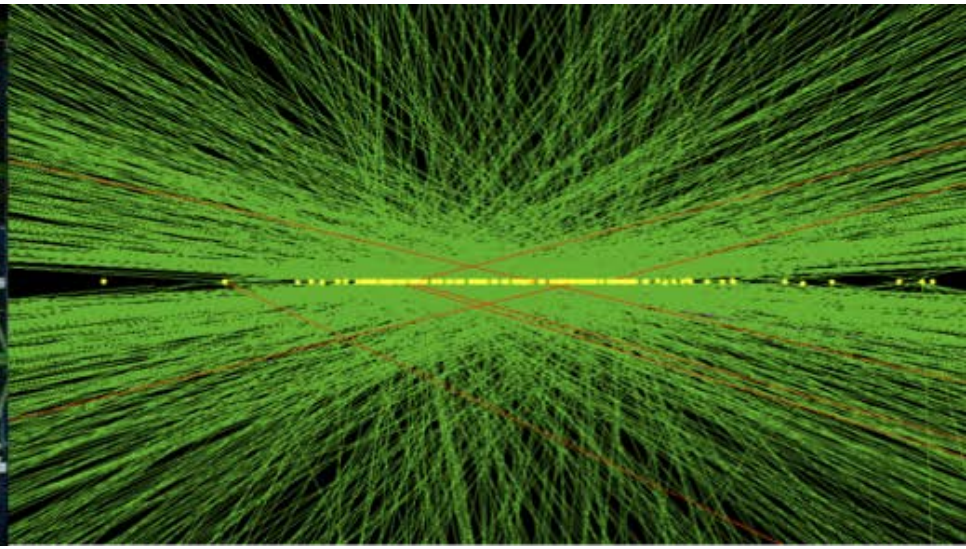
P05: MTD Cost, Schedule, Risk and Outcome of the OPSS Review

Frank Chlebana (Deputy L2 MTD Manager)

Fermilab CD-1 Director's Review

19 March 2019



Outline

- Basis of estimate
- Schedule development
- Responses to the OPSS review
- Costs
- Milestones
- Synchronization with the international MTD schedule
- Risk
- Critical Path
- Float

Basis of Estimate (BoE)

Basis of Estimates and supporting documentation are available in DocDB

Detailed description of scope, vendor quotes, and a summary of how the costs and labor effort was determined

L2 Parent:WBS : 402.8 TL - TIMING LAYER (12)	
L3 Parent:WBS : 402.8.2 TL - Management (1)	
402.8.2 TL - Management	CMS-doc-13508
L3 Parent:WBS : 402.8.3 BTL - Barrel Timing Layer (6)	
402.8.3.1 BTL - LYSO Scintillator	CMS-doc-13589
402.8.3.2 BTL - SiPMs	CMS-doc-13590
402.8.3.3 BTL - Concentrator Cards	CMS-doc-13591
402.8.3.4 BTL - Assembly	CMS-doc-13592
402.8.3.5 BTL - System Testing	CMS-doc-13599
402.8.3.6 BTL - Integration and Commissioning	CMS-doc-13593
L3 Parent:WBS : 402.8.4 ETL - Endcap Timing Layer (5)	
402.8.4.1 ETL - LGAD Sensors	CMS-doc-13594
402.8.4.2 ETL - Frontend ASICs	CMS-doc-13595
402.8.4.3 ETL - Assembly	CMS-doc-13597
402.8.4.4 ETL - System Testing	CMS-doc-13737
402.8.4.5 ETL - Integration and Commissioning	CMS-doc-13598

Example of documentation for the BTL Concentrator Cards saved in DocDB

Files in Document:

- BoE---402-8-3-3---BTL---Concentrator-Cards-6 (2).docx (11.5 MB)
- Excel: M&S and Labor tables (BTL---Concentrator-Card---cost-estimate-V2.xlsx, 506.0 kB)

Other Files:

- Activity list (CC_ActivityList_v0 (3).docx, 20.3 kB)
- M&S 2019 prototype BOM (MS-1_CC_prototype_2019_BOM.pdf, 22.9 kB)
- M&S CC production BOM (MS-15_CC_production_2021_BOM.pdf, 23.3 kB)
- M&S CC prototype assembly (MS-2_CC_prototype_2019_Assembly.pdf, 498.1 kB)
- M&S FEAST adapter PCB material (MS-6_FeastAdapter_2019_PCB.pdf, 86.0 kB)
- M&S FEAST adapter board BOM (MS-5_FeastAdapter_2019_BOM.pdf, 22.0 kB)
- M&S FEAST component quotes (MS-7_FeastAdapter_2019_components.pdf, 228.3 kB)
- M&S Feast adapter production BOM (MS-16_FeastAdapter_2021_BOM.pdf, 18.3 kB)
- M&S Test Stand components quote (MS-13_TestStand_components.pdf, 2.9 MB)
- M&S Test stand BOM (MS-12_TestStand_BOM.pdf, 46.5 kB)
- M&S Test stand quote for bare board (MS-11_TestStand_BareBoard.pdf, 84.6 kB)
- M&S Vivado 1y license for test stand (MS-14_TestStand_license.pdf, 104.0 kB)
- M&S quote for FR4 halogen-free PCB material for CC card (MS-4_CC_PCB_quote.pdf, 80.8 kB)
- M&S quotes for CC components, excluding lpGBT and VL+ (MS-3_CC_components_wo_lpGBT_and_VLplus.pdf, 785.1 kB)
- Quote for PCIe card for the test stand (MS-8_TestStand_PCIe.pdf, 257.1 kB)
- Quote for Stencil board for the test stand (MS-10_TestStand_Stencil.pdf, 216.1 kB)
- Shipping rates (MS-9_ShppingRates.pdf, 438.1 kB)

Vendor Quotes

All estimates for the major cost drivers are based on recent vendor quotes

LYSO: 14 vendors contacted, received quotes from 11 vendors (as of Nov 10, 2018)
SiPM: Hamamatsu-SiPM (Feb 26, 2019)
Concentrator Cards: Bill of material parts list, PCB production (Sep 10, 2018)
BTL Assembly: Pick and place gantry and stencil printer (Aug 15, 2018)

LGAD: Shipping estimate (Sep, 2018), FBK-LGAD (Nov 10, 2018)
ASIC: MWP, Fabrication, Estimates for Multi-project Wafer submission and maskset are based on contractual agreement between CERN and foundry (Sep 20, 2018)
ETL Assembly: Service contract, misc parts, AIN quote (Jan 2019)

System testing: *Estimates based on previous experience from the Phase 1 Tracker*

OPSS Review

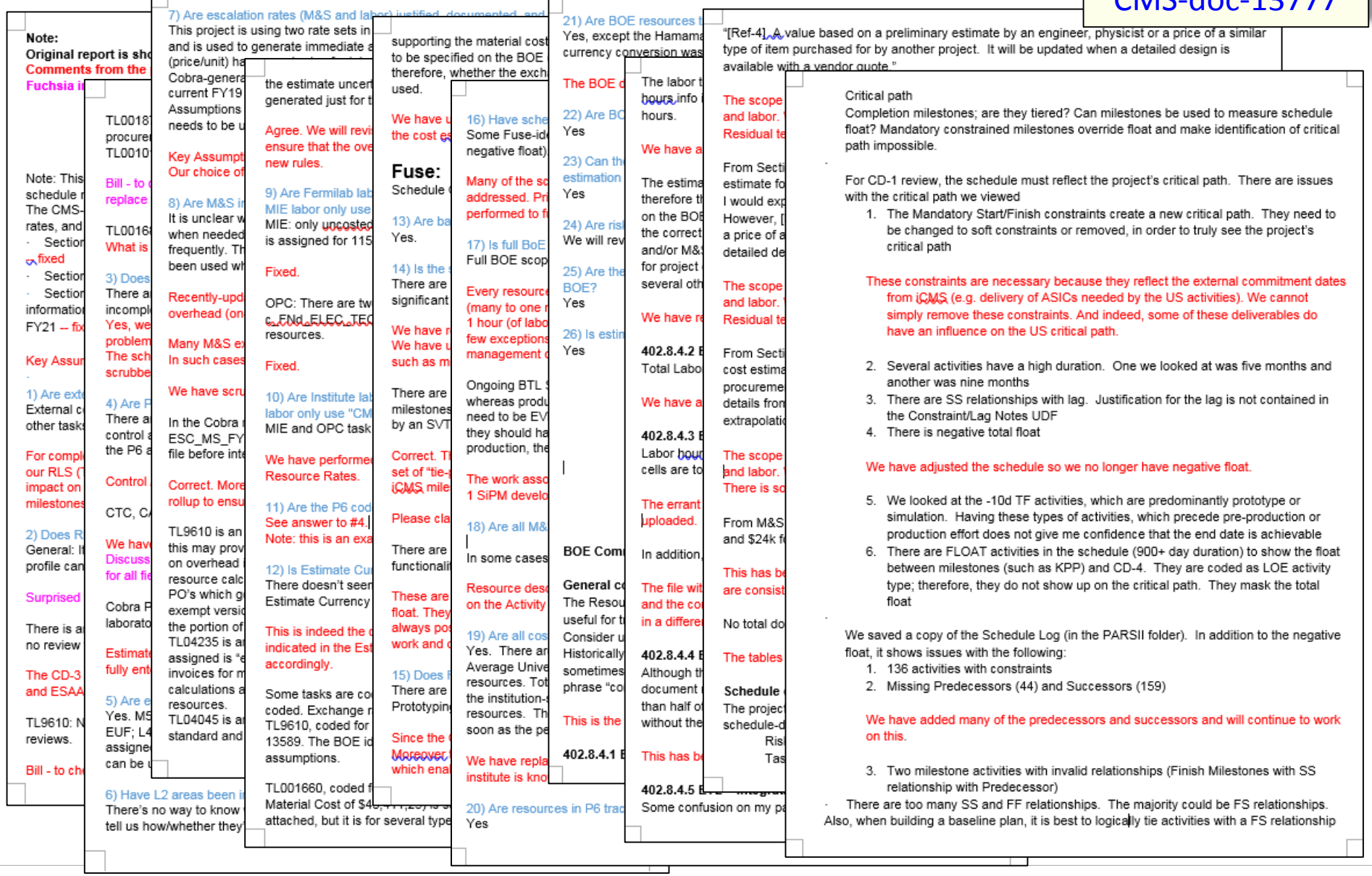
Cost and schedule were reviewed during the Office of Project Support Service's (OPSS) Cost, Schedule, and Risk (CSR) review in Jan 2019

- Provided a detailed list of feedback (next slide)
- Clarify / improve BOE documentation
- Fix schedule logic (missing successors, predecessors)
- Add missing codes to P6
- Change generic university with institute specific codes
- Add correct MIE / OPC codes
- Establish critical path
- *Long duration activities with Start-to-start logic (being worked on)*

We have implemented updates to the schedule and have provided responses to most of the feedback

OPSS Review Feedback and Responses

CMS-doc-13777



Critical path

Completion milestones; are they tiered? Can milestones be used to measure schedule float? Mandatory constrained milestones override float and make identification of critical path impossible.

For CD-1 review, the schedule must reflect the project's critical path. There are issues with the critical path we viewed

1. The Mandatory Start/Finish constraints create a new critical path. They need to be changed to soft constraints or removed, in order to truly see the project's critical path

These constraints are necessary because they reflect the external commitment dates from iCMS (e.g. delivery of ASICs needed by the US activities). We cannot simply remove these constraints. And indeed, some of these deliverables do have an influence on the US critical path.

2. Several activities have a high duration. One we looked at was five months and another was nine months
3. There are SS relationships with lag. Justification for the lag is not contained in the Constraint/Lag Notes UDF
4. There is negative total float

We have adjusted the schedule so we no longer have negative float.

5. We looked at the -10d TF activities, which are predominantly prototype or simulation. Having these types of activities, which precede pre-production or production effort does not give me confidence that the end date is achievable
6. There are FLOAT activities in the schedule (900+ day duration) to show the float between milestones (such as KPP) and CD-4. They are coded as LOE activity type; therefore, they do not show up on the critical path. They mask the total float

We saved a copy of the Schedule Log (in the PARSII folder). In addition to the negative float, it shows issues with the following:

1. 136 activities with constraints
2. Missing Predecessors (44) and Successors (159)

We have added many of the predecessors and successors and will continue to work on this.

3. Two milestone activities with invalid relationships (Finish Milestones with SS relationship with Predecessor)

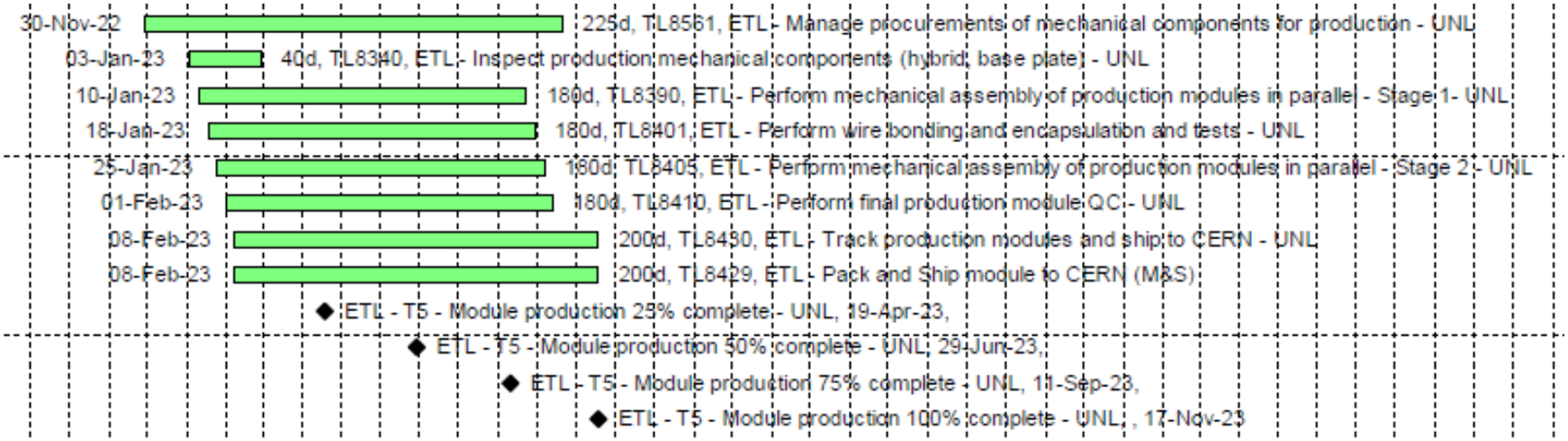
- There are too many SS and FF relationships. The majority could be FS relationships. Also, when building a baseline plan, it is best to logically tie activities with a FS relationship

OPSS Review Follow Up

We will continue to improve the schedule between now and the CD-1 review

- Further develop the system testing plan
- Break up the long duration activities
- Remove SS and lags in the connection logic
- Refine the interface with international deliverables (bump bonding)
- Review activity sequencing to see if we can increase the float

Example of using long duration activities with start-to-start logic and a lag in the schedule to get the cost estimate → *split into finer detailed activates to facilitate monitoring by the CD-1 review*



The MTD schedule is well advanced, provides a solid cost estimate, allows us to do a critical path analysis, and estimate the risk impact to the schedule

Timing Layer Costs (Project Cost Book)

CMS-doc-13777

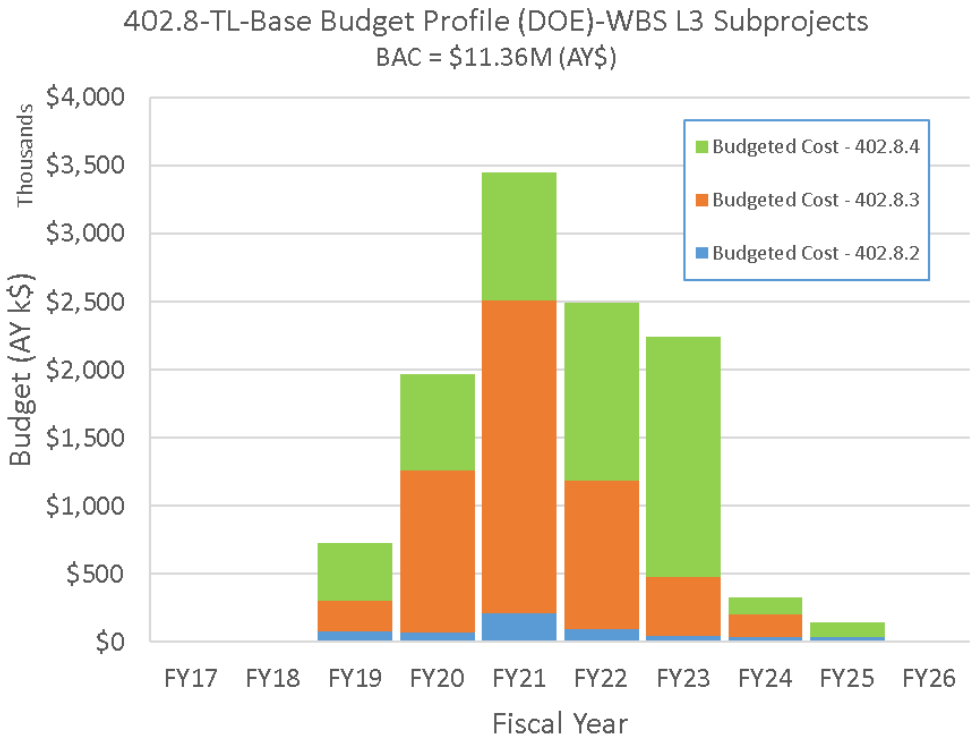
WBS	Direct M&S ($)	Labor (Hours)	FTE	Direct + Indirect + Esc. ($)	Estimate Uncertainty ($)	Total Cost ($)
CD1-v2-DR-402.8 402.8 TL - Timing Layer	6,561,457	161764	91.50	11,364,763	3,026,706	14,391,469
CD1-v2-DR-402.8.2 TL - Management	433,000	26520	15.00	568,714	144,562	713,276
CD1-v2-DR-402.8.2.1 TL - Management Labor	0	26520	15.00	0	0	0
CD1-v2-DR-402.8.2.2 TL - Management Travel	233,000	0	0.00	349,488	34,949	384,436
CD1-v2-DR-402.8.2.3 TL - Common Infrastructure	200,000	0	0.00	219,226	109,613	328,840
CD1-v2-DR-402.8.3 BTL - Barrel Timing Layer	3,352,236	49800	28.17	5,410,860	1,318,476	6,729,336
CD1-v2-DR-402.8.3.1 BTL - LYSO Scintillator	1,178,868	2946	1.67	1,301,006	191,882	1,492,888
CD1-v2-DR-402.8.3.2 BTL - SiPMs	1,135,400	5384	3.05	1,740,686	296,166	2,036,852
CD1-v2-DR-402.8.3.3 BTL - Concentrator Cards	492,896	5147	2.91	925,645	306,932	1,232,577
CD1-v2-DR-402.8.3.4 BTL - Assembly	343,120	19353	10.95	989,999	383,042	1,373,042
CD1-v2-DR-402.8.3.5 BTL - System Testing	78,952	6322	3.58	110,401	49,734	160,135
CD1-v2-DR-402.8.3.6 BTL - Integration and Commissionin	123,000	10648	6.02	343,123	90,719	433,842
CD1-v2-DR-402.8.4 ETL - Endcap Timing Layer	2,776,221	85444	48.33	5,385,188	1,563,669	6,948,857
CD1-v2-DR-402.8.4.1 ETL - LGAD Sensors	0	3872	2.19	0	0	0
CD1-v2-DR-402.8.4.2 ETL - Frontend ASICs	1,922,500	22588	12.78	3,874,081	1,039,579	4,913,660
CD1-v2-DR-402.8.4.3 ETL - Assembly	680,860	30088	17.02	1,145,013	397,283	1,542,296
CD1-v2-DR-402.8.4.4 ETL - System Testing	79,561	6322	3.58	103,418	38,340	141,759
CD1-v2-DR-402.8.4.5 ETL - Integration and Commissionin	93,300	22574	12.77	262,676	88,467	351,143

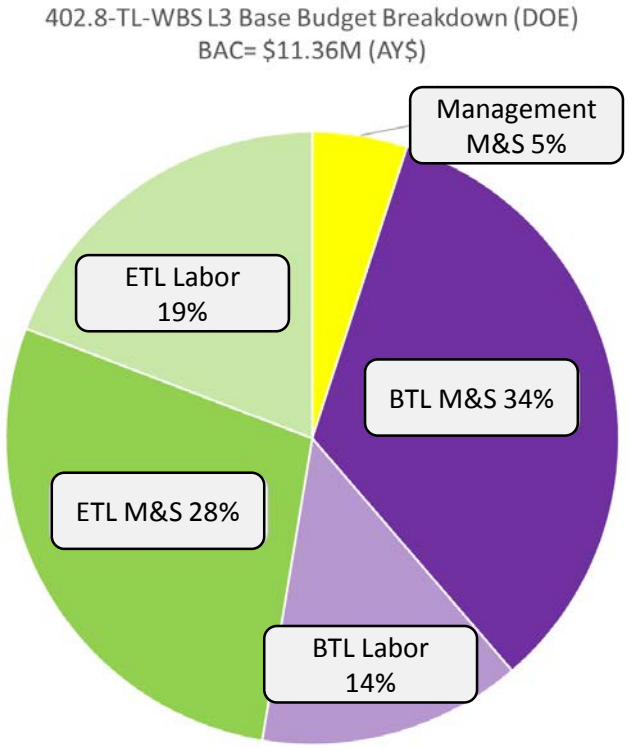
The MTD costs derived from the P6 schedule include institutional specific labor rates, overheads, escalation, and estimate uncertainty and is within 14.39M$

Costs at Level 3

CMS-doc-13215

WBS	Direct M&S ($)	Labor (Hours)	FTE	Direct + Indirect + Esc. ($)	Estimate Uncertainty ($)	Total Cost ($)
CD1-v2-DR-402.8 402.8 TL - Timing Layer	6,561,457	161764	91.50	11,364,763	3,026,706	14,391,469
CD1-v2-DR-402.8.2 TL - Management	433,000	26520	15.00	568,714	144,562	713,276
CD1-v2-DR-402.8.3 BTL - Barrel Timing Layer	3,352,236	49800	28.17	5,410,860	1,318,476	6,729,336
CD1-v2-DR-402.8.4 ETL - Endcap Timing Layer	2,776,221	85444	48.33	5,385,188	1,563,669	6,948,857





Main M&S Cost Drivers (>500k$)

Material	Obligation Date	Direct Cost (k$)	Total Cost (k$)	Approval Date
SiPM production	8/1/2020	950	1200	CD-3b (Apr 2020)
LYSO production	6/1/2020	1137	1421	CD-3b (Apr 2020)
ETROC preproduction	1/1/2022	728	939	CD-3 (Nov 2020)
ETROC production	7/1/2022	887	1166	CD-3 (Nov 2020)

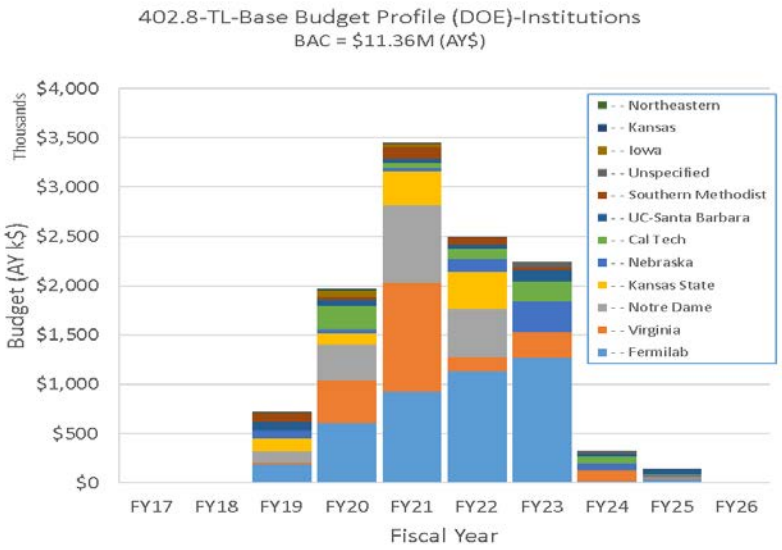
Main cost drivers represent ~46% of the MTD M&S cost
Estimate uncertainty of 15%

ETROC pricing is well-defined via the IMEC/CERN agreement.

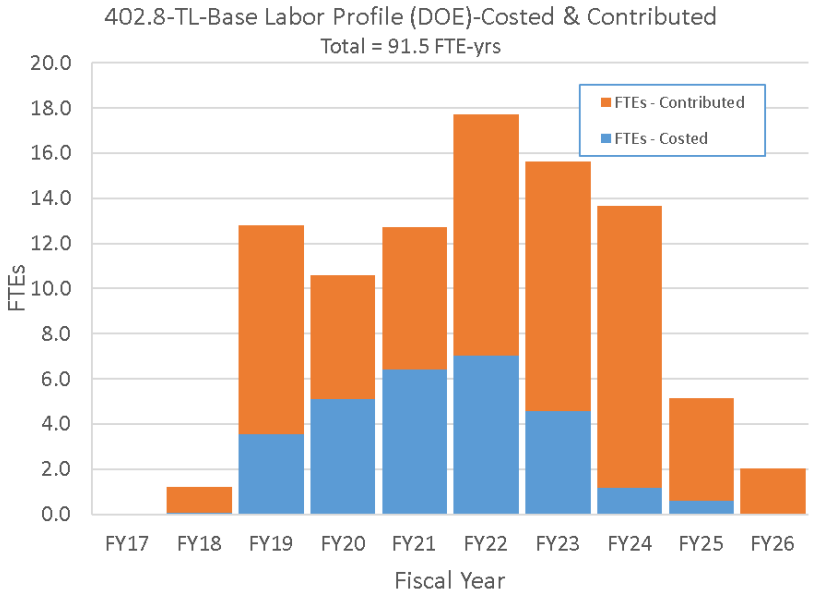
The LYSO pricing is based on the recent vendor quotes from 8 vendors, and our assumed cost is the mean of the responses from the vendors. LYSO is a commonly available commodity in the medical industry. We are not doing anything exotic in terms of its specification or preparation --hence our needs are similar to existing designs with little or no modifications.

SiPM pricing is based on a recent vendor quote from HPK. These SiPMs that were the subject of the vendor quote reflect a nearly-completed design and are similar to the design used for the HCAL upgrade, for which costs are documented.

Timing Layer Labor



The main labor cost is for the ASIC development



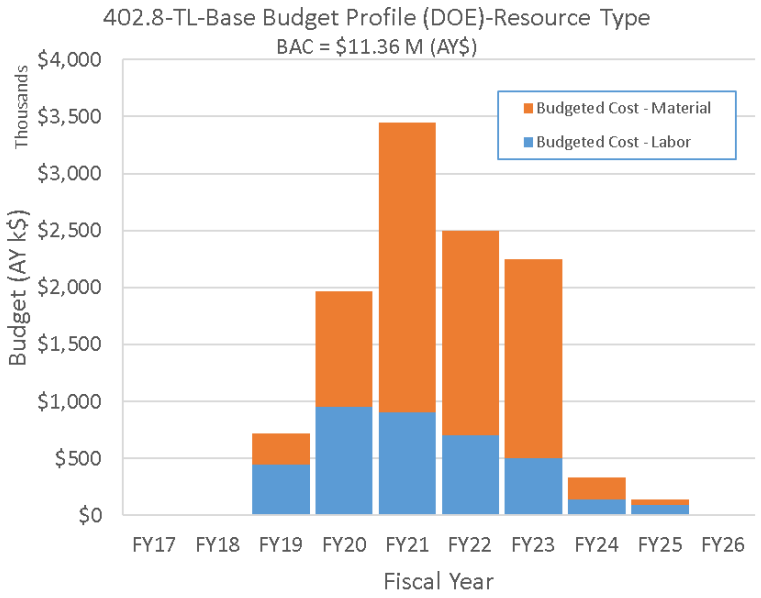
Contributed labor is mainly in the LYSO, LGAD, System testing, I&C, and the R&D phase of Assembly

The areas with technical deliverables, SiPM, CC, ASIC, are done with mostly costed labor

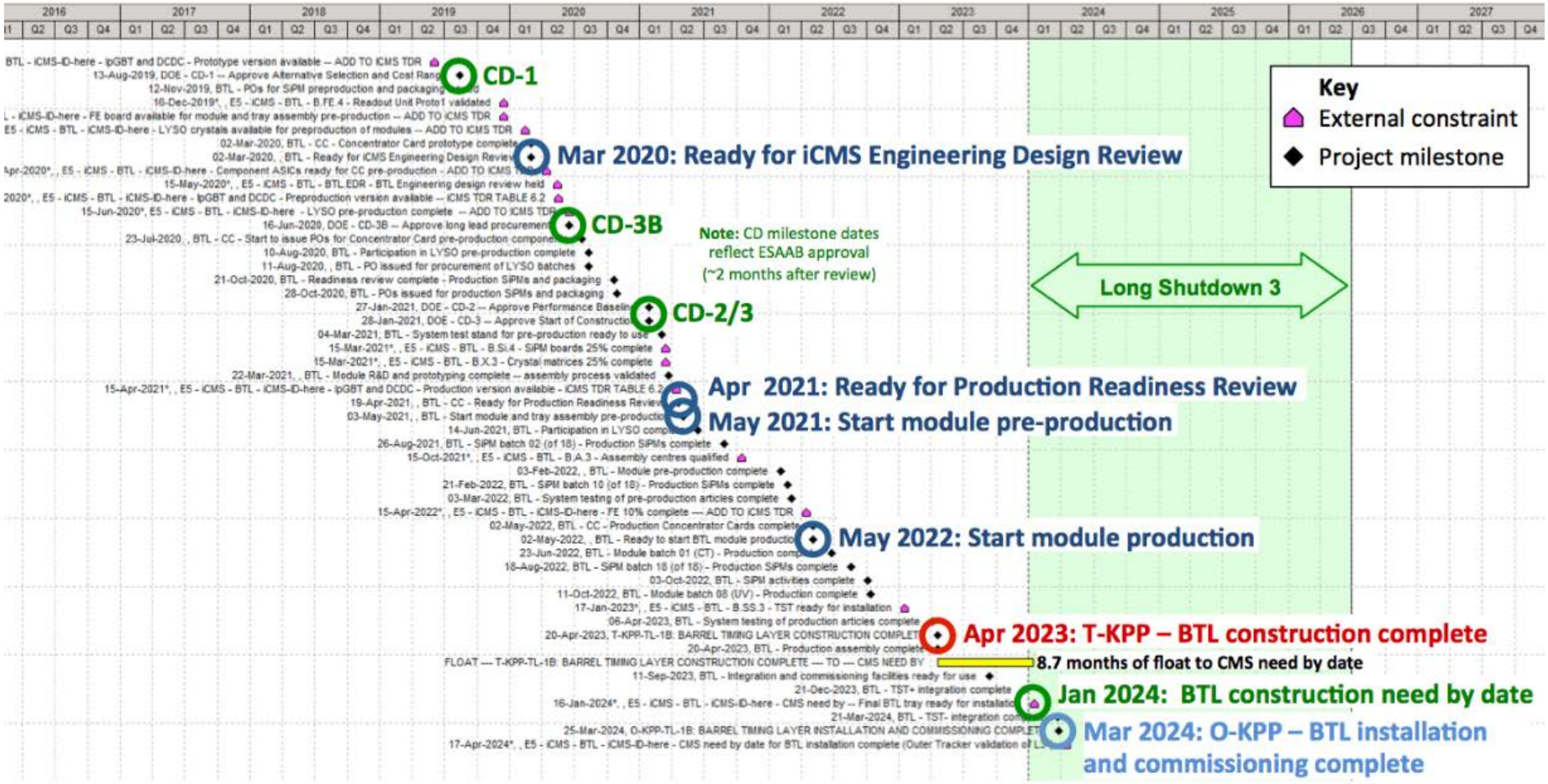
Assembly production is done with a combination of costed and contributed labor

Leading Cost Drivers (M&S + Labor)

CMS Driver	Labor (FTE-yrs)	Labor (M$)	M&S (M$)	Labor + M&S (M$)	Estimate Uncertainty (M$)	Total (M$)
TL - ETL frontend ASIC development (v3) - M&S	0.0	0.0	1.9	1.9	0.3	2.2
TL - ETL frontend ASIC prototyping (v2) - Labor	7.7	1.2	0.0	1.2	0.5	1.7
TL - ETL module assembly	11.3	0.3	0.8	1.1	0.4	1.5
TL - BTL LYSO crystals [CORE]	0.0	0.0	1.2	1.2	0.2	1.4
TL - BTL assembly	10.8	0.6	0.4	1.0	0.4	1.4
TL - BTL SiPM production [CORE]	0.0	0.0	1.0	1.0	0.2	1.2
TL - BTL Concentrator Cards - production	1.6	0.2	0.5	0.7	0.2	0.9
TL - ETL frontend ASIC development (v3) - Labor	3.7	0.5	0.0	0.5	0.2	0.7
TL - BTL SiPM QC labor	3.0					
TL - BTL installation and commissioning	3.0					
TL - Management Travel and misc. support M&S	0.0					
TL - BTL Concentrator Cards - prototyping and preproduction	1.3					
TL - ETL installation and commissioning	1.1					
TL - ETL frontend ASIC prototyping (v2) - M&S	0.0					
TL - iCMS common infrastructure [CORE]	0.0					
TL - BTL system testing	0.1					
TL - ETL system testing	0.0					
TL - BTL SiPM NRE and preproduction SiPMs [CORE]	0.0					
TL - BTL SiPM prototyping and preproduction - misc.	0.0					
TL - BTL LYSO travel and COLA	0.0					
TL - BTL SiPM travel and shipping	0.0					



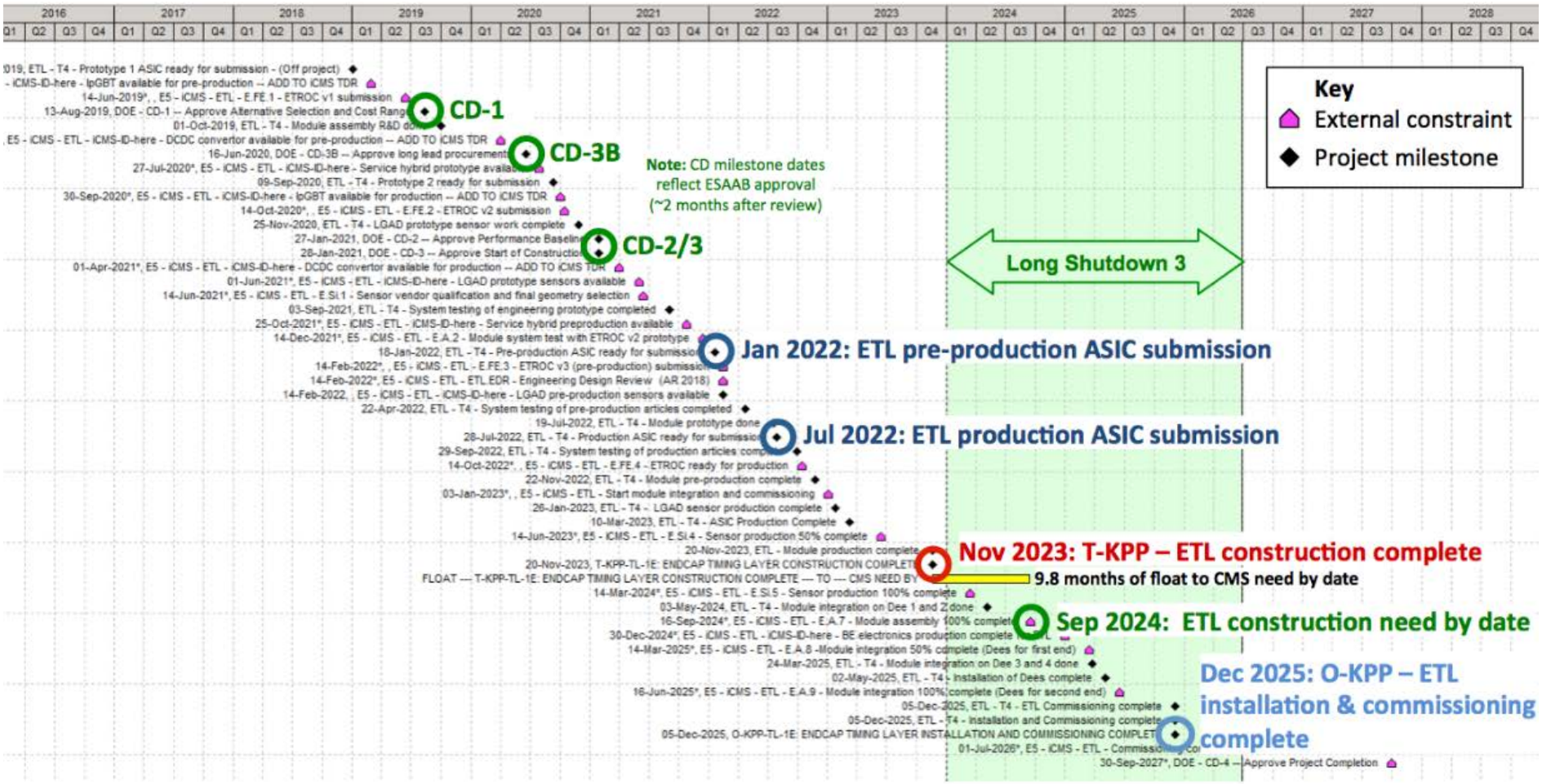
BTL Key Milestones



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

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

ETL Key Milestones



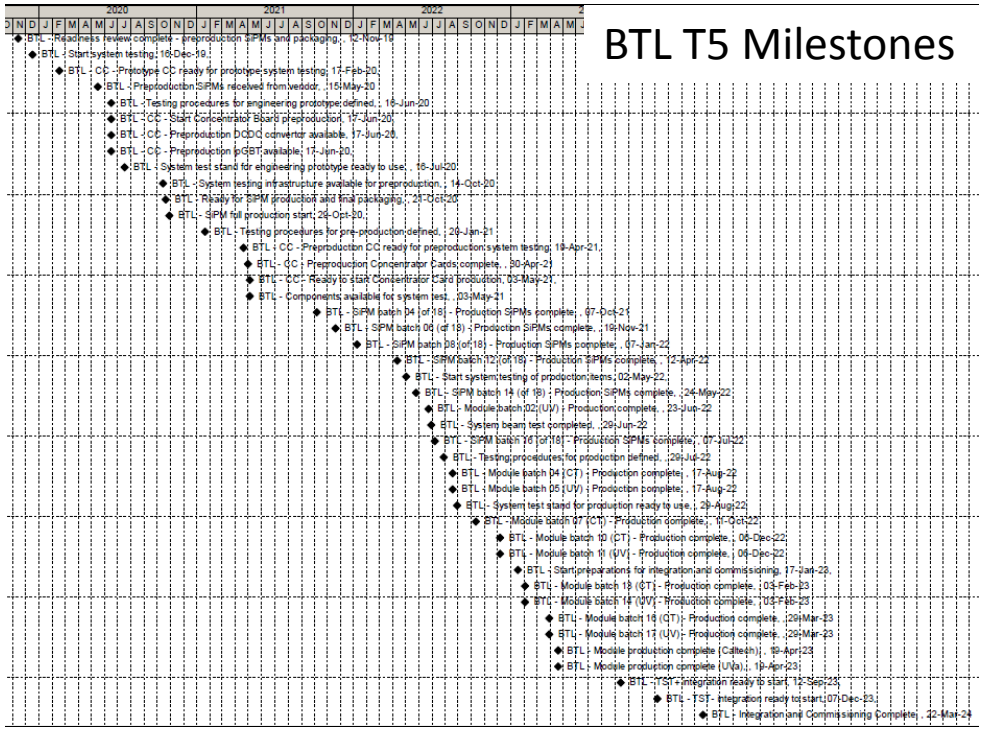
Threshold KPP: ETL construction is de-coupled from LHC schedule

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

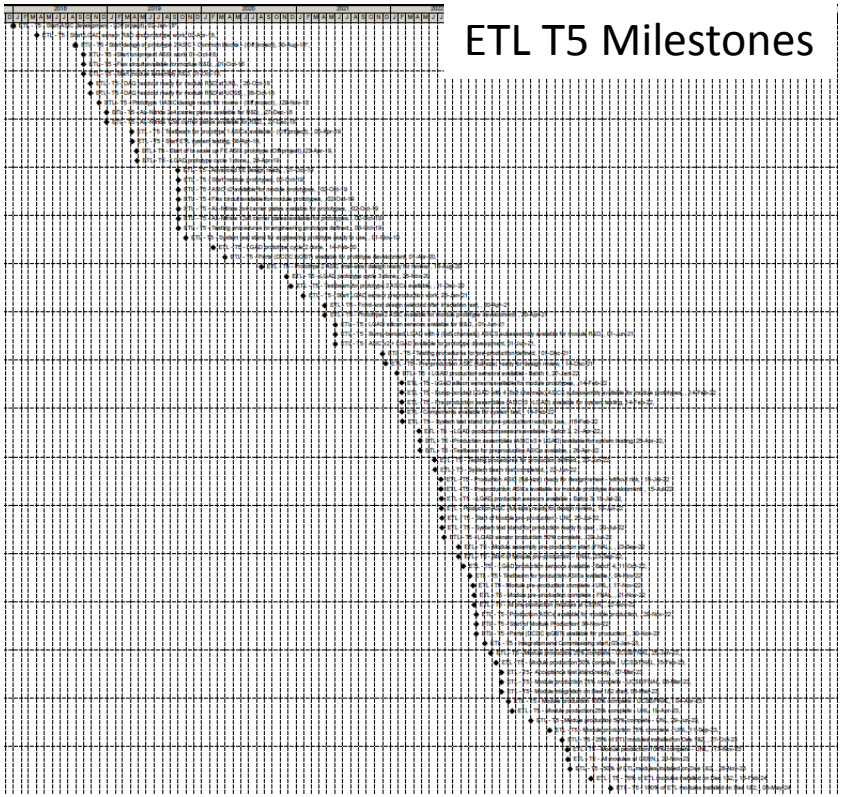
Milestones to Monitor Progress (Tier 5)

We have additional milestones throughout the MTD project to monitor technical progress, Tier 5 milestones are monitored by subproject manager

BTL T5 Milestones



ETL T5 Milestones



Complete list of milestones are listed in the Milestone Dictionary (CMS-doc-13321)

Synchronization with MTD Schedule

International milestones and need by dates are tabulated in the TDR and included in the US schedule logic to ensure we are aligned with the MTD schedule

The US deliverables precede the CMS request-by-dates with sufficient float

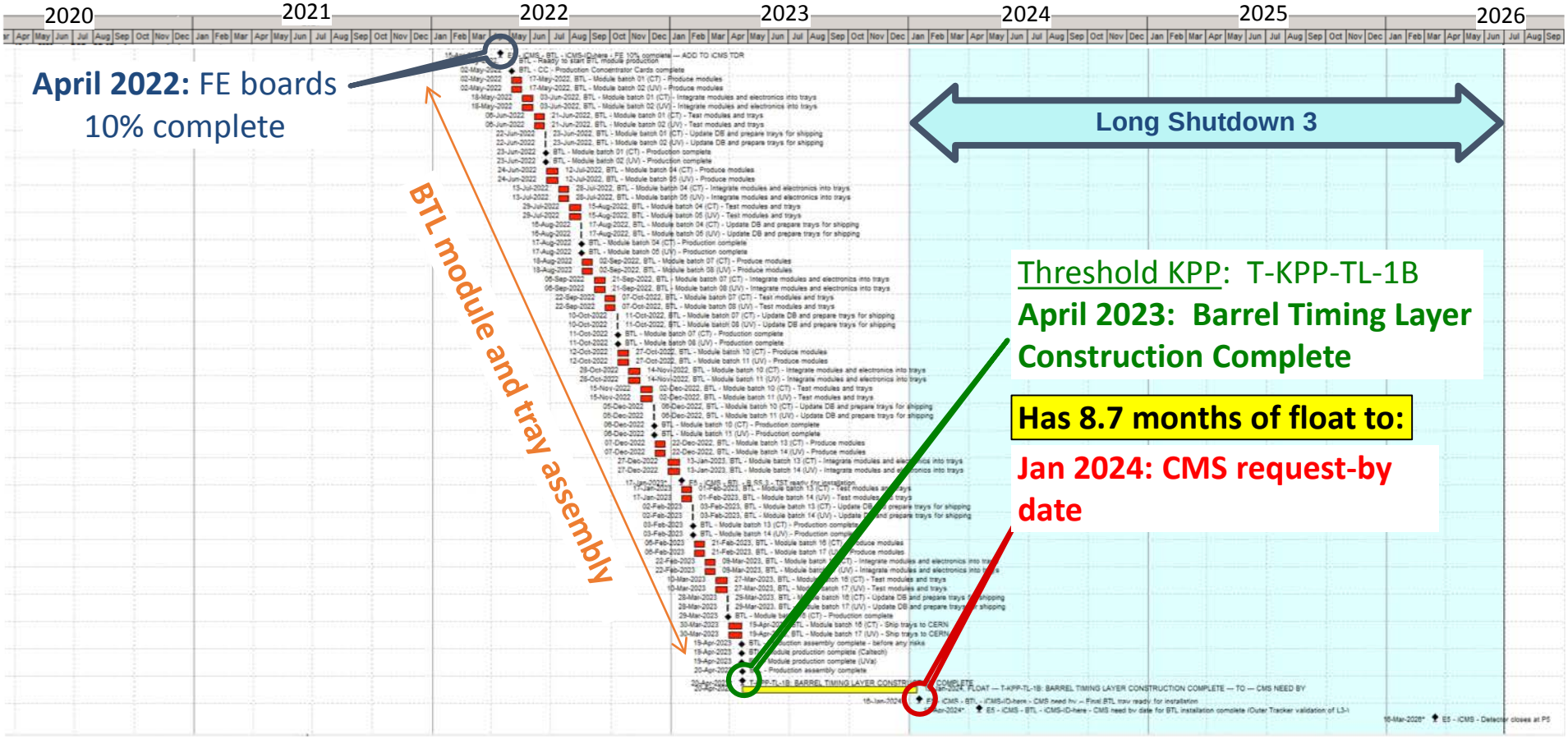
We also have a watch list of external deliverables with people assigned to monitor progress

lpGBT, DC/DC converter, TOFHIR

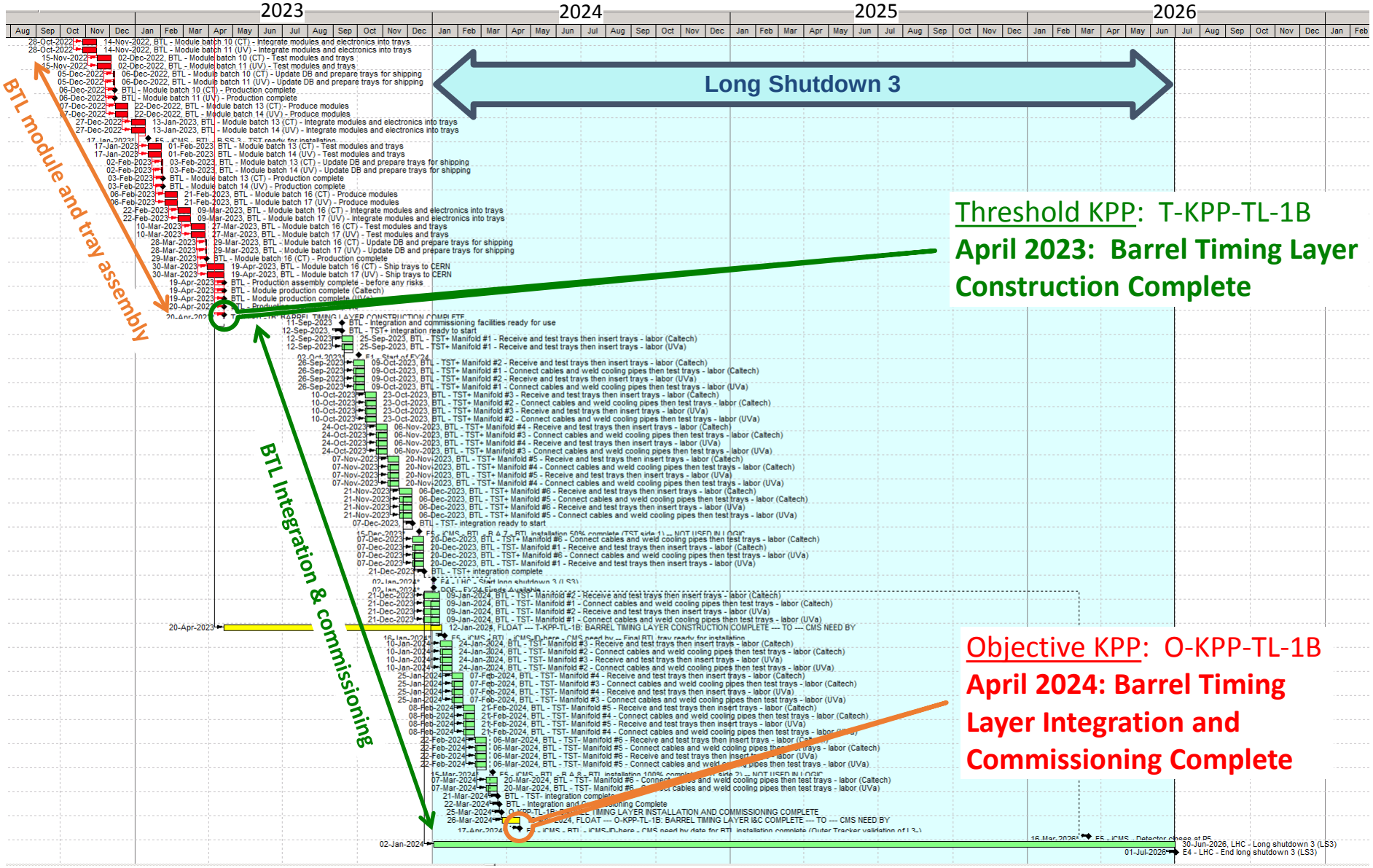
Expected delivery dates are included in the schedule and drive some activities

We are directly involved in developing the international MTD schedule and fully synchronized with international MTD planning

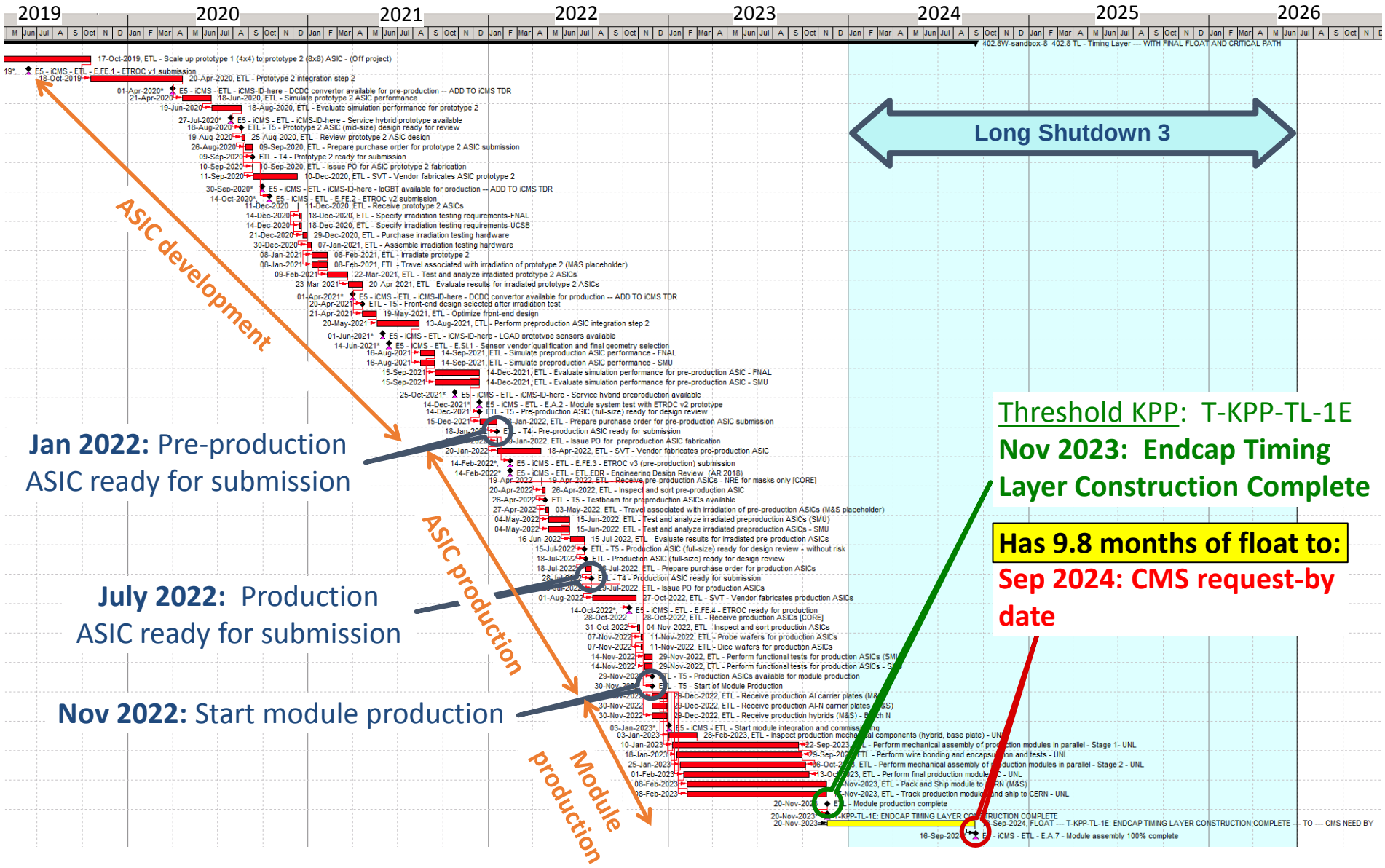
BTL Critical Path and Schedule Contingency



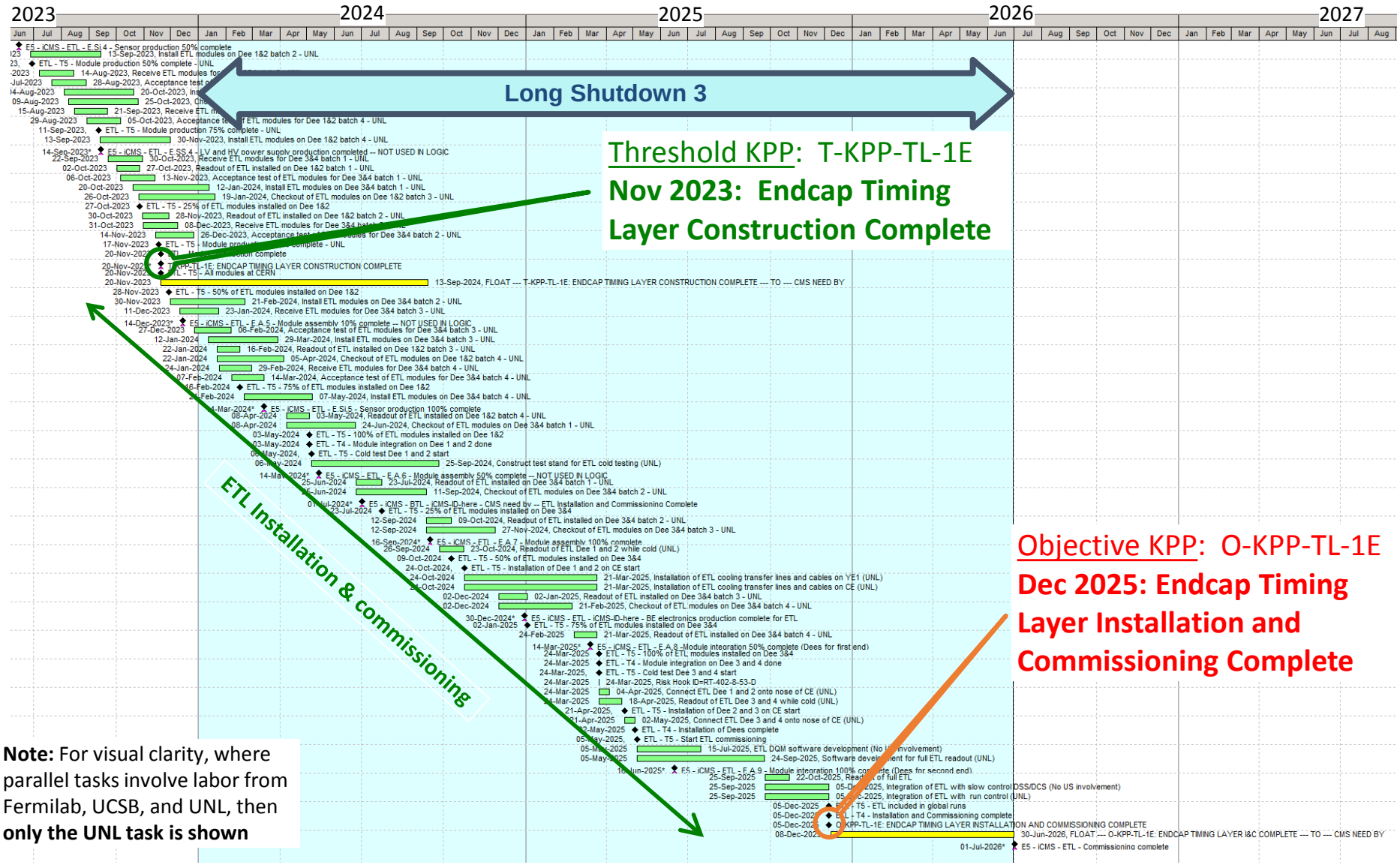
BTL Installation and Commissioning



ETL Critical Path and Schedule Contingency



ETL Installation and Commissioning



Note: For visual clarity, where parallel tasks involve labor from Fermilab, UCSB, and UNL, then **only the UNL task is shown**

P6 Schedule Adjustments for IPR

- We are following a staged approach for the schedule development:
  1. US activities entered into P6 to produce our technically driven schedule.
     DONE and frozen for this review
  2. International schedule formalized for the LHCC/UCG Step 2 approval.
     Being done now
  3. Complete set of international project / external tie points entered into P6.
     Many already implemented
  4. Recommendations from OPSS review and the DR implemented.
     Majority of OPSS recommendations already in place

- We've started to implement the following changes in the P6 sandbox
  - Implement bump bonding external tie point
  - Implement UNL external constraint and optimize UNL/FNAL workload sharing

- We expect to complete stages 3 and 4 listed above and freeze the schedule for the June 2019 IPR by end of April

Risks

BTL Risk Workshop: Nov 7, 2018: https://indico.fnal.gov/event/19025/
ETL Risk Workshop: Nov 8, 2018: https://indico.fnal.gov/event/19026/

Panel of external reviewers found that we have a comprehensive list of risks
Provided feedback on: *consolidating risks, improving impact estimates, improving descriptive text, fixing missing risk register field entries*

Risk impact on the cost has been included in the total project cost
Risks have now been included in the P6 schedule to get a better understanding of the schedule impact

A detailed description of the methodology used for the risk analysis can be found in CMS-DocDB-13481

General Risks (3)

WBS / Ops Lab Activity : 402.8 TL - Timing Layer (general risks) (3)

Risk Type : Threat (3)

			Probability	Cost impact	Schedule impact	P*impact (k$)
2 (Medium)	RT-402-8-91-D	TL - Shortfall in Timing Layer scientific labor	30 %	0 -- 0 -- 421 k$	0 months	42
2 (Medium)	RT-402-8-90-D	TL - Key Timing Layer personnel need to be replaced	25 %	45 -- 135 -- 261 k$	0 -- 0 -- 3 months	37
2 (Medium)	RT-402-8-43-D	TL - System Testing - components late for system test	30 %	0 -- 10 -- 20 k$	4 months	3

BTL and ETL Risks

BLT Risks (15)

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

Risk Type : Threat (15)

			Probability	Cost impact	Schedule impact	P*impact (k$)
2 (Medium)	RT-402-8-05-D	BTL - Change in interfaces of tray assembly components	20 %	150 -- 250 -- 350 k$	3 months	50
2 (Medium)	RT-402-8-33-D	BTL - Difficulties procuring LYSO from international suppliers	10 %	200 -- 450 -- 700 k$	3 -- 6 -- 9 months	45
2 (Medium)	RT-402-8-14-D	BTL - Problems with SiPM vendor	20 %	32 -- 96 -- 128 k$	2 -- 6 -- 8 months	17
2 (Medium)	RT-402-8-30-D	BTL - Concentrator Card requires significant design changes	10 %	1 -- 50 -- 100 k$	1 -- 3 -- 6 months	5
2 (Medium)	RT-402-8-07-D	BTL - Concentrator Card delay in external component deliveries	20 %	0 k$	1 -- 3 -- 6 months	0
1 (Low)	RT-402-8-15-D	BTL - Batch shipment of SiPMs lost in transport	5 %	224 k$	1 months	11
1 (Low)	RT-402-8-35-D	BTL - Delays or damage of tray in transport to CERN	5 %	220 k$	1 months	11
1 (Low)	RT-402-8-04-D	BTL - LYSO matrices not meeting specifications	10 %	100 k$	1 -- 2 -- 3 months	10
1 (Low)	RT-402-8-36-D	BTL - Interface to iCMS changes	20 %	30 k$	1 -- 2 -- 3 months	6
1 (Low)	RT-402-8-34-D	BTL - Delay in delivery of components from iCMS	20 %	10 -- 20 -- 30 k$	1 -- 2 -- 3 months	4
1 (Low)	RT-402-8-08-D	BTL - Delay in cooling plate delivery	10 %	10 -- 20 -- 30 k$	1 -- 2 -- 3 months	2
1 (Low)	RT-402-8-18-D	BTL - Concentrator card production & testing facility problem	20 %	10 k$	0.5 -- 1 -- 2 months	2
1 (Low)	RT-402-8-42-D	BTL - Problems with module assembly site	10 %	10 -- 20 -- 30 k$	1 -- 2 -- 3 months	2
1 (Low)	RT-402-8-16-D	BTL - Problems with SiPM QC test site	20 %	2 -- 5 -- 10 k$	0.25 -- 0.5 -- 1 months	1
1 (Low)	RT-402-8-44-D	BTL - Concentrator Card batch shipment lost/damaged/delayed	5 %	0 -- 3 -- 9 k$	0 -- 0.5 -- 1 months	0

ETL Risks (11) + Opportunity (1)

WBS / Ops Lab Activity : 402.8.4 ETL - Endcap Timing Layer (12)

Risk Type : Threat (11)

3 (High)	RT-402-8-01-D	ETL - Additional FE ASIC prototype cycle is required	50 %	500 -- 600 -- 700 k$	4 -- 5 -- 6 months	300
2 (Medium)	RT-402-8-03-D	ETL - FE ASIC does not meet specs - needs another pre-prod run	10 %	914 -- 970 -- 1026 k$	6 -- 7.5 -- 9 months	97
2 (Medium)	RT-402-8-02-D	ETL - Problems with ETL module assembly facility	50 %	30 k$	1 months	15
2 (Medium)	RT-402-8-10-D	ETL - Sensor quality problem during production	15 %	28 -- 52 -- 109 k$	2 -- 3 -- 6 months	9
1 (Low)	RT-402-8-53-D	ETL - Integration facility at CERN runs out of components	25 %	21 k$	3 months	5
1 (Low)	RT-402-8-48-D	ETL - Delay in delivery of parts from iCMS	20 %	10 -- 20 -- 30 k$	1 months	4
1 (Low)	RT-402-8-31-D	ETL - Storage-related degradation of LGADs	10 %	18 k$	3 months	2
1 (Low)	RT-402-8-52-D	ETL - Module Radiation Tolerance	10 %	15 k$	1 months	2
1 (Low)	RT-402-8-49-D	ETL - Delays or damage in transport of ETL modules to CERN	5 %	10 k$	1 months	1
1 (Low)	RT-402-8-50-D	ETL - Module assembly yield is low	10 %	0 -- 5 -- 15 k$	0 -- 0 -- 1 months	1
1 (Low)	RT-402-8-51-D	ETL - Problem with AlN vendor	5 %	0 -- 15 -- 30 k$	1 -- 2 -- 3 months	1

Risk Type : Opportunity (1)

2 (Medium)	RO-402-8-01-D	ETL - Use AltiROC	10 %	-760 k$	-8 months	-76

Timing Layer Risks

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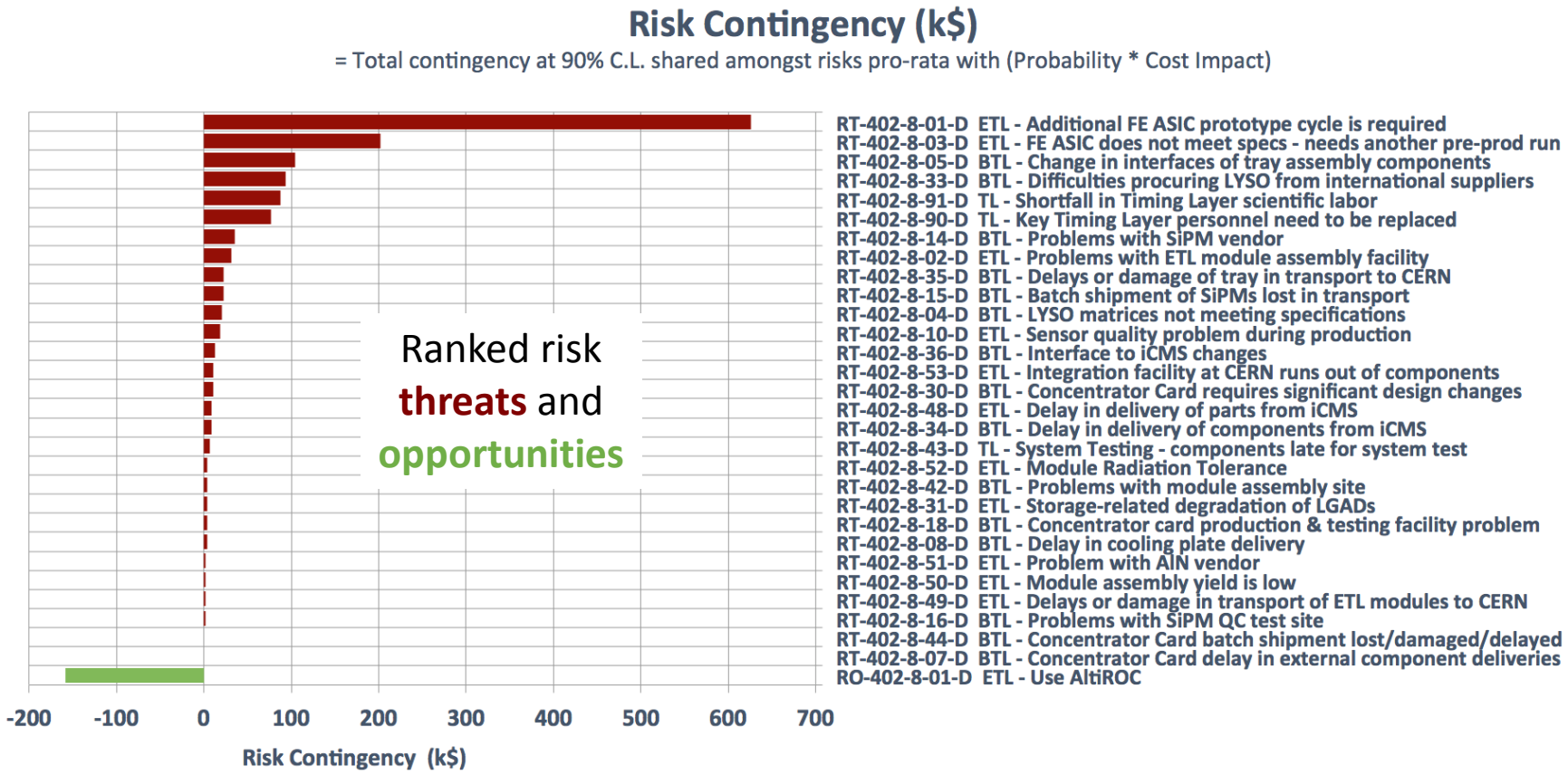
RT-402-8-01-D ETL - Additional FE ASIC prototype cycle is required

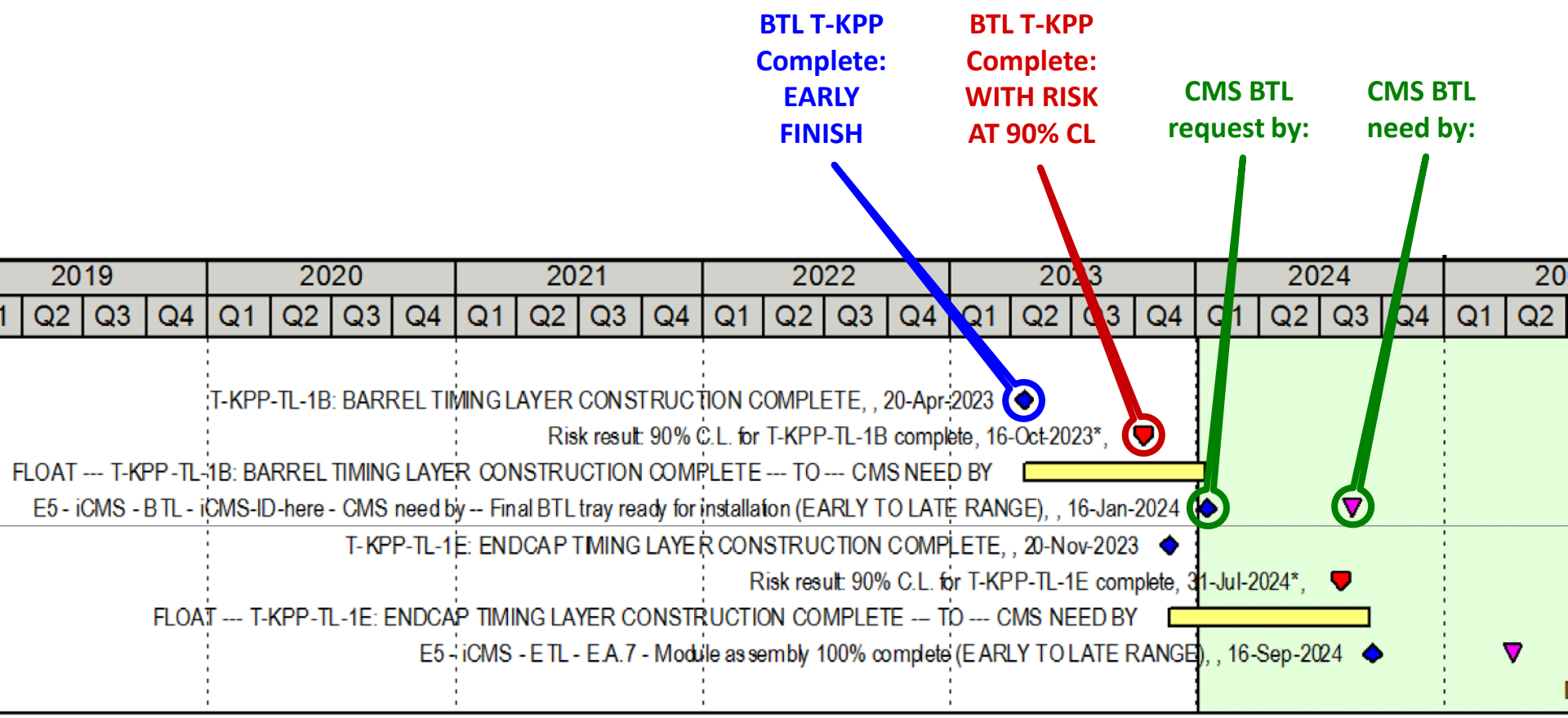
Risk Rank:	3 (High) **Scores:** Probability : 4 (H) ; Cost: 2 (M) Schedule: 2 (M))	**Risk Status:**	Open
Summary:	This risk can have multiple causes. 1) If the necessary performance (precision vs power consumption) is not achieved during the last prototype cycle, an additional prototype cycle may be necessary causing a delay and incurring a cost increase. 2) ASIC specification has changed due to external reasons, such as lpGBT clock distribtution does not meet specifications.		
Risk Type:	Threat	**Owner:**	Tiehui Liu
WBS:	402.8.4 ETL - Endcap Timing Layer	**Risk Area:**	Technical Risk / Reliability or Performance
Probability (P):	50%	**Technical Impact:**	0 (N) - negligible technical impact
Cost Impact:	PDF = 3-point - triangular Minimum = 500 k$ Most likely = 600 k$ Maximum = 700 k$ Mean = 600 k$ P * <Impact> = 300 k$	**Schedule Impact:**	PDF = 3-point - triangular Minimum = 4 months Most likely = 5 months Maximum = 6 months Mean = 5 months P * <Impact> = 2.5 months
Basis of Estimate:	The cost for a MPW run is 400k, and we include 100-300k for additional engineering.		
Cause or Trigger:	Prototype 2 does not meet requirements and we cannot include changes in the preproduction submission.	**Impacted Activities:**	Risk could delay completion of ASIC prototyping
Start date:	1/Mar/2020	**End date:**	1/Jan/2022
Risk Mitigations:	We have increased the effort for the design simulation and verification.		
Risk Responses:	We include an additional prototype cycle.		
More details:			

Timing Layer risks

- **TL risk contingency ≈ $1.27M** = $1.43M threats − $0.16M opportunities



Threshold KPPs – Schedule contingency



We have sufficient float in our schedule to accommodate the impact of our risks (at 90% CL)

Summary

The US scope is well defined and we now have a detailed schedule in P6 that has well motivated cost and labor estimates that are documented in the BOEs

The detailed resource loaded schedule has been reviewed by OPSS in Jan/Feb 2019 and we have addressed most of the feedback

We are working closely with international MTD to ensure planning is synchronized and have sufficient milestones in the P6 schedule to monitor progress

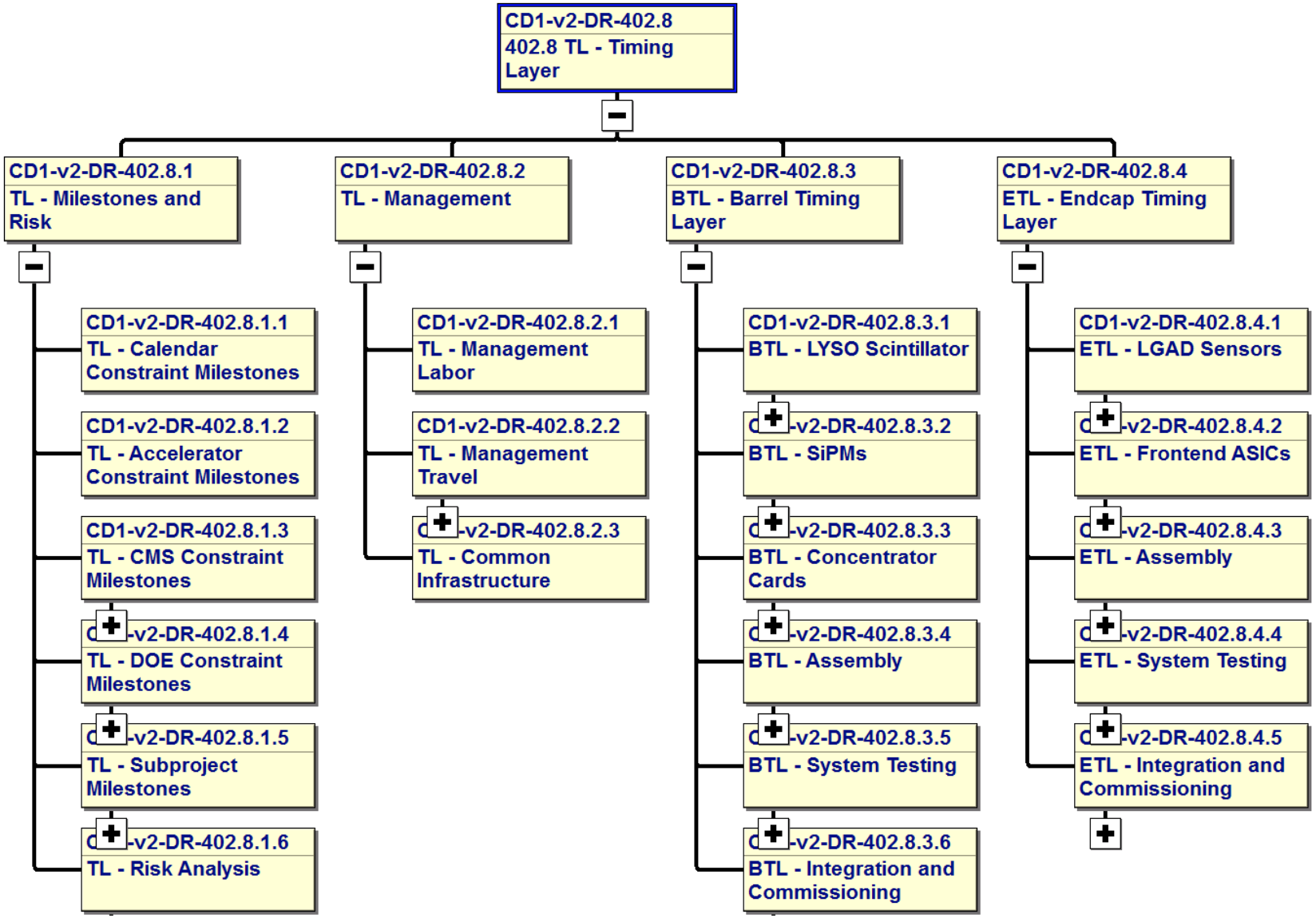
Risks have been identified and reviewed and are now linked in the schedule allowing us to better estimate the schedule impact

Some adjustments to the schedule will be implemented prior to the IPR review, we do not expect they will have a significant impact on the cost and schedule

We have made significant progress with the MTD schedule allowing us to: develop an accurate cost estimate using recent vendor quotes and institution specific labor rates which includes cost escalation, determine the critical path, full MC risk analysis, and we are syncronizing with international MTD planning

Backup Slides

Work Breakdown Structure



Threshold and Objective KPPs

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Barrel Timing Layer

WBS	Threshold KPP	Objective KPP
402.8 Timing Layer	T-KPP-TL-1: BARREL TIMING LAYER CONSTRUCTION COMPLETE The project will construct and qualify concentrator cards (CCs) and trays of modules+readout units (RUs) for the BTL. CC and module+RU performance will match the specification of production prototypes, whose sensor components and associated front-end readout electronics have been demonstrated in cosmic ray, source, and/or test beam exposures to be capable of measuring the arrival time of minimum-ionizing particles with a resolution of < 40ps at the start of the HL-LHC run. The specification further states that the time resolution will be < 60ps even after withstanding the radiation damage from fluences corresponding to an integrated 4000/fb of HL-LHC luminosity, as borne out in prototype testing of irradiated components. The project shall deliver to CERN 100% of the CCs (476 which includes 10% spares) and approximately 60% of the total trays needed for the BTL.	O-KPP-TL-1: BARREL TIMING LAYER INSTALLATION AND COMMISSIONING COMPLETE The project will construct and qualify concentrator cards (CCs) and trays of modules+readout units (RUs) for the BTL. CC and module+RU performance will match the specification of production prototypes, whose sensor components and associated front-end readout electronics have been demonstrated in cosmic ray, source, and/or test beam exposures to be capable of measuring the arrival time of minimum-ionizing particles with a resolution of < 40ps at the start of the HL-LHC run. The specification further states that the time resolution will be < 60ps even after withstanding the radiation damage from fluences corresponding to an integrated 4000/fb of HL-LHC luminosity, as borne out in prototype testing of irradiated components. The project shall deliver to CERN 100% of the CCs (476 which includes 10% spares) and approximately 60% of the total trays needed for the BTL. The project shall participate in the integration of the BTL trays into the MTD detector at CERN. The project shall additionally participate in the installation, testing and calibration of the detector.

Threshold and Objective KPPs

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Endcap Timing Layer

WBS	Threshold KPP	Objective KPP
402.8 Timing Layer	**T-KPP-TL-2: ENDCAP TIMING LAYER CONSTRUCTION COMPLETE** The project shall provide and qualify the front-end ASIC design for the ETL. The project shall construct and qualify modules for the ETL. The project shall deliver to CERN at least 50% of the ETL modules. ASIC and module performance will match the specification of production prototypes, whose sensor components and associated front-end readout electronics have been demonstrated in cosmic ray, source, and/or test beam exposures to be capable of measuring the arrival time of minimum-ionizing particles with a resolution of < 40ps per track, for most tracks, at the start of the HL-LHC run. The specification further states that the time resolution will remain < 60ps even after withstanding the radiation damage from fluences corresponding to an integrated 4000/fb of HL-LHC luminosity, as borne out in prototype testing of irradiated components.	**O-KPP-TL-2: ENDCAP TIMING LAYER INSTALLATION AND COMMISSIONING COMPLETE** The project shall provide and qualify the front-end ASIC design for the ETL. The project shall construct and qualify modules for the ETL. The project shall deliver to CERN at least 50% of the ETL modules. ASIC and module performance will match the specification of production prototypes, whose sensor components and associated front-end readout electronics have been demonstrated in cosmic ray, source, and/or test beam exposures to be capable of measuring the arrival time of minimum-ionizing particles with a resolution of < 40ps per track, for most tracks, at the start of the HL-LHC run. The specification further states that the time resolution will remain < 60ps even after withstanding the radiation damage from fluences corresponding to an integrated 4000/fb of HL-LHC luminosity, as borne out in prototype testing of irradiated components. The project shall participate in the integration of the ETL modules into the MTD detector at CERN. The project shall additionally participate in the installation, testing and calibration of the detector.

Costs at Level 3 / 4

CMS-doc-13215

WBS	Direct M&S ($)	Labor (Hours)	FTE	Direct + Indirect + Esc. ($)	Estimate Uncertainty ($)	Total Cost ($)
CD1-v2-DR-402.8 402.8 TL - Timing Layer	6,561,457	161764	91.50	11,364,763	3,026,706	14,391,469
CD1-v2-DR-402.8.2 TL - Management	433,000	26520	15.00	568,714	144,562	713,276
CD1-v2-DR-402.8.2.1 TL - Management Labor	0	26520	15.00	0	0	0
CD1-v2-DR-402.8.2.2 TL - Management Travel	233,000	0	0.00	349,488	34,949	384,436
CD1-v2-DR-402.8.2.3 TL - Common Infrastructure	200,000	0	0.00	219,226	109,613	328,840
CD1-v2-DR-402.8.3 BTL - Barrel Timing Layer	3,352,236	49800	28.17	5,410,860	1,318,476	6,729,336
CD1-v2-DR-402.8.3.1 BTL - LYSO Scintillator	1,178,868	2946	1.67	1,301,006	191,882	1,492,888
CD1-v2-DR-402.8.3.2 BTL - SiPMs	1,135,400	5384	3.05	1,740,686	296,166	2,036,852
CD1-v2-DR-402.8.3.3 BTL - Concentrator Cards	492,896	5147	2.91	925,645	306,932	1,232,577
CD1-v2-DR-402.8.3.4 BTL - Assembly	343,120	19353	10.95	989,999	383,042	1,373,042
CD1-v2-DR-402.8.3.5 BTL - System Testing	78,952	6322	3.58	110,401	49,734	160,135
CD1-v2-DR-402.8.3.6 BTL - Integration and Commissionin	123,000	10648	6.02	343,123	90,719	433,842
CD1-v2-DR-402.8.4 ETL - Endcap Timing Layer	2,776,221	85444	48.33	5,385,188	1,563,669	6,948,857
CD1-v2-DR-402.8.4.1 ETL - LGAD Sensors	0	3872	2.19	0	0	0
CD1-v2-DR-402.8.4.2 ETL - Frontend ASICs	1,922,500	22588	12.78	3,874,081	1,039,579	4,913,660
CD1-v2-DR-402.8.4.3 ETL - Assembly	680,860	30088	17.02	1,145,013	397,283	1,542,296
CD1-v2-DR-402.8.4.4 ETL - System Testing	79,561	6322	3.58	103,418	38,340	141,759
CD1-v2-DR-402.8.4.5 ETL - Integration and Commissionin	93,300	22574	12.77	262,676	88,467	351,143

Costs: Barrel Timing Layer

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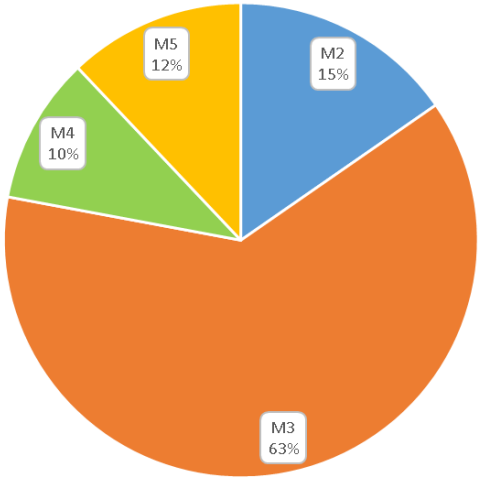
WBS	Direct M&S ($)	Labor (Hours)	FTE	Direct + Indirect + Esc. ($)	Estimate Uncertainty ($)	Total Cost ($)
CD1-v2-DR-402.8 402.8 TL - Timing Layer	6,561,457	161764	91.50	11,364,763	3,026,706	14,391,469
CD1-v2-DR-402.8.2 TL - Management	433,000	26520	15.00	568,714	144,562	713,276
CD1-v2-DR-402.8.3 BTL - Barrel Timing Layer	3,352,236	49800	28.17	5,410,860	1,318,476	6,729,336
CD1-v2-DR-402.8.3.1 BTL - LYSO Scintillator	1,178,868	2946	1.67	1,301,006	191,882	1,492,888
CD1-v2-DR-402.8.3.1.1 BTL - LYSO Scintillator - Technical participation	1,136,668	2946	1.67	1,235,626	185,344	1,420,970
CD1-v2-DR-402.8.3.1.2 BTL - LYSO Scintillator - Travel and COLA	42,200	0	0.00	65,380	6,538	71,918
CD1-v2-DR-402.8.3.2 BTL - SiPMs	1,135,400	5384	3.05	1,740,686	296,166	2,036,852
CD1-v2-DR-402.8.3.2.1 BTL - SiPMs - Prototyping	10,000	880	0.50	111,376	22,224	133,600
CD1-v2-DR-402.8.3.2.2 BTL - SiPMs - Preproduction	132,500	2020	1.14	335,945	73,827	409,773
CD1-v2-DR-402.8.3.2.3 BTL - SiPMs - Production	954,500	2484	1.40	1,241,126	194,891	1,436,017
CD1-v2-DR-402.8.3.2.4 BTL - SiPMs - Travel and COLA	38,400	0	0.00	52,238	5,224	57,462
CD1-v2-DR-402.8.3.3 BTL - Concentrator Cards	492,896	5147	2.91	925,645	306,932	1,232,577
CD1-v2-DR-402.8.3.3.1 BTL - Concentrator Cards - Prototyping	27,172	1132	0.64	136,735	37,510	174,245
CD1-v2-DR-402.8.3.3.2 BTL - Concentrator Cards - Pre-Production	21,800	1141	0.65	127,466	60,841	188,307
CD1-v2-DR-402.8.3.3.3 BTL - Concentrator Cards - Production	443,924	2874	1.63	661,444	208,582	870,026
CD1-v2-DR-402.8.3.4 BTL - Assembly	343,120	19353	10.95	989,999	383,042	1,373,042
CD1-v2-DR-402.8.3.4.1 BTL - Assembly - Prototyping	242,920	4641	2.63	502,835	172,192	675,027
CD1-v2-DR-402.8.3.4.2 BTL - Assembly - Preproduction	0	888	0.50	30,958	15,479	46,437
CD1-v2-DR-402.8.3.4.3 BTL - Assembly - Production	100,200	13824	7.82	456,206	195,371	651,577
CD1-v2-DR-402.8.3.5 BTL - System Testing	78,952	6322	3.58	110,401	49,734	160,135
CD1-v2-DR-402.8.3.5.1 BTL - System Testing - Establish Infrastructure	60,103	1898	1.07	70,898	33,667	104,565
CD1-v2-DR-402.8.3.5.2 BTL - System Testing - Preproduction	9,448	1878	1.06	17,247	6,804	24,051
CD1-v2-DR-402.8.3.5.3 BTL - System Testing - Production	9,401	2546	1.44	22,256	9,264	31,520
CD1-v2-DR-402.8.3.6 BTL - Integration and Commissioning	123,000	10648	6.02	343,123	90,719	433,842
CD1-v2-DR-402.8.3.6.1 BTL - Integration and Commissioning - TST plus	0	4440	2.51	69,697	34,849	104,546
CD1-v2-DR-402.8.3.6.2 BTL - Integration and Commissioning - TST minus	0	4440	2.51	71,319	35,660	106,979
CD1-v2-DR-402.8.3.6.3 BTL - Integration and Commissioning - General	123,000	1768	1.00	202,107	20,211	222,317
CD1-v2-DR-402.8.4 ETL - Endcap Timing Layer	2,776,221	85444	48.33	5,385,188	1,563,669	6,948,857

Costs: Endcap Timing Layer

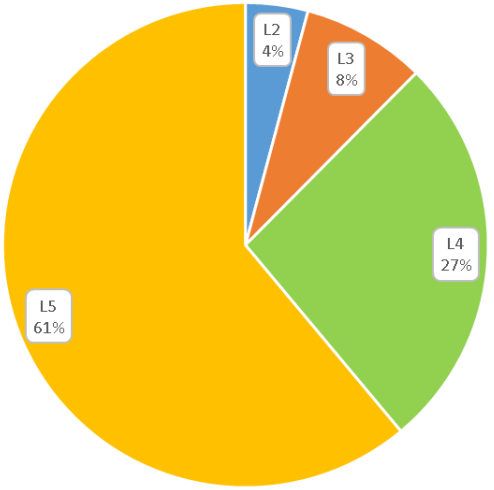
WBS	Direct M&S ($)	Labor (Hours)	FTE	Direct + Indirect + Esc. ($)	Estimate Uncertainty ($)	Total Cost ($)
CD1-v2-DR-402.8 402.8 TL - Timing Layer	**6,561,457**	**161764**	**91.50**	**11,364,763**	**3,026,706**	**14,391,469**
CD1-v2-DR-402.8.2 TL - Management	**433,000**	**26520**	**15.00**	**568,714**	**144,562**	**713,276**
CD1-v2-DR-402.8.3 BTL - Barrel Timing Layer	**3,352,236**	**49800**	**28.17**	**5,410,860**	**1,318,476**	**6,729,336**
CD1-v2-DR-402.8.4 ETL - Endcap Timing Layer	**2,776,221**	**85444**	**48.33**	**5,385,188**	**1,563,669**	**6,948,857**
CD1-v2-DR-402.8.4.1 ETL - LGAD Sensors	**0**	**3872**	**2.19**	**0**	**0**	**0**
CD1-v2-DR-402.8.4.1.1 ETL - LGAD Sensors - R&D and Prototypes	**0**	**2400**	**1.36**	**0**	**0**	**0**
CD1-v2-DR-402.8.4.1.2 ETL - LGAD Sensors - Pre-Production and Production	**0**	**1472**	**0.83**	**0**	**0**	**0**
CD1-v2-DR-402.8.4.2 ETL - Frontend ASICs	**1,922,500**	**22588**	**12.78**	**3,874,081**	**1,039,579**	**4,913,660**
CD1-v2-DR-402.8.4.2.3 ETL - Frontend ASICs v2 development	**256,000**	**14634**	**8.28**	**1,474,236**	**556,360**	**2,030,596**
CD1-v2-DR-402.8.4.2.4 ETL - Frontend ASICs v3 development	**1,666,500**	**7954**	**4.50**	**2,399,845**	**483,219**	**2,883,064**
CD1-v2-DR-402.8.4.3 ETL - Assembly	**680,860**	**30088**	**17.02**	**1,145,013**	**397,283**	**1,542,296**
CD1-v2-DR-402.8.4.3.1 ETL - Assembly R&D and Prototypes	**268,660**	**19164**	**10.84**	**488,722**	**152,824**	**641,546**
CD1-v2-DR-402.8.4.3.2 ETL - Module Assembly Pre-production	**62,000**	**626**	**0.35**	**91,721**	**25,958**	**117,679**
CD1-v2-DR-402.8.4.3.3 ETL - Module Assembly Production	**350,200**	**10298**	**5.82**	**564,569**	**218,501**	**783,070**
CD1-v2-DR-402.8.4.4 ETL - System Testing	**79,561**	**6322**	**3.58**	**103,418**	**38,340**	**141,759**
CD1-v2-DR-402.8.4.4.1 ETL - System Testing - Prototyping	**60,448**	**1898**	**1.07**	**79,459**	**30,061**	**109,520**
CD1-v2-DR-402.8.4.4.2 ETL - System Testing - Preproduction	**9,584**	**1878**	**1.06**	**12,004**	**4,154**	**16,158**
CD1-v2-DR-402.8.4.4.3 ETL - System Testing - Production	**9,529**	**2546**	**1.44**	**11,955**	**4,125**	**16,080**
CD1-v2-DR-402.8.4.5 ETL - Integration and Commissioning	**93,300**	**22574**	**12.77**	**262,676**	**88,467**	**351,143**
CD1-v2-DR-402.8.4.5.1 ETL - I&C - Assembly Setup	**0**	**1768**	**1.00**	**0**	**0**	**0**
CD1-v2-DR-402.8.4.5.2 ETL - I&C - Assembly	**93,300**	**14434**	**8.16**	**164,318**	**39,288**	**203,606**
CD1-v2-DR-402.8.4.5.3 ETL - I&C - Cold Testing	**0**	**1888**	**1.07**	**20,355**	**10,178**	**30,533**
CD1-v2-DR-402.8.4.5.4 ETL - I&C - Mount ETL on EC	**0**	**948**	**0.54**	**78,003**	**39,001**	**117,004**
CD1-v2-DR-402.8.4.5.5 ETL - I&C - Commissioning	**0**	**3536**	**2.00**	**0**	**0**	**0**

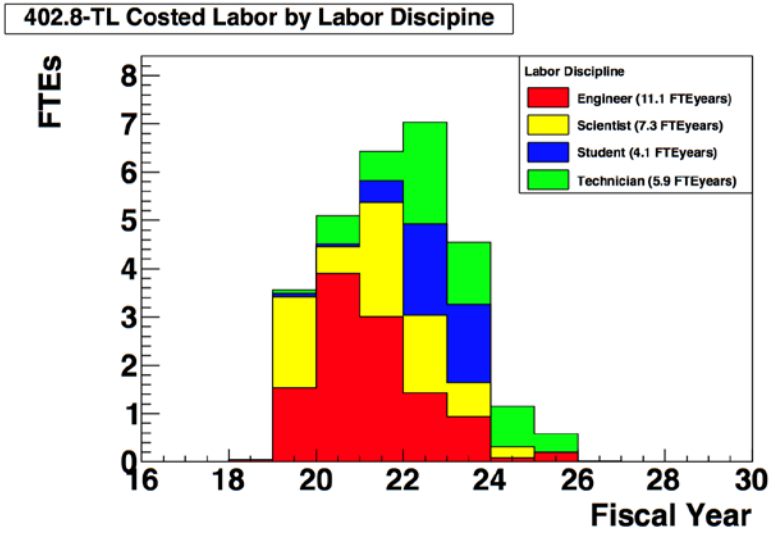
M&S and Labor Estimate Uncertainty

402.8-TL-Estimate Uncertainty Breakdown-M&S (DOE)
BAC (M&S)=$7.61M (AY$)



402.8-TL-Estimate Uncertainty Breakdown-Labor (DOE)
BAC (Labor Budget)=$3.76M (AY$)





Contributed Labor

WBS Area	Contributed FTE	Total FTE	Contributed / Total (%)
Management	15	15	100
BTL – LYSO	1.67	1.67	100
BTL – SiPM	0	3.05	0
BTL – CC	0	2.91	0
BTL – System Testing	3.47	3.58	97
BTL - Assembly	4.83	10.95	44
BLT - I&C	5.02	6.02	83
ETL – LGAD	2.19	2.19	100
ETL – ASIC	1.43	12.78	11
ETL – System Testing	3.58	3.58	100
ETL - Assembly	13.88	17.02	82
ETL- I&C	11.96	12.77	94
Total	63.03	91.52	69

Risk Register CMS-doc-13480

- High and medium-rank Timing Layer risks

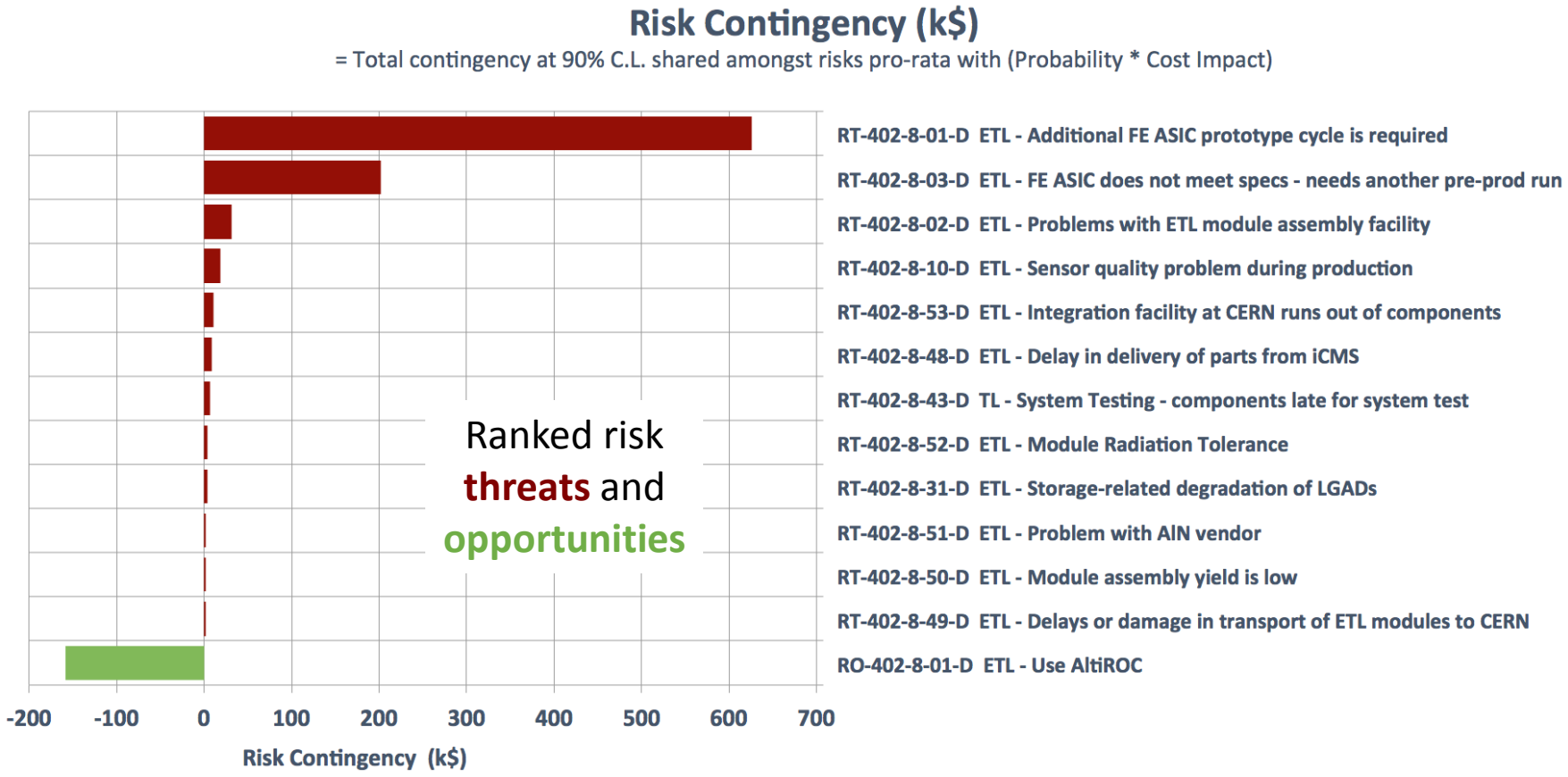
Risk Rank	RI-ID	Title	Probability	Schedule Impact	Cost Impact	P * Impact (k$)
Risk Rank : 3 (High) (1)						
Risk Type : Threat (1)						
3 (High)	RT-402-8-01-D	ETL - Additional FE ASIC prototype cycle is required	50 %	4 -- 5 -- 6 months	500 -- 600 -- 700 k$	300
Risk Rank : 2 (Medium) (12)						
Risk Type : Opportunity (1)						
2 (Medium)	RO-402-8-01-D	ETL - Use AltiROC	10 %	-8 months	-760 k$	-76
Risk Type : Threat (11)						
2 (Medium)	RT-402-8-03-D	ETL - FE ASIC does not meet specs - needs another pre-prod run	10 %	6 -- 7.5 -- 9 months	914 -- 970 -- 1026 k$	97
2 (Medium)	RT-402-8-05-D	BTL - Change in interfaces of tray assembly components	20 %	3 months	150 -- 250 -- 350 k$	50
2 (Medium)	RT-402-8-33-D	BTL - Difficulties procuring LYSO from international suppliers	10 %	3 -- 6 -- 9 months	200 -- 450 -- 700 k$	45
2 (Medium)	RT-402-8-91-D	TL - Shortfall in Timing Layer scientific labor	30 %	0 months	0 -- 0 -- 421 k$	42
2 (Medium)	RT-402-8-90-D	TL - Key Timing Layer personnel need to be replaced	25 %	0 -- 0 -- 3 months	45 -- 135 -- 261 k$	37
2 (Medium)	RT-402-8-14-D	BTL - Problems with SiPM vendor	20 %	2 -- 6 -- 8 months	32 -- 96 -- 128 k$	17
2 (Medium)	RT-402-8-02-D	ETL - Problems with ETL module assembly facility	50 %	1 months	30 k$	15
2 (Medium)	RT-402-8-10-D	ETL - Sensor quality problem during production	15 %	2 -- 3 -- 6 months	28 -- 52 -- 109 k$	9
2 (Medium)	RT-402-8-30-D	BTL - Concentrator Card requires significant design changes	10 %	1 -- 3 -- 6 months	1 -- 50 -- 100 k$	5
2 (Medium)	RT-402-8-43-D	TL - System Testing - components late for system test	30 %	4 months	0 -- 10 -- 20 k$	3
2 (Medium)	RT-402-8-07-D	BTL - Concentrator Card delay in external component deliveries	20 %	1 -- 3 -- 6 months	0 k$	0
Risk Rank : 1 (Low) (17)						

Barrel Timing Layer risks

- **BTL risk contingency ≈ $0.35**

Endcap Timing Layer risks

- **ETL risk contingency ≈ $0.76M** = $0.92M threats − $0.16M opportunities



Risk cost contingency by L2 area

	Base cost (M$)	Risk contingency (90% CL) (M$)	Risk contingency (90% CL) (% of base)
402.1 Project Management	18.13	5.65	31.2%
402.2 Outer Tracker	42.03	1.06	2.5%
402.4 Calorimeter Endcap	39.90	1.93	4.8%
402.6 Trigger and DAQ	8.92	0.74	8.3%
402.8 Timing Layer	11.36	1.27	11.2%
Total	**120.34**	**10.64**	**8.8%**

OT fraction ~6% for threats only (i.e. if without opportunities)

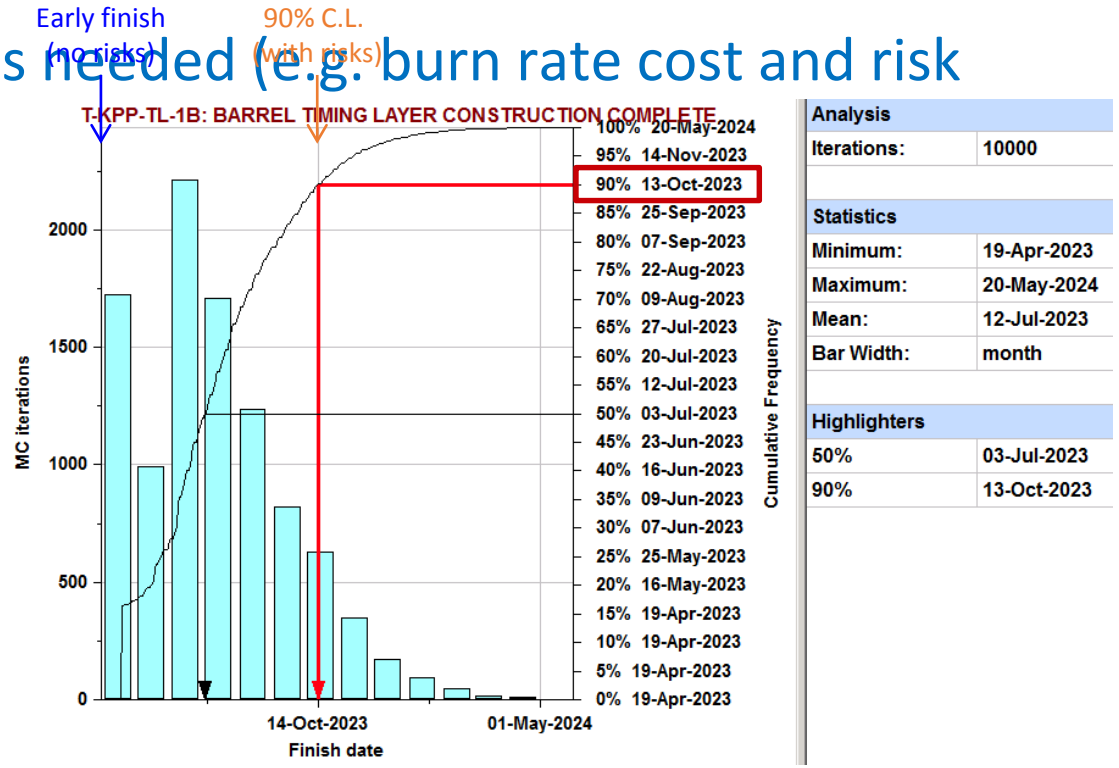
Threshold KPP finish date at 90% C.L.

- MC models the stochastic schedule impacts of ***all*** risks
  - Project-wide risks and L2-specific technical risks (H/M/L rank)
  - Risk events are inserted into the P6 logic where they could occur
  - Include correlations as needed (e.g. burn rate cost and risk delay)

BTL Construction complete

Schedule has **8.7 months** of float to the CMS need-by date

Risks will delay T-KPP by **< 5.8 months** (at 90%C.L.)



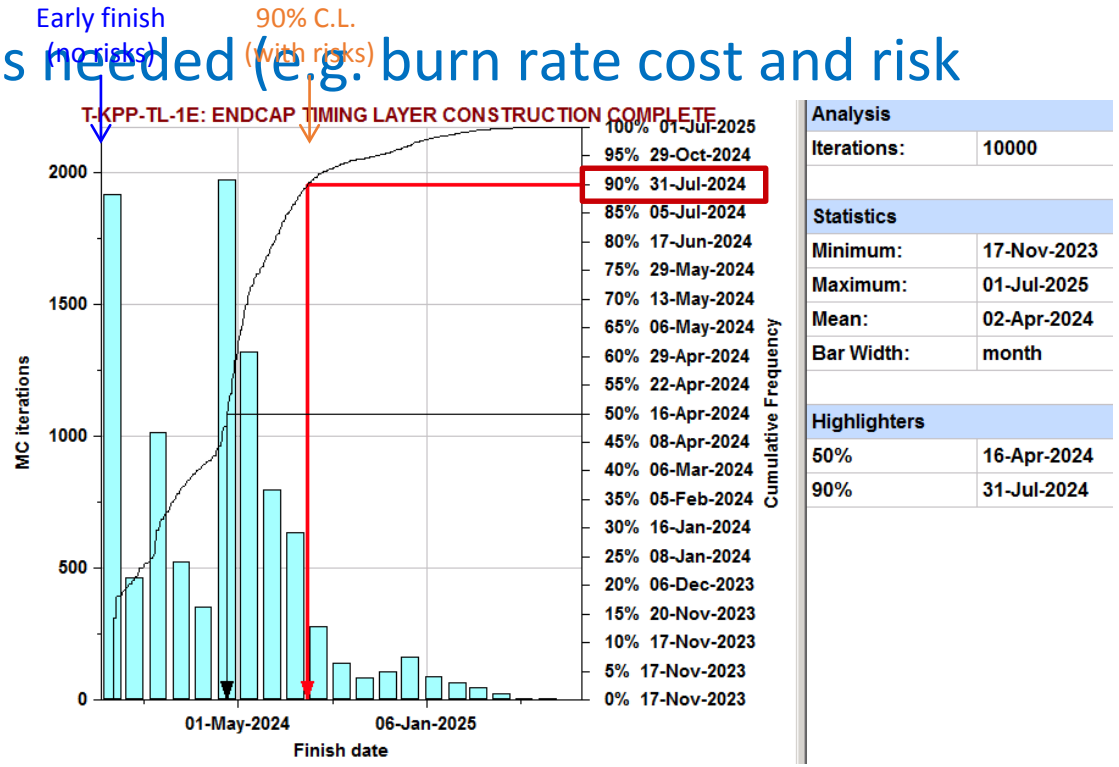
Threshold KPP finish date at 90% C.L.

- MC models the stochastic schedule impacts of ***all*** risks
  - Project-wide risks and L2-specific technical risks (H/M/L rank)
  - Risk events are inserted into the P6 logic where they could occur
  - Include correlations as needed (e.g. burn rate cost and risk delay)

ETL Construction complete

Schedule has **9.8 months** of float to the CMS need-by date

Risks will delay T-KPP by **< 8.3 months** (at 90%C.L.)



US-MTD Schedule in P6