B06 - OT Path to Baseline

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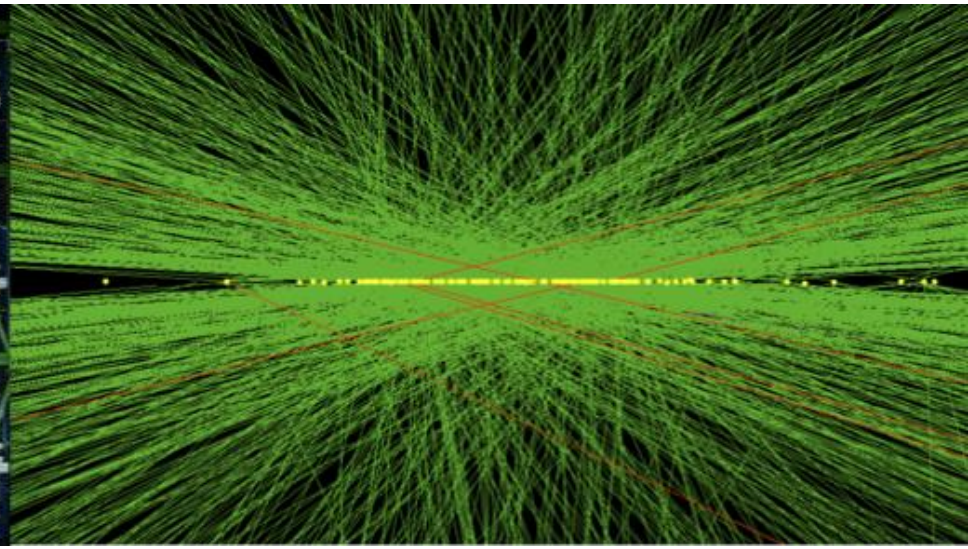
HL LHC CMS Detector Upgrade CD-1 Review

October 23rd, 2019



Prerequisites for Baseline

- Preliminary design

  Charge #2

  - Resolve remaining technical questions
  - Definitive scope, cost, and schedule
  - Resource loaded schedule suitable to measure Earned Value
- Implementation of Earned Value Monitoring System (EVMS)

  Charge #3

  - Measure performance against fixed baseline
  - Formal change control
  - Analyze cost and schedule variances
  - Produce metrics for DOE's project reporting system (PARS-II).

Preliminary Design

Charge #2

- Predecessors to "Ready for CD2" milestone
  - T4 - Outer Tracker - Ready for CD-3A 9/30/2019
    - CMS - OT sensor contract placed by CERN 9/30/2019
  - T4 - MaPSA Prototyping complete 8/12/2020
  - T5 - Functional PS module completed (East Coast) 10/9/2020
  - T5 - Functional PS module completed (Fermilab) 10/9/2020
  - T5 - First functional CBC3 prototype available 7/21/2020
  - T5 - Inner plank prototype tested 5/1/2020
  - T4 - Ring Mechanics Prototype Complete 3/16/2020
  - T5 - Inner layer prototype assembly complete 7/8/2020

	Sensors		Electronics		Modules		Mechanics		Integration		AVE		BAC	
OT	Mgmt	Tech	Mgmt	Tech	Mgmt	Tech	Mgmt	Tech	Mgmt	Tech	Mgmt	Tech	Mgmt	Tech
Conceptual Design	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Preliminary Design	100%	100%	98%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Final Design	100%	100%	100%	95%	100%	86%	93%	95%	87%	95%	96%	94%	99%	91%
Detailed Design	50%	80%	50%	20%	50%	20%	50%	20%	50%	20%	50%	32%	50%	31%
Construction Readiness	48%	75%	19%	20%	22%	20%	19%	20%	19%	20%	25%	31%	26%	30%

Preliminary Design – Sensors

Charge #2

- Contract was signed between CERN and HPK (8/23/19)
  - Cost is fixed (in JPY)
  - Delivery schedule is agreed upon
  - Sensor specifications are finalized
- Sensor thickness decision was taken (9/17/19)
  - Demonstrated that FZ290 sensors satisfy our needs
- Sensor design is close to final
  - Final PS-s design was transmitted to HPK
  - 2S design is being finalized
  - PS-p design will be finalized after experience with prototypes
- QC center setups close to complete
  - Brown is hosting a CMS-wide sensor QC workshop in November to finalize procedures
  - Will be ready to accept preproduction sensors in 2020
- We are ready for CD3a (target: March 2020)

Preliminary Design – MAPSA

Charge #2

- MaPSA prototype round 2
  - Round 1 of prototype MaPSAs (Oct 2019 and Jan 2020)
  - Round 2 of prototype MaPSAs (May 2020)
    - Contract awarded to two vendors
  - Test round 2 prototype MaPSAs
- Ready for CD-2 in August 2020

Preliminary Design – 2S Modules

Charge #2

- Complete 2S module design
  - CMS milestone on 3/31/20
  - Adapt current design to final sensor thickness
- Functional 2S prototype modules
  - CMS has built 17 2S functional modules, 2 with 8CBC3 hybrids
    - includes 2 at FNAL and 3 at Brown, 1 with 8CBC3 hybrids
    - Noise performance within specs (<10k e^-)
  - Service hybrids needed for full functionality (Q2-2020)
- Assembly procedure
  - Decide about automation options (Dec 2019)
- Ready for CD2 in July 2020

Preliminary Design – PS Modules

Charge #2

- Complete PS module design
  - CMS milestone on 7/20/20
  - Adapt current design to final sensor thickness
- Needed to build functional PS module
  - MaPSA (Oct 2019)
  - PS-s sensor (Jan 2020)
  - PS-FEH for 1.6 mm modules (Apr 2020)
  - PS-POH and PS-ROH (Q2 2020)
- Assembly procedure
  - Ready for automated assembly in Jul 2020
- Ready for CD-2 in October 2020

Preliminary Design – Mechanics & Integration

Charge #2

- Build and test inner plank prototype
  - Perform final thermal and mechanical tests (May 2020)
  - Fabricate final prototypes (Feb 2020)
  - Plank Mechanics Prototype Design Complete (Sep 2019 - done)
- Build ring mechanics prototype
  - Done
- Assemble inner layer prototype
  - Mechanical coupling of tilted and flat barrels
  - Fiber/cable routing prototype
  - Cooling manifold prototype
- Ready for CD-2 by July 2020

Scope, Cost, and Schedule

Charge #3,7

- Scope defined in KPPs

WBS	Threshold KPP	Objective KPP
402.2	T-KPP-OT-1: OUTER TRACKER CONSTRUCTION	O-KPP-OT-1: OUTER TRACKER CONSTRUCTION AND INTEGRATION
Outer Tracker	The Project will build, test, and grade approximately 30% of the total number of Modules needed for the Outer Tracker. 952 Modules will be used to construct the "Flat" Inner Barrel, the inner three layers of barrel modules. The modules and Flat Barrel shall have sufficient granularity and noise performance to ensure a projected occupancy of < 5%, and capable of forming and sending track pT information to the L1 trigger at LHC bunch crossing rates.	The Project will build, test, and grade approximately 33% of the total number of Modules needed for the Outer Tracker. 952 Modules will be used to construct the "Flat" Inner Barrel, the inner three layers of barrel modules. The modules and Flat Barrel shall have sufficient granularity and noise performance to ensure a projected occupancy of < 5%, and capable of forming and sending track pT information to the L1 trigger at LHC bunch crossing rates. The project shall integrate the "Flat" Inner Barrel detector into the full Outer Tracker, and test and calibrate it.

- Refined Estimates of Resources and Durations
  - Fundamental structure of sequenced activities is established
  - Further rounds of prototyping should validate estimated hours and durations
  - Completion of vendor inquiries and validation iterations will confirm costs and procurement structures

Cost – Basis of Estimate

Charge #3,7

https://go.usa.gov/xnSwv

- Project divided into 15 estimate documents
  - Maintain similarity in topics while parsing into finite number of digestible chunks
- Follows Project Office guidance via Key Assumptions Document
- Standard BOE format
  - Scope
  - Narrative for cost basis
    - May cite supplementary material in same or connected DocDB container
  - Summary Tables
    - M&S and Labor
    - Connected to costbook via "BoeRef"

L2 Parent:WBS : 402.2 OT - OUTER TRACKER (15)	
L3 Parent:WBS : 402.2.2 OT - Management (1)	
402.2.2 OT - Management	CMS-doc-12824
L3 Parent:WBS : 402.2.3 OT - Sensors (4)	
402.2.3.1 OT - QC Centers	CMS-doc-12989
402.2.3.2 OT - PS-P Sensors	CMS-doc-12991
402.2.3.3 OT - PS-S Sensors	CMS-doc-12993
402.2.3.4 OT - 2S Sensors	CMS-doc-12995
L3 Parent:WBS : 402.2.4 OT - Electronics (3)	
402.2.4.1 OT - Macro Pixel Sub-Assembly	CMS-doc-12997
402.2.4.2 OT - Test Systems	CMS-doc-12998
402.2.4.3 OT - DAQ	CMS-doc-13000
L3 Parent:WBS : 402.2.5 OT - Modules (5)	
402.2.5.1.1 OT - Module Assembly Facilities - East Coast	CMS-doc-13008
402.2.5.1.2 OT - Module Assembly Facilities - Fermilab	CMS-doc-13009
402.2.5.1.3 OT - Module Assembly Infrastructure	CMS-doc-13002
402.2.5.2 OT - Module Components	CMS-doc-13010
402.2.5.3 OT - Module Assembly	CMS-doc-13012
L3 Parent:WBS : 402.2.6 OT - Mechanics (1)	
402.2.6 OT - Mechanics	CMS-doc-13005
L3 Parent:WBS : 402.2.7 OT - Integration and Testing (1)	
402.2.7 OT - Integration and Testing	CMS-doc-13014

Cost – Example BOE

Charge #3,7

CMS Document 12991-v41

BoE for: 402.2.3.2 OT - PS-P Sensors

Document #: CMS-doc-12991-v41
Document type: Other
Submitted by: Steven Christopher Nahn
Updated by: Ulrich Heintz
Document Created: 01 Jun 2016, 19:52
Contents Revised: 09 Oct 2019, 10:47
Metadata Revised: 09 Oct 2019, 10:47

Update Document | Update Metadata | Add Files | Create Similar | Watch Document

Abstract:
BoE for: 402.2.3.2 OT - PS-P Sensors

Files in Document:

- BoE for 402.2.3.2 PS-P Sensors (BoE---402-2-3-2---OT---PS-P-Sensors.pdf, 999.2 kB)

Other Files:

- BoE Source file (BoE---402-2-3-2---OT---PS-P-Sensors.docx, 80.2 kB)
- Order document for PS-p prototype sensors from HPK (Order Document - CA 1557954.pdf, 85.8 kB)

Get all files as tar.gz, zip.

Topics:

- Countries:USA:US HL-LHC Upgrades:US HL-LHC BoE:BoEs: 402.2 Outer Tracker
- Countries:USA:US HL-LHC Upgrades
- Countries:USA:US HL-LHC Upgrades:US HL-LHC BoE

Authors:

- Ulrich Heintz

Notes and Changes:
Final corrections before CD-1 review

Related Documents:

- CMS-doc-13139: Supporting BoE materials for 402.02.03

11. Summary of M&S Resources

Table 1: Summary of inputs to the M&S cost estimate. The meanings of the contingency codes are described in the Key Assumptions document [Ref-3].

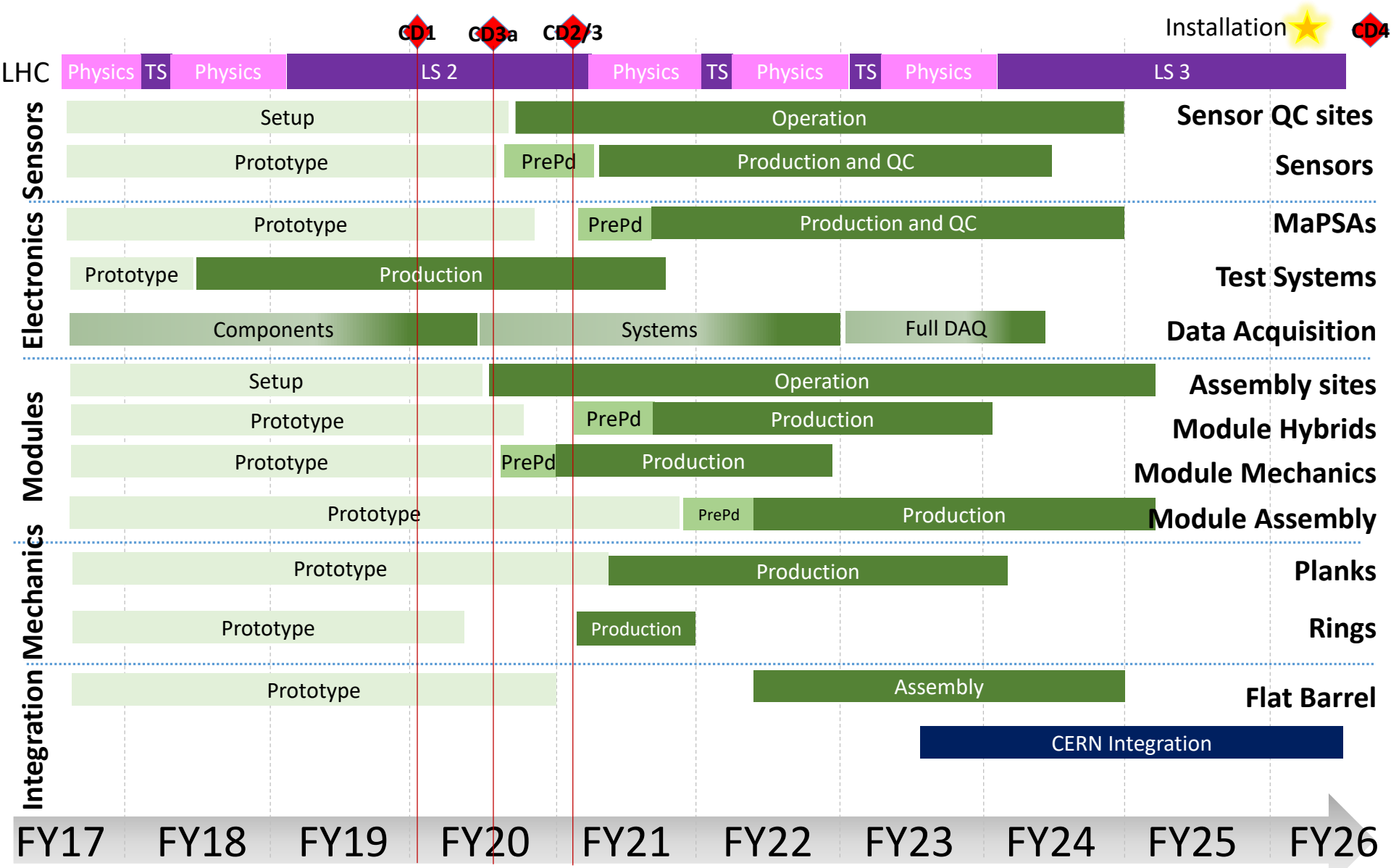
WBS - Name	BoE Ref	Name	Est. Type	Institute	Direct M&S
402.2.3.2.1 OT - PS-P Sensor Prototypes	CMS-doc-12991-MS-01	PS-P sensor prototypes	M1	TD2	54,357
	CMS-doc-12991-MS-02	Prototype shipping	M3	BR	550
				UR	550
			M1	BR	1,100
				UR	1,100
	CMS-doc-12991-MS-04	Cadium Sheet	M1	BR	400
	CMS-doc-12991-MS-05	Prototype Irradiations	M1	BR	1,500
	CMS-doc-12991-MS-06	Travel - RINSC	M1	BR	400
	CMS-doc-12991-MS-07	Travel - LANSCE	M1	BR	3,000
402.2.3.2.1 Total					**62,957**
402.2.3.2.2 OT - PS-P Sensor Production	CMS-doc-12991-MS-09	PS-p Preproduction	M3	TD2	48,091
	CMS-doc-12991-MS-10	PS-p Production	M3	TD2	688,160
	CMS-doc-12991-MS-13	Production Irradiation	M4	BR	6,000
				FN	5,500
	CMS-doc-12991-MS-14	Travel - RINSC	M4	BR	2,400
402.2.3.2.2 Total					**750,151**
Grand Total					**813,108**

HL-LHC CMS Detector Upgrades Project | **Costbook (DOE OPC and MIE)** | Lucas Taylor 06-Oct-2019 04:35 | Page 12 (of 175)

Activity ID	Activity Name	Institute	Resource Name	Labor (hours)	Direct M&S $	Direct + Indirect + Esc ($)	Estimate Uncertainty (%)	Estimate Uncertainty ($)	Total Cost ($)
Resource Type: Material				0	750,151	797,447		161,692	959,139
BoE Ref: CMS-doc-12991-MS-09				0	48,091	49,484		9,897	59,381
OT320550	CERN delivers preproduction PS-P sensors	TD2	M&S Exempt - Award	0	18,171	18,697	20%	3,739	22,437
OT320550	CERN delivers preproduction PS-P sensors	TD2	M&S Exempt - Award	0	29,920	30,787	20%	6,157	36,944
BoE Ref: CMS-doc-12991-MS-10				0	688,160	725,940		145,188	871,128
OT320780	CERN delivers production PS-P sensors (Lot 01)	TD2	M&S Exempt - Award	0	68,816	72,594	20%	14,519	87,113
OT320960	CERN delivers production PS-P sensors (Lot 02)	TD2	M&S Exempt - Award	0	68,816	72,594	20%	14,519	87,113
OT321140	CERN delivers production PS-P sensors (Lot 03)	TD2	M&S Exempt - Award	0	68,816	72,594	20%	14,519	87,113
OT321320	CERN delivers production PS-P sensors (Lot 04)	TD2	M&S Exempt - Award	0	68,816	72,594	20%	14,519	87,113
OT321500	CERN delivers production PS-P sensors (Lot 05)	TD2	M&S Exempt - Award	0	68,816	72,594	20%	14,519	87,113
OT321680	CERN delivers production PS-P sensors (Lot 06)	TD2	M&S Exempt - Award	0	68,816	72,594	20%	14,519	87,113
OT321860	CERN delivers production PS-P sensors (Lot 07)	TD2	M&S Exempt - Award	0	68,816	72,594	20%	14,519	87,113
OT322040	CERN delivers production PS-P sensors (Lot 08)	TD2	M&S Exempt - Award	0	68,816	72,594	20%	14,519	87,113
OT322220	CERN delivers production PS-P sensors (Lot 09)	TD2	M&S Exempt - Award	0	68,816	72,594	20%	14,519	87,113
OT322400	CERN delivers production PS-P sensors (Lot 10)	TD2	M&S Exempt - Award	0	68,816	72,594	20%	14,519	87,113

OT Cartoon Schedule

Charge #2,3



Resource-Loaded Schedule (RLS)

Charge #3,7

Layout: UH - my layout | Filter: All Activities

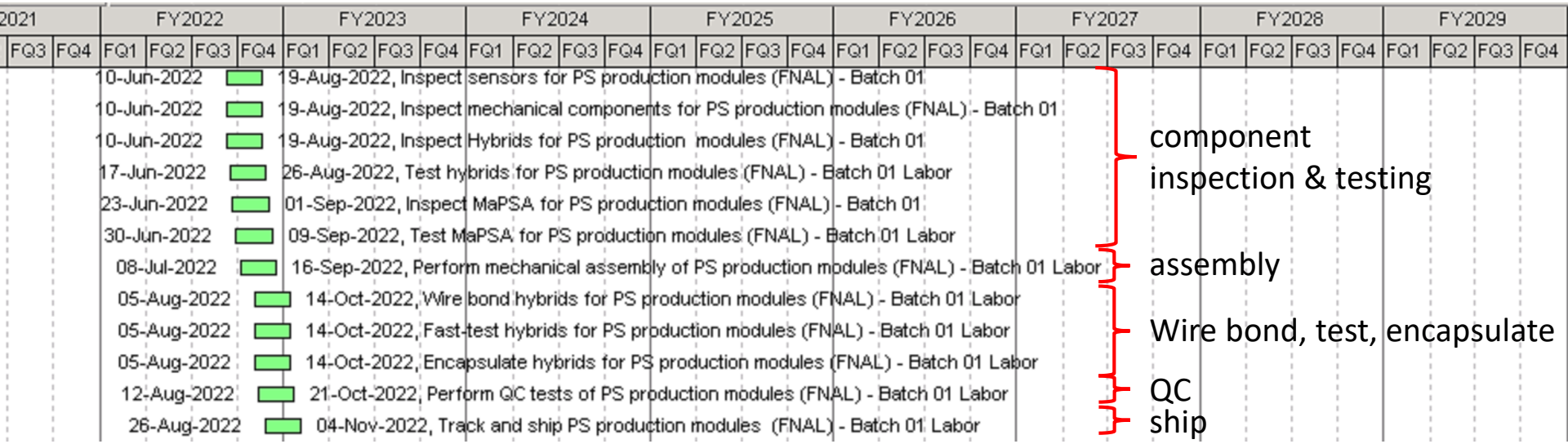
#	Activity ID	Activity Count	Planned Duration	Start	Finish	Planned Labor HRs	Planned Labor Cost	Planned NonFNAL labor HRs	Planned NonFNAL Labor Cost	Planned M/S Burdened Cost	Planned Total Burdened Cost
1	DOE-CD1-402.2 402.2 OT - Outer Tracker (at DOE CD1)	3835	2950d	04-Jan-2016	01-Oct-2027	151230h	$10,448,899.16	225849h	$8,581,485.53	$23,841,144.34	$42,871,529.03

- Fully Resource-Loaded Schedule captures the OT project
  - Follows best practices of FNAL Office of Project Support Services
    - Vetted by other O413.3B projects: Mu2e, g-2, Phase 1, LBNF/DUNE, et al
  - Uses Industry-standard scheduling (Primavera, aka “P6”) and cost processing tools (Cobra)
  - Site-specific overhead, escalation computed by tools
    - M&S budgeted in direct dollars
    - FNAL labor and Institute labor budgeted in hours, site-specific labor rates applied
- Reviewed by OPSS in March 2017
  - 47 comments, all addressed: DocDB 13298
  - Valuable learning experience for the OT team

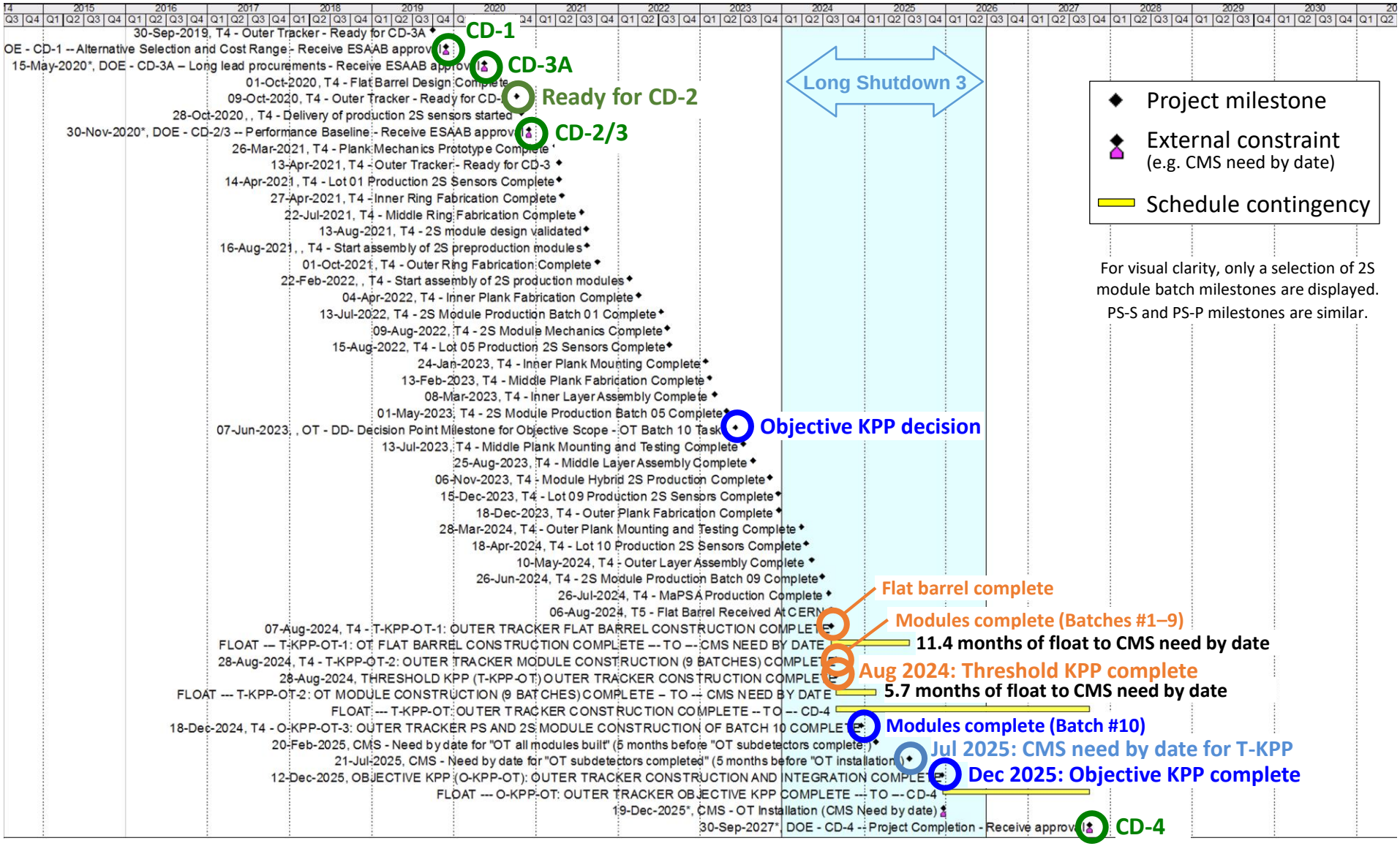
Production Schedule

Charge #3

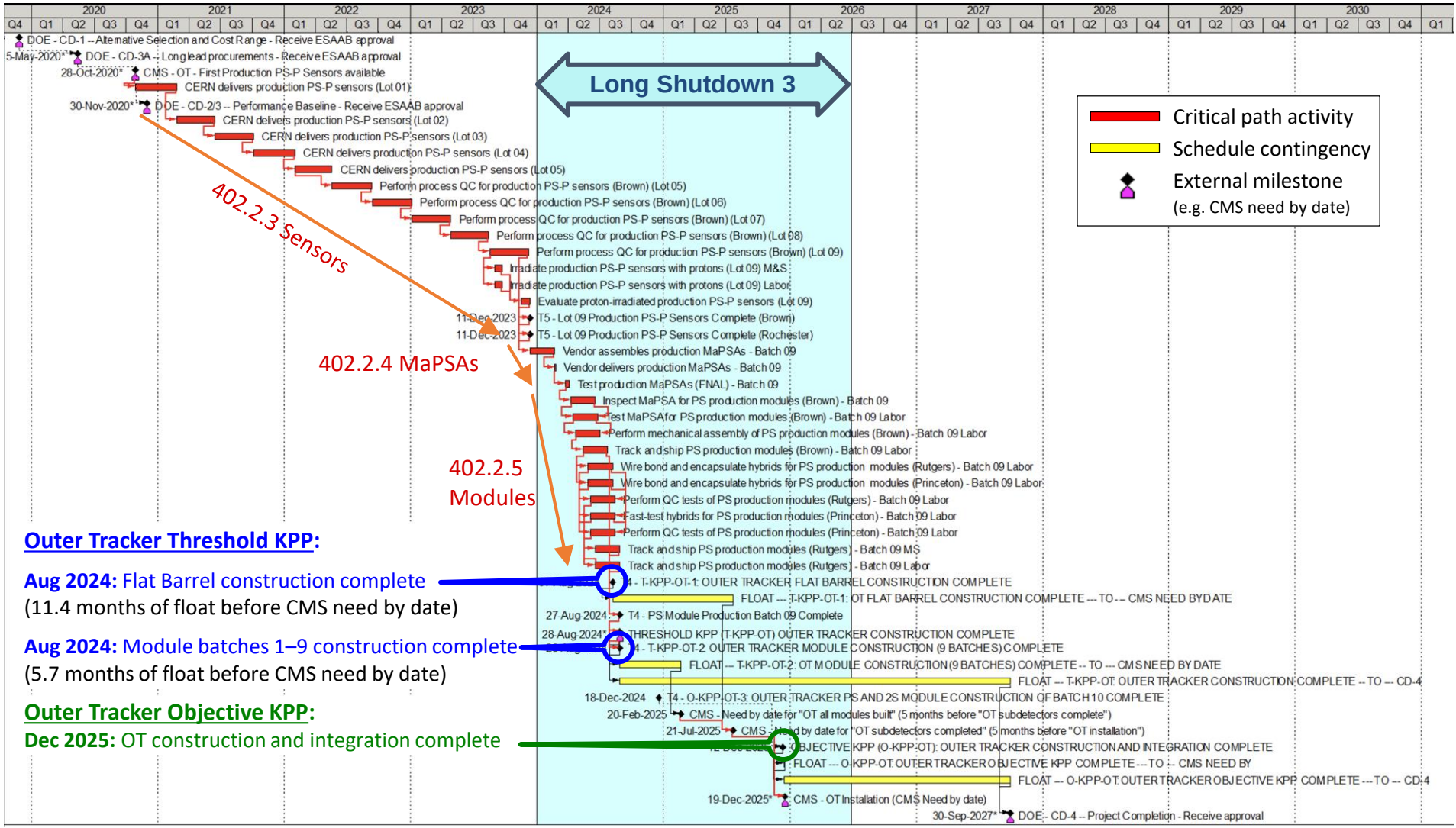
- Balance between granularity and maintainability
  - Cannot have activities for each of the module
- Break up production for each type of module into batches
  - Preproduction + 10 production batches
  - Propagates to Sensors, MaPSAs, Components, Assembly
  - Example: PS Assembly Batch takes 104 workdays to process, all pipelined



Key milestones and schedule contingency



Critical Path and Schedule Contingency



Outer Tracker Threshold KPP:

Aug 2024: Flat Barrel construction complete
(11.4 months of float before CMS need by date)

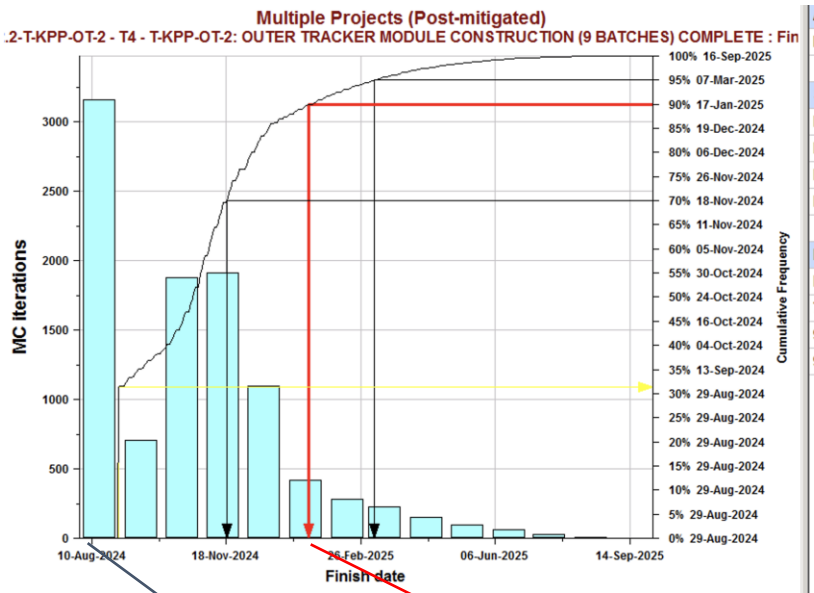
Aug 2024: Module batches 1–9 construction complete
(5.7 months of float before CMS need by date)

Outer Tracker Objective KPP:

Dec 2025: OT construction and integration complete

Schedule Contingency: Modules

- Risk MC aggregates delays stochastically in the full P6 schedule
- Risks will delay finish by **< 4.7 months** at 90% confidence level
- Plan has **5.8 months** of float before the CMS need by date
- T-KPP will finish before the need by date at 94% confidence level
- Will revisit schedule risk when new LHC schedule is known



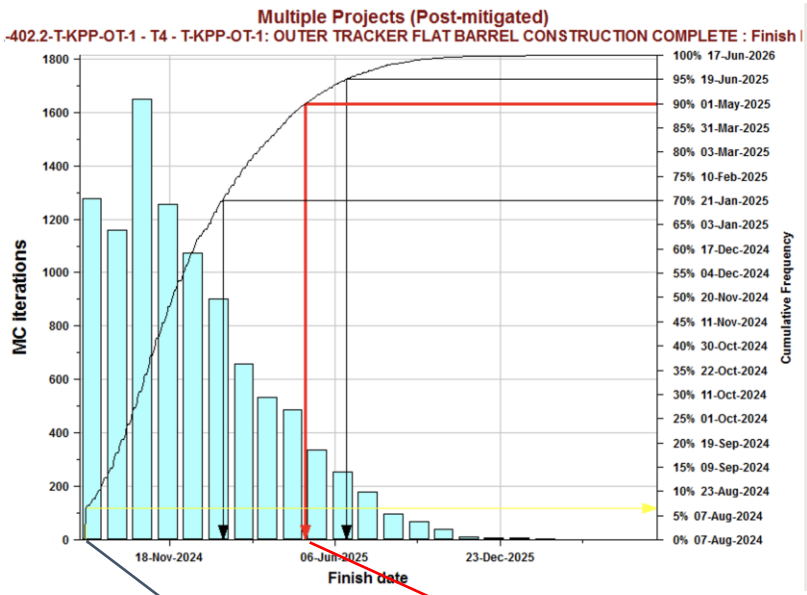
Analysis	
Iterations:	10000
Statistics	
Minimum:	29-Aug-2024
Maximum:	16-Sep-2025
Mean:	28-Oct-2024
Bar Width:	month
Highlighters	
Deterministic (29-Aug-2024)	31%
70%	18-Nov-2024
90%	17-Jan-2025
95%	07-Mar-2025

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-OT-2	Outer Module (9 Batches) Construction Complete	28-Aug-2024	20-Feb-2025	5.8	17-Jan-2025	4.7	94%

Schedule Contingency: Flat Barrel

- Risk MC aggregates delays stochastically in the full P6 schedule
- Risks will delay finish by < **8.8 months** at 90% confidence level
- Plan has **11.4 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:	07-Aug-2024
Maximum:	17-Jun-2026
Mean:	12-Dec-2024
Bar Width:	month
Highlighters	
Deterministic (07-Aug-2024)	6%
70%	21-Jan-2025
90%	01-May-2025
95%	19-Jun-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-OT-1	Outer Tracker Flat Barrel Construction Complete	7-Aug-2024	21-Jul-2025	11.4	1-May-2025	8.8	97%

Responsibility Assignment Matrix

Charge #3

- RLS fully factorized into Earned Value Monitoring Units
  - Control Accounts are the lowest level quantum for agency monitoring

402.2 OT - Outer Tracker (at DOE CD1)	42,871,529
Narain, Meenakshi	15,379,014
OT - Module Sites	5,324,064
OT - Module Assembly	10,054,950
Heintz, Ulrich	7,371,148
OT - Sensors	7,371,148
Spiegel, Lenny	6,406,966
OT - Module Components	6,406,966
Gershtein, Yuri	857,430
OT - Test Systems	857,430
Gruenendahl, Stefan	6,366,701
OT - FB Mechanics	2,380,031
OT - Integration and Testing	3,986,670
Merkel, Petra	1,125,217
OT - Management	1,125,217
Canepa, Anadi	5,365,054
OT - Macro Pixel Sub-Assembly	2,468,116
OT - DAQ	2,896,938

Statusing

Charge #3

- What is it?
  - Monthly collection of Work Performed
    - Objective measure based on pre-declared measurement technique (Performance Measurement Technique, "PMT")
  - Monthly collection of Actual Cost
    - From FNAL fiscal system
- When does it start?
  - Required to demonstrate >3 months of EVMS reporting before CD-2
- OT started statusing a practice schedule in Jan 2018
  - Experience with the process while the schedule can still be modified
  - Project team gets familiar with the demanding EVMS cycle
  - Added benefit: Can relinquish contingency on completed activities
  - Project office resources were not sufficient to sustain monthly statusing while developing CD-1 documentation for all subprojects
  - Plan is to resume monthly statusing following this review

Summary

- Design Maturity
  - Preliminary design essentially complete
  - Ready for CD3a (long lead time procurements)
  - Further prototype cycles to validate design
- OT Cost and Schedule
  - Structure is suitable for the deliverables of the project
  - BOE documentation is well developed
  - Firm up cost and schedule based on prototyping and vendor surveys
- Resource Loaded Schedule
  - Developed beyond requirements for CD-1
  - Suitable to support EVMS
  - Already conducted first statusing exercises
- Target for CD-2 review is November 2020