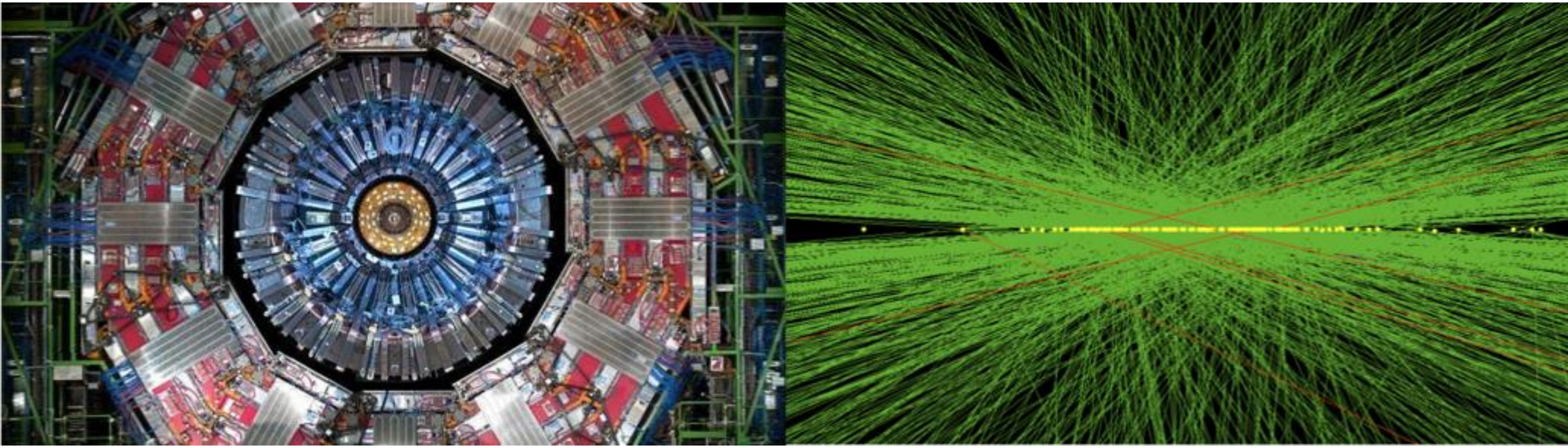
402.4.5 EC - Cassettes

Zoltan Gecse (Fermilab)

HL LHC CMS Detector Upgrade CD-1 Review

October 22nd, 2019



Outline

- Scope of Cassettes, WBS 402.4.5
- Conceptual Design
- Cost and Schedule
- Organizational aspects
- Contributing Institutions
- Optimization
- ES&H
- QA/QC
- Summary

Biographical Sketches

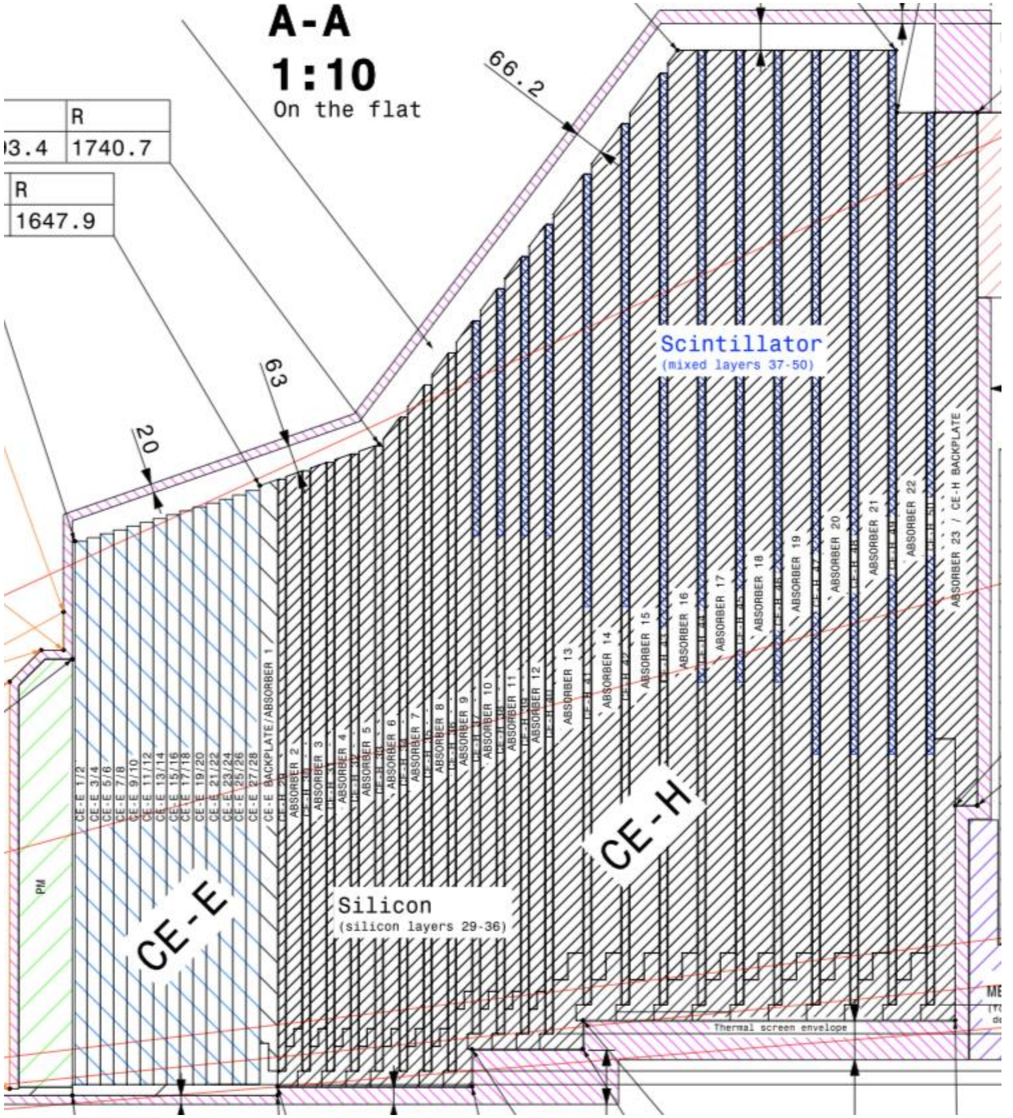
Charge #5

- 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 mechanical cassette mockup
  - ATLAS Transition Radiation Tracker readout firmware upgrade to 100kHz L1 rate
  - Convener of the MET based Supersymmetry Group in ATLAS

Scope

Deliverables for Cassettes 402.4.5

- US is responsible for assembling the active layers of the CE-H and shipping to CERN
- Active layers are inserted into absorber in pairs of 30-degree cassettes
    - 2 endcaps
    - 22 layers in each endcap
    - 12 cassettes in each layer
    - Total of **528** cassettes
    - Additional **22** cassettes for test beam purposes

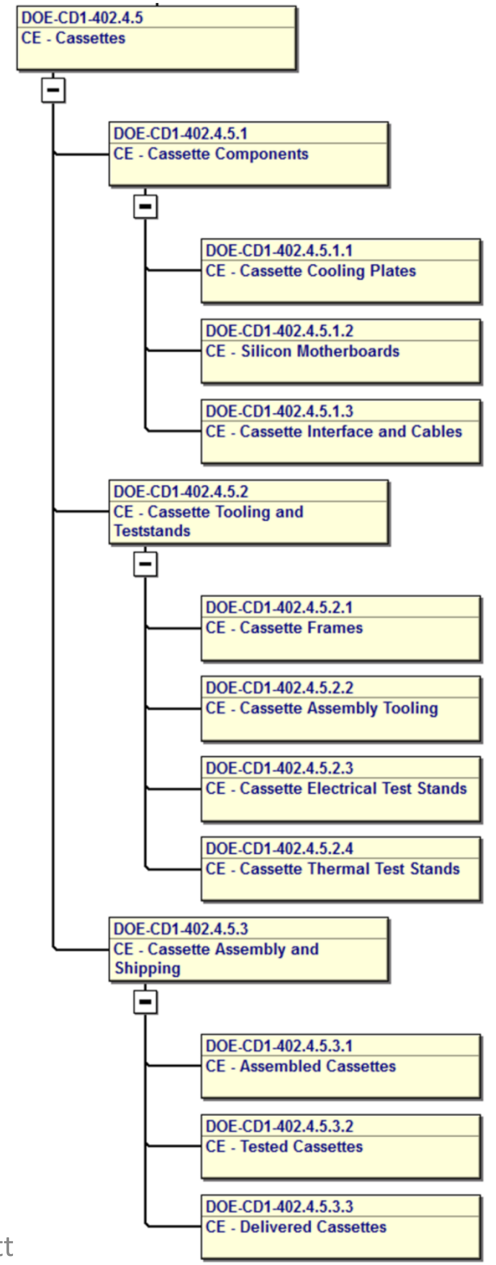


22 layers of CE-H

402.4.5 WBS Structure

Charge #7

- Cassette components
  - Cooling plates and cover
  - Silicon and scintillator modules
    - WBS 402.4.4 and WBS 402.4.6
  - Silicon motherboards (separate talk)
  - Scintillator motherboards
    - WBS 402.4.6
  - Cassette interface and cables
- Cassette tooling and factory
  - Frames and carts
  - Assembly tooling
  - Electrical test stands
  - Thermal test stands
- Cassette assembly, testing and shipping



Conceptual Design

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)

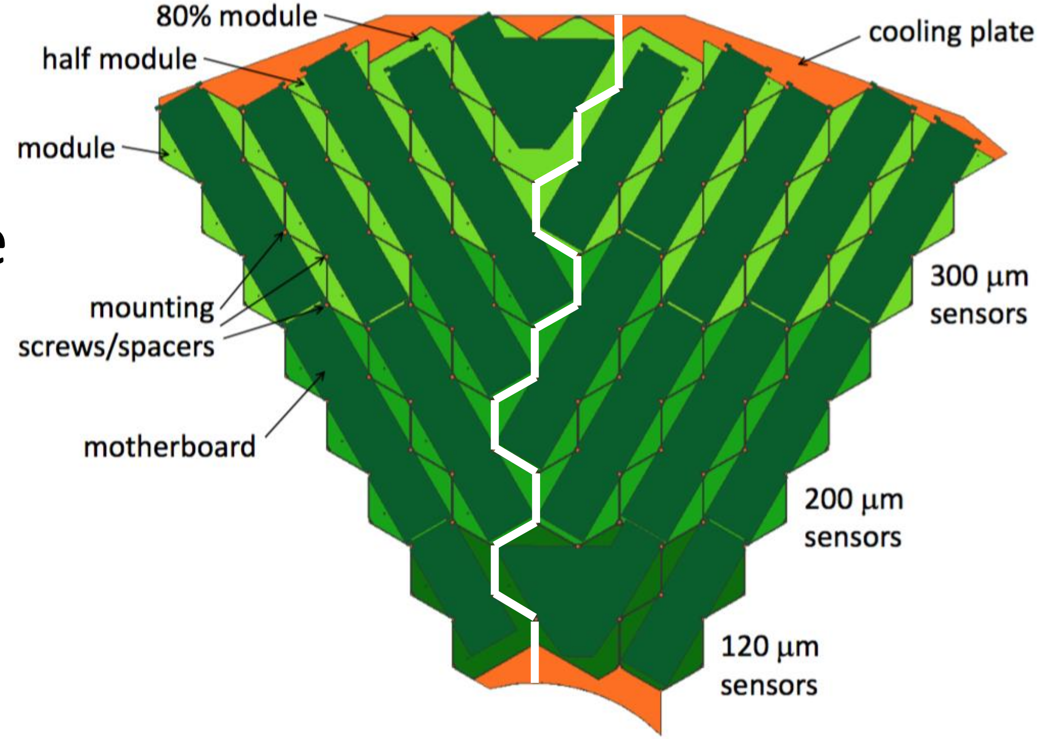
Charge #2

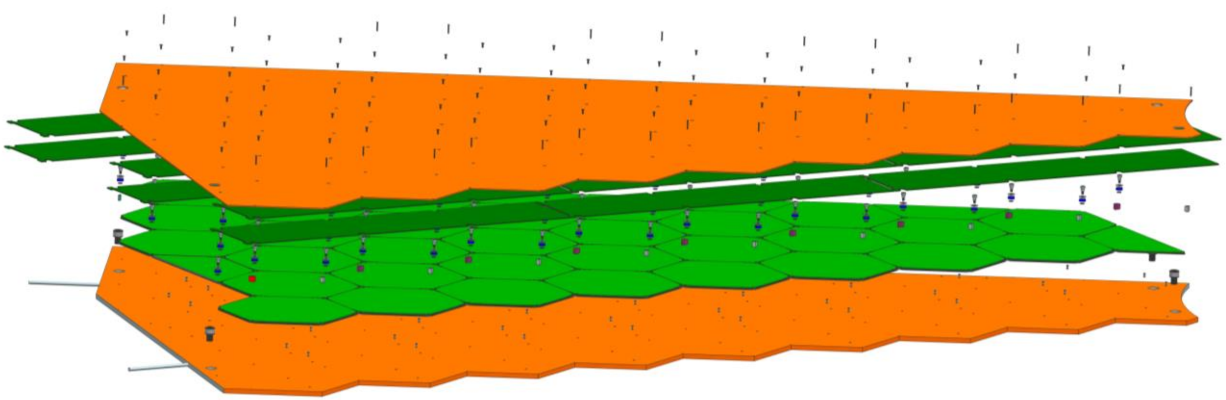
- The cassettes must:
  - Provide a robust mechanical structure for the active detectors elements that have different CTE
  - Conform to the endcap geometry (EC-sci-engr-011, EC-engr-001, EC-engr-095), which is set by
    - $r_{min}(z)$ and $r_{max}(z)$ (interface with the rest of CMS)
    - defined 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.

All Silicon Cassette Design

Charge #1

- 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





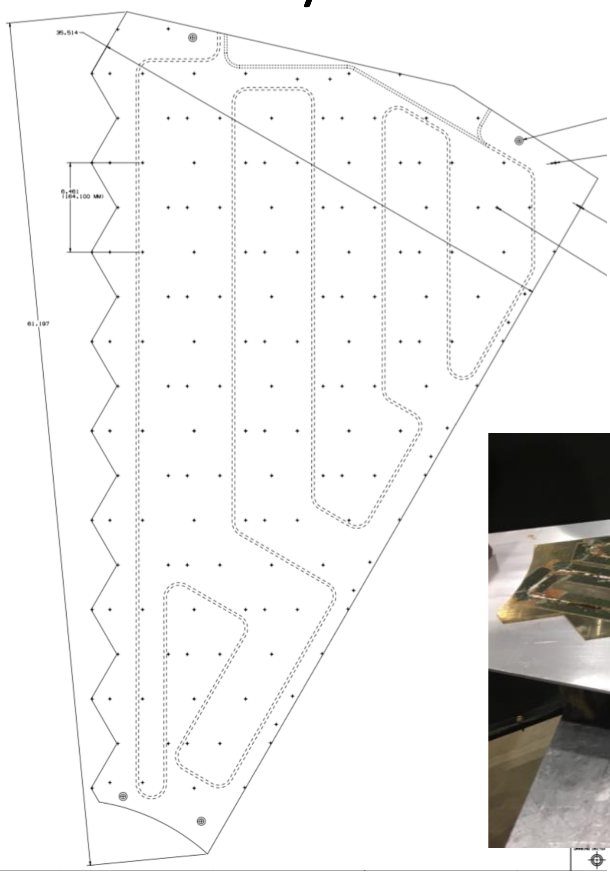
Cover	WBS 402.4.5.1.1
Motherboards	WBS 402.4.5.1.2
Modules	WBS 402.4.4
Cooling plate	WBS 402.4.5.1.1

Cooling Plate

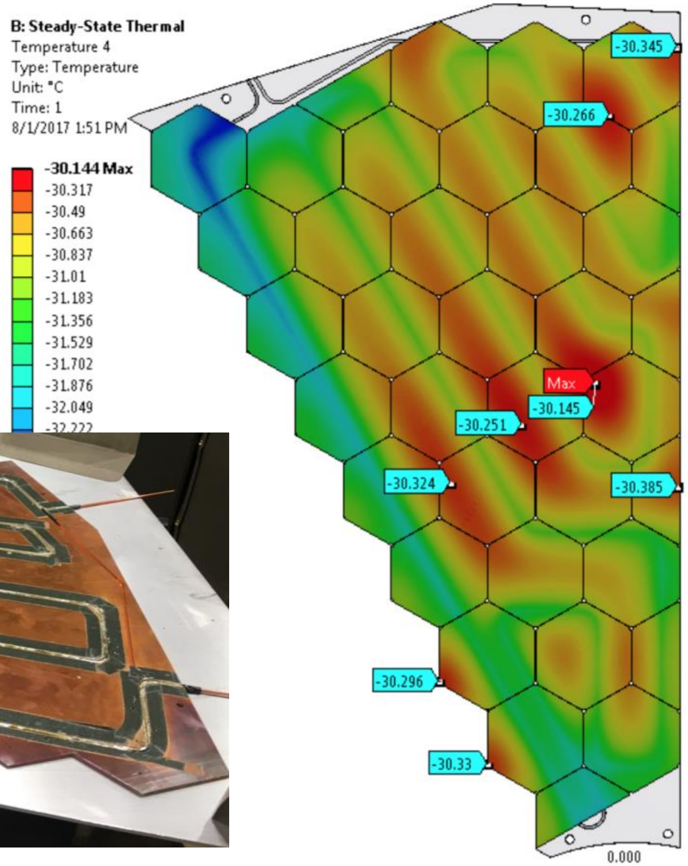
Charge #2

WBS 402.4.5.1.1

- Copper cooling plate is the mechanical support for modules and keeps them cold with 2-phase CO_2 cooling
- Cooling performance verified with simulation and prototypes
- 30 different shapes to be designed, but with a large degree of similarity



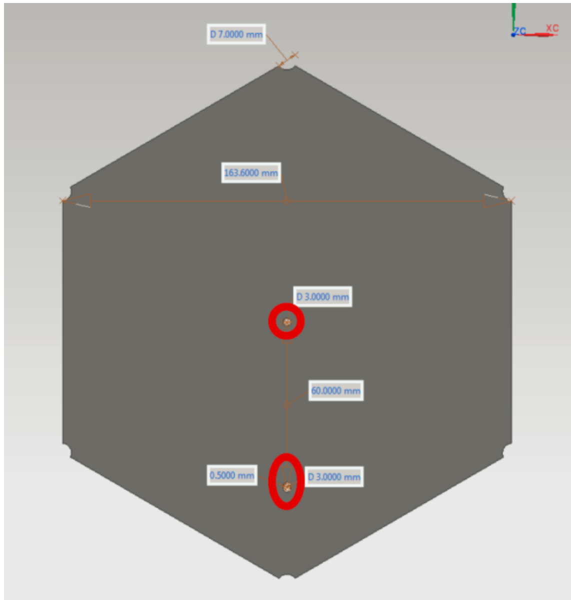
Cooling tube soldered into a groove with low temperature solder

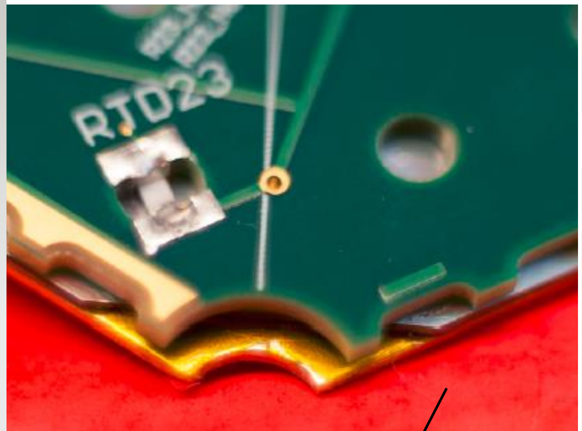


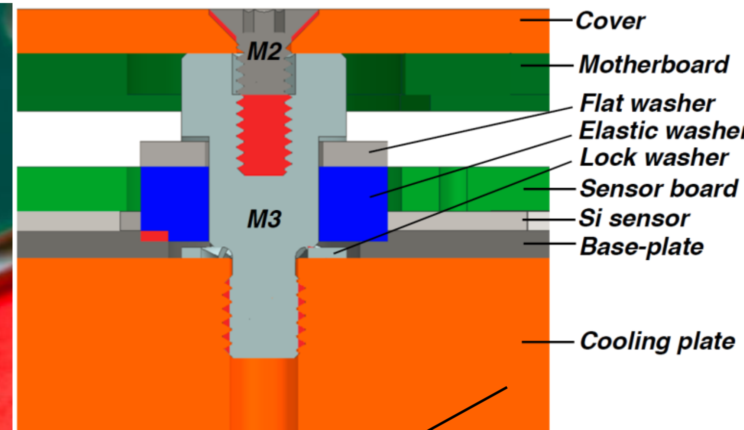
Dynamic Mounting of Silicon Modules

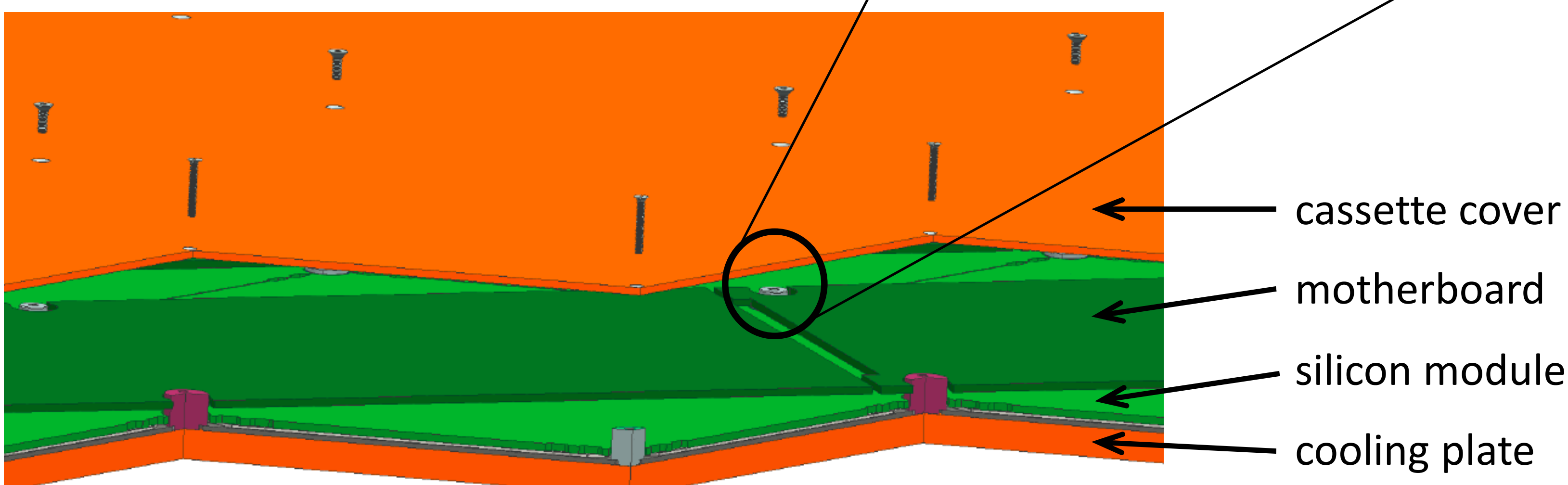
WBS 402.4.5.3.1

- Modules can have different CTE and expand wrt cooling plate

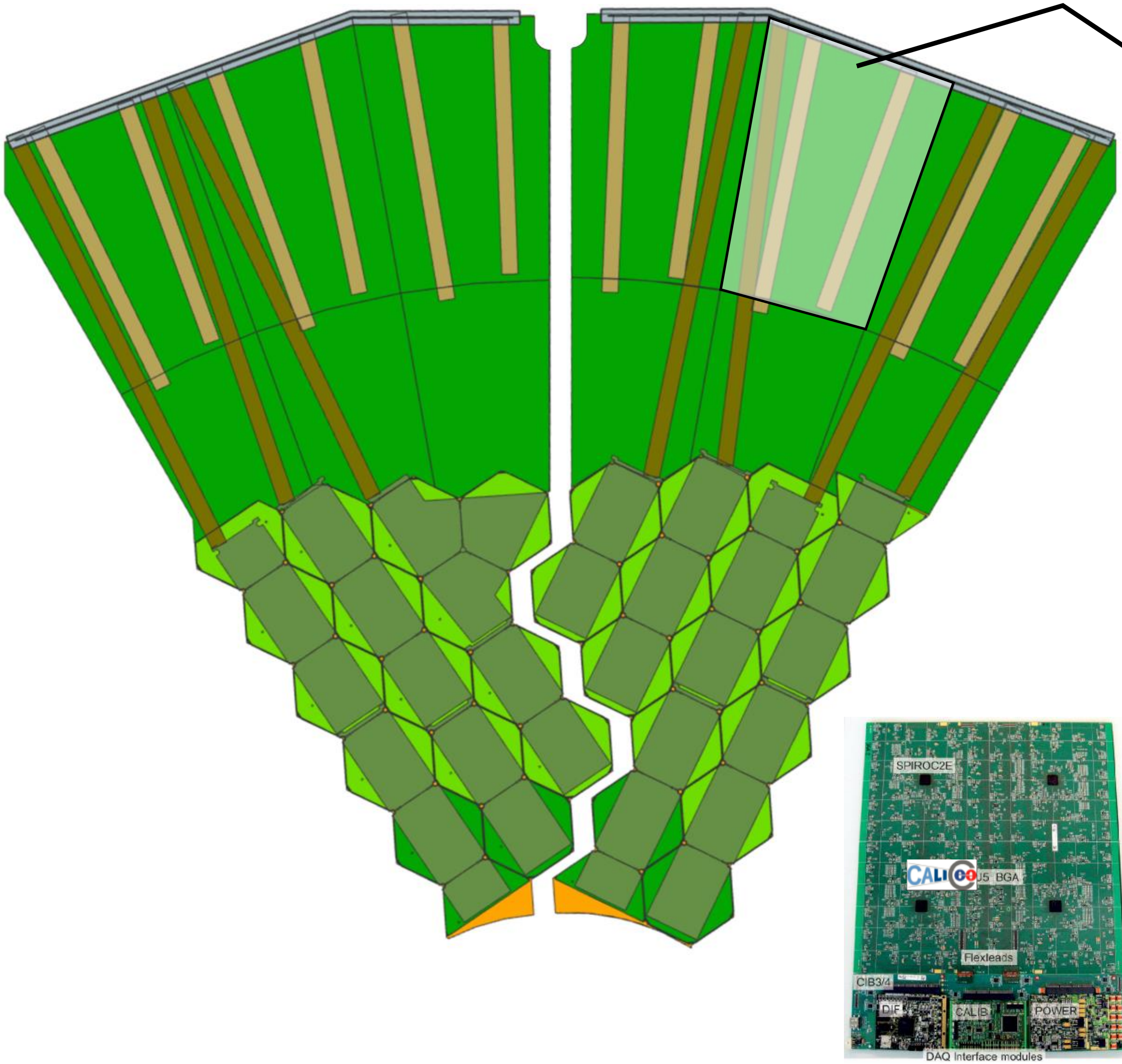




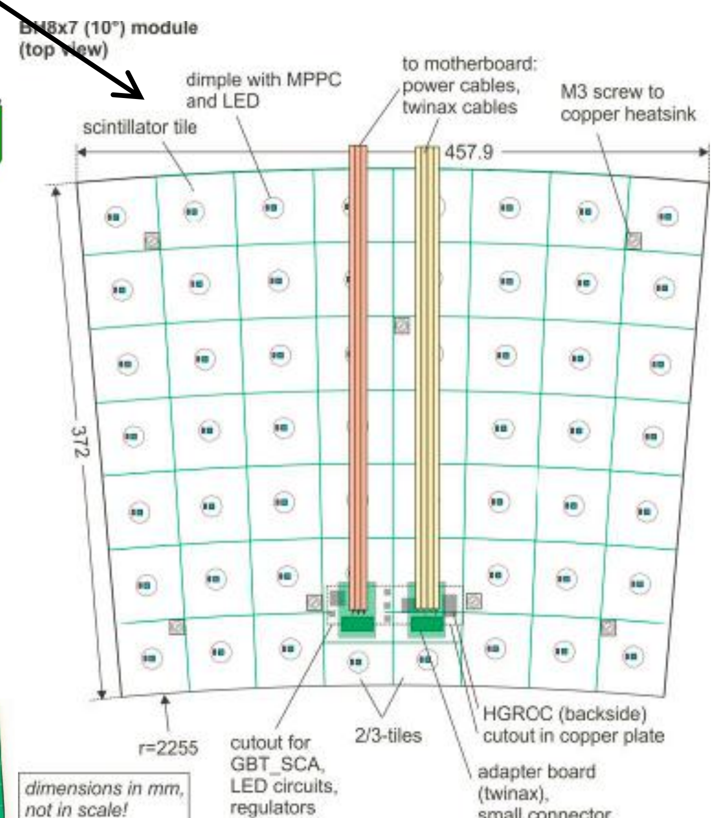




Mixed Silicon-Scintillator Cassettes



Scintillator/SiPM Tile-Module

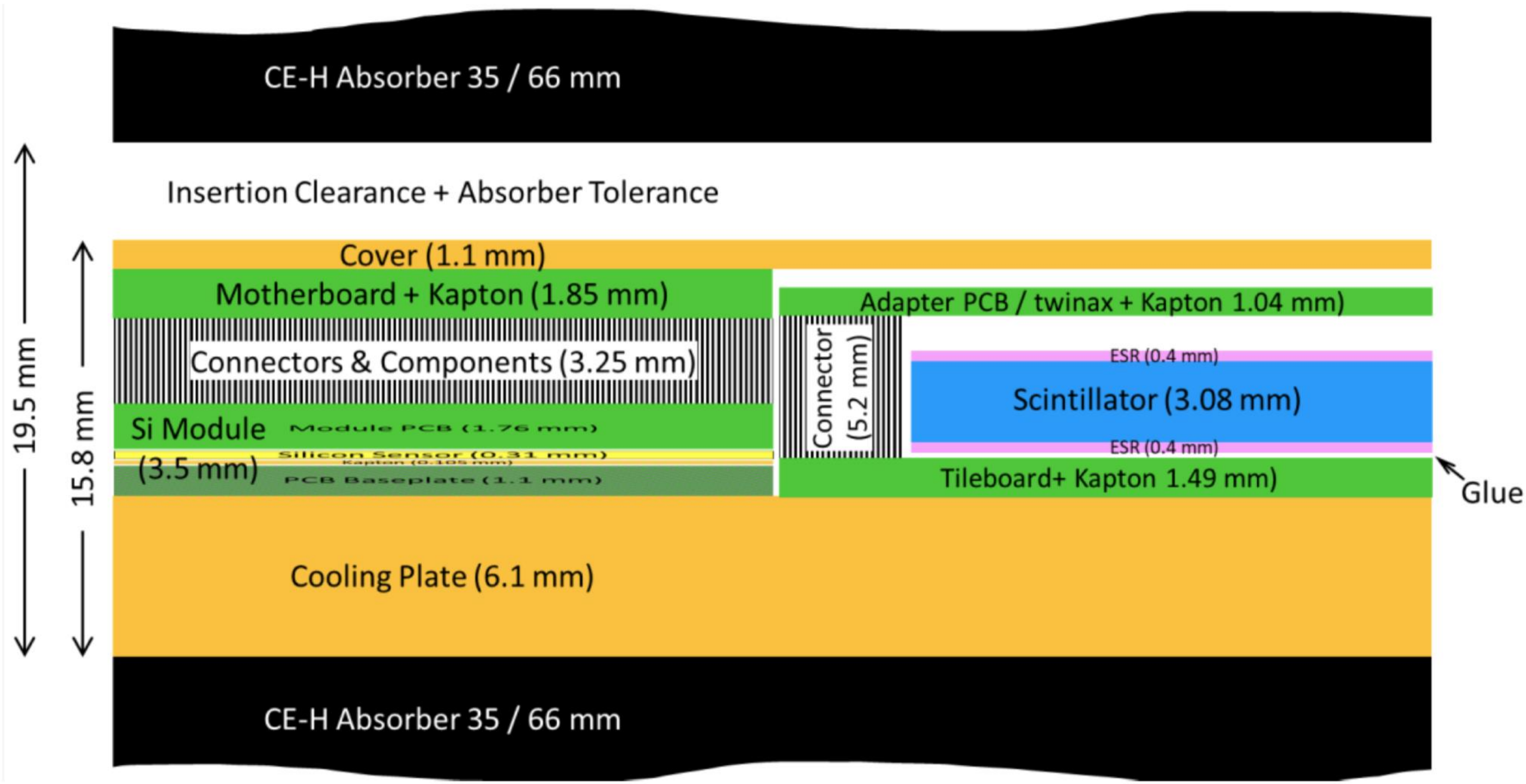


WBS 402.4.6

Height of CE-H cassettes

Charge #8

- Envelope thicknesses are shown for two types of active elements
- To account for tolerance build-ups an additional 3.7mm is added to the gap



Assembly Procedure

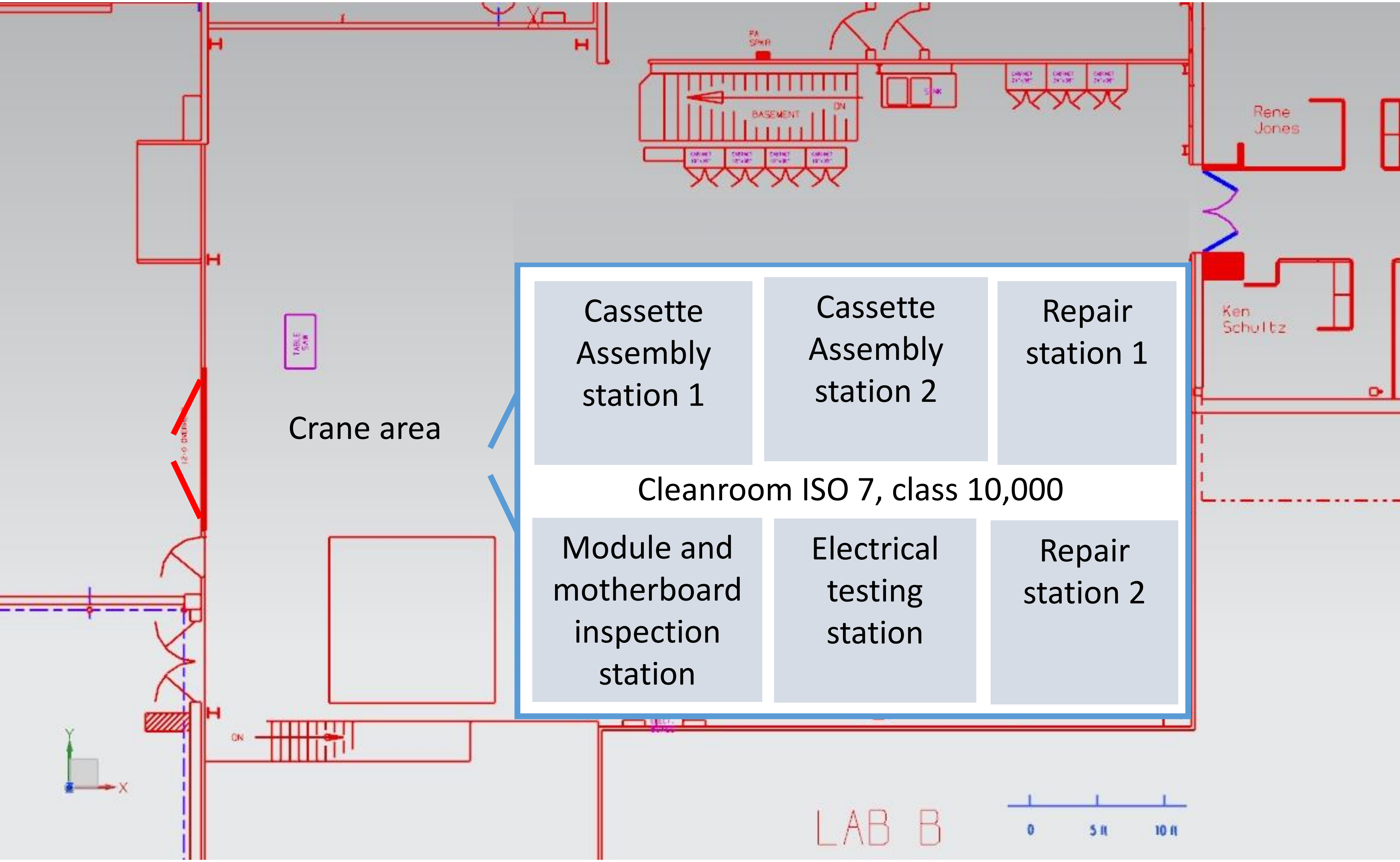
Charge #3

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

WBS 402.4.5.2.2

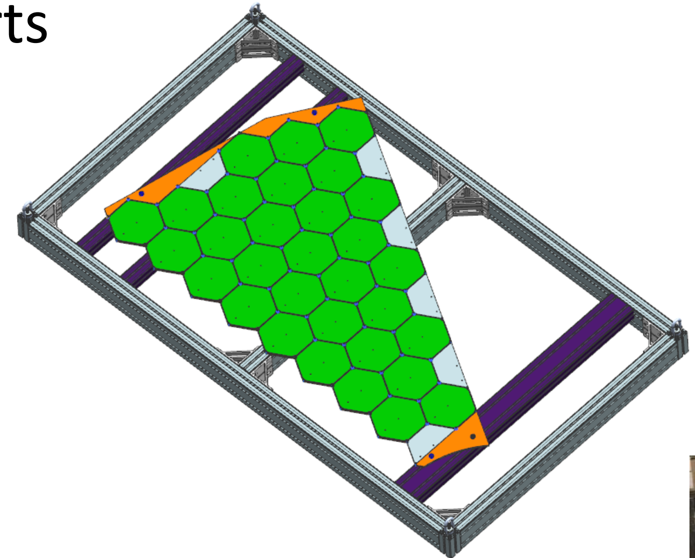


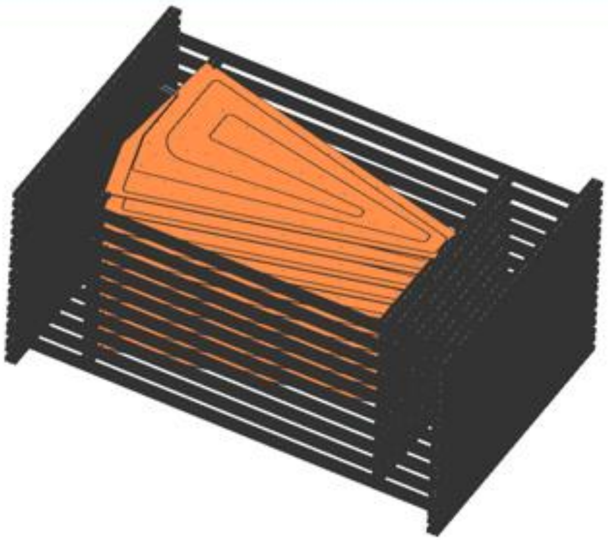
Cassette Handling Tools

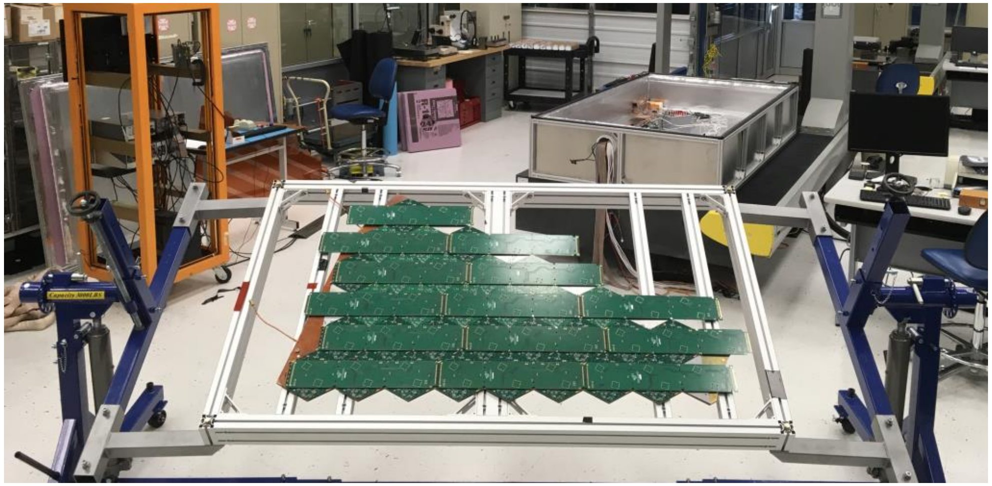
Charge #4

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







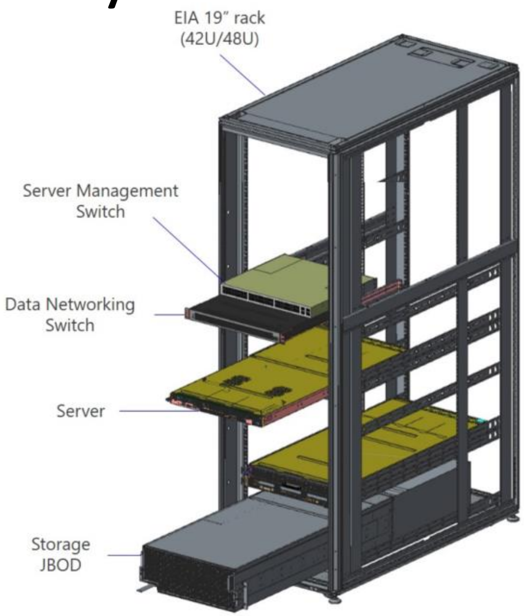
Cold Testing with CO2

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 CO2 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
- 2 cold rooms of 22 capacity are planned to allow acceleration
- Qualified CO2 cooling plant already exists in Lab C

Cassettes slide into custom (wider) rack based on commercial shelving technology



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 (CE-H1 and CE-H15^{mix})
  - Fully functional prototypes using first complete front-end chip HGCROC-V2 and a motherboard with FPGA for the concentrator
  - Design work started this spring, milestone to fully test by Aug 2020
    - Cooling plate design finished, motherboard design well underway, see dedicated talk
- Prototype series #2 (2x CE-H1, 2x CE-H9^{mix}, 2x CE-H15^{mix})
  - Prototype with (near) final front-end HGCROC-V3 and motherboard with concentrator ASIC
  - Design work to start in 2020, milestone to fully test by Sep 2021

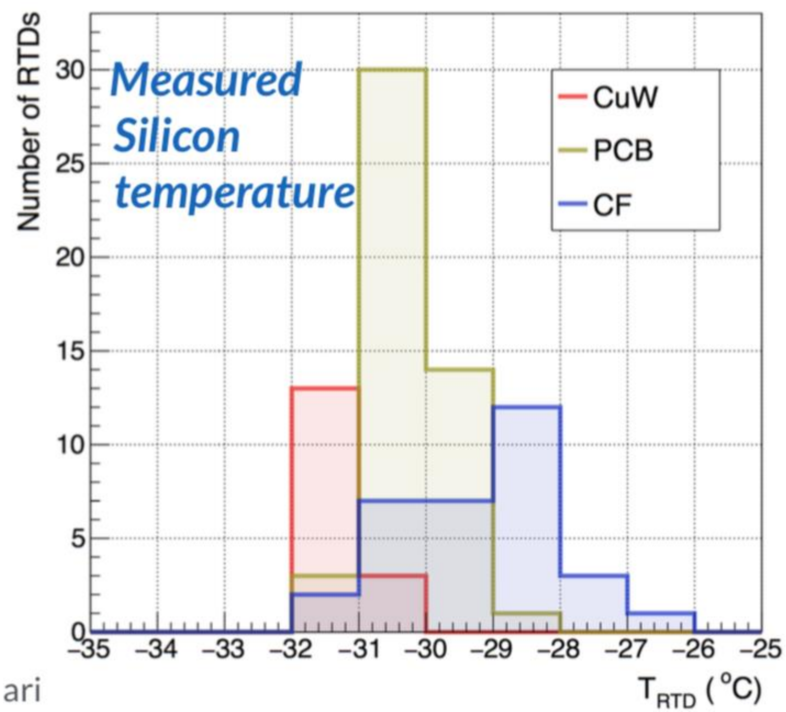
Thermo-electro-mechanical mockup

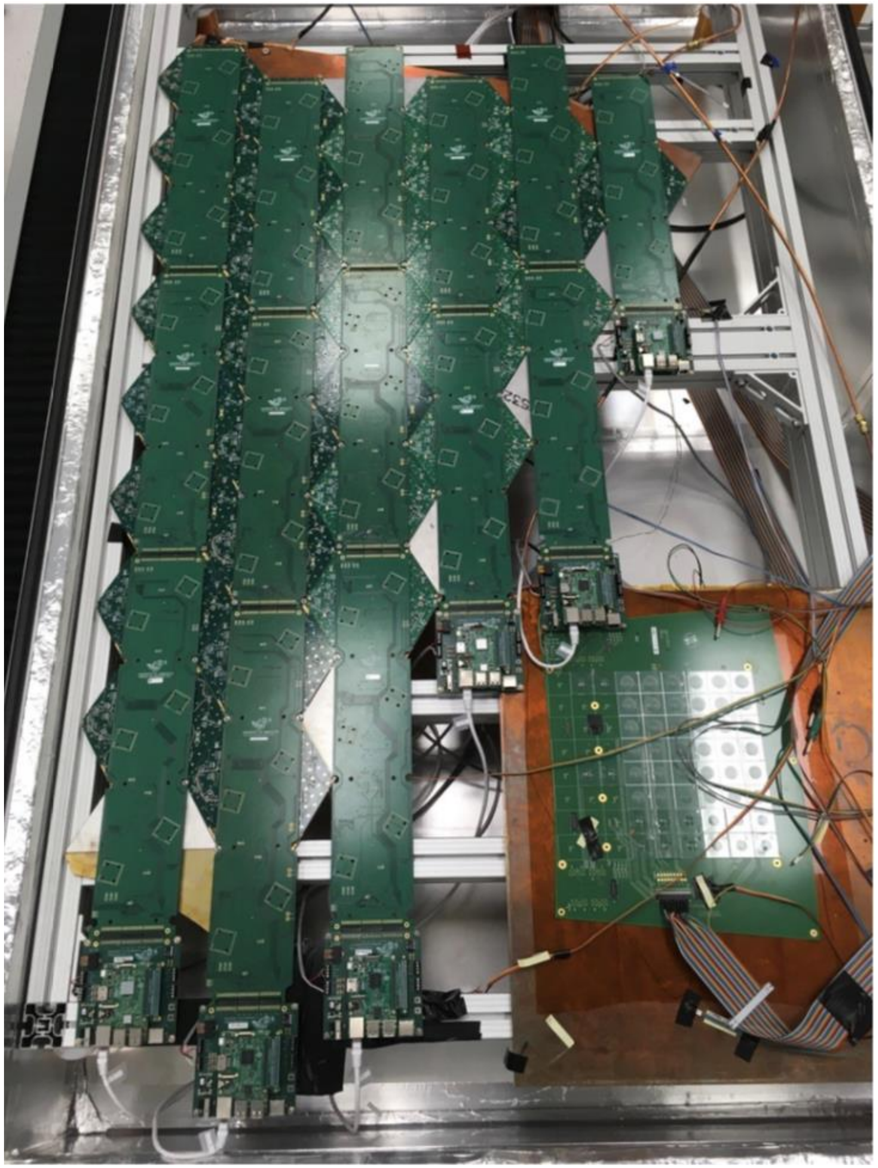
- Study thermal performance of cassette
  - Measure temperature distributions of cooling plate and silicon sensors, compare to FEA calculations
  - Study working points of CO2 system
- Study mechanical properties of the cassette
  - Demonstrate mounting scheme of modules including those at the edge of 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

completed

Mockup Results

- Mockup cassette fabricated and assembled
- Cold tested with CO2
- Measured temperature distributions on Si sensors with RTDs
- Observed -30C with -35C CO2 temperature





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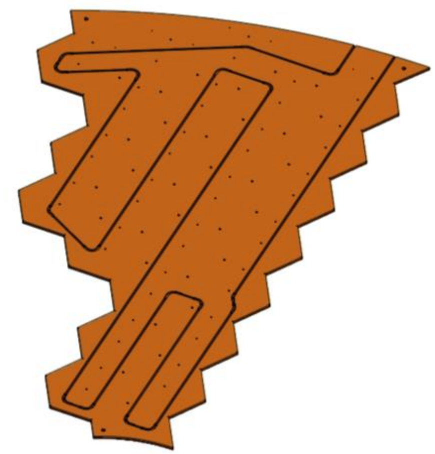
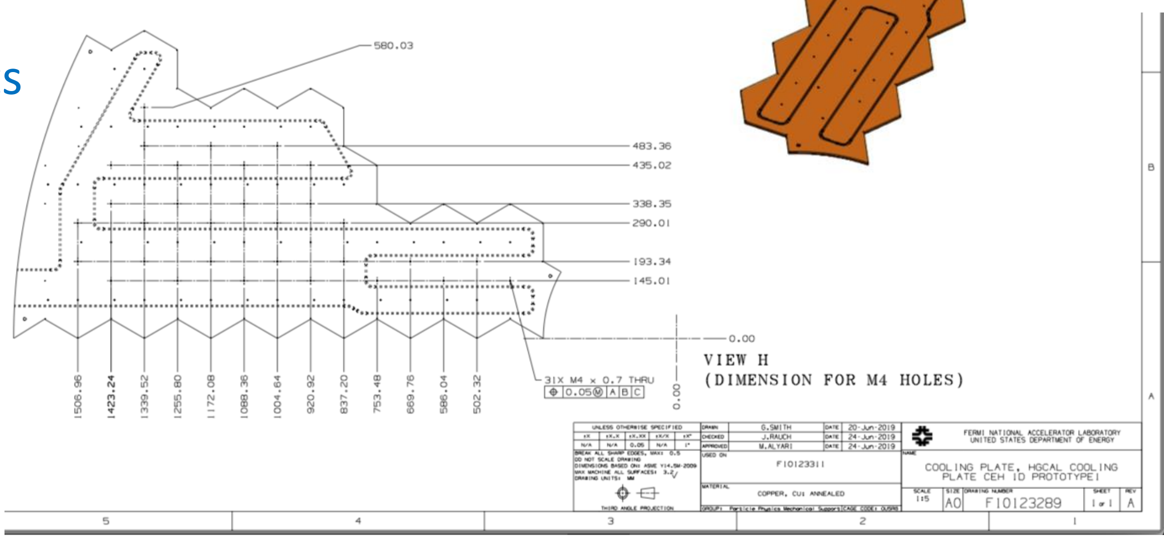
Prototype Series #1

- 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.
- Design of the cooling plate is finished
  - Sent to collaborators for fabrication





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
  - "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 and Cost

Milestones

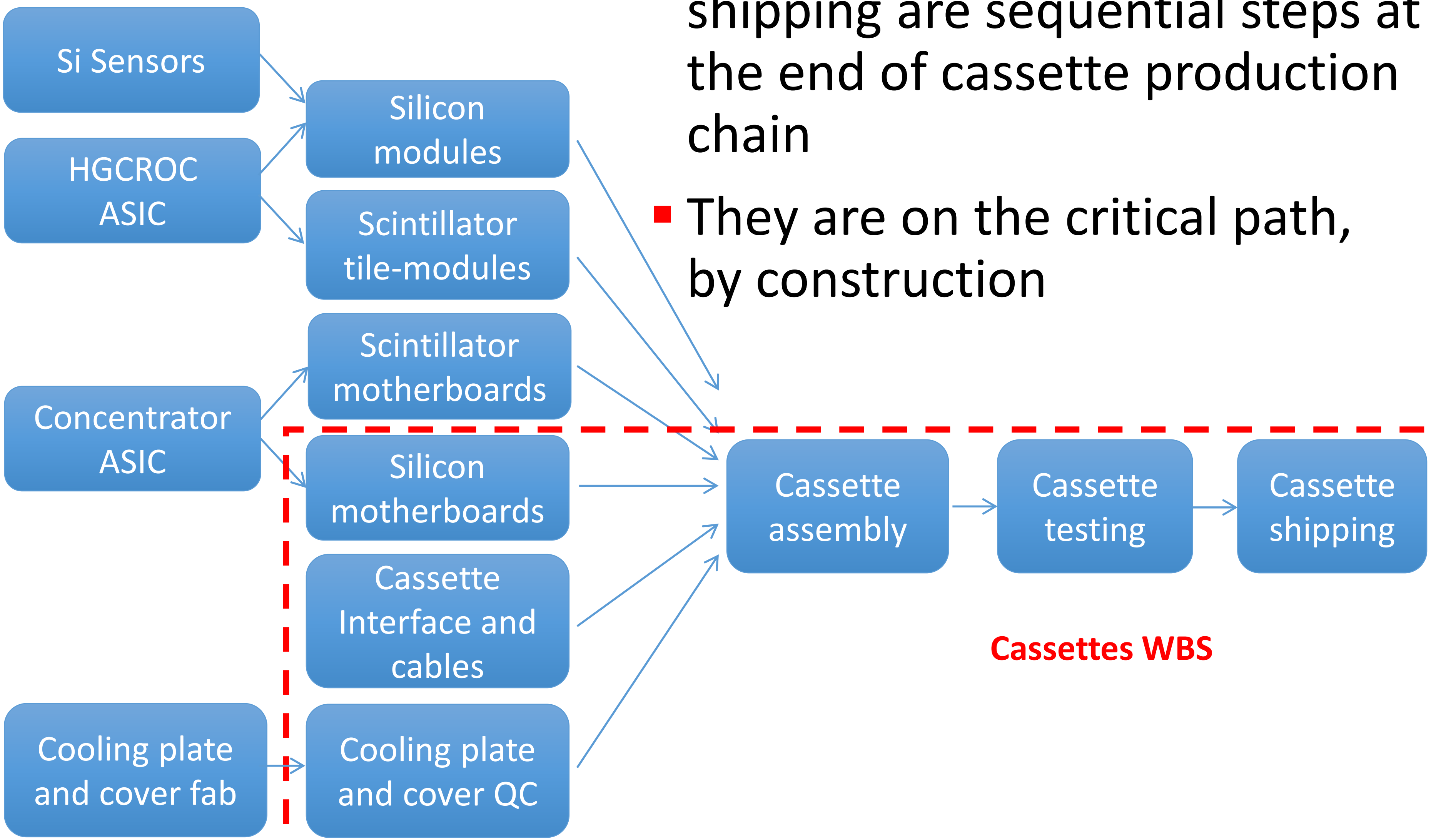
Charge #3

Activity ID	Activity Name	Start	Finish
402.4W.5.1	**CE - Cassette Components**	02-Jan-2018	27-Jul-2023
Milestone Tier: T5	**T5 Milestone - Sub-project Manager**	02-Jan-2018	27-Jul-2023
CP11000	T5 - EC Cassette Cooling Plate Start	02-Jan-2018	
CM12080	T5 - ECC - MBD -- EC Prototype 1 Motherboard Start	22-Oct-2018	
CI13251	T5 - Cassette interface ready for CD2 (Technical)		05-Sep-2019
CP11151	T5 - Cooling plates ready for CD2 (Technical)		06-Jan-2020
CM12290	T5 - ECC - MBD -- EC Prototype 1 Motherboard Complete		28-Apr-2020
CM12291	T5 - Silicon motherboards ready for CD2 (Technical)		28-Apr-2020
CM12300	T5 - ECC - MBD -- EC Prototype 2 Motherboard Start	11-May-2020	
CM12550	T5 - ECC - MBD -- EC Prototype 2 Motherboard Complete		01-Sep-2021
CM12580	T5 - ECC - MBD -- EC Motherboard Production Start	02-Sep-2021	
CP11250	T5 - Start production of cooling plates at international partner	04-Jan-2022	
CP11240	T5: Ready for start of production cooling plates	04-Jan-2022	
CM12990	T5 - ECC - MBD -- EC Motherboard System Complete		16-Nov-2022
CP11990	T5 - EC Cassette Cooling Plates Complete		27-Jul-2023
402.4W.5.2	**CE - Cassette Tooling and Teststands**	02-Jan-2020	16-Feb-2021
Milestone Tier: T5	**T5 Milestone - Sub-project Manager**	02-Jan-2020	16-Feb-2021
CT22050	T5 - Start of Procurements for Cassette Assembly Tooling	02-Jan-2020	
CT21101	T5 - Cassette frames ready for CD2 (Technical)		30-Apr-2020
CT24021	T5 - Cassette teststands ready for CD2 (Technical)		07-Jul-2020
CT22370	T5 - Finish of Procurements for Cassette Assembly Tooling		16-Feb-2021
402.4W.5.3	**CE - Cassette Assembly and Shipping**	03-Jan-2017	06-Mar-2024
Milestone Tier: T5	**T5 Milestone - Sub-project Manager**	03-Jan-2017	06-Mar-2024
CA31010	T5 - Begin mockup development	03-Jan-2017	
CA31000	T5 - Begin engineering on cassettes	03-Jan-2017	
CA31130	T5 - Ready to begin assembly of prototype 1 of cassettes	08-Apr-2020	
CA32011	T5 - Cassette assembly and test ready for CD2 (Technical)		11-Aug-2020
CA31170	T5 - Ready to begin assembly of prototype 2 of cassettes	31-Mar-2021	
CA31260	T5 - Ready to begin production assembly of cassettes	24-Jun-2022	
CA31350	T5 - Resume cassette assembly pipeline after preseries tests	07-Oct-2022	
CA31580	T5 - On-detector cassettes completed		17-Nov-2023
CA33340	T5 - ECC - On-detector-required silicon cassettes delivered to CERN		31-Jan-2024
CA31990	T5 - Cassette assembly complete		20-Feb-2024
CA32990	T5 - ECC - Cassette cold testing complete		06-Mar-2024

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 cassettes/day
- Design assembly factory for a capability of assembling and testing 4 cassettes/day
  - Allows to keep the subproject end date in case of delayed inputs
- Build two cold rooms
- Convert repair stations to assembly stations
- 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

Cost Estimate Overview

Charge #3,7

WBS	Direct M&S ($)	Labor (Hours)	FTE	Direct + Indirect + Esc. ($)	Estimate Uncertainty ($)	Total Cost ($)
DOE-CD1-402.4 402.4 CE - Calorimeter Endcap (at DOE CD1)	21,051,786	332579	188.11	40,672,474	10,143,585	50,816,059
DOE-CD1-402.4.5 CE - Cassettes	3,677,813	47416	26.82	9,422,794	3,065,143	12,487,937
DOE-CD1-402.4.5.1 CE - Cassette Components	2,671,722	17168	9.71	5,226,651	1,933,964	7,160,616
DOE-CD1-402.4.5.2 CE - Cassette Tooling and Test stands	754,300	2923	1.65	1,316,290	403,513	1,719,803
DOE-CD1-402.4.5.3 CE - Cassette Assembly and Shipping	251,791	27325	15.46	2,879,852	727,666	3,607,518

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

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

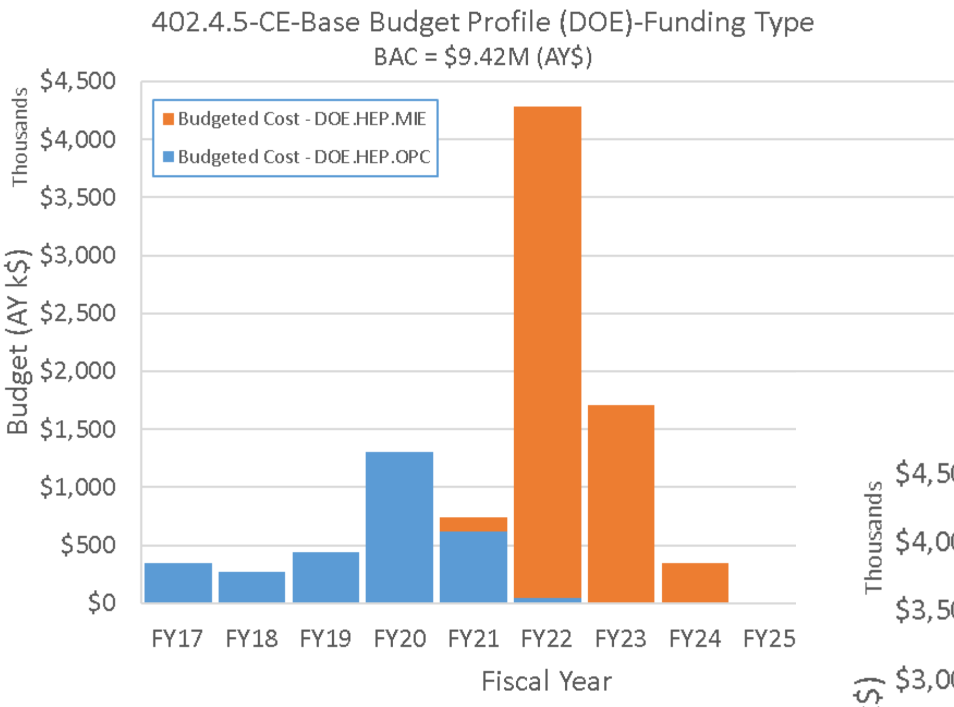
Cost Estimate at Level 5

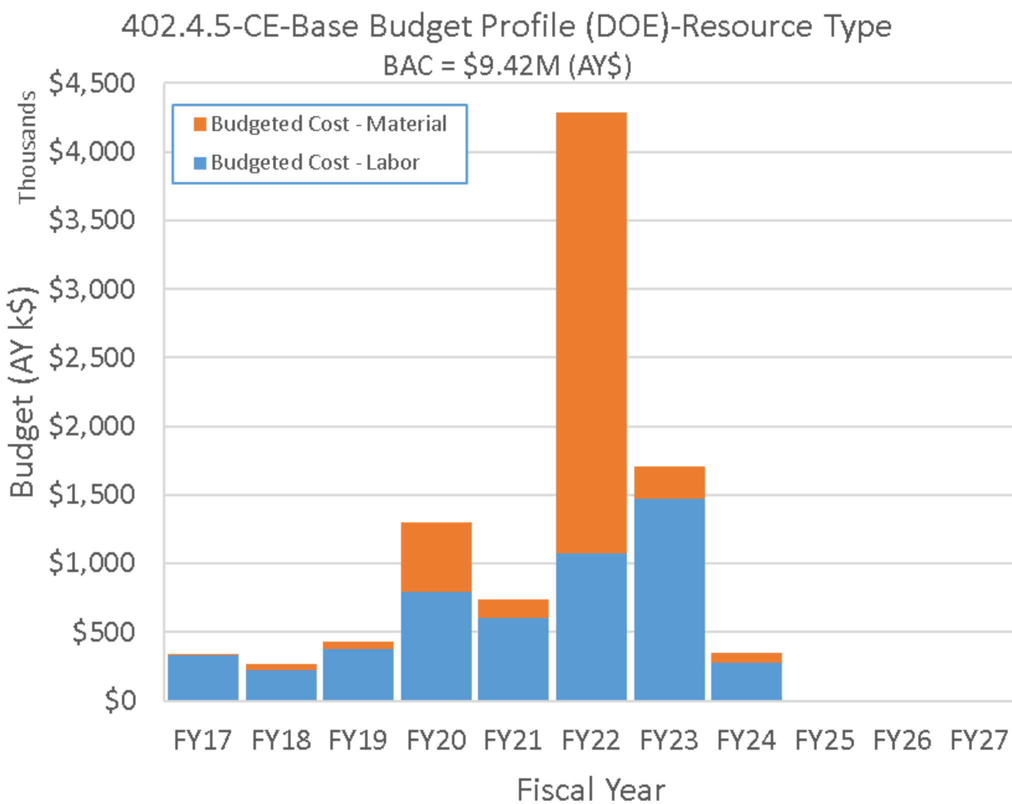
Charge #3

WBS	Direct M&S ($)	Labor (Hours)	FTE	Direct + Indirect + Esc. ($)	Estimate Uncertainty ($)	Total Cost ($)
DOE-CD1-402.4 402.4 CE - Calorimeter Endcap (at DOE CD1)	21,051,786	332579	188.11	40,672,474	10,143,585	50,816,059
DOE-CD1-402.4.2 CE - Management	1,934,243	82022	46.39	3,807,266	622,019	4,429,285
DOE-CD1-402.4.3 CE - Sensors	7,501,635	14846	8.40	8,393,032	1,722,630	10,115,663
DOE-CD1-402.4.4 CE - Modules	2,932,730	96412	54.53	8,405,886	1,435,046	9,840,932
DOE-CD1-402.4.5 CE - Cassettes	3,677,813	47416	26.82	9,422,794	3,065,143	12,487,937
DOE-CD1-402.4.5.1 CE - Cassette Components	2,671,722	17168	9.71	5,226,651	1,933,964	7,160,616
DOE-CD1-402.4.5.1.1 CE - Cassette Cooling Plates	59,600	6440	3.64	866,898	287,956	1,154,853
DOE-CD1-402.4.5.1.2 CE - Silicon Motherboards	2,245,755	7688	4.35	3,600,258	1,296,667	4,896,926
DOE-CD1-402.4.5.1.3 CE - Cassette Interface and Cables	366,367	3040	1.72	759,496	349,341	1,108,836
DOE-CD1-402.4.5.2 CE - Cassette Tooling and Teststands	754,300	2923	1.65	1,316,290	403,513	1,719,803
DOE-CD1-402.4.5.2.1 CE - Cassette Frames	239,000	475	0.27	330,776	61,287	392,063
DOE-CD1-402.4.5.2.2 CE - Cassette Assembly Tooling	247,000	928	0.52	440,832	135,507	576,339
DOE-CD1-402.4.5.2.3 CE - Cassette Electrical Test Stands	75,100	400	0.23	155,185	21,568	176,753
DOE-CD1-402.4.5.2.4 CE - Cassette Thermal Test Stands	193,200	1120	0.63	389,497	185,152	574,649
DOE-CD1-402.4.5.3 CE - Cassette Assembly and Shipping	251,791	27325	15.46	2,879,852	727,666	3,607,518
DOE-CD1-402.4.5.3.1 CE - Assembled Cassettes	41,278	22117	12.51	2,155,092	451,206	2,606,298
DOE-CD1-402.4.5.3.2 CE - Tested Cassettes	19,203	2921	1.65	264,659	98,417	363,076
DOE-CD1-402.4.5.3.3 CE - Delivered Cassettes	191,310	2287	1.29	460,101	178,043	638,144
DOE-CD1-402.4.6 CE - Scintillator Calorimetry	2,084,047	60875	34.43	4,196,710	1,244,785	5,441,494
DOE-CD1-402.4.7 CE - Electronics and Services	2,921,318	31008	17.54	6,446,786	2,053,962	8,500,748

Fiscal Year Cost Profile

Charge #3





Risks

Charge #3

RI-ID	Title	Probability	Cost Impact	Schedule Impact	P * Impact (k$)	P * Impact (months)
WBS / Ops Lab Activity : 402.4 CE - Calorimeter Endcap (16)						
Risk Rank : 3 (High) (2)						
RT-402-4-18-D	CE - Additional concentrator ASIC engineering (MPW) run is required	50 %	164 -- 241 -- 385 k$	6 -- 7.5 -- 9 months	132	3.8
RT-402-4-01-D	CE - Additional FE ASIC engineering run required	25 %	336 k$	8 months	84	2.0
Risk Rank : 2 (Medium) (6)						
RT-402-4-22-D	CE - Additional production acceleration required	20 %	564 -- 564 -- 777 k$	1 months	127	0.2
RT-402-4-91-D	CE - Shortfall in Calorimeter Endcap scientific labor	30 %	0 -- 0 -- 982 k$	0 months	98	0.0
RT-402-4-04-D	CE - Concentrator does not meet specifications	10 %	907 -- 971 -- 1035 k$	6 -- 7.5 -- 9 months	97	0.8
RT-402-4-90-D	CE - Key Calorimeter Endcap personnel need to be replaced	25 %	75 -- 225 -- 555 k$	0 -- 0 -- 3 months	71	0.3
RT-402-4-02-D	CE - Infrastructure failure at module assembly facility	30 %	100 -- 336 k$	1 -- 4 months	65	0.8
RT-402-4-13-D	CE - HGCROC front end chip is delayed	20 %	21 -- 126 -- 252 k$	1 -- 6 -- 12 months	27	1.3
Risk Rank : 1 (Low) (8)						
RT-402-4-23-D	CE - Si Motherboard complexity is much higher than expected	5 %	383 -- 575 -- 767 k$	0 months	29	0.0
RT-402-4-16-D	CE - Cassettes damaged or lost in assembly, testing or shipping	5 %	100 -- 1000 k$	3 months	28	0.2
RT-402-4-15-D	CE - Motherboard and interface board fabrication failure	10 %	73 -- 193 k$	3 months	13	0.3
RT-402-4-20-D	CE - Boundary between Si and scintillator sections is moved	5 %	252 k$	0 months	13	0.0
RT-402-4-17-D	CE - Cassette assembly site failure	10 %	73 -- 163 k$	3 months	12	0.3
RT-402-4-09-D	CE - Module PCB batch failure	5 %	144 -- 186 k$	2 -- 4 months	8	0.2
RT-402-4-14-D	CE - Cassette cooling plate fabrication failure	10 %	73 -- 83 k$	3 months	8	0.3
RT-402-4-10-D	CE - Silicon sensor has low yield	1 %	542 -- 784 k$	2 -- 4 months	7	0.0

- 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

RT-402-4-16-D CE - Cassettes damaged or lost in assembly, testing or shipping

Risk Rank:	1 (Low) **Scores:** Probability : 1 (VL) ; Cost: 2 (M) Schedule: 1 (L))	**Risk Status:**	Open
Summary:	If a cassette gets damaged during assembly or a batch of 15 cassettes get damaged during cold testing or a batch of 15 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.		
Risk Type:	Threat	**Owner:**	Zoltan Gecse
WBS:	402.4 CE - Calorimeter Endcap	**Risk Area:**	Management Risk / Experience or Capability
Probability (P):	5%	**Technical Impact:**	0 (N) - negligible technical impact
Cost Impact:	PDF = 2-point - flat range Minimum = 100 k$ Most likely = N/A Maximum = 1,000 k$ Mean = 550.0 k$ P * <Impact> = 28.0 k$	**Schedule Impact:**	PDF = 1-point - single value Minimum = N/A Most likely = 3.0 months Maximum = N/A Mean = 3 months P * <Impact> = 0.15 months
Basis of Estimate:	The cost estimate is based on the cost of losing up to 15 cassettes. We will be assemblying and testing in batches of 15, and shipping them to CERN in batches of 15. We calculate the cost by simply rolling up the cost of producing 375 cassettes, and taking (15/375) of this cost for the maximum cost impact. The cost of producing and testing all components, including silicon modules and scintillator tile-modules, and the cost of cassette assembly, testing, and shipping, are included. We do not include the cost of HGCROC and ECON ASIC as enough spares are expected to be purchased so we do not need an addition production run of these chips. The delays is based on the time needed to replace the lost cassettes.		
Cause or Trigger:		**Impacted Activities:**	Linked to Ship cassettes 331 - 360
Start date:	1-Jan-2021	**End date:**	12-Dec-2023
Risk Mitigations:	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 15 and no more than one of each type per shipment. Planned production includes 1 spare cassette of each type (for the test beam wedge). 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:	Response depends on the exact lost, if losing an entire batch of 15 cassettes in shipping, or damaging some cassettes in a batch(es) during handling in the assembly, testing, or shipping. In the worst case of losing all 15 cassettes in a batch, we will order additional parts as needed and make the additional 15 cassettes. The 15 test beam wedge cassettes may be used in the detector if this is needed tgo avoid significant delays. As needed we will accelerate the cassette assembly and testing. The cost of accelerating the cassette production is included in a separate risk entry.		
More details:			

Risk of Cassette Assembly Site Failure

RT-402-4-17-D CE - Cassette assembly site failure

Risk Rank:	1 (Low) **Scores:** Probability : 2 (L) ; Cost: 1 (L) Schedule: 1 (L))	**Risk Status:**	Open
Summary:	If the cleanroom area of the cassette assembly site gets damaged or if the CO_2 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.		
Risk Type:	Threat	**Owner:**	Zoltan Gecse
WBS:	402.4 CE - Calorimeter Endcap	**Risk Area:**	External Risk / Facilities
Probability (P):	10%	**Technical Impact:**	0 (N) - negligible technical impact
Cost Impact:	PDF = 2-point - flat range Minimum = 73 k$ Most likely = N/A Maximum = 163 k$ Mean = 118.0 k$ P * <Impact> = 12.0 k$	**Schedule Impact:**	PDF = 1-point - single value Minimum = N/A Most likely = 3.0 months Maximum = N/A Mean = 3 months P * <Impact> = 0.3 months
Basis 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.		
Cause or Trigger:		**Impacted Activities:**	JM: Inserted into assembly between 150 and 151
Start date:	1-Jan-2021	**End date:**	12-Dec-2023
Risk Mitigations:	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:			
More details:	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), N. Strobbe (prof)
- Brown: Cooling tube fabrication
  G. Landsberg (prof)
- Alabama: Cassette frame fabrication
  C. 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

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