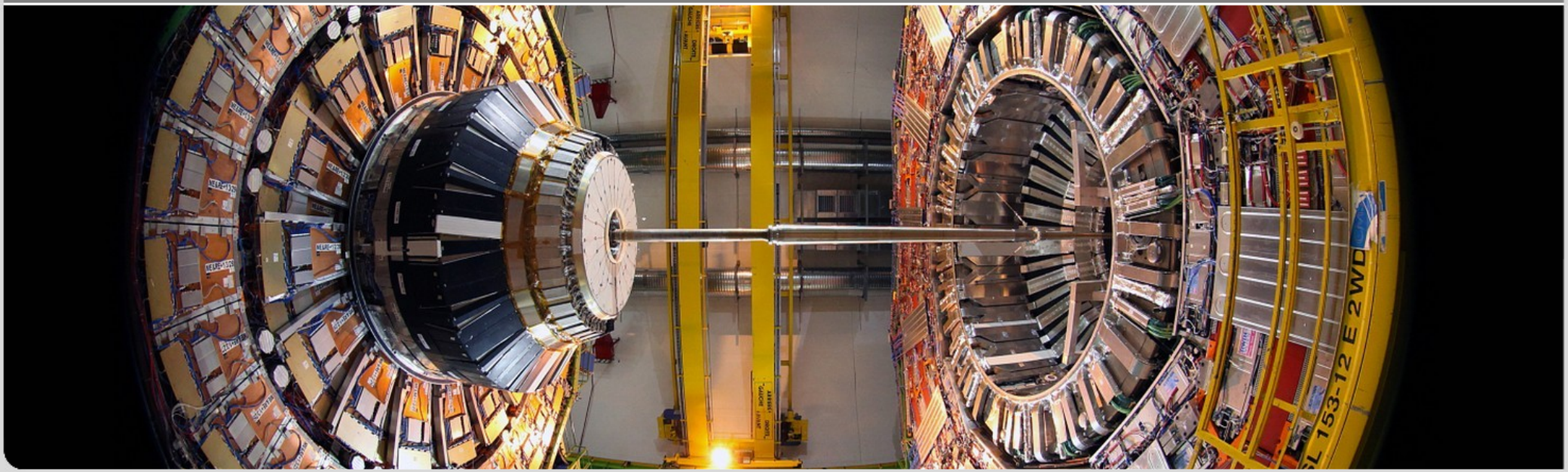
Karlsruhe Institute of Technology

CMS Status Report

142nd LHCC Open Session

Erik Butz, Karlsruhe Institute of Technology
On behalf of the CMS Collaboration

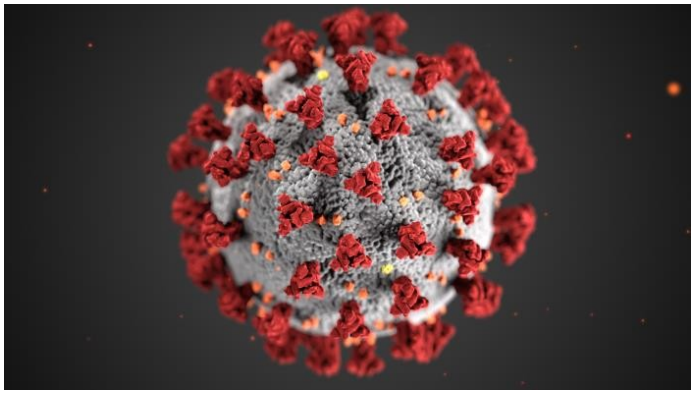
Institute of Experimental Particle Physics (ETP)



Overview

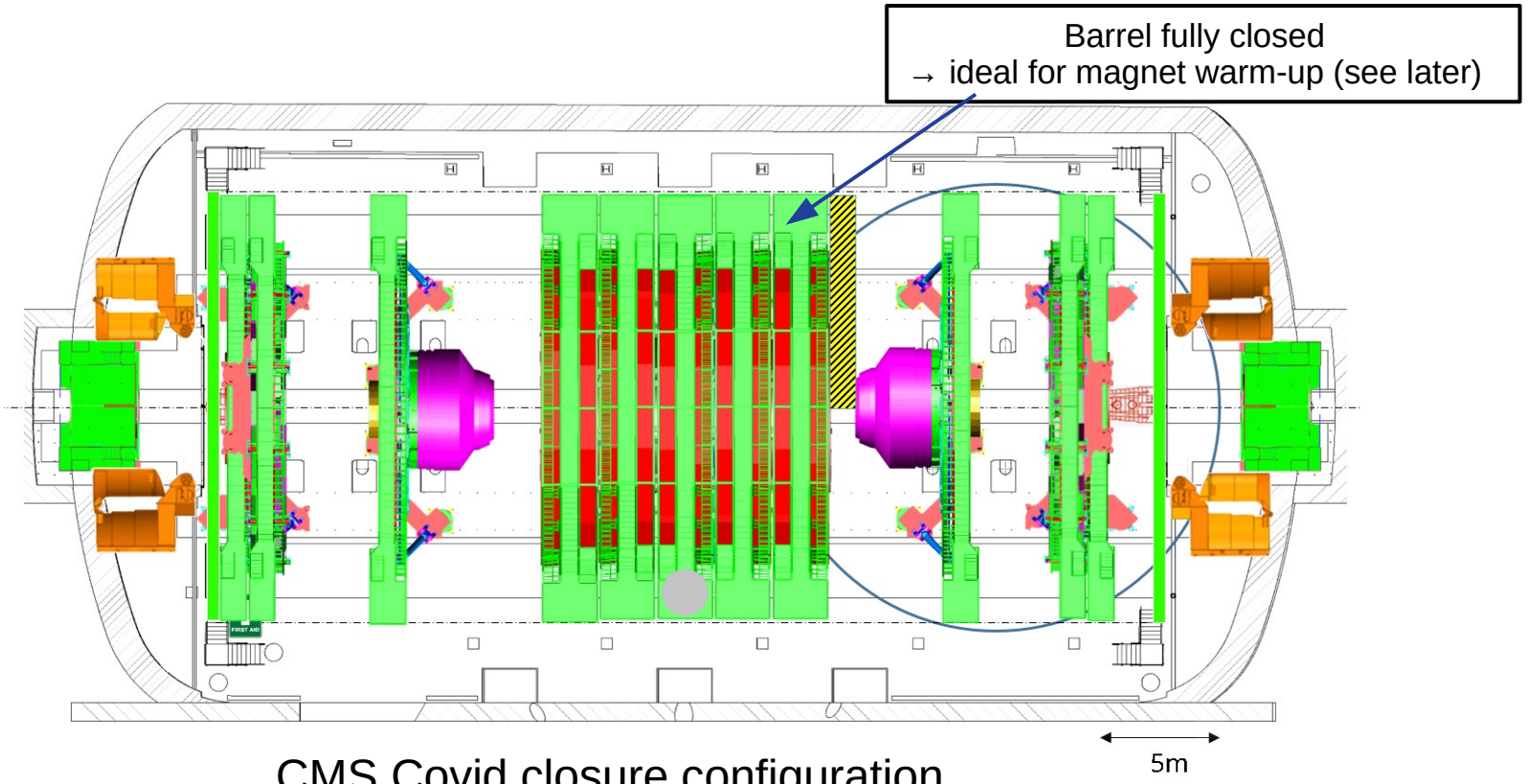
- Status of CMS during the Covid pandemic
  - Detector status during the lockdown
  - CMS magnet warm-up
  - Path towards LS2 completion
- Preparations for Run 3
- Some physics highlights
- News from the Phase-2 upgrades

Status of CMS during the Covid Pandemic



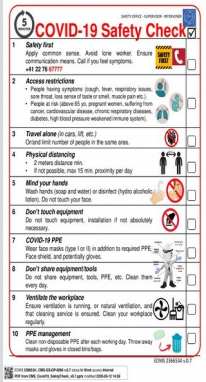
Status of CMS during the Covid Pandemic

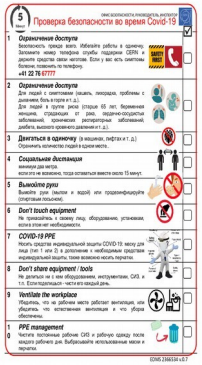
- Wide spread effect on CMS collaborators around the globe from the pandemic
- Teleworking continues where possible
- At P5: site in year-end closure-like mode since mid-March
  - Daily safety tours to verify safety and integrity of equipment
- Since May 18th: restarting first critical activities at CERN



CMS Covid closure configuration

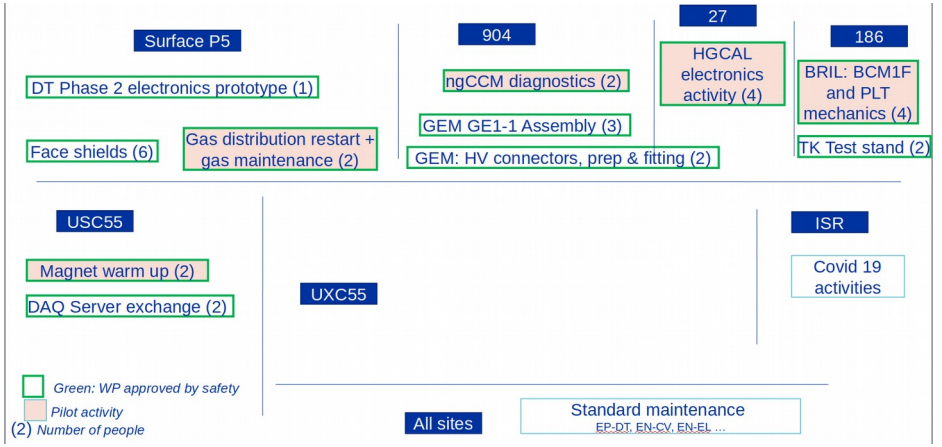
CMS Staged Restart

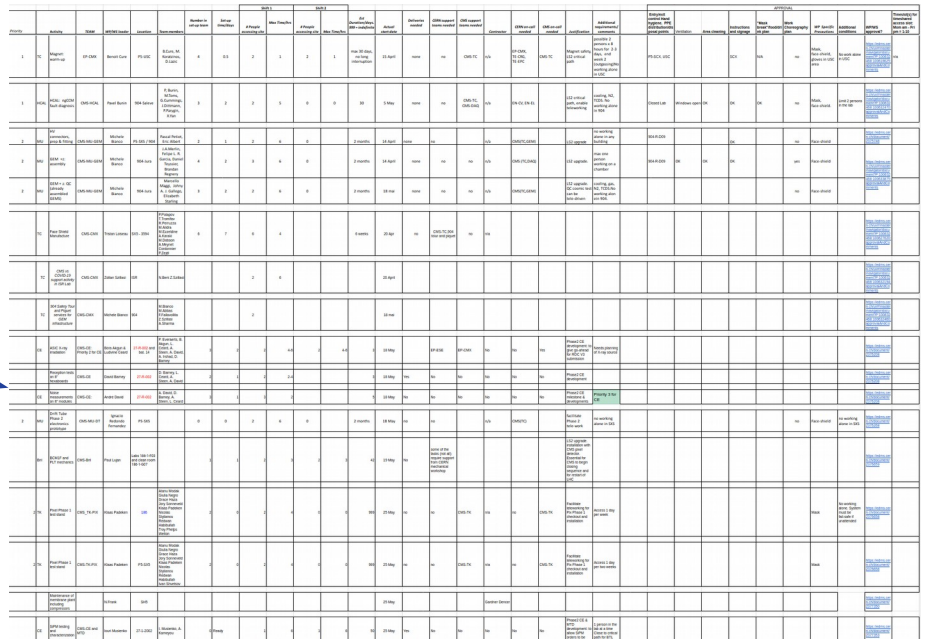




- CMS is organizing staged restart of critical activities
  - LS2 critical path at P5
  - **Pilot activities** have been defined to commission safe working conditions in critical lab spaces
- Need to rely exclusively on resident teams
- physical distancing to be implemented for complex work choreography
- EDMS check list has been prepared for activities
- List of ongoing workpackages is being maintained for full overview of ongoing activities
- Enabling and furthering of teleworking has priority wherever possible

Activity overview (example)



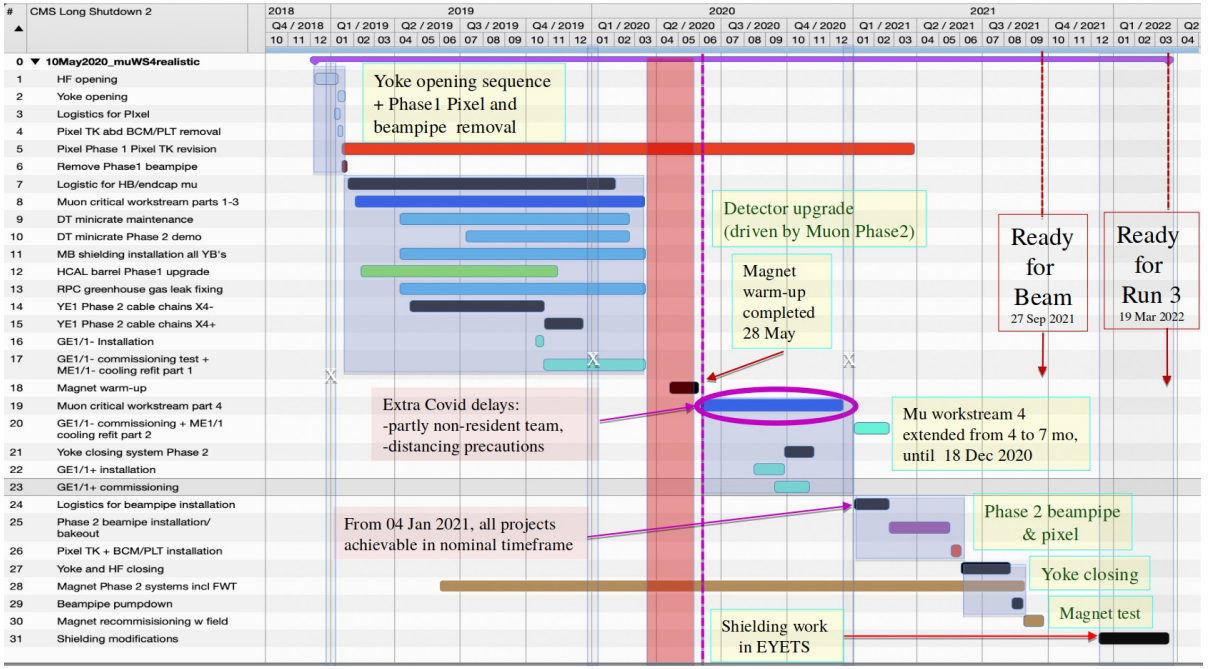


Selection of approved Workpackages with detailed information collected for each

Covid-19 checklist in English/French/Russian

LS2 Critical Path

- LS2 critical path delayed by Covid closure somewhat beyond length of the lockdown
- Muon endcap Phase-2 upgrade expected to finish around end of 2020
- Installation and Bakeout of CMS Phase-2 Beampipe (from mid Feb 2021)
- Re-installation of CMS Pixel (around end May 2021)
- CMS Yoke closed and beam pipe under vacuum late August 2021
- Magnet commissioning completed around end of September 2021 (CMS ready for beam)
- Additional work on the horizon: about 3 months needed for rework of forward shielding
  - Currently foreseen for YETS21/22
  - Has to be done before substantial luminosity is integrated in Run 3



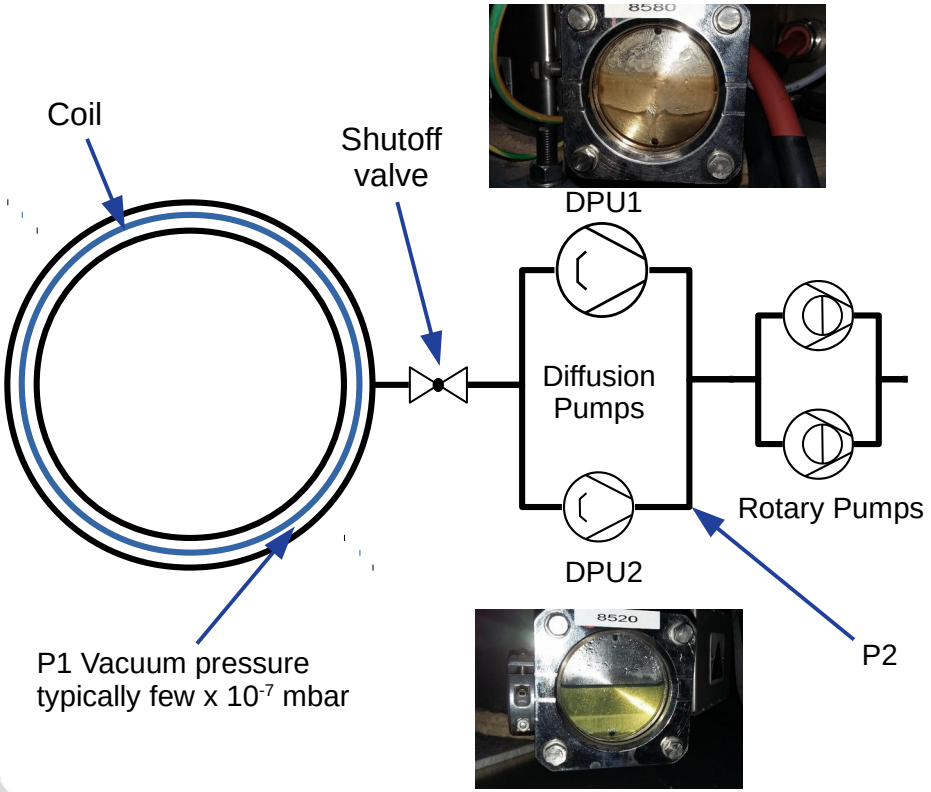
CMS ready for beam end of September 2021

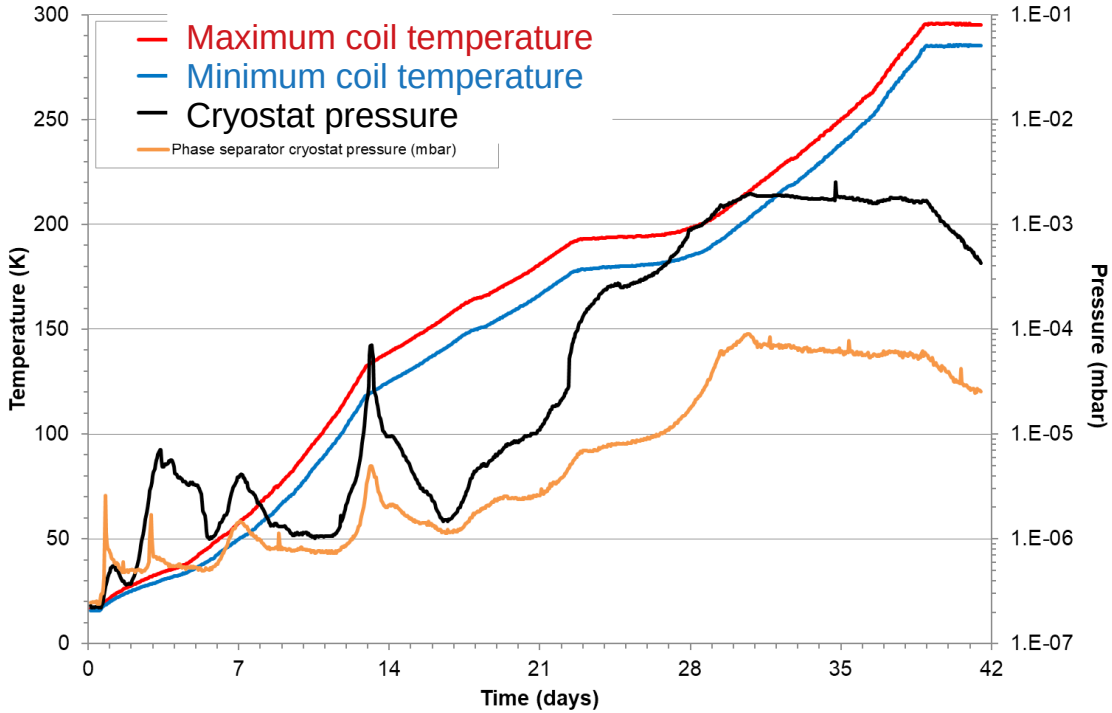
CMS Magnet Status

- CMS magnet cryo system experienced water leak in 1 of 2 pumps for the primary vacuum
  - Decision to warm up magnet for exchange of the pump
  - Backup pumping group has been installed just before Covid shutdown

Many thanks to TE Department

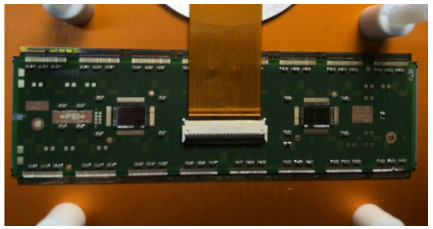
- ΔT of magnet coil was under control during full warm-up (risk of delamination)
- CMS Magnet at room temperature since May 24th (first time since LS1)
- Refurbishment of magnet cryo system (vacuum) ongoing
- Further inspections to ensure good state of system planned

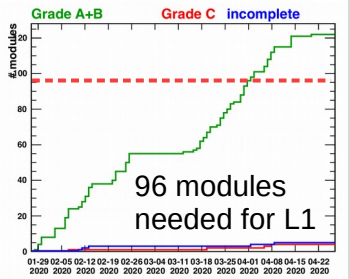


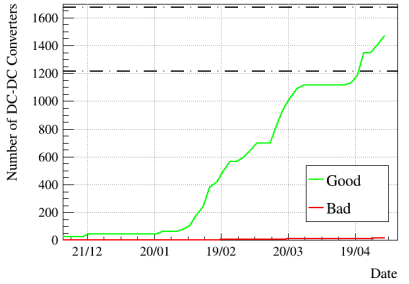


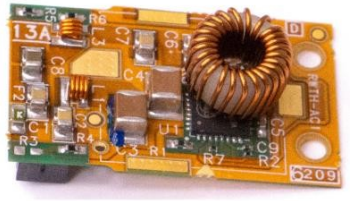
Preparing for Run 3 – LS2 activities

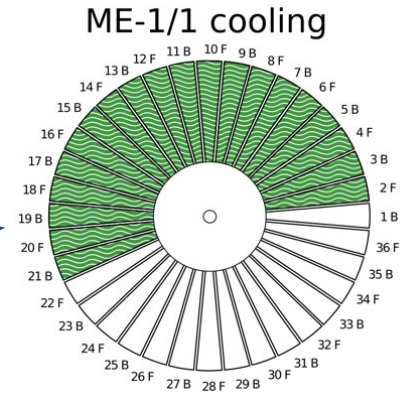
- Pixel Detector
  - **Production of modules** for new Barrel Layer 1 has been **completed**
    - Additional x-ray test program delayed by pandemic but slowly restarting
  - DCDC Converter production almost complete
    - already enough converters in hand for detector installation
- BRIL BCM/PLT rebuild has restarted (pilot activity B186)
- Muon System
  - RPC negative endcap station 4 re-installation pending
    - Services for 3.1 and 4.1 stations **60% complete**
  - GEM positive endcap to be installed
    - **25 SuperChambers** (out of 36 → ~70%) **fully assembled**
    - **15 SuperChambers** (~42%) fully validated, **ready for installation**
  - CSC
    - Jointless cooling circuits to be installed on negative ME1/1 chambers (top sectors already done)
    - Electronics replacement on stations ME-[234]/1 to be done











→ most activities were stopped during the lockdown
(some managed to continue despite difficulties) now slowly restarting

Preparing for Run 3 – Restarting Commissioning Activities

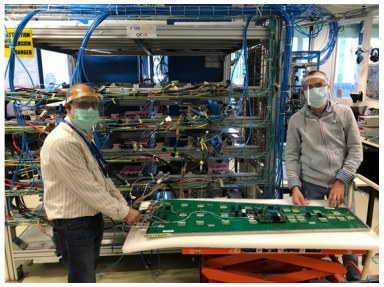
- CMS detector commissioning operations stopped during lockdown now gradually restarting
  - A pool of local shifters identified to mitigate effect of travel restrictions
- Strategies under study to make the CMS Control Room compliant with COVID19 rules and constraints
  - Reducing the shift length to mitigate the difficult working conditions, such as wearing a mask
  - Minimizing the possible number of people present in the Control Room at all times
  - “disperse” Control Room to different locations at P5
- Plan to restart in the next 2 weeks and steadily increase the commissioning activities
  - Planning towards a with **first cosmic data taking** with all CMS detectors sometime **during summer**

Not possible anymore….

Pictures **from last MWGR in January**
→ all not conforming to physical distancing

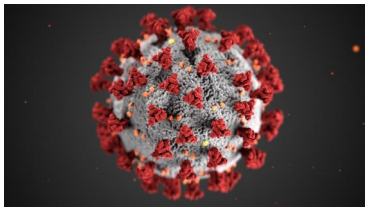
PPE distribution station@P5

...working with PPE...



...keeping distance...

CMS vs Covid

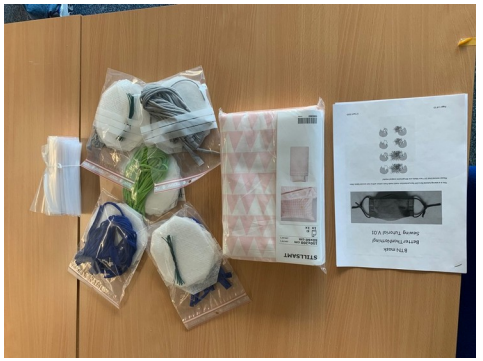


- Volunteers working on projects to help mitigate effects of pandemic
  - Production of face shields
  - Evaluation of physical distancing aids
  - Disinfectant methods e.g. by use of UV light
  - Opportunistic use of small part of CMS High-Level Triger farm to contribute to Folding@Home project
  - Supporting of private “BetterThanNothing” face mask initiative for non-medical use
  - Participation in international consortia for production of equipment to protect medical personnel
- Summary of all efforts can be found at:

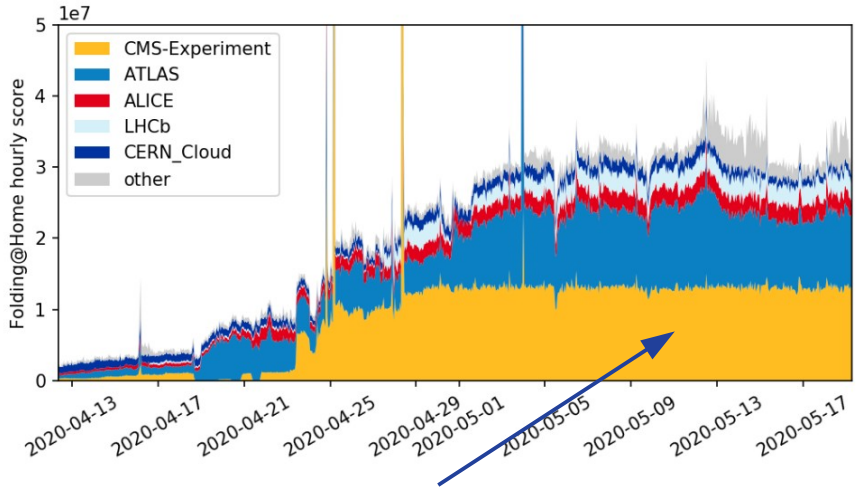
  `https://cms-against-covid19.web.cern.ch/`

Physical distancing aids

Face shield production

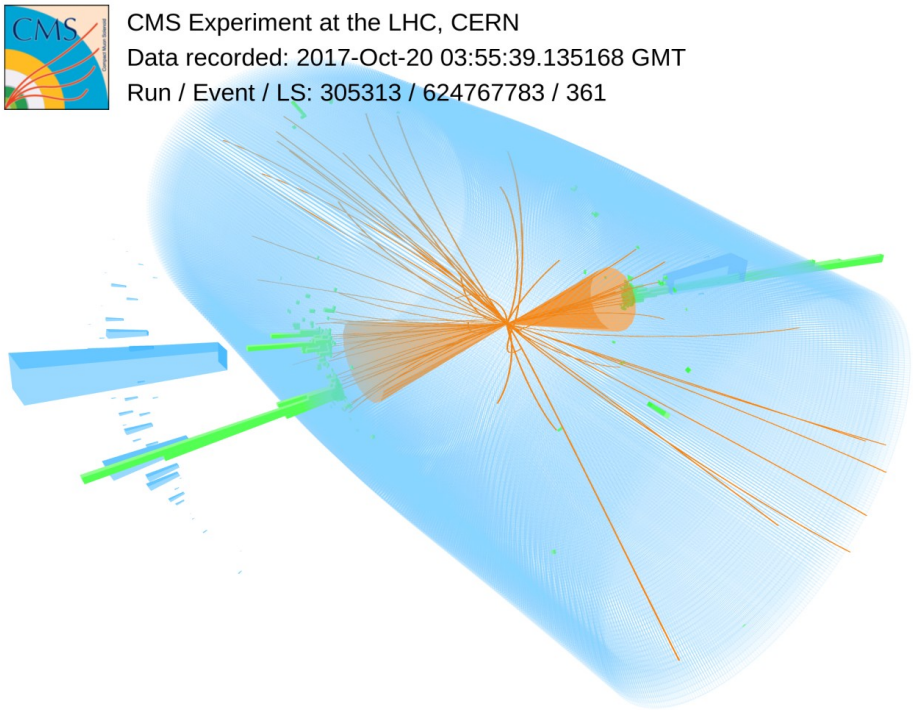


BetterThanNothing masks



Folding@Home on the CMS HLT

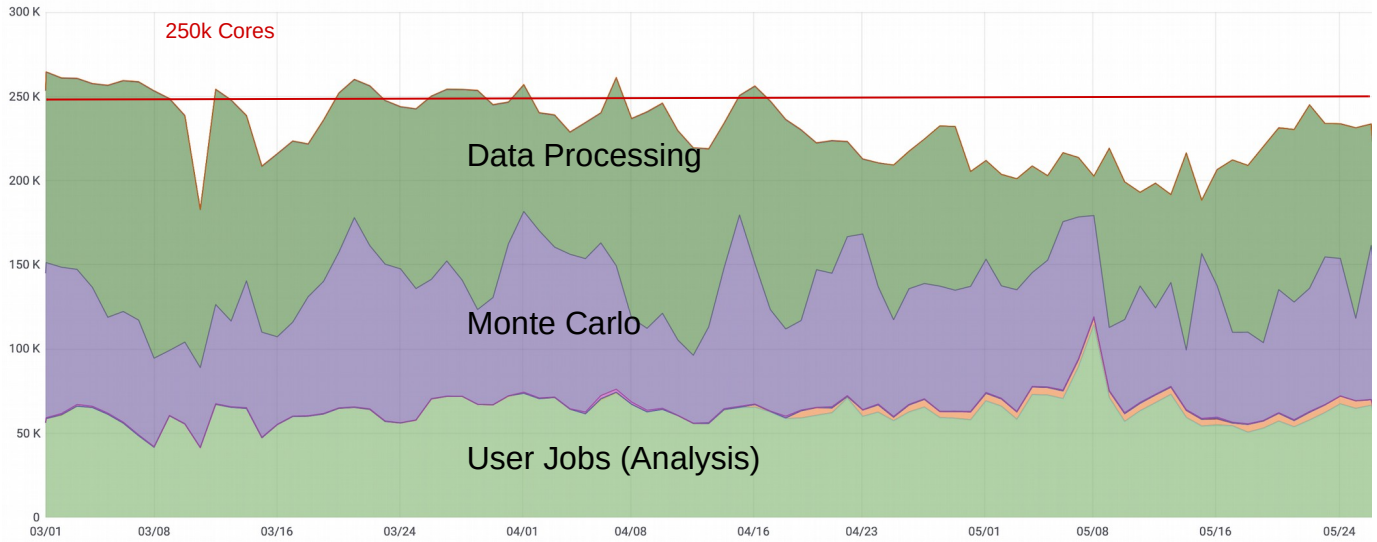
Computing, Datasets & Physics Analyses



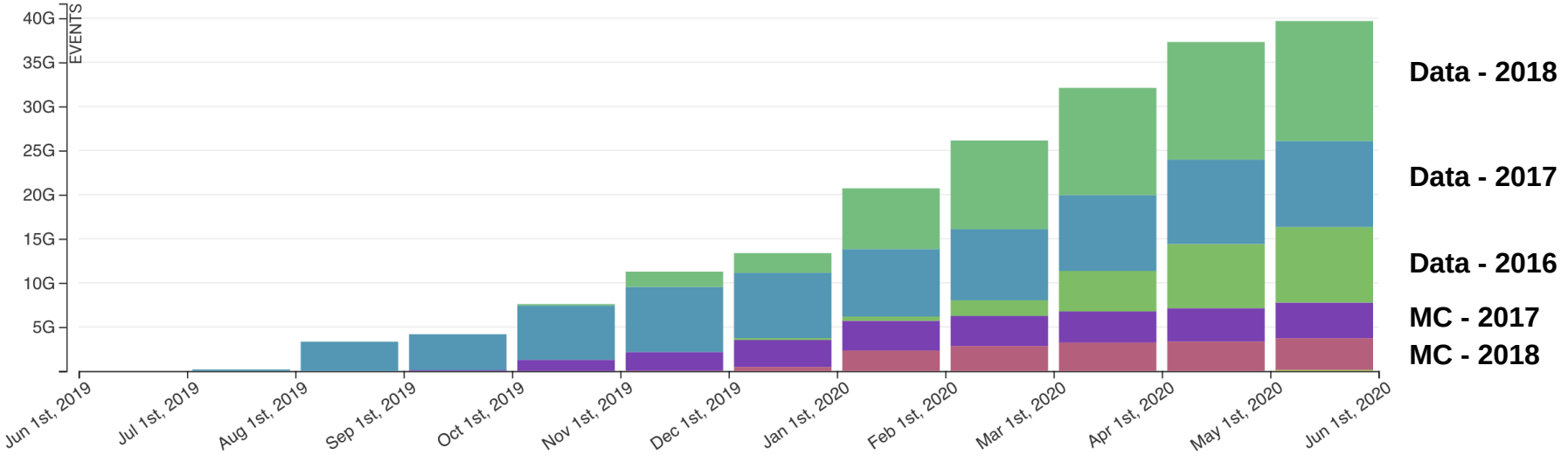
Displays of events from an inclusive search for highly-boosted Higgs bosons decaying to bottom quark-antiquark pairs

Offline Software and Computing

- Excellent usage of resources during the lockdown
  - Impact of COVID barely noticeable
  - Great performance of CMS operations and sites
- Lots of progress on the software side:
  - Migration of detector description tool to the community software solution DD4HEP towards completion
  - Latest Geant 4 release (10.6) fully integrated
  - Ready to incorporate ROOT 6.22 as soon it is released (in the next few days)
- Milestone in the migration to new data management tool, Rucio, another community tool
  - Management of NanoAOD(Sim) datasets will be handed over to Rucio in the next few days
  - First step in the decomissioning of the existing in-house solution, PhEDEx
  - Excellent work of the data management development team: move transparent for the users!



CMS Run-2 Legacy Reprocessing

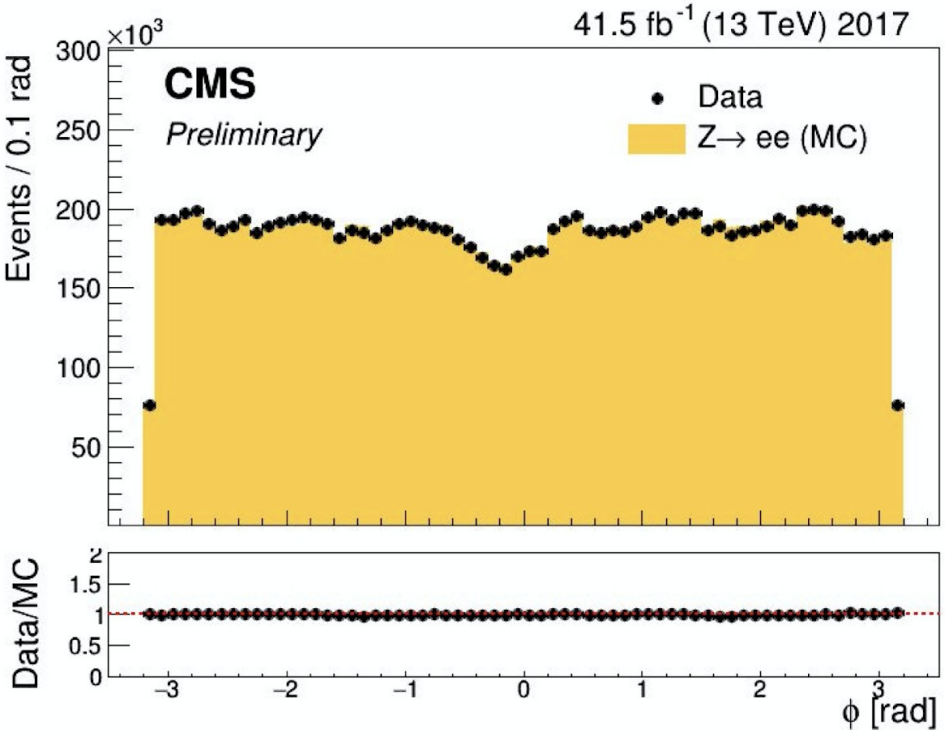


- The Run-2 Legacy program was started two years ago
  Since then, 40B Legacy events have been produced, including
  - 32B events of data, covering standard pp 13 TeV collisions, special runs (not including ~12B B-Parking events)
  - 8B events of MC, so far, for 2017-2018, used by Physics Object Groups (POG) to produce final energy corrections and efficiency scale factors.
- Much more MC to come, for 2016 calibrations (~4B events), and for physics analyses (initially planning for about 10B events in the coming months).

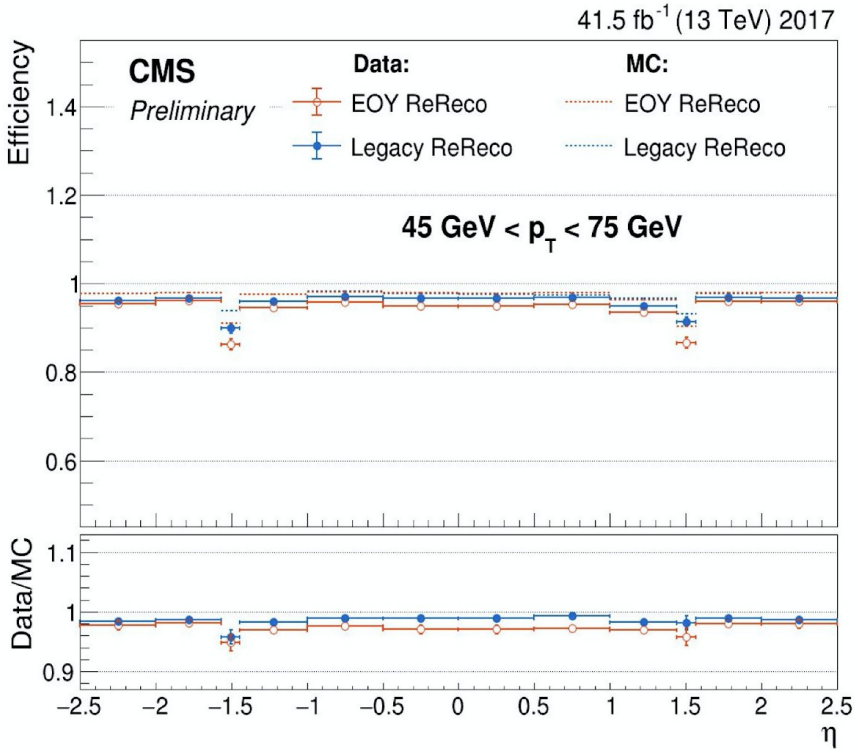
CMS Run-2 Legacy Reprocessing

Performance improvement in Legacy datasets

CERN-CMS-DP-2020-024



Impressive agreement between Data and MC of electron phi due to Legacy alignment and improvement in the simulation of detector conditions.

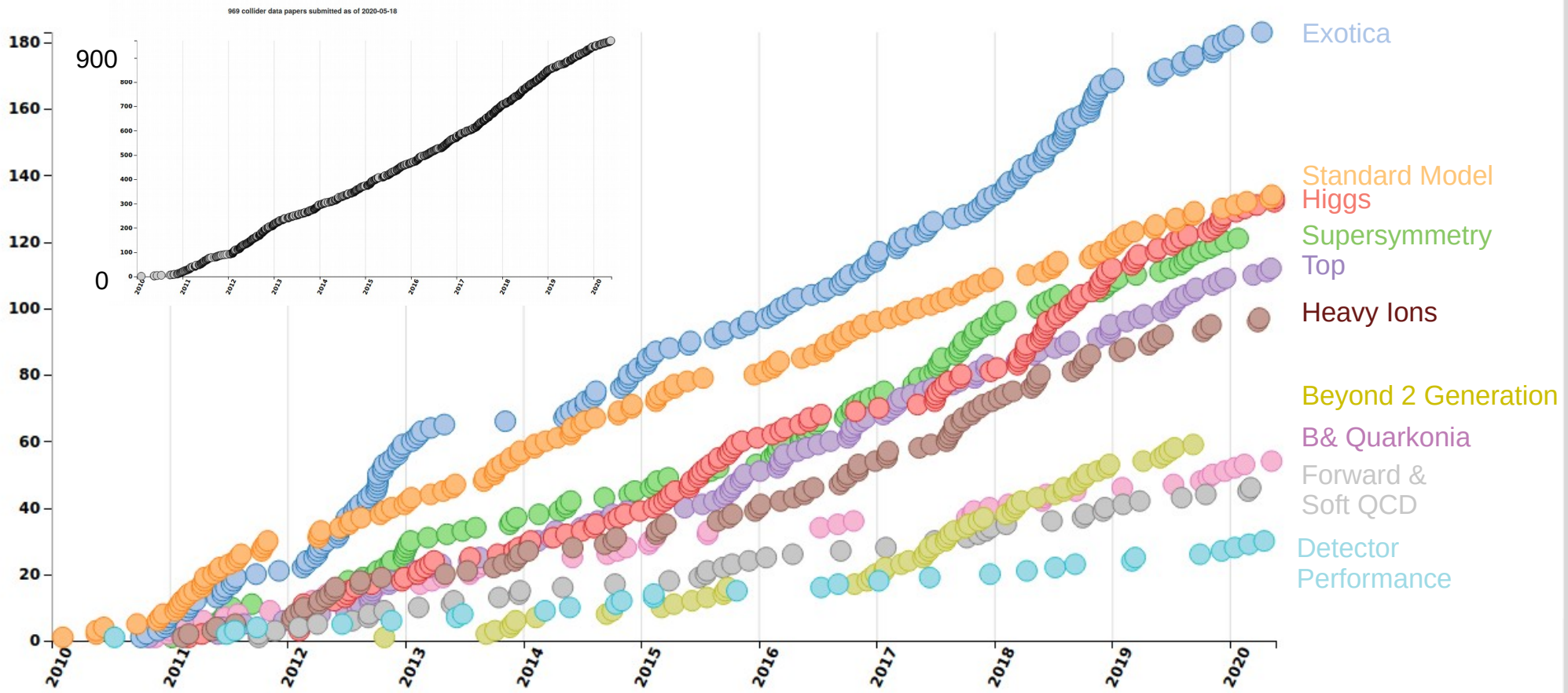


Improvement in electron reconstruction efficiency compared to End-Of-Year reconstruction.

Presented at LHCP

Published CMS Results

970 collider data papers submitted as of 2020-06-01
(25 data on cosmics data before start of collisions)



New CMS Papers and Public Results

995	HIN-18-020	Measurement of b jet shapes in proton-proton collisions at $\sqrt{s} = 5.02$ TeV
994	HIG-18-021	Search for a light charged Higgs boson in the $H^{\pm} \to cs$ channel in proton-proton collisions at $\sqrt{s} = 13$ TeV
993	HIG-18-024	Search for a light pseudoscalar Higgs boson in the boosted $\mu\mu\tau\tau$ final state in proton-proton collisions at $\sqrt{s} = 13$ TeV
992	SMP-19-003	Dependence of inclusive jet production on the anti-k_T distance parameter in pp collisions at $\sqrt{s} = 13$ TeV
991	BPH-17-005	Observation of the $B_s^0 \to X(3872)\phi$ decay
990	TOP-19-004	Combination of the W boson polarization measurements in top quark decays using ATLAS and CMS data at $\sqrt{s} = 8$ TeV
989	SMP-19-012	Measurements of production cross sections of WZ and same-sign WW boson pairs in association with two jets in proton-proton collisions at $\sqrt{s} = 13$ TeV
988	TOP-17-012	Measurement of CKM matrix elements in single top quark t-channel production in proton-proton collisions at $\sqrt{s} = 13$ TeV
987	JME-18-002	Identification of heavy, energetic, hadronically decaying particles using machine-learning techniques
986	EXO-19-010	Search for disappearing tracks in proton-proton collisions at $\sqrt{s} = 13$ TeV
985	HIN-18-018	Measurement of quark- and gluon-like jet fractions using jet charge in PbPb and pp collisions at 5.02 TeV
984	HIN-18-016	The production of isolated photons in PbPb and pp collisions at $\sqrt{s_{NN}} = 5.02$ TeV
983	HIG-19-013	Measurements of $t\bar{t}H$ production and the CP structure of the Yukawa interaction between the Higgs boson and top quark in the diphoton decay channel
982	TOP-18-002	Measurement of the cross section for $t\bar{t}$ production with additional jets and b jets in pp collisions at $\sqrt{s} = 13$ TeV
981	FSQ-16-006	Study of central exclusive $\pi^+\pi^-$ production in proton-proton collisions at $\sqrt{s} = 5.02$ and 13 TeV
980	JME-18-001	Pileup mitigation at CMS in 13 TeV data
979	FSQ-12-033	Measurement of single-diffractive dijet production in proton-proton collisions at $\sqrt{s} = 8$ TeV with the CMS and TOTEM experiments
978	SMP-18-007	Measurement of the cross section for electroweak production of a Z boson, a photon and two jets in proton-proton collisions at $\sqrt{s} = 13$ TeV and constraints on anomalous quartic couplings

New papers (submitted or published)

18 new papers published or submitted since last LHCC session in February

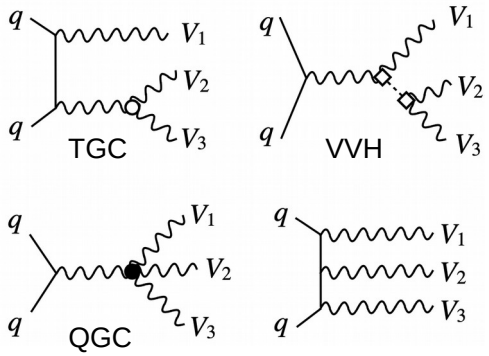
31 new public results (including preliminary results)

All info at: `http://cms-results.web.cern.ch/cms-results/public-results/publications/index.html`

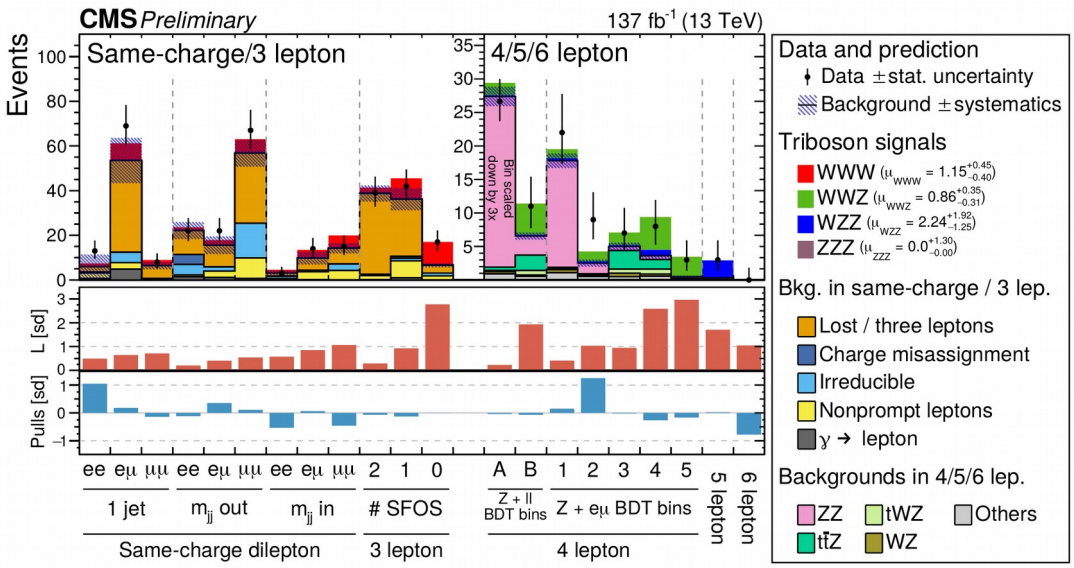
Observation of VVV production in leptonic final states

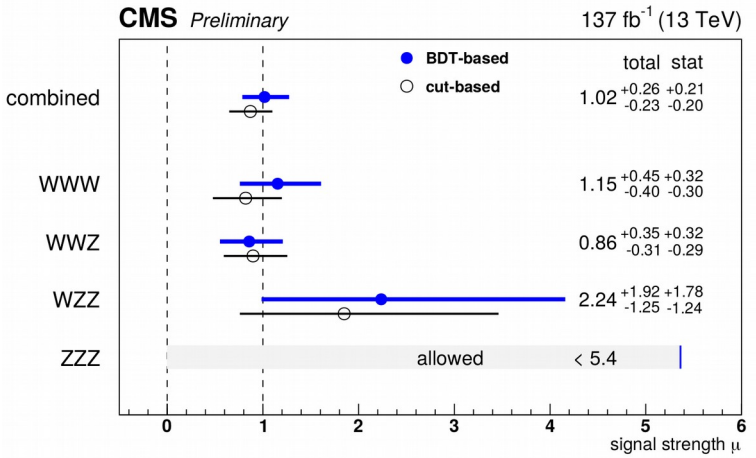
CMS-PAS-SMP-19-014

- Analysis at the edge of sensitivity, production mechanism gives access to many interesting couplings (TGC, QGC, VVH)
- First observation of VVV production
  - Significance: 5.7 s.d. (5.9 expected)
  - WWW and WWZ above 3 s.d. individually
  - Result is consistent with Standard Model
- Cut-based and BDT-based analysis performed
  - Full Run 2 statistics
  - Several categories defined to optimize sensitivity
    - Same-charge dilepton plus jets, 3 – 6 leptons



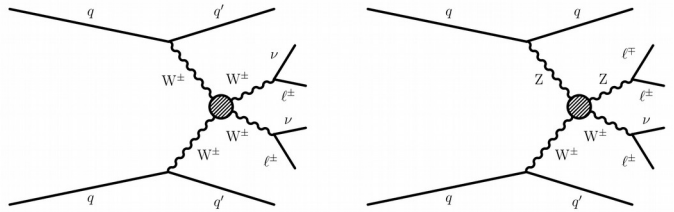
Significance	Observed BDT – based	Expected BDT – based
WWW	3.3	3.1
WWZ	3.4	4.1
WZZ	1.7	0.7
ZZZ	0.0	0.9
Total VVV	5.7	5.9



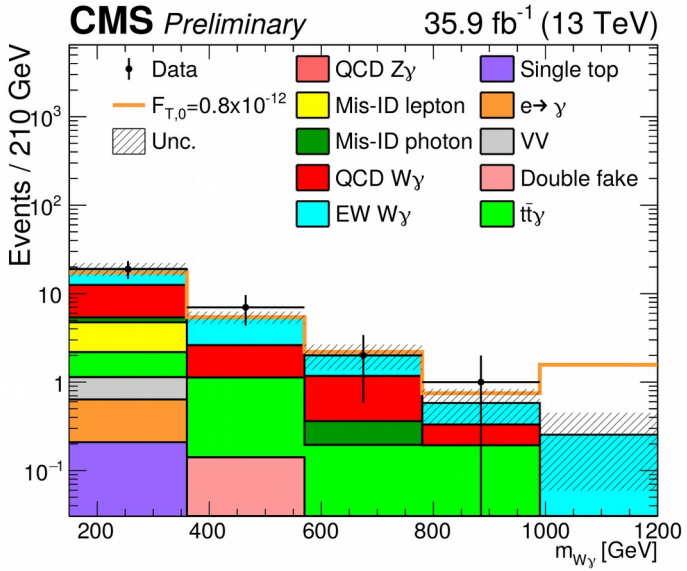


Standard Model – Vector Boson Scattering (VBS) Dibosonproduction

VBS WW/WZ

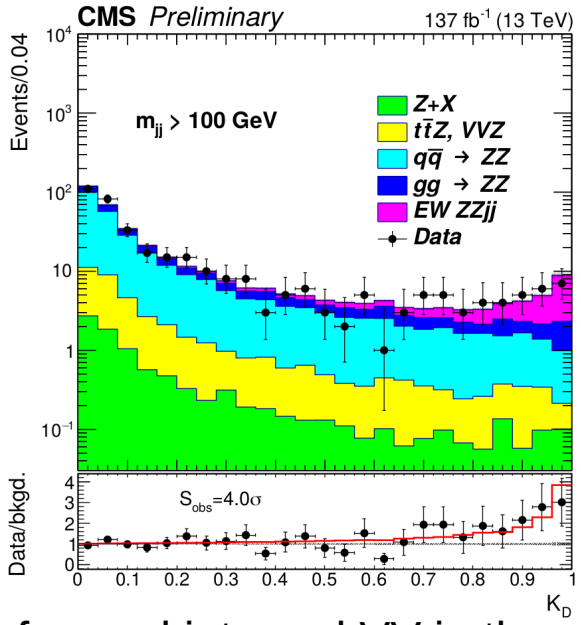


SMP-19-012



The $m_{W\gamma}$ distribution used to set constraints on the anomalous coupling parameters

Wγ VBS **SMP-19-008**



SMP-20-001

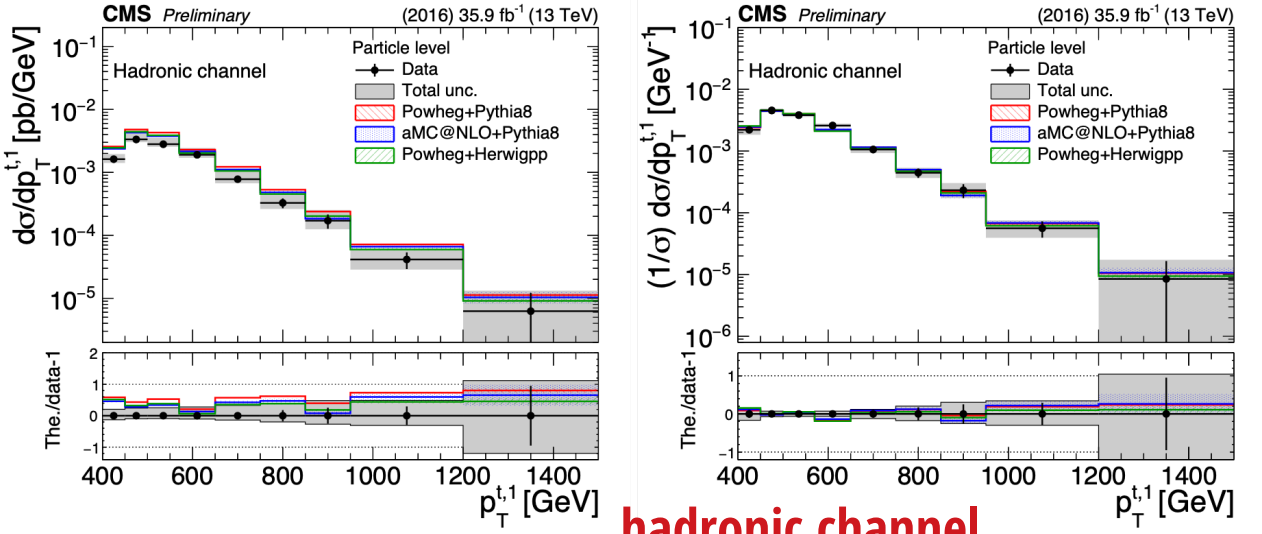
VBS ZZ

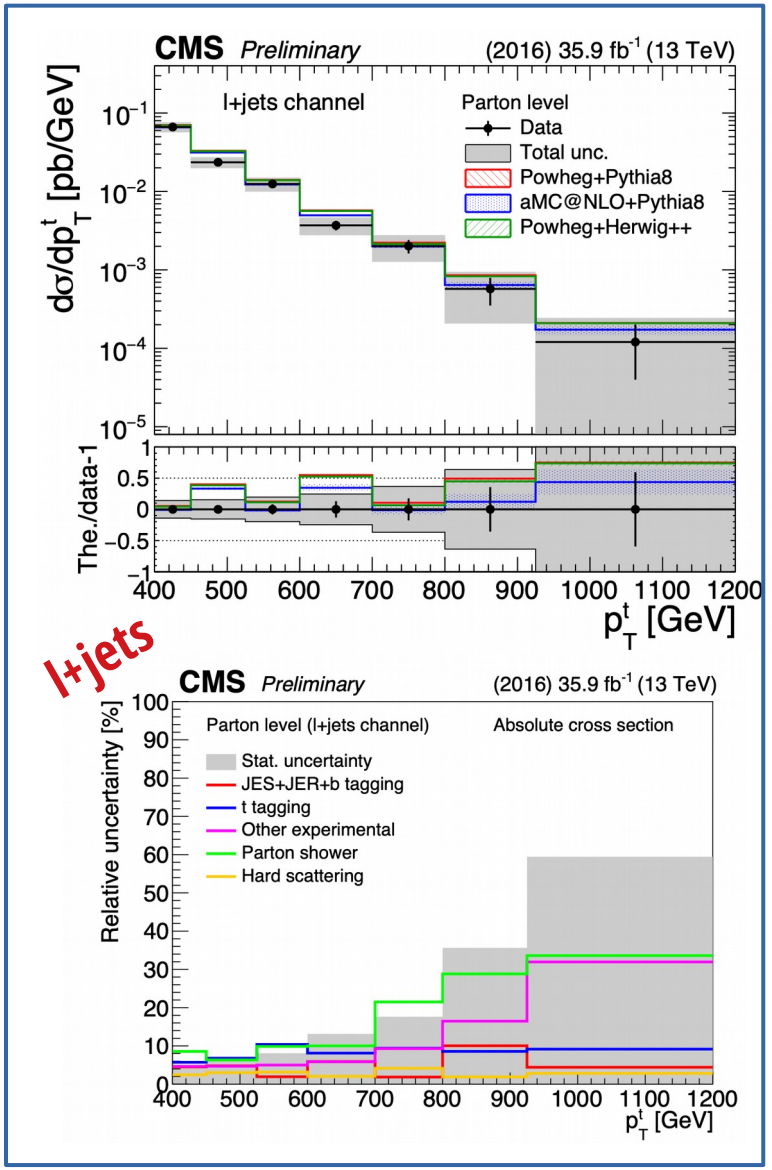
- VBS: 2 forward jets and VV in the central region
- Common challenge for all channels: small Xsec
- Results for: ZZjj → 4ljj, Wγjj → lνγjj, WW → lνlνjj, WZ → lνlljj
- First observation EW Wγ production with obs(exp): 5.3(4.8) s.d.(combined with 8TeV results)
- Observation of WZ with obs(exp): 6.8(5.3) s.d.
- Evidence for ZZ with obs(exp): 4.0(3.5) s.d.
- Measurements of $W^{\pm}W^{\pm}$, WZ, ZZ are used to set limits on anomalous quartic gauge (aQCG) couplings

Measurement of differential $\bar{t}t$ cross sections

CMS-PAS-TOP-18-013

- Measurement performed for high-p_T top pairs
  - One highly boosted top with hadronic decay (jet p_T>400 GeV)
  - Both hadronic and leptonic decays considered for second top
- At high p_T, absolute cross sections lower than predictions, but normalized distributions agree
- Cross sections unfolded to both particle and parton level

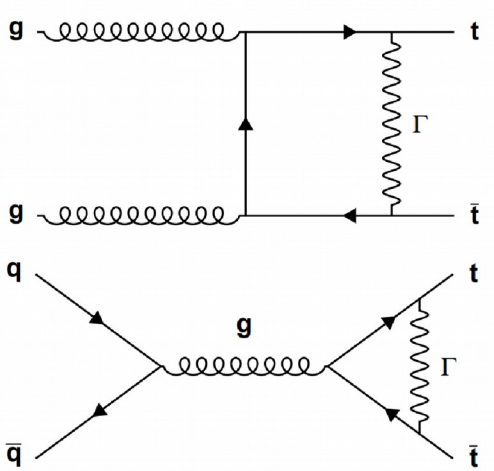




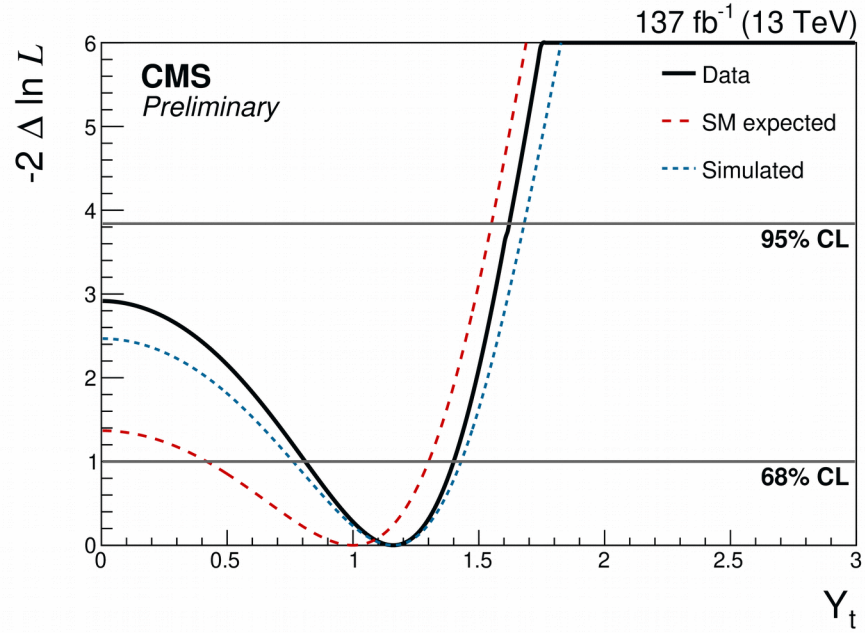
Top quark Yukawa coupling from $\overline{\text{t}}\text{t}$ dilepton decays

CMS-TOP-19-008

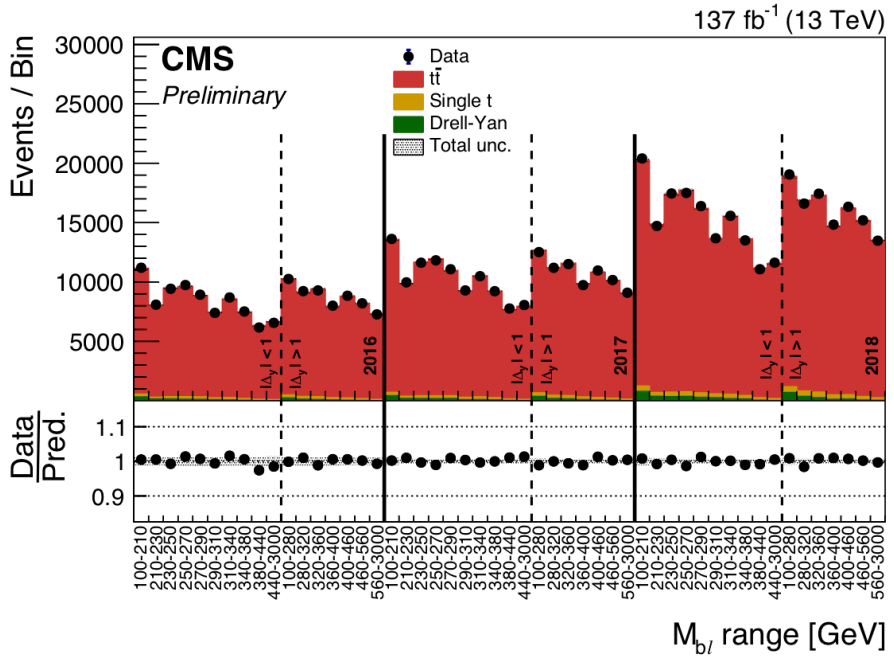
- Effect of virtual Higgs boson exchange on $\overline{\text{t}}\text{t}$ kinematics used to extract information about the coupling strength Y_t from kinematic distributions.
  - Lower sensitivity than ttH but does not need assumptions on other Yukawa couplings
  - $\overline{\text{t}}\text{t}$ dilepton with ee, $\mu\mu$ or eμ final states and 2 b-jets
  - Full run 2 data set



Γ = neutral gauge bosons



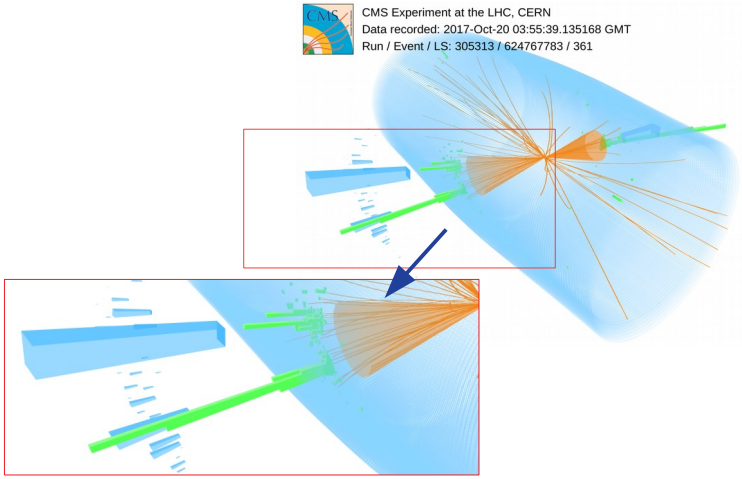
$Y_\text{t} = 1.16^{+0.25}_{-0.35}$ and $Y_\text{t} \in [0, 1.62]$ @ 95% confidence level

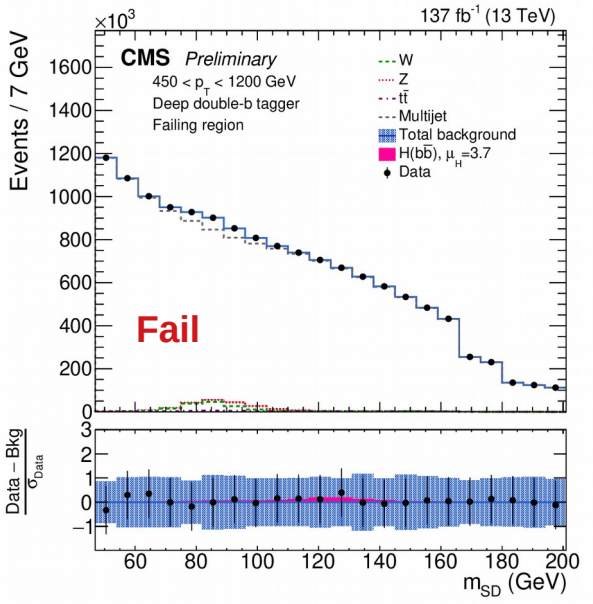


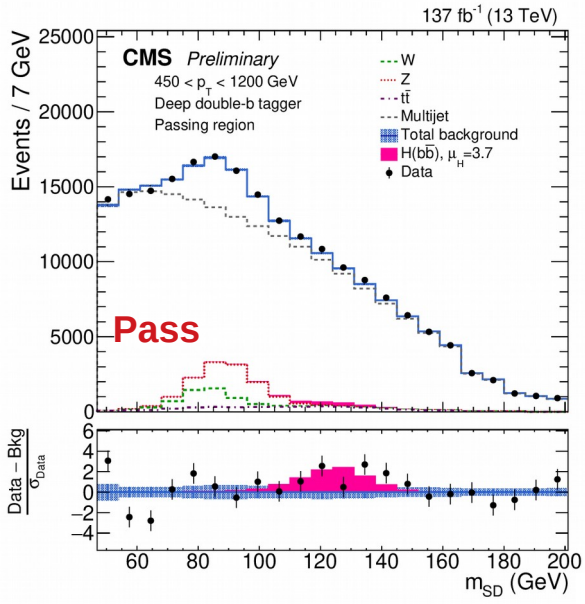
Search for a boosted H decaying to bb

- Inclusive search for H → bb as a single large-radius jet
  - selection uses substructure and deep double-b tagging
  - signal strength from fit to b-tag pass / fail regions, binned in m_{SD} and p_T
- Improvement by factor 2 compared to previous CMS result
  - Increased luminosity
  - Improved b-tagging
  - Smaller theoretical uncertainties

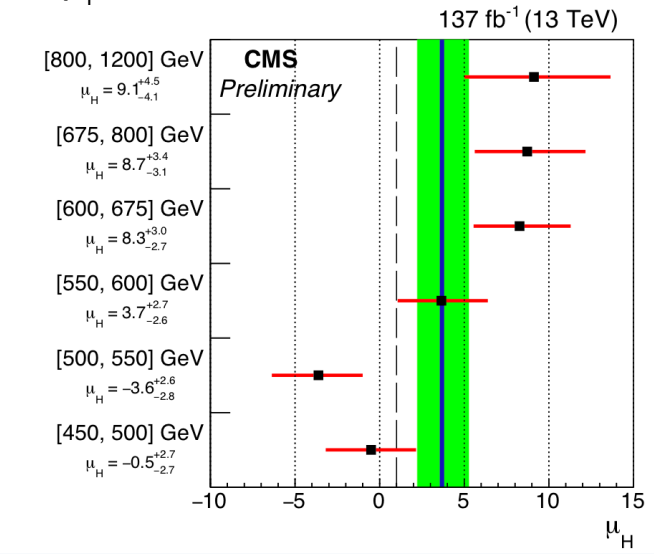
CMS-PAS-HIG-19-003







Six p_T bins between 450 and 1200 GeV



Local significance 2.54 (0.71) observed(expected)

Signal strength

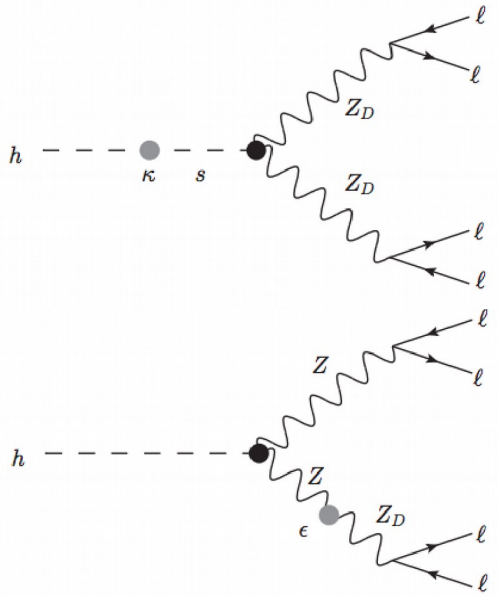
$$\mu_H = 3.68 \pm 1.20(\text{stat})^{+0.63}_{-0.66}(\text{syst})^{+0.81}_{-0.46}(\text{theo})$$

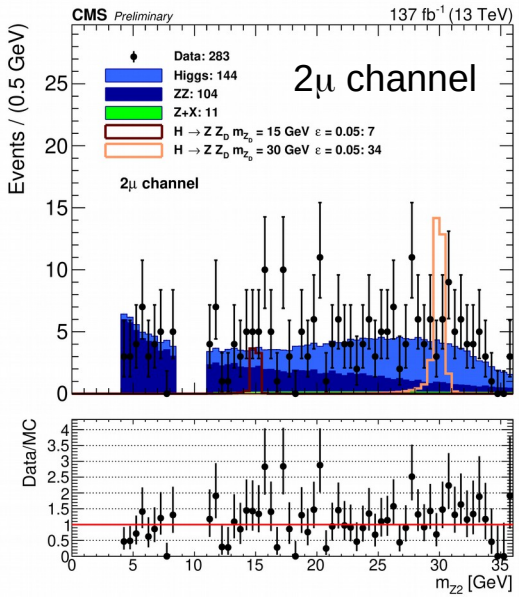
Search for low-mass resonances in H → 4l

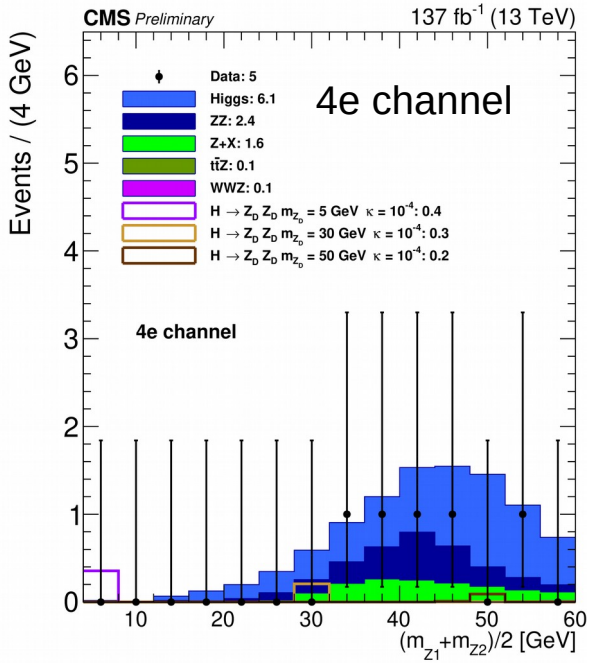
- Generic search for a low mass dilepton resonance in the H → 4l final state
- Decay via two BSM particles or one BSM particle+Z
- Uses full Run 2 luminosity
- No deviation from SM expectation is seen
  → Model independent cross section limits set
- Additionally: derived limits for models with dark photons and axion-like particles

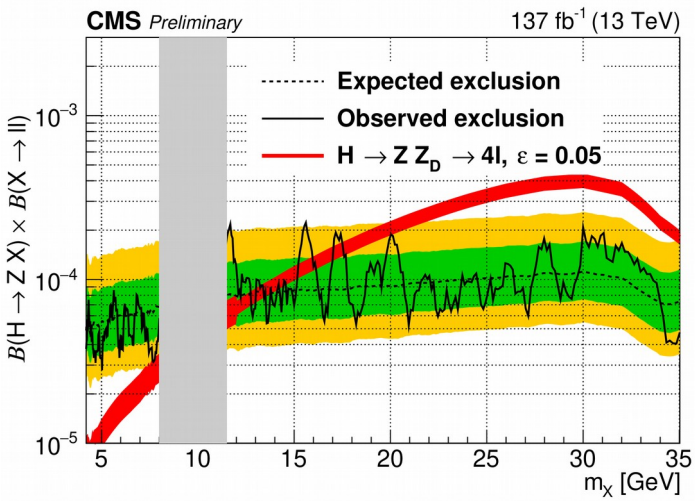
Karlsruhe Institute of Technology

CMS-PAS-HIG-19-007





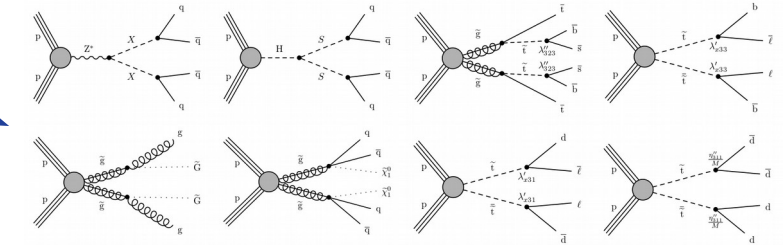


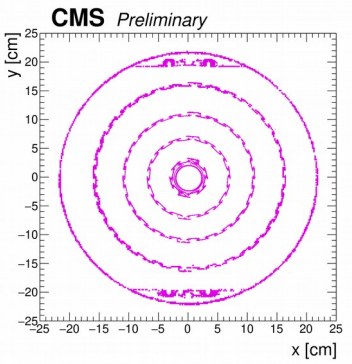


Search for long-lived particles

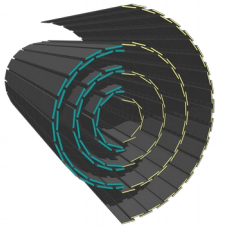
CMS-PAS-EXO-19-021

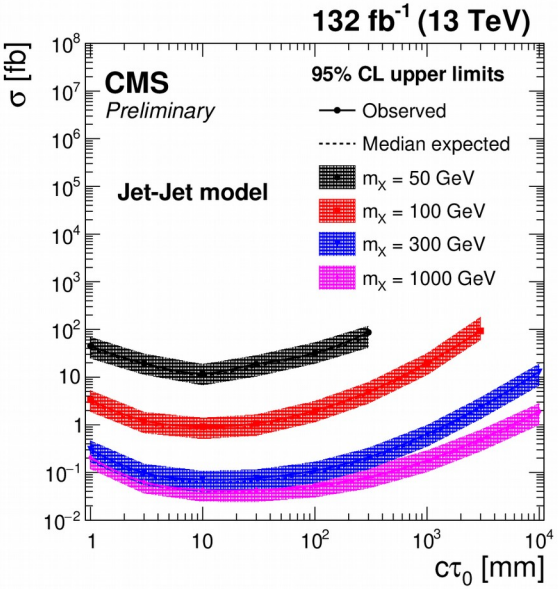
- Search for displaced tracks and vertices in a dijet system using displaced & inclusive jet triggers
- inclusive search applicable to a large range of models
- 2017/2018 data, combining with existing 2016 result
- select displaced tracks and reconstruct secondary vertices
  - uses a NI veto map covering the pixel structure
  - final decision using a gradient BDT
- Most stringent limits for many models

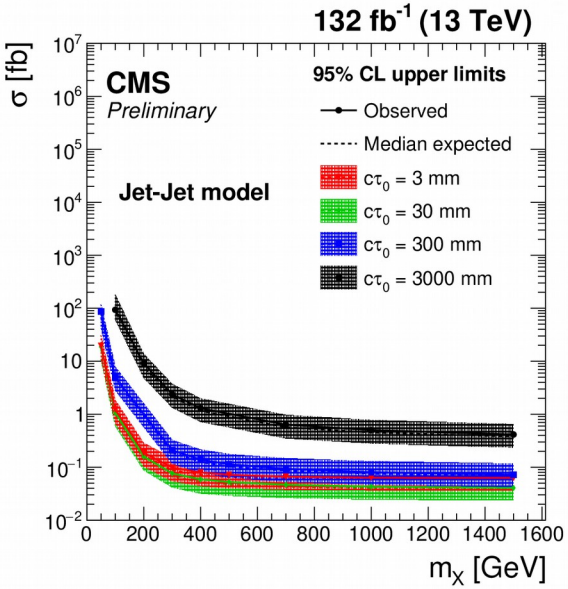


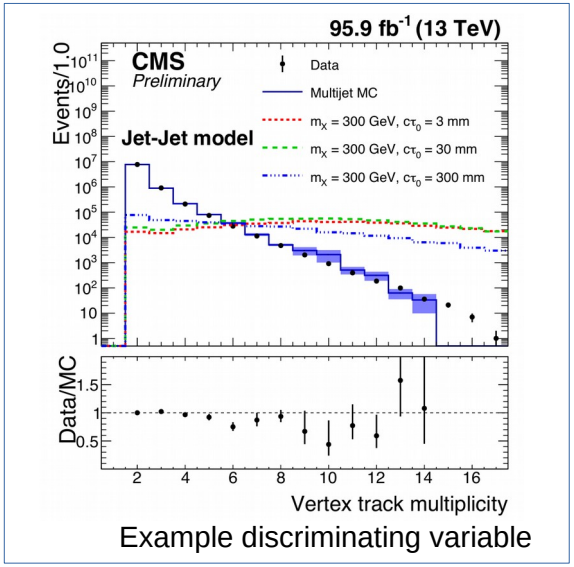


Veto map for nuclear interactions
In the region of the Pixel detector
2017/18: Phase-1 (4-layers)
2016: Phase-0 (3-layers)









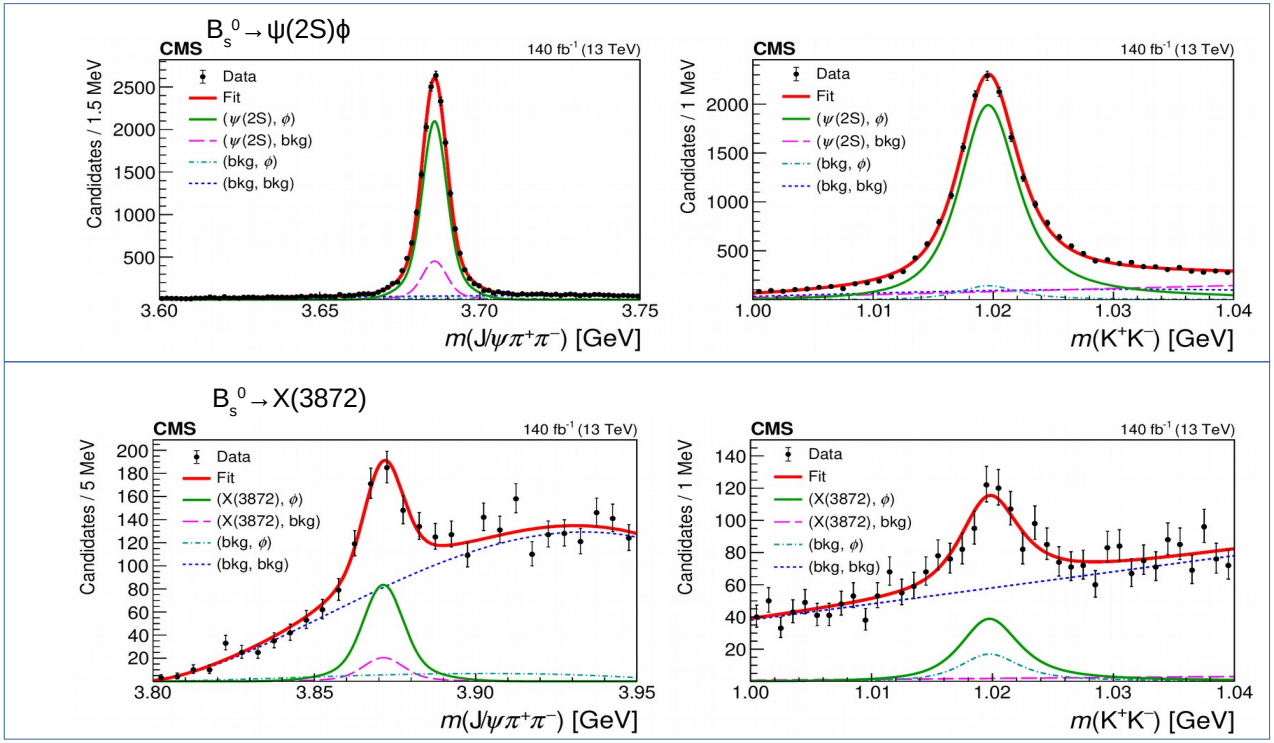
Example discriminating variable

Observation of the $B_s \rightarrow X(3872)\phi$ decay

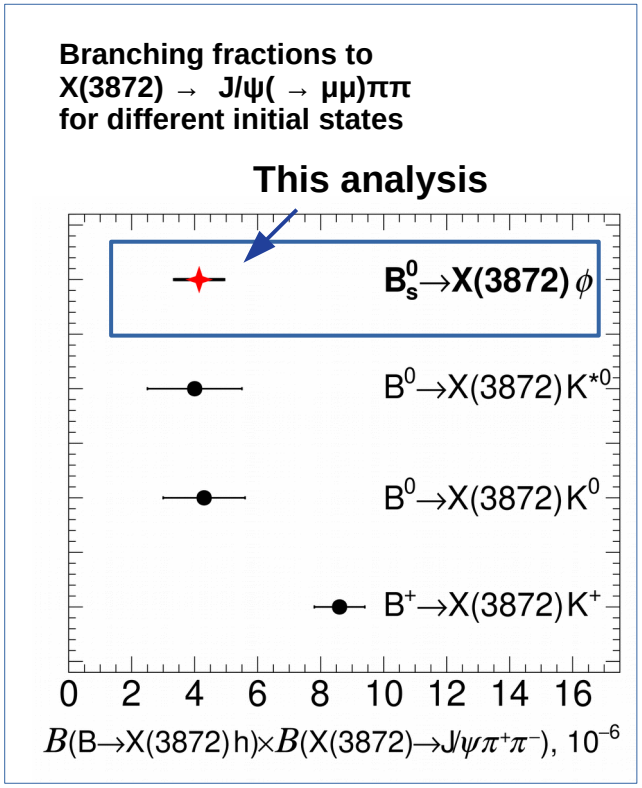
- State discovered in 2003 by Belle but its nature is still unclear (tetraquark? molecular state? ...)
  → observation of X(3872) in different B-hadron decays is important to elucidate the nature of this state
- **Now: First observation in B_s decays**
  - search performed in the X(3872) → J/ψ(→ μμ)ππ decay mode
- Normalization to the analogous ψ(2S) channel helps with cancellation of many systematic effects
- Significance from 2D fit > 6σ

CMS-BPH-17-005
(submitted to PRL)

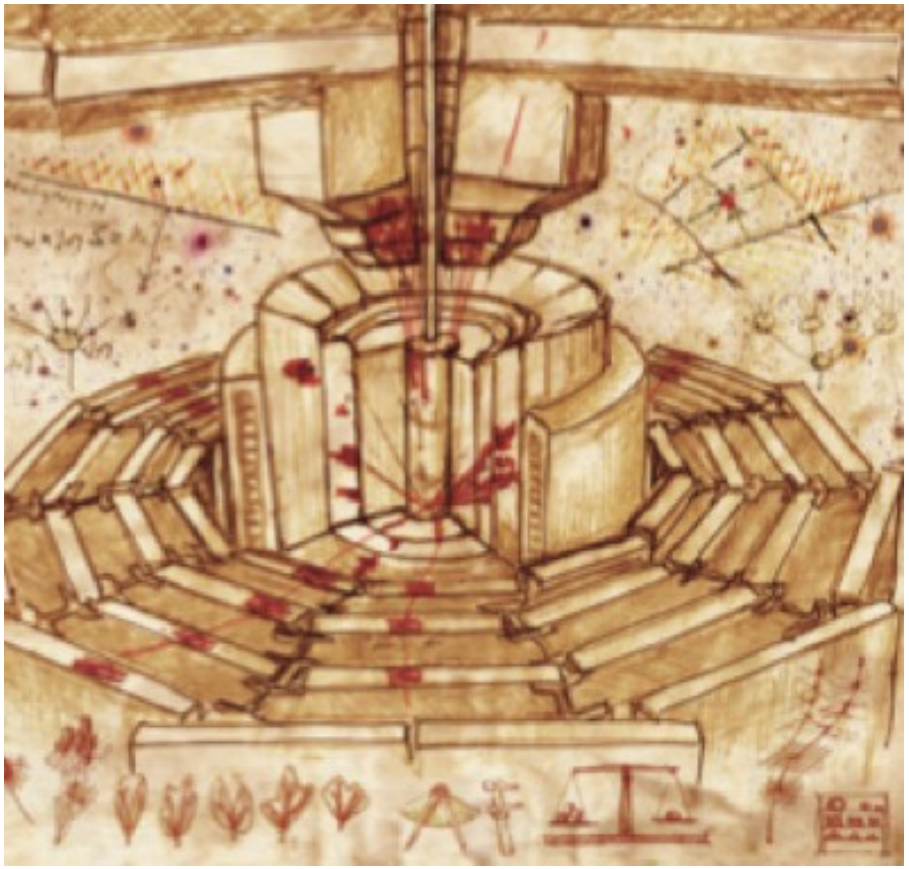
$$R = \frac{B(B_s^0 \rightarrow X(3872)\phi \times B(X(3872) \rightarrow J/\Psi\pi\pi)}{B(B_s^0 \rightarrow \Psi(2S)\phi \times B(\Psi(2S) \rightarrow J/\Psi\pi\pi)} = (2.21 \pm 0.29(\text{stat}) \pm 0.17(\text{syst}))$$



Branching fractions to X(3872) → J/ψ(→ μμ)ππ for different initial states



Some Highlights from the Phase-2 Upgrade



Artistic illustration for the L1 Trigger TDR

A very dense overview

Technical proposal CERN-LHCC-2015-010 https://cds.cern.ch/record/2020886
Scope Document CERN-LHCC-2015-019 https://cds.cern.ch/record/2055167

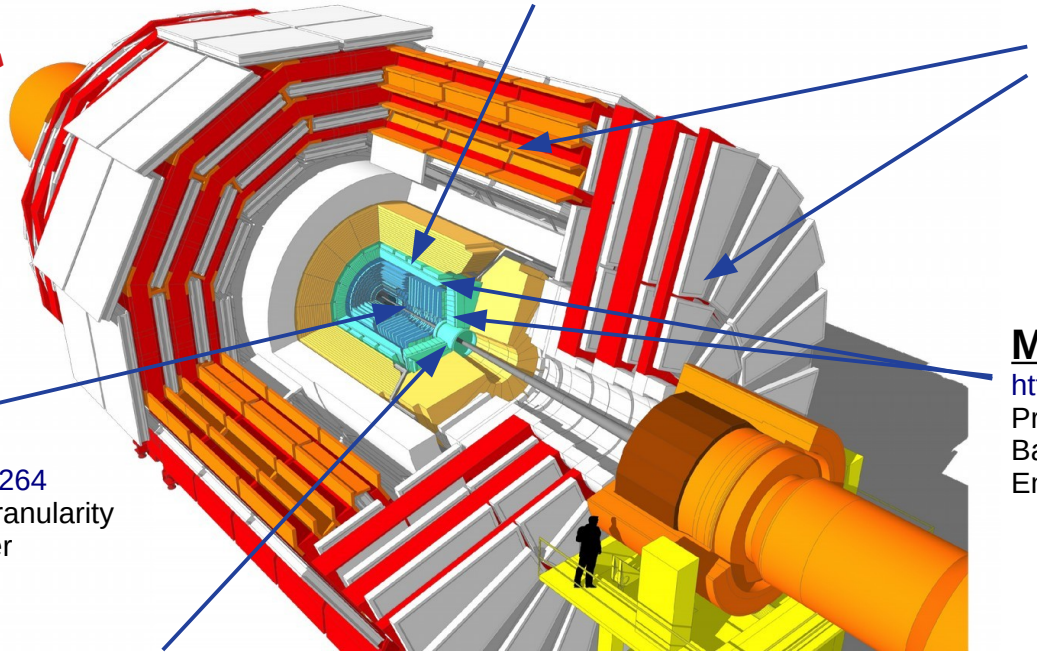
L1-Trigger/HLT/DAQ

https://cds.cern.ch/record/2283192
https://cds.cern.ch/record/2283193
Tracks in L1-Trigger at 40 MHz
PFlow-like selection 750 kHz output
HLT output 7.5 kHz

L1 TDR will be recommended for approval by LHCC and UCG

Barrel Calorimeters

https://cds.cern.ch/record/2283187
ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
ECAL and HCAL new Back-End boards



Muon systems

https://cds.cern.ch/record/2283189
DT & CSC new FE/BE readout
RPC back-end electronics
New GEM/RPC $1.6 < \eta < 2.4$
Extended coverage to $\eta \simeq 3$

MIP Timing Detector

https://cds.cern.ch/record/2296612
Precision timing with:
Barrel layer: Crystals + SiPMs
Endcap layer: LGADs

Tracker

https://cds.cern.ch/record/2272264
Si-Strip and Pixels increased granularity
Design for tracking in L1-Trigger
Extended coverage to $\eta \simeq 3.8$

Calorimeter Endcap

https://cds.cern.ch/record/2293646
3D showers and precise timing
Si, Scint+SiPM in Pb/W-SS

Beam Radiation Instr. and Luminosity, and Common Systems and Infrastructure

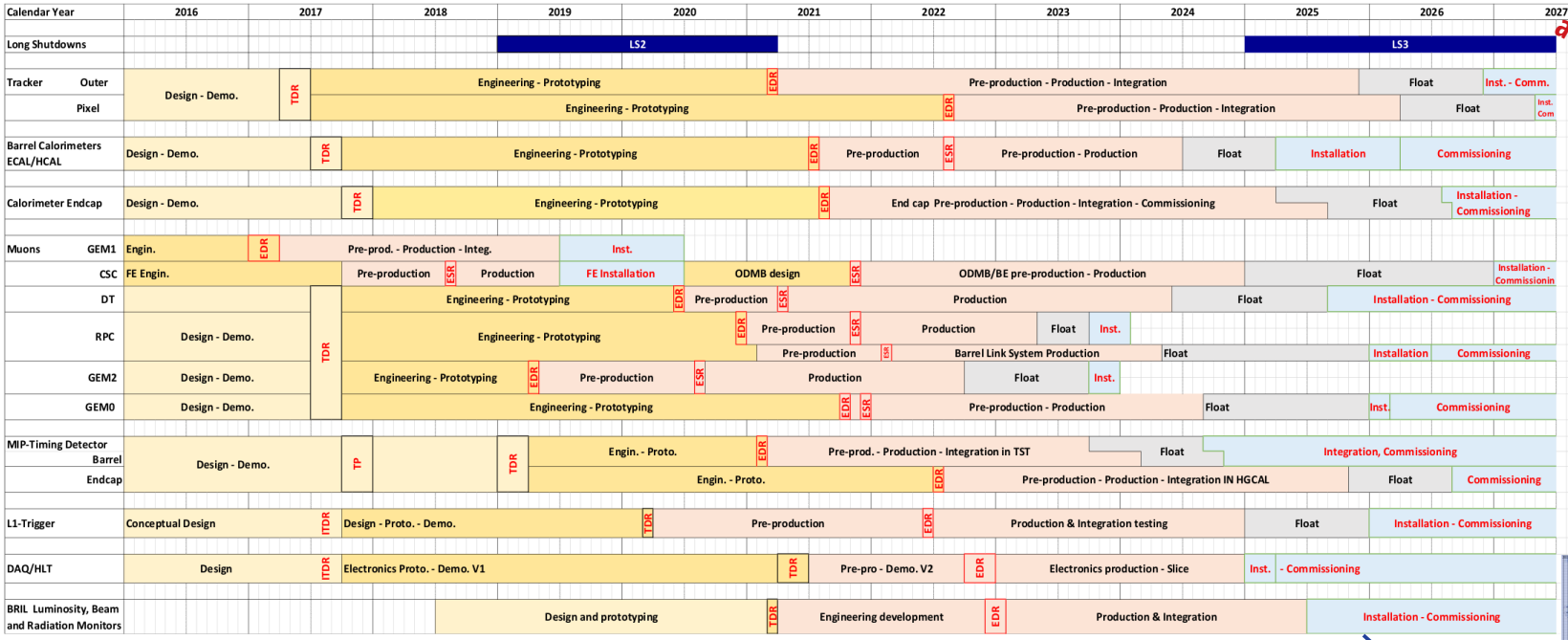
https://cds.cern.ch/record/002706512
Offline bunch-by-bunch (BbB) luminosity with 1% precision for physics
Online (BbB) & orbit integrated luminosity with < 2% precision

New paradigms (design/technology) for an HEP experiment to fully exploit HL-LHC luminosity

+PPS EoI send for info to LHCC

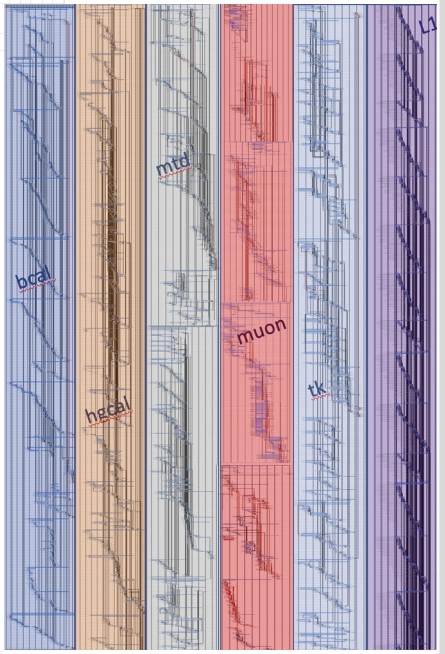
The near and far future for the Phase-2 Upgrade

The overview...



No Covid adjustments

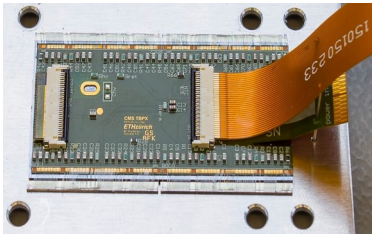
...and all details



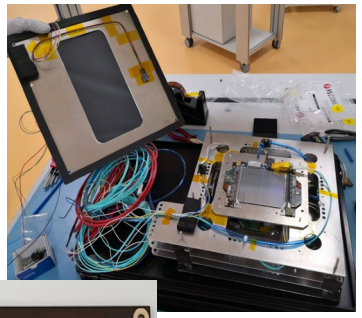
- Project schedules have been adapted to account for shift of LS3
  - Increase of internal float (risk mitigation) where reasonable
  - Healthy end float remains
- Installation of Phase-2 Upgrade in **LS2**, **YETS23/24** and **LS3**
- DAQ/HLT and BRIL TDR due Q2 2021
- Farther in the future: Computing TDR

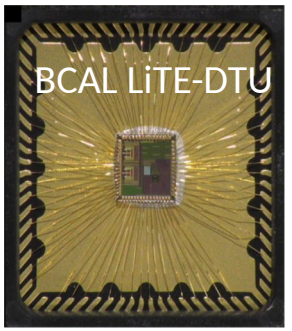
Some highlights from the detectors

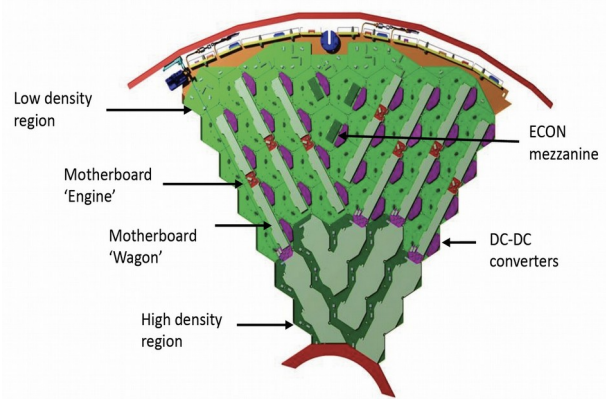
- Tracker
  - Mini Tracker – several OT modules built in short time for test beam – latest hybrids have production quality
  - OT sensor production started at HPK
  - Currently Building O(100) pixel modules for system test
- HGCAL
  - Final 8” sensor prototypes imminent
  - Good progress on electronics architecture
  - Excellent progress on mechanics: CE-E., CE-H, Thermal Screen
- Good progress in BCAL electronics
  - CATIA in hand and LiTE-DTU1.2 has been submitted
- MTD BTL ASIC TOFHIR2V1 back from foundry
- First GEM ME0 prototype module
- Procurement Readiness Reviews in full swing
  - TK OT: Silicon Sensors PRR: **passed**
  - TK OT: composite materials PRR: **passed**
  - TK OT: CBC ASIC PRR: **passed**
  - MTD: Crystal Matrices PRR **passed**

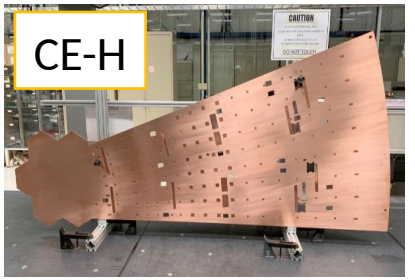


A quad-chip module prototype





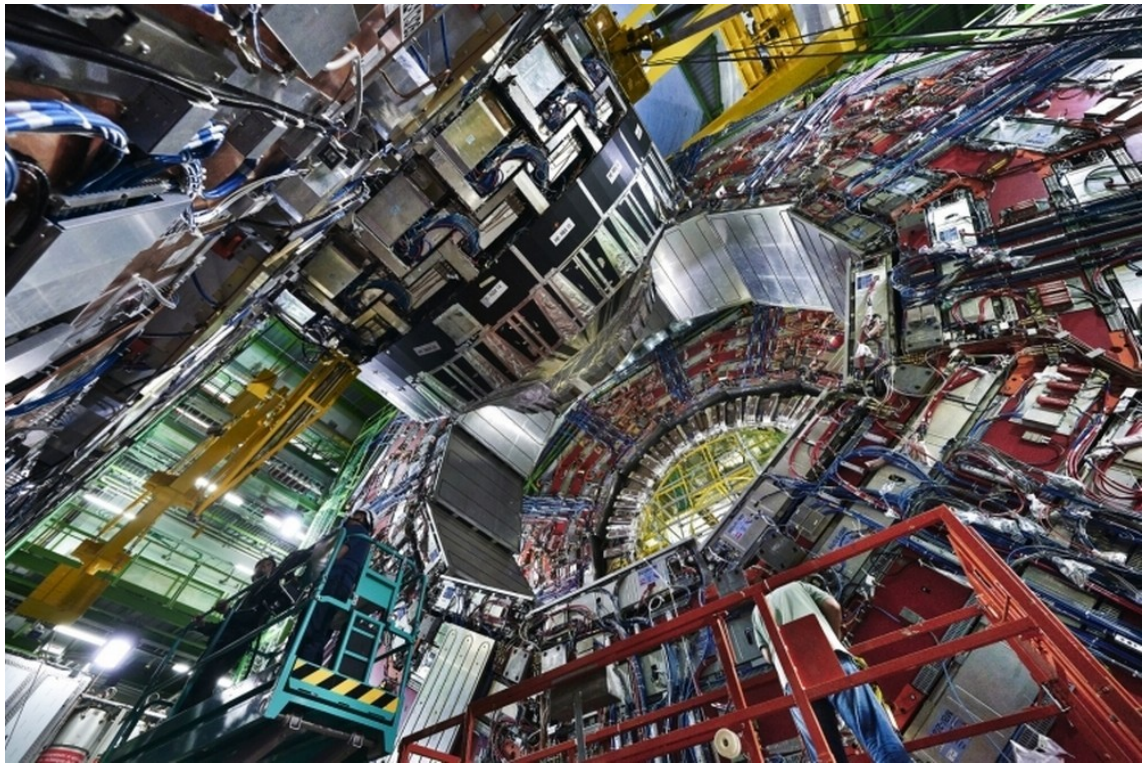




Conclusions

- Obviously also CMS is heavily affected by the Covid pandemic
  - Activities are now slowly restarting at CERN and around the world
  - Preparations for Run 3 continue
- CMS Magnet has been warmed up to room temperature
  - Work on vacuum system is underway
- Rich physics harvest of Run 2 continues
  - 18 new published or submitted papers since last LHCC session
  - 31 new public results
- Legacy reprocessing of Run 2 data is close to completion
  - Starting MC production for physics analyses
- Upgrade
  - Schedule has been re-baselined for shifted LS3 start
  - Work in many areas is continuing despite pandemic
  - L1 Trigger TDR in last review phase
  - Some projects are fast approaching (pre-)production

Thank you
for
your attention

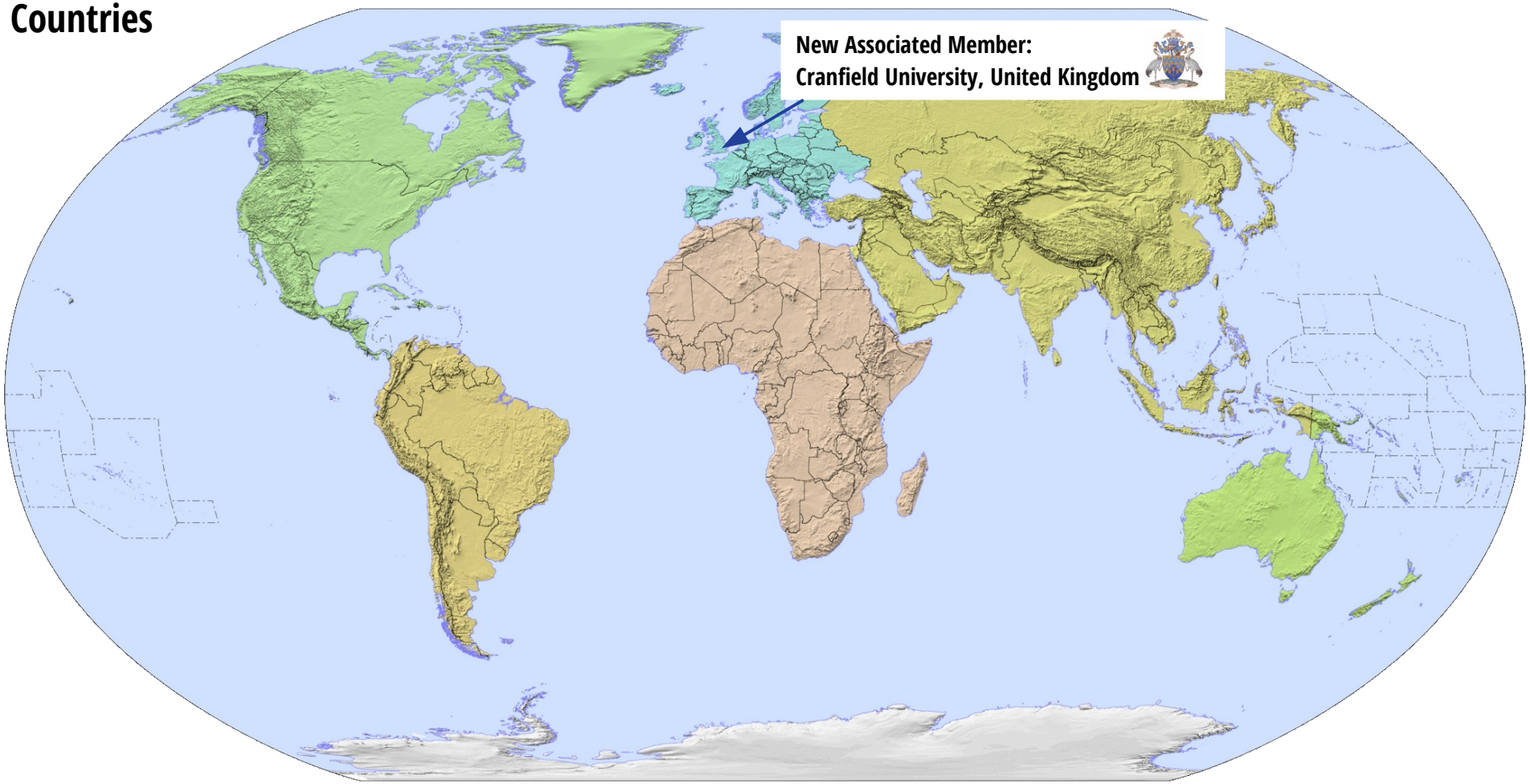


BACKUP

New Institutes in CMS

237 Institutes (including 21 Associated and 8 Cooperating)

55 Countries



1 application for associated membership under consideration

https://ian.macky.net/pat/map/world/world_robinson_blue_shaded_conts_pol2_md.gif