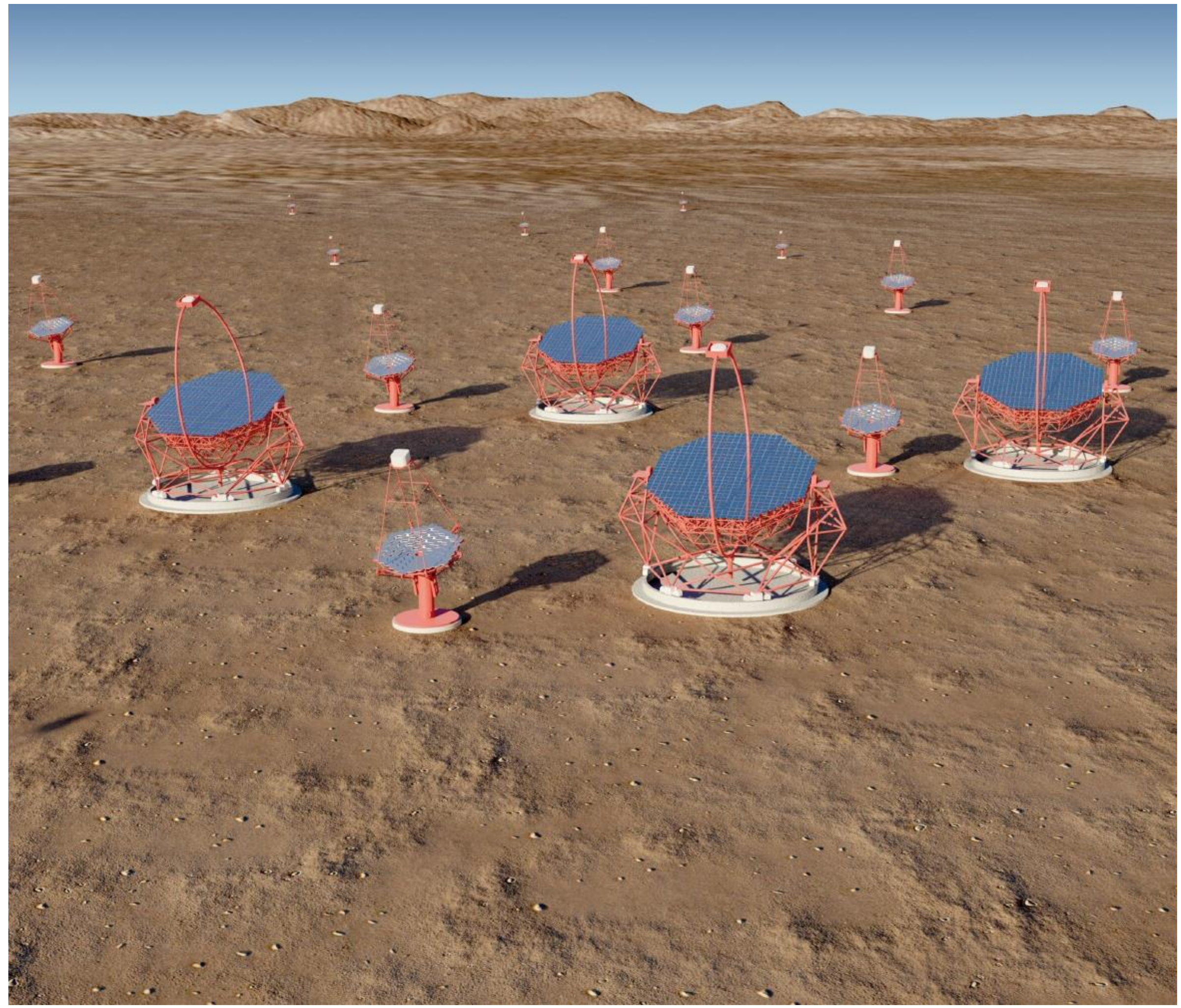
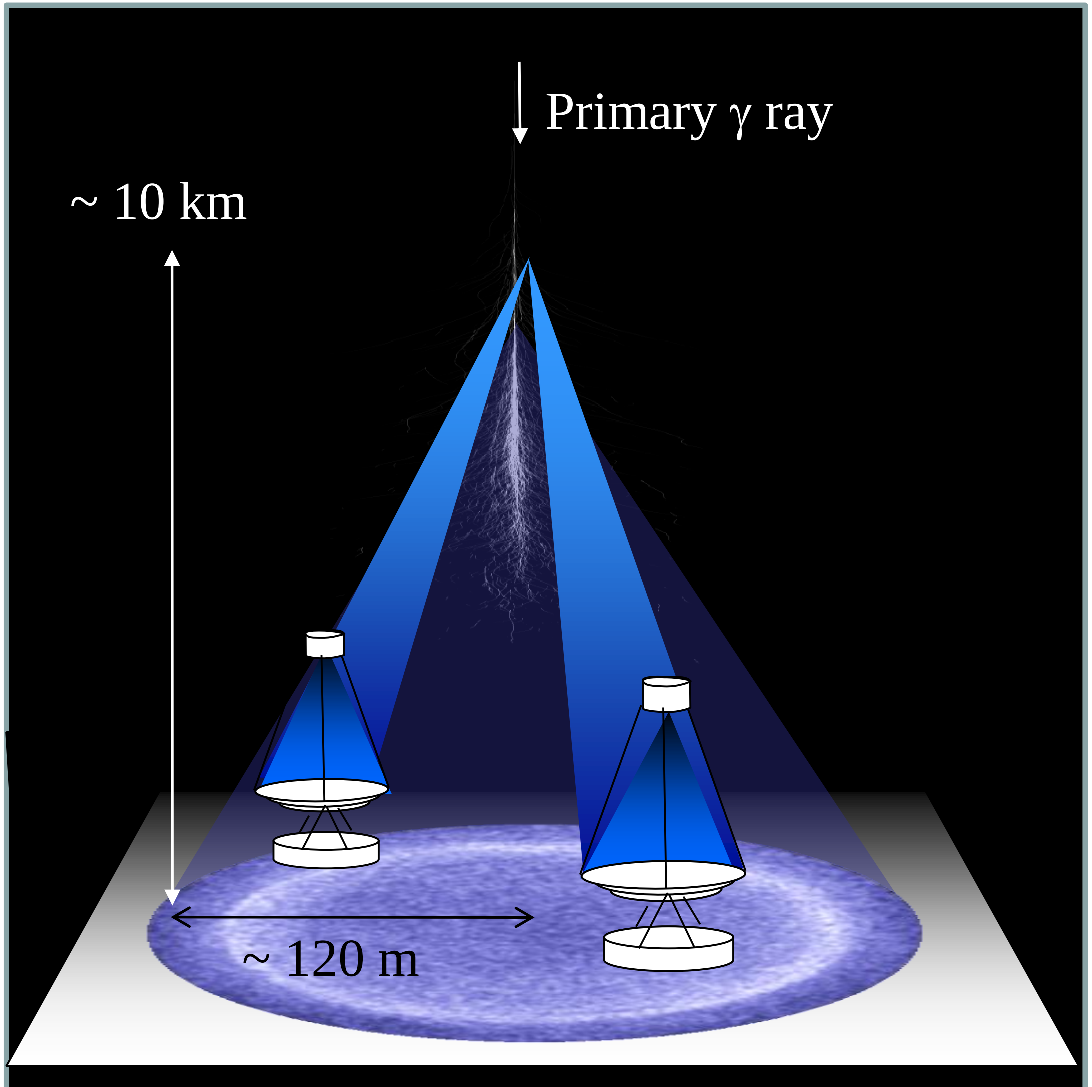
The Gamma-ray Cherenkov Telescope for CTA

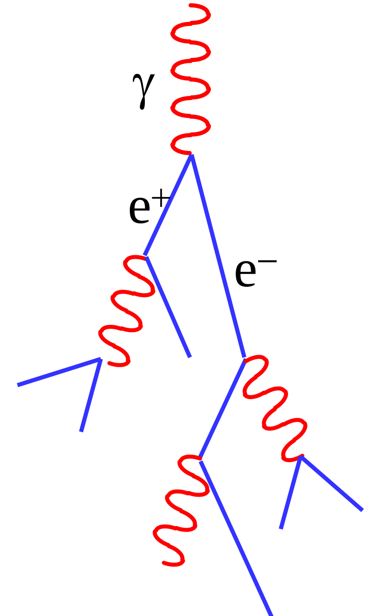
- Introduction.
- Cherenkov radiation from air showers.
- The CTA concept.
- Evolution of imaging atmospheric Cherenkov telescopes.
- The SSTs and the development of the Gamma-ray Cherenkov Telescope.
- Next steps for the GCT.
- Summary.



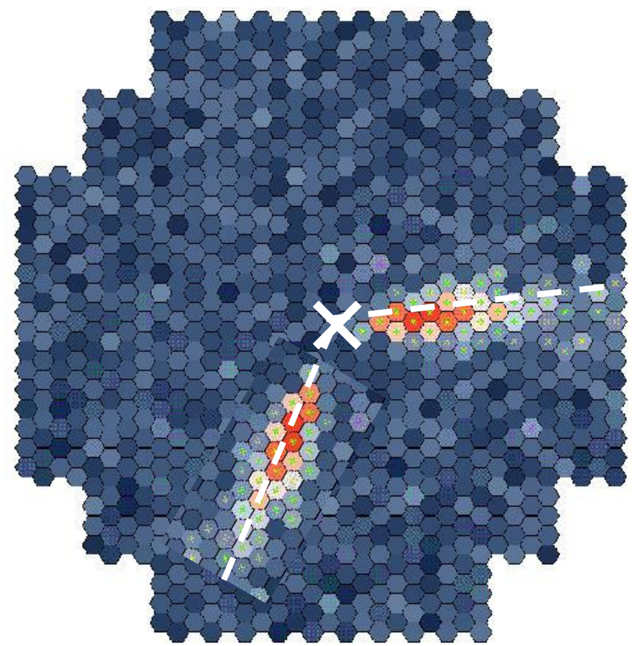
Tim Greenshaw, Liverpool University

Detecting high energy γ rays



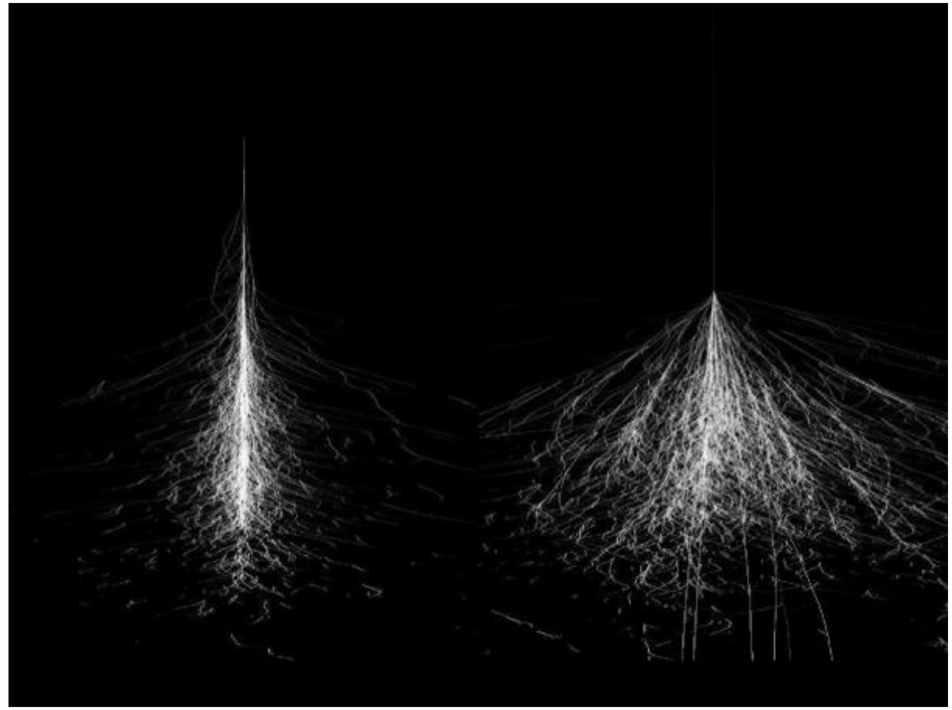


- VHE γ causes EM shower with max. at alt. ~ 10 km.
- Cherenkov angle ~ 1°: get ~ 10 ns light flash on ground with radius ~ 120 m.
- Detect with camera made of PMs.



Detecting high energy γ rays

- Cherenkov emission, attenuation in air, QE of photomultiplier lead to:
  - About 1 p.e./m^2 in few ns for (frequent) 100 GeV γ-ray.
  - About 10^3 p.e./m^2 in few 10 to 100 ns for (infreq.) 10 TeV γ-ray.
- Limitations:
  - E < 100 GeV, Night Sky Background.
  - E ~ 0.1...5 TeV, Cosmic Rays (need γ/h sep).
  - E > 5 TeV, rate.
- Array of telescopes with different sizes copes best with these different regions.

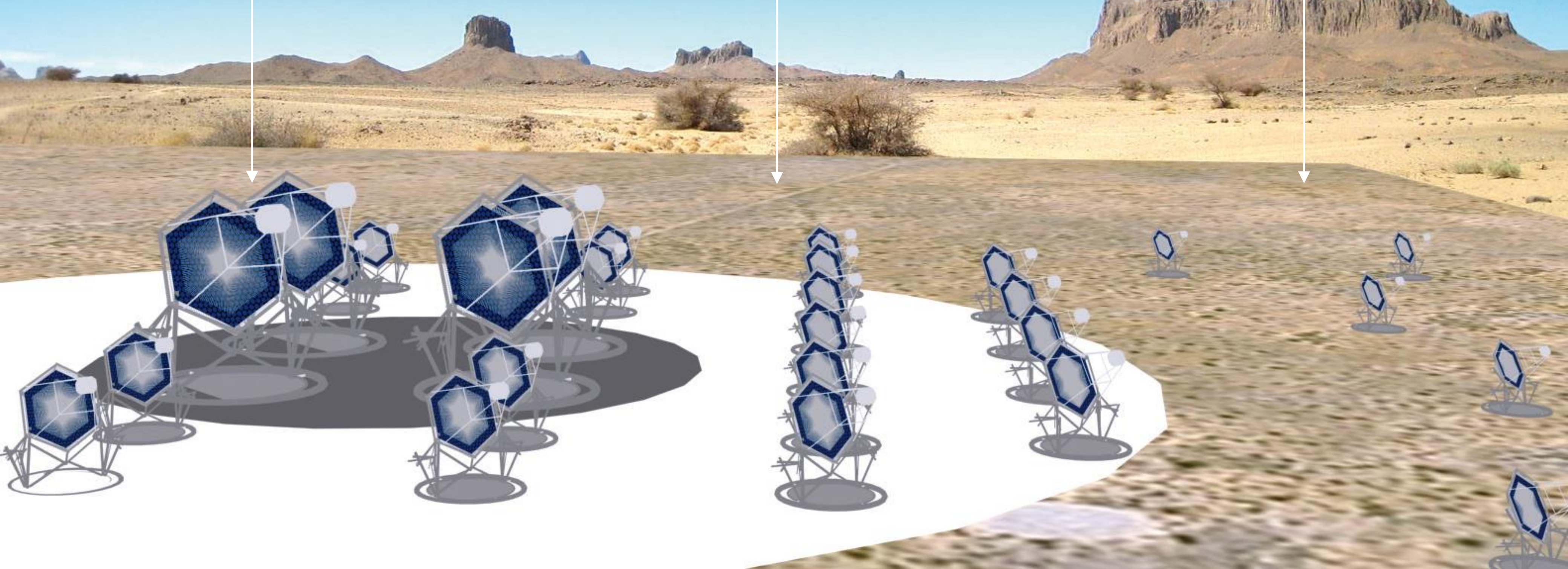


The Cherenkov Telescope Array concept

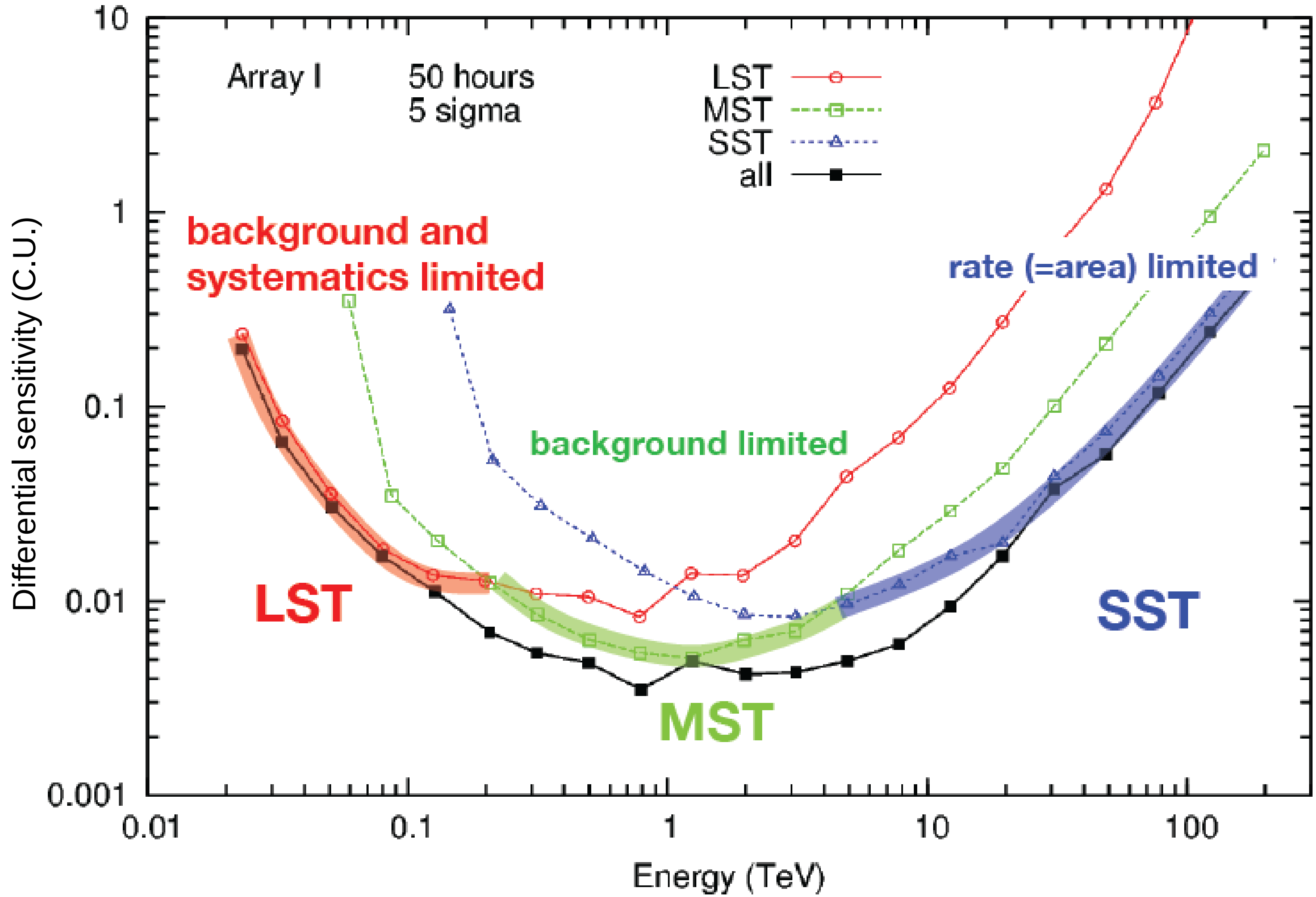
Low energy
Four 23 m telescopes
4.5^{o} FoV
~2000 pixels
~ 0.1^{o}

Medium energy
About twenty-five 12 m telescopes
8^{o} FoV
~2000 pixels
~ 0.18^{o}

High energy
About seventy 4 m telescopes
9^{o} FoV
1000…2000 pixels
~ 0.17^{o}…0.23^{o}

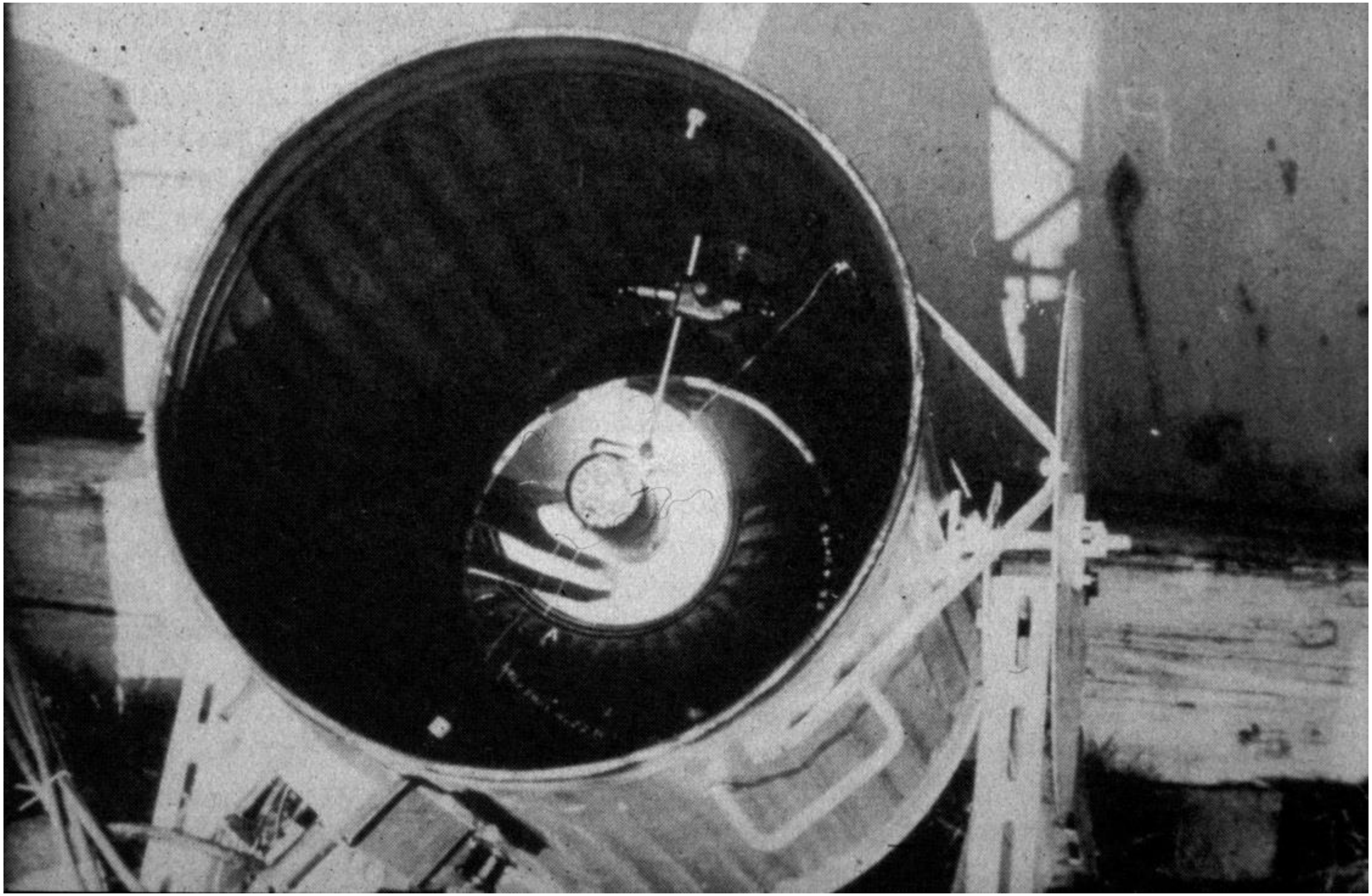


CTA sensitivity



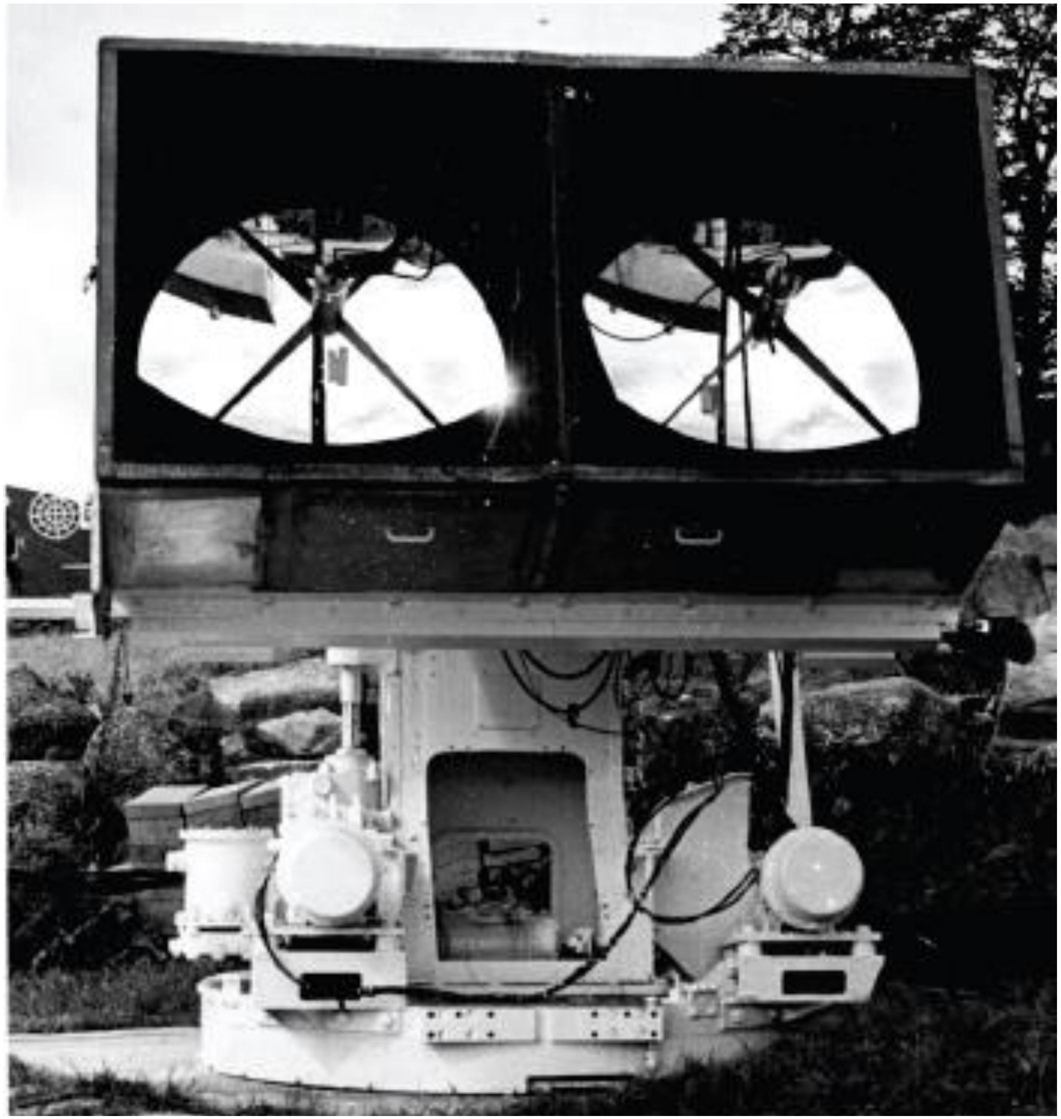
The first Atmospheric Cherenkov Telescope

- Galbraith and Jelley, Harwell, 1953.



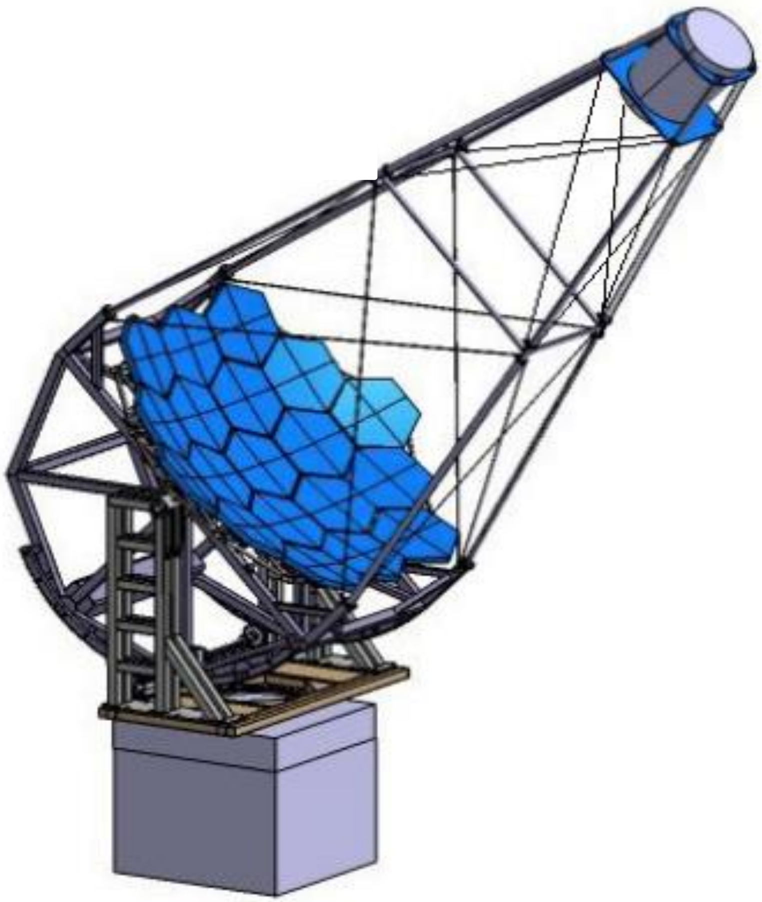
The first dual mirror ACT?

- An early “dual mirror” gamma ray telescope, Porter and Jelley, Glencullen (Ireland), 1962.
- Gun mount and searchlight mirrors from WWII.



The SSTs – take one

- Davies-Cotton 7 m telescope designed for CTA.



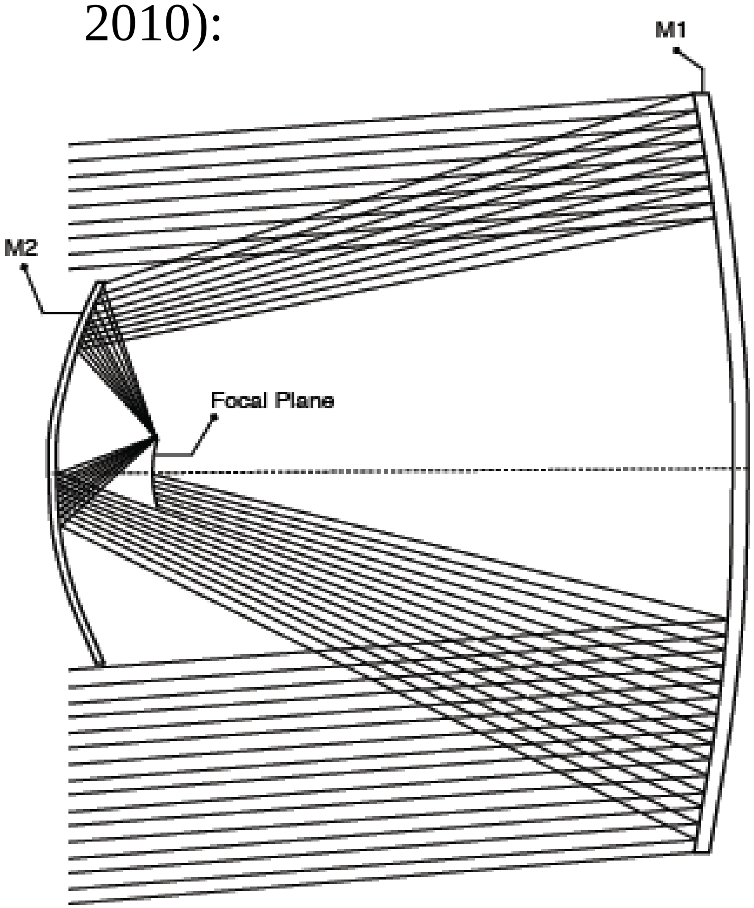
- This is a viable solution for the SST.
- But, the camera:
  - Has a diameter of about 1.6 m.
  - Weighs about 2 tonnes.
  - Is expensive, in no small part because of the price of the PMTs.
- The cost of the camera dominates that of the telescope.
- Making it cheaper would allow the construction of more telescopes and hence improve CTA performance.

The SSTs – take two

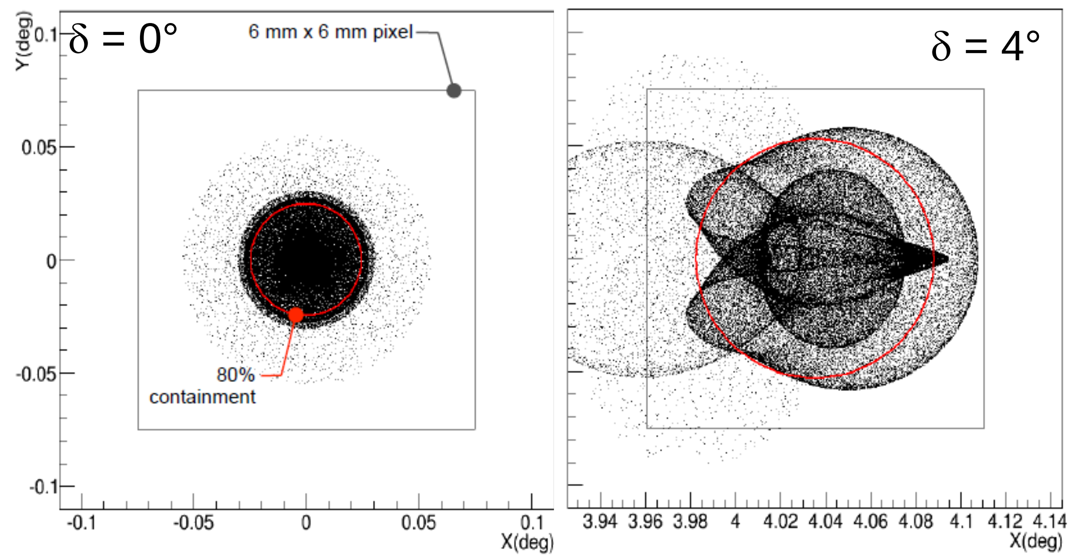
- Can we use cheaper sensors (e.g. SiPMs) in a compact camera?
- Must have F ~ 2 m so ~ 6 × 6 mm^2 pixels commercially available match required angular resolution of ~ 0.2°.
- Need reasonable area, D > 3 m, hence "fast" focal ratio (f = F/D small).
- Primary aberrations:
  - Spherical ~ $1/f^3$.
  - Coma (1st order) ~ δ/f^2.
- Require sophisticated optics to correct for aberrations at large field angles.
- Look at two-mirror telescope designs, c.f. 9 m dual mirror telescope originally proposed by Vassiliev for AGIS.

Gamma-ray Cherenkov Telescope optics

- Design (Liverpool, Durham 2010):



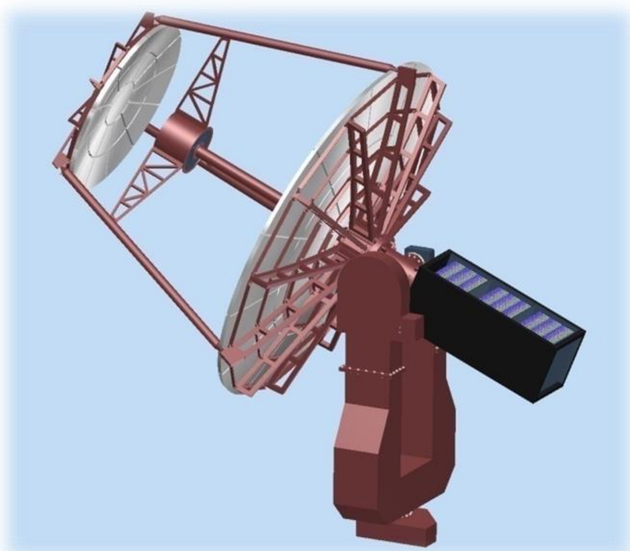
- Images of point source at infinity:



- For field angles below about 5°, over 80% of the light from a point source at infinity (or at 10 km with refocusing) is contained in a 6 × 6 mm^2 pixel.

Mechanical design

- Durham 2011.

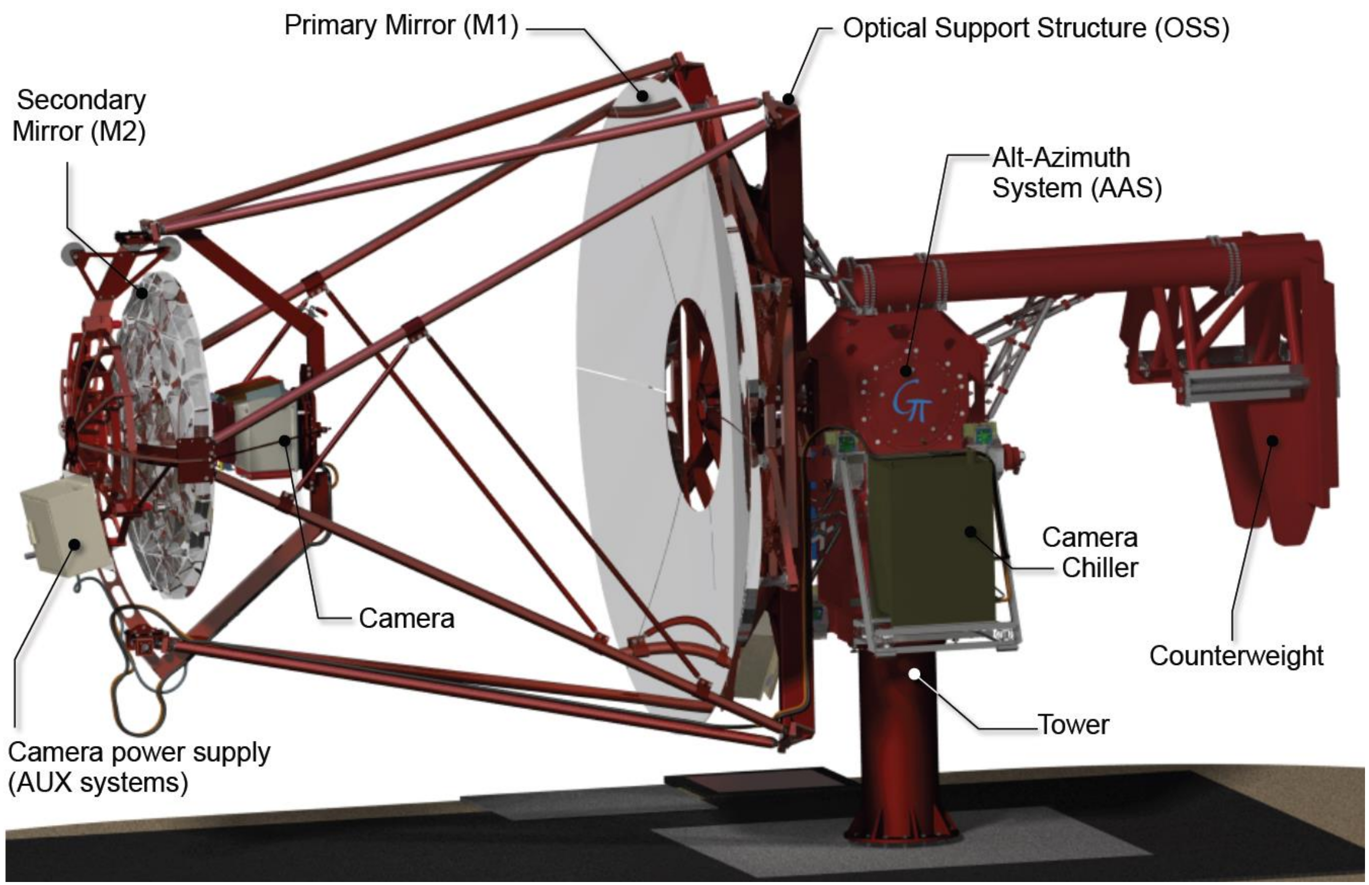


- Long fork.
- Central tube supports camera.
- Tripod supports secondary mirror
- Electronics in counterweight.
- Aluminium structure.

- Paris, 2012.
- Short fork.
- Primary dish support separated from secondary support.
- Camera attached to secondary.
- Shaped counterweight.
- Steel structure, aluminium mirrors.

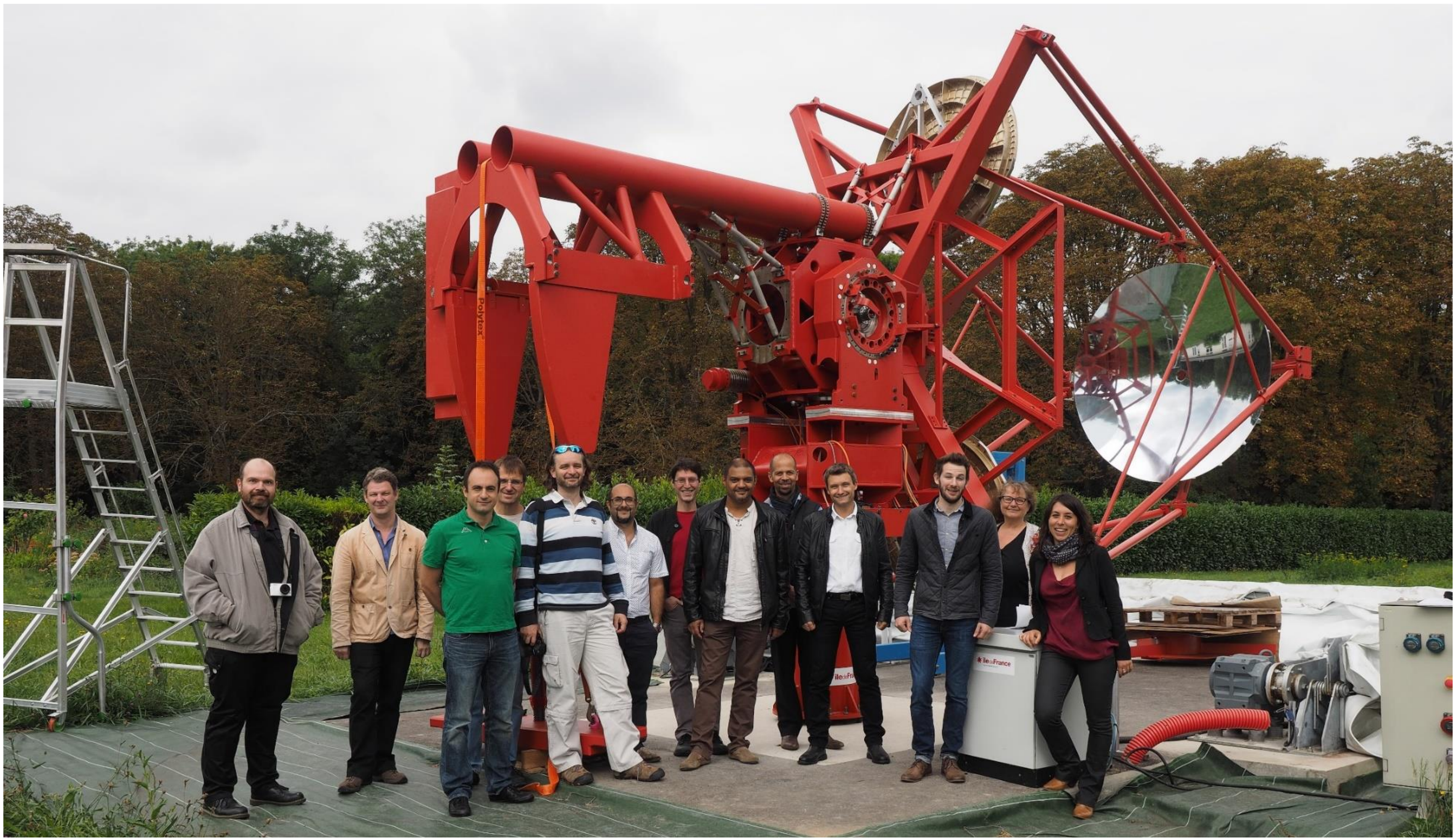
Mechanical design

- Paris 2015.
- Four masts to support secondary.
- Same motors on both axes.
- Primary mirror rotation mechanism to facilitate mirror installation.
- Camera removal mechanism.

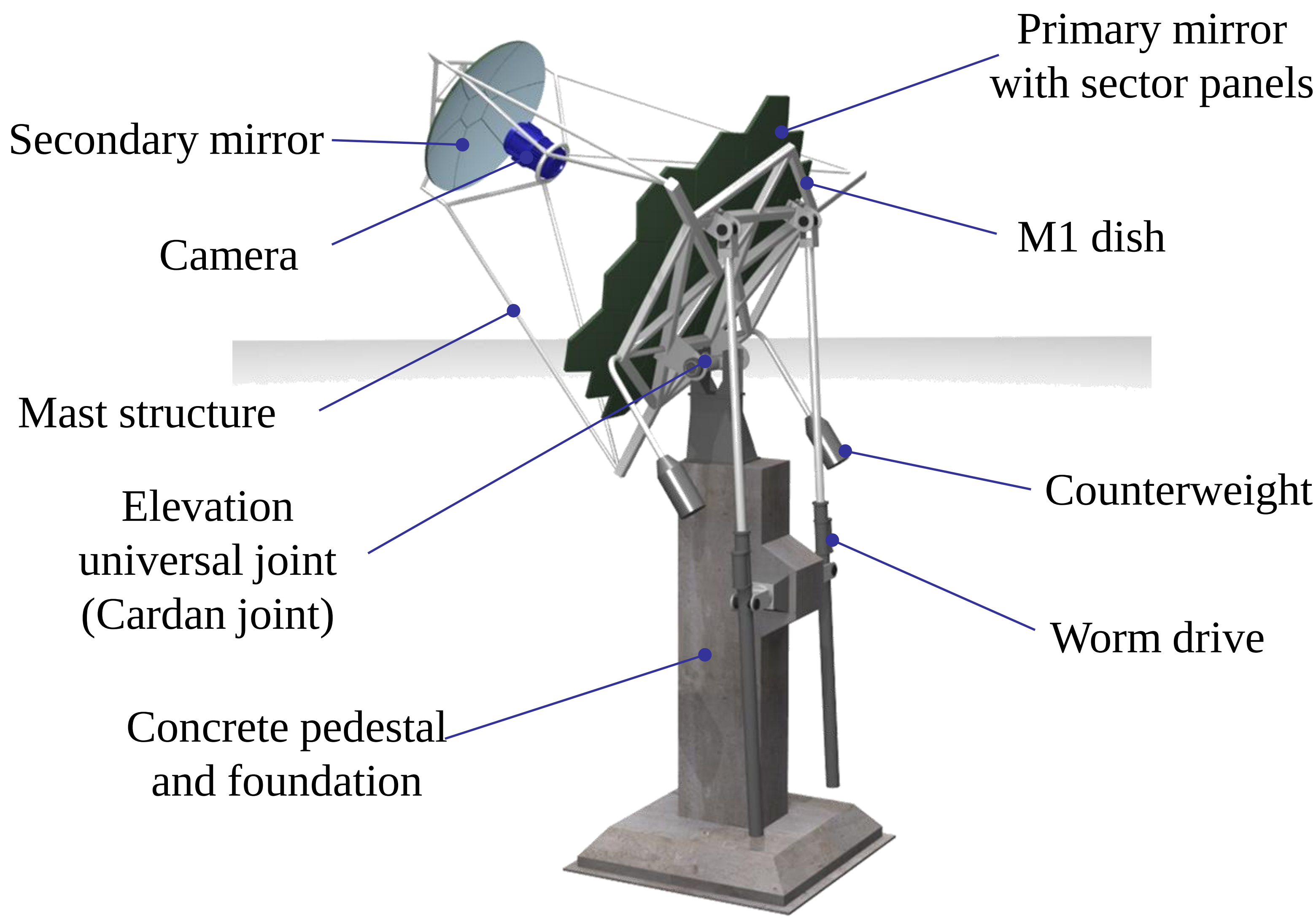


Mechanical structure

- Prototype structure assembled in April, visited by ESO team in September.



Dual Mirror – alternative Italian design



SST-1M prototype

- Davies-Cotton optics.
- Mirror 4 m diameter.
- Focal length 5.6 m.
- Mass ~ 9 t.
- SiPM based camera.
- Diameter ~ 1 m.
- Mass ~ 200 kg.

ASTRI prototype

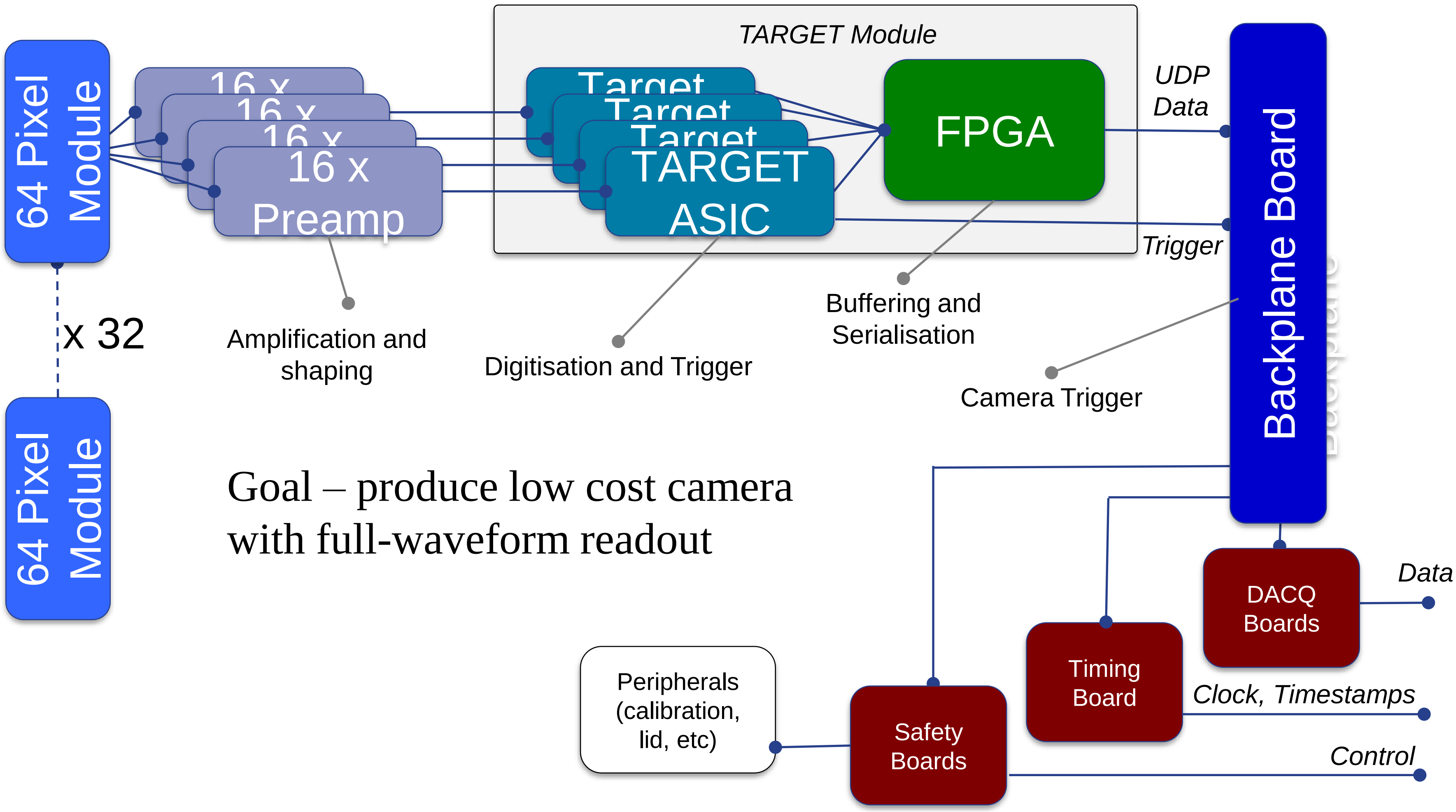
- Primary 4.3 m diameter.
- Focal length 2.2 m.
- Mass ~ 20 t.
- Camera diameter about 0.4 m.
- Mass ~ 70 kg.

- Note, astronomical telescopes are protected from the elements…
- …but ACTs generally aren’t!

A shelter for the GCT

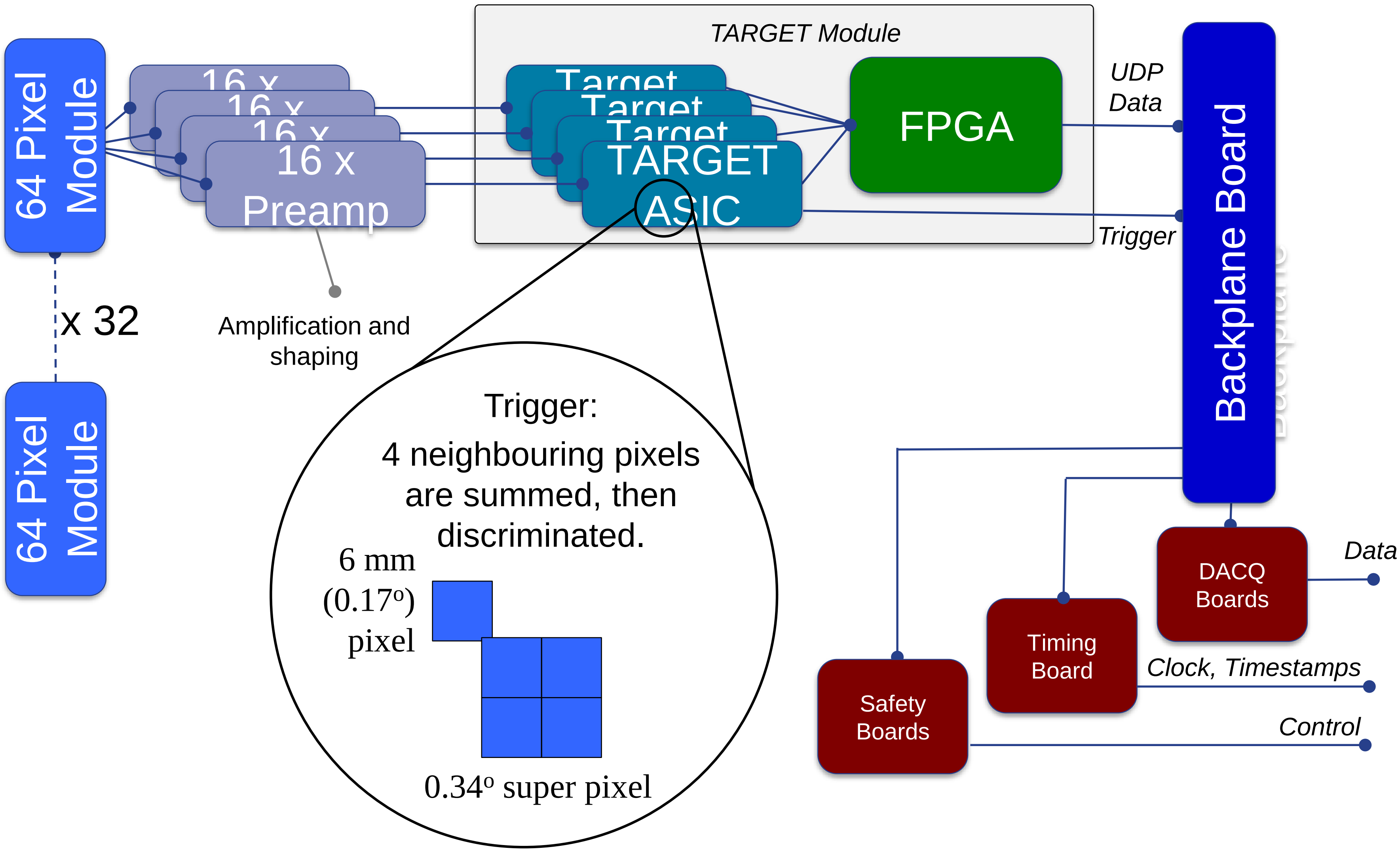
- "Pram cover" shelter used to protect the GCT prototype in Paris.
- Cost benefit on southern site, reduced frequency of mirror recoating.

Camera design



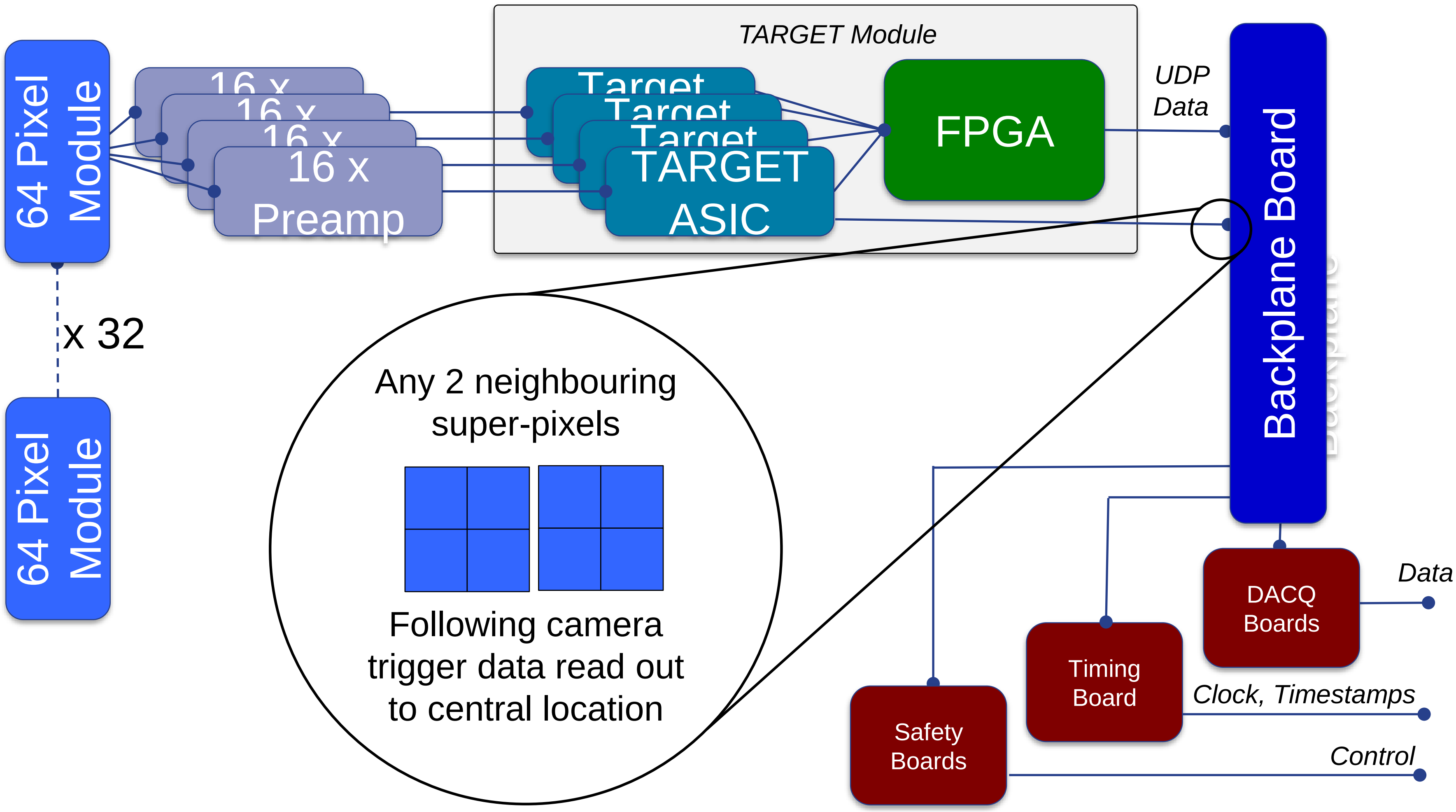
Goal – produce low cost camera with full-waveform readout

Camera



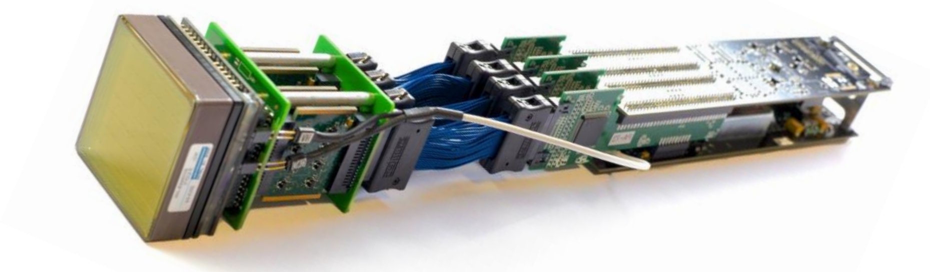
TARGET Module
64 Pixel Module
16 x Preamp
Target
TARGET ASIC
FPGA
UDP Data
Trigger
Backplane Board
x 32
64 Pixel Module
Amplification and shaping
Trigger:
4 neighbouring pixels are summed, then discriminated.
6 mm (0.17°) pixel
0.34° super pixel
DACQ Boards
Data
Timing Board
Clock, Timestamps
Safety Boards
Control

Camera


TARGET Module
64 Pixel Module
16 x Preamp
Target
TARGET ASIC
FPGA
UDP Data
Backplane Board
x 32
64 Pixel Module
Any 2 neighbouring super-pixels
Following camera trigger data read out to central location
DACQ Boards
Data
Timing Board
Clock, Timestamps
Safety Boards
Control

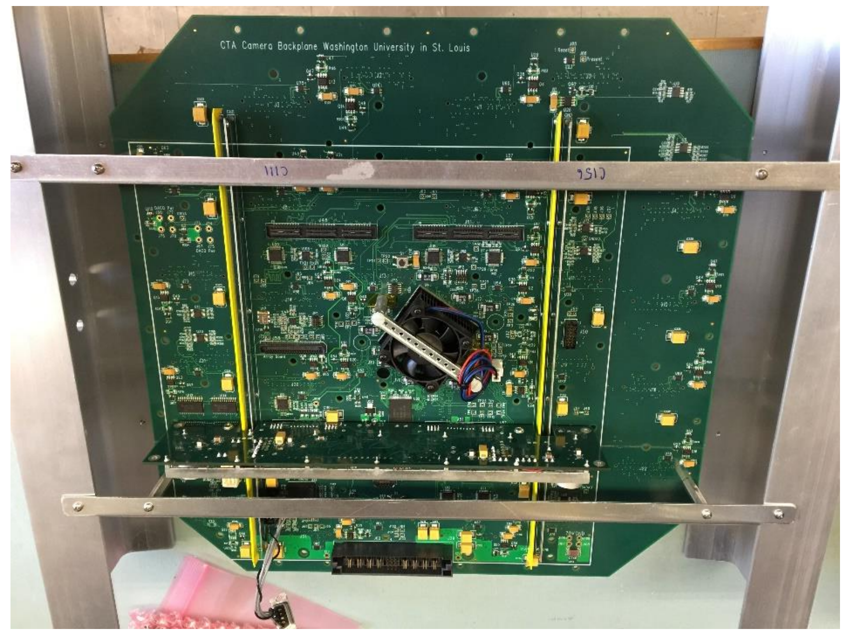
Development of the camera

- Leicester 2012, start construction of camera with MAPMs – CHEC-M.
- Electronics based around TARGET (Hawaii/SLAC and Erlangen).



- DAQ using White Rabbit for timing (Amsterdam).

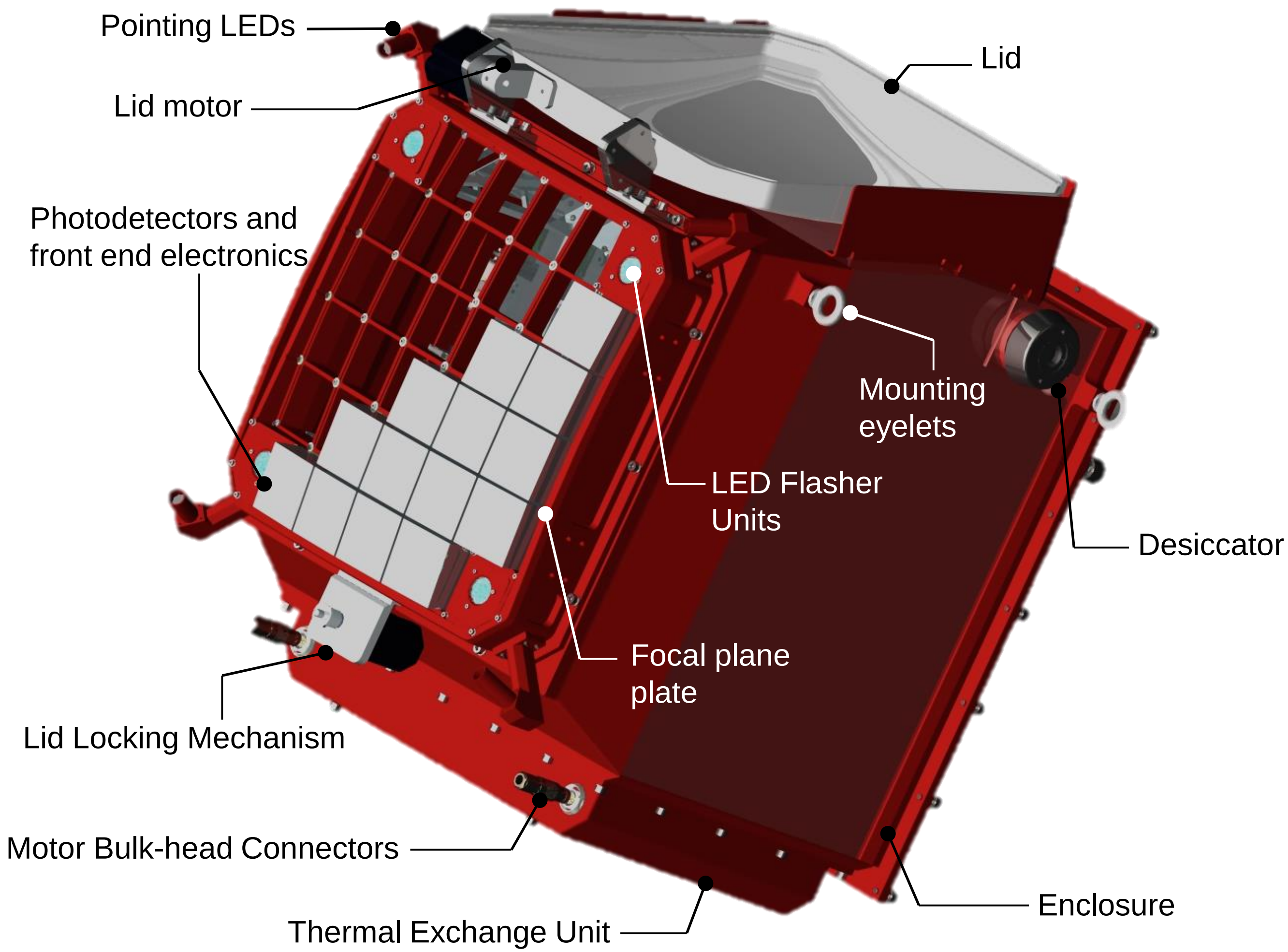
- Backplane, common with SCT (Washington University).



- Flashers (Durham) and Peripherals Board (Liverpool) complete camera.

Development of the camera

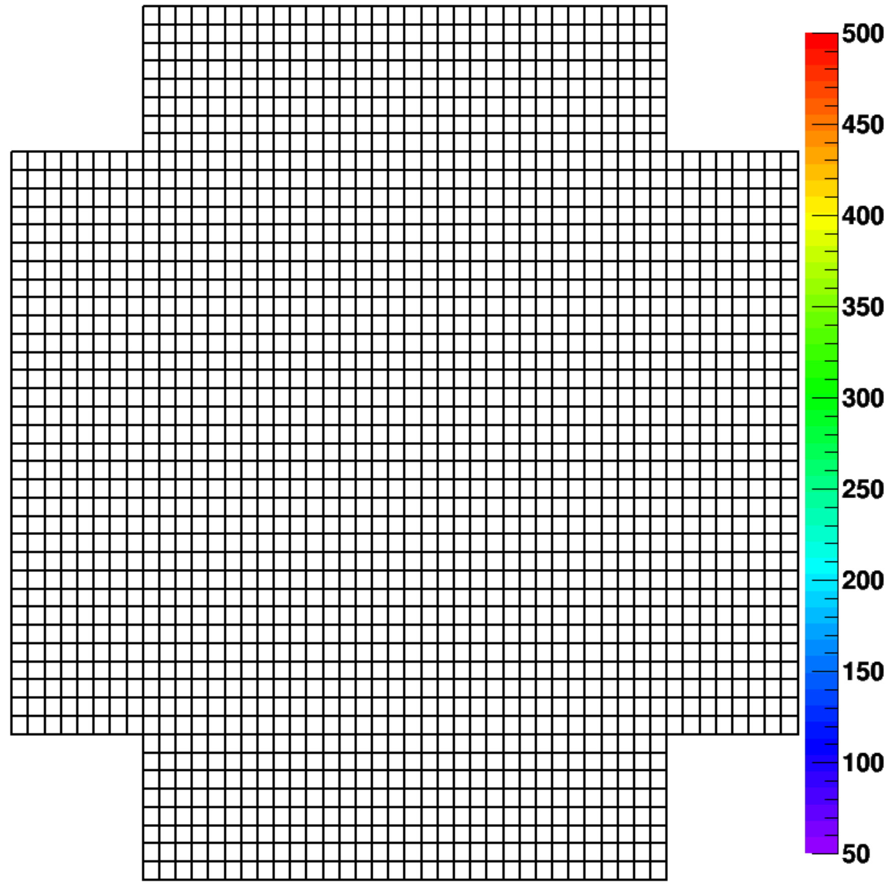
- Leicester 2015, CHEC-M complete.



Camera tests

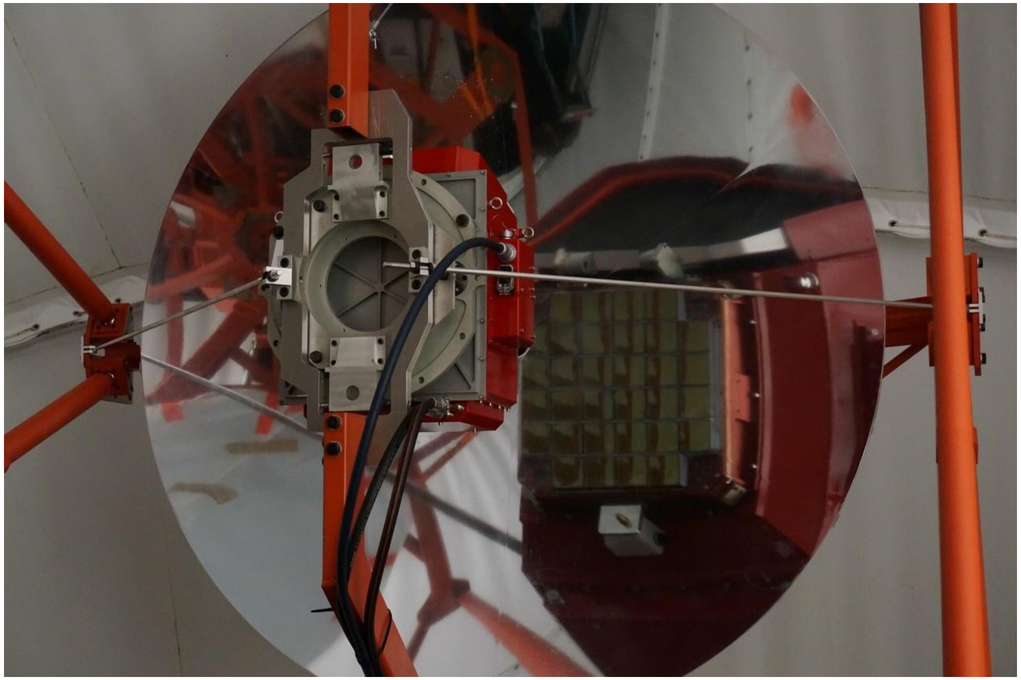
- Camera in dark box with laser mounted on robot arm.

- Lab. tests results (here with external trigger).



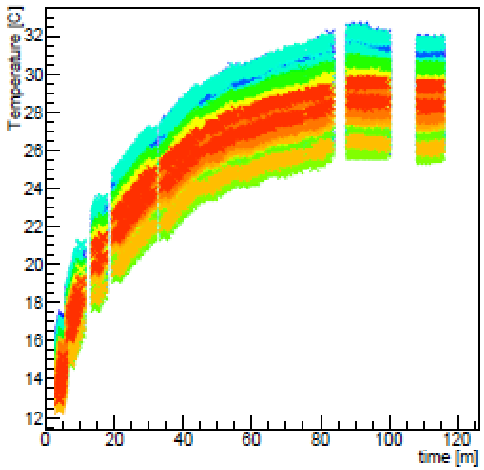
Completing the GCT prototype

- Camera shipped to Paris, arrived Friday 13th November.
- Checked in lab and mounted on telescope on 20th November…

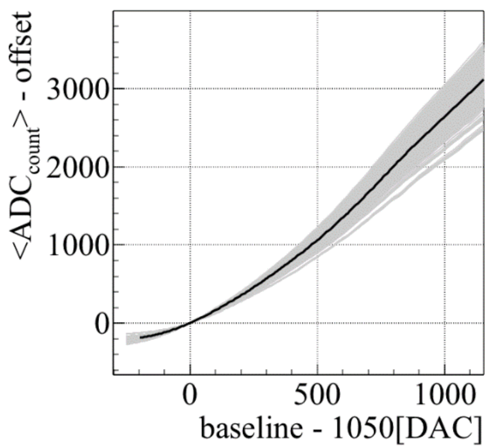


Verify camera operation on telescope

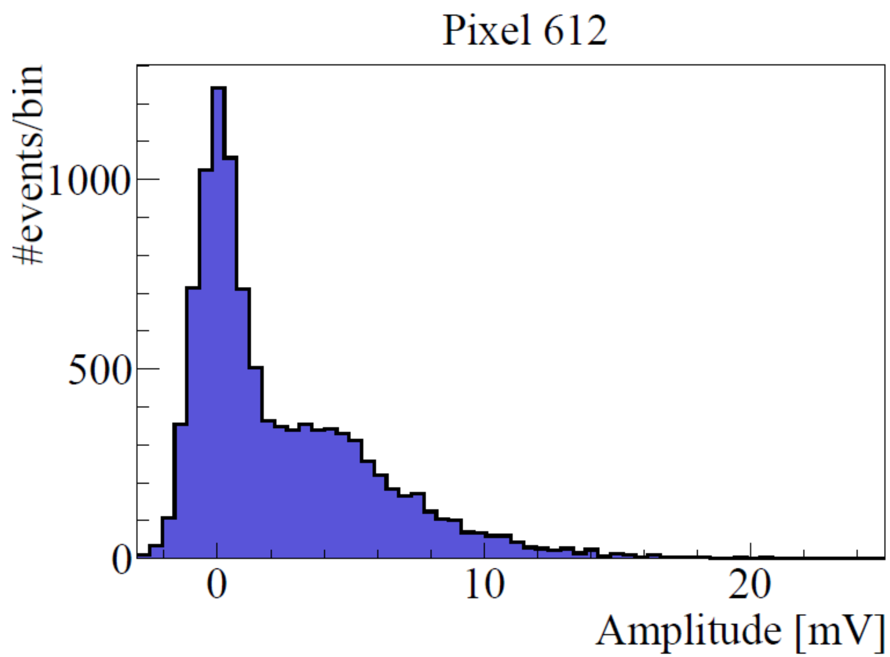
- Check that operation safe, e.g. TARGET module temperatures.



- Check electronics performance, e.g. transfer functions.



- Check that MAPMs functioning as expected – look for single photo-electron peak:

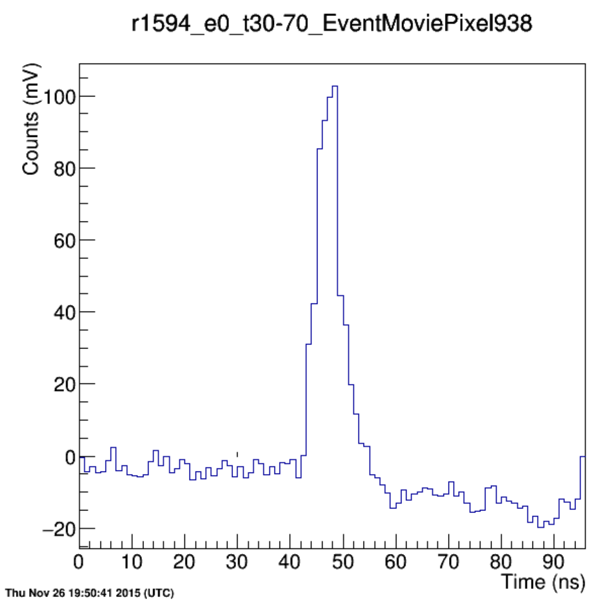


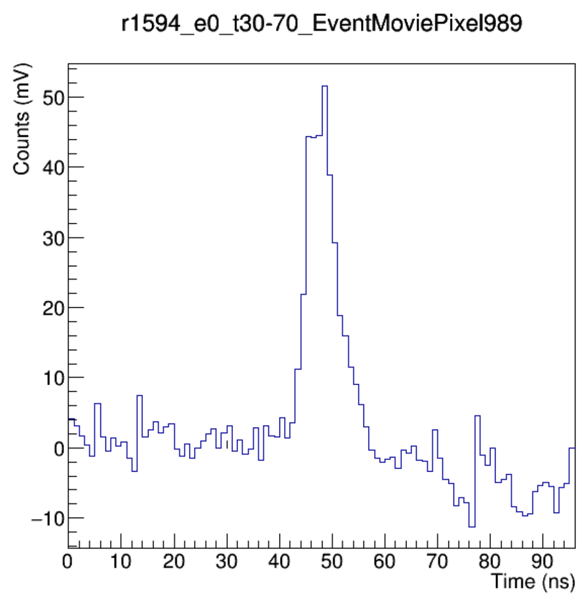
First tests of the GCT prototype on sky

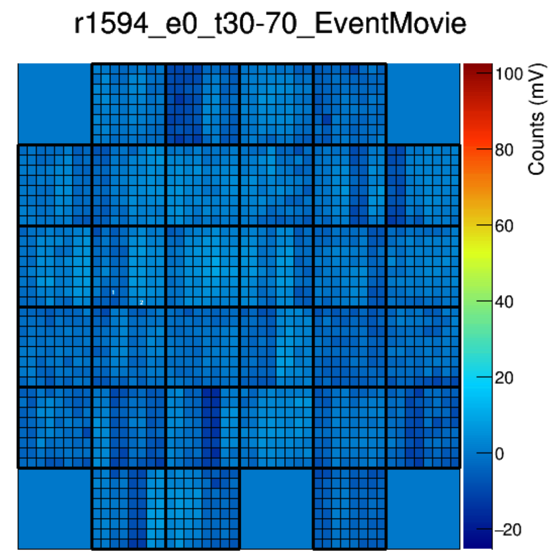
- Thursday 26th Nov, night sky background 20 to 100 times higher than CTA site…

First tests of the GCT prototype on sky

- …but successfully observed Cherenkov light from ~ 50 TeV showers.

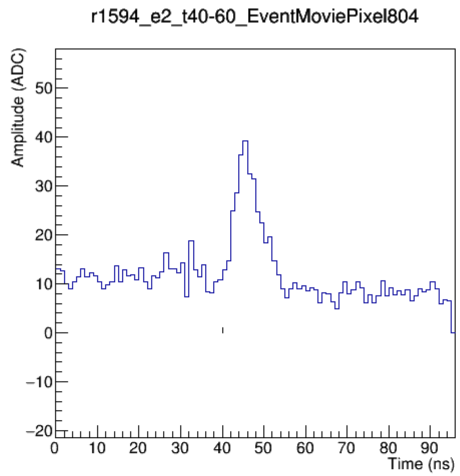


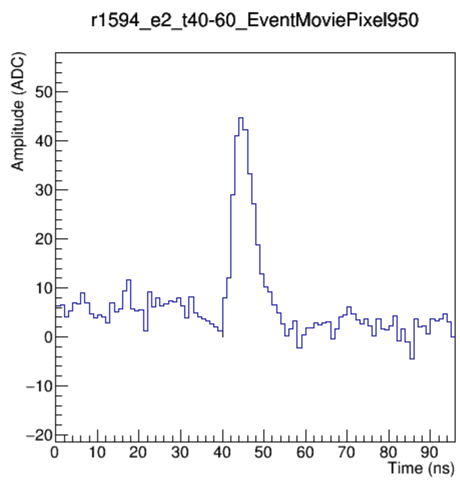


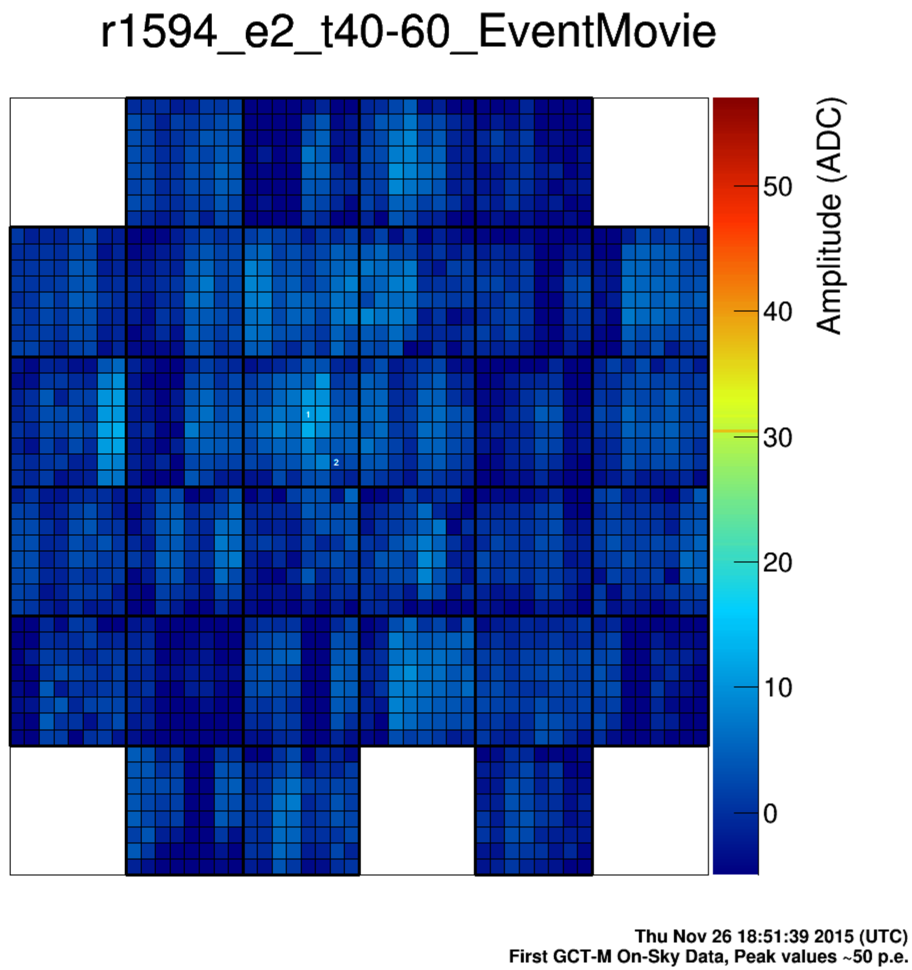


First tests of the GCT prototype on sky

- Thursday 26th November.

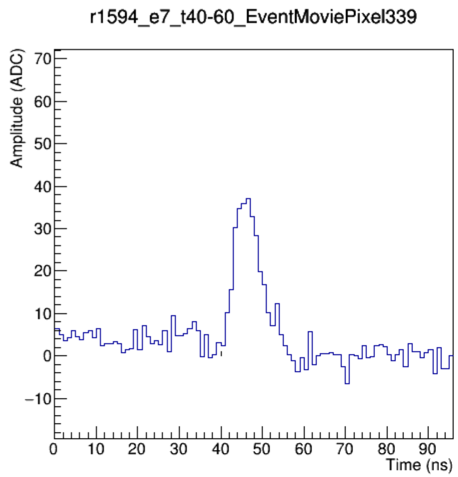


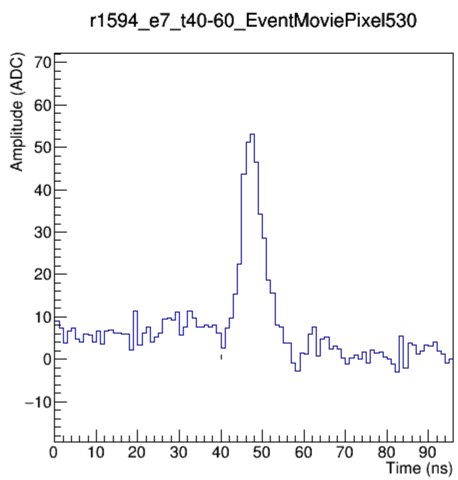


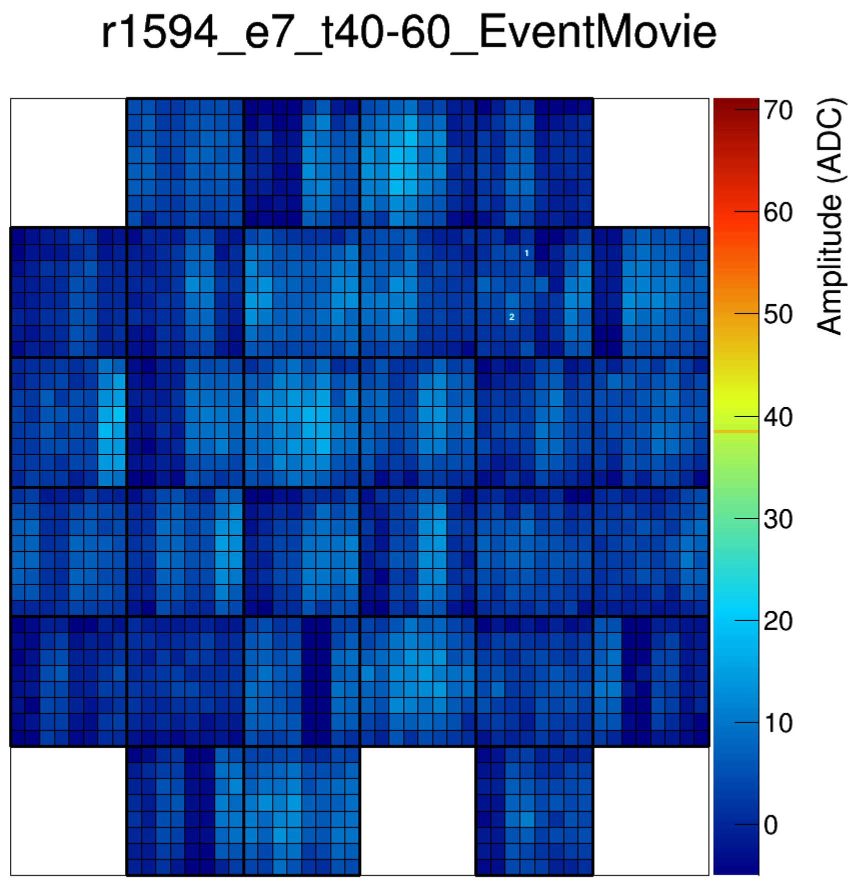


First tests of the GCT prototype on sky

- Thursday 26th November.



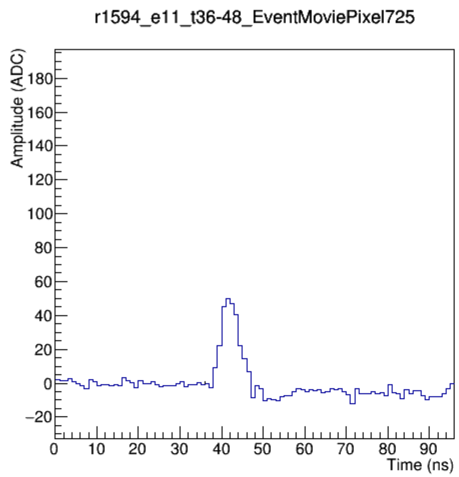


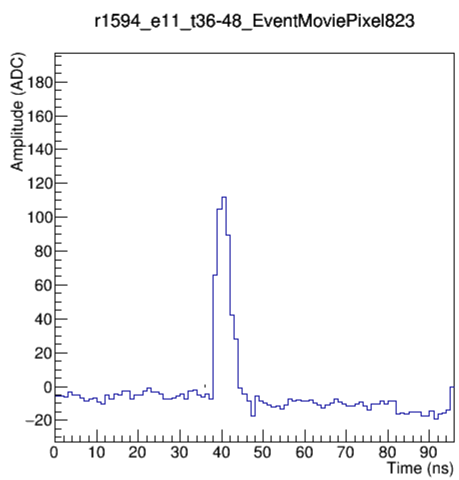


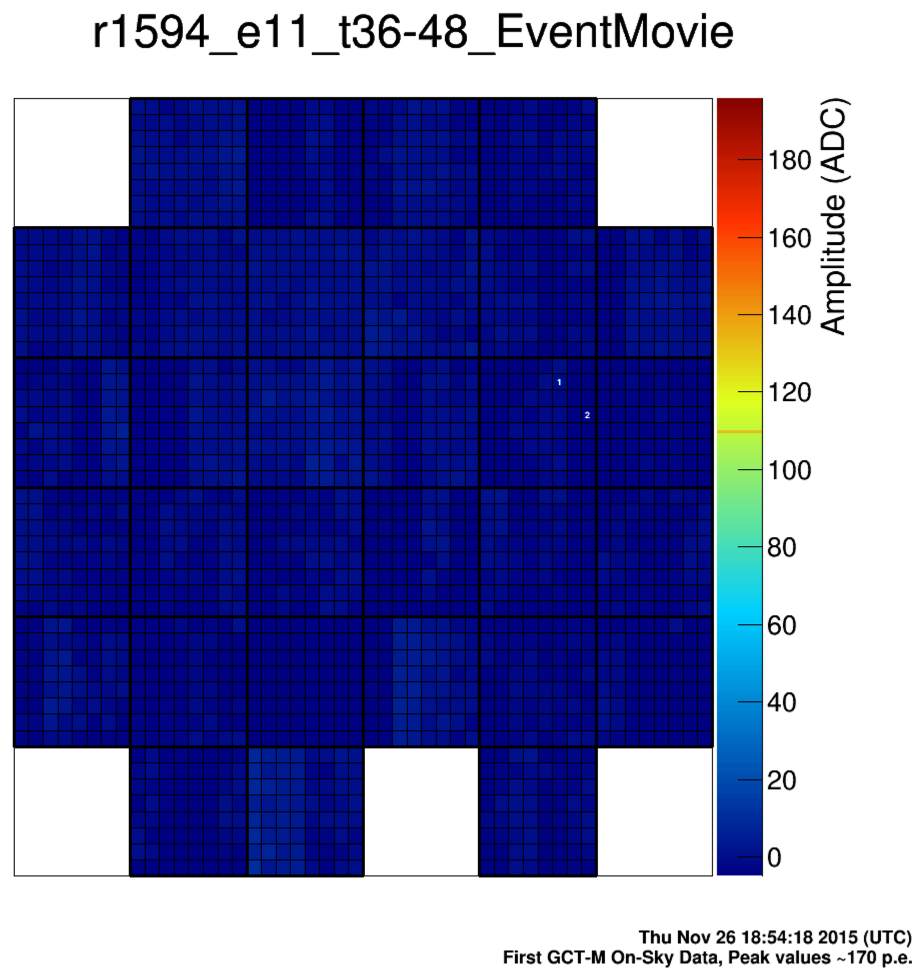
Thu Nov 26 18:52:07 2015 (UTC)
First GCT-M On-Sky Data, Peak values ~70 p.e.

First tests of the GCT prototype on sky

- Thursday 26th November.







Inauguration of the telescope

- Party on 1st Dec. 2015!

What have we learnt?

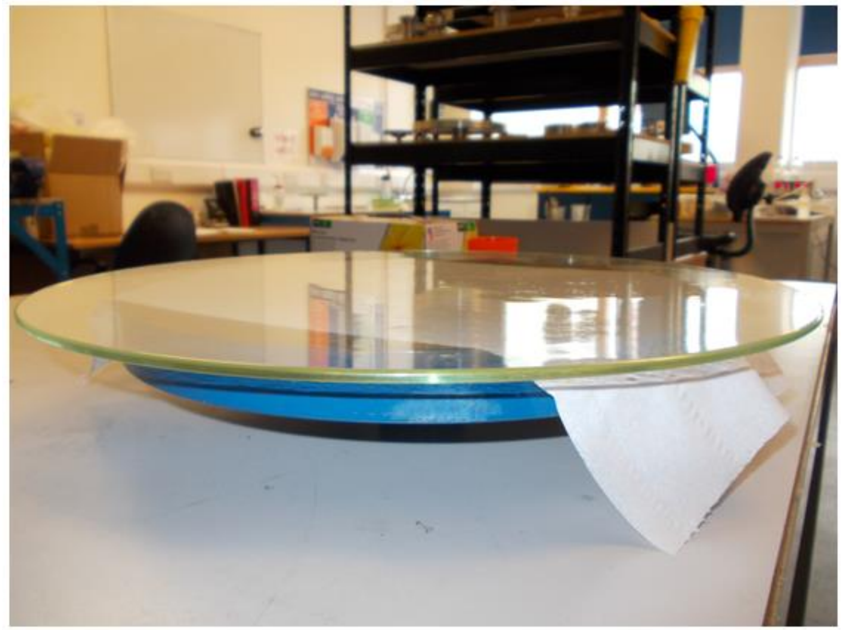
- We need to work on mirrors and mirror production processes.
- Can see by eye that two panels of the secondary are of poor quality (despite nominally all being same).
- Try casting aluminium, machining, applying nickel layer, polishing, coating with aluminium and SiO_2.
- Nickel layer improves surface quality, but also needed if mirror to be recoated, otherwise old Al coating cannot be stripped off.
- Good quality control needed.
- Casting should also reduce cost.
- (Applies also to structural elements.)

- Bad panel in GCT secondary.

Glass mirror studies

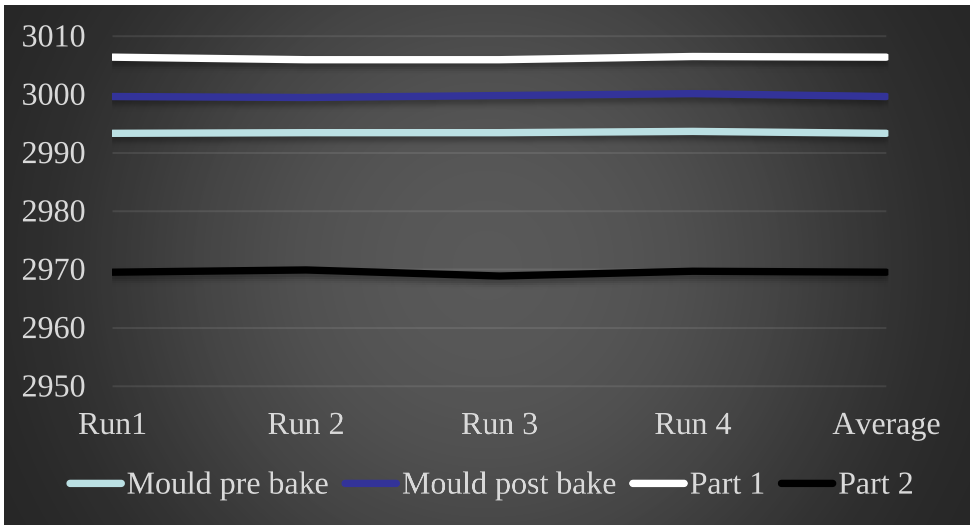
- Hot slump glass mirrors using concave mould.
- Proof-of-principle studies.
- Grind a ceramic mould with radius of curvature of 3 m.

- Level mould in oven and slump 4 mm thick glass sheet, 35 cm diameter, using carefully controlled temperature cycle.



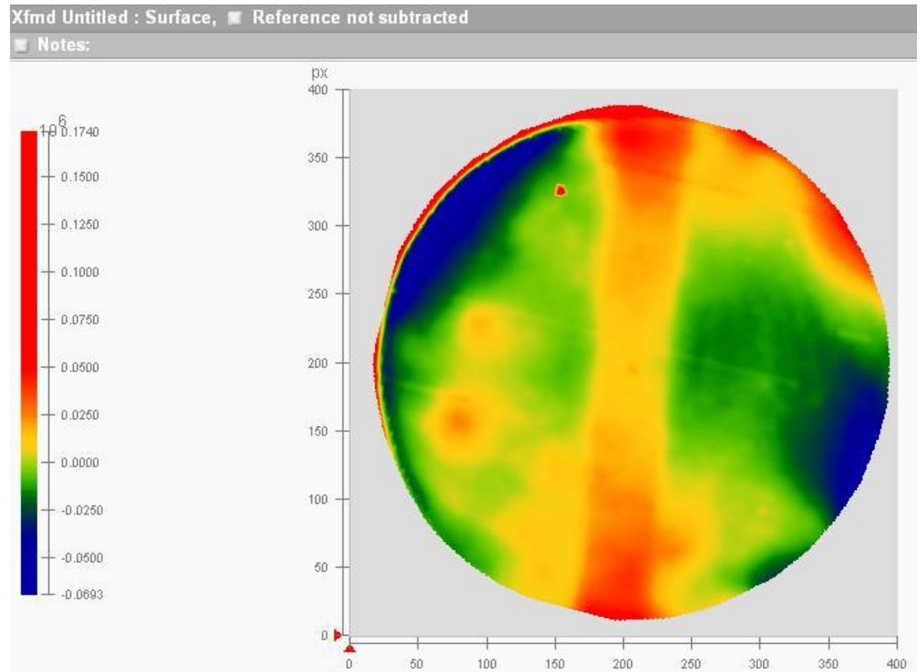
First glass mirror studies

- Measure RoC of glass samples and of mould.



- Mould shrinks slightly after baking.
- Part 1, slumped simultaneously with mould baking, during power cut.
- Part 2, smaller RoC than mould.

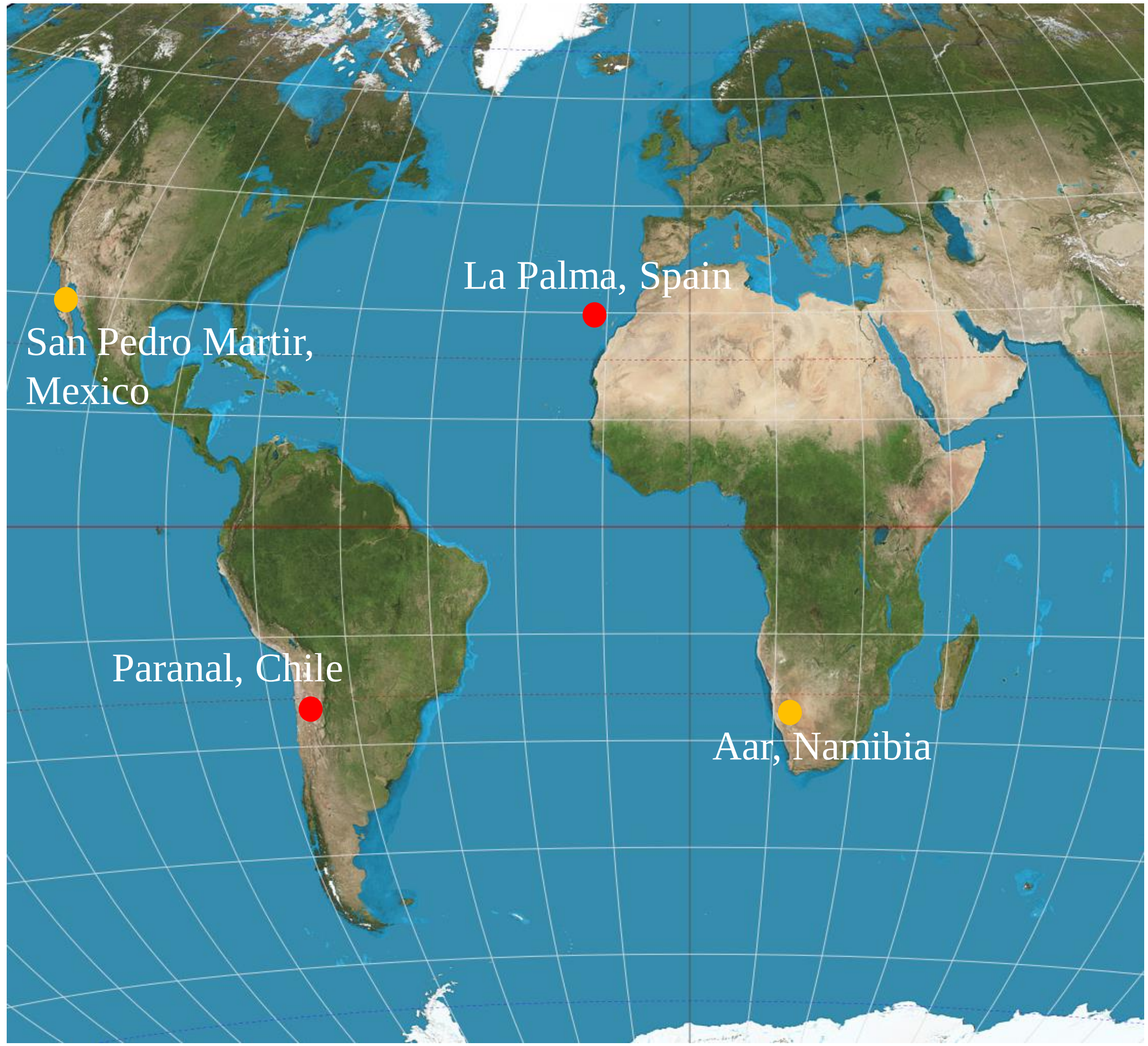
- Glass follows shape of details of mould.



- Next steps, larger samples, petal shapes, smaller RoC, coating…

Next steps for the GCT

- Complete commissioning and testing of GCT camera and structure.
- Complete SiPM-based camera and test.
- Design pre-production camera and telescope.
- Produce three pre-production instruments and install on southern site from end 2017.
- Produce further 32 telescope and deliver 35 systems to CTA Observatory.



ESO Paranal site in Chile

Summary

- Progress with GCT good.
- First of CTA's prototypes to observe Cherenkov light images of air showers.
- Comprehensive prototype telescope and camera test programme underway.
- Design and review pre-production structure by end of 2016.
- Test SiPM camera early in 2017.
- Plan to install first telescopes on southern and northern sites in 2017.