# Microscopic Characterization of Hybrid Photo Diode

Departmental Project – 1

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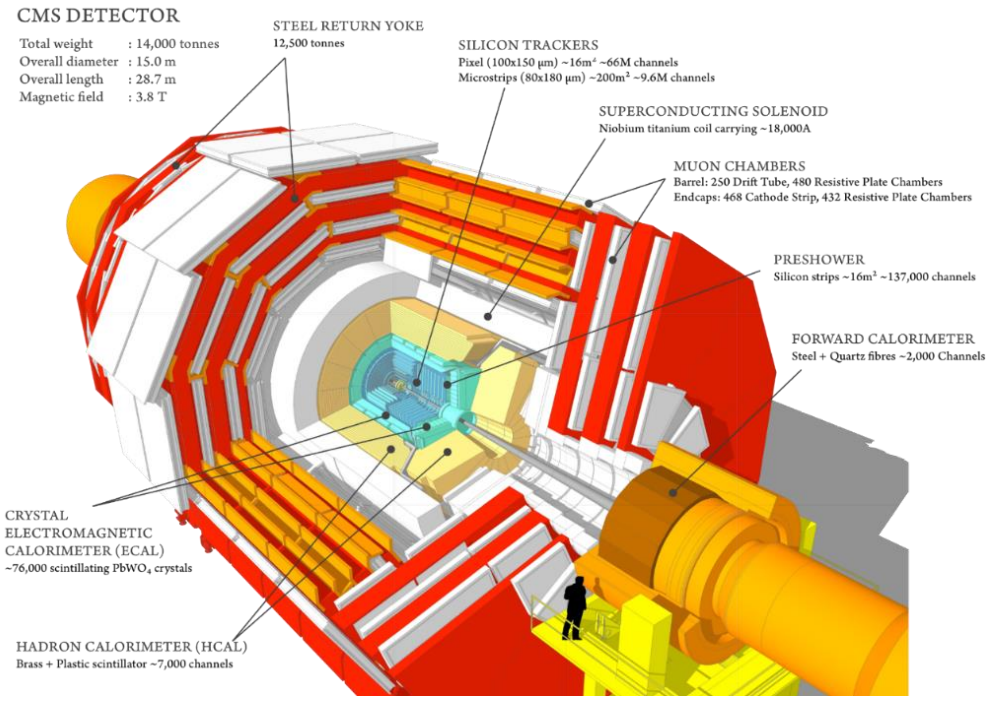
# CMS Detector

- The CMS detector is designed to study pp collisions at the LHC.
- Hadron Barrel calorimeter and Hadron End-Cap calorimeter are made up of alternating layers of absorber and scintillator.
- Collected scintillation light is transported to photodetectors (HPD in the past, now SIPM)
- Signal loss in HE data was observed over years.
- Decoupling of signal loss due to degradation of HPD and scintillator




http://cms.web.cern.ch/news/cms-detector-design

# Signal Collection In HE

Scintillator → WLS → Clear Fibers → … → Optical Decoding Unit → Hybrid photodiode (HPD)

- Segmentation into $\eta - \phi$ towers, where $\eta$ is pseudorapidity,

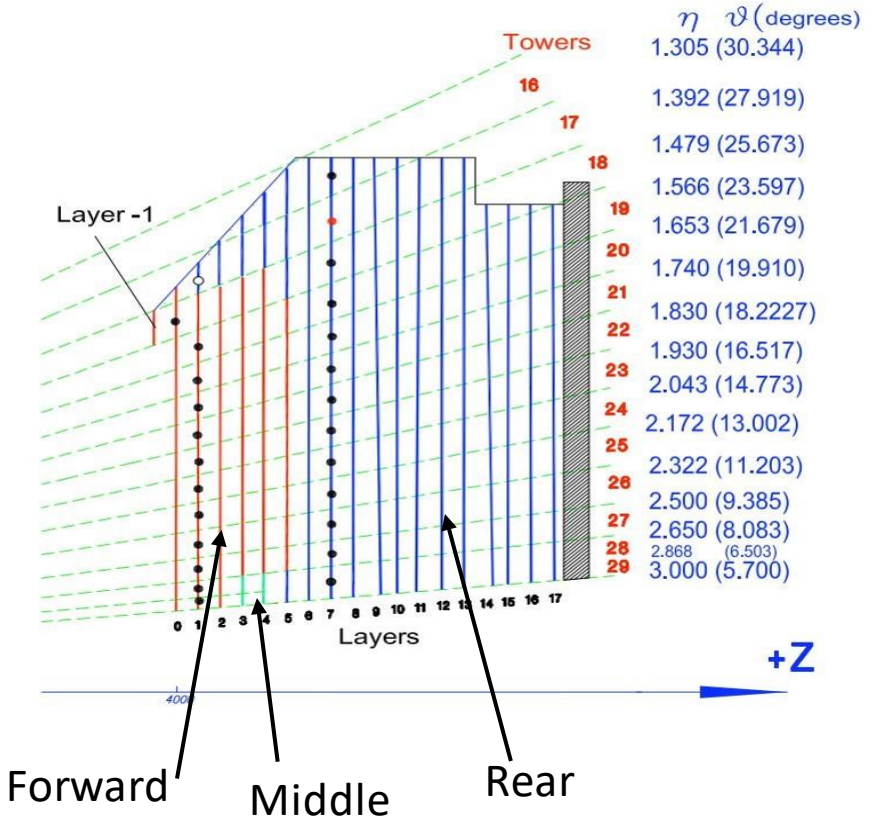
$$\eta = -\ln(\tan\frac{\theta}{2})$$

- HE is segmented into $\eta - \phi$ towers of granularity

$\Delta\eta \times \Delta\phi = 0.087 \times 0.087$ for $|\eta| < 1.6$, and

$\Delta\eta \times \Delta\phi = 0.170 \times 0.170$ for $|\eta| \geq 1.6$

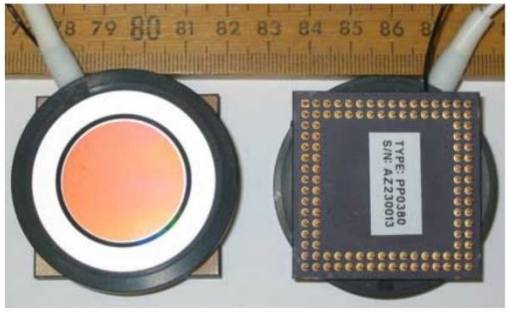
- Optical Decoding Unit(ODU): HE tower mapping on HPD



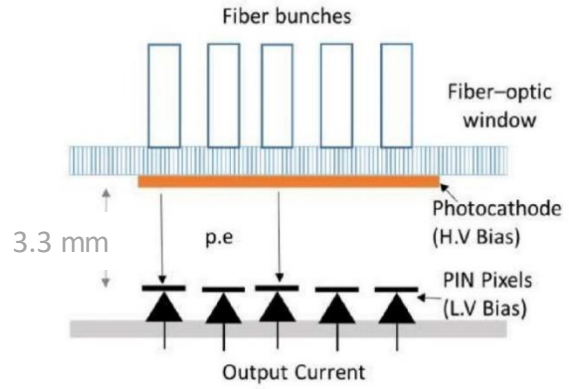

arXiv:1806.09887 [physics.ins-det]

# Hybrid Photo Diode (HPD)

- Design of HPD:
  - Hexagonal shaped active region
  - Fiber Optic Window
  - Common photocathode
  - 3.3 mm vacuum gap, reverse bias: $V_{gap}$ = – 6 kV to –10 kV
  - 19 PIN diodes underneath photocathode of size = 5.4 mm and hexagonal in shape, referred as pixels.
    Reverse bias = – 80 V
- 19 output channels



Nucl.Instrum.Meth. A587 (2008) 250-258 CERN-CMS-NOTE-2008-011

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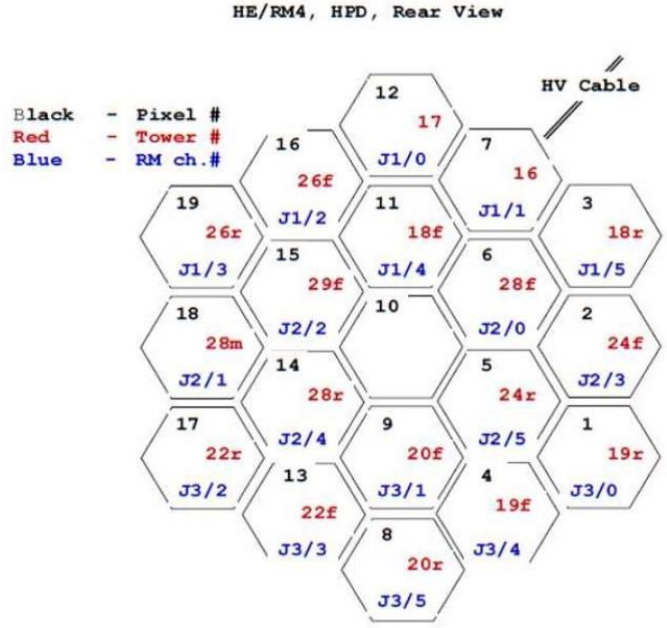
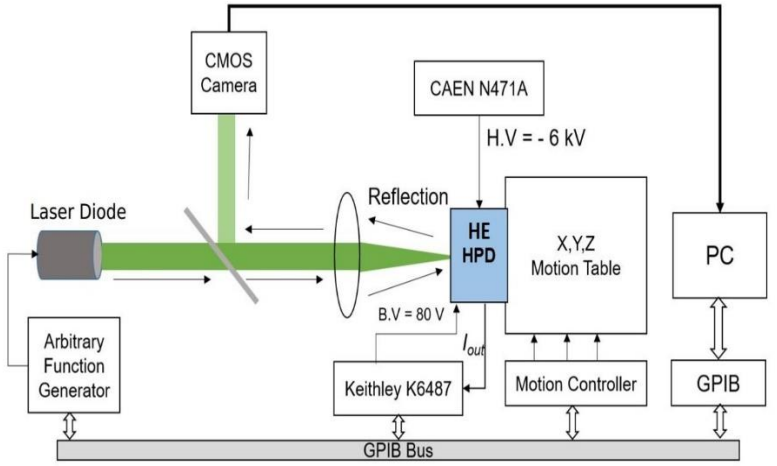


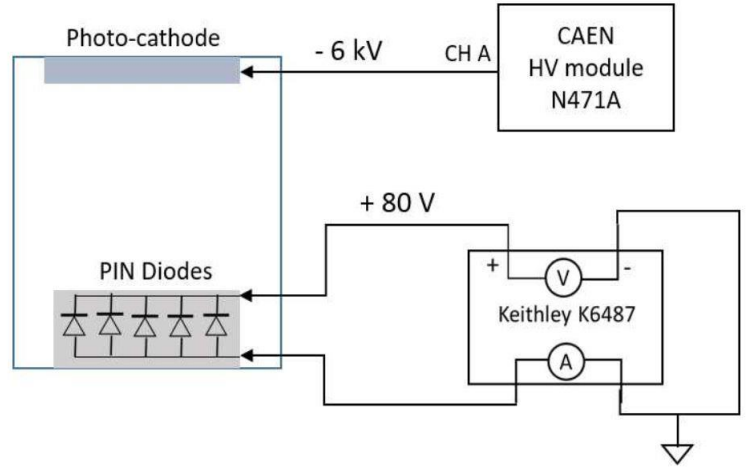

arXiv:1806.09887 [physics.ins-det]

# Experimental Setup (MROS)

- Green laser: Operated in CW mode at low intensity.
- Motion Controller: Capable of moving the HPD with a resolution of 0.1 $\mu m$.
- CMOS Camera: Preliminary survey of HPD surface. Helps in roughly finding the focal plane of laser beam.
- Keithley Power Supply: Reverse biasing of PIN diodes (-80 V)
- CAEN HV Module N471A: Reverse biasing of photocathode (-6000 V)
- HPD decommissioned from HE.
- Automation of setup through GPIB interface under LABVIEW based framework.
- Collective current of all the 19 pixels was read instead of individual pixel current.

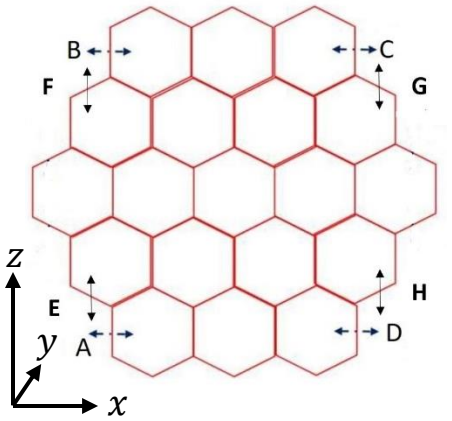



arXiv:1806.09887 [physics.ins-det]



# Focal Plane Determination

- Preliminary survey of HPD surface using CMOS camera revealed mounting imperfections.
- Dynamical adjustment of focal axis coordinate during surface scans
- Alignment of focal plane of laser with HPD surface. Modified knife edge method.
  - Start with expected position of focal plane.
  - For each value of y, HPD is moved in the path of beam (50 steps along x with step size = 5 $\mu m$).
  - Boundary between dead and active region of HPD acts as edge.
  - $\frac{dI}{dx}$ vs x is plotted and RMS of Gaussian distribution gives beam spot size.
  - 12 steps along y with step size = 20 $\mu m$.

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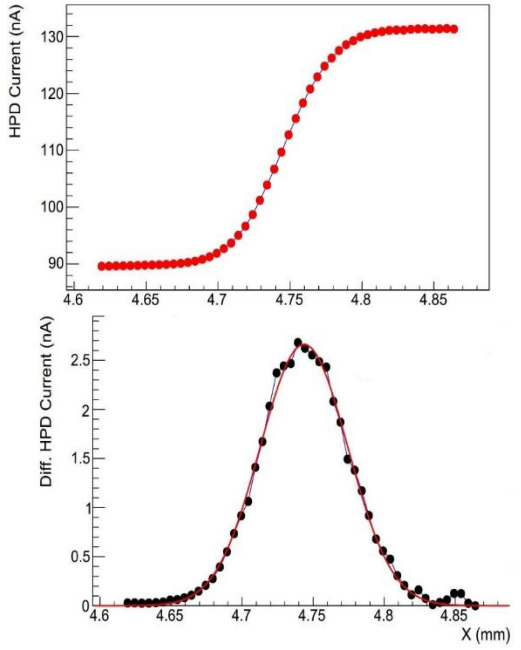
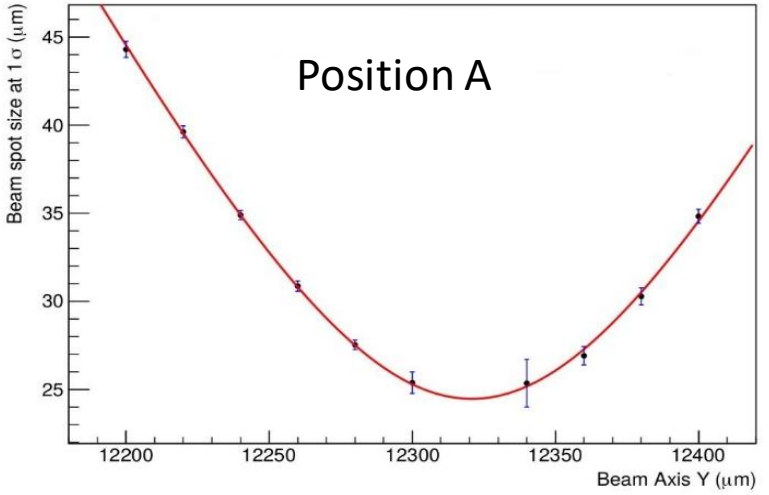
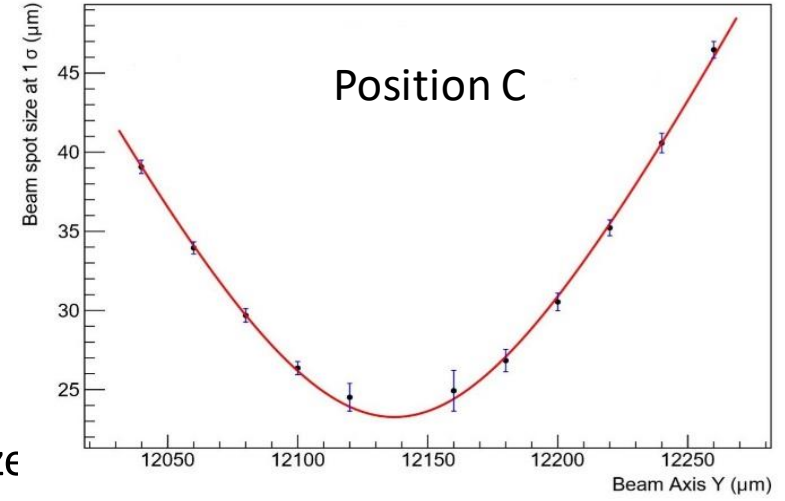


# Focal Plane Determination

- The data generated is fitted to functional form

$$\sigma(y - y_o) = \sigma_o \times \sqrt{1 + \left(\frac{M^2\lambda(y - y_o)}{4\pi\sigma_o^2}\right)^2}$$




where,

$\lambda$ is the wavelength of the laser beam (520 nm)

$M^2$ is beam quality factor

$\sigma_o$ is the minimum beam spot size

$\sigma$ is the beam spot size at a distance $y - y_o$ relative to minima

$y_o$ is the position of HPD corresponding to the minimum beam spot size

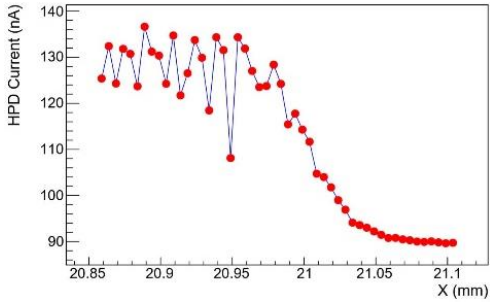
# Focal Plane Determination

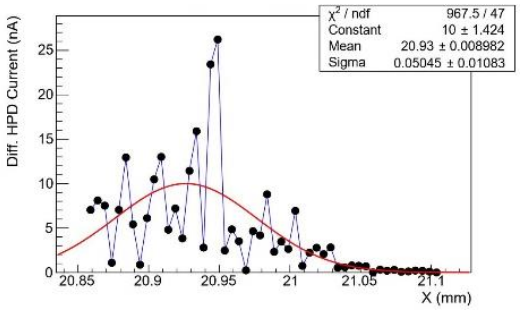
- Position A:
  - Beam Spot size = 24.5 $\mu m \pm 0.3\ \mu m$
  - Focal Plane (y) = 12320.8 $\mu m \pm 0.8\ \mu m$
- Position C:
  - Beam Spot size = 23.3 $\mu m \pm 0.4\ \mu m$
  - Focal Plane (y) = 12137.1 $\mu m \pm 0.7\ \mu m$
- M = 13.5

- Modulation of current near the focal point due to structure of optic fiber window.

| Position | Focal Plane (y, mm) |
|---|---|
| A | 12.32 |
| B | 12.26 |
| C | 12.14 |
| D | 12.22 |
| E | 12.32 |
| F | 12.26 |
| G | 12.14 |
| H | 12.18 |

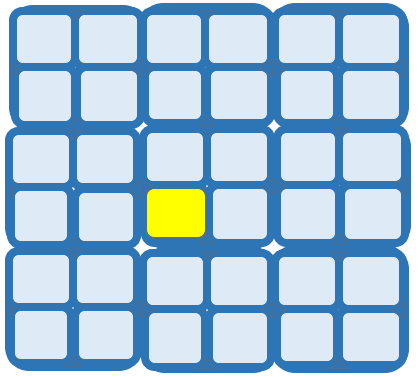
Focal point for other positions, Ref: arXiv:1806.09887 [physics.ins-det]

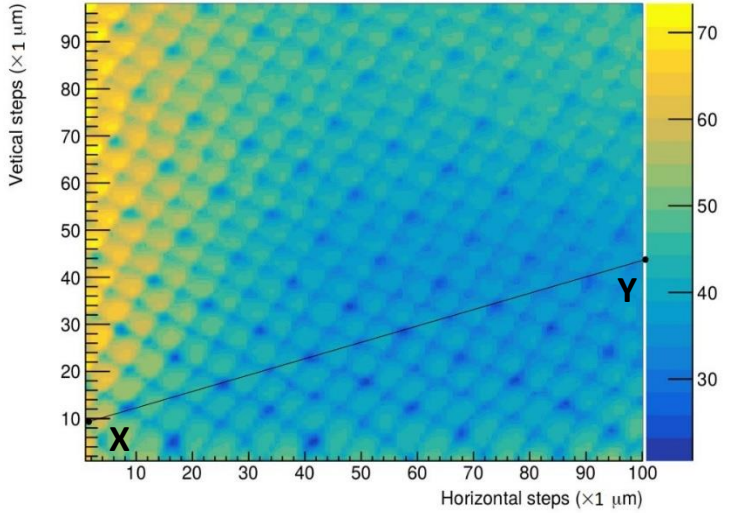


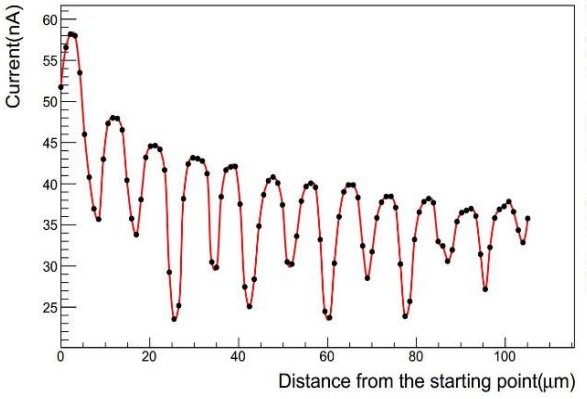



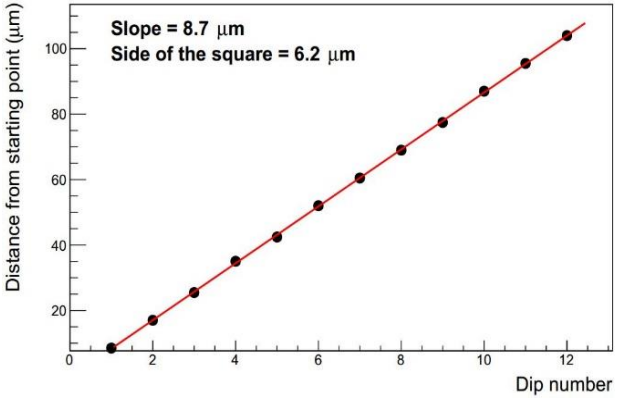
# Ultra-Fine Scan

- Step size = 1 $\mu m$
- Plot of variation of current along the line
- Side of the square unit = 6.2 $\mu m$
- Laser beam spot size < 1.7 $\mu m$ and < 6.2$\mu m$
  - Much smaller than step size in all the surface scans



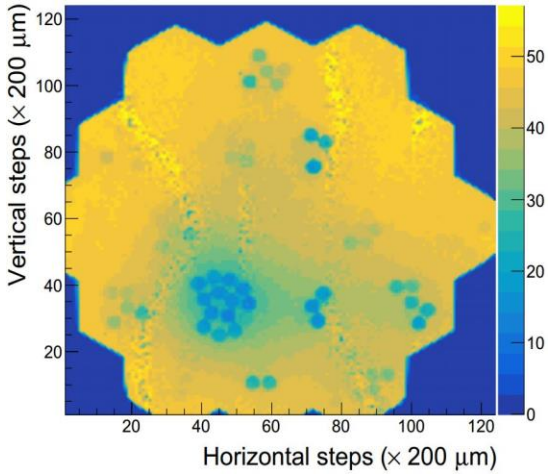


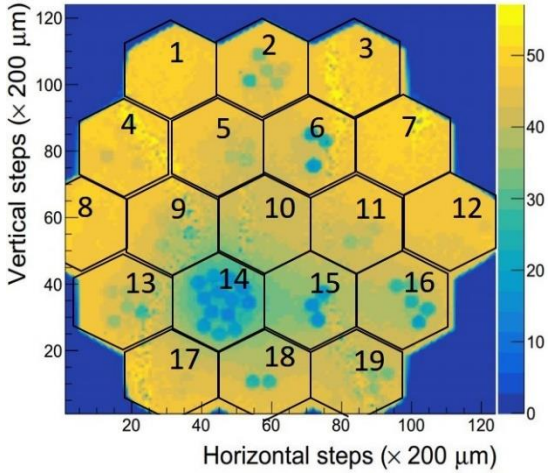



# Surface scans of HPD and Position Dependent Response

- Full Scan:
  - To analyze the surface of HPD
  - Step size = 200 $\mu m$
  - Non Uniform Response
  - Damage in circular regions
  - Pixel 14 – Most Damaged
  - Pixels scanned: 14, 13, 11, 18, 5

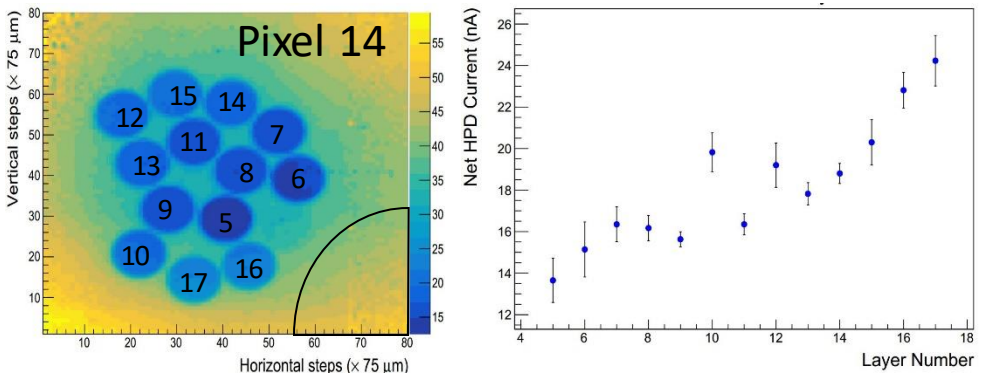



arXiv:1806.09887 [physics.ins-det]



# Localized Scans

- Step size = 75 $\mu m$, much greater than beam spot size
- Percentage signal loss in each pixel
  - Mean current in fiber imprint
  - Mean current in undamaged region of pixel

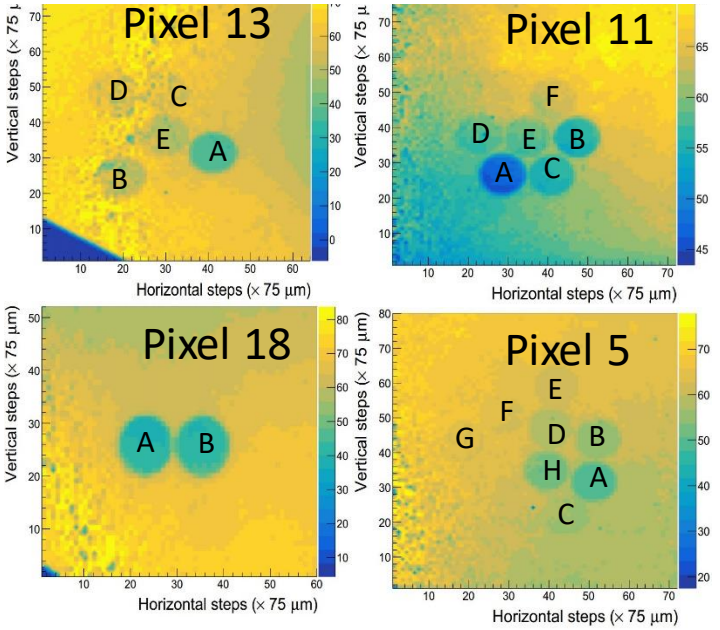



| Layer | Radius ( $\times 75\ \mu m$) | No. of readings | Mean Current (nA) | Std. Dev (nA) |
|---|---|---|---|---|
| (1,1) | 10 | 111 | 50.9 | 4.9 |
| (79,1) | 20 | 355 | 46.6 | 3.7 |
| (1,79) | 20 | 355 | 43.3 | 3.5 |
| (79,79) | 30 | 736 | 44.8 | 4.0 |
| Mean | | | 46.4 | |

| Layer | Mean Current (nA) | Std. Dev. (nA) | % Signal Loss |
|---|---|---|---|
| 5 | 13.7 | 1.1 | 70.6 |
| 6 | 15.1 | 1.3 | 67.4 |
| 7 | 16.4 | 0.8 | 64.8 |
| 8 | 16.2 | 0.6 | 65.1 |
| 9 | 15.6 | 0.4 | 66.3 |
| 10 | 19.8 | 0.9 | 57.3 |
| 11 | 16.4 | 0.5 | 64.8 |
| 12 | 19.2 | 1.1 | 58.6 |
| 13 | 17.8 | 0.5 | 61.6 |
| 14 | 18.8 | 0.5 | 59.5 |
| 15 | 20.3 | 1.1 | 56.2 |
| 16 | 22.8 | 0.9 | 50.8 |
| 17 | 24.2 | 1.2 | 47.8 |
| Mean | | | 60.8 |

# Localized Scans

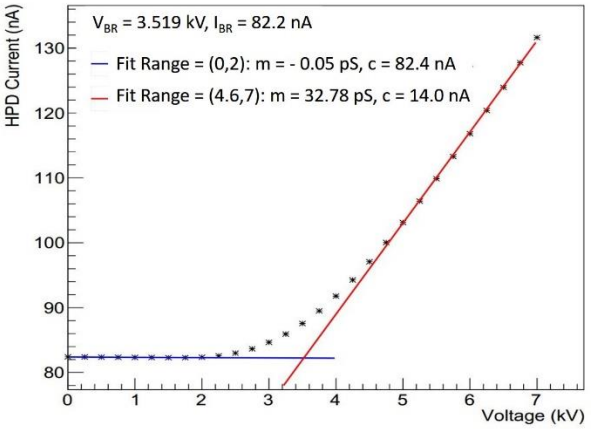
- Damage increases with pseudorapidity.
- Damage in forward region > Middle region
- Damage in Pixel 14 (tower 28r) > Pixel 6 (tower 28f) and Pixel 18 (tower 28m).
  - 13 fibers coming from very high pseudorapidity region
  - Significant spread damage to neighboring regions



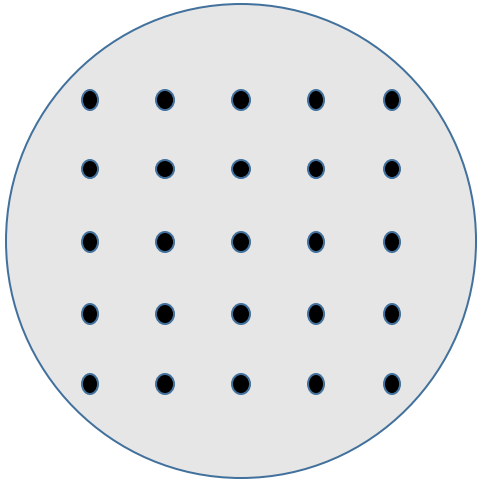

| Pixel | Tower Index | $\eta$ | No. of layers | Signal Loss (%) |
|---|---|---|---|---|
| 11 | 18f | 1.566 | 6 | 11.9 |
| 13 | 22f | 1.930 | 6 | 16.3 |
| 2 | 24f | 2.172 | 6 | 25.0 |
| 5 | 24r | 2.172 | 12 | 10.6 |
| 16 | 26f | 2.500 | 6 | 41.0 |
| 6 | 28f | 2.868 | 3 | 55.0 |
| 18 | 28m | 2.868 | 2 | 38.9 |
| 14 | 28r | 2.868 | 13 | 60.8 |
| 15 | 29f | 3.000 | 3 | 59.0 |

Signal loss in pixel 2, 6, 15, 16 Ref: arXiv:1806.09887 [physics.ins-det]

# Threshold voltage analysis

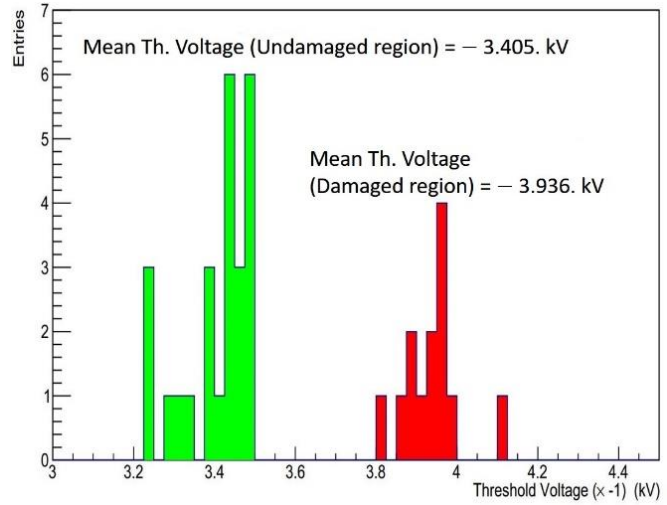


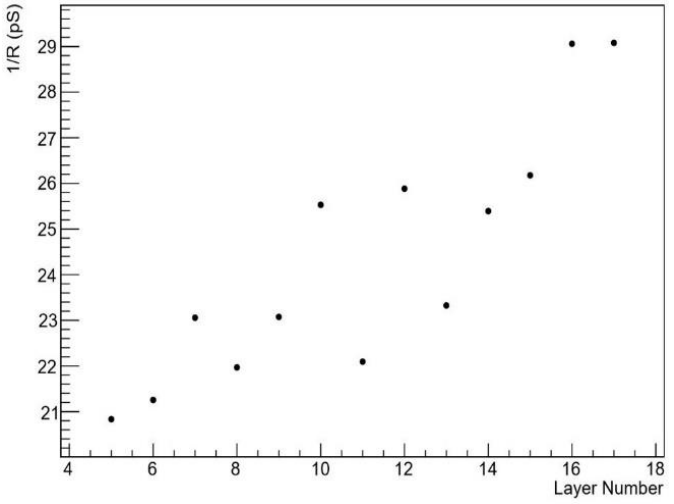

- Minimum $V_{gap}$ such that the PIN diodes produce a significant amount of output current.
- Beyond this $V_{gap}$, HPD current increases linearly with over voltage.
- Expected increase in threshold voltage of the damaged regions.
- Measurement of threshold voltage in different regions
  - Damaged region – Center of 13 fiber imprints of pixel 14
  - Undamaged region – 25 randomly chosen points over the active region in the form of 5×5 matrix.



# Threshold Voltage Analysis

- Bias voltage across pin diodes = – 80 V
- CW mode operation of laser at low intensity
- HV ramped up from 0 to – 7000 V in steps of 250 V.
- Mean threshold Volatge in
  - Undamaged region = – 3.405 kV
  - Damaged region = – 3.936 kV
- Conductance increases with layer number



# Summary

- The characterization of fiber optic window was done with a step size of 1 $\mu m$ along transverse axis. It was found to be made up of square units of size = 6.2 $\mu m$.
- Localized scans of damaged pixels were done with a step size of 75 $\mu m$. The damage to photocathode due to scintillation light is prominent only in the region exposed to optical fiber.
- Damage is higher for regions on photocathode which received light from higher pseudorapidity regions of HE detector.
- The maximum observed signal loss is = 60.8 %.
- Modulus of Threshold voltage was measured in damaged and undamaged regions. Threshold voltage of damaged region is ~500 V higher than undamaged region.

# References


- R A Shukla, V G Achanta, P D Barbaro, S R Dugad, A Heering, S K Gupta, I Mirza, S S Prabhu, P Rumerio, "Microscopic Characterisation of Photo Detectors from CMS Hadron Calorimeter". arXiv:1806.09887 [physics.ins-det].
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