Design Concepts for the Cherenkov Telescope Array

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Outline

- Motivation
- Technique
- Cherenkov Telescope Array - Layout
- Monte Carlo Simulations
- Telescopes: Large, Medium and Small Size
- Mount and Dish
- Mirrors
- Photo-detectors
- Polish Consortium CTA

Why Ground-based?

- Astronomy at the highest photon energies:
  - Typical flux: ~10^{-12} erg cm^{-2} s^{-1}:
    - ~1 photon/day/m^2 @ 1GeV
    - ~0.2 photons per year per m^2 @ 1TeV
    - ~20 per hour per km^2

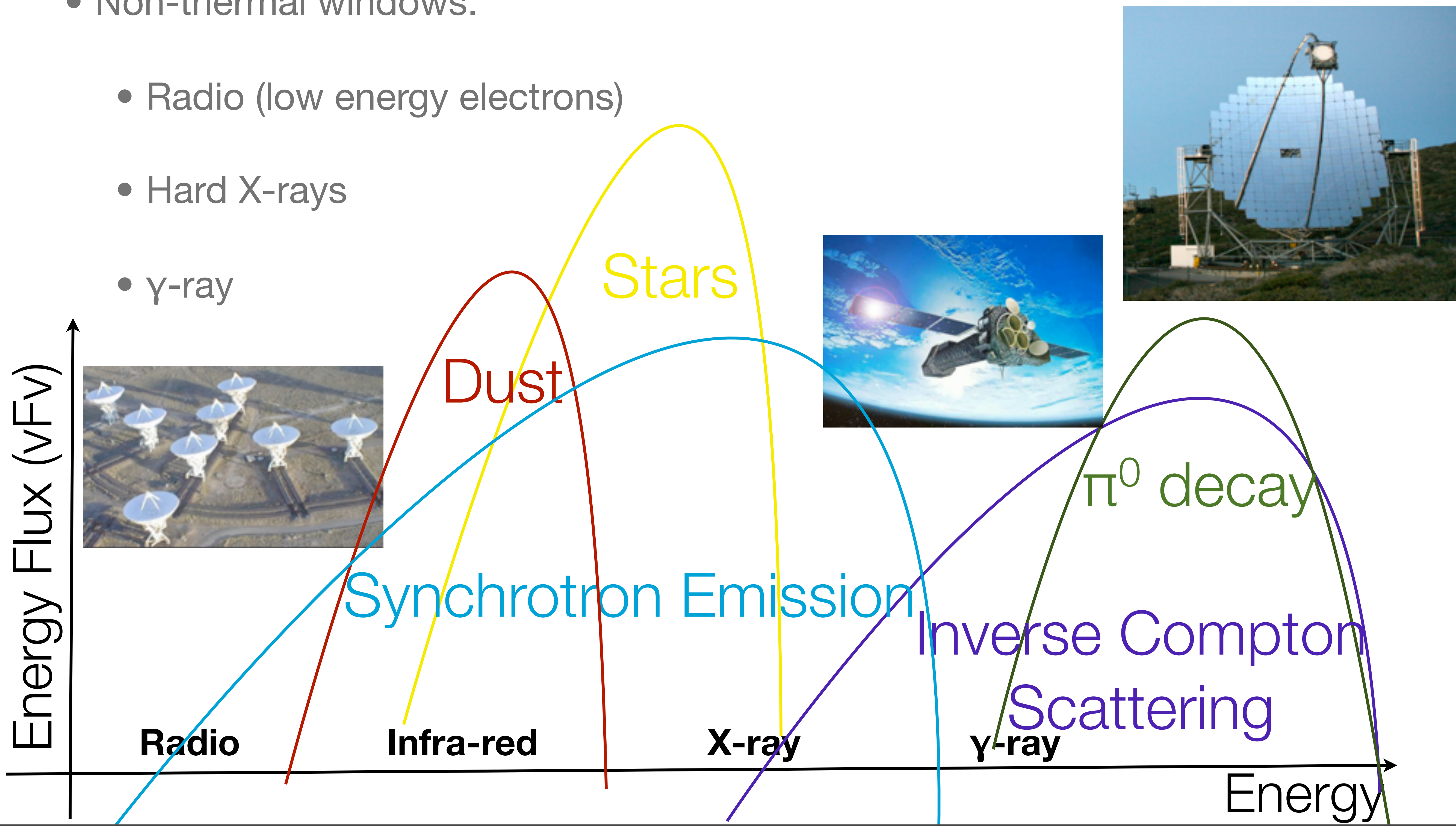
X-rays
2-10 keV very
good resolution

MeV-GeV
poor angular resolution
full sky coverage
~ 1 m^2 detector area

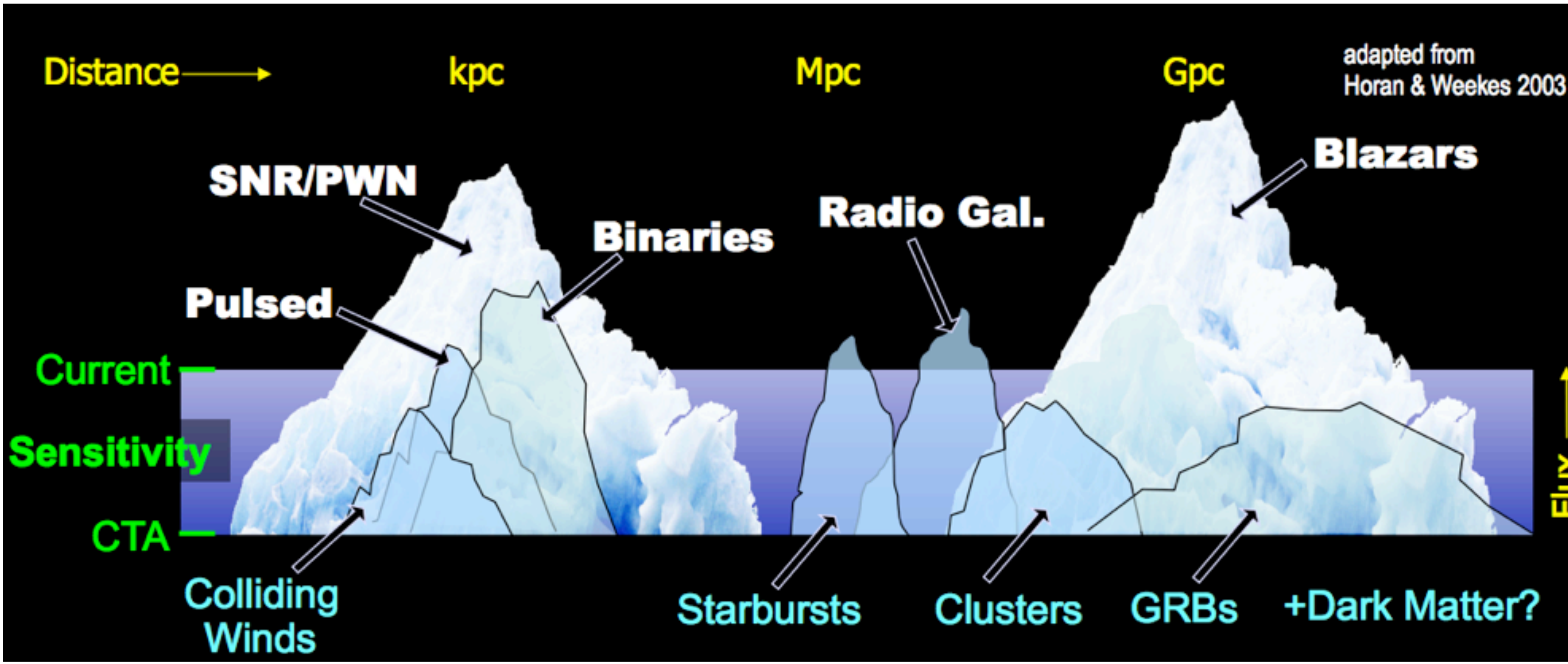
TeV
better angular resolution
5-10 deg FoV
~ 1 km^2 detector area

Non-Thermal Windows

- Non-thermal windows:
  - Radio (low energy electrons)
  - Hard X-rays
  - γ-ray



Science Potential



The Cherenkove Telescope Array CTA

CTA is a project for ground based gamma-ray astronomy

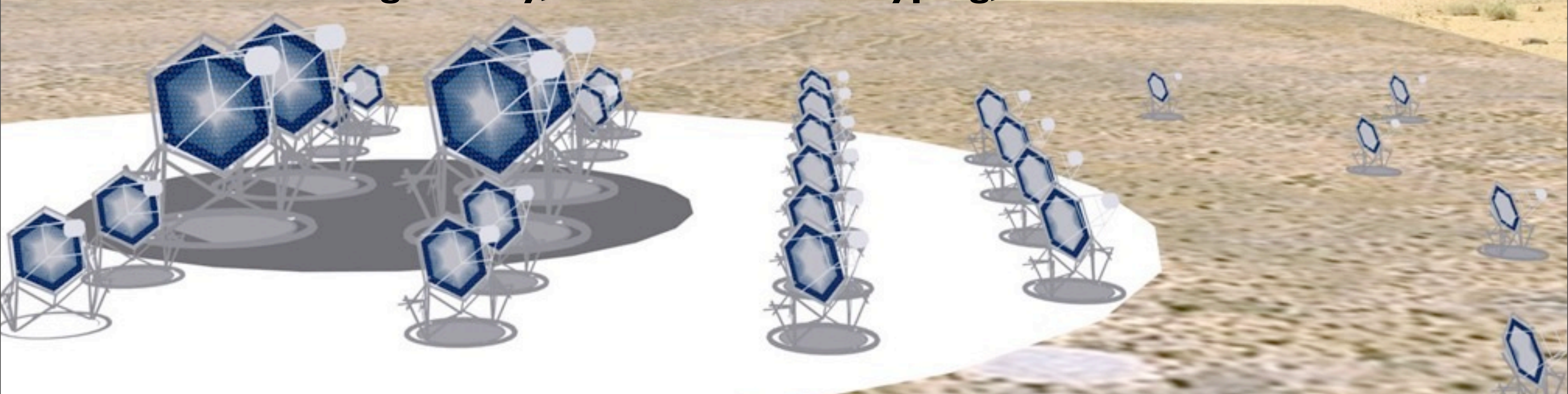
International Collaboration:

> 800 scientists and engineers

> 100 institutes

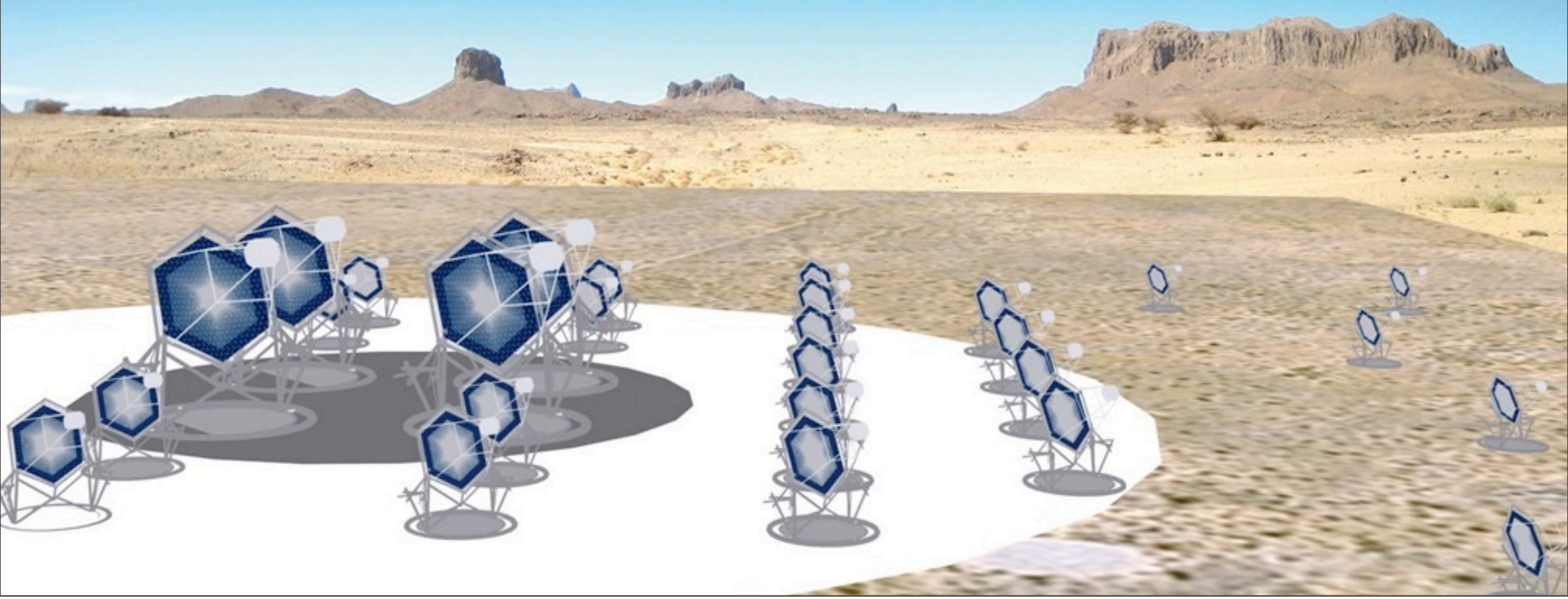
25 countries

2008-2011Design Study, 2011-2013 Prototyping, 2013-2018 Construction



Scientific goal

Scientific goal is to build telescope array:
- 10 times more sensitive than current instruments
- with better energy and angular resolution
- with wider field of view and energy coverage
- with budget ~ €190 M



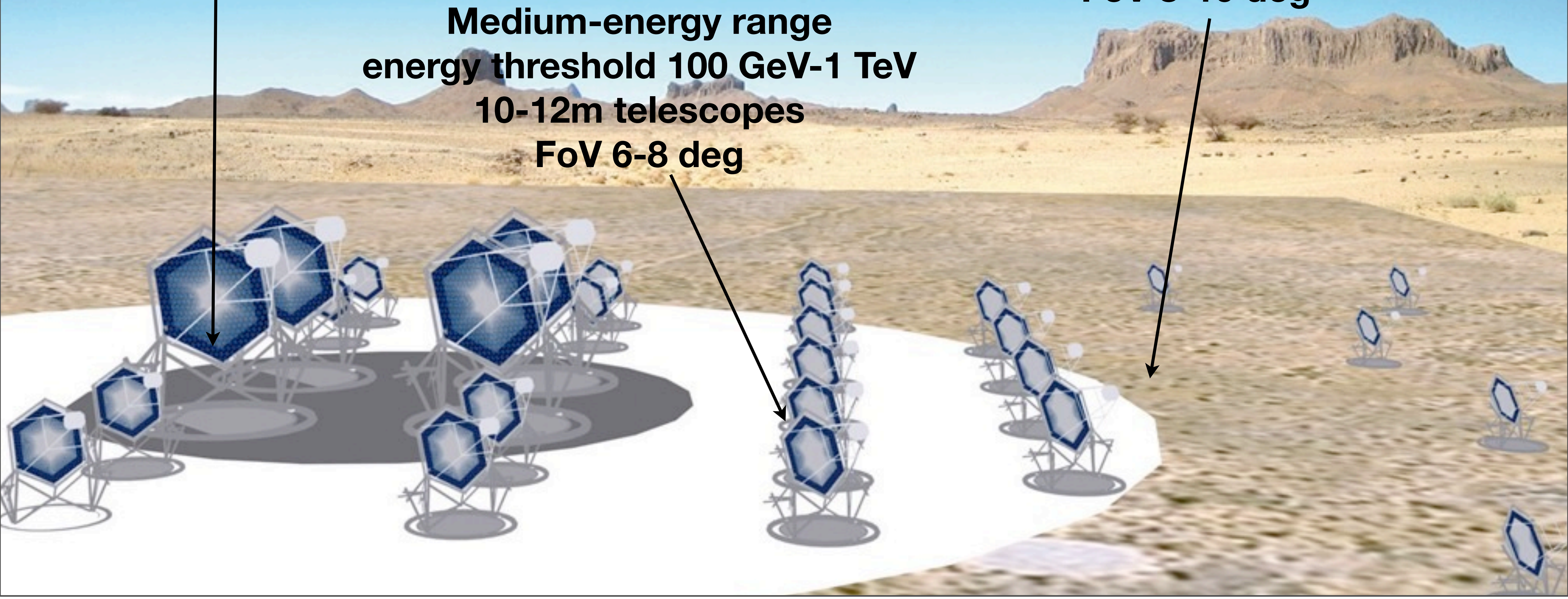
Array: 50-100 Cherenkov telescopes

3 telescope size: small, medium and large

Low-energy instrumentation
energy threshold 20-30 GeV
a few 23m telescopes
field of view (FoV) 4-6 deg

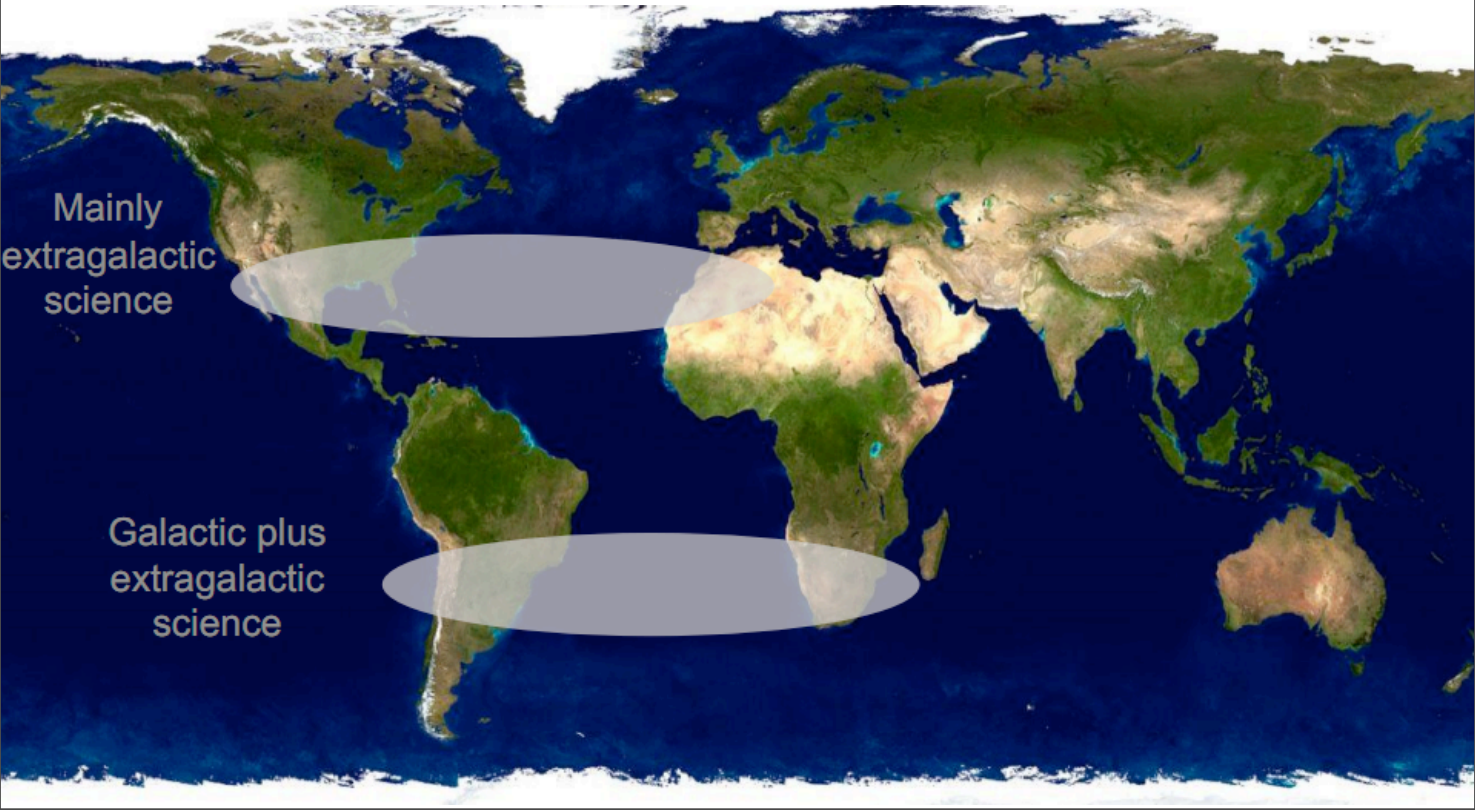
High-energy instruments
above 10TeV
a large number of 4-6 m telescopes
FoV 8-10 deg

Medium-energy range
energy threshold 100 GeV-1 TeV
10-12m telescopes
FoV 6-8 deg

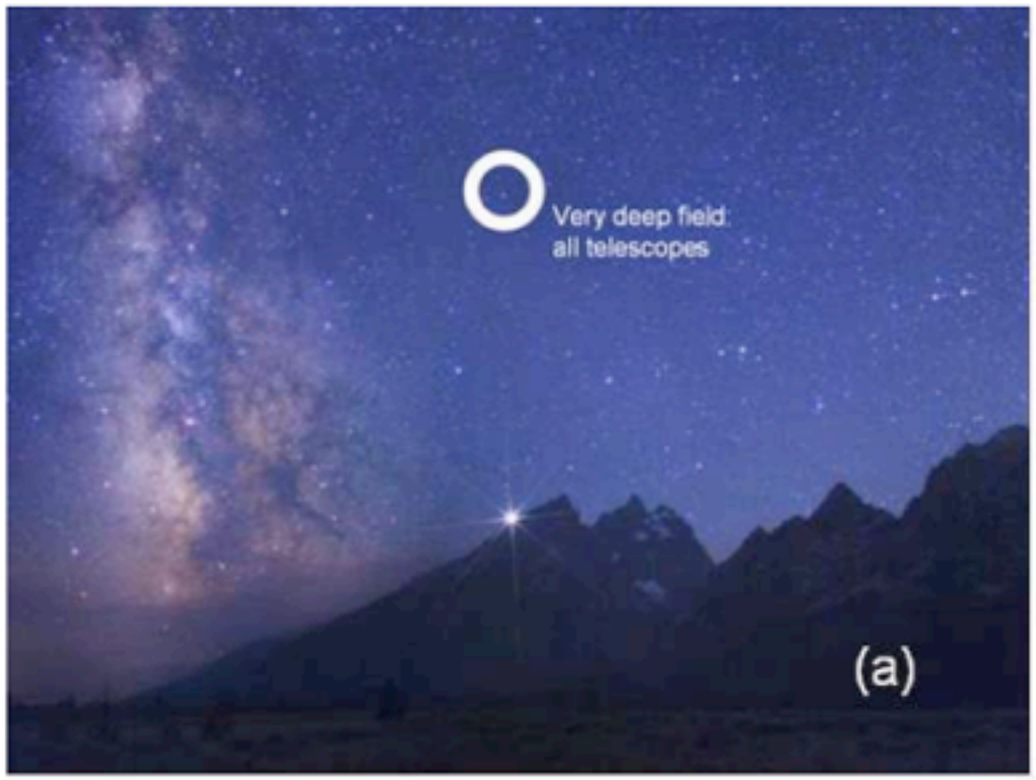


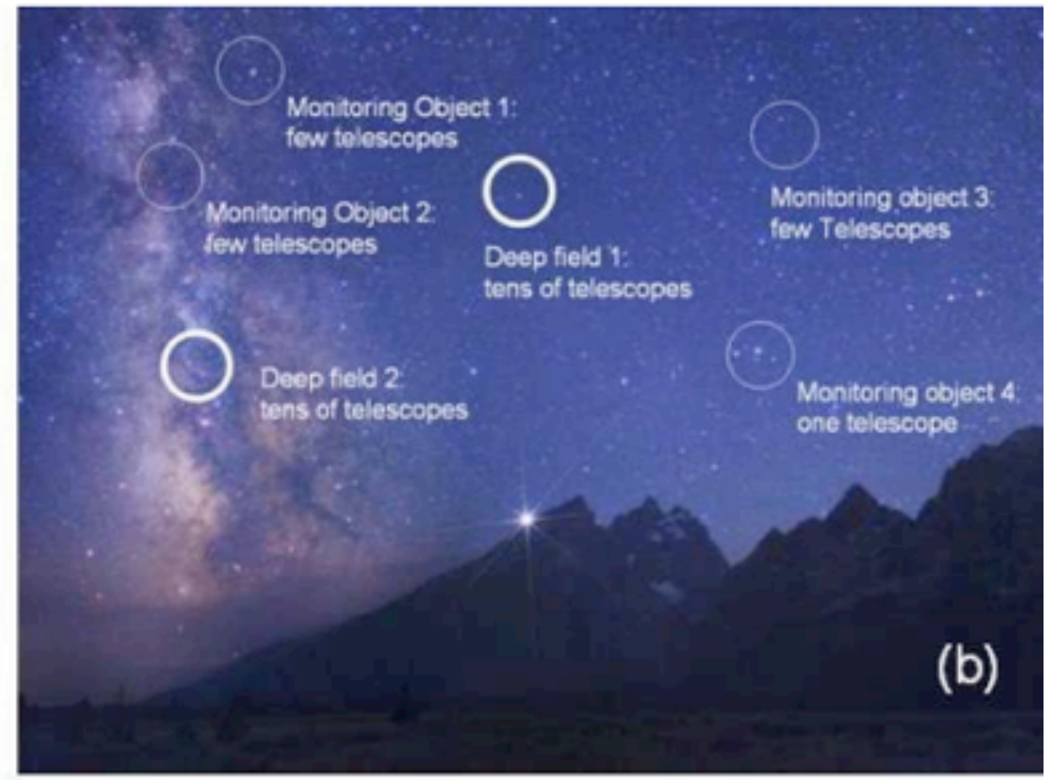
Observatory with two sites (north and south)

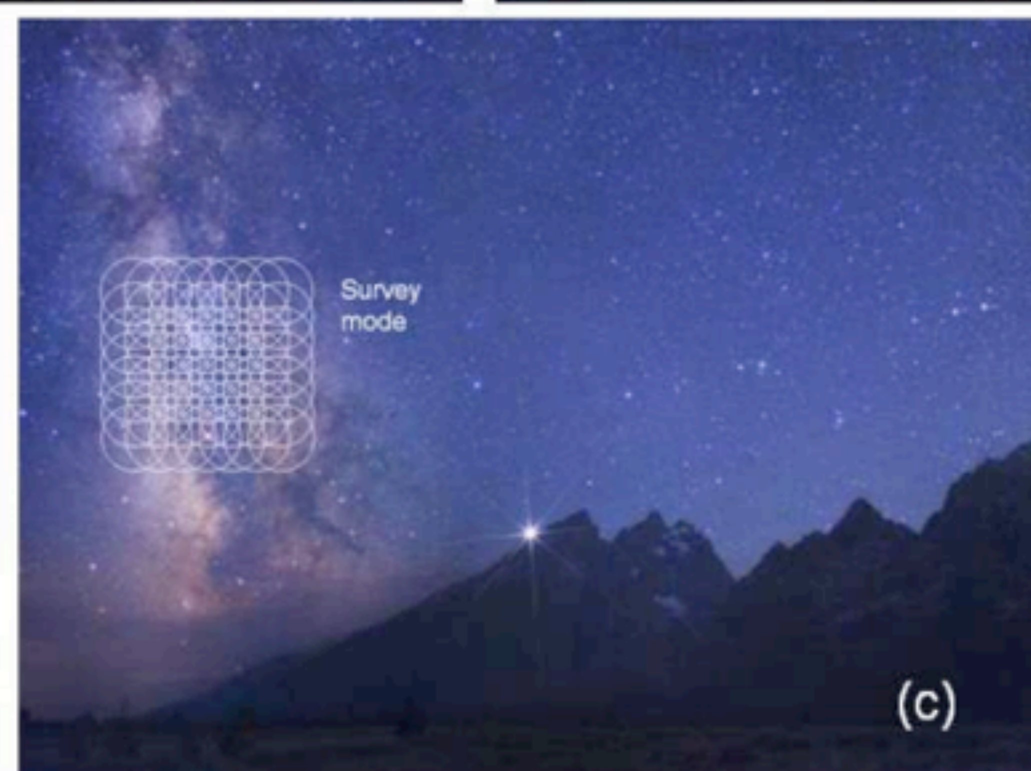
Requirements: flat area 10 km^2, altitude 1.5-4 km, minimum cloud cover, ...



Operation Mode

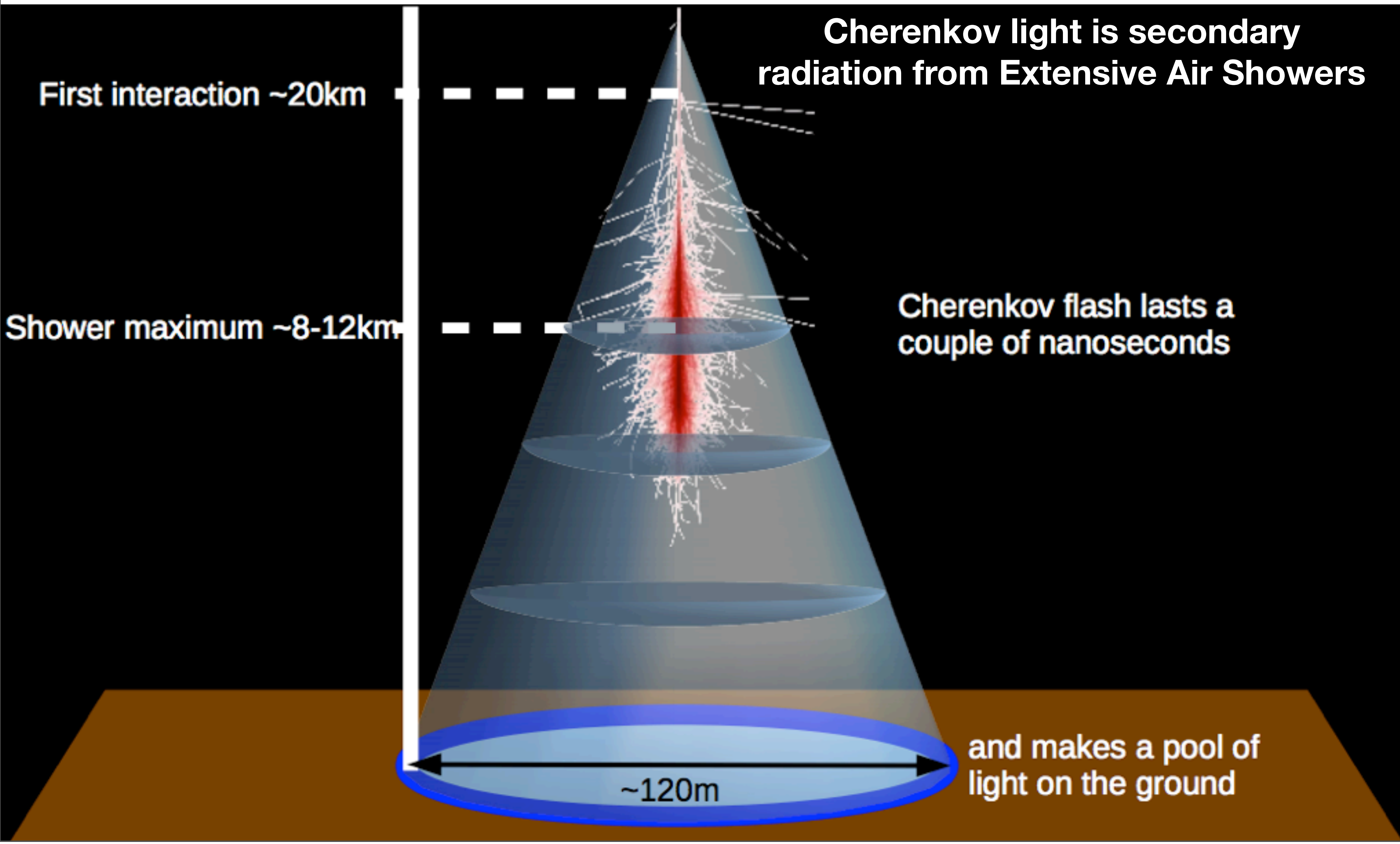




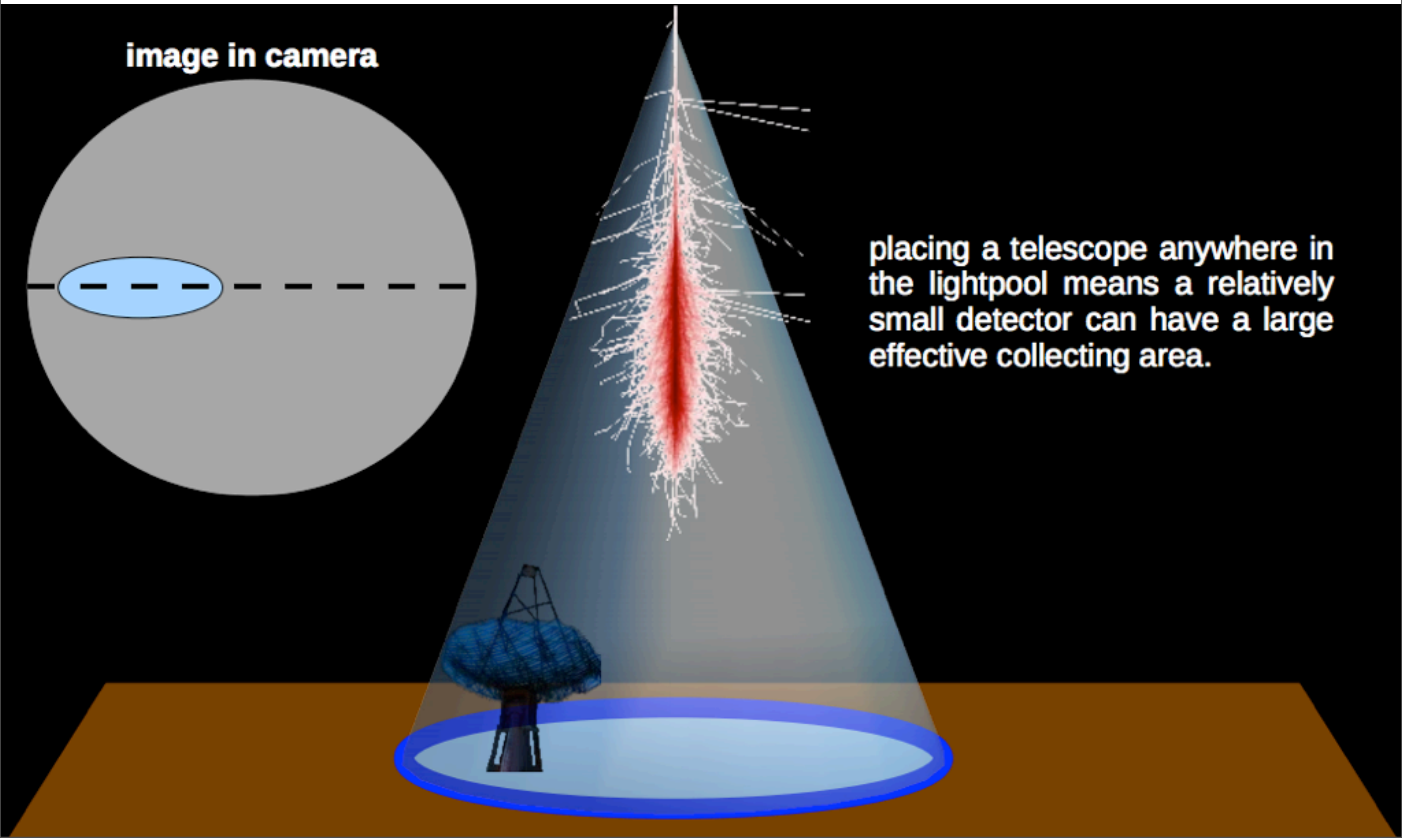


CTA aims to provide full sky coverage from multiple observatory sites, using transparent access and identical tools to extract and analyse data

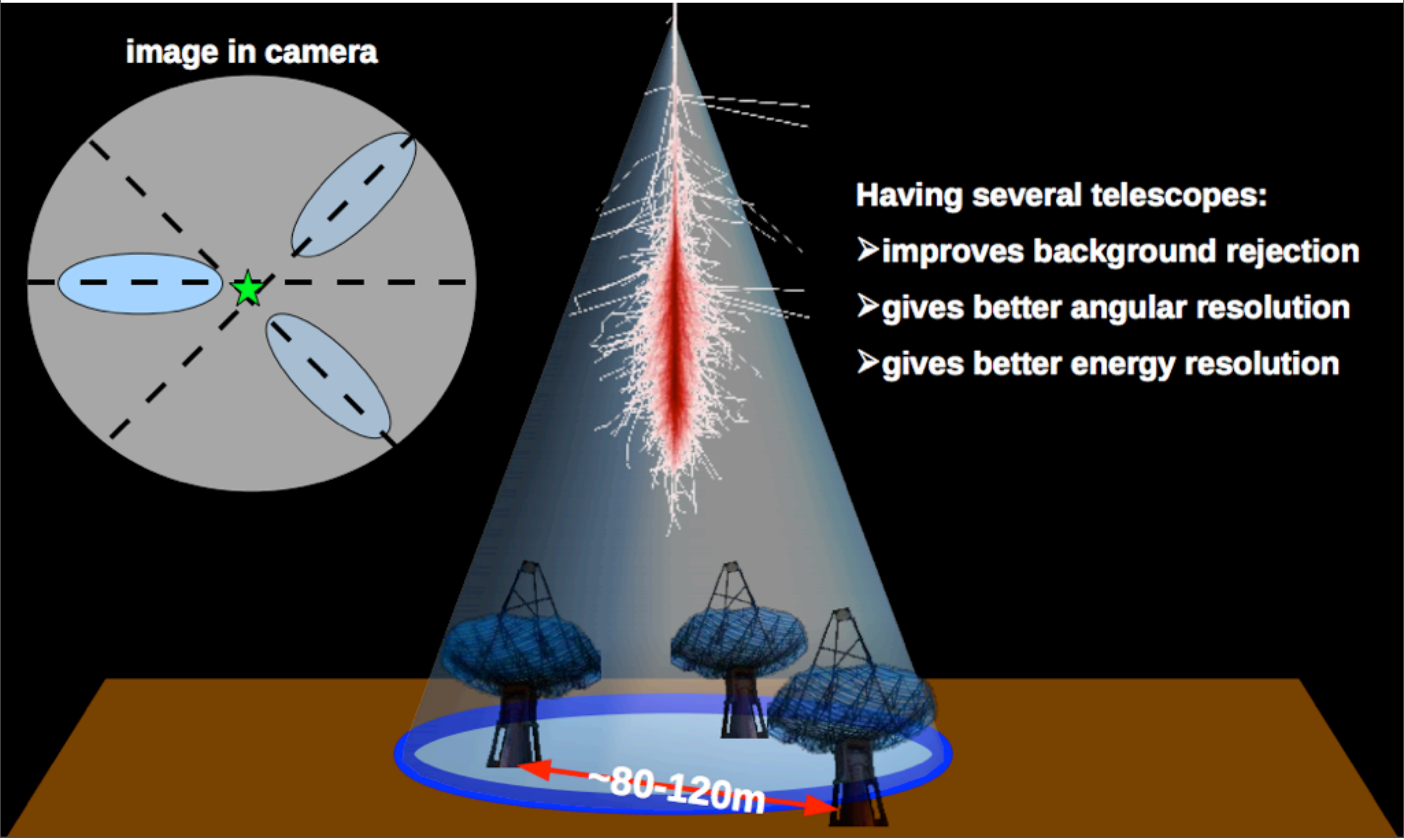
The Imaging Atmospheric Cherenkov Technique



An Imaging Cherenkov telescope



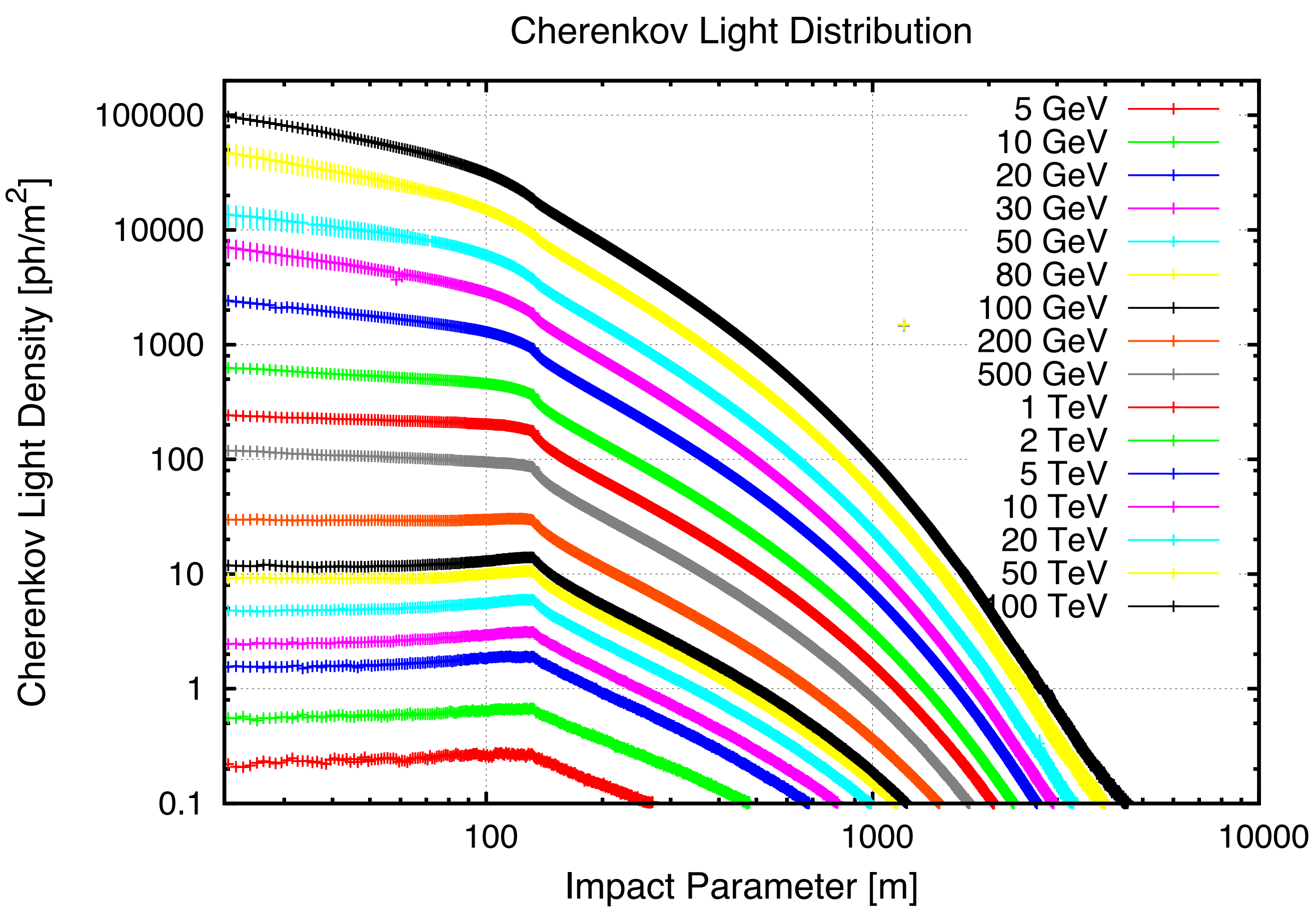
A Stereoscopic Cherenkov Telescope Array



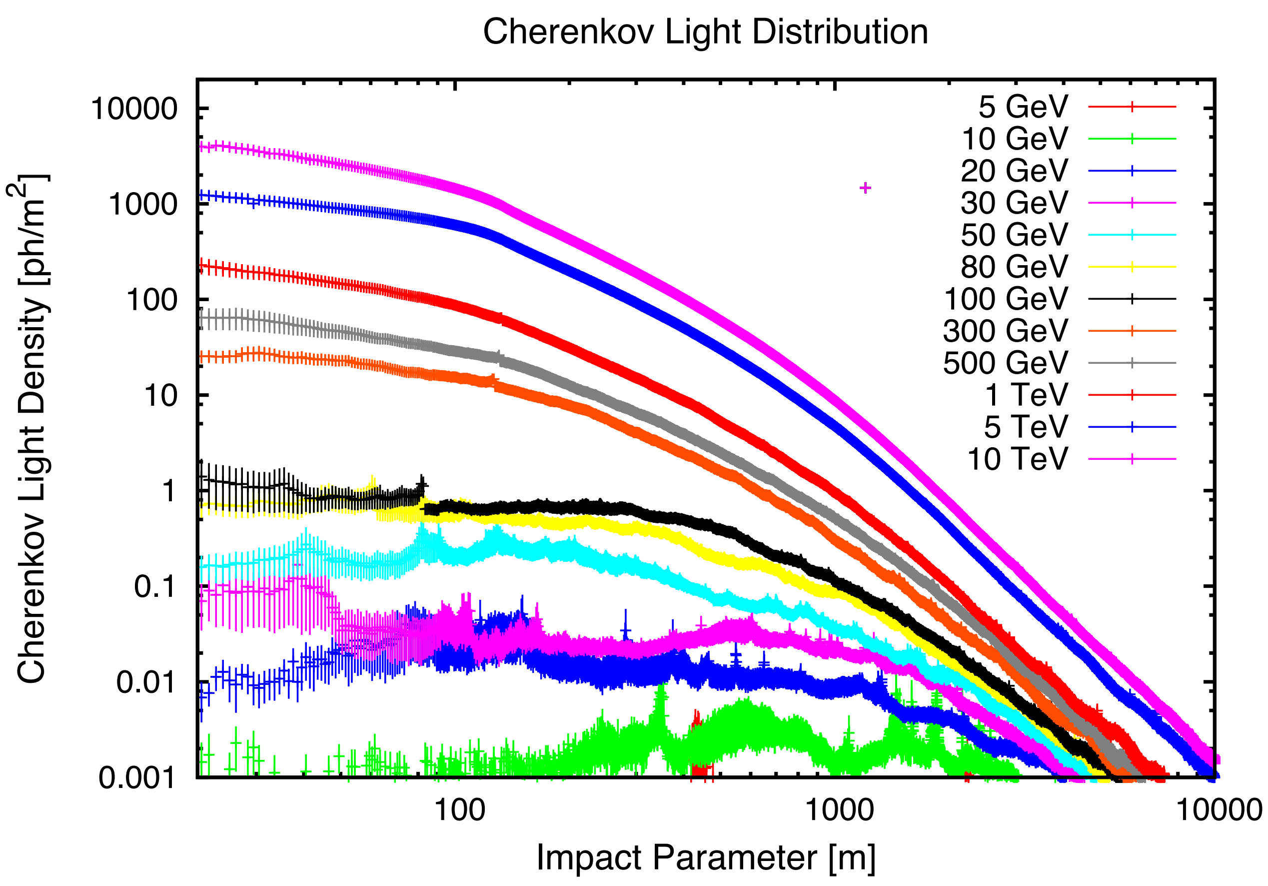
Having several telescopes:

- improves background rejection
- gives better angular resolution
- gives better energy resolution

Cherenkov Light Distribution

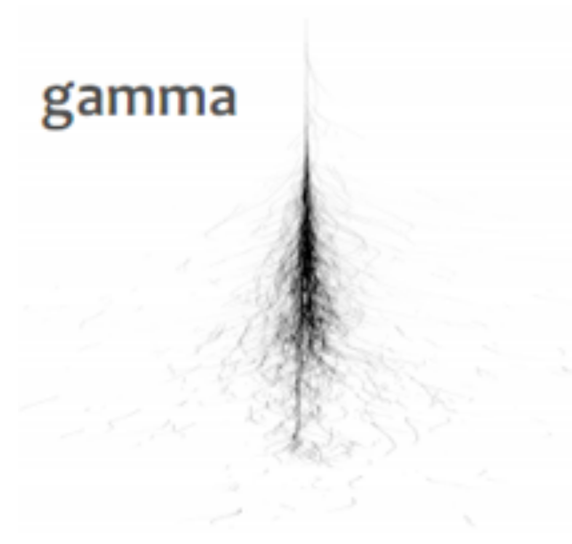


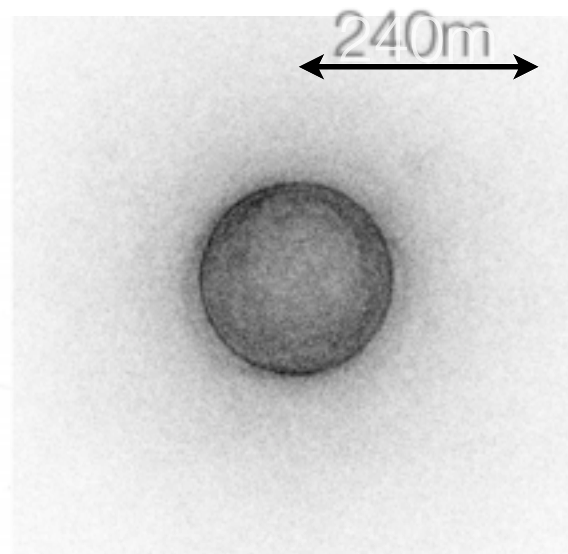
Gamma

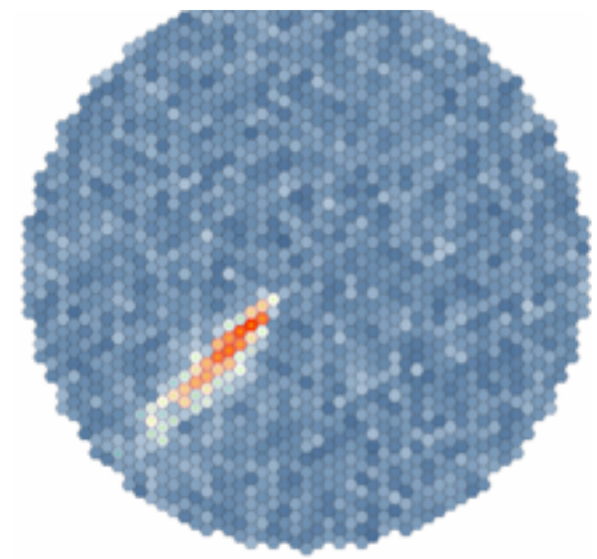


Proton

What we detect with Cherenkov telescopes



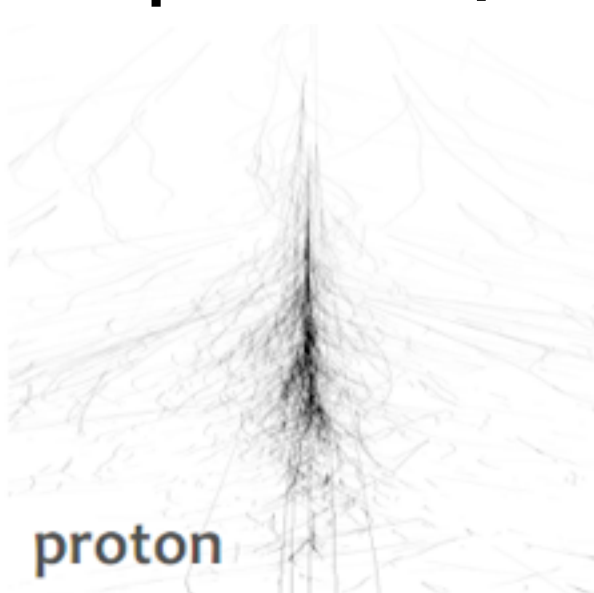


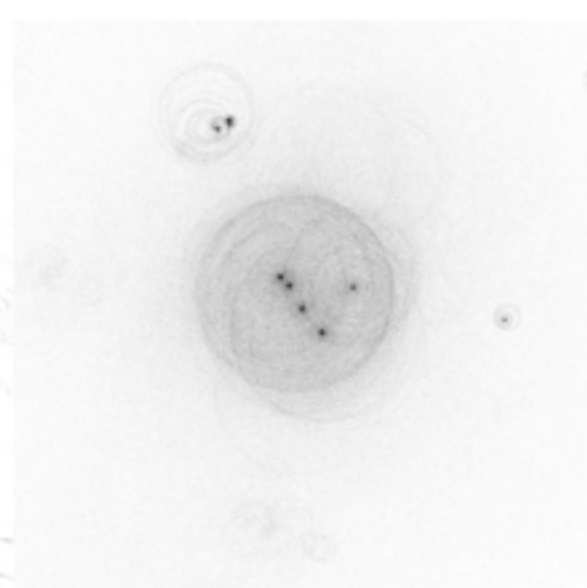


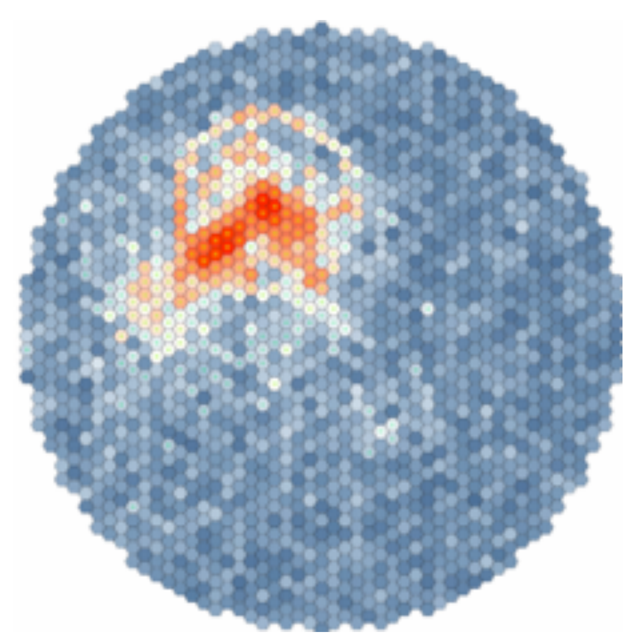
Shower developing in the atmosphere

Distribution of Cerenkov photons on the ground level

Camera Image

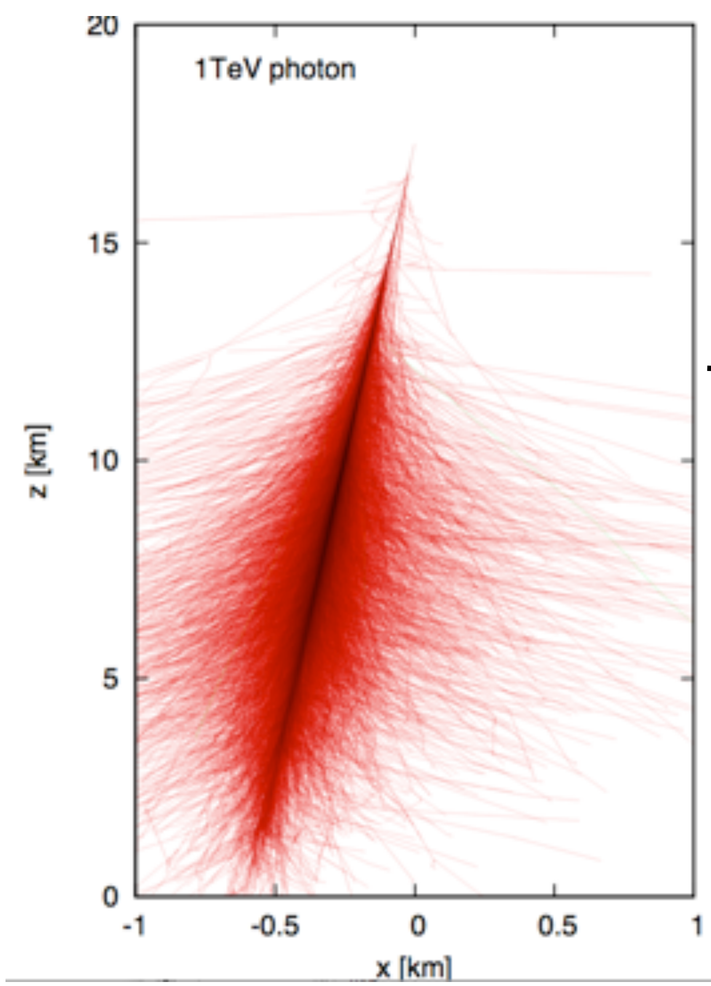






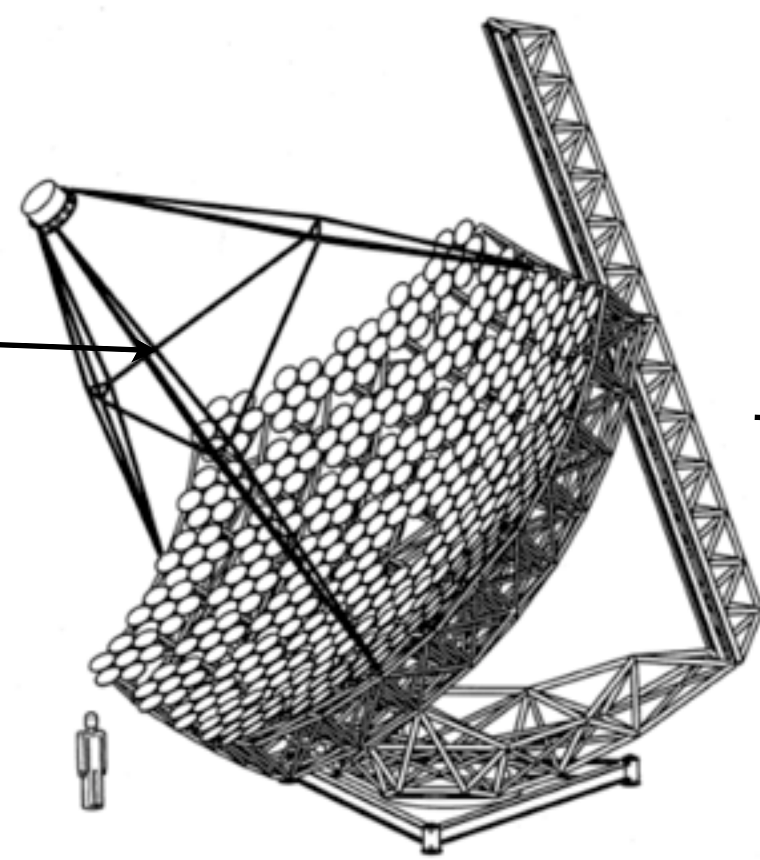
Monte Carlo Simulations

Phase 1
CORSIKA



Showers simulation

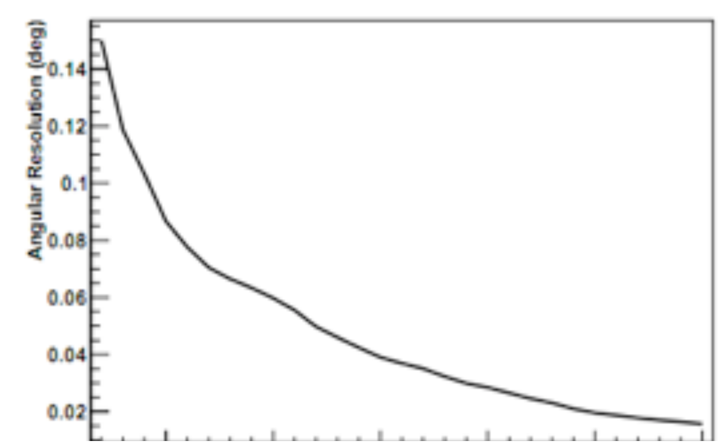
Phase 2
sim_telarray



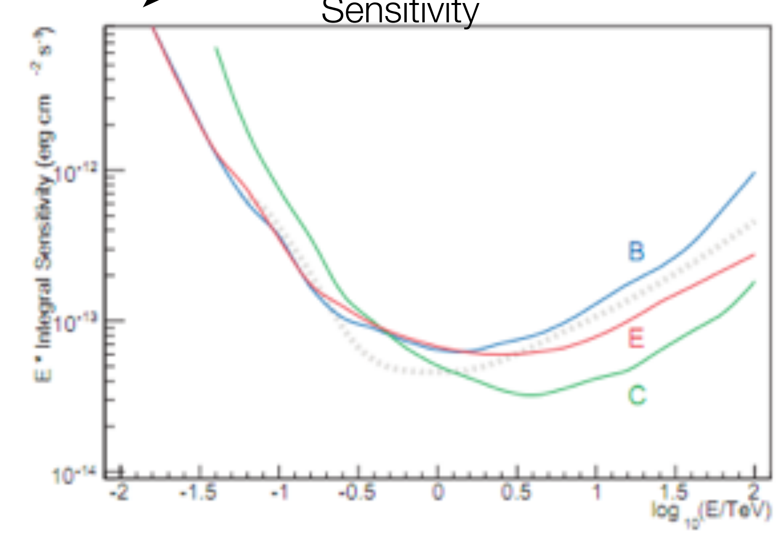
Telescope array
simulation
(275 tel, 5 types)

Phase 3
read_hess

Angular Resolution

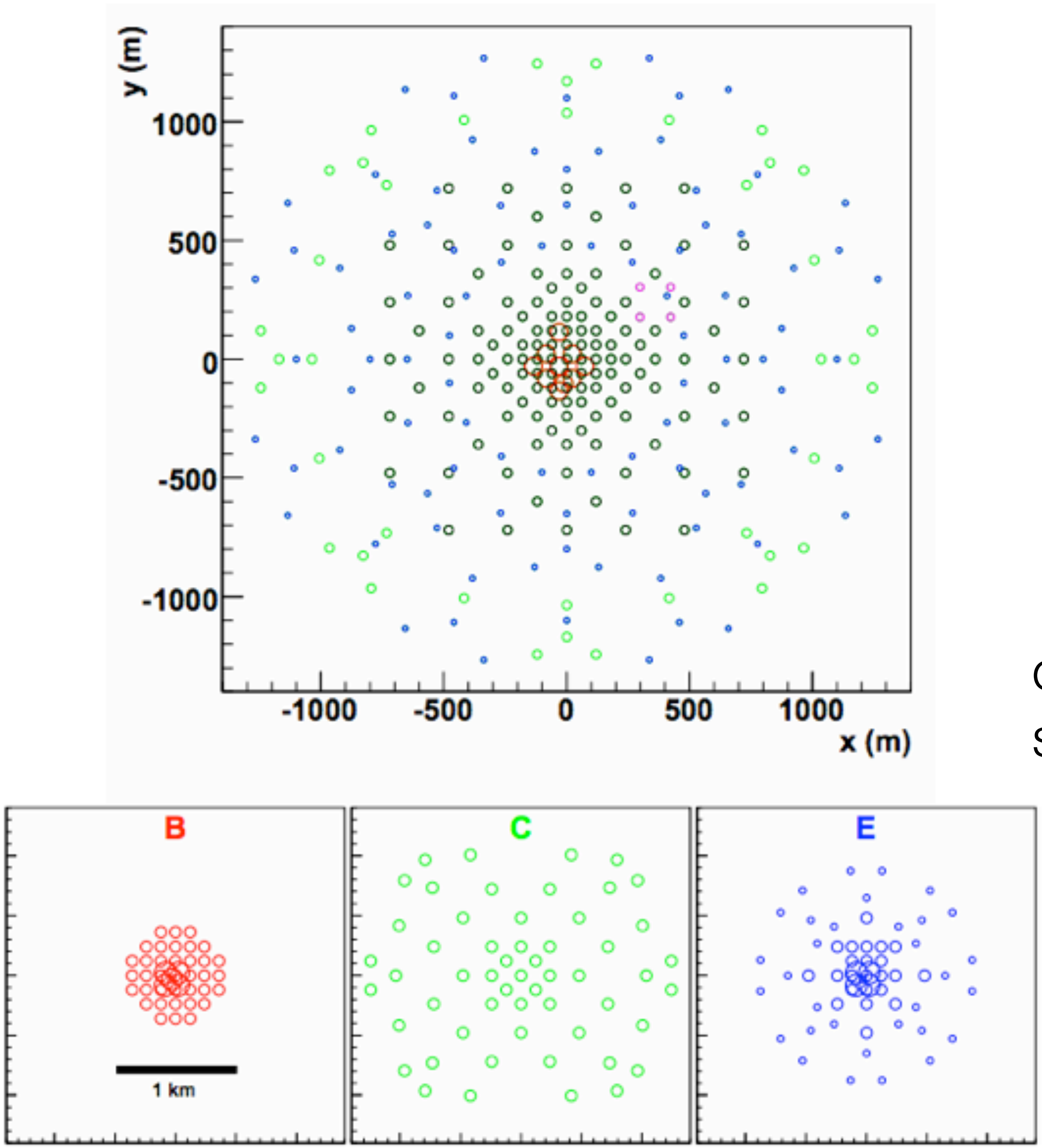


Sensitivity



Results analysis

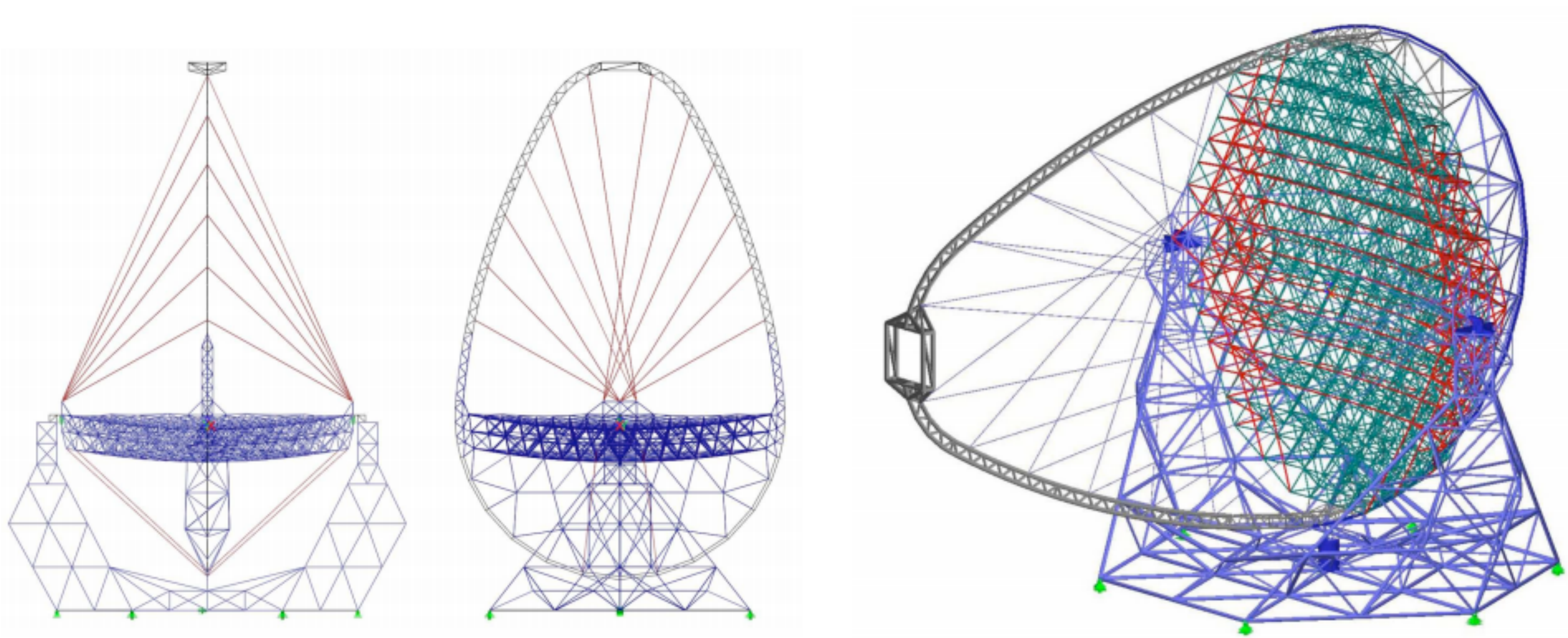
Array Layout



Top: 275 telescope super-configuration for the MC mass production. 5 telescope types are simulated (red: 24 m diameter telescopes, black and green: 12 m, pink: 10 m, blue: 7 m), with the circle size proportional to the mirror area. Bottom: Three example candidate configurations (B, C & E) which are subsets of the 275 telescope array and would all have an approximate construction cost of 80 Me.

Large Size Telescope LST

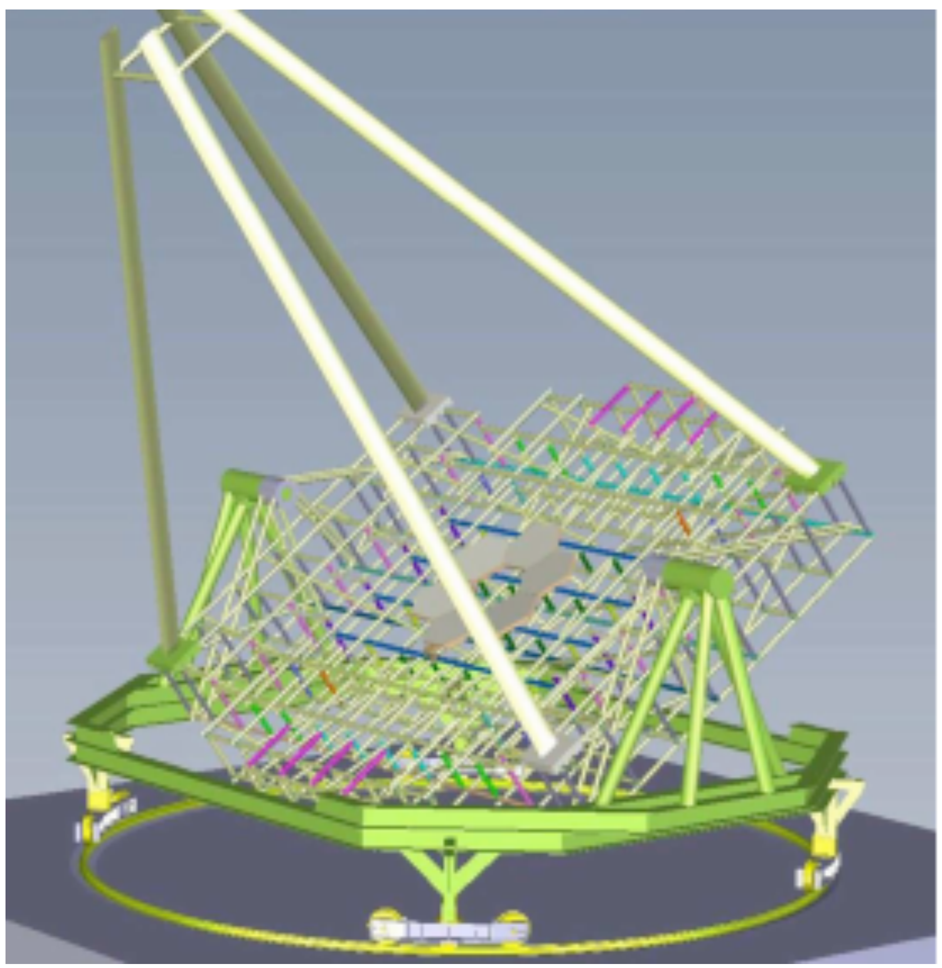
Requirements:
Large collection area to lower energy threshold



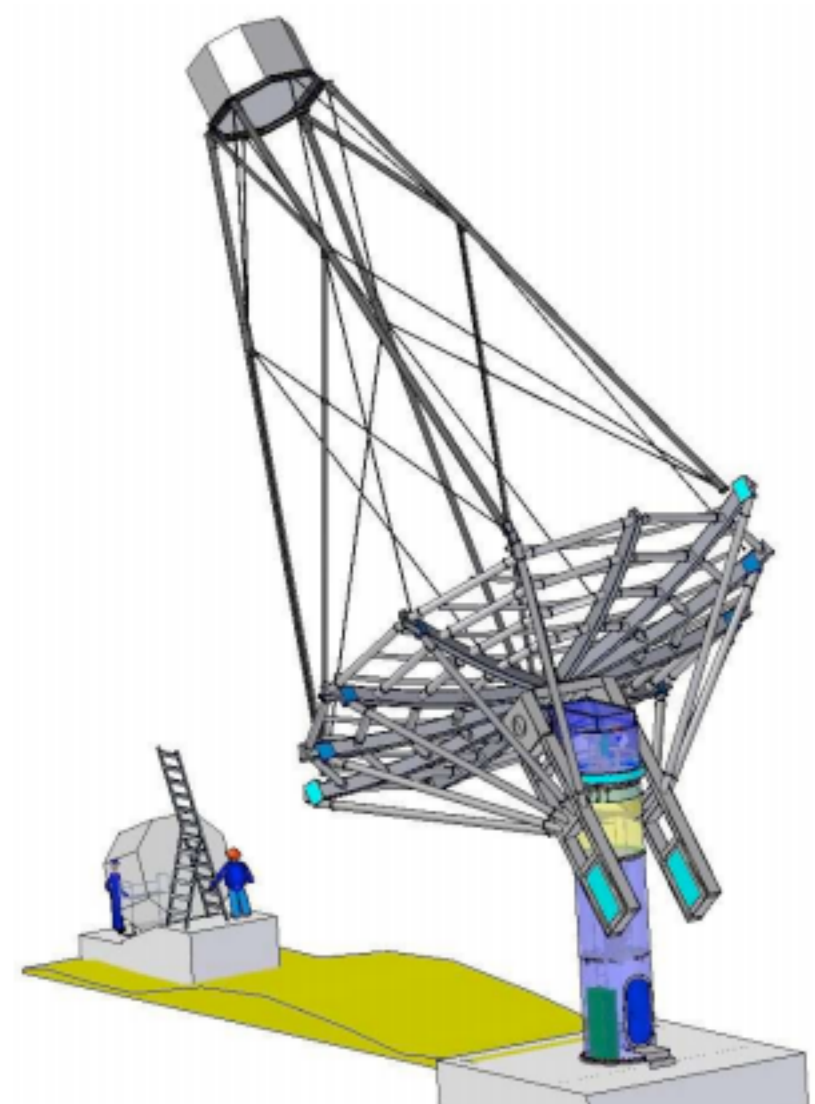
Conceptual layout of the LST. The dish has a diameter of 23 m.

Medium Size Telescope MST:

Requirements: Needs to cover large energy range

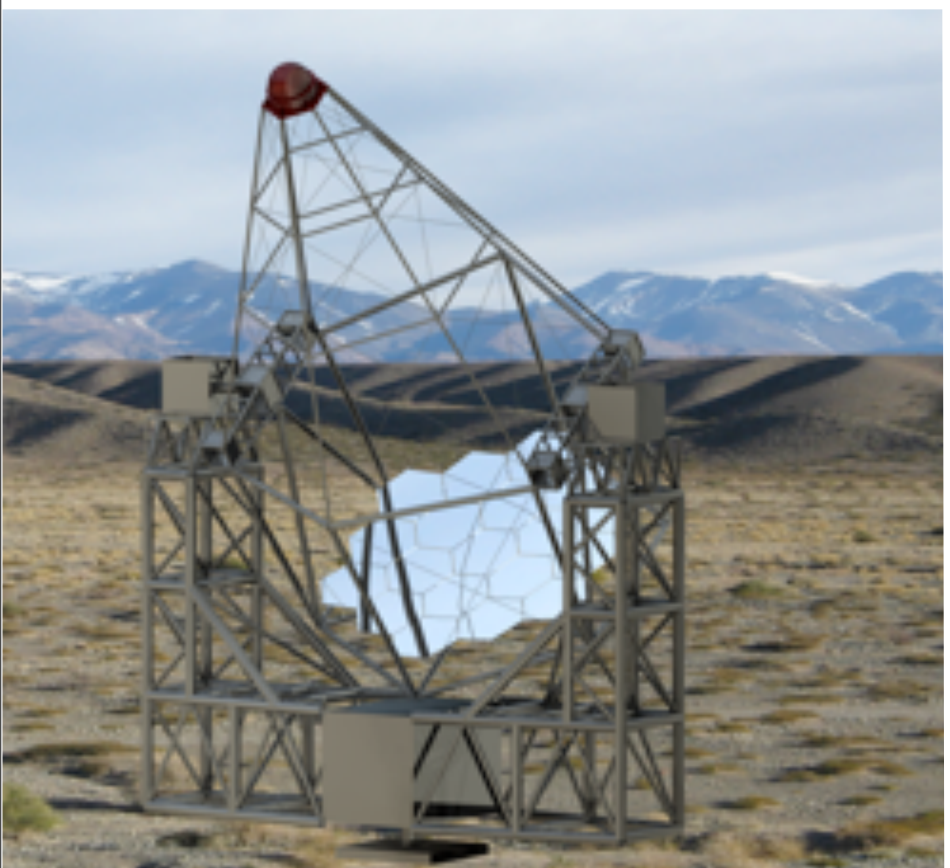


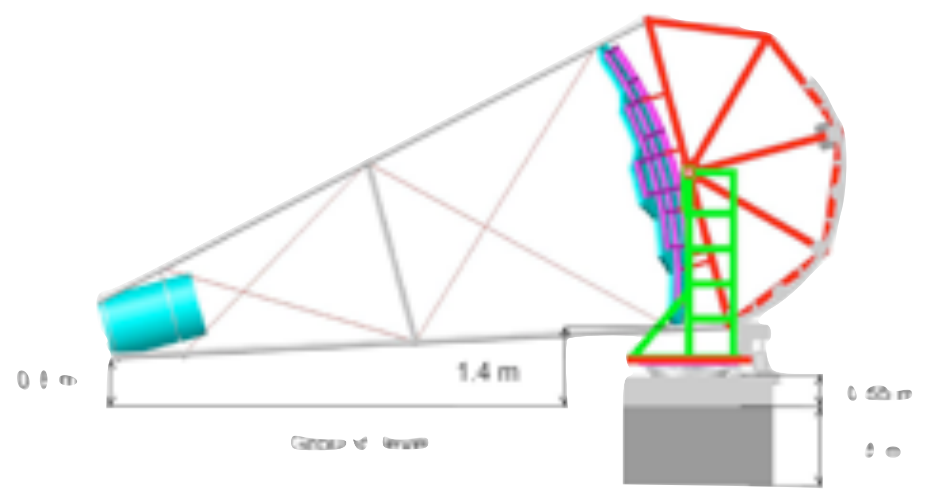
A CFRP dish on a steel mount. In both cases the dish is held at the edge and the azimuthal movement is realised by rails. Putting the telescope into a pit reduces the height of the telescope



This design makes use of a positioner for the movement around the azimuthal and elevation axis

Small Size Telescope SST

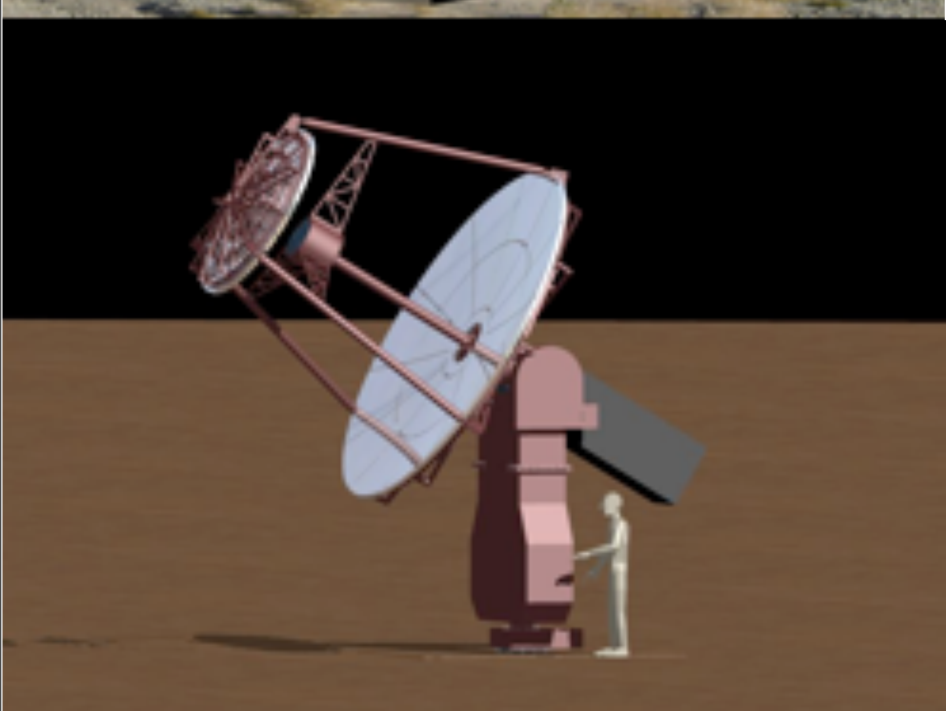




Requirements:

Large FoV
Large Camera
Stable structure

Should be cheap



Telescope Mount and Dish

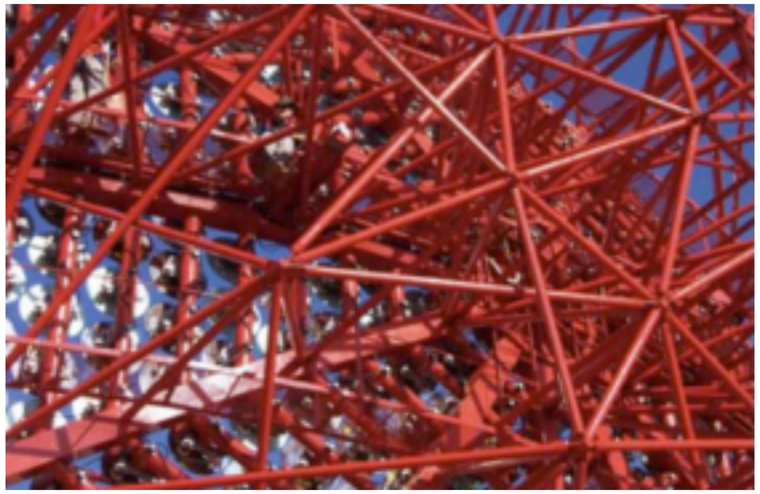
- must allow the slewing of the dish
- must allow the tracking of celestial objects
- supports the segmented reflector and the camera
- support which holds the camera at the focus on the reflector.

Critical properties:

- Positioning of mirror facets
- Mechanical stability of the optical system
- Pointing and tracking precision
- Efficiency of construction, transport, and installation
- Safety considerations

Dish Structure and Camera Support

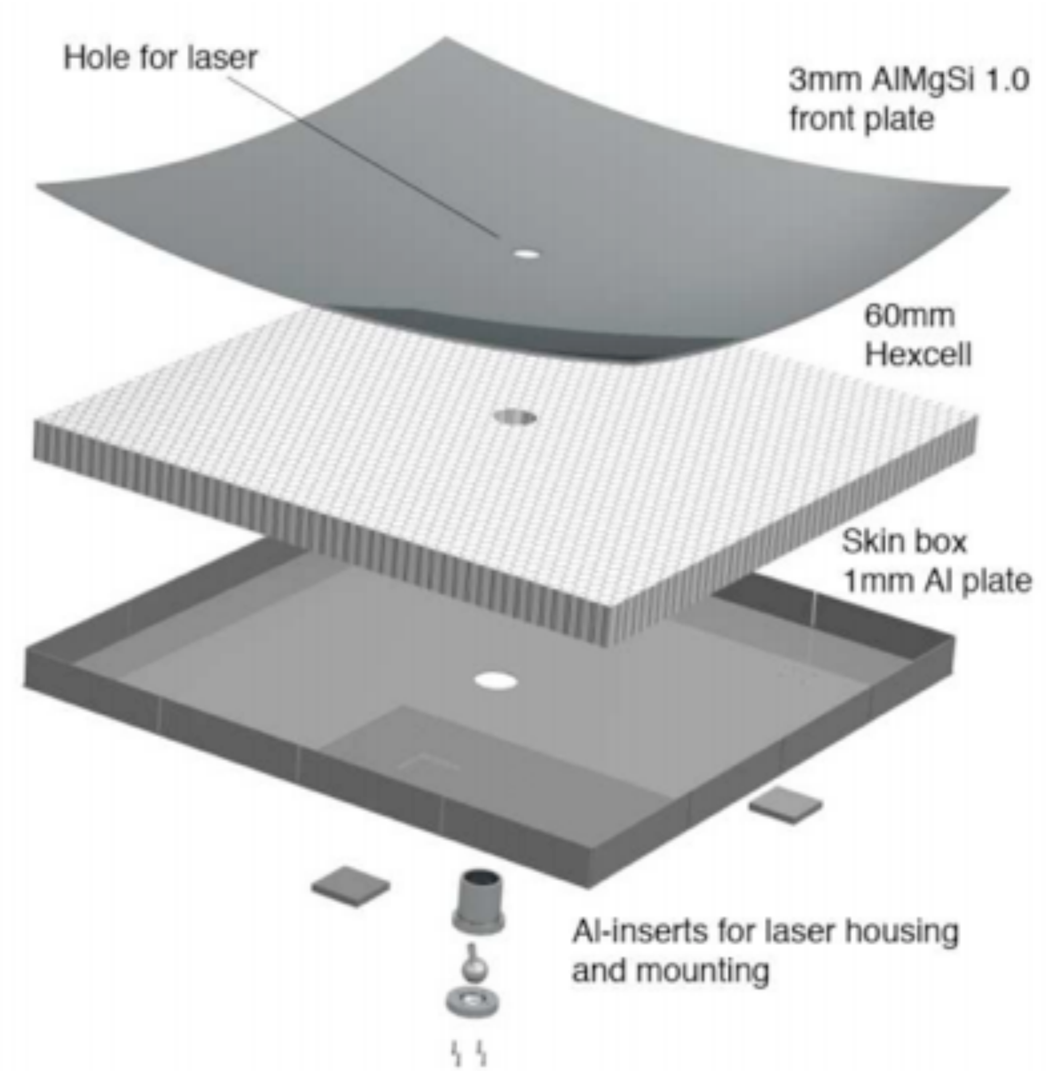
- Construction materials:
  - Steel: steel is the most commonly used material for past constructions, such as H.E.S.S.and VERITAS. It is generally the cheapest material, but results in rather heavy constructions.
  - Aluminium: Aluminium is less heavy than steel, it has the largest thermal expansion of all three materials considered here.
  - CFRP: CFRP is the strongest of the three materials and has the lowest weight, but it is the most expensive. It undergoes very little thermal expansion and is better as regards oscillation damping than the other materials, but connecting different elements is more difficult.



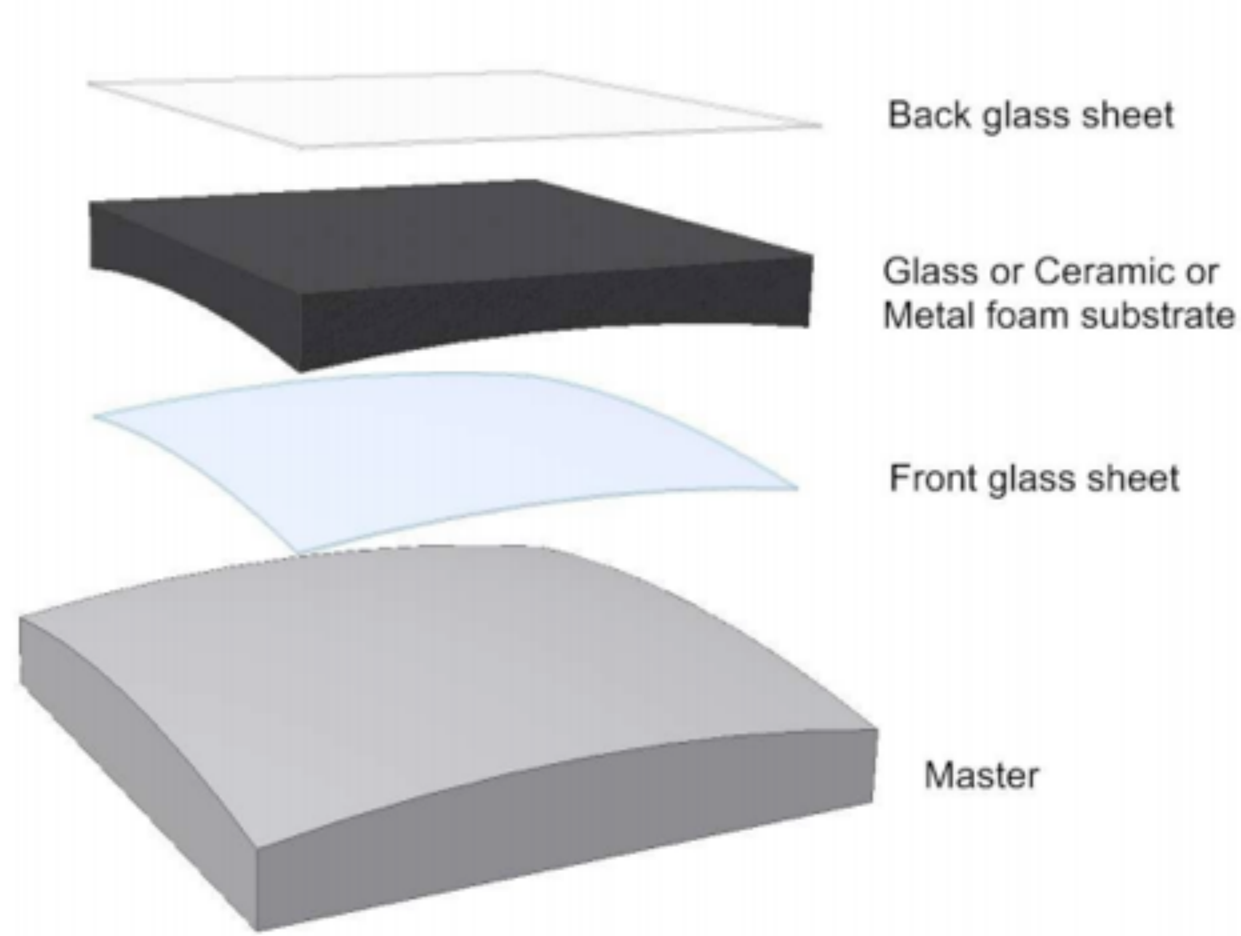
Examples of the space-frame construction. H.E.S.S. steel space-frame (up) and the MAGIC three-layers CFRP space-frame (down).

Mirror Facets

CTA will need of the order of 10^4 m^2 of mirror area



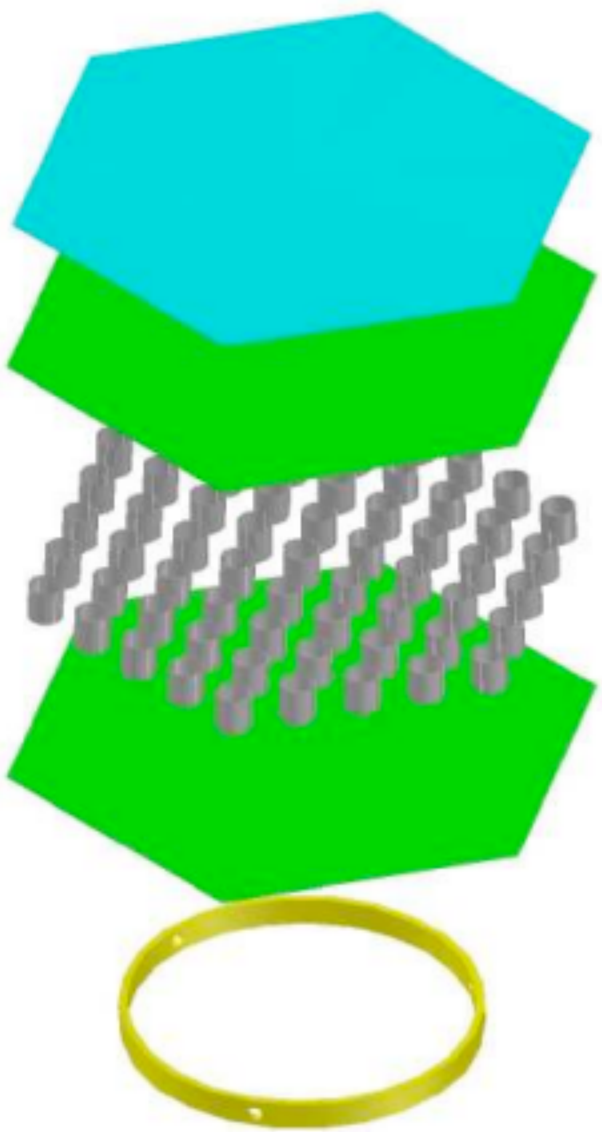
Diamond-milled aluminium honeycomb mirrors.



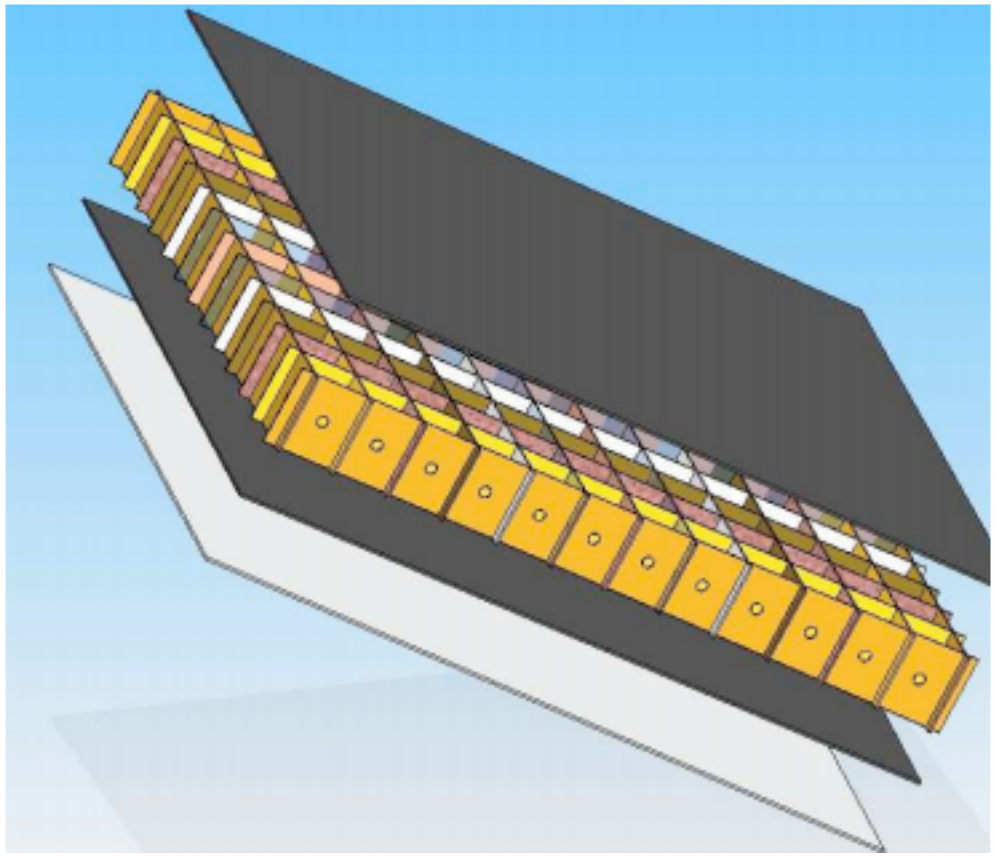
Cold slumped glass-foam sandwich mirrors.

Mirror Facets

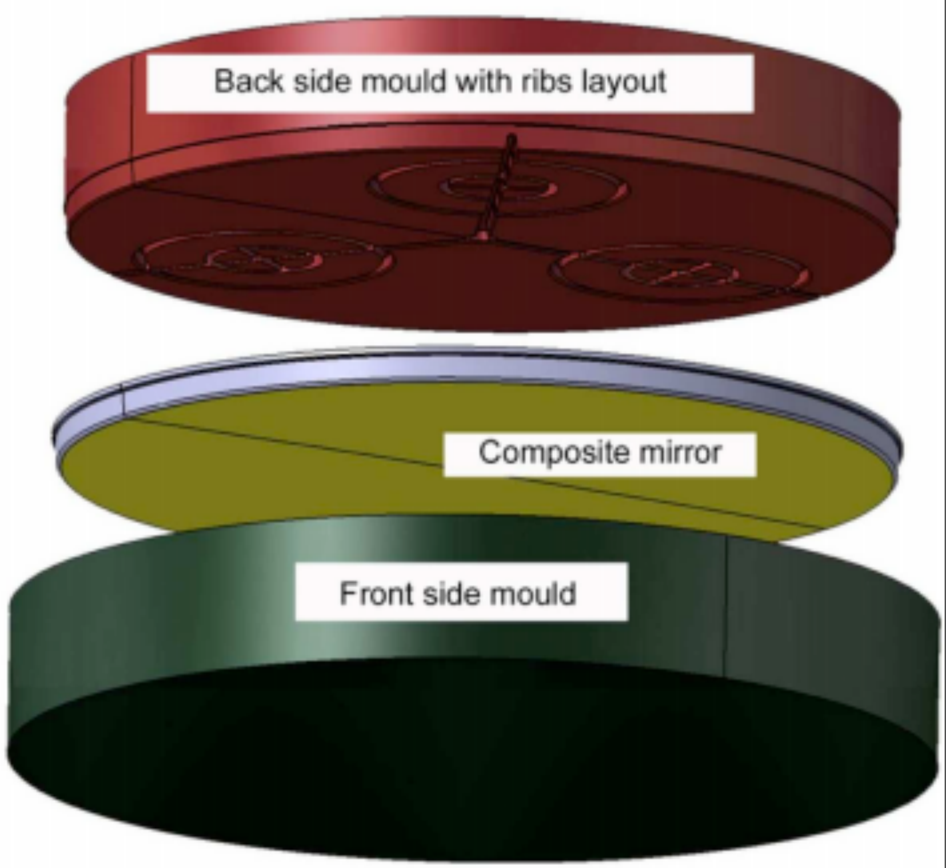
CTA will need of the order of 10^4 m^2 of mirror area



Open fibre-reinforced plastics mirror (carbon fibre or glass fibre).



Carbon-fibre composite mirror with CFRP honeycomb



Carbon-fibre composite mirror produced with SMC technology

Photon Detection

Criteria for Photo-detectors:

- **Spectral sensitivity:** The spectrum of Cherenkov light is cut off below 300 nm, due to atmospheric transmission effects, and falls off as $1/\lambda$ towards longer wavelength. Candidate photo-detectors should be matched to the peak in this spectrum at around 350 nm.

- **Sensor area:** Currently favoured pixel sizes are around 0.1 for the LST, 0.18 for the MST, and 0.25 for the SST.

- **Dynamic range and linearity:** Sensors should be able to detect single photons and provide a dynamic range of up to 5000 photo-electrons.

- **Temporal response:** The time dispersion of Cherenkov photons across a camera image (from ~10 ns to ~100 ns)

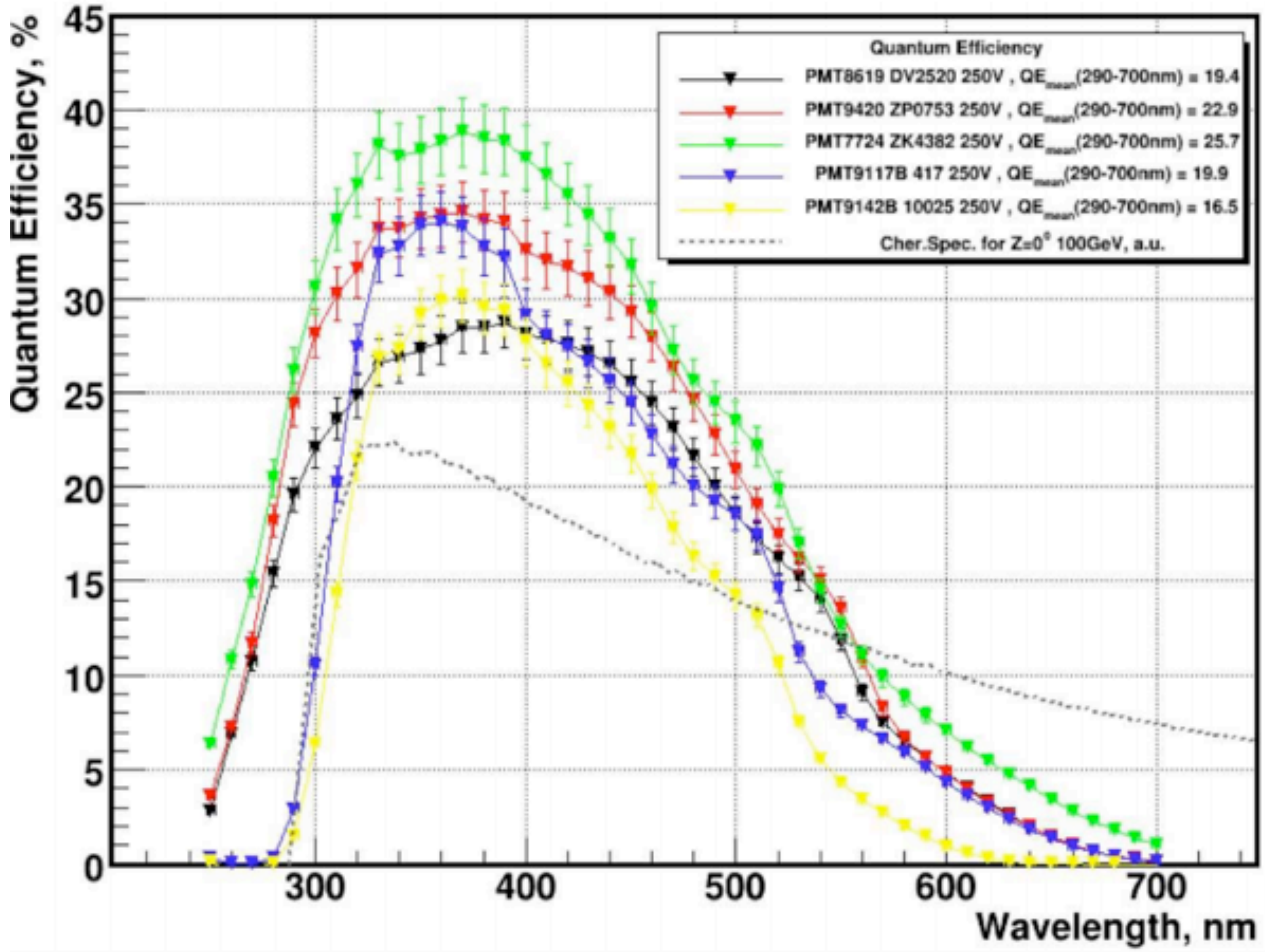
Photon Detection

Criteria for Photo-detectors:

- **Lifetime**: Sensors will detect photons from the night-sky background at a typical rate of about 100 to 200 MHz for the telescopes with large collection areas (MST and LST). If operation is attempted when the moon is up, this rate can increase by an order of magnitude. Sensors should have a lifetime of 10 years for an annual exposure of up to ~2000 hours.

- **Cost and manufacturing considerations:** In total, the CTA consortium is intending to use ~ 10^5 sensor channels. One important criterion is that the manufacturer/supplier must be able to provide the necessary number of sensors to the required specification with an acceptable and reliably known lead time.

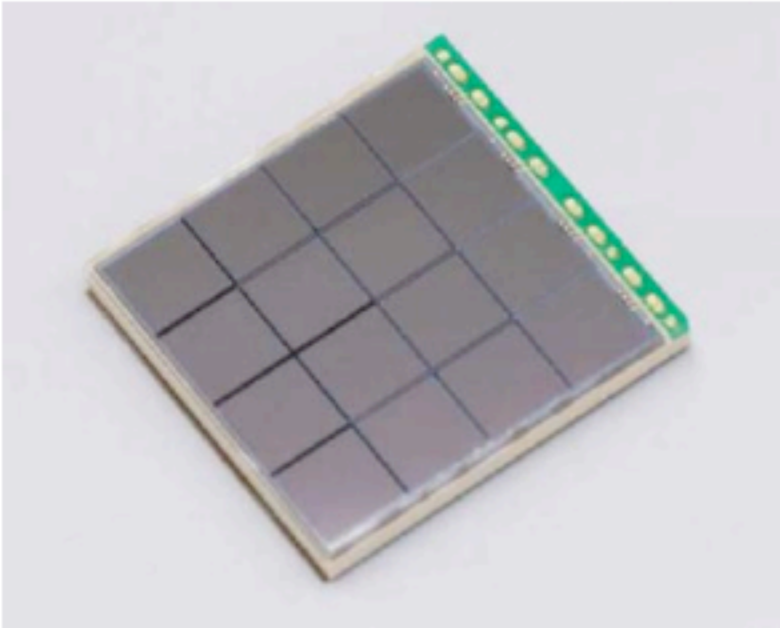
Candidate Photo-detectors



Spectral response of several types of super bi-alkali PMTs from Hamamatsu (green, red and black) and Electron Tubes Enterprises (yellow and blue), compared to the spectrum of Cherenkov light produced by vertical 100 GeV gamma rays on the ground (grey, dashed), convoluted with the standard atmospheric transmission for the observation height of 2200 m a.s.l.. The numbers in the inset give the convolution of the QE curve of a given PMT with the dashed line.

Silicon Photomultipliers (SiPMs):

Monolithic MPPC array in SMD package
S11828-3344M



■Features

- Monolithic array: 16 ch (4 x 4 array)
- Nonmagnetic package
- Effective active area: 3 x 3 mm/ch
- Pixel pitch: 50 μm
- Allows multiple devices to be arranged in a buttable format

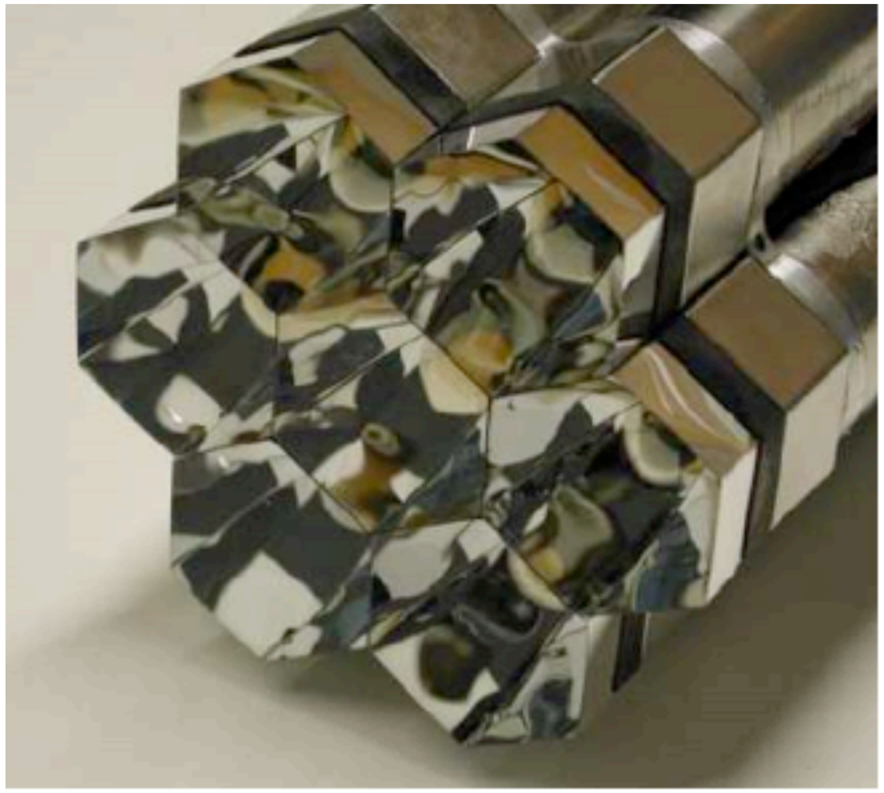
■Specifications

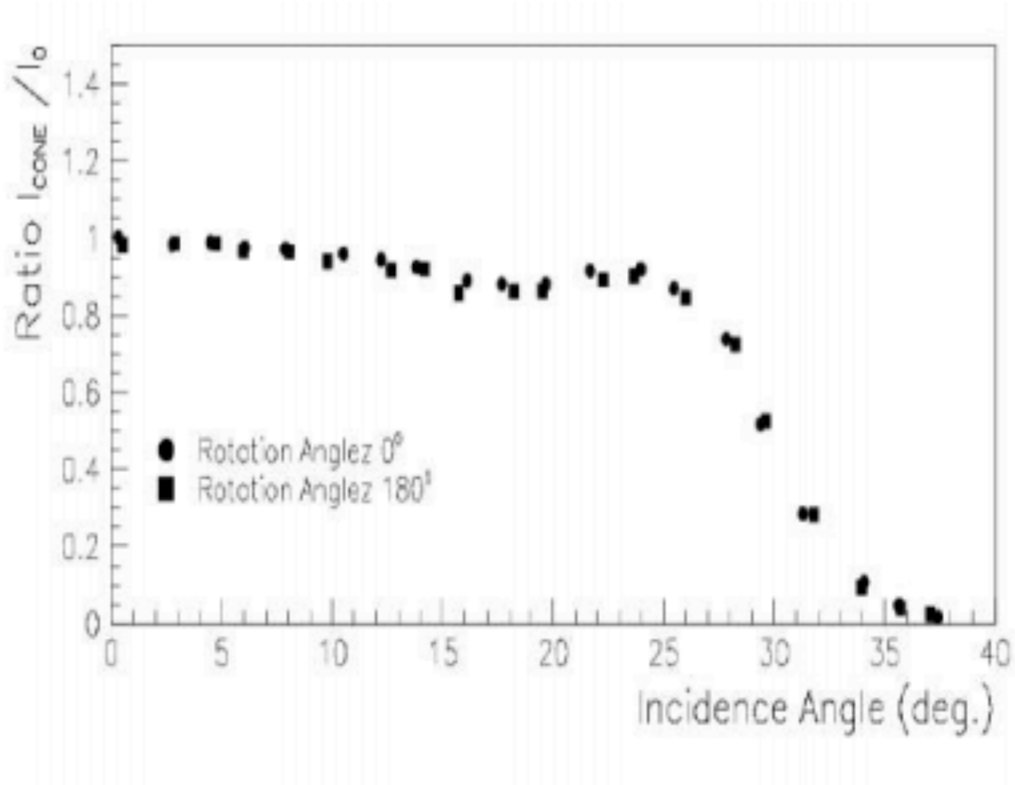
Parameter	Condition	Value	Unit
Number of elements		16 (4 x 4)	elements
Effective active area / channel		3 x 3	mm
Pixel pitch		50	μm
Number of pixels / channel		3600	-
Number of pixels / device		57600	-
Fill factor		61.5	%
Photon detection efficiency *	λ=440 nm	50	%
Dark current / channel	per channel	3	μA
Terminal capacitance / channel		320	pF
Gain		7.5×10^5	-

* Includes cross-talk and after-pulse

Light-collecting Winston cones

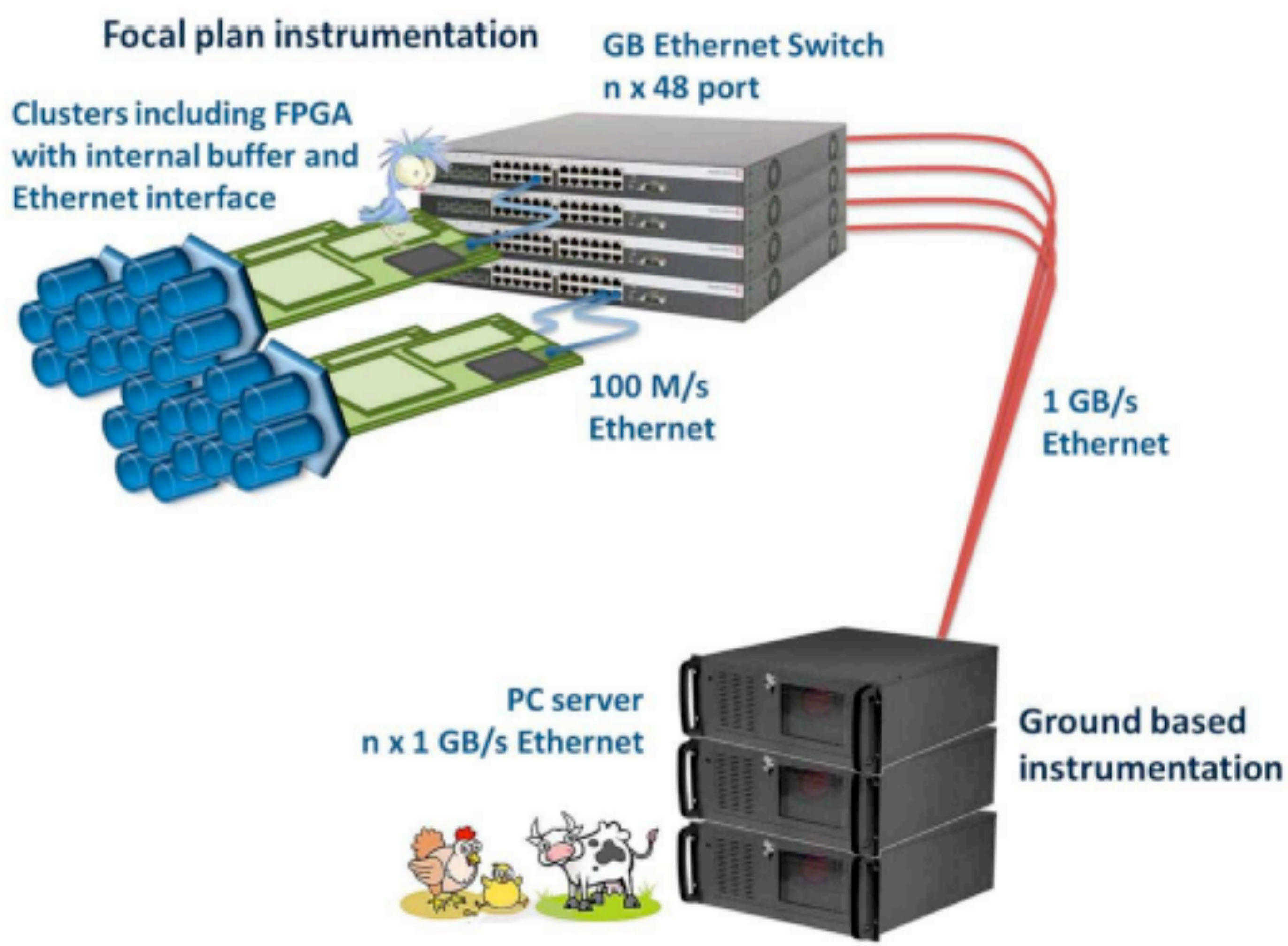
Winston cones placed in front of any sensor could reduce the required sensor size by a factor of 3 to 4.
Compression is limited by Liouville's theorem, which states that the phase-space volume of an ensembleof photons is conserved.
Lightcones can minimise the dead space between pixels and reduce the amount of stray light from the night sky impinging on the sensors at large incidence angles.





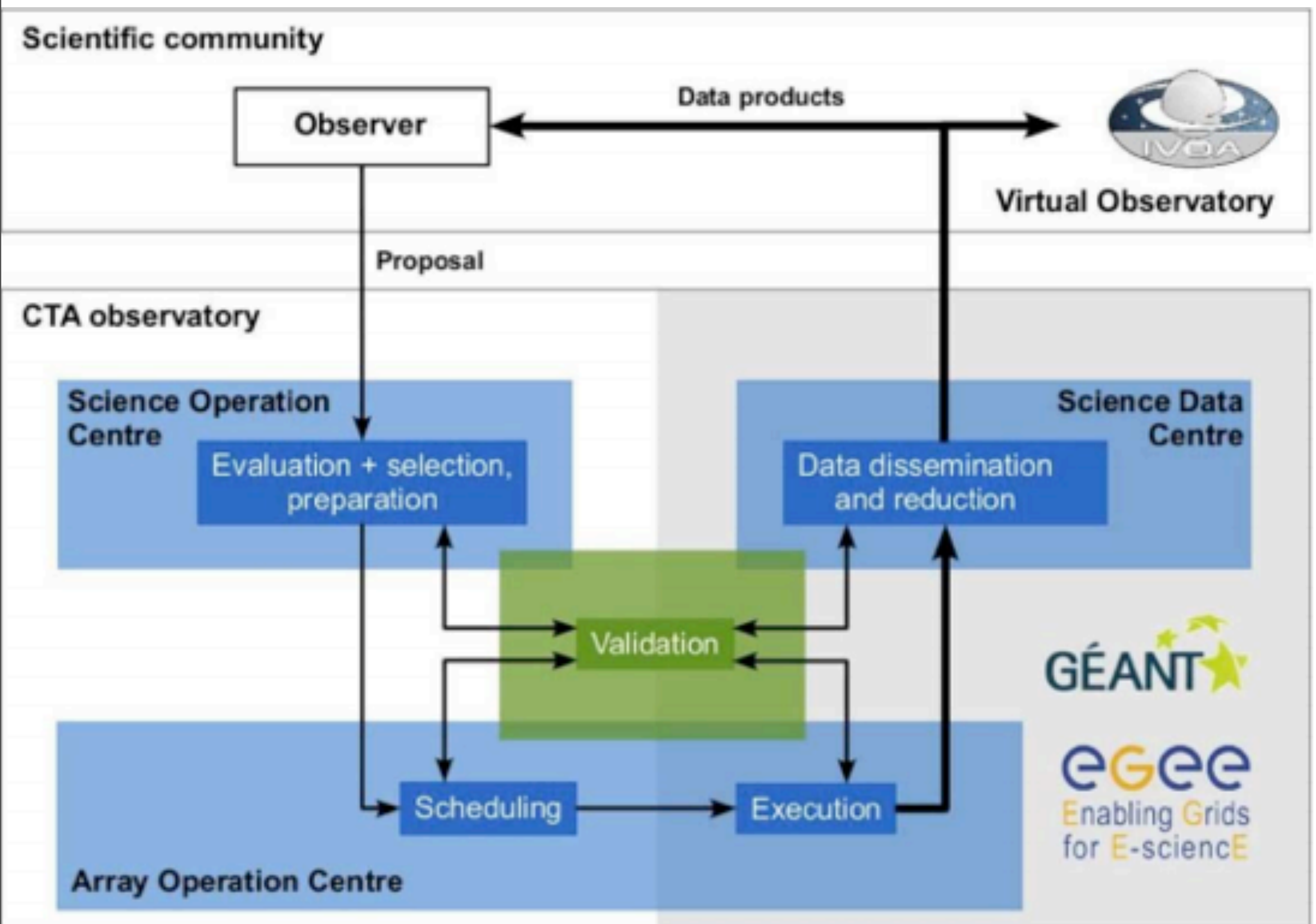
Left: PMT pixel cluster with light funnels. Right: Angular response of a typical light funnel, normalised to the on-axis response.

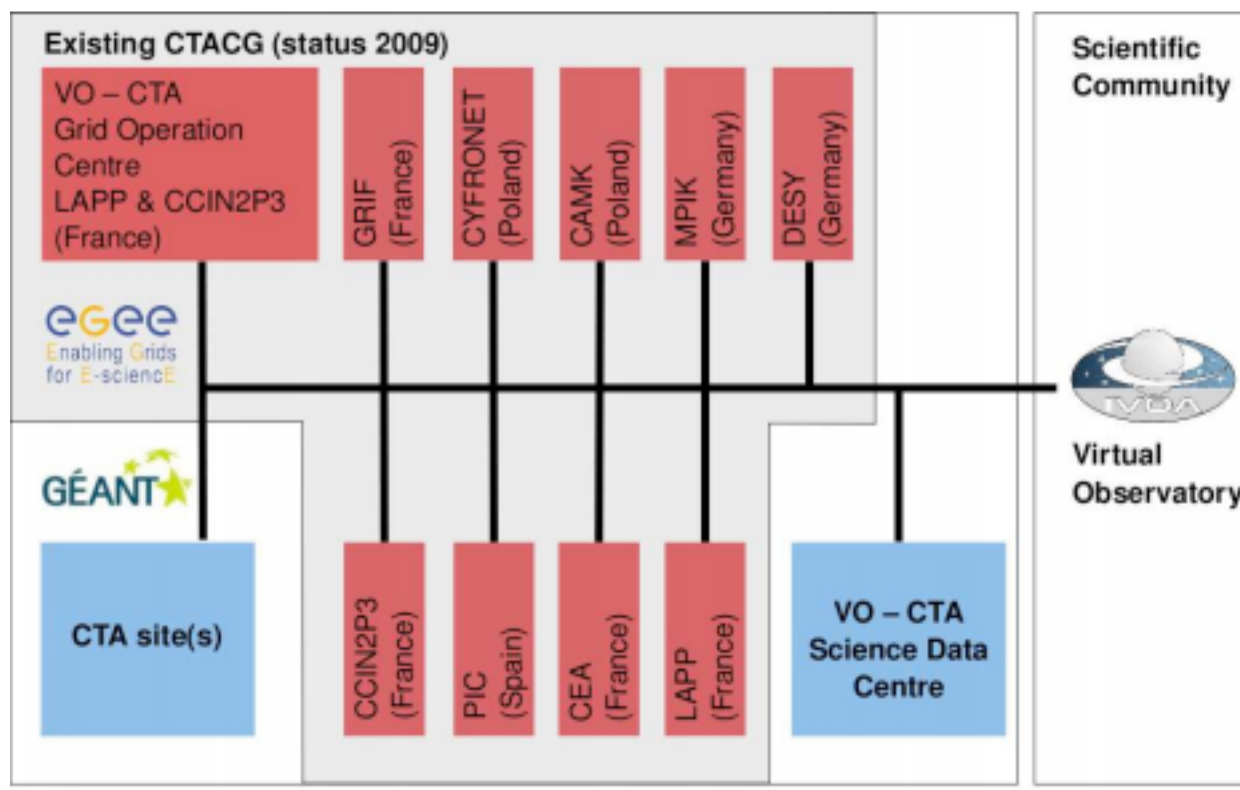
Signal Recording Electronics



Possible scheme for an Ethernet-based front-end to back-end readout. A group of pixels with their ADCs is controlled by a dedicated FPGA. The same FPGA can be used to buffer the data and to transmit them through a dedicated Ethernet network to a camera computer (PC Server), which buffers the data in its RAM and preprocesses events before sending them to an event building farm

Operation of CTA as an Open Observatory





Work flow diagram of the CTA observatory.
The three main elements are:
Science Operation Centre,
Array Operation Centre and the Data Centre.
Data handling and dissemination will build on
infrastructures, such as EGEE and GEANT.

Polskie konsorcjum CTA

- Uniwersytet Jagielloński, Wydział Fizyki, Astronomii i Informatyki Stosowanej – koordynator Konsorcjum
- Akademickie Centrum Komputerowe "CYFRONET" w Krakowie
- Akademia Górniczo-Hutnicza im. S. Staszica w Krakowie
- Centrum Astronomiczne im. M. Kopernika PAN w Warszawie
- Centrum Badań Kosmicznych PAN w Warszawie
- Instytut Fizyki Jądrowej im. H. Niewodniczańskiego PAN w Krakowie
- Uniwersytet Mikołaja Kopernika, Wydział Fizyki, Astronomii i Informatyki Stosowanej
- Uniwersytet Łódzki, Wydział Fizyki i Informatyki Stosowanej
- Uniwersytet Warszawski, Wydział Fizyki

http://obserwatorium-cta.pl/

Poland is building SST prototype

Digital Camera: UJ, AGH

Trigger System: CAMK,UJ

Mirrors: IFJ, CBK

Structure: IFJ

Data Acquisition system: CAMK

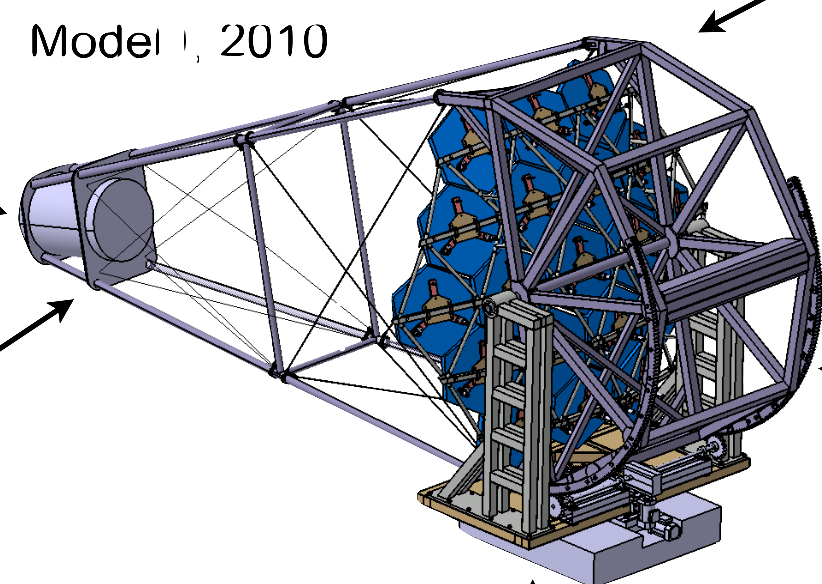
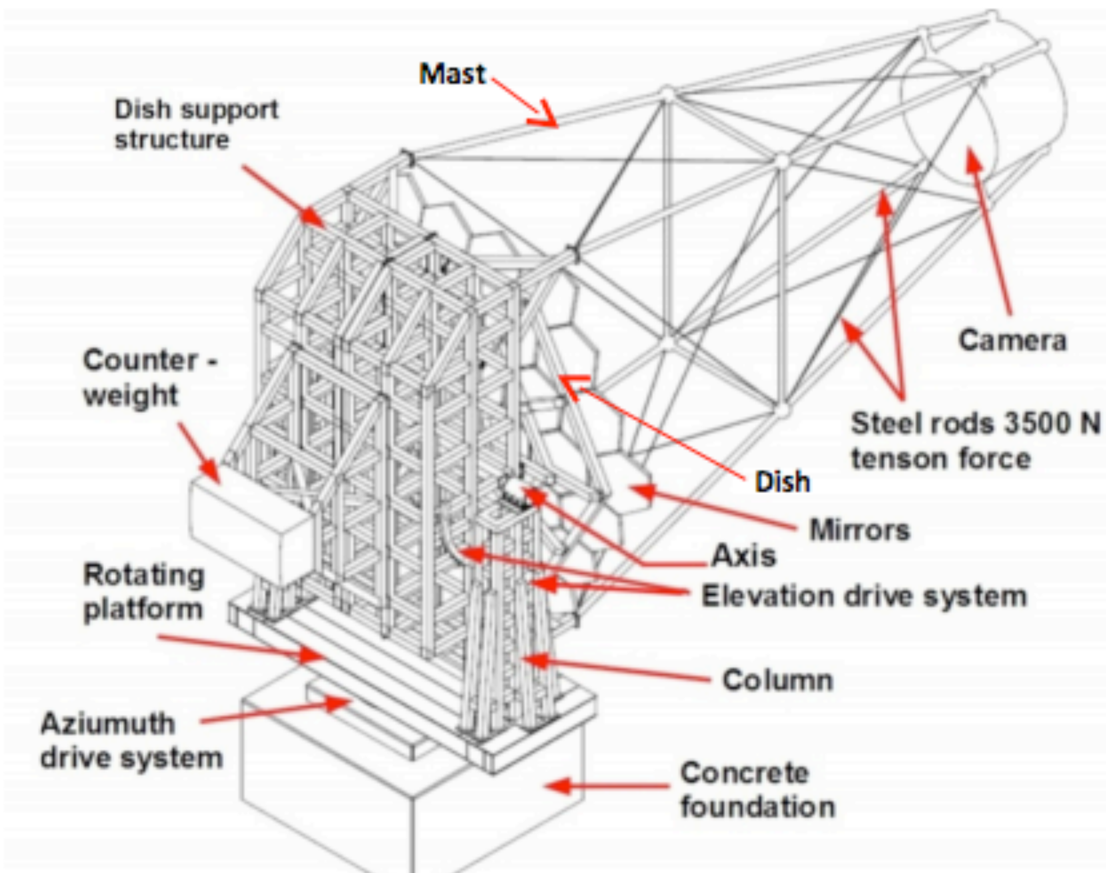
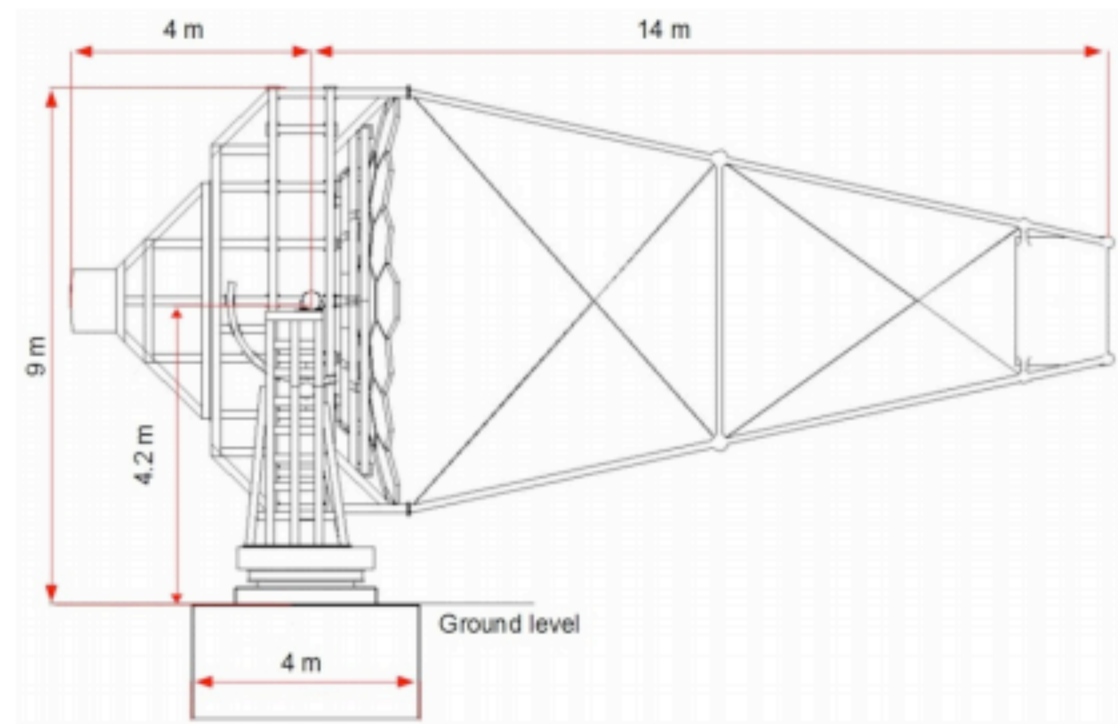
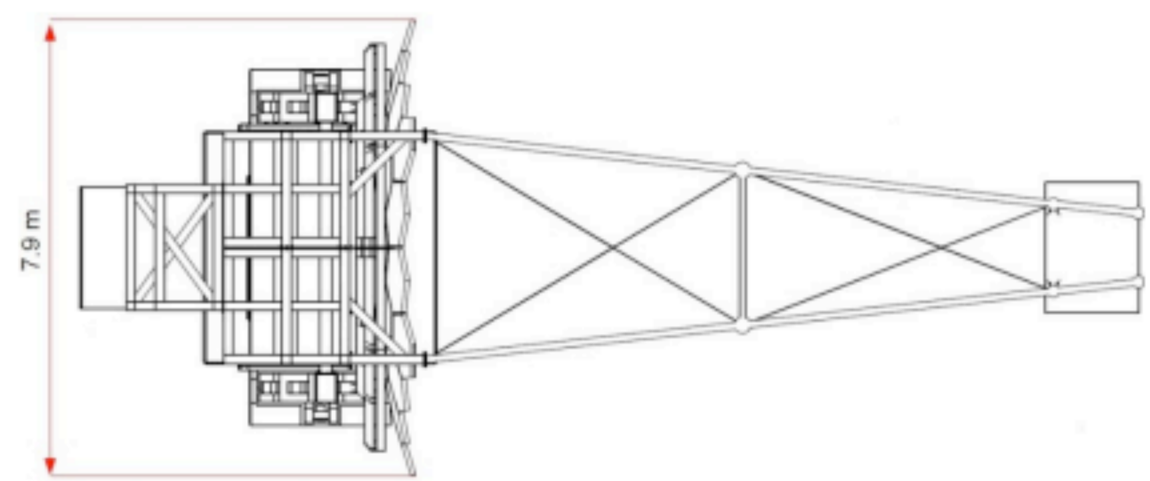


Image: Focal length 9 m, dish diameter 6 m, camera weight 1.6 t (One of the ideas presented by IFJ)

IFJ PAN Davies-Cotton Small Size Telescope



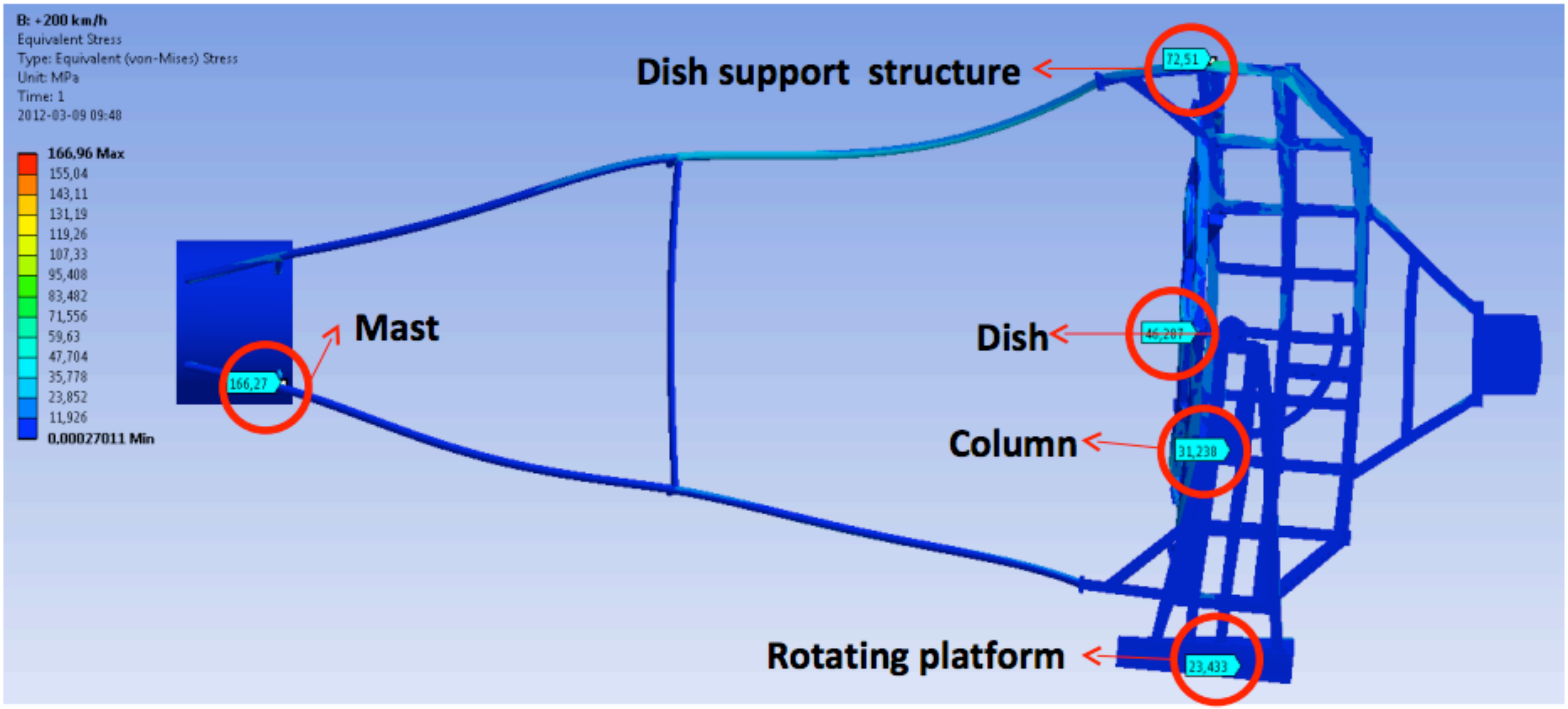




Tubes Dimensions [mm]:

- Column: steel square tubes 150x150x8,6,4
  130x130x4
- Dish support structure: 150x150x3,4,6,8
- Mast: steel round tubes Ø120x4
  Ø100x4

IFJ PAN Davies-Cotton Small Size Telescope



Maximum stresses in the specific telescope components:

Rotating platform - 24 MPa

Column - 31 MPa

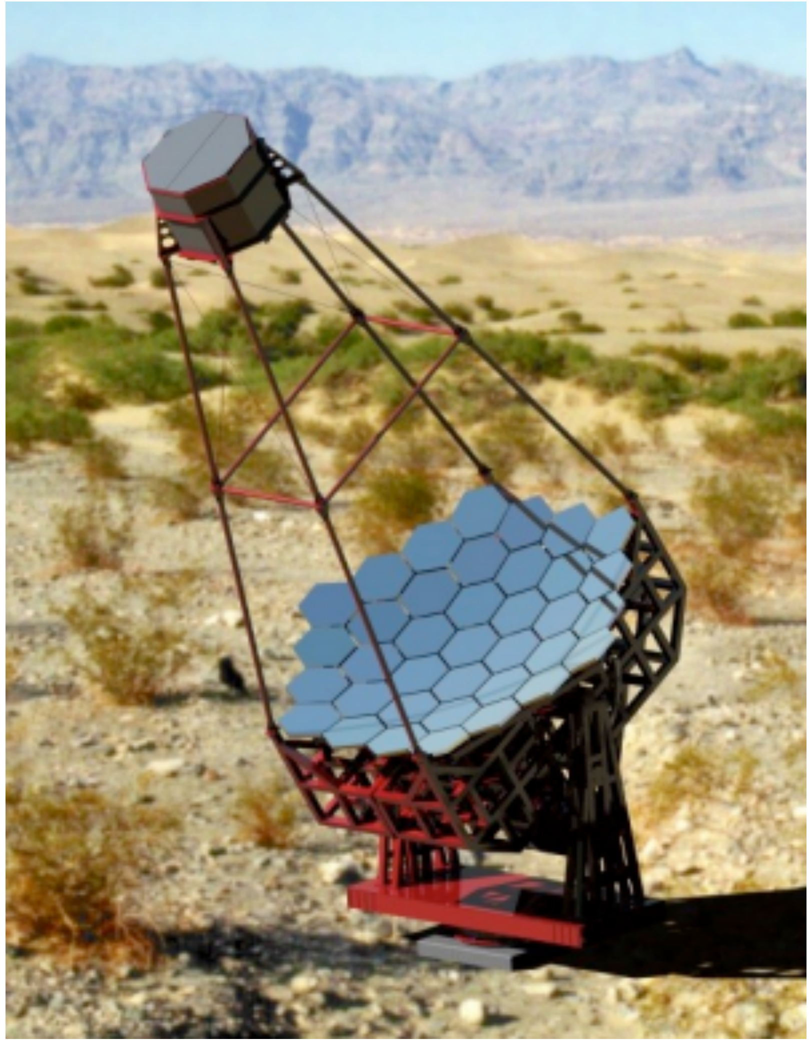
Dish - 46 MPa

Dish support structure - 73 MPa

Mast - 167 MPa (connection mast – camera not technically designed)

IFJ PAN Davies-Cotton Small Size Telescope

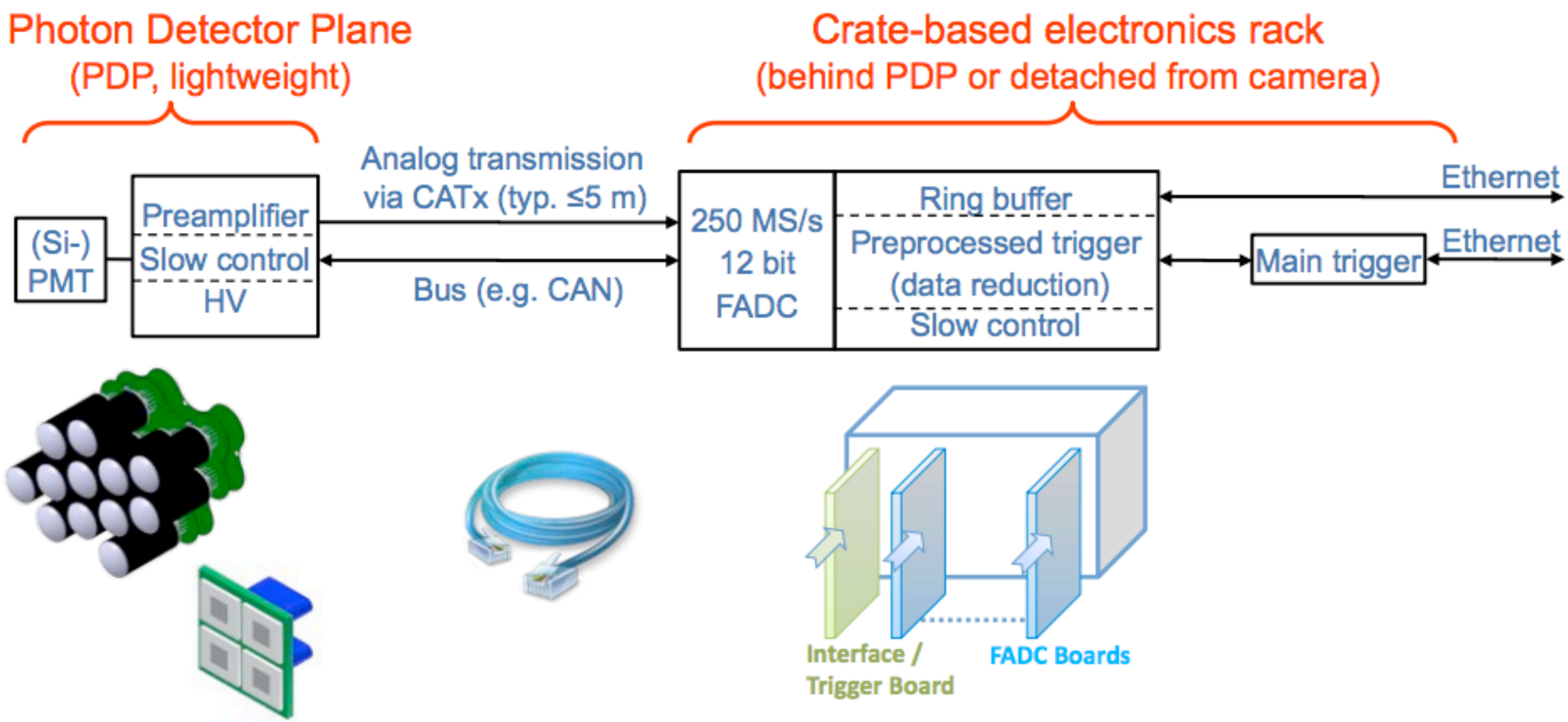
- FEM analysis: earthquake, snow, ice, temperature – in progress ..
- 2. Final modification of the structure – in progress..
- 3. Technical design in collaboration with Polish industry – start June 2012
- 4. Preparation of the tender for the telescope structure – August 2012
- 5. Realistic cost estimate – September 2012



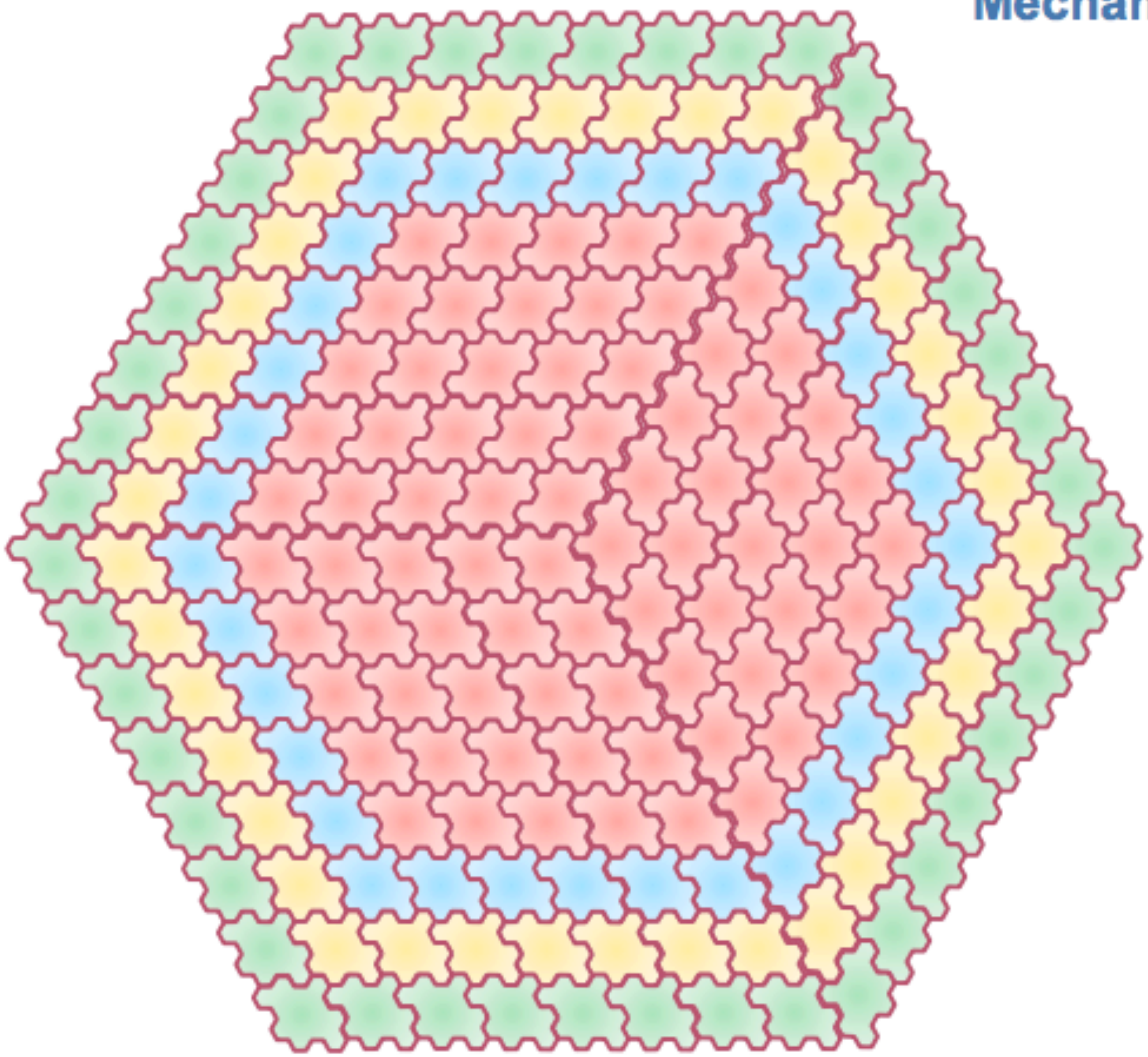
Digital Camera - AGH, UJ -FlashCam

- Simple concept based on commercially available chips
- Trigger decision based on digitized signals
- No separate trigger path
- Programmable and flexible
- Nearly deadtime free
- Low power (<0.5 W/channel) 12-bit FADCs currently available up to 250 MS/s.

Digital Camera - AGH, UJ -FlashCam - Camera scheme



Digital Camera - AGH, UJ -FlashCam - Camera scheme

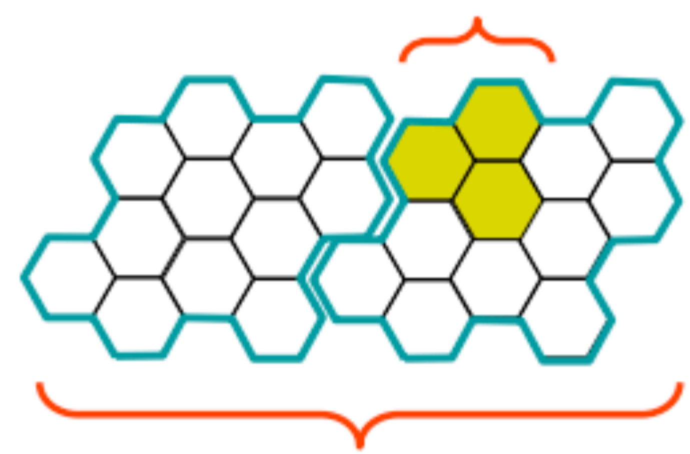


3 sectors, rotated by 120 deg
Hexagonal structure, perfect edges

Mechanical PDP grouping: modules of 12 PMT pixel

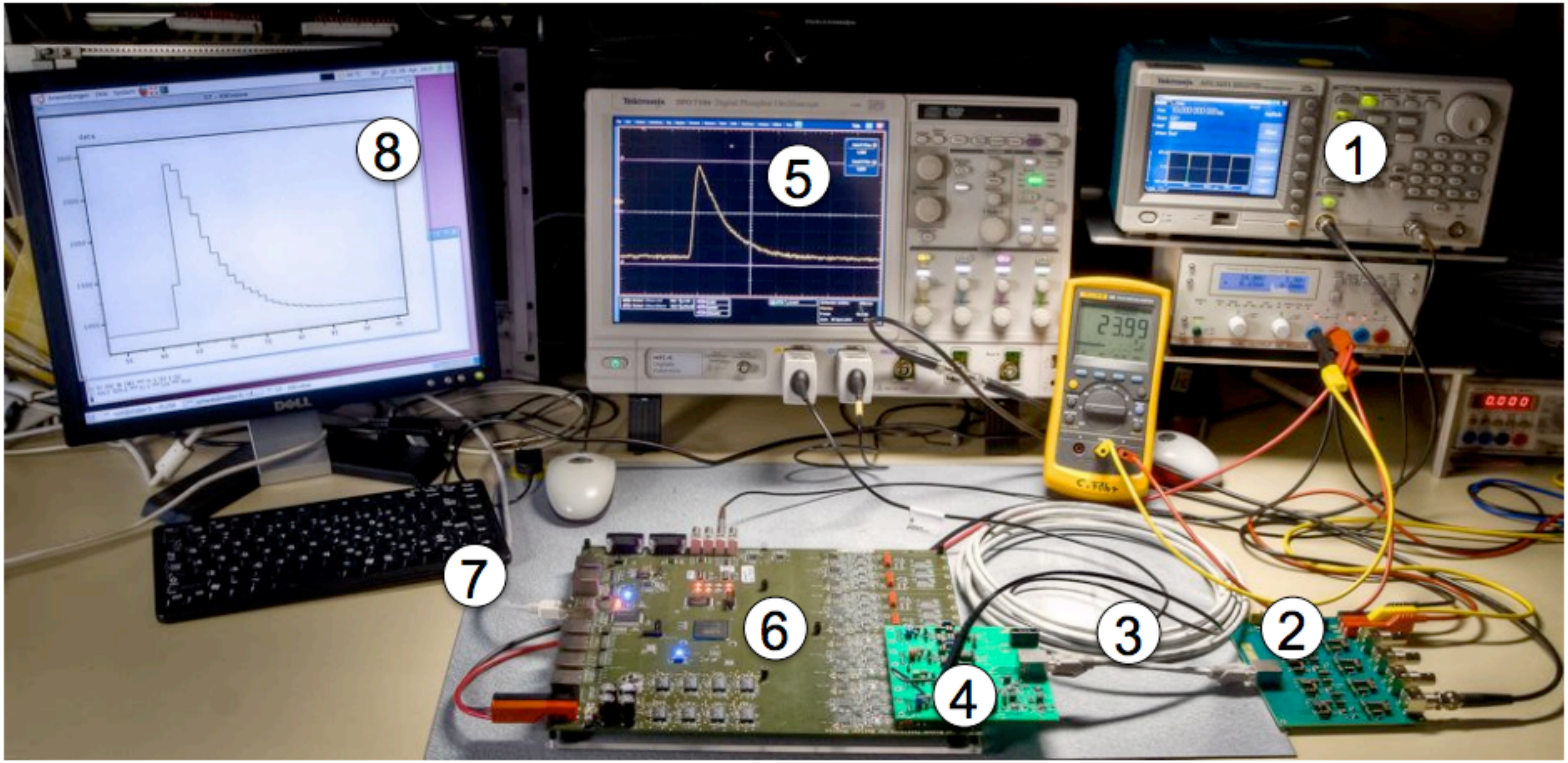
	900 pixel, 1550 mm	SST
	1296 pixel, 1860 mm	SST
	1764 pixel, 2170 mm	MST
	2304 pixel, 2480 mm	>LST

Trigger patch size: 3 pixel



Readout electronics: FADC boards serving 24 pixel

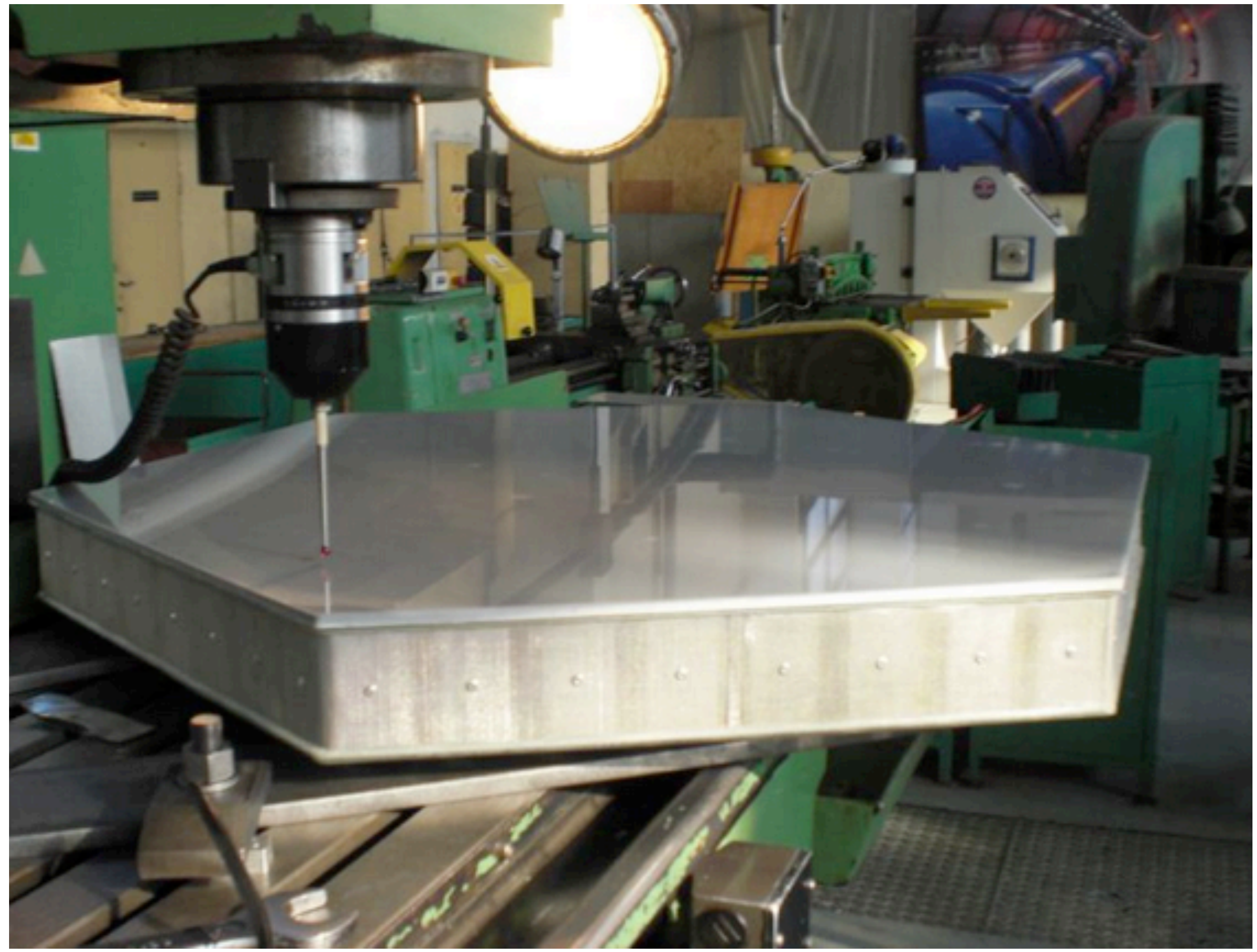
FlashCam Demo board setup



1 PMT pulse generator
2 Preamplifier board
3 Analogue signal transmission (CAT5)
4 ADC driver board
5 Analogue pulse before ADC
6 Demo board with 8 parallel FADCs and FPGA
7 Event transmission via LAN
8 Digitized pulse (4 ns / step)

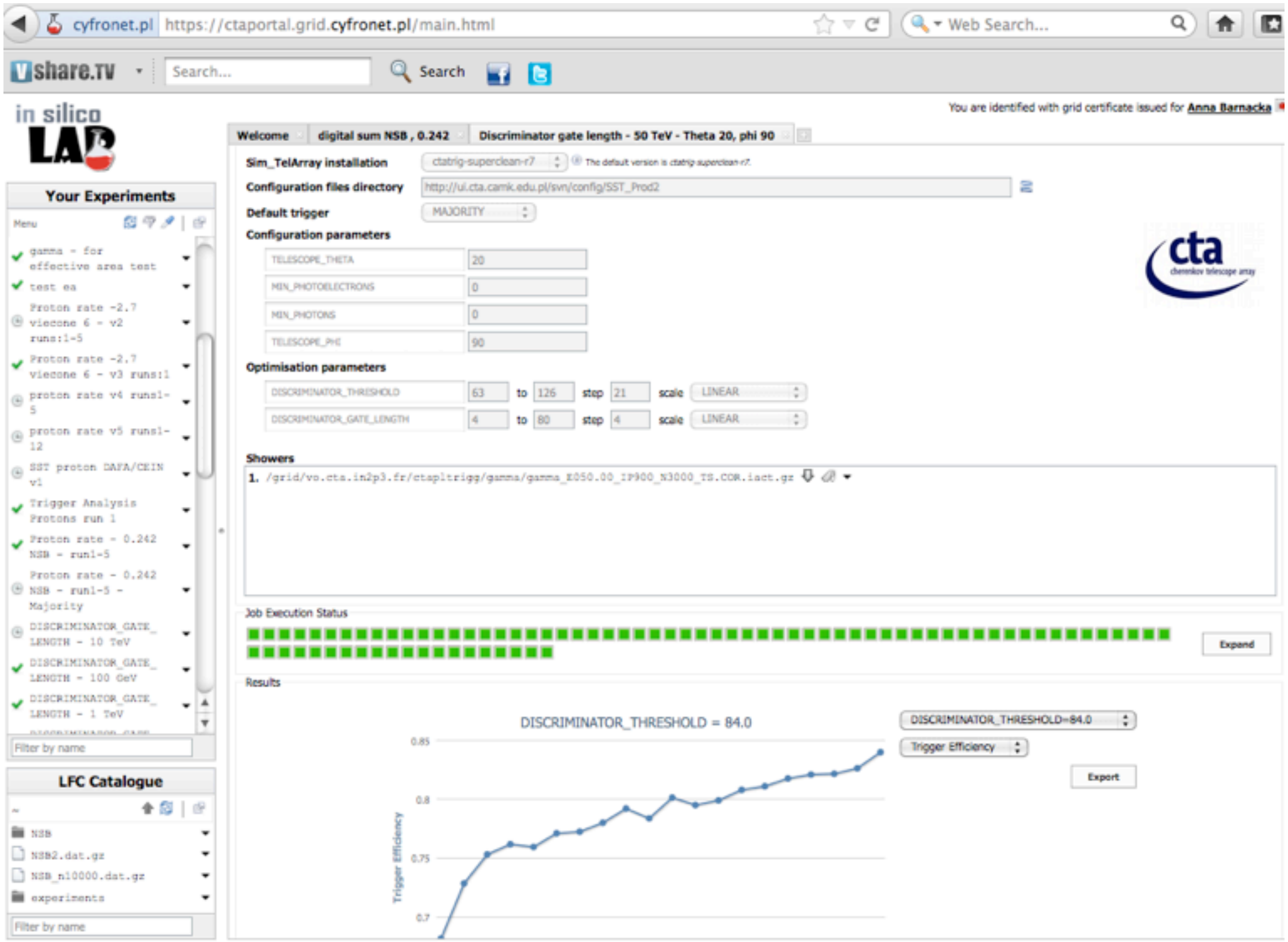
Mirror prototype testing and mirror testing system - CBK

Prototyp zwierciadła realizowanego przez CBK PAN



Pomiar kształtu zwierciadła na frezarce numerycznej realizowane przez IFJ PAN

e-Infrastructure: CYFRONET



Współpraca nauki z przemysłem - projekt CTA

obserwatorium-cta.pl/konferencja

Projekt CTA

- Aktualności
- Opis projektu CTA
- Polskie Konsorcjum Projektu CTA
- Wyniki projektu
- Użytkowanie aparatury
- Członkowie polskiego zespół CTA
- Kontakt

Zadania projektu

- Główne zadania projektu
- Konstrukcja teleskopu
- Kopozytowe zwierciadła
- Kamera cyfrowa
- Trigger
- Obsługa danych

Linki

- CTA dla przemysłu
- Międzynarodowe Konsorcjum CTA

O konferencji · Agenda · Oferta dla przemysłu · Miejsce i kontakt · CTA w liczbach · Prelegenci CTA · Partnerzy konferencji · Zarejestrowane firmy

Konferencja pt. "Współpraca nauki z przemysłem - projekt "Cherenkov Telescope Array" - 8 maja w Warszawie

Polskie zespoły badawcze biorą obecnie udział w wielkich międzynarodowych eksperymentach naukowych i w związku z tym pojawia się możliwość realizowania części zamówień związanych z tym projektami w kraju. W ramach międzynarodowego projektu badawczego przygotowującego budowę obserwatorium astronomii gamma najwyższych energii „Cherenkov Telescope Array" (CTA), tworzymy bazę danych o firmach, które byłyby zainteresowane włączeniem się w prace przy budowie obserwatorium CTA.

Prace te będą realizowane po roku 2013, jednak już teraz poszukujemy firm, które byłyby zainteresowane **uzyskaniem wstępnych informacji o projekcie, które pozwoliły by im przygotować się o krajowych i europejskich przetargów** na realizacje części planowanej infrastruktury badawczej, w tym na wykonanie teleskopów lub ich wybranych elementów, infrastruktury informatycznej obserwatorium, prac w zakresie zapewnianie jakości i niezawodności, oraz obsługi gromadzenia i analizy danych projektu CTA. Dla niektórych firm mogło by tez być interesujące **włączenie się do innowacyjnych prac realizowanych przez zespoły naukowe w ramach obecnej fazy przygotowawczej projektu.**

Dla Polskiego Konsorcjum Projektu CTA, w którego w skład wchodzi 9 uniwersytetów i instytutów Polskiej Akademii Nauk, istotne jest, aby zwiększyć szansę na sukces polskich firm przez wczesne przygotowanie do ewentualnego współzawodnictwa o najciekawsze kontrakty, w sytuacji gdy Polska może mieć znaczny udział finansowy **w projekcie wycenianym w całości na 150 milionów Euro**. Dodajmy, że w obecnej fazie projektu Polska jest jednym z głównych partnerów współpracy międzynarodowej angażującej 25 państw.

http://obserwatorium-cta.pl/konferencja