# Status update for the Gamma-ray Cherenkov Telescope (GCT) camera's Front End Electronics

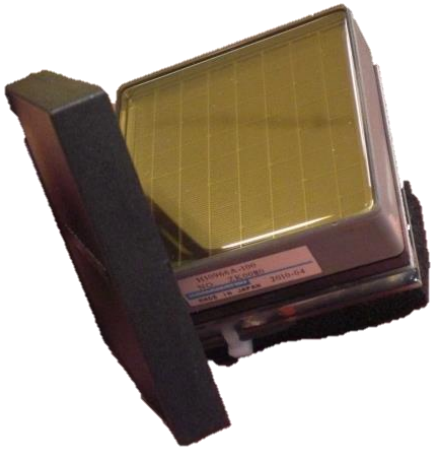
Andrea De Franco*

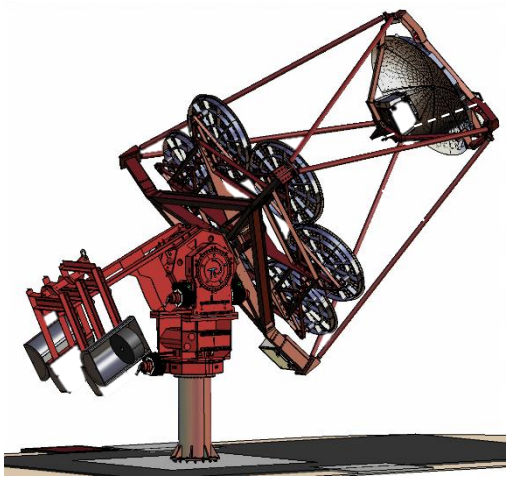
Supervisor: Garret Cotter

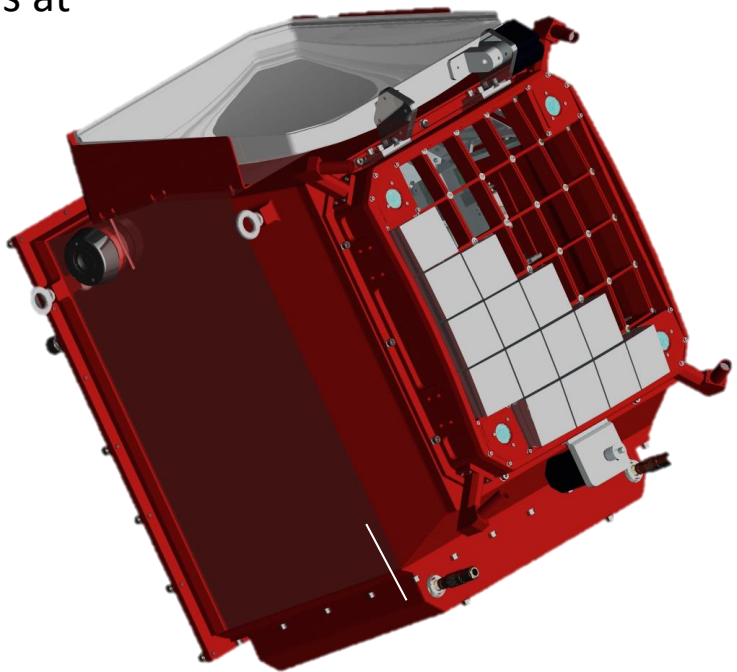
* Supported by the EU FP7-PEOPLE-2012-ITN project nr. 317446, INFIERI, "Intelligent Fast Interconnected and Efficient Devices for Frontier Exploitation in Research and Industry". ESR9

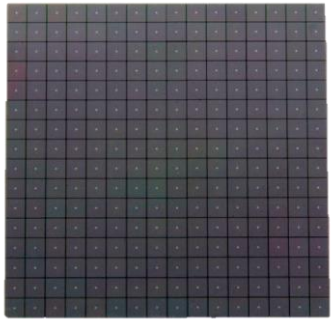
# The GCT Camera

- UK, US, Germany, Japan, Netherlands, Australia
  - 2 prototype cameras
    - CHEC-M based on MAPMs
    - CHEC-S based on SiPMs
  - At least 3 Pre-Production phase cameras
  - 35 Production phase cameras
- Philosophy: High performance at low cost
    - ~150 kE
    - Full waveforms (128 ns) from 2048 pixel at 1 GSample/s at an event rate of 600Hz









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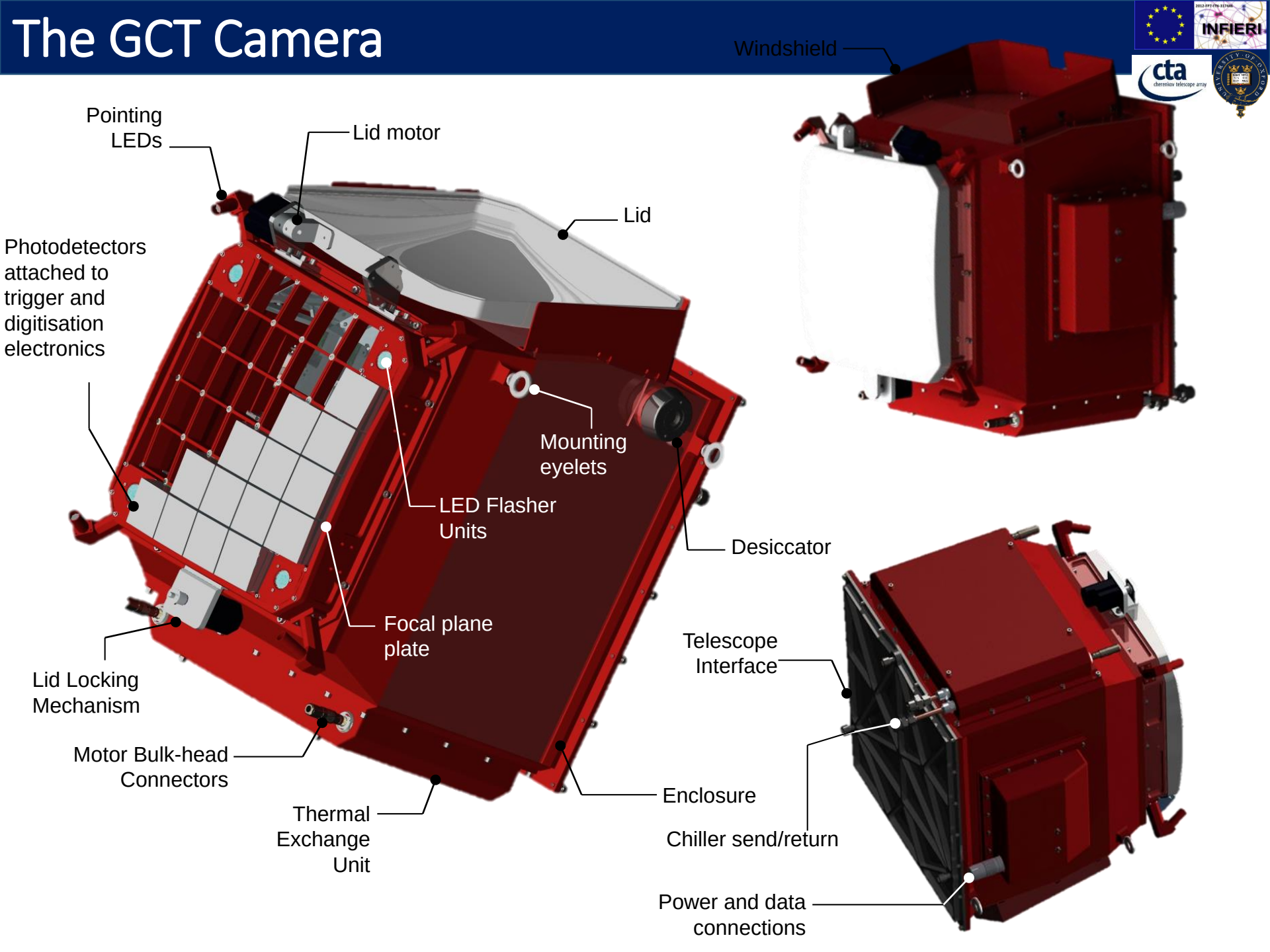

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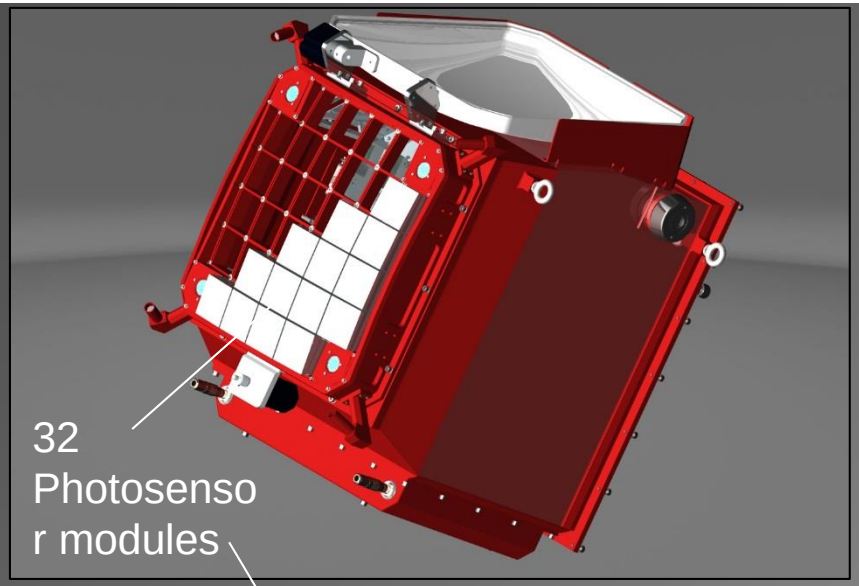


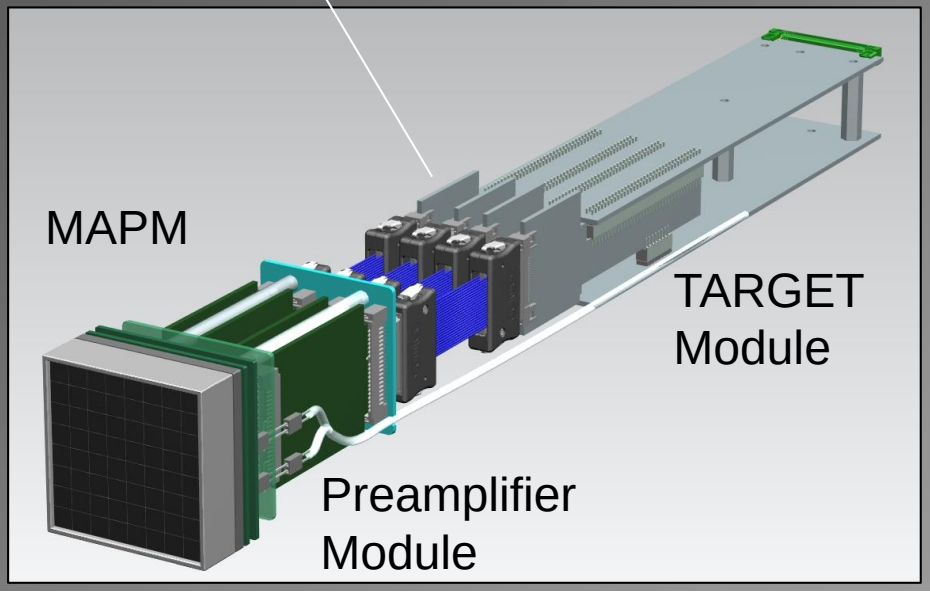


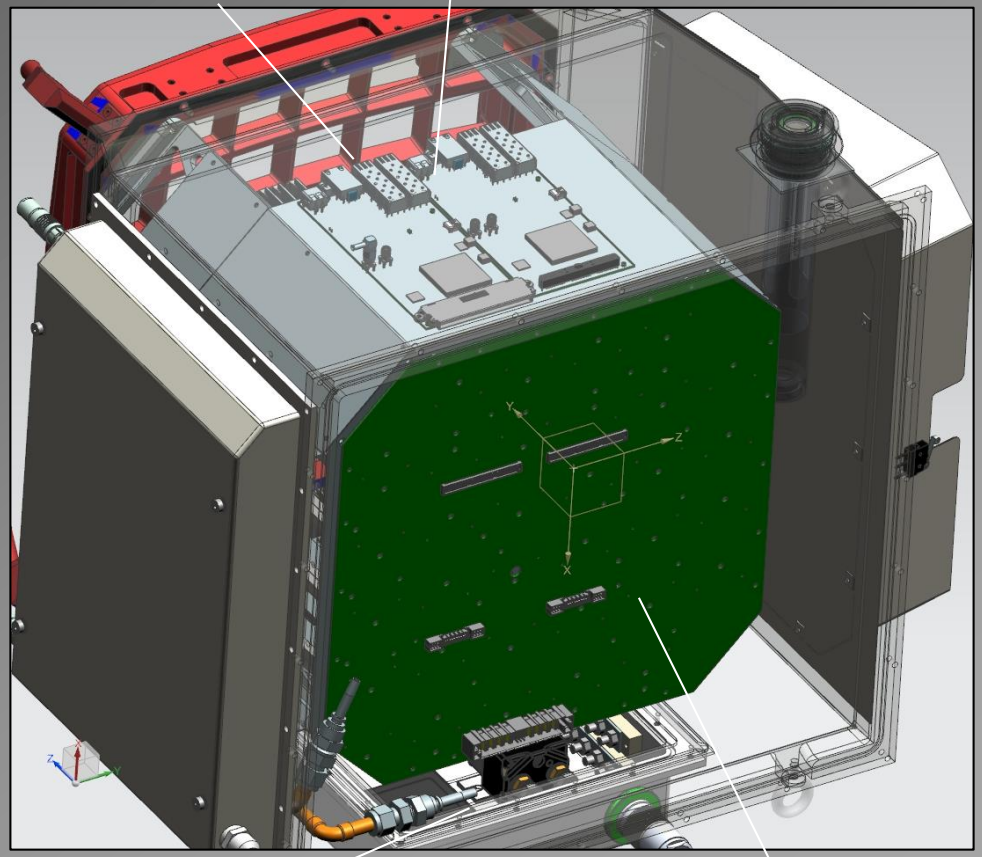

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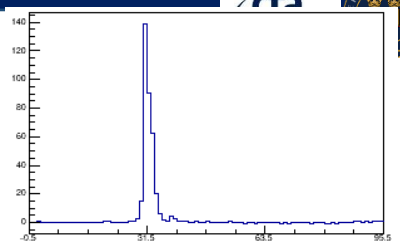


Buffering and Serialisation

Digitisation and 1st level Trigger

Amplification and shaping

TARGET Module

64 Pixel Module

16 x Preamp

TARGET ASIC

FPGA

Data x 64

Trigger x 16

Backplane Board

x 2048

64 Pixel Module

x 32

**1st Level Trigger**

Photosensor pixel

"super pixel"

Analog sum of 4 neighbouring pixels over threshold

**Camera Trigger**

2 neighbouring "super pixel" trigger

DACQ Boards

Data

Timing Board

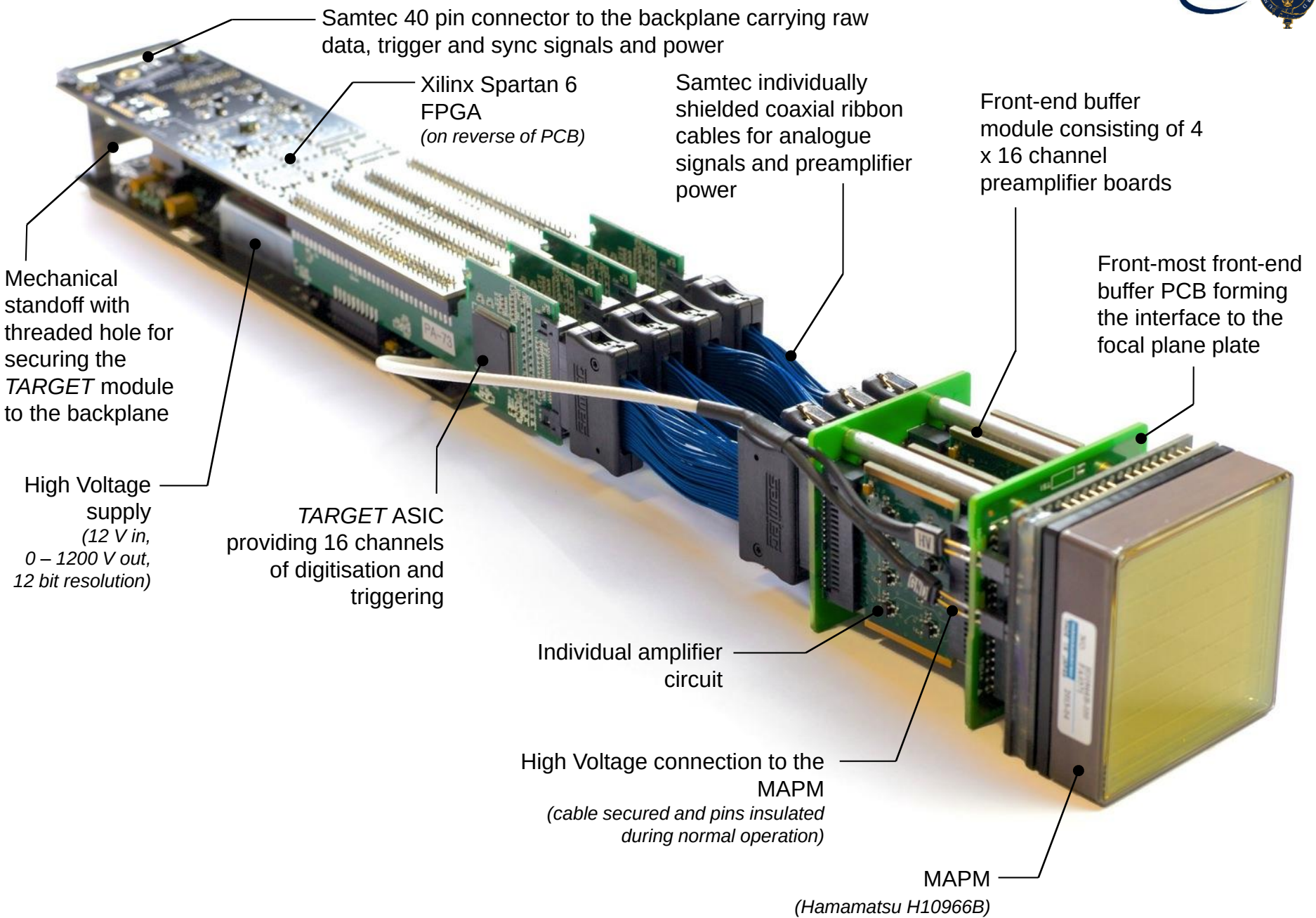
Clock, Timestamps

Peripherals (calibration, lid, etc)

Safety Boards

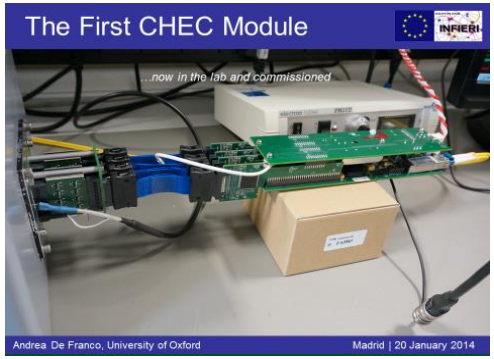
Control

# Front End Module - TARGET



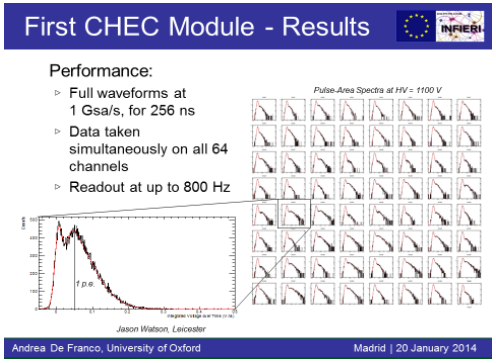
# CTA WP1 Deliverables ?

***CTA-Level1-Trigger*** *feasibility study.*
Month 12




From my slides in 2014

***CTA-Level1-Trigger*** *Prototype design.*
Month 36



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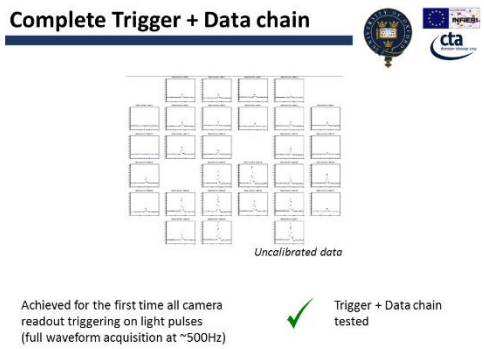


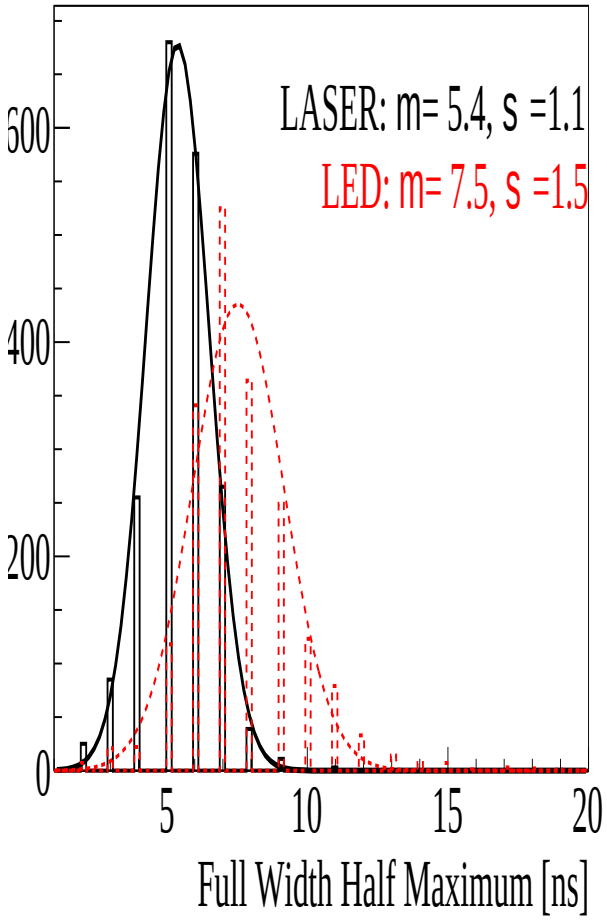

From my slides in 2015

***CTA-Level1-Trigger*** *Prototype design.*
Month 36

# Further Lab Measurement - Timing

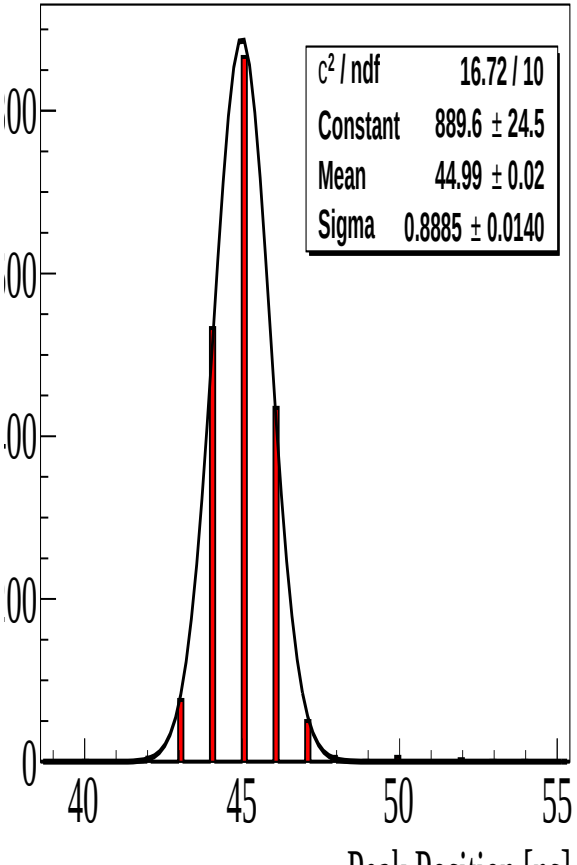
## Pulse width

- 5.4 ns (using 200 ps laser)
- 7.5 ns (using LED flasher)
- LED flasher performs as expected
- Monte-Carlo simulations indicated that 5.5. – 10.5 ns was optimal



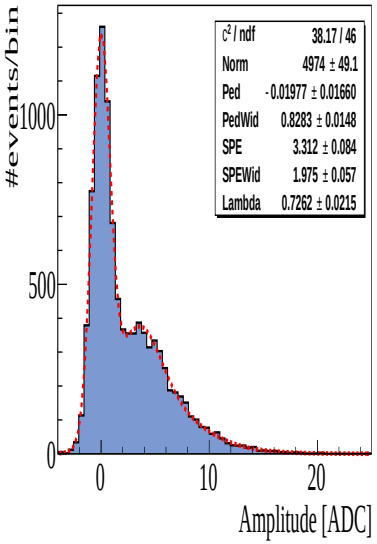

## Pulse arrival time

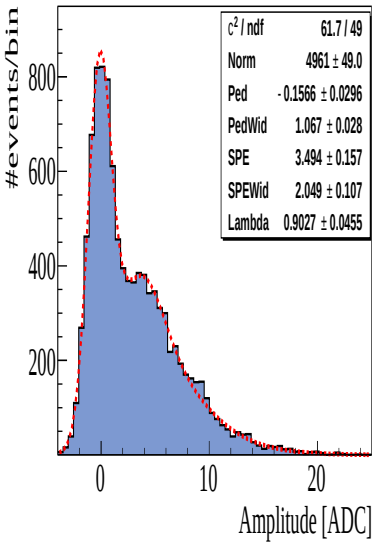
< 1ns (meets CTA requirements)

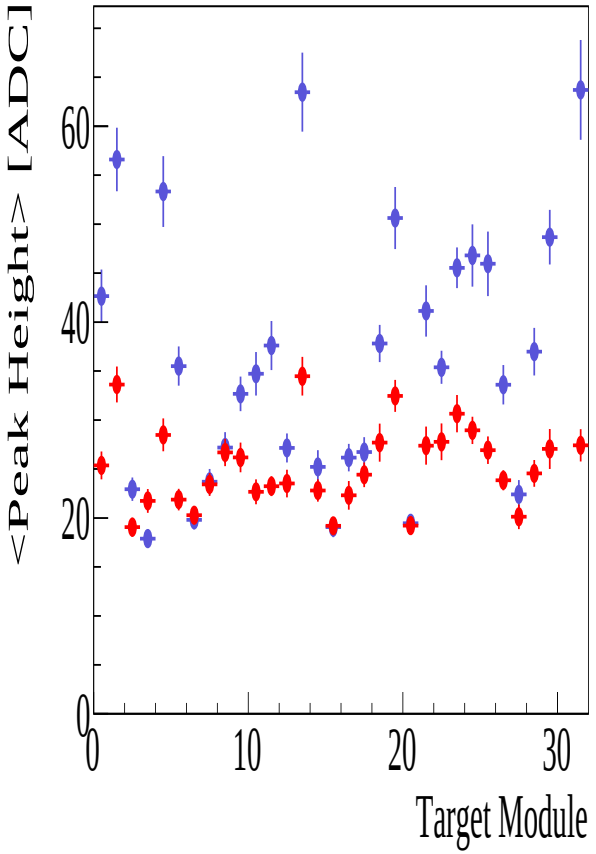


# Further Lab Measurement – Single P.E.

- Single P.E. measured for every pixel at 1100 V
  - Uniform illumination via laser in the lab
- Preliminary fit
  - Gain obtained
  - Final fit will use multiple pixels
- Average gain per MAPM used to set HV
  - Each MAPM only has 1 HV supply
  - Pulse height vs. HV used to extrapolate to obtain gain at lower HV



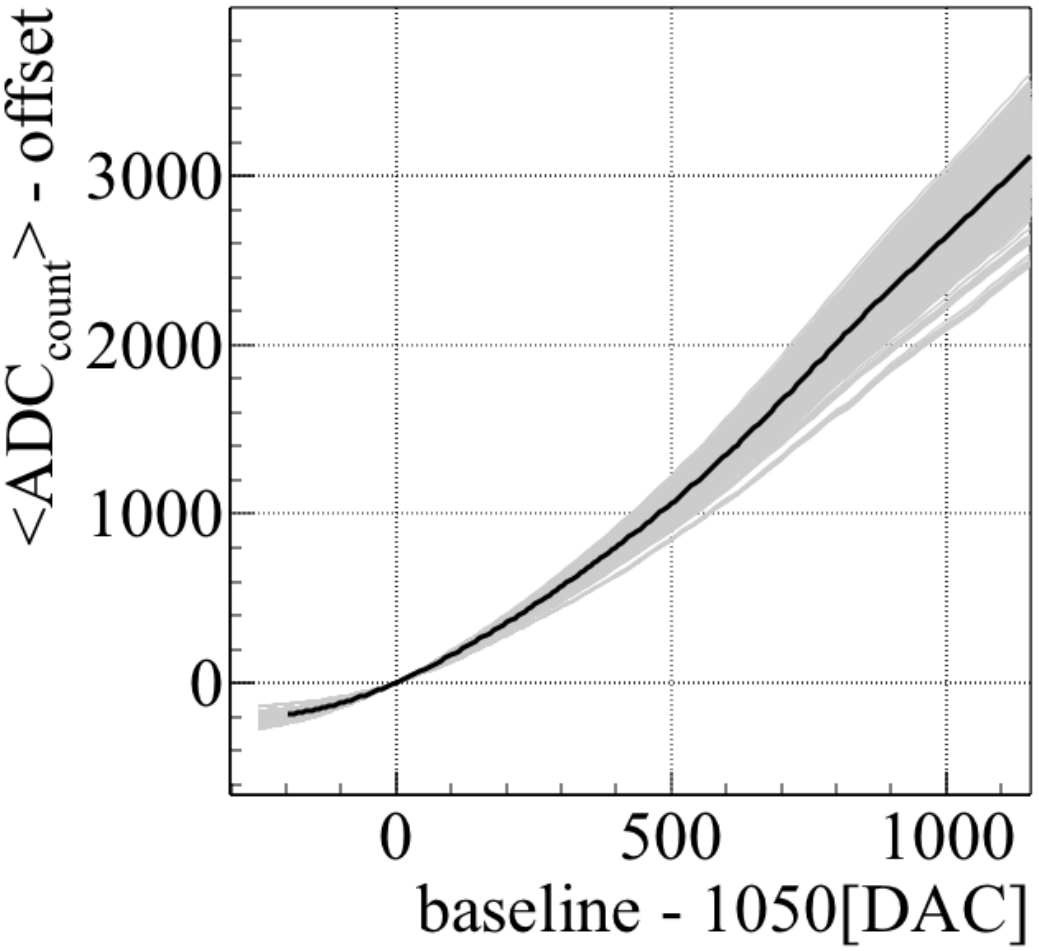




Before gain-matching

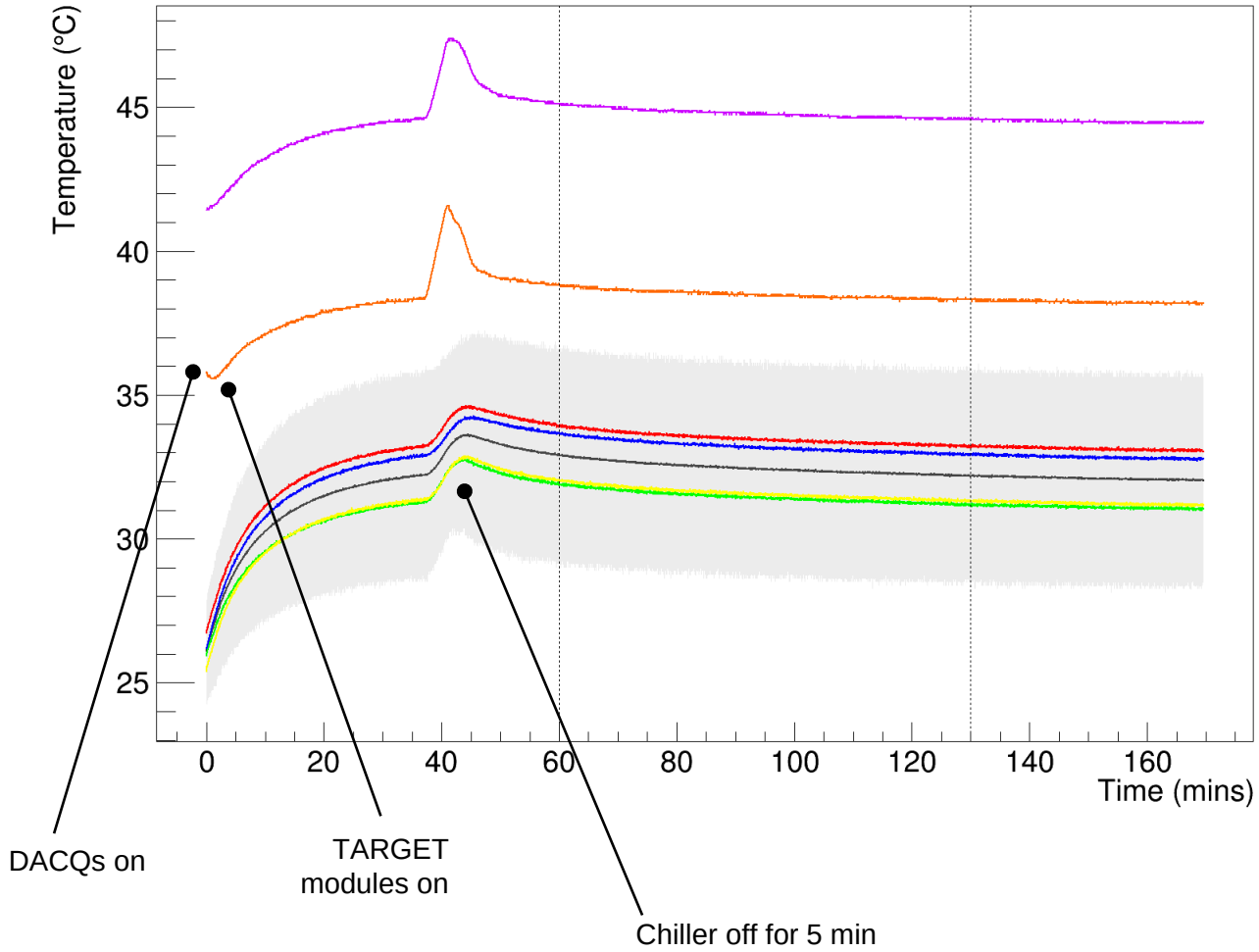
After gain matching (16% RMS)

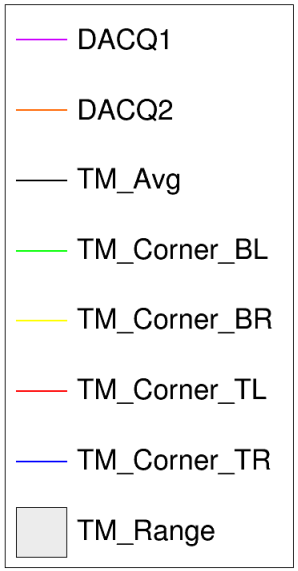
# Further Lab Measurement – Transfer Function

- Transfer function of each cell(16k) in each TARGET-5 ASIC measured
- Readout camera:
  - 128 ns x 2048
  - 500 Hz
  - Calibration run for entire camera takes ~3 min
- Averages of transfer functions per ASIC used as look-ups to calibrate raw ADC counts

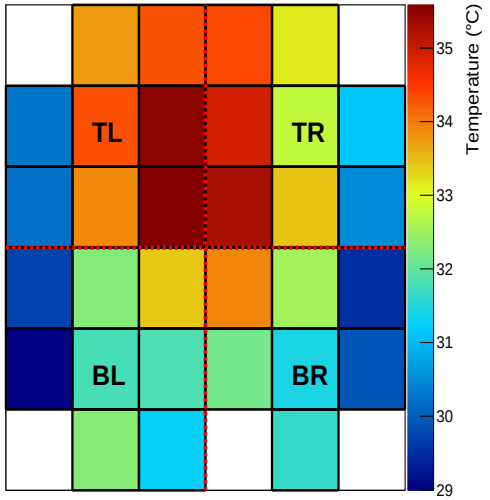


# Further Lab Measurement – Temperature

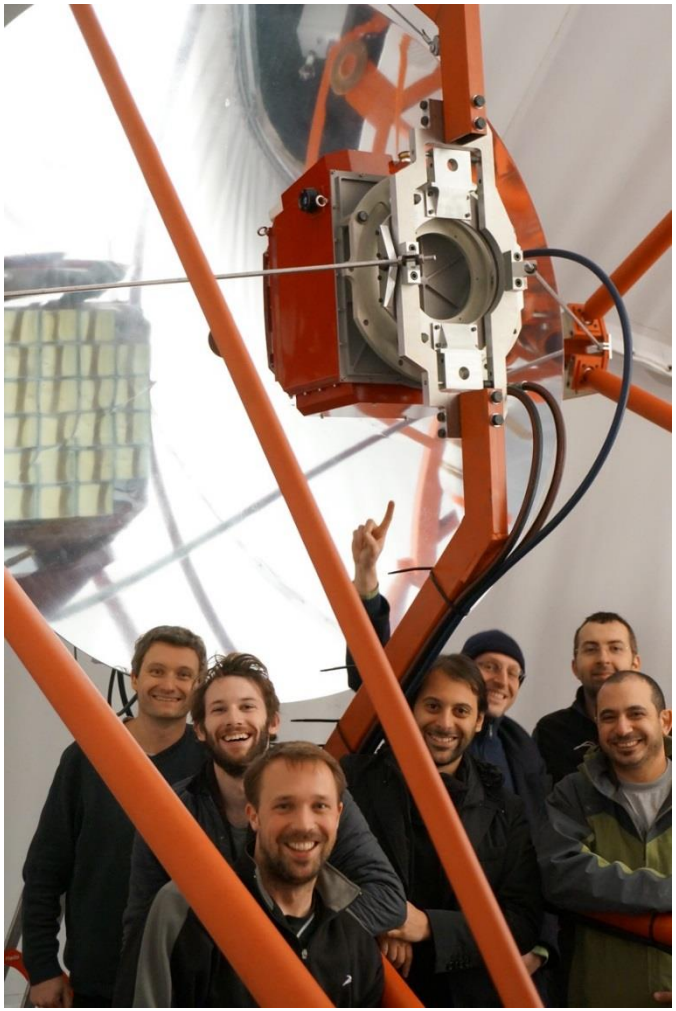


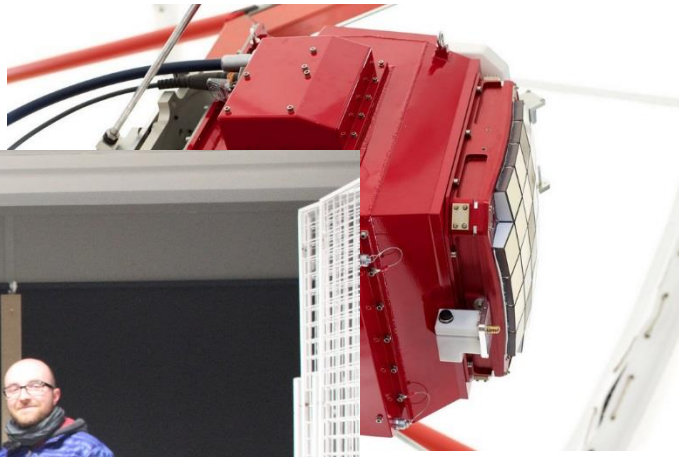

22°C ambient, chiller at 15°C



# Integration with Telescope structure



# First Event Recorded



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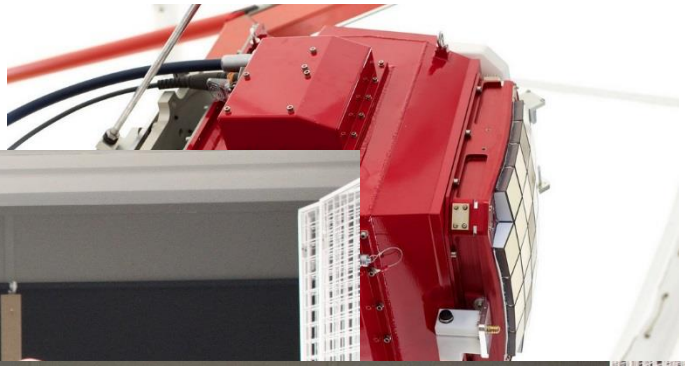

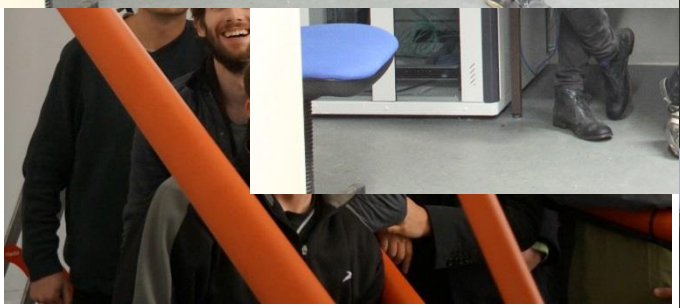

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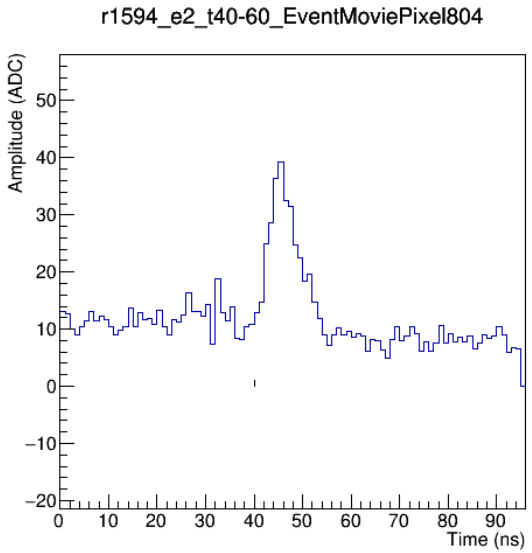


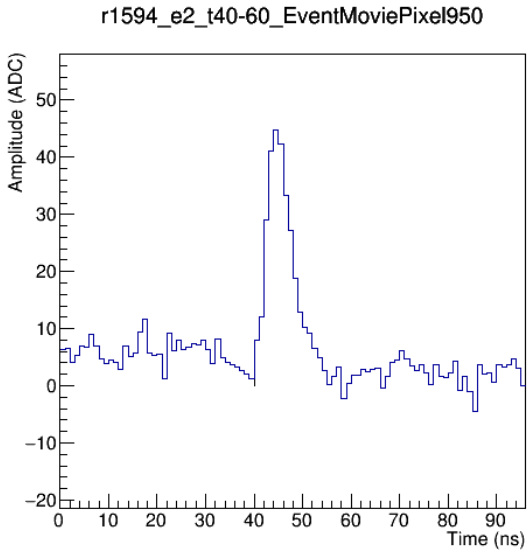


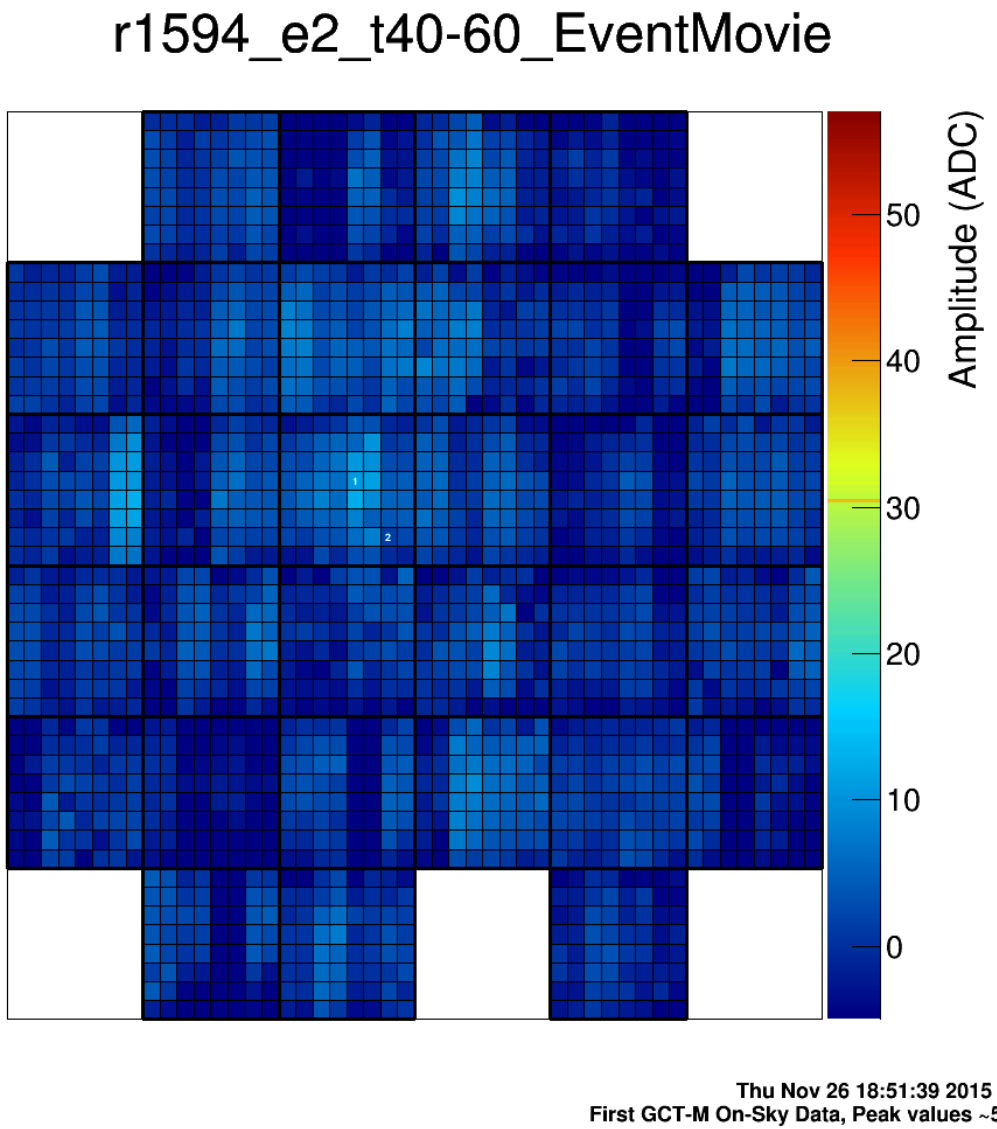


See Jason's Talk on Thursday

# GCT prototype inauguration

## Dec 1st Meudon (Paris)

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Major milestone for research by Dr Garret Cotter, Fellow in Physics

Tue, 09/02/2016

Scientists developing the world's next-generation high-energy gamma-ray observatory, including Exeter's Fellow in Physics Dr Garret Cotter and Exeter DPhil student Andrea De Franco (2013, Astrophysics), achieved a major milestone recently when a prototype telescope recorded its first observations of light from high-energy cosmic rays during testing at l'Observatoire de Paris in Meudon, France.

The Cherenkov Telescope Array (CTA) is a global initiative to build the world's largest and most sensitive high-energy gamma-ray observatory. CTA uses technologies from both astronomy and particle physics to detect the intense, but extremely short, bursts of light released when extremely high energy cosmic rays and gamma-rays from space collide with the top of the Earth's atmosphere. These air-showers consist of what is known as Cherenkov light, bursts of very blue light lasting only a few billionths of a second.

CTA will serve as an open observatory to a wide astrophysics community and will provide a deep insight into the non-thermal high-energy universe. The aims of the CTA project include improving our understanding of the origin of cosmic rays and their role in the universe, helping us to comprehend the nature and variety of particle acceleration around black holes, and searching for the ultimate nature of matter and physics beyond the Standard Model.

CTA includes the creation of at least three types of telescope – small-, medium- and large-size telescopes – distributed over two observatories – one in the northern hemisphere and one in the southern hemisphere. These will enable the CTA observatory to detect high-energy radiation with unprecedented accuracy and approximately 10 times the sensitivity of current instruments, providing novel insights into some of the most extreme and violent events in the universe.

*The GCT prototype. Credit: Akira Okumura*

It is an ambitious, multi-million pound project involving scientists and engineers from 32 countries and over 170 research institutes. In the UK the universities of Durham, Leicester, Liverpool and Oxford are participating in the design and construction, and the Oxford group is led by Exeter physics Fellow Dr Garret Cotter. Dr Cotter's team have been working on the software and electronics for the camera for one of the small-size telescope prototypes, the Gamma-ray Cherenkov Telescope (GCT).

During two weeks in November 2015 the GCT team battled poor weather to install and begin testing the GCT camera on the telescope structure in Paris. On the evening of Thursday, 26 November, they turned the telescope away from a nearly full moon and the bright lights of Paris towards a clear patch of sky. After 20 seconds, a single event triggered the camera, then another – in just over 300 seconds 13 events were captured. It was instantly clear that they were what the team was looking for – images of air showers created in the atmosphere by

Tweets

Observatoire de Paris centre de recherche et enseignement en astronomie et astrophysique relevant du Ministère de l'Enseignement supérieur et de la Recherche.

http://www.obspm.fr/inauguration-at-the-paris.html

Press releases

Press release | Paris' Observatory

Inauguration at the Paris Observatory of the « Gamma-ray Cherenkov Telescope »

**Prototype telescope for an international observatory for the study of the extreme universe using gamma rays**

On December 1st 2015, the Paris Observatory, on its Meudon site, will inaugurate the prototype for a new kind of telescope: the Gamma-ray Cherenkov Telescope – ternational consortium, in preparation – CTA, which will be the largest gamma ionned, towards 2020 at Paranal sible to study very high energy cosmic universe.

Until the end of the 1980s, astrophysicists only knew the Universe via its radio, infra-red, visible, X and low energy gamma ray emissions, as well as via cosmic ray particles However, there are also in the Universe many

org/Pages/News.aspx

**CTA Telescope Prototype, the Gamma-ray Cherenkov Telescope, Inaugurated on 1 De**

*1 December 2015*

*Photo Credits: Akira Okumura*

On 1 December 2015, l'Observatoire de Paris hosted the inauguration of the Gamma-ray Cherenkov Telescope (GCT) prototype. T the Cherenkov Telescope Array (CTA).

The event was held at the Observatory's Meudon site with speeches and presentations by representatives from l'Observatoire de P Council (STFC), Region Ile-de-France, the CTA and GCT consortia.

Claude Catala, President of l'Observatoire de Paris, opened the presentation saying, "The GCT prototype represents an immense worked day and night over the last couple of weeks to make this happen."

Following the presentation, attendees were given a tour of the telescope and its camera, which captured CTA's first Cherenkov ligh

The telescope is one of the very first to use the Schwarzschild-Couder dual-mirror optical design, which has recently been recognized as well-suit large field of view and allowing the construction of telescopes and cameras that are more compact than the single-mirror systems that are current

Meudon (92190)

**A Meudon, ce télescope va scruter les confin**

J. Va | 01 Déc. 2015, 14h32 | MAJ : 01 Déc. 2015, 14h32

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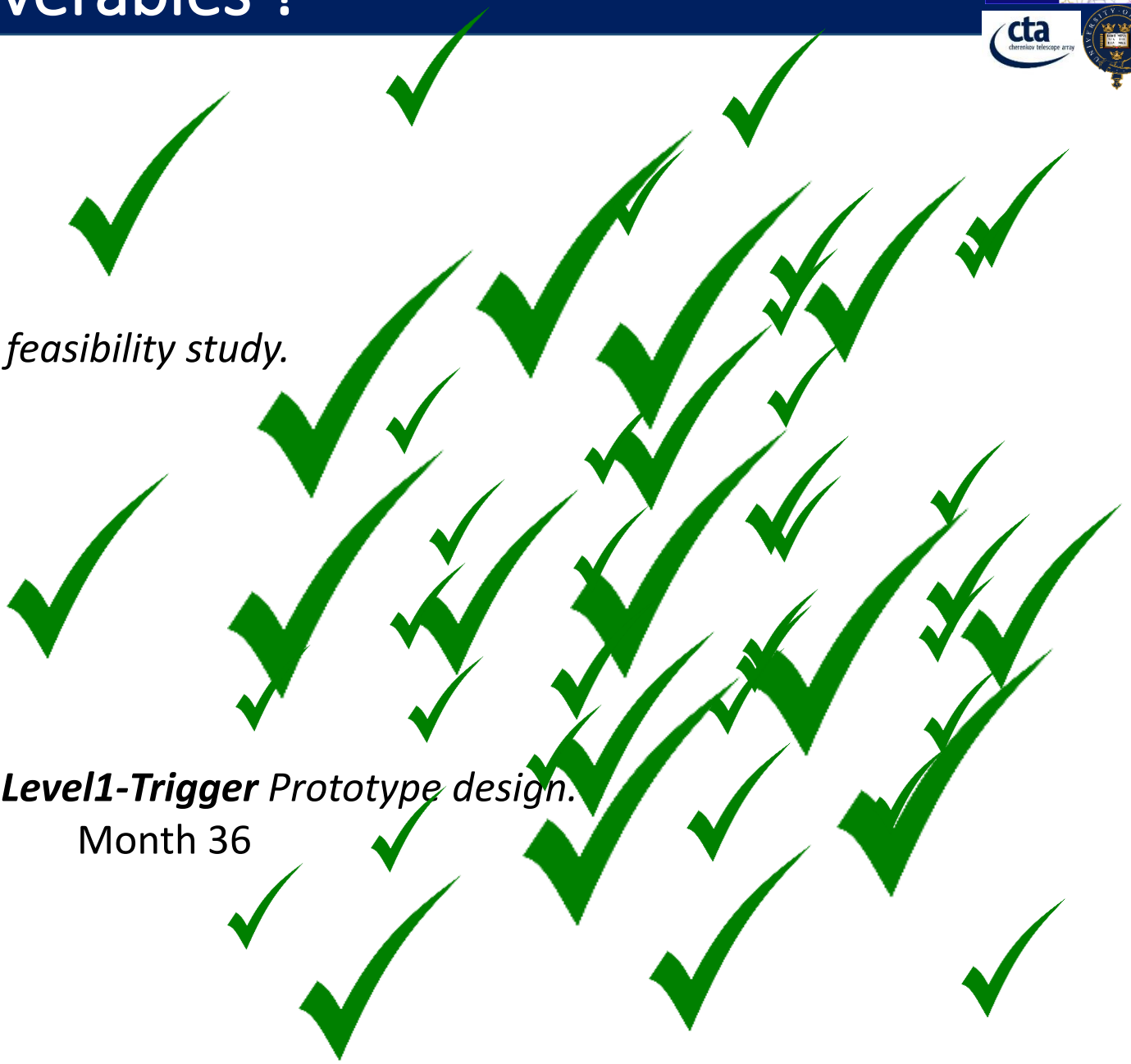
Month 12

***CTA-Level1-Trigger*** *Prototype design.*
Month 36



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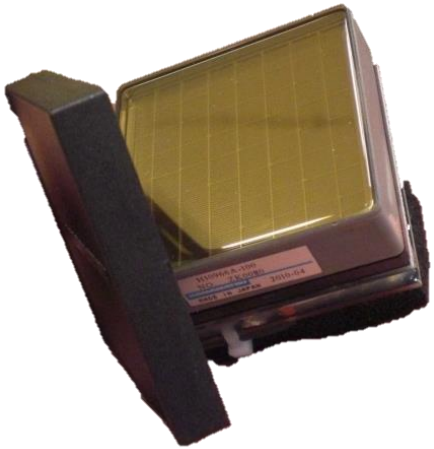
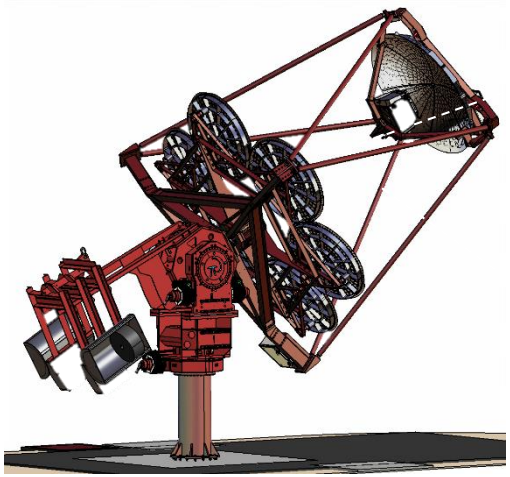
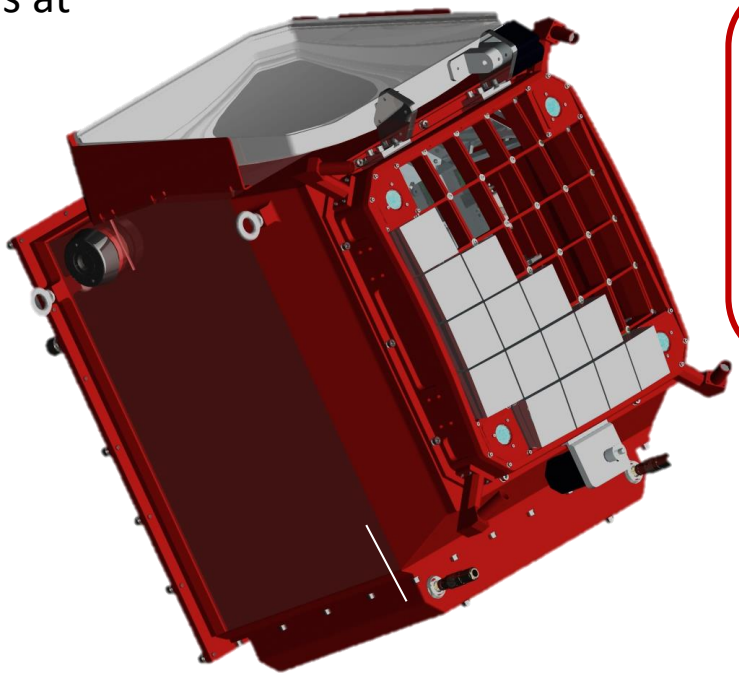
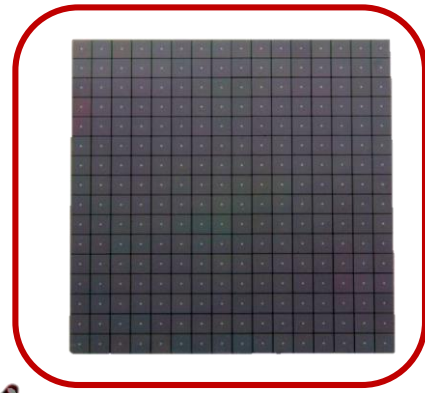






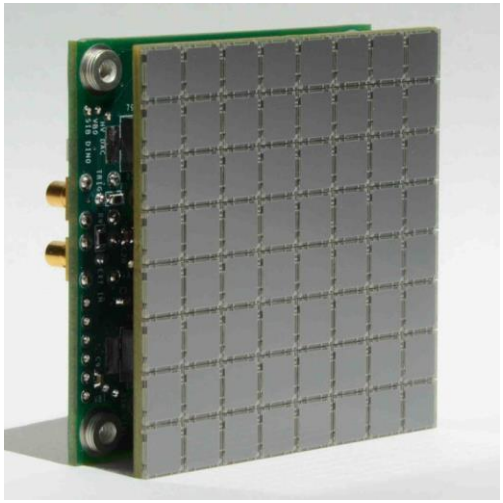


# MAPM Vs. SiPM

MAPM
Multi Anode PhotoMultiplier

PMT technology with common photocathode and a matrix of dynode chain.

SiPM
Silicon PhotoMultiplier



Very fine pixelated Geiger Mode avalanche photodiodes. (Reverse biased PN junction operating above breakdown voltage.

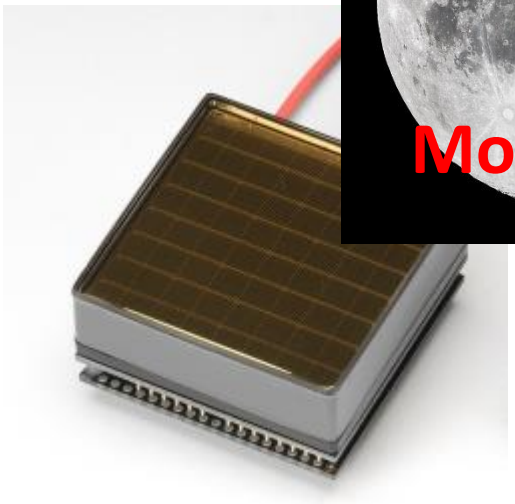
# MAPM Vs. SiPM

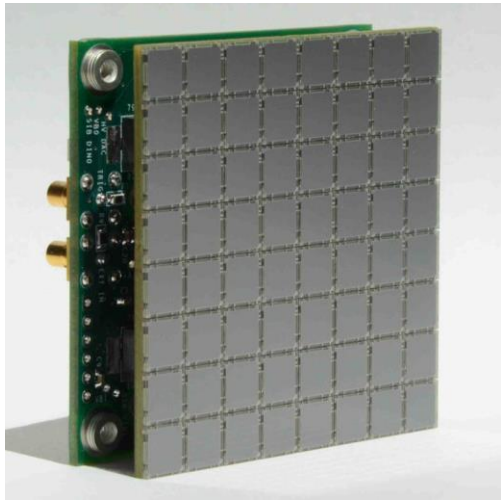
| MAPM<br>Multi Anode PhotoMultiplier | SiPM<br>Silicon PhotoMultiplier |
|---|---|
| - Fragility (sealed vacuum tube) | + Ruggedness |
| - Operation under high voltage | + Low voltage operation (~ 20-100 V) |
| - Aging | + Resistance to high light levels |
| - Limited photon detection efficiency | + High photon detection efficiency in principle achievable |
| - Sensitivity to Earth magnetic fields | + Insensitivity to magnetic fields |
| - Limited pulse height resolution | + Excellent pulse height resolution |
| | + Rapidly decreasing cost |
| + Time FWHM (1 ns) | - Time FWHM (>20 ns) |
| + Low dark noise | - Dark Noise |
| | - Strong Temperature dependence |
| | - Cross talk |

# MAPM Vs. SiPM

MAP
Multi Anode Ph


SiPM
Silicon PhotoMultiplier





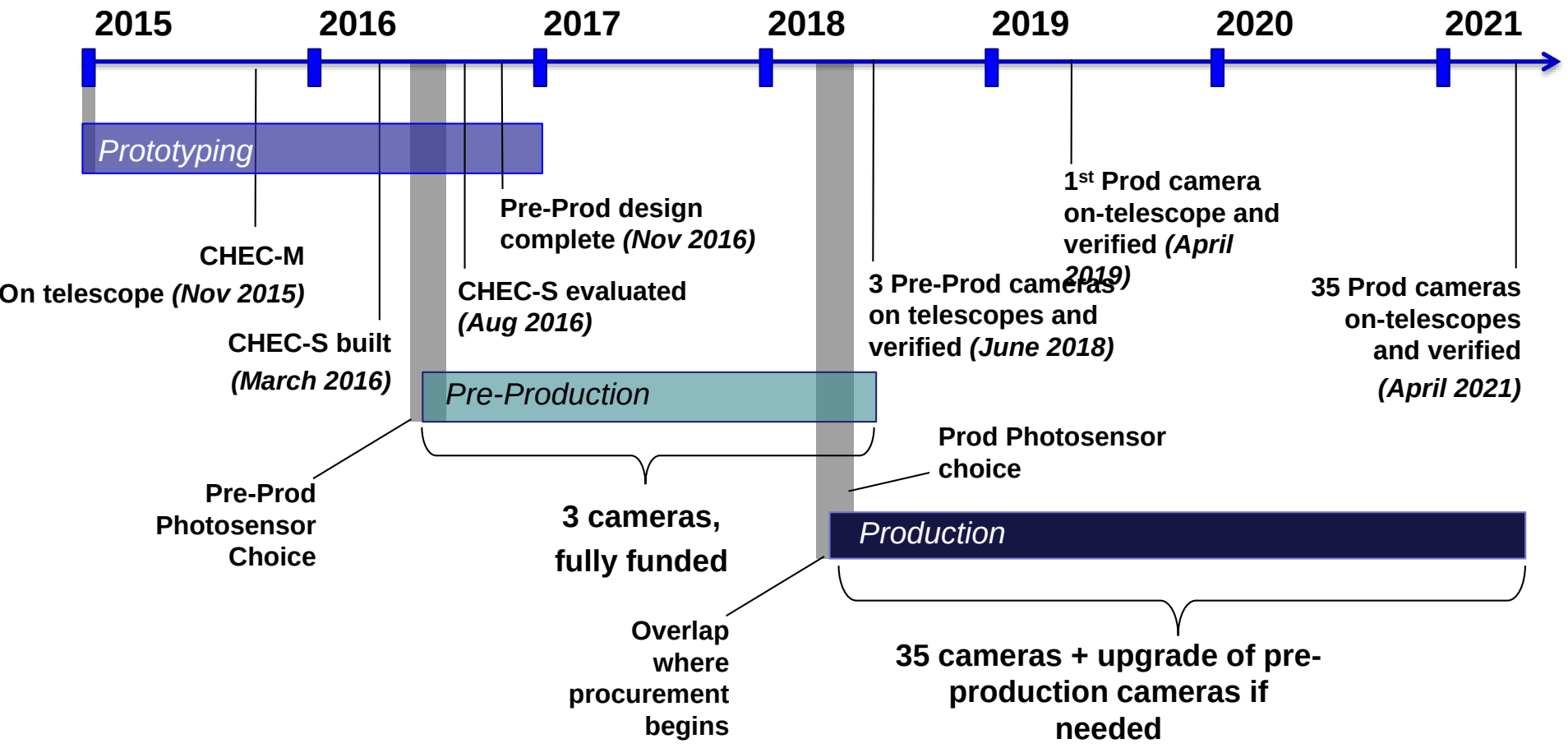
PMT technology with common photocathode and a matrix of dynode chain.

Very fine pixelated Geiger Mode avalanche photodiodes. (Reverse biased PN junction operating above breakdown voltage)

# Impact on FEE

- Has to accommodate for SiPM → different preamp.
- TARGET – ASIC split into 2. Waiting for new batches to come.
- Firmware needs improvement in the comms. Looking at standard Ethernet core
- Driver software developed, under debugging. To account for multi version, multi-purpose cases.

# Schedule


2015
2016
2017
2018
2019
2020
2021
Prototyping
CHEC-M
On telescope (Nov 2015)
CHEC-S built
(March 2016)
Pre-Prod design
complete (Nov 2016)
CHEC-S evaluated
(Aug 2016)
1st Prod camera
on-telescope and
verified (April
2019)
3 Pre-Prod cameras
on telescopes and
verified (June 2018)
35 Prod cameras
on-telescopes
and verified
(April 2021)
Pre-Production
Pre-Prod
Photosensor
Choice
3 cameras,
fully funded
Prod Photosensor
choice
Production
Overlap
where
procurement
begins
35 cameras + upgrade of pre-
production cameras if
needed

# Status update for the Gamma-ray Cherenkov Telescope (GCT) camera's Front End Electronics

Andrea De Franco

Supervisor: Garret Cotter

The research leading to these results has received funding from the People programme (Marie Curie Actions) of the European Unions Seventh Framework Programme FP7/2007-2013/ under REA grant agreement n [317446] INFIERI "INtelligent Fast Interconnected and Efficient Devices for Frontier Exploitation in Research and Industry".