

143rd LHCC Meeting Open Session on Sep 2nd, 2020

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On behalf of the CMS Collaboration



CMS STATUS REPORT

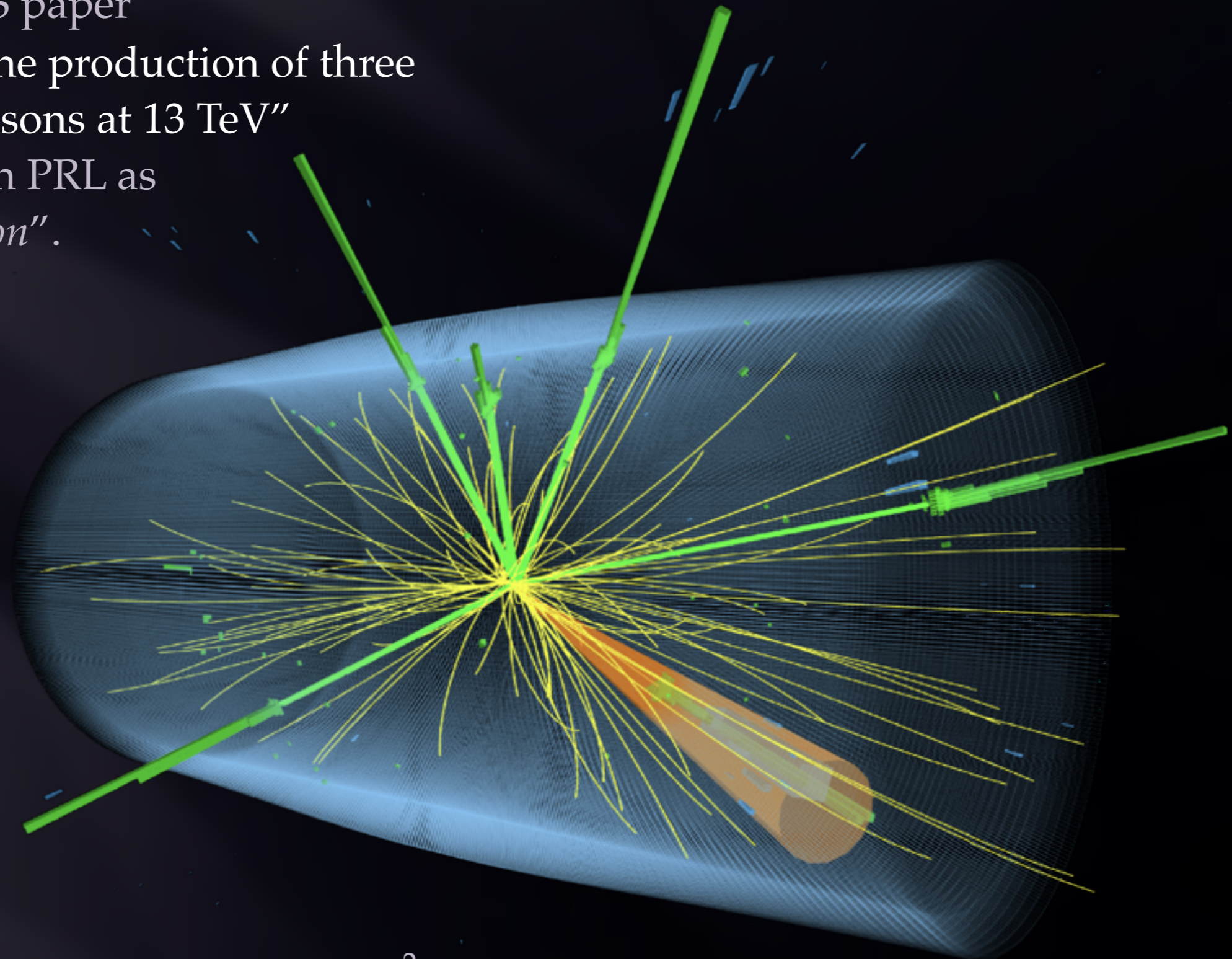
Cover Story

1000th CMS paper

“Observation of the production of three massive gauge bosons at 13 TeV”

to be published on PRL as

“Editors’ Suggestion”.



Ref.
CMS-SMP-19-014
CERN-EP-2020-076
[arXiv:2006.11191](https://arxiv.org/abs/2006.11191)



Outline

CMS Status at Point 5

Recent LS2 Activities

Computing & Data Production

Physics Highlights

Upgrade Activities

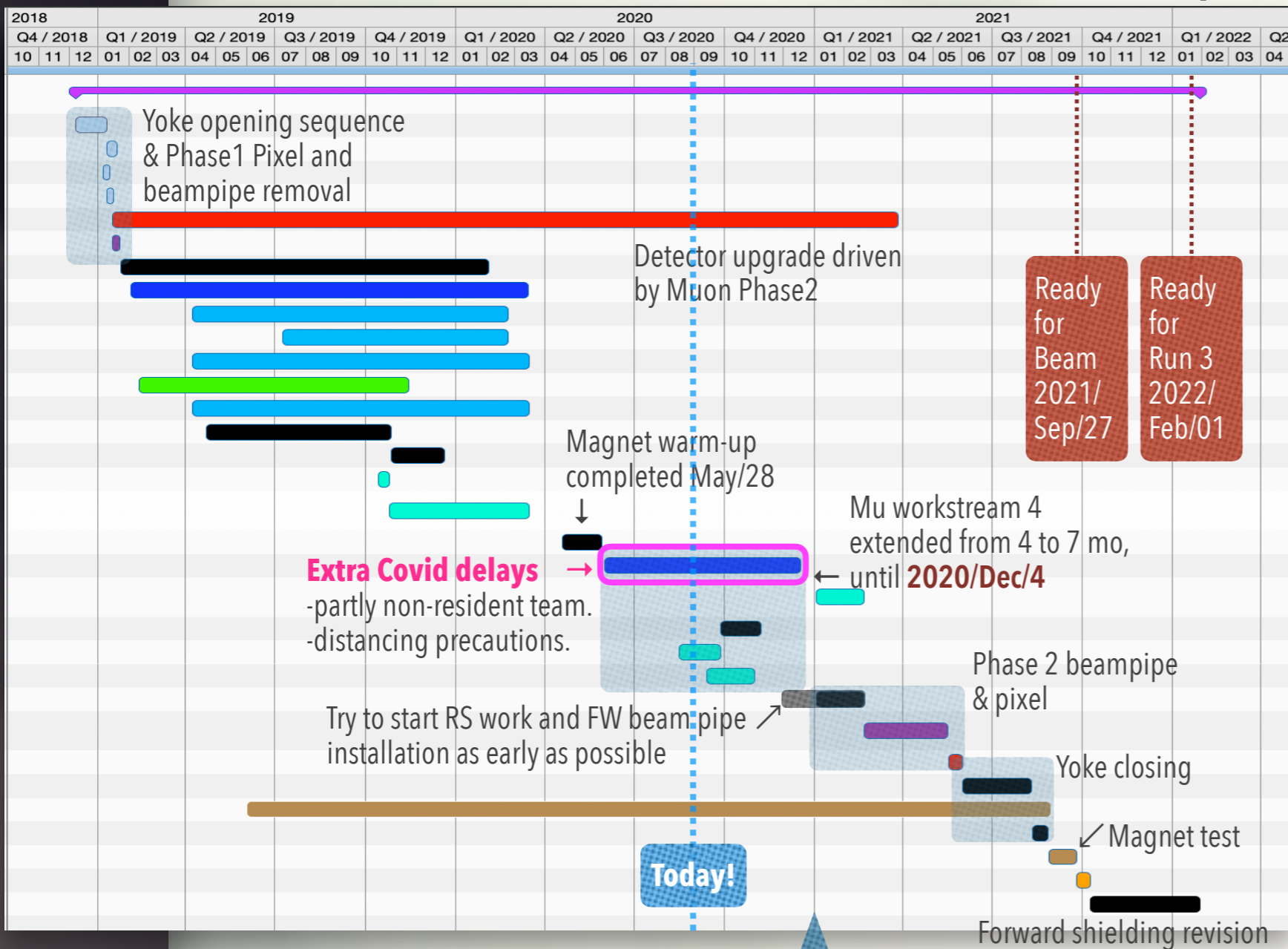


STATUS AT P5, LS2 ACTIVITIES, COMPUTING

- ❖ *CMS COVID Status*
- ❖ *Preparation for Run-3*
- ❖ *Legacy Data Samples*

CMS Status at P5

On schedule w.r.t. baseline plan



From 2021 / Jan / 04, all projects achievable in nominal timeframe

- ◆ Muon upgrade (*main objective of LS2*) ends Dec/4, takes longer because of anti-Corona measures and travel restrictions.
- ◆ All following projects achievable in normal time frame.
- ◆ Main risks:
 - Corona outbreak at P5;
 - Travel restrictions for key experts.
- ◆ **Current progress is according to post-lockdown plan.**

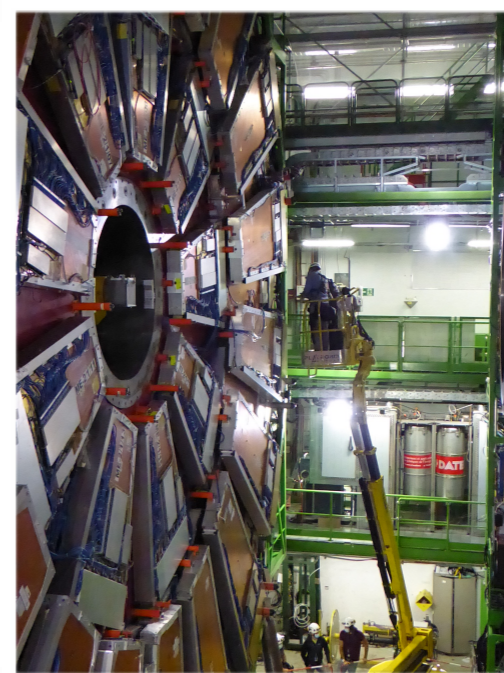
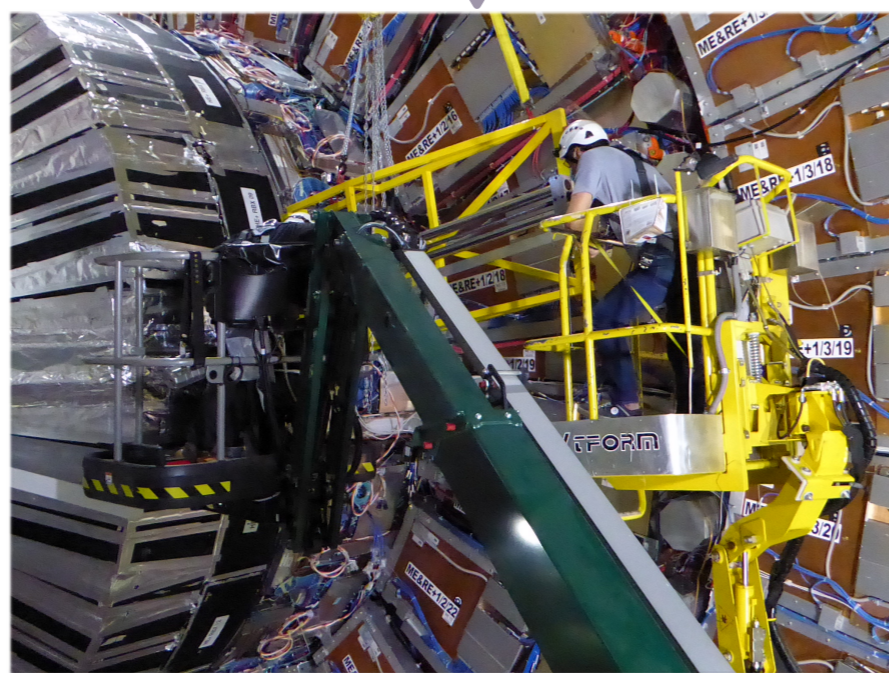
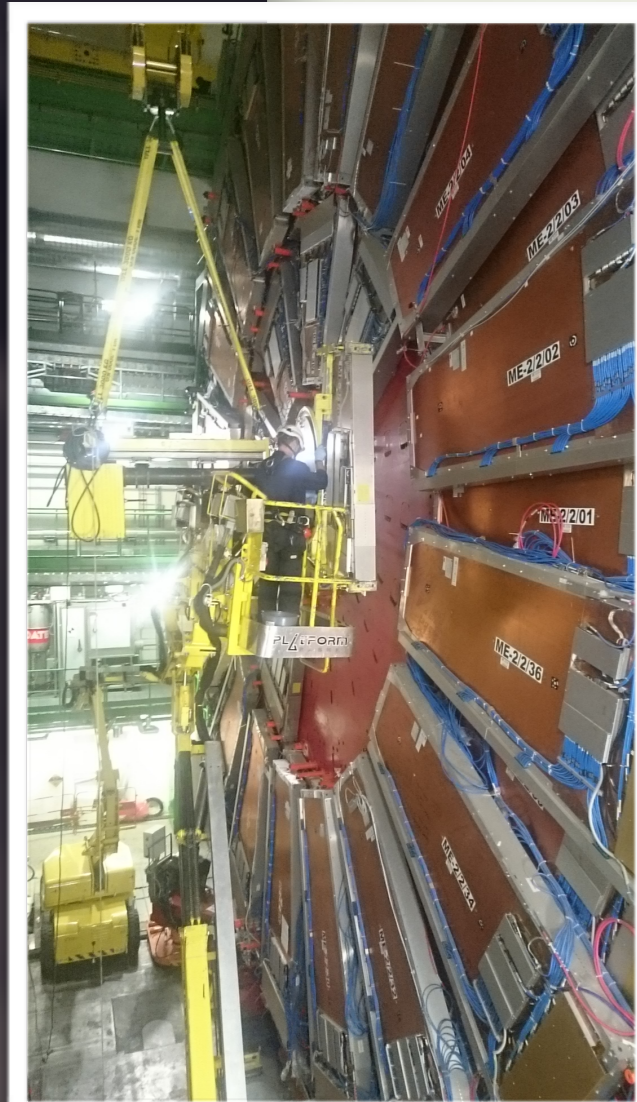
CMS Status at P5

Muon upgrade is again in full swing, will define the critical path until Dec 4, 2020!

Inner ring muon chambers installation after on-board electronics upgrade

New GEM chamber installation

Service and Shielding Installation

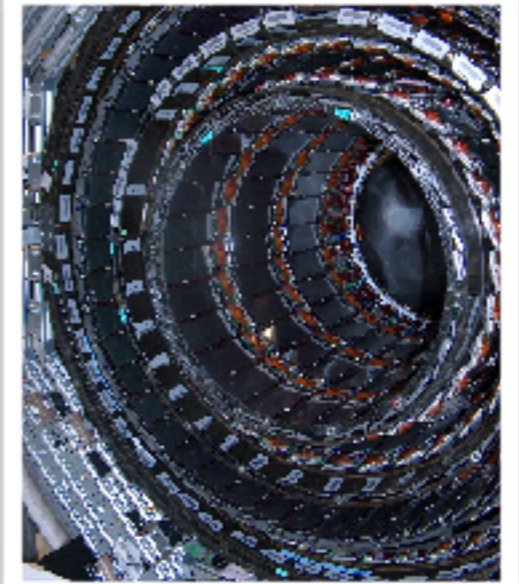


LS2 Activities



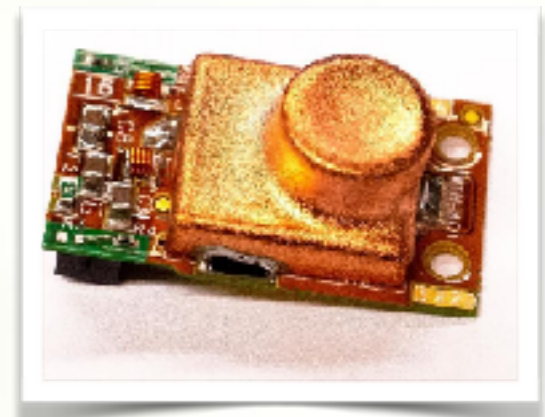
Tracker

- ◆ Major update of the DCS system.
- ◆ **Strips:** detector maintained at 0° C to prevent reverse annealing; routine maintenance operations performed throughout the LS2.
- ◆ **Pixels:** BPIX layer-1 replacement module production and testing complete; FPIX preventative maintenance.
- ◆ **DCDC converters:** All required modules now at P5 integration center.



ECAL

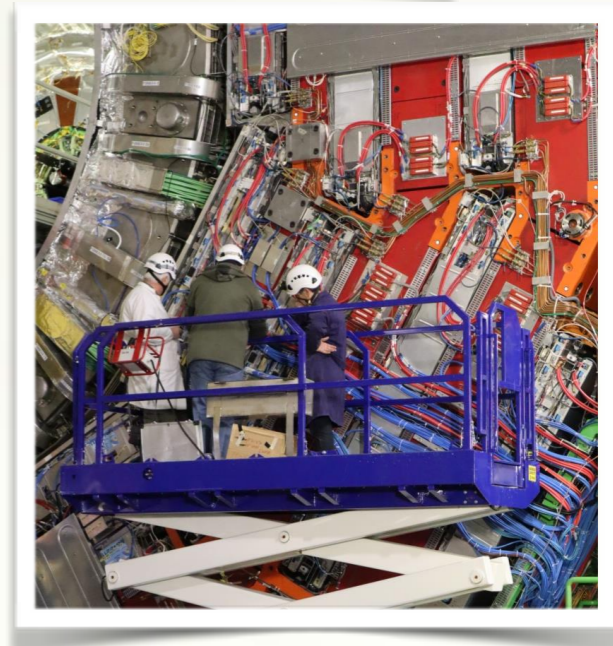
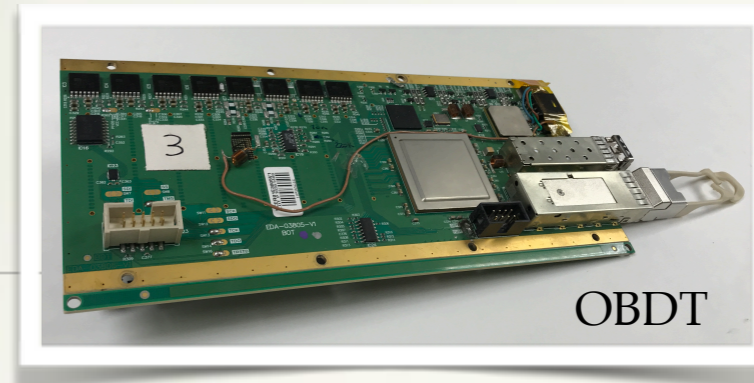
- ◆ Safety system fully upgraded and validated!
- ◆ Calibration workflows being revised and further automatized.
- ◆ Baseline clustering algorithms optimized for Run3, **now investigating new ML-based techniques.**



LS2 Activities

Muon System

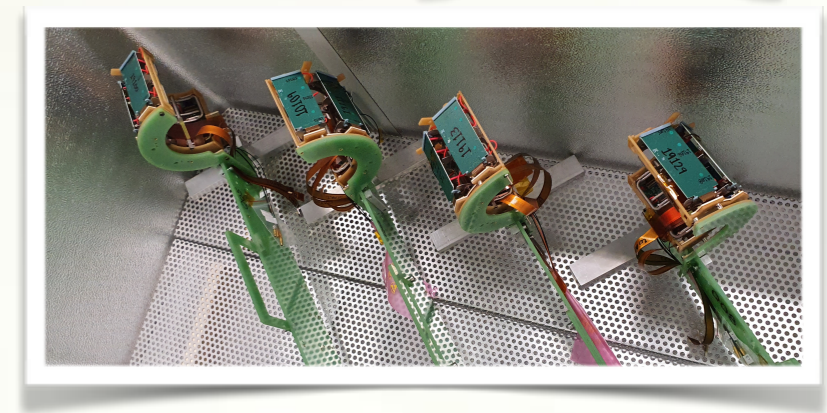
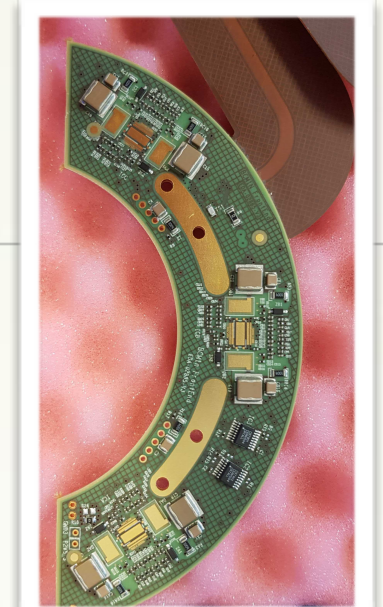
- ◆ **DT:** carried an extended cosmic data taking campaign. Excellent results have validated the Phase 2 architecture.
- ◆ **RPC:** Extensive RPC leak repair campaign carried out during LS2, most of the repairable chambers were fixed, restoring exhaust gas flow $>300\text{l/h}$.
 - R134 recuperation prototype installed. Good separation efficiency $\sim 85\%$ obtained.
- ◆ **CSC:** Replace the on-chamber electronics on the inner ring chambers; new improved cooling system to be installed too.
- ◆ **GEM:** Super Chambers production 100%; commissioning for negative endcap / installation ongoing for positive endcap.



LS2 Activities

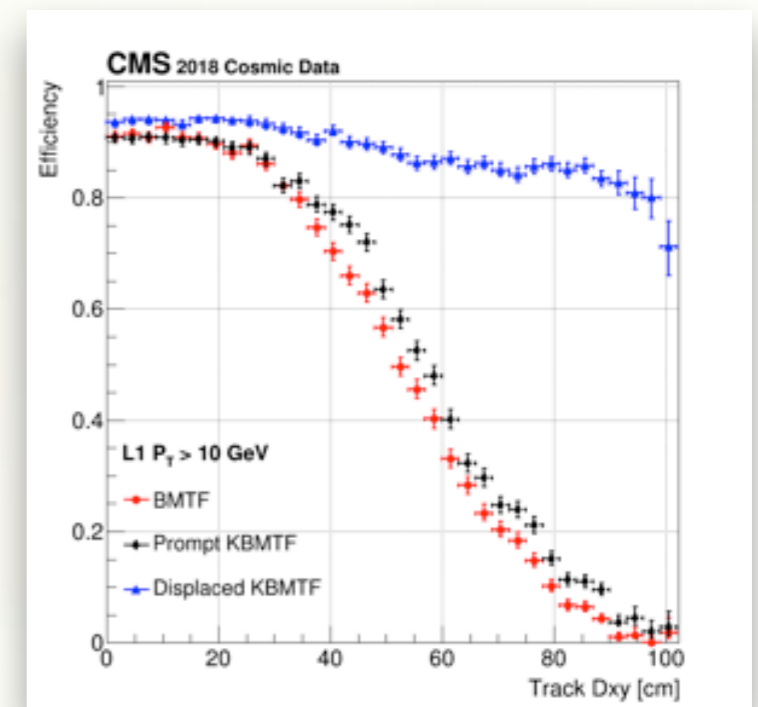
Bril / Lumi monitoring

- ◆ **Fast Beam Condition Monitor** with Silicon sensors:
 - PCB Boards produced, and assembled with passive components \Rightarrow assembly & test.
- ◆ **Pixel Luminosity Telescope**: 4 working frontend cassettes ready; to be install for Run-3.



L1 Trigger

- ◆ The **Kalman Barrel Muon Track Finder** algorithm was deployed at the end of Run-2.
 - Better efficiencies for displaced muons; will be the primary algorithm for Run-3.
- ◆ Ongoing work: inclusion of GEM hits, improving displaced triggers, etc.

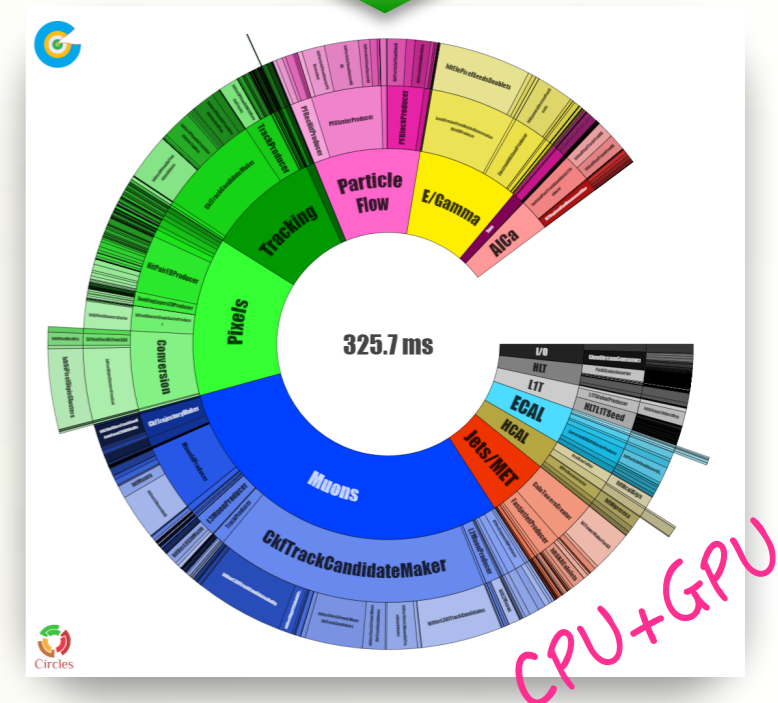
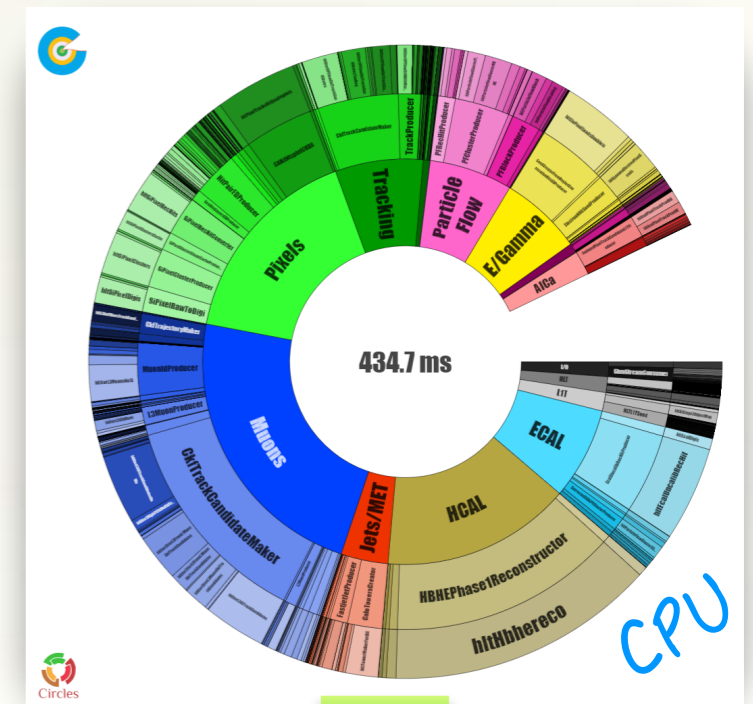


LS2 Activities

Current timing of representative Run3 menu running on 2018 data

High-level Trigger

- ❖ Offloading HLT algorithms to GPUs is the focus!
 - Gain experience with heterogeneous architectures ahead of Phase-2 (*when it becomes a real requirement!*).
 - Plan to equip each node with GPU, reduce the overall CPU of the farm by the amount we can offload to the GPU.
- ❖ Porting of codes is progressing well:
 - Currently ported: ECAL & HCAL local reconstruction, pixel reconstruction & tracking.
 - Have offloaded **~25% of the current menu** to the GPU already.
 - On going to get further improvements.
- ❖ **Final decision on whether to proceed or not will be taken later this year.**



Software & Computing

Excellent utilisation of computing resources!

⇒ Both WLCG and beyond-pledge, e.g. HPCs in Europe and US

Steadily improves during LS2 in preparation for Run 3,
as a testbed for solutions targeting Phase-2.

For example:

- ◆ Target to have a complete migration workflow management to **Python3** by early next year, ie. 2021:
 - Support for Python3 usage in the underlying CMSSW applications will be available already in 2020.
- ◆ Data management — community tool **Rucio** replacing the in-house solution PhEDEx:
 - NanoAOD data managed by Rucio since 3 months:
no significant disruption observed.
 - Preparation being made to manage other data tiers before Phedex retirement, planned at the end of November.



Software & Computing

Deployment of internal CMS computing services portfolio to **Kubernetes (k8s)**:

- K8s: container orchestration system — replace the existing virtual machine layer;
- 6 out of 7 services successfully stress-tested and ready to run on the new infrastructure;
- Switch planned in September.

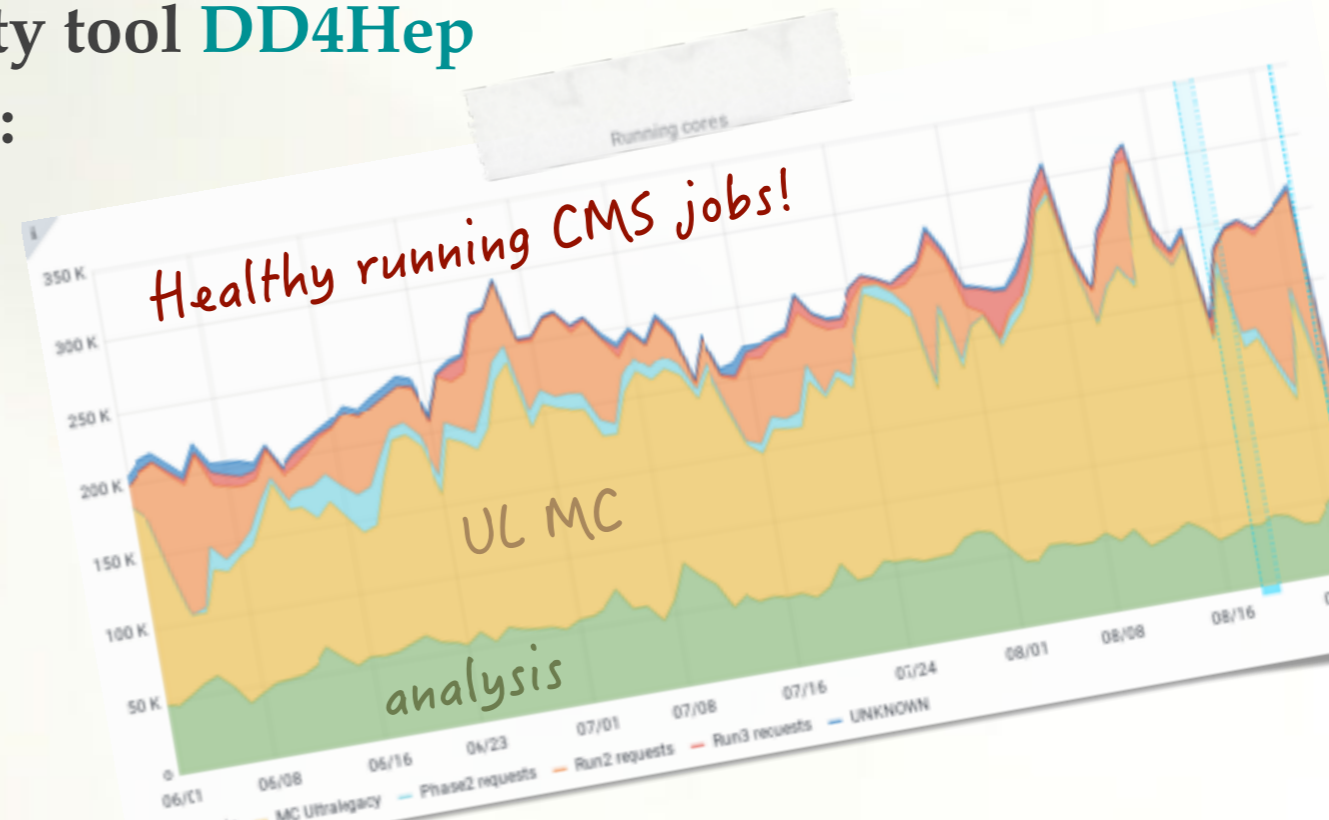


Geometry description: community tool **DD4Hep** replacing the in-house DDD tool:

- Migration almost complete, switch planned in September

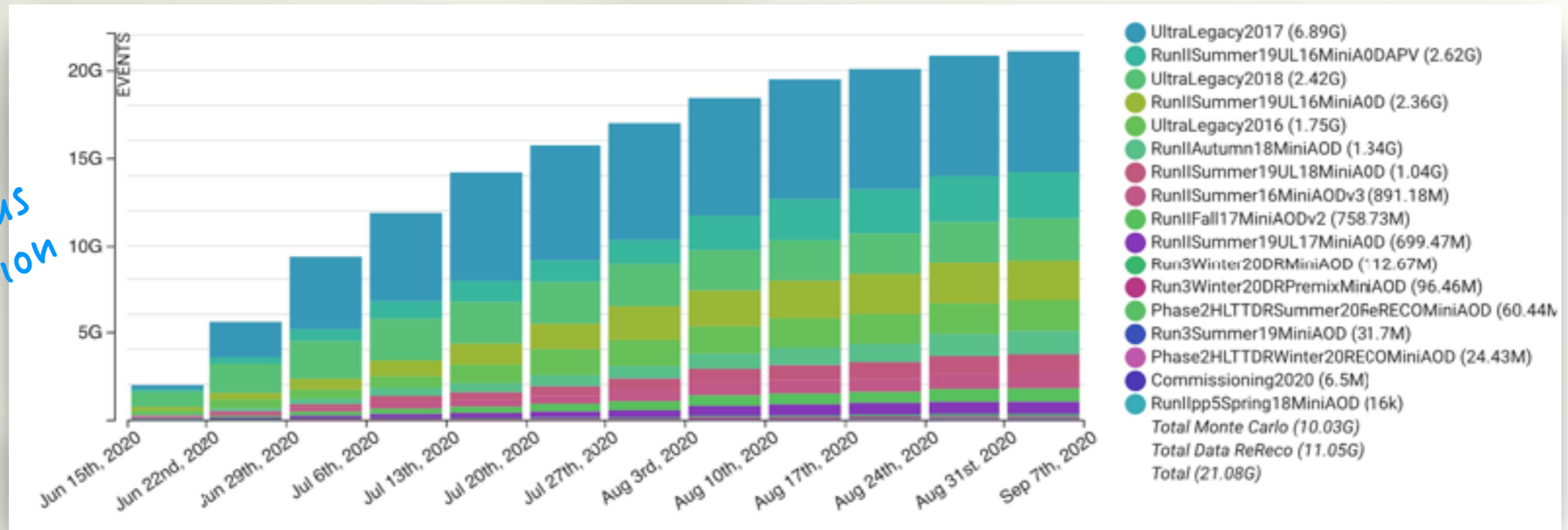
Most recent software integrated:

- e.g. ROOT 6.20 in production, Geant4 10.6, ...



Monte Carlo & Data Production

Smooth
continuous
production



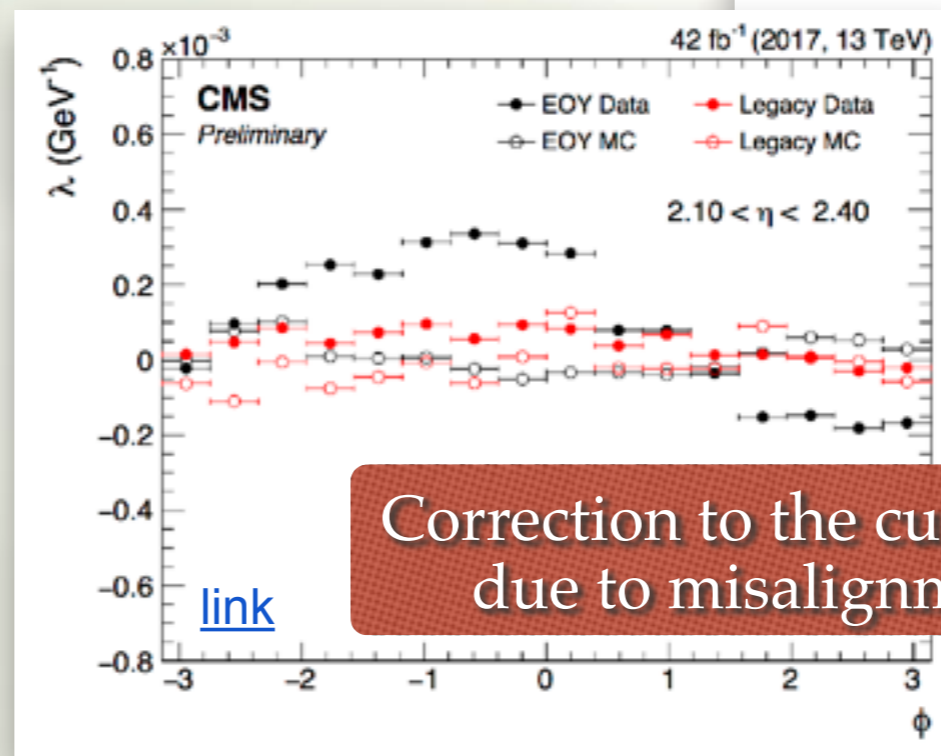
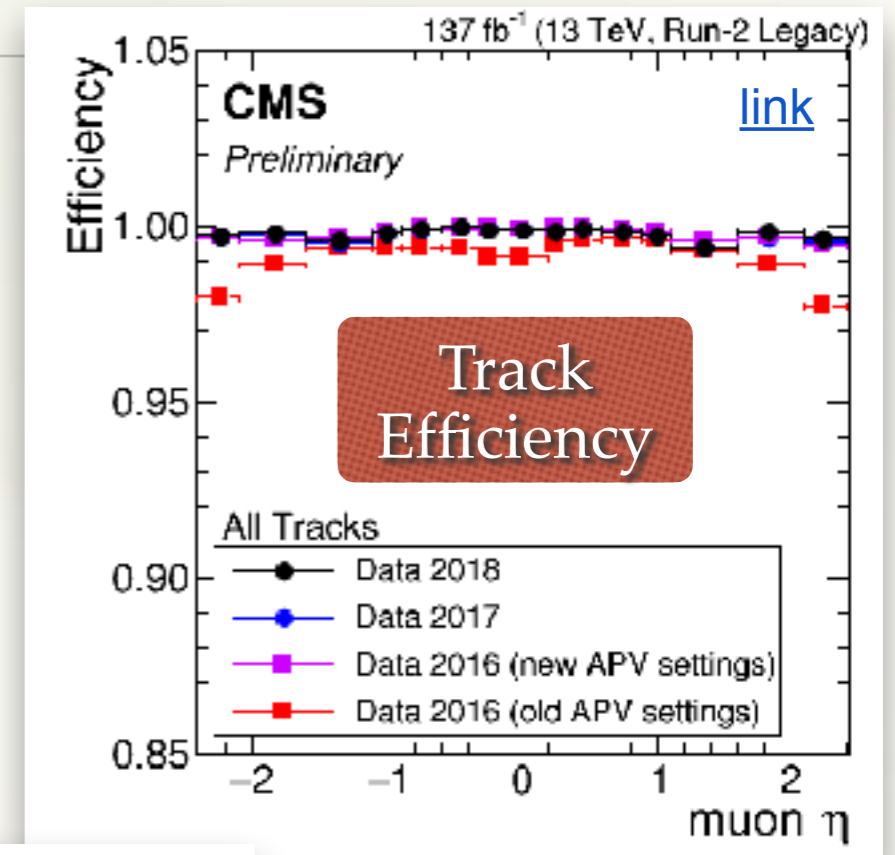
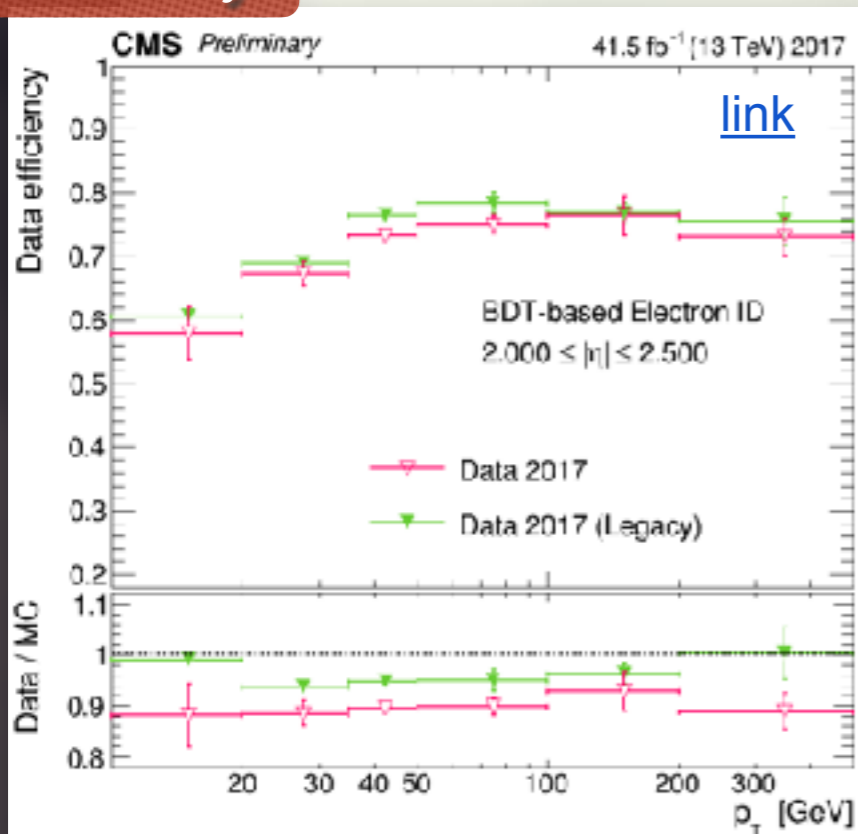
- ◆ Total of 21B events (data and MC) processed in the past 12 weeks:
 - **11B** data events re-reconstructed;
 - **6.8B** Legacy MC events for final final energy corrections and efficiency scale factors.
 - **3.0B** events of “Run-2” MC, for ongoing physics analyses
 - **60M** events created for the preparation of the HLT-TDR

CMS Run-2 “Legacy” Performance

Legacy reprocessing complete:

- ➔ Finalizing calibrations, efficiencies, resolutions, and corrections, etc.
- ➔ *CMS analyses starting to move to Legacy-reconstructed data and MC.*

Electron ID efficiency



Performance improvements seen in legacy datasets.

Correction to the curvature due to misalignment

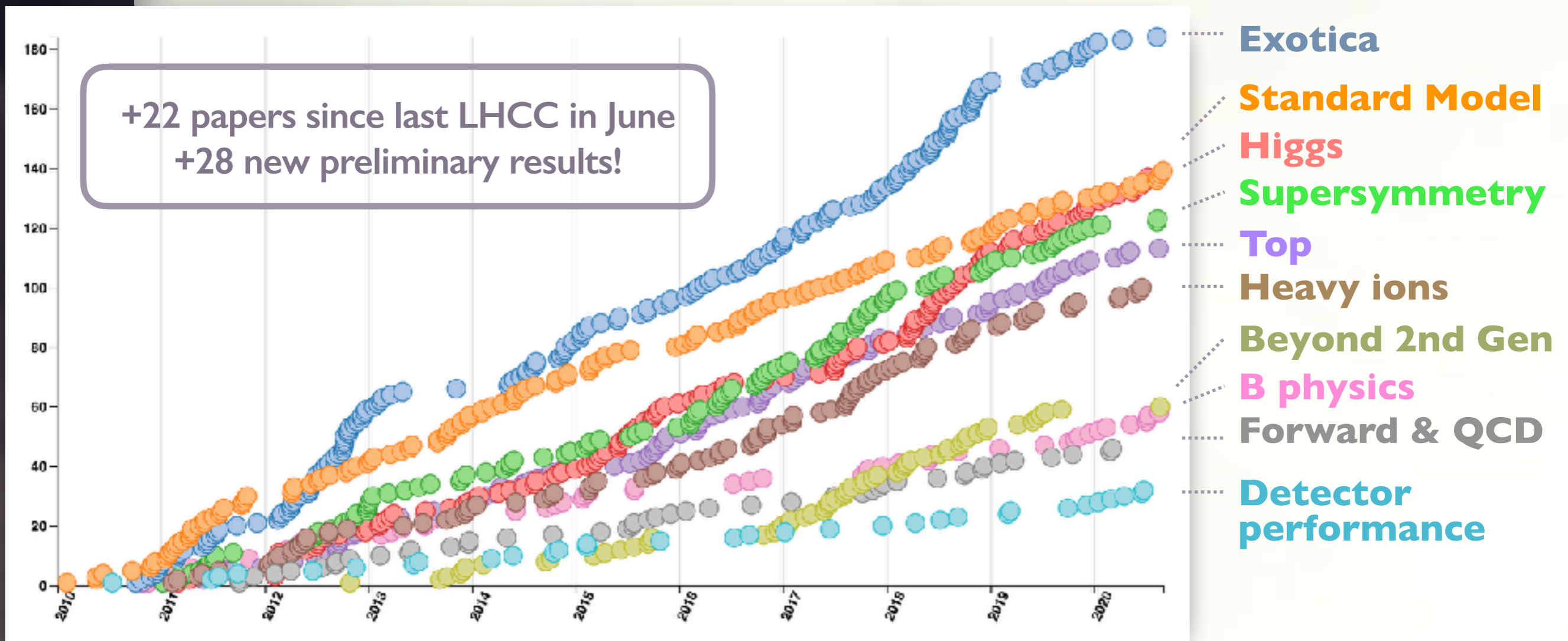


PUBLICATIONS, PHYSICS HIGHLIGHTS

- ❖ *Paper Luminosity*
- ❖ *Physics Highlights at ICHEP*

CMS Integrated Paper Luminosity

992 collider data papers submitted as of 2020-09-01
(25 on cosmic data before start of collisions)



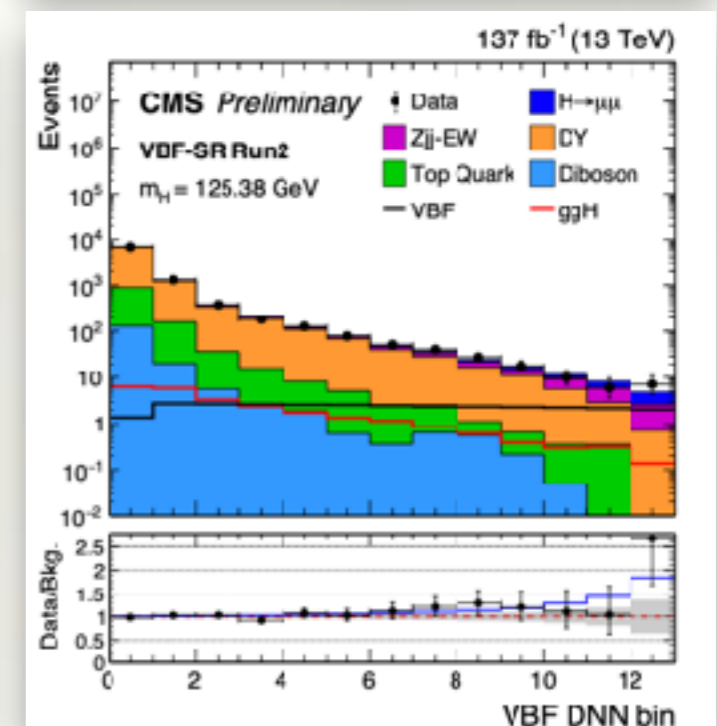
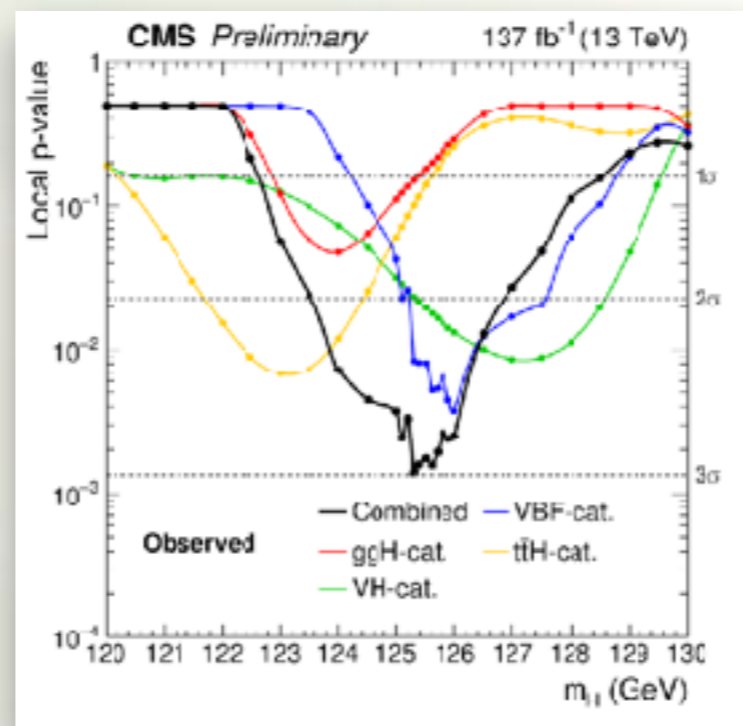
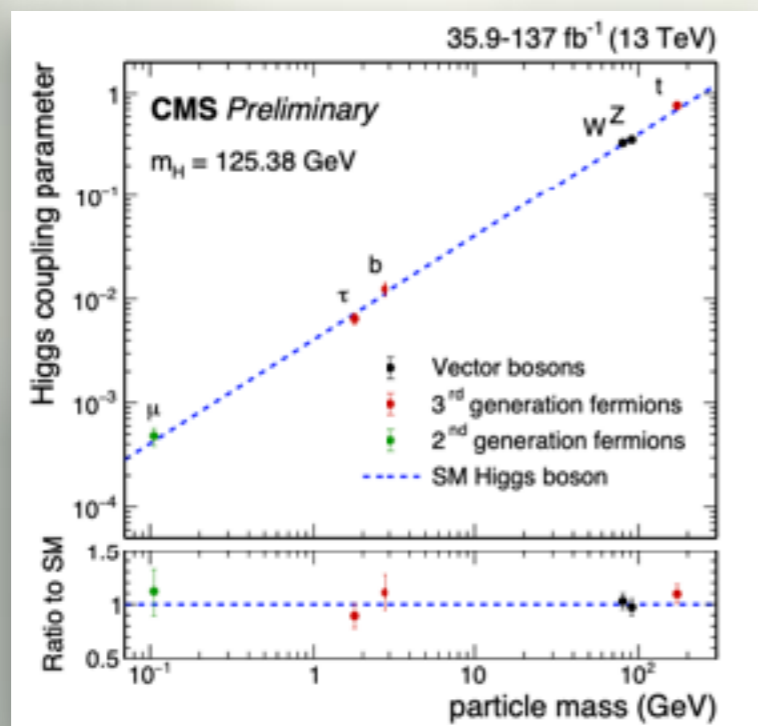
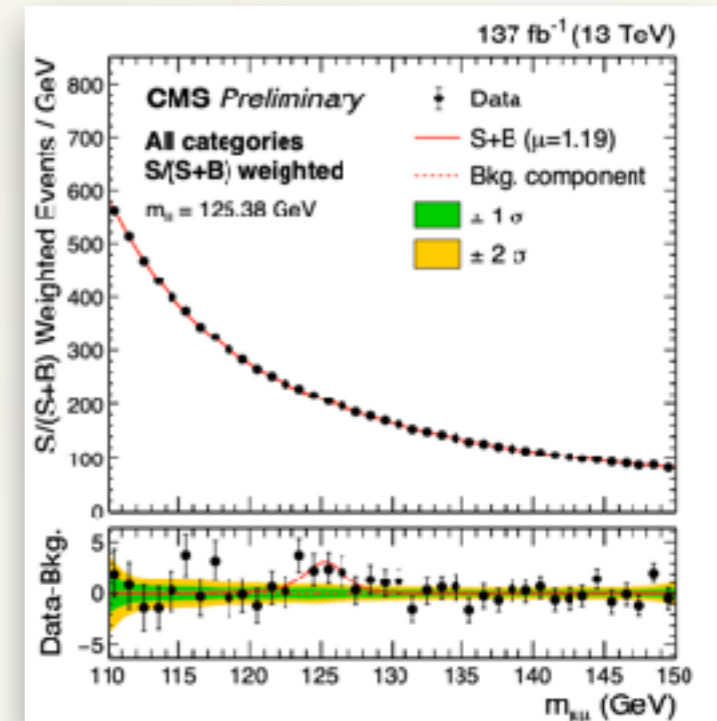
See CMS Publications for details:

<http://cms-results.web.cern.ch/cms-results/public-results/publications/index.html>

First Evidence of $H \rightarrow \mu^+ \mu^-$

HIG-19-006

- ◆ Analysis of Run-2 data (137fb⁻¹):
 - Four components: ggH, VBF, VH & ttH;
 - Similar sensitivity for ggH & VBF:
 - ggH with highest cross-section.
 - VBF signature provides main sensitivity.
- ◆ Combined with Run-1 data.
- ◆ **First evidence established: 3.0σ obs (2.5σ exp.)**
 - $\mu = 1.19^{+0.41}_{-0.39}$ (stat) $^{+0.17}_{-0.16}$ (syst)
 - At the most up-to-date $m_H = 125.38$ [ref]



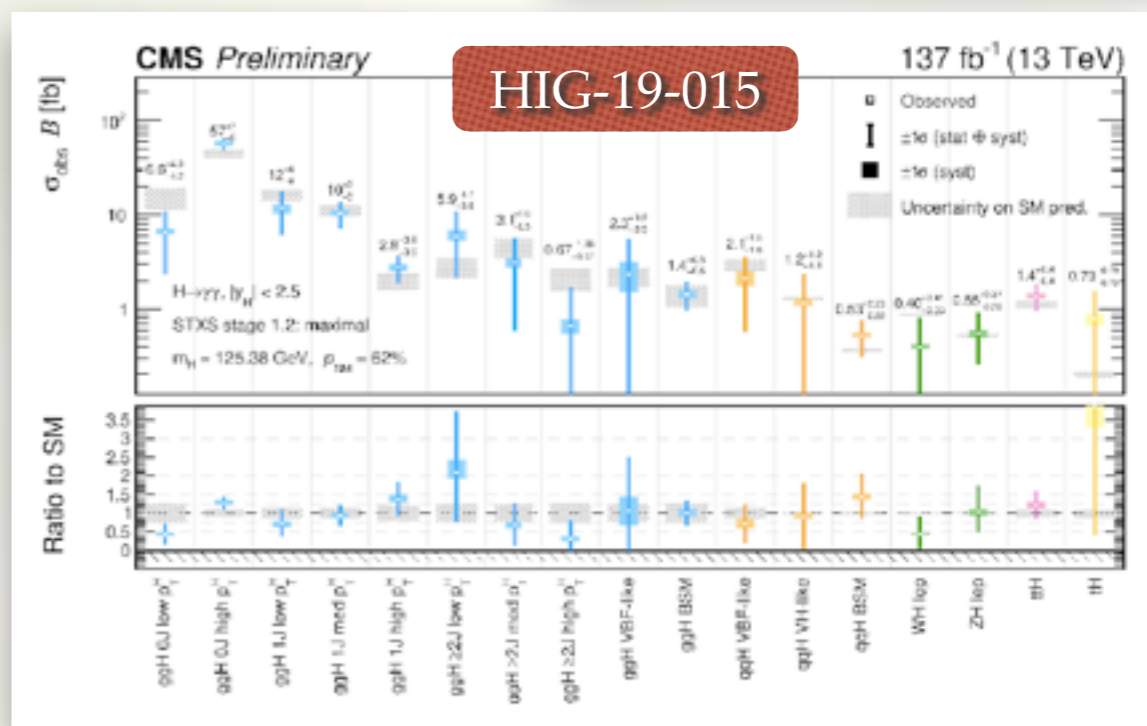
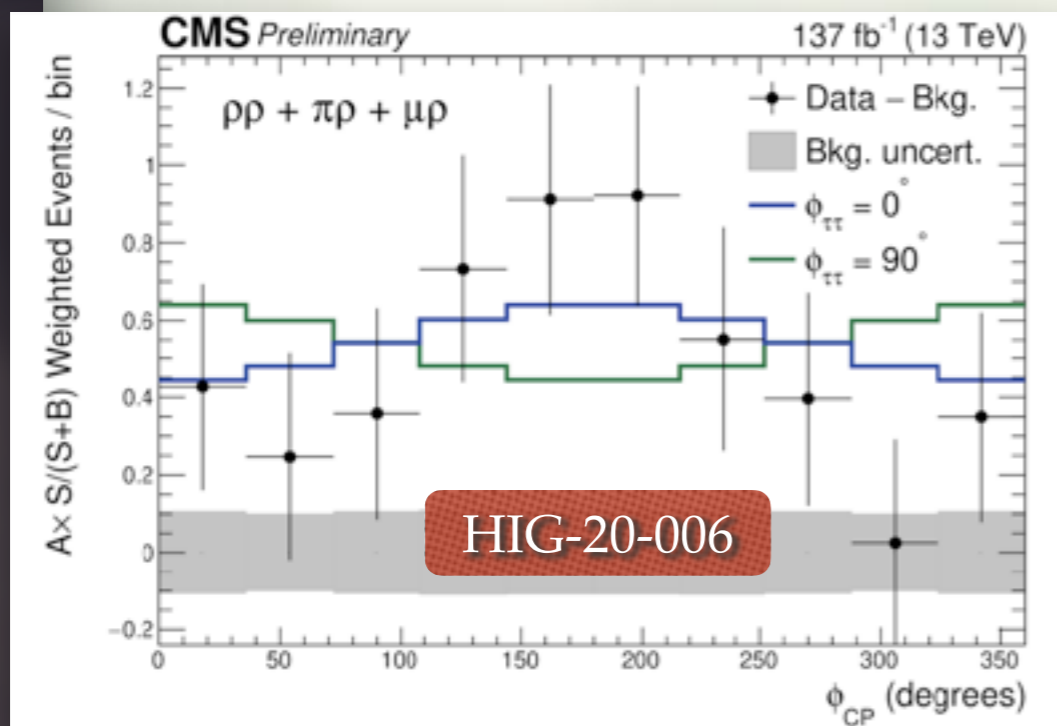
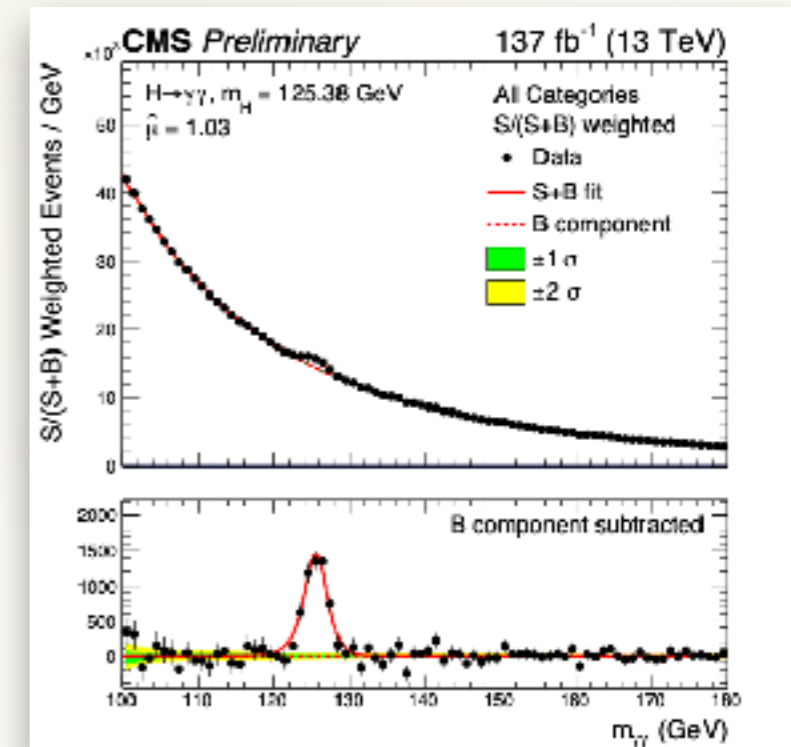
Examination of Higgs Properties

Higgs signal strengths and couplings in $H \rightarrow \gamma\gamma/\tau\tau$:

- Categorized in the “simplified template cross section scheme” (STXS).

CP structure in $H \rightarrow \tau\tau$:

- Mixing angle between CP-even and CP-odd coupling found to be $4 \pm 17^\circ$ (SM = 0)
- Pure pseudoscalar hypotheses is excluded at 3.2σ (2.3σ exp).

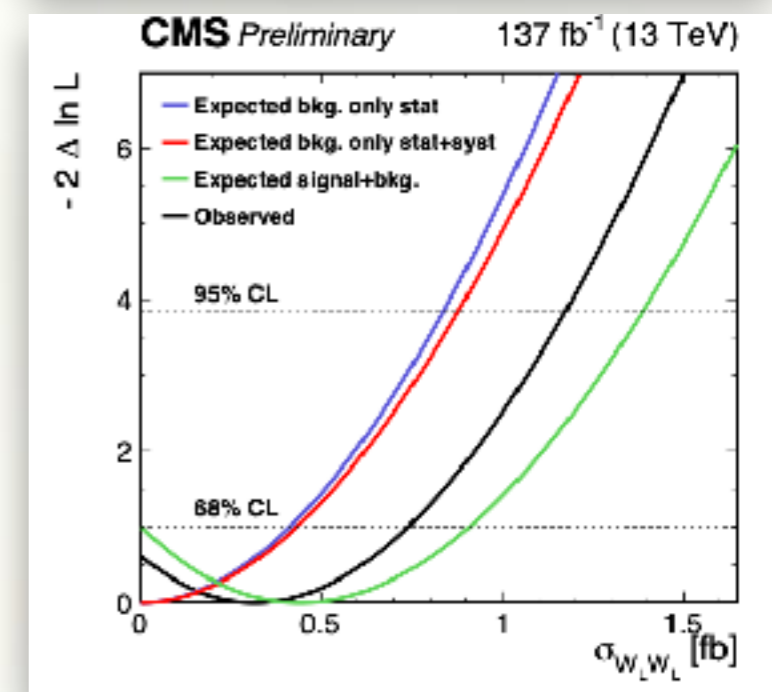
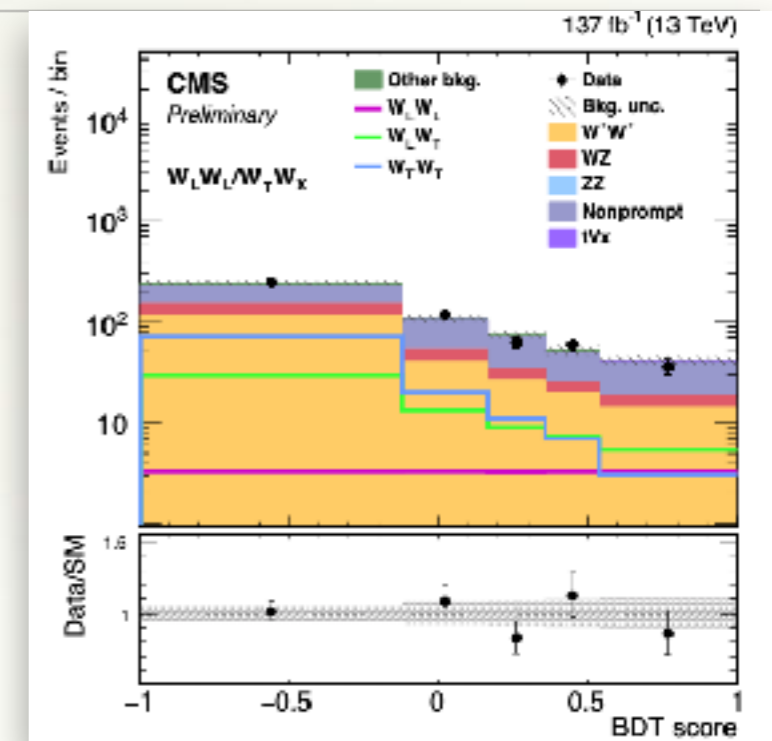


Polarized $W^\pm W^\pm$ Pairs

SMP-20-006

- ◆ VBS production of longitudinally polarized vector bosons, linked to the core of **EW symmetry breaking**:
 - Modifications of the production cross sections are expected in BSM models.
 - **First measurement of production cross section of polarised WW pairs!**
 - Backbone on SMP-19-012, just published in PLB.
- ◆ **Production with at least one W_L measured with 2.3σ (3.1σ exp).**
- ◆ Upper limits for $W_L W_L$ production at 1.17 fb (0.88 fb exp).

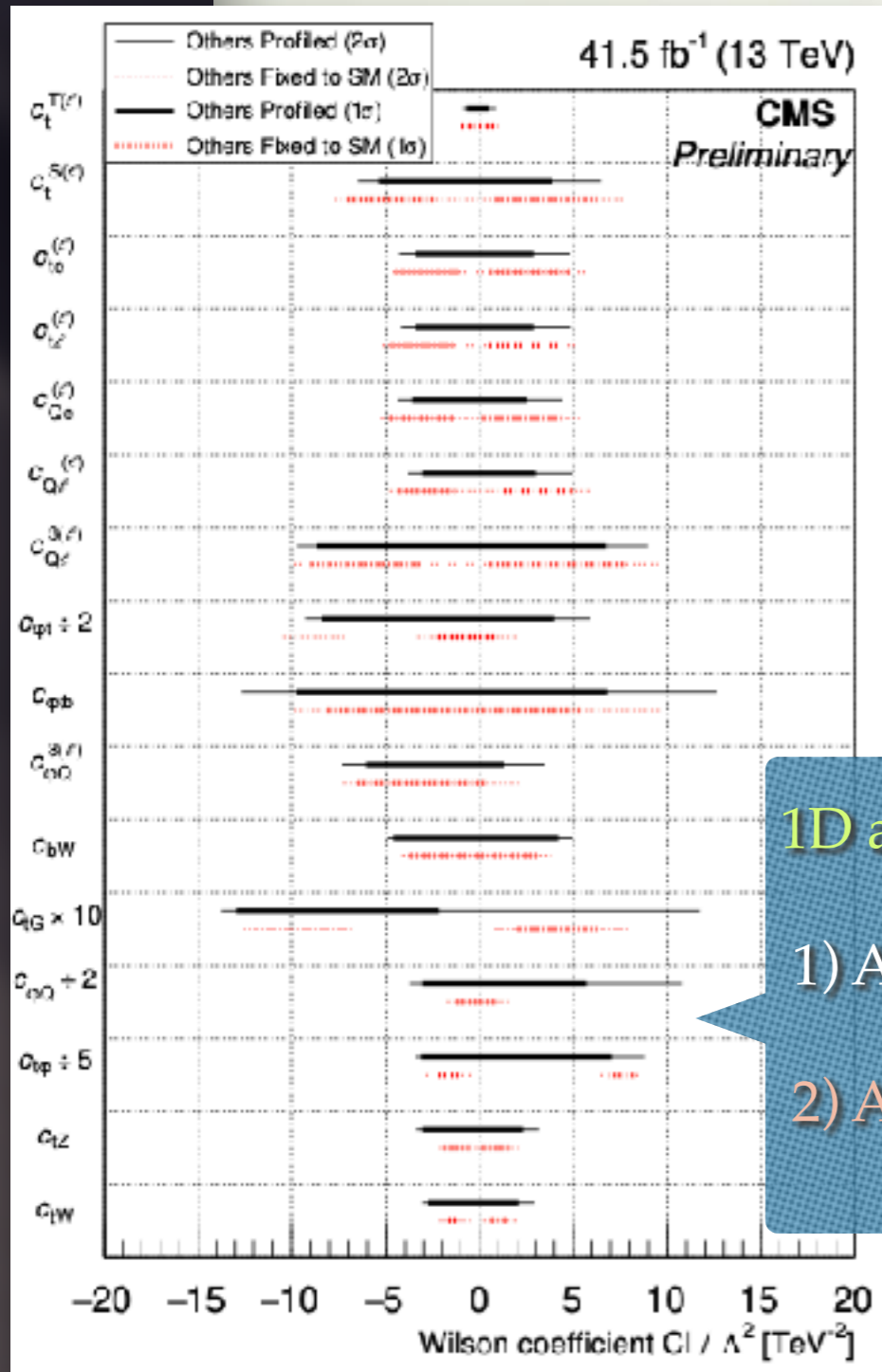
| Process | $\sigma \times \mathcal{B}$ (fb) | TH prediction (fb) |
|-----------|----------------------------------|--------------------|
| $W_L W_L$ | $0.32^{+0.42}_{-0.40}$ | 0.44 ± 0.05 |
| $W_X W_T$ | $3.06^{+0.51}_{-0.48}$ | 3.13 ± 0.35 |
| $W_L W_X$ | $1.20^{+0.56}_{-0.53}$ | 1.63 ± 0.18 |
| $W_T W_T$ | $2.11^{+0.49}_{-0.47}$ | 1.94 ± 0.21 |



EFT Interpretation of Top+X

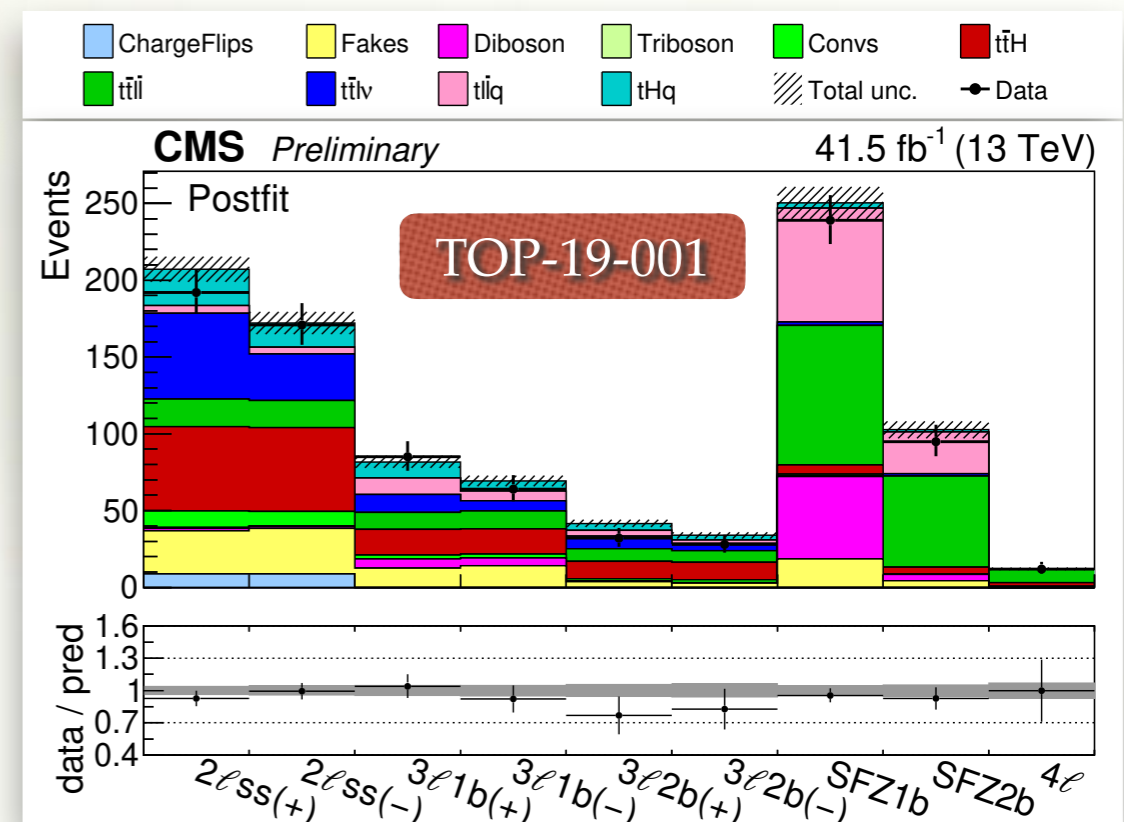
New approach to derive constraints from analysis of $tt+X$ & $t+X$ productions:

- Using ttH , $ttll$, $ttl\nu$, $tllq$, and tHq in multilepton final states;
- Parameterization in the quadratic dependence of yields on 16 coefficients for a simultaneous fit.



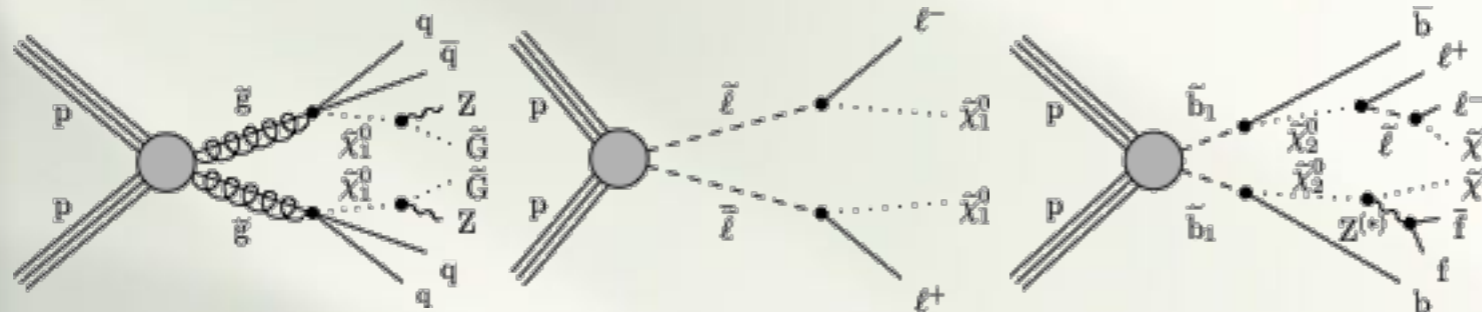
1D and 2D limits in two scenarios:

- 1) All other coefficients profiled
- 2) All other coefficients fixed to SM.



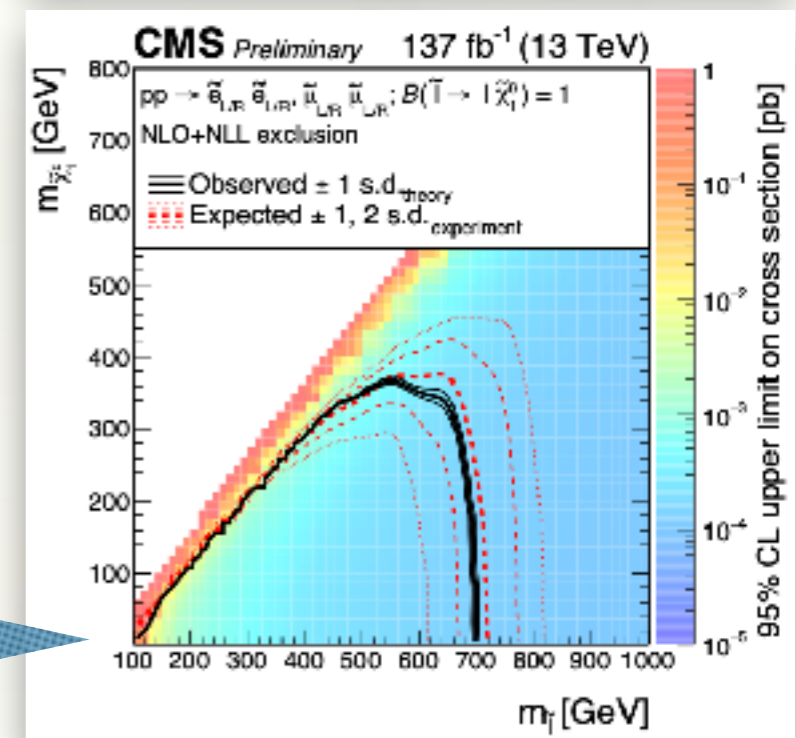
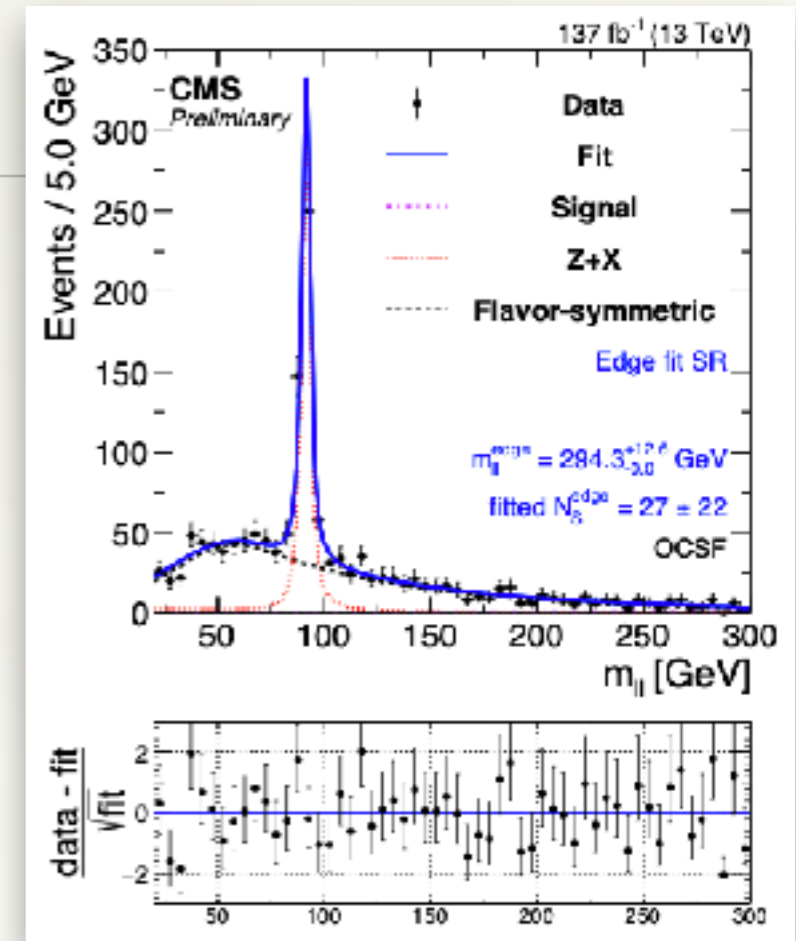
SUSY with Leptons

- Searches for SUSY with a generic analysis of events with 2 opposite-charge same-flavor leptons:
 - 3 signal signatures investigated: **Resonant dilepton at Z mass** / **Non-resonant di-lepton** / **Mass-edge search**.



- Various regions (n-jets, n-bjets, etc..) defined to probe different SUSY scenarios;
- Extend the reach of previous CMS results by hundreds of GeV.**

Limit on slepton pair production, as a function of slepton and lightest neutralino masses



Diphoton Production w/ Intact Protons

Search for exclusive diphoton production with intact protons detected in the TOTEM detector:

- Addressing high mass, $M_{\gamma\gamma} > 350$ GeV;
- data collected in 2016, $L = 9.6$ fb $^{-1}$

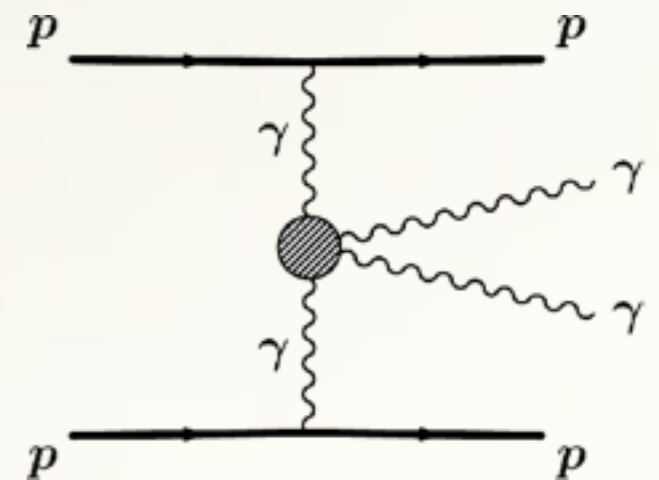
No events observed when requiring *matching between the mass and rapidity extracted from photons and protons*.

Upper limits at 95% CL on the 4-photon anomalous quartic couplings:

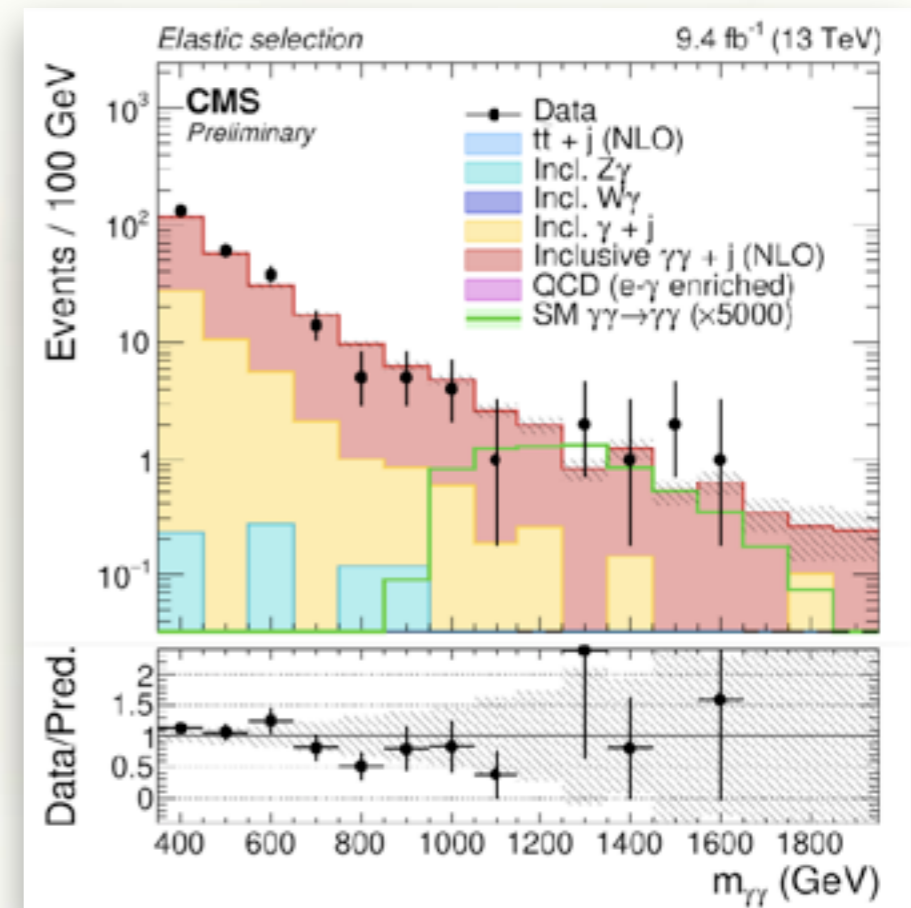
$$L_8^{\gamma\gamma\gamma\gamma} = \zeta_1 F_{\mu\nu} F^{\mu\nu} F_{\rho\sigma} F^{\rho\sigma} + \zeta_2 F_{\mu\nu} F^{\mu\rho} F_{\rho\sigma} F^{\sigma\nu}$$

$$|\zeta_1| < 3.7 \times 10^{-13} \text{ GeV}^{-4} \quad (\zeta_2 = 0)$$

$$|\zeta_2| < 7.7 \times 10^{-13} \text{ GeV}^{-4} \quad (\zeta_1 = 0)$$



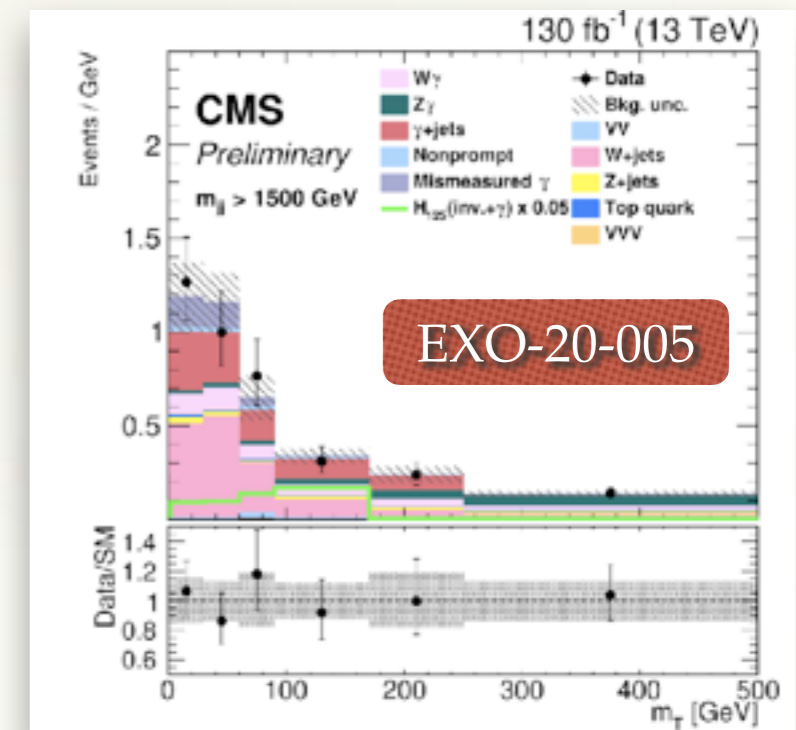
EXO-18-014



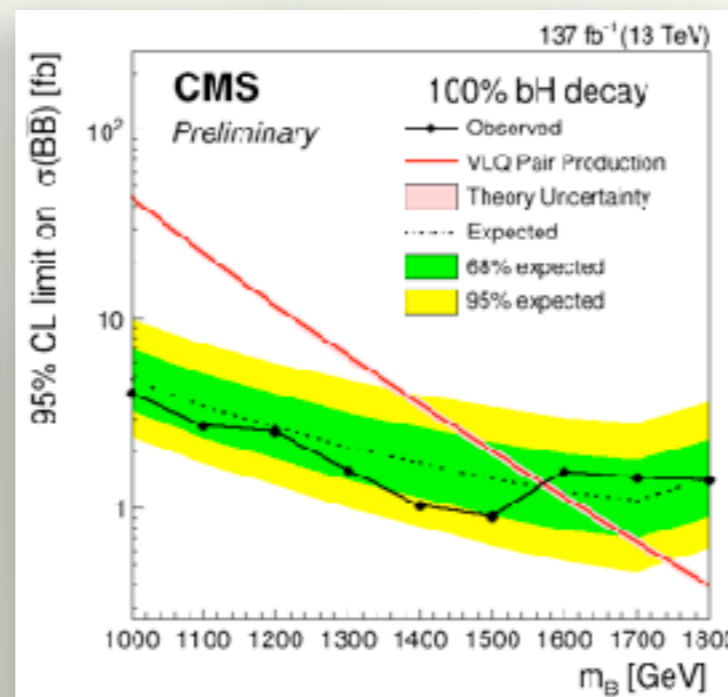
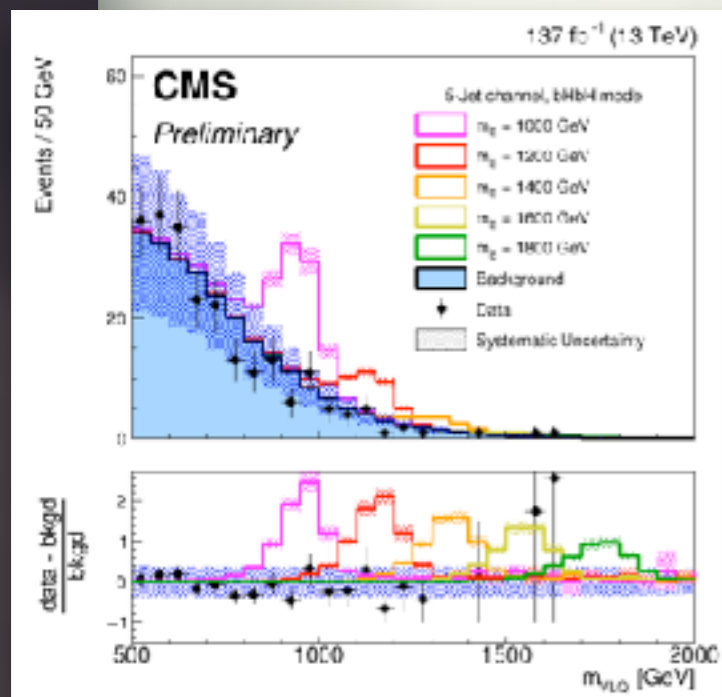
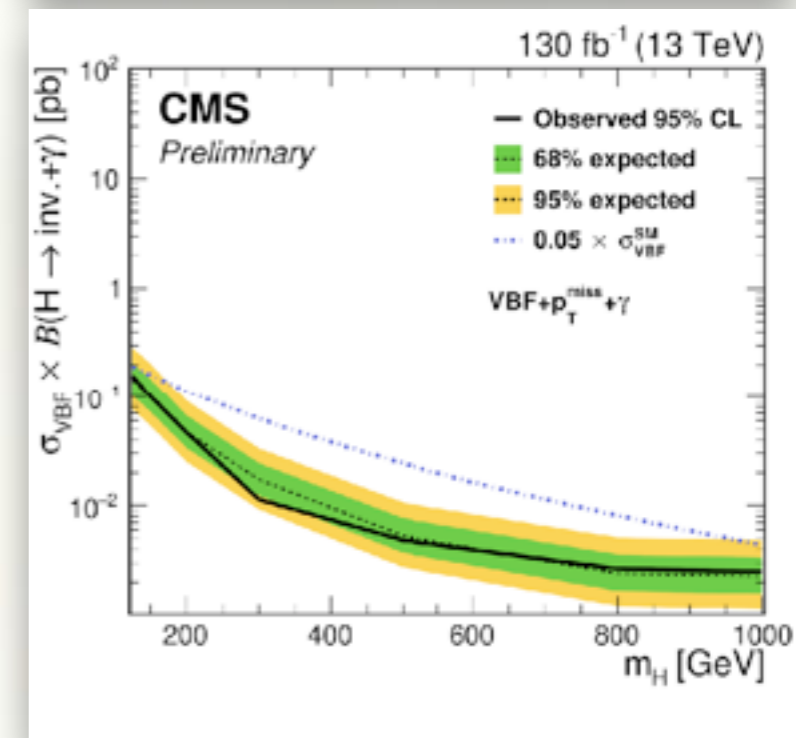
Searches for VLQ & Dark Photons

- Bottom-type vector-like quarks (VLQs):
 - Decay into a b quark and a Higgs or a Z.
 - Limit on VLQ mass: 1.39~1.57 TeV.**

- Dark photons from Higgs decays:
 - Higgs decays into photon plus a dark photon (*undetected*) with VBF tag.
 - Limit on $\mathcal{B}(H \rightarrow \gamma \gamma_D)$ with VBF+ZH: 2.9% (2.1% exp).**

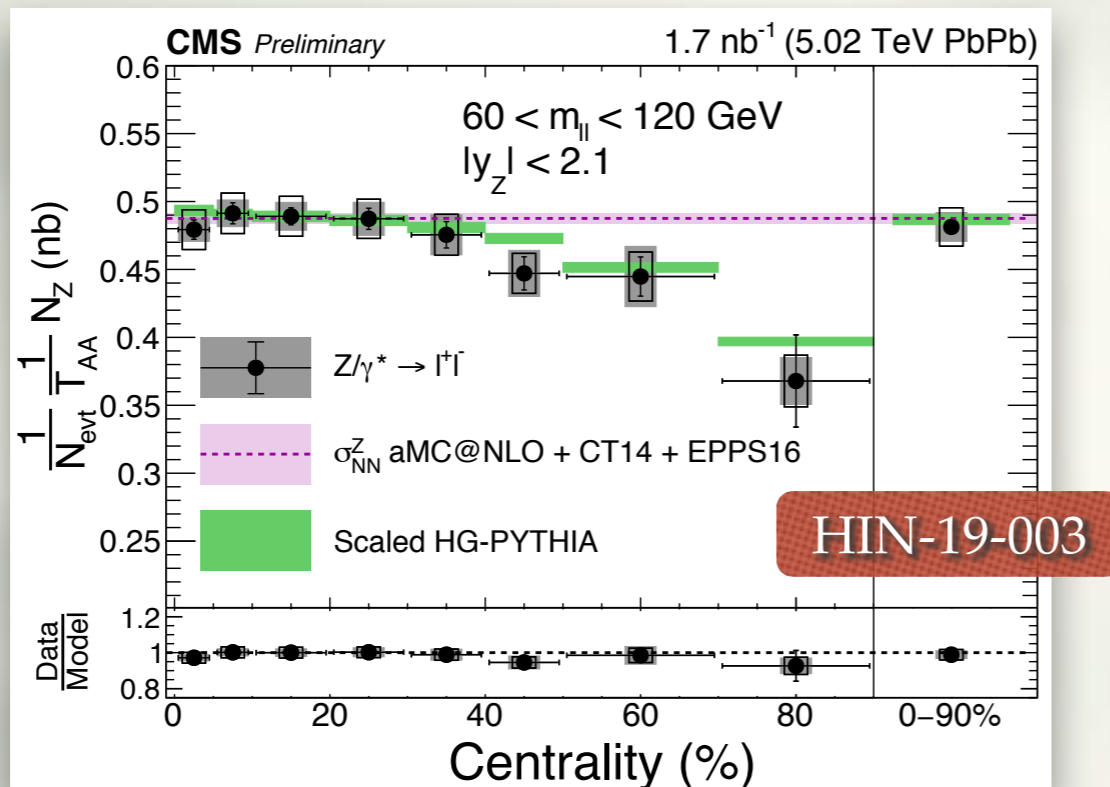


B2G-19-005



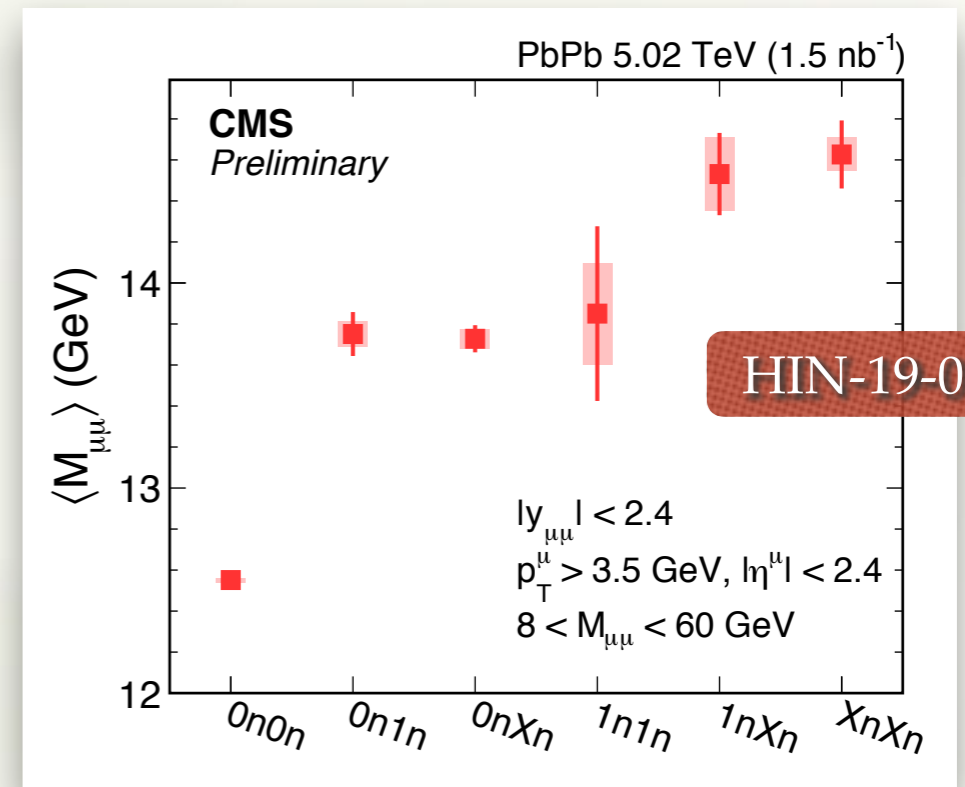
Heavy Ions Highlights

Z boson in PbPb

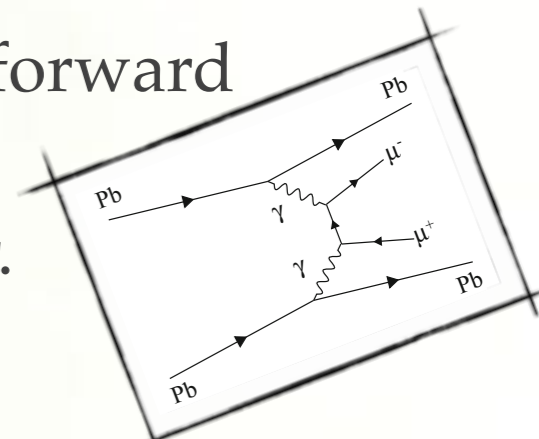


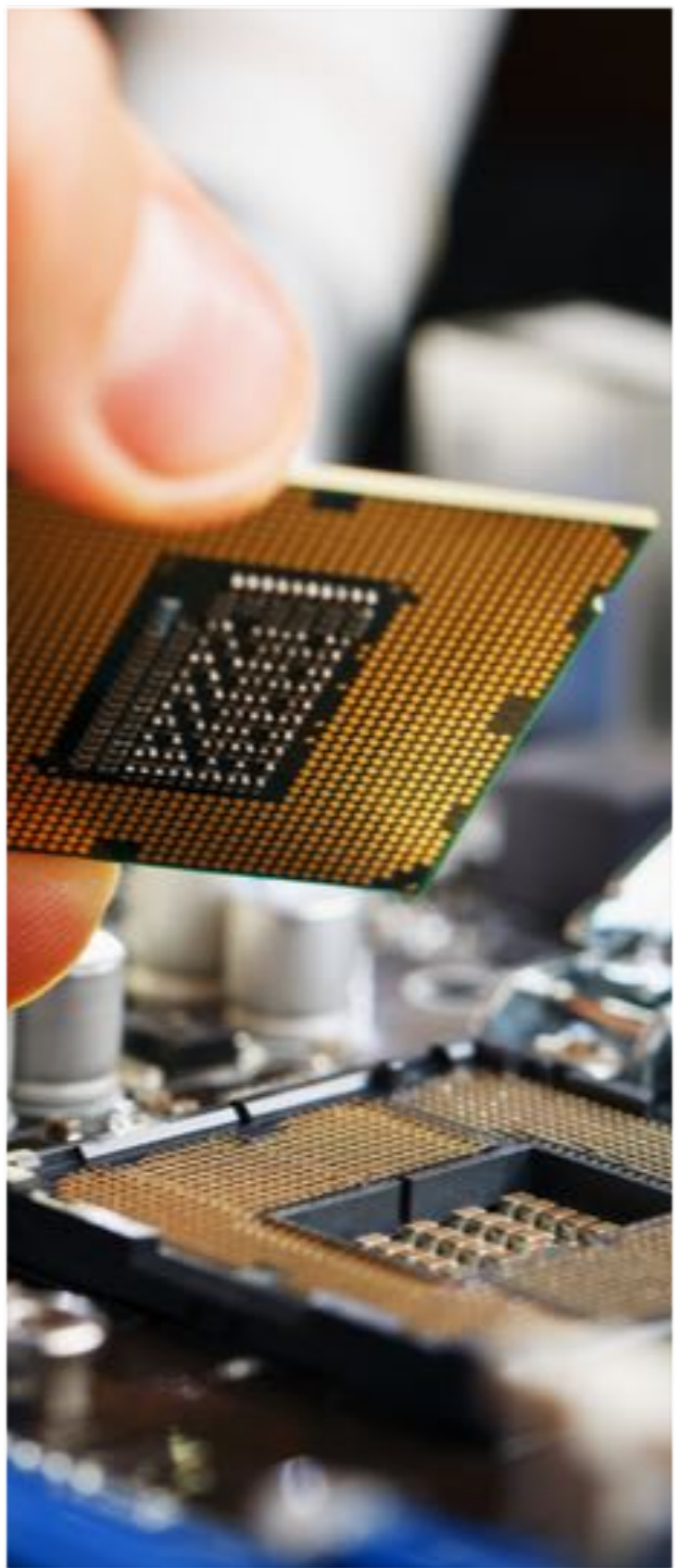
- High precision measurement of **Z boson in PbPb collisions**;
- Probing geometry+selection effects in peripheral collisions.

Ultra-peripheral dimuon in PbPb



- Exclusive dimuon topology in **ultra-peripheral collisions**;
- Small number of forward neutrons \Leftrightarrow large impact parameter.





PHASE-2 UPGRADE ACTIVITIES

✿ *In preparation for HL-LHC*

CMS Upgrade

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

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/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

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

Beam Radiation Instr. and Luminosity

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

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

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 and precise timing
Si, Scint+SiPM in Pb/W-SS

Tracker

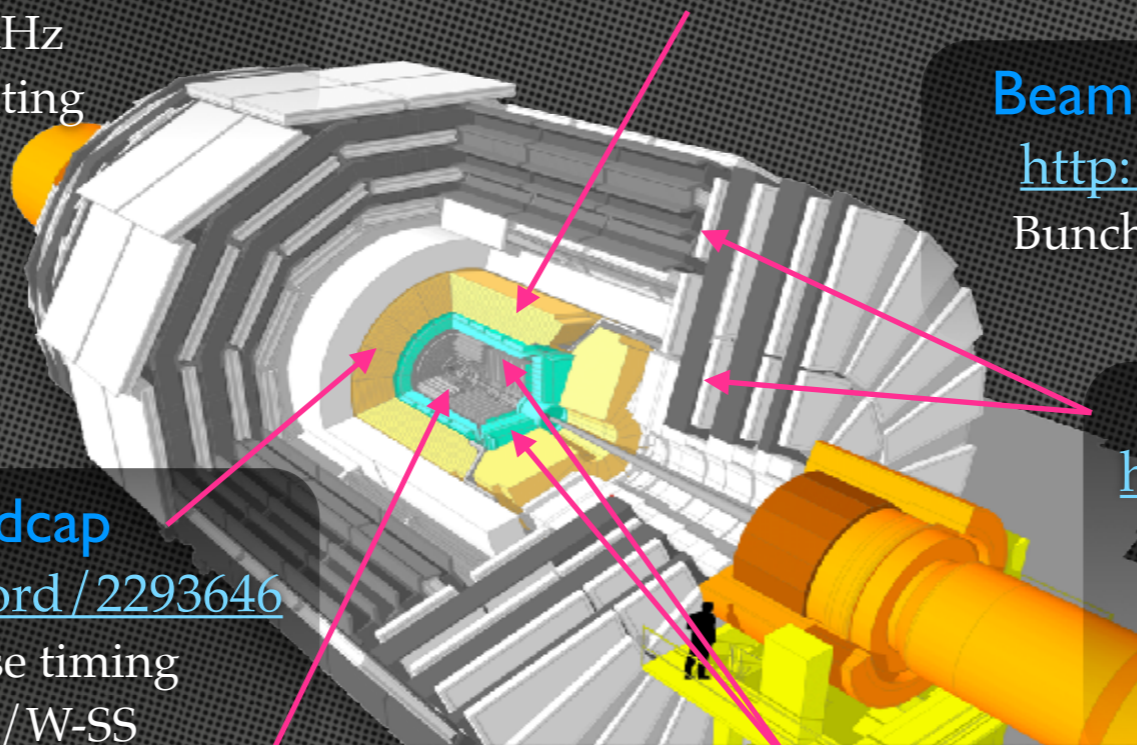
<https://cds.cern.ch/record/2272264>

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

MIP Timing Detector

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

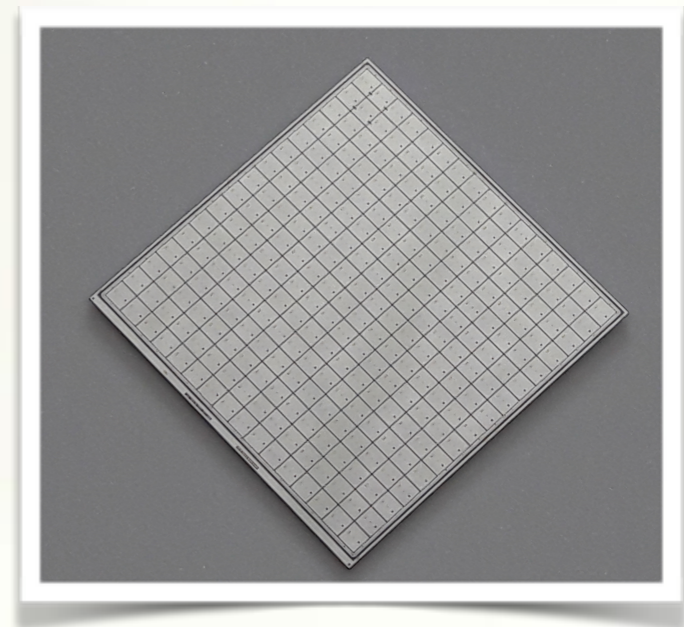
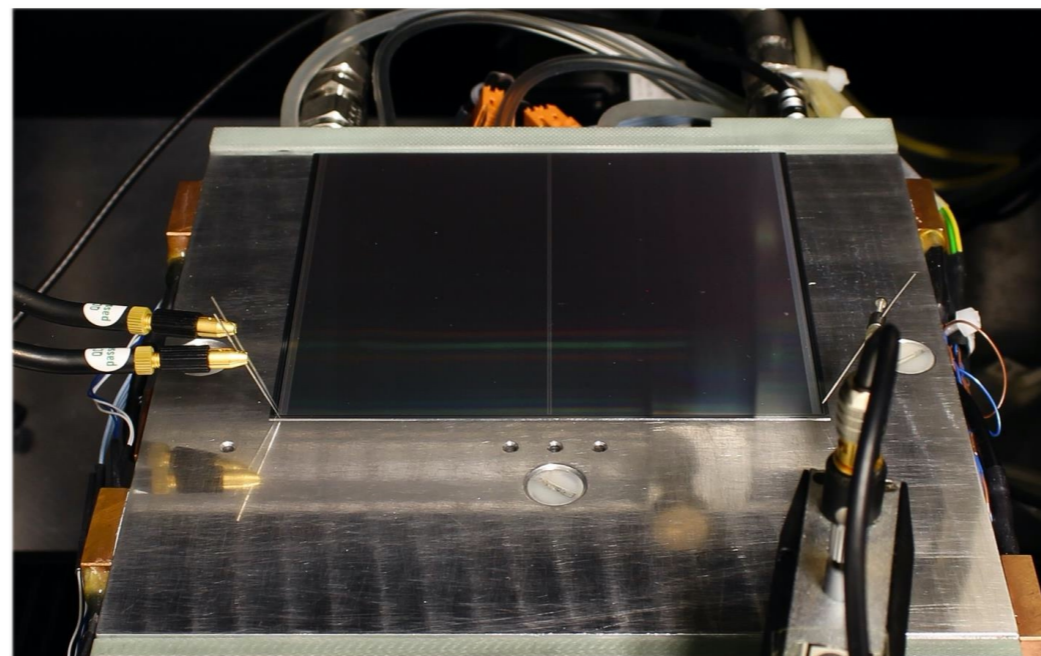
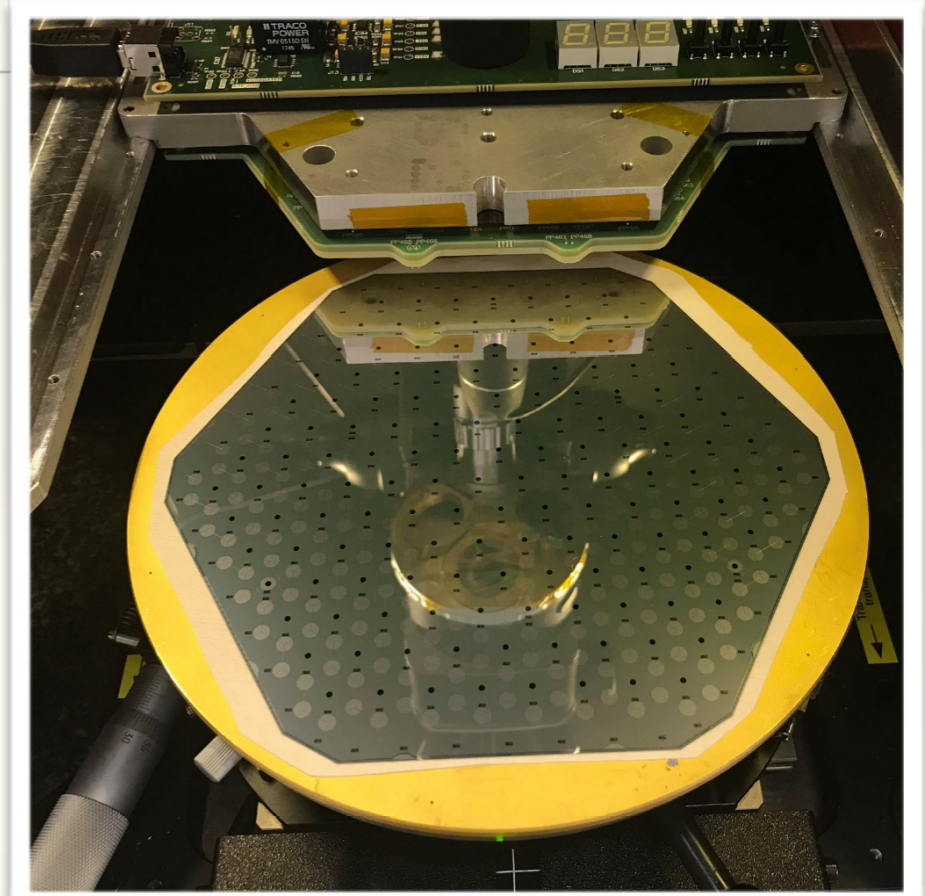
Precision timing with:
Barrel layer: Crystals + SiPMs
Endcap layer: Low Gain Avalanche Diodes



Detector Highlights

Silicon Sensors

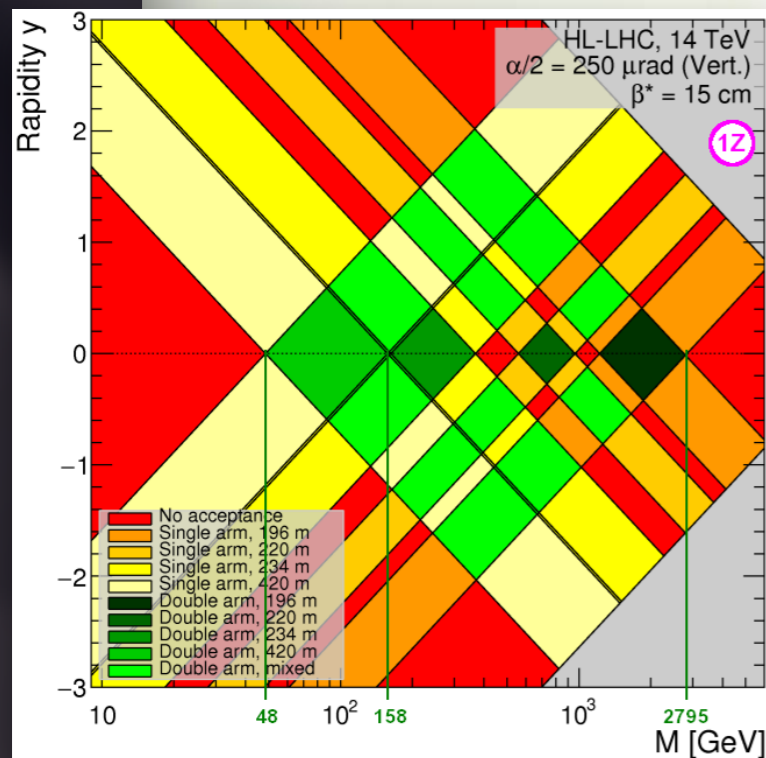
- ◆ Outer tracker **started production.**
- ◆ HGCAL is measuring final prototype sensors;
- ◆ Timing detector (ETL, Endcap timing layer) is measuring prototype V2.



— NOT YET CMS BASELINE —

Precision Proton Spectrometer PPS for Phase-2

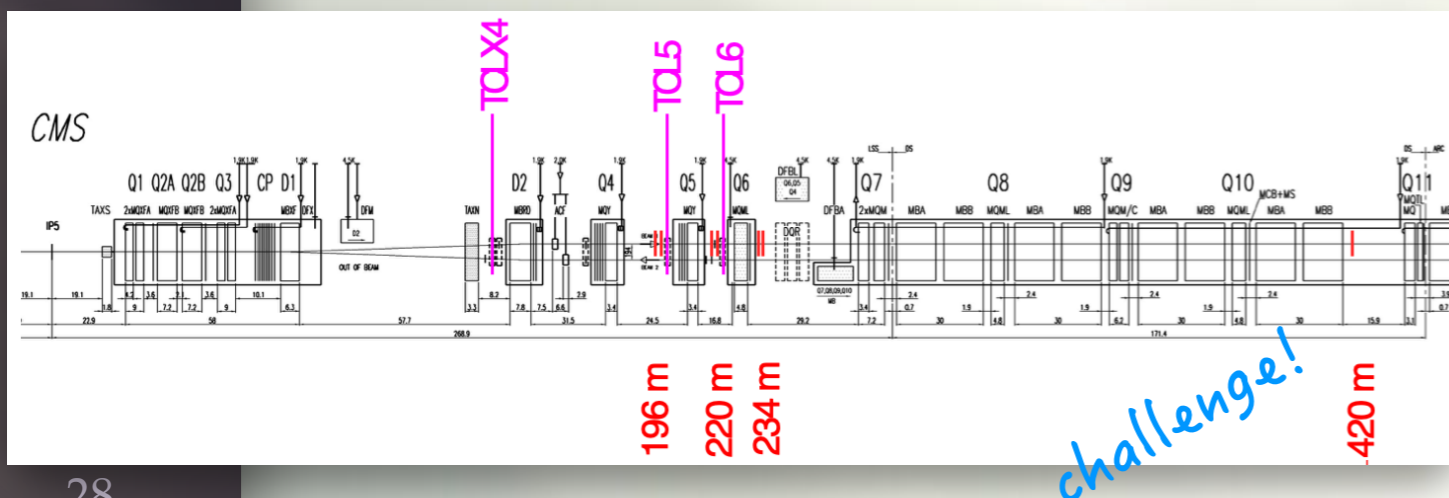
Large (not completely contiguous) acceptance in masses of “X”
in $pp \rightarrow pXp$ from ~ 50 GeV to ~ 3 TeV



- ◆ EoI to be published as a CMS note later this fall.
- ◆ 4 relevant locations on both sides of IP5:

| | | |
|------------------|-------|------------------------------|
| Just before TCL5 | ~196m | high masses (1~2.72 TeV) |
| Just before TCL6 | ~220m | interm. masses (520~960 GeV) |
| Just after Q6 | ~234m | lower masses (264~370 GeV) |
| (cold section) | 420m | lowest masses (44~160 GeV) |

➔ 420m requires non-traditional RP technology!



- ◆ Technologies under investigation:
 - Diamonds – ToF
 - 3D silicon – tracking
- ◆ **MTD $|\eta| < 3$ helps significantly to reduce timing precision requirement.**

Summary

CMS is progressing
in all aspects!

◆ Lots of works have been carried out during LS2:

- **Recovered from COVID stop.**
- The repairing and maintenance works for each sub-detector are ongoing.
- Excellent utilisation of computing resources, steadily improves in preparation for Run-3.
- CMS starting to move to Legacy-reconstructed data and MC.

◆ Fruitful physics results:

- **22 submitted papers since last LHCC session.**
- 28 new preliminary results.

◆ Upgrade activities:

- **Significant progresses in multiple directions.**
- PPS EoI to be published as a CMS note later this fall.