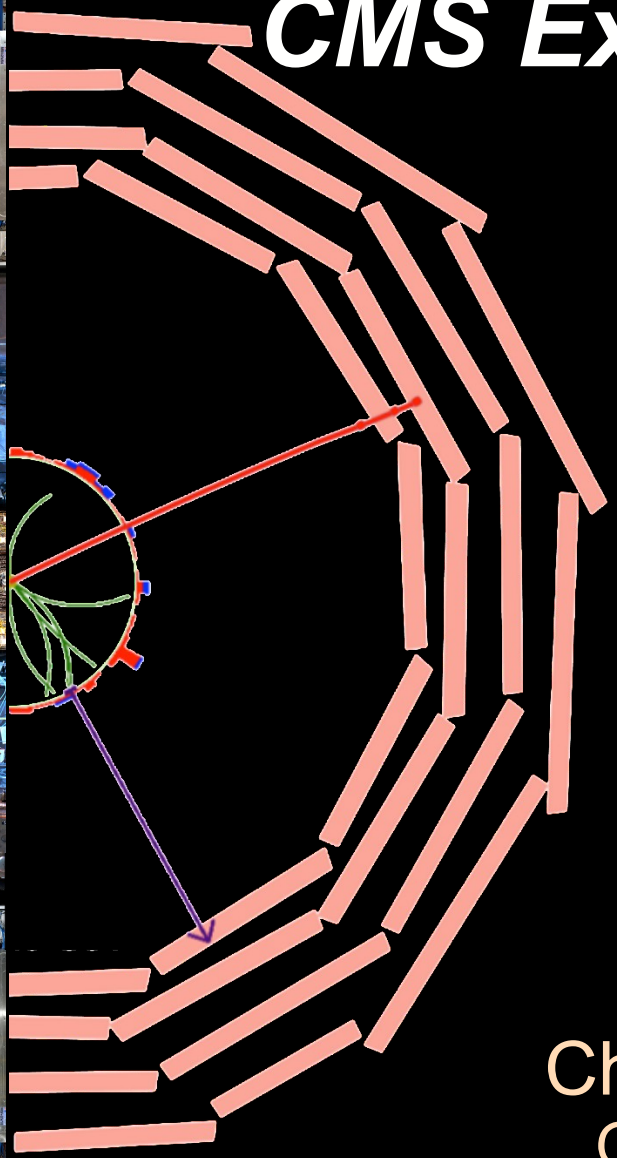


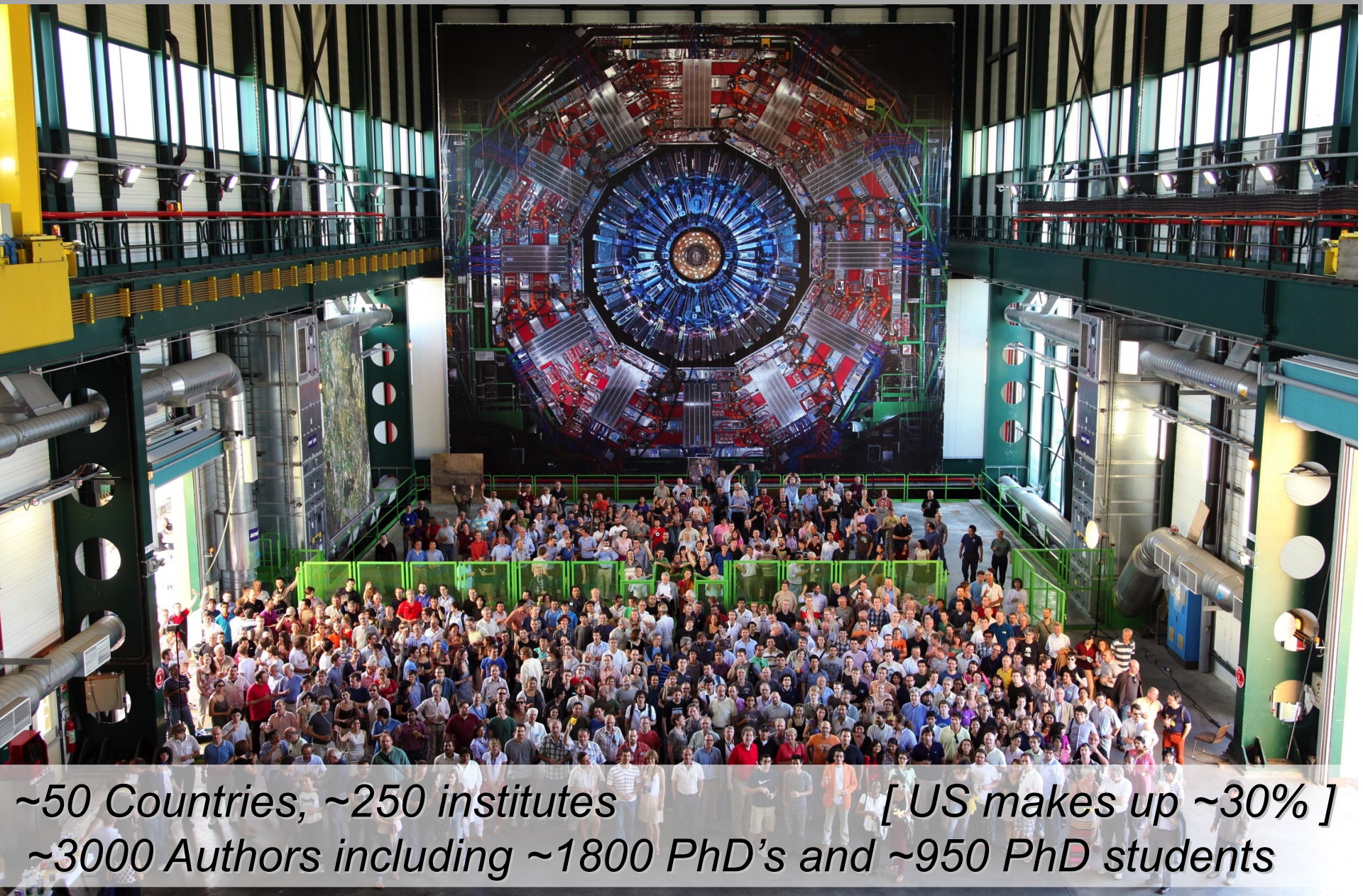
Introduction: CMS Experiment Detector Projects

Christoph Paus

October 8, 2024

DOE Visit

MIT is member of the CMS Collaboration



~50 Countries, ~250 institutes *[US makes up ~30%]*

~3000 Authors including ~1800 PhD's and ~950 PhD students

The CMS group at MIT

High Energy Physics

- 2 faculty: Philip Harris, Christoph Paus
- ~ 8 graduate students in steady state

Heavy Ion Physics

- 5 faculty: Wit Busza (emeritus), Gian Michele Innocenti, Yen-Jie Lee, Gunther Roland, Bolek Wyslouch
- ~ 8 graduate students in steady state

Share as we can

- office/lab space, CMS organization and project overlaps

Our priorities

CMS HEP Faculty and Funding

- **Highest priority:**
  CMS HEP group needs junior faculty hire
- Cost of graduate students at MIT higher than at comparable places
- Continued support for research computing
- Struggling with funding for administrative support

Particle Physics Collaboration (PPC)

Faculty

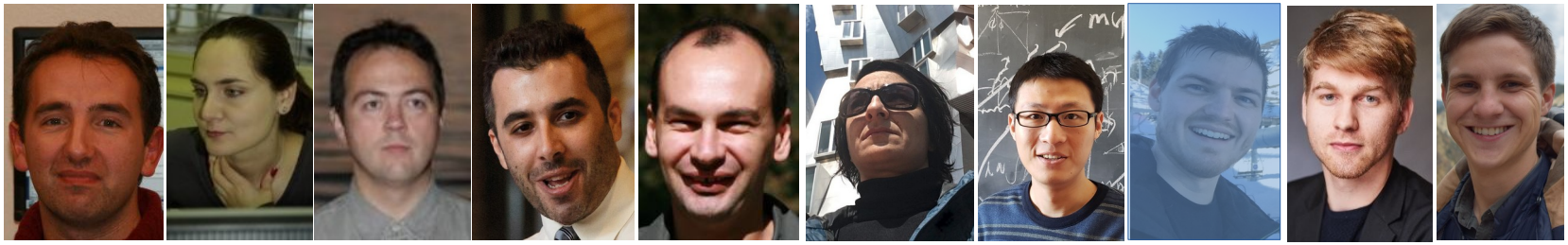
Christoph Paus

PPC web site: https://ppc.mit.edu/

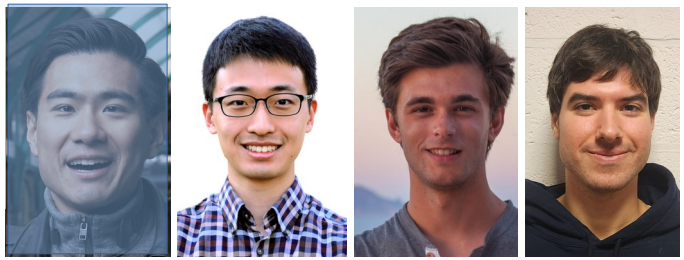
A number of crucial operational responsibilities

► **~ half of the people at CERN**

Research Scientists, Postdocs



Graduate Students

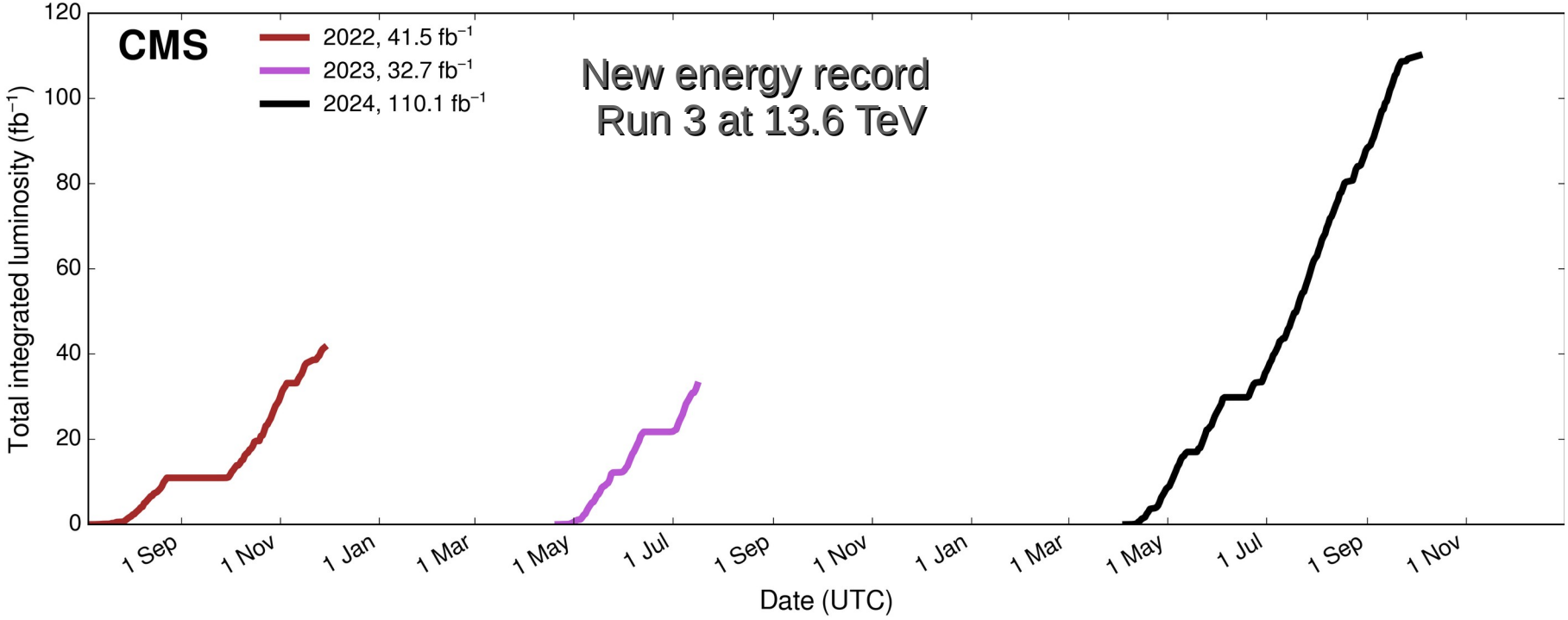


Visiting Students

Undergrads many many many

Joining for lunch...

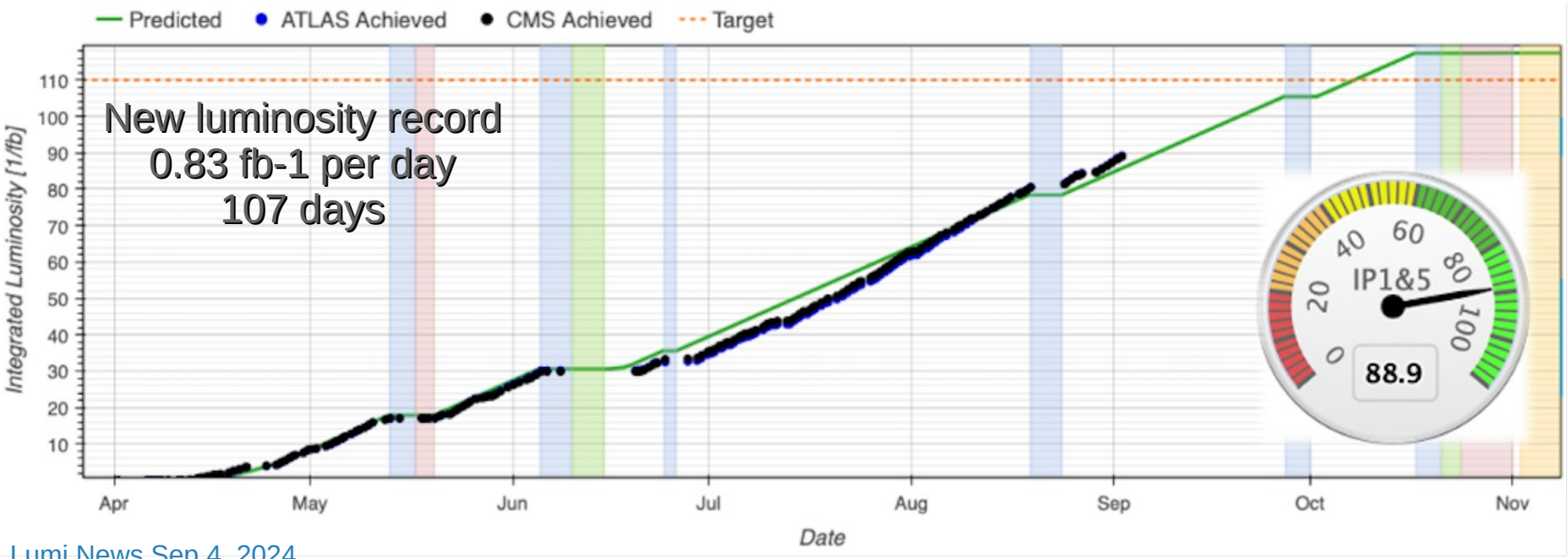
LHC Data – Newest 2022-24



Mixed years 2022 and 2023; 2024 spectacular

- Start went well, with commissioning ramp
- ... but big quench and other repairs (LHC shows its age)
- Hoping for ~250 fb^{-1} at 13.6 TeV by end of 2025

LHC Data – Newest 2024

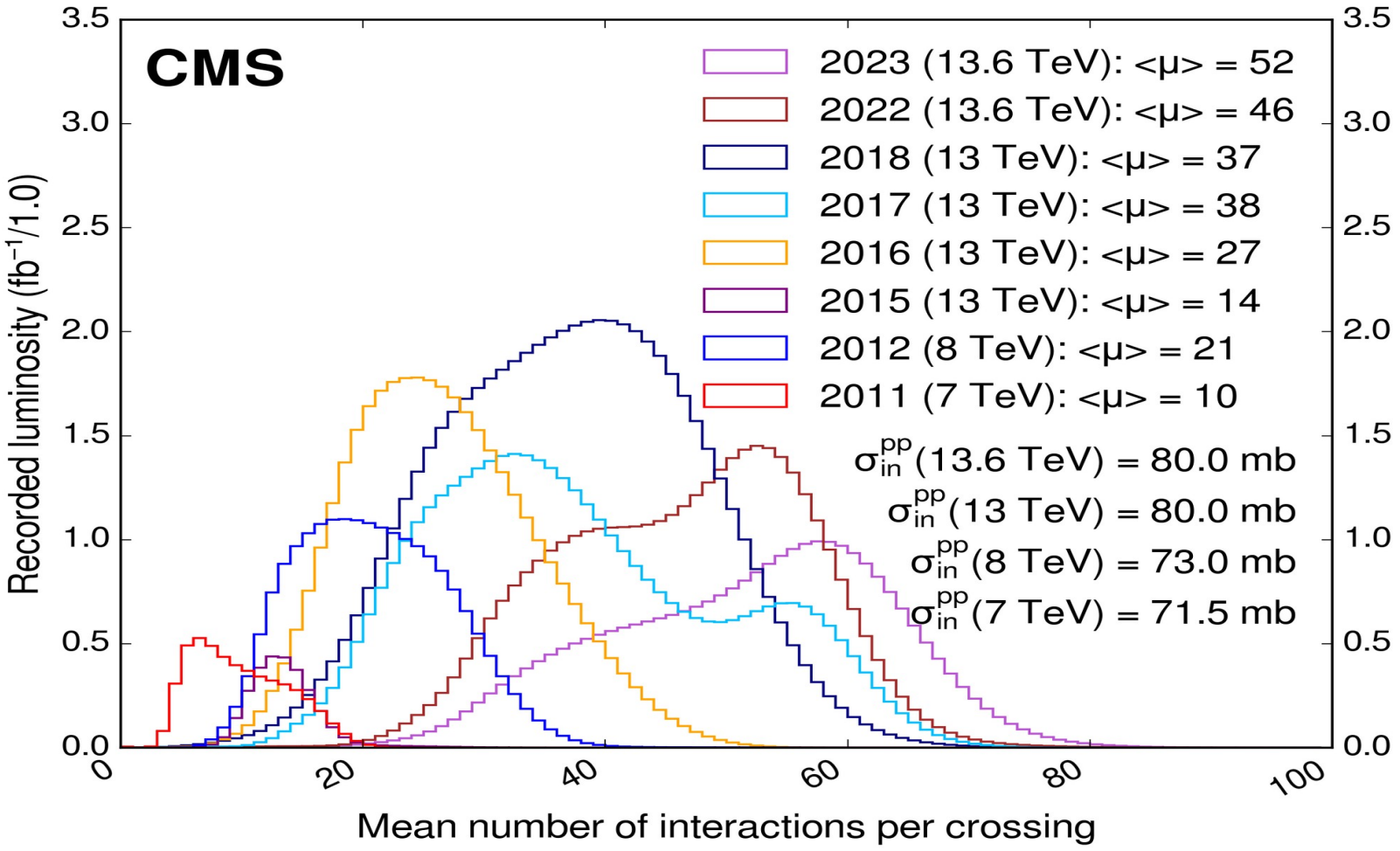


Lumi News Sep 4, 2024

Record breaking 2024

- LHC will likely provide more int. luminosity than anticipated
- The run has its issue but excellent planning and dedicated work keeps this machine performing extremely well

LHC Steady Increase



Pileup expresses instantaneous lumi

- Event complexity also increasing: towards PU 200 at HL-LHC

First Run 3 analyses from PPC

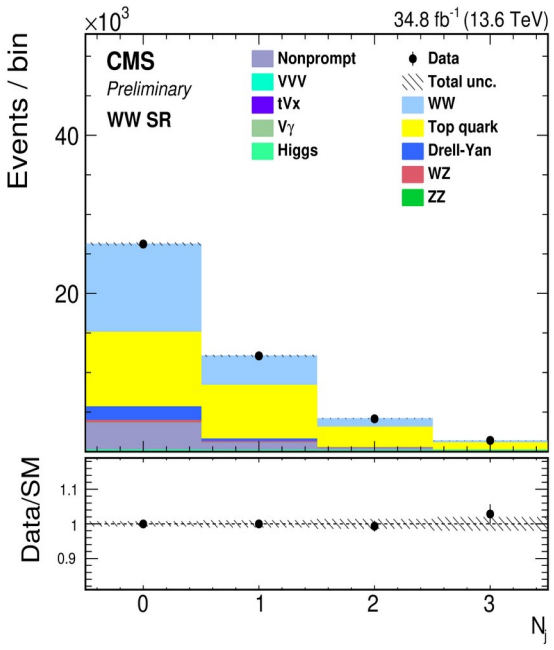
First diboson measurements at LHC in Run 3: $W^+W^- \rightarrow e\nu\mu\nu$

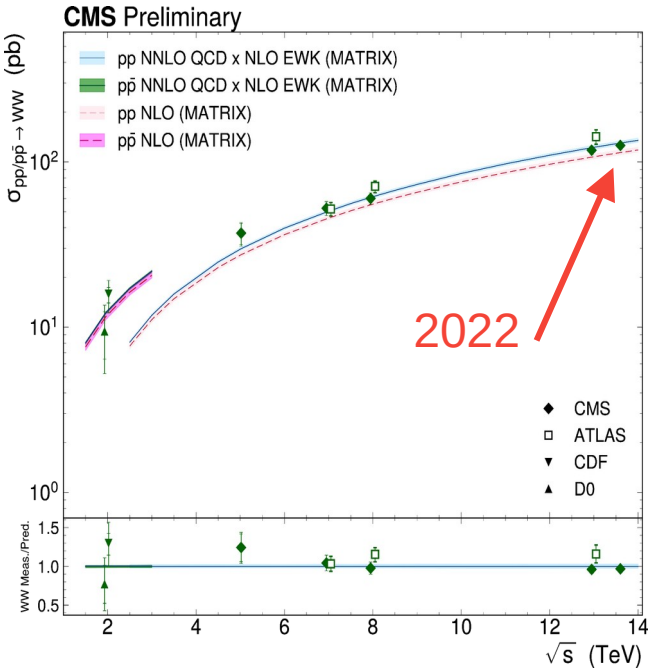
- ~35 fb^{-1} of CMS data collected in 2022

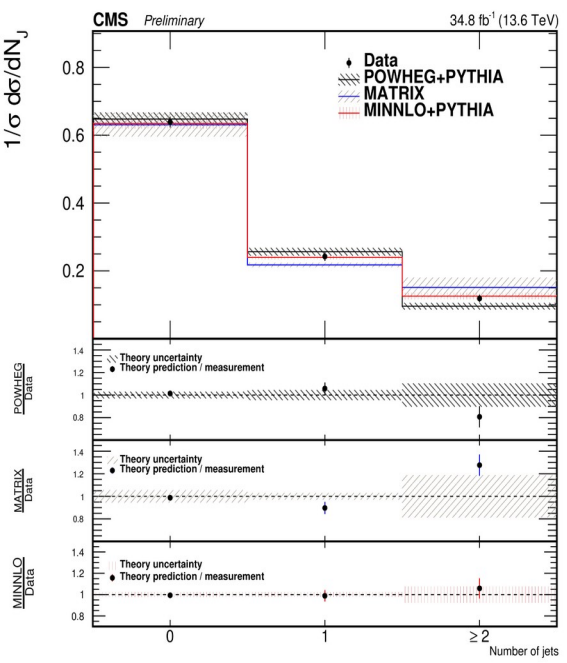
Max. likelihood fit using signal and backgr. enriched categories:

- electron-muon events split by lepton charges, the number of jets, and number of jets identified as originating from b quarks

Inclusive cross section: 125.7 ± 5.6 pb agrees with predictions







Public: CMS PAS SMP-24-001, paper submitted

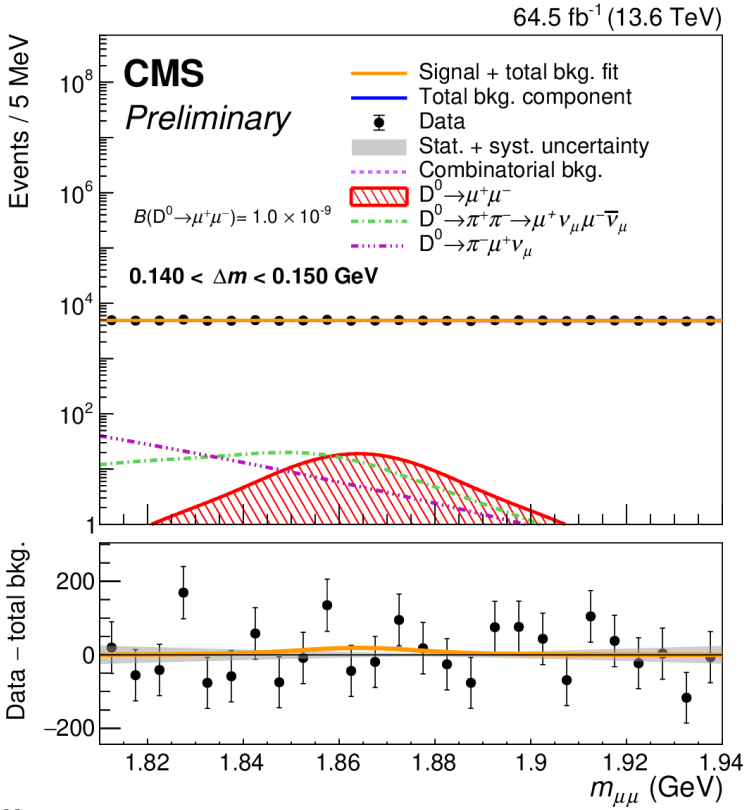
First Run 3 analyses from PPC

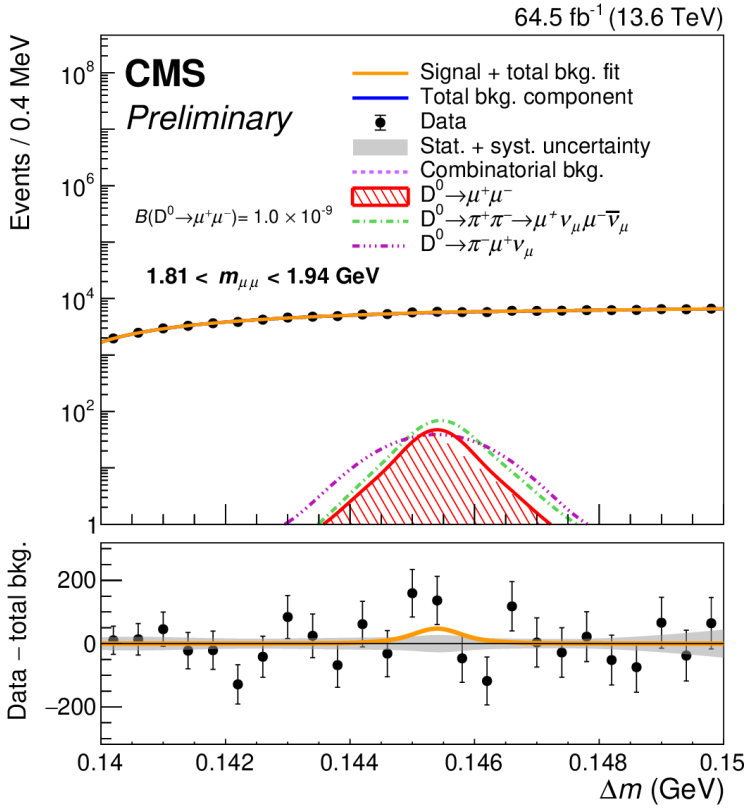
World best limit

$$(D^0 \to \mu + \mu -)) < 2.6 \times 10^{-9} \quad \text{at } 95\% \quad \text{C.L.}$$

Most stringent limit on flavor-changing neutral currents in charm sector, setting additional constraints on new physics models that modify the decay branching fraction of *D0→μ+μ−*.

Low level PPC work: overhauled low momentum muon trigger and reconstruction

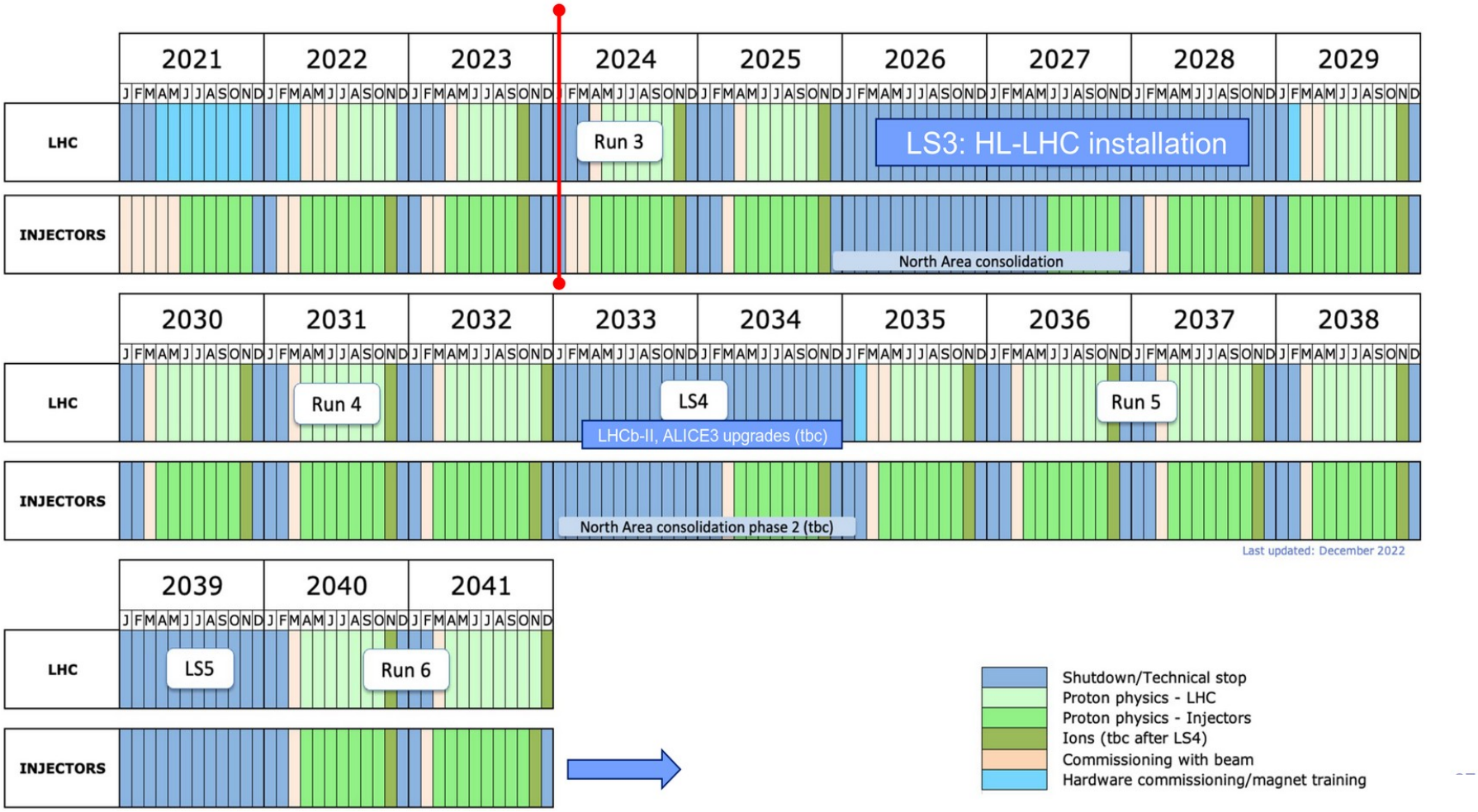




Public: CMS PAS BPH-23-008, paper submitted

LHC Schedule – Long Term

Indicative timeline out to 2041



(HL-)LHC Physics highest priority for HEPAP's P5

Upgrade Projects

Storage Manager and Data Transfer system

- HL-LHC will need significantly larger system: design studies for completely new system in progress

Tier-2 Computing center (joint with LHCb, CLAS12, ATLAS?)

- Needs to transition to new storage concept (cephFS)
- Massive hardware expansion needed: CPU, GPU, networking

Tape Pilot project

- Demonstration project to establish tape storage at MIT completed
- The NESE tape facility in Holyoke is fully integrated into the CMS storage system, commissioning now

Future Analysis Facility concept development (R&D)

- New concept to support HL-LHC-and-beyond analysis is being developed (we have a battle tested prototype)

MIT will be a major computing site for HL-LHC

PPC Leadership

CMS Higgs Rare decays (L3)

- Mariarosaria D'Alfonso

CMS B Physics convener (L2)

- Dmytro Kovalskyi

CMS Computing Operations (L2)

- Dmytro Kovalskyi

Rare decays (L3)

- Zhangqier Wang

Guillelmo Gomez-Ceballos foreseen as Physics Coordinator...

FCC project

- FCC-ee Higgs convener: Jan Eysermans
- FCC-ee Precision Electroweak convener: Christoph Paus

Recent Highlights
from the detector projects

Storage Manager / File Transfer

Purpose

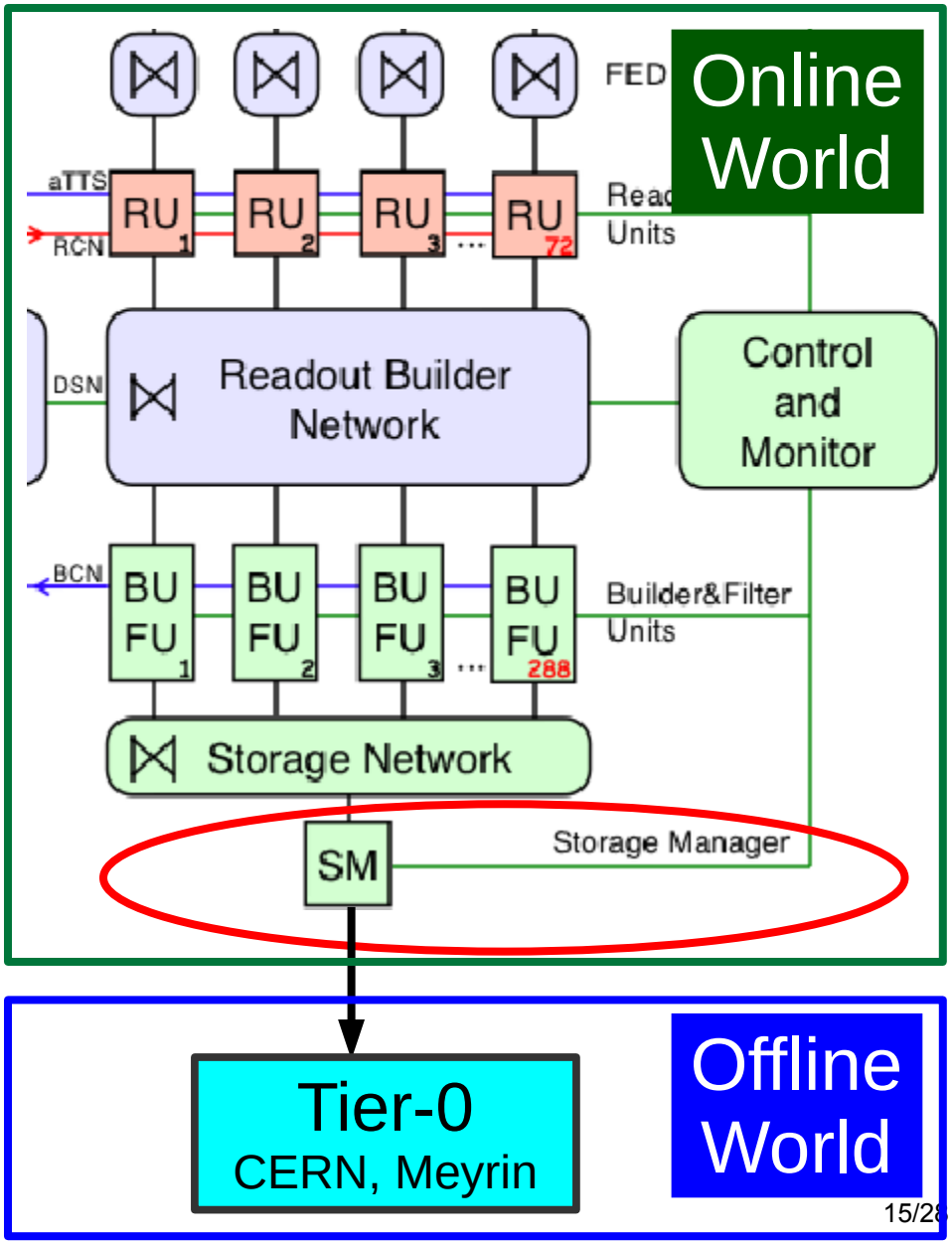
- Last stage of **online world**: DAQ system
- Buffer data, provide data safety
- Transfer to **offline world**

History

- MIT designed, built, commissioned, and 24/7 operated system since start
- Rebuilt entire system each Run

Run 3

- Design throughput 7 GB/sec
- Achieved 15 GB/sec, fine for pp
- Heavy Ion: asks 30 GB/sec
- We implemented temporary solution* from scratch that gives HI a chance to record 30 GB/sec



* big unplanned effort, serves as R&D for next system

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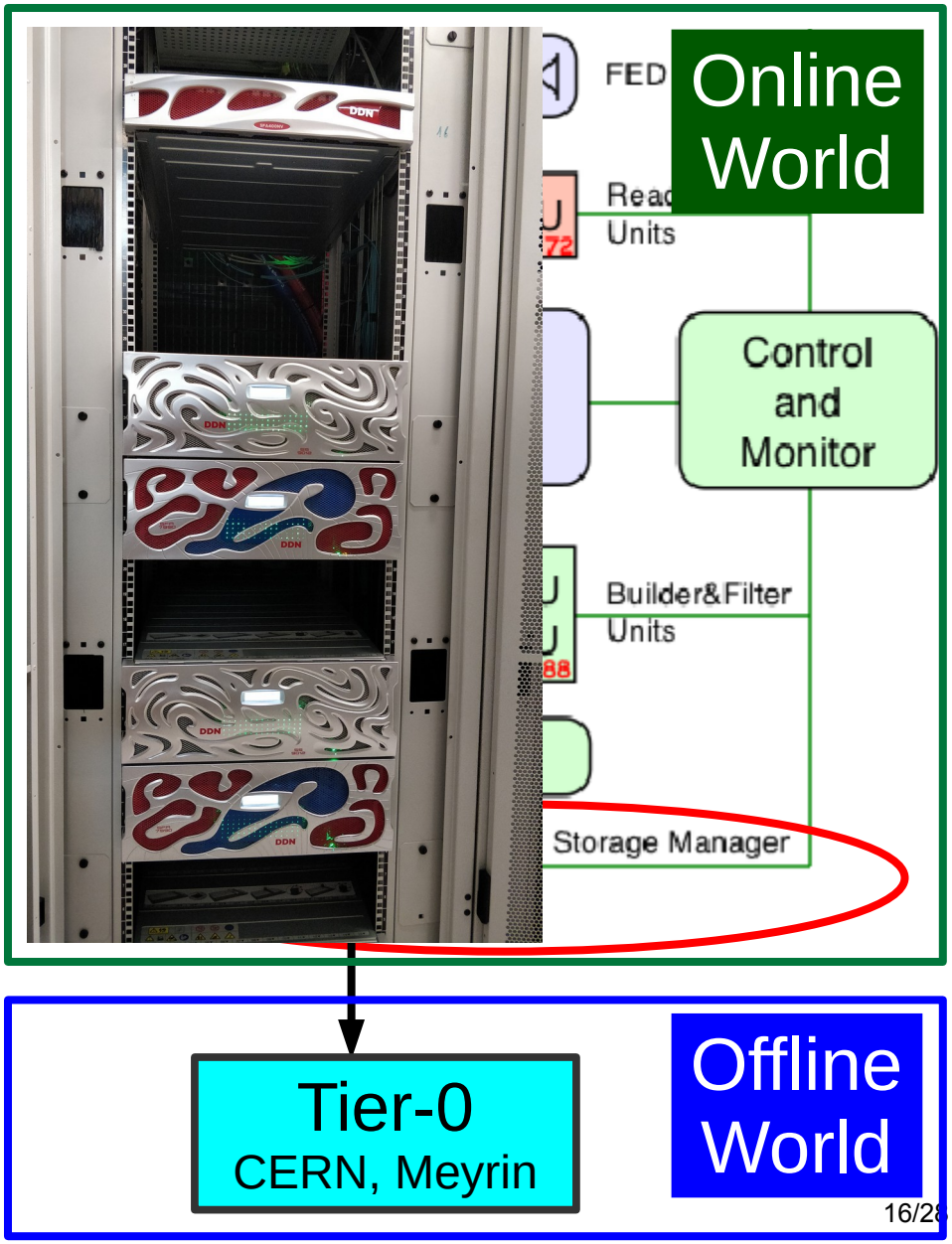

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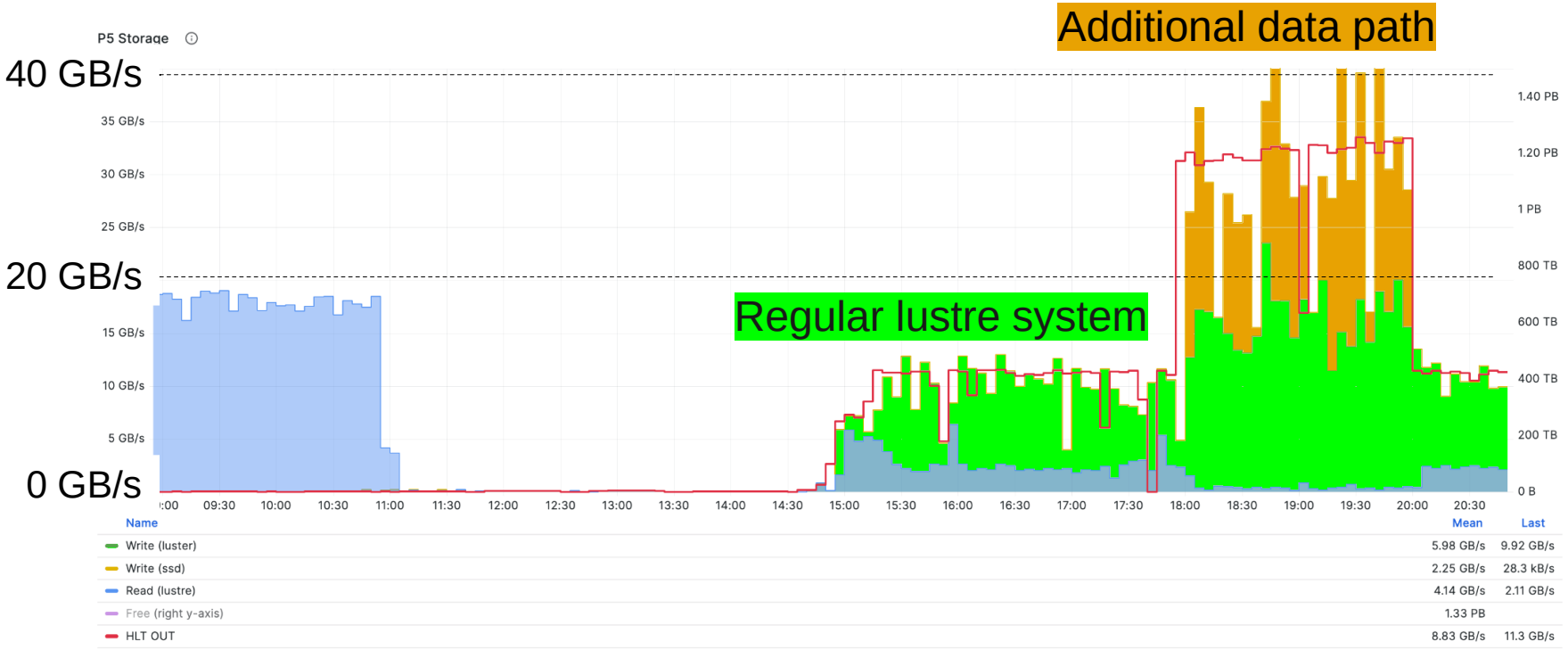
Storage Manager / File Transfer



PPC News Post

First tests of additional temporary data path

- Bandwidth usually below 15 GB/sec; Can sustain 30 GB/sec data transfers!
- New data path has **no buffering** and will burn out the hardware relatively quickly
- Accurate book keeping was most laborious, great test for HL-LHC
- Heavy Ion run: **November 6-24, 2024**
- Tier-0 adjustments and communication needed: all in PPC hands

Computing Operations

Purpose

- Process and re-process all CMS data, produce all MC simulations, and distribute the data on the world wide CMS computing system so they are available for physics analysis: active 24/7 year around

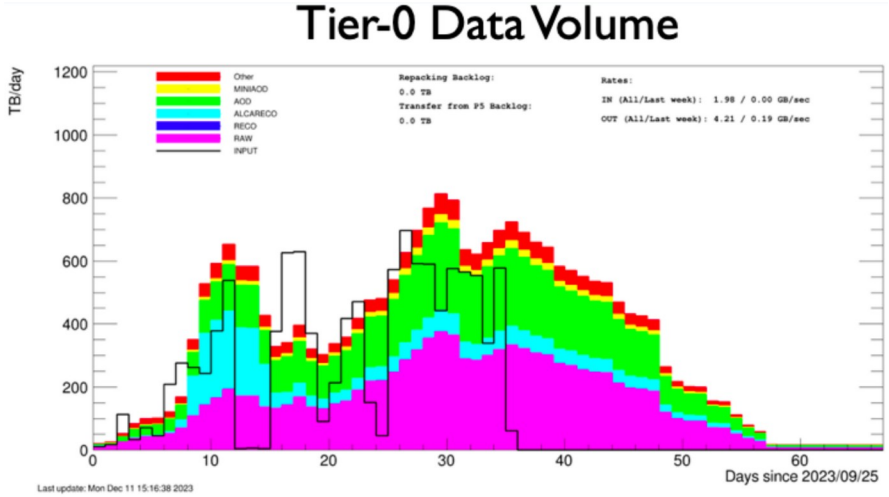
History

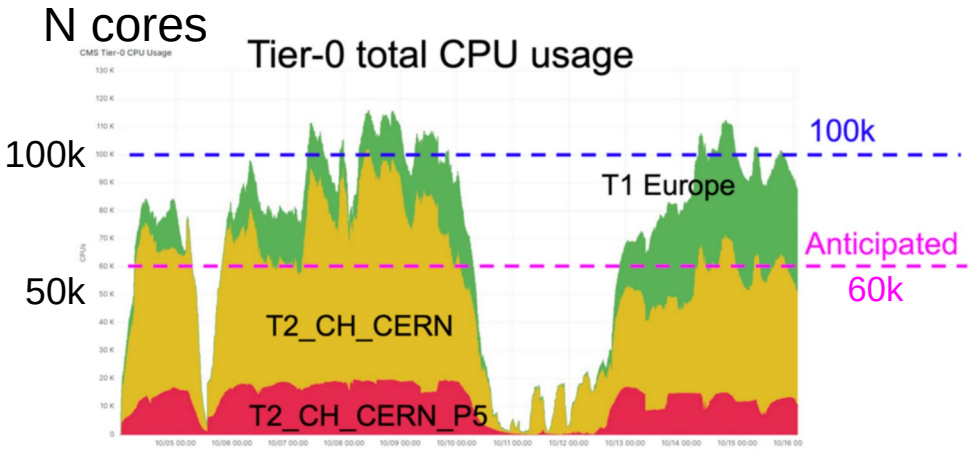
- Computing Operations was originally set up by Paus (MIT) and Bauerdick (FNAL), 2008 and ever since was under MIT co-leadership
- This is considered an MIT institutional commitment to CMS
- Long list of researchers, postdocs and students to cover this important task, focus always on Tier-0
- Long effort in data transfers shifted mostly now to the overall processing

MIT's unique role

- Continuity is essential for the operation of the offline computing system
- Very closely tied with the Online/P5 through storage manager and data transfer system

Tier-0 Operations





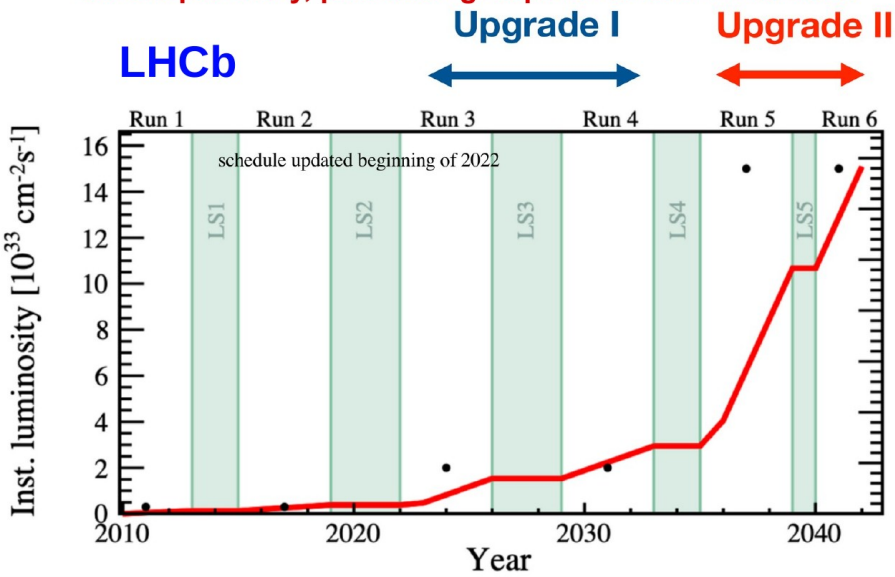
Continuous expansion of resource usage

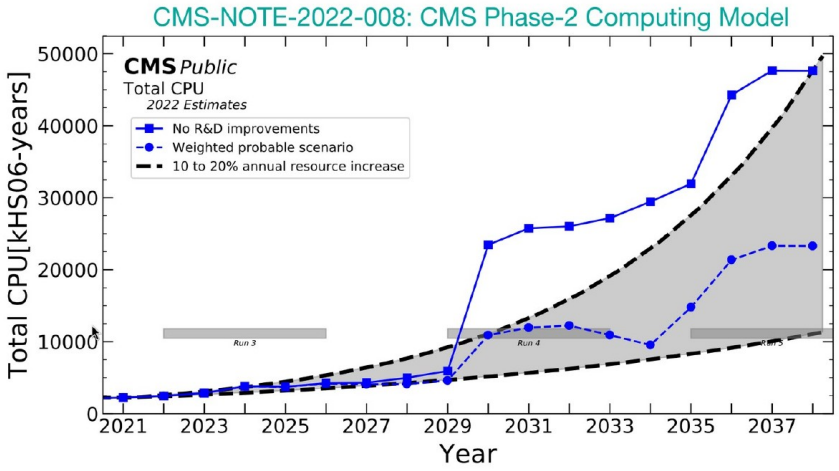
- Tier-0 is processing substantially more data than what was anticipated, to enable more physics analyses
- During Heavy Ion run we always push the boundaries hardest
  - In 2023: 0.6 PB per day for over 10 days
- In 2023 for the first time we commissioned Tier-1 centers to act as Tier-0 for processing: Finished all HI data within 3 weeks of running
- Pushed beyond 100k cores processing in parallel
- Tier-0 book keeping updates for 2024 HI run are implemented and ready

Future Computing in CMS

Recent and upcoming upgrades

- **ALICE** and **LHCb** just went through their **Run 3 updates**, order of magnitude higher rate than Runs 1 / 2.
- **ATLAS** and **CMS** will see major upgrades in **LS3** for **HL-LHC**:
  - Luminosity $2 \times 10^{34} s^{-1} cm^{-2}$ to **$7.5 \times 10^{34} s^{-1} cm^{-2}$ ($\mu = 200$).**
- **LHCb Upgrade 2** and **ALICE 3** in the planning for **LS4**.
- **Consequentially, processing requirements will increase**.





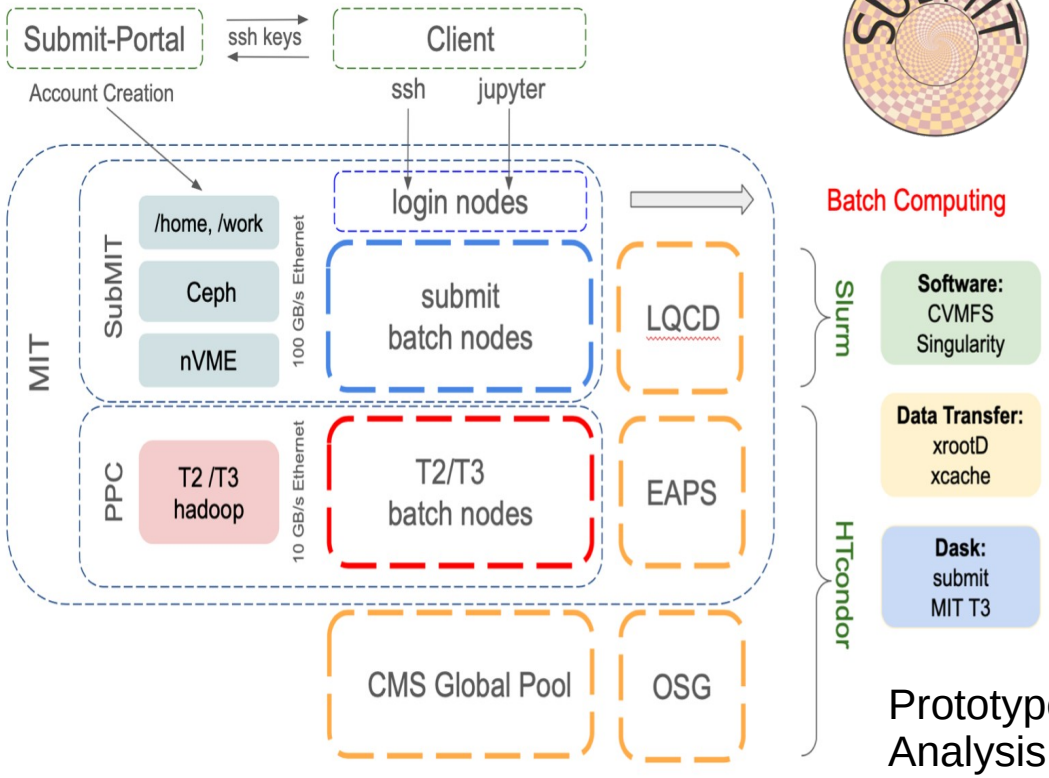
From ICHEP 2024 (17-24 July 2024 Prague)

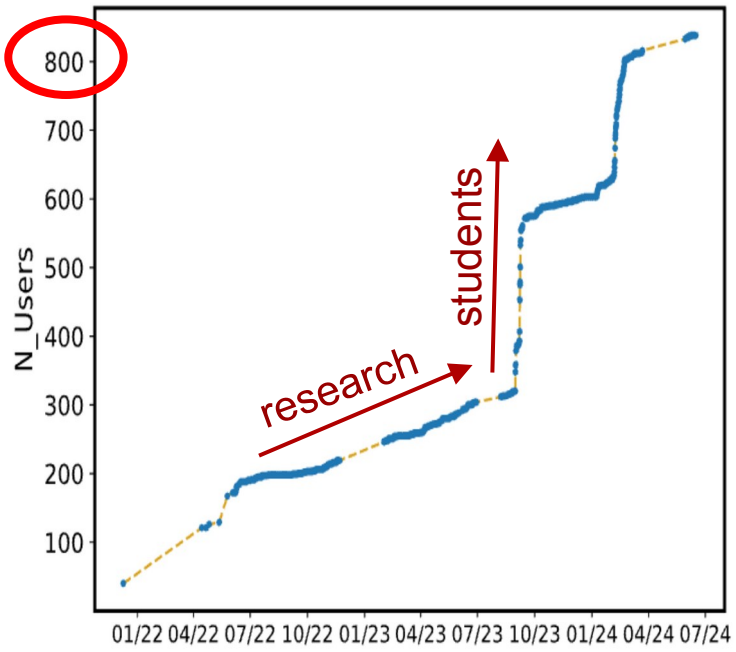
- Expected growth in data and computing needs is substantial
- CMS has to address general computing and in particular analysis needs

Analysis Facility Prototype

Building an analysis eco-system for CMS during HL-LHC

- MIT has a lot of analysis and computing experience
- Tier-2 and Tier-3 center locally (batch oriented)
- Added interactive facility ~ 2020 to access remote resources





Prototype (subMIT) also serves as a major data Analysis hub for the physics department.

Analysis Facility R&D

Building an analysis eco-system for CMS during HL-LHC

- MIT has a lot of analysis experience on local system
- All analyses presented later have been run on this facility

	WWos SMP-24-001	Hrare HIG-23-005	SUEP EXO-23-001 EXO-23-002 EXO-23-003	MW SMP-23-002
data volume	7.5 TB	50 TB	100 TB	16 TB
input	NanoAOD	custom NanoAOD	custom NanoAOD	custom NanoAOD
environment	CMS-SW	conda	conda	Singularity
high level interface	RDataFrame	RDataFrame	Coffea	RDataFrame
compute	Slurm/HTcondor	multi-threading	Slurm	multi-threading
histogramming	ROOT	ROOT		Boost
plotting	python shell	python shell	Jupyter	python shell
statistical	Combine	Combine	Combine	TensorFlow

Table 1: CMS data Analyses executed on subMIT: used tools

~1.8 billion events analyzed in 30mins

Analysis Facility R&D

Analysis eco-system for CMS during HL-LHC

- Score sheet for implementations at MIT, CERN, Purdue, FNAL, Nebraska
- MIT has a prototype and also commissions analyses on other US facilities

	subMIT (MIT)	SWAN (CERN)	Purdue	EAF (Fermilab)	coffea casa (UNL)
Access	MIT account	SSO cern	SSO cern	account VPN	SSO cern
Software stack					
Data access: xcache					
Interactive					
Local Cluster (one node)					
Distributed (multi node)	DASK + SLURM	Spark + HTcondor Dask + HTcondor	DaskGateway + K8s	DaskGateway + K8s	DaskGateway + K8s

Analysis Facility R&D

Analysis eco-system for CMS during HL-LHC

- Score sheet includes all below topics
- MIT has a prototype but also commissions analysis on other US facilities

	subMIT (MIT)	SWAN (CERN)	Purdue	EAF (Fermilab)	coffea casa (UNL)
Access	MIT account	SSO cern	SSO cern	account + VPN	SSO cern
Software stack	CONDA `myenv`	`'Bleeding Edge' 'lcg/views/ LCG_105a_swan'`	CONDA `/depot/cms/ kernels/root632`	CONDA `myenv`	CONDA `myenv`
Data access: xcache		not available yet		not yet	
Interactive Local Cluster (one node)					
Distributed (multi node)	DASKGateway+ SLURM	Spark + HTcondor	DASKGateway + K8s	DASkGateway + K8s	DASkGateway + K8s
	DASK + SLURM	DASK + HTcondor			

in progress

work

didn't work

not tried

Future of The Energy Frontier

January FCC Physics program at MIT

- Outreach and PR work to attract students to the field
- Future of the field depends on us being able to involve young students

The steps

- 8 undergrads worked with PPC to get involved in FCC in 2023 (US FCC week and CERN)
- New group started in 2024 and US FCC Week took place at MIT
- Students also went to CERN and worked on FCC and some on CMS

Conclusion

PPC has a long history with CMS

- Led the Higgs discovery from CMS side
- Major player in CMS for detector and physics *see following talks*
- Deep investment in Software, Computing, DAQ, and Detector projects that are crucial for CMS's success

Substantial involvement in CMS HL-LHC upgrade and future collider projects (FCC) with well aligned R&D

It is an amazing time to work at the Energy Frontier!

9% **LHC Status:** **Restarted end of April**

The Four Questions

Q1 – Alignments with national/international priorities

- LHC/HL-LHC are the highest P5 priority for the short/medium term
- FCC-ee: explicitly mentioned as off-shore Higgs factory, next highest priority
- PPC plans align perfectly with large science plans for short/medium/long term

Q2 – Support needed to continue research excellence

- **CMS HEP needs additional junior faculty**
- Continued strong computing support is crucial for success of the LHC efforts
- Graduate student cost is high compared with peers
- Administrative support is minimal and would make research more effective

Q3 – Community support

- Generally: **more in-person activity**
- Continue to support the dedicated efforts put in place for the various groups

Q4 – LNS organizational structure/administrative support

- Fiscal office is excellent and supports grant applications/reports well
- Secretarial support is very limited

Long Shutdown 2 finished 2019-2022