Cherenkov Telescope Array and FACT

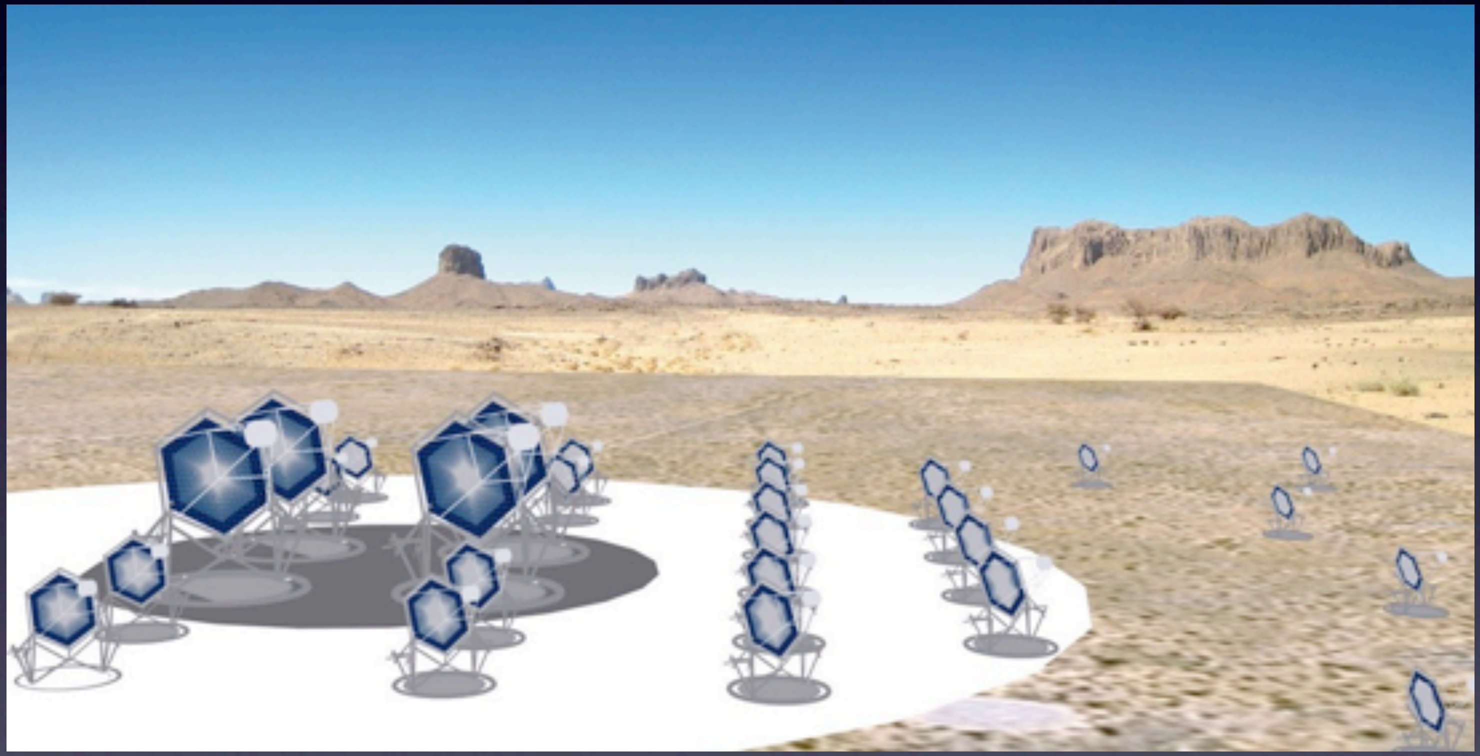
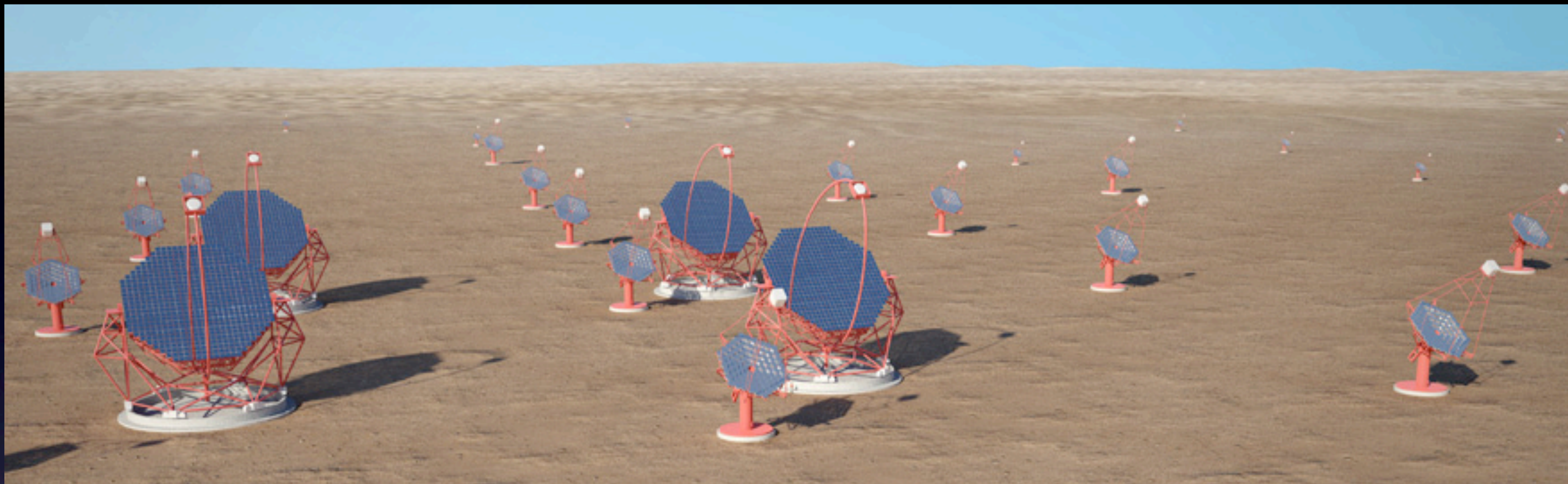


Photo: Daniela Dorner

Vittorio Boccone, Juan Antonio Aguilar Sanchez, Teresa Montaruli, Frank Cadoux

Journée de réflexion du DPNC18 June 2012

The Cherenkov Array Telescope



Conceptual layout of a possible Cherenkov Telescope Array (not to scale)

The CTA project is an initiative to build the next generation ground-based very high energy gamma-ray instrument. It will serve as an open observatory to a wide astrophysics community and will provide a deep insight into the non-thermal high-energy universe.

http://www.cta-observatory.org/

The science of CTA

1. Understanding the origin of cosmic rays and their role in the Universe
2. Understanding the nature and variety of particle acceleration around black holes
3. Searching for the ultimate nature of matter and physics beyond the Standard Model

Galactic Gamma-Ray Sources
- Supernova Remnants
- Pulsar Wind Nebulae
- Pulsar Physics
- Star-Formation Regions
- The Galactic Centre
- X-Ray Binaries & Microquasars

Extragalactic Gamma-Ray Sources
- Active Galactic Nuclei
- Extragalactic Background Light
- Gamma-Ray Bursts
- Galaxy Clusters

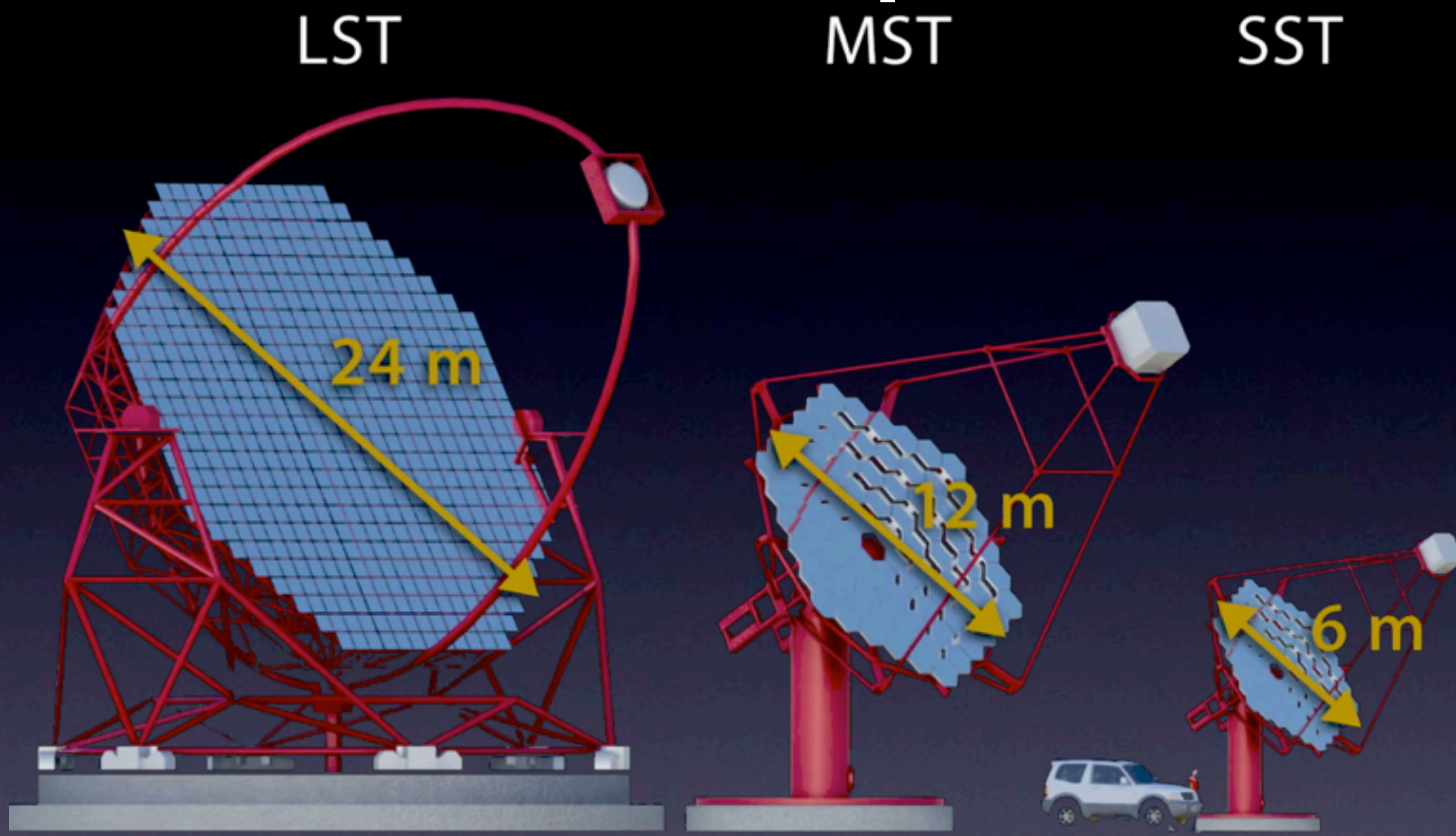
Surveying the Sky with CTA

Fundamental Physics
- Dark Matter
- Quantum Gravity
- Charged Cosmic Rays

Optical Images of Stellar Surfaces

Each of those topics is a talk of its own!

Telescopes



LST: E ≤100 GeV

A small number of very large telescopes, typically with about a 20 m to 30 m dish diameter,

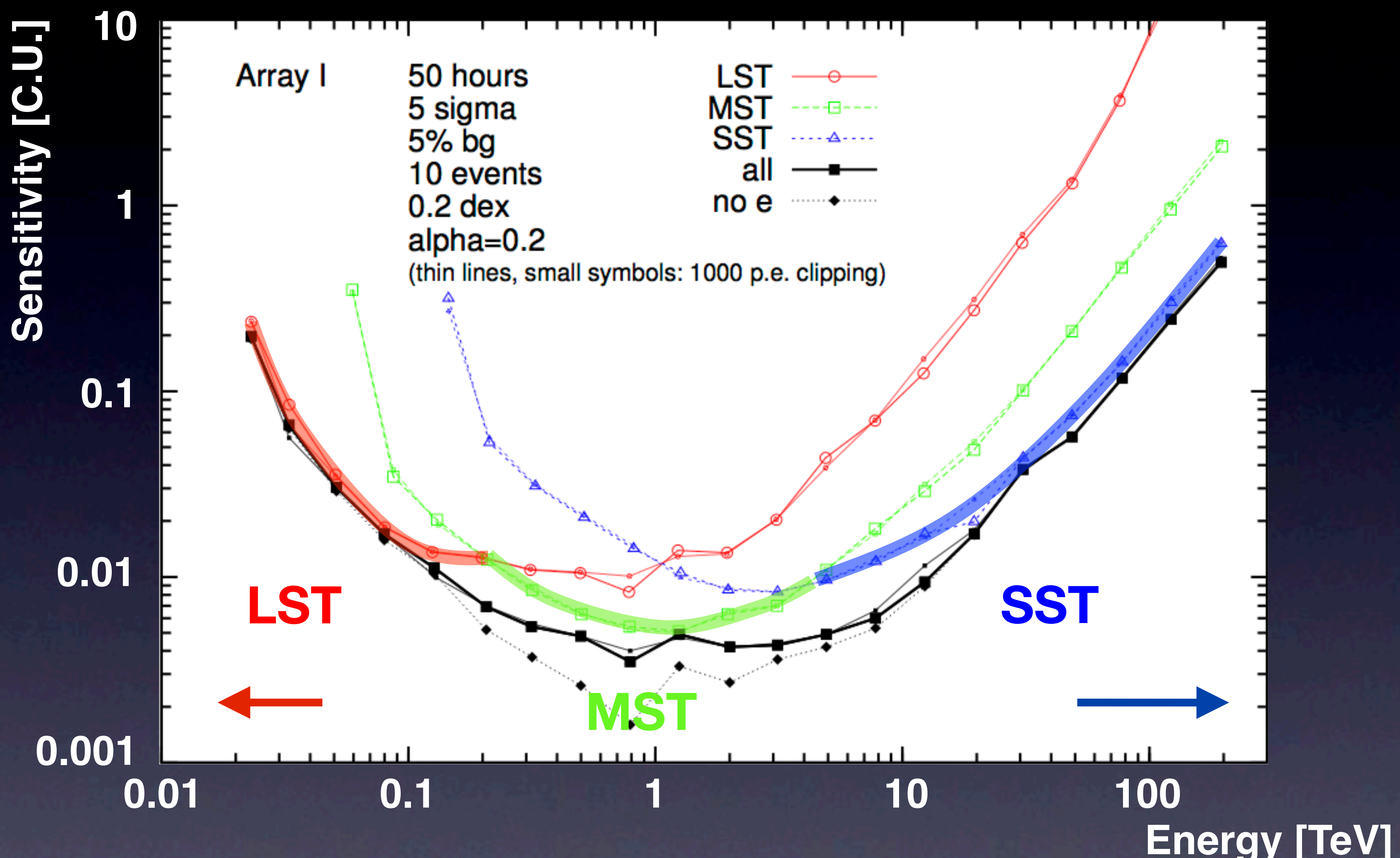
MST: 100 GeV < E < 10 TeV

grid of telescopes of the 10 to 15m class, with a spacing of about 100 m

LST: E >10 TeV

large number of smaller telescopes 4-7 m spaced by more than 100m

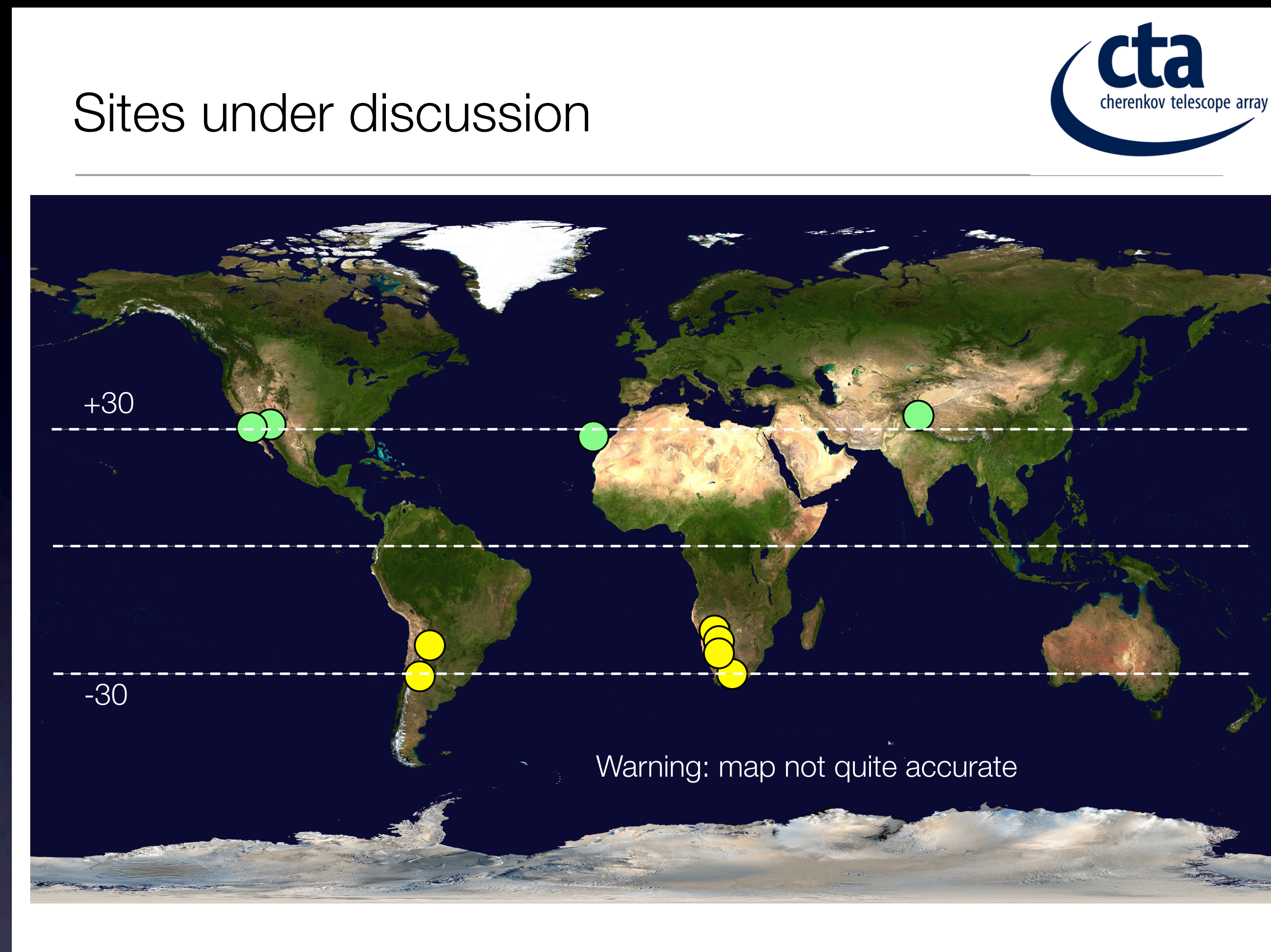
Energy sensitivity



Discovery sectors: < 50 GeV (Large-Size Telescopes for GRBs, pulsars, DM); > 5 TeV (Small-Size Telescopes for hadronic phenomena - connects to neutrinos, EBL (informs us on cosmological distribution of sources), intergalactic magnetic fields, unidentified galactic PeVatrons that produce CRs at the knee, acceleration of particles to the highest energies, jet formation in BHs, new physics (VLI).

Multi-messenger approach: only measurements in different bands and with different messengers (from ground and from space) can help reconstructing how sources work.

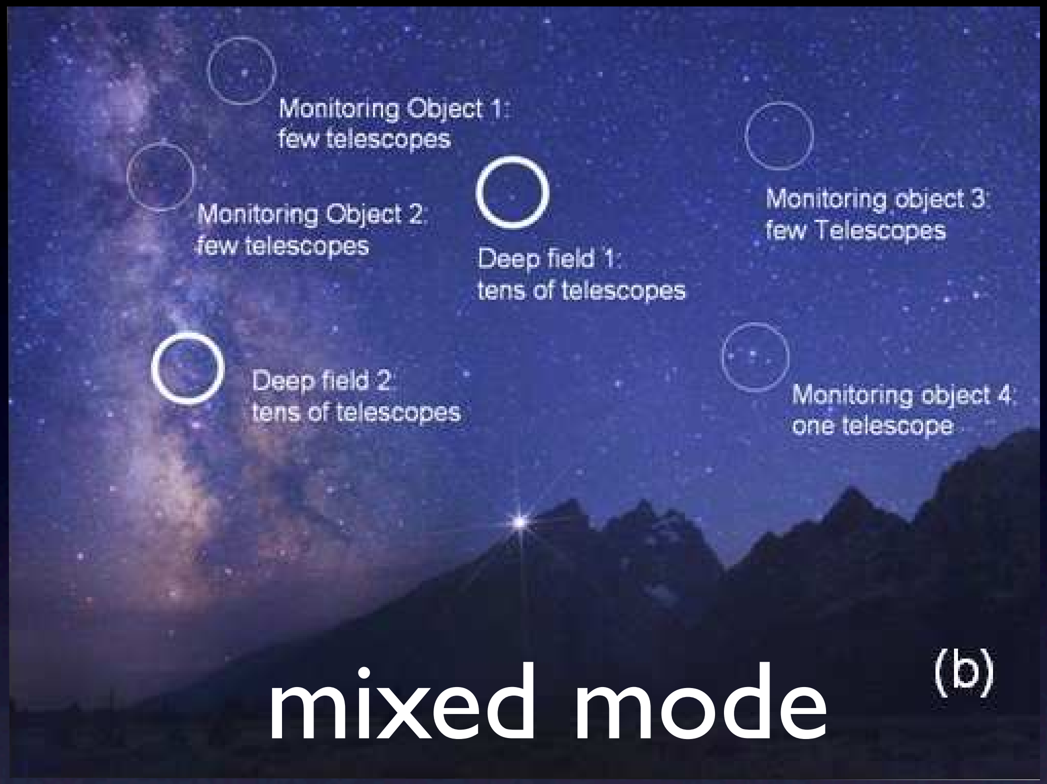
CTA possible sites

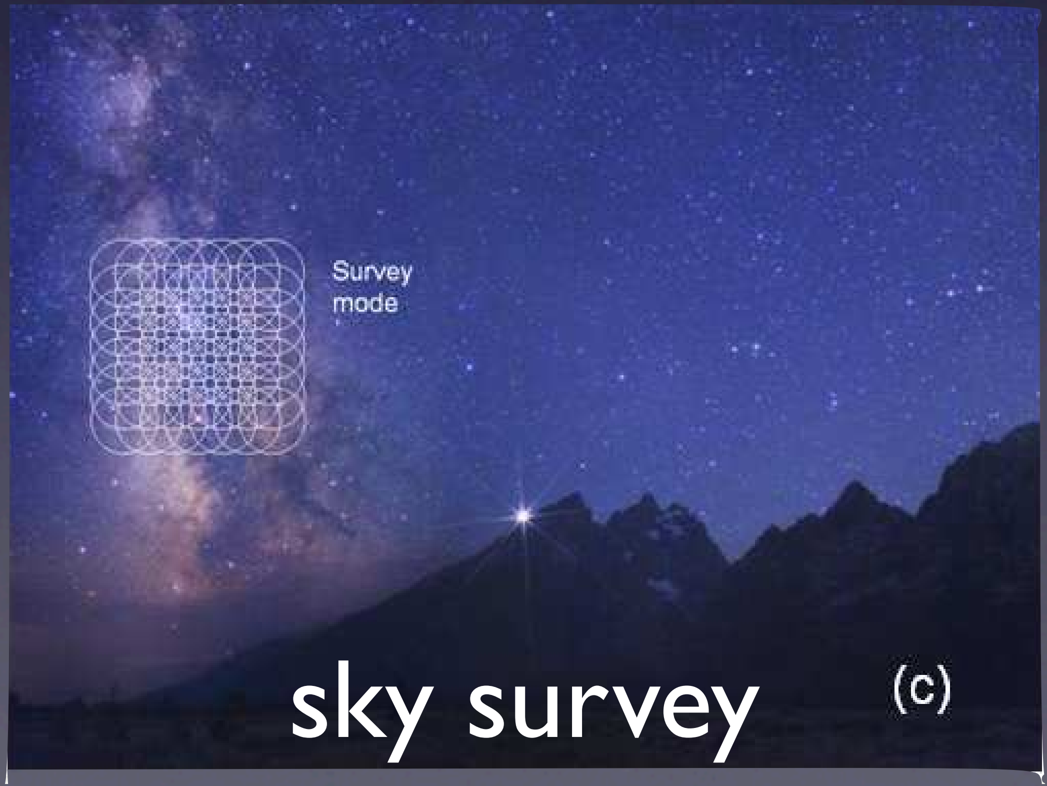


2 Sites (North/South) to cover full sky of O(100) telescopes of 3 different sizes.

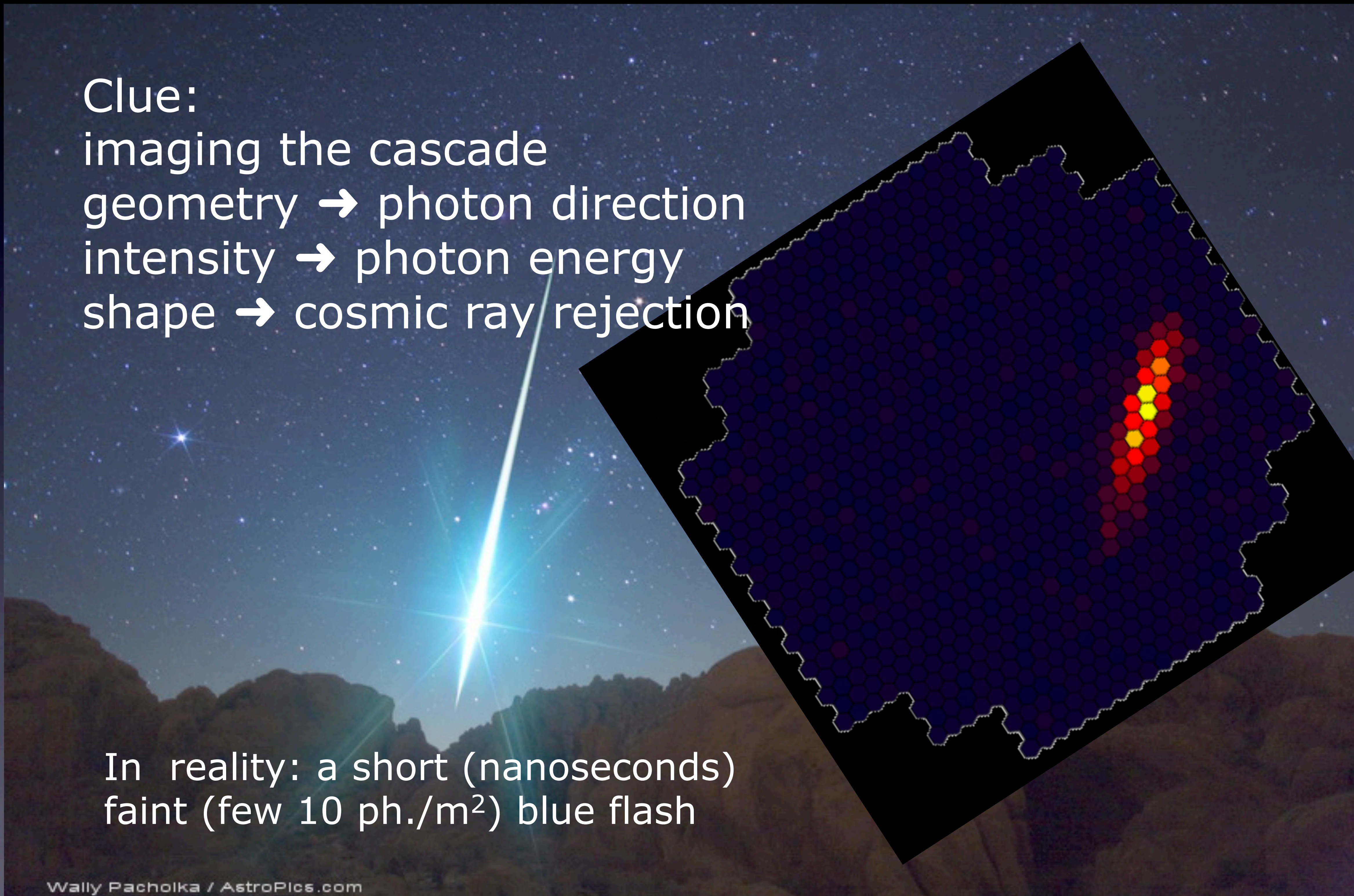
South site is most important site in the due to better Galactic plane exposure. Decision on site in about 1 yr (Namibian sites, Tenerife seem very good options).

Operation modes





Technique

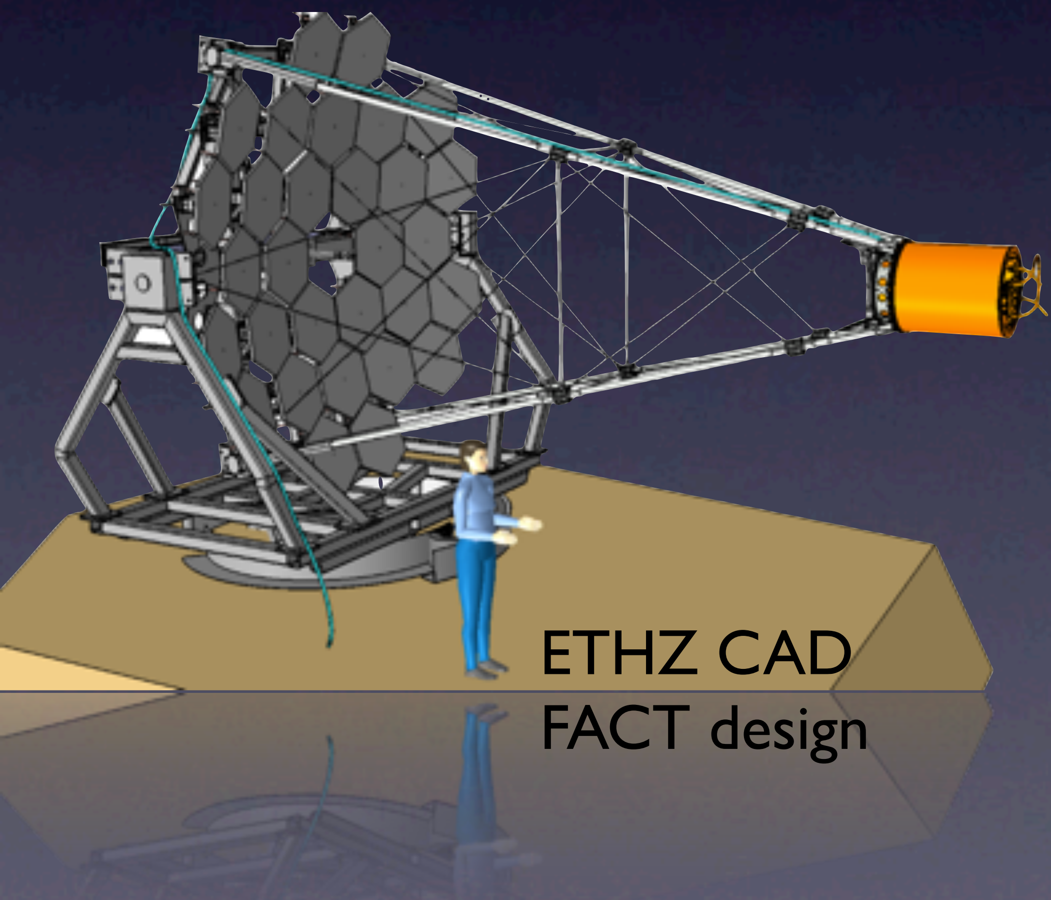


Clue:
imaging the cascade
geometry ➜ photon direction
intensity ➜ photon energy
shape ➜ cosmic ray rejection

In reality: a short (nanoseconds) faint (few 10 ph./m^2) blue flash

a 4m Davis Cotton SST

Physics program in the multi-TeV regime requires a rather large FoV of ~10° and reasonably good angular resolution ~0.03°
Davies-Cotton design has an adequate resolution over this FoV with no need to be larger than D ~ 4 m



Objectives:
- Simplest telescope structure Davis cotton 4m;
- Focus on camera: FlashCam, FACT camera;
- Concept easily extensible for the 2nd camera generation;

Challenges based on unique experience:
- prove mass-producibility and low cost of detector plane;
- low maintenance parts;
- reduce weight;
- innovation in photo-detection: G-APD

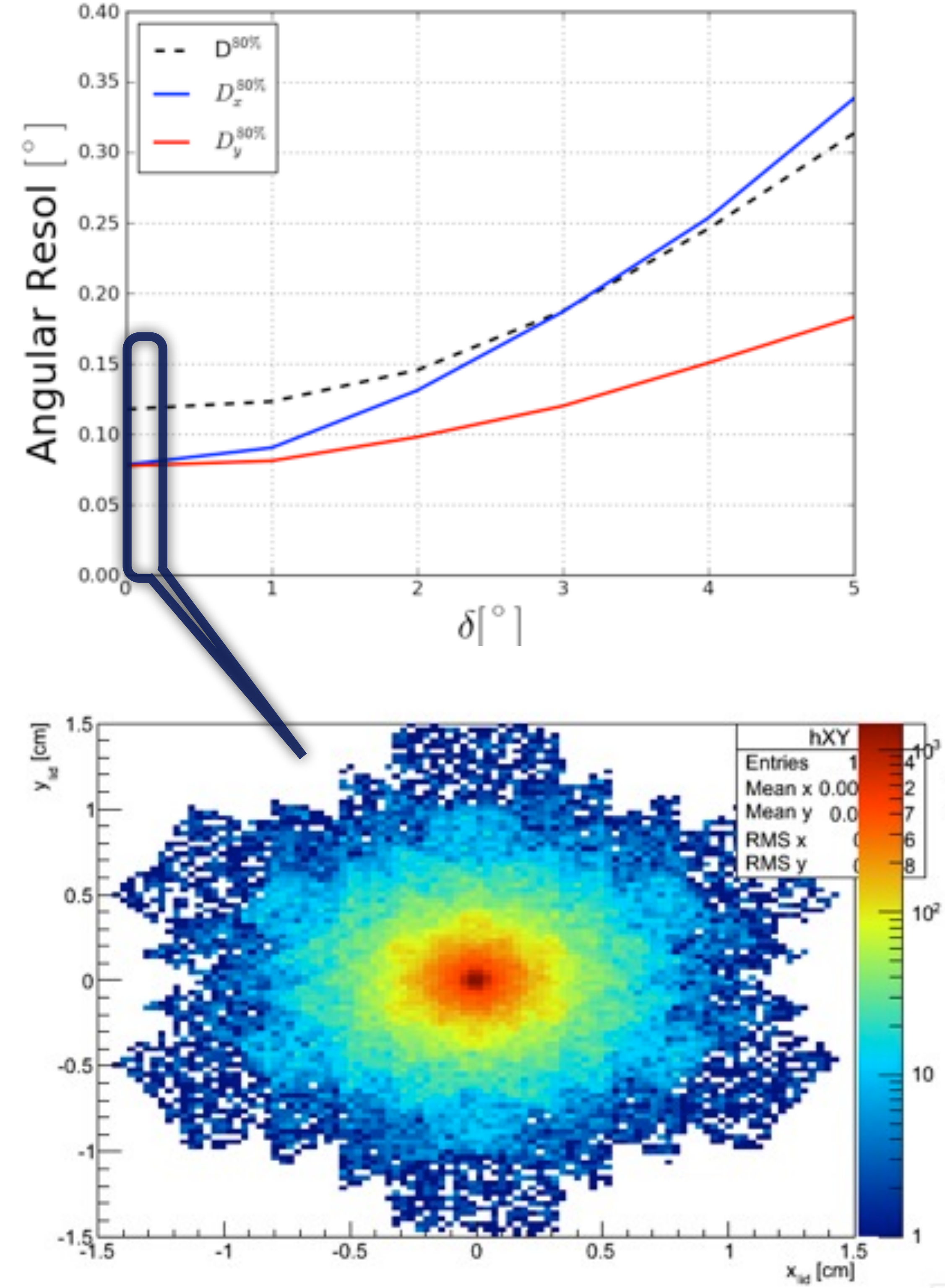
a 4m Davis Cotton SST

We propose a Davis Cotton SST

- f/D = 1.4;
- D = 4 m, f = 5.6 m;
- FoV = 10 deg;
- Angular pixel size: 0.28 deg
- Physical pixel size (diameter): 2.70 cm
- Side for an hexagonal sensor is: 0.5 cm
- N_{pixels} is: ~1300
- Mirrors, two solutions:
  - 18x 80 cm;
  - 36x 60 cm (better for angular res.);

The final dimension of the mirrors and of the pixels will be fixed in few days in the 4m Davis Cotton SST working group (which we organized)

36x 60 cm mirrors



CTA - Our proposal for the SST

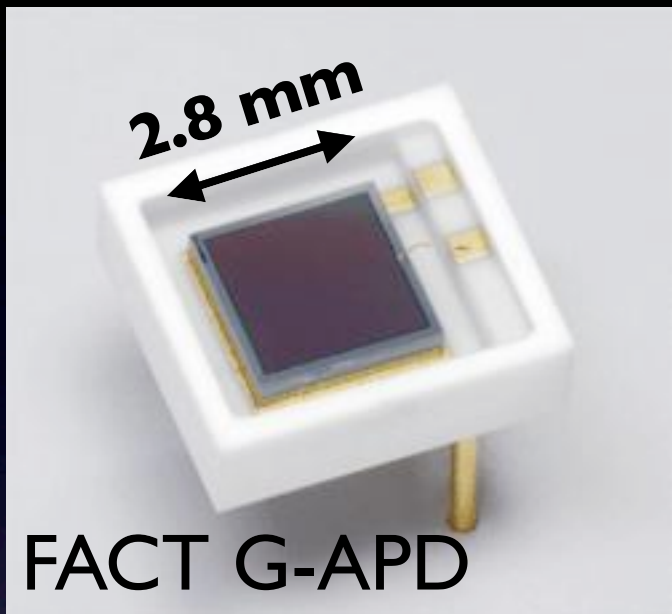
Organization

Project Manager
T. Montaruli

Technical Manager
(TBD)

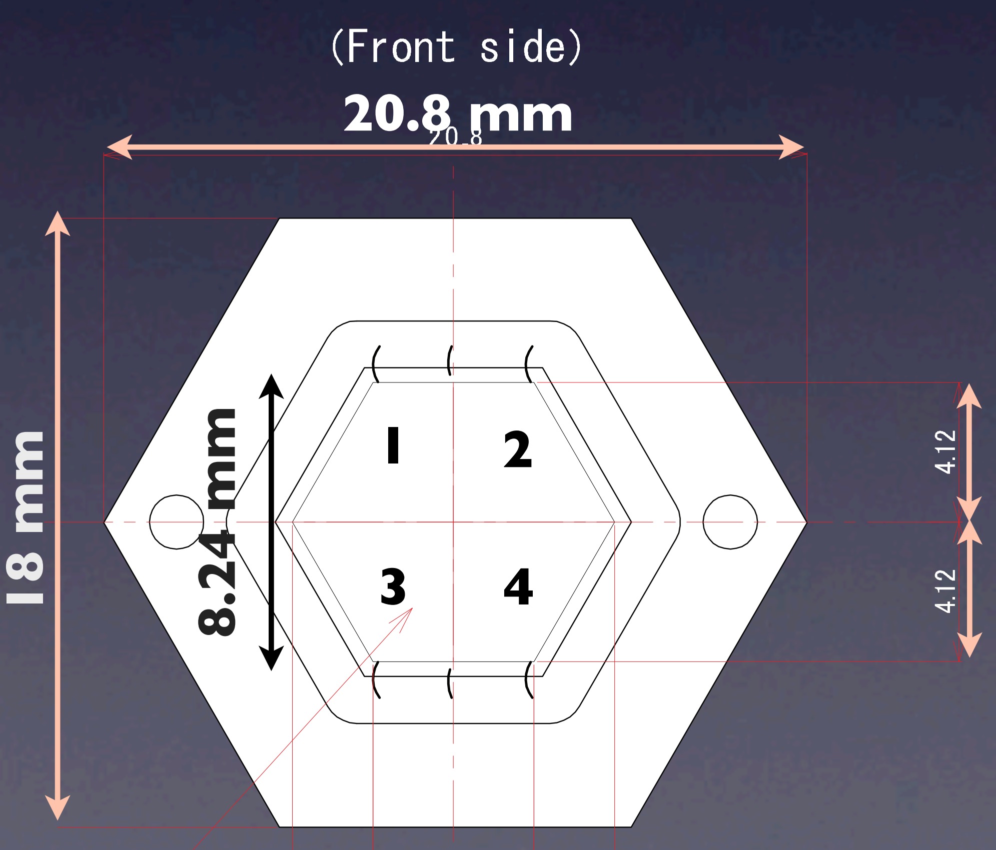
- **DC-MECH**
  Mechanical System
  J. Niemiec, PL
  - Mechanical Structure
    Argentina, Poland
  - Servo motor system, gears, breaks
    Argentina, Poland
- **DC-OPT**
  Optical System
  K. Seweryn, PL
  - Mirror glass - Armenia?
    comp. - Poland, Argentina
  - Actuators
    PL, Tübingen, Heidelberg, Zurich
  - Alignment system for mirror
    PL, ??
- **DC-CAM**
  Camera System
  K. Zietara, PL/??
  - Camera Mechanics & Cooling system
    Poland/Argentina
  - MPPC Detector Plane, light funnels
    DPNC,EPFL,CPPM
  - Electronic-Preamp and bias voltage
    ETHZ, DPNC
  - Electronics DC-FlashCam
    Digitization, Trigger
    Power units
    Heidelberg, Poland, Tübingen, Zurich
- **DC-Control**
  Control System, DAQ Software & Calibrations
  Argentina/Switzerland?
  - Camera Slow Control PLC,
    ETHZ, DPNC, Argentina
  - Electronics DC-DAQ
    Server/event builder
    has to comply with CTA standards
    CPPM, ISDC
  - Monitoring Console
- **DC-SIMU**
  Simulation
  R. Moderski, PL
  - Camera Simulation
    Tübingen, Heidelberg, Zurich,,Poland
  - Simulation of full telescope
    Poland, DPNC
  - Simulated data analysis
    Poland, DPNC
  - Simulation of array of telescopes
    Poland, DPNC,??
- **DC-INFRA**
  Infrastructure
  Argentina
  - Necessary Infrastructure at the CTA Site
    Cabling
    Power supplies
    Hut
    Cooling system

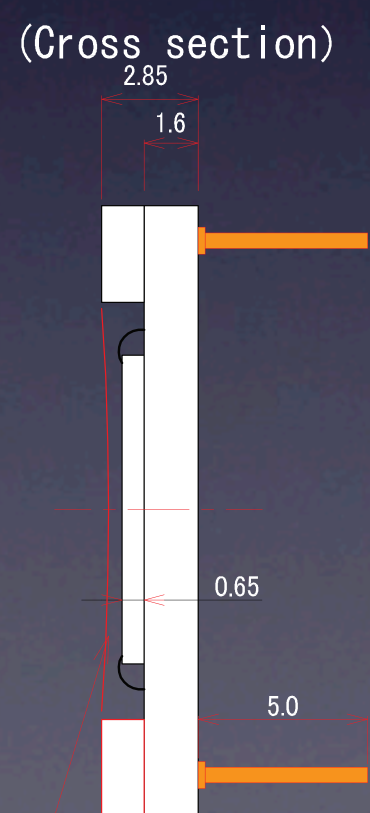
The G-APD detectors



Why SiPM?

- Good PDE > 25% integrated between 300<λ/nm<650 (50 μm);
- Excellent s.p.e. discrimination;
- Large Dark Count rate (but << NSB);
- Crosstalk (about 12% at nominal voltage);
- in FACT and 1.5% comes from electronics.
- Single devices match the required SST pixel size once topped with light concentrators;
- Low operating voltage, robust (survive direct exposure to sunlight, aging);
- Lightweight camera: simplified support structure;



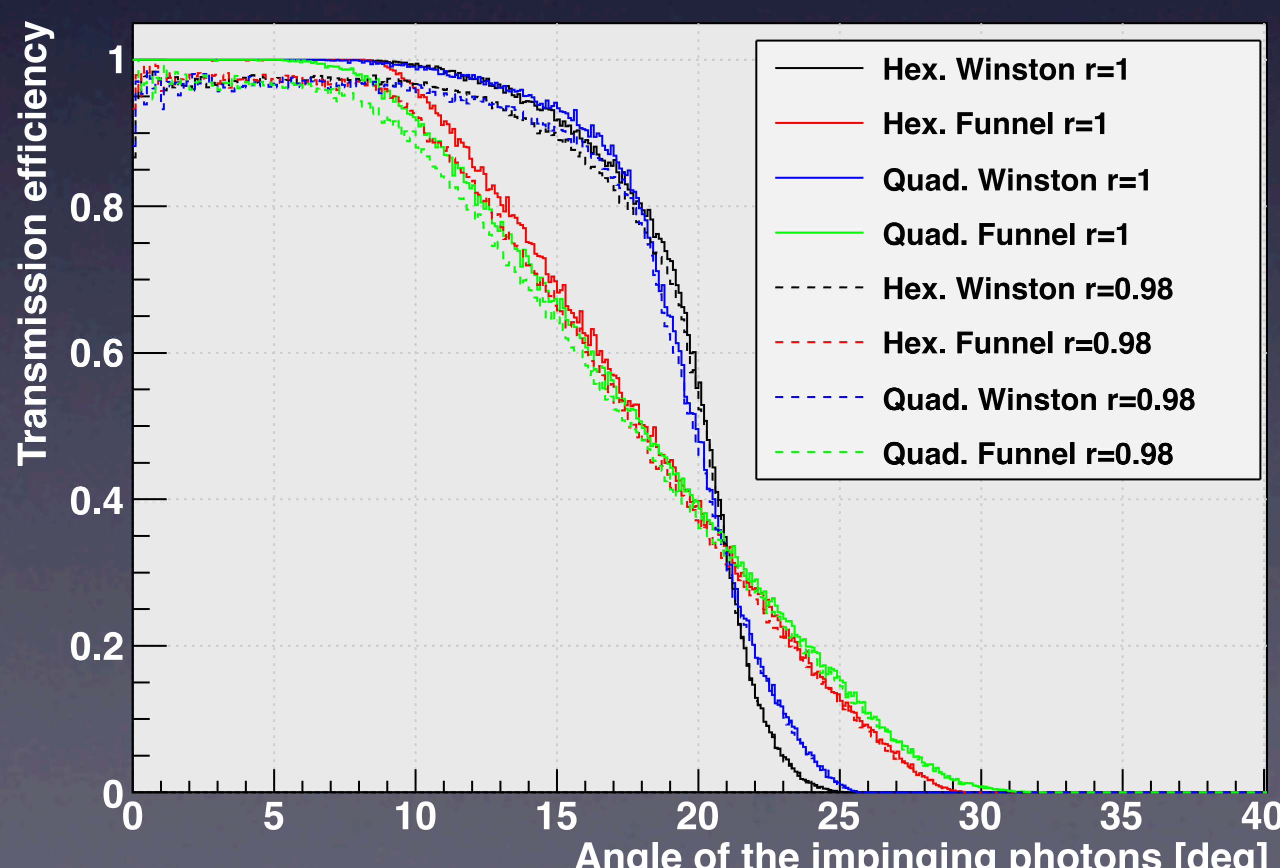


- Custom design from Hamamatsu to avoid square to hexagon adaptation of the light concentrators;
- Test of the photo-detection-efficiency in collaboration with the GAP OPTIQUE (Group of Applied Physics)

Design of the light concentrators

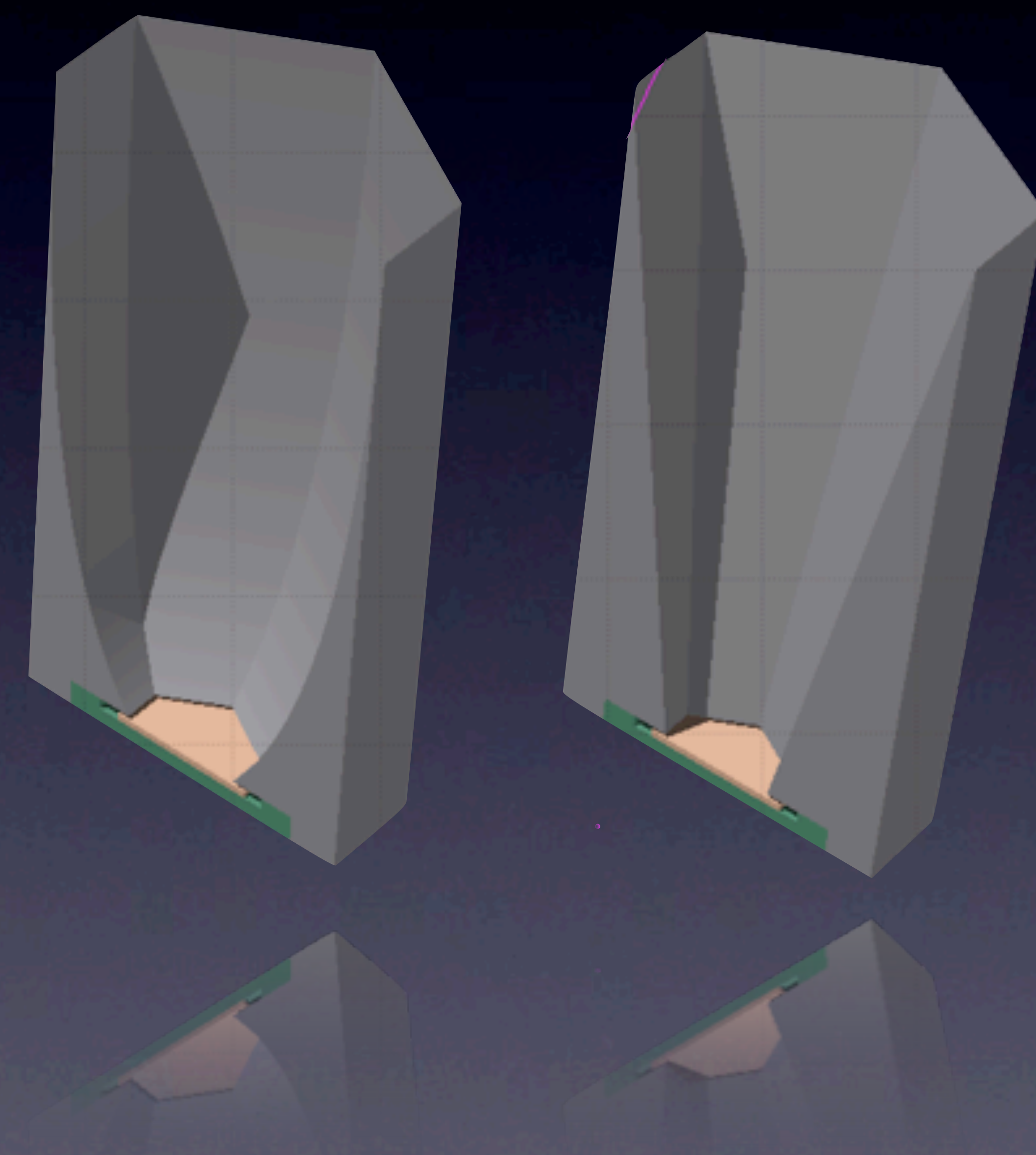
First results of FLUKA initial simulation (detailed ZEMAX simulation will follow):
No PMMA entrance window yet
Light 400nm, no wavelength reflectivity dependence.

Comparison of parabolic (Winston -like) and flat reflectors;
10M perfectly diffused photons on the top of the funnel,
Hexagonal/Square pixel comparison;
Real reflectivity of the 3M Vikuiti ESR foil 98%;
Ideal reflector -> 100% reflectivity;

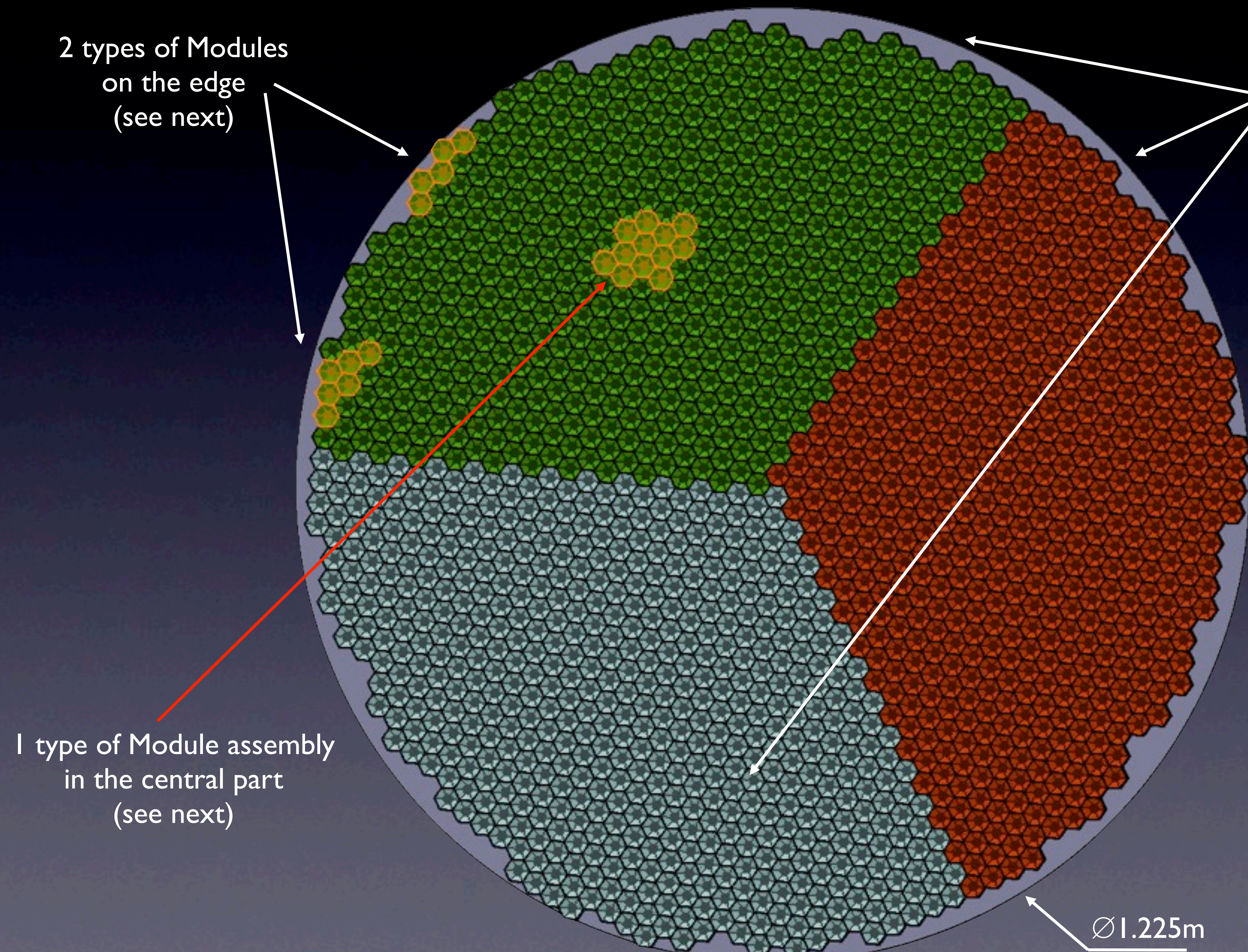


parabolic Winston-Cone concentrator

flat funnel concentrator

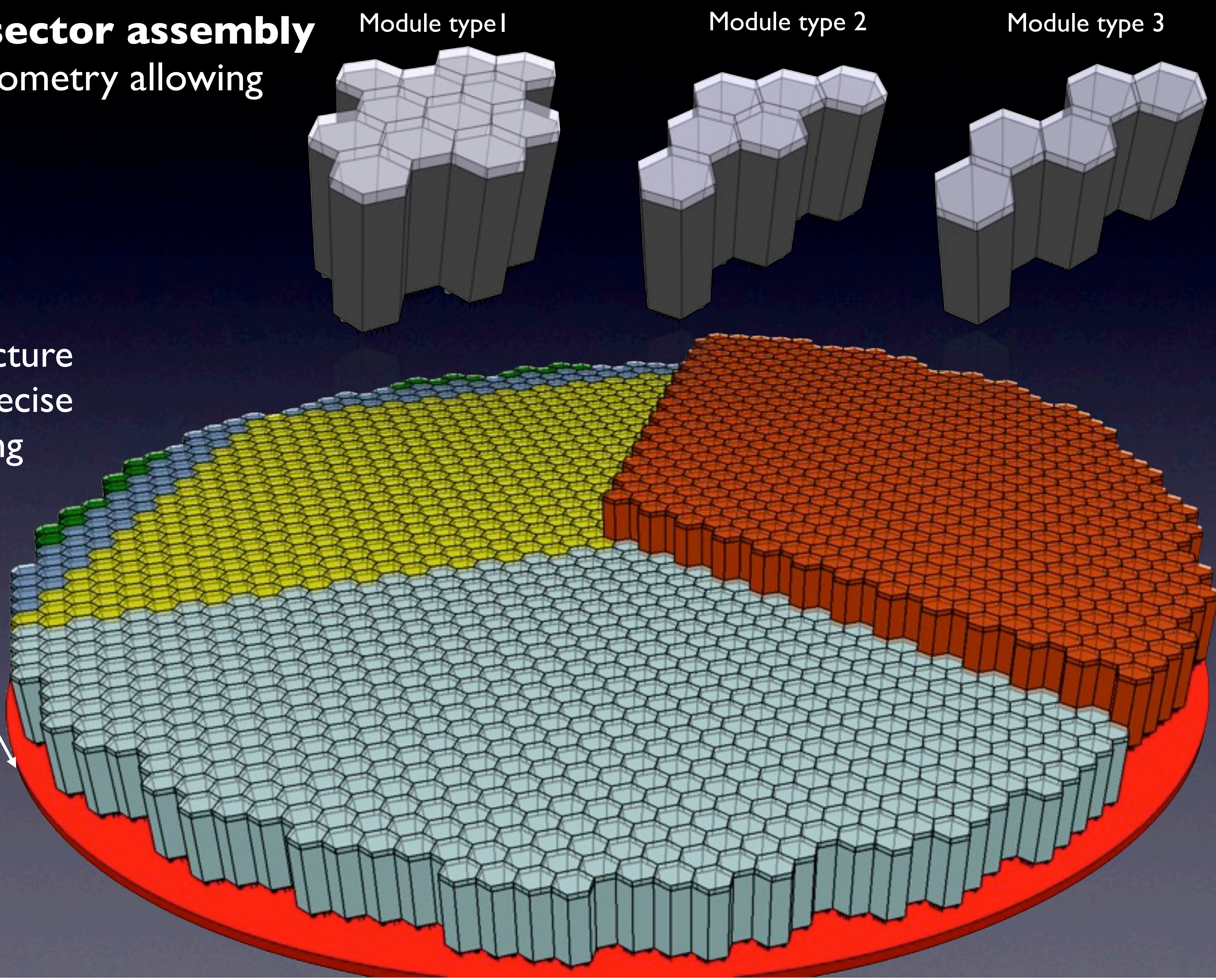


The camera plane model



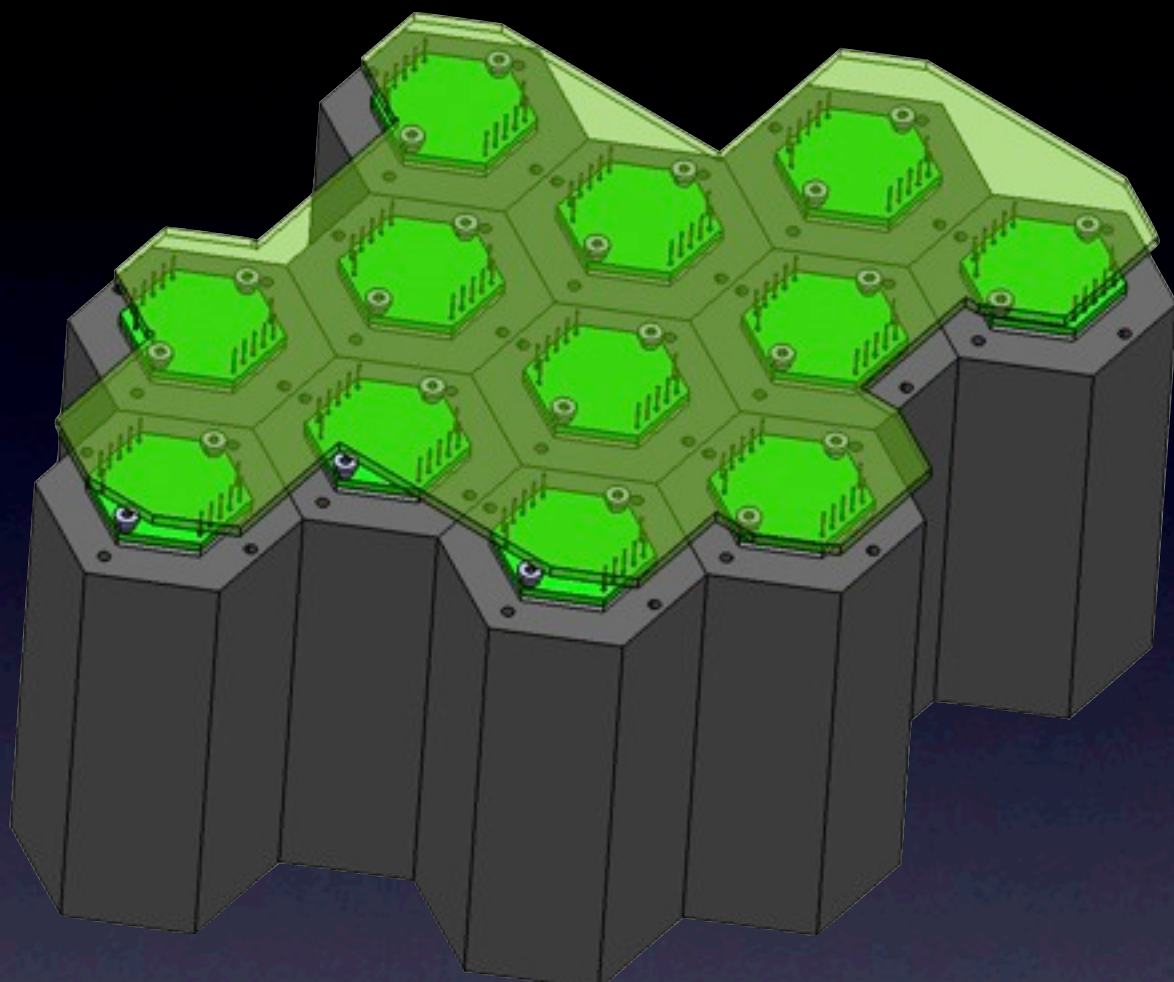
Detector segmentation

Overview on sector assembly
Module type 1 geometry allowing such organization



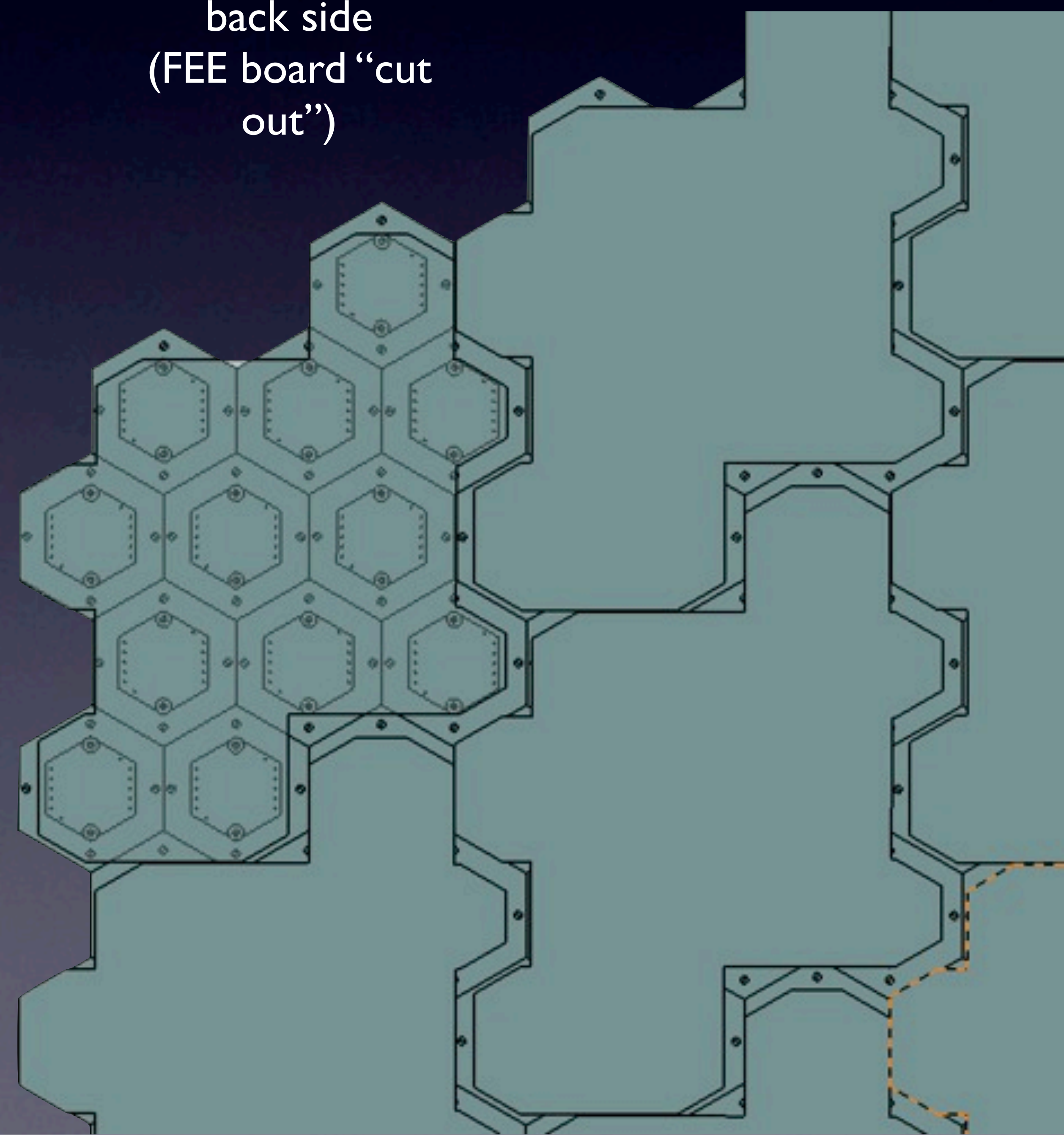
Honeycomb structure which provide precise module positioning

Detector segmentation

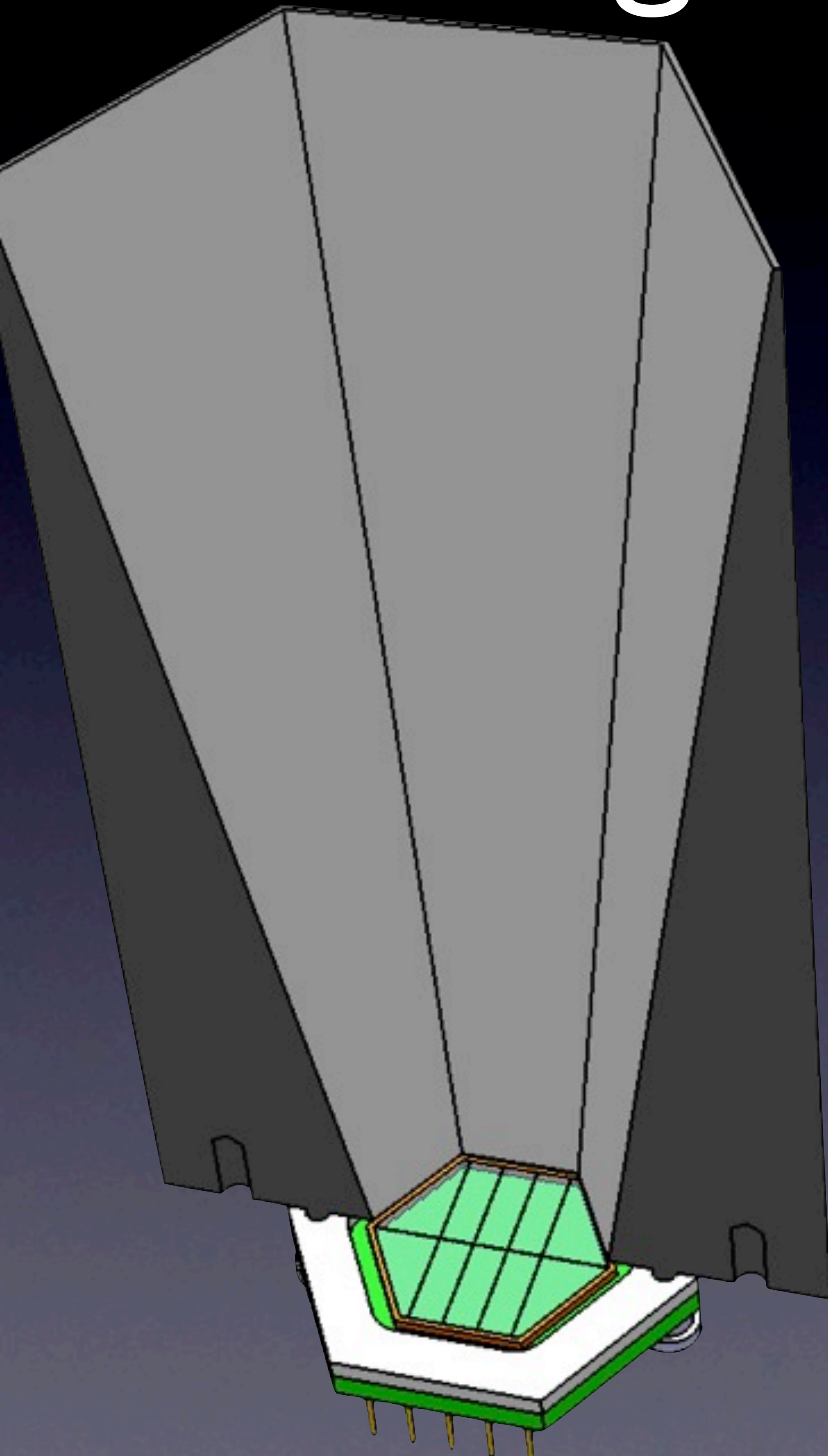


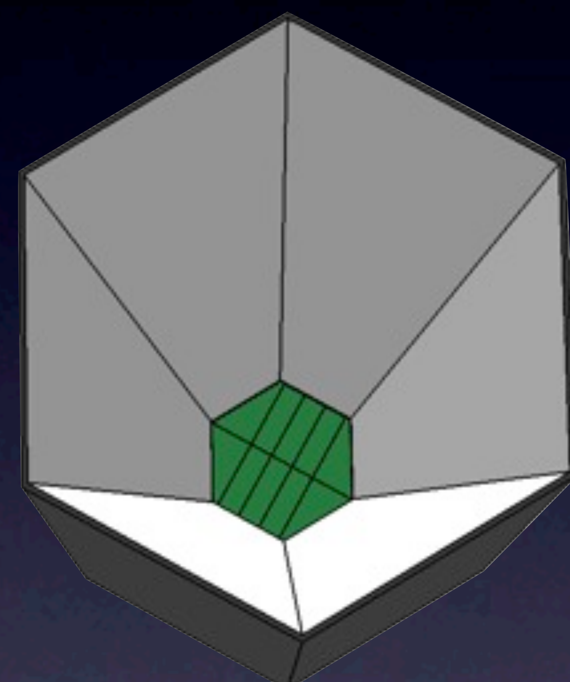
fits FlashCam

Seen from the back side (FEE board "cut out")

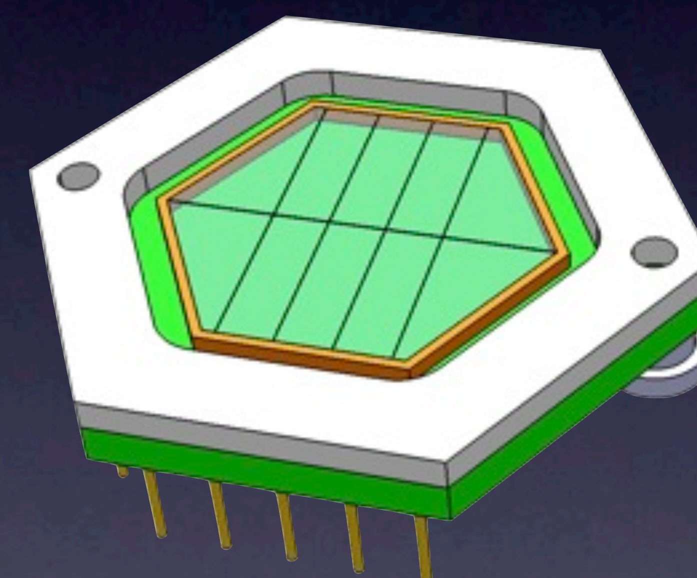


Single Pixel overview





A single cone approach
(see next the multi cone approach)

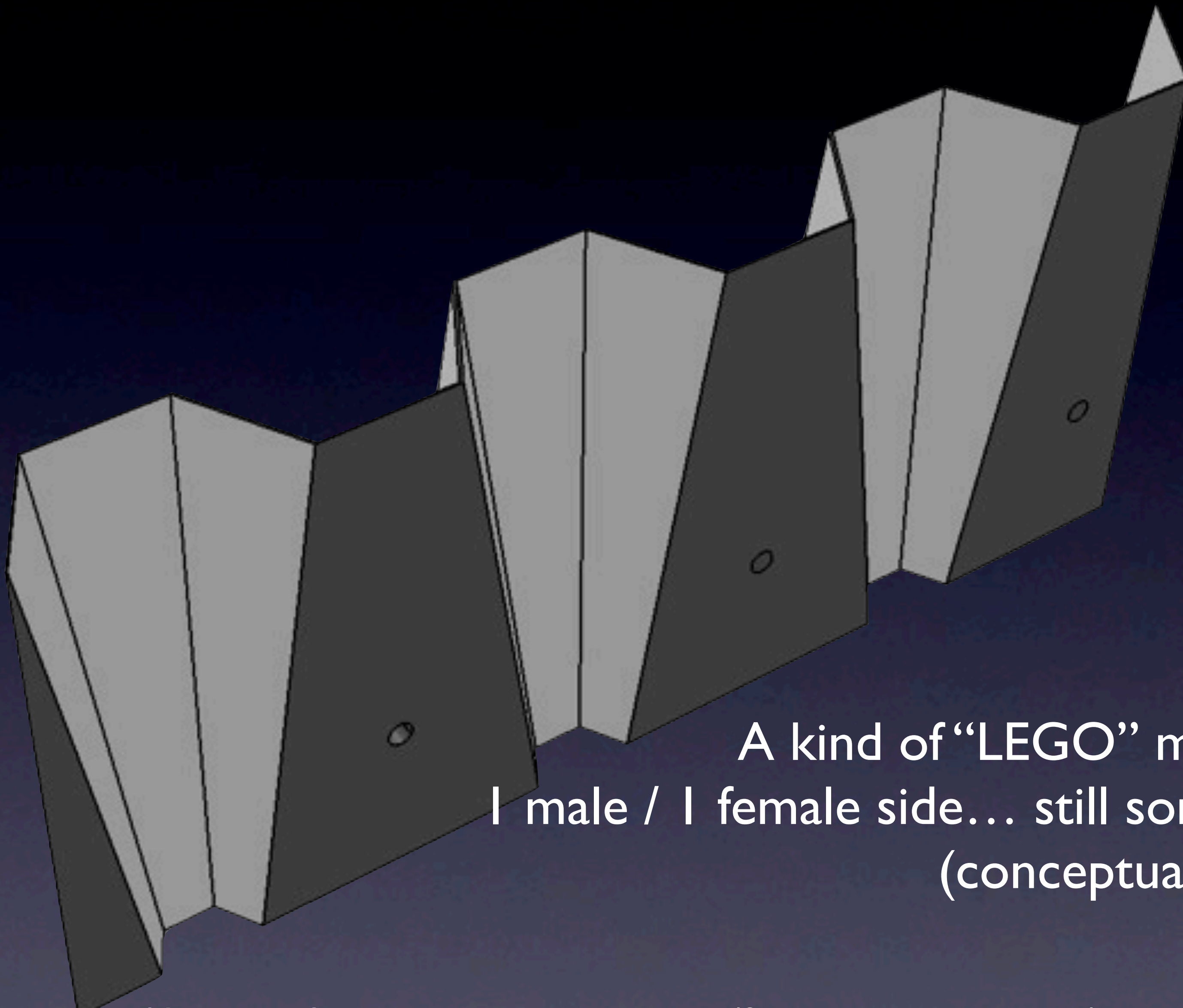


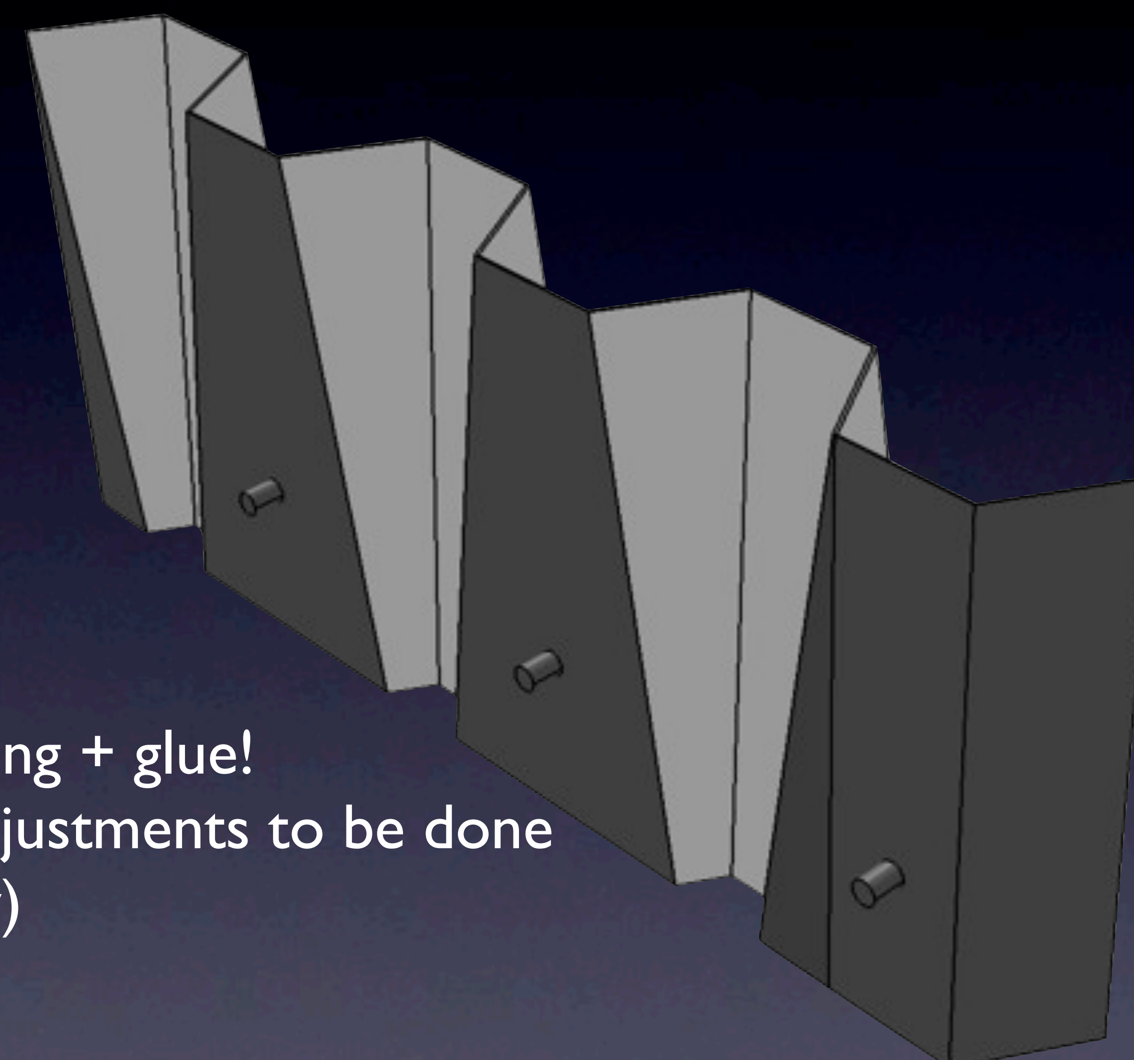
Filling factor (~1300 cones): nearly **94%**

- Number of Module type1: 36x3 (1296 cones)
- Number of Module type2: 15x3 (270 cones)
- Number of Module type3: 4x3 (60 cones)

Assembly

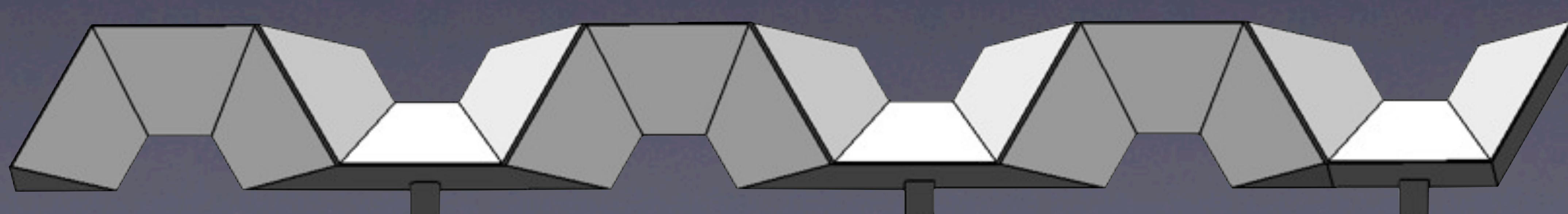
Winstone Cone/Funnel and module Assembly…towards a new concept to simplify coating process





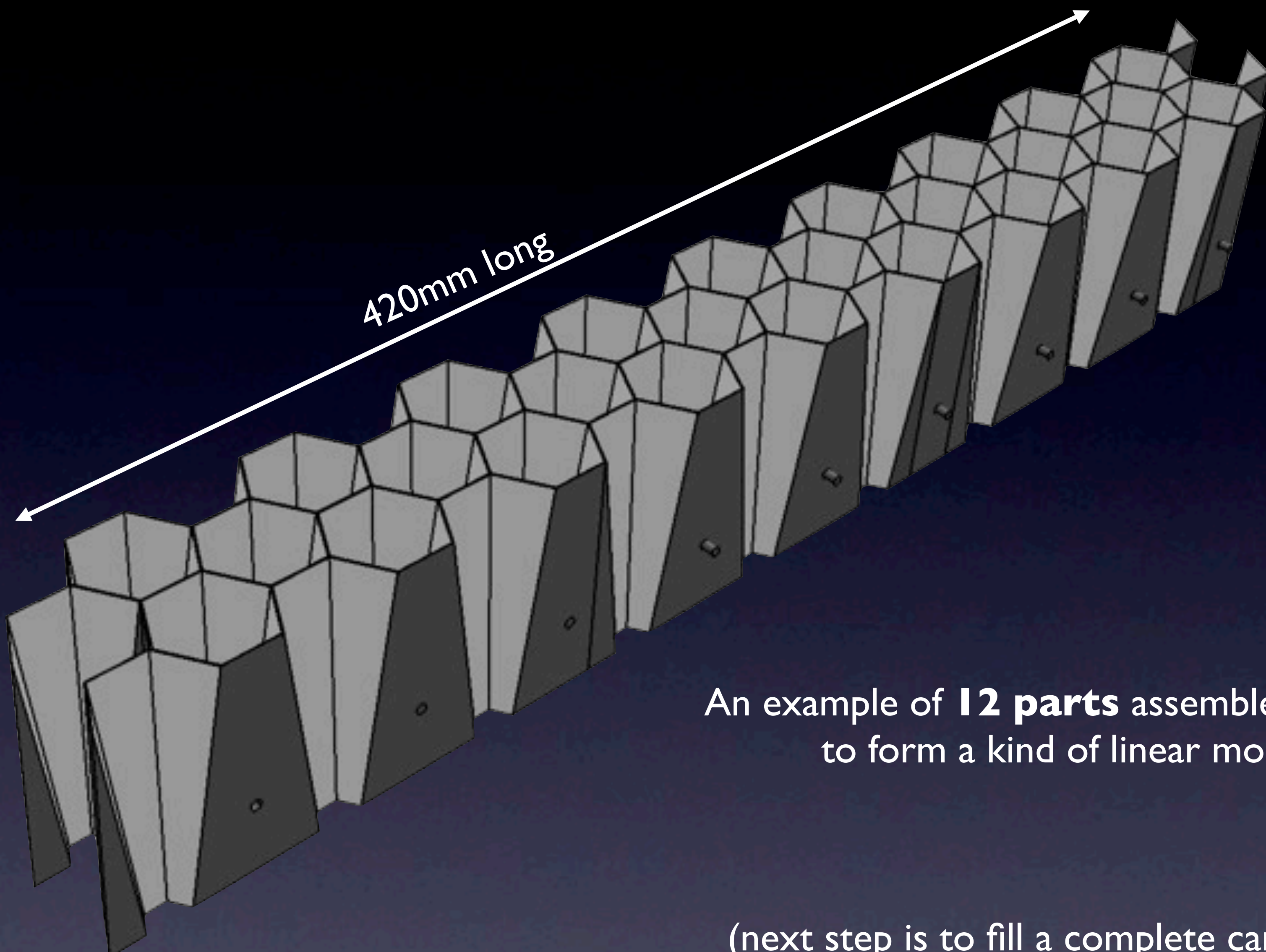
A kind of "LEGO" mounting + glue!
1 male / 1 female side… still some adjustments to be done
(conceptual view)

About **140 mm** long plastic piece (from plastic injection)…easy to perform a "vapor deposition" (open surfaces)



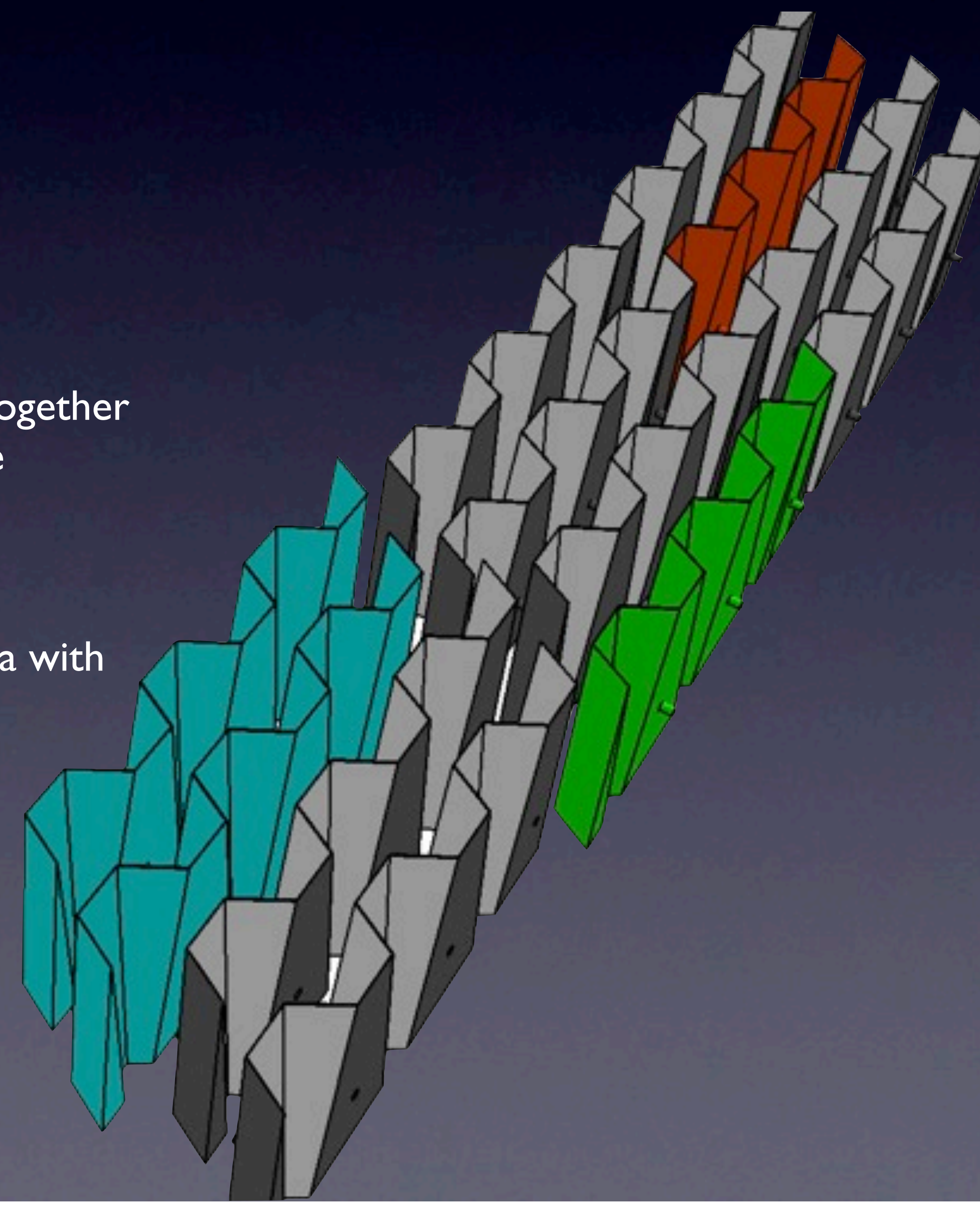
Camera

Winstone Cone and module types…towards a new concept!



An example of **12 parts** assembled together
to form a kind of linear module

(next step is to fill a complete camera with
this approach))

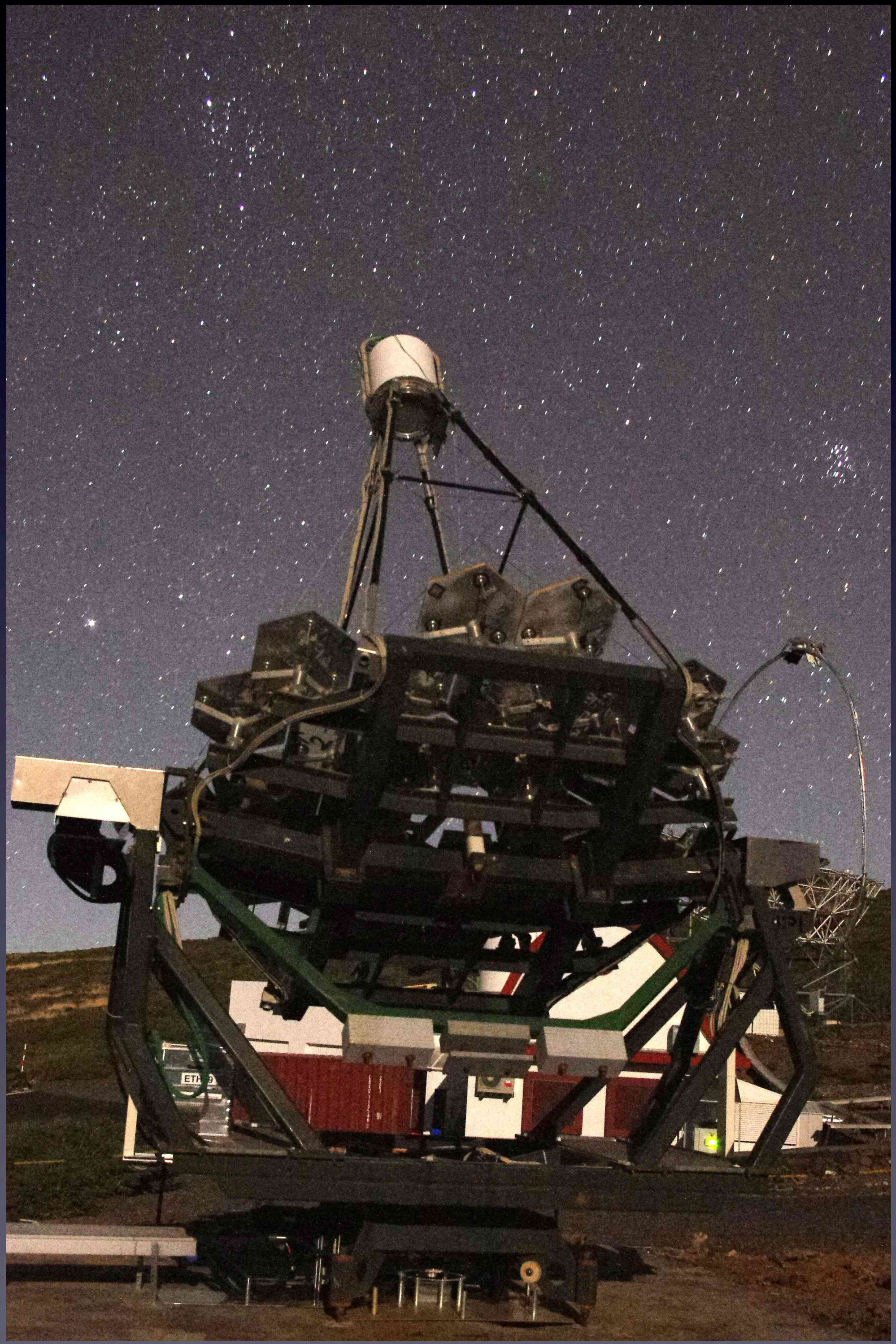


FACT

The First G-APD Cherenkov Telescope

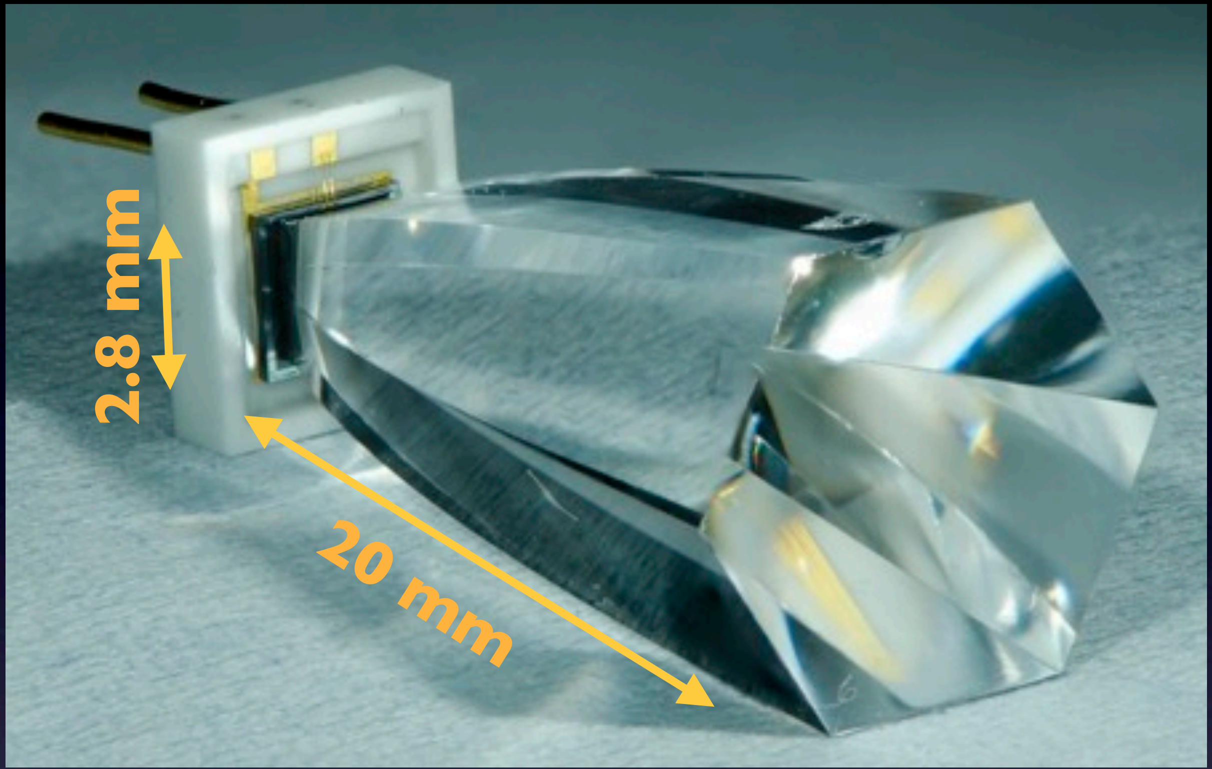
The **F**irst G**A**PD **C**herenkov **T**elescope (FACT) is the first imaging atmospheric Cherenkov telescope using Geiger-mode avalanche photodiodes (G-APDs) as photo sensors.

The rather small, low-cost telescope will not only serve as a technology test bench for Cherenkov astronomy, but also monitor bright active galactic nuclei (AGN) in the TeV energy range.



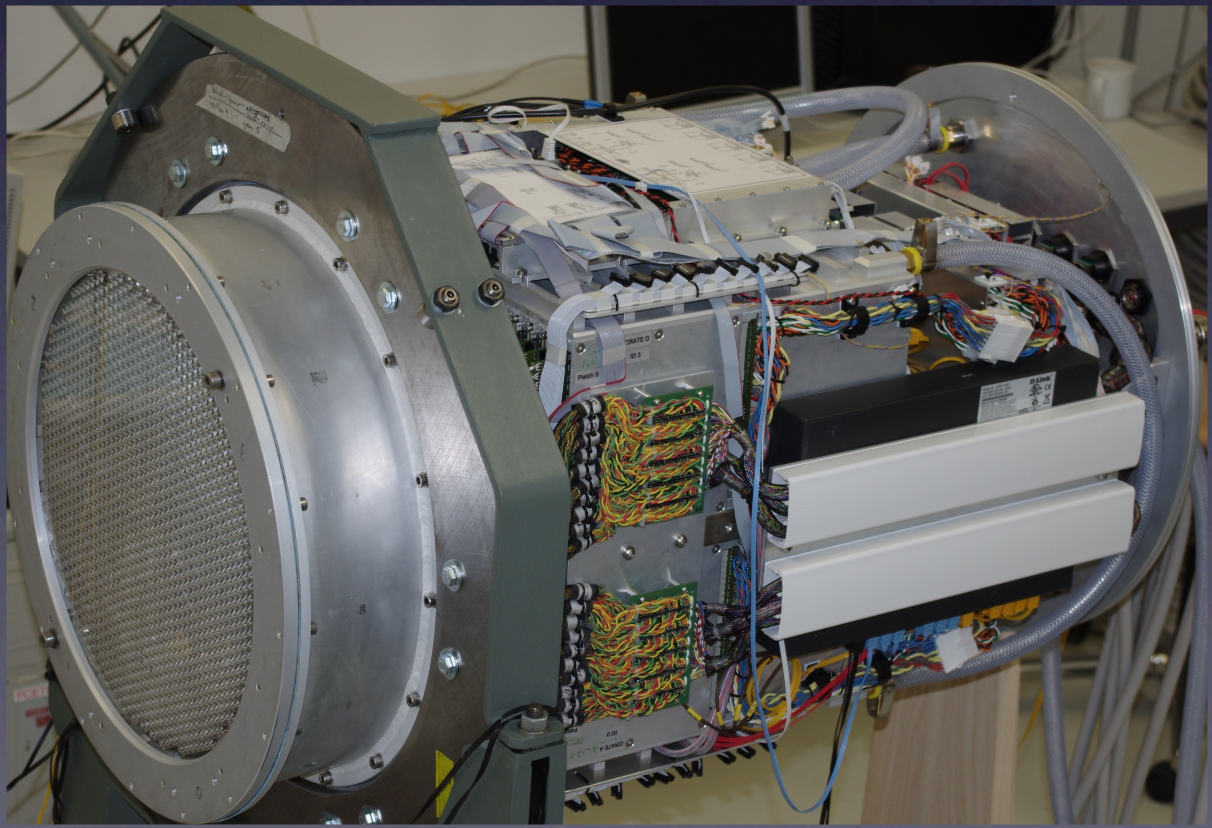
The FACT telescope

- On the MAGIC site, (La Palma)
- HEGRA CT3 mount with new 9.5m^2 mirrors;
- Longterm goal: monitoring of AGNs such as Mrk421 or Mrk501: search for strong flux variabilities.

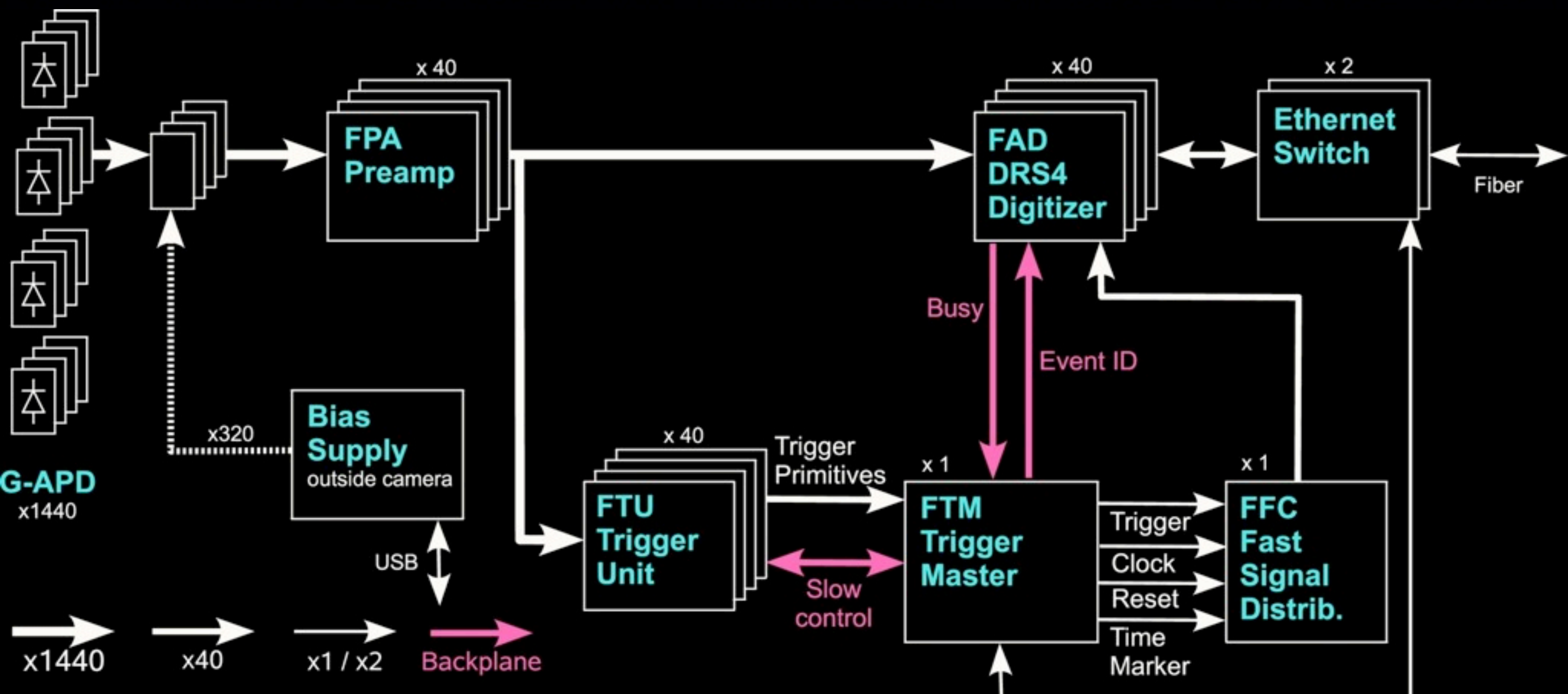


Main goal: show applicability of G-APD as IACT photosensor:

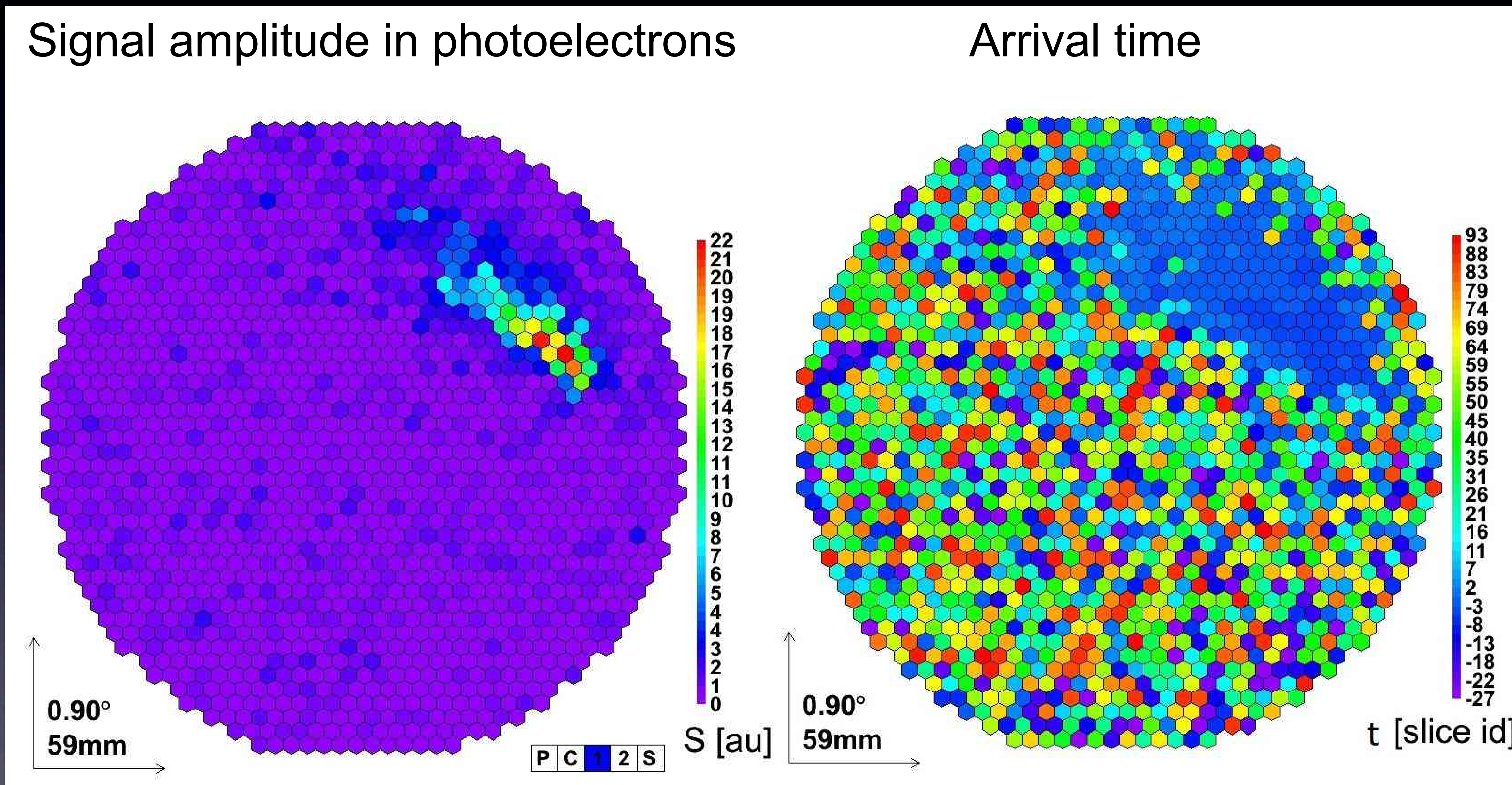
- 1440 pixels (G-APDs) weight: 150 kg
- power consumption: 550 W
- Sampling: 2 GHz (DRS 4)
- Integrated electronics (ethernet readout);
- Passive water cooling of electronics;



FACT - The detector



An event seen by fact

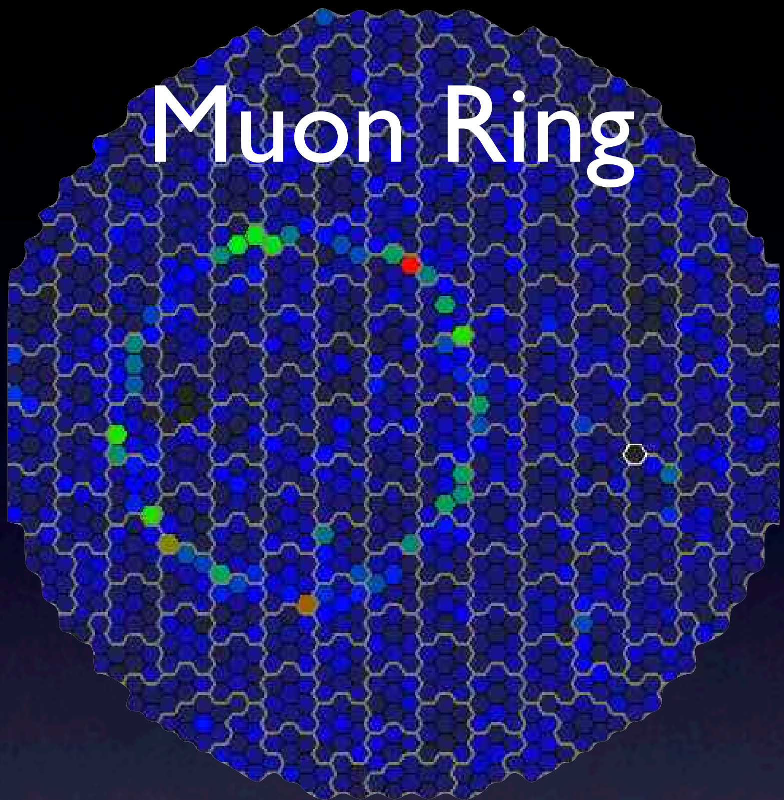


from Patrick Vogler SPS Annual Meeting, June 21 2012, Zürich

Status

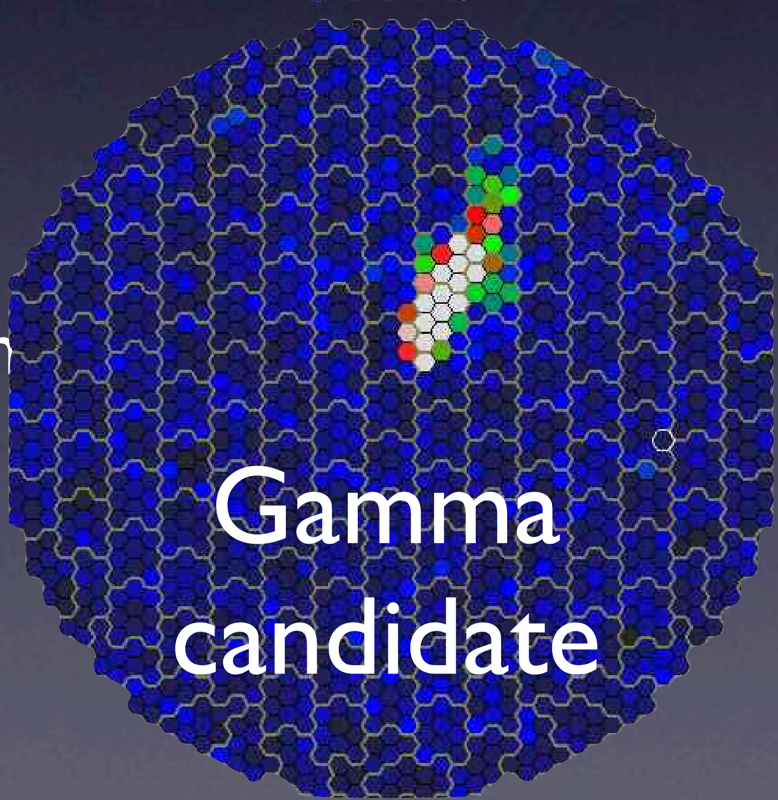
Operation and detector commissioning

- Hardware working well since autumn 2011, no hardware failure during operation;
- Semi-remote shift done routinely;
- Data archive (in FITS format) at ISDC.



Analysis:

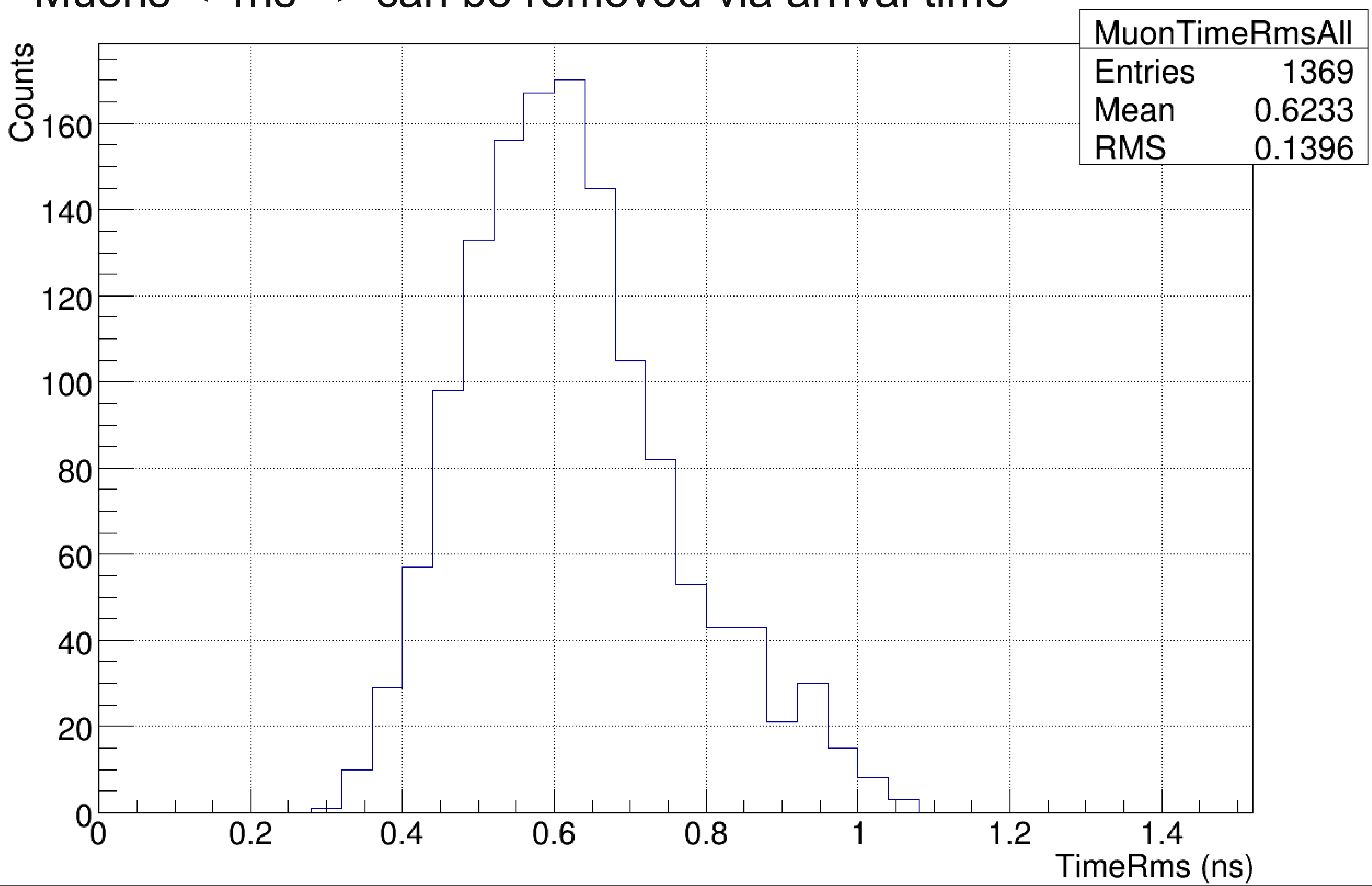
- First analysis chain available;
- Clear VHE signal from Crab measured using MAGIC analysis methods;
- Reached sensitivity of Hegra stereoscopic system
- Not yet any optimization of cleaning and cuts;
- Not yet optimization for G-APDs (very simple calibration).



Muon discrimination

data of 2012/03/01

Muons < 1ns => can be removed via arrival time



Our contribution in FACT

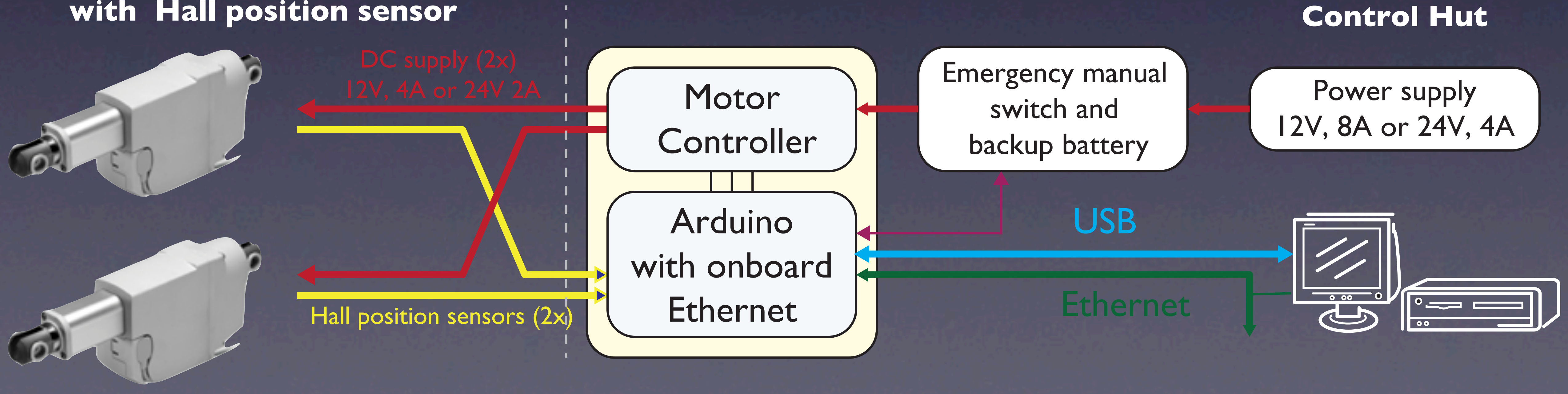
- Install a real remote controllable shutter;
- Study the FACT detector plane design caveats;
- Study the stability and the signal of the G-APD detector plane in order to improve the design of the SST detector plane and slow control.

FACT shutter

call-La-Palma-to-open

Nice remote controllable shutter

Shutter: 2x Linear Actuators with Hall position sensor



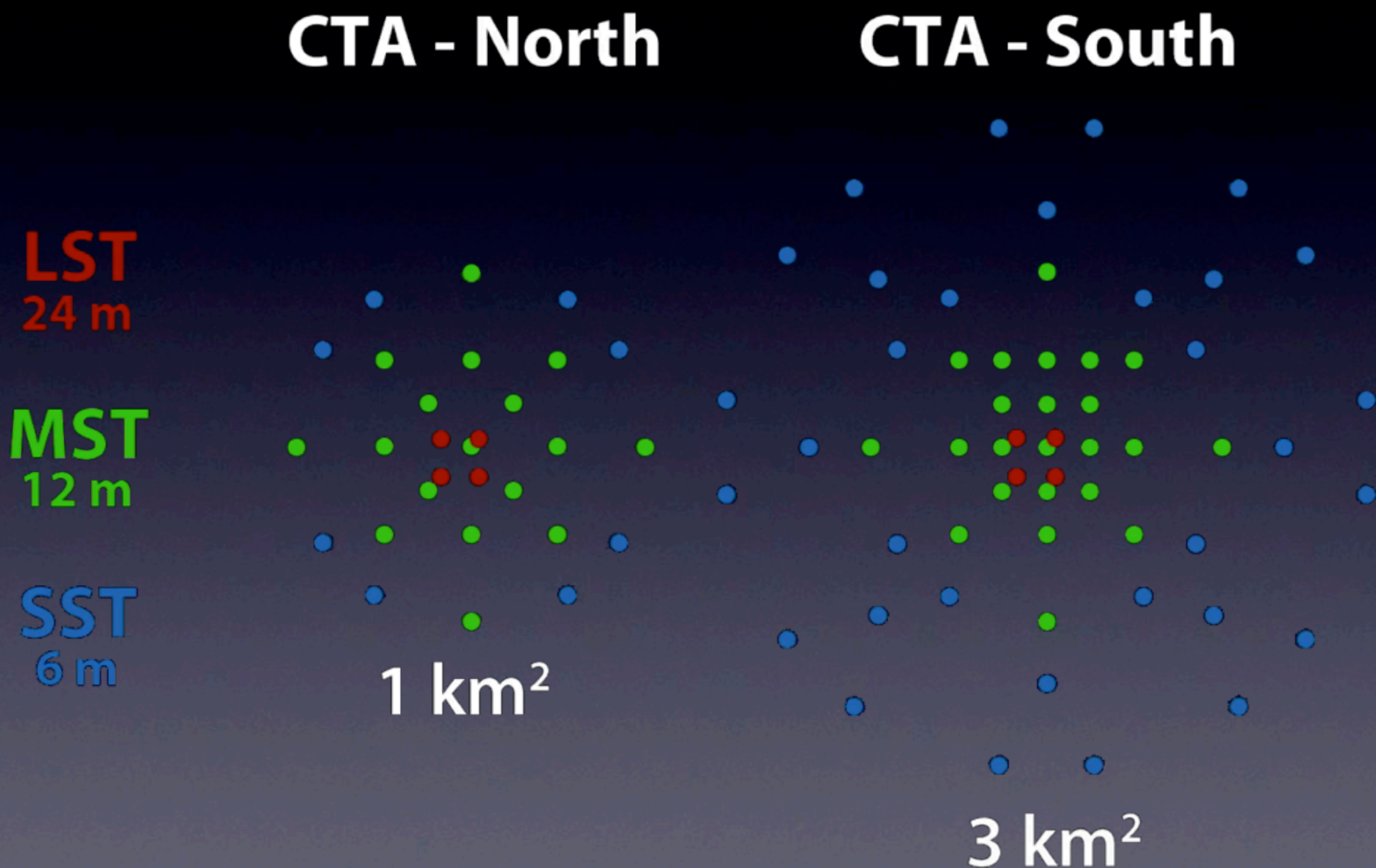
Summary

- The DPNC is joining CTA with the group of Prof.Montaruli and is doing a big effort in proposing (and supporting) a G-APD based Small Size Telescope for the CTA project;
  - optimization of the parameters of such telescope;
  - simulation of the relevant physics cases;
  - development the detector plane (custom hex. G-APDs);
  - development (adaptation) of existing front-end electronics.

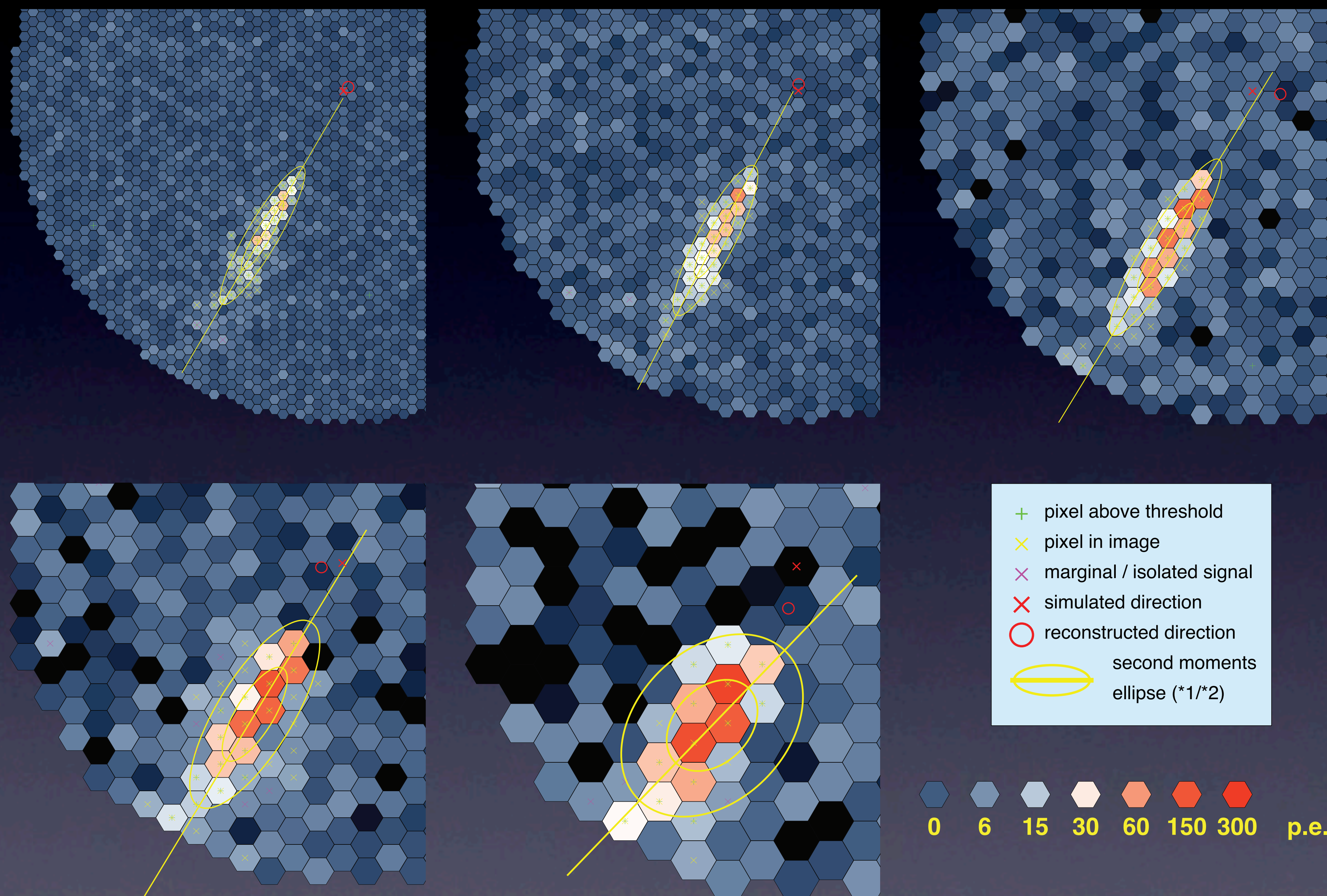
- Meanwhile we are gaining experience in the operation of a SiPM based telescope - FACT - which is similar to the SST for dimensions and number of channels;
  - commissioning the FACT remotely controlled shutter which will allow full remote operation;
  - study of the raw data signal, gain stability etc...

Backup slides

Typical array distribution

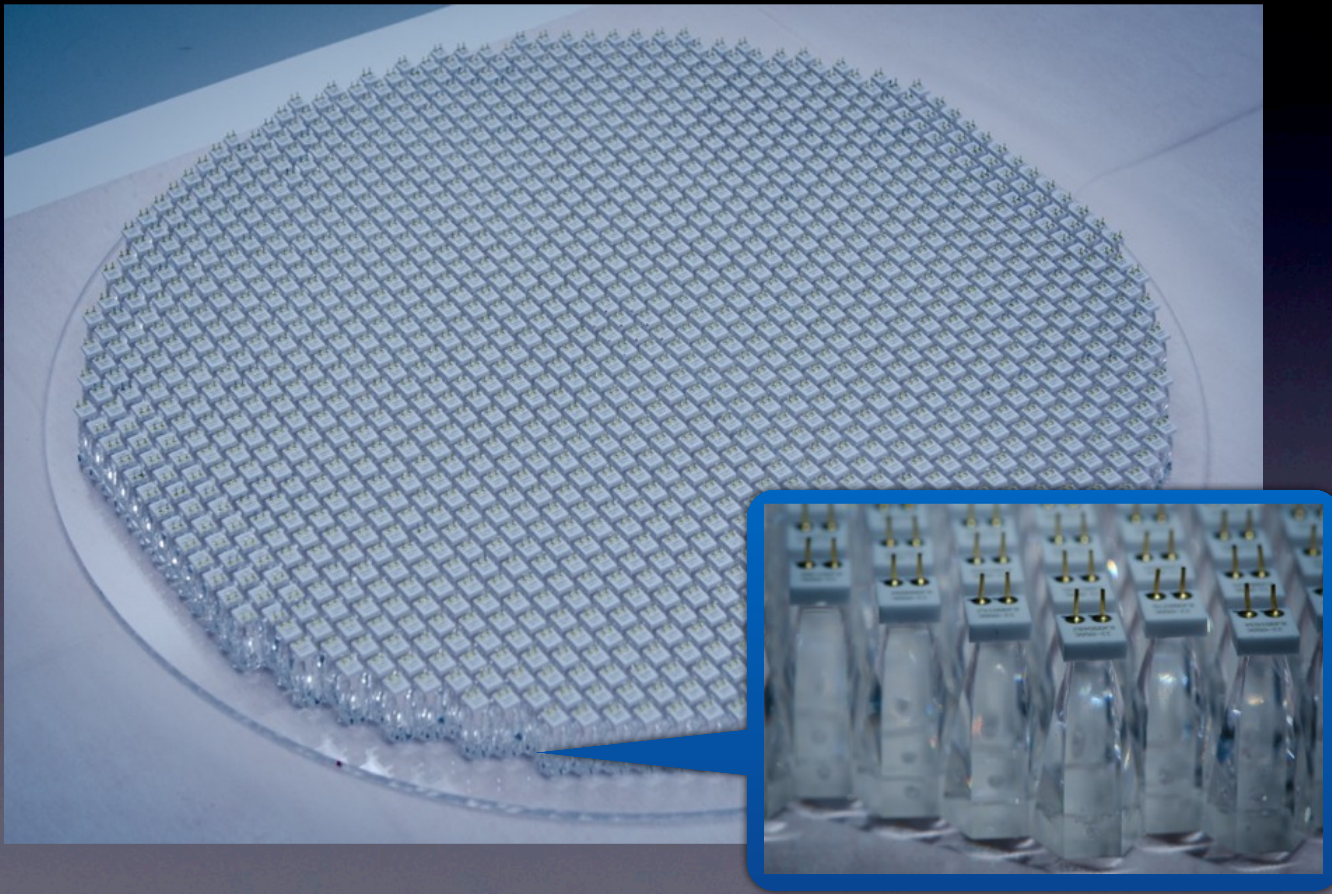


Effect of pixel size

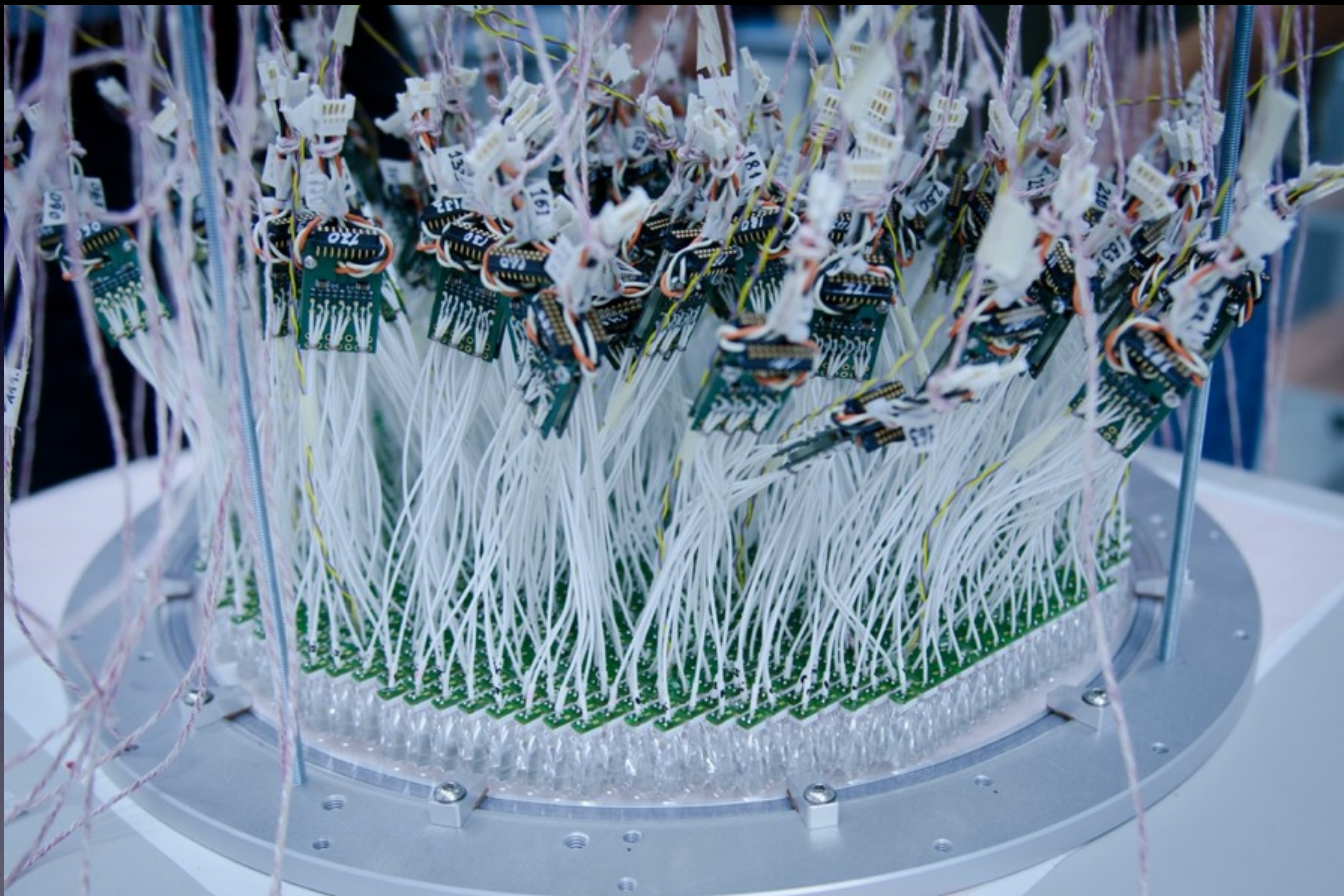


Example of LST: Effect of the pixel size (0.07, 0.10, 0.14, 0.20, and 0.28°) but identical field-of-view (of about 6°), viewing the same shower (460 GeV gamma- ray at 190 m core distance) with a 420 m2 telescope.

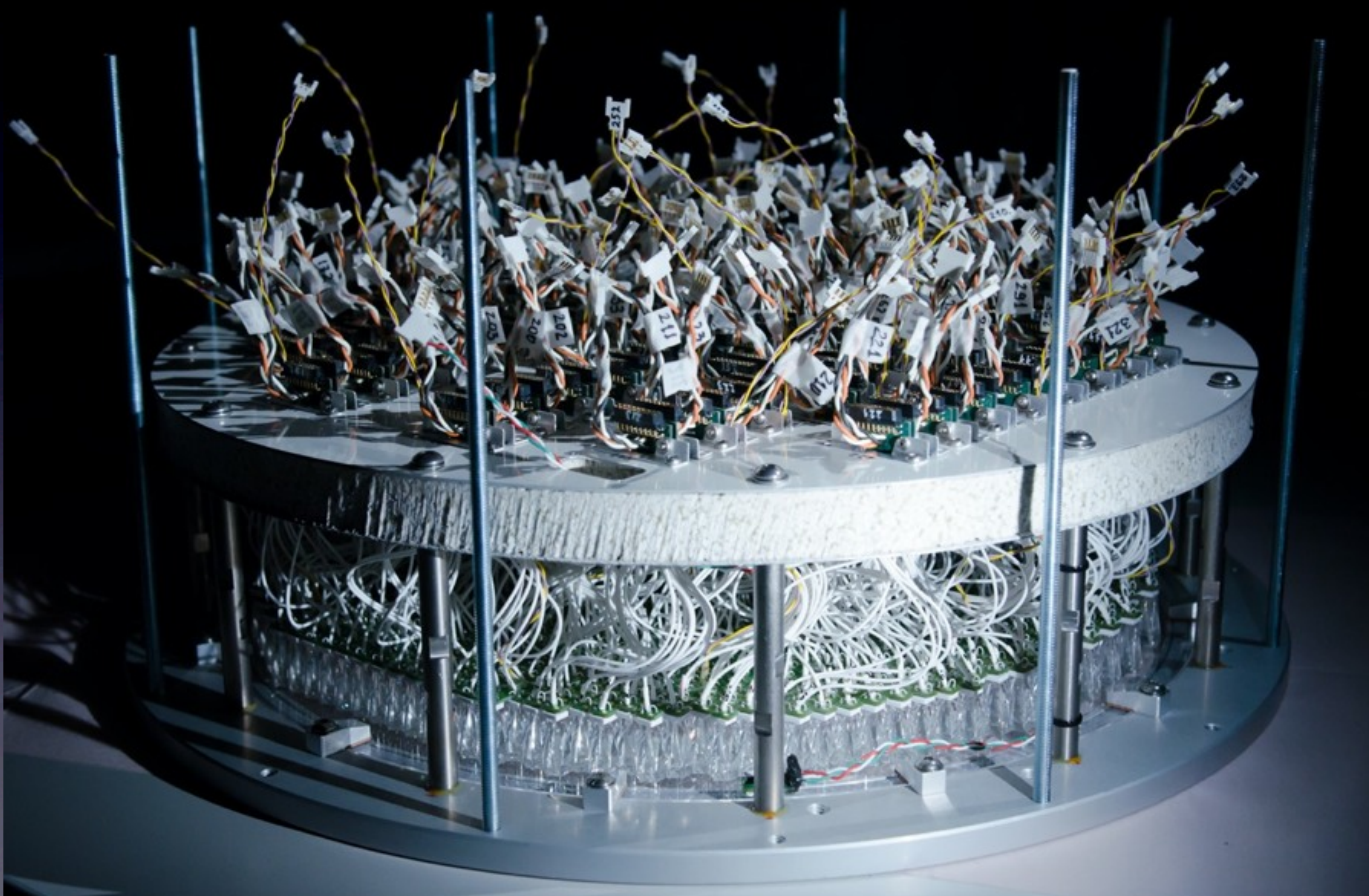
FACT detector assembly



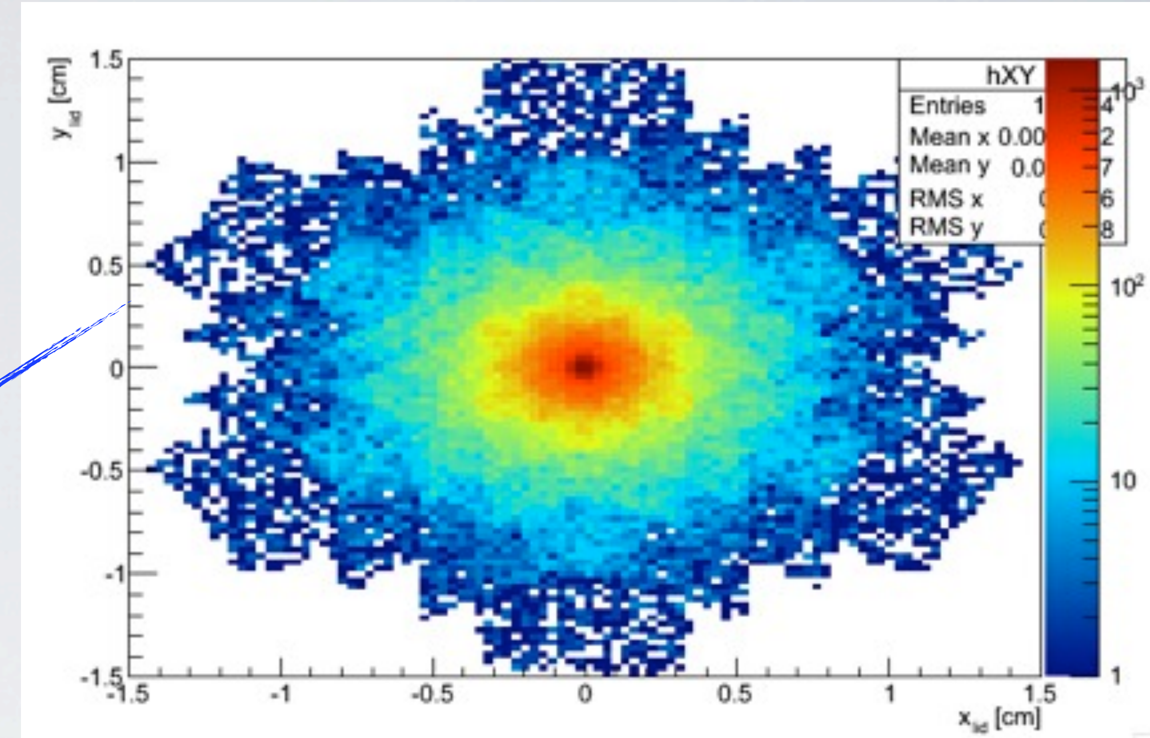
FACT detector assembly



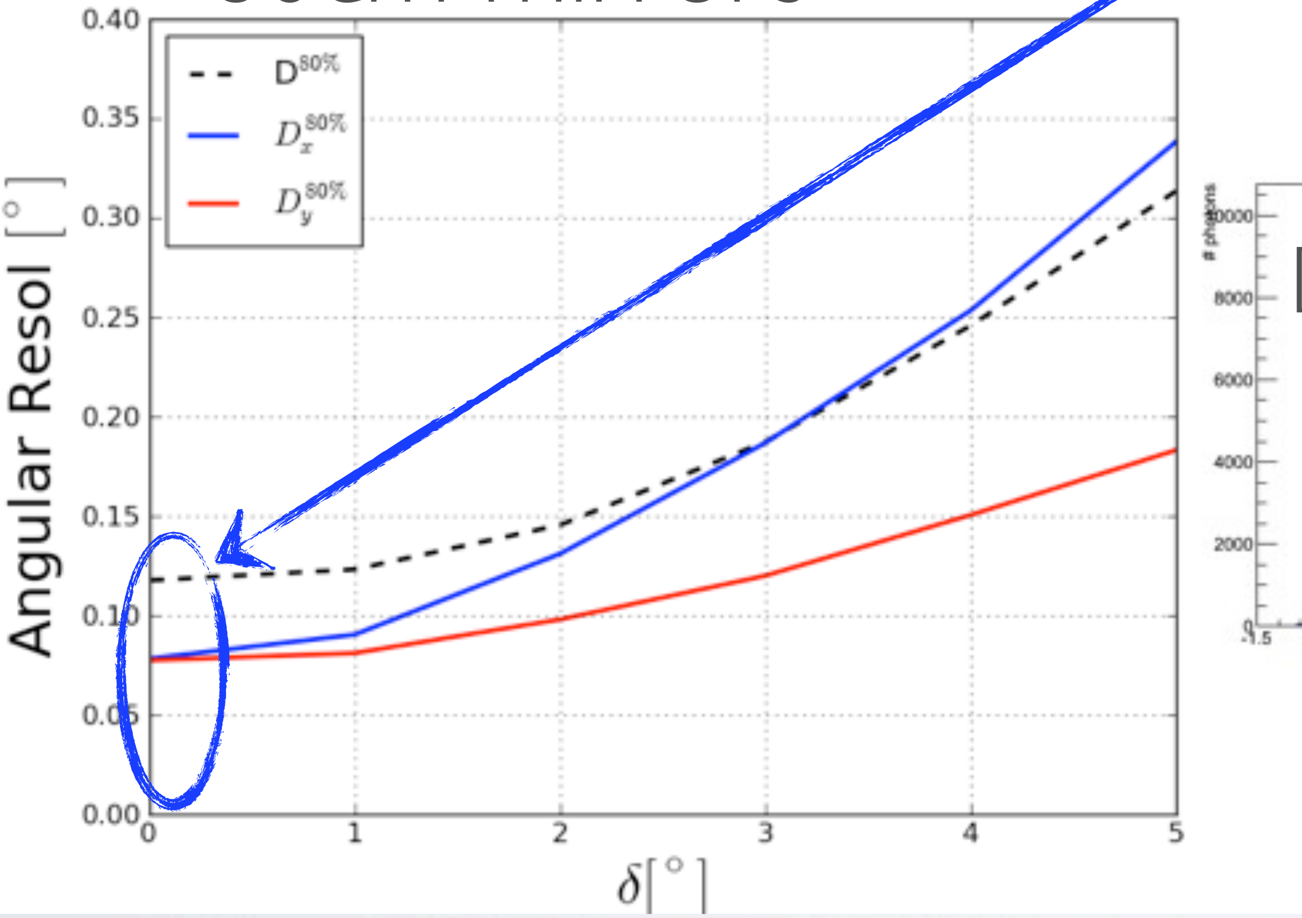
FACT detector assembly

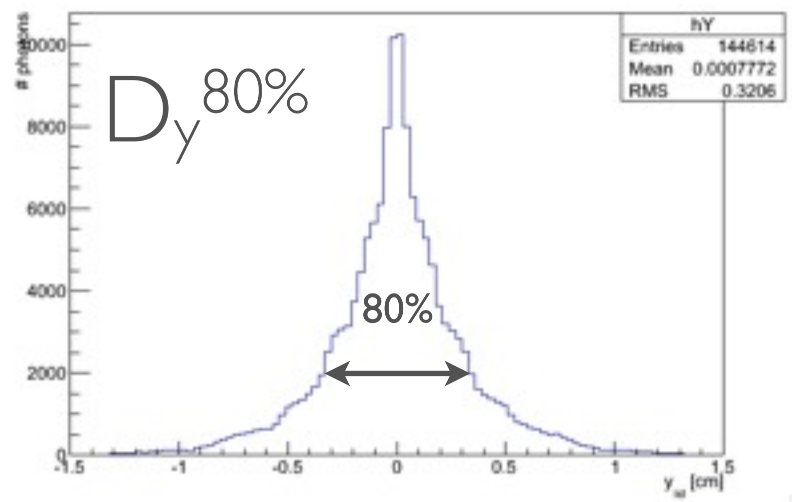


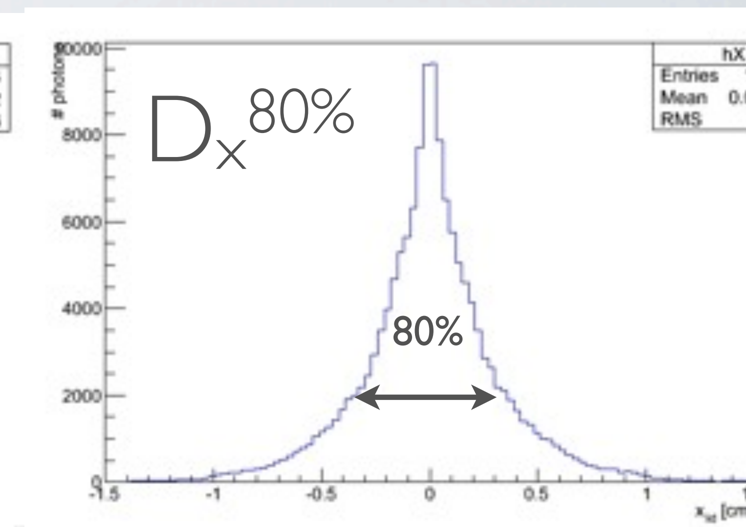
ANGULAR RESOLUTION

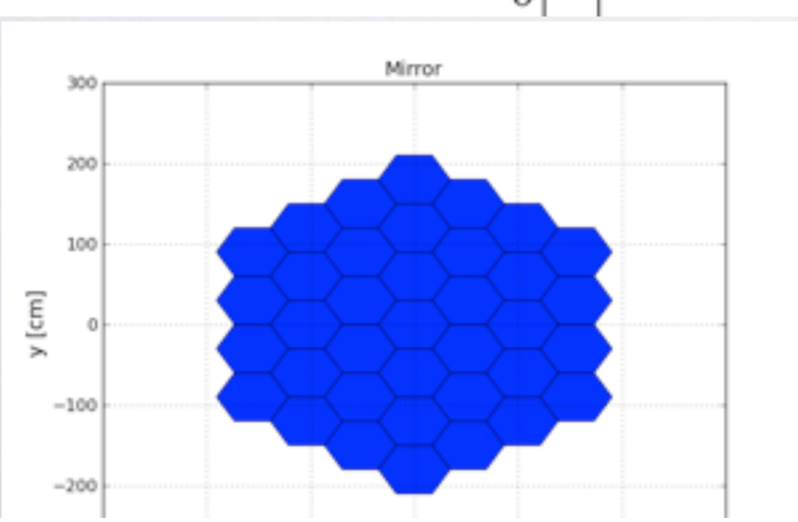


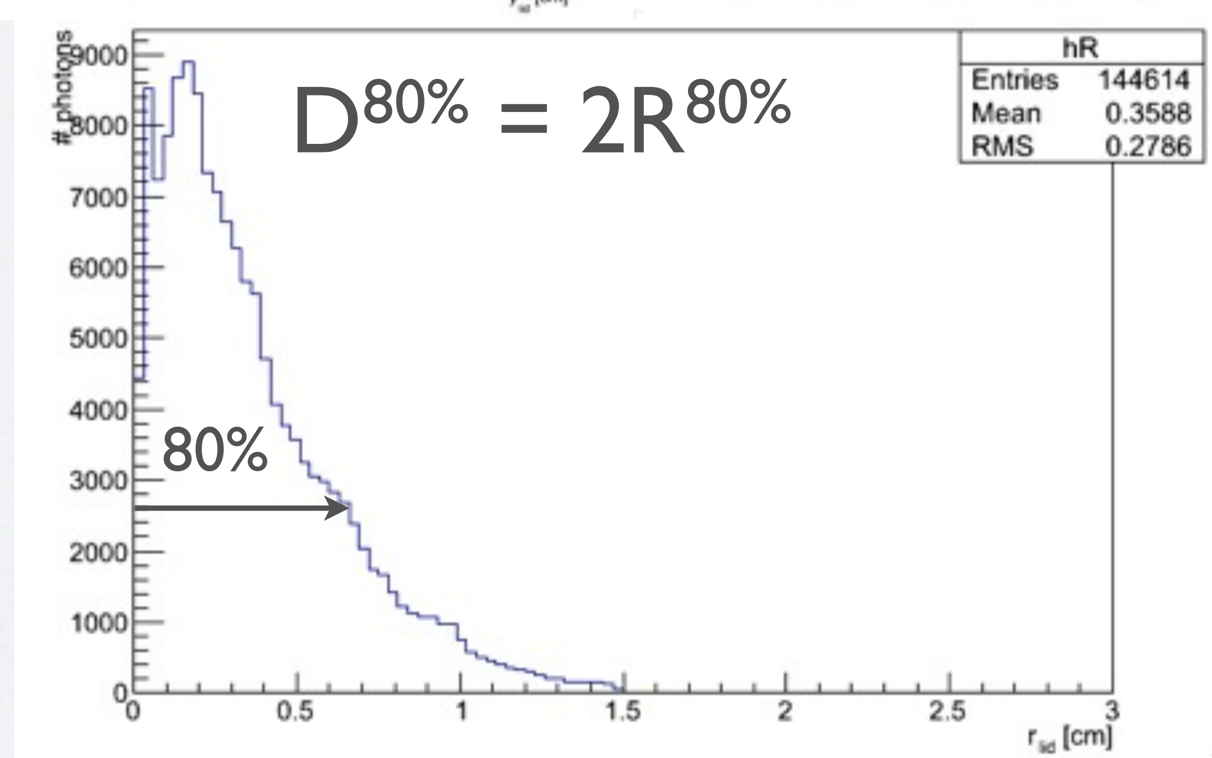
60cm mirrors











Specifications on PSF

PSF: can be understood only with full simulation of array E and CORSIKA showers applying same conditions of trigger and analysis

fluctuations of showers taken into account but line extrapolated with no statistical errors

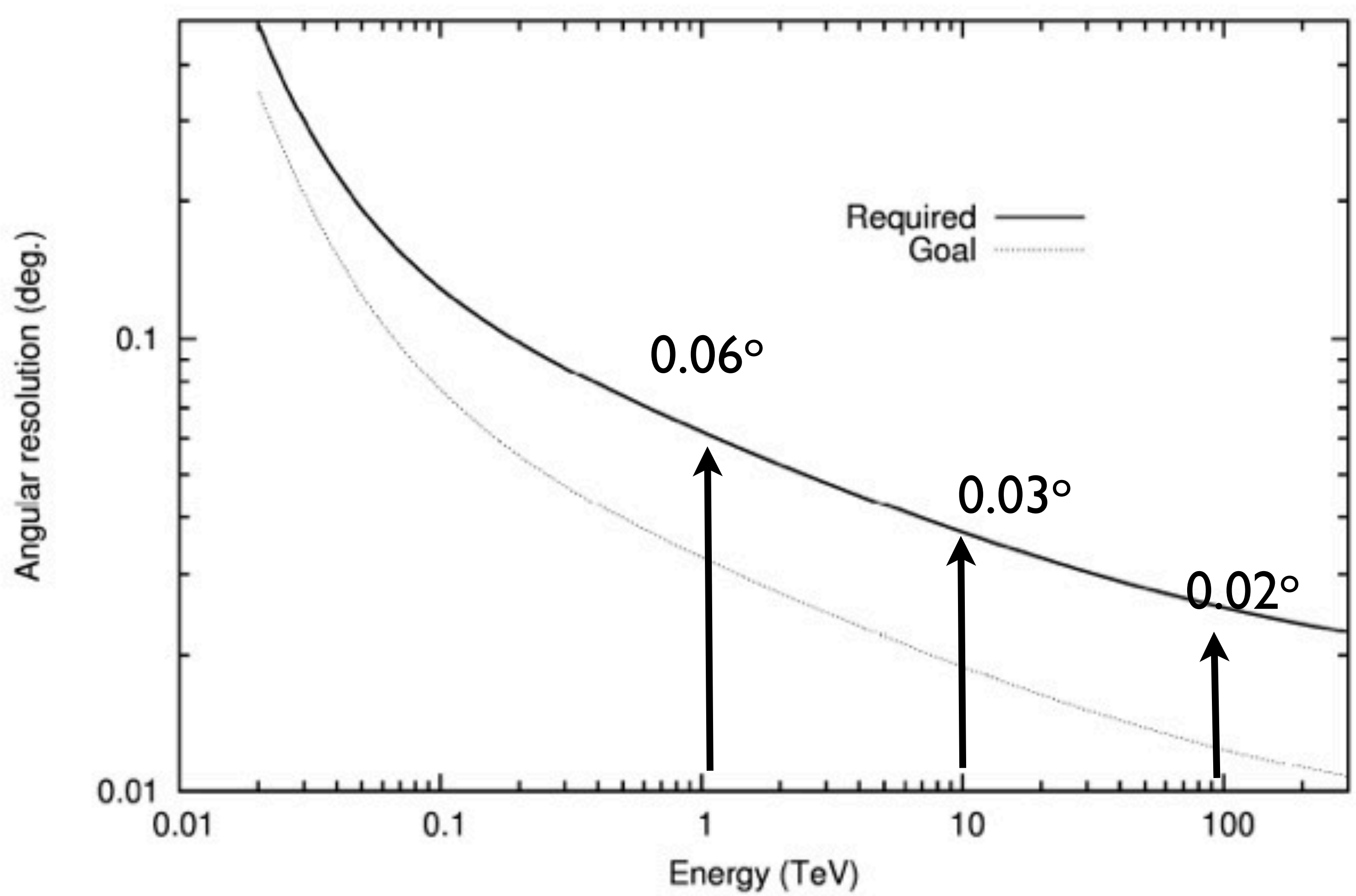


Figure 3: ***Required*** and ***goal*** angular resolution for the CTA Southern Array as a function of energy, showing the 68% containment radius. The corresponding curves for the CTA Northern Array are identical below 20 TeV, and not specified above 20 TeV.