



B08: MTD Cost and Schedule Overview

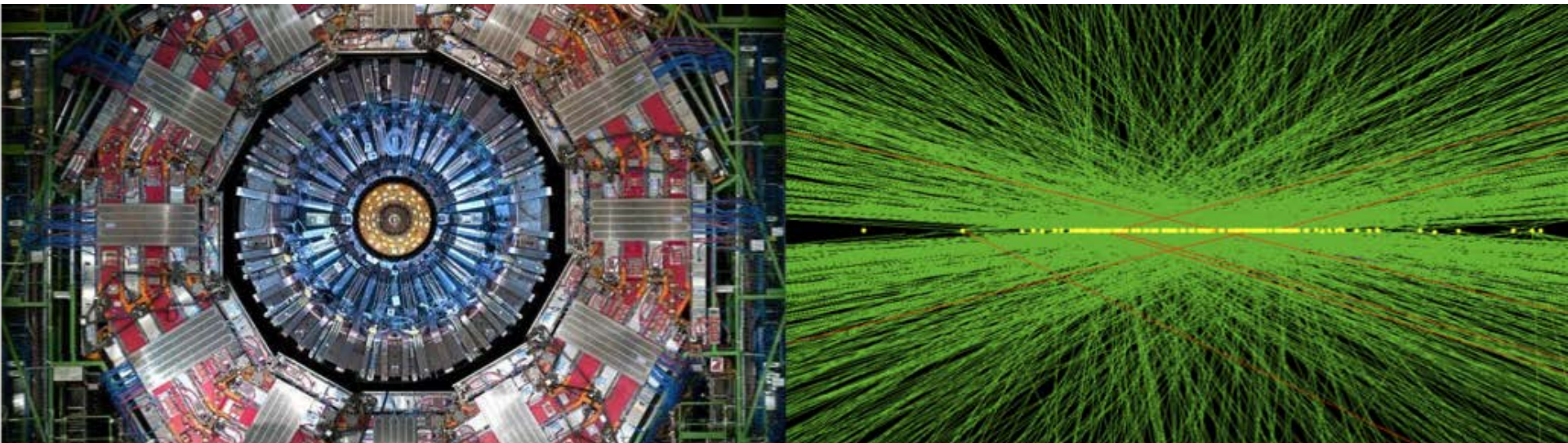
402.8

Frank Chlebana, MTD Deputy L2 Manager

Fermilab

HL-LHC CMS CD-1 Review

23 October 2019





Biographical Sketch

Frank Chlebana, Senior Scientist at Fermilab

- Serving as deputy L2 in US-MTD
- Experience in construction, commissioning, operations, and project planning while on CMS, CDF, and ZEUS

Deputy head of the Fermilab CMS Department

Former deputy L2 for the HCAL phase 1 upgrades

Former HGCal DPG co-convener

Former HCAL DPG co-convener

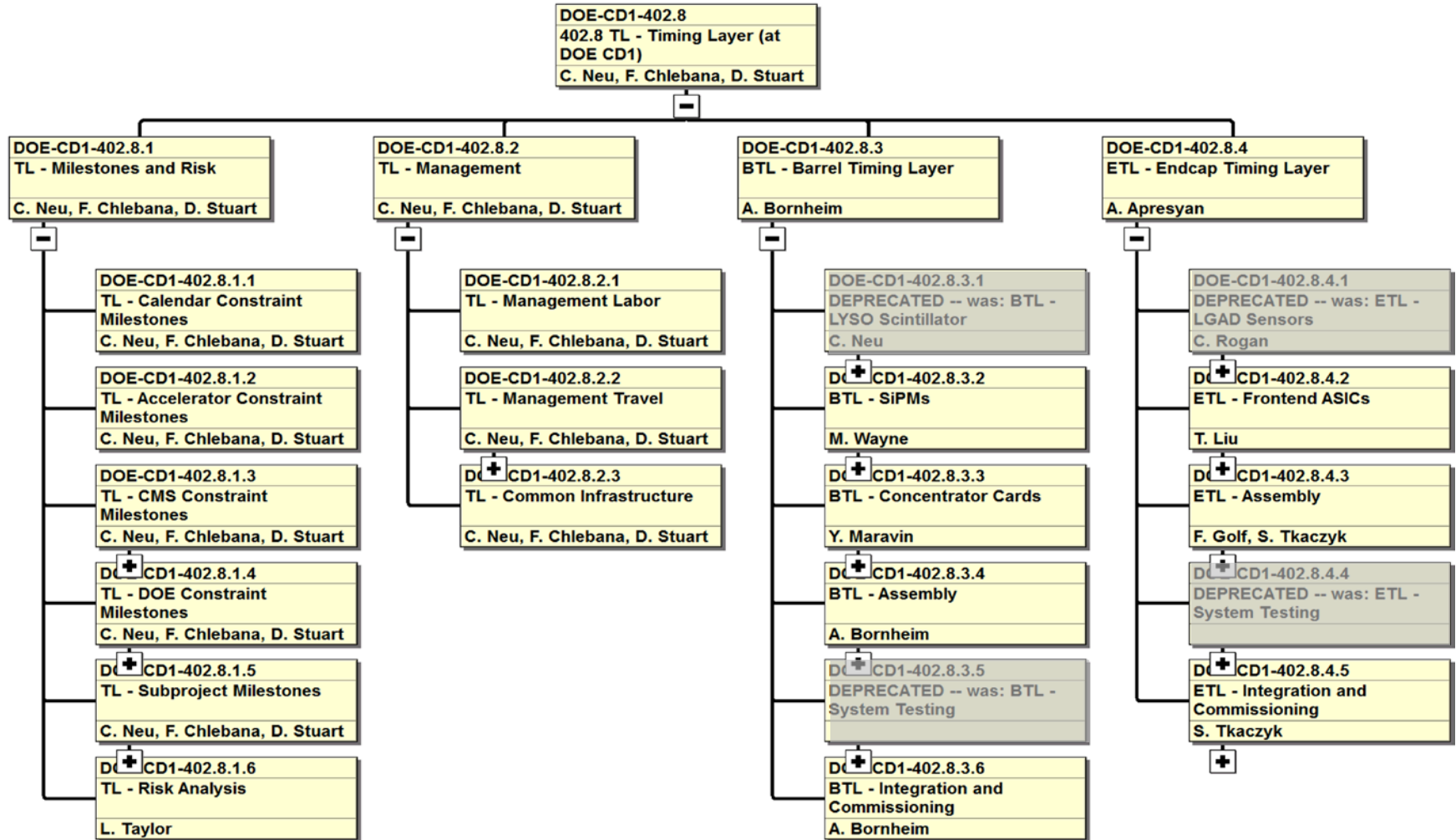
Former head of the DAQ group at CDF



Outline

- Schedule Development
- Costs
- Critical path
- Milestones
- Float
- Risks

MTD Work Breakdown Structure



Deprecated WBS areas were included before scope optimization
 Removed LYSO and LGAD WBS elements → moved LYSO contribution to “Common Infrastructure”
 System testing focuses on US deliverables → moved related activities to the associated assembly WBS



Schedule Development

MTD schedule has about **~1500 activities** (including milestones)

A comprehensive set of tiered milestones allows us to monitor technical progress

BTL **~60 milestones**

ETL **~90 milestones**

Activity durations are **less than 3 months** to allow monitoring progress

Some exceptions (Supervision activates treated as LOE activates, extended burn-in activities...)

BTL and ETL production model updated to reflect the **design presented in the TDR** and taking **input from recent reviews**: CD-1 IPR (2018), Technical review (Nov 2018), OPSS cost and schedule review (Jan 2019), Director's Review (Mar 2019)

We are **directly involved** with developing the iMTD schedule and **fully synchronized** with iMTD planning

Adi Bornheim (BTL L3 manager) is the international BTL coordinator

David Stuart (MTD Deputy L2 manager) is the international ETL coordinator



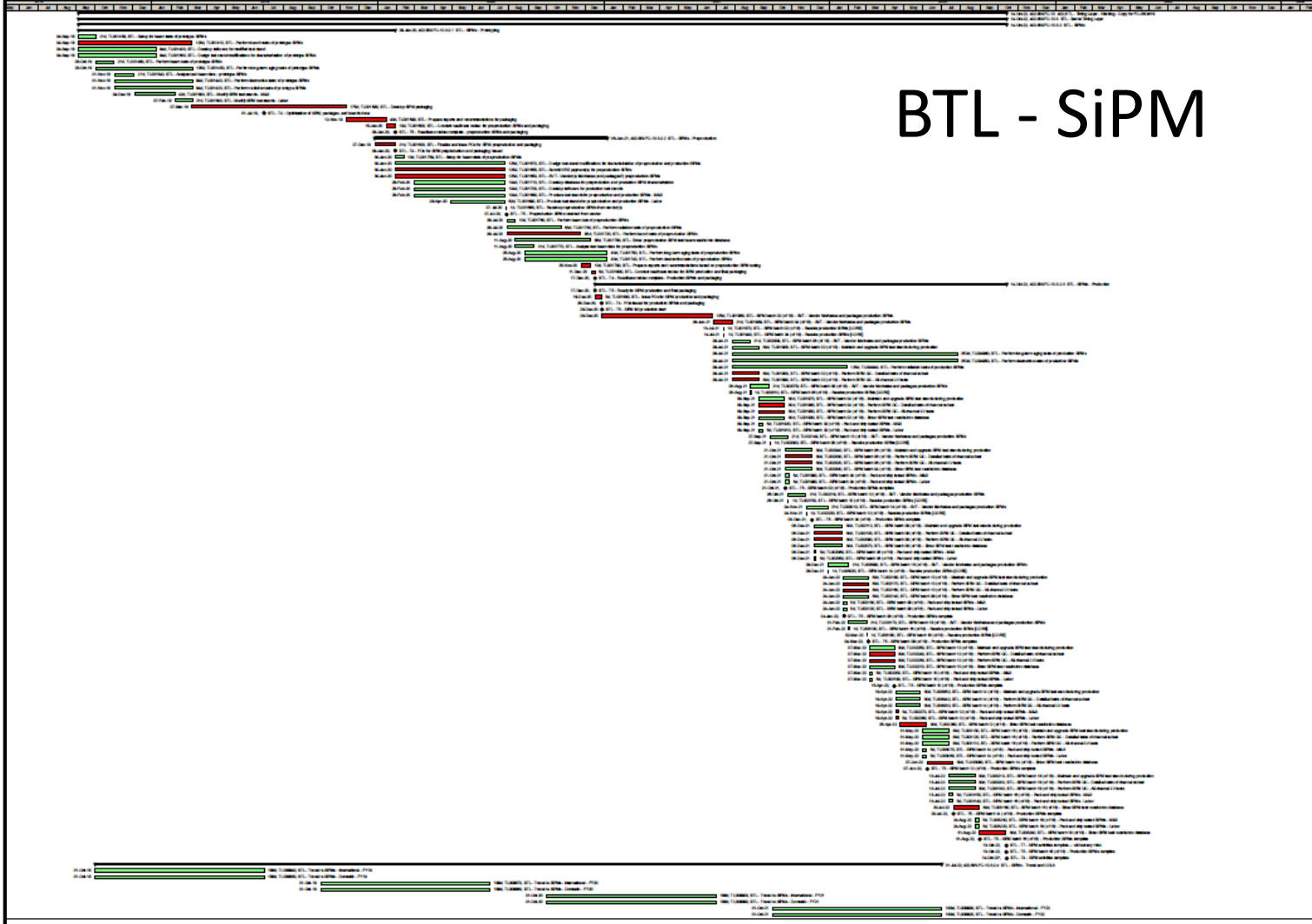
BTL - SiPM

02.8 TL - Timing Layer - Working - Copy for FC-03Oct19

MTD - Costs - Printout

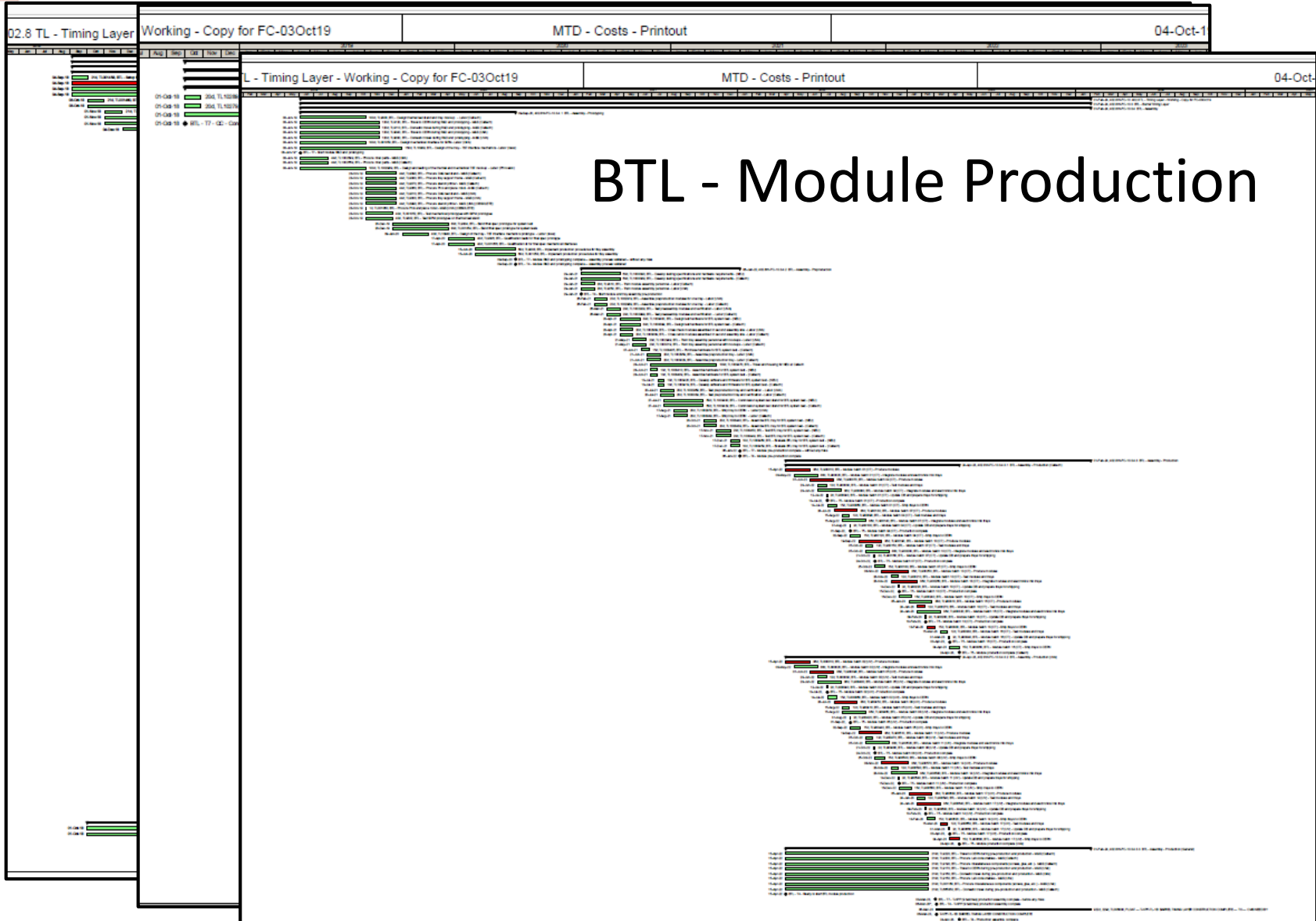
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BTL - SiPM



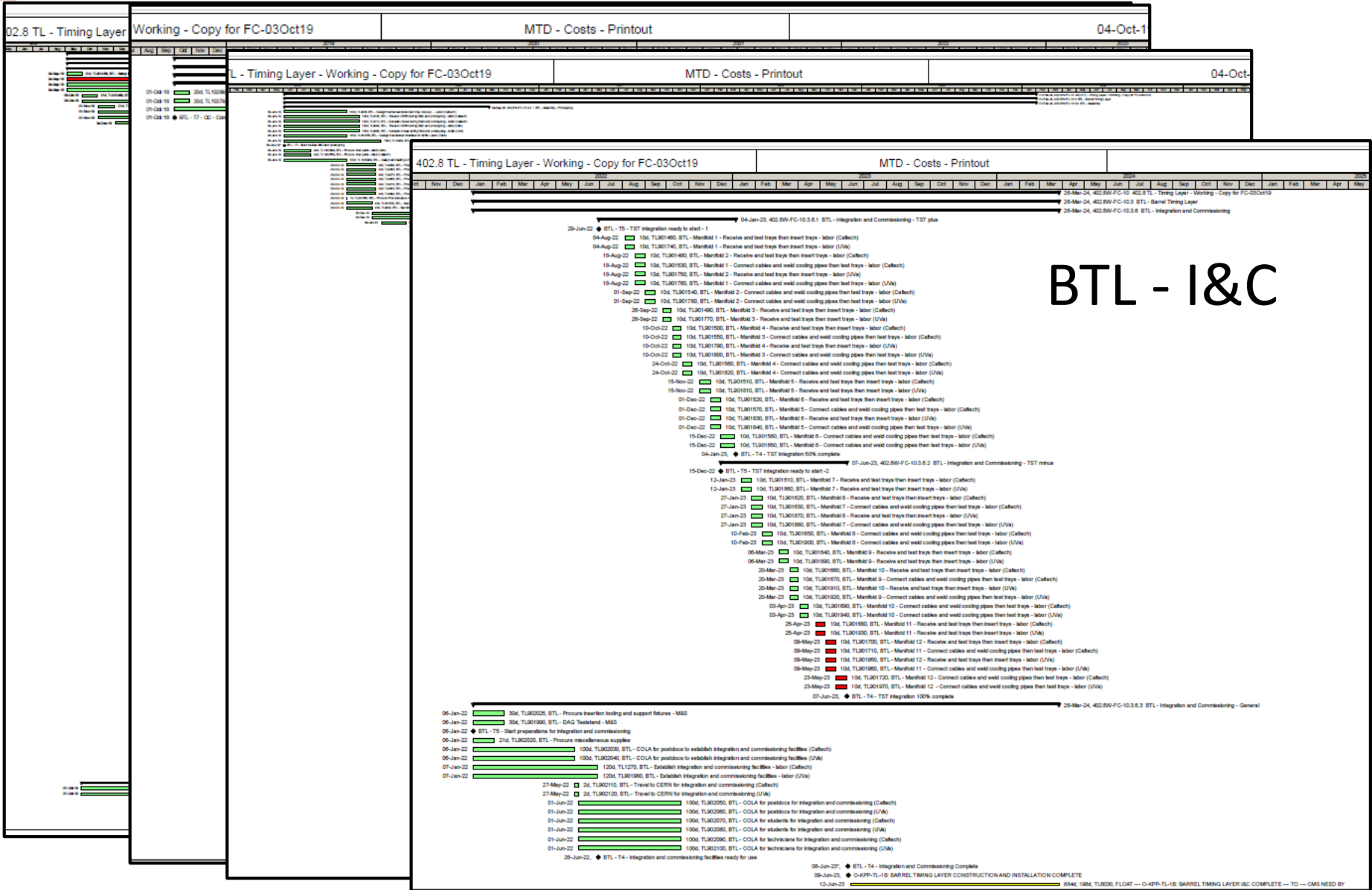


BTL - Module Production





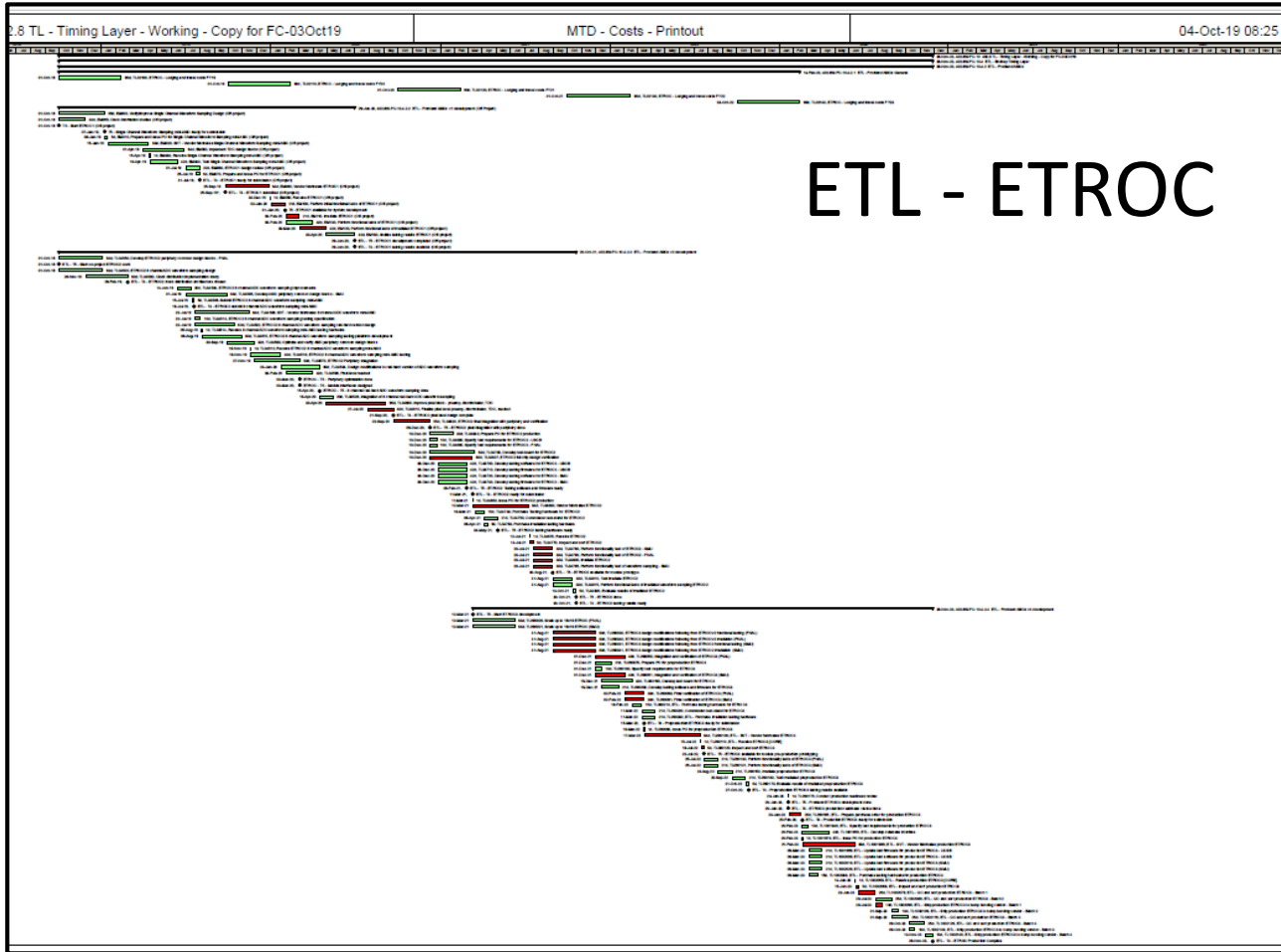
BTL - I&C



BTL - I&C

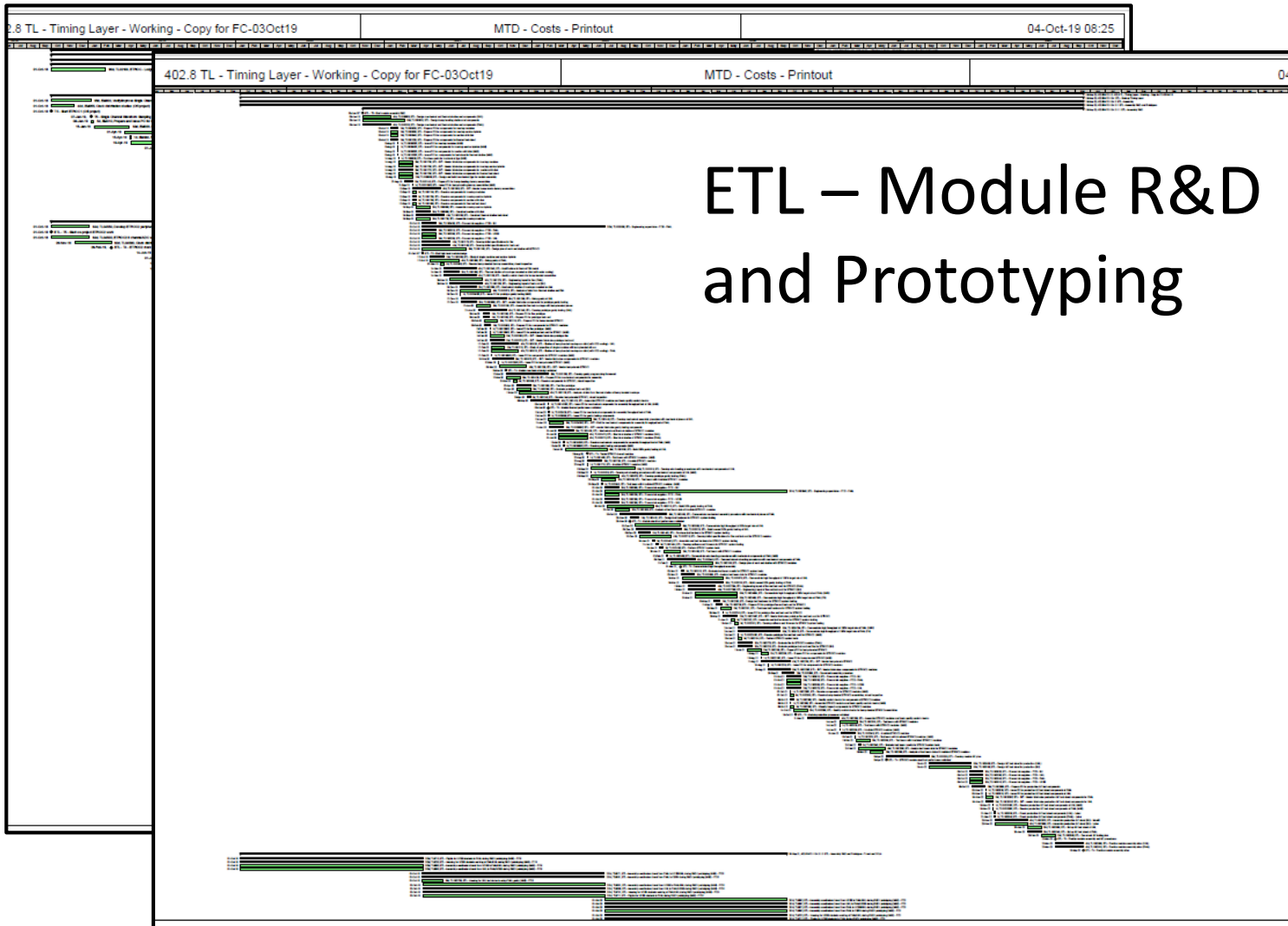


ETL - ETROC



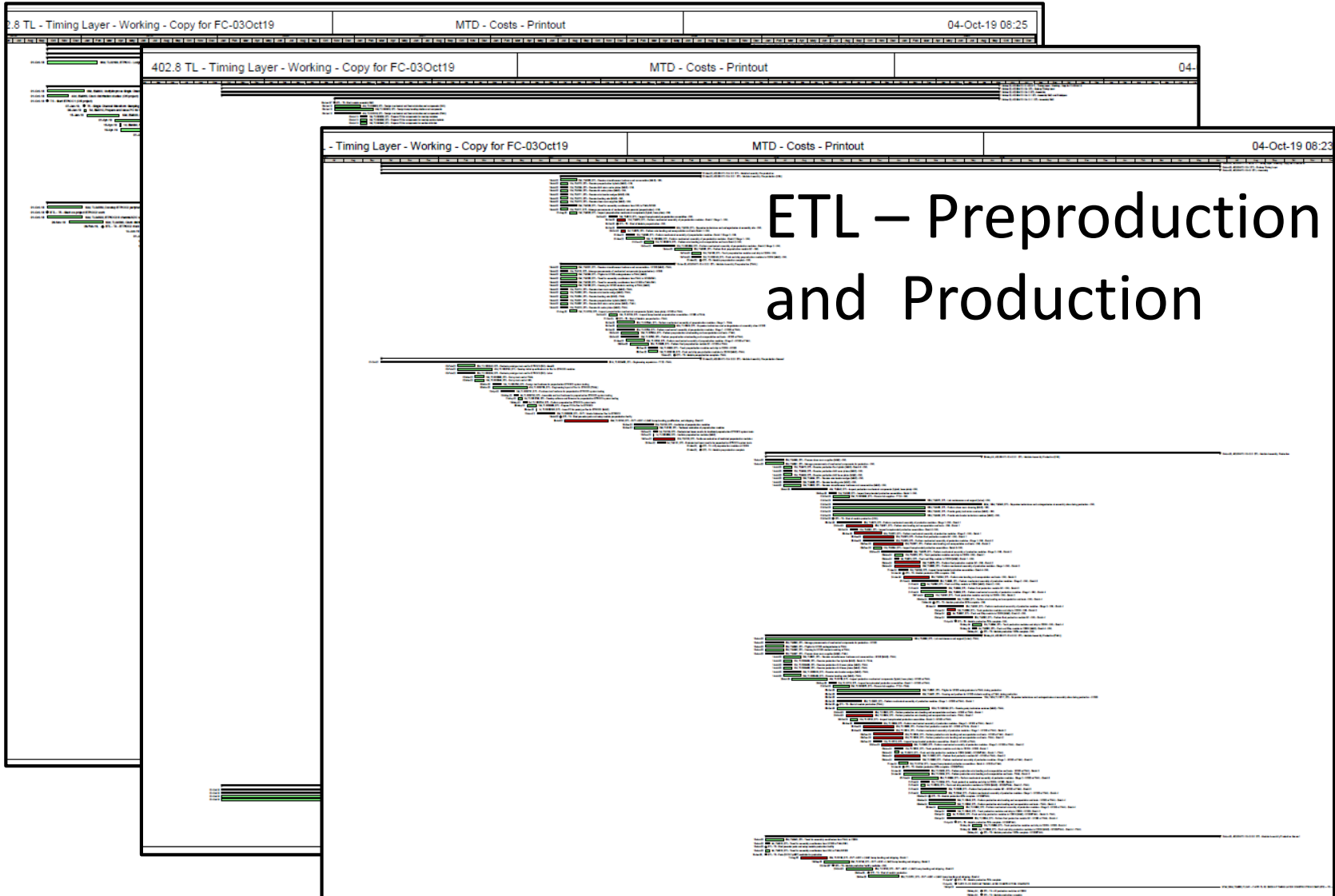


ETL - Module R&D and Prototyping



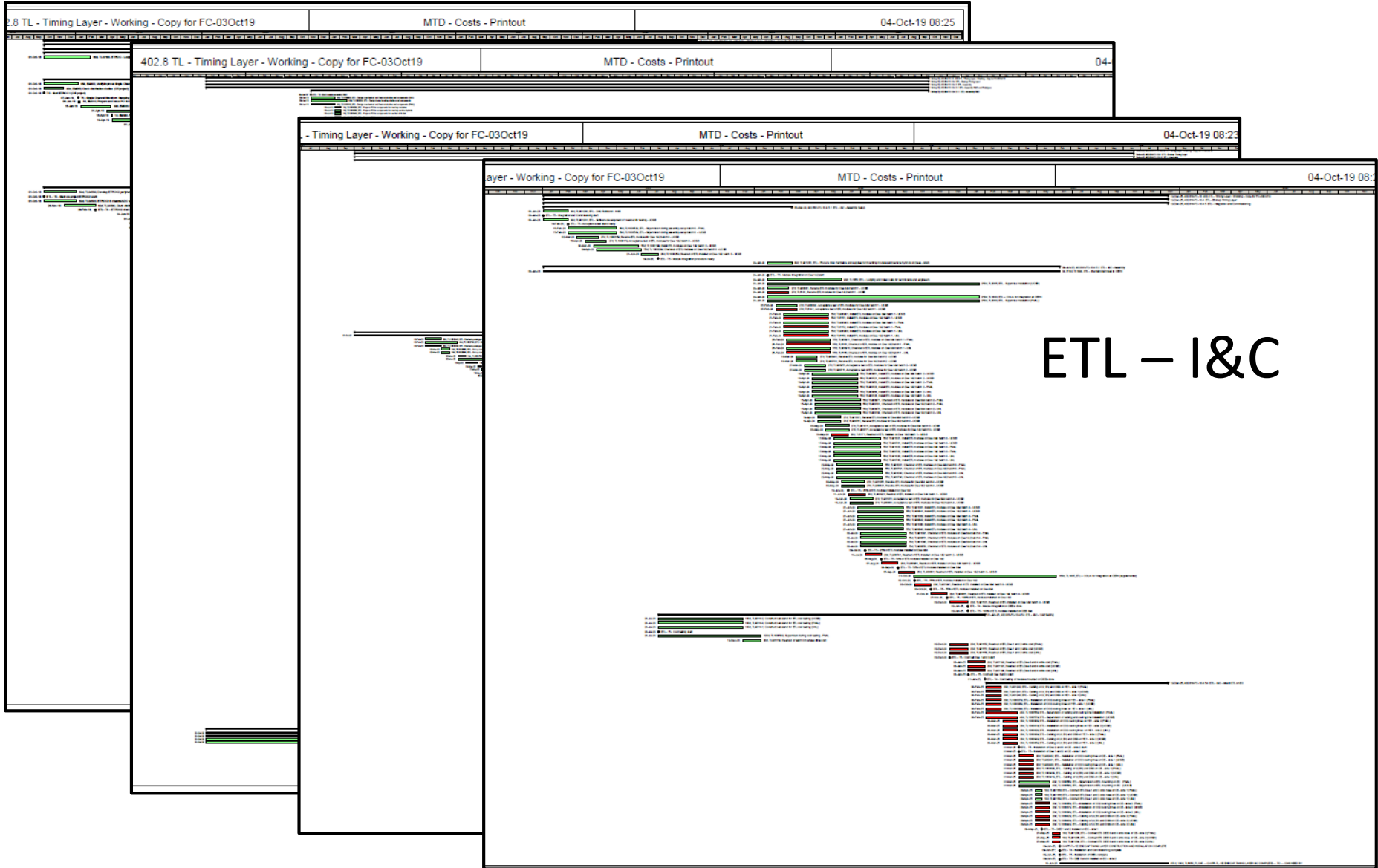


ETL – Preproduction and Production





ETL - I&C



ETL - I&C



Basis of Estimate (BoE)

Basis of Estimates and supporting documentation are available in DocDB

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

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 (4)

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](#)

402.8.3.6 BTL - Integration and Commissioning [CMS-doc-13593](#)

L3 Parent:WBS : 402.8.4 ETL - Endcap Timing Layer (3)

402.8.4.2 ETL - Frontend ASICs [CMS-doc-13595](#)

402.8.4.3 ETL - Assembly [CMS-doc-13597](#)

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:

- [M&S and Labor estimates excel spreadsheet \(BTL---Concentrator-Card---cost-estimate-V9.1.xlsx, 503.0 kB\)](#)
- [Main BoE file \(BoE---402-8-3-3---BTL---Concentrator-Cards-11.pdf, 650.9 kB\)](#)

Other Files:

- [Activity list \(CC_ActivityList_v0 \(3\).docx, 20.3 kB\)](#)
- [BOE Source file \(BoE---402-8-3-3---BTL---Concentrator-Cards-11.docx, 1.6 MB\)](#)
- [BOM \(Bill of Materials-CC_V1Quote Updated 6-14-2019 for Yurii.xls, 42.5 kB\)](#)
- [GBT-SCA receipt \(quote\) \(GBT-SCARceipt.pdf, 6.7 kB\)](#)
- [M&S Test Stand components quote \(MS-13_TestStand_components.pdf, 2.9 MB\)](#)
- [PCB production quote \(Quote_278697.pdf, 200.9 kB\)](#)
- [PCB quote \(103369-A.pdf, 71.7 kB\)](#)
- [Samtec board quote \(Samtec Quote 201906-11157.pdf, 49.0 kB\)](#)
- [Spreadsheet to calculate costs for production \(MandS.xlsx, 17.0 kB\)](#)
- [Test Stand BOM \(MS-12_TestStand_BOM.pdf, 46.5 kB\)](#)
- [Test Stand stencil quote \(MS-10_TestStand_Stencil.pdf, 216.1 kB\)](#)
- [Trenz Electronics board quote \(Trenz Electronics 88-3981 Order Confirmation.pdf, 91.8 kB\)](#)
- [Vivado license quote \(EF-VIVADO-DESIGN-FL Xilinx Inc. _ Development Boards, ...pdf, 240.6 kB\)](#)
- [XILINX KCU105 board quote \(EK-U1-KCU105-G Xilinx Inc. _ Development Boards, Kits,...pdf, 851.3 kB\)](#)
- [IpGBT receipt \(quote\) \(IpGBTReceipt.pdf, 6.7 kB\)](#)



Vendor Quotes

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

LYSO: Received quotes from multiple vendors (Nov 10, 2018)

Non-binding RFQ issued in June 2019, average price was 6% lower

Our contribution to the LYSO purchase is a fixed dollar amount

SiPM: Hamamatsu-SiPM (Apr 1, 2019)

Concentrator Cards: Bill of material parts list (June 6, 2019), PCB production (Sep 12, 2019)

BTL Assembly: Pick and place gantry and stencil printer (Aug 15, 2018)

ASIC: MPW, 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)



Timing Layer Costs (Project Cost Book)

CMS-doc-13777

WBS	Direct M&S (\$)	Labor (Hours)	FTE	Direct + Indirect + Esc. (\$)	Estimate Uncertainty (\$)	Total Cost (\$)
DOE-CD1-402.8 402.8 TL - Timing Layer (at DOE CD1)	6,845,630	156109	88.30	12,718,472	3,230,993	15,949,466
DOE-CD1-402.8.2 TL - Management	1,051,980	26520	15.00	1,245,677	221,782	1,467,459
DOE-CD1-402.8.2.1 TL - Management Labor	0	26520	15.00	0	0	0
DOE-CD1-402.8.2.2 TL - Management Travel	233,000	0	0.00	349,612	27,526	377,138
DOE-CD1-402.8.2.3 TL - Common Infrastructure	818,980	0	0.00	896,064	194,256	1,090,321
DOE-CD1-402.8.3 BTL - Barrel Timing Layer	2,832,903	47774	27.02	5,141,304	1,263,514	6,404,817
DOE-CD1-402.8.3.2 BTL - SiPMs	1,785,400	5384	3.05	2,474,076	392,929	2,867,005
DOE-CD1-402.8.3.3 BTL - Concentrator Cards	559,143	4506	2.55	936,334	194,269	1,130,603
DOE-CD1-402.8.3.4 BTL - Assembly	290,360	27236	15.40	1,293,636	553,215	1,846,851
DOE-CD1-402.8.3.6 BTL - Integration and Commissioning	198,000	10648	6.02	437,258	123,101	560,359
DOE-CD1-402.8.4 ETL - Endcap Timing Layer	2,960,747	81815	46.28	6,331,492	1,745,697	8,077,190
DOE-CD1-402.8.4.2 ETL - Frontend ASICs	2,110,992	24495	13.85	4,186,640	839,972	5,026,613
DOE-CD1-402.8.4.3 ETL - Assembly	641,455	38348	21.69	1,754,080	787,463	2,541,542
DOE-CD1-402.8.4.5 ETL - Integration and Commissioning	208,300	18972	10.73	390,773	118,262	509,035

The MTD costs derived from the P6 schedule include institutional specific labor rates, overheads, escalation, and estimate uncertainty

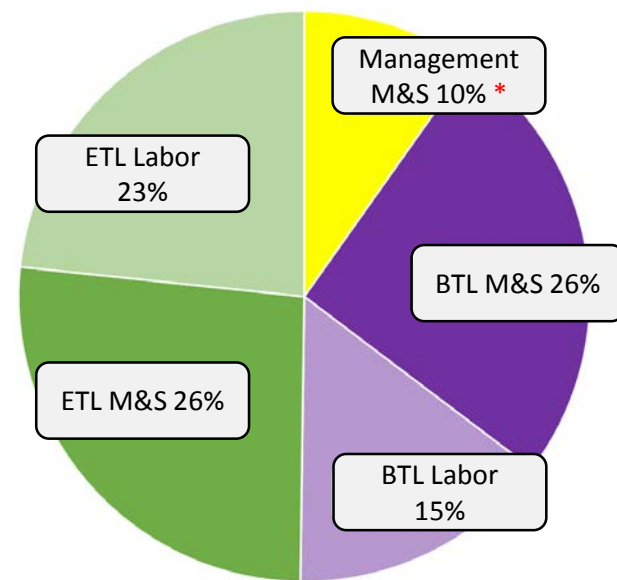
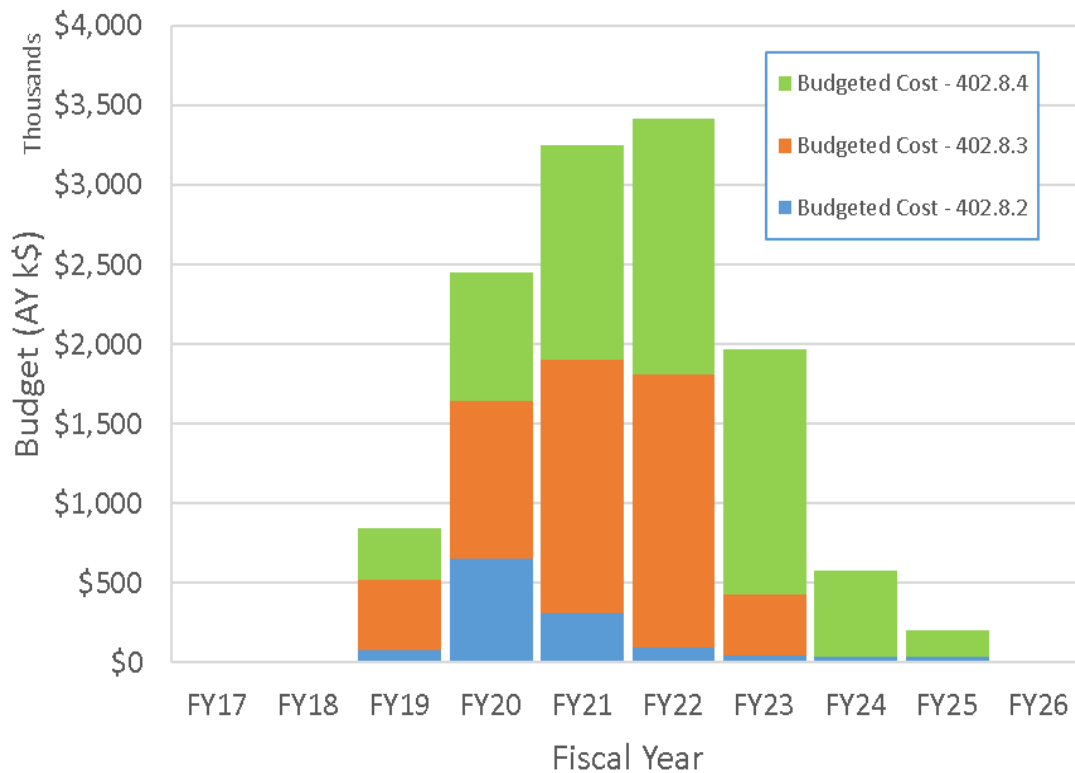
The MTD total project cost is: 15.95M\$ = 12.72 (BAC) + 3.23 (EU)



Costs at Level 3

CMS-doc-13215

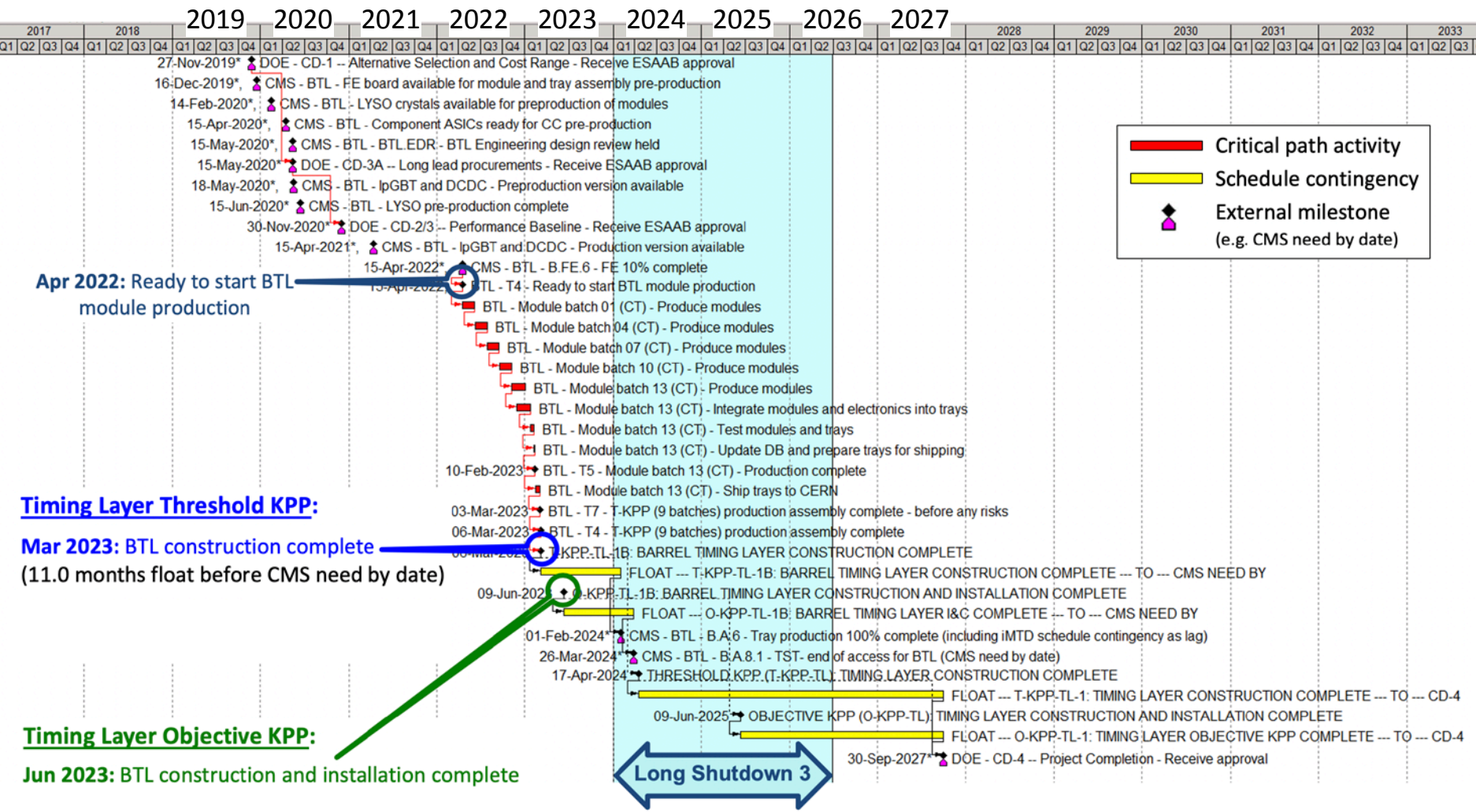
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* Management includes:
 2.8% Travel
 7.2% Common infrastructure (LYSO, Cooling, Engineering support)

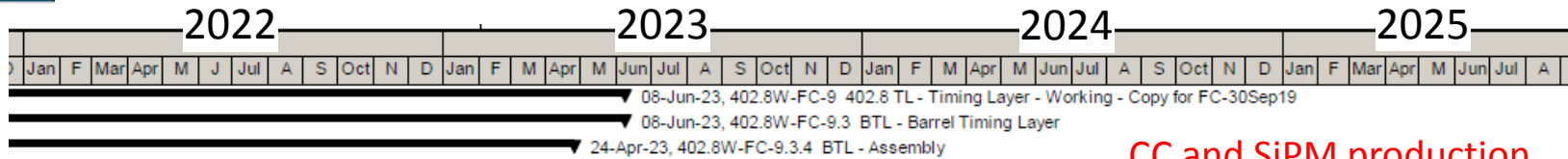


BTL Critical Path and Schedule Contingency

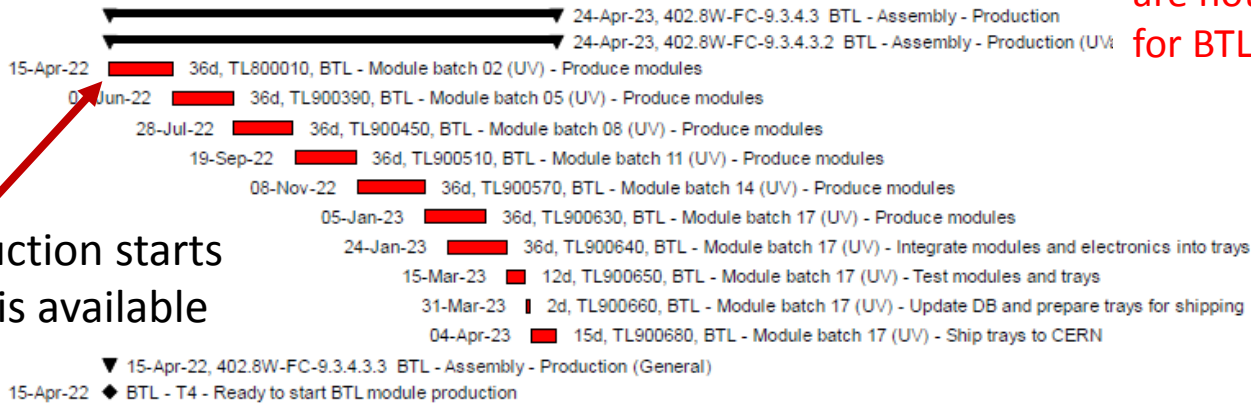




BTL Critical Path

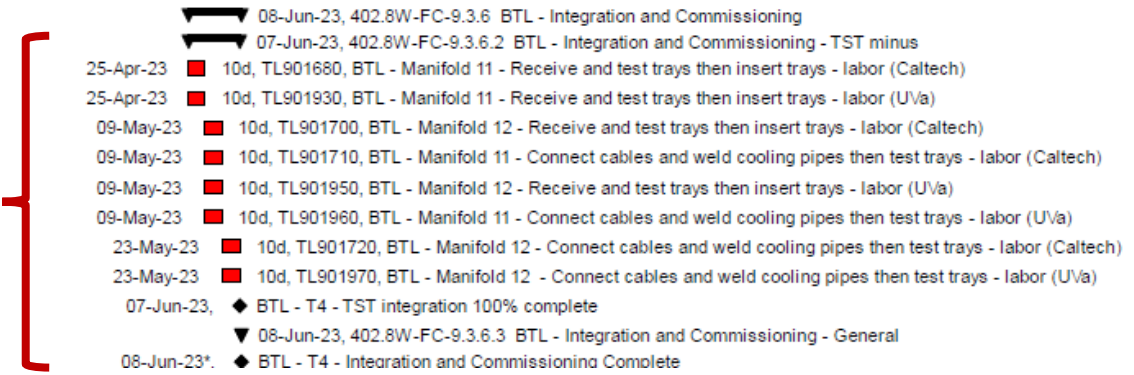


CC and SiPM production are not on the critical path for BTL module production



Module production starts when 10% FE is available

Tray installation into TST



T-KPP (9/12 batches) production assembly complete (75%), 6-Mar-23
 T4 Production assembly complete (100%), 24-Apr-23



BTL Critical Activities

Critical activities identified by fixing the date of the last milestone in the sequence

SiPM

SiPM production and QC starts before module production starts, completed off of the critical path

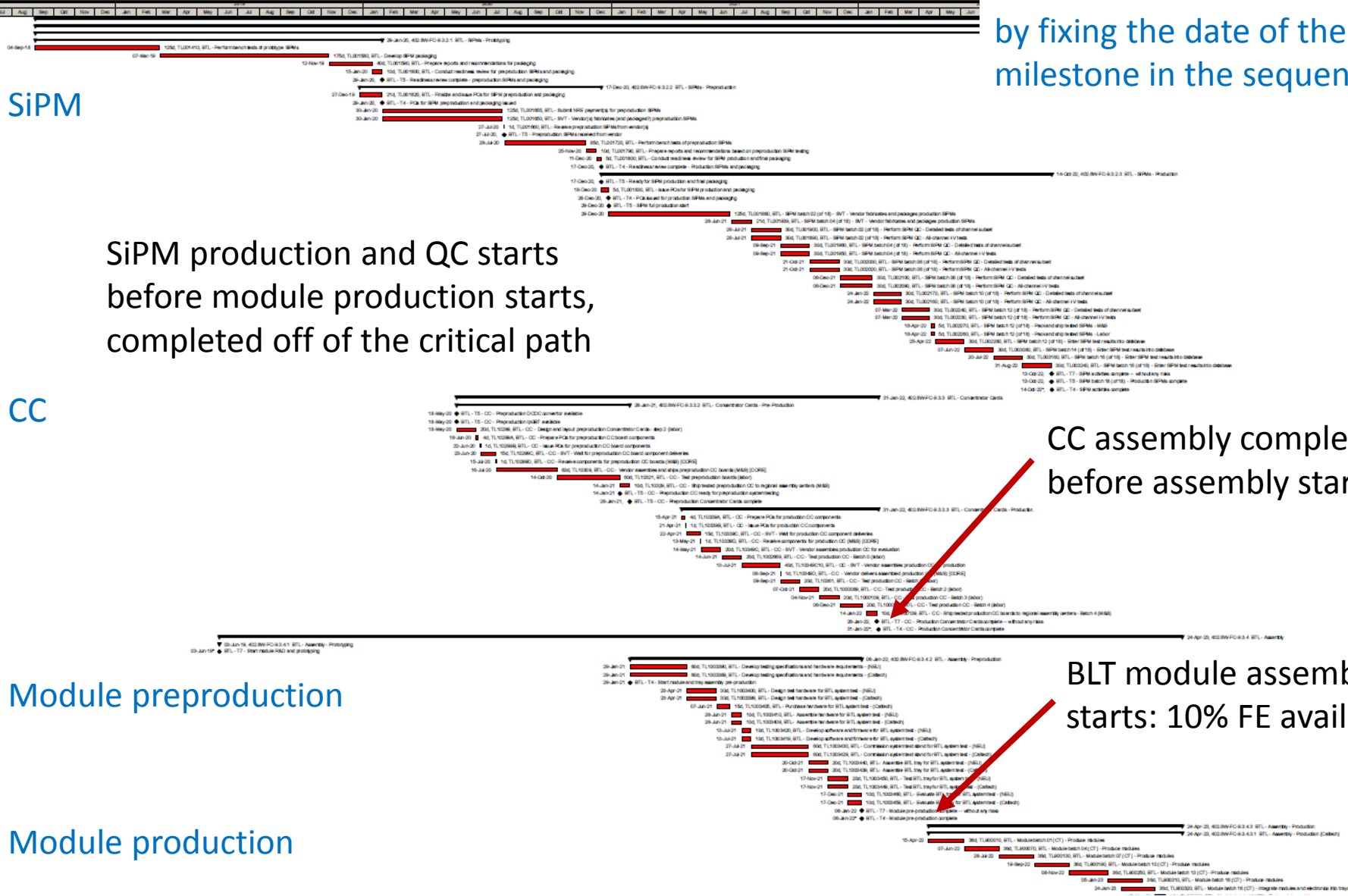
CC

CC assembly completed before assembly started

Module preproduction

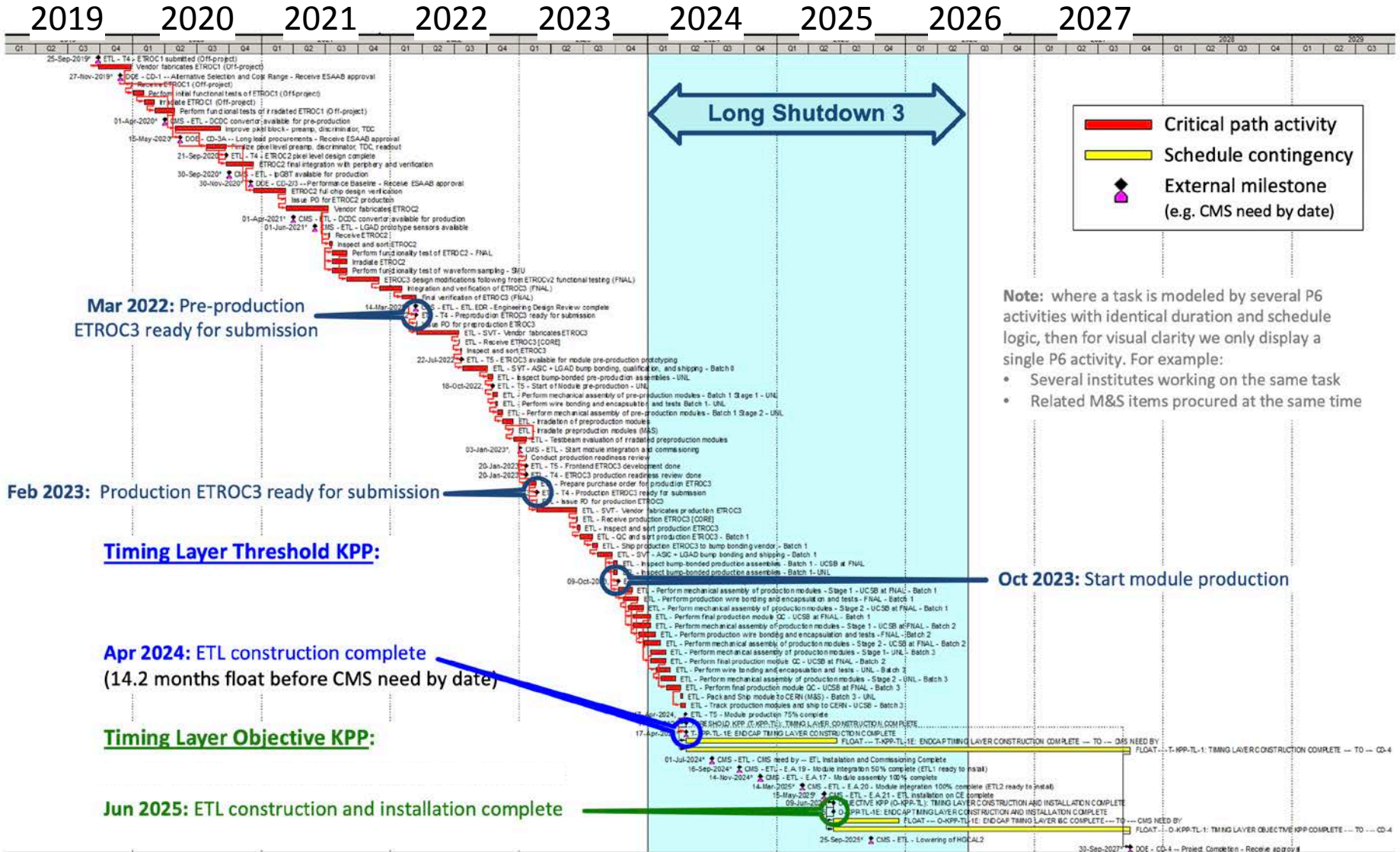
BLT module assembly starts: 10% FE available

Module production



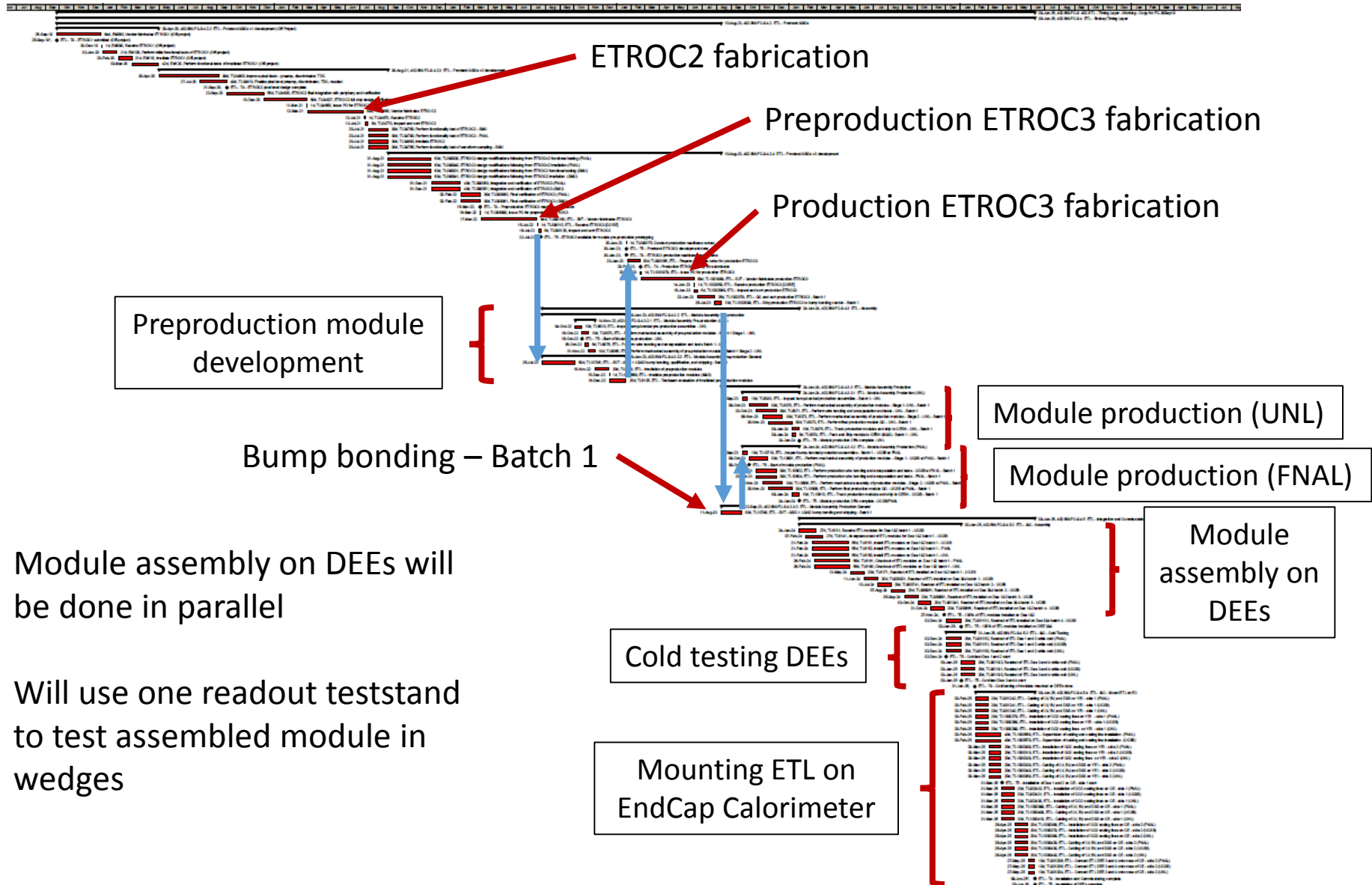


ETL Critical Path and Schedule Contingency





ETL Critical Path

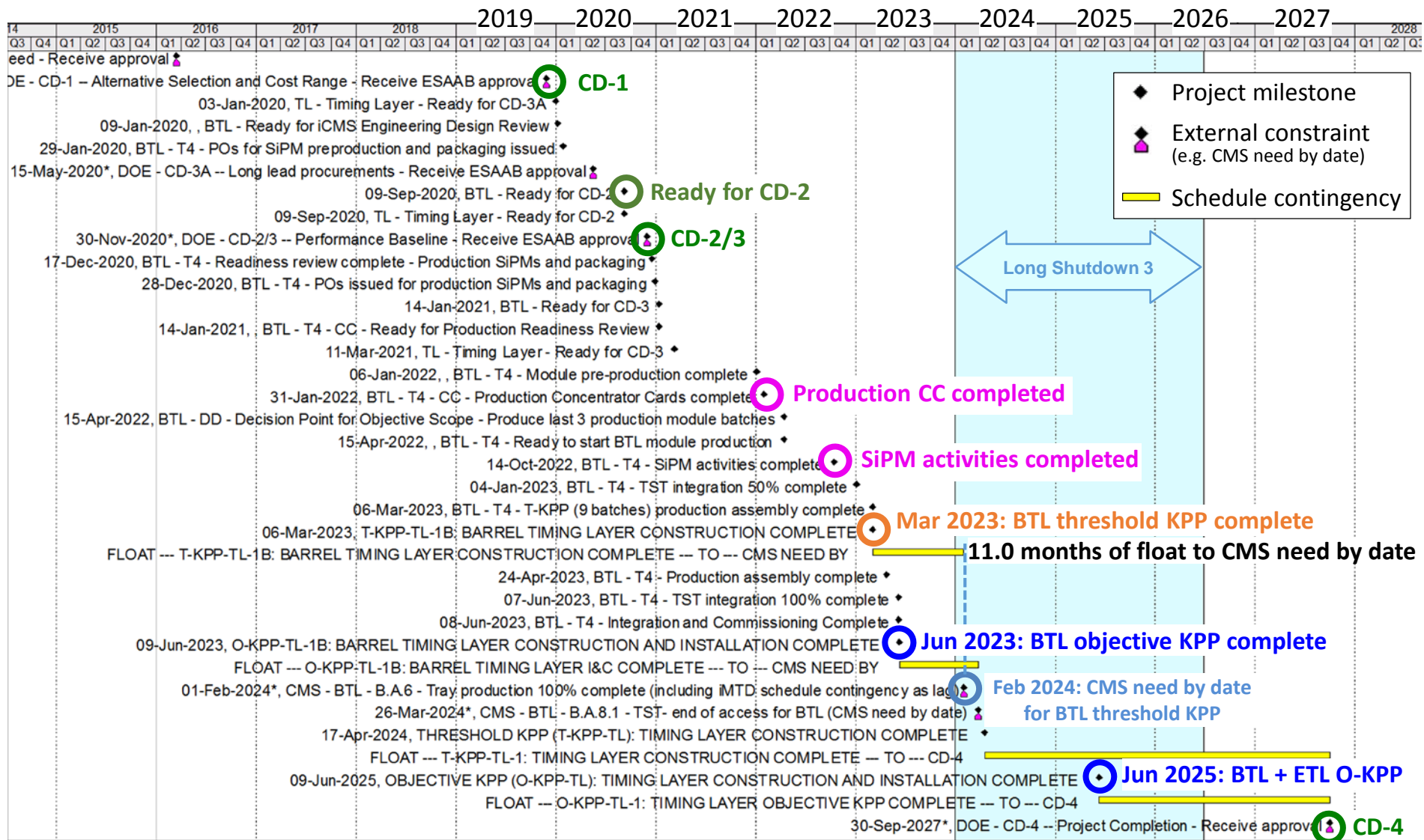


Module assembly on DEEs will be done in parallel

Will use one readout teststand to test assembled module in wedges

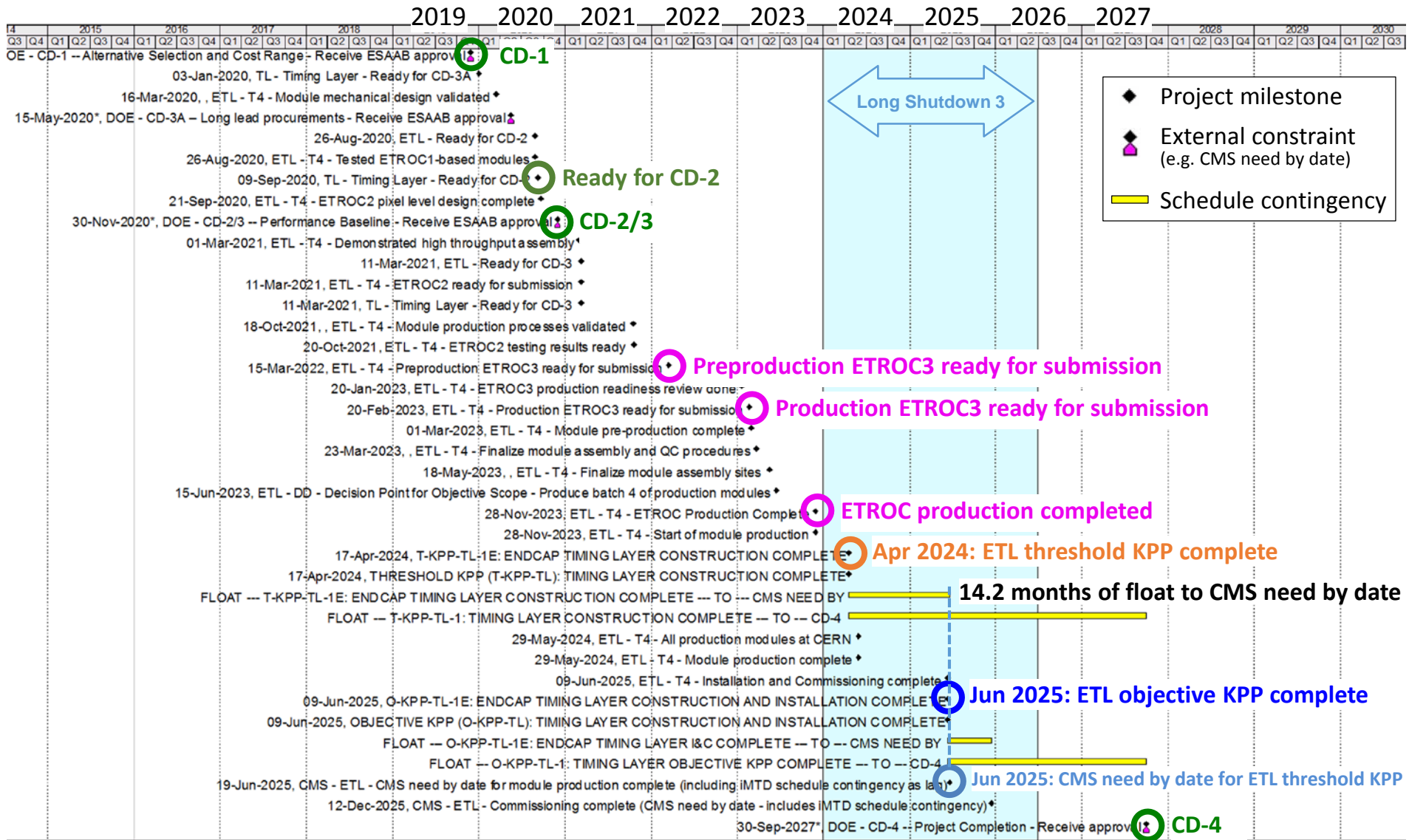


BTL Key Milestones and Schedule Contingency





ETL Key Milestones and Schedule Contingency





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

Material	Obligation Date	Direct Cost (k\$)	Direct+Esc (k\$)	Relevant Review
LYSO production	June 2020	500	523	CD-3a (May 2020)
SiPM production	Dec 2020	1600	1765	CD-2/3 (Nov 2020)
ETROC preproduction	Mar 2022	728	816	CD-2/3 (Nov 2020)
ETROC production	Feb 2023	887	1014	CD-2/3 (Nov 2020)

Main cost drivers represent ~54% of the MTD M&S cost

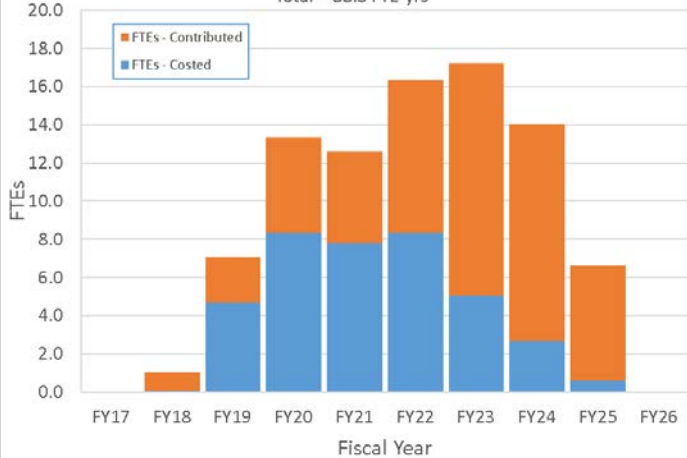
ETROC pricing is well-defined via the IMEC/CERN agreement.

The LYSO pricing is based on multiple vendor quotes and we contribute a fixed cost. *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 well documented.*

Timing Layer Labor

402.8-TL-Base Labor Profile (DOE)-Costed & Contributed
Total = 88.3 FTE-yrs



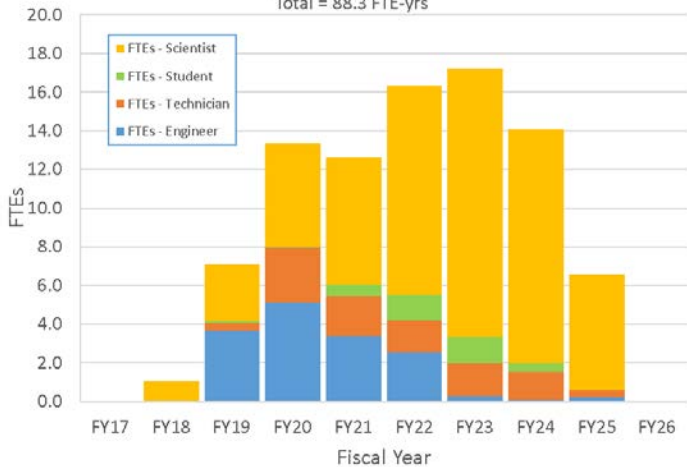
The areas with technical deliverables, SiPM, CC, ASIC, are done with mostly costed labor

The main labor cost is associated with the ASIC development

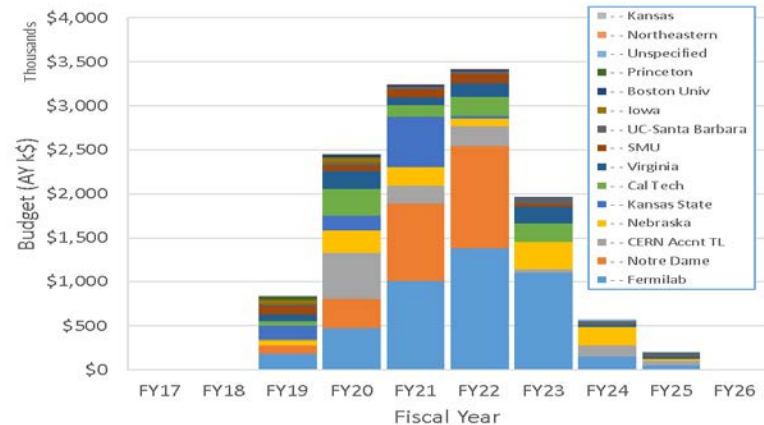
Contributed labor is used during the R&D phase of module assembly, system testing, I&C

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

402.8-TL-Base Labor Profile (DOE)-Resource Discipline
Total = 88.3 FTE-yrs



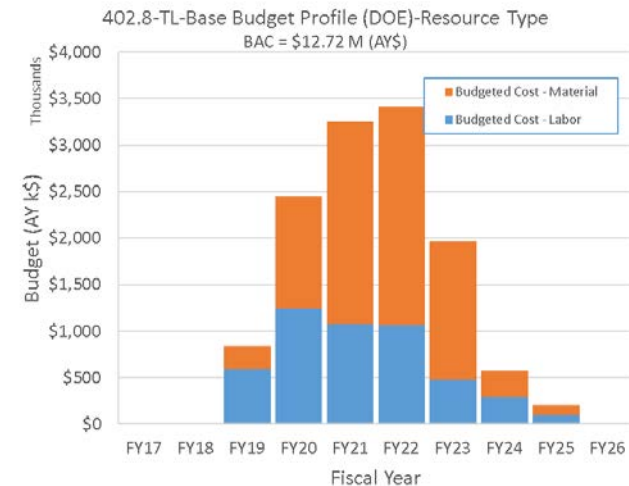
402.8-TL-Base Budget Profile (DOE)-Institutions
BAC = \$12.72M (AY\$)





MTD Cost Drivers

CMS Driver	Labor (FTE-yrs)	Labor BAC (M\$)	M&S BAC (M\$)	Total BAC (M\$)
TL - ETL ASIC Development	12.5	1.8	1.3	3.2
TL - BTL Production SiPMS [CORE]	0.0	0.0	1.8	1.8
TL - ETL module assembly	15.4	1.0	0.7	1.8
TL - BTL module assembly	15.1	0.9	0.5	1.5
TL - ETL Production ASICs [CORE]	0.0	0.0	1.0	1.0
TL - Timing Layer installation and commissioning	6.5	0.3	0.6	0.9
TL - BTL SiPM labor	3.0			
TL - BTL LYSO crystals M&S [CORE]	0.0			
TL - BTL electronics - concentrator board [CORE]	0.0			
TL - BTL electronics - concentrator board	2.5			
TL - Travel	0.0			
TL - BTL iCMS common core infrastructure [CORE]	0.0			
TL - ETL iCMS common core infrastructure [CORE]	0.0			



* BAC = Budget at Completion (=direct + indirect + escalation)



MTD Risks

Risks modelling is included in the P6 schedule and a risk analysis has been done to determine the cost and schedule impact

A detailed description of the methodology used for the risk analysis can be found in [CMS-doc-13481](#)

General Risks (2)

WBS / Ops Lab Activity : 402.8 TL - Timing Layer (general risks) (2)

Risk Rank : 2 (Medium) (1)

RT-402-8-91-D	TL - Shortfall in Timing Layer scientific labor	30 %	0 -- 0 -- 611 k\$	0 months	61	0.0
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Risk Rank : 1 (Low) (1)

RT-402-8-90-D	TL - Key Timing Layer personnel need to be replaced	25 %	45 -- 135 -- 261 k\$	0 -- 0 -- 3 months	37	0.3
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BTL Risks

RI-ID	Title	Probability	Cost Impact	Schedule Impact	P * Impact (k\$)	P * Impact (months)
WBS / Ops Lab Activity : 402.8 TL - Timing Layer (general risks) (2)						
WBS / Ops Lab Activity : 402.8.3 BTL - Barrel Timing Layer (14)						
Risk Rank : 3 (High) (2)						
RT-402-8-30-D	BTL - Concentrator Card requires significant design changes	50 %	40 -- 135 -- 175 k\$	1 -- 3 -- 6 months	58	1.7
RT-402-8-07-D	BTL - Concentrator Card delay in external component deliveries	50 %	50 k\$	3 -- 6 -- 9 months	25	3.0
Risk Rank : 2 (Medium) (4)						
RT-402-8-05-D	BTL - Change in interfaces of tray assembly components	20 %	150 -- 250 -- 350 k\$	3 months	50	0.6
RT-402-8-46-D	BTL - Problems with sensor gluing facility	50 %	90 k\$	1 -- 2 -- 3 months	45	1.0
RT-402-8-33-D	BTL - Difficulties procuring LYSO from international suppliers	10 %	100 -- 250 -- 400 k\$	3 -- 6 -- 9 months	25	0.6
RT-402-8-14-D	BTL - Problems with SiPM vendor	20 %	32 -- 96 -- 128 k\$	2 -- 6 -- 8 months	17	1.1
Risk Rank : 1 (Low) (8)						
RT-402-8-15-D	BTL - Batch shipment of SiPMs lost in transport	5 %	224 k\$	1 months	11	0.1
RT-402-8-35-D	BTL - Delays or damage of tray in transport to CERN	5 %	220 k\$	1 months	11	0.1
RT-402-8-04-D	BTL - LYSO matrices not meeting specifications	10 %	100 k\$	1 -- 2 -- 3 months	10	0.2
RT-402-8-36-D	BTL - Interface to iCMS changes	20 %	30 k\$	1 -- 2 -- 3 months	6	0.4
RT-402-8-34-D	BTL - Delay in delivery of components from iCMS	20 %	10 -- 20 -- 30 k\$	1 -- 2 -- 3 months	4	0.4
RT-402-8-18-D	BTL - Concentrator card production & testing facility problem	20 %	10 k\$	0.5 -- 1 -- 2 months	2	0.2
RT-402-8-08-D	BTL - Delay in cooling plate delivery	10 %	10 -- 20 -- 30 k\$	1 -- 2 -- 3 months	2	0.2
RT-402-8-42-D	BTL - Problems with module assembly site	10 %	10 -- 20 -- 30 k\$	1 -- 2 -- 3 months	2	0.2
WBS / Ops Lab Activity : 402.8.4 ETL - Endcap Timing Layer (10)						

BTL Risks (14)



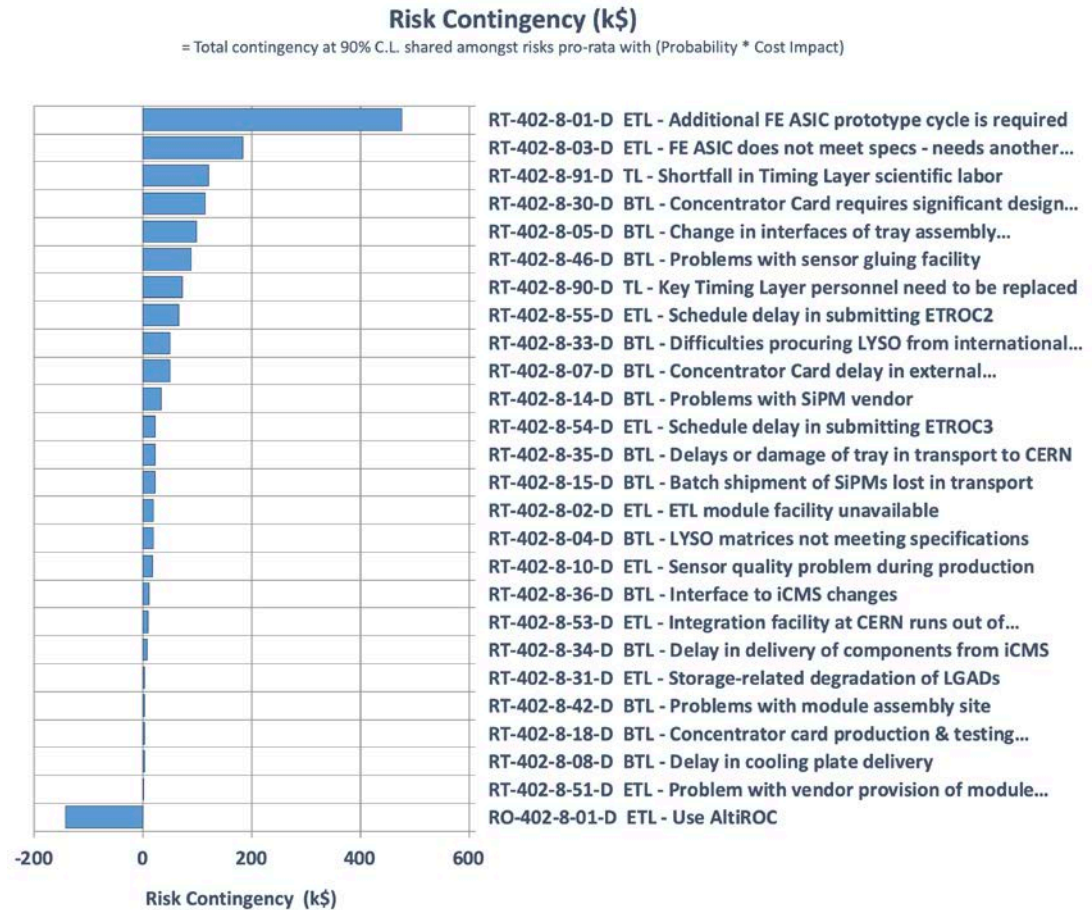
ETL Risks

RI-ID	Title	Probability	Cost Impact	Schedule Impact	P * Impact (k\$)	P * Impact (months)
<input type="checkbox"/> WBS / Ops Lab Activity : 402.8 TL - Timing Layer (general risks) (2)						
<input type="checkbox"/> WBS / Ops Lab Activity : 402.8.3 BTL - Barrel Timing Layer (14)						
<input type="checkbox"/> WBS / Ops Lab Activity : 402.8.4 ETL - Endcap Timing Layer (10)						
ETL Risks (10)						
<input type="checkbox"/> Risk Rank : 3 (High) (1)						
RT-402-8-01-D	ETL - Additional FE ASIC prototype cycle is required	40 %	500 -- 600 -- 700 k\$	4 -- 5 -- 6 months	240	2.0
<input type="checkbox"/> Risk Rank : 2 (Medium) (5)						
RT-402-8-03-D	ETL - FE ASIC does not meet specs - needs another pre-prod run	10 %	874 -- 930 -- 986 k\$	6 -- 7.5 -- 9 months	93	0.8
RT-402-8-55-D	ETL - Schedule delay in submitting ETROC2	30 %	55 -- 110 -- 165 k\$	2 -- 4 -- 6 months	33	1.2
RT-402-8-02-D	ETL - ETL module facility unavailable	50 %	20 k\$	2 months	10	1.0
RT-402-8-10-D	ETL - Sensor quality problem during production	15 %	28 -- 52 -- 109 k\$	2 -- 3 -- 6 months	9	0.6
RO-402-8-01-D	ETL - Use AltiROC	10 %	-720 k\$	-8 months	-72	-0.8
<input type="checkbox"/> Risk Rank : 1 (Low) (4)						
RT-402-8-54-D	ETL - Schedule delay in submitting ETROC3	20 %	27.5 -- 55 -- 82.5 k\$	1 -- 2 -- 3 months	11	0.4
RT-402-8-53-D	ETL - Integration facility at CERN runs out of components	25 %	21 k\$	3 months	5	0.8
RT-402-8-31-D	ETL - Storage-related degradation of LGADs	10 %	18 k\$	3 months	2	0.3
RT-402-8-51-D	ETL - Problem with vendor provision of module components	5 %	0 -- 15 -- 30 k\$	1 -- 2 -- 3 months	1	0.1

MTD Risk Cost Impact

Main risk changes in past 12 months are

- Detailed risk analysis of both BTL and ETL
- Careful alignment with iCMS (TDR) plans
- External risk reviews
- ASIC risks to cover realistic scenarios and submission delays



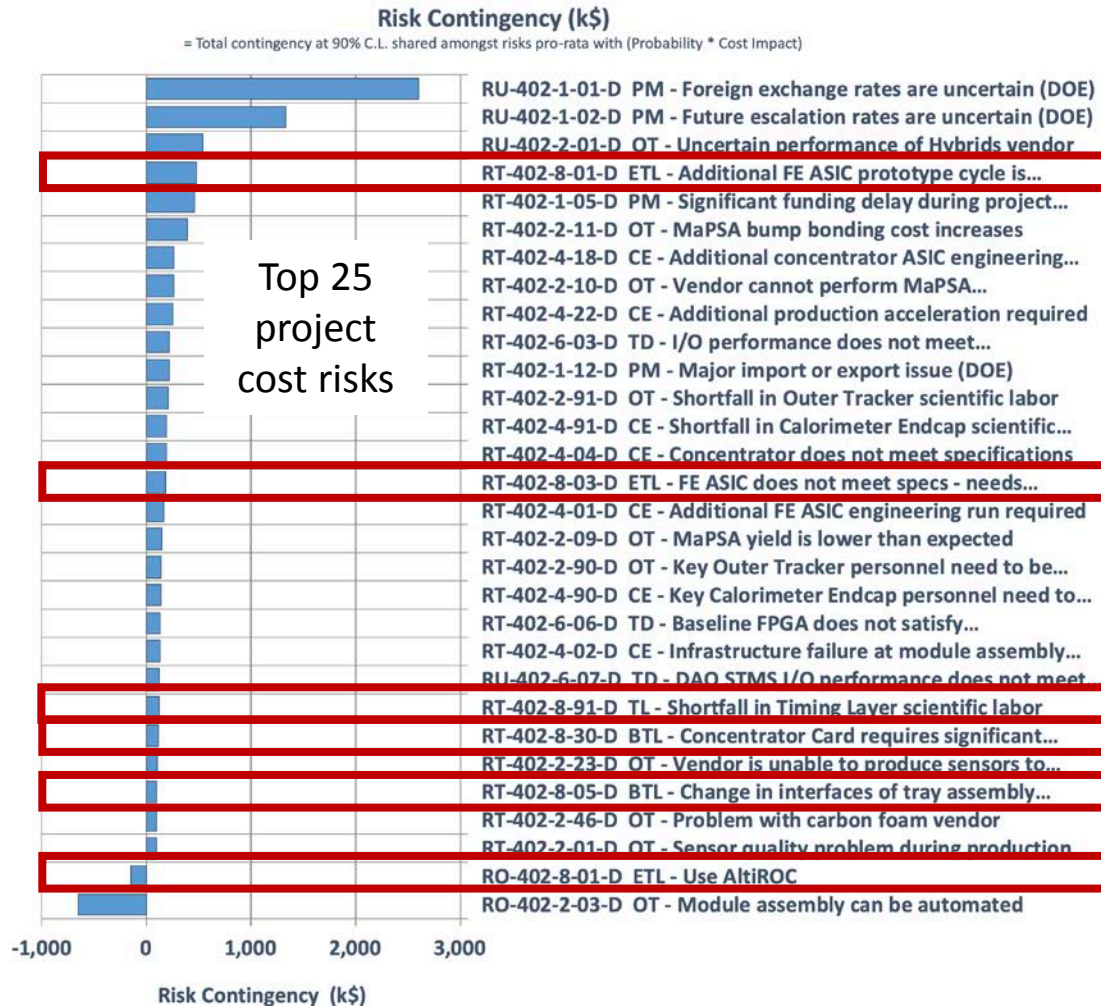
MTD risk contingency ≈ \$1.95M (15.3% of MTD BAC)

MTD risk contingency includes cost weighted fraction of project wide common risks (exchange rate, escalation, funding delay, import/export issues, OH, ES&H incident)

Project Cost Risks

Main risk changes in past 12 months are

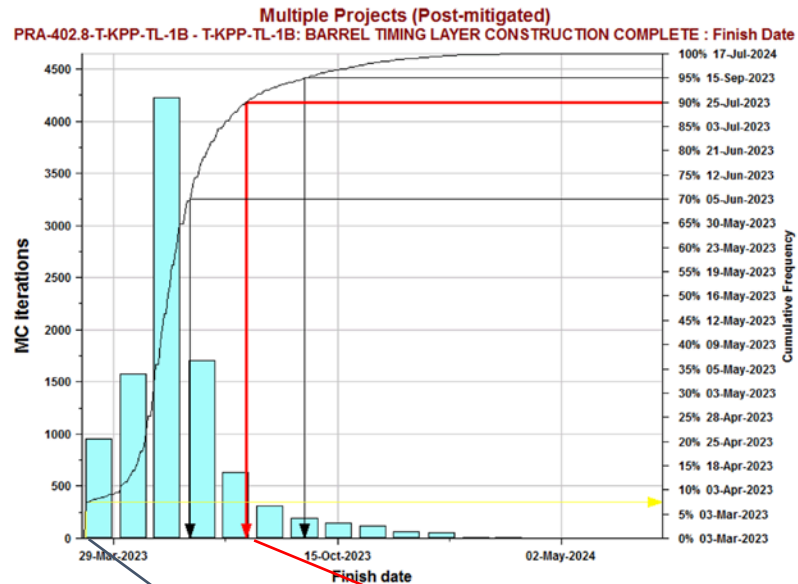
- Reviewed and updated full spectrum of risks
- New:** detailed risk analyses of BTL & ETL
- Re-aligned with the evolving iCMS plans
- Held external risk reviews
- Escalation, overheads, and exchange rate risks decreased (we have advanced by one year)



Project Risk-based contingency ≈ \$10.07M (8.1% of BAC)

BTL Schedule Contingency

- Risk MC aggregates delays stochastically in the full P6 schedule
- Risks will delay finish by **< 4.6 months** at 90% confidence level
- Plan has **10.9 months** of float before the CMS need by date
- T-KPP will finish before the need by date at **99% confidence level**
- Will revisit schedule risk when new LHC schedule is known



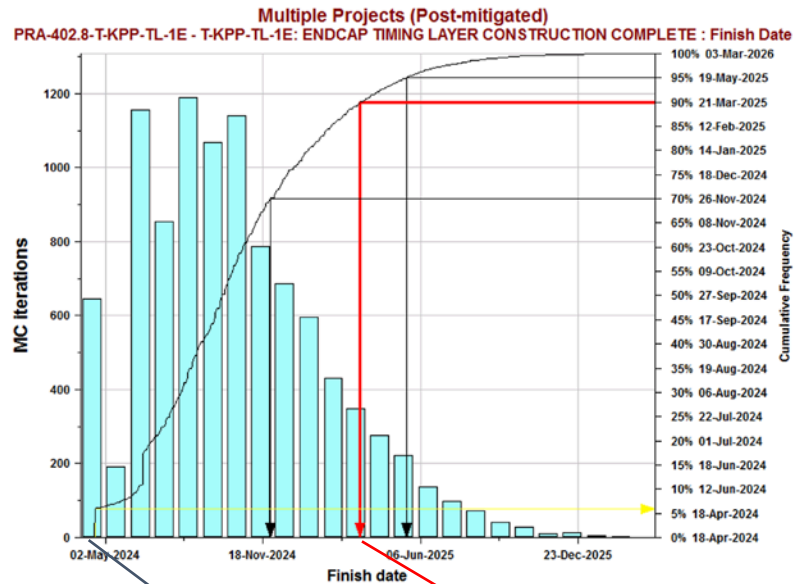
Analysis	
Iterations:	10000
Statistics	
Minimum:	03-Mar-2023
Maximum:	17-Jul-2024
Mean:	25-May-2023
Bar Width:	month
Highlighters	
Deterministic (03-Mar-2023)	8%
70%	05-Jun-2023
90%	25-Jul-2023
95%	15-Sep-2023

Results of schedule risk MC

	Finish date (early)	CMS need by date	Float to CMS need by date (months)	Finish date (90% C.L.)	Delay due to risk (90% C.L.) (months)	Confidence level to finish before CMS need by date
T-KPP-TL-B Barrel Timing Layer Construction Complete	6-Mar-2023	1-Feb-2024	10.9	25-Jul-2023	4.6	99%

ETL Schedule Contingency

- Risk MC aggregates delays stochastically in the full P6 schedule
- Risks will delay finish by **< 11.1 months** at 90% confidence level
- Plan has **14.1 months** of float before the CMS need by date
- T-KPP will finish before the need by date at **97% confidence level**
- Will revisit schedule risk when new LHC schedule is known



Analysis	
Iterations:	10000
Statistics	
Minimum:	18-Apr-2024
Maximum:	03-Mar-2026
Mean:	13-Oct-2024
Bar Width:	month
Highlighters	
Deterministic (18-Apr-2024)	6%
70%	26-Nov-2024
90%	21-Mar-2025
95%	19-May-2025

Results of schedule risk MC

	Finish date (early)	CMS need by date	Float to CMS need by date (months)	Finish date (90% C.L.)	Delay due to risk (90% C.L.) (months)	Confidence level to finish before CMS need by date
T-KPP-TL-E Endcap Timing Layer Construction Complete	17-Apr-2024	19-Jun-2025	14.1	21-Mar-2025	11.1	97%



Summary

The BTL and ETL design is mature and we have a well-developed schedule that reflects the design described in the MTD TDR and includes recommendations from the previous reviews

The detailed schedule in P6 has well motivated cost and labor estimates that are documented in the BOEs

Risks have been identified and reviewed and are linked in the schedule allowing us to model the cost and schedule impact

The MTD cost estimate and schedule is advanced, and we are well on the way to being prepared for CD-2