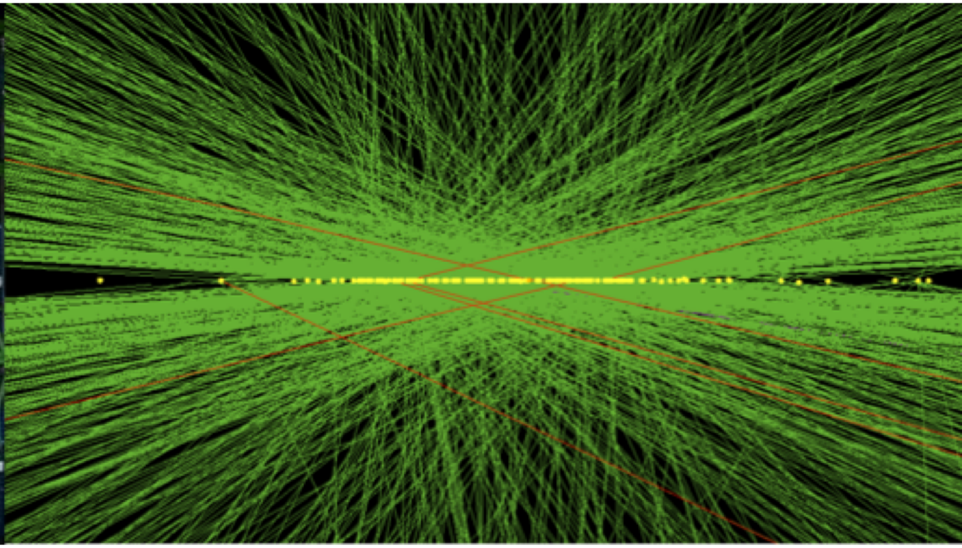
402.4.5 EC - Cassettes

Zoltan Gecse (Fermilab)

HL LHC CMS Detector Upgrade CD-1 Review

March 20th, 2019



Outline

- Conceptual Design
- Prototyping Program
- Schedule
- Summary
- Costs
- Organizational aspects
- Contributing Institutions
- Optimization
- ES&H
- QA/QC

Biographical Sketches

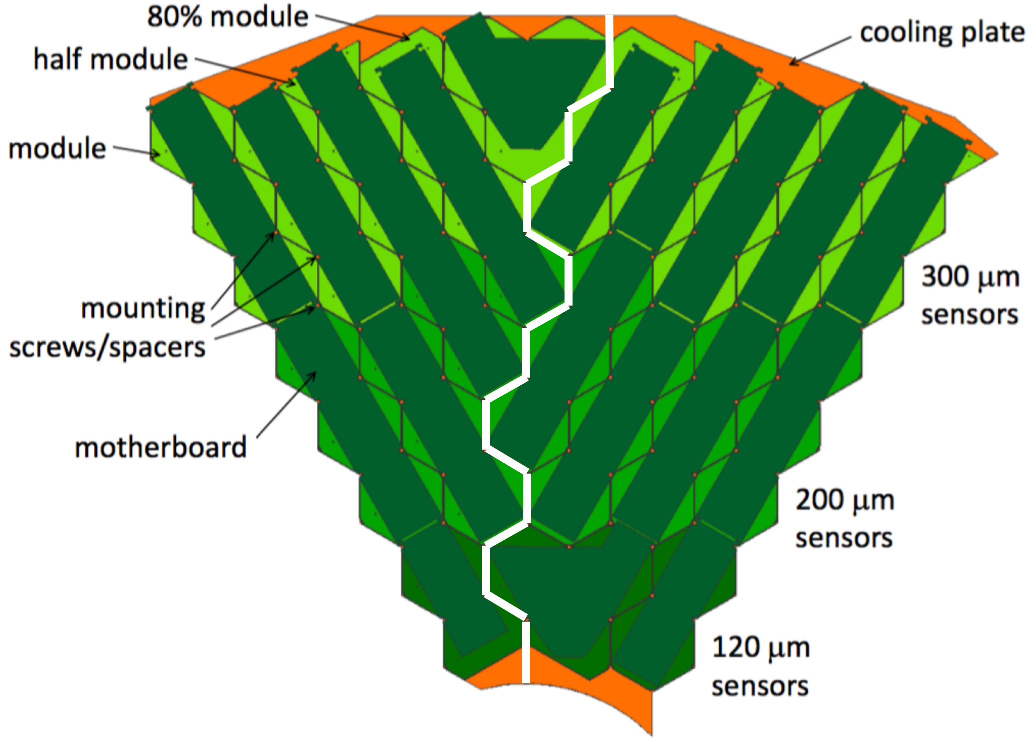
Charge #5

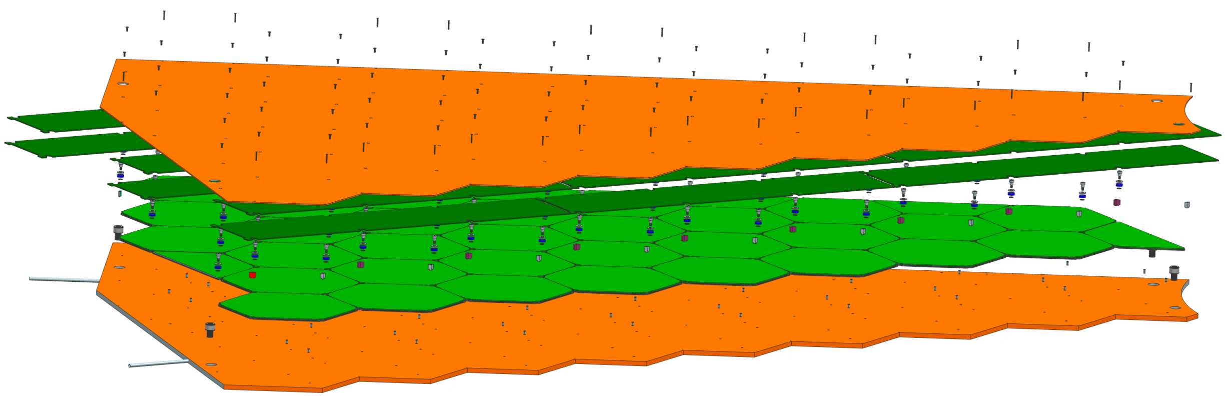
- L3 Manager: Zoltan Gecse
  - Associate Scientist at Fermilab
  - International coordinator of Cassettes L2 area
  - ~4 years of R&D experience within the HGCAL
    - Silicon sensor probing and design for HGCAL
    - Construction and operation of the first HGCAL test beam prototype and data analysis
    - Cassettes design and prototyping, built and tested a thermal and mechanica cassette mockup
  - ATLAS Transition Radiation Tracker readout firmware upgrade to 100kHz L1 rate
  - Convener of the MET based Supersymmetry Group in ATLAS

Conceptual Design

All Silicon Cassette Design

- Cassette boundaries follow whole module boundaries when possible
- 30-degree cassettes can be inserted in pairs
- 30-degree cassette have a manageable size for handling and assembly





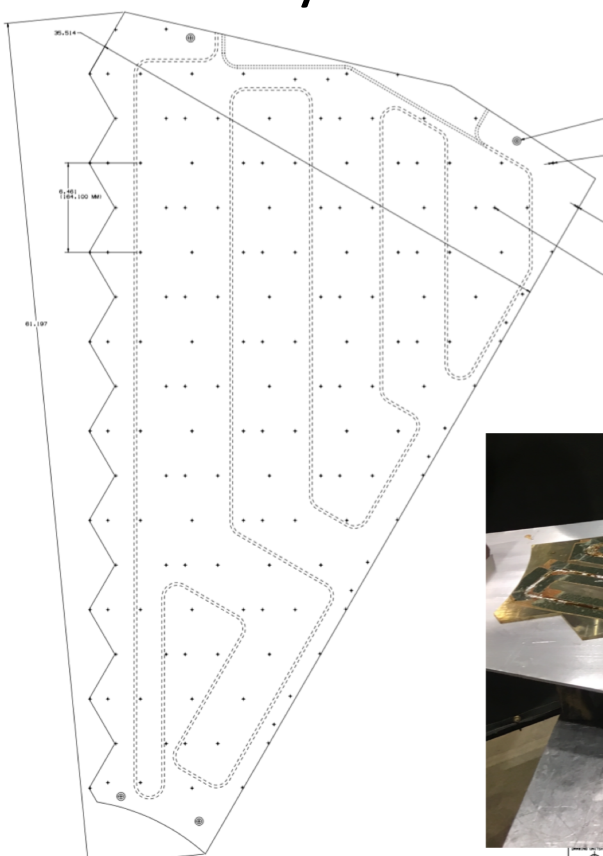
Cover	WBS 402.4.5.1.1
Motherboards	WBS 402.4.5.1.2
Modules	WBS 402.4.4
Cooling plate	WBS 402.4.5.1.1

Cooling Plate

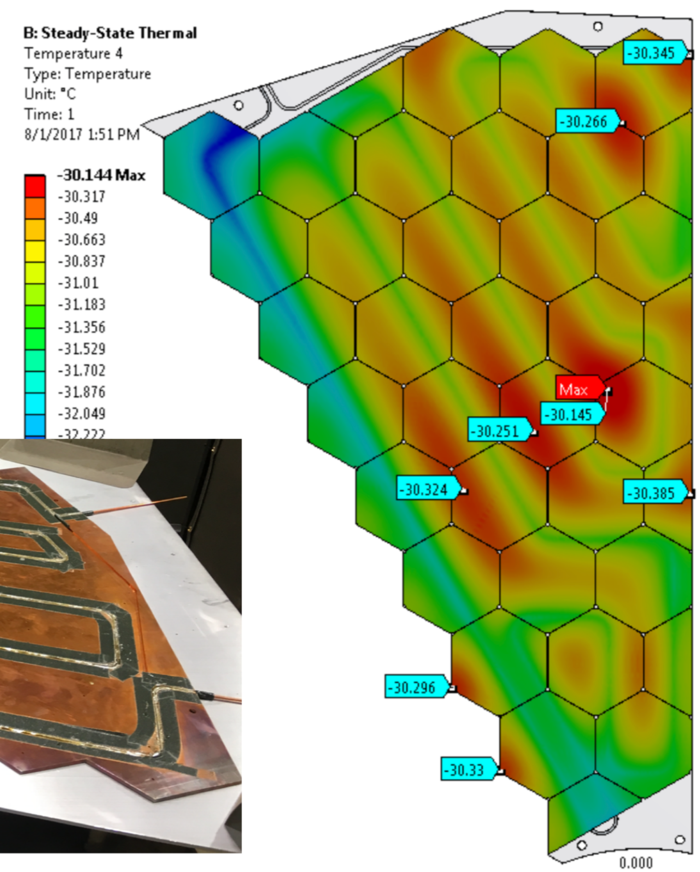
Charge #2

WBS 402.4.5.1.1

- Copper cooling plate is the mechanical support for modules and keeps them cold with 2-phase CO2 cooling
- Cooling performance verified with simulation and prototypes
- 30 different shapes to be designed, but with a large degree of similarity



Cooling tube soldered into a groove with low temperature solder

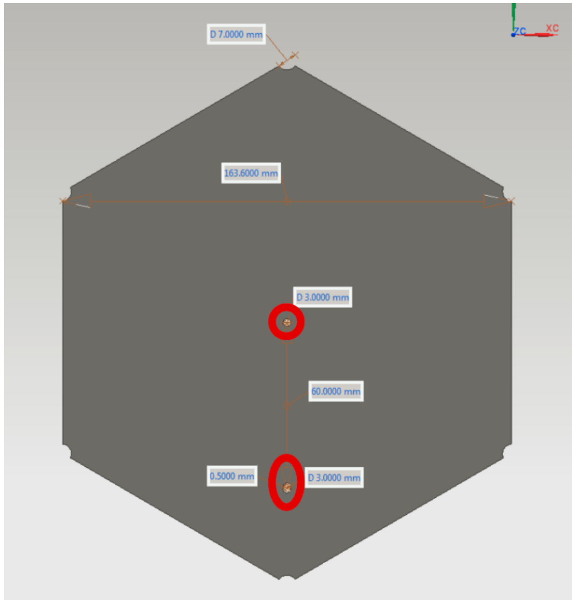


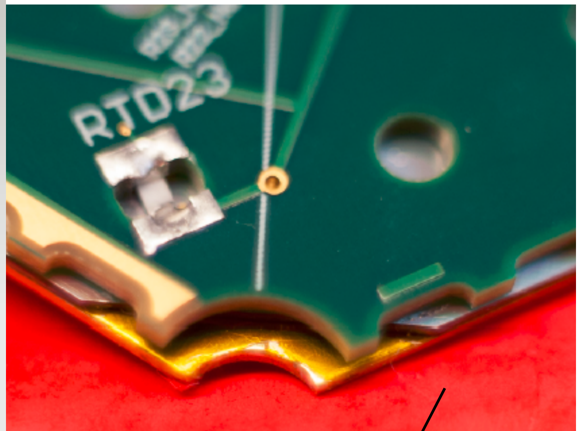
Charge #2

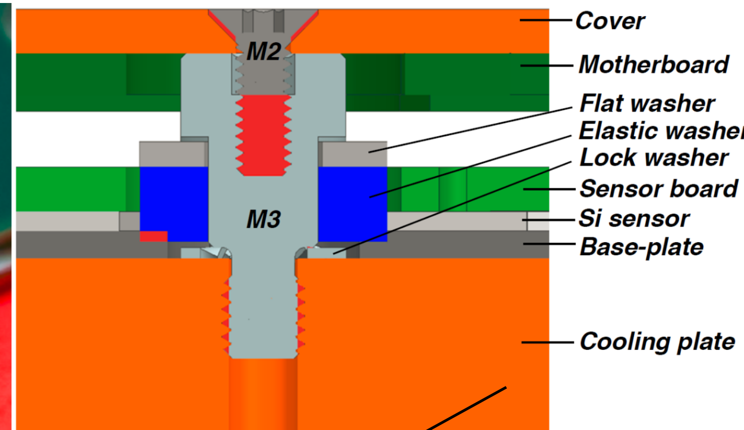
Dynamic Mounting of Silicon Modules

WBS 402.4.5.3.1

- Modules can have different CTE and expand wrt cooling plate



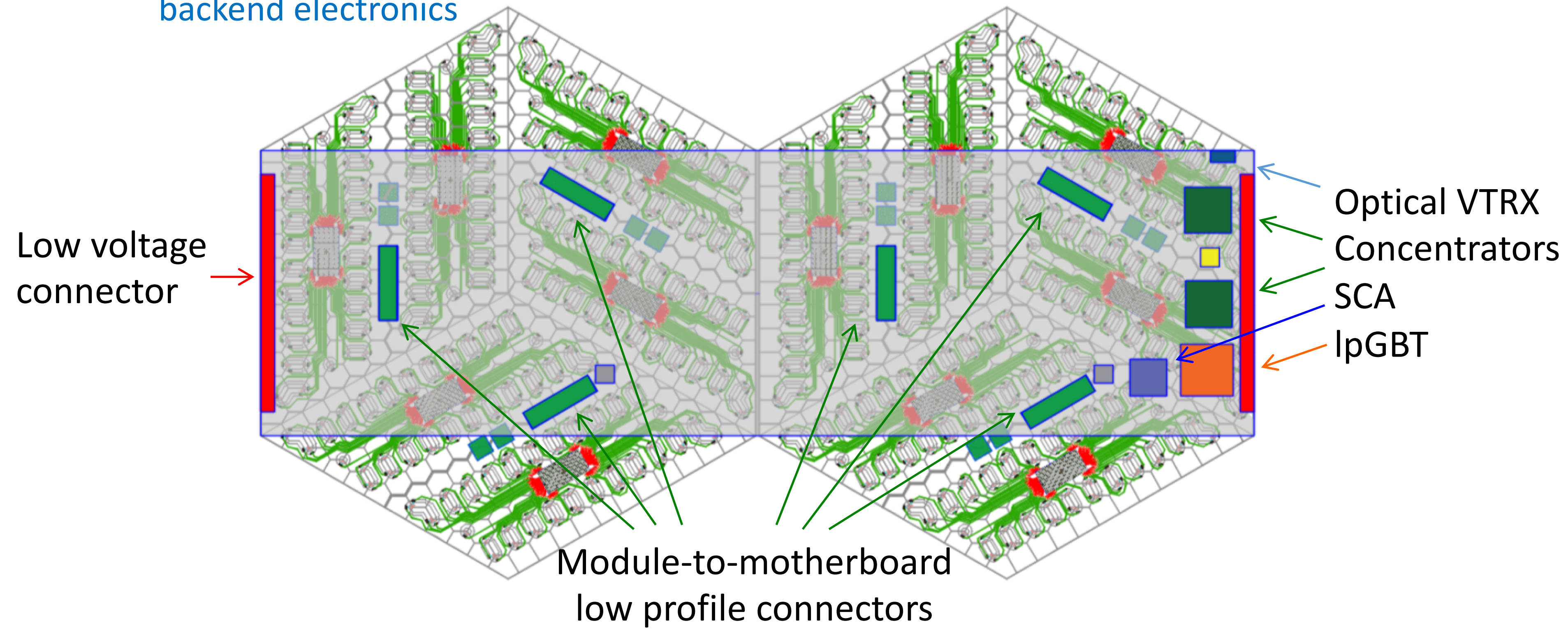




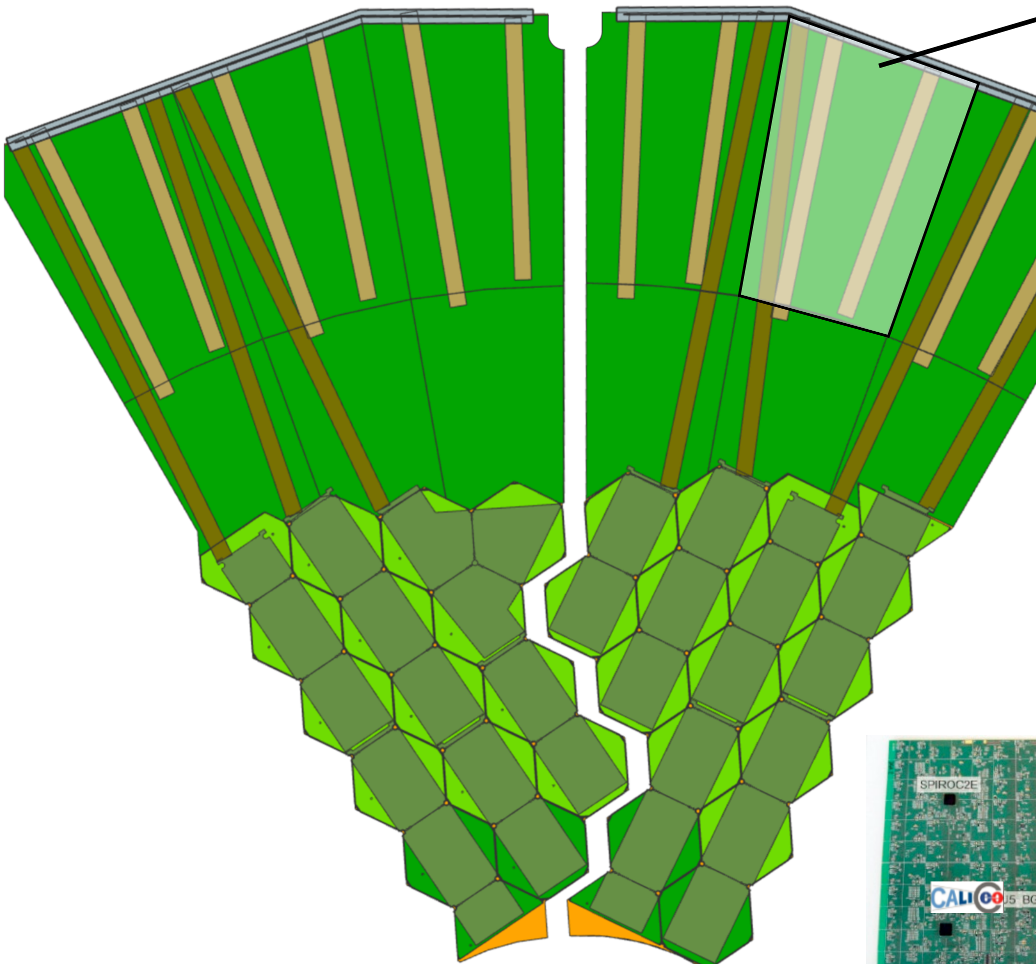
Silicon-Module Motherboards

WBS 402.4.5.1.2

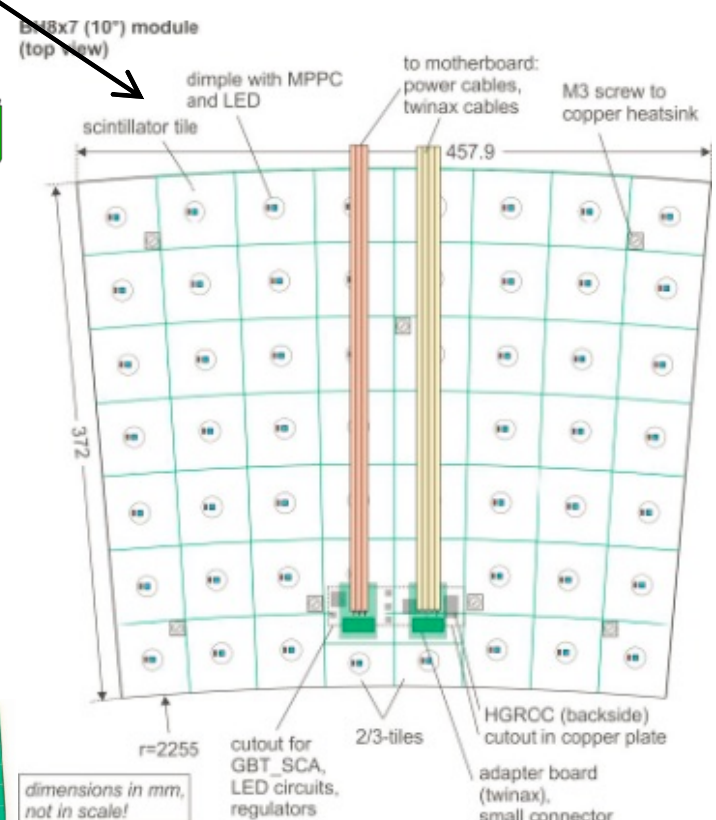
- Motherboards communicate with strips of modules, strip geometry helps to minimize motherboard variants to be designed
- Low voltage power is delivered along the strips from the edge of the cassette
- Motherboards clip on modules via low profile connectors
  - Easy assembly saves on labor
- Concentrator chip located on motherboard and drive the optical output
  - Better utilization of optical bandwidth saves on number of required optical links and backend electronics



Mixed Silicon-Scintillator Cassettes



Scintillator/SiPM Tile-Module



WBS 402.4.6

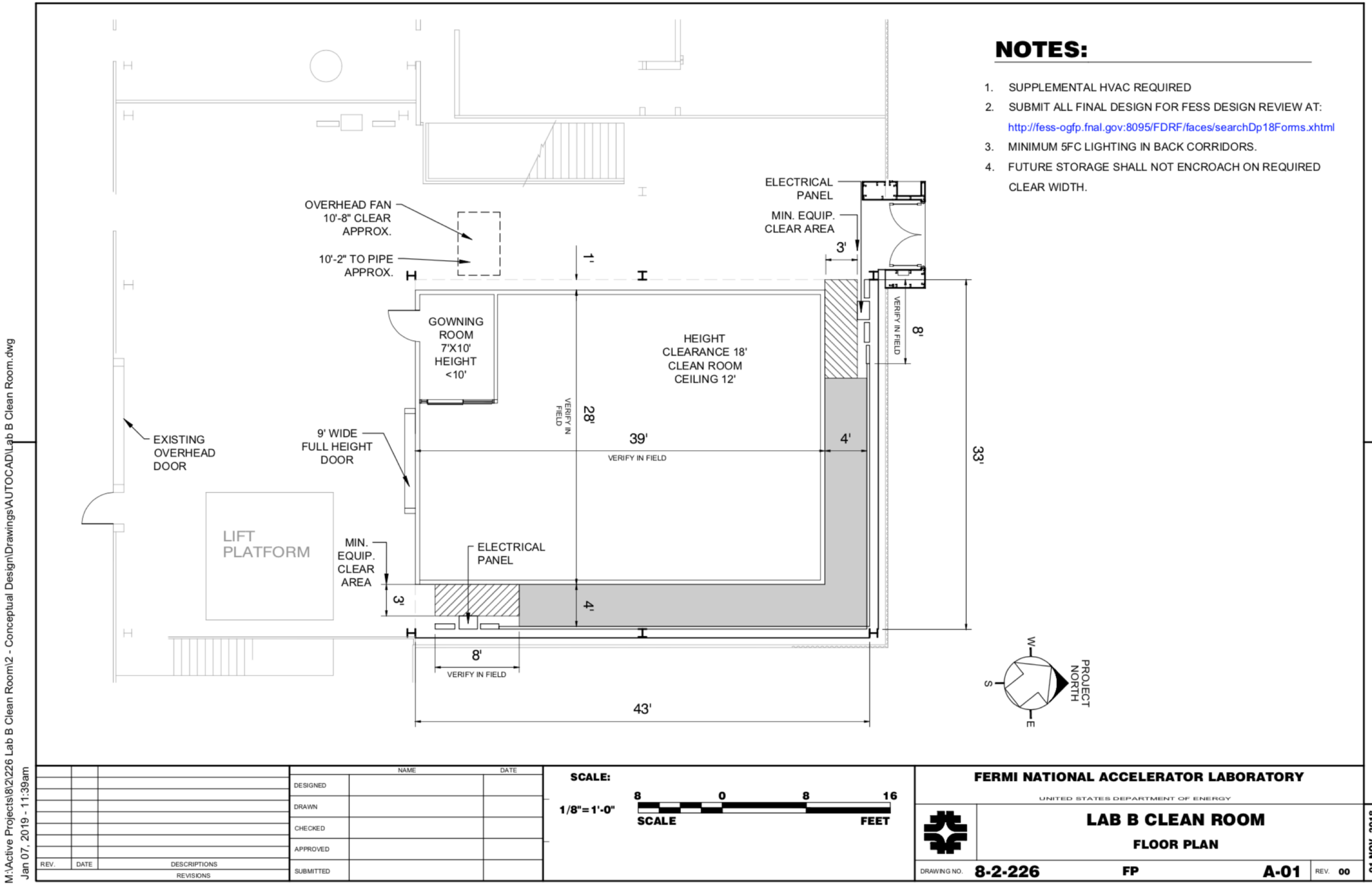
Assembly Procedure

Charge #3

WBS 402.4.5.3.1

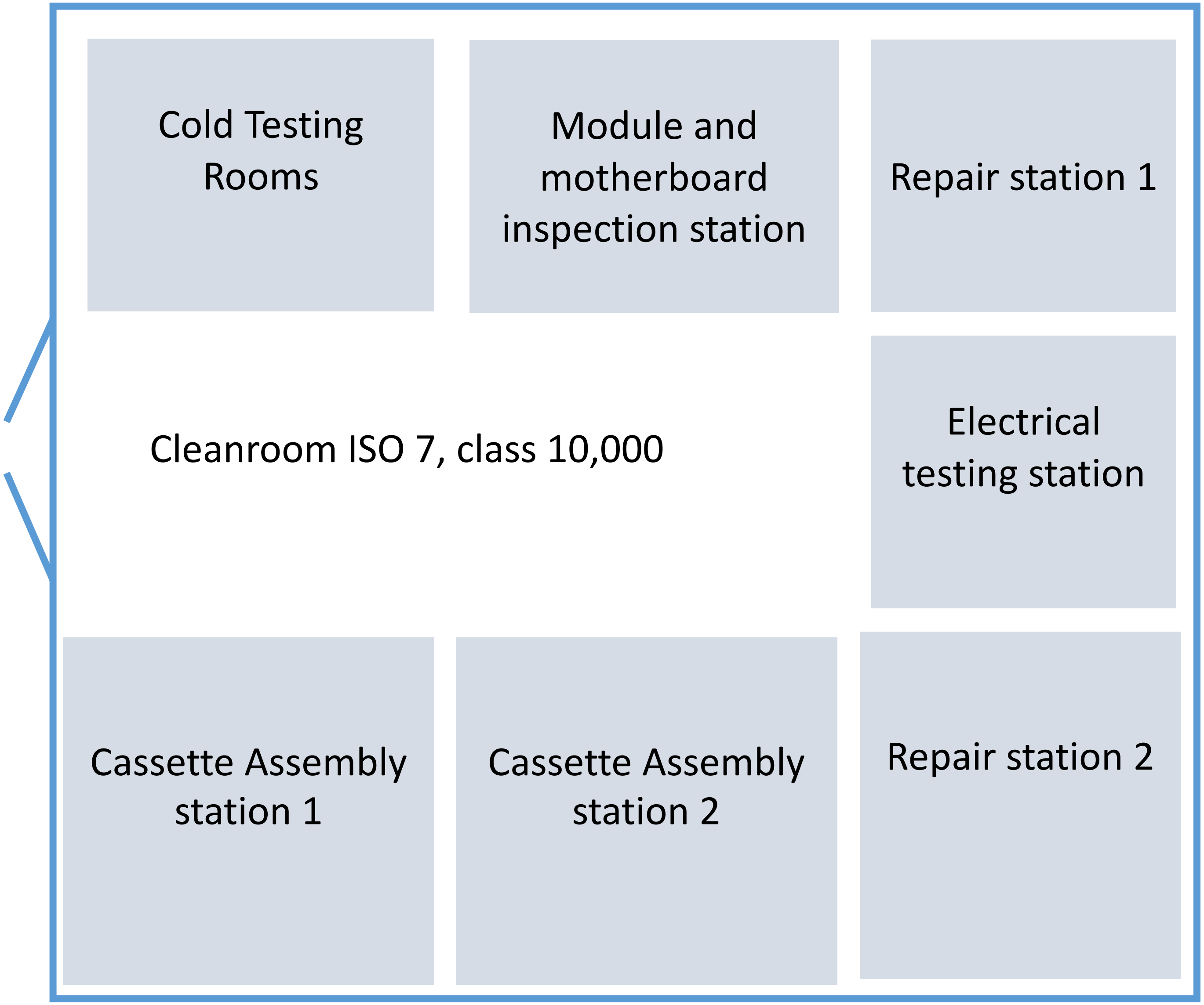
- Inspect and test received cooling plate/cover
  - Verify outline and flatness / thickness as well as location of holes on cooling plate / cover using CMM
  - Pressure test and flow test cooling tube
- Inspect and test received modules and motherboards
  - Electrical tests: high voltage current, low voltage current, communication
- Update database
- Install modules on cooling plate
- Install services: motherboards, cables; quick electrical test
- The nominal throughput of assembly is 2 cassettes / day
- Projecting experience with the mockup cassettes, each cassette will require two technicians working full time along with a supervisor coordinating the efforts

Future Clean Room Floor Plan in Lab B



Clean Room Floor Plan in Lab C

WBS 402.4.5.2.2

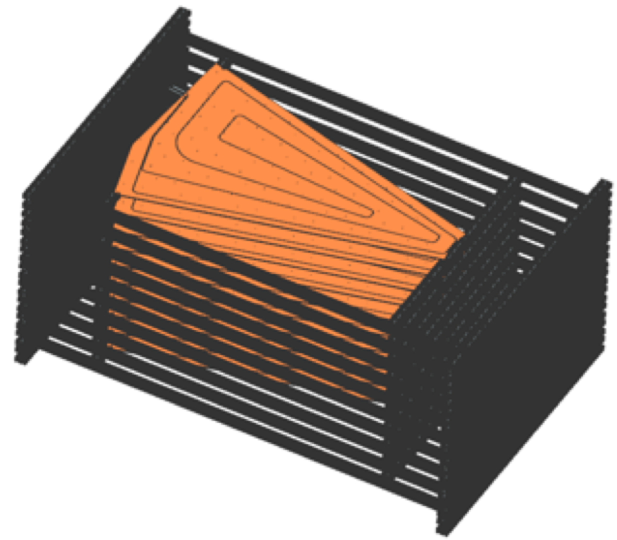


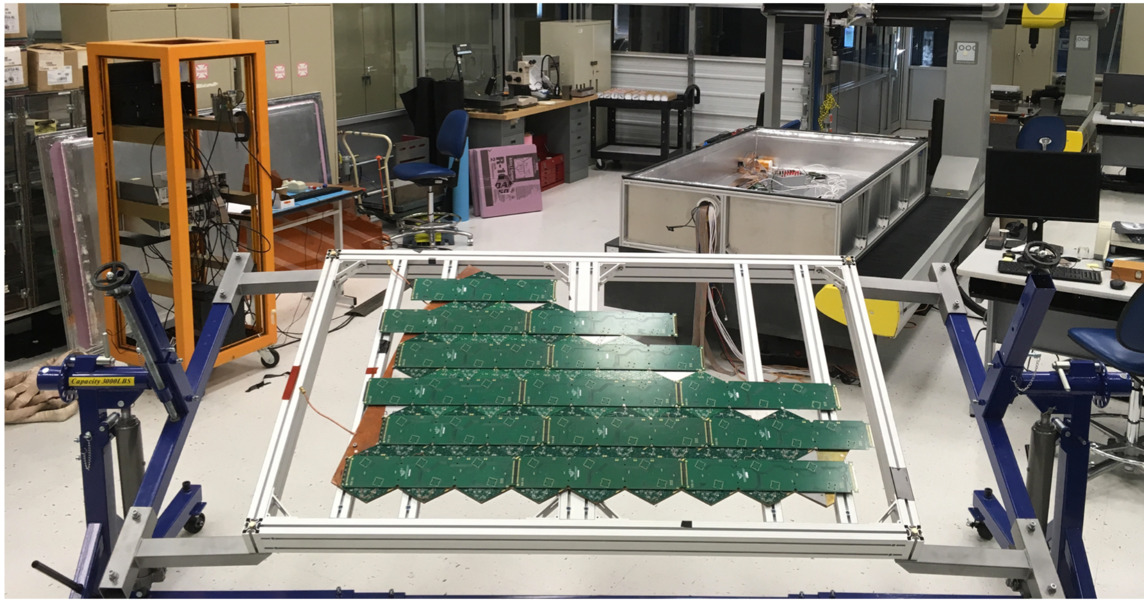
Cassette Handling Tools

Charge #4

WBS 402.4.5.2.1

- Cooling plates are framed to ease handling and keep them straight
- The frames are also used for shipping and storage
- Framed cassettes are wheeled around on carts



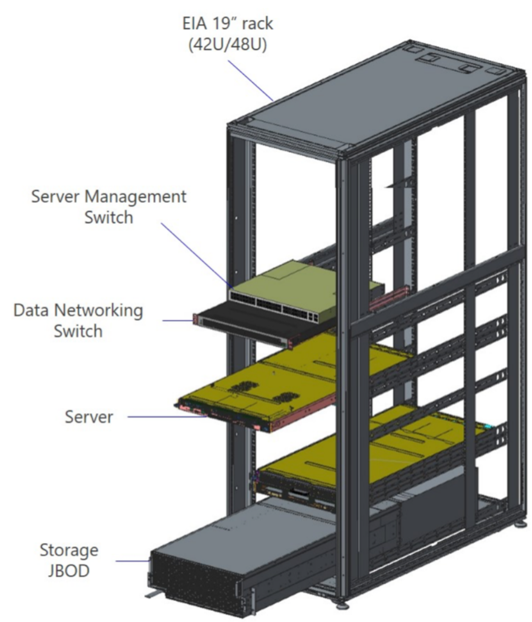


Cold Testing with CO_2

WBS 402.4.5.2.4
WBS 402.4.5.3.2

Charge #4

- Assembled cassettes cold tested for 2 weeks
  - Insert cassettes into insulated rack with dry environment
  - Connect all services, data connections and CO_2 cooling lines
  - Thermal cycle several times during testing
  - Collect cosmic muon data and confirm proper operation
- 2 weeks of testing requires testing 20 cassettes at a time, plan for 2 cold rooms to avoid critical path
- Qualified CO_2 cooling plant already exists in Lab C



Cassettes slide into rack

Cassette Prototyping Program

The cassette prototype program proceeds in 3 phases…

- Thermo-electro-mechanical mockup (CE-H8 and CE-H15^{mix})
  - With blank silicon sensors and heaters for front-end electronics
  - International milestone met in Aug 2018
- Prototype series #1 (2x CE-H8 and 2x CE-H15^{mix})
  - Fully functional prototypes using first complete front-end chip HGCROC-DV1 and a motherboard with FPGA for the concentrator
  - Design work to start this spring, milestone to complete by Jul 2020
- Prototype series #2 (2x CE-H1, 2x CE-H9^{mix}, 2x CE-H15^{mix})
  - Prototype with (near) final front-end HGCROC-DV2 and motherboard with concentrator ASIC V2
  - Design work to start in 2020, milestone to complete by Jul 2021

… leading to the international engineering design review in Jan 2021

Thermo-electro-mechanical mockup

- Study thermal performance of cassette
  - Measure temperature distributions of cooling plate and silicon sensors, compare to FEA calculations
  - Study working points of CO_2 system
- Study mechanical properties of the cassette
  - Demonstrate mounting scheme of modules including those at the edge of cassette
  - Study production issues like tolerances, fixtures and ease of assembly
  - Investigate thermal contraction issues
  - Demonstrate cassette cover mounting
- Study electrical properties (limited being a mockup)
  - Demonstrate module-to-motherboard and motherboard-to-motherboard connections
  - Study connection quality and robustness for high speed communications
  - Study LV drops and HV leakage currents

Mockup Module

Printed Circuit Board; 1.6 mm thick

- Enables performing thermal studies

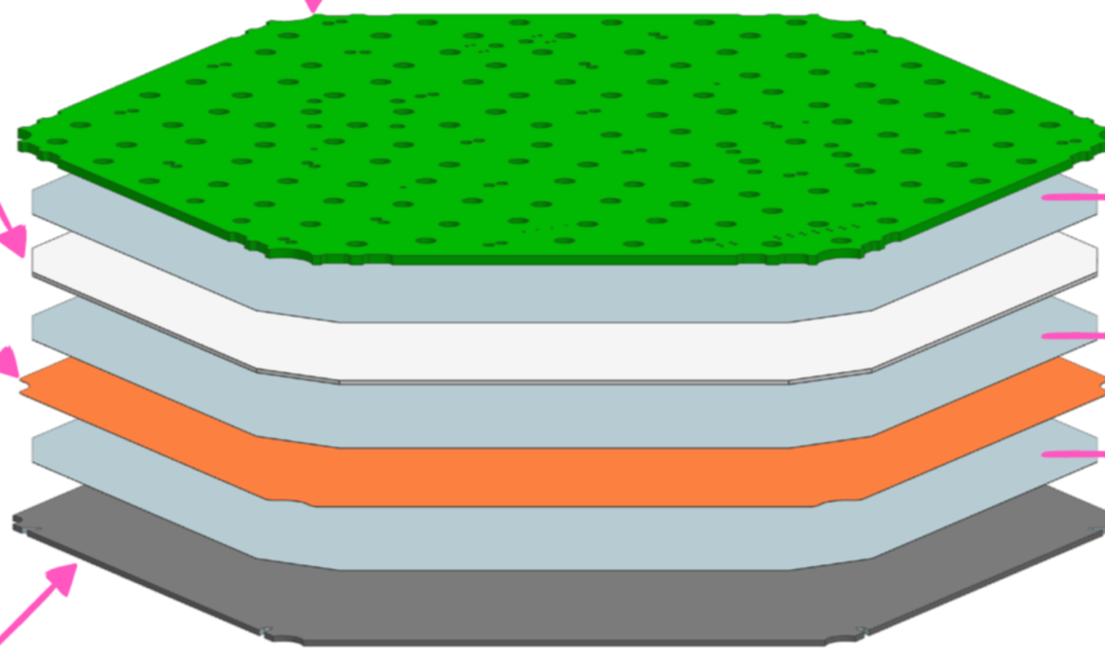
Silicon; 750/320 μm thick

Kapton sheet; 110 μm thick

- Provides electrical insulation of the sensor back-plane from the baseplate

Base plate; 1 mm thick

- Provides support for the active element
- Enables mounting



Glue; 100 μm thick

Mockup Readout Board

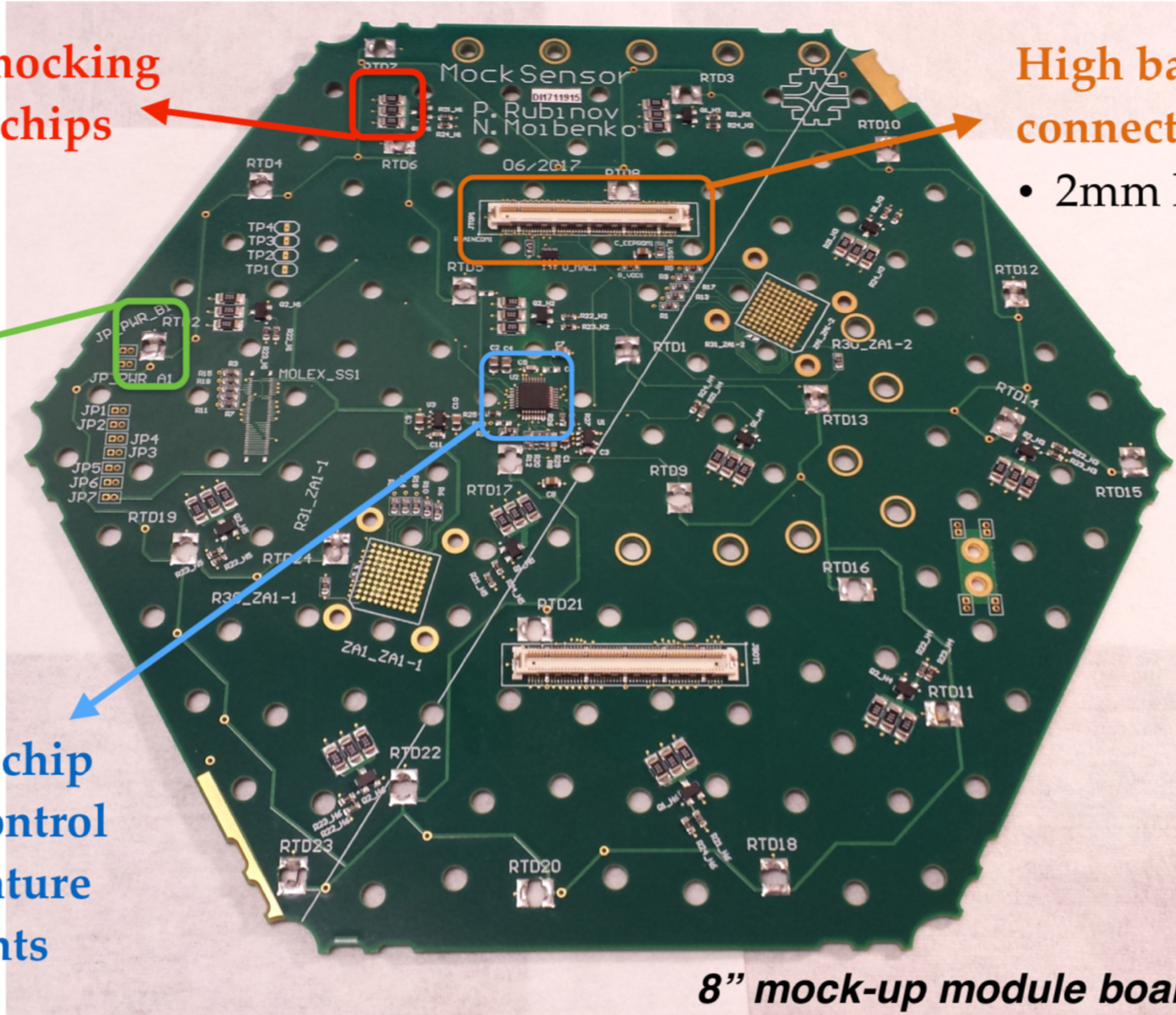
12 heaters mocking
12 read-out chips

High bandwidth connectors

- 2mm high rigid

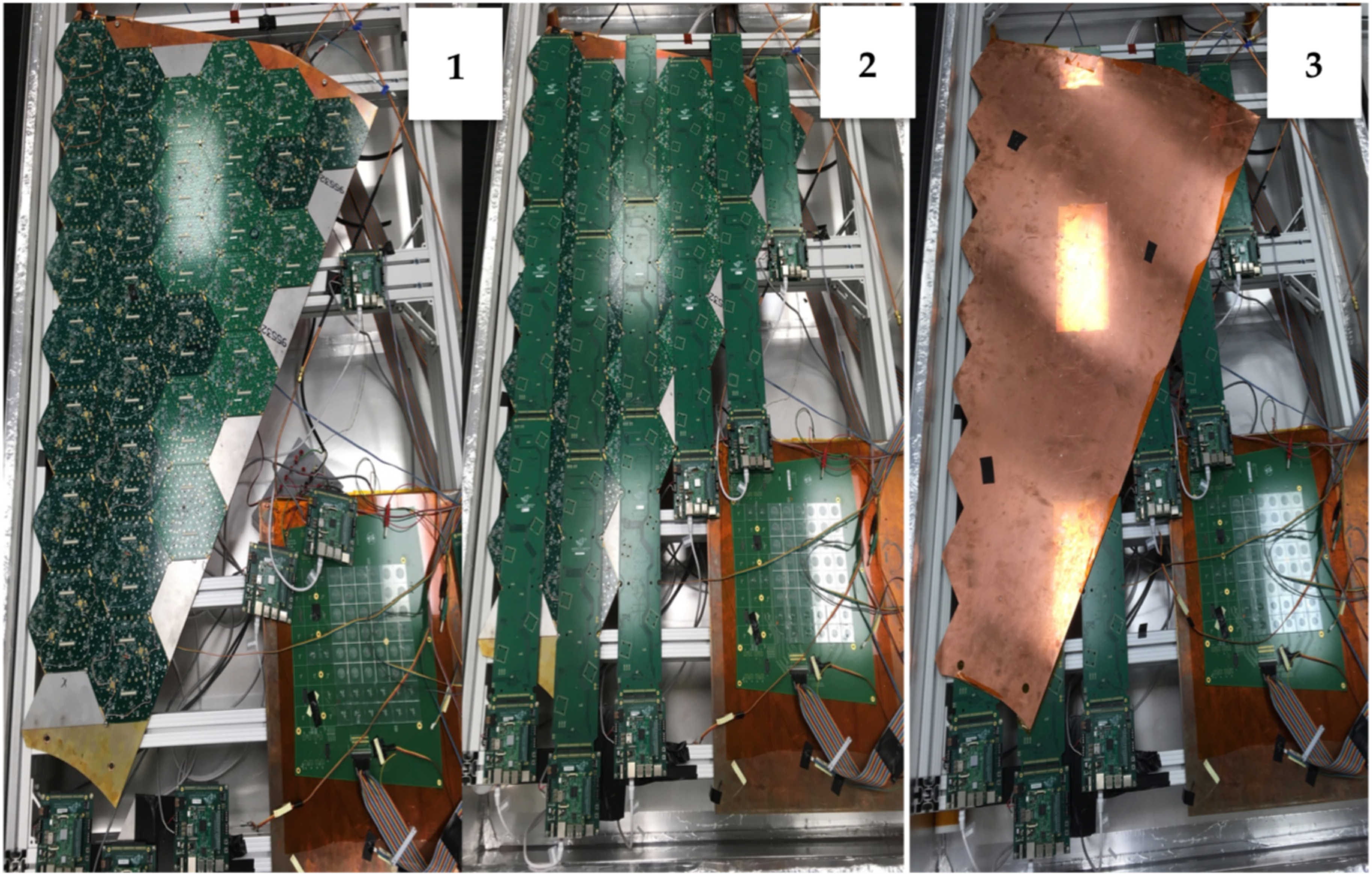
8 RTDs in contact with Silicon

ADS124S0x chip for heater control and temperature measurements



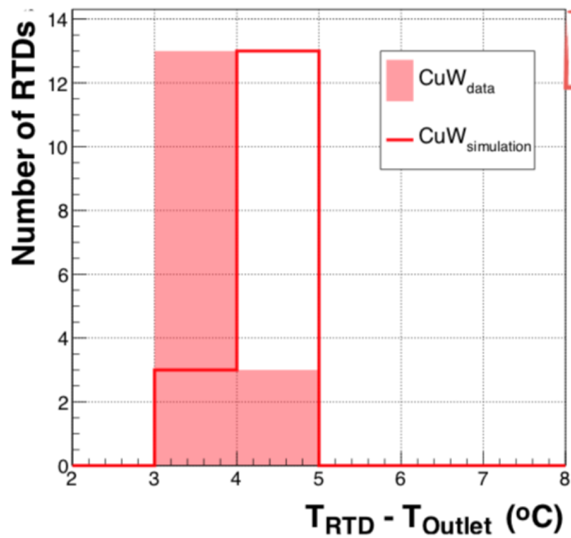
8" mock-up module board

Assembled Mockup Cassette



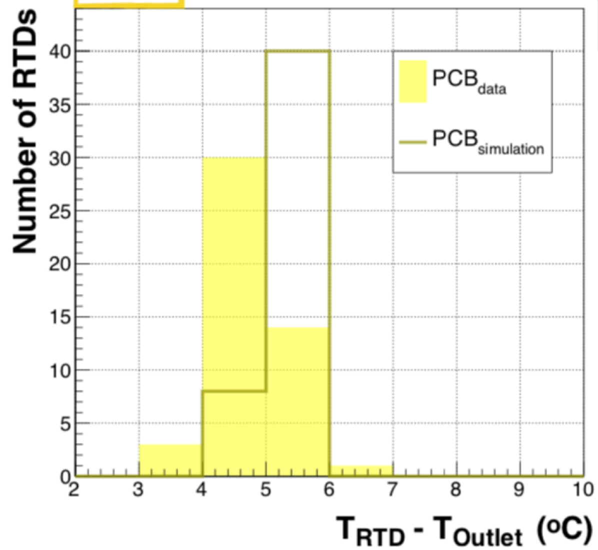
Mockup Cassette Results

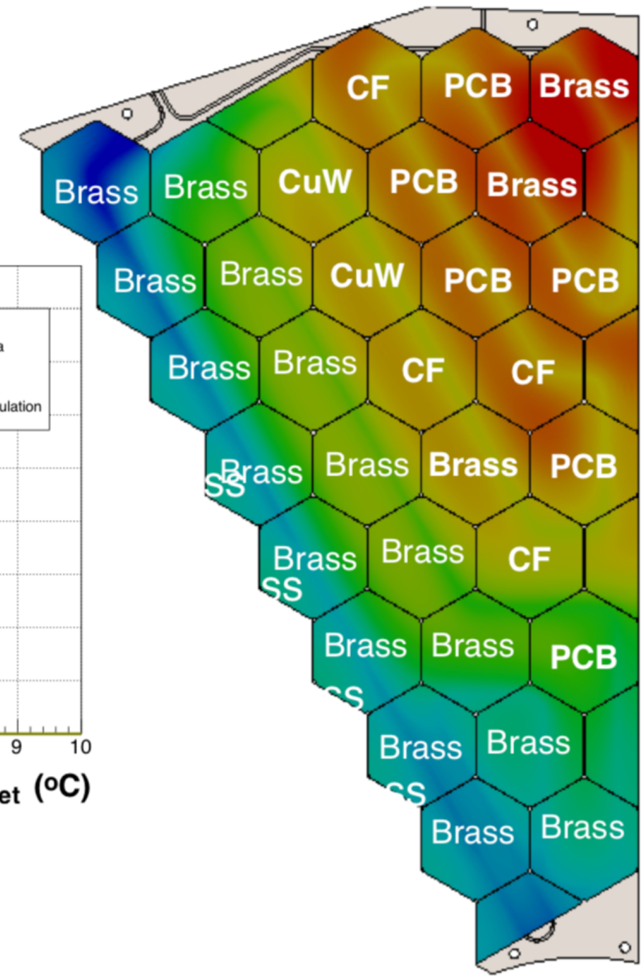
- The expected heat load of **270 W** has been applied with resistors.
- The temperature of Silicon surface has been measured with RTDs.

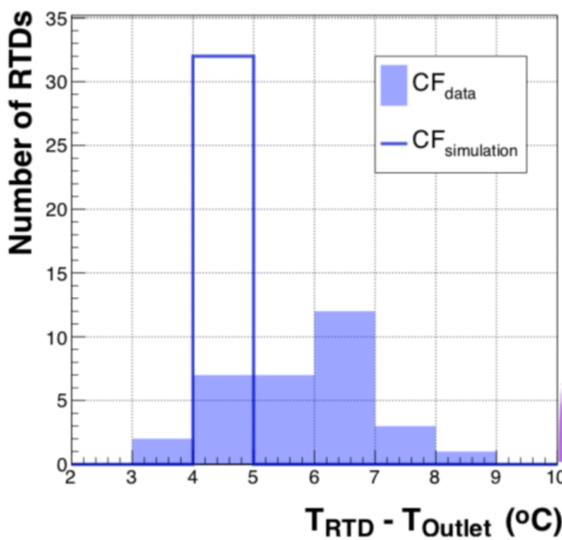


CuW

PCB







CF

Conclusions from Mockup Testing

- The cooling performance of the cassette is adequate
  - Sensor temperature is below -30C when CO_2 is at -35C
- The thermal contact between the modules and the cooling plate is sufficient if the baseplate of the modules is made of CuW or PCB
  - Modules warp in the beneficial direction
- Assembly of cassette is straightforward
  - Modules can be placed on locating pins with ease
  - Motherboards connect to modules despite several connectors

Prototype Series #1

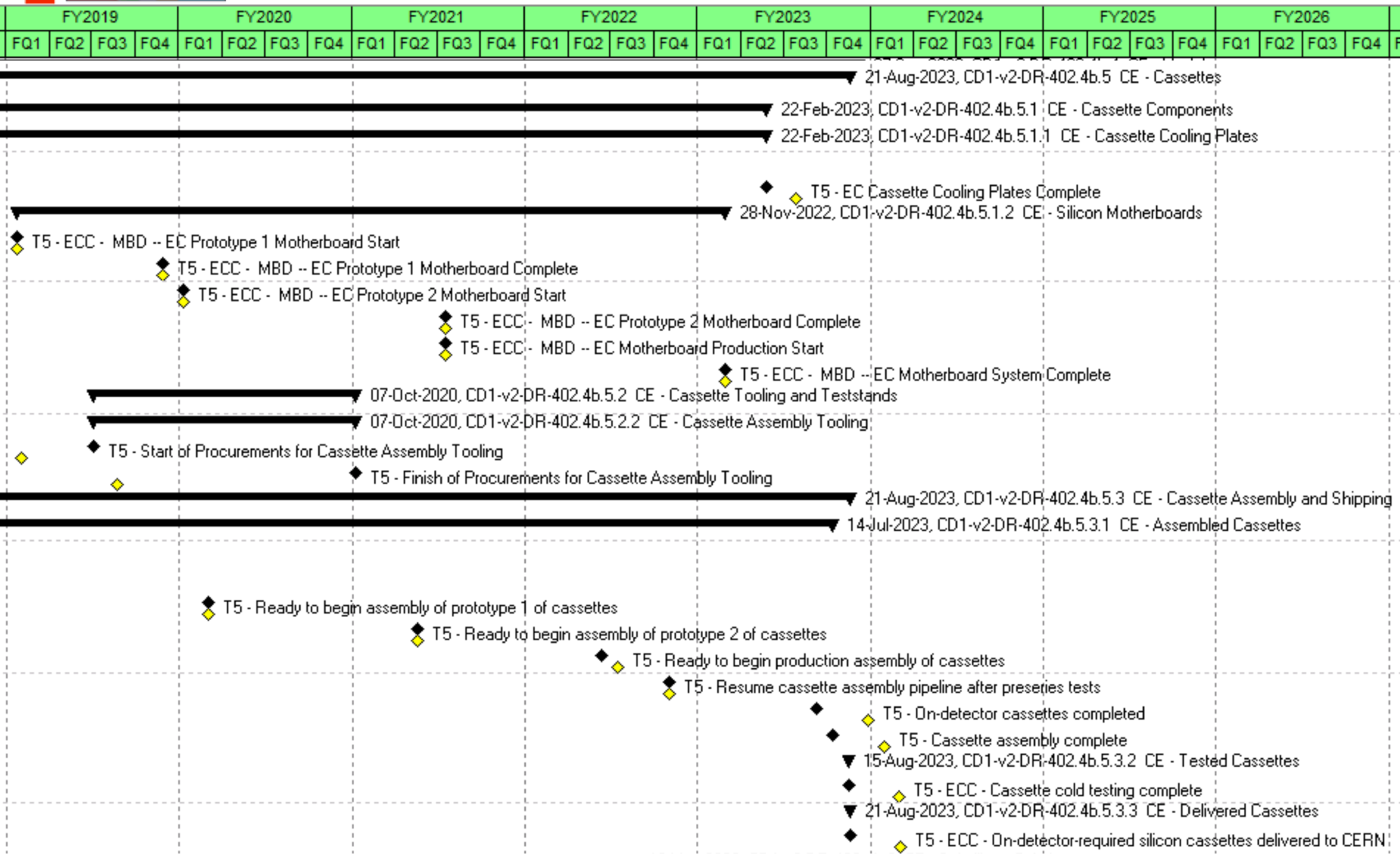
- Real 8” silicon modules and scintillator/SiPM tile-modules.
  - Active 8” silicon sensors
  - Fully active front-end PCB (“hexaboard”)
  - Tile-modules with full array of scintillator tiles and SiPMs
  - Front-end electronics based on first fully-functional version of the front-end chip “HGCROC-V2”
- Fully functional motherboards
  - Function of concentrator will be provided by FPGAs
  - Prototype cassette interface
- Fully realistic cooling plate design –
  - Two 30° cassettes to form a 60° “insertion unit”
- Goals:
  - Test of all detector elements to the extent possible with first round of electronics.

Prototype Series #2

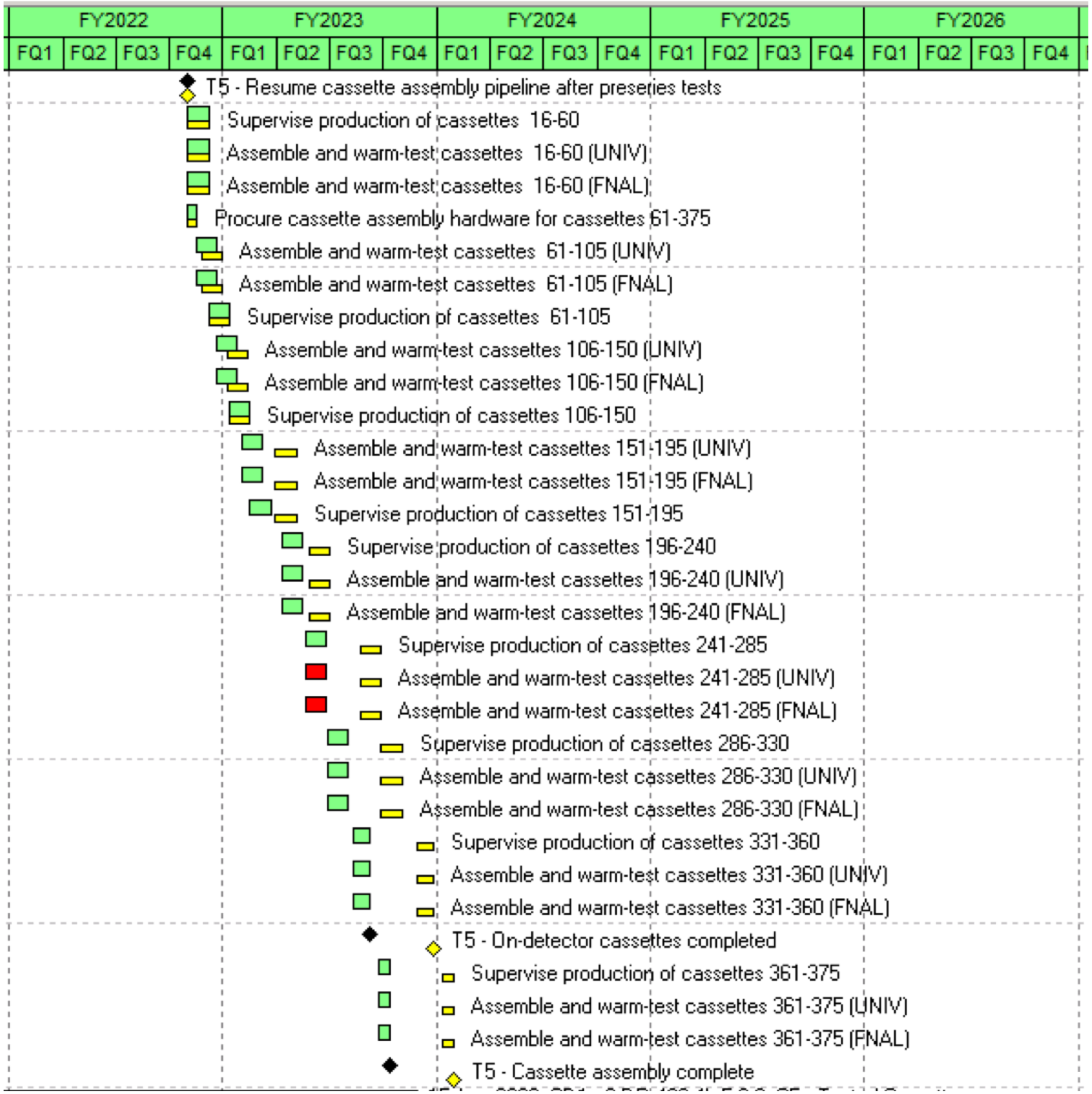
- 8” silicon modules and scintillator/SiPM tile-modules of (nearly) final design.
  - Front-end electronics based on (nearly) final front-end chip “HGCROC-V3”
  - Both full and partial modules available
- Motherboards of (nearly) final design
  - Concentrator ASIC V2
  - “Final” cassette interface
- Final cooling plate design
- Include three cassette sizes
- Goals:
  - Develop and validate final assembly and testing procedures
  - Full validation of final cassette design including performance of final module and electronics elements
  - Provide feed-back for final iterations of all designs

Schedule

Milestones


FY2019
FY2020
FY2021
FY2022
FY2023
FY2024
FY2025
FY2026
FQ1 FQ2 FQ3 FQ4
21-Aug-2023, CD1-v2-DR-402.4b.5 CE - Cassettes
22-Feb-2023, CD1-v2-DR-402.4b.5.1 CE - Cassette Components
22-Feb-2023, CD1-v2-DR-402.4b.5.1.1 CE - Cassette Cooling Plates
T5 - EC Cassette Cooling Plates Complete
28-Nov-2022, CD1-v2-DR-402.4b.5.1.2 CE - Silicon Motherboards
T5 - ECC - MBD -- EC Prototype 1 Motherboard Start
T5 - ECC - MBD -- EC Prototype 1 Motherboard Complete
T5 - ECC - MBD -- EC Prototype 2 Motherboard Start
T5 - ECC - MBD -- EC Prototype 2 Motherboard Complete
T5 - ECC - MBD -- EC Motherboard Production Start
T5 - ECC - MBD -- EC Motherboard System Complete
07-Oct-2020, CD1-v2-DR-402.4b.5.2 CE - Cassette Tooling and Teststands
07-Oct-2020, CD1-v2-DR-402.4b.5.2.2 CE - Cassette Assembly Tooling
T5 - Start of Procurements for Cassette Assembly Tooling
T5 - Finish of Procurements for Cassette Assembly Tooling
21-Aug-2023, CD1-v2-DR-402.4b.5.3 CE - Cassette Assembly and Shipping
14-Jul-2023, CD1-v2-DR-402.4b.5.3.1 CE - Assembled Cassettes
T5 - Ready to begin assembly of prototype 1 of cassettes
T5 - Ready to begin assembly of prototype 2 of cassettes
T5 - Ready to begin production assembly of cassettes
T5 - Resume cassette assembly pipeline after preseries tests
T5 - On-detector cassettes completed
T5 - Cassette assembly complete
15-Aug-2023, CD1-v2-DR-402.4b.5.3.2 CE - Tested Cassettes
T5 - ECC - Cassette cold testing complete
21-Aug-2023, CD1-v2-DR-402.4b.5.3.3 CE - Delivered Cassettes
T5 - ECC - On-detector-required silicon cassettes delivered to CERN

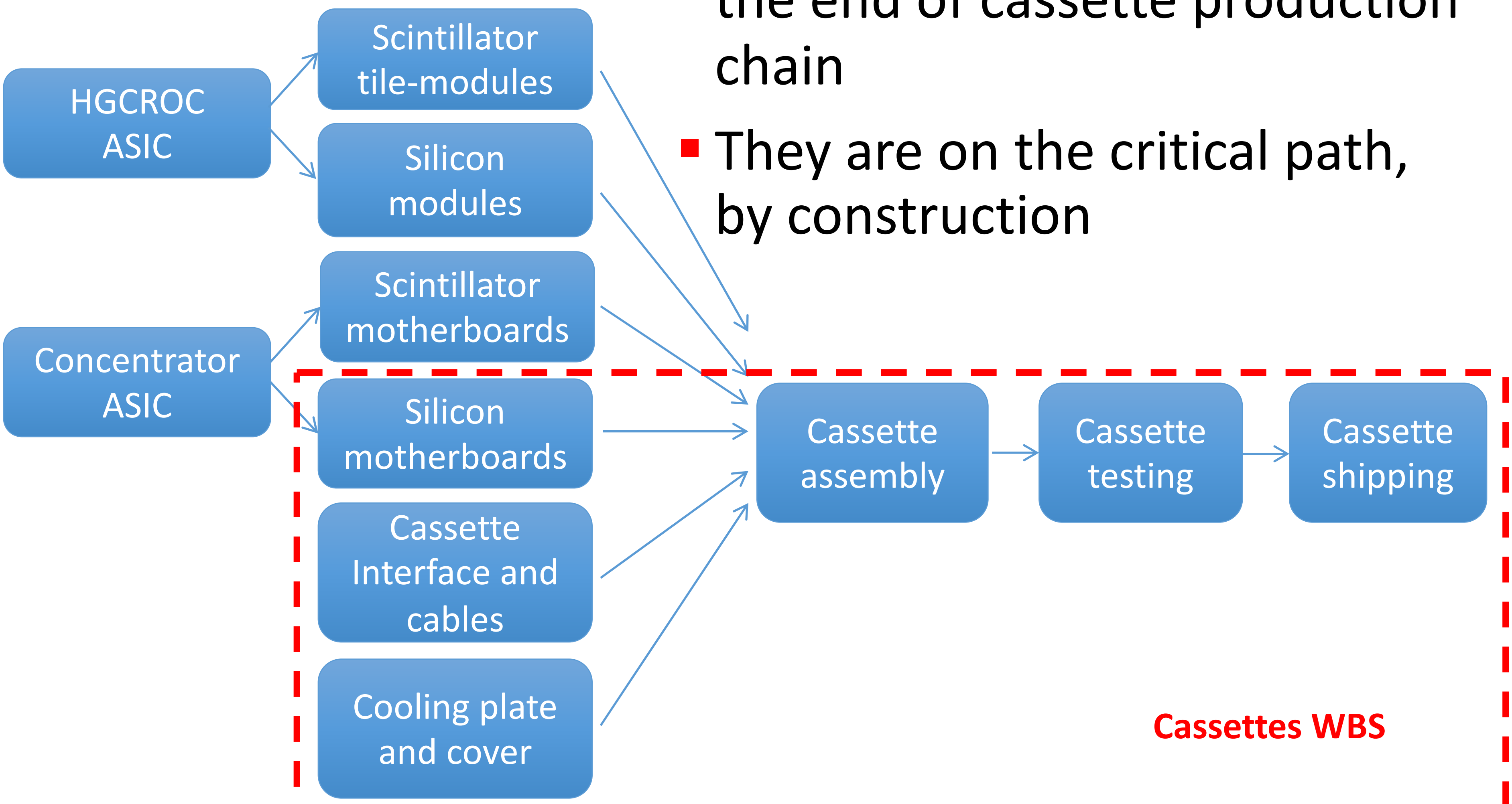
Cassette Assembly Contingency



Cassette Dependencies

Charge #3

- Cassette assembly, testing and shipping are sequential steps at the end of cassette production chain
- They are on the critical path, by construction



Critical Path Mitigation

Charge #3

- Planned throughput of cassette assembly: 2 cassette/day
- Design assembly factory for a capability of assembling 3 cassettes/day
  - Allows to keep the subproject end date in case of delayed inputs
- Design for plenty of storage of partially assembled cassettes
  - If waiting for a particular part to finish assembly
- Perform plenty of assembly and testing trials during prototyping phase to avoid unexpected problems during production

Summary

- The Cassettes area has a well defined scope and clear deliverables
- A conceptual design fulfilling the requirements have been developed
- Good progress is being made towards a preliminary design
  - An R&D program with 3 phases has been planned with well defined questions to answer
- A resource loaded schedule has been defined
  - Cost estimates are documented in BoEs
  - The schedule and dependencies are established and understood
  - Risk have been identified and are being managed
- Contributing institutions have been identified and optimized based on capabilities
- ES&H and QA/QC aspects are being closely tracked

Requirements (1)

Charge #2

- Cassettes are complete, self-contained detector sub-assemblies, which are assembled into the HGCAL mechanical structure to form the Endcap Calorimeters.
- The cassettes must:
  - Combine silicon and scintillator modules and their respective motherboards into an integrated detector, ready to be read out.
  - Provide a mechanism to maintain the temperature of the active detectors (silicon sensors and SiPMs) at a stable temperature $\leq$ -30°C (EC-engr-093)
  - Provide interfaces to the services necessary to test and operate the detectors (EC-engr-091):
    - HV to bias the sensors
    - LV to power the on-detector electronics
    - Fibers to read out the data and send control signals
    - Refrigeration fluid

Requirements (2)

Charge #2

- The cassettes must:
  - Provide a robust mechanical structure for the active detectors elements that have different CTE
  - Conform to the endcap geometry (EC-sci-engr-011, EC-engr-001, EC-engr-095), which is set by
    - $r_{min}(z)$ and $r_{max}(z)$ (interface with the rest of CMS)
    - defined sampling structure of the calorimeter in z-direction
  - Be of minimal thickness to maximize the density of the calorimeter (EC-engr-004)
  - Be of manageable size and weight to facilitate (EC-engr-009)
    - Handling during assembly and testing
    - Shipping from cassette assembly site to CERN/CMS
    - Handling during insertion into the endcap mechanical structure
  - Minimize the complexity of requirements placed on the detector elements that are integrated into the cassette.

Cost Estimate Overview

Charge #3,7

WBS	Direct M&S ($)	Labor (Hours)	FTE	Direct + Indirect + Esc. ($)	Estimate Uncertainty ($)	Total Cost ($)
CD1-v2-DR-402.4 402.4 CE - Calorimeter Endcap	20,943,332	309602	175.12	39,898,172	11,010,672	50,908,844
CD1-v2-DR-402.4.5 CE - Cassettes	3,322,995	44748	25.32	9,217,378	3,225,677	12,443,055
CD1-v2-DR-402.4.5.1 CE - Cassette Components	2,413,039	16584	9.38	4,928,150	1,971,637	6,899,788
CD1-v2-DR-402.4.5.2 CE - Cassette Tooling and Teststands	756,200	2572	1.45	1,279,257	367,637	1,646,893
CD1-v2-DR-402.4.5.3 CE - Cassette Assembly and Shipping	153,756	25592	14.48	3,009,971	886,403	3,896,374

L3 Parent:WBS : 402.4.5 EC - Cassettes (5)

402.4.5.1.1 EC - Cassette Cooling Plates	CMS-doc-13034
402.4.5.1.2 EC - Silicon Module motherboards	CMS-doc-13035
402.4.5.1.3 EC - Cassette Interface and Cables	CMS-doc-13036
402.4.5.2 EC - Cassette Tooling and Test Stands	CMS-doc-13205
402.4.5.3 EC - Cassette Assembly and Shipping	CMS-doc-13206

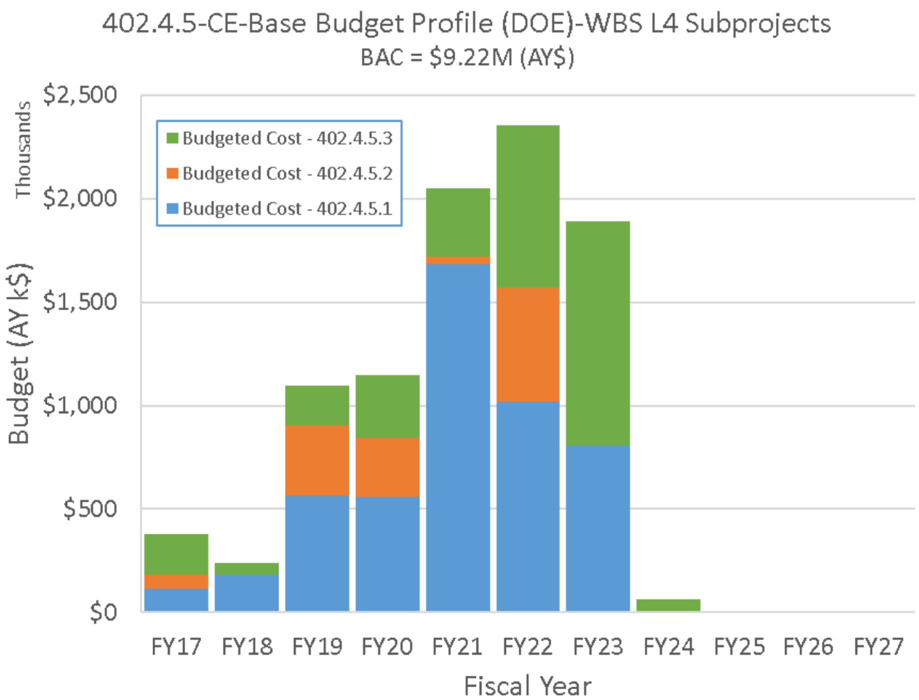
Cost Estimate at Level 5

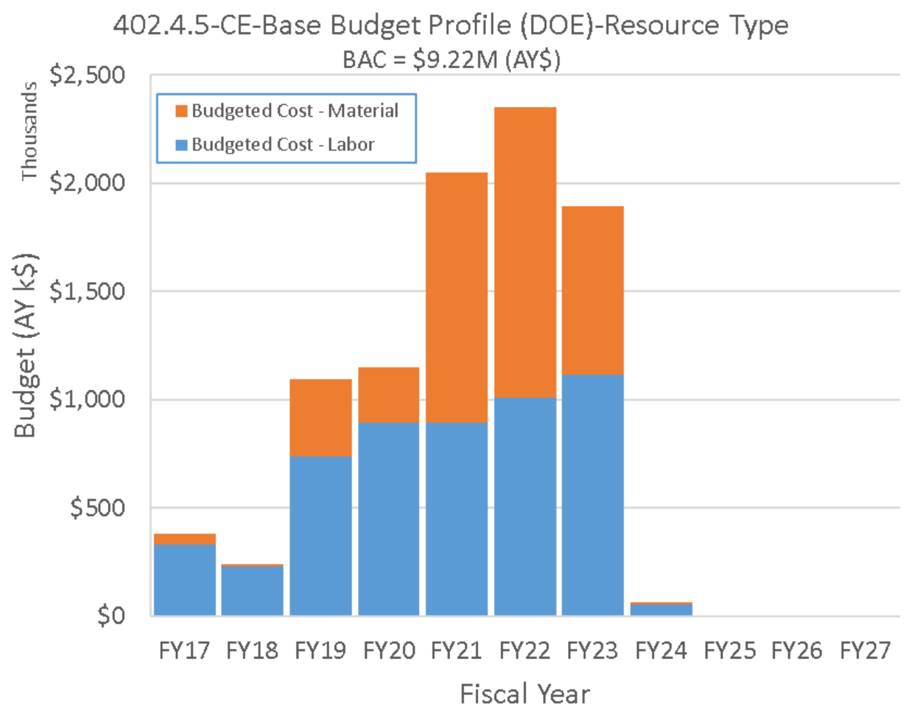
Charge #3

WBS	Direct M&S ($)	Labor (Hours)	FTE	Direct + Indirect + Esc. ($)	Estimate Uncertainty ($)	Total Cost ($)
CD1-v2-DR-402.4 402.4 CE - Calorimeter Endcap	20,943,332	309602	175.12	39,898,172	11,010,672	50,908,844
CD1-v2-DR-402.4.2 CE - Management	1,903,843	84232	47.64	3,784,827	629,965	4,414,792
CD1-v2-DR-402.4.3 CE - Sensors	7,470,621	11110	6.28	8,239,938	2,326,482	10,566,420
CD1-v2-DR-402.4.4 CE - Modules	2,925,152	92062	52.07	8,272,878	1,488,933	9,761,812
CD1-v2-DR-402.4.5 CE - Cassettes	3,322,995	44748	25.32	9,217,378	3,225,677	12,443,055
CD1-v2-DR-402.4.5.1 CE - Cassette Components	2,413,039	16584	9.38	4,928,150	1,971,637	6,899,788
CD1-v2-DR-402.4.5.1.1 CE - Cassette Cooling Plates	804,020	6440	3.64	1,754,350	790,580	2,544,930
CD1-v2-DR-402.4.5.1.2 CE - Silicon Motherboards	1,311,876	7592	4.29	2,552,604	900,866	3,453,470
CD1-v2-DR-402.4.5.1.3 CE - Cassette Interface and Cables	297,143	2552	1.44	621,196	280,191	901,388
CD1-v2-DR-402.4.5.2 CE - Cassette Tooling and Teststands	756,200	2572	1.45	1,279,257	367,637	1,646,893
CD1-v2-DR-402.4.5.2.1 CE - Cassette Frames	309,000	380	0.21	403,009	73,896	476,905
CD1-v2-DR-402.4.5.2.2 CE - Cassette Assembly Tooling	217,000	832	0.47	396,332	114,217	510,549
CD1-v2-DR-402.4.5.2.3 CE - Cassette Electrical Test Stands	75,100	400	0.23	154,408	21,568	175,976
CD1-v2-DR-402.4.5.2.4 CE - Cassette Thermal Test Stands	155,100	960	0.54	325,508	157,956	483,464
CD1-v2-DR-402.4.5.3 CE - Cassette Assembly and Shipping	153,756	25592	14.48	3,009,971	886,403	3,896,374
CD1-v2-DR-402.4.5.3.1 CE - Assembled Cassettes	28,503	21055	11.92	2,388,571	645,901	3,034,472
CD1-v2-DR-402.4.5.3.2 CE - Tested Cassettes	14,013	3151	1.78	322,806	123,290	446,096
CD1-v2-DR-402.4.5.3.3 CE - Delivered Cassettes	111,240	1386	0.78	298,595	117,211	415,806
CD1-v2-DR-402.4.6 CE - Scintillator Calorimetry	1,993,407	47998	27.15	3,790,474	1,256,122	5,046,596
CD1-v2-DR-402.4.7 CE - Electronics and Services	3,327,314	29452	16.66	6,592,676	2,083,494	8,676,170

Fiscal Year Cost Profile

Charge #3





Risks

Charge #3

Risk Rank	RI-ID	Title	Probability	Schedule Impact	Cost Impact	P * Impact (k$)
WBS / Ops Lab Activity : 402.4 CE - Calorimeter Endcap (16)						
Risk Type : Threat (16)						
3 (High)	RT-402-4-18-D	CE - Additional concentrator ASIC engineering (MPW) run is required	50 %	6 -- 7.5 -- 9 months	164 -- 241 -- 385 k$	132
3 (High)	RT-402-4-01-D	CE - Additional FE ASIC engineering run required	25 %	8 months	336 k$	84
2 (Medium)	RT-402-4-22-D	CE - Additional production acceleration required	20 %	1 months	564 -- 564 -- 777 k$	127
2 (Medium)	RT-402-4-23-D	CE - Si Motherboard complexity is much higher than expected	20 %	0 months	383 -- 575 -- 767 k$	115
2 (Medium)	RT-402-4-91-D	CE - Shortfall in Calorimeter Endcap scientific labor	30 %	0 months	0 -- 0 -- 982 k$	98
2 (Medium)	RT-402-4-04-D	CE - Concentrator does not meet specifications	10 %	6 -- 7.5 -- 9 months	907 -- 971 -- 1035 k$	97
2 (Medium)	RT-402-4-90-D	CE - Key Calorimeter Endcap personnel need to be replaced	25 %	0 -- 0 -- 3 months	75 -- 225 -- 555 k$	71
2 (Medium)	RT-402-4-02-D	CE - Infrastructure failure at module assembly facility	30 %	1 -- 4 months	100 -- 336 k$	65
2 (Medium)	RT-402-4-13-D	CE - HGCROC front end chip is delayed	20 %	1 -- 6 -- 12 months	21 -- 126 -- 252 k$	27
2 (Medium)	RT-402-4-20-D	CE - Boundary between Si and scintillator sections is moved	10 %	0 months	252 k$	25
1 (Low)	RT-402-4-16-D	CE - Cassettes damaged or lost in assembly, testing or shipping	5 %	3 months	100 -- 1000 k$	28
1 (Low)	RT-402-4-14-D	CE - Cassette cooling plate fabrication failure	10 %	3 months	73 -- 213 k$	14
1 (Low)	RT-402-4-15-D	CE - Motherboard and interface board fabrication failure	10 %	3 months	73 -- 193 k$	13
1 (Low)	RT-402-4-17-D	CE - Cassette assembly site failure	10 %	3 months	73 -- 163 k$	12
1 (Low)	RT-402-4-09-D	CE - Module PCB batch failure	5 %	2 -- 4 months	144 -- 186 k$	8
1 (Low)	RT-402-4-10-D	CE - Silicon sensor has low yield	1 %	2 -- 4 months	542 -- 784 k$	7

- For each failure take the value of the affected area
- Estimate the time it would take to replace the lost items
- Probabilities are based on prior experience

Risk of Damaging or Losing Cassettes

ID / Title: **RT-402-4-16-D CE - Cassettes damaged or lost in assembly, testing or shipping**

Summary: If a cassette gets damaged during assembly or a batch of 10 cassettes get damaged during cold testing or a batch of 10 cassettes get lost during shipping then the lost cassettes need to be fabricated and assembled again, which may jeopardize the delivery of cassettes to CMS on time.

Explanation of estimate: The cost estimate is based on the cost of the lost cassettes, including costs of modules. The delays is based on the time needed to replace the lost cassettes.

Risk mitigations (in base plan): Set in place carefully designed tooling and safe handling procedures.
Do not handle many cassettes at the same time; limit number of cassettes in a shipment to ~10 and no more than one of each type per shipment.
Planned production includes 1 spare cassette of each type. Ensure adequate quantity of spare parts to allow rapid assembly of replacement cassettes.
Ensure that all shipments are adequately insured.
Contracts to include options for later delivery of additional components.

Risk responses (if risk should occur):

Risk Type:	Threat
Project:	CMS HL-LHC
WBS:	402.4 CE - Endcap Calorimeter
Risk Area:	Technical Risk / ES&H
Owner:	Zoltan Gecse
Risk Status:	Open
Probability (P):	5%
Technical Impact:	0 (N) - negligible technical impact
Cost impact	
-- P.D.F.:	2-point - flat range
-- Minimum:	100 k$
-- Most likely:	k$
-- Maximum:	1000 k$
-- Mean:	550 k$
-- P * <Impact>	28 k$
Schedule impact:	
-- P.D.F.:	1-point - single value
-- Minimum:	months
-- Most likely:	3 months
-- Maximum:	3 months
-- Mean:	3 months
-- P * <Impact>	0.2 months
Risk Scores:	Probability : 1 (VL) Cost: 2 (M) Schedule: 1 (L)
Risk Rank:	1 (Low)
Start date:	1/Jan/2021
Expiry date:	12/Dec/2023
More Information:	

Risk of Cassette Assembly Site Failure

ID / Title: **RT-402-4-17-D CE - Cassette assembly site failure**

Summary: If the cleanroom area of the cassette assembly site gets damaged or if the CO2 cooling plant fails then the assembly and testing procedure will stop until the problems are fixed and it may jeopardize the delivery of cassettes to CMS on time.

Explanation of estimate: The estimate is based on the range of costs needed to replace the damaged equipment = 10 - 100k$. The 3 month delay is estimated based on the time it may take to fix the problems.

The L3 burn rate due to the delay of downstream activities is $21k/month (CMS-doc-13481).

Min cost = $10k + 3 months * $21k burn rate = $73k.

Max cost = $100k + 3 months * $21k burn rate = $163k.

Risk mitigations (in base plan): To mitigate the impact on the schedule, the capacity of the assembly and testing facility is planned to twice larger than required for normal operations.

Risk responses (if risk should occur):

Risk Type:	Threat
Project:	CMS HL-LHC
WBS:	402.4 CE - Endcap Calorimeter
Risk Area:	External Risk / Facilities
Owner:	Zoltan Gecse
Risk Status:	Open
Probability (P):	10%
Technical Impact:	0 (N) - negligible technical impact
Cost impact	
-- P.D.F.:	2-point - flat range
-- Minimum:	73 k$
-- Most likely:	k$
-- Maximum:	163 k$
-- Mean:	118 k$
-- P * <Impact>	12 k$
Schedule impact:	
-- P.D.F.:	1-point - single value
-- Minimum:	months
-- Most likely:	3 months
-- Maximum:	3 months
-- Mean:	3 months
-- P * <Impact>	0.3 months
Risk Scores:	Probability : 2 (L) Cost: 1 (L) Schedule: 1 (L)
Risk Rank:	1 (Low)
Start date:	1/Jan/2021
Expiry date:	12/Dec/2023
More Information:	CMS-doc-13481

Contributing Institutions and Resource Optimization

Contributing Institutions

Charge #4

- Fermilab: Cooling plate design/prototyping, assembly site and tooling
  M.Alyari (postdoc), P.Rubinov (eng), S.Timpone (eng), E.Voirin (eng), H.Cheung (sci), Z.Gecse (sci), J.Strait (sci)
- Minnesota: Silicon motherboard design/fabrication
  M.Revering (student), E.Frahm (eng), J.Mans (prof), R.Rusack (prof)
- Brown: Cooling tube fabrication
  Greg Landsberg (prof)
- Alabama: Cooling plate fabrication
  Conor Henderson (prof)
- Collaboration with LLR/CERN on cassette design
  LLR: C.Ochando (sci), T.Pierre-Emile (eng), G.Fayolle (eng), M.Roy (tech)
  CERN: H.Gerwig (eng), S.Surkov (eng)
- Other institutes may join cassette assembly

Resource Optimization

Charge #4

- Cassette Assembly Site
  - Fermilab is a natural choice for assembly of large and heavy objects given its large lab space, crane coverage, coordinate measuring machines and a CO2 cooling system for testing
  - Fermilab can also host technicians from universities to participate in the assembly
- Cooling plate design and fabrication
  - Fermilab has extensive expertise in cryogenics and mechanical engineering as well as suitable machine shops
  - Alabama and Brown Universities have technicians and machine shop to contribute to this area
- Motherboard
  - University of Minnesota has engineering expertise of high-speed PCB technology from CMS Phase-1 uHTR electronics
- Vendors are always considered when cost effective

ES&H

Charge #6

- All ES&H aspects of the HL LHC CMS Detector Upgrade Project will be handled in accordance with the Fermilab Integrated Safety Management approach, and the rules and procedures laid out in the Fermilab ES&H Manual (FESHM)
- We are following our Integrated Safety Management Plan (cms-doc-13395) and have documented our hazards in the preliminary Hazard Awareness Report (cms-doc-13394)
- Standard industrial hazards:
  - Lifting heavy objects (cooling plates)
  - Ergonomics of cassette assembly: e.g. leaning to install modules in the middle of a cooling plate, repetitive motions, etc.
  - Potentially sharp edges of components
- High voltage
- Cryogenic (-30°) operations
- Possible ODH from CO_2 coolant or dry nitrogen.
  (Very large leaks would be required to generate an ODH condition. The CO2 plant at Sidet is fully qualified.)

Quality Assurance and Quality Control

- Cooling Plate
  - QA: Develop a robust design with as much standard fabrication procedures as possible
  - QC: Use CMM machines to inspect fabricated parts
  - QC: Test cooling tube for flow and leakage
- Motherboard
  - QA: Use design techniques that follow industry standards
  - QC: Perform extensive testing of PCB and chips before assembly
- Cassette Assembly
  - QA: Develop robust assembly procedures with several tests at intermediate stages
  - QA: Maintain a construction database to track quality of parts
  - QC: Perform long-term electrical and thermal test of cassettes before shipping to CERN
- Conform to cms-doc-13093