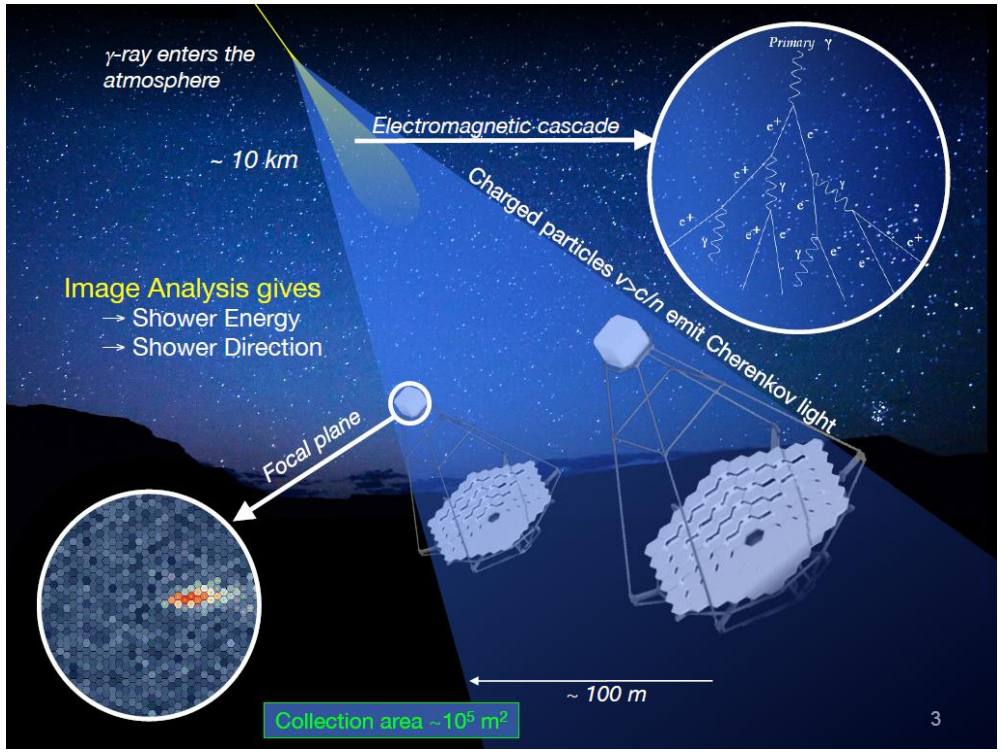
256-pixel SiPM based Imaging Camera and Its Status

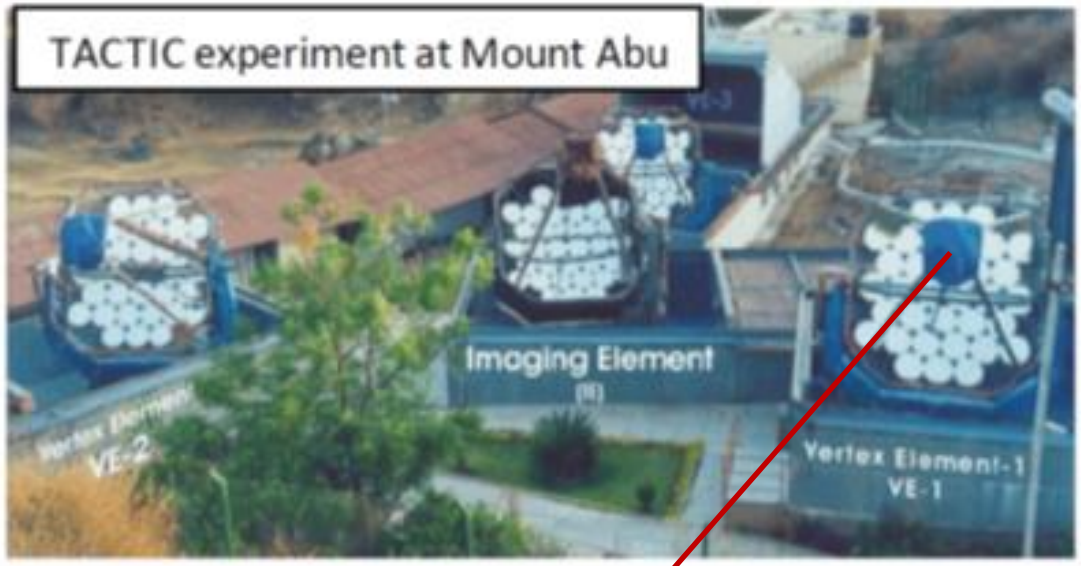
On behalf of the Gamma Ray Austronomy Group, DHEP

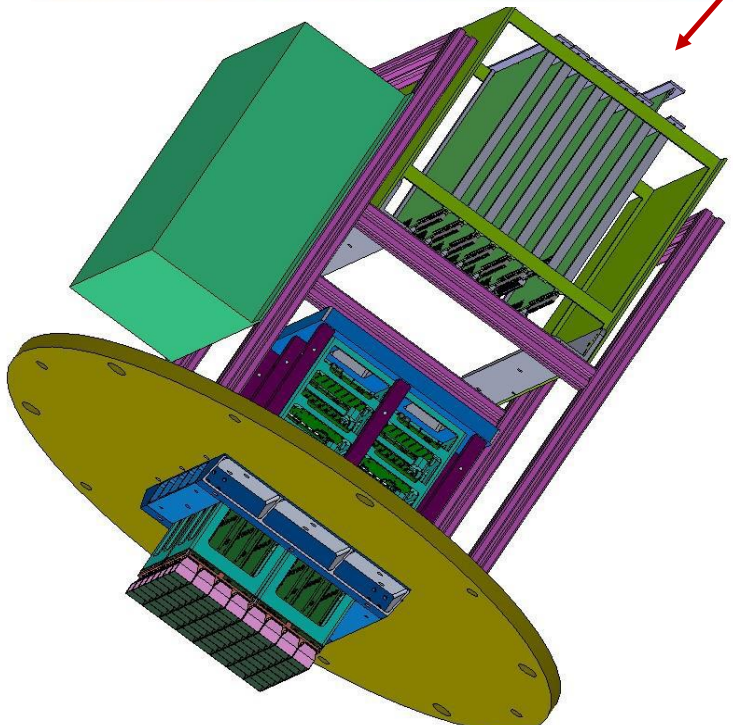
Overview of Talk

- Introduction
- SiPM sensor
- Imaging Camera Electronics
- SW scheme
- 64-pixel Camera prototype
- 256 pixel Camera status

Introduction





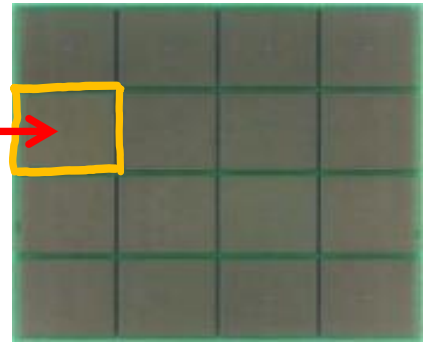


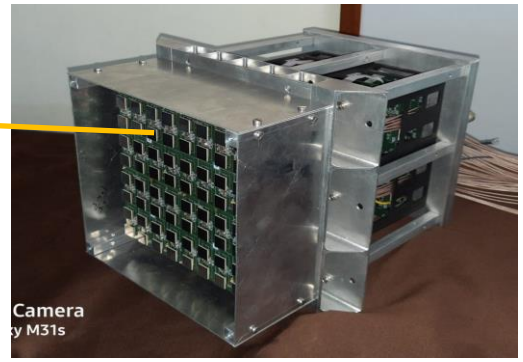
Camera Specifications

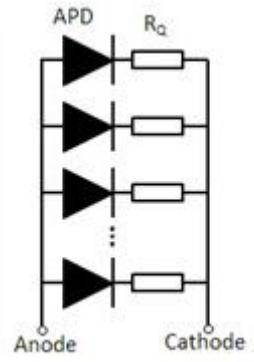
- Field of View of 5.0^{o}X5.0^{o} with pixel resolution of 0.3^{o}
- Number of pixels: 256
- Operating condition at Mount Abu and Hanle
  - Hanle 4300m altitude with temperature range of -30^{o}C to 40^{o}C
- SiPM as pixel sensor primarily to increase the observation duty cycle
- Pixel dynamic range: up to 1500 pe
- In-situ gain Calibration of pixel channel
- Recording of pulse profile @1GSPS
- Trigger rate up to 100 Hz with 3 or 4 nearest neighbouring pixels crossing a set threshold as trigger criteria

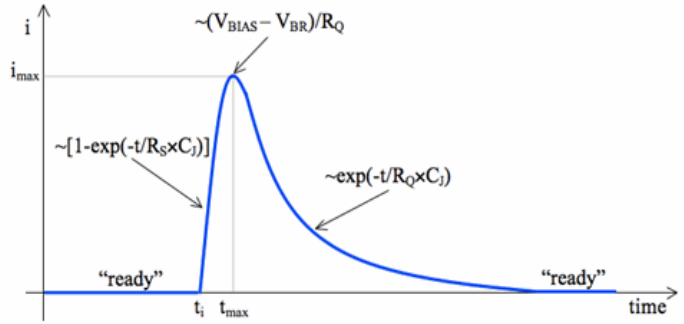
SiPM as a pixel sensor

4x4 SiPM (Hamamatsu S13361-3050AS-04)





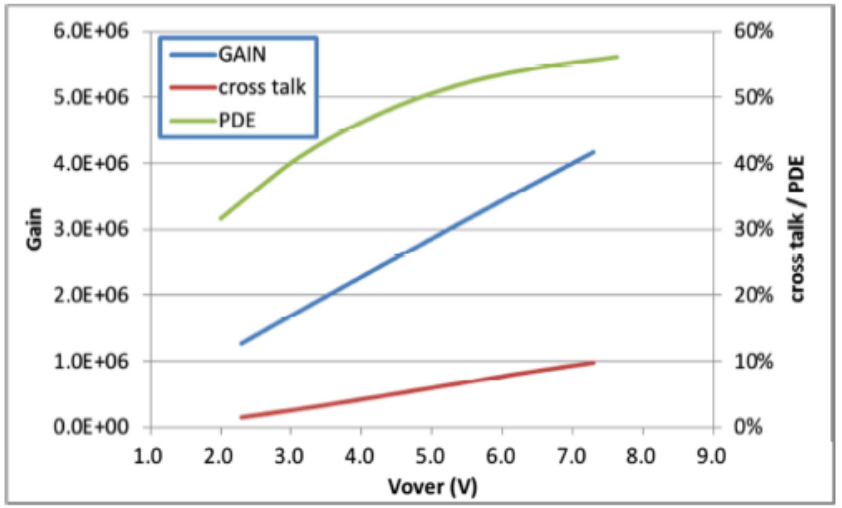


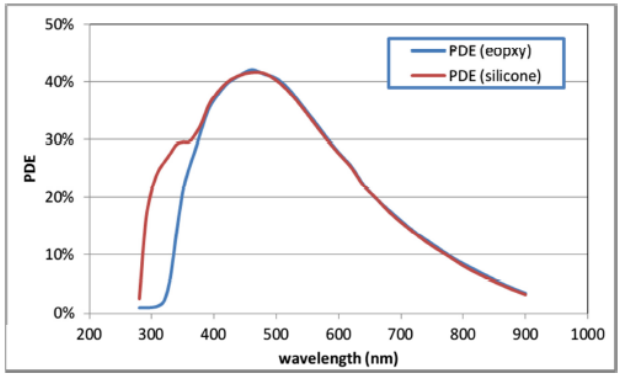


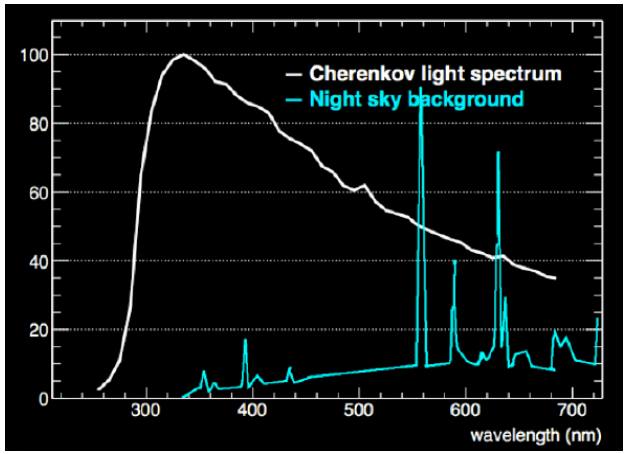
Photon detection efficiency vs. wavelength (measurement example)

- 13x13mm – 4x4 array
- Sub-pixel : 3584 micro-cells of 50 µm pitch
- Low voltage (V_{op}=~55V Typ.) operation
- High gain: 10^5 to 10^6
- Operating temp -20 to +60^0 C
- Dark count: 0.5 Mcps @ 25^0C @V_{ov} =3V
- Cross talk: 3% @ 25^0 C @V_{ov} =3V
- Temp coeff of V_{bd} : ~52 mV / ^{0}C

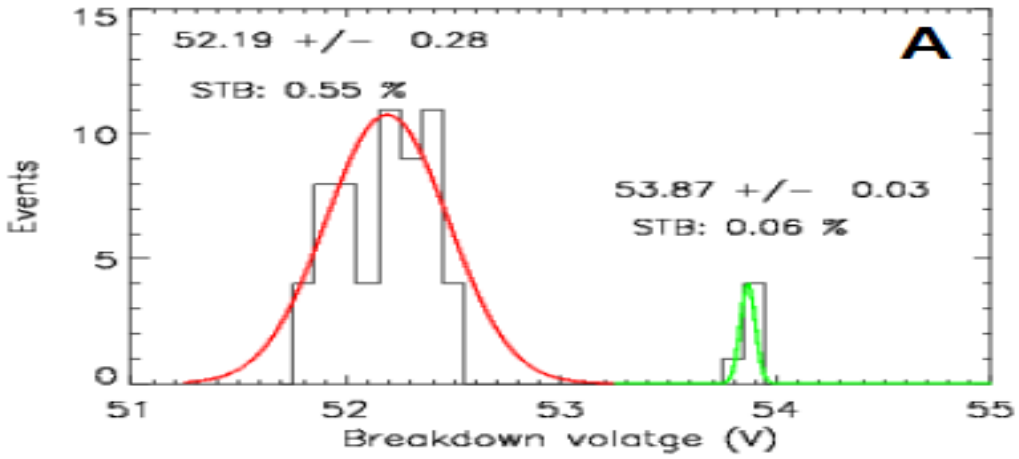
Characteristics Vover dependence (measurement example)

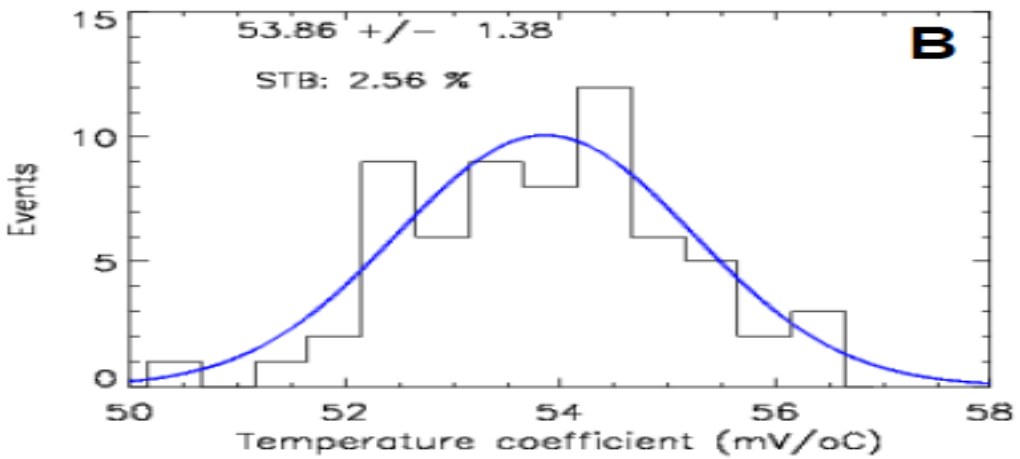


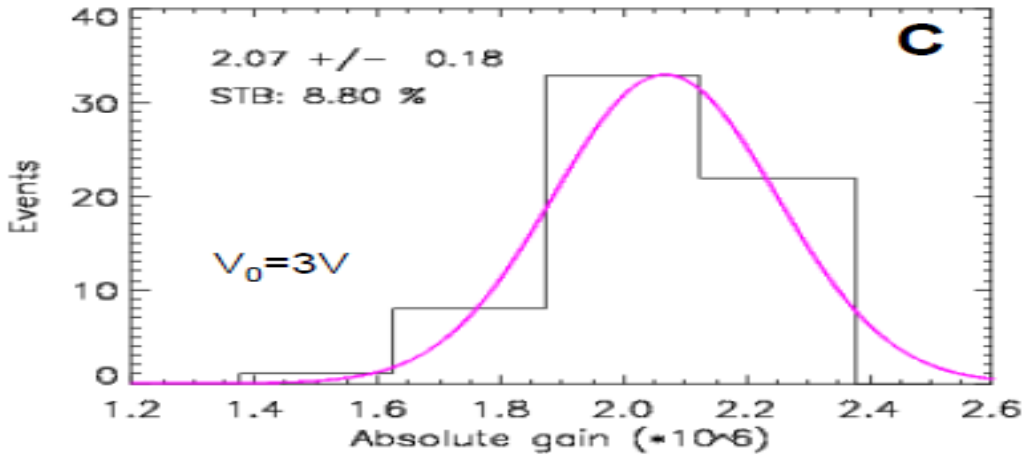


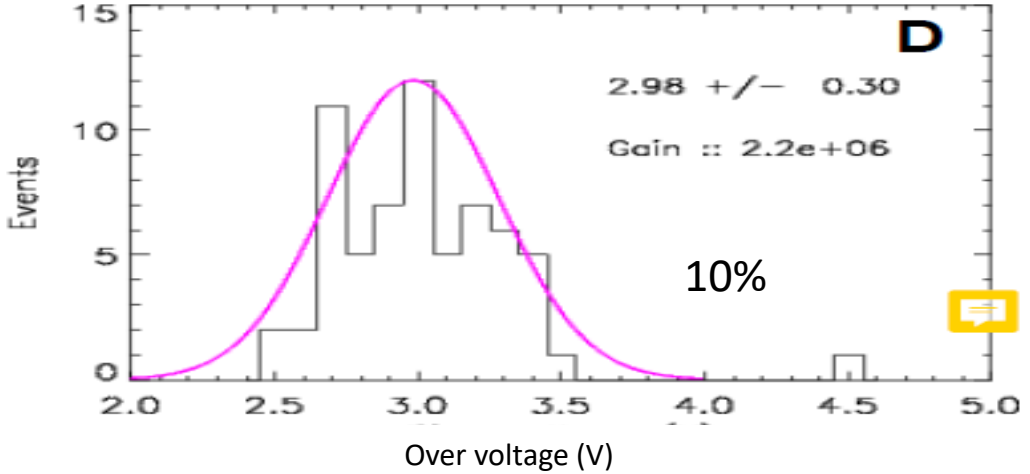


SiPMs Charactrization



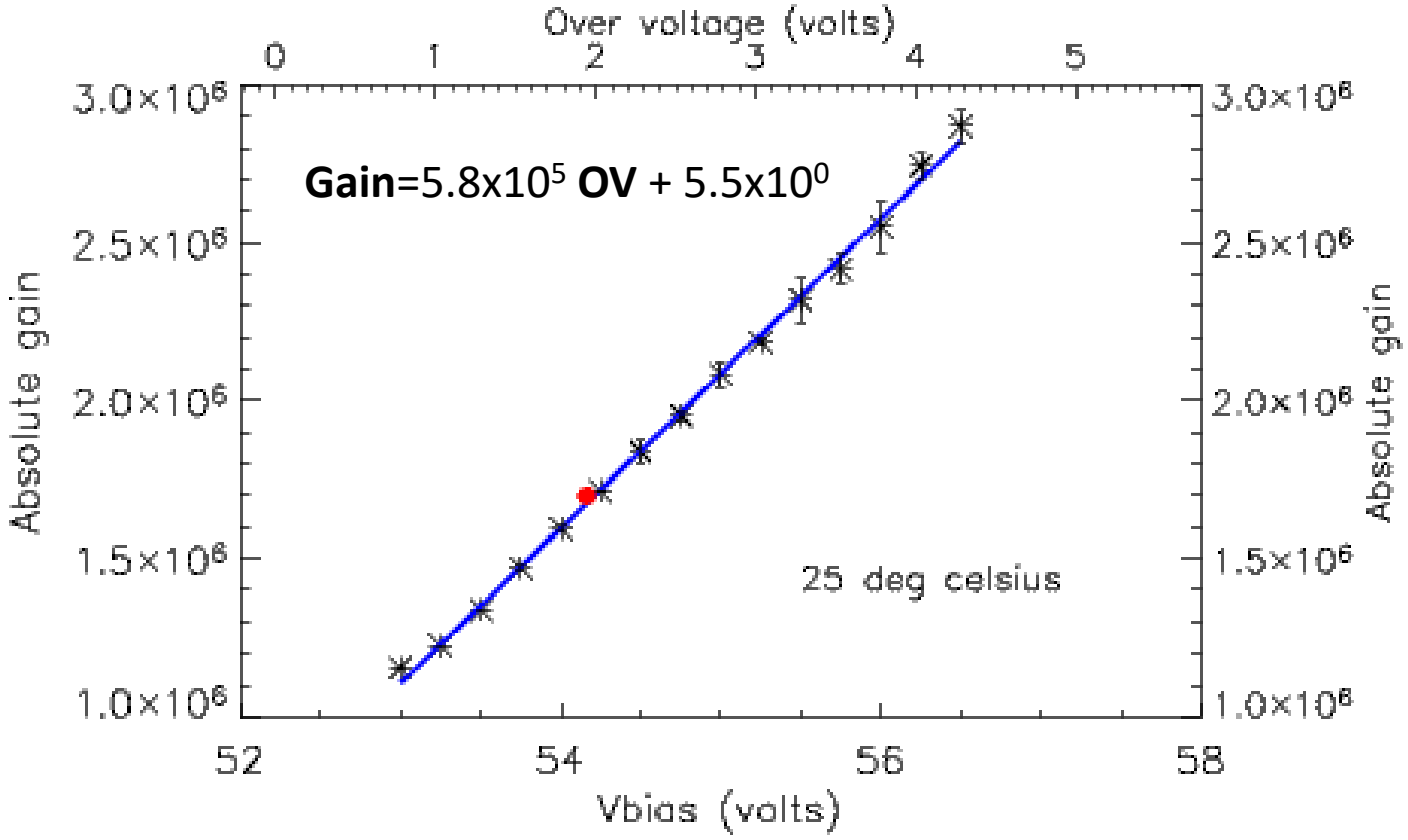


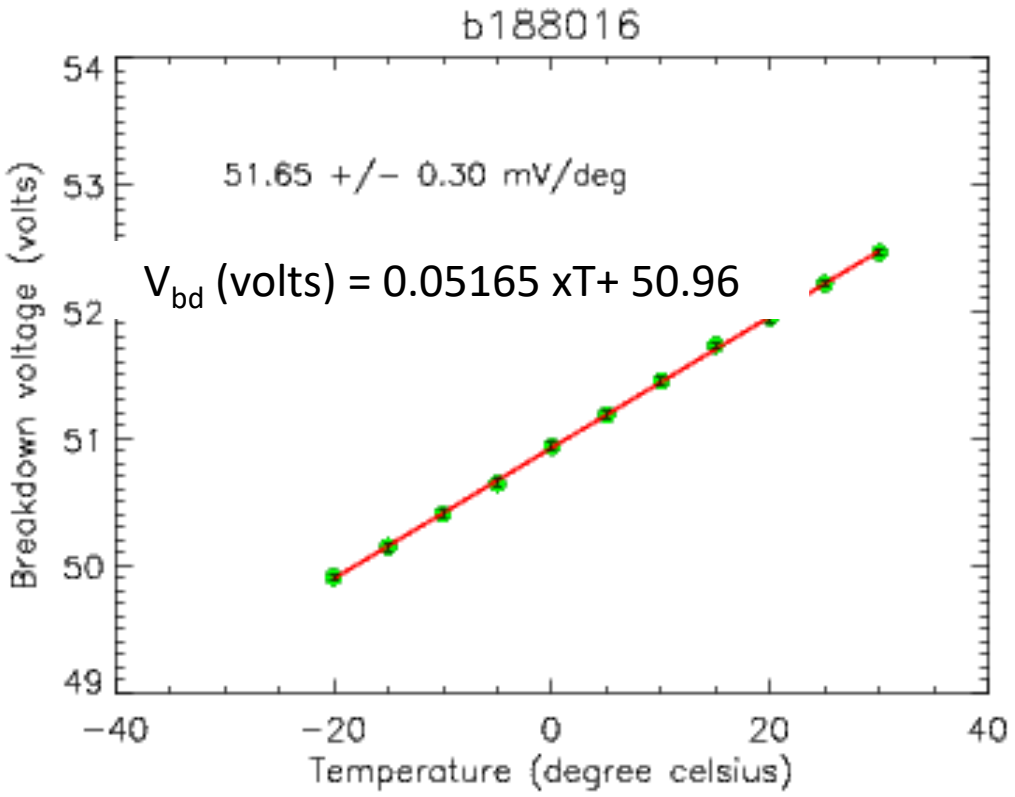




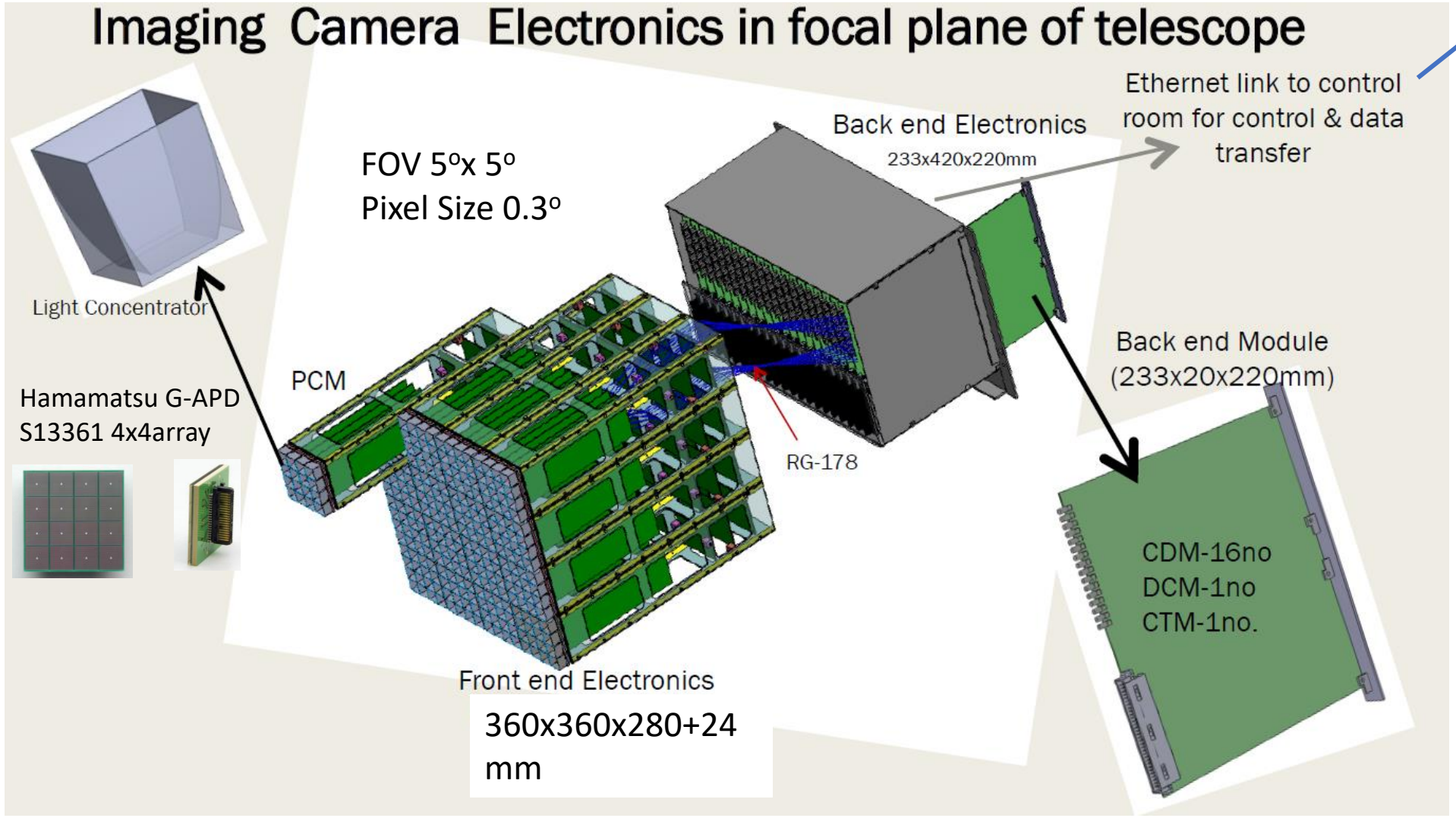
- Overvoltage variation of 10% seen , **Independent Pixel Bias control** needed
- SiPM temp coeff varies by 2.56 % across SiPMs, We need **independent temperature coeffs for gain compensation.**

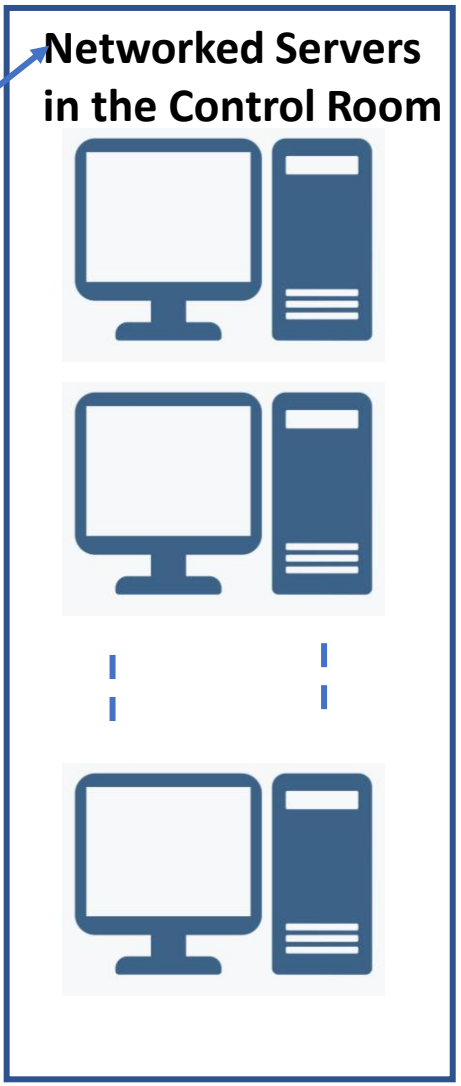
SiPM characterization…contd.





Imaging Camera and DAQ

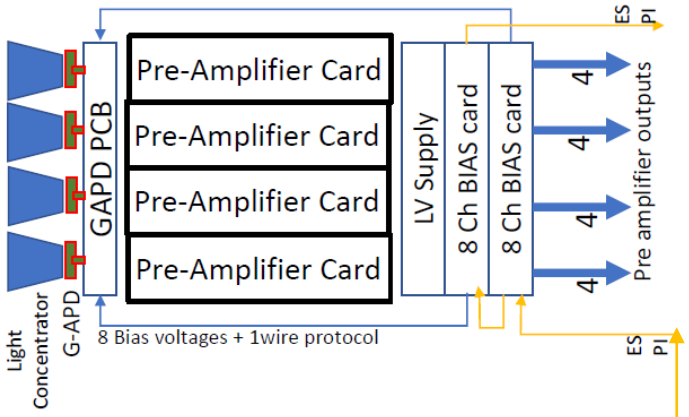




CAMERA ELECTRONICS

Front End Electronics

16 Pixel Cluster Module(PCM-1)



PCM-2

PCM-16

Bias Control (Raspberry Pi-Master)

Back end Data Electronics (Processing & Data Acquisition)

Cluster Digitizer Module (CDM-1)

16 Pixels LG-HG Amplifier

DRS Digitizer Board (DDB)

Diff Amplifier+Pixel-Trigger+DRS+ADC+FIFO+Serializer

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Diff Amplifier+Pixel-Trigger+DRS+ADC+FIFO+Serializer

Trigger Logic (FT&PT) Control & Monitoring

NIOS

SL

F TRG

CSL

CSPI

FT & PT

CDM-2

CDM-16

Back panel

DCM

SL

8 DCs

TOE

SL

8 DCs

TOE

CTM

F TRG

FT & PT

Trigger & Monitoring

RTC Event Number

CSL

NIOS (SPI Master)

TOE

Network switch

Optical link

Front-end Electronics

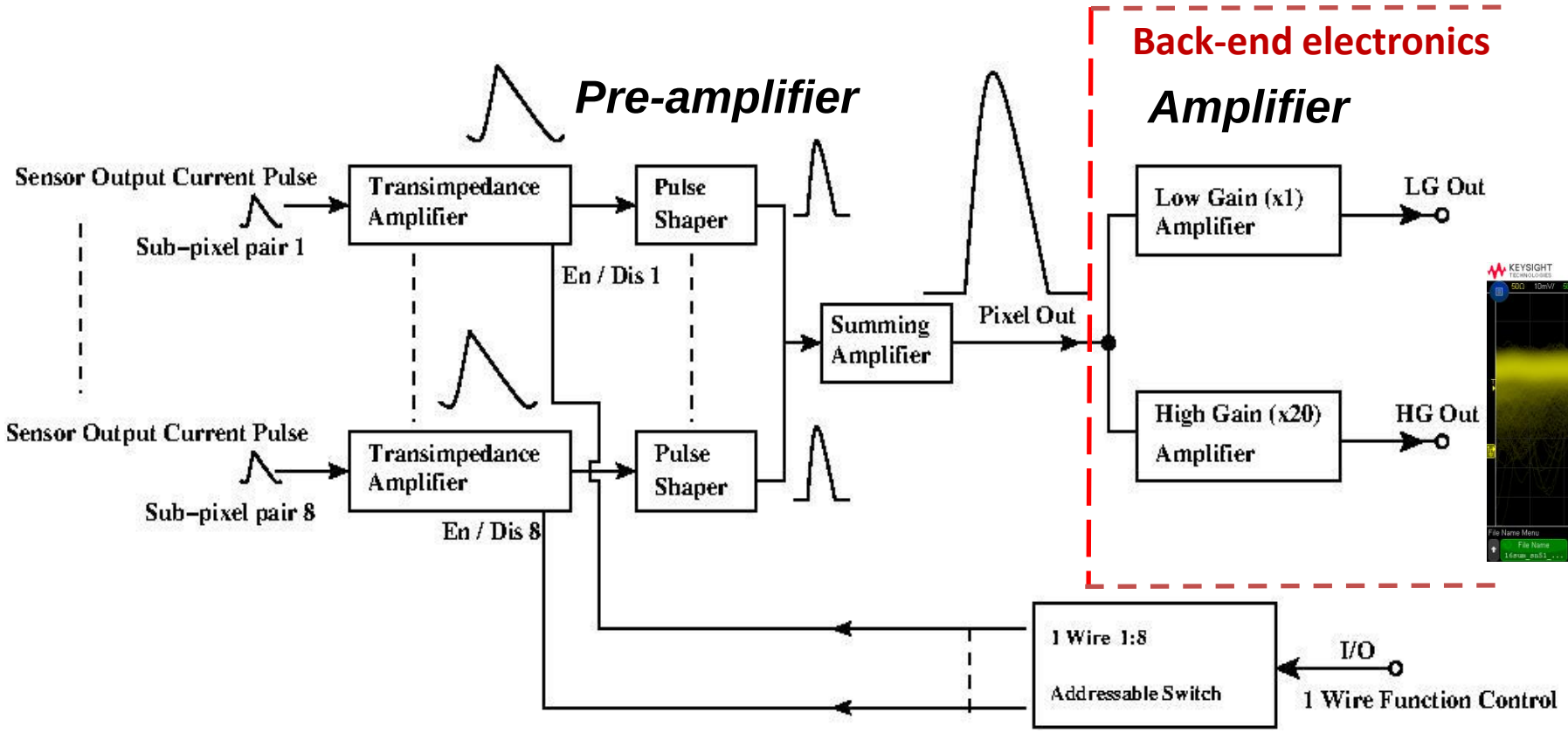
Front-end Electronics Design Constraints

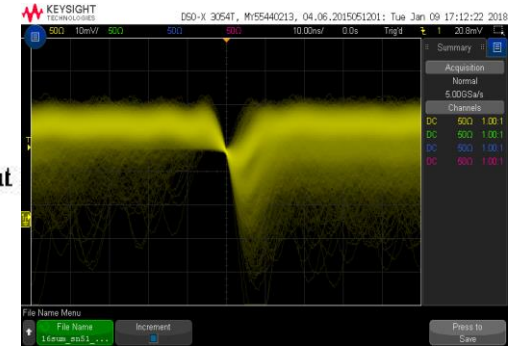
- 16 sub-pixel output to be processed and combined to form a pixel signal
  - Large components count, space and power!
- Long Decay time of the pulse (~80 ns)
  - More noise!
- Large Detector capacitance : ~320pF per sub-pixel
  - Very low input impedance of the preamplifier needed
- Noise sources:
  - Night sky background (NSB) : ~0.5 pe /sub-pixel for 80 ns integration time; NSB goes up by several orders of magnitude during a Moonlit night
  - Dark count rate : ~0.5 MHz per subpixel or 0.01 pe /80 ns….. Negligible
    - Need to shorten the SiPM pulse
- Power consumption for Front-end electronics: < 1 W / pixel

- Size : The signal processing electronics for a pixel in the 21 mm of PCB width.

The preamplifier has to be a low power, low noise and wide bandwidth circuit that has just few mm PCB width available for each sub-pixel signal processing.

Analog Signal Processing





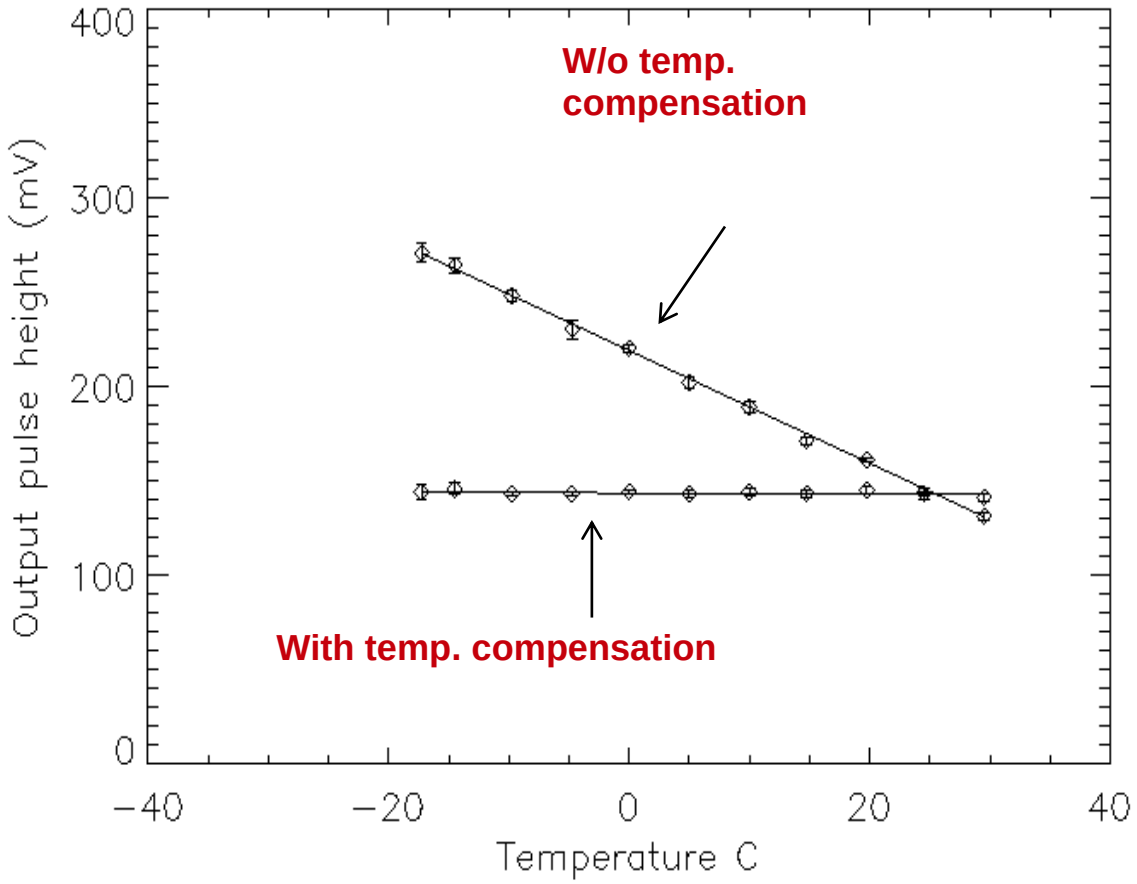
- Transimpedance amplifier
- Sub-pixel enable-disable feature allows for single photoelectron gain calibration more accurately owing to improved SNR.
- Pulse shaper : based on pole-zero cancellation
- Amplifier output pulse : Rise time <6 ns;
  Base width ~20 ns
- Dual gain (high and low) to achieve the required dynamic range and finer resolution needed to estimate single pe gain

8-channel Bias Supply for SiPMs

Requirement : To provide bias voltage of about 52-58 V maintaining constant gain

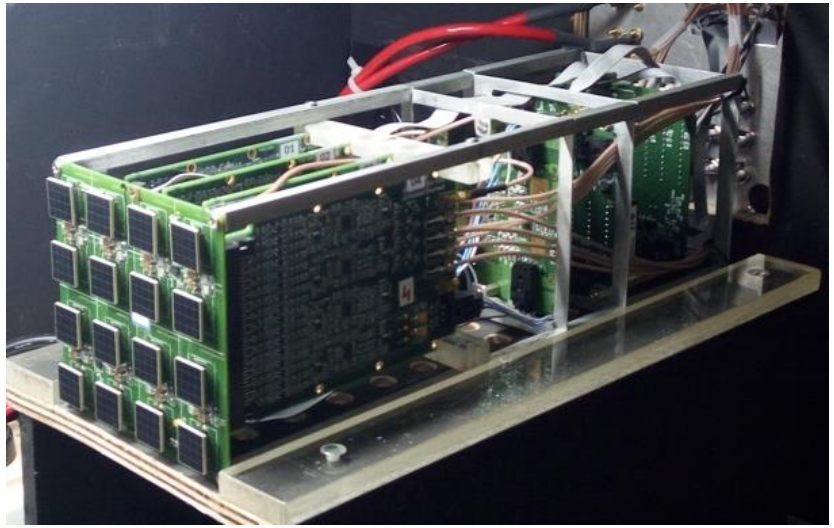
Temperature and background light level dependency of the SiPM gain

- ➢Based on DC/DC converter HV80 from AiT Instruments and Xmega micro-controller
- ➢Provides voltage range of 0-80 V with 4 mA load
- ➢Bias voltage variation in steps of 5 mV
- ➢Over-current shut-down feature
- ➢Each supply board caters to eight pixels
- ➢Remote access through ESPI communication via Raspberry Pi
- ➢SiPM gain stability improved from 97% to 3% over the temperature range -20 C to +30 C



LC Assembly

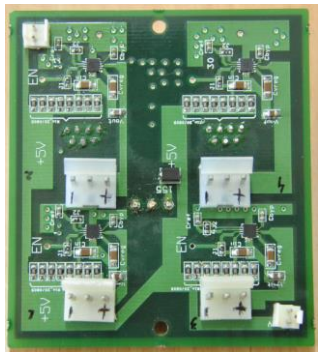
Camera Front-end - PCM



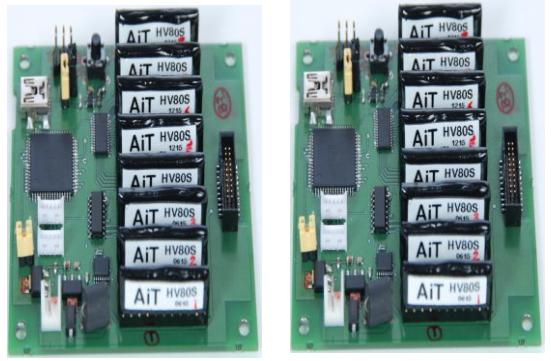
SiPM mount PCB

4 Pixel Pre-Amplifier

LV PS



8 ch. Bias Card

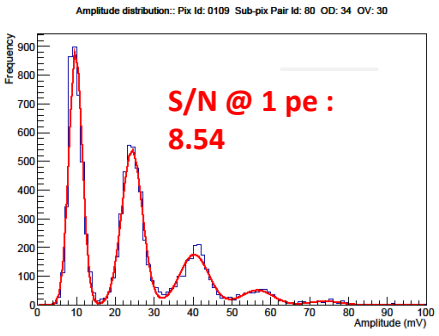


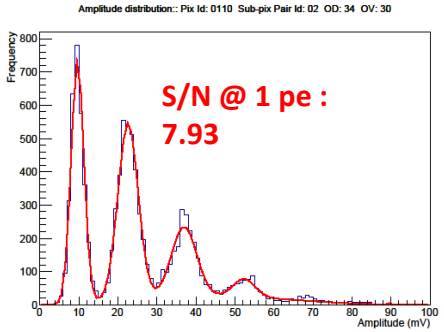
8 Cards inside a PCM (9x9x28cm)

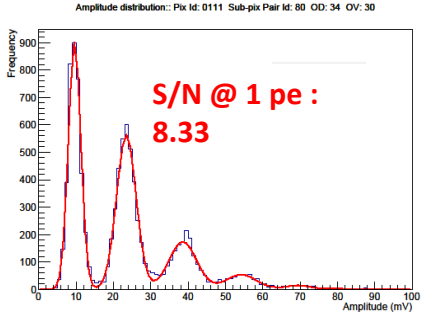
Amplitude spectrum and S/N ratio at Single PE

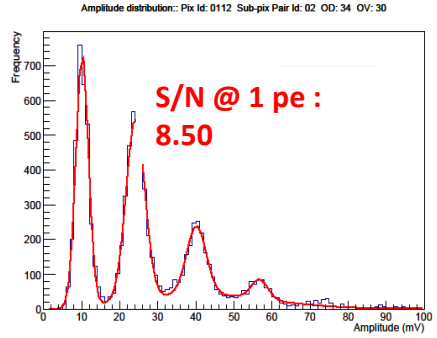
Overvoltage: 3 V

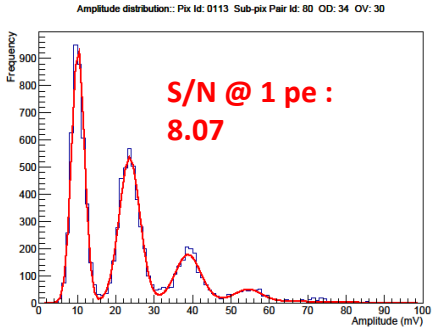
SPE for Single Sub-pixel pair of different pixels exposed to pulsed laser

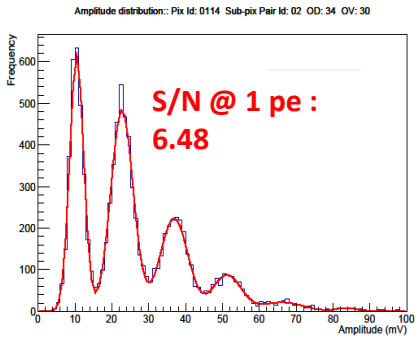


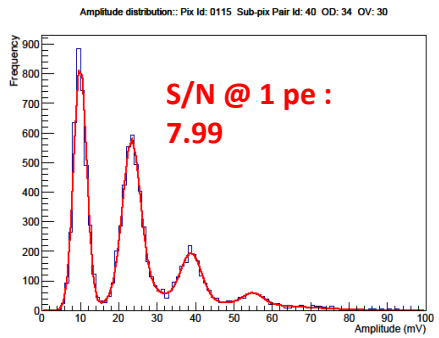


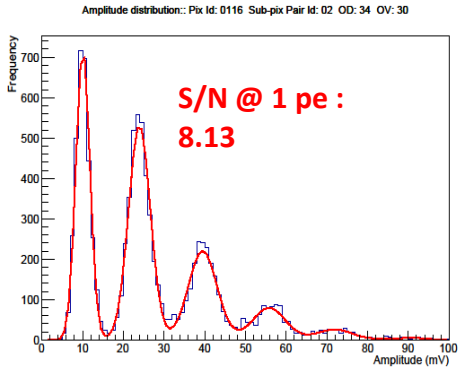








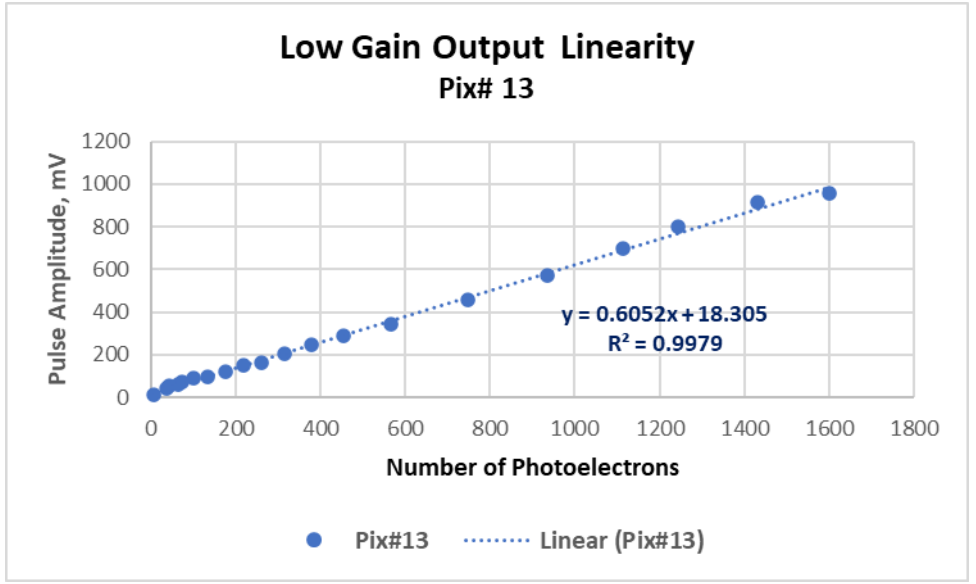


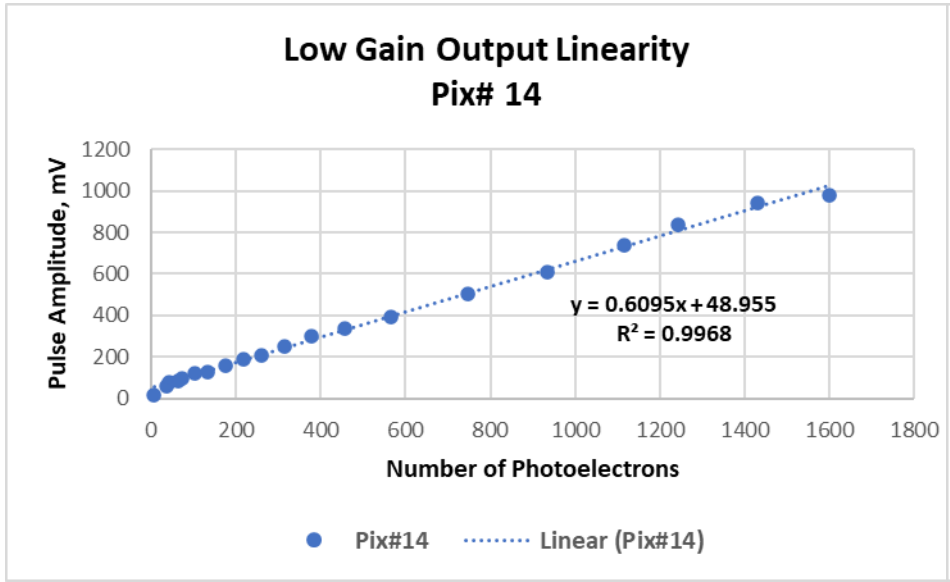


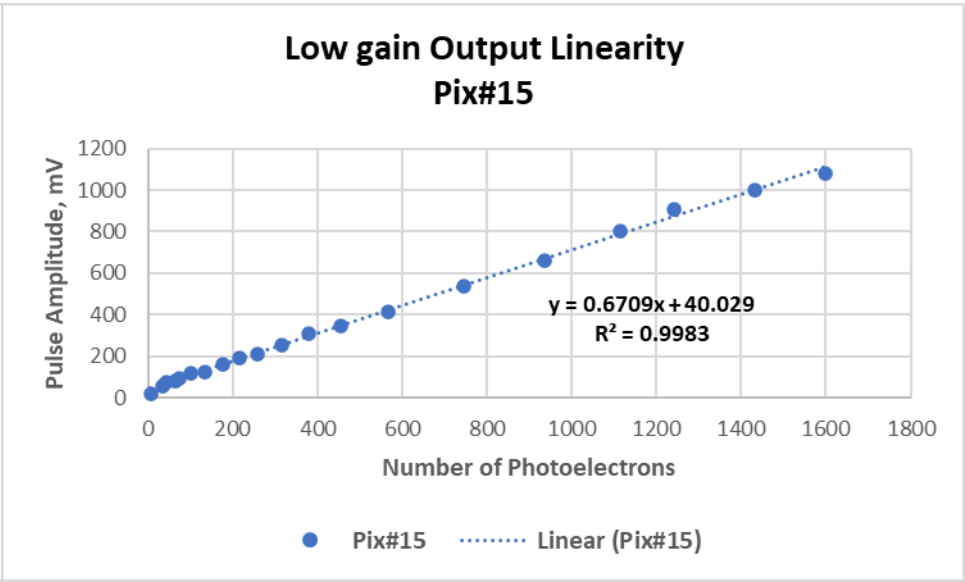
Over 64 sub-pixel pairs in 8 pixels at overvoltage of 3 V
S/N @ 1 pe : 6.35 ± 1.00

Linear Dynamic Range

(Pulsed Laser with varying intensity)





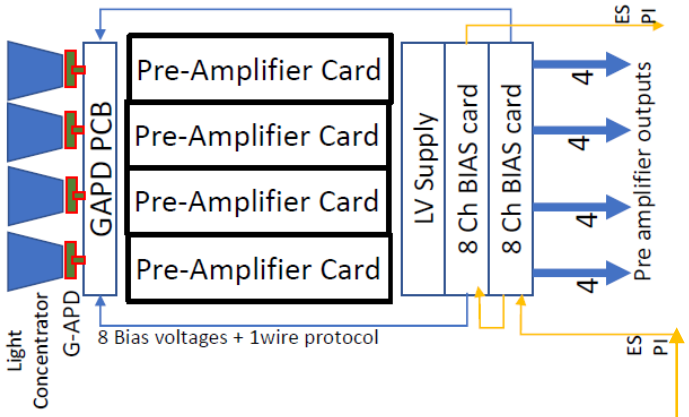


Back-end Electronics

CAMERA ELECTRONICS

Front End Electronics

16 Pixel Cluster Module(PCM-1)



PCM-2

PCM-16

Bias Control (Raspberry Pi-Master)

Back end Data Electronics (Processing & Data Acquisition)

Cluster Digitizer Module (CDM-1)

16 Pixels LG-HG Amplifier

DRS Digitizer Board (DDB)

Diff Amplifier+Pixel-Trigger+DRS+ADC+FIFO+Serializer

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Diff Amplifier+Pixel-Trigger+DRS+ADC+FIFO+Serializer

Trigger Logic (FT&PT) Control & Monitoring

NIOS

CSPI

SL

F TRG

CSL

CSPI

FT & PT

CDM-2

CDM-16

Back panel

DCM

SL

8 DCs

TOE

SL

8 DCs

TOE

CTM

F TRG

FT & PT

Trigger & Monitoring

RTC Event Number

CSL

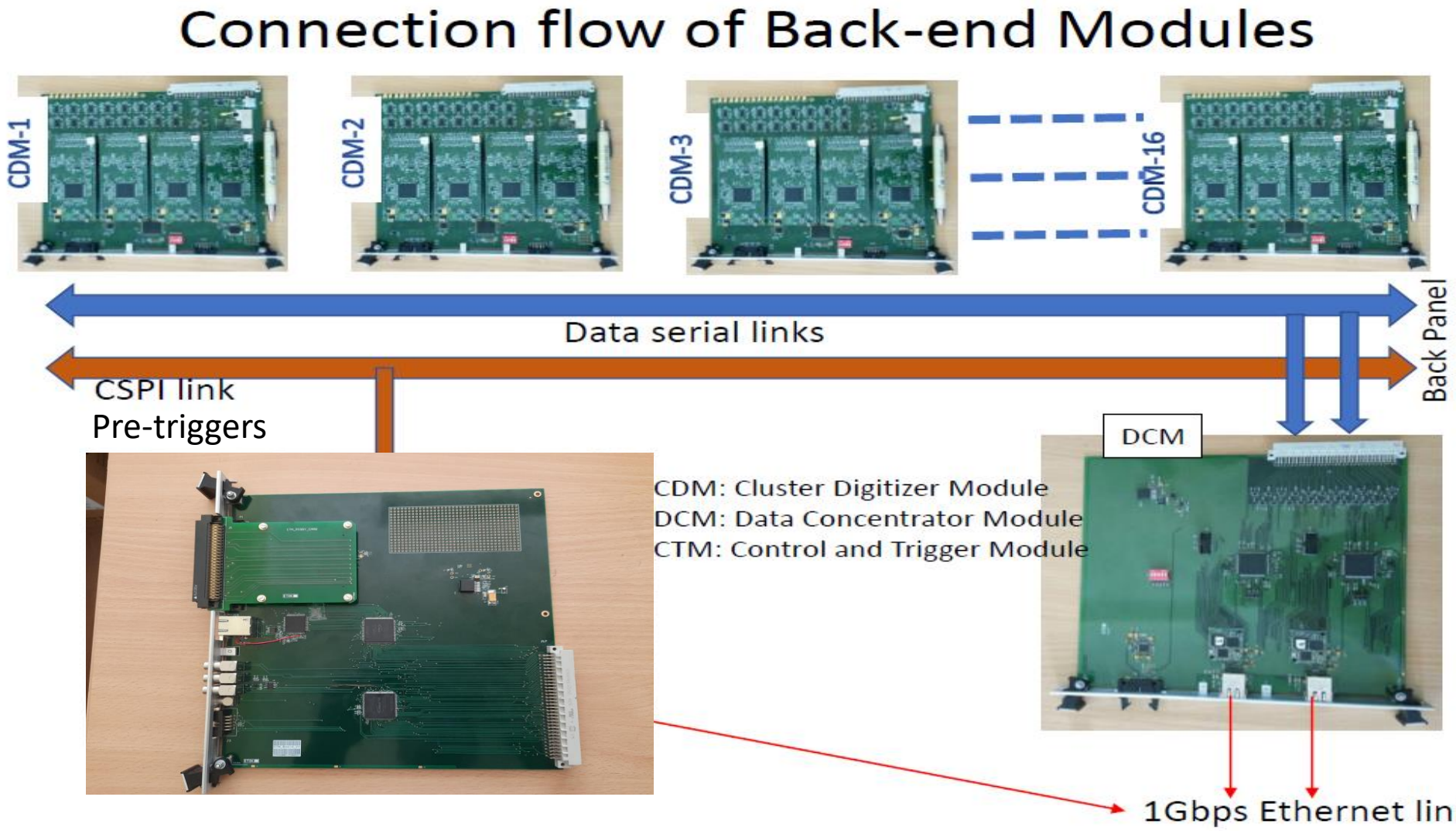
NIOS (SPI Master)

TOE

Network switch

Optical link

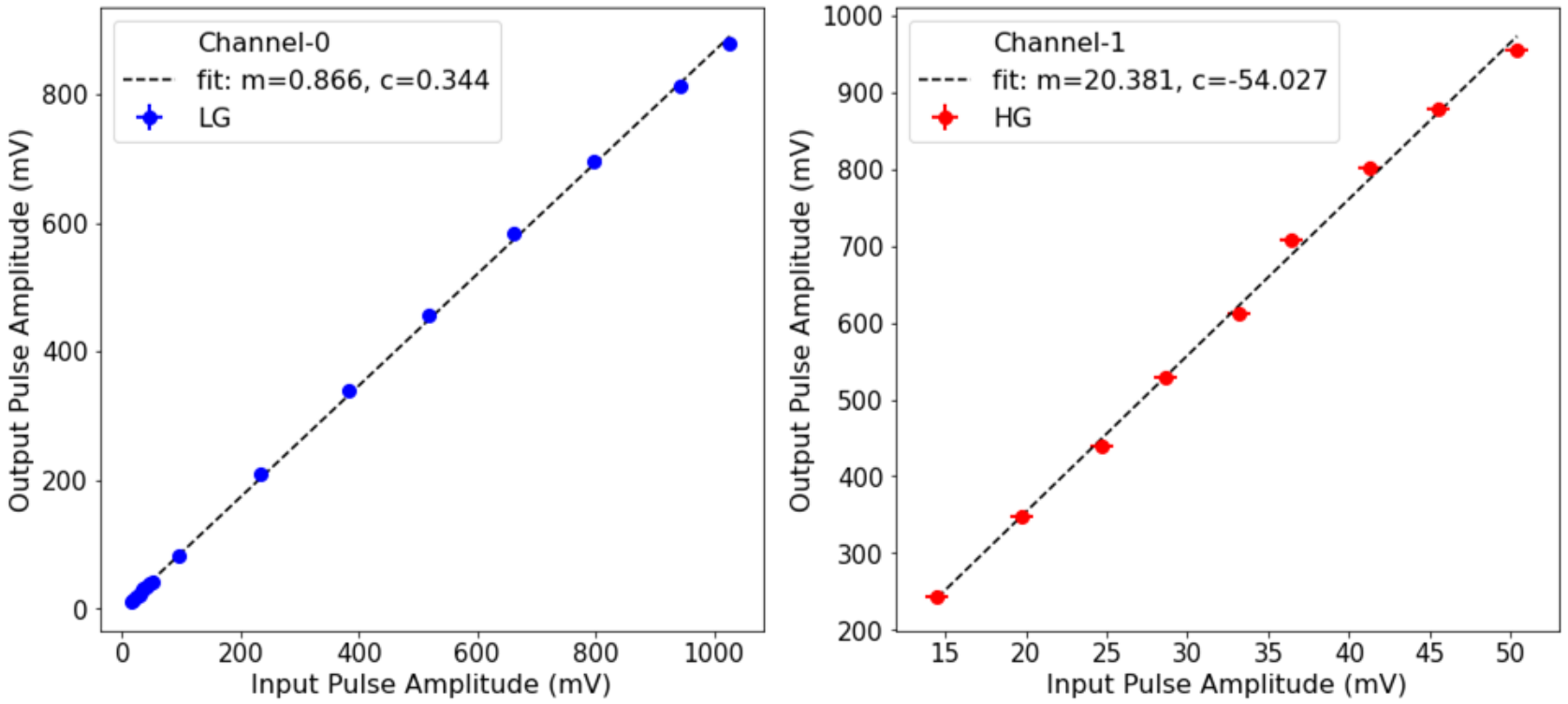
Camera Back-end



Absolute Gains at CDM Input Channels

- 16 input channels at each CDM.
- Each input channel is divided into a low gain and high gain channel to increase the dynamic range of the camera up to 2000 photoelectrons.
- Estimation of absolute gains at all low and high gain channels
  - Triangular pulses of different heights but same rise-time (5 ns), decay time (8 ns) from function generator fed to the CDM input channels. Pulse profile resembles actual pulses from SiPM pixels.
  - 5000 events recorded for each pulse height.
  - At all low and high gain channels, pulse height distributions fitted with Gaussian.
  - Slope of the straight line fitting the "Recorded mean pulse height" vs "Input pulse height" graph⇒ Absolute gain.

Example of Gain Linearity in first input channel of CDM-05



DDB channels systematic noise and correction result

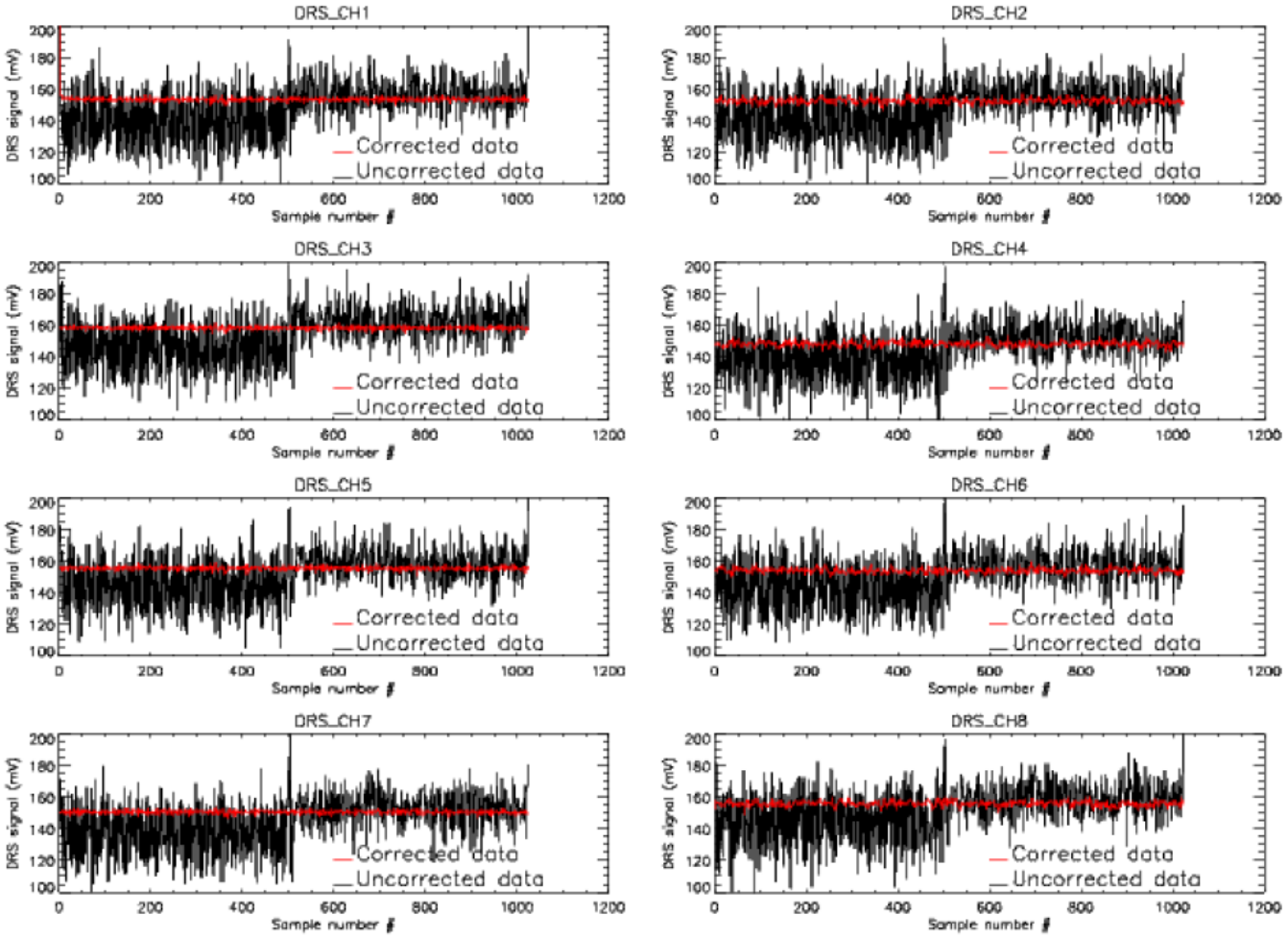
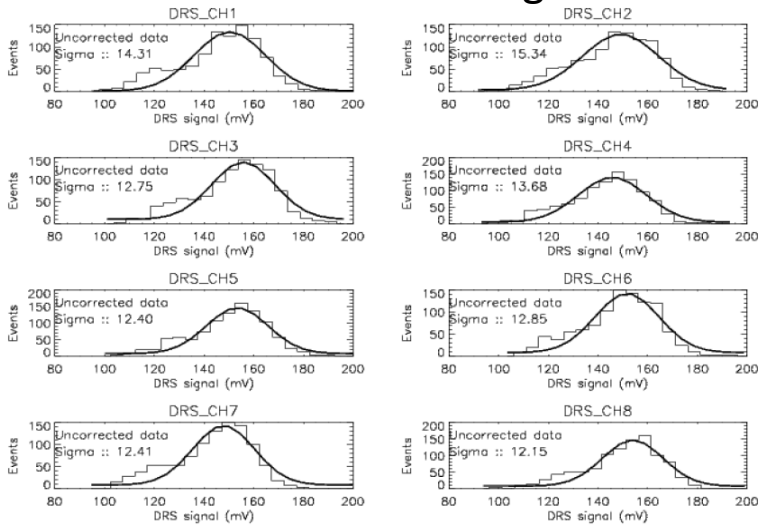
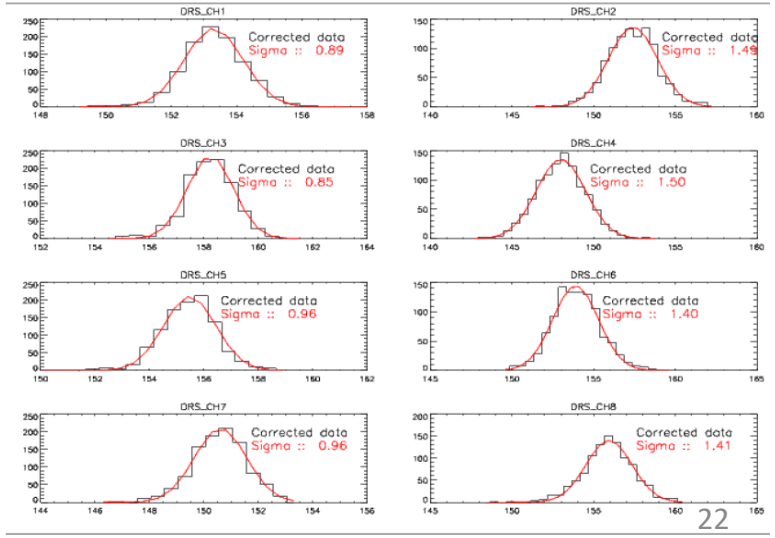


Figure-4: The DC (0V) signal sampled at 1 GSPS before and after (red color) offset correction. Spike at 1-2 ns in the first DRS/DDB channel. This spike is present only in the first event data..

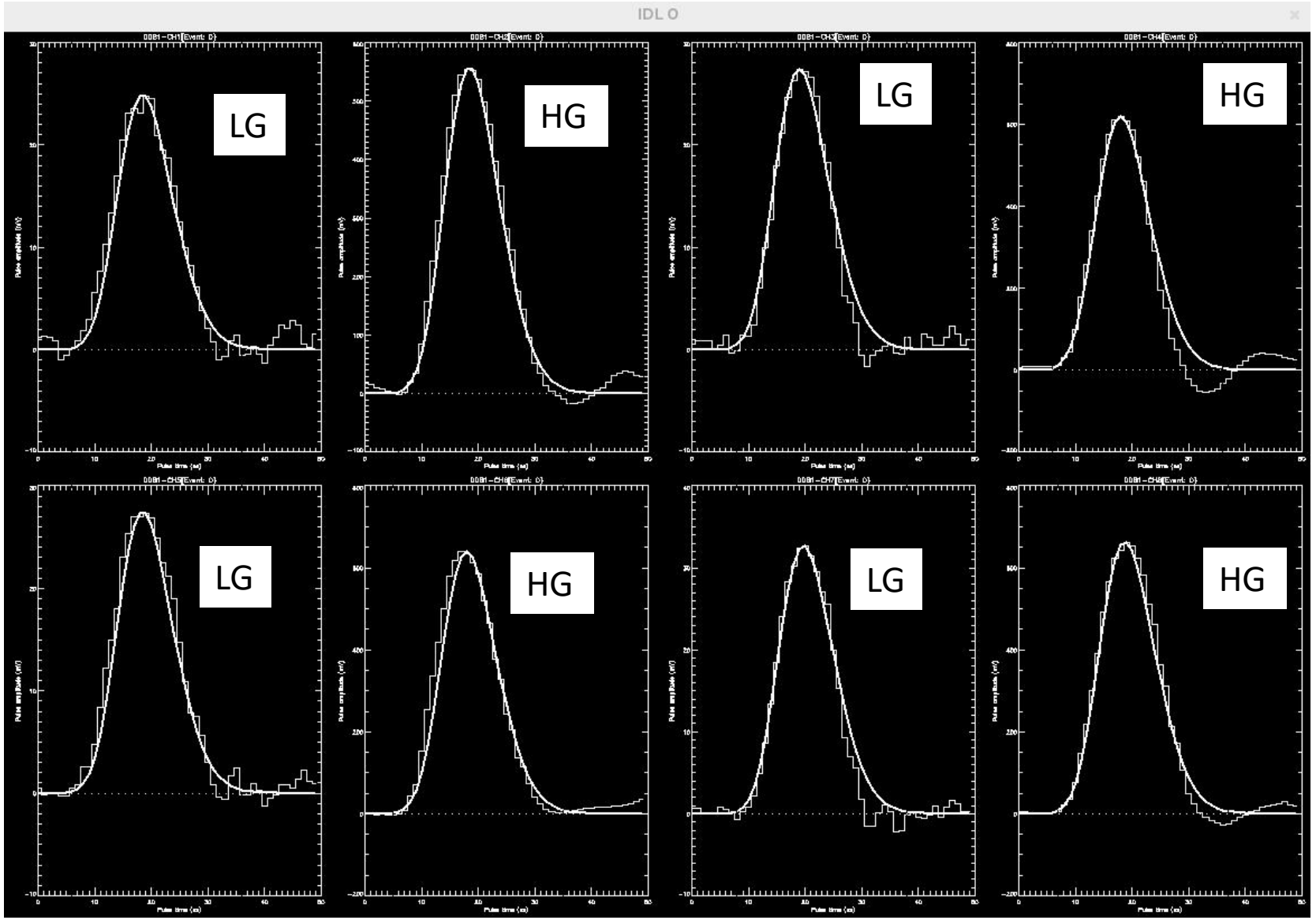
Before correction: sigma of 13mV



After correction : sigma of 1mV

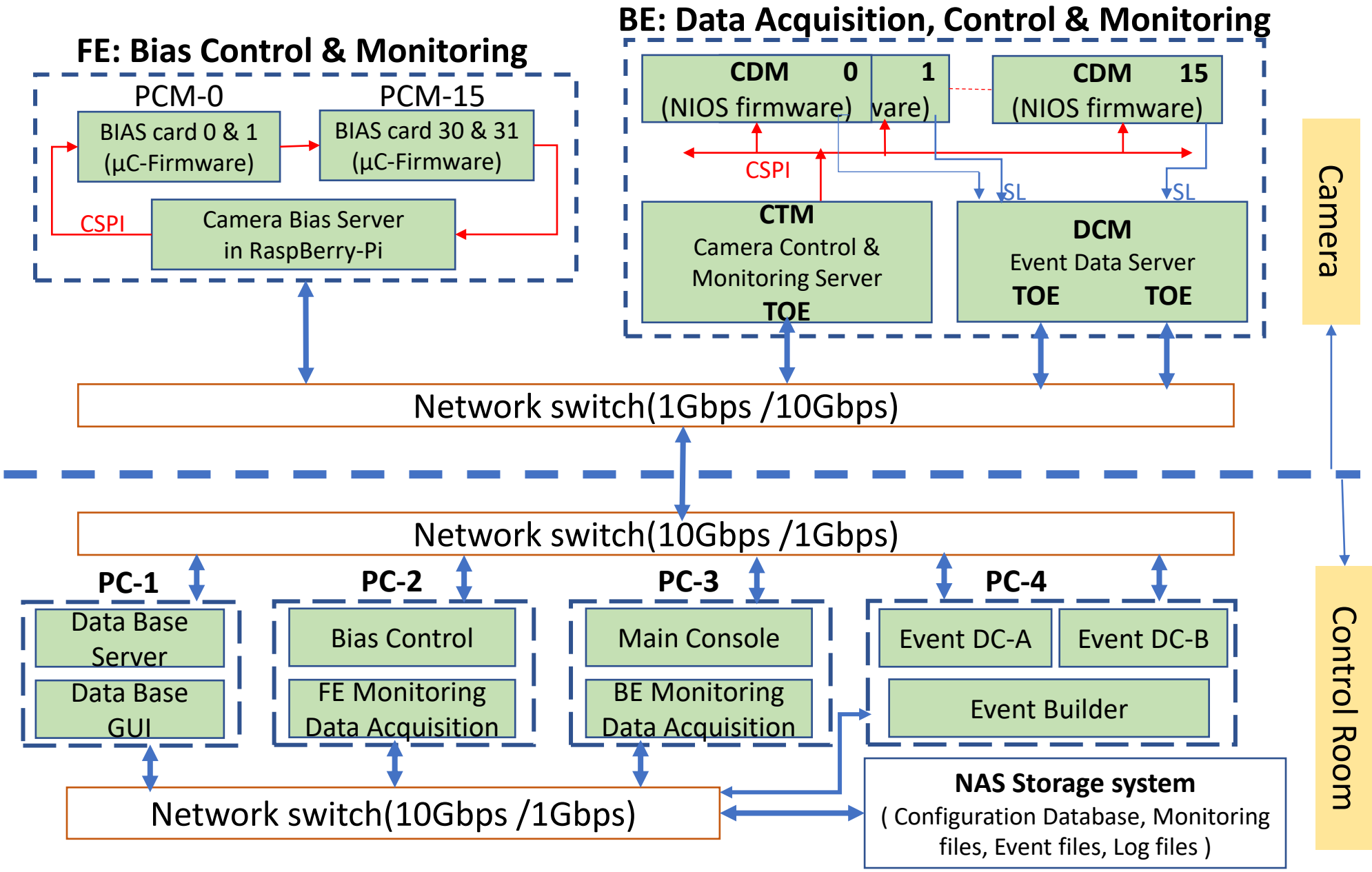


Pixel HG chl pulses of a DDB for pulsed light flash
After baseline correction from off pulse region



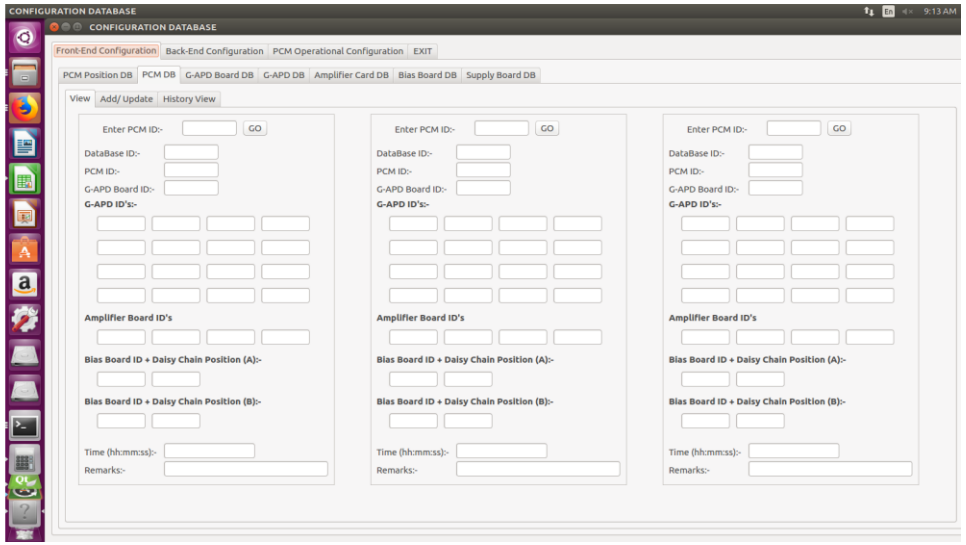
Software

Camera - Software Scheme



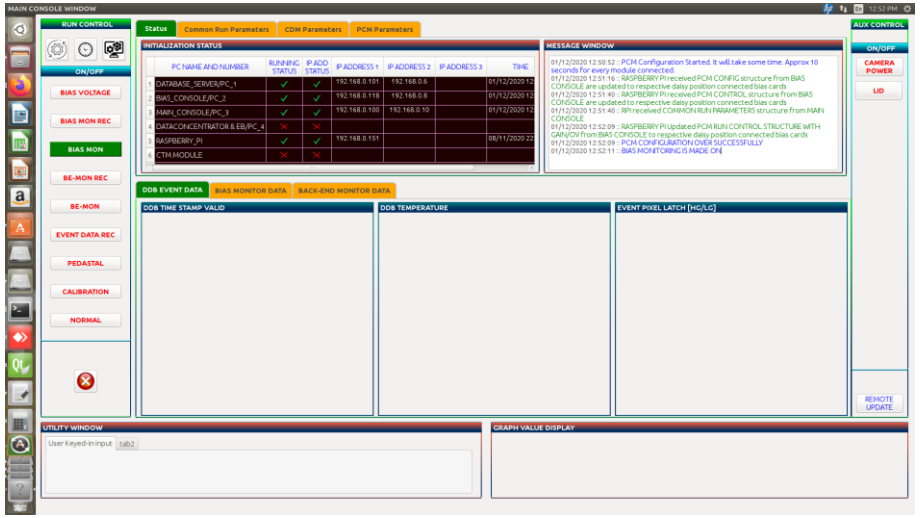
Network of Servers in Control room to Configure, control and monitor the Camera

Configuration, Control Data base GUI



FE Monitoring

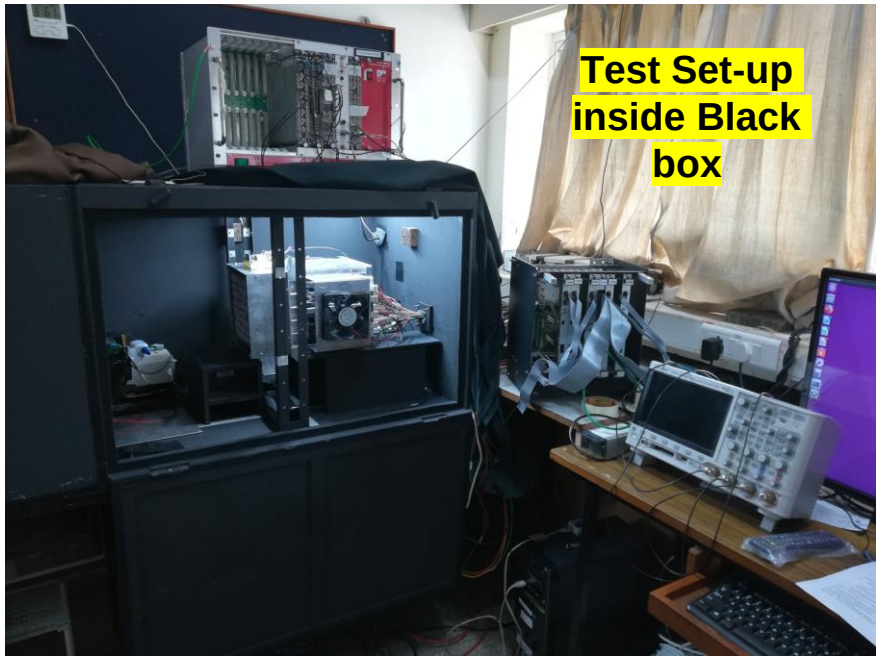
Main Console & BE monitoring



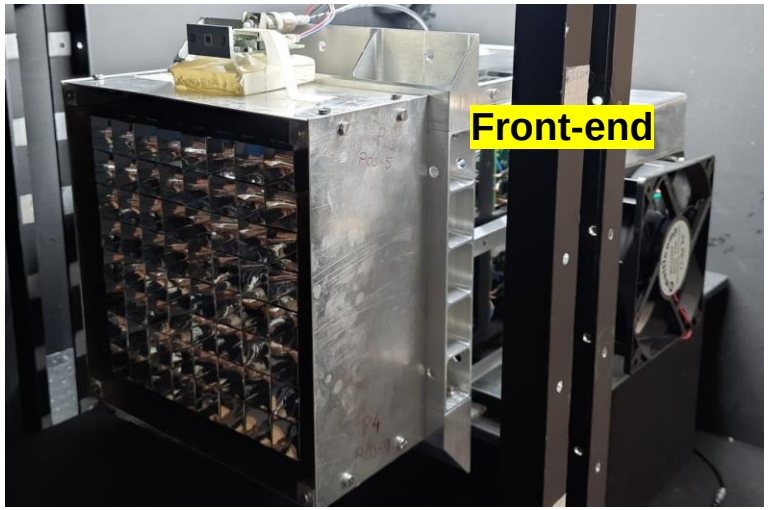
Event Data Concentrators A&B
Event builders

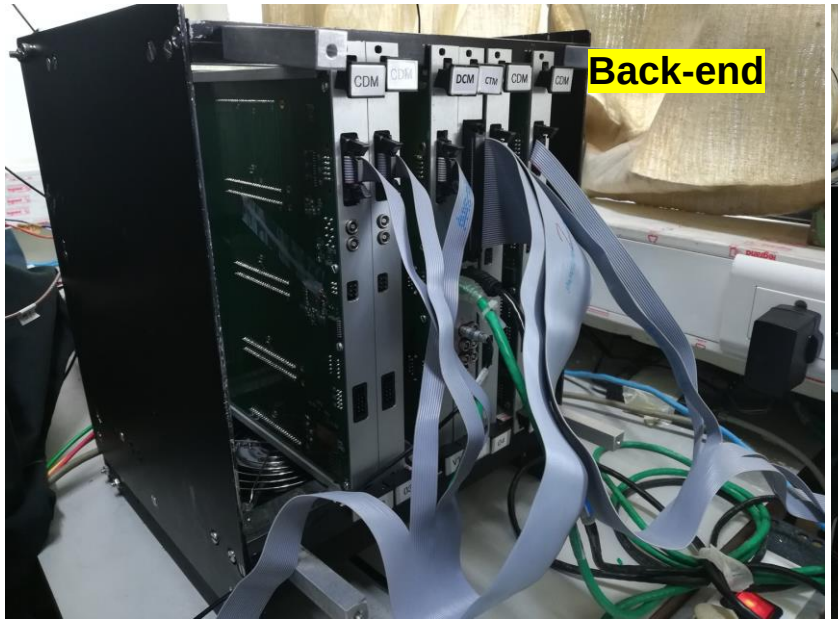
Full 64-pixel camera Integration

The 4-module SiPM-Camera



- Total 64 SiPM pixels.
- Light concentrators attached in front (~75% efficiency).
- Front-end connected to back-end via RG178 cables.
- Data acquisition and monitoring controlled by 4 P.C.s.

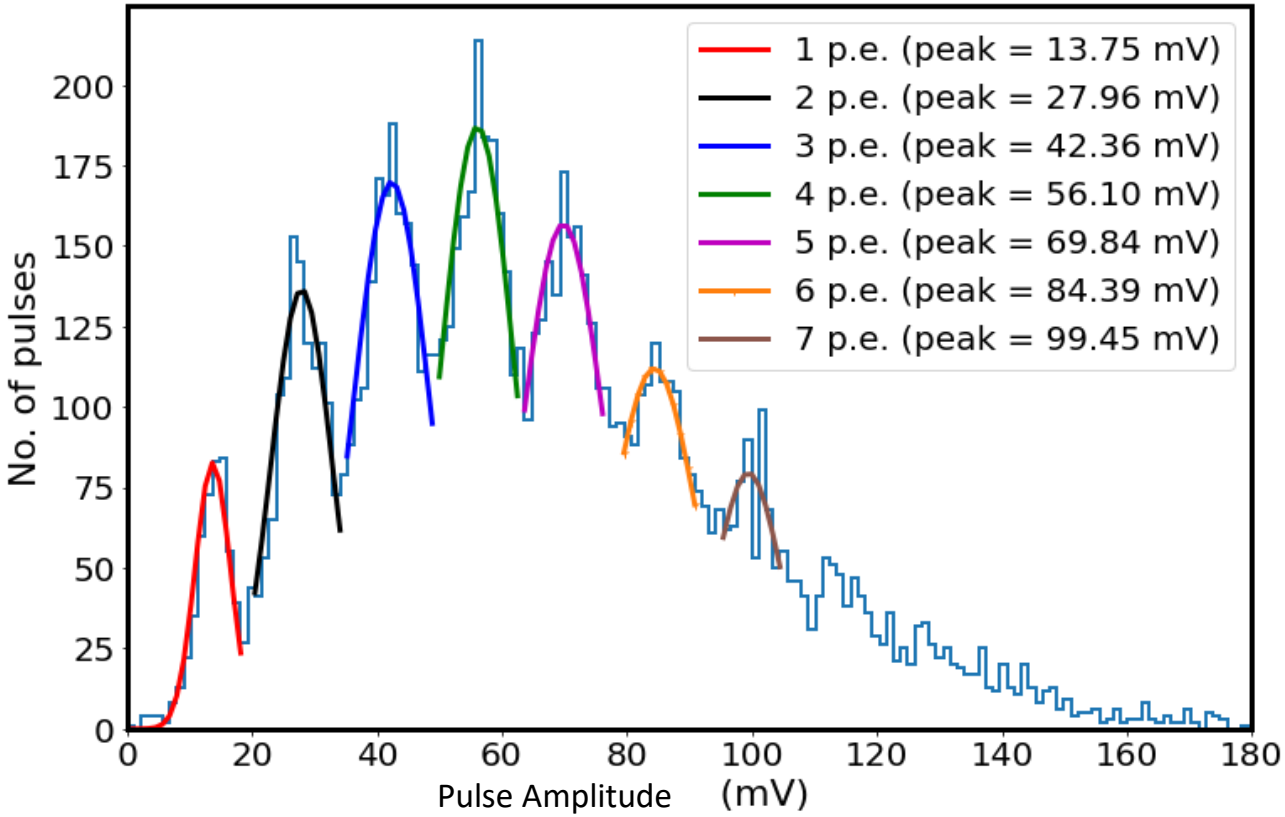


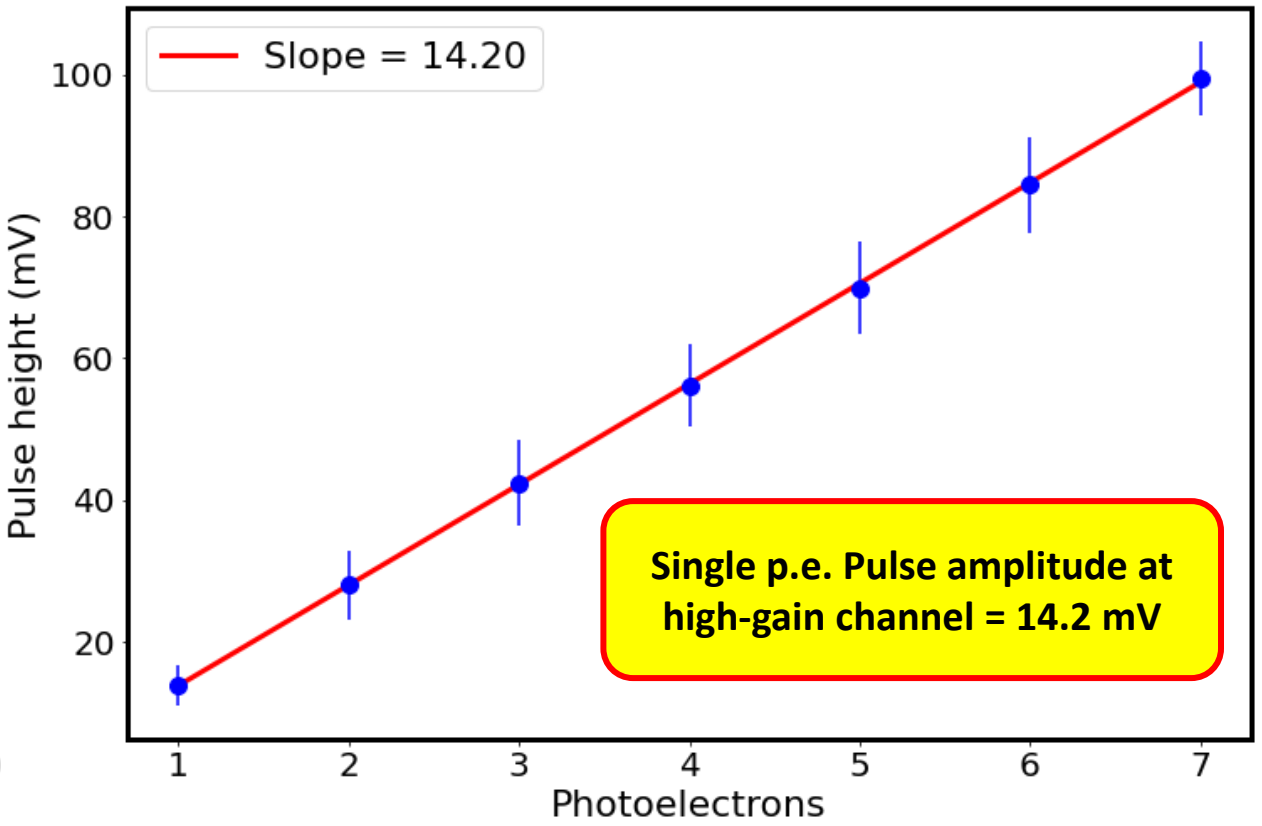


Photoelectron Spectrum at SiPM Pixel

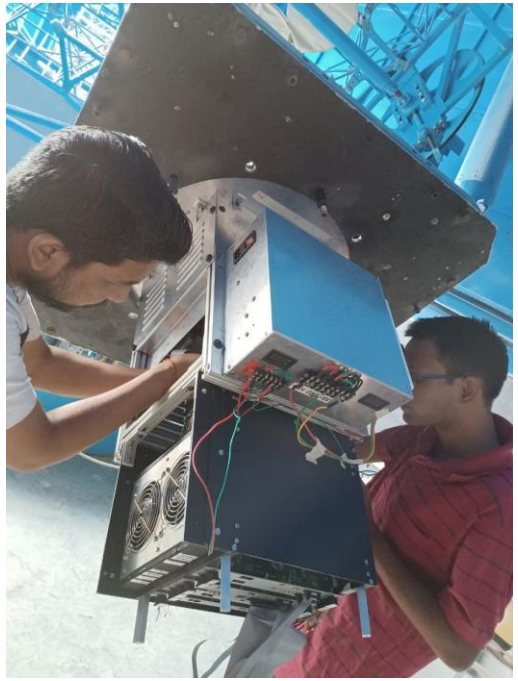
- Very important to know how many photons arrived at a pixel in an event.
- Computation of SiPM pulse amplitude with the number of arrived photons.
- Check for linearity in response with increase in number of photoelectrons.
- The light source was kept at very low intensity, so that the mean is around 2-3 photons at once.

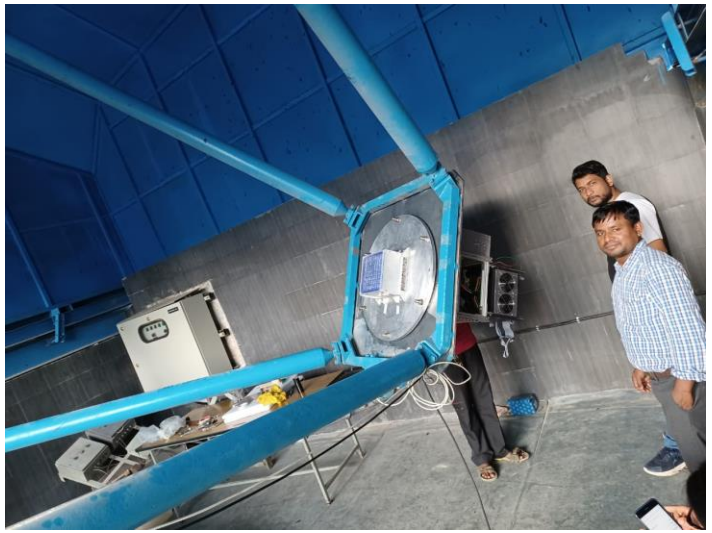
Photoelectron Spectrum at PCM-05, DDB-03, Pixel-02

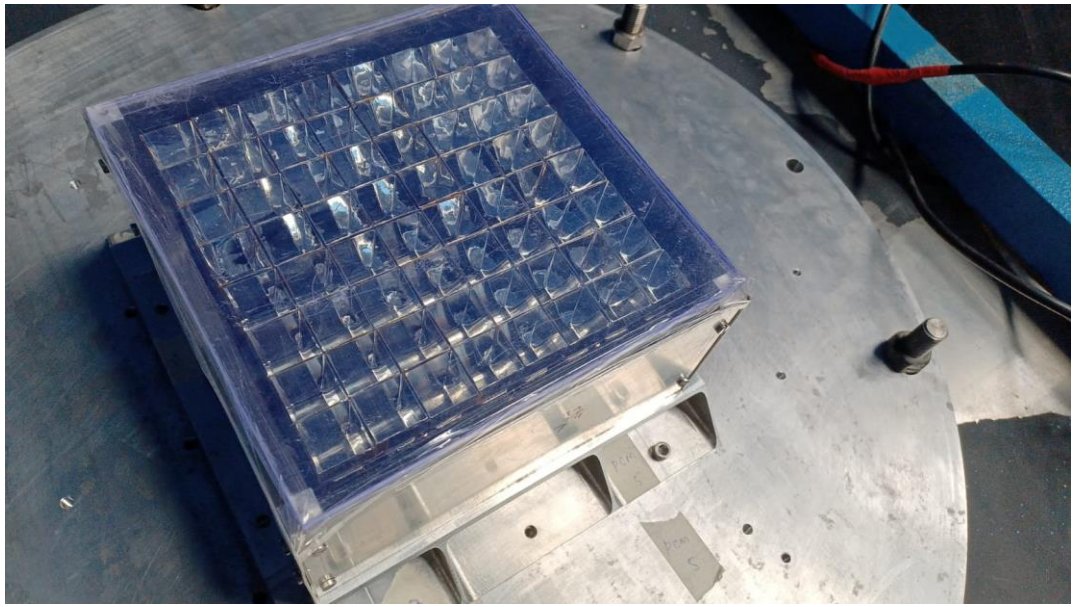




64-Pixel camera Assembly and Mounting on TACTIC







Current Status and Future plans

- 64 pixel prototype camera is now installed on one of the TACTIC telescopes in Mt Abu, Rajasthan.
- It would be the first time that the mini camera would be exposed to night sky in Mt Abu. The camera would be put to tests during the 2 observation seasons before monsoon sets in.
- Further refinement in the hardware and software design during monsoon in Mumbai Lab
- The camera tests with TACTIC to resume back after monsoon
- 256-pixel full camera to be ready by March, 2022.

Our Team

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…Thank you…