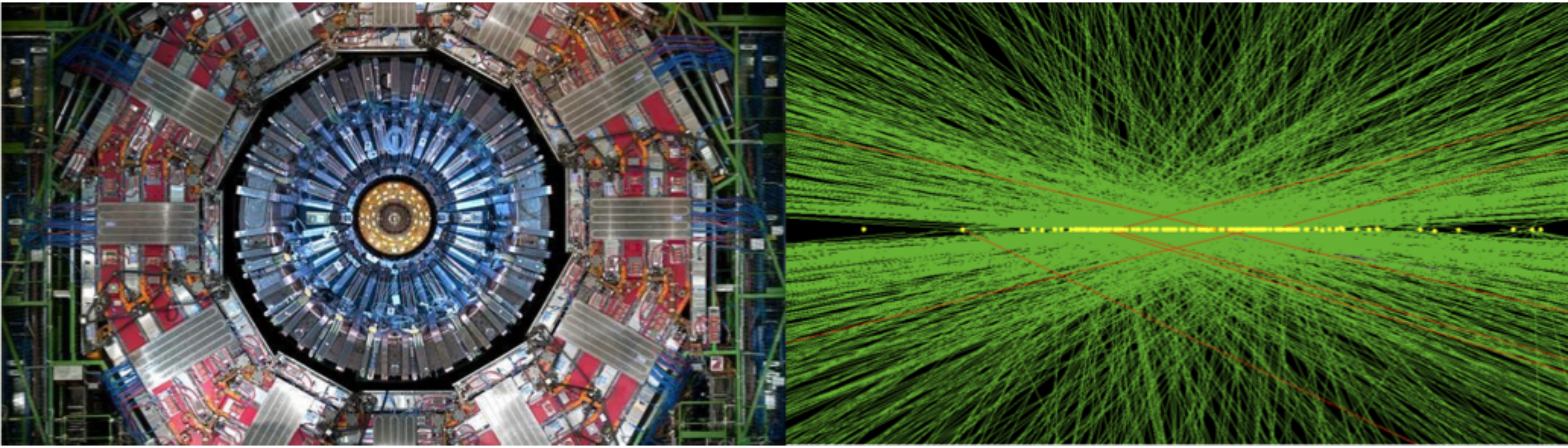
P03
L2 Overview: MIP Timing Detector – 402.8

Chris Neu
Fermilab Director’s Review
19 March 2019



Charge #5

Biographical Sketch

- Chris Neu
  - L2 manager for US MTD
  - Associate Professor, University of Virginia (2008-present)
  - Member of the MTD Steering Group
  - Served as co-convener of the MTD Simulation and Performance group through June 2018
  - Previously served as co-convener in CMS subgroups associated with top-Higgs and top quark physics
  - Formerly a member of CDF working on the XFT track trigger, L2 trigger upgrade for Run IIb, CMU/P upgrade, COT wire planes
  - Physics interests: top-Higgs coupling, top quark measurements, dark matter

Outline

- Introduction and Motivation
- The MIP Timing Detector
  - System Requirements
  - Conceptual Design and Maturity
  - US Scope and Deliverables
- Project Organization
  - WBS and Organization
  - Resource Optimization and Value Engineering
  - Interfaces
- Technical Progress
- Cost, Schedule, Risk
- Plan for CD-2/Preliminary Design
- ESH&Q
- Response to Previous Reviews
- Breakout Session topics
- Summary

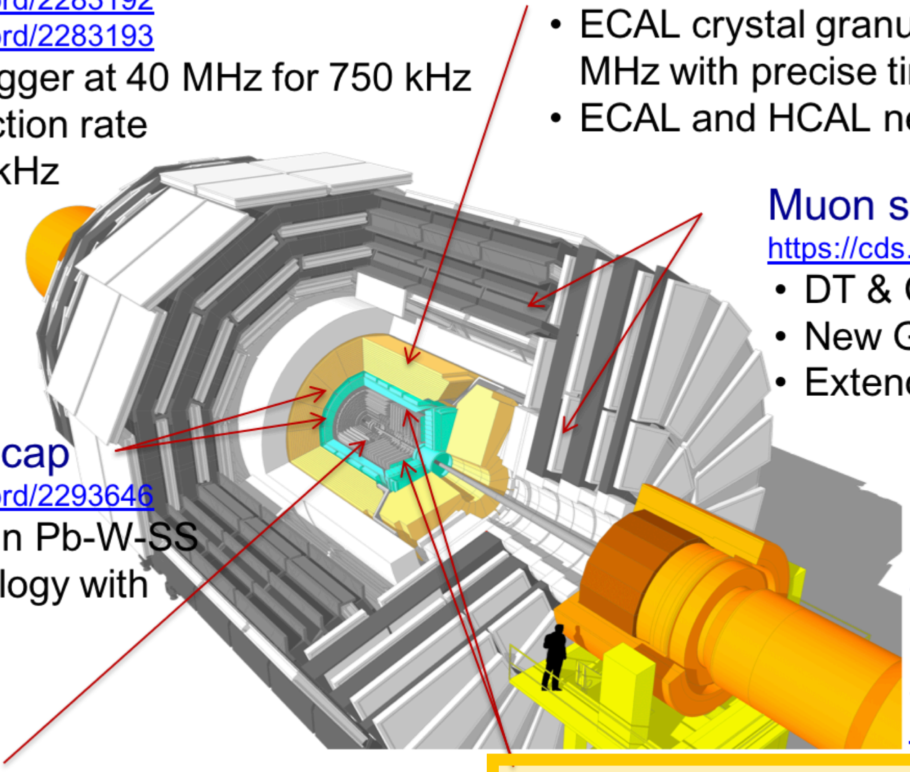
Covered in David’s talk

Covered in Frank’s talk

Covered in a dedicated breakout session talk

Also covered in David’s and Frank’s talks

CMS HL-LHC Upgrade Overview



L1-Trigger/HLT/DAQ

https://cds.cern.ch/record/2283192
https://cds.cern.ch/record/2283193

- Tracks in L1-Trigger at 40 MHz for 750 kHz PFlow-like selection rate
- HLT output 7.5 kHz

Barrel Calorimeters

https://cds.cern.ch/record/2283187

- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards

Muon systems

https://cds.cern.ch/record/2283189

- DT & CSC new FE/BE readout
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$

Calorimeter Endcap

https://cds.cern.ch/record/2293646

- Si, Scint+SiPM in Pb-W-SS
- 3D shower topology with precise timing

Beam Radiation Instr. and Luminosity, and Common Systems and Infrastructure

https://cds.cern.ch/record/2020886

Tracker https://cds.cern.ch/record/2272264

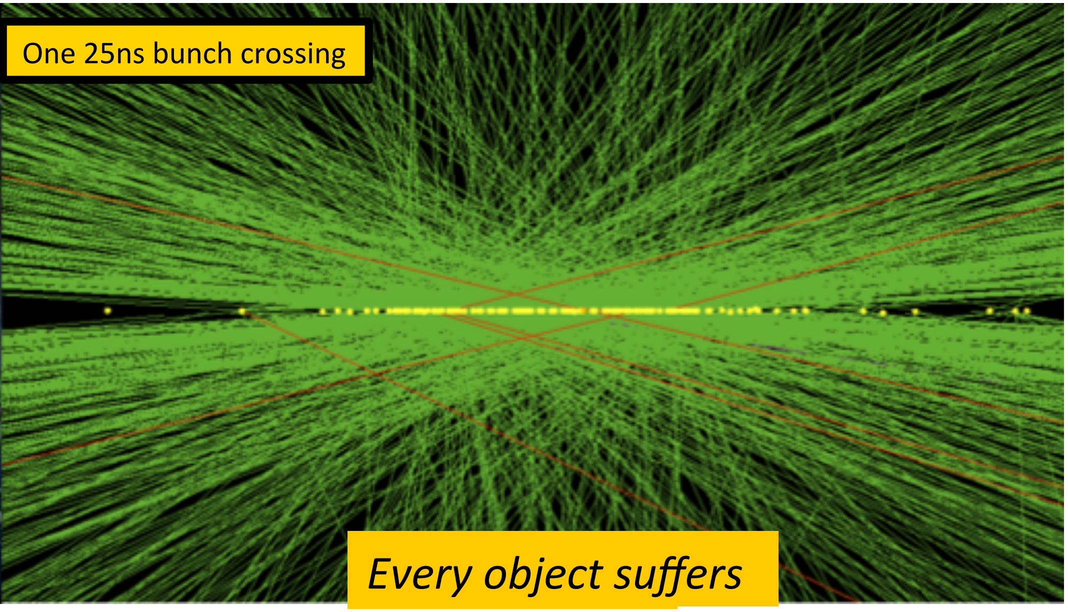
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$

MIP Timing Detector

https://cds.cern.ch/record/2296612

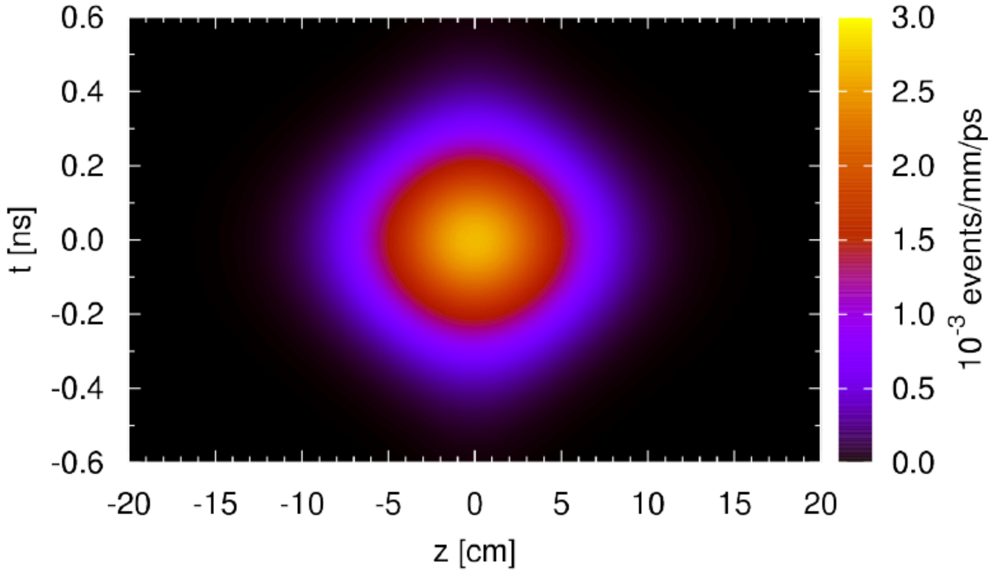
- $\simeq$ 30 ps resolution
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

The Challenge of the HL-LHC era



One 25ns bunch crossing

Every object suffers

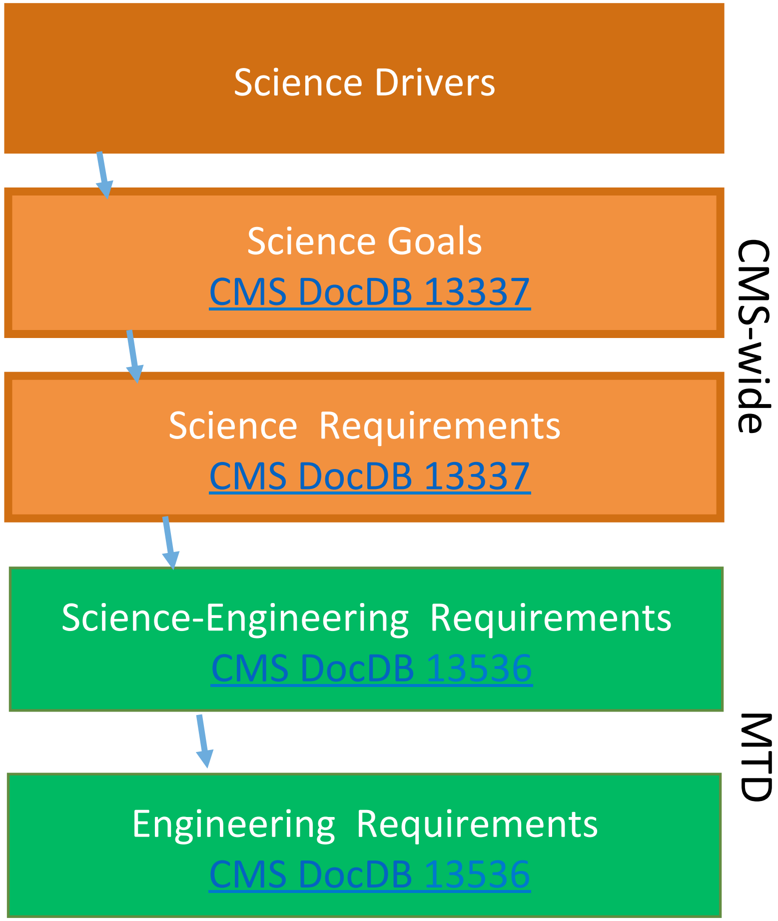


- Mitigating the effects of pileup interactions will be a major challenge of the HL-LHC era
- Although PU interactions significantly overlap in space, they are **more separable in space + time.**
- Imagine separating the 25ns beam crossing into consecutive time slices
  - **Each exposure has far fewer vertices** than when integrating over an event's complete time profile.
- Per-particle timing provided by the MIP Timing Detector (MTD) allows 4D track and vertex reconstruction
  - PU reduced in each time slice
  - **Significant benefit for all physics objects**.

Charge #2

Science Flowdown

- The MTD, like all USCMS upgrade projects, follows this bottom-up design approach:
  - Start from **Science Drivers** for U.S. particle physics from P5
  - Science Drivers inform **Science Goals**
    - Examples:
      - Precision Higgs coupling measurements
      - Search for BSM Physics
  - Science Goals inform **Science Requirements**
    - Primary Vertex reconstruction
    - Pileup mitigation
    - b-tag efficiency and purity
    - MET resolution
    - etc
  - Science Requirements inform **MTD Science-Engineering Requirements**
    - These define the MTD design principles
  - MTD Science-Engineering Requirements inform **MTD Engineering Requirements**
    - These define MTD design specifications



Science Drivers

Science Goals
CMS DocDB 13337

Science Requirements
CMS DocDB 13337

Science-Engineering Requirements
CMS DocDB 13536

Engineering Requirements
CMS DocDB 13536

CMS-wide

MTD

More in C. Hill's talk in B/O: Project Management

Charge #2

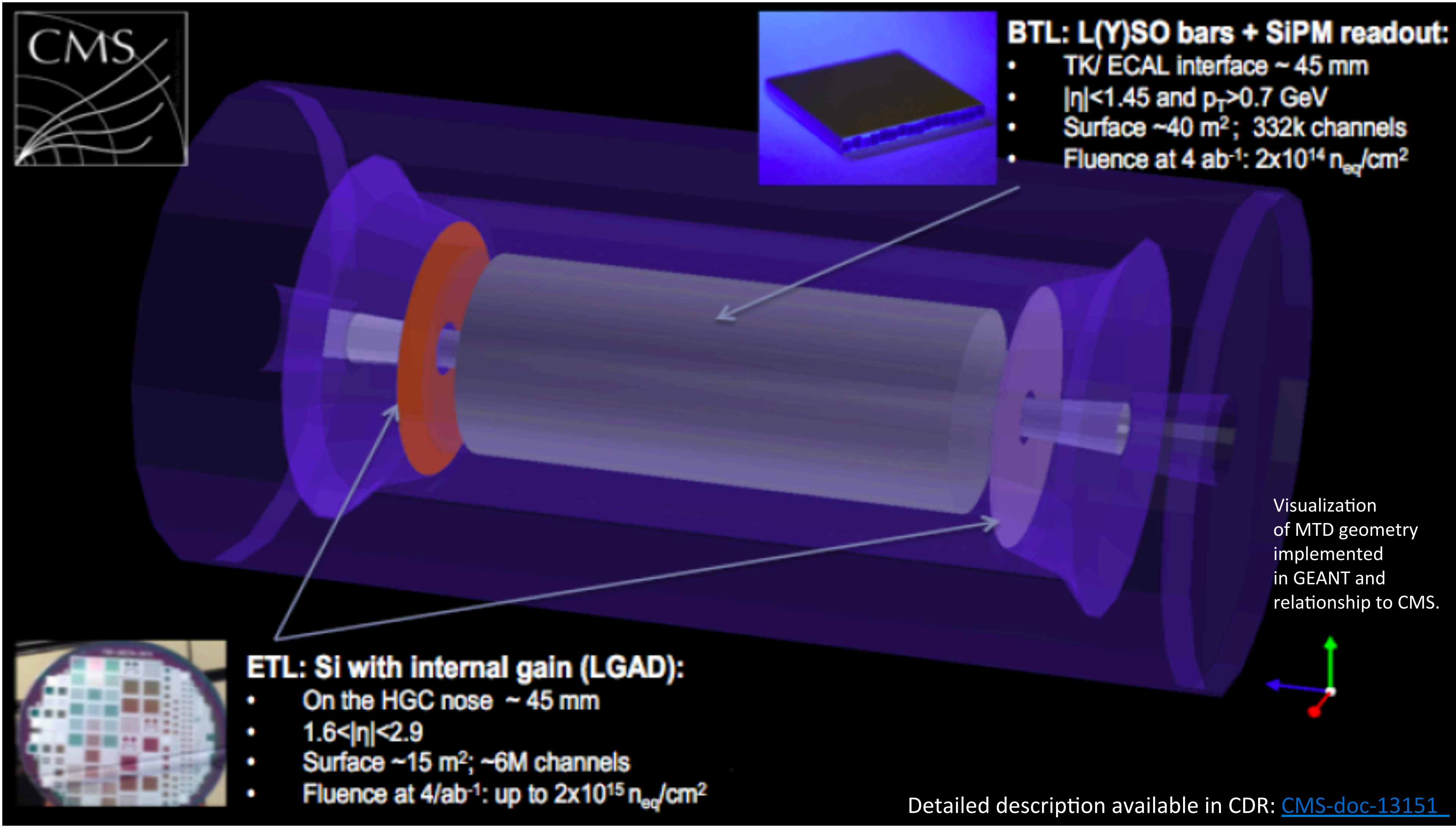
MTD Science Engineering Requirements

Title	ID	Requirement	Rationale
MIP Timing	01	The MTD shall provide time-of-arrival information for MIPs with **sufficient resolution to disambiguate spatially-coincident vertices**	Improve the particle-flow performance at high pileup (PU) to a level comparable to the Phase-1 CMS. Extend the CMS physics reach in a broad class of NP searches for long-lived particles.
Material budget	02	MTD shall have **low material density** to reduce multiple scattering and to avoid EM showers ahead of calorimetry	Energy measurements are performed by the calorimeters, and therefore particle energy losses and changes in their trajectory before calorimeter surface must be minimized.
Reliability and maintainability	03	The MTD shall operate within the CMS detector for **a minimum of 10 years**.	Barrel section of the MTD will be installed within the tracker support tube (TST), which will be inaccessible for repairs once installed. The endcap section will be accessible for repairs during extended technical stops and long shutdowns.
Integration	04	The MTD shall **fit within the envelope** and parameters to conform to in situ CMS detector and other HL-LHC systems.	The overall geometric envelope and certain other infrastructure and services are not subject to upgrade, and the MTD must maintain compatibility with these pre-existing constraints.
Data Throughput	05	The MTD data readout shall have **sufficient bandwidth** to accommodate the expected hit rates for up to 200 PU.	Maintain bandwidth compatibility with the backend electronics constraints.
Occupancy	06	The MTD shall **not exceed 10% occupancy** per readout channel at 200 PU interactions.	Multiple hits per channel would cause an ambiguous assignment of the time information per charged particle, and would also distort a given particle's pulse shape.
Coverage	07	MTD **shall cover the range |eta|<3.0** in order to provide precision timing information in the region covered by the precision calorimetry, muons, and tracker.	Improve charged lepton isolation measurements, b-tag and PU jet identification efficiencies, and MET resolution in the regions of highest sensitivity for Higgs boson measurements and new physics searches.

CMS-doc-13536

Charge #2

MTD Conceptual Design



BTL: L(Y)SO bars + SiPM readout:

- TK/ ECAL interface ~ 45 mm
- $|\eta|<1.45$ and $p_T>0.7$ GeV
- Surface ~40 m^2; 332k channels
- Fluence at 4 ab^{-1}: 2×10^{14} n_{eq}/cm^2

ETL: Si with internal gain (LGAD):

- On the HGC nose ~ 45 mm
- $1.6<|\eta|<2.9$
- Surface ~15 m^2; ~6M channels
- Fluence at 4/ab^{-1}: up to 2×10^{15} n_{eq}/cm^2

Visualization of MTD geometry implemented in GEANT and relationship to CMS.

Detailed description available in CDR: CMS-doc-13151

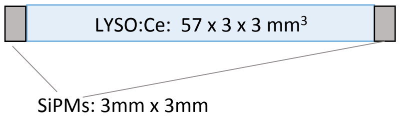
MTD provides precision time measurement for MIPs with σ_t=30-40ps with sufficient radiation tolerance to maintain σ_t<60ps up to 4000/fb.

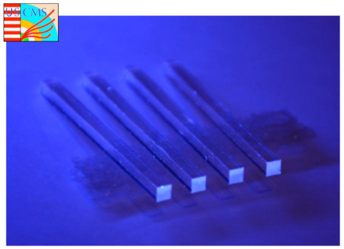
Charge #2

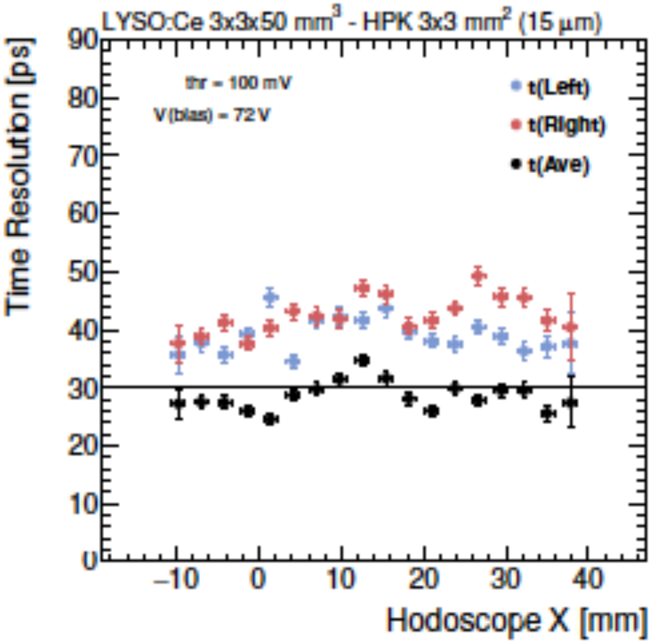
BTL Overview

= USCMS area of activity

Active elements:

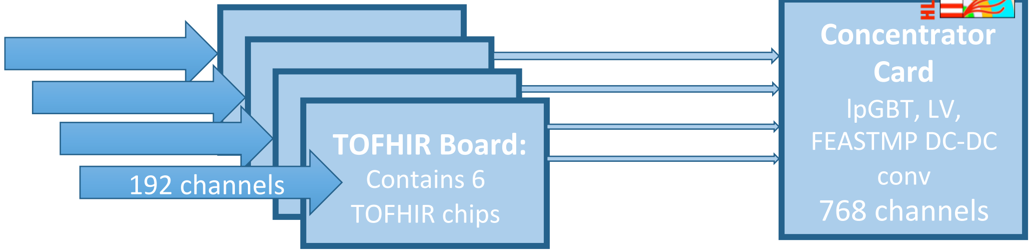






- LYSO:Ce bar glued to SiPMs on each end
  - Fast and bright crystal
  - Radiation tolerant
  - Well-understood commodities

Readout Unit:



192 channels

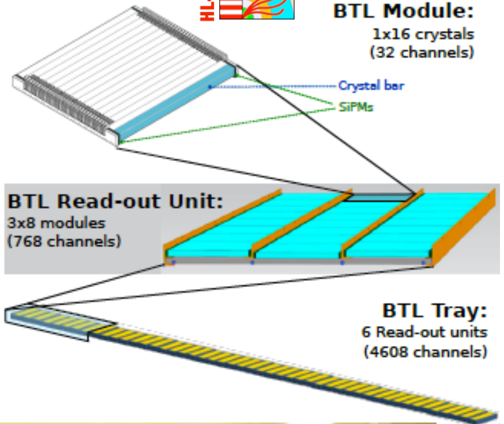
TOFHIR Board:
Contains 6
TOFHIR chips

Concentrator Card
lpGBT, LV,
FEASTMP DC-DC
conv
768 channels

Mechanics and integration:

- BTL will reside in the Tracker Support Tube (TST)
- Modules and Readout Units are assembled onto aluminum cooling trays
- Trays are a deliverable of the BTL assembly project – sent to CERN for integration
- 332k total channels
  - Compare to 215M for Outer Tracker – relative 0.2% in number of channels

Construction



BTL Module:
1x16 crystals
(32 channels)

BTL Read-out Unit:
3x8 modules
(768 channels)

BTL Tray:
6 Read-out units
(4608 channels)

BTL detector
72 trays: 2(z) x 36(φ)
332k channels

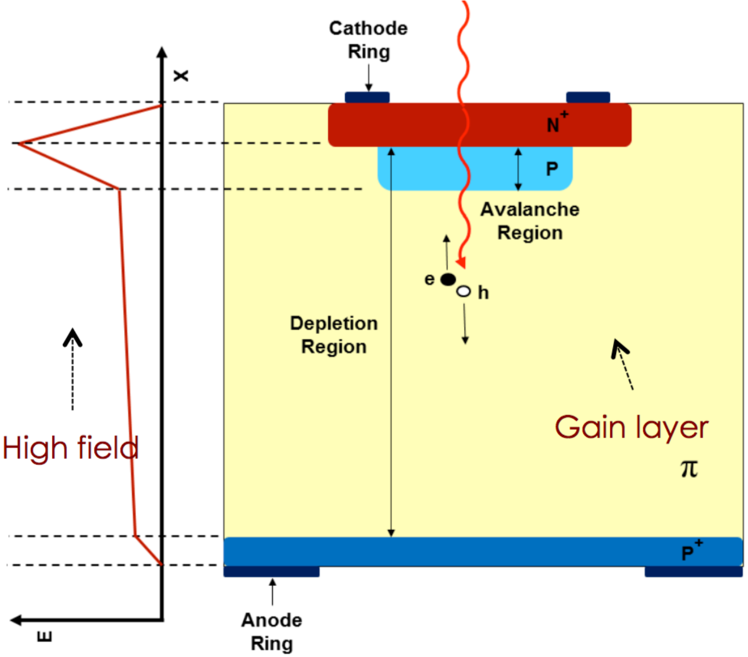
Integration & Commissioning

More in BTL talks in B/O: MTD

Charge #2

ETL Overview

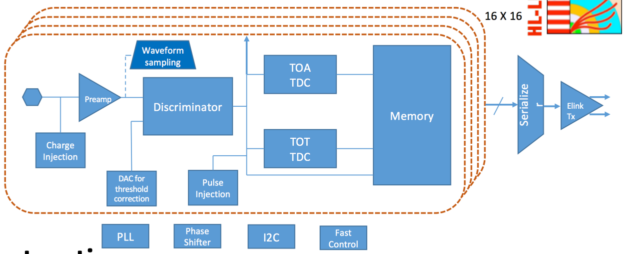
Active element:



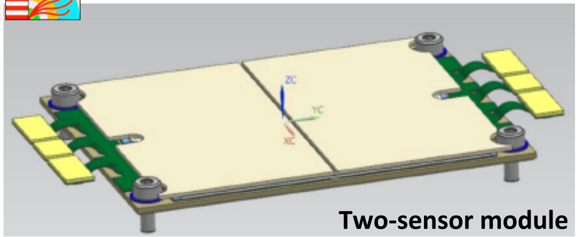
- **“Low-Gain Avalanche Detector” (LGAD)**
  - Large signal, large slew-rate ⇒rapid electrical response
  - More signal in less material ⇒ short drift time, better timing resolution
  - Low gain ⇒ low shot noise, below electronics pedestal

Sensors, ASICs and Modules:

- Each sensor: 2x4 cm^2 array of 512 1.3x1.3 mm^2 pixels
- Module is an sub-assembly of sensor + ASICs
- One or two sensors per module, ~9000 total modules ➔ ~9M pixels
  - Relative 4% in number of channels wrt OT



Construction

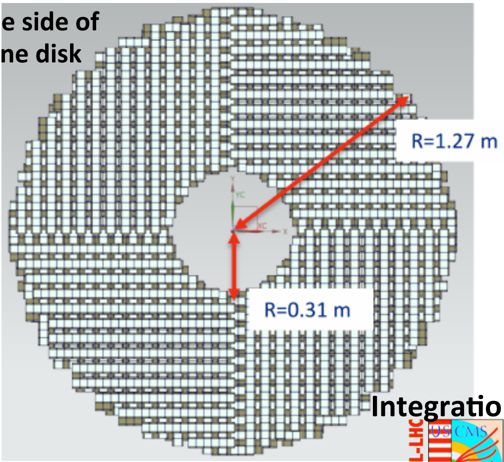


Two-sensor module

Mechanics and Integration:

- Two double-sided disks on each endcap
- Each disk has 85% coverage
- Allows two time meas per track
- Stageable, serviceable, maintainable

One side of one disk



Integration & Commissioning

More in ETL talks in B/O: MTD

Charge #2

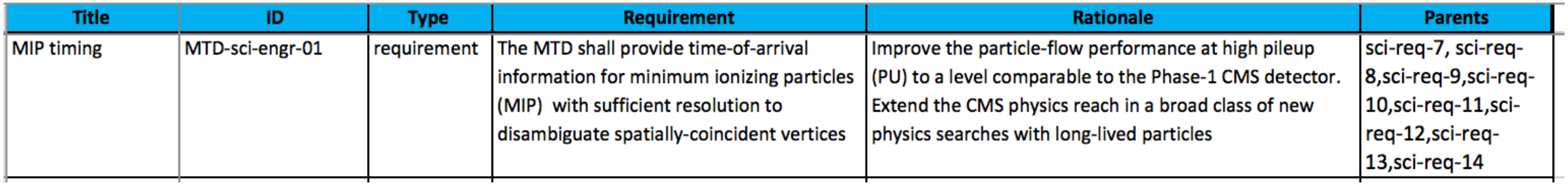
MTD Engineering Requirements

- The MTD Science-Engineering Requirements inform the MTD Engineering Requirements
  - MTD has 45 Engineering Requirements in total
  - Categorized under different headings:

General engineering	*Logistics*
Cooling	*Sensor*
Integration	*Electronics*
ES&H	*Modules & Components*

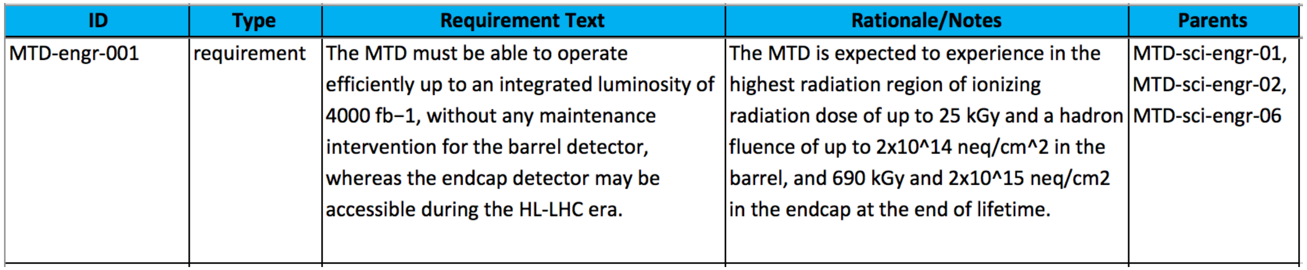
  - Example:
    - MTD Sci-Eng Requirement 041informs MTD Engineering Requirement 001:

MTD Science Engineering Requirement 01



Title	ID	Type	Requirement	Rationale	Parents
MIP timing	MTD-sci-engr-01	requirement	The MTD shall provide time-of-arrival information for minimum ionizing particles (MIP) with sufficient resolution to disambiguate spatially-coincident vertices	Improve the particle-flow performance at high pileup (PU) to a level comparable to the Phase-1 CMS detector. Extend the CMS physics reach in a broad class of new physics searches with long-lived particles	sci-req-7, sci-req-8,sci-req-9,sci-req-10,sci-req-11,sci-req-12,sci-req-13,sci-req-14

MTD Engineering Requirement 001



ID	Type	Requirement Text	Rationale/Notes	Parents
MTD-engr-001	requirement	The MTD must be able to operate efficiently up to an integrated luminosity of 4000 fb−1, without any maintenance intervention for the barrel detector, whereas the endcap detector may be accessible during the HL-LHC era.	The MTD is expected to experience in the highest radiation region of ionizing radiation dose of up to 25 kGy and a hadron fluence of up to 2x10^14 neq/cm^2 in the barrel, and 690 kGy and 2x10^15 neq/cm2 in the endcap at the end of lifetime.	MTD-sci-engr-01, MTD-sci-engr-02, MTD-sci-engr-06

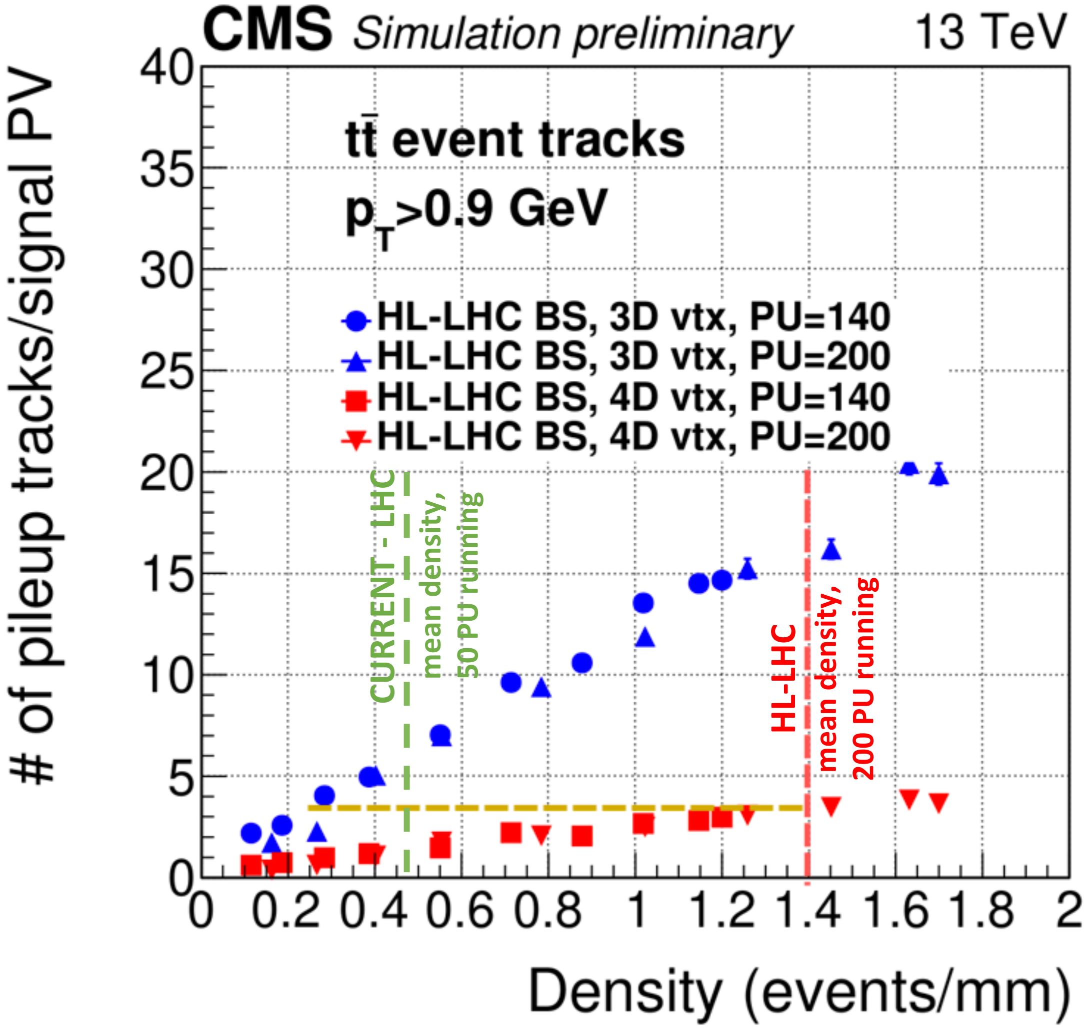
- All details are ready for inspection in [CMS-doc-13536]
- **Summary**: Requirements are well defined and traceable.

Performance Meets Requirements

- Primary mission of the MTD: **pileup mitigation**
- **Time-aware primary vertex reconstruction** reduces incorrect association of tracks from nearby pileup interactions
  - Every object benefits
- Further, there are **additional profound benefits** to lifetime tagging and long-lived exotica searches
- June 2018 IPR:

  > *"Overall, the addition of the MTD corresponds to a 20-30% effective luminosity increase for CMS. The physics case for the MTD detector is very strong."*

- We do not discuss physics performance in this review. See the relevant sections of the CDR.



The incidence of PU tracks being incorrectly associated to the hard interaction vertex is reduced by a factor of 5 – ***returning to the level of the current LHC era!***

Charge #3

US-MTD Scope

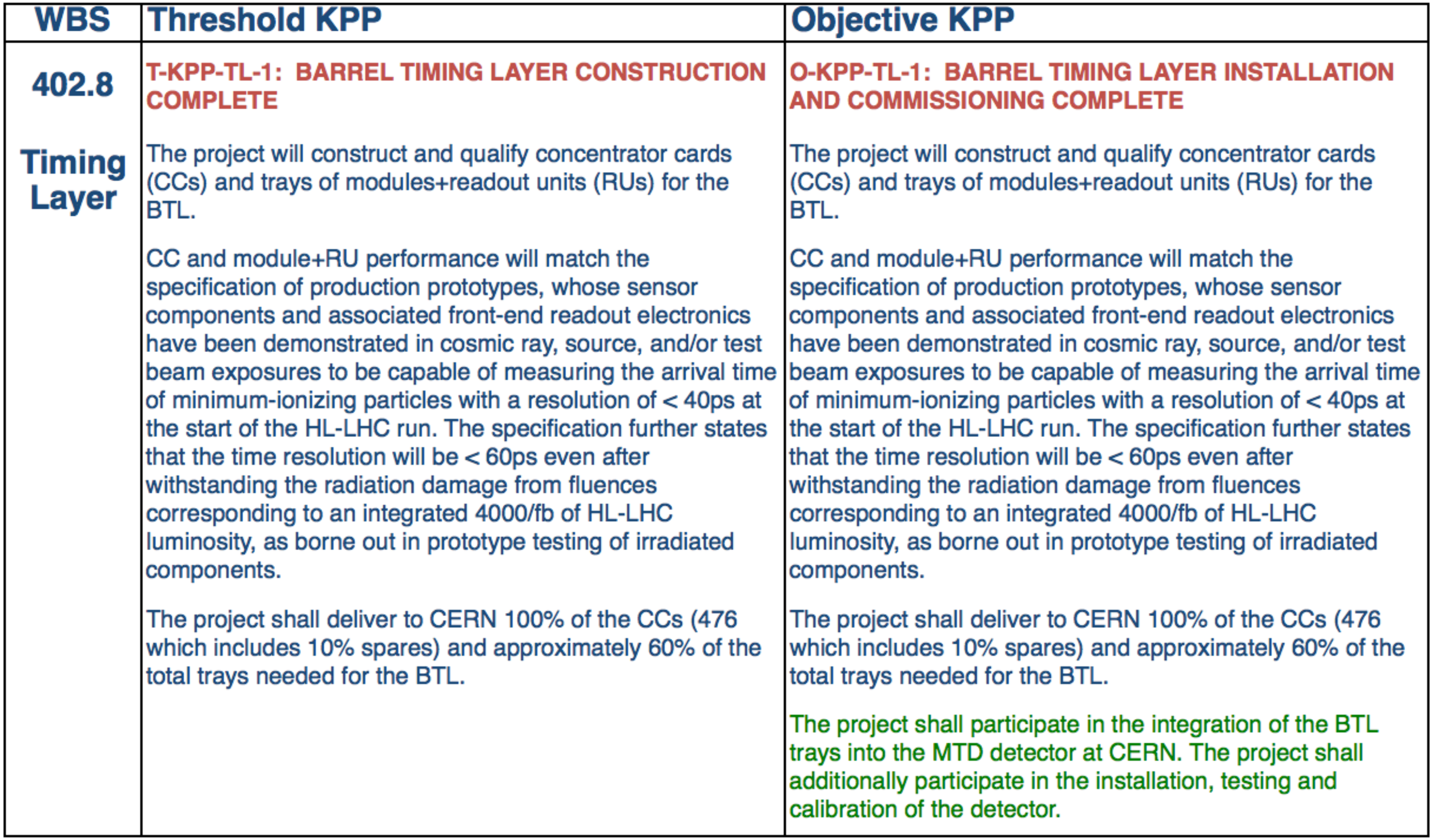
- BTL:
  - Purchase of **40% of the production-era BTL LYSO crystals**. Limited participation in LYSO QC.
  - Prototype, pre-production BTL SiPM studies. **Provision of 34% and QC testing of 50% of the production-era SiPMs**.
  - Design and prototyping of the BTL Concentrator Card (CC). **Provision and QC testing of 100% of the production-era CCs** (476 cards, incl. spares).
  - Lead R&D for BTL assembly and define procedures. **Perform assembly of 60% of the BTL trays and associated QC testing**, delivery to CERN.
  - **Participation in BTL integration** of trays into the TST and checkout commissioning
- ETL:
  - Design and prototyping of the ETL FE ASIC. **Provision and QC testing of 50% of the production-era ASICs.**
  - Lead R&D and prototyping for assembly procedures. **Perform assembly of 50% of the ETL modules and associated QC testing**, delivery to CERN
  - **Participation in ETL integration** of modules onto the ETL support structure, installation on the endcap and checkout commissioning

Charge #3,7

Draft KPPs

- Barrel Timing Layer

CMS-doc-13237



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.

Charge #3,7

Draft KPPs

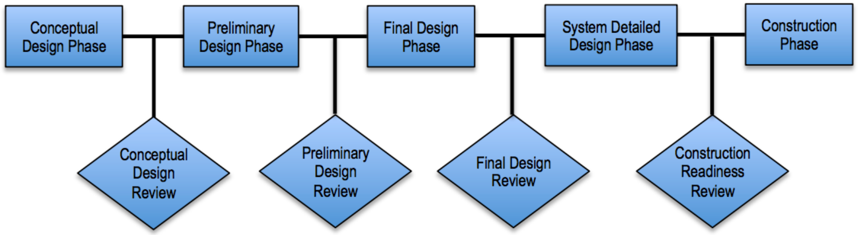
CMS-doc-13237

- 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.

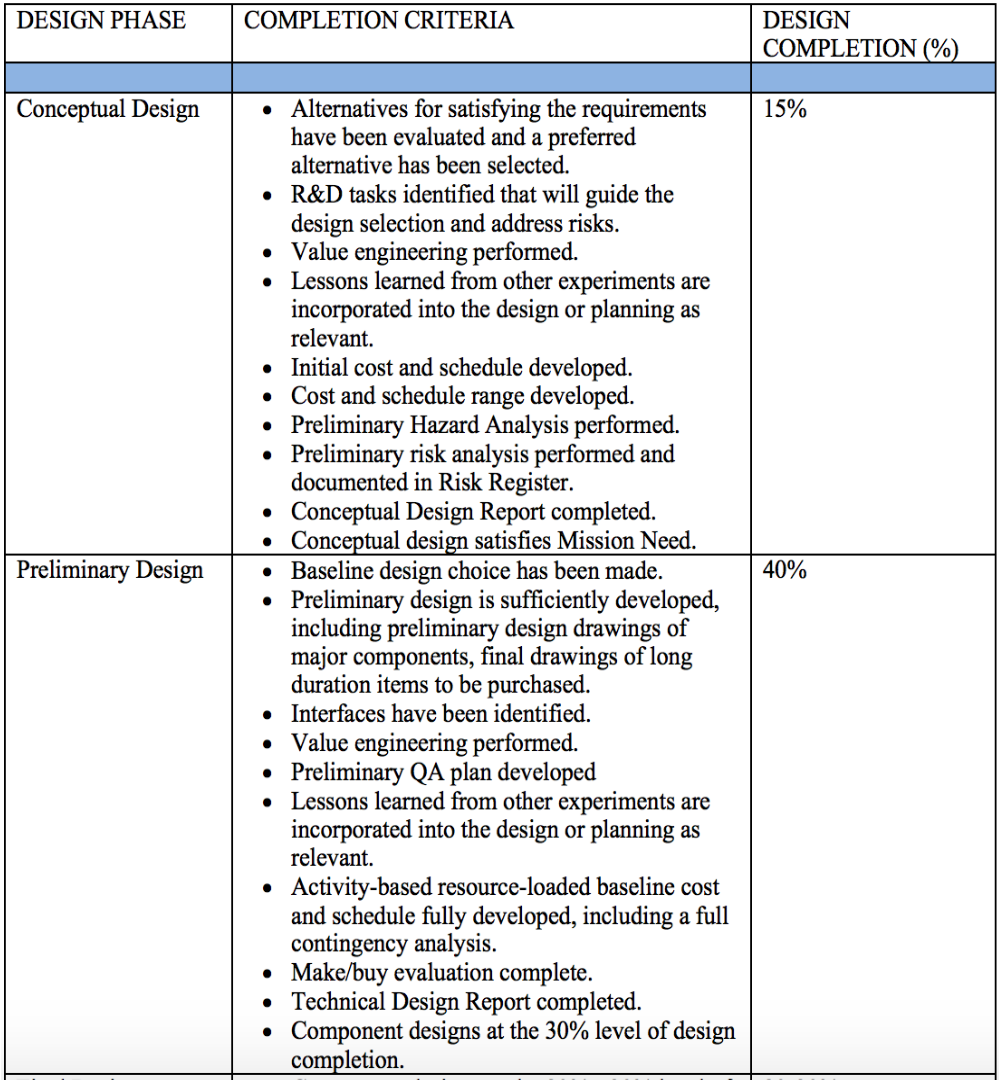
Estimating Design Maturity

Charge #2,7



- To estimate the maturity of our design, we follow the approach outlined in CMS-doc-13471
  - Allows assessment of maturity as required in DOE O413.3b procedures.
- Different stages of maturity of design:
  - Conceptual [15% complete]
  - Preliminary [40% complete]
  - Final [80-90% complete]
  - Detailed System Design [100% complete]
- Rubric was developed for ANL light source. Later adopted by mu2e and now here.

Rubric:

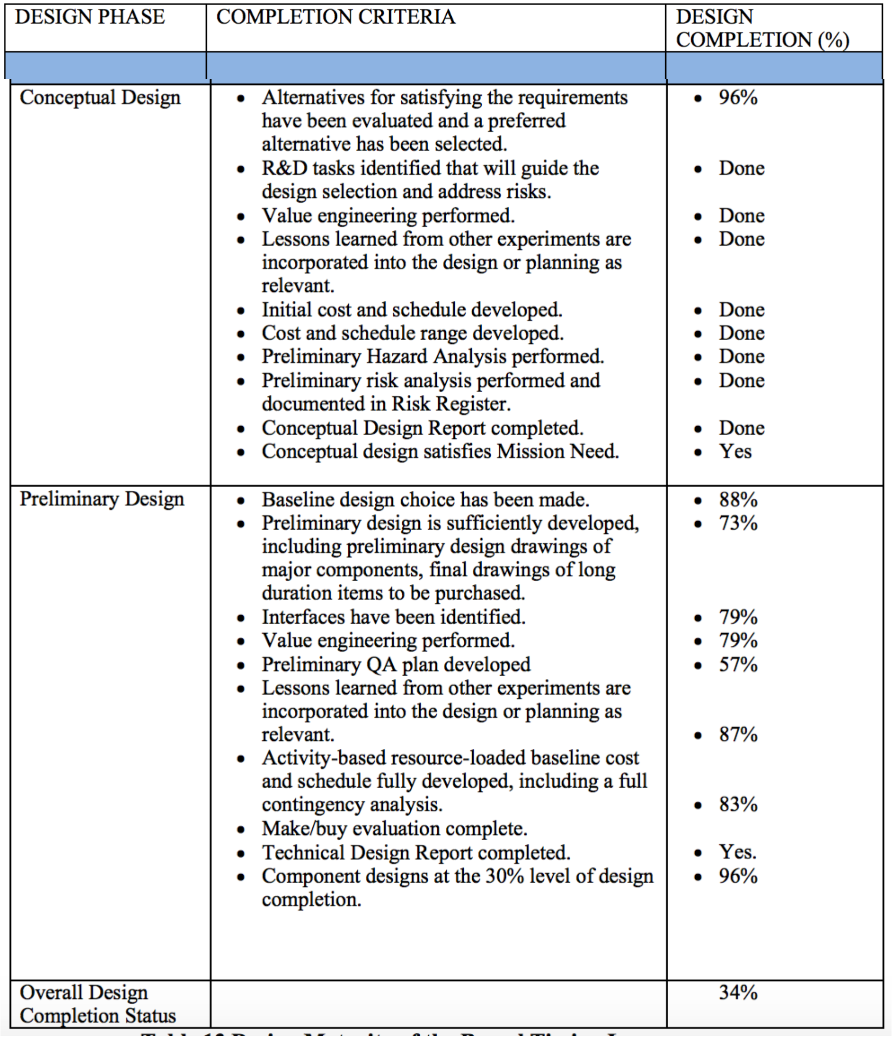


DESIGN PHASE	COMPLETION CRITERIA	DESIGN COMPLETION (%)
Conceptual Design	• Alternatives for satisfying the requirements have been evaluated and a preferred alternative has been selected. • R&D tasks identified that will guide the design selection and address risks. • Value engineering performed. • Lessons learned from other experiments are incorporated into the design or planning as relevant. • Initial cost and schedule developed. • Cost and schedule range developed. • Preliminary Hazard Analysis performed. • Preliminary risk analysis performed and documented in Risk Register. • Conceptual Design Report completed. • Conceptual design satisfies Mission Need.	15%
Preliminary Design	• Baseline design choice has been made. • Preliminary design is sufficiently developed, including preliminary design drawings of major components, final drawings of long duration items to be purchased. • Interfaces have been identified. • Value engineering performed. • Preliminary QA plan developed • Lessons learned from other experiments are incorporated into the design or planning as relevant. • Activity-based resource-loaded baseline cost and schedule fully developed, including a full contingency analysis. • Make/buy evaluation complete. • Technical Design Report completed. • Component designs at the 30% level of design completion.	40%

Charge #2,7

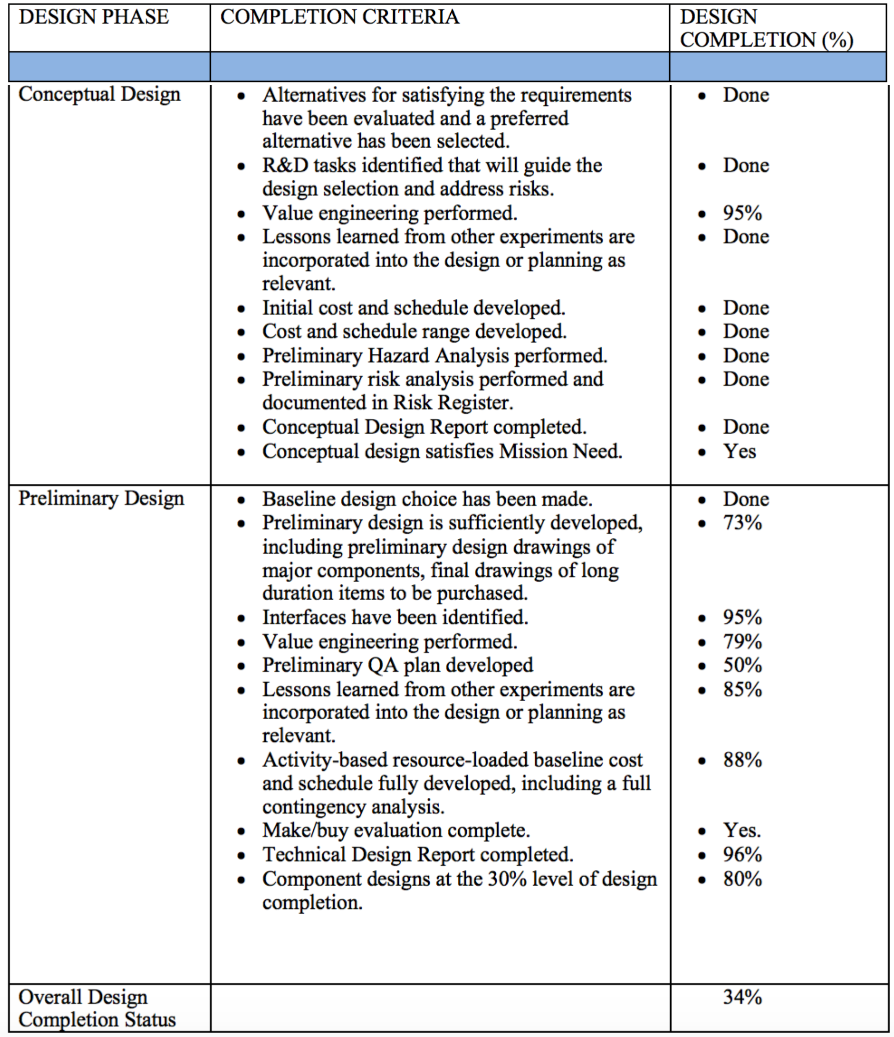
MTD Design Maturity

BTL



DESIGN PHASE	COMPLETION CRITERIA	DESIGN COMPLETION (%)
Conceptual Design	Alternatives for satisfying the requirements have been evaluated and a preferred alternative has been selected.	96%
	R&D tasks identified that will guide the design selection and address risks.	Done
	Value engineering performed.	Done
	Lessons learned from other experiments are incorporated into the design or planning as relevant.	Done
	Initial cost and schedule developed.	Done
	Cost and schedule range developed.	Done
	Preliminary Hazard Analysis performed.	Done
	Preliminary risk analysis performed and documented in Risk Register.	Done
	Conceptual Design Report completed.	Done
	Conceptual design satisfies Mission Need.	Yes
Preliminary Design	Baseline design choice has been made.	88%
	Preliminary design is sufficiently developed, including preliminary design drawings of major components, final drawings of long duration items to be purchased.	73%
	Interfaces have been identified.	79%
	Value engineering performed.	79%
	Preliminary QA plan developed	57%
	Lessons learned from other experiments are incorporated into the design or planning as relevant.	87%
	Activity-based resource-loaded baseline cost and schedule fully developed, including a full contingency analysis.	83%
	Make/buy evaluation complete.	Yes.
	Technical Design Report completed.	96%
	Component designs at the 30% level of design completion.	
Overall Design Completion Status		34%

ETL

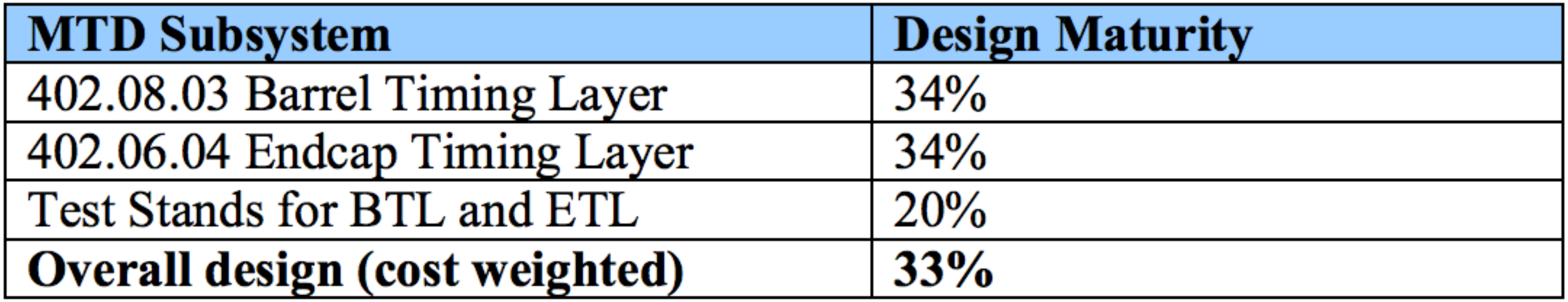


DESIGN PHASE	COMPLETION CRITERIA	DESIGN COMPLETION (%)
Conceptual Design	Alternatives for satisfying the requirements have been evaluated and a preferred alternative has been selected.	Done
	R&D tasks identified that will guide the design selection and address risks.	Done
	Value engineering performed.	95%
	Lessons learned from other experiments are incorporated into the design or planning as relevant.	Done
	Initial cost and schedule developed.	Done
	Cost and schedule range developed.	Done
	Preliminary Hazard Analysis performed.	Done
	Preliminary risk analysis performed and documented in Risk Register.	Done
	Conceptual Design Report completed.	Done
	Conceptual design satisfies Mission Need.	Yes
Preliminary Design	Baseline design choice has been made.	Done
	Preliminary design is sufficiently developed, including preliminary design drawings of major components, final drawings of long duration items to be purchased.	73%
	Interfaces have been identified.	95%
	Value engineering performed.	79%
	Preliminary QA plan developed	50%
	Lessons learned from other experiments are incorporated into the design or planning as relevant.	85%
	Activity-based resource-loaded baseline cost and schedule fully developed, including a full contingency analysis.	88%
	Make/buy evaluation complete.	Yes.
	Technical Design Report completed.	96%
	Component designs at the 30% level of design completion.	80%
Overall Design Completion Status		34%

- Separate treatment for BTL and ETL given the different technologies

Charge #2,7

MTD Design Maturity



MTD Subsystem	Design Maturity
402.08.03 Barrel Timing Layer	34%
402.06.04 Endcap Timing Layer	34%
Test Stands for BTL and ETL	20%
Overall design (cost weighted)	**33%**

- Test Stands are separated here since they are partly correlated among BTL and ETL – easier to track their maturity this way

- MTD overall design maturity: 33%
  - Beyond the conceptual design stage [15%]
  - Maturity level similar to other upgrade projects' current values

Charge #5

Int'l MTD Project and US Participation

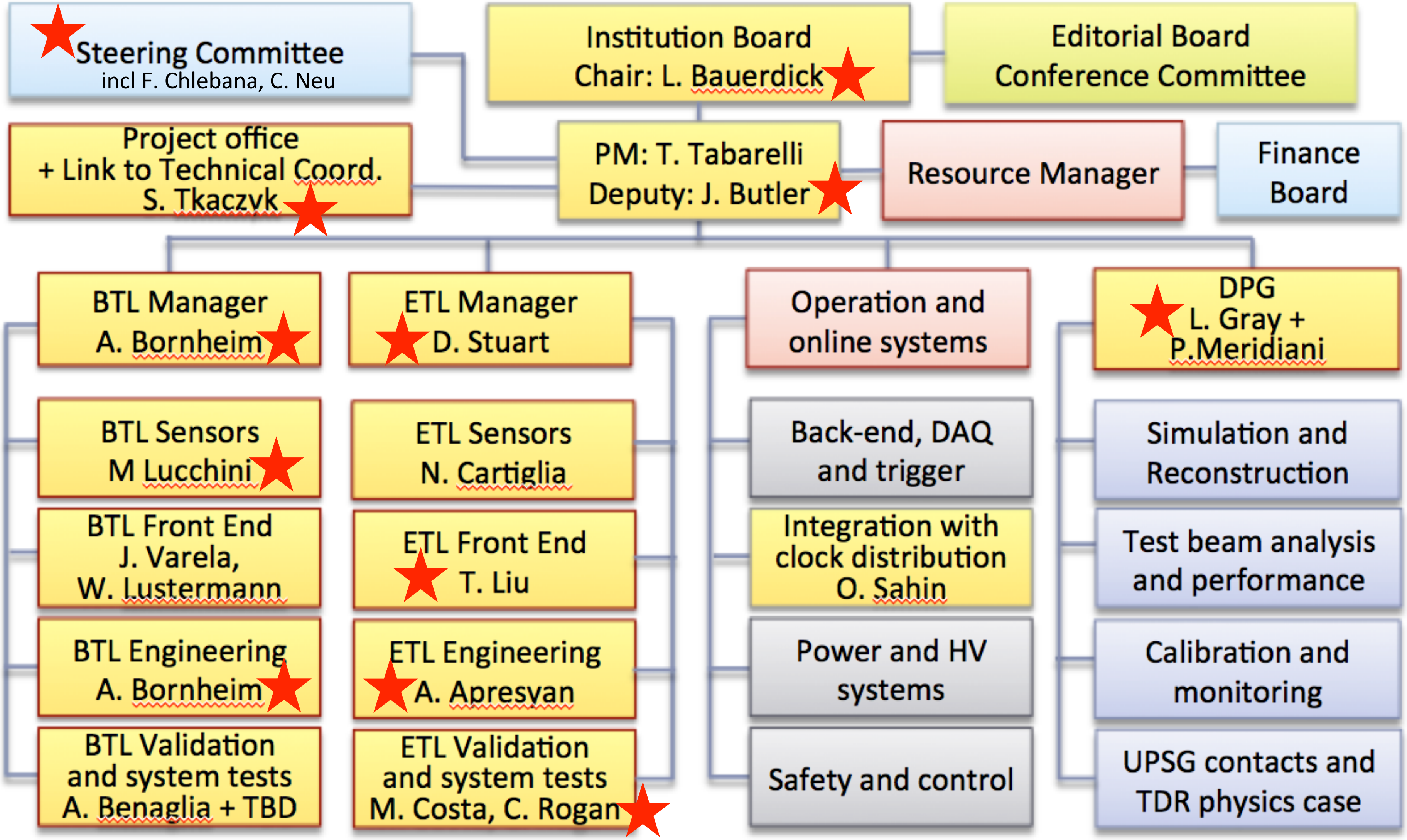
- MTD received Step 1 approval from the LHCC and CERN RB in March 2018
- As we proceed to Step 2, we have prepared the MTD TDR and we are developing model for sharing work and costs:
  - TDR currently in CMS internal collaboration-wide review, release to LHCC 29 March
    - LHCC review of TDR week of 3 June
  - LHCC Upgrade Cost Group package submitted mid-May
    - UCG review week of 9 September
- The MTD has **broad international participation**
  - 36 institutes from 13 countries
- The US is a **major technical and intellectual driver** of the international MTD project
  - Personnel from twelve US institutions, significant contributions to hardware and performance studies in BTL and ETL
- Hence **US has large footprint** within MTD project

Belarus
China
Finland
France
Germany
Hungary
Italy
Lithuania
Portugal
Russia
Spain
Switzerland
US

Charge #5

MTD Organization Chart

★: US personnel



★Steering Committee
incl F. Chlebana, C. Neu

Institution Board
Chair: L. Bauerdick★

Editorial Board
Conference Committee

Project office
+ Link to Technical Coord.
S. Tkaczyk★

PM: T. Tabarelli
Deputy: J. Butler★

Resource Manager

Finance
Board

BTL Manager
A. Bornheim★

ETL Manager
★D. Stuart

Operation and
online systems

DPG
★L. Gray +
P.Meridiani

BTL Sensors
M Lucchini★

ETL Sensors
N. Cartiglia

Back-end, DAQ
and trigger

Simulation and
Reconstruction

BTL Front End
J. Varela,
W. Lustermann

ETL Front End
★T. Liu

Integration with
clock distribution
O. Sahin

Test beam analysis
and performance

BTL Engineering
A. Bornheim★

ETL Engineering
★A. Apresyan

Power and HV
systems

Calibration and
monitoring

BTL Validation
and system tests
A. Benaglia + TBD

ETL Validation
and system tests
M. Costa, C. Rogan★

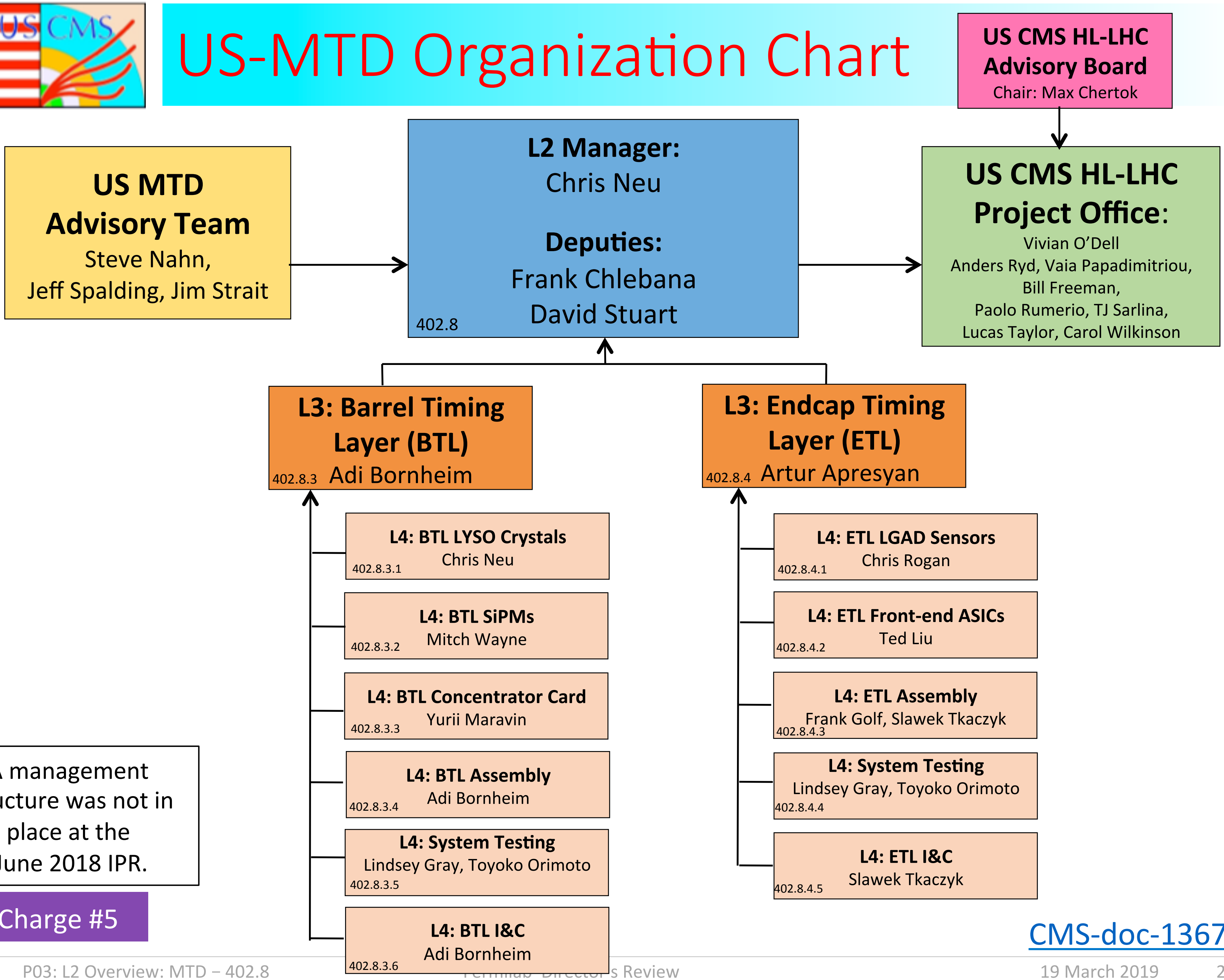
Safety and control

UPSG contacts and
TDR physics case

Grey, pink, blue areas also covered but not explicitly listed here.

CMS-doc-13653

US-MTD Organization Chart



US CMS HL-LHC Advisory Board
Chair: Max Chertok

US MTD Advisory Team
Steve Nahn,
Jeff Spalding, Jim Strait

L2 Manager:
Chris Neu

Deputies:
Frank Chlebana
David Stuart
402.8

US CMS HL-LHC Project Office:
Vivian O'Dell
Anders Ryd, Vaia Papadimitriou,
Bill Freeman,
Paolo Rumerio, TJ Sarlina,
Lucas Taylor, Carol Wilkinson

L3: Barrel Timing Layer (BTL)
402.8.3 Adi Bornheim

- **L4: BTL LYSO Crystals**
  Chris Neu
  402.8.3.1
- **L4: BTL SiPMs**
  Mitch Wayne
  402.8.3.2
- **L4: BTL Concentrator Card**
  Yurii Maravin
  402.8.3.3
- **L4: BTL Assembly**
  Adi Bornheim
  402.8.3.4
- **L4: System Testing**
  Lindsey Gray, Toyoko Orimoto
  402.8.3.5
- **L4: BTL I&C**
  Adi Bornheim
  402.8.3.6

L3: Endcap Timing Layer (ETL)
402.8.4 Artur Apresyan

- **L4: ETL LGAD Sensors**
  Chris Rogan
  402.8.4.1
- **L4: ETL Front-end ASICs**
  Ted Liu
  402.8.4.2
- **L4: ETL Assembly**
  Frank Golf, Slawek Tkaczyk
  402.8.4.3
- **L4: System Testing**
  Lindsey Gray, Toyoko Orimoto
  402.8.4.4
- **L4: ETL I&C**
  Slawek Tkaczyk
  402.8.4.5

A management structure was not in place at the June 2018 IPR.

Charge #5

CMS-doc-13678

Deputy L2 Managers

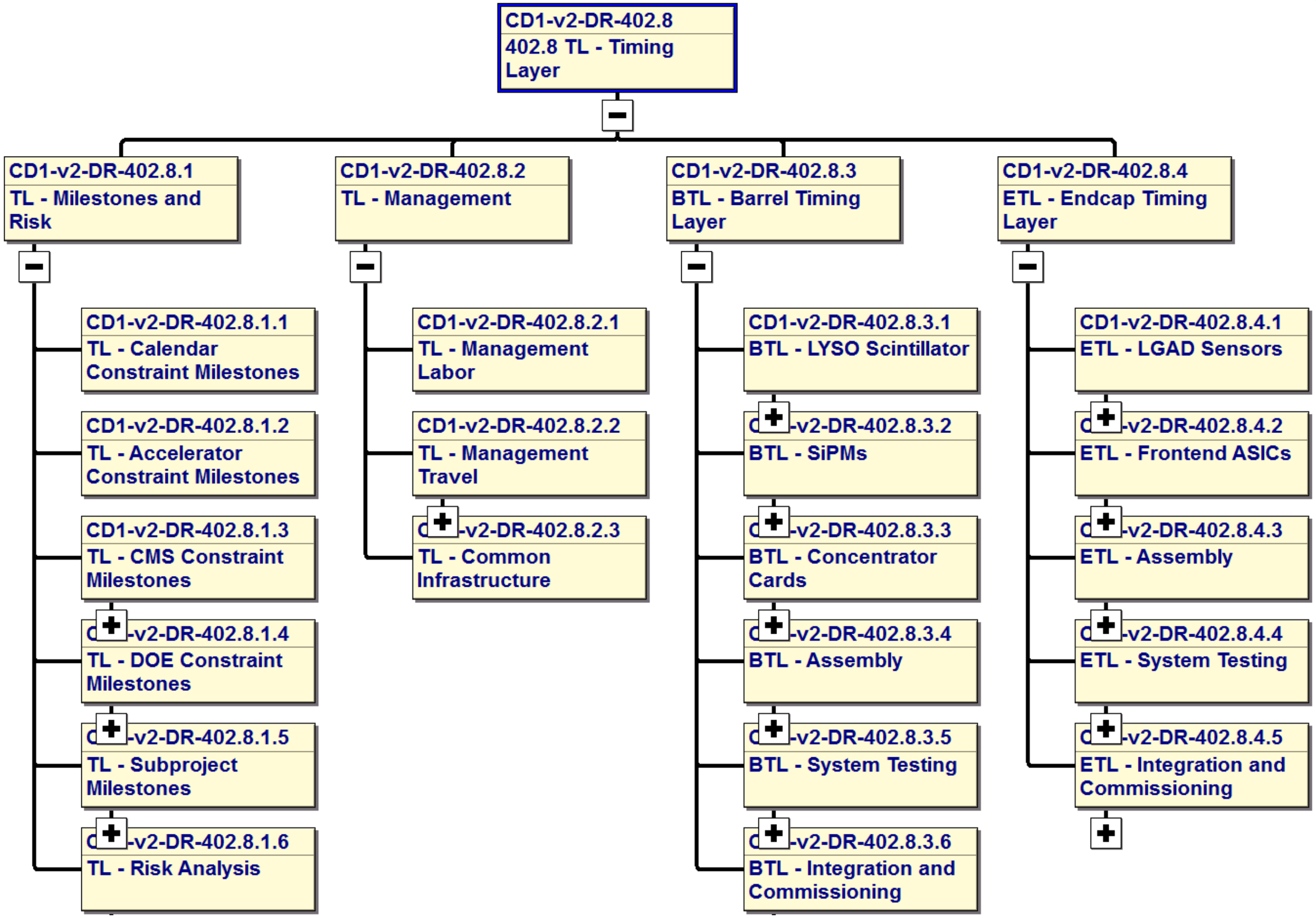
- Frank Chlebana
  - Senior Scientist, Fermilab
  - Experience in construction, commissioning, operations, and project planning while on CMS, CDF, and ZEUS
  - Deputy head of the Fermilab CMS Department
  - Deputy L2 manager for the HCAL Phase 1 upgrades
  - HGCal DPG co-convener (ramping down)
  - Former CMS HCAL DPG convener
  - Former head of the DAQ group at CDF

- David Stuart
  - Professor, UCSB
  - Serving as ETL Technical Coordinator in iMTD
  - Experience with design, construction, and operation of tracking detectors at AMY, CDF, CMS
  - Track reconstruction and b-tag development
  - Searches for new phenomena at CDF and CMS
  - Convener of CDF exotics and CMS SUSY groups
  - Fast timing R&D for SSC with Charpak group

Frank and David bring considerable technical, project management, and leadership experience to the US-MTD management team.

Charge #5,7

Work Breakdown Structure



- CD1-v2-DR-402.8 402.8 TL - Timing Layer
  - CD1-v2-DR-402.8.1 TL - Milestones and Risk
    - CD1-v2-DR-402.8.1.1 TL - Calendar Constraint Milestones
    - CD1-v2-DR-402.8.1.2 TL - Accelerator Constraint Milestones
    - CD1-v2-DR-402.8.1.3 TL - CMS Constraint Milestones
    - C -v2-DR-402.8.1.4 TL - DOE Constraint Milestones
    - C -v2-DR-402.8.1.5 TL - Subproject Milestones
    - C -v2-DR-402.8.1.6 TL - Risk Analysis
  - CD1-v2-DR-402.8.2 TL - Management
    - CD1-v2-DR-402.8.2.1 TL - Management Labor
    - CD1-v2-DR-402.8.2.2 TL - Management Travel
    - C -v2-DR-402.8.2.3 TL - Common Infrastructure
  - CD1-v2-DR-402.8.3 BTL - Barrel Timing Layer
    - CD1-v2-DR-402.8.3.1 BTL - LYSO Scintillator
    - C -v2-DR-402.8.3.2 BTL - SiPMs
    - C -v2-DR-402.8.3.3 BTL - Concentrator Cards
    - C -v2-DR-402.8.3.4 BTL - Assembly
    - C -v2-DR-402.8.3.5 BTL - System Testing
    - C -v2-DR-402.8.3.6 BTL - Integration and Commissioning
  - CD1-v2-DR-402.8.4 ETL - Endcap Timing Layer
    - CD1-v2-DR-402.8.4.1 ETL - LGAD Sensors
    - C -v2-DR-402.8.4.2 ETL - Frontend ASICs
    - C -v2-DR-402.8.4.3 ETL - Assembly
    - C -v2-DR-402.8.4.4 ETL - System Testing
    - C -v2-DR-402.8.4.5 ETL - Integration and Commissioning

- BTL and ETL activities naturally uncorrelated, hence this WBS arrangement
- Beneficial for activity+resource mapping in RLS

US-MTD Expertise Matches Contributions

- US institutes involved in the MTD have expertise and capabilities matched to their area of contribution. Primary examples:
    - **Caltech** has a history in generic R&D in **precision timing applications** in particle detection techniques, as well as institutional expertise in scintillating crystals. Experience in CMS ECAL.
    - **Fermilab** has a unique capability in terms of the **ASIC design group**, allowing for value engineering from development of other chips. ETL module assembly can utilize existing infrastructure at the **SiDet facility**.
    - **Iowa** has an experienced **mechanical engineering team.**
    - **Kansas** has new lab space, with sufficient space to perform QC tests on LGAD modules.
    - **Kansas State** has **an excellent digital electrical engineer** within the department for design of the CC, with experience from similar electronics for mu2e.
    - **Nebraska** has extensive **experience in silicon detector assembly** projects and related infrastructure.
    - **Northeastern** is planning to engage in the backend electronics for the ECAL barrel upgrade, an experience that will be useful in integrated system testing.
    - **Notre Dame** has significant experience on CMS with **SiPM evaluation and qualification**, for instance in the HCAL Phase 1 upgrade.
    - **Princeton** has experienced **mechanical engineering** support on staff able to contribute to the studies for the impact of the BTL on the TST, as well as leadership in **scintillating crystal evaluation**.
    - **UCSB** has significant institutional experience in **building silicon detectors** and the necessary infrastructure for ETL module R&D.
    - **Virginia** has experience in **scintillating crystal R&D**, radiation tolerant photodetectors.
- Institutes involved are engaged in areas where they have a history of expertise and current available infrastructure + personnel

Charge #4

US-MTD Assembly Centers

- Assembly centers:
  - US MTD institutions have the expertise, capability, space, human resources and bandwidth to contribute to the ultimate assembly of the MTD
  - BTL:
    - Caltech and Virginia, with equal split of US scope
    - Pre-production starting Q4 CY2020, production in Q3 CY2022
  - ETL:
    - FNAL and Nebraska, US scope split 20/80
    - Pre-production starting Q1 CY2023, production in Q4 CY2023

See backup for site descriptions

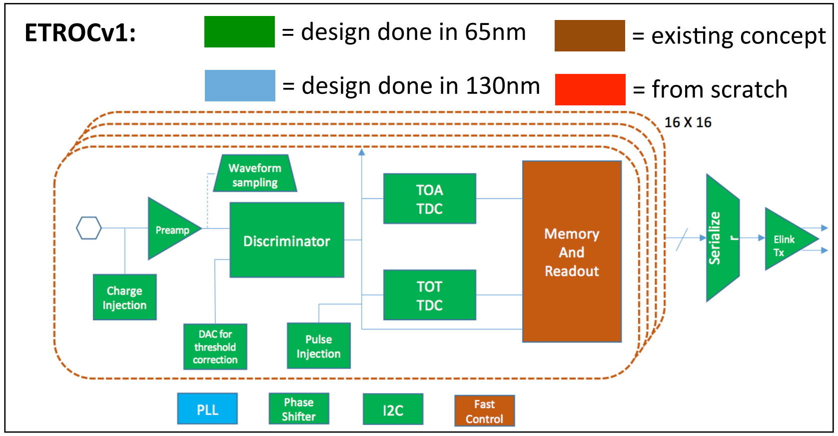
- Site visits and verification:
  - Each assembly center is familiar with the necessary oversight of ongoing construction projects and we understand its importance
  - Our strategy is to have common procedures at each BTL and each ETL assembly center to simplify the assembly portion of the project
  - A detailed schedule for site visits and QA audits will be developed

More in TJ Sarlina's talk in B/O: Project Management

Charge #4,7

Value Engineering

- Value engineering is a planned evaluation of a project to identify alternative approaches to providing the needed assets.
- There are many ways that we are leveraging existing infrastructure and experience for cost and schedule efficiency, see CMS-doc-13475
- Examples:
    - Pre-assembly of LYSO crystal matrices and reflective coating will be **performed by the manufacturer** rather than doing the work in-house at US-MTD institutes
    - Assembly procedures for a system similar to that of BTL were **pioneered by CALICE**, an international collaboration working on calorimeter designs.
    - Reuse of **existing ASIC library blocks** is part of the design plan the ETROC ASIC rather than rewriting these blocks from hand.
    - Rather than design our own service chips, many of the MTD detector elements were developed as **common CERN projects**, in industry, or by other CMS projects. These include the low-power GBT transceivers, versatile link drivers, FEAST family of DC-to-DC converters, the e-link protocol, etc.
    - Instead of designing+building a new test stand, we plan to re-use of the **cosmic-ray test stand and DAQ** developed for use in the checkout of mu2e cosmic-ray veto modules being assembled at UVa for BTL module QA

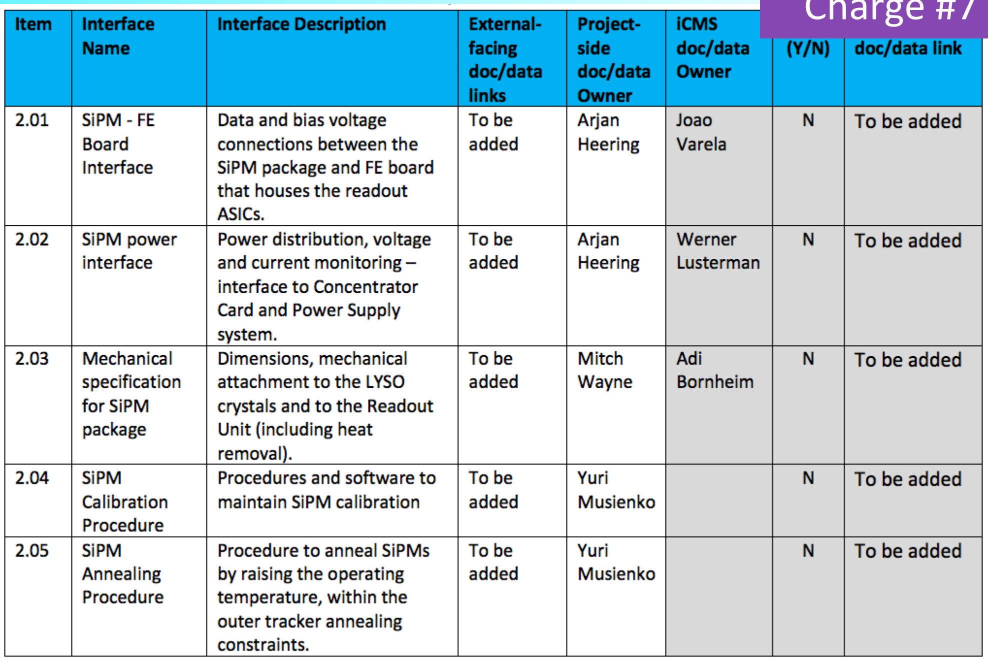


UVa mu2e cosmics teststand

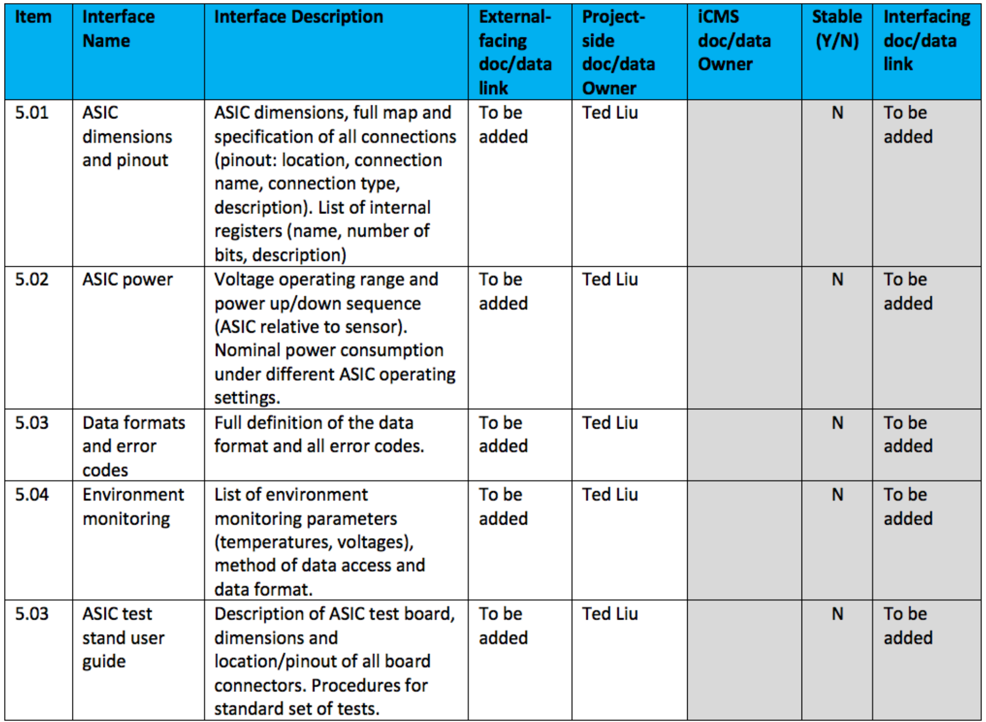
Interfaces

Charge #7

- Interface management is a responsibility shared among management team members
- Often the reporting hierarchy is seamless since several people have roles in both US-MTD and the international MTD project.
- Interfaces exist with other CMS subsystems, common services, with non-US parts of MTD and within US-MTD
- All interfaces have been identified. Organized into 6 categories:
  - General
  - BTL SiPMs
  - BTL CC
  - BTL trays and assembly
  - ETL Readout ASIC
  - ETL modules and assembly
- We have an Interface Control Document, CMS-doc-13536, which has the detailed complete list
- iMTD has a change control process, which will include the project's engineering design documents



Item	Interface Name	Interface Description	External-facing doc/data links	Project-side doc/data Owner	iCMS doc/data Owner	(Y/N)	doc/data link
2.01	SiPM - FE Board Interface	Data and bias voltage connections between the SiPM package and FE board that houses the readout ASICs.	To be added	Arjan Heering	Joao Varela	N	To be added
2.02	SiPM power interface	Power distribution, voltage and current monitoring – interface to Concentrator Card and Power Supply system.	To be added	Arjan Heering	Werner Lusterman	N	To be added
2.03	Mechanical specification for SiPM package	Dimensions, mechanical attachment to the LYSO crystals and to the Readout Unit (including heat removal).	To be added	Mitch Wayne	Adi Bornheim	N	To be added
2.04	SiPM Calibration Procedure	Procedures and software to maintain SiPM calibration	To be added	Yuri Musienko		N	To be added
2.05	SiPM Annealing Procedure	Procedure to anneal SiPMs by raising the operating temperature, within the outer tracker annealing constraints.	To be added	Yuri Musienko		N	To be added



Item	Interface Name	Interface Description	External-facing doc/data link	Project-side doc/data Owner	iCMS doc/data Owner	Stable (Y/N)	Interfacing doc/data link
5.01	ASIC dimensions and pinout	ASIC dimensions, full map and specification of all connections (pinout: location, connection name, connection type, description). List of internal registers (name, number of bits, description)	To be added	Ted Liu		N	To be added
5.02	ASIC power	Voltage operating range and power up/down sequence (ASIC relative to sensor). Nominal power consumption under different ASIC operating settings.	To be added	Ted Liu		N	To be added
5.03	Data formats and error codes	Full definition of the data format and all error codes.	To be added	Ted Liu		N	To be added
5.04	Environment monitoring	List of environment monitoring parameters (temperatures, voltages), method of data access and data format.	To be added	Ted Liu		N	To be added
5.03	ASIC test stand user guide	Description of ASIC test board, dimensions and location/pinout of all board connectors. Procedures for standard set of tests.	To be added	Ted Liu		N	To be added

Charge #3

Cost Summary

HL-LHC CMS Upgrades	M&S				Labor					Total = Base + Contingency		
Project costs including direct costs, indirect costs, escalation and cost contingency	Direct Cost (M$)	Base Cost (M$)	EU (M$)	**M&S (M$)**	Contrib (FTE-years)	Costed (FTE-years)	Base Cost (M$)	EU (M$)	**Labor (M$)**	Base Cost (M$)	Contin-gency (M$)	**Total (M$)**
402.1 PROJECT MANAGEMENT	10.00	7.00	0.65	**7.66**	1.79	30.82	11.12	1.51	**12.63**	18.13	2.16	**20.29**
402.2 OUTER TRACKER	20.98	24.55	7.10	**31.65**	99.21	104.90	17.48	4.69	**22.18**	42.03	11.80	**53.83**
402.4 ENDCAP CALORIMETER	20.94	23.77	6.58	**30.35**	79.62	95.50	16.13	4.43	**20.56**	39.90	11.01	**50.91**
402.6 TRIGGER AND DAQ	3.66	4.36	1.34	**5.70**	31.69	30.51	4.56	1.22	**5.78**	8.92	2.57	**11.48**
402.8 TIMING LAYER	6.56	7.61	1.52	**9.12**	63.02	28.47	3.76	1.51	**5.27**	11.36	3.03	**14.39**
RISK CONTINGENCY											10.64	**10.64**
Total Cost	**62.15**	**67.28**	**17.20**	**84.48**	**275.33**	**290.20**	**53.05**	**13.36**	**66.42**	**120.34**	**41.20**	**161.54**
Funding Guidance												**161.55**

2019-03-04---cost-rollup---CD1-v2-DR.xlsx
Last updated: Lucas Taylor 2019-03-04

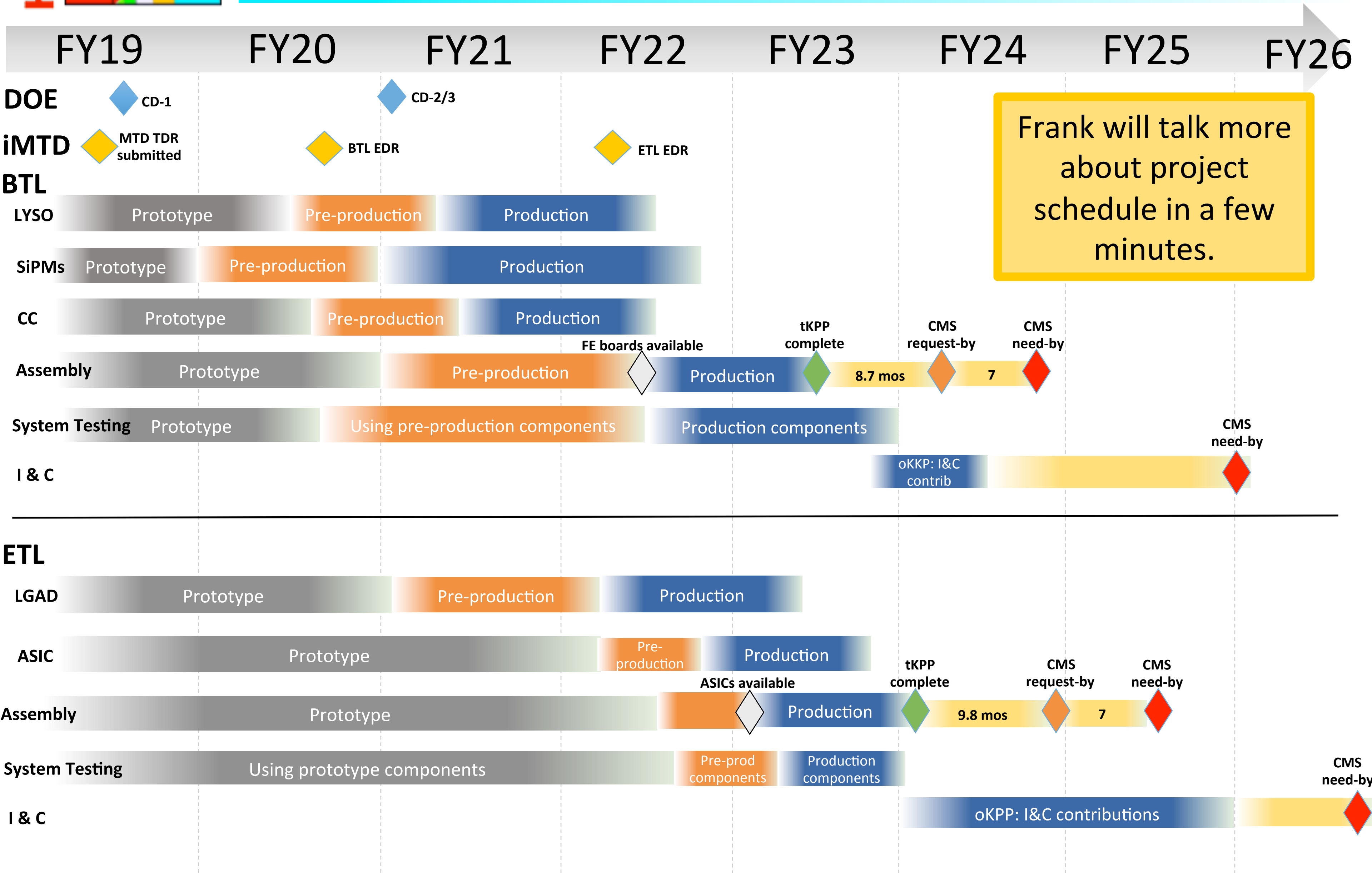
Note: Base Cost = Direct + Indirect + Escalation

- Total cost for MTD is base cost + EU = $14.4M
- Base costs split evenly between BTL and ETL activities ($5.41M and $5.39M, respectively)
- MTD cost unchanged since June 2018 IPR

Details of the cost estimate are a major focus of Frank’s talk in a few minutes

Charge #3

US-MTD Schedule in P6

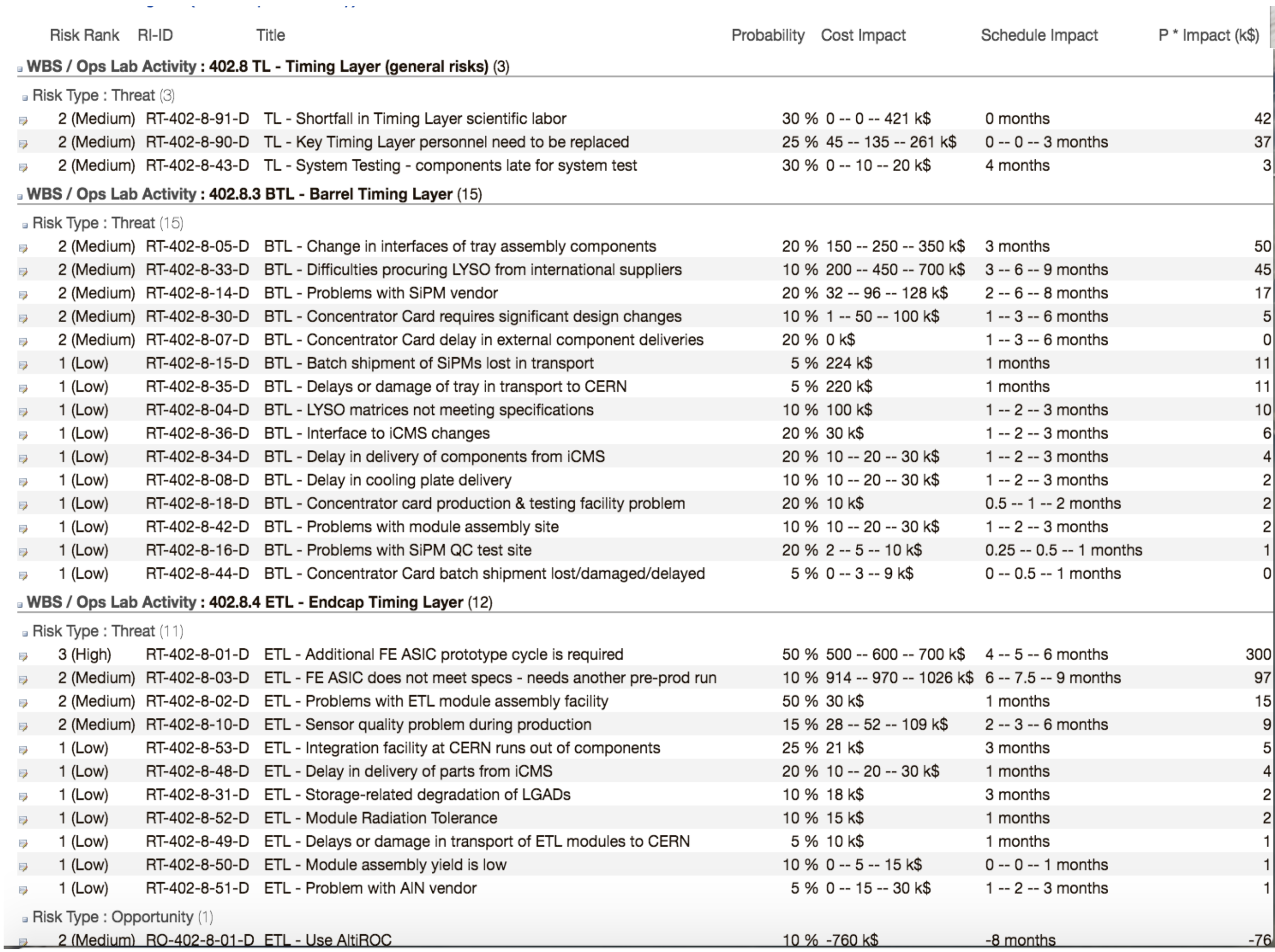


Frank will talk more about project schedule in a few minutes.

Charge #3

Risks

- We have included the assessment of the impact of risks in our project planning to both cost and schedule
  - 29 threats, 1 opportunity
  - Subject of a dedicated MTD Risk Workshop in Nov 2018
- Top 3 risks:
  1. Needing an additional prototyping cycle for ETROC ASIC
  2. Addt'l pre-production run for ETROC
  3. Changes in BTL tray specs impacting assembly
- We understand the need to keep our risk assessment in sync with evolving designs and plans



Risk Rank	RI-ID	Title	Probability	Cost Impact	Schedule Impact	P * Impact (k$)
WBS / Ops Lab Activity : 402.8 TL - Timing Layer (general risks) (3)						
Risk Type : Threat (3)						
2 (Medium)	RT-402-8-91-D	TL - Shortfall in Timing Layer scientific labor	30 %	0 -- 0 -- 421 k$	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
WBS / Ops Lab Activity : 402.8.3 BTL - Barrel Timing Layer (15)						
Risk Type : Threat (15)						
2 (Medium)	RT-402-8-05-D	BTL - Change in interfaces of tray assembly components	20 %	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
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

Frank will talk more about risk in a few minutes.

Charge #6

ES&H

- MTD included in the HL-LHC CMS Upgrade Preliminary Hazard Awareness Report (CMS-doc-13394)
  - Performed hazard identification for both university and lab sites.
  - Overall there are ten hazards identified with MTD activities. Examples:
    - There is a cryogenics hazard associated with operation of the CO_2 cooling system at FNAL-SiDet
    - Each BTL tray will have a length of 2.5m and mass of ~19kg. Transported in pairs, this implies a mechanical hazard requiring a 2-person protocol for handling and training on proper lifting techniques.
    - There are radiation hazards associated with use of the FNAL testbeam facility and use of radioactive sources in component testing
  - Conclusion: No unique hazards encountered in MTD

- All R&D and construction era work will be performed at existing facilities, and all materials are benign and commonly used in industry.
  - No new environmental impact studies are needed beyond those that have already been performed for these sites.

- The commodities used in the construction of the MTD – scintillating crystals, SiPMs, silicon sensors, cooling plates, PCBs, electrical components, cables, connectors, power supplies – are benign and similar or identical to ones found commonly in industry.
  - The MTD poses no unique environmental risks.

More in TJ Sarlina's talk in B/O: Project Management

Charge #6

Quality Assurance and Quality Control

- The primary goal of Quality Assurance for U.S. CMS deliverables is to ensure that the CMS experiment achieves its science requirements and goals

- For MTD, this means ensuring all components satisfy our Science-Engineering and Engineering requirements, as described earlier.

- The QA work in MTD will draw upon guidance from the overall USCMS HL-LHC Quality Assurance Plan (CMS-doc-13093)
  - Specific QA plans for MTD are outlined for each WBS area in our QAP Appendix
  - An example: BTL SiPMs 402.8.3.2
    - Activity:
      - Measurement and characterization of approximately 175,000 channels of SiPM
    - Requirement:
      - SiPM radiation hardness
    - Measurement:
      - IV curves will be measured for each channel to determine breakdown voltage; capacitance and pulse shape will be measured for 2% of channels; radiation studies and other destructive tests will be done on 1% of channels
    - Training:
      - Training on use of bench test system and data base. Radiation training as needed.

More in C. Wilkinson's talk in
B/O: Project Management

Responses to Recommendations from Previous Reviews

Charge #8

- We are tracking responses from three reviews:
  - USCMS HL-LHC 2018 June IPR
  - Technical Review, November 2018
  - OPSS Review of Cost, Schedule, Risk Jan-Feb 2019

- Responses are recorded at CMS-doc-13604

- Here I will discuss recommendations, followed by responses, from the IPR. David will discuss responses from the TR, and Frank will discuss those from the OPSS review.

Responses to Recommendations from June 2018 IPR

Charge #8

- R37: MIP: ETL—Allocate sufficient expert ASIC design engineering resources to ensure meeting the requirements on the ASIC design schedule.

A redesign of the ETL FE ASIC workplan and schedule has been completed. The engineering resources are understood and mapped to **identified individuals with appropriate expertise and bandwidth** to complete this project in the coming years. An **external review team** has been assembled to focus specifically on the ETL FE ASIC.

✓ Status: Closed 15 February 2019

From the Technical Review closeout:
"...the ASICS team is world class, and as capable to succeed as any assembled."

More details on the ETROC project in Ted Liu's talk in the breakout session tomorrow.

Charge #8

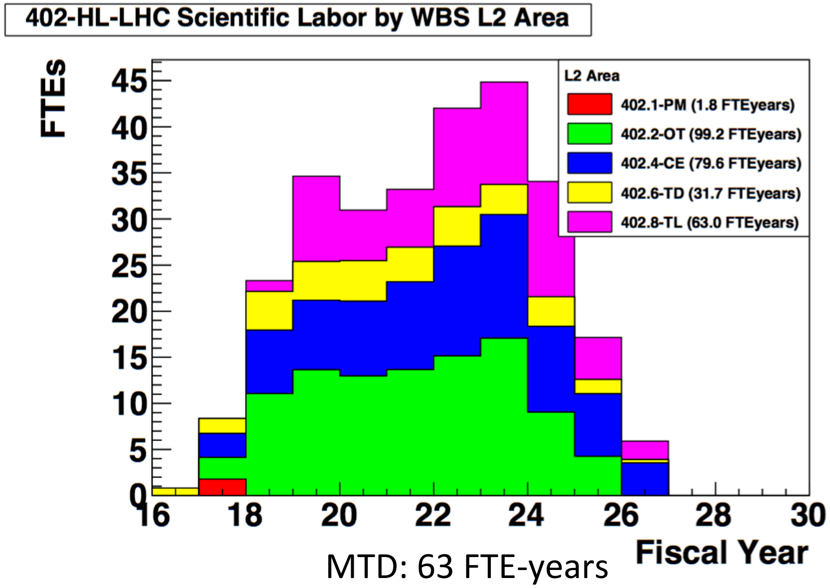
Responses to Recommendations from June 2018 IPR

- R36: MIP: BTL/ETL—Reduce reliance on contributed labor and improve its estimate.

This has been done. **The number used at the June 2018 IPR was not an estimate of contributed labor.** We now have a bottom-up estimate of our labor needs, both costed and contributed (scientific) labor.

When comparing labor utilization for similar work activities, **our contributed/costed labor ratio is similar to that of other projects.**

✓ Status: Closed 25 November 2018



MTD: 63 FTE-years

OT: 99 FTE-years CE: 76 FTE-years

How does our reliance on contributed labor compared to other projects?

Apples-to-apples comparison difficult given differences in how activities are organized within different projects.

Ex:

- Management everywhere is 100% contributed labor, but FTE needs are different.
- MTD LYSO, LGADs are 100% contributed by our design.
- MTD I&C participation is through travel+COLA for postdoc/PhD's

Excluded from comparison any MTD/OT/CE activity area with >85% contributed labor:

	Uncosted	**Total**	**Uncosted/Total**
MTD	20.14	46.71	0.431
OT	76.21	181.11	0.421
CE	38.99	127.48	0.306

MTD fraction similar to OT, CE

Responses to Recommendations from June 2018 IPR

- R35: MIP: BTL/ETL—As soon as possible, and no later than Q3 CY 2018 develop the managerial part of the project, i.e. nominate L2/3/4 managers, develop milestones, cost uncertainty and risk/mitigation analyses, and planning packages into work packages.

Management structure L2/L3/L4 was put in place by October 2018. Milestones (internal and external) have been set, and cost uncertainty and risk/mitigation analyses have been presented to DOE at the December 3, 2018 PEMP Notable briefing. The planning packages have been already developed into work packages.

✓ Status: Closed 25 January 2019 (the time of the OPSS review)

Responses to Recommendations from June 2018 IPR

Charge #8

- R50: Cost & Schedule: Prior to seeking ESAAB approval for CD-1, the schedule, WBS Dictionary, risk register, cost estimates, and other relevant CD-1 documents for 402.8 Timing Detector need to be developed to achieve CD-1 quality.

  These documents have been developed through the preparations for this Director's Review and we feel they are at CD-1 quality.

  - ✓ Status: Closed 5 March 2019

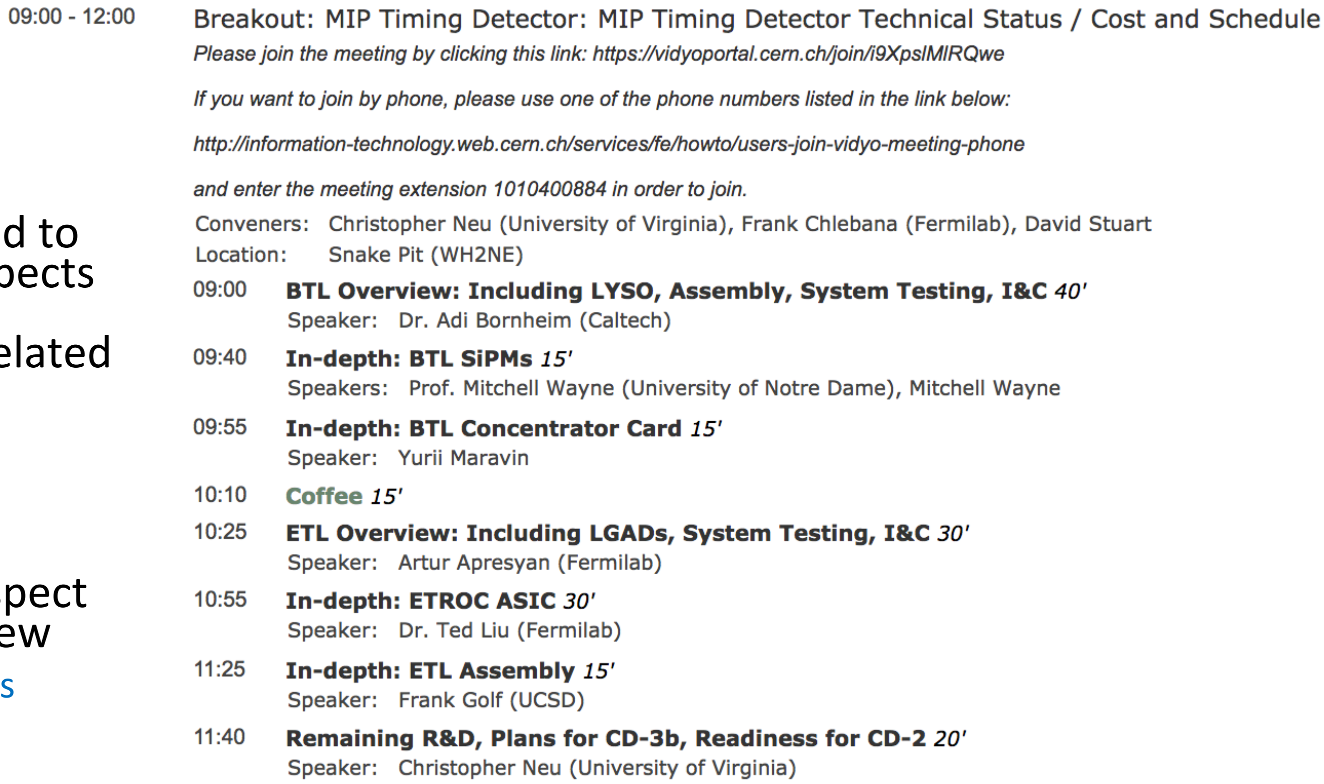
Documentation for CD-1

- We have a complete set of documentation:
  - **Science goals and requirements**: DocID:13337
  - **Engineering requirements**: DocID:13536
  - **CDR**: DocID:13151 (chapter 6 focuses on MTD)
  - **Interfaces**: DocID:13536
  - **KPPs**: DocID:13237
  - **Scope options**: DocID:13357
  - **QAP**: DocID:13093
  - **BOEs:** all areas available in BOE index
  - **WBS Dictionary**: DocID:13213
  - **Risks:** analysis completed and collection in Risk Register
  - **Project Management Plan:** DocID:13104
  - **Value engineering**: DocID:13475
  - **Estimate of Completeness of Design**: DocID:13417
  - **pHAR:** DocID:13394
- All documents are available from this SharePoint repository

More in V. Papadimitriou's talk in B/O: Project Management

Wednesday Breakout Session

- Review talks are designed to address the technical aspects of the MTD project with emphasis on the areas related to US scope
- We will address every aspect of the charge of the review
  - Look for purple call-outs
- The US-MTD management team is available beyond the structured session times to go into specific topics in further detail



09:00 - 12:00

Breakout: MIP Timing Detector: MIP Timing Detector Technical Status / Cost and Schedule

Please join the meeting by clicking this link: https://vidyoportal.cern.ch/join/i9XpslMIRQwe

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 1010400884 in order to join.

Conveners: Christopher Neu (University of Virginia), Frank Chlebana (Fermilab), David Stuart
Location: Snake Pit (WH2NE)

09:00 **BTL Overview: Including LYSO, Assembly, System Testing, I&C** *40'*
Speaker: Dr. Adi Bornheim (Caltech)

09:40 **In-depth: BTL SiPMs** *15'*
Speakers: Prof. Mitchell Wayne (University of Notre Dame), Mitchell Wayne

09:55 **In-depth: BTL Concentrator Card** *15'*
Speaker: Yurii Maravin

10:10 **Coffee** *15'*

10:25 **ETL Overview: Including LGADs, System Testing, I&C** *30'*
Speaker: Artur Apresyan (Fermilab)

10:55 **In-depth: ETROC ASIC** *30'*
Speaker: Dr. Ted Liu (Fermilab)

11:25 **In-depth: ETL Assembly** *15'*
Speaker: Frank Golf (UCSD)

11:40 **Remaining R&D, Plans for CD-3b, Readiness for CD-2** *20'*
Speaker: Christopher Neu (University of Virginia)

Summary

- The conceptual design of the MTD satisfies the performance requirements needed to achieve the CMS scientific goals in the HL-LHC era.
- The DOE O413.3b documentation is complete and justifies the sub-project's costs and duration.
- The project team is well-prepared to deliver a credible technical, cost, and schedule baseline.
- MTD is now ready to proceed to CD-1.

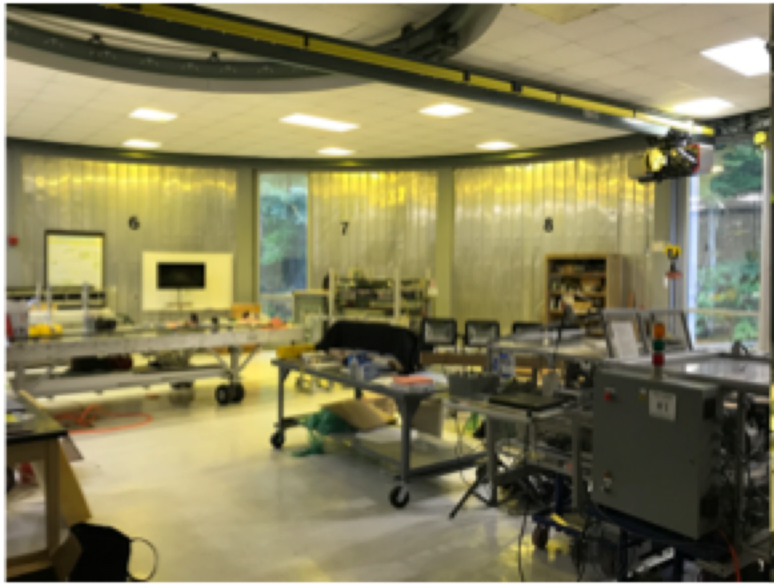
Extra Material

University of Virginia

- High Energy Physics Laboratory
  - Dedicated building just for experimental HEP
- Facilities
  - Assembly room: 2000 ft^2
    - Temperature controlled: 72±1^{o}F
    - Humidity controlled: 50±5%
    - 5-ton overhead crane
  - Electronics lab
    - Used for many projects including CMS HCAL and ECAL Phase 2 electronics upgrades, scintillator and photodetector R&D
  - Clean room capabilities
    - Formerly operated at ISO class 5 level
  - Small mechanical shop for light machining

- People:
  - Three senior faculty
  - One senior scientist, one emeritus
  - Three postdocs
  - Eight PhD students
  - Numerous active undergraduates
  - Electrical technician: **Thomas Anderson**

University of Virginia



Caltech

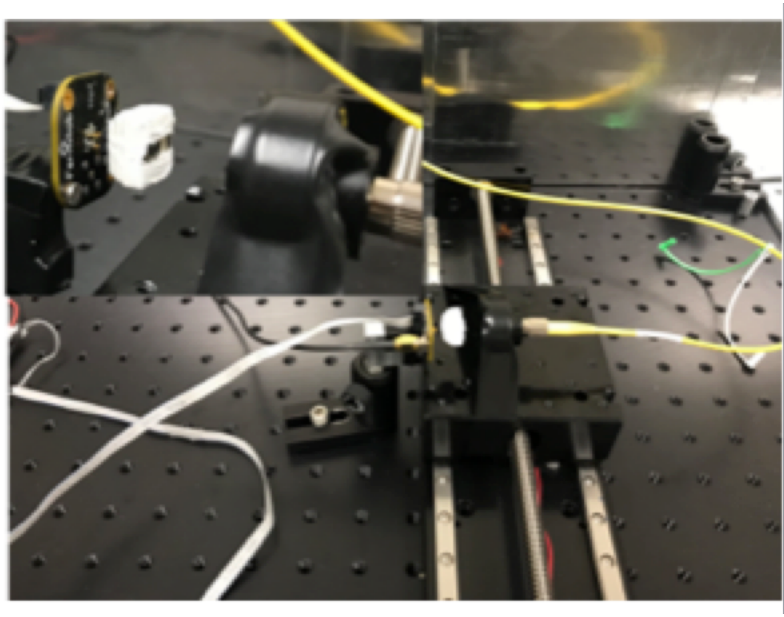
- Facilities: **Lauritsen High Energy Particle Physics Laboratory**
  - Crystal lab (Zhu), Mu2e (Hitlin), NOVA (Patterson), LIGO (vast engineering personnel), AMO/QIS/NP (Hutzler), CMP(Endres)
  - CPT Labs/Assembly Hall (Spiropulu): 1800 ft^2
    - Temperature stability ±1°F, -30 C cold box, optical tables
    - High performance electronics equipment: 25 Gs/s AWG, 50 ps width lasers373 nm (LYSO scintillation light) 407 nm1060 nm, (63 GHz, 160 Gs/s) oscilloscope (6 GHz, 20 Gs/s) oscilloscope, precise x-y stage for BTL module scan, 16 Channel DRS4 digitizer700 MHz, 5Gs/s, Photek 240 MCP-PMT< 10 ps time resolution
  - Clean Rooms Access (ISO-6-7)
  - Mechanical Shops, 3D printing
  - MicroDevices Lab (MDL) at JPL
  - Access: FQNET (FNAL), CERN/ETH labs, Test Beams (FNAL & CERN)

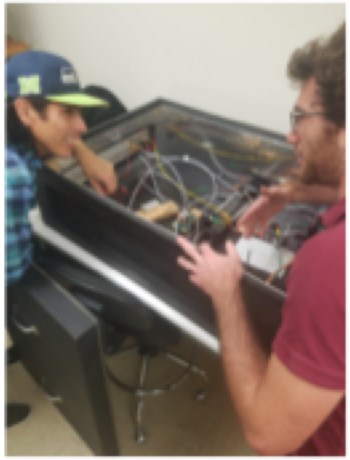
- People:
  - 1 faculty CPT , 1 Faculty ECAL
    - Spiropulu, Newman
  - 3 research faculty/scientists
    - Bornheim, Xie, Zhu
  - 2 postdocs
    - Lu
  - 7 graduate students
  - Many undergraduates
  - Senior EE (Abott), Junior EE (Narvaez), HEP Tech Support (Trevor)

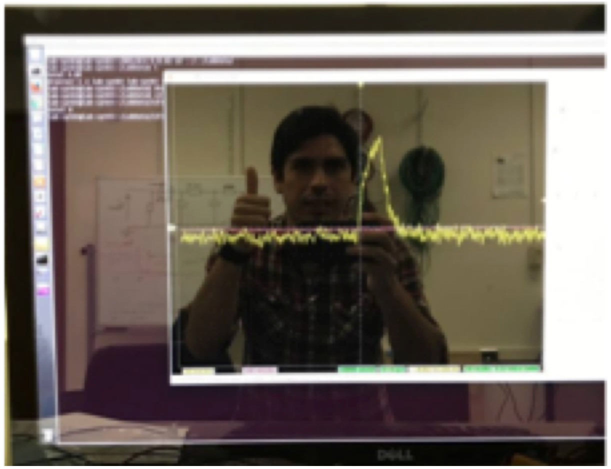
- R&TD/Expertize
  - Sensor R&D , characterization, systems integration, QA, assembly
  - Radiation Damage Studies
  - Scintillator R&D, SiPM readout electronics, TOFPET2 Interface Board, Test Beams

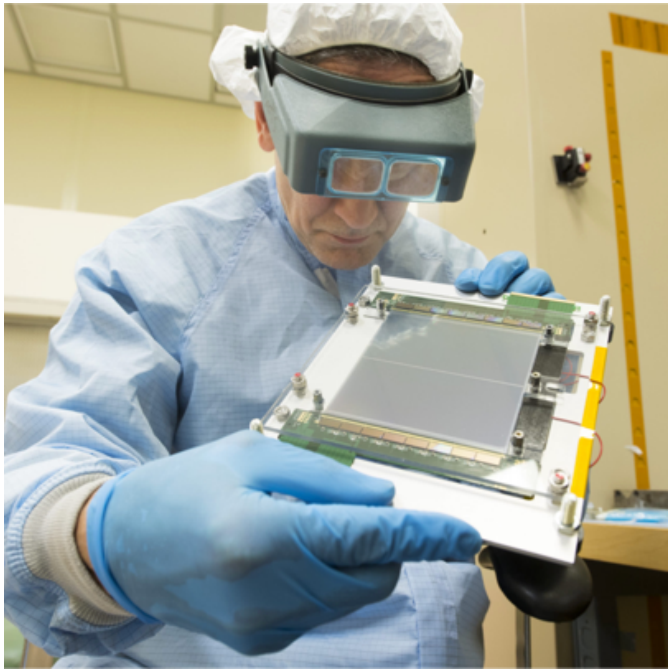
Caltech

- Facilities:
  - BTL Module assembly:
    - LCE measurements
    - Na22 and beta source measurements
    - Energy and time resolution 373 nm picosecond laser measurements
    - Time resolution DAQ X-Y scan.
- Module cooldown and monitoring being commissioned now
- PCB stuffing: Pick and place robots for module assembly





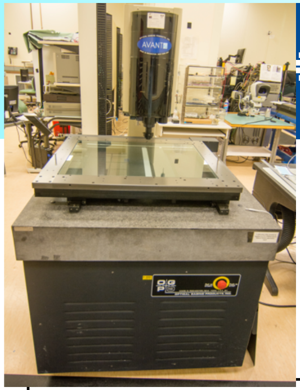




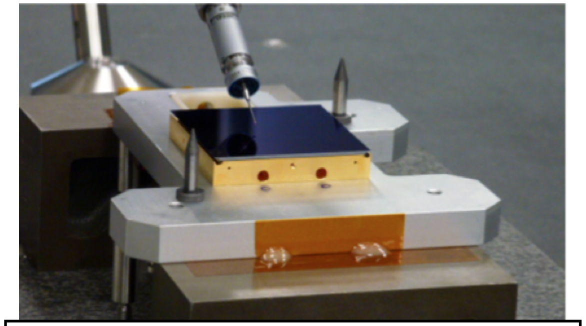
- **Facilities:**
  - Test beam facility
  - Silicon Detector facility
  - Precision Metrology facility
  - Rapid prototyping and Special Materials
  - Scintillator Detector Development
  - ASIC Development Facility
- **Engineering groups:**
  - ASIC development,
  - Cryogenics
  - Data Acquisition
  - Mechanical Engineering
- **MTD People:**
  - 6 scientists
    - Apresyan, Bauerdick, Chlebana, Gray, Liu, Tkaczyk
  - 1 Lederman Fellow
    - Peña
  - 1 Postdoc
    - Heller

SiDET

- **Precision Metrology:**
  - several CMMs, few µm accuracy
  - Micro/macro assembly and quality control
  - Recent new additions is the large volume CMM
  - Trained operators provided by the facility
- **Quality control on Silicon components (Front-End readout chips and Sensors), debugging of modules**
  - Good optics for visual inspection,
  - Probe stations equipped with testing equipment
  - Fully-automatic micro-bonding machines

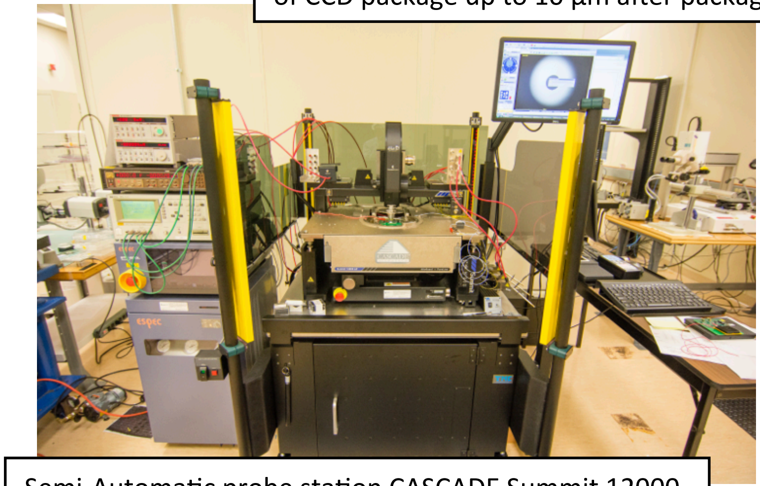


High accuracy Optical Gauging Product (OGP)



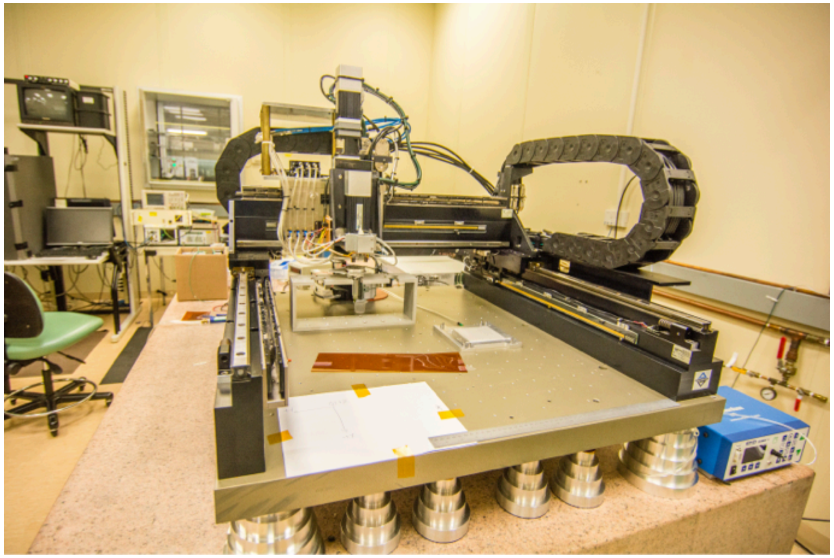
Precision metrology: measuring the flatness of CCD package up to 10 µm after packaging

- Clean rooms: 6000 ft2 class 10k, 240 ft2 class 100
- Wirebonding lab, with deep access capabilities
- Large volume CO_2 cooling plant



Semi-Automatic probe station CASCADE Summit 12000 AP, 8 inch wafer chuck, capable of cold testing

Assembly/Integration



- Aerotech gantry robot AGS10000
  - High velocity to 3 m/s and high acceleration to 3 g
  - High-power linear brushless servomotors
  - Customizable Z and theta axes

- CMMs and production tables
  - 5 micron repeatability accuracy

University of Nebraska-Lincoln

- Jorgensen Hall
  - Modern building with dedicated space for HEP group
- Facilities
  - HEP laboratory: >2000 ft^2
    - Temperature and humidity controlled
    - Adjacent high bay and loading area
  - Clean room: ~400 ft^2
    - Previously used for Phase-I FPIX module assembly
    - Potential to ~double size if needed
  - Instrument shop
    - Experienced staff, including with prior HEP projects (e.g. Phase-I FPIX)
    - Custom CAD/CAM design, CNC, EDM, lathes, grinding, welding, etc.
- People:
  - Four faculty
  - Three postdocs, hiring fourth
  - Five PhD students
  - Numerous active undergraduates
  - Technicians: Anatoly Mironov, Brian Farleigh
    - Experienced wire bonders, worked on Phase-I FPIX module assembly

University of Nebraska-Lincoln