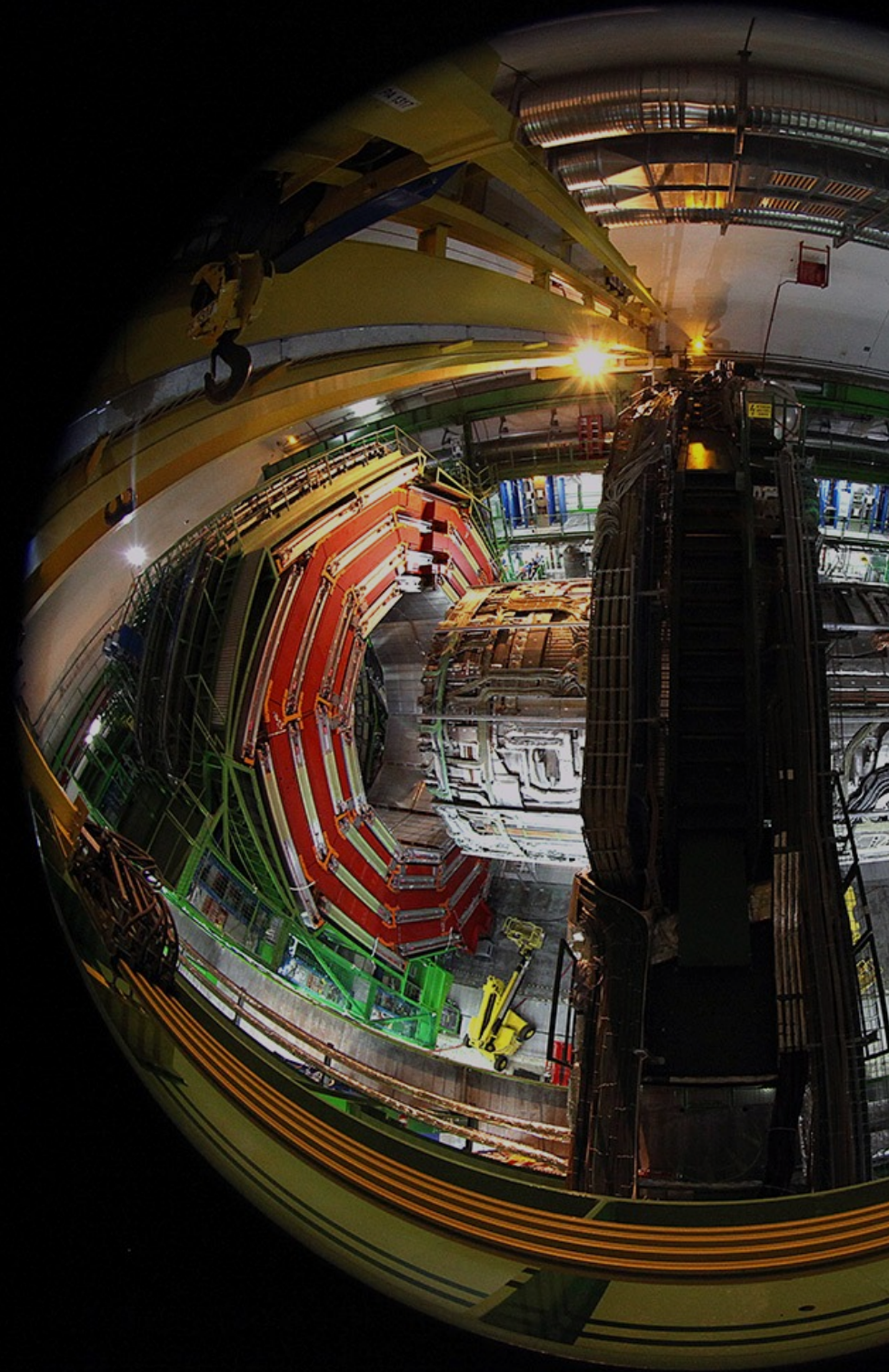


*Status report of the*  
**CMS Experiment**

*144<sup>th</sup> LHCC Meeting Open Session, 18 Nov 2020*

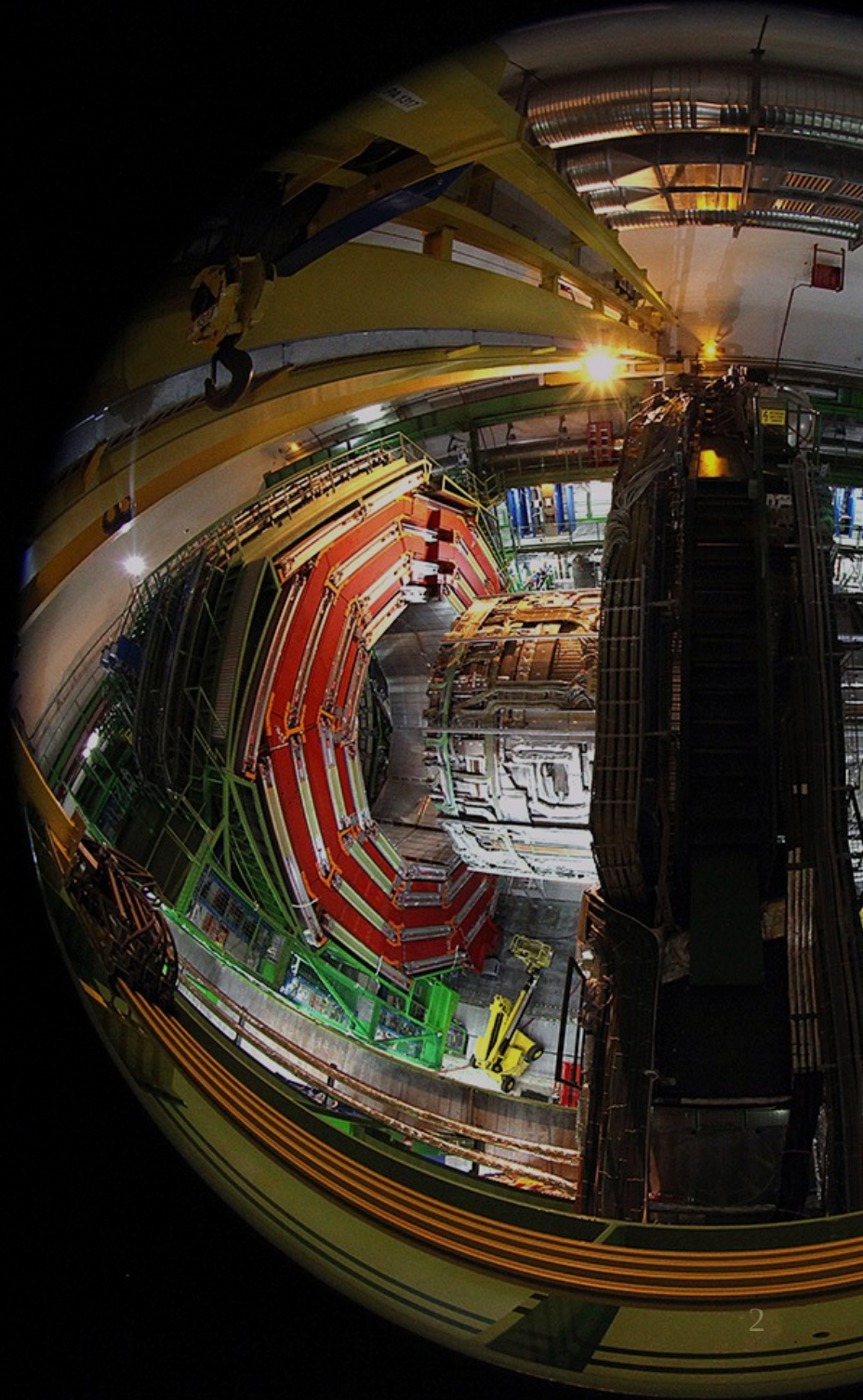


Abideh Jafari,  
for the CMS collaboration

**HELMHOLTZ**  
SPITZENFORSCHUNG FÜR  
GROSSE HERAUSFORDERUNGEN

# Outline

- CMS activities during LS2
- Computing & Data production
- Publications and physics highlights
- Progress with upgrade



# Muon system marked a milestone!

The **GE1/1** section of the muon GEM\* detectors has finished the installation of the chambers

→ Commissioning ongoing

*The first Phase-2 upgrade finished in LS2!*

Services for future\*\* GE2/1 and RPC installation complete



*In the occasion of 144<sup>th</sup> LCC open meeting!*

\* GEM: gas electron multiplier

\*\* Chamber installation during End Year Technical Stop 23/24

# Covid impact

COVID-19

**PROTECT YOURSELF AND OTHERS** 

**Keep your distance.** 

**Wear a mask.** 

**STILL IMPORTANT:**

-  Wash your hands thoroughly.
-  Avoid shaking hands.
-  Cough and sneeze into a tissue or the crook of your arm.
-  Stay at home if you experience symptoms.
-  Always call ahead before going to the doctor's or the emergency department.

<https://hse.cern>

 [Coronavirus information](#)

CERN version: 18.5.2020

**Work at P5** continues to be organized in work packages (WP)

- WPs proceed in bubbles to limit inter-group interactions
- Most of the work performed by the long-term locally-resident CMS institute staff (CERN users)

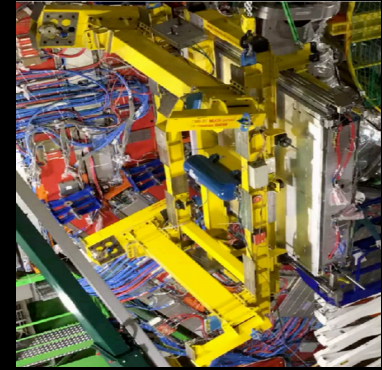
**LS2** schedule re-organized to minimize impact of *~3months* delay

**Upgrades** expect similar impact *~3–5 months*

# Continued LS2 activities: *muon system*

**Drift Tubes** had a successful data taking campaign

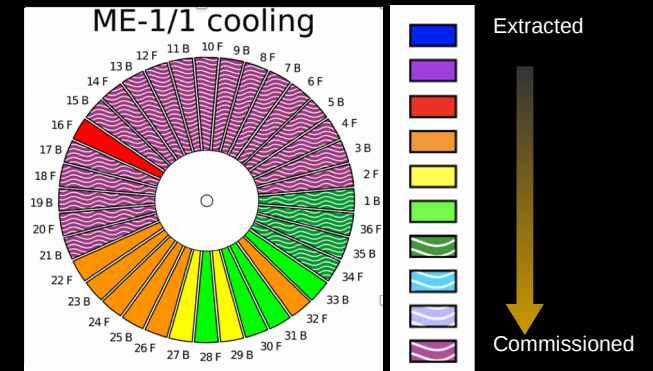
- Demonstrating new Phase-2 electronics architecture
- Evaluating trigger primitive algorithm performance
- LS2 maintenance almost done
- The top MB4 shielding fully installed



*DT Chamber extraction for repair*

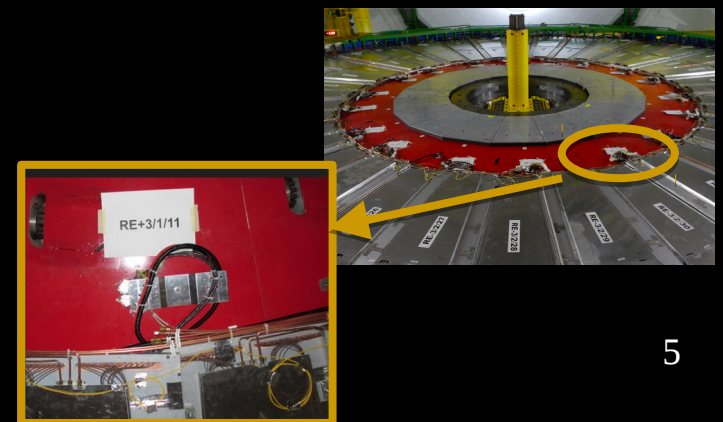
**CSC** electronics replacement finished.

- The new cooling system is in place for ME1/1 and ongoing for ME-1/1



**RPC** has finished the services installation of RE3/1 and 4/1 sections

- Reinstallation of the RE-4 stations (dismounted for CSC electronic refurbishment) is going on and will be finished in a few days.



# Continued LS2 activities

**L1 Muon trigger** advances with Kalman track finding that provides better efficiency for displaced muons

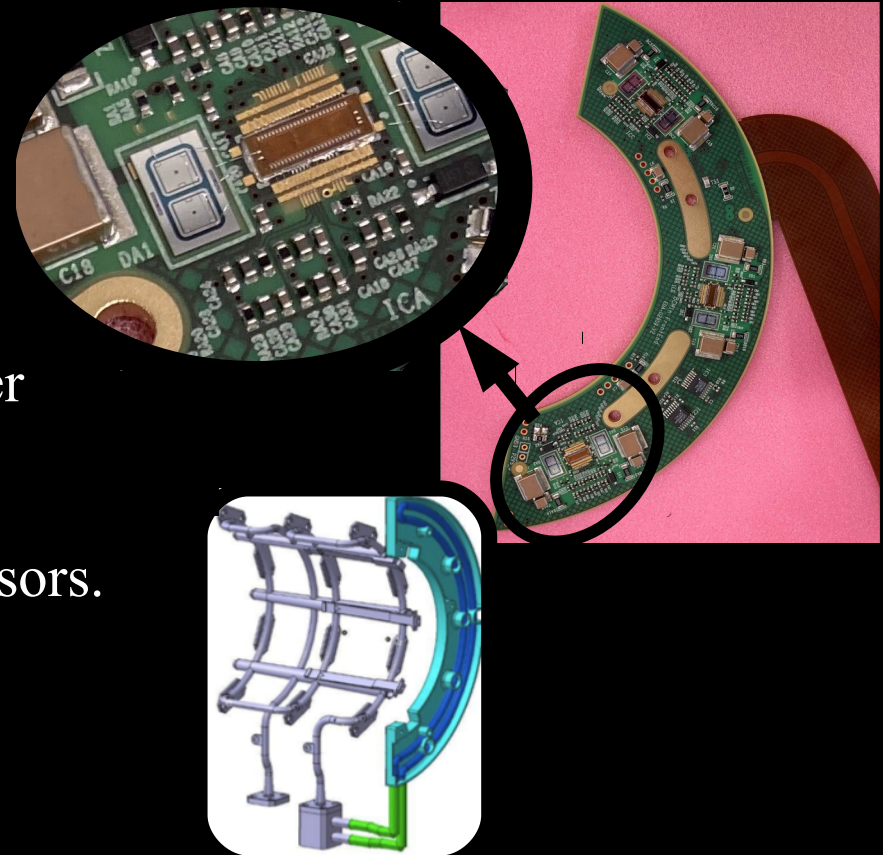
- Changes to firmware and software, being tested now
- Further tuning of the algorithm and seed design ongoing

**BRIL** moves forward with refurbishment and improvement of dedicated luminometers

Fast Beam Conditions Monitor (BCM1F)

- Silicon sensors produced on Phase-2 Tracker PS wafers
- Space for active cooling contacts
- One (out of 4) **PCB fully equipped** incl. sensors.
- Tests showing good performance

**Ongoing:** integration with the pixel telescope luminometers (PLT)



# Continued LS2 activities: *tracker*

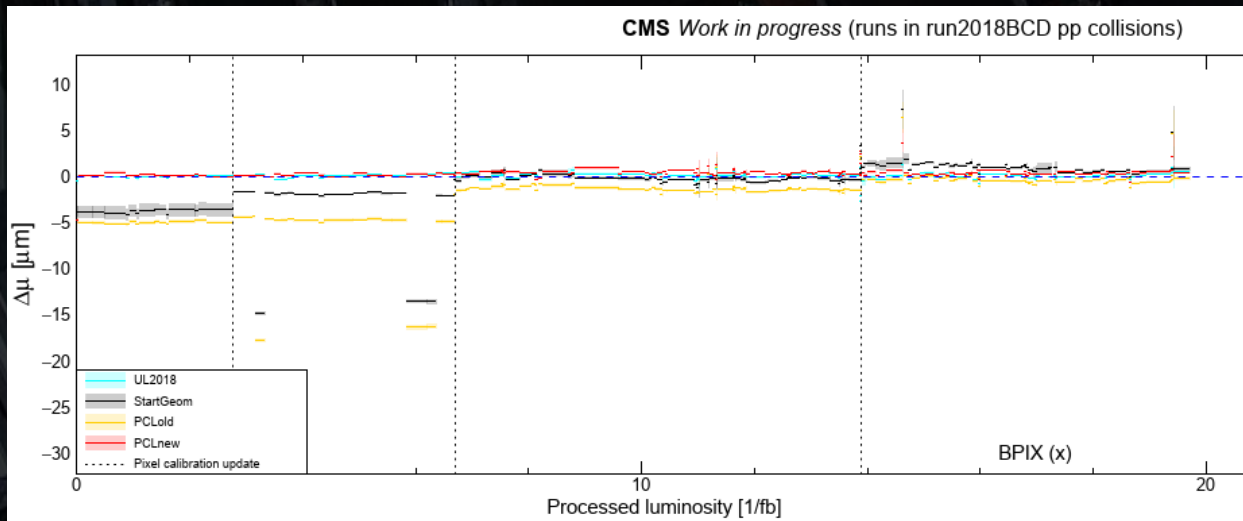
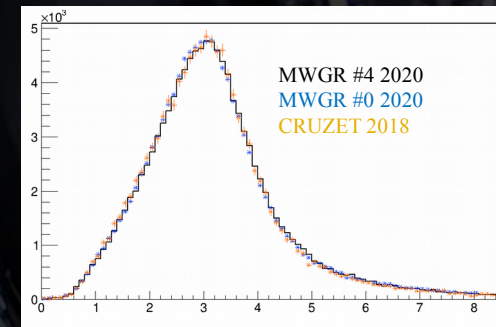
## Strip detector

- Several maintenance carried out on the detector and primary cooling systems
- Recommissioned detector and joined latest global run
- Performance very compatible with 2018 cosmic ray data

## Detector performance

- Alignment method improved in the prompt calibration loop (PCL)
- Quality now approaching that of final Run-2 Legacy\* dataset

*Strip cluster charge in cosmic events*



*Average position bias (times 2)  
after correction by alignment*

# Continued LS2 activities: *tracker*

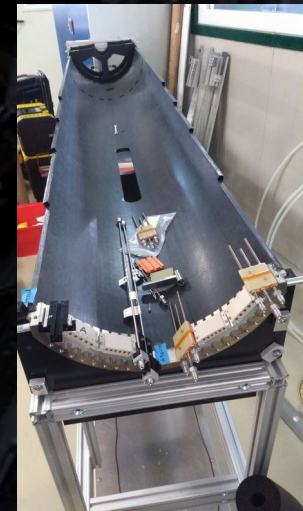
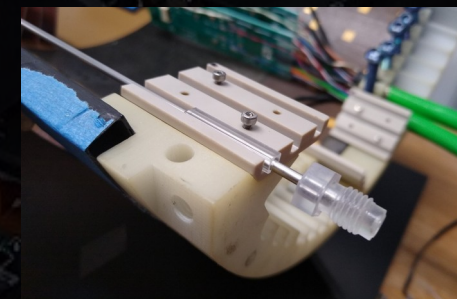
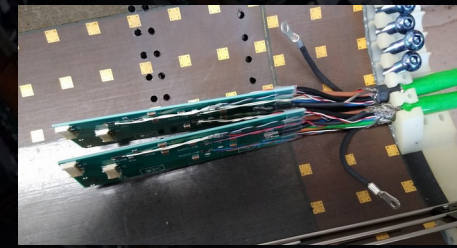
## Barrel Pixel

- New layer 1 has arrived to P5
- All modules went through X-ray and calibration tests



## Forward Pixel

- The half-cylinder was checked out and calibrated after long dormant period
- Mock-up is being prepared to exercise the repair work, potentially with remote supervision
  - Compliant with Covid-19 restrictions



## Pixel DAQ

- Improved configuration time before a run
- Established fast reprogramming mechanism of front-end during data-taking



# Continued LS2 activities: *PPS*

## Run II Legacy

- Final proton calibrations for the entire data
- Proton vertex reconstruction from time of flight in 2017+2018 data
- Full characterization of irradiated double-diamonds in test beams
  - Results used to guide improvements for **Run 3**

## Towards Run 3

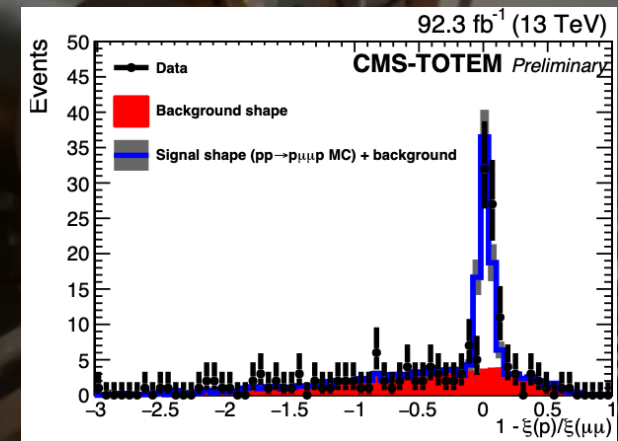
### Completed

- RP reconfiguration for second timing detector station
- Final metrology of both arms, in coll. with survey teams and EP-DT

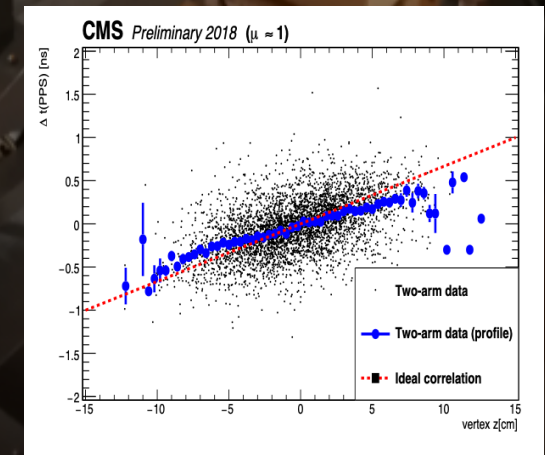
### Ongoing

- Production and tests of new sensors and electronics, for both tracking and timing detectors
- New automated calibration procedures

*Calibration validation with single-arm  $\gamma\gamma \rightarrow \mu\mu$  data*



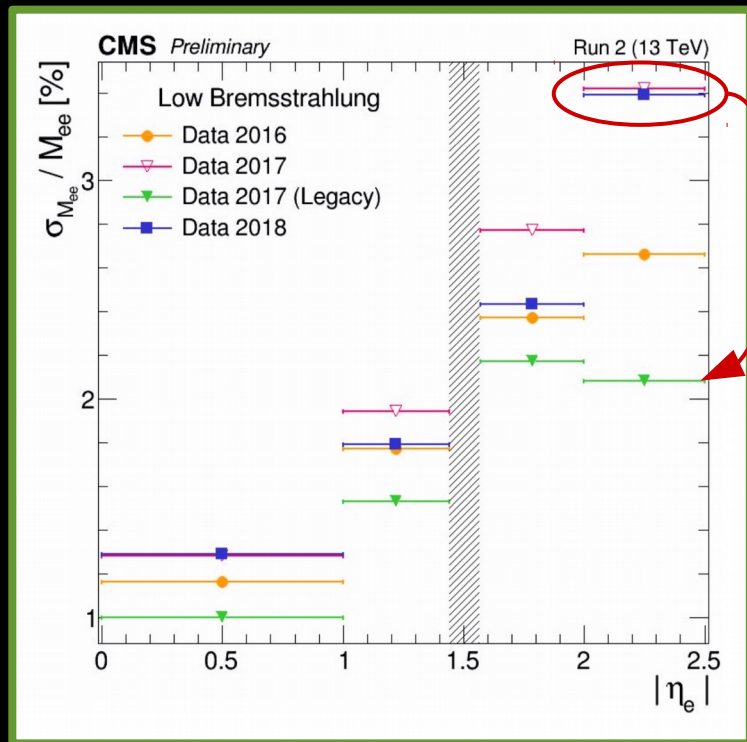
CERN-CMS-DP-2020/047



CERN-CMS-DP-2020/046

*Vertex reco. validated with 2-arm events in low-pileup*

# Run-2 legacy dataset performance

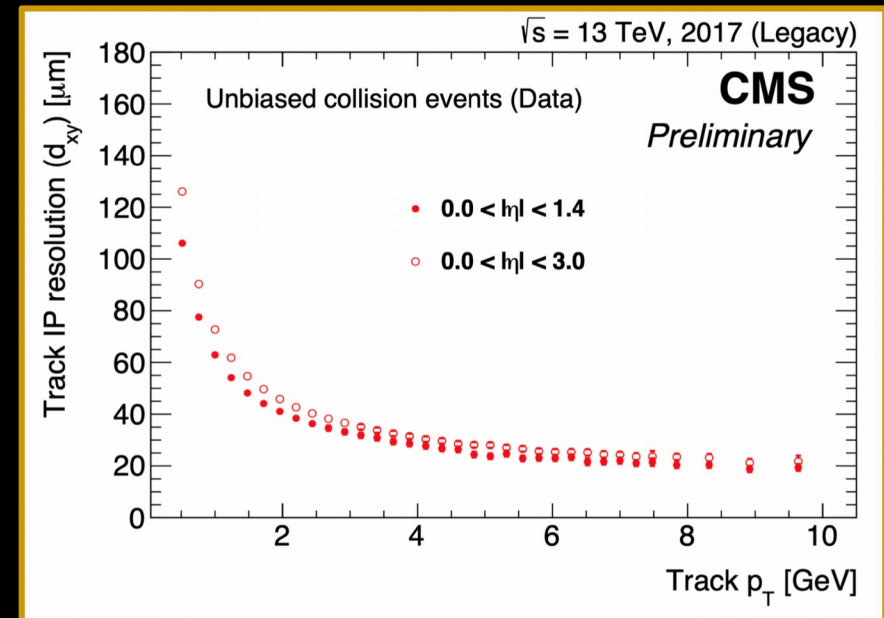


Improved resolution in  $Z (\rightarrow ee)$  boson mass

- Particularly in the endcap for 2017 data
- Similar improvement expected in 2018!

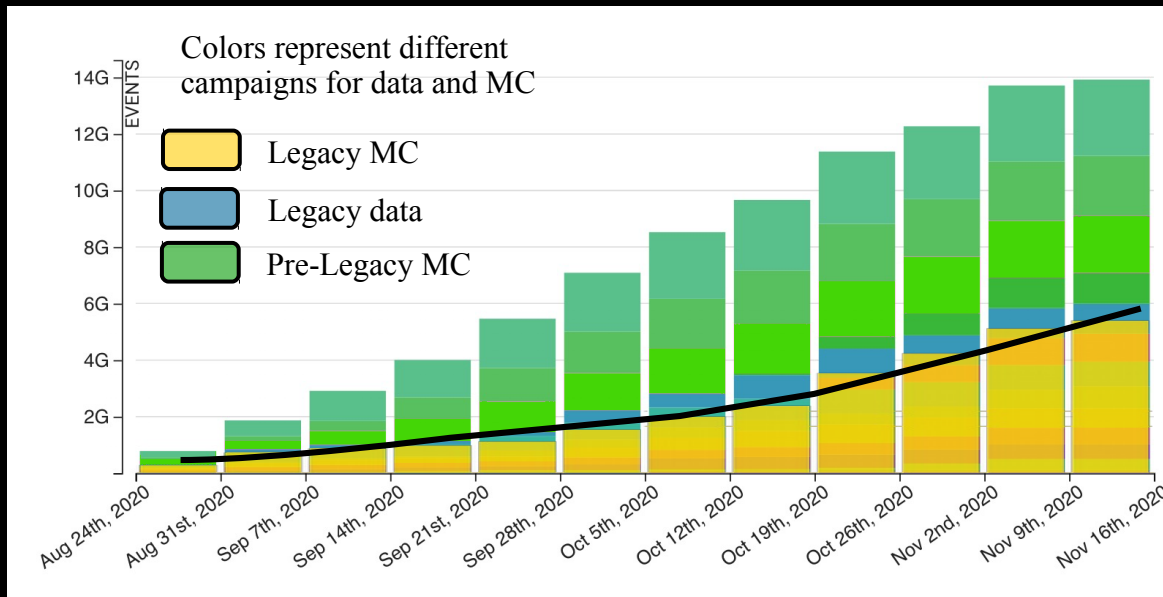
Reliable baseline to assess the detector performance:

- Phase-1 Pixel improves over phase-0 by 20–30% in track IP resolution



Track IP resolution with Phase-1 Pixel detector

# Monte Carlo and Data production



Now moving from production of Run-2 “Pre-Legacy” Simulation to:  
Run-2 “Legacy” MC Simulation for continued physics analysis

Over the past 12 weeks, total of 14B unique events produced:

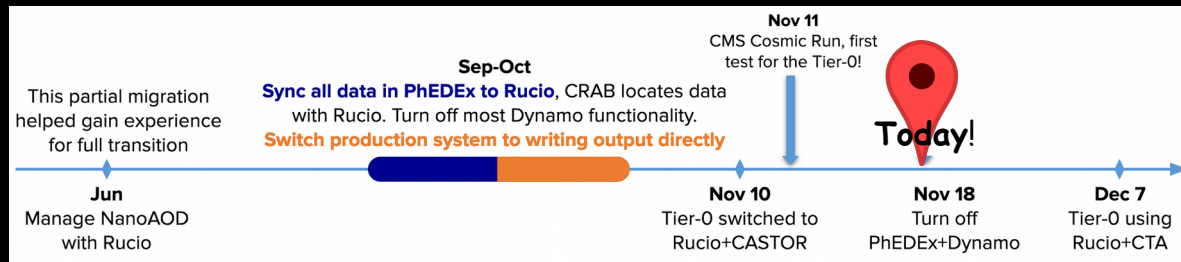
- 7B events of “pre-Legacy” MC: → ~1B events over the next months
- 5B “Legacy” MC events: → additional 20B events by early 2021
- 2B data events: tail of Run-2 “Legacy” Re-Reconstruction

**Next:** update existing MiniAOD and NanoAOD with latest calibrations and corrections

# Software and Computing

*Substantial progress towards Run 3 & Phase-2, in software & computing tools areas*

- New data management tool, Rucio, deployed according to schedule
- No interruption of service visible to the experiment, e.g. user or production jobs



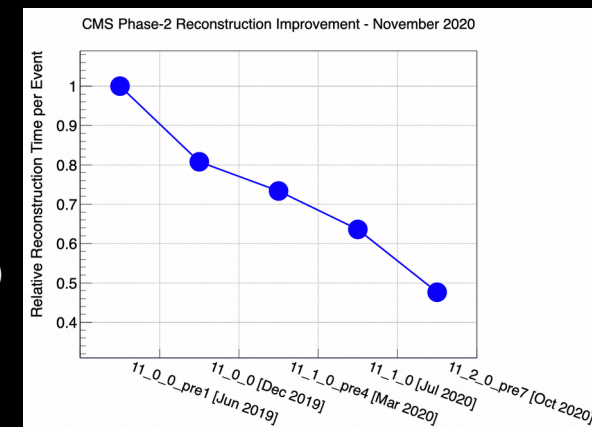
Transition succeeded with no production system downtime!

Phase-2 reconstruction was made *two times faster* wrt 1.5 year ago

- Joint efforts of many groups committed to the same goal
- Widespread usage of cutting edge profiling tools
- New compilers, vectorisation, efficient code, best programming practices
- Algorithmic refinements, e.g. behavior at high pile up (140-200)

Several new features integrated

CMS plans to pursue this effort in the future

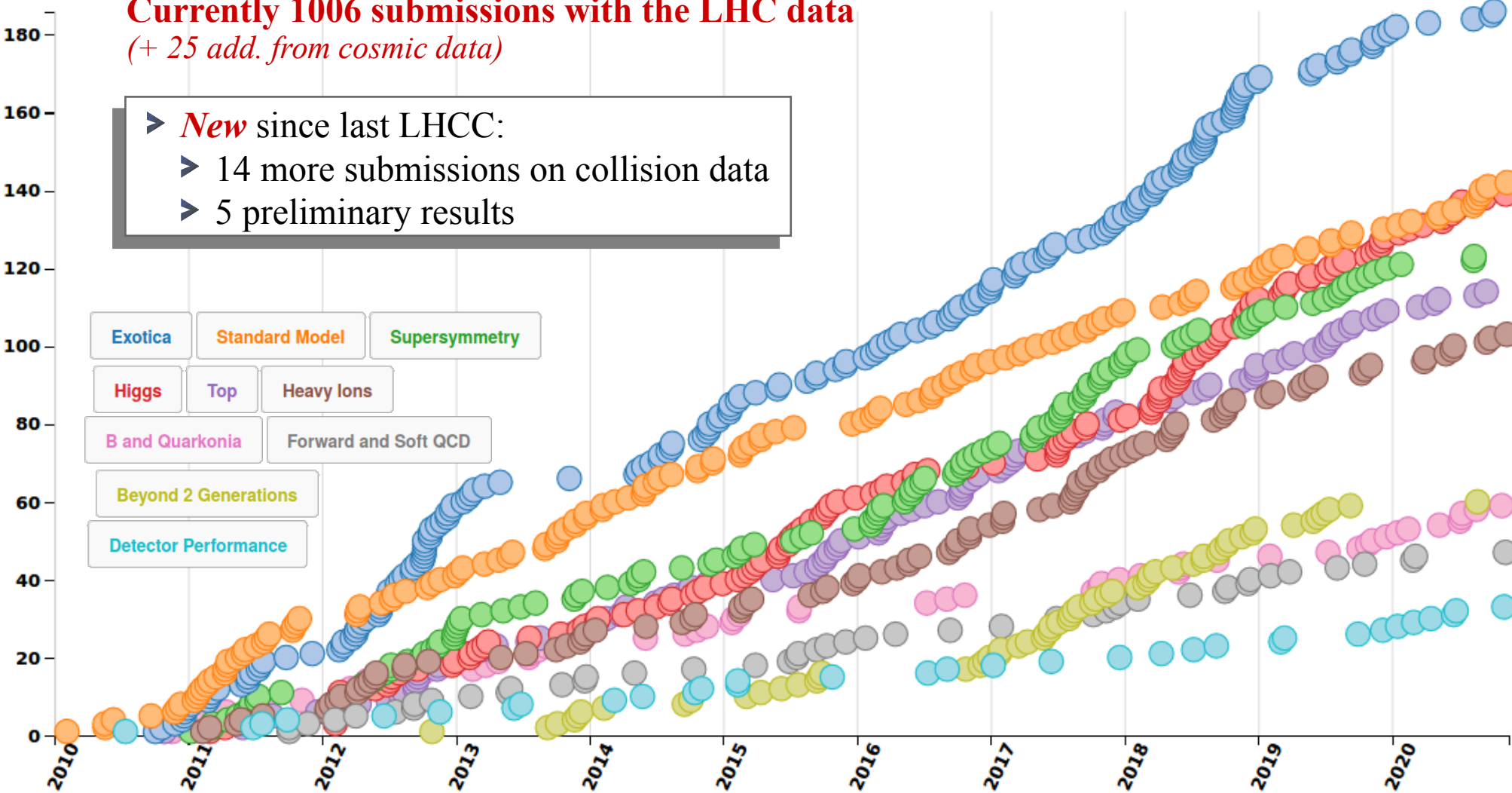


# 1000<sup>th</sup> submission with LHC data on Oct. 6<sup>th</sup>

Currently 1006 submissions with the LHC data  
(+ 25 add. from cosmic data)

- *New* since last LHCC:
  - 14 more submissions on collision data
  - 5 preliminary results

CMS Collision papers submitted to journals



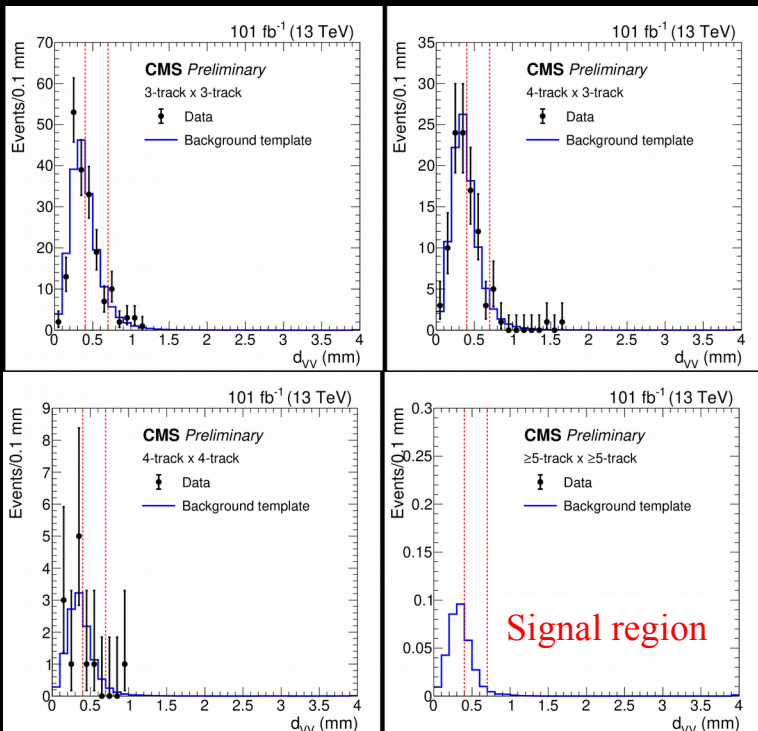
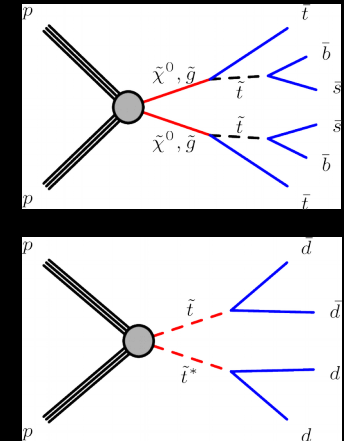
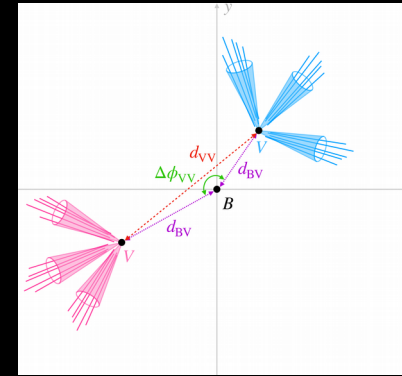
# Search for LLP decaying to jets with displaced vertices

CMS-PAS-EXO-19-013

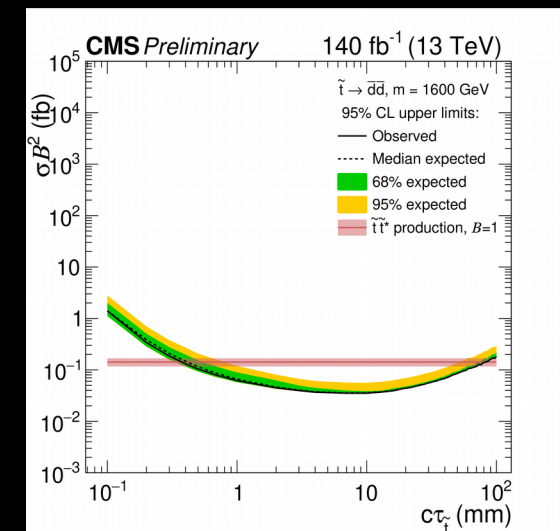
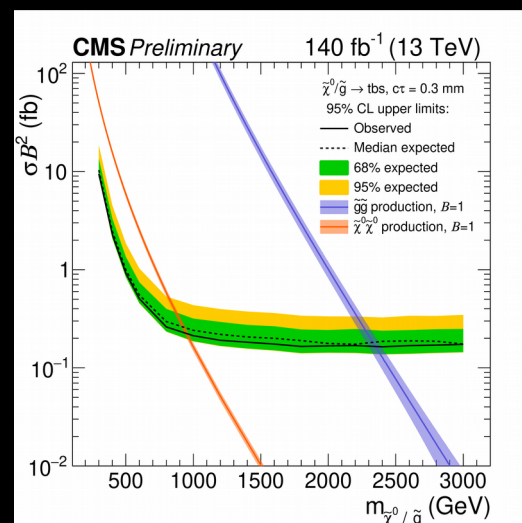
- Full Run 2 analysis 2015 to 2018, corresponding to a total integrated luminosity of  $140 \text{ fb}^{-1}$
- Target Long Lived Particles with mean decay length  $0.1\text{--}100 \text{ mm}$  each decaying into two or more quarks.
- Decays are searched for within the beam pipe

Search variable:  $d_{VV}$  distance between two vertices

Background: determined from one-vertex data



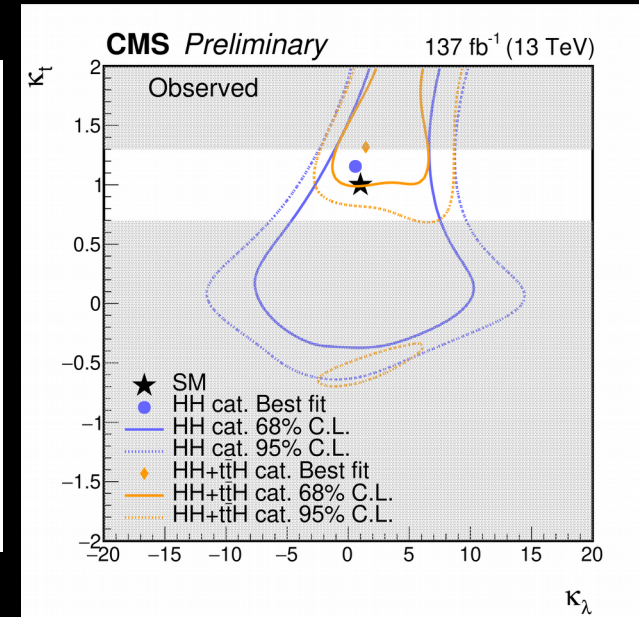
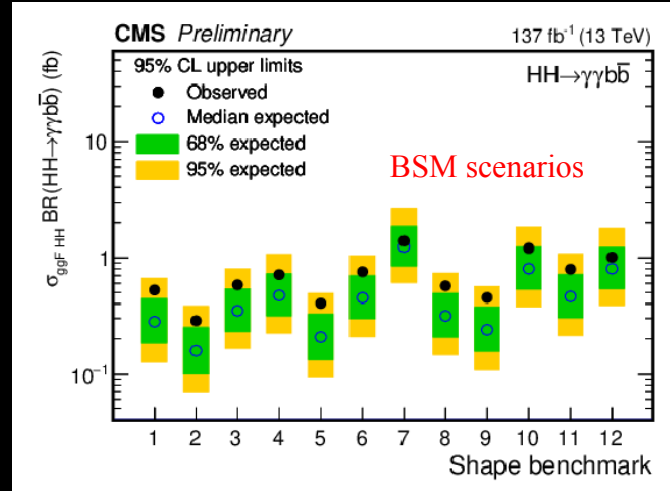
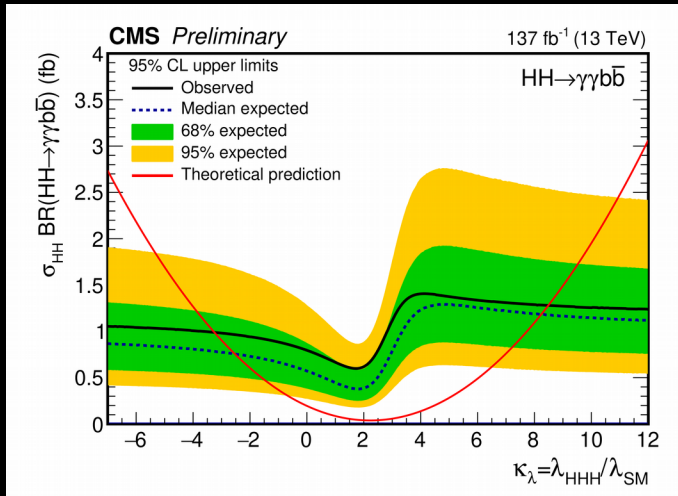
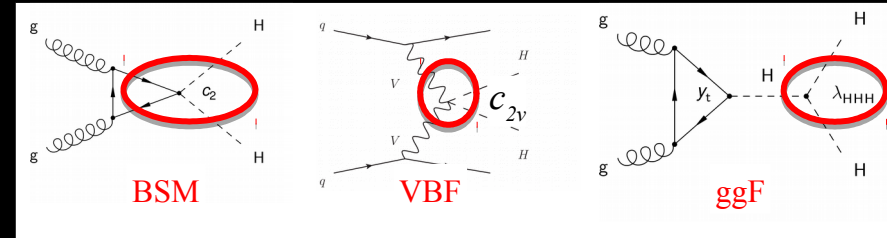
No events observed in signal region, exclusion limits extracted with several assumptions



# Search for non resonant H pair production in $\gamma\gamma b\bar{b}$

CMS-PAS-HIG-19-018

- Analysis of ggF and VBF topologies with  $137 \text{ fb}^{-1}$
- Sensitive to different Higgs couplings
- Combination with  $ttH(\gamma\gamma)$  for simultaneous constraints on  $\kappa_\lambda$  and  $\kappa_t$
- Constraints on many BSM benchmarks

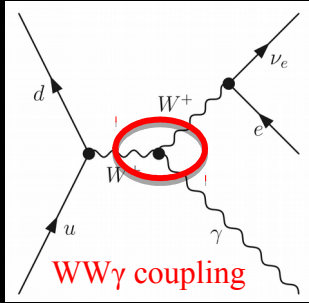


Observed (expected) bounds @ 95% CL:  
 $\sigma_{HH} \text{B}(HH \rightarrow \gamma\gamma b\bar{b}) < 0.67$  (0.45) fb  
 $\rightarrow 7.7$  (5.2)  $\times \text{SM}$

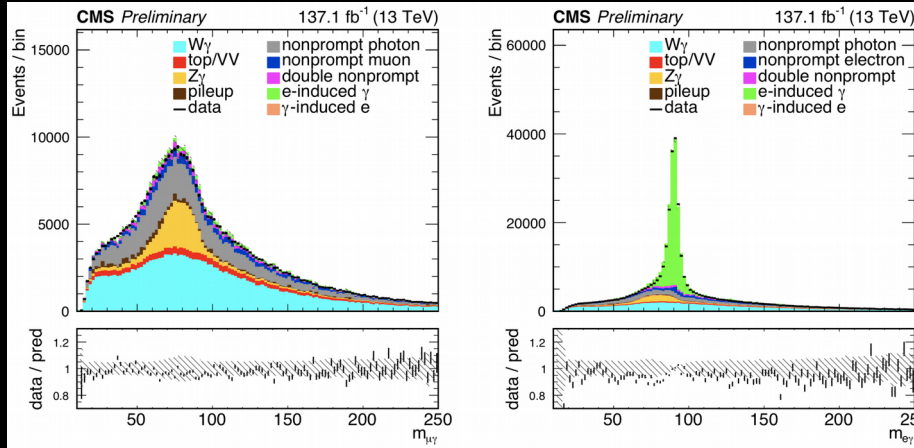
# Inclusive $W\gamma$ production and EFT constraints



First measurement of  $\sigma_{W\gamma}$  at 13 TeV with  $137 \text{ fb}^{-1}$  in the  $e/\mu$  channels



CMS-PAS-SMP-19-002



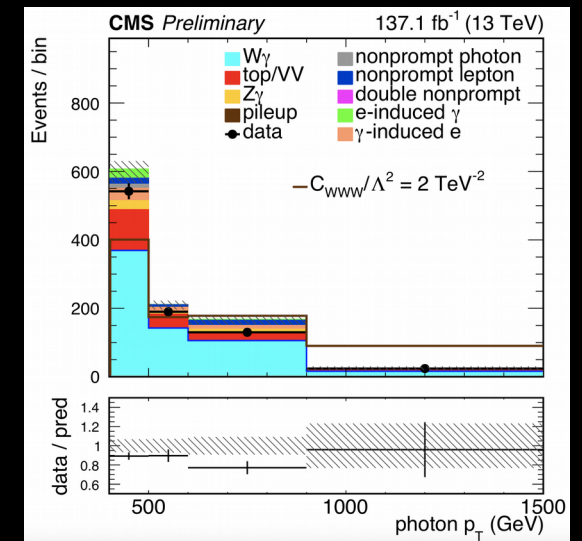
$\sigma_{W\gamma} = 15.58 \pm 0.75 \text{ pb}$   
4.5% precision!

Limits on dim-6 EFT operators affecting  $WW\gamma$ , using photon  $p_T$

Most stringent to date!

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{c_{WWW}}{\Lambda^2} \mathcal{O}_{WWW} + \frac{c_W}{\Lambda^2} \mathcal{O}_W + \frac{c_B}{\Lambda^2} \mathcal{O}_B + \frac{c_{W\tilde{W}W}}{\Lambda^2} \mathcal{O}_{W\tilde{W}W} + \frac{c_{\tilde{W}}}{\Lambda^2} \mathcal{O}_{\tilde{W}}$$

Coefficient	Exp. Lower	Exp. Upper	Obs. Lower	Obs. Upper
$c_{WWW}/\Lambda^2$	-0.85	0.87	-0.90	0.91
$c_W/\Lambda^2$	-45.5	44.6	-39.7	40.7
$c_B/\Lambda^2$	-45.5	44.6	-39.7	40.7
$c_{\tilde{W}W}/\Lambda^2$	-0.4	0.4	-0.45	0.45
$c_{\tilde{W}}/\Lambda^2$	-22.8	22.3	-20.3	20.0





# Search for CP violating anomalous top quark couplings

CMS-PAS-TOP-18-007

- Use  $t\bar{t}$  events with 2 leptons in 2016 data
- Measure the asymmetry of the Levi-Civita tensors of the four-momenta of charged leptons, jets originating from b quarks, and top quarks.

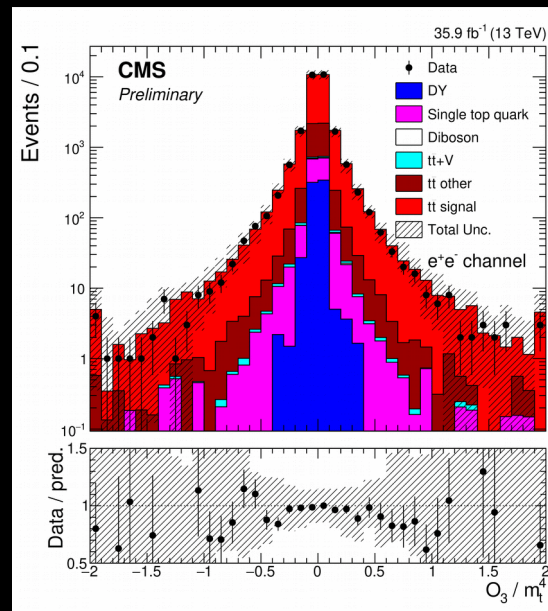
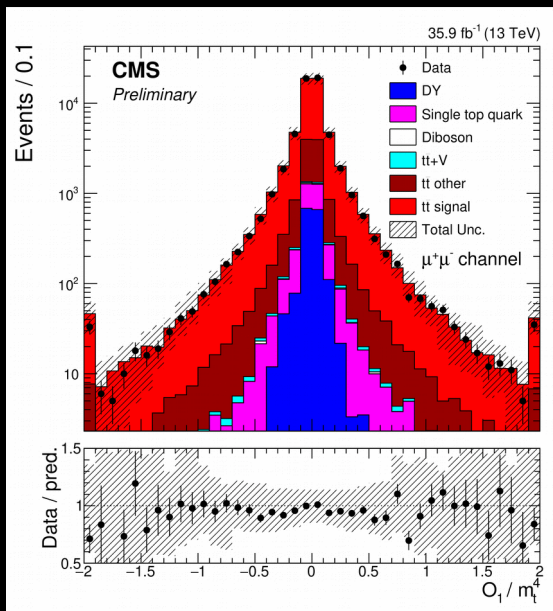
*Levi-Civita tensors  $\mathcal{O}_1$  and  $\mathcal{O}_3$*

$$\mathcal{O}_1 = \epsilon(p_t, p_{\bar{t}}, p_{\ell^+}, p_{\ell^-}) = \begin{vmatrix} E_t & p_{t_x} & p_{t_y} & p_{t_z} \\ E_{\bar{t}} & p_{\bar{t}_x} & p_{\bar{t}_y} & p_{\bar{t}_z} \\ E_{\ell^+} & p_{\ell^+_x} & p_{\ell^+_y} & p_{\ell^+_z} \\ E_{\ell^-} & p_{\ell^-_x} & p_{\ell^-_y} & p_{\ell^-_z} \end{vmatrix}$$

$$\mathcal{O}_3 = \epsilon(p_b, p_{\bar{b}}, p_{\ell^+}, p_{\ell^-}) = \begin{vmatrix} E_b & p_{b_x} & p_{b_y} & p_{b_z} \\ E_{\bar{b}} & p_{\bar{b}_x} & p_{\bar{b}_y} & p_{\bar{b}_z} \\ E_{\ell^+} & p_{\ell^+_x} & p_{\ell^+_y} & p_{\ell^+_z} \\ E_{\ell^-} & p_{\ell^-_x} & p_{\ell^-_y} & p_{\ell^-_z} \end{vmatrix}$$

*Asymmetry definition*

$$A_i = \frac{N(\mathcal{O}_i > 0) - N(\mathcal{O}_i < 0)}{N(\mathcal{O}_i > 0) + N(\mathcal{O}_i < 0)}$$



Asymmetries consistent with 0, CEDM consistent with the SM (negligibly small)

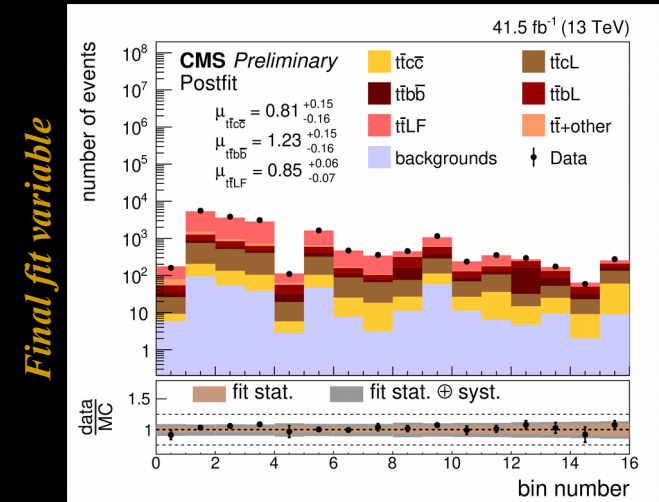
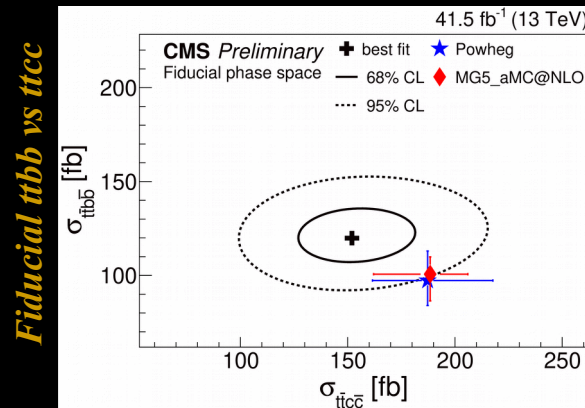
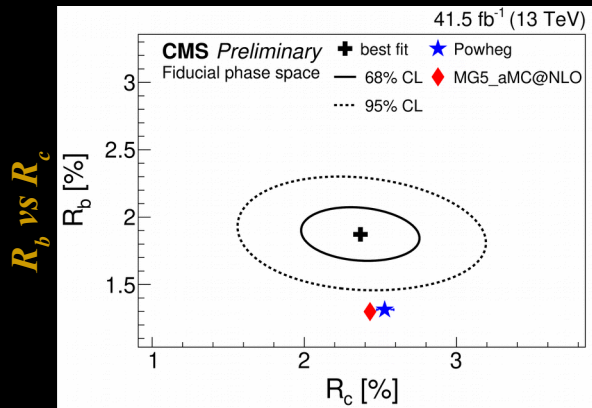
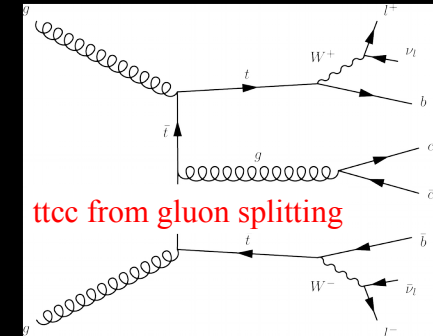
Physics observable	$d_{tG}$	CEDM ( $10^{-18} \text{ g}_s \cdot \text{cm}$ )
$\mathcal{O}_1$	$0.10 \pm 0.12(\text{stat}) \pm 0.12(\text{syst})$	$0.58 \pm 0.69(\text{stat}) \pm 0.70(\text{syst})$
$\mathcal{O}_3$	$0.00 \pm 0.13(\text{stat}) \pm 0.10(\text{syst})$	$-0.01 \pm 0.72(\text{stat}) \pm 0.58(\text{syst})$

# First measurement of inclusive ttcc cross section

The tt+HF is an irreducible background to ttH, hard to model  
 A coherent measurement, simultaneously measure ttcc, ttbb, ttLF and  
 $R_{c/b} = \sigma(ttcc/ttbb)/\sigma(ttjj)$

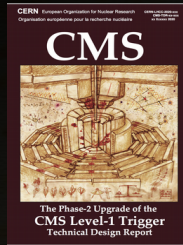
Key ingredients:

- Exploit ML techniques for the event hypothesis and signal extraction
- Rely on charm-jet identification
- Full shape calibration of the c-tagger discriminants



Precision in the fiducial phase space: 20% ttcc, 13% ttbb, 9% ttLf  
 Maximum tension with predictions: ~2.5σ for R<sub>b</sub>, confirming previous ttbb results

# CMS Upgrade – our future unprecedented beauty



## L1-Trigger HLT/DAQ

<https://cds.cern.ch/record/2714892>

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

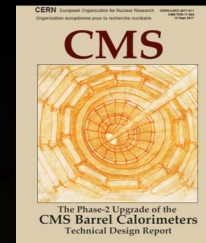
- Tracks in L1-Trigger at 40 MHz
- PFlow selection 750 kHz L1 output
- HLT output 7.5 kHz
- 40 MHz data scouting

DAQ/HLT TDR Q2.2021

## Barrel Calorimeters

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

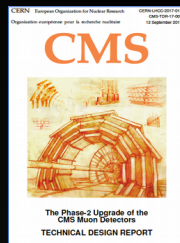
- ECAL crystal granularity readout at 40 MHz with precise timing for  $e/\gamma$  at 30 GeV
- ECAL and HCAL new Back-End boards



## Muon systems

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

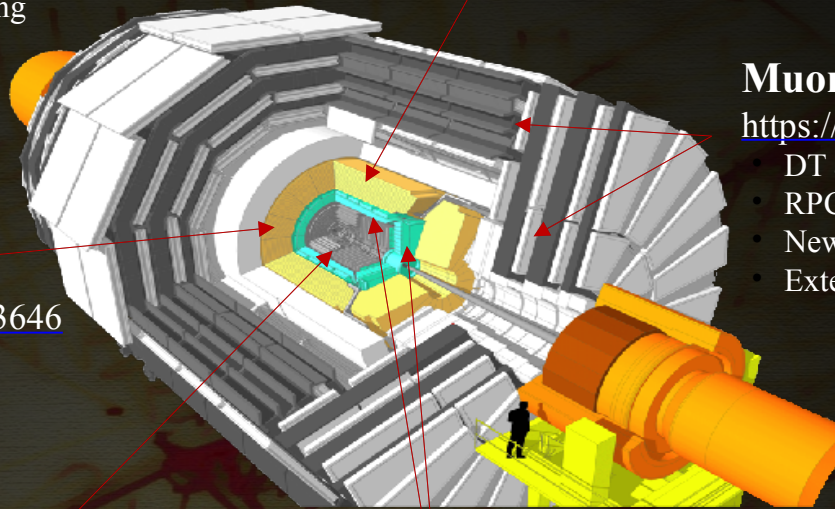
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC  $1.6 < \eta < 2.4$
- Extended coverage to  $\eta \approx 3$



## Calorimeter Endcap

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

- 3D showers & precise timing
- Si, Scint+SiPM in Pb/W-SS



## Beam Radiation Instr. and Luminosity

<http://cds.cern.ch/record/002706512>

- Bunch-by-bunch luminosity measurement: 1% offline, 2% online

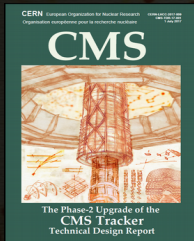
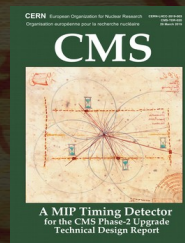
Conceptual Design  
TDR Q2.2021

## MIP Timing Detector

<https://cds.cern.ch/record/2667167>

Precision timing with:

- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes



## Tracker

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

- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to  $\eta \approx 3.8$

General good progress despite Covid-19 (3-5m delay)

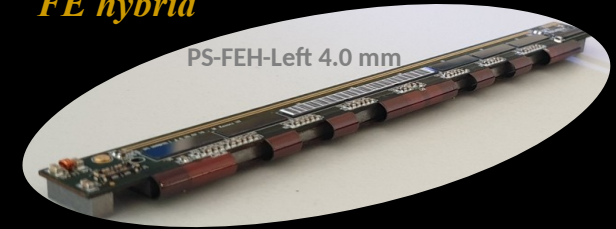
# CMS Upgrade – *our future unprecedented beauty*

PPS EoI completed collaboration-wide review

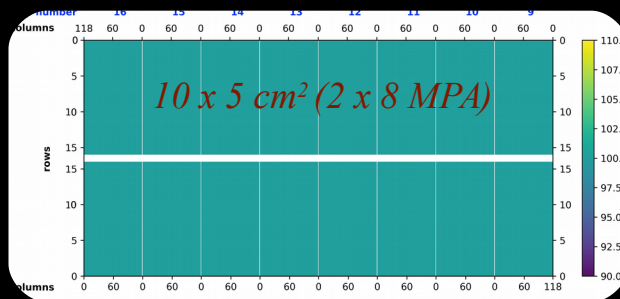
## Outer Tracker (OT)

- CMS Binary Chip ASICS in *production*
- Final prototypes of *all* OT hybrid types in production or in hand
- *Sensor production* and quality control ongoing
- Good results on *large area bump bonding* in PS modules
- Progressing on mechanics

*FE hybrid*



*Sensor QC*



*Channel alive map*

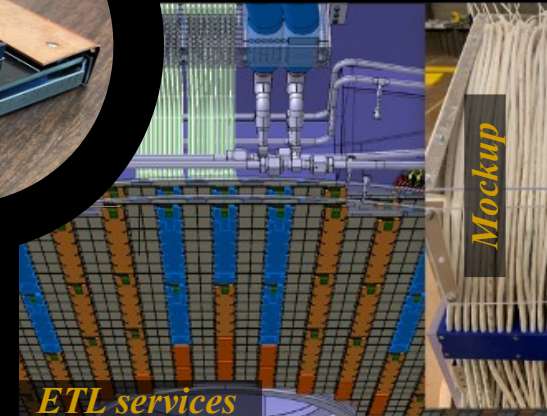


*OT Endcap proto (DEE)*

# CMS Upgrade – *our future unprecedented beauty*

## MIP Timing Detector

- Market survey & proceeding to tender for sensors
  - LYSO, SiPM, LGAD
- Excellent results for ASIC prototypes in barrel & endcap
- Work on reducing the operation temperature
  - Mitigate Dark Count Rate, improve time resolution
    - SiPMs show higher DCR after radiation than anticipated



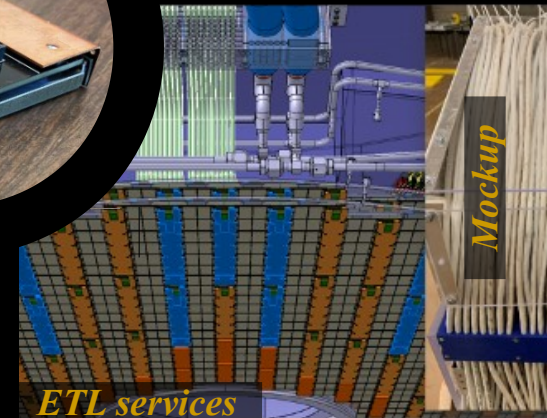
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    - SiPMs show higher DCR after radiation than anticipated



*BTL module*

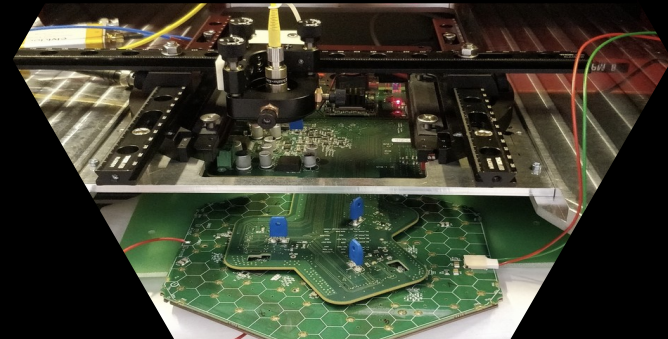
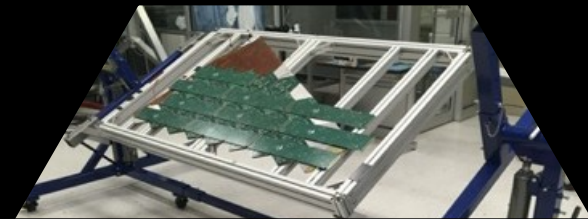


*ETL services*

## HGCAL in full prototype & station setup mode

- HGROC submission by the end of the year
- Good progress on mechanics
- Several perfect 8" silicon sensor received, radiation studies ongoing. One more prototype round to go

*Cassette proto station*



*Laser testing of silicon modules*

# Summary

*CMS is well on track, accounting for delays imposed by Covid-19*

**Lots of activities in sub-detectors to prepare for Run 3**

- The GE1/1 has finished installation
- Commissioning using cosmic rays

**Full speed processing of the data and MC with Legacy conditions**

- Already in use for detector performance studies and upcoming physics analyses

**Achievements in software and computing using advanced techniques**

- A factor of two gain in speed for Phase-2 reconstruction!
- New data management tool in place

**A wealth of physics results in various areas**

- 1006 papers on LHC data (+25 on cosmic data) submitted to journals.  
14 submissions since last LHCC

**Remarkable progress with Phase-2 upgrade in different directions**

- Real production started for part of the program





