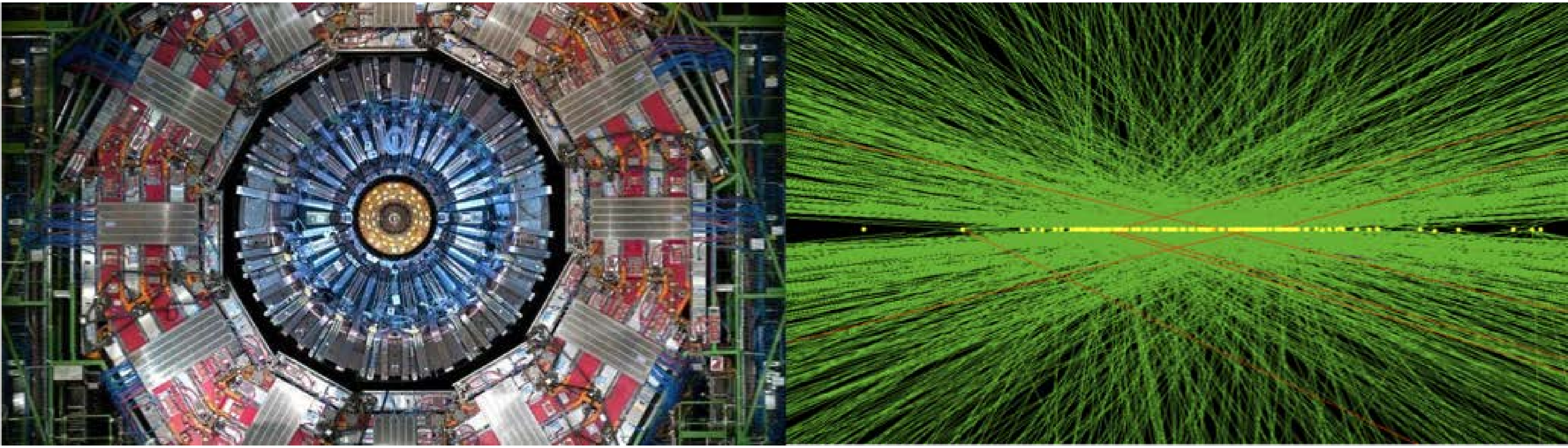
BTL Overview

402.8.3
Including LYSO, Assembly, System Testing, Integration & Commissioning

Adi Bornheim

HL-LHC CMS Upgrade CD-1 Director’s Review

20 March 2019



Brief Biographical Introduction

Charge #5

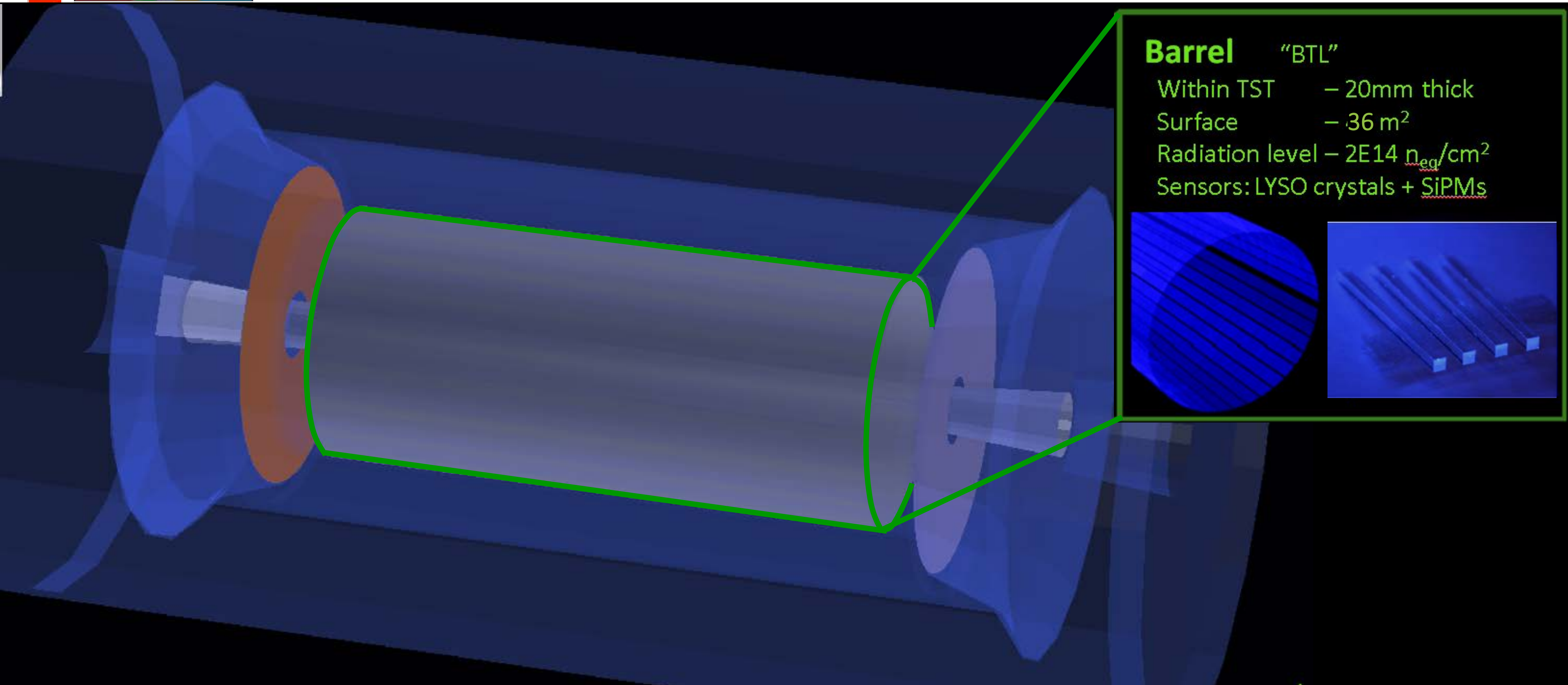
- Adi Bornheim, Caltech
- Roles in international MTD :
  - L3: BTL Technical Manager BTL
  - L4 : BTL Manager of Mechanics & Integration
- Roles in USCMS MTD :
  - L3 : BTL Manager
  - L4 : BTL Assembly, Integration and Commissioning
- Experience :
  - CMS since 2002
  - CMS ECAL R&D, installation, commissioning, operation, Higgs and SM physics
  - Precision timing detector R&D since 2012
  - Postdoc on CLEO, PhD on ZEUS/HERA

Outline

- Conceptual Design
- Scope and Deliverables for BTL (402.8.3)
- Cost and Schedule
- Contributing Institutions
- Resource Optimization
- ES&H
- QA/QC
- Summary

Conceptual Design, Scope and Deliverables

Introduction to BTL



BTL technology choice – SiPM/LYSO :

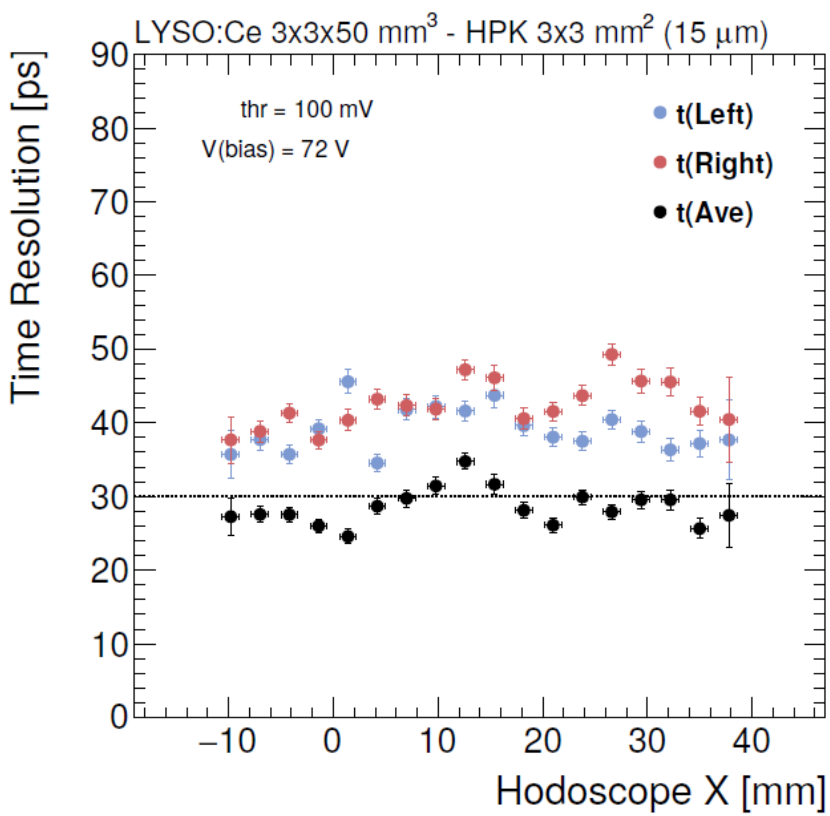
- **Timing performance <30 ps with MIPs in LYSO/SiPM demonstrated.**
- **Radiation hardness established at the required level.**
- **Extensive experience with SiPM in CMS & LYSO in HEP & PET**
- **Cost effective mass market components**

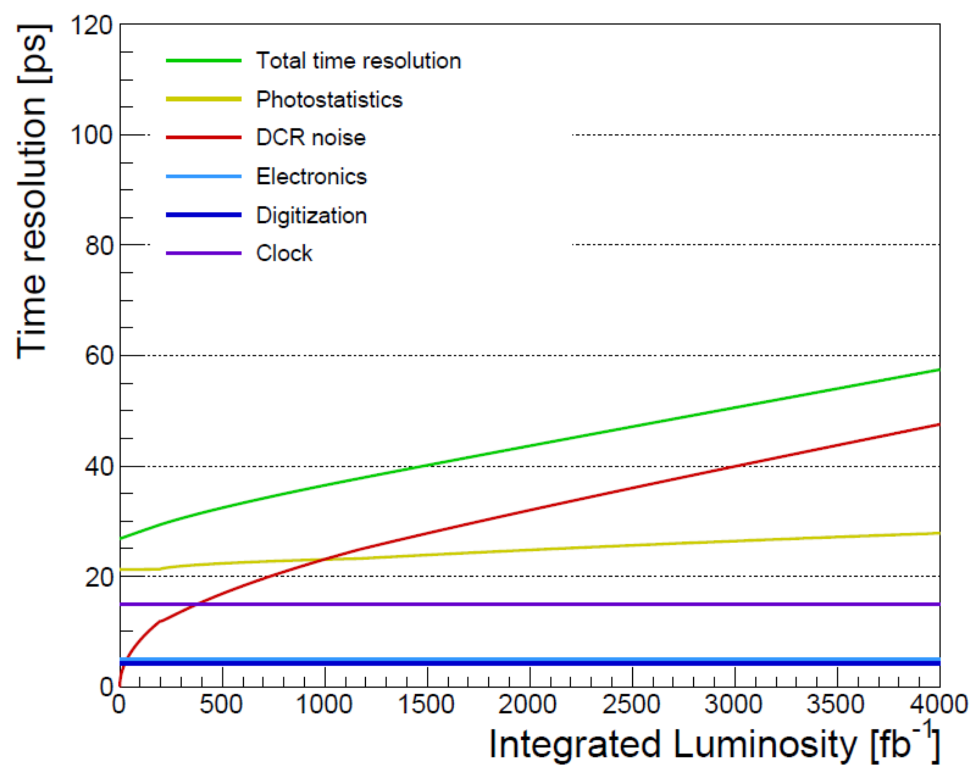
Design constraints

- Time resolution 30-40 ps at the start of HL-LHC, <60 ps up to fluences 4000 fb^{-1}.
- Cover about 36 m^2 of area at the outer circumference of the CMS tracker (TRK).
- Radiation levels for BTL at the end of HL-LHC :
  - Fluence $1.7 – 2 \times 10^{14}$ n_{eq}/cm^2 , Dose : 16-25 kGy
- Maintenance free operation inside the TRK cold volume.
  - Requirement to run SiPMs at -30 C to limit dark count rate (DCR).
- Design facilitating quick and efficient assembly and integration.

BTL Performance

- Time resolution of <30 ps established with design layout.
- With Dark Count Rate as expected for the SiPM at 4 ab^{-1} resolution remains <60 ps.

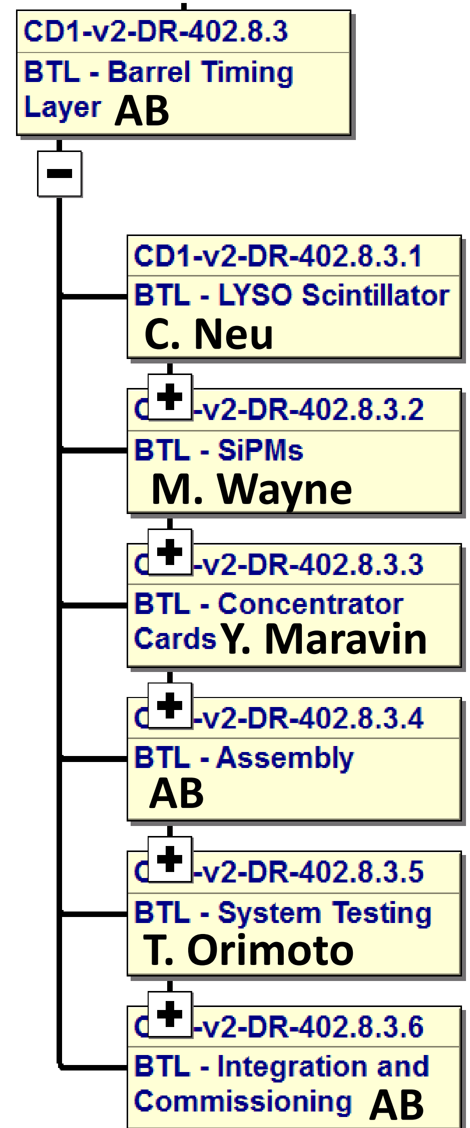




BTL (402.8.3) WBS Structure

Charge #4

- BTL project (402.8.3) subdivided into 6 tasks :
  - LYSO Scintillator (402.8.3.1)
    - C. Neu
  - SiPM sensor (402.8.3.2)
    - M. Wayne → separate talk
  - Concentrator Card (402.8.3.3)
    - Y. Maravin → separate talk
  - Assembly (402.8.3.4)
    - A. Bornheim
  - System Testing (402.8.4.5)
    - T. Orimoto, L. Gray
  - Integration and Commissioning (402.8.3.6)
    - A. Bornheim



Design Considerations for 402.8.3

Charge #1,2

- LYSO (402.8.3.1) :
  - Radiation hardness, cost, commercial availability.
- SiPM (402.8.3.2) :
  - Radiation hardness, lowest possible power consumption at highest possible PDE, low cost
- Concentrator Card (402.8.3.3) :
  - Interfacing ASIC boards with standardized CMS backend and power systems
- Assembly (402.8.3.4) :
  - Designed to allow accelerated assembly by parallelizing work, cost efficient and reliable.
- System Testing (402.8.3.5) :
  - Complement our understanding of the integrated system.
- Integration and Commissioning (402.8.3.6) :
  - Fast, efficient and reliable design, allowing to work in parallel with Tracker.

BTL Layout

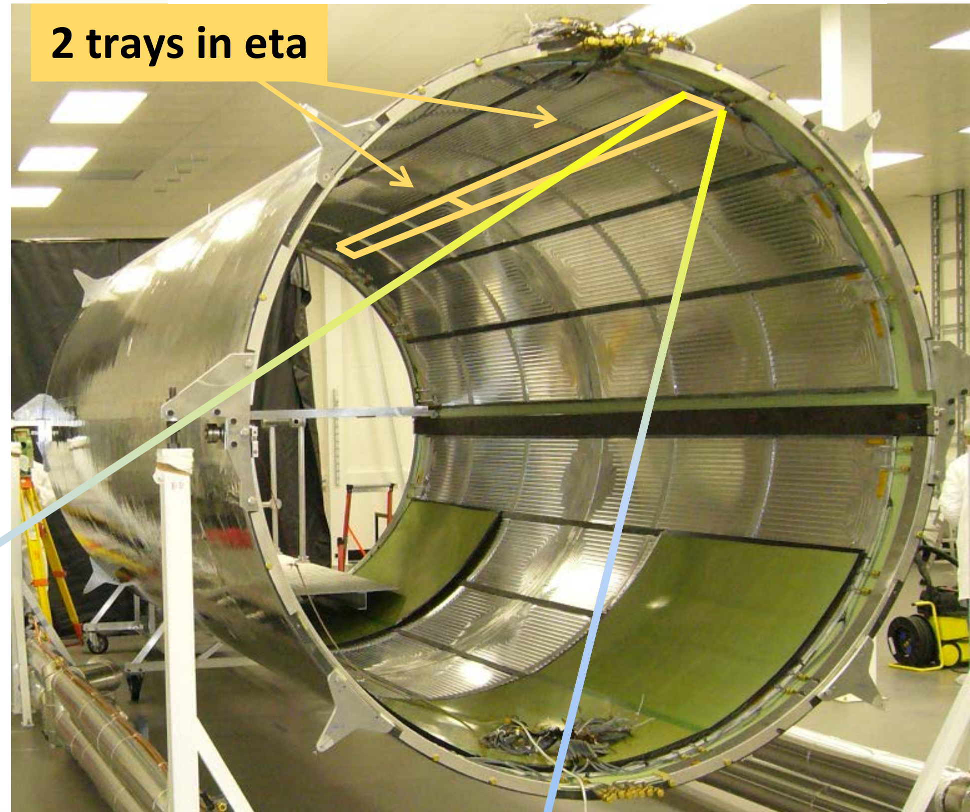
BTL will be attached to the inner wall of the Tracker Support Tube (TST).

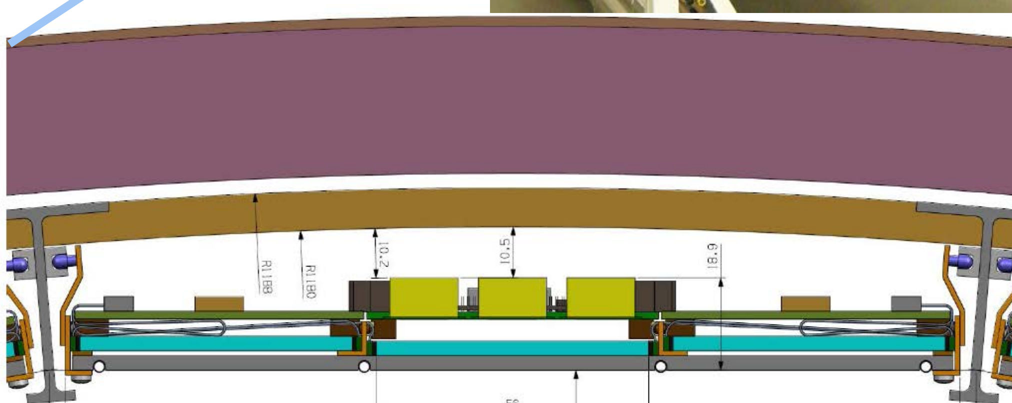
Cold volume shared with Tracker (TRK).

BTL Segmentation :

- 72 trays (36 in $\varphi \times 2$ in η)
- Tray : 250 x 18 x 2.5 cm
- 331k channels, organized in 6 Readout Units per tray.

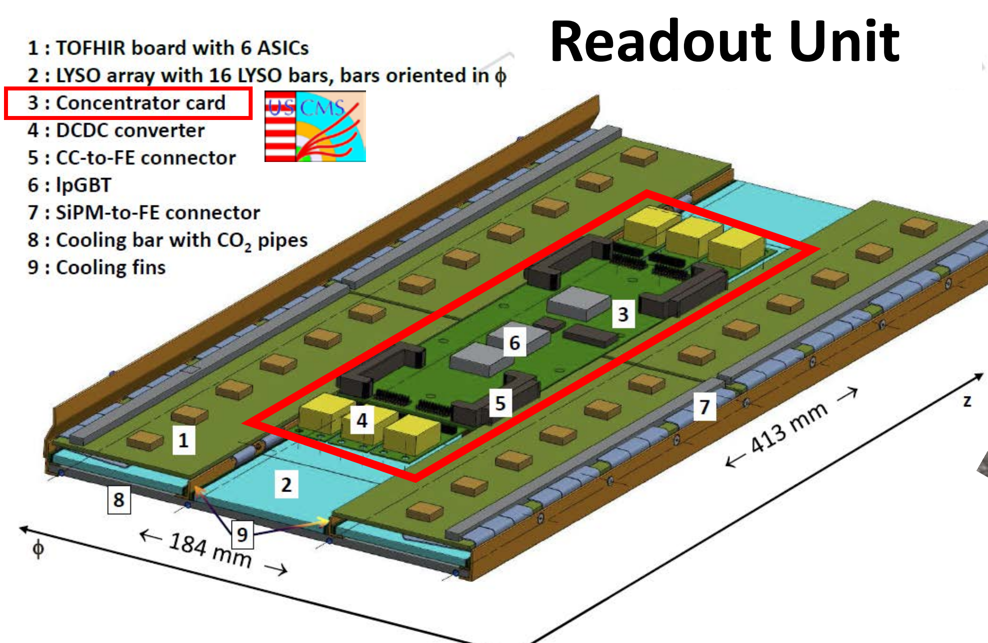
Current TST – Phase 2 very similar

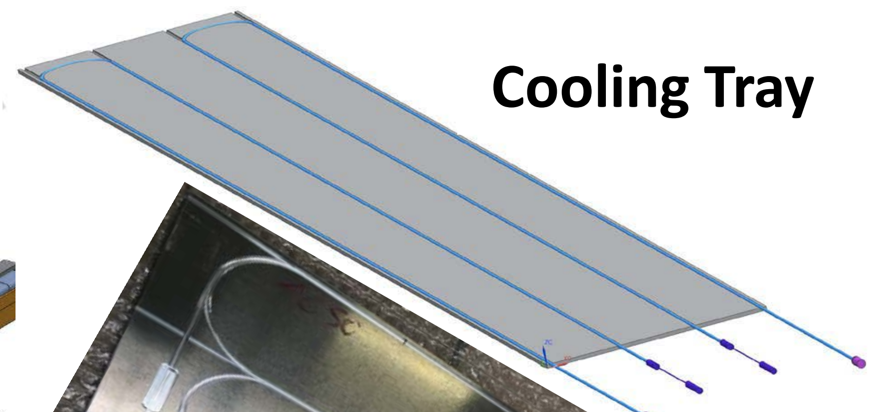


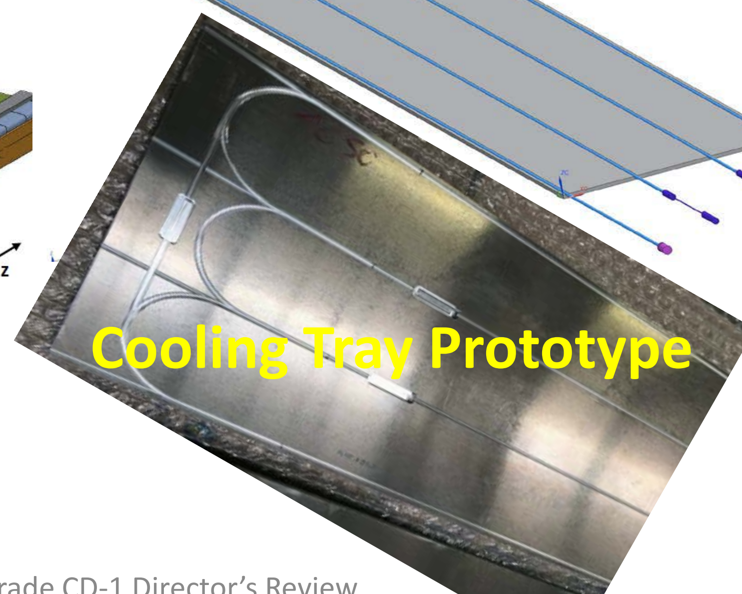


BTL tray

- BTL tray design :
  - Front End electronics, segmented into Readout Units
  - Sensor layer, segmented into modules
  - Cooling tray, providing mechanical support and houses CO_2 cooling pipes.

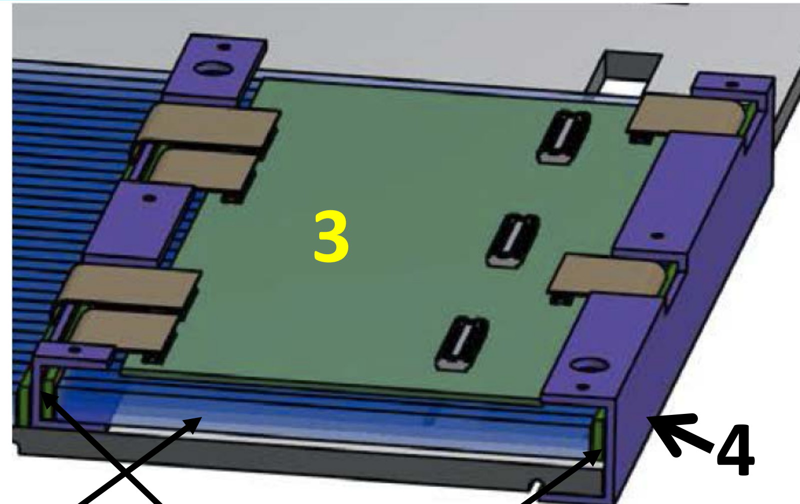






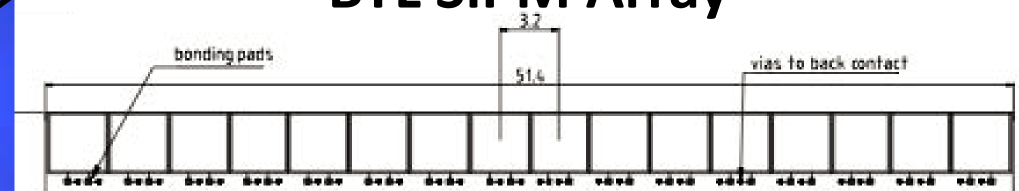
BTL Modules

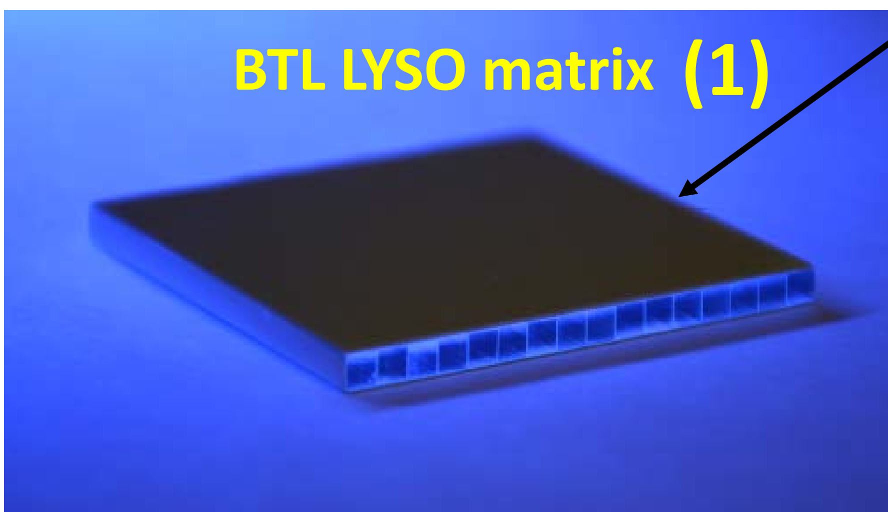
- BTL module :
  1. LYSO matrix
  2. SiPM array
  3. Connectivity to FE cards
  4. Aluminum profiles providing mechanical and thermal contact to cooling tray.



(2)

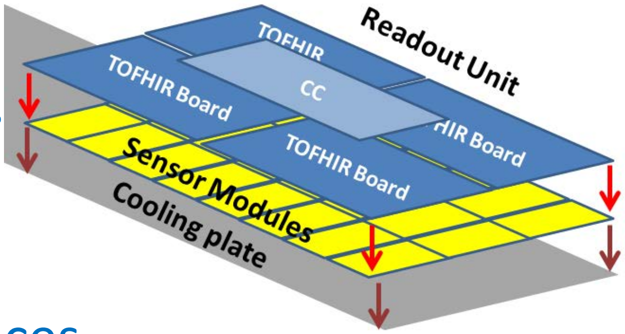
BTL SiPM Array





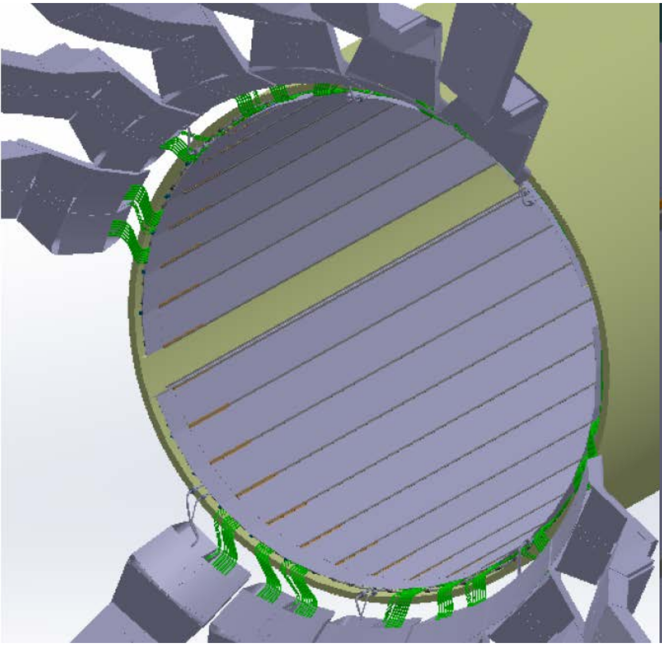
BTL Assembly, Integration & Commissioning

- Module and tray assembly :
  - Mating of LYSO and SiPM, connecting cables.
  - Mounting of modules and RU on cooling plate.
  - 2 assembly centers in the US

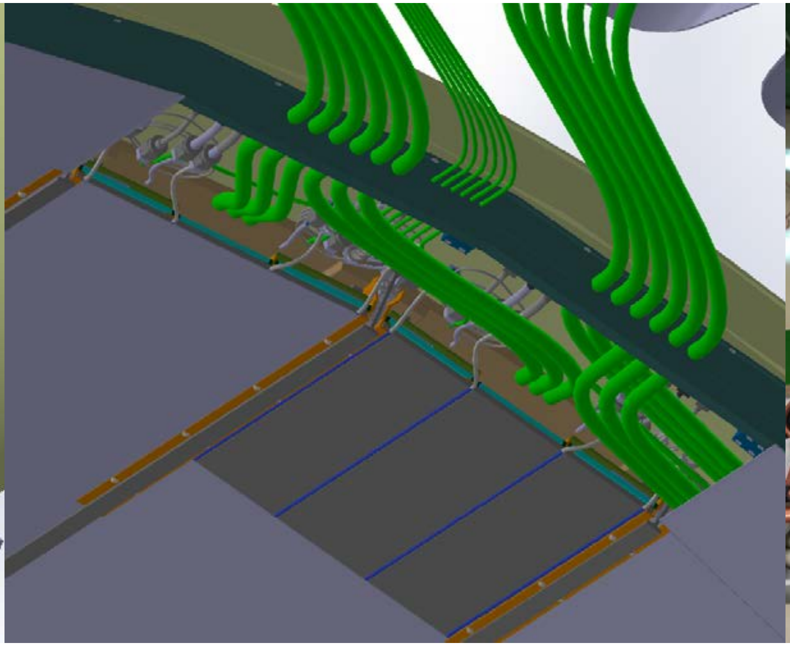


- Integration into the TST :
  - Trays sliding into support rails, connecting services.

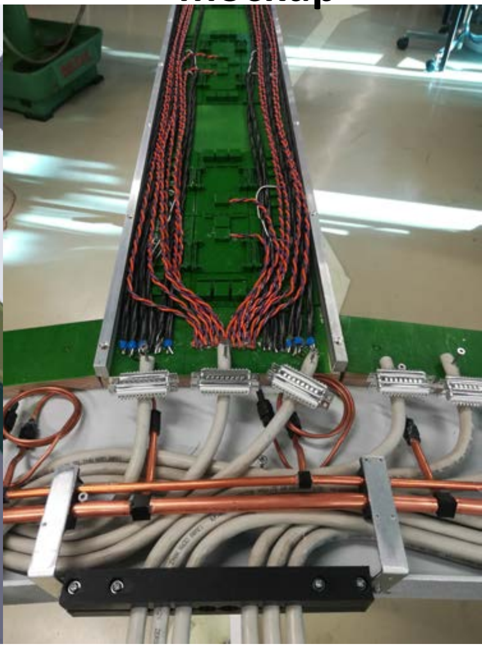
TST with BTL trays and services



BTL services channel



BTL services channel mockup



R&D Achieved

Charge #1,2

- LYSO
  - Benefit from extensive R&D preceding BTL project, dedicated R&D for BTL very limited.
  - Radiation hardness fully validated for our application.
- SiPM
  - Profiting from many years of R&D for HCAL
- Concentrator Card
  - Prototyping ongoing, using common components from CMS
- Assembly
  - Benefit from experience gained in existing detector projects : CMS ECAL, CMS HCAL, CALICE AHCAL.
  - Specific solution being developed.
- Integration and Commissioning
  - Joined project with Tracker, schedule and location (TIF) agreed.
  - Specific solutions are being developed jointly.

R&D needed before production

Charge #2, 4

- Sensor R&D concluding
  - LYSO R&D limited to producer choice and production details selection from commercially available solutions.
  - Gluing and wrapping of LYSO
  - SiPM : See presentation by M. Wayne
- Concentrator Card :
  - See presentation by Y. Maravin
- Assembly
  - Module and tray design now transitioning from conceptual to engineering design.
  - Industrialization options for module production being explored in detail.
- Installation and Commissioning
  - Installation procedure to be worked out in detail.

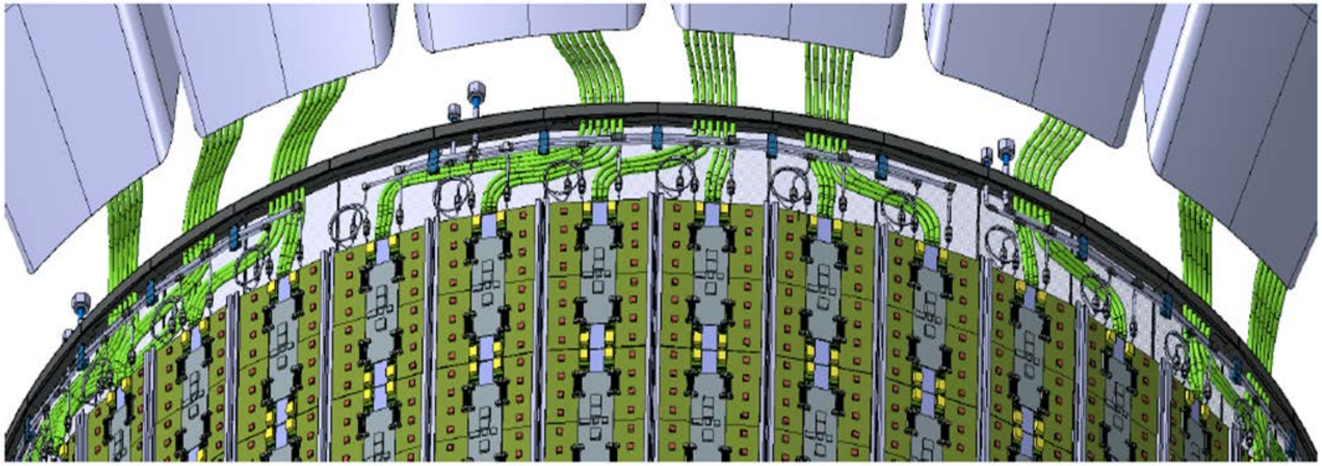
Scope and Deliverables for 402.8.3

Charge #4

- LYSO :
  - Purchase of fraction of LYSO, limited participation in the QA/QC procedure to ensure standardized procedures at the integration center.
- SiPM :
  - Purchase and testing of part of the SiPMs : See talk by M. Wayne
- Concentrator Card :
  - Design and production of all CC : See talk by Y. Maravin
- Assembly :
  - Assembly of 2/3 of the modules and the trays, delivery to CERN.
- Integration and Commissioning :
  - Participation in I&C activity at CERN, jointly with other BTL collaborators.
- Details are described in the respective BoEs.

Interfaces and dependencies

- Sensors :
  - Specs of LYSO and SiPMs, sensor boards, connectivity to FE
- Readout electronics :
  - Matching specs of CC and ASIC card, services, tray mechanics.
- Overall detector dependencies :
  - BTL resides in the same cold volume as TRK, radial space assignment to BTL signed off by TRK.
  - BTL shares service channel – cooling, power, data fibers - with the TRK. Preliminary design of all services exists.
- Documented in cms-doc-13536

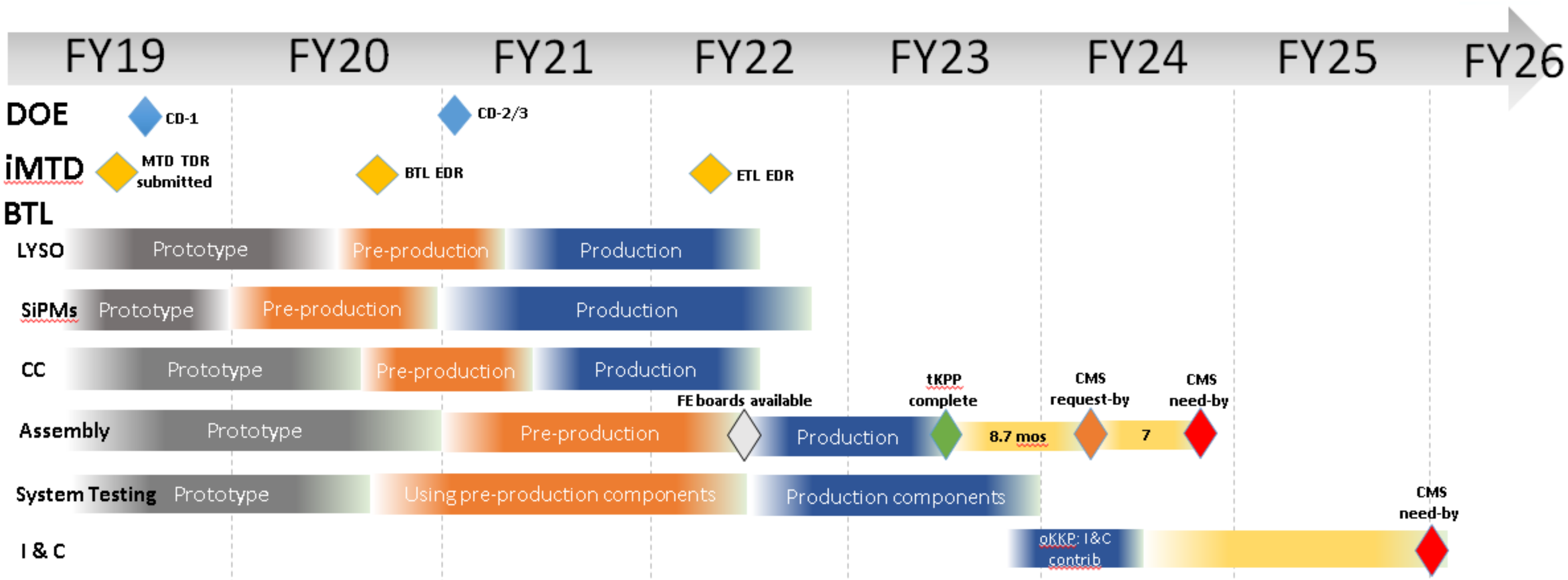


Schedule and Cost

Schedule Overview

Charge #3

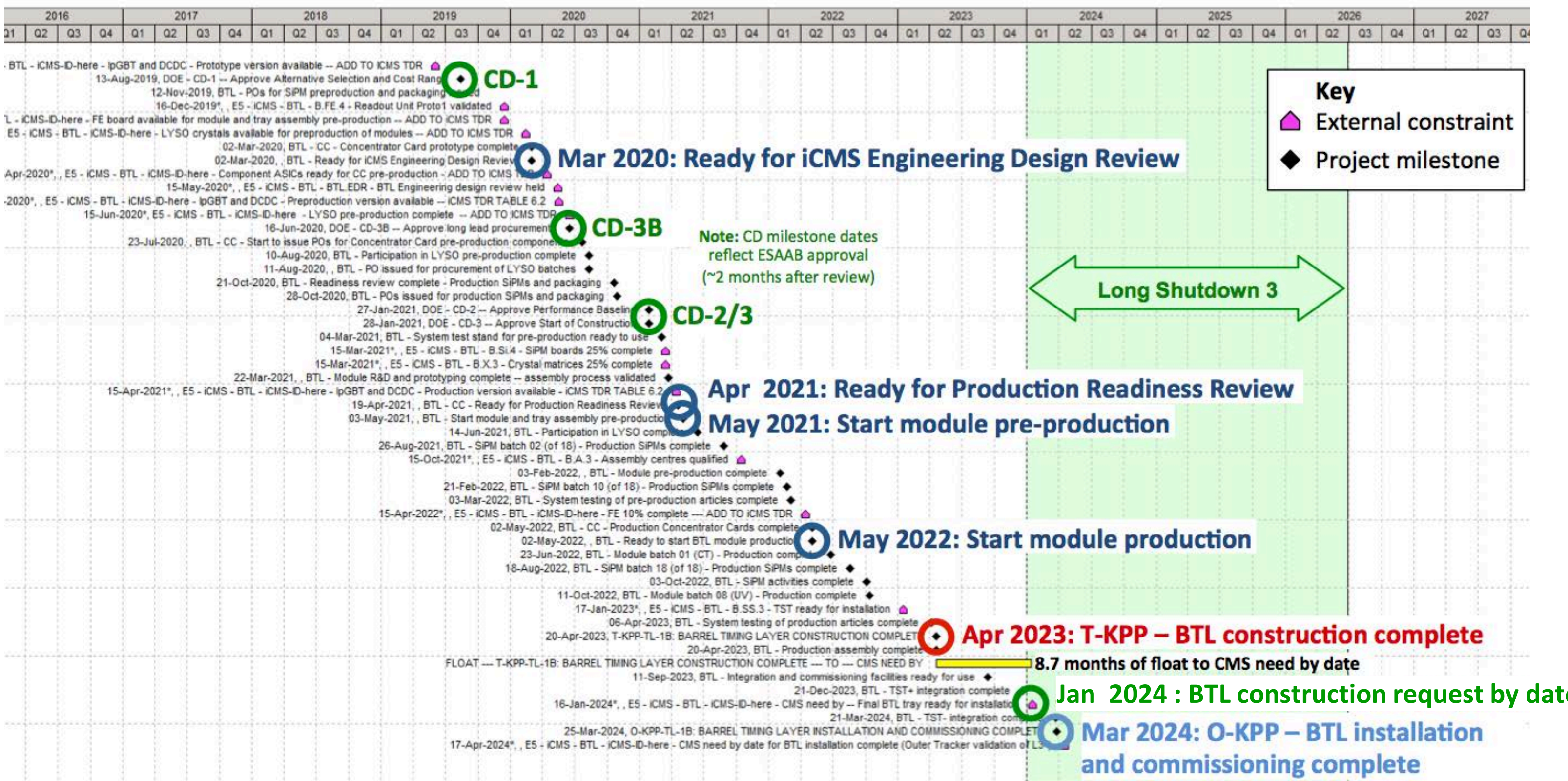
- BTL schedule constrained by Tracker integration
  - Tracker takes priority over BTL, still some flexibility though.
- BTL schedule driven by ASIC development.
  - ASIC schedule solidified since TR
  - TOFHIR prototype delivered, tested at LIP, beam test expected in June
- Assembly and integration driven by FE boards (ASIC).
  - Assembly can be accelerated using teams working in parallel.
- Detailed schedule, resource loaded, now available.
  - Scrutiny in context of TDR review, in preparation for LHCC



Milestones for 402.8.3

Charge #3

- Major milestones for end preproduction, production and end of the project defined. [cms-doc-13321]
  - Finer grained milestones are listed in P6

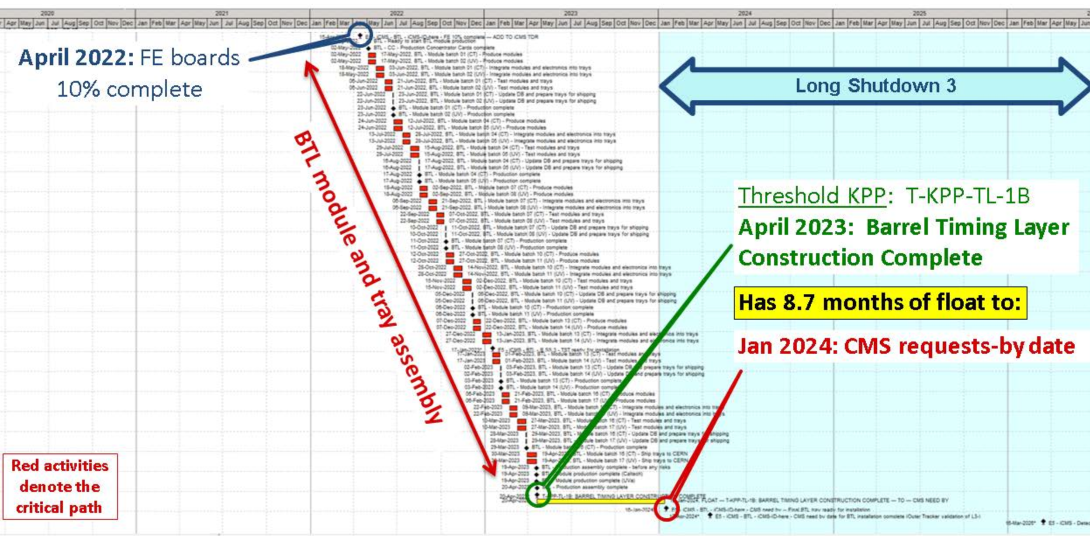


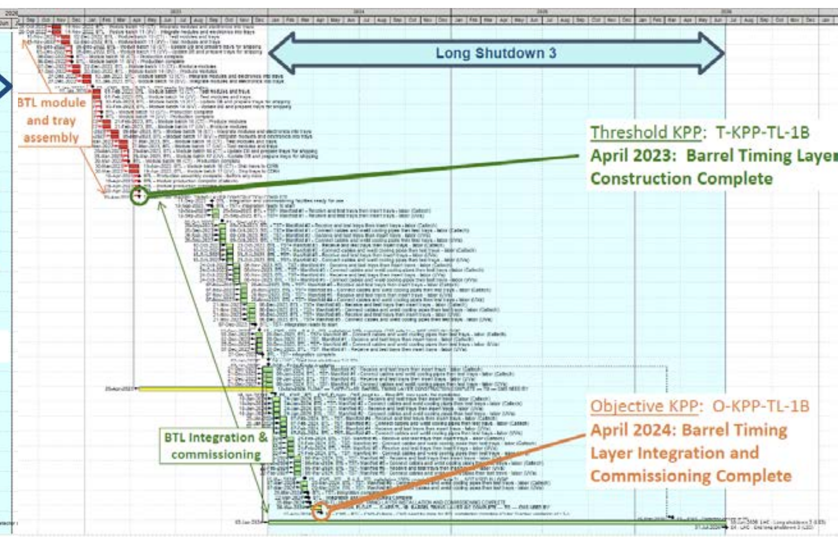
Threshold KPP: BTL module and tray construction is de-coupled from LHC schedule

Objective KPP: Participation in integration and commissioning with iCMS at CERN

Critical Path items for 402.8.3

- International schedule driven by ASIC development.
  - Drives availability of Front End cards.
- Concentrator Card :
  - See presentation by Y. Maravin
- US critical path driven by assembly
  - Assembly depends on availability of FE cards.
  - Flexibility of assembly procedure specifically designed to cope with late arrival of ASIC
- Schedule impact reflected in Risk Registry

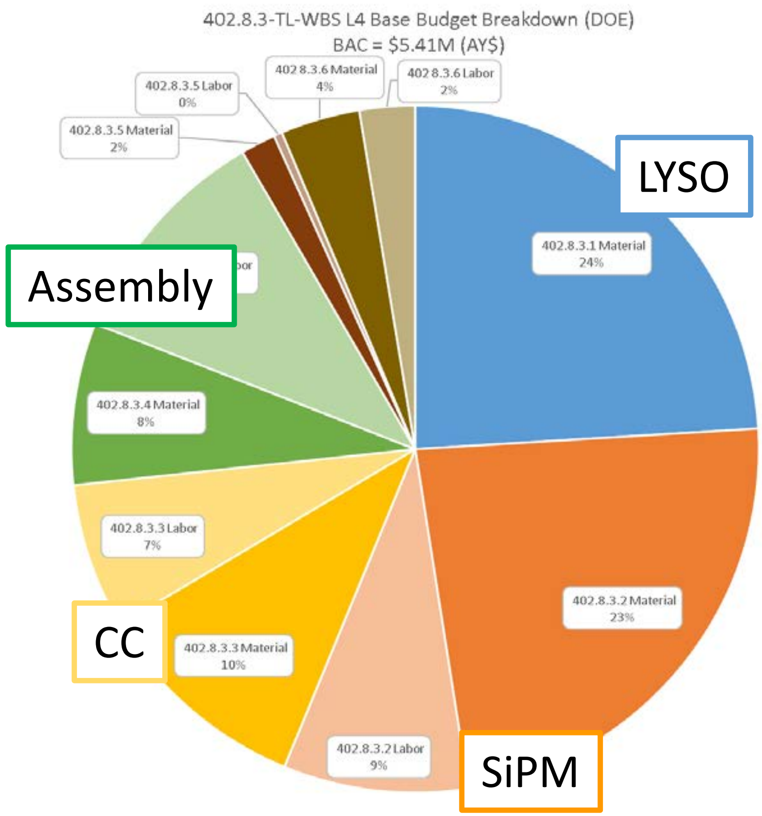


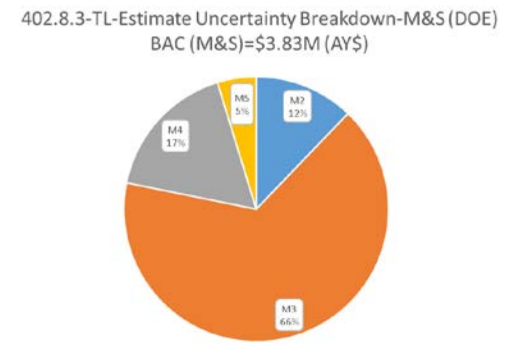


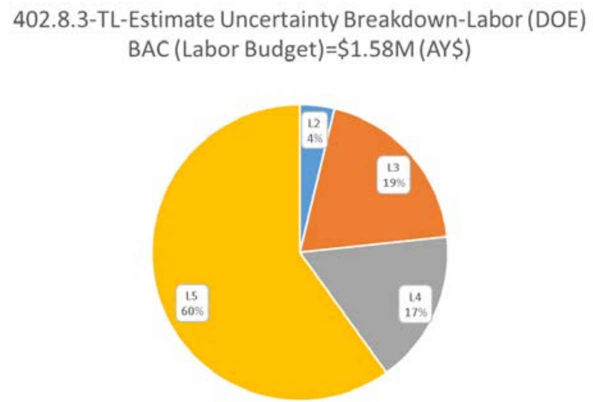
Charge #3

Cost Estimate for 402.8.3

- M&S cost drivers :
  - Purchase of fraction of SiPM & LYSO
- Labor cost drivers :
  - CC card design and production, module and tray assembly

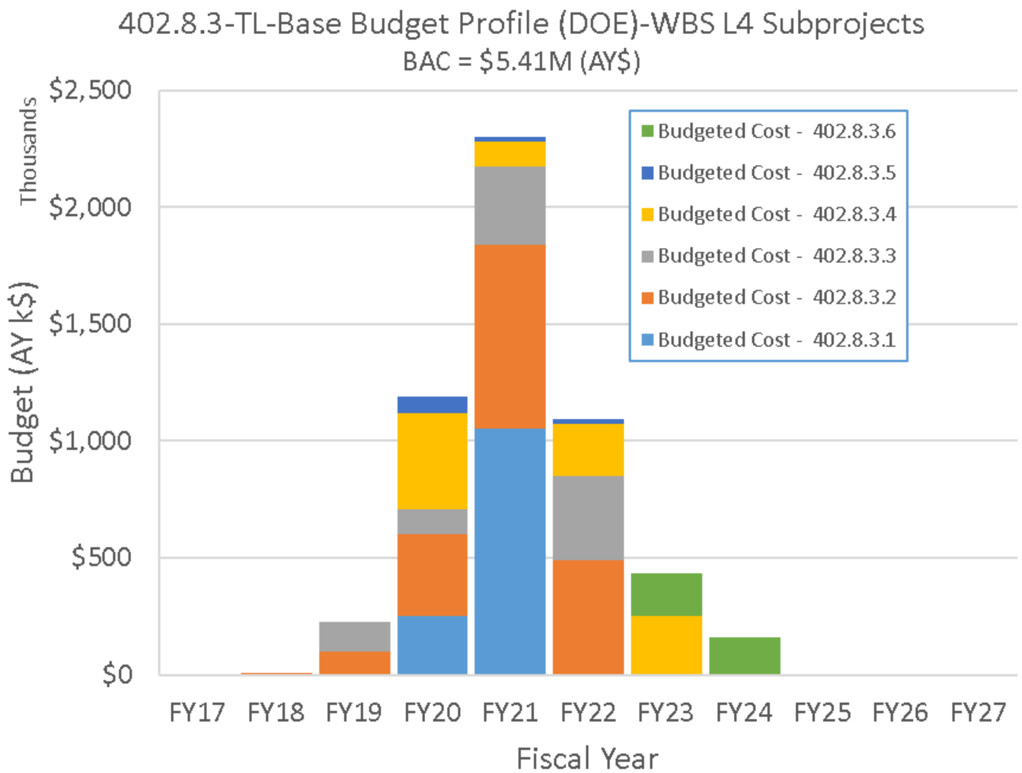


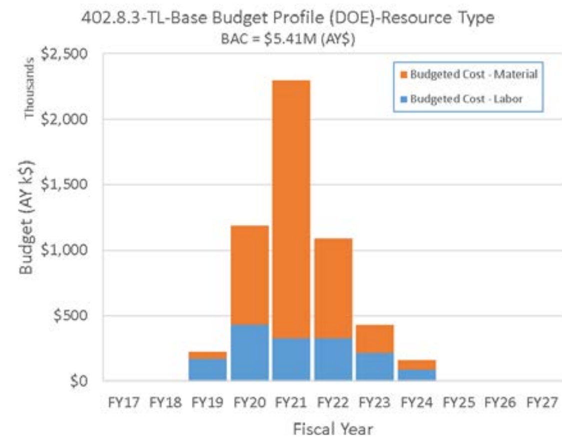


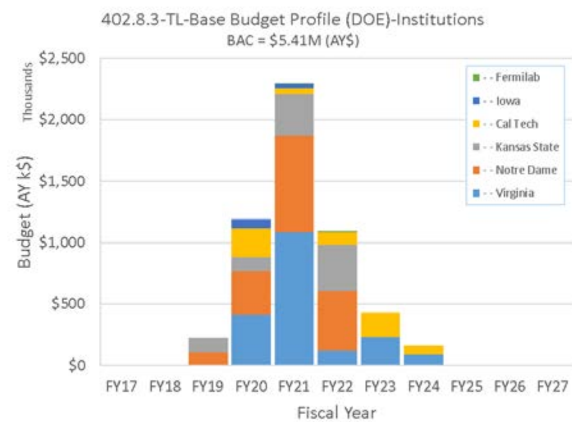


Budget profiles for 402.8.3

- Expenditures peaking in 2021.







BTL Risks

Charge #3

- Project governed by Fermilab Risk Management plan.
- Risk workshop with external reviewers conducted.
- Dominated by changes to interfaces (assembly) and delays in LYSO procurement.
- Documented in [cms-doc-13480](cms-doc-13480)

WBS / Ops Lab Activity : 402.8.3 BTL - Barrel Timing Layer (15)

Risk Type : Threat (15)

2 (Medium)	RT-402-8-05-D	BTL - Change in interfaces of tray assembly components	20 %	3 months	150 -- 250 -- 350 k$
2 (Medium)	RT-402-8-33-D	BTL - Difficulties procuring LYSO from international suppliers	10 %	3 -- 6 -- 9 months	200 -- 450 -- 700 k$
2 (Medium)	RT-402-8-14-D	BTL - Problems with SiPM vendor	20 %	2 -- 6 -- 8 months	32 -- 96 -- 128 k$
2 (Medium)	RT-402-8-30-D	BTL - Concentrator Card requires significant design changes	10 %	1 -- 3 -- 6 months	1 -- 50 -- 100 k$
2 (Medium)	RT-402-8-07-D	BTL - Concentrator Card delay in external component deliveries	20 %	1 -- 3 -- 6 months	0 k$
1 (Low)	RT-402-8-15-D	BTL - Batch shipment of SiPMs lost in transport	5 %	1 months	224 k$
1 (Low)	RT-402-8-35-D	BTL - Delays or damage of tray in transport to CERN	5 %	1 months	220 k$
1 (Low)	RT-402-8-04-D	BTL - LYSO matrices not meeting specifications	10 %	1 -- 2 -- 3 months	100 k$
1 (Low)	RT-402-8-36-D	BTL - Interface to iCMS changes	20 %	1 -- 2 -- 3 months	30 k$
1 (Low)	RT-402-8-34-D	BTL - Delay in delivery of components from iCMS	20 %	1 -- 2 -- 3 months	10 -- 20 -- 30 k$
1 (Low)	RT-402-8-08-D	BTL - Delay in cooling plate delivery	10 %	1 -- 2 -- 3 months	10 -- 20 -- 30 k$
1 (Low)	RT-402-8-18-D	BTL - Concentrator card production & testing facility problem	20 %	0.5 -- 1 -- 2 months	10 k$
1 (Low)	RT-402-8-42-D	BTL - Problems with module assembly site	10 %	1 -- 2 -- 3 months	10 -- 20 -- 30 k$
1 (Low)	RT-402-8-16-D	BTL - Problems with SiPM QC test site	20 %	0.25 -- 0.5 -- 1 months	2 -- 5 -- 10 k$
1 (Low)	RT-402-8-44-D	BTL - Concentrator Card batch shipment lost/damaged/delayed	5 %	0 -- 0.5 -- 1 months	0 -- 3 -- 9 k$

Contributing Institutions and Resource Optimization

Contributing Institutions

Charge #4

- Main contributing institutions for the WBS 402.8.3 are Caltech, Iowa, Notre Dame, UVA, KSU, Princeton, FNAL, NEU.
- All have substantial experience in detector design, R&D, prototyping, construction and commissioning as well as in generic detector R&D.
- In CMS, experience in ECAL and HCAL
- Substantial experience with scintillating crystals, SiPMs and precision timing.

Resource Optimization

- We follow value engineering in organization of the project and optimal use of resources (cms-doc-13475).
- Participating institutions has very strong track record in the relevant technologies.
- Make maximal use of commercially available items for cost drivers (LYSO and SiPMs).
- Make maximal use of industrial processes and techniques for production and assembly.

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)
  - The current construction plan involves no materials of identified environmental risk : cooling plant is based on CO_2
- Detector will be operated in a refrigerated mode (-30°C), similar to TRK.
  - Standard operational procedures will be developed and documented to allow safe operation
- Handling of trays with a weight of 20 kg.
  - Proper handling procedures will be applied.
- Electrical hazards and discharges, voltages up to 100 V.
  - Standard operational procedures will be developed and documented to allow safe operation
- R&D and some production testing will involve the use of ionizing radiation and lasers.
  - These tests will be performed at commonly-used radiation and test beam facilities
- Documented in cms-doc-13394

Quality Assurance and Quality Control

- Following the strategy of maximal usage of commercial and industrial technologies, use respective standards for QA/QC.
- Extensive testing in prototyping, preproduction and production.
- Quality Assurance & Control plan documented in cms-doc-13093.

L2 WBS	Subsystem title	L2 Lead
402.08	MIP Timing Detector	Chris Neu

WBS	WBS Title	L2, L3, L4 Lead	Sub-Project/Sub-component	Institution/ Work Area	QA Coordinator/ Contact	QA Activity ID	Quality Control or Assurance Activity/ Parameter	Validation / Verification & Inspection / Acceptance Test Activities	Requirements/ Specifications	Tech Requirement ID
402.8.3.1	BTL: LYSO Crystals	Chris Neu, Adi Bornheim, Chris Neu	Prototype/preproduction iterations. Production part QC.	Work to be performed at U. Roma. Personnel from University of Virginia, Caltech will participate at a limted level.	Chris Neu	MT -QA-001	Uniformity of all parts, measurements of each dimension, consistency. Measurement of light yield, scintillation time.	A subset of parts will be independently reinspected. Visual inspection for damage and crystal uniformity. Light yield, rise time measurement.	CMS DocDb Ref # 13536	MTD-engr-017
402.08.3.2	BTL: SiPMs	Chris Neu, Adi Bornheim, Mitch Wayne	Prototype/preproduction iterations. Production part QC.	University of Notre Dame / work to be performed in our SiPM lab at CERN	Yuri Musienko	MT -QA-002	Measurement and characterization of approximately 175,000 channels of SiPM	SiPM parameters measured in QA/QC will be verified in beam tests and radiation studies on batches. Characterize each SiPM channel to compare with specifications. SiPMs will be sorted (e.g. by breakdown voltage) if necessary.	CMS DocDb Ref # 13536	MTD-engr-016
402.8.3.3	BTL Concentrator Card	Chris Neu, Adi Bornheim, Yurii Maravin	Prototype testing and qualification. Production testing of all parts.	Kansas State University	Yuri Maravin	MT -QA-003	Power test and digital functionality	Verification of full electrical functionality. Verify each part with visual inspection for any circuit anomalies. Standard set of functional tests with long period of operation.	CMS DocDb Ref # 13536	MTD-engr-013, 026, 027
402.8.3.4	BTL Assembly	Chris Neu, Adi Bornheim, Adi Bornheim	Prototype qualification. Production inspection and testing.	University of Virginia, Caltech	Adi Bornheim	MT -QA-004	Measurement of mechanical parameters. Measurement of performance.	Validation of electrical performance. Measurement of conformity to physical specification. Characterization of electrical performance.	CMS DocDb Ref # 13536	MTD-engr-002, 006, 007, 008, 009, 010, 011, 012, 014, 015, 019, 021, 030; 035, 036
402.8.3.5	BTL: Integration and Commissioning	Chris Neu, Adi Bornheim, Adi Bornheim	Participate in installation and commissioning at CERN with international partners	University of Virginia, Caltech, Notre Dame, KSU / CERN	Adi Bornheim	MT -QA-005	Measurement of electronic performance and cooling and mechanical conformity.	Validation of full tray with background rate and cosmic ray based tests. Measurement of conformity to mechanical specifications and electrical performance.	CMS DocDb Ref # 13536	MTD-engr-003, 004, 010, 011, 012, 014, 015

Summary

- BTL has made significant progress since TR :
  - BTL design well defined
  - SiPM and LYSO ready to move from R&D to preproduction
  - ASIC prototype being tested in Portugal, TB in summer 2019
  - Close collaboration with Tracker on integration and technical coordination.
- Cost, schedule and risks are understood and documented
- Strong team of contributing institutions with significant experience of designing, building, and testing scintillator based detectors.
- Strong international partners.
- Entire team is eager to build BTL.

Responses to Technical Review (1)

Charge #8

- ***BTL-R1: It is crucial to follow the schedule of beam test and/or system integration tests to verify functionality of the readout unit and compatibility with the other systems.***
- **BTL systems testing, beginning from sensor-loaded readout units, is being planned using the results of the various prototyping efforts in the BTL international project. Similar to ETL-R1, reports will be provided at each major stage of development (final engineering prototype, pre-production prototype, and production). These reports will be based on the most complete integrated system that can be assembled at that time, in order to mitigate risks for later stages of the project.**
- **BTL-R2: In P6, identify the external dependencies such as LpGBT, DC-DC converter, and ETH manufacturing of the DC-DC converter board.**
- **International CMS maintains a full list of milestones and dates for major deliverables which is tabulated in the Technical Design Report. We have a high level watch list of external dependencies that the US project depends on, with assigned contacts responsible to monitor their progress. All external dependencies and international milestones that impact the US project have been included in the P6 schedule and are linked to the appropriate activities in our schedule so that we fully account for the impact of any delays on dependent activities. We are working closely with iMTD to develop the iMTD schedule and the US schedule in P6 is fully aligned with the iMTD schedule.**

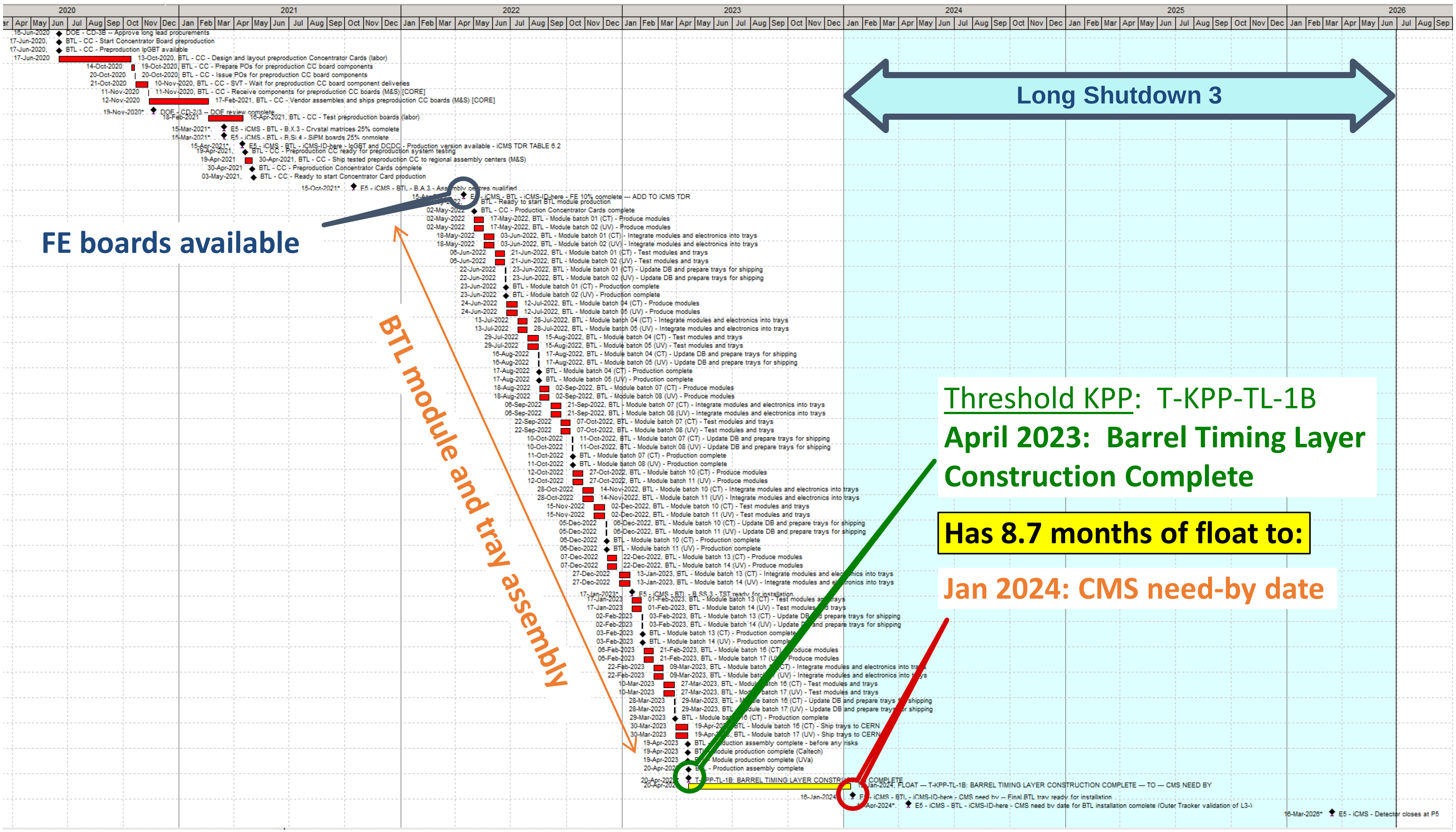
HL-LHC US CMS

Responses to Technical Review (2)

Charge #8

- ***BTL-R3: Consider setting granularity of number of chips/card so that one DC-DC converter is matched to a single TOFHIR readout card.***
- **The current design takes this suggestion into account by assigning a single DC-DC converter per single TOFHIR readout card. Thus, four DC-DC converters serve four TOFHIR cards, and the remaining two are used to power the Concentrator Card.**
- ***BTL-R4: Develop a plan for powering up the ASICs cards connected to the concentrator card and for exploiting the LpGBT capabilities for control and environmental monitoring.***
- **The capabilities for powering up/down, control, and environmental monitoring are given below. They allow full control to implement powering up/powering down scheme that will be designed together with the detector control specialists and MTD teams. Each FE board DC-DC converter enable will be controlled from a GBT-SCA GPIO pin. The PGood signal from each dc- dc converter will be monitored by a GBT-SCA GPIO pin. Each DC-DC converter output voltage will be monitored by a GBT-SCA analog input. The board input voltage will be monitored by a GBT-SCA analog input. The temperature of the PCC and FE boards will be monitored by a GBT-SCA analog input. Four SiPM temperature sensors will be monitored by the LpGBT analog inputs. Total bias current for every 16 SiPM's will be monitored by GBT-SCA analog inputs (12 from each FE board). Internal temperature sensors in each GBT-SCA (2) and each LpGBT (2) will monitor temperature of the CC.**

Critical Path and Schedule Contingency



Installation and Commissioning