



The LHC Physics Center

Bo Jayatilaka

Fermilab PAC Meeting

6 June 2023



lpc.fnal.gov

Origins of the LPC

- Idea first introduced by Dan Green (FNAL) at USCMS meeting in 1999
 - Initially had very “lukewarm support” from FNAL management and DOE/NSF
- Gained traction in late 2003
 - First coordinators Sarah Eno (UMD) and Avi Yagil (FNAL)
 - Formally proposed to Fermilab in February 2004

Dear Professor Witherell:

I am writing to you on behalf of a group of University professors who met on February 12, 2004 at FNAL to discuss how to organize an effort to prepare for data taking and physics analysis with the CMS detector at the LHC while at the same time fulfilling our ongoing commitments to experiments currently running in the US, such as BaBar, CDF, and DØ. We invited Dan Green, Avi Yagil, John Womersley, and Lothar Bauerdick to our meeting, to help us understand whether our interests/needs coincide with the lab’s plans for an LHC physics center (LPC). The purpose of this letter is to inform you of our thoughts on this subject, and also of the ways we hope the lab can help us on what we think is an effort which could very well determine the health of our field in the United States, both during the LHC era and afterwards.

We unanimously agreed that the only way in the short term we could both prepare for CMS data taking and continue our vital work on running experiments is to find a way to make it effective for postdocs and students to work on both efforts at the same time, and the only way to do this is to cluster them in a place like the proposed LPC. We were also all hopeful that, if started now, such a center could become our preferred place for clustering even after the start of CMS data taking, so that we travel to CERN only approximately 4 times per year, and travel regularly instead to FNAL to interact with our students and postdocs. Whether this works or not depends crucially on the LPC becoming a power research center well before the LHC data taking starts in 2007.



Dr. Sarah Eno
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301.405.7179 TEL. 301.699.9195 FAX

13 February 2004

Mike Witherell, Director
Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, IL 60302

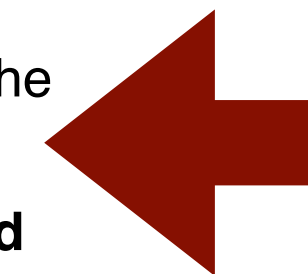
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Most of the current indirect evidence for the scale of new physics hints that the LHC may be able to make a major discovery shortly after turn on. The discovery will go to the collaborations and physicists that are best prepared at the start of data taking. CMS takes this possibility very seriously, and has established the “Physics Reconstruction and Selection” (PRS) groups to make sure the collaboration is prepared. Over the next two years, this preparatory work will take the form of the writing of a “Physics TDR”. If US CMS wants to play a leading role in these discoveries, we need to lead in the preparation of this TDR through participation in the PRS groups. We also need to do the kind of activities that are going on now within CMS that will enable us to have an intimate understanding of the detector, especially participating in test beams, but also understanding calibration systems, and the development of robust analysis tools. To be successful, we decided we need the following:

- ⟨ In the next 6 months: establish a physical place at FNAL in the Hirise with first class computing and video conferencing for a core team of about six researchers working full time on CMS who will collectively develop expertise in all areas of the CMS reconstruction code and prepare to support and help the postdocs who will join them, working part-time on CMS.
- ⟨ Within the next year: have an additional 10 University postdocs and some number of students working part-time on CMS and part time on a running experiment join the core team. These part-time postdocs and students would need desks in the same physical location as the 6 core researchers.
- ⟨ In the following years: increase the number of University postdocs shared between CMS and a running experiment to 20 by the end of 2005 and 35 by the end of 2006, and start to have students who will do an LHC thesis working at the center.



Origins of the LPC

- Idea first
- Initial
- Gained
- First
- Formal



Response from Witherell

Meeting in 1999
DOE/NSF

Dear Colleagues:

I am writing to respond to your letter concerning the LHC Physics Center at Fermilab. In that letter you expressed interest in the development of such a center and stated how important it would be for U.S. university groups to take full part in research with the CMS data sample.

Dear
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Both Fermilab and the leadership of the US-CMS research program have also expressed support for the LHC Physics Center (LPC). One goal of the center is the one you articulated, that is, to make it possible for U.S. physicists working on CMS to be innovative leaders in LHC physics. The other is that Fermilab remain an intellectual center for collider physics in the LHC era. I think that both of these goals serve the larger purpose of advancing particle physics in the U.S.

A broad group of the involved parties recognizes the need of a transition period in which physicists will share effort between CDF or D0 and one of the LHC experiments. This sharing will make it possible to sustain the needed effort to operate CDF and D0 effectively, at the same time that it brings a lot of experience from the Tevatron program to the LHC. At our Annual Program Review, both CDF and D0 said that they are moving to make it easier for scientists to be an active member of their collaborations while sharing time with CMS or ATLAS. P.K. Williams expressed to me his encouragement of the LHC Physics Center here as an effective way of sharing university physicists between CDF or D0 and CMS.

I want to make the LHC Physics Center into one of the leading centers in the world for producing particle physics results, and am ready to commit resources to that end. In planning this startup we will work closely with you and with leadership of the US-CMS research program to make sure that we are establishing an institution that serves all of the interested parties well.

30 Apr 04

Sarah Eno, US CMS Meeting, Princeton

UNIVERSITY OF
MARYLAND

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What is the LPC? a 2004 view



What is the LPC?

Slide from Sarah Eno (UMD)
US CMS Collaboration Meeting
April 2004

An attempt to reproduce the benefits of being at the lab in our time zone, on our side of the Atlantic.

- a **critical mass** (clustering) of young people who are actively working on software (reconstruction, particle identification, physics analysis)
- one stop shopping for your analysis questions
- analysis tools such as large meeting rooms, video conferencing, large scale computing, “water cooler”
- virtual control room for active participation in the running and quality control of the experiment

30 Apr 04

Sarah Eno, US CMS Meeting, Princeton

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What is the LPC? present day

- An established center of excellence in CMS
 - Serves as an intellectual hub and resource for physics at CMS
 - Over **500 LPC users** including from **all active US CMS institutions**
- Unique resource for CMS physicists
 - Physically located on the 10th and 11th floors of Wilson Hall
 - Proximity to broad range of resources and expertise
 - Computing resources, software support, engineering staff, Fermilab theory division, admin support
 - **Remote Operations Center** for CMS shifts
- LPC focus is on three primary thrusts
 1. Community support and engagement
 2. Training and education
 3. Computing



LPC staff

- **Coordinators**

- Serve staggered two year terms
- 1x university faculty, 1x FNAL staff
- Maximum of two terms each
- Advised by LPC management board

- **Support scientists**

- PhD physicists
- Supported by USCMS ops
- Based at LPC
- Long-term continuity

- Significant **admin support** from FNAL PPD-CMS



Kevin Black (UW-Madison)



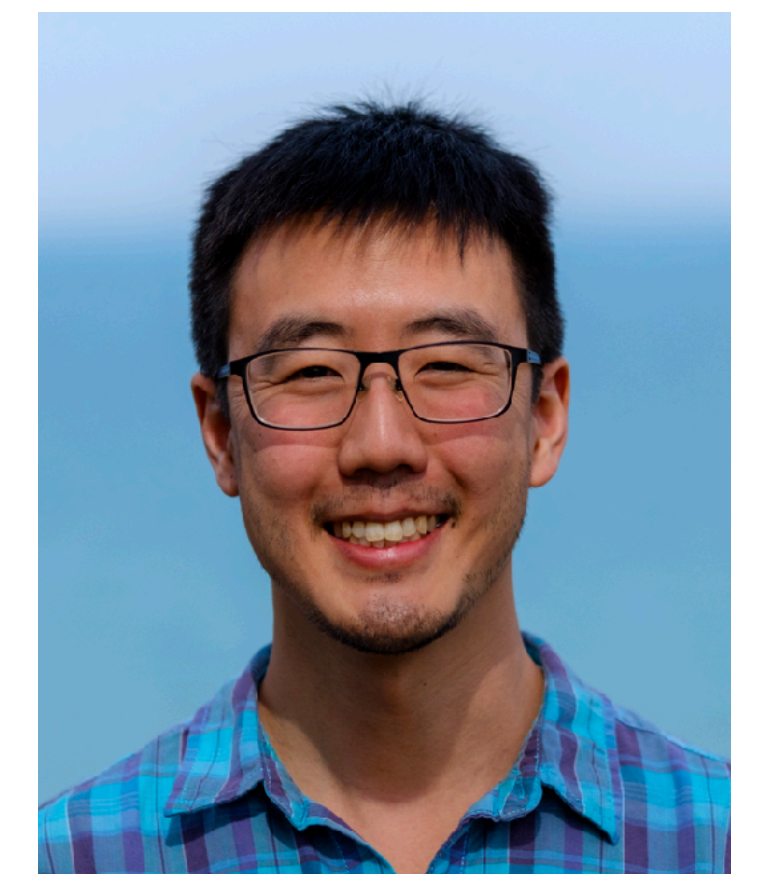
Bo Jayatilaka (FNAL)



Gabriele Benelli (Brown)
Physics support lead



Marguerite Tonjes (UIC)
Computing support lead



David Yu (Nebraska)
Operations support lead

LPC programs of support

- **LPC Distinguished Researchers (DR)**: flagship program of the LPC
 - Current and future leaders in CMS; responsible for projects at the LPC
 - Leading roles in nearly all LPC events
 - Award provides partial support for ~50% time at the LPC; Typically 12-15/year
 - Junior (postdoc) and senior (faculty) categories
 - Includes a travel award
 - Many choose to stay resident at the LPC beyond their DR term(s)
- **Guest and Visitor (G&V) program**
 - Facilitates CMS members to spend time at the LPC working on targeted projects
 - Detector, upgrade, and/or software and often with a physics component
- **Graduate Scholars (GS)**
 - Exceptional PhD students at USCMS institutions
 - Support for spending ~1 year at the LPC pursuing research towards their PhD

Supported by DOE
EF Research

Supported by
USCMS Operations

2023 Distinguished Researchers and Graduate Scholars

Distinguished Researchers



Sridhara Dasu*
UW, Madison



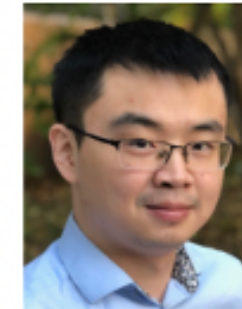
Daniel Diaz
UCSD



Jennet Dickinson
FNAL



Michael Krohn
Minnesota



Jingyu Luo
Brown



Garyfallia (Lisa) Paspalaki
Purdue



Juska Pekkanen**
Buffalo



Deborah Pinna
UW, Madison



Titas Roy
UIC



Ozgur Sahin*
CEA Saclay



Robert Schofbeck*
HEPY



Nick Smith
FNAL



Daniel Spitzbart
Boston U.



Nadja Strobbe*
Minnesota



Jonathan Wilson
Baylor



Fengwangdong Zhang
UC Davis



Jingyu Zhang
Florida State

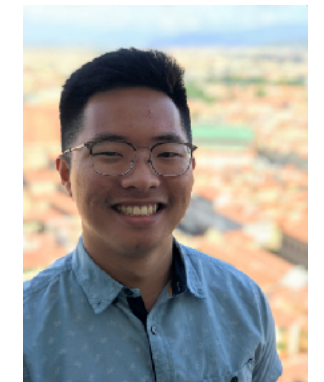
*Senior DR

**Partial year (left CMS)

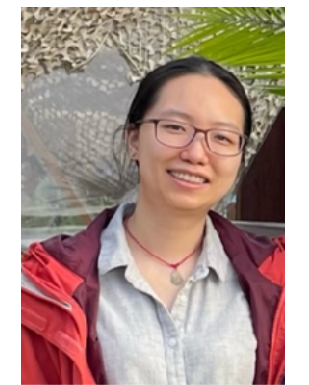
Graduate Scholars



Raghav Kansal
UCSD



Ryan Kim
FSU




Wei Wei
UC Davis

Example DR synergy: EFT


- Multiple 2023 LPC DRs with analysis interests involving Effective Field Theory (EFT)
- Fostered further collaboration and innovation while at the LPC
- Organizing a focused EFT workshop at the LPC

GARYFALLIA (LISA) Paspalaki




... events containing three heavy bosons (VVV) searches and their interpretation in the content of an Effective Field Theory using the full Run 2 dataset ... integration of a new method to mitigate the pile up effects using Graph Neural Networks (GNNs) ...

JONATHAN Wilson



... HGCal electronics: firmware design for emulation and testing of the trigger concentrator (ECON-T) and data concentrator (ECON-D) ... top quark studies using effective field theory ...

JENNET Dickinson




... measurements of high-energy Higgs boson production ... explore possible interpretations in terms of Effective Field Theory (EFT) ... CMS Outer Tracker upgrade ... development of testing and quality assurance procedures for modules and macro-pixel sub-assemblies (MaPSA) ... possibility of using machine learning on-ASIC to simplify data read-out ...

NICK Smith



... building the CMS Higgs-EFT effort ... large-scale combination analysis within the SMEFT framework. ...

ROBERT Schöfbeck



... explore SM-EFT in searches and measurements in the Top & Higgs sectors with new dedicated machine learning algorithms ... making high-dimensional SM-EFT results a reality....

From:

https://lpc.fnal.gov/fellows/index_2023.shtml

LPC Guest and Visitor program

- Offers partial support (per diem) for short and long-term stays at the LPC
 - Durations range from a few days up to one year
- Targets **operational and upgrade activities**
 - Activities can be detector or software and computing
 - Many visitors also pursue analysis activities taking advantage of LPC resources
- Significant **geographic and institutional diversity** in G&V recipients
 - 2023 International G&Vs from Armenia (ANSL), Germany (Hamburg) India (Kolkata-Saha, Panjab U), Italy (INFN Bari, Torino), Portugal (LIP), S. Korea (CNU, KNU)
 - 2023 Domestic G&Vs from Alabama, Brown, Caltech, Iowa, Kansas, Nebraska, Notre Dame, Princeton, Siena College, Rice, Tennessee, UCSD

Regular LPC events: seminars

- **Topic of the Week**
 - Typically collider experimental/theory seminars
 - Speakers typically have “office hours” with LPC community
 - >180 since 2012
- **Physics Forum**
 - More informal/interactive discussions/seminars
 - Use of smart board encouraged
 - >140 since 2013
- **Colliders of Tomorrow (New - 2023!)**
 - Seminars focused on future collider topics
 - Aimed at developing relevant expertise in the US community



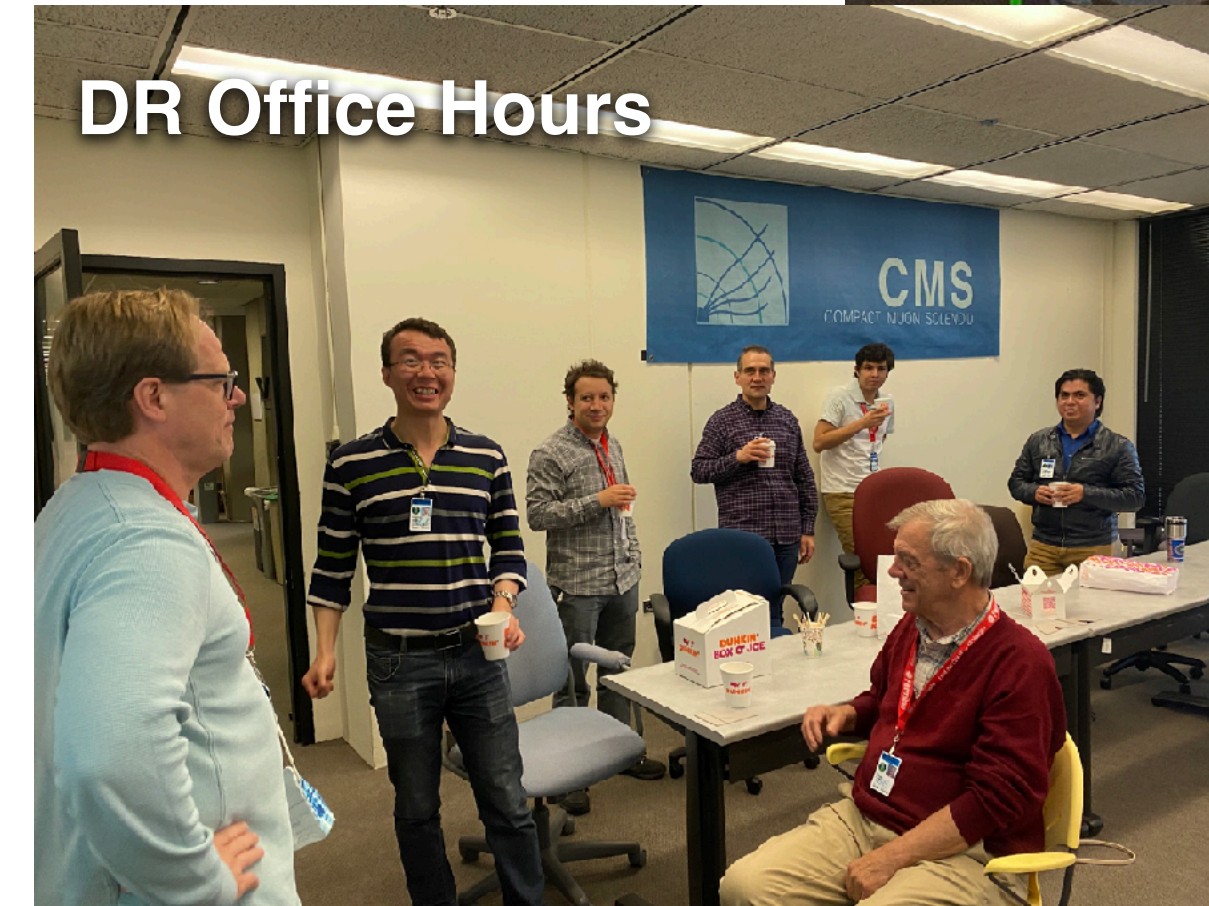
Regular LPC events: discussions

- **LPC Journal Club**
 - No-reading required journal club for LPC community
 - Participants vote on which papers to discuss
- **LPC Coffee Hour**
 - Informal discussion on interesting topic
 - Food/coffee/tea provided
- **DR Office Hours**
 - Weekly informal gathering encourages networking
 - Junior members of community have chance to ask questions
- **LPC Physics Analysis Discussions**
 - Weekly roundtable from physics tools experts
 - Initially started to help jumpstart Run 2 analyses. Now Run 3
- **LPC Computing Discussions**
 - Forum to discuss/ask questions about computing issues

LPC Journal Club April 2022



DR Office Hours



LPC Coffee Hour Aug 2022



Advanced topic workshops at the LPC

- Many focused workshops organized at the LPC
 - All have at least one DR involved in organizing
- Recent and upcoming
 - ML@L1 Trigger Workshop (Oct 2022)
 - FastSim Days 2022 (Oct 2022)
 - [CMS Open Data Workshop](#) (July 2023)
 - EFT Workshop (~Sep 2023)



Start your day with a cup of
CMS open data

Available at a computer near you!

CMS open data workshop
at the LPC

Jul 11 - 14, 2023
Fermilab Wilson Hall
America/Chicago timezone

Enter your search term

Double Higgs Production
at Colliders

4-8 September 2018 • Fermilab/LPC

Recent results from LHC
Advances in theoretical calculations
Analysis techniques
BSM phenomenology
EFT interpretations

ORGANIZING COMMITTEE
John Allison, U Chicago
Olivier Bondia, FNRS/CP3-Louvain
Sally Dawson, Brookhaven
Biagio Di Micco, INFN Roma 1
Christoph Englert, U Glasgow
Maxime Gouzevitch, CNRS/UCB Lyon 1
Giacomo Ortona, LLR

LOCAL ORGANIZATION COMMITTEE
John Allison, U Chicago (chair)
Zhen Liu, Fermilab/U Maryland (chair)
Caterina Vernieri, Fermilab (chair)
Luca Cadamuro, U Florida
Marcela Carena, U Chicago/Fermilab
Jacobo Kongsberg, U Florida
Gabriele Benelli, Brown U (LPC event committee)
Ben Keis, Fermilab (LPC event committee)
Nicola DeFilippis, INFN (LPC event committee)

https://indico.cern.ch/event/hh-2018

Fermilab
U.S. DEPARTMENT OF ENERGY | Office of Science
Fermilab Research Alliance LLC

Training and education: CMS Data Analysis School (DAS)

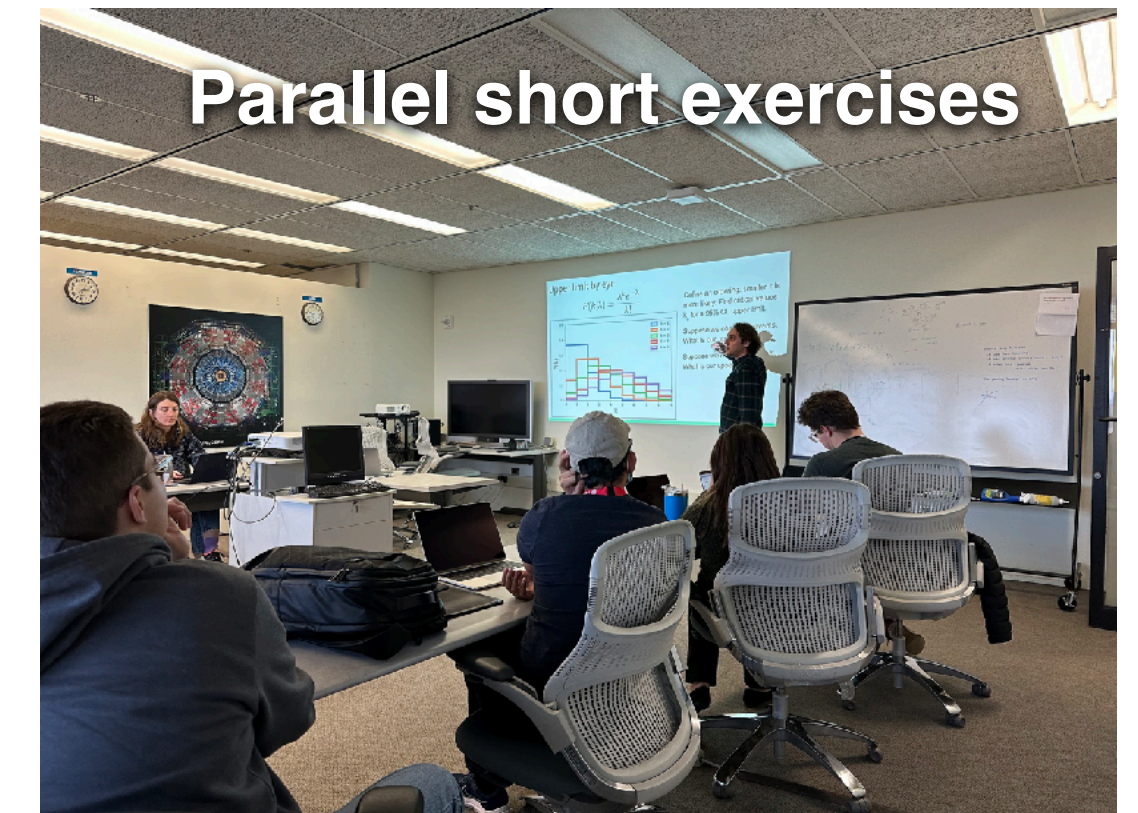
- Annual “boot camp” for new CMS students/postdocs
 - One week school from basics to complete analysis as group exercise
 - Pioneered at LPC (started as “J-Term” in 2006)
 - Format emulated at CERN and elsewhere
 - Held annually at the LPC



25th CMS DAS: Jan 9-13, 2023



Plenary lectures



Parallel short exercises



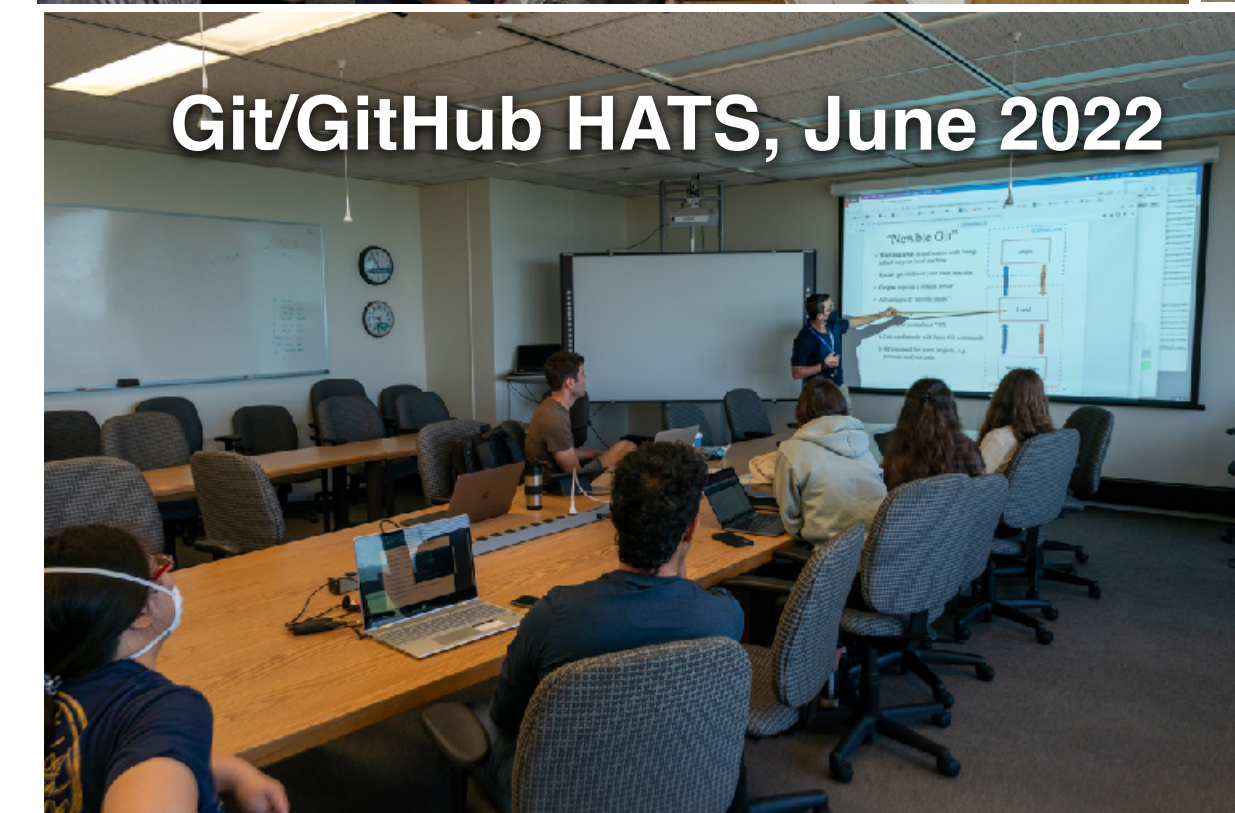
Group long exercises



Final group presentations

Training and education: HATS and graduate courses

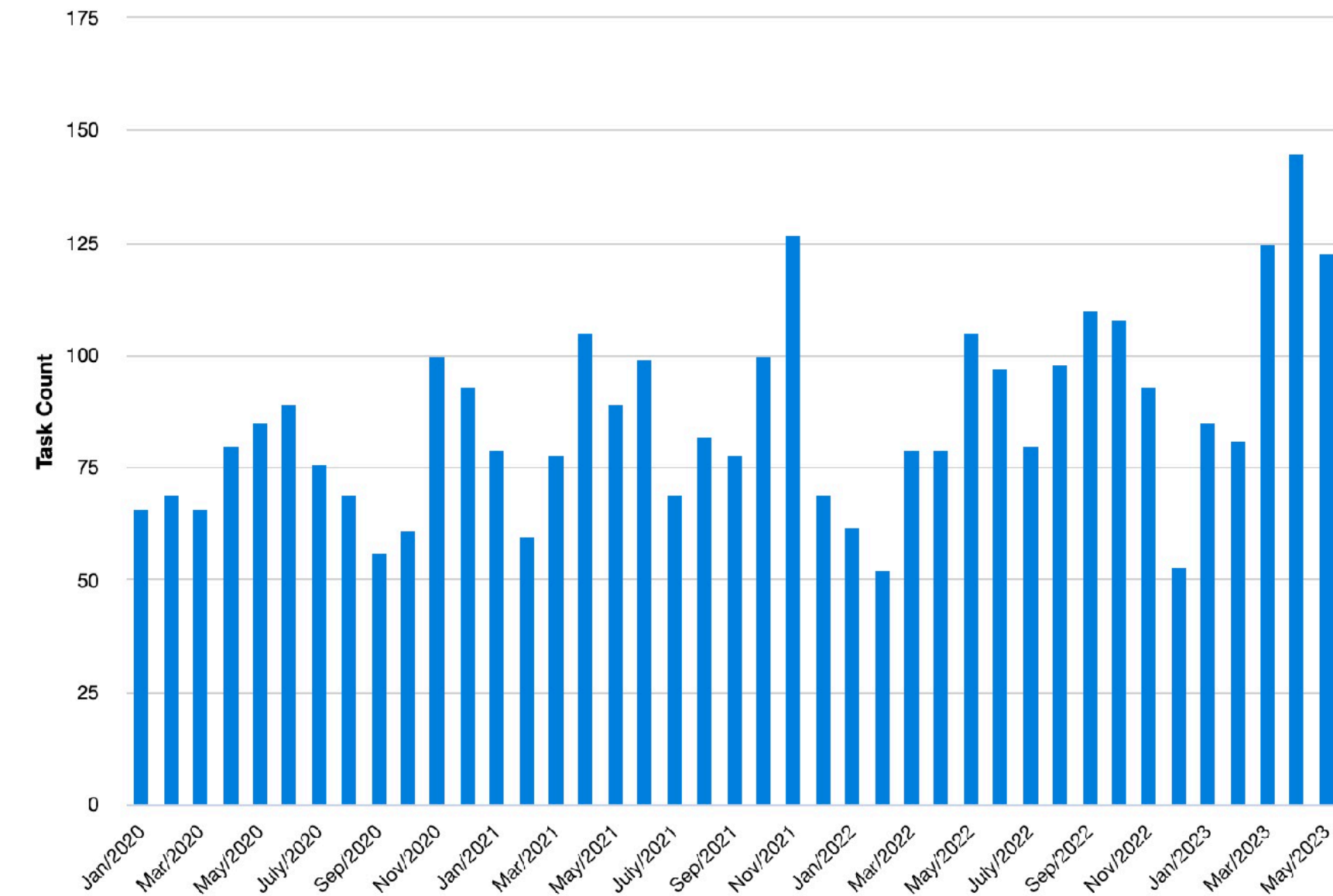
- Hands on Advanced Tutorial Sessions (HATS)
 - Hands-on training for specific tools and topics for physics analysis
 - e.g. Jet substructure, particle flow, machine learning, tagging, software and analysis tools
 - Held throughout the summer
 - **>150 HATS** since 2013!
- Graduate courses at the LPC
 - LPC facilitates remote participation in graduate courses taught by USCMS faculty
 - LPC students can receive course credit with advisor agreement
 - Recent courses include computational physics, statistics for experimental physics, ML/AI
 - Typically one course offered per term (fall or winter)



Computing at the LPC

- Dedicated LPC analysis cluster (>5k core)
 - Open to any CMS collaborator
 - Nearly 900 unique users annually
 - Extension of resources at FNAL Tier-1
 - Backed by same expert support
 - Key resource for CMS DAS
 - Significant user support resources via LPC
 - Includes dedicated GPU
- Analysis data storage (>5 PB)
 - Carrot: Group quotas granted only for multi-institute collaborations
- New: Elastic Analysis Facility →
 - Enables more modern analysis tools
 - e.g. Jupyter notebooks

graph: CMS all new and renew users monthly since Jan 2020



Server Options

- CMS** (CVMFS, HTCondor, COFFEA)
 - CPU Interactives: SL7 COFFEA-Dask
 - NVIDIA@ A100 GPU: SL7 - 10GB GPU slot
- DUNE** (LBNF DUNE/ProtoDUNE, CVMFS, LarSoft)
 - CPU Interactives: SL7 Vanilla
 - NVIDIA@ A100 GPU: SL7 - 20GB GPU slot
- SL7 Vanilla
- NVIDIA@ A100 GPU: SL7 - 10GB GPU slot

LPC EOS storage servers

Shifts at the LPC: The Remote Operations Center (ROC)

- Initial LPC proposal included a “virtual control room”
 - Ability to take remote CMS shifts at Fermilab
 - **Remote Operations Center (ROC)**
 - Initially on 11th floor of Wilson Hall
 - Moved to eventual home in first floor by first collisions in 2008
- Significant aspect of LPC
 - Allows for a variety of remote CMS shifts
 - Used in VIP visits/tours
 - Served as a model for ROC West used by Neutrino/muon experiments



The ROC in Run 3

- Revitalized in Run 3 with several shift types
 - Data quality monitoring (DQM)
 - Tracker offline
 - Trigger
 - **In 2022 alone, ~50 DQM and ~300 Tracker shifts**
- Provides essential support to CMS and LPC
 - Makes shifts more inclusive and accessible to US collaborators
 - Particularly (CERN) night shifts
 - Cost and CO₂ savings!
 - Invigorates LPC with operations as part of daily life
- Dedicated resources
 - Shifter workstations, smartphone w/ CERNphone app, local experts, *free coffee*
 - LPC-organized in-person trainings and tutorials



VIP visits and outreach at the ROC



DOE Science Director Dr. Berhe
July 2022



NAS EPP March 2023



DOE Oppenheimer Cohort March 2023



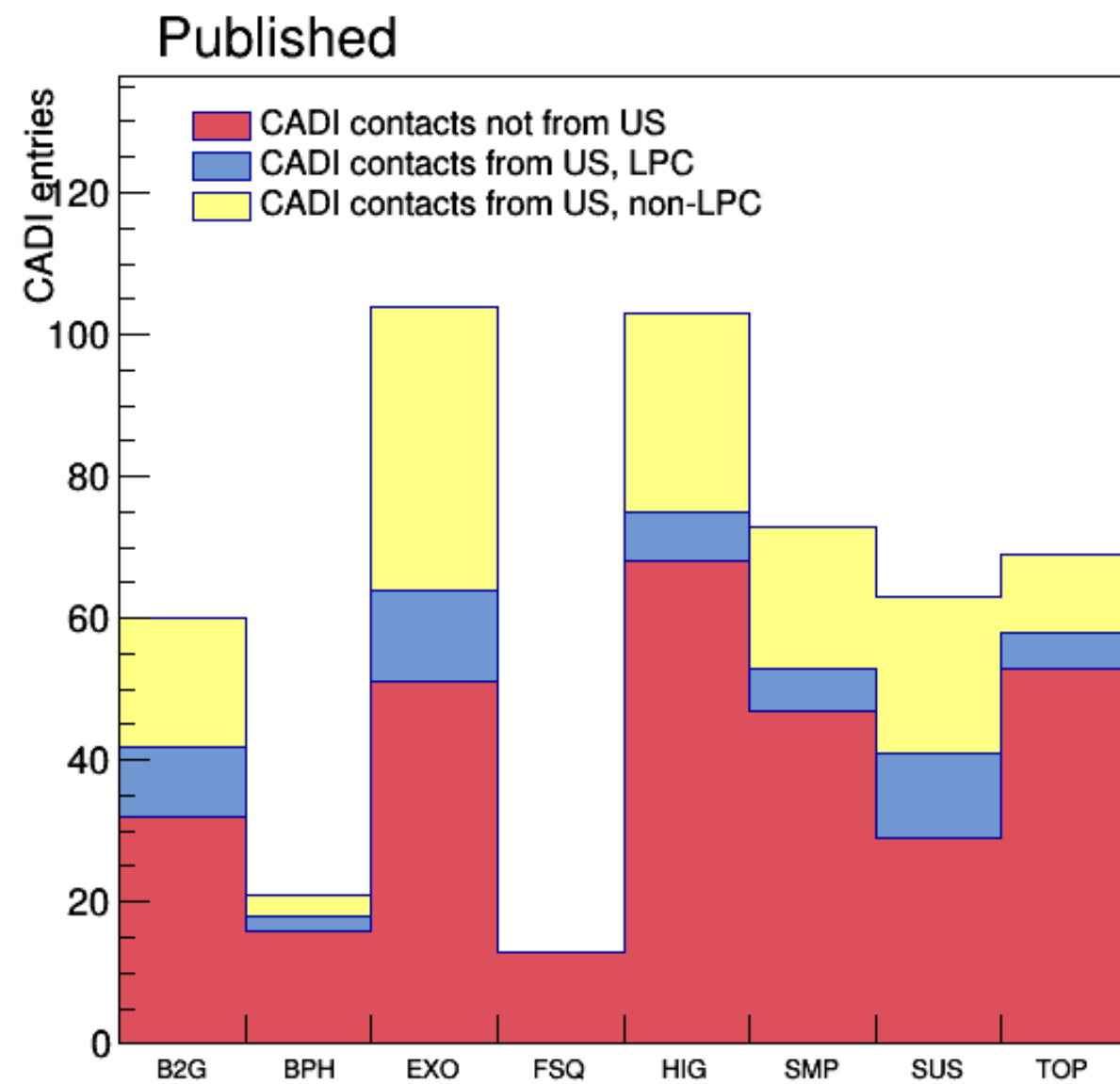
P5 Panel March 2023



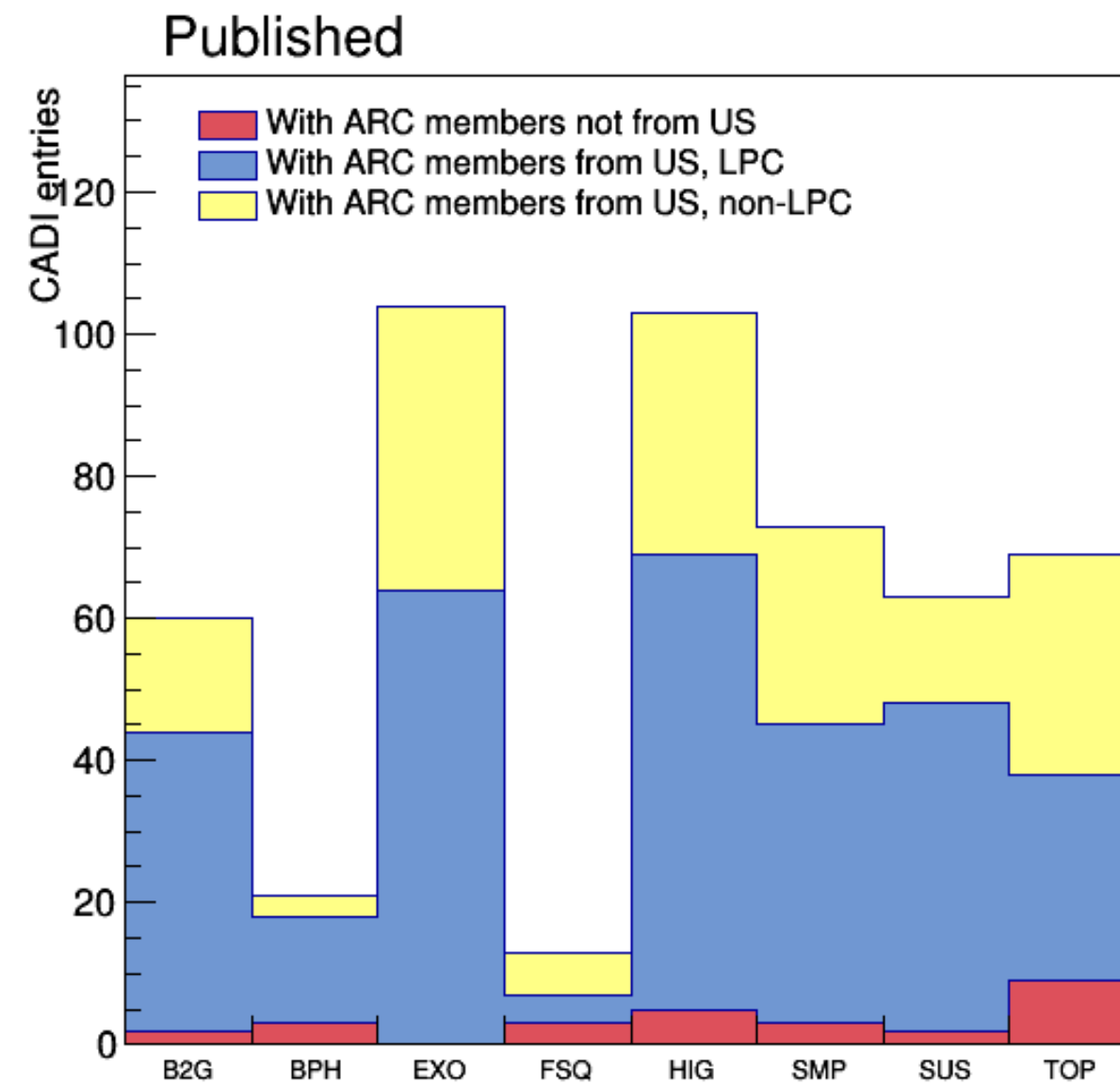
FRA Board April 2023

LPC impact on CMS physics

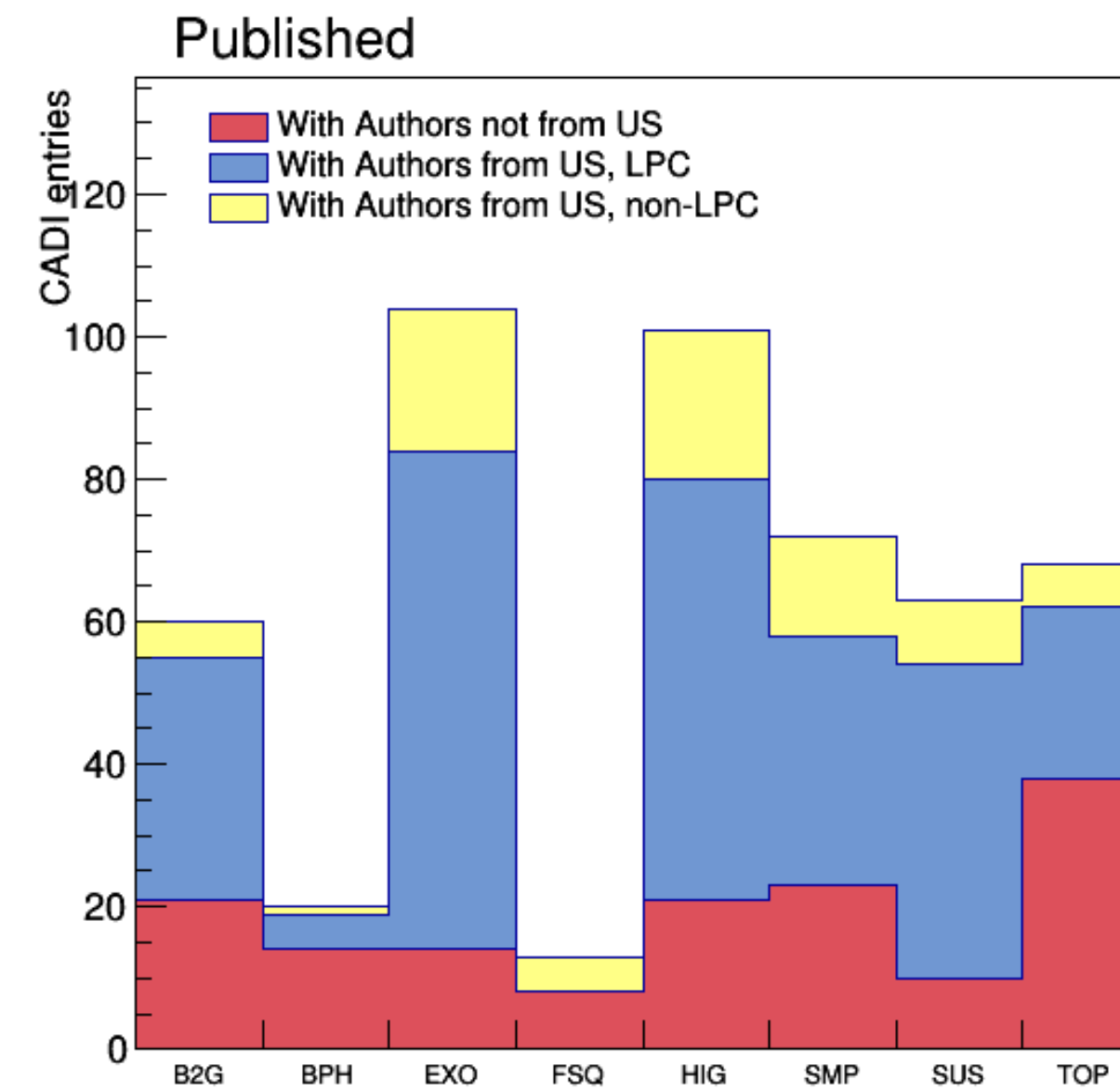
Published CMS papers 2016-2023*, by physics group, with LPC users as:



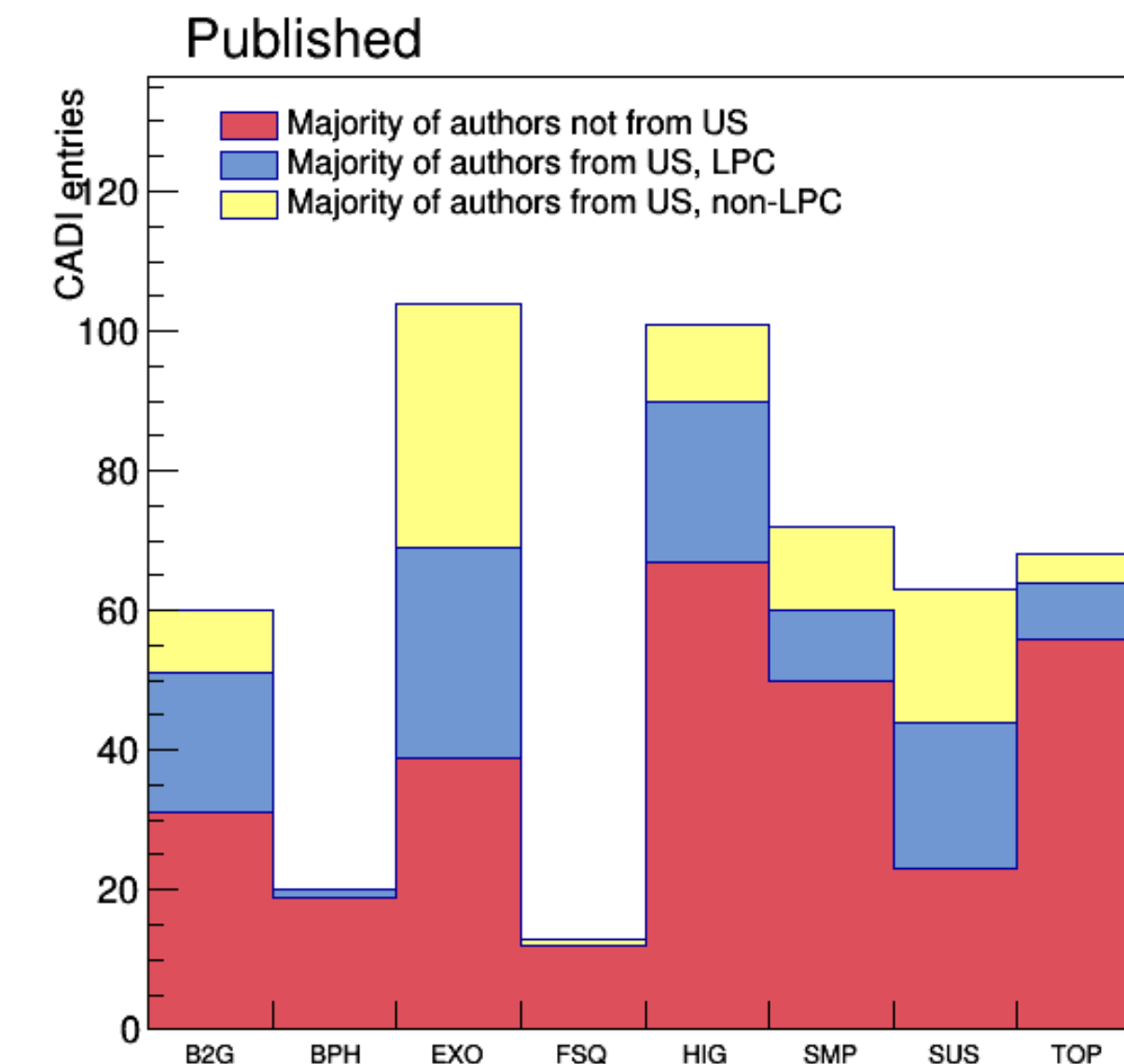
Primary analysis contacts
11%



Analysis Review Committee members
60% (21% of chairs)



with LPC authors
54%



with majority LPC authors
23%

*CMS publications were held from Feb 2022 to Mar 2023 pending author list decision

Broader LPC impacts

- Supporting future leaders in the field
 - **45% of junior DRs** in the past five years have gone on to tenure-track positions
- Training new members of CMS
 - 50-70 students annually take part in LPC-hosted CMS DAS
 - ~200 participants in HATS annually
- Improving DEI in the field: **US CMS PURSUE program**
 - The LPC plays a key role in the USCMS internship program for underserved minorities and women undergraduates
 - Virtual-only in 2022, in person this year (started this week!)
 - LPC hosts all interns for initial two weeks and a fraction for the entire summer
 - Training and computing resources also supported by the LPC
- Model for other centers of excellence in the field
 - Neutrino Physics Center and Cosmic Physics Center at Fermilab modeled on the LPC

LPC impacts: extending participation

- **All** active (> 0 authors) US CMS institutions participate in the LPC
 - Participation defined as active use of LPC facilities, participation in LPC programs, communication within LPC fora
 - Includes **all (14/14) small US CMS groups** (< 10 authors)
 - Includes **all (4/4) non-R1 university/college US CMS groups**
 - Affiliated CMS faculty from three PUIs (Bethel, Siena, US Naval Academy) all participate in LPC
 - All former LPC DRs
- Significant non-US participation in LPC
 - Many international G&Vs from countries underrepresented in CMS
 - Significant fraction of Senior DRs (e.g., 2/4 in 2023) from non-US institutions

Recent challenges

- Significant loss of institutional presence during COVID lockdown
 - LPC residence still significantly lower than during 2019
 - 2023 is a significant increase from 2022 so trends are promising
- Funding
 - DOE EF research funding to LPC significantly reduced
 - Effectively ~halved in 2017
 - Limits size of DR program
 - Typically more highly qualified candidates than the program can support
 - Successive LPC Coordinators worked with Ops program to find some stopgaps
 - Now funding entire G&V program as well as LPC GS program
- Fermilab site access
 - Many users/affiliates face access challenges
 - Significant barrier in further recruiting university community to come to LPC
- Limited Fermilab on-site housing
 - Major challenge in summer 2023

Conclusions

- The LHC Physics Center is a unique hub at Fermilab for CMS research
 - Confluence of physics, technical, and administrative expertise for CMS collaborators all under one roof
- LPC events bring members of the community together
 - Typically >100 LPC “residents” in a given year
 - Several talks/seminars a week and several large workshops a year
 - Comparable to a research university physics department!
- Challenges to “restarting” LPC after COVID lockdown
 - Activity continues to ramp up
 - >50 university users intend to spend time at the LPC this summer alone
- US CMS and Fermilab committed to maintaining the LPC’s vibrancy
 - Especially as the HL-LHC is on the horizon
 - Can also serve as a hub for future collider activities in the US



lpc.fnal.gov

Backup

Charge and recommendations

Charge: The PAC is asked to review the status of the LHC physics center (LPC) and of the recommendations from previous reviews.

Recommendations:

1. Essential facts about the structure of the LPC and its successes be disseminated in a concise document, which can be useful to the Center itself, and to other communities that may want to replicate the ideas.
2. Given the Center's unique role in training and in creating networks among CMS scientists, the LPC compile information about the degree of participation in and benefit from LPC programs among scientists from smaller US-CMS institutions, underrepresented demographic groups in the US, and nations with low representation in CMS.
3. The LPC management team continue its efforts on all fronts to maintain the operations of the Center, which requires that the budget is not further decreased, and is ideally increased to better serve more early career researchers.

Distinguished researcher selection

- DR candidates submit application material via AJO
 - Research statement, CV, cover letter
 - Junior applicants also have three letters of reference
- LPC MB reviews applications and makes recommendation to fund
 - Factors considered include strength of proposed research and synergies with ongoing LPC activities
 - In nearly all years funding is the limiting factor in how many DRs are awarded
- Application process is an opportunity for Junior DR applicants
 - Often apply for DR 1-2 years before applying for faculty jobs; offers a chance to put together an “application packet” for the first time

Upgrade activities at Fermilab

L1 Trigger/HLT/DAQ

- L1 40 MHz in/750 kHz out
- Tracking for PF-like selection
- HLT 7.5 kHz out

Barrel Calorimeters

- ECAL single crystal granularity in L1 Trigger with precise timing for e/γ at 30 GeV
- ECAL and HCAL new back-end electronics

Muon Systems

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

Beam Radiation and Luminosity, Common Systems, Infrastructure

Calorimeter Endcap

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

Also known as HGCAL

MIP Timing Detector

- < 75 ps resolution
- Barrel: Crystals + SiPMs
- Endcap: LGADs

Also known as "Timing Layer" (TL)

Tracker

- Si Strip Outer Tracker designed for L1 Track Trigger
- Pixelated Inner Tracker extends coverage to $|\eta| < 3.8$

