LST Camera Specifications

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Applicable Documents

No.	Version	Ref.	Date	Title

List of Abbreviations

History

Version	Date	Observation
1	01/09/2013	Implementing new macros to improve usability, document generation
1.1	08/09/2013	Updating with latest specs. Removed blanks
1.7	11/10/2013	Added some corrections from Victor Diez
1.9	18/10/2013	Minor cosmetic corrections
1.11	07/01/2014	Included feedback from Victor, Jim and Oscar, added Levels B/C/D
1.13	17/02/2014	Modified Mass allocation for camera to include contingency
1.15	24/02/2014	Added requirements for LEDs and targets
1.16	26/02/2014	Added mass of external Cooling Unit
1.17	10/03/2014	Minor Corrections
1.18	15/04/2014	Corrected Reference Code
1.19	14/07/2014	Updated to LST Requirements 3.02:
.		Added C-LST.0127, direct from A-ENV-0250
.		Updated C-LST.0126 according to upstream requirements. Checked dependencies
.		Updated C-LST-CAM.0004, C-LST.0150, C-LST.0151 references to system and camera lifetimes (A-RAMS-0510 and A-RAMS-0520)
.		Updated C-LST-CAM.0140 due to change on B-LST-1170
.		Added references to Calibration Requirements B-LST-1350 to -1400

Distribution	

Contents

2 # Scope of Document

3 This document contains the Technical Specification for the camera of the LST telescope.

4 The camera of the LST telescopes is the assembly that detect and captures the images from the air showers. The image of the shower is projected into the camera by the optical system of the telescope. A posterior analysis combining the image data of multiple telescopes allows the reconstruction of the energy and orientation of the original gamma.

5 The camera is a self-contained unit from the logical and functional point of view. The components of the camera are mechanical structure, photodetectors, signal processing and Auxiliary systems.

6 *Mechanical structure* provides mechanical support to all other camera components and the interface with telescope structure. It also maintains stable operation conditions inside the camera, protecting it from external environment conditions and aggressions.

7 *Photodetectors* are the elements to collect and convert the light arriving at the camera into an electric signal. The photodetector contains optical elements to concentrate the light on the active area of the sensor, the photosensor itself (a photomultiplier tube) and the specific power supply (High Voltage) for the sensor.

8 *Signal Processing* includes the digitalization of the signal and the trigger system of the camera. *Trigger system* performs a simplified but fast analysis of the photodetectors signal, aimed to detect patterns matching the electromagnetic showers. *Digitization* converts the signal from photodetectors to digital format each time a Camera Trigger is generated.

9 *Auxiliary systems* include additional components as data network, low voltage supplies, environment control, protections, reference LEDs and slow control systems needed by the correct operation of the instrument.

10 The baseline design of the camera of the LSTs has most of the electronics integrated in the focal plane, inside the main camera body. The only exceptions are the calibration box (center of the dish), the external cooling unit (Lower Structure) and part of the DAQ (Camera Server, in the control room).

11 ## Physical implementation in Camera Clusters

12 The LST camera is composed of many identical clusters which include a number of photodetectors and corresponding signal processing. This design decision has been taken with manufacturing and maintenance as priority.

In turn, each cluster is composed by a set of printed circuit boards that implement the different functionalities for photodetector control, trigger and digitization. In the baseline design for the first LST camera, each cluster is composed of the following elements:

· *Photosensor:* The standard Photon Multiplier Tube.
· *HV PS:* A commercial module generating the HV for the PMT, manufactured by Hamamatsu.
· *Pre-amplifier:* A small PCB with the PACTA chip.
· *FPI Slow Control Board:* A PCB that controls the HV PS and monitors the voltages and anode currents of each PMT in the cluster.
· *Readout Board:* A PCB that integrates the signal conditioning, signal digitization and the Ethernet controller used for data transfer and cluster slow control.
· *L0 and L1 Mezzanines:* A set of two daughter boards that implement the Trigger Decision. L0 processes the trigger at cluster level while L1 generates a camera trigger combining the information from the L0 trigger of each cluster and its neighbours.
· *Backplane:* A PCB that implements the Trigger and Clock Distribution.

13 ## Camera modes

14 Several modes are defined for the camera, each corresponding to a set of camera use cases *(scientific observation, protect camera from adverse environment…)* and defined by a combination of status of the sub-components *(front end electronics, shutter…)* and environment conditions inside the camera *(temperature, humidity…)* needed in each case. In normal operation the camera mode will be selected by the CTA Central control standard operation following the observation schedule and calibration strategies. During commissioning and maintenance, the camera mode will be selected by a local control system close to the telescope.

The modes in which the camera will be used are constrained by external environment conditions *(Observing, Transitional, Safe…)* and also the general state of the telescope *(which is also closely tied to the environment conditions)*.

The camera will implement the following modes:

15 **MODE:** OFF
Description: All power to the camera is off, no sub-components active, closed shutter.
Intended Uses: Transportation, maintenance, power outage, failure (short-circuit in camera, temperature too high even with FEE off)
Applicable Environment: Safe, Transportation and Storage conditions, Day and Night.
Applicable Requirements: The camera should be able to remain in OFF mode for extended time periods without suffering damage.

16 **MODE:** Operational
Description: All sub-components of the camera are powered and functional, communication between CC and Camera works without errors, FEE configuration is loaded (HV, Thresholds, etc…), internal temperature stable within operation range, open shutter.
Intended Uses: Scientific data acquisition, Calibration using external light source, CLF, and/or hadrons, pedestal runs.
Applicable Environment: Observing and Transitional (for the time it takes to go to Ready mode), Night time only.
Applicable Requirements: All Performance requirements (sensitivity, rates, etc...) when in Observing conditions, prevent water, humidity into the camera when in Transitional conditions.

17 **MODE:** Ready
Description: As in Operational but with closed shutter.
Intended Uses: Preparation for Operational (minimize time to go into Operational mode by stabilizing temperature while there is still some day light remaining), wait for weather conditions to improve (if environment conditions exceed the ones allowed for telescope Observing state, keep the temperature in camera stable to minimize wait in case conditions improve), Calibration/tests that can be done during daytime with shutter closed.
Applicable Environment: Observing and Transitional, Day and Night.
Applicable Requirements: Limitation on the amount of light the shutter let to enter the camera, internal temperature / RH range, no damage.

18 **MODE:** Standby
Description: Only the Slow Control and Temperature Control sub-components of the camera are powered, shutter closed
Intended Uses: Monitor camera status during daytime (i.e. make sure T and RH inside camera is safe before going to Ready mode), Reduce thermal stresses in camera components (i.e. keep camera warm during winter), prevent freezing of coolant during winter.
Applicable Environment: Safe, Observing, Transitional, Day and Night.
Applicable Requirements: Temperature stable (with wider range) at least for Operational/Transitional. The camera should be able to remain in this mode for extended time periods without suffering damage.

19 **MODE:** T-Points
Description: As in Standby but with shutter in "Star Imaging" mode (acting as a screen where optical imaging of stars can be projected)
Intended Uses: Measure optical properties of telescope (absolute reflectivity, PSF, scattering), Calibrate telescope drive, Generate bending models.
Applicable Environment: Observing, Transitional (for the time it takes to go to Ready mode), Night time only.
Applicable Requirements: Performance for "Star imaging" when in Observing, prevent water humidity into camera when in Transitional.

20 Mode Transitions

21 Transitions between modes are normally triggered by the standard operation of the telescope following the observation schedule and calibration strategies. Each allowed transition has been named in a distinct way that would correspond to the command sent from CTA Central Control. Some mechanisms that automatically trigger a mode transition for a specific camera will be implemented in the Camera and the CTA Central Control, usually for safety.

These are the expected transitions from one mode to the other:

22 **PowerON:** (OFF to Standby)
This happens after camera is installed in the telescope or test stand and main power is switched on.

Automatic Transition: The camera should go by itself to Standby mode and be able to remain in that mode for extended periods of time.

23 **PowerOFF: (**Standby to OFF)
Complete switch off of the camera, once installed on the telescope, should only occur in case of camera maintenance, replacement or if a serious problem has been found (temperature too high while in Standby, for instance).

24 **Initialization: (**Standby to Ready)
This transition will occur before starting observations, if the conditions inside the camera (temperature, RH, light) are within allowed range. Even if there is still some daylight outside, the FEE will be switched on and the configuration loaded, allowing the temperature to stabilize so observation can start as soon as it is dark enough and external environment conditions allow it.
For some tests that do not require the shutters open, this transition can happen during day time. Some mechanism to prevent transition from Ready to Operational in this case has to be included.

25 **Sleep:** (Ready to Standby)
This will happen when the observations end, whatever is due to end of the observation time, bad weather conditions (that are not expected to revert during the night) or a problem is detected in the camera.
This transition can also happen during daytime if camera was in Ready mode to perform some tests with shutter closed.
Automatic Transition: CTA CC should trigger this automatically if conditions inside camera (T/RH/light) are not safe. Camera Controller should also implement this but with longer reaction time, so it should only happen if CTA CC does not react. The Camera Controller should also trigger this transition if communications with CTA CC are not available for a long time.

26 **OpenShutter:** (Ready to Operational)
This will happen only during night time, when it is dark enough and the environment conditions are in the range defined for the telescope Observing state.

27 **CloseShutter:** (Operational to Ready)
This will happen when the observations end, the external environment conditions are outside Operation range or as a first step to go to standby is a severe problem (i.e. excessive internal temperature) is found in the Camera. Except on the case of a problem, the camera will remain in Ready mode, waiting for orders from the CTA Central Control (in case weather improves back and operations are resumed or it is decided to end the observations for that night). As the transition is not immediate, environment conditions corresponding to the Transition Telescope state are to be expected.
Automatic Transition: CTA CC should trigger this transition automatically if the conditions inside camera (T/RH/light) are not safe. As a bugs and communication failures in CC are possible, the camera controller should also implement this automatic transition but with slower reaction time (using a longer timeout or higher thresholds) so it should only happen if CC does not react. The Camera Controller should also trigger this transition if communications with CTA CC are not available for a long time.

28 **OpenTarget:** (Standby to TPoint)
This will happen during night time only, to perform optical measurements that require the shutter to be in a special mode that allows the imaging of stars. No normal observation is possible in this case and this will most likely happen during moon time, so there no need to switch on the FEE.

29 **CloseTarget:** (TPoint to Standby)
This will happen after the measurements are complete or if the environment conditions are outside the range for the telescope Observing state.

30 **PowerFailure:** (ANY to Standby)
Circuit breakers on the main telescope cabinet can produce this transition in case a short is detected, to protect the rest of the electrical network and prevent damage to the camera (Nothing we can control here).

31 Camera States

32 The camera will report its overall state to the CTA Control. When all conditions of an operation mode (sub-components status, internal environment conditions) are reached, the state of the camera will correspond to that mode (i.e OFF, Ready…). As the transition between modes is not immediate (it takes some time for the sub-components to respond after power on and the temperature to stabilize), the camera can be temporarily in states that do not correspond to the defined modes. In this case, the state of the camera will be corresponding to the transition in course (**PowerON**, **Initialization**…).

33 In addition to the well defined states corresponding to the camera modes and transitions, a number of error states can occur. For instance, temperature inside camera may be too high, some sub-component of the camera may have a failure or a transition may take too long to complete. Camera SC and CTA CC should take those into account to provide the information to Operator, Technician or to trigger automatic responses. (TBD: define error states)

34 Engineering Products

35 The design of the camera shall produce the following documentation:
- Electronic schematics and board layouts
- Electrical schematics
- Mechanical blueprints
- Bill of Materials
- Production Plan (Procurement, Assembly, Quality Control and Scheduling)
- Reliability estimation and spare plan
- Procedures for operation
- Procedures for safe routine maintenance, diagnostics and repair

36 Reference Documents

37 MAN-PO/120726: Basic Definitions
MAN-PO/120806: LST Requirements

38 Environment and Usage Conditions

39 Usage Conditions

40 C-LST-CAM.0004 The LST Camera must remain operative during 20 years

41 C-LST.0150 The camera will be used in Ready and Operational modes for over 2000 hours per year.

42 C-LST-CAM.0007 The camera will operate within specs at zenith angles within the range 65 to -65 degrees.

43 C-LST-CAM.0008 The camera will operate within specs at azimuth tracking accelerations of 45.2µrad/s².

44 C-LST-CAM.0009 The camera wilk operate within specs at elevation tracking accelerations of 0.7µrad/s².

47 C-LST.0151 The telescope will reposition an average of 3000 times per year, 10 times per night.

48 C-LST-CAM.0011 The maximum acceleration on the Azimuth axis during repositioning will be 47mrads/s².

49 C-LST-CAM.0012 The maximum acceleration on the Elevation axis during repositioning will be 24mrads/s².

50 C-LST.0156 It is considered the Emergency Stop will be activated at most once per year.

51 C-LST-CAM.0030 The camera must survive without damage emergency stop accelerations of 0.1rad/s².

52 Observing Environment Conditions

54 C-LST.0100 All components of the LST must perform as required at a altitude of 1500 to 3800m above sea level.

55 C-LST-CAM.0003 The acceptance tests for the camera can be performed at any altitude between sea level and 3800m (on site).

56 C-LST.0101 All components of the LST will perform as required during observations with an external temperature range of -15 to +25 °C.

57 C-LST.0103 All components of the LST will perform as required during observations with temperature variations < 7.5 °C/hour.

58 C-LST.0105 All components of the LST will perform as required during observations with an external relative humidity range of 2 to

90 %.

59 C-LST.0112 No rain will be present during observation.

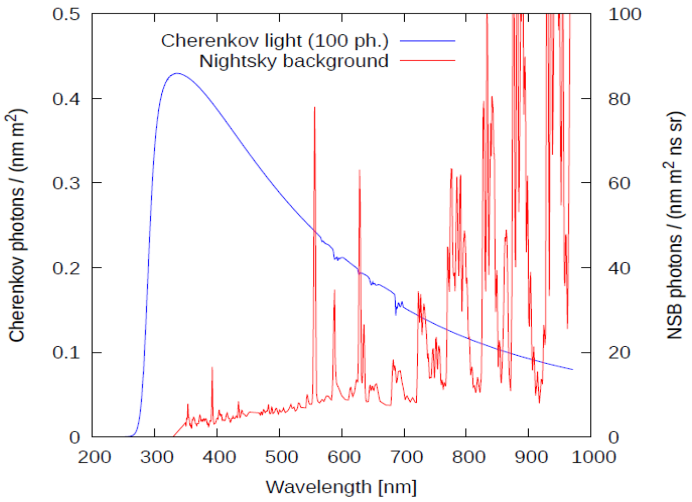
60 C-LST.0114 No snow will be present on the ground during observation.

61 C-LST.0116 No ice will be present on any surfaces during observation.

62 C-LST.0118 All components of the LST will perform as required during observations with 10-minute mean wind velocity <36 km/h, as defined in Eurocode EN 1991-1-1:2005 (at 10m above ground).

63 C-LST-CAM.0014 The camera will operate within specs with a air pressure between 600 and 900 hPa.

65 C-LST.0128 The LST Camera will perform as required during observations with an ambient (night sky backgound, NSB) light level in the range given, with a spectrum of the form shown in the Figure, in the wavelength range 300-650 nm. The nominal NSB level corresponds to the lowest end of this range, with partial moonlight observations as the upper bound [2, 3, 4]. 0.24-1.2 $ns^{-1}\,sr^{-1}\,cm^{-2}$.



66 C-LST-CAM.0018 The NSB detected rate to consider on each photosensor of the camera (taking into account all telescope and camera efficiencies), is 260 MHz for extra-galactic observations (best case) and 1300 MHz for moon observations (worst case).

67

Safe Environment Conditions

69 C-LST.0102 The extreme air temperature range where telescopes must suffer no damage will be -20 to +40 °C.

70 C-LST.0104 The natural temperature shocks (within 24 hours) will be less than +/-30 °C.

410 C-LST.0127 All structures on site must withstand continuous temperature gradients of at least 0.72 °C/min for 25 minutes.

71 C-LST.0106 The camera must survive without damage, in OFF and Standby modes, with external relative humidity in the range 2 to 100 %.

72 C-LST.0108 The maximum rain precipitation in 24 hours is 200 mm.

73 C-LST.0109 The maximum rain precipitation in one hour is 70 mm.

74 C-LST.0110 No equipment must incur damage (survival condition) for precipitation in the form of rain, snow and hail for wind speeds <90 km/h.

76 C-LST.0115 Damage beyond the SL level must not be incurred during Safe state for a snow accumulation (at an assumed density of 200 kg/m³) on the ground of <50 cm.

77 C-LST.0130 All elements of the system must be undamaged in their Safe positions by the impact of 20mm hailstones with an impact energy of 1 Joule.

78 C-LST.0117 Damage beyond the SL level must not be incurred during Safe state for an ice thickness (on all surfaces) of <20 mm.

80 C-LST.0120 Telescopes must not incur damage beyond the SL level whilst in the Safe state for 1-s gusts of <200 km/hour or 10-minute average wind speeds <120 km/h.

82 C-LST.0121 The maximum solar radiation is 1200 W/m^2 (averaged over a 1 hour period, survival condition). Note that this radiation level must be considered for the survival of all equipment when the maximum ambient temperature is at the extreme of requirement A-ENV-0220.

83 C-LST.0133 All components exposed to direct solar radiation must be UV resistant and not suffer degradation which cannot be recovered during the normal maintenance conditions.

84 C-LST.0124 Damage Limitation requirement: Peak horizontal ground acceleration <0.26g and peak vertical ground acceleration <0.3g with 10% probability of exceeding these figures within 10 years (reference return period 95 years). With these conditions, system shall meet the Damage Control Limit requirement as defined in CTA Basic Definitions.

85 C-LST.0125 Collapse Prevention requirement: Peak horizontal ground acceleration <0.49g and peak vertical ground acceleration <0.6g with 10% probability of exceeding these figures within 50 years (reference return period 475 years). With these conditions, system shall meet the Collapse Prevention Limit requirement as defined in CTA Basic Definitions.

86 (todo) We need feedback from the structure for the amplification factor and reactions the structure transmits to the camera

87 C-LST.0126 Each site will be considered a lighting protection zone (LPZ) 0A and have lightning current parameters corresponding to the lighting protection level (LPL) I, as defined in EN 62305:2011.

88 C-LST.0129 The camera must survival undamaged illumination of any or all pixels for up to 10 seconds at an intensity of 10^6 ph. $ns^{-1}sr^{-1}cm^{-2}$, with a recurrence rate of once per week.

89 Transition Environment Conditions

90 C-LST.0113 During transitions the maximum rainfall is 0.5 mm/minute.

91 C-LST.0119 During transitions (telescopes moving to the Safe state), the 10-minute average wind speed is <50 km/h.

92 Transportation and Storage Environment Conditions

96 C-LST-CAM.0091 The camera must survive without damage, during transport and storage, temperatures between -20 to 50 °C (TBR)

97 C-LST-CAM.0092 The camera must survive without damage, during transport and storage, humidity between 0 and 100%

98 C-LST-CAM.0093 The camera must survive without damage, during transport, sudden changes of temperature up to 20 °C.

99 C-LST-CAM.0094 The camera must survive without damage, during transport, the following vibrations:
2-20Hz +/-2mm
20-50Hz 0.85G
50-100Hz 2G

100 C-LST-CAM.0095 The camera must survive without damage, during transport, a shock of 4.2G during 20ms, half sinusoidal.

102 C-LST-CAM.0097 The camera must survive without damage, during transport in the range, external air pressures in the range of 600 to 1050hPa.

103 Additional Protection Specifications

104 In order to achieve the required reliability the camera must protect its components from immediate threats but also provide a controlled environment preventing degradation of the components. Most protection will be provided by the Mechanical Structure of the camera, including the shutter. Electrical protection should also be provided on all cameras to prevent damage propagation.

The following specifications are derived from the Environment conditions present in the different camera modes.

105 C-LST-CAM.0040 Camera will protect its components from environment (water, humidity, ice, dust, temperature changes, direct sunlight).

108 C-LST-CAM.0043 With open shutter, the camera will be at least IP64 protected while in Operational and Tpoint modes.

109 C-LST-CAM.0044 The camera will be IP66 protected while in OFF, Standby and Ready modes.

110 C-LST-CAM.0046 All external elements of the camera (including shutter, enclosure, fixation mechanism, etc…) will be protected against oxidation.

111 C-LST-CAM.0047 The camera will have at least a IK06 impact protection level while in OFF, Standby and Ready modes.

112 C-LST-CAM.0050 Camera will protect its components from overvoltage, surges, drops, power failures and nearby but not direct lightning impact.

115 C-LST-CAM.0048 All mechanical parts of the camera must be electrically connected to a common Earth ground.

116

Reliability and Maintenance

118 C-LST-CAM.0101 The Camera must be operational 99% of the available observation time.

119 C-LST-CAM.0102 The camera is considered inoperative when more than 2% of all pixels are dead or operate out of specs (excluding photodetectors disabled due to bright stars). In this case a non-regular maintenance operation will be performed to repair or replace the camera.

120 C-LST-CAM.0103 Routine maintenance of the camera will not exceed 6 person·hours/months.

121 C-LST-CAM.0104 Non regular maintenance and repair of camera must not exceed 4 person·hours/month.

124 To do -> include RAMS requirements for Environment requirement

125 C-LST-CAM.0130 Any electronic component of the camera must be accessible and dismountable on site. Replacement will take less than 2 hours work of 2 people once the camera on the repair position (removed from the camera frame and placed on the Access Tower).

126 C-LST-CAM.0131 Installation / Removal of camera must take less than 4 hours work of 3 people (from power-off to stowed in transport unit).

127

Performance Specification

128 C-LST-CAM.0001 The Camera will detect images produced by the air showers and provide charge and arrival time .

129

Design Constrains

130 C-LST-CAM.0500 The maximum mass for the LST camera (including 500kg contingency) is 2500kg.

393 C-LST-CAM.0513 A contingency of 500kg in the camera mass must be considered to ensure survival of camera support and telescope structure in worst conditions.

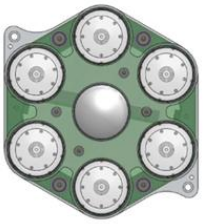
131 C-LST-CAM.0502 The total cost of the camera will be less than 800€/photodetector.

133 C-LST-CAM.0504 The total electrical power consumption of the camera including environment control system will be <10kW.

134 C-LST-CAM.0505 The Power dissipated by the components inside the camera body will be <7kW.

136 C-LST-CAM.0510 All commercial electronic parts inside the camera must be at least commercial grade and able to operate with air temperatures from 0 to 70 °C.

137 C-LST-CAM.0511 The LST camera will be composed of clusters of 7 photodetectors, arranged in a hexagon.



139 ## Optical Performance

140 The overall Optical performance of the telescope depends on many factors. From the camera side, the contributions include the shadowing produced by the opened shutter, the entrance window transmission, the dead space between photo-detectors, the light guides reflectivity and geometry and the photo-sensor PDE.

141 C-LST-CAM.0140 The Photon Detection Efficiency of the camera, averaged over Atmospheric Cherenkov spectrum at ground (300-550nm) will be > 17%.

142 C-LST-CAM.0141 The overall photon detection efficiency must not deteriorate by more than 10% due to factors other than possibly unavoidable aging of sensors, over the life cycle of the camera.

143 C-LST-CAM.0142 The total shadowing produced with the camera with the open shutter will be less than 9 m^2.

144 ## Telescope Connection

145 The Telescope Connection is the mechanic assembly that allows fixing the camera to its support structure in the telescope. It must also allow some adjustment range, during installation, to ensure the camera is focussed at the right distance.
It is still discussed if this component should be a part of the telescope structure or the camera.

146 C-LST-CAM.0150 The Telescope Connection will allow setting the focus at the entrance window of the photodetectors from 2.5km to infinity during the camera installation.

147 C-LST-CAM.0154 The Telescope Connection will allow setting the focus at the imaging surface at the front side of the camera from 2.5km to infinity during camera installation.

148 C-LST-CAM.0155 The adjustment of the Camera Position, along the optical axis, will be -10 to +25cm from its nominal position.

149 C-LST-CAM.0151 The maximum allowed play in the camera connection with the telescope, in any direction, is 1mm.

150 C-LST-CAM.0120 The camera enclosure will include an external visual indicator of the position of the focal plane inside the camera the camera, to be used as reference when removing and re-installing the camera with a 1mm accuracy along the optical axis.

152 C-LST-CAM.0153 The allocated mass of the connection to the camera frame, assigned to the elements in the camera body, is 100kg.

153 ## Mechanics

154 C-LST-CAM.0800 The allocated mass for the Camera Body is 900kg.

155 C-LST-CAM.0801 The allocated mass for the Camera Enclosure (excluding Entrance window) is 100 kg.

156 C-LST-CAM.0802 The width of the Camera will be 2894 mm.

157 C-LST-CAM.0803 The height of the Camera will be 2894 mm.

158 C-LST-CAM.0804 The depth of the Camera body will be less than 1400mm.

159 C-LST-CAM.0508 Overall focal plane deformations relative to fixing points of mast (support) structure must be <1mm.

394 C-LST-CAM.0805 The Mechanics structure of the camera will provide supports for 4 targets for the Distance Meter, placed at the corners

of the frontal side of the camera, as represented in the following picture:

395 C-LST-CAM.0806 The size of each target for the Distance Meter will be up to 400x400mm.

396 C-LST-CAM.0807 The allocated mass for each Distance Meter target is 1kg.

397 C-LST-CAM.0808 The targets for the Distance Meter can be placed behind the shutter and they don't need to be visible when the shutter is closed.

398 C-LST-CAM.0809 The material for the Distance Meter targets will be XXXX.

405 C-LST-CAM.0810 The Camera Mechanics must include mouting points that allow temporary installation of additional devices covering the front side of the camera, with a maximum mass of 20kg. This additional mass will not be considered in the camera mass budget.

160

Mechanics: Entrance Window

161 C-LST-CAM.0175 The entrance window will be airtight.

162 C-LST-CAM.0176 No deformation of the Entrance window will result in contact with the photodetectors or the shutter.

163 C-LST-CAM.0177 The allocated mass for the entrance window is 40kg.

164 C-LST-CAM.0178 The optical Efficiency of the Entrance Window will exceed 90% for all wavelentghts in between 300 and 550nm.

165 C-LST-CAM.0182 The curvature of the entrance window (combing) will be less than XX mm.

166 C-LST-CAM.0181 The entrance window will deform less than XXmm during operation.

167

Mechanics: Shutter

168 The Shutter is the component of the camera that protects the Photodetectors from light and the Entrance Window from direct environment conditions. As it is intended to be able to fully power the Camera during daytime for diagnostics, the Shutter should be light tight.

169 C-LST-CAM.0160 The Shutter must be able to open and close for any zenith angle between 100 and -65 degrees.

170 C-LST-CAM.0161 The Shutter must be light tight when closed and allow powering the photodetectors during daytime. When shutter is closed no photosensor should produce more than $40\cdot10^{6}$ photoelectrons/second.

171 C-LST-CAM.0162 The Shutter will cover 100% of the active area when closed.

172 C-LST-CAM.0163 The Shutter must not vignette the FOV of the camera when opened.

173 C-LST-CAM.0166 The Shutter will support remote, local and manual operation.

174 C-LST-CAM.0167 The Shutter will close automatically in case of a power cut to the telescope or if communication with array control is lost (only while in remote operation).

176 C-LST-CAM.0169 The position, operation more and status (open, closed, unavailable) of the Shutter must be monitored.

177 C-LST-CAM.0173 Once the Shutter is opened or closed, its motors will be off and its position fixed by holding brakes so they do not introduce electronic noise.

178 C-LST-CAM.0170 The Shutter must provide a method to prevent or stop its motion during maintenance operations by including an emergency stop button.

179 C-LST-CAM.0174 There must exist a mechanism to protect the photodetectors in case of Shutter motor or power failure.

180 C-LST-CAM.0171 The shutter will open and close in less than 30 seconds.

181 C-LST-CAM.0172 The shutter will open and close an average of 4 cycles/night.

182 C-LST-CAM.0180 | The allocated mass for the shutter is 100kg.

183 C-LST-CAM.0183 | The allocated Power consumption for the shutter motors and endswitches is 100W, only needed when moving.

184

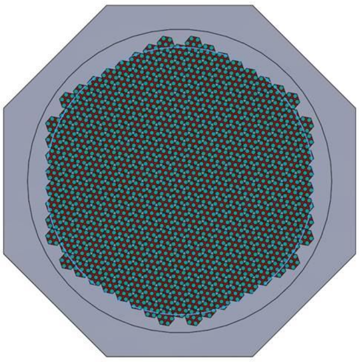
Photodetectors

186 C-LST-CAM.0201 | The active area of the LST camera will cover a circle of 2200mm diameter.

187 C-LST-CAM.0202 | The LST camera will have at least 1855 photodetectors.

188 C-LST-CAM.0232 | The photodetectors and corresponding electronics will be distributed in 265 clusters.

189 C-LST-CAM.0233 | The position and numbering of photodetectors and clusters will be according to LST-CAM/120427-3.



191 C-LST-CAM.0204 | The separation between the center of two photodetectors will be 50mm.

192 C-LST-CAM.0205 | The entrance window of the photodetector will be hexagonal and at least 49mm flat to flat.

194 C-LST-CAM.0207 | The dead space between photodetectors will be at most 1mm.

195 C-LST-CAM.0208 | The efficiency of the camera due to the dead space between photodetectors will be >96%.

199 C-LST-CAM.0212 | The transmittance of the Light Concentrator will be at least 83% for all incidence angles smaller than α_c (cutoff angle) and wavelengths in the range 300-550nm.

197 C-LST-CAM.0210 | The cutoff angle (α_c) of the Light Concentrator will be between 27 and 28 degrees.

201 C-LST-CAM.0228 | The maximum tilt of a photodetector relative to the optical axis of the camera will be less than 0.3 degrees.

202 C-LST-CAM.0229 | The maximum displacement from its nominal position of a photodetector, in any axis, will be less than 1mm.

203 C-LST-CAM.0230 | The depth of the the light concentrators from the tip of the photosensor, will be at most 65mm.

204 C-LST-CAM.0214 | The camera will use the Photonsensors (PMT) selected by the CTA collaboration.

205 C-LST-CAM.0220 | The Photon Detection Efficiency of the PMT will be at least 23% in the wavelengths in the range 300-550nm.

206 C-LST-CAM.0215 | The gain of photodetectors will be remotely adjustable.

207 C-LST-CAM.0216 | Camera will allow switching ON and OFF individual photodetectors remotely.

210 C-LST-CAM.0221 | The HV power supply for the photosensor will be able to provide any voltage from 0 to -1800V.

211 C-LST-CAM.0222 | The setting resolution for the HV power supply voltage will be 20V.

212 C-LST-CAM.0223 | The accuracy in the HV Power Supply for the photosensor bill be less than +/-10V.

213 C-LST-CAM.0224 | The voltage applied to each photosensor will be monitored and reported during operation.

214 C-LST-CAM.0225 | The DC component of the current on the anode of the photosensor will be monitored and reported during operation.

215 C-LST-CAM.0231 | The Photodetectors should suffer no damage in case of power failure.

216 C-LST-CAM.0226 | The nominal gain of the photosensor will be 40000.

217 C-LST-CAM.0219 | The mass of the light concentrators will be 22.2 gr/photodetector. This includes the light guide (17gr) and the plastic holder (5.2gr).

218 C-LST-CAM.0501 | The mass of the photosensor (PMT assembly) will be 95gr. This includes the PMT, the HV PS and Preamplifier.

219 C-LST-CAM.0227 | The mass of the HV PS for each photosensor is included in the photosensor mass.

220 C-LST-CAM.0234 | The mass of the Preamplifier board is already included in the photosensor mass.

221 C-LST-CAM.0235 | The mass of the FPI Slow Control Board will be less than 36 gr/pixel.

222 C-LST-CAM.0236 | The consumption of the HV PS of the photosensor is less than 35mW per unit.

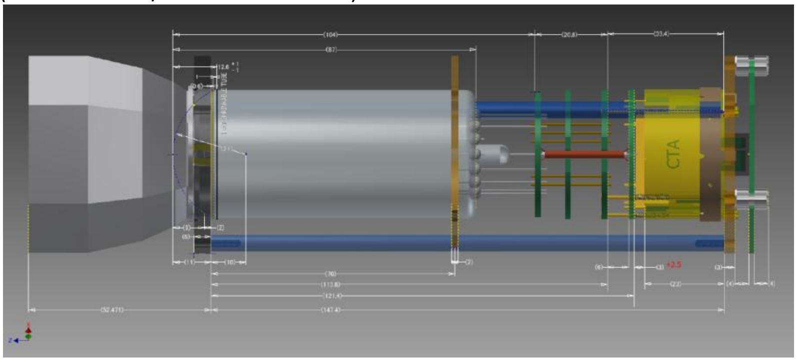
223 C-LST-CAM.0238 | The consumption of the FPI Slow Control Board is less than 2.5mW per unit.

224 C-LST-CAM.0237 | The Power consumption of the Preamp is less than 150 mW per unit.

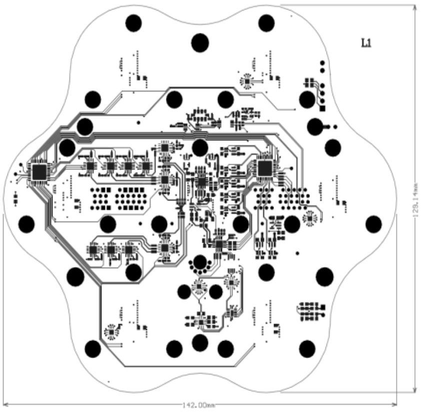
225 C-LST-CAM.0241 | The maximum DC current the HV power supply for the photosensor will be limited by design, so it will not be able to damage the sensor or associated devices in case the photosensor is illuminated continuously.

226 C-LST-CAM.0242 | The preamplifier board will no suffer any damage with the maximum amplitude pulses the photosensor is able to produce.

227 C-LST-CAM.0239 | The dimensions of the photosensor (PMT assembly) including HV PS and Preamplifier board are those (see LST-CAM/130228b for details).



228 C-LST-CAM.0240 | The dimensions of the FPI Slow Control board are those (see LST-CAM/130228c for details).



Signal Processing: Digitization

C-LST-CAM.0318 The digitization must be able to digitize the electrical signal from the photodetectors and send the samples to the analysis facilities.

C-LST-CAM.0300 The camera will be able to capture the signal on all photodetectors that received Cherenkov light from the event.

C-LST-CAM.0301 The charge range to measure, for each photodetector, will correspond to 0.2 to 1000 photoelectrons.

C-LST-CAM.0302 The error in the measured charge after calibration due to electronics non idealities will be less than 2%.

C-LST-CAM.0303 Cherenkov Photons arriving from a shower will be measured for at least 30ns after the arrival time of the first photon.

C-LST-CAM.0304 The Time Resolution of the camera will be better than 1ns.

C-LST-CAM.0305 Absolute time error (all camera), relative to GPS, must be <2 ns.

C-LST-CAM.0306 The readout electronics must support a readout rate of events of 10 kHz.

C-LST-CAM.0330 The fraction of the time that an individual telescope is unavailable for recording of events (due for example to inefficiency in data collection, transport and storage) during observations must be <8 %.

C-LST-CAM.0331 The fraction of time dedicated to calibration events while observing (interleaved events) will be <1%.

C-LST-CAM.0332 The fraction of time a telescope is unavailable due to data transfer efficiency and state change in the SW (i.e. new run) while observing will be <1%

C-LST-CAM.0307 Dead time of digitization and readout, during operation, will be <5%.

C-LST-CAM.0310 The LST camera will use Analog Memories to buffer the signal from the sensors.

C-LST-CAM.0311 The LST camera will sample the signal at 1Gsps.

C-LST-CAM.0312 The total noise introduced by the electronics after the PMT will be less than 0.2phe RMS.

C-LST-CAM.0313 The -3dB upper cutoff frequency of the Analog chain will be at 300 MHz.

C-LST-CAM.0315 The digitization electronics will be able to buffer the analog signal for at least 3500ns.

C-LST-CAM.0317 The width and the offset of the readout window will be remotely configurable.

C-LST-CAM.0321 The digitization will include the relative offset of the readout window to the global readout trigger in the event data of each pixel.

C-LST-CAM.0323 The Digitization will perform self-calibration operations on request. [TBC]

C-LST-CAM.0327 The sampling rate of the digitization will be remotely adjustable.

C-LST-CAM.0316 The allocated mass of the Readout Board is 30gr per photodetector (210gr per cluster).

C-LST-CAM.0328 The Power consumption of the Digitization (Readout Board) will be less than 1.364 W per photodetector (9.55W per cluster).

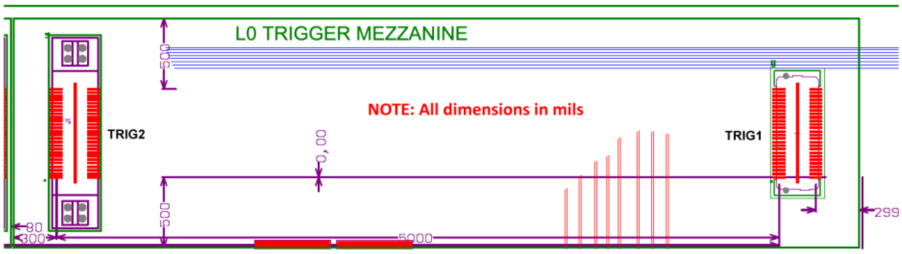
C-LST-CAM.0329 The size of the digitization board is 130x300 mm
(see LST-CAM/130226 for details)

Signal Processing: Trigger Decision

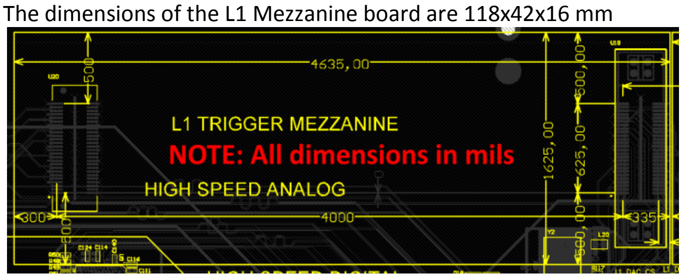
C-LST-CAM.0401 Trigger will keep operating and reporting triggers to array trigger even if readout is busy.

C-LST-CAM.0402 Information on the pixels (individual or group) that generated the camera trigger, for each event must be integrated in the event data stream. This needs the implication of both the Trigger and the digitization. The trigger must signal the digitization when a cell or a pixel has produced a trigger. When the digitization receives the readout signal, it must be able to identify that it corresponds to the signal it received before and include that information together with the data from the photosensor signal.

267	C-LST-CAM.0403	Trigger system will allow remote adjustment of its sensitivity (thresholds?).
268	C-LST-CAM.0404	Trigger system will allow disabling pixels (individual or group) (not producing a camera trigger).
269	C-LST-CAM.0405	Trigger will provide statistics on pixels rates to ACTL for testing purposes, not all at same time.
271	C-LST-CAM.0420	The trigger cover all the active area of the camera.
272	C-LST-CAM.0421	The value of the threshold image (50% detection probability) will be 50 phe.
273	C-LST-CAM.0422	The Camera Trigger will support rates of at least up to 100kHz.
275	C-LST-CAM.0424	The Trigger Efficiency and NSB rejection must not vary more than 10% during 60s (excluding stars and real gamma changes).
276	C-LST-CAM.0425	The combined latency of L0 and L1 trigger will be less than 50ns.
277	C-LST-CAM.0426	The power consumption of the L0 Mezzanine will be less than 300mW per channel.
278	C-LST-CAM.0427	The total mass of the L0 Trigger mezzanine will not exceed 7gr per photodetector.
279	C-LST-CAM.0437	The dimensions of the L0 Mezzanine board are 150x42x16 mm



280	C-LST-CAM.0428	The bandwidth of the L0 Sum Trigger will be larger than 350MHz.
281	C-LST-CAM.0429	The input signal will have an amplitude of 20 mV per phe.
282	C-LST-CAM.0430	The L0 should be able to manage up to 20 phe per channel.
284	C-LST-CAM.0432	The signal to noise ratio (S/N) at L0 Trigger input will be larger than 4.
285	C-LST-CAM.0433	The output noise of L0 Trigger will be less than 1 phe.
286	C-LST-CAM.0434	L0 Trigger will use SPI for its control.
287	C-LST-CAM.0435	The power consumption of the L1 Mezzanine will be less than 140mW per channel.
288	C-LST-CAM.0436	The total mass of the L1 Trigger mezzanine will not exceed 3gr per photodetector.
289	C-LST-CAM.0438	The dimensions of the L1 Mezzanine board are 118x42x16 mm



290 ## Signal Processing: Trigger and Clock Distribution

291 C-LST-CAM.0450 The maximum delay due to the internal trigger distribution (from any cluster to the coincidence unit and back) will be less than 300ns.

292 C-LST-CAM.0451 The Trigger distribution of a camera will be able to work in stand-alone mode or in coincidence with camera triggers from the rest of the LST array, through the Trigger Interface Board.

293 C-LST-CAM.0452 The Clock Distribution system will distribute two signals, a 1PPS signal and a 10MHz clock signal, to all clusters.

294 C-LST-CAM.0453 The inaccuracy of the clock signal distributed to any cluster, including jitter and skew, in relation to the external clock input, will be <200ps.

295 C-LST-CAM.0454 The clock and trigger distribution will able to bypass malfunctioning clusters.

296 C-LST-CAM.0455 The Clock and Trigger system will be used to identify the physical location and configure the clusters in the camera.

297 C-LST-CAM.0456 The power consumption of the Clock and Trigger distribution (backplane) is 350mW per channel.

298 C-LST-CAM.0457 The total mass of the Backplane will not exceed 25gr per photodetector.

299 ## Signal Processing: Stereo and External Triggers

300 C-LST-CAM.0419 Trigger Interface Board will be able to initiate the acquisition of the photodetector signal (trigger the camera readout) from different sources: Camera Trigger, External Trigger (i.e. Calibration, pedestals) and in coincidence with neighbour LSTs.

417 C-LST-CAM.0418 The Trigger Interface Board will allow different tirgger sources to be active at same time, allowing for interleaved calibration and pedestal events during datataking.

301 C-LST-CAM.0407 The Trigger Interface Board will notify the array trigger when the readout is triggered, including information if is a stand-alone Camera Trigger, coincidence with neighbours or Calibration / Pedestal triggered.

302 C-LST-CAM.0408 Trigger Interface Board will be able to adjust from remote commands, the global delay of the different trigger sources (Camera, external, etc…) to compensate for the different electrical signal and light travel times.

303 C-LST-CAM.0409 Trigger Interface Board system will allow remote switching ON/OFF each global trigger source.

305 C-LST-CAM.0413 The allocated Power Consumption for the Trigger Interface Board is 50W.

306 C-LST-CAM.0416 The allocated Power Consumption for the Array Trigger Board is 50W.

307 C-LST-CAM.0417 The Trigger Interface Board will implement a busy function that will supress triggering the camera readout for a configurable amount of time while the Readout Board is processing a previous trigger.

308 C-LST-CAM.0411 The Trigger Interface board will notify the Array Trigger about readout status (busy) even if the camera readout is not triggered.

309 ## Signal Processing: Camera DAQ

310 C-LST-CAM.0470 The Readout and Control of the clusters will be implemented in a single Ethernet bus. Standard twisted pair cables will be used inside the camera and optical fibers for the communication with the Camera Server.

311 C-LST-CAM.0471 The Readout bus will be able to support a continuous data rate of 80Mbps per cluster.

312 C-LST-CAM.0472 The Readout bus will be able to support an aggregate data rate of 20Gbps.

313 C-LST-CAM.0473 The MAC address of each cluster will be used as unique identificator.

314 C-LST-CAM.0474 The mass of the Ethernet Switches will not exceed 15kg.

315 C-LST-CAM.0475 The allocated Power consumption for the Ethernet Switches is 1000W.

316
Calibration Systems

317 The measure of the charge and time performed by the Digitization may have a number of non-idealities such as offset and non linearity. It is foreseen that some calibration procedures, which may include additional components, will be implemented in order to obtain the required final charge and time resolutions in the measurements. Nevertheless, the calibration needed will depend on the technology used on the Photo-detectors and Digitization so the definition of exact calibration procedures is left to the detailed camera implementations.
The telescope structure tolerances and deformations make necessary an accurate measurement of the position of the camera. This will be performed by a system external the camera and it may change considerably for each telescope type. Nevertheless, the camera must provide some reference markers that can monitored through external devices like CCD cameras to calculate its position.

318 C-LST-CAM.0600 Camera will include calibration system and procedures in order to achieve the required performance.

325 C-LST-CAM.0605 The mass of the devices for the calibration of the electronics will not exceed 15kg.

326 C-LST-CAM.0606 The mass of the devices for the measurement of the camera positioning will not exceed 15 kg.

399
Reference LEDs

320 C-LST-CAM.0602 The camera will include 12 reference LEDs, placed in a circular pattern at the frontal side of the camera, as represented in the following picture:

321 C-LST-CAM.0603 The reference LEDs can be placed behind the shutter and they don't need to be visible when the shutter is closed.

327 C-LST-CAM.0609 The allocated Power Consumption for the Reference LEDs is 25W.

401 C-LST-CAM.0611 At least 4 reference LEDs need to be visible when the SIS (Star Imaging Screen) is used.

402 C-LST-CAM.0612 The wavelength of the reference LEDs must be between XXX and XXX nm.

403 C-LST-CAM.0613 A failure on a single reference LED will not produce a failure on the remaining ones.

322 C-LST-CAM.0604 The intensity of the reference LEDs, as well as switching them ON/OFF, will be remotely controllable.

323 C-LST-CAM.0164 The camera will include a remotely operable Star Imaging Screen (SIS) that will cover the central part of the front side of the camera.

324 C-LST-CAM.0165 The postion of the SIS should be 80 mm (±Xmm) in front of the camera focal plane.

406 C-LST-CAM.0190 The size of the SIS (Star Imaging Screen) will be at least 500x500 mm.

407 C-LST-CAM.0191 The targets for AMC must have a reflectivity >XX% for wavelengths between XXXX and XXXXnm.

408 C-LST-CAM.0192 The SIS must be moveble to the side of the camera (or big enough) so it can be used for absolute reflectivity measurements.

328
Calibration Light Source

329 The Calibration Light Source will generate light pulses that iluminate the camera homogeneously in order to calibrate the photodetectors, the trigger and the digitization electronics. The Calibration Light Sources will generate triggers synchronous to the light pulses and also pedestal triggers for the camera.
The possibility to use dual wavelengthslaser will be examined.
The need of random pedestal triggers will be examined too.

330 C-LST.1001 The width of the light pulse will be less than 2ns FWHM.

331 C-LST.1002 The wavelength of the light will be between 300 and 400 nm.

332 C-LST.1003 The Light Source will iluminate a circle of 2.4m diameter at 28 meters.

333 C-LST.1004 The Uniformity of the Light source will be < 2%.

334 C-LST.1005 The Intensity of the light source will be adjustable within a range corresponding to 0.2 to 1000 phe per photodetector.

335 C-LST.1006 The light source will be able to generate light pulses with at least three different intensities settings between 1 and 20 phe.

336 C-LST.1007 The standard deviation of the Light Pulses intensity, on a period of 30 minutes, will be less than 5%.

337 C-LST.1008 The Light Source will generate its own trigger pulses.

338 C-LST.1017 The rate of light pulses will be betwheen 1 and 2000 Hz.

339 C-LST.1009 The rate of light pulses and number of pulses (or continuous pulsing) will be remotely configurable.

340 C-LST.1010 The Light Source will provide a Trigger signal to the Camera that can be remotely switched on and off.

341 C-LST.1011 The width of the digital trigger output will be at least 10 ns.

342 C-LST.1012 The jitter of the trigger output, relative to the light pulse, will be around 200ps RMS.

343 C-LST.1018 The Calibration Light Source will also generate pedestal triggers with a configurable rate and number of pulses for the camera.

344 C-LST.1019 The rate of the pedestal triggers will be up to 8 kHz.

345 C-LST.1013 The Calibration Light Source will be remotely switched on and off.

346 C-LST.1014 The Calibration Light Source will monitor its internal environment conditions (T/RH).

347 C-LST.1015 The Calibration Light Source will monitor the rate and intensity of the generated light pulses.

348 C-LST.1016 The Calibration Light Source will monitor its status and report failure status.

349 C-LST.1020 The Calibration Light Source will use standard AC 230V 50/60Hz power.

350 C-LST.1021 The Calibration Light Source will be remotely controlled using OPC/UA protocol on Fiber Optic Ethernet.

351 C-LST.1022 The Calibration Light Source will be installed at the center of the dish.

352

Auxiliary Systems: Power Supplies

353 C-LST-CAM.0620 The standard voltage used in the Power distribution of the camera for all devices including clusters, trigger boards, LEDs, shutter and network devices, will be 24V.

355 C-LST-CAM.0506 The main camera Power Supply will be 3 P+N+E 400V AC.

356 C-LST-CAM.0507 Camera must be able to operate with Voltage is stable within xx %, frequency within xx %.

357 C-LST-CAM.0622 The maximum ripple on the LV Power Distribution will be 1%.

358 C-LST-CAM.0623 The maximum long term variations (temperature drifts, load dependance etc) of the LV Power distribution will be 2%.

359 C-LST-CAM.0624 The efficiency of Low Voltage Power supplies and cabling will be 90%.

360 C-LST-CAM.0625 The mass of the Low Voltage Power supplies will be less than 15kg.

361 C-LST-CAM.0626 The Low Voltage Power Supplies will include protections against shorts, overloads and transients.

362 C-LST-CAM.0627 The mass of the Electrical Protection devices will be less than 5kg.

363 Auxiliary Systems: Environmental Control

364 The aim of Environmental Control is to ensure that all other camera components operate in optimal conditions but it must also reduce thermal shocks during day-night cycles and other variations of external and internal conditions to prevent early degradation of components.

365 C-LST-CAM.0650 The camera will have a dedicated environmental control qualified for high altitude that will ensure all components remain at a stable temperature within its nominal range in all modes besides OFF.

391 C-LST-CAM.0663 The Camera Environment Control will keep operating functionalities within an external temperature range between -20 to 40 °C.

392 C-LST-CAM.0664 The Camera Environment Control will keep operating functionalities within an external temperature gradient of 7.5 °C/h.

366 C-LST-CAM.0651 Environmental Control must minimize temperature changes due to switching on camera or varying external conditions.

367 C-LST-CAM.0652 The Camera Environmental Control System will measure and report the temperature and relative humidity inside camera body.

368 C-LST-CAM.0653 The Camera Environmental Control System will report its status and possible failures.

370 C-LST-CAM.0656 The maximum mass of the Camera Environment Control system, in the focal plane of the telescope, is 200kg.

409 C-LST-CAM.0665 The maximum mass for the external chiller for the Camera Environment Control system (not in the focal plane of the telescope is 600kg,

371 C-LST-CAM.0657 The environment control system will be operating during all day to prevent sudden changes inside the camera.

372 C-LST-CAM.0607 After stabilization, the temperature inside the camera should not vary more than +/-3 °C.

373 C-LST-CAM.0608 The maximum temperature diffence between two any points of the front end electronics will be 10 °C.

374 C-LST-CAM.0658 The temperature inside the camera will be stable 30 minutes after starting transition from Standby to Ready Mode.

375 C-LST-CAM.0659 The Cooling system will be able to handle the heat generated inside the camera, up to 7kW.

376 C-LST-CAM.0660 The allocated Power consumption for the Cooling Devices in the camera (Fans, AC units, electrovalves) is 500W.

390 C-LST-CAM.0662 The allocated power consumption for the extenal devices for the camera environment control (chiller) is 3000W.

377 C-LST-CAM.0661 The environment control system will prevent humidity inside the camera to exceed 65%.

378 Auxiliary Systems: Slow Control

379 As with the rest of the systems in the CTA telescopes, the camera will be operated remotely; direct intervention on the camera should only be needed for regular maintenance or repairs. The status and configurable settings of all components (some of them already listed on the requirements above) must be accessible from the central Array Control. It is left to each camera detailed design whatever the access to camera configuration is centralized through a Camera Server or specific Slow Control PLCs or if components with interfaces directly compatible with CTA Array Control are used. Slow control refers to any control loop between the camera components and the CTA Array Control. In addition, the Slow Control should include safety functions that protect the camera in case a failure in critical components is detected or suspected, even if Array Control is not available.

380 C-LST-CAM.0700 Camera must support full remote control and monitoring.

381 C-LST-CAM.0701 Camera will be able to power on and off remotely (except basic safety systems that will always be on).

382 C-LST-CAM.0702 Camera will provide means to remotely evaluate its performance / status.

383 C-LST-CAM.0703 Camera will report Voltages, Currents and status for the Power Supplies in the camera.

384 C-LST-CAM.0704 Slow Control will be able to automatically switch off Camera if dangerous temperature / humidity or any water inside the camera body is detected.

385 C-LST-CAM.0705 Slow Control will be able to automatically switch off the rest of the Camera in case of overcurrent or overvoltage.

386 C-LST-CAM.0706 Slow Control will be able to automatically switch off Camera and close shutter (go to Standby mode) when operating remotely in case communication with Array Control is not available for more than 1 minute.

387 C-LST-CAM.0707 Camera will be able to report communication errors in any component.

388 C-LST-CAM.0708 The mass of the Embedded Controller will be less than 10kg.

389 C-LST-CAM.0709 The allocated Power consumption for the Camera PLC (or equivalent device) and associated modules (PS, expansion modules, etc…) is 200W.