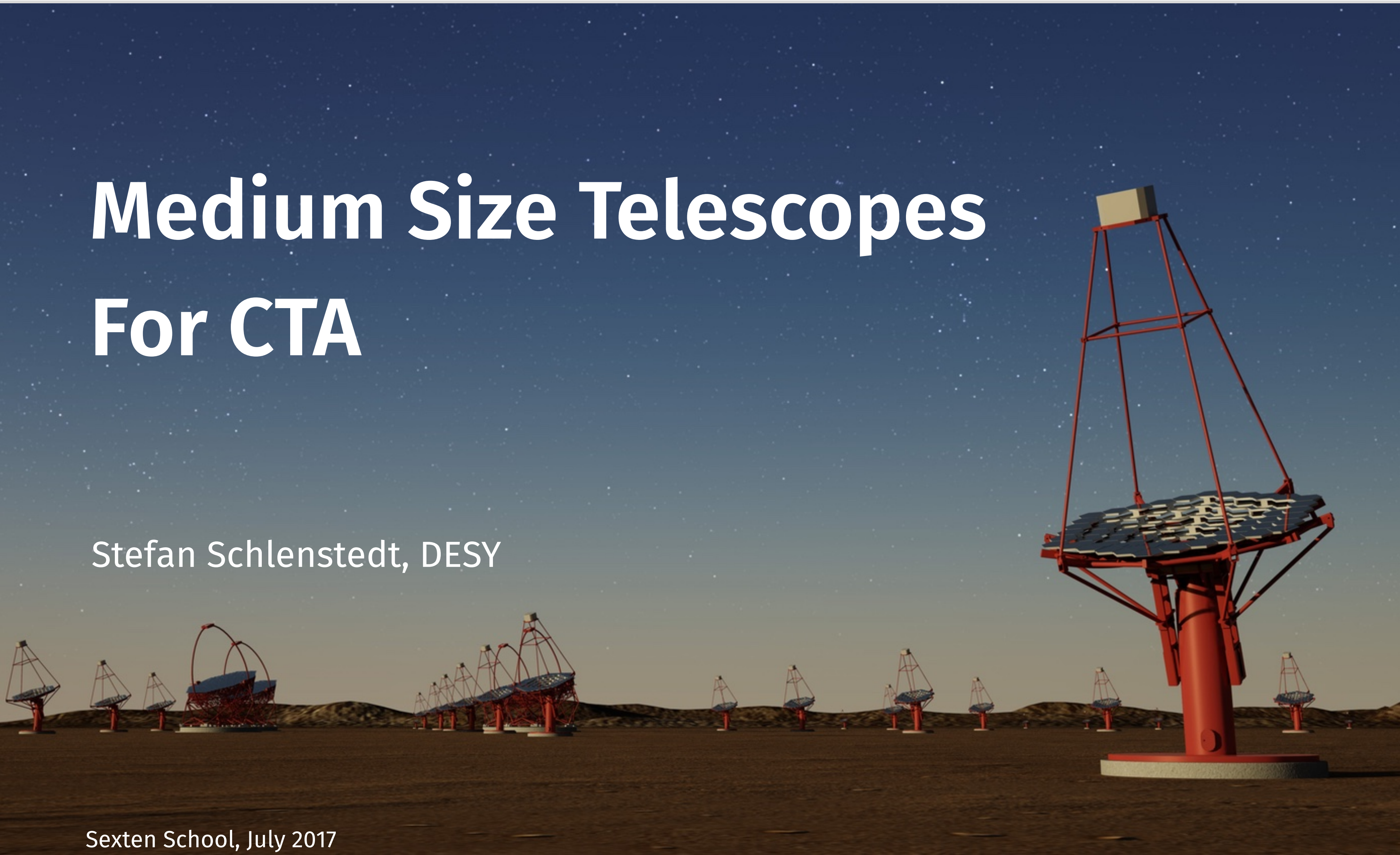
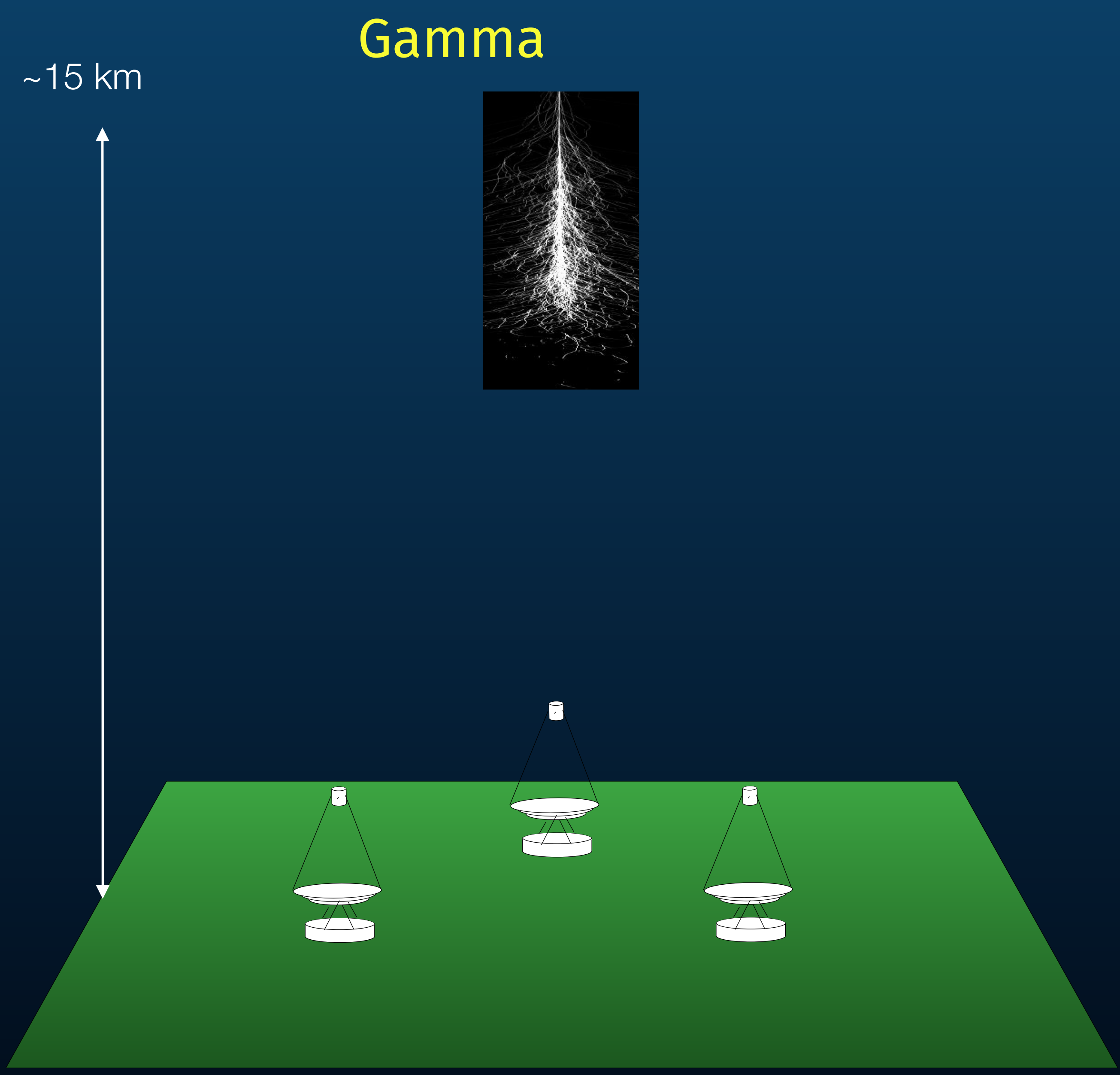
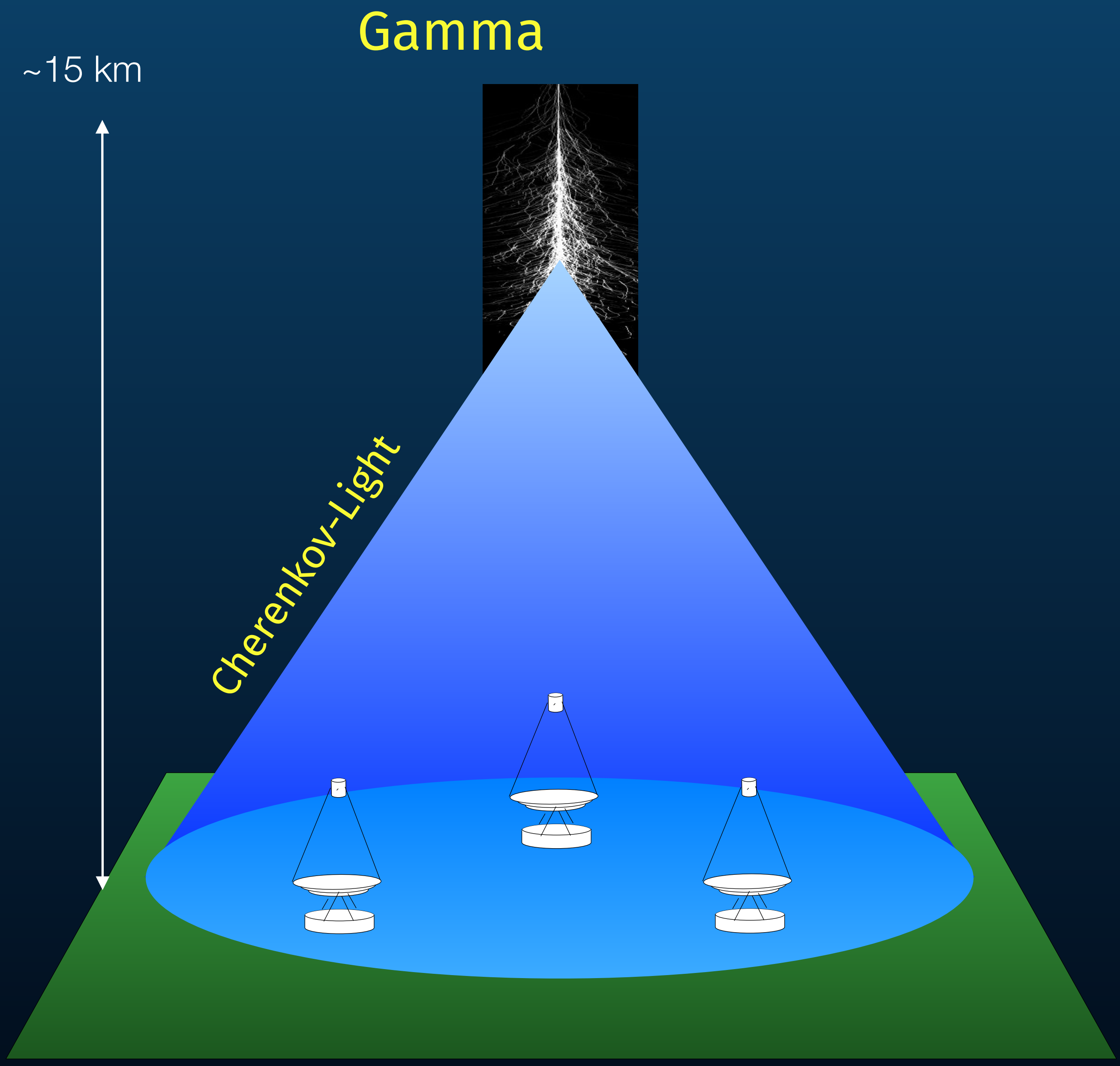
Medium Size Telescopes For CTA

Stefan Schlenstedt, DESY

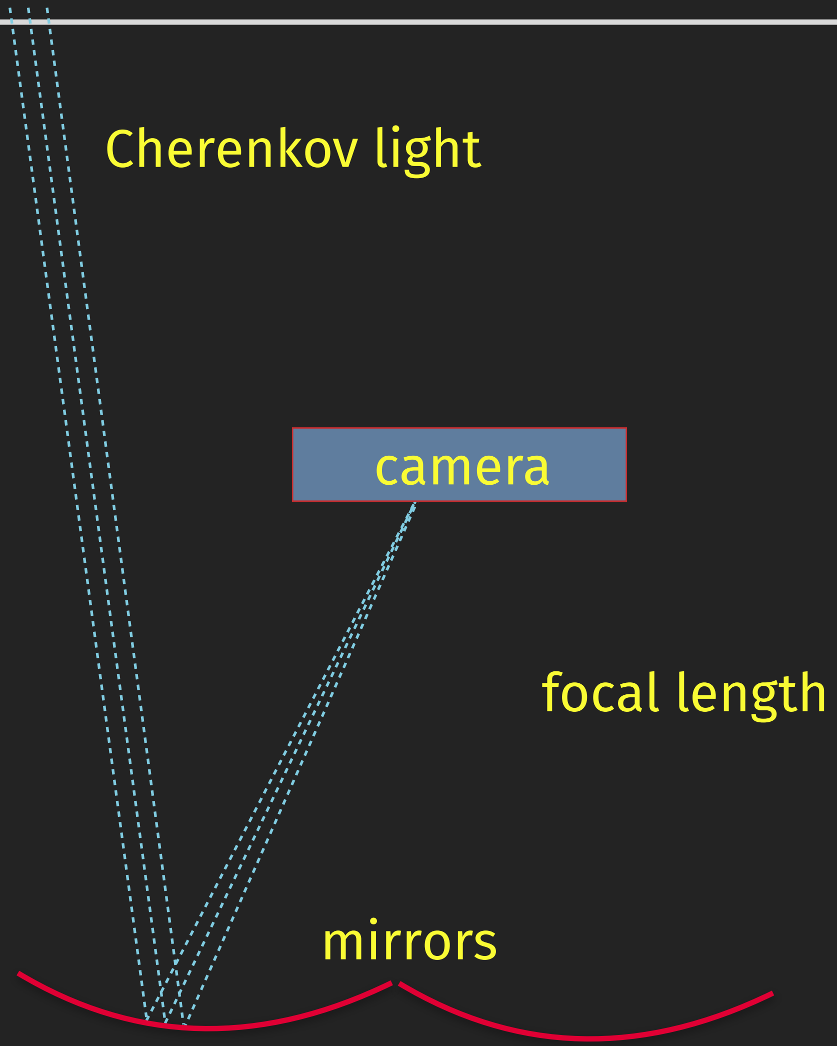


Sexten School, July 2017


Gamma
~15 km

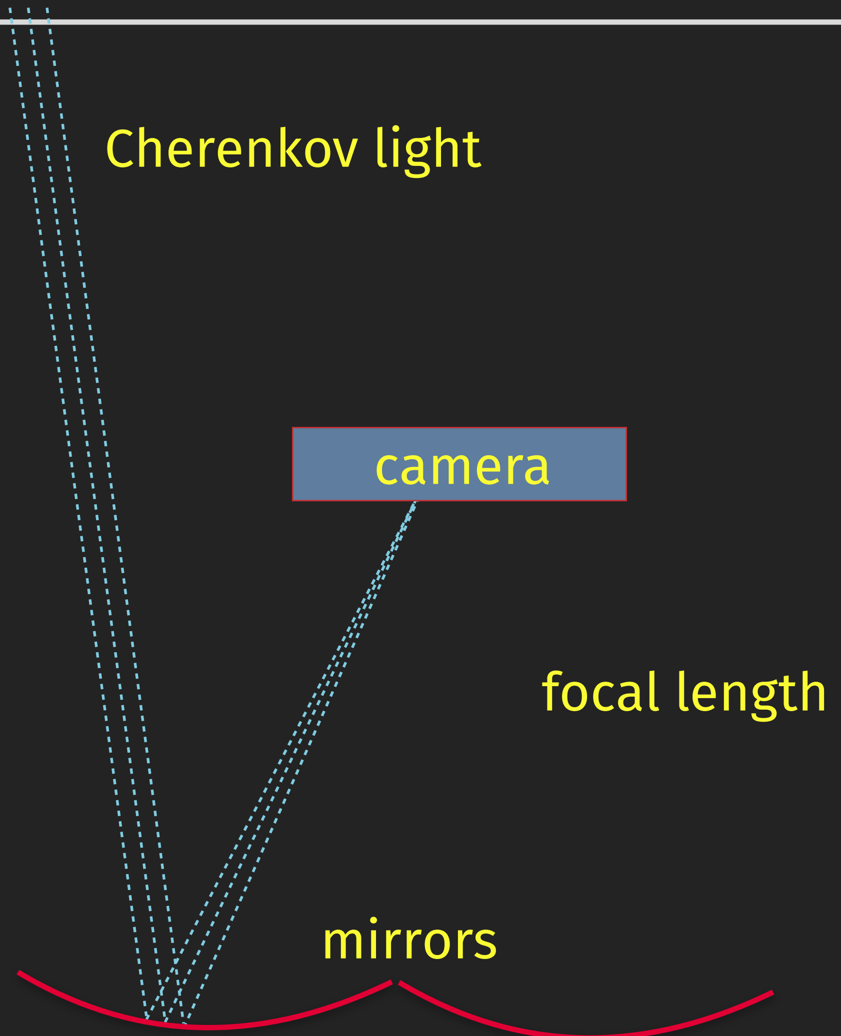

Gamma
~15 km
Cherenkov-Light

Measurement Principle



not to scale

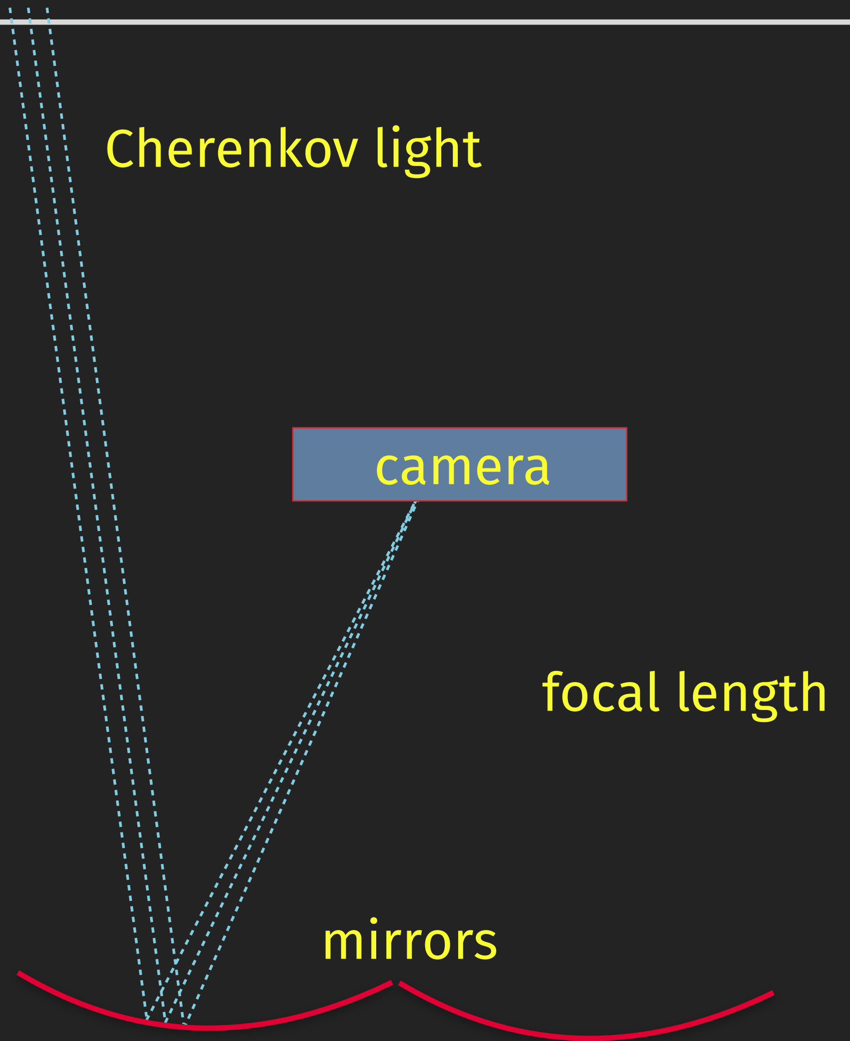
Measurement Principle



Move and control the telescope

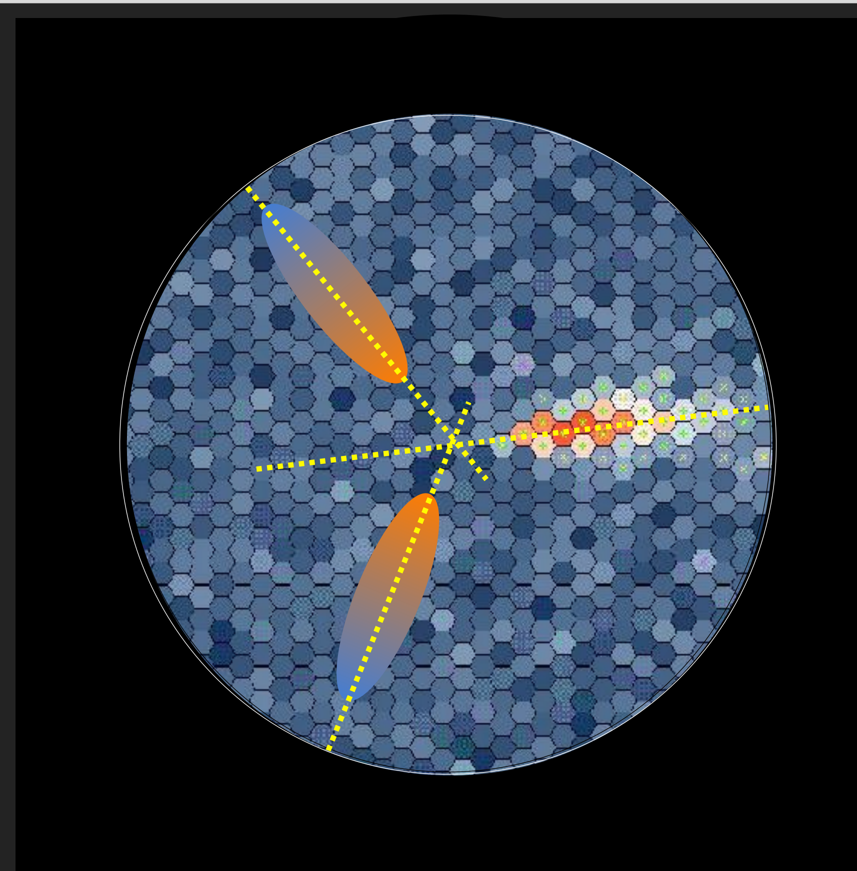
not to scale

Measurement Principle



Move and control the telescope

not to scale



Intensity → energy
Orientation → direction
Shape → primary particle
Stereo → source position

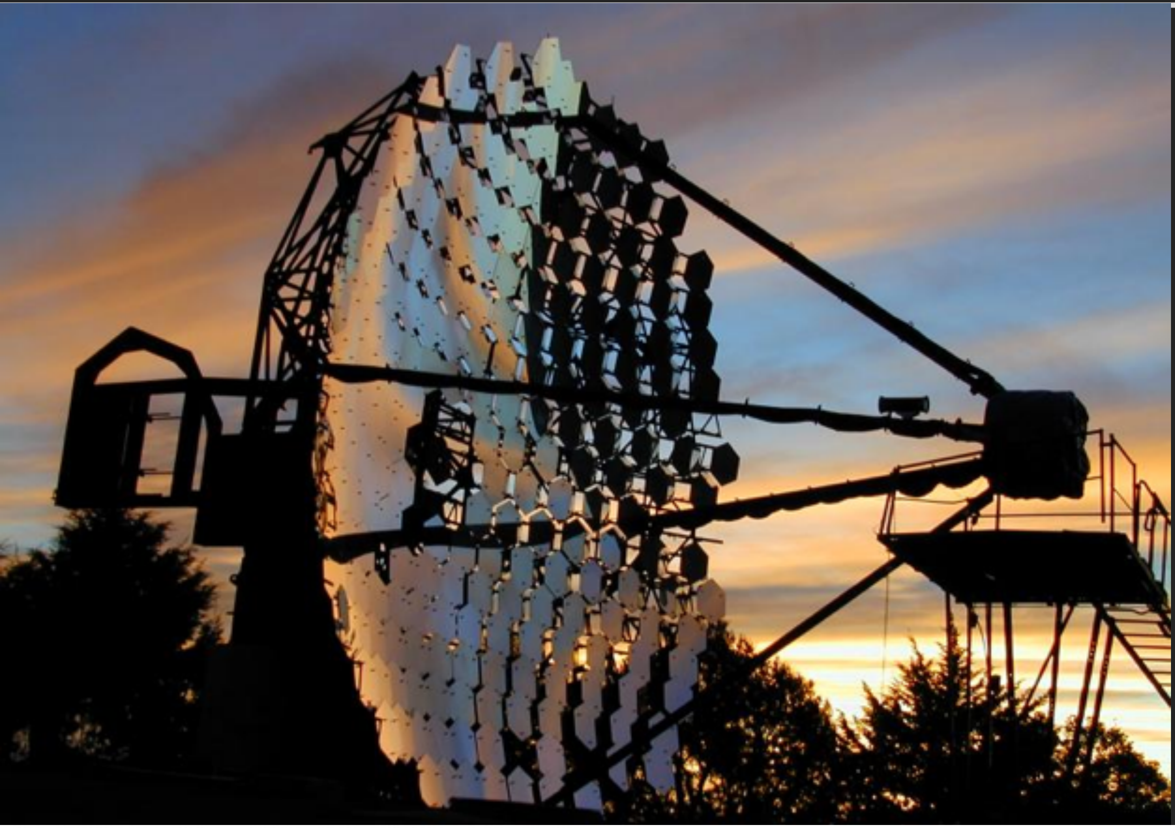
Whipple Telescope
The Pioneering Experiment

- 10m Davies-Cotton

THE ASTROPHYSICAL JOURNAL, 342:379–395, 1989 July 1

OBSERVATION OF TeV GAMMA RAYS FROM THE CRAB NEBULA USING THE ATMOSPHERIC CERENKOV IMAGING TECHNIQUE

Whipple Telescope
The Pioneering Experiment

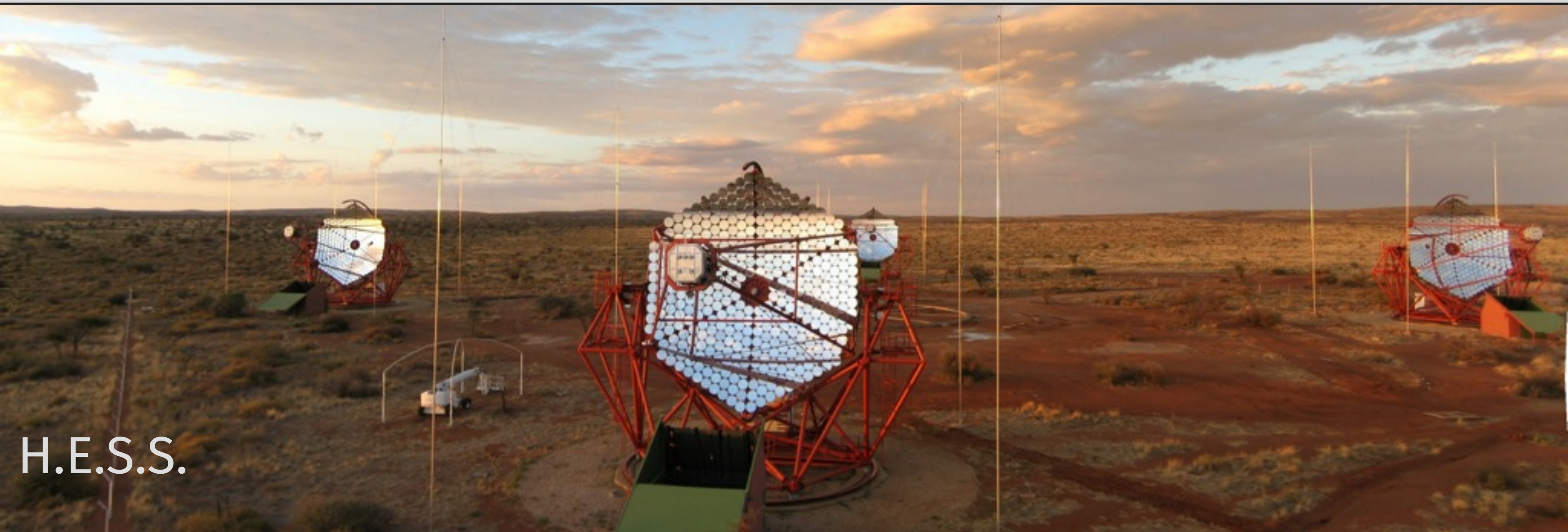


- 10m Davies-Cotton
- Started 1968
- Established all essential techniques
- Crab Nebula in 1986
- Stopped 2011

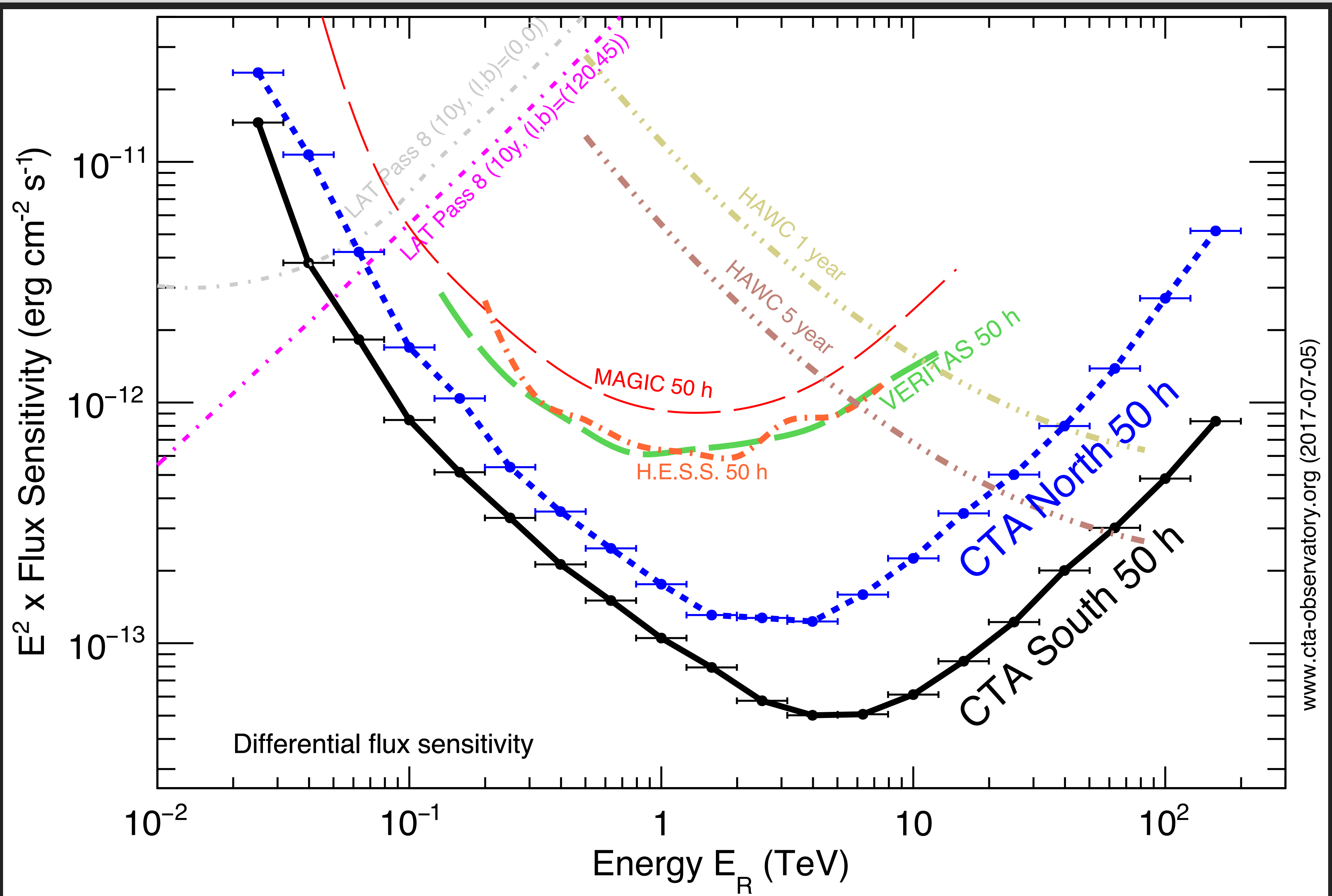
THE ASTROPHYSICAL JOURNAL, **342**:379–395, 1989 July 1

OBSERVATION OF TeV GAMMA RAYS FROM THE CRAB NEBULA USING THE ATMOSPHERIC CERENKOV IMAGING TECHNIQUE

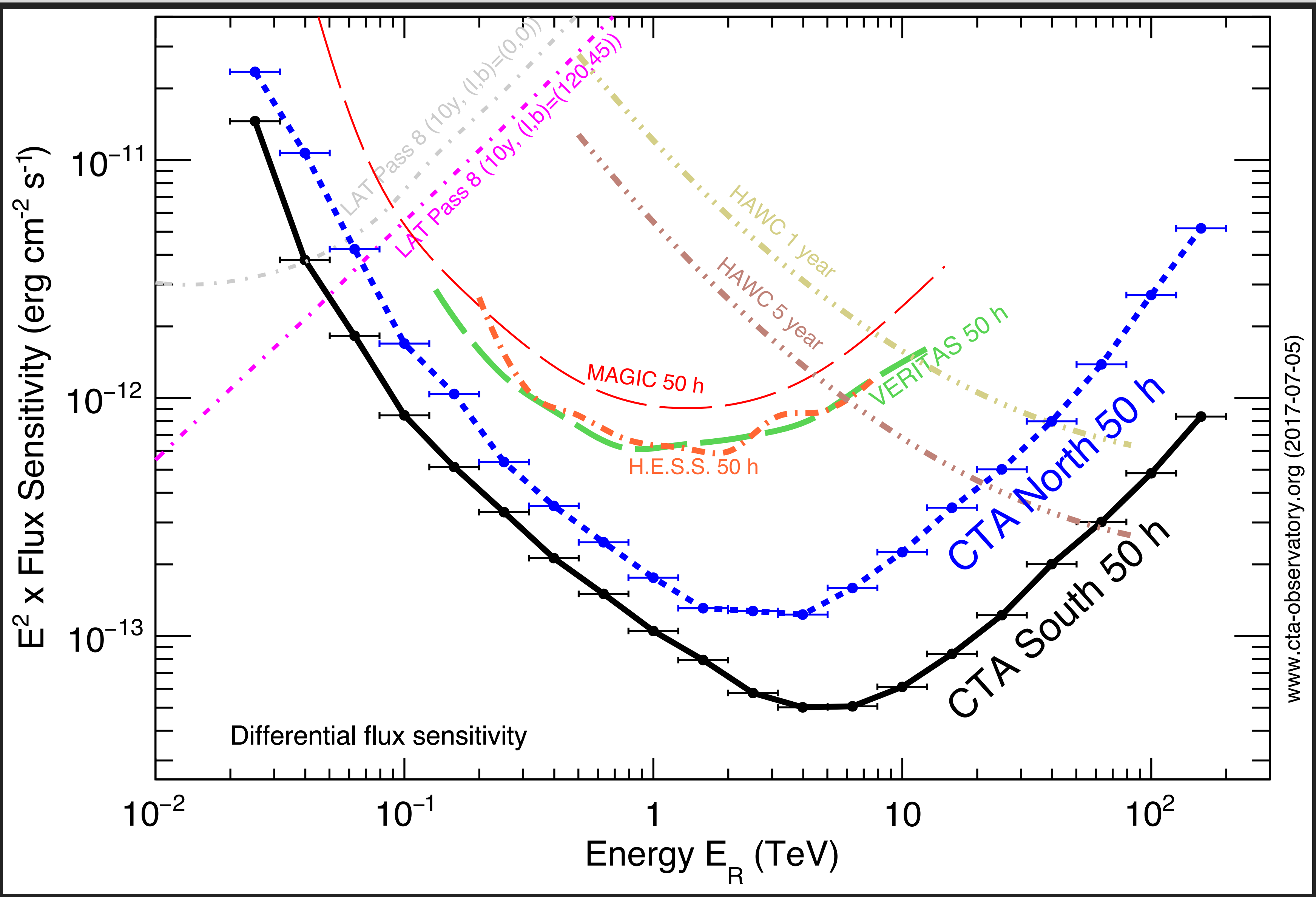
2nd Generation of 12m Telescopes



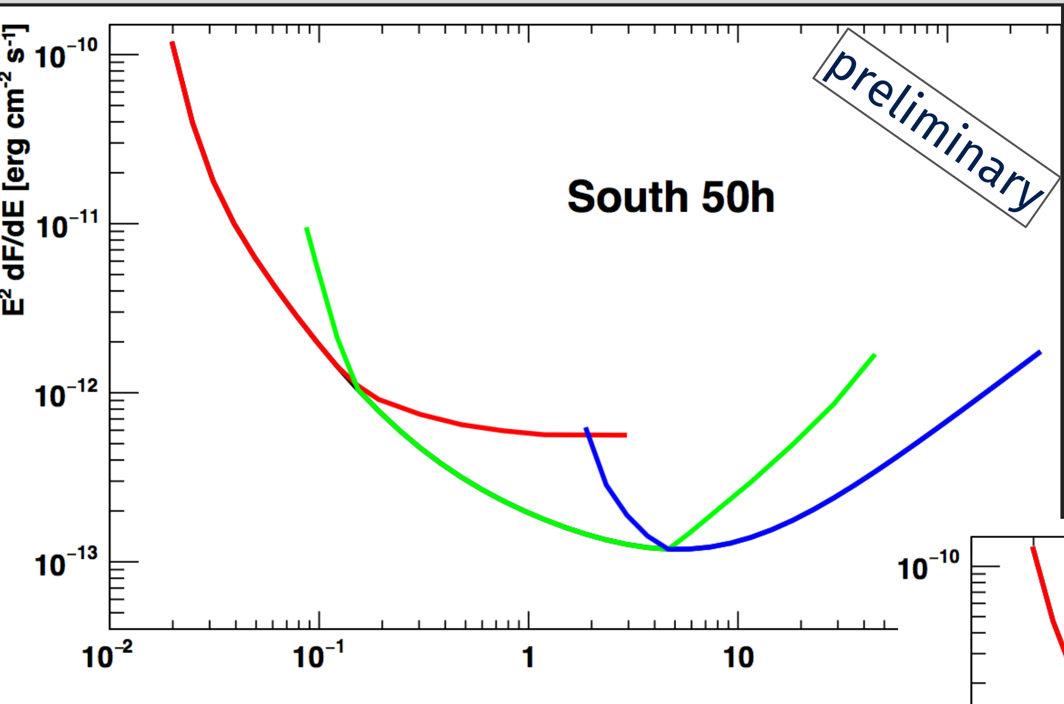
CTA Sensitivity

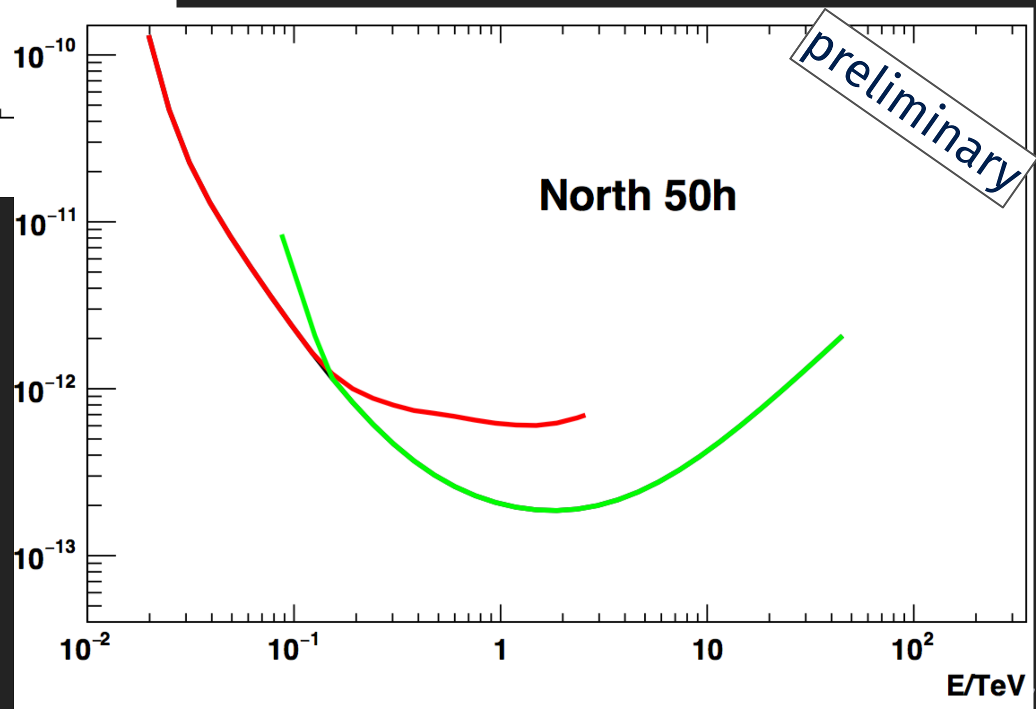


CTA Sensitivity
Different Telescopes



CTA Sensitivity – Different Telescopes





Medium Size Telescopes

CTA Work Packages to Build Medium Size Telescopes

- MST: Single mirror, 12 meter dish
  - STR
    - Mechanics, control, safety
    - Optical system
    - Software
  - NectarCAM
  - FlashCam

CTA Work Packages to Build Medium Size Telescopes

- MST: Single mirror, 12 meter dish
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    - Software
  - NectarCAM
  - FlashCam

Baseline:

- 25 MSTs South
- 15 MSTs North

CTA Work Packages to Build Medium Size Telescopes

- MST: Single mirror, 12 meter dish
  - STR
    - Mechanics, control, safety
    - Optical system
    - Software
  - NectarCAM
  - FlashCam
- Schwarzschild-Coudet Telescope: Dual mirror, 10 m primary
  - STR
    - Mechanics, control, safety
  - Optical system
  - Camera

Baseline:

- 25 MSTs South
- 15 MSTs North

Medium Size Telescope
MST

Medium Size Telescope
MST Requirements

Slewing Speed 90 seconds

36km/h wind, earthquakes

Tracking accuracy 0.1°

Pointing accuracy 20 arcsec

Effective mirror area 88 m^2

Focal length 16 meter

Point Spread Function 0.18°

Field of view 7°

Photon Detection Eff 17%

Dead time 5%

Readout rate 4.5 kHz

Linearity 8%

Afterpulsing, amplitude resolution...

Medium Size Telescope
MST Requirements

Reliability >97%

Lifetime of up to 30 years

Slewing Speed 90 seconds

36km/h wind, earthquakes

Tracking accuracy 0.1°

Pointing accuracy 20 arcsec

Effective mirror area 88 m^2

Focal length 16 meter

Point Spread Function 0.18°

Field of view 7°

Photon Detection Eff 17%

Dead time 5%

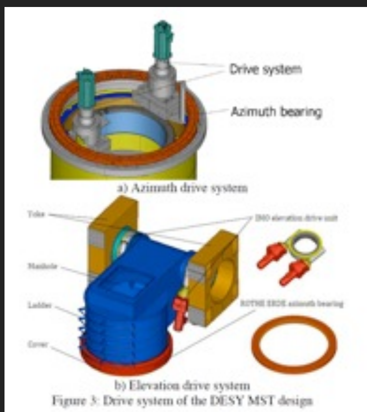
Readout rate 4.5 kHz

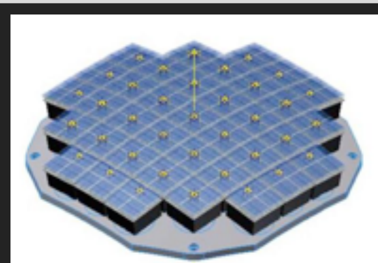
Linearity 8%

Afterpulsing, amplitude resolution...

Telescope

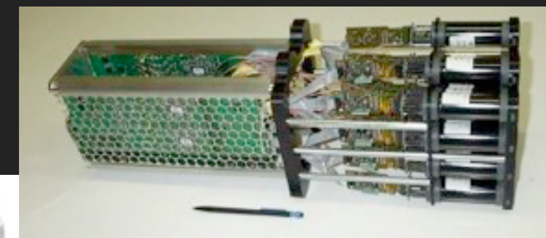
Drives

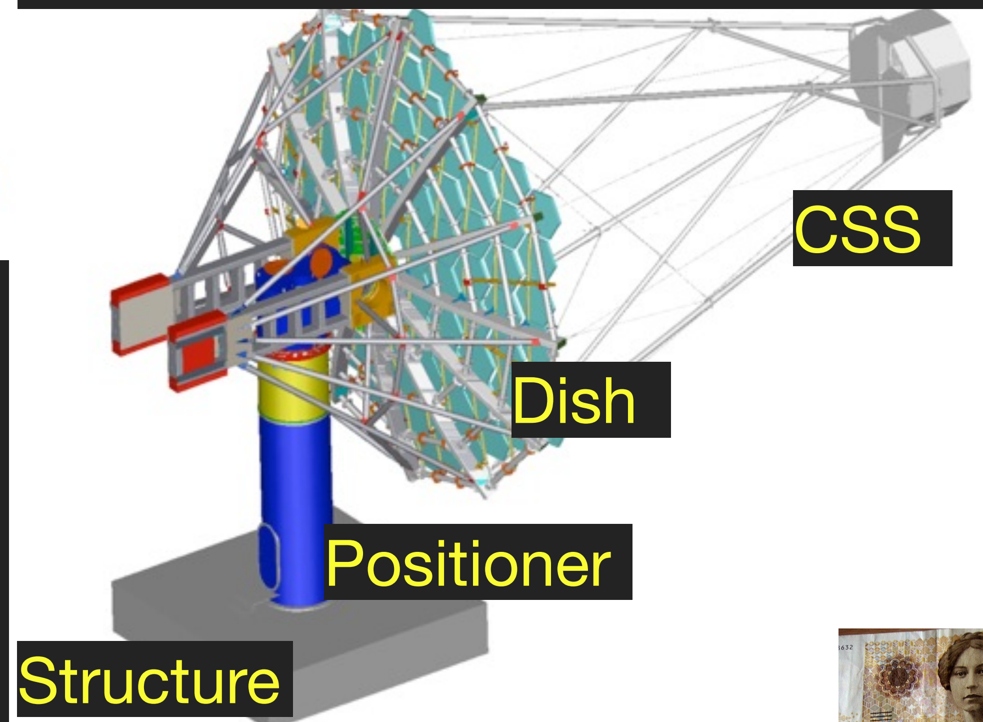




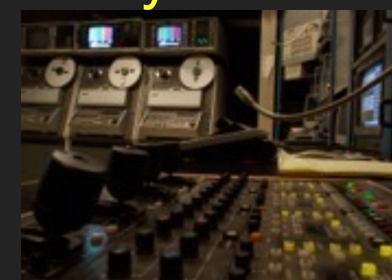
Mirror

Camera





Array control



Infrastructure

Safety

Power management

Dish
Optimized

- Simpler, lighter, cheaper
- Direct mirror connections
- Installed this summer

Dish Back Structure Optimization

- Get rid of last in-field-welds
- Control stiffness in the process
- Custom parts

Mirror Access Platforms

- Install mirrors and performed cabling on the dish on ground

  - Faster than installation in park position
  - Reduced risks for work at height
- Add mirror access platforms

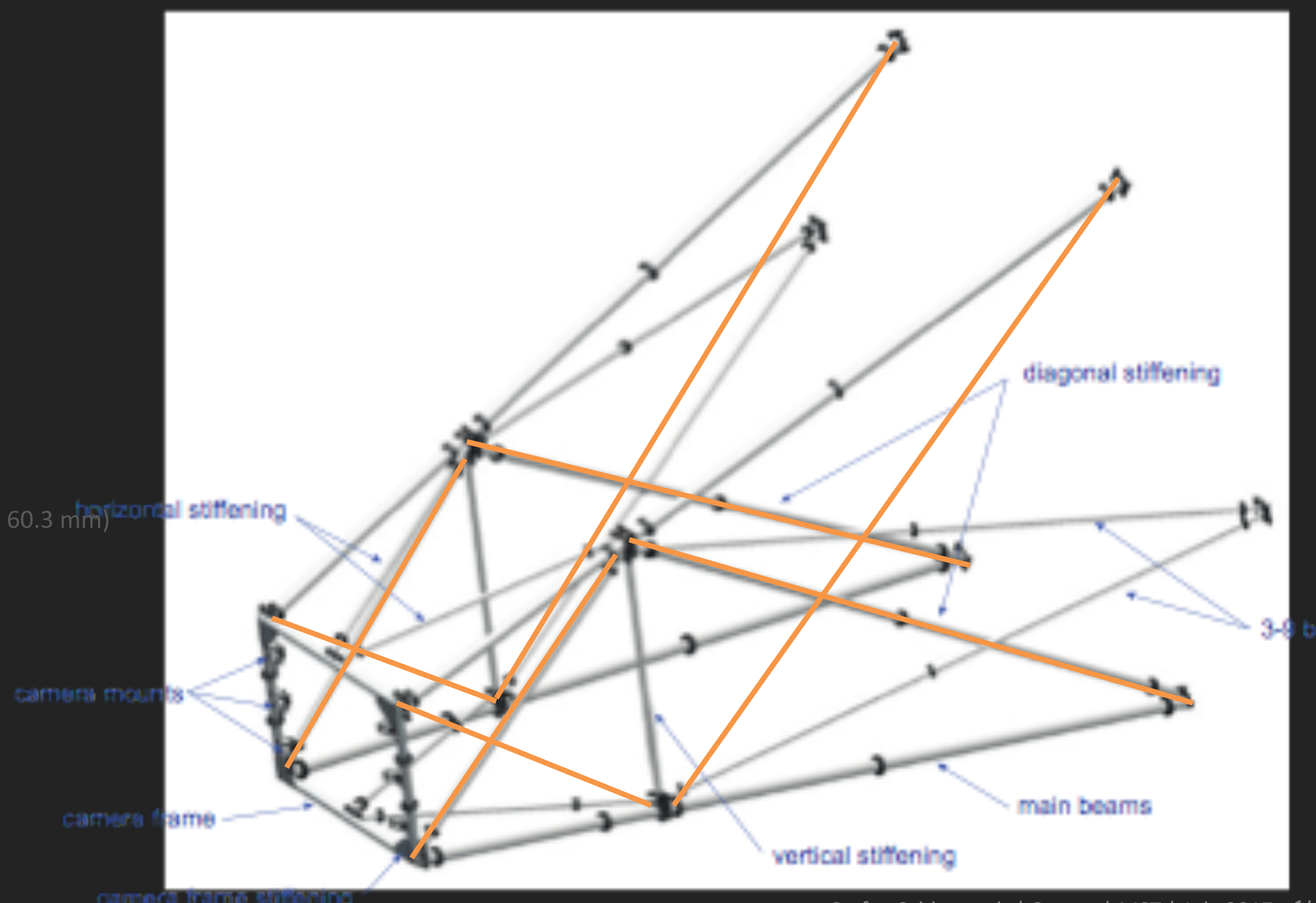
Camera Support Structure Optimisation

- Goal: reduce weight and shadowing
- Re-design finished successfully,

➡ Pre-production

	old	new
weight [t]	4.5	3.8
shadow [m^2]	86.8	88.7

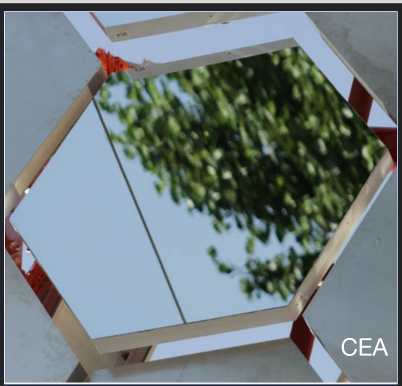
(114.3 mm → 60.3 mm)

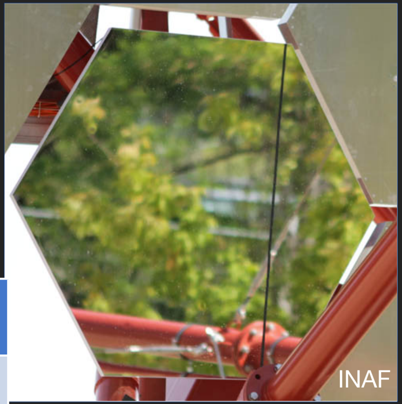


Camera Support Structure Optimisation

MST Mirrors

- Hexagon shape: 1.2 m width (side/side), $r = 32.16$ m, $R_{300\text{-}500\ nm} > 85\%$
- Several providers:
  - Higher production rate
  - Different technologies
- Unified interface to mirror control
- Specification validation CTA wide



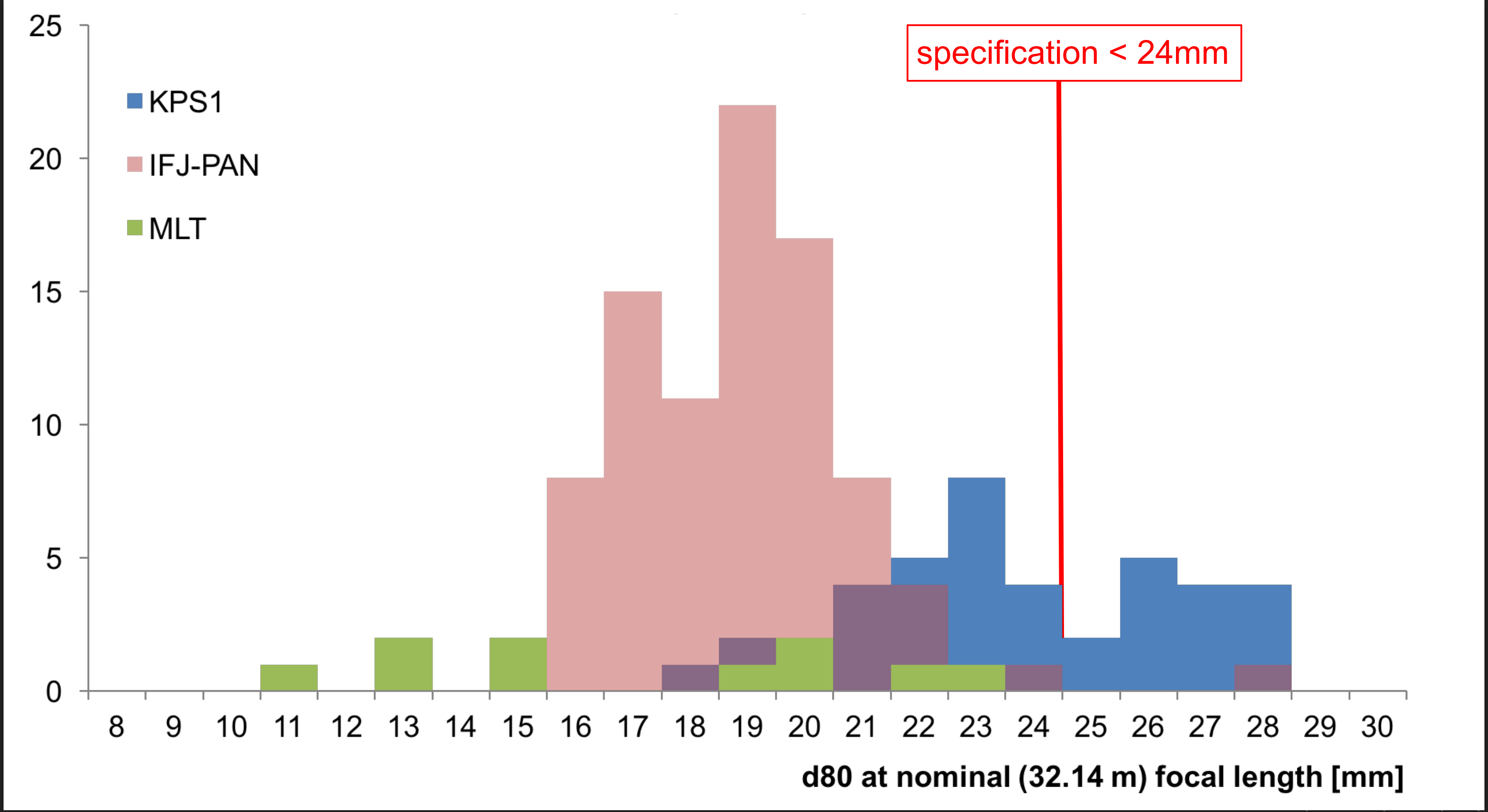


Mirror technology	Description	Coating (PVD)	Width / Weight	Responsible institution
Glass replica mirrors (sandwich structure design)	Two glass sheets, cold slumped, with Al honeycomb in between. Plastic profile to protect the edges and seal the honeycomb structure.	$Al+SiO_2$	25mm / 16kg	INAF, Italy
	Two glass sheets, cold slumped. Glass side walls.	$Al+SiO_2+HfO_2+SiO_2$	40mm / 19kg	CEA, France
	Core made of two glass sheets separated by Al tube spacers, open structure (not sealed). Reflective surface made of an pre-coated glass sheet, glued using the cold slumping technique to the core substrate. Glass epoxy layer between the glued surfaces.	$Al+SiO_2+HfO_2+SiO_2$	60mm / 33kg	IFJ-PAN, Poland

MST Mirror Performance

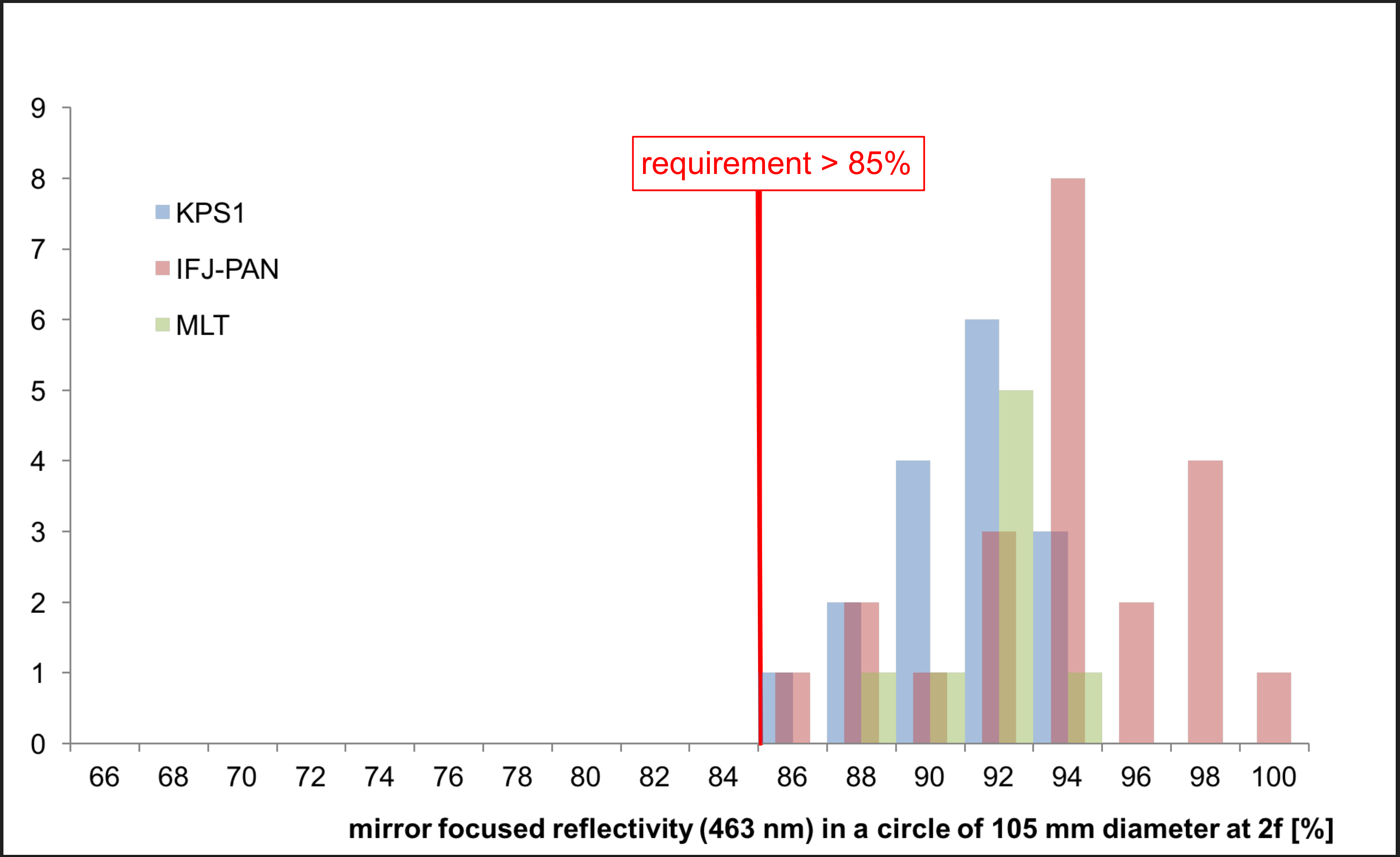
d_{80}

- Mirror PSF measurements performed at DESY 2f-setup
- Most of the mirrors fulfill the specification
- Improvement of design ongoing

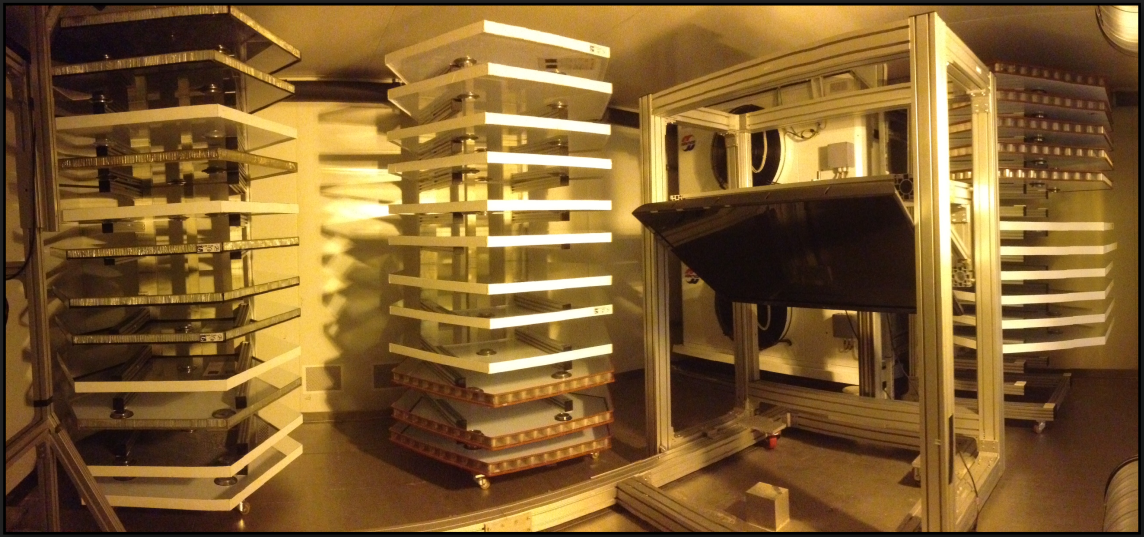


MST Mirror Performance
Focused Reflectivity

- All mirrors fulfill the requirement



MST Mirror Performance
Measure Long-term Degradation

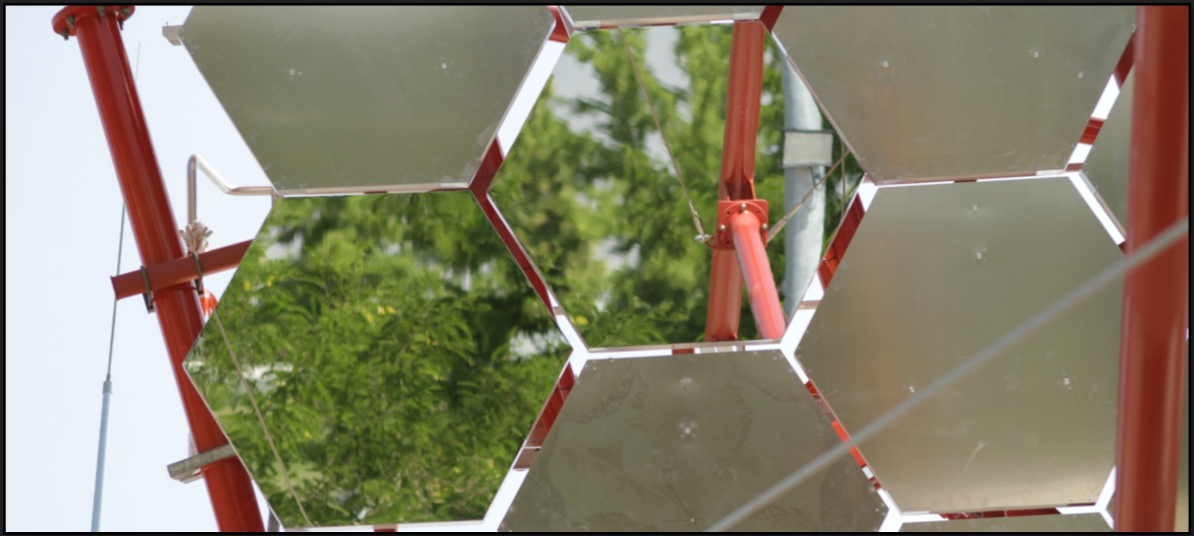


Climate chamber:

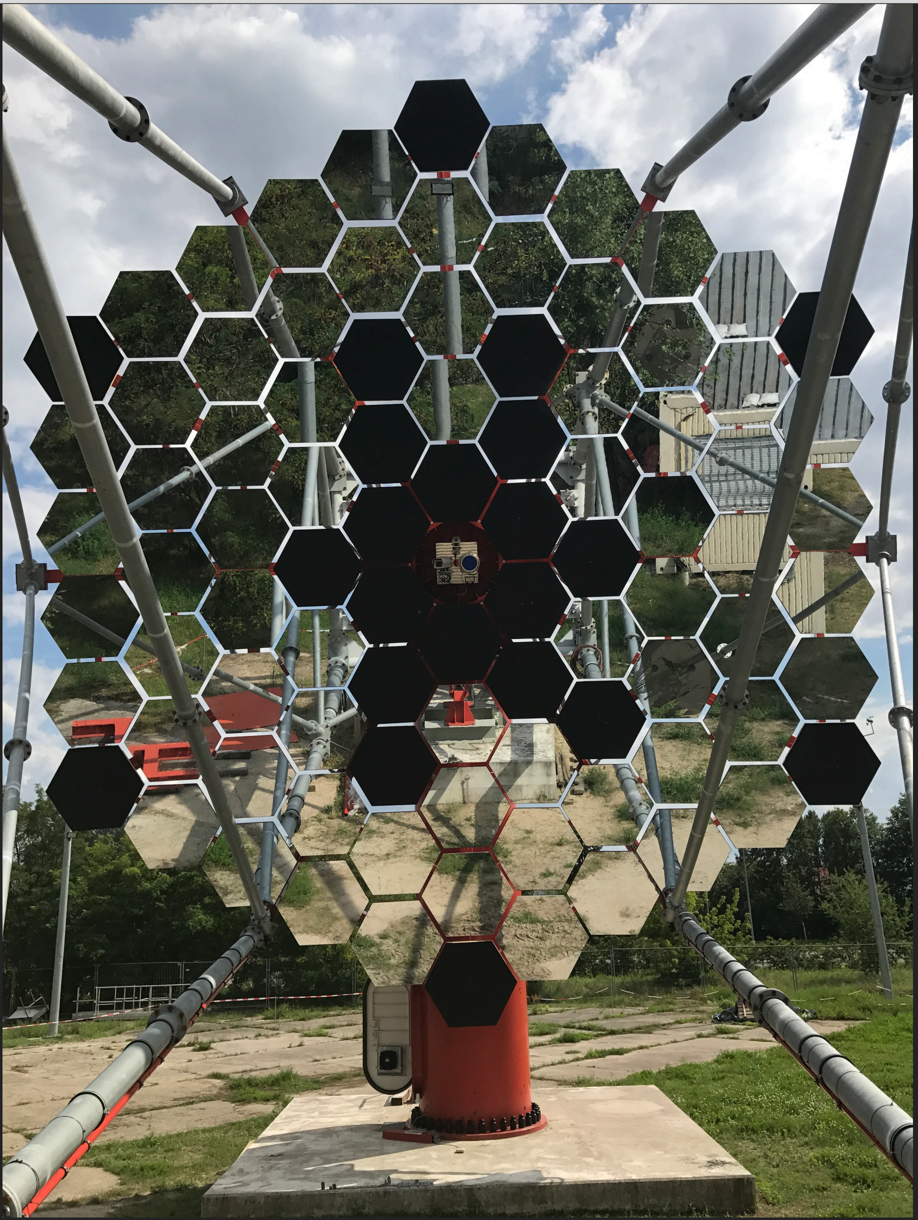
- More than 600 cycles -20 … 30°C
- Routinely measure the mirror performance

Environmental impacts at the MST prototype in Berlin:

- One year exposure used for this study

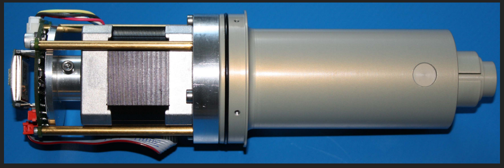


Optical System for the MST
Preparation of Optics Verification



- Dish supports 86 mirrors
- Different mirror types mounted
- Reduce background light
  - Black painted dummies
  - Baffle at the focal plane

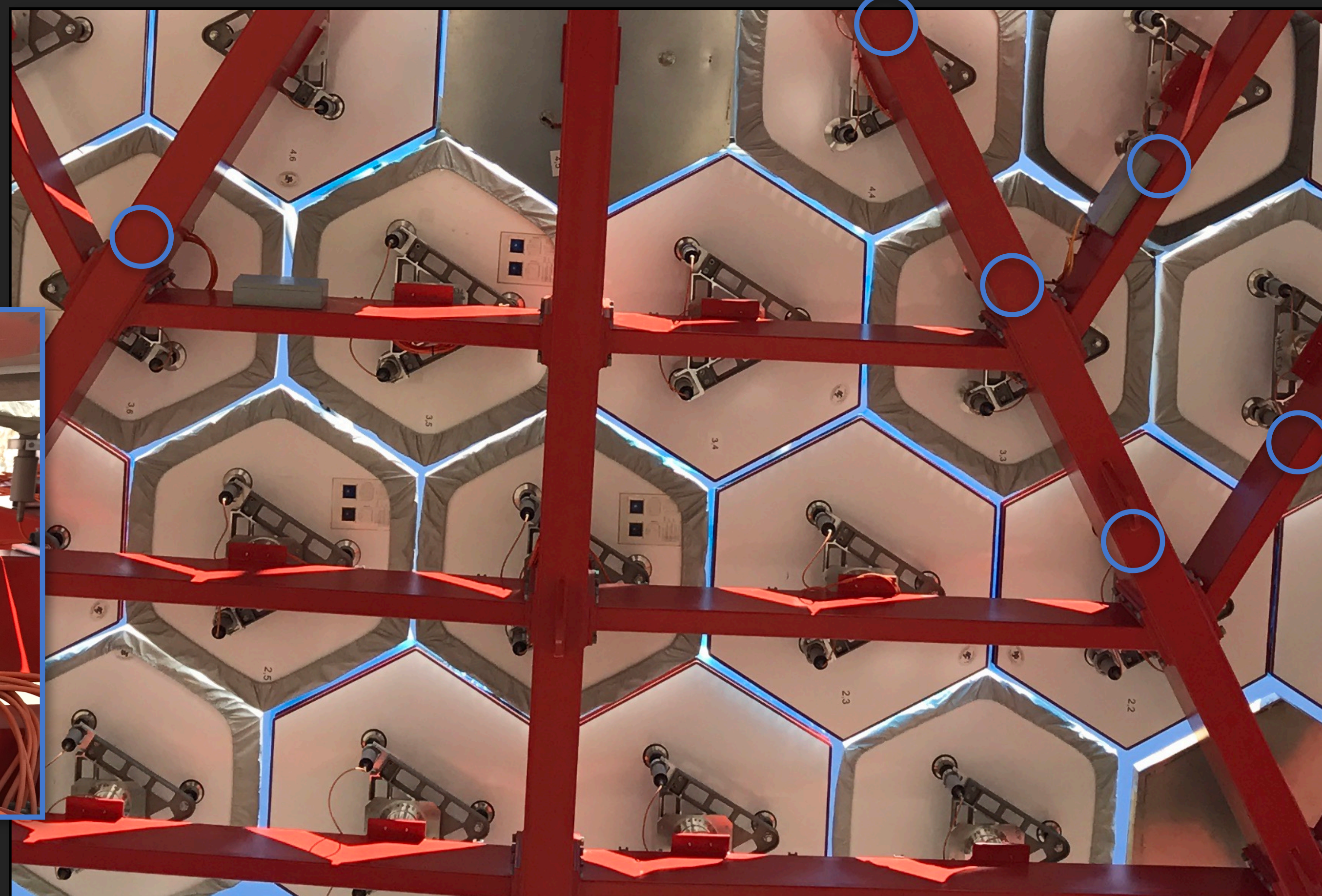
- All mirrors with Mirror Control systems



Optical System for the MST
Preparation of Optics Verification

Test AMC at New Dish Structure

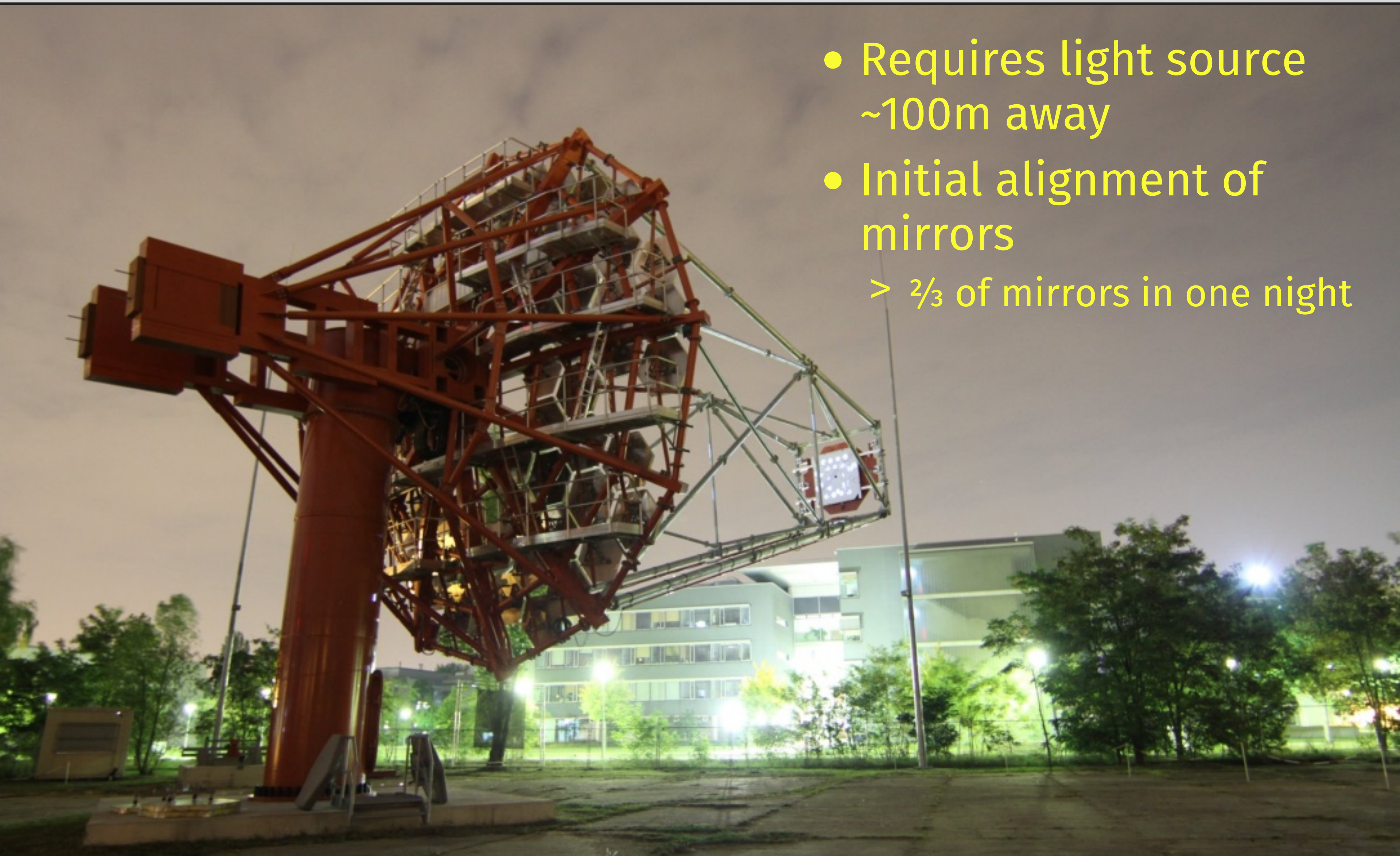
- Test how shadowing of new dish effects signal strength



Test AMC at New Dish Structure

- Test how shadowing of new dish effects signal strength
- AMCs with wireless communication – all involved systems (AMCs, gateway, ZigBee library) operate stably for many weeks
- Conclusions from first tests:
  - Two antennas necessary and sufficient to reach all installed actuators
  - No actuators in dish centre → future tests

Initial Mirror Alignment with the Bokeh Method



- Requires light source ~100m away
- Initial alignment of mirrors
  - > ⅔ of mirrors in one night

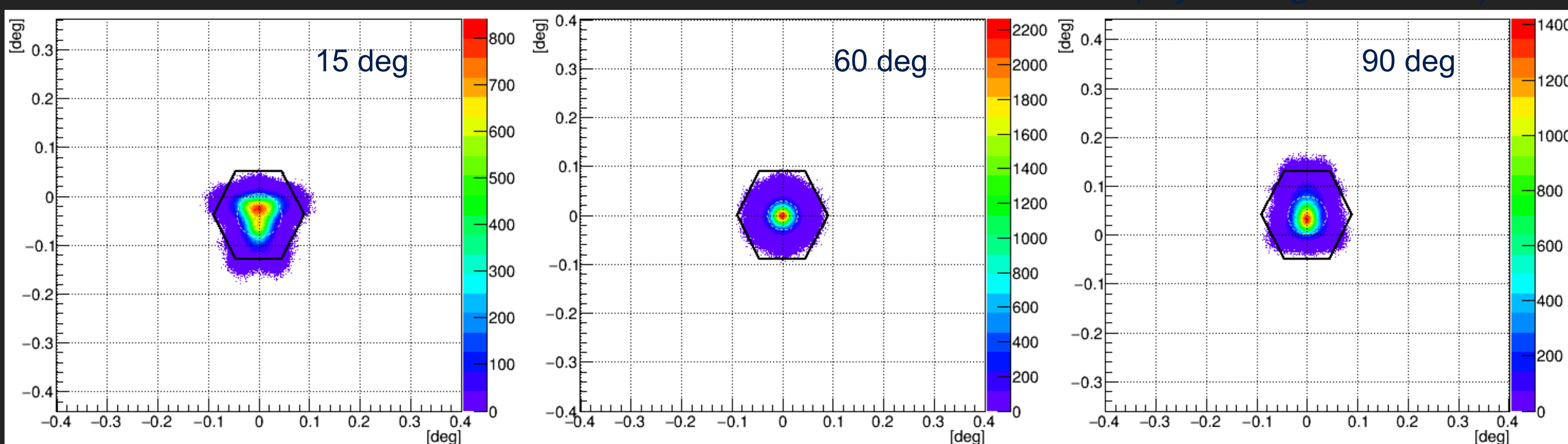
okeh Method

- Requires light source ~100m away
- Initial alignment of mirrors
  - > ⅔ of mirrors in one night

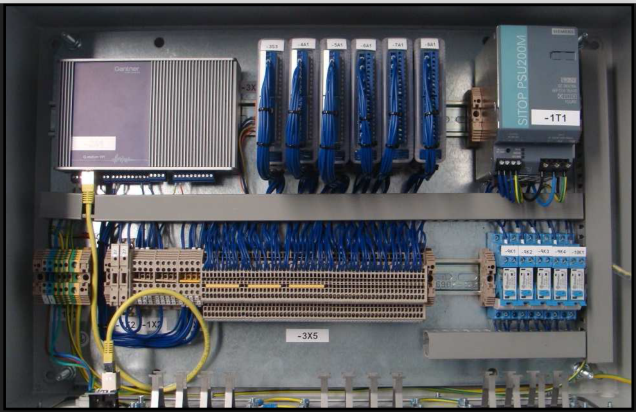
Point Spread Function
PSF

- MST PSF requirement B-MST-0130: <0.18°
- MST PSF depends on:
  - Telescope geometry (modified Davies-Cotton design)
  - Stiffness of the OSS
  - Accuracy of the AMCs
  - Individual mirror characteristics

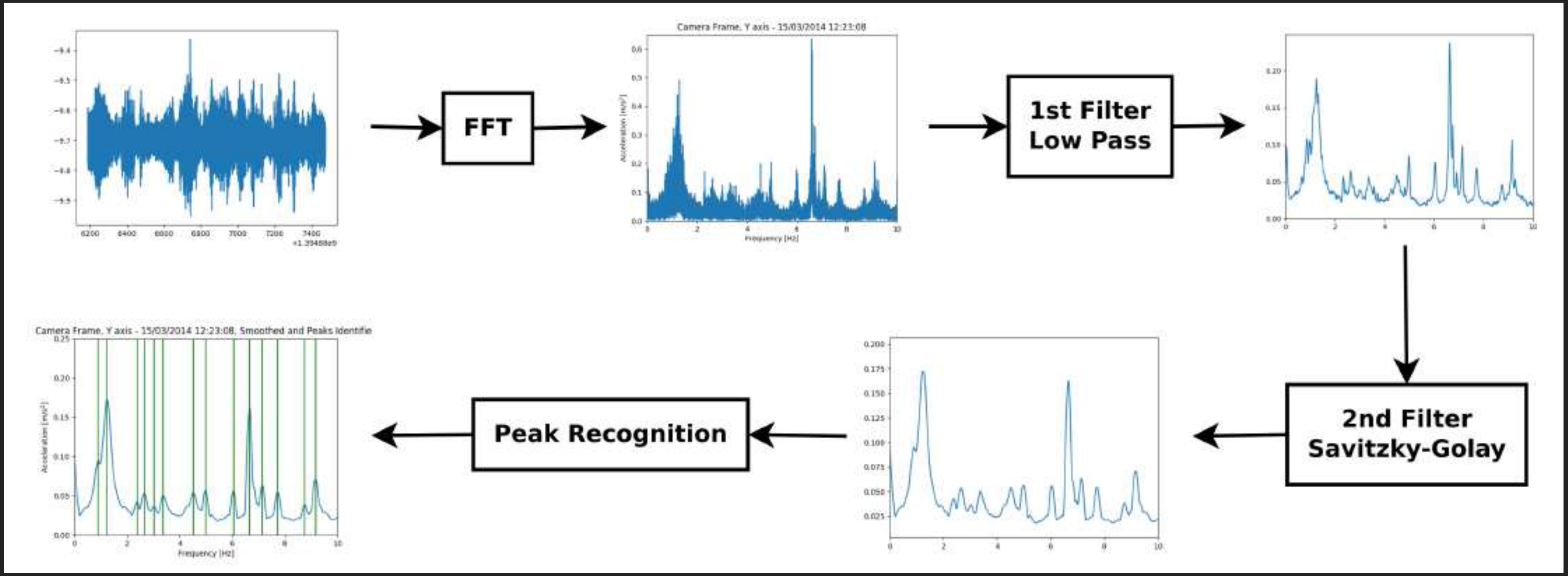
Effect of the OSS deformations on the PSF (ray-tracing simulation)



Structure and Drive Monitoring



- Merged structure and drive monitoring
- Gantner q-station, uniaxial IEPE and tri & biaxial inclination sensors
- Reviewed location of sensor
- Automatic data synchronization with MongoDB, python based offline analysis



Electrical System Optimization

- Experience from MST and SCT prototypes:
  - Redundancy, main and safety PLC, UPS
  - Integrated cabling plan

Electrical System Optimization

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- Portable emergency cabinet and power generator

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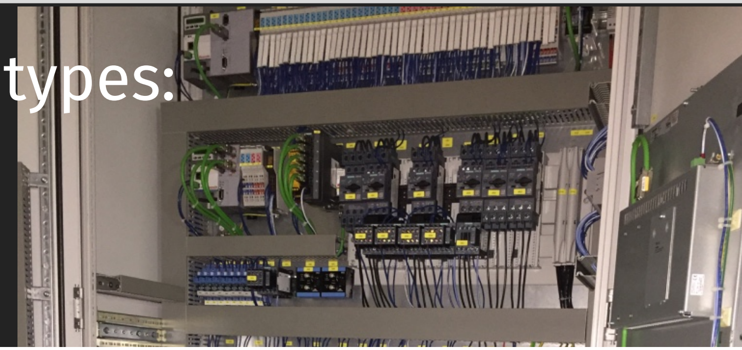
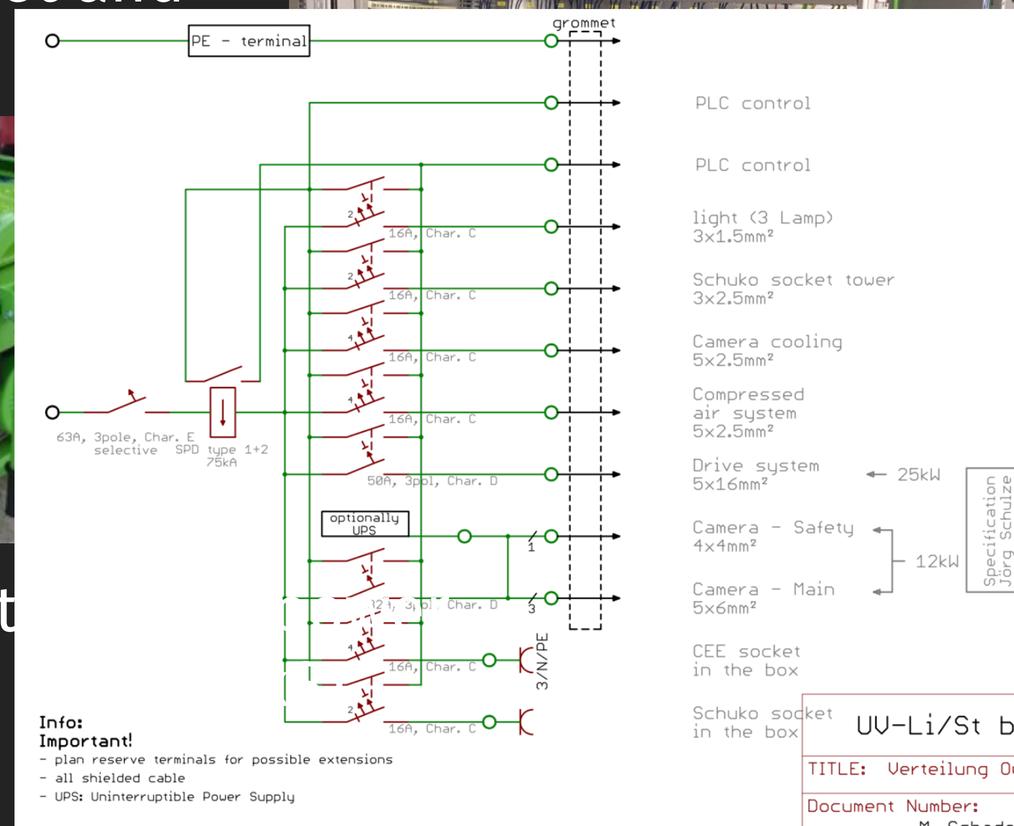


- Standard interface cabinet and data cable close to foundations

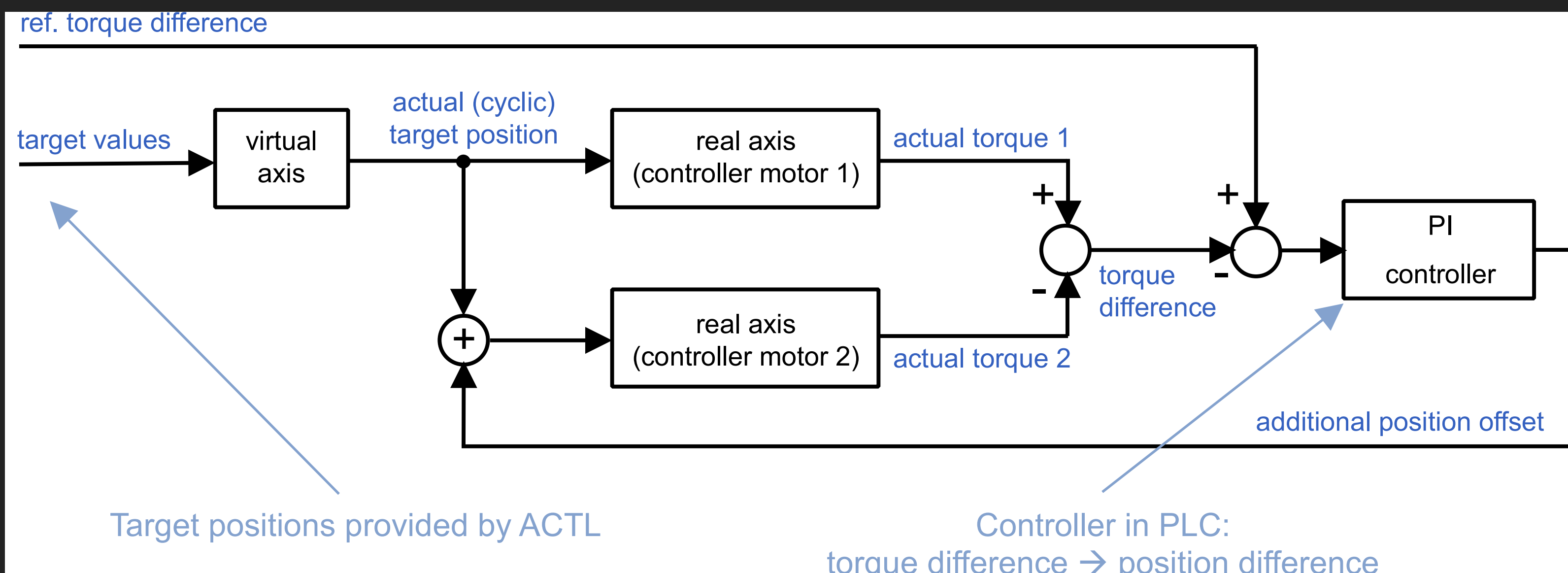


Drive System of the MST

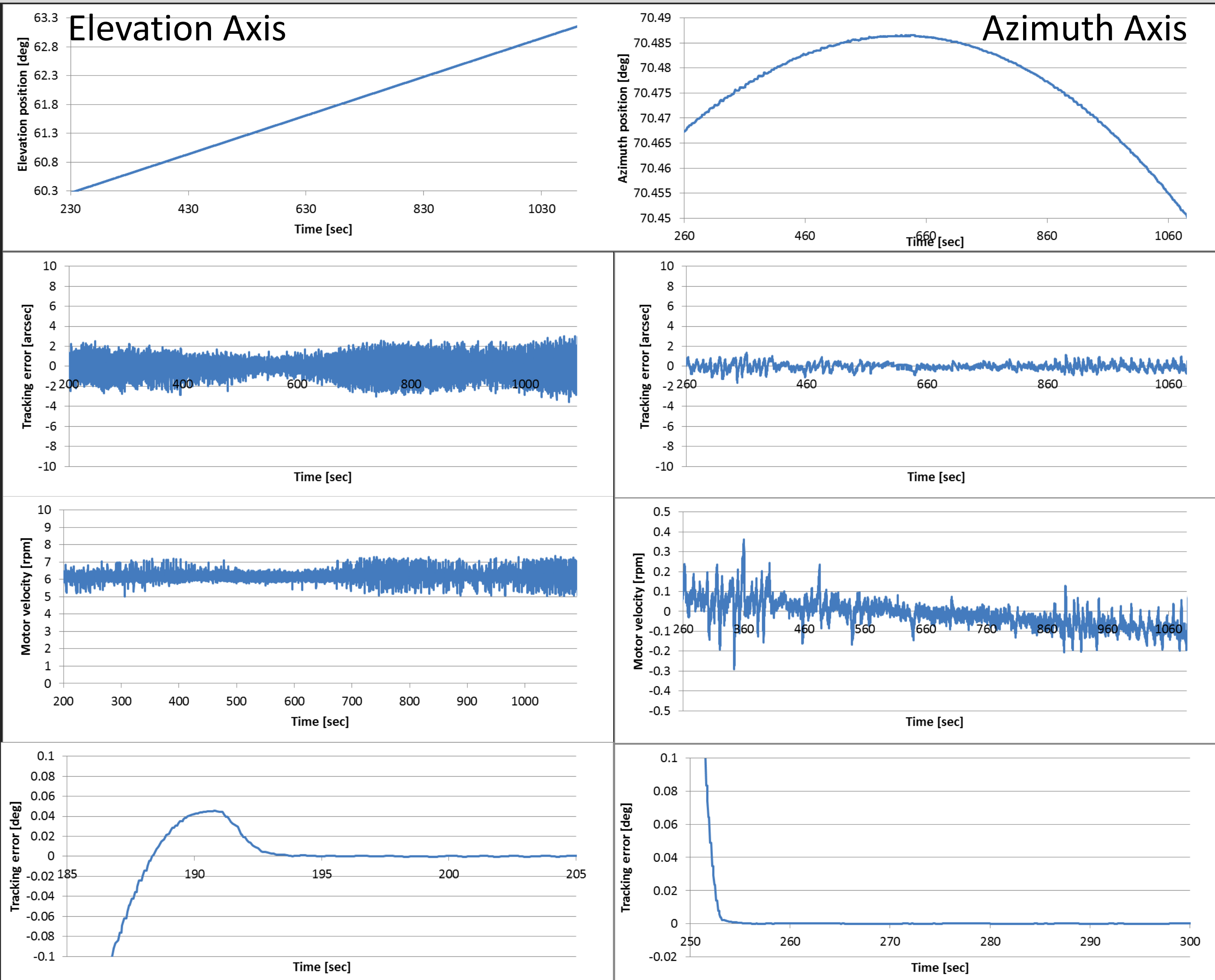
- Elevation drive: two x2 slewing drives
  - Gantry axis
- Azimuth drive systems: two drives
- Redundant critical components for power, PLC, motors, …
- Backlash elimination
- Automatic lubrication
- Drive condition monitoring
- Active vibration damping

Drive System of the MST
Implementation of > Two Motors per Axis

- Higher reliability: Telescope can be moved to safe parking position even when one motor fails
- Higher tracking accuracy: The master motor follows the target values, the slave motor eliminates gear backlash
- Better performance: During acceleration both motors supply their power simultaneously and increase the movement torque



Drive System of the MST Performance



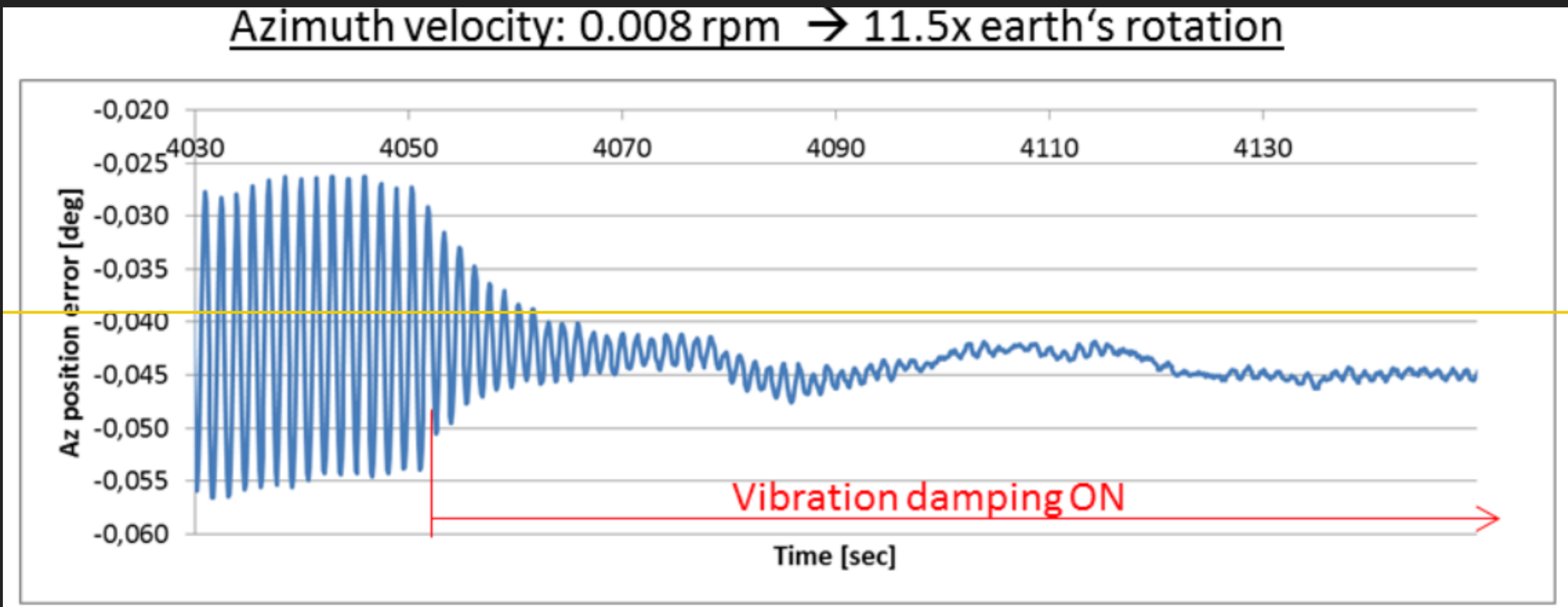
Tracking error
El < 3 arcsec
Az< 2 arcsec

Motor velocity

Slewing to target position

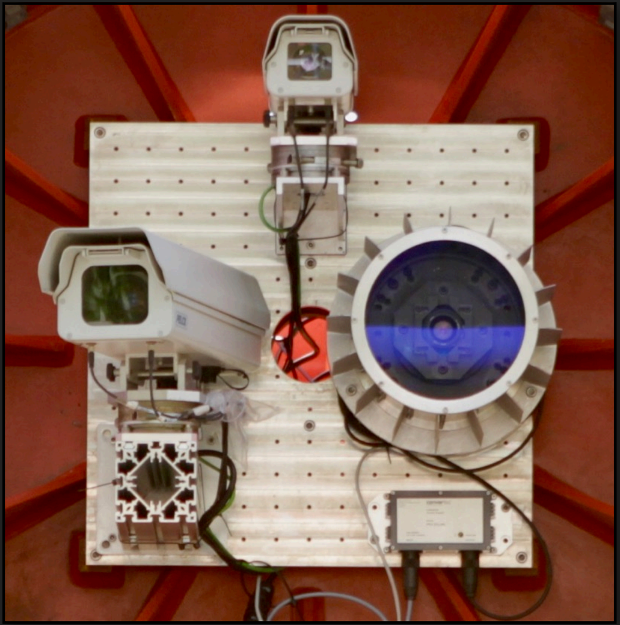
Drive System of the MST
Active Vibration Damping

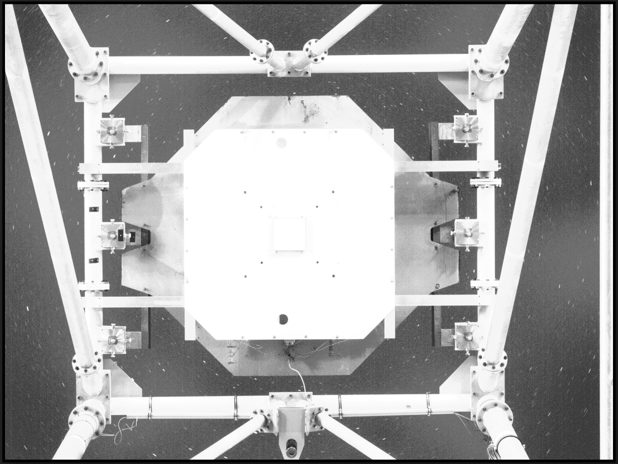
- Actual and reference acceleration are continuously compared and filtered for a defined frequency range
- PLC code generates a velocity offset for oscillation damping



Pointing
Status SingleCCD camera

- One year experience at the prototype
- Improvement of the design:
  - Anti-reflective front window
  - Black painted housing internal walls
  - Heating of front window and heat sink
- ~99% of images can be resolved
- Pointing model shows residuals resulting in ~20” accuracy
- Improvement of precision ongoing
  - Further tests on H.E.S.S. site with second CCD camera

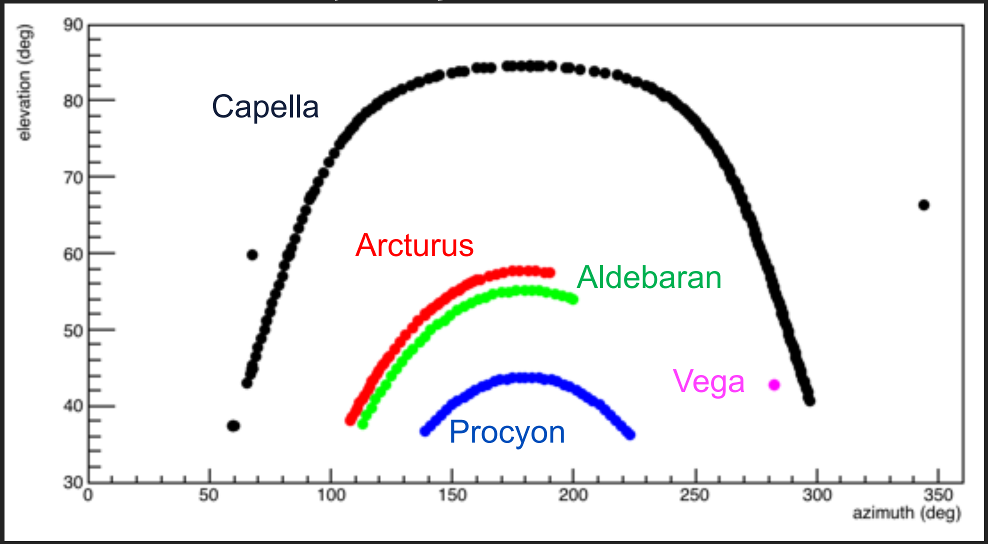


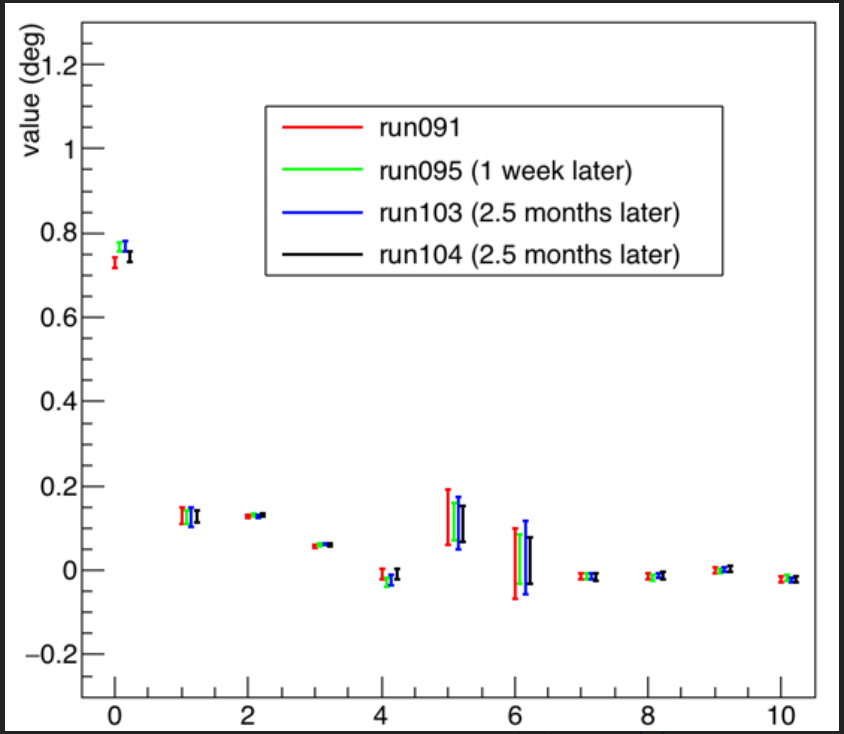


MST-STR Software and Pointing Status

- Continuous, remote scheduled operation of the telescope
- Python based scripts for control of all assemblies
  - Cooperation with SST-1M and SCT teams
- Development of expert GUIs and analysis tools (pointing, mirror alignment) in progress

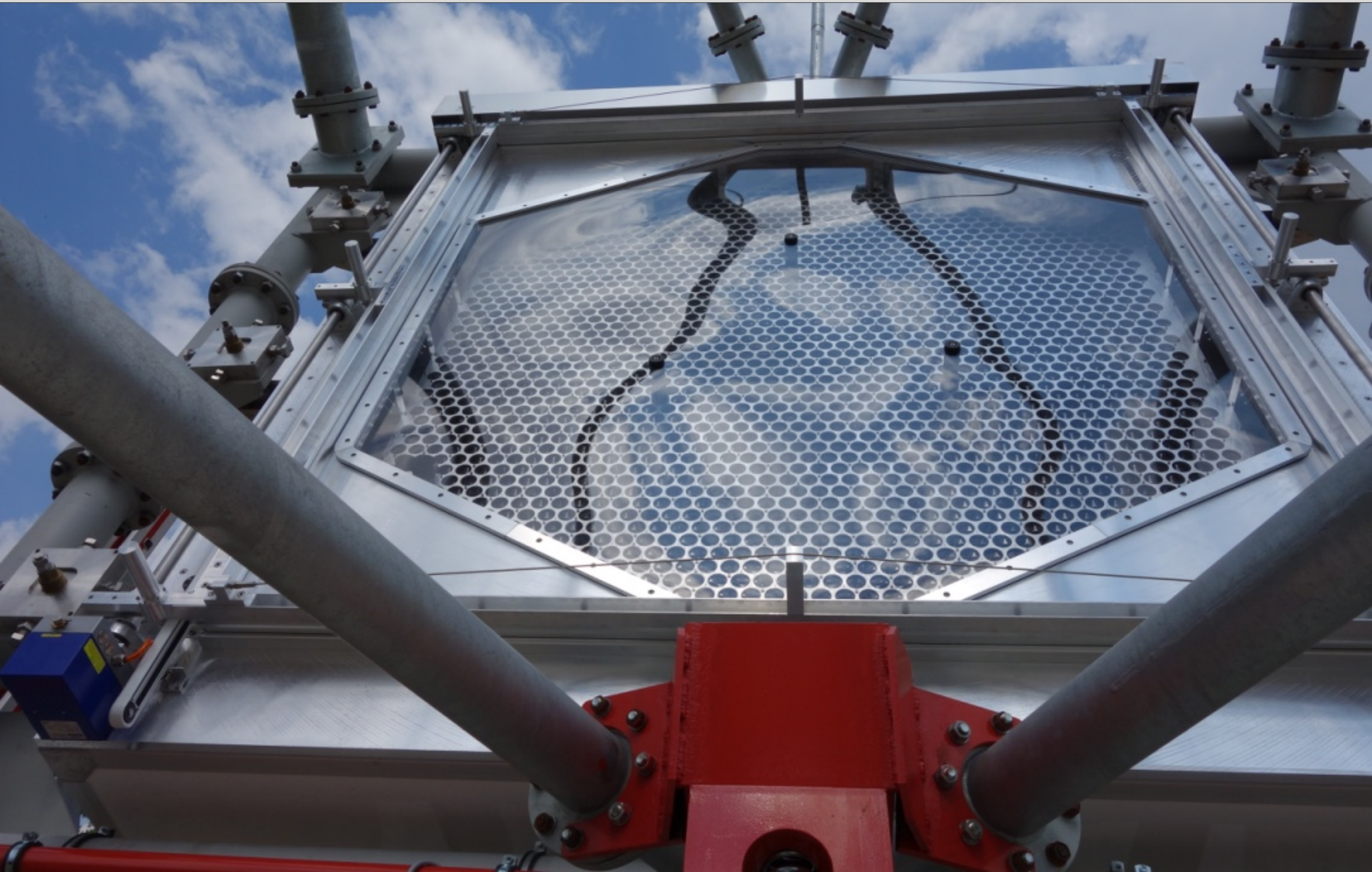
- Limited coverage of celestial sphere
- Sensitivity improved now





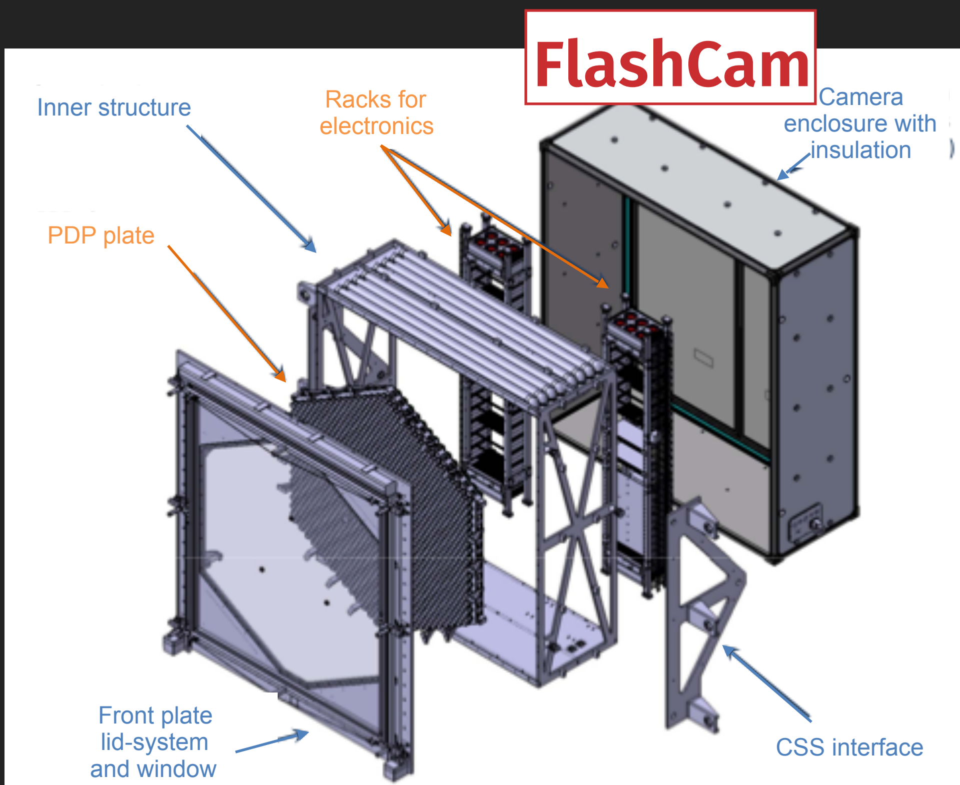
pointing model parameter

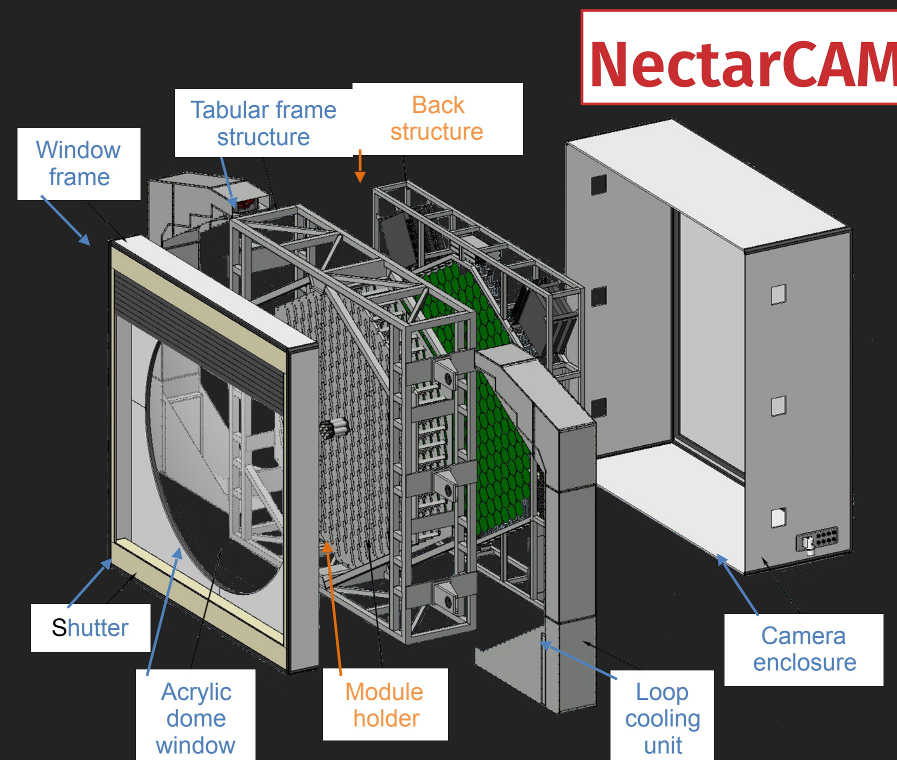
MST Gamma-Ray Cameras
PMTs



MST Gamma-Ray Cameras

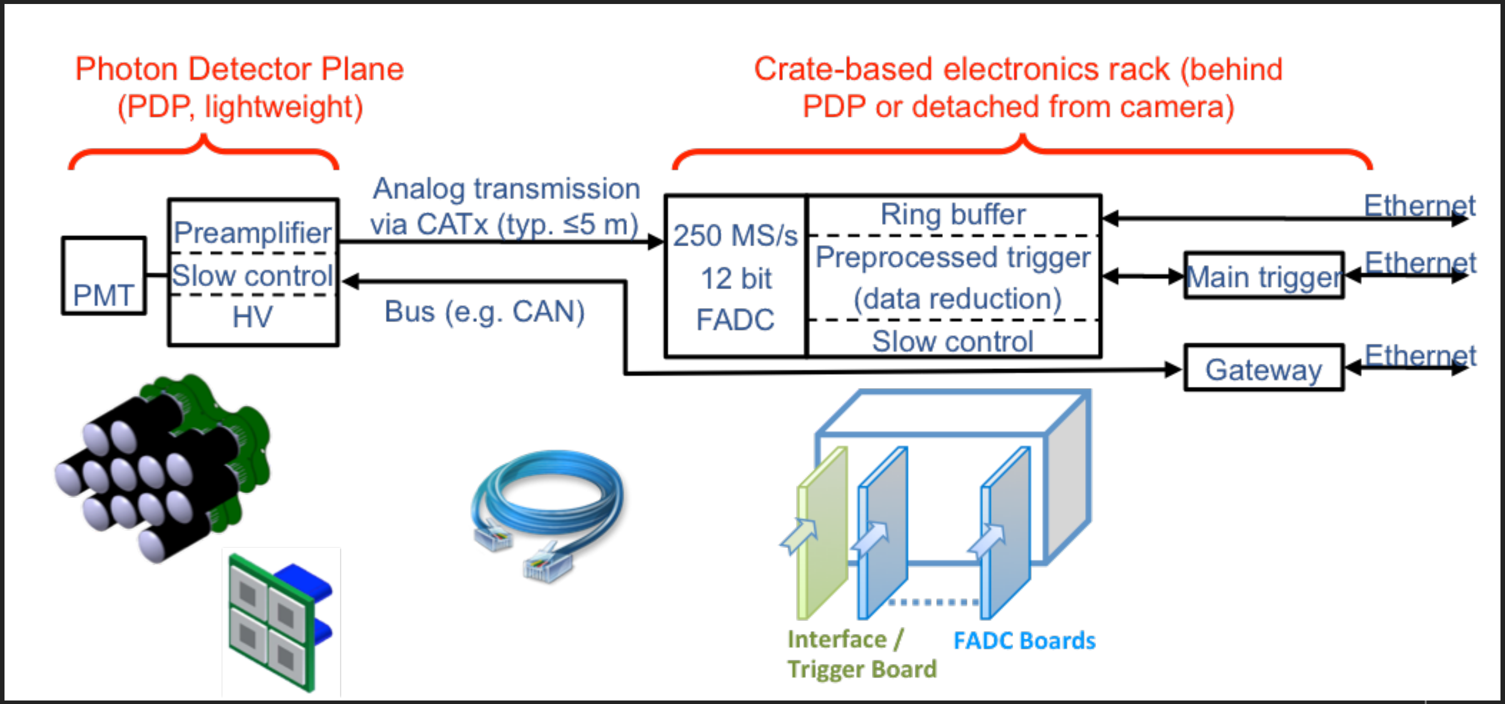
- Two camera designs with different architecture and technology meeting CTA requirements
- Unified interface to telescope structure – cameras exchangeable





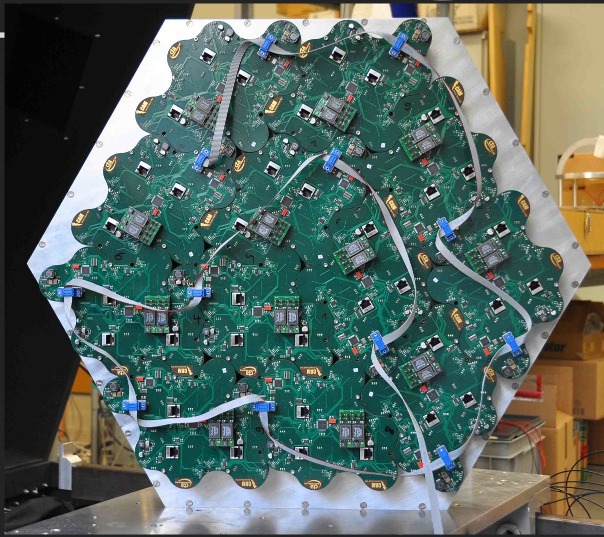
MST Gamma-Ray Camera
FlashCam

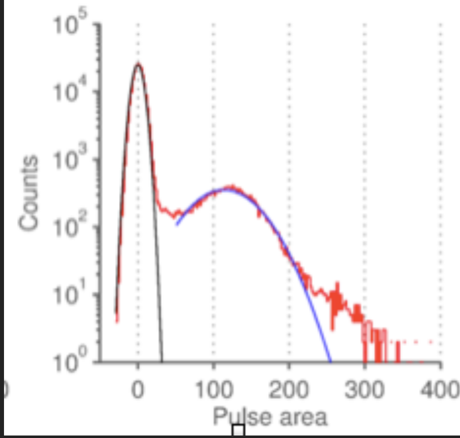
- Full digital approach based on commercially available chips
  - Continuous signal digitization with FADCs, signal processing in FPGAs
  - Trigger decision based on digitized signals
- Horizontal integration: self contained photodetector plane
- Ethernet based read-out

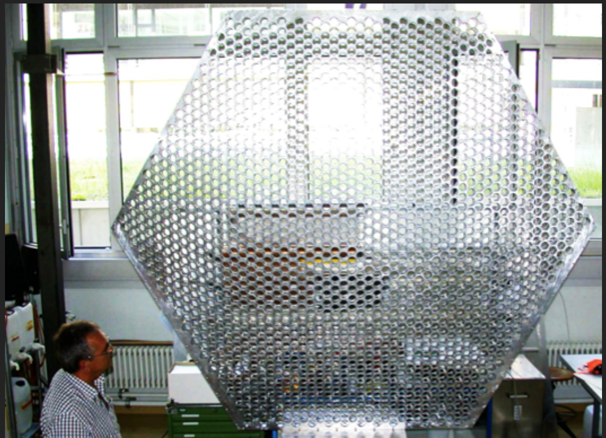


MST Gamma-Ray Camera
FlashCam Prototyping

- 12 PDP modules assembled with a mix of PMTs (Hamamatsu and Photonis)
  - Simultaneous readout of 144 pixels
- Data transfer up to 0.3 GByte/s via 4 x 1Gbit Ethernet
- Performance confirms extensive simulations and results from demonstrator hardware

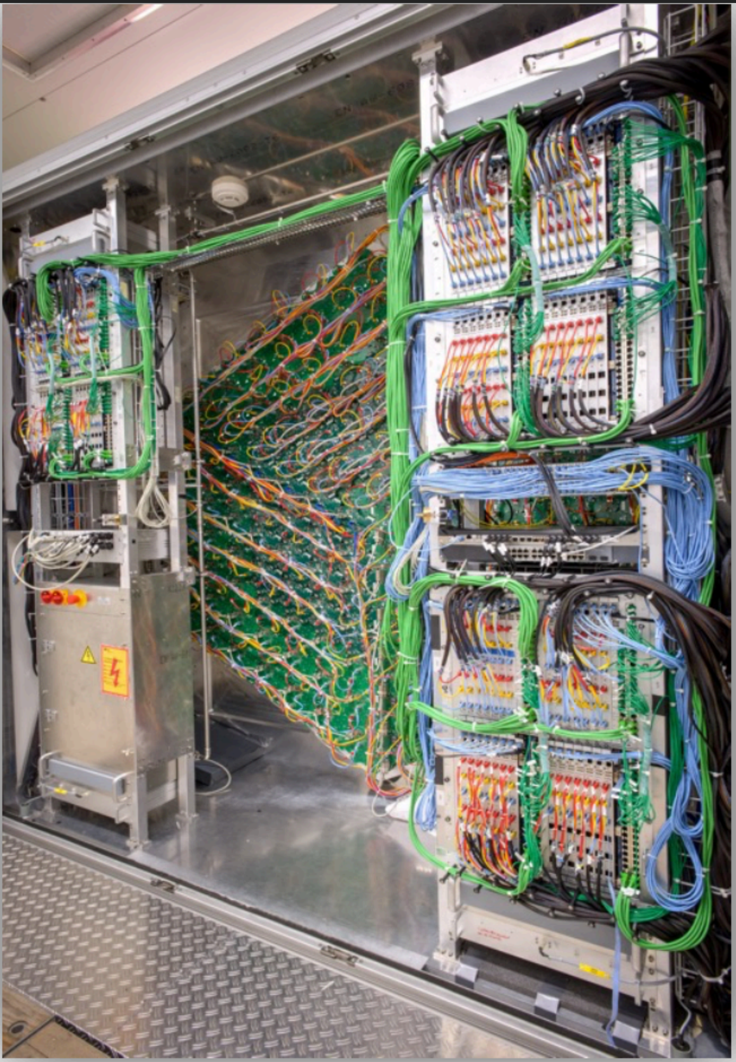


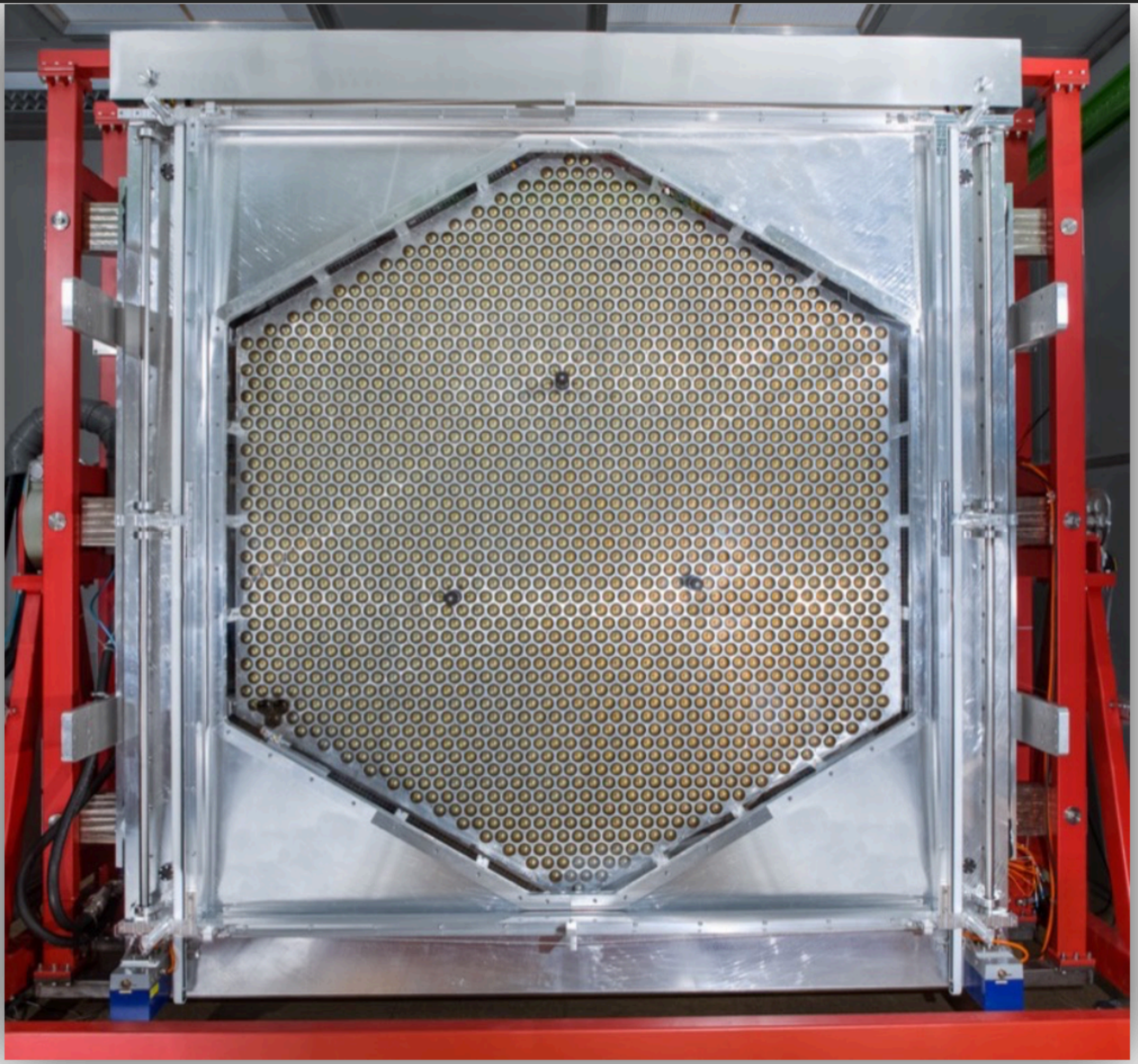




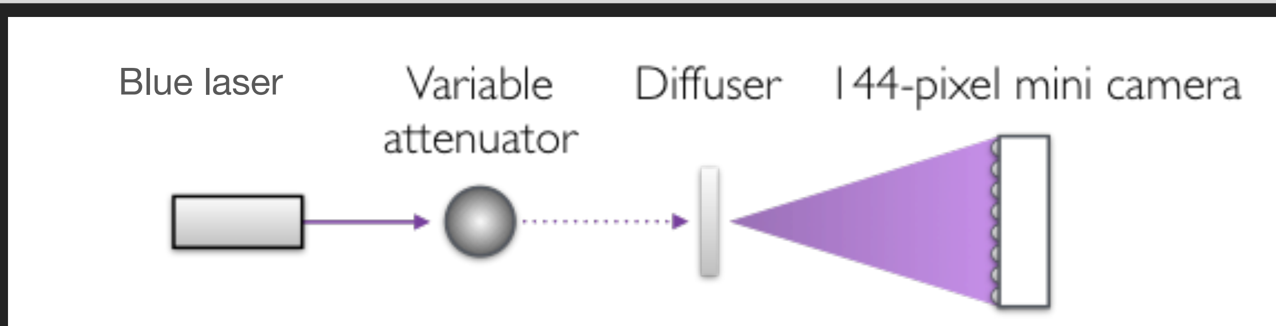
Full-scale camera prototype including cooling

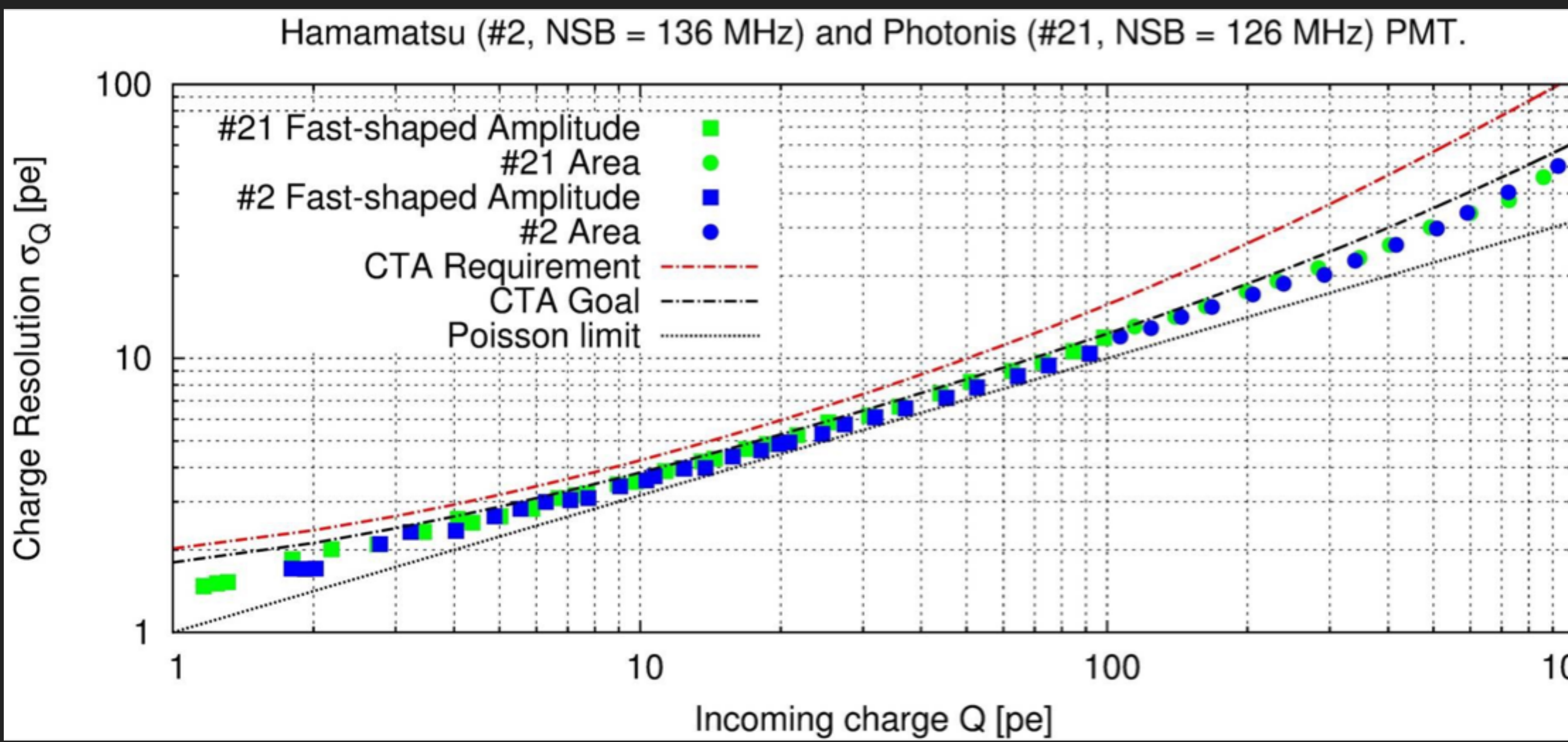
MST Gamma-Ray Camera
FlashCam Full Size Prototype > one year





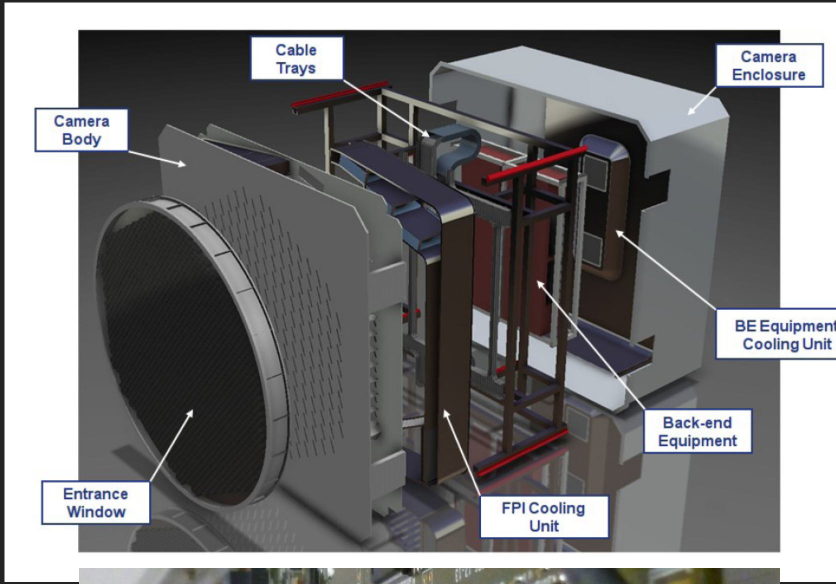
MST Gamma-Ray Camera
FlashCam Performance – Example: Charge Resolution

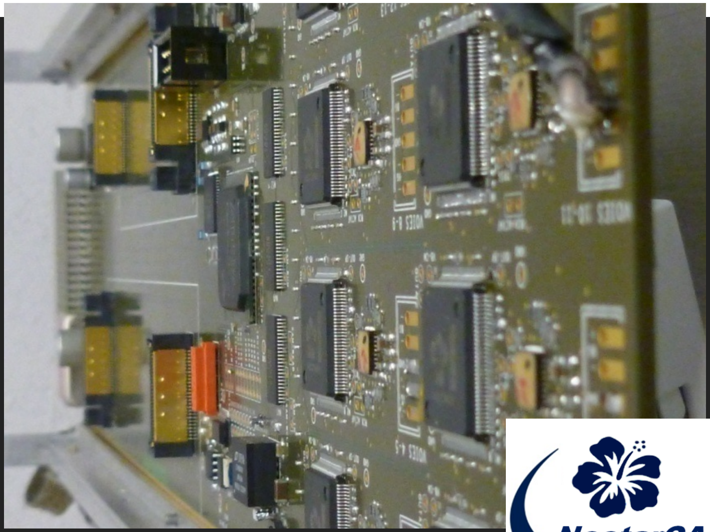




MST Gamma-Ray Camera NectarCAM

- Modular camera for MST
- Large number of elements designed commonly with LST-CAM
- 7-pixel module based on custom-made NECTAr chip with GHz sampling analogue memory and embedded 12-bit ADC
- Analogue bandwidth > 250 MHz
- Gbit Ethernet based read-out

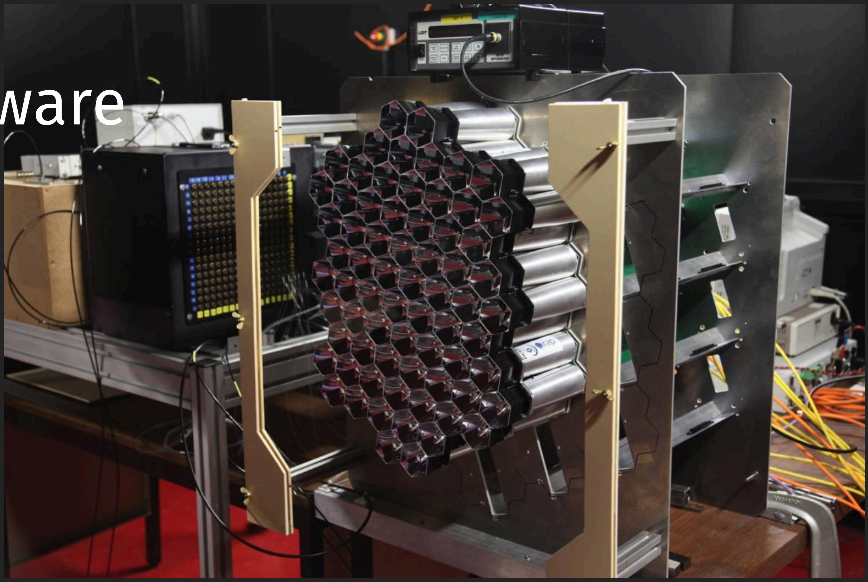




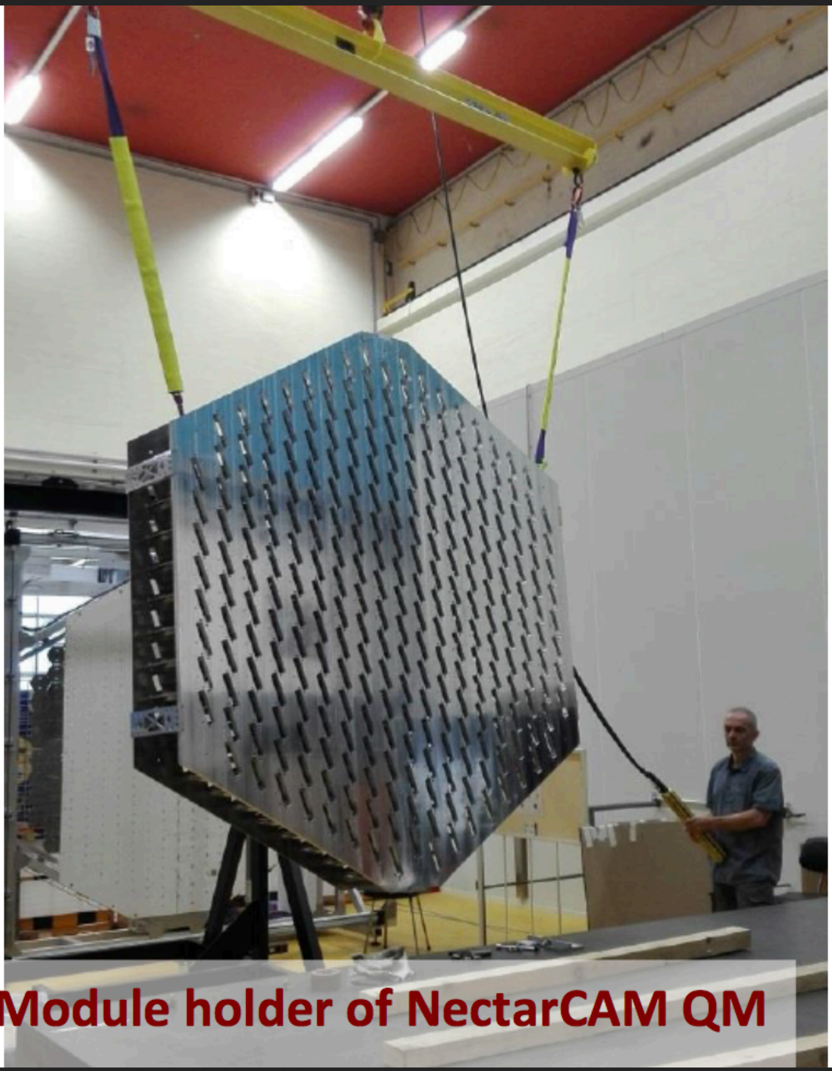
NectarCAM

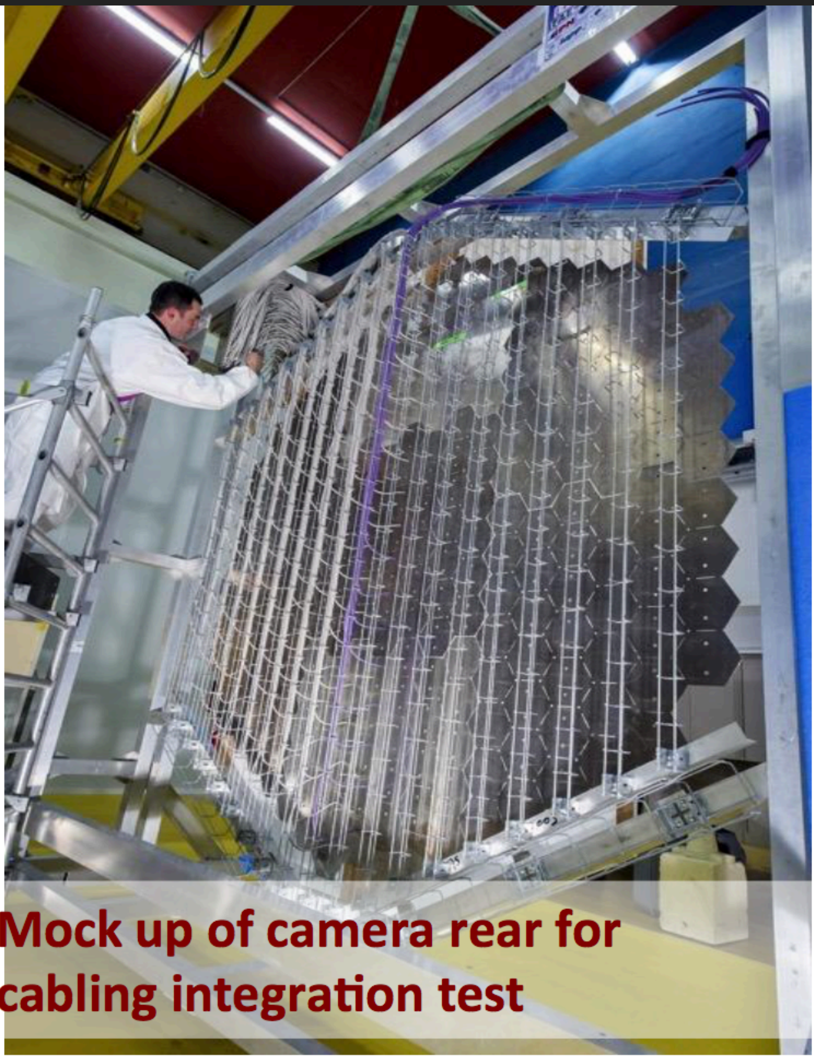
MST Gamma-Ray Camera
NectarCAM Prototyping

- Design similar to LST camera (mechanics, focal plane instrumentation, cooling...)
- Focal plane instrumentation available
- Front end electronics fully characterized on single modules
- DAQ successfully tested with bursts of simulated data
- Slow control hardware and software tested
- Cooling system qualified with demonstrator
- 19 module mini-camera

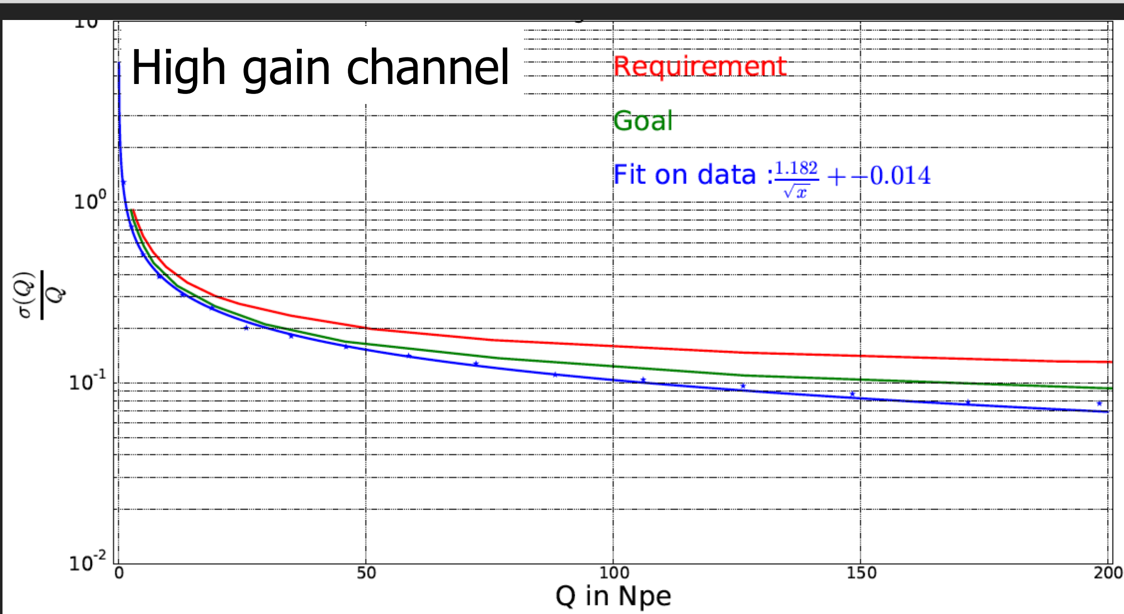


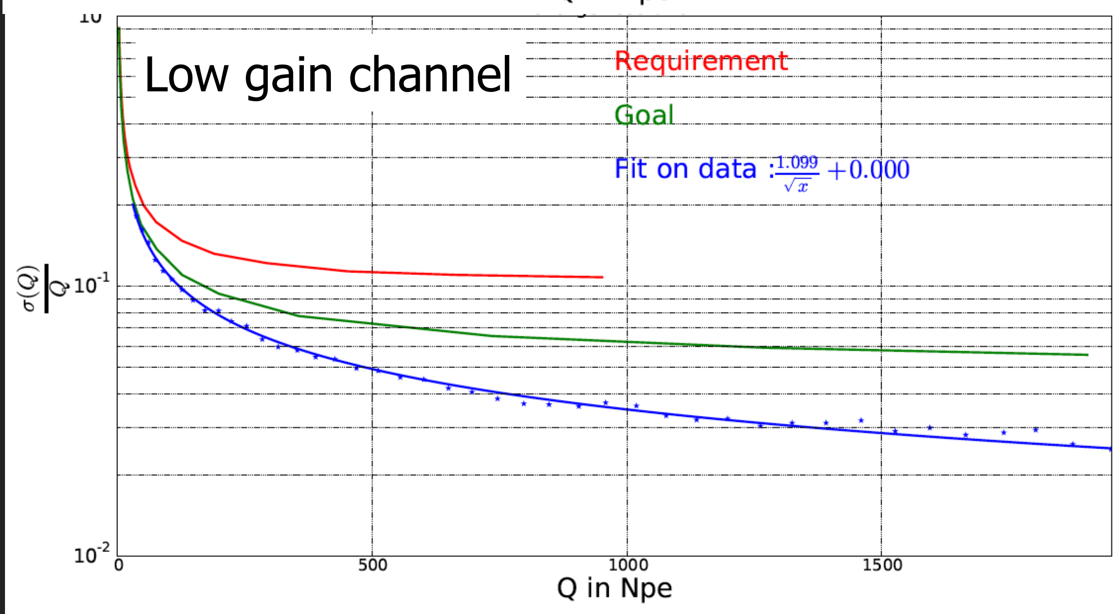
MST Gamma-Ray Camera
NectarCAM Full Size Prototype in Preparation


Module holder of NectarCAM QM


Mock up of camera rear for cabling integration test

MST Gamma-Ray Camera
NectarCAM Performance – Example: Charge Resolution



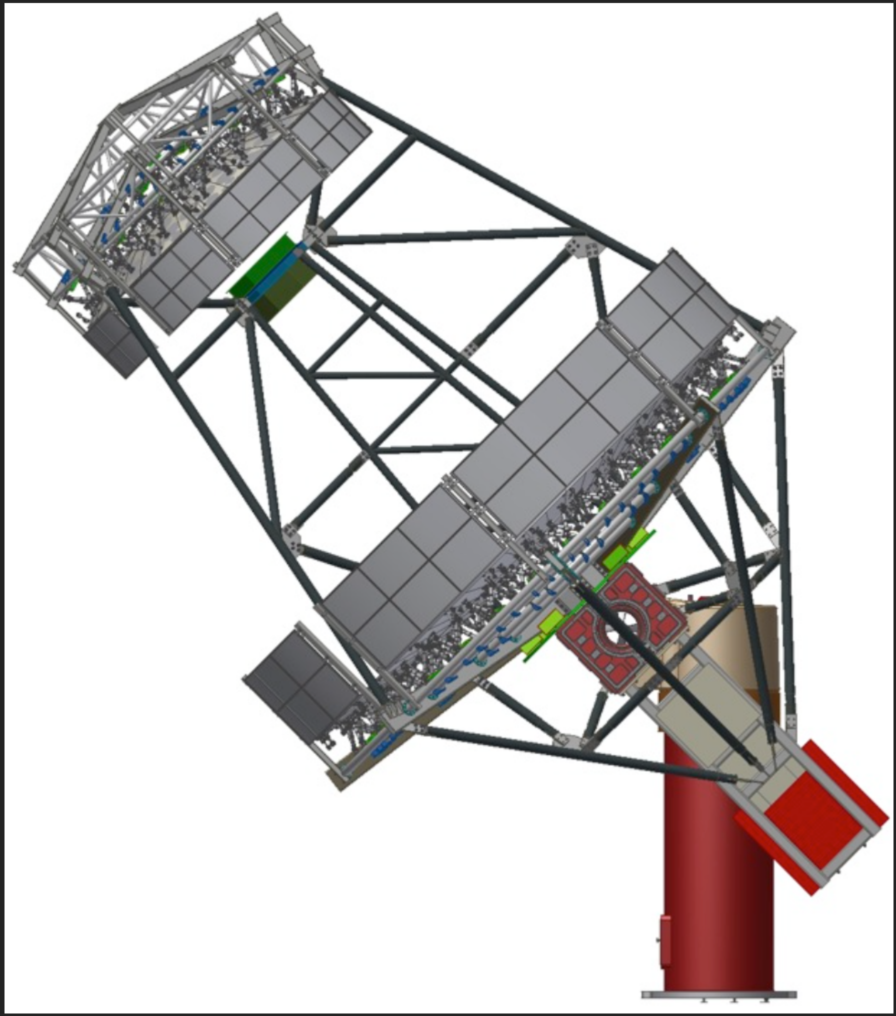


Two gain channels with overlap region

Schwarzschild-Couder Telescope

Dual mirror telescope with superior angular resolution

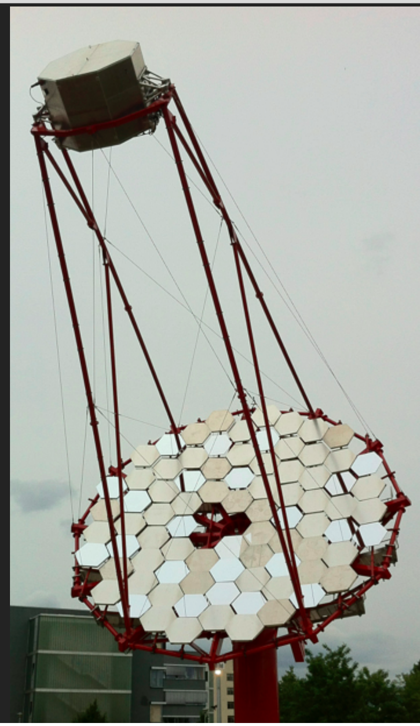
- Aspherical mirrors with big curvature (in particular for the secondary)
- Effective mirror 47 m^2
- Focal length 5.6 meter
- Field of view 8°



Trade off:
MST versus Schwarzschild-Couder Telescope

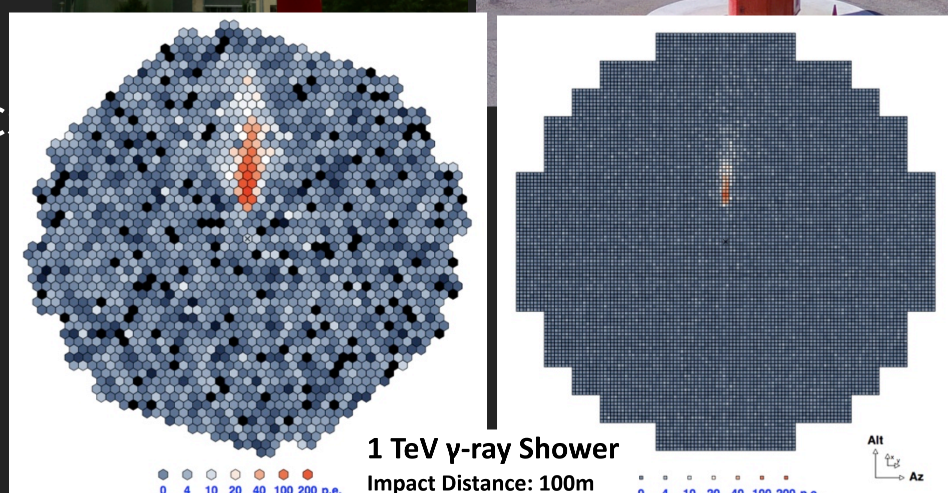
DC-MST:

- Well tested, low risk technology
- Improved angular resolution (f/1.2)
- Relatively low cost 12m aperture, segmented spherical optic



SC-MST:

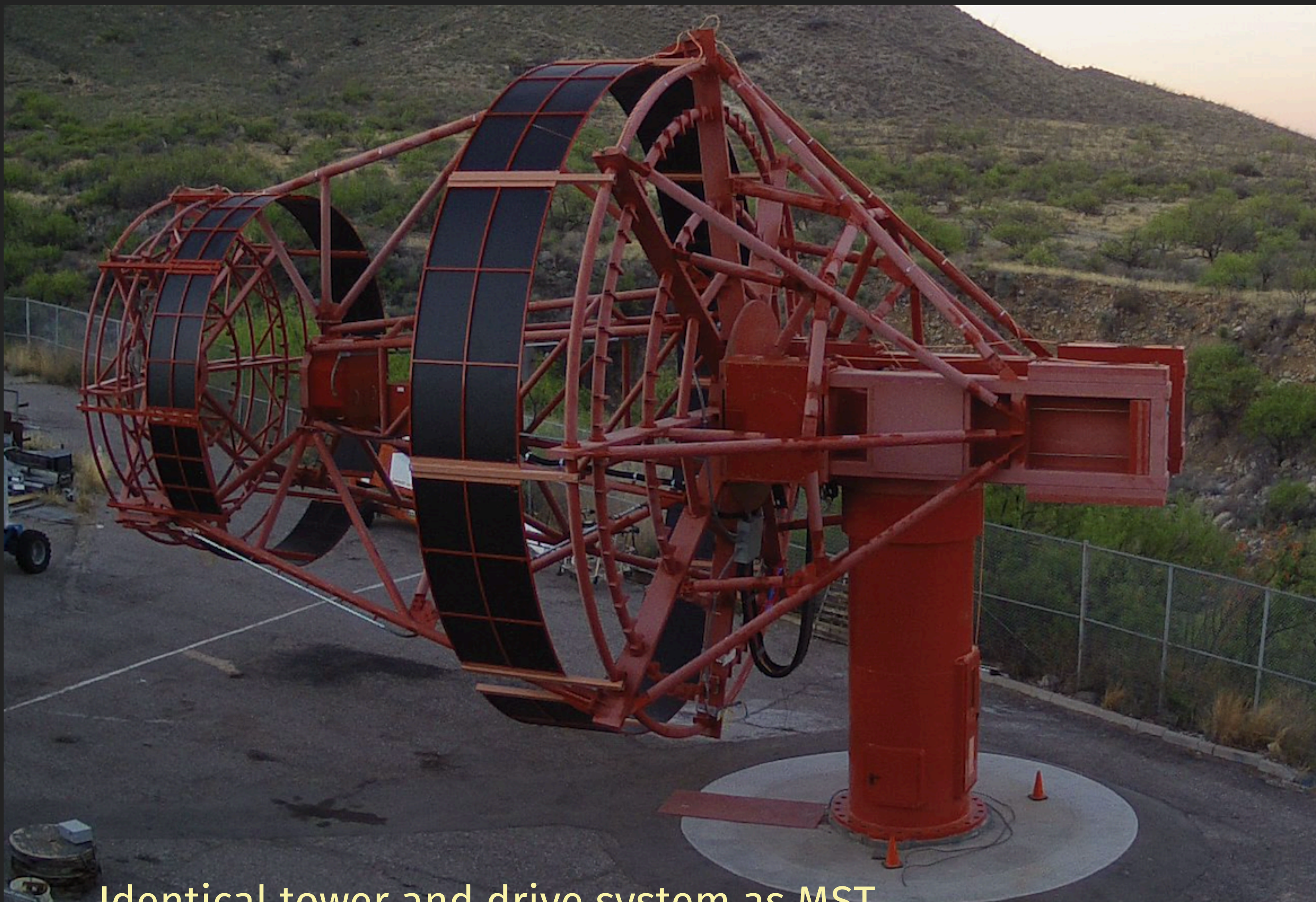
- Excellent angular resolution
- High resolution imaging
- Small plate scale (f/0.6)
- Low cost per pixel (SiPMs)
- Optical System and camera costs are balanced
- Low cost aspheric mirror technology is critical



1 TeV γ-ray Shower
Impact Distance: 100m

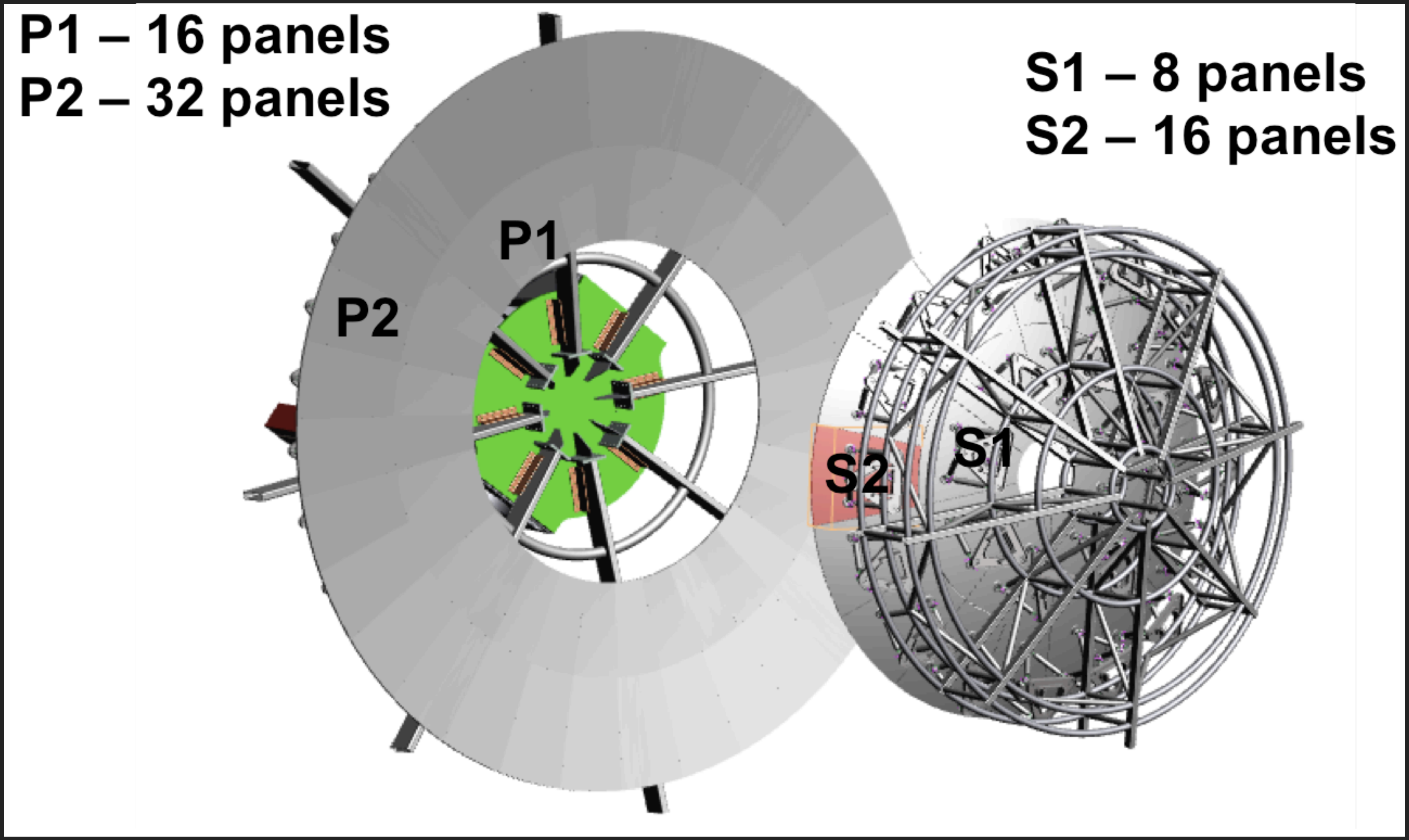
V Vassiliev, pSCT

Schwarzschild-Couder Telescope Prototype in Arizona



Identical tower and drive system as MST

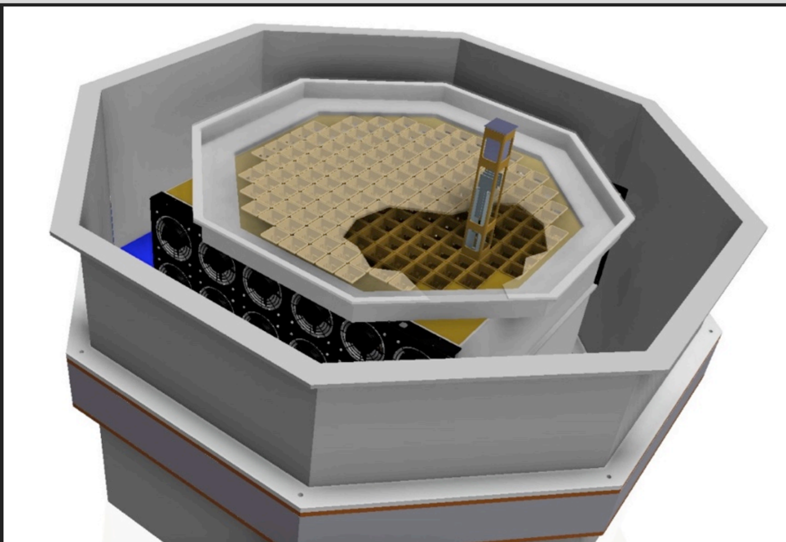
Schwarzschild-Couder Telescope
Optical system



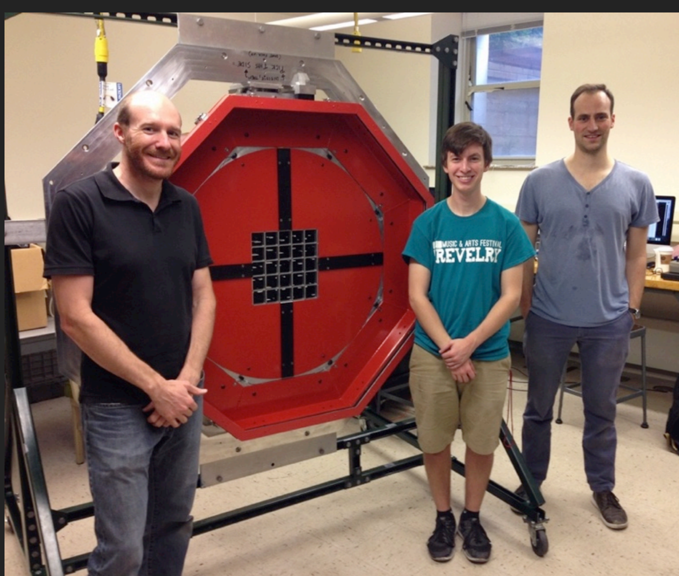
Primary (M1) and secondary (M2) mirrors are segmented (two types)

V Vassiliev, pSCT

Schwarzschild-Couder Telescope Camera



- 8° FoV, 81 cm diameter
- 11,328 pixels (6x6 mm^2) ≈ 0.067° in 177 modules
- SiPM (temperature-stabilized)
- ASIC: TARGET 7
- 1 GSa/s, 10 bits effective
- Readout directly behind focal plane



initially 25 modules installed

V Vassiliev, pSCT

MST Project
Work Breakdown Structure and Scopes

WBS	Element	Scope
7	MST	Production, assembly, commissioning and hand-over of 40 ready-to-use MST products to CTAO at the observatory sites.
7.0	Data and Documentation (DOC)	Acquisition, editing, assembly and reproduction of available working data from the MST work packages into the specific formats and packages required by external stakeholders, such as CTAO, funding agencies and legal bodies.
7.1	Mechanical assembly (MECH)	Procurement, production, pre-assembly, quality assurance and shipment of mechanical structures to the observatory site.
7.2	Optical assembly (OPT)	Procurement, production, quality assurance and shipment of the optical assembly components to the observatory site. Optical characterisation of the mirrors and test of the AMC actuators. Support during the installation of mirrors and AMC on the OSS during pre-production phase.
7.3F	FlashCam	Procurement, production, quality assurance, assembly, test and initial characterisation of 20 MST FlashCam cameras with cooling, calibration and readout assemblies. Shipment of the cameras and supplementary assemblies to the observatory site. Integration of the assemblies with the telescope structures and commissioning during the pre-production phase.
7.3N	NectarCAM	Procurement, production, quality assurance, assembly, test and initial characterisation of 20 MST NectarCAM cameras with cooling, calibration and readout assemblies. Shipment of the cameras and supplementary assemblies to the observatory site. Integration of the assemblies with the telescope structures and commissioning for the first units.
7.4	Auxiliary assemblies (AUX)	Procurement, production and quality assurance of auxiliary components such as electrical cabinets, calibration and monitoring assemblies. Shipment of the auxiliary components to the observatory site.
7.5	Project management (PM)	Administrative planning, organizing, directing, coordinating, controlling and approval of activities, which are needed to reach the overall MST objectives and are not associated with individual sub-projects.
7.6	Quality management (QM)	Design, implementation and verification of policies and procedures with individual work packages to ensure that the delivered MSTs meet their performance requirements and maintain their functionality throughout their foreseen lifetime.
7.7	Systems engineering (SE)	Integrated engineering services including analysis, allocation and traceability of requirements and interfaces related to the complete product; quality assurance, logistics support, and configuration control for development and production activities that are not associated with specific sub-systems.
7.8	Assembly, integration and test (AIT)	Assembly and commissioning of the MSTs at the observatory site. Conducting of formal performance and acceptance tests as required by CTAO. Training of CTAO personnel during pre-production phase. Hand-over of the ready-to-use MSTs to CTAO.
7.9	Software	Development, test and debugging of hardware control and operation software including OPC-UA servers, ACS bridges, expert GUIs and higher-level calibration and analysis tools for the individual MST assemblies. Support of the telescope commissioning tasks during the pre-production phase.

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Camera sub-projects

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MST-STR sub-project

Camera sub-projects

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Camera sub-projects

MST-STR sub-project

MST Project

MST PBS (Product Breakdown Structure)
All hardware and software items, services, supplies, data and documentation which are part of a ready-to-use MST product.

MST WBS (Work Breakdown Structure)
Work necessary to produce all items listed in the MST PBS, plus …

… work for MST product integration & commissioning and project management.

MST Organisation
All organizational entities contributing to the MST project.

MST RAM (Responsibility Assignment Matrix)
Allocation of work packages to contributing organizational entities.

From MST-TDR

Towards Pre-Production

- Validation of Requirements
- Documentation
  - TDR and Project Management Plan
  - Schedule
  - WBS and PBS (down to lowest line replaceable unit) – connected to:
  - Manufacturing and Engineering Bill of Material (MBOM and EBOM)
  - Manufacturing Project Plan
  - Mounting Plan
  - Interfaces
  - Non-conformance documentation
  - Unified CAD documentation for MECH and AUX
  - Execution design - detailed structural engineering
  - FMEA, Product Assurance/ Quality Plan
  - User and emergency manuals

Medium-Sized Telescopes In CTA

- Prototypes and longterm tests of all MST assemblies: gamma-ray cameras, mechanics with drive and safety system, mirrors, pointing...
- Integration with Array Control software
- Interfaces to on-site infrastructure
- Prepare reviews of design and deployment
- Prepare pre-production of three MSTs in 2018
- Plan for 25 MSTs in the South and 15 MSTs in the North