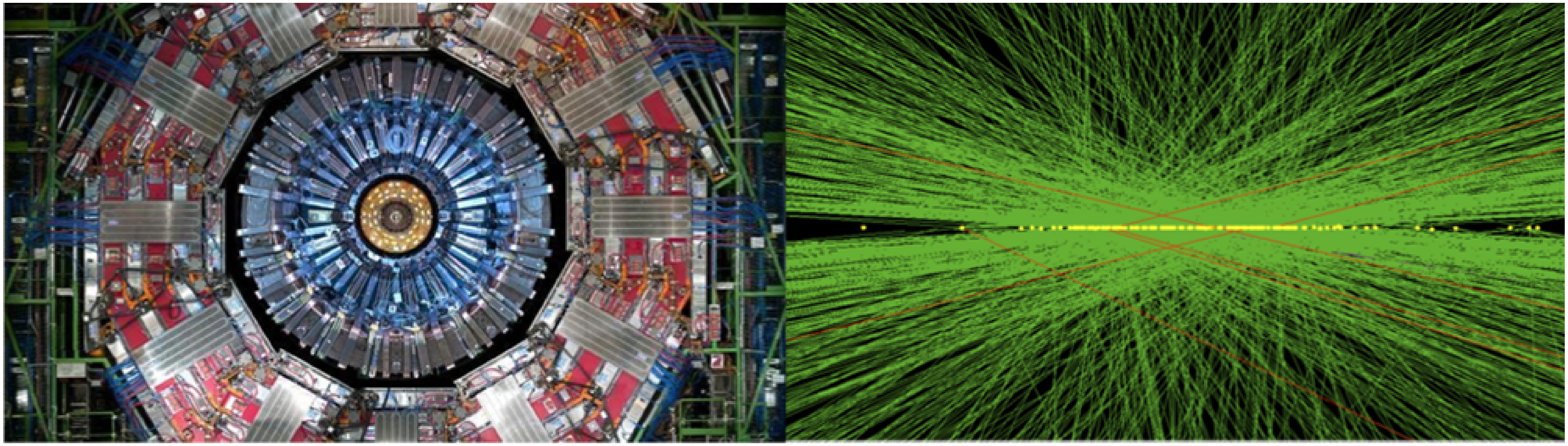
P07: L2 Overview - Trigger and DAQ - 402.6

Jeffrey Berryhill, L2 Manager

HL-LHC CMS Detector Upgrade CD-1 Review

October 22, 2019



Outline

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

Charge #5

Biographical Sketches

- L2 Manager: Jeffrey Berryhill, Senior Scientist, Fermilab
  - Physics PhD (Chicago 2000), PMP certified (2016)
  - CMS, BaBar, CDF collaborator
  - Working on CMS trigger at FNAL since 2006
  - Int'l CMS L1 Trigger Upgrade Co-coordinator 2018-
  - USCMS L2 manager for Trigger/DAQ upgrade 2015-
  - Int'l CMS PM for LS1 upgrade of calorimeter trigger 2014-5
  - CMS Convener: Standard Model Physics 2012-3
- L2 Manager: Keith Ulmer, Professor, Colorado-Boulder
  - Physics PhD (Colorado 2007)
  - CMS Phase 2 Track Trigger to L1 Trigger interface coordinator 2019-
  - CMS Convener: SUSY group 2014-2015
- L2 Deputy: Rick Cavanaugh, Professor, UIC/Fermilab
  - International CMS L1 trigger Phase 2 Upgrade Co-manager 2016-18
  - LS1 upgrade of calorimeter trigger 2014-2015
  - USCMS Coordinator: LHC Physics Center 2010-2013
  - CMS Convener: Particle Flow & Tau ID Group, CMS, 2007-2008

CMS Upgrade Scope

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

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

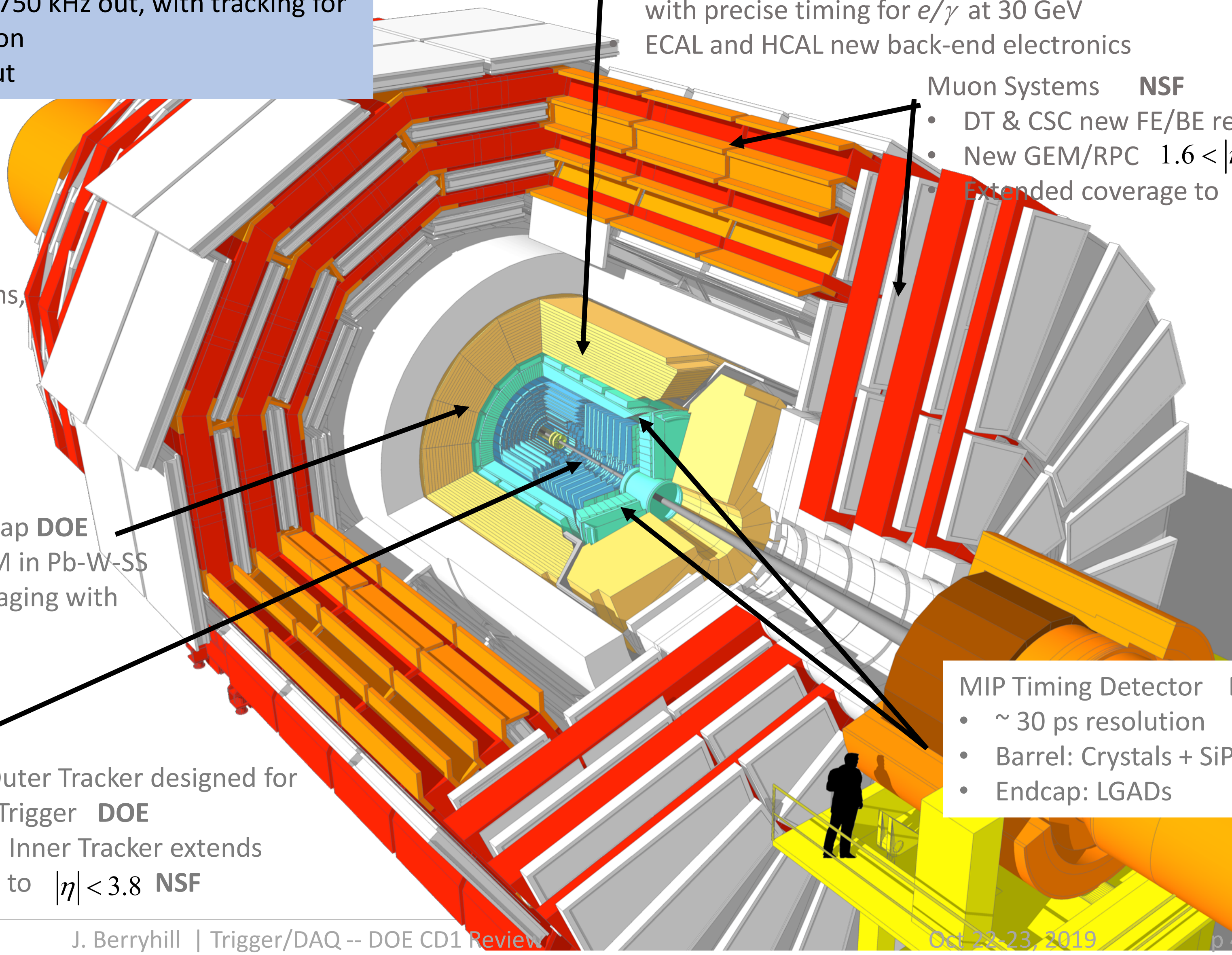
Muon Systems NSF
- DT & CSC new FE/BE readout
- New GEM/RPC $1.6 < |\eta| < 2.4$
- Extended coverage to $|\eta| < 3.0$

Beam Radiation Iand Luminosity, Common Systems, Infrastructure

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

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

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



Charge #2

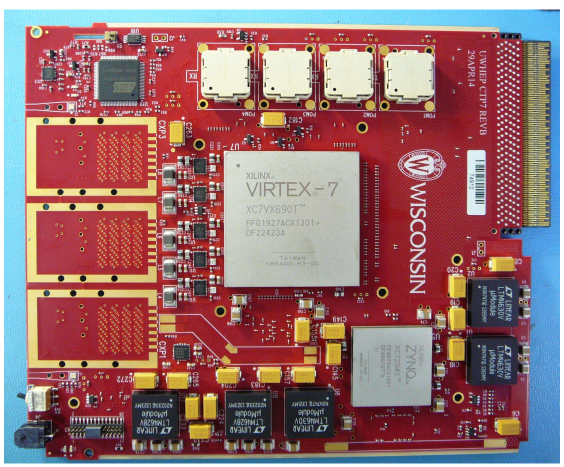
402.06 Upgrade Motivation

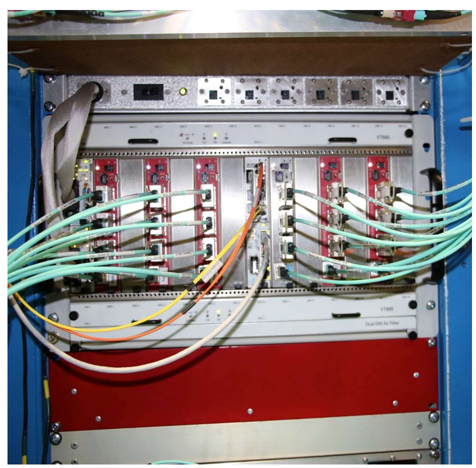
- The L1 trigger system efficiently identifies scientifically relevant pp collisions with low latency to reduce the recorded data output event rate by CMS from 40 MHz down to a rate which meets output DAQ capability.
- HL-LHC upgrade expands DAQ capability to **750 kHz output** and extend latency to **12.5** μ**s**.
  - DAQ expansion keeps up with rising signal rates.
  - Longer latency and new backend systems to enhance background rejection.
- Barrel calorimeter readout electronics will be upgraded to output higher granularity data (all ECAL crystals). **Calorimeter Trigger** will be upgraded to accept and process these for highest precision energy cluster reconstruction, as well as accepting and combining clusters from CE and HF.
- New **Correlator Trigger** system will combine tracking data with cluster data to reconstruct the entire event at the particle level ("particle flow"), which allows for highest precision object reconstruction, pileup mitigation, and background rejection.
- **DAQ** capacity is expanded to ship up to 31 GB/s for offline reconstruction at HL-LHC startup.

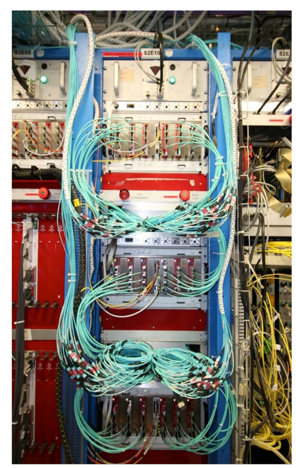
402.06 Conceptual Design

Charge #2

- Chief computing unit for L1 trigger systems is an **ATCA blade** mounted with high-speed, high I/O **FPGA**(s), linked to other blades with **10-28 Gb/s fiber optic** I/O.
- **Calorimeter Trigger** is a two-stage network of blades which 1) regionally clusters data from the BC backend electronics and 2) globally merges and sums data, including HF and CE, and identifies energy clusters of scientific interest (jets, taus, electrons/photons).
- **Correlator Trigger** is a two-stage network which 1) merges tracking, calorimeter, and muon data to perform particle reconstruction and mitigate pileup and 2) reconstructs particles of interest (jets, leptons, photons, sums, composites, etc.) for final trigger decision.







Installed Phase 1 μTCA-based hardware with 10 Gb/s optical I/O.

CMS HL-LHC Trigger Architecture

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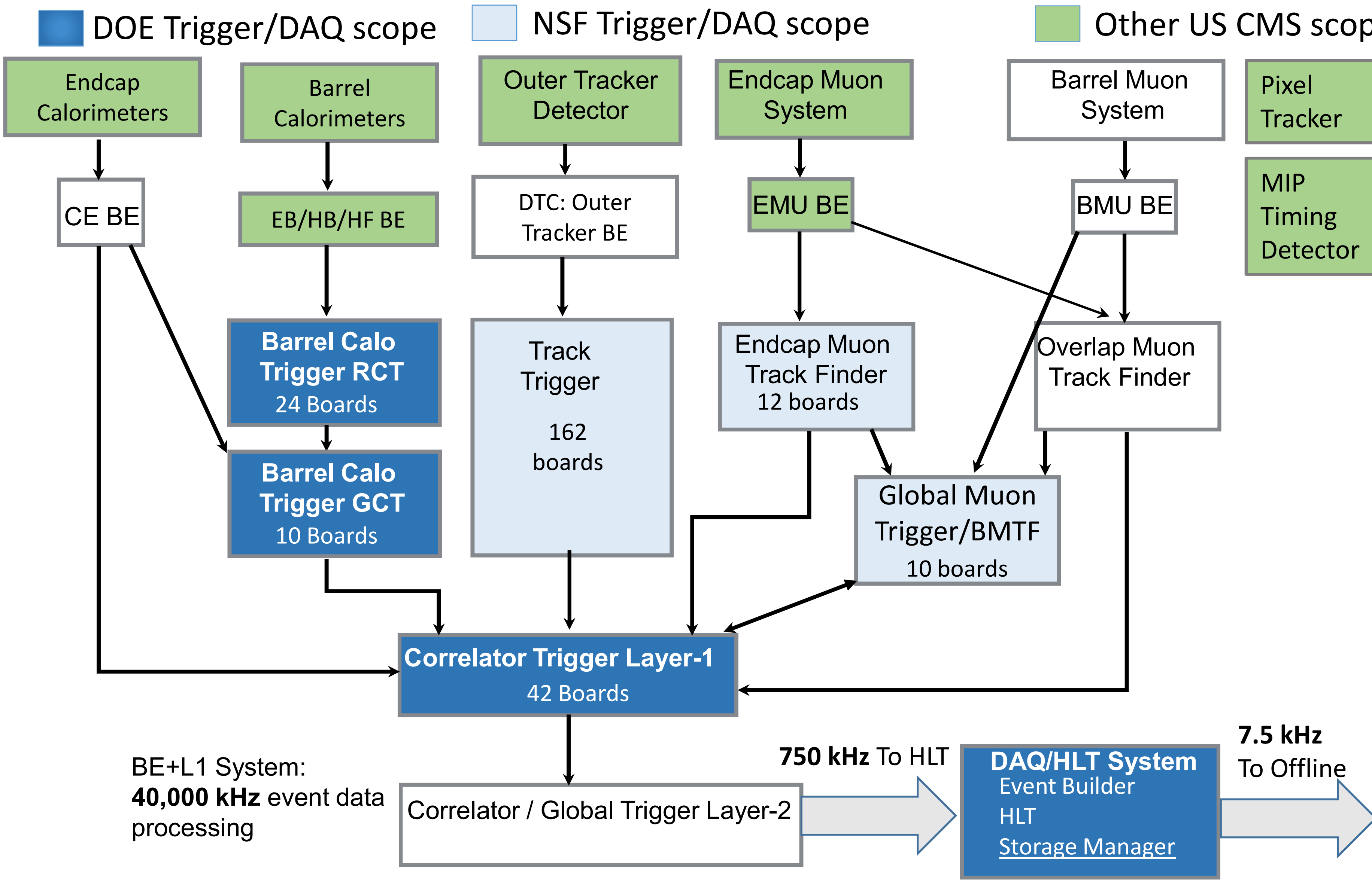
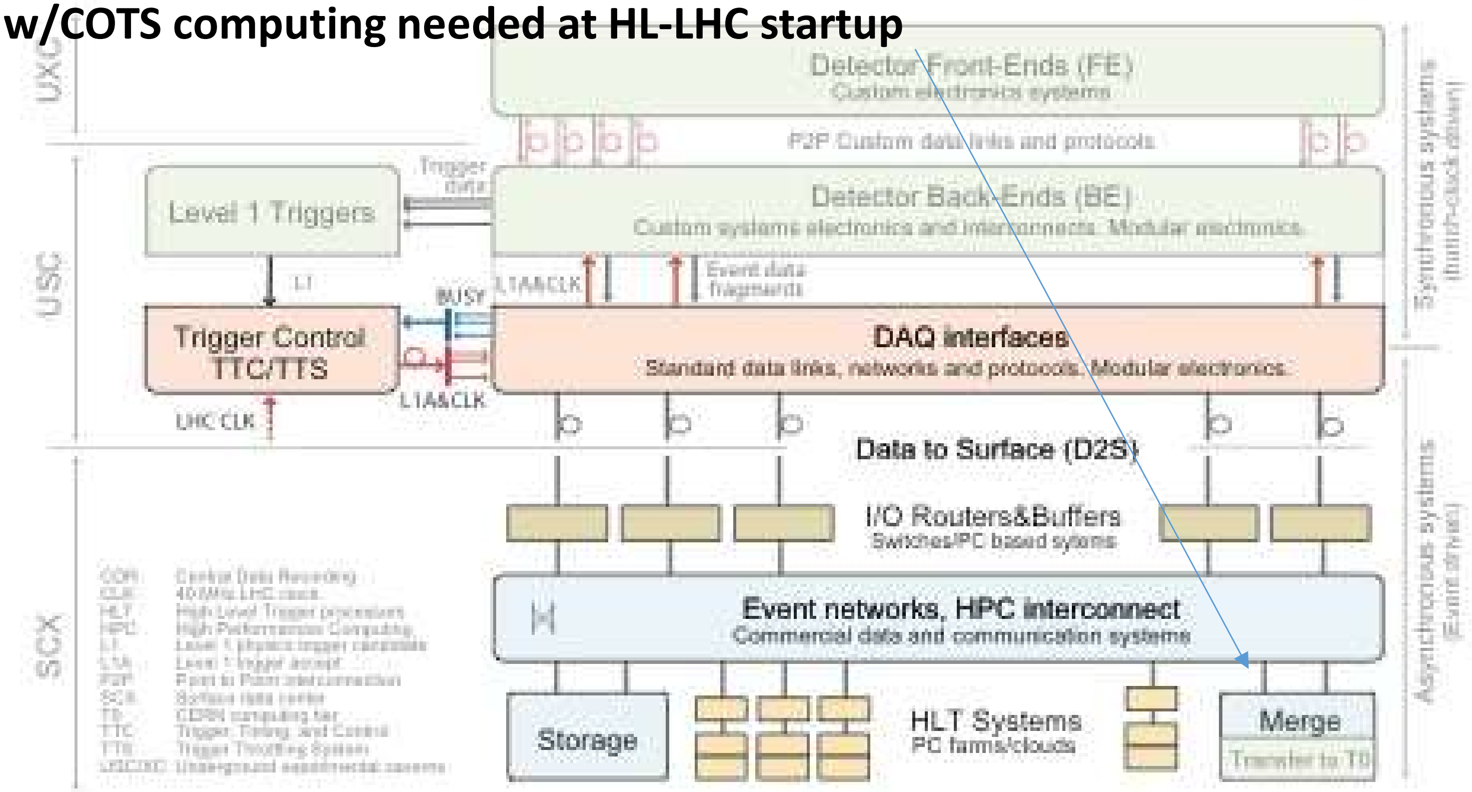


DAQ Architecture

- Synchronous timing and control for L1 trigger and backend electronics
- Data to surface routing and buffering
- Event networks for building events from BE fragments
- HLT filtering of built events
- **Local storage (~2.7 PB) and transfer (up to 31 GB/s) of accepted events to T0 w/COTS computing needed at HL-LHC startup**



Charge #2

Trigger/DAQ Upgrade Scope Summary

- Trigger/DAQ DOE project consists of digital electronics, associated infrastructure, firmware, and software to enhance or replace the existing CMS L1 trigger system.
  - Replace **L1 calorimeter trigger system (402.6.3)** to exploit new calorimeter electronics
  - New **L1 correlator trigger system (402.6.5)** to enhance trigger decision-making
  - Replace **Storage Manager and Transfer System (402.6.6)** for the DAQ
- L1 Calorimeter trigger
  - 34 ATCA boards, firmware, software, and infrastructure for accepting "trigger primitive" calorimeter detector input from the barrel calorimeter systems BE electronics and output cluster/particle/sums data to the Correlator Trigger. Benchmarks for electromagnetic cluster position and energy resolution.
- L1 Correlator Trigger
  - 42 ATCA boards, firmware, software, and infrastructure for accepting input from the track trigger, muon trigger, and calorimeter triggers and output particle candidates for downstream use in the correlator trigger system. Benchmarks for track-cluster and track-muon matching efficiency.

Trigger/DAQ Scope 2019 CD1 vs. 2018 IPR

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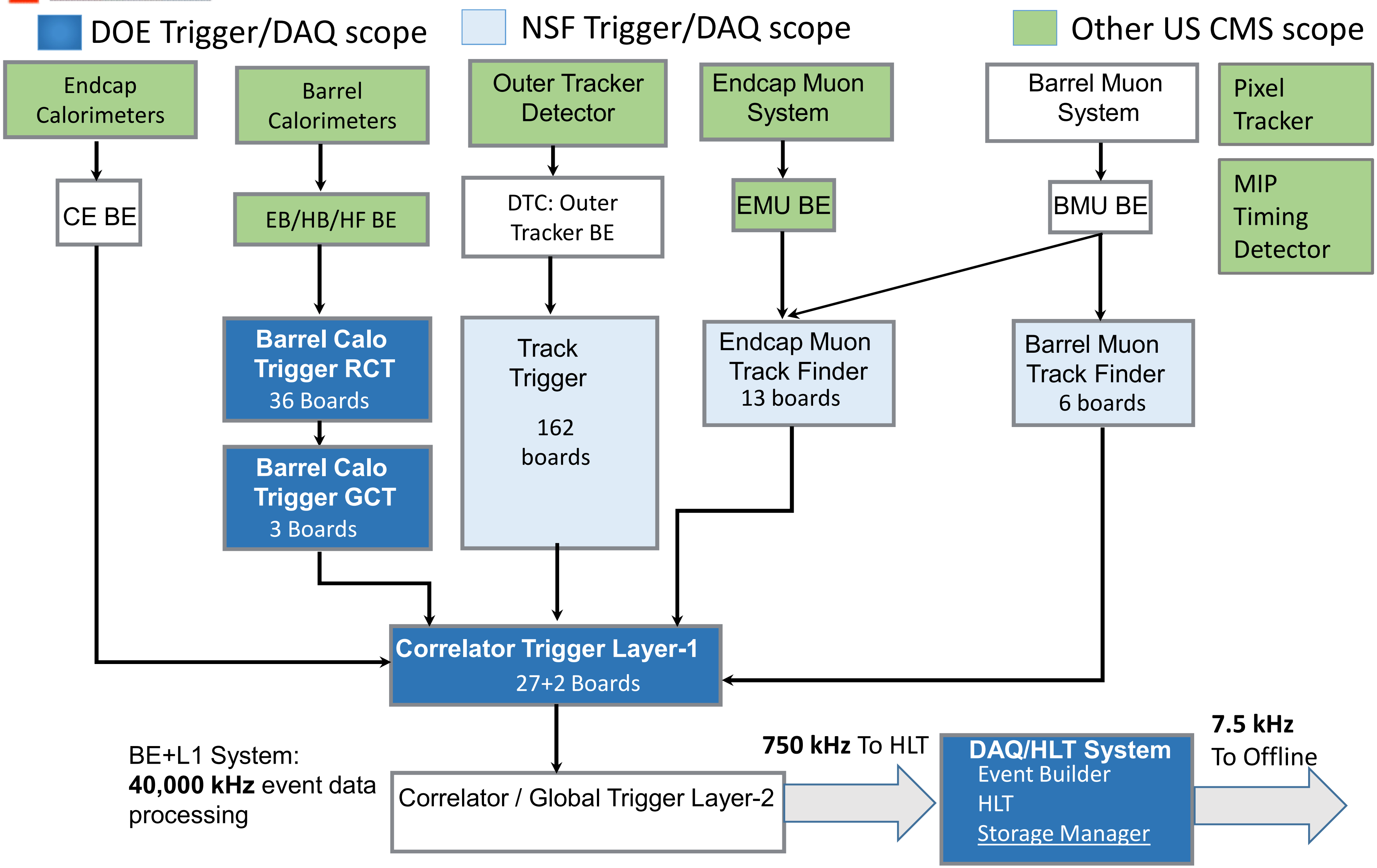
- USCMS Trigger/DAQ scope was based on requirements specified in 2017 CMS L1 Trigger interim TDR.
- CMS L1 Trigger will submit/approve/publish its final TDR in March/June/Sept 2020.
- In June 2019 CMS L1 Trigger agreed to requirements and architecture for the final TDR (JB is co-manager of the CMS L1 trigger Upgrade):
- L1 Calorimeter trigger
  - Value engineering has arrived at a design for the Regional Barrel Calorimeter Trigger of reduced size and cost (36 → 24 boards in the production system)
  - Global Calorimeter Trigger expanded to accept CE inputs (3 → 10 production boards)
- L1 Correlator Trigger
  - Firmware requirements for particle flow reconstruction led to expanding the size of Layer-1 (27 → 36 boards).
  - Vertexing boards expanded to include track-object reconstruction (2 → 12 boards); scope subdivided 50/50 with international partner (US scope = 6 boards).
- Cost model changes (net neutral):
  - Infrastructure (crates, DAQ cards, fibers, patch panels) costs were outsourced to a partner, but are now included.
  - Board costs are reduced upon value engineering and discounted FPGA costs.
- Final cost book will be determined in summer 2020 prior to CD 2.

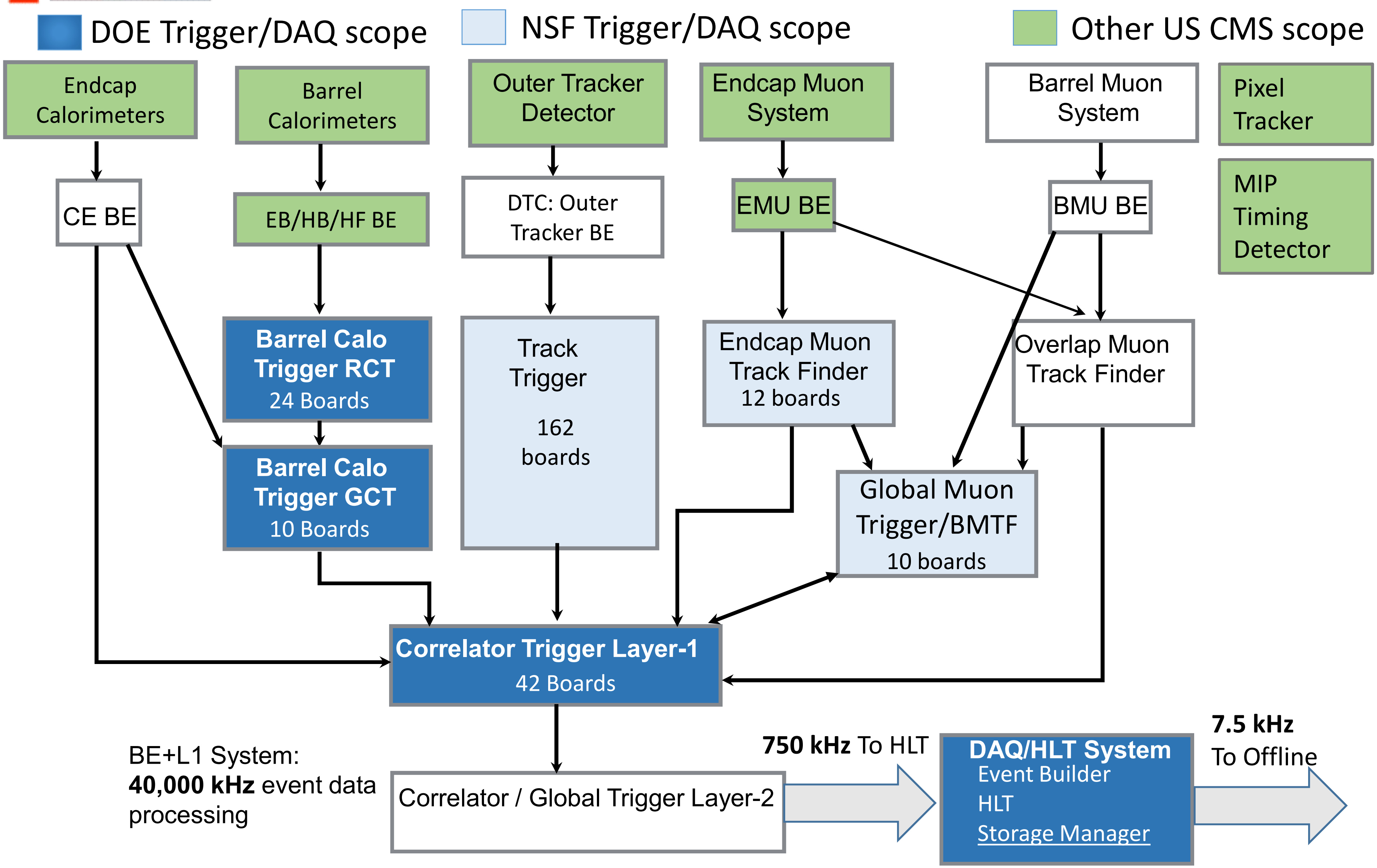
Charge #2

USCMS scope, 2018 IPR



Charge #2

US CMS Scope, 2019 CD 1



402.6 Trigger and DAQ

Threshold and Objective KPPs

Charge #2

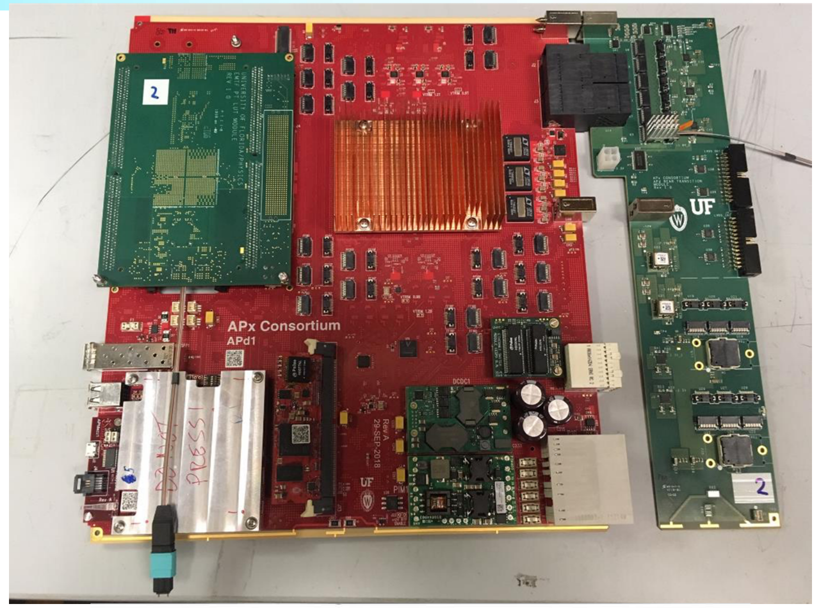
CMS-doc-13237

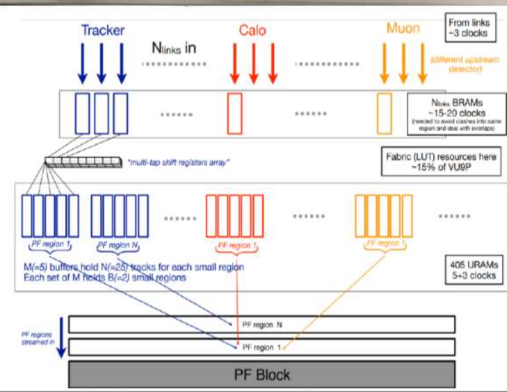
WBS	Threshold KPP	Objective KPP
402.6	T-KPP-TD-1: TRIGGER CONSTRUCTION	T-KPP-TD-1: TRIGGER AND DAQ CONSTRUCTION AND INSTALLATION
Trigger and DAQ	The project shall design, produce, and test both the Barrel Calorimeter electronics required for receiving and processing data from the barrel calorimeter and the Corrrelator Trigger electronics required for receiving and processing data from the calorimeter, muon, and track trigger systems, both of which transmit output to the downstream trigger components and DAQ. The project also includes development of software and firmware needed to operate the electronics and implement L1 trigger reconstruction. The Barrel Calorimeter trigger shall be validated, based on test data patterns from simulations verified against detector readout data, to provide a position resolution of R = 0.01 and energy resolution of 10% for electrons and photons in the energy range 20-30 GeV. The Correlator trigger shall be validated, based on simulated test data patterns verified against detector readout data, to correlate identified input track, calorimeter cluster, and muon trigger-level primitives efficiently. For 20 GeV electrons (muons), the matching efficiency of the Correlator trigger between received primitive tracks and received primitive clusters (muons) must be greater than 95%.	The project shall design, produce, and test both the Barrel Calorimeter electronics required for receiving and processing data from the barrel calorimeter and the Corrrelator Trigger electronics required for receiving and processing data from the calorimeter, muon, and track trigger systems, both of which transmit output to the downstream trigger components and DAQ. The project also includes development of software and firmware needed to operate the electronics and implement L1 trigger reconstruction. The Barrel Calorimeter trigger shall be validated, based on test data patterns from simulations verified against detector readout data, to provide a position resolution of R = 0.01 and energy resolution of 10% for electrons and photons in the energy range 20-30 GeV. The Correlator trigger shall be validated, based on simulated test data patterns verified against detector readout data, to correlate identified input track, calorimeter cluster, and muon trigger-level primitives efficiently. For 20 GeV electrons (muons), the matching efficiency of the Correlator trigger between received primitive tracks and received primitive clusters (muons) must be greater than 95%. The project shall specify, procure, and test the equipment needed for the startup online Storage Manager and Transfer System, and the software used for collecting, aggregating and distributing events accepted by the high-level trigger. The Storage Manager startup hardware shall be sized to support data buffering of at least 1 day of data from the HLT at a minimum of 31 GB/s, concurrently transferring data to CERN central computing and transferring monitoring data to the online monitoring system. Both the Calorimeter trigger and Correlator Trigger shall be installed, commissioned and validated in situ using full-speed connections from testing data sources and to data storage using the simulated test data patterns.

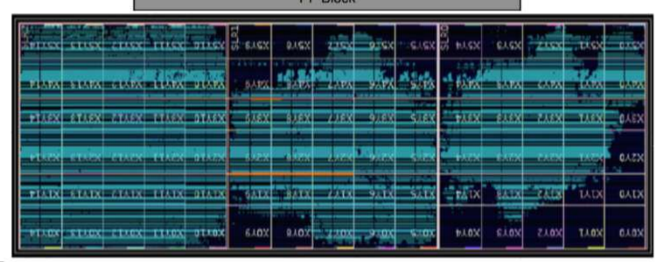
Charge #2

402.6 Technical Progress since 2018 IPR

- First ATCA prototype trigger boards produced and operating successfully
  - 96 optical links in and out transmitting data at 25 Gb/s with no errors.
  - Two prototypes transmitting data to one another.
  - Xilinx Virtex Ultrascale Plus FPGA processing (VU9P)
  - Embedded linux SoC control, IPMC, gigabit Ethernet switching
- Mature firmware design for trigger algorithms
  - Algorithms meeting requirements compiled and tested on Xilinx FPGAs
  - Data protocols for high-speed links completed
- Oct.-Dec. 2019 for exercising firmware on prototype hardware, followed by preproduction phase starting Jan. 2020.







Charge #2

402.6 Maturity

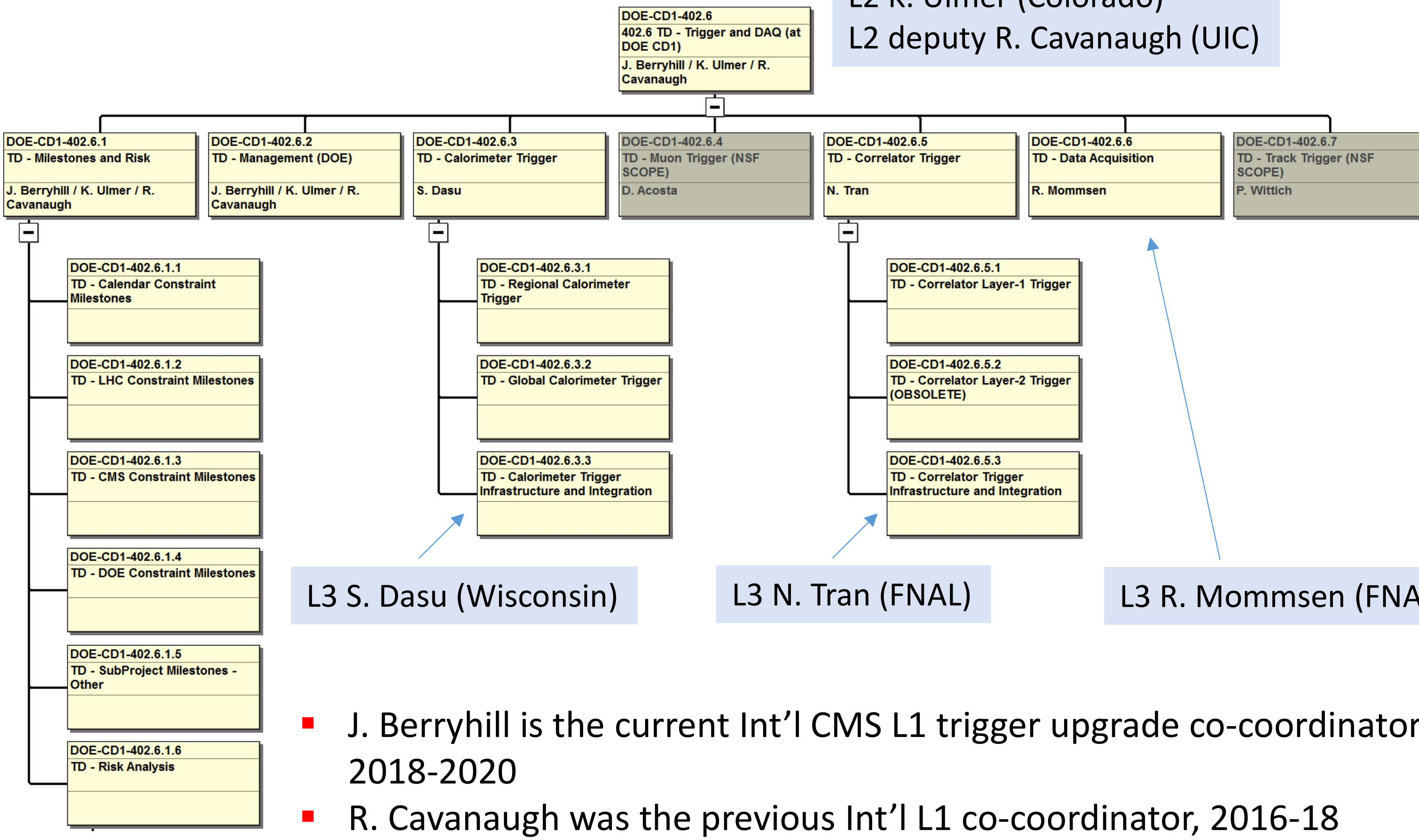
- For June 2018 IPR, technical maturity was at 30% level
  - ATCA control mezzanines completed, first prototype design in progress
- Using 402 project rubric, preliminary design is almost complete, with final/detailed design tasks underway.
  - Successful first hardware prototype
  - Prototype algorithm SW and FW developed
  - Design and algorithm decisions made for L1 Trigger TDR
- Outstanding maturity to be gained for CD-2: L1 TDR approval, preproduction design

	L3s									
	Calo Trig		Corr Trig		DAQ		AVE		BAC	
TD	Mgmt	Tech	Mgmt	Tech	Mgmt	Tech	Mgmt	Tech	Mgmt	Tech
Conceptual Design	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Preliminary Design	95%	95%	95%	95%	90%	60%	93%	83%	94%	91%
Final Design	100%	70%	100%	70%	100%	40%	100%	60%	100%	67%
Detailed Design	0%	45%	0%	45%	0%	0%	0%	30%	0%	40%
Construction Readiness	75%	50%	75%	50%	75%	50%	75%	50%	75%	50%

Charge #5

402.6 Organization

L2 J. Berryhill (FNAL)
L2 K. Ulmer (Colorado)
L2 deputy R. Cavanaugh (UIC)



L3 S. Dasu (Wisconsin)

L3 N. Tran (FNAL)

L3 R. Mommsen (FNAL)

- J. Berryhill is the current Int'l CMS L1 trigger upgrade co-coordinator, 2018-2020
- R. Cavanaugh was the previous Int'l L1 co-coordinator, 2016-18
- R. Mommsen is the current Int'l DAQ Deputy PM

402.6 Trigger and DAQ

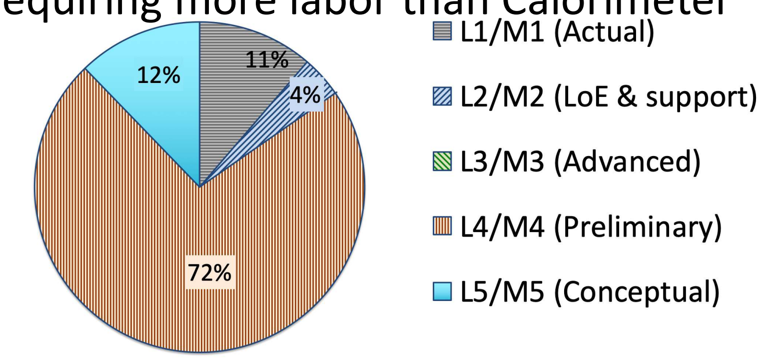
Charge #3

Cost Summary at Level 3 CMS-doc-13215

WBS	Direct M&S ($)	Labor (Hours)	FTE	Direct + Indirect + Esc. ($)	Estimate Uncertainty ($)	Total Cost ($)
DOE-CD1-402.6 402.6 TD - Trigger and DAQ (at DOE CD1)	4,004,125	107439	60.77	9,087,893	2,438,143	11,526,036
DOE-CD1-402.6.2 TD - Management (DOE)	171,594	25470	14.41	215,167	13,745	228,912
DOE-CD1-402.6.3 TD - Calorimeter Trigger	1,400,335	31043	17.56	3,266,174	808,451	4,074,625
DOE-CD1-402.6.5 TD - Correlator Trigger	1,664,196	50926	28.80	4,667,023	1,146,183	5,813,206
DOE-CD1-402.6.6 TD - Data Acquisition	768,000	0	0.00	939,529	469,764	1,409,293

- 11.5 M$ total with escalation and uncertainty
- 14% complete with $7.8M cost-to-go
- risk contingency adds 1.1M$ → 12.6M$
- (estimate uncertainty + risk contingency)/cost-to-go = (2.4+1.1)/7.8 = 45%
- 50/50 Labor/M&S
  - labor primarily firmware engineering labor
  - M&S primarily ATCA blades
  - Correlator firmware has multiple interfaces requiring more labor than Calorimeter
- DAQ is 100% M&S COTS computing (1.41M$)
- Estimate maturity is 88% “preliminary” or better, with a 12% “conceptual” component for DAQ

Cost-weighted estimate maturity: 402.6 Trigger and DAQ



Cost Summary at Level 3 CMS-doc-13215

Charge #3

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DOE-CD1-402.6.2 TD - Management (DOE)	171,594	25470	14.41	215,167	13,745	228,912
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DOE-CD1-402.6.6 TD - Data Acquisition	768,000	0	0.00	939,529	469,764	1,409,293

- 2019 TPC 0.4 M$ less than in June 2018 IPR (-3%)
- Some cost uncertainty retired (2018 actuals)
- Some firmware labor reduced
- Board cost and numbers revised, infrastructure costs added (+$341k direct M&S)

WBS June 2018 IPR	Direct M&S ($)	Labor (Hours)	FTE	Direct + Indirect + Esc. ($)	Estimate Uncertainty ($)	Total Cost ($)
402.6 TD - TRIGGER AND DAQ	$3,662,994	111126	62.85	$9,155,653	$2,777,343	$11,932,996
402.6.2 TD - Management	$162,000	26133	14.78	$213,104	$21,310	$234,414
402.6.3 TD - Calorimeter Trigger	$1,426,855	31043	17.56	$3,461,136	$958,265	$4,419,400
402.6.4 TD - Muon Trigger	$9,594	0	0.00	$10,001	$0	$10,001
402.6.5 TD - Correlator Trigger	$1,296,545	53950	30.51	$4,530,645	$1,327,385	$5,858,030
402.6.6 TD - Data Acquisition (DAQ)	$768,000	0	0.00	$940,767	$470,384	$1,411,151

Cost Drivers: Trigger and DAQ

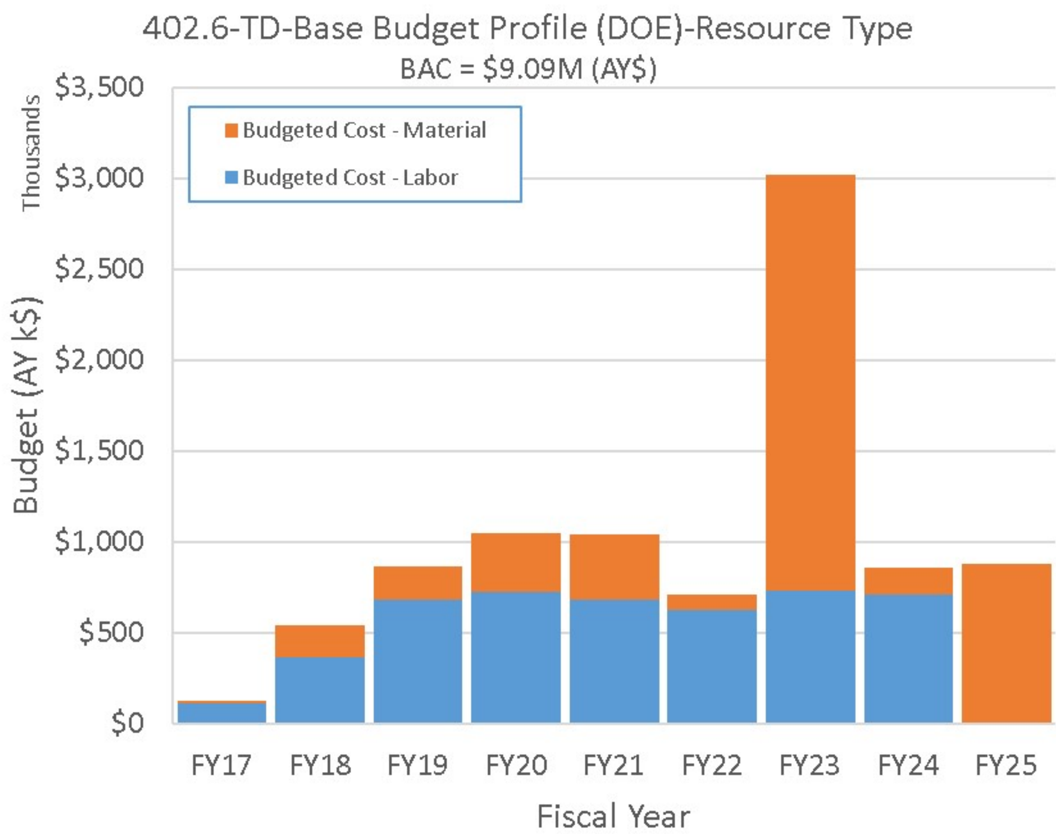
Trigger board M&S, Firmware labor, DAQ M&S are largest cost drivers

CMS Driver	Labor (FTE-yrs)	Labor BAC (M$)	M&S BAC (M$)	Total BAC * (M$)
TD.5 - Correlator Trigger delivery (M&S)	**0.0**	**0.0**	**1.6**	**1.6**
TD.5 - Correlator Trigger firmware	**7.1**	**1.3**	**0.0**	**1.3**
TD.3 - Calorimeter Trigger delivery (M&S)	**0.0**	**0.0**	**1.1**	**1.1**
TD.3 - Calorimeter Trigger delivery (labor)	6.1	0.9	0.1	0.9
TD.6 - Data Acquisition	0.0	0.0	0.9	0.9
TD - Trigger/DAQ installation and commissioning	5.0	0.8	0.1	0.9
TD.5 - Correlator Trigger delivery (labor)	5.5	0.8	0.0	0.8
TD.3 - Calorimeter Trigger firmware and software	7.2	0.6	0.0	0.6
TD.2 - Travel	0.0	0.0	0.3	0.3
TD.5 - Correlator Trigger software	2.9	0.3	0.0	0.3
TD.3 - Calorimeter Trigger delivery (m&s)	0.0	0.0	0.2	0.2
TD.4 - Muon Track Finder R&D	0.0	0.0	0.0	0.0

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

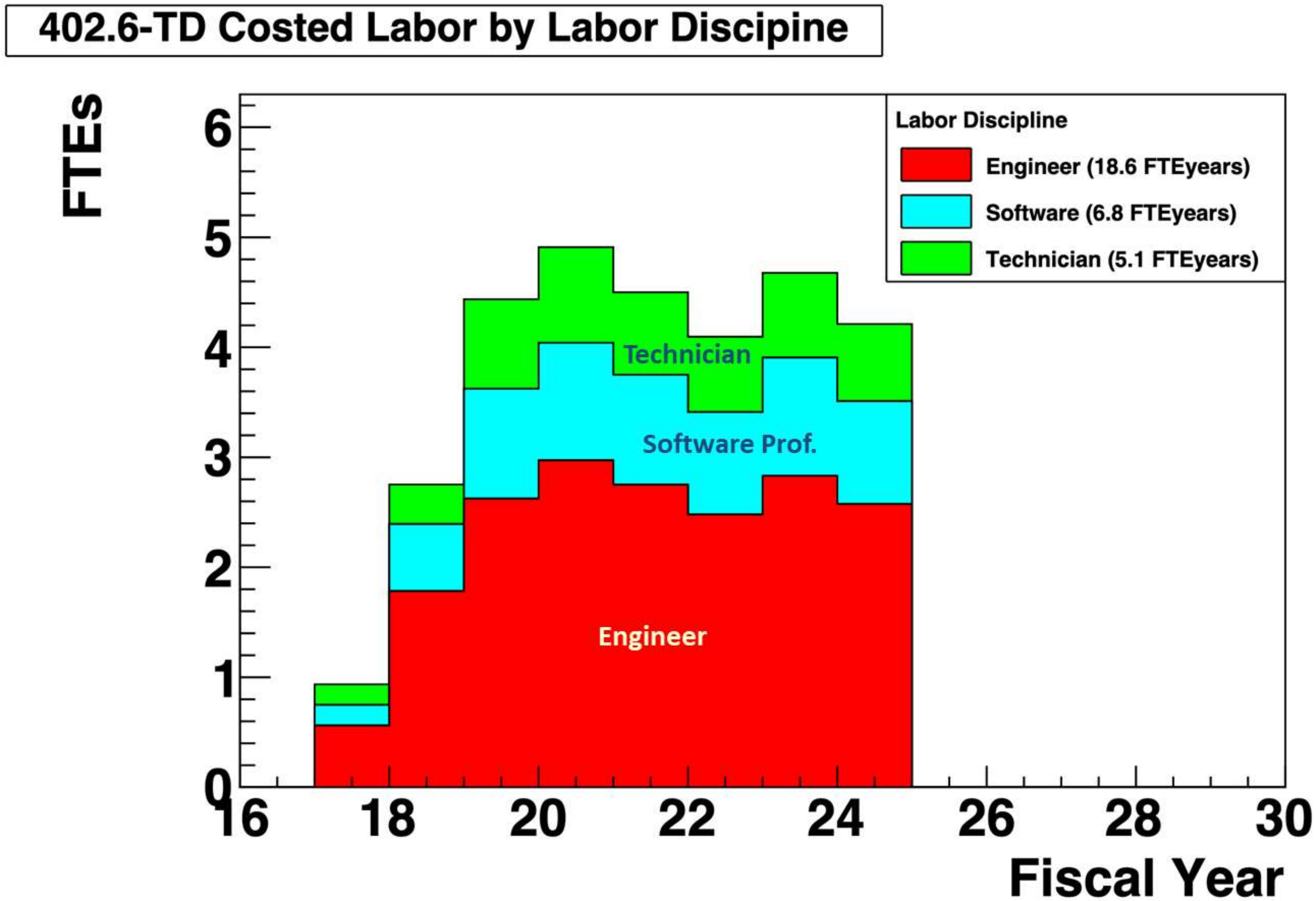
402.06 Cost Profile

- Prior to final board procurement in FY23, L1 trigger projects are predominantly a steady rate of labor expenses for prototyping, preproduction, and pilot production
- Final board procurement in FY23 (2.4 M$)
- DAQ procurement in FY25



Charge #4

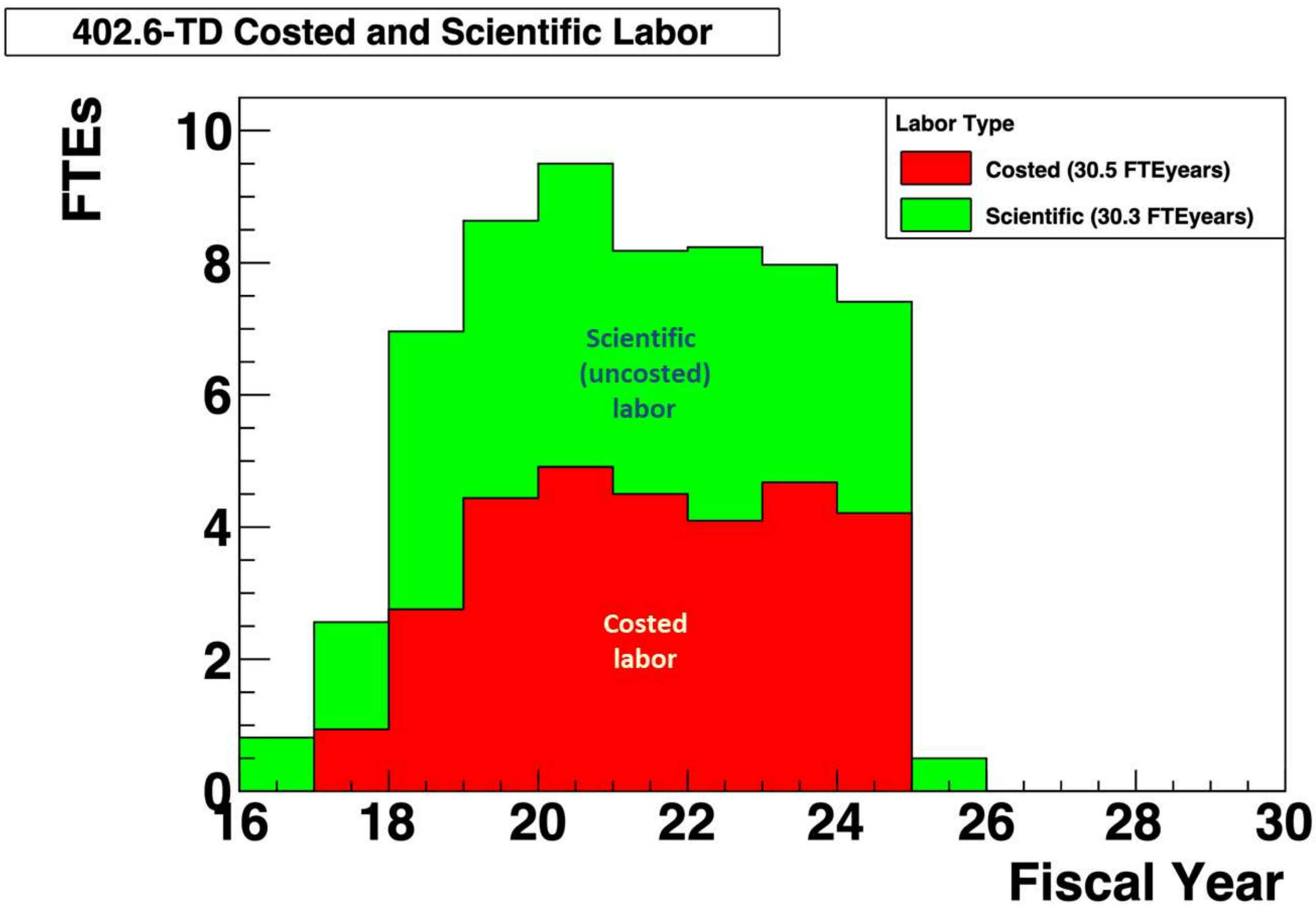
Costed Labor Profile



- Costed labor distribution roughly:
  - 1 part SW
  - 1 part tech
  - 1 part EE design
  - 2 parts firmware engineering
  - All required costed personnel are currently on staff

Costed Labor and Contributed Labor

- Costed labor for electronics, software, firmware engineering at ~4.5 FTE/yr during construction
- Comparable contributed labor required for algorithm development and management



Charge #4

402.6 Labor Resources: Institutions

Calorimeter Trigger

Institution	Responsibility
Wisconsin	HW & FW engineering, SW and algorithm development

Correlator Trigger

Institution	Responsibility
Fermilab	FW engineering, algorithm development
Florida	FW engineering, SW and algorithm development
MIT	Algorithm development
Northwestern	Algorithm development
Colorado	FW engineering, SW and algorithm development
UIC	Algorithm development
Wisconsin	HW & FW engineering, SW and algorithm development

DAQ

Institution	Responsibility
Fermilab	Storage Manager specification, procurement, operations
MIT/Rice/UCSD	Storage Manager specification, operations

Charge #4

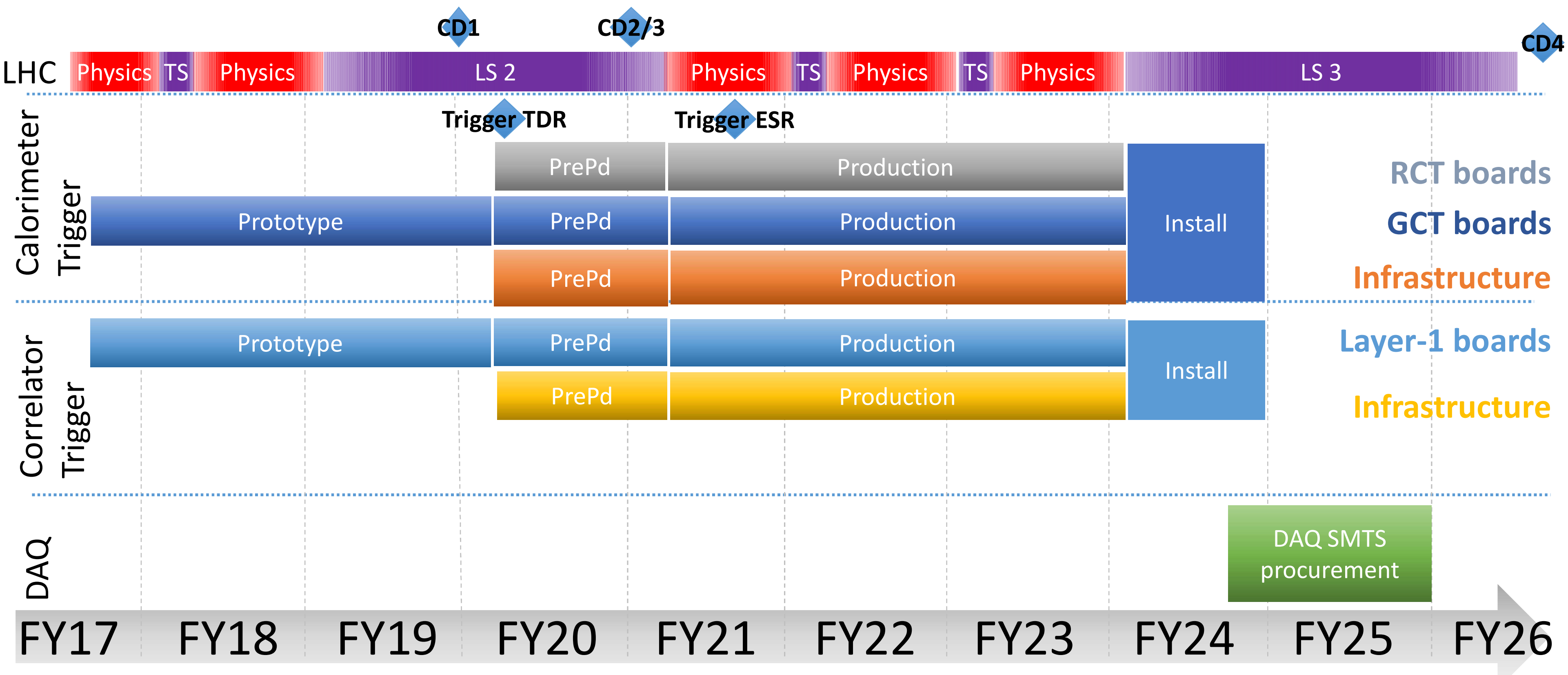
402.6 Labor Resources

- All required costed personnel are currently on staff
- A single production line for blades is handled by technical staff and senior engineering at Wisconsin.
- Due to many scientific requirements, significant contributed labor is required to develop algorithms and assess their performance in testing. Adequate labor levels here was successfully demonstrated for a recent CMS internal annual review of L1 trigger.
- Due to multiple interface requirements in the correlator trigger, firmware development is distributed to several developers responsible for each interface (UW/BC, UF/Muon, Colorado/L1TT, FNAL/EC+Layer2)

Charge #3

402.6 High-Level schedule

L1 Prototyping/R&D phase 2017-2019, for L1 Trigger TDR at end of 2019
L1 Preproduction phase 2020, for Trigger ESR
L1 Production phase 2021-2023
L1 Installation phase 2024
DAQ procurement 2024-2025, need by Run 4 start



Charge #3

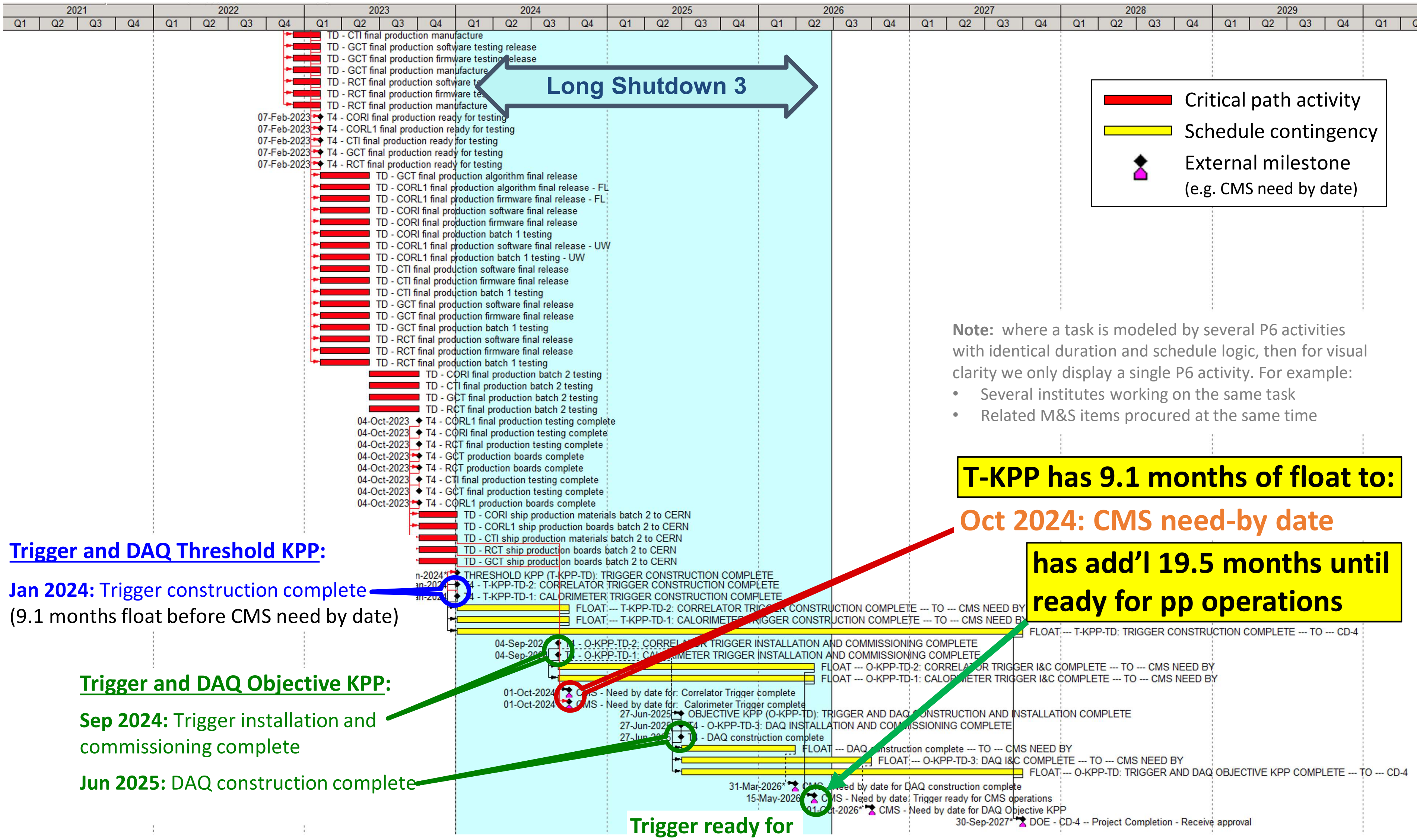
402.6 Recent schedule performance

- The schedule was constructed based on previous engineering experience (original design, phase 1)
- The plan was to update it based on the experience from prototyping
- The prototyping performance since the 2018 IPR was in line with the planned schedule
  - July 2018 APd prototype board design complete
  - Nov. 2018 first APd prototype board components procured
    - 4 month duration
    - 1 month slippage due to realized risk of non-performing vendor
  - Feb. 2019 assembled APd prototype board ready for testing
    - 3 month duration, on time
  - May 2019 APd prototype board tested
    - 3 month duration, on time
  - Aug. 2019 APd revision B prototype design complete
    - 3 month duration, on time
- Based on recent actuals, we modified the 2018 IPR schedule to increase board design and testing time, decrease procurement and assembly time.

402.6 Trigger and DAQ

Critical Path and Float

Charge #3



Trigger and DAQ Threshold KPP:

Jan 2024: Trigger construction complete (9.1 months float before CMS need by date)

Trigger and DAQ Objective KPP:

Sep 2024: Trigger installation and commissioning complete

Jun 2025: DAQ construction complete

Trigger ready for CMS operations

Note: where a task is modeled by several P6 activities with identical duration and schedule logic, then for visual clarity we only display a single P6 activity. For example:

- Several institutes working on the same task
- Related M&S items procured at the same time

T-KPP has 9.1 months of float to:

Oct 2024: CMS need-by date

has add'l 19.5 months until ready for pp operations

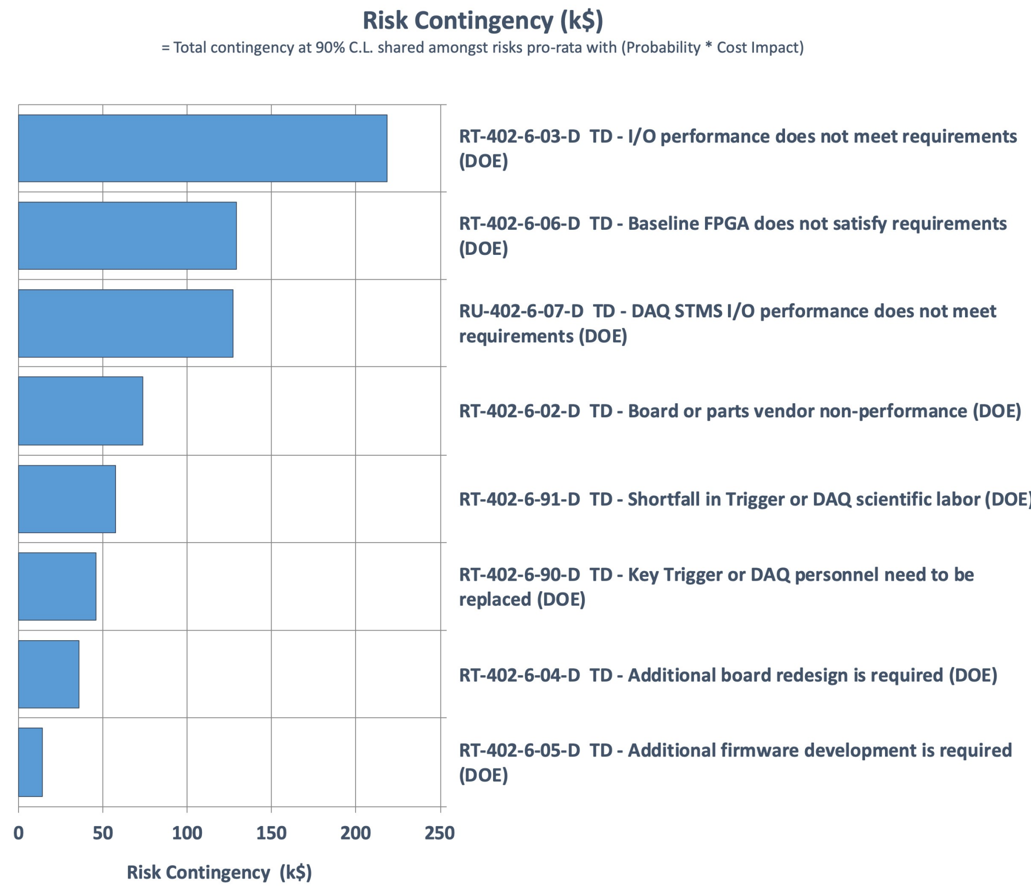
Charge #3

402.6 Risks

- Risk ranking and mitigation
  - Largest risks are having to increase board production or buying bigger FPGAs to meet evolving requirements (probability*cost impact ~$200k), or changes in DAQ STMS size requirements (~$130k)
    - Mitigation strategy: carefully track requirements and interfaces, schedule board demonstrations emulating or including all interfaces at each prototyping and production stage
  - Next are vendor issues with PCBs or PCB redesign (probability*cost impact ~$60k)
    - Mitigation: several rounds of incremental prototyping to vet vendors and discover any design issues early. Pilot production round to ensure minimal rework.

Trigger and DAQ risks

- Main risk changes in past 12 months are
  - Key personnel and scientific labor risks now managed at L2
  - DAQ performance uncertainty added (+130k$)



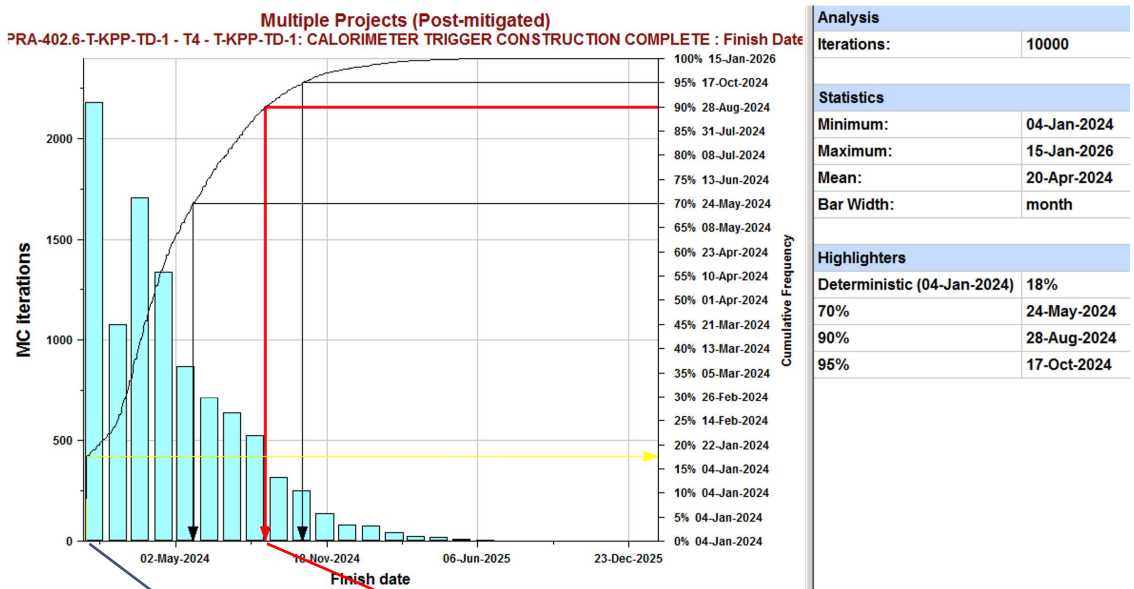
TD risk contingency ≈ $1.11M * (12.2% of TD BAC)

Was $0.5M at DOE IPR, June 2018

* Total includes the OT share of common risks (escalation, OH, exchange rates, etc.)

Schedule Contingency

- Risk MC aggregates delays stochastically in the full P6 schedule
- Risks will delay finish by **< 7.8 months** at 90% confidence level
- Plan has **8.9 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



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-TD-1	Calorimeter Trigger Construction Complete	5-Jan-2024	1-Oct-2024	**8.9**	28-Aug-2024	**7.8**	**94%**

Correlator trigger very similar, T-KPP finish at 93% CL

Charge #8

June 2018 IPR Trigger/DAQ Recommendations

- ***"Restructure Key Performance Parameters (KPPs) for the Calorimeter Trigger and the Correlator Trigger to eliminate external dependencies prior to CD-1 approval. This is to ensure the KPP can be met prior to the start of data taking."***
- **Action:** KPPs for trigger subsystems will include simple performance metrics which are decoupled from interfacing performance requirements
- Calorimeter Trigger:
  - electron photon and tau trigger performance →
  - electromagnetic cluster position and energy resolution
- Correlator Trigger:
  - electron photon muon and tau trigger performance →
  - track-cluster and track-muon matching efficiency
- **From DR: Simplification of KPPs** → combined L3s eliminating redundant descriptions

- ***"Update the WBS dictionaries for the Calorimeter Trigger and Correlator Trigger to cover all major activities including those involving hardware, firmware, and software."***
- **Action:** WBS dictionary to include firmware and software delivery

402.6 Progress towards CD-2/CD-3

- Production cost and schedule largely unchanged since last summer.
- Schedule of preproduction and production to be updated and refined to reflect R&D actuals.
- Large procurement costs will not be incurred until Q4 2022, no CD-3a required.
- L1 TDR baseline architecture agreed upon internationally.
- Final international cost book/division of scope, and schedule (ESR and need-by dates) will be finalized when TDR is approved (June 2020) and preproduction design is complete (May 2020).
  - JB is CMS L1 trigger upgrade coordinator and signs off on all decisions.
- **Expect well-developed cost and schedule for CD-2 based on recent actuals, a successful R&D phase, and a L1 trigger TDR baseline.**

ES&H

Preliminary Hazard Analysis Report DocDb 13394

Charge #6

- All delivered electronics is off-detector and out of radiation areas. Requirements and hazards are typical of any small scale commercial electronics project: electrical, fire, flammable materials, ESD.
- No hazardous materials. No special labor conditions required. No high voltages used.
- Safety: follows procedures in CMS-doc-11587, FESHM.
- All activities and personnel at CERN regulated by CERN Safety Rules.
- Optical fiber and cabling required to be non-halogen. Optical links operate with Class 1 lasers (i.e. safe under all conditions of normal use).
- 200W power ceiling on ATCA blades to avoid special labor (dB limits for ear protection, e.g.) and equipment conditions related to cooling.

Charge #6

Quality Assurance/ Quality Control

- All QA aspects of the HL LHC CMS Detector Upgrade Project will be handled in accordance with the Fermilab Integrated Quality Management approach, and the rules and procedures laid out in the project-wide QA plan
  - Project-wide Quality Assurance Program DocDB 13093
- QA/QC plan written following the guidance of the Nov. 2018 QA/QC workshop
  - Management plan, activity catalog, design validation and quality verification methods specified.
- All hardware deliverables data and testing results are tracked in a database
- A complete set of verification tests are specified
  - Hardware performance tests (link speed, power and cooling)
  - Design reviews
  - Latency and algorithm validation tests
  - Scientific performance tests by simulation
- Firmware & software: follows Fermilab Software Quality Assurance (QAM 12003,12090).

402.6 Interfaces and Externals

- International partners at L3 have well-defined scope:
  - Correlator trigger has a Layer-2/Global Trigger component with **UK (Imperial/Bristol/RAL)/CERN** responsible
  - Correlator trigger has division of scope with **UK** for vertexing and track-based reconstruction with no interdependence.
- Key interfaces (mostly US-owned): cms-doc 13318
  - Calo trigger inputs with **EB (US)** and **HB (US), HF (US) and CE (UK/Croatia/France)**
  - Correlator trigger inputs with **calo/muon/track trigger (US)** and **CE (UK/Croatia/France)**
  - DAQ storage manager interface with the rest of **DAQ**
  - All: output of trigger data to **DAQ** (standard blades from DAQ group)
- External watchlist: cms-doc 13742
  - Data and Timing Hub blade required for each L1 trigger crate (provided by CERN/DAQ group)
  - Prototype DTH needed for preproduction phase 2020
  - Preproduction DTH needed before starting final production 2022

402.6 Breakout Sessions

08:00 - 12:30

Breakout: Trigger/DAQ

Please join the meeting by clicking this link: https://vidyoportal.cern.ch/join/eU8308Udna

If you want to join by phone, please use one of the phone numbers listed in the link below:

http://information-technology.web.cern.ch/services/fe/howto/users-join-vidyo-meeting-phone

and enter the meeting extension 105676592 in order to join.

Conveners: Jeffrey Berryhill (Fermilab), Richard Cavanaugh (Fermilab and University of Illinois Chicago), Richard Cavanaugh (University of Illinois at Chicago and Fermilab), Dr. Keith Ulmer (University of Colorado), Keith Ulmer

Location: Fermilab (Directors' (WH2E))

08:00 **TDAQ project management plan and schedule** *1h0'*
Speaker: Jeffrey Berryhill (Fermilab)

09:00 **TDAQ L1 Trigger algorithms, firmware, and testing status** *1h0'*
Speaker: Nhan Tran (FNAL)

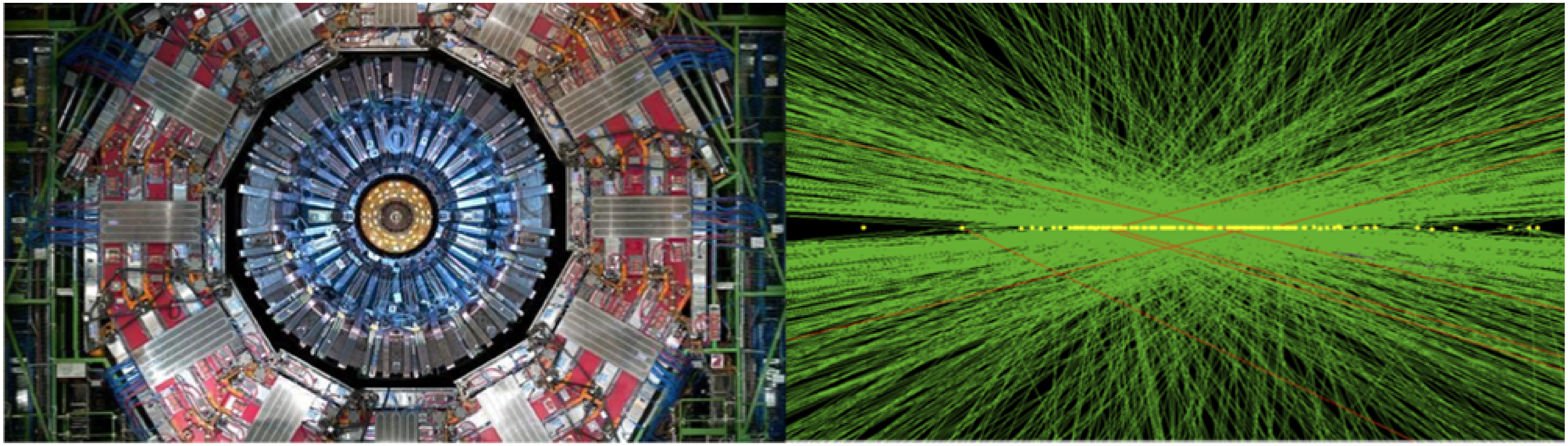
10:00 **TDAQ L1 trigger hardware R&D** *1h0'*
Speakers: Prof. Sridhara Dasu (University of Wisconsin), Mr. Thomas Gorski (University of Wisconsin)

11:00 **TDAQ DAQ upgrade project** *30'*
Speakers: Remi Mommsen, Dr. Remigius Mommsen (Fermilab)

402.6 Summary

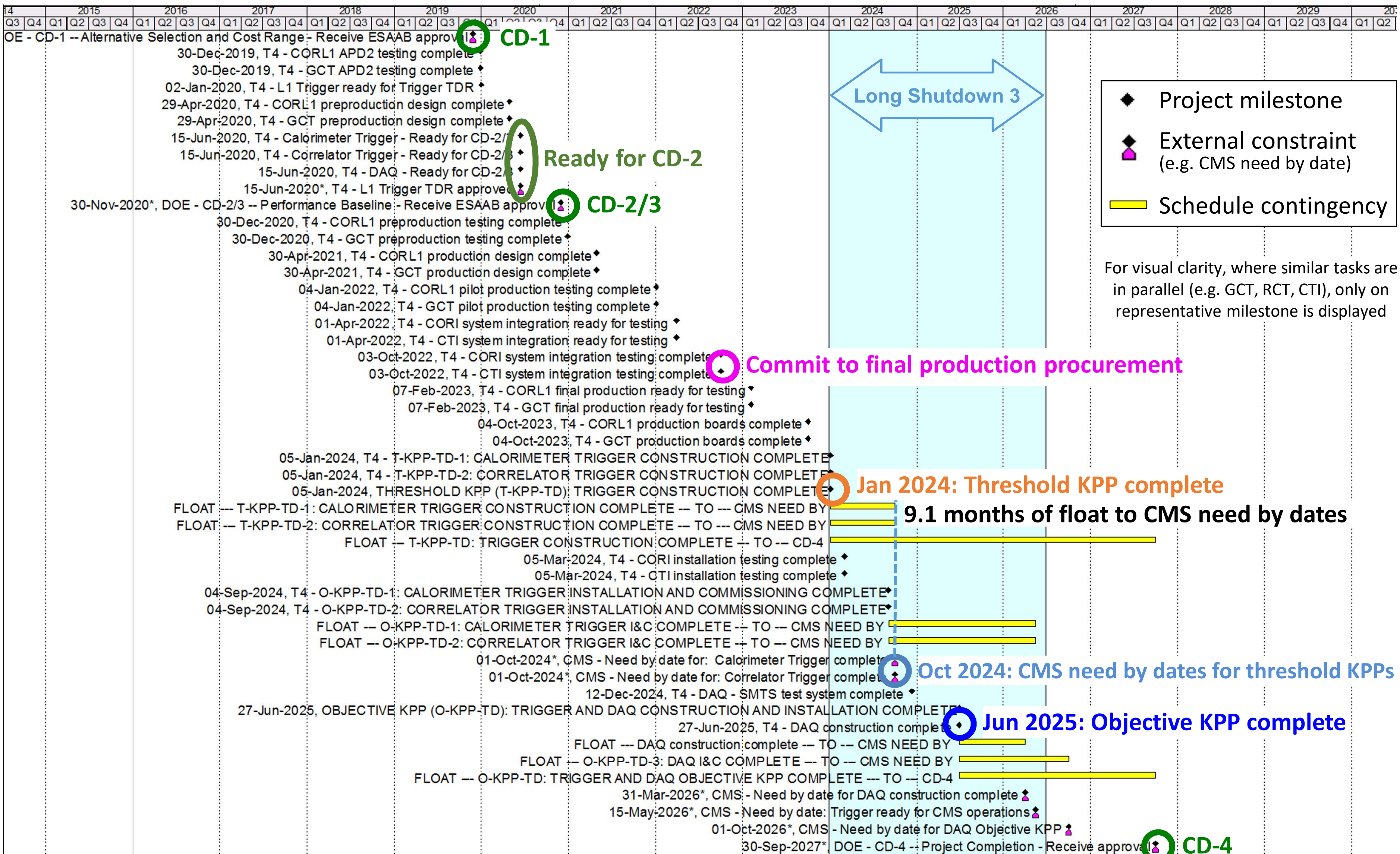
- Hardware and firmware for L1 Trigger components have progressed well since June 2018 IPR:
  - including a first demonstrator prototype
  - firmware demonstration on available hardware
  - ready for firmware demonstration on first prototypes
- In sync with planning for L1 Trigger TDR in 2020.
- Will be ready for CD2/3 upon R&D completion, L1 TDR approval next year.
- We have addressed all recommendations and comments from previous reviews.
- Project plan is ready for CD-1.

Backup



402.6 Trigger and DAQ

Key milestones and schedule contingency



Science Requirements

- HL-LHC presents experimental challenges that place scientific requirements on upgraded CMS in order to meet the science goals

- The flow from science goals to science requirements is documented in https://cms-docdb.cern.ch/cgi-bin/DocDB/ShowDocument?docid=13337

"Parents" column indicates link to scientific goals

Title	ID	Type	Requirement	Parents
Redundancy & Robustness	sci-req-1	requirement	CMS detectors must be capable of high performance until 3 ab-1 integrated to carry out physics program.	sci-goal-1, sci-goal-2, sci-goal-3, sci-
Electroweak Scale Trigger Thresholds	sci-req-2	requirement	Efficient reconstruction of Higgs decays requires trigger thresholds of ~M_W/2 (H to WW). The same thresholds are also necessary for DM candidates, rare SM processes, or BSM signals.	sci-goal-1, sci-goal-2, sci-goal-3, sci-goal-4
Charged Particle Tracking	sci-req-3	requirement	Efficient reconstruction of Higgs decays, DM candidates, rare SM processes, or BSM signals requires efficient charged particle tracking.	sci-goal-1, sci-goal-2, sci-goal-3, sci-
Primary Vertex Identification (and purity)	sci-req-7	requirement	Accurate reconstruction of Higgs decays requires accurate primary vertex identification (H to γγ). Accurate reconstruction is also necessary for DM candidates, rare SM processes, or BSM signals.	sci-goal-1, sci-goal-2, sci-goal-3, sci-goal-4
Pileup Mitigation	sci-req-10	requirement	CMS requires mitigation of the effects of pileup such that LHC performance is recovered at HL-LHC (with up to 200 PU)	sci-goal-1, sci-goal-2, sci-goal-3, sci-

- For Trigger/DAQ, the most relevant subset of sci-requirements are:
  - **Electroweak scale trigger thresholds** to maintain the precision Higgs program and provide broadest acceptance for searches
  - Redundant and robust performance up to the **highest luminosity**
  - **Primary vertex identification** to identify pileup
  - **Pileup Mitigation** to reject background and reduce trigger rates
- Science requirements of Trigger/DAQ, chiefly validated by exercising hardware with scientific simulated data to check requirements are being met

Science – Engineering Requirements

- Flow from science requirements to engineering requirements documented in https://cms-docdb.cern.ch/cgi-bin/DocDB/ShowDocument?docid=13318
- Examples shown here:
  - System and subsystem levels

Requirements Document

Title	ID	Type	Scope	Requirement Text	Rationale	Parents
Trigger Science and Engineering Requirements						
Trigger rate and latency	Trig-sci-engr-001	requirement	DOE/NSF	The trigger system shall be capable of providing a L1A signal to the DAQ at 750 kHz L1A rate and within a total latency of 12.5 us	A latency of 12.5 us is the combined latency of the entire trigger path, which is set by the readout buffers of the tracker. This latency includes the latency taken by other systems, muon track finder, calorimeter, correlator and global L1 trigger elements. Each individual system will have an allocation, and the combined budget is being tracked to ensure the total is not to exceed the 12.5 us	sci-req-2, sci-req-14
Redundancy Robustness	Trig-sci-engr-003	requirement	DOE/NSF	The trigger must be capable of nominal operations and performance until luminosities of 7.5x10^-34 cm^-2 s^-1 (200 PU)	To meet the science requirements of the HL-LHC, each trigger algorithm must provide acceptable trigger efficiency, while maintaining a total L1 Trigger Menu rate of less than 750 kHz, during nominal HL-LHC operations.	sci-req-14
Trigger Algorithm Thresholds	Trig-sci-engr-004	requirement	DOE/NSF	Must maintain trigger thresholds that are similar to Phase-1	To meet the science requirements of the HL-LHC, efficient collection of datasets containing Higgs bosons requires trigger thresholds of ~MW/2 (H to WW). The same thresholds are also necessary for DM candidates, rare SM processes, or BSM signals.	sci-req-2
Muon Trigger Requirements		**Heading**				
Muon Trigger System 2	Trig-sci-engr-029	requirement	NSF	The Muon Trigger shall maintain at least 95% average efficiency for identifying muons.	To meet the science requirements of the HL-LHC, the identification of muons from Higgs decays (e.g. H to ZZ to 4l), DM candidates, rare SM processes, or BSM signals needs to be efficient, with acceptable rate.	sci-req-1, sci-req-2, sci-req-12
Track Trigger Requirements		**Heading**				
Track Trigger System 1	Trig-sci-engr-032	requirement	NSF	The Track-finder Trigger shall have a latency for trigger processing not more than 5 microseconds	To meet the science requirements of the HL-LHC of being able to tolerate operational luminosities and to meet the trigger requirements of providing a L1A signal to the DAQ within a total latency of 12.5 us.	sci-req-14, Trig-sci-engr-001
Track Trigger System 2	Trig-sci-engr-033	requirement	NSF	The Track-finder Trigger shall have the ability to reconstruct charged particle tracks with a pT of at least 2 GeV	To meet the science requirements of the HL-LHC, it is important to have good MET resolution. This will require the mitigation of the effects of pileup such that LHC performance is recovered at HL-LHC (with up to 200 PU), which implies that low energy calorimeter deposits associated with low momentum PV tracks and low momentum PU tracks must be identified and separated.	sci-req-2, sci-req-3, sci-req-5, sci-req-7, sci-req-10, sci-req-11, sci-req-12

Engineering Requirements

Requirements Document

Title	ID	Type	Scope	Requirement Text	Rationale	Parents
Trigger/DAQ Fiber Data Rate	Trig-engr-002	requirement	DOE/NSF	Links shall support transceiver rates between (3-25) Gbps on optical fibres	The CMS detector operates in an I/O environment of 100s Tbps	Trig-sci-engr-001, Trig-sci-engr-003
Trigger Latency	Trig-engr-003	requirement	DOE/NSF	The trigger shall issue a L1 accept (L1A) signal within a target of (9.5 microseconds)	This is an external constraint to US CMS: there is 12.5 microsec total budget, including 30% contingency	Trig-sci-engr-001
Track Finder Trigger - Tracklet (TFT) & Components Engineering Requirements						
Number of TFT boards	Trig-engr-011	requirement	NSF	The Track Trigger shall be capable of receiving and processing all stub data (about 15000 per BX) transmitted from the Data, Trigger, Control (DTC) boards so as to deliver tracks with pT (above 2 GeV) within (5 microseconds).	To satisfy the HL-LHC Physics Requirements, the Track-finder Trigger must have sufficient bandwidth to receive and sufficient resources to be able to process the Trigger Primitive data. This determines the number of boards, given the link, bandwidth, and processing capacity of each board.	Trig-sci-engr-007
Endcap(E) and Barrel (B) Muon Track Finder (MTF) Trigger & Components Engineering Requirements						
FPGA Thermal	Trig-engr-031	requirement	NSF	FPGAs shall operate at die temperatures that are below their manufacturer-specified maximum for operation	Excessive temperatures have a negative impact on reliability and electronics lifetime.	Trig-sci-engr-003, Trig engr-006

- Technical engineering requirements mapped to science-engineering requirements
- Examples shown for system and sub-system levels

Resource Optimization

- University/Lab Resources highly qualified and optimally distributed
  - **One production line for electronics**: U. Wisconsin has an experienced engineering, technical, firmware and software team that has delivered two successful CMS calorimeter trigger electronics systems on schedule and on budget.
  - **Mutual support and task sharing** through APx consortium members
    - Fermilab, U. Florida, Notre Dame, U. I. Chicago, U. Virginia
  - All participating L1 trigger institutions have **previous successes** in L1 trigger construction and/or track trigger prototyping
  - Fermilab has constructed and operated the DAQ storage manager **since original construction.**
- Vendor Resources appropriate for cost-effective and timely procurement
  - The Wisconsin team works with experienced vendors regularly qualified through R&D, pre-production and production orders for board manufacture, parts ordering and board assembly.
  - Where possible, State of Wisconsin purchasing is leveraged with placement of major parts orders through State Contract Vendors.
  - Fermilab has long standing experience with required DAQ storage manager vendors.
- Value engineering is/has been part of the R&D program and will determine optimal computing resources to meet the requirements for the TDR/baseline design.

Value Engineering

- At each design stage, evaluate choice of link speed, links per FPGA, FPGA resources
- E.g. Prototype FPGA (VU9P) chosen as ~30% less expensive computing per link than Phase-1 architecture (Virtex-7). Higher link speeds also proven to be more economical.
- For preproduction phase, will pursue dual-FPGA design in RCT to balance I/O and resources per link.
- Will consider alternative FPGAs as the resource and performance requirements become (even) better known, and as price quotes evolve.

Changes since 2018 IPR - TD

All resources

	2019	Change: {Now/Then-1}				
L2/L3 Area	BAC	M&S	Hours	Cost	EU	Total
TD	**9,088**	**10%**	**-3%**	**-1%**	**-12%**	**-3%**
TD - Mgmt	215	6%	-3%	1%	-35%	0%
TD - Cal Trig	3,266	-2%	0%	-6%	-16%	-8%
TD - Corr Trig	4,667	28%	-6%	3%	-14%	-1%
TD - DAQ	940	0%	0%	0%	0%	0%

Contributed Labor

	2019	Change
L2/L3 Area	Contributed Hours	Hours
TD	**53,497**	**-5%**
TD - Mgmt	25,470	-3%
TD - Cal Trig	8,784	0%
TD - Corr Trig	19,243	-9%

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