The CMS Collaboration
A View in 2023

Patricia McBride, for the SP Team
Special Symposium to celebrate the retirement of Matthias Kasemann - DESY
June 26, 2023

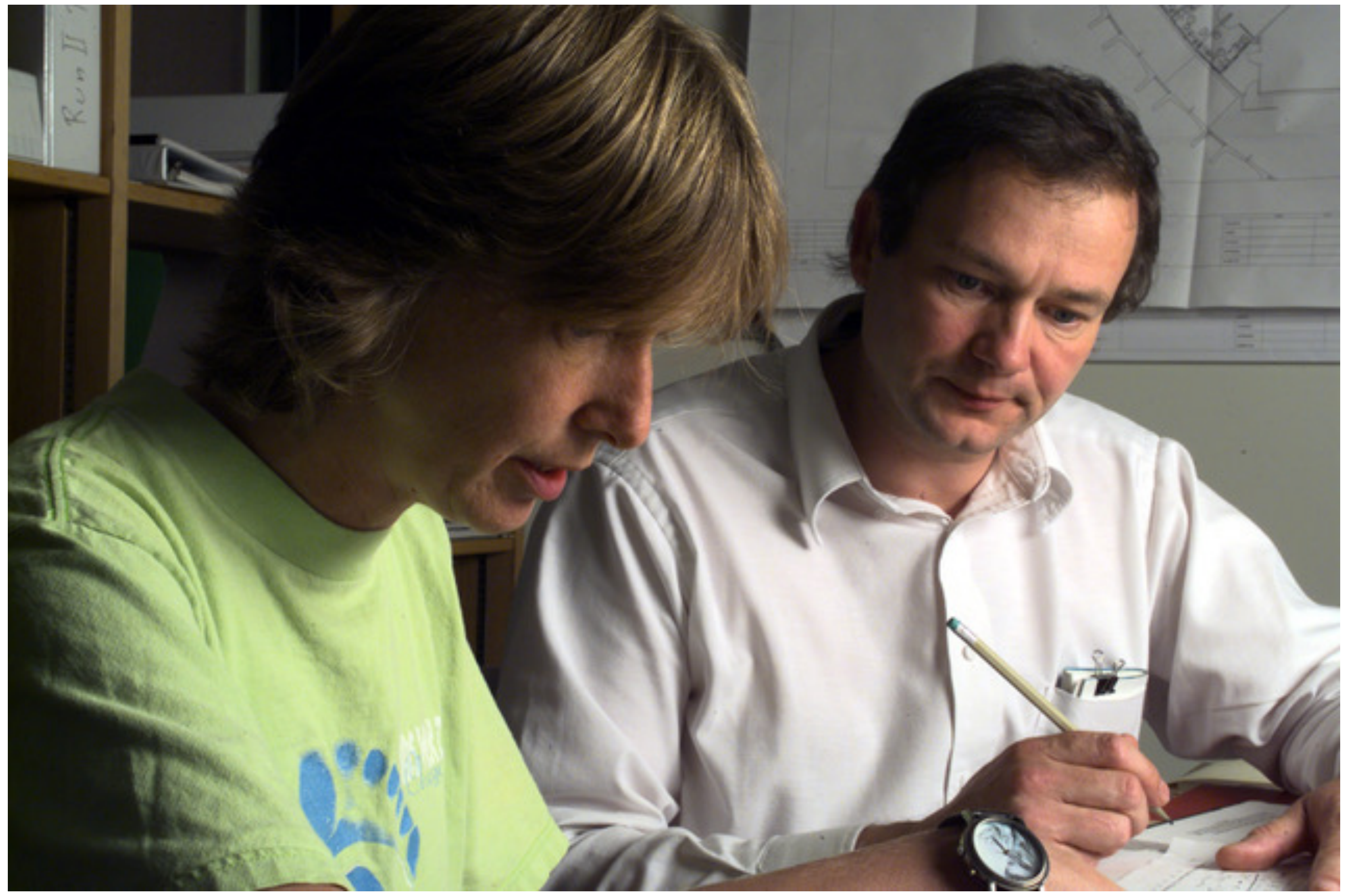
OUTLINE

- Short detour to Fermilab
- CMS Collaboration
- Update on CMS in 2023

Short Detour:

Fermilab

- **Matthias joined Fermilab in 1998**
  - HEP software and computing was undergoing a revolution
    - Move to C++, Linux, Open Source, ROOT for Tevatron Run 2
    - Major changes in hardware, networking, data management
  - Distributed Computing for HEP analysis- was still a dream (MONARC)
    - Distributed computing for Babar (~2001)
    - GRID for LHC (discussions started around ~2000)



MK and Vivian O'Dell discuss plans for CMS Software and Compuint at Fermilab - in 1999

FNAL PC Farm in 1999

"To Get Science Done"

DESY's Matthias Kasemann will head Fermilab's Computing Division.

by Judy Jackson, Office of Public Affairs

When the new head of Fermilab's Computing Division takes up his job on October 1, his first priority, he says is "to get experiments working."

But, says Matthias Kasemann, "this includes the role of Computing in giving service to all the areas of the lab. Computing is critical for data-taking and data analysis, for sure. But services for administration and engineering and all the other parts of the laboratory also belong to the effort, because they are all part of the work that contributes in the end to get science done."

In meeting the challenges coming up in Run II, with its huge amount of data, Kasemann said, it's important not to neglect the other computing needs of the laboratory, which he views as "at least as important" in achieving Fermilab's science goals.

Kasemann, 41, a high-energy physicist born in Dortmund, Germany, is currently a collaborator on the ZEUS experiment at Hamburg's DESY laboratory, where he has managed offline computing. He's working to complete a ZEUS detector upgrade, a project that will keep him in Europe until October.

Kasemann will replace Fermilab physicist Joel Butler as division head. Butler, who led the division for four years, began a new assignment on July 1 as leader of the Particle Physics Division's BTeV R&D Group, whose mission is to determine the scientific merit and technical feasibility of a proposed B physics experiment at the new CZero collision hall.

Fermilab physicist Steve Wolbers will serve as acting head of the Computing Division until Kasemann formally joins the laboratory in the fall.

"I've asked Steve to run the division until I can come to Fermilab, with frequent discussions with me," Kasemann said. "He is doing a great job, and I very much enjoy working with him."

Before joining DESY in the early 1990s, Kasemann spent several years at CERN, where he did his thesis research and joined the ALEPH collaboration at CERN's LEP collider. One of the great strengths of computing at Fermilab, as Kasemann sees it, is the number of scientists working in the Computing Division, and the resulting close ties to experiments.

"Compared to CERN and DESY," he said, "there is much more interaction between the Computing Division and the experiments. I think this is a good thing, because it helps to get efficient solutions to the challenges that the experiments face."

Fermilab officials were pleased to have recruited Kasemann, whose appointment resulted from the work of a search committee led by Fermilab theorist Estia Eichten.

"Matthias is very knowledgeable technically," said Associate Director Tom Nash, "and he is a careful, thoughtful decision-maker. He takes the time to find the best solution to both technical and human problems—and it's not always the most obvious solution, at first glance."

As a high-energy physicist, will Kasemann join a Fermilab experiment himself? Not right away, he says.

"For the first year or so, I have enough to do to try to step into Joel's footsteps. He was a good leader and he has an expert knowledge of the Laboratory, which I have to learn. So for the first year at least I will concentrate completely on the job of being Computing Division head. Afterwards, I am looking forward to participating in experiments. Because, in the end, I am a scientist and I want to work as a scientist."

Any thoughts about where he might find an experimental home?

"No," said Kasemann. "But I've already had some suggestions." ■

Photo by Reidar Hahn

Matthias Kasemann, new Computing Division head will arrive at Fermilab October 1, 1998.

MK Fermilab

- Matthias was the Head of the Fermilab Computing Division from (Oct 1998-2002).
- He also served the U.S CMS Acting Project Manager for Software and Computing
  - Built the Regional User Facility that became the Fermilab Tier-1 Center for CMS
  - Initiated R&D for the U.S. Tier-2 facilities
  - Developed the initial U.S. Tier-2 proposal

Fermilab

Steve Wolbers, Scientist Emeritus
Fermilab
Former Deputy Computing
Division Head

S. Wolbers and M. Kasemann - Fermilab Wine and Cheese Feb 2002

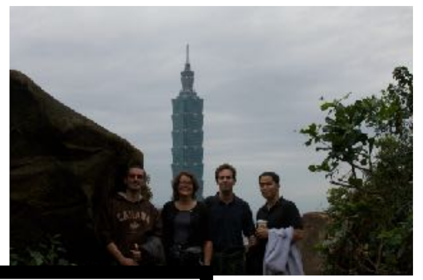
"I first met Matthias when we were reviewing the Computing Technical Proposals of CMS and ATLAS for the LHCC, back in the 1990's. We got along incredibly well and had a good time. Sometime later he joined **Fermilab as Head of the Computing Division** and I served as **his deputy**. Matthias deserves a great deal of credit for leading the Division as it took on the preparations for **Collider Run 2 computing, the US CMS computing center, Sky Survey computing**, and many other important projects. There were massive changes in networking, computing hardware, power and cooling and space, software - all of which were required while maintaining full functionality and physics productivity at the lab. Matthias worked tirelessly to move everything forward, all the while with a positive attitude, a level head, and with good working relations with people inside the lab and elsewhere. He helped Fermilab Computing connect more with the rest of the world.

I have very fond memories of Matthias and I really liked working with him. He had a wonderful attitude toward Fermilab and wished nothing more than for Fermilab to succeed in all of the areas of science that it was involved with. He got along well with people and really cared about them. It was a shame that he stayed such a short time at Fermilab, but his influence and the impact of his work there lasted for many years. "

CMS Tier-1 Tour

- The CMS Computing Coordination Team did a tour of the seven CMS Tier-1 Centers in Nov/ Dec 2007 in preparation for LHC startup.

Photos from the visit to Fermilab

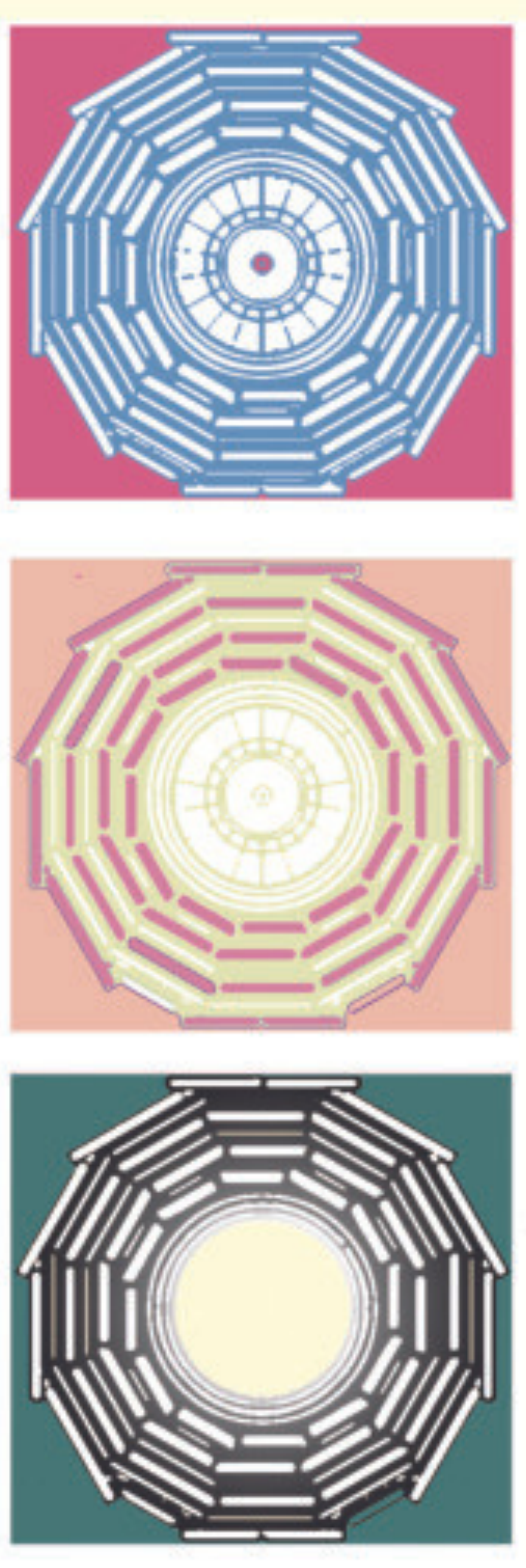


ASGC - Taipei
FNAL
CNAF Bologna
FZK (KIT)
IN2P3 - Lyon
RAL - Oxfordshire
PIC - Barcelona

CMS Computing Team dinner in Bologna - Computing Management Meeting during Physics Week - Sept 2009

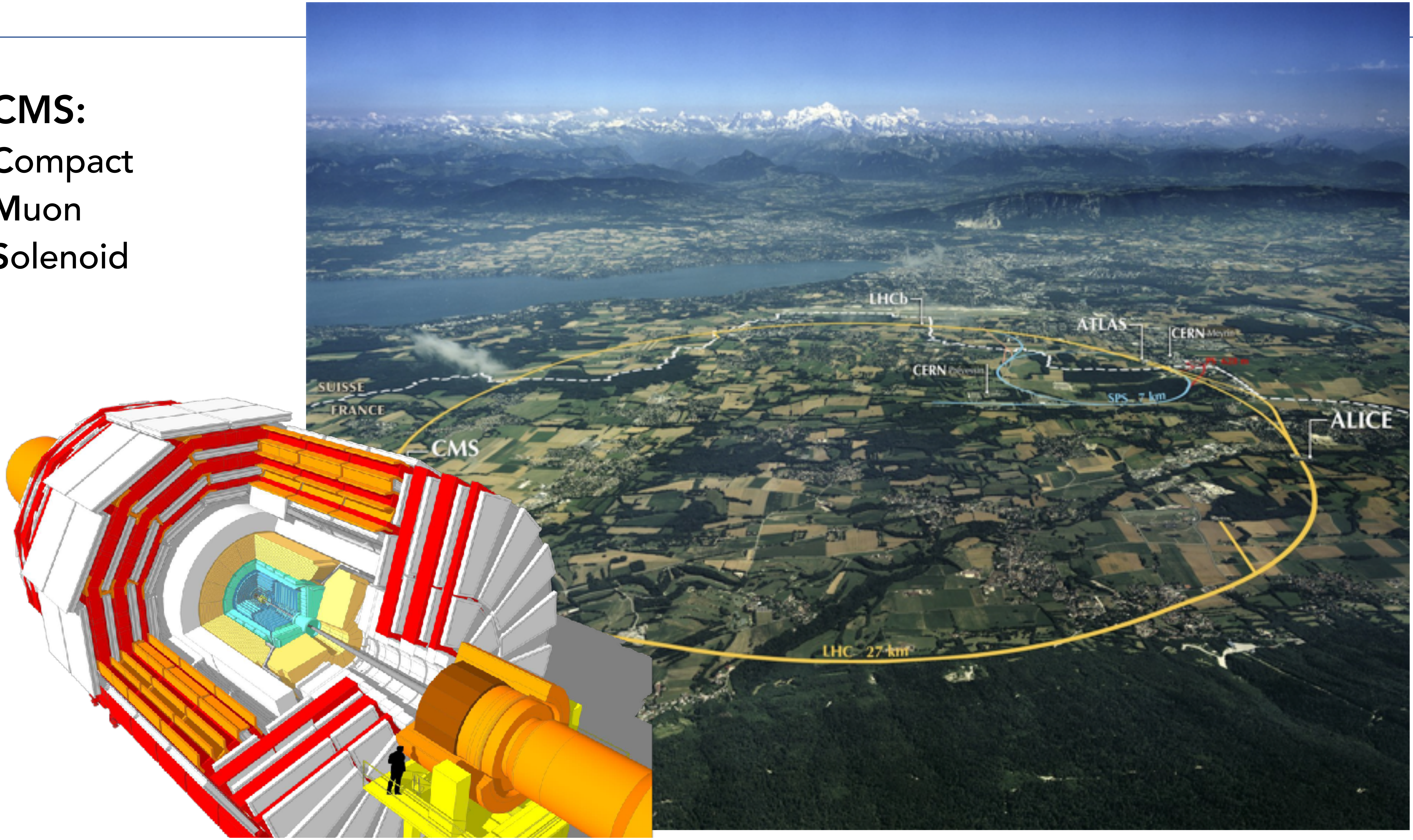
MK ready to hand the leadership of Computing Coordination to Ian Fisk

CMS Collaboration



CMS at the Large Hadron Collider

CMS:
Compact
Muon
Solenoid



100 m underground at LHC Point-5 (P5)

close to the village of Cessy

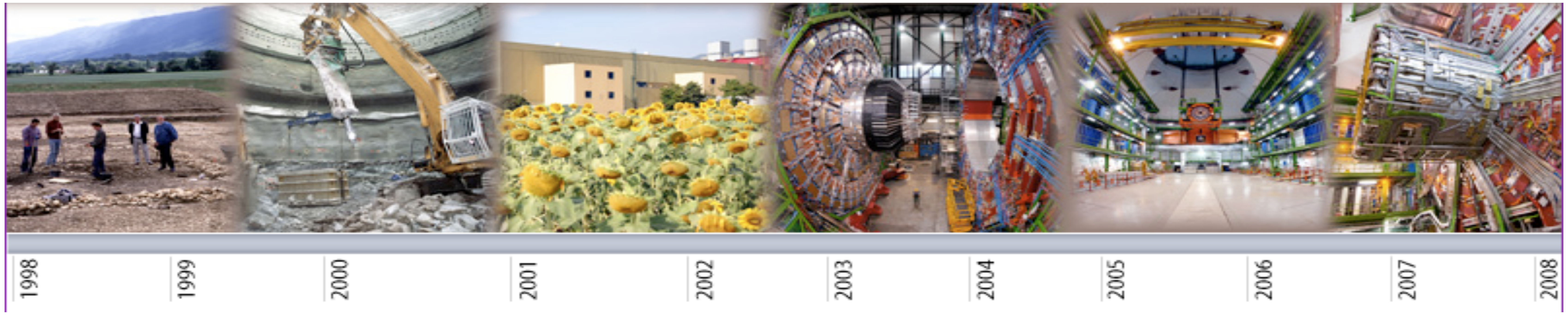
at the foot of the Jura mountains

A truly global project

- **1984** Workshop on a Large Hadron Collider in the LEP tunnel, Lausanne
- **1987** "Long-Range Planning Committee" recommends LHC as the right choice for CERN's future
- **1990** ECFA LHC Workshop, Aachen
  CMS design first presented!
- **1992** Meeting on LHC Physics and Detectors, Evian
- **1993** Letters of Intent
  CMS selected by LHCC
- **1994** Technical Proposals approved
- **1996** Approval to move to construction
- **1998** Memoranda of Understanding signed
- **1998** Construction begins (after approval of Technical Design Reports)
- **2000** CMS assembly begins above ground. LEP closes
- **2004** CMS Underground Caverns completed
- **2008** CMS ready for LHC beams
  LHC "incident" 19th Sept
- **2009** CMS records first collisions

- 2015 Start of LHC Run 2
- 2022 Start of LHC Run 3
- 2029 Planned start of LHC Run 4

10 years of construction




ME&RE-1/3/04
ME&RE-1/2/02
ME&RE-1/2/36
ME&RE-1/3/34

CMS Collaboration 2023

The CMS Collaboration

250 Institutes

215 full members

8 cooperating

27 associated

from

57 Countries or Regions

2234/6102 Authors/Members

1537/2123 PhD Physicists (18% ♀)

665/1184 PhD Students (26% ♀)

32/1086 Engineers (14% ♀)

0/1310 Undergraduates (29% ♀)

0/399 Technicians,Admins

Our "nation"

"The Parliament"

CMS is a collaboration of Institutes

"The Government"

Collaboration Board

Management Board

Committees

Authorship Committee

Conference Committee

Publications Committee

etc.

Extended Executive Board

CMS Management

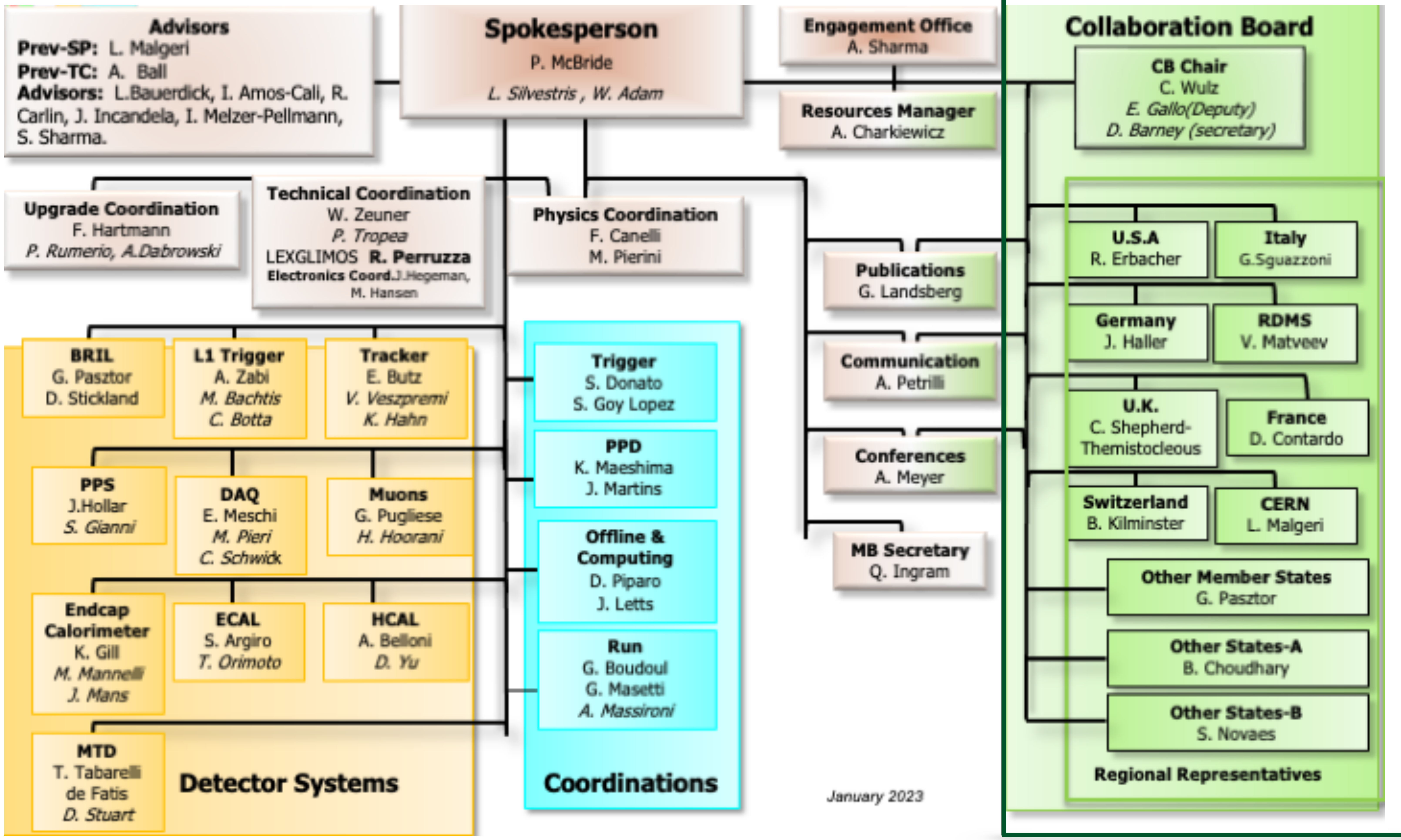
Matthias Kasemann, DESY

Collaboration Board Chair
Term: Sept 1, 2017 - Aug 31, 2019

Also:
Deputy Collaboration Board Chair (2011-2012)

First survey of the collaboration and brought Electronic Voting to the SP election (and eventually) to the CB.

Worked with the SP to establish the Engagement Office and the Upgrade Project Office.



Incoming Collaboration Board Chair

Elisabetta Gallo, DESY

Term: Sept 1, 2023 - Aug 31, 2025

CMS Management Board in 2023

Authorship in CMS

Authorship is not so easily defined in large collaborations where so many have made significant contributions.
Clear rules are needed (and must be well communicated.)

CMS publishes O(100) papers per year!

IUPAP recommendations for authorship in large collaborations:

"The Collaborations shall have clear internal rules regarding who is an eligible author for each publication. The rules shall be public and transparent and follow the guideline that "authorship should be limited to those who have made a significant contribution to the concept, design, execution and interpretation of the research study. **All those who have made significant contributions should be offered the opportunity to be listed as authors."** (See, as an example: American Physical Society Guidelines for Professional Conduct). "

Assessment of Individual Achievements in Large Collaborations in Particle Physics

- Report of Commission 11 (C11), Particles and Fields, of the International Union of Pure and Applied Physics (IUPAP)
- September 2008

MK served as Chair of the CMS Authorship Committee (2014-2017)

From the CMS Constitution:

- The main task of the **Authorship Committee** is **to harmonize and monitor the author list**.

Author information

Authors and Affiliations

Yerevan Physics Institute, Yerevan, Armenia

V. Khachatryan, A. M. Sirunyan & A. Tumasyan

Institut für Hochenergiephysik der OeAW, Wien, Austria

W. Adam, T. Bergauer, M. Dragicevic, J. Erö, M. Friedl, R. Frühwirth, V. M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler, W. Kiesenhofer, V. Knünz, M. Krammer, I. Krätschmer, D. Liko, I. Mikulec, D. Rabady, B. Rahbaran, H. Rohringer, R. Schöfbeck, J. Strauss, W. Treberer-Treberspurg, W. Waltenberger & C.-E. Wulz

National Centre for Particle and High Energy Physics, Minsk, Belarus

V. Mossolov, N. Shumeiko & J. Suarez Gonzalez

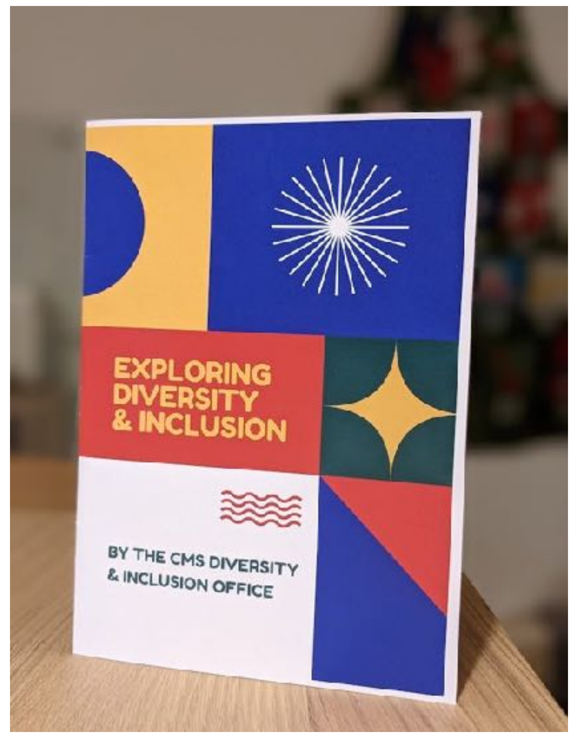
Training and Career Development

- **CMS Data Analysis School** (CMSDAS) is a well established CMS training event for new collaborators.
- The most recent school took place at CERN in early June.
  - **First in-person CMSDAS in Europe since COVID**
  - Productive week with **64 participants +** 48 exercise facilitators & organizers
  - A **CMSDAS** was held at Fermilab in Jan 2023
- All pre-exercise and short exercise materials remain available online
- The next CMS school will be a joint **Physics Object & Data Analysis School at DESY 9-18 October**

Diversity, Inclusion and Equity

- CB oversees DEI in the collaboration.
- Recent Task Forces have addressed issues such as improving monitoring, incorporating DEI principles in appointments, better inclusivity in meetings.
- The CMS Diversity Office helps to foster DEI in CMS and propose actions to promote diversity and create awareness.

Anonymus Message Box



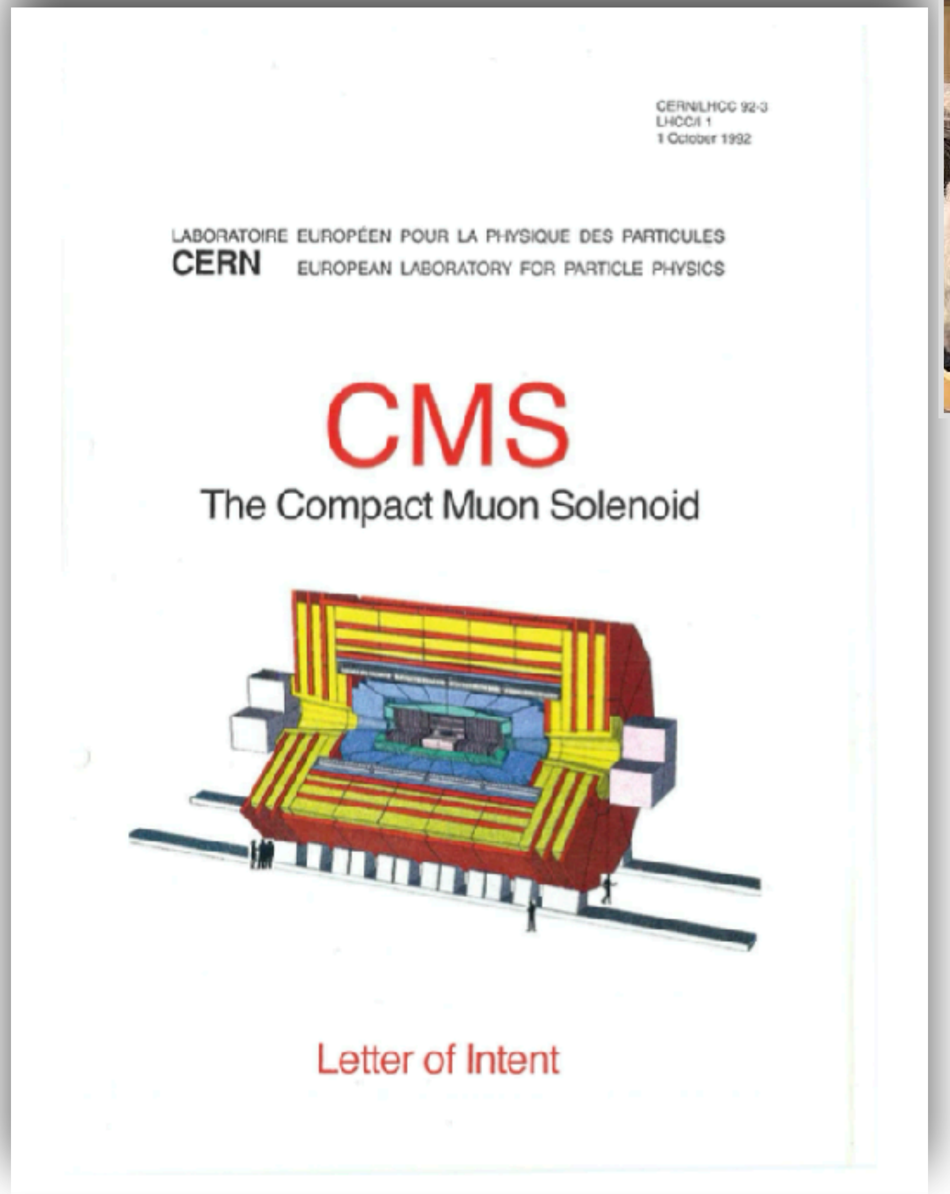
D&I booklet

Code of Conduct

CMS @ 30

S. Cittolin

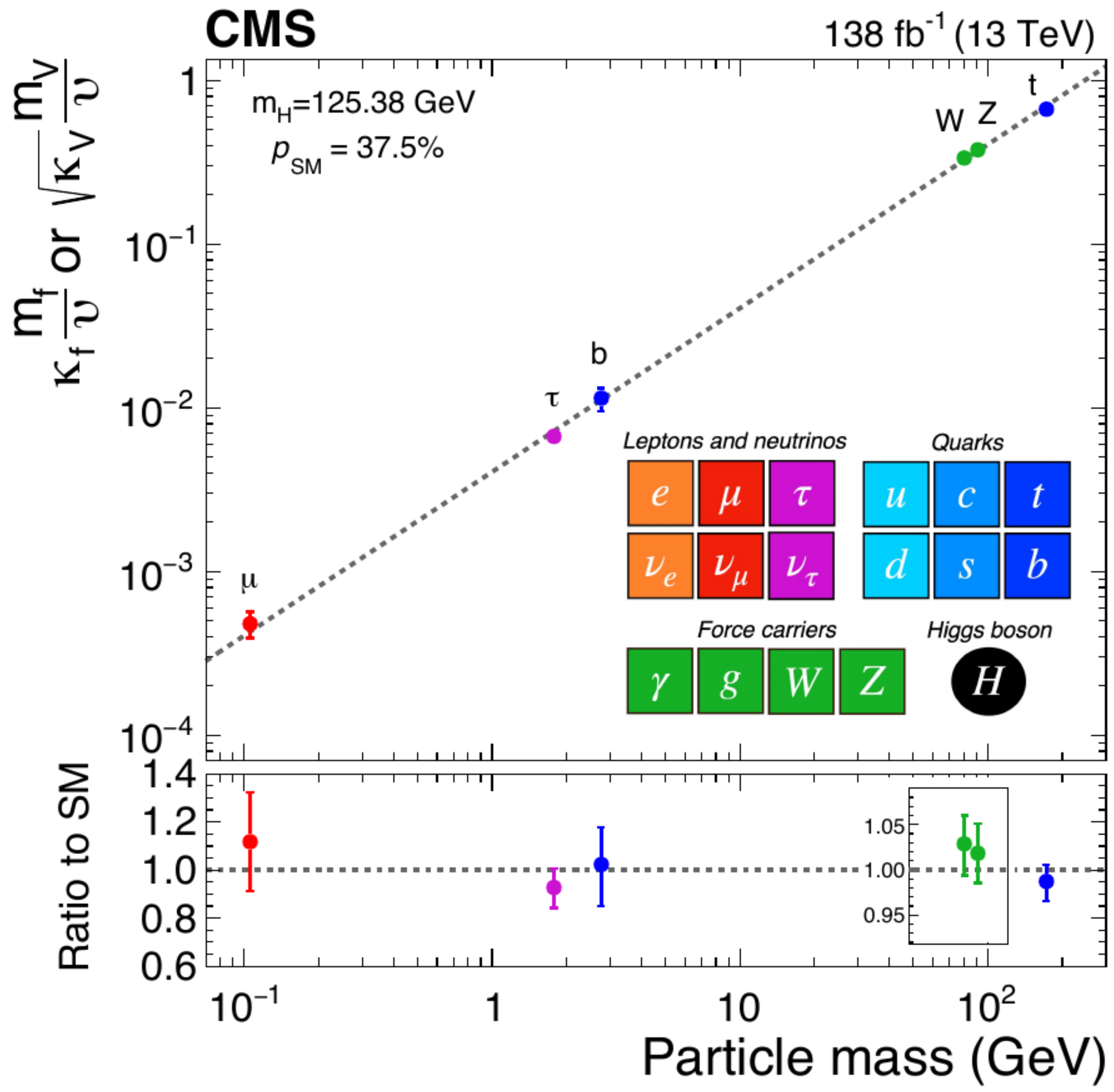
In 2022, the Collaboration celebrated 30 years since the submission of the Letter of Intent to CERN

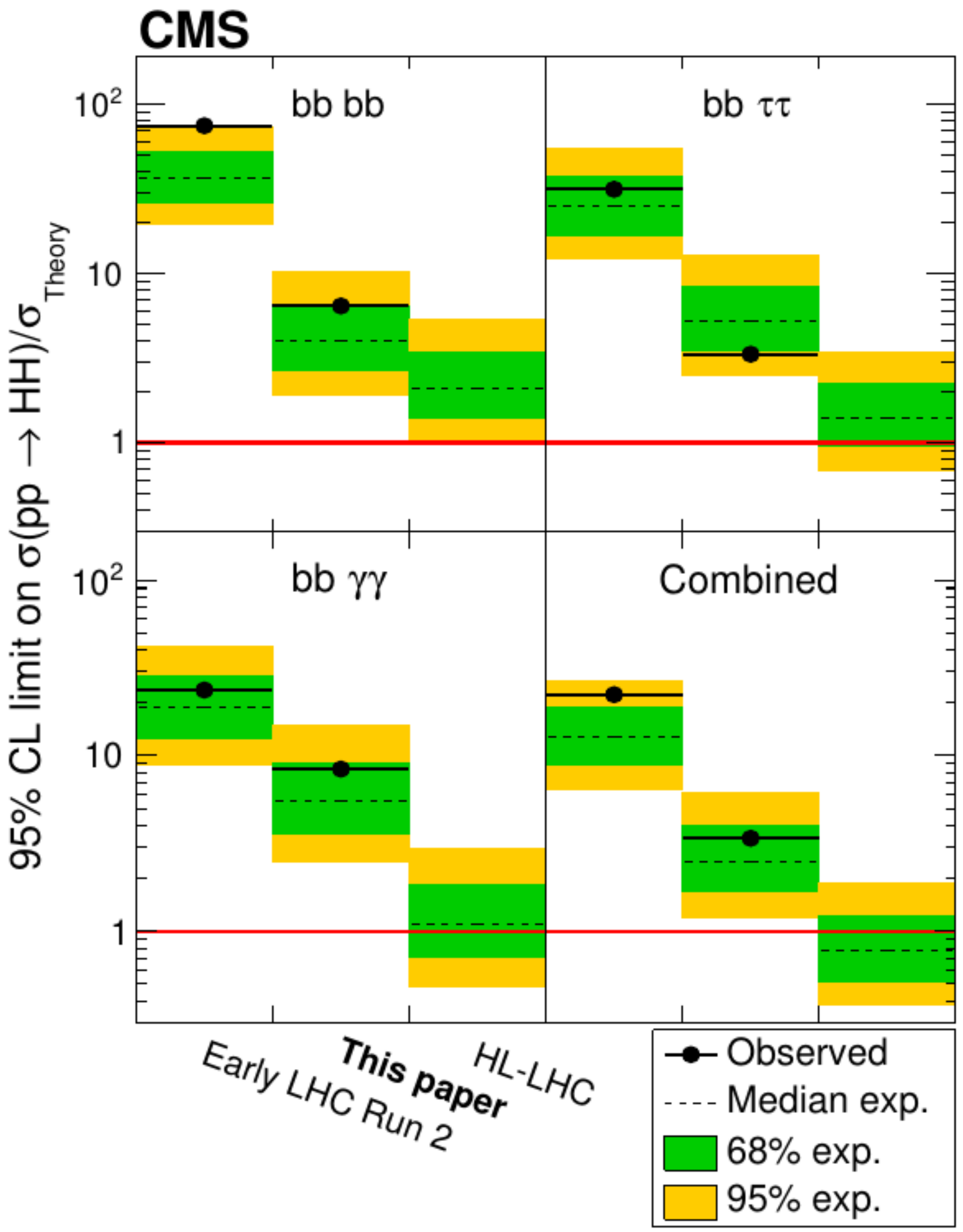


[30 Years of CMS Video history project]

The CMS Collaboration is a vibrant and diverse community after 30 years and we look forward to the opportunities of the Run 3 and the HL-LHC

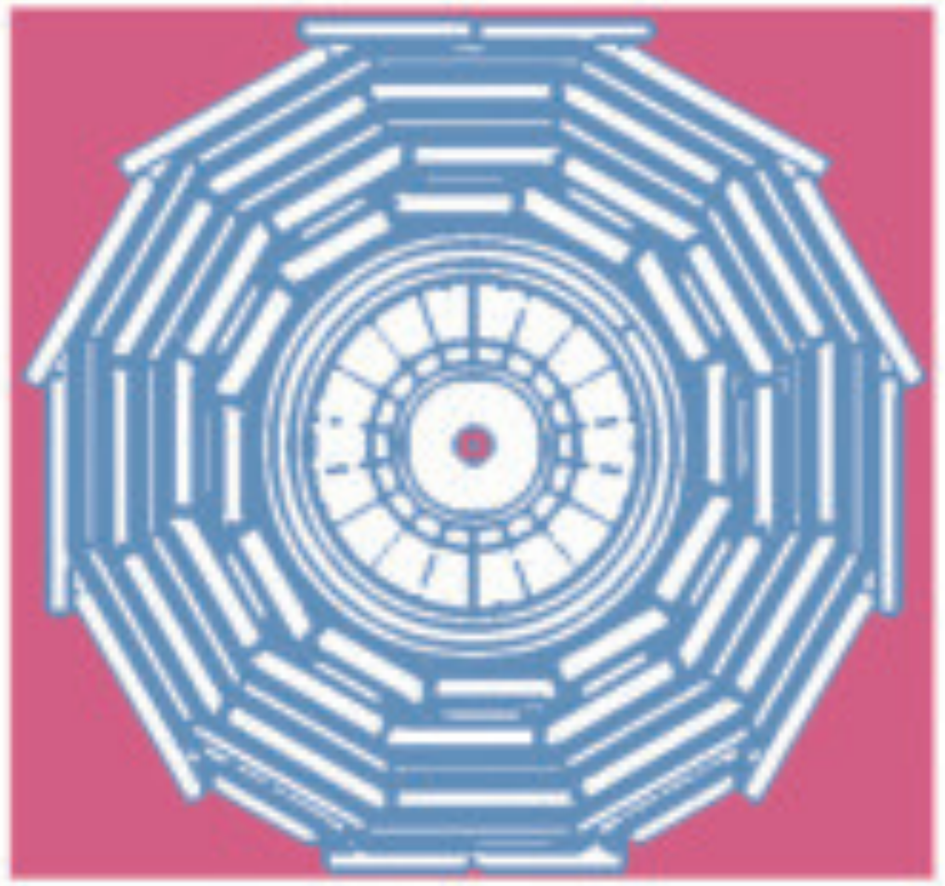
CMS celebrated ten years of Higgs boson measurements

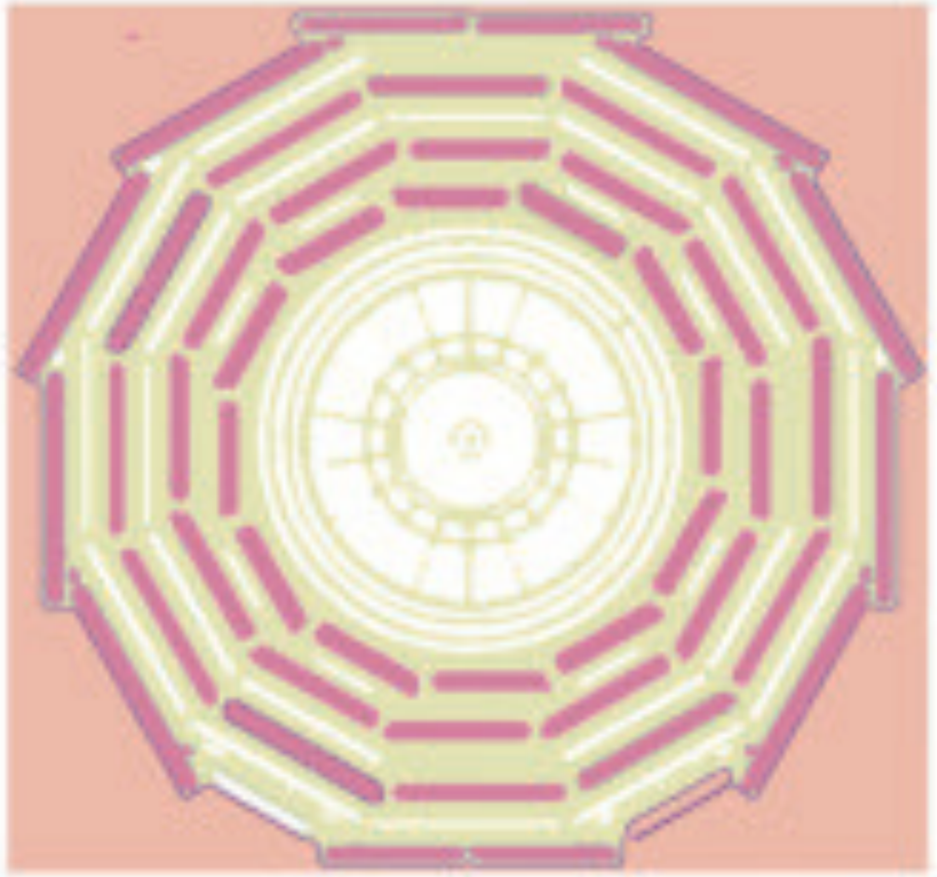


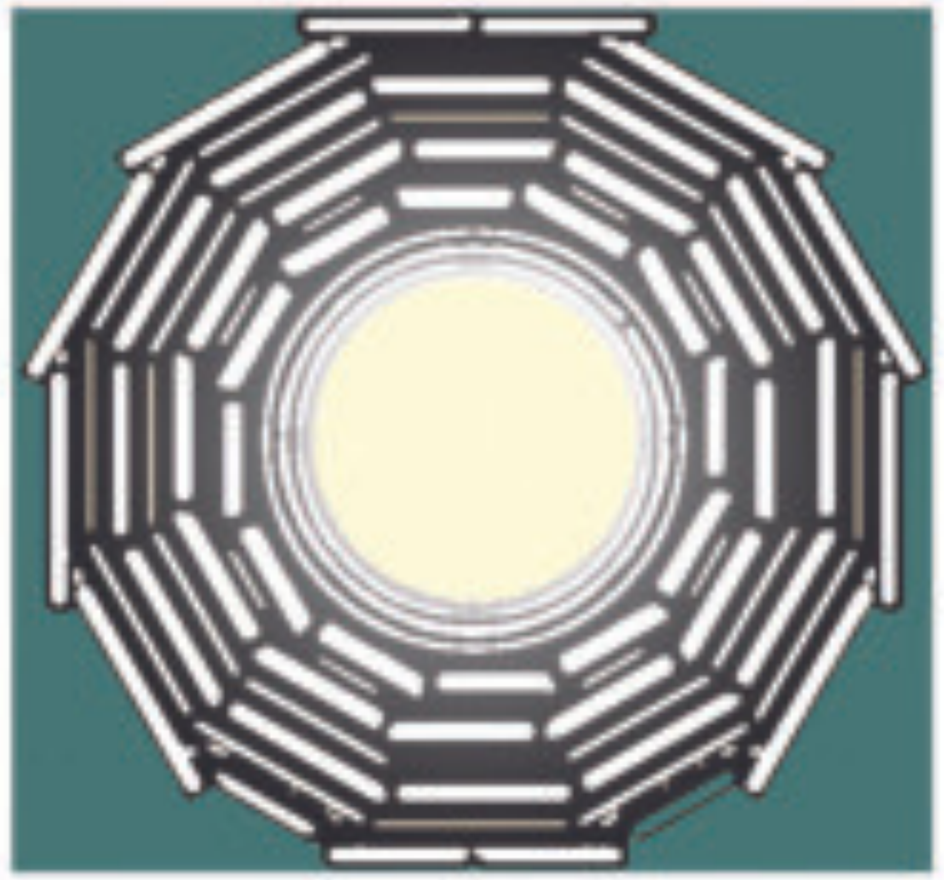


JULY 2022

CMS in 2023

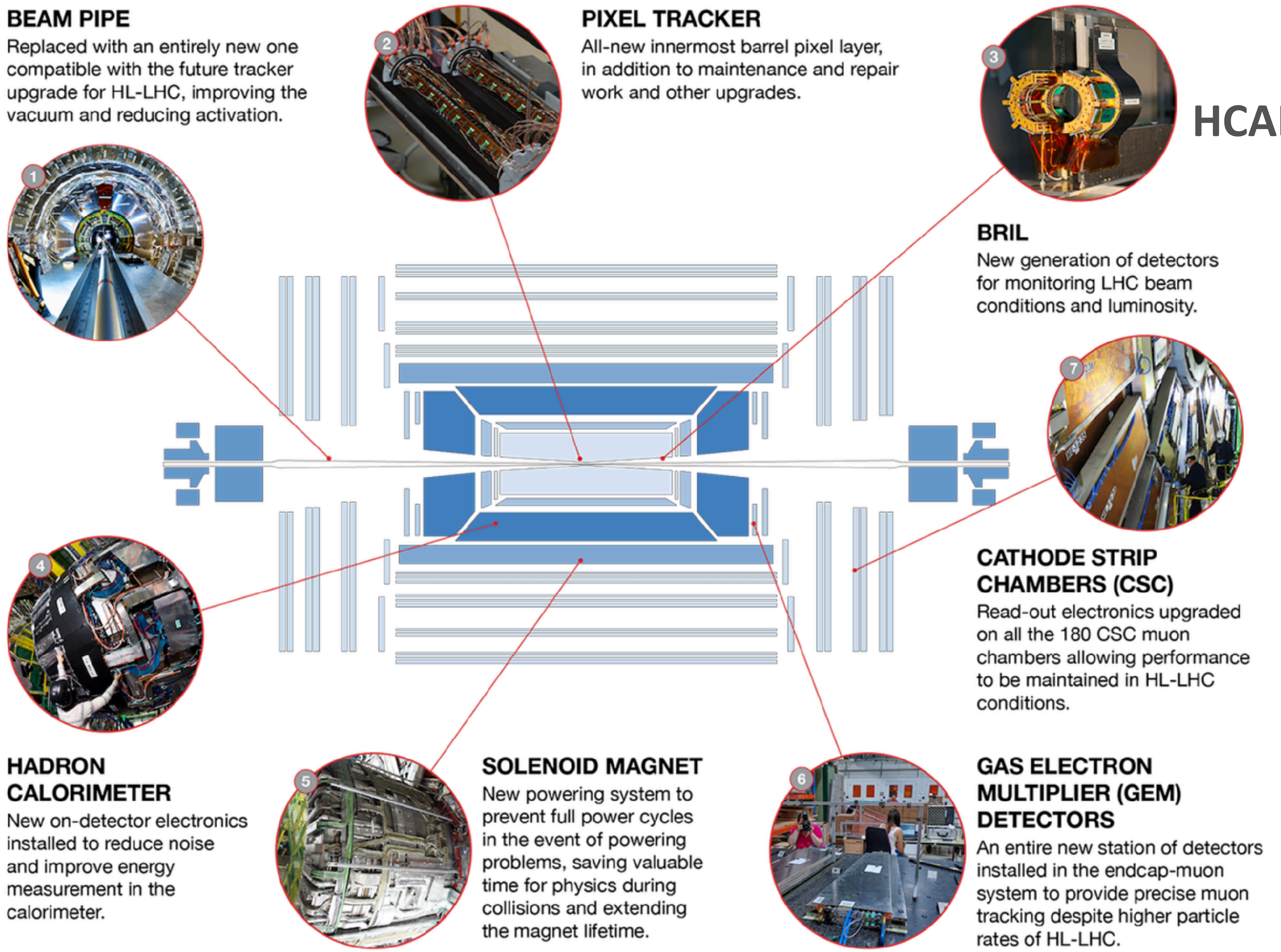






Fermilab

LS2 Activities



Major LS2 milestones

HCAL Barrel readout upgrade complete in Oct. 2019

Muon activities completed in Dec. 2020

Beam-pipe installation and bake-out completed in May 2021

Pixel Detector installation completed in June 2021

Yoke closed end of Sep 2021 (with some delays)

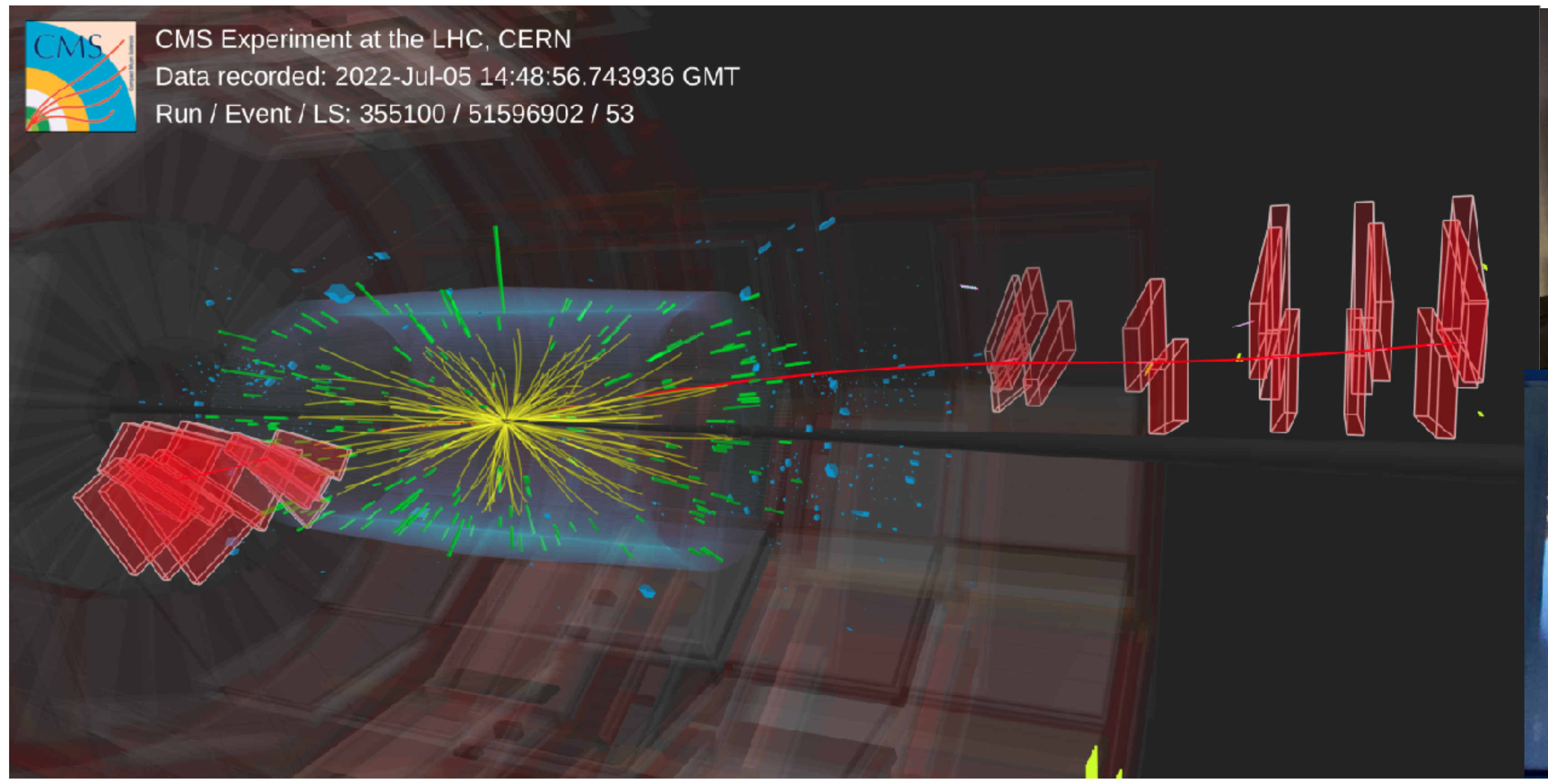
Magnet restart (3.8T) and commissioning (beg. Oct 2021)

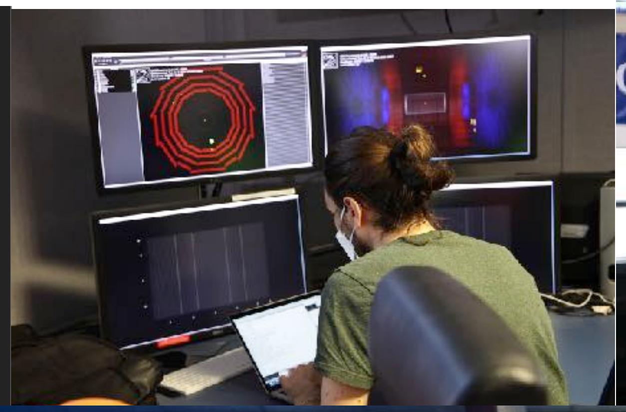
CMS was ready to take data at the start of Run 3 collisions in 2022

Official Launch of Run 3

On the 5th of July 2022, the LHC delivered stable proton-proton collisions at the energy of 13.6 TeV.

- A big thank you to the LHC team!
- CMS recorded these first collisions with all systems on and working well.





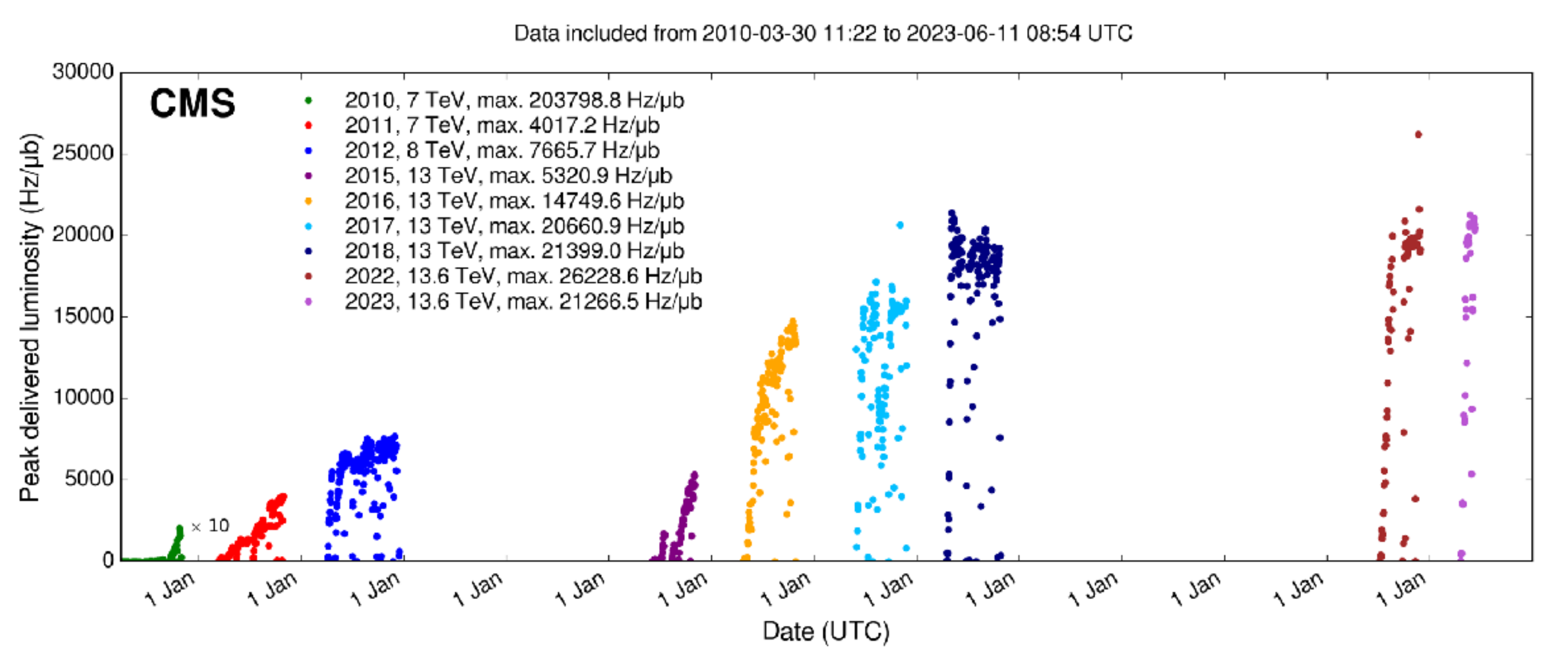
LHC Run 3

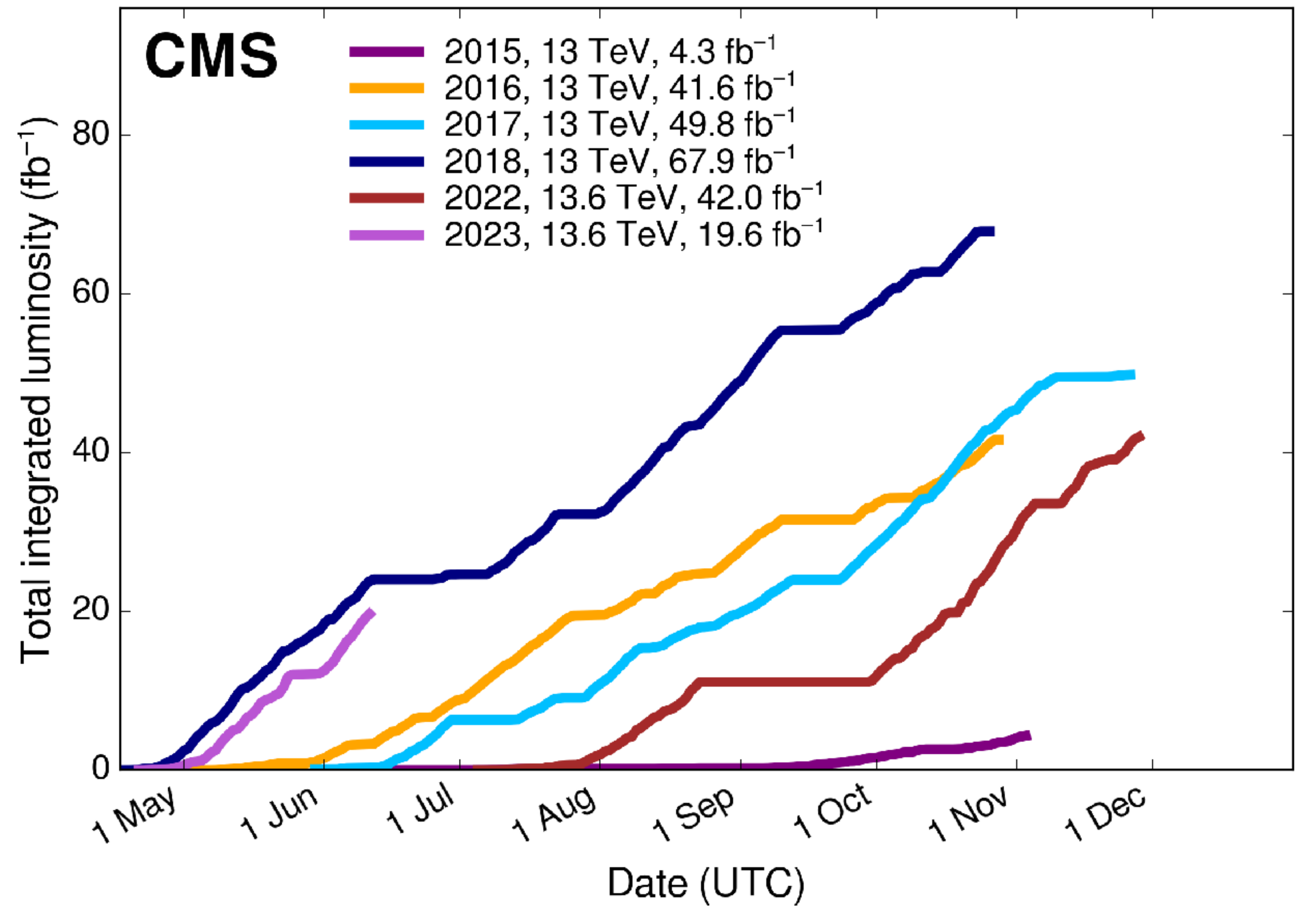
Fermilab

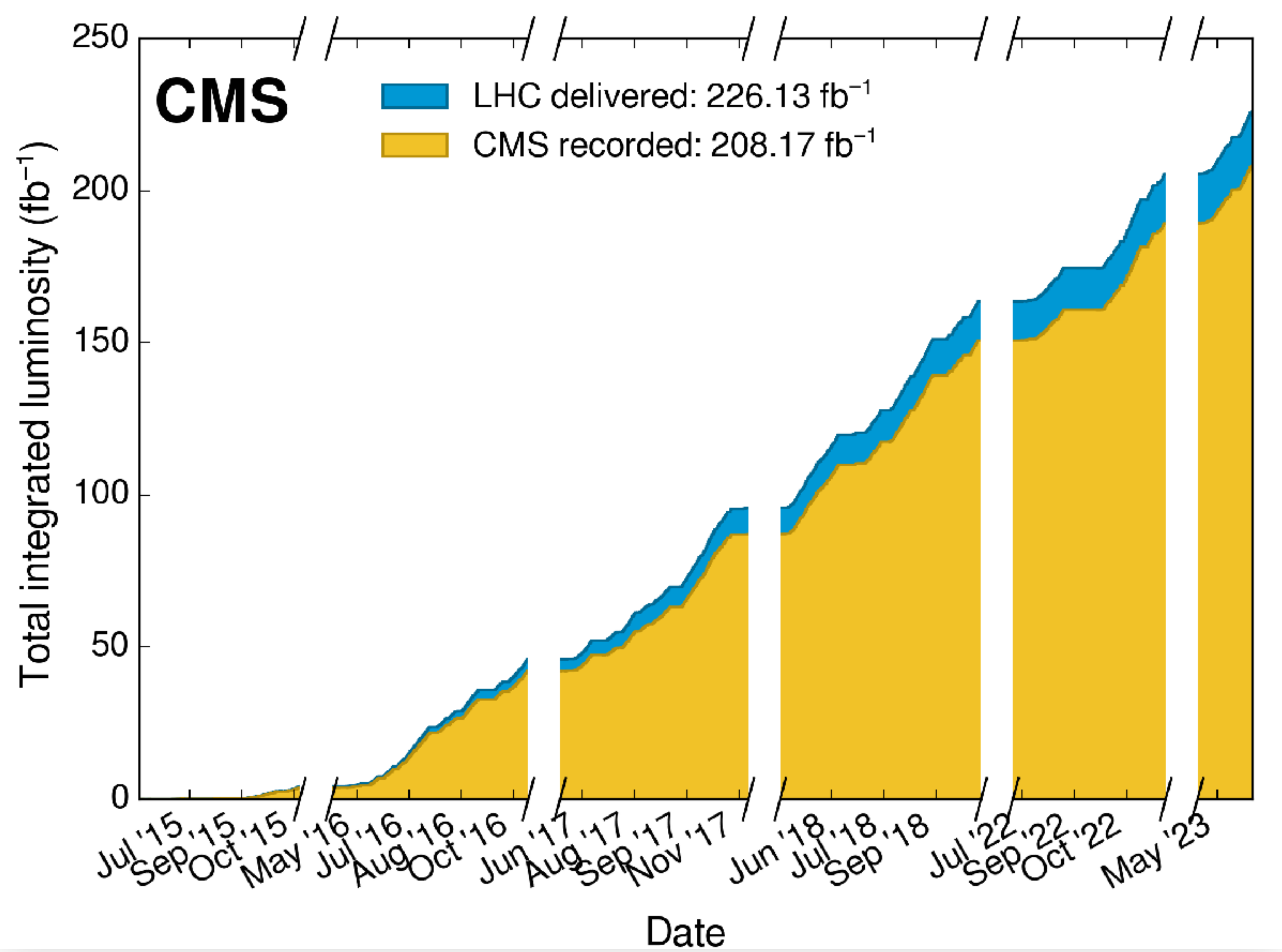
13.6 TeV pp collision data (2022-2023)

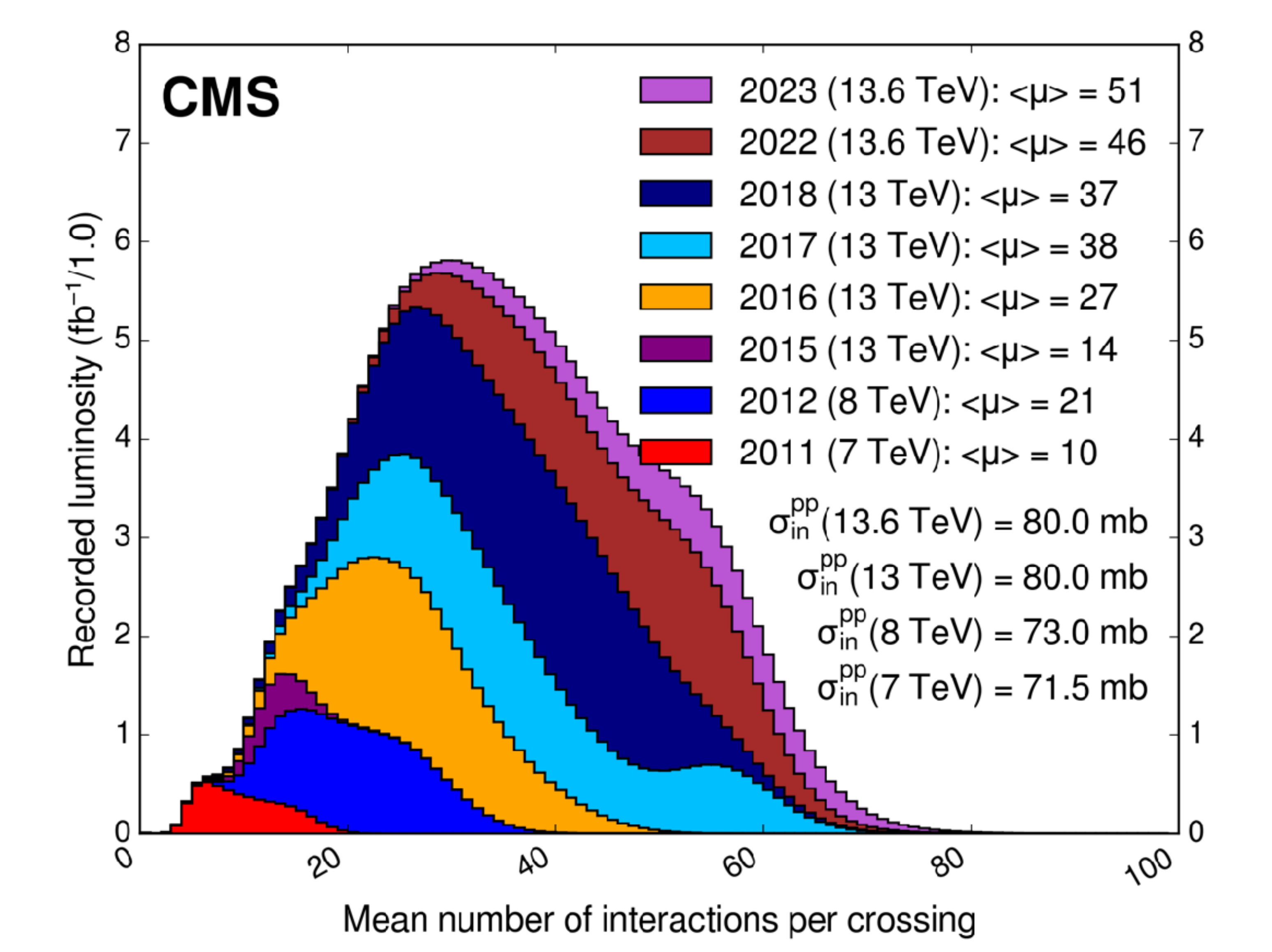
~ 60 fb^{-1} delivered so far in LHC Run 3

CMS data taking efficiency ~92%





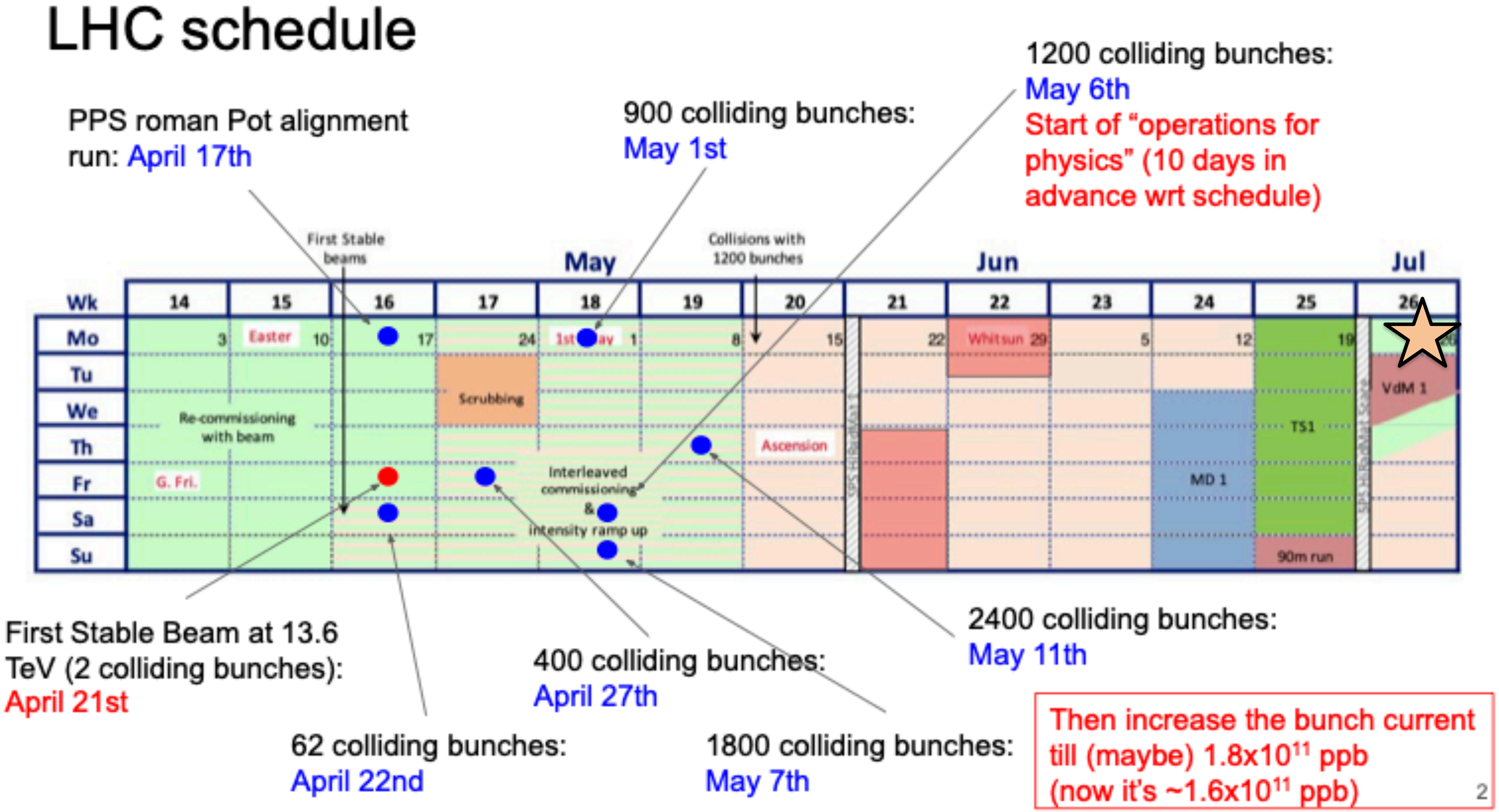




Link to the public Data Quality twiki page [here]

Link to the public luminosity twiki page [here]

2023 LHC schedule



The 2023 run is well underway

CMS is running well.

70-75 fb^{-1} of pp in 2023 expected

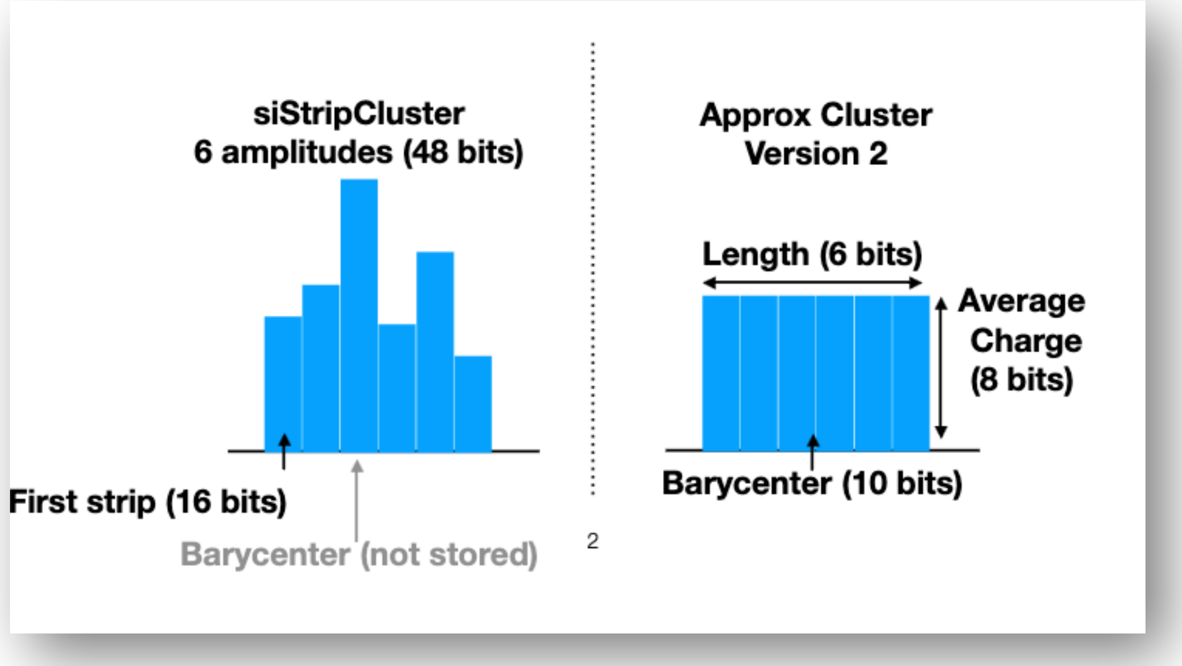
- Overall integrated luminosity depends on LHC availability.
- 2024/2025: ~90 fb^{-1} of pp
- Note: Run 2 - ~150 fb^{-1} recorded

Lumi-leveling with high pileup (PU ~ 60)

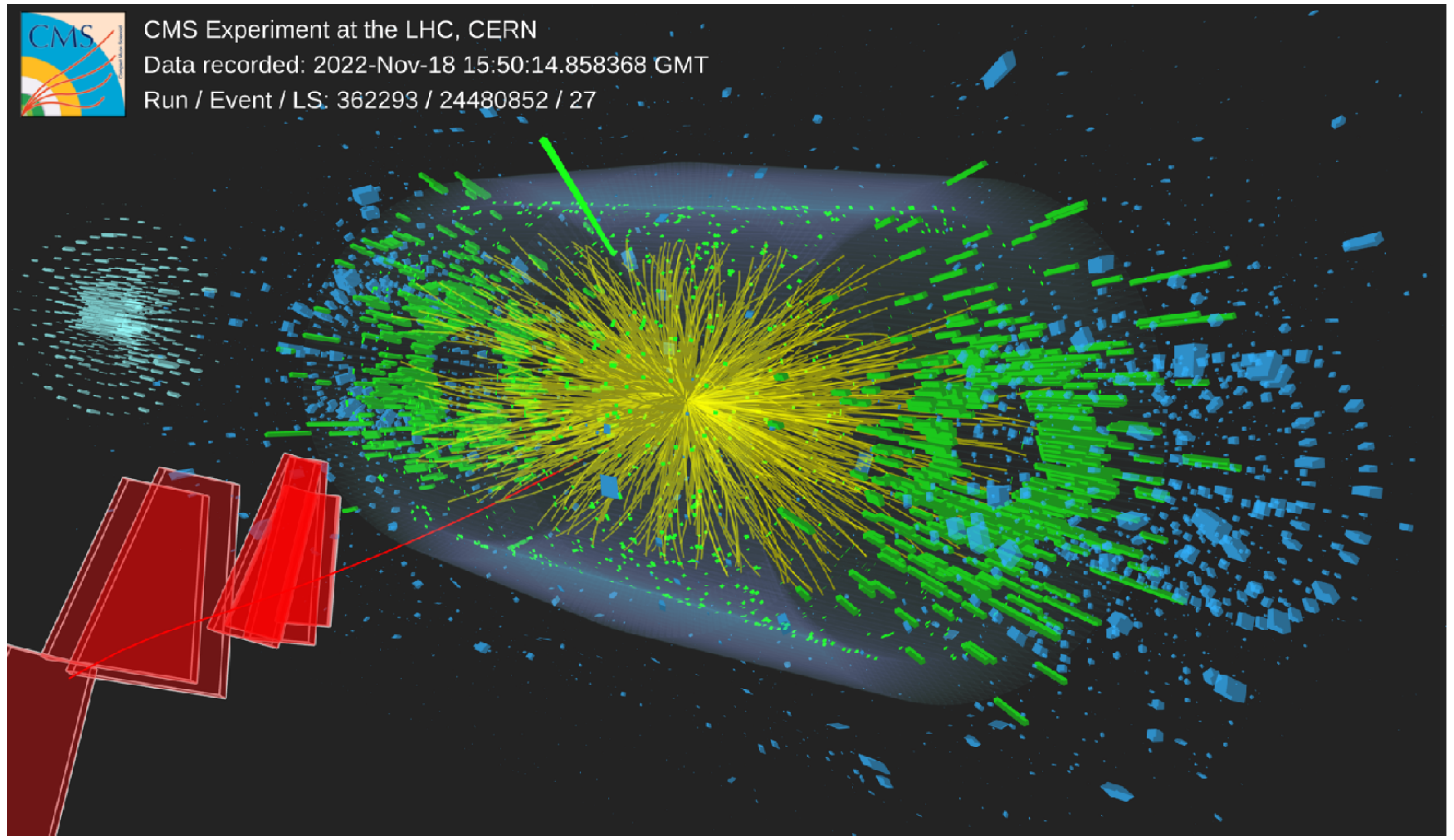
- The lumi-leveling time has increased in 2023.

Short PbPb test in 2022

- **Successful commissioning in 2022:**
  - L1 + HLT triggers commissioned
  - ECAL, tracker readout configuration for Heavy Ions implemented
  - Data reduction method with reduced RAW tested



LHC delivered 0.4 ub^{-1}, CMS recorded 0.3 ub^{-1}

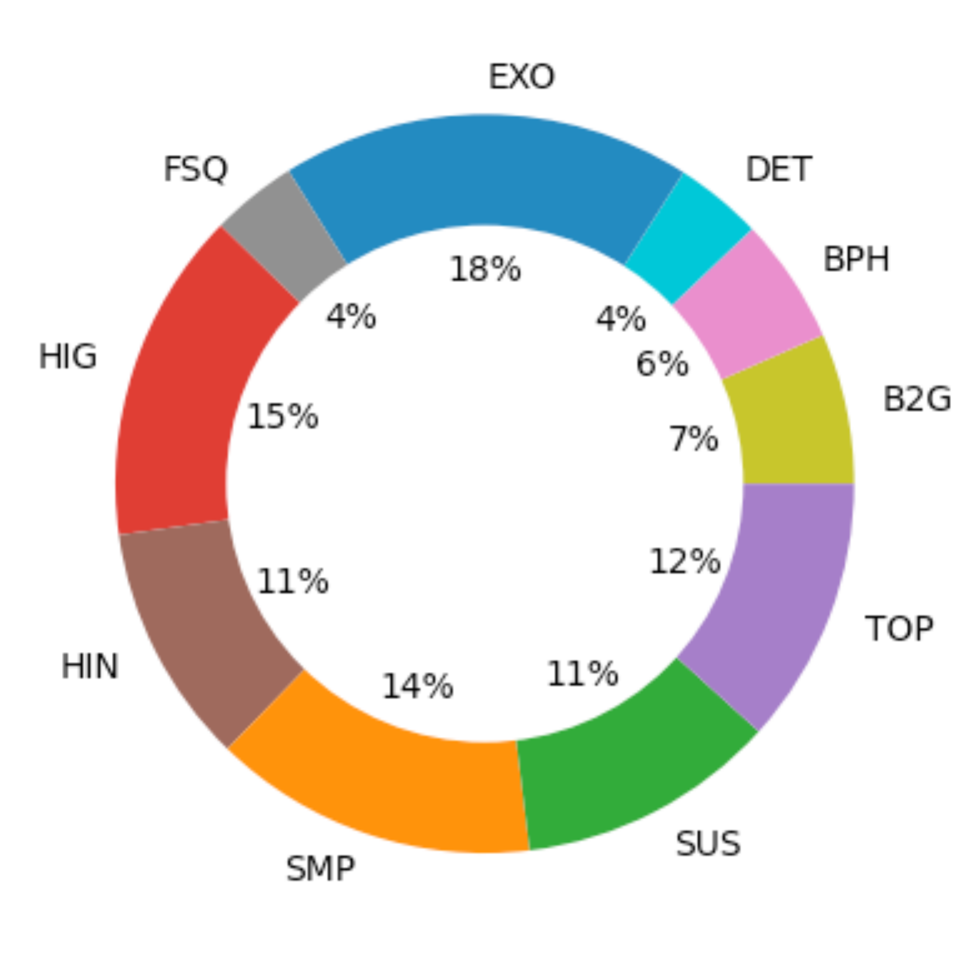


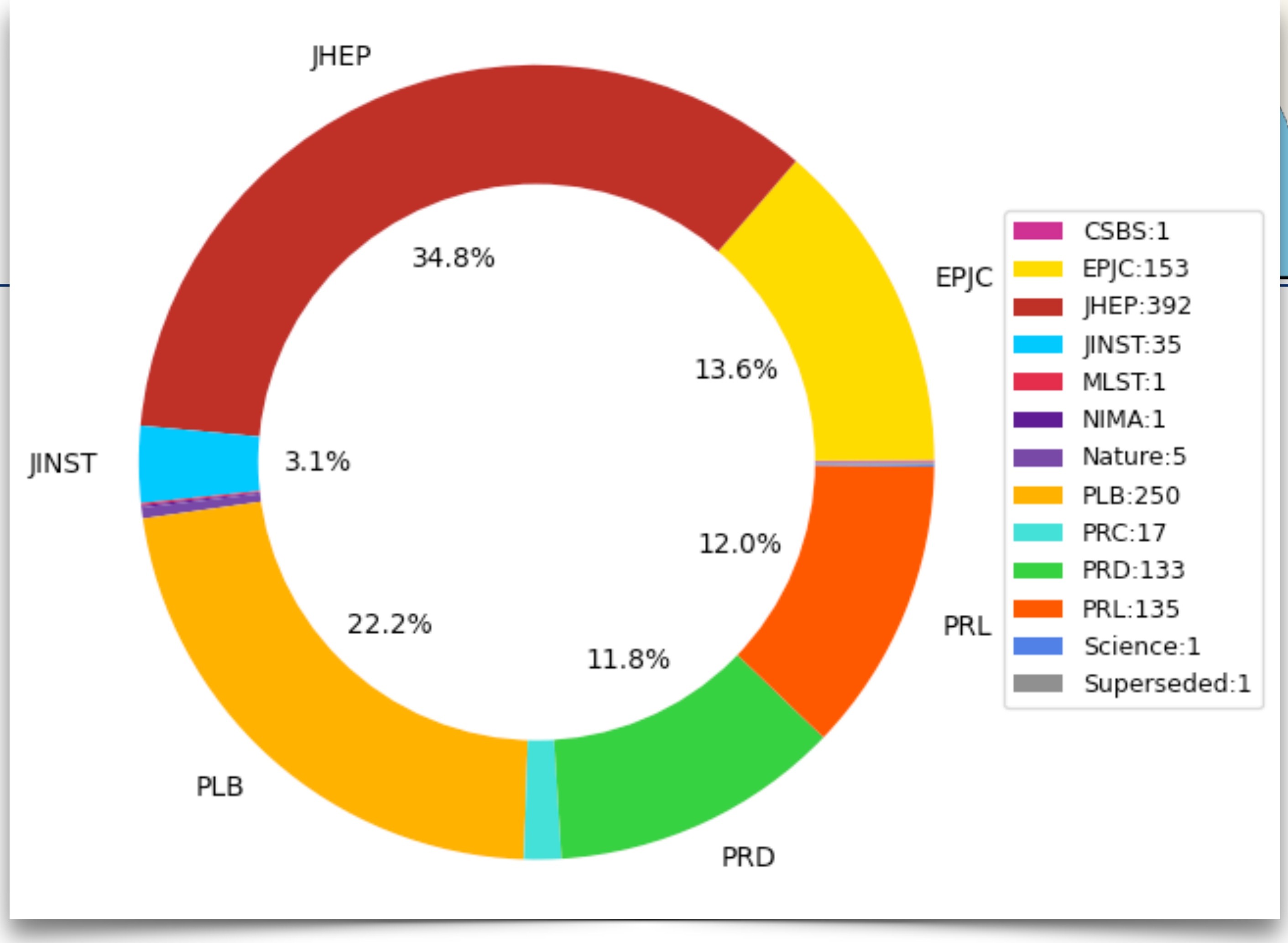
An excellent start to Run 3 HI program.

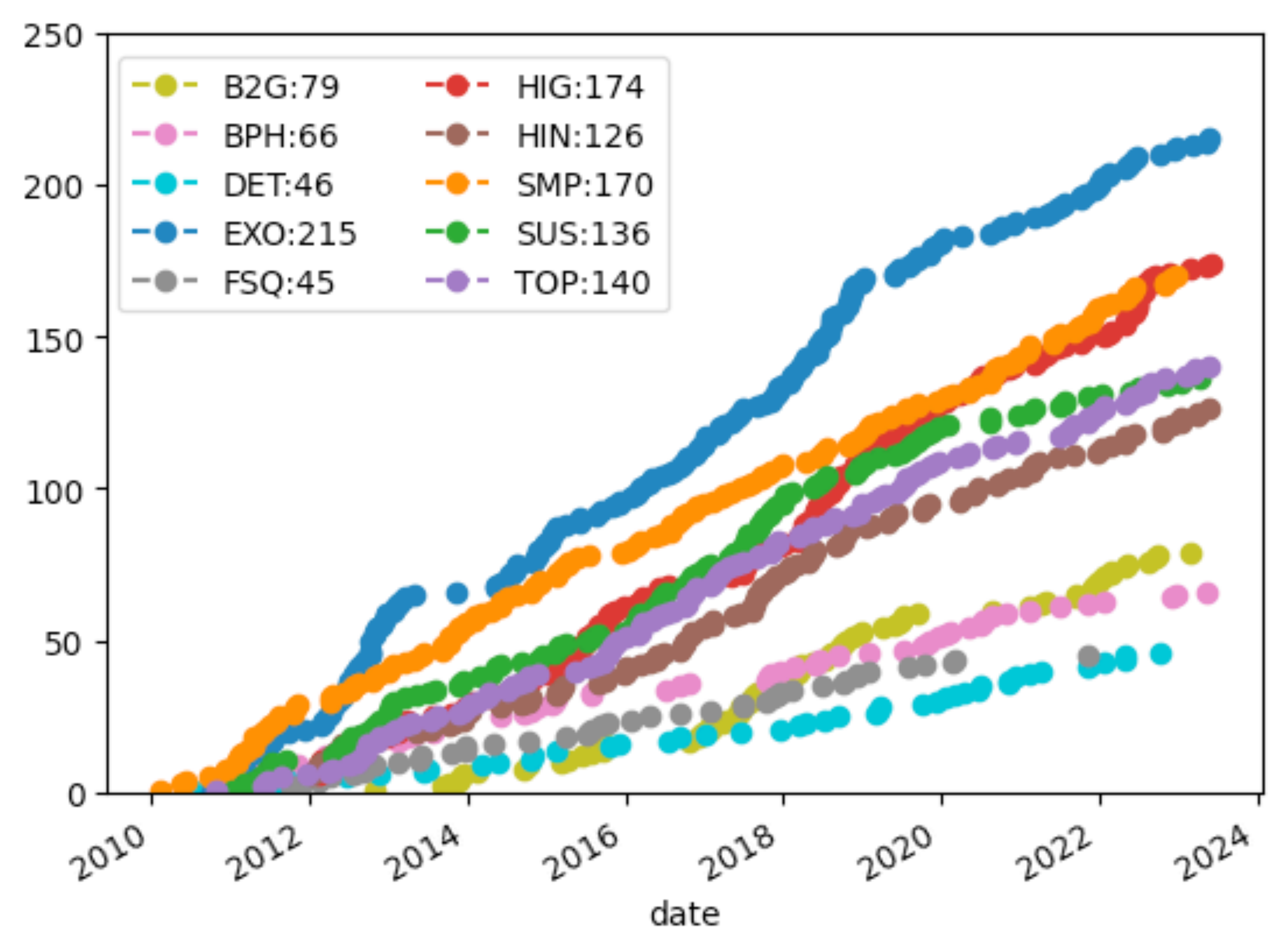
CMS is well prepared for the 2023 Heavy Ion run that will start in September.

CMS Publications

1197 papers based on collision data
- 1125 published as of 29/05/2023

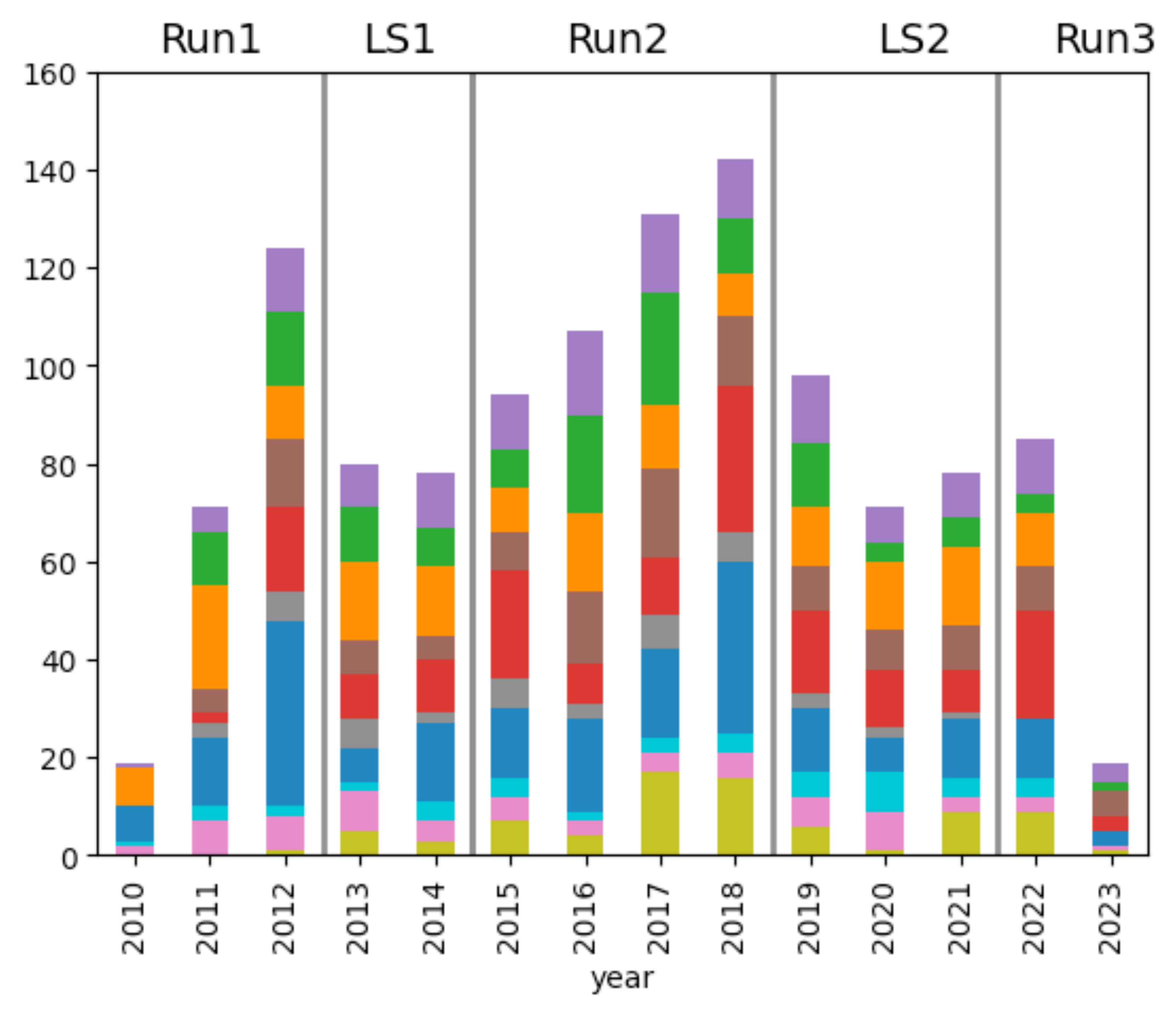






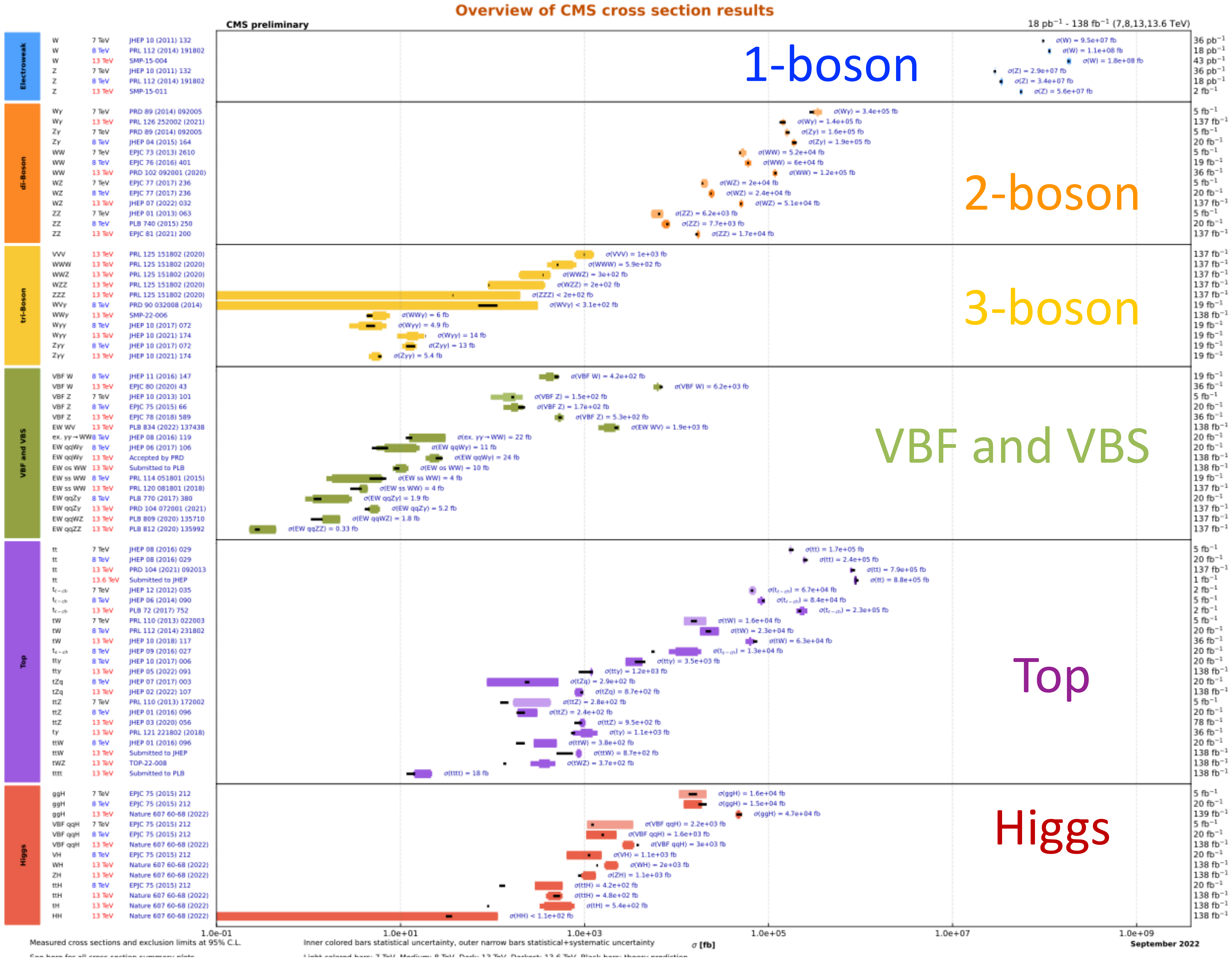
CMS titles
- 602 "Search"
- 53 "Observation"
- 21 "Evidence"
- 337 "Measurement"
- 42 "Study"

CMS with friends
- ATLAS: 6 (5 JHEP, 1 PRL)
- LHCb: 1 (Nature)
- TOTEM: 5 (1 JHEP, 3 EPJC, 1 JINST)



http://cms-results.web.cern.ch/cms-results/public-results/publications-vs-time/

Many many measurements



In good agreement with SM!

+ additional summaries:

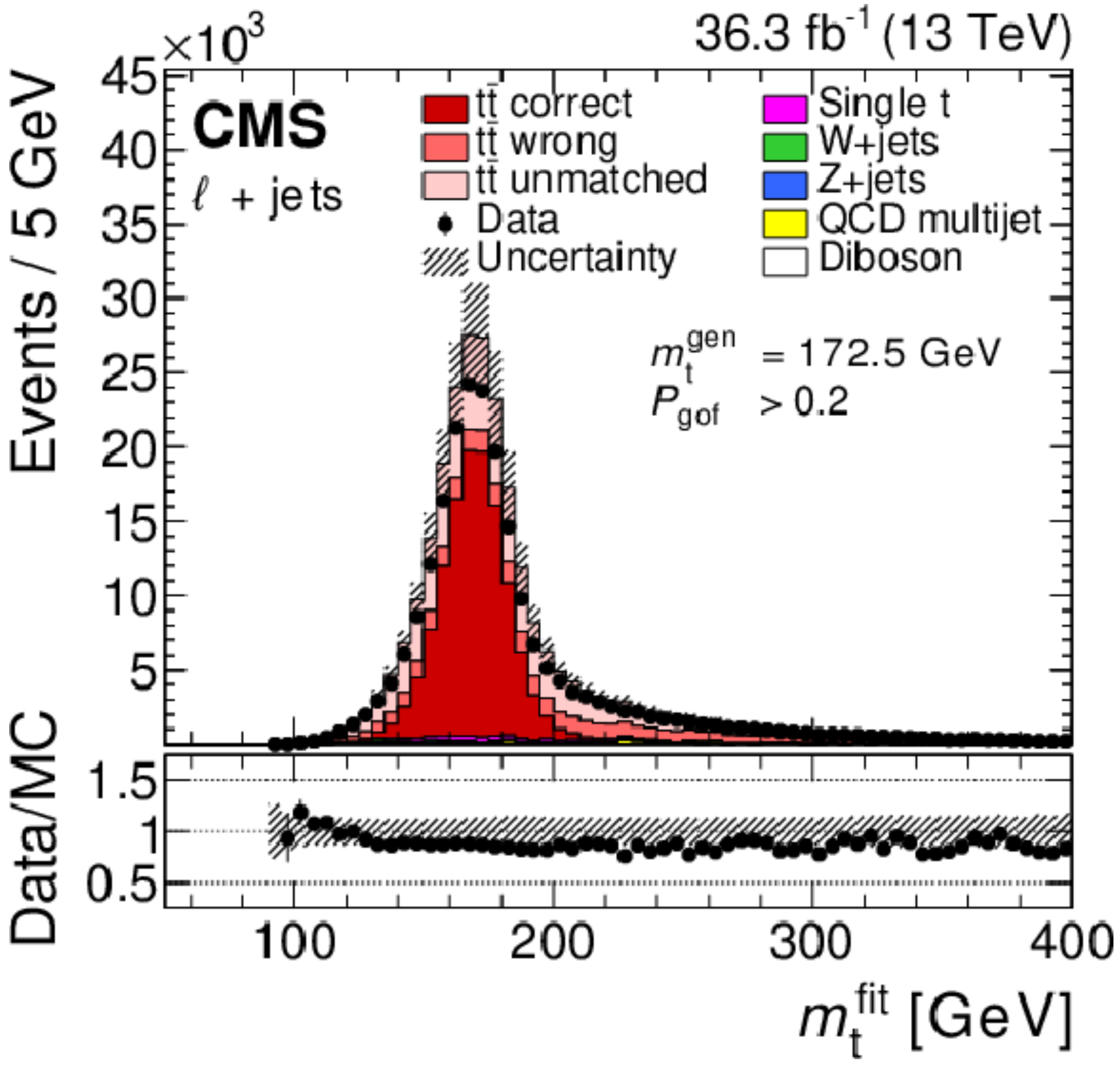
Exotica
B2G
SUSY
Higgs
Top

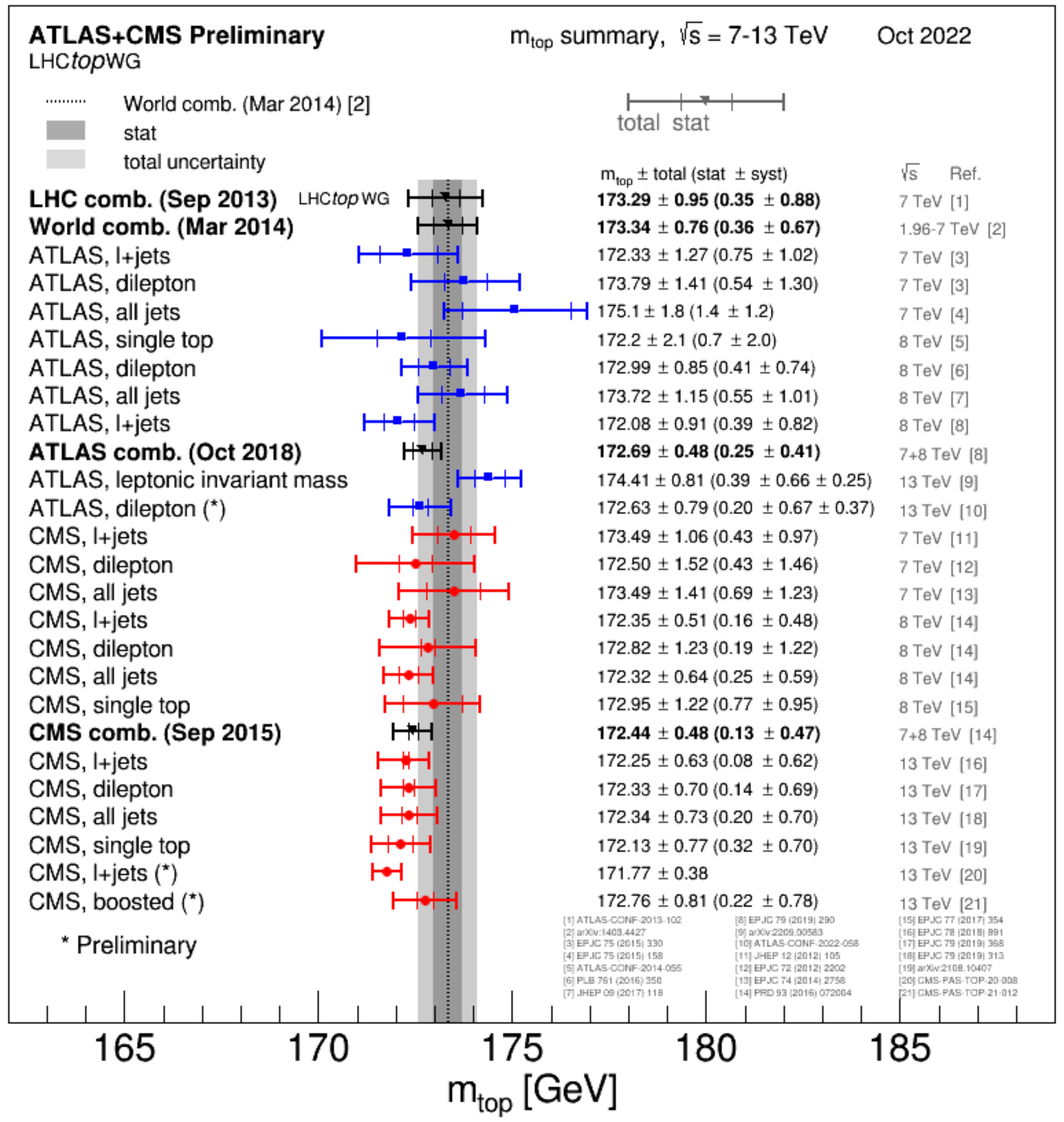
Cross section measurements for SM processes

Precise top mass measurements

[TOP-20-008]

- Direct measurement with **5D fit** constraining jet uncertainty from W peak
  - $m_t = 171.77 \pm 0.37$ GeV
- Measurement from tt+jet cross section
  - $m_t = 172.94 \pm 1.37$ GeV
- Measurement of mass distribution and m_t in hadronic decay to boosted jets
  - $m_t = 172.76 \pm 0.81$ GeV





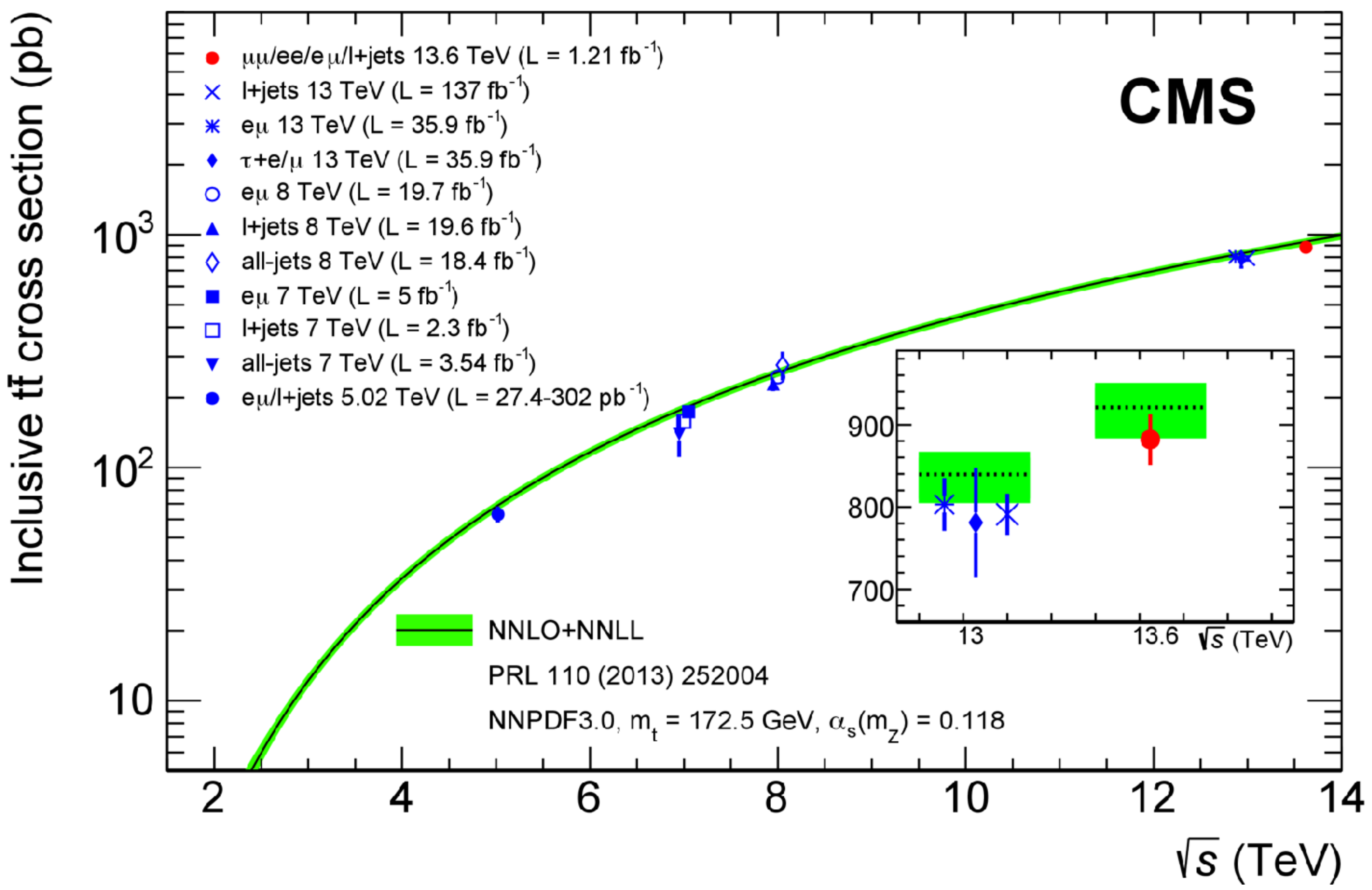
Comparison to previous measurements

Some physics highlights

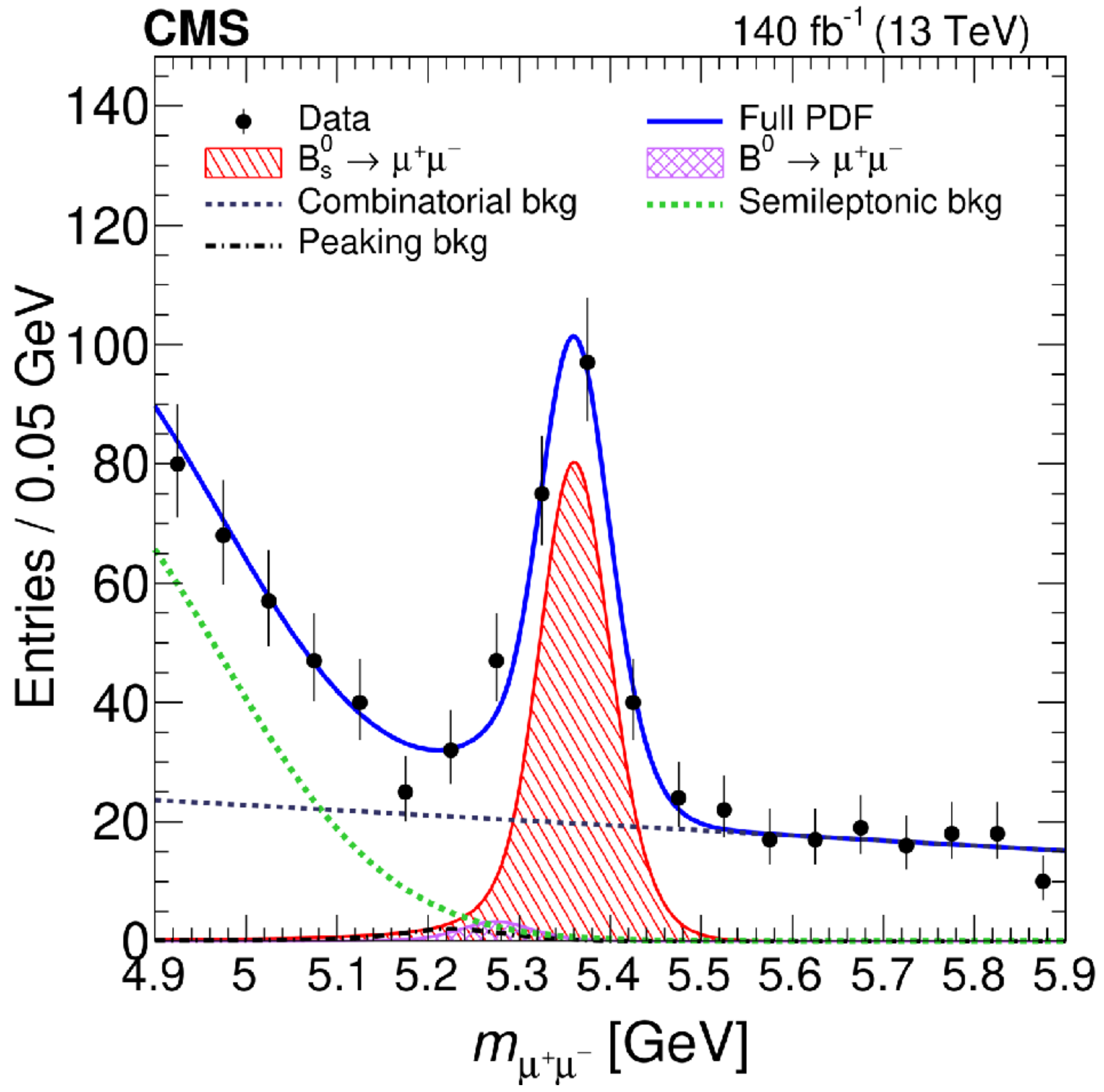
- First Run 3 result! [TOP-22-012]
  - First measurement of σ(tt) @ 13.6 TeV

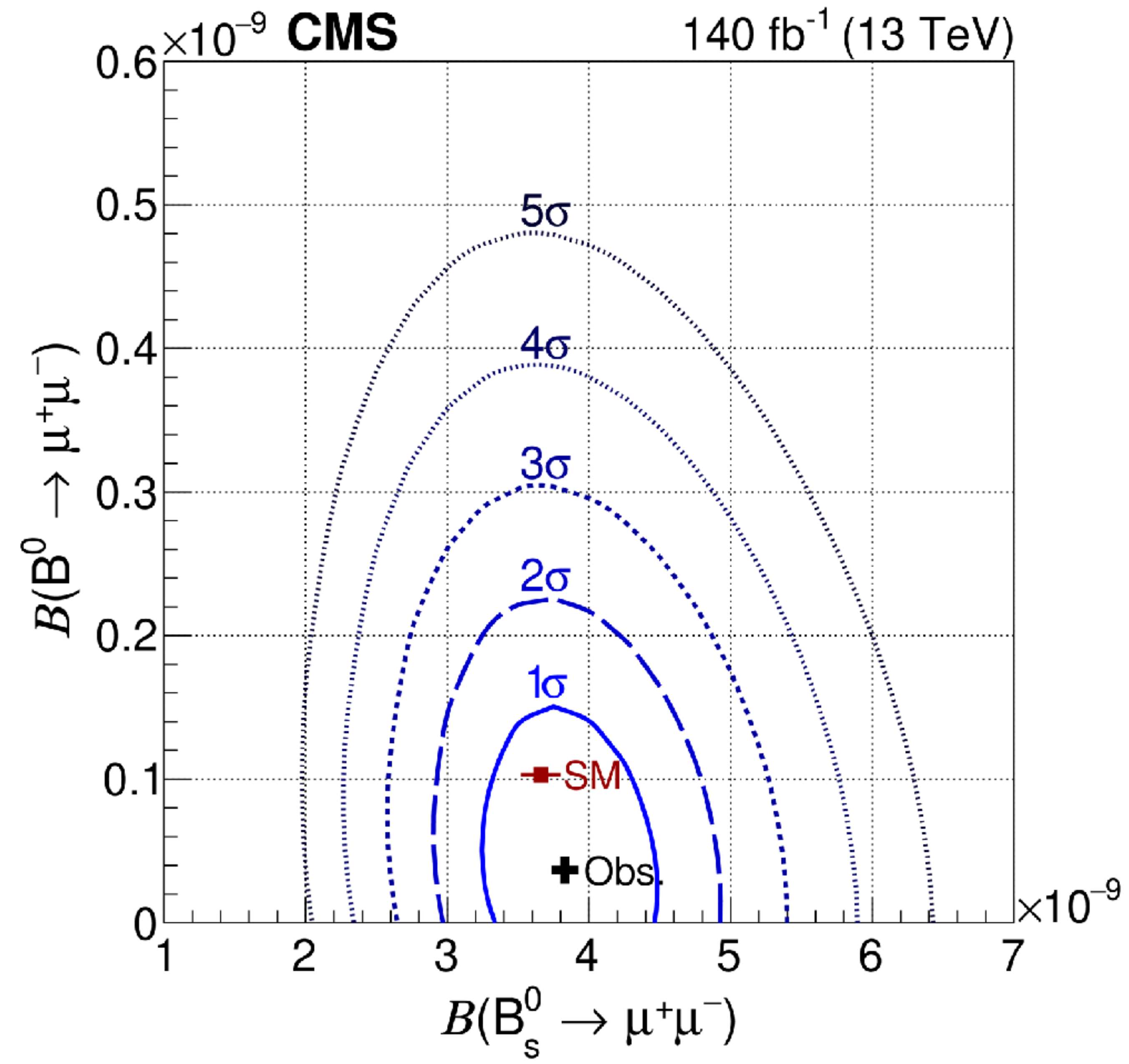
Measured: $\sigma_{t\bar{t}} = 887^{+43}_{-41}(\text{stat}+\text{syst}) \pm 53(\text{lumi})\,\text{pb}$

Theo. pred: $\sigma(t\bar{t}) = 921^{+29}_{-37}\,\text{pb}$



- Full Run 2 result on $B_s \to \mu\mu$ [BPH-21-006]
  - $\mathcal{B}(B^0_s \to \mu\mu) = (3.83^{+0.38}_{-0.36}(\text{stat})^{+0.24}_{-0.21}(\text{syst})) \times 10^{-9}$
    - Most precise single exp. measurement
  - Most precise measurement of lifetime



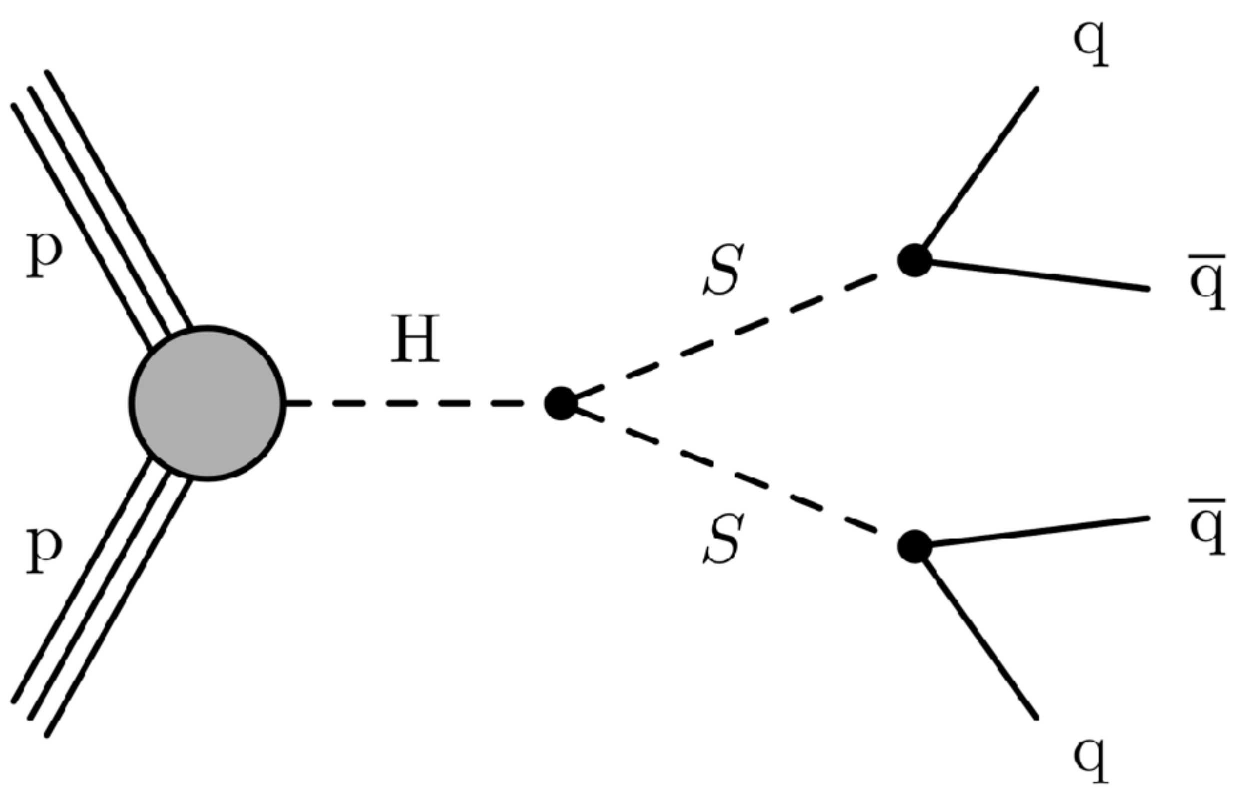


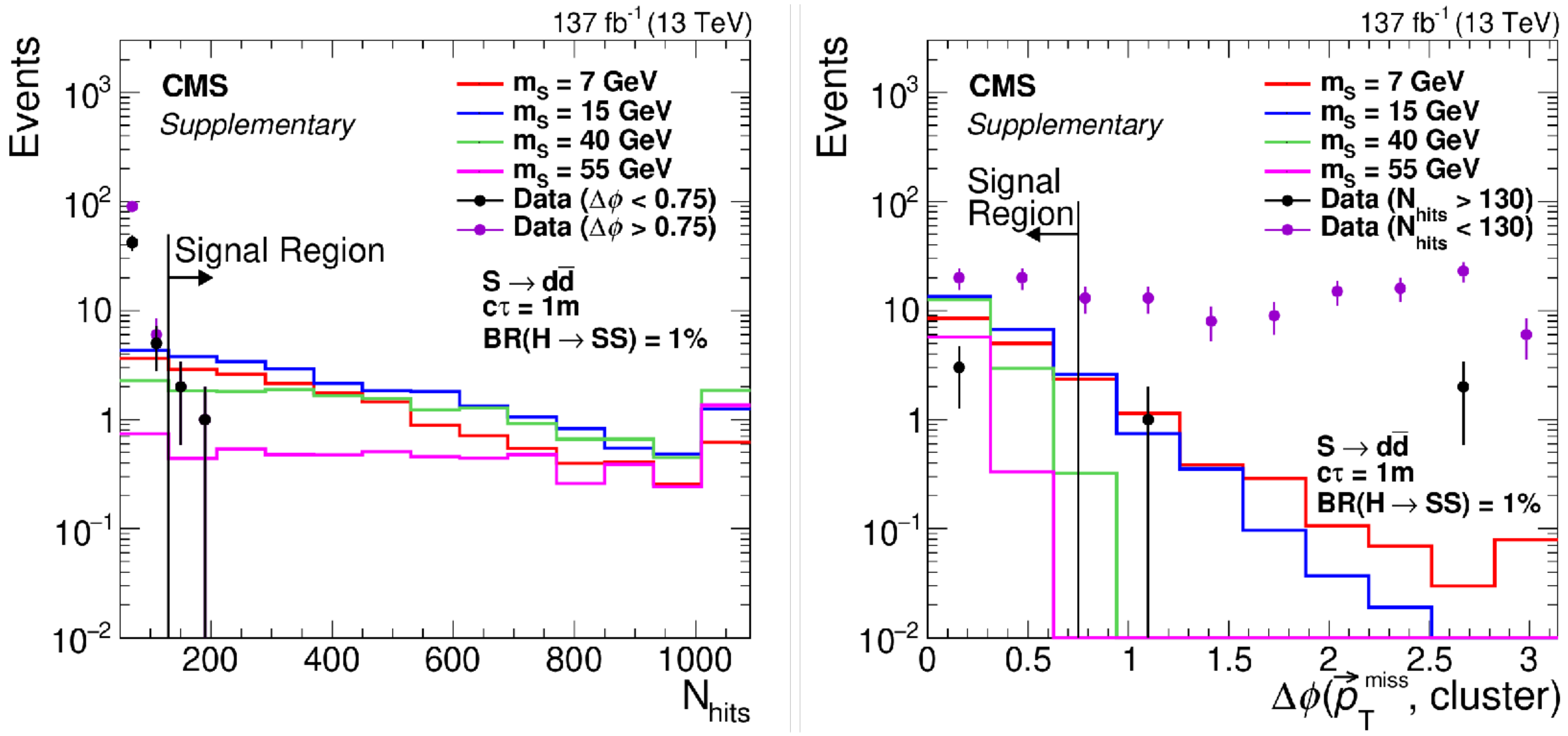
Exploring new phase spaces

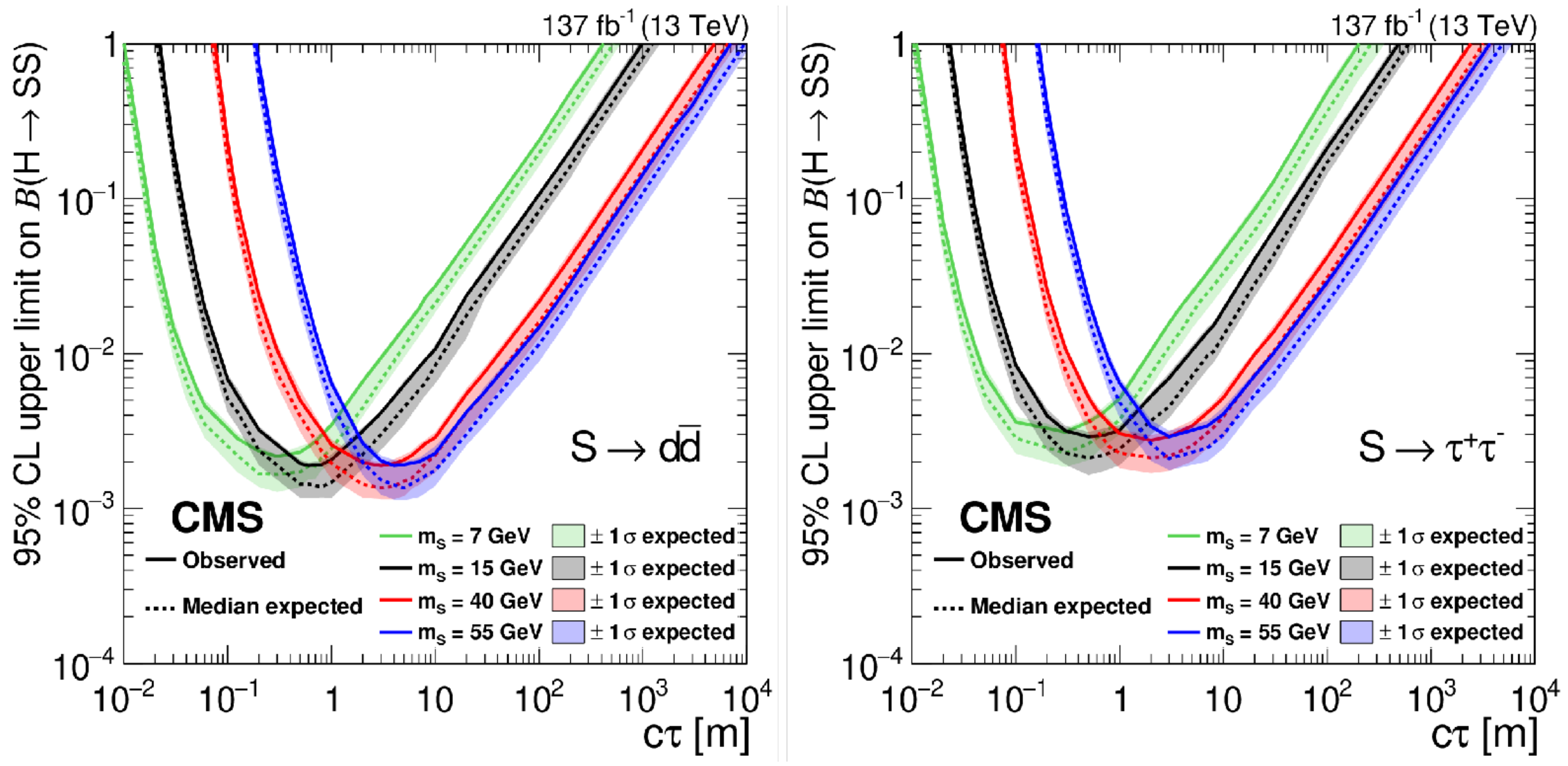
Searching for Long Lived Particles in the muon detectors

CMS-EXO-20-015

- A first search for LLPs performed using the CSC detector as a calorimeter
- Looking for a SM Higgs boson decaying into a pair of long-lived scalars
- The number of hits in the CSC is used, together with the requirement of transverse missing momentum pointing towards the CSC hit cluster



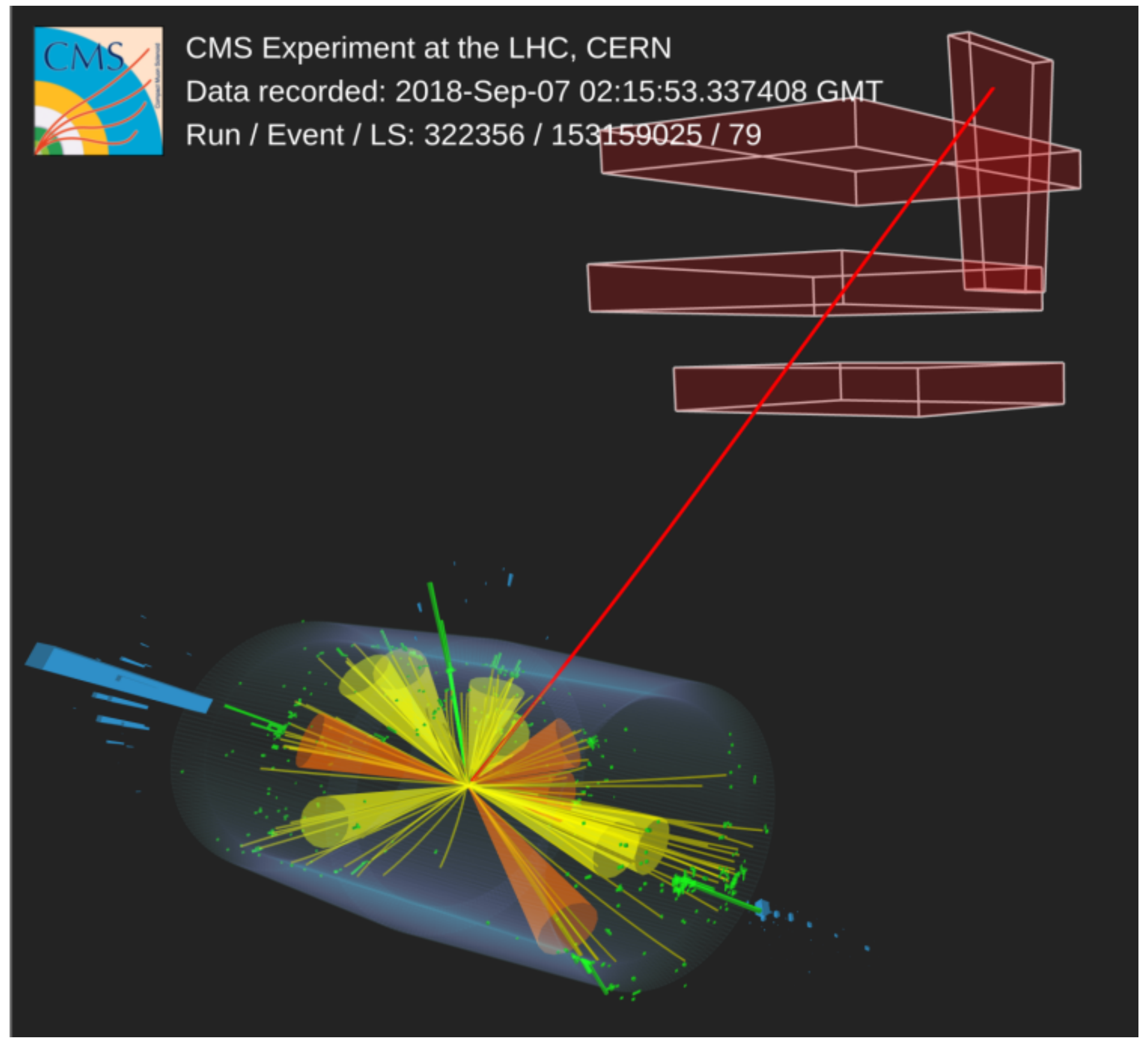




Four top production

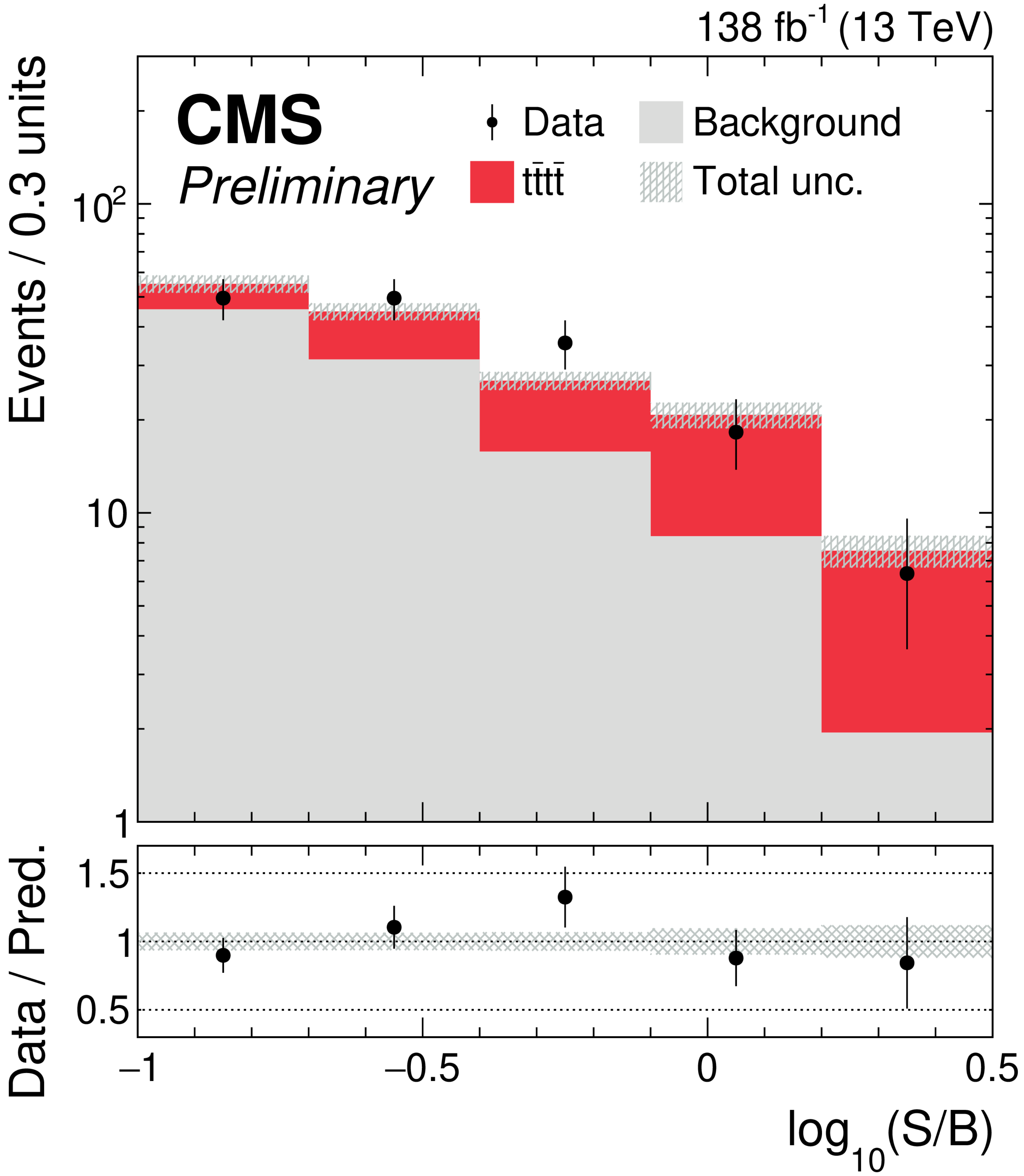
TOP-22-013

- **CMS observed the production of four-top quarks (@13 TeV)**
- Events: two same-sign, three, and four charged leptons (electrons and muons) and additional jets
  - Measured cross section($t\bar{t}t\bar{t}$) : $17.9\ ^{+3.7}_{-3.5}\ (stat)\ ^{+2.4}_{-2.1}\ (syst)\ fb$
  - Result is in agreement with the SM predictions.
- Observed (expected) significance is 5.5 (4.9) standard deviations



Analysis improved using Machine Learning:

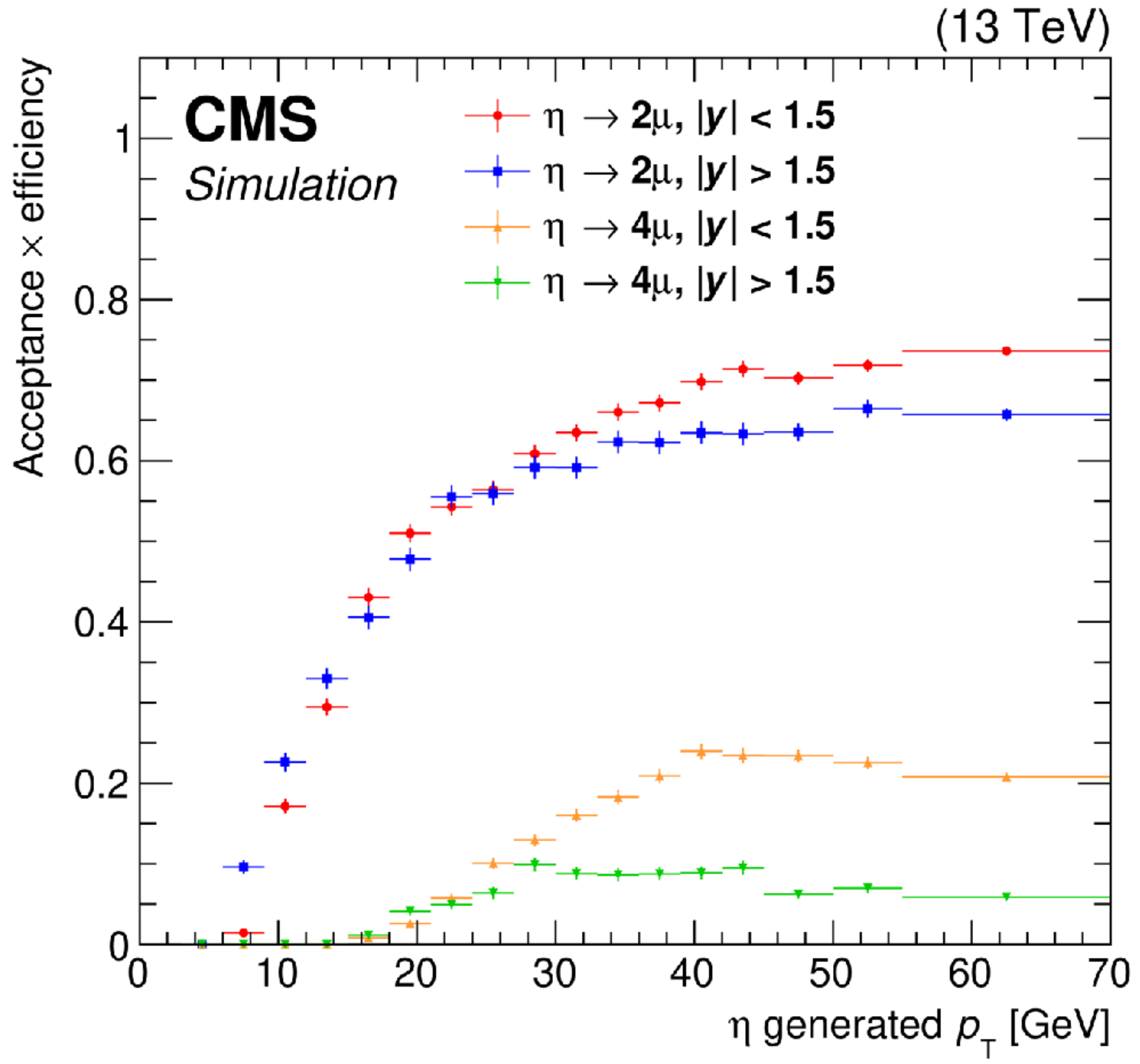
1. lepton ID,
2. bjet tagging, and
3. discrimination of signal and background



Observation of η→4μ decay

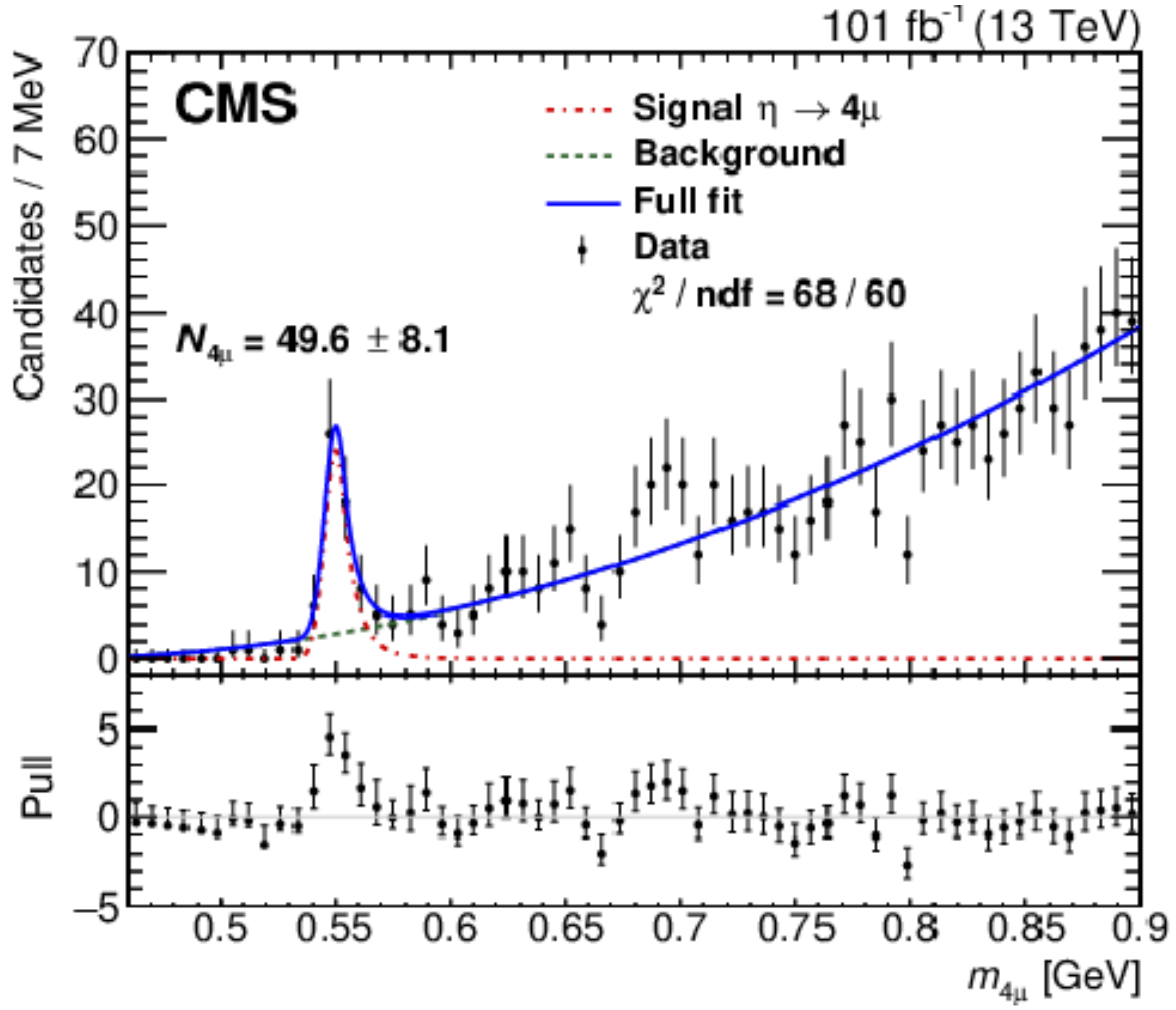
- Probe rare **η→**4μ (expected BR~4x10-9) using high rate scouting data
- Need to understand detection efficiencies well
- Expect improved precision with Run 3 scouting data

BPH-22-003



BR measured wrt η→2μ.

First observation of the BR (η→4μ) — compatible with SM expectation



$$\mathcal{B}(\eta \to 4\mu) = (5.0 \pm 0.8\,(\text{stat}) \pm 0.7\,(\text{syst}) \pm 0.7\,(\mathcal{B})) \times 10^{-9}.$$

Search for lepton flavor violating tau into 3 muons

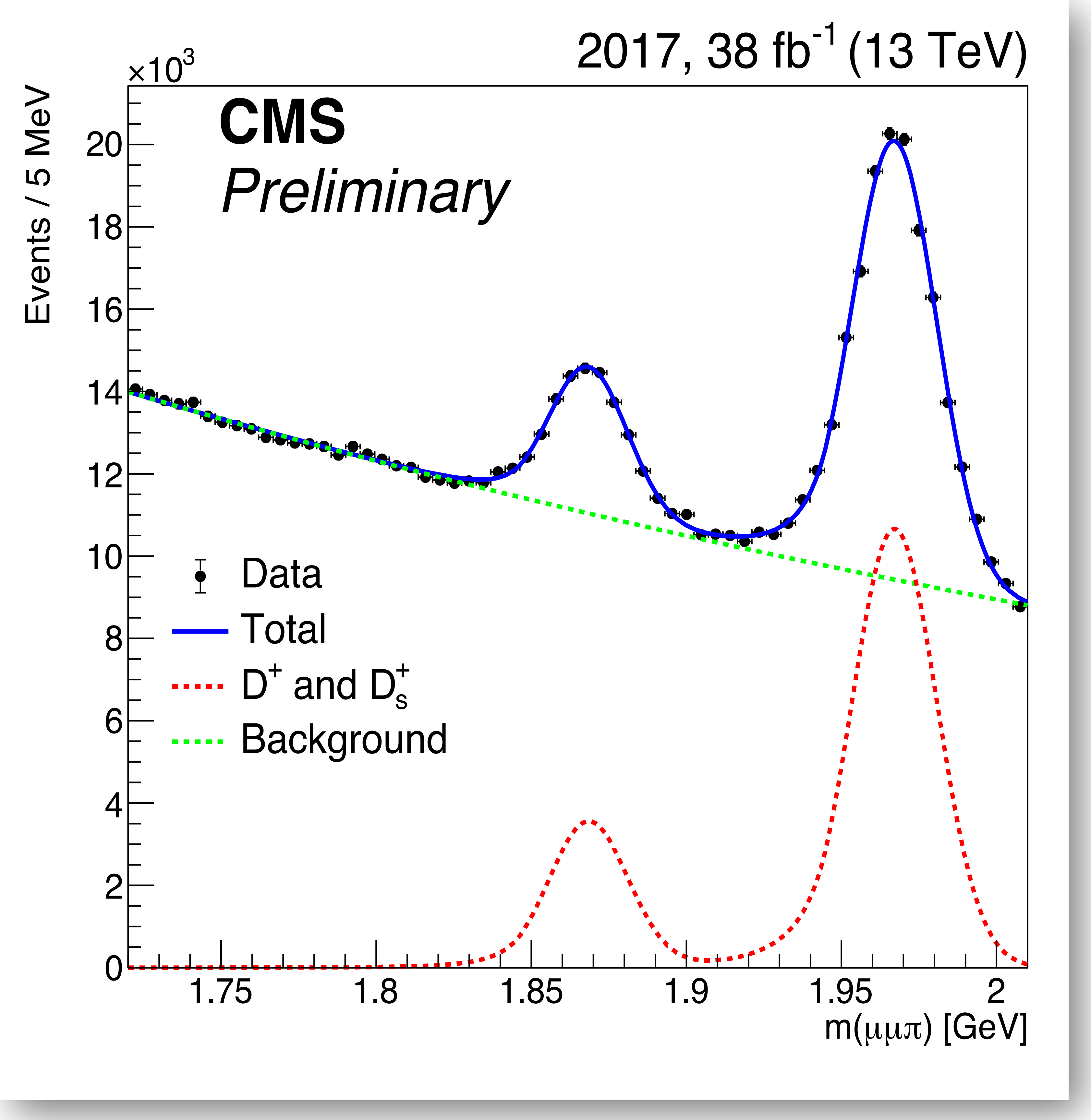
Fermilab

BPH-21-005

$\tau \longrightarrow 3\mu$ decays: clean signature given by three muons final state.

Sources of τ leptons

- heavy flavor (HF) mesons ~10^{11} τ per/fb
  - low-p_T and high $|\eta|$ → less efficient trigger selection
  - more sensitive to fake signal muons from π's and K's
- production in the W channel ~10^{7} τ per /fb
  - harder spectra and more central decay → more efficient trigger selection
  - properties of W → $\tau\nu$ bring additional handles for background suppression (large MET, low hadron activity, larger signal p_T)
- multivariate (BDT) analysis for both channels

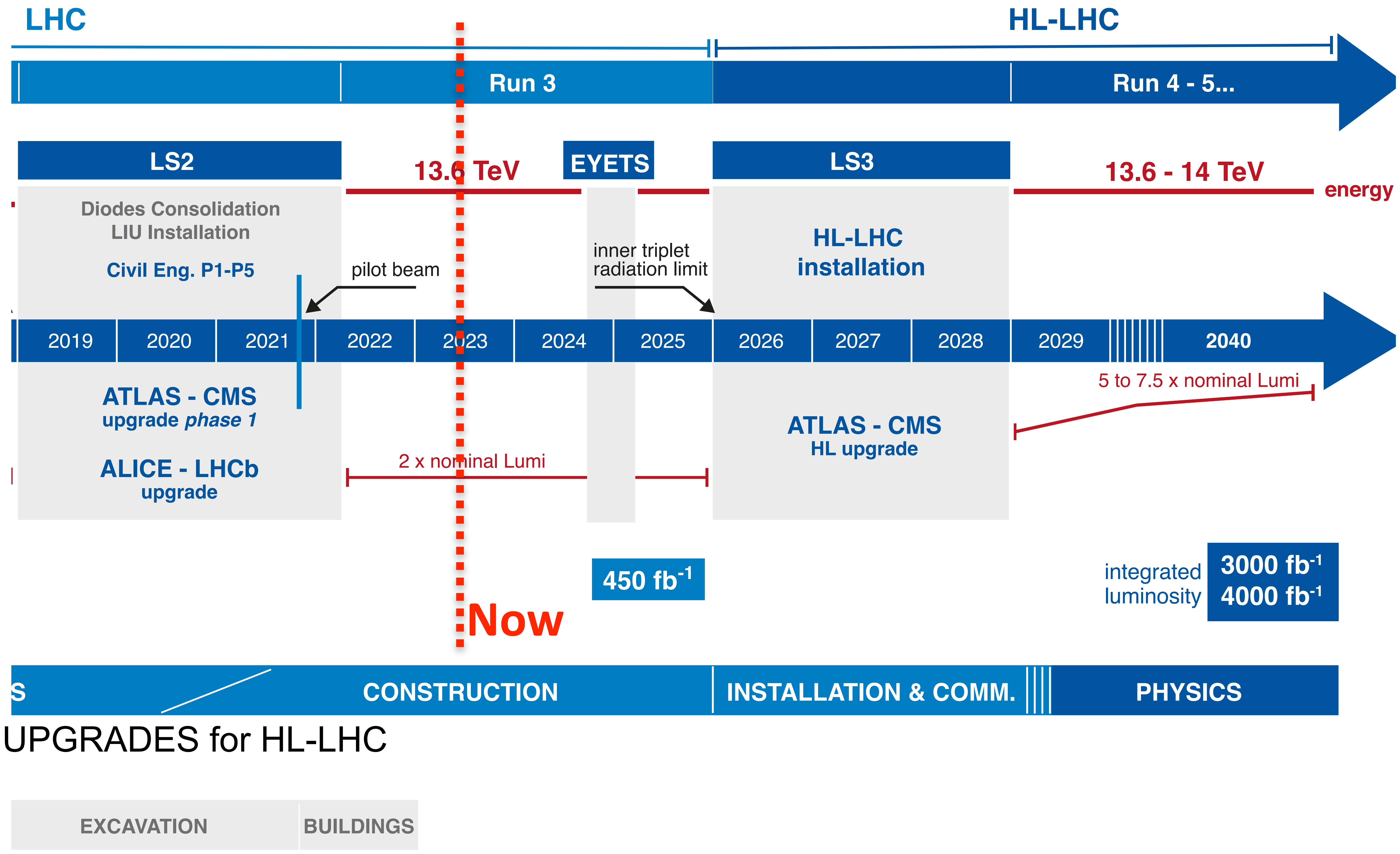


Observed (Expected) upper limits (with full run2)

$\mathcal{B}(\tau \rightarrow 3\mu)$ is 2.9 (2.4) x10^{-8} at 90% CL

Best $\mathcal{B}(\tau \rightarrow 3\mu)$ at the moment when comparing with hadron collider and BaBar experiment.

HL-LHC

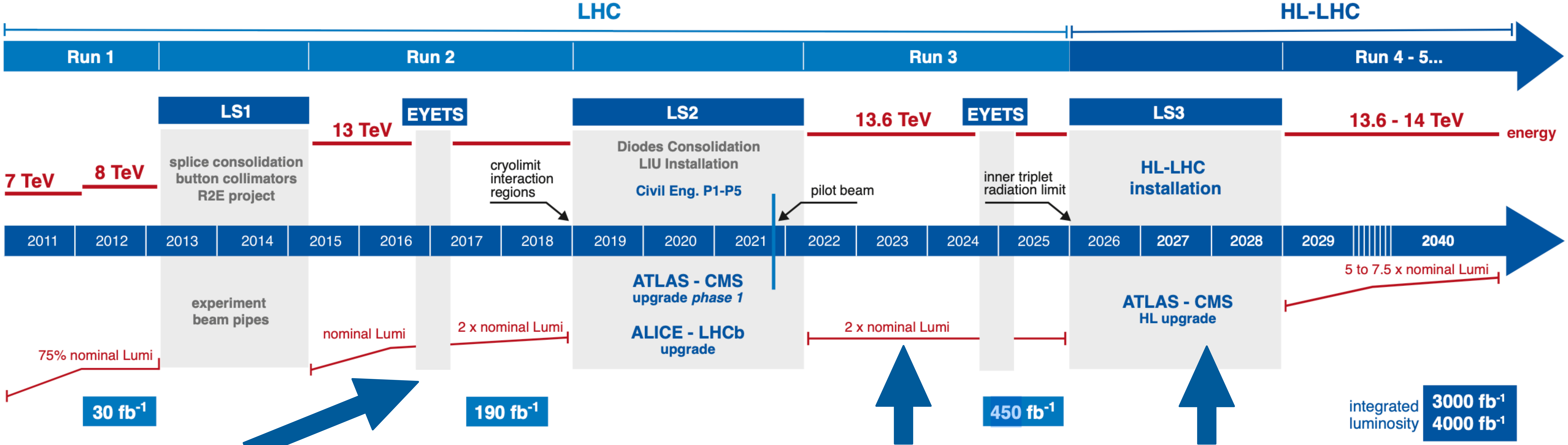


Current HL-LHC schedule.

Energy considerations could continue to impact the annual running time.

Running conditions for Run 4 are under discussion. (Electron cloud, electricity costs)

… and CMS activities



Analysis of Run 2 data

- well-understood data set
- many results are available, but more to come

Run 3 activities

- record data & ~double $\int \mathscr{L} dt$
- validate & calibrate data and start analysis

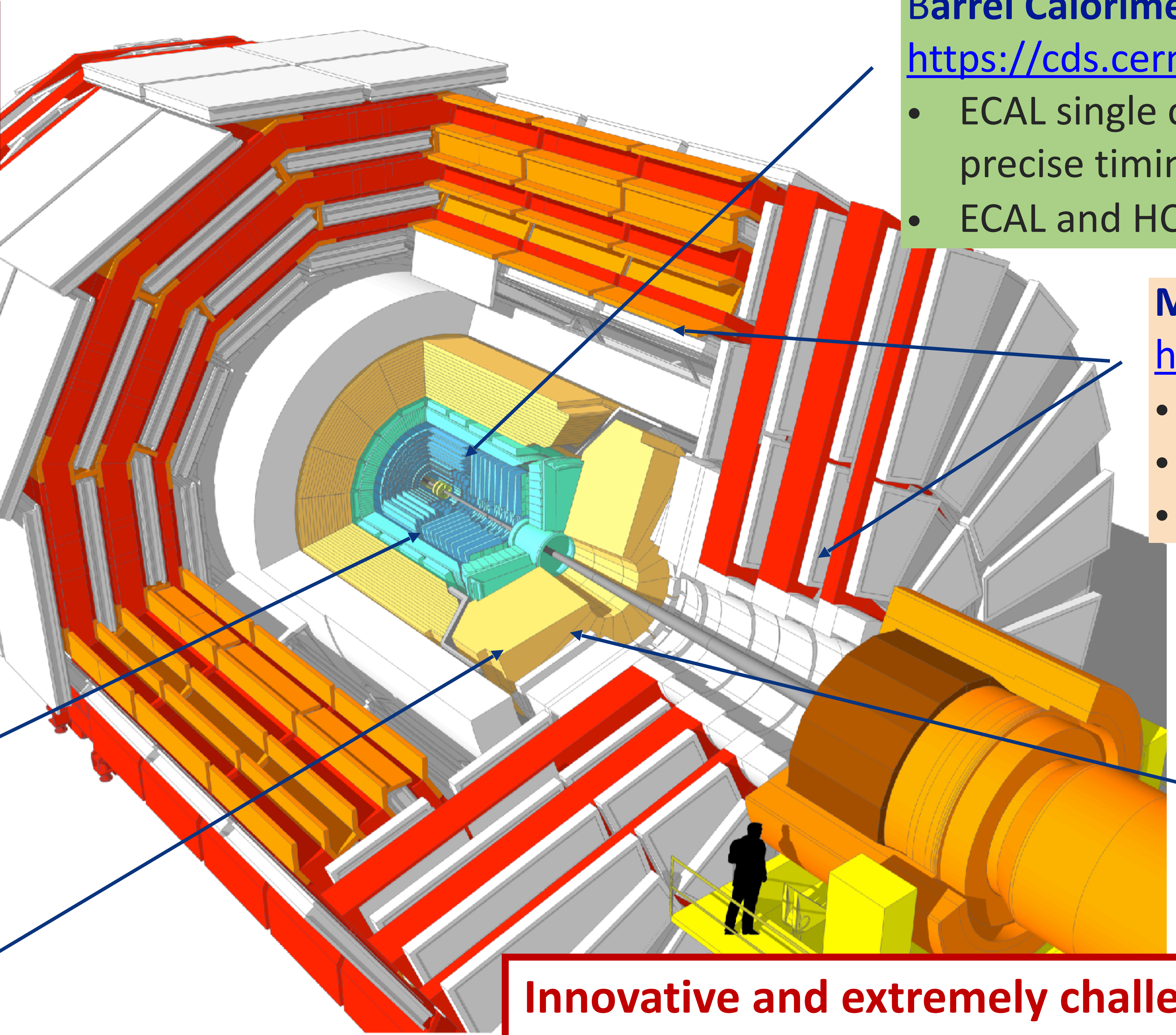
"Phase 2" CMS upgrade

- upgrade / replace CMS detector systems
- increase dataset to ~ 10x

The CMS HL-LHC Upgrade

Technical proposal CERN-LHCC-2015-010 https://cds.cern.ch/record/2020886

Scope Document CERN-LHCC-2015-019 https://cds.cern.ch/record/2055167/files/LHCC-G-165.pdf

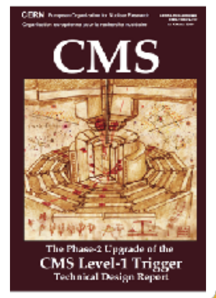


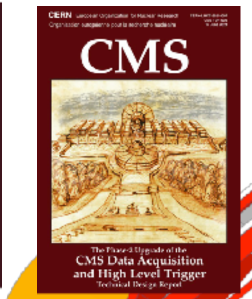
L1 Trigger/HLT/DAQ

https://cds.cern.ch/record/2283192

https://cds.cern.ch/record/2283193

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





Barrel Calorimeters

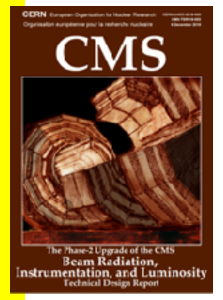
https://cds.cern.ch/record/2283187

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

Beam Radiation and Luminosity

https://cds.cern.ch/record/2020886

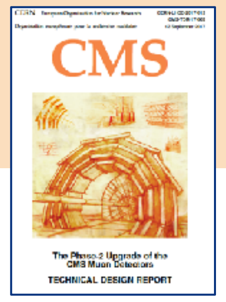
- Bunch-wise Luminosity
- Beam Monitoring



Muon Systems

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

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



Tracker

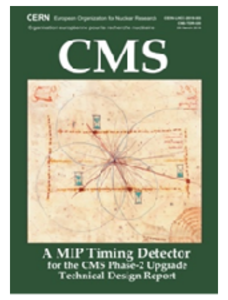
https://cds.cern.ch/record/2272264

- Si Strip **O**uter **T**racker designed for L1 Track Trigger
- Pixelated **I**nner **T**racker extends coverage to $|\eta| < 3.8$

MIP Timing Detector

https://cds.cern.ch/record/2296612

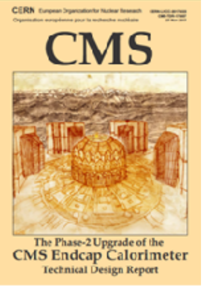
- < 75 ps resolution
- Barrel: Crystals + SiPMs
- Endcap: LGADs



Calorimeter Endcap *Also known as HGCal*

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

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

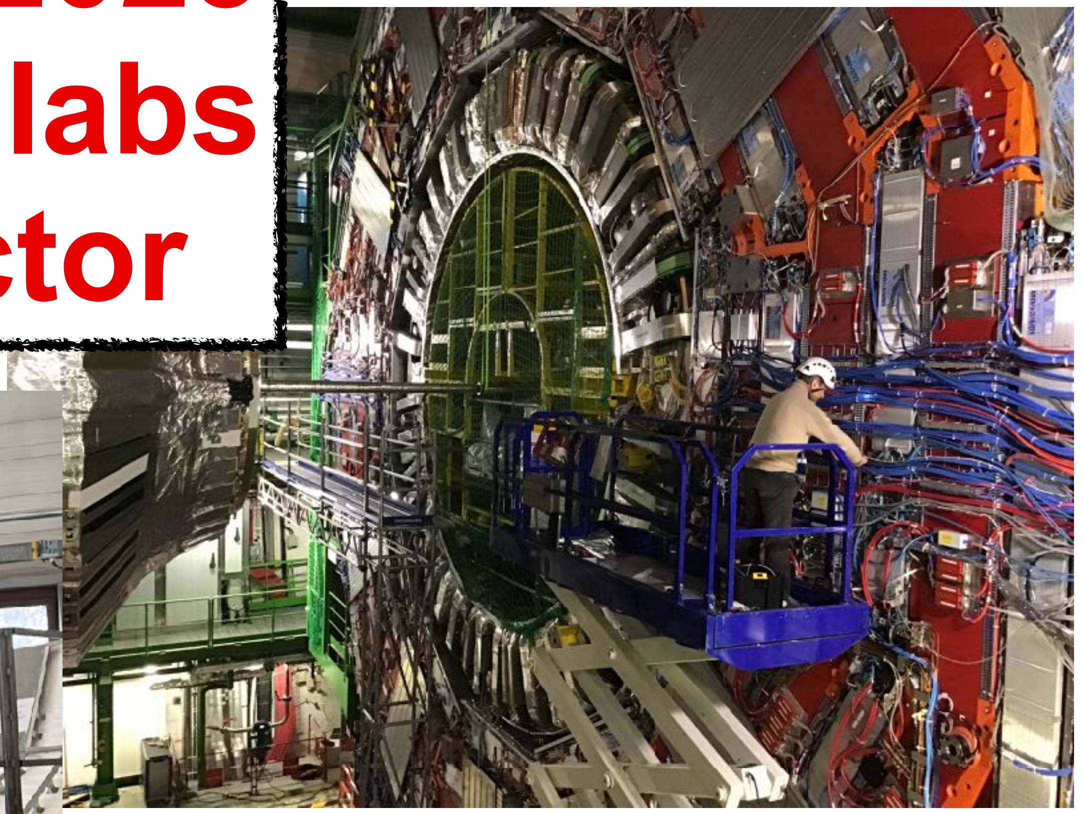


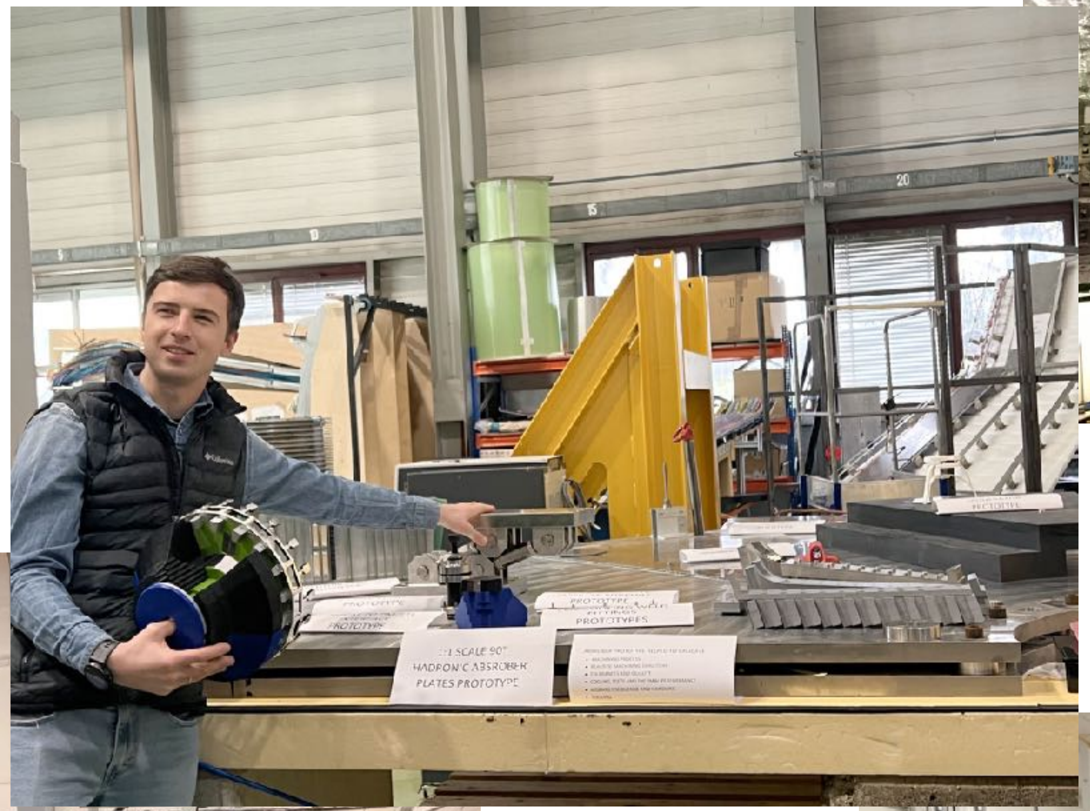
Innovative and extremely challenging new capabilities:

- **Level 1 track trigger**
- **Timing detector**
- **Highly granular endcap calorimeter**

CMS Phase-2 upgrades

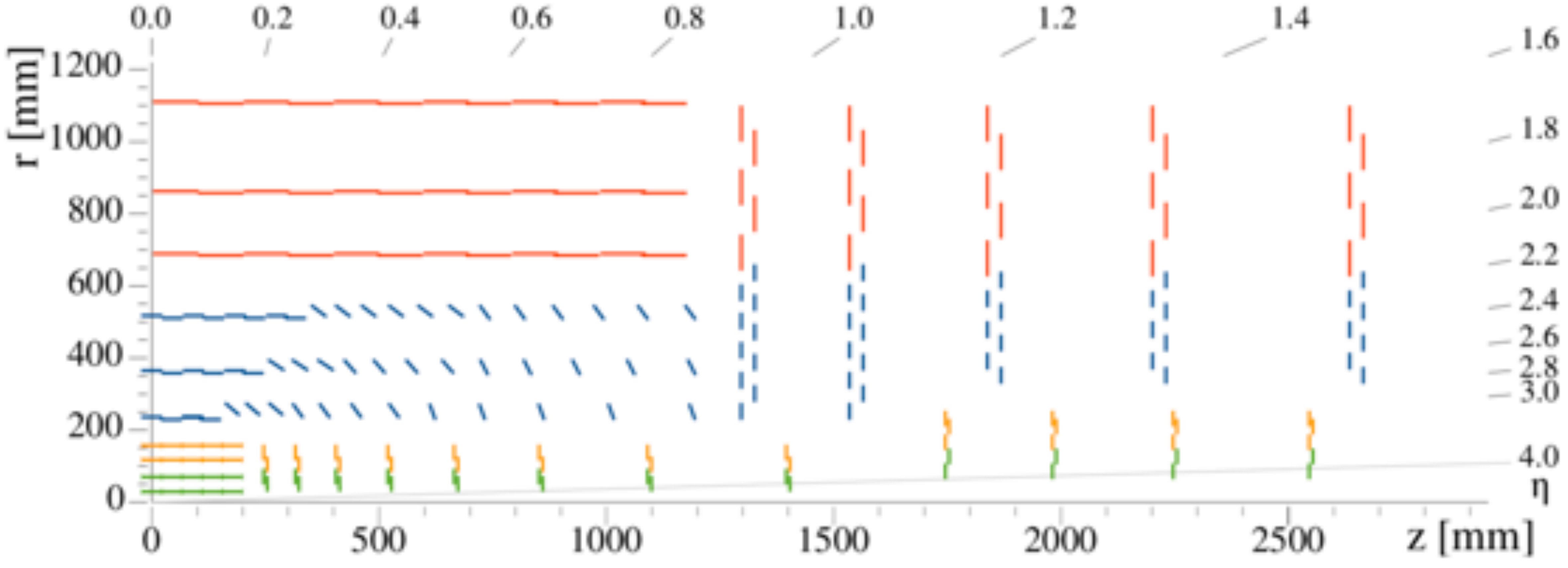
Upgrade days Feb. 2023 with visits to CERN labs and the CMS detector

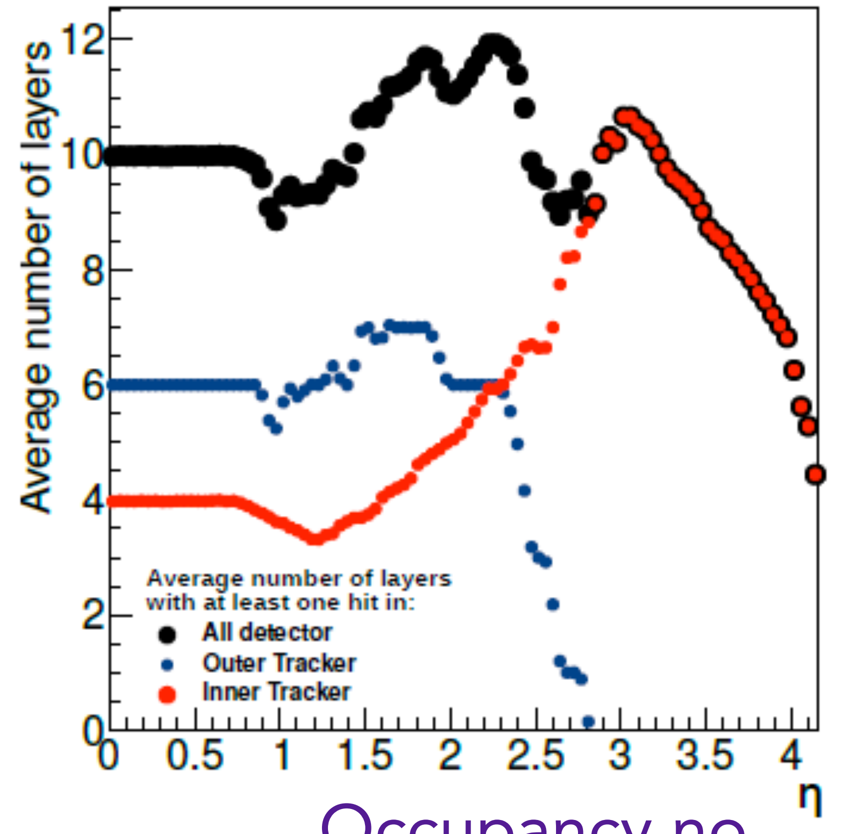




CMS Phase2 Tracker

Key features
- more granularity
- lower material budget
- extended coverage
- tracking included at L1-trigger level

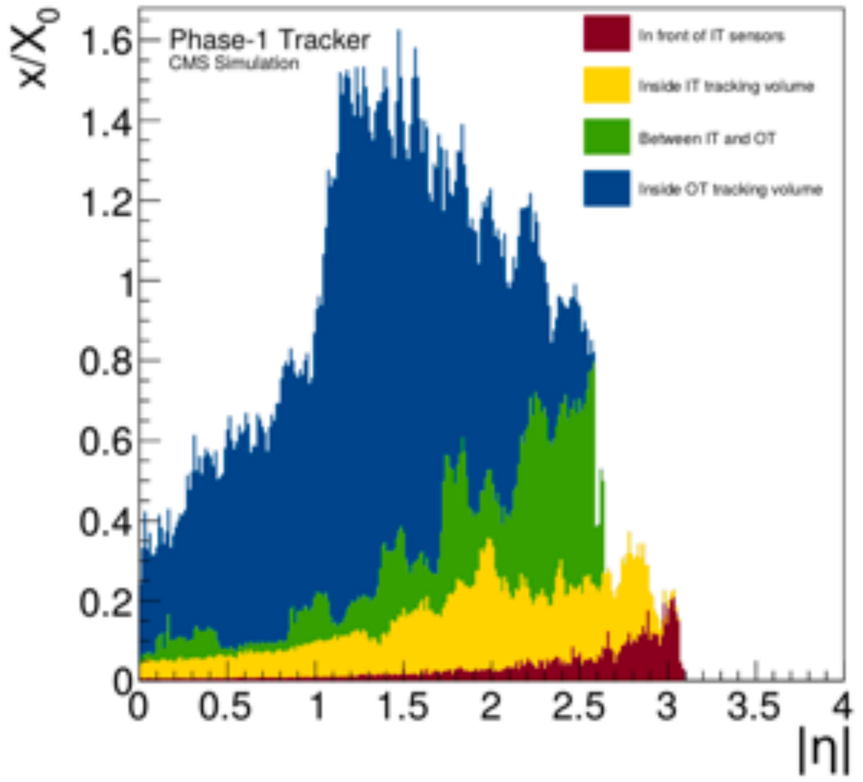




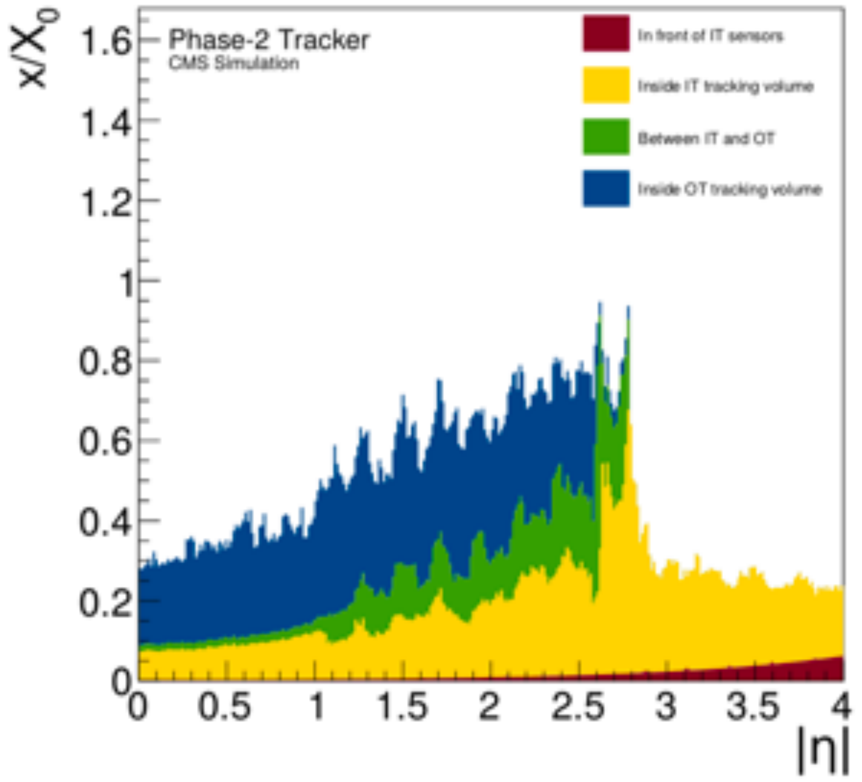
Occupancy no larger than 3%

Material budget

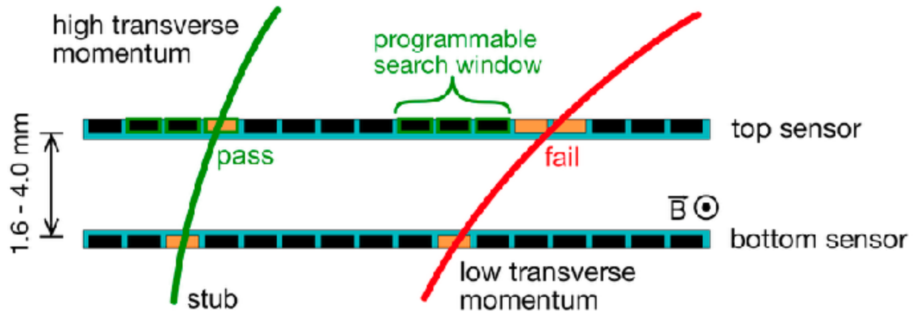
present tracker



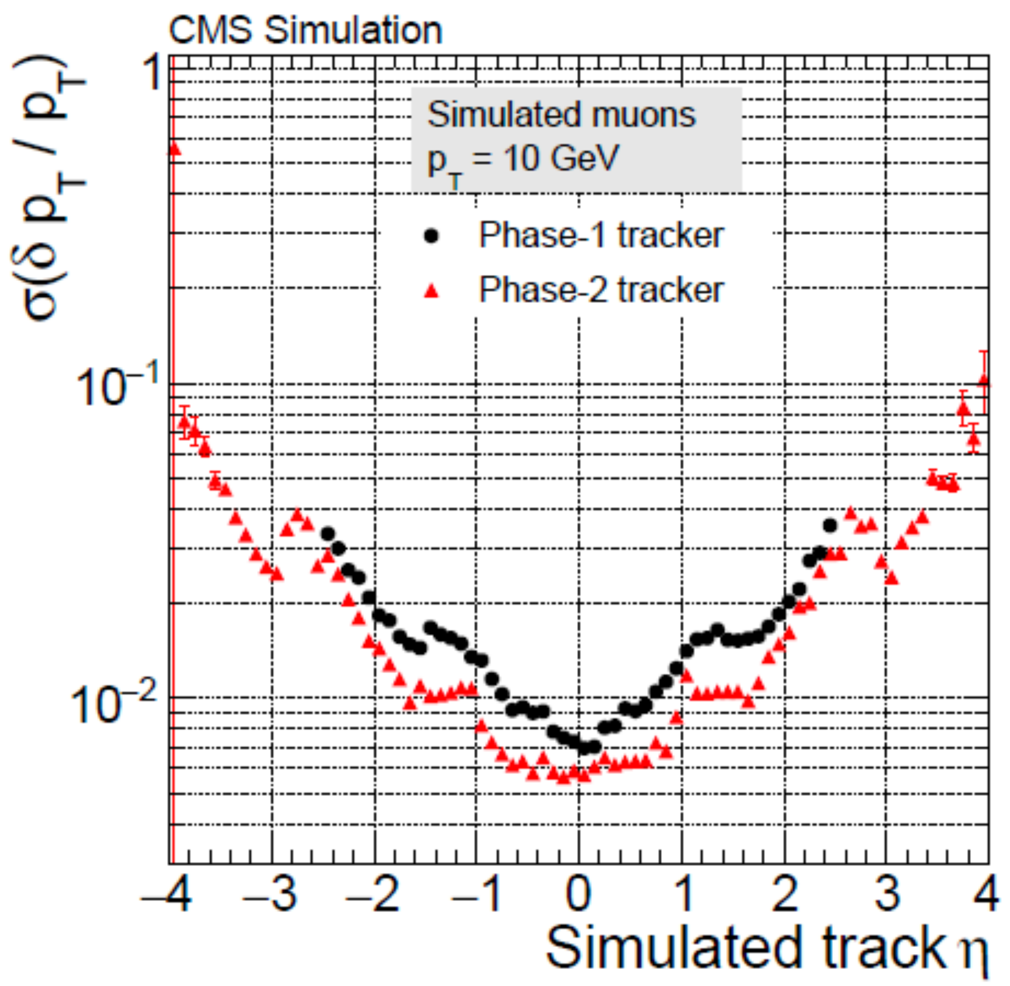
upgraded tracker



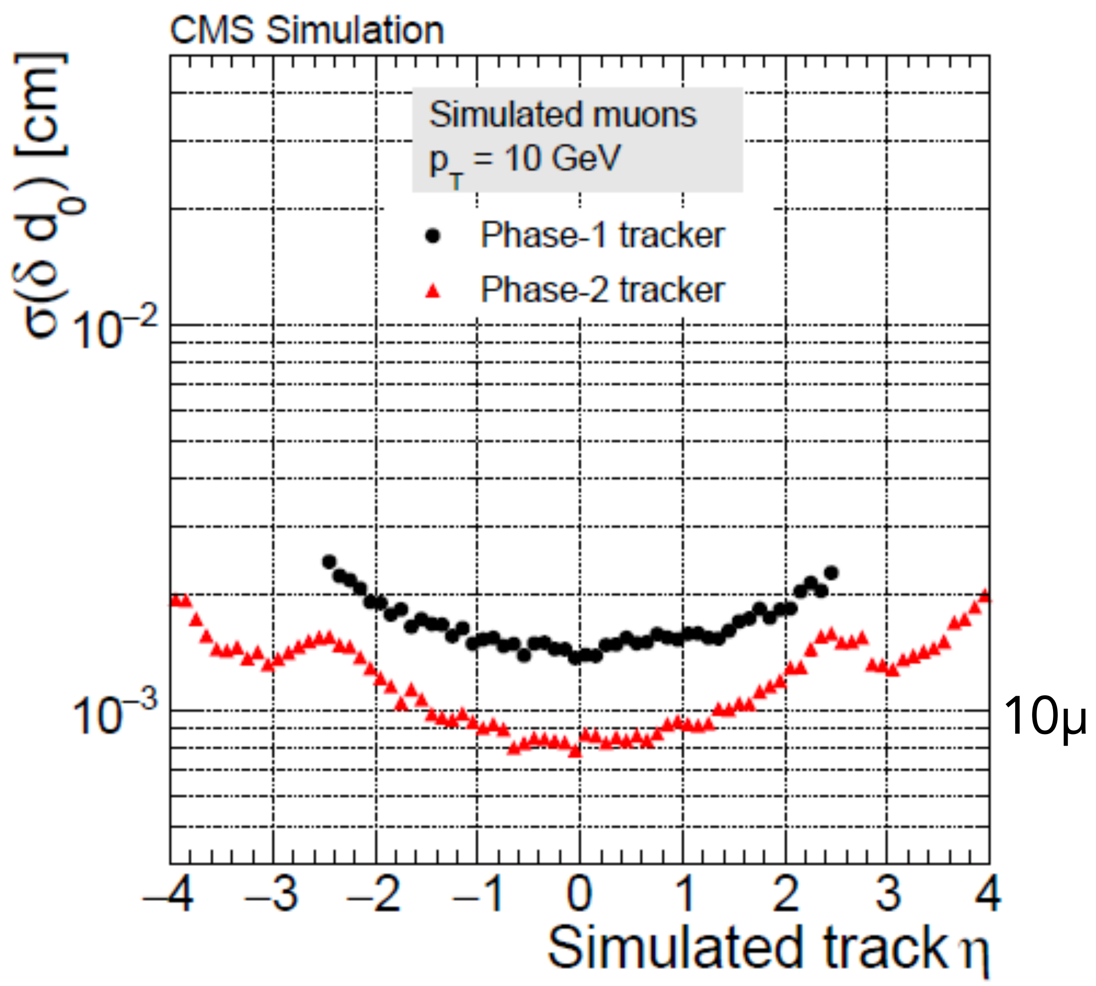
Local rejection of low p_T tracks



Expected performance compared to present tracker



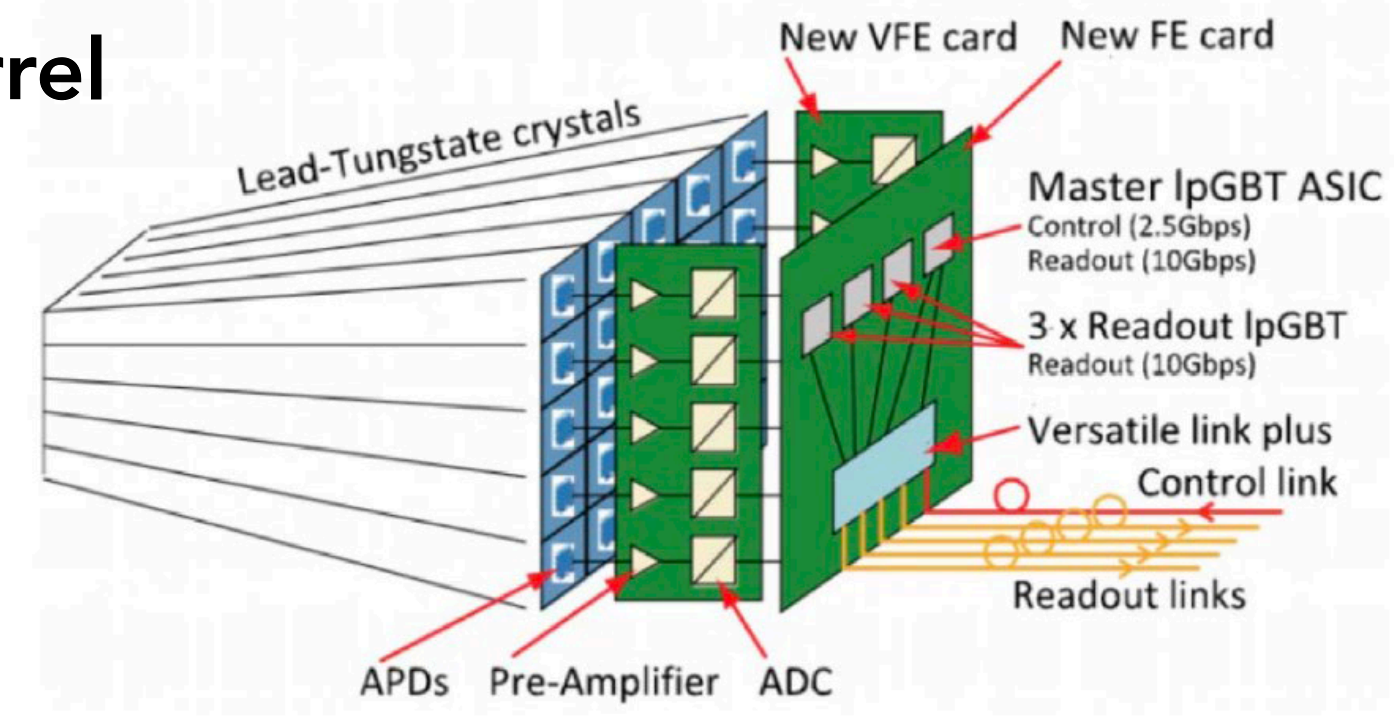
transverse momentum



transverse impact parameter

CMS Phase2 Calorimetry

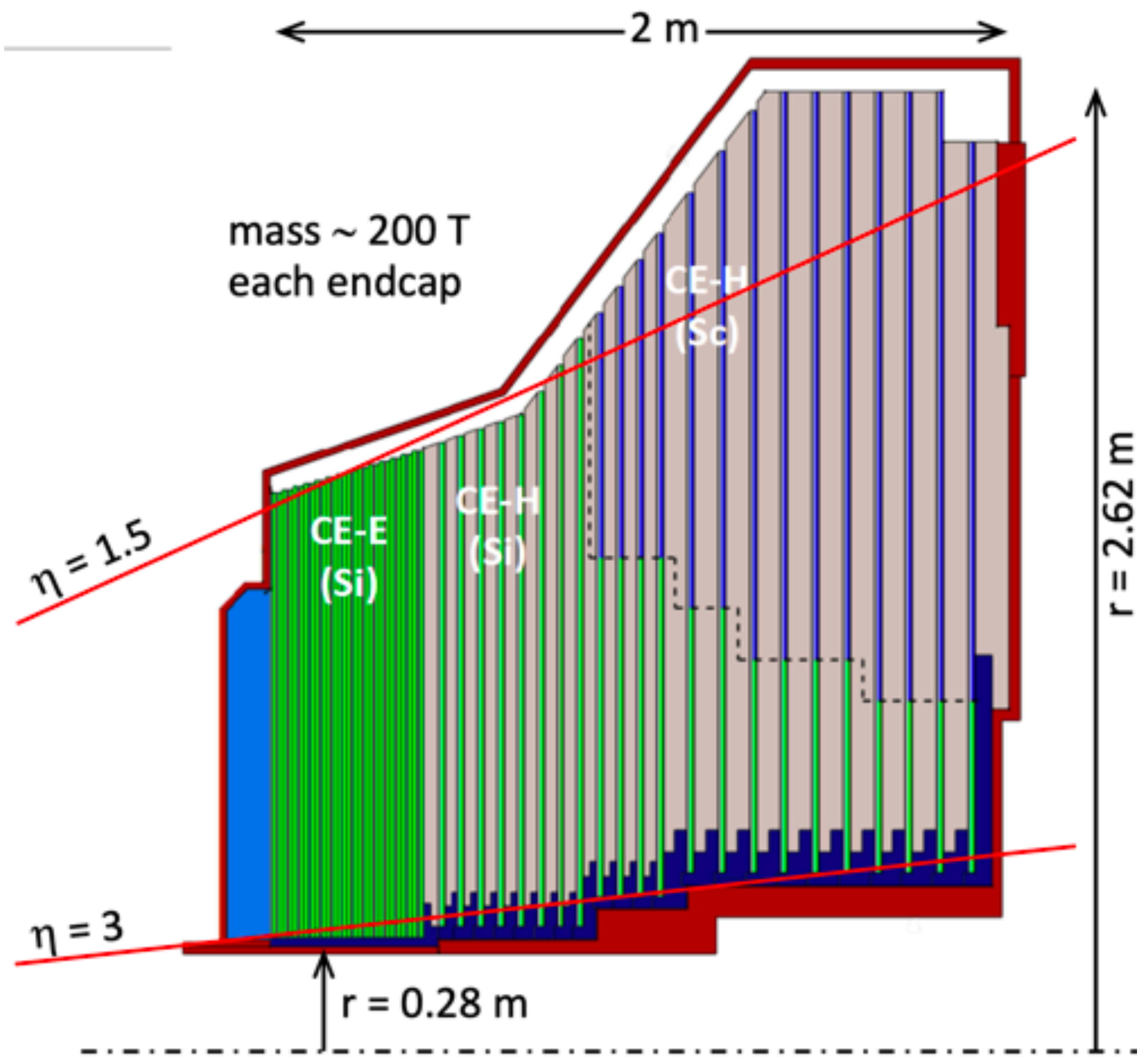
Barrel

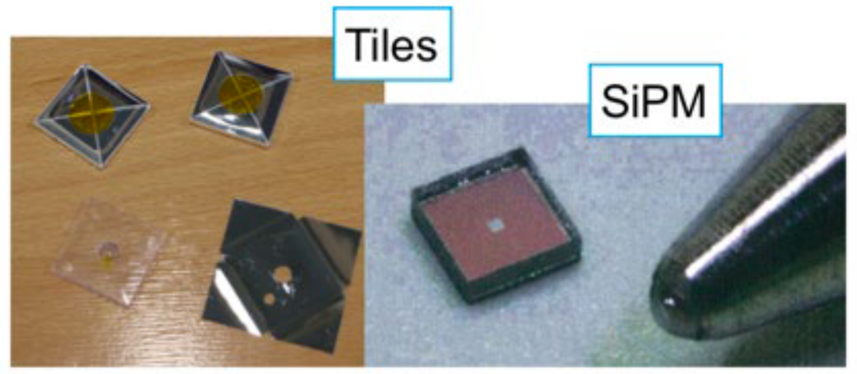


New ECAL on-detector electronics

- digitisation at 160 MHz
- online pulse shape discrimination against spikes
- trigger granularity = single crystal
- 30 ps time resolution (E_γ > 50 GeV)
- cooled at 9°C to mitigate APD ageing

Endcaps: High-Granularity Calorimeter (HGCAL)





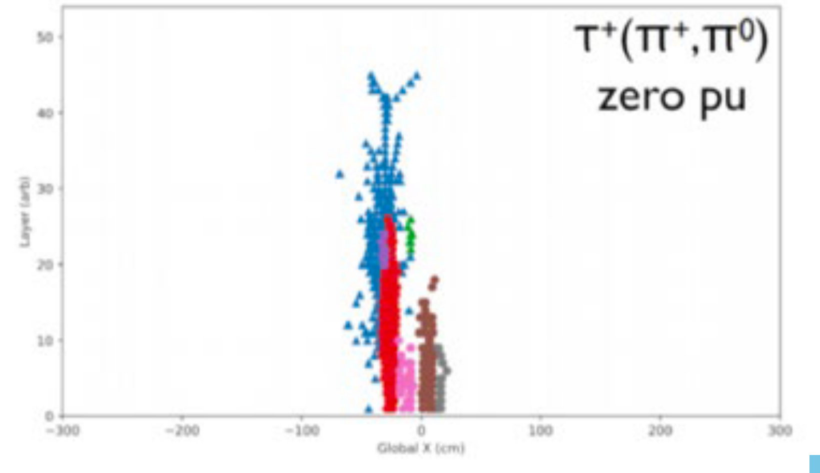
Electromagnetic (CE-E)

- Cu/CuW/Pb absorbers
- Si sensors, hexagonal modules
- 27 layers
- 25.5Xo and 1.7λ

Hadronic (CE-H)

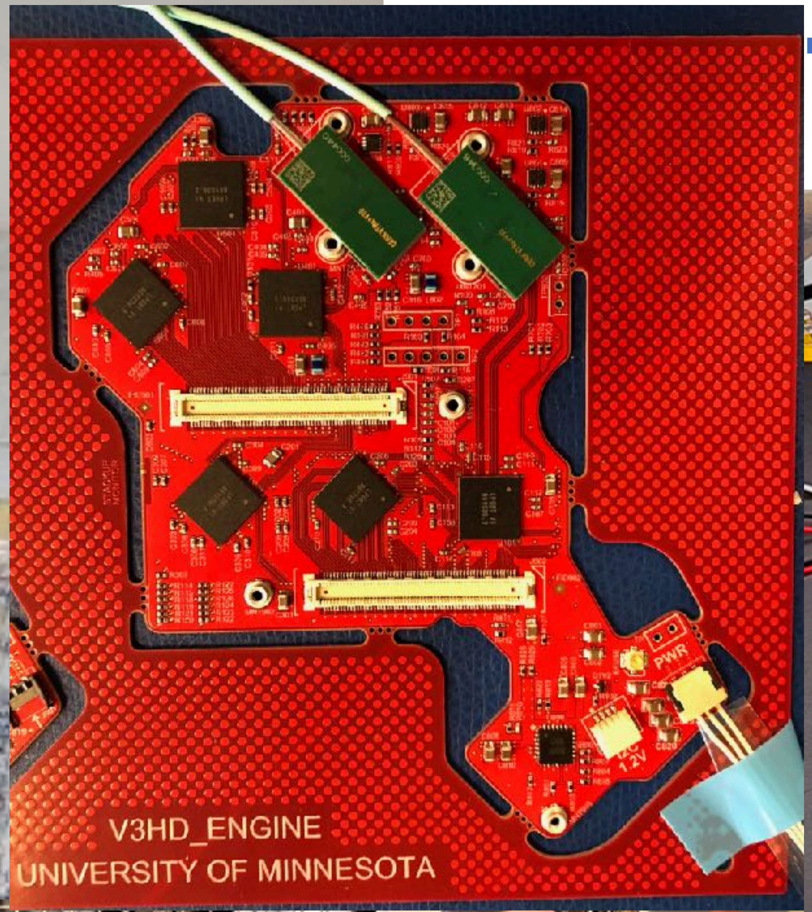
- steel absorbers
- High-radiation regions: Si sensors
- Low-radiation regions: scintillation tiles with SiPM readout
- 20 layers
- 9.5λ (including CE-E)

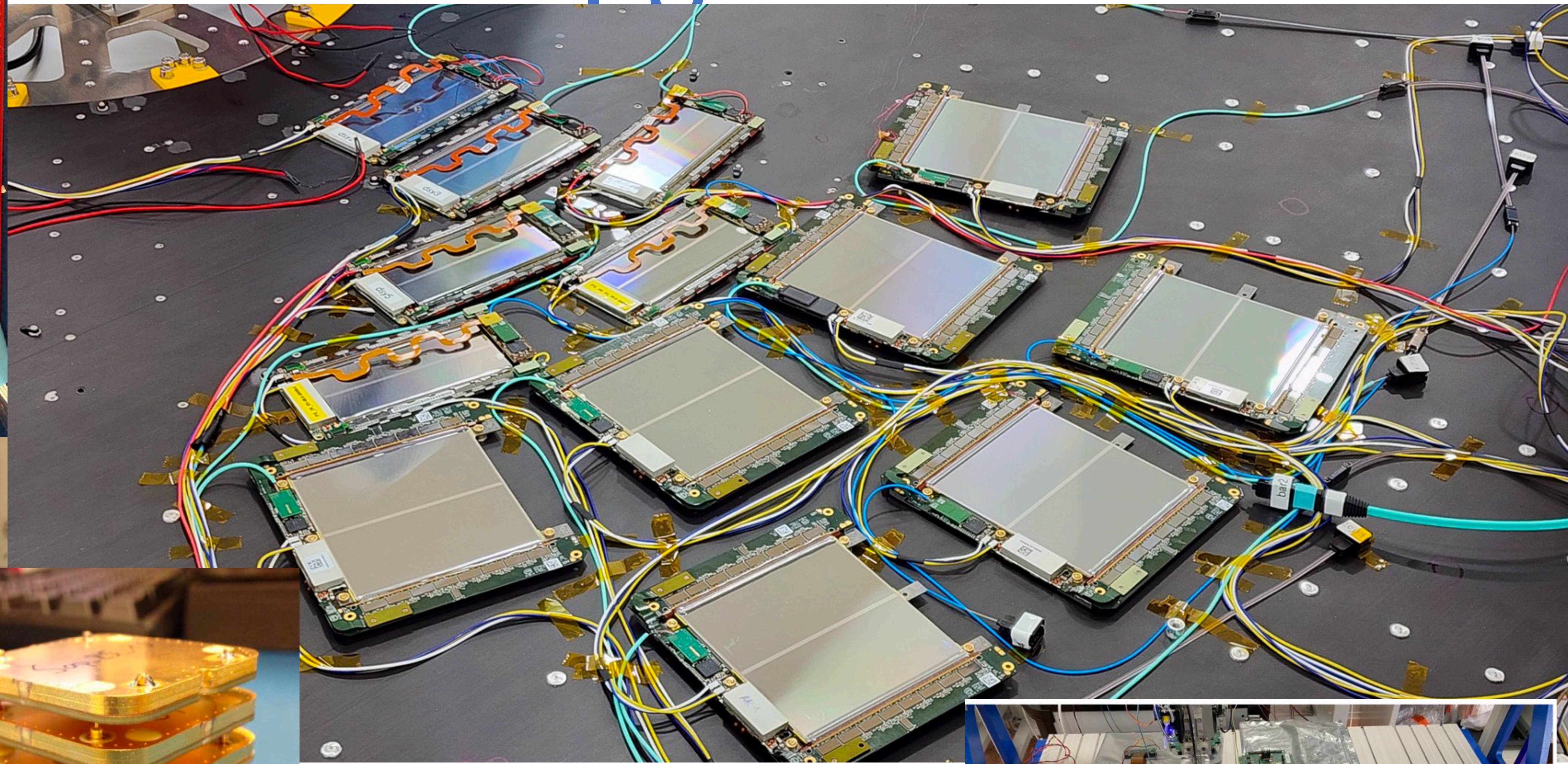
6M Si channels
240k scint. channels

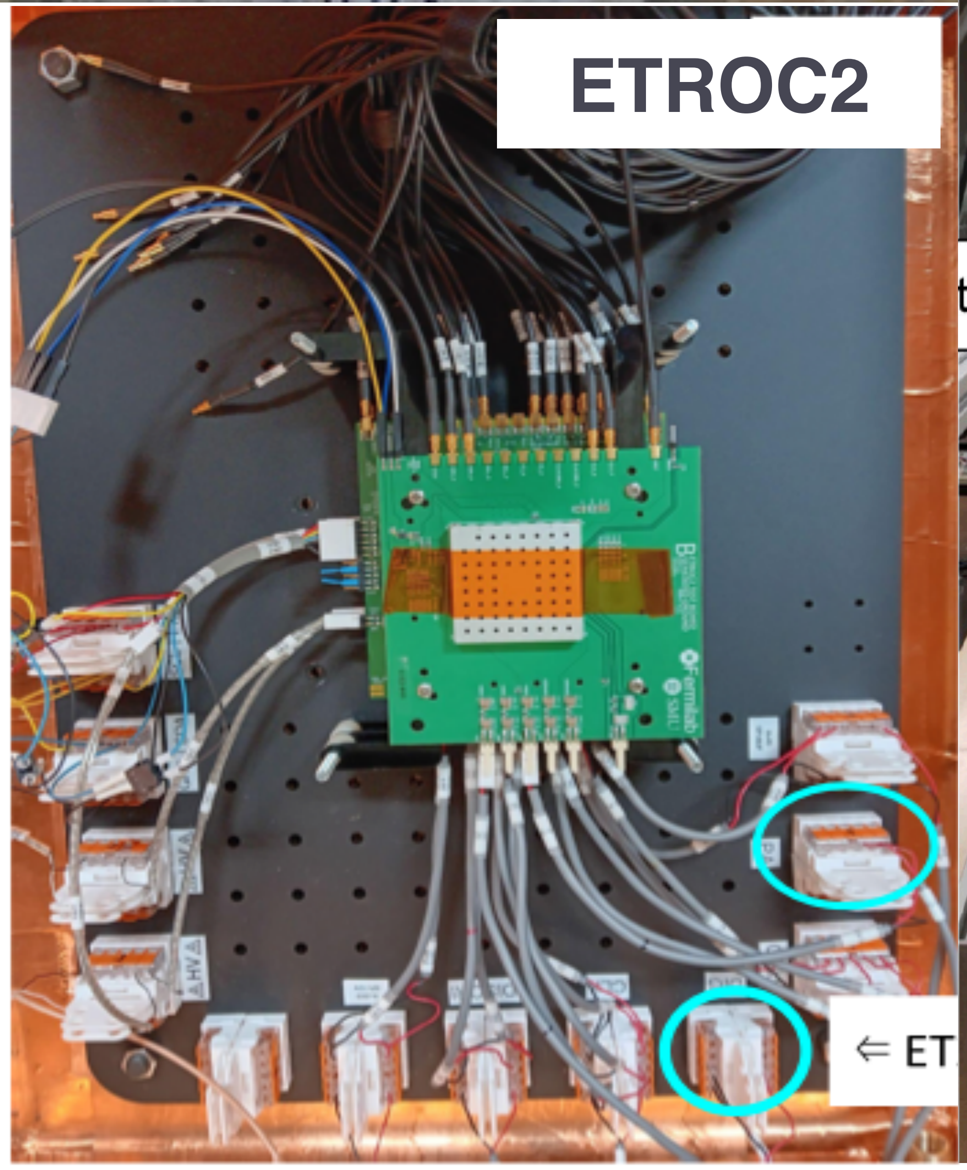


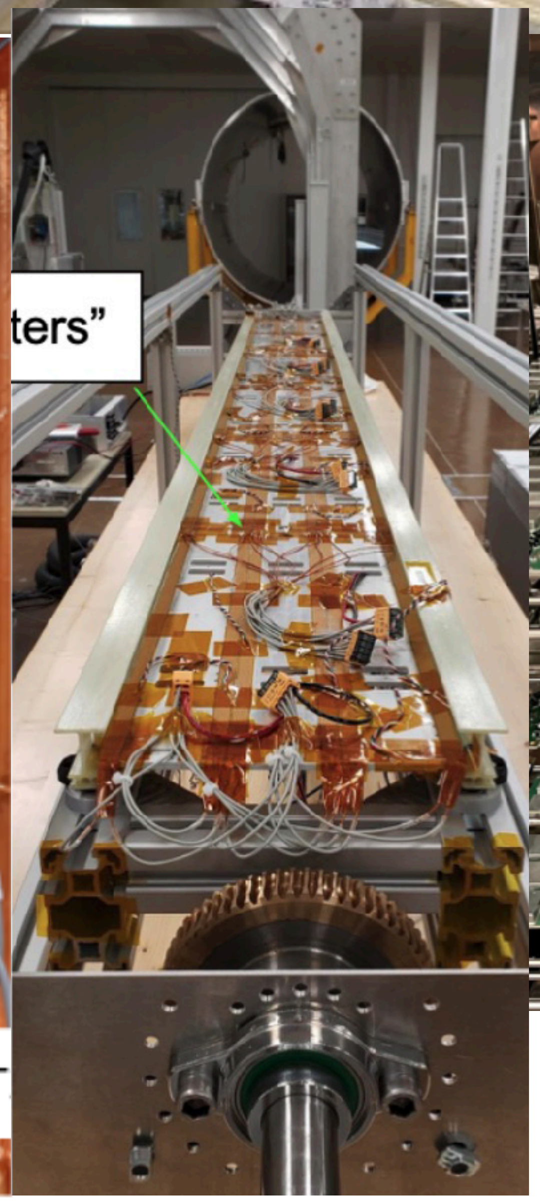
The CMS Upgrade

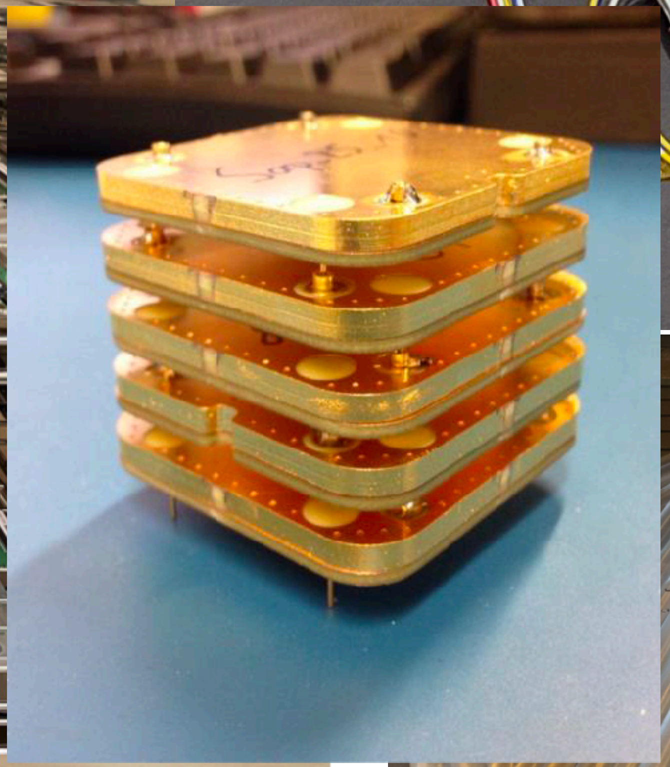
CMS 19.06.2023

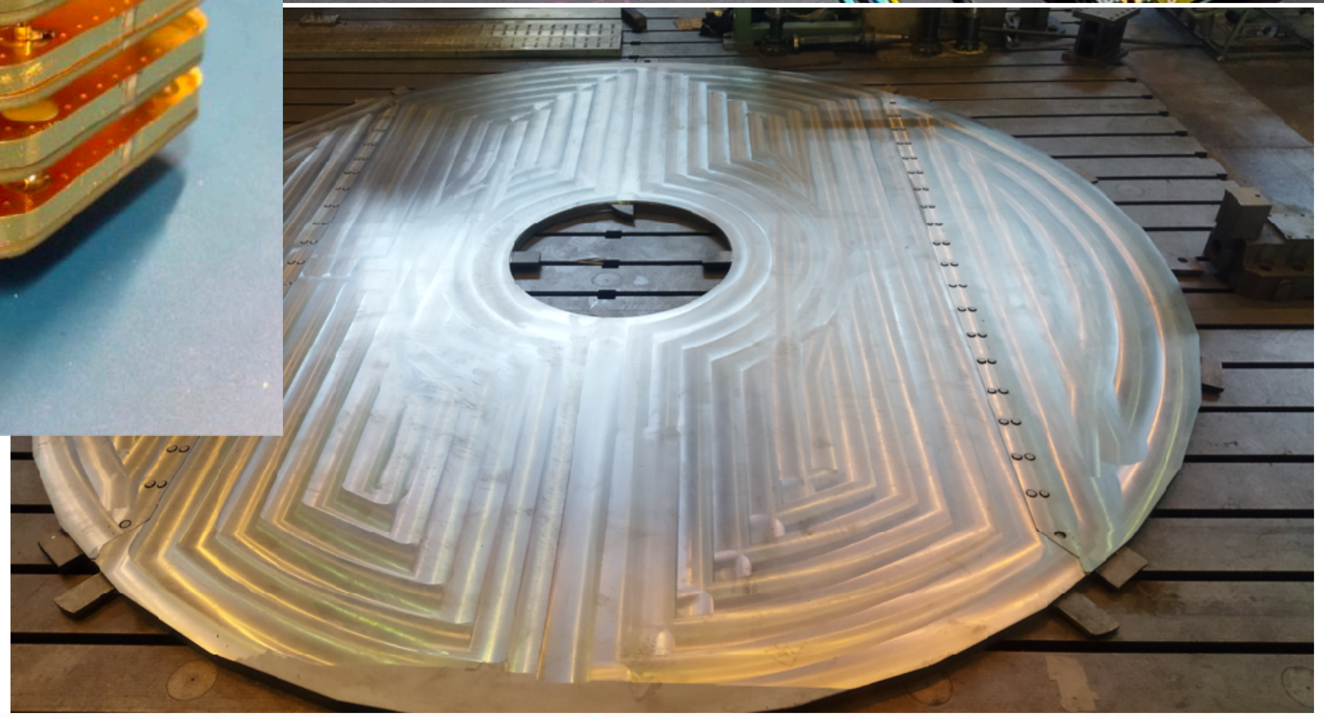


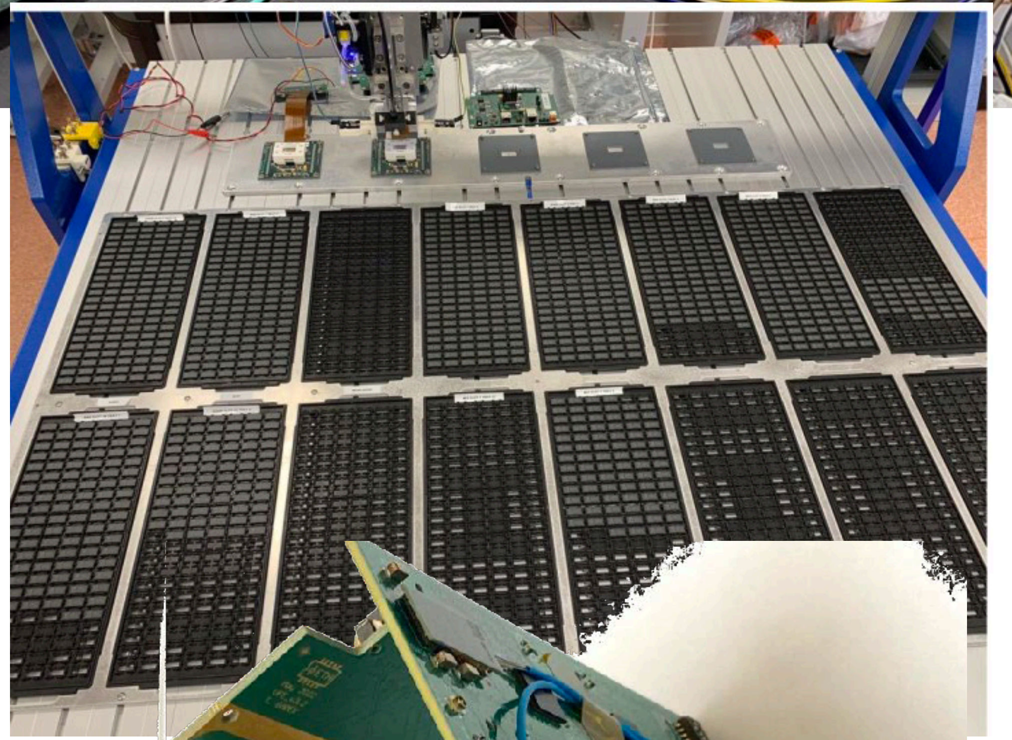


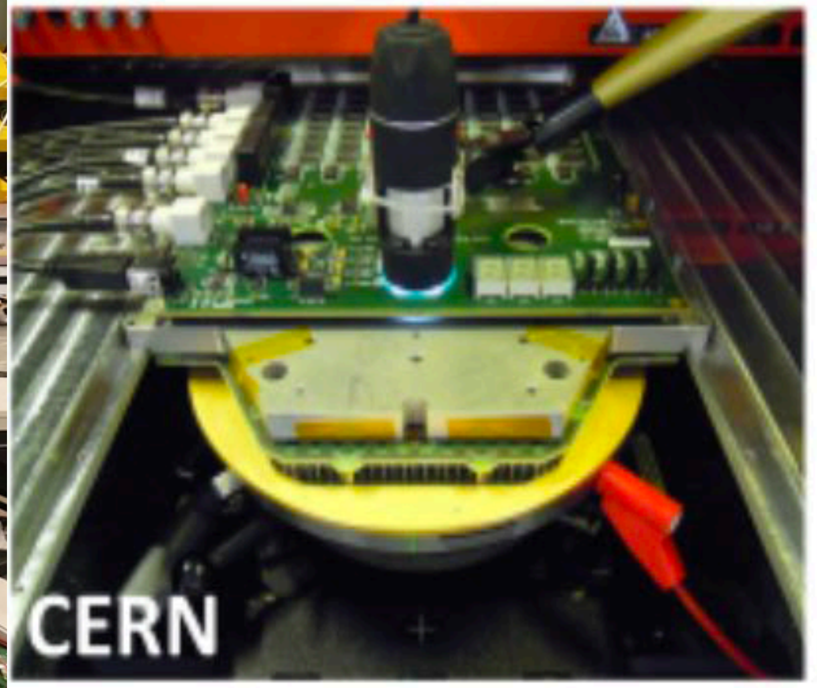


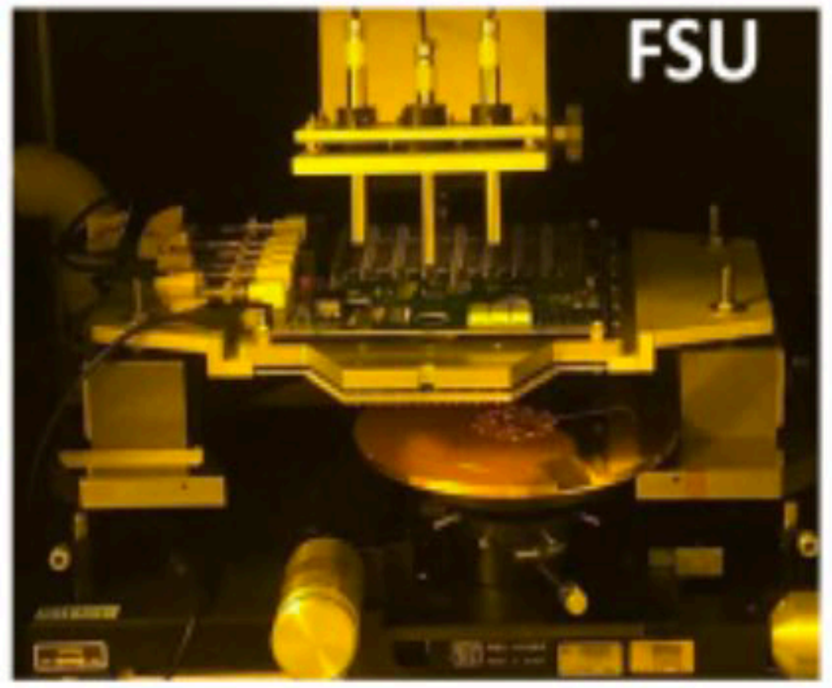


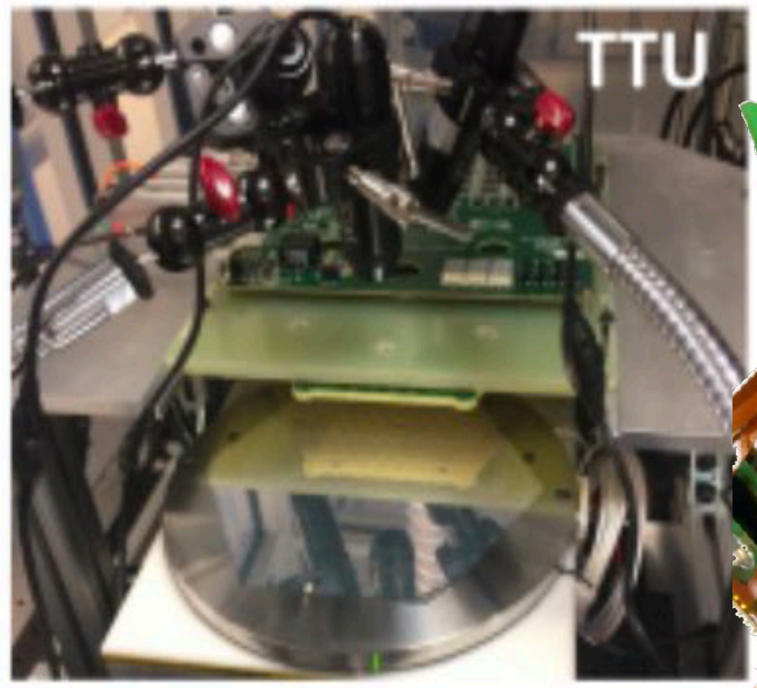


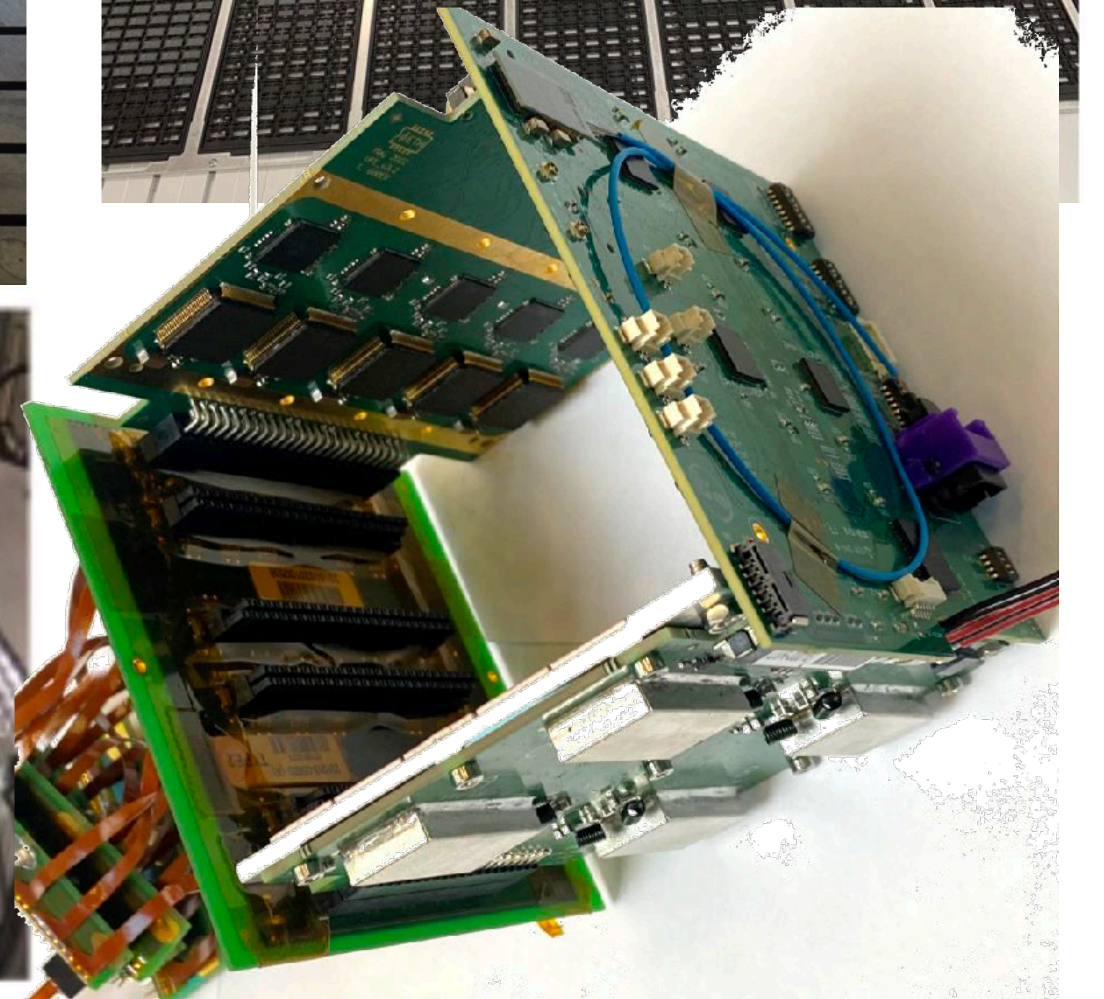










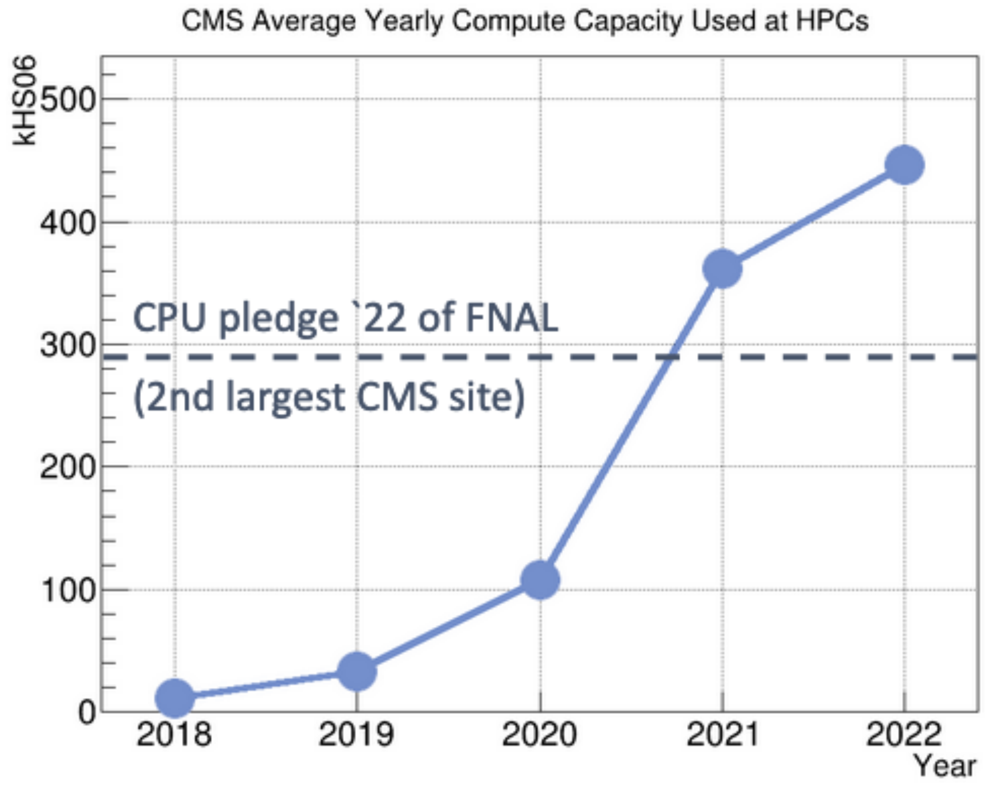


Fermilab

CMS Offline Software and Computing Today: Future Perspectives

- **We are in the middle of a paradigm shift: the utilization of accelerators for HEP data processing**
- Successful deployment at the CMS HLT in Run 3: now we need to expand GPU usage offline
- Problem: implies a re-invention of algorithms and data structures for the "extreme" architectures
  - The solution requires talented physicists-developers (brainpower)
- The computing infrastructure has to accommodate this paradigm shift:
  - Efficient scheduling, hardware discovery, efficient usage of accelerators, High Performance Computers
- Energy consumption is also part of this equation: we need to further develop our computing model to accommodate potential future constraints on energy consumption.
- … and all this in a resource-constrained environment
- No silver bullet to solve *that* problem. **Preserving and expanding the flexibility of the computing model is a key ingredient**, e.g. innovative data taking modes, new software solutions, more agile computing operations

NanoAOD
1 kB/evt



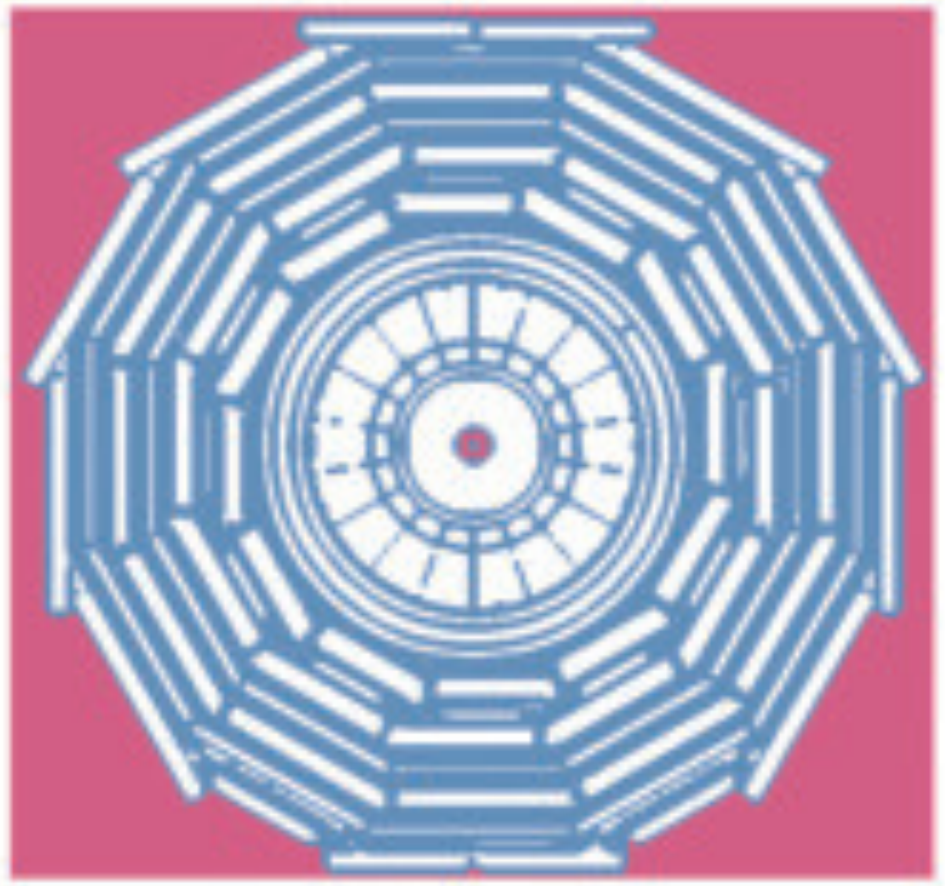
Concluding remarks

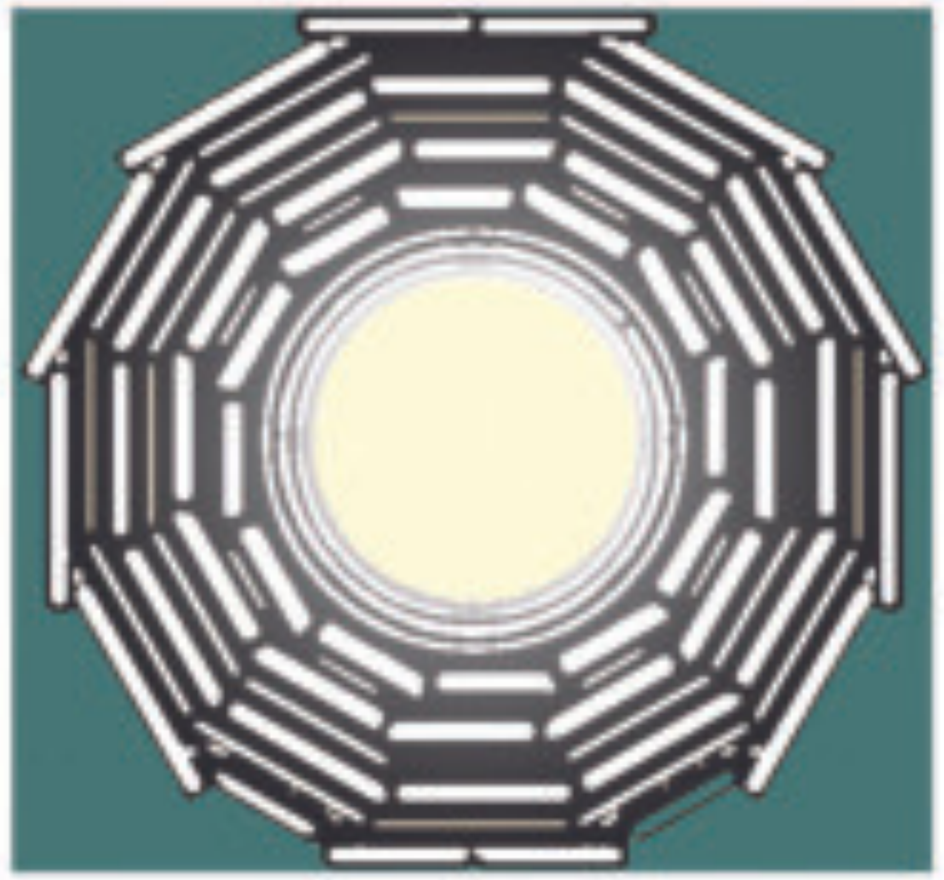
- **The CMS Collaboration is strong and**
- **Run 3 is underway and CMS is performing well.**
- **Many new Run 2 CMS results were released for Winter and Spring Conferences.**
  - More expected this summer.   And Run 3 results will be coming soon
- **The CMS upgrades are making good progress, and we are shifting our focus to pre-production and production.**
  - Resources are tight across the collaboration, so there is for the continued success of CMS.
- **HL-LHC Computing will be challenging** - we need to continue with a spirit of innovation to effectively develop and utilize the computing systems of the future.

We thank Matthias for his many contributions to CMS

Thank you!

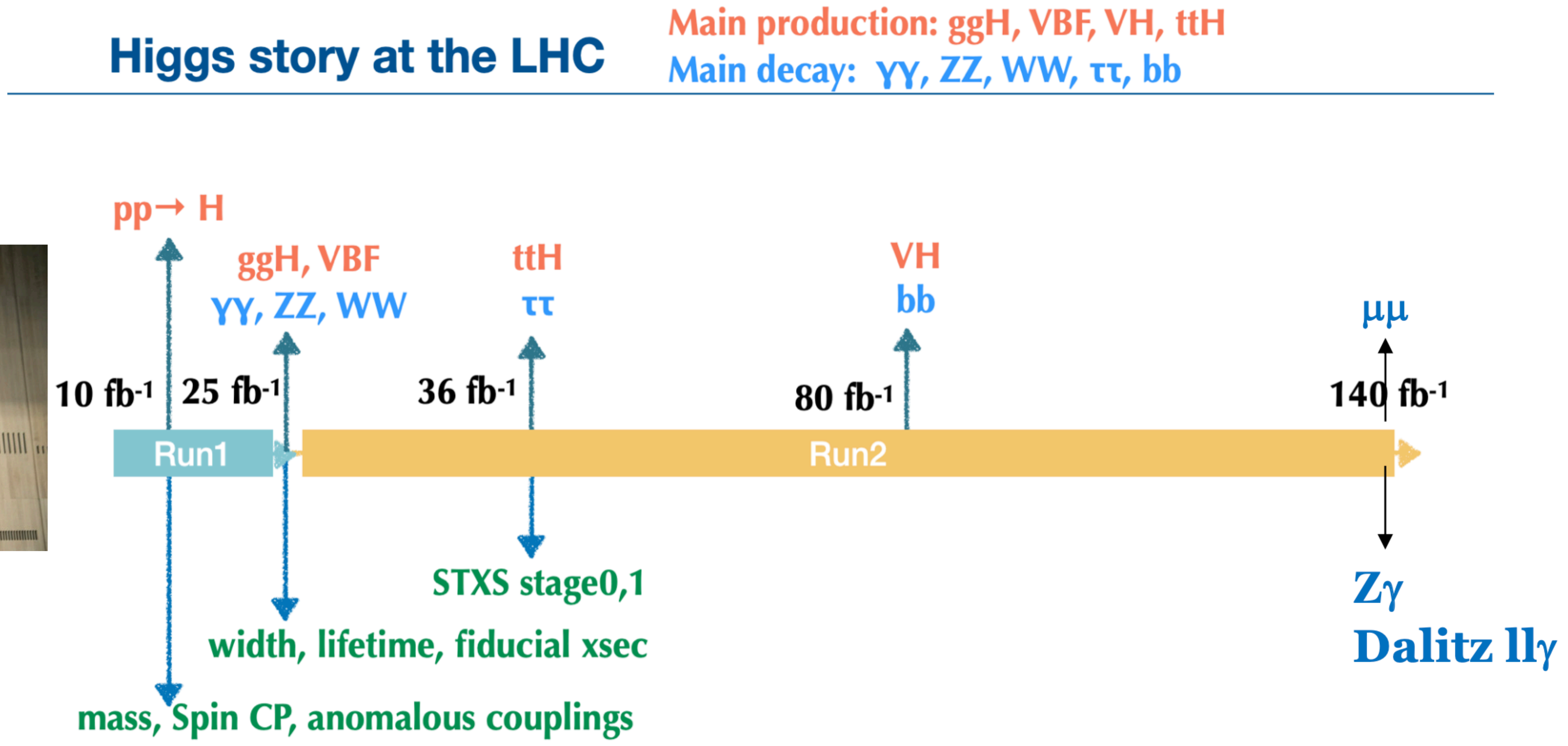
All our best wishes for your retirement, Matthias!





Extra slides

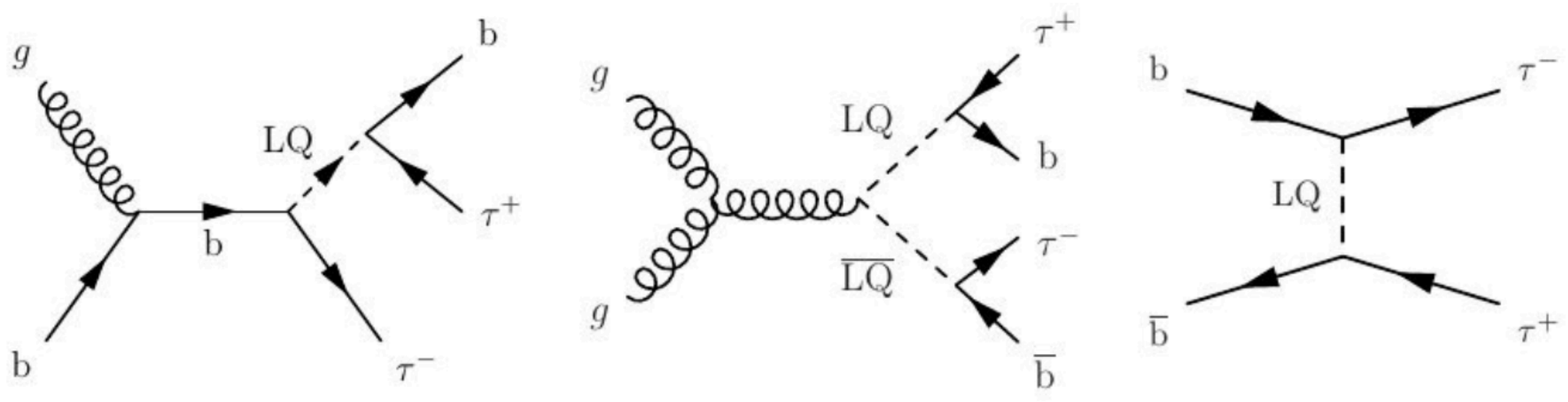
10+1 years of Higgs

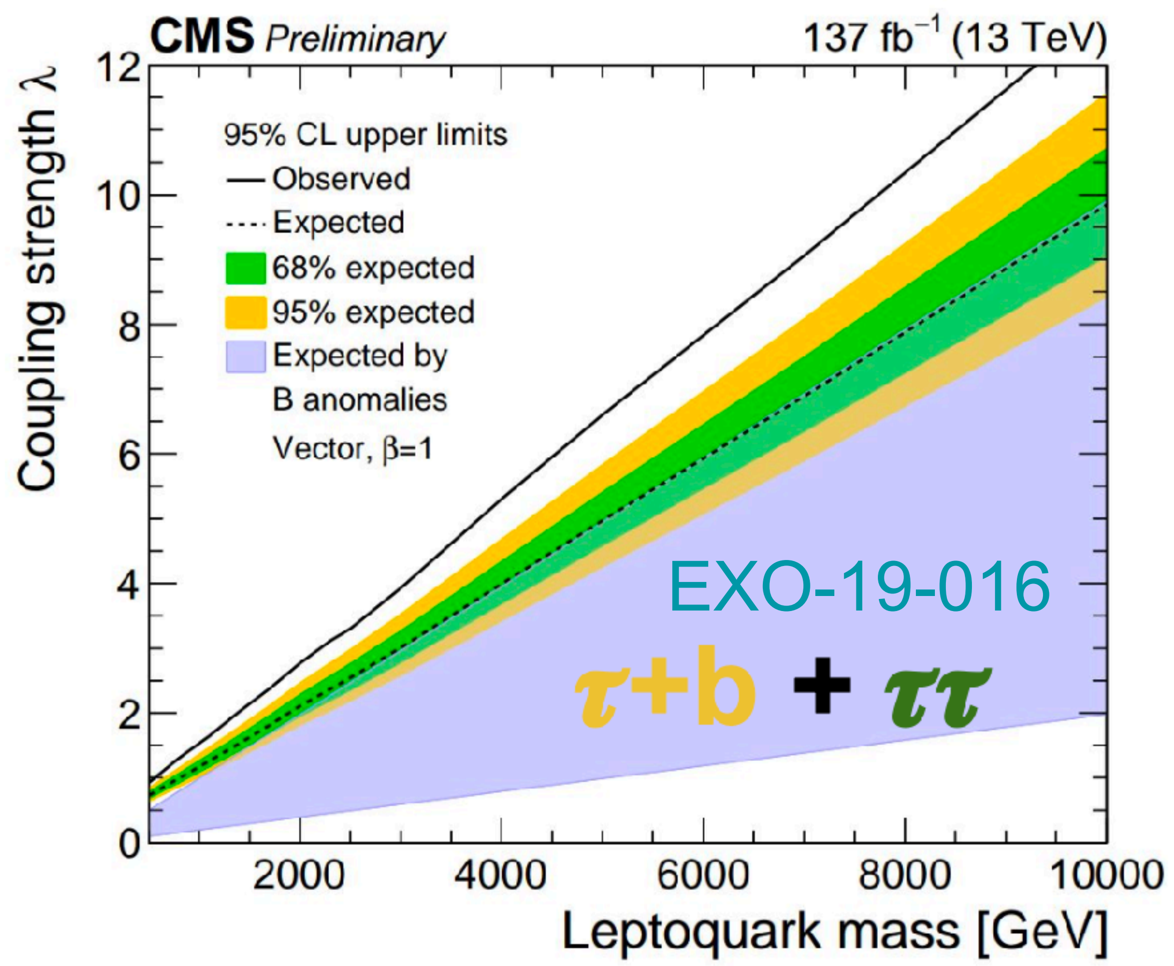


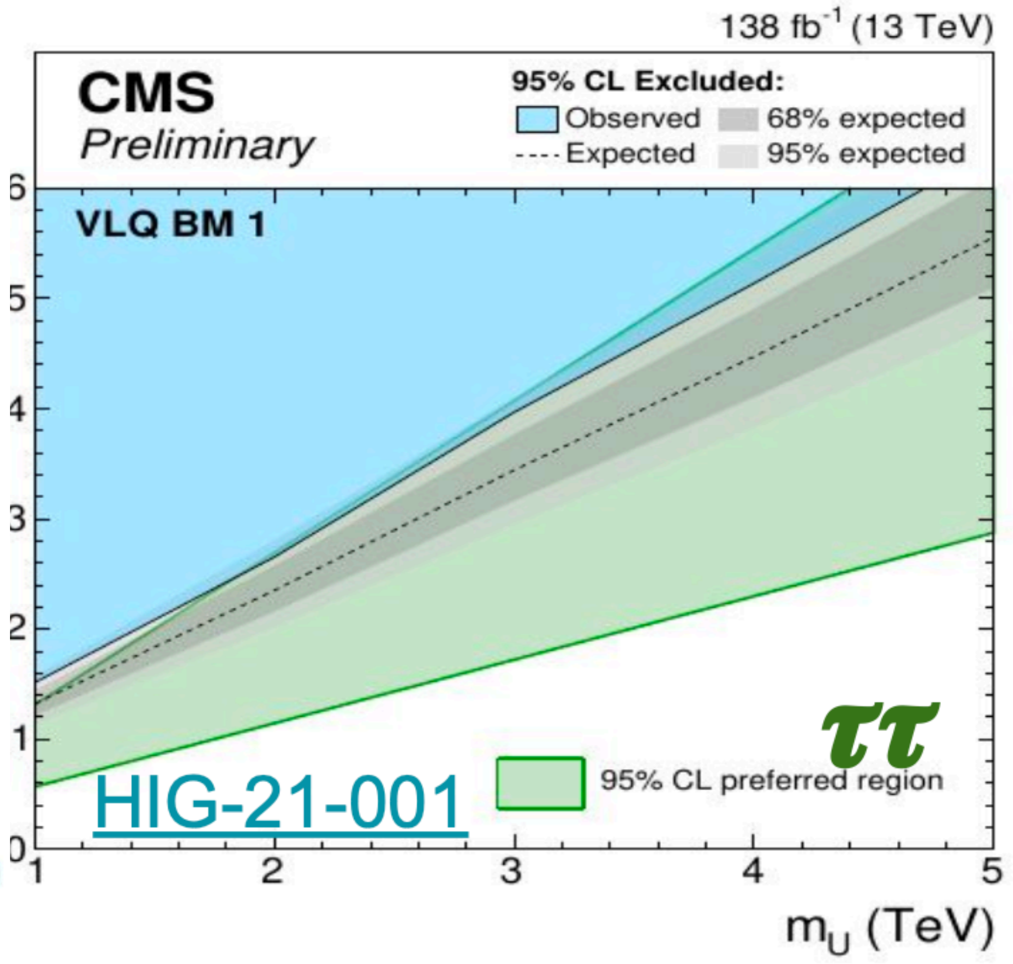
©Meng Xiao

Legacy of Run2: some excesses to be watched during Run3!

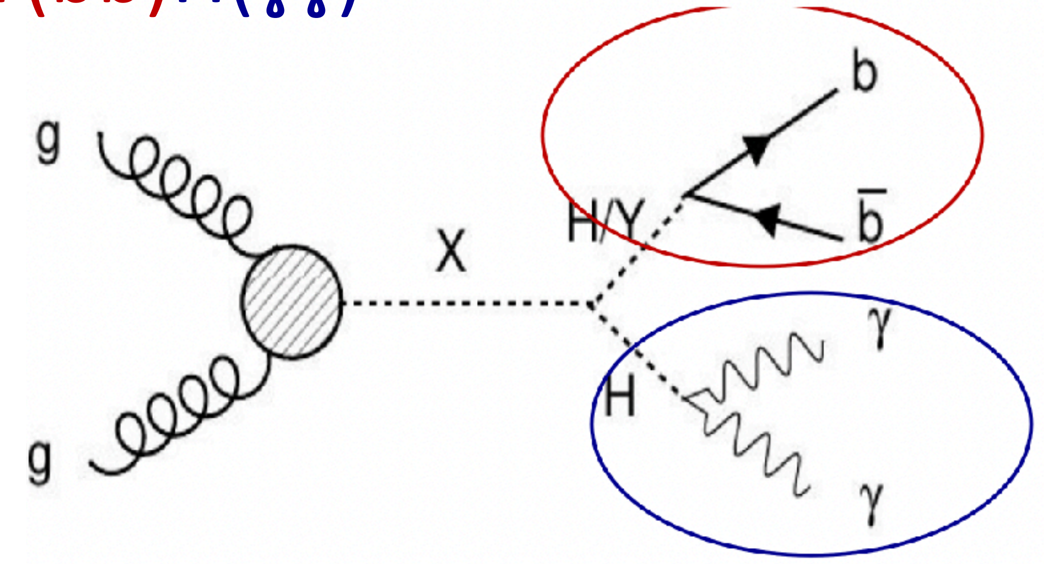
Analysis inspired by the b-anomalies (via leptoquarks production).
Intriguing excess in tau-tau final states.





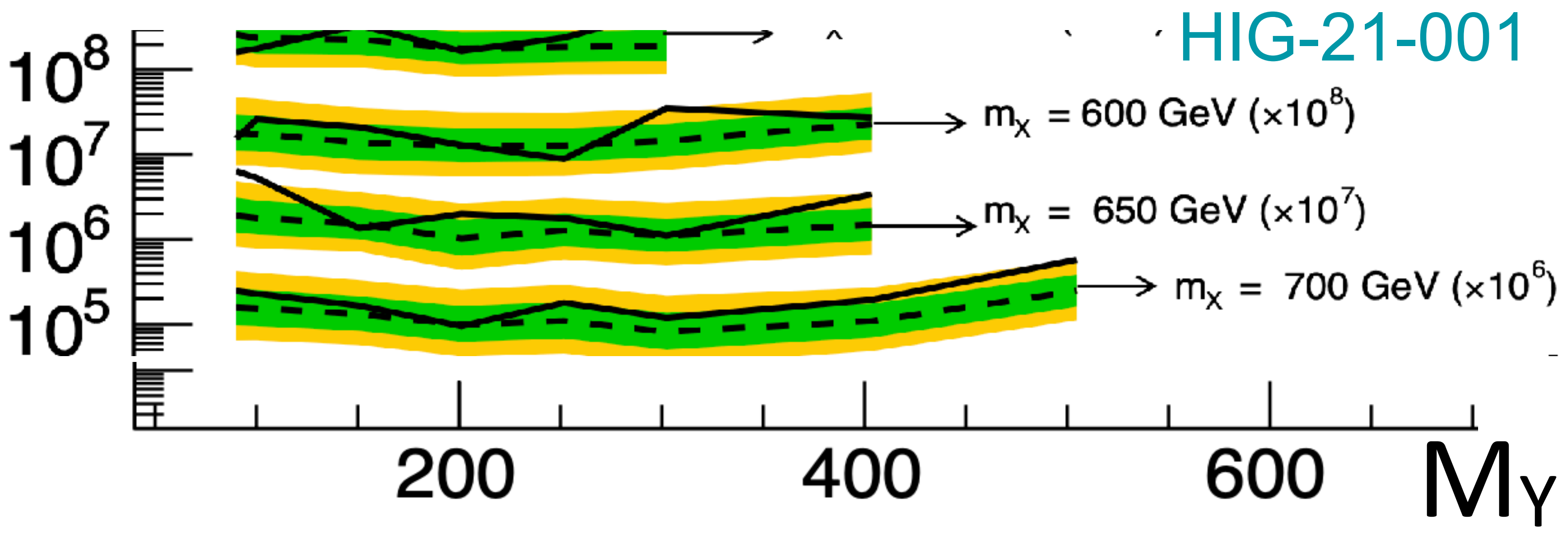


Search for resonances (X) decaying to H/Y(bb)H(γγ)



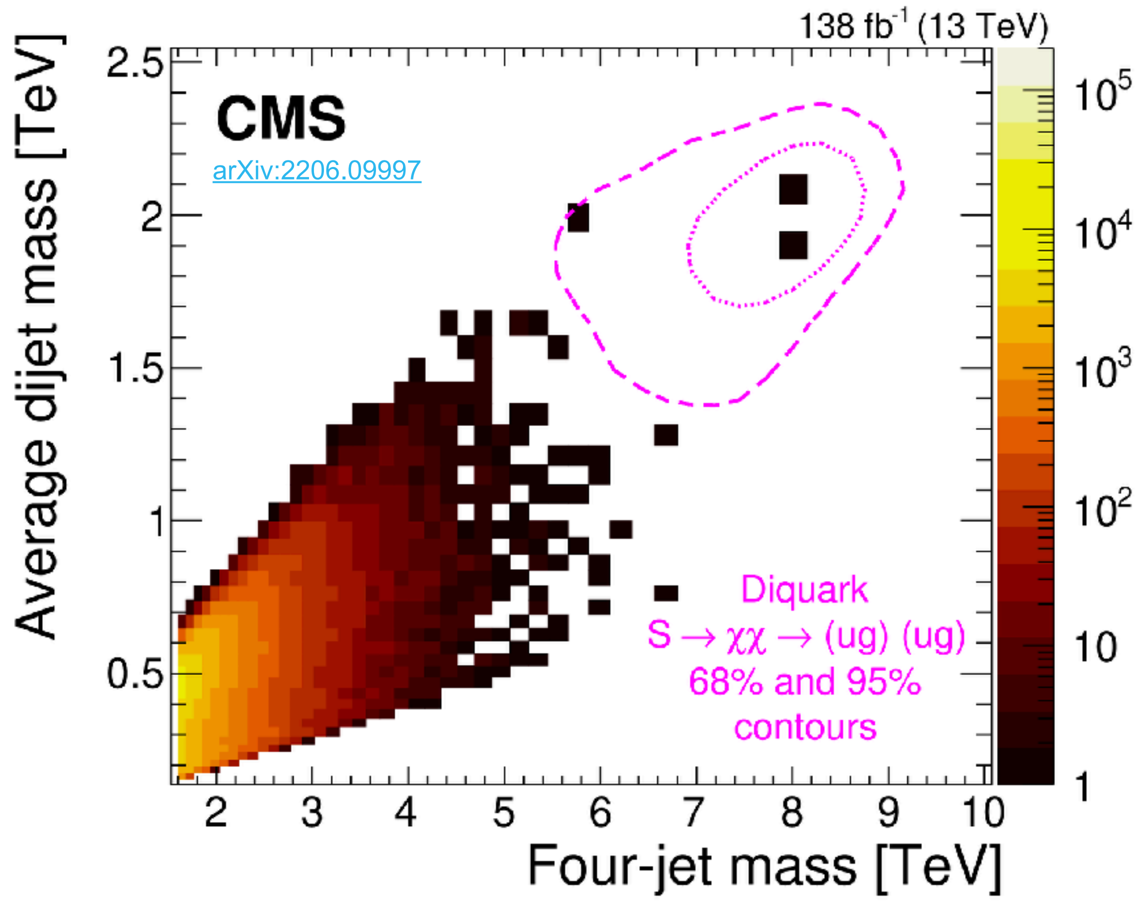
Excess at (90,100) with a 650 GeV heavy resonance mass

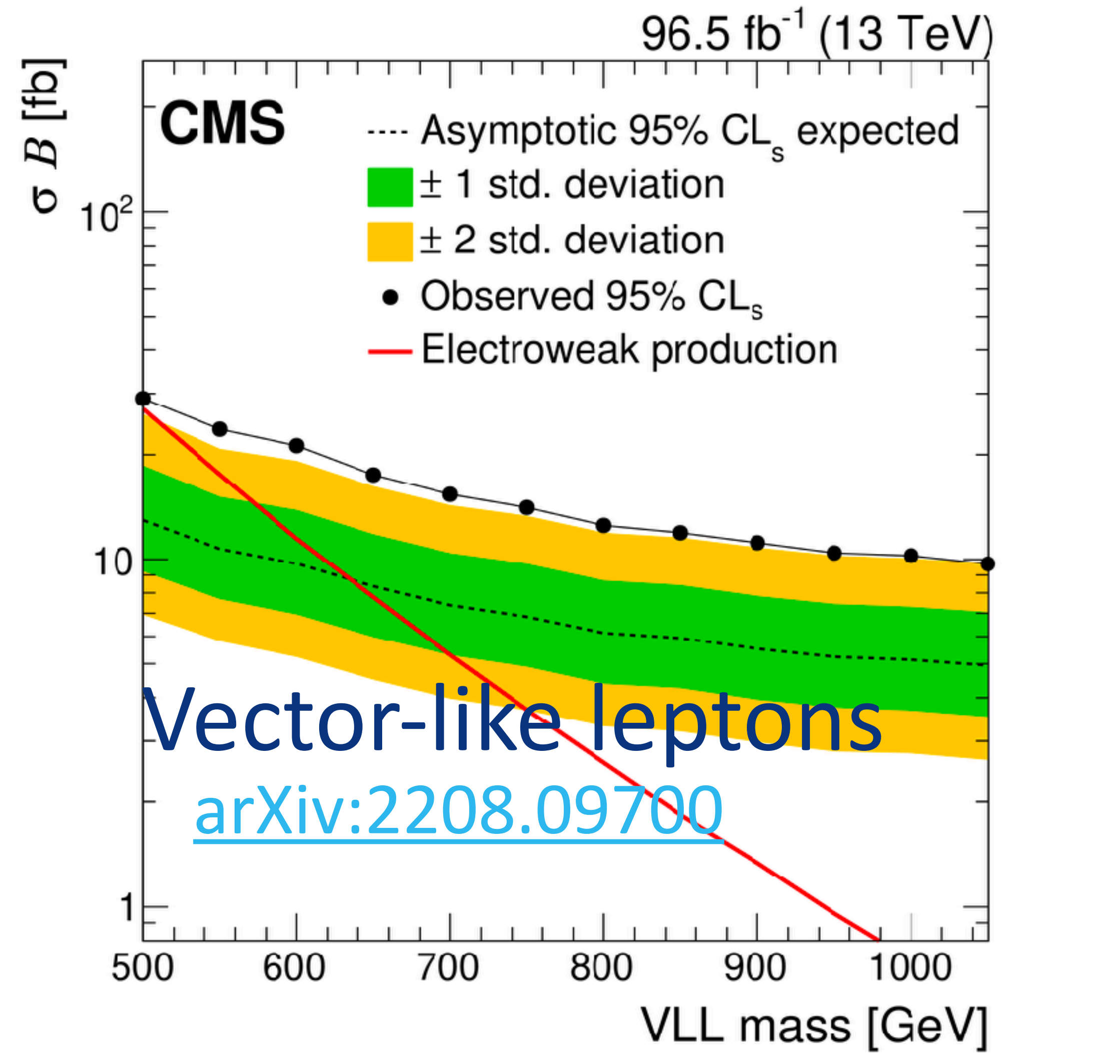
(~3.8 σ local and 2.8 σ global)



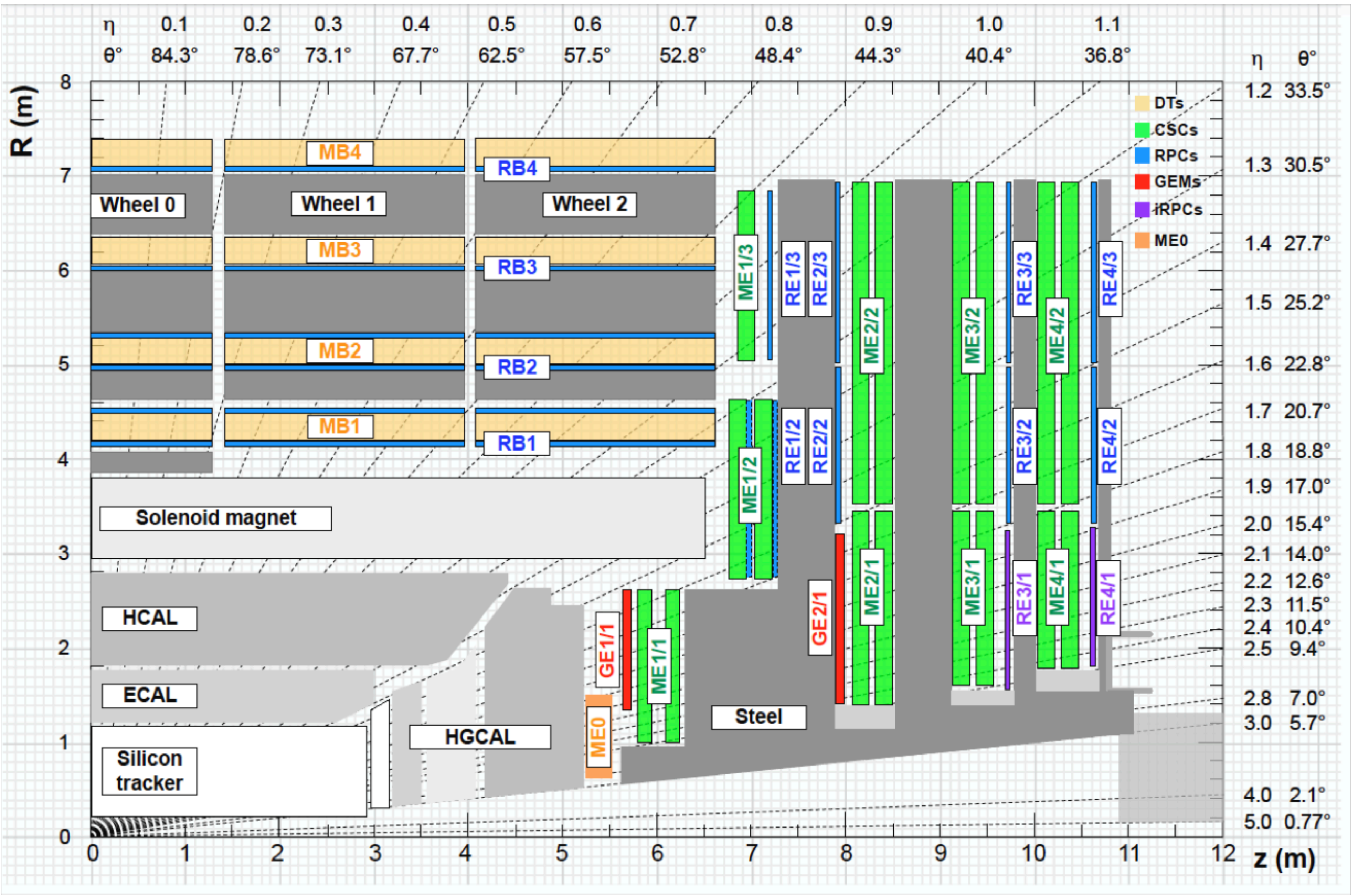
Tantalising excesses common to γγ and ττ final states!

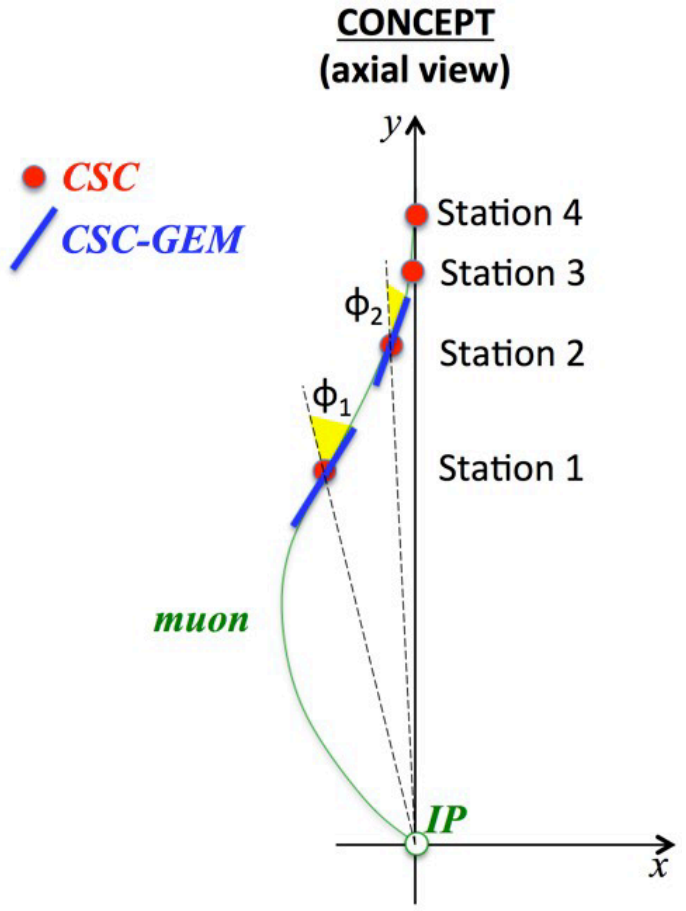
Di-jet pairs

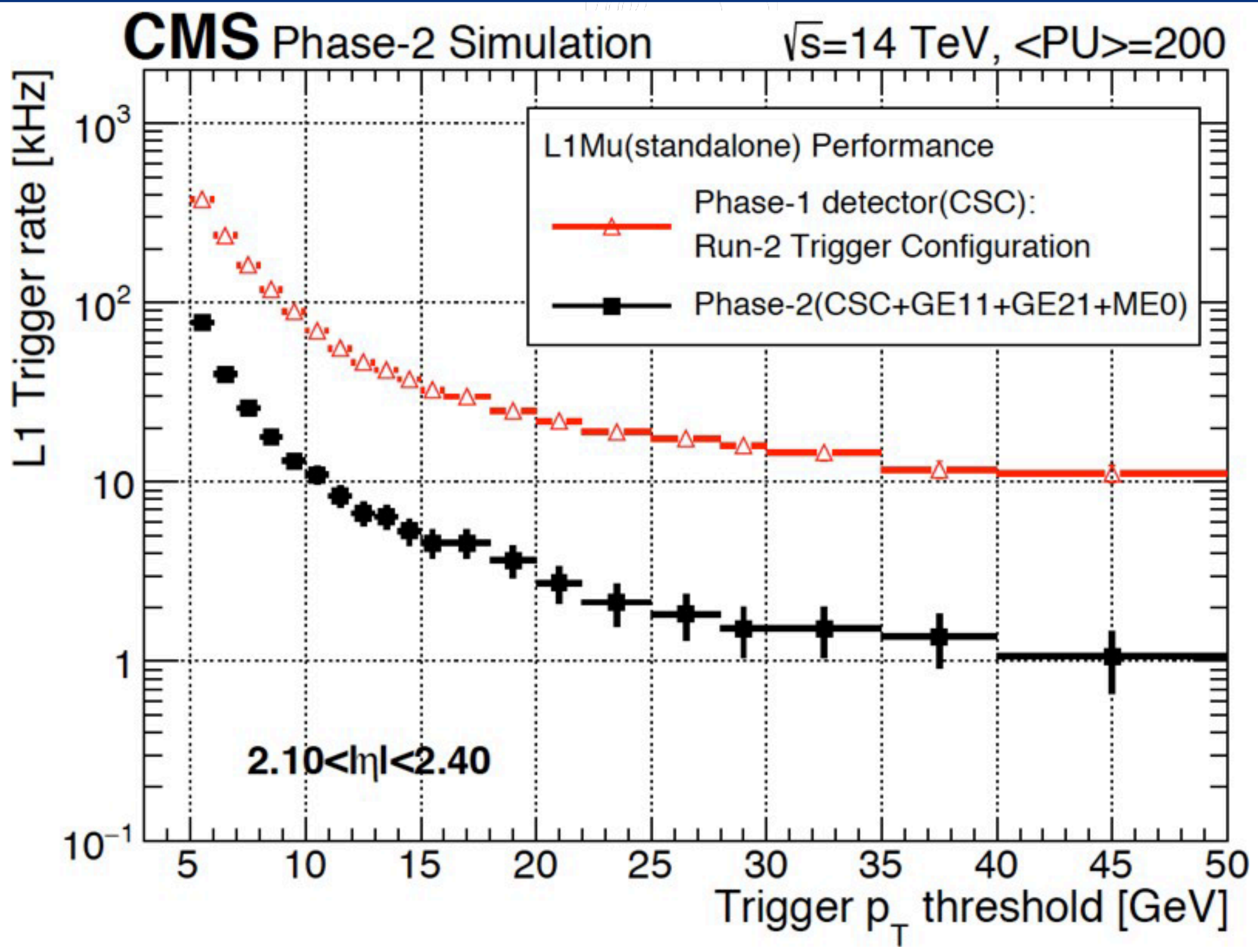




CMS Phase2 Muon System







Barrel and Endcaps

- Replacement of readout electronics for the new L1 trigger conditions

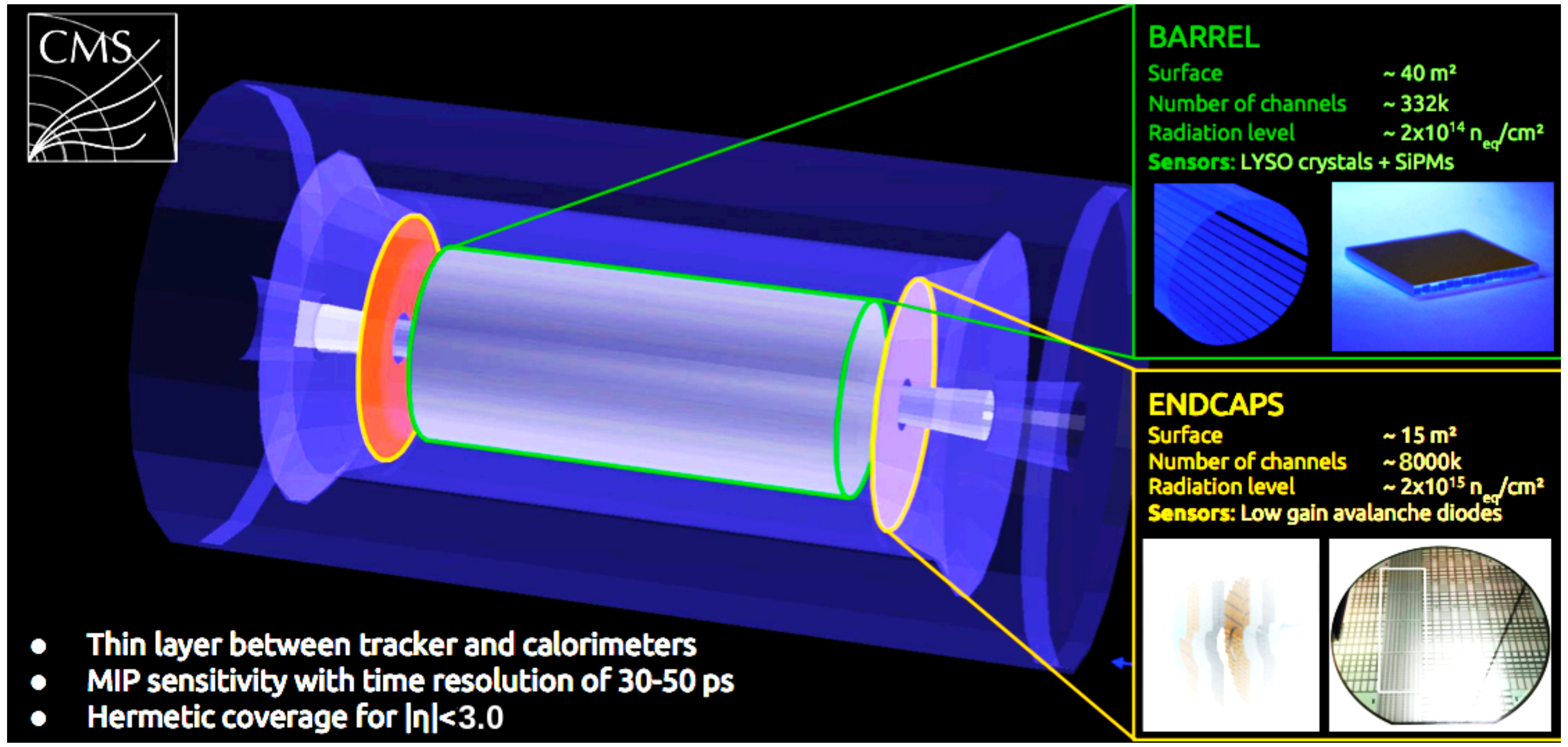
Endcaps

- Robust trigger up to |η| = 2.4 thanks to **RPC stations** RE3/1 and RE4/1 and 2-layer **GEM stations** GE1/1 and GE2/1
- Trigger extension up to |η| = 2.8 6-layer **GEM station** ME0

2 GEM/CSC "tandems"

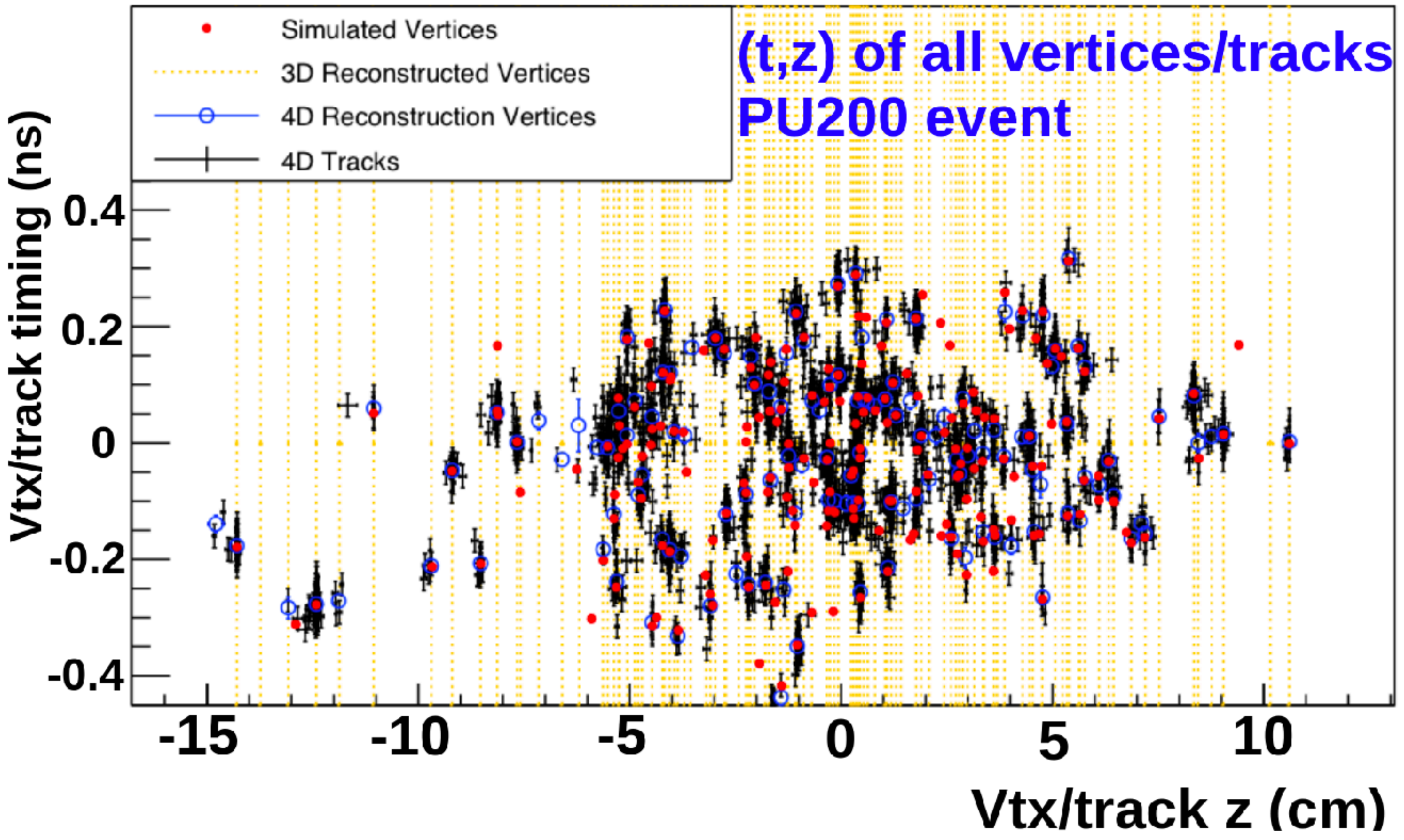
- measurement of "local" μ direction (sensitive to p_T)
- standalone L1-trigger rate drops by factor up to 10
- important for off-pointing muon triggers (search for LLPs)

CMS Phase2 Timing Detector



The MTD features

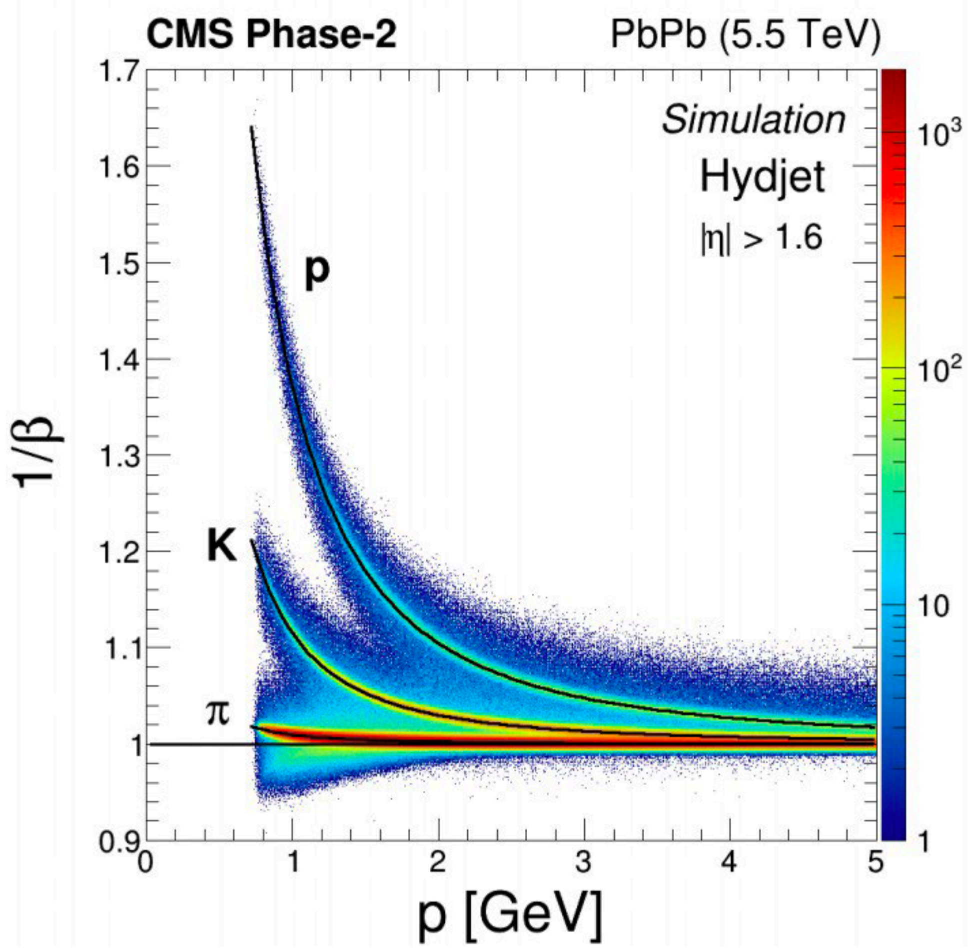
- a time resolution of 30-50 ps for MIPs
- a 4th dimension for PU rejection



Precise timing allows for the removal of spurious tracks from PU, this improving on

- lepton isolation and identification
- jet reconstruction and flavour tagging
- missing p_T reconstruction

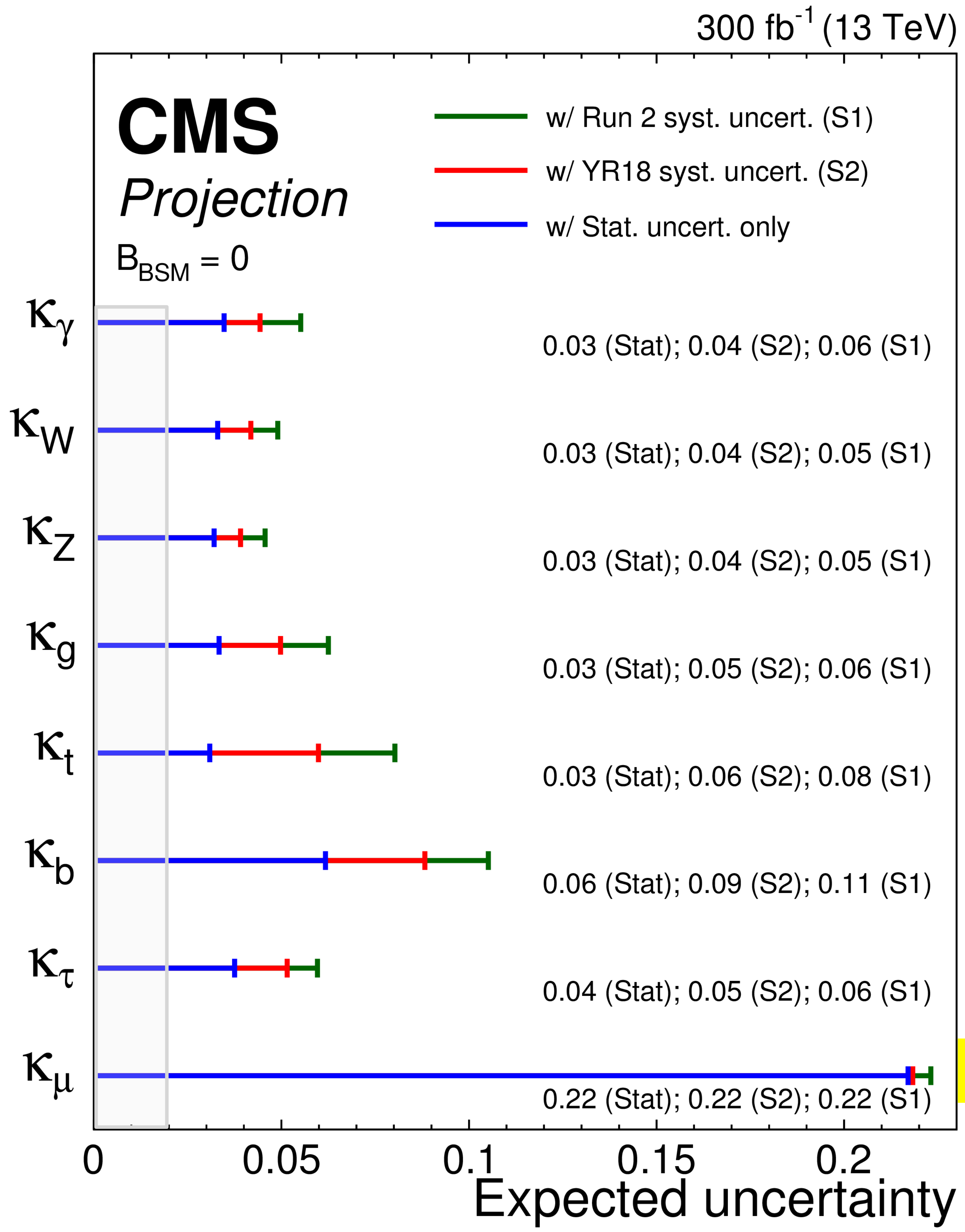
Precise timing also offers time-of-flight identification at low momenta (relevant in HI)



The MTD uses well-established technologies

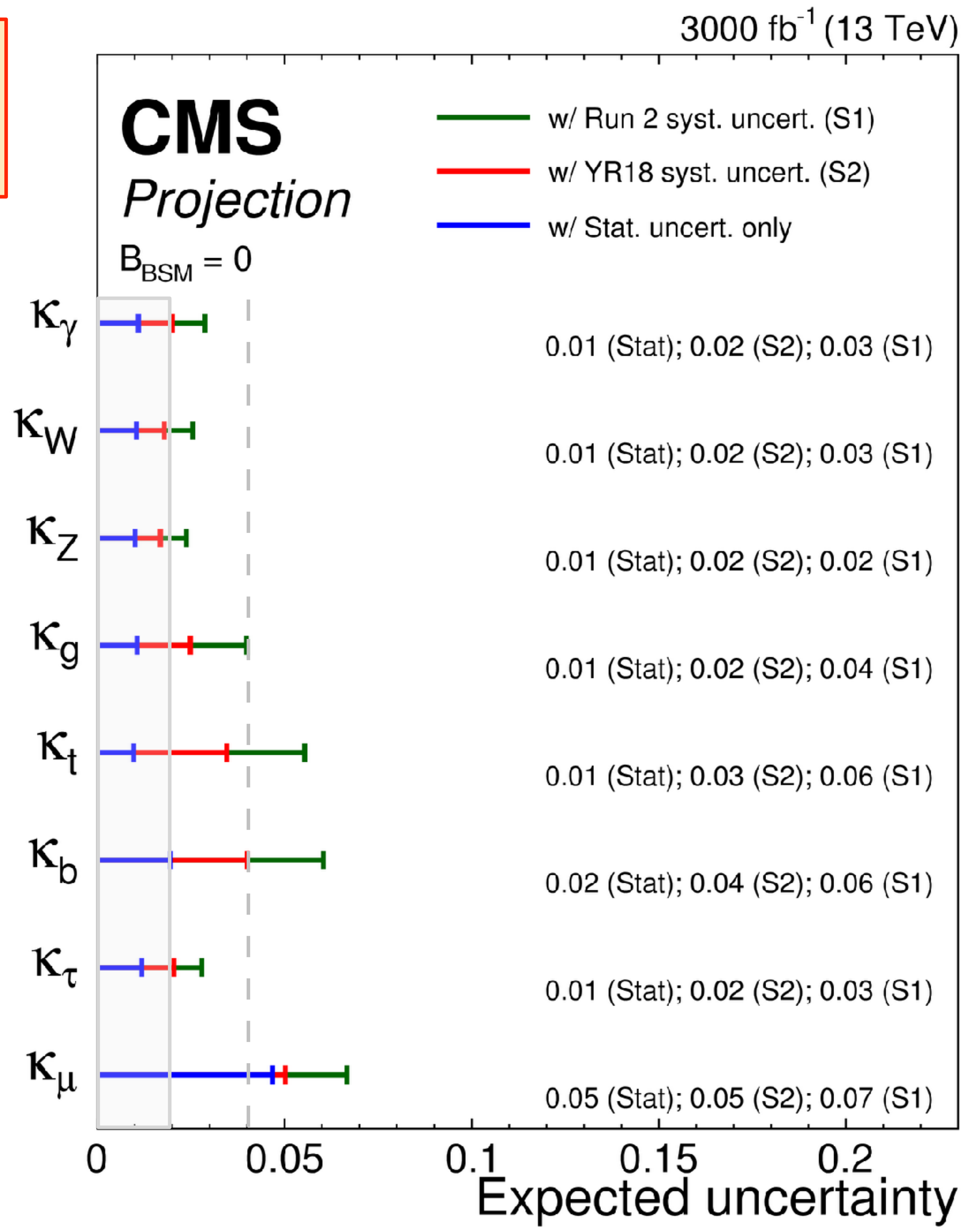
- Barrel:
  LYSO crystals with dual end SiPM readout
- Endcaps:
  Low Gain Avalanche Detectors (LGAD)

CMS Phase2: expectations on Higgs



CMS End of Run-3
13 TeV
300 fb^{-1}

4%
4%
4%
5%
6%
9%
5%
22%



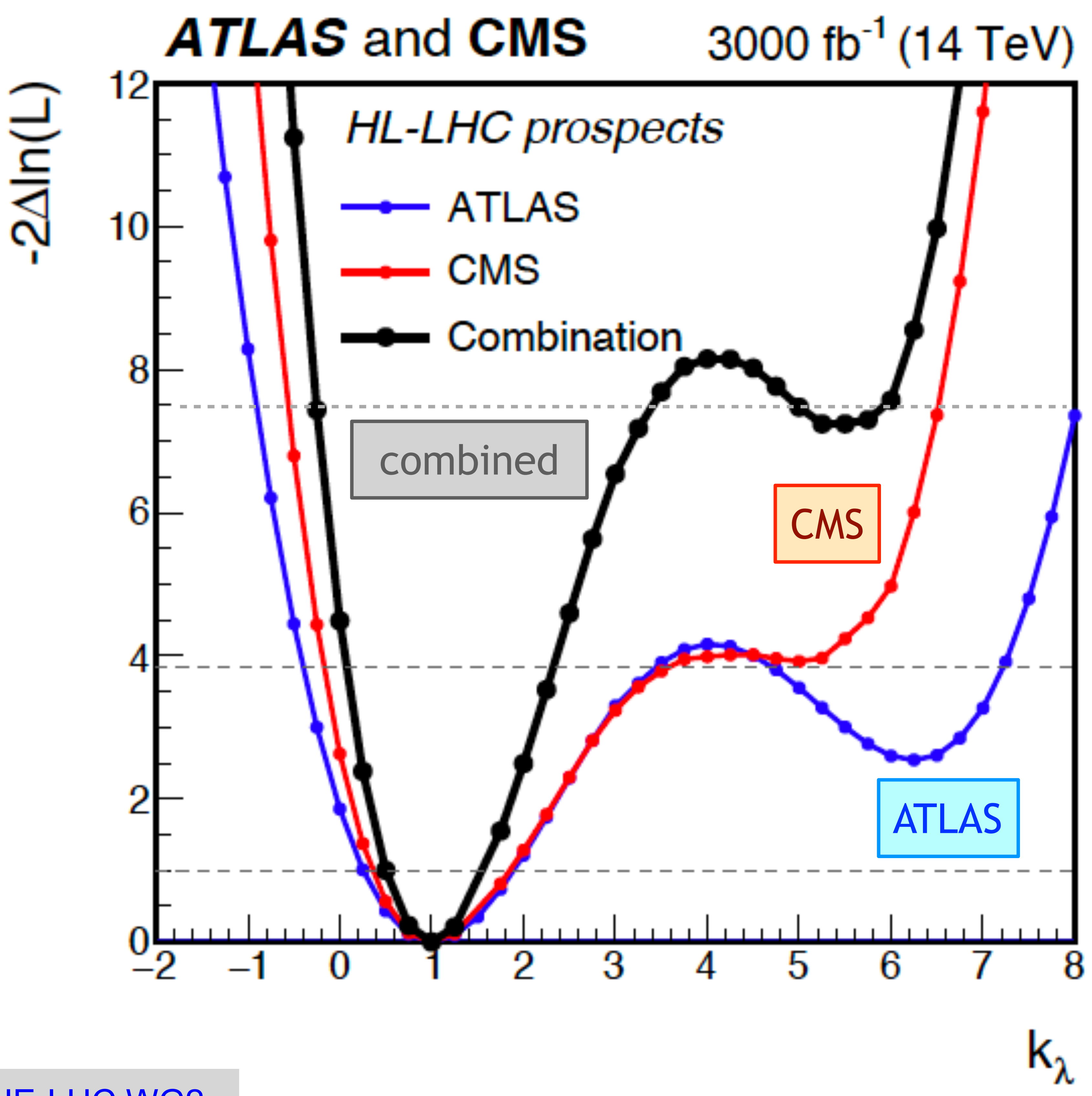
CMS HL-LHC
13 TeV
3 ab^{-1}

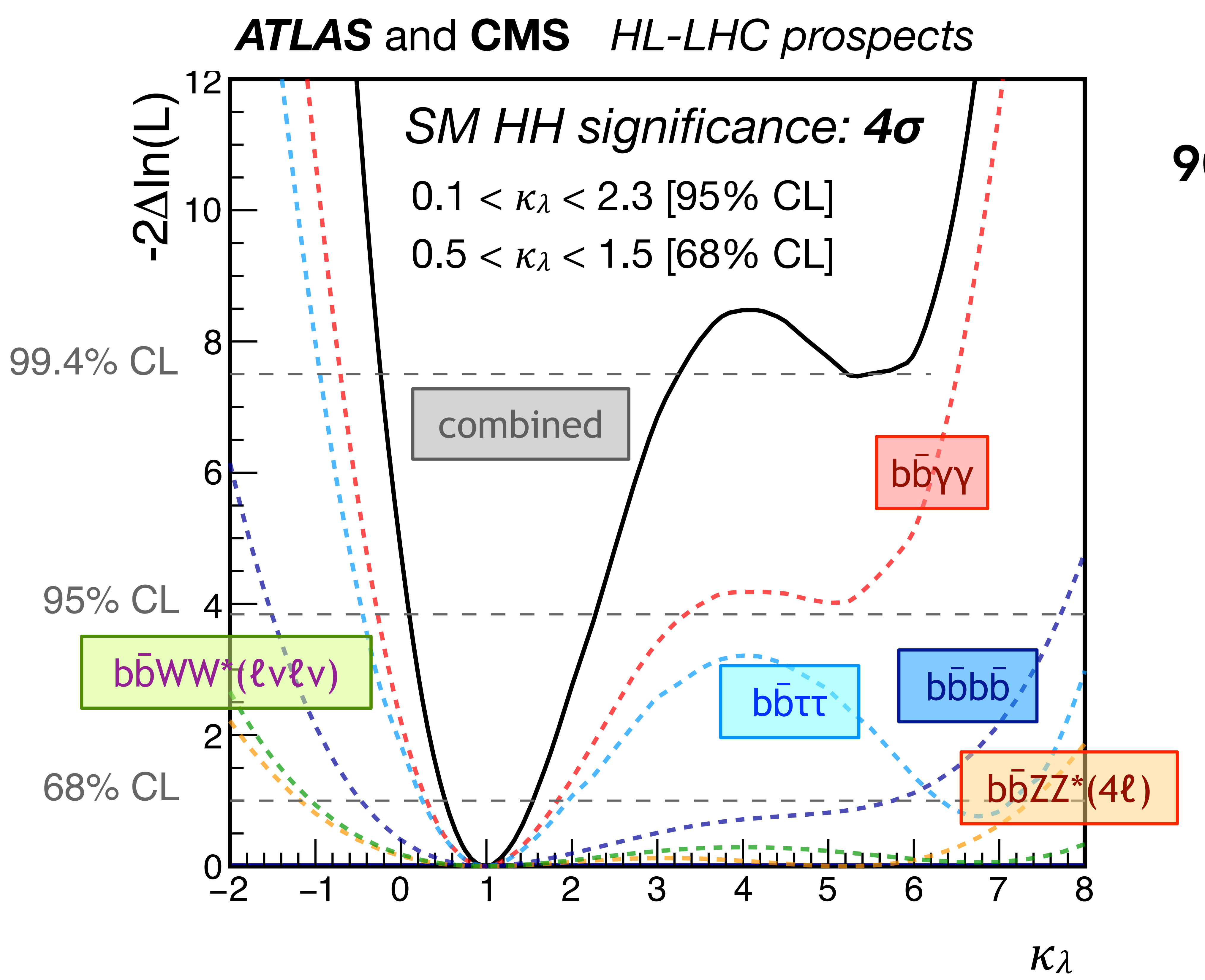
2%
2%
2%
2%
3%
4%
2%
5%

Most Higgs couplings known to better than 4%, dominated by systematic uncertainties

[CMS-PAS-FTR-18-011]

CMS Phase2: expectations on di-Higgs





HL/HE-LHC WG2

90k HH pairs produced

combined significance: 4σ

κ_λ "measured" with a precision of ±50%