Status of the CMS Experiment

Sergo Jindariani

(on behalf of the Fermilab CMS group)

Fermilab PAC meeting, December 2020

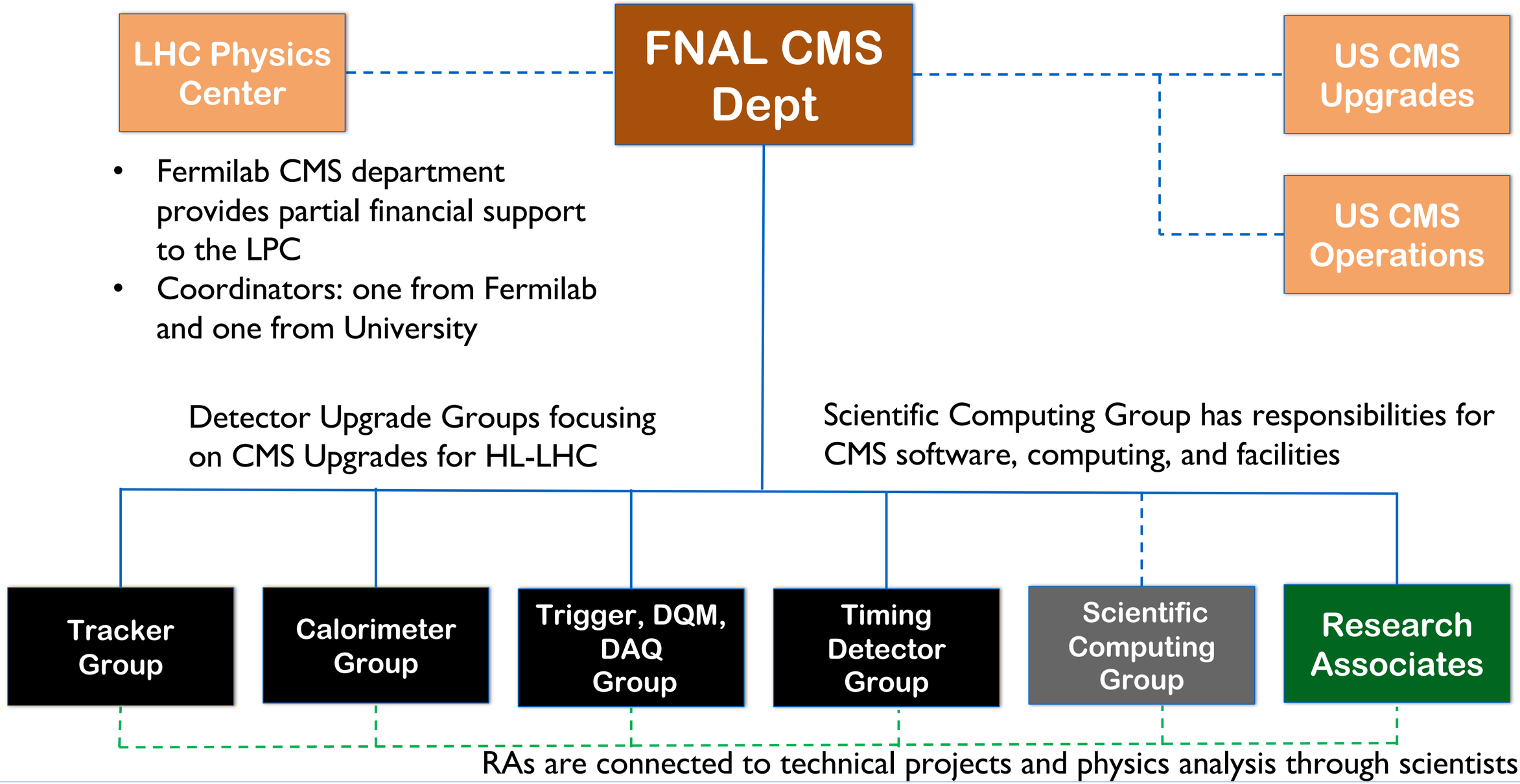
Outline

- Overview of the Fermilab CMS Department
- Physics highlights from the group
- The group's responsibilities in Upgrades and S&C
- Status of the recommendations made in January and July
  - Succession Planning
  - LHC Physics Center (LPC)
  - HPC centers
- Summary and Conclusions

CMS Group at Fermilab

- The Fermilab group consists of 37 Scientists and 17 Research Associates
- Committed to and plays a leading role in data analysis, detector upgrades, computing, SW R&D and maintenance, and operations
- Collaboration leadership roles:
  - Patty McBride (deputy spokesperson 2018-2020)
  - Boaz Klima (publication committee Chair 2018-current)
  - 13 managers in CMS and 28 in USCMS in Physics, Upgrades and Computing organizations
- Fermilab is the host laboratory for USCMS:
  - Manages USCMS Ops Program (Lothar Bauerdick)
  - Manages HL-LHC Upgrade (Steve Nahn)
  - Hosts the LHC Physics Center (Sergo Jindariani)
  - Hosts the US Tier-1 (the largest of all CMS Tier-1s)

CMS Group at Fermilab



- Fermilab CMS department provides partial financial support to the LPC
- Coordinators: one from Fermilab and one from University

Detector Upgrade Groups focusing on CMS Upgrades for HL-LHC

Scientific Computing Group has responsibilities for CMS software, computing, and facilities

RAs are connected to technical projects and physics analysis through scientists

Awards and Recognition since July

APS Fellow: Kevin Burkett

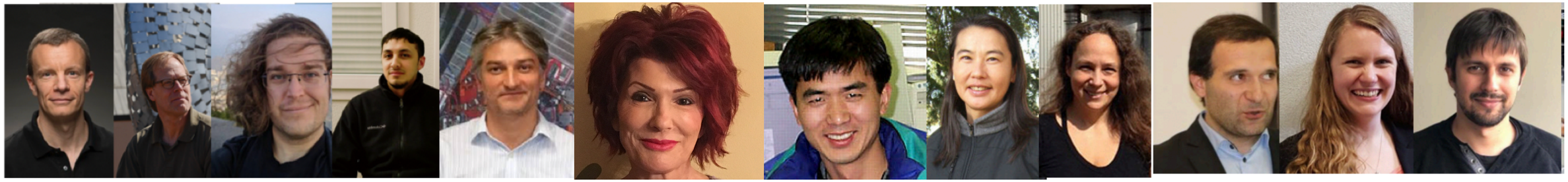
DOE Project Management Achievement Award: Steve Nahn

CMS Young Researcher Prize: Lindsey Gray

CMS Achievements Award: Chris Madrid *(as a student at Baylor, now RA with FNAL)*

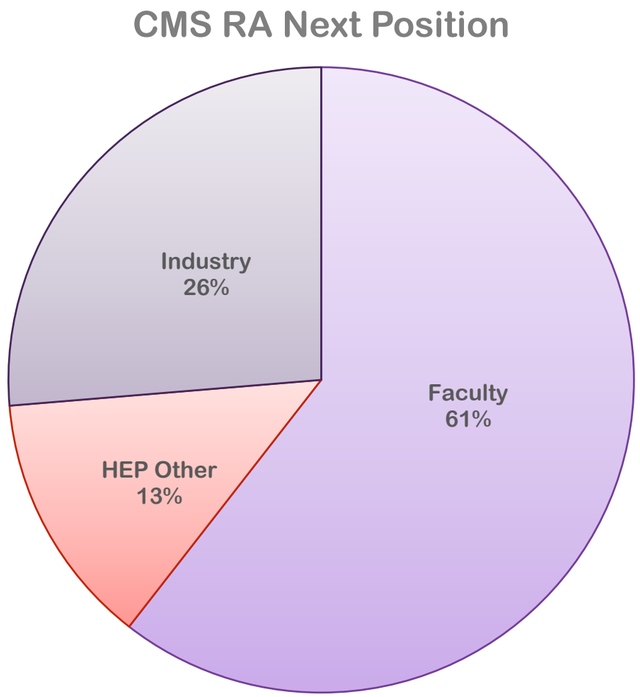
Exceptional Performance Recognition Award: Zoltan Gecse, Terry Grozis, Ted Liu, Kaori Maeshima, Petra Merkel

LHC Physics Center Distinguished Researchers: Aram Apyan, Allie Hall, Fabio Ravera



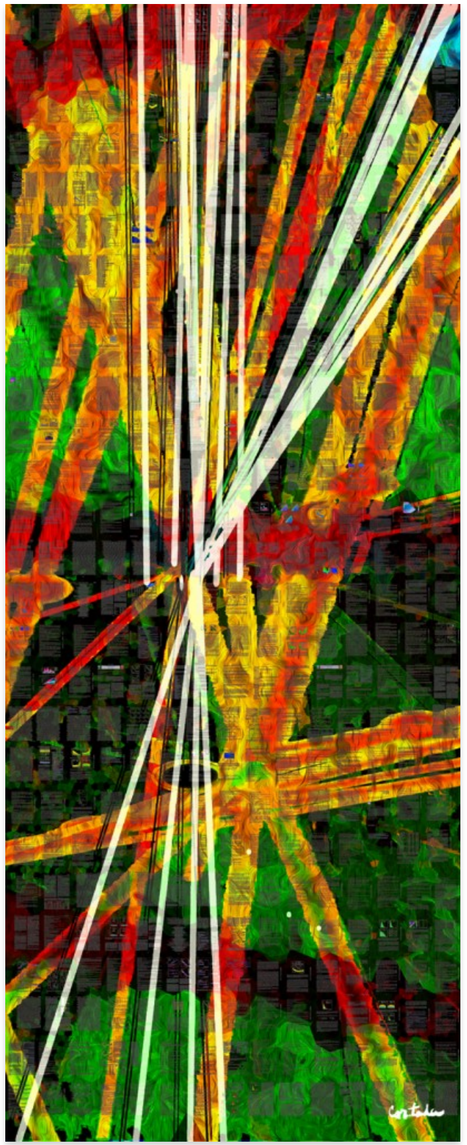
Fermilab CMS Postdoc Placement

- Majority of CMS department postdocs have found faculty positions
  - Since 2005, 38 RAs have completed their postdoctoral research on CMS
  - 23 found a tenure track position in HEP at a university (15) or lab (8): 61%
    - ★ Compared to 20% of physics postdocs (APS)
  - 5 went on to a second postdoc or other position in HEP (one had that goal): 13%
  - 10 got a job in private industry: 26%
    - ★ Half of those in data science



- Recent examples:
  - Caterina Vernieri: Phase 2 Pixels & boosted H→bb (6 interviews, accepted Panofsky Fellowship in 2018)
  - Nadja Strobbe: SUSY and HCAL (2 interviews, accepted assistant professor position at Minnesota in 2019)
  - Mia Liu: SUSY/SMP, FPIX/ML (7 interviews, accepted assistant professor position at Purdue in 2020)
  - Ben Kreis: Higgs/LLP, Trigger (data scientist at Apple)

Physics Highlights



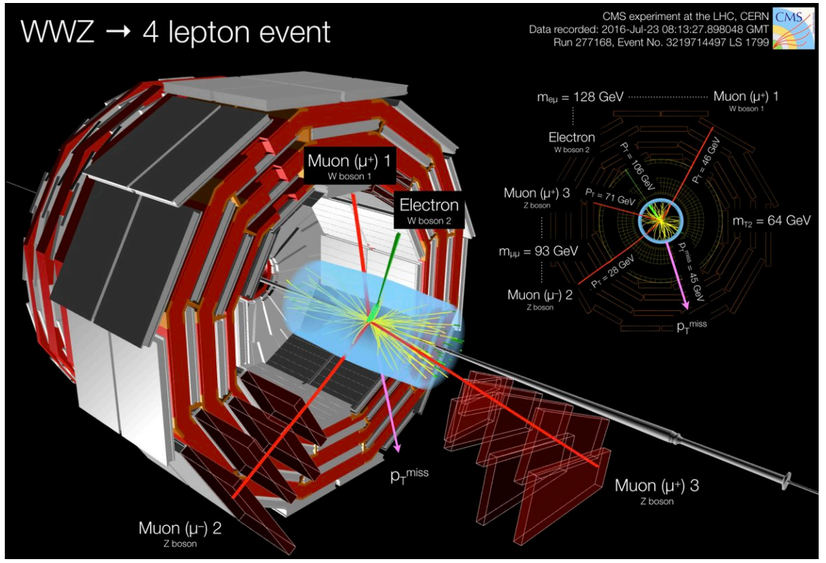
Physics Priorities

- Aligned with Particle Physics Project Prioritization Panel (P5) science drivers:
  - Use the Higgs boson as a new tool for discovery
  - Pursue the physics associated with neutrino mass
  - Identify the new physics for dark matter
  - Understand cosmic acceleration
  - Explore the unknown

- Fermilab CMS groups physics efforts are focused on addressing P5 science drivers (shown in blue above)
- A balanced, prioritized portfolio of classic analyses and new ideas (examples on the next few slides)
- Physics subgroup convenerships held by group members (Mantilla Suarez in Higgs, Apyan in Standard Model, Herwig in SUSY, DiPetrillo in Exotica, Cremonesi in JetMet)

The story of 1000th paper

- CMS submitted 1000th paper on June 19th 2020
- Fermilab scientists are working closely with LPC collaborators on Physics Analysis
- The 1000th paper (Observation of VVV production) is a prime example of the such synergy
  - Collaborative effort of Fermilab, UCSD, Caltech, Northwestern, LLR
  - From FNAL: Jindariani (scientist), Weber, Liu, DiPetrillo (RAs)
  - 3 LPC Distinguished Researchers and 1 LPC Graduate Scholar among the leading contributors
  - Working together on this topic since 2016
  - Observation PRL selected as Editor's Suggestions



Event display of a 4-lepton event from the 1000th paper: Observation of VVV production

Featured in Physics | Editors' Suggestion | Open Access

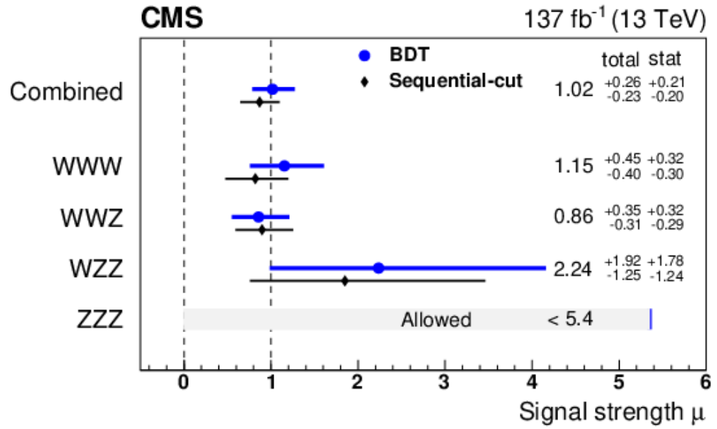
Observation of the Production of Three Massive Gauge Bosons at $\sqrt{s} = 13$ TeV

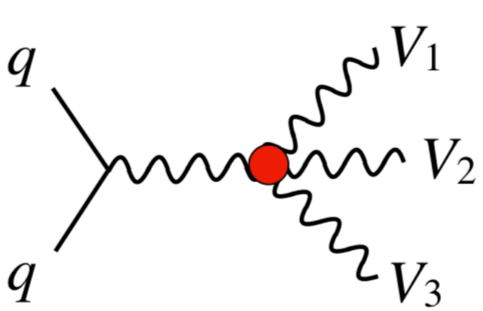
A. M. Sirunyan *et al.* (CMS Collaboration)
Phys. Rev. Lett. **125**, 151802 – Published 5 October 2020

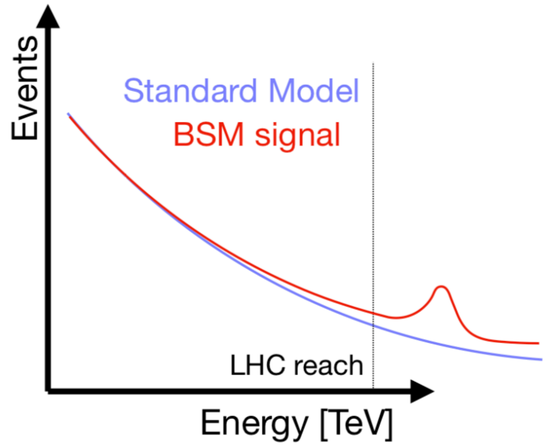
Physics See synopsis: Hat Trick Observation for Bosons

Examples of “Classic” Analyses

VVV: From SM observation to BSM probe:

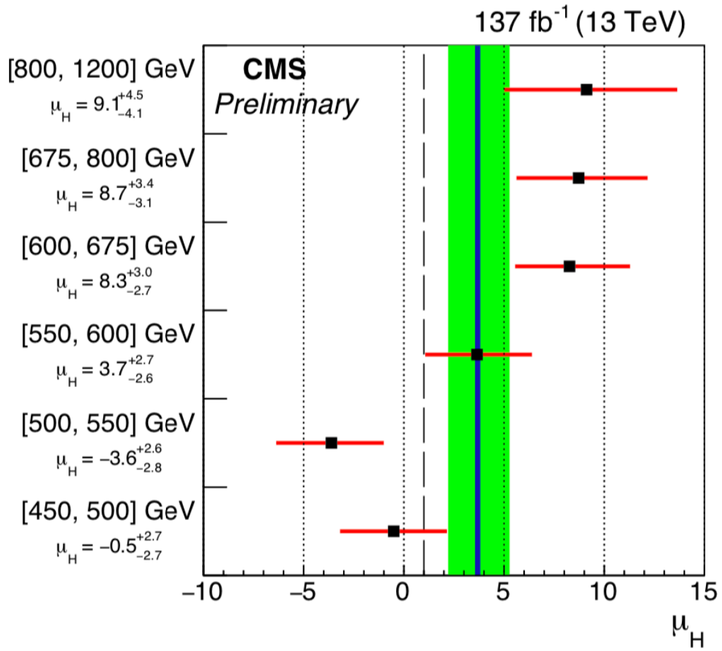






- Include semi-leptonic (and hadronic?) final states
- Both model-specific and EFT approaches
- Work ongoing, targeting a publication in 2021

Inclusive H→bb: Observed significance: 2.5σ



Intriguing excess at high pT

With JHU, MIT, Brown, Aachen and more

Innovative analysis with many breakthrough reconstruction techniques

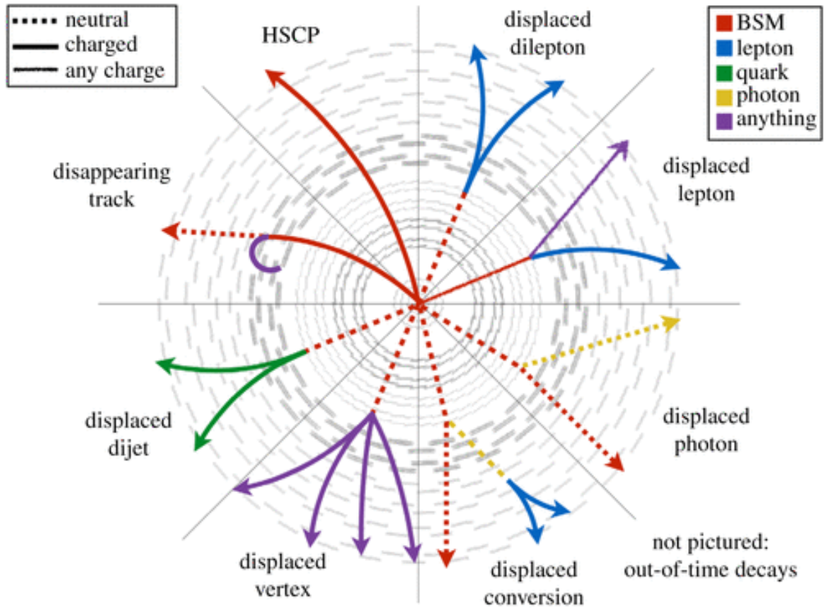
Future directions:

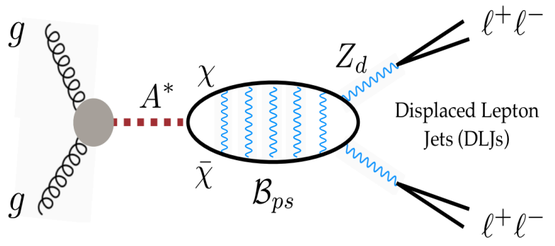
- VBF and VH tagged boosted H→bb
- Semi-leptonic H→WW
- H→cc (Higgs-charm coupling)
- Di-Higgs

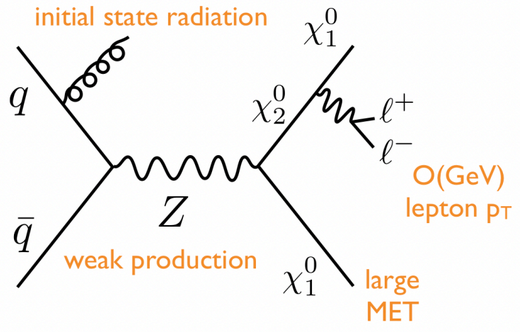
New Directions : Long-Lived particles

Comprehensive program using innovative reconstruction

- Z+displaced jets (Tracker):
  - Fermilab and FSU, Targeting Moriond 2021
- Showers in Muon System
  - New experimental signature
  - Fermilab, Caltech, Hamburg, UCSB, Targeting Moriond 2021
- Delayed Trackless Jets in Calorimeters
  - Fermilab, Caltech, Hamburg, Summer 2021
- Delayed photons in ECAL
  - Improved displaced photon ID
  - Fermilab and Caltech, Run-2 Legacy result in late 2021
- Collimated leptons from dark photon decays
  - Custom reconstruction techniques
  - Fermilab, Cornell, UC Riverside, Nebraska, Moriond 2021
- Soft and displaced dileptons
  - Arises in Higgsino scenarios
  - Fermilab, CERN, Athens, Late 2021





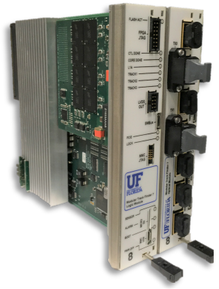


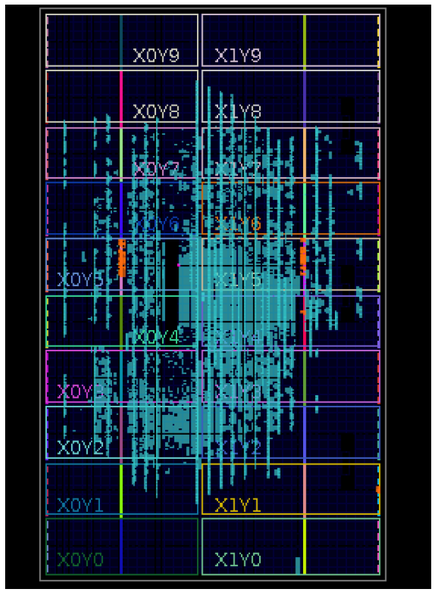
LLP physics is synergistic with our hardware interests

An LLP-aware detector

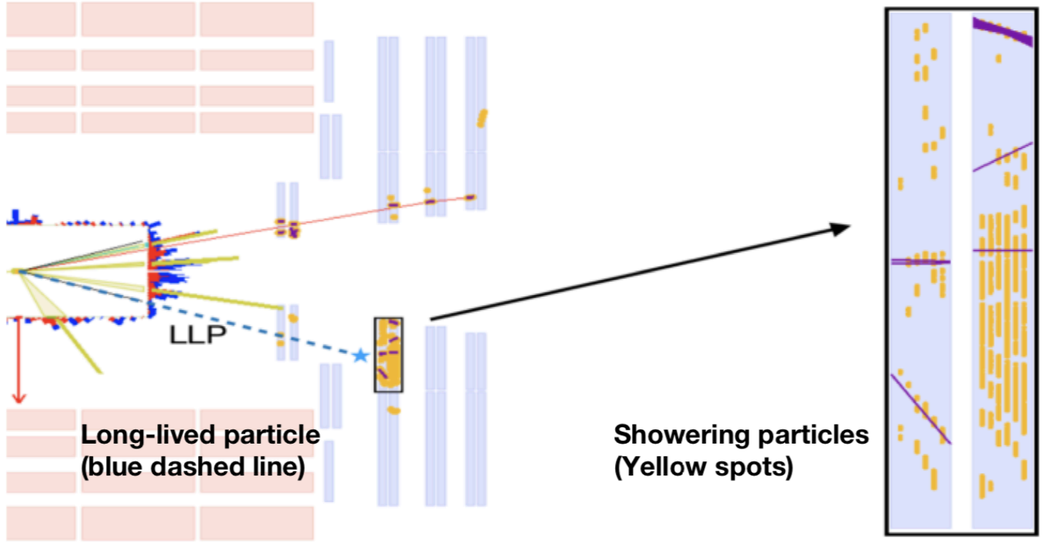
- LLP Triggers for Run-3 and HL-LHC: upgrades towards an LLP-aware detector
  - Displaced Standalone L1 Muons in the Endcap
  - Muon System (CSC) LLP-Shower L1 Trigger (30x better acceptance) – Run3
  - Delayed Jets using ECAL Timing at L1 (10x better acceptance) – HL-LHC
  - Fermilab, Caltech, Rice, Florida

Implementation of displaced muon reconstruction using a Neural Network in Virtex-7 FPGA using MTF-7 boards





Showers in the CMS Endcap Muon system produced by an LLP decay



New Directions : Dark QCD

With many collaborators

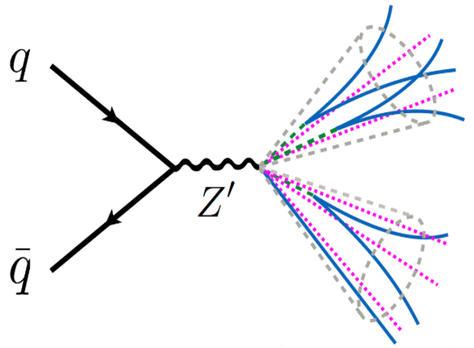
- Strongly-coupled hidden sector ("Dark QCD") produces hadron-like dark matter → interesting alternative to standard WIMPs, etc.
- Gaps in LHC coverage:

Semi-visible jets: Most existing collider dark matter searches ignore events with jets aligned with missing energy → unexplored signature in existing data

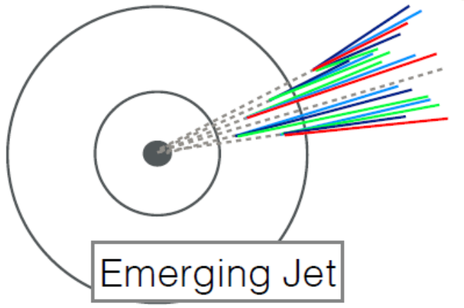
Semi-visible jets don't occur in standard model → distinct from tagging e.g. top quarks or Higgs bosons

SUEPs aka “soft-bombs”: large multiplicity of soft particles, spherical event shape. Assumed impossible with current LHC triggers

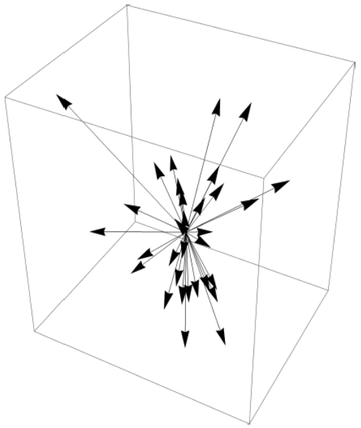
Expect first sensitivity! with potential to improve triggers and analysis strategy in Run 3 and beyond



Semi-visible jets (*s*-channel)
(finalizing the interpretation)



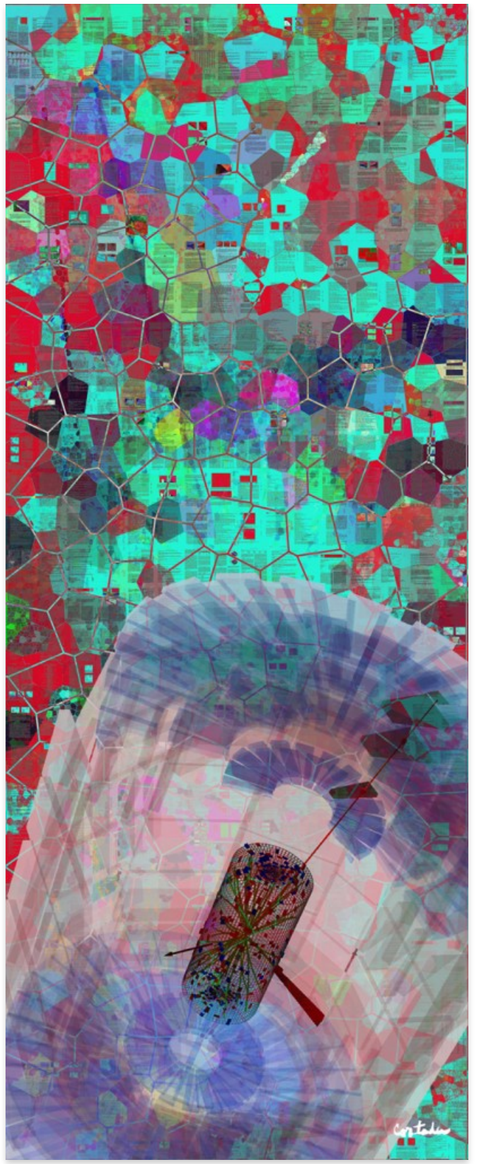
Emerging jets
(full Run 2 update ongoing)



Soft Unclustered Energy Patterns (SUEPs)
(newly started analysis)

Phase-2 Upgrades

Recent indicates progress made since ~time of the last PAC meeting in July



Phase-2 Upgrades Scope

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 $|\eta| < 3.0$

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

Beam Radiation and Luminosity, Common Systems, Infrastructure

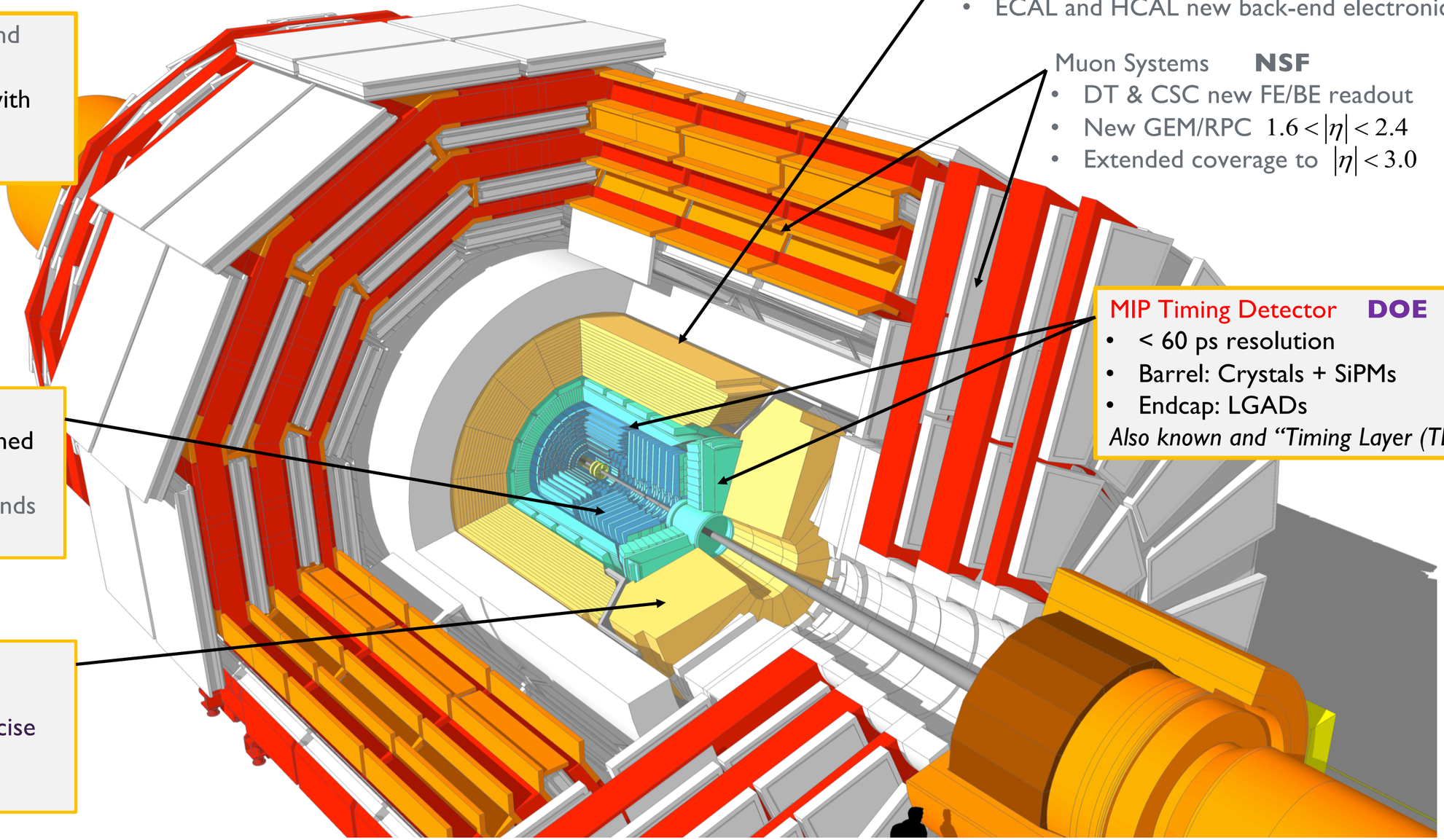
MIP Timing Detector **DOE**
- < 60 ps resolution
- Barrel: Crystals + SiPMs
- Endcap: LGADs

Also known and "Timing Layer (TL)

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

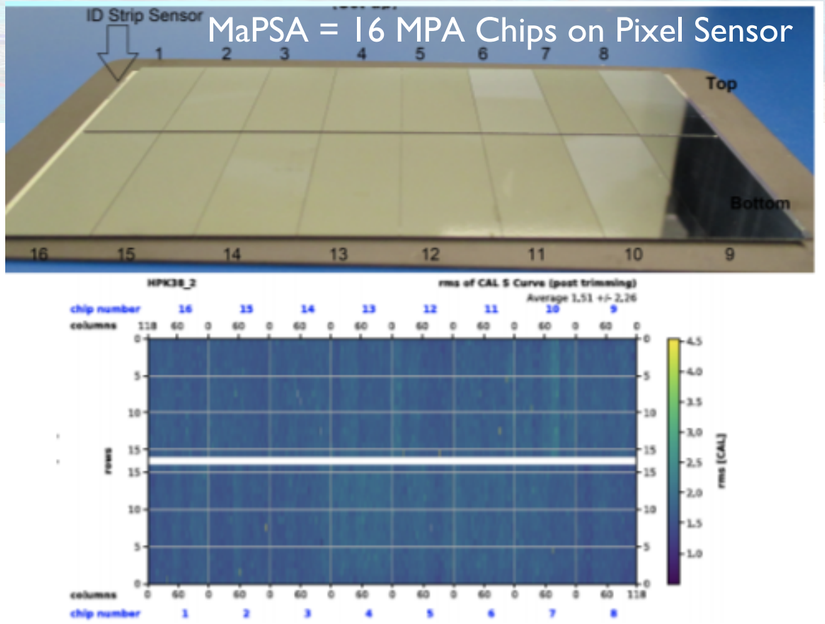
Calorimeter Endcap **DOE**
- Si, Scint + SiPM in Pb-W-SS
- 3D shower imaging with precise timing

Also known as HGCal



Outer Tracker

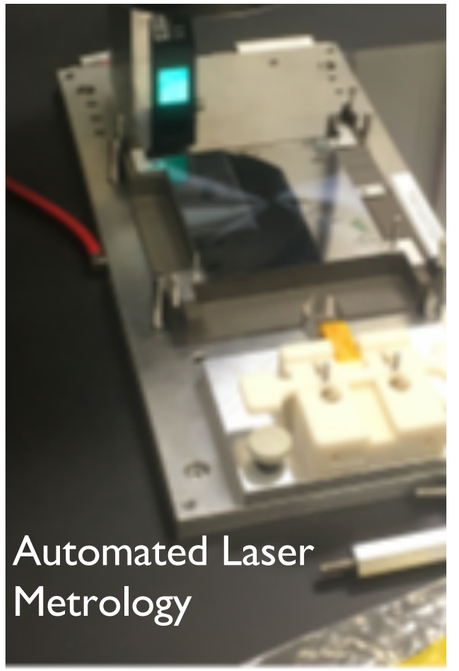
Scientists: Nahn, Berry, Canepa, Lipton, Merkel, Mills, Murat, Spiegel, Uplegger
Ras: Ravera, Weber, *Horyn, Dickinson (new)*

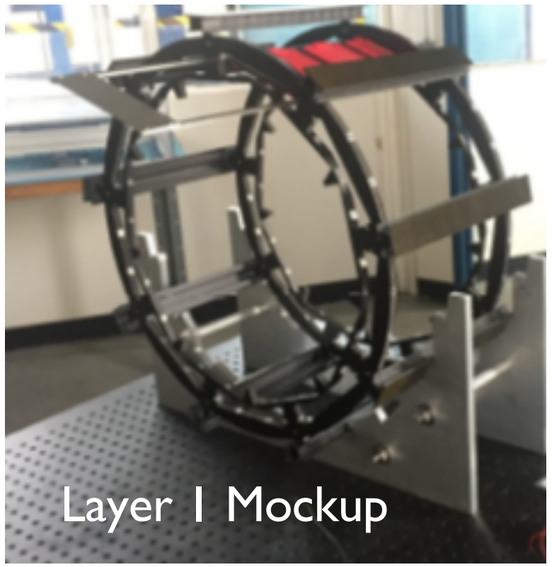


- US Deliverables (Fermilab deliverables)
  - Assemble 4500 Silicon Modules, ½ done at Fermilab
  - Mount 1000 Modules onto Carbon Fiber Structure which comprises central section of inner 3 layers of CMS Tracker
  - deliver all 6400 MAPSAs (vendor selection and qualification, testing, distribution)

- Key FNAL Resources
  - Labor: Microfabrication and Specialized material expertise, Scientific Oversight and QC
  - Facilities: SiDet, Irradiation Test Area, Test Beam, Carbon-Fiber fabrication

- **Recent** Accomplishments
  - MaPSA prototyping well underway
  - Semi-Automization of Module Assembly
  - Module QC Apparatus complete
  - Assembly of full-size mockup of central section


Automated Laser Metrology


Layer 1 Mockup

Endcap Calorimeter

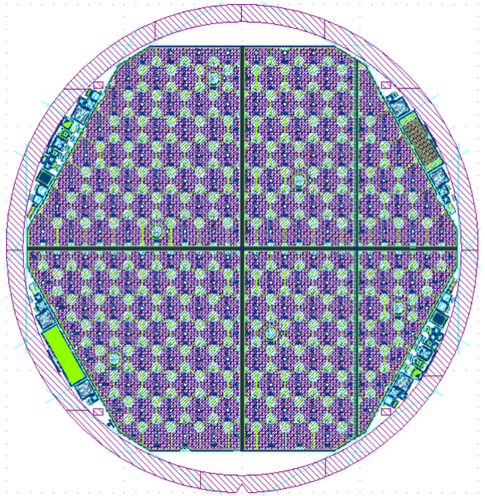
Scientists: Cheung, Alyari, Banerjee, Freeman, Gecse, Hirschauer, Joshi, Lincoln, Lipton, Rubinov, Strait

RAs: Apyan, Mantilla Suarez (new)

- Deliverables (Fermilab deliverables)
  - Assemble 13,500 Silicon modules and 1404 Tile Modules
  - Assemble 550 Cassettes
  - Design/Fabricate Concentrator ASIC for on-detector data handling (so called ECON)

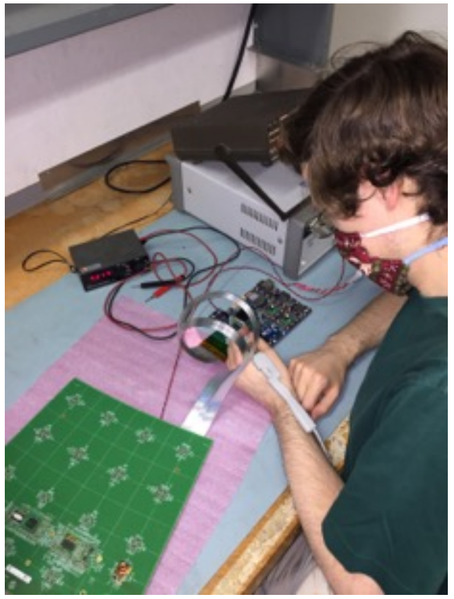
- Key FNAL Resources
  - Labor: ASIC Engineering, Scientific oversight and QC
  - Facilities: SiDet, Lab 6, Irradiation Test Area

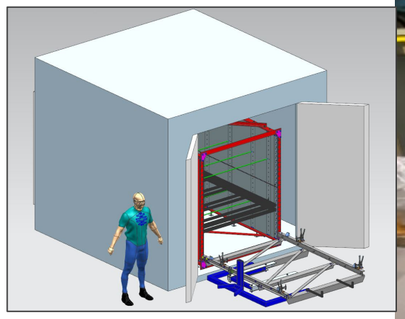
- **Recent** Accomplishments:
  - Completed design for low density multi-geometry Silicon sensor mask, finalizing high density one
  - Completed and tested prototyping cassette cooling rack and lifting platform
  - Created test stand for testing scintillator tile module PCB that can be operated remotely
  - ECON-T went through a few design reviews, changes to address comments and integrated fixed/updated lpGBT block, integrated new ASIC engineers in the team, still finalizing layout for submission (probably February 2021).



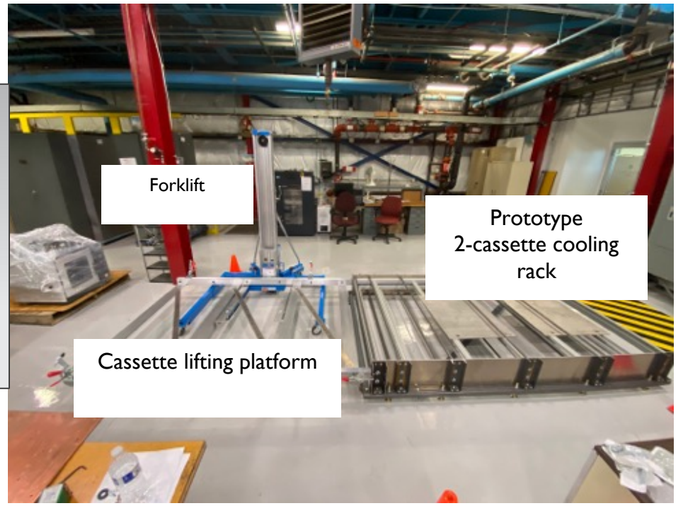
LD multi-geometry sensor design

Setting up remote Tile Module test stand/cosmic ray testing (LPC PD/Students)





Full-size cooling rack and cold room design

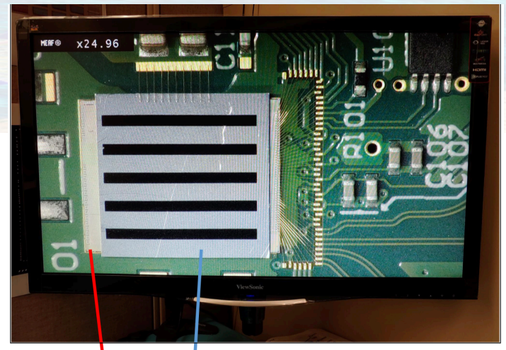


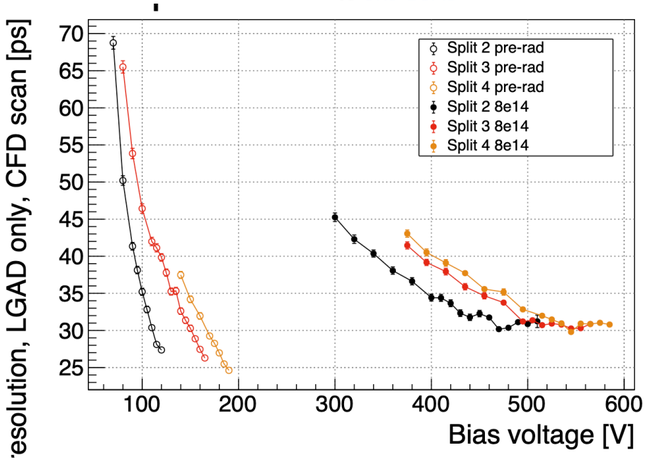
MIP Timing Detector

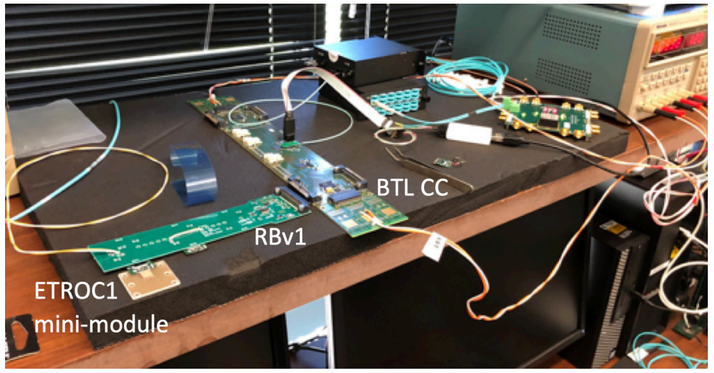
Scientists: Bauerdick, Apresyan, Butler, Chlebana, Gray, Liu, Ristori, Tkaczyk
RAs: DiPetrillo, Heller, *Madrid (new)*

- Deliverables (Fermilab deliverables)
  - Barrel Timing Layer (BTL)
    - ★ Assemble all 432 Concentrator Cards
    - ★ Assemble 6000 Readout Modules to populate 45 trays
  - Endcap Timing Layer (ETL)
    - ★ Assemble 4700 Endcap Modules, Develop the design of ETL modules, and assemble 1/2 of modules
    - ★ Develop and Fabricate Endcap Readout ASIC
- Key FNAL Resources
  - Labor: ASIC (ETROC) engineering, Microfabrication expertise, Scientific oversight and QC
  - Facilities: SiDet, Test Beam, Irradiation Test Area

- **Recent** Accomplishments
  - ETROC1 successfully tested, ETROC2 design has major progress
  - LGAD sensor design and detailed characterization with β-source in SiDet: latest production meets HL-LHC rad-tolerance and timing requirements
  - Electrical tests of ETROC1- based modules proceeding, first end-to-end system tests
  - Module assembly facility at SiDet is being commissioned, based on gantry







Also a lot of generic R&D work (see backup)

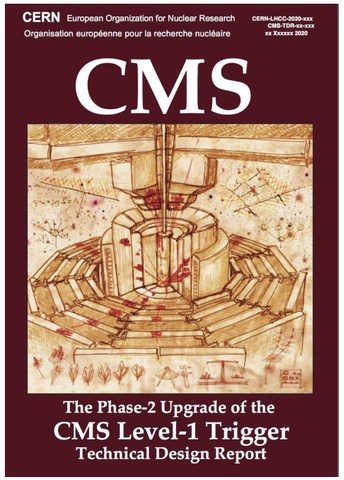
Trigger/DAQ

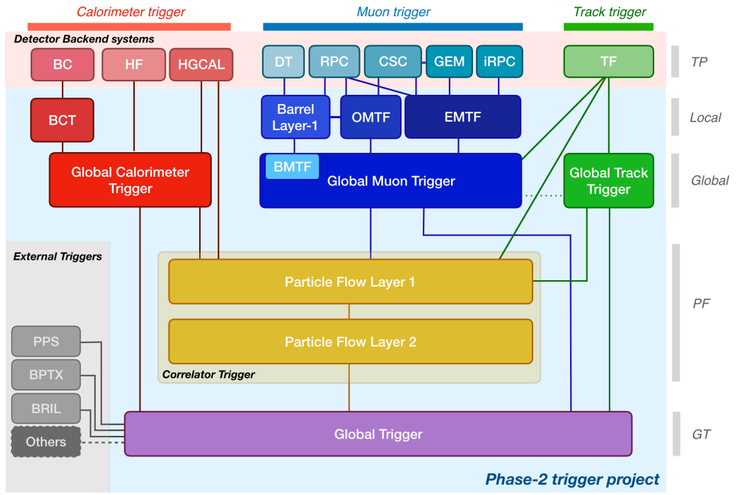
Scientists: Berryhill, Cavanaugh, Jindariani, Tran
RAs: Herwig

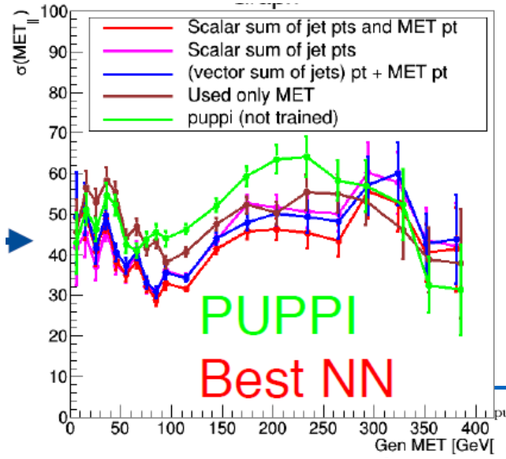
- Deliverables (Fermilab deliverables)
  - Develop hard/firm/soft -ware algorithms for Calorimeter Trigger and Correlator Trigger
    - ATCA platform, latest 25 Gbps architecture and FPGAs
  - Procure and Deploy Data Logger
    - Commodity procurement at the end of the project

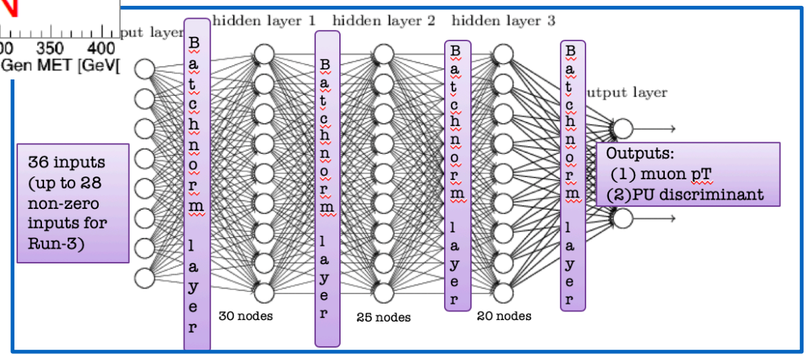
- Key FNAL Resources
  - Labor: FPGA engineering, Scientific oversight and algorithm development/testing

- **Recent** Accomplishments
  - Completed prototype firmware for particle flow, with successful hardware demonstration
  - Successful technical review of the firmware for prompt and displaced muon reconstruction in the endcap
  - Developed algorithm of an ML-based missing energy trigger







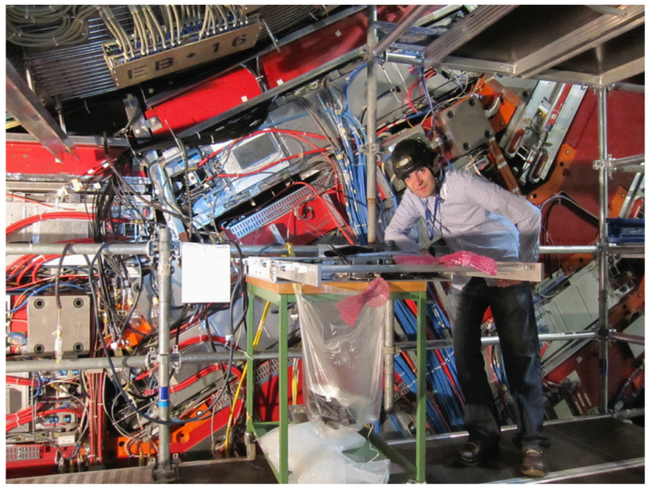


Detector Operations

- Data Quality Monitoring;
  - Kaori Maeshima renewed term as CMS DQM co-convener
  - DQM development, operations, and data certification (DC)
  - All of Run 2 Legacy Data Certification completed
  - Several successful global run exercises at Point 5 this summer and fall: fully remote shifters, new DQM GUI, ML-supported DQM, smooth operation throughout

New Online DQM GUI (beta version: online)

- HCAL Operation:
  - Aram Apyan operations co-coordinator in 2018
    - ★ Responsible for all aspects of HCAL operations
    - ★ achieved 99+% good quality data
  - Overall, very good performance of the Phase-1 upgraded HCAL detector



Software and Computing

International CMS Org Chart

Offline Software and Computing - September 1st, 2020

Coordinators
D. Piparo, J. Letts

Core Software
S. Muzaffar, M. Kortelainen

Computing Operations
C. Paus, N. Smith

Dyn. Res. Provisioning
D. Spiga, C. Wissing

Facility Services
G. Bagliesi, S. Lammel

Simulation
V. Ivantchenko, S. Bein

Workload/Data Mgt Devel
K. Lannon, K. Ellis

Reconstruction
S. Krutelyov, J. Pata

Resource Management
J. Flix, D. Lange

Monitoring & Analytics
V. Kuznetsov, F. Legger

Offline Release Planning
S. Donato, Q. Li

Upgrade Software
[K. Pedro]

Submission Infra
A. Perez-Calero, M. Mascheroni

Analysis Infra & Support
S. Belforte, S. Malik, M. Tonjes

Upgrade R&D and T
M. Girone, D. Elvira

Web Services & Security
A. Pfeiffer, TBD

Generators *
A. Grosjean, G. Chahal

L1 Software **
V. Rekovic

DPOA ***
K. Lassila-Perini, E. Carrera

Machine Learning *
J.R. Vlimant, G. Kasieczka

Computing Resources Board
J. Hernandez, K. Bloom

* Joint with Physics / ** Joint with L1 DPG / *** Joint with CB Mandates here

USCMS S&C:
Dave Mason is L2 for facilities
Saba Sehrish is L2 for Software
Tanya Levshinka is L2 for Operations
Margaret Votava is Deputy S&C ops program manager
Oliver Gutsche is S&C ops program manager

Software and Computing

accomplishments in 2020

- Rucio Transition:
  - Successfully retired the old data management solution PhEDEx and **transitioned to the community solution Rucio**

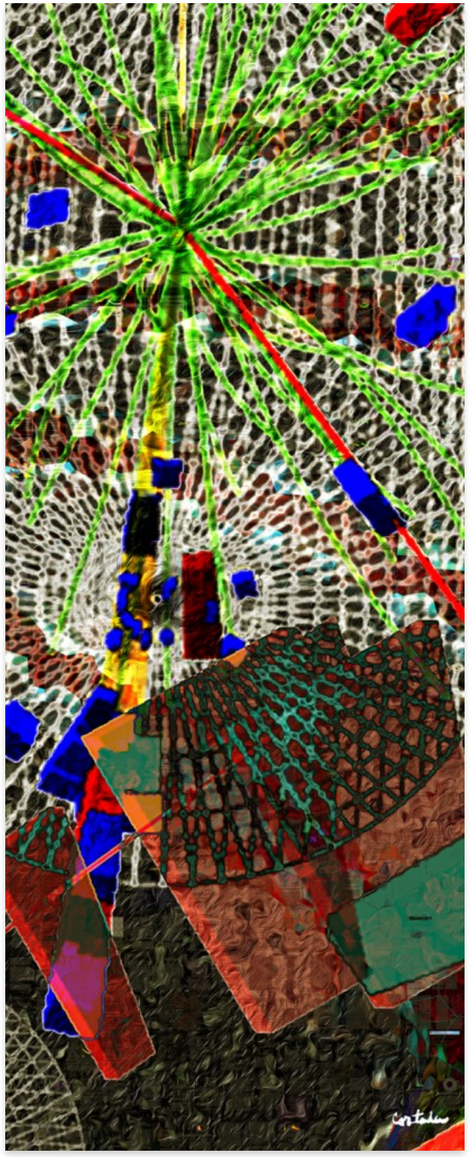
- HEP-CCE: enabling experiments to efficiently use DOE HPC machines, progress on two projects:
  - Portable Parallelization Solutions (PPS) **ported three use cases (one from ATLAS, CMS and DUNE) to first technology that allows simultaneous execution on CPU and accelerators.**
  - I/O solutions **wrote benchmark application simulating I/O patterns of experiment workflows** to study scaling behavior

- Tracking algorithms on GPUs
  - Speeding up Particle Track Reconstruction using a **Parallel Kalman Filter Algorithm**, JINST 15 P09030,
  - **Ongoing mkFit algorithm integration in CMSSW** for Run 3

- Artificial Intelligence
  - ML inference as a service (SONIC) in official CMS software; **performance (latency decrease) demonstrated in real HLT workflows using Nvidia Triton for GPUs** (https://arxiv.org/abs/2007.10359) and custom server for FPGAs (https://arxiv.org/abs/2010.08556)
  - First results from summer interns **using ML denoising to improve faster, lower-quality detector simulations** - FNAL leading CMS ML4Sim working group

Succession Planning

Recommendation: We recommend the Laboratory, in coordination with DOE, to support the request to hire an Associate Scientist and Senior Scientist dedicated to supporting the HL-LHC activities



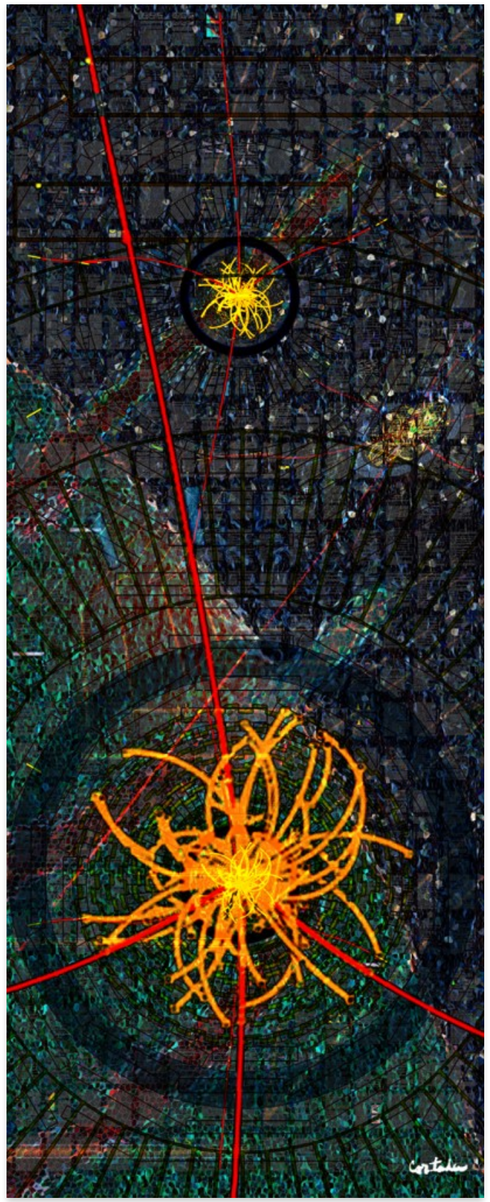
Succession Planning

- The department continues to execute the succession plan presented over the past years while adapting the strategy to new circumstances
  - Hired two associate scientists in 2019 (Phase 2 tracker upgrade, Software and Computing)
  - Searching for associate scientist with focus on the Phase 2 tracker upgrade and detector R&D for future colliders (*to mitigate the impact of 6 of 8 members of the tracker group acquiring additional responsibilities, moving on, retiring*)
  - Seeking a senior scientist who would help coordinating the Phase 2 activities at the lab
  - Planning to open a position for associate scientist to work on Phase 2 upgrades in the next FY (*needs in the tracker and MIP timing detector groups*)

- Including RAs, the number of FTEs continues to decrease despite the recent hires
  - This has resulted in decreased presence in detector operations and partially physics analysis
  - Down by 10 FTEs with respect to the last DOE Comparative Review in 2015
  - Further reductions will jeopardize the FNAL upgrade deliverables
  - Continued support to scientists and RAs through a healthy research program is essential to the execution and success of the CMS program at the laboratory and internationally

LHC Physics Center (LPC)

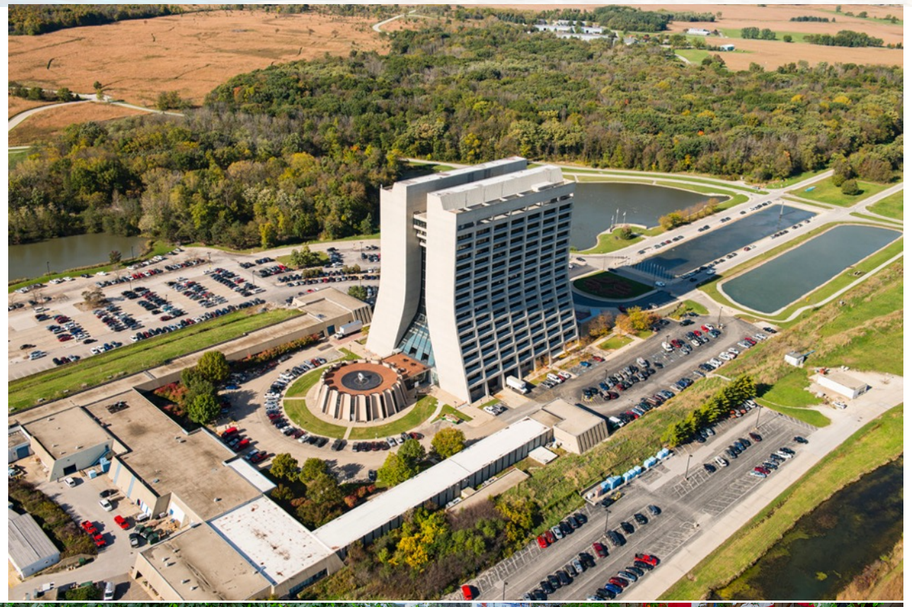
Recommendation: The PAC recommends the Laboratory coordinate with DOE to provide the necessary level of support for LPC activities, and strongly endorses the request for additional funding for dedicated Snowmass activities and to strengthen their efforts in ML/AI related projects



Fermilab's LHC Physics Center

- A regional center for excellence in CMS. Established in 2004 – 16 years in the making
- Serves as a critical link for remote physicists to participate directly in the CMS experiment
- Funded by the DOE, the USCMS Operations Program and the Fermilab CMS Department

- The LPC offers access to resources:
  - Outstanding computing & software and computing support
  - Engineering staff, hardware experts, laboratory space
  - Remote operations center
  - Education
  - Theory department
  - Seminars and workshops
  - Office and Meeting Space
  - Administrative Support
- A vibrant intellectual community

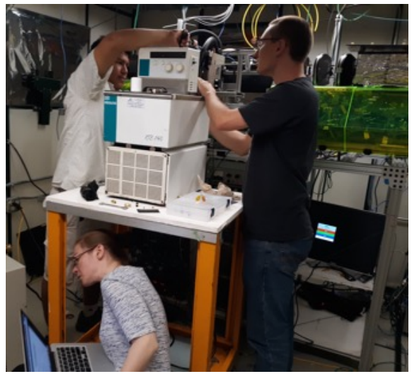


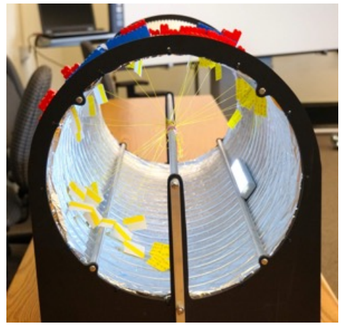
Participants of the Data Analysis School hosted by the LPC in 2020

LPC at Work

More than 90% of USCMS institutions have members affiliated with the LPC

- More than 500 users and 150 residents
- 900 CMS collaborators use the LPC computing cluster for data processing and analysis
- Nearly 800 people participate in LPC-organized workshop and events, fostering interactions with theorists and non-CMS members





- The LPC is significantly involved in all major areas of physics analysis
- Nearly 30% of the papers published in the last two years have majority (> 50%) of analyzers affiliated with the Fermilab LPC
- The Distinguished Researcher (DR) program plays central role in the success of LPC

Adjusting to COVID

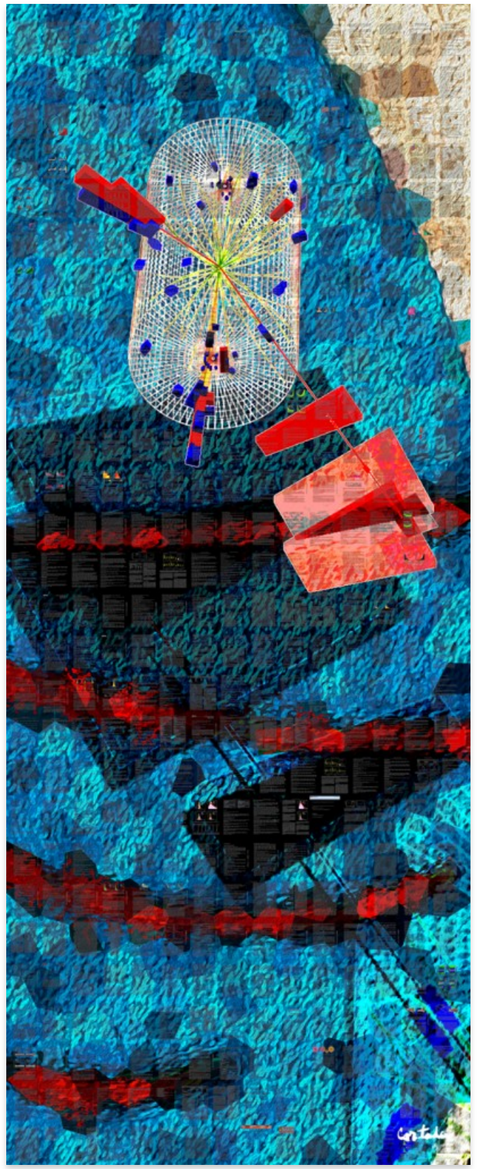
- The LPC continues to operate most of its regular events in the virtual mode:
  - Topic of the Week, Physics Forum, Physics Discussion Groups, Journal Club and DR Office Hours now take place over Vidyo/Zoom with very good attendance (regularly 50+ participants).
  - In FY20: 7 workshops, 13 TOTW, 15 Physics Forums, 3 Coffee Hours.
- Awarded 15 DR's in 2021 (12 junior, 3 seniors). All required to present a credible program in case lab access remains restricted.
- G&V program is now accepting applications on the rolling basis, quick turnaround for users who need to be onsite to do essential work
- In 2020, the center hosted 16 remote Summer HATS + 3 offline HATS
  - On average 50 participants per HATS (in 2019 we had 25)
  - All HATS are being recorded and will be posted online. Offline help offered.
- Many CMS results released in 2020 are led by the LPC users (VVV observation, boosted Higgs, LLPs, etc)
  - LPC computing resources (both CPU and storage) continue to be in high demand
- New "Particle Physics Instrumentation" 2-semester course offered in Fall'20-Spring'21. Taught by Roger Rusack (Minnesota, LPC DR)
- Record students in CMSDAS in the last 3 years. Accepting registration for 2021 LPC CMSDAS (fully remote)
  - Build on experience and lessons learned from past schools and from CMSDAS@CERN in September 2020

LPC funding

- Annual plan for FY2021 contains only 300k total (less after Fermilab OH) from Research
- In 2021, the DR program can mostly continue thanks to support from the Fermilab CMS department (through a modest carryover from 2020), support from Ops, and reduced travel needs
- **However, in the absence of supplemental funds the current level of support does not allow for long term continuation of the program as we know it**
  - Funding would only allow for 4 juniors and no seniors DRs
  - Not possible to sustain current effort in physics/upgrades/operations
  - Cancellation of CMSDAS and HATS
  - **Long Term impact if funding trend continues:**
    - Significant reduction of participation in lab-based activities: upgrade, computing, lab/ university partnerships
    - Significant reduction of US impact to CMS in entire program (physics analysis, upgrade,...)
- 600k total would enable us to:
  - Maintain selected Physics/Upgrade/Computing activities
  - Will be able to offer CMSDAS and HATS
  - Start introducing new initiatives: AI fellowship and Snowmass activities
- The ideal budget request for the DR program would be $1M total
  - Maintaining strong USCMS participation in CMS physics and supporting the level of training for junior members of the collaboration that has proven to be effective and a fruitful investment by DOE

HPC Resources

Recommendation: The Committee recommends that CMS understand how much the usage of HPC can be increased under the assumption that no additional resources such as personnel to adapt the current software are allocated.



HPC Resource Properties

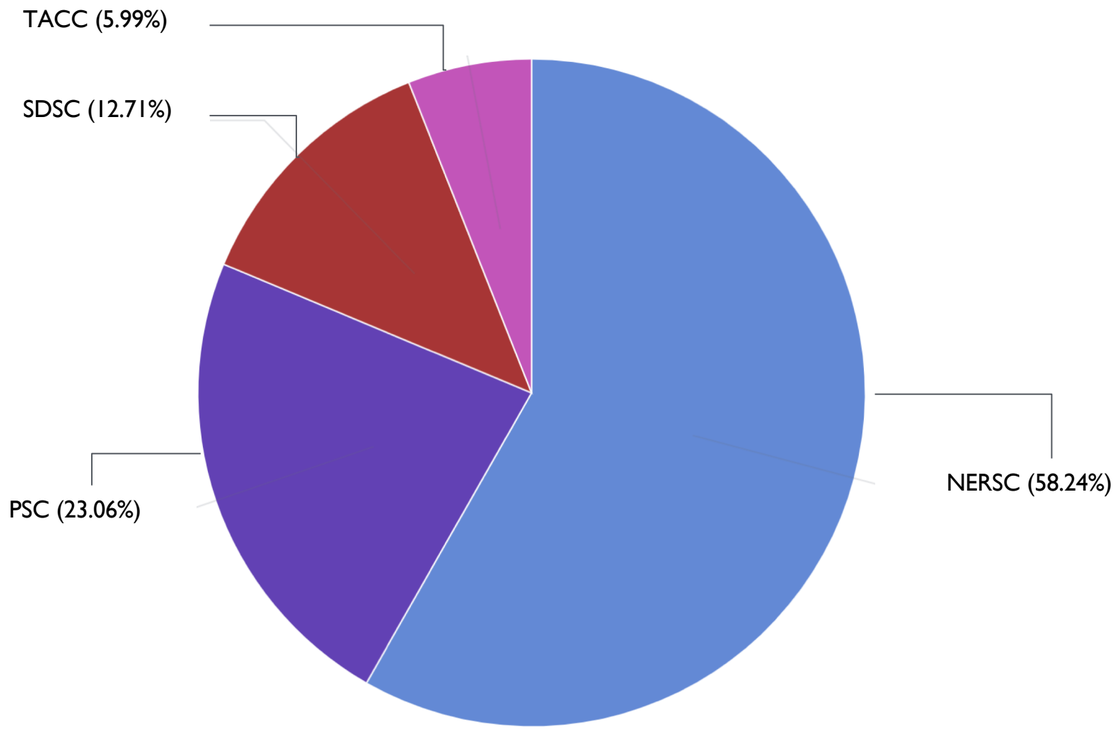
Most of HPC resources are different from Grid-like resources:

- Each HPC site is different, requiring additional efforts for integration. Currently we need some extra steps to run a CMS workflow on HPCs.
- Limited access to site storage ➜ all CMS workflows need access to data, either as input or to mix PileUp (>= 500 TB)
- Limited outbound connectivity from worker nodes on some HPCs ➜ CMS workflows need to contact external services for conditions and calibration data, as well as staging out output to CMS accessible storage
- The availability of a HPC resource depends on other (non-CMS or non-LHC or non-OSG) users. There is no guarantee of stable access to a HPC resource, and potential loss of some fraction of an allocation is possible if they are not consumed within the allocation time period

Potentially, HPCs provide a significant amount of CPU resources. In aggregate our current allocations can provide ~2.5B simulated events/year, a roughly 3% increase in total CMS production capacity.

HPC Resources Usage

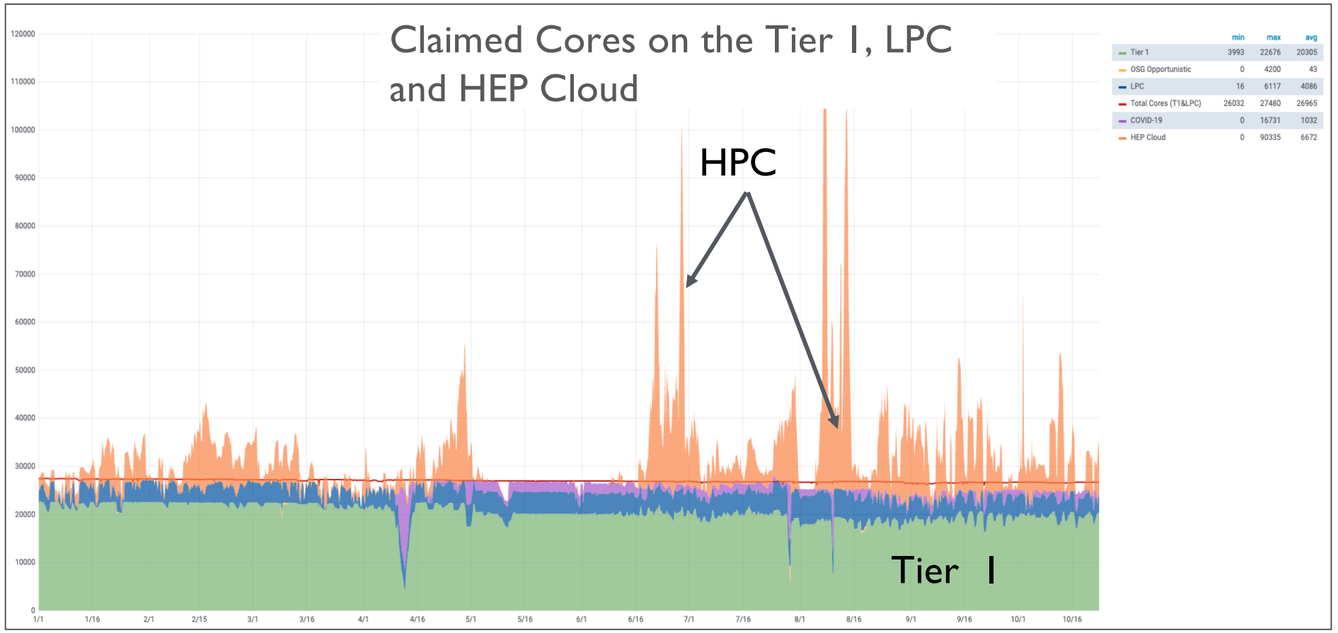
We are currently running at NERSC, PCS Bridges, TACC and SDSC Comet.



HPC Resource	Type of Resources	Core Hours since Jan 2020 (M)
NERSC	2 x 16-core 2.3 GHz Intel Xeon E5-2698v3 (Haswell) HT enabled	24.7
PSC Bridges	2 x 14-core 2.3 GHz Intel Xeon E5-2695v3 (Haswell) HT disabled	10.0
SDSC Comet	2 x 12-core 2.5 GHz Intel Xeon E5-2680v3 (Haswell) HT disabled	5.5
TACC Stampede2	Intel Xeon Platinum 8160 (“Skylake”)	1.8
TACC Jetstream	2 x 24-core Intel Haswell	5.7
Total		47.7

HPC Resource Provisioning

- On a “good” day we were able to use more cores than Tier-1 can provide
- On a “bad” day we are not getting any resources. It is especially painful during prolonged HPC downtimes but could also happen due to a lack of constant pressure of the CMS jobs queued for execution on HPC resources (e.g lack of work during NanoAOD processing).



HPC Summary

- If the HPC resources are Grid like resources (all current NSF installations, NERSC Cori II and ANL Theta), we technically can run our software
  - Limitations exist that not all machines can run all our applications
- If the HPC resources are accelerator based (GPUs), then we need software that can run on accelerators
  - We don't have software yet that can efficiently use an accelerator-based machine. We need to support different GPUs (and other accelerators in the future).
- We need guaranteed and long-term allocations at the HPC centers
  - Currently, allocations are awarded yearly through a proposal process. This is not feasible as CMS needs computing that supports a diverse set of physics goals with overlapping data/MC needs.
- We need the HPC centers to be available for processing throughout the year
  - Our experience so far that HPC centers do not optimize for stability but for performance.

- **In short:**
  - If Grid-like HPC centers are available, we can use them with no additional effort
  - If accelerator based HPC machines need to be used, we need a lot more effort for algorithm development, framework development, allocation management, operations.
  - In the future, we expect all new HPC machines to be accelerator based. With the exception of TACC Frontera (NSF), that means we cannot increase the usage of HPC resources without additional resources

Summary and Outlook

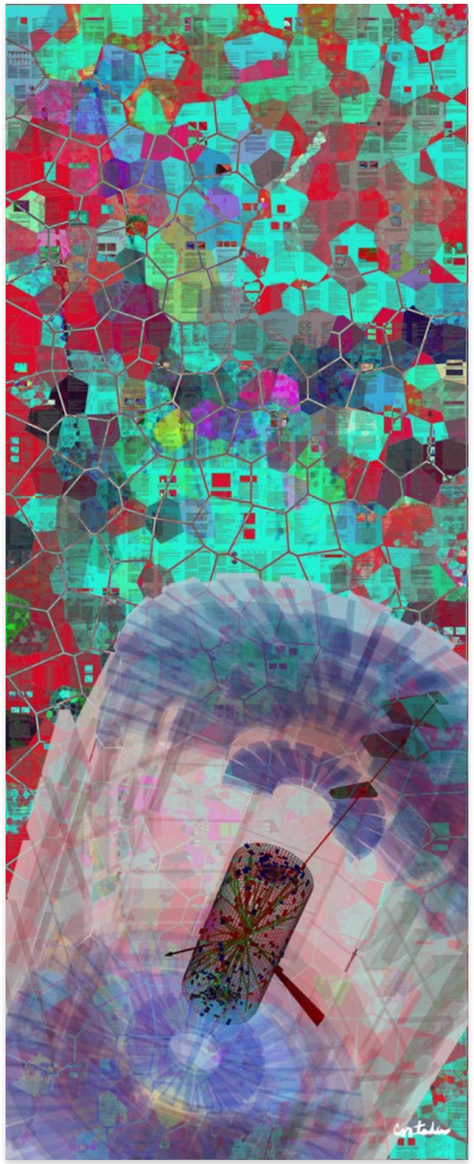
- The Fermilab CMS group continues to play major roles in CMS
  - Leading many high-profile data analysis
  - Major involvement in Phase-2 upgrades, Software and Computing, and Detector Operations. **A lot of progress on all fronts in the last 6 months.**
  - Fermilab scientists and RAs occupy leadership roles in CMS and USCMS organizations

- Succession planning strategy has been developed and is being executed
  - Due to limited funding, the group had to reduce its contributions to Operations and Physics. Further reductions will jeopardize Fermilab upgrade deliverables
  - **Continued support to scientists and RAs through a healthy research program is essential to the execution and success of the CMS program at the laboratory and internationally**

- LPC continues to operate very efficiently in the times of COVID
  - However, in the absence of supplemental funds the current level of support does not allow for continuation of the Distinguished Researcher program as we know it
  - **Adequate support for the Distinguished Researcher program is necessary for the LPC's success**

- HPC studies
  - Usage of accelerator based HPCs requires a lot more effort for algorithm development, framework development, allocation management, operations
  - **Additional resource are needed to increase usage of HPC resources**

Extras



Phase-2 Upgrades Progress

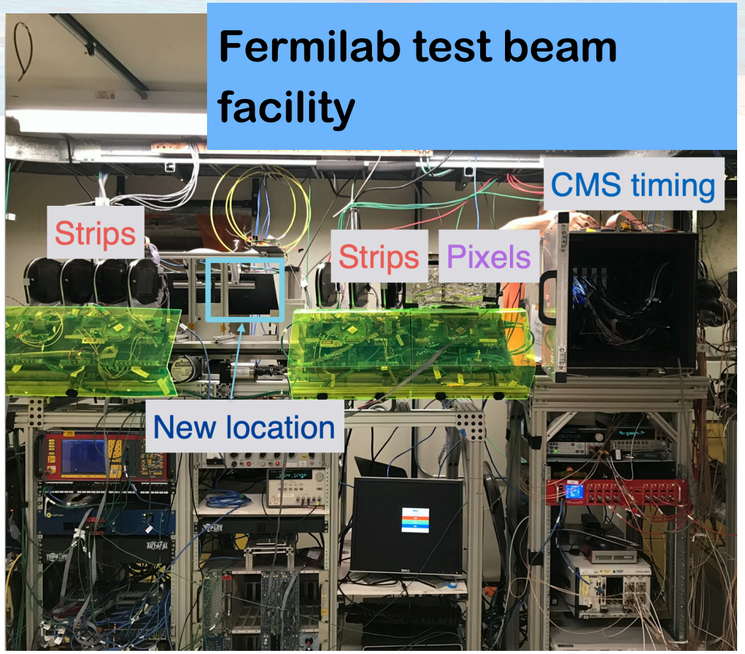
- Focus is on preparations for potential baseline Review in mid-2021
  - Reprising Technical reviews for OT and HGCal in November
  - Cost and Schedule Assessment in December
  - Director's Review in April preceding DOE OPA Review in July for
    - CD-2 Project baseline
    - CD-3b Procurement of Production Components
- Technical progress reasonable given pandemic situation
  - "Computer-based" work proceeds from home with reasonable efficiency
  - After shutdown in April-June, laboratory facilities are all open but operate at decreased capacity
    - "Single occupancy" tasks have decent efficiency, group efforts reduced by distancing constraints
    - Project working on incorporating COVID impacts and future delay estimates into planning tools, to provide accurate impact assessment impact and progress monitoring with COVID
- **Recent** Highlights:
  - Production Silicon for Tracker delivery starts
  - Fabrication processes for HGCal getting finalized
  - Trigger preproduction design nearly complete
  - Testing first ASIC+Sensor assembly for Endcap Timing Layer

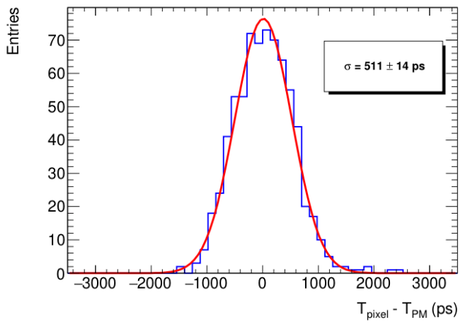
Fermilab group and the LPC

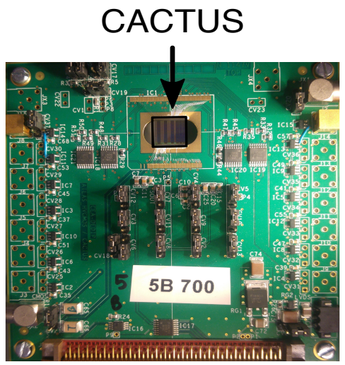
- Fermilab group is an integral part and a major contributor to the LPC activities
  - Approximately 20-25% of junior DR's are Fermilab postdocs. Selected on competitive basis from the same applicant pool as everybody else.
  - Fermilab scientists serve on the LPC Management Board, G&V committee
  - Co-chair Events, TOTW, Physics Forum, Journal Club committees
- Fermilab scientists and DRs are often catalysts of new ideas that grow into larger LPC efforts and lead to impactful results, e.g.:
  - Fast Machine Learning
  - Substructure and boosted Higgs program
  - Triboson observation
  - SUSY Hadronic
  - Searches for Long-Lived signatures
- Contributions to training programs:
  - CMSDAS: 7/11 short and 7/8 long exercises have facilitators from Fermilab
  - HATS: 9/18 have a facilitator from Fermilab. 2 of them are lead facilitators.
- Management (one of the coordinators is from Fermilab)

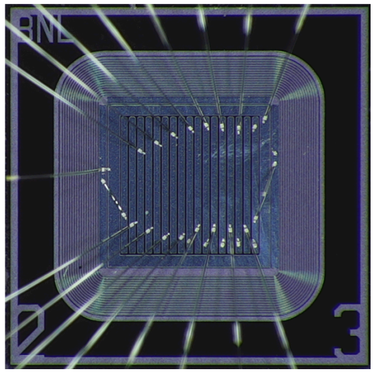
CMS Timing Group and Sensor Work

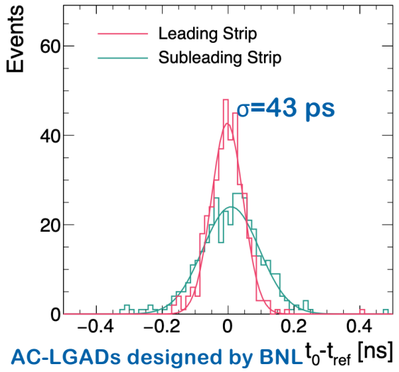
- Mature sensor characterization facilities
  - Mitigate access restrictions to beams, large sample testing
  - Key links established between beam, β-rays, and probe station measurements
  - Development of readout electronics, DAQ, and system integration
- Versatile generic R&D on precision timing detectors, several collaborations:
  - Saclay: HV-CMOS timing detectors, 2nd round in preparation
  - UCSC: LGAD characterization and design
  - BNL+KEK: 2nd round of funding from US-JAPAN DOE awards. The new round of 3-year award the consortium will include also UCSC





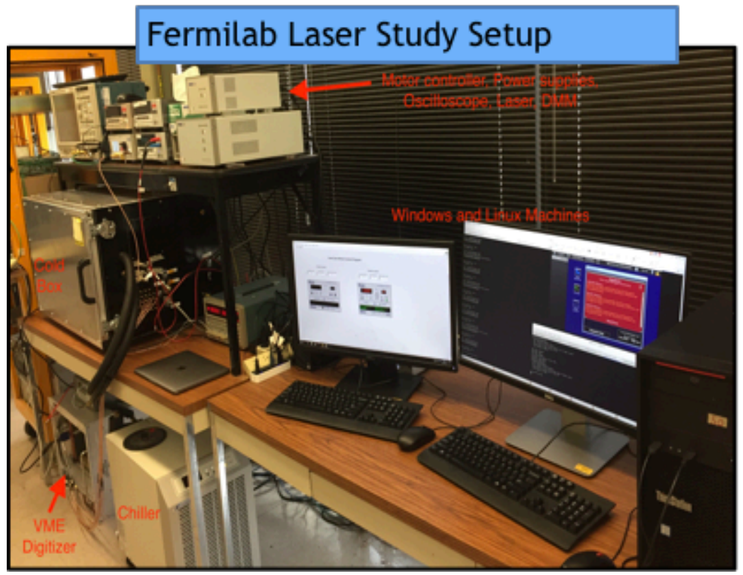






CACTUS: a depleted monolithic active timing sensor using a CMOS radiation hard technology: https://doi.org/10.1088/1748-0221/15/06/P06011

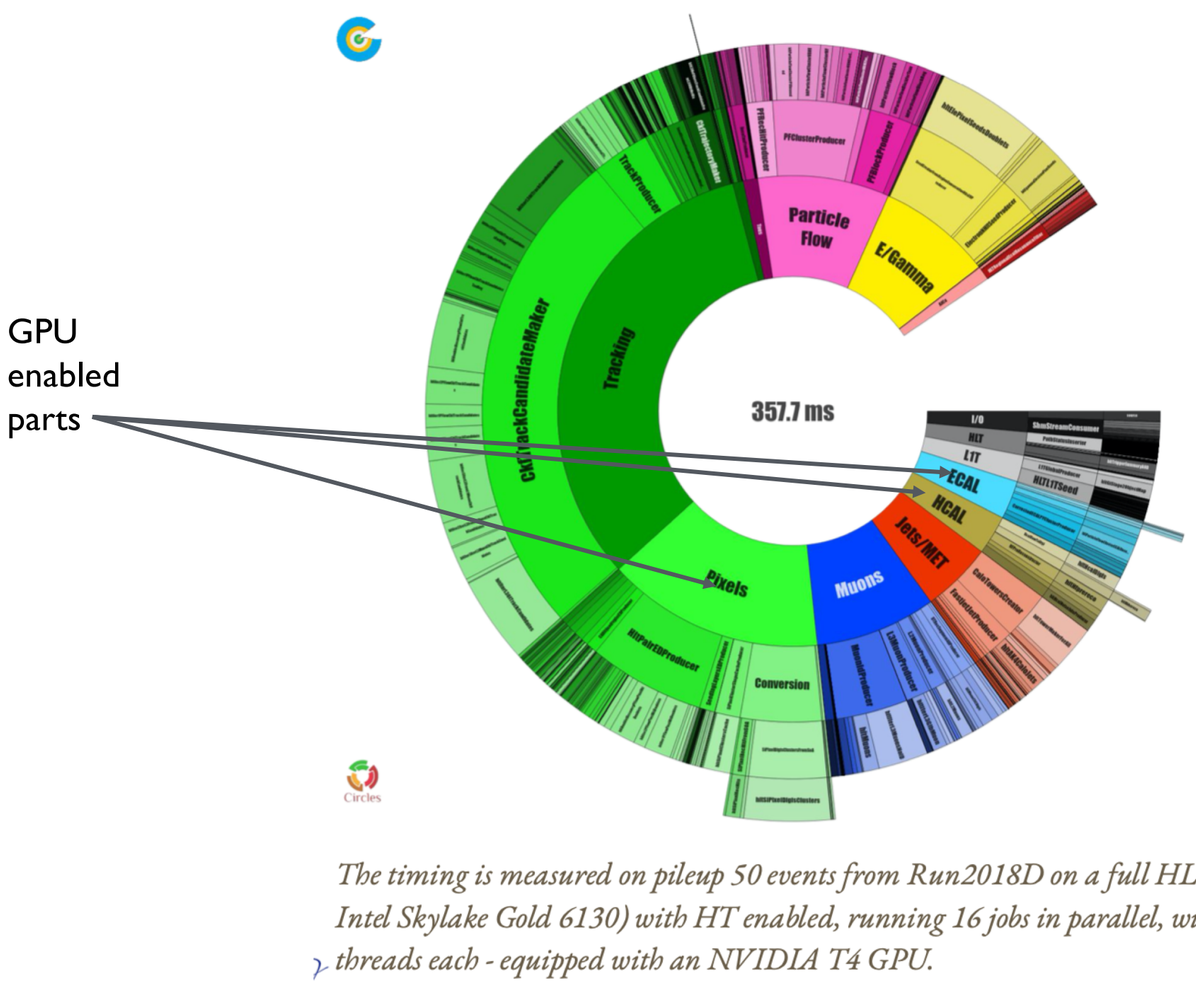
Measurements of an AC-LGAD strip sensor with a 120 GeV proton beam: https://dx.doi.org/10.1088/1748-0221/15/09/p09038



New HPC Resources

- We were accepted to be part of the Early Access program for both SDSC Expanse and PSC Bridges-2. Expect to get access to Expanse very soon, Bridges-2 likely will be a bit later.
- 2021 ERCAP (NERSC) request for 200 M CPU hours (= 2.5B events) has been submitted in October (previous allocation was 104 M CPU hours)
- The new challenges for this year are the onboarding of ANL Theta and TACC Frontera where we were awarded an allocation in July 2020.
  - Theta (475,000 node hours = 28M events)
  - Frontera (500,00 node hours = 1B events)
- There are additional limitations introduced by Frontera and Theta that we need to address. If we could come up with a common approach it could be make HPCs integration more straightforward.
- Although we received a small allocation on Summit at ORNL (NVidia GPUs and PowerPC CPUs), we don’t have workflows to run there efficiently

Backup: CMS HLT application using CPU and GPU



The timing is measured on pileup 50 events from Run2018D on a full HLT node (2x Intel Skylake Gold 6130) with HT enabled, running 16 jobs in parallel, with 4 threads each - equipped with an NVIDIA T4 GPU.

Current status of heterogeneous HLT:

- CPU usage reduced by 21%
- Throughput increased by 26%

Includes:

- Memory copies
- Conversion of copied results to legacy formats

From: CERN-EP Software Seminar: Real-time heterogeneous event reconstruction with GPUs at CMS and LHCb during LHC Run-3: https://indico.cern.ch/event/927838/

HPC Summary (detailed)

- If the HPC resources are Grid like resources (all current NSF installations, NERSC Cori II and ANL Theta), we technically can run our software
  - Limitations exist that not all machines can run all our applications (memory limitations on the nodes, input data requirements, etc.)
- If the HPC resources are accelerator based (GPUs, like the new DOE machines at NERSC (Perlmutter), ANL (Aurora) and ORNL(Frontier)), then we need software that can run on accelerators
  - We don't have software yet that can efficiently use an accelerator-based machine (most flops come from accelerators), the HLT is making first steps for Run 3, production workflows with many algorithms being able to exploit accelerators are still far in the future
  - We need to support different GPUs (and other accelerators in the future). Which means today that you have to use different APIs and programming techniques to specifically program for an individual accelerator (NVidia, AMD or Intel GPU) or use a portability abstraction layer (U.S. CMS is collaborating with the HEP-CCE project to establish recommendations for the experiments about portability frameworks)
- We need guaranteed and long-term allocations at the HPC centers
  - Currently, allocations are awarded yearly through a proposal process that requires detailed physics justifications. This is not feasible as CMS needs computing that supports a very diverse set of physics goals with overlapping data and MC needs.
- We need the HPC centers to be available for processing during the year
  - Our experience so far that HPC centers are more often down and/or in maintenance than our grid resources. They also update more frequently and do not optimize for stability but for performance.

- **Short Summary:**
  - If Grid-like HPC centers are available, we can use them with no additional effort
  - If accelerator based HPC machines need to be used, we need a lot more effort for algorithm development, framework development, allocation management, operations.
  - In the future, we expect all new HPC machines to be accelerator based. With the exception of TACC Frontera (NSF), that means we cannot increase the usage of HPC resources without additional resources