

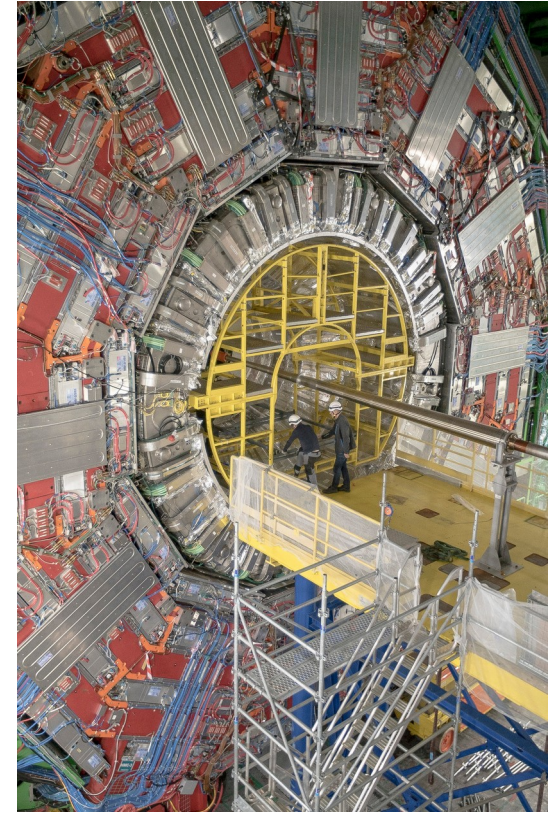


Overview of the CMS program

Frank Chlebana (CMS Group, Deputy Head)

7 Aug 2024

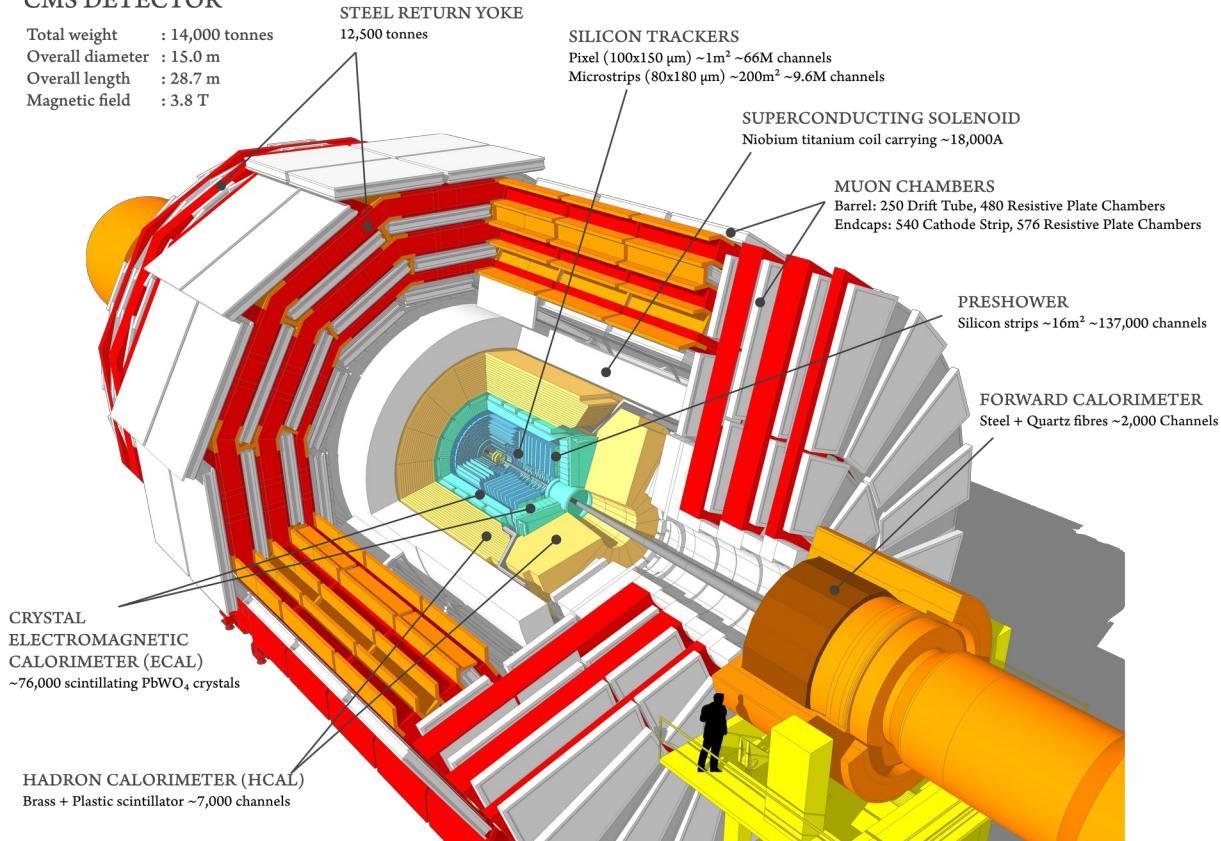
The Large Hadron Collider and the CMS experiment



The Large Hadron Collider and the CMS experiment

CMS DETECTOR

Total weight : 14,000 tonnes
 Overall diameter : 15.0 m
 Overall length : 28.7 m
 Magnetic field : 3.8 T

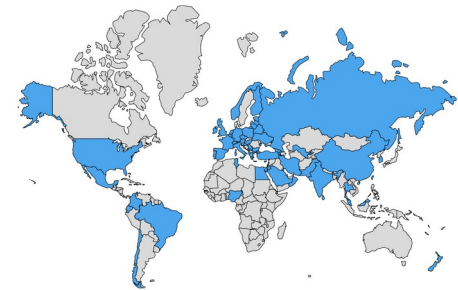


CMS, USCMS and FNAL

- CMS has >2300 authors (~6000 active members)
 - Fermilab has the largest number of active members, after CERN.
- The **U.S. CMS Collaboration (USCMS)** is formed of 49 U.S. Universities plus Fermilab, **425 authors, 1600 active members**
 - USCMS corresponds to ~30% of CMS (PhD authors).
 - Fermilab is the largest group in USCMS.



The CMS experiment has **5799** active members from **257** institutes coming from **58** countries.



2053	1160	1253	971	251	106
Phd Physicists (391 women 1662 men)	Physics Doctoral Students (315 women 845 men)	Non Doctoral Students (352 women 901 men)	Engineers (146 women 825 men)	Technicians (22 women 229 men)	Administratives (67 women 39 men)



US Institutes Contributing to CMS

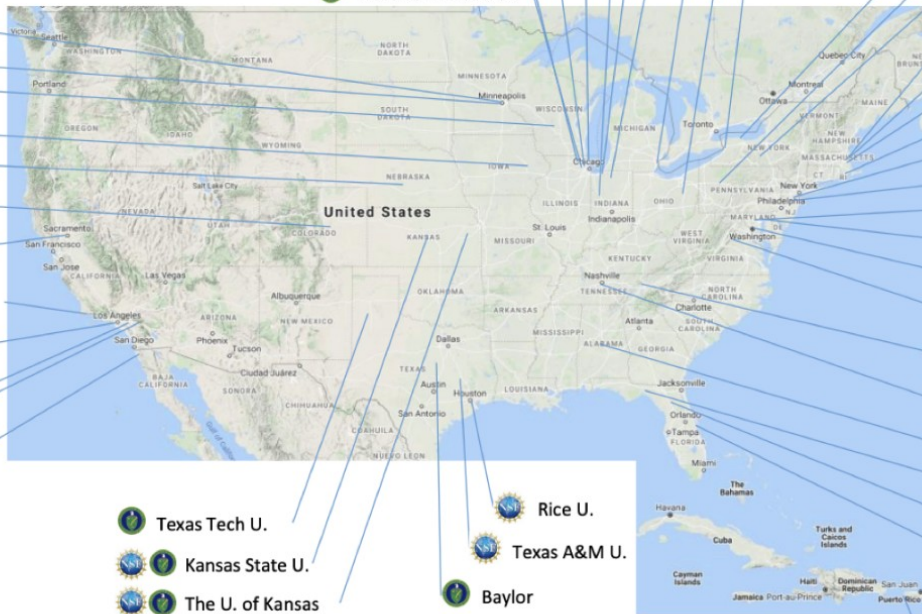


Work supported by NSF MREFC



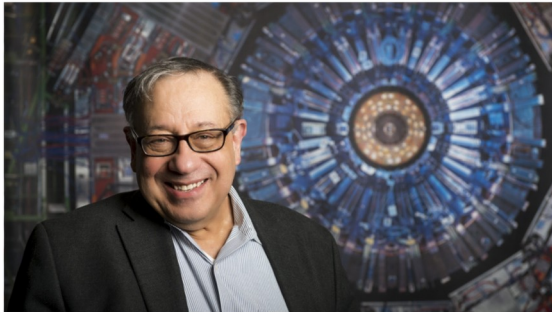
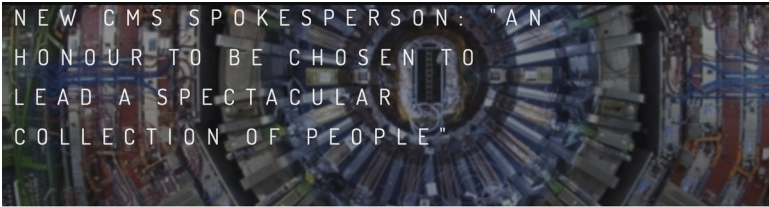
Work supported by the U.S. DOE

- U. of Minnesota
- Bethel U.
- U. of Wisconsin - Madison
- U. of Iowa
- U. of Nebraska - Lincoln
- U. of Colorado Boulder
- U. of California Davis
- U. of California Santa Barbara
- U. of California Los Angeles
- California Inst. of Technology
- U. of California Riverside
- U. of California San Diego



Fermilab Leadership in CMS

2016 – 2018 *Joel Butler*



Joel Butler, CMS spokesperson elect. (Image: Reidar Hahn/Fermilab)

NEWS

All

Collaboration

Detector

Physics

Engage with CMS



2022 – 2024 *Patty McBride*

Fermilab's Patty McBride elected next CMS spokesperson

March 3, 2022 | Sarah Charley



In ninth grade, Patty McBride wrote a homework assignment about what she wanted to be when she grew up.

"I wanted to be a musician, set designer or nuclear physicist," she said. "I wrote a little homework assignment about what it would be like to be a physicist."

McBride grew up in a small town where "nuclear physicist" was an atypical career choice. She remembers the teacher commenting on her essay and saying that — while it was very well written — she was skeptical about McBride's scientific aspirations.

McBride not only became a physicist, but she will now lead one of the largest scientific collaborations in history: the CMS experiment, which collects and studies particle collision data from the Large Hadron Collider at the international laboratory CERN.

CMS is a five-story-tall particle detector at the LHC, located just outside Geneva, Switzerland, and 300 feet underground. The international CMS collaboration comprises 3,000 scientists from more than 40 countries across the world. About a third of the scientists come from institutions in the United States. Every other year, the CMS collaboration elects a new spokesperson for a two-year term. The spokesperson is responsible for guiding CMS's technical and scientific endeavors, as well as representing the experiment on an international stage.

McBride was elected the next CMS spokesperson on Feb. 11, 2022, and will start her term Sept. 1. Her tenure coincides with a pivotal moment for the LHC, which will start its third run of operations this summer. Run III will boost the LHC's collision rate, but CMS is also currently preparing for the High Luminosity LHC, which will make its debut in 2029 and increase the collision rate by a factor of 5 beyond the LHC's design luminosity.



Patricia McBride. During her more than 15 years working on CMS, McBride has seen the experiment evolve far beyond its original scope. Photo: Fermilab

2024 – 2026 *Anadi Canepa*

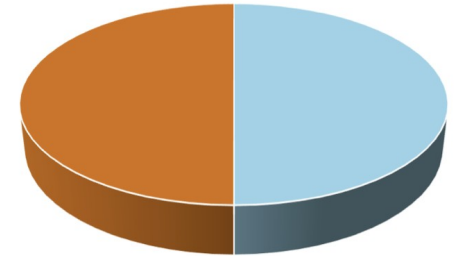
Elected as next deputy CMS spokesperson



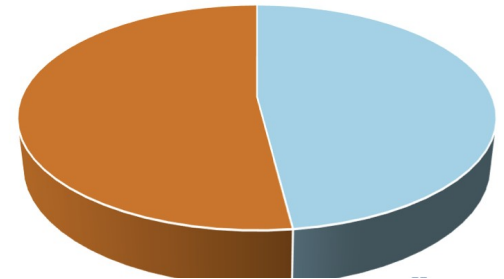
Diversity, Equity, Inclusion and Accessibility

CMS department at FNAL

Tenure and Tenure-Track Hires Sept. 2015 to Sept. 2022



■ Non-URM ■ URM or Women
Research Associate Hires Sept. 2015 to Sept. 2022

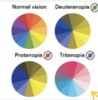


WHAT IS COLOUR-BLINDNESS?



Colour blindness or Colour Vision Deficiency (CVD) is a predominantly inherited condition that affects the cones in our eyes, which are sensitive to colour.

- Affects more than 300 millions people worldwide
- 1 in 12 males and 1 in 200 females are affected
- Currently no cure available



THERE ARE MANY TYPES OF CVD

Learn more:



What can we do to help?

- Avoid using colour solely to distinguish categories
- Try not to use red and green together
- Use CVD-friendly palettes!
- Check your slides are clear when viewed in greyscale

04

IMPLICIT BIAS

What is it? Why does it matter?

- Implicit bias is a form of bias that occurs automatically and unintentionally, that nevertheless affects judgments, decisions, and behaviors.
- Think about these examples: "The nurse came to help the patient"; "the renowned professor gives the lecture". What gender do people usually assume?

How to counteract them?

1. Think about counter-stereotypic examples: are there examples of people who are good but are not part of the majority?
2. Stand in their shoes: how would you react if other people question your skills because of your identity?
3. Implement measures to reduce such biases. For example, set some fixed standards before reviewing candidates for a given job.
4. Educate yourself! Join various trainings on this topic and check out free online resources.

Explore implicit bias with the Implicit Association Test from Project Implicit.



05

TEST YOUR DIVERSITY, EQUITY & INCLUSION VOCABULARY



What is the most gender-inclusive way to say...

1. A Manpower
- B (Wo)manpower
- C Personpower

A three-story office building that does not have a working elevator is an example of...

2. A Eurocentrism
- B Cisgender
- C Ableism

3. If a teacher likes ___ students, ___ will find work more enjoyable.
 - A their... they
 - B his/her... her/she
 - C her... she



Someone whose gender identity and expression line up with their birth-assigned sex is:

4. A Cisgender
- B Intersex
- C Transgender

What is equity?

5. A Everyone is given the same resources
- B Everyone is given the resources they need to succeed
- C The same as Equality

06

EXPLORING DIVERSITY & INCLUSION

BY THE CMS DIVERSITY & INCLUSION OFFICE

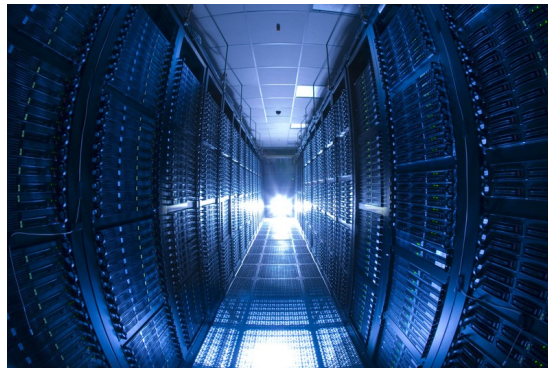
Fermilab is the Host Laboratory for USCMS

We host the national centers:

- **Remote Operation Center** (First CMS ROC outside of CERN qualified for online shifts)
- **U.S. Tier-1 Center** (Largest computing center outside of CERN)
- **LHC Physics Center** (Training resource for US institutes)



We manage the national programs: **USCMS Operations** and **Detector Upgrade Project** and **Accelerator Upgrade**



LHC Physics Center

- **Established center of excellence founded in 2004**
 - Co-coordinated by B. Jayatilaka (FNAL), K. Black (UW)
 - Serves as an intellectual hub and provides resources for **500 users and 90% of USCMS institutions**
- **Three thrusts**
 - **Education** (weekly seminars, classes for credit, conferences)
 - **Training** (data analysis school, advanced tutorial, workshops)
 - **Users support** (software and computing, shifts management and coordination)



G. Benelli (Brown U) M. Tonjes (UIC) D. Yu (UNL)



Plenary lectures



Parallel short exercises



Group long exercises



Final group presentations



DR Office Hours

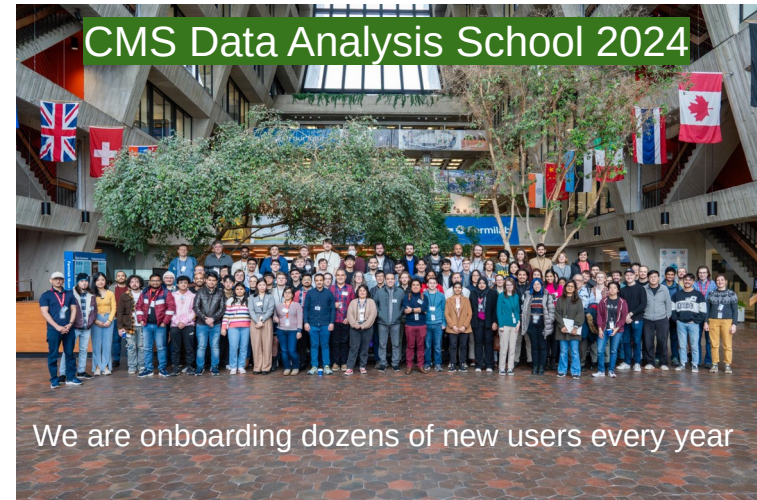
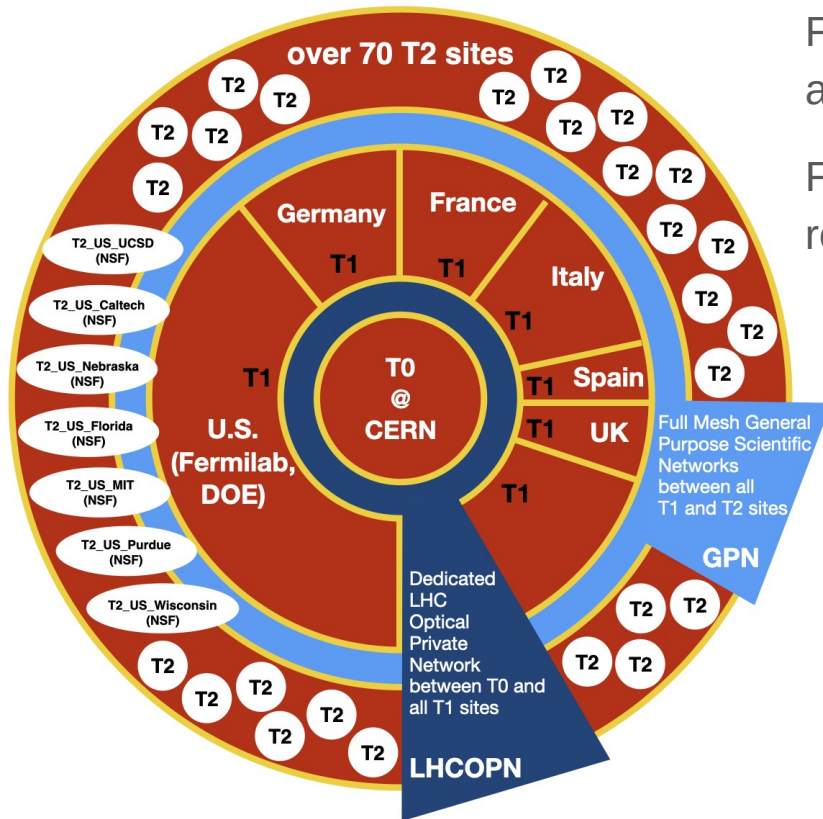


Colliders of Tomorrow-Feb 2023

Fermilab is the regional computing center for U.S. CMS

Fermilab hosts 40% of the Tier-1 computing of CMS, and is the regional center to 7 U.S. Tier-2 sites

Fermilab is the analysis center of the U.S. with ~900 researchers using analysis computing on-site per year



Fermilab is the Intellectual Hub for U.S. CMS Software & Computing R&D

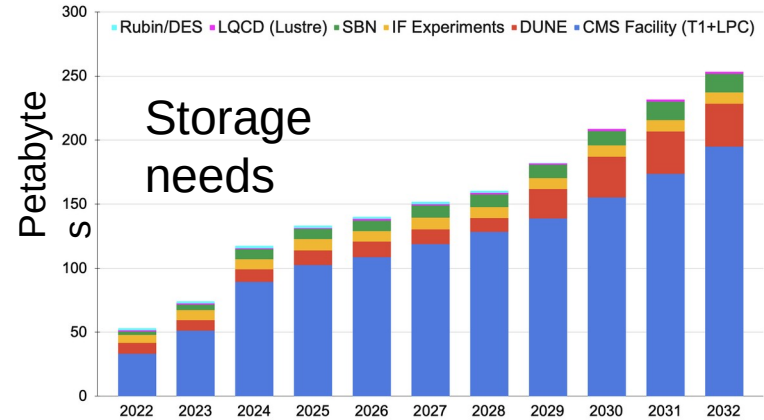
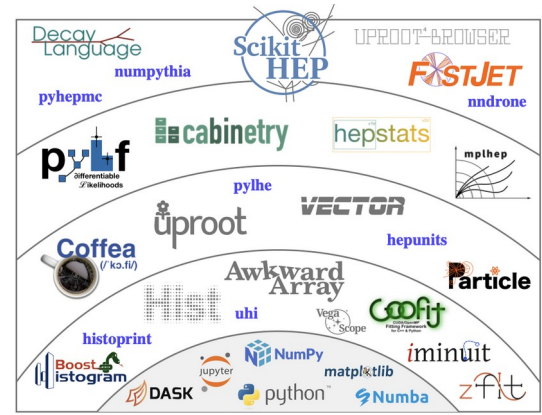
Fermilab experts and scientists are responsible for the CMS software framework

- orchestrates 4 Million lines of C++ code and 1 Million lines of python into one application
- primarily algorithms to reconstruct detector signals

Fermilab experts and scientists are leading crucial R&D for HL-LHC (starting in 2029):

- GPU software
- HPC utilization (NERSC and LCFs)
- Columnar Analysis Facility using industry python tools

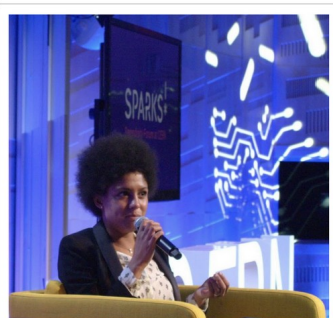
CMS will dominate on-site computing resources at Fermilab when the HL-LHC starts in 2029



Fermilab researcher receives two prestigious awards in AI and ML research

June 7, 2023

[Share](#) [Tweet](#) [Email](#)



Associate scientist Jennifer Ngadiuba received two top awards last fall to advance artificial intelligence and machine-learning research in high-energy physics. Photo: Jennifer Ngadiuba

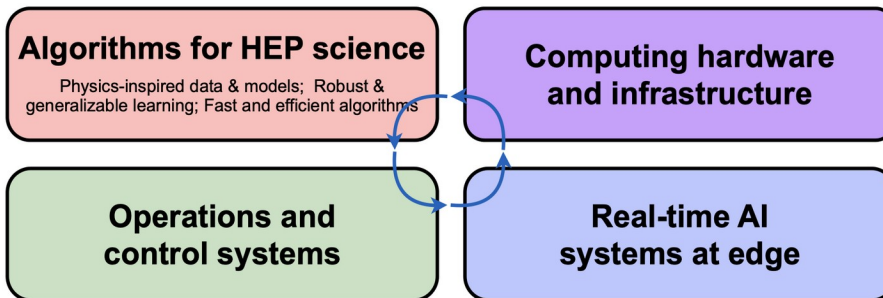
Jennifer Ngadiuba, an associate scientist at Fermilab on the [Compact Muon Solenoid](#) experiment, was always curious — she felt like the world was a puzzle to be solved. When she was young, she knew she wanted to study science to help solve this puzzle. Later, she realized her curiosity and research could help advance human knowledge and well-being in general.

The need to understand the truth behind mysteries of the physical world has guided her career. Her curiosity has led to Ngadiuba's receiving two prestigious awards: The U.S. Department of Energy's [AI4HEP award](#) and the Schmidt Futures [AI2050 Early Career Fellows award](#). Both will enable her to expand development of new methods for more reliable and robust machine learning, using physics-informed models where humans are not needed in the decision-making loop.

Ngadiuba's research focuses on designing efficient edge artificial intelligence for the real-time processing system of the CMS experiment. In the last year, her research has focused on understanding the feasibility of a novel data-acquisition approach for CMS, based on unsupervised learning. This approach, also called anomaly detection, has the potential to lead the field to uncover unknown and beyond the Standard Model physics.

She will now expand her research to improve the efficiency and robustness of edge AI models with physics information for different high-energy physics applications, including CMS, the Deep Underground Neutrino Experiment and

accelerator technology.

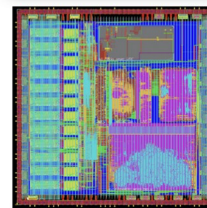


Courtesy of N. Tran



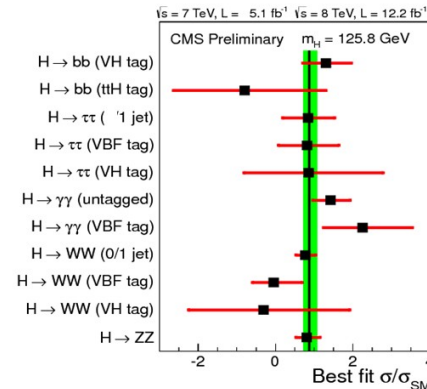
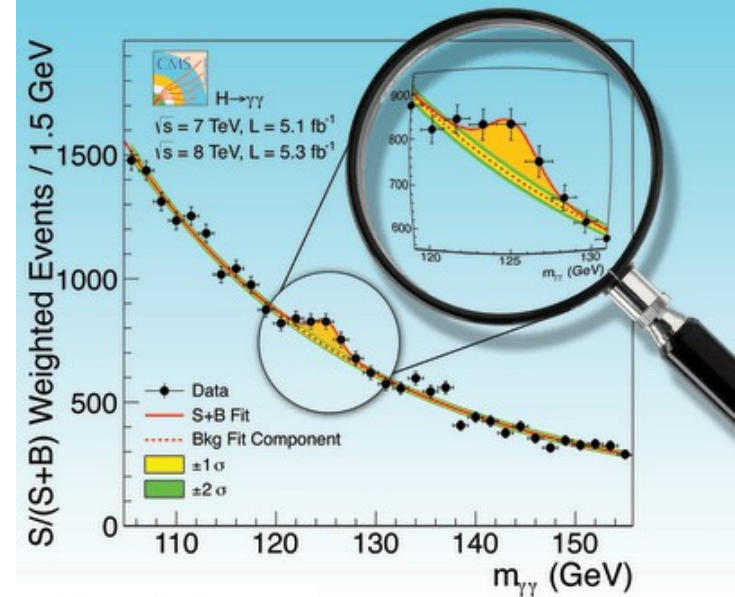
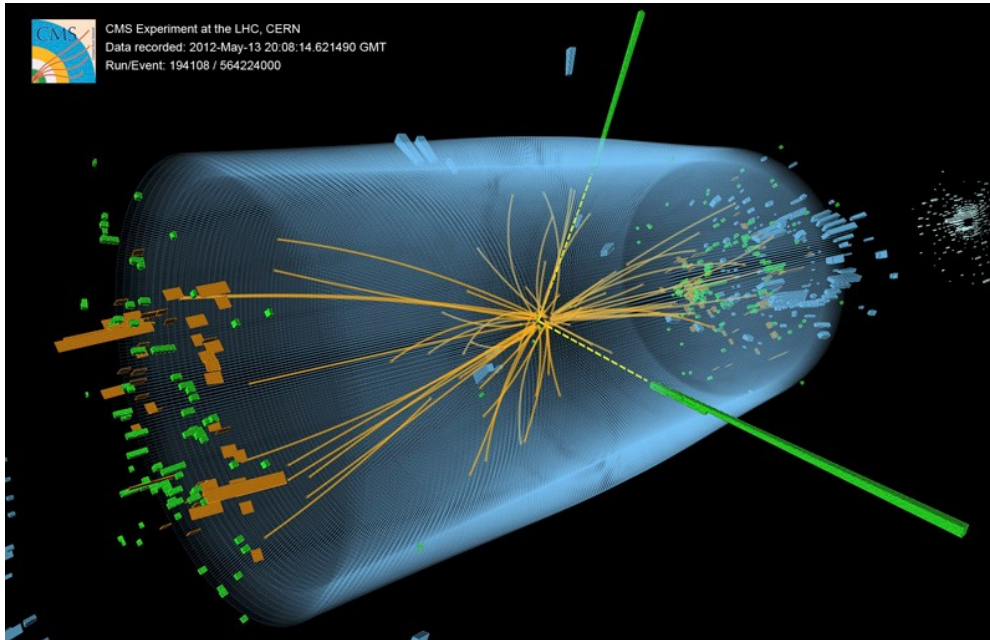
Data compression encoder ASIC for CMS HGCaI

- First **design and implementation** of modern DL for HEP on ASIC
- **Enables powerful non-linear data compression schemes** on detector; better trigger primitives downstream
- Chips fabricated and tested, performed well under functional/radiation validation



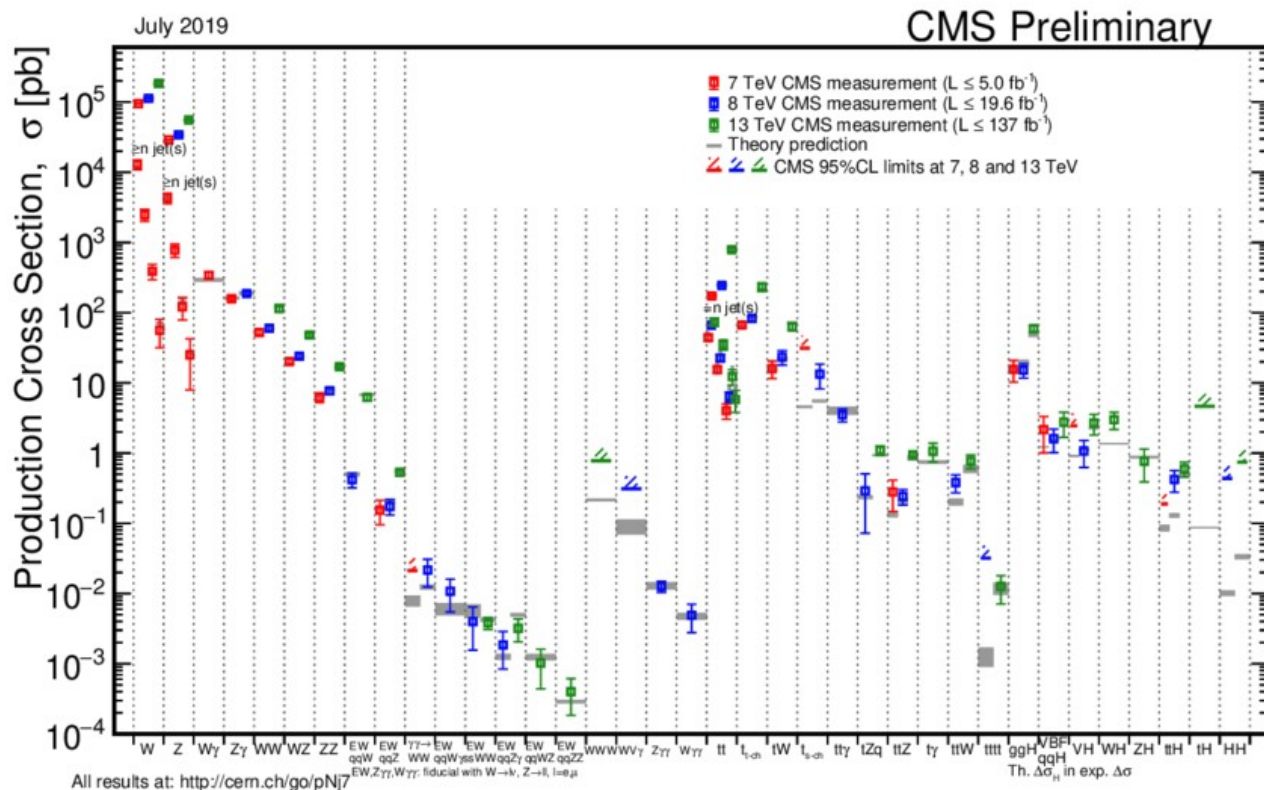
Higgs Discovery

Observation of Higgs production decaying to two photons



Explore the Higgs properties predicted by the Standard Model

CMS is a general purpose detector allow us to explore a wide variety of particle production and their properties



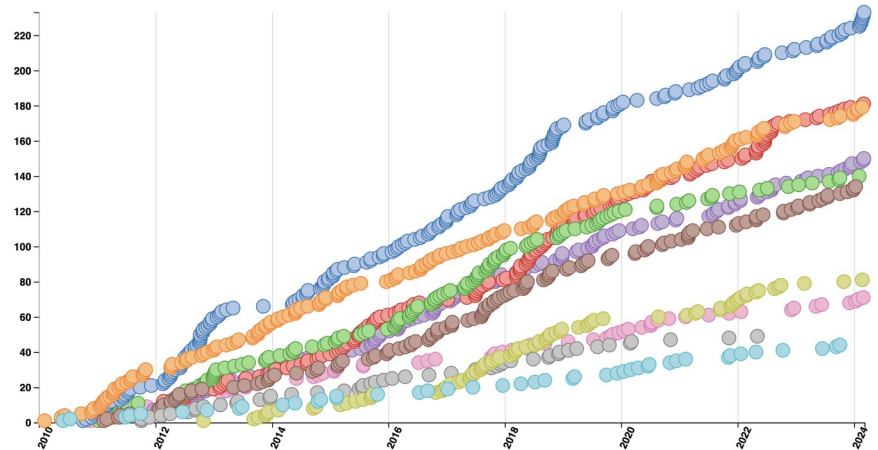
1262 collider data papers submitted as of 2024-03-05

HISTORICAL MOMENT IN PHYSICS: 2012, DISCOVERY OF THE HIGGS BOSON



Show all Total Exotica Standard Model Supersymmetry Higgs Top Heavy Ions
B and Quarkonia Forward and Soft QCD Beyond 2 Generations Detector Performance

1262 collider data papers submitted as of 2024-03-05

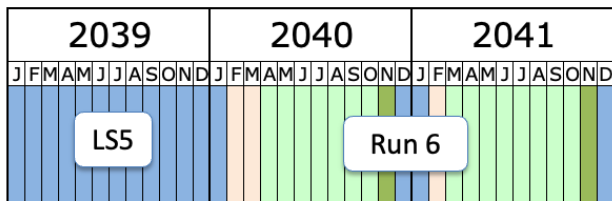
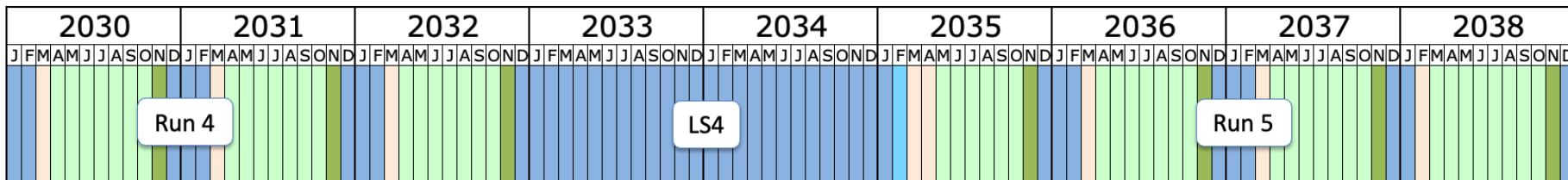
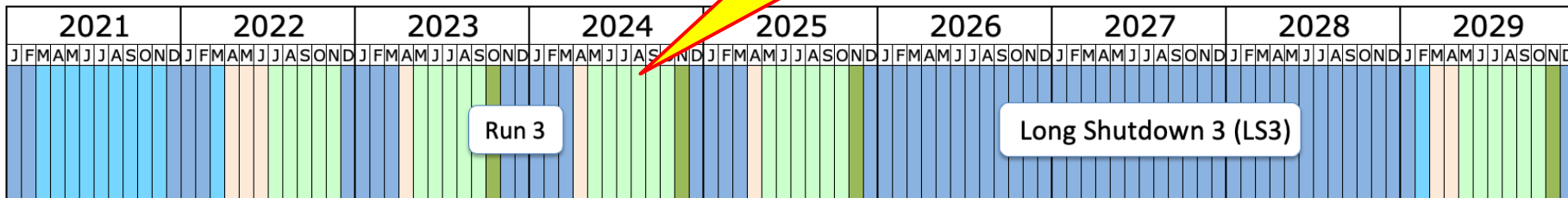


Nearly 30% of Run 2 publications have a majority of LPC contributors (~300 publications)

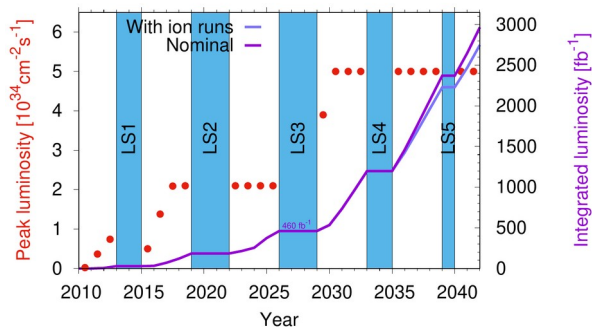
HL-LHC Long Term Schedule

You are here

HL-LHC



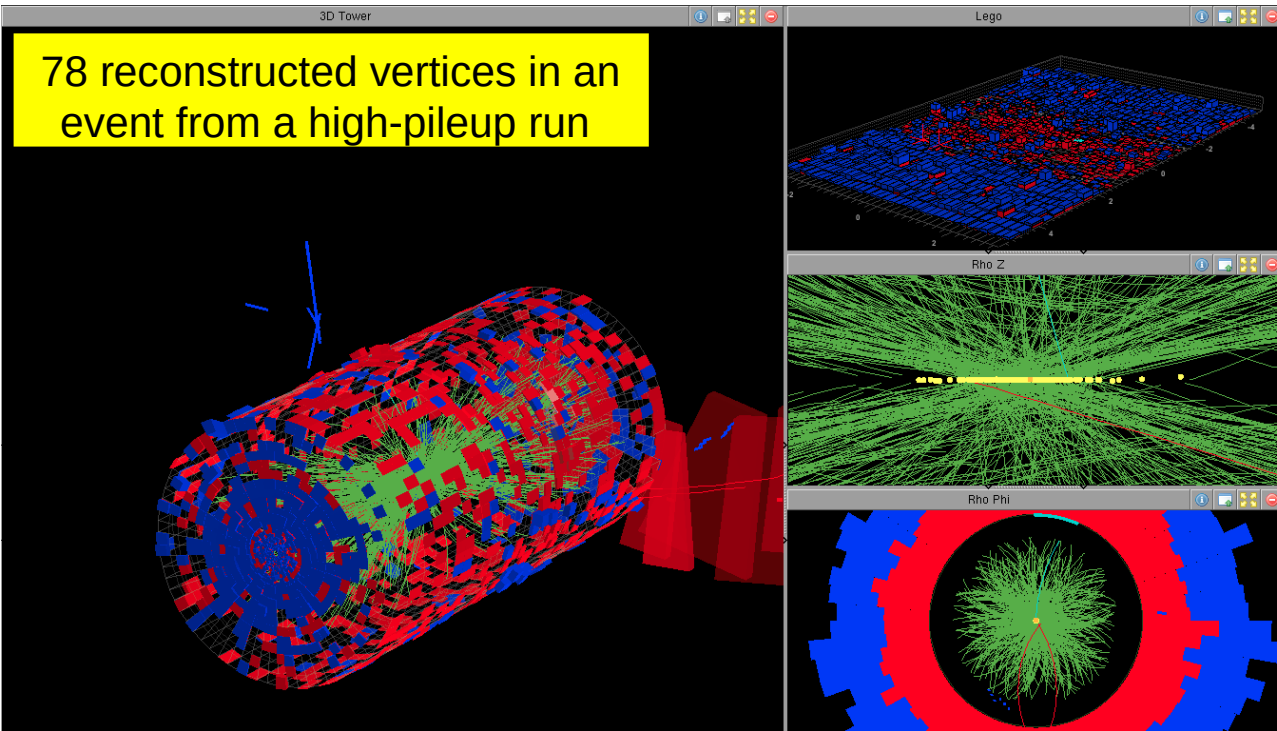
Last update: April 2023



- Shutdown/Technical stop
- Protons physics
- Ions
- Commissioning with beam
- Hardware commissioning

Challenges for the HL-LHC

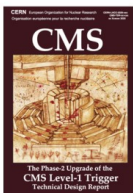
HL-LHC will use more densely packed proton beams to increase the collision rate. On average we will have **140 collisions / crossing** (designed to handle up to 200)



78 reconstructed vertices in an event from a high-pileup run

CMS Detector Upgrade for HL-LHC

Our scope aligns with the lab's unique capabilities in **silicon- and scintillator-based detectors** (trackers, calorimeters, timing detectors) **trigger systems**, **ASIC development**

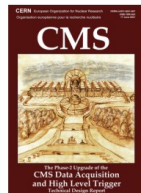


L1-Trigger



<https://cds.cern.ch/record/2714892>

- Tracks in L1-Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting



DAQ & High-Level Trigger

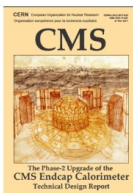
<https://cds.cern.ch/record/2759072>

- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

Barrel Calorimeters

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

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

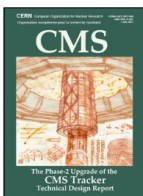


Calorimeter Endcap



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

- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

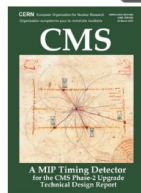


Tracker



<https://cds.cern.ch/record/2272264>

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



MIP Timing Detector



<https://cds.cern.ch/record/2667167>

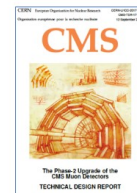
Precision timing with:

- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

Muon systems

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

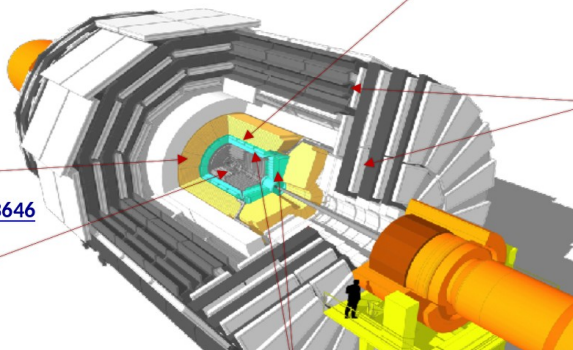
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \approx 3$



Beam Radiation Instr. and Luminosity

<http://cds.cern.ch/record/2759074>

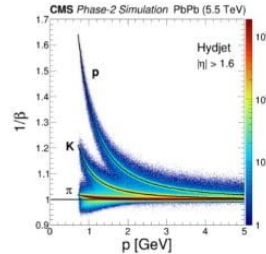
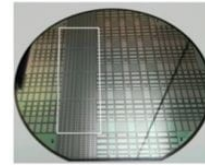
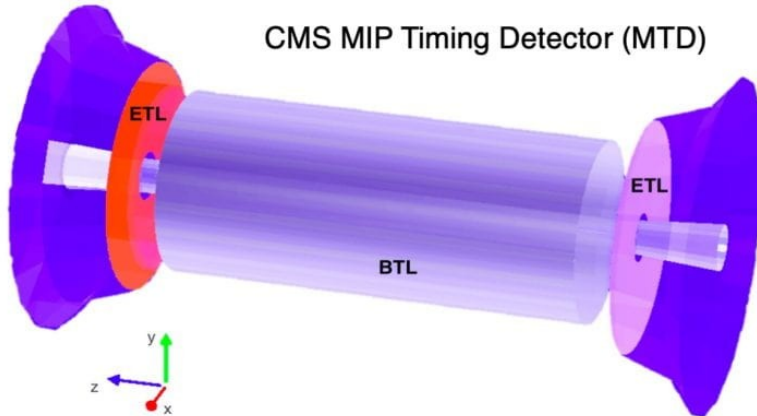
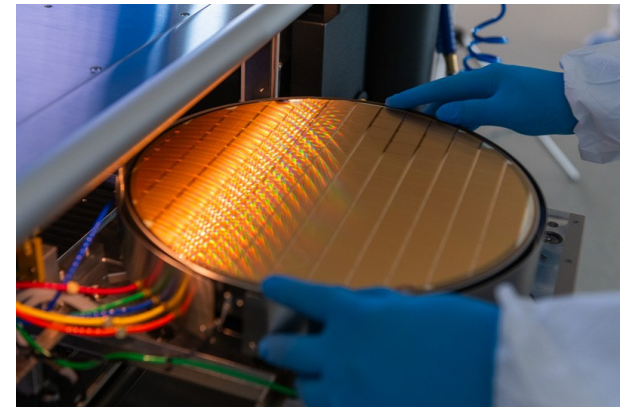
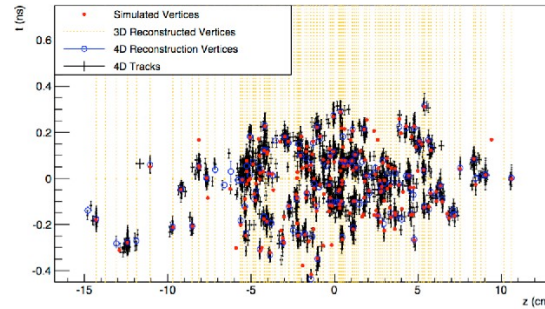
- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch luminosity: 1% offline, 2% online
- Neutron and mixed-field radiation monitors



MIP Timing Detector (ETROC)

The MIP Timing Detector (MTD) adds precision timing information for charged tracks and will help reduce the effects of pile-up.

Individual collisions within a bunch crossing occur at different times since the bunches, which are a few centimeters in length, take on order of a nanosecond to fully pass through each other even though they are traveling at nearly the speed of light.

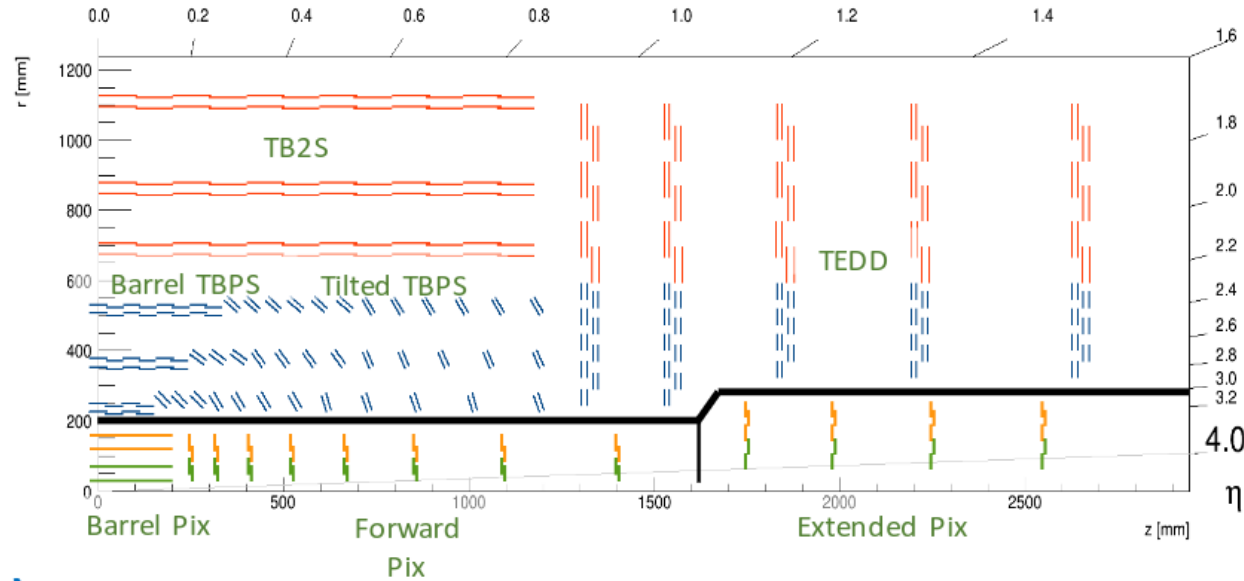
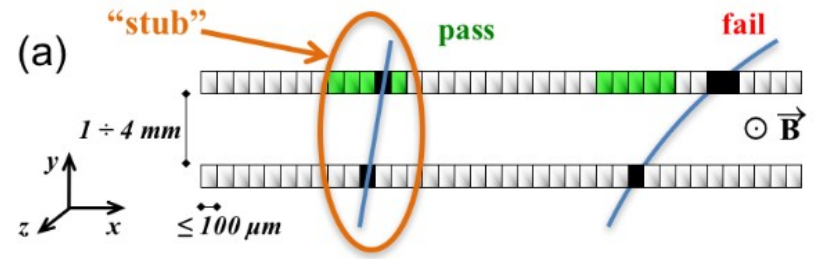


Outer Tracker

New Si based tracker

OT instrumented with pT discriminating modules allowing for track selection at the L1 trigger

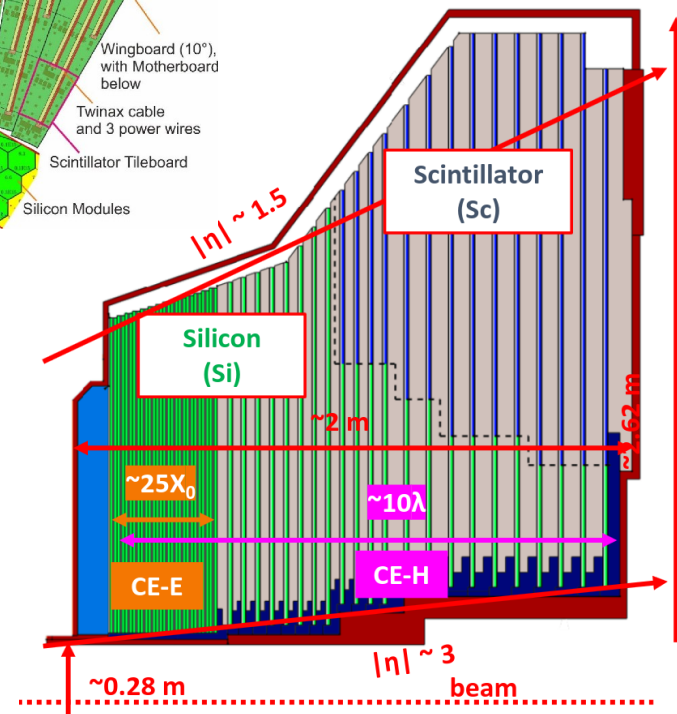
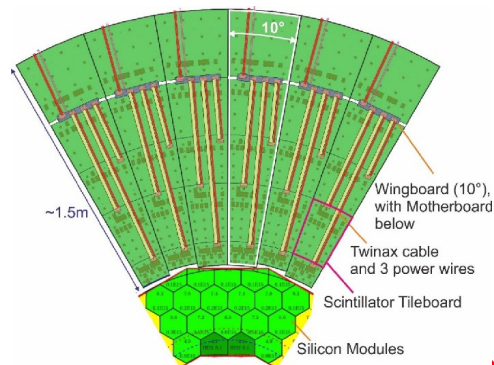
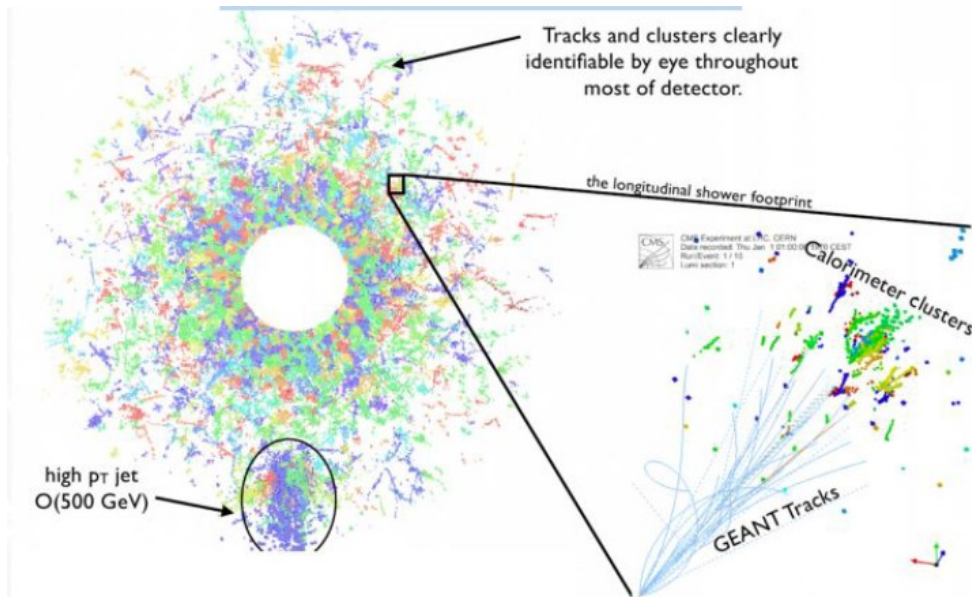
Inner tracker provided extended coverage in the forward regions (closer to the beam pipe)



High Granularity Calorimeter

The HGCal has approximately six million silicon sensor channels and about four hundred thousand scintillator tiles readout with on-tile silicon-photomultipliers.

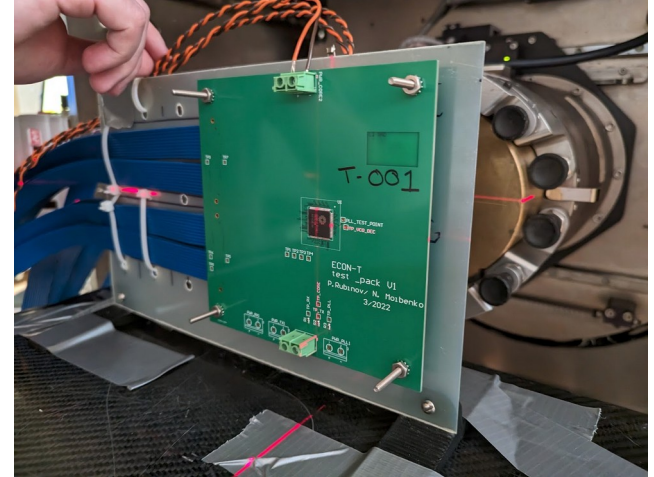
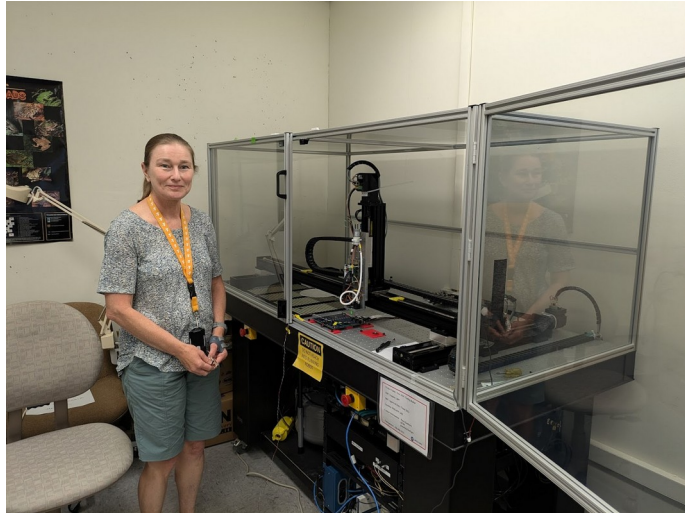
In addition to measuring the energy and position of the energy deposits we can also measure the shower's time of their arrival.



HGCaI: ECON

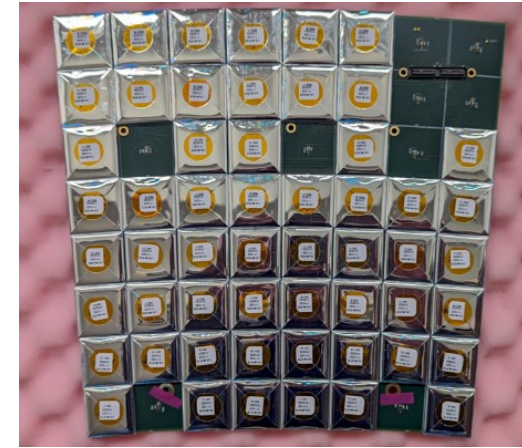
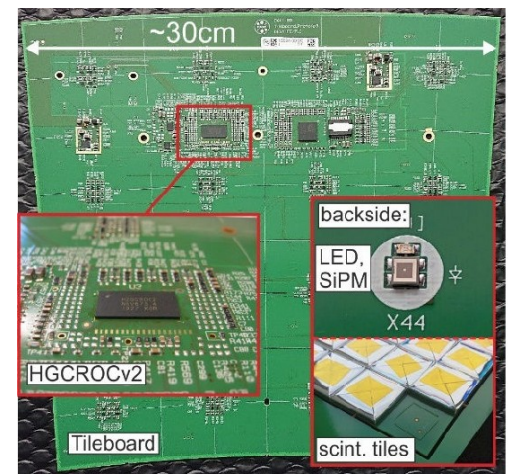
With over 6 million channels, the High Granularity Calorimeter for the CMS HL-LHC upgrade requires the development of custom ASICs to provide on-detector data compression and selection for the trigger path (ECON-T) and data acquisition path (ECON-D).

The ASICs, fabricated in 65 nm CMOS, are radiation tolerant up to 200 Mrad and designed to require low power consumption



HGCal: Scintillator Tiles

Scintillator tiles will be produced at Fermilab and assembled onto “tileboards” using a robotic gantry
The tileboards will then be mounted on the cassette cooling plates



HGCal: Cassette Assembly



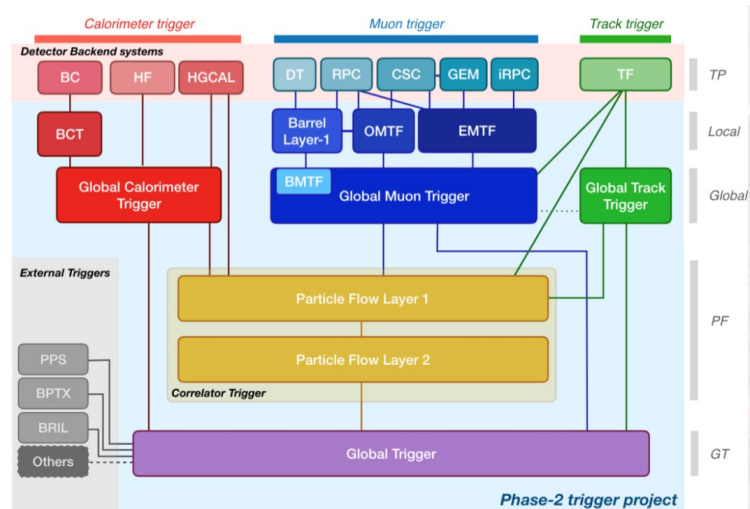
HGCal cassettes will be assembled and tested at Fermilab and shipped to CERN for integration



Level-1 Trigger

CMS is designing an efficient data-processing hardware trigger that will utilize information from the high-granularity calorimeter, tracker, and muon detectors.

Trigger data analysis will be performed through sophisticated algorithms such as particle flow reconstruction, including the widespread use of Machine Learning.



The Calorimeter trigger combines active cells into clusters

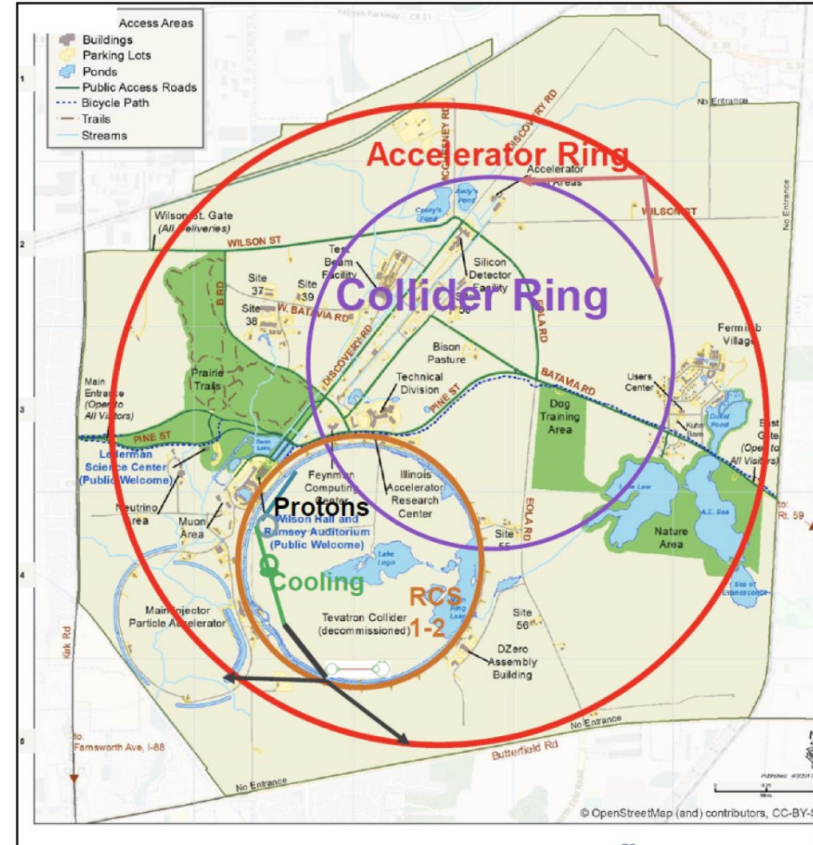
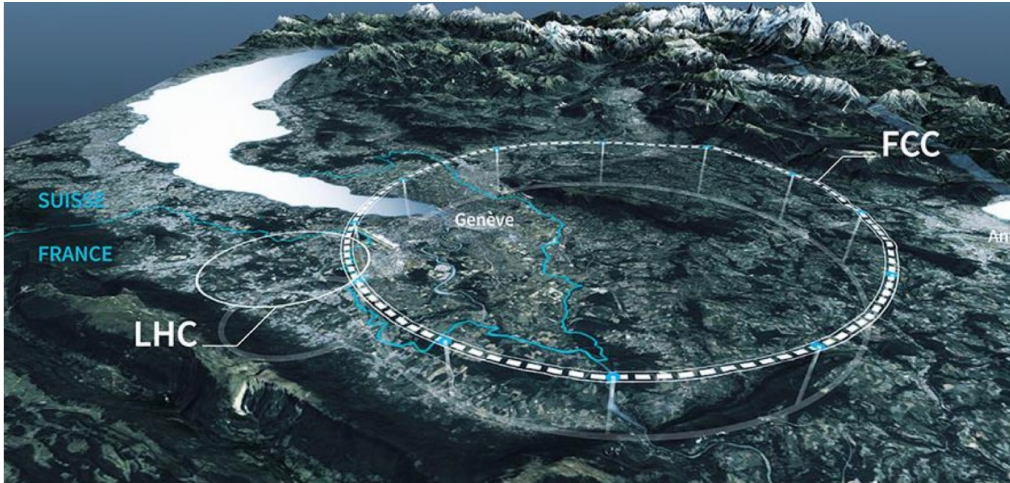
The Correlator trigger combines input from each sub system

The Global trigger issues final L1 trigger decision

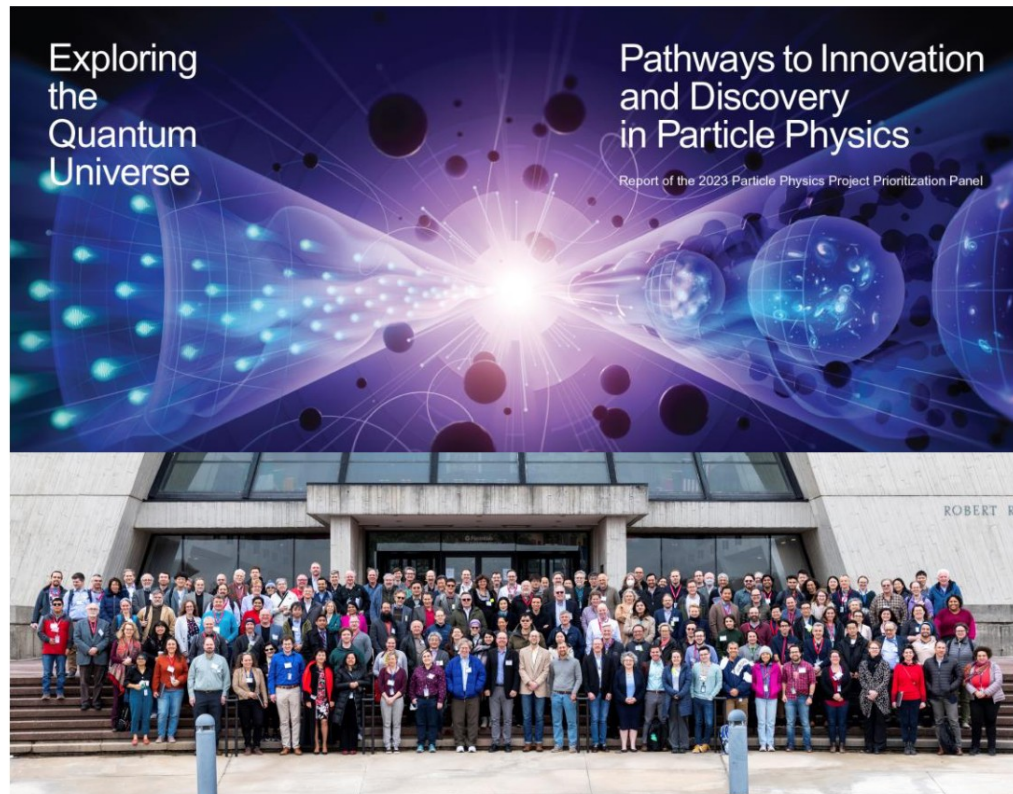
Planning for the Future

HL-LHC operations expected to end in 2041

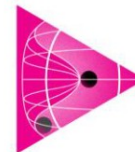
Need to engage in planning and R&D for the next collider



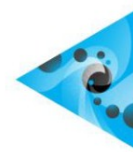
2023 P5 Report



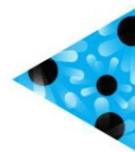
Elucidate the Mysteries of Neutrinos



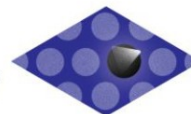
Reveal the Secrets of the Higgs Boson



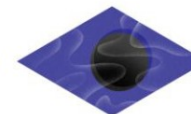
Determine the Nature of Dark Matter



Understand What Drives Cosmic Evolution



Search for Direct Evidence of New Particles



Pursue Quantum Imprints of New Phenomena

Fermilab's vision is well aligned with the 2023 P5 report

The DC Trip

69 participants, met with 384 offices (out of 538)
 Advocate for the FY25 budget / presented the new P5 plan

The P5 plan is an important tool demonstrating coordinated unity and an thoughtful vision of the future



FY 2023 Budget	Spend the Fiscal Year Budget																																						
FY 2024 Budget	OMB Review			Budget Release			Congressional Budget and Appropriations									Spend the Fiscal Year Budget																							
FY 2025 Budget	DOE Internal Planning with OMB and OSTP Guidance												OMB Review			Budget Release			Congressional Budget and Appropriations									Spend the Fiscal Year Budget											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep			
	CY 2022			Calendar Year 2023												Calendar Year 2024												Calendar Year 2025											

P5 report released

DC Trip

Source: Gina Rameika

Conclusions

The Fermilab CMS Department has a long history of engagement on CMS and has developed a well balanced program that covers detector development, commissioning, operations, physics analysis, management, and planning for the future

Fermilab is the host lab for USCMS and supports the HEP community with the LHC Physics Center, Remote Operations Center, and Tier 1 computing

The detector upgrades for the HL-LHC require innovative designs and new computing techniques (ML/AI) to mitigate high pileup and to process more complex event topologies

Plenty of interesting technology to get involved in and to build up your experience (students, postdocs, technicians, engineers, faculty...)

The P5 report is an effective tool used to advocate for funding and demonstrates we have a comprehensive plan for the future

Planning for the future (post HL-LHC) has started...