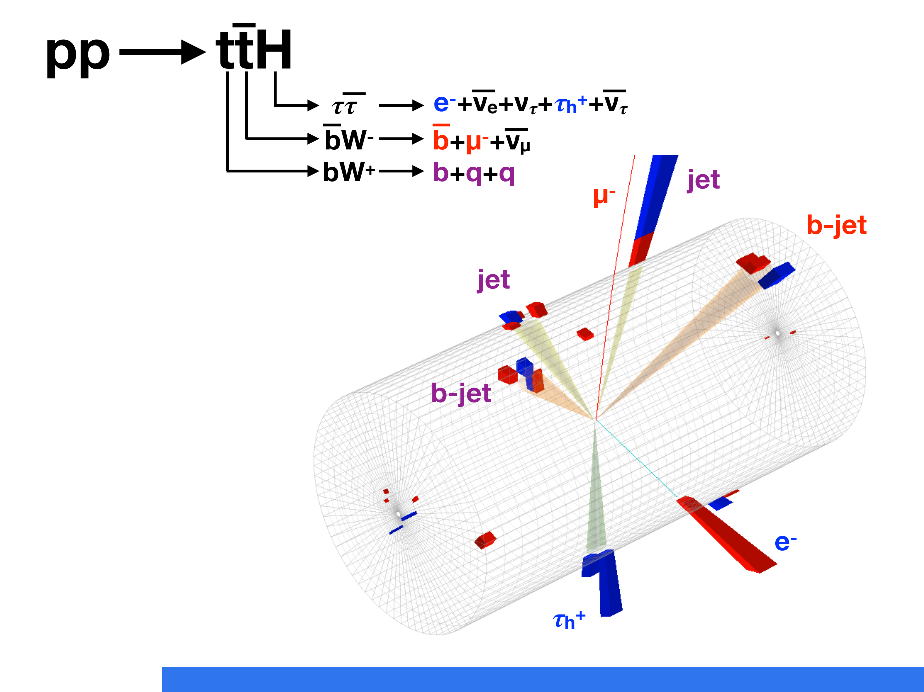
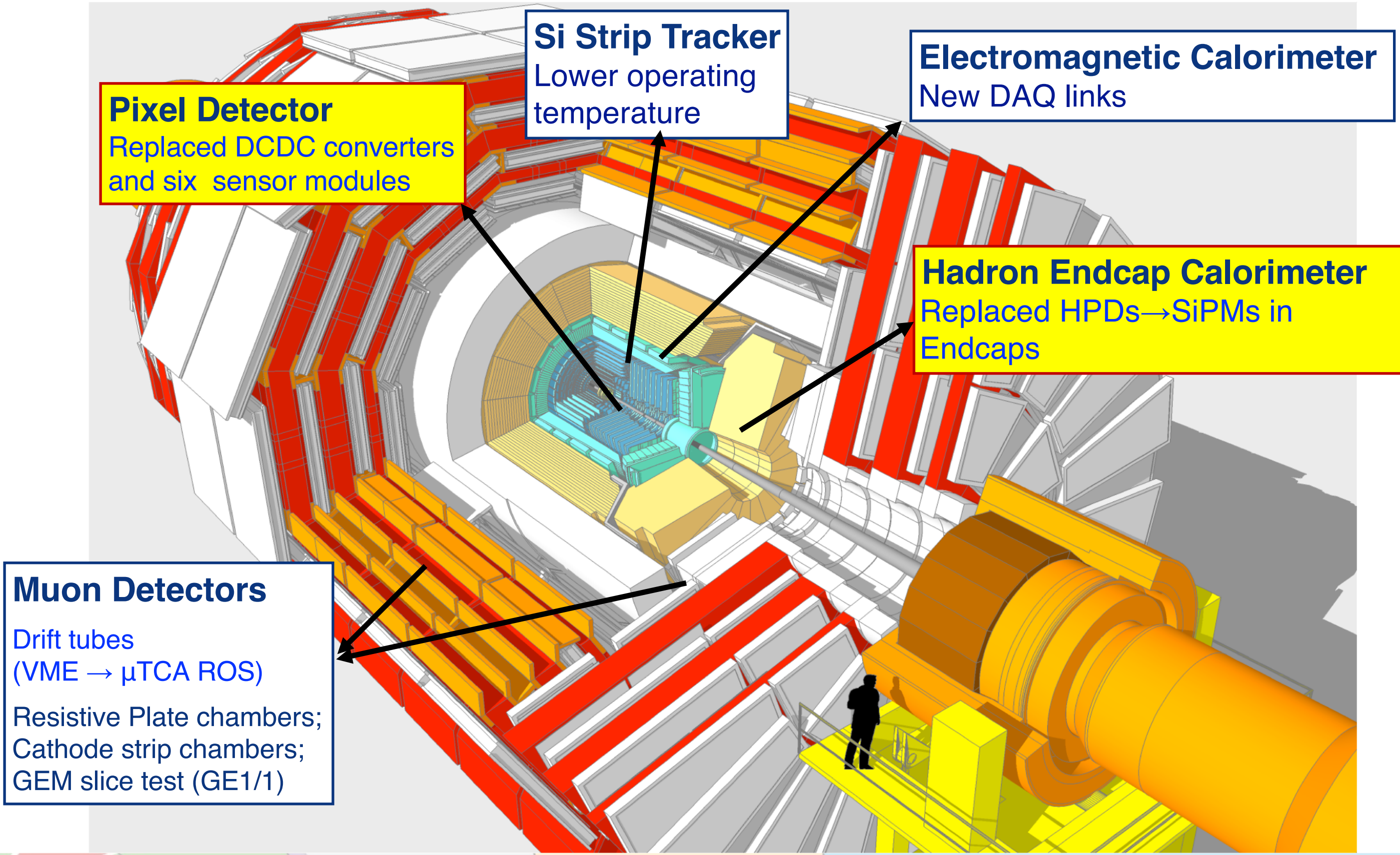


Status and Highlights from the CMS experiment

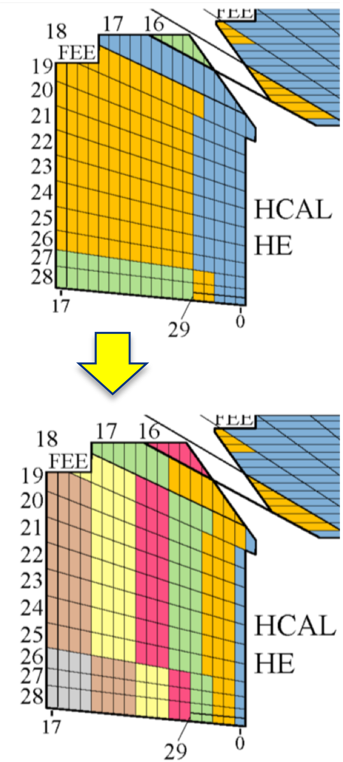
R. Carlin 04.06.2018

CMS status after 2017-18 Year End Technical Stop

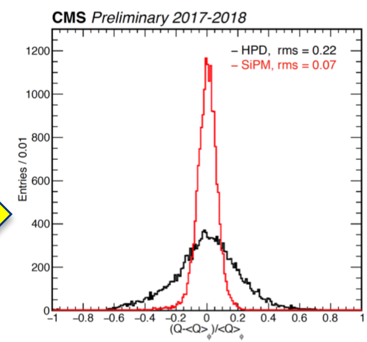
What is New in CMS in 2018



Hadron Calorimeter Endcap (HE)



- The Hcal Endcap Phase-1 upgrade has been completed
  - SiPMs replacing HPDs
- The upgrade has brought various benefits:
  - Finer longitudinal segmentation is possible
  - Eliminated strong, progressing (and phi-asymmetric) HPD damage
  - Increased photo-detection efficiency by x2.5
  - Eliminated sources of coherent noise
  - Uniformity of detector response much improved
- Now working on exploiting the segmentation at all levels



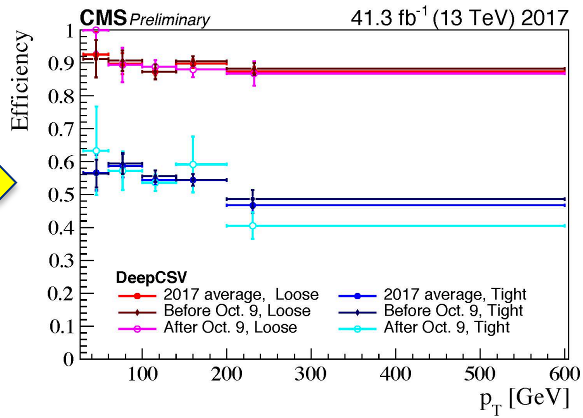
Pixels (DC/DC converters)

About 5% of the DC/DC power units of the newly installed pixel detector failed in late 2017

- The impact of DC/DC failures on 2017 data quality was marginal
  - 4 layers provided redundancy, mitigating actions in the tracking were implemented

Removed, opened and reinserted the pixel detector, replacing all of the 1200 DC/DC modules

- And replaced 6 sensor modules in the inner barrel layer, that were damaged as a side effect
- **Thanks to LHC and the other experiments for the 1+1 weeks extension of the technical stop**



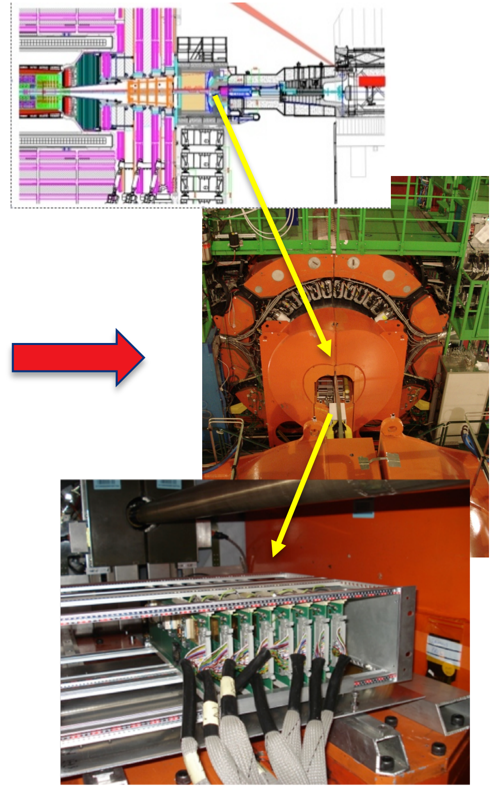
b tagging efficiency in 2017

Presently the CMS pixel detector has a fraction of active channels as high as at beginning of 2017 (~96%)

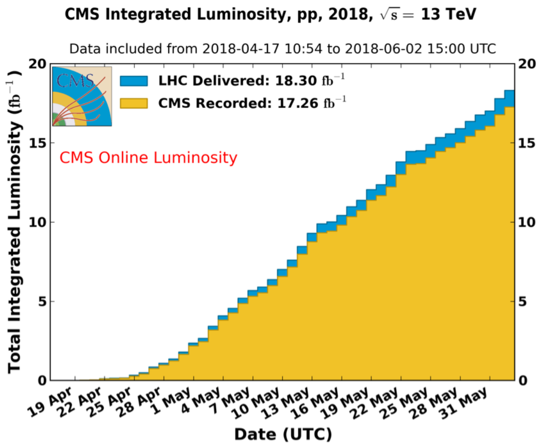
- No "2017 like" DCDC converter failure so far

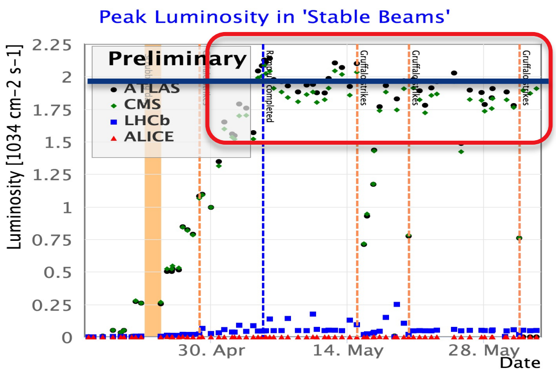
Pixels (DC/DC converters)

- Up to few weeks ago there was understanding of what was broken, but not why
- **Recent progress by the chip designers in understanding the mechanism of the failure in the DC/DC converter FEAST ASIC in CMS environment**
  - FEAST chip irradiation tests are being performed at CERN IRRAD and in CMS environment (“castor table”)
  - Some damage similar to what CMS experienced starts to be seen
  - **Recently failures were seen also after irradiation with X-rays, possibly related to toggling power enable/disable.**
- Meanwhile a new, more robust FEAST ASIC has been designed and will be available in July



CMS is running very well





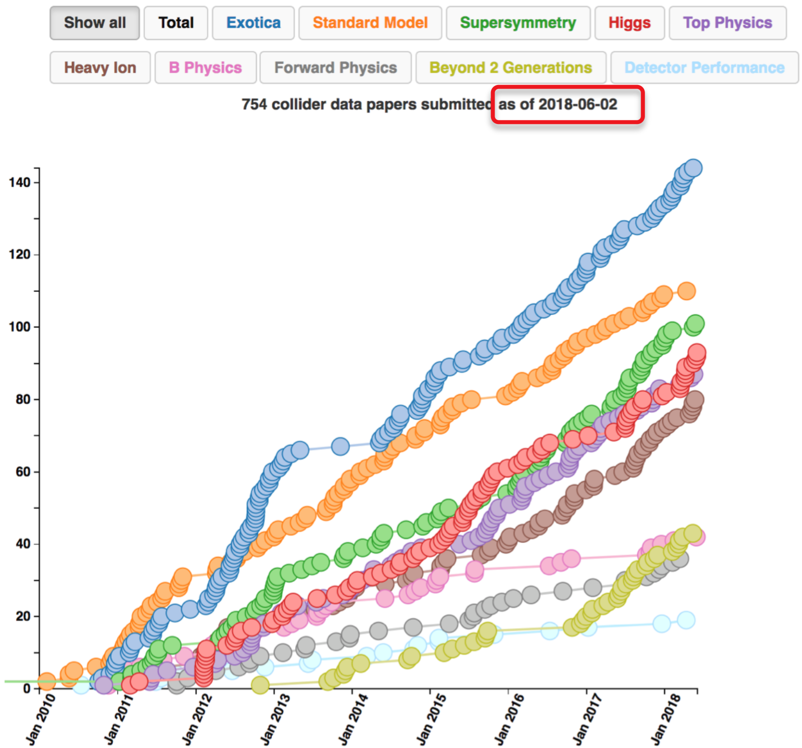
- **Very fast commissioning of CMS,** matching the fast ramp-up of LHC
  - Despite the tight technical stop with unplanned Pixel detector refurbishment

- **Very good recording efficiency, above 94%**
- **Peak luminosity** $\sim 2 \cdot 10^{34}\ Hz/cm^2$
  - **Corresponding to Pile-Up > 55**
  - Deadtime negligible also at the highest luminosity (factor 2 higher than design)

- **Fraction of active channels is high and stable**

Highlights from Physics Analyses

Physics Analyses



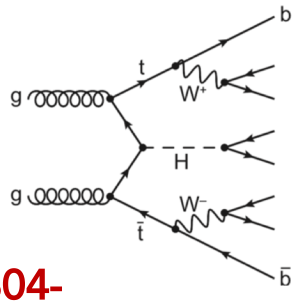
- The experiment is very active, on all fronts
  - 754 collider data papers submitted for publication
    - 736 on physics analyses
  - 141 in the last year (from June 2017)
  - 26 new results released for Moriond
  - 14 new results for Quark Matter
  - >20 more now

Measurements:
the precision frontier, in search of the unexpected

Higgs coupling to top quarks

Goal: study the tree-level coupling of Higgs boson to top quarks

- **Previous status**
  - Evidence reported by CMS on H→multileptons at Moriond 2017, with 2015+2016 datasets
  - Stronger evidence published in December by ATLAS in several topologies



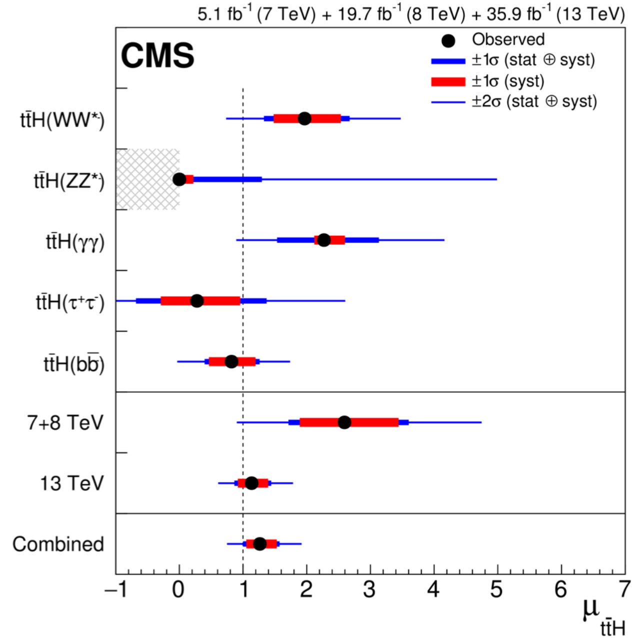
- **Present CMS result submitted on Apr 8th [ArXiv: 1804-0261] and published today in PRL [Phys. Rev. Lett. 120, 231801 (2018)] :**
  - Combination of Run-1 and 2016 CMS data: 7TeV($5.1 fb^{-1}$), 8TeV($19.7 fb^{-1}$) and 13TeV($35.9 fb^{-1}$)
  - Independent analyses of several final-states topologies

$$H \rightarrow WW^*, ZZ^*, \gamma\gamma, \tau^+\tau^-, b\bar{b}$$

    - For 7-8 TeV analysis, Higgs boson mass updated to 125.09 GeV, signal, normalisation and uncertainties updated to latest values from LHC Higgs XS WG
    - Correlations between Run1 and Run2 studies, experimental uncertainties largely uncorrelated

Observation of ttH production

- 5 independent signal strength modifiers for the decay channels considered, all compatible within uncertainties
- **Only tt$(H \to ZZ, \gamma\gamma)$ still dominated by statistics uncertainties**
- **Overall signal strength $\mu_{t\bar{t}H}$ compatible with SM within 1σ**



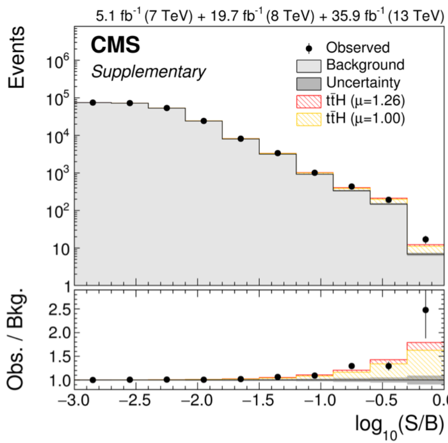
$$\mu_{t\bar{t}H} = 1.26^{+0.31}_{-0.26} = 1.26^{+0.16}_{-0.16}(\mathrm{stat.})\,^{+0.17}_{-0.15}(\mathrm{exp.})\,^{+0.14}_{-0.13}(\mathrm{bkg.\,th.})\,^{+0.15}_{-0.07}(\mathrm{sig.\,th.})$$

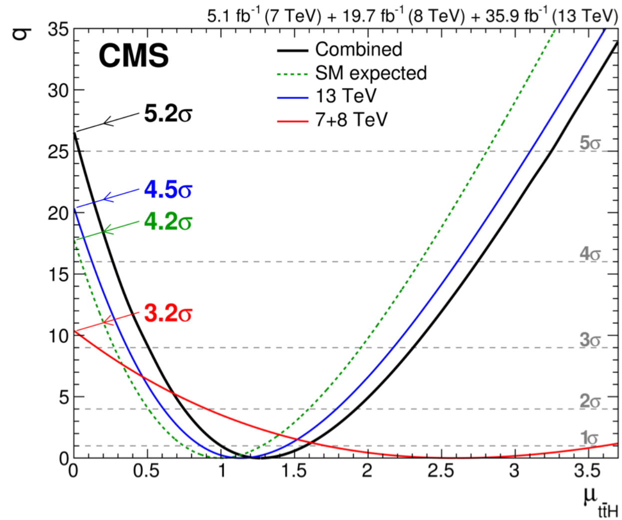
Phys. Rev. Lett. 120, 231801 (2018)

Observation of ttH production

A total of 88 event categories enter the combination. Excess best seen in the distribution of all events as a function of $\log_{10}(S/B)$.

- Clear excess in the most signal-sensitive bins





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

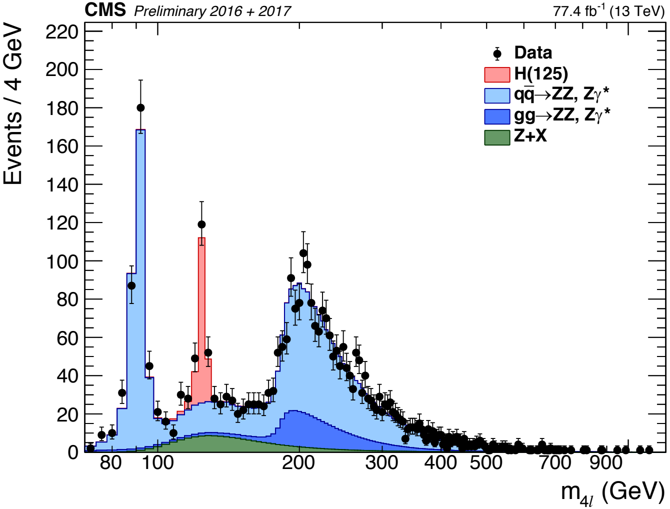
- **First observation of the $t\bar{t}H$ production**
- Establishes directly the tree-level coupling to an up-type quark

Phys. Rev. Lett. 120, 231801 (2018)

$H \to ZZ^* \to 4l$

This is one of the Higgs boson "discovery" channels, now measured also with the 2017 dataset

- Low statistics but clean signal from the combined 77.3 fb^{-1} dataset (2016+2017)
  - 2017 analysis improved with upgraded detector, new multivariate tool for better electron ID, new discriminant for enhanced VH and VBF categories, new categories targeting ttH production



Signal strength for the combined 2016-2017 CMS $H \to 4l$ measurement:

$$\mu = \frac{\sigma}{\sigma_{SM}} = 1.06^{+0.15}_{-0.13} = 1.06^{+0.10}_{-0.10}(\mathrm{stat.})\,^{+0.08}_{-0.06}(\mathrm{sys.\,exp.})\,^{+0.07}_{-0.05}(\mathrm{sys.\,th.})$$

In very good agreement with Standard Model

CMS-PAS-HIG-18-001

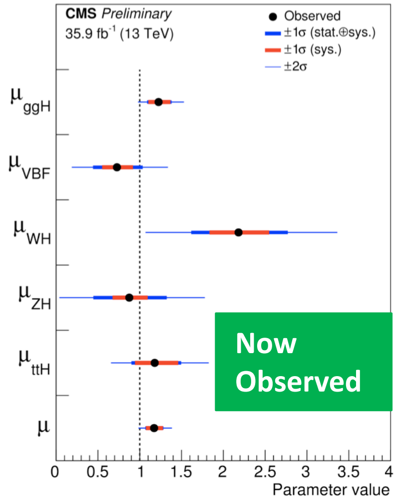
Combined Higgs Boson Couplings

	ggF	VBF	VH	ttH
H→ZZ→4l	●	●	●	●
H→γγ	●	●	●	●
H→WW	●	●	●	●
H→bb	●		●	●
H→ττ	●	●		●
H→μμ	●	●		
H→inv	●	●	●	

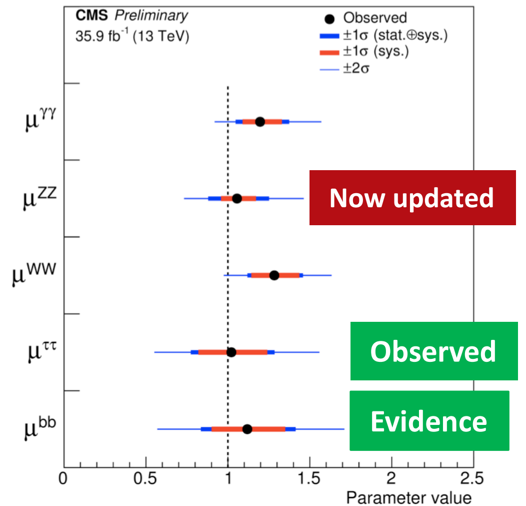
Close to have observed the couplings with all 3rd generation fermions

- **One of the targets of LHC Run2**

Per production mode



Per decay mode



CMS 13 TeV 2016 combination

$$\mu = 1.17^{+0.10}_{-0.10} = 1.17\boxed{^{+0.06}_{-0.06}}\,(\text{stat.})\,\boxed{^{+0.06}_{-0.05}}\,(\text{sig. th.})\,\boxed{^{+0.06}_{-0.06}}\,(\text{other sys.})$$

- Overall signal strength compatible with the SM
- Not anymore dominated by statistics, already moving to less inclusive measurements

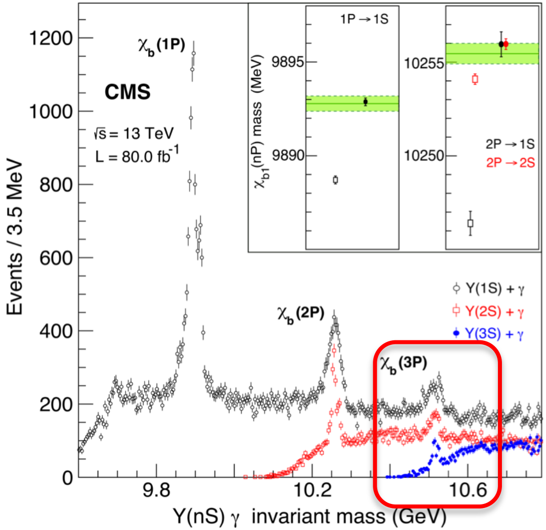
CMS-PAS-HIG-17-031

Observation of the $\chi_b(3P)$ states

$\chi_b(3P)$ $b\bar{b}$ state has been discovered by ATLAS in 2011 and observed by D0 and LHCb

- The new CMS analysis uses the full 2015-2017 dataset, 80.0 fb^{-1}
- $\chi_b(3P)$ is measured through the radiative decay $\chi_b(3P) \rightarrow \Upsilon(3S)\gamma \rightarrow \mu\mu\gamma$
  - Low statistics but best resolution for the low energy photon converted to e^+e^- pair in the silicon tracker

photon energy scale corrected using $\chi_{c1} \rightarrow J/\psi\gamma \rightarrow \mu\mu\gamma$



arXiv1805.11192

Observation of the $\chi_b(3P)$ states

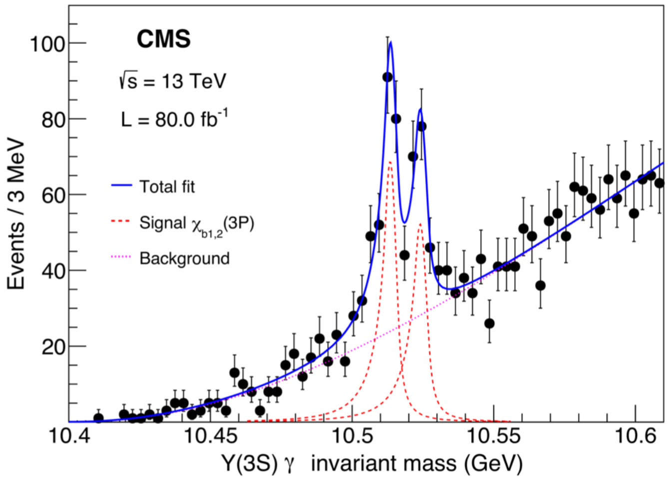
For the first time the two states $\chi_{b1}(3P)$ and $\chi_{b2}(3P)$, corresponding to J=1,2, are resolved

The mass difference is measured to be:

$\Delta M = 10.60 \pm 0.64(\mathrm{stat.}) \pm 0.17(\mathrm{syst.})$ MeV

- Most predictions from non-perturbative QCD range from 8 to 18 MeV
- One predicts -2 MeV reflecting the coupling with the open-beauty threshold

$\chi_b(3P)$ mass resolution 2.2MeV



The masses of the two states are

$M_1 = 10513.42 \pm 0.41(stat.) \pm 0.18(syst.)$ MeV

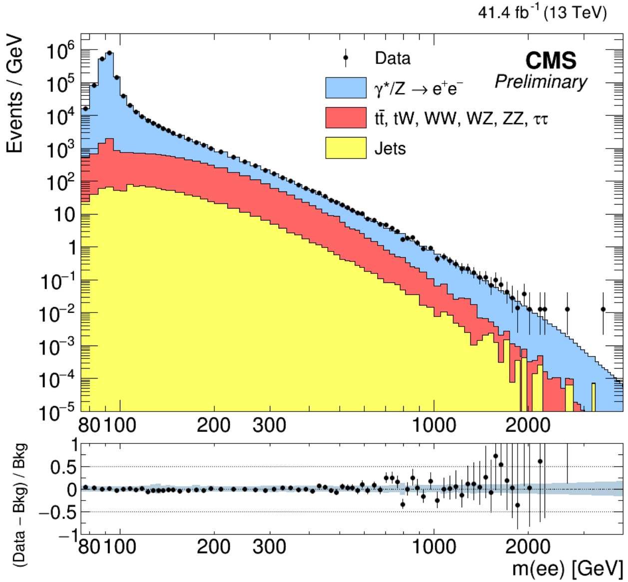
$M_2 = 10524.02 \pm 0.57(stat.) \pm 0.18(syst.)$ MeV

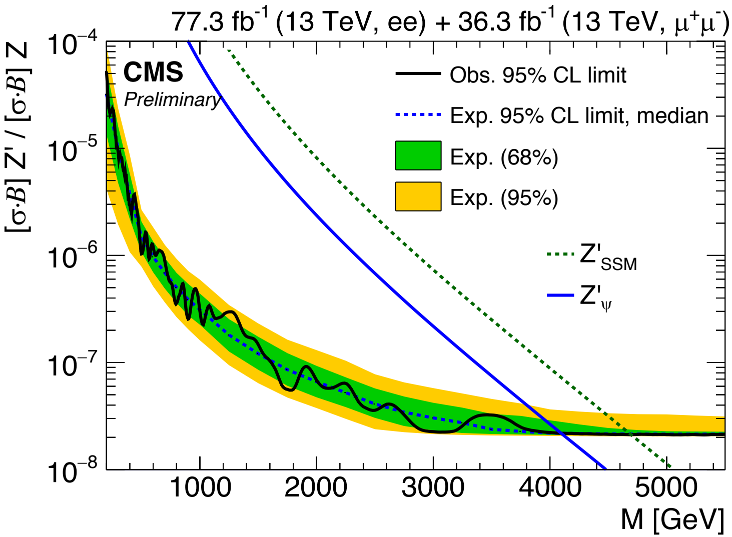
arXiv1805.11192

Direct Searches for physics Beyond the Standard Model

Searches for high-mass di-lepton resonances

First 2017 analysis





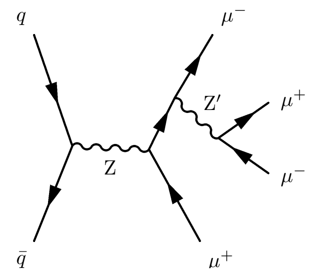
Limits for high mass searches extending beyond 4 TeV

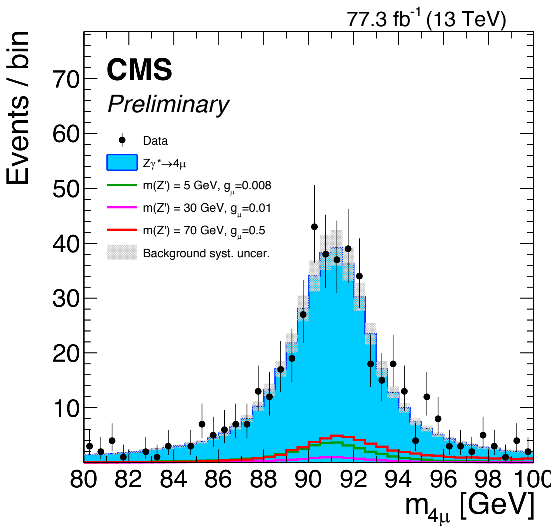
Channel	Model	Obs. limit (TeV)	Exp. limit (TeV)
ee (2017)	Z'_{SSM}	4.10	4.15
	Z'_{ψ}	3.35	3.55
ee (2016 and 2017) + $\mu\mu$ (2016)	Z'_{SSM}	4.7	4.7
	Z'_{ψ}	4.1	4.1

CMS-PAS-EXO-18-006

Search for an $L_\mu - L_\tau$ gauge boson

- Search for a narrow **light Z′** decaying in $\mu^+\mu^-$ using $Z \to 4\mu$ events
  - Interesting because these $L_\mu - L_\tau$ symmetries could explain possible LF universality violations in B-meson decays (and muon g-2 anomaly)
- CMS uses the 2016+2017 dataset (77.7 fb^{-1})
- Observations are consistent with the SM predictions

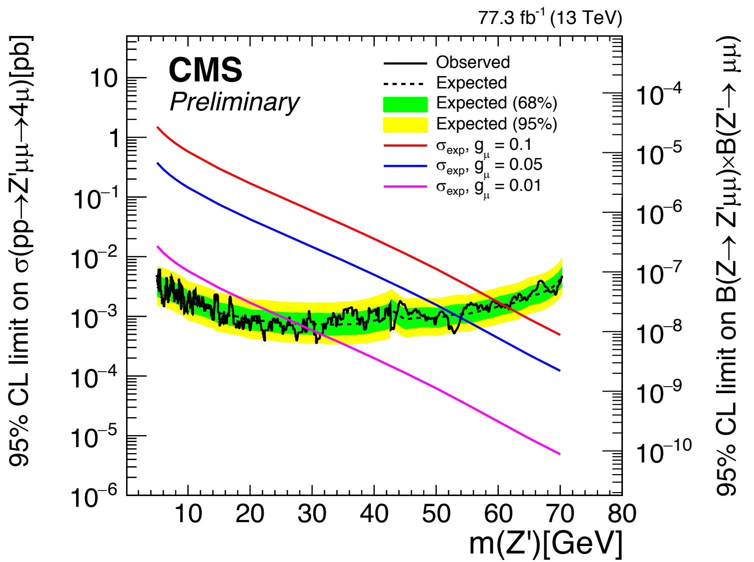


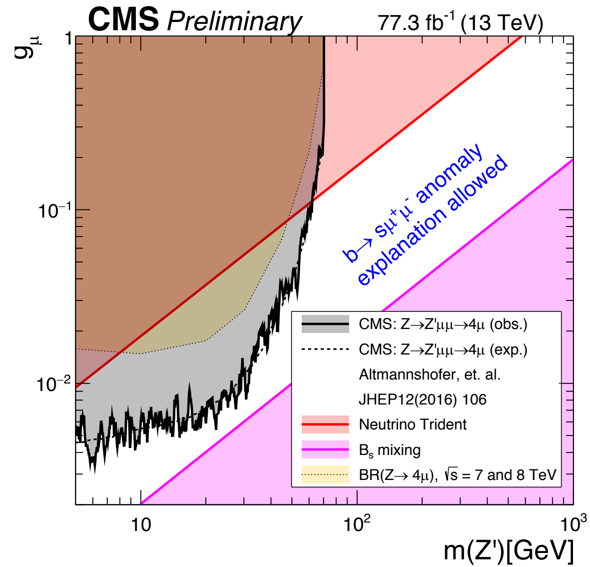


CMS-PAS-EXO-18-008

Search for an $L_\mu - L_\tau$ gauge boson

- Upper limits can be set on the product of Z′ production cross section and branching fractions, and on the coupling strength g_μ as a function of m(Z′) constraining the explanation of a possible lepton flavour universality anomaly

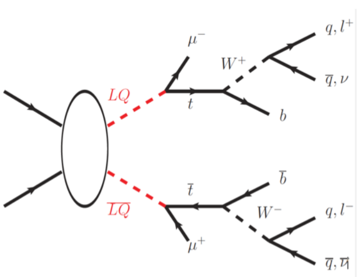




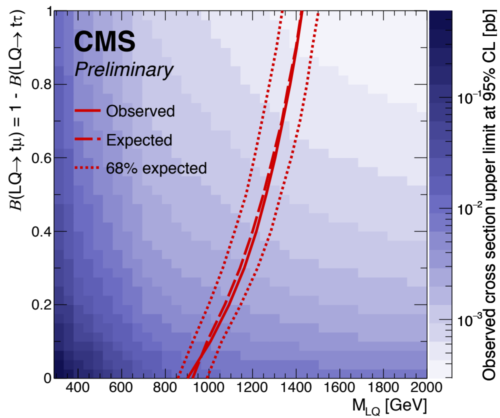
CMS-PAS-EXO-18-008

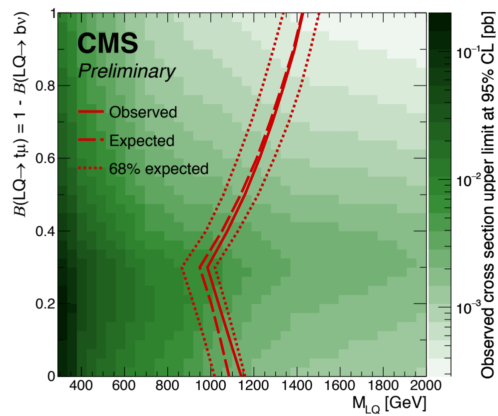
Search for a $LQ \rightarrow t\mu$

- New search for pair-produced third-generation leptoquarks decaying in $t\mu$, using 2016 dataset (35.9 fb^{-1})
  - Again, could explain a possible LF universality violations in B-meson decays (and muon g-2 anomaly)
  - Complements searches already presented for third-generation LQ decaying into $t\tau$ and bν
- Observed mass limit: $M_{LQ} \geq \mathbf{1470\ GeV}$ at 95% CL for LQ decaying exclusively in $t\mu$
- Third-generation LQs can be excluded below 900GeV for any value of branching ratio for decays in $t\mu$, $t\tau$ and bν



CMS-PAS–B2G-16-027

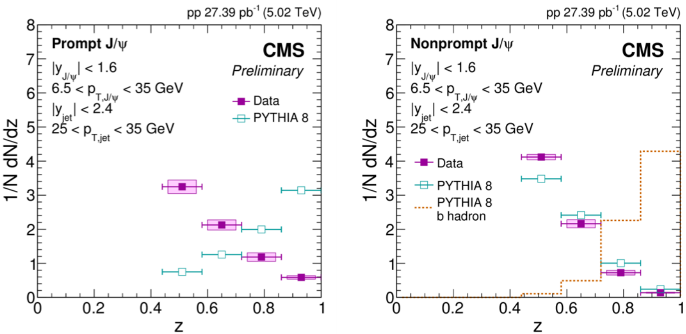




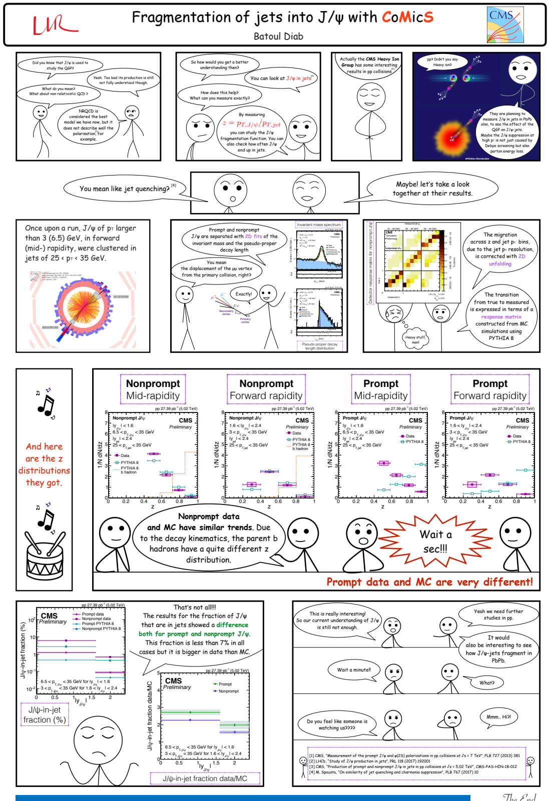
Heavy Ions

Several new results presented at Quark Matter in Venice conference Using PbPb, pPb and pp collisions at 5.02 TeV (also 8.16 TeV for pPb) and XeXe collisions at 5.44 TeV.

pp reference studies for PbPb



- Study of prompt and non-prompt J/ψ mesons in jets in pp collisions at $\sqrt{s} = 5.02\ TeV$
  - Low pile-up pp reference run for the PbPb collisions run, where J/ψ suppression is measured
- The p_T fraction z of prompt J/ψ in jets, and the fraction of J/ψ in jets is not well described by models



Similar result were found by LHCb at $\sqrt{s} = 13\ TeV$ and different kinematic range

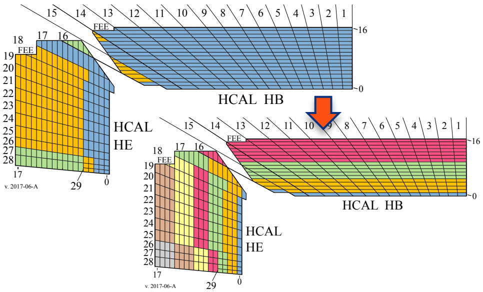
Batoul Diab, LLR,best poster in QM 2018

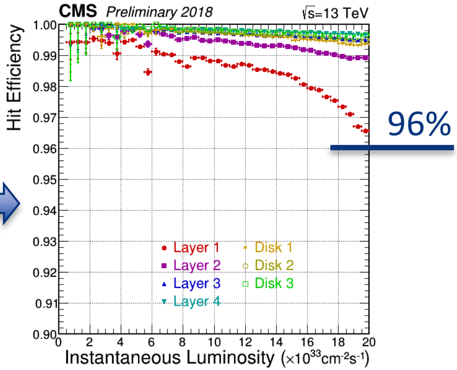
CMS-PAS-HIN-18-012

Outlook to LS2 – Run 3

To be done in Long Shutdown 2

- **Most of the CMS Phase-1 upgrades are already integrated and working great.** Still we need to:
  - Upgrade barrel HCAL (HB) as was done for HE
  - Replace all DC/DC converters in Pixel using a new FEAST ASIC
  - Replace the inner barrel layer of pixel
    - planned to sustain radiation damage
    - profit to implement a new readout chip with **better S/N**, reduced dynamic inefficiency at high PU and a new TBM control chip, more resistant to SEUs



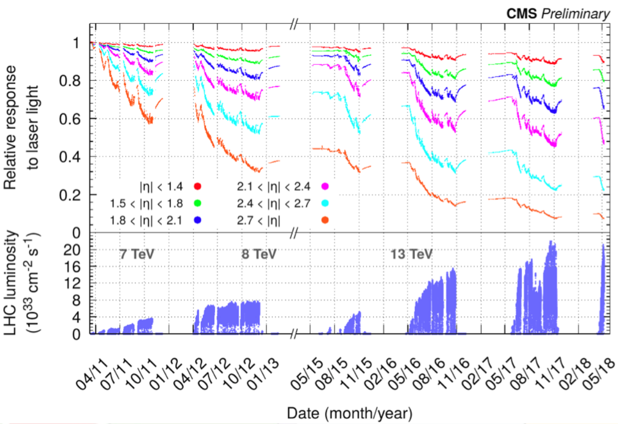


- **And start already with Phase 2 activities**
  - Install First GEM station GE1/1, upgrade endcap muon electronics
  - Install new beam-pipe, plenty of activities on infrastructure

Luminosity in Run 3

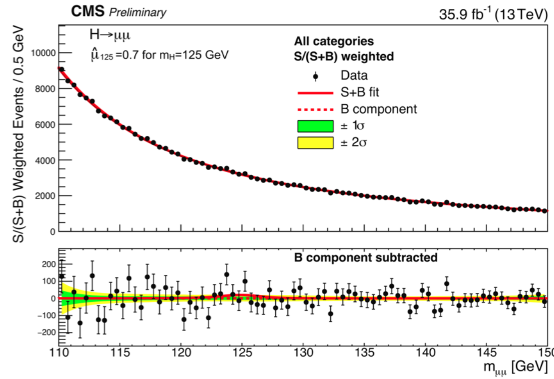
LHC has started a task force to define the goals for Run 3, to report around end 2018

- We are evaluating the impact of significant luminosity (> 450 fb^{-1}) integrated from 2010 to 2023
- Lumi-levelling at $2 \cdot 10^{34}\ Hz/cm^2$, PU<60, we know how to handle it
- Studies focusing on radiation damage in endcap calorimeters, HE and EE



ECAL endcap light yield vs time

Challenges but also big opportunities for searches in every corner of the phase space and for precision physics studies



$H \rightarrow \mu\mu$ invariant mass from 2016 dataset

- is evidence for $H \rightarrow \mu\mu$ reachable in Run3?

- And to begin to deploy solutions we are designing for HL-LCH

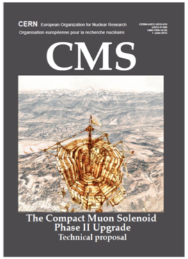
Phase 2 upgrade for HL-LHC

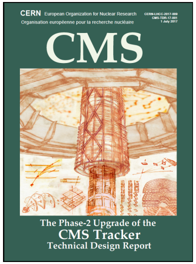
Most of first step is done

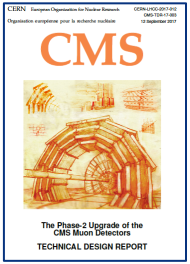
CMS is proud of the design of an upgrade with many innovative detectors

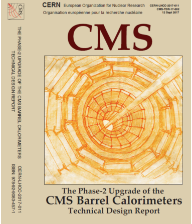
- Tracker, Barrel Calorimeter, Endcap Calorimeter, Muons TDR approved by CERN RB
- MIP precision timing detector approved to go from TP to TDR
- L1 trigger, HLT trigger and DAQ TDRs will follow

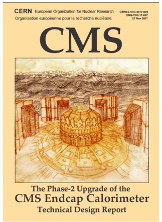
- **Entering a new phase of engineering, prototyping, construction**



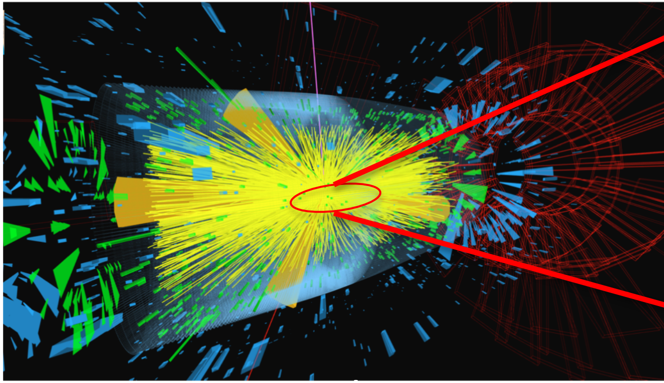




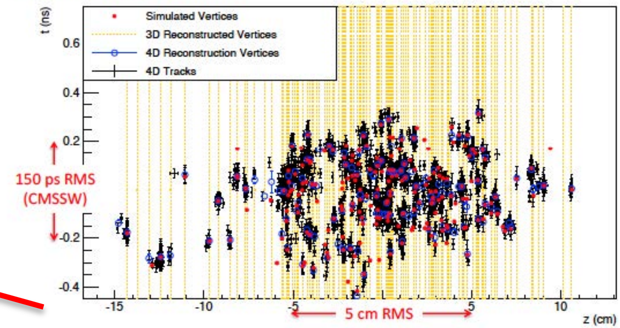


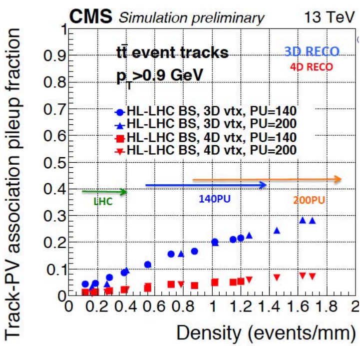


MIP precision timing detector



○ 200 pileup collisions

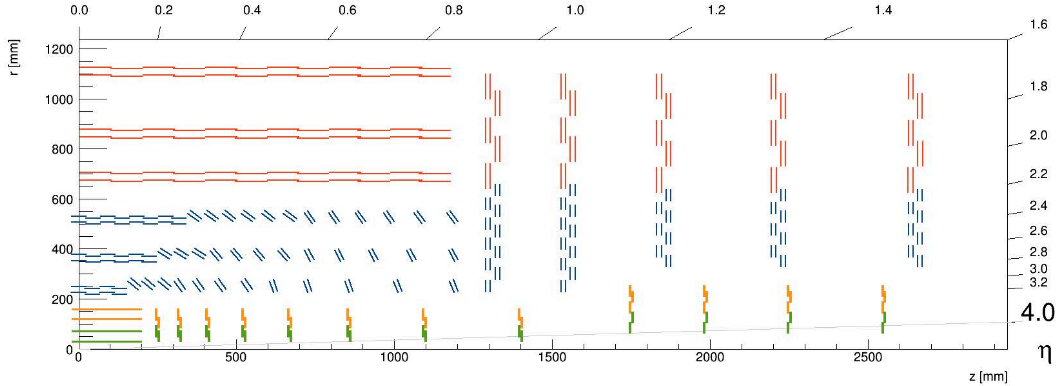




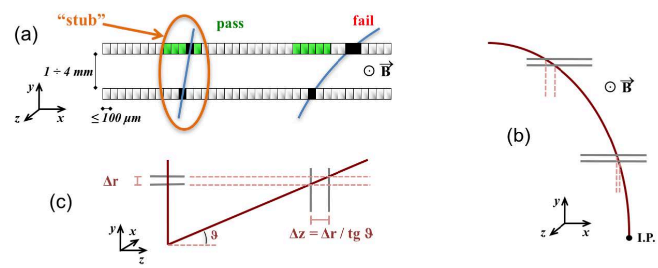
~ 30ps TOF precision for individual tracks just outside the tracker, $|\eta|<3$

- Design based on LYSO+SiPMs in the barrel, and LGAD in the endcaps
- Complements similar time resolution for showers in the upgraded calorimeters
- Provides a factor 4-5 effective pileup reduction
- Reduces merged vertices in high density events
- Provides flexibility adding a 4th coordinate to CMS event reconstruction

Tracker and its trigger



- Full-silicon, high granularity tracker, as pioneered by CMS, with extended coverage out to $|\eta|=4$
- Tracking trigger at L1, finds all tracks with p_T>~2 GeV in less than 4μs
  - Tracking information + long L1 trigger latency (12μs) will allow complex algorithms like Particle Flow at L1 trigger

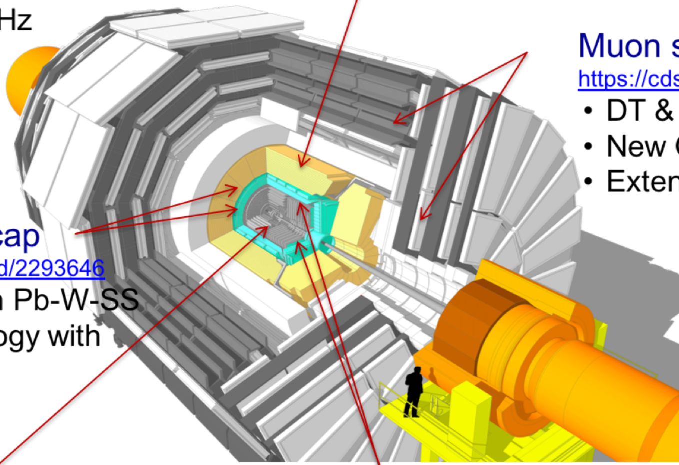


Full scope of CMS phase 2 upgrade

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

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
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$



Calorimeter Endcap
https://cds.cern.ch/record/2293646
- Si, Scint+SiPM in Pb-W-SS
- 3D shower topology with precise timing

Beam Radiation Instr. and Luminosity, and Common Systems and Infrastructure
https://cds.cern.ch/record/2020886

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

MIP Timing Detector
https://cds.cern.ch/record/2296612
- $\simeq$ 30 ps resolution
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

Conclusions

- CMS restarted at full speed from a very challenging technical stop
- Keeps on producing many excellent physics results
- Has sound plans for Run 3 (2021-23) and HL-LHC

- It is a very interesting time to be in an LHC experiment, in particular for young physicists; despite the size and timescale, presently we are, at the same time:
  1. Operating the detector, taking data in extremely challenging conditions
  2. Analysing vast amounts of data, using the most advanced techniques
  3. Designing, prototyping, testing and building even more challenging large scale detectors

- **We have a great detector operating in an incredible machine. We see every day the ingenuity of our scientists in improving the quality of the results, and we are just at the beginning of a long luminosity ride**
- It is our mission to explore every corner in every possible way, and yes, "still round the corner there may wait, a new road or a secret gate"

THANK YOU FOR YOUR ATTENTION

And many thanks to the accelerator teams, LHC performances are really amazing

Backup Slides

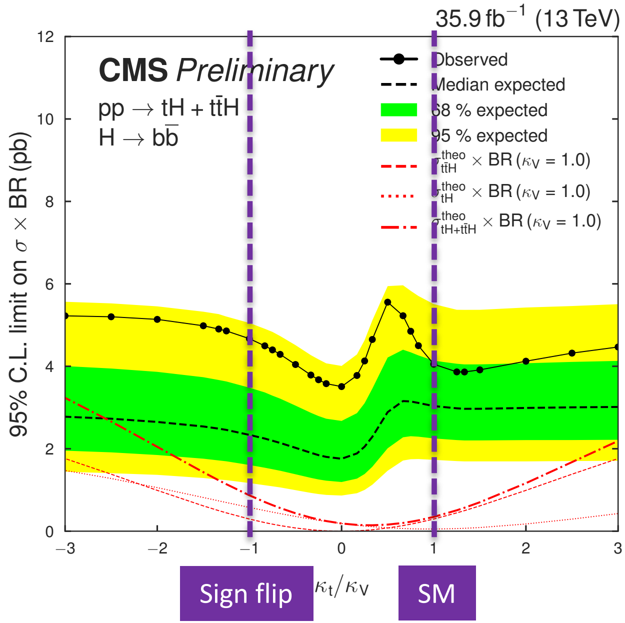
ttH combination

Parameter	Best fit	Uncertainty: Stat	Expt	Thbgd	Thsig
$\mu_{\mathrm{t\bar{t}H}}^{\mathrm{WW^*}}$	$1.97^{+0.71}_{-0.64}$	$^{+0.42}_{-0.41}$	$^{+0.46}_{-0.42}$	$^{+0.21}_{-0.21}$	$^{+0.25}_{-0.12}$
	$\left(^{+0.57}_{-0.54}\right)$	$\left(^{+0.39}_{-0.38}\right)$	$\left(^{+0.36}_{-0.34}\right)$	$\left(^{+0.17}_{-0.17}\right)$	$\left(^{+0.12}_{-0.03}\right)$
$\mu_{\mathrm{t\bar{t}H}}^{\mathrm{ZZ^*}}$	$0.00^{+1.30}_{-0.00}$	$^{+1.28}_{-0.00}$	$^{+0.20}_{-0.00}$	$^{+0.04}_{-0.00}$	$^{+0.09}_{-0.00}$
	$\left(^{+2.89}_{-0.99}\right)$	$\left(^{+2.82}_{-0.99}\right)$	$\left(^{+0.51}_{-0.00}\right)$	$\left(^{+0.15}_{-0.00}\right)$	$\left(^{+0.27}_{-0.00}\right)$
$\mu_{\mathrm{t\bar{t}H}}^{\gamma\gamma}$	$2.27^{+0.86}_{-0.74}$	$^{+0.80}_{-0.72}$	$^{+0.15}_{-0.09}$	$^{+0.02}_{-0.01}$	$^{+0.29}_{-0.13}$
	$\left(^{+0.73}_{-0.64}\right)$	$\left(^{+0.71}_{-0.64}\right)$	$\left(^{+0.09}_{-0.04}\right)$	$\left(^{+0.01}_{-0.00}\right)$	$\left(^{+0.13}_{-0.05}\right)$
$\mu_{\mathrm{t\bar{t}H}}^{\tau^+\tau^-}$	$0.28^{+1.09}_{-0.96}$	$^{+0.86}_{-0.77}$	$^{+0.64}_{-0.53}$	$^{+0.10}_{-0.09}$	$^{+0.20}_{-0.19}$
	$\left(^{+1.00}_{-0.89}\right)$	$\left(^{+0.83}_{-0.76}\right)$	$\left(^{+0.54}_{-0.47}\right)$	$\left(^{+0.09}_{-0.08}\right)$	$\left(^{+0.14}_{-0.01}\right)$
$\mu_{\mathrm{t\bar{t}H}}^{\mathrm{b\bar{b}}}$	$0.82^{+0.44}_{-0.42}$	$^{+0.23}_{-0.23}$	$^{+0.24}_{-0.23}$	$^{+0.27}_{-0.27}$	$^{+0.11}_{-0.03}$
	$\left(^{+0.44}_{-0.42}\right)$	$\left(^{+0.23}_{-0.22}\right)$	$\left(^{+0.24}_{-0.23}\right)$	$\left(^{+0.26}_{-0.27}\right)$	$\left(^{+0.11}_{-0.04}\right)$
$\mu_{\mathrm{t\bar{t}H}}^{\mathrm{7+8\,TeV}}$	$2.59^{+1.01}_{-0.88}$	$^{+0.54}_{-0.53}$	$^{+0.53}_{-0.49}$	$^{+0.55}_{-0.49}$	$^{+0.37}_{-0.13}$
	$\left(^{+0.87}_{-0.79}\right)$	$\left(^{+0.51}_{-0.49}\right)$	$\left(^{+0.48}_{-0.44}\right)$	$\left(^{+0.50}_{-0.44}\right)$	$\left(^{+0.14}_{-0.02}\right)$
$\mu_{\mathrm{t\bar{t}H}}^{\mathrm{13\,TeV}}$	$1.14^{+0.31}_{-0.27}$	$^{+0.17}_{-0.16}$	$^{+0.17}_{-0.17}$	$^{+0.13}_{-0.12}$	$^{+0.14}_{-0.06}$
	$\left(^{+0.29}_{-0.26}\right)$	$\left(^{+0.16}_{-0.16}\right)$	$\left(^{+0.17}_{-0.16}\right)$	$\left(^{+0.13}_{-0.12}\right)$	$\left(^{+0.11}_{-0.05}\right)$
$\mu_{\mathrm{t\bar{t}H}}$	$1.26^{+0.31}_{-0.26}$	$^{+0.16}_{-0.16}$	$^{+0.17}_{-0.15}$	$^{+0.14}_{-0.13}$	$^{+0.15}_{-0.07}$
	$\left(^{+0.28}_{-0.25}\right)$	$\left(^{+0.15}_{-0.15}\right)$	$\left(^{+0.16}_{-0.15}\right)$	$\left(^{+0.13}_{-0.12}\right)$	$\left(^{+0.11}_{-0.05}\right)$

Uncertainty source	$\Delta\mu$	
Signal theory	+0.15	−0.07
Inclusive ttH normalisation (cross section and BR)	+0.15	−0.07
ttH acceptance (scale, pdf, PS and UE)	+0.004	−0.004
Other Higgs boson production modes	+0.002	−0.003
Background theory	+0.14	−0.13
tt + bb/cc prediction	+0.13	−0.11
tt + V(V) prediction	+0.06	−0.06
Other background uncertainties	+0.03	−0.03
Experimental	+0.17	−0.15
Lepton (inc. τ_{h}) trigger, ID and iso. efficiency	+0.08	−0.06
Misidentified lepton prediction	+0.06	−0.06
b-Tagging efficiency	+0.05	−0.04
Jet and τ_{h} energy scale and resolution	+0.04	−0.04
Luminosity	+0.04	−0.03
Photon ID, scale and resolution	+0.01	−0.01
Other experimental uncertainties	+0.01	−0.01
Finite number of simulated events	+0.08	−0.07
Statistical	+0.16	−0.16
Total	+0.31	−0.26

Search for $tH(H \rightarrow b\bar{b})$ process

- ttH is not sensitive to the sign of the Yukawa coupling y_T of the Higgs boson to the t quark
- y_T<0 not excluded, though disfavoured if no BSM particles in loops, e.g. in $H \rightarrow \gamma\gamma$
- tH is sensitive to the sign through interference in production modes involving a quark or a W
  - If the sign flips the cross section would increase of about a factor 10 making this rare process, with large background (mostly ttH) more accessible
- Complex analysis using multiple BDT techniques

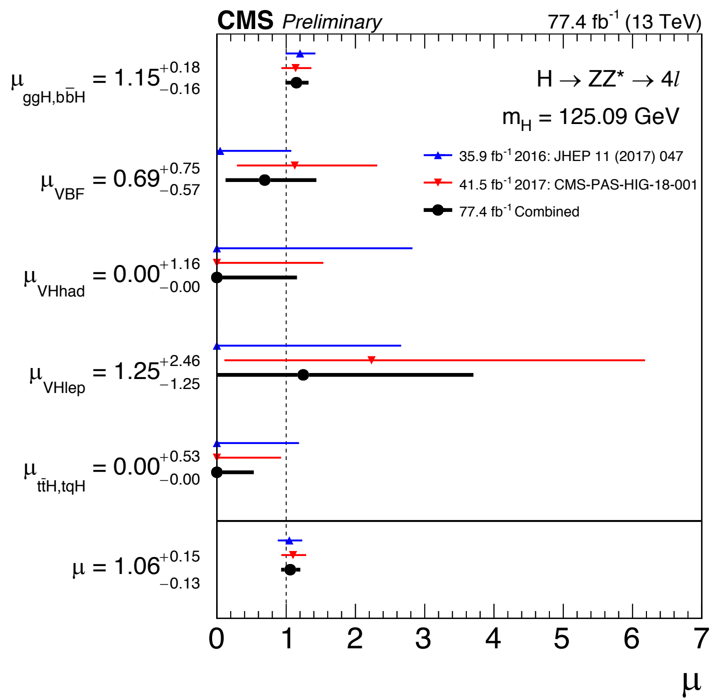


The observed limit in case of inverted top-Higgs coupling is set to 5.83 (2.94) times the prediction

CMS-PAS-HIG-17-016

$H \rightarrow ZZ^{*} \rightarrow 4l$

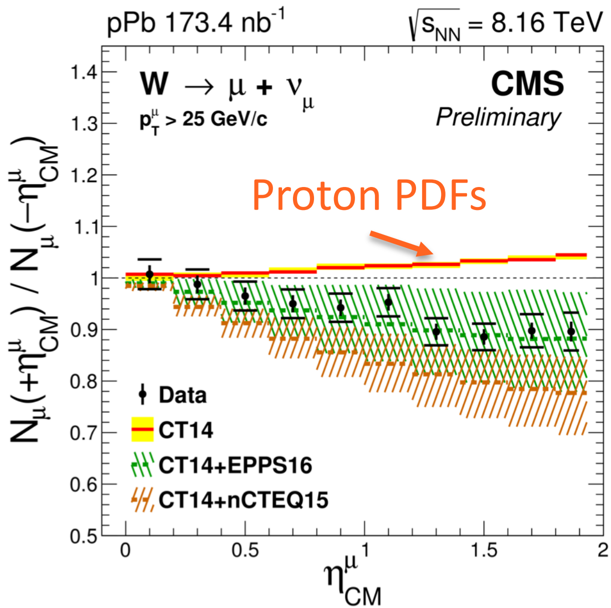
- Measured inclusive and per-category signal strength for the main SM Higgs boson production modes
- Also here approaching the systematic limit



CMS-PAS-HIG-18-001

Heavy Ions

Several new results presented at Quark Matter conference, using PbPb, pPb and pp collisions at 5.02 TeV (also 8.16 TeV for pPb) and XeXe collisions at 5.44 TeV



Example:

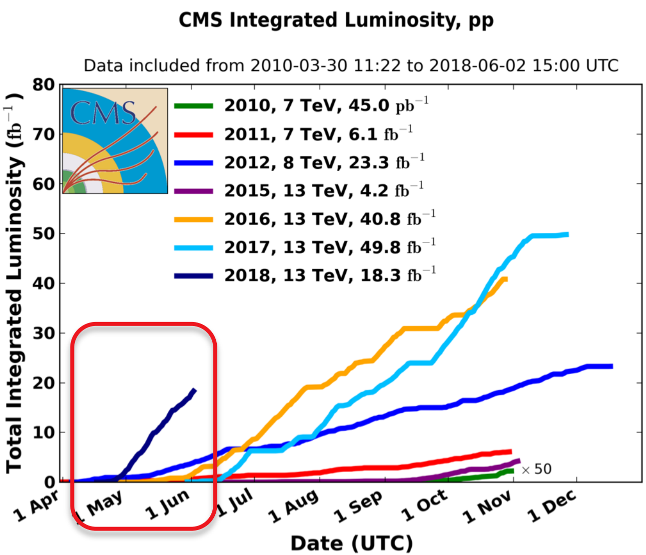
- Measurement of $W \rightarrow \mu\nu$ in pPb using 173.4 nb^{-1} at $\sqrt{s_{NN}} = 8.16$ TeV
- Provide constraints to nuclear modifications of the (quark) PDFs
  - The leptonic W decay minimizes the impact of the nuclear medium

Muon forward/backward ratio compared with PDFs

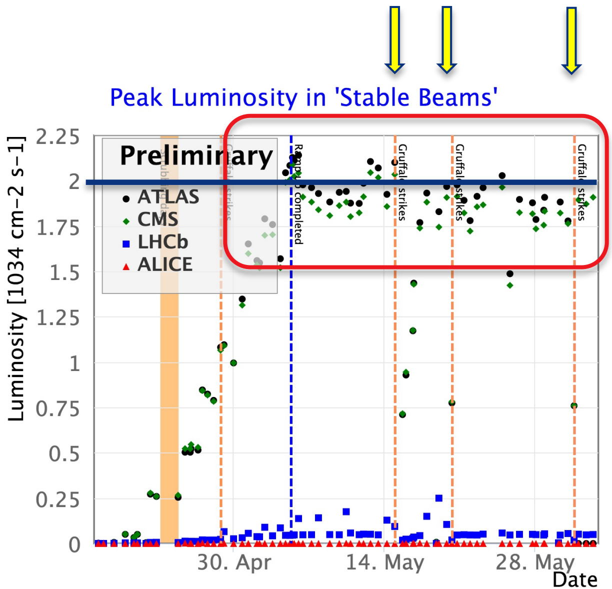
- favours the predictions including the nuclear modifications

CMS-PAS-HIN-17-007

LHC



- Great start from LHC!
  - despite the unexpected reappearance of the 16L02 induced beam dumps



- Peak luminosity ~ $2 \cdot 10^{34}\ Hz/cm^2$
  - Corresponding to Pile-Up above 55