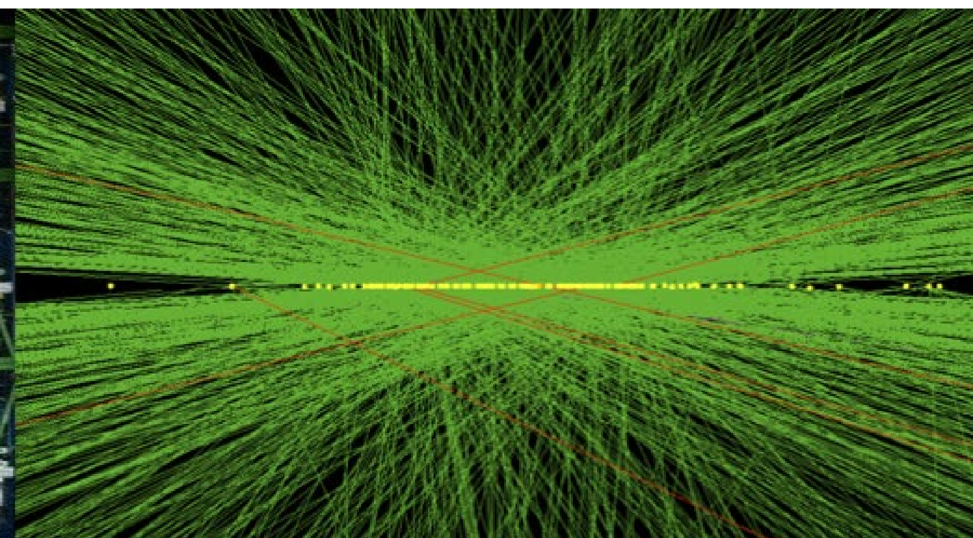
P06: 402.4 Calorimeter Endcap (CE)

Jeremiah Mans, L2 Manager

CD1 Review

October 22, 2019



Outline

- Introduction
- Design of the Endcap Calorimeter
  - Motivation, Scope, and Deliverables
- Updates since 2018 IPR
  - Conceptual Design, Maturity
  - Organization, Cost, Schedule
  - Risks
- Response to Previous Reviews
  - (Includes 2018 IPR Recommendations and 2019 DR Recommendations)
- Progress towards CD-3a/CD-2
- Breakout Session topics
- Summary

Charge #5

Biographical Sketches

- L2 Manager: Jeremiah Mans
  - Professor (University of Minnesota)
  - L2 Manager for CMS HCAL portion of US LHC Upgrade Project (2013-2015)
  - Developed full resource-loaded schedule from the beginning of the project, led HCAL team through CD1, CD2/3 reviews
  - International Endcap Calorimeter Project Office, L2 Coordinator for scintillator system (2016-current)
  - Deputy International CMS Phase 2 Upgrade Coordinator (2013-2015)
  - Co-led preparation of CMS Phase 2 Upgrade Technical Proposal and Scoping Document, lead editor for calorimetry chapter of technical proposal
  - Physics: Search for new physics in dilepton/dijet channel, electroweak physics measurements
  - Technical work: development of HCAL Phase 1 offline electronics, evaluation of commercial solutions for on-detector radiation-tolerant FPGAs
- L2 Deputy: Harry Cheung
  - Senior Scientist (Fermilab)
  - L3 Manager/CAM for Components in CMS Forward Pixels (2013-2017)
  - Developed design and RLS from R&D through CD1, CD2/3 and CD4
  - Co-convenor of the CMS Tracker Upgrade Simulations working group (2007-2012)
  - USCMS Operations L3 Manager for Storage Manager software (2007-2009)
  - Constructed early scintillating-fiber electromagnetic calorimeter for E831 (1988-1993)

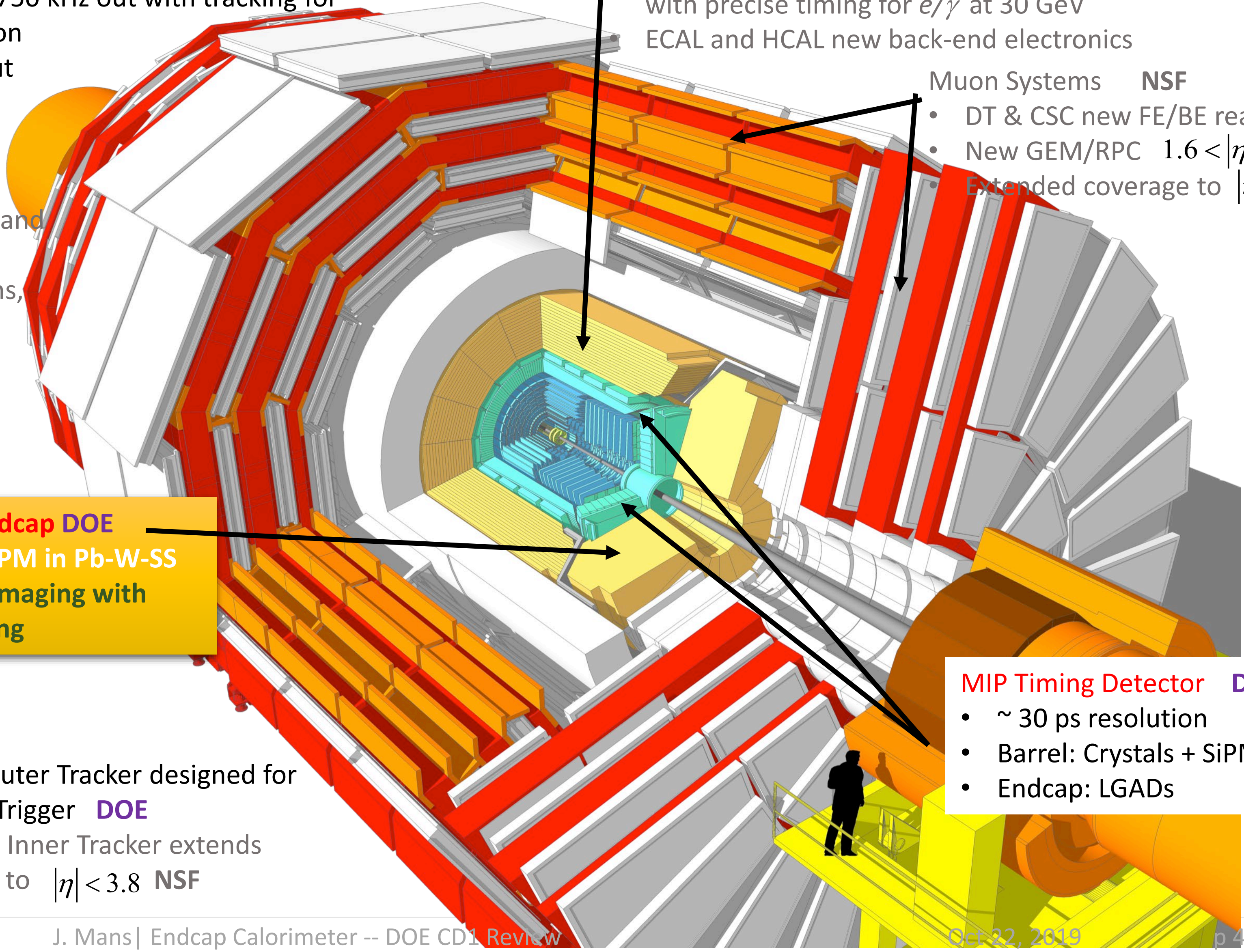
CMS Upgrade Scope

L1 Trigger/HLT/DAQ **NSF** and **DOE**
- L1 40 MHz in/750 kHz out with tracking for PF-like selection
- HLT 7.5 kHz out

Barrel Calorimeters **NSF**
- ECAL single crystal granularity in L1 Trigger with precise timing for e/γ at 30 GeV
- ECAL and HCAL new back-end electronics

Muon Systems **NSF**
- DT & CSC new FE/BE readout
- New GEM/RPC $1.6 < |\eta| < 2.4$
- Extended coverage to $|\eta| < 3.0$

Beam Radiation and Luminosity, Common Systems, Infrastructure



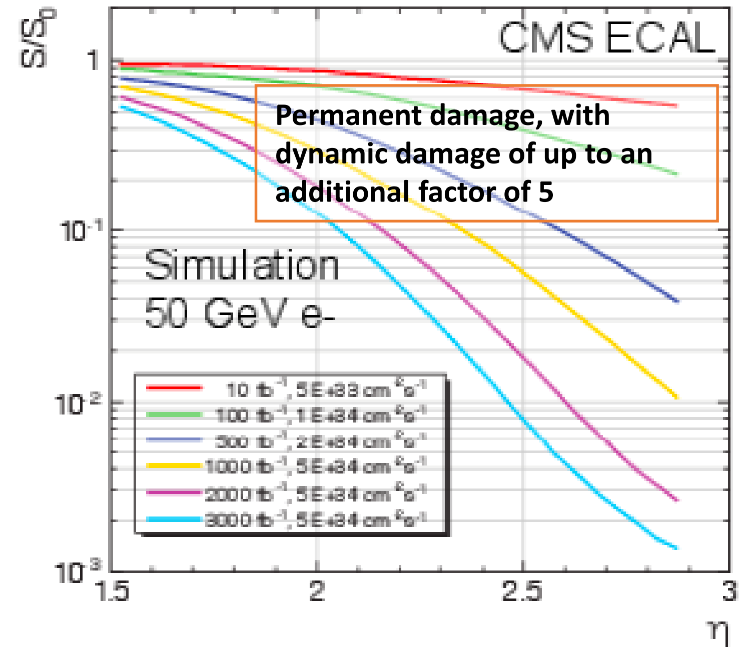
Calorimeter Endcap DOE
- **Si, Scint + SiPM in Pb-W-SS**
- **3D shower imaging with precise timing**

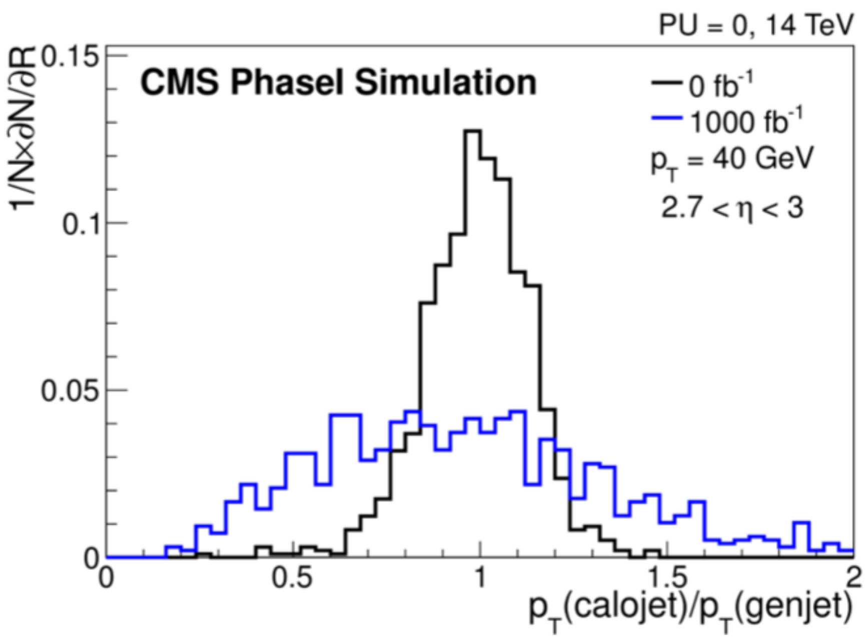
MIP Timing Detector **DOE**
- ~ 30 ps resolution
- Barrel: Crystals + SiPMs
- Endcap: LGADs

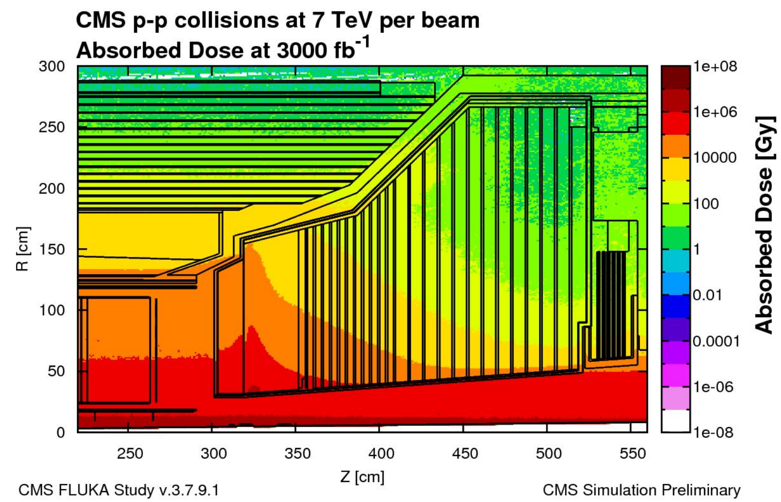
Tracker
- Si Strip Outer Tracker designed for L1 Track Trigger **DOE**
- Pixelated Inner Tracker extends coverage to $|\eta| < 3.8$ **NSF**

402.4 Upgrade Motivation

- Radiation-induced darkening is reducing the signal from the current scintillator-based endcap calorimeters
  - Up to 90% signal loss in some regions
    - "Dealing with EE noise/fake jets" is now a regular topic of the CMS analysis groups
  - HL-LHC will require good operation with radiation loads 10-20x higher

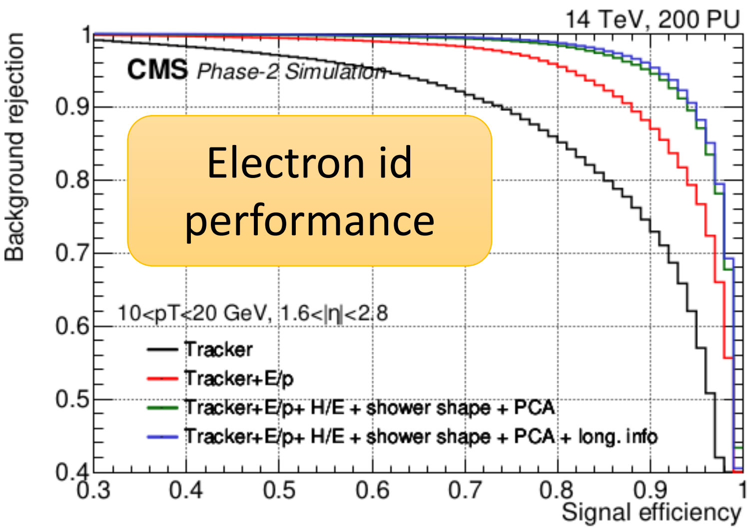




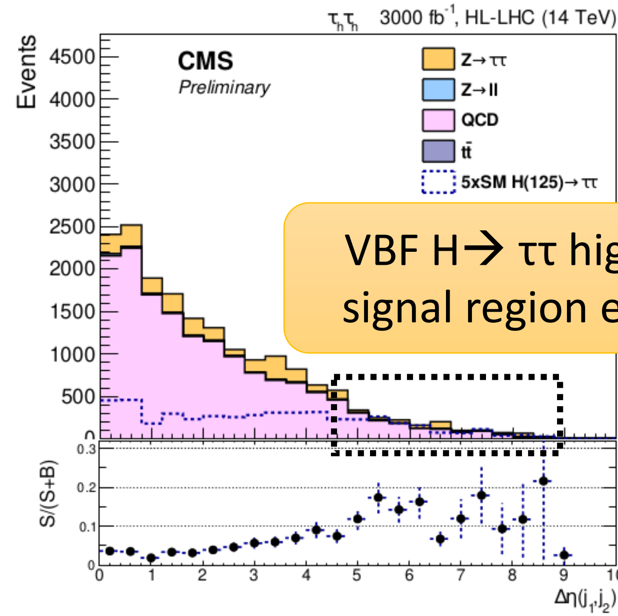


402.4 Science Drivers

- The performance of the endcap calorimeter controls the science yield of the HL-LHC CMS detector in several areas
  - Higgs physics including H→γγ and all studies using the VBF Higgs production mechanism [sci-goal-1, sci-goal-4]
  - Missing transverse energy resolution at high pileup, for dark-matter searches/studies [sci-goal-2, sci-goal-3]
  - New capabilities (precision timing) for long-lived particle signatures [sci-goal-3]



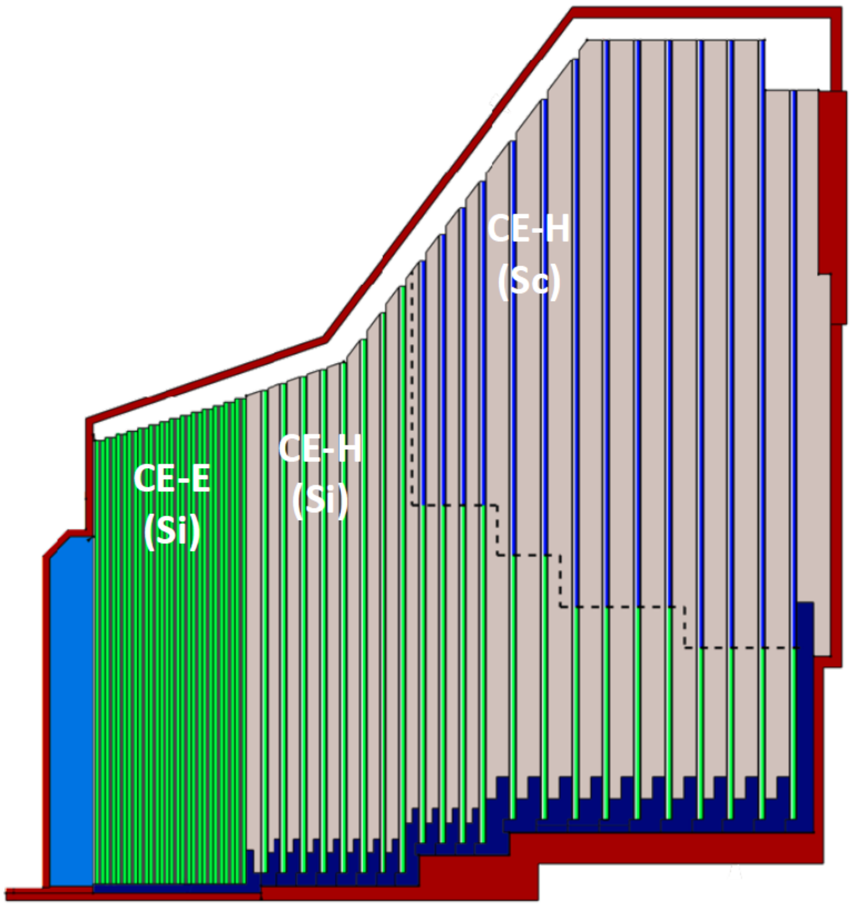
Electron id performance



VBF H→ ττ highlighting key signal region enabled by CE

402.4 Conceptual Design

- High radiation zones (CE-E and portions of CE-H)
  - Silicon active material
  - EM absorber: lead+tungsten
  - HAD absorber: stainless steel
- Low radiation zones (CE-H)
  - Scintillator tile direct readout (SiPMs)
- Overall detector organized into **cassettes** comprised of a cooling plate with multiple **silicon modules** and **tile-modules** mounted onto it
- Full detector operated -30°C using CO_2 cooling
- Documented in approved international TDR and US CDR (cms-docdb-13151)

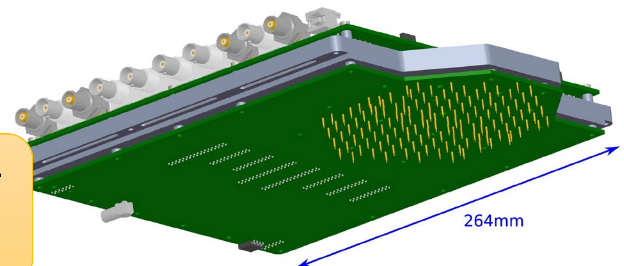


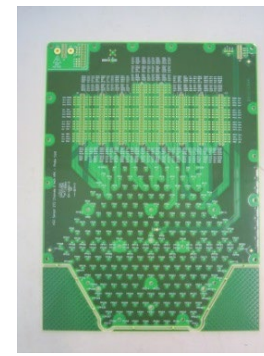
- Requirements flowdown from science goals (cms-doc-13337) to subsystem requirements (cms-doc-13447)

Design Parts and Progress: Silicon

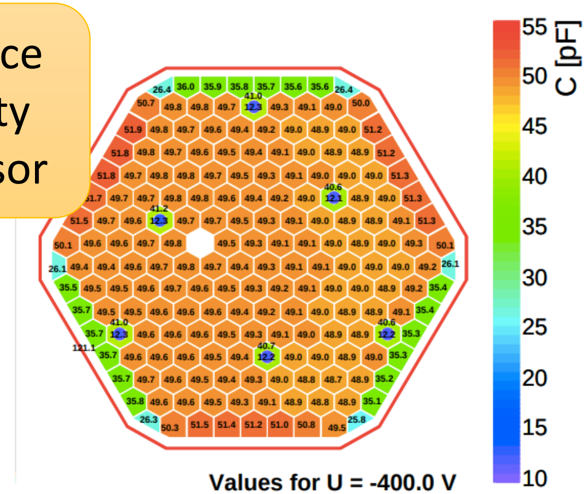
- Silicon sensors are the active element for the high-radiation portion of the calorimeter
  - Radiation tests on 6” wafers show expected performance (increase in leakage current) and no breakdowns (including on wafers with large irradiation gradients)
  - Received good quality 8” sensors from HPK and the infrastructure is being commissioned at multiple sites for the necessary QC of received sensors and process-quality-control tests
    - Radiation tests have begun for the 8” sensors but only a few data points are available so far
- Moving on schedule to be ready for CD-3a review of sensors

Full-Sensor Tester



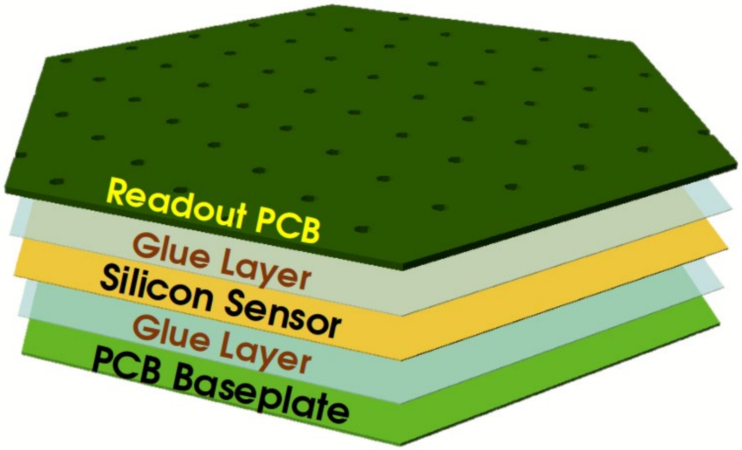


Capacitance Uniformity on 8” sensor

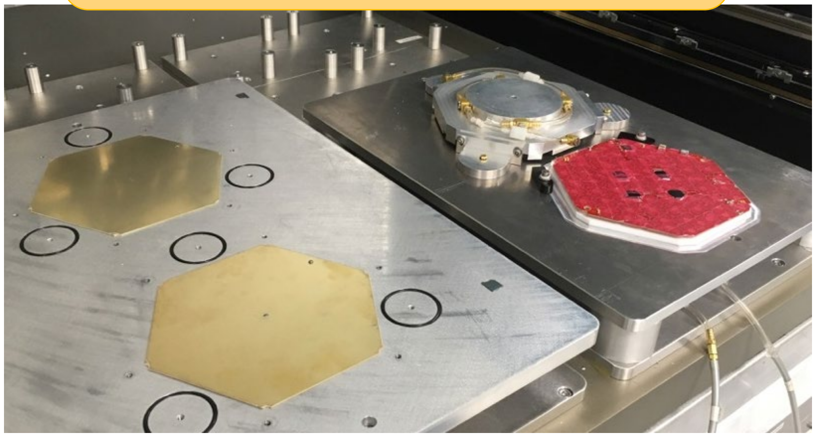


Design Parts and Progress: Modules

- Automation fully demonstrated at UCSB by production run of 55 6” modules over a three week period in fall 2018
  - Checklists for all procedures
  - Inspection of all components, measurements of thickness and flatness for key components
  - Storage of construction and test data into local database for batch transfer to construction database
- Tooling adapted for 8” modules and several successful 8” modules have been produced in 2019
- Assembly centers at TTU and CMU have most of equipment in place and are in the commissioning processes
- Design simplification for CE-H modules through use of PCB baseplate
- Module assembly ready for CD2

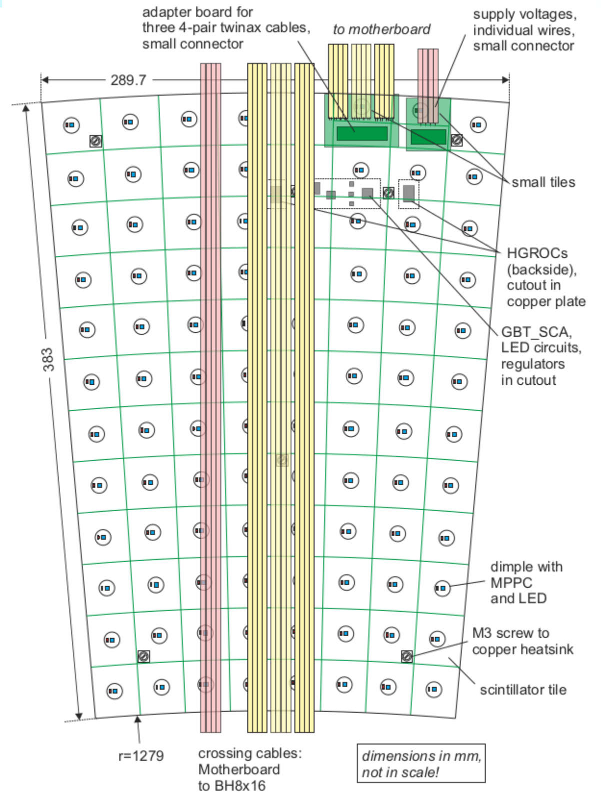


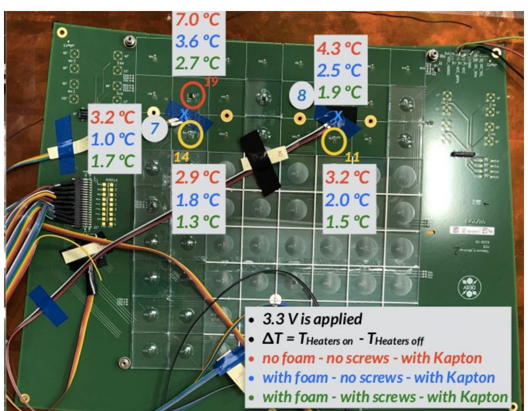
8” modules under automated assembly at UCSB

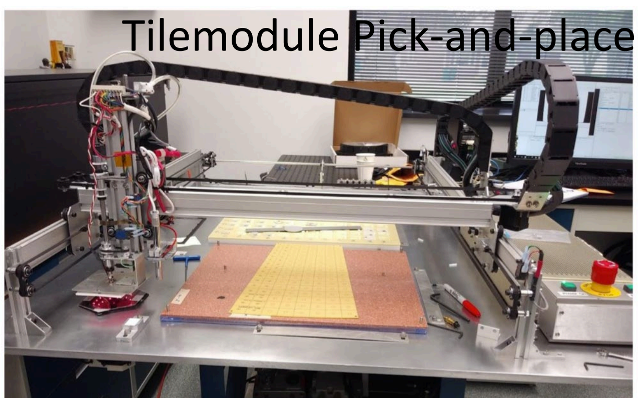


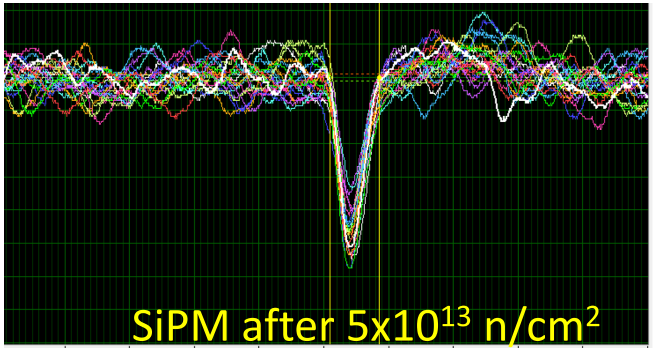
Design Parts and Progress: Scintillator

- Scintillator section is based on SiPMs directly observing individual scintillator tiles mounted on a PCB with the HGCROC
- Good progress in several areas
  - SiPM performance is established to required neutron fluence
  - Thermal performance of tileboard/cassette system has been studied in a thermal mockup
  - Detailed engineering ongoing for tileboards and associated readout/service infrastructure
  - Demonstrated automated tile placement for tile modules
- Prototype progress on schedule to be ready for CD2



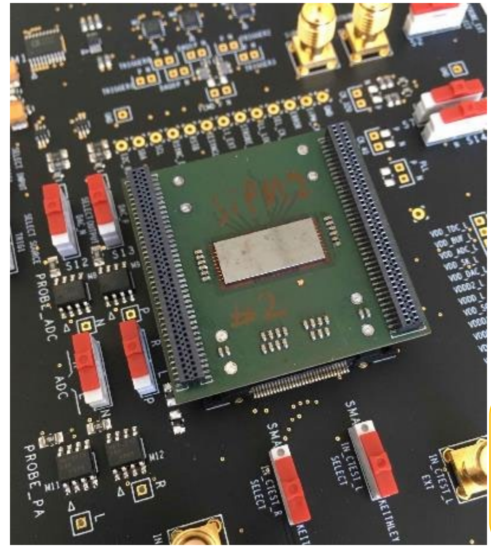


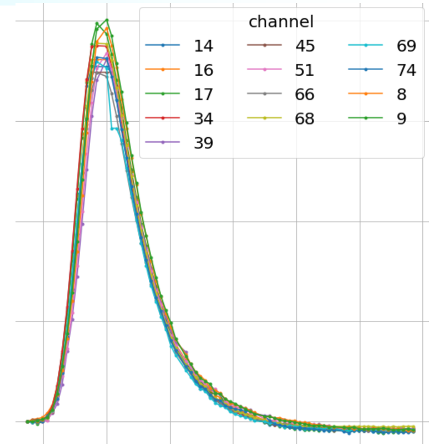




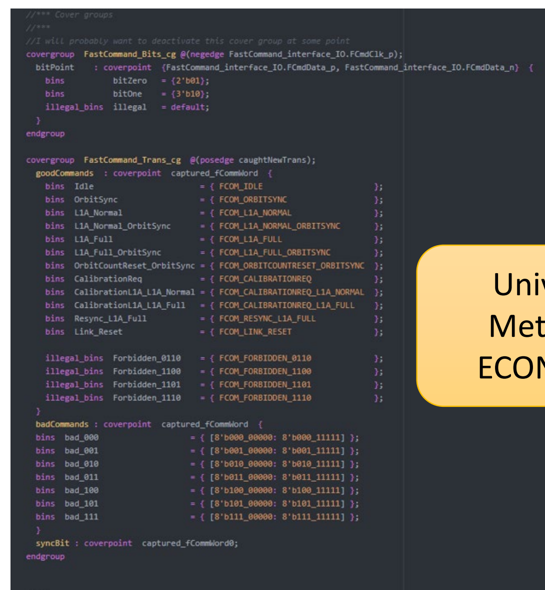
Design Parts and Progress: Electronics

- HGCROCV2 readout ASIC [France] received, under test by international team
  - Very good results so far on all aspects
  - V3 will add last piece of the full derandomizer and carry out bug-fixes
  - Some radiation issues identified in V1, fixes being studied in small test vehicle and will be implemented in V3
- ECON concentrator ASIC [US] progressing well
  - Significant simplification by removal of 10 Gbps links and limiting chips to cover one module
  - Several blocks have been completed through full implementation, coordinated plan for continued progress
  - With updated plan, concentrator ASIC is ready for CD2





Above: uniformity of pulse shapes across channels
Left: HGCROCV2 under test

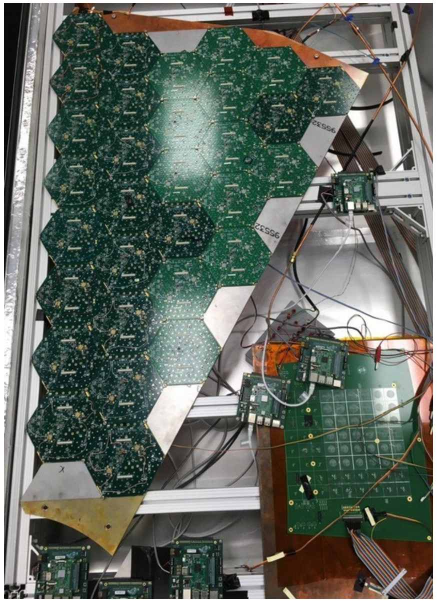


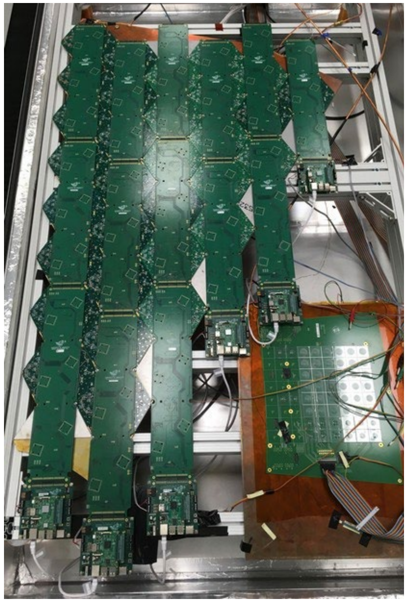
```
//*** Cover groups
//***
//I will probably want to deactivate this cover group at some point
covergroup  FastCommand_Bits_cg @(negedge FastCommand_interface_IO.FCmdClk_p);
  bitPoint    : coverpoint  {FastCommand_interface_IO.FCmdData_p, FastCommand_interface_IO.FCmdData_n}  {
    bins          bitZero   = {2'b01};
    bins          bitOne    = {3'b10};
    illegal_bins  illegal   = default;
  }
endgroup

covergroup  FastCommand_Trans_cg  @(posedge caughtNewTrans);
  goodCommands  : coverpoint  captured_fCommWord  {
    bins  Idle                        = { FCOM_IDLE                        };
    bins  OrbitSync                   = { FCOM_ORBITSYNC                   };
    bins  L1A_Normal                  = { FCOM_L1A_NORMAL                  };
    bins  L1A_Normal_OrbitSync        = { FCOM_L1A_NORMAL_ORBITSYNC        };
    bins  L1A_Full                    = { FCOM_L1A_FULL                    };
    bins  L1A_Full_OrbitSync          = { FCOM_L1A_FULL_ORBITSYNC          };
    bins  OrbitCountReset_OrbitSync   = { FCOM_ORBITCOUNTRESET_ORBITSYNC   };
    bins  CalibrationReq              = { FCOM_CALIBRATIONREQ              };
    bins  CalibrationL1A_L1A_Normal   = { FCOM_CALIBRATIONREQ_L1A_NORMAL   };
    bins  CalibrationL1A_L1A_Full     = { FCOM_CALIBRATIONREQ_L1A_FULL     };
    bins  Resync_L1A_Full             = { FCOM_RESYNC_L1A_FULL             };
    bins  Link_Reset                  = { FCOM_LINK_RESET                  };

    illegal_bins  Forbidden_0110      = { FCOM_FORBIDDEN_0110              };
    illegal_bins  Forbidden_1100      = { FCOM_FORBIDDEN_1100              };
    illegal_bins  Forbidden_1101      = { FCOM_FORBIDDEN_1101              };
    illegal_bins  Forbidden_1110      = { FCOM_FORBIDDEN_1110              };
  }
  badCommands : coverpoint  captured_fCommWord  {
  bins  bad_000                   = { [8'b000_00000: 8'b000_11111] };
  bins  bad_001                   = { [8'b001_00000: 8'b001_11111] };
  bins  bad_010                   = { [8'b010_00000: 8'b010_11111] };
  bins  bad_011                   = { [8'b011_00000: 8'b011_11111] };
  bins  bad_100                   = { [8'b100_00000: 8'b100_11111] };
  bins  bad_101                   = { [8'b101_00000: 8'b101_11111] };
  bins  bad_111                   = { [8'b111_00000: 8'b111_11111] };
  }
  syncBit : coverpoint  captured_fCommWord0;
endgroup


//***
```

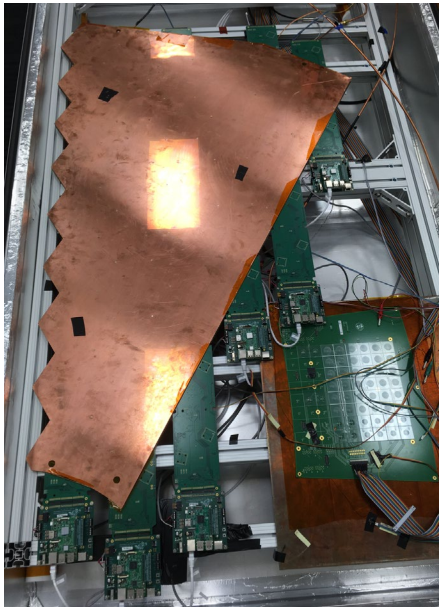
Universal Verification Method in use for the ECON fast control block

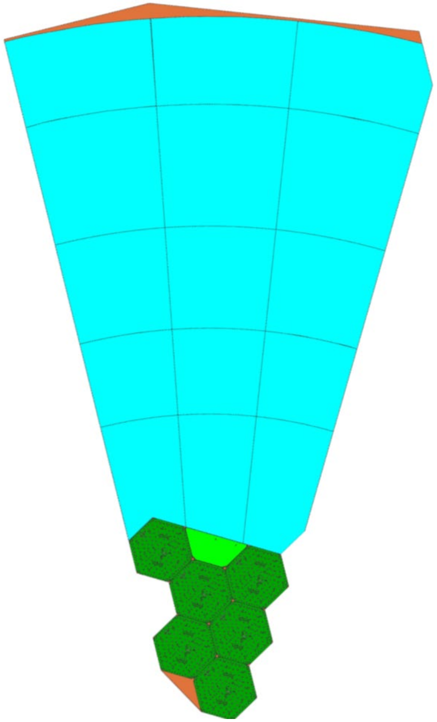
Design Parts and Progress: Cassettes

- Cassette design and assembly validated through active mockup campaign
  - Included thermal loads and measurement system which validated the models of the cooling plates and helped identify good solutions for module mounting to achieve necessary thermal performance
  - Required fixturing and infrastructure has also been validated through the mockup campaign
- Current joint effort with scintillator portion of the system to complete similar tests for integrated mixed cassettes
- Cassette effort will be ready for CD2 through ongoing major system prototype 1









Scope organization principle

- Since the original construction of CMS, the US has had a leading role in hadron calorimetry and in automated assembly of silicon detectors
  - Construction of the scintillator-based barrel hadron calorimeter, electronics for all hadron calorimeter sections (including Phase 1 Upgrade)
  - Construction of a large fraction of the tracker outer barrel, construction of the forward pixel Phase 1 Upgrade
- For the HL-LHC upgrades, the US contributions center on the production of the hadronic calorimeter silicon and scintillator modules and cassettes and aspects of the electronics and services where the US can provide particular leadership

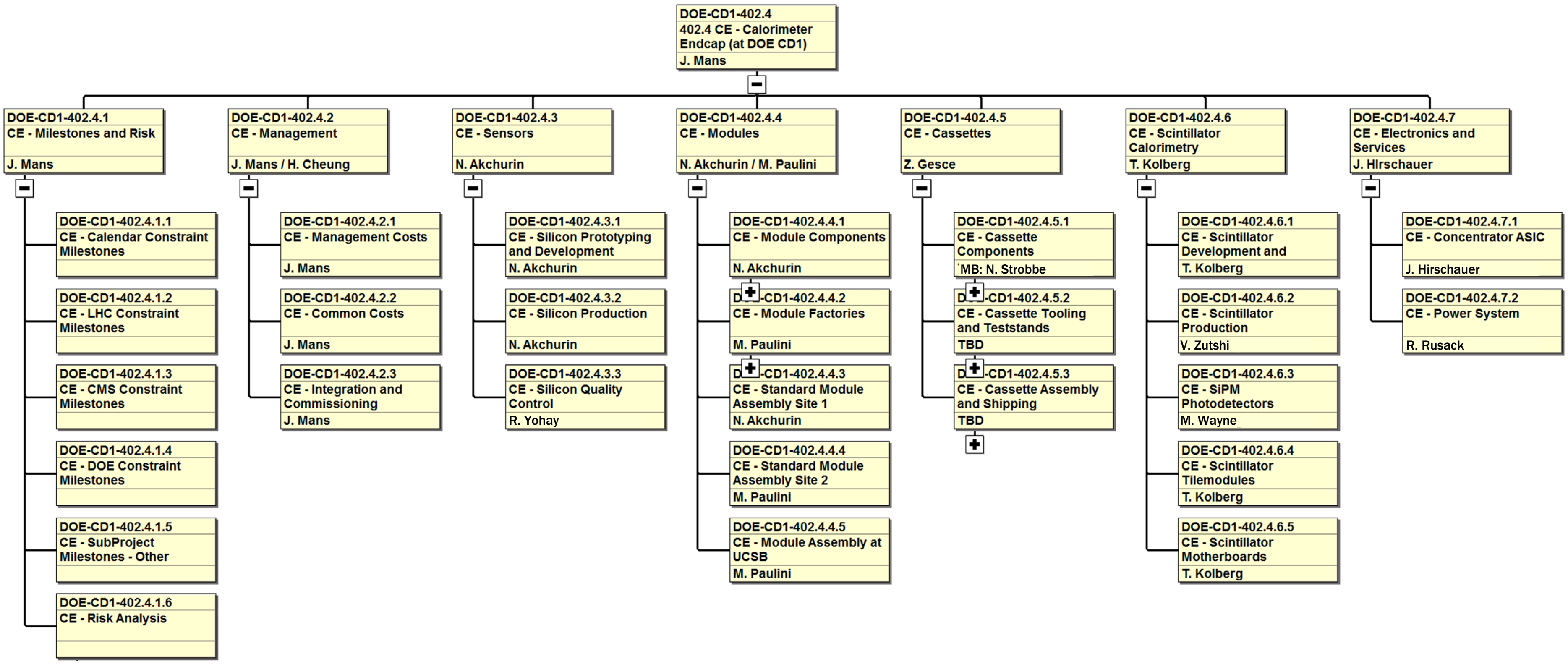
US Scope Outline

- Module Construction
  - US develops detector-wide standard procedures for silicon module construction, constructs all low-density hadronic silicon modules (10,140) and all odd-size/edge modules for the electromagnetic section (3489)
- Scintillator tilemodules
  - US wraps scintillator tiles (150k), constructs readout PCBs, procures and mounts SiPM photodetectors (142k), assembles and tests tile modules (1404)
- Electronics
  - US responsible for the design and development of the concentrator ASIC, development of motherboards for silicon and scintillator hadronic sections
  - Specification and procurement of LV/HV power supplies for the hadronic section
- Cassette Assembly
  - US develops cassette cooling plate design and assembly procedure, assembles cassettes of hadronic calorimeter (550)
- Key Performance Parameters defined encapsulating the project
  - Threshold: Construction of the cassettes and delivery to CERN
  - Objective: Integration of the cassettes into the absorber, initial commissioning of integrated detector, procurement of LV/HV power supplies, construction of testbeam wedge

Changes to Scope/WBS Since June 2018

- Value Engineering
  - Concept of PCB baseplate for silicon modules eliminated the requirement to produce, QC, and process separate kapton layers for the CE-H modules
- Detector geometry updates
  - Requirement of additional volume for the tracker and additional internal space between the calorimeter layers for electronics resulted in a design update which removes the last two layers of the hadron calorimeter → 12.5% decrease in scintillator motherboards
- International scope balancing
  - Like all of the CMS upgrade, the endcap calorimeter effort involves multiple international partners with differing technical skill levels and abilities
  - Some items which have a low technical content (e.g. PCB baseplates, machining scintillator tiles) have been transferred to international partners who are capable of completing the work, to allow more resources in the US for critical tasks such as concentrator development and rapid cassette assembly
    - In every case where this has been done, the US retains the resources for reception quality control to ensure that good-quality components are always used to create larger assemblies
- Scope changes are minor, adjustment of unit counts, removal of items

402.4 Organization



402.4 Maturity

Charge #2

October 2019

CE	Sensors Mgmt	Sensors Tech	Modules Mgmt	Modules Tech	Cassettes Mgmt	Cassettes Tech	Scintillator Mgmt	Scintillator Tech	Electronics Mgmt	Electronics Tech	AVE Mgmt	AVE Tech	BAC Mgmt	BAC Tech
Conceptual Design	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Preliminary Design	100%	100%	100%	94%	88%	79%	95%	81%	100%	86%	97%	88%	96%	89%
Final Design	80%	90%	51%	22%	21%	14%	26%	18%	53%	19%	46%	33%	47%	34%
Detailed Design	0%	45%	0%	0%	0%	0%	0%	0%	0%	0%	0%	9%	0%	10%
Construction Readiness	40%	50%	0%	0%	0%	0%	0%	0%	0%	0%	8%	10%	9%	11%

(L3s: Sensors, Modules, Cassettes, Scintillator, Electronics)

June 2018

CE	Sensors Mgmt	Sensors Tech	Modules Mgmt	Modules Tech	Cassettes Mgmt	Cassettes Tech	Scintillator Mgmt	Scintillator Tech	Electronics Mgmt	Electronics Tech	AVE Mgmt	AVE Tech	BAC Mgmt	BAC Tech
Conceptual Design	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Preliminary Design	93%	95%	89%	60%	75%	50%	65%	40%	45%	22%	73%	53%	76%	56%
Final Design	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

(L3s: Sensors, Modules, Cassettes, Scintillator, Electronics)

- Design maturity has advanced significantly relative to June 2018 IPR
  - In June 2018, conceptual design was complete but preliminary design was just starting in some areas
  - Now preliminary design is quite advanced in all areas (>75%) and on track for CD2 or CD3a as appropriate

402.4 Cost Summary

October 2019

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-CD1-402.4.6 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

	2019	Change: {Now/Then-1}				
L2/L3 Area	BAC	M&S	Hours	Cost	EU	Total
CE	**40,672**	**-2%**	**8%**	**-1%**	**-15%**	**-4%**
CE - Mgmt	3,807	0%	-3%	-5%	-17%	-7%
CE - Sensors	8,393	1%	57%	3%	-26%	-3%
CE - Modules	8,406	-13%	0%	-12%	-28%	-15%
CE - Cassettes	9,423	9%	8%	4%	-8%	1%
CE - Scintillator	4,197	0%	36%	10%	-5%	6%
CE - Electronics	6,447	-13%	10%	1%	-6%	-1%

Legend
< -50%
-50%
-25%
0%
25%
50%
> 50%

- Changes are well-understood
  - Scope changes in modules and cassettes discussed above
  - Updated costs as design maturity advances
  - Increased labor for sensor-testing, scintillator assembly

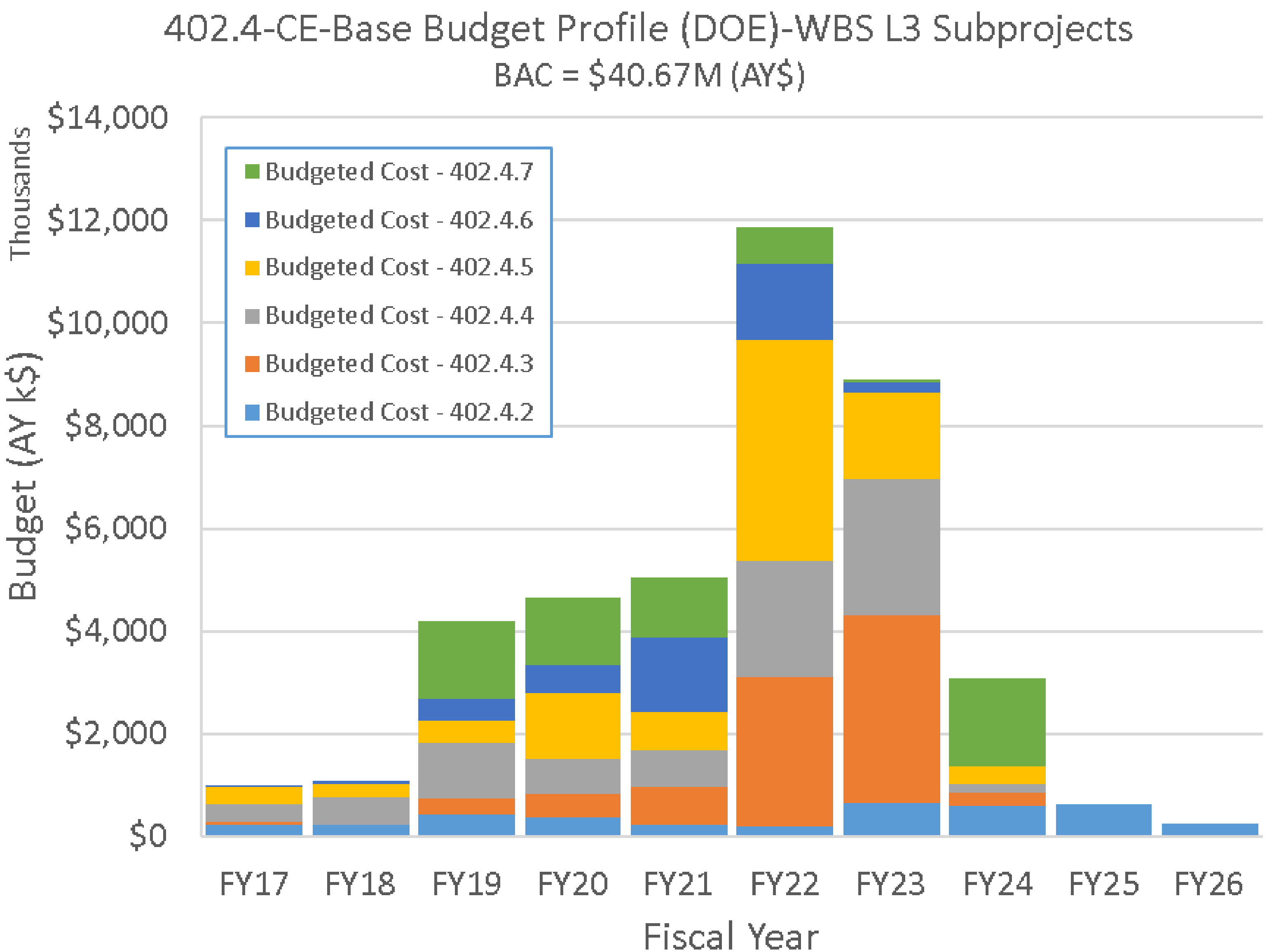
HL-LHC US CMS

402.4 Cost Drivers

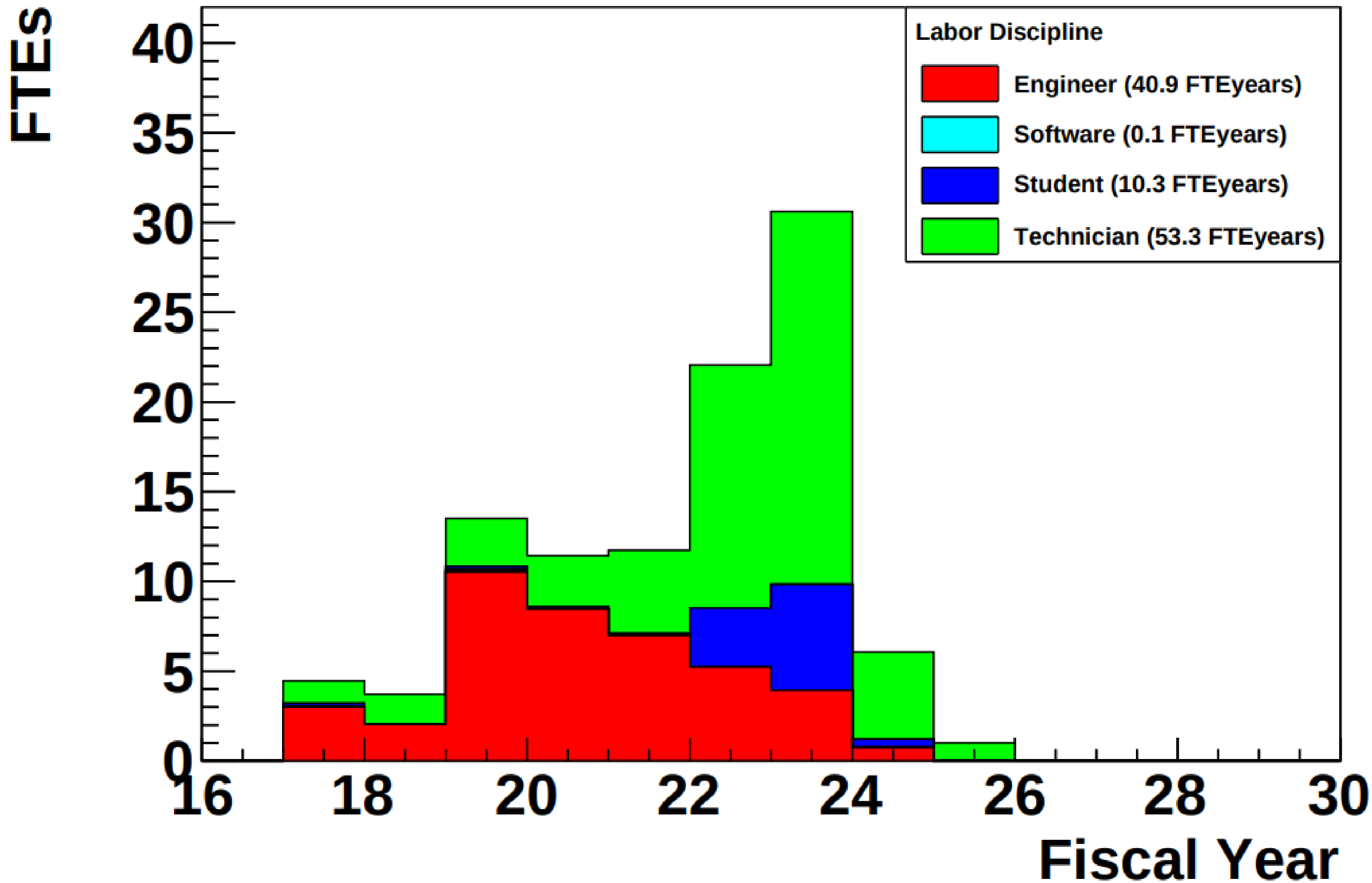
CMS Driver	Labor (FTE-yrs)	Labor BAC (M$)	M&S BAC (M$)	Total BAC (M$)
CE.3 - Si sensors purchase (M&S)	0.0	0.0	7.7	7.7
CE.7 - Concentrator ASIC (labor)	9.7	2.8	0.0	2.8
CE.5 - Silicon motherboard (M&S)	0.0	0.0	2.5	2.5
CE.5 - Cassette assembly and testing (labor)	15.9	2.4	0.1	2.4
CE - Calo Endcap integration and commissioning	5.0	0.6	1.7	2.3
CE.4 - Module circuit boards	2.8	0.3	1.6	1.9
CE.7 - Power system	1.3	0.2	1.6	1.9
CE.6 - Scintillator panels	12.9	0.9	0.8	1.7
CE.7 - Concentrator ASIC (M&S)	0.0	0.0	1.7	1.7
CE.4 - Module assembly and testing (UCSB)	14.1	1.4	0.1	1.5
CE.5 - Cassette tooling and test stands	1.8	0.4	0.9	1.3
CE.4 - Module assembly and testing (Texas Tech)	14.4	1.2	0.1	1.3
CE.4 - Module assembly and testing (CMU)	13.5	1.1	0.1	1.2
CE.5 - Silicon motherboard (labor)	4.3	1.1	0.0	1.1

- Leading cost driver is silicon sensor purchase (CD-3a Scope)
- Next tier includes engineering for the concentrator ASIC and the labor for the various subsystem assembly tasks
- Identity of cost drivers unchanged since June 2018 IPR

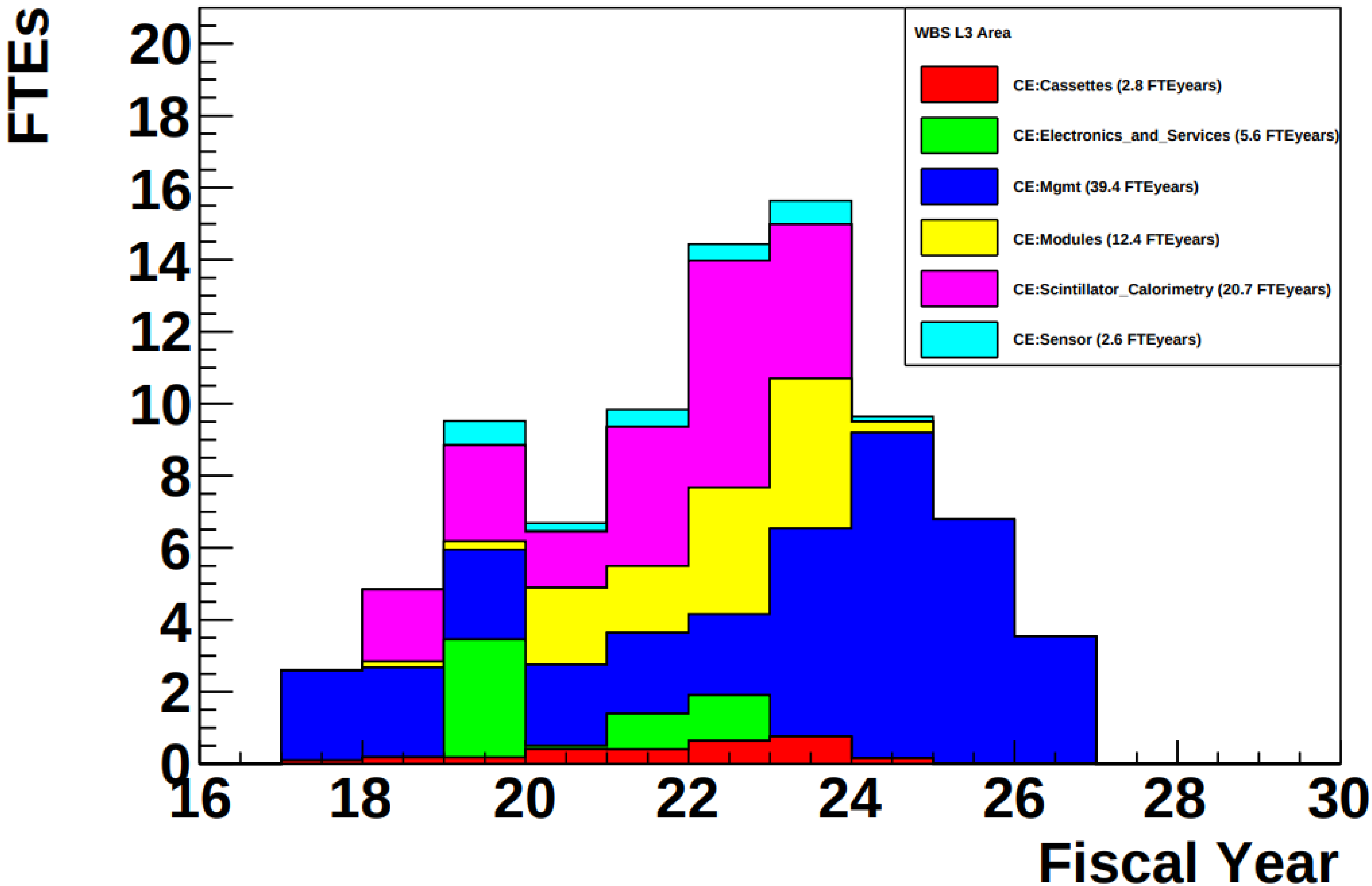
402.4 Cost Profile



402.4 Costed Labor Profile



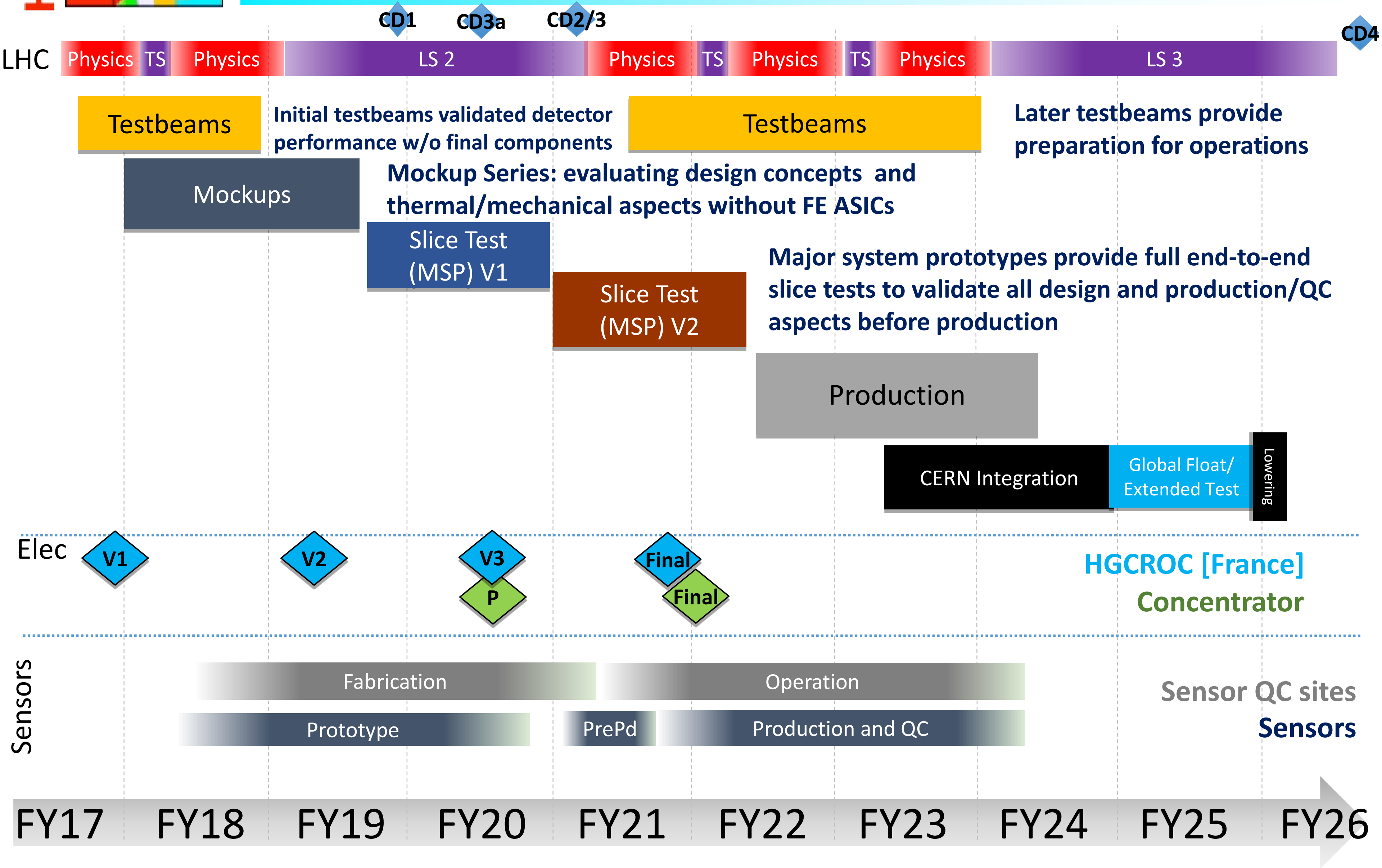
402.4 Contributed Labor



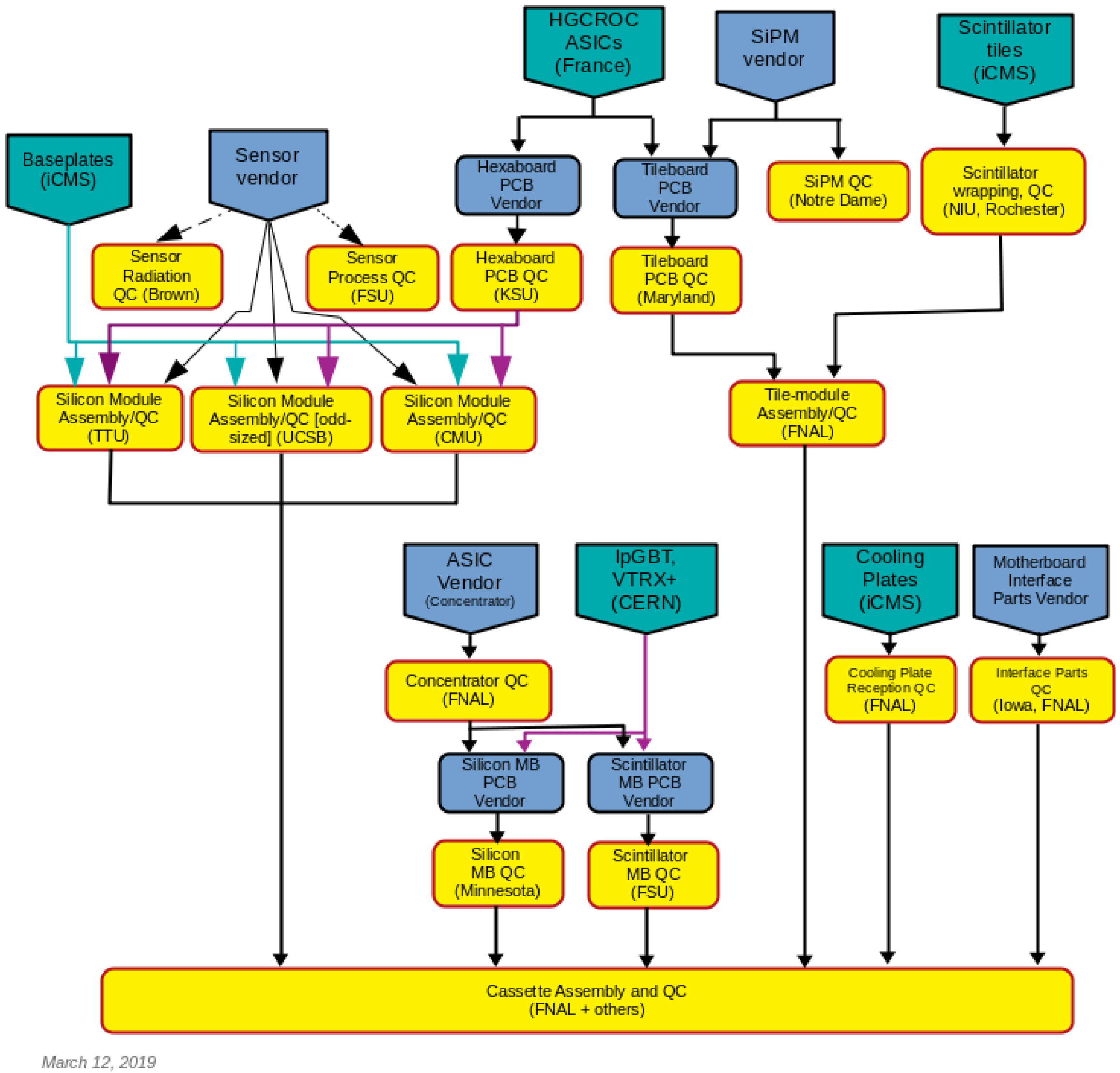
402.4 Labor Resources

- Assignment of R&D and production tasks arranged to take advantage of existing facilities for testing and construction, where possible, and to efficiently utilize expertise and human resources
- Institutions
  - Fermilab, Alabama, Baylor, Brown, Carnegie Mellon, Fairfield, Florida State, Florida Institute of Technology, Iowa, Kansas State, Maryland, MIT, Minnesota, Northern Illinois, Notre Dame, Northwestern, Rochester, Texas Tech, UC-Santa Barbara
- The set of key personnel evolves throughout the project
  - Primary criteria is ability to replace a given person with without significant disruption to schedule or cost
  - Key personnel table prepared and being tracked/updated by management quarterly
    - Currently: key engineers, developers of key processes (such as module assembly)
    - In the future: assembly site managers, QC experts
  - Demands of multiple efforts on identified key engineers are tracked by L2s, PM

Cartoon Schedule

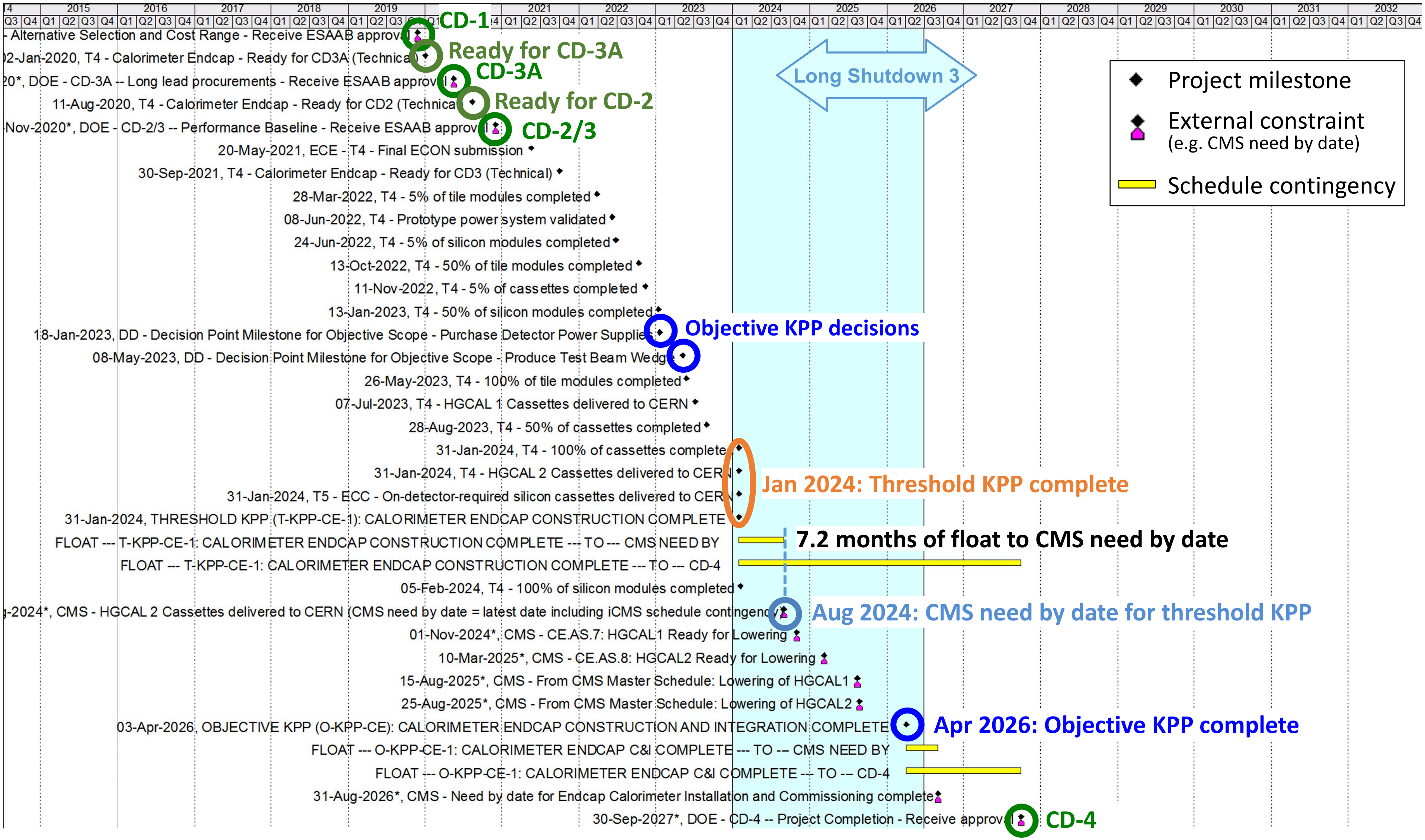


Workflow for the Project



- This chart, which is part of the project QA/QC documentation outlines the flow of the project through the construction phase and can be mapped directly onto the WBS structure

Key milestones and schedule contingency

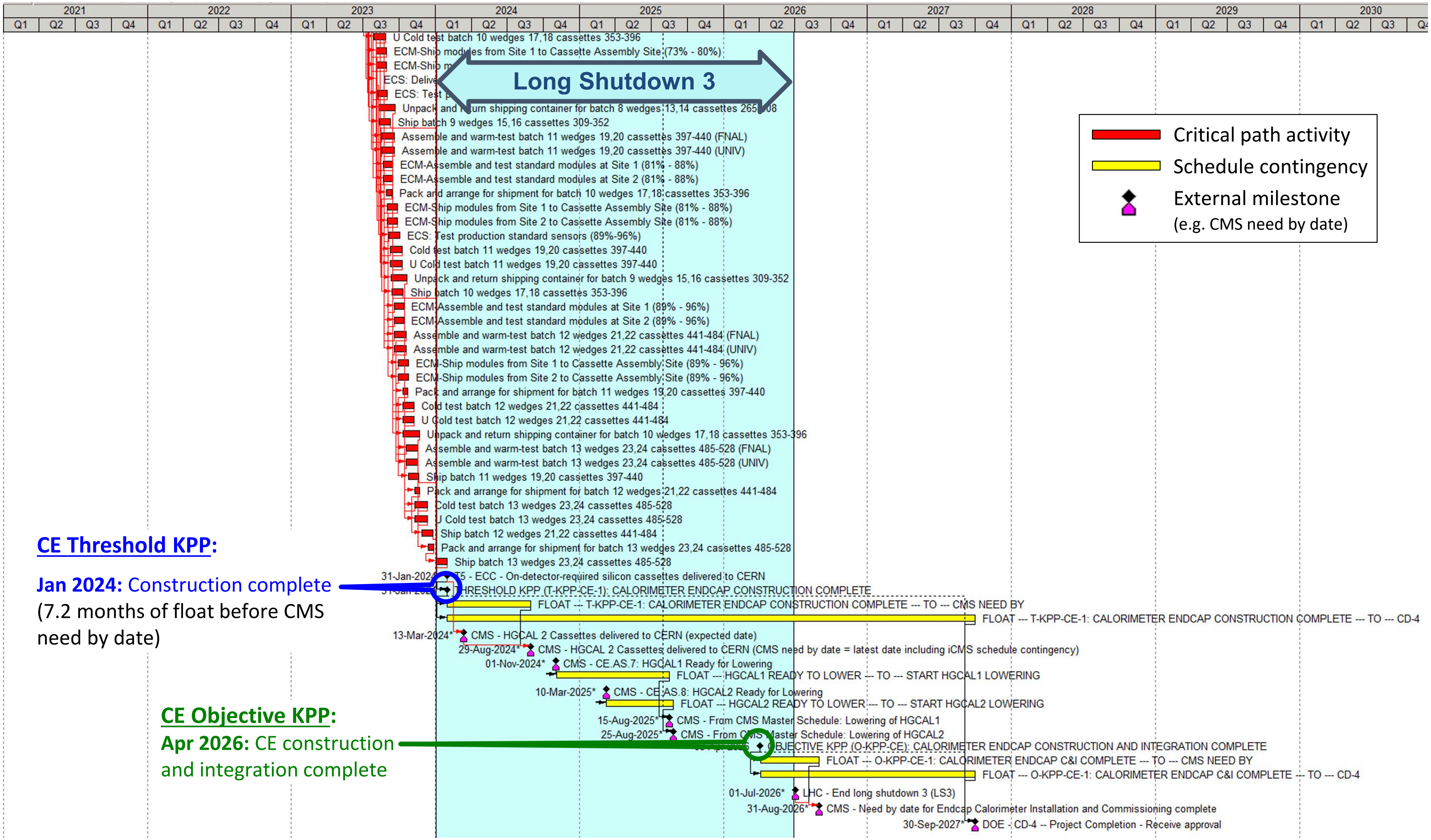


402.4 Schedule Changes Since 2018 IPR

- Largest change is that the silicon delivery schedule is slower than originally expected
  - Sensor delivery schedule becomes the driver of the critical path after the midpoint of the cassette production
  - Timely CD3a approval is important to keeping delivery on schedule
- Other changes
  - Some delays to major system prototype 1 due to HGCROCV2 development time
  - Removal of link-demonstrator prototype of concentrator made schedule more efficient
  - International project re-evaluated the integration time requirements, making more time available at the end of the project
- Schedule has been adapted to match updated HGCROC delivery schedule and sensor delivery schedule
  - Capacity for module and cassette production increased to minimize the impact of delays
  - Progress towards major system prototype 1 has been steady in last six months

Charge #3

402.4 Critical Path and Float



CE Threshold KPP:

Jan 2024: Construction complete
(7.2 months of float before CMS need by date)

CE Objective KPP:

Apr 2026: CE construction and integration complete

402.4 Risks

- Risk Changes since June 2018
  - Retire opportunity of cheaper p-on-n sensors (no vendor for 8” wafers)
  - Added risk for possible additional production acceleration requirement (P*I=$127k)
  - Added risk for possible increased engineering costs for Si motherboards (P*I=$29k)
    - Mitigation through proposed modular design with a single ‘core’ motherboard design and multiple passive support motherboard designs, probability has fallen from 20% to 5% since February 2019 DR
  - Added risks for replacement/retraining of key endcap calorimeter personnel (P*I=$71k) and a shortfall in scientific labor (P*I=$98k)
- Leading risks
  - Additional concentrator prototype run (MPW) required (P*I=$132k, delay=6-9m) and Concentrator does not meet specifications (P*I=$97k, delay=6-9m)
    - Mitigation by proper targeting of prototype functionality and working to finalize algorithms
  - Additional production acceleration required
    - Mitigation is through successful prototype 2 series and management tracking of dependency deliveries
  - Additional “emergency” FE ASIC engineering run required (P*I = 84k, delay=8m)
    - Cost impact due to standing-army costs and international project-wide tax for (internationally) unbudgeted ASIC run

402.4 Response to June 2018 IPR Items

- *4. The aggregator ASIC, the ECON, is a critical U.S. deliverable and a potential schedule driver for cassette production. Maintain close interaction with FNAL management to ensure the necessary access to ASIC designers and engineers*
  - The PM, L2, and L3 have worked through the FNAL ASIC PMG and direct communication with FNAL management to obtain the necessary access to ASIC engineers. There were delays in 2018, but the ECON is making rapid progress in 2019 with substantial engineering resources active on the effort.
- *5. For CD-2, develop simulation tools to determine the dependence of HGCAL performance on the assumed level and distribution of dead and noisy cells.*
  - Such a simulation tool has been developed and is in use to validate the detailed specifications, such as those being provided to the silicon sensor vendor.
- *6. For CD-2, develop the combined tracker-HGCAL simulation to provide an expectation of the physics performance of the upgraded calorimeter using the full particle flow technology. A suitable physics process to consider is VBF Higgs production with invisible Higgs decay.*
  - The study of physics objects and their reconstruction with full particle flow is underway at the international level. The completion and approval of a formal physics analysis study is not part of the US project scope. The existing simulation as documented in the Endcap Calorimeter TDR demonstrates that the design will achieve the physics goals of the project.

402.4 Response to June 2018 IPR Items

- *7. By third-quarter CY 2018 define the goals and schedule for the cassette prototype P1 to ensure that the feedback which is necessary for CD-2 is obtained.*
  - The goals and schedule for cassette P1 were re-evaluated in light of the ASIC schedule and the schedule for CD-2. The prototype efforts have been are ongoing and much of the necessary information for CD-2 has already been gathered (e.g. validation of module assembly labor estimate)
- *8. For CD-2 develop a strategy to deal with the variation of gain stability of the SiPMs against temperature variations across the active layers.*
  - A strategy which includes the use of RTD sensors and a software loop to adjust SiPM bias voltages has been developed. The technique was validated with CALICE hardware in a 2018 testbeam and will be demonstrated using the CMS Tileboard-1 Prototype before CD-2
- *9. By third-quarter CY 2018 establish a high-level schedule of external dependencies and associated milestones defined by suppliers and/or international CMS. Review these dependencies and schedule regularly with the integrated project team.*
  - Such a high-level schedule of external dependencies has been developed. It is reviewed quarterly for any schedule implications, additions, or deletions. (cms-doc-13742)

402.4 Response to Mar 2019 DR Items

- Consider removing the 10 Gbps links from the ECON ASICS to reduce schedule and performance risks.
  - Adopted -- After careful evaluation of the impact of this change, the US project proposed it to the international project and it was accepted in June 2019. It has been the baseline since June. This change removed the need for a first prototype to validate the 10 Gbps link performance.
- Prior to a DOE CD1 IPR, add a risk to the register associated with the possibility of delays in each ASIC submission
  - The CE risk register now contains risks covering delays to each ASIC submission or the requirement for an additional ASIC submission which would also incur a schedule delay. Prior to the DR, there was no risk for the 10Gbps-link-evaluation prototype, but this step has been removed from the project
- **We have responded to all review recommendations**

402.4 Progress towards CD-3a

- CD-3a Scope
  - Production and QC of sensors (full and odd-sized)
  - Sensor production is an extended process at the vendor so contracts need to be placed in FY20 to allow timely delivery
    - Sensors are the critical path to completion
- Progress
  - Sample 8" sensors have been received and performance has been validated, including in full modules
  - Radiation tests underway
  - Detailed specification prepared and frame contract signed between CERN and vendor establishing the parameters of the purchase, subject to several options affecting quantity
- Efforts are on-schedule for CD-3a review in early 2020

WBS	Direct M&S ($)	Labor (Hours)	FTE	Direct+Indirect +Esc. ($)	Estimate Uncertainty ($)	Total Cost ($)
402.4.3 CE - Sensors	6,809,750	7746	4.38	7,398,226	1,582,838	8,981,065
402.4.3.2 CE - Silicon Production	6,809,750	0	0	7,126,403	1,530,407	8,656,810
402.4.3.3 CE - Silicon Quality Control	0	7746	4.38	271,823	52,431	324,254

402.4 Progress towards CD2

- Several areas of the project have reached full design maturity for CD2
  - Module assembly, ECON ASIC (after design updates this year), cooling plates
  - Some managerial work remaining in these areas to obtain full-production quotes, etc
- Rest of the areas will be validated through ongoing major system prototype 1 efforts
  - Candidate final SiPM under manufacture by vendor
  - Silicon motherboard detailed design making rapid progress
  - Scintillator system under validation with tileboard 1 and full-cassette electromechanical mockup
- Project is on track for CD2 readiness and the project file contains a set of milestones to track CD2 readiness for each WBS area at L4 or below

ES&H

Preliminary Hazard Analysis Report: cms-doc-13394

- Careful analysis of safety and production risks has been carried out
  - SiDet has Operational Readiness Clearance for required CO_2-based cooling (cryogenic, oxygen-deficiency, and CO_2 toxicity risks)
  - Handling of heavy items (cassettes) will be reviewed as procedures develop
  - Items comply with local safety standards in site of fabrication and operation
  - Connection to individual institutes established through L2/L3 Managers to institute PIs. Safety contacts specified/updated as part of annual SOW process with institutes
  - Site visits have been established with first visit to UCSB module site in July 2019 (report in cms-doc-13856)
- Endcap Calorimeter participated in the Nov 29 2018 ESH&Q review

QA/QC

Quality Assurance Plan: cms-doc-13093

Charge #6

- Quality assurance
  - Prototype sequence to validate vendors and procedures, requires sufficient quantity in prototypes
  - Stress-testing of design using radiation (total dose/fluence), beams (single-event effects), thermal cycling, shipping tests
  - International CMS approval for the prototype plan and international coordination of testing strategies, equipment
- Quality control
  - Combine known-good sub-assemblies when constructing more complex objects (silicon sensors are the most-expensive single input)
  - Use databases to track all components through the assembly and testing procedures (development of databases has started)
  - Procedures are being developed and documented through the prototype/slice test sequence
- Costs for QA/QC activities are captured in P6
- Recent activities
  - QA site visit to UCSB module site in July 2019 (report in cms-doc-13856), expect further visits in 2020 as P1 activities continue

402.4 Interfaces

Interfaces: cms-doc-13447

- Key interfaces identified
  - Mechanical: dimensions of absorber void volumes in which cassettes are placed
  - Cooling: pressure, arrangement of CO_2 cooling lines, connector type and location
  - Electrical: low-voltage and high-voltage supplies
  - Optical: data and control fibers
  - Electronic: data flow between HGCROC and Concentrator ASICs
- Interface and configuration details are managed using the CERN-developed EDMS system, which allows clear approval and notification processes for configuration changes
- Interface management is facilitated by US team members who have roles in the international project
  - J. Strait (Deputy international PM), P. Rubinov (lead engineer for cassette system design), J. Mans (Project Office, Scintillator L2), Z. Gesce (Cassettes L2), J. Hirschauer (Concentrator L3), J. Incandela (Modules L2)

Breakout Session

08:00 **B01: Endcap Calorimeter: Sensors** *20'*
(remote speaker)
Speaker: Ms. Rachel Yohay (Florida State University)
Material: Slides

08:25 **B02: Endcap Calorimeter: HGCROC and Hexaboards** *20'*
Speakers: Prof. Nural Akchurin (Texas Tech University), Nural Akchurin
Material: Slides

08:50 **B03: Endcap Calorimeter: Si Modules** *20'*
Speaker: Manfred Paulini (Carnegie Mellon University)
Material: Slides

09:15 **B04: Endcap Calorimeter: Scintillator System** *30'*
Speakers: Ted Kolberg, Ted Kolberg (Florida State University)
Material: Slides

09:50 **B05: Endcap Calorimeter: Concentrator ASIC** *25'*
Speaker: James Hirschauer (Fermi National Accelerator Laboratory)
Material: Slides

10:20 **B06: Endcap Calorimeter: Si Motherboards** *15'*
Speaker: Nadja Strobbe (Fermilab)
Material: Slides

10:40 **B07: Endcap Calorimeter: Cassettes** *20'*
Speaker: Zoltan Gecse (Fermilab)
Material: Slides

11:05 **B08: Endcap Calorimeter: Summarize Path to CD3A, CD2** *20'*
Speakers: Jeremiah Mans, Jeremiah Mans (University of Minnesota)

Summary

- Endcap Calorimeter Project has made strong progress in multiple areas since June 2018
  - 8” sensors produced by HPK, initial results are good
  - Automated module assembly demonstrated at full scale for 6” modules and also with 8” modules
  - Cassette integration and thermal performance validated with mockup
  - SiPM R&D converging on an excellent candidate device and package
- Some areas have experienced challenges, but are now making progress
  - ECON ASIC had some delays due to resource availability, now proceeding strongly with design simplifications
  - Management tracking issues actively and seeking both technical and planning possibilities to maintain project schedule float
- We have a plan to converge on necessary technical and cost/schedule input for both CD-3a (sensors) and CD-2/3 as envisioned by the project
- Ready for CD1!

402.4 Risk Register

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

Threshold and Objective KPPs

CMS-doc-13237

WBS	Threshold KPP	Objective KPP
402.4	T-KPP-CE-1: CALORIMETER ENDCAP CONSTRUCTION	O-KPP-CE-1: CALORIMETER ENDCAP CONSTRUCTION AND INTEGRATION
Endcap Calorimeter	The project shall construct the silicon modules and scintillator modules for the hadron section of the endcap calorimeter, and integrate them onto cassettes. In addition, the project shall assemble the odd-sized modules for the electromagnetic calorimeter for delivery to collaborators, and design, produce, and test the data/trigger concentrator ASIC(s) required for the endcap calorimeter. Calorimeter silicon and scintillator modules shall have sufficient granularity, noise level, and radiation tolerance to enable cell-by-cell calibration at the 5% level through the end of operation. The cassettes shall be demonstrated to operate standalone and delivered to CERN.	The project shall construct the silicon modules and scintillator modules for the hadron section of the endcap calorimeter, and integrate them onto cassettes. In addition, the project shall assemble the odd-sized modules for the electromagnetic calorimeter for delivery to collaborators, and design, produce, and test the data/trigger concentrator ASIC(s) required for the endcap calorimeter, and procure power supplies for the hadron section of the calorimeter. The fabrication shall include sufficient components for a testbeam calibration system. Calorimeter silicon and scintillator modules shall have sufficient granularity, noise level, and radiation tolerance to enable cell-by-cell calibration at the 5% level through the end of operation. The cassettes shall be demonstrated to operate standalone and delivered to CERN, where they shall be assembled, and integrated into the endcap calorimeter. The project shall additionally participate in the installation, testing and calibration of the detector.

Contributed Labor Profile and Changes

L2/L3 Area	2019 Contributed Hours	Change Hours
CE	**147,664**	**8%**
CE - Mgmt	69,630	-3%
CE - Sensors	4,660	199%
CE - Modules	21,890	7%
CE - Cassettes	4,951	34%
CE - Scintillator	36,589	31%
CE - Electronics	9,944	-9%

Legend
< -50%
-50%
-25%
0%
25%
50%
> 50%