AMIGA at the Auger Observatory: The PMT testing facilities and their application in CTA

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Test Facility characteristics

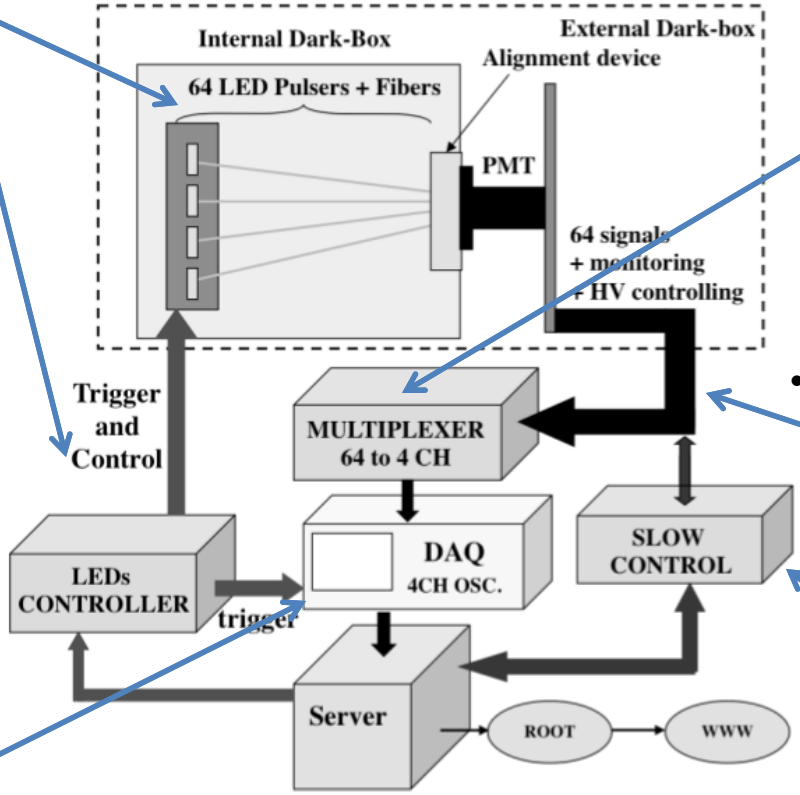
- Test and characterize each of 64 pixels of the Hamamatsu H8804-200MOD.
  - Complete PMT test takes 1 day, test rate ~3 pixels/Hr (includes re-tests).
  - Easy operation, QA and safety plans implemented.
  - Stable system during testing
  - Expected total number of PMTs to be tested are approximately 400 (including spares)

- <u>Features</u>
  - Low systematic errors (low cabling attenuation and Crosstalk).
  - Good Electromagnetic Compatibility (improve SNR)
  - Good Optical Shielding
  - Optical coupling & alignment
  - Temperature monitoring inside the darkbox
  - Object oriented programming
    - Test system framework to control the instrumentation and to perform the data analysis
  - Database : root Files, plots & data files

Test Facility – **Setup description**

•Light Source:
- LED controller + 64 blue LED pulsers
- LED coupled with the PMT by 64 WLS fibers (as in the detector)

Two Dark-box for Optically shield



• RF Multiplexer (64 to 4)

• Cabling
- 50 ohms transition line.

•Acquisition System:
- 4 ch oscilloscope (1,5 GHz ; 10 GS/s)

•PC System (Server)
- System control & Data analysis

•Slow control:
- HV & Monitoring

PMT Testing - **Tests Performed**

- GAIN
  - Not used for AMIGA but necessary for PMT calibration for test system and modules R&D and scanning

- SPE (Peak)
  - This test help us to know if the PMTs can resolve the SPE peak distribution from the pedestal.

- DR
  - Affect to the over-counting
  - Affect to the anode life time

- XT
  - Affect to the over-counting

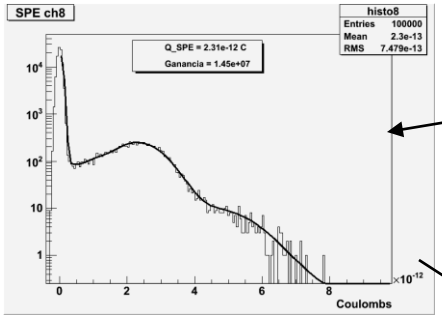
Specifications to be defined by the Analysis group

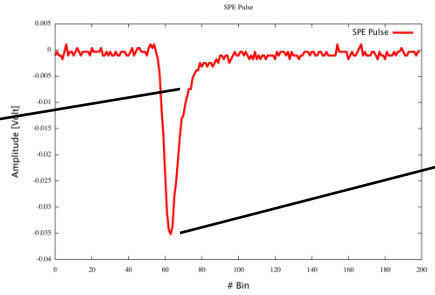
PMT Testing - **SPE**

- **Definition :** SPE study gives the distribution of the charge gain and pulse peak value.
- **Procedure**

Fire the LED at a low intensity to ensure that ~10% times SPE pulses are seen

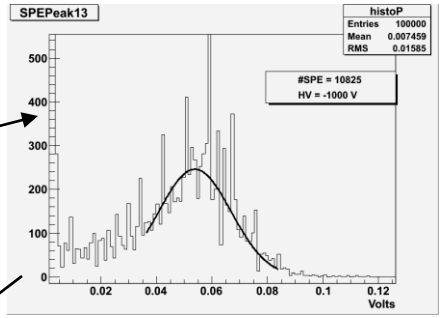
Charge histogram

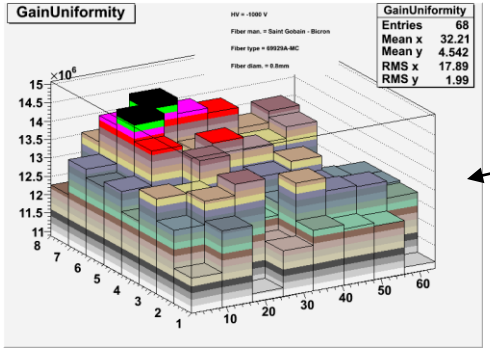




X 100.000 frames

Peak histogram





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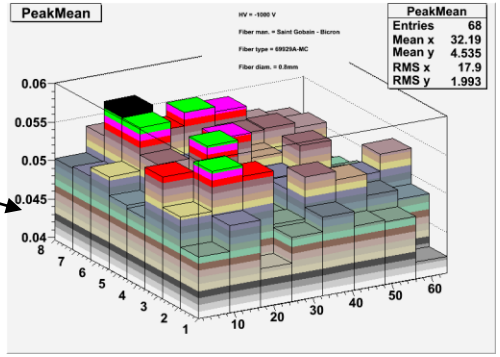

PMT Testing - **DR**

- **Definition :** Rate of pulses at the PMT outputs above a threshold (1/3 PE) with no photo-cathode excitation
- **Procedure**

Turn off the light source and acquire output pulses obtained in a period “T” (after 10 hs cool down).

$$DR = \frac{\#\,Pulses}{T}$$

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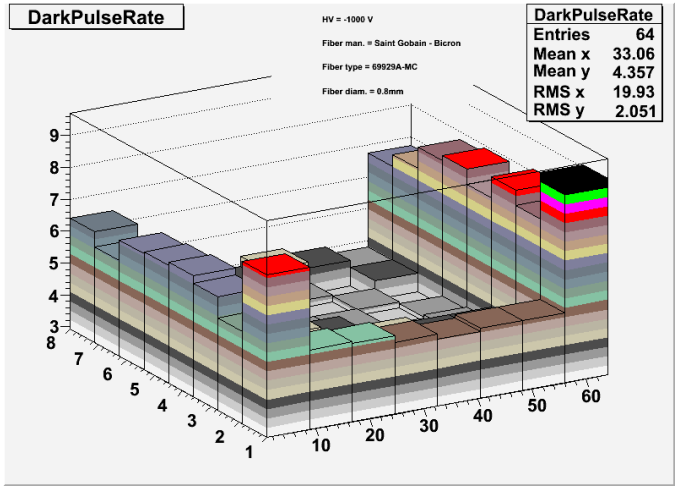


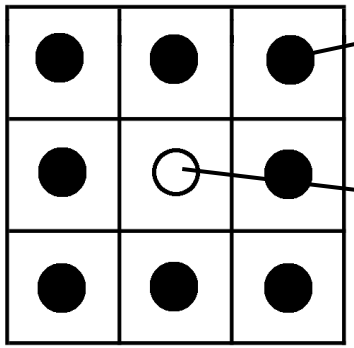
PMT Testing - **XT**

- **Definition :** Ratio of the currents measured between two different channel anodes when the photo-cathode region corresponding to only one of these channels is excited.
- **Procedure :**

Excite a central pixel and get total charge of both anodes. Integrate the surrounding pixel from the 1/3 SPE threshold.

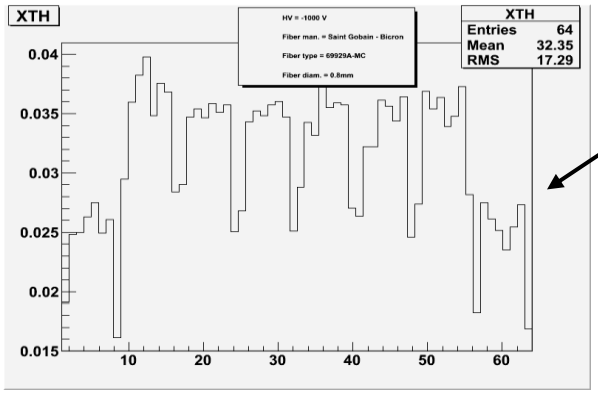
Gain is need to get the PE´s equivalent

Study of one Pixel (example)



$$XT_{ij} = \frac{G_i}{Q_i}\frac{Q_j}{G_j}[\%]$$

PMT_ID.ROOT



0.31	1.04	0.29
0.58	100	0.8
0.3	1.06	0.3

$$XT_i = \sum_j XT_{ij}$$

Tests being developed - **AP & QE**

- **AP**
  - **Definition :** Unwanted signals that appear at a delayed time from the main pulse (Event). These after-pulses could be counted as a event if the signal is above 1/3 phe.
    - Two kind of AP are being detected:
      - AP (delayed signal in the same anode)
      - Correlated After Pulses (CAP, delayed signal in other anode correlated with a main pulse in other pixel).

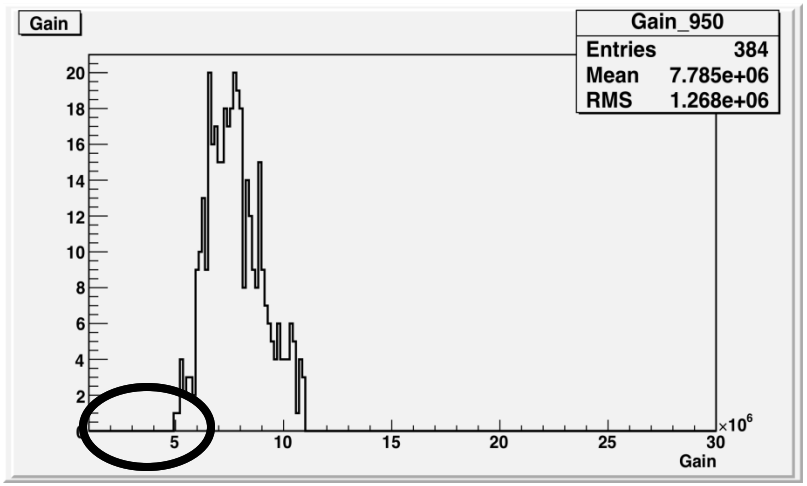
- **QE**
  - **Definition :** Ratio of the number of electrons that leave the Photo-cathode to the number of incident photons on the photo-cathode.
    - we cant measure QE because the PMT is into a casing
      - So, we have to measure relative QE.

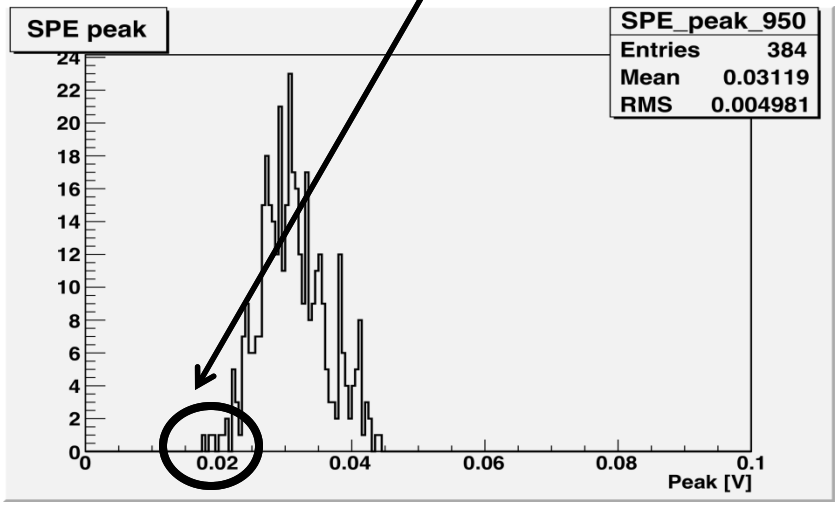
WORKING ON…..

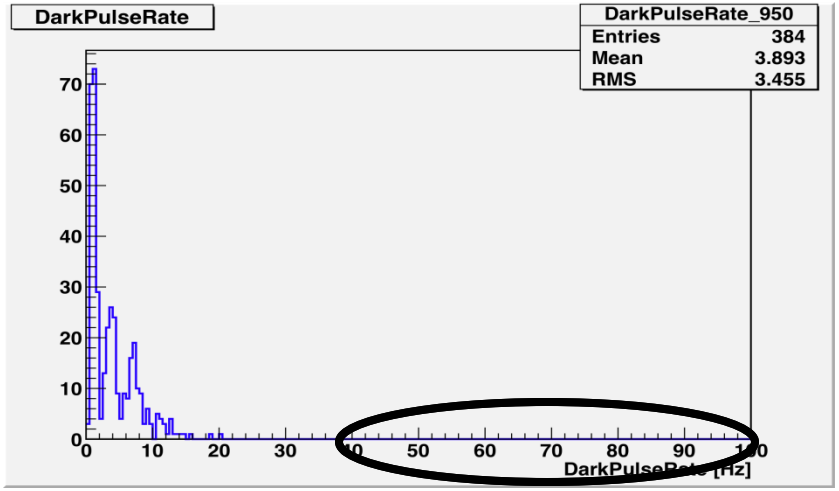
Results – **Gain, SPE(peak), DR, XT**

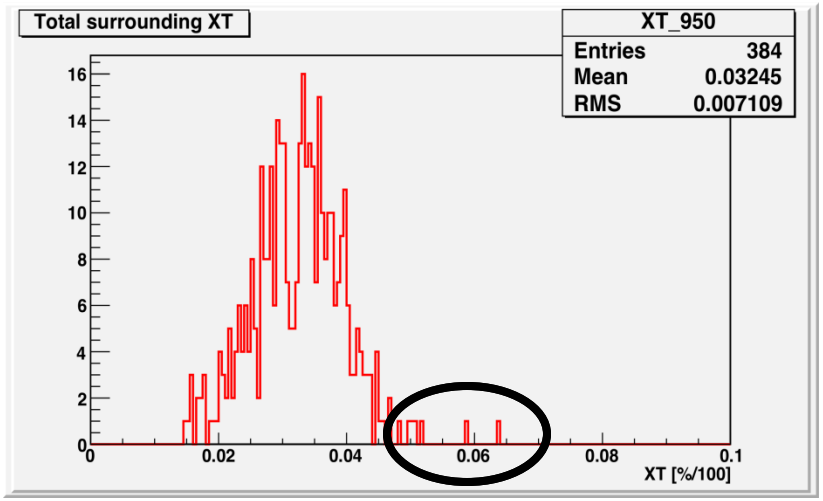
- All pixels of 6 PMTs tested (64 x 6 = 384)
  - HV=-950V with a 0.8mm Bicron WLS Fiber

Warning PMTs



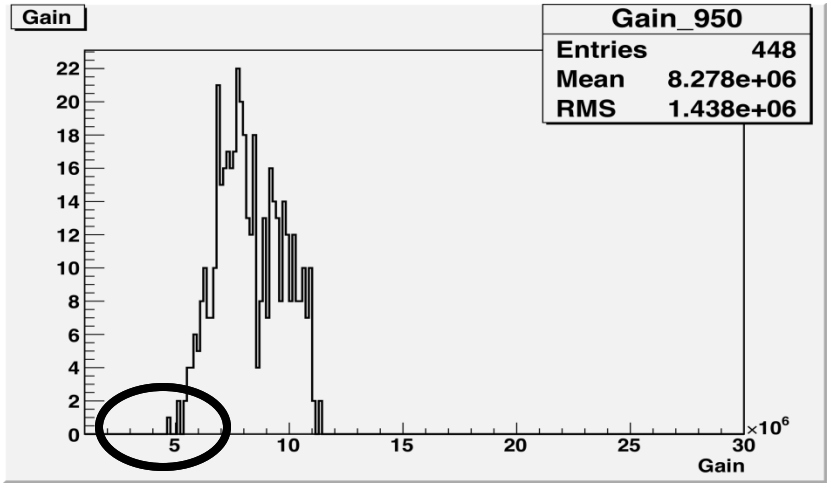


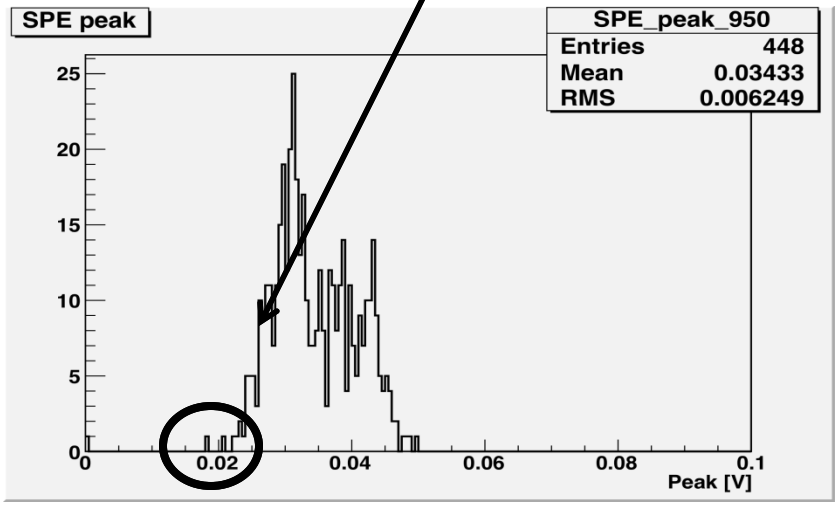


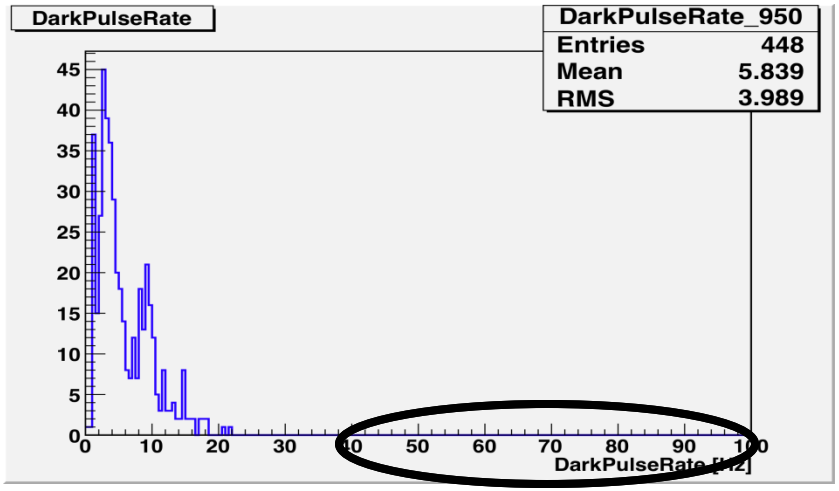


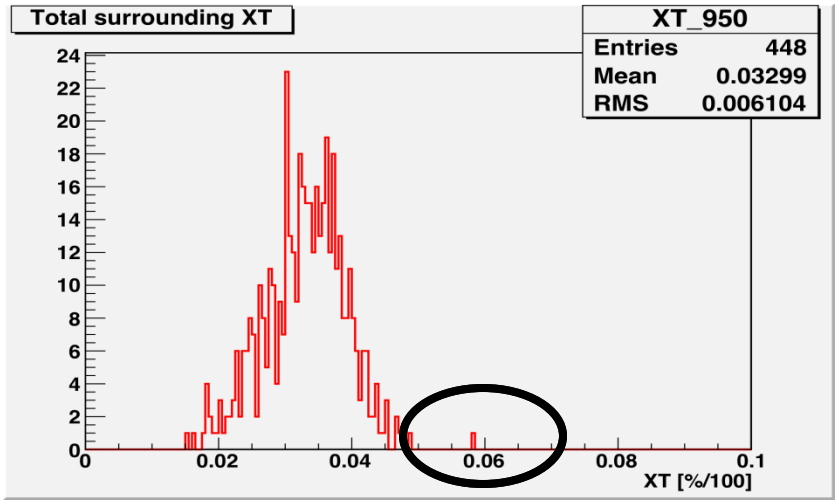
Results – **Gain, SPE(peak), DR, XT**

- All pixels of 7 PMTs tested (64 x 7 = 448)
  - HV=-950V with a 1.2mm Bicron WLS Fiber









PMT Testing – **Improvements**

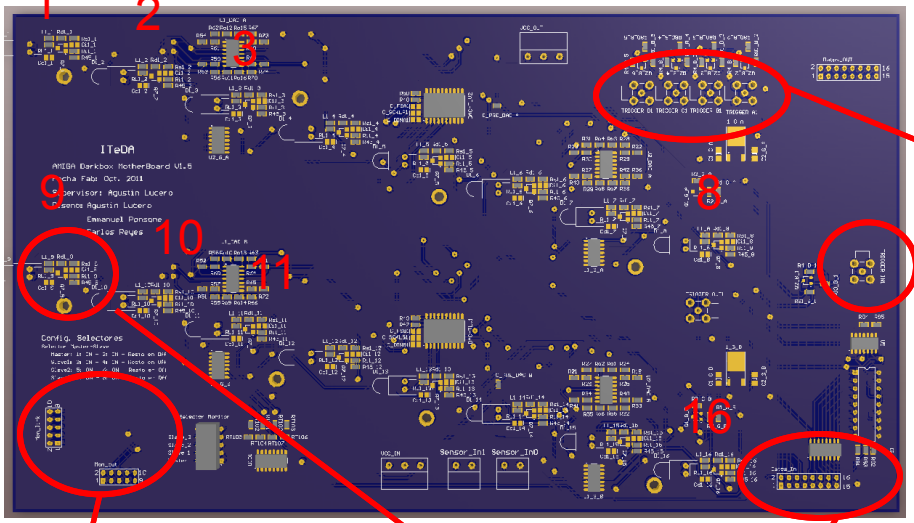
- Implement Effective quantum efficiency test (Eqe = Qe x Ce)
  - *Install New Darkbox system design that support effective quantum efficiency test & prevent dead times due to failures (Darkbox 2.0 : Design and construction ready)*
  - *Enhance monitoring system (HV, Light source power supply)*
  - *Develop software & integration (to be done)*

- Implement Afterpulsing test (AP)
  - *Install new multiplexer for Improving signal integrity (Done)*
  - *Develop software & integration* (to be done)

- Test System Performance
  - Reference PMTs to test long term Stability of the system (Working on)
  - Understand systematic uncertainties
    - Hardware : Cabling attenuation (Done)
    - Method and analysis used in each test (Working on)

- Database implementation available for collaboration members (working on)

PMT Lab – **Light Source (EQe, AP)**



16 LED Flasher and trigger are integrated in the same board.

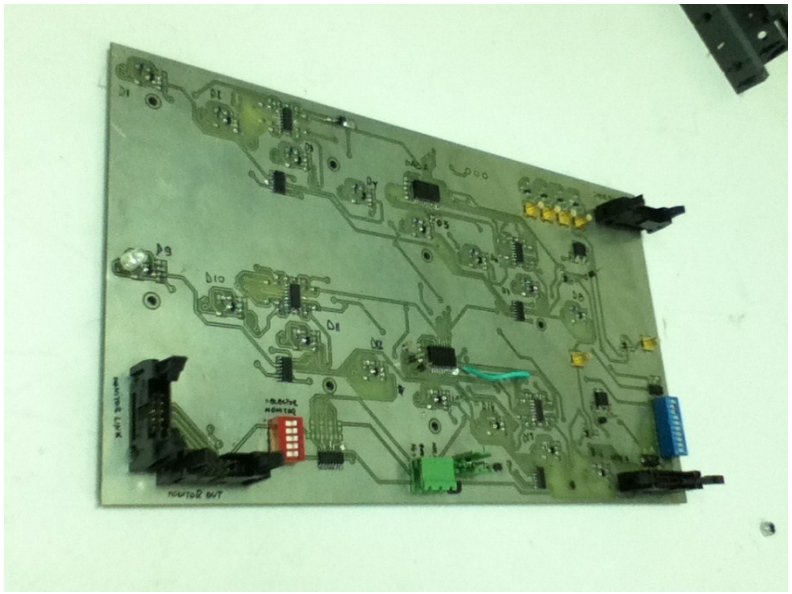
Trigger Distributor

Trigger Input

Monitoring Output

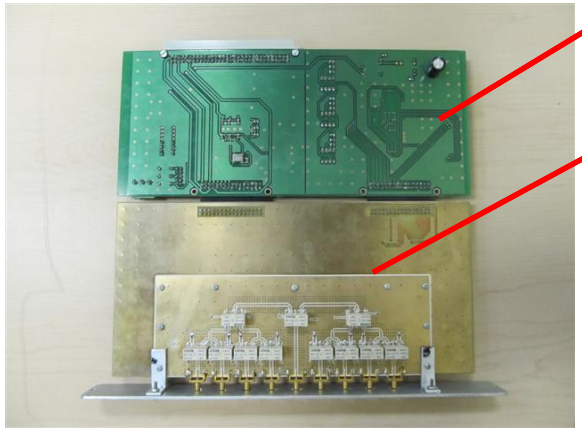
Integrated Led Flasher

Data input



Prototype of new Light Source board made at ITeDA. The new Light Source was designed to be controlled by present hardware (LED Controller)

PMT Testing – **Multiplexer (AP)**

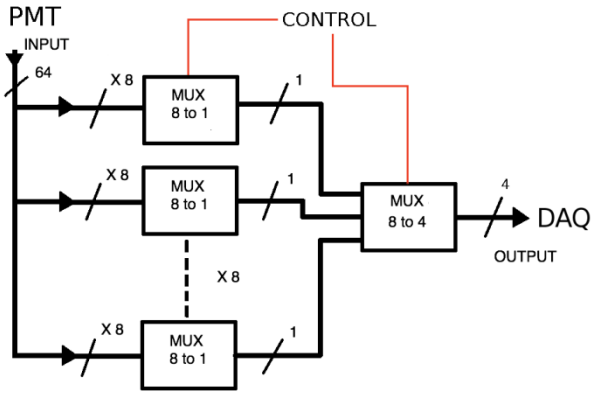


Digital Control Board

8 inputs to 1 output Analog board (~1GHz)

- Tyco 3Ghz Relays
- 4 Layer for High Frequency

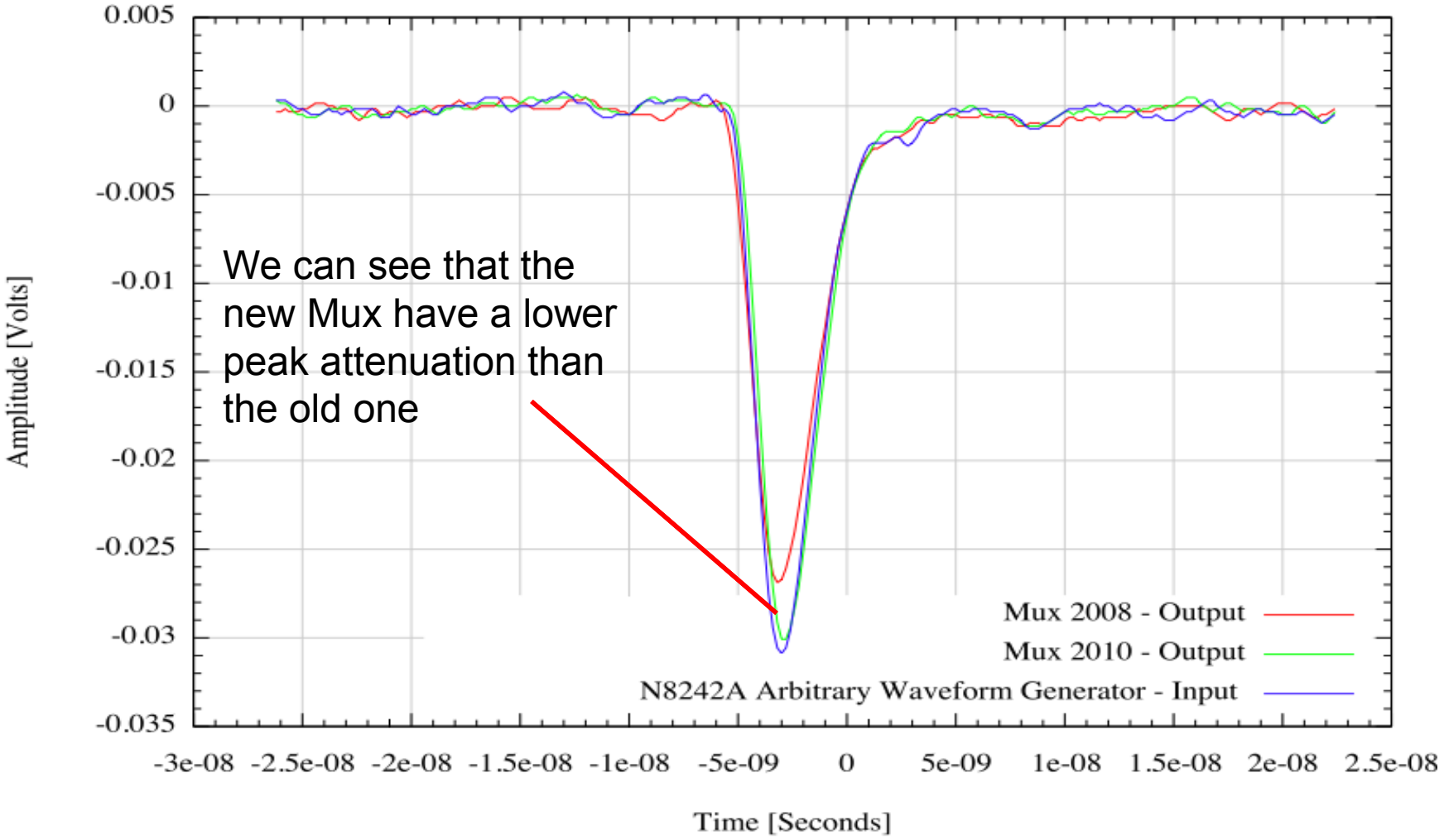
8 to 1 module for the new Mux



Schematics Diagram

Multiplexer 2.0 at ITeDA

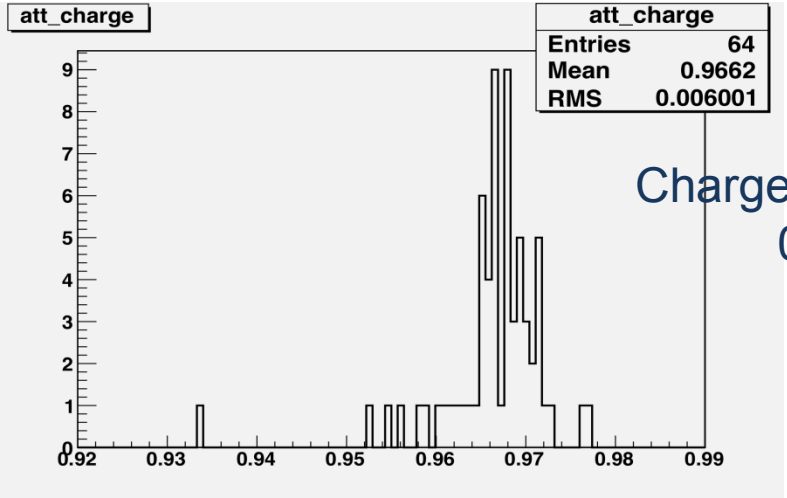
PMT Testing – **Multiplexer (AP)**



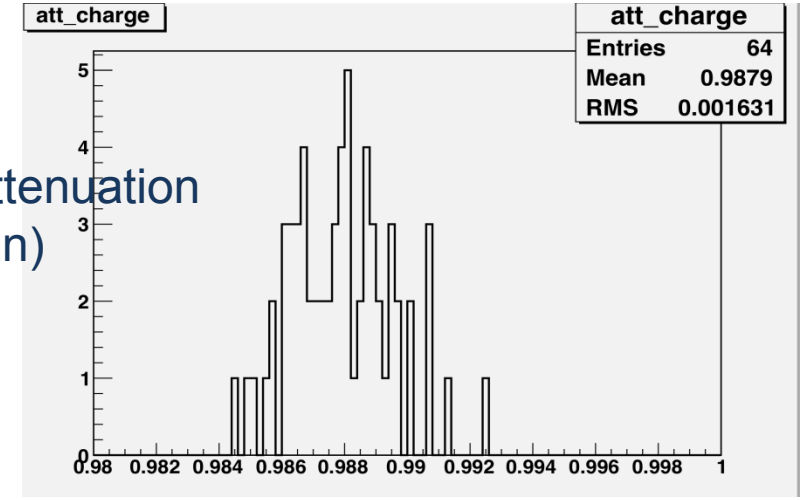
Comparison between the output of both multiplexer for a same input signal

PMT Testing – **Hardware:** systematic uncertainties

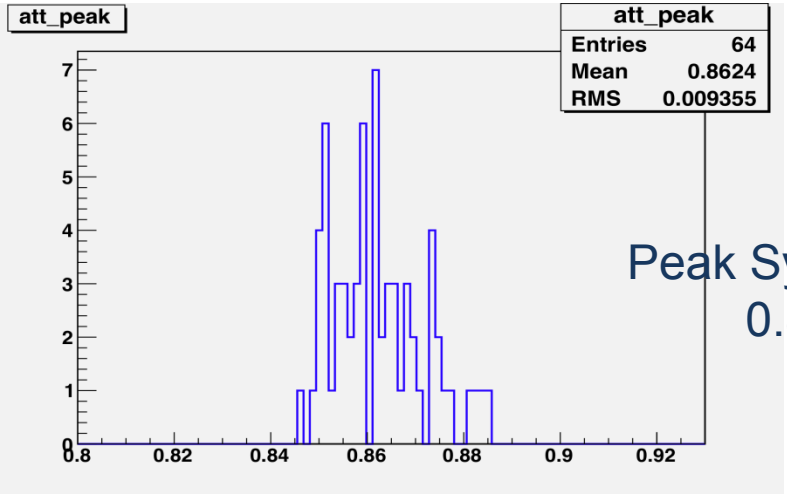
Cabling attenuation



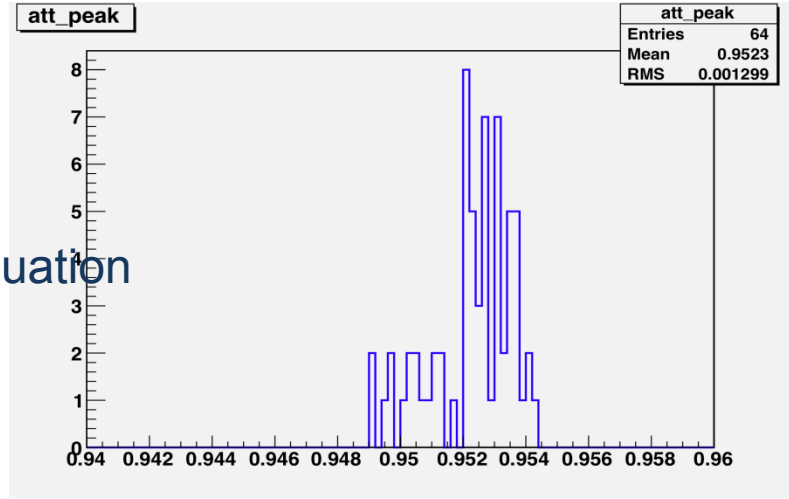
Multiplexer attenuation



Charge System Attenuation
0.954 (mean)



Peak System Attenuation
0.821 (mean)



An application to CTA: Advantages and Challenges

Advantages:

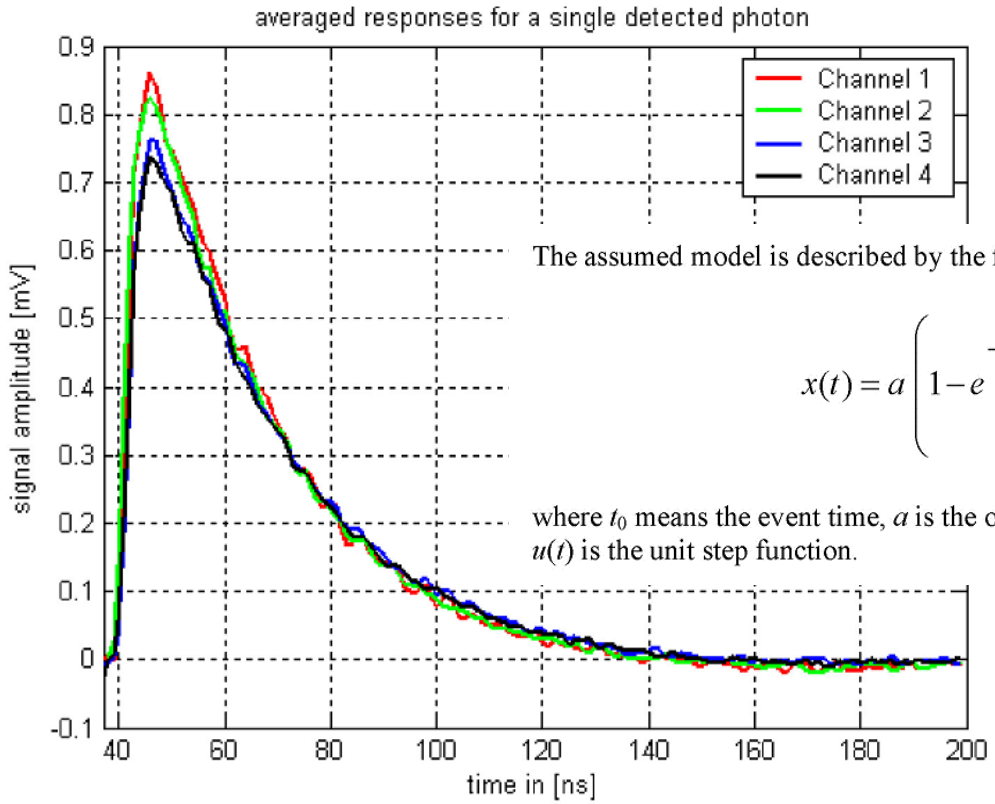
1. An already developed hardware and software DB
2. Dark box currently working
3. Cabling and multiplexing already installed for multiple channel PMs

Challenges:

1. The light source must be adapted to allow laser flashing for Si PMs
2. The Dark box must be adapted to a climate chamber to allow a precise control of temperature
3. The High Voltage ranges must be modified

Si PMs: A Typical Pulse Response

S10985-050P (SMD) 6mm^2 from Hamamatsu



The assumed model is described by the following formula

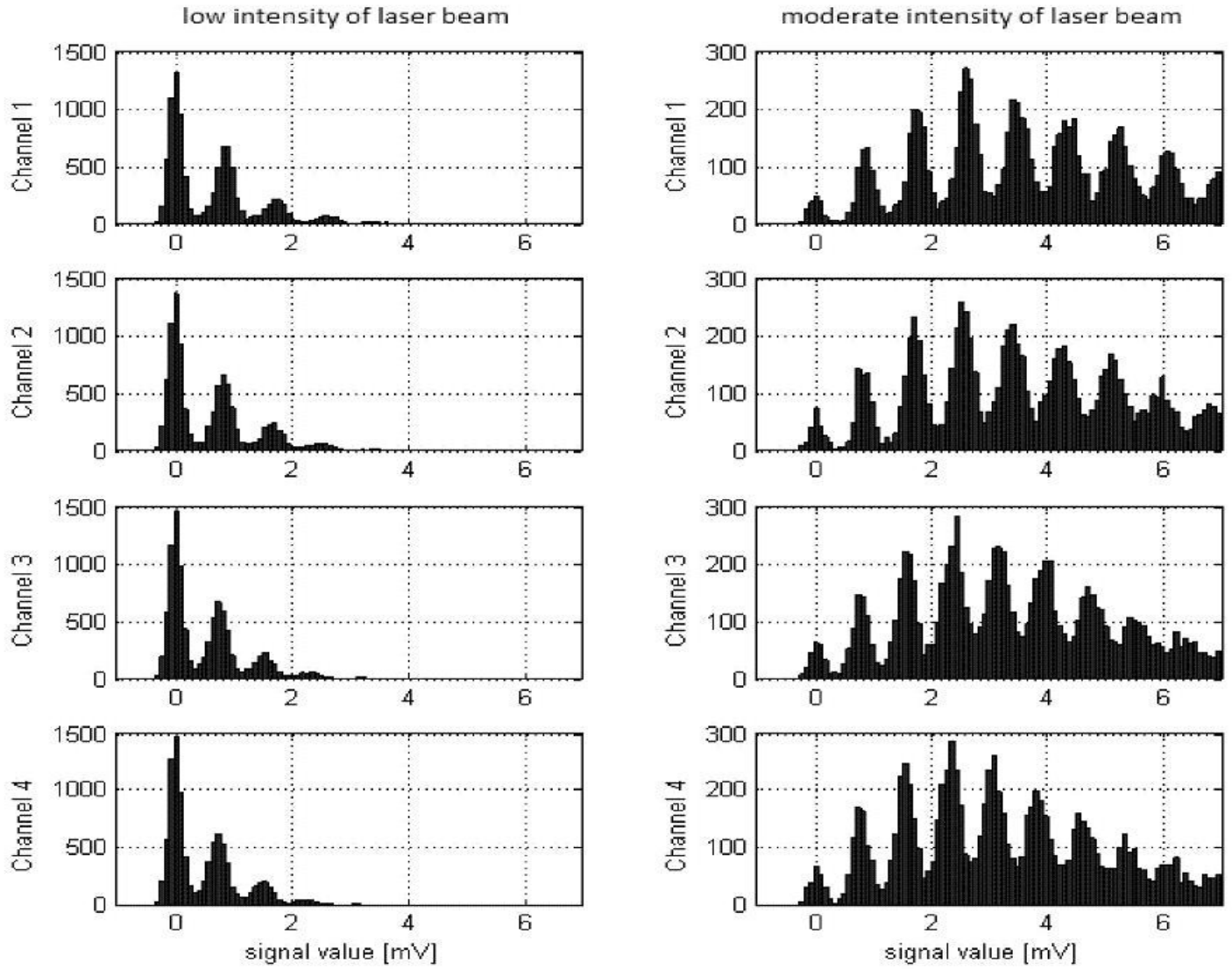
$$x(t) = a\left(1 - e^{-\frac{t-t_0}{\tau_1}}\right)\left(e^{-\frac{t-t_0}{\tau_2}}\right)u(t-t_0)$$

where t_0 means the event time, a is the overall gain of the system, τ_1 and τ_2 are time constants. Term $u(t)$ is the unit step function.

Channel	N	τ_1 [ns]	τ_2 [ns]	a [V]	t_0 [ns]
1	1994	3.14	22.59	0.001279	39.83
2	1998	2.93	23.01	0.00121	39.67
3	2137	2.65	25.22	0.00105	40.50
4	2057	2.87	25.02	0.00105	40.35
weighted average	8176	**2.74**	**24.04**	0.00113	40.20

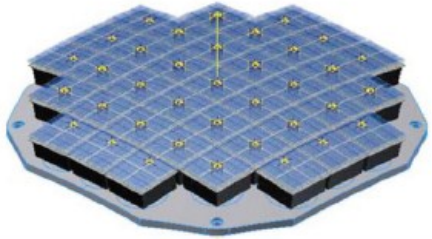
Si PMs: Test results w/laser pulser

S10985-050P (SMD) 6mm^2 from Hamamatsu

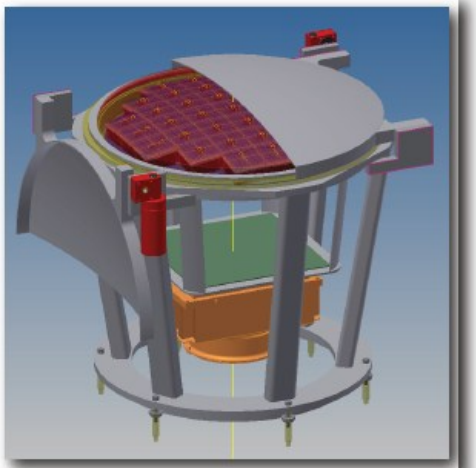


Application to CTA: The ASTRI camera

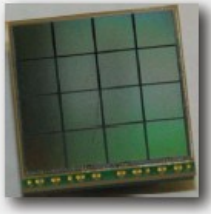
Mechanical housing drawing and 37 Photon Detection Modules mounted on the mechanical housing.



Mock-up of the mechanical housing + PDMs and sketch of the ASTRI Camera with the Camera-Telescope I/F.



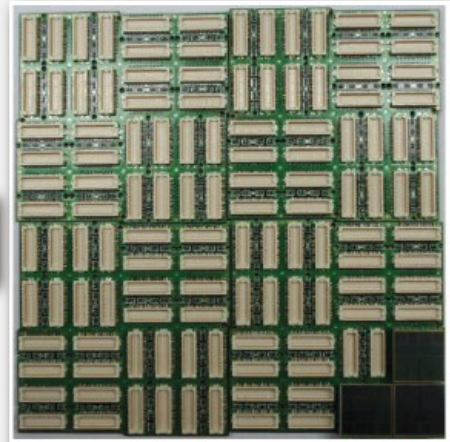
SiPM 4x4 Board n.1



Photon Detection Module - Board n.2

PDM top view with mounted one matrix SiPM 4x4

Focal Plane PDM Mosaic

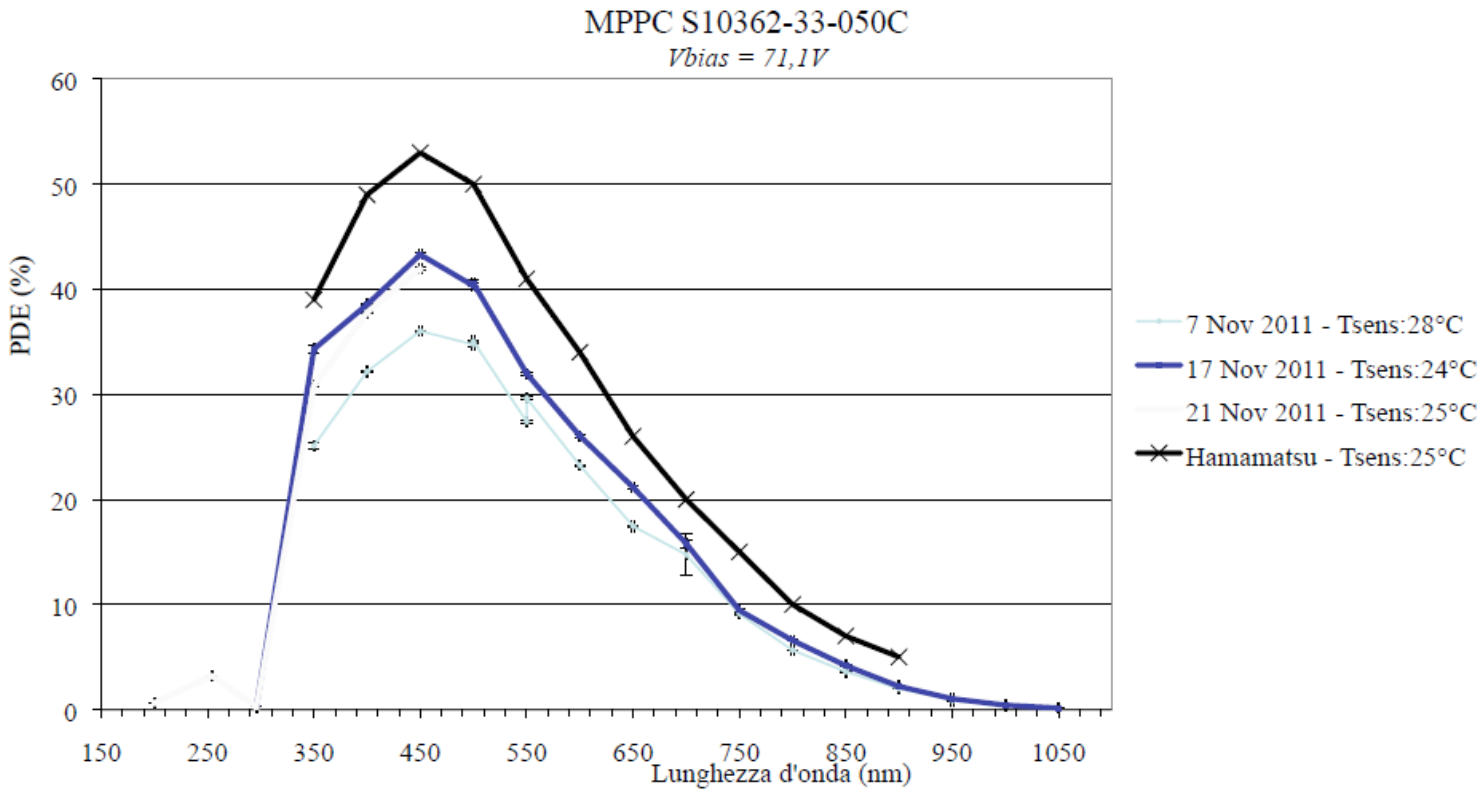


Mosaic of four PDM with mounted three matrix of SiPM 4x4

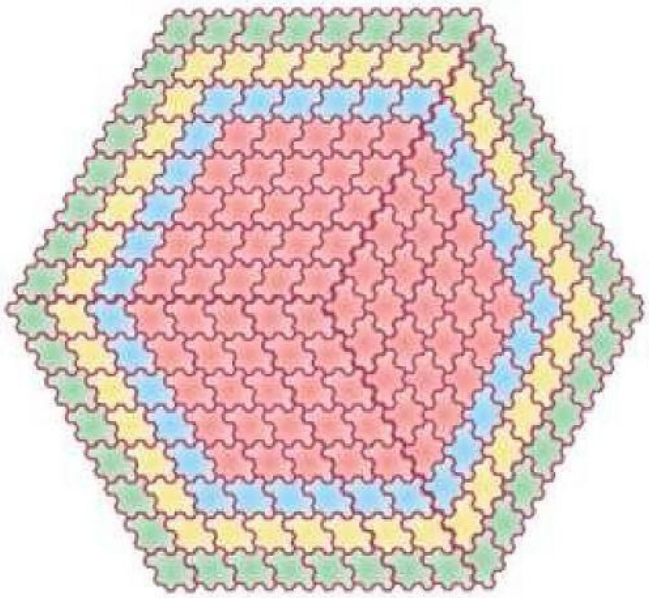
Application to CTA: The ASTRI camera

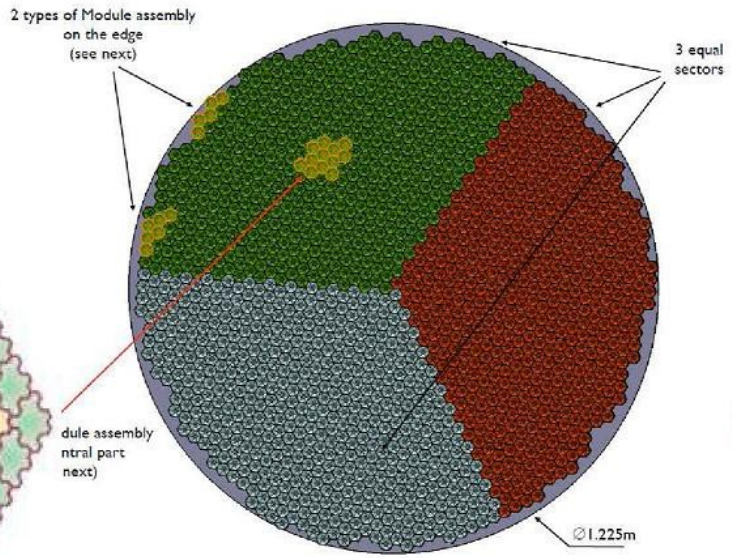
QE for the S11828-3344M from Hamamatsu

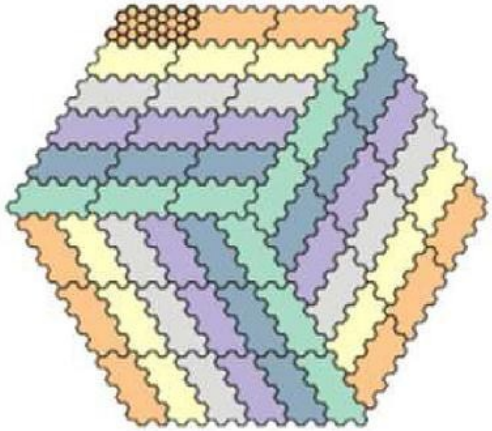
Photon Detection Efficiency measurements



Application to CTA: The 4m telescope PDP flash camera







900 pixel, 1550 mm SST

1296 pixel, 1860 mm SST

1764 pixel, 2170 mm MST

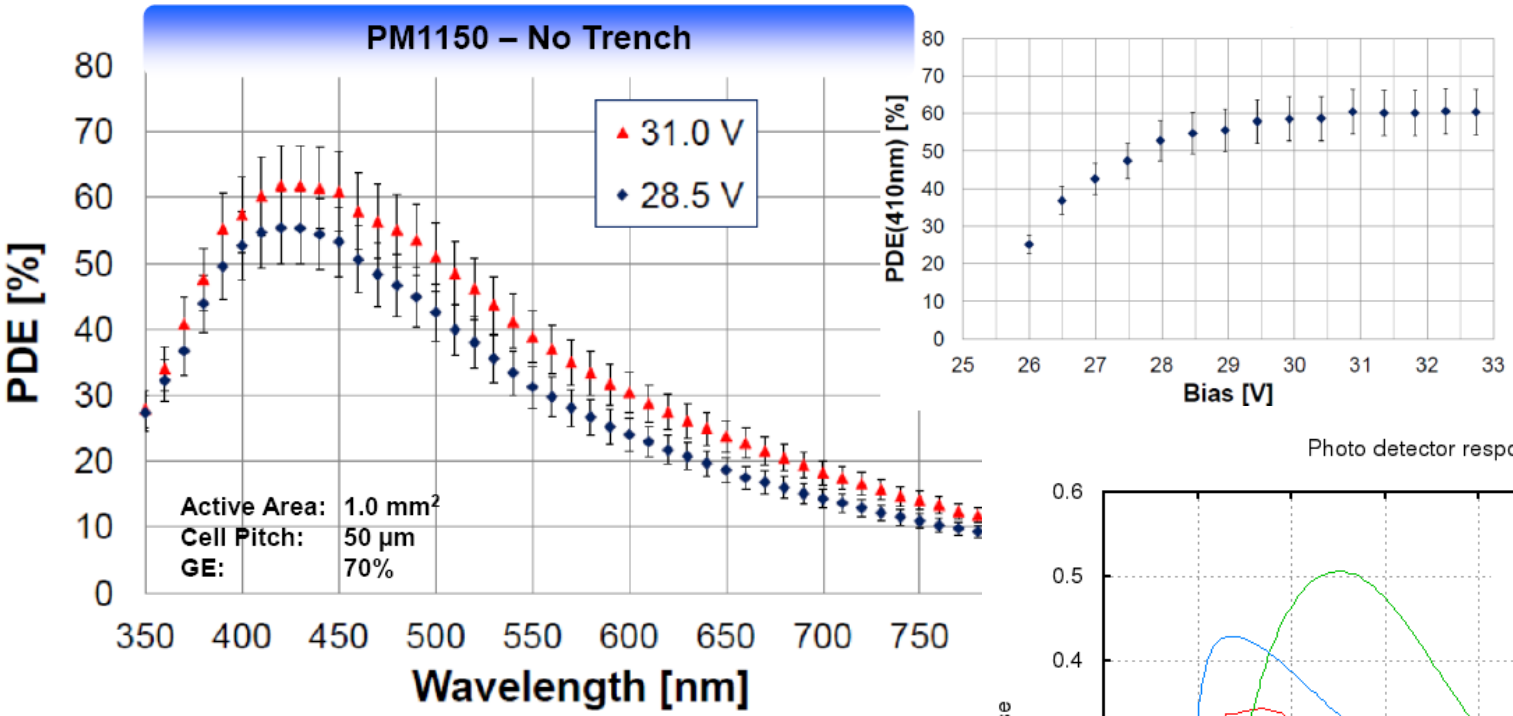
2304 pixel, 2480 mm LST

1626 Pixels:

- **1296 => 3s x 6c x 12p**
- **+330 => 3s x**
  - **15m x 6p (ma2)**
  - **4m x 5p (ma3)**

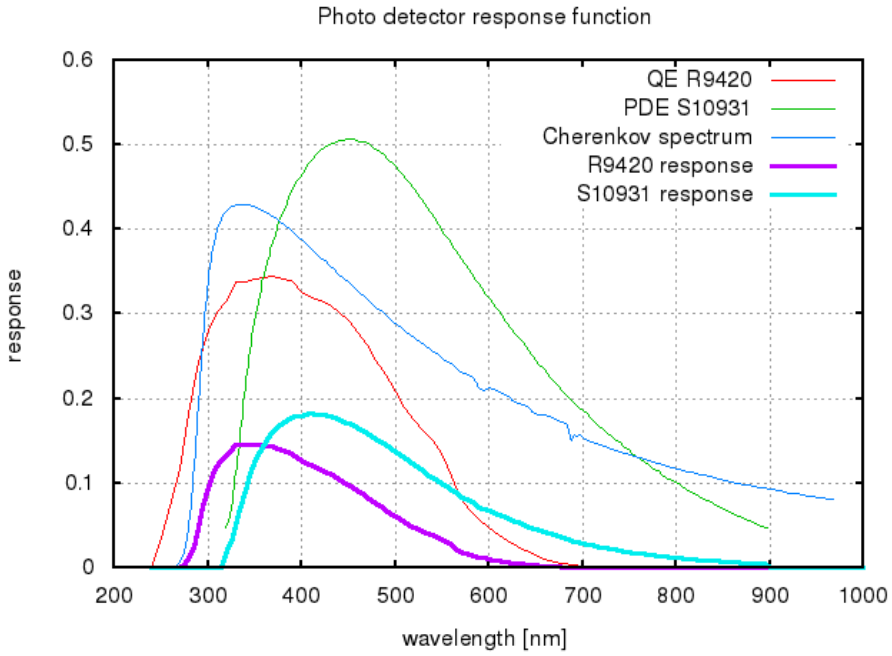
1296-pixel Compact Cluster

Photon detection efficiency measurements for other Si PMs



Tested photodetectors:

R9420 by Hamamatsu
PDE S10931 by Hamamatsu
PM1150 by Ketek



Conclusions

We present a testing system for photomultipliers already implemented for the AMIGA project at the Pierre Auger Observatory

We showed the system performance and the uncertainties

We show how it can be used for two of the CTA 4m telescopes cameras

As an important part of the R&D done for the Pierre Auger Observatory, most of our facilities can be used for CTA with minor modifications