CMS Status Update

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Fermilab PAC
19 July 2019

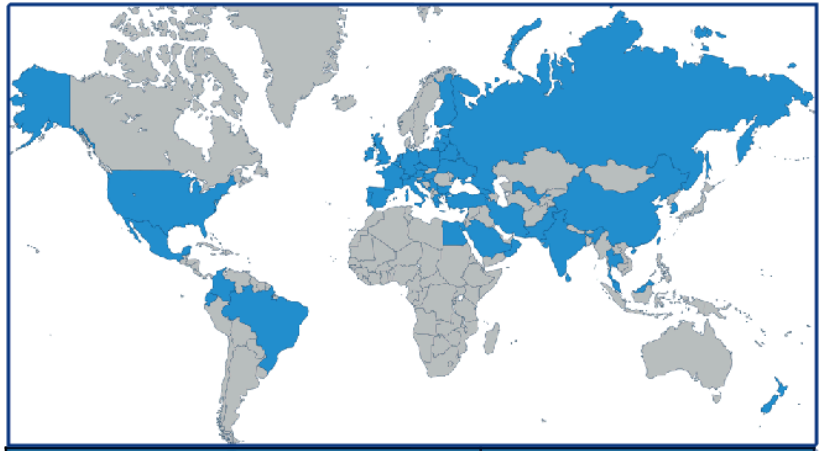
In partnership with:

CERN CMS

CMS Update


CMS
IP

CMS Collaboration

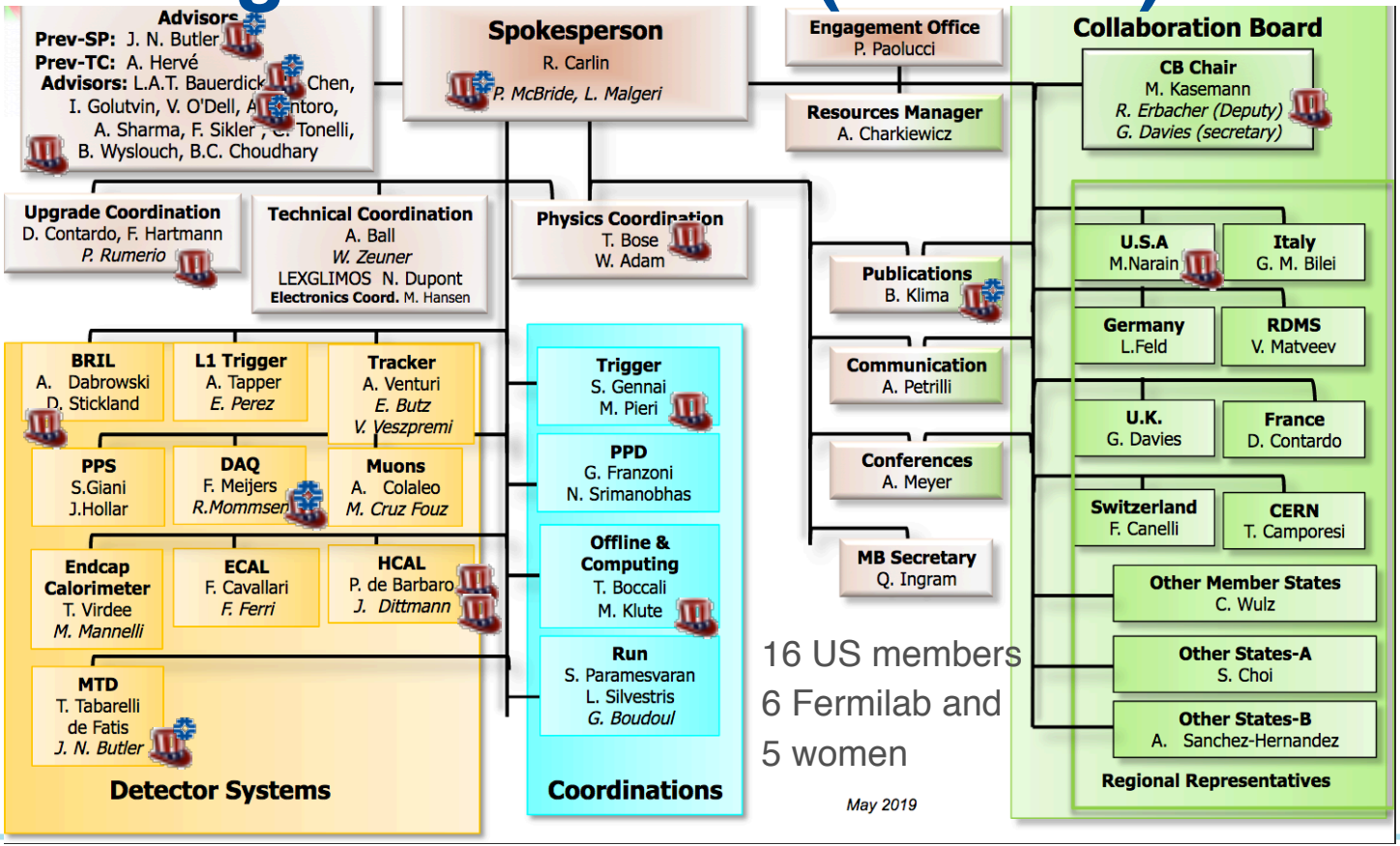


CMS Collaboration	Statistics
Countries	51
Member Institutes	229
CMS PhD physicists	1906
CMS Members	5428
Graduate Students	1036

US CMS

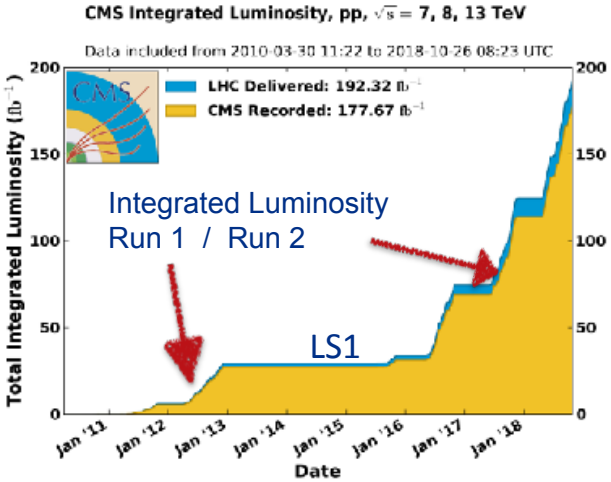
- 51 Institutions
- 718 Scientific Authors
- 211 Graduate Students

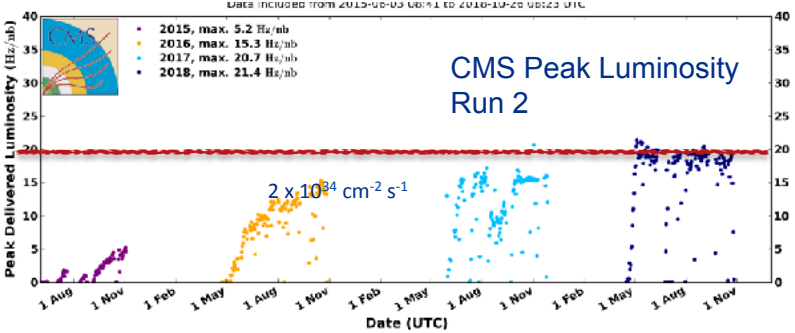
CMS Management Board (2018/19)



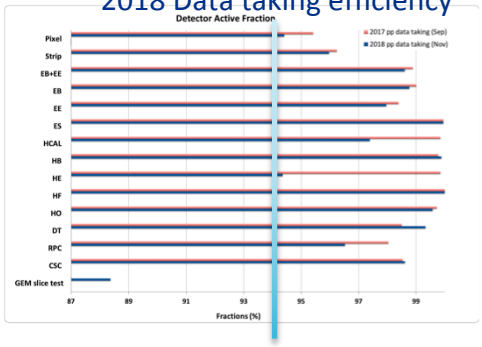
J. Strait- Deputy PM - Endcap Calorimeter starting in September

CMS Run 2 at the LHC @ 13 TeV





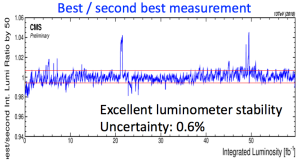
2018 Data taking efficiency

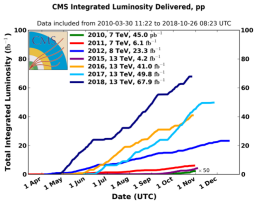


94%

Luminosity in run 2

Best / second best measurement

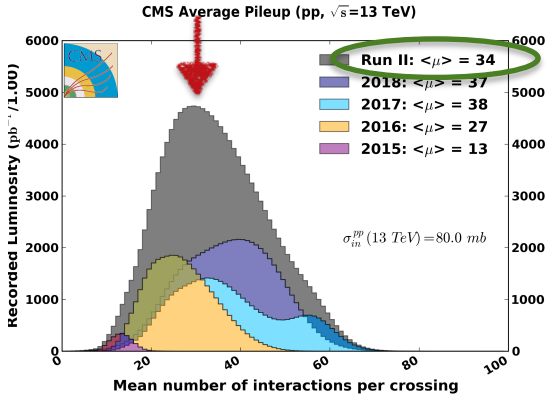




- Public documentation available for all preliminary Run2 calibration results (link)
- Uncertainties:
  - 2.3 – 2.5% for pp@13 TeV in single year
  - 1.7% for pp@13 TeV <PU>=3 in 2017
  - 2.3% for pp@5.02 TeV in 2015
  - 3.5% for pA@8.16 TeV in 2016
- 2018 dominant systematics due to x-y correlation: study ongoing to measure the bias, after correction expect improved uncertainty
- 2015/2016 luminosity paper in internal review: expect significant improvement

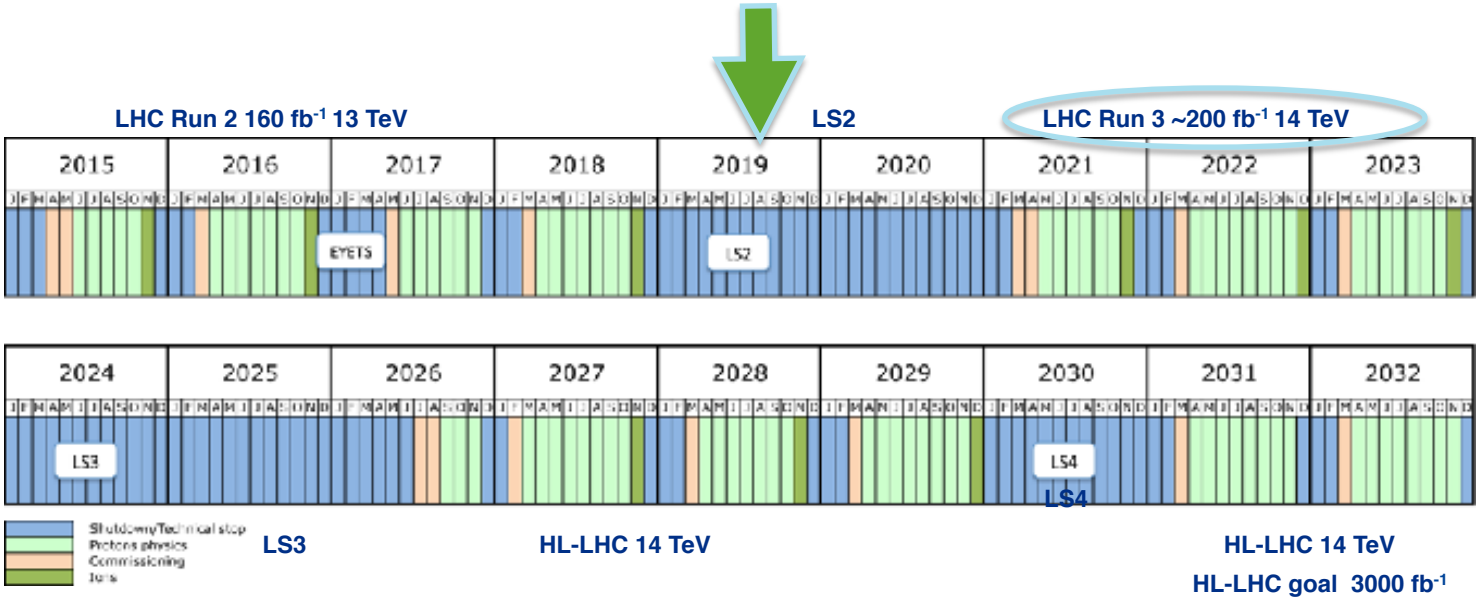
2018 pp@13 TeV	Systematic	Correction (%)	Uncertainty (%)
Normalization	Length scale	−0.8	0.2
	Orbit drift	0.2	0.1
	x-y nonfactorization	0.0	2.0
	Beam-beam deflection	1.5	0.2
	Dynamic-β*	−0.5	
	Beam current calibration	2.3	0.2
	Ghosts and satellites	0.4	0.1
	Scan to scan variation	—	0.3
	Bunch to bunch variation	—	0.1
	Cross-detector consistency	—	0.5
	Background subtraction	0 to 0.8	0.1
Integration	Afterglow (HFOC)	0 to 4	0.1⊕0.4
	Cross-detector stability	—	0.6
	Linearity	—	1.1
	CMS deadtime	—	<0.1
	Total		2.5

CMS-PAS-LUM-18-002



CMS Average Pileup Run 2

Looking ahead



- CERN discussion of Run 3 schedule - November 27, 2019
  - This meeting will follow the cost and schedule review of the injectors
  - The goal will be to take stock of the progress of LS2 work and to discuss how best to optimize the physics output of the LHC program.

A challenging LS2

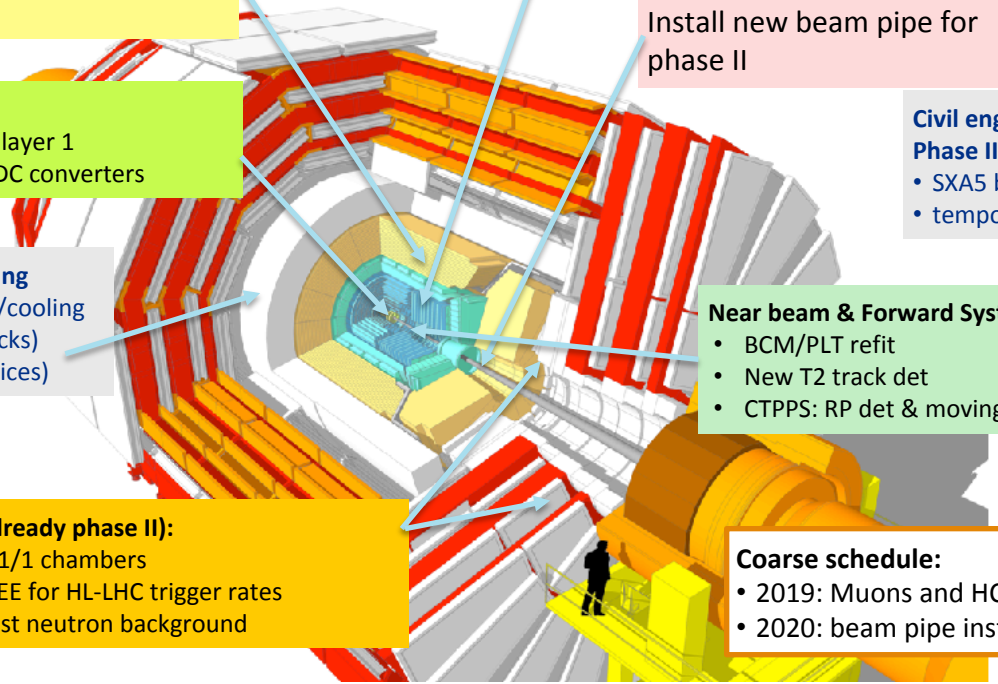
Keep strip tracker cold to avoid reverse annealing

HCAL barrel (last Phase I):
install SiPM+QIE11-based 5Gbps readout

Install new beam pipe for phase II

Pixel detector:
- replace barrel layer 1
- replace all DCDC converters

Civil engineering on P5 surface to prepare for Phase II assembly and logistics
- SXA5 building
- temporary buildings for storage/utility



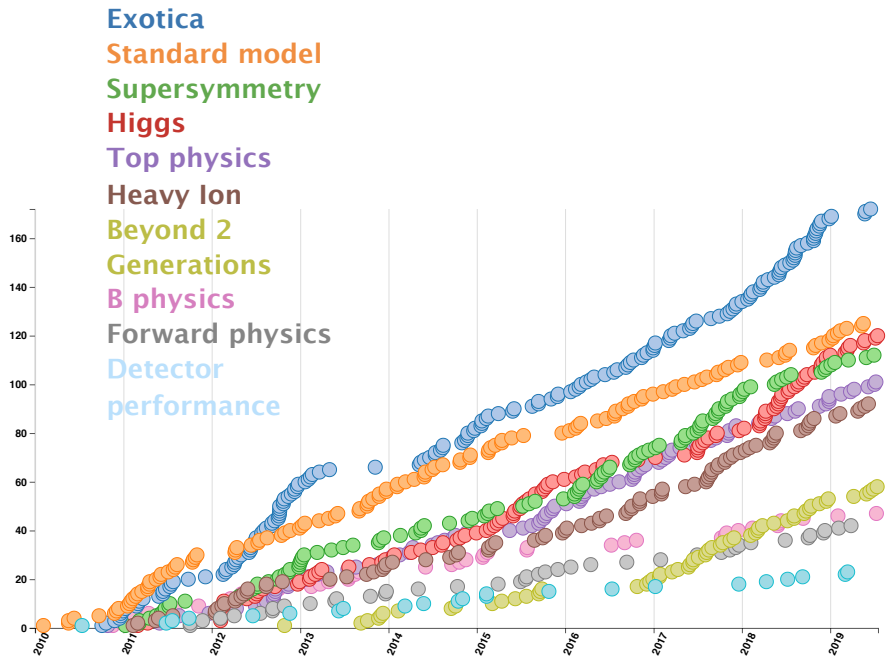
MAGNET (stays cold!) & Yoke Opening
- Cooled freewheel thyristor+power/cooling
- New opening system (telescopic jacks)
- New YE1 cable gantry (Phase2 services)

Near beam & Forward Systems
- BCM/PLT refit
- New T2 track det
- CTPPS: RP det & moving sys upgrade

Muon system (already phase II):
- install GEM GE1/1 chambers
- Upgrade CSC FEE for HL-LHC trigger rates
- Shielding against neutron background

Coarse schedule:
- 2019: Muons and HCAL interleaved
- 2020: beam pipe installation, then pixel installation

CMS Publications - 894 collider papers submitted



- CMS is still submitting papers at a very high pace
- Including CMS papers not based on collisions, we passed the 900 mark in mid-May
- ~70 new results since the beginning of 2019, and starting to see results with full Run 2 dataset
- 141 publication submitted last year

CMS at Fermilab

CMS at Fermilab

- One of the pillars of the CMS collaboration (2nd largest group after CERN)
- Major contributions in physics analysis, Phase 1 and Phase 2 upgrades, reconstruction/simulation, and computing/operations
- As a testimony of the essential contributions made by Fermilab over the years, Fermilab scientists selected to serve as **high level managers within CMS**:
  - P. McBride (**deputy spoke-person**), B. Klima (**Chair of Publication Committee**)
  - Phase 2 Level-1 Trigger project: J. Berryhill (**L1 manager**)
  - Phase 2 HGCAL project: J. Strait (**L1 deputy manager, technical coordinator, L2 manager for engineering**); Z. Gecse (**L2 manager for cassettes**); J. Hirschauer (**L3 manager for on-mother board electronics**); R. Lipton (**L3 manager for silicon sensors**)
  - Phase 2 MTD project: J. Butler (**L1 deputy project manager**); S.Traczyk (**technical coordinator**); T.Liu (**L3 manager for ETL front-end electronics**); A. Apresyan (**L3 manager for ETL engineering**); L. Gray (**L2 manager for detector performance**)
  - DAQ project: R. Mommsen (**L2 deputy project manager**)
  - Physics, Performance, and Datasets Group: K. Maeshima (**L2 manager for data quality monitoring and data certification**)

Awards and Recognition since Summer 2018 (1)

DOE Early Career Award: Artur Apresyan,

APS 2019 Primakoff Award: Nhan Tran

CMS Detector Award: Zoltan Gecse, Nadja Strobbe

CMS Achievements Award: Artur Apresyan, Kevin Pedro, Nick Smith

Laboratory Directed R&D: Nhan Tran, Lindsey Gray

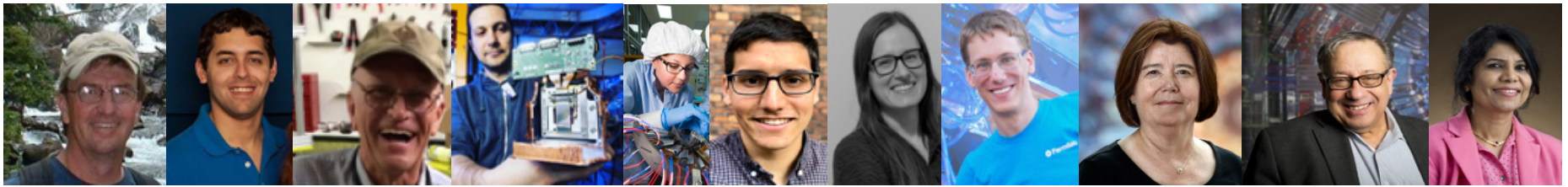
Awards and Recognition since Summer 2018 (2)

Exceptional Performance Recognition Award: William Freeman, Kevin Pedro, Anatoly Ronzin, Lorenzo Uplegger

Reward and Recognition Award: Maral Alyari

LHC Physics Center Distinguished Researchers: Javier Duarte, Nadja Strobbe, Hannjoerg Weber

Recognitions: Patty McBride, Carnegie Mellon University Alumni Award; Joel Butler elected AAAS Fellow; Pushpa Bhat elected to the AAAS Council



Research Associate Mentoring Program

- Integrated approach involving supervision team (supervisor, technical guide & analysis guide, mentor, RA mentoring committee), regular events
  - Procedures are documented, review meetings held regularly
- Majority of CMS department RAs have found faculty positions
  - 34 RAs have completed their postdoctoral research on CMS as of Jul 2019
  - 21 found a tenure track position in HEP at a university or laboratory: **62%**
  - 4 have a 2nd postdoc position or other position in HEP: **12%**
  - 9 went on to a permanent position in private industry: **26%**
- Example of a mentoring success this year:
  - N. Strobbe (**Asst. Prof U. Minnesota**), J. Duarte (**Asst. Prof UCSD**), Z. Hu (**Asst. Prof Tsinghua University**), B. Kreis (**Senior data scientist at Apple**), S. Hasegawa (**Scientist at Toshiba Memory**)
- **Very successful training program for RAs, extended to the entire laboratory**

Group Composition in FY19

- The department has followed up on the succession plan outlined in the past years
  - Hired an associate scientist with focus on the Phase2 upgrade and detector R&D for future experiments
  - Selected an associate scientist with focus on SW&C, with specialization in ML/AI, new architectures, *etc*. (waiting for offer to be made)
- A senior scientist from the Accelerator Division has joined the department to strengthen the Phase 2 project office
  - In total 17 scientists serve as L1/L2/L3 managers of Phase 2 upgrade project
- Two senior scientists moved on to different positions/jobs
- **Including RAs, the number of FTEs is decreasing (46.5 in FY18 to 42 budgeted in FY20)**
  - Continued support for RAs through a healthy research program is absolutely essential to the FNAL CMS program (analysis, upgrade, computing)

Fermilab CMS Physics Program

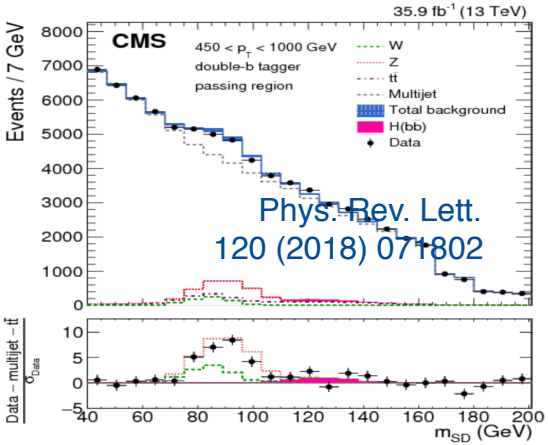
- Strategy
- Higgs Program
- Search for Dark Matter
- Search for the Unknown
- Precision Program

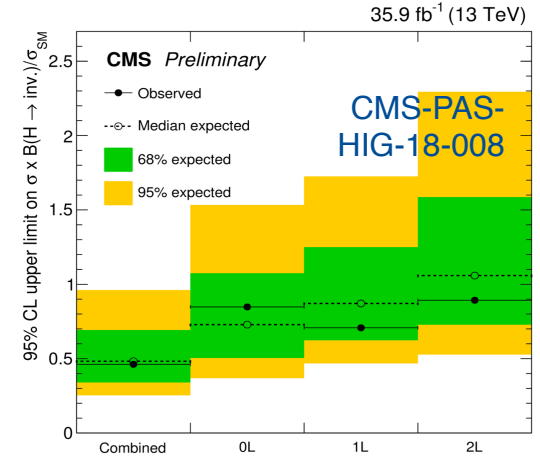
Strategy and Leadership in Analysis

- **Leading role in the CMS physics program addressing 3 out of 5 P5 science drivers**
  - Using the Higgs as a tool for discovery, search for Dark Matter, search for the unknown (via direct BSM searches and precision measurements of the SM parameters)
- Significant investment in the **development of advanced tools** to enhance the sensitivity to challenging corners of the parameter and phase space
  - Innovative tagging of bosons, deployment of machine learning, *etc*.
- **High profile physics leadership positions**
  - 4 physics conveners
  - SUSY combination coordinator and SUSY Upgrade studies coordinator
- FNAL physicists serving on numerous analysis review committees and presenting results at major international conferences (**48 talks since Summer 2018**) and dedicated workshops

Recent highlights in Higgs Physics

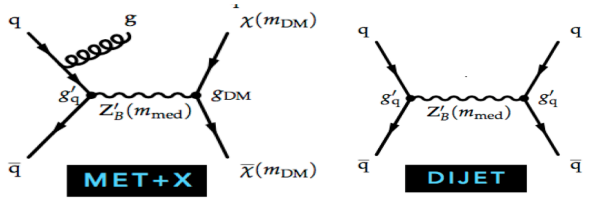
- Historically major contributions in the discovery and characterization of the ZZ and WW decay modes
- **Recently pioneered identification of boosted Higgs bosons decaying into a pair of highly collimated b-jets**
  - Opening unexplored region of phase space with high sensitivity to BSM and extending the sensitivity to Hbb through a channel deemed impossible at hadron colliders
- Now exploring the challenging **decay of Higgs into charm quarks**
  - Analyses enabled by tagging of b- and c-jets **using Deep Neural Network**
- Re-interpretation of SUSY searches to set limits on the Higgs decaying to invisible in the ttH topology (BR<0.46)



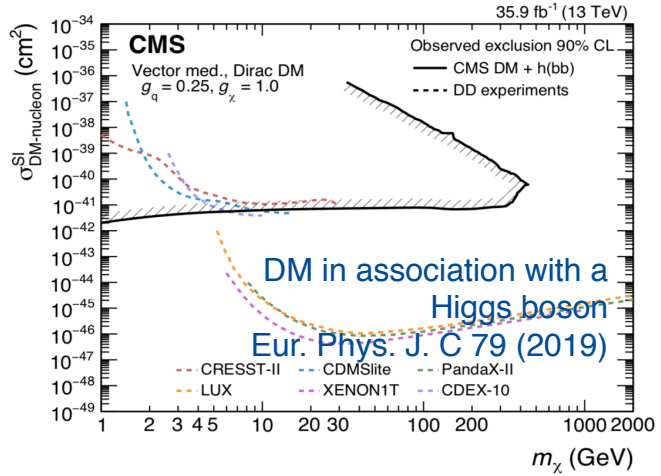


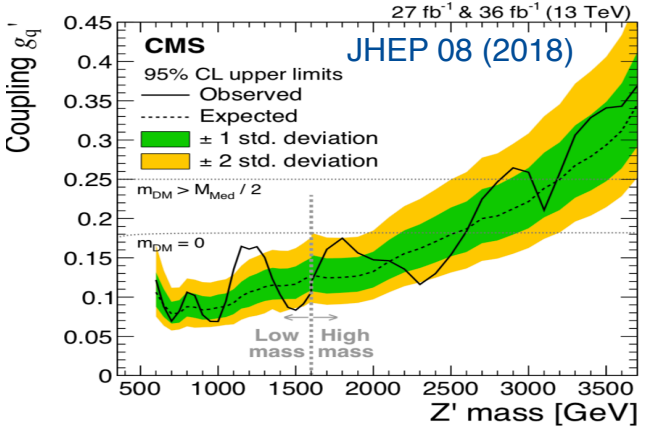
Recent highlights in Dark Matter

- **Multi-prong approach by direct searches for the production of dark matter candidates and for the interaction's mediator**



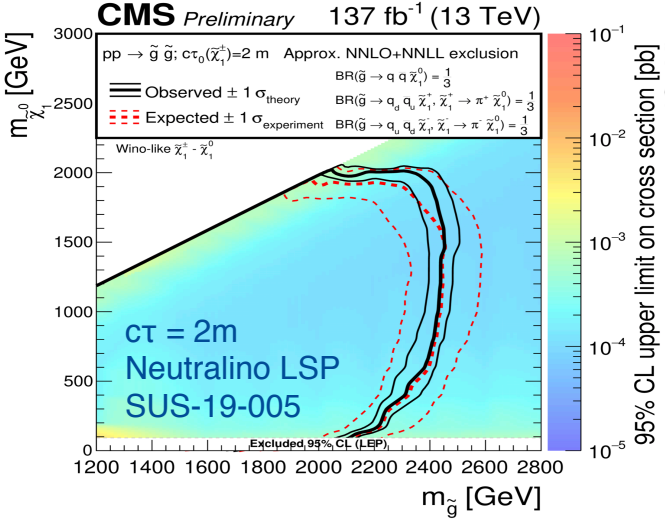
- Searches in the mono-X final states
  - Now **adding searches for long lived dark matter candidates** (sensitive to models of self-interacting dark matter)
- Searches in di-jet resonances
  - Innovative experimental technique to lower the trigger thresholds ('**data scouting**')

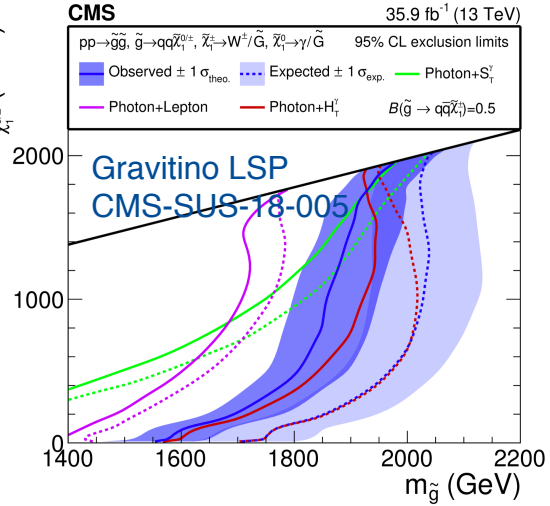




Recent highlights in BSM: Supersymmetry

- **Very broad and innovative program of searches targeting production of:**
  - Gluinos and 1st/2nd generation squarks with various assumptions on the LSP nature and including including final states **with long lived electro-weakinos (new!)**
  - 3rd generation squarks
  - Electro-weakinos (including **studies at HL and HE-LHC**)

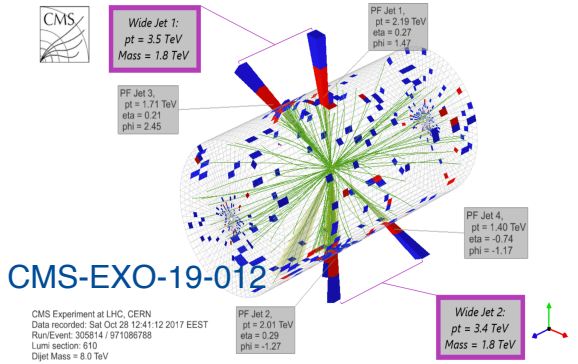




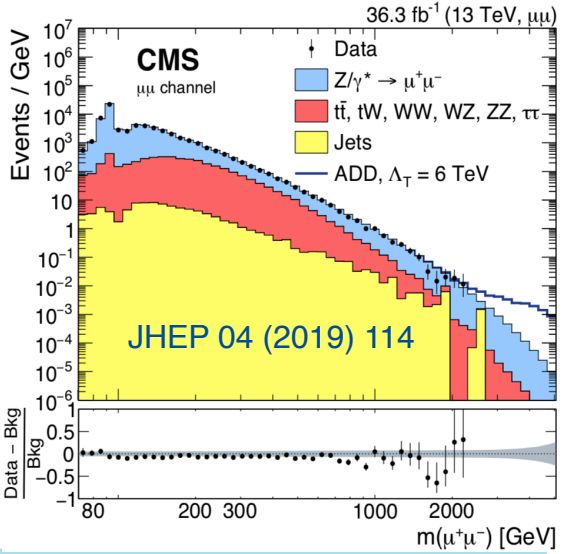
In total **8 public/ published results** in the past year **and 5 more** expected in next months
Now expanding to searches for RPV/Stealth scenarios

Recent highlights in BSM: Exotica

- Classical searches for BSM signals manifesting themselves as a narrow or broad excess over a smoothly falling background (*a.k.a* resonance searches)
  - Searches for a narrow resonances decaying into two jets
    - **Intriguing event** that sparked a lot of interest in the theory community (1810.09429)!
    - Extended significantly sensitivity to low mass Z' by requesting an additional photon boosting the signal or an additional jet
  - Searches for a narrow and a broad resonance decaying into two leptons
- In total **5 public/published results in the past year**. Now expanding to final states with multiple jets and bosons

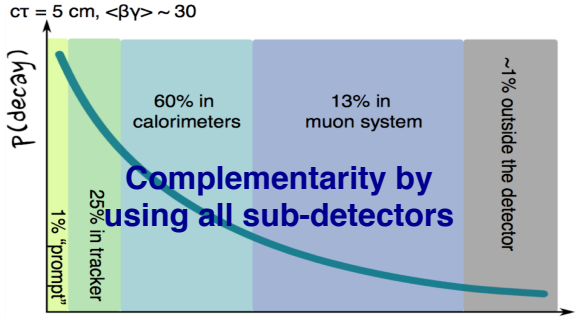


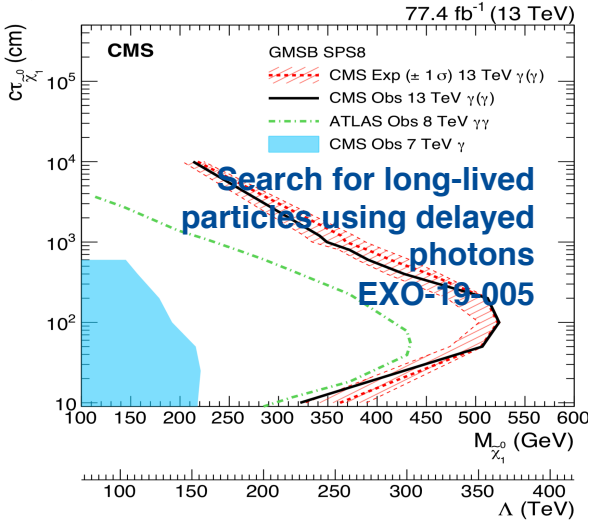
CMS-EXO-19-012



Recent highlights in BSM: Long Lived Particles

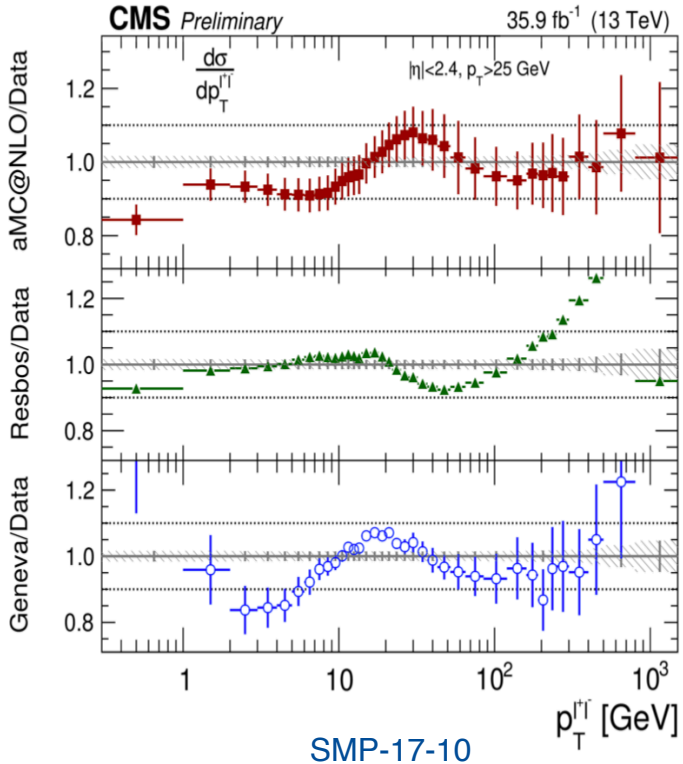
- Numerous BSM models predict the existence of LLPs (SUSY, neutral naturalness, ...)
- **Search for LLP is becoming one of the highest priorities at CMS, established new effort in the recent months**
- Complex search needing new trigger, reconstruction, identification, background estimate models
  - Final state fully dependent on the decay length of the BSM candidate and its decay modes
- Started including timing information in baseline analyses and expanding search to final states with delayed (b-)jets





Recent highlights in SM Measurements

- Extensive program of precision measurement of the SM parameter with focus on EWK bosons
  - Measurement of the Vector Boson Scattering cross-section as a test of the Higgs mechanism (SMP-18-006 submitted, SMP-18-001 accepted)
    - **Signal of EW WZ production at 2.2 sigma**
  - Measurement of the **Z pT, unprecedented precision < 0.5%** for normalized cross-sections, SMP-17-10
  - Measurement of the differential Z cross section and measurement of the W pT using dedicated low pile-up run (2 papers to be released soon)
- **Significant participation in LHC EW precision group**



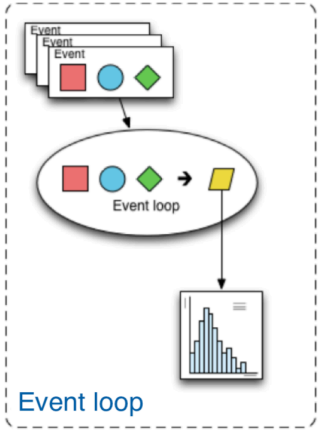
SMP-17-10

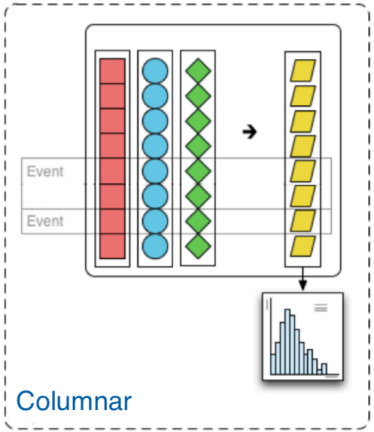
Synergy between the CMS and the Theory Departments

- In preparation for the re-start of the LHC the CMS department created dedicated task forces of CMS physicists and members of the FNAL theory department
  - Higgs physics, Supersymmetry, Exotics, Long Lived Particles, Standard Model
- The task forces were asked to review the CMS (and ATLAS) program and to make recommendations for Run2 and Run3 analyses
  - Very successful exercise developed over the course of 3 months
  - Task forces released their recommendation during two internal meetings
  - Many new idea for further exploration emerged!
    - **Thank you to our theorists colleagues for their the enthusiastic participation!**
- The collaboration between the CMS Department and the Theory Department will continue to grow in the coming years

“Coffea”

- To enable a fast turn around of data analysis, the CMS department has initiated the R&D of a cutting edge analysis framework: Columnar Object Framework for Effective Analysis (or “coffea”)
  - Columnar data analysis **aligns with strengths of modern CPUs** and can produce plots without intermediate skimming/slimming
- Coffea is a collection of SW packages leveraging the scientific python ecosystem and big data technologies to optimize the development of analysis code
- Already in use by 2 CMS analyses (Dark Matter search, Hbb/cc)
- **Wider community involvement, *e.g* significant engagement and synergy with IRIS-HEP**
- (To be) presented at **workshops/conferences**: HOW2019 Workshop JLAB, DPF 2019 Boston, CHEP2019 Adelaide (Nov)

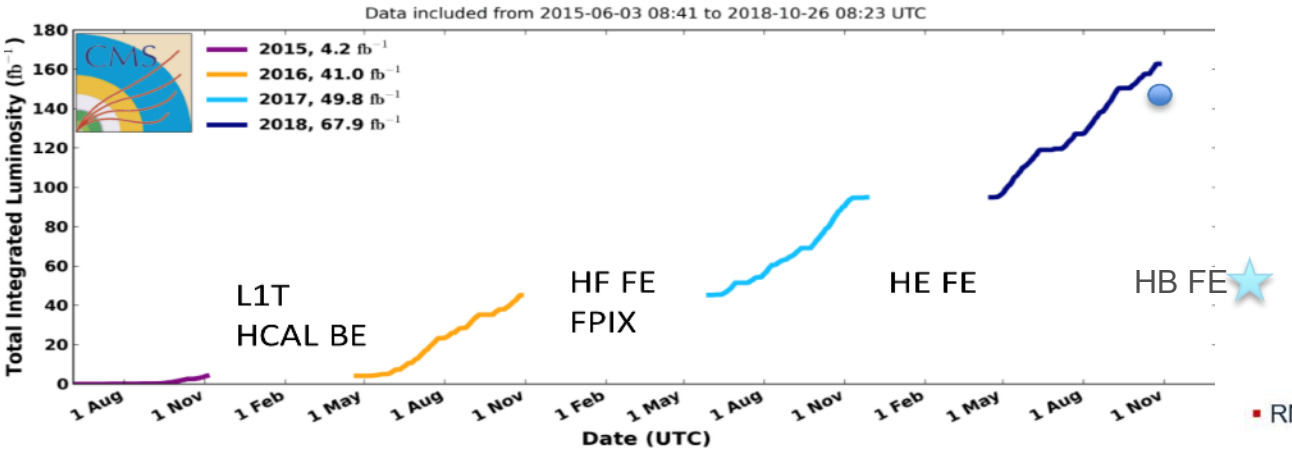


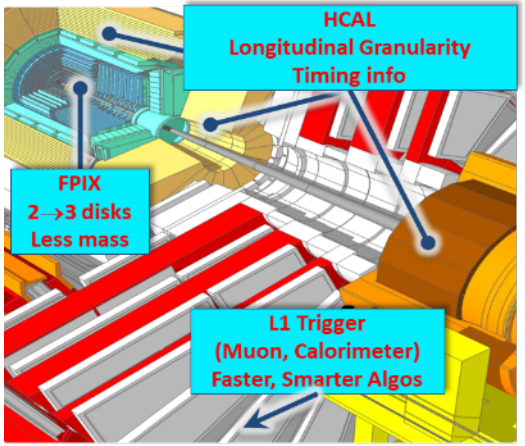


CMS Phase 1 and Phase 2 Upgrades

- Phase 1 Upgrade
- Phase 2 Upgrade

CMS Phase 1 Upgrade Project Complete!



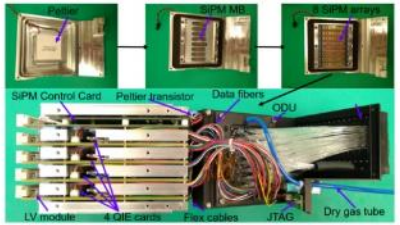


HCAL Barrel and Endcap Front End electronics completed in March 2019

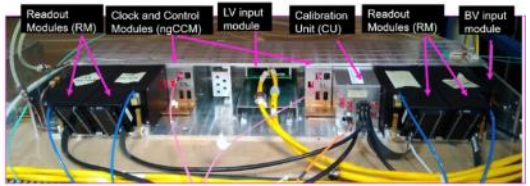
Final CD4 review May 1st, ESAAB June 10, 2019

Completed on time and under budget

- RMs



- RBX



CMS Phase 2 Upgrade Scope

L1 Trigger/HLT/DAQ **NSF + DOE**
- L1 40 MHz in/750 kHz out with tracking for PF-like
- 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

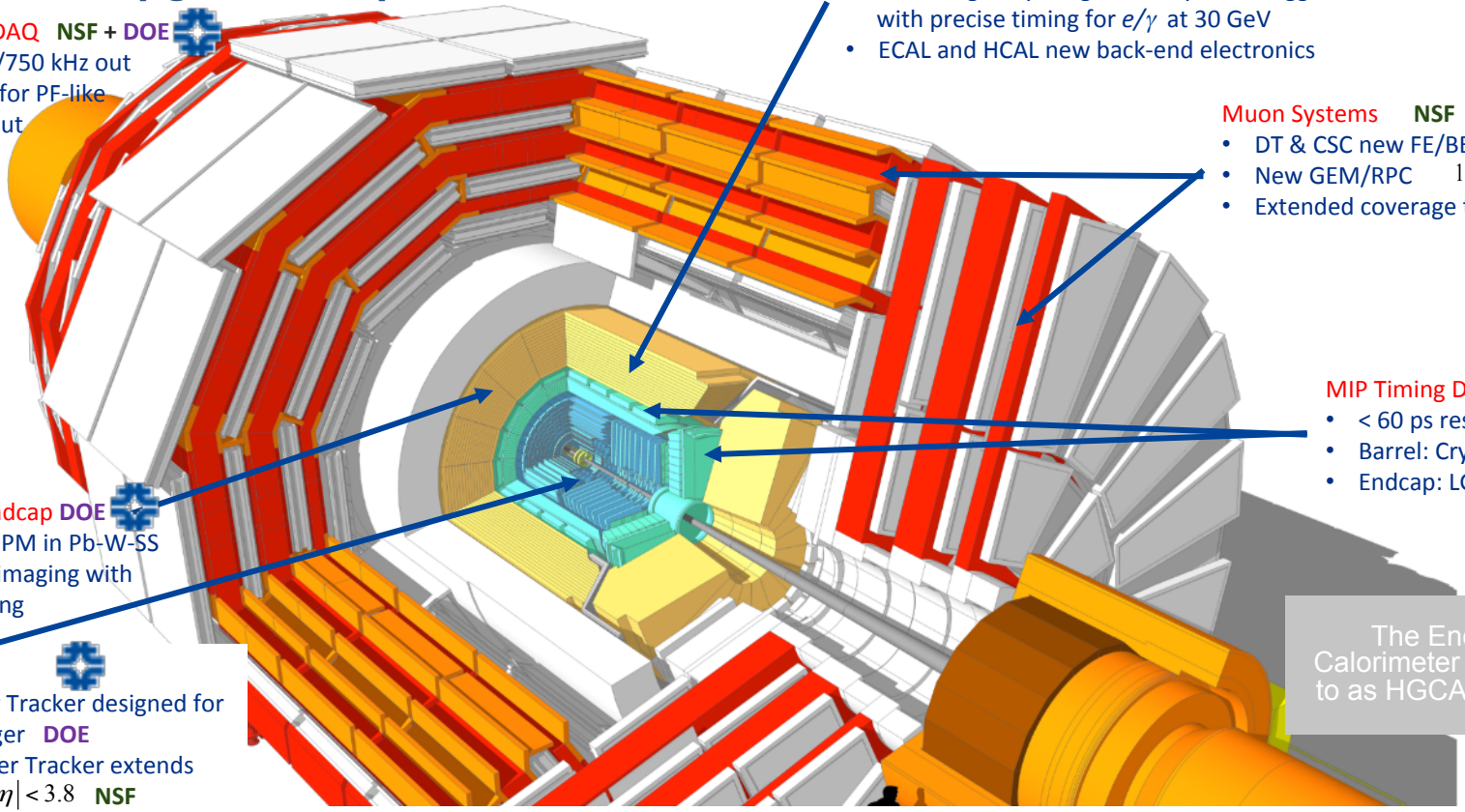
Muon Systems **NSF**
- DT & CSC new FE/BE readout
- New GEM/RPC $1.6 < |\eta| < 2.4$
- Extended coverage to $|\eta| < 3.0$

Beam Radiation and Luminosity, Common Systems, Infrastructure

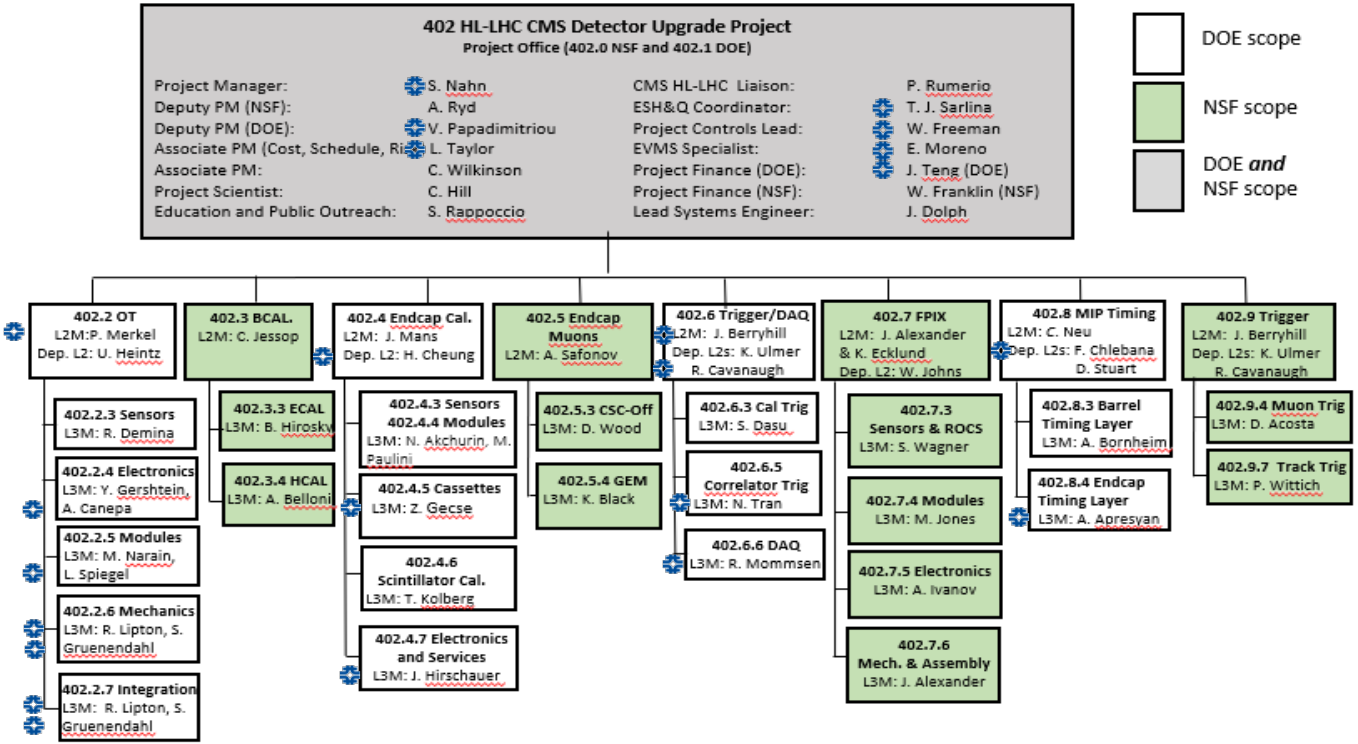
MIP Timing Detector **DOE**
- < 60 ps resolution
- Barrel: Crystals + SiPMs
- Endcap: LGADs

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**



The End Cap Calorimeter is referred to as HGCAL, EC, CE



- FNAL led management
  - Project Office + L2 managers for OT, TDAQ + Deputy L2s for HGCAL, MTD, TDAQ
  - Office of Project Support Services provides essential support and guidance, resource negotiation

HL LHC Upgrade Project Status in a Nutshell

- Deep into preparation for CD-1 Review, Oct 22-24, 2019
  - **Successfully passed the Director's review in March 2019**
    - Strengthened the management team and improved schedule and cost estimates

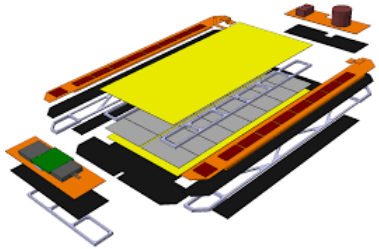
- In the mean time, continue progressing towards CD-2 (Nov 2020)
  - Working through prototyping iterations with successively more sophisticated components
    - Validation of design concepts and new/novel developments
    - Confirmation of assembly procedures and development of Quality Control mechanisms
  - Building up production sites and QA/QC procedures
    - HGCAL: (CE cassettes, CE tileboard), MTD: ETL modules, Tracker (OT…)
  - Continuing to build the schedule towards CD-2 readiness
    - Preparing for Earned Value Monitoring starting in FY20
    - Sharpening the schedule and the point estimate of cost

Major Fermilab Roles

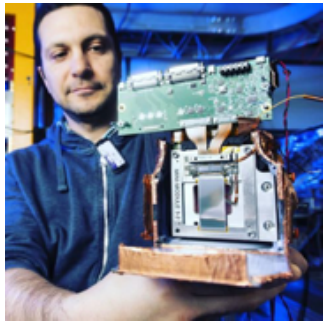
- Outer Tracker (OT)
  - Module Assembly Facility: 2300 out of 13,000 modules (SiDet)
  - “Flat Barrel” assembly facility: inner 3 layers of the central PS barrel section (Lab 3, SiDet)
- Endcap Calorimeter (HGCAL/CE)
  - Development of ECON data concentration ASIC (WH 14th floor)
  - Design and Fabrication of 528 out of 756 Cassettes, Module Loading (SiDet)
- Mip Timing Detector (MTD)
  - ETROC ASIC development (WH 14th floor)
  - Module Assembly Facility: 835 out of 3340 ETL modules (SiDet)
- Trigger and Data Acquisition (TDAQ)
  - Algorithm development for Correlator trigger (WH 14th floor, FCC)
- Large scope and juggernaut of cutting edge technologies at the lab
  - Highly dependent on implementation of succession planning for engineers and technicians

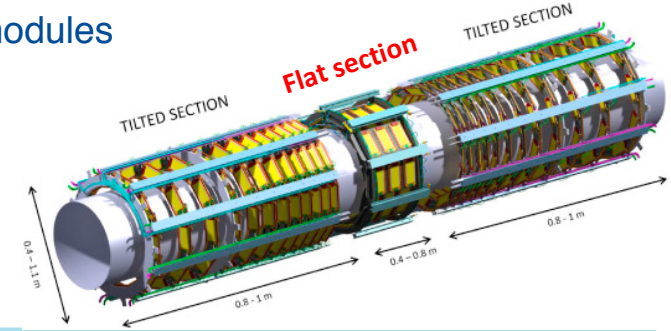
Highlights of Fermilab Upgrade Work

Outer Tracker Upgrade at Fermilab



- Advanced technology enabling the transmission of tracking information to the Level-1 trigger at 40MHz for the first time at hadron collider
- ~2300 out of 13,000 silicon modules
  - Two flavors (pixel-strip [PS], strip-strip [2S])
  - Responsibility for bare PS module development and fabrication (MaPSA)
  - Fabricate module mechanics (Al-CF, CF)
  - Develop assembly automation
  - Work closely with U.S. East Coast institutions and our international partners
- Flat Barrel
  - three innermost central layers of the barrel formed of ~950 PS modules
  - Design and construction of planks and layers
- DAQ and test systems
  - Design multi-module burn-in box test system
  - Responsible for DAQ s/w and f/w talking to the chips
  - Expertise in global DB

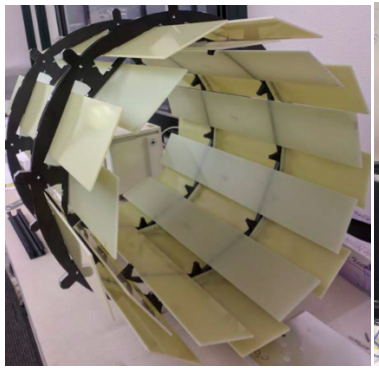




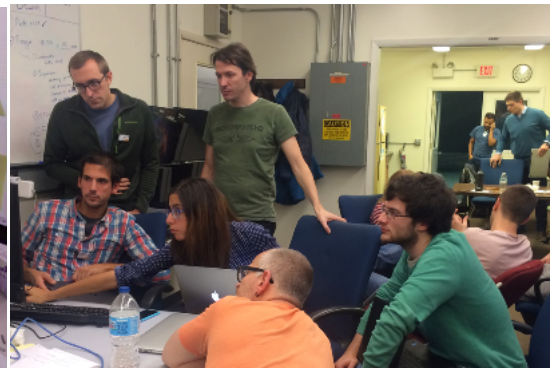
Recent OT achievements at Fermilab

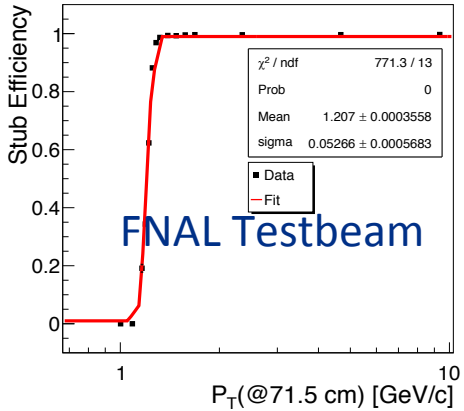
- FNAL built one of the first functional 2S modules
- Extensive tests on the bench and in test beams, including irradiation
- Test stands set up at SiDet; multi-module burn-in box finalized and working to specifications
- Excellent progress on plank prototyping, support beams, grounding scheme, cooling loops and interface with rest of OT barrel

1st functional 2S module in US



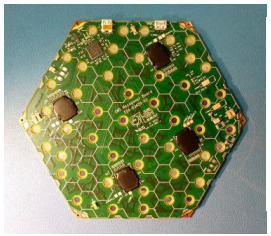
Layer 1 Mock-up

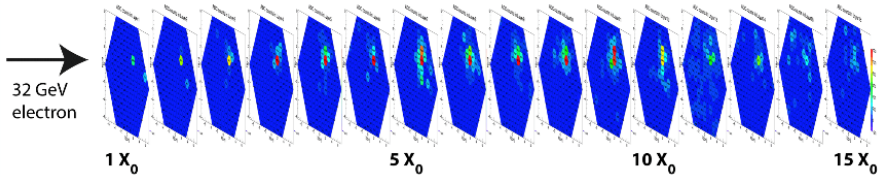




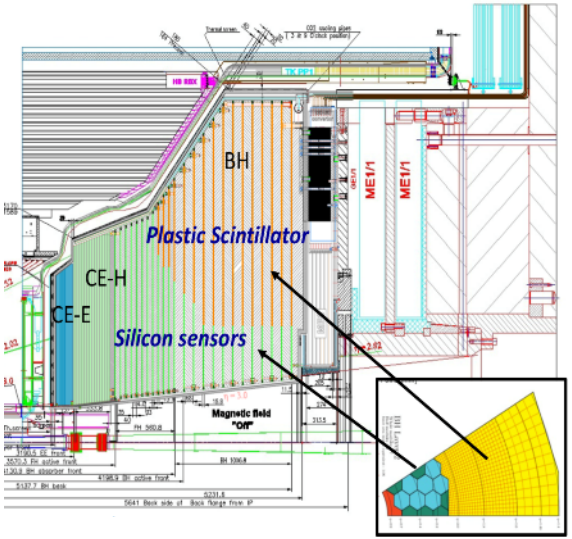
High Granularity Calorimeter (HGCAL)

- Exporting silicon-based tracking to calorimetry
  - 28 electromagnetic layers, silicon modules (CuW/Pb absorber, 25 X_0, 1.7 lambda)
  - 22 hadronic layers: 8 Si + 14 Si/SiPM layers (stainless steel absorber, 8 lambda)
  - High granularity (200k → 6M channels) in 3D and good timing resolution, 50 ps
  - Good cluster energy resolution, detailed topological information, excellent 2-particle cluster resolving power
    - Suitable for particle-flow like reconstruction in high density environment





FNAL Testbeam



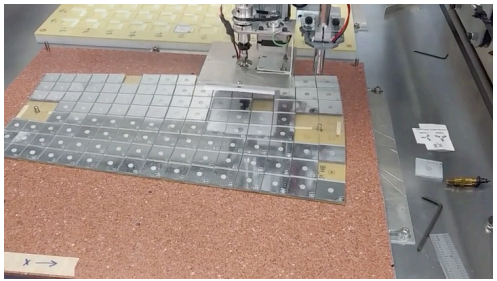
HGCAL at Fermilab

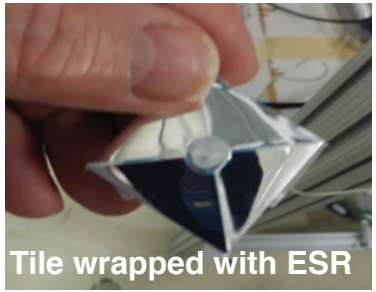
Design: Silicon sensor, scintillator, concentrator ASIC (ECON) and motherboards, cassettes

Deliverables: cassettes for the hadronic section, including scintillator modules

Recent HGCAL achievements at Fermilab

- Developed the all silicon prototype to evaluate thermal and mechanical properties
- Now designing and building a mixed cassette (Silicon + Scintillator) mockup to study the mechanics in time for CD-1 review in October
- Evaluation of: cooling plate, dummy tileboards, test of module assembly, module emulators, twinax assembly, wing board



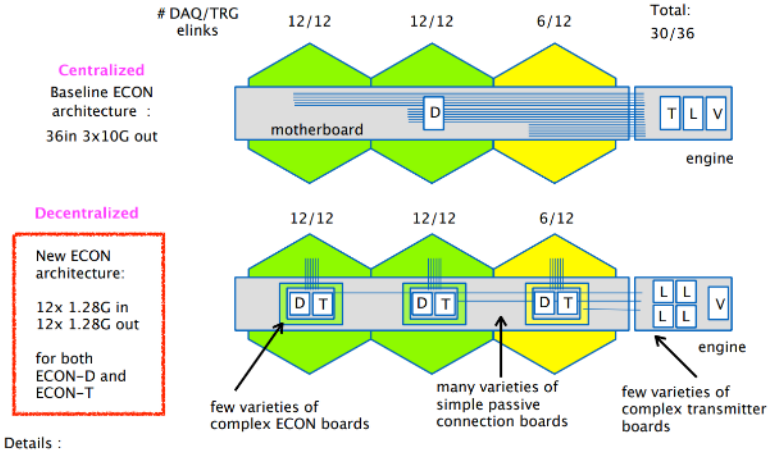


Tile wrapped with ESR

- Test beam studies of scintillator-tile response uniformity
- Commissioning of pick and place gantry for automated assembly of tile modules within tolerance

HGCAL: ECON ASIC

- ECON is the concentrator of the module data for transmission off detector
- Development team has been strengthened through improved collaboration and a new hire
- ECON Internal mini-review May 14@CERN
  - Proposed decentralized design to reduce complexity by downgrading link speed and distributing Concentration ASICs across motherboards
  - New plan reduces development duration by 6 months, easing a tight schedule
- Earlier this month, decentralized design has been selected as the new baseline design



Details :

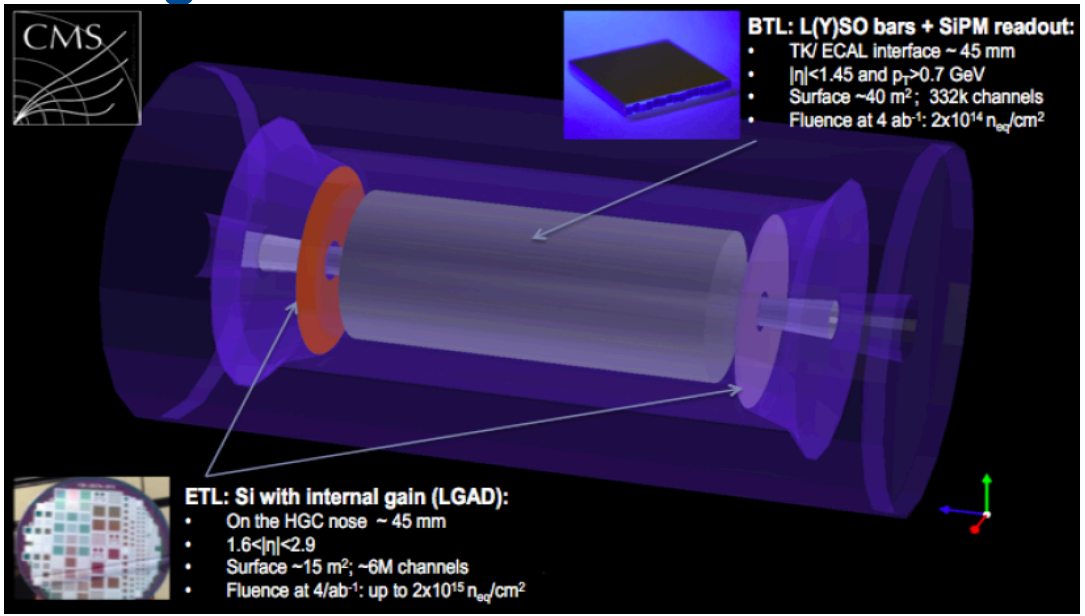
- ECON boards would also hold SCA and clock fanout
- Signals run both directions : data ➔ , ⬅ clock/control

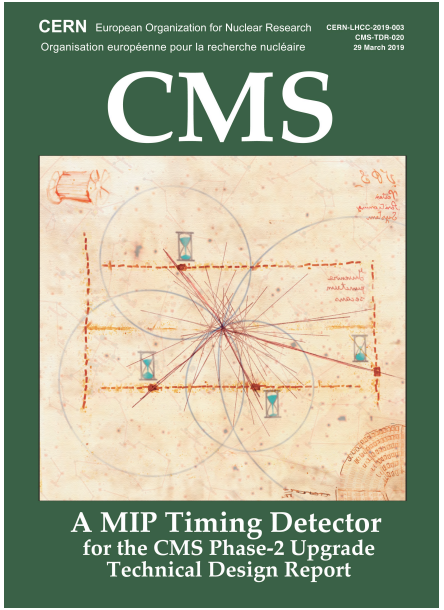
	Centralized 36x1G in (3/1)x10G out	**Decentralized** 12x1G in 12x1G out

Pluses	• Less dense 2-chip engine
	• more flexible load balancing
	• transmitter redundancy
	• ~25% lower power
		• More naturally allows isolation of complexity into
		  • ECON board
		  • Transmitter board
		• More unified ECON-D / ECON-T architectures
		• Less ECON design time, lower risk of ECON prototype problems
		• Naturally accommodates FPGA ECON emulator board for early system prototyping
		• Simpler / less expensive ECON package
		• decentralization lowers single point failure risk

Minuses	• Longer ECON design time • Higher risk of ECON prototype problems • Single point failure	• More dense 4-chip engine • Less flexible load balancing

MIP Timing Detector





The LHCC has recommended the MTD project to proceed forward

LHCC was impressed with the team and noted in particular the "vibrant young physicists" working on a future-oriented detector*, many of whom are from the US*

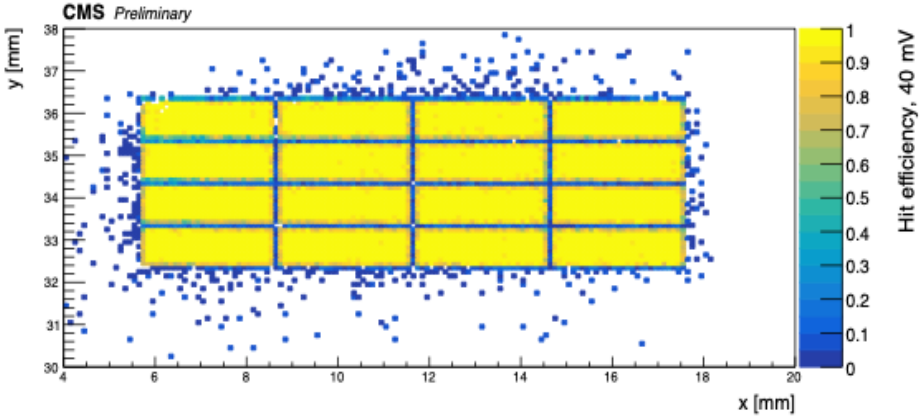
Fermilab played a crucial role in the re-design of ETL

Endcap MIP Timing Detector (ETL)

- Innovative detector providing timing information with 30 ps nominal timing resolution
  - LGAD: 1.3 x 1.3 mm^2, 9M channels, 15.8m^2
  - Cutting edge front end read out

ETL at Fermilab

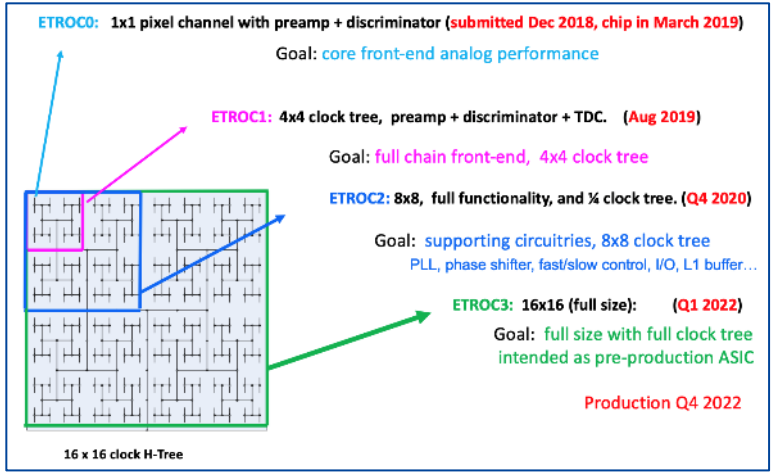
- Design: readout ASIC (ETROC), mechanics & engineering, ETL modules
- Deliverables: Design, testing, and procurement of ETROC, ETL module assembly

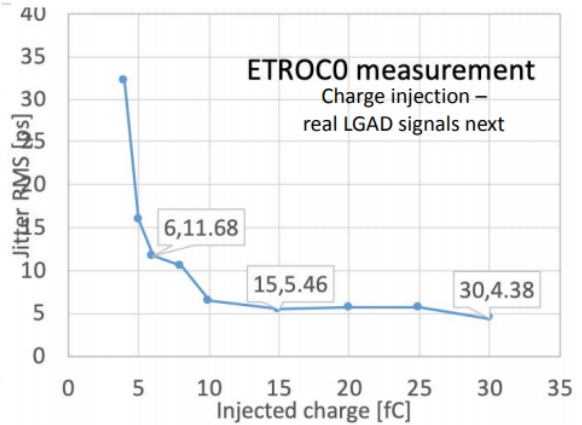


Upgraded test beam infrastructure and parasitic installation, substantially accelerated R&D

ETL: ETROC ASIC

- ETROC: MTD Endcap Timing Layer Readout Chip
  - ASIC contribution to time resolution < ~40ps
  - TDC range: ~5ns TOA and ~10ns TOT
  - Power consumption < 1W/chip
- ETROC0: the first prototype chip
  - Focus on preamp and discriminator
  - **Submitted Dec 2018, delivered end of March, testing started in April**
- **Performance is consistent with expectations from simulation**
  - ~12ps jitter for nominal input charge of 6fC
  - For larger input charge, jitter approaches 5ps
- Power consumption within expectation



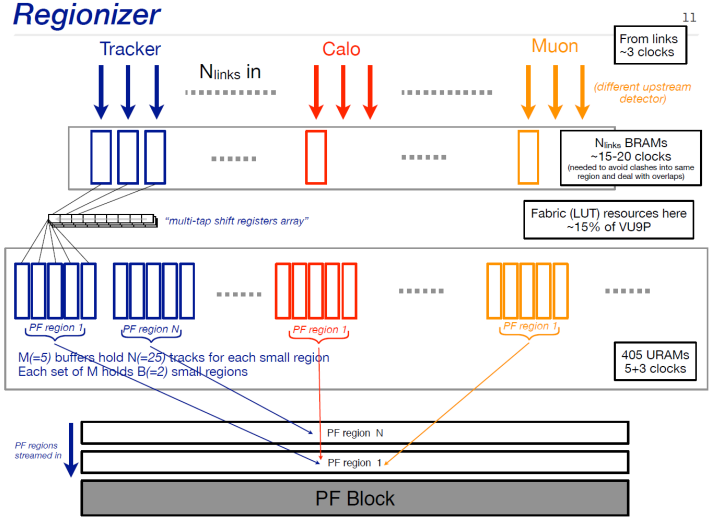


Trigger/DAQ: Recent Progress

- **Revolutionary L1 trigger**
- Exploiting tracking, high granularity calorimetry, muon information
- Matching tracks with calorimeter clusters, fitting muon and tracks together
- Producing complex objects with corrections for PU

- **ATCA prototype boards now in hand for calorimeter trigger and correlator trigger projects**
- Preliminary testing concludes in June, followed by **algorithm firmware demonstration in the summer and fall** before entering the preproduction phase in 2020.
- **Firmware of input data organization** for particle flow reconstruction recently determined in detail.

APx consortium trigger board prototype

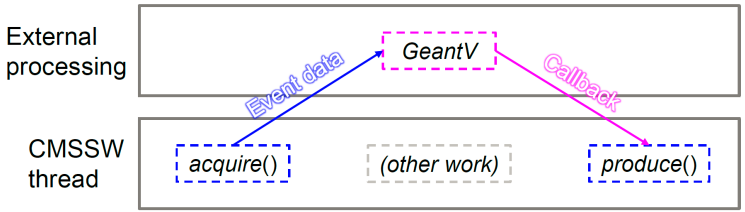


CMS Fermilab and US CMS SW and Computing Program

- Simulation
- Reconstruction
- Machine Learning
- Computing

R&D in Simulation Software

- Challenge: higher physics accuracy within computing budget
- Leadership in CMS: L2 Simulation Convener, L2 Upgrade Software Coordinator (including simulation and reconstruction for HL-LHC detector upgrades)
- Developing cutting edge R&D to adapt simulation code to work efficiently on modern computing architectures
  - Common geometry package (in collaboration with CERN)
  - Prototype of Geant vectorized transport (in collaboration with CERN) with support of DOE Computational HEP (in collaboration with CERN)
  - Collaboration with Geant Exascale project (LBL, Oakridge supported by Exascale Computing Project (ECP) and DOE Computational HEP)

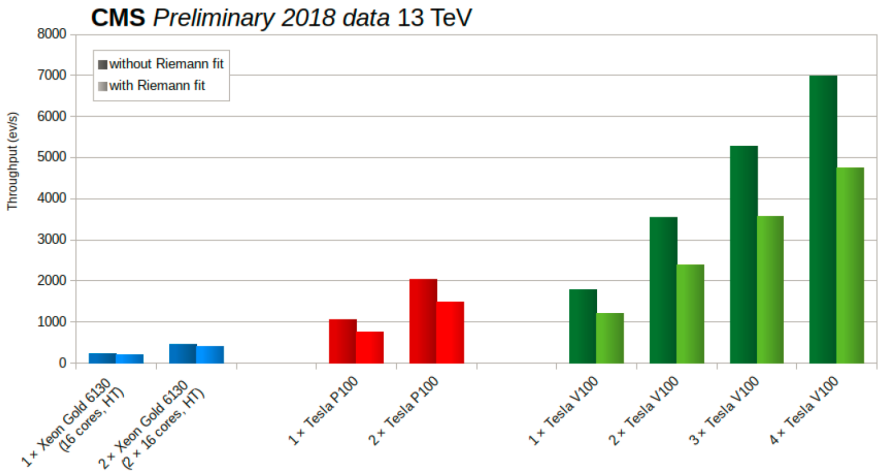


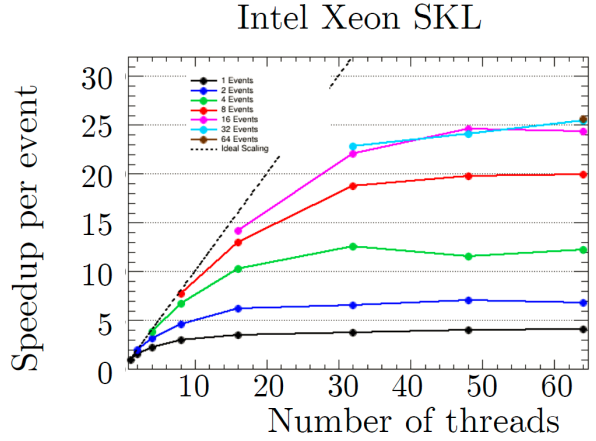
EXASCALE COMPUTING PROJECT

www.exascaleproject.org

R&D in Reconstruction Software

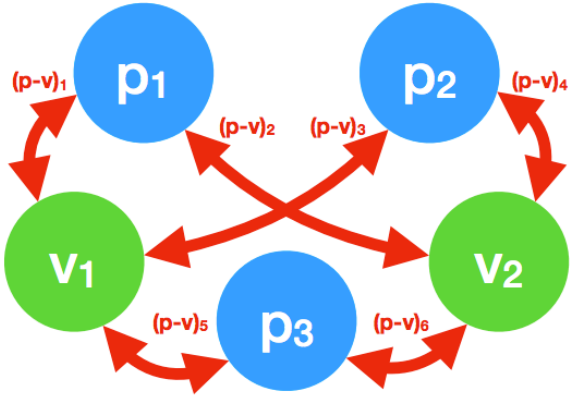
- Advanced R&D in reconstruction SW to face the challenges under high luminosity/ pileup conditions
- **Leadership in HGCAL and MTD Detector Performance Groups**
- Proposing new approaches for track reconstruction:
  - "Patatrack", in collaboration with CERN, INFN, SINP): tracking algorithms to run on GPUs → aimed for Run3 HLT
  - mkFit (parallel Kalman filter), in collaboration with Cornell, Princeton, UCSD): vectorization to accelerate tracking for new computing architectures



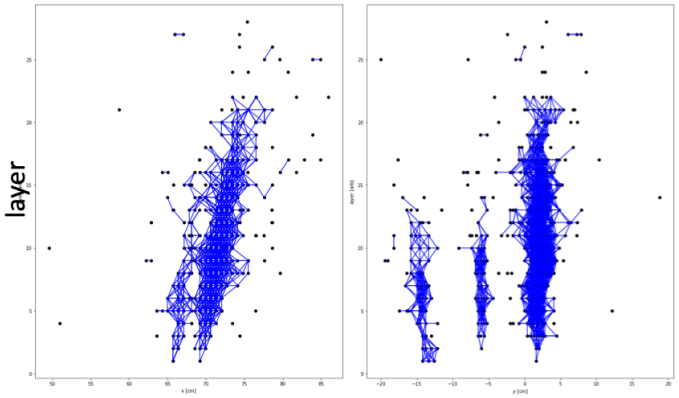


Machine Learning For Reconstruction

- Deep learning Higgs tagging
  - Using deep learning to achieve big performance gain
  - Exploring modern (convolution, recurrent) architectures, low-level features, new interaction structures
- Tracking and clustering (HGCAL)
  - ExaTrkX - for tracking with machine learning
  - LDRD - for using (accelerated) graph neural networks for HGCAL clustering

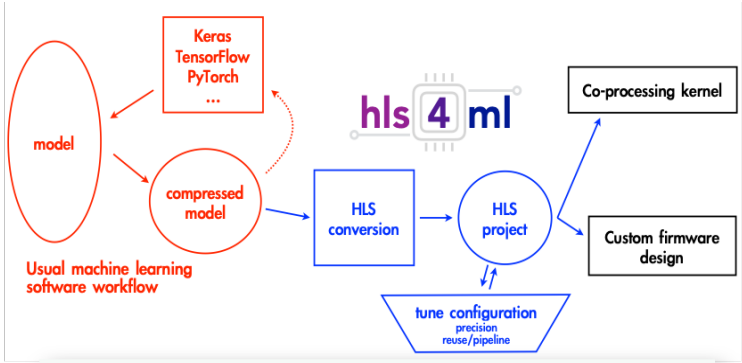


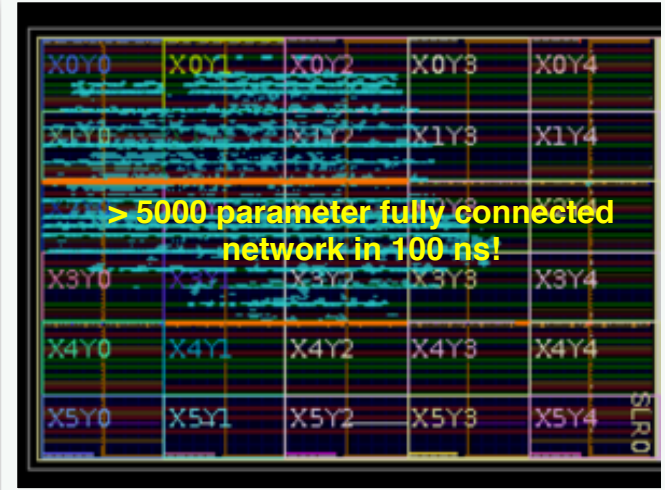
example of cluster graphs in HGCal



Machine Learning in the HW Trigger

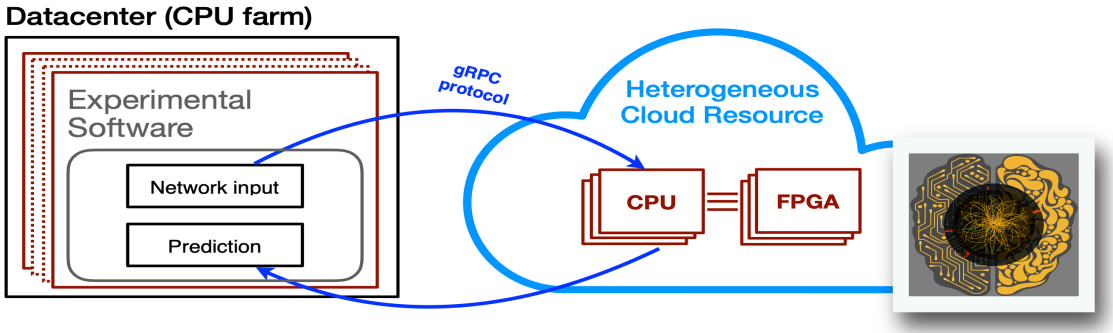
- Incorporating ML for on-detector real-time processing (L1 Trigger)
- Development of hls4ml, automated translation tool from ML models to firmware
  - https://hls-fpga-machine-learning.github.io/hls4ml/
  - https://arxiv.org/abs/1804.06913
  - **Featured on the Xilinx front page!**
- Applications growing: muon momentum regression, topology classifiers, cluster filtering, tau identification, ⋯
- Many offshoots! High level trigger coprocessors, accelerator control systems, ASIC design…





Accelerated Machine Learning for Future Computing

- Proof-of-concept study: capitalize on connection between ML and heterogeneous computing architecture to solve future computing challenges
- FPGAs for fast inference as a service can improve computing throughput by order(s) of magnitude without disrupting HEP computing model
- Collaboration with Microsoft Azure and Research teams



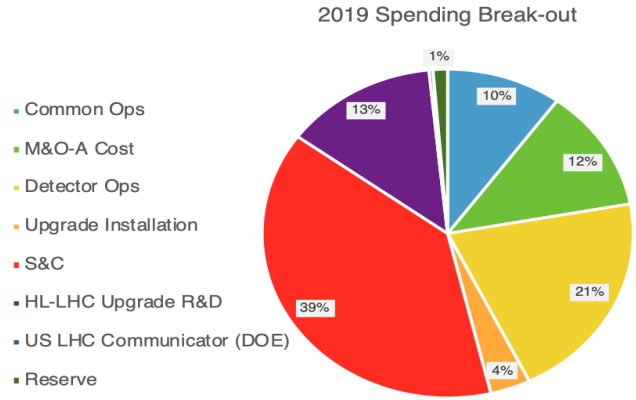
- For modern neural networks, 30-175x speed up over CMS CPU
- FPGAs have same throughput at local large-batch GPU

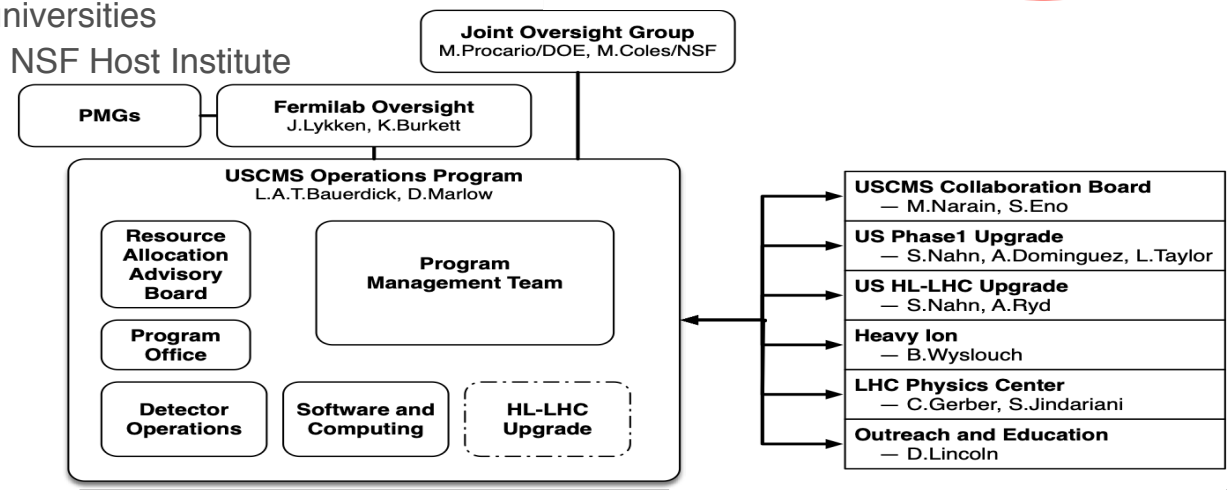
US CMS program

- Operations
- Computing

Fermilab Runs the U.S. CMS Operations P

- **U.S. CMS Operations** is a ~$36M/year program
  - Most funding spent as salaries and M&S in the U.S.
  - about ~26% are pass-through funding to CERN team accounts, al
- Fermilab serves as **Host Lab** for US CMS operations
  - the lab to advocate and speak for the CMS national program
  - DOE funding for US CMS flows through Fermilab
  - subcontracting with some 45 universities
  - Princeton University serves as NSF Host Institute
- Project oversight through DOE/NSF Joint Oversight Group (JOG)

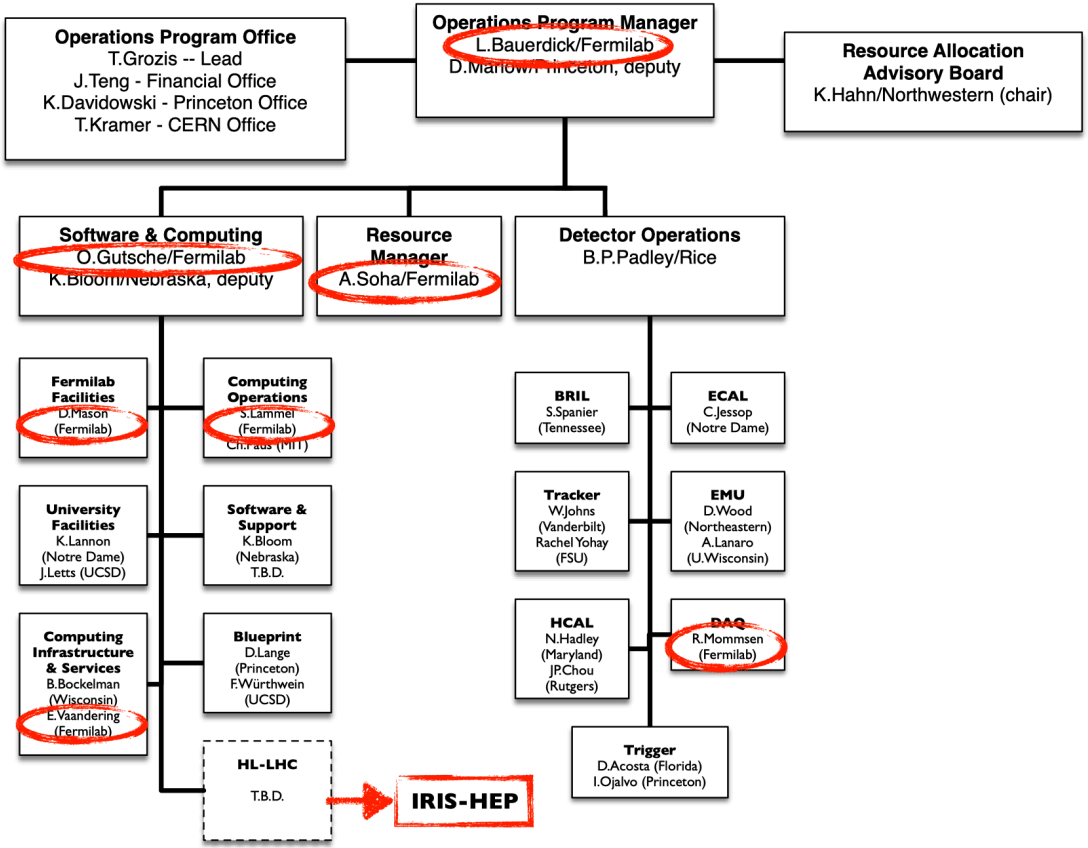




U.S. Responsibilities: Detector Ops, Software & Computing

- Operations responsibilities focus on **components that the U.S. contributed** to CMS
  - Tracker: all of the original and the upgraded Forward Pixel, 30% of Outer Tracker
  - HCAL: most of all aspects of HCAL, leading role in its operations
  - Endcal Muon: all of Cathode Strip Chambers, including electronics, trigger readout etc
  - ECAL: laser calibration and low voltage systems
  - Trigger: first layer of the calorimeter trigger and the endcap muon track finder
  - DAQ system: online storage and transfer system, event builder, online monitoring system
  - other contributions like Pixel Luminosity Telescope, etc
- **U.S. provides key contributions to CMS computing**
  - **Tier-1 facility at Fermilab**, representing about 40% of the CMS Tier-1 resources
    - also 7 Tier-2 facilities at U.S. Universities, including equipment and personnel for operation
  - **Software and computing** systems, including:
    - development, support of event processing framework, core software services, workflow and data management
    - cybersecurity for distributed computing and web-based components, software build and tools
    - running production workflows for reconstruction and simulation
    - **innovative approaches** to operations (e.g. HEPCloud), trigger and analysis (e.g. deep learning)
- **R&D in preparation for HL-LHC** software and computing needs
  - these efforts are NOT included in the HL-LHC upgrade project

U.S. CMS Ops Program Organization, Fermilab Leadership



U.S. CMS Operations Metric Reached or Exceeded

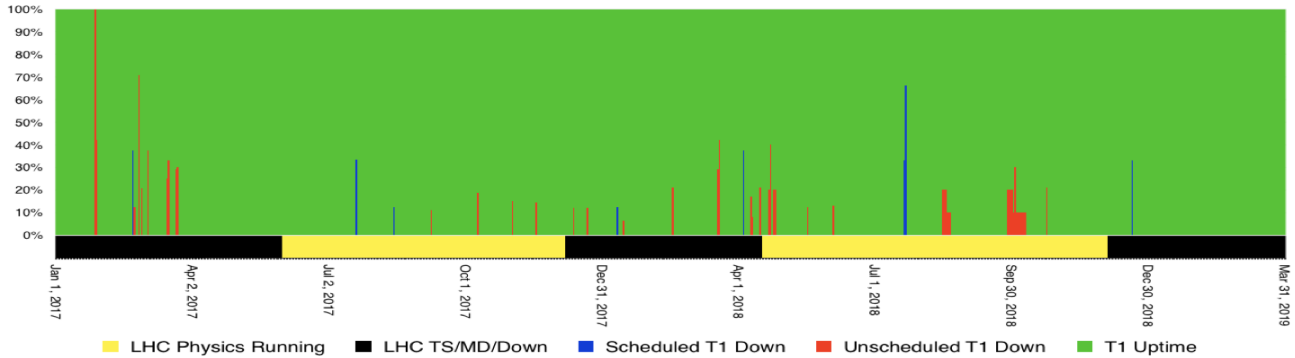
- **Overall performance of CMS is excellent**, and U.S. contributions are operating well
  - Overall data taking efficiency ~94%, DAQ dead time due to back-pressure is < 1%
  - ECAL, HCAL, CSC have working channels at >98% level, Outer Tracker >95%

- Detector repairs and installation of upgraded detector components during the) are proceeding well and are on scheduleshutdown (LS2
  - Installation of **HCAL barrel front end electronics upgrade** (major Fermilab contributions)
  - Refurbishment and upgrade of **on-chamber readout electronics for endcap muon system**
  - Repairs of other systems, including Pixel (**DC/DC converters**), Pixel Lumi Telescope

- Excellent performance of computing facilities and services
  - **Fermilab Tier-1 continues is one of the most reliable computing centers in CMS**, all 7 Tier-2 centers perform excellently, provide adequate resource levels
  - Investing in **software engineering** enable significant computing cost savings
    - Developed software and computing services to enable flexible use of resources, including allocations at high performance computing centers and commercial cloud facilities
    - Software performance improvements x4 over past 4 years, **scaling of CPU performance** ~ linear up to PU of 50 (but becomes exponential above 50)

Fermilab Tier-1 Performance

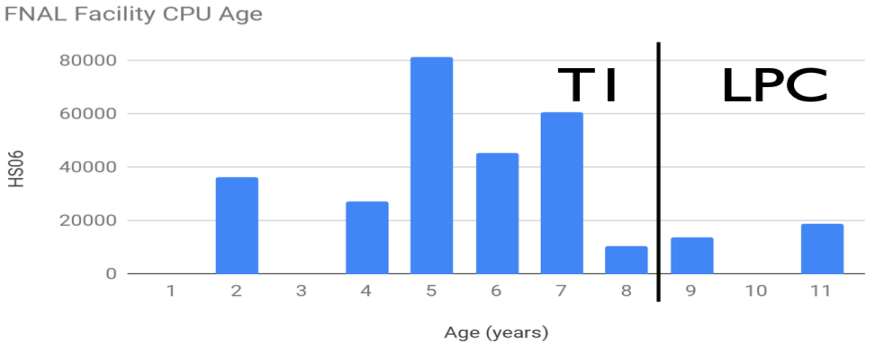
- Fermilab has a critical role to play in CMS computing, as the largest Tier-1 in the experiment
  - provides computing resources as the largest CMS Tier-1 center, by far
  - is major hub for operating computing workflows
  - **enables CMS to access High-Performance Computing centers (HPC) through HEPcloud**
- Successfully gained operational efficiencies through improved technology and integration with Fermilab SCD, even as LHC date volumes and computing needs have grown exponentially
  - 11.8 FTE for Tier-1 operations in 2019, down from 13 FTE in 2016 and earlier
- The Fermilab team maintains **excellent quality of services**, 98.7% availability

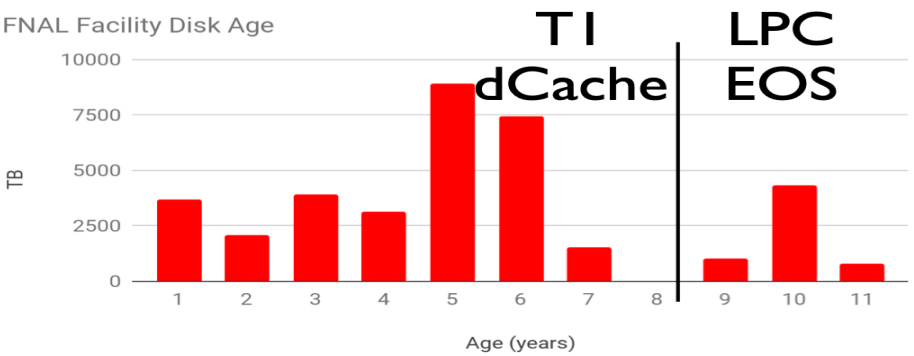


- Fermilab also supports the **LPC physics analysis facility** (CAF)
  - Very successful and popular over a dozen years of operations, > 100 active users every month
  - US CMS provides 1 FTE for user support

Fermilab Tier-1 Equipment needs Refurbishment

- US CMS had to delay replacement of **end-of-life equipment**
- Shortfall of Ops funds poses risks to the required reliability and capacity of the main Tier-1 facility that CMS depends on
  - CPU servers and disk storage equipment are kept in service for 8 years in the Tier-1, and for 11 years in the LPC-CAF
  - this is much longer than “industry best practices”
  - for FY19 US CMS has requested help from DOE to rectify the situation, however, required supplemental funds have not yet become available





Plans to mitigate US CMS Tier-1 Budget Shortfall

- Insufficient Tier-1 resources would have severe impact on CMS science, so we plan to replace missing CPU capacity with **dependable multi-year HPC allocations** (NERSC)
  - technical groundwork for provisioning "pledged" Tier-1 resources through HPC allocations was laid: HEPcloud, inclusion of HPC in CMS production workflows, remote data access
- HPC resource allocations would be incremental to Fermilab capacity
  - **Fermilab to continue providing reliable and predictable Tier-1 services** at a service quality level agreed in WLCG MOUs, however at lower capacity
  - significant challenges to be addressed in providing robust commitments and dependable turn-around times for HPC resources to become part of Tier-1 resources pledged to CERN RRB
  - **In FY20 CMS would require much beyond this year's "opportunistic" allocation** (about 200 million MPP)
- Recommendations from recent US CMS Ops Program agency review:
  - “Coordinate with the agencies on their HPC allocation processes to arrive at joint CMS and ATLAS programmatic, multi-year proposals by end CY 2019”
  - “Work with the agencies, and US ATLAS if appropriate, to find a sustainable mechanism to secure the necessary S&C resources in case of a flat budget scenario”
  - “Some flexibility in the DOE funding profiles for operations, research, and HL-LHC upgrades would support optimization of the overall US CMS program” […] “Work directly with Fermilab management and the CMS HL-LHC upgrade project to develop coherent messages to the agencies regarding budgetary needs, priorities, and overall CMS program optimization”

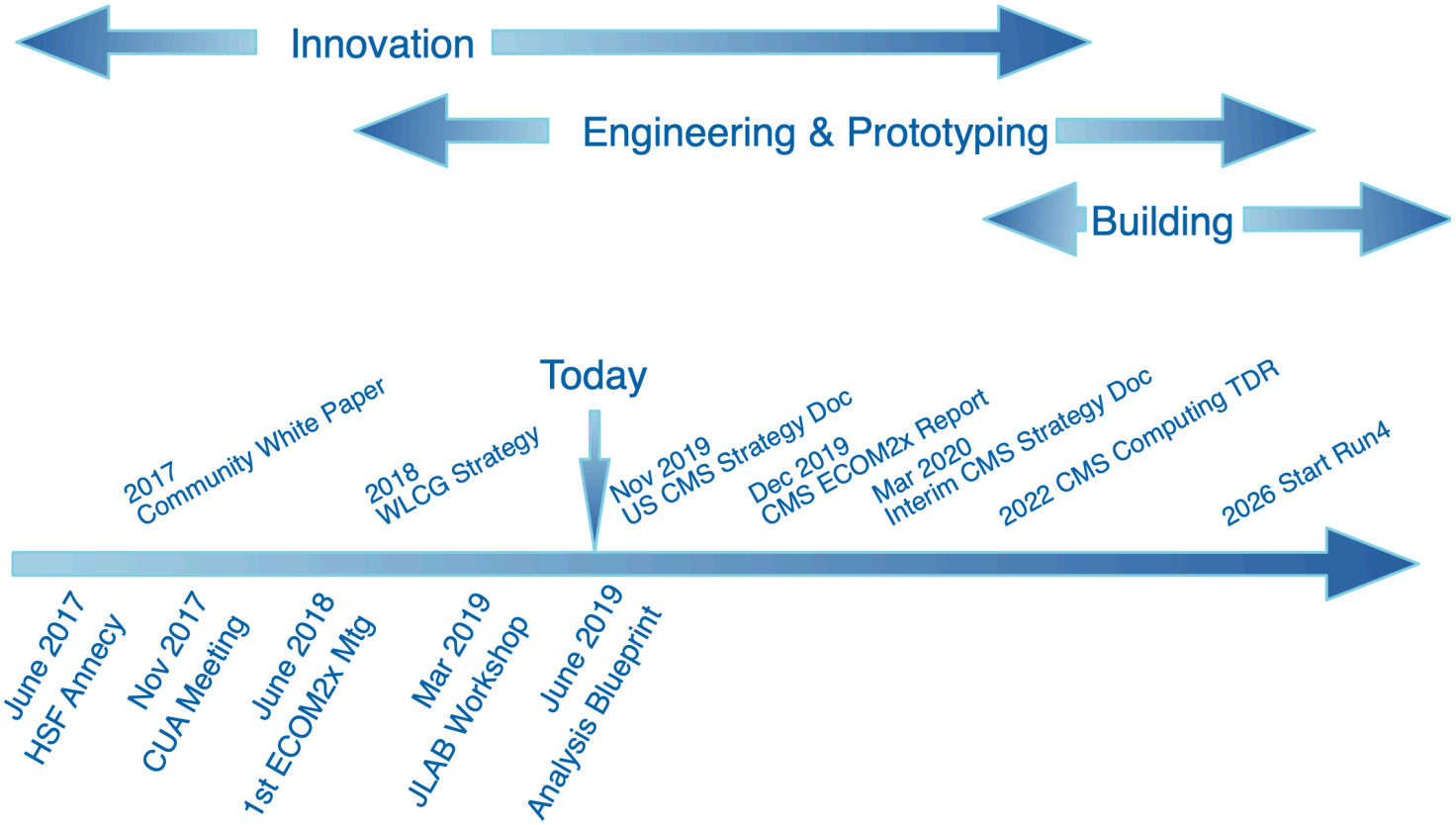
Fermilab is central to CMS HL-LHC Computing R&D

- CMS aims to for HL-LHC Computing to succeed within current funding levels, but we need an infusion of R&D now
  - Physics choices will be made to contain cost, and CMS has a record of being able to do that

- The core to solving HL-LHC computing lies in **modernizing the physics software, algorithms and data structures**, to allow cost effective computing solutions based on industry trends and emerging science infrastructures
  - **Storage is the cost driver**, our data storage systems cannot be done “opportunistically”, Fermilab has to be the central data hub, while CPU will come from several sources
  - The CPU challenge is about physics algorithms, how they run at high pile-up, on various machine architectures
  - Fermilab and our collaborating universities are central to addressing these challenges, in particular given the special role of Fermilab and the US for CMS

- Fermilab and US CMS already are part of a broad eco-system of R&D, which also includes the neutrino program
  - we can bring to bear the lab’s computing core competencies, SCD capabilities and leadership, and a unique opportunity for close interactions between physicists and computing experts
  - have a number of successful collaborative project with US ATLAS, funded by SciDAC and CompHEP
  - **US CMS would like to partner** more closely, sustained, and coherently coordinated with Fermilab and CCE, with other OHEP computing initiatives, including in ASCR and ECP

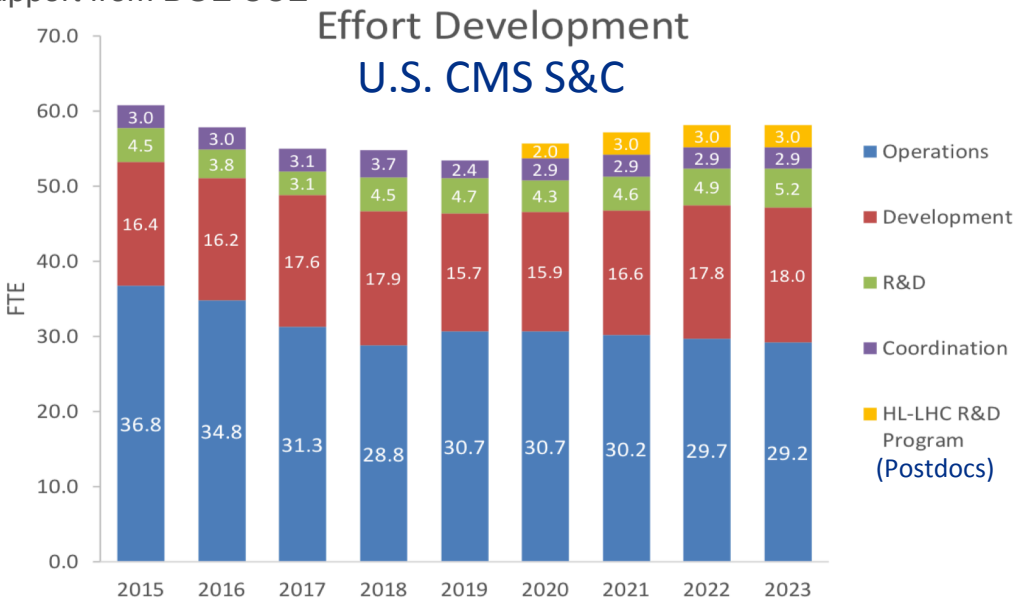
Time Line for HL-LHC Computing R&D



Ramping up the US CMS HL-LHC Computing R&D effort

- US CMS needs to ramp up software engineering team: Run3 and prep for HL-LHC
  - S&C efforts are depleted due to multiple years of below-target budgets
    - Computing and facility operations has been streamlined and made as efficient as possible
    - Review: “The committee felt 2.5-3 FTEs is not a sufficient staffing level to address the challenges of HL-LHC R&D”; also recommended to enlist support from DOE CCE
- US CMS is forming a HL-LHC coordination area
  - Made a strategic hire at Fermilab to bolster framework / core software skills, interfaces to key physics software areas, like tracking and clustering for HL-LHC
  - plan to start a postdoc-based program for HL-LHC computing R&D, augmenting NSF IRIS-HEP efforts

Needed HL-LHC computing effort level estimated to **15 FTE in 2023** (current plan: <10 FTE)

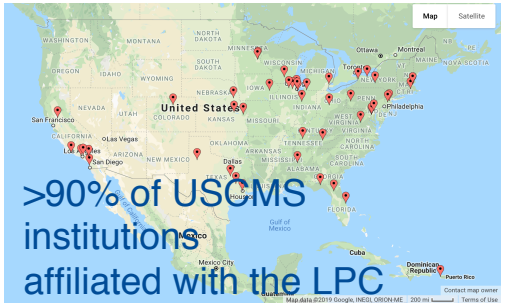


LHC Physics Center

- Fermilab as host of the LHC Physics Center
  - Major investment of FNAL scientists and RAs

LHC Physics Center (1)

- Established center of excellence for CMS
  - > 500 users and 150 residents;
  - 900 CMS collaborators use the LPC computing cluster;
  - 800 people participate in LPC-organized events, fostering interactions with theorists and non-CMS members

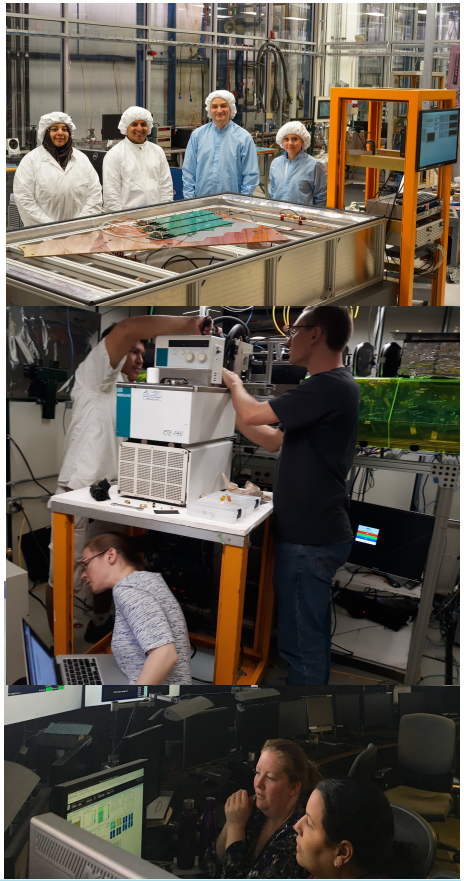


- The LPC has transformed the way CMS educates young students and post-docs
  - 50-70 students per year attend the CMS Data Analysis School (CMSDAS)
  - Nearly 400 students attend the summer Hands On Tutorials (HATS)
  - 20-50 students completed each course for credit
- LPC offers local software and computing expertise, helpdesk and documentation

The LPC depends on the continuation of the DR program, which is part of the research program and thus under severe budget constraints

LHC Physics Center (2)

- The LPC is a hub for diverse synergistic contributions across a broad range of **detector and computing R&D areas**
  - The program of each DR/G&V includes 50% analysis and 50% detector/computing/operation activities
- The LPC coordinates shifts for detector and computing operations (based in the Remote Operations Center)
- The Fermilab Analysis Facility (LPC CAF) is a major USCMS analysis computing infrastructure
- The LPC is significantly involved in all major areas of physics analysis
  - **Nearly 30% of CMS Run 2 publications have a majority (>50%) of LPC contributors**



Former PAC Recommendations and Comments (1)

- **January 2019:**
  - CMS plans to start using the new and unique Irradiation Test Area at MTEST in April 2019 to validate sensors for the Outer Tracker. The availability of this facility is critical to meet the CMS testing and qualification schedule.
    - Clean up of the area nearly complete, operations limited by funding availability.
  - The two concentrator ASICs (ECONs) of the HGCAL are delayed due to insufficient expert availability. Fermilab is mitigating the problem by injecting new engineering effort. […] we recommend that the Laboratory considers some reinforcement of its ASIC group to avoid risks.
    - Resources allocated by the PPD Engineering group to the development of the ECON
    - Dedicated effort by PPD to regularly monitor resources allocation across projects and technical progress
  - The Fermilab CMS group has lost key people because of career evolution and retirements. Without replacement, the laboratory may lose the ability to execute succession planning for its leadership in the HL-LHC upgrades as well as software and computing, posing a threat to the delivery of committed projects to CMS.
    - Hired an associate scientist focusing on Phase 2 upgrade and long term detector R&D
    - Sent the director a recommendation to hire an associate scientist focusing on cutting SW&Computing R&D

Addressed	In progress	Remains to be addressed

Former PAC Recommendations and Comments (2)

- **July 2018:**
  - The PAC encourages the Laboratory to ensure that the CD-1 review process is completed as soon as possible
    - Project office re-organized and strengthened with the addition of the L1 deputy and E&S coordinator
    - Successful Director's Review in Spring 2019, in preparation for CD-1 review in Fall 2019
  - The PAC concurs that it is very important to start the planning and implementation of [SW & Computing] strategies now […]. The different planned efforts described cover a wide range of ideas, from more straightforward (consolidating data, centralized data analysis facilities, etc.) to some that will require innovative R&D (machine learning, new algorithm development, etc.). Based on Fermilab's legacy on scientific computing and its longstanding success and leadership at the LHC, the PAC encourages the Laboratory to continue engaging in strategic planning for the success of computing and software in the HL- LHC era.
    - Establishment of new programs in S&C (see dedicated slides)
    - Innovative program on ML/AI
- November 2017
  - Budget provisions exhibit a significant decrease in the proton research funding that would strongly affect the successful LPC visitor program, reduce Fermilab staff for operations support and management at CERN, reduce the visibility of Fermilab scientists and postdocs at HEP conferences and workshops, and, most importantly, the execution of the ambitious HL-LHC upgrade and computing development plan […].
    - Not addressed yet

Addressed	In progress	Remains to be addressed

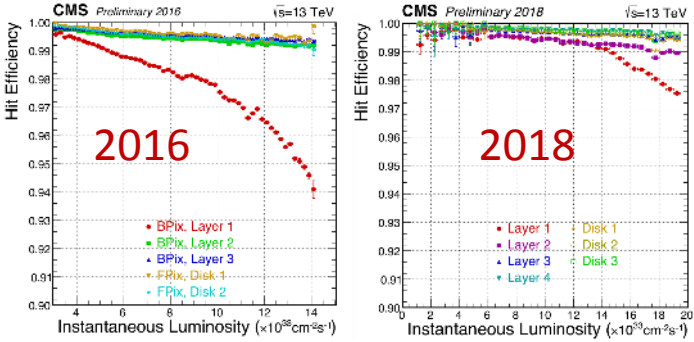
Conclusions

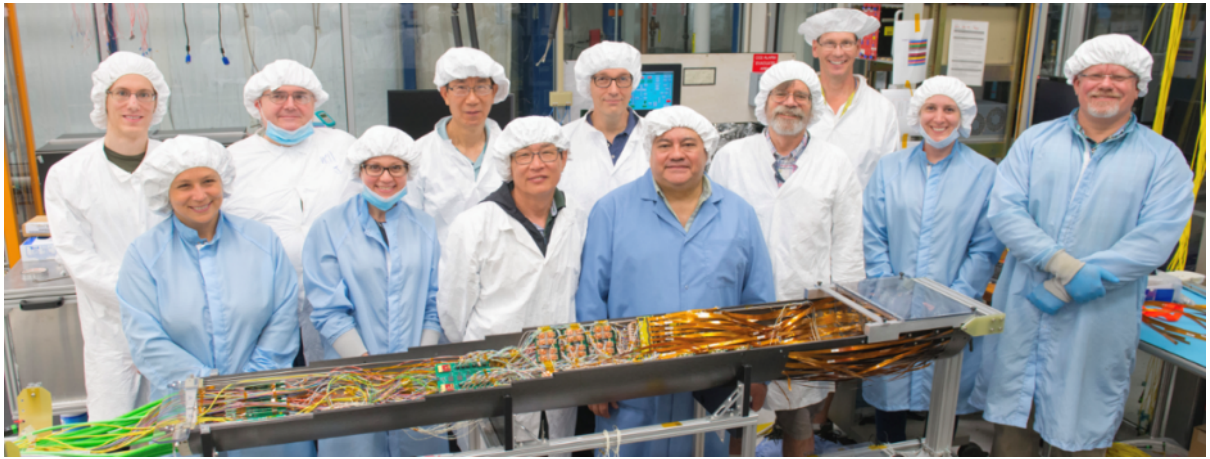
- **CMS** is very busy during LS2!
  - Vibrant **physics research** program exploiting Run 2 data
  - Well-honed and **efficient operations program** to exploit Run 3 and prepare for HL-LHC
  - Exciting, cutting edge slate of **upgrades** for Run 4 and beyond (HL-LHC)
- **Fermilab** is the nexus of U.S. CMS enterprise
  - Driving the physics program across the spectrum of interesting analyses
  - Leading the effort on the upgrades
  - Ensuring the data quality and enabling physics analysis for the whole collaboration
  - Innovating advances in computing
- Laboratory support is vital to the program
  - **CMS cannot be successful without strong support for U.S. CMS and Fermilab**
    - Operations, Research, and Upgrade
- The success of the LHC experiments is vitally important for the field.
  - US HEP strongly endorsed the LHC experiments through the HL-LHC era

Additional Material

Forward Pixel Detector

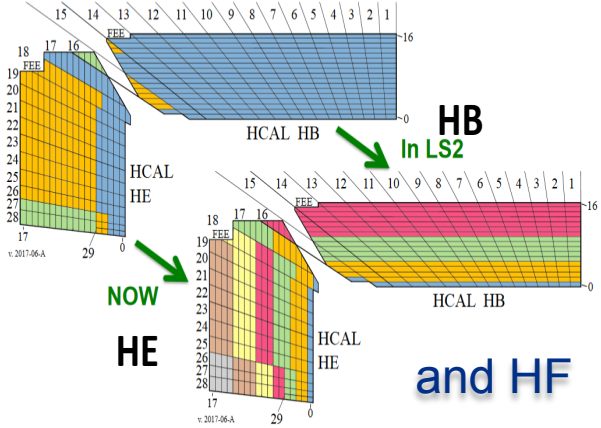
- New vertex detector with one additional layer closer to the beam
  - More precise tracking
  - improved vertex separation
- 672 modules for a total of 45 million pixels read out at 100 kHz
- Fully digital ASIC with deeper buffer, reduced material
- Integration of modules into large structures at Sidet, FNAL



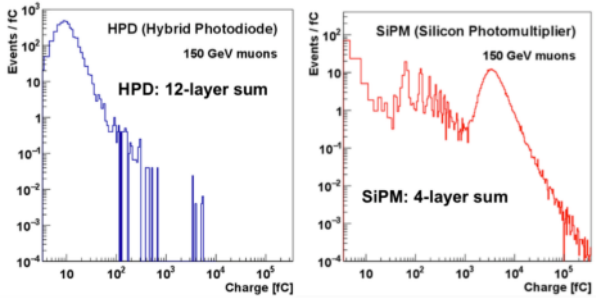


HCAL Upgrade

- Upgrade (HF) and replacement (HE/HB) of the photodetectors with SiPMs
  - Increasing granularity of the energy measurement and providing timing measurement
- Hadronic Endcap and Hadronic Forward Calorimeters
  - Installed, commissioned, operated in 2017 and 2018
- Hadron Barrel Calorimeter Installation & commissioning now
  - Requiring extended access to the inner guts of the detector!
  - Full upgrade ready for the first data of Run 3, expected mid 2021

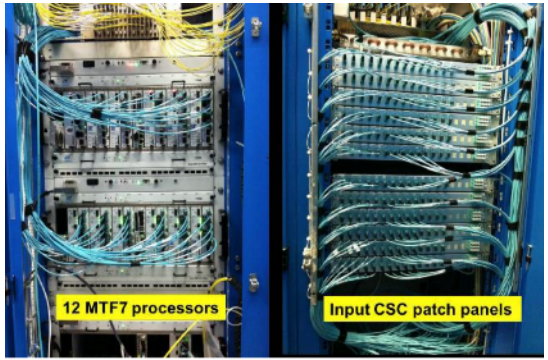


- FNAL designed charge integrating ADC, with integrated TDC (QIE10 and QIE11)



L1 Trigger Upgrade

- State-of-the-art electronics (FPGAs) and high-bandwidth optical transmission, allowing for more granular input data and more complex filtering algorithms with pileup suppression
- Forefront of the uTCA revolution
  - New generation FPGAs with on-board processors, high bandwidth I/O, higher granularity in the trigger
- Innovative full implementation of High-Level-Synthesis (HLS) allowing physicists to code firmware
- Parasitic confirmation in 2015, default L1T in 2016

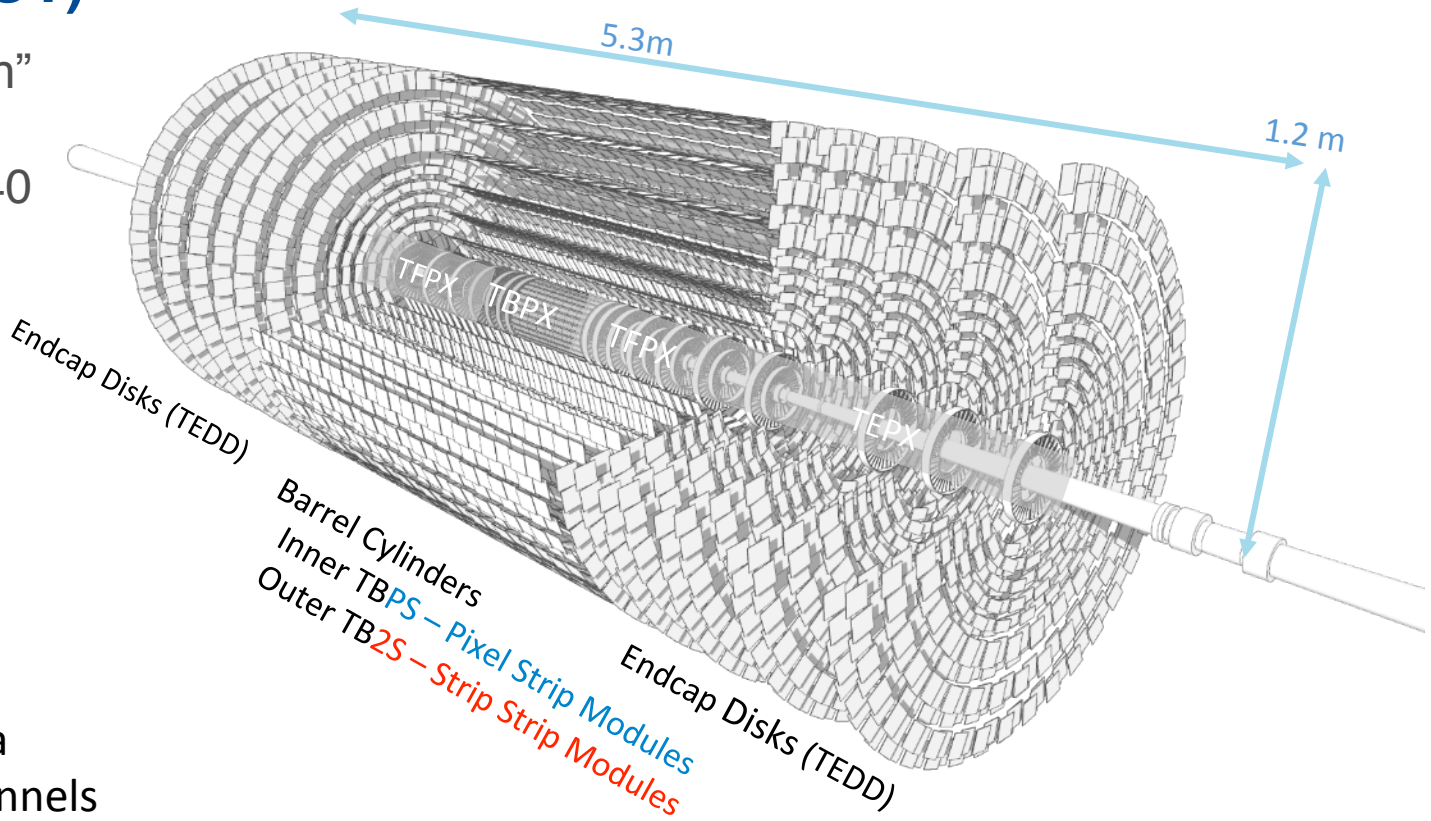


CTP7 board for L1 Calo

Phase 2

Outer Tracker (OT)

- Module "sandwich" allows Track Triggering at L1 (40 MHz)

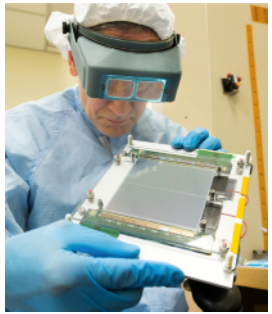


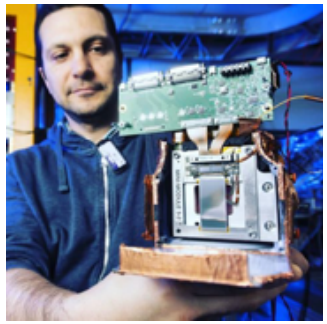
OT Numbers

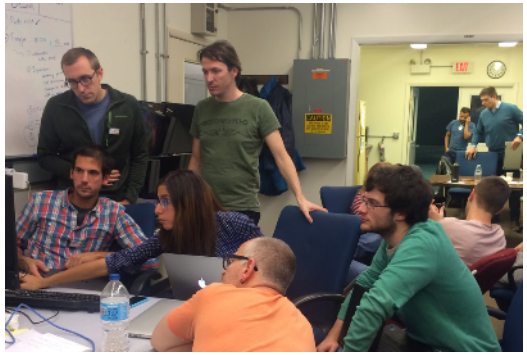
- 23.5 m^3 volume
- ~1600 kg
- 75 kW total power
- 192 m^2 Silicon Area
- 215 M readout channels

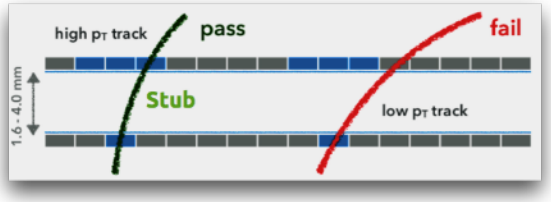
Outer Tracker

- Advanced technology enabling the transmission of tracking information to the Level-1 trigger at 40MHz for the first time at hadron collider
- Local data reduction based on two-layer silicon modules
  - Standalone units equipped with Front End ASICs that perform bottom and top sensor correlation providing track pT measurement
    - 2S modules with 2 strip sensors
    - PS modules with 1 pixelated sensor and 1 strip sensor
  - 200 tracks with $p_T > 2$ GeV leading to 15k stubs

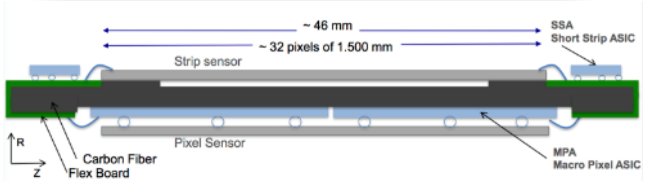








CMS-TDR-014

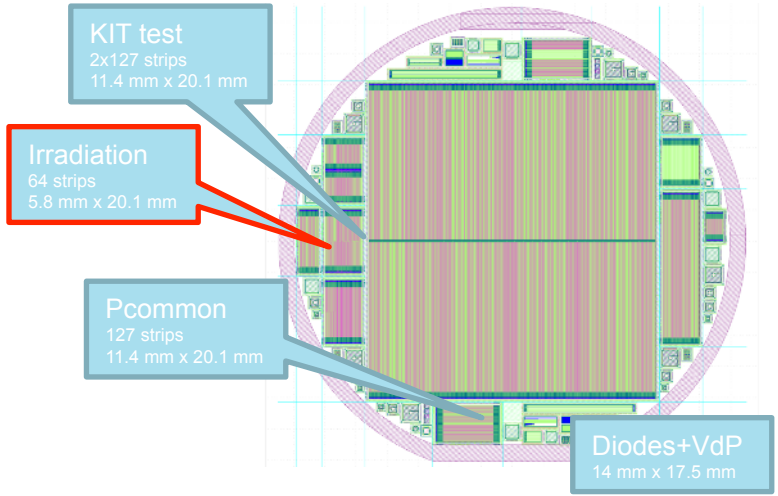


- Design: Flat Barrel, modules, DAQ/DTC
- Deliverables: 30% of the modules (4500), entire flat barrel, 100% of MaPSAs (6400), contribution to DAQ and DTC

HPK Irradiation Campaign

Compare FZ290 and thFZ240 Fluences

	R=20 cm	R=80 cm
neutron fraction	40%	80%
2S (3000/fb)		
PS (3000/fb)		
PS (4000/fb)		



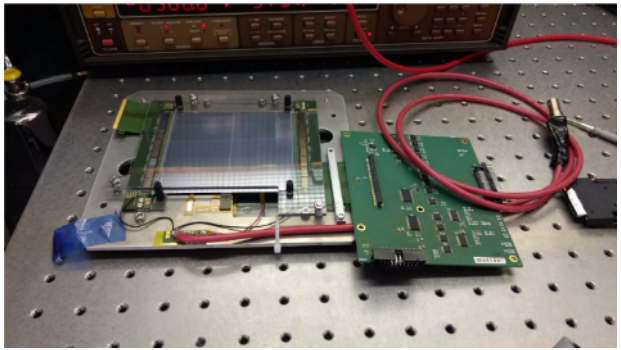
Irradiation/measurement sites in US

- Neutrons only: neutrons@RINSC – measurements@Brown
- High E mixed: neutrons@RINSC, protons@FNAL – measurements@Brown

- Measurements
  - Before/after irradiation: IV/CV, sample strips on probe station
  - Anneal to equivalent of 417 days @ RT on Alibava station in seven steps
    - Measure pedestals, calibration, source run for 100V<Vbias<1000V @ -20°C for each step
  - After annealing: IV/CV @ -20°C, sample strips on probe station
- Complete all measurements by May 2019

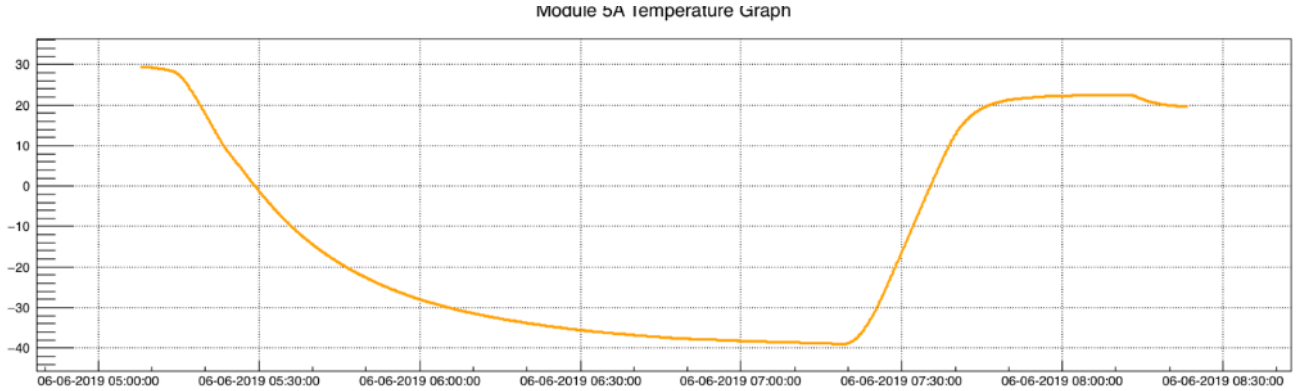
OT: Second functional 2S module @FNAL

- Used 2S module #2 to check a theory that very low temperatures may lead to the loss of wire bonds if the encapsulant becomes too stiff.
  - Speculated following observations of lost connections on a mini-module.
  - The Dow Corning Sylgard 186 elastomer should be okay down to -55°C per the spec sheet.
  - The CERN recommendation is actually an 80/20 mixture of Sylgard 186 and 184.
- Use environmental chamber to thermal cycle 10 times @
  - 0, -10, -20, -30, -35, -40 °C



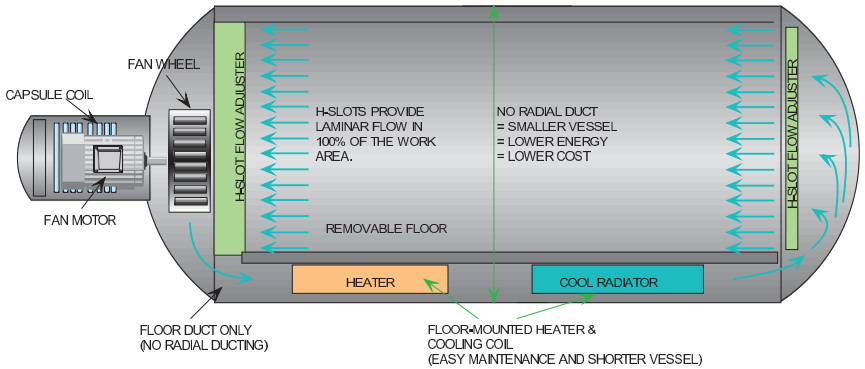
OT: Multi-Module Burn-in Box

- Burn-in box has been successfully thermally tested with the full 100W heat load
- Humidity well under control
- Full thermal cycle between +30C and -40C takes ~2h15, allowing for up to 10 cycles/24h



New Autoclave @FNAL

- ASC Econoclave 4x10 autoclave
- 4 ft inner diameter, 10 ft clear length, max. pressure 10 bar, max. temperature 450ºF
- Standard curing pressure for carbon fiber laminates is 6-8 bar



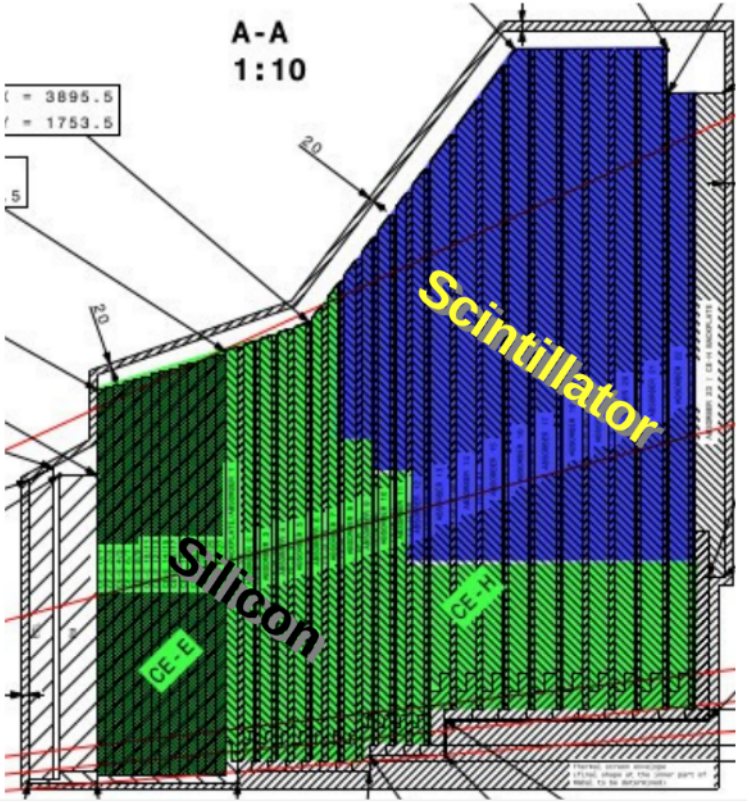
ASC's Econoclave ®

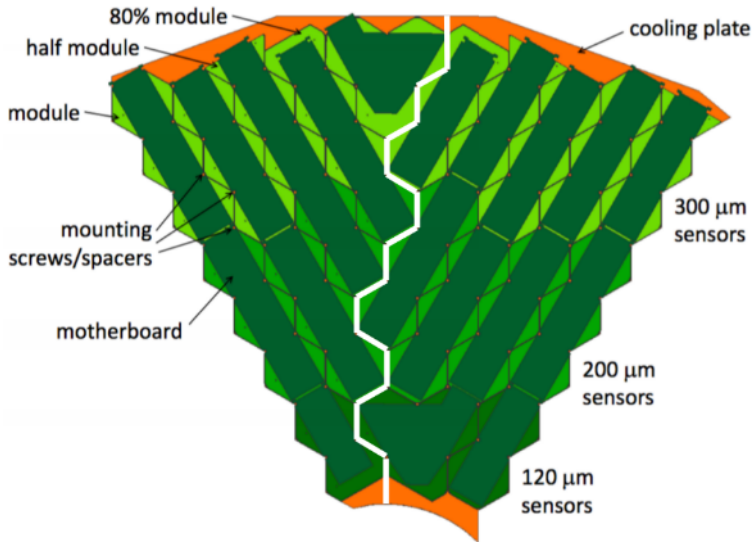
Autoclave @MAB
1/22/2019

Tracker DAQ Middleware development

- The DAQ software for the tracker is divided in two blocks:
  - high level software taking care of the state machine and interface with the central DAQ
  - low level software, the Middleware (MW), directly interfacing with the hardware, defining the calibration procedures, decoding data, etc.
- Fermilab group took the responsibility of coordinating the Outer Tracker MW development.
  - Test stands were set up at SiDet to qualify the assembled prototypes and test the MW developments.
- The calibration procedures developed by the different groups developing the hardware prototypes being reorganized for better maintainability.
- Calibration procedures based on generic registers scans: faster implementation of newer calibrations, possibility to generalize for chips from other modules (SSA, MPA, RD53).
- Tools for the 2S modules well advanced and used for prototype tests; PS modules being introduced in the code now.

Calorimeter Endcap (CE or HGCAL)



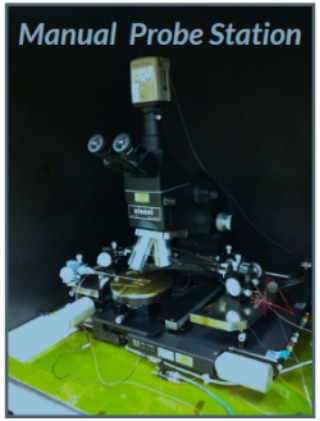


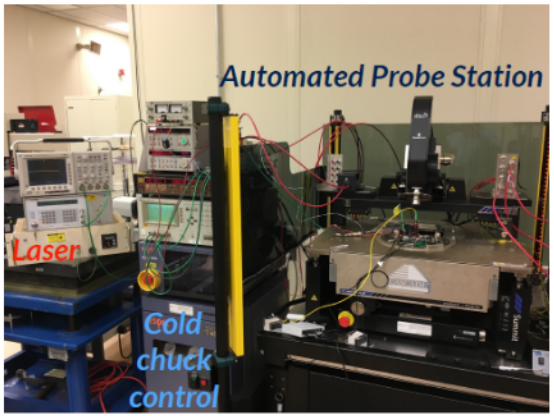
- Novel Imaging Calorimeter, highly segmented 4-D image of jet

CE Si Sensor Design and Testing

At Class 10000 cleanroom

- Three manual probe stations
- One *automated probe station with cold chuck*

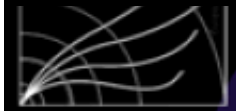


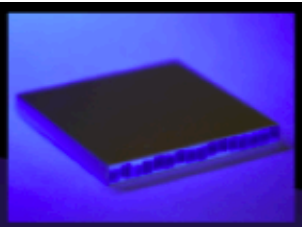


Capabilities (At room temperature and cold temperature):

- Laser scan tests
  - Study the *charge collection efficiency* as a function of bias voltage
- I-V tests
  - Study the *leakage current* as a function of bias voltage
- C-V tests

MIP Timing Detector (MTD)





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

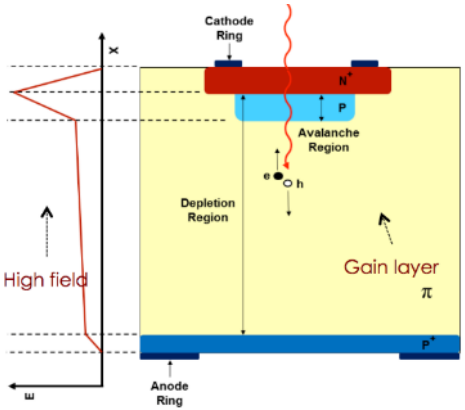
ETL: Si with internal gain (LGAD):

- 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

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.

ETL Overview

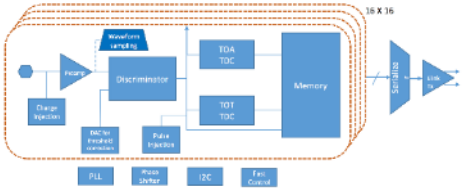
Active element:

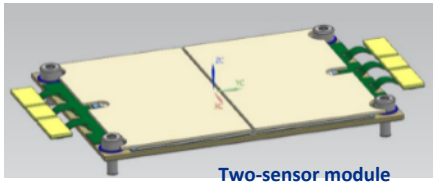


- **"Low-Gain Avalanche Detector" (LGAD)**
  - Large signal, large slew-rate ⇒rapid electrical response
  - More signal in less material ⇒ short drift time, better timing resolution
  - Low gain ⇒ low shot noise, below electronics pedestal

Sensors, ASICs and Modules:

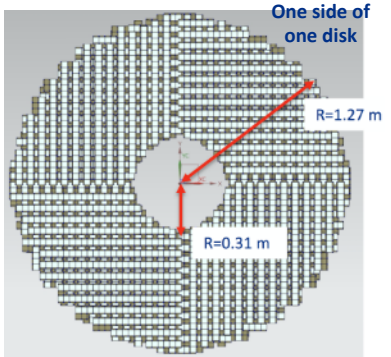
- Each sensor: 2x4 cm^2 array of 512 1.3x1.3 mm^2 pixels
- Module is an sub-assembly of sensor + ASICs
- One or two sensors per module, ~9000 total modules ➔ ~9M pixels
  - Relative 4% in number of channels wrt OT




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



Fermilab Test Beam Facility

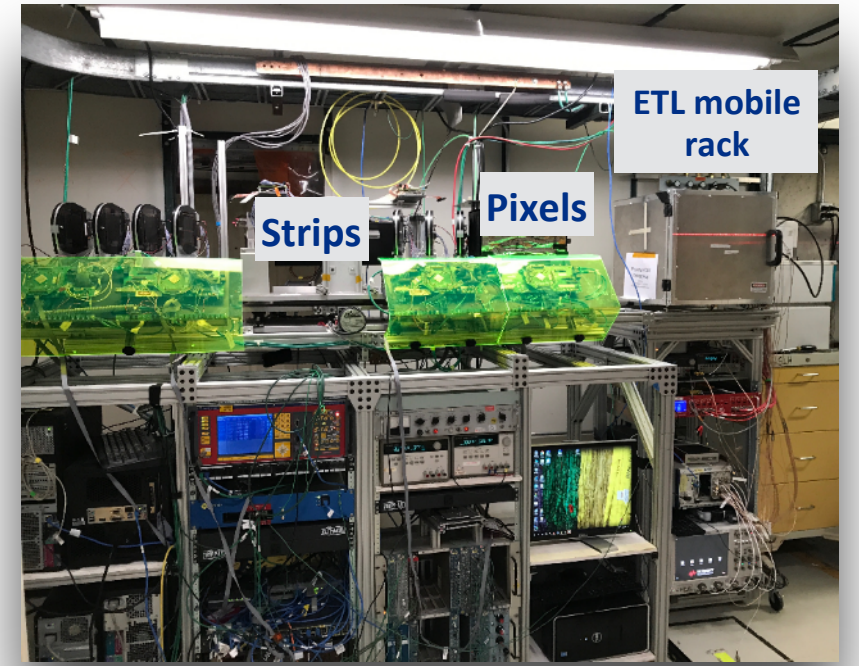
Major test beam infrastructure upgrades this year

Digitization: Keysight scope
High bandwidth, 40 GS/s, high ADC resolution
Fully exploit “burst” beam structure:
Record 100k events to memory at once, write to disk between bursts → much higher throughput.

Tracker
Add layer after ETL box; reject scattering events
Measure efficiencies ~ 100%

Permanent mechanical structure
Mobile: slide in and out of beamline as needed
Parasitic use of beam!

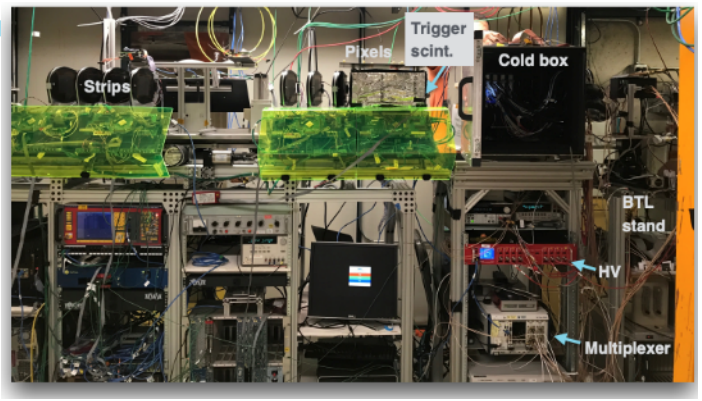
Automated remote control, logging & reconstruction.



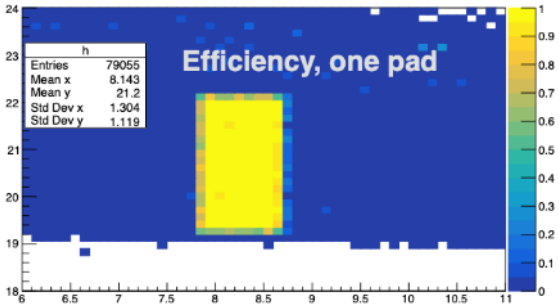
MTD at MTest

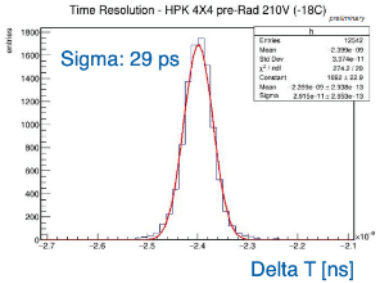
Very valuable April and June testbeam runs for both BTL and ETL

FTBF availability in the coming months+years is crucial for completing our project.

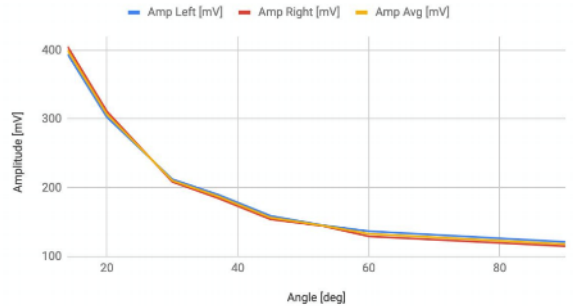


ETL: Tests of 4x4 sensors from HPK





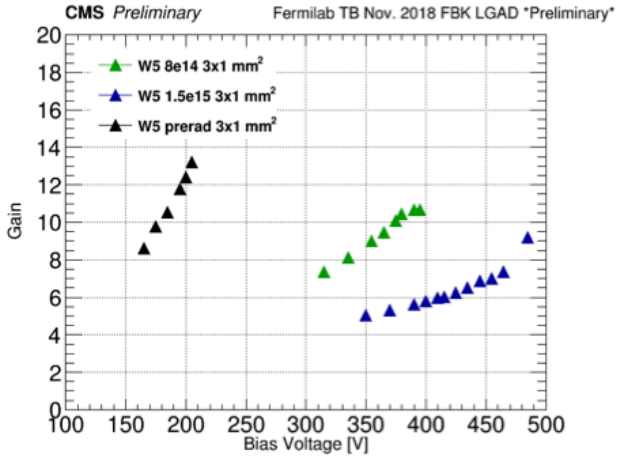
BTL: Angle scans for single LYSO bars, double-ended SiPM readout



Test Beam Activities this Year

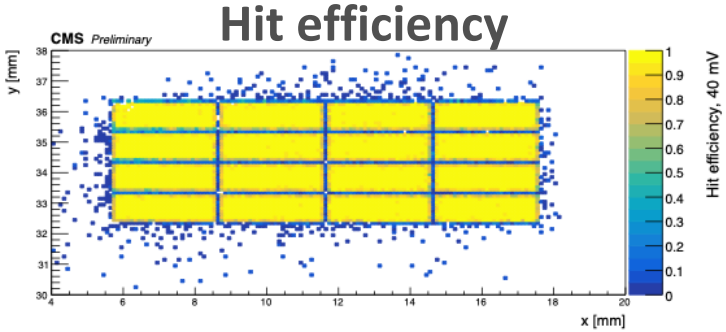
FBK UFSD3:

- Main challenge accomplished—maintain gain to end of life (and beyond)!
- Minor flaw due to stepper: premature “popcorn” noise prevents operation at highest gain.
- Expect follow-up production (UFSD 3.1) will resolve popcorn & meet ETL specifications.

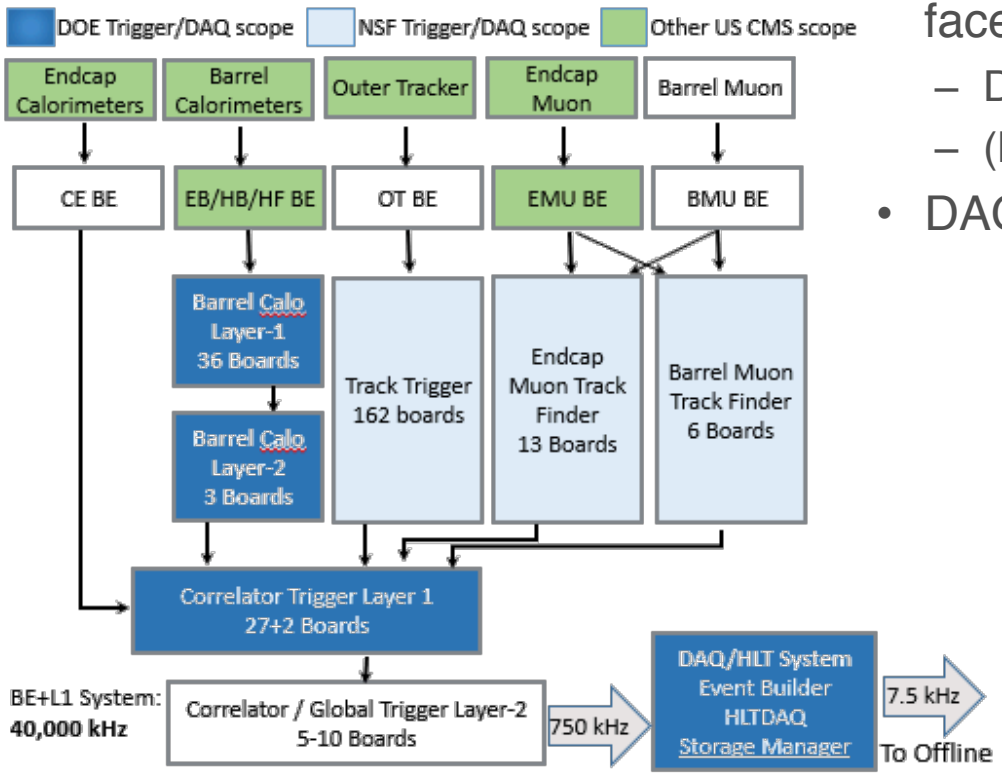


Key development: 16-channel readout board study large arrays for the first time!
e.g. HPK type 3.1, 4x4 array (3x1 mm2 pads)

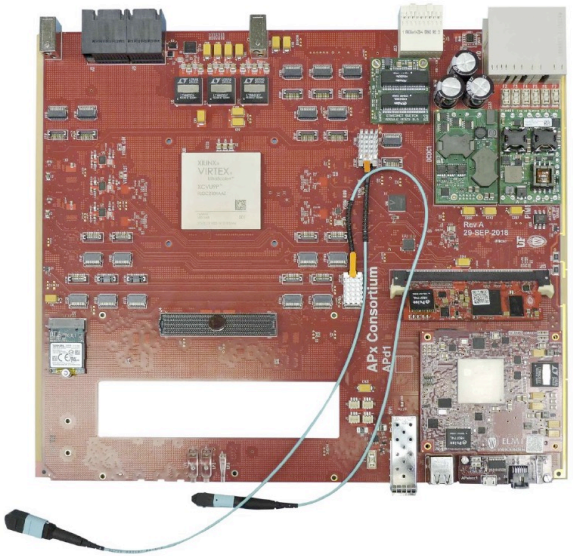
Upgraded test beam infrastructure: create this map in hours, not days!



L1 Trigger and DAQ (TDAQ)



- Trigger – maintain low thresholds in the face of higher $\mathcal{L}_{inst}$, pileup
  - DOE: Calorimeter, Correlator Triger
  - (NSF: Muons, Tracker)
- DAQ: Increase throughput

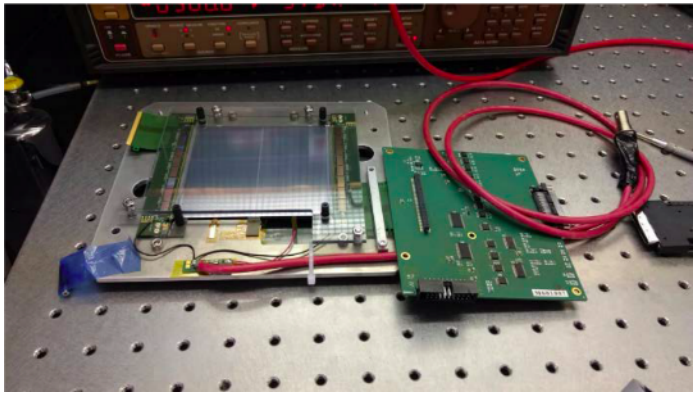


Prototype ATCA board

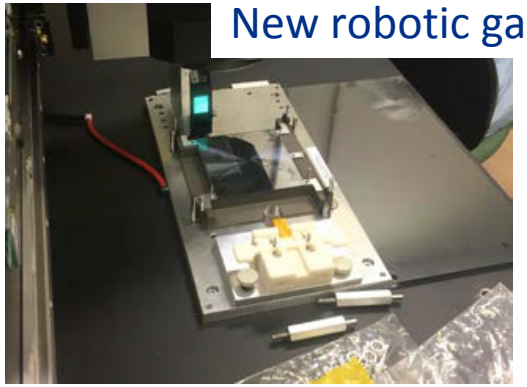
OT: Module Assembly and Testing

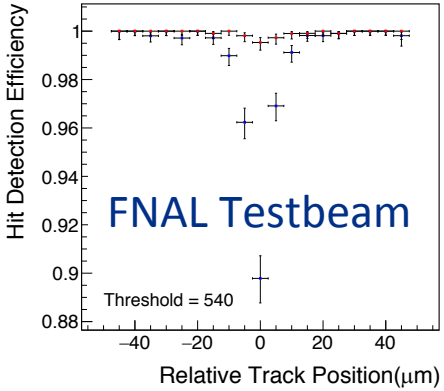
- FNAL built one of the first functional 2S modules
- Extensive tests on the bench and in test beams, including irradiation
- Test stands set up at SiDet; multi-module burn-in box finalized and working to specifications
- FNAL in charge of developing Middleware, software directly interfacing with hardware, decoding data, defining calibration procedures, etc.
- Major opportunity identified: partial automation of gluing and metrology workflow could allow for large cost savings and higher quality

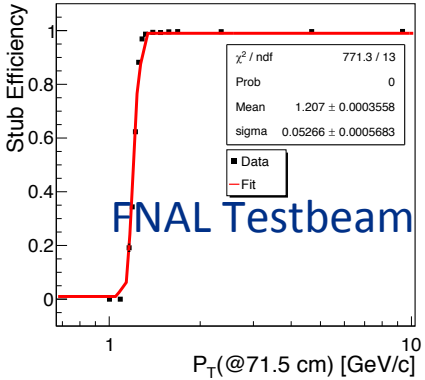
1st functional 2S module in US



New robotic gantry



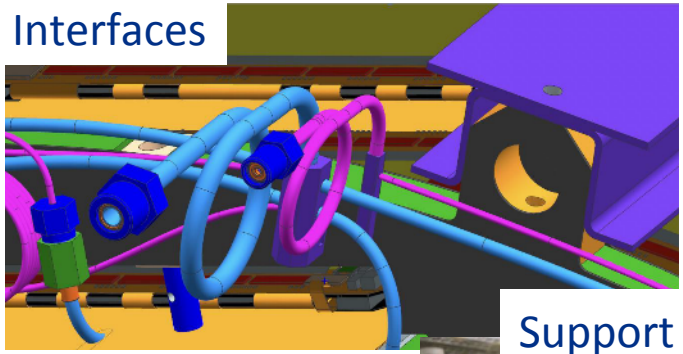




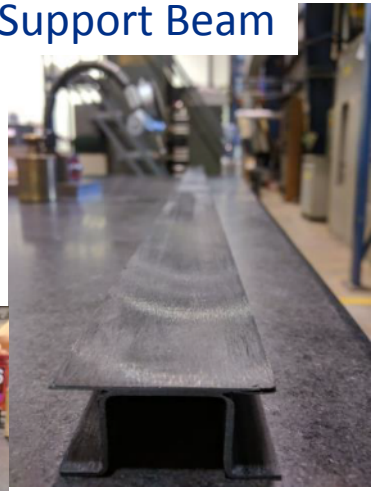
OT: Flat Barrel Mechanics

- Fermilab responsible for design, construction and assembly of L1-L3 of central barrel (~950 PS modules)
- Excellent progress on plank prototyping, support beams, grounding scheme, cooling loops and interface with rest of OT barrel

Interfaces

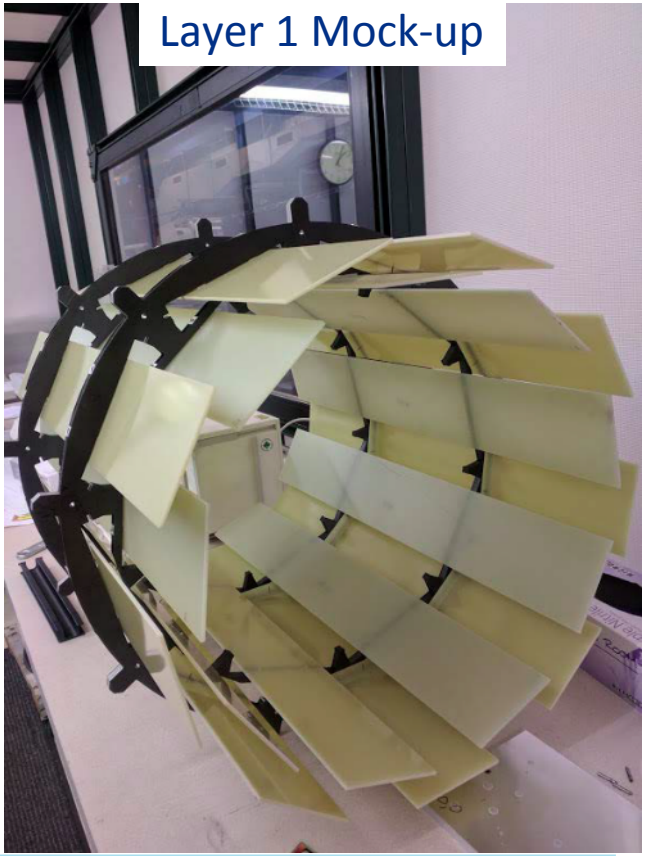


Support Beam

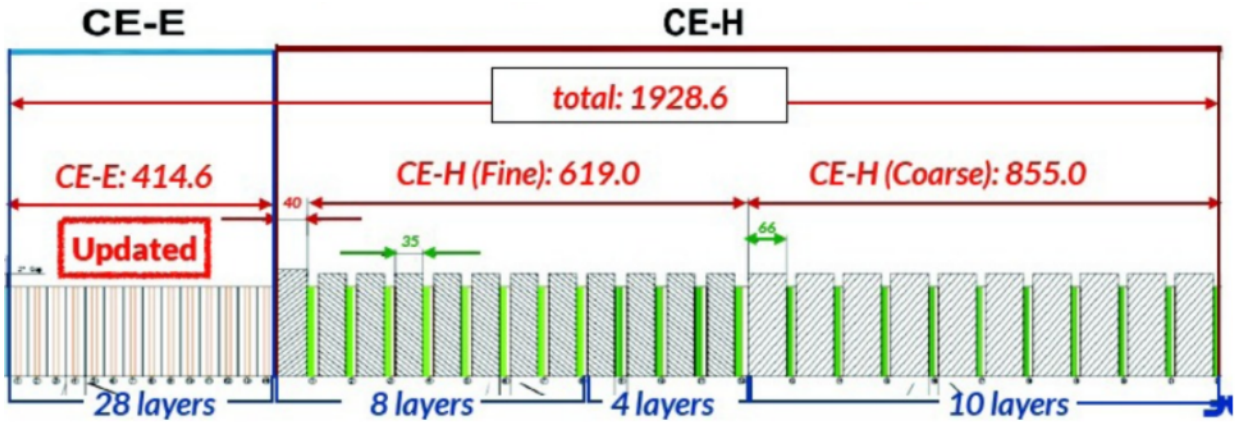


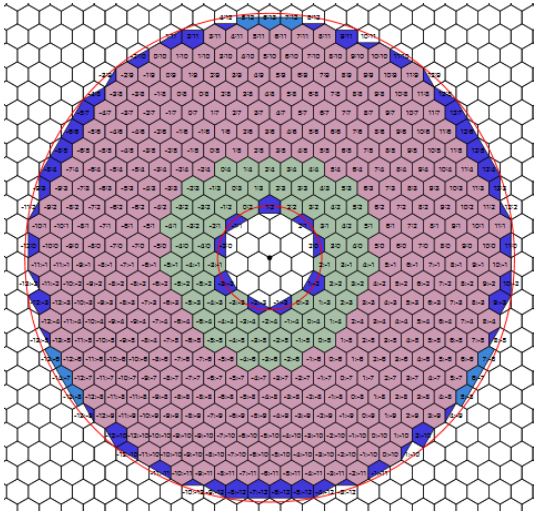
Support Beam

Layer 1 Mock-up



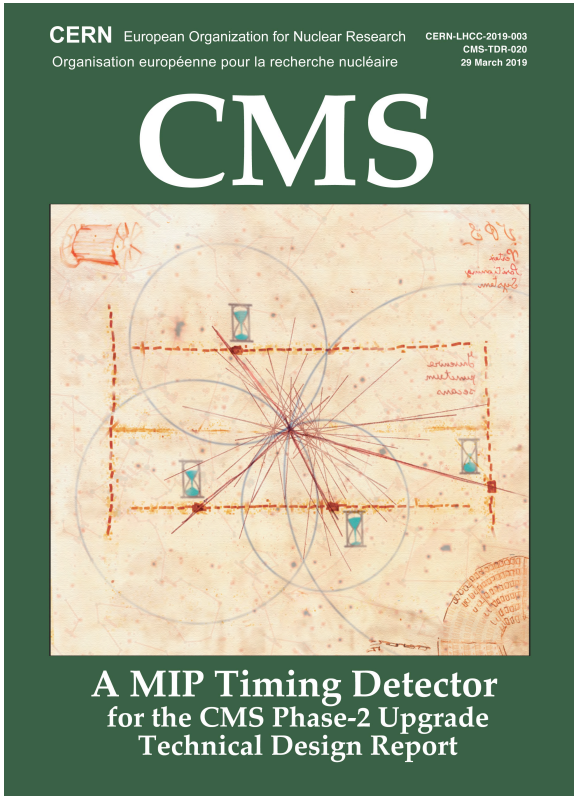
HGCAL: Simulation





We have a major role in the development of the HGCAL simulation and geometry updates
HGCAL longitudinal structure has recently been modified and the last 2 layers of the hadronic part have been dropped.
Changes in the longitudinal structure affects also radiation levels as a function of r-z
A new Fluka simulation is available and was used to recompute the division of 3 types of silicon wafers and also silicon-scintillator boundaries
Introduction of partial wafers in the simulation to provide more realistic coverage

MTD Technical Design Report



The LHCC has recommended the MTD project to proceed forward

The reviewers were enthusiastic about the well-motivated physics case for a CMS MIP timing detector with nearly hermetic coverage and time resolution of 30—50 ps

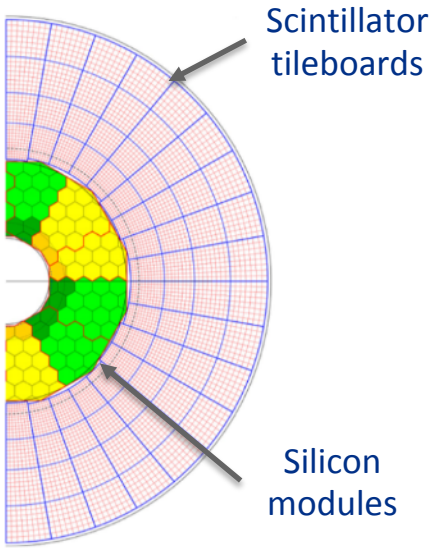
MTD brings pileup suppression benefits equivalent to an effective 2-3 years of luminosity
TOF-based particle ID adds new capabilities for HI physics and long-lived new particle searches.

LHCC was impressed with the team and noted in particular the "vibrant young physicists" working on a future-oriented detector, *many of whom are from the US*

Recent HGCAL achievements

Developed the all silicon prototype to evaluate thermal and mechanical properties

Now developing a mixed cassette (Silicon + Scintillator) mockup to study the mechanics in time for CD-1 review in October



Evaluation of: cooling plate, dummy tileboards, test of module assembly, module emulators, twinax assembly, wing board

HGCAL: Scintillator Module Production Status

Improve light tightness and uniform response across tiles

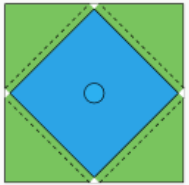


Figure 6: CALICE Style

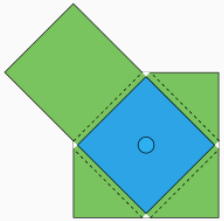


Figure 8: NIU Style

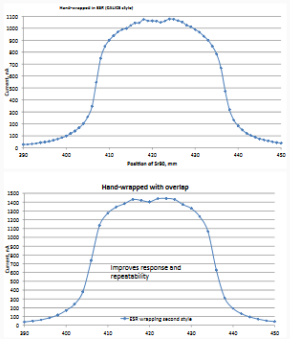
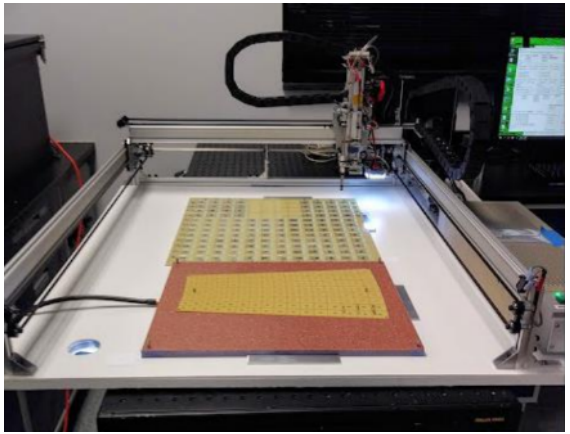


Figure 7: Response of CALICE style (Top) and NIU style (Bottom)

Test beam studies:

- Injection molded tiles vs cast
- Wrapped tiles
- Tile shape
- Performance of enhanced specular reflector (ESR) vs Tyvek wrapping
- Radiation damage



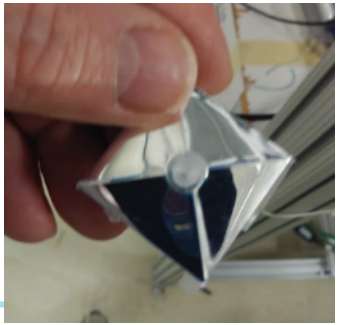
Pick and place gantry transfers scintillator tiles in assembly tray to the PCB

Able to place tiles with 0.1 mm alignment accuracy

Addition of wrapping will obscure the tile edges

Added vision part detection to the pick and place to improve placement and correct tile orientation

Tile wrapped with ESR



U.S. Focus Areas for HL-LHC Computing R&D


agreement at joint workshop with DOE/NSF at CUA in 2018

Focus Areas for HL-LHC R&D

C1	Data Analysis Systems
C2	Reconstruction and Trigger Algorithms
C3	Applications of Machine Learning
C4	Data Organization, Management and Access
C5	Simulation
C6	Storage infrastructure and Facilities
C7	Data Transfer and networking infrastructure
C8	Workflow and Resource management
C9	Event Processing Frameworks
C10	Data and Software Preservation
C11	Physics Generators
C12	Visualization
C13	Software Development, Deployment and Validation/Verification

…

S^2I^2 Focus Areas

(highest-priority areas for initial S2I2 investment)

Evolved by Blueprint Activity

12

Work Breakdown for HL-LHC Computing R&D

U.S. CMS HL-LHC deliverable	Computing Challenge	Computing Area of US Interest	Technologies and Paradigms	Connections, Stakeholders	Sources of Support
Tracker	pattern reco, pile-up, 4D tracking and vertexing	C2, C3	FPGAs, GPUs, optimized data structures	ATLAS, SciDAC RAPIDS, ORNL, IRIS-HEP,NSF	CompHEP, SciDAC (FNAL + ORNL), LDRD, HSF, NESAP
High-Granularity Calorimeter	fine granularity clustering, pile-up, complex geometries, particle flow	C2, C3, C5	GNN, VecCore, kokkos, RAJA	IRIS-HEP, ECP	LDRD, ECP
Trigger	event rates, pile-up, track trigger	C2, C3, C6	FPGAs, HLS4ML, Microsoft Azur Brainwave	ATLAS, DUNE, Accelerator Controls	LDRD
Data Analysis	DOMA, event throughput, optimizing algorithms and innov. approaches, usability, interactivity, data analysis facility	C1, C6, C7, C8, C9, C10, C11	Data Science eco-system, SPARK, Fermi-Striped, uproot, awkward arrays, aws	ATLAS, IRIS-HEP, NOvA, DUNE, ECP	CompHEP, ECP, IRIS-HEP, HSF, Intel, CERN Openlab

– Recent Fermilab/USCMS briefing to DOE demonstrated that initial DOE-funded computing R&D efforts already cover a large subset of the computing areas of interest to U.S. CMS, and showed the connections with existing projects and non-LHC stakeholders

Support for Experiment Operations

- Last year, CMS lost a key operations person to Mu2e, and we need to replace this Application Physicist position between Operations and Research
  - this person is sorely missed in day-by-day operations and Run Coordination, in keeping the link with Fermilab and US CMS operations management (“boots on the ground” and “eyes and ears” at CERN)
  - recent safety incidents and the large amount of on-the-ground work required (HCAL, EMU, Pixels, installation dn commissioning etc) demonstrate the need for such a US person, to keep the close link with the USCMS host lab and address risks and protect investments
  - USCMS has identified funds to support this personnel cost — high-priority item in USCMS spending plan — but partial support from Research is needed, and we need to get around the Fermilab hiring freeze
  - USCMS and Fermilab to work together towards sufficient support of detector operations, including to allocate sufficient travel support, e.g. for stays of postdocs involved in CMS operations at CERN — this is in the current plan for the CMS group at Fermilab and in the USCMS spending plan