SST Camera: Engineering Development & Verification Plan

SST-CAM-PLA-009

Version 1.c

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1a	20/10/2022	Initial Version	GG, RW	R. White
1b	17/11/2022	Completed sections 7,8,9 with	SST Programme	G. Giavitto

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1. Introduction

1.1 Scope & Purpose

This document describes the plan for completing SST Camera (SST-CAM) instrument engineering work **prior to the series production of SST Cameras**, namely: finalisation of the camera design, verification of that design, and technical preparation for the series production of cameras.

The development of camera software will be covered in a dedicated document. The camera series-production plans will either be covered in separate document, or this document will be extended.

1.2 Context

This document flows from the SST Programme Management Plan [AD1] and forms part of the documentation specified in the SST Programme Configuration and Data Management Plan [AD2].

The work describer takes place in the SST **Bridging Phase** (SST-BP) and the **Design Consolidation Phase** (SST-DCP). The timeline for this work is shown in Figure 1. Prior to the Production Phase there are several reviews foreseen following the SST DVER (Design & Value Engineering Review) that took place in 2020 [RD1]. All reviews will result in RIX (Review Item Discrepancy, Question or Comment) that will need to be addressed prior to series production.

- **Product Review (PR):** Acts as a gateway from the SST-BP to the SST-DCP. The PR is internal to SST with invited CTAO participation.
- **Camera Critical Design Review (CDR):** A CTAO led review of the Camera design.
- **SST Critical Design Review (CDR):** As per the Camera CDR, but on the overall SST level, considering previous RIX, but not revisiting previously approved elements. Passing the CDR results in acceptance of the design for inclusion in CTAO.
- **Production Readiness Review (PRR):** A CTAO led review of the production plans and the onsite AIV plans. Passing the PRR results in the start of the Production Phase. Currently foreseen to be undertaken jointly on the Structure and Camera.

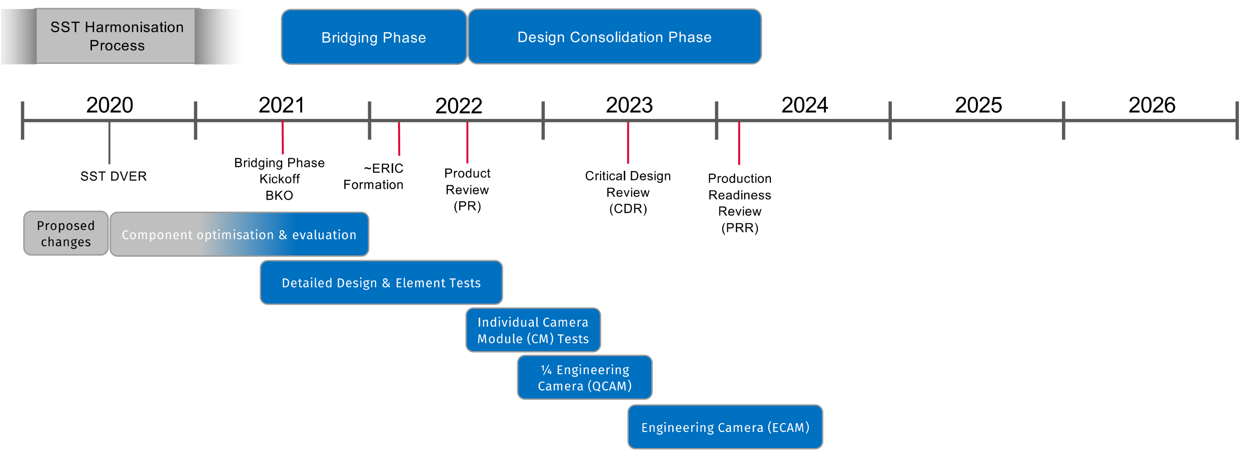

Figure 1: SST Camera design finalisation timeline (as constructed at the BKO).

1.3 Applicable Documents

[AD1] SST Programme: Management Plan (SST-PRO-PLA-001)

[AD2] SST Programme: Configuration and Data Management Plan (SST-PRO-PLA-002)

[AD3] SST Camera Product Breakdown Structure (SST-CAM-PM-001) (link)

1.4 Reference Documents

[RD1] CTA-SST Engineering Review Panel Report, 03 Sep. 2020 (link)

1.5 Abbreviations

AIT	Assembly Integration and Testing
AIV	Assembly Integration and Verification
ASIC	Application Specific Integrated Circuit
ASTRI	Astrophysics with Italian Replicating Technology Mirrors
BKO	Bridging phase Kick-Off
BP	Backplane
CDR	Critical Design Review
CHEC-M	CHEC – MAPM version
CHEC-S	CHEC- SiPM version
CM	Camera Module
CMT	Camera Maintenance Tools
COTS	Commercial Off-the-Shelf (Product)
CSS	Camera Support Systems
CSW	Camera Control Software
CTA	Cherenkov Telescope Array
CTAO	Cherenkov Telescope Array Observatory
CU	Camera Unit
DVER	Design Verification Engineering Review
ECAM	Engineering Camera
FoV	Field of View
FPE	Focal Plane Electronics
GCT	Gamma Cherenkov / GATE-CHEC Telescope
ICD	Interface Control Documents
IKC	In Kind Contribution
KO	Kick-Off
MAPM	Multi-anode Photomultiplier
MCAM	Mechanical Camera
MS	Milestone
PBS	Product Breakdown Structure
PM	Project Manager
PMMA	Polymethyl methacrylate
PR	Product Review

PR	Product Review
PRR	Production Readiness Review
QBP	Quarter Backplane
QCAM	Quarter Camera
QM	Quality Manager
RAMS	Reliability, Availability, Maintainability & Safety
RIX	Review Item Discrepancy, Question or Comment
SiPM	Silicon Photomultiplier
SST	Small Size Telescope
TM	TARGET Module
VCD	Verification Control Document
VCM	Verification Compliance Matrix
VMX	Verification Matrix
VSD	Verification Specification Document

2. SST Camera Overview

The SST Camera forms the detector element of the CTA Small-Sized Telescopes (SSTs). The SSTs offer an opportunity to provide CTA with unprecedented sensitivity and the highest angular resolution of any instrument operating above X-rays. To achieve this many SSTs are required. An optimal SST camera is therefore low-cost, reliable and easily maintainable. Such a camera should have a large FoV (to capture large and off-axis images), have fine pixelisation (to resolve small images and isolate signal from background) and have a large readout window (to fully contain images with a large time gradient).

The SST Camera contains 2048 pixels instrumented by 32 tiles each containing 64 SiPM 6×6 mm^2 pixels. Tiles are arranged in the focal plane to approximate the radius of curvature resulting from the telescope optics. Each tile is connected to a set of Focal Plane Electronics (FPE) and a TARGET Module (TM); to provide SiPM control and monitoring, pulse-shaping & amplification, digitisation (using TARGET CTC ASICs) and the first level of triggering (using TARGET CT5TEA ASICs). All TMs are connected to a single backplane (BP) that provides the camera-level trigger and a 10 Gbps connection for raw data. An array-wide White Rabbit system connected inside the camera provides absolute timing. The camera includes an illumination system to provide calibration via fast, variable intensity, flashes. An entrance window and external door system provide protection from the elements. Thermal control is via an external chiller. Fans internal to the camera circulate the resulting cooled air. The camera is hermetically sealed and a breather-desiccator maintains an acceptable level of humidity.

The SST Camera is being developed by an international team, consisting of: U. Adelaide (AUS), U. Amsterdam (NL), DESY (DE), Durham U. (UK), ECAP (DE), U. Groningen (NL), U. Leicester, U. Liverpool, MPIK (Germany), Nagoya U., and U. Oxford (UK).

The high-level camera Product Breakdown Structure (PBS) is shown in Figure 2 [AD3]:

- **Camera Unit (CU):** The physical camera, as mounted in the focal plane of the SST.
- **Camera Support Systems (CSS):** All elements needed to support the CU, installed on/at the SST, including cabling, pipework, the camera chiller.
- **Camera Control Software (CSW):** Any and all software needed for the control, readout, and monitoring of the CU & CSS, installed on the CTAO computing farm.
- **Camera Maintenance Tools (CMT):** Any and all items needed onsite by CTAO to access and maintain the CU, CSS, CSW, not provided by CTAO.

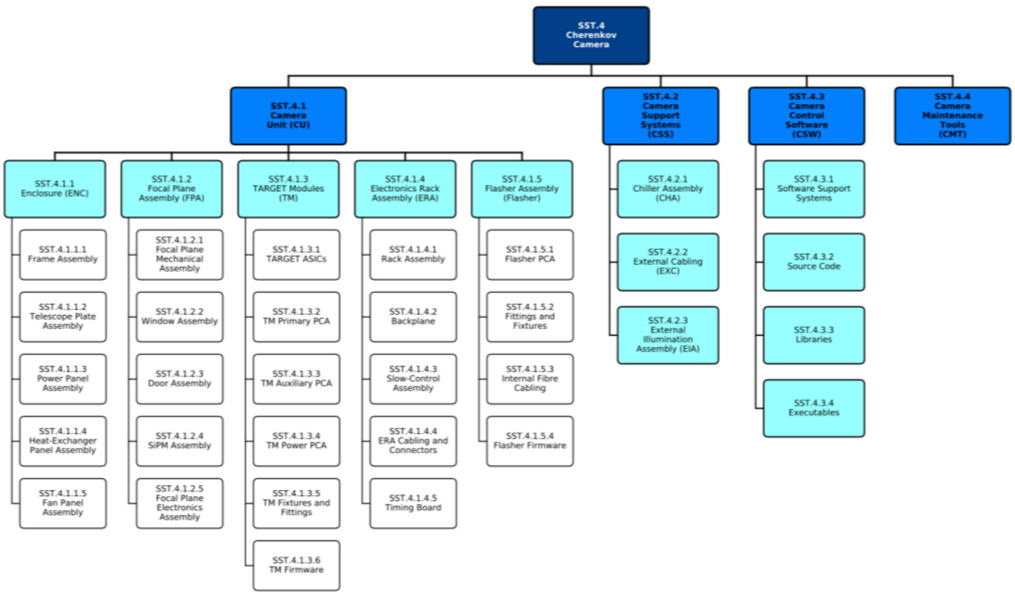

Figure 2: SST Camera Product Breakdown Structure

3. SST Camera Development Status

Two SST Camera prototypes have been built and tested. The first, CHEC-M, was based on multi-anode PMTs (MAPMs) and served as a proof of principle of the digitisation, trigger, control and readout systems. CHEC-M underwent extensive lab tests and was deployed on the GCT prototype structure in Meudon, where it was used to record the first Cherenkov images seen by a CTA prototype. CHEC-M is fully described in [RD03].

The second prototype camera, CHEC-S was based on SiPMs (the chosen sensor technology for the SST Camera). CHEC-S used Hamamatsu S12642-1616PA-50 SiPMs. Each 6 x 6 mm^2 camera pixel is made up by combing four 3 x 3 mm^2 pixels. SiPM technology moves quickly, and the CHEC-S devices rapidly became outdated. The final SST Camera will be based on the lasted available SiPM technology offering increased performance. The FEE modules are under iteration to include a re-optimisation of the pulse-shaping circuit for use with the new SiPMs. The BP is also being iterated to directly include the functionality of XDACQ board (and potentially the timing board). The slow control and power distribution system used in CHEC-S was an early prototype. An iteration is underway to improve easy of assembly, maintainability and reliability. The camera thermal control and mechanical system is undergoing a revision increase cooling capacity. The CHEC-S camera window, which was curved to follow the camera focal plane, was made from uncoated PMMA. The final window will be flat glass with a multi-layer coating to maximise Cherenkov signal transmission whilst minimizing contamination from the night sky.

Table 1 summarizes the current Technical Readiness Level (TRL) of the camera elements.

Table 1: Technical readiness of camera elements.

	TRL	Technical Work to be Done	COTS / Custom
Camera Unit			
ENC	4	Build, test, revise as needed	In-house mechanics, COTS power supplies
FPA			
FP Mechanics	4/5	Complete production, test with ENC	In-house mechanics
Window	6	Consistency testing (multiple windows)	In-house mechanics, custom glass coating
Doors	5	Detailed FW development & test	In-house mechanics, COTS motors
SiPMs	4/5	Receive from HPK, test	Custom from HPK (based on COTS)
FP Electronics	4	Produce, test, revise if needed	Custom, production in industry
TM			
TARGET ASICs	6	Receive latest run, test	Custom, production in industry
TM PCAs	3/4	Complete detailed design, build, test	Custom, production in industry
ERA			
Rack	4	Build, test, revise as needed	In-house mechanics
Backplane	3	Complete QBP FW & tests, extend to BP, build, test	Custom, production in industry
Slow-Control Assembly	4	Produce, complete FW, test, revise	Custom, production in industry
Timing Board	6	Integrate functionality into BP	Custom, production in industry
Flasher	3	Complete v4 design, build, test	Custom, production in industry
Camera Support Systems			
Chiller Assembly	5	Test & decide between two procured options	Customised by company (based on COTS)
External Cabling	3	Define routing and hose cladding	COTS
External Illumination	3	Define fibre & routing, test mock-up	COTS components, in-house assembly

Level 1	Prototype tested in full camera (CHEC-M/S)	Level 6	Engineering model tested
Level 2	Design meets critical requirements	Level 7	Engineering model tested in full camera
Level 3	Design revisions defined	Level 8	Design verified
Level 4	Detailed design complete	Level 9	RAMS complete
Level 5	Engineering model built	Level 10	Series Production documentation complete

4. Model Philosophy

The approach to finalisation of the SST Camera is shown in Figure 3 including engineering development and verification steps.

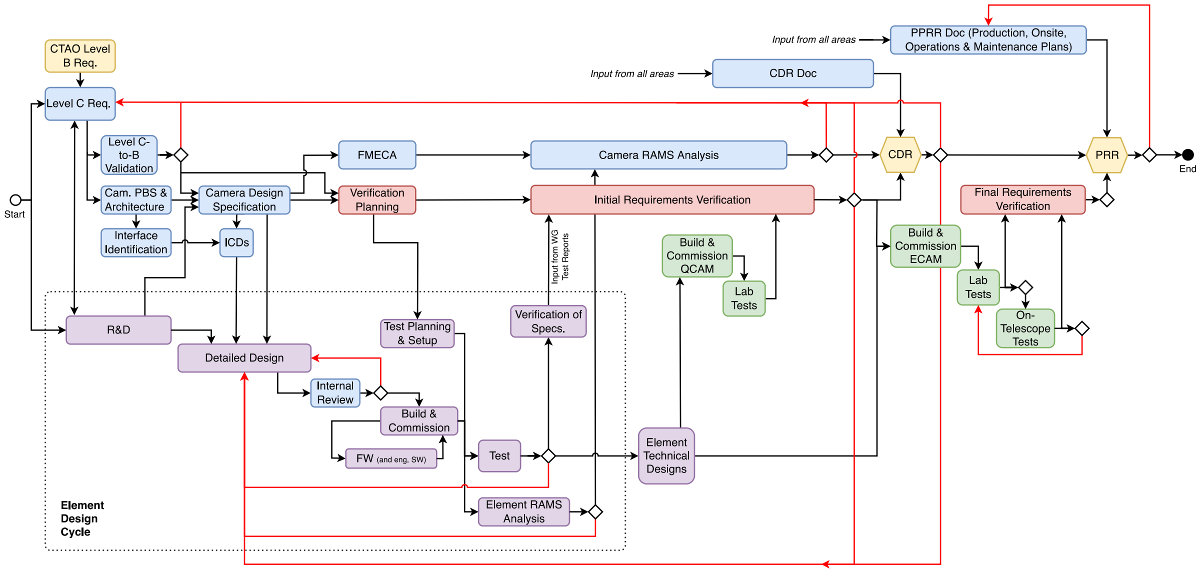

Figure 3: SST Camera design finalisation flow. Note: the PR may be thought of as a preliminary-CDR in this scheme, looping back as needed before the CDR.

In order to efficiently verify the camera design in stages, a model philosophy has been developed consisting of the following elements:

- Mathematical Models
    - Camera Monte Carlo Model
    - Camera Thermal Model
    - Camera CAD Model
    - Camera Structural Model
- Testable Elements
    - Window (WIN)
    - Camera Modules (CM) (Mini-window, SiPM tile, FPE, TM)
    - TARGET Modules (TM)
    - ¼ Backplane (QBP), then full BP
    - Chiller
    - Flasher
    - Slow-Control Assembly (SCA)
    - Door Bench Assembly
- Mechanical Camera (MCAM)
    - Consisting of a window, Focal Plane Mechanics and Enclosure
- ¼ Camera (QCAM)
    - Consisting of a full set of mechanics, working doors, SCA, and 8 of 32 SiPM tiles, FPE, and TMs connect to the QBP.
- Engineering Camera (ECAM)
    - First full Cherenkov camera.
- ECAM-On-Telescope
    - The Engineering Camera install on a prototype telescope structure.

This philosophy then sets the basis for the development path and shown in Figure 4, and further elaborated in Section 5 as well as the verification approach presented in Section 6. At various stages there exists the opportunity for design review and iteration.

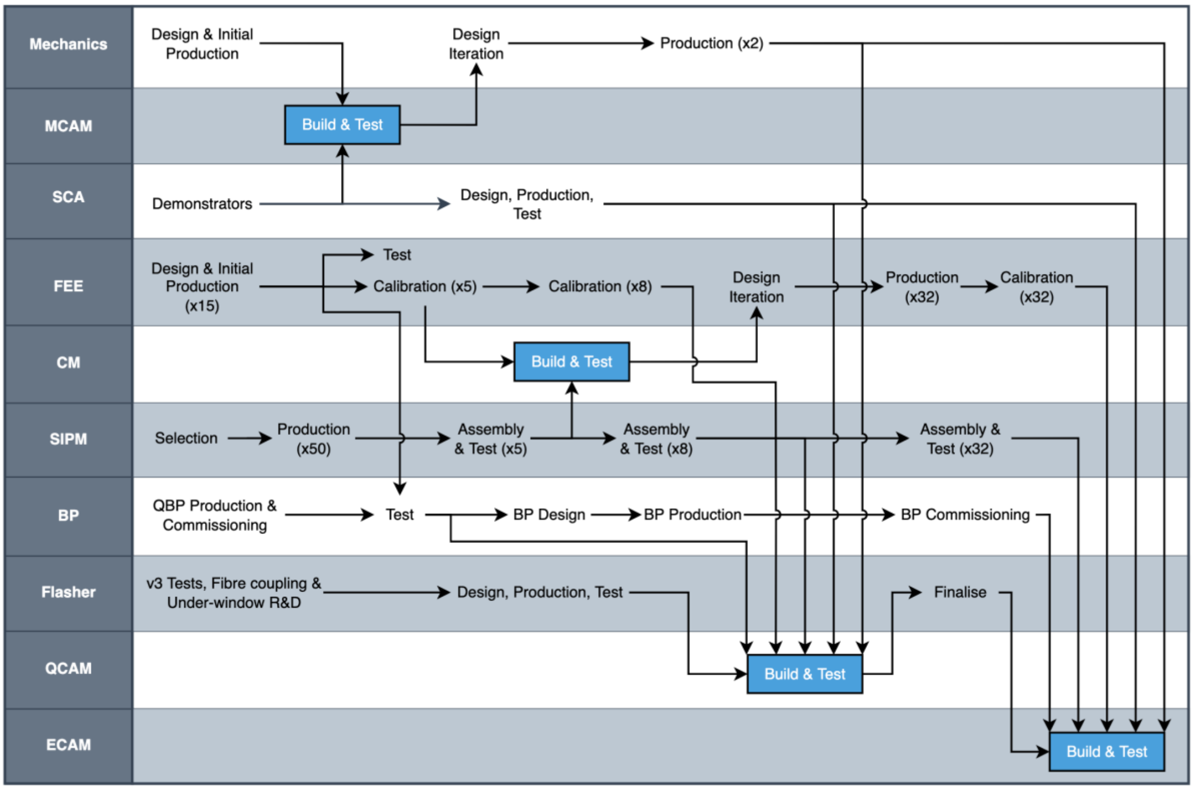

Figure 4: Technical development path following the model philosophy for the SST Camera.

5. Development Plan

This section outlines the plan to achieve design finalisation following the engineering approach / model philosophy presented in the previous section, including development responsibilities, milestones, deliverables, key technical decisions and current schedule.

5.1 Responsibilities

Table 2 indicates the design finalisation responsibilities as mapped between PBS items and institutes. All teams will contribute to design-verification work through simulations, analysis and instrument commissioning for QCAM & ECAM. AIT / AIV of QCAM and ECAM will take place at MPIK using elements delivered by institutes following the responsibility matrix.

Table 2: SST Camera design finalisation responsibilities.

PBS Item	Institute										
	MPIK	DESY	ECAP	UoLE	UoLI	UoOx	DrU	NgU	UoAD	UvA	UGr
Camera Unit											
ENC	**Lead**			Assist							
FPA											
FP Mechanics	Assist			**Lead**							Assist
Window	Assist			Assist			**Lead**				Assist
Doors	Assist			Assist	**Lead**						Assist
SiPMs				**Co-Lead**				**Co-Lead**			Assist
FP Electronics				**Lead**		Assist					Assist
TM											
TARGET ASICs			**Lead**					Assist	Assist		
TM PCAs			Assist	**Lead**							
TM Firmware			**Lead**								
ERA											
Rack		**Lead**		Assist							
Backplane		**Lead**									
Slow-Control Assembly	**Lead**										
ERA Cabling & Con.		**Lead**									
Timing Board		**Lead**									
Flasher	Assist			Assist			**Lead**				
Camera Support Systems											
Chiller Assembly	Assist								**Lead**		
External Cabling	**Lead**			Assist							
External Illumination	Assist						**Lead**				

5.2 Design-Finalisation Milestones

The SST Camera design-finalisation milestones (MS) are shown in Table 3.

Table 3: SST Camera design finalisation milestones.

ID	Milestone	Description	External Dep.	Baseline Date	Current Estimate	Actual Date
M1.01	**Design Finalisation Starts**	Nominal start date for tracking the finalisation of the camera design. Project scope is agreed and SST BKO has occurred.	SST (BKO)	13/09/21	13/09/21	13/09/21
M1.02	**Prelim. IKC Distribution Agreed**	A draft distribution of IKC is internally agreed between the CB.	CTA (Money Matrix)	08/10/21	08/10/21	08/10/21
M1.03	**SiPM Selection Made**	Candidate SiPMs have been evaluated and a choice has been made and approved by the CB.	-	08/10/21	08/10/21	22/10/21
M1.04	**QBP Produced**	QBP populated and on bench ready for commissioning.		07/11/21	25/01/22	25/01/22
M1.05	**First FPE & TM Produced**	Initial FPE and TM design complete, reviewed, ordered and delivered.		08/06/22	31/01/23	
M1.06	**Mechanical Camera (MCAM) Built**	Camera mechanics, fans, heat exchanger, power supplies, doors and some form of control assembled and ready for test.		27/06/22	15/01/23	
M1.07	**First Full BP Ordered**	QBP design has been evolved to the full BP, the design has been reviewed and an order for full BPs has been placed.		07/09/22	TBD	
M1.08	**PR**	The date of the SST internal Product Review. Preliminary documentation should be prepared in advance.	SST	05/09/22	16/02/23	
M1.09a	**Initial SiPMs Delivered**	First set of SiPMs delivered, mounted on PCBs.	HPK	30/09/22	30/01/23	
M1.09b	**Final SiPMs Delivered**	Remaining ECAM (and spare) SiPMs delivered, mounted on PCBs.	HPK	13/03/23	TBD	
M1.10	**CM AIT Begins**	Several copies of TMs, SiPMs and FPE are commissioned and available to be assembled into full Camera Modules (CM)s along with holding / cooling mechanics and a single-CM window. A SW release is due at this point.	-	17/06/22	TBD	
M1.11	**QCAM Built**	The QCAM is built from pre-tested sub-assemblies, consisting of: a full enclosure, focal plane mechanics, doors, window, rack, SCA, TB, QBP, Flasher, and 8 x (SiPMs, FPE, TM). All HW is delivered with working FW. A SW release is due at this point.	-	02/09/22	TBD	
M1.12	**ECAM TM & FPE Ordered**	Following lessons learnt from CM AIT, the FPE and TM design is updated, reviewed, and a full camera's worth ordered.		01/11/22	TBD	
M1.13	**First Full BP Produced**	BP populated and on bench ready for commissioning.	-	01/12/22	TBD	
M1.14	**IKC Agreements in Place**	All funding is in place, the scope of the project is confirmed, the IKC distribution is agreed and the IKC agreements are signed. All plans required for the Production Phase are complete. Updates in accordance with PRR RIX are still possible.	SST, ERIC, Funding Agencies	01/04/23	TBD	
M1.15	**ECAM Built**	The full ECAM is built from pre-tested elements and sub-assemblies. ENS documentation is provided along with the HW deliverables. All HW is delivered with working FW. A SW release is due at this point.	-	10/02/23	TBD	
M1.16	**CDR**	The date of the SST Camera Critical Design Review. Preceded by a documentation preparation step. Followed up with RIX. The CDR requires that the QCAM is fully tested. The design has been verified. The SE FMECA and RAMS process is preliminarily complete and documented.	SST, CTAO	11/07/23	TBD	
M1.17	**ECAM Installed on Telescope**	Essential ECAM lab tests are complete. The camera is transported to site, prepared, mounted on telescope and functionally checked ready for observations. A SW release is due at this point.	-	08/09/23	TBD	
M1.18	**PRR**	The date of the SST Camera Production Readiness Review. Existing documents are collated and summarised ready for the PRR, including productions plans, updates to the PMP, all pre-shipment AIT/V procedures and on-site plans. All review RIXs required for design acceptance are addressed and CTAO has accepted the design.	SST, CTAO	15/01/24	TBD	
M1.19	**Design Finalisation Complete**	Extended element and camera testing is complete. All required work with the ECAM is complete including all outstanding data analysis and 'rehearsals' of production AIV procedures. The PRR RIX resolutions have been accepted and CTAO gives the green light to start Series Production.	-	22/03/24	TBD	

5.3 Design-Finalisation Deliverables

The project design-finalisation deliverables are shown in Table 4.

Table 4: SST Camera design finalisation deliverables.

ID	Deliverable	Description	Due @ Milestone	Responsible WG	Status
D1.01	**PR Pack**	All documents and material needed for the Product Review. This pack will consist of documentation focussed on the requirements and interfaces, along with several updated DVER documents.	M1.08	WG-PM	Outstanding
D1.02	**QCAM**	A full set of camera mechanics partially populated with photosensors, front-end and backend electronics, including firmware.	M1.11	WG-TD	Outstanding
D1.03	**IKC Documentation**	The IKC Agreement(s) and associated documentation.	M1.14	WG-PM	Outstanding
D1.04	**ECAM**	A fully built camera (including firmware), ready for commissioning, testing, and use on an SST telescope.	M1.15	WG-TD	Outstanding
D1.05	**CDR Pack**	All documents and material needed for the Critical Design Review. Includes all technical design files.	M1.16	WG-PM	Outstanding
D1.06	**PRR Pack**	All documents and material needed for the Product Review. The documents in this review will focus on production and deployment plans.	M1.18	WG-PM	Outstanding
D1.07	**Camera SW**	The Camera SW ready for (preliminary) deployment on-site.	M1.19	WG-SW	Outstanding

5.4 Key Technical Decisions

Several key decisions are required on the path to completing the camera design as shown in Table 5.

Table 5: SST Camera key technical decisions.

ID	Decision	Description	Target Date	Actual Date	Decision Made
KD1.01	**SiPM Choice**	Choice of SiPM made, with the intension that the specified devices are used during serial production (barring problems).	Oct-21	Oct-21	Hamamatsu, LVR3, 6 mm, 50 µm, uncoated
KD1.02	**Window Coating Choice**	Initial window coating choice made. Multiple options can be selected for test with ECAM, but one must be chosen for use in Prod-6 MC.	Mar-22	Mar-22	"Run 3"
KD1.03	**Chiller Choice**	Initial chiller choice to be procured and tested.	Mar-22	Mar-22	LaserChill & Thermex
KD1.04	**Flasher Location**	The choice to include a flasher behind M2, vs running a fibre from the camera vs flashing at M2, and whether M2 will have a hole in the centre vs uncoated glass.	Apr-22	Sep-22	Hole to be made in M2, flasher to be fibre coupled
KD1.05	**Under-Lid Flasher Geometry**	Preliminary decision as to the location and orientation of the scintillating fibre located under the entrance window.	May-22	Aug-22	Closest candidate groove to the glass, coupled with a matt-white internal door paint.
KD1.06	**PSU Location**	Following an initial choice to attempt to include the PSUs inside the camera, this decision marks whether that is successful, or whether work is needed to accommodate them outside of the camera.	Mar-23		
KD1.07	**Timing Solution**	Whether to adopt the 7-Sol timing board, or integrate a WR node into the Backplane.	Jan-23		

5.5 Current Schedule

An overview of the current SST Camera Project schedule for the completion and verification of the camera design is shown in Figure 5.

Note: the schedule is updated regularly and the progress indicated in the snapshot below should not be assumed up to date.

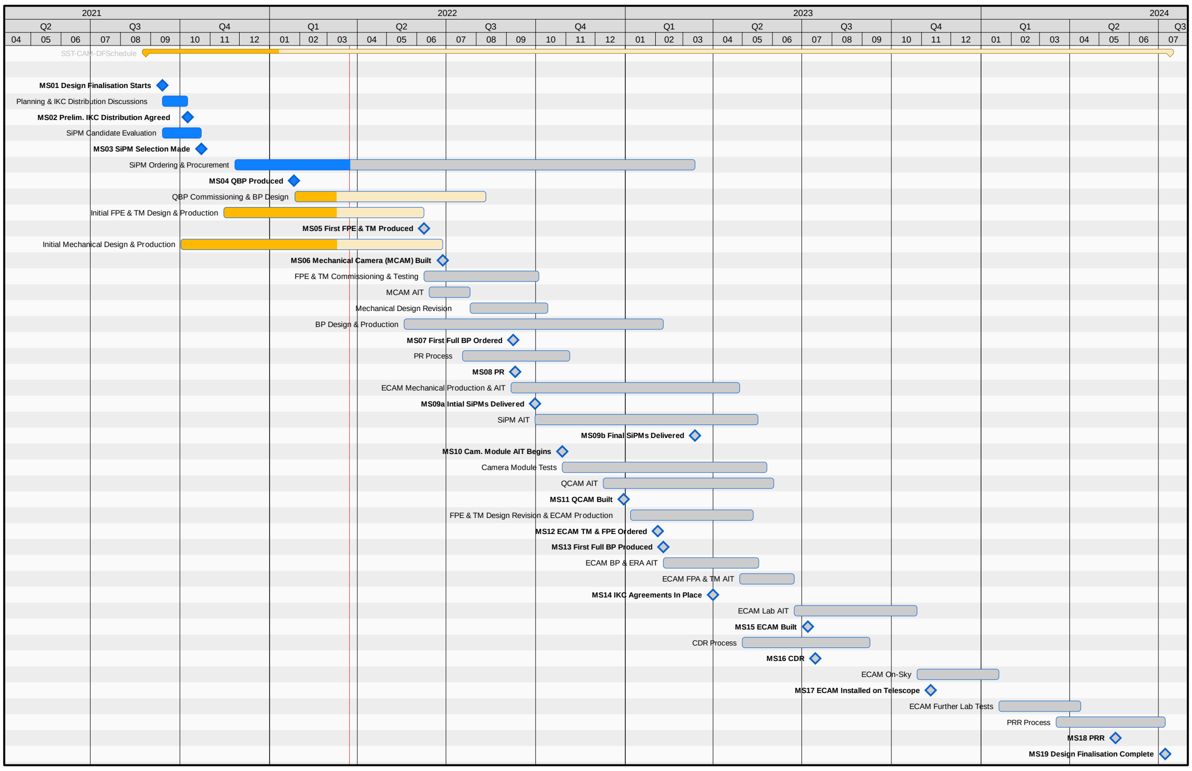

Figure 5: Snapshot of the camera schedule overview.

5.6 Internal SST Camera Technical Reviews

As recommended by the SST DVER panel [RD1], internal reviews for all major camera elements will take place during the finalisation of the design. Reviews are planned following a design cycle, prior to fabrication. Each review is tailored to the items under review and will follow a pragmatic format:

- Two weeks prior to the review, material will be circulated to the review panel. Material will consist of design files and any notes / reports needed to communicate the design.
- The review panel can ask questions at any time before the review.
- The review will be a simple, several-hour, walk through of the design in which questions / concerns are addressed.
- All follow up items are recorded as RIX items in a global project RIX log stored in the SST Camera shared file space.
- A review report is released summarising the review and listing the resulting RIX.
- Additional meetings are scheduled as needed based on the RIX.
- RIX are addressed by completing a template response per item by the responsible party, stored in SST Camera shared file space.

Table 6 below shows the currently envisaged internal reviews, with approximate dates.

Table 6: SST Camera internal technical reviews.

ID	Internal Review	Description	PBS Items Covered	Approx. Date	Required as Input (TBC)	Status
IR-QBP	**Quarter Backplane**	Covering the schematics and layout for the QBP, done before manufacturing the QBP.	QBP	Q1 '21	PCB Design	Complete
IR-Mech1	**Mechanics Part 1**	Covering details of the FPA mechanics and assembly, as well as the ERA Rack and the placement of items within the Enclosure. Done in parallel to producing the first FPP (which can then be revised as needed).	Doors, Window Frame, FPP, Transition Plate, Rack	Q4 '21	Mechanics CAD	Complete
IR-FEE	**Front-End Electronics**	Covering the SiPM PCB design, all boards of the FPE and TM. Prior to production of any FEE.	SiPM, FPE, TM	Q2 '22	SiPM Data sheet PCB Designs FPE R&D Report	In Progress
IR-Mech2	**Mechanics Part 2**	Covering RIX from IR-Mech1, and design changes since IR-Mech1, and the Enclosure design.	Enclosure	Q2 '22	Mechanics CAD FPP R&D Report	Complete
IR-Flasher	**Flasher**	Covering the performance of v3 flasher, concepts flasher positions and optics, and the v4 flasher design. Done prior to v4 production.	Flasher, EIA	Q4'22	Flasher R&D Report PCB Design	Pending
IR-SCA	**Slow Control Assembly**	Covering the SCA and the Door control hardware. Done prior to Slow Board production.	SCA	Q1 '23	PCB Design	Pending
IR-BP	**Backplane**	Covering the performance and lessons learnt from the QBP and the detailed BP design. Done prior to BP manufacture.	BP	Q1 '23	QBP Test Report PCB Design	Pending
IR-MCAM	**MCAM**	Covering MCAM, done once built and environmentally tested.	ENC, FPM, WIN, Doors, Rack	Q1 '23	MCAM Test Report Mechanics CAD	Pending
IR-CM	**Camera Module**	Covering the performance and design of the full Camera Module consisting of SiPM, FPE and TM. Includes review of any proposals for design changes prior to ECAM. Done after essential CM tests.	SiPM, FPE, TM	Q2 '23	CM Test Report PCB Designs	Pending
IR-QCAM	**QCAM**	Covering performance and lessons learnt from the QCAM and any changes needed for ECAM.	CU	Q2 '23	QCAM Test Report	Pending
IR-ECAM	**ECAM**	Covering performance of ECAM and any issues encountered, proposals for final design changes.	CU	Q3' 23	ECAM Test Report	Pending

6. Verification Approach

In this section the approach to verification is outlined following the model philosophy presented in Section 4, including the overall strategy, the overview test plan showing what tests are done on which models, and the definition of the verification methods used§

6.1 Design Verification Strategy

The verification strategy of the SST Camera has been designed to confirm (through demonstration) that the camera (design) is compatible with the requirements of CTAO.

An outline of the intended strategy to verify the camera design is shown in Figure 6. At the top level, the SST Camera Production Requirements are taken as a starting point. These are constructed in such a way that all applicable higher-level requirements are included. A Verification Matrix (VMX) is constructed, showing the mapping of these requirements to the higher level, and indicating the intended verification method(s) for each requirement. A Verification Specification Document (VSD) describes the intended verification steps for each requirement. Verification activities are then done at the appropriate stage of development (i.e., at the appropriate point in the model philosophy). Internal procedures and reports are generated as needed and grouped pragmatically (for example, a single report for the inspection, demonstration and test of ECAM may be produced). Reports are collated and summarised in the Verification Control Document (VCD), which lists all requirements and includes a verification statement for each. A Compliance Matrix (VCM) is produced, which is an updated version of the Verification Matrix including the status of verification for each requirement.

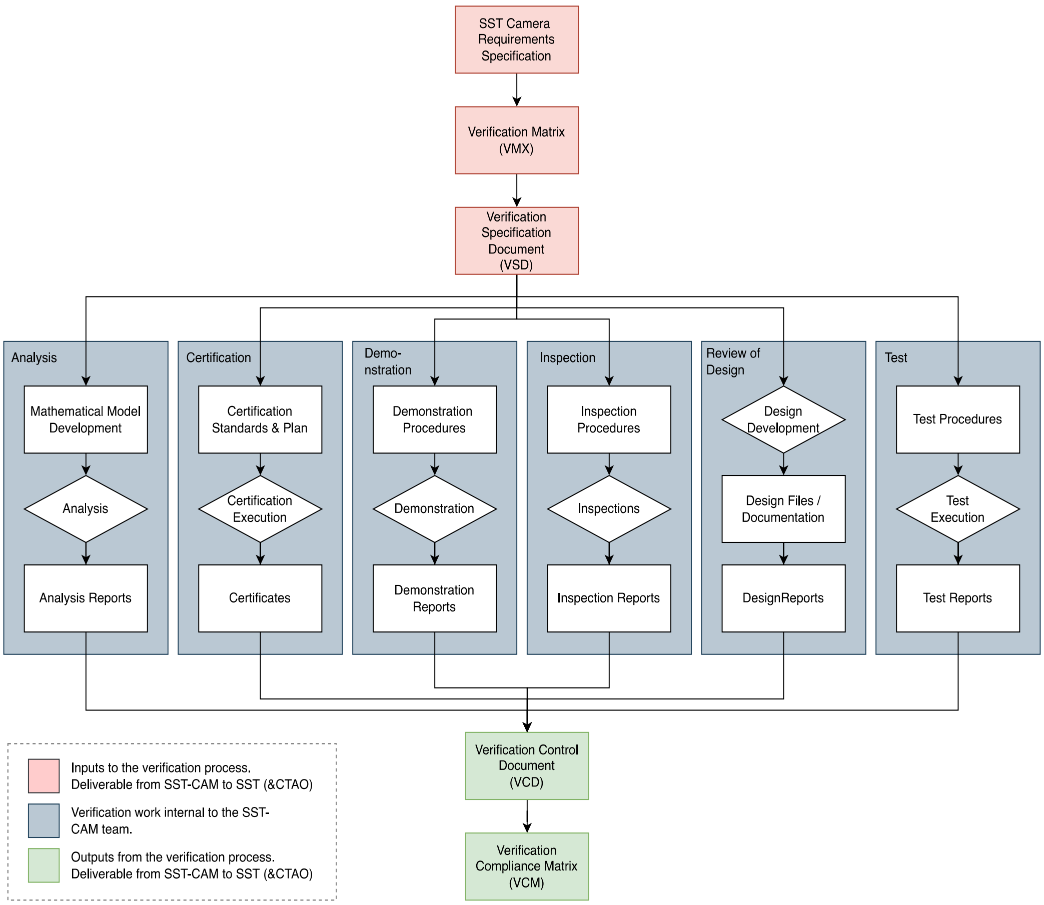

Figure 6: SST Camera verification strategy.

6.2 Verification Methods

For each requirement verification shall be accomplished by one or more of the following:

- Analysis
- Certification
- Demonstration
- Inspection
- Review of design
- Test

The chosen methods are based upon design analyses, design maturity, complexity of the item, criticality category and associated cost. Analysis and testing are the primary methods used to verify performance.

6.2.1.1 Analysis

Verification by Analysis consists of the use of analytical data or simulations under defined conditions to show theoretical compliance. Analysis (including simulation) is used where verifying to realistic conditions cannot be achieved or is not cost-effective and when such means establish that the appropriate requirement, specification, or derived requirement is met by the proposed solution.

6.2.1.2 Certification

Certification is a written assurance that the product or article has been developed and can perform its assigned functions in accordance with legal or industrial standards. The development reviews and verification results form the basis for certification; however, certification is typically performed by outside authorities, without direction as to how the requirements are to be verified. For example, this method is used for electronics devices via CE certification in Europe and UL certification in the United States and Canada.

6.2.1.3 Demonstration

Verification by Demonstration consists of a qualitative exhibition of functional performance, usually accomplished with no or minimal instrumentation. Demonstration (a set of verification activities with system stimuli selected by the system developer) may be used to show that system or subsystem response to stimuli is suitable. Demonstration may also be appropriate when requirements or specifications are given in statistical terms.

6.2.1.4 Inspection

Verification by Inspection consists of performing an examination of the item against applicable documentation to confirm compliance with requirements. Inspection is used to verify properties best determined by examination and observation.

6.2.1.5 Review-of-design

Verification by Review of Design consists of using approved records or evidence that unambiguously show that the requirement is met. For example, design documents and reports, technical description documents, and engineering drawings.

6.2.1.6 Test

An action by which the operability, supportability, or performance capability of an item is verified when subjected to controlled conditions that are real or simulated. These verifications often use special test equipment or instrumentation to obtain very accurate quantitative data for analysis.

6.3 Test Matrix

Table 7 indicates the test philosophy for each model (see Section 4). Further breakdown will take place in the Verification Specification Document.

Table 7: SST Camera overview test matrix. A: Analysis, T:Test, I:Inspection, R:Review of Design

	Mathematical Models	Testable Elements	MCAM	QCAM	ECAM	ECAM-On-Telescope
Environmental						
Wind	A	T				
Leak			I, T	I, T	I, T	I, T
Other			I		I	
Structural					T	
Mass / Size	A		I, T		I, T	T
Static Bending	A			T		T
Earthquake	A			T		
Thermal						
Power Consumption	A	T			T	
Cooling Performance	A			T	T	T
Humidity Control	A			T	T	T
Optical						
Shadowing	A					
Throughput	A	T				T
Functional		T	T	T	T	
State Transitions				T	T	
Data Throughput		T		T	T	
Other		T			T	
Performance		T		T	T	T
Intensity / Charge	A	T		T	T	
Trigger	A	T		T	T	
Timing		T		T	T	
Cherenkov	A					T
Slow Signal	A	T		T	T	
Pointing	A					T
Other						
SST Interfaces	A		R, I, T	R, I	R, I	T

7. AIT / AIV Tools & Facilities

Test facilities and tools are required during the finalisation and verification of the camera design, and for series production of the cameras.

Each sub-system will require dedicated setups for AIT, which will be the responsibility of the contributing institute to provide. A full camera dark box with stable and known illumination sources will be provided for CM, QCAM and ECAM qualification at MPIK (Figure 7). Camera handling and manoeuvring equipment will also be procured. A chiller unit and associated pipework for connection to the camera are needed along with power and data cabling matching those used on telescope. A high-end camera server computer is needed to record data and control and monitor the camera.

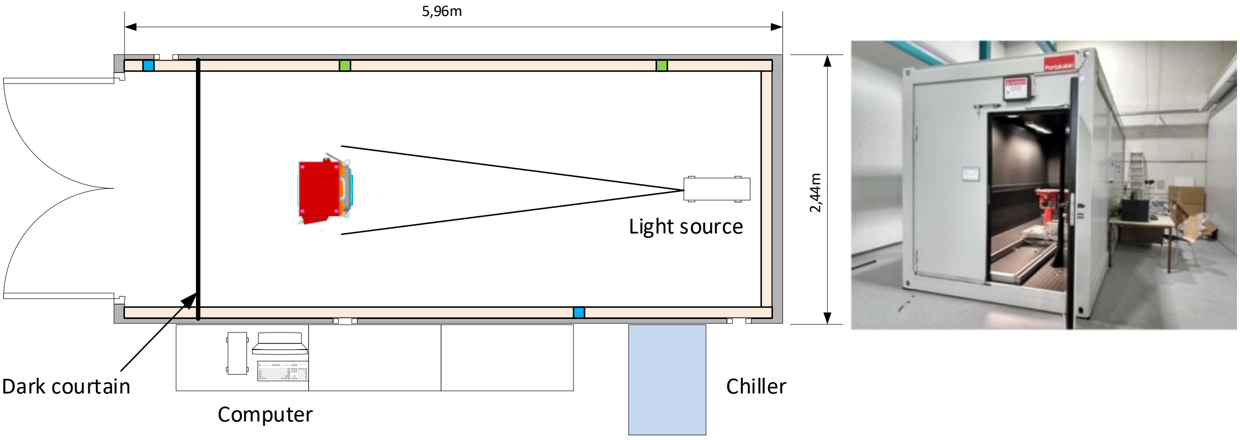

Figure 7: Camera illumination setup.

The illumination setup includes a stable laser light source capable of uniformly illuminating the Camera across a dynamic range of four orders of magnitude. A robot arm position between the laser light source and the Camera allows the diffused laser beam profile to be measured routinely and automatically via readout of a reference sensor. The robot arm may also be used to scan a Cherenkov-like image across the camera during trigger tests. Calibrated PMTs positioned at fixed locations in the vicinity of the Camera allow the absolute light level in every flash be monitored. DC LEDs provide a calibrated source of constant illumination at a settable level to mimic the night-sky background. A rotational stage on the camera mount allows the angular response of the Camera to be verified.

Appropriate manual handling training is needed to unpack, pack, store, manoeuvre, and mount / unmount the Camera. Laser training and appropriated safety precautions are required for camera operators. The camera dark chamber will include an interlock system to ensure that any light sources presenting a risk to human safety are disabled upon access. An internal ambient light sensor will ensure that the camera cannot be powered with the lights on to prevent accidental damage.

Custom tools for SiPM handling are required. Custom transport and storage containers will be provided for at least the window, SiPM tiles and FPA, for use in transporting items between institutes (see Figure 13). All PCBs must be transported with ESD protection. A custom camera container will be provided for QCAM and ECAM, with a shock-absorbing platform, accelerometer data loggers (see Figure 13).

Figure 8: SiPM (FPSSA) and Camera storage and shipping containers.

A system will be implemented to identify and track elements of the camera. All camera subassemblies will include unique identification numbers. All PCAs will include 1-wire serial identification chips that may be read back via a hand tool and remotely via the Camera software. All components will be tracked from initial receipt the procuring institute through the Camera production process. The same system will be utilised on-site for tracking full Camera and spare LRUs and LLRUs through commissioning. This system may also be suitable to track elements through the operation and maintenance of cameras in the Operation Phase of CTA.

End of the document