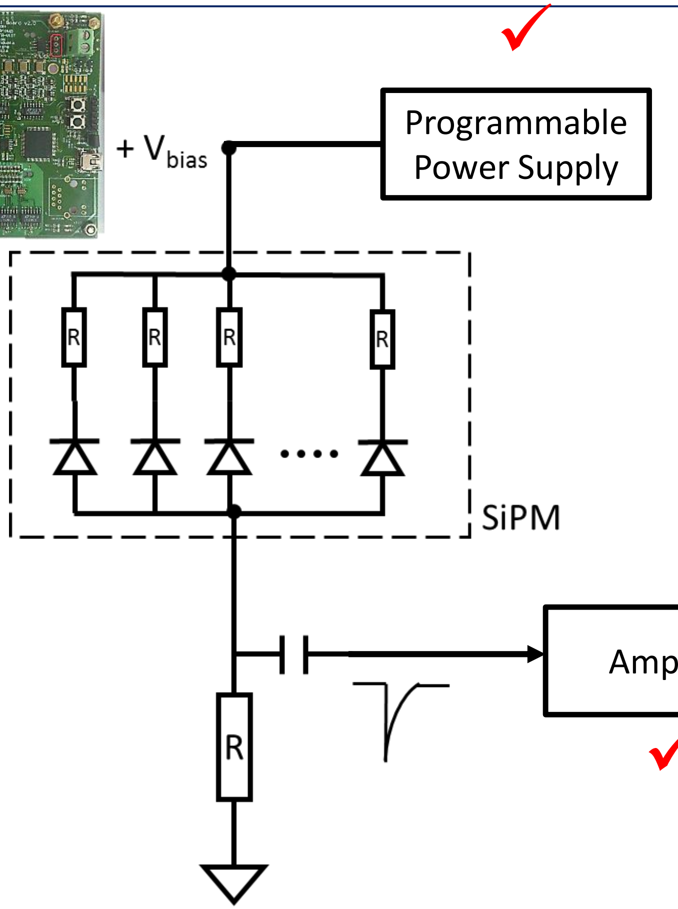






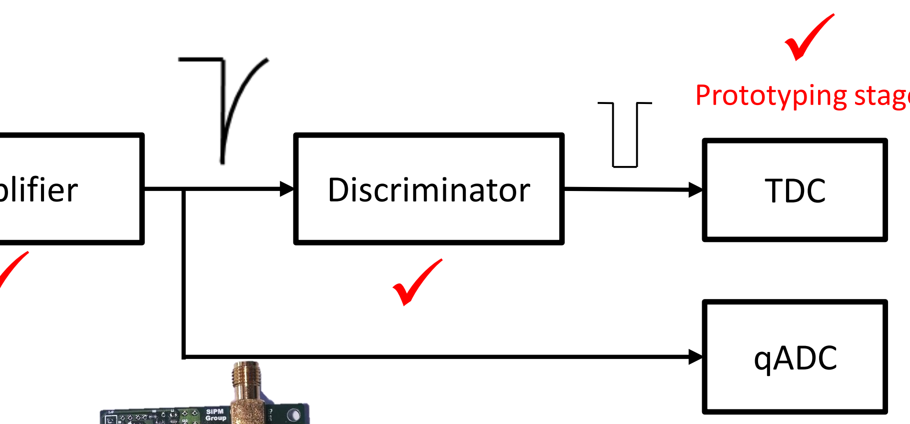
Instrumentation for SiPM

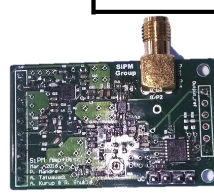




Various instrumentation blocks developed in the group will be used for following applications

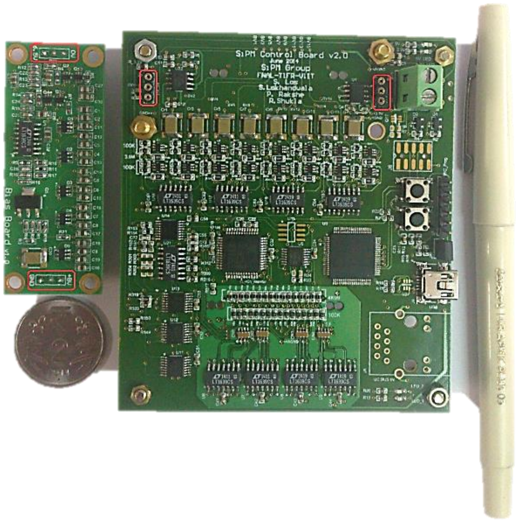
- ❑ Vehicle Monitoring System
- ❑ CMS experiment upgrade
- ❑ GRAPES-3 experiment

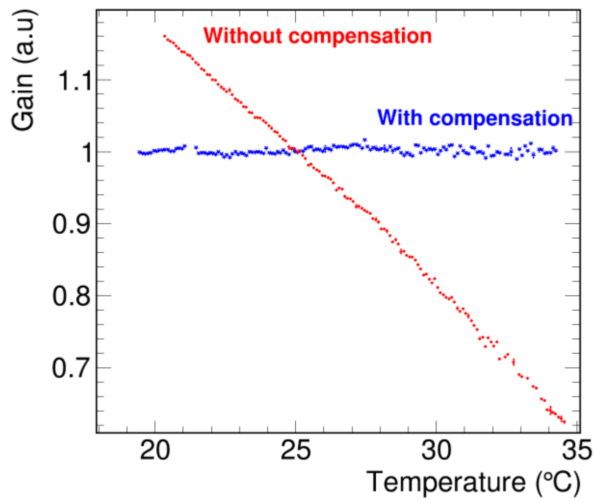


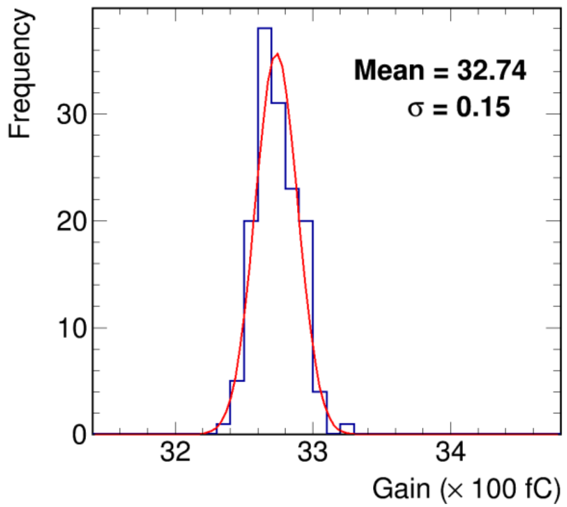


❖ A high speed digitizer development is underway, which will complete the front end instrumentation vertical slice.

PPS testing with SiPM: Results





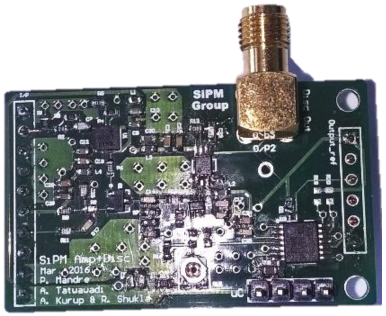


- Gain stabilized to ~0.5% over 15°C

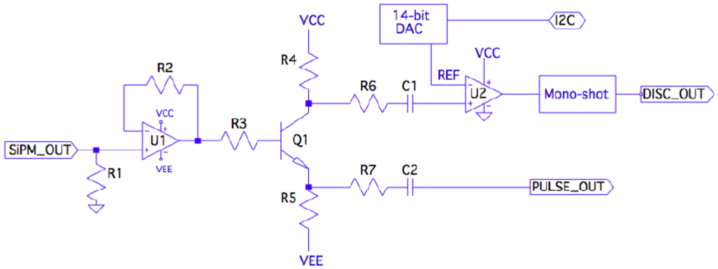
Authors	Gain stability results
Z. Li et al	6% in 5.1℃ to 33.3℃.
R. Bencardino and J. Eberhardt	1% in range of 3˚C
Licciulli et al.	2% in 20℃ to 30℃
R. Shukla et. al	**0.5% in 20°C to 35 °C (dt = 15 °C)**

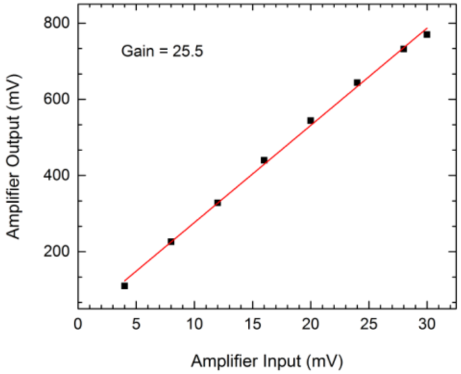
Development of High Speed Amplifier and Discriminator

- Front-end analog electronics is key block for the SiPM signal conditioning.
- SiPM signals are very weak (~200 µV/pixel) and fast (rise time ~ 1 ns)
- High Speed Amplifier with integrated discriminator for SiPM (Photo-detectors) offer high bandwidth (~ 200 MHz), high gain (~40) amplifier
- Very compact form factor; can be integrated into many systems and applications



High speed amplifier + Discriminator



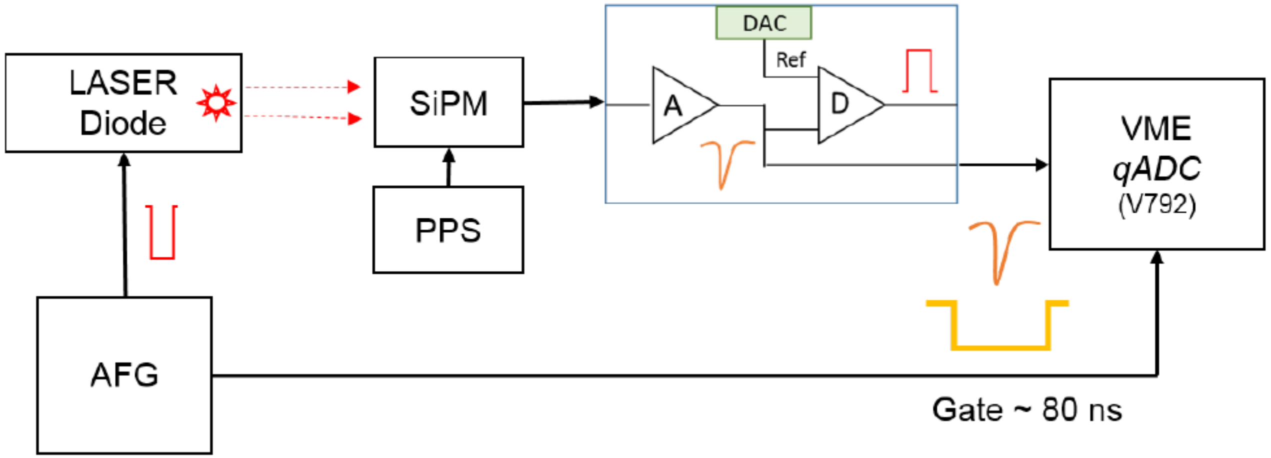


Transfer function with AFG input (pulsed)

Discriminator threshold can be programed over I^2C

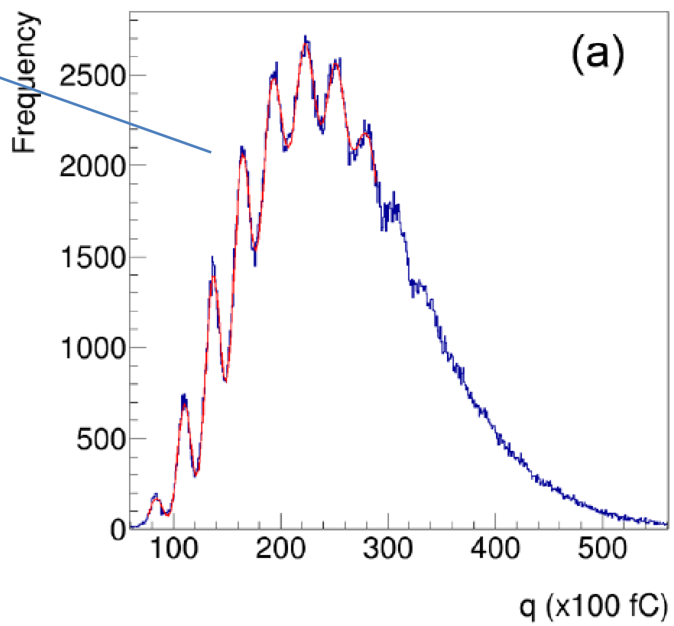
Amplifier Testing and Calibration with SiPM

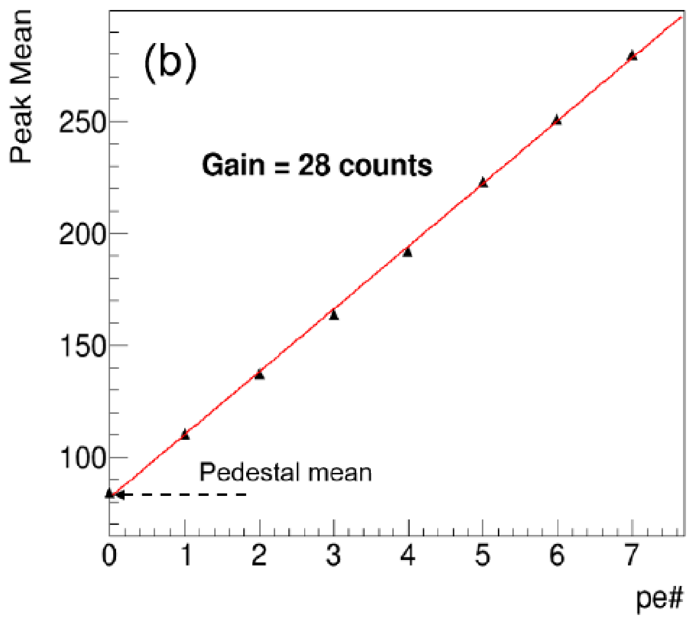
- Amplifier response in connection with SiPM and calibration of amplifier+qADC system was performed
- SiPM was exited with LASER pulses and SiPM response was recorded by the qADC synchronous to the LASER excitation



SiPM Laser Response

Individual Photons can be resolved

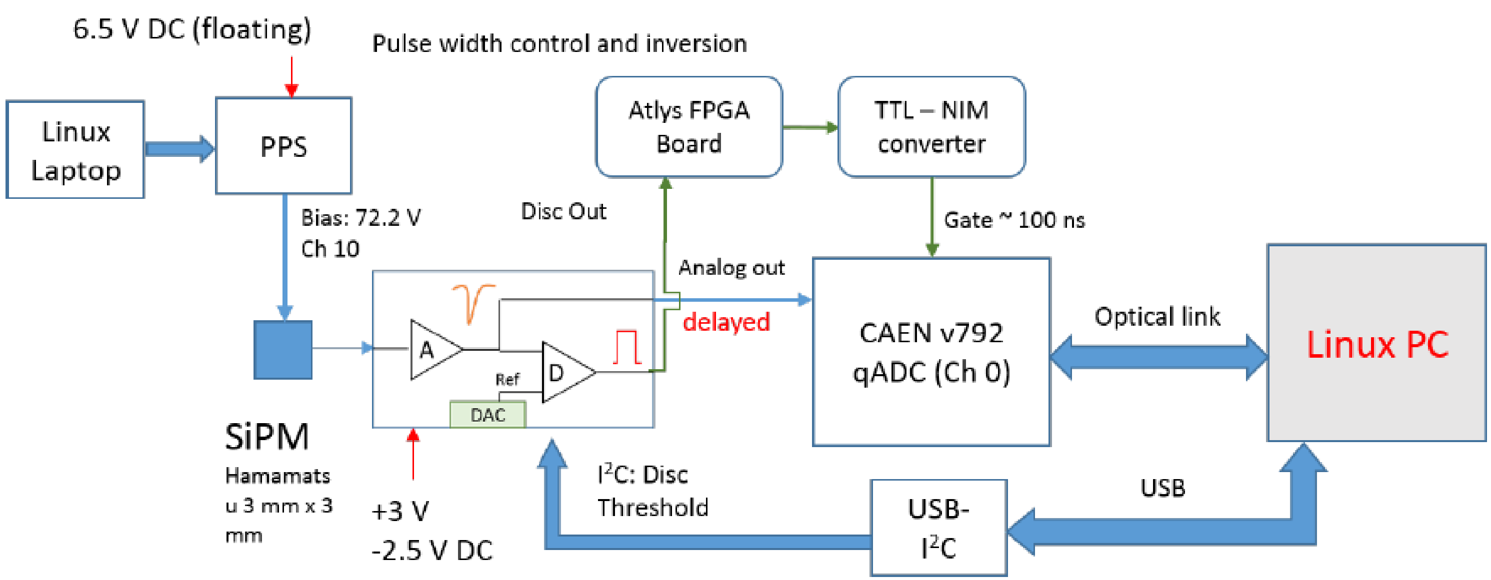




- The Gain of the SiPM was thus established to be 28 counts

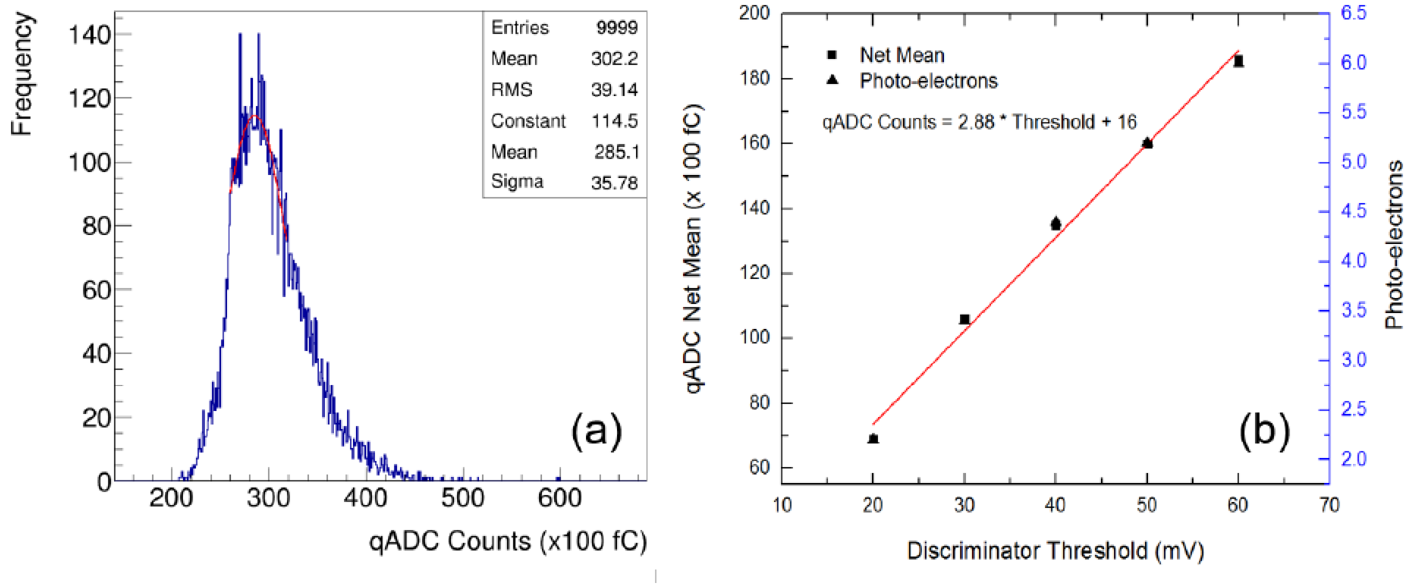
(1 qADC count = 100 fC)

Amplifier and Discriminator with SiPM

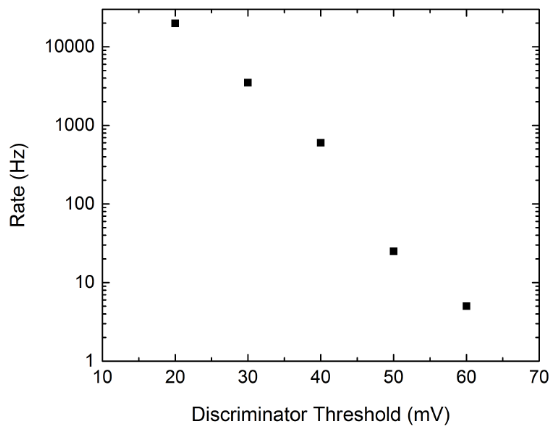


- Complete test to establish the working of the amplifier and discriminator module
- The analog output is appropriately delayed so as to have SiPM signal within the Gate

Results



Frequency
140
120
100
80
60
40
20
0
200
300
400
500
600
qADC Counts (x100 fC)
Entries 9999
Mean 302.2
RMS 39.14
Constant 114.5
Mean 285.1
Sigma 35.78
(a)
qADC Net Mean (x 100 fC)
200
180
160
140
120
100
80
60
10
20
30
40
50
60
70
Discriminator Threshold (mV)
Net Mean
Photo-electrons
qADC Counts = 2.88 * Threshold + 16
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
Photo-electrons
(b)

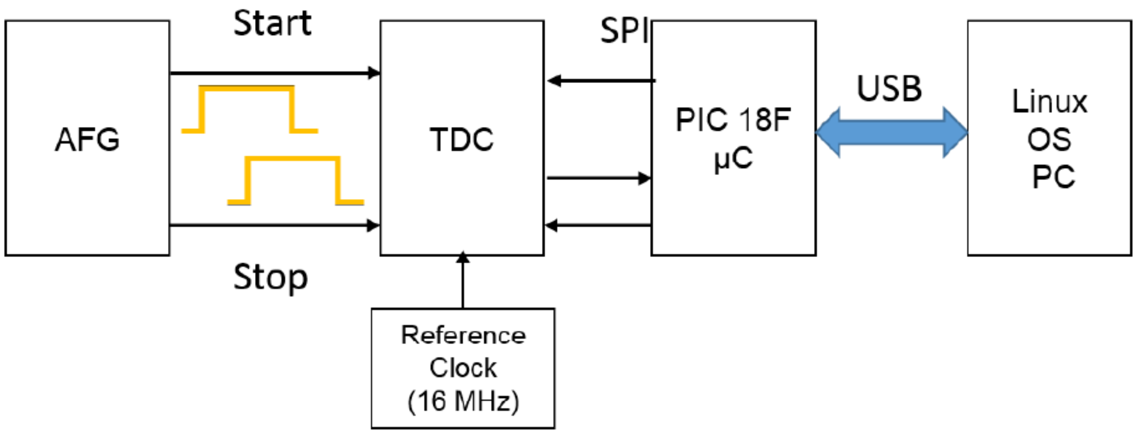


Rate (Hz)
10000
1000
100
10
1
10
20
30
40
50
60
70
Discriminator Threshold (mV)

Timing Measurement: Development of TDC Module

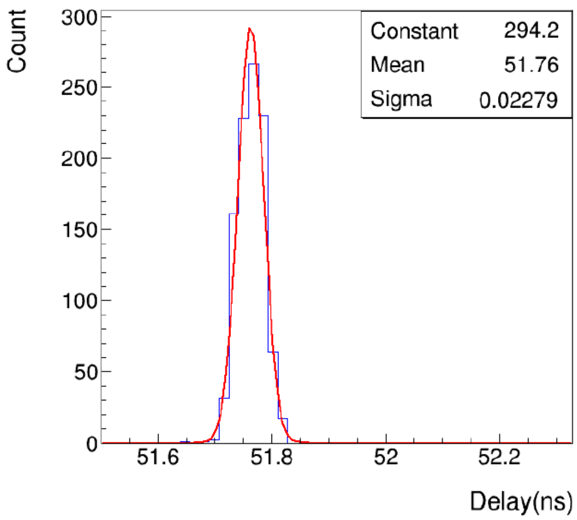
- In many experiments it's important to know the exact arrival time of the SiPM signal (event generating the signal).
- Along with fast response time of SiPM, with sophisticated instrumentation timing can be measured with very high precision.
- Typically Time to Digital Converter (TDC) are used.
- We have explored, commercially available IC TDC7200
- Measurement within 100 ps accuracy possible

Block diagram of test setup

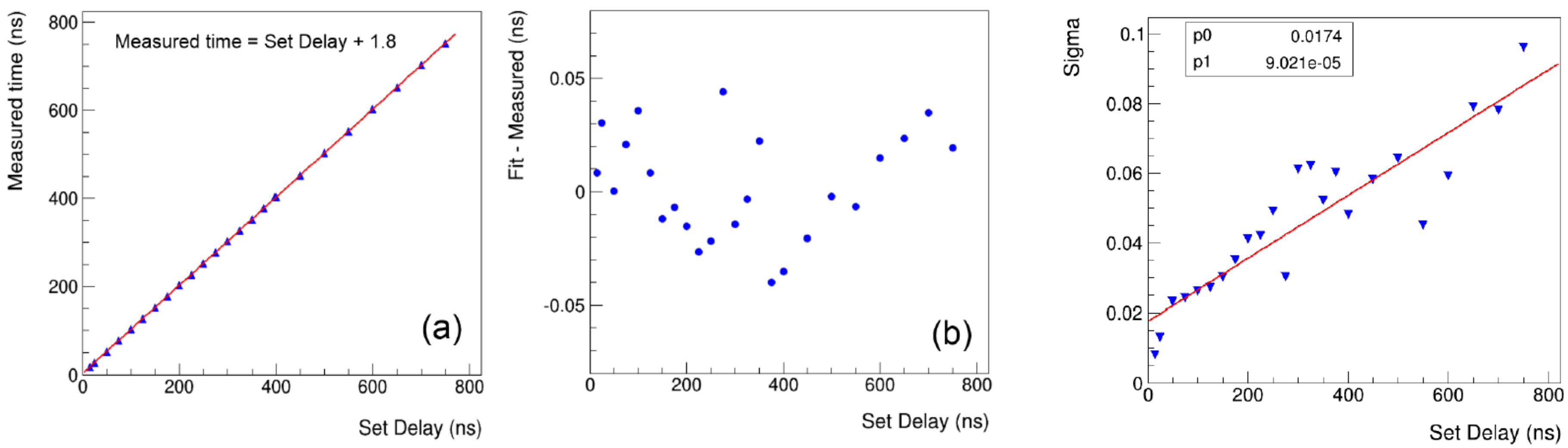


Event rate up to 1 kHz is easily recorded with current system

Histogram of timing data collected with TDC
The variation is about 23 ps



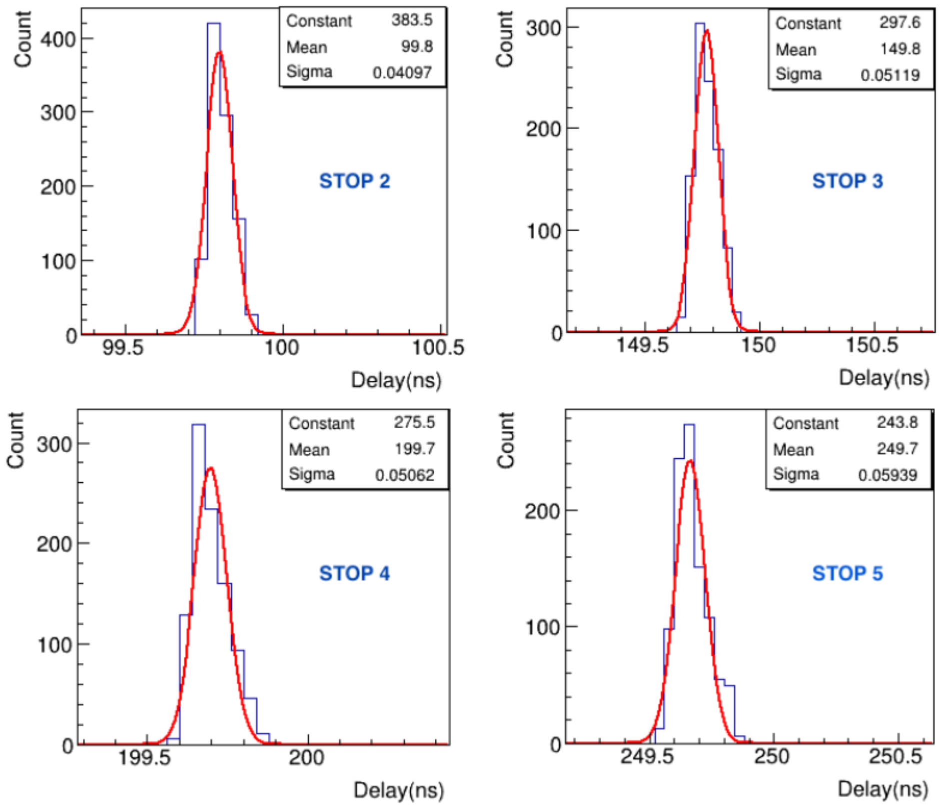
Mode-1 test results



Mode 1 specified for 12 – 500 ns. However, can be successfully used up to 800 ns.

TDC Multi Stop Testing

- The TDC7200 supports 5 stop pulses and time difference from start pulse to each stop pulse is recorded in different registers.
- This multi-stop capability was tested with 5 stop pulses for different delays



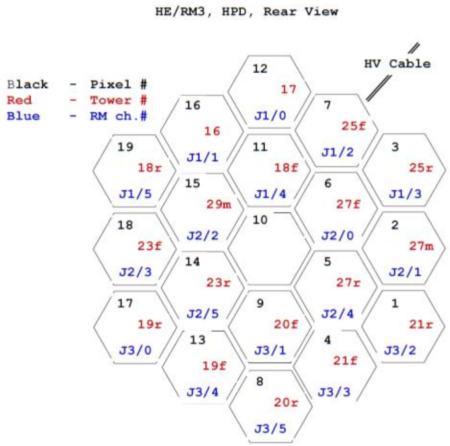
HO/HE-HPD Fine Scan using MROS

CERN Collaborators: P. De-barbaro, A. Heering, P. Rumerio

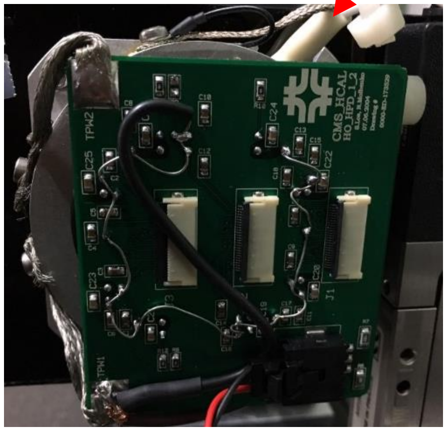
Overview

- Fine scanning of the HPD was taken up with Micron Resolution Optical Scanner (MROS) (*R.A. Shukla et al., Review of Scientific Instruments 85, 023301 (2014); doi: 10.1063/1.4863880*)
- Focal plane position along beam axis and beam spot size was established before beginning the 2D scan with modified *knife-edge* method using LASER at two different wavelengths (650 nm and 520 nm)
- 2D scan of HO/HE-HPD surface with step size of 75-300 μm in both directions have been performed using LASER at two different wavelengths (650 nm and 520 nm)
  - HE-HPD was scanned only with 520 nm exitation
- Results of these studies are presented
- Fiber imprints on the photo-cathode with highly depleted and varying response have been observed

Orientation of the HO-HPD Mounting Arrangement

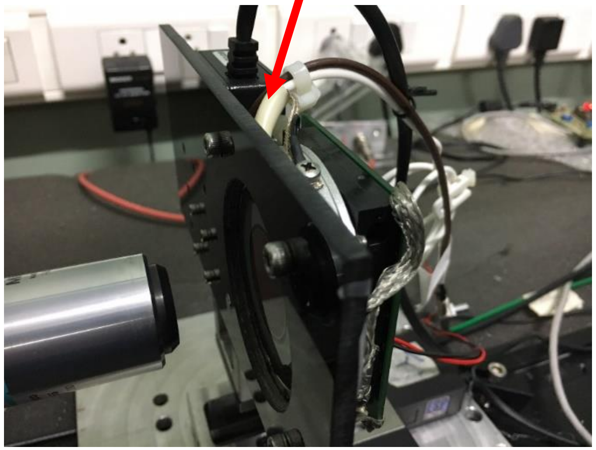


HV Cable



Rear View

HV Cable



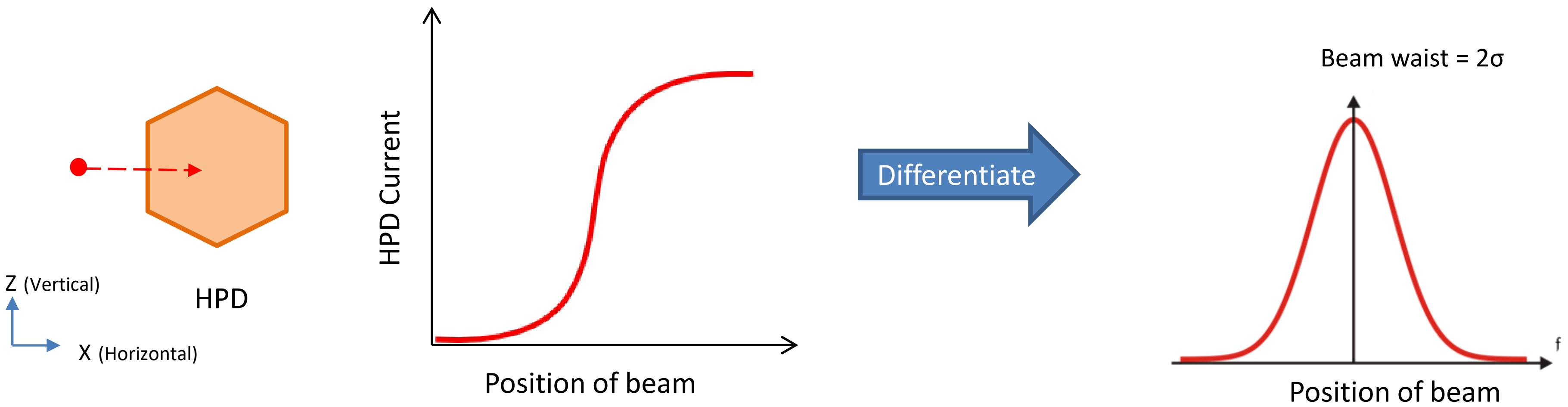
Front View

Establishing focal plane position for HPD scan

- Micron Resolution Optical Scanner (MROS) houses a 50x lens to focus laser beam to obtain ultra fine beam size (~ 1.7 μm)
- To have optimum beam spot size for scanning the HPD, HPD sensitive surface should be aligned with focal plane.
- Rough alignment is performed by imaging active surface of HPD with CCD imaging system built into MROS.
- For exactly determining focal plane position and effective beam spot size, a method was designed by modifying standard knife-edge method, utilizing HPD features.
- The Focal plane scan has been performed at many different places along the surface of the HPD since there can be small tilt in HPD surface due to imperfect mounting
    - Tilt results in slightly different focal plane positions along surface of the HPD.

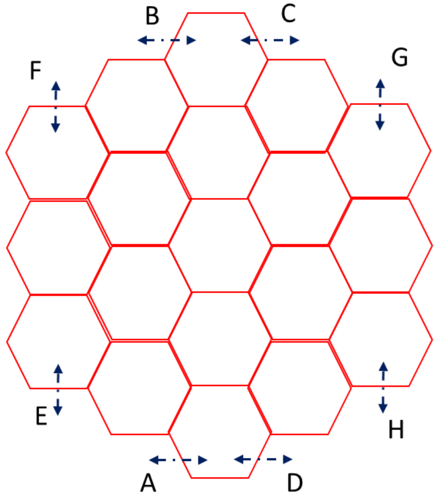
Same Procedure has been followed for HO and HE HPD

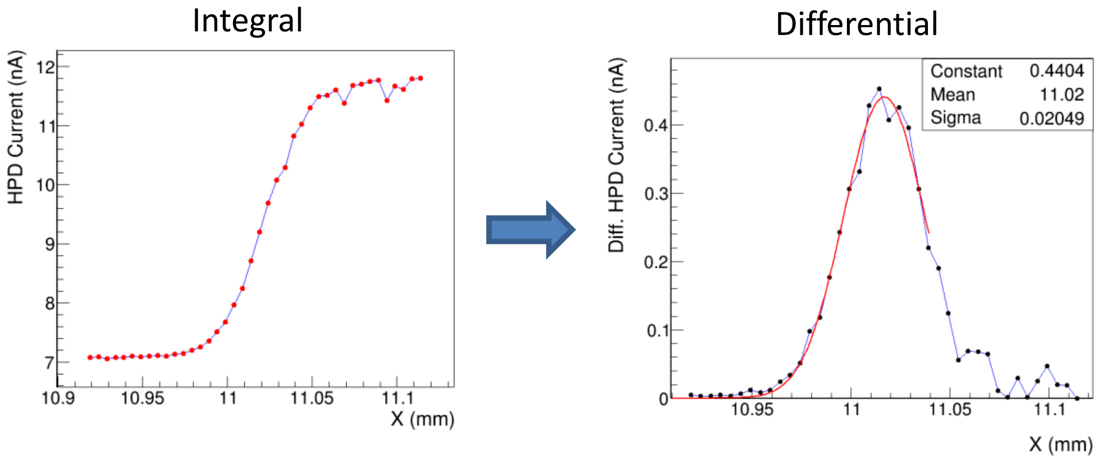
Focal axis scan



- The laser beam is scanned across different edges of the HPD recording HPD current at every position.
- The transition from dead area to an active area of the device acts as a knife-edge
- The recorded data (current at each scan position) is differentiated to obtain a Gaussian beam profile.
- The width of differentiated distribution indicates the beam size
- This exercise is repeated at different positions along the focal plane

Focal Scans at different locations

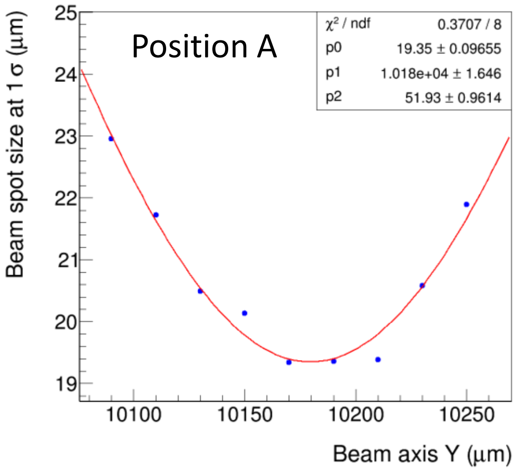




Typical row scan data

- Different locations across entire area of the HPD (named A-H) were chosen to carry out focal axis scan which yields focal plane positions at each of these points.
- Shown data is from one of the HO-HPD focal scans.

HO-HPD Focal Scan Results (λ=650 nm)



$p0 = \sigma_0$
$p1 = z_0$
$p2 = M^2$

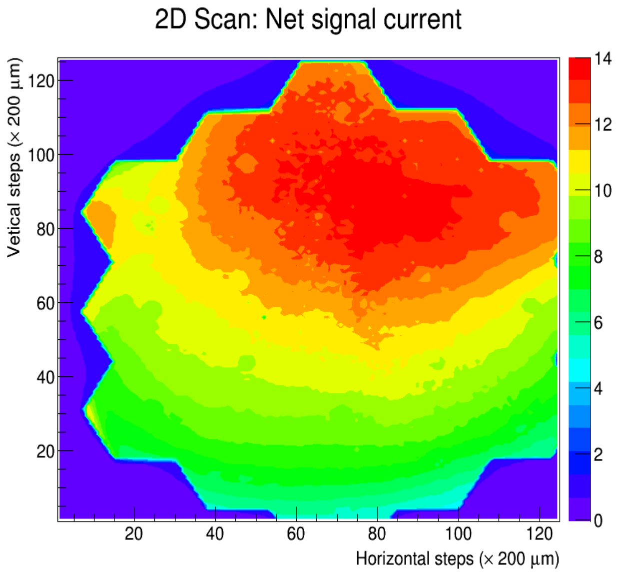
- When beam size is plotted as function of HPDs position along beam axis, the curve can be fitted with well known Gaussian optics beam propagation equation:

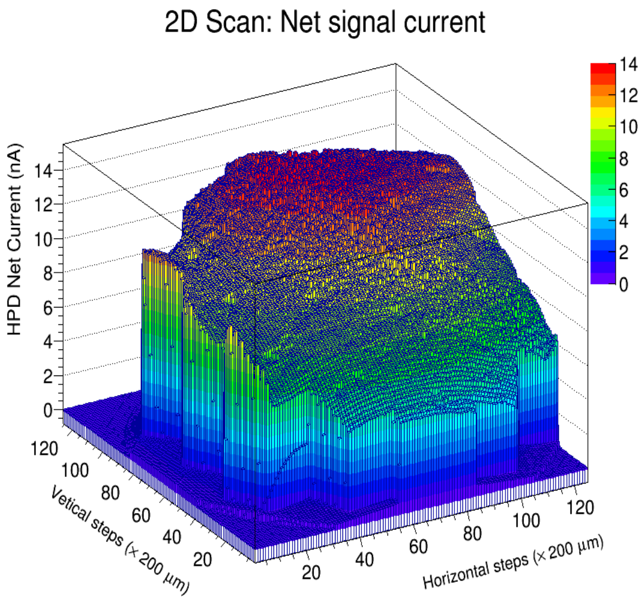
$$\sigma(z - z_0) = \sigma_0 \times \sqrt{1 + \left(\frac{M^2 \lambda (z - z_0)}{4\pi\sigma_0^2}\right)^2}.$$

Where, λ is wavelength (650 nm), σ is beam spot size obtained by fitting Gaussian beam profile and M^2 is beam quality factor.

First 2D scan without focal axis correction
Run No. 27, λ=650 nm, Step Size: 200 μm

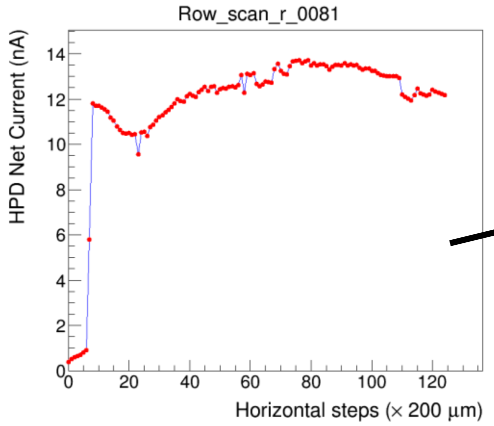
Net Current = Ped Subtracted

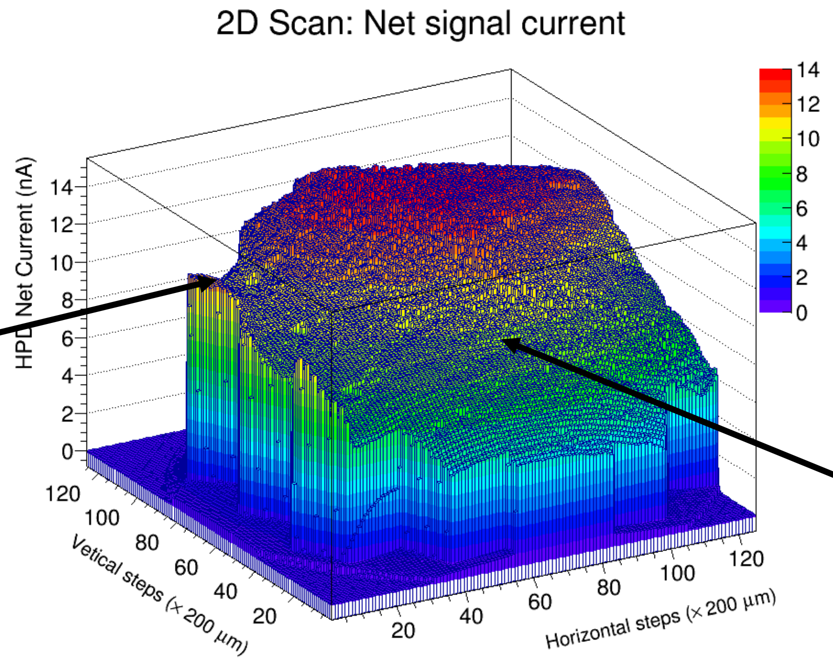




- A 2D scan of HO-HPD was taken with coarser step size of 200 μm in each direction.
- Our linear motion stages have only 25 mm dynamic range, thus small portion of the device has been skipped in the scans.
- Laser illumination was kept low so as to obtain HPD current of about 12 nA (ped subtracted).
- Bias Conditions: PIN BV = 80 V and H.V = - 6 kV

Some Features
Run No. 27, λ=650 nm, Step Size: 200 µm



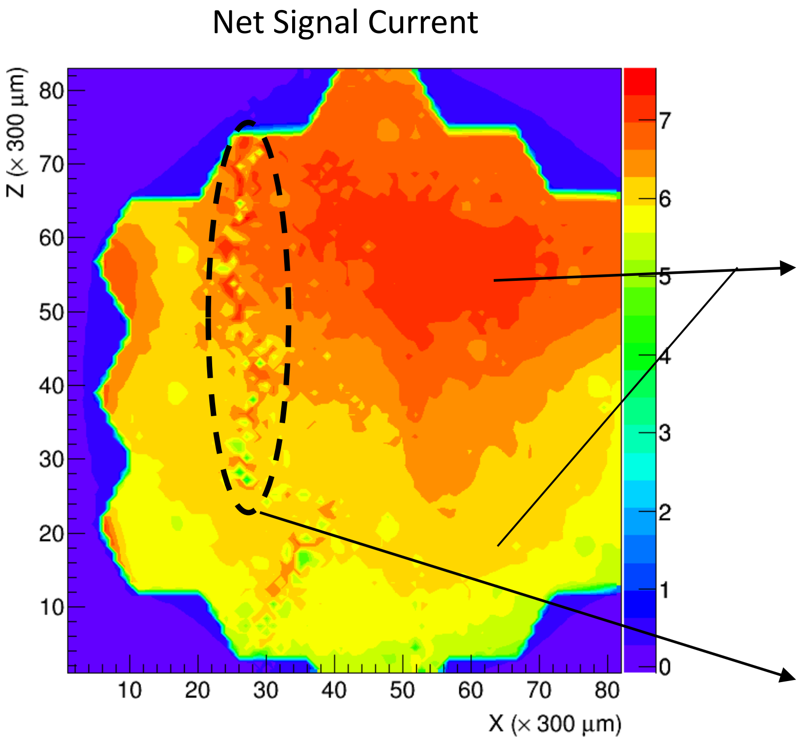


Response spikes at edge

Gradient in response of the HPD

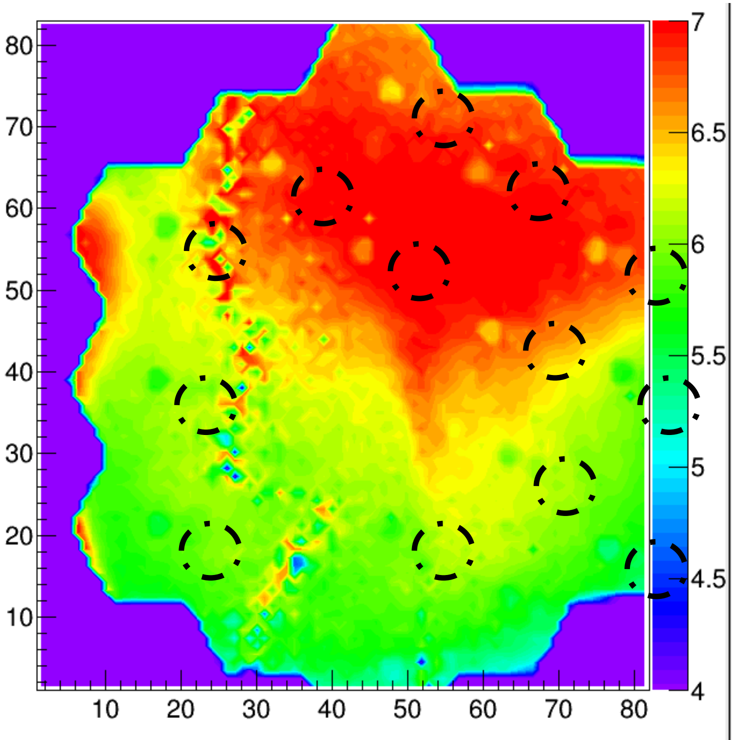
- About factor of two variation in the signal current (after subtracting dark current) has been observed across surface of the HPD
- Increase in signal current in certain edge region of the HPD has been also observed.

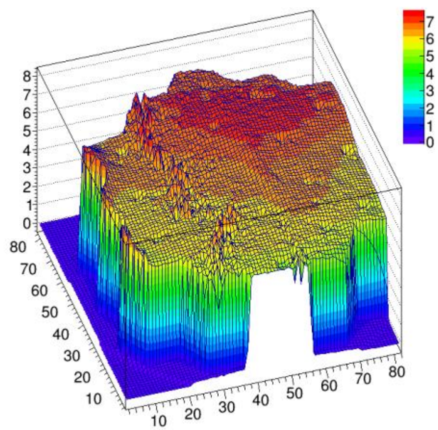
Coarse HO-HPD 2D-scan with 520 nm Laser (Run 49, Step Size 300 µm)

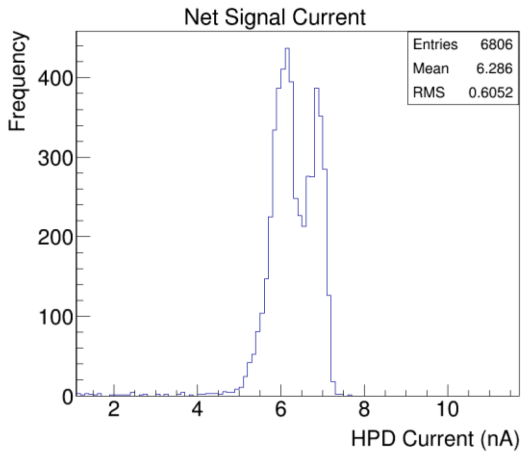


- **A 2D scan with 300 µm step size has been recorded with 520 nm exaltation.**
- **Very interesting features are noted in the scan.**
  - **A. The non-uniformity in the response is less compared to that observed while using 650 nm Laser, however, trend is similar.**
  - **B. Finer features are visible thanks to smaller beam spot size arising due to smaller excitation wavelength**
  - **C. Intermittent spots are visible where response is slightly degraded (more on next slide)**
  - **D. Oscillations are seen in some area, which could be related to pixel border as well as square pattern on the photo-cathode (as discussed in slide 21).**

Visibility of regularly spaced spot degradation







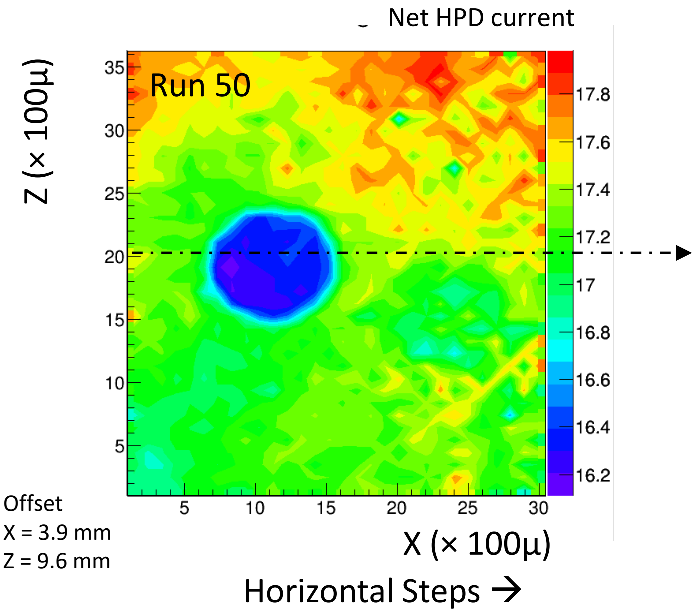
Distribution of net signal (pedestal subtracted) current shows good uniformity (~10% over entire area)

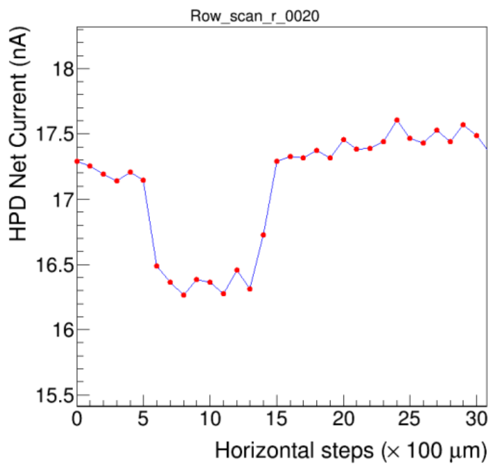
Z range has been selected so as to amplify the spots

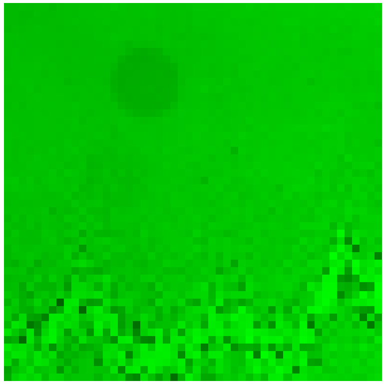
These spots can be attributed to calibration fibers !

HO-HPD Fine scans taken around fiber spots
Run 50, Step Size = 100 µm, λ=520 nm

- To investigate such spot degradation further fine scans were conducted with finer step size of 100 µm around few of such locations known from last scan.
- Signal intensity was also increased
- **Images of fibers on the HPD are clearly observed in most of the pixels.**

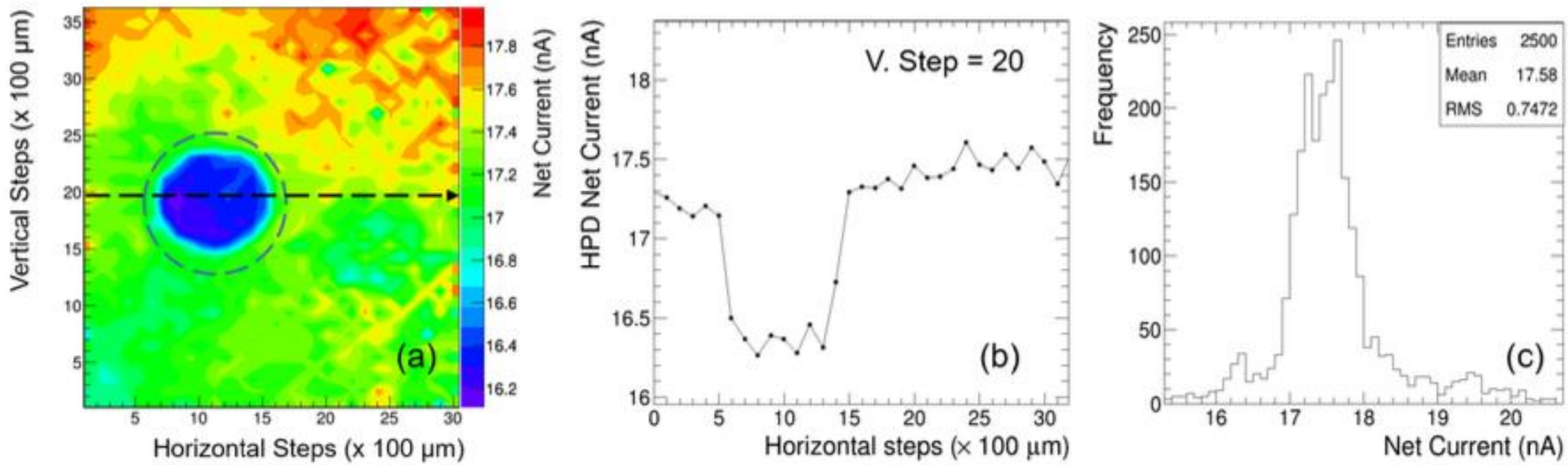


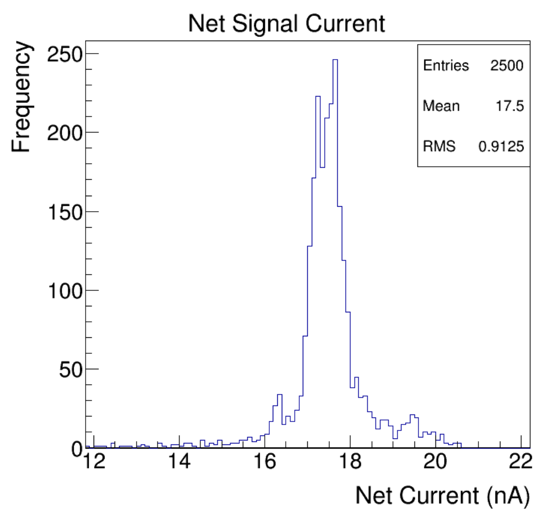


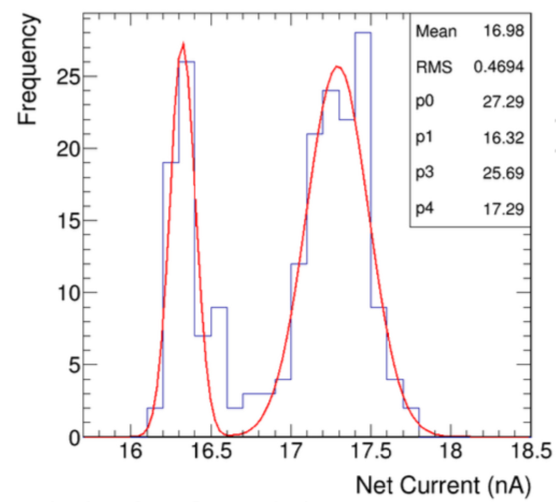


Smoothening + Thresholding to enhance fiber impressions
> Done with OpenCV

Run 50: Deeper look





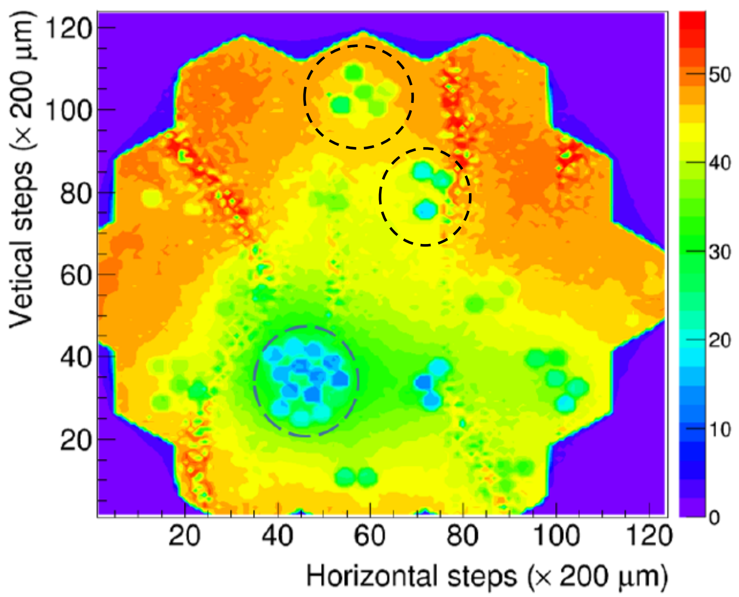


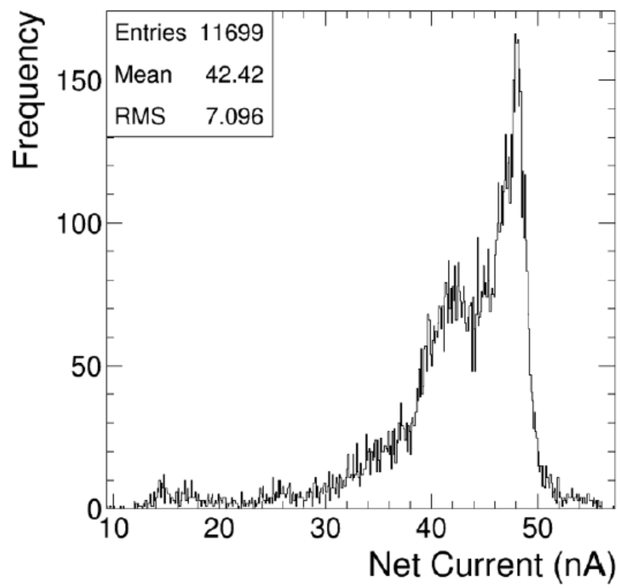
Overall degradation: 1 - 16.32/17.29 = 0.06

Variation of response within signal fiber region is not very significant (~ 5%)

HE HPD Scans (Decommissioned from RM4)

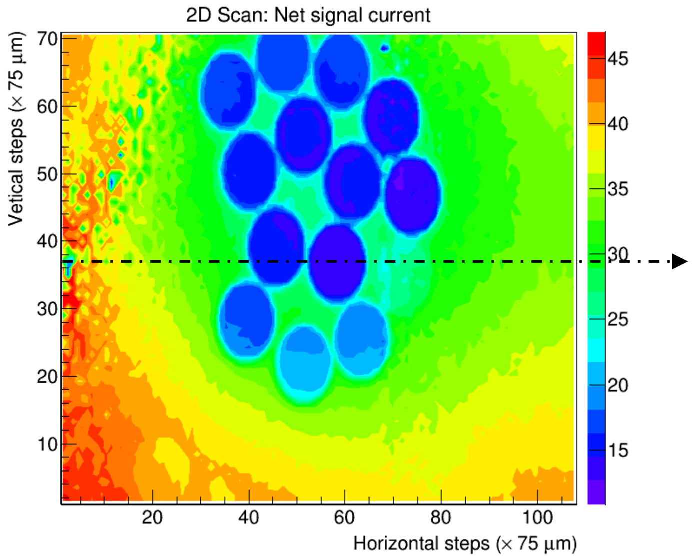
HE-HPD 2D Scans:
Run 72 Step Size = 200 μm, λ=520 nm

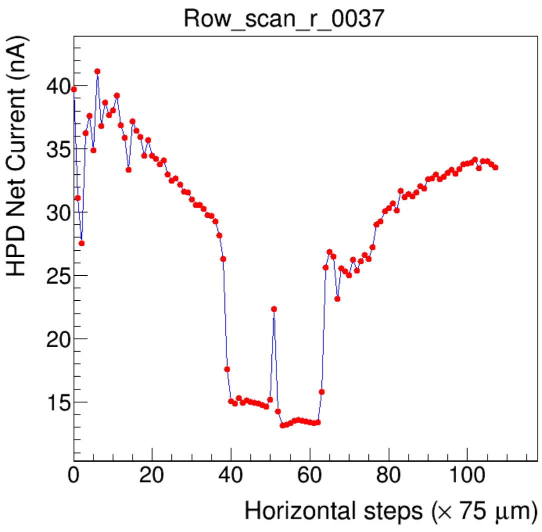


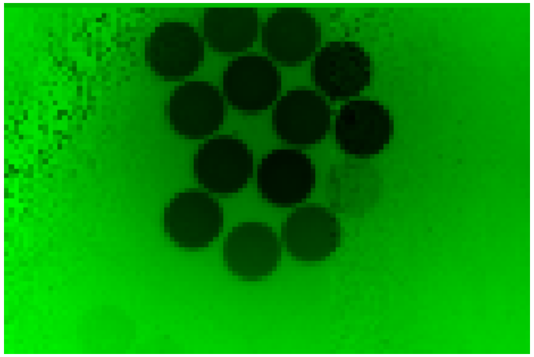


- Many impressions of the fibers can be seen !
- Indicates damage of the photo-cathode.

HE-HPD Regional 2D Fine Scans: Run 86 Step Size = 75 µm, λ=520 nm





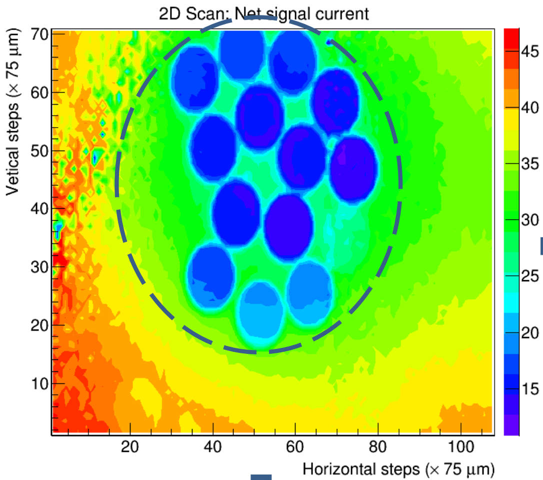


Smoothening + Thresholding to enhance fiber impressions
> Done with OpenCV

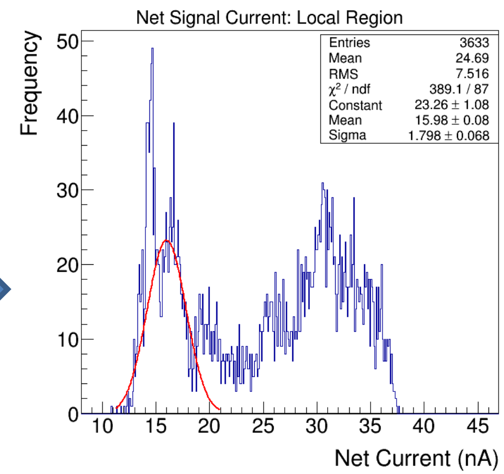
Scan parameters:

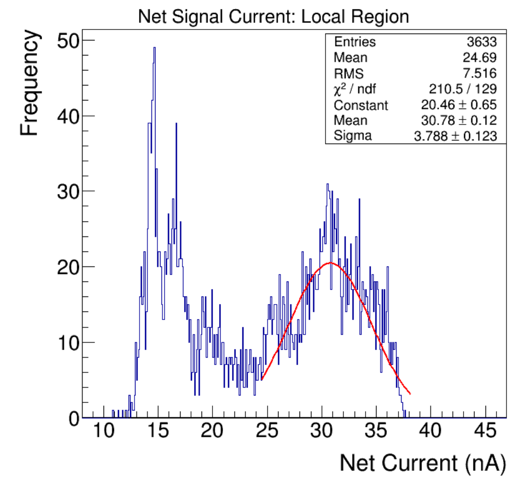
Scan size: 72 x 108 steps, Step size: 75 um, Focal axis correction every 5 mm

Run 86

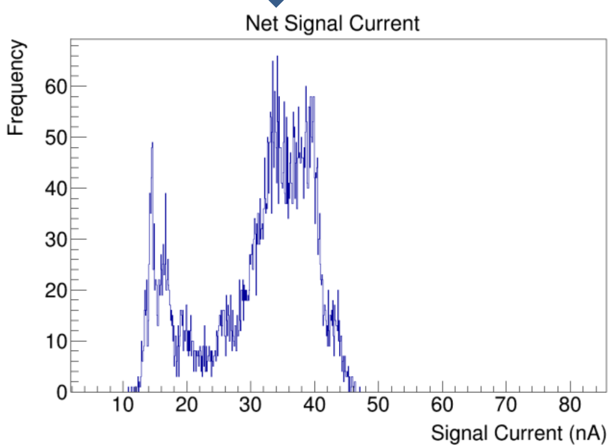


Fill selective data points



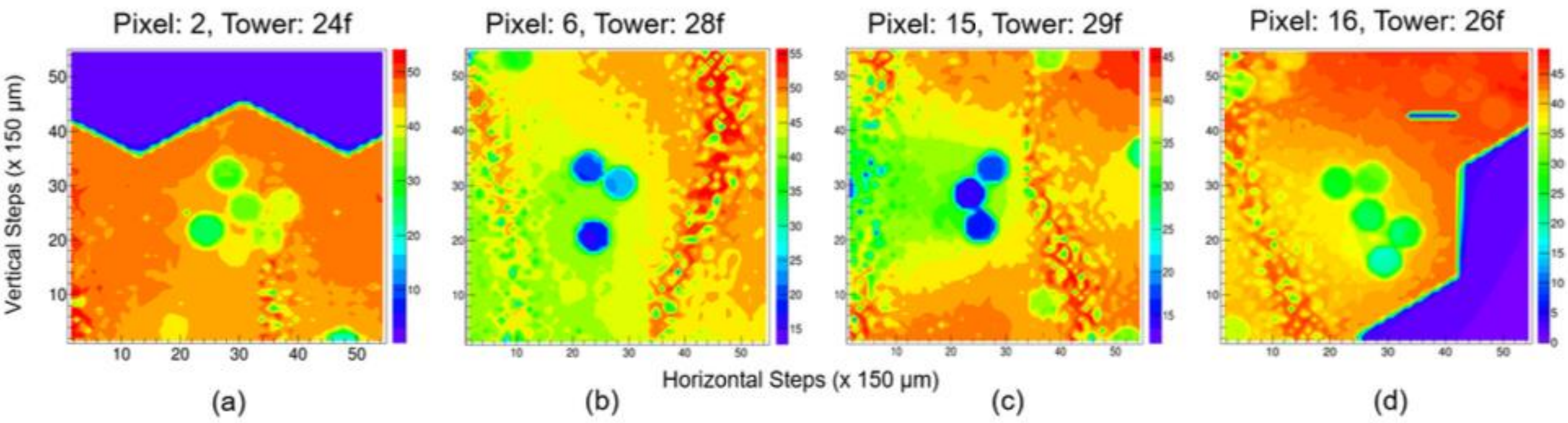


Fill all data points



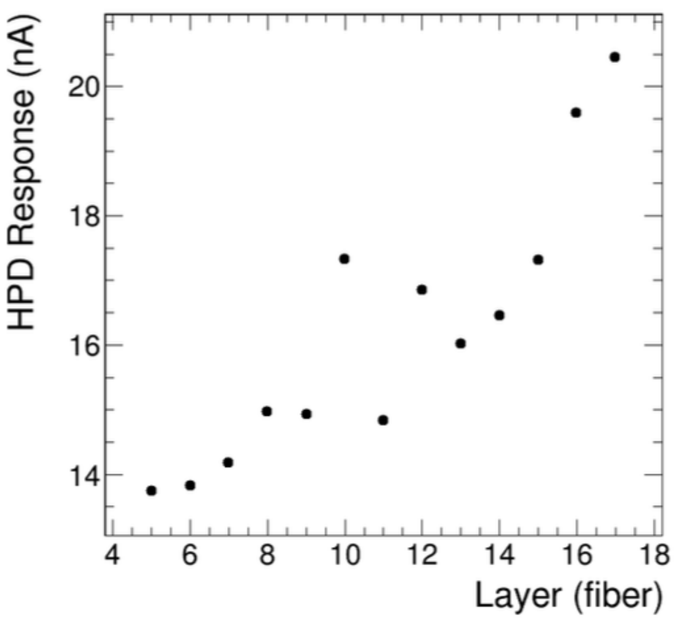
- Overall degradation of the response = 1- 16/30.8 = **0.48**
- Variation of the response within the fiber area = 1.8/16 = **0.11**
- **Actual variation in the signal fiber response could be higher since, all fiber contact points does not seem to be degraded**

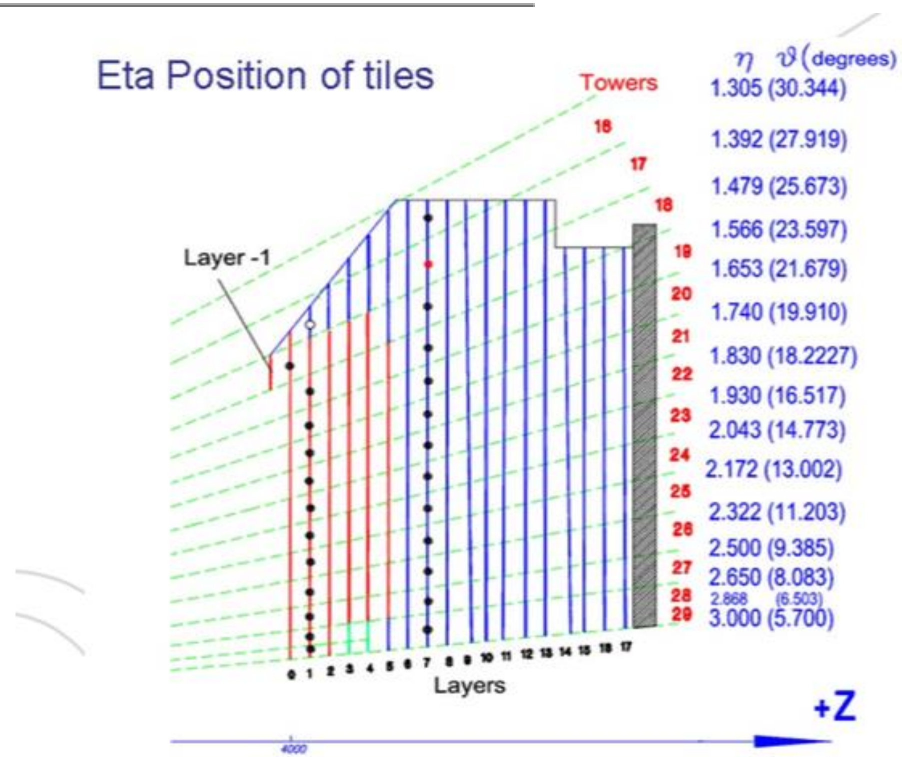
More fine scans



Damage correlation

Pixel	Fibers (layers)	Tower	Eta	% Damage
2	5	24f	2.172	22
16	5	26f	2.5	50
14	13	28r	2.868	54
6	3	28f	2.868	56
15	3	29f	3	60





Detailed Detector Note (DN) has been prepared and under process at CMS

CMS DN-18-004

The Compact Muon Solenoid Experiment

Detector Note

The content of this note is intended for CMS internal use and distribution only

2018/04/26
Head Id: 457311
Archive Id: 448365:457311M
Archive Date: 2018/04/26
Archive Tag: trunk

Ultra Fine Characterization of Hybrid Photo Detectors decommissioned from End-cap (HE) and outer hadron (HO) calorimeter using Microscopic Resolution Optical Scanner

Applications of the SiPM and Associated Instrumentation

✓The in-house developed instrumentation blocks coupled together with Hamamatsu SiPM have successfully used for **Muon detection** using plastic scintillators.

✓The instrumentation has been also used to establish prototype of Laser Wall, a possible application of the SiPM.

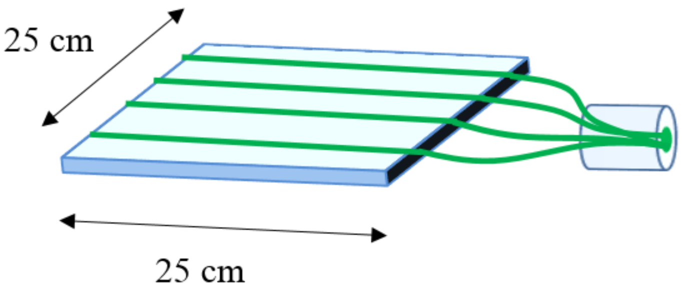
✓Detailed simulations with SiPM based detectors have been carried out using GEANT-4 to demonstrate **‘Muon Tomography’,** an effective technique to detect Hi-Z materials.

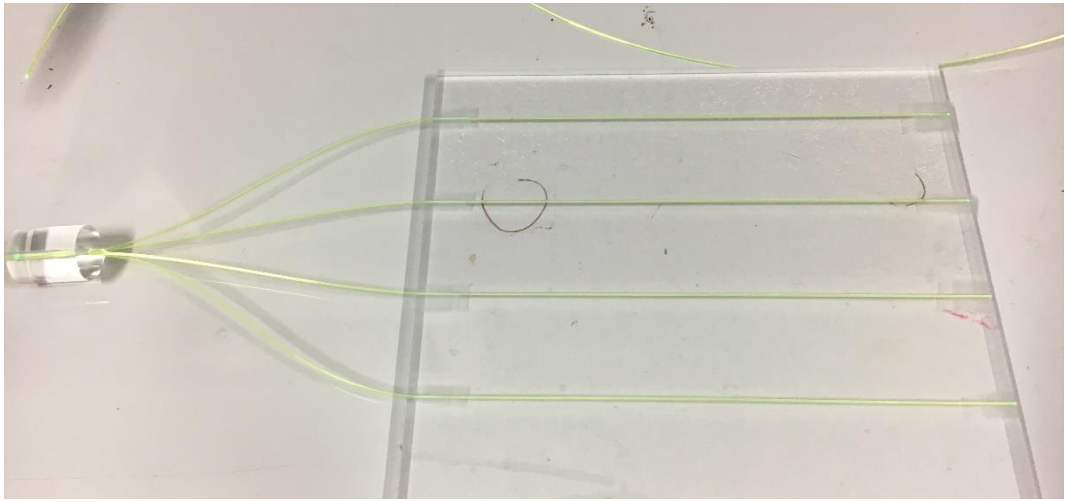
Summary

Application of the SiPM and associated instrumentation in detecting cosmic ray **Muons**

Summary

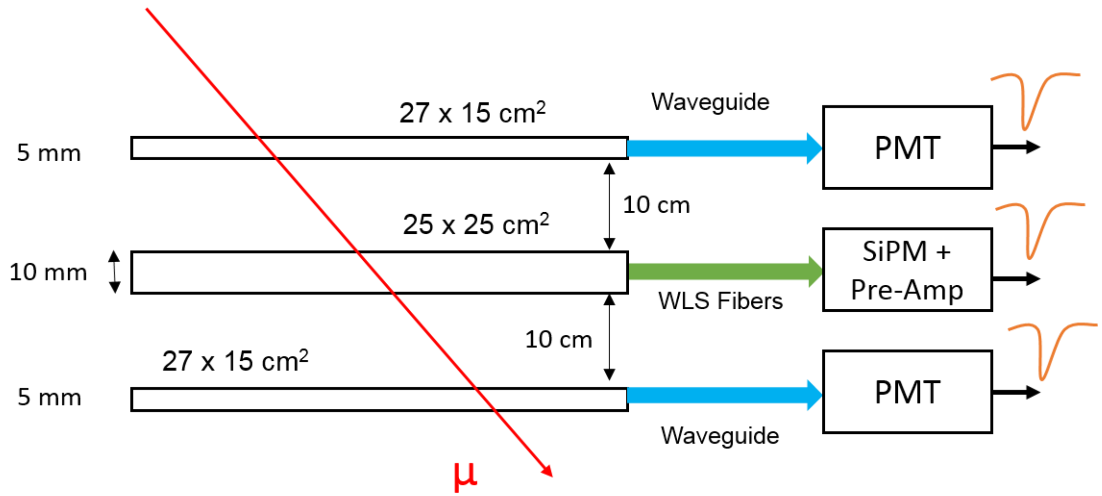
Plastic Scintillator and WLS fibers





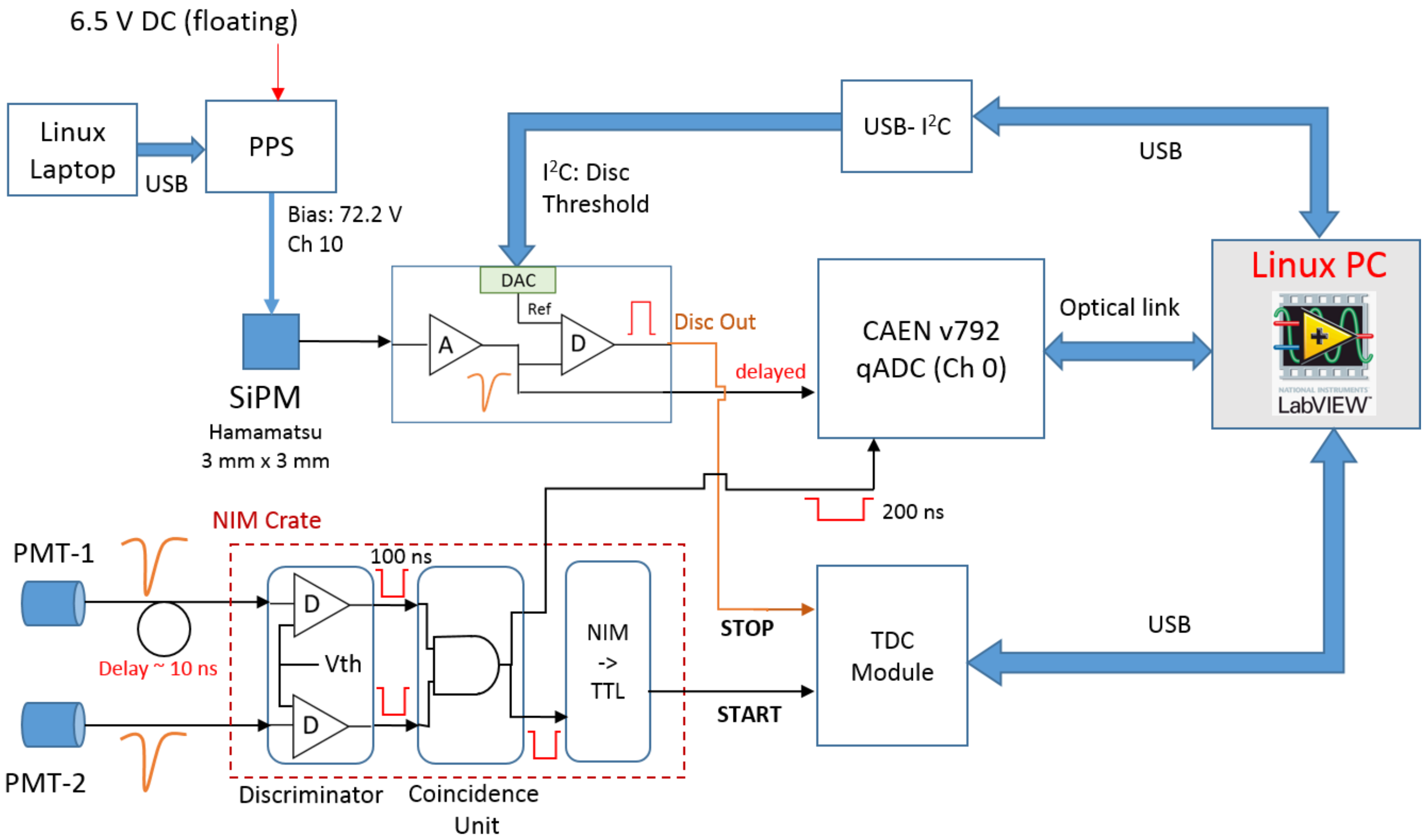
Wavelength Shifting Fiber (WLS) emission = 500 nm
Energy loss by minimum ionizing radiation = 2 MeV/gm-cm^2

Scintillator Arrangement

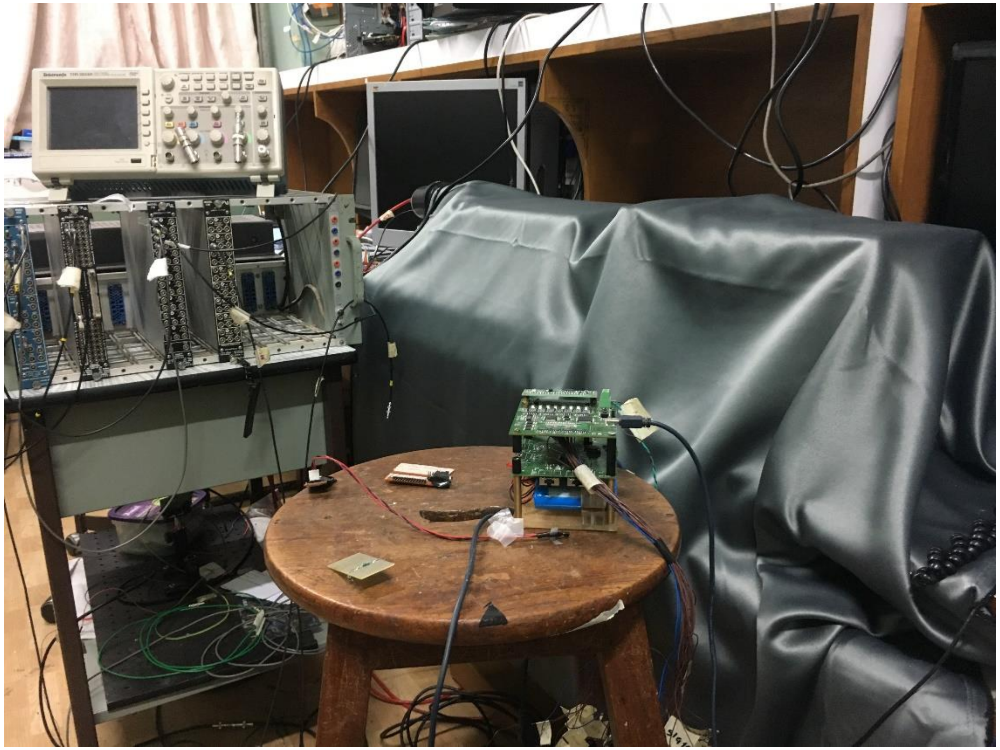


- Coincidence of two PMT outputs after discriminator used to generate muon trigger
- Length of one pulse cable is longer, which delays it and reduces timing jitter in trigger signal

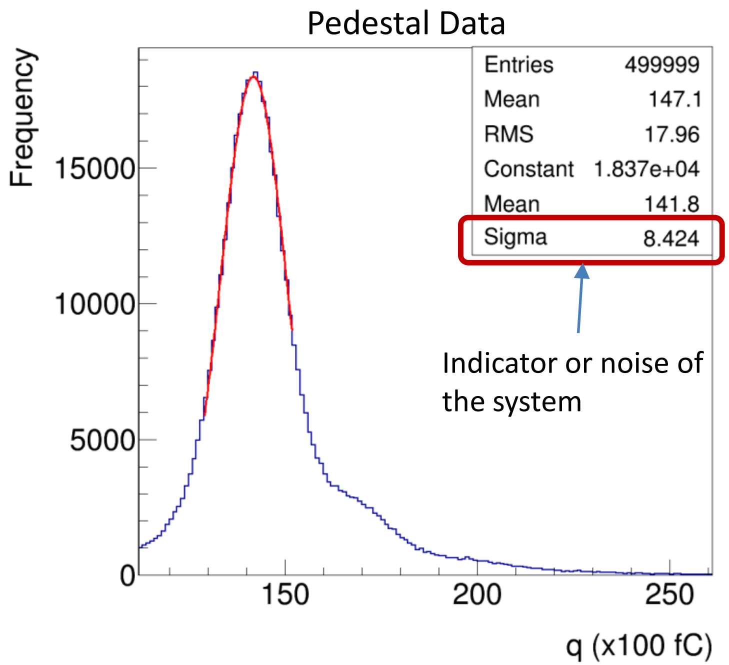
Experimental Setup

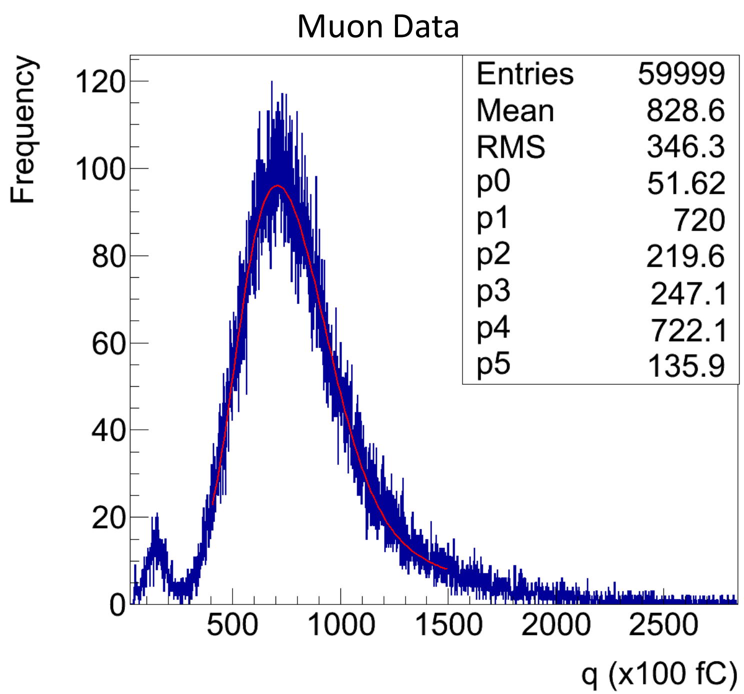


Experimental Setup



QADC Data



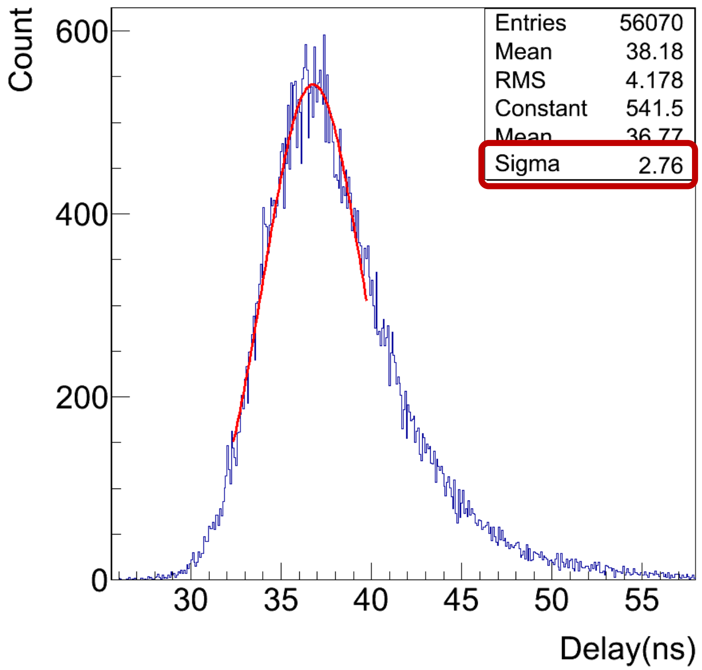


Net Muon Signal = 722 – 142 = 580

No of p.e = 580/28 = ~ 20

Signal to background ratio = Mean/sigma (ped)
= 80/8.4
= 69

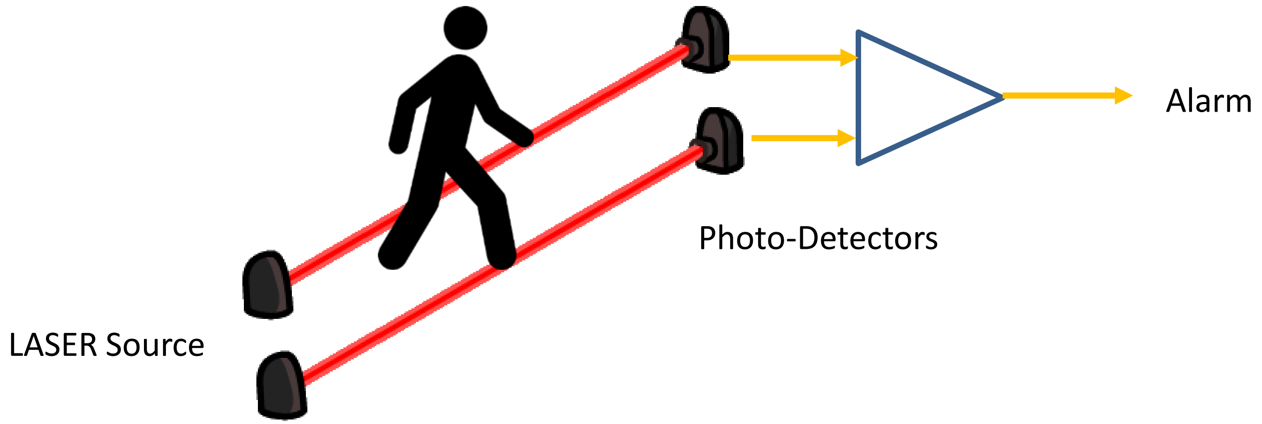
TDC Data



Fluctuations observed in the timing data in good agreement with monte-carlo simulations performed by Mohanty et.al

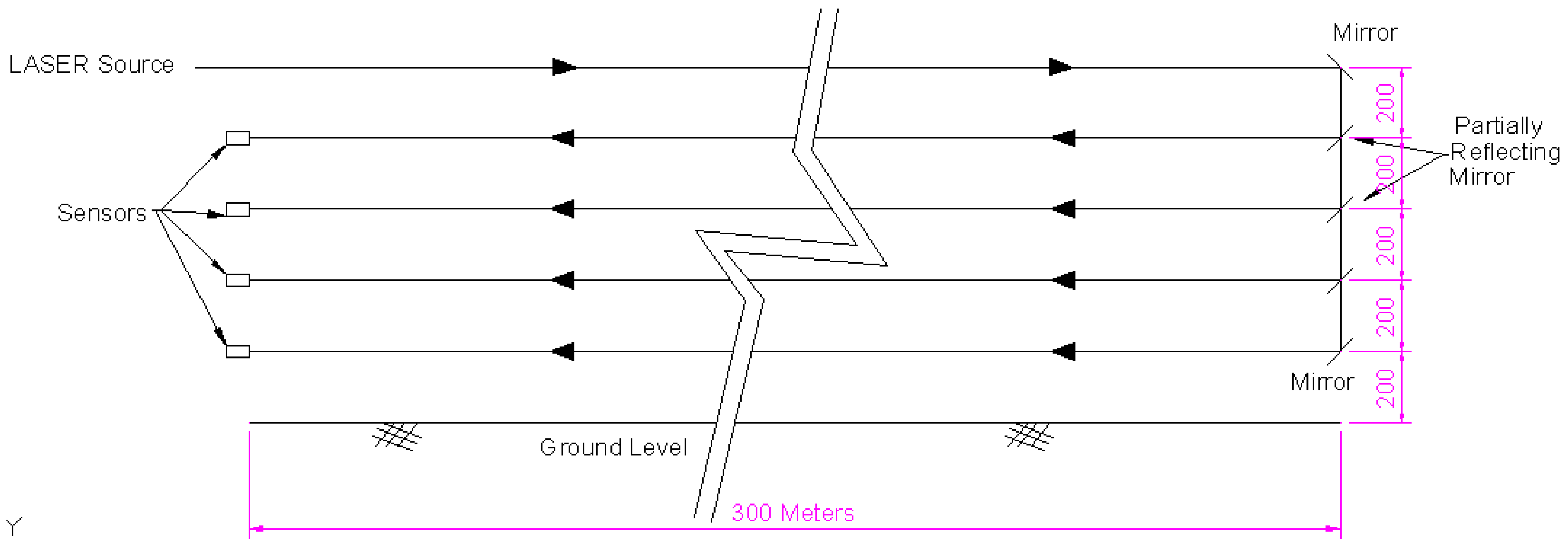
Application of the SiPM for Security Applications

Intrusion Detection in Sensitive Areas using LASER Wall



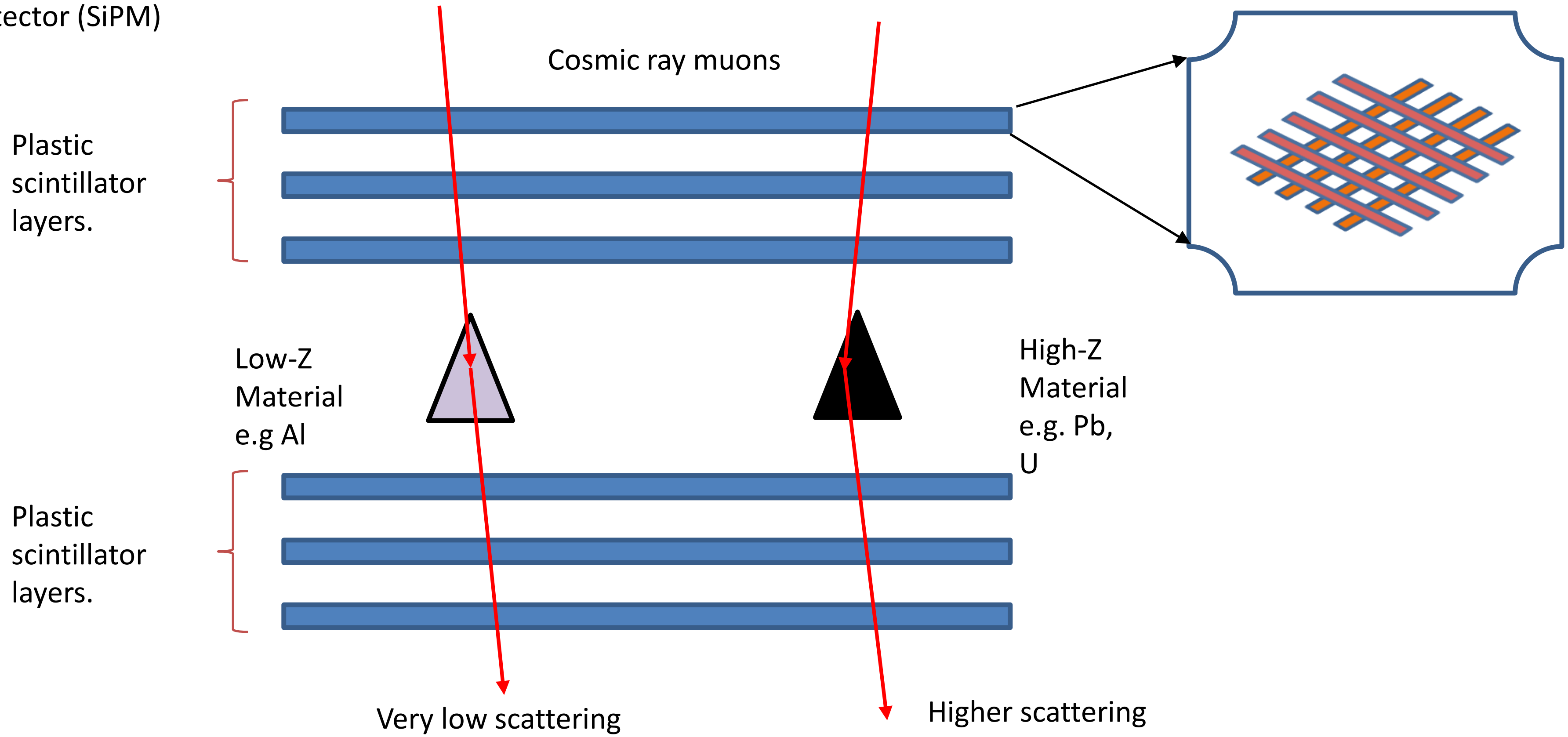
- It is of immense use to our national security
- Few System are deployed, very costly
- Using in-house expertise on optics, photo detector etc., we have successfully developed a 1st stage of prototype with a range of 50 meter
- Plan to develop 2nd stage of prototype with a range of 300-500 meter
- After carrying out all feasibility tests, we will make final stage of 1km range
- Algorithms to be developed for robust and stable performance

Proposed structure for laser wall

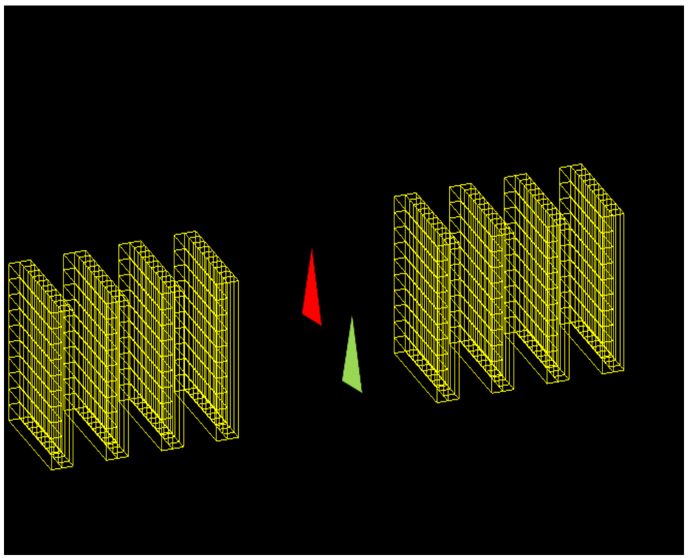


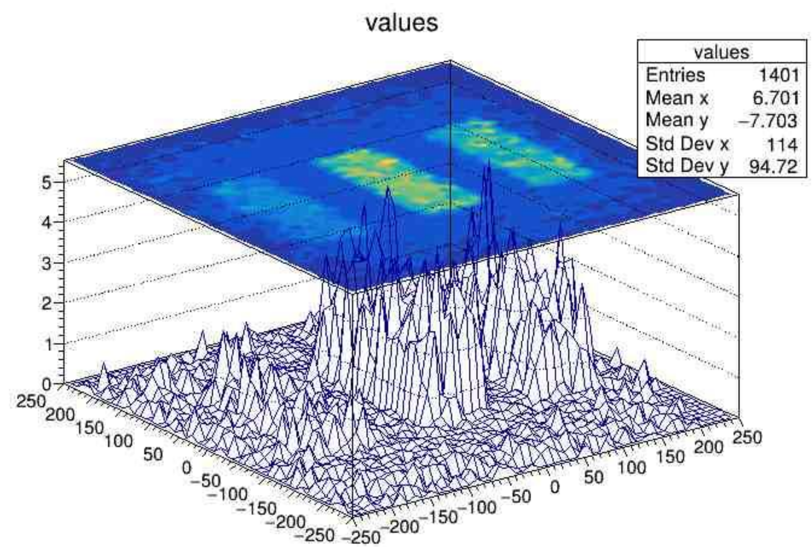
Muon Tomography

Each scintillator layer is composed of array of closely spaced orthogonal scintillator strips individually coupled to an photo-detector (SiPM)

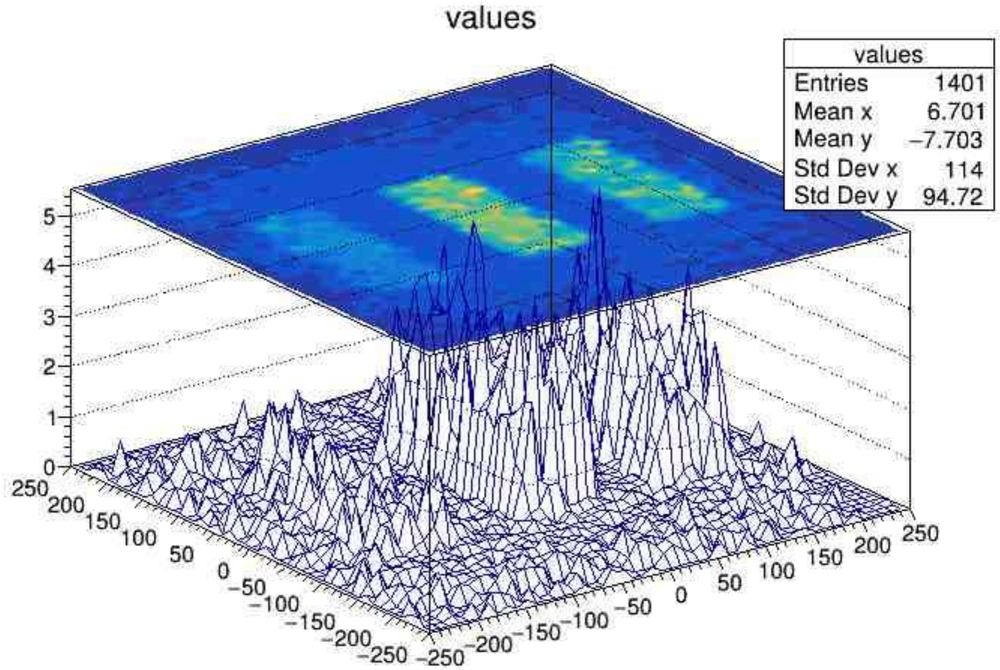


Simulations





Simulation Results: Comparison of Al, Pb, U



Summary

SiPM Development:

- All round development on the SiPM front, design to application.
- First prototype of the device will be available soon.
- Various applications of the SiPM have been demonstrated with in-house developed instrumentation
- The special characterization facility developed for SiPM (MROS) is extended to scan HPDs decommissioned from CMS experiment.

HPD Scans:

- The scan results clearly indicate damage to the photo-cathode surface of the HPDs scanned.
- HE HPD shows significant damage compared to HE HPD.
- The amount of damage is proportional to the radiation received by the detector which is dependent on scintillator size and position in the detector.

Damage α Scint. Size , eta

- *Results presented at LHCC Review Meeting*

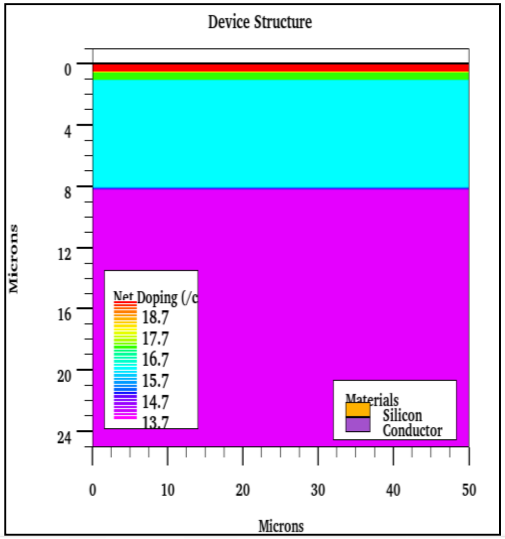
BACKUP

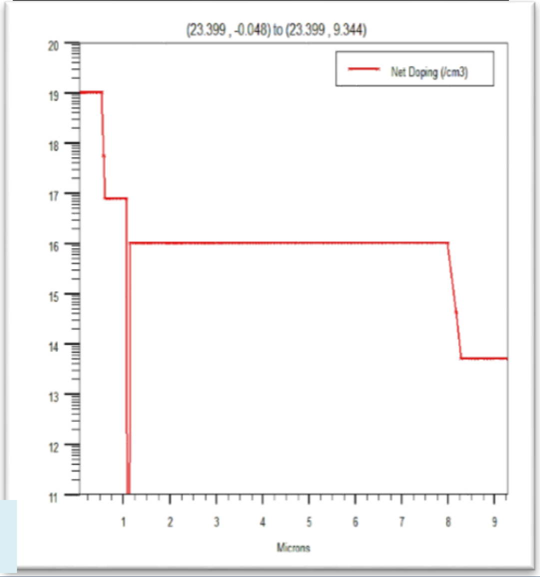
Overview

- Development of SiPM
  - Simulations (recap)
  - Fabrication (latest developments)
- Development of Associated Electronics
- SiPM Characterization
- SiPM Applications
- Extension of MROS to HPD scanning: Results and Implications

Device Level Simulations

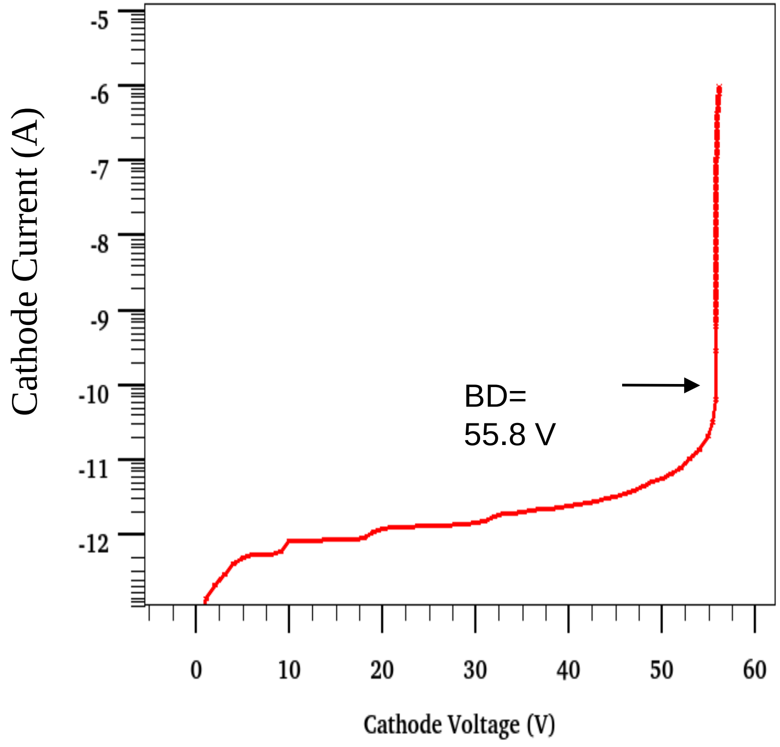
- With confidence from abrupt junction studies, more practical, a multilayer device level structure was simulated
- Structure has been optimized for moderate breakdown voltage of ~56V, considering junction capacitance.
- The junction depth has been kept ~ 1.5 – 2.5 µm for optimum absorption of light (λ ~ 500nm) near junction region.
- Device characterization done with electric as well as opto-electronic simulations.
    - I-V and C-V Characteristics
    - Spectral Response
    - Transient Response

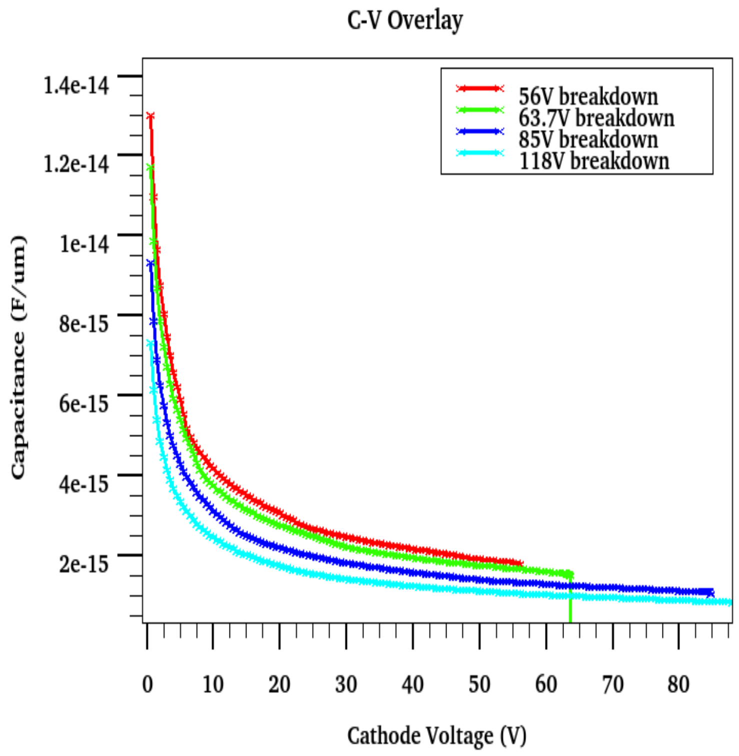




Doping Profile

Device Level Structure: I-V and C-V characteristics

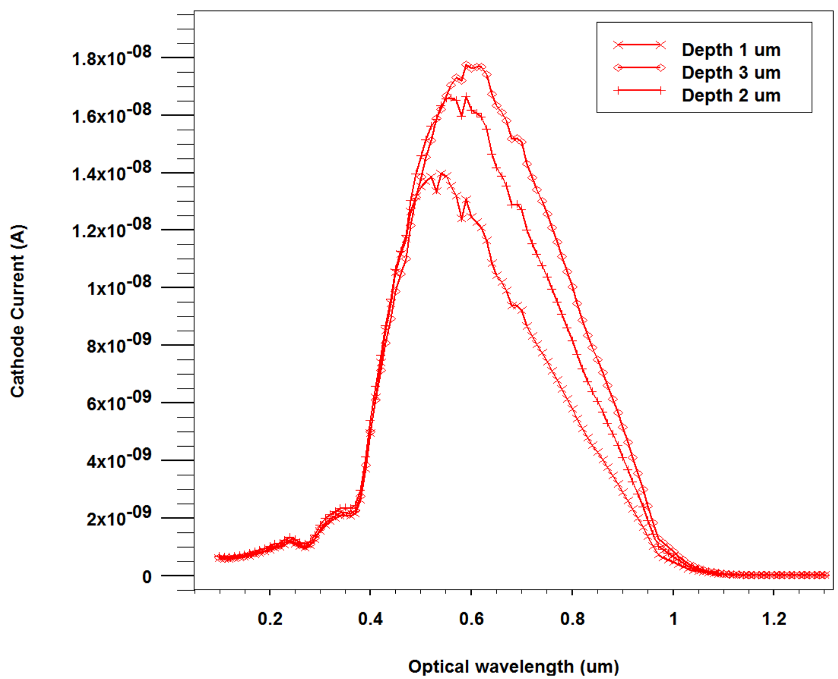




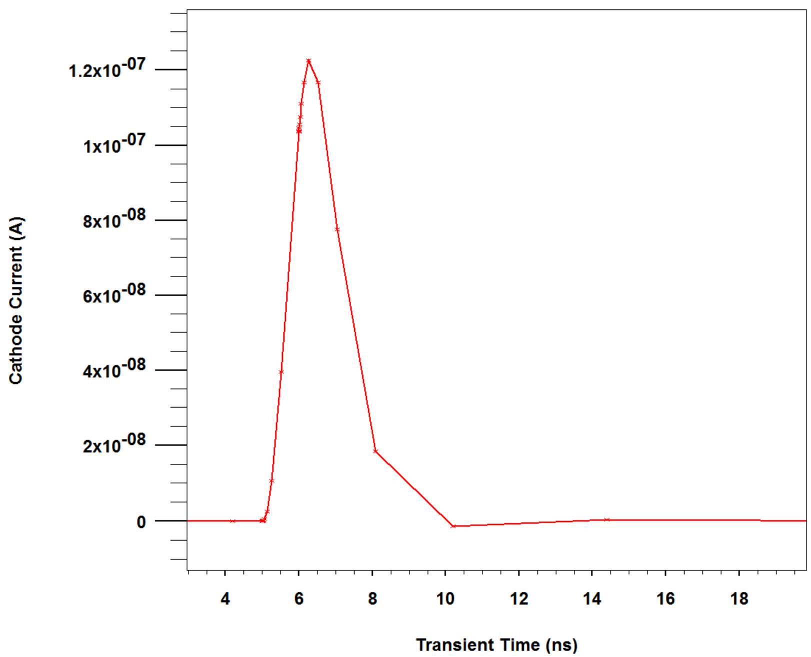
I- V characteristics

C - V characteristics

Device Level Structure: Optical Simulations



(a)

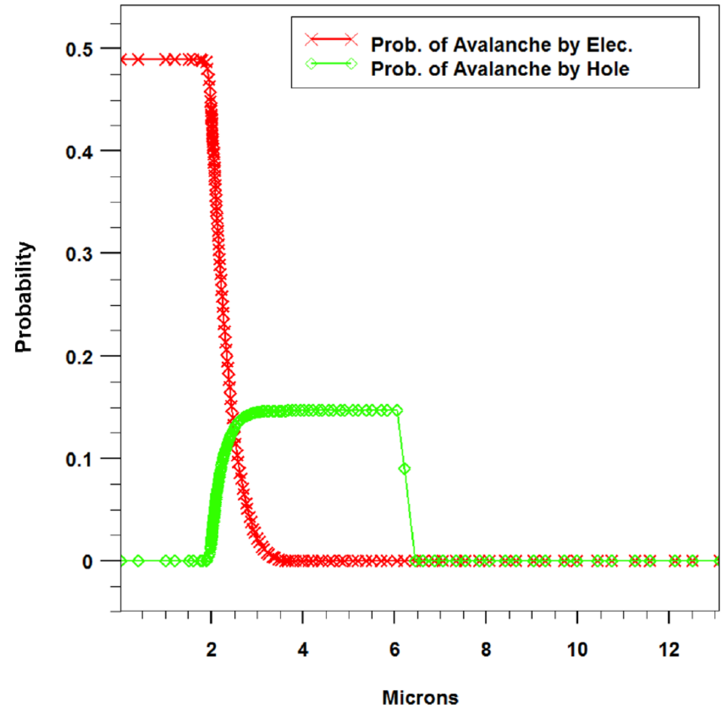


(b)

Spectral response

Transient response

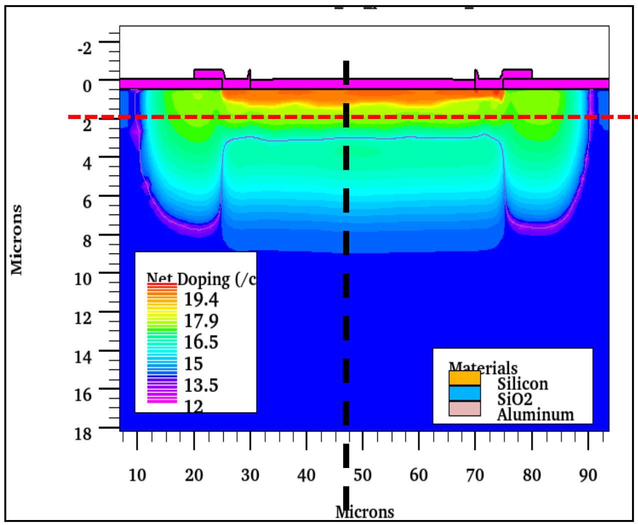
Breakdown Initiation Probability

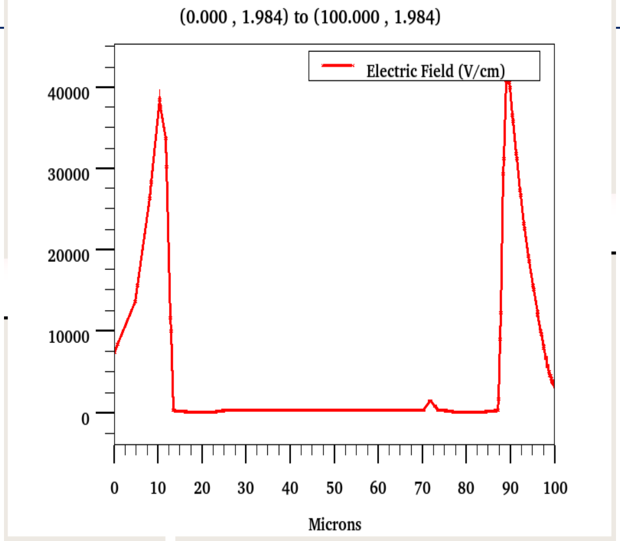


- Not every carrier absorbed generates a breakdown or generated avalanche is terminated before it causes breakdown
- The breakdown initiation probability depends upon the applied over-voltage, as the over voltage increases the probability increases
- Breakdown initiation probabilities of the device at device level has been simulated

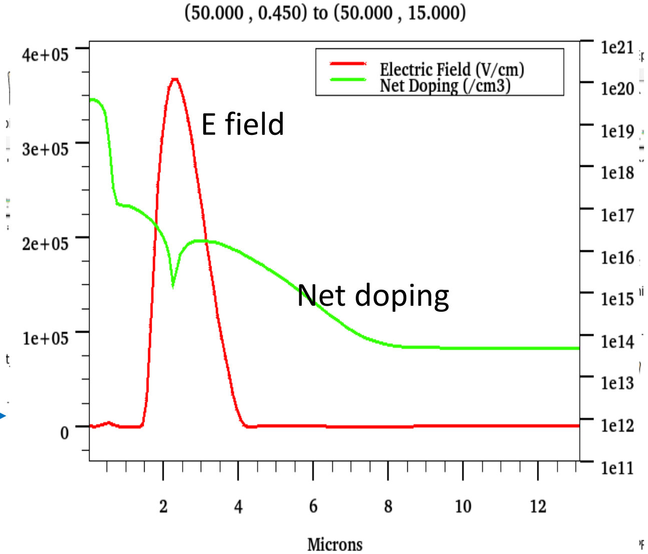
Process Simulations: Structure Doping and Electric Field Profile

Electric field with horizontal cut is shown with red dotted line (Guard rings reduce the electric field)





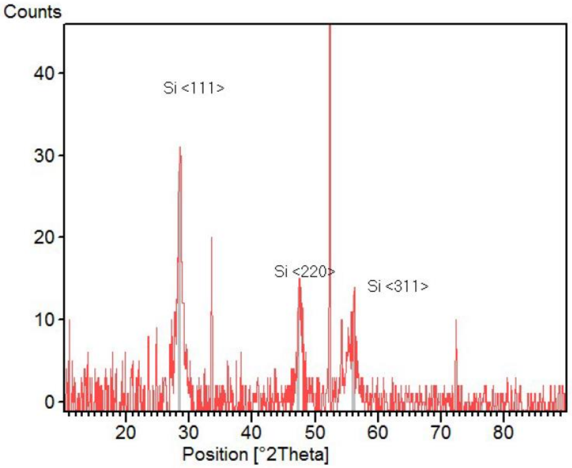
Electric field and net doping in vertical direction



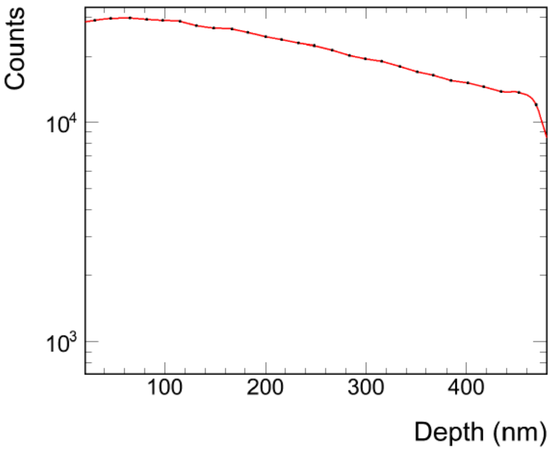
Development of Poly-silicon film

- In-situ boron doped poly-si film is deposited using Hot Wire CVD, available at IIT Bombay, Mumbai
- Film has been optimized with various deposition parameters such substrate temperature, boron doping for desired resistivity
- Resistivity measurement done with four probe measurement (~ 0.1 ohm-cm)
- Developed films are characterized by X-ray diffraction to check crystalinity
- Doping profile along the thickness is measured using SIMS (Secondary Ion Mass Spectroscopy)

Hot-Wire CVD



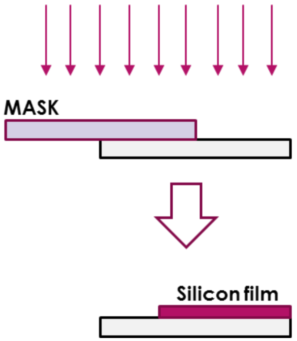
XRD Results



SIMS Results

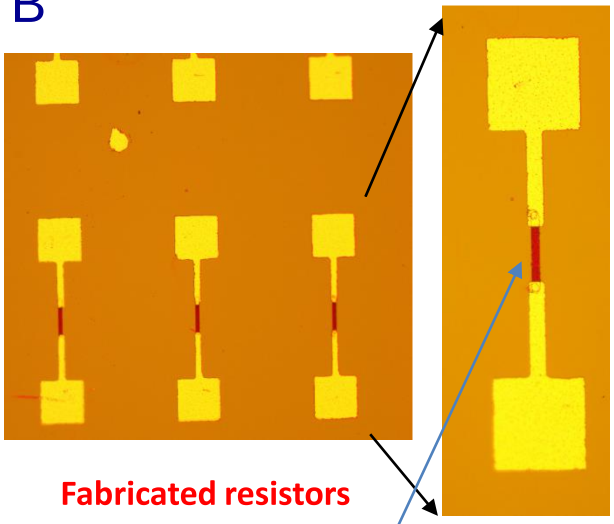
Patterning of the poly-si

- Resistors are patterned with optical (UV) lithography
- Plasma assisted reactive ion etching used
- PECVD used for deposition of SiO_2 layer for passivation.
- Total process involves three masks and thus accurate alignment between subsequent lithography steps
- Masks designed at TIFR and fabricated at IITB



Mask aligner

ICP- RIE Plasma Etcher

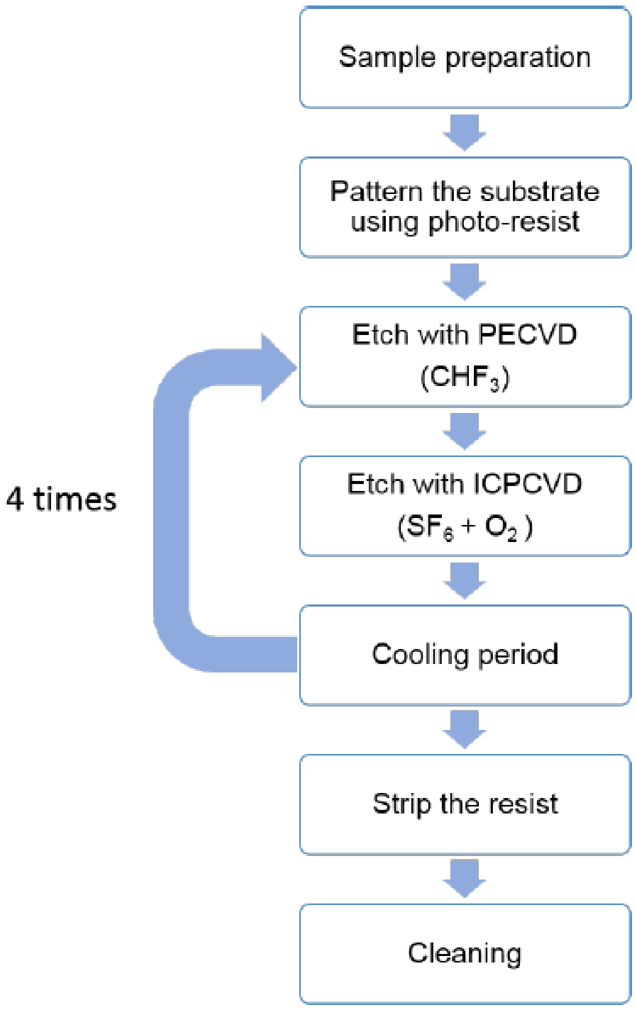


Fabricated resistors

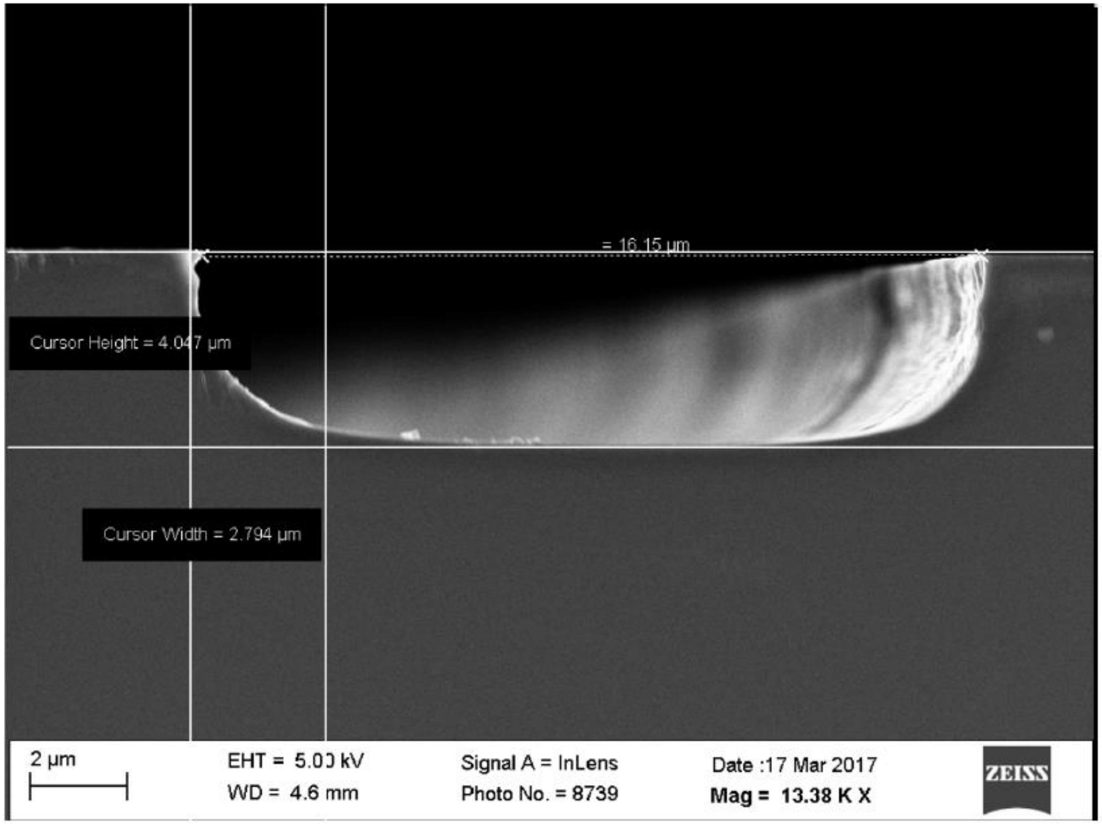
50 μm x 10 μm

Fabrication Process

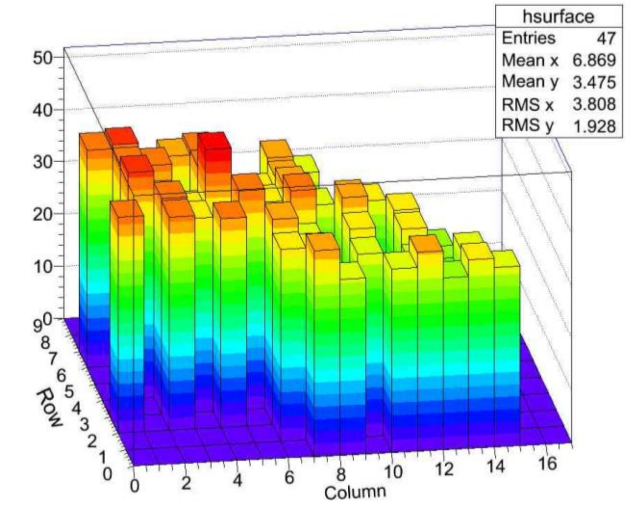
- Dry etching of Silicon with Sentech ICPRIE
- Bosch like process:
  - Process with CHF3 for small etch and polymerization on side walls
  - Process with SF6 + O2 for deep etching
- Currently deep trenches up to 4 μm with fairly vertical side walls have been obtained.

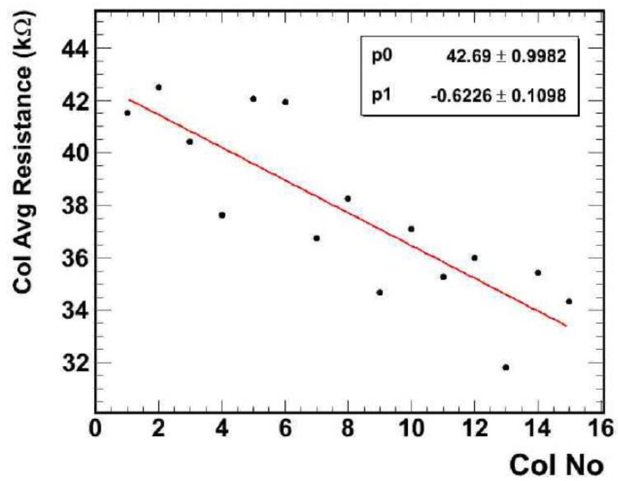


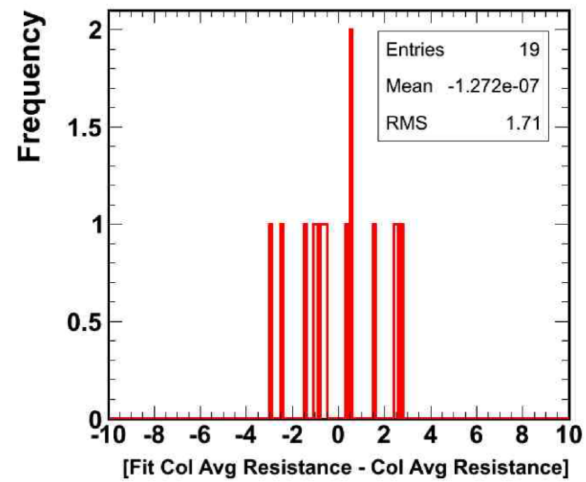
Trench fabrication: Results



Investigation: Variation of resistor along the surface







Average resistance of each column as function of col number : Clear trend is visible

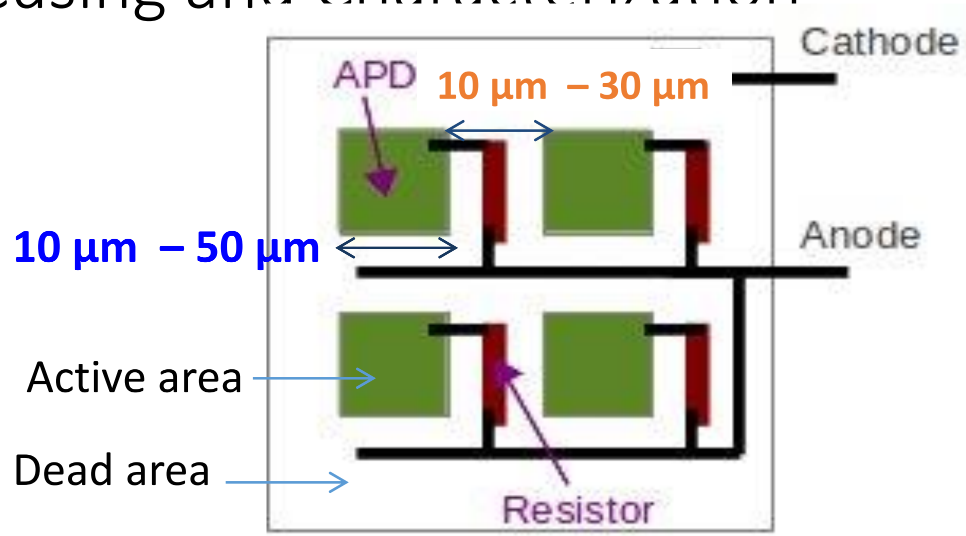
Observations:

1) The resistance variation in a particular column (vertical direction) is within expected tolerance (~5%)

2) The resistance varies systematically over the horizontal direction (same row, different cols)

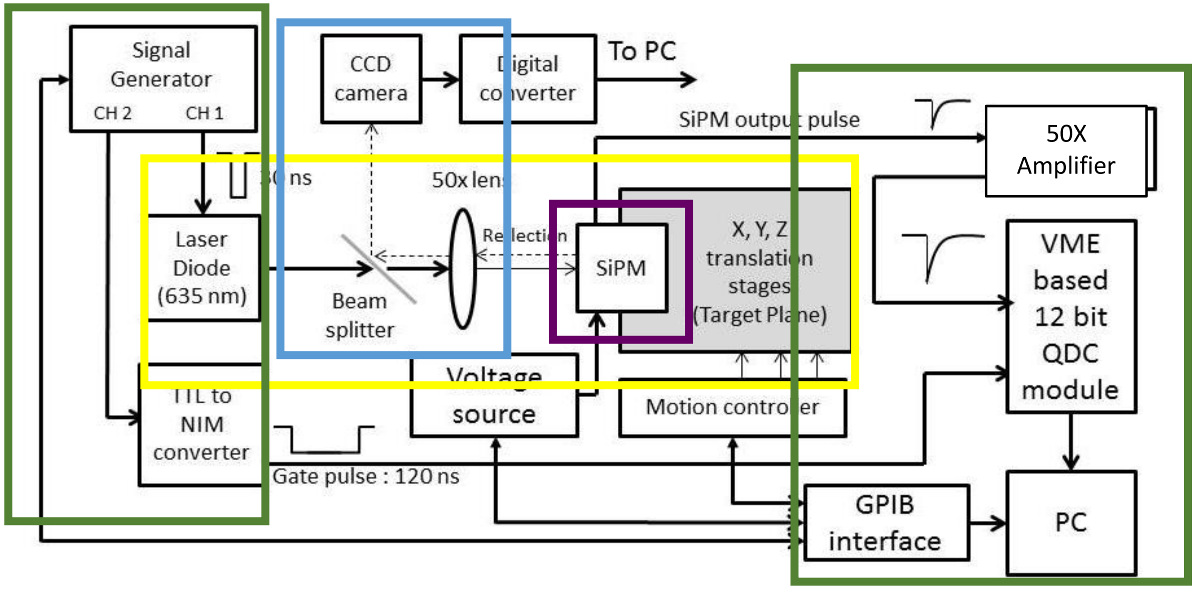
1) The variation could be attributed to non-uniformity in Silicon film thickness

Beam Focusing and Characterization



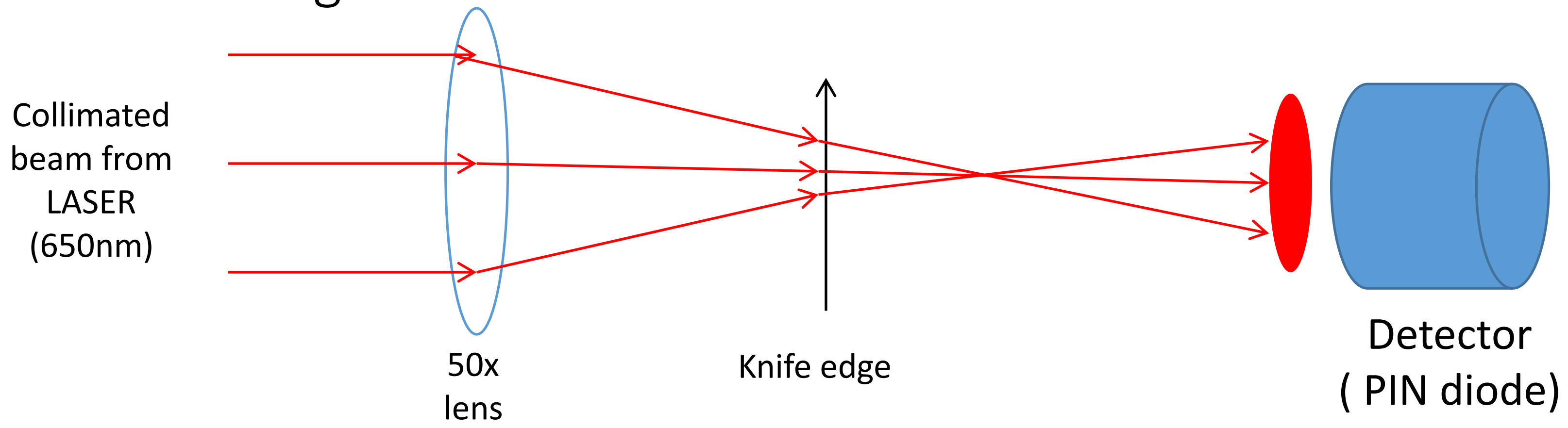
- LASER beam should be much smaller than 10µm
- 20x and 50x objectives have been tried
- Beam profile was obtained by classic Knife-edge method
- Obtaining the sharply focused light beam is the heart of this experiment

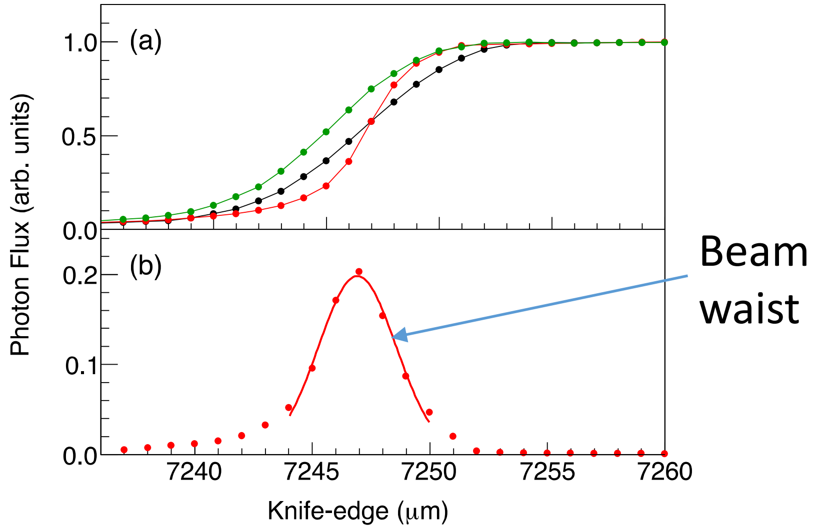
Experimental Setup

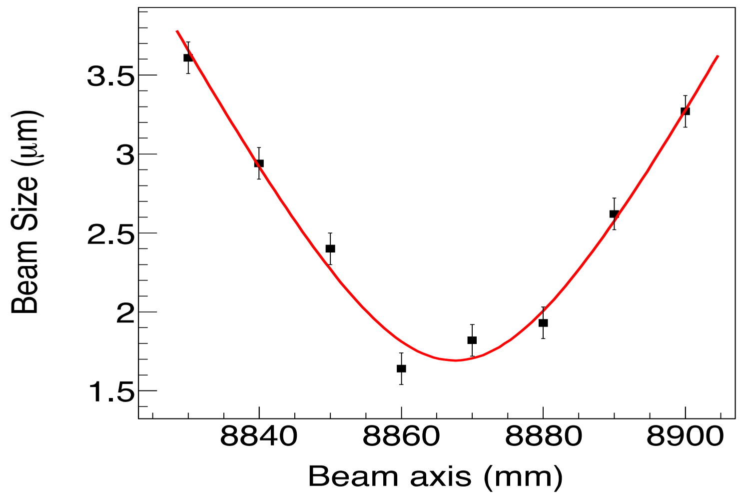


- Major components:
  - Device Under Test, SiPM
  - LASER beam focusing &
  - Sample scanning mechanis
  - Imaging (Online Microscope)
  - Data Acquisition System

Characterization of the LASER beam: Knife Edge Method

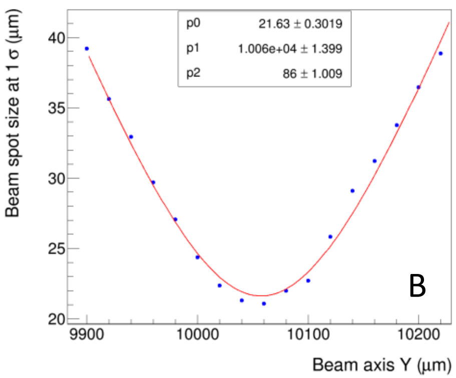


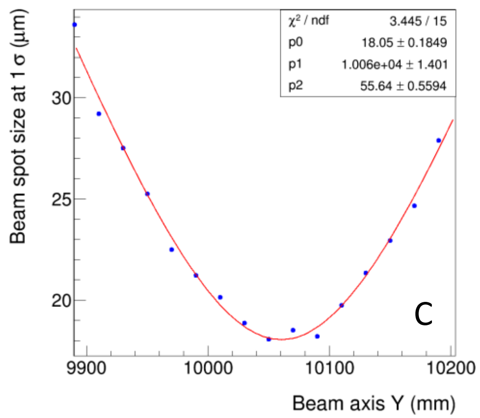


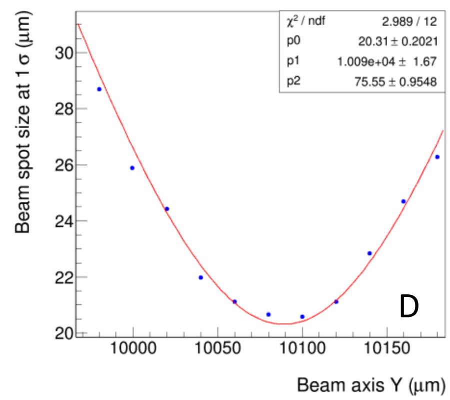


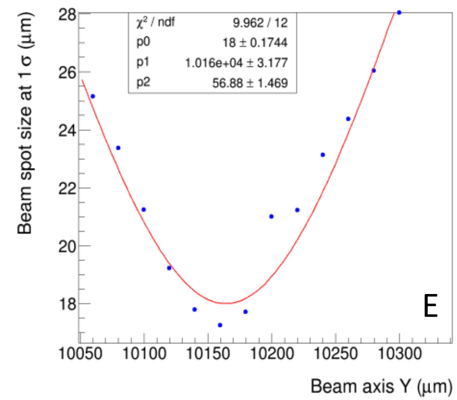
With 50x lens beam spot size obtained is 1.7 μm at 1σ level

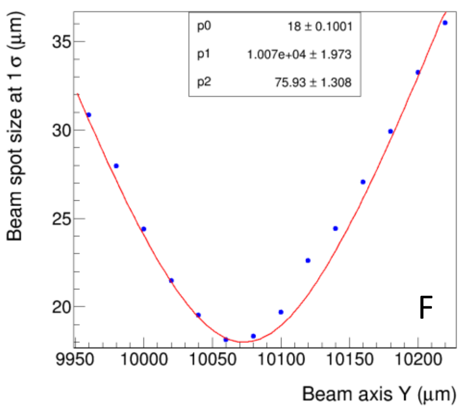
HO-HPD Focal Scan Results at different positions (λ=650 nm)

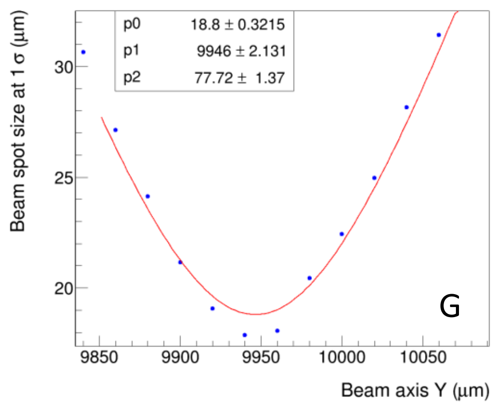


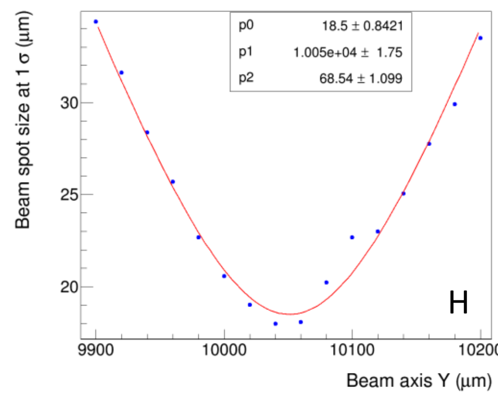






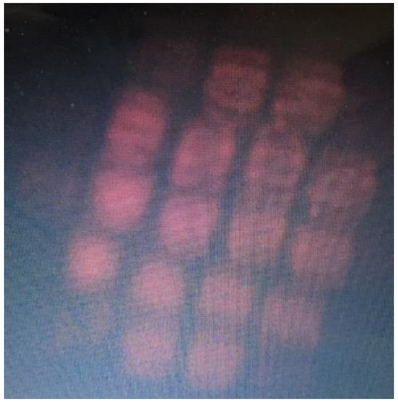


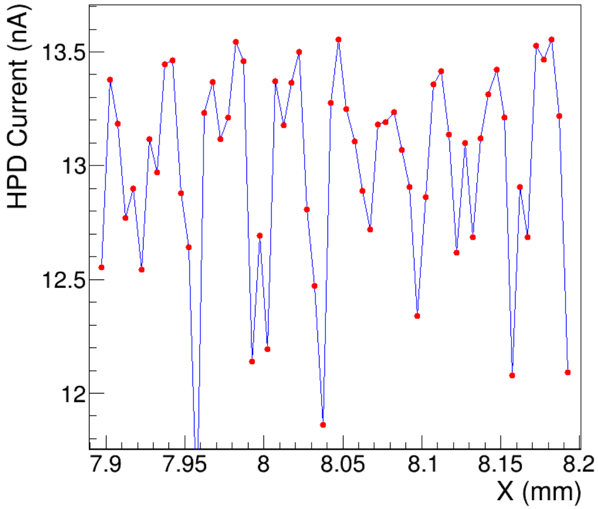




CCD Imaging of photo-cathode

- CCD imaging was done before starting the scan to determine rough focal plane position.
- The photo-cathode has a square pattern, which may be giving rise to oscillations in active area at focal plane.
- Since at focal plane the beam spot size becomes smaller than feature size of the pattern, effect is prominant
- We will do proper imaging under microscope once all scans are over

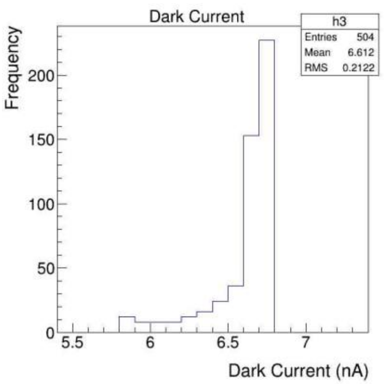




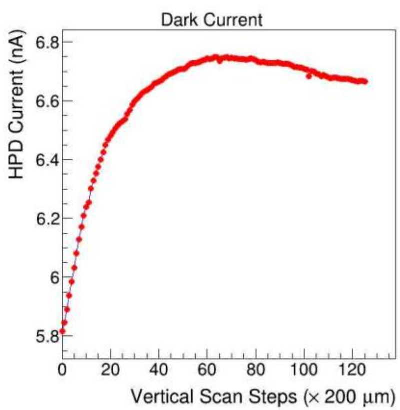
One of the short fine scan with 5 μm step size indicates sensitivity to this pattern

HO-HPD Dark Current and Net Signal Current
Run No. 27, λ=650 nm, Step Size: 200 μm

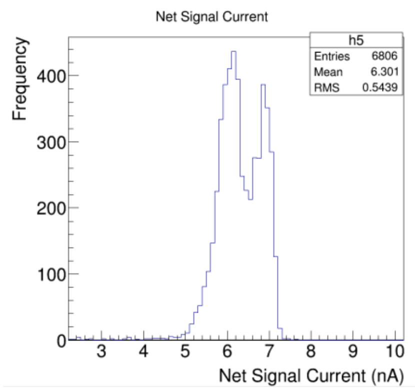
- The HPD is scanned in raster fashion row by row
- The HPD dark current is recorded every row (4 readings of 8 accumulations each) before starting row scan
- By subtracting dark current recorded for each row from signal current recorded at various position in that row, net signal current is obtained



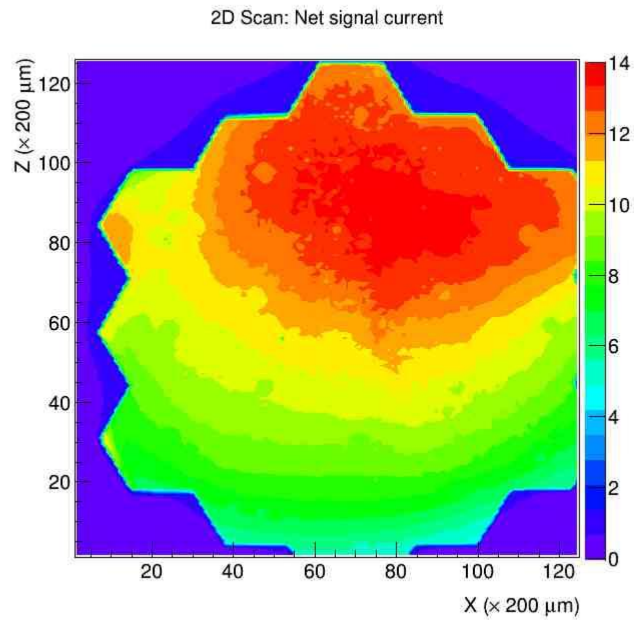
Distribution of dark current



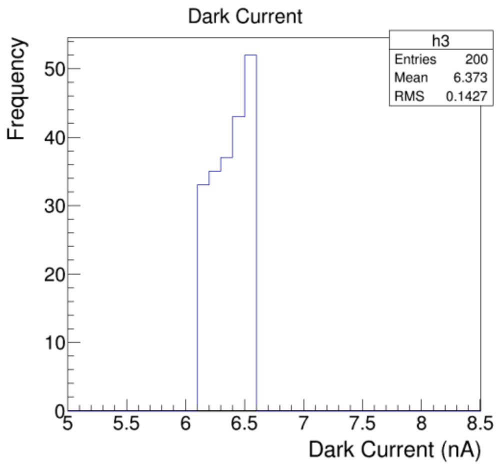
Variation of dark current as a function of row number



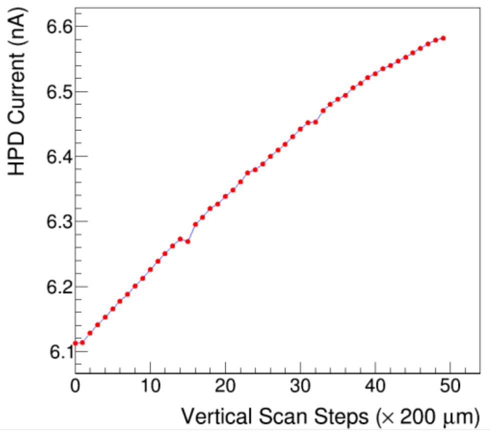
Distribution of net signal current



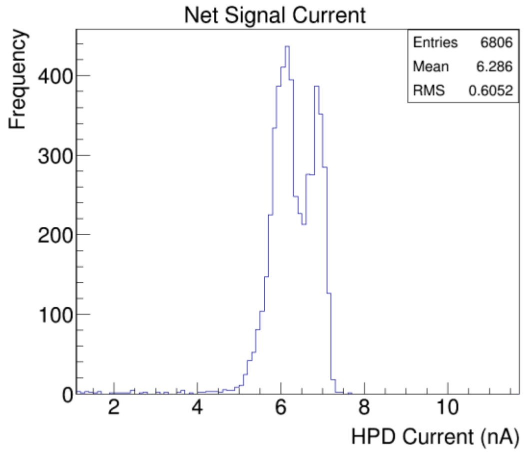
2D scan more plots



Distribution of dark current

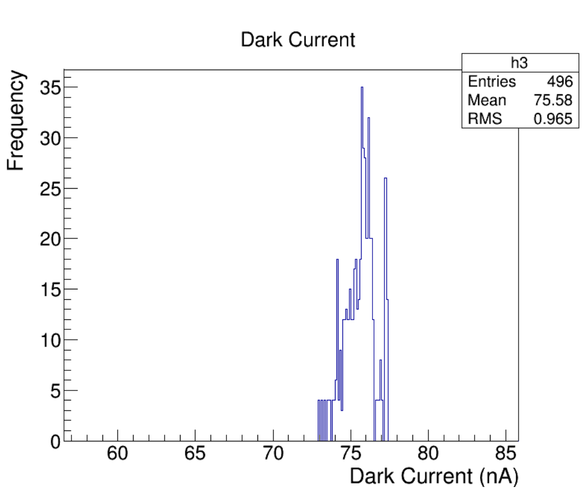


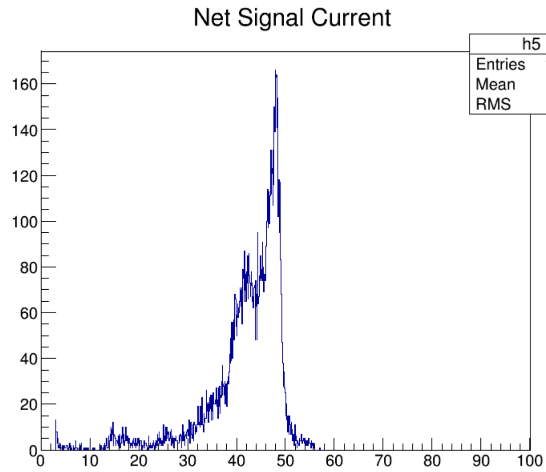
Variation of dark current as a function of row number

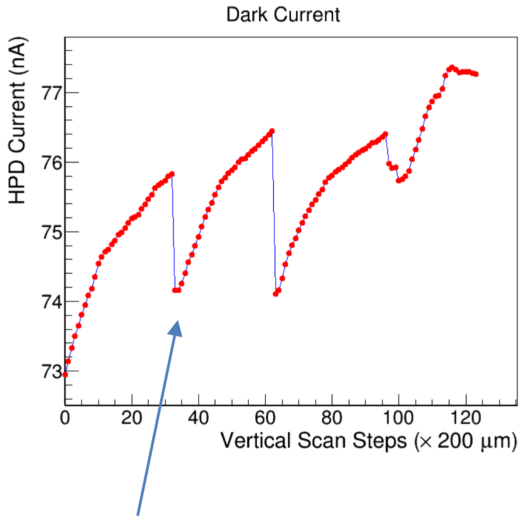


Distribution of net signal (pedestal subtracted) current shows good uniformity (~10% over entire area)

Run 72: Contd ..

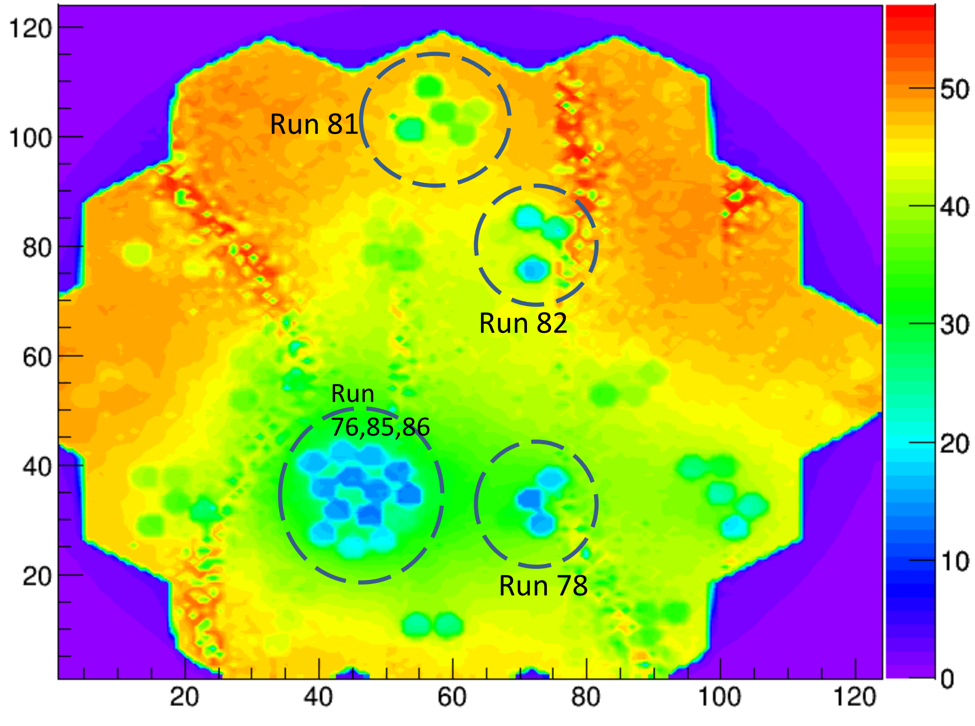






Pattern due to temperature variation: Matches with AC pattern (compensated by subtracting dark current at each row separately)

Regional finer scans near damaged areas



Simulation snapshot