Fermilab

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

CMS Program

Kevin Burkett

DOE Institutional Review

February 10, 2015

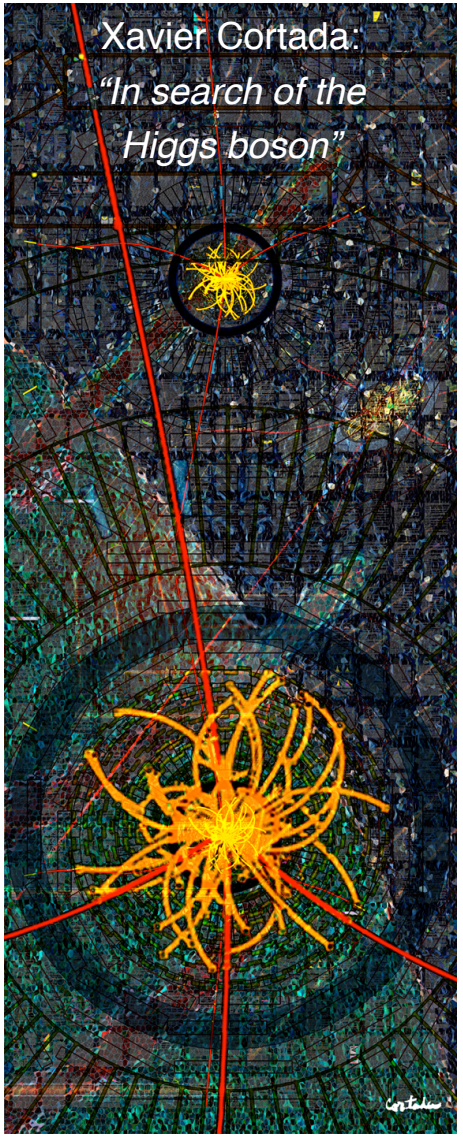
Introduction

- The LHC experiments were strongly endorsed by P5
  - "LHC upgrades constitute our highest-priority near-term large project."
- Among the Science Drivers:
  - Higgs as a new tool for discovery
  - Explore the unknown
  - Dark Matter

- The CMS effort at Fermilab is aligned with these priorities through:
  - Physics research corresponding to the key science drivers
  - A leading role for CMS and USCMS in R&D and construction of detector and accelerator upgrades

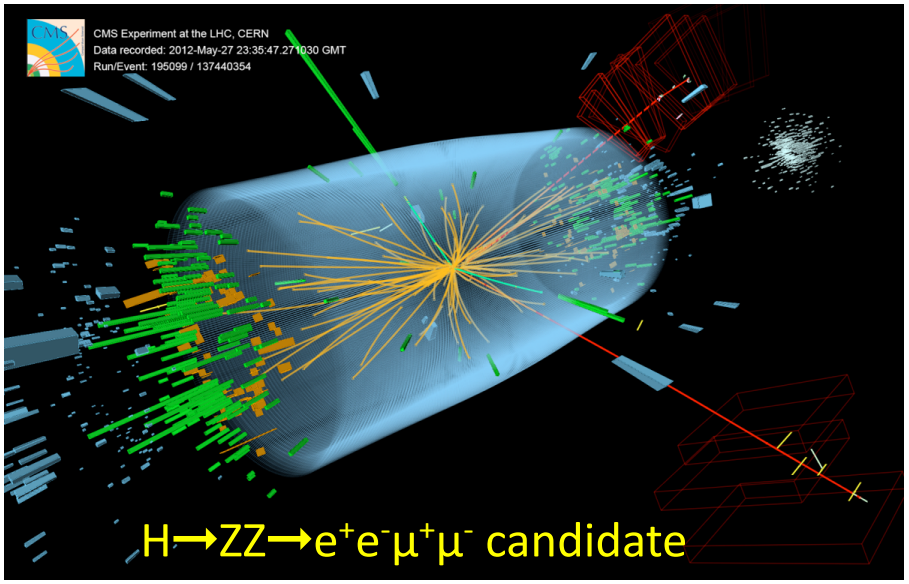
Outline

- CMS and LHC Schedule
- Overview of CMS Activities at Fermilab
- Physics Analysis
- LHC Physics Center
- Detector Activities and Upgrades
- Software and Computing
- LHC Accelerator R&D Program

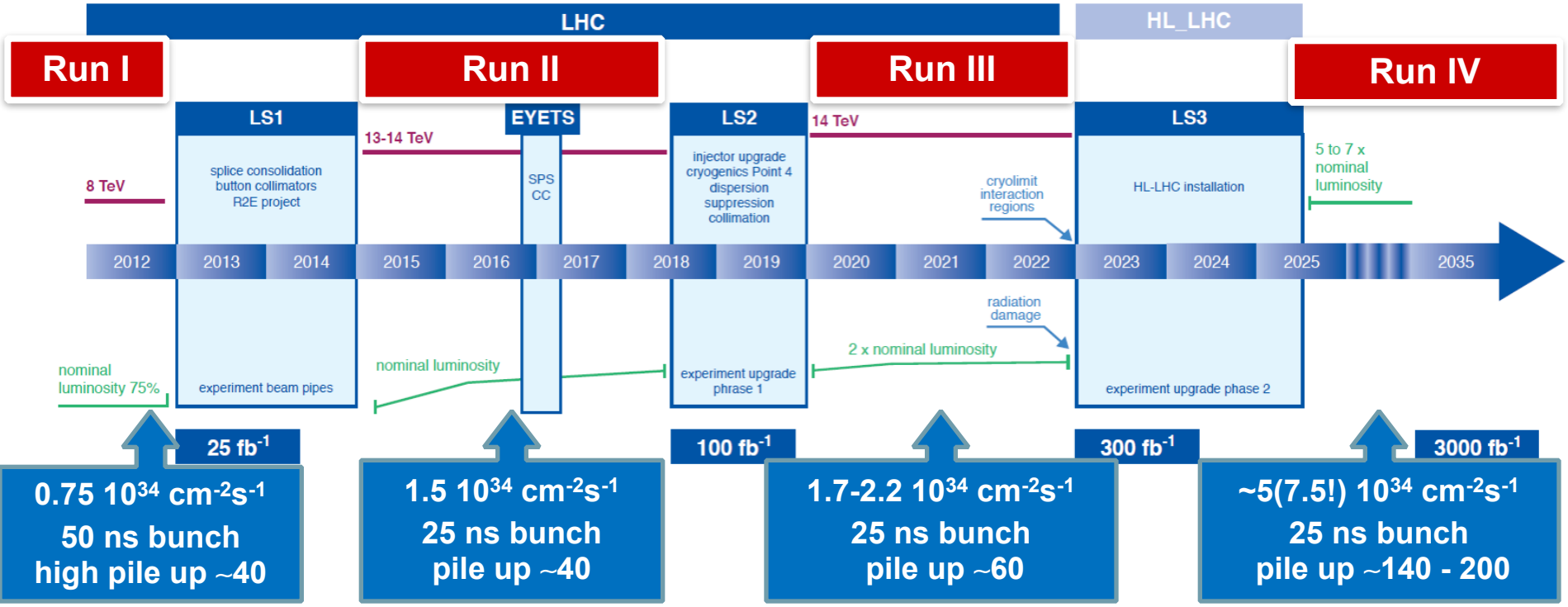


Introduction

- LHC Run 1 was a great success, highlighted by the discovery of the Higgs Boson by ATLAS and CMS
- But this is only the start of the LHC program
- The LHC is about to start a new run at $\sqrt{s}$=13 TeV
  - Will we see evidence of new physics?
  - Can we say something about dark matter?
  - What will we learn from precise measurements of Higgs properties?

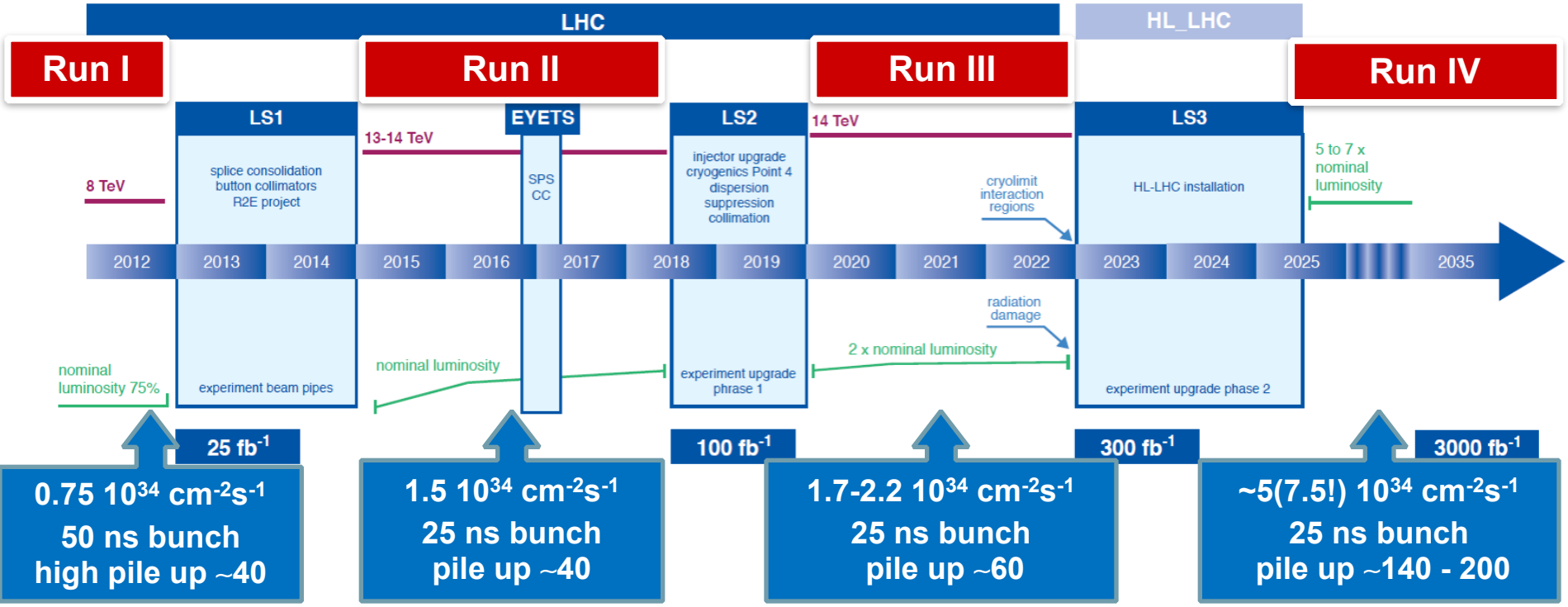


LHC: The Plan



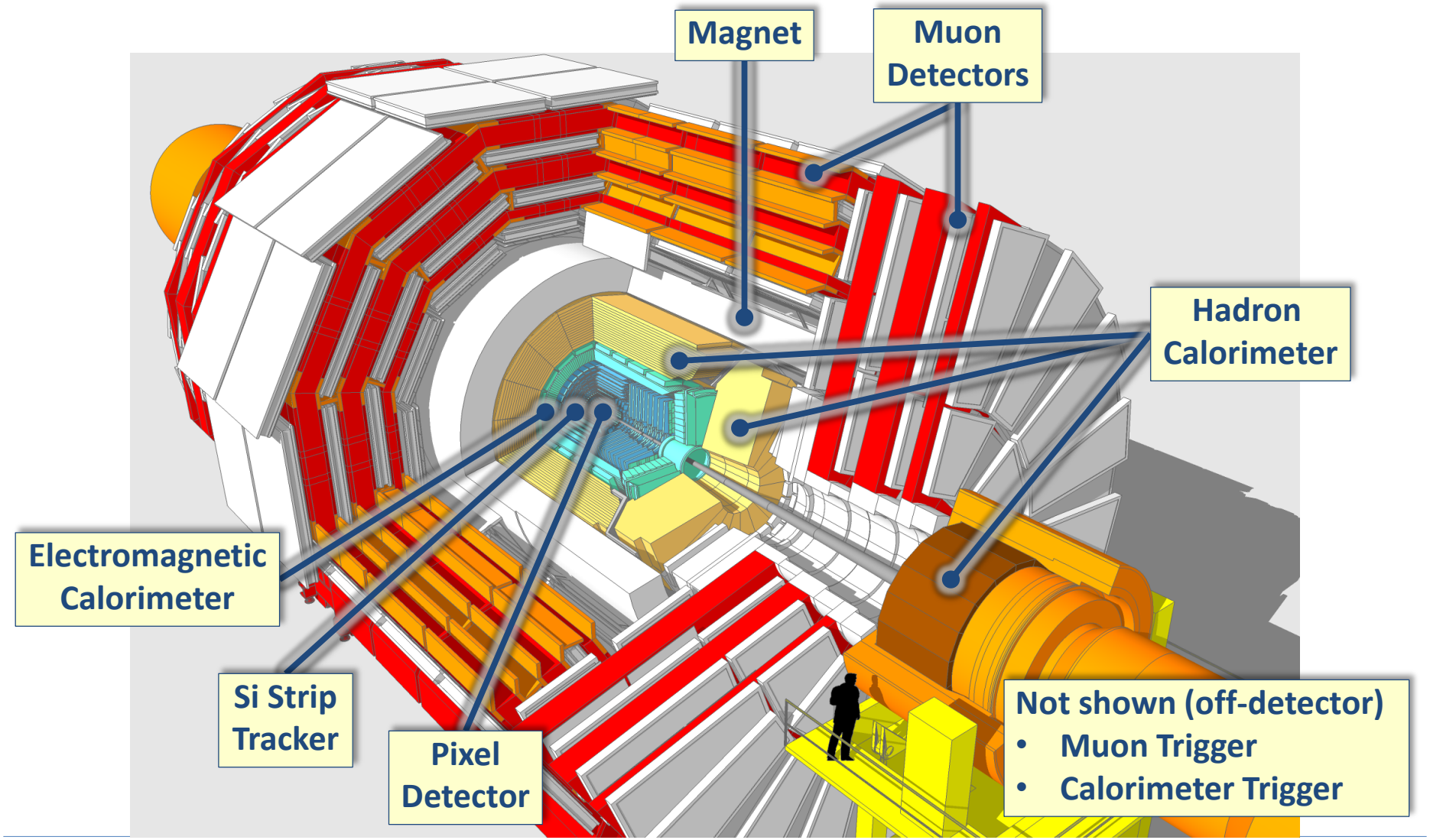
Fermilab

LHC: The Plan



- Two rounds of upgrades with the goal of maintaining the same performance (efficiency, resolution, background rejection) as Run 1
  - Phase 1: ongoing, completed by end of 2nd Long Shutdown (LS2)
  - Phase 2: aimed for HL-LHC operation

CMS Detector



CMS at Fermilab

- Fermilab personnel are currently active in:
  - Analysis of CMS Data
  - Preparation for Run 2
  - Construction of Phase 1 Upgrades and R&D for Phase 2: Hadron Calorimeter, Forward Pixels, Tracker, Trigger
  - Computing - Host of US Tier-1 (largest of all T1s)
  - Core, reconstruction, and simulation software

- In addition, Fermilab:
  - Manages USCMS Operations Program and Upgrade Projects
  - Hosts LHC Physics Center (LPC)
  - Hosts Remote Operations Center (ROC)

Overview of the Group

- CMS collaboration currently has ~2100 authors with ~600 from the US
  - US has the largest national representation in CMS
  - Fermilab is the largest US group and the second largest group overall in CMS

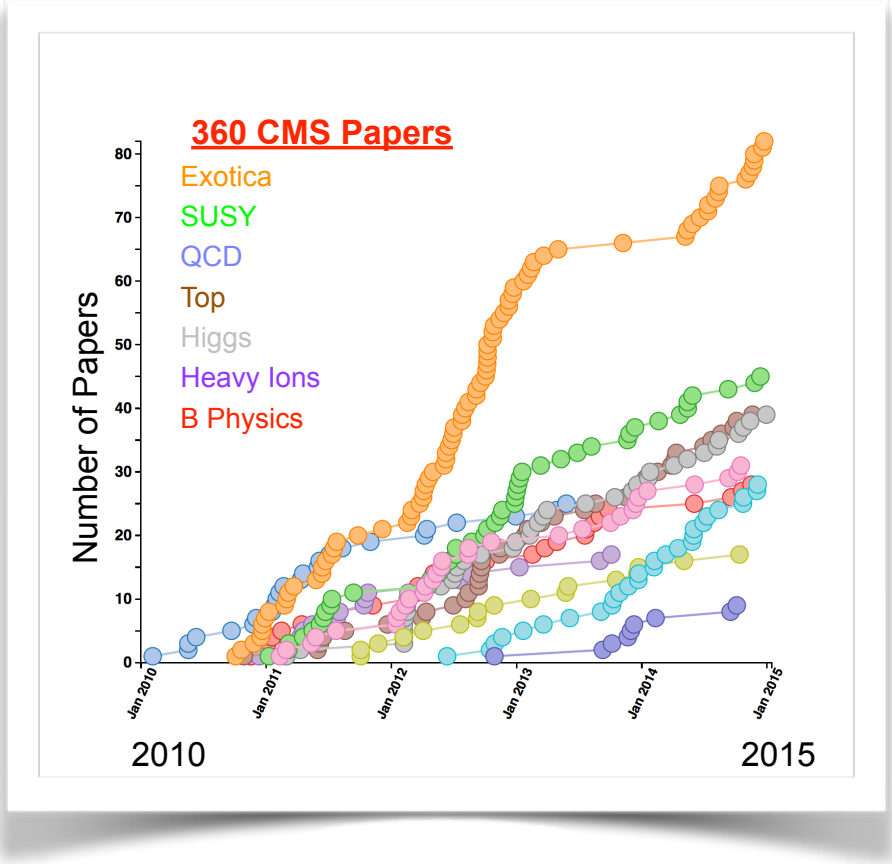
- In 2015 we will have 55 CMS authors (+ 5 emeritus), including 15 postdocs

- Total Fermilab effort (incl. professionals) on CMS is >100 FTE
  - Seamless collaboration of scientists from Particle Physics Division and Scientific Computing Division in analysis
  - Same is true for supervising/mentoring postdocs

Physics in LHC Run 1

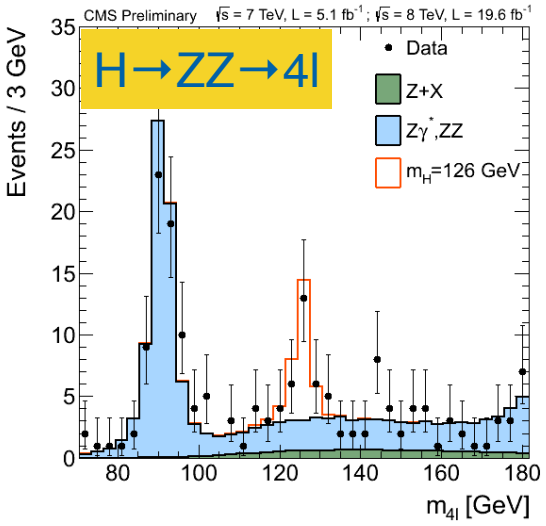
- CMS had great success in Run 1, with over 350 papers published so far

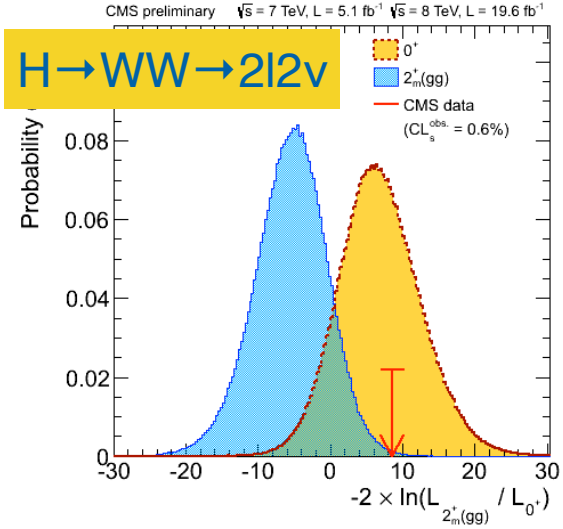
- The efforts of the Fermilab CMS group were focused primarily on:
  - Higgs Physics
  - SUSY Searches
  - Standard Model measurements (esp. EWK, top) as indirect probes of new physics

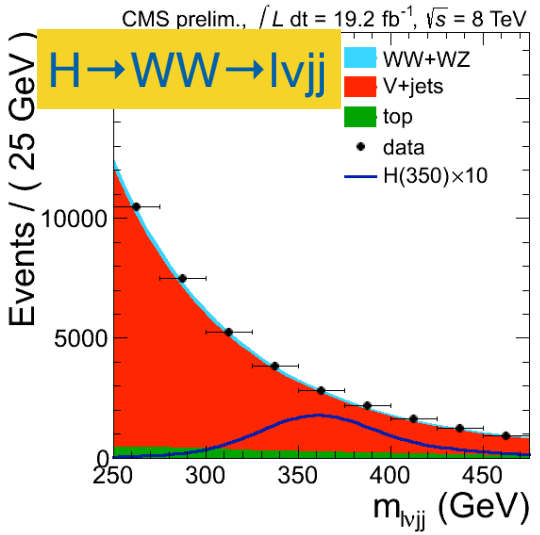


Fermilab Contributions to Higgs Physics

- **H→ZZ→4l**: Kinematic discriminant to separate signal from continuum ZZ background
- **H→WW→2l2v**: Development of spin/parity analysis to test non-SM Higgs
- **H→WW→lvjj**: Sensitive to high mass Higgs

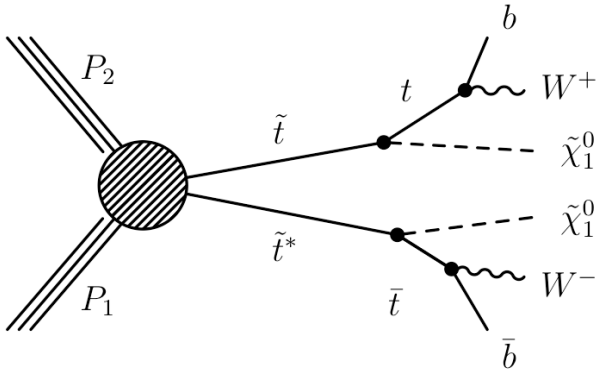


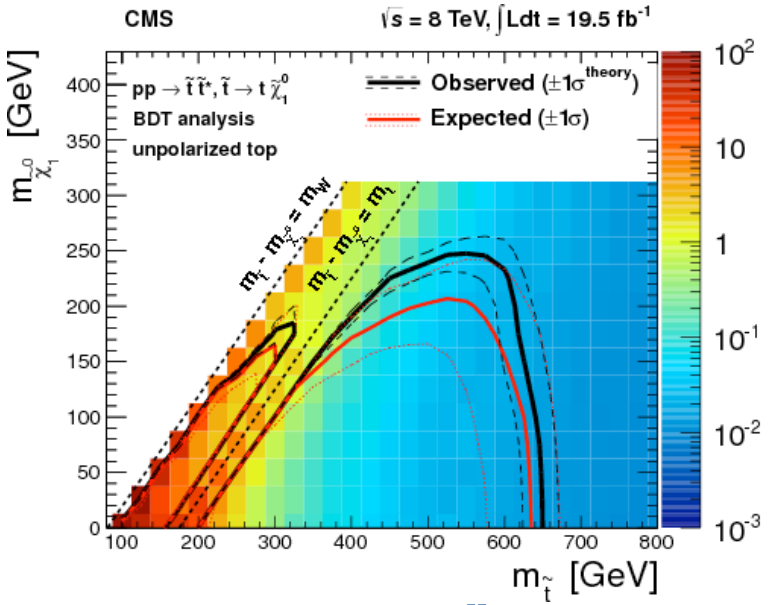




Fermilab Contributions to SUSY Searches

- **Hadronic searches** using all-jets and γ+jets final states
  - Multijet search for squarks and gluinos
  - Direct stop production
- **Leptonic searches** using 1- and 2-lepton final states
  - Inclusive searches with opposite charge dileptons and same charge dileptons
  - Direct stop production in single lepton final state
- Significant LPC collaboration
- Five FNAL group members selected as CMS SUSY subgroup leaders

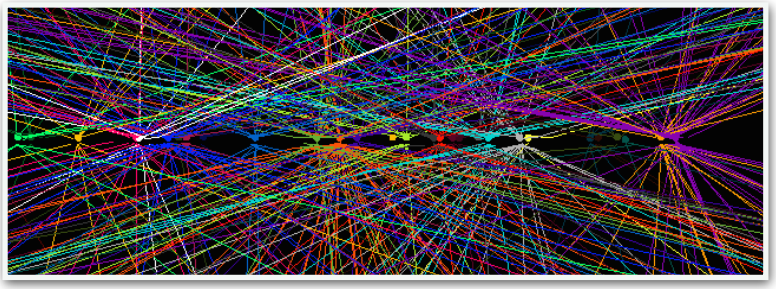




Fermilab

Fermilab Plans for Physics in Run 2

- New tools have been developed in preparation for Run 2
  - Boosted jets - understanding the structure of very energetic jets increases reach of LHC searches
  - New algorithms for pileup removal



- With first data, recommission detector and reconstruction

- **With the increase in the LHC energy, SUSY results will be the most anticipated from early Run 2**

➡ Continue our successful SUSY efforts from the past

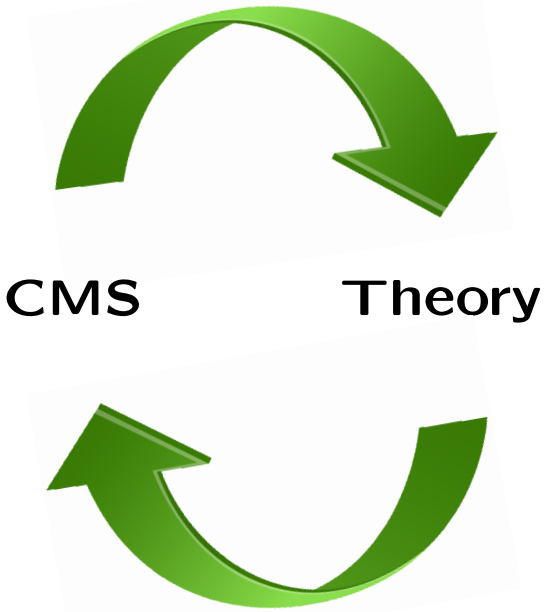
  - Specifically, inclusive multi-jets search and stop searches in both all-hadronic and single lepton channels
  - Analyses have been improved, including the integration of boosted jet techniques, which will be important for many searches even beyond SUSY

- Exotica with a hadronic signature
- Higgs and Vector boson physics - esp. VH(bb) and VV anomalous couplings

Connection with Theory

"These regions of parameter space are now ruled out."

"Your estimate of NNLO corrections provides a poor fit to the data."



"Please extend your search to smaller masses."

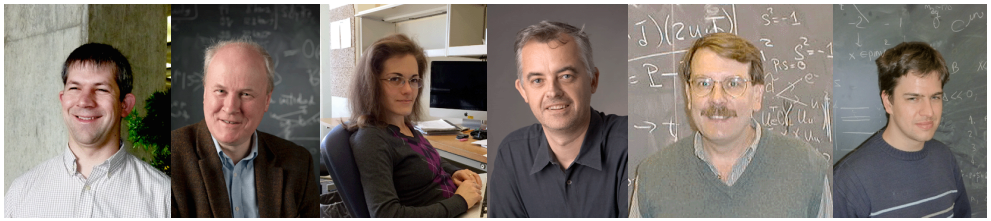
"Here's a type of particle that no one has ever searched for."

Bogdan Dobrescu
"LPC Turns 10" Symposium

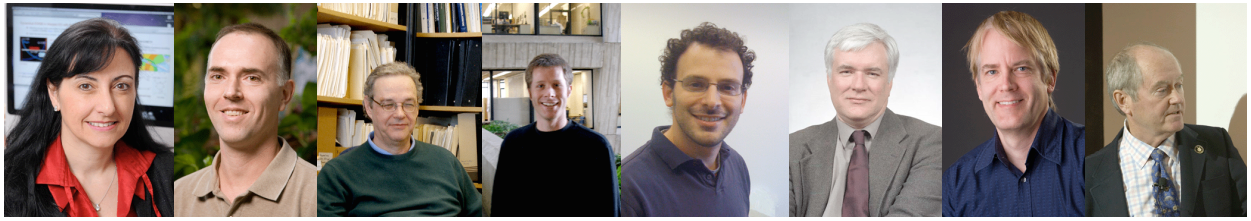
Connection with Theory

Many FNAL theorists making vital contributions to LHC program

QCD, backgrounds: Campbell, Ellis, Furlan, Giele, Parke, Röntsch

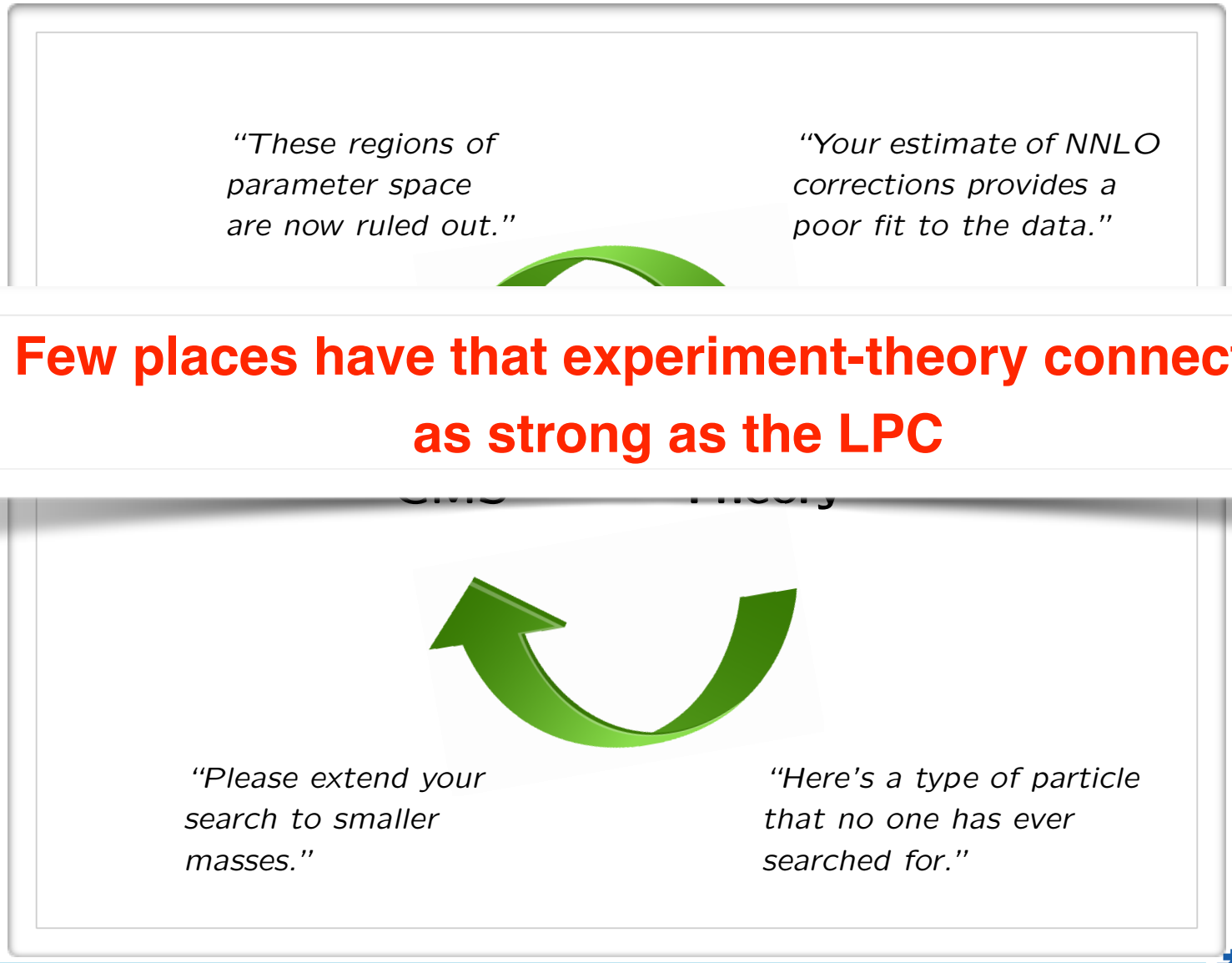


Higgs, Dark Matter, New Particle Searches: Agrawal, Bishara, Carena, Dobrescu, Eicthen, Fox, Frugiuele, Harnik, Hill, Kearney, Lykken, Quigg



➡ J. Campbell's talk this afternoon

Connection with Theory



Few places have that experiment-theory connection as strong as the LPC

Fermilab

LHC Physics Center at Fermilab - LPC

- LPC was founded in 2004 as a regional center for CMS
- Serves as a resource and physics analysis hub, primarily for USCMS
- Housed on 10th and 11th floors of Wilson Hall
  - Proximity to a broad range of CMS expertise in variety of areas under one roof
  - Easy access to Fermilab resources:
    - outstanding computing
    - software support
    - engineering staff, hardware experts
    - theory department

➡A vibrant intellectual community

- Coordinators: Meenakshi Narain (Brown), Boaz Klima (FNAL)

Programs and Activities at the LPC

- The LPC hosts a range of activities for members of CMS and the wider LHC community, including ATLAS and theorists
  - **CMS Data Analysis School (CMSDAS)**
    - 5-day school with hands-on exercises designed to teach new members how to use CMS software and do analysis at CMS
  - **Hands-On Advanced Tutorials (HATS)** - 1-2 day tutorials on a specific topic
  - **Topic of the Week lectures**
    - Visiting scientists give 1-2 seminars on a specific topic related to LHC theory/ phenomenology or experimental methods
    - Organizing committee includes two FNAL theory contacts
  - **Physics Forum**
    - Two scientists leading “blackboard” style discussion
    - “Open” forum pairs a scientist with a theorist
    - “Closed” allows for internal CMS discussion
  - **Coffee chat** - informal discussion once per month

CMS Data Analysis School

9th CMS Data Analysis School

12-16 January 2015 at the Fermilab LPC

This school is designed to teach CMS members how to perform data analyses with the CMS analysis software. The school starts with inspirational plenary lectures, followed by many hands-on short tutorials and long physics exercises.

The focus of this school is "Preparation for Run2 Physics"

Organizing Committee: Boaz Klima, Sudhir Malik, Meenakshi Narain

Plenary Lectures:
Welcome: Boaz Klima (Fermilab)
The CMS Data Analysis School: Sudhir Malik (UPRM)
The CMS Detector: Tiziano Camporesi (CERN)
The LHC: Chandrashekhara Bhat (Fermilab)
The Big Picture: Natalia Toro (Perimeter Institute)
CMS Physics & Outlook: Jim Olsen (Princeton University)
CMS Software, Computing Model and Analysis Tools: Maria Girone (CERN)
Closeout: Meenakshi Narain (Brown University)

Short Exercises (Physics Objects/Tools):
Triggers, Electrons, Photons, Muons,
Jets, Missing Et, Pile-up, Tracking,
b-tagging, Generators,
Event displays,
Statistics

Long Exercises (Physics Analysis):
Heavy T5/3 search with same-sign dileptons
SUSY: razor search with jet substructure
$Z'/t\bar{t}$ resonances with jet substructure
Dark matter searches with photons
SUSY searches (hadronic modes)
Exotica with displaced vertices
Higgs properties, Higgs → $b\bar{b}$
Exotica with boosted jets
Dijet resonances

Facilitators:
J. Antonelli (*OSU*), A. Apresyan (*Caltech*), A. Askew (*FSU*), A. Avetisyan (*BU*), S. Bein (*FSU*), G. Benelli (*KU*), T. Bose (*BU*), A. Cakir (*DESY*), G. Cerati (*UCSD*), S. Das (*Florida*), J. Dolen (*Buffalo*), D. Duggan (*Rutgers*), P. Dudero (*TTU*), D. Ferencek (*Rutgers*), R. P. Gandrajula (*Iowa*), C. Gerber (*UIC*), F. Golf (*UCSB*), B. Gomber (*UW*), R. Harris (*FNAL*), M. Hildreth (*Notre Dame*), Z. Hu (*Fermilab*), A. Kalsi (*Punjab*), S. Khalil (*KSU*), F. Lacroix (*UCR*), G. Landsberg (*Brown*), H. Liu (Baylor), S. Malik (*UPRM*), S. Mrenna (*FNAL*), M. Narain (*Brown*), N. Neumeister (*Purdue*), A. Perloff (*Texas A&M*), J. Pilot (*UC Davis*), D. Rankin (*BU*), C. Richardson (*BU*), S. Rappoccio (*Buffalo*), L. K. Saini (*KSU*), D. Sandoval (*UIC*), A. Santra (*FSU*), S. Sekmen (*CERN*), J. Stupak (*Purdue/Calumet*), N. Tran(*FNAL*), S. Toda (*KSU*), P. Turner (*UIC*), C. Vernieri (*FNAL*), J.-R. Vlimant (*CalTech*), M. Weinberg (*FSU*), Y. Wen (*Peking Univ.*), A. Whitbeck (*Fermilab*), F. Yumiceva (*Florida Tech*)

LPC Support: Jesus Orduna, Zhenbin Wu
Administrative Support: Carrie Farver, Terry Grozis, Terry Read, Sonya Wright

Photo CERN

~120 attendees

Past Topic of the Week Speakers

	THEORY	
Nathaniel Craig (IAS)	Ian Low (Northwestern, ANL)	Andrzej Siodmok (Karlsruhe)
Hooman Davoudiasl (BNL)	Markus Luty (UC Davis)	Michael Spannowsky (Durham)
Sally Dawson (BNL)	Konstantin Matchev (Florida)	Matt Strassler (Rutgers)
Bogdan Dobrescu (FNAL)	Michele Papucci (LBL)	Zack Sullivan (IIT)
Steve Ellis (U. Washington)	Maxim Perelstein (Cornell)	Raman Sundrum (Maryland)
Jared Evans (Rutgers)	Michael Peskin (SLAC)	Tim Tait (UC Irvine)
Jonathan Feng (Irvine)	Frank Petriello (Northwestern, ANL)	Jesse Thaler (MIT)
Roni Harnik (FNAL)	Markus Schulze (ANL)	Natalia Toro (Perimeter Institute)
Yevgeny Kats (Rutgers)	Yael Shadmi (IIT)	Chris Vermilion (Louisville)
Can Kilic (UTexas)	David Shih (Rutgers)	Liantao Wang (UChicago)

Past Topic of the Week Speakers

	EXPERIMENT	
Juan Alcaraz (CIEMAT)	Daniel Elvira (FNAL)	Sanjay Padhi (UCSD)
Artur Apresyan (CalTech)	Paolo Giacomelli (INFN,Bologna)	Alexander Paramonov (ANL)
Pushpa Bhat (FNAL)	Marcus Hohlmann (FIT)	Anton Poluektov (Warwick)
Antonio Boveia (UChicago)	Deepak Kar (Glasgow)	Harrison Prosper (FSU)
Sara Bolognesi (JHU)	Evan Friis (Wisconsin)	Ricardo Vasquez Sierra (Davis)
Adolf Bornheim (CalTech)	Ben Kilminster (Zurich)	Thomas Speer (Brown)
Oliver Buchmueller (Imperial College London)	Andrey Korytov (Florida)	Roberto Tenchini (Sezione di Pisa)
Claudio Campagnari (UCSB)	Christos Leonidopoulos (Edinburgh)	Mayda Velasco (Northwestern)
Tiziano Camporesi (CERN)	Hugh Lippincott (FNAL)	Si Xie (CalTech)
Frank Chlebana (FNAL)	Ted Liu (Fermilab)	Roger Wolf (MIT)
Bob Cousins (UCLA)	Steven Lowette (UCSB)	Steve Worm (RAL)
Albert De Roeck (CERN)	William Murray (STFC Warwick)	

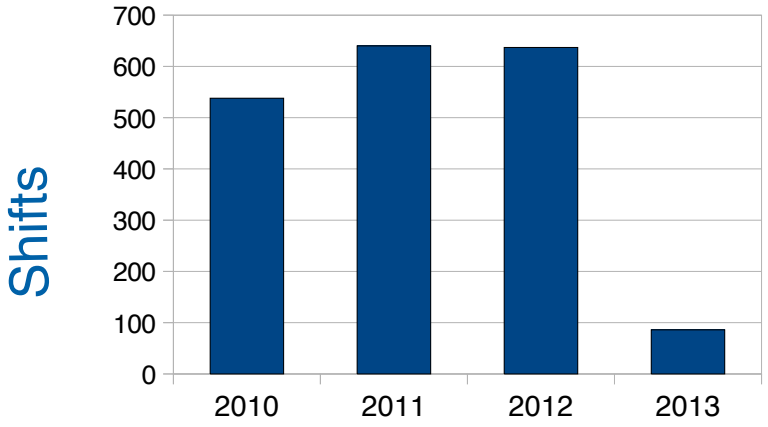
Programs and Activities at the LPC

- Attract key scientists to spend time at LPC
  - **CMS Distinguished Researchers**
    - Current and future leaders, responsible for projects at LPC and in CMS
    - Provides support and some travel funding for ~50% time at LPC
    - 37 DRs awarded in the last two years, with a roughly 2:1 ratio of junior (postdoc) to senior (faculty)
  - **Guest & Visitors**
    - Facilitates CMS members to spend time at the LPC working on projects (hardware/software/physics) that advance, enrich, and impact CMS
    - Two calls for proposals each year
    - 36 proposals funded in FY14

Remote Operations Center

- ROC established in 2007
  - (2008: Centers at CERN Meyrin, DESY)
- Participation in commissioning, first beam, and steady data taking

- Shift Activities
  - 50% of all CMS Offline DQM shifts
  - Online DQM shifts during commissioning
  - Tracker, HCAL subsystem shifts
  - Tier-1 primary shifts, computing shifts



- Between 2/15/10 and 2/18/13, 1901 Offline DQM shifts were taken at the Fermilab ROC by individuals from ~25 U.S. Inst. + Mexico
  - Integrate into CMS operations while saving on travel expenses
  - Already in use during cosmic runs in preparation for Run 2

Fermilab Strategy for Upgrades

- Overall strategy is to build on past strength and expertise, choose projects that are important to USCMS, and partner with USCMS colleagues to increase the impact of their contributions

  - Past experience: HCAL, Tracker/FPIX, Trigger
  - Resident expertise: ASIC engineering
  - Take advantage of unique FNAL facilities
    - Test beam, SiDet, LPC, ROC
  - Connect to simulation and reconstruction software expertise to optimize design through MC studies

Forward Pixels, Tracker

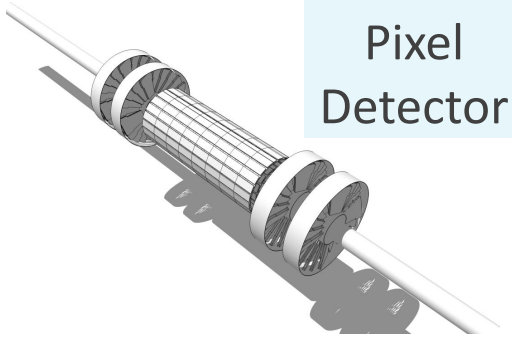
- **CMS Tracking effort at Fermilab has included a diverse set of activities:**
  - detector construction, operations, offline calibration and reconstruction, detector R&D
  - Silicon detector activities focused around SiDet facility

  - Construction of present FPIX detector was centered at SiDet, as well as construction of Tracker Outer Barrel modules
  - Engineers, technicians from SiDet serviced FPIX during the past shutdown to recover modules that were not operating correctly

Forward Pixels, Tracker - Upgrades

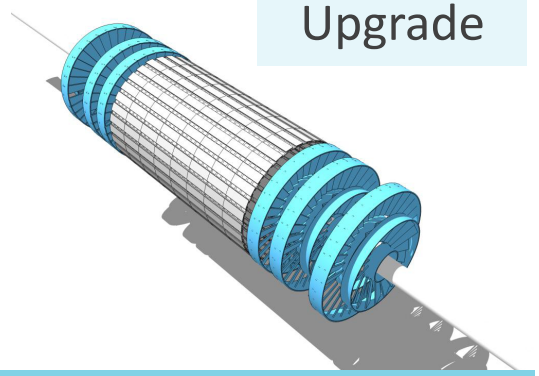
- **Leading and hosting construction of Phase 1 FPIX upgrade**
  - Responsible for new CO_2 cooling and low mass carbon fiber support, module electronics
  - Detector components will be tested, graded, assembled into final detector at SiDet, by teams of FNAL scientists and university collaborators

Current Pixel Detector



- **R&D underway for Phase 2 Tracker and FPIX**
  - Work at FNAL includes
    - sensor design
    - readout circuit development
    - beam tests of sensors and readout chips
    - development of mechanical and thermal support structures
  - Final scope of US, FNAL involvement still discussion

Upgrade



FPIX: Buffalo, Colorado, Cornell, FNAL, KSU, Kansas, Mississippi, Nebraska, Purdue, Purdue-Calumet, Rice, Rutgers, UC Davis, UC Riverside, UIC, Vanderbilt

Hadron Calorimeter

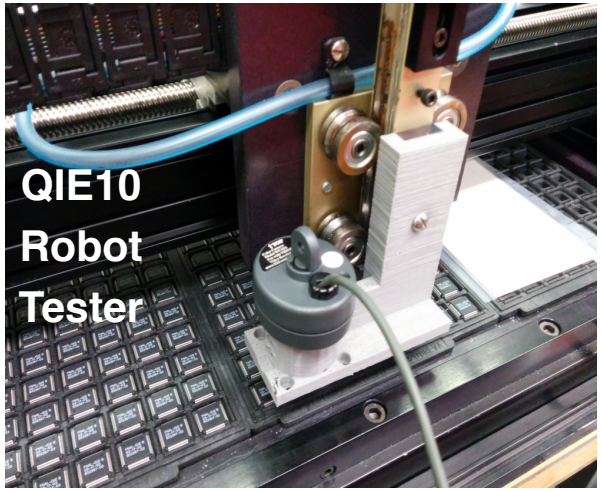
- **FNAL group has a long history in HCAL for CMS, covering the full spectrum from detector to analysis**
  - Development of QIE readout chips and electronics
  - Active in operations, detector performance, and management (project manager, convener of Detector Performance Group)
  - US collaborators in HCAL Detector Performance Group have worked closely on software development with LPC experts
  - Significant use of ROC for remote monitoring shifts during Run 1
  - Commissioning of Jet and Missing E_T reconstruction
  - Physics analysis: dijet resonances, hadronic SUSY

- In preparation for Run 2, developing improved reconstruction techniques for 25ns LHC operation

Hadron Calorimeter - Upgrades

- **Phase I upgrades improve photo-detectors, readout electronics**
  - HPDs replaced by SiPMs
    - Pioneered SiPM-based readout
    - Coordinated SiPM installation effort during LS1
  - Continuing development of next gen QIE chip

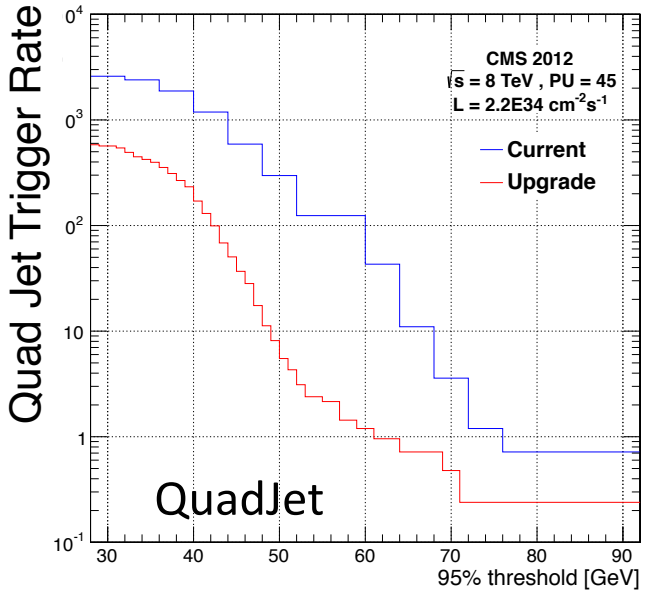
  ➡ DOE Early Career Award
  - Readout electronics and cooling and mechanics of readout boxes

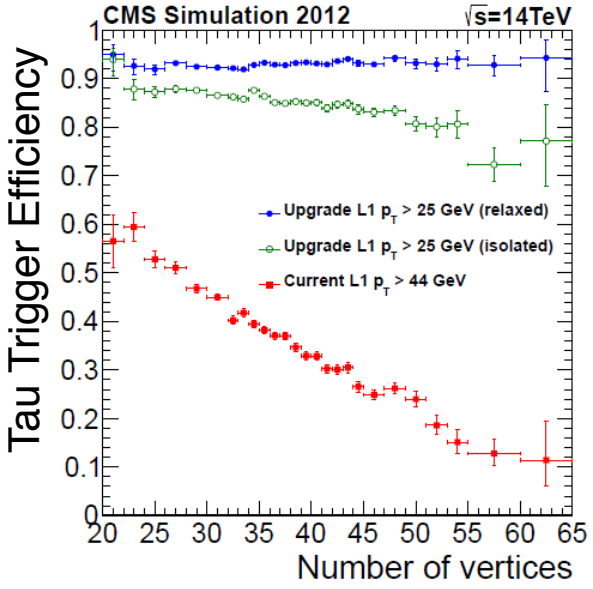


- **CMS is about to make the technology choice for Phase 2**
  - *Regardless of the choice, FNAL is eager to have a significant role*
    - Front-end electronics, scintillator development
    - Sensor development, mechanics, cooling for one option
    - Tight connection to simulation effort for optimization of detector design and reconstruction

Trigger

- **Maximize Level 1 Trigger performance in 2015**
  - Global Calorimeter Trigger reconstructs jets, energy sums, τ, e/γ
  - New hardware uses single, powerful Virtex 7 FPGA
    - can use improved algorithms for pileup subtraction, tau clustering
    - collab. w/US (MIT, Rice, UIC, Wisconsin) and UK(Bristol, Imperial, RAL)
  - FNAL scientists, engineers responsible for new FPGA firmware

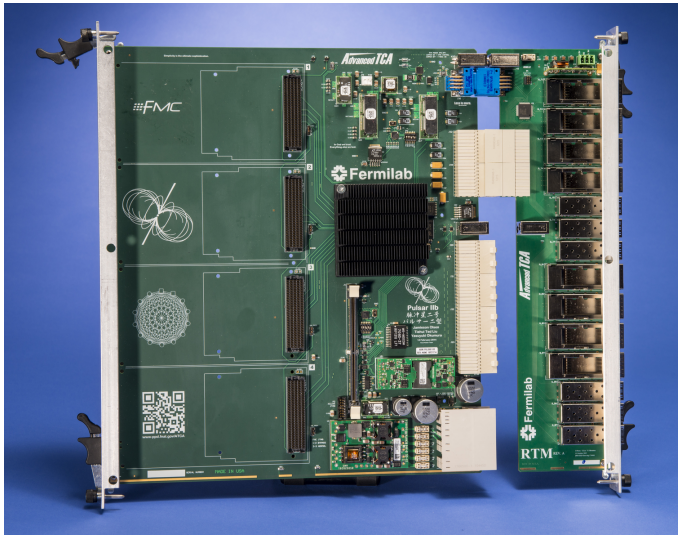




Fermilab

Trigger - Upgrades

- Adding tracking to L1 trigger is mandatory for Phase-II
- FNAL is leading R&D on implementation of tracking in L1
  - Pursuing associative memory approach for pattern recognition (CDF SVT and ATLAS FTK)
    - Collab. w/Florida, Northwestern, Texas A&M, Lyon, INFN, Brazil
    - New hardware under development using same Virtex 7 FPGA
    - Custom ASIC needed w/higher speed, increased pattern density
      - First VIPRAM chip designed, produced, tested by FNAL engineers, scientists in 2014
  - Demonstration system targeted for late 2016
    - Mandatory to finalize Phase-II tracker design



Upgrade Work Spans the Entire Lab

- **Fermilab engineering is a key to the success of all upgrades**
  - ASIC development for HCAL QIE, VIPRAM for track trigger
  - Readout electronics for HCAL, FPIX
  - FPGA programming for Trigger
  - Cooling, mechanical support for FPIX, HCAL
- **SiDet Expertise**
  - Organizing FPIX assembly
  - Key for prototyping, testing modules for FPIX, Tracker
  - Significant potential for module production for Phase 2
- **Extensive use of Test Beam Facility**
  - Qualification of electronics for HCAL, FPIX
  - Scintillator R&D for HCAL
  - High rate tests of new sensors, chips for FPIX, Tracker
- **Synergy with reconstruction and simulation software expertise in SCD**
- **Leaders in upgrade R&D are part of lab's Detector R&D organization**
  ➡ See E. Ramberg's talk

Fermilab

Software & Computing: Core Software

- **FNAL is involved in all aspects of maintaining, evolving the computing and software infrastructure for Run 2 and beyond:**
  - Core software
  - Simulation
  - Computing Infrastructure Software
  - CMS Tier-1 Site Support
  - LPC Analysis cluster

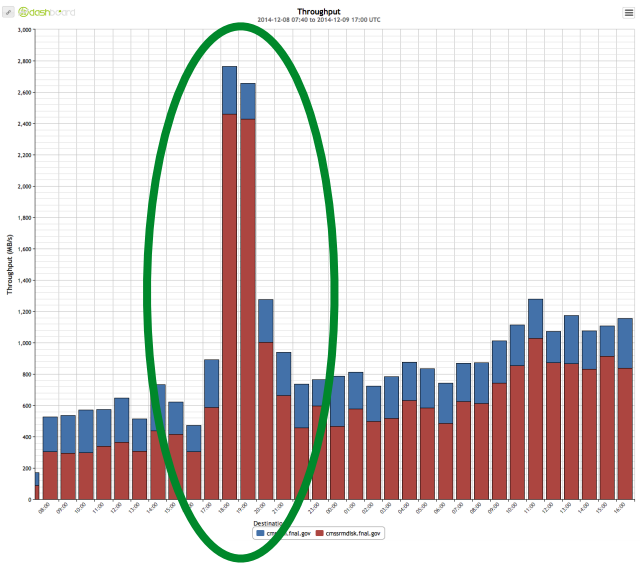
- **Simulation**
  - FNAL leads Phase 2 simulation software infrastructure development
    - Implementation of full geometry, detector simulation, electronics, pileup
    - Benefit from large FNAL Geant4 development, support team
    - Synergy with local HCAL effort
  - Significant resident Pythia expertise

Software & Computing: Tier-1 and LPC

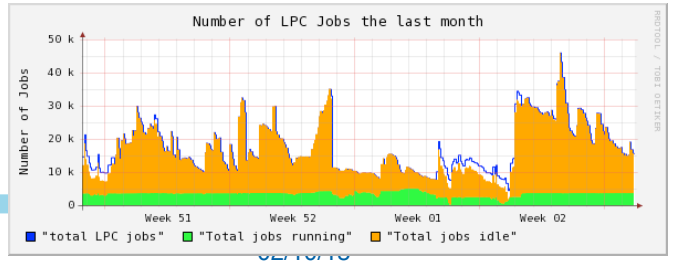
- **USCMS Tier-1 and Central Computing Ops**
  - FNAL is home to the US CMS Tier-1 site, most reliably available CMS Tier-1 site in the world.
    - Outstanding support from SCD professionals
    - CMS relies on FNAL for the most difficult tasks
    - Work of FNAL experts has been a key to enabling CMS to rapidly and efficiently extract physics results from the recorded and simulated events.

- **Analysis facilities at the LPC**
  - USCMS physicists rely heavily on interactive and batch computing resources at the LPC analysis facility.
  - Supported by experts from the Tier-1 team and the software and computing development and operations teams

Transfer capabilities from CERN to FNAL: reached 3 GB/s for couple of hours



LPC batch facility in high demand, always lots of pending jobs



LHC Accelerator R&D Program

- Fermilab has been collaborating with other US labs at part of LARP since its inception in 2003
- Major goal is the design of the low-β quads for HL-LHC
- Short term goal of building and testing full aperture prototypes and developing needed tooling
- Expect HL-LHC Upgrade project to start in 2018 with FNAL working on construction and testing of cold masses for IR quads

- **See talks by H. Padamsee, S. Nagaitsev, and G. Apollinari (breakout) for details**

Summary

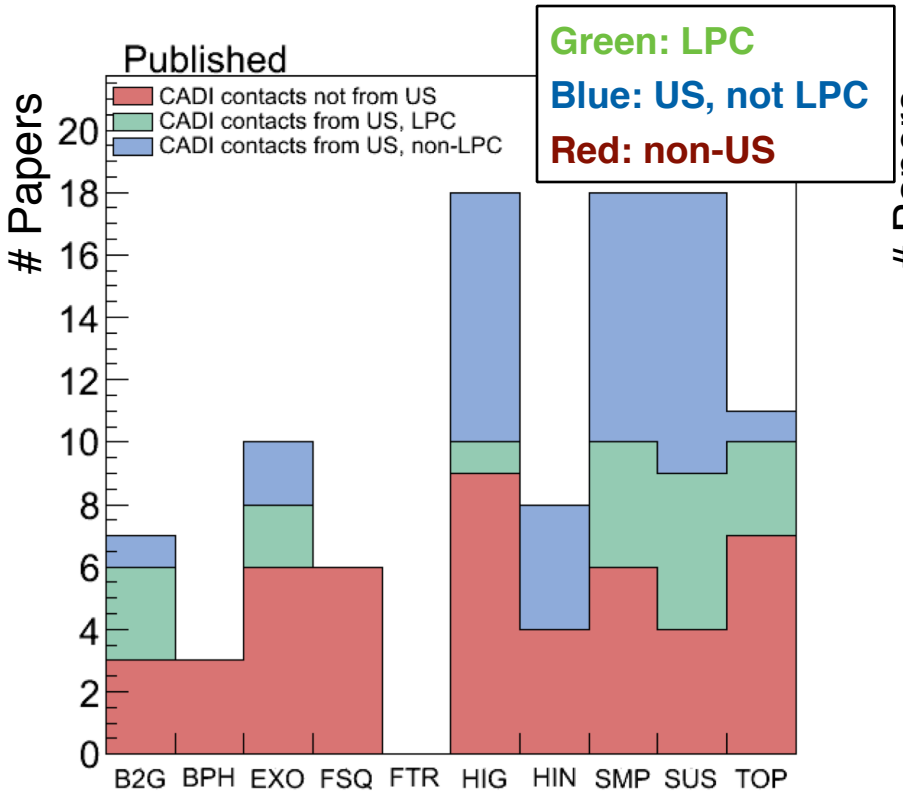
- Run 1 at the LHC was a great success for CMS and also for the CMS effort at Fermilab
- We are now busy with preparation for Run 2 physics, construction of the Phase 1 upgrades, and R&D for the Phase 2 upgrades, plus software and computing for CMS
- These activities depend on contributions from divisions across the lab
- The LPC and the ROC, hosted by FNAL, have both been successful in creating a hub of activity within the US, increasing the impact of USCMS physicists, and creating a tight connection with the theory group and wider theory community
- Our analysis activities, upgrade work, and hosting of these facilities are all well-aligned with the priorities from P5

Fermilab

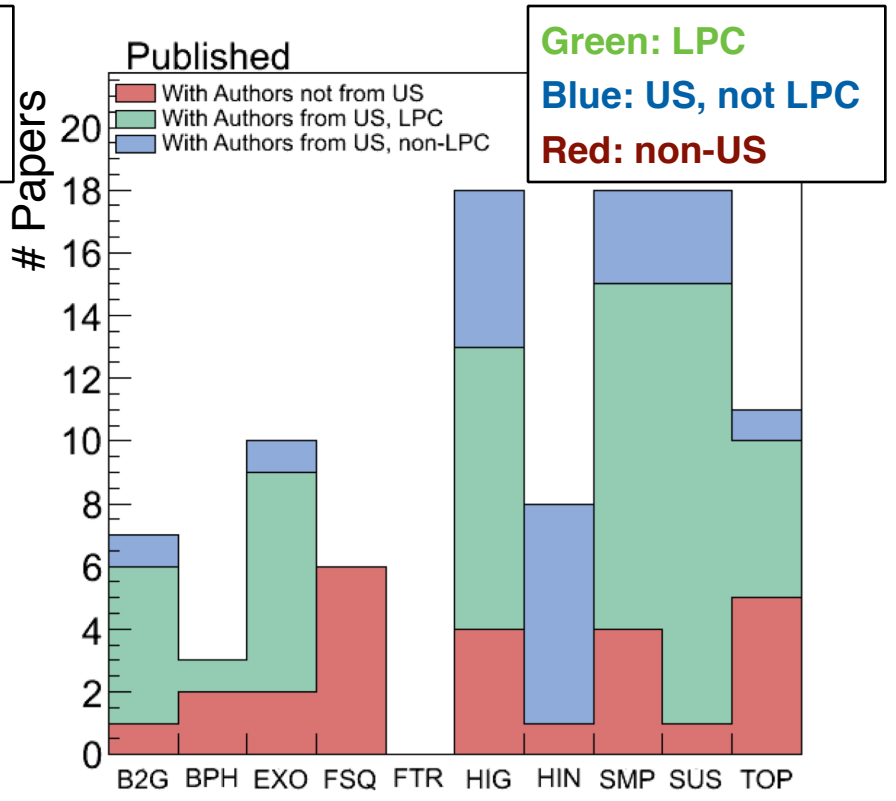
BACKUP MATERIAL

Physics Impact of the LPC

- Use CMS analysis database to study LPC connections
  - "Analysis Contact" for paper
  - Author of supporting notes



Contact in 18% of pubs



Contributing to 52% of pubs

Fermilab

Conveners…

- **SUSY (Five Subgroup Conveners)**
  - Ben Hooberman (SUSY in lepton channel, 2012-13)
  - Dave Mason (SUSY in photon channel, 2012-13)
  - Rick Cavanaugh (SUSY in 3rd Generation, 2012-13)
  - Daniel Elvira (SUSY in Hadronic channel, 2009-10)
  - Seema Sharma (SUSY in Hadronic channel, 2014-15)
- **Standard Model (Three PAG and three subgroup conveners)**
  - Vivian O'Dell (QCD Convener, 2008-9)
  - Kostas Kousouris (QCD and Standard Model Convener, 2011-12)
  - Jeff Berryhill (Standard Model Convener, 2012-13)
  - Vasu Chetluru (QCD Photon Subgroup, 2009-10)
  - Slawek Tkaczyk (SMP Boson subgroup, 2012-13)
  - Jacob Linacre (Top Properties subgroup, 2013-14)
- **Exotica (Four Subgroup Conveners)**
  - Jim Hirschauer (Exotica Lepton+Jets, 2012-13)
  - Keti Kaadze (Exotica Lepton + Jets, 2014-15)
  - Robert Harris (Exotica Multijets, 2012-13)
  - Steve Mrenna (Monte Carlo Interpretations, 2014-15)
- **Objects (Four POG and five subgroup conveners)**
  - Kevin Burkett (Tracking Convener, 2008-09)
  - Daniel Elvira (JetMET Convener, 2008-09)
  - Robert Harris (JetMET Convener, 2010-11)
  - Lindsey Gray (Electron/Photon Convener, 2014-15)
  - Robert Harris (JetMET Jet Energy Correction Subgroup, 2008-09)
  - Kostas Kousouris (JetMET, Jet Energy Correction Subgroup, 2010)
  - Niki Saoulidou (JetMET, Jet Algorithms Subgroup, 2011-12)
  - Lindsey Gray (Photon Subgroup, 2013)
  - Nhan Tran (JetMET Algorithms and Reconstruction Subgroup, 2013-14)

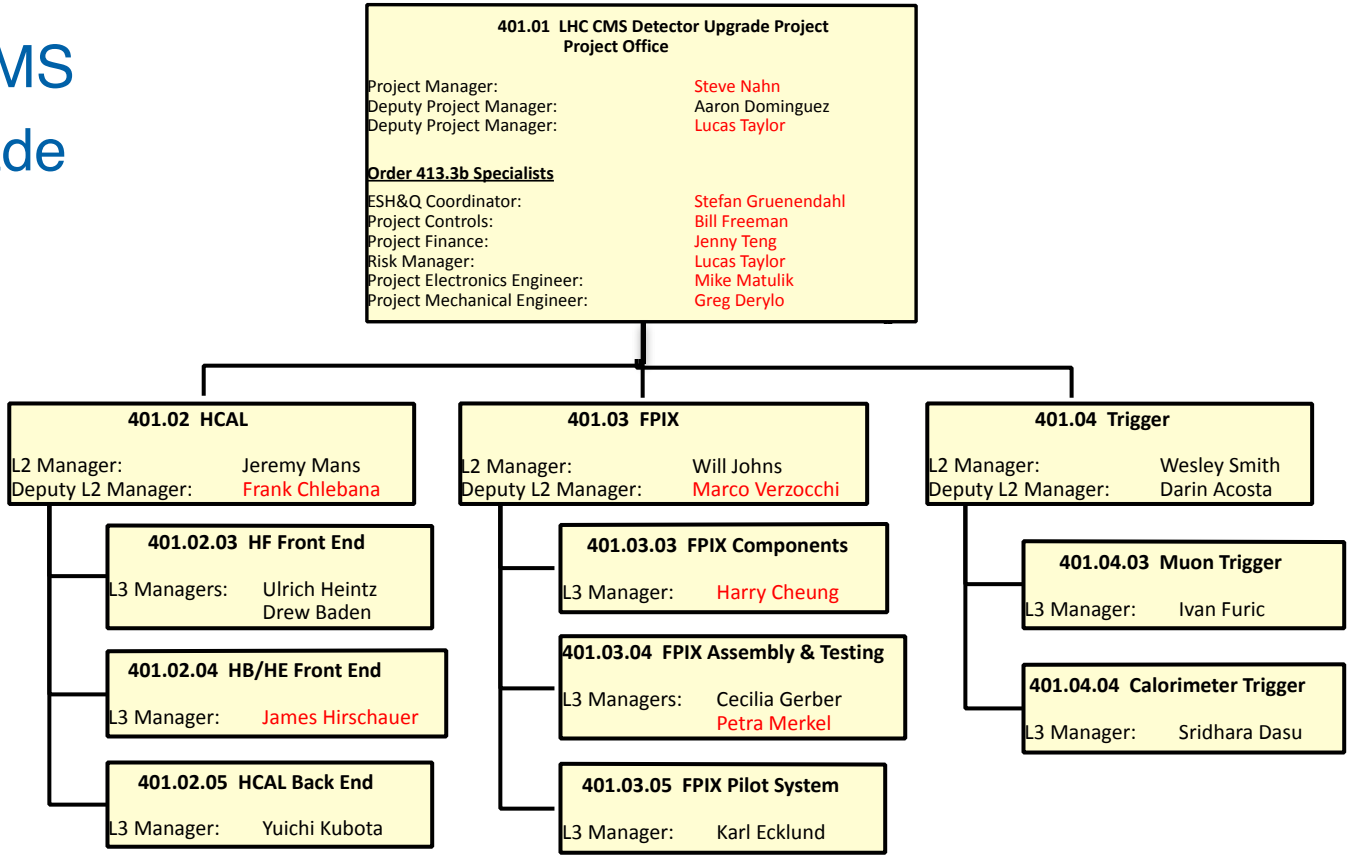
Current Positions of Past FNAL Postdocs

Jake Anderson	*Data Scientist, Pearson Education Software*
Ingo Bloch	*DESY Staff*
Vasundhara Chetluru	*Data Scientist, Jump Trading*
Yanyan Gao	*Postdoc, U. of Edinburgh*
Oliver Gutsche	*Scientist, SCD, Fermilab*
Jim Hirschauer	*Wilson Fellow, PPD, Fermilab*
Benjamin Hooberman	*Asst. Professor, UIUC*
Ketino Kaadze	*Asst. Professor, Kansas State*
Konstantinos Kousouris	*CERN Staff*
Verena Martinez Outschoorn	*Asst. Professor, UIUC*
Dave Mason	*Applications Physicist, SCD, Fermilab*
Kalanand Mishra	*Data Scientist, Vectra Networks*
Carsten Noeding	*System & Flight Safety Engineer, Northrop Grumman*
Seema Sharma	*Asst. Professor, IISER Pune India*
Ping Tan	*Postdoc, University of Iowa*
Lorenzo Uplegger	*Applications Physicist, SCD, Fermilab*
Fan Yang	*Trader, Quantitative Analyst, White Bay PT LLC, NY*
Francisco Yumiceva	*Asst. Professor, Florida Institute of Technology*

Project Management

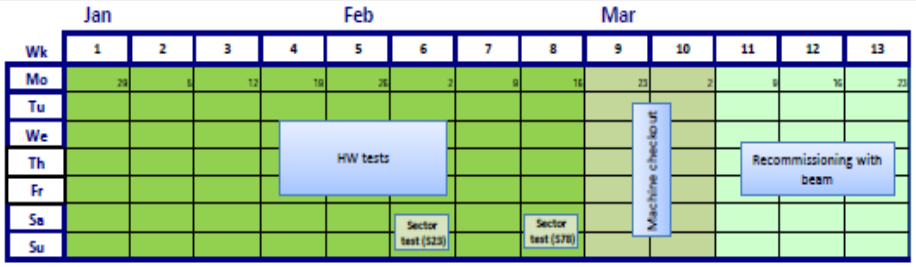
Fermilab hosts USCMS Operations Program and Upgrade Projects with close collaboration of universities

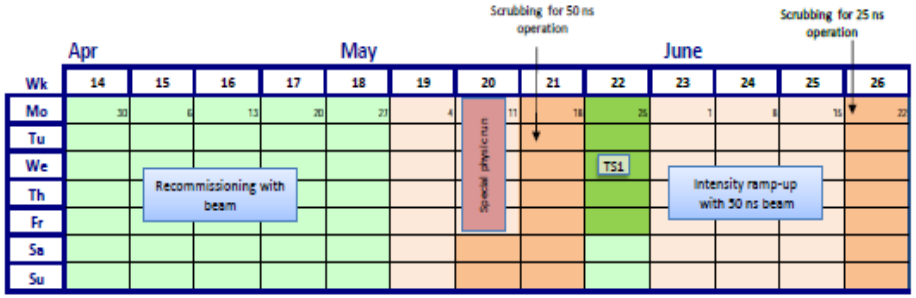
Example: USCMS Phase 1 Upgrade Project



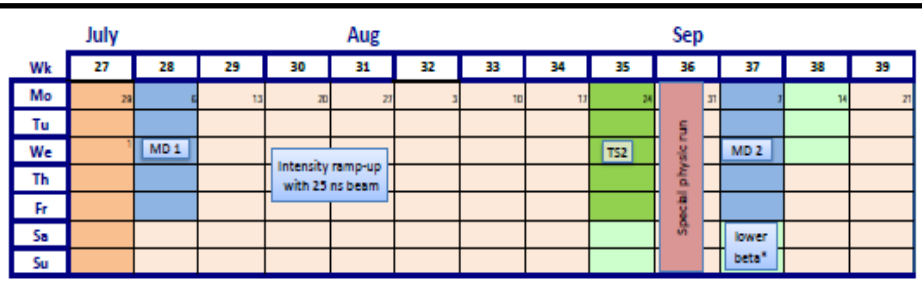
LHC Plan for 2015

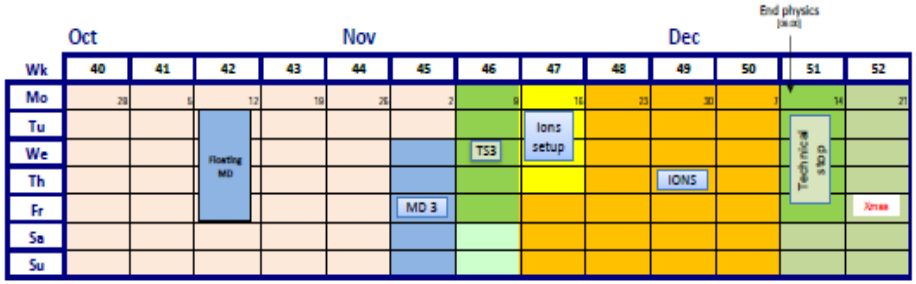
January-June





July-December





Period	N_{bunch} [10^{11}]	ε* [μm]	k	β* [cm]	L [$cm^{-2}s^{-1}$]	<μ>	Days(*)	∫L [fb^{-1}]
50 ns	1.2	2.2	≈1370	80	5.3×10^{33}	30	21	≈1
25 ns / 1	1.2	2.5	≈2500	80	8.1×10^{33}	26	44	≈4
25 ns / 2	1.2	2.5	≈2500	**40**	14.7×10^{33}	45	46	≈13

2015 LPC Distinguished Researchers

SENIOR RESEARCHERS		JUNIOR RESEARCHERS	
Cecilia Gerber	*UIC*	*Artur Apresyan*	*CalTech*
Greg Landsberg	*Brown*	*Gabriele Benelli*	*Kansas*
Martin Mulders	*CERN*	*Giuseppe Cerati*	*UCSD*
Sal Rappoccio	*Buffalo*	*Souvik Das*	*Florida*
Roger Rusack	*Minnesota*	*Phil Dudero*	*Texas Tech*
		Dan Duggan	*Rutgers*
		Sadia Khalil	*Kansas State*
		Hongxuan Liu	*Baylor*
		Maurizio Pierini	*CalTech*
		John Stupak	*Purdue-Calumet*

Summary of 2014 LPC Activities

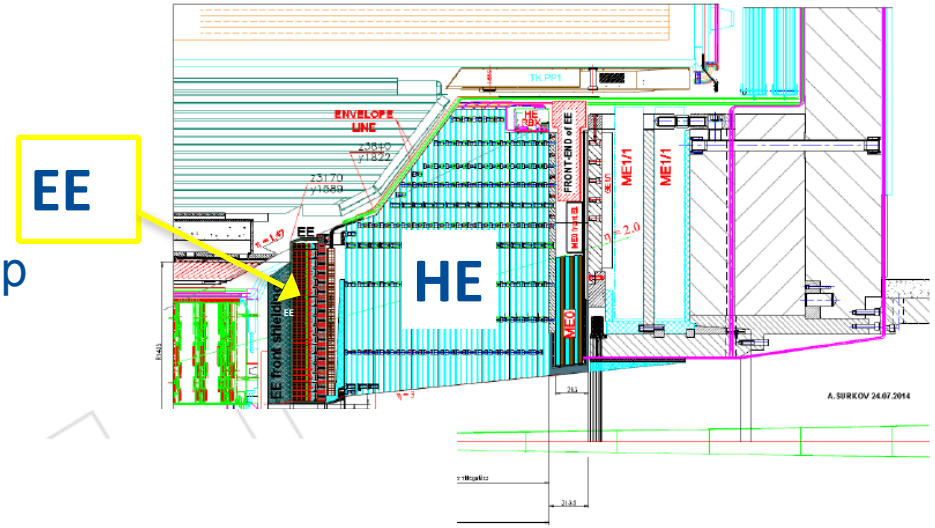
- CMSDAS – 1
- Workshops – 8
  - CMS only – 6 (JME, TP, HCAL, Trig/Track, B2G, SUSY)
  - Global – 2 (BSM Higgs, Future Colliders)
- HATS – 11
  - ID – 4 (e, ET, b-tag, Jet-substructure)
  - Upgrade – 3 (Calo, Tracker, Trigger)
  - Tools – 4 (Statistics, Roostat, CRAB3, Delphes)
- TOTW – 19
- PF – 17
- CH – 9

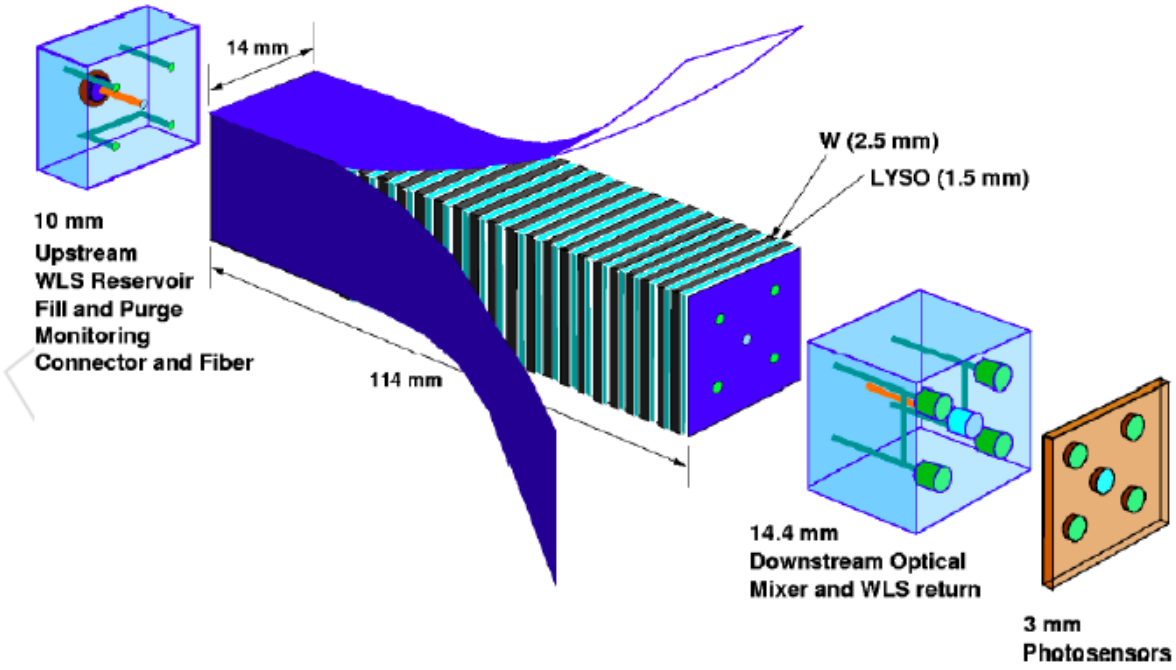
Endcap Calorimeter Options

- Maintain current geometry (Shashlik)
  - Replace ECAL endcap, refurbish HCAL endcap with radiation hard technologies
- High Granularity Calorimeter (HGCal)
  - Finely segmented calorimeter
    - Contains both electromagnetic and hadronic sections
      - 600 m2 silicon pads in W/Cu structure
      - Readout as much information as possible
        - Nicely complements the CMS emphasis on particle flow
      - + Rebuild HCAL endcap with reduced depth

Endcap Calorimeter: Shashlik option

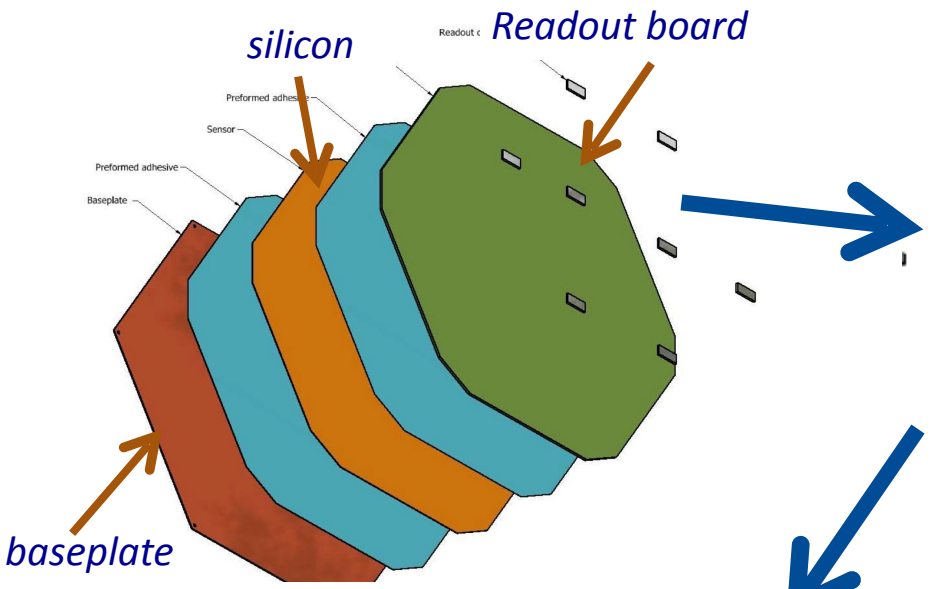
- W-absorber, LYSO scintillator
  - CeF_3 is an alternative
- Compact (~ 11cm long)
- Small Moliere radius (14mm)
- fine granularity ($14m^2$) to mitigate pileup
- High light yield for good e/γ energy resolution ~10%/sqrt(E) + 1%

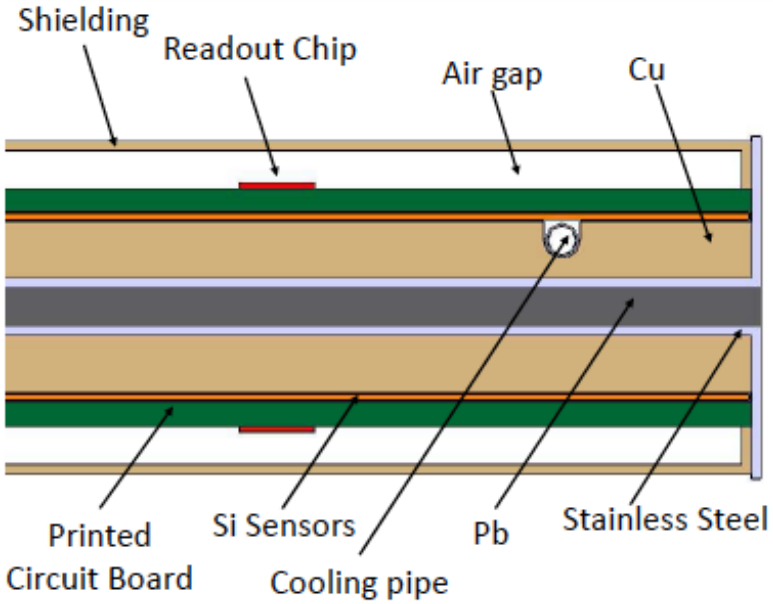




- Readout with WLS capillaries (CeF_3)
- No depth segmentation – but investigating extraction of signal near shower max with precise timing

Endcap Calorimeter: HGCal option





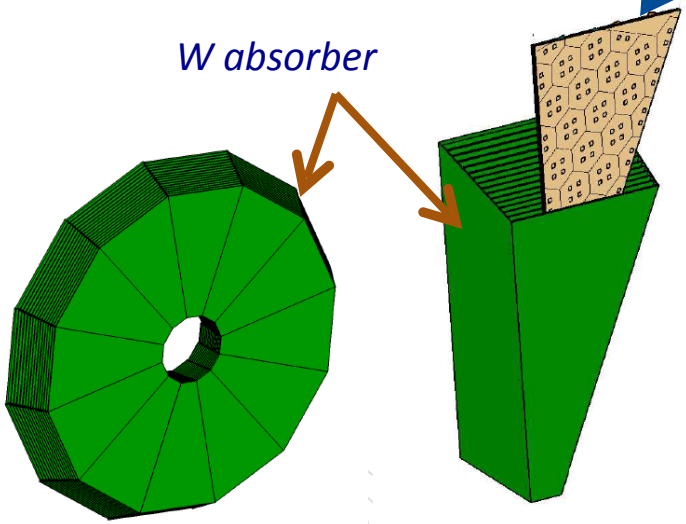
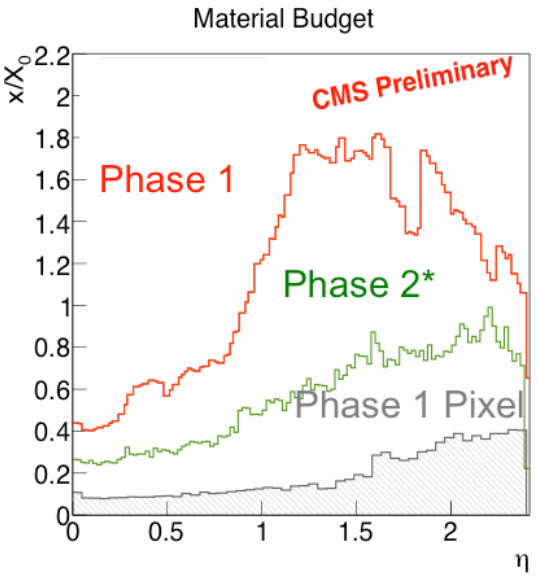


Table 3.4: Parameters of the E-HG and H-HG.

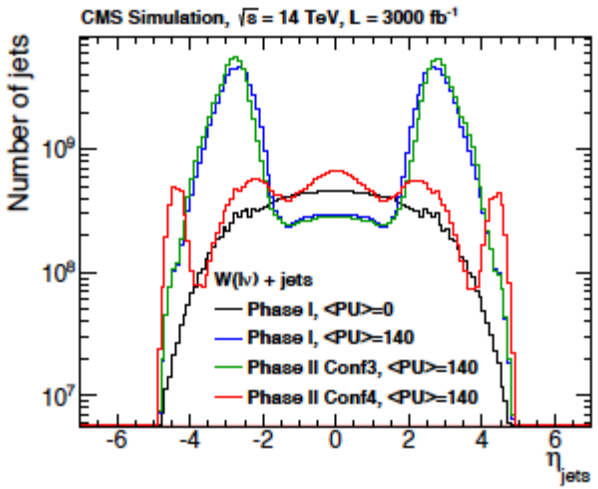
	E-HG	H-HG	Total
Area of silicon (m^2)	420	241	661
Channels	6.0M	2.7M	8.7M
Detector modules	18.2k	10.5k	28.7k
Weight (one endcap) (tonnes)	18	81	99
Number of Si planes	30	12	42

HL-LHC Tracker replacement



Requirements

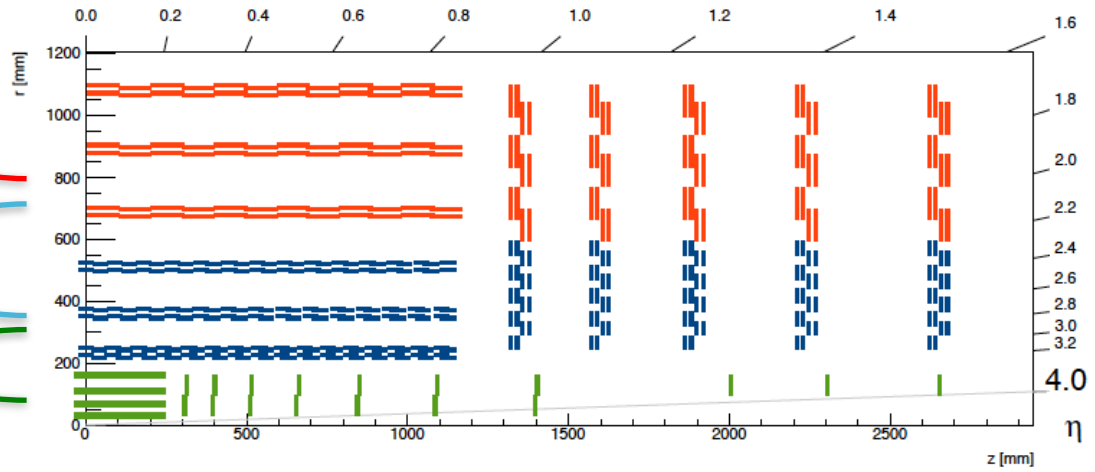
Radiation tolerance
Increased granularity
Improved 2-track separation
Reduced material
Robust pattern recognition
Support for L1 trigger upgrade
Extended tracking acceptance



Strip/Strip modules SS (pairs of strip sensors)

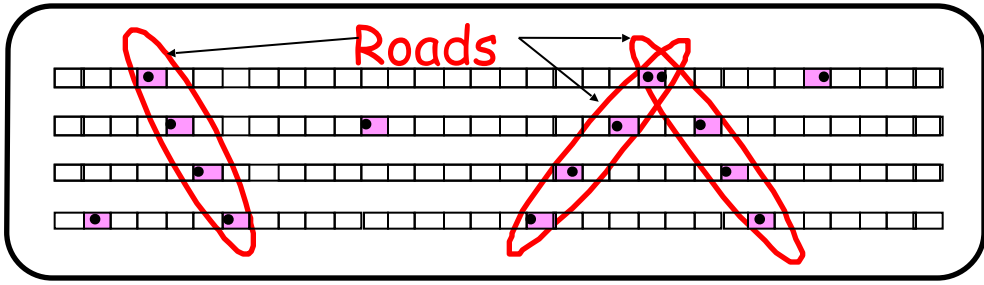
Strip/Pixel modules PS

Pixel modules

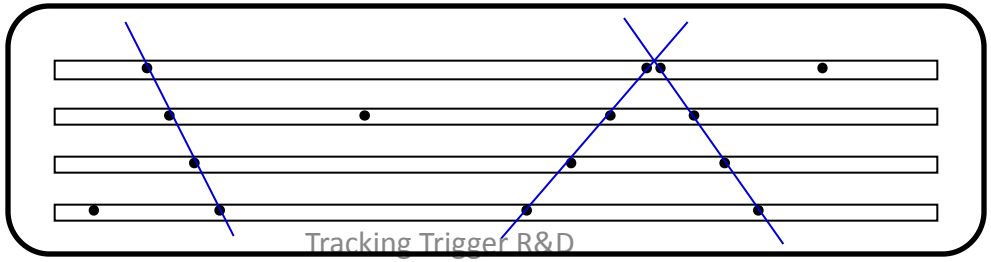


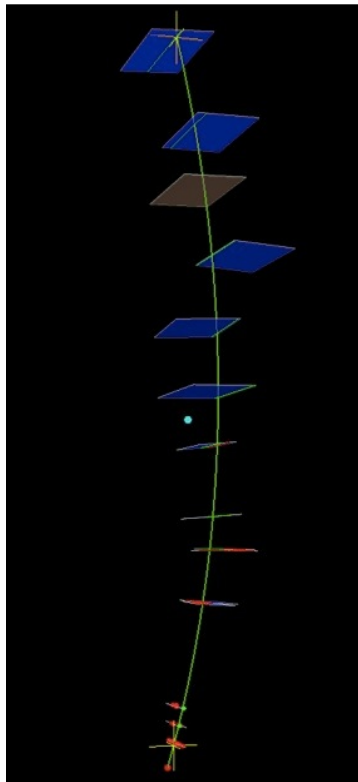
Fermilab

Pattern Recognition Associative Memory approach



- Pattern Recognition using Associative Memory (AM):
  - Massive parallel processing to tackle the intrinsically complex combinatorics of track finding algorithms, *avoiding the typical power law dependance of execution time on occupancy*
  - solving the pattern recognition in times roughly proportional to the number of hits, making the downstream task much easier
  - Usually requires custom ASIC
- The Track Fitting stage (in FPGA) after AM:
  - Examples: linearized track fitting, Hough transform … etc
  - The more powerful the AM stage, the less demand on TF/FPGA
  - The more powerful the TF/FPGA, the less demand on AM



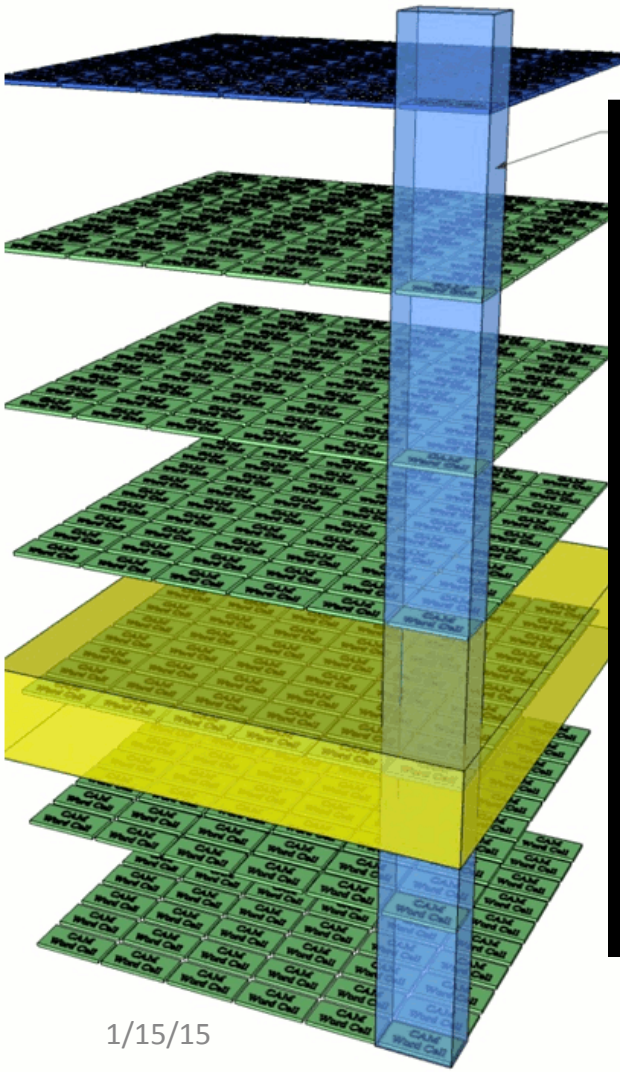


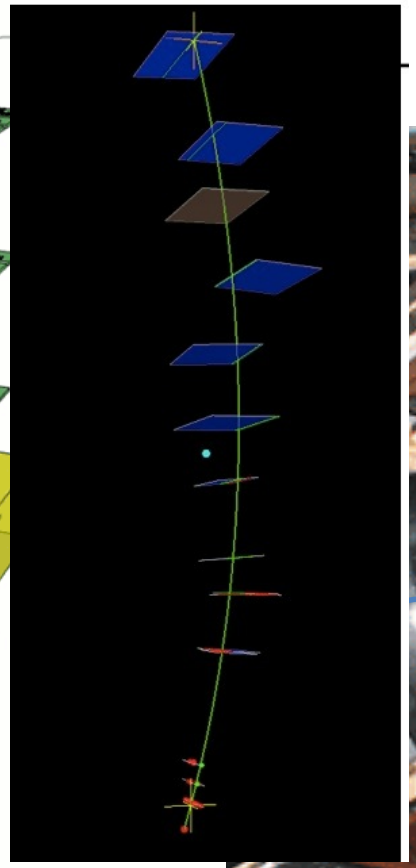
"A New Concept of Vertically Integrated Pattern Recognition Associative Memory"

TIPP 2011 Proceedings

http://www.sciencedirect.com/science/article/pii/S1875389212019165

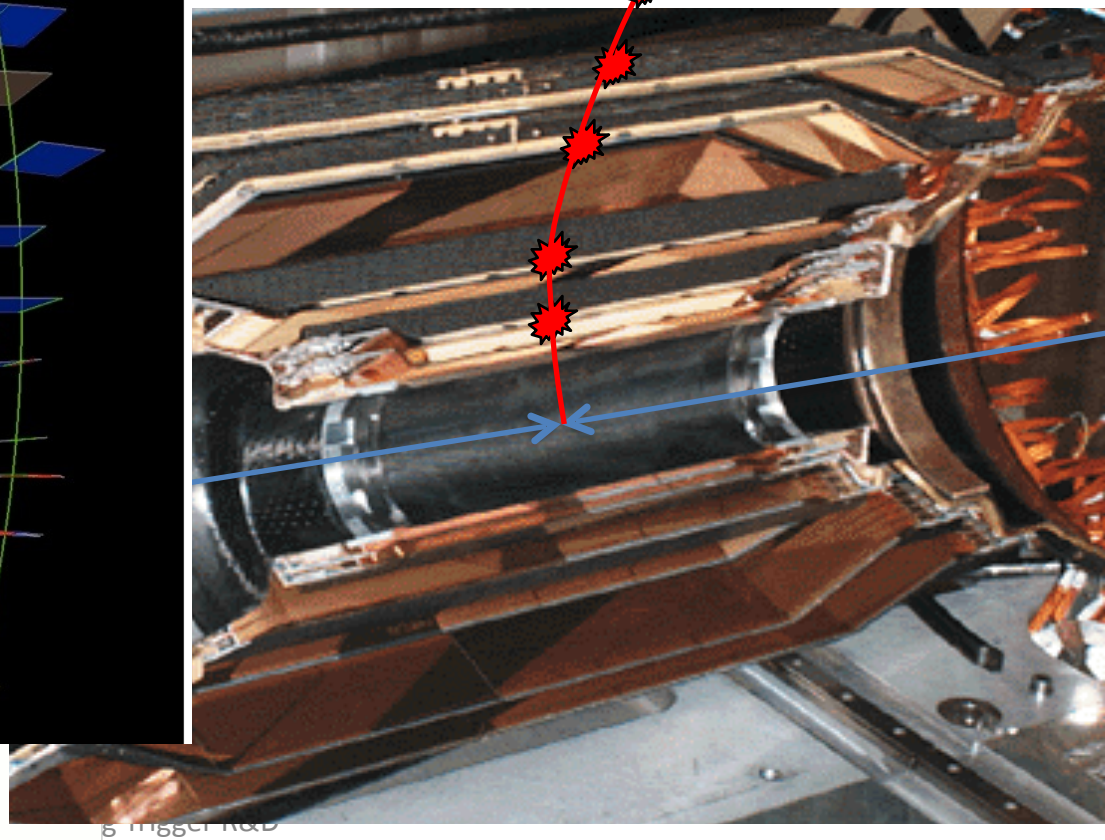
fired road





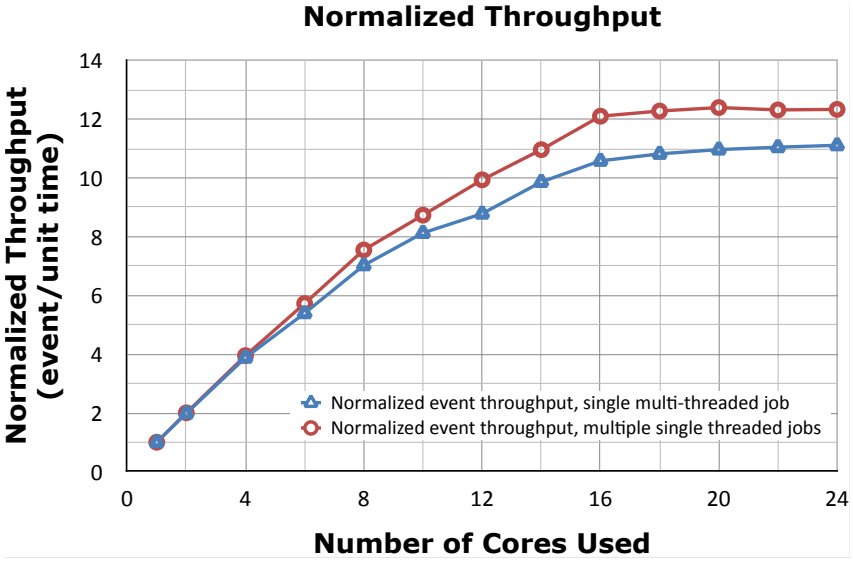
Pattern recognition for tracking is naturally a task in 3D

track

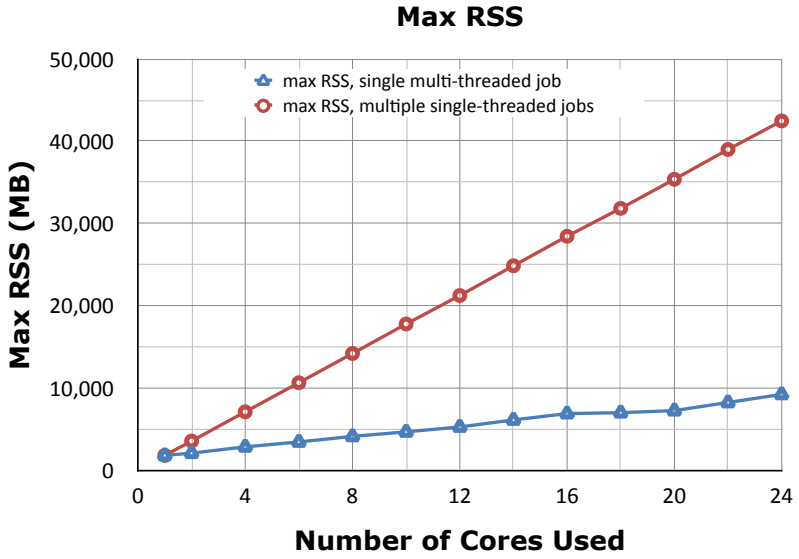


Software & Computing: Core Software

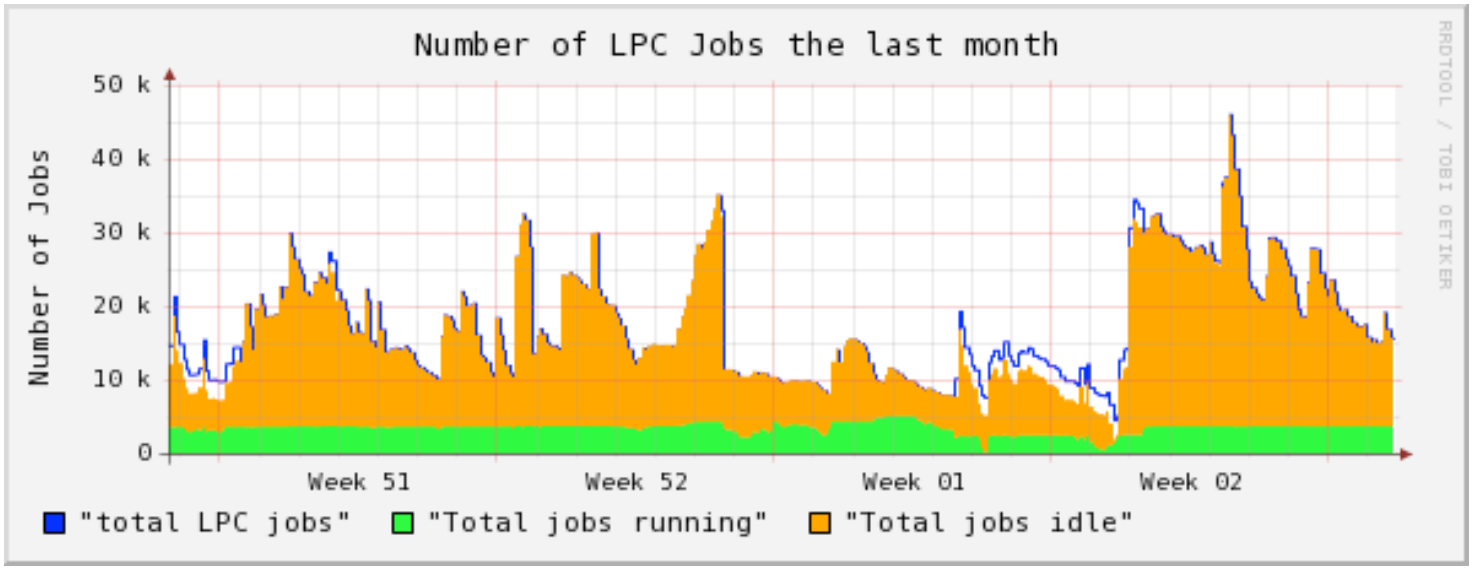
- FNAL is involved in all aspects of maintaining, evolving the software and computing infrastructure for Run 2 and beyond.
- Software framework is basis of all data and MC production, processing, and analysis.
- Fermilab software experts lead and are at the heart of the development team.
- Significant milestone reached in 2014 enabling the framework to run in multithreaded mode using several CPU cores concurrently to process multiple events simultaneously.



95% efficiency compared to single-threaded jobs at significant memory savings



- CMS was the first HEP experiment to have a multi-threaded application
- Reconstruction enabled for multithreading, simulation and HLT trigger to follow soon
- Beyond LHC Run 2, extend parallelism to process a single event on multiple cores



Occupancy of LPC farm this past month — preparing for the run (and CMSDAS likely) — idle jobs reaching the 30k-40k level and green running job slots completely full