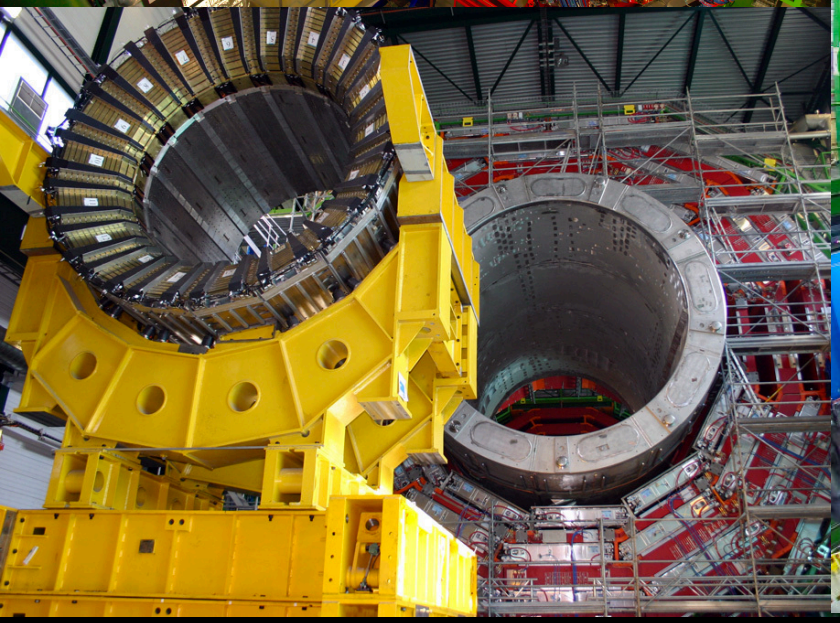
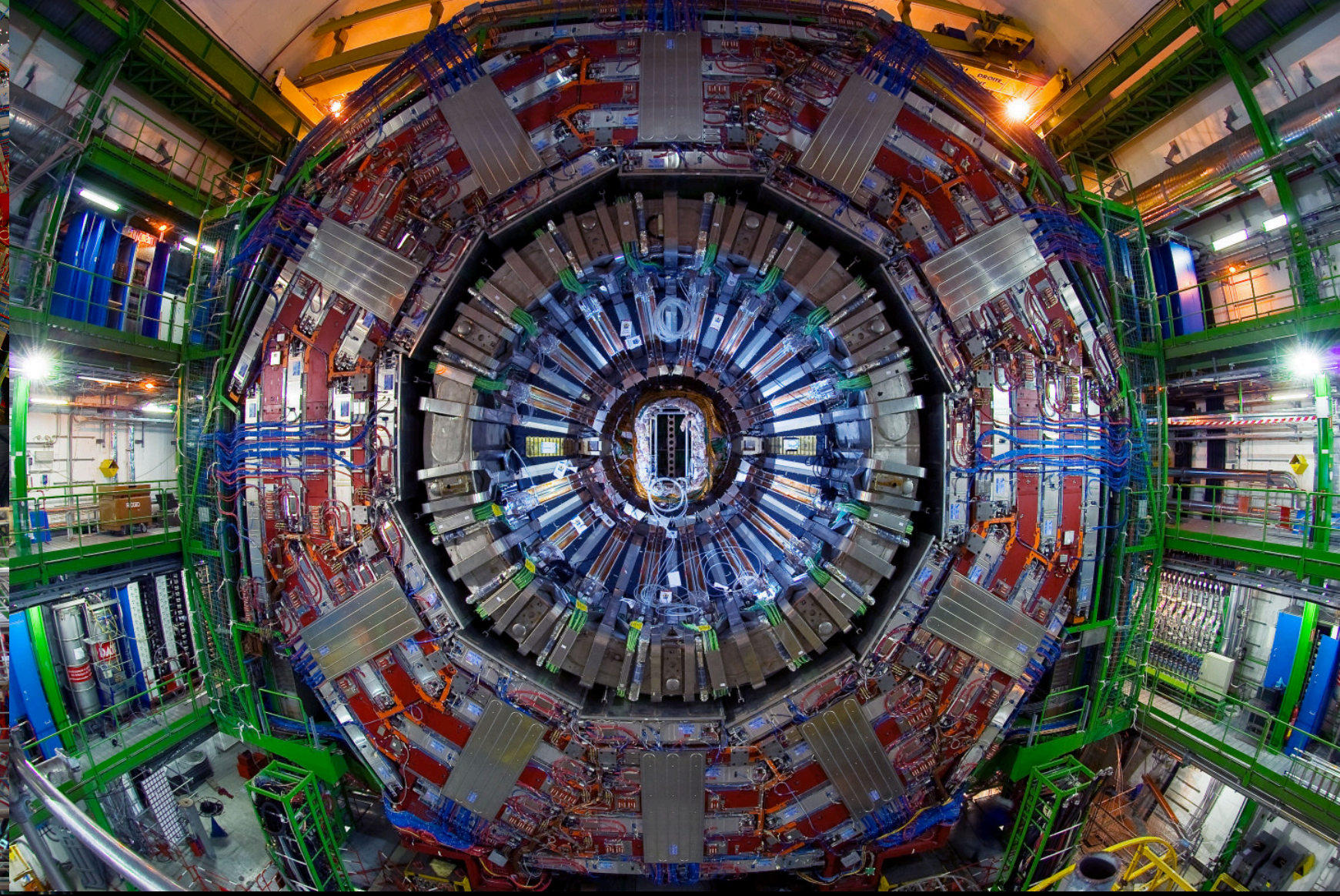
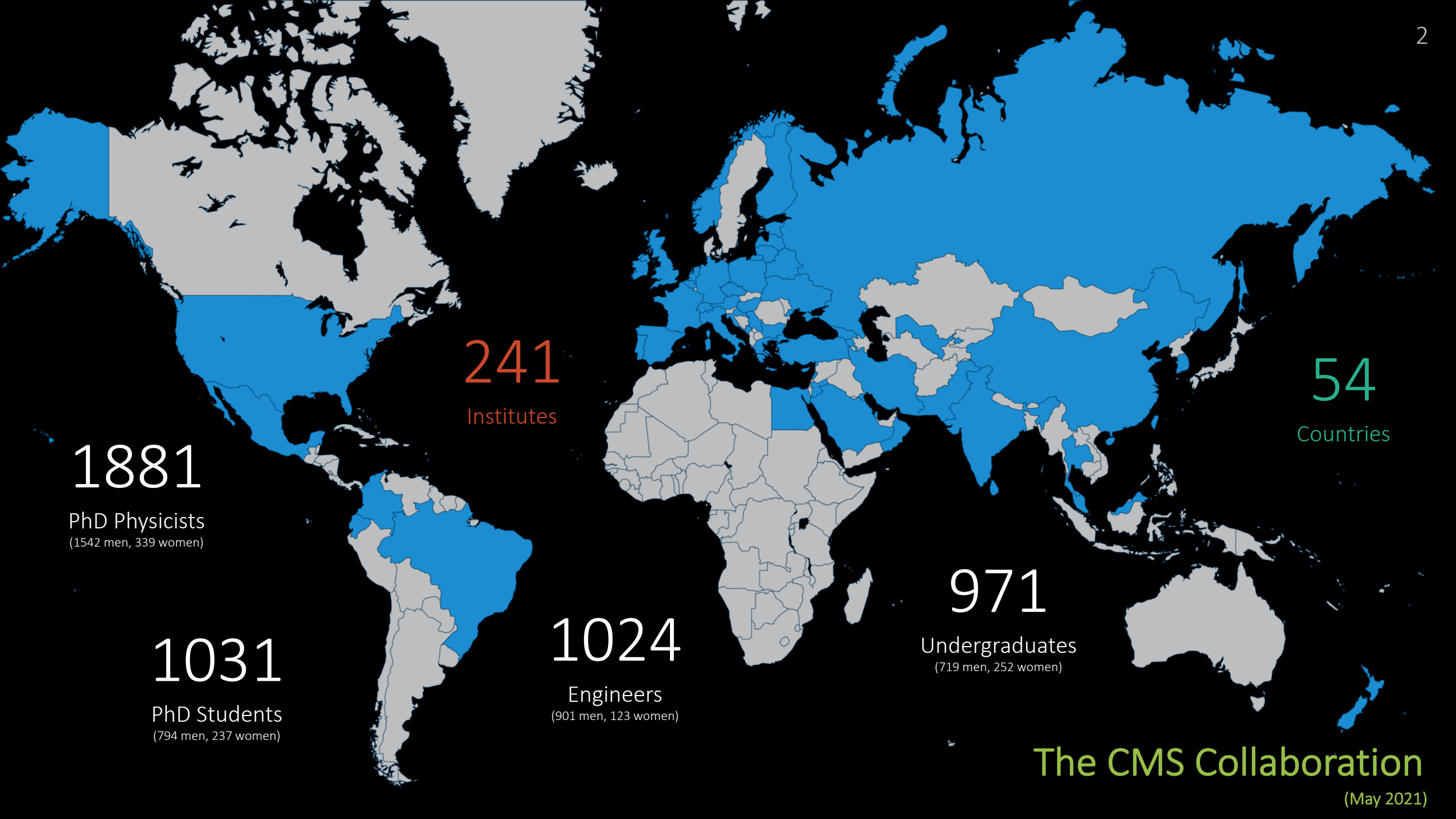




Highlights from the CMS Experiment

Cristina Oropeza Barrera
Universidad Iberoamericana CDMX



241
Institutes

54
Countries

1881
PhD Physicists
(1542 men, 339 women)

971
Undergraduates
(719 men, 252 women)

1024
Engineers
(901 men, 123 women)

1031
PhD Students
(794 men, 237 women)

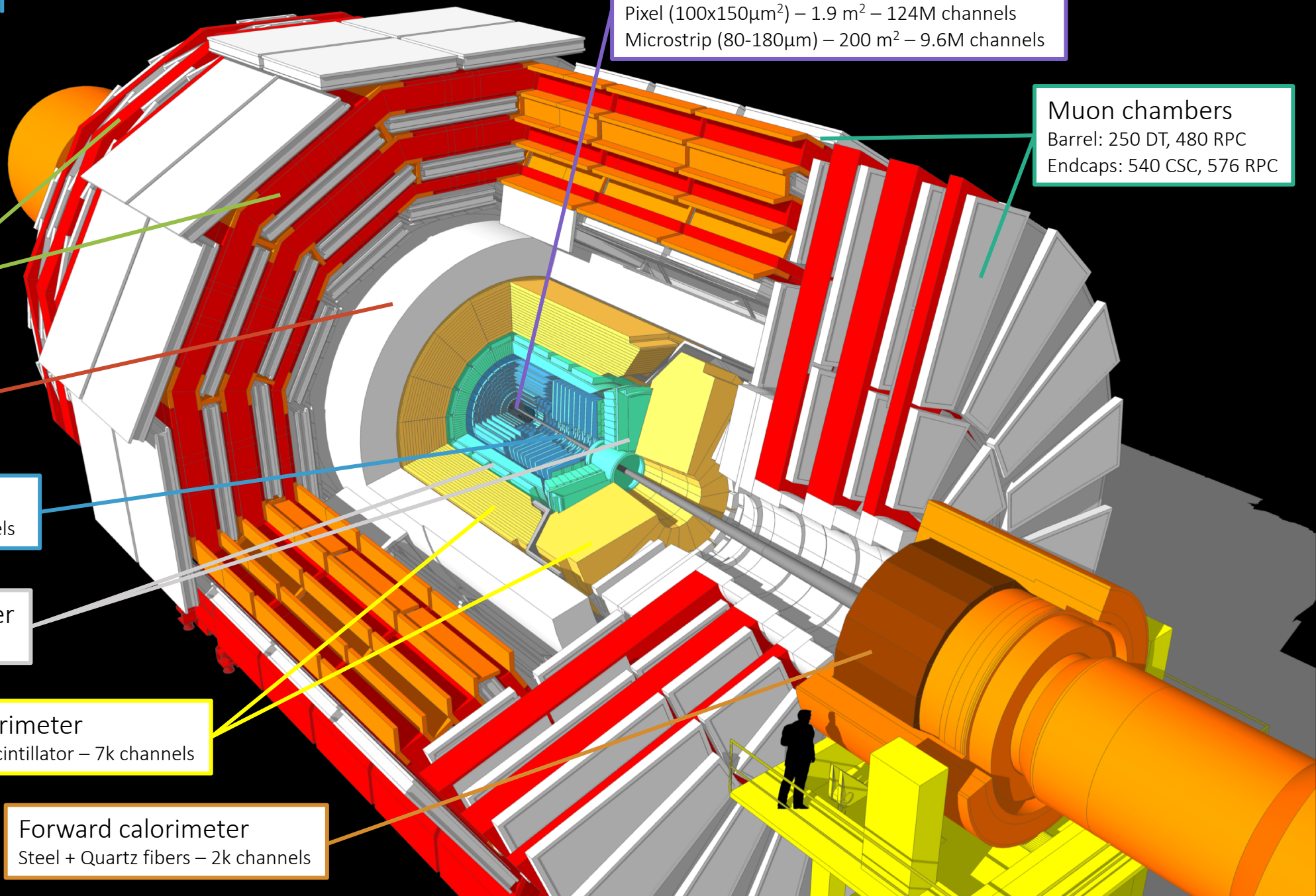
The CMS Collaboration

(May 2021)

The CMS Detector

(Run 2)

Total weight: 14,000 tonnes
Overall diameter: 15 m
Overall length: 28.7 m
Magnetic field: 3.8 T



Silicon trackers
Pixel (100x150µm^2) – 1.9 m^2 – 124M channels
Microstrip (80-180µm) – 200 m^2 – 9.6M channels

Muon chambers
Barrel: 250 DT, 480 RPC
Endcaps: 540 CSC, 576 RPC

Steel return yoke
12,500 tonnes

Superconducting solenoid
Niobium titanium coil – 18,000 A

Preshower
Si strips – 16m^2 – 137k channels

Electromagnetic calorimeter
76k scintillating $PbWO_4$ crystals

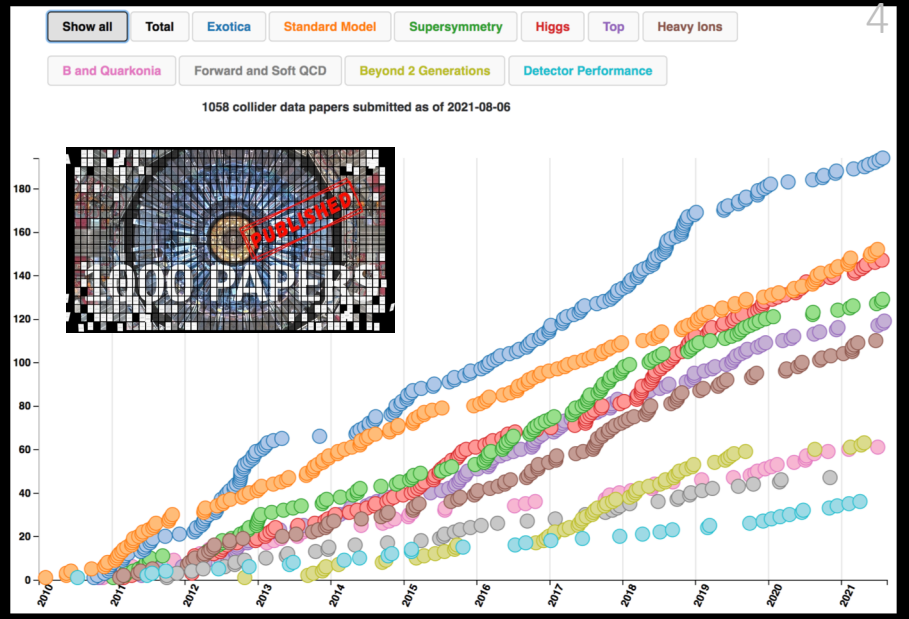
Hadron calorimeter
Brass + plastic scintillator – 7k channels

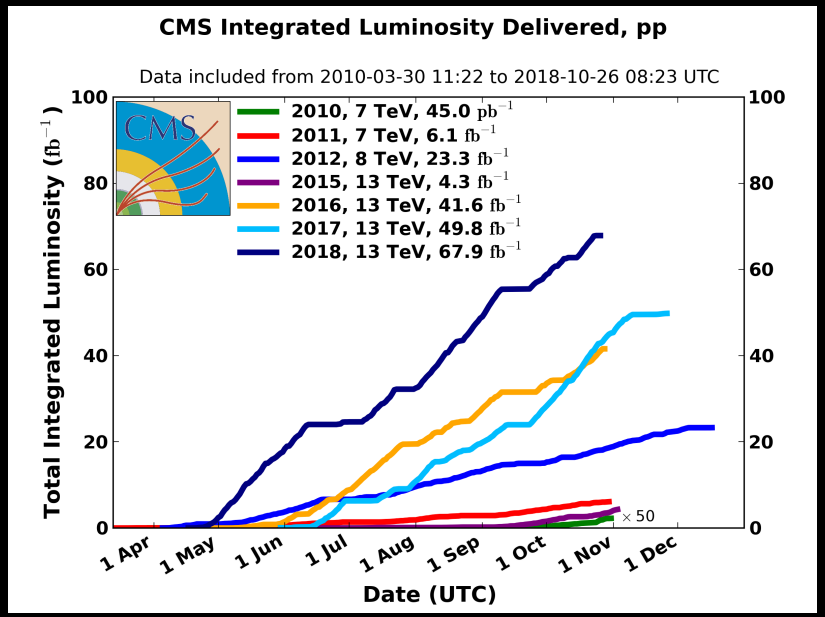
Forward calorimeter
Steel + Quartz fibers – 2k channels

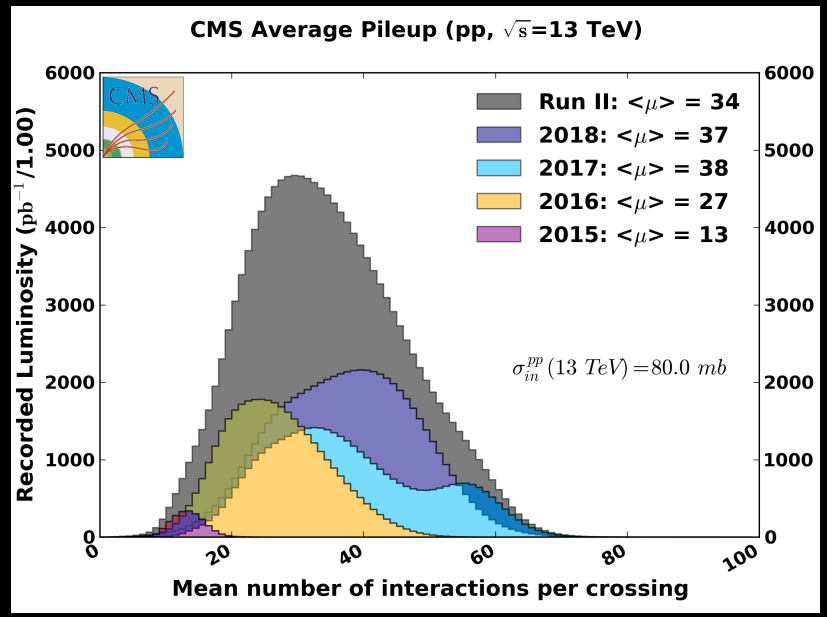
CMS in Runs 1 & 2

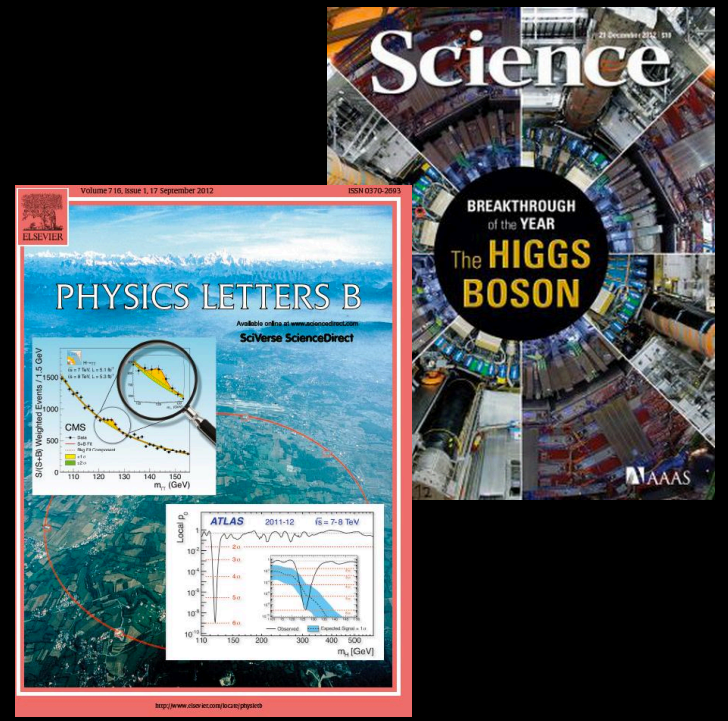
- Excellent performance of the LHC.
- In Run 2:
  - 137 fb^{-1} of proton-proton data good for physics.
  - Data-taking efficiency > 92% (2018: 94%).
  - Number of pp interactions per beam crossing (PU): <μ> = 34.
  - Maximum instantaneous LHC luminosity (2018):
    $\mathcal{L}_{max} = 2.14 \times 10^{34}\ cm^{-2}s^{-1}$ (2x higher than design parameters)

- Over 1000 physics publications.









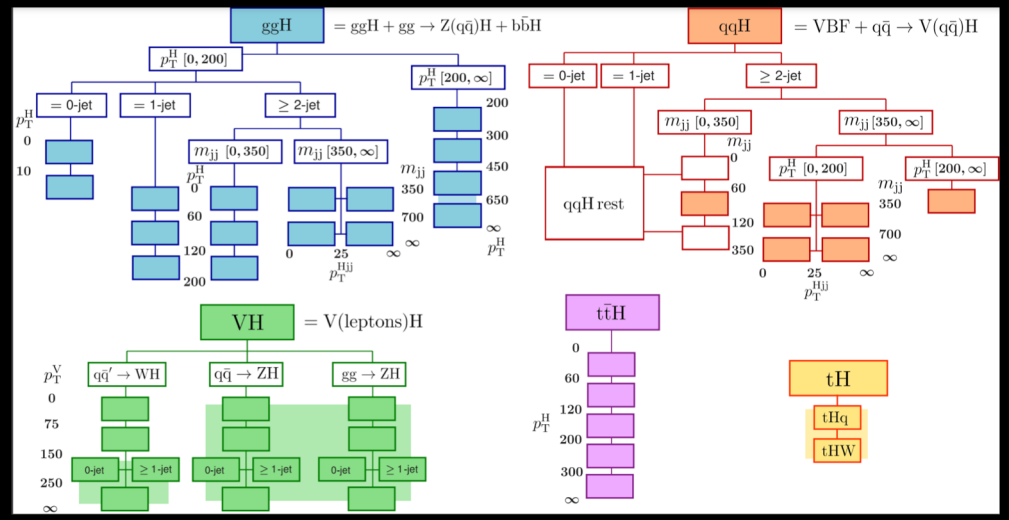
Selected Run 2 Results

All CMS publications and PAS available here: http://cms-results.web.cern.ch/cms-results/public-results/publications/

Higgs boson production cross-sections in the $\gamma\gamma$ channel

137 fb^{-1}

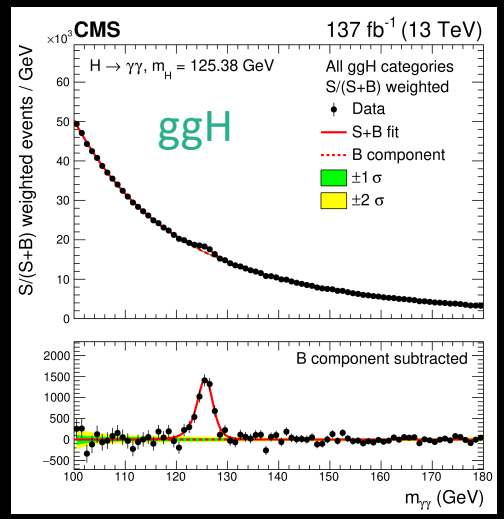
JHEP 07 (2021) 027

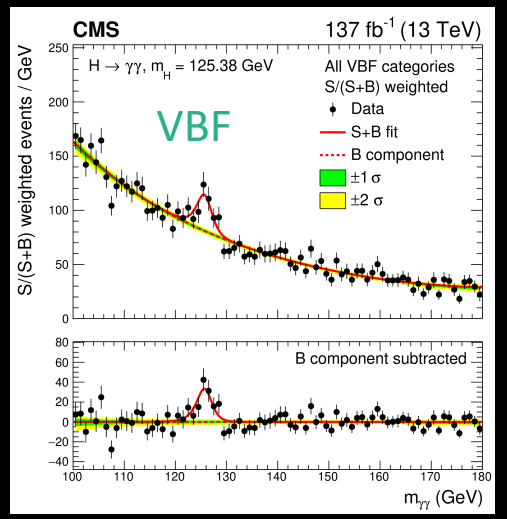


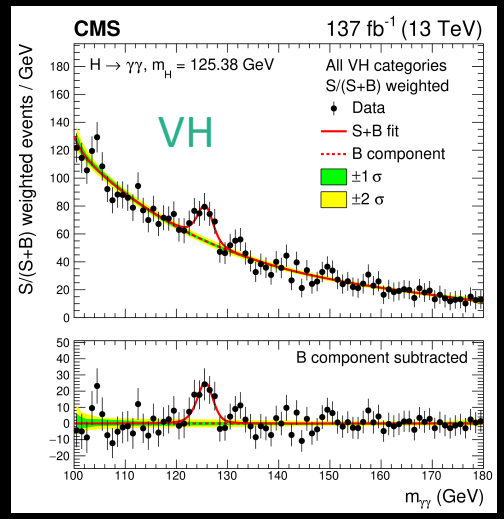
Measurements are performed in several kinematic regions for the different Higgs production modes.

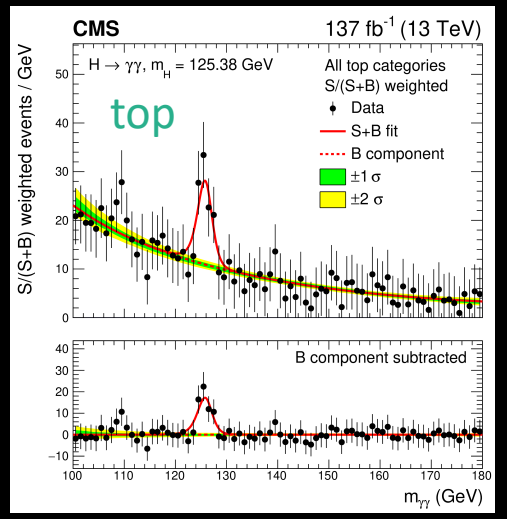
ML algorithms (BDTs) are used to classify events or discriminate between signal and background processes.

Clear signals observed in the main four production modes.





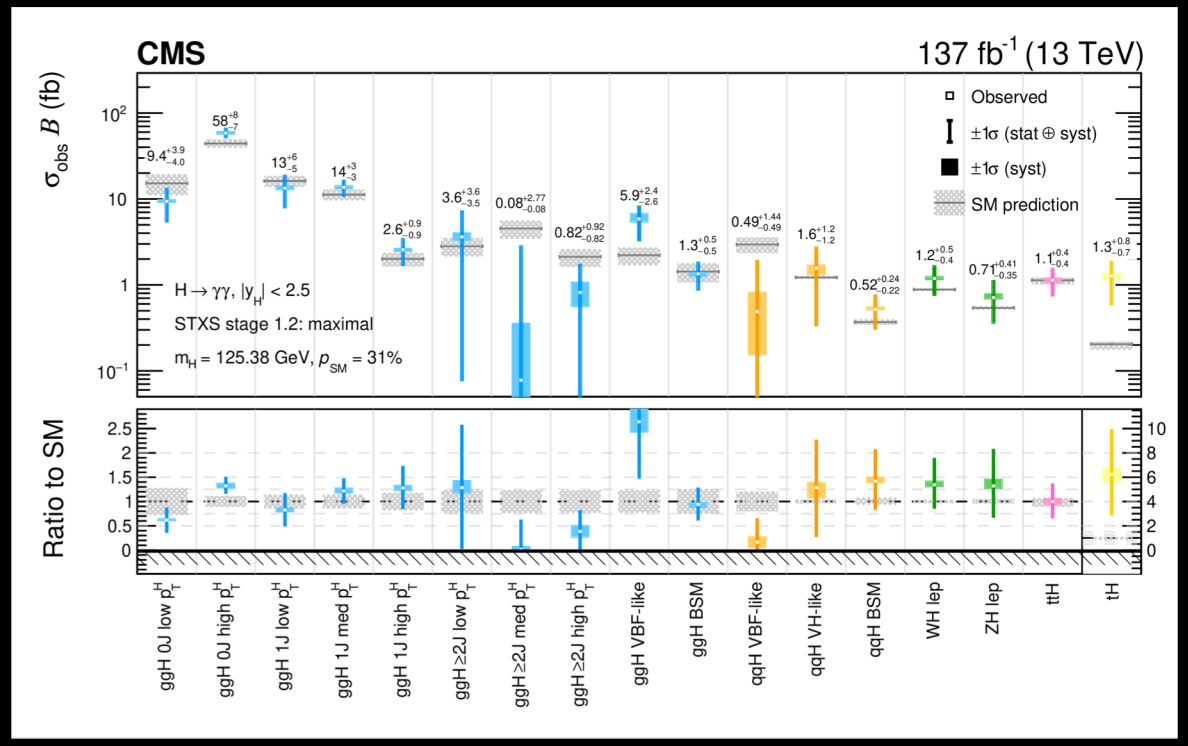


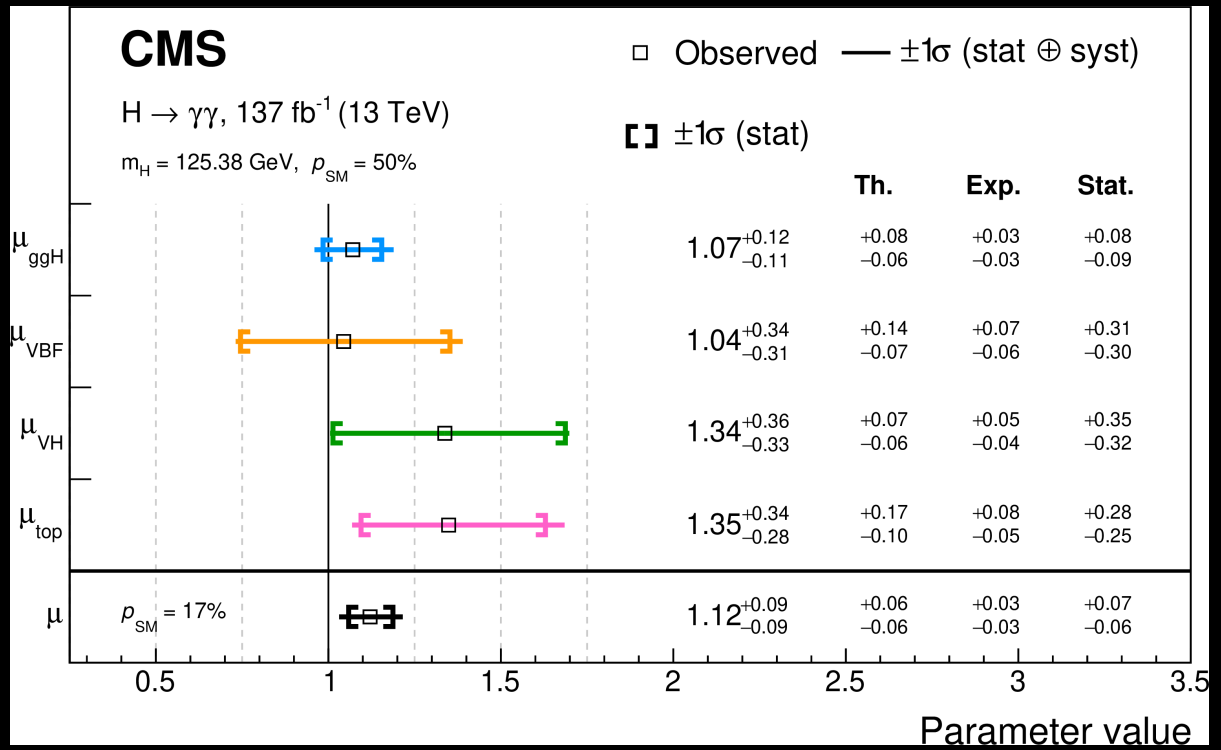


Higgs boson production cross-sections in the $\gamma\gamma$ channel

137 fb^{-1}

JHEP 07 (2021) 027





All measurements found to be consistent with the SM predictions.
Several measurements are the most precise made in a single channel to date.

The total Higgs boson signal strength, relative to the SM prediction, is measured to be 1.12 ± 0.09.

Top quark pair production with charm jets

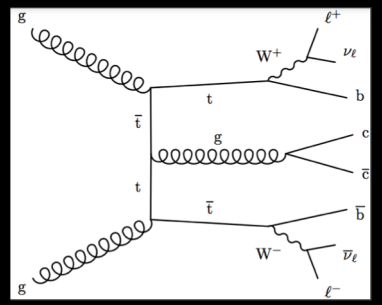
41.5 fb^{-1}

Phys. Lett. B. 820 (2021) 136565

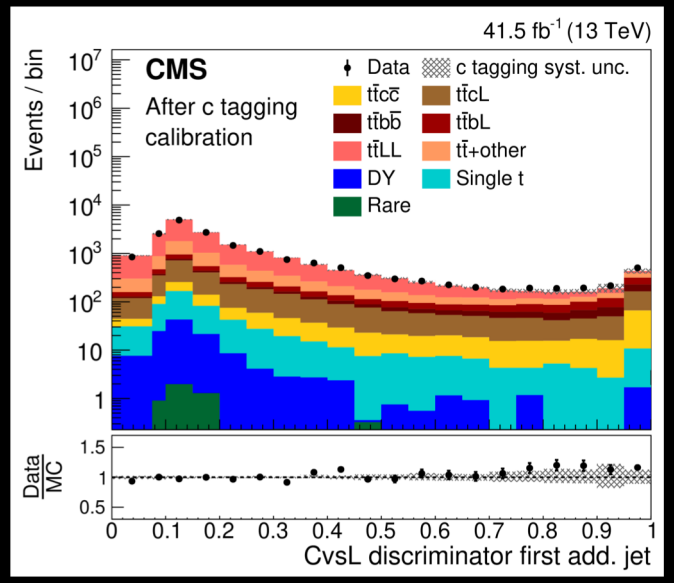
First measurement of the inclusive ttcc cross-section and its ratio to the inclusive tt + two jets (ttjj) cross section.
=> Important also for ttH measurements.

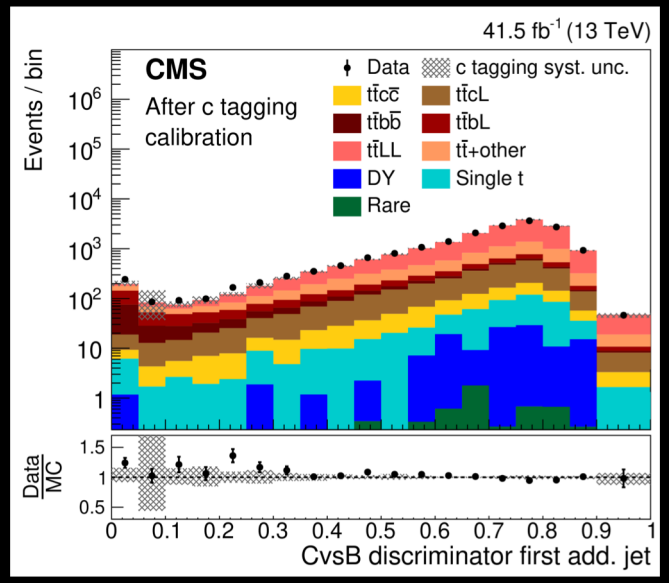
Technique that simultaneously extracts the cross-sections for ttcc, ttbb, and ttLL (light quark/gluon).

Dileptonic decay channel of the tt system.



	Result	POWHEG	MadGraph5_aMC@NLO
	Fiducial phase space		
$\sigma_{t\bar{t}c\bar{c}}$ [pb]	$0.207 \pm 0.025 \pm 0.027$	0.187 ± 0.038	0.189 ± 0.032
$\sigma_{t\bar{t}b\bar{b}}$ [pb]	$0.132 \pm 0.010 \pm 0.015$	0.097 ± 0.021	0.101 ± 0.023
$\sigma_{t\bar{t}LL}$ [pb]	$5.15 \pm 0.12 \pm 0.41$	5.95 ± 1.02	6.32 ± 0.94
R_c [%]	$3.01 \pm 0.34 \pm 0.31$	2.53 ± 0.18	2.43 ± 0.17
R_b [%]	$1.93 \pm 0.15 \pm 0.18$	1.31 ± 0.12	1.30 ± 0.16
	Full phase space		
$\sigma_{t\bar{t}c\bar{c}}$ [pb]	$10.1 \pm 1.2 \pm 1.4$	9.1 ± 1.8	8.9 ± 1.5
$\sigma_{t\bar{t}b\bar{b}}$ [pb]	$4.54 \pm 0.35 \pm 0.56$	3.34 ± 0.72	3.39 ± 0.66
$\sigma_{t\bar{t}LL}$ [pb]	$220 \pm 5 \pm 19$	255 ± 43	261 ± 37
R_c [%]	$3.36 \pm 0.38 \pm 0.34$	2.81 ± 0.20	2.72 ± 0.19
R_b [%]	$1.51 \pm 0.11 \pm 0.16$	1.03 ± 0.08	1.03 ± 0.09





NN to evaluate best permutations.

Charm jet identification algorithm uses a combination of two discriminators: CvsL and CvsB

Searches for heavy resonances decaying to ZH

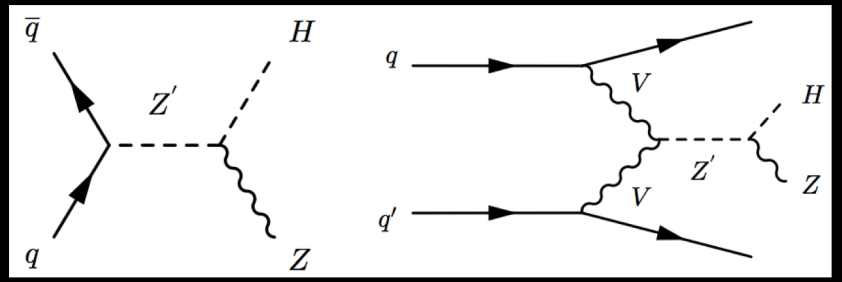
137 fb^{-1}

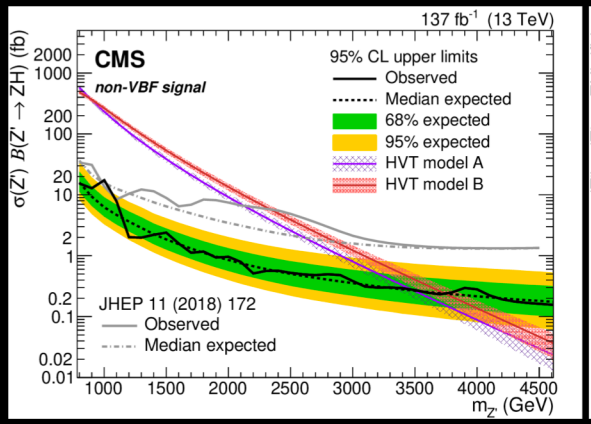
Eur. Phys. J. C 81 (2021) 688

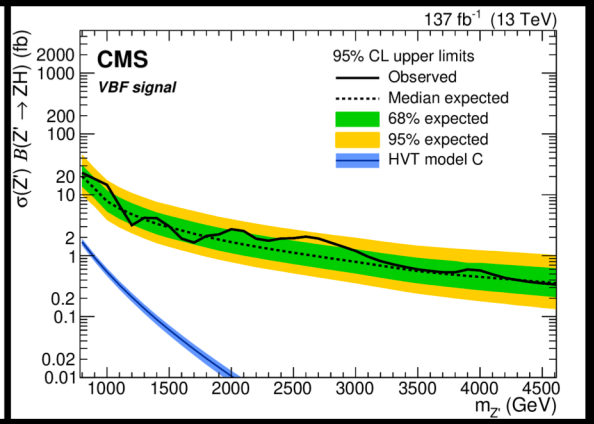
Motivated by hierarchy problem.

Z boson decay to leptons: e, μ and $\boldsymbol{\nu}$
H boson hadronic decay (either directly to a pair of heavy quarks, or via decays dominated by WW and ZZ)

Higgs candidate reconstructed as single large-radius jet (Lorentz-boosted)

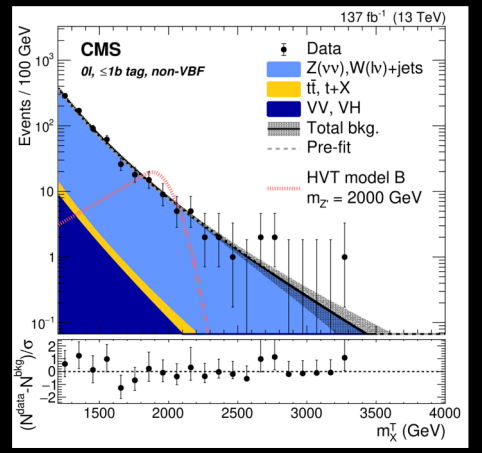






Events are classified depending on the number and flavor of leptons, the number of b-tagged subjets of the Higgs candidate jet, and the presence of forward jets consistent with VBF production => 12 categories

0ℓ, 2b tag, non-VBF	0ℓ, 2b tag, VBF
2e, 2b tag, non-VBF	2e, 2b tag, VBF
2μ, 2b tag, non-VBF	2μ, 2b tag, VBF
0ℓ, $\leq$1b tag, non-VBF	0ℓ, $\leq$1b tag, VBF
2e, $\leq$1b tag, non-VBF	2e, $\leq$1b tag, VBF
2μ, $\leq$1b tag, non-VBF	2μ, $\leq$1b tag, VBF



Most stringent limits placed on the Heavy Vector Triplet Z' model to date.

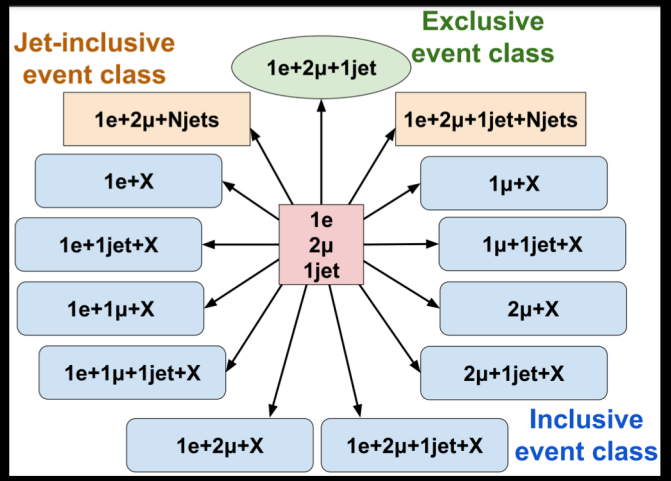
Model-unspecific searches in CMS (MUSiC)

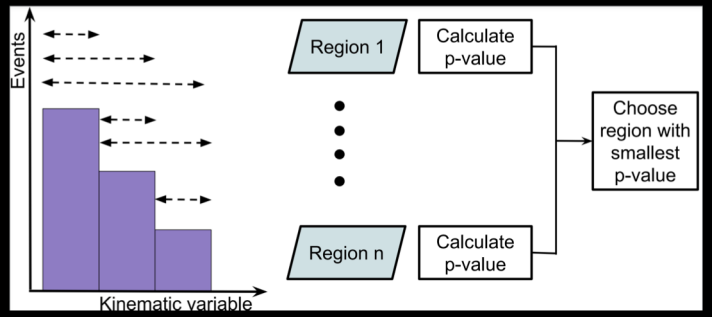
35.9 fb^{-1}

Eur. Phys. J. C 81 (2021) 629

Automated approach to quantify deviations between MC simulations of SM processes and data in a wide variety of final states, in order to detect discrepancies that could be hints of BSM physics or other neglected or unknown phenomena.

Restricted to final states that contain at least one isolated lepton (electron or muon).





498
exclusive

571
inclusive

530
Jet-inclusive

It is necessary to determine the physics object content of each event unambiguously → tight selection criteria to minimise the effect of misidentification.

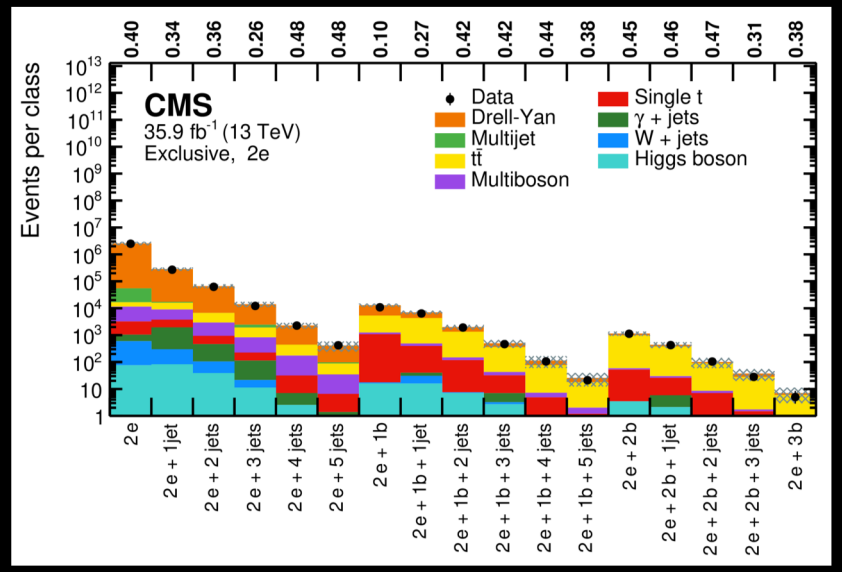
Each event is sorted into three different types of event classes:
exclusive, inclusive, jet-inclusive

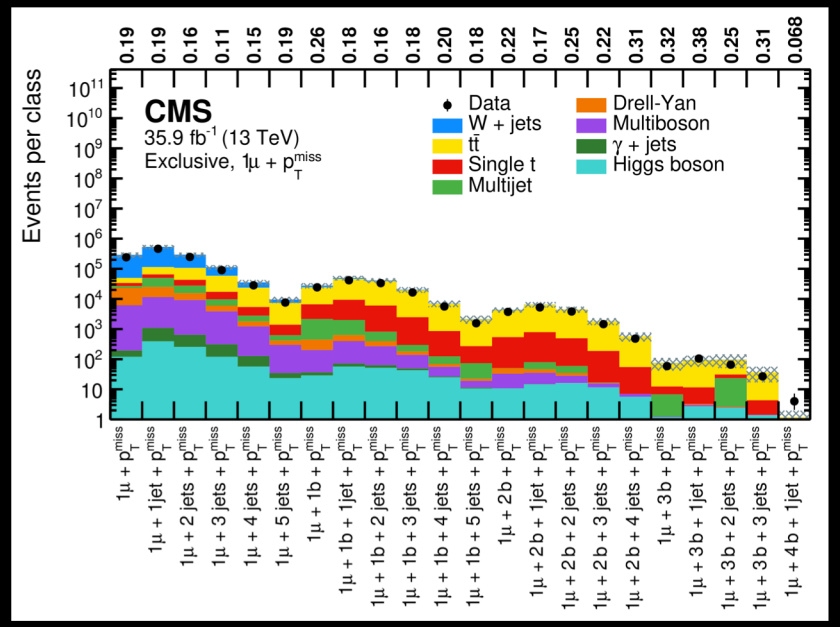
Kinematic distributions of interest:
S_T, M or M_T, P_T^{miss}

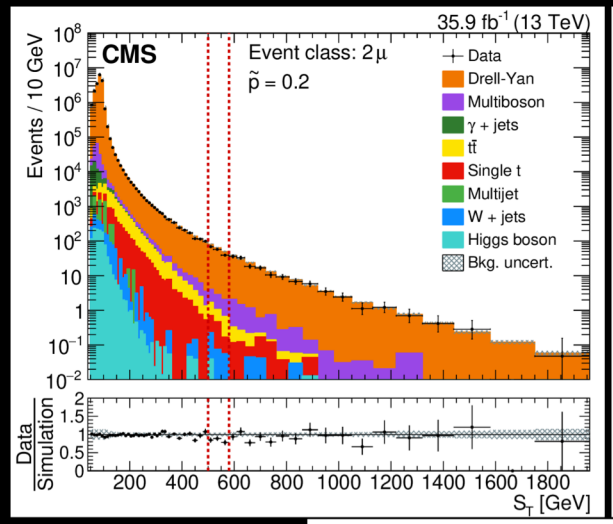
Model-unspecific searches in CMS (MUSiC)

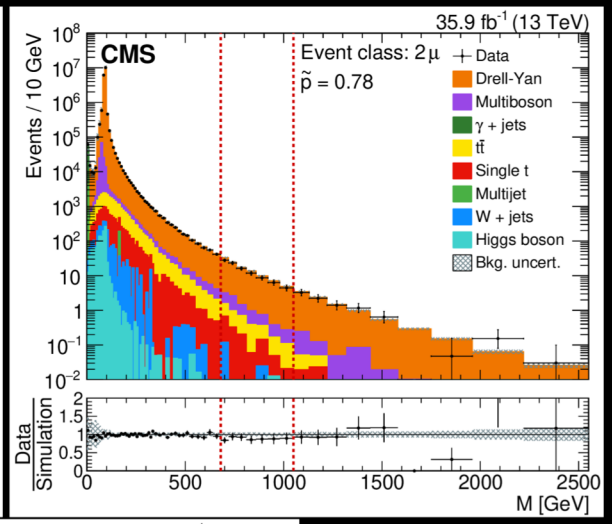
35.9 fb^{-1}

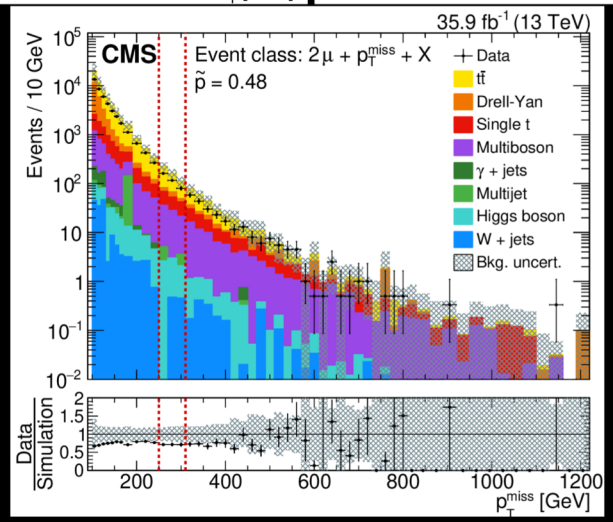
Eur. Phys. J. C 81 (2021) 629









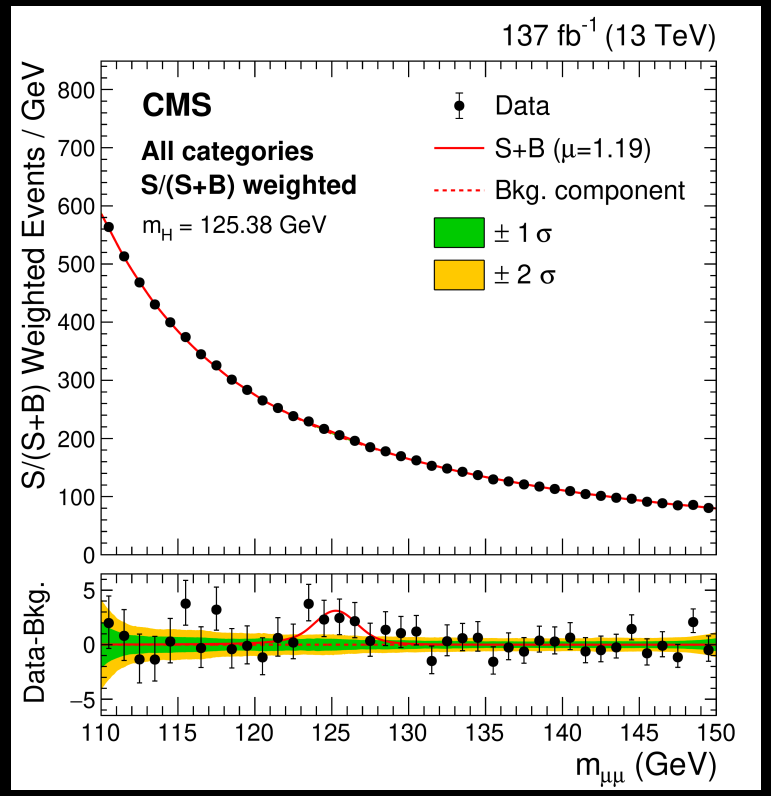


No event classes with an outstanding deviation from the SM simulation beyond the expectation have been found.

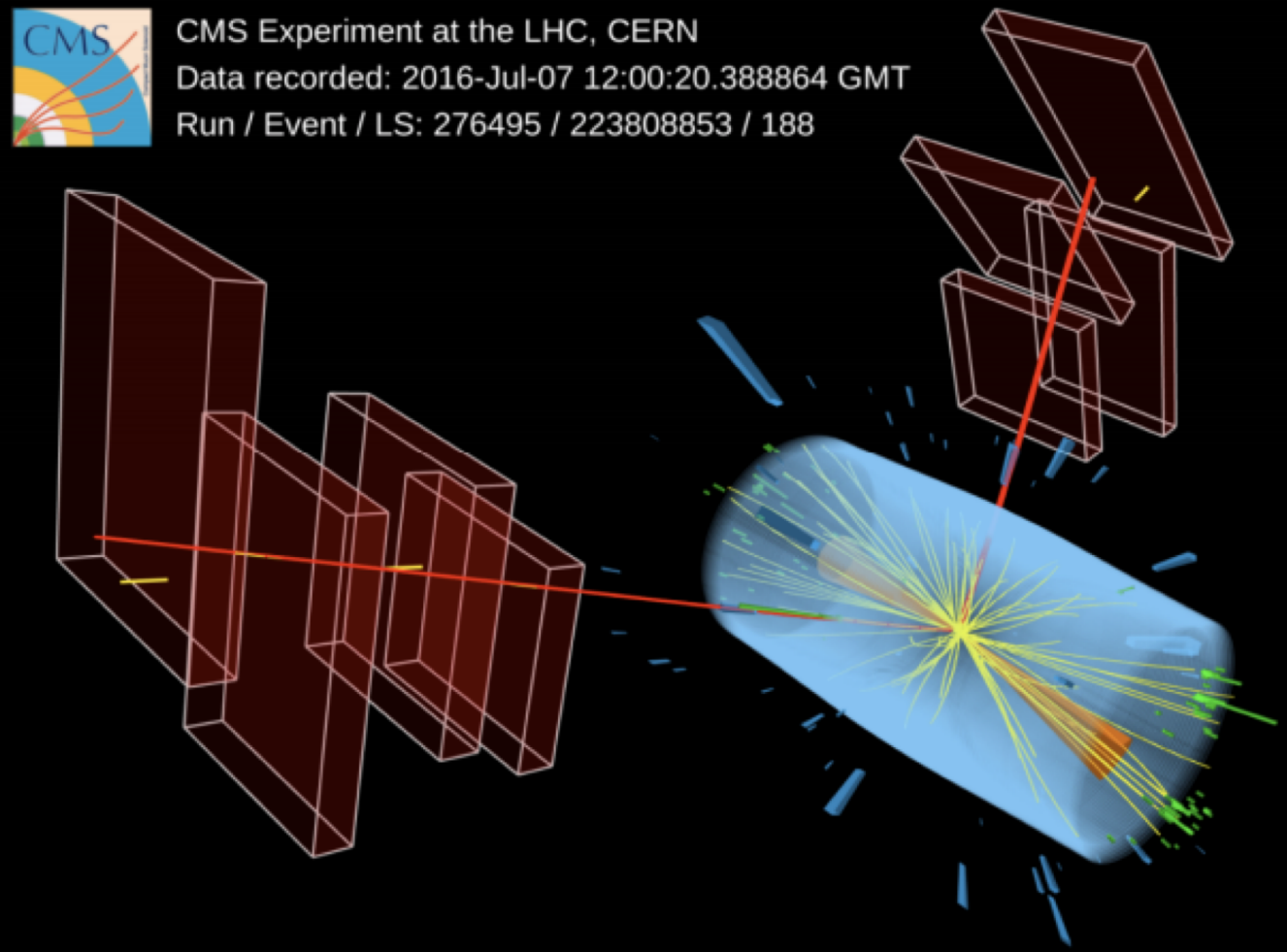
Evidence for Higgs boson decaying to two muons

137 fb^{-1}

JHEP 01 (2021) 148



The $m_{\mu\mu}$ distribution for the weighted combination of all event categories.

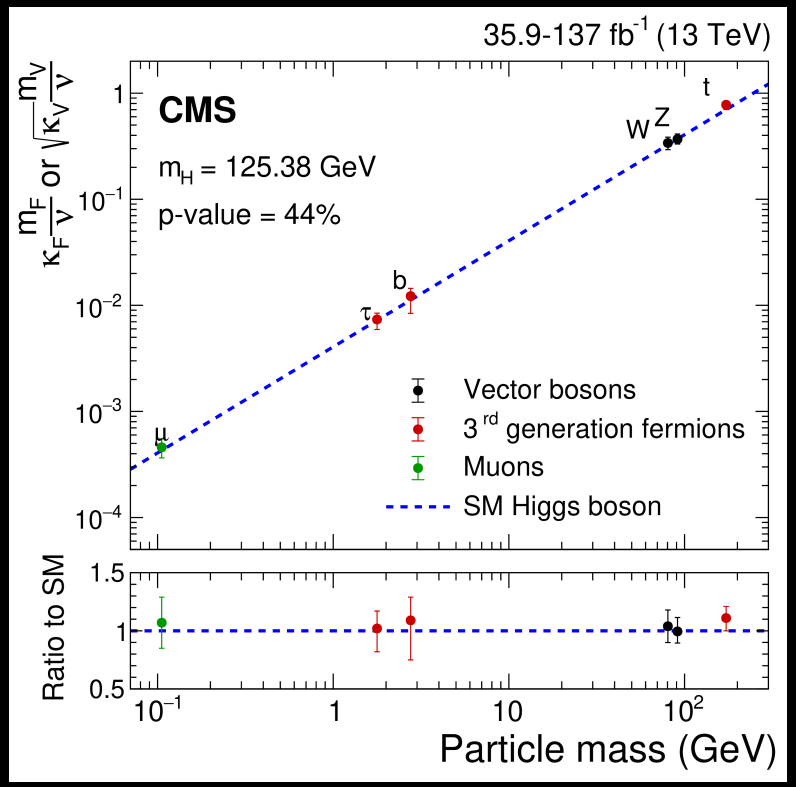


Evidence for Higgs boson decaying to two muons

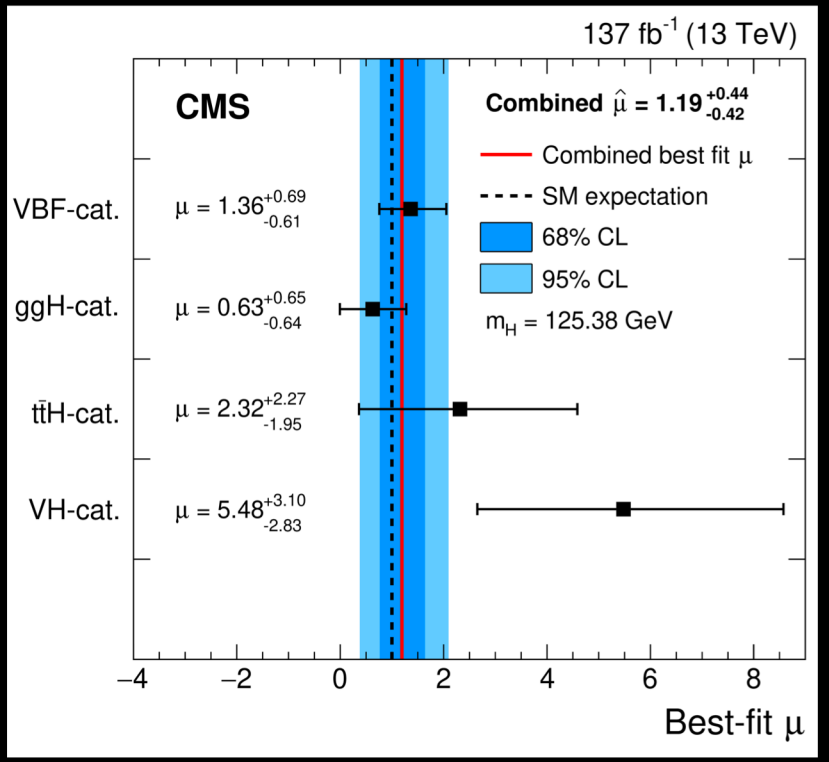
137 fb^{-1}

JHEP 01 (2021) 148

Signal strength modifiers measured for m_H= 125.38 GeV in each production category (black points) are compared to the result of the combined fit (solid red line) and the SM expectation (dashed grey line).



Best fit estimates for the reduced coupling modifiers extracted for fermions and weak bosons from the resolved κ-framework compared to their corresponding prediction from the SM.



$$\mu(\mu\mu) = 1.19^{+0.41}_{-0.39}\,(\text{stat})^{+0.17}_{-0.16}\,(\text{syst})$$

Obs. (exp.) significance: 3.0 (2.5) σ

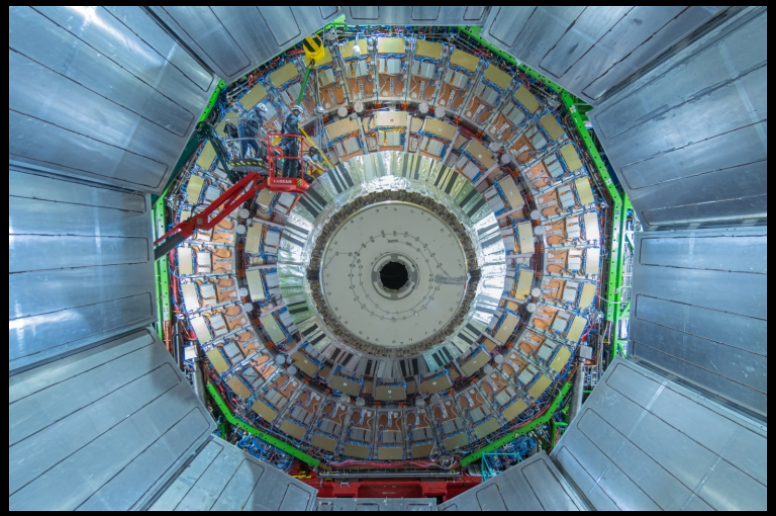
The road ahead

LS2 & Run 3

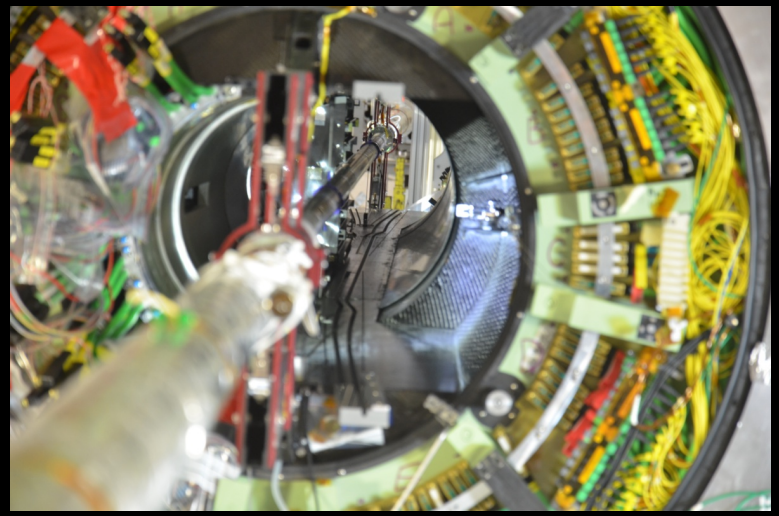
Long shutdown 2 (LS2): 2019 – 2021
Run 3: scheduled to start in 2022 and collect twice the integrated luminosity of Run 2.

Cosmic runs started
Pilot test beam in October

Installation of new beampipe



Installation of GEM detector (Phase-II)



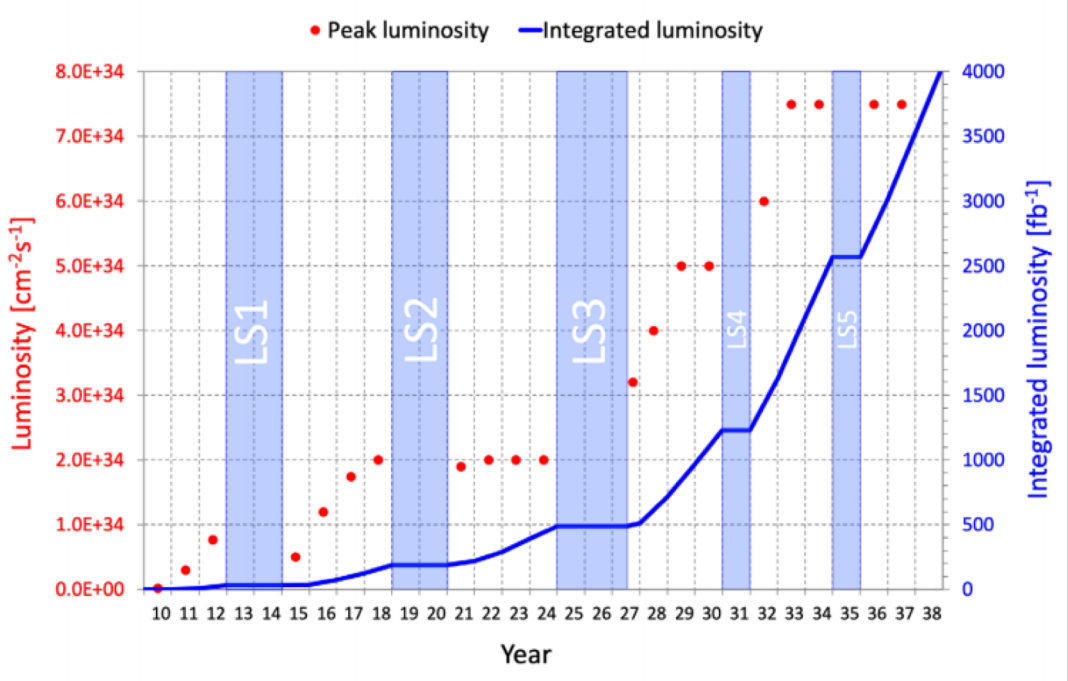
Installation of new Barrel Pixel layer 1

Replacement of BCM1F & PLT detectors

+ HCAL readout upgrade,
Muon demonstrators,
Civil engineering work for Phase-II,
…

The High-Luminosity LHC

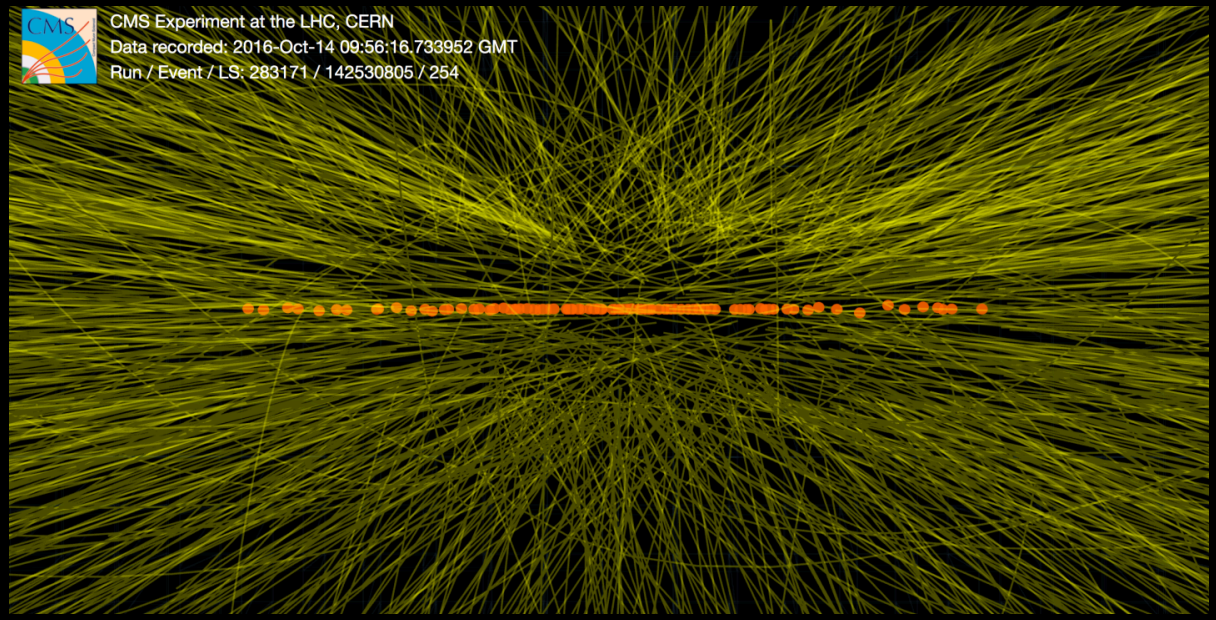
(Phase-II)



Scheduled to begin in 2027, a baseline instantaneous luminosity of 5×10^{34} $cm^{-2}s^{-1}$ with an average pileup of 140 is expected, with a maximum performance scenario of 7.5×10^{34} $cm^{-2}s^{-1}$ and an average of 200 interactions per bunch crossing.

It will allow a rich physics programme to be developed:

- Precision SM measurements and access to rare processes.
- Explore new regions of phase-space to search for new physics.



High pileup and harsh radiation environment will require major updates to the detector to maintain performance.

The CMS Detector

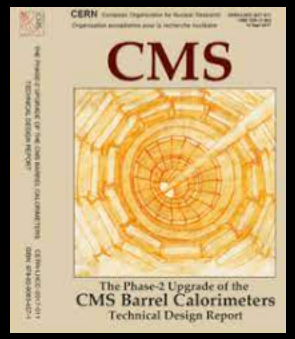
(Phase-II)

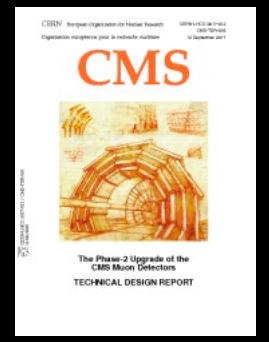
Muon system

DT & CSC new FE/BE readout

RPC BE electronics; iRPC chambers

Extended coverage to $|\eta|$ = 3



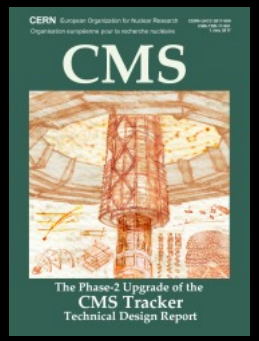


Barrel calorimeters

Crystal granularity readout at 40 MHz (ECAL)

Precision timing for e/γ for vertex id

New BE boards



Silicon trackers

Reduced material budget

Si-strip and pixels increased granularity

Extended coverage to $|\eta|$ = 3.8

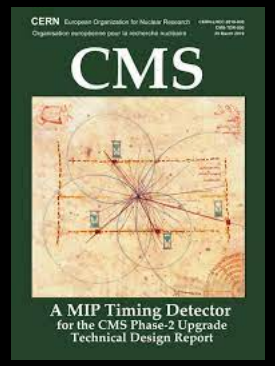
The CMS Detector

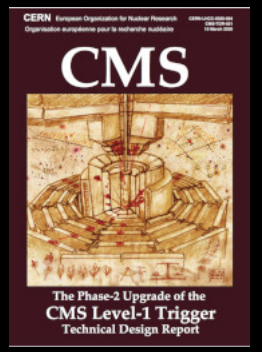
(Phase-II)

Level-1 Trigger

Tracks in L1 trigger at 40 MHz

Trigger on displaced muons & long-lived particles



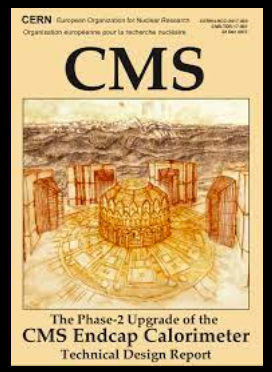


A MIP Timing Detector (MTD)

Precision timing for PU mitigation

Barrel layer: Crystals + SiPMs

Endcap layer: Low Gain Avalanche Diodes



Endcap calorimeters

silicon pixels (EM) & scintillators + SiPMs (HAD)

3D showers imaging for pattern recognition

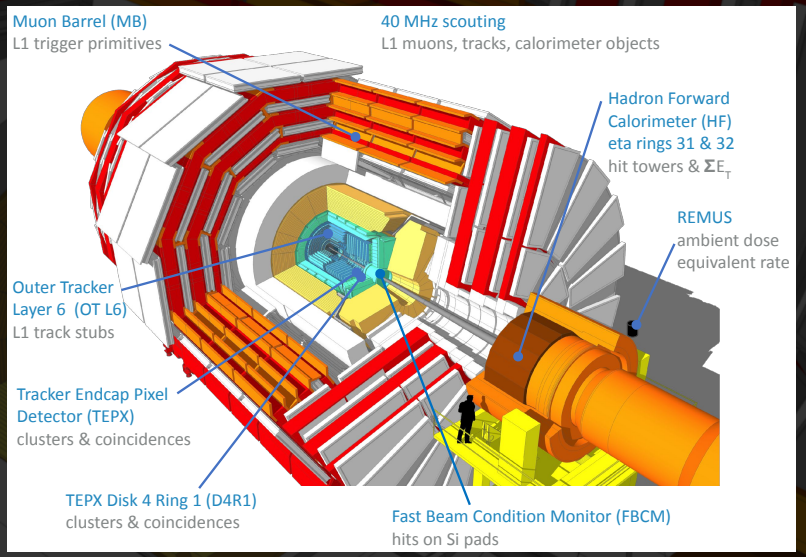
Precision timing for PU mitigation

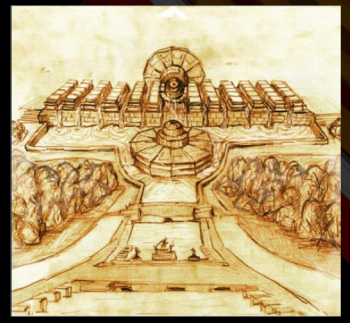
The CMS Detector

(Phase-II)

BRIL

The Phase-2 Upgrade of the CMS Beam Radiation, Instrumentation, and Luminosity Detectors





DAQ/HLT

The Phase-2 Upgrade of the CMS Data Acquisition

Summary

- Excellent performance of machine & experiment has led to a plethora of nice physics results.
  - Today only a handful were shown, totally biased based on personal interests.
- LS2 is coming to an end and preparations are underway for Run 3.
- Upgrade (Phase-II) work is also in full swing with pretty much all the TDRs ready.
  - Last two are under review.
- Much to do in CMS for both undergraduate & postgraduate students in physics analysis, detector performance, simulations, prospective studies, etc.