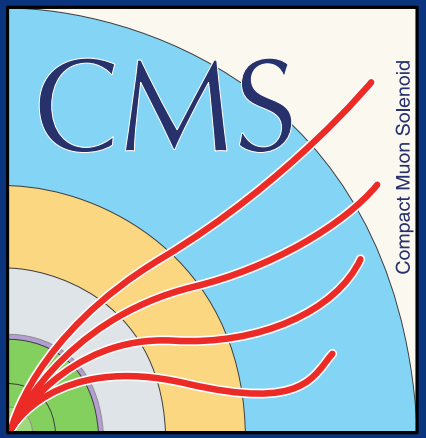
CMS Status Report

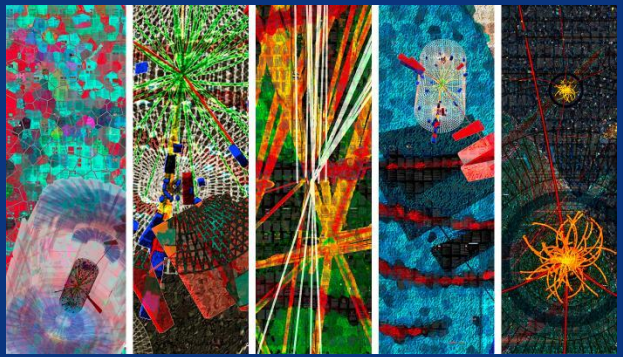


Talk Presented to

23nd CERN-Korea meeting

Roberto Carlin

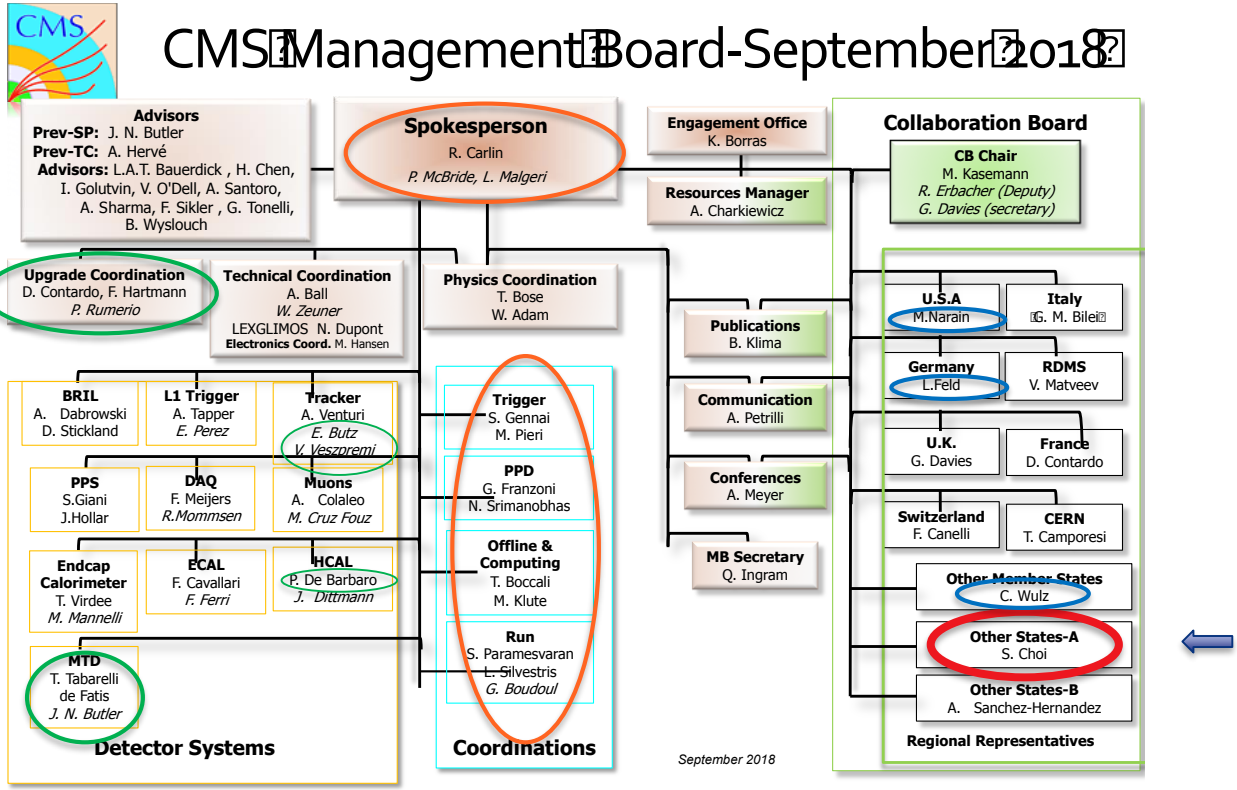
Oct. 29, 2018



Xavier Cortada (with the participation of physicist Pete Markowitz), “In search of the Higgs boson,” digital art, 2013

Collaboration news

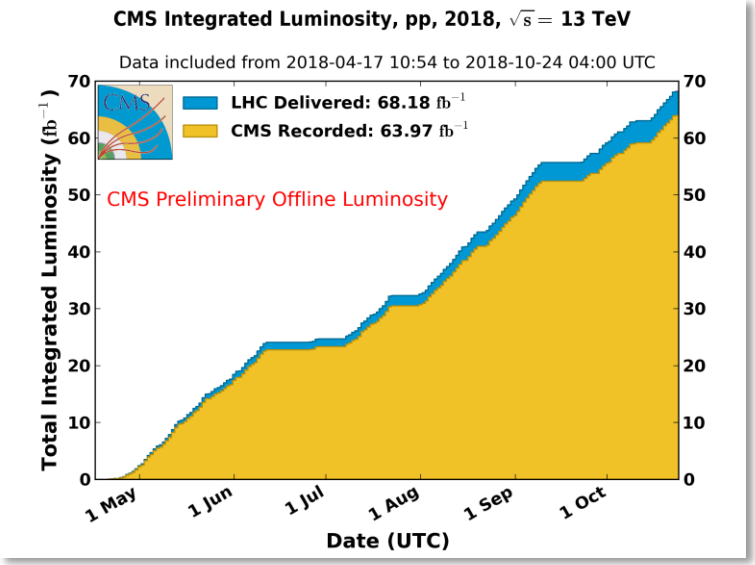
New Org Chart



CMS in 2018

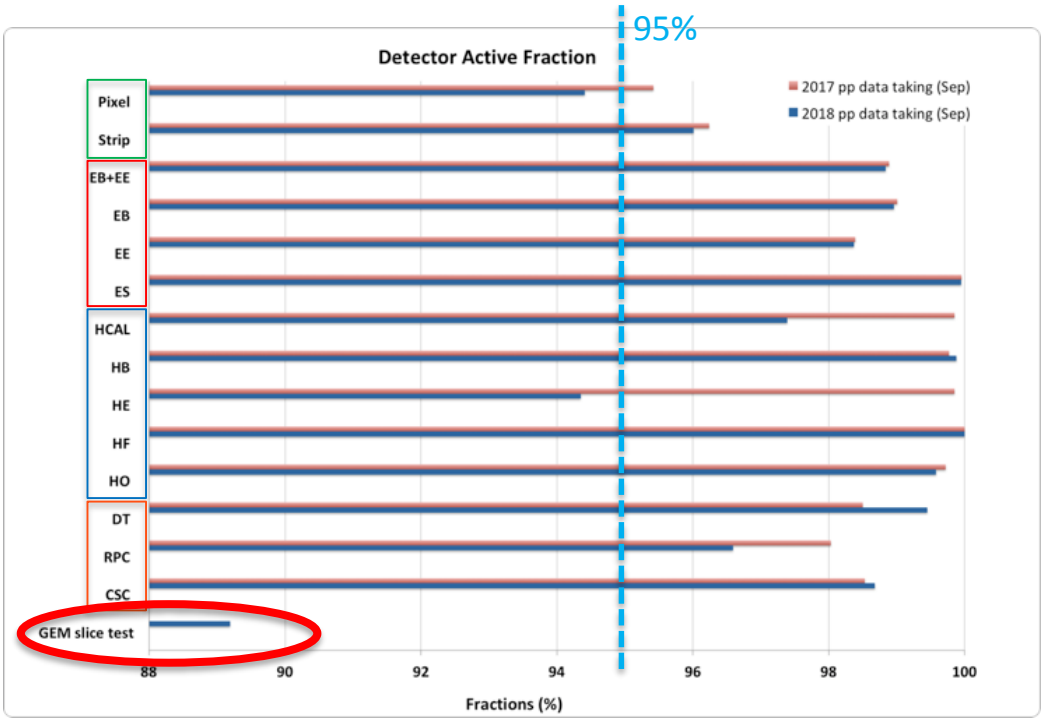
CMS in 2018

- **Excellent performance of LHC** and of CMS
  - LHC goal of 150 fb^{-1} in Run 2 reached, several weeks before moving to Heavy Ions program
  - Final score is 68.2 fb^{-1} delivered to CMS in 2018, 163 fb^{-1} delivered overall in Run 2
  - CMS recording efficiency has been about 94%in 2018
  - Very good performance of PPS in 2018
    - PPS data available in ~95% of the CMS data, excellent for a Roman Pot detector
  - Aggressive use of the DAQ bandwidth with B-parking
    - With smooth computing operations



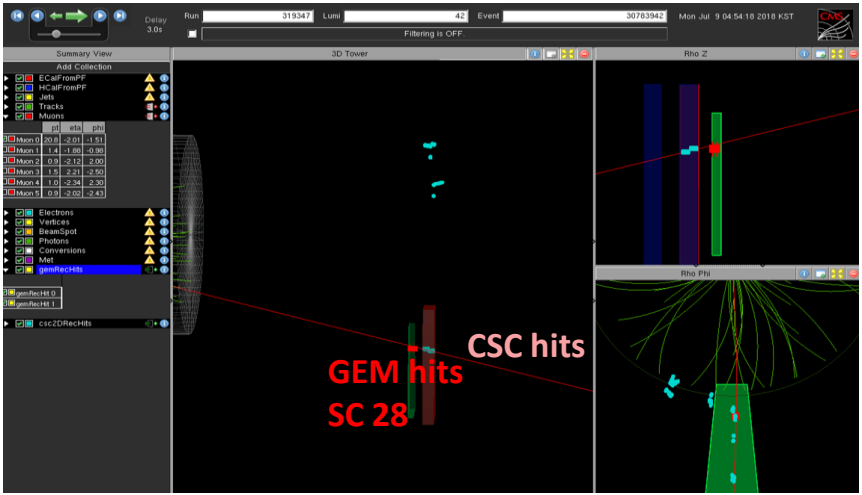
Many thanks to LHC !

Excellent and stable performance of all CMS subdetectors



GE1/1 slice in CMS

- Strong contribution from Korea in this enterprise



NB, the GE1/1 slice is integrated in CMS runs. The GE1/1 will be the first Phase II detector to be integrated in CMS, already in 2019-20

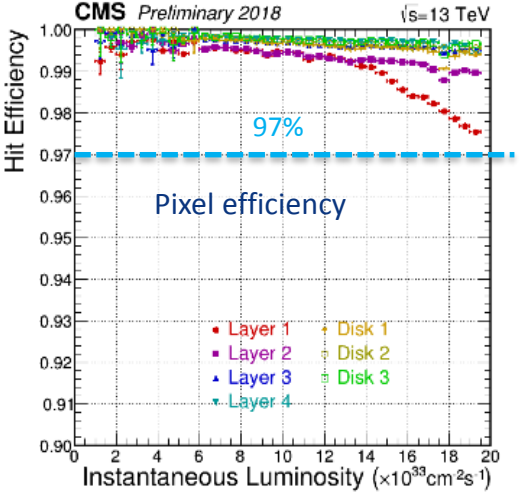
Quality of data

CMS is taking excellent quality data, including in **several special runs**

- VdM scans, 90m β* CMS-TOTEM joint run, Low PU run (HI run is next)

DC/DC converters, **failure mode understood** as the combined result of irradiation and use of the enable/disable feature

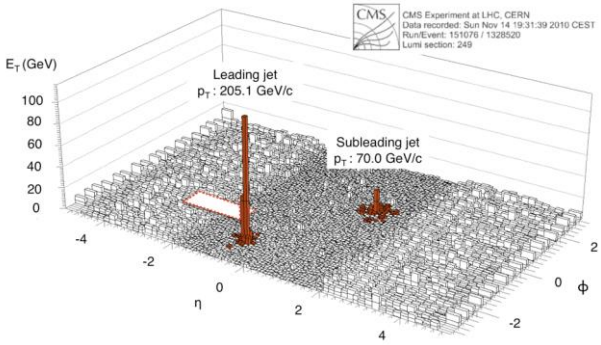
- **This understanding allowed us to prevent it to happen in 2018**
- Many thanks to the CMS Tracker Team, Technical Coordination , and the CERN FEAST design team



Quality of data

- 2018 problem: a fake fire alarm ended up in the loss of two adjacent sectors in hadronic calorimeter endcap (HE)
  - About 2% of the acceptance of full hadronic calorimetry
  - The chain of reasons was fully understood after extensive studies (very rare error in a widely used power supply) and mitigation actions taken

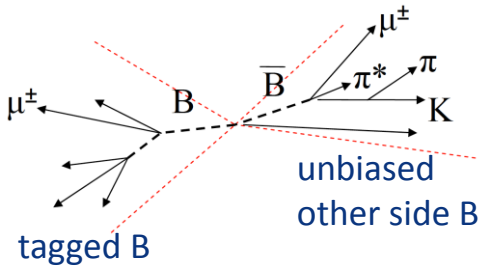
- The impact on data has been studied in detail and **found small** (also thanks to the use of PF reconstruction)
- Mitigations are under validation but **even without those prompt data is good for physics**.

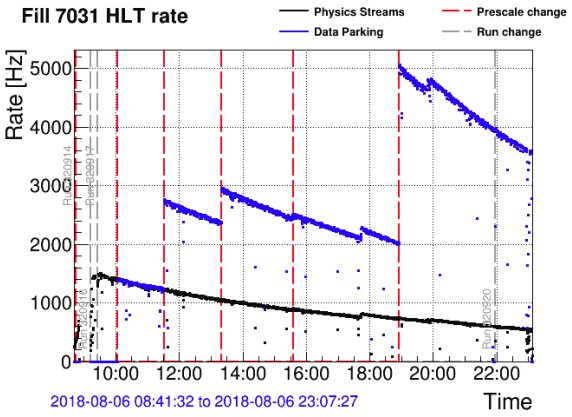


B parking

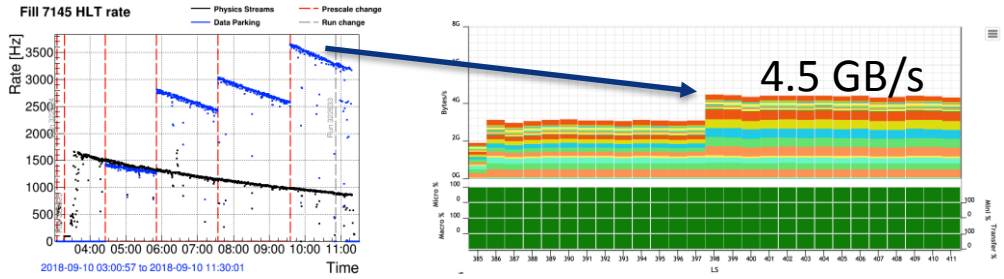
Plan: store an unbiased B hadron sample by tagging on the «opposite side» B

- It has to be a very large sample, as the branching ratios for interesting events are small, $\sim 10^{-7}$
- CMS is parking (→ no prompt reconstruction, opportunistic reconstruction during LS2) a large amount, aiming to store several billions of unbiased B events

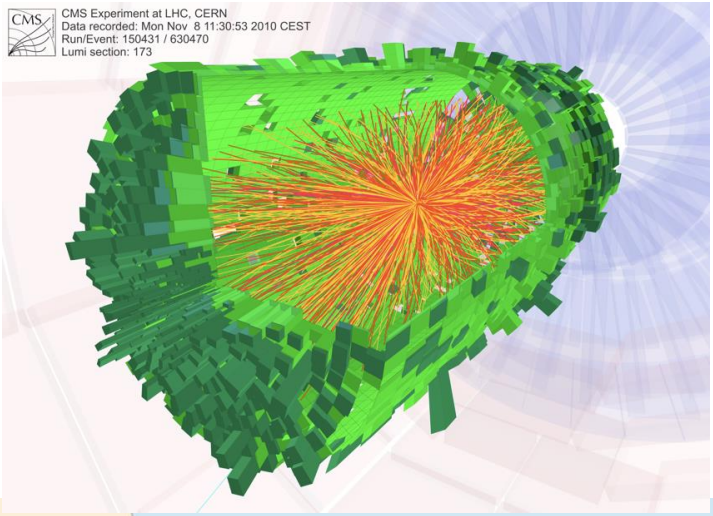




Ready for 2018 Heavy Ions run

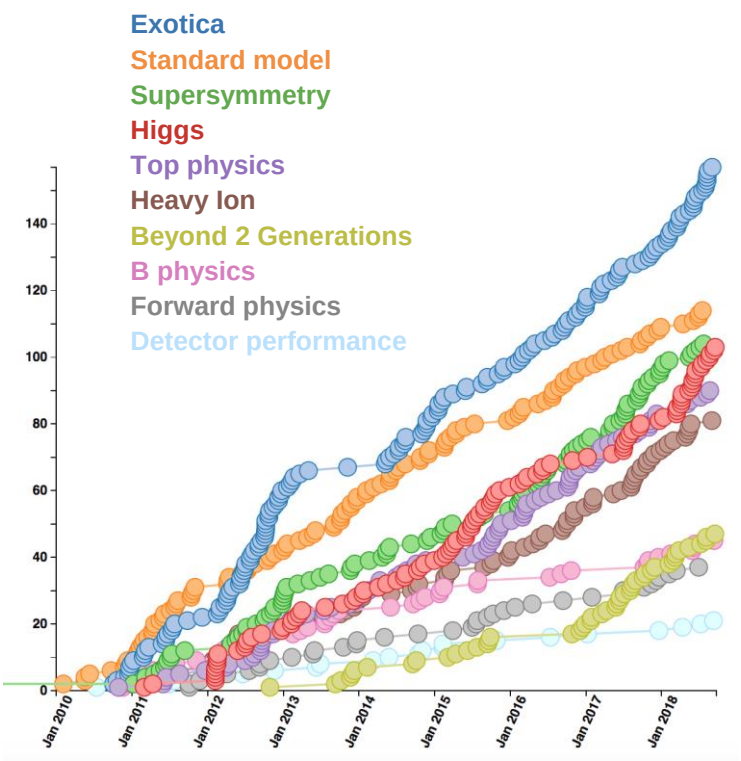


- B-parking uses the high throughput of the CMS DAQ, very smooth at 4.5 GB/s
- The high DAQ throughput will also be used in the Heavy Ion run at the end of 2018
  - Extensive and intensive preparation with tests of all the chain
  - Goal is 1.2 ÷ 1.8 nb^{-1} + a large O(6B) minimum bias sample



Status of publications and highlights of Physics Analyses

Publications

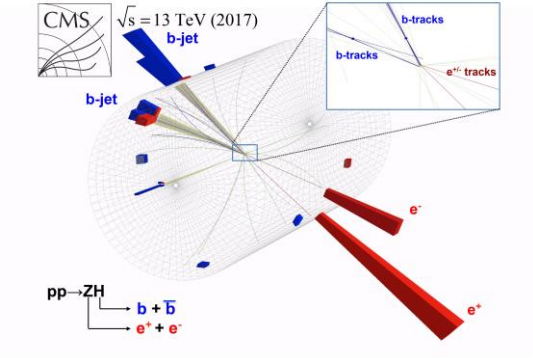


CMS has submitted more than 800 publications on collisions data in a wide variety of physics (and detector) topics.

- Staggering publication rate: 104 per year since Jan 2010
- No sign of slowing, on the contrary 144 papers in the past year
- Strong Korean contribution with more than 12% of articles with KCMS contributions

2018 is the year of the Yukawa couplings

- This summer CMS presented at conferences and in a CERN seminar together with ATLAS the **observation** of the Higgs boson coupling to b quarks. With the recent observation of the couplings to τ lepton and top quark, we completed the observation of the coupling to 3rd generation fermions
  - **A great success of LHC and the experiments, much earlier than expected thanks to the outstanding performance of LHC but also to very refined analysis techniques**

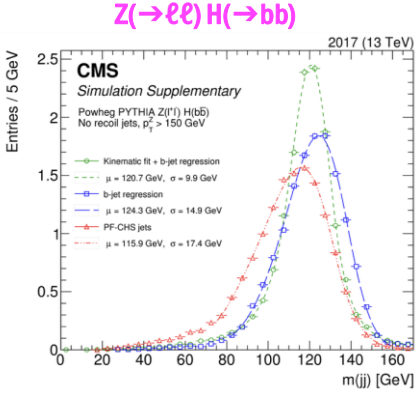


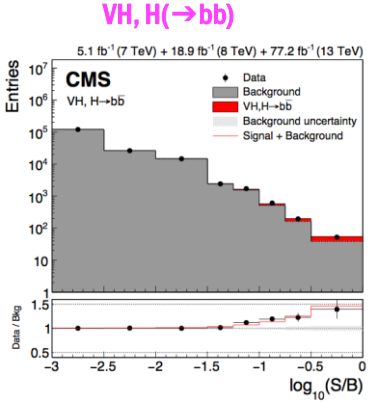
$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}D\psi + |D_\mu\phi|^2 - V(H)$$

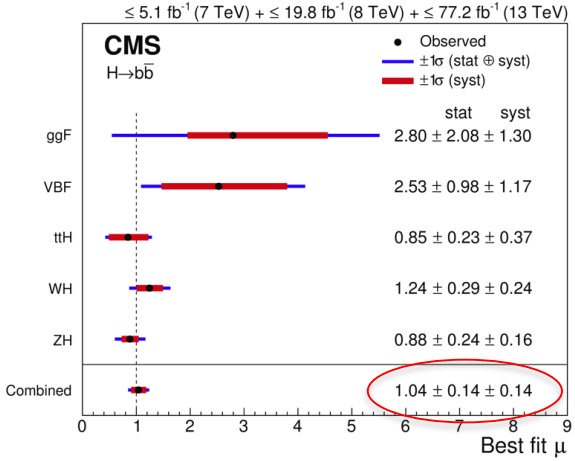
$$+Y_{ij}\psi_i\psi_j\phi + \text{h.c.}$$

Observation of H→bb

- corner stone: improved VH(bb) analysis with 2017 data
  - among others: better b-jet identification, energy regression for b jets, use of deep neural networks for these items and S/B discrimination
- combination VH(bb): 4.8σ observed; all production modes: 5.6σ observed

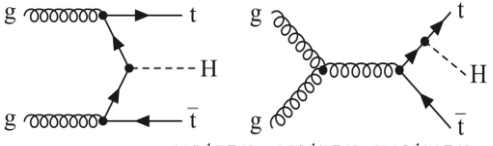


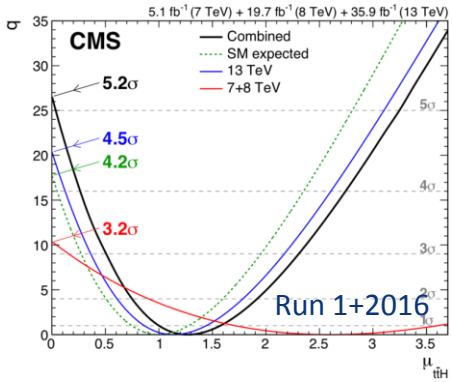




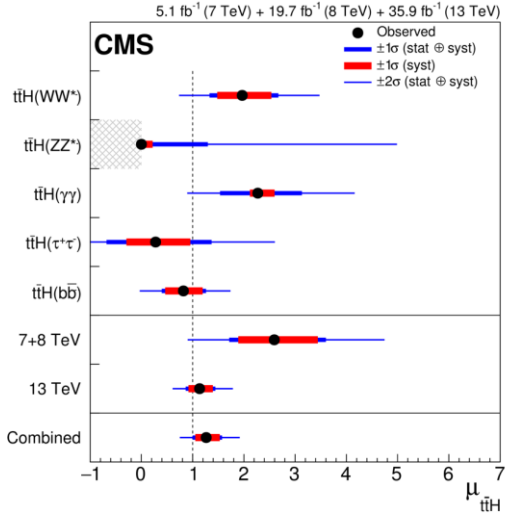
Observation of ttH production: 7, 8 and 13 TeV combined

Submitted Apr 2018, now
Phys. Rev Lett. 120 (2018) 231801





Observed significance is 5.2σ [4.2σ expected] with respect to the background-only hypothesis ($\mu_{t\bar{t}H} = 0$)



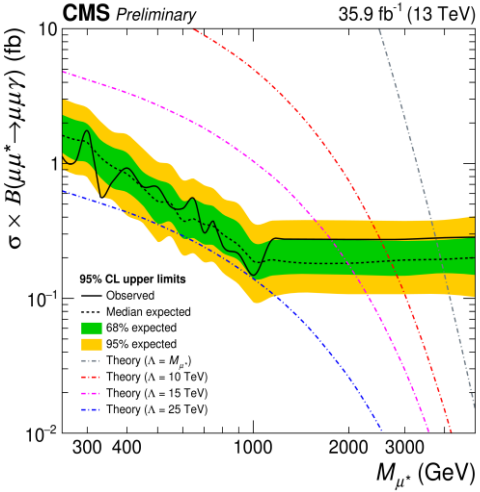
$$\mu_{t\bar{t}H} = 1.26^{+0.31}_{-0.26} = 1.26^{+0.16}_{-0.16}(\text{stat.})\,^{+0.17}_{-0.15}(\text{exp.})\,^{+0.14}_{-0.13}(\text{bkg.th.})\,^{+0.15}_{-0.07}(\text{sig.th.})$$

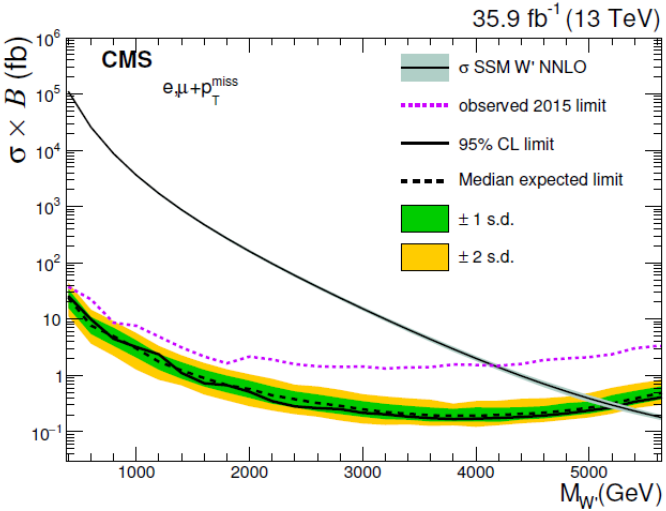
Overall signal strength $\mu_{t\bar{t}H}$ **compatible with SM within 1σ**

- **Only tt($H \to ZZ, \gamma\gamma$) still dominated by statistics uncertainties**

Searches

- Strong program of searches for new physics, several analyses by KCMS
  - W' search
  - Excited leptons
  - … many more

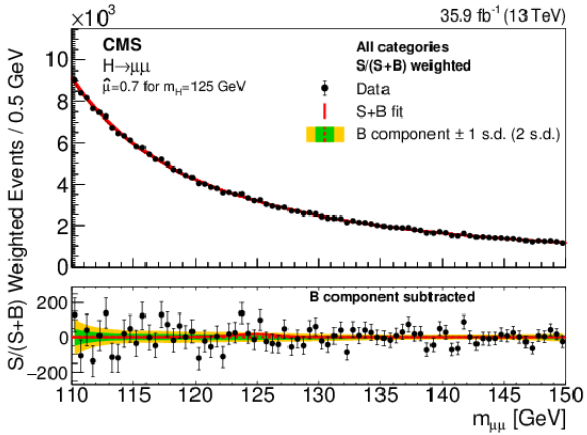


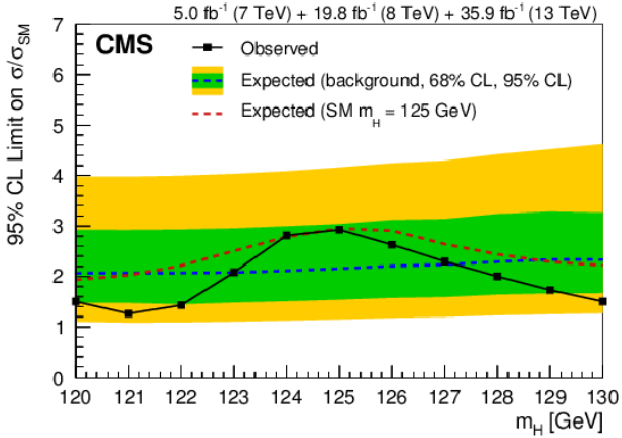


2016

Higgs to two muons

arXiv:1807.06325 , submitted to PRL





Already tackling H →μμ thanks to excellent detector performance

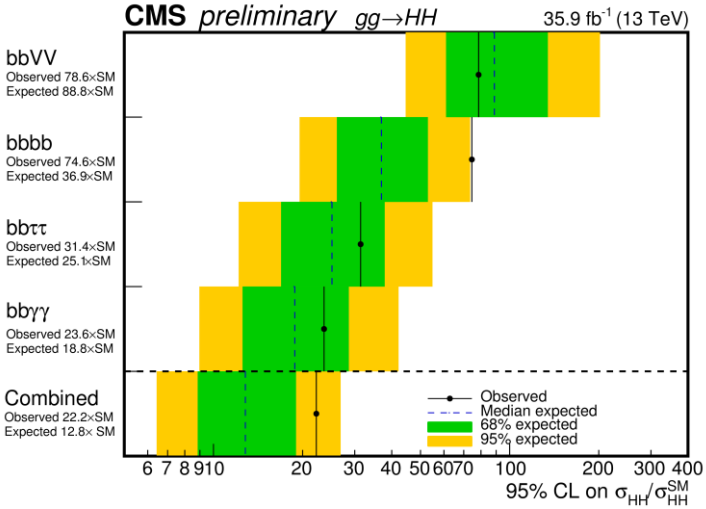
- Looking forward to updated result with > 150 fb^{-1}

2016

Upper limit on the SM Higgs branching fraction to muons of 6.4 x 10^{-4}. UL observed (expected) is 2.92 (2.16) times the SM value.

Higgs boson pair production

PAS-HIG-17-030



95% confidence level exclusion limits on the SM non-resonant Higgs boson pair production cross section.

- Observed (expected) 95% confidence level upper limit corresponds to 22.2 (12.8) times the prediction for the SM cross section.
- Here we really need HL-LHC!

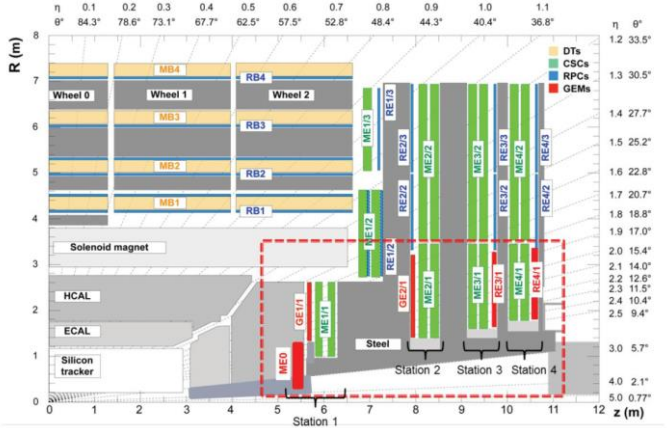
The coming years:
Phase I upgrade and LS2

CMS Phase I Upgrade

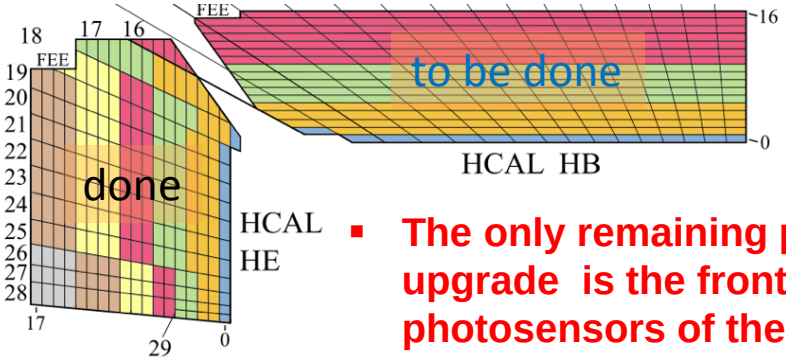
- Phase I CMS upgrade is almost done, and in line with the planned budget, providing substantial benefits already during Run 2
  - The Muon Upgrade, CSCs and RPCs, were done in LS1
    - Outstanding work by KCMS on the RPC endcap muon system
  - Drift tubes trigger upgrade done in YETS 2015/16
  - Drift tubes readout upgrade has been done during YETS 2017/18 and is taking data smoothly
  - L1 Trigger upgrade was installed in 2015 and used starting in 2016
  - Hadron forward calorimeter (HF) upgrade was started in LS1, completed in the EYETS 2016/17, and ran successfully from 2017
  - Pixels were installed in the EYETS 2016/17
  - Hadron endcap calorimeter front-end electronics and photosensors have been upgraded in YETS 2017/18

Korean Contributions in Phase-I Upgrade

- Made all 660 gaps for the last plane of the Endcap Muon RPCs, which has provided robust muon detection and triggering at the higher collision rates in the current Phase-I Period and will beyond, through the end HL-LHC program.



CMS Phase I Upgrade



- **The only remaining part of Phase I CMS upgrade is the front-end electronics and photosensors of the hadron barrel calorimeter**
  - Based on endcap calorimeter experience
  - On track to be installed/commissioned during LS2
  - One benefit is longitudinal segmentation, which will allow improved algorithms and more precise calibration of radiation damage to scintillator

A challenging LS2

Keep **strip tracker** cold to avoid reverse annealing

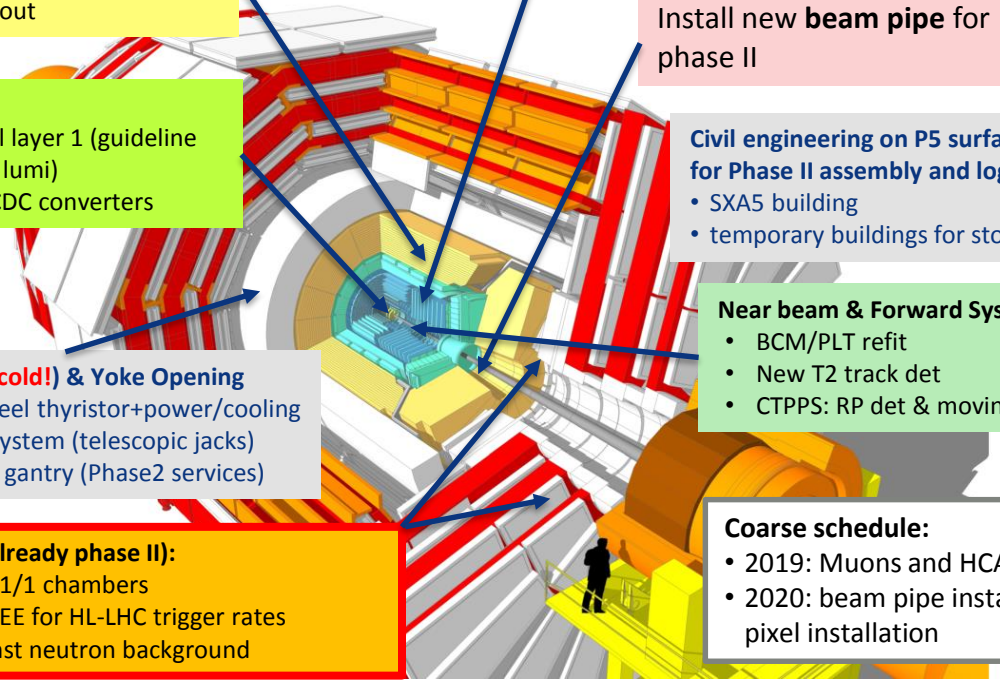
HCAL barrel (last phase I): install SiPM+QIE11-based 5Gbps readout

Install new **beam pipe** for phase II

Pixel detector:
- replace barrel layer 1 (guideline 250 fb-1 max lumi)
- replace all DCDC converters

Civil engineering on P5 surface to prepare for Phase II assembly and logistics
- SXA5 building
- temporary buildings for storage/utility

Near beam & Forward Systems
- BCM/PLT refit
- New T2 track det
- CTPPS: RP det & moving sys upgrade



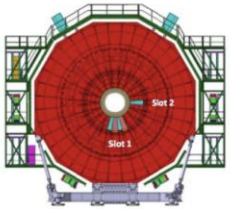
MAGNET (stays cold!) & Yoke Opening
- Cooled freewheel thyristor+power/cooling
- New opening system (telescopic jacks)
- New YE1 cable gantry (Phase2 services)

Muon system (already phase II):
- install GEM GE1/1 chambers
- Upgrade CSC FEE for HL-LHC trigger rates
- Shielding against neutron background

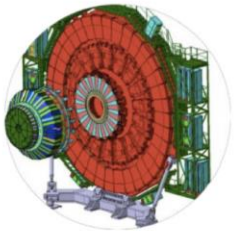
Coarse schedule:
- 2019: Muons and HCAL interleaved
- 2020: beam pipe installation, then pixel installation

GE1/1

- Very important contribution from Korea
  - 30 detectors, about 17% share from KCMS
  - Setup of the foil production and chamber production, getting ready for rest of the HL-LHC program



- Installed 2018
- Slice Test
- 5 GE1/1 detectors



- LS2 2019
- GE1/1
- 144 chambers in 2 endcaps

The coming years: Phase II upgrade

CMS Phase-II upgrades for HL-LHC

L1-Trigger/HLT/DAQ
- Tracks in L1-trigger at 40MHz for 750 kHz PFlow-line selection rate
- Latency up to 12.5 μs
- HLT output 7.5 kHz
- Several detector electronics upgrades needed to cope with trigger rates and latency

https://cds.cern.ch/record/2283192
https://cds.cern.ch/record/2283193

Barrel Calorimeters
- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30GeV
- Low operating temperature $\simeq$ 10C
- ECAL & HCAL new back-end boards

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

Muon Systems
- DT&CSC new FE/BE readout, new RPC electronics
- New GEM/iRPC 1.6<η<2.4
- Extended coverage to $\eta\simeq$3

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

Calorimeter Endcap (HGCAL)
- Si, Scint+SiPM
- 3D shower topology with precise timing

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

Mip Timing Detector
- 30 to 40 ps resolution
- Barrel: LYSO crystals + SiPMs
- Endcap: Low Gain Avalanche Diodes

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

Tracker
- Si-Strip and pixels, increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta\simeq$3.8

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

Beam Radiation instrumentation and Luminosity measurement

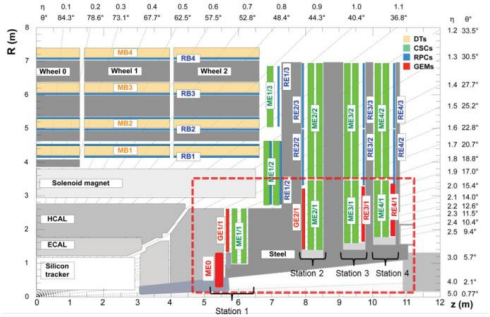
https://cds.cern.ch/record/2020886

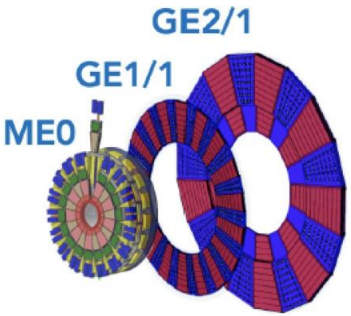
Key Features of CMS Upgrade for HL-LHC

- Tracking information in “L1 track-trigger”
  - Tracker designed to find all tracks with P_T>~2 GeV < 4 μs.
- Tracker is AGAIN ALL SILICON but now with much higher granularity, **and out to |η| =4** with >2 billion pixels and strips
- High Granularity Endcap Calorimeters
  - Sampling of EM-showers every ~1λ_{rad} (28 samples) with small silicon pixels and then every ~0.35λ_{abs} (24 samples) with combination of silicon pixels and scintillator to map full 3-dimensional development of all showers (~6M channels in all)
- Precision timing of all objects, including single charged tracks, provides a 4th dimension to CMS object reconstruction to combat pileup (~200K sensors in barrel section)
- Extended muon coverage up to η < 3 and ability to trigger on long-lived particles

KCMS in HL_LHC

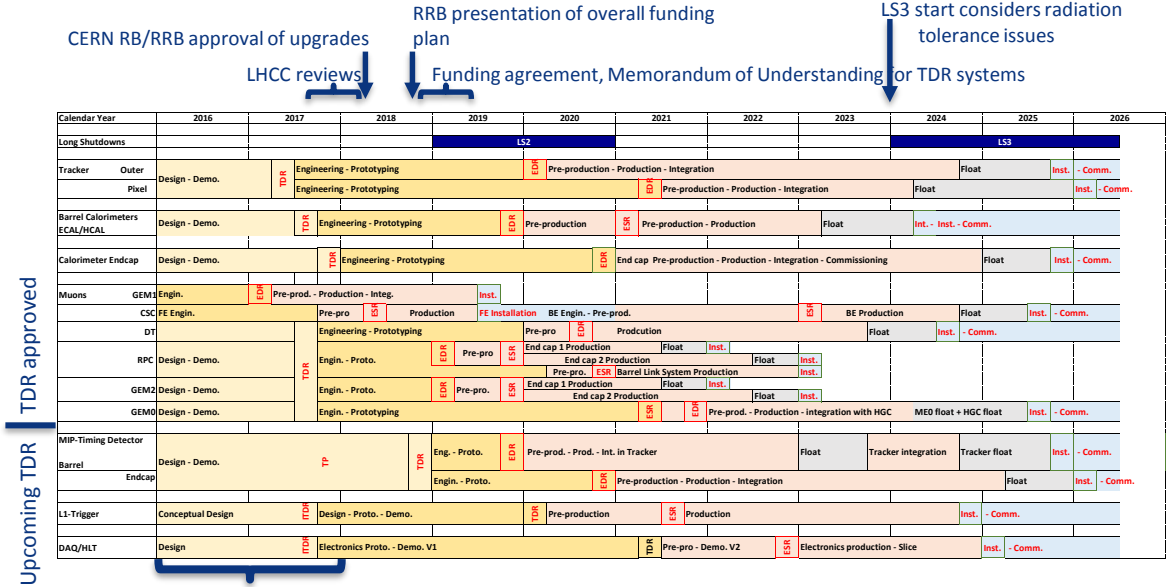
- Essential contribution of Korea in GE2/1, ME0, iRPC upgrade
  - Equip the key forward area of the muon detector
- Korea is the second site, after CERN, able to produce fully qualified Gem foils, CMS counts strongly on that
  - Mass production is expected from next year





- LS3 2022
- Full Upgrade
- GE2/1
- ME0 increases η coverage from 2.4 to 2.8

CMS Phase-2 Upgrade schedule



- Technology R&D and Technical Design up to TDR
  - TDR Completed for Tracker, Barrel and Endcap Calorimeters and Muons
  - MIP Timing Detector* TDR submission Q1-2019
  - L1-Tigger* TDR submission spring Q1-2020 and DAQ/HLT* TDR Q2-2021
    - Shorter production time allow to benefit from technology progress

** MTD Technical Proposal and L1-Trigger and DAQ/HLT Interim TDRs were approved by LHCC end-17 beg-18*

Preparing for HL-LHC Computing

- We plan to align the CMS computing TDR with the WLCG TDR.
- Active R&D program(s) required in 2019-2020 – before the TDR(s). CMS has set-up a **ECoM2X task force** to attack the Phase II computing model.
  - Participation from Physics, Trigger, PPD, SW experts, Computing Experts, 7 WGs defined
  - 4 milestones set for Xmas on the understanding of physics needs, initial technology survey, and describing the modelling to the involved parties
  - Important to consider new architectures and the impact of new technologies (e.g. Machine Learning)

1. Technology tracking and expectations from industry
2. LHC and CMS modelling (parameters). This includes general status of event sizes, cpu requirements of HL-LHC software today, premixing. It thus includes where we are today, and where we think we need to get to as a goal to make reasonable budget assumptions.
3. Physics choices and their impact. HLT rate, (re)processing model (prompt vs scouting vs parking). Definition of analysis data tiers. Definition of benchmark analyses. Physics impact of budgetary constraints on things like tracking (higher minimum pT cut etc.), HGCal granularity in reconstruction, HLT rate, ...
4. CMS SW: frameworks, access to heterogeneous computing, architecture unaware programming.
5. CMS SW: algorithms for RunIV. Identification of resource critical algorithms / parts. Estimates of utilization of GPUs / accelerators / … Impact of generators and Simulation / fast simulation
6. Facilities and distributed computing. Data model, data lake, T0/HLT integration. HPC integration. Analysis facilities
7. R&D in CMS/HSF/WLCG/Industries/Countries

Contributions to CMS Computing from Korea

- We are very thankful for Korea's contribution of Tier-2 resources to CMS and pleased to see they will continue with the new arrangement with KISTI
- As we look seriously at new approaches to improve software efficiency, e.g. Machine Learning, we need to consider centers of specialized hardware and services, e.g. "training centers" for ML
  - This would be an excellent opportunity for educating a new generation of computer/data scientists
  - These are best co-located with an analysis facility and active data analysts to keep it all "real"
  - CERN-Korean machine learning session in ICHEP2018

Korea has already demonstrated that it is an outstanding partner with proven capabilities and and and excellent candidate for an expanded role in CMS computing

Conclusions

Thanks to KCMS!

- The growth of participation in CMS from 2013 to 2018 has been very impressive and welcome
  - CMS Korea now consists of 8 institutions with 35 PhD physicists and about 60 graduate students, applications from new institutions are in view
  - It is the 10th biggest nation in CMS
  - It is especially important that Korea is contributing more than ever to the physics of CMS in key areas such as top and Higgs physics, searches for new physics, and Heavy Ions
  - Korea did outstanding work on the RPC endcap muon system for the Phase-I upgrade
  - Korea has already acquired **unique capabilities and capacity for production of GEM foils** and is well-positioned to continue its leadership role in the endcap muon system for the HL-LHC (Phase-II) upgrade
  - Collaborators are acquiring more leadership roles in CMS
  - **We hope this progress will continue and even accelerate because the challenges we face, especially the Phase-II upgrade, will be exciting but very technically challenging**