Fermilab

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CMS Near-Term Update

Kevin Burkett

Fermilab Physics Advisory Committee

January 16, 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 Fermilab CMS group is aligned with these priorities through:
  - Physics research corresponding to the key science drivers
  - A leading role for CMS and USCMS in building Phase-1 upgrades and R&D for Phase-2

Outline

- CMS Activities at Fermilab
- Overview of Fermilab CMS group
- Physics Analysis in Run 1 and plans for Early Run 2
- Detector Upgrade Activities
- Software and Computing
- LHC Physics Center
- Remote Operations Center

CMS at Fermilab

- Fermilab scientists are currently active in:
  - Analysis of CMS Data
  - Preparation for Run 2
  - Building Phase-1 Upgrades - HCAL, FPix, Trigger
  - R&D for Phase-2 Upgrades - HCAL, Tracker, FPix, Track 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

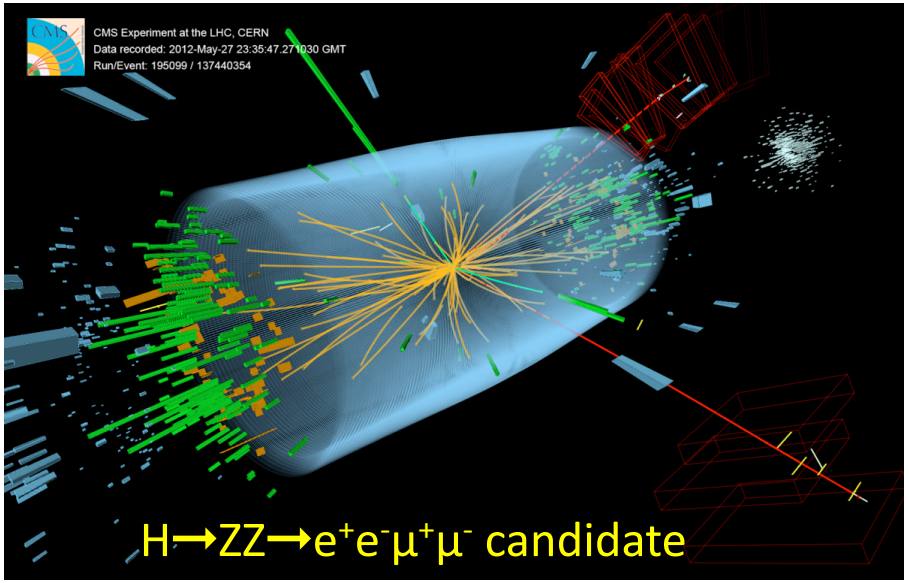
- CMS collaboration currently has ~2100 authors with ~700 from the US
  - Fermilab is the largest US group and the second largest group overall in CMS
- In 2015 we will have 55 CMS authors (+ 5 emeritus)
  - Total Fermilab effort (incl. professionals) on CMS is >100 FTE
- Research program supports 53 FTE
  - Concentrated in Particle Physics Division, Scientific Computing Division, with additional people in Technical Division
  - Includes 15 postdocs, 2 Wilson Fellows

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*

Physics in LHC Run 1

- CMS had great success in Run 1, including the discovery of the Higgs Boson together with ATLAS
- Efforts of the Fermilab CMS group were focused primarily on:
  - Higgs Physics
  - SUSY Searches
  - Standard Model measurements (esp. top, EWK) as indirect probes of new physics



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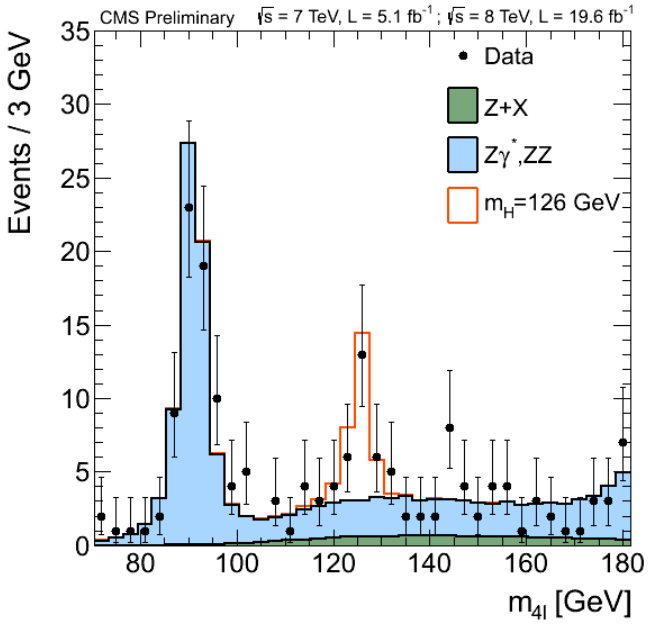
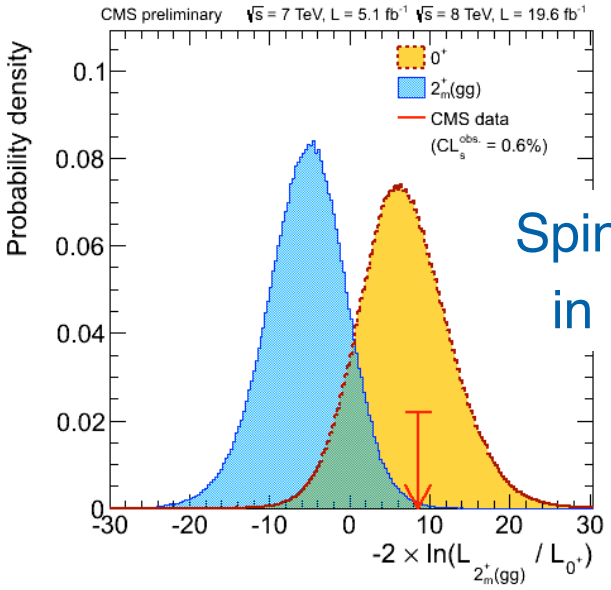
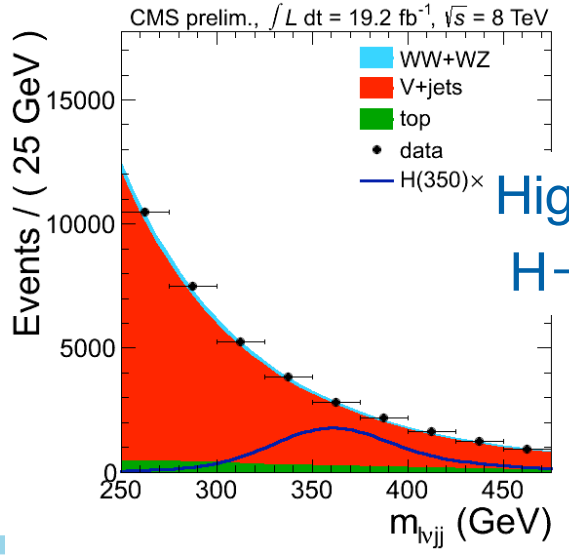
Higgs Physics



Kinematic discriminant for H→ZZ→4l



Spin/parity analysis in H→WW→2l2ν



High Mass Higgs Search H→WW→lνjj

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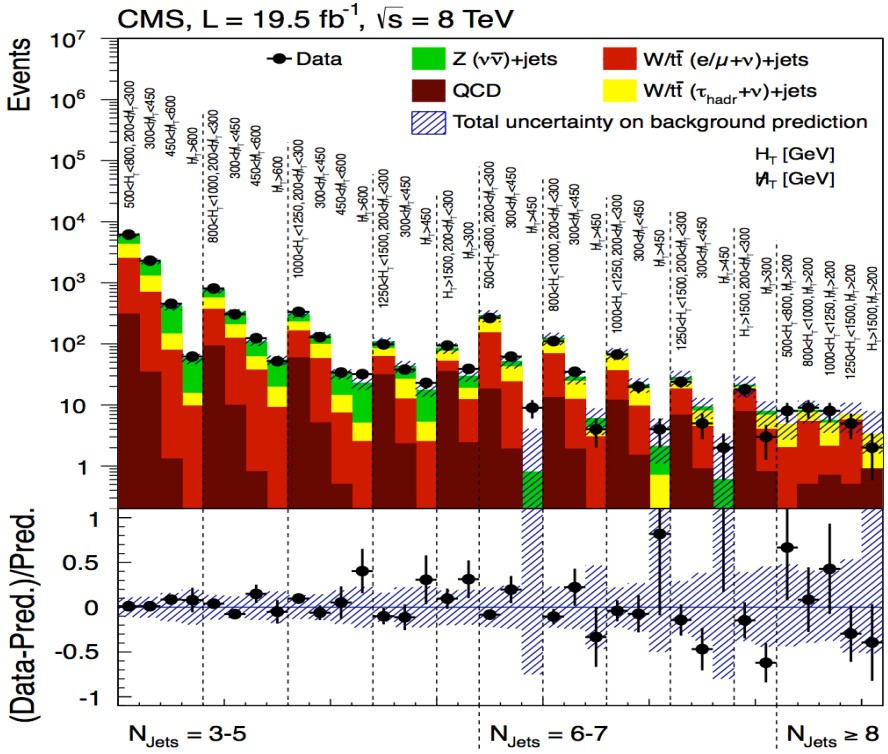
SUSY Searches (1)

- Hadronic searches using all-jets and γ+jets final states
  - Multijet search for gluinos and light squarks
  - Direct stop production
  - Gauge mediation (and extra dimensions)

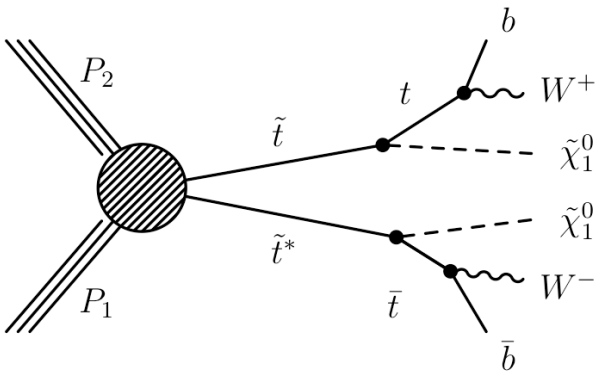
- Significant LPC collaboration
- Five FNAL group members became SUSY subgroup leaders

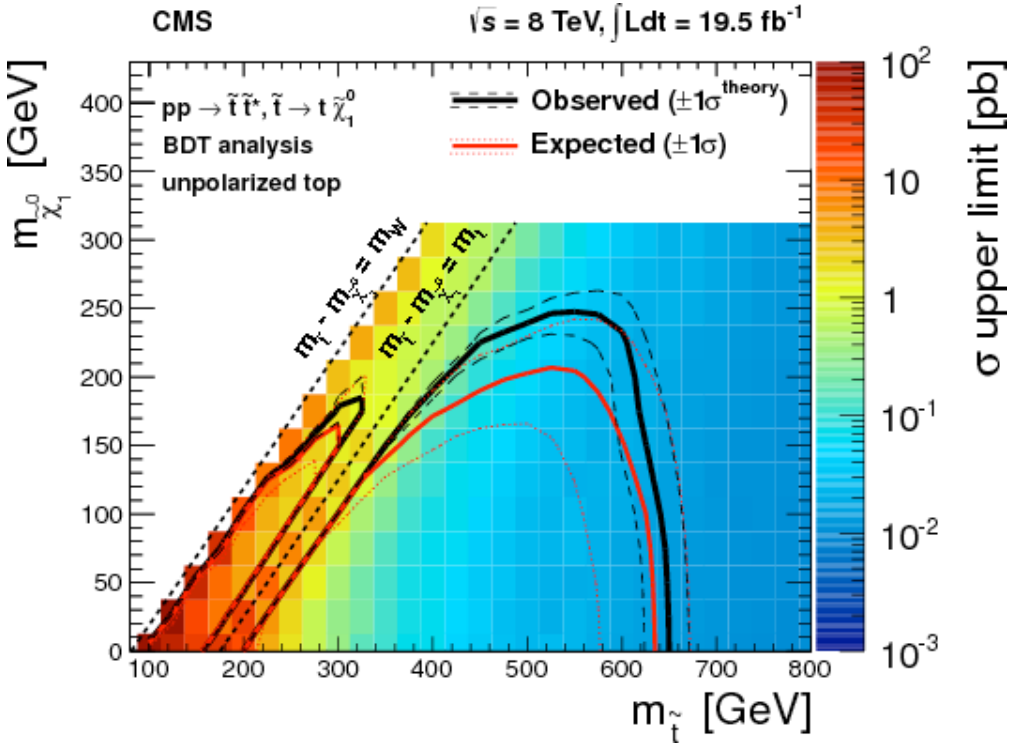


Collaborators: Baylor, Carnegie-Mellon, Colorado, Florida International, Florida State, Hamburg-DESY, UI Chicago, Iowa State, Notre Dame, UC Riverside, Rutgers, Rockefeller, Virginia

SUSY Searches (2)

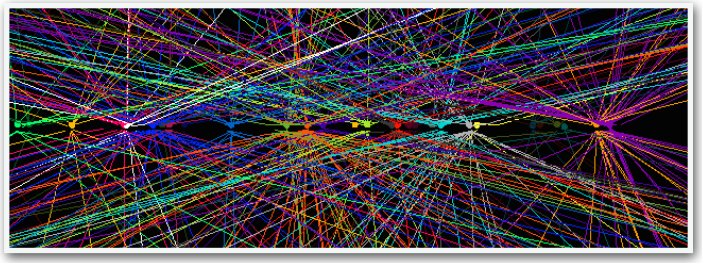
- Leptonic searches using 1- and 2-lepton final states
  - Inclusive searches with opposite charge dileptons and same charge dileptons
  - Direct stop production in single lepton final state





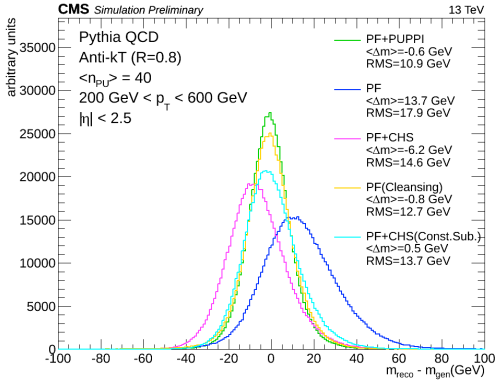
Collaborators: Aachen, DESY, ETH-Zurich, Florida, Strasbourg, UCSB, UCSD

LHC Run II and beyond - “boosted jets”

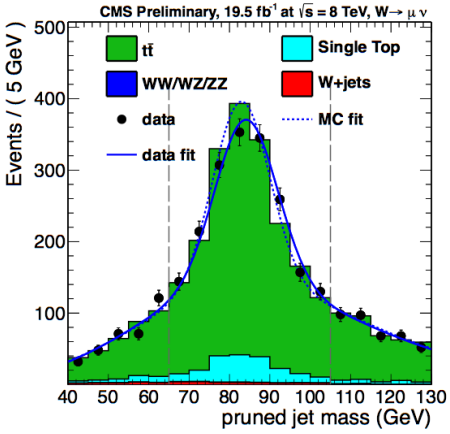


coherent, **per particle**, treatment of pileup improves performance of all CMS reconstruction **[PUPPI]**

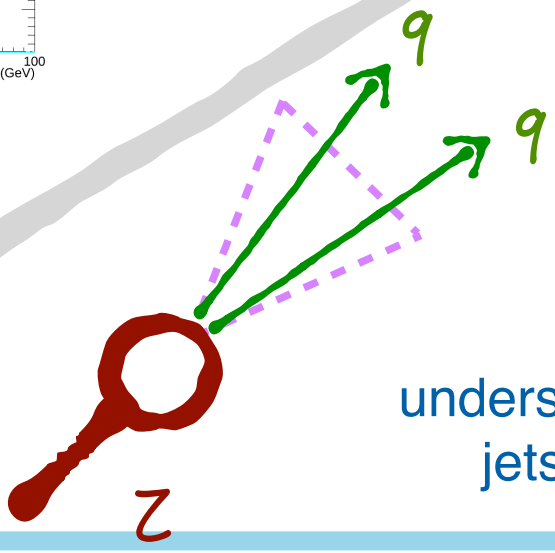
more energy
more boost



characterizing radiation



more collisions
more pileup



understanding structure of very energetic jets increases reach of LHC searches

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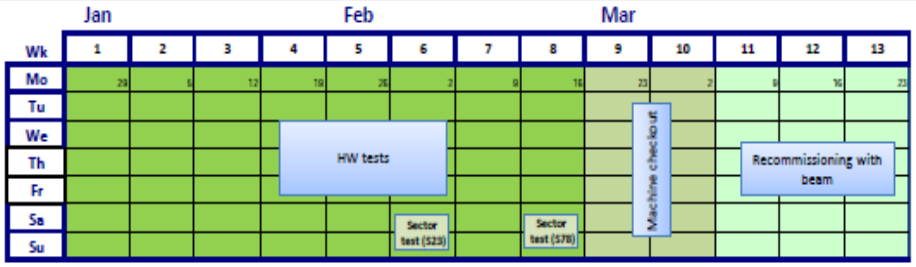
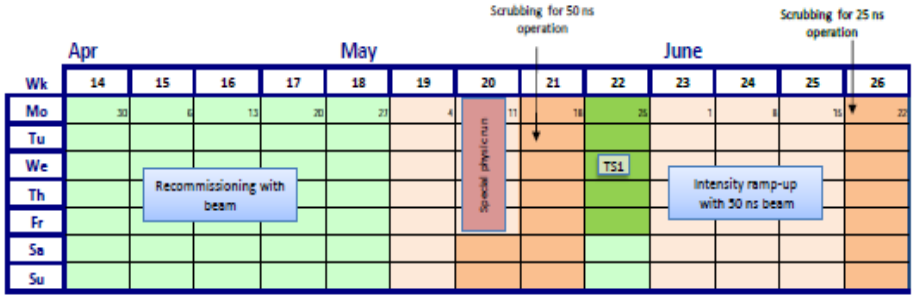
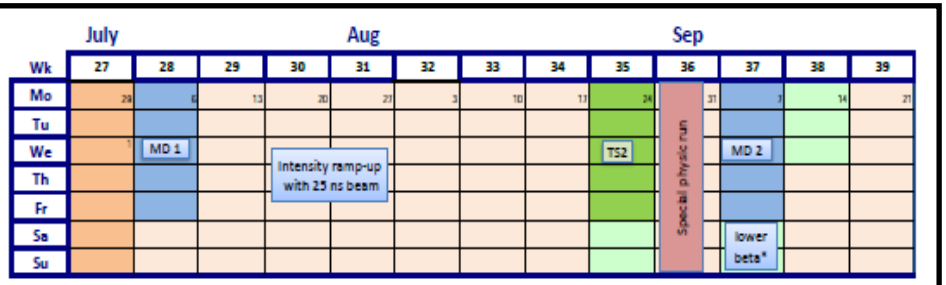
LHC Plan for 2015

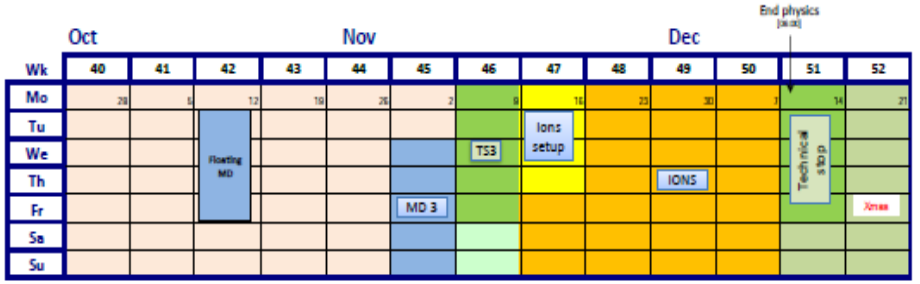
January-June





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

Physics Plan for Early Run 2

- With the increase in the LHC energy, SUSY results will be the most anticipated from early Run 2
- We plan to continue our successful SUSY efforts from the past
  - Specifically, inclusive multi-jets search and stop searches in both all-hadronic and single lepton
  - “Teams” have changed, with younger people taking new roles, and some new collaborating institutions
  - Analyses have been improved, including the integration of boosted jet techniques, which will be important for many searches even beyond SUSY
- Pursue SM measurements, such as dibosons to study anomalous couplings, where there is significant gain from the increase of energy

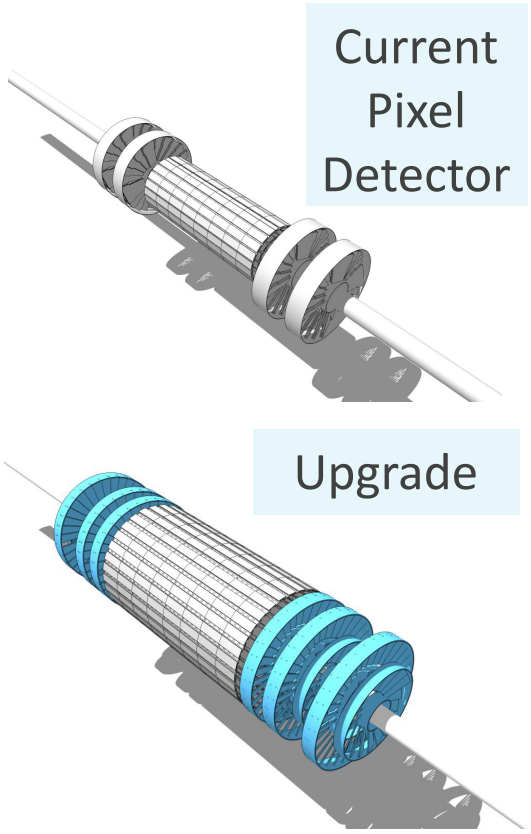
Fermilab Strategy for Upgrades

- 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

Upgrade Activities: FPIX, Tracker

- Leading and hosting construction of Phase I FPIX upgrade
  - Responsible for cooling and mechanics, module electronics
  - Assembly, testing at SiDet in collaboration with universities
- R&D underway for Phase-II Tracker and FPIX
  - Work at FNAL includes sensor design, readout circuit development, beam tests of sensors and readout chips, development of high rate low power optical links, development of mechanical and thermal support structures
  - Scope of US, FNAL involvement still under discussion



Upgrade Activities: HCAL

- Phase I upgrades improve photo-detectors and readout electronics
  - HPDs replaced by SiPM for HB/HE, new multi-anode PMT in HF
  - SiPMs installed for HO in LS1
- Significant contributions to R&D for Phase-II
  - Unified QIE-based readout for Shashlik+HE
  - Radiation tolerant scintillators for HE
- Regardless of the technology choice for Phase-II, FNAL expects to have a significant role
  - Front-end electronics, scintillator development for either choice
  - Sensor development, mechanics, cooling for HGCAL
  - Tight connection to simulation effort for optimization of detector design and reconstruction
- Additionally involved in preparation for Run 2 with improved reconstruction techniques for 25ns LHC operation

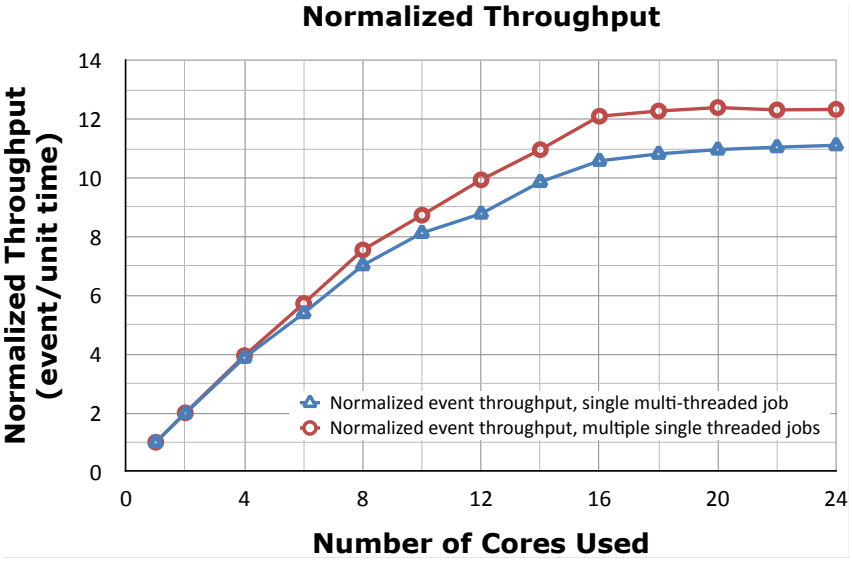
Upgrade Activities: Trigger

- Phase I effort focused on maximizing performance of Level-1 Trigger in Run 2
  - Global calorimeter trigger hardware being replaced in current shutdown
  - Fermilab responsible for upgraded FPGA firmware

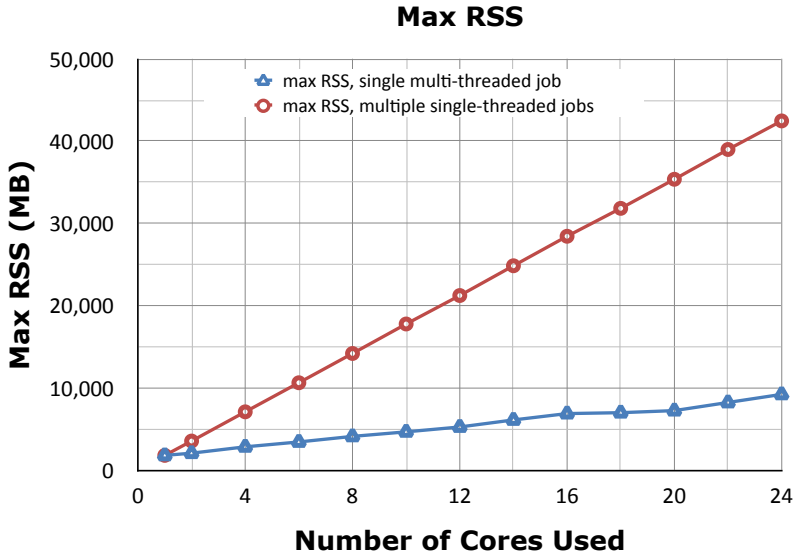
- Leading development of Level-1 track trigger for Phase-II
  - Adding tracking to Level-1 trigger is mandatory to preserve efficiency in the face of rising rates
  - Design is based on associative memory approach for pattern recognition (CDF SVT and ATLAS FTK)
    - Requires new hardware to transmit data from detector for track finding
    - New AM chip with higher speed and increased pattern density needed
  - Demonstration system planned for end 2016
    - Mandatory to finalize Phase-II tracker design

Software & Computing: Core Software

- 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

S&C: Simulation and Computing Infrastructure

- **Simulation**
  - FNAL CMS group benefits from large FNAL Geant4 development and support team
    - Synergies with CMS HCAL group in PPD, contributions from USCMS O&C program
  - FNAL leads phase 2 upgrade simulation software infrastructure development
    - Implementation of full geometry, detector simulation (Geant4), electronics, pileup
    - Validation of Geant4 physics for phase 2 detectors
    - Eventually implement parallelism to process single Geant4 event on multiple cores

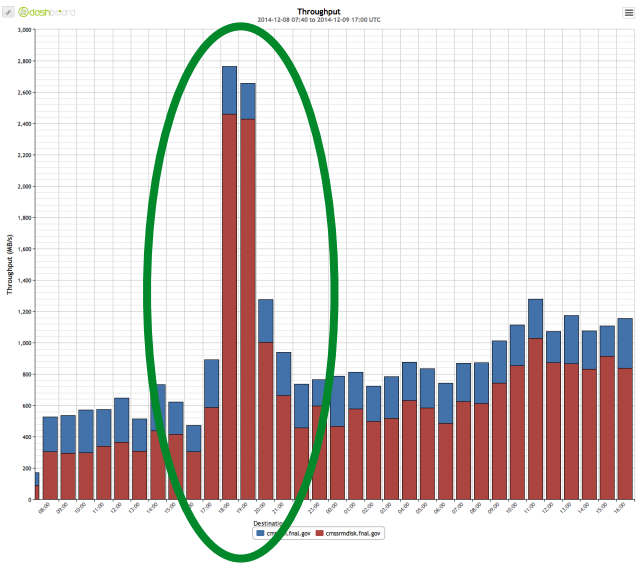
- **Computing Infrastructure Software**
  - Experts leading development of the most critical tools for the CMS collaboration: Tier-0 and central processing infrastructure and metadata catalog.
  - To prepare for Run 2, CMS under the leadership of Fermilab finalized significant changes to the software and computing systems during LS 1
  - Example: glideinWMS, the GRID and Cloud submission infrastructure
    - Tier-0 at CERN will now be included in the world-wide glideinWMS system extending available resources for prompt data reconstruction to also include Fermilab and other Tier-1 centers

Software & Computing: Tier-1 and LPC

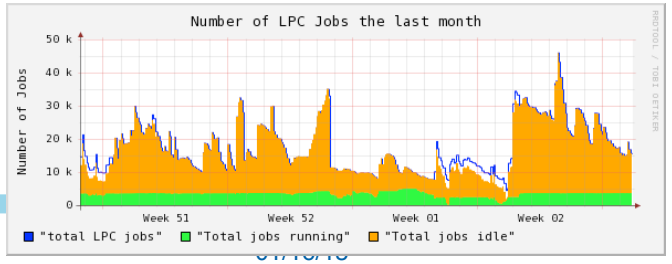
- **USCMS Tier-1 site and Central Computing Operations**
  - FNAL is home to the only CMS Tier-1 site in the US and the most reliably available CMS Tier-1 site in the world.
    - Quality of the support by professionals from the Fermilab SCD surpasses all other Tier-1 sites
    - CMS relies heavily on FNAL for the most difficult tasks, such as the Phase II Upgrade MC workflows.
  - FNAL experts are involved in the complex operation of the different and diverse components and workflows
    - enabling CMS to rapidly and efficiently extract physics results from the recorded and simulated events.

- **Analysis facilities at the LPC**
  - US 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 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 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
  - Multi-day workshops (CMS-only and global), hands-on tutorials
  - “Topic of the Week” lectures
  - Physics Forum
- Programs to 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
  - Guest & Visitors
    - facilitates CMS members to spend time at the LPC working on projects (hardware/software/physics) that advance, enrich, and impact CMS

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'/tt̄ resonances with jet substructure
Dark matter searches with photons
SUSY searches (hadronic modes)
Exotica with displaced vertices
Higgs → bb̄
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

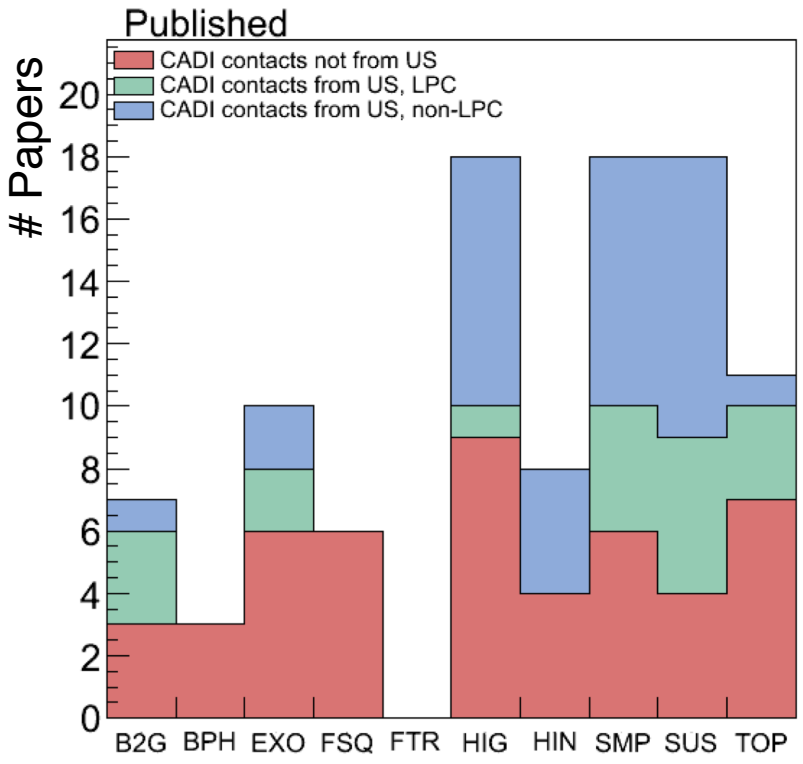
Ongoing now! ~120 attendees

2015 LPC Distinguished Researchers

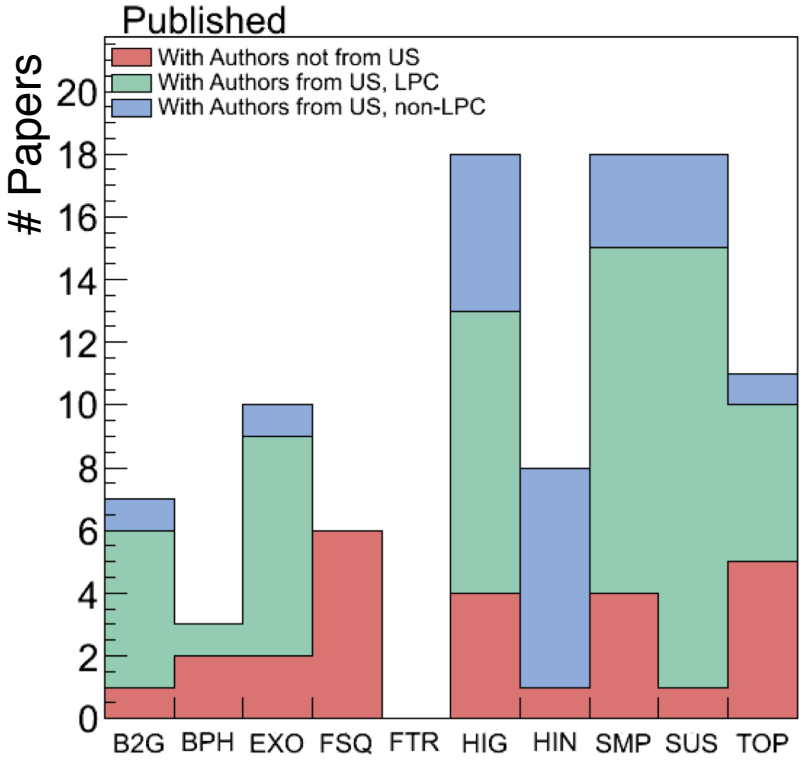
- Senior:
  - Cecilia Gerber (UIC)
  - Greg Landsberg (Brown)
  - Martijn Mulders (CERN)
  - Sal Rappoccio (Buffalo)
  - Roger Rusack (Minnesota)
- Junior
  - Artur Apresyan (CalTech)
  - Gabriele Benelli (Kansas)
  - Giuseppe Cerati (UCSD)
  - Souvik Das (Florida)
  - Phil Dudero (Texas Tech)
  - Dan Duggan (Rutgers)
  - Sadia Khalil (KSU)
  - Hongxuan Liu (Baylor)
  - Maurizio Pierini (CalTech)
  - John Stupak (Purdue-Calumet)

Physics Impact of the LPC

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



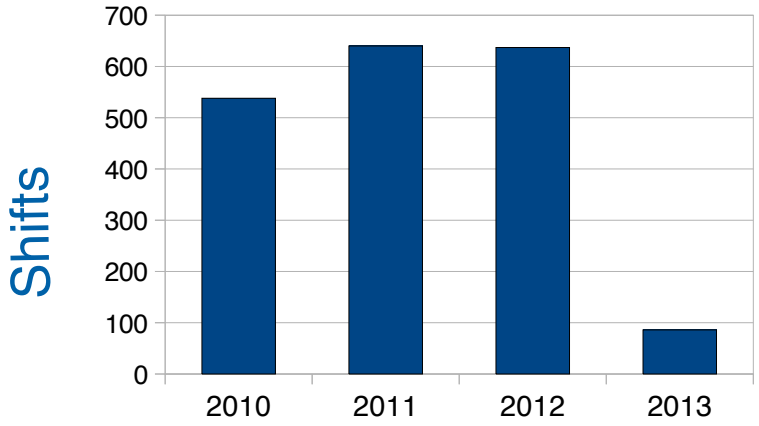
Contact in 18% of pubs



Contributing to 52% of pubs

Remote Operations Center

- ROC established in 2007
  - (2008: Centers at CERN Meyrin, DESY)
- Participation in commissioning, first beam, first collisions, and steady data taking
- Pioneered remote operations
- Shift Activities
  - 50% of all CMS Offline DQM shifts (two 6-hour shifts/day)
  - 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 99 individuals from ~25 U.S. Institutions + Mexico
  - Integrate into CMS operations while saving on travel expenses
  - Already in use during cosmic runs in preparation for Run 2



Summary

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

Today's Joint Experimental-Theoretical Physics Seminar (a.k.a. Wine and Cheese)

John Paul Chou, Rutgers

"New Physics from CMS:
Hints from Run 1 and Prospects for Run 2"

BACKUP MATERIAL

Remote Operations Center ("ROC")

- ROC established in 2007
  - (2008: Centers at CERN Meyrin, DESY)
- Participation in commissioning, first beam, circulation, collisions, steady data taking
- Pioneered remote operations
- Features:
  - Flexible configuration (displays, network)
  - Continuous hi-def video with other sites, conferencing equipment
  - Adjoining conference room
  - High profile location
- Infrastructure for continuous operation:
  - Networking, power, linux, windows, video, projection, lighting, HVAC
- Additionally, a powerful tool for outreach
  - hundreds of tours for students, teachers, media, and community


Located in Wilson Hall, 1st floor

ROC - Run 1 Users and Activities

- Users
  - Coordinate their shift activity with work at LPC, or workshops, etc.
  - Wide range of career stages (professors on weekends between teaching, grad. students who are resident at Fermilab for extended periods)
  - Have come from ~25 U.S. Institutions + Mexico
  - Integrate into CMS operations while saving on travel expenses
- Shift Activities
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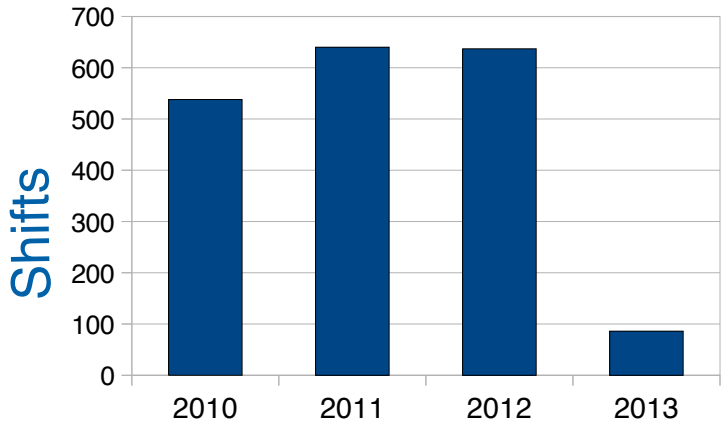
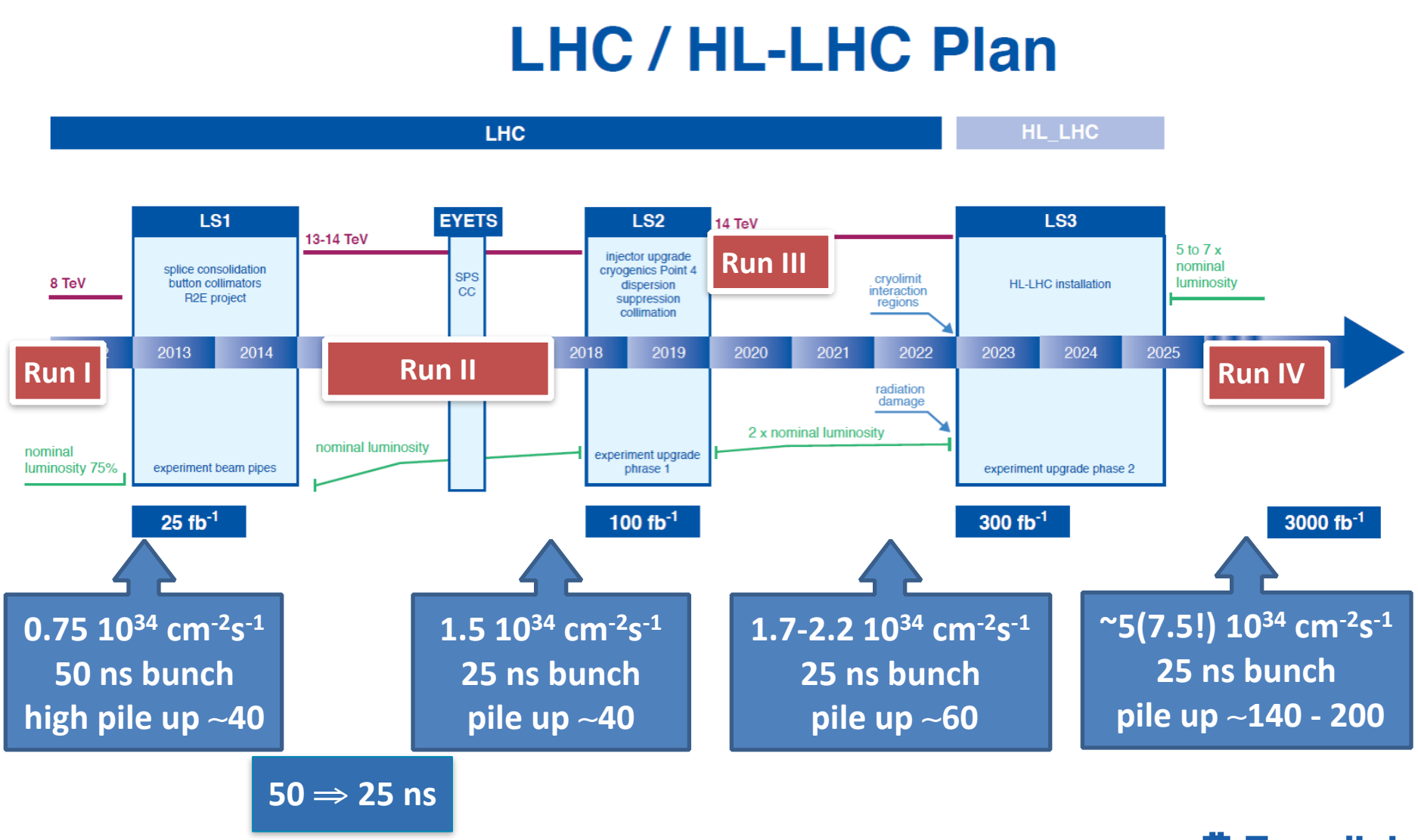
  - Between 2/15/10 and 2/18/13, 1901 Offline DQM shifts were taken at the Fermilab ROC by 99 individuals
  - **Already in use during cosmic runs in preparation for Run 2**

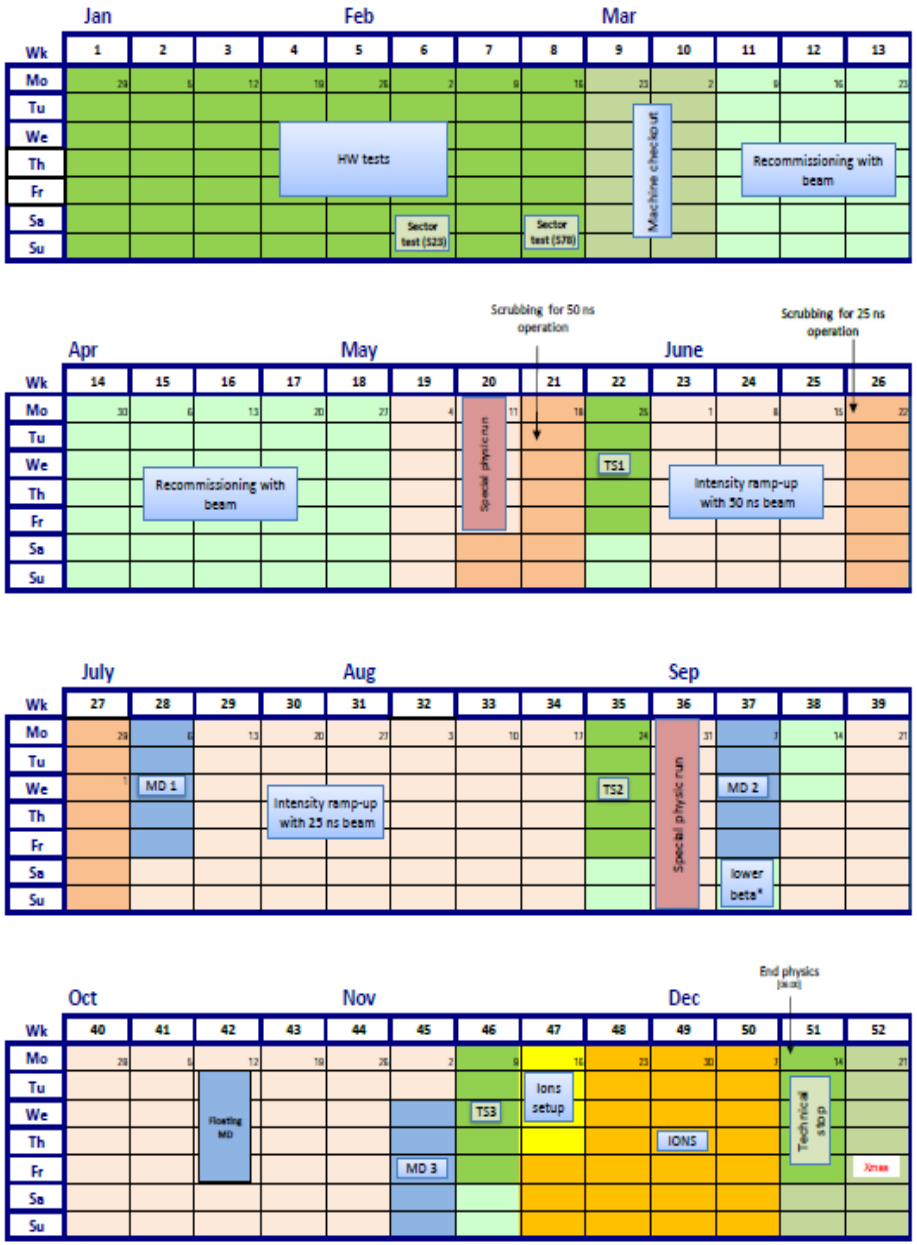


LHC: the plan


LHC / HL-LHC Plan
LHC
HL_LHC
LS1
splice consolidation
button collimators
R2E project
EYETS
SPS
CC
LS2
injector upgrade
cryogenics Point 4
dispersion
suppression
collimation
LS3
HL-LHC installation
8 TeV
13-14 TeV
14 TeV
Run III
cryolimit
interaction
regions
5 to 7 x
nominal
luminosity
Run I
2013
2014
Run II
2018
2019
2020
2021
2022
2023
2024
2025
Run IV
radiation
damage
2 x nominal luminosity
nominal
luminosity 75%
experiment beam pipes
nominal luminosity
experiment upgrade
phrase 1
experiment upgrade phase 2
25 fb-1
100 fb-1
300 fb-1
3000 fb-1
0.75 10^34 cm^-2s^-1
50 ns bunch
high pile up ~40
1.5 10^34 cm^-2s^-1
25 ns bunch
pile up ~40
1.7-2.2 10^34 cm^-2s^-1
25 ns bunch
pile up ~60
~5(7.5!) 10^34 cm^-2s^-1
25 ns bunch
pile up ~140 - 200
50 ⇒ 25 ns

Strategy for 2015

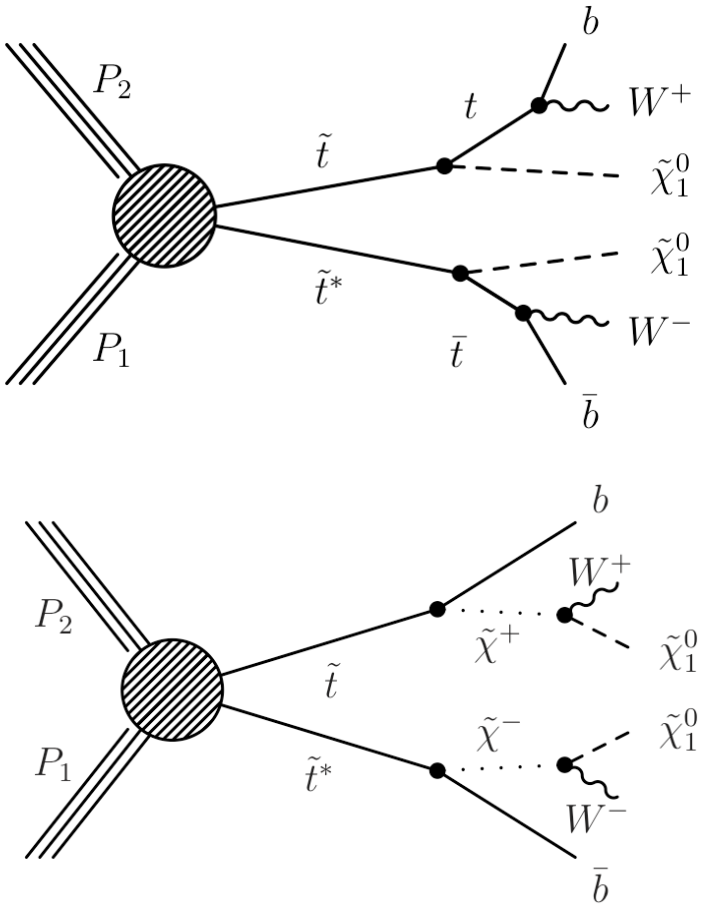
- Restart with the similar 2012 parameters and a relaxed β* (80cm) (Alice 10m; LHCb 3m) to establish asap collisions at 13 TeV with 50 ns bunch spacing, no combined collide-squeeze, ramp-squeeze,…
- LHCf request and VdM with same optics
- 1st scrubbing run (50ns+25ns; 7-9 days); accumulate up to 1fb-1 with 50 ns (around 20 days)
- Establish the running with 25 ns: enough time for the scrubbing (10-15 days and no pressure for production)
- Run at 25ns with β* (80cm) for 40 days and decrease the β* (60 cm- 40 cm?) to have around 44 days of operation to prepare 2016 and 2017
- One month for heavy ions

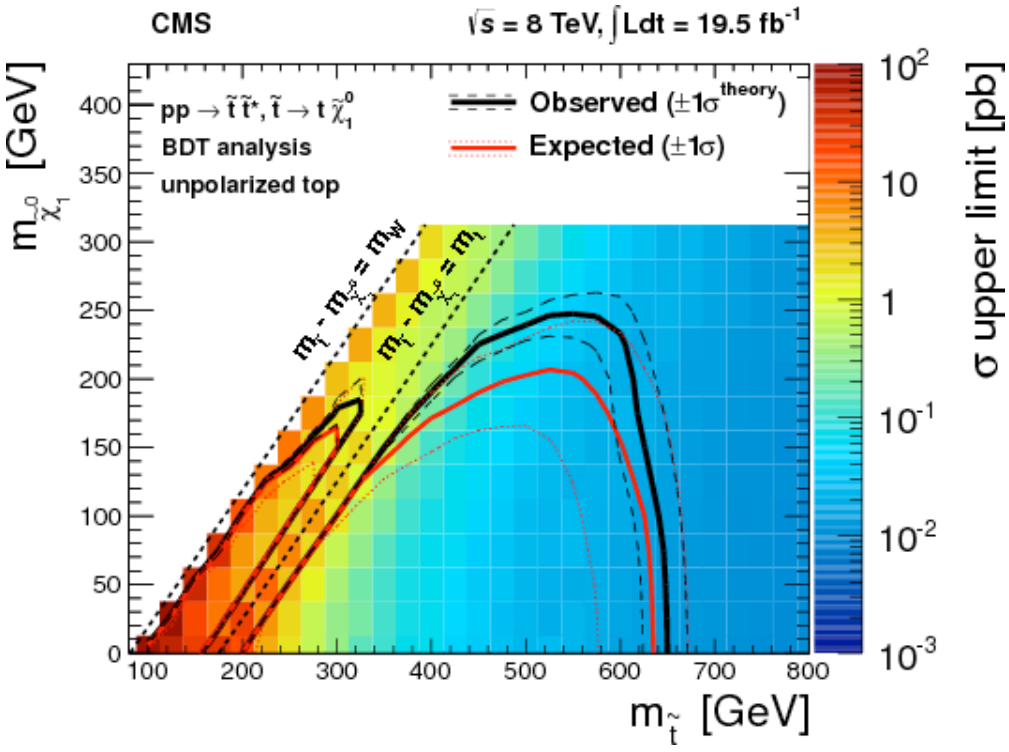


SUSY Searches

Search for direct top squark pair production in the 1-lepton final state

(FNAL, UCSB, UCSD, DESY, Strasbourg)



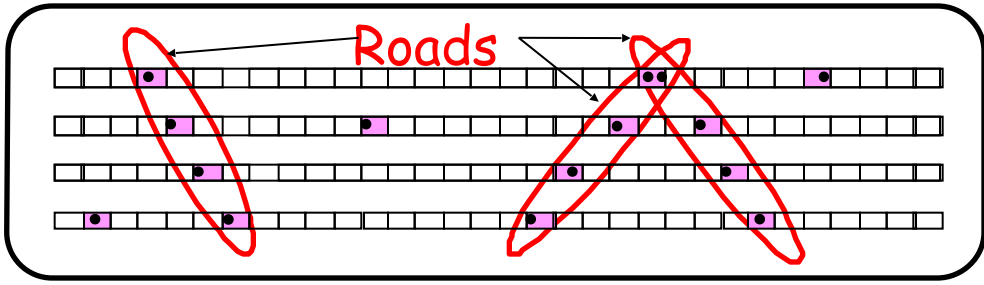


Fermilab

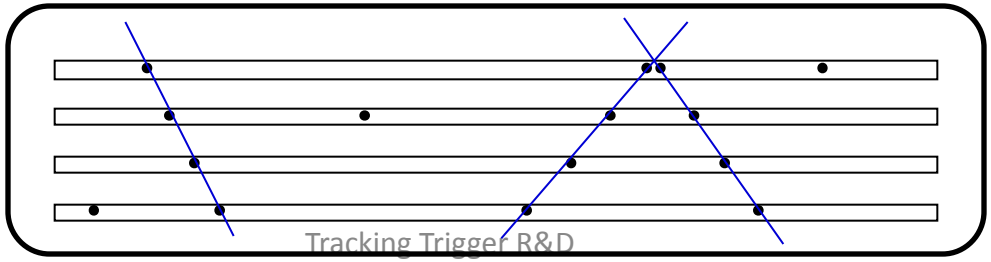
Summary of 2014 LPC Activities

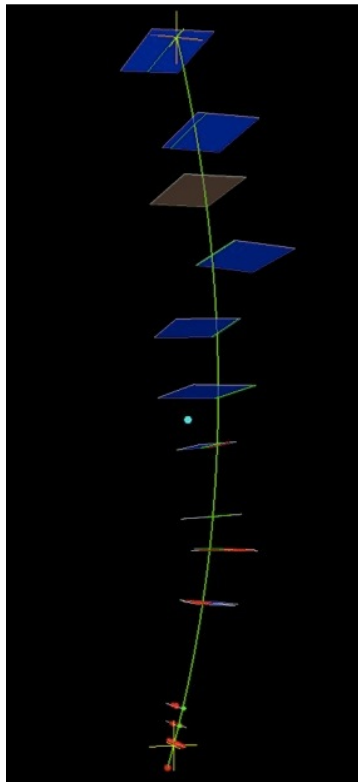
- CMSDAS – 1
- Workshops – 8
  - CMS only – 6 (JME, TP, HCAL, Trig/Track, B2G, SUSY)
  - Global – 2 (BSM Higgs, Future Colliders)
- HATS – 11
  - ID – 4 (e, $\not{E}_T$, b-tag, Jet-substructure)
  - Upgrade – 3 (Calo, Tracker, Trigger)
  - Tools – 4 (Statistics, Roostat, CRAB3, Delphes)
- TOTW – 19
- PF – 17
- CH – 9

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



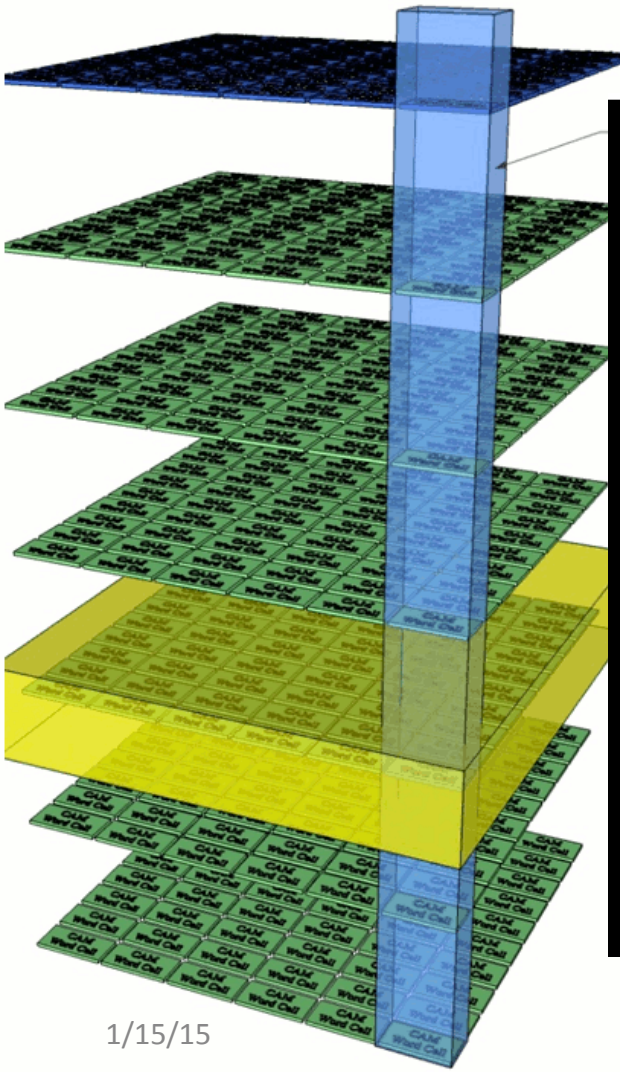


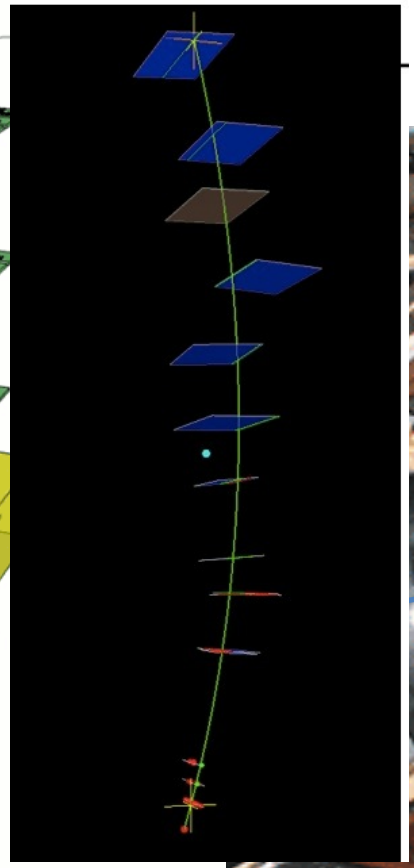
"A New Concept of Vertically Integrated Pattern Recognition Associative Memory"

TIPP 2011 Proceedings

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

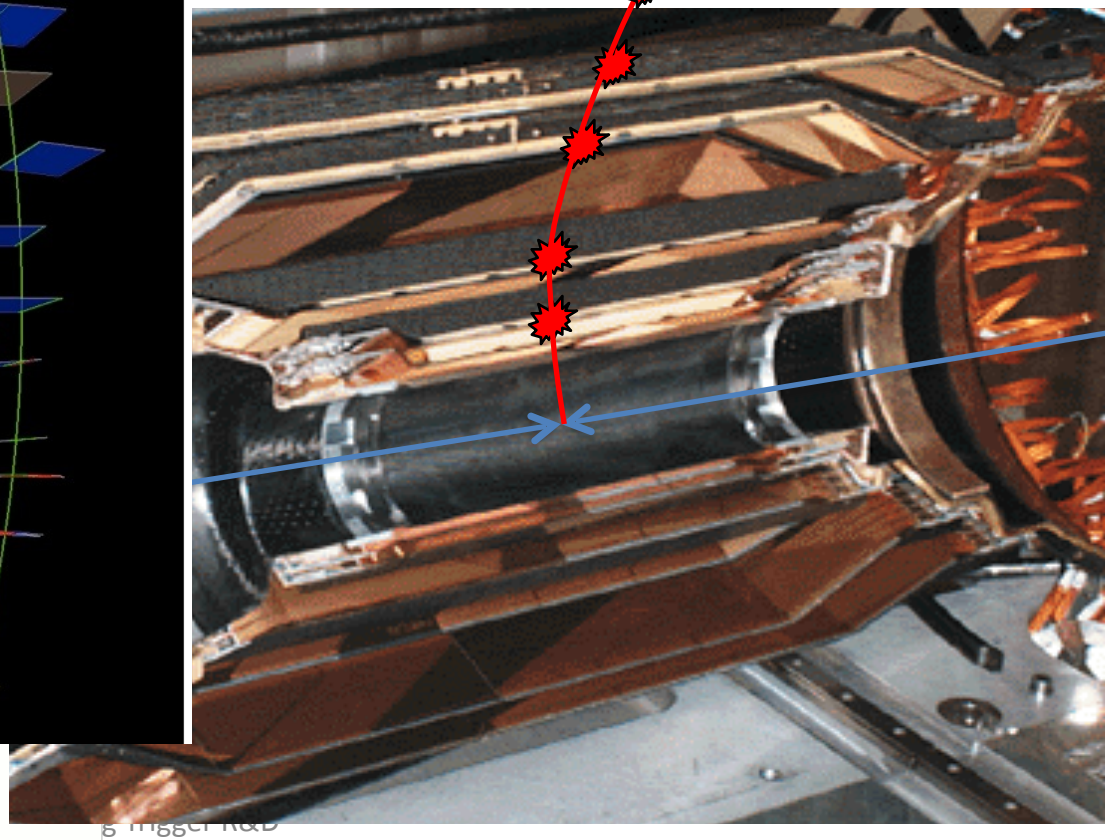
fired road



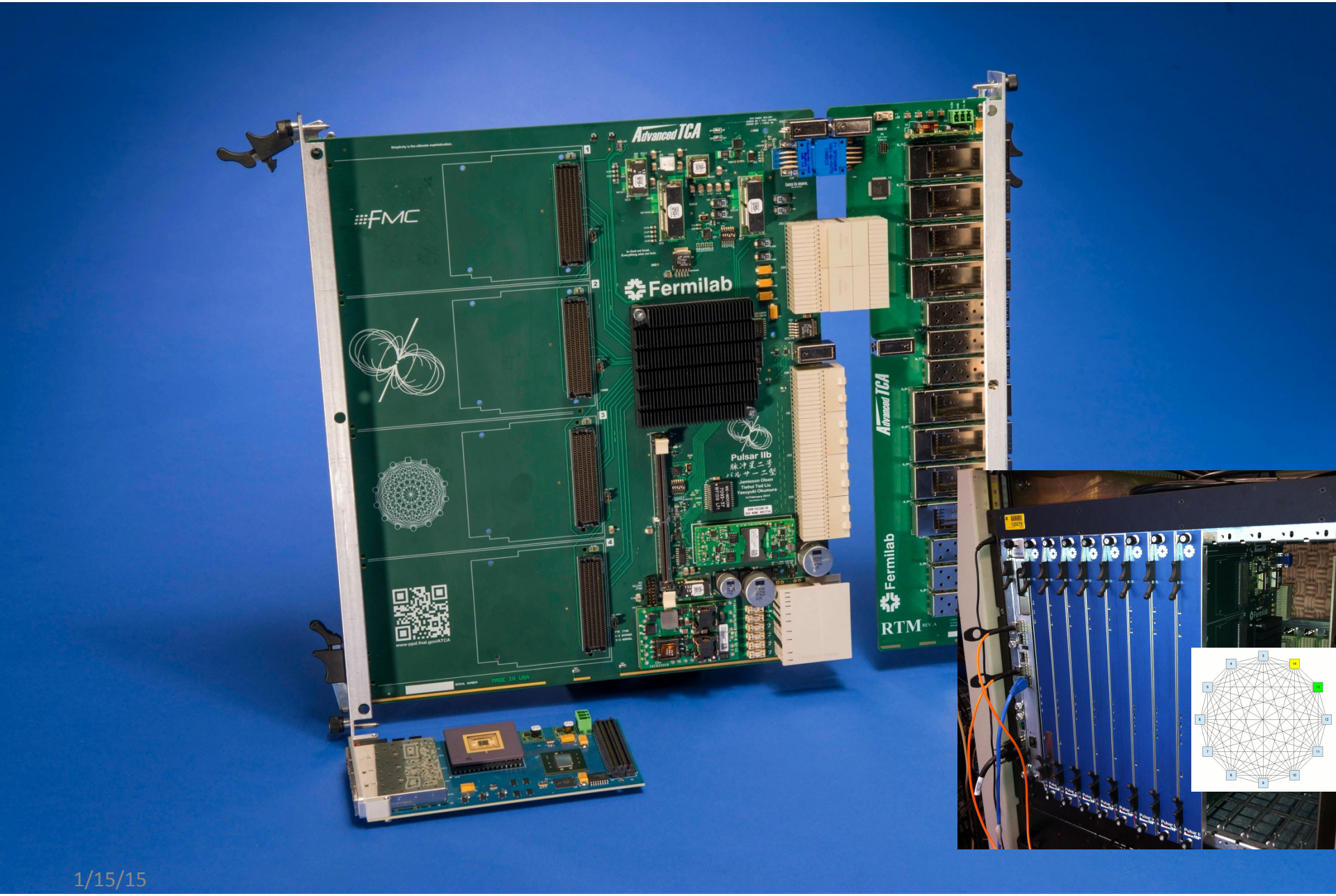


Pattern recognition for tracking is naturally a task in 3D

track

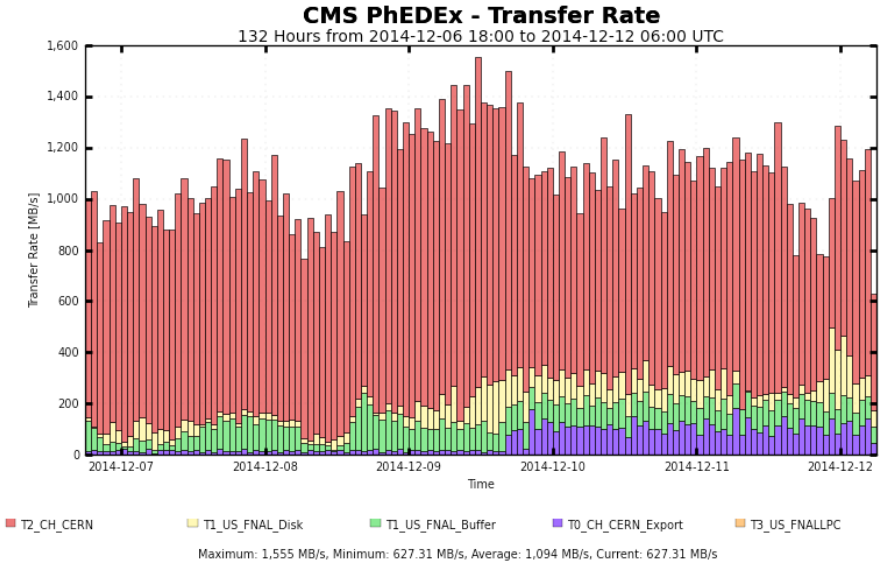


Pulsar II Web page: http://www-ppd.fnal.gov/EEDOffice-w/Projects/ATCA/
User information: https://twiki.cern.ch/twiki/bin/view/Main/PulsariibTesting

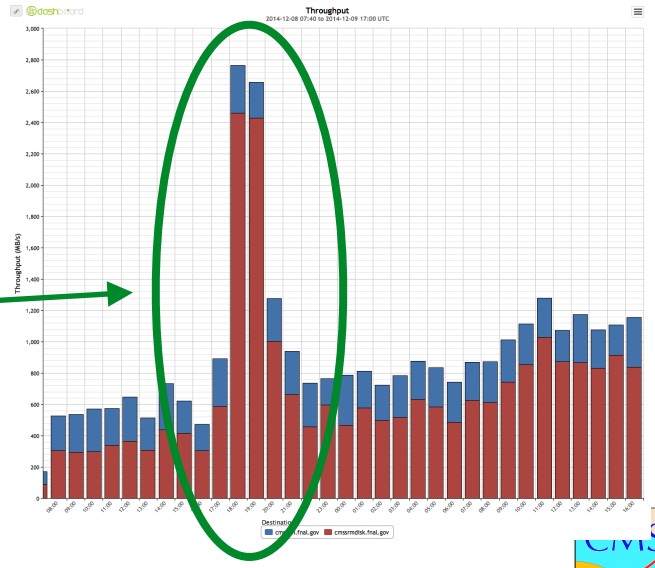


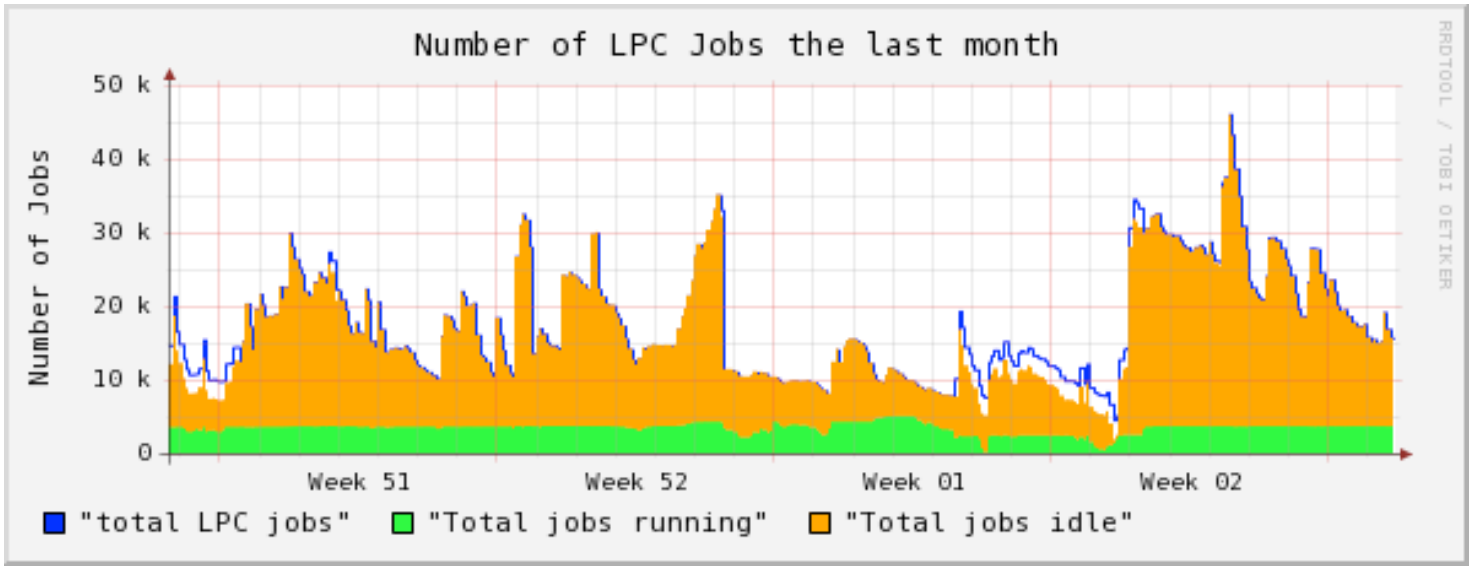
The Continuous Transfers

- Maintained continuous test transfers between CERN and FNAL at (at least) Run 2 expected rates all during this transition!
  - (~1 GByte/sec aggregate)



- With an added spectacular spike of 3 Gbyte/sec of production transfers for a few hours on monday!





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