

CMS Status Report

Sam Harper



Science & Technology
Facilities Council

UK Research
and Innovation

on behalf of the CMS collaboration

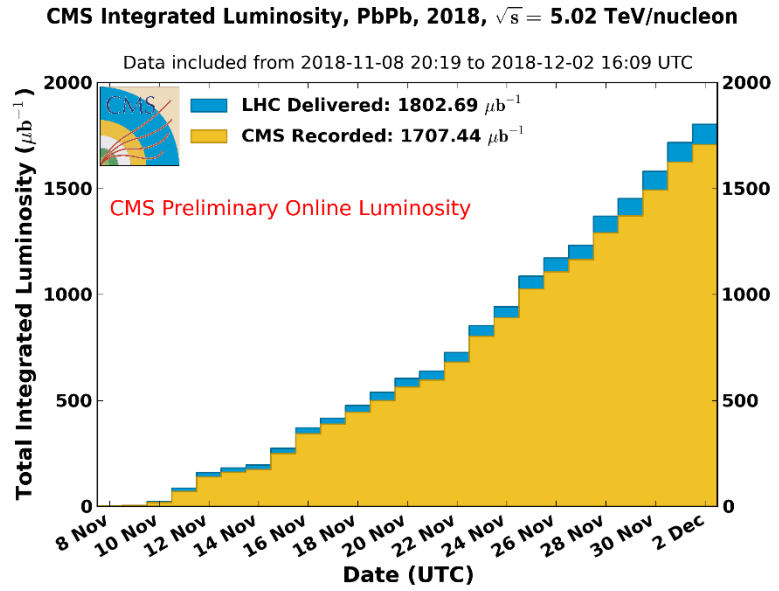
LHCC Open Session
27 February 2019

Outline

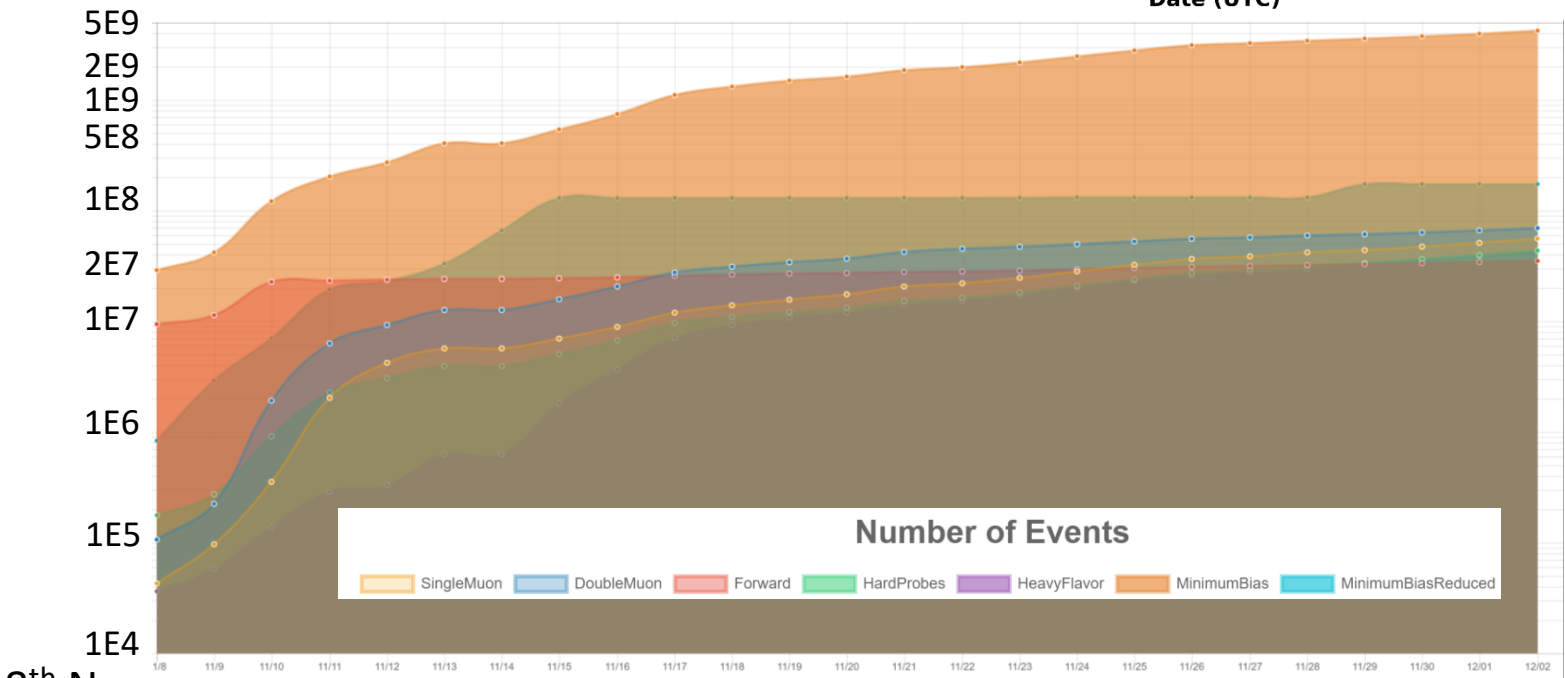
- Summary of Heavy Ion Run
- Plans & Status for LS2
- Computing & Subsystems Status
- Latest Physics Results & Publications

Heavy Ion Run Summary

- HI: 1.80nb⁻¹ delivered, 1.71nb⁻¹ recorded
 - ~95% data taking efficiency
- ~4.5 billion minimum bias events collected
 - sustained ~7GB/s HLT rate
 - non-trivial to achieve, for example required custom tracker firmware to achieve
- highly successful run, full dataset is now in the hands of eager analysers



number of events by dataset



Heavy Ion Run Summary (II)

- LHC schedule optimised up to the last moment to give us maximal lumi!
 - last fill was just 2hrs long but gave us an additional 0.5% lumi!
- a very successful end to a very successful Run

Last physics fill of Run2 dumped on Dec 2nd @17:05

LHC Page1 Fill: 7492 E: 6369 Z GeV t(SB): 01:03:28 02-12-18 16:56:19

ION PHYSICS: STABLE BEAMS

Energy:	6369 Z GeV	I(B1):	4.82e+12	I(B2):	4.07e+12
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Inst. Lumi [(b.s) ⁻¹]	IP1: 1572.36	IP2: 481.95	IP5: 1547.18	IP8: 172.20
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FBCT Intensity and Beam Energy Updated: 16:56:19

Instantaneous Luminosity Updated: 16:56:18

Comments (02-Dec-2018 15:12:28)	BIS status and SMP flags	
Physics fill with reduced number of bunches 313b in B1 271b in B2	Link Status of Beam Permits	B1 B2
DUMP at 5pm	Global Beam Permit	true true
	Setup Beam	false false
	Beam Presence	true true
	Moveable Devices Allowed In	true true
	Stable Beams	true true

AFS: 75_150ns_733Pb_733_702_468_42bpi_20inj PM Status B1 ENABLED PM Status B2 ENABLED

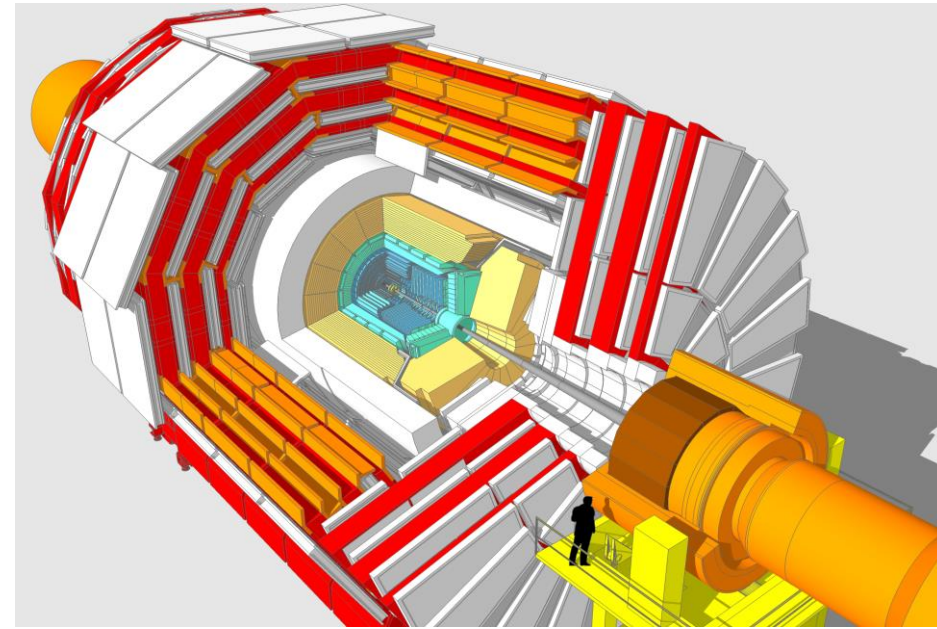
Many thanks to the LHC team and LPC coordinators!
See you in Run3!

Outline

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First a reminder, CMS detector was far from static over Run2, evolved significantly

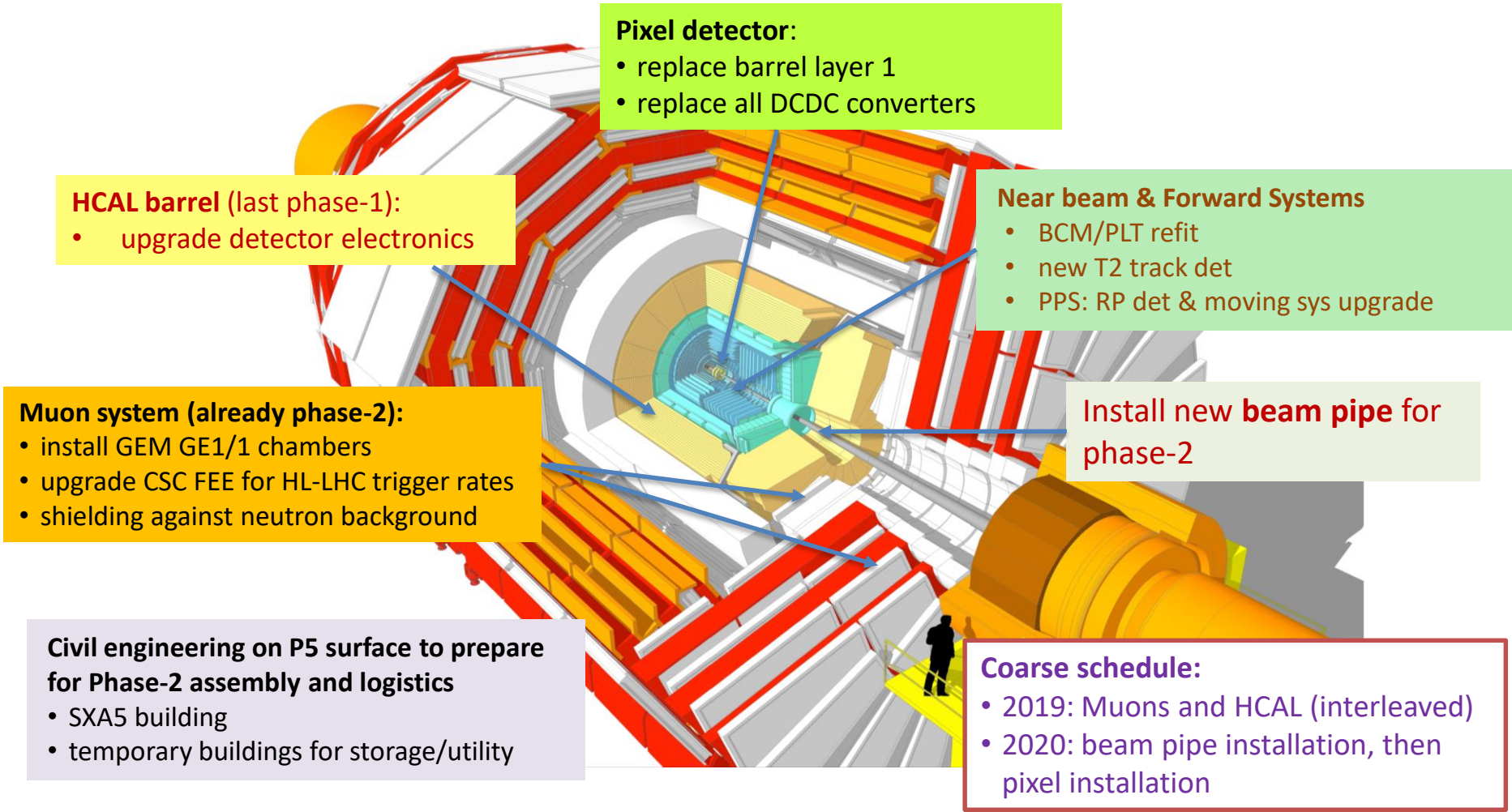
- 2016:
 - L1 trigger fully upgraded, now time multiplexed architecture using FPGAs, significant granularity improvements
 - precision proton spectrometer installed
- 2017:
 - pixel detector replaced; extra barrel and disk layers
 - one ϕ sector of HCAL endcap electronics upgraded
 - forward HCAL upgrade complete
- 2018:
 - HCAL endcap electronics upgraded; reduced noise, x3 increase in longitudinal segmentation
 - GEM slice test installed
 - pixel dc/dc converters replaced



continuously updating our detectors has given us valuable recent experience on how to perform and utilise upgrades
→major advantage for CMS in LS2 / Run3

LS2 Major Projects

Summary: Finish Phase-1, Prepare for Phase-2



Pixel detector:

- replace barrel layer 1
- replace all DCDC converters

HCAL barrel (last phase-1):

- upgrade detector electronics

Near beam & Forward Systems

- BCM/PLT refit
- new T2 track det
- PPS: RP det & moving sys upgrade

Muon system (already phase-2):

- install GEM GE1/1 chambers
- upgrade CSC FEE for HL-LHC trigger rates
- shielding against neutron background

Install new beam pipe for phase-2

Civil engineering on P5 surface to prepare for Phase-2 assembly and logistics

- SXA5 building
- temporary buildings for storage/utility

Coarse schedule:

- 2019: Muons and HCAL (interleaved)
- 2020: beam pipe installation, then pixel installation

LS2 Status

- LS2 progressing well and on schedule
- pixel detector and beam pipe now removed!
- HCAL barrel electronics upgrade on going
 - **completes phase-1 upgrade**
- muon endcap upgrades about to proceed
 - **marks start of phase-2 upgrade!**



LS Status (II): Phase-2 Muon Upgrade

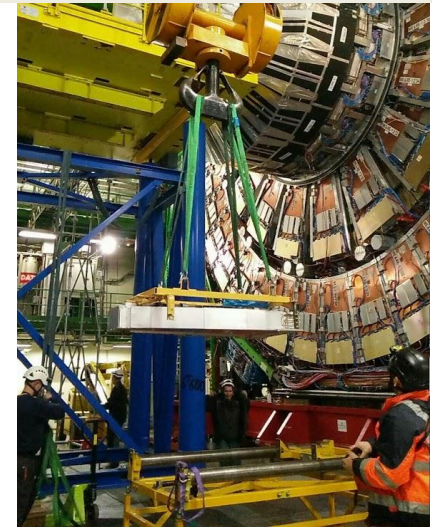
1) replacement of all on-CSC and part of on-disk electronics

- component production for new on-chamber electronics is on schedule → on target for the “ready for installation” milestone (11 Mar 2019)

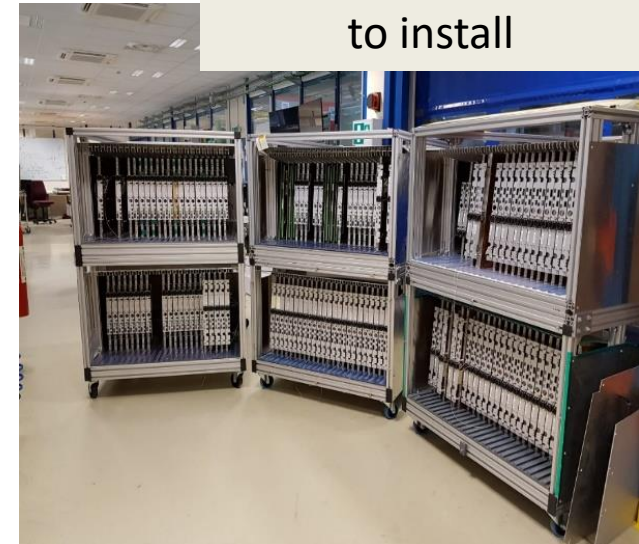
2) 144 triple-GEM chambers to be added to the first endcap station

- additional layer in front of existing muon station (ME1/1) at $1.6 \leq |\eta| \leq 2.2$
- necessary for phase-2 to control trigger rates but get to reap benefits in Run3
- all GE1/1 chambers have been built and validated
- electronics production on-going
- on schedule to start installation at end of Aug 2019

the first ME1/1 is extracted on Jan 22 for electronics upgrades



GEM chambers ready to install

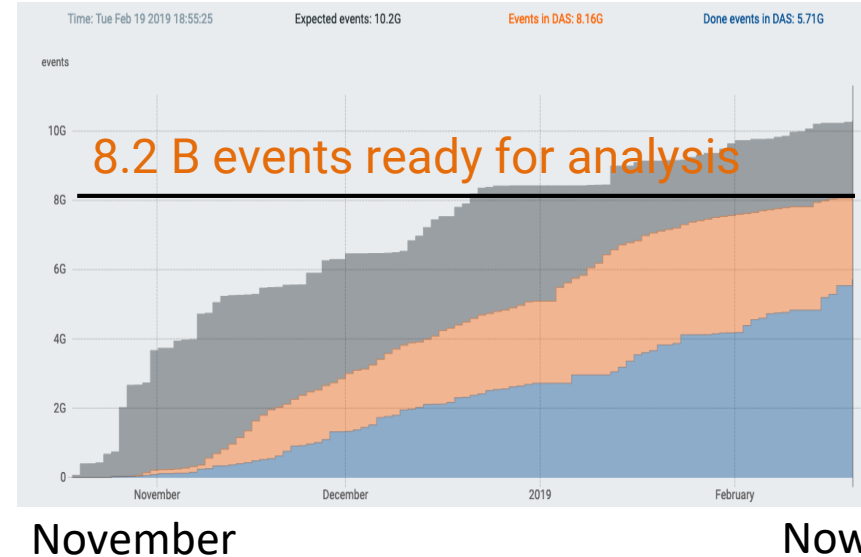


Outline

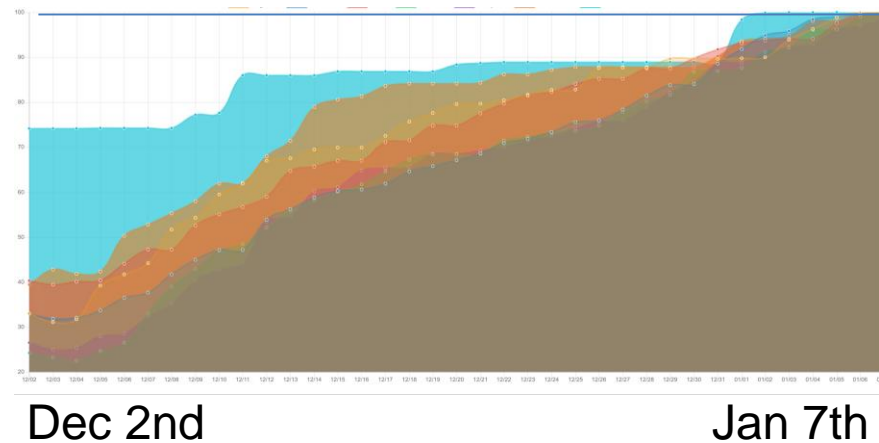
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Computing: Production activities since last LHCC

- samples for Moriond 19 finalized → 8.2B events done, at AOD/Mini/Nano level
 - nanoAOD: very light weight dataformat
 - now routinely used by analysis teams
- sample @PU=200 for the MTD TDR done
- HI reco done just after winter break, using Tier-0 and HLT resources → ~4.7B events ready for analysis
- ~ 300kCores available for offline (prod + analysis) jobs during the break
 - a record for CMS!
- we are well prepared for the complete reprocessing of Run2 data & MC
 - improved detector calibrations & object reco required for precision analyses
 - scheduled to start in May

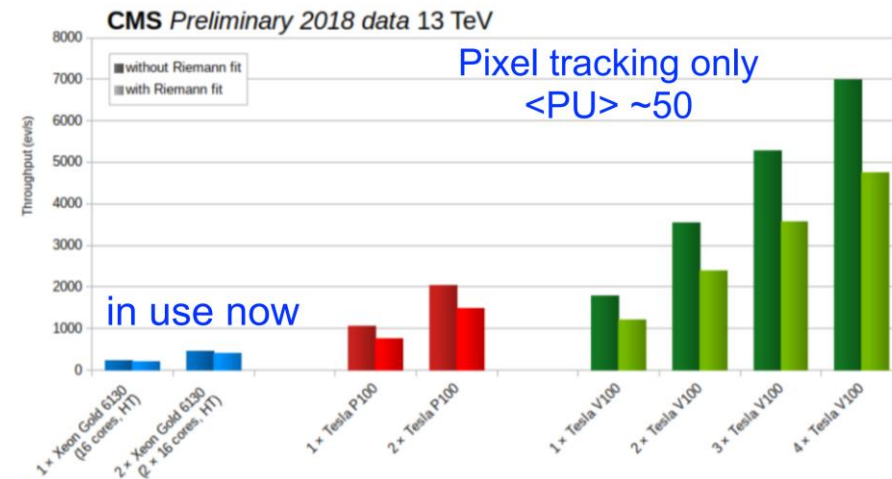


100% Threshold



Computing: Other relevant activities

- about to start the full processing of the 12B event b parking dataset
 - includes new optimized electron reco specifically developed for this analysis
 - extends the physics reach of CMS to a new phase space!
- transition to new (Run3) software stack progressing as expected
 - Rucio (Data Management), DD4HEP (Geometry Description), CRIC (Information System)
- latest CMSSW version contains the first framework code to handle heterogeneous architectures
 - FPGA, GPU/CUDA already prototyped
 - a per module, per event, per job, per... granularity
 - expands our robust multithreading framework which has been critical to Run2 data taking
 - to be finalized in next major version (expected late spring)



advantages of using GPUs in tracking in HLT
throughput increases by order of magnitude

L1 Trigger

operations

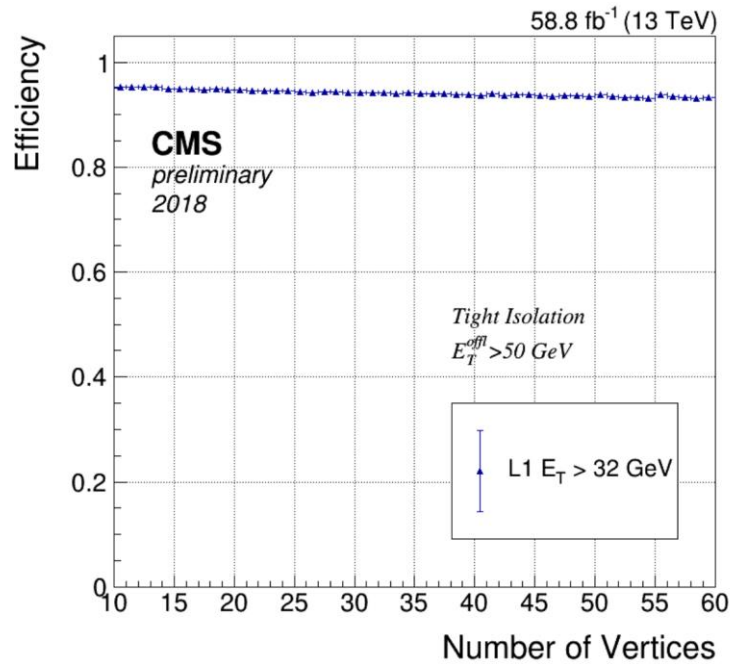
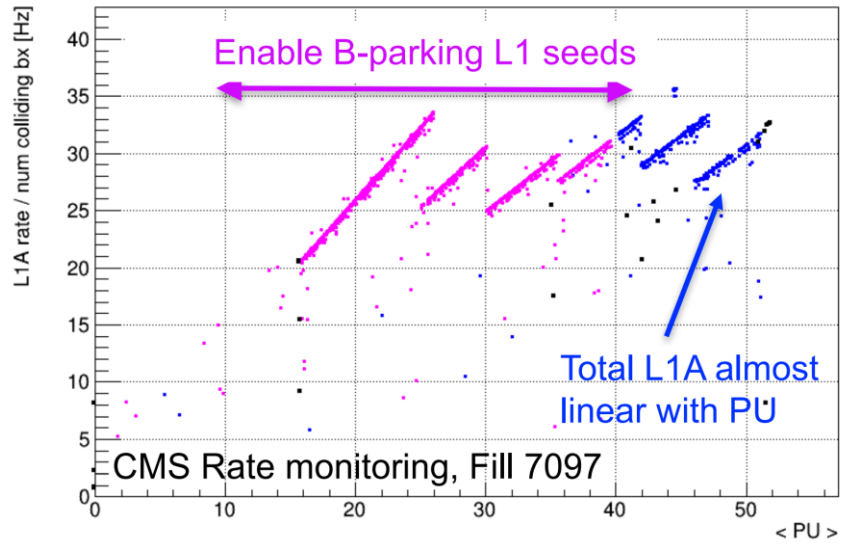
- extremely good year for L1T
- downtime was 50% of 2017

performance in 2018

- performance improved w.r.t 2017
 - lowered to ~28 GeV electrons, ~22 GeV muons
- rate linear with PU
 - significant work here into refining noise/PU suppression algos
- L1 accept rate typically 90kHz with approx. 340 L1 seeds

improvements in LS2

- exploit new information in Run3 available at L1: HCAL depth, GE1/1
- Kalman-filter based muon track finding for barrel, tested in 2018



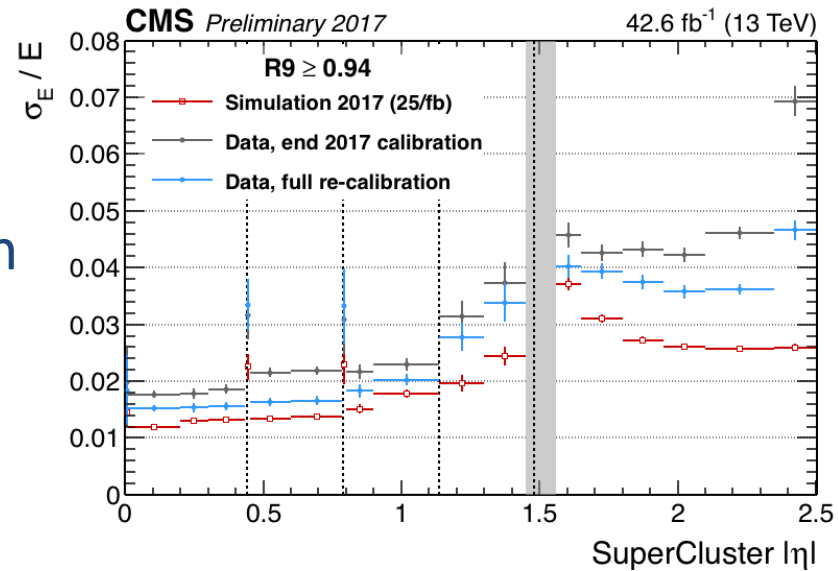
Calorimeters

ECAL:

- prepared final calibrations for precision re-reconstruction of Run2 data
- first test chips available for phase-2 (very) front end drivers
 - ASIC works with all features functional
 - qualitative performance in agreement with expectations

HCAL:

- endcap upgraded detector understood and has good data/MC agreement
 - improvements will be fed into the re-reco Run2 data scheduled to start in May
- barrel upgrade in progress

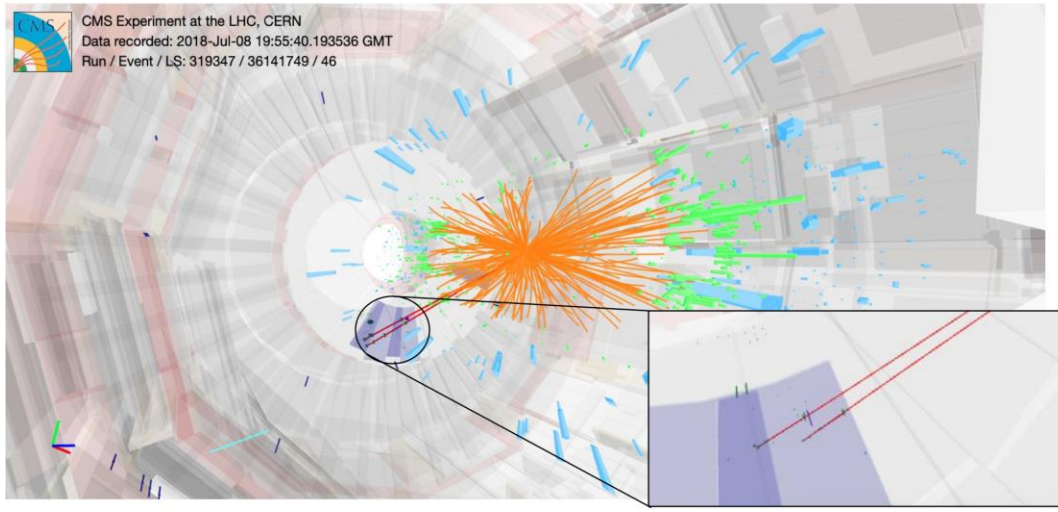
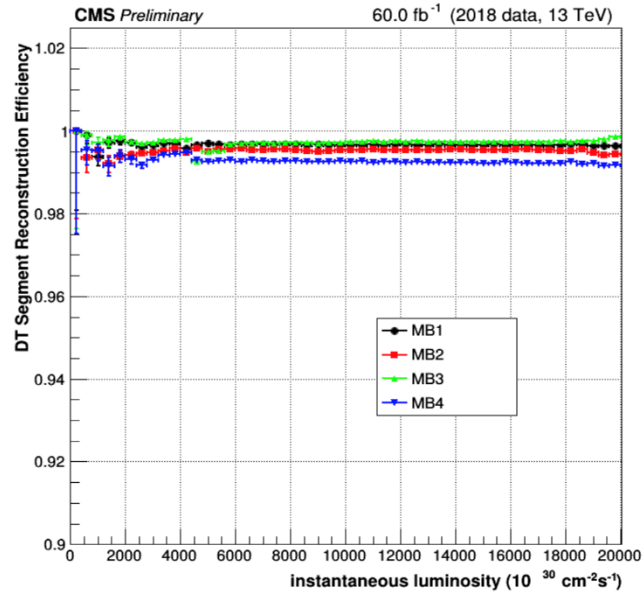


Analog test setup at Saclay for ECAL VFEDs



Muon System

- analysis of the full 2018 data set confirms the excellent performance of the CMS muon systems
 - already submitted physics results using it!
- 2018 saw the introduction of a single slice of the new GEM upgrade
 - regular part of the readout system
 - obtained valuable experience in operating it
 - now studying the performance while the full system is being installed



Precision Proton Spectrometer

- Run2: summary
 - total of >100fb-1 recorded for physics with Roman Pots inserted from 2016-2018
- LS2: status
 - RP tracking and timing detector packages removed from tunnel for upgrades/refurbishment for Run3
 - work proceeding on schedule
- HL-LHC : motivation for continuing PPS program beyond Run3
 - feasibility of machine interface, detectors, under evaluation

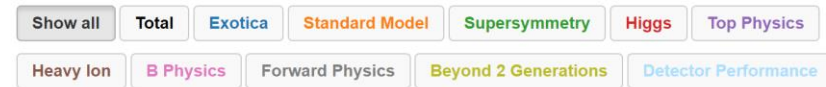


Outline

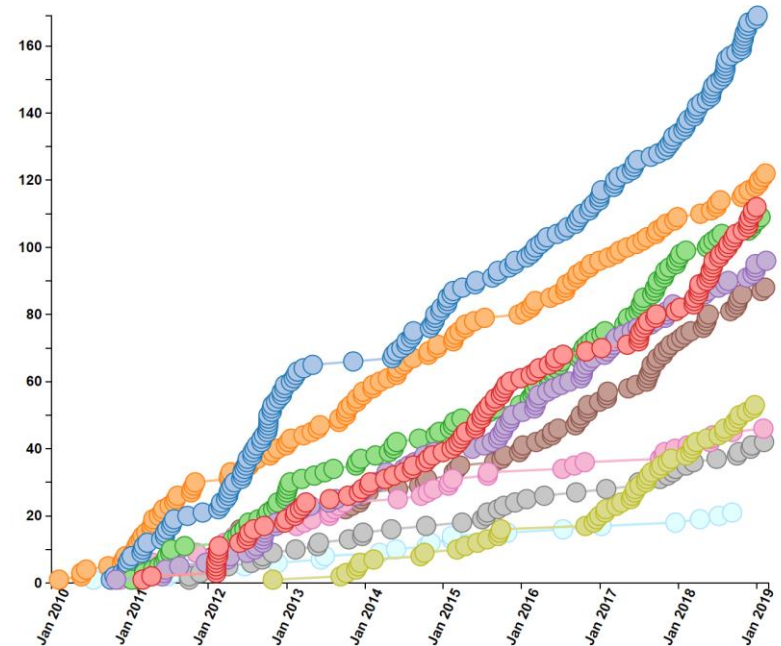
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Publications Report

- CMS has now submitted **857** collider data papers since 2010
 - 30 since last LHCC meeting in Nov
 - full list: <https://tinyurl.com/y9odauv6>
- 2018 was a record year, submitted 141 papers!
 - highest ever in any HEP experiment
 - previous record was CMS with 132 papers in 2017



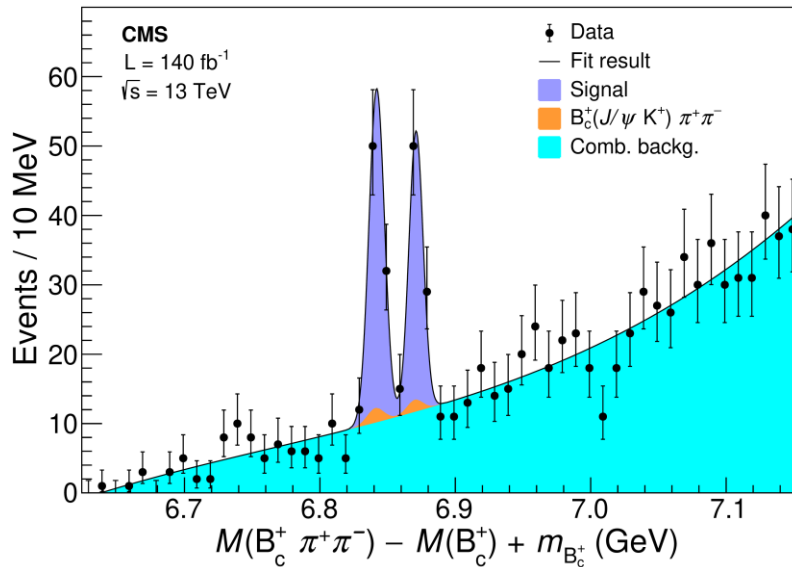
857 collider data papers submitted as of 2019-02-25



Physics results since the last LHCC meeting

- b physics: observation of new excited B_c^+ states : BPH-18-007
- top & standard model physics
 - tZq: TOP-18-008
 - top spin correlations: TOP-18-006
 - single top combination with ATLAS: TOP-17-006
 - top mass at 13 TeV in all jets + comb. with l + jets: TOP-17-008
 - search for W boson decays to three charged pions: SMP-18-009
- searches:
 - exotic decay $H \rightarrow \phi\phi \rightarrow X + 2\mu + 2b\text{-jets}$: HIG-18-011
- HL-LHC / HE-LHC yellow reports:
 - ~40 analyses for HL/HE LHC submitted (~23 since last LHCC meeting)
 - <http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/FTR/index.html>
 - main WG yellow reports submitted

First (in LHC) Run2 paper submitted!



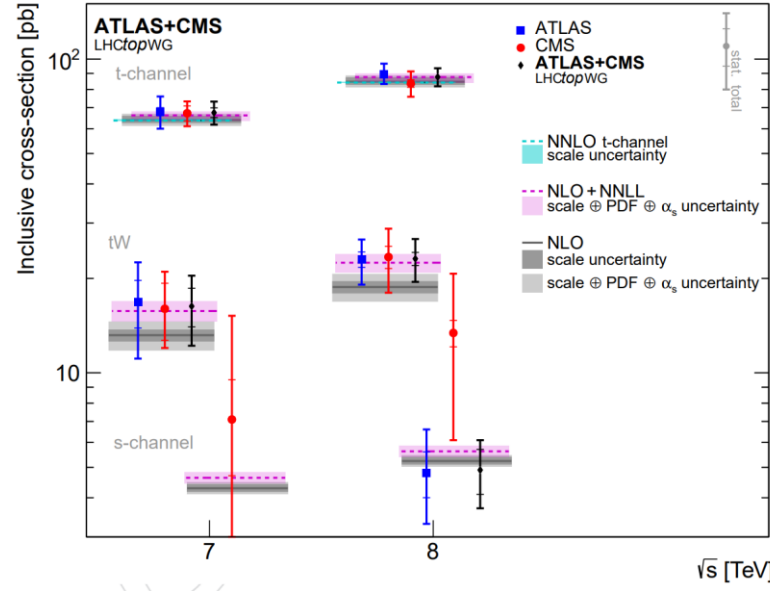
Observation of two excited B_c^+ states and measurement of the $B_c^+(2S)$ mass in pp collisions at $\sqrt{s} = 13 \text{ TeV}$

Ready with 140 fb^{-1} after just two months from the end of the run demonstrates that that the detector and computing work flows are performing extremely well!

Abstract: Signals consistent with the $B_c^+(2S)$ and $B_c^{*+}(2S)$ states are observed in proton-proton collisions at $\sqrt{s} = 13 \text{ TeV}$, in an event sample corresponding to an integrated luminosity of 140 fb^{-1} , collected by the CMS experiment during the 2016, 2017, and 2018 LHC running periods. These excited $\bar{b}c$ states are observed in the $B_c^+ \pi^+ \pi^-$ invariant mass spectrum, with the ground state B_c^+ reconstructed through its decay to $J/\psi \pi^+$. The two states are well resolved from each other and are observed with a significance exceeding five standard deviations. The mass of the $B_c^+(2S)$ meson is measured to be $6871.0 \pm 1.2 \text{ (stat)} \pm 0.8 \text{ (syst)} \pm 0.8 \text{ (} B_c^+ \text{)} \text{ MeV}$, where the last term corresponds to the uncertainty in the world-average B_c^+ mass.

Single Top: ATLAS + CMS Run1 Combination

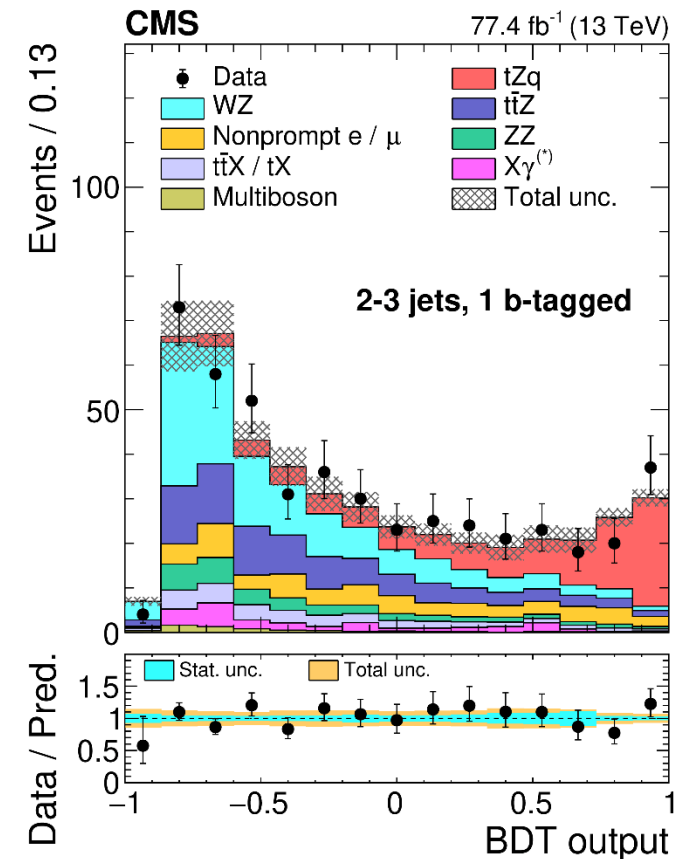
- sensitive test of new physics that modify tWb couplings or have new particles/interactions
- combine with ATLAS to maximise sensitivity to any SM cross-section deviations
 - combination reduces the 68% confidence interval on x-sec by 4 to 15% depending on process
 - excellent example of what can be achieved together
 - ATLAS will show the extracted V_{tb} results
- compatible with SM prediction



\sqrt{s}	process	ATLAS (pb)	CMS (pb)	Combined (pb)	68% CI reduct
7 TeV	t-channel	68 ± 8	67.2 ± 6.1	67.5 ± 5.7	6.5%
	tW	16.8 ± 5.7	16_{-4}^{+5}	16.3 ± 4.1	9%
	s-channel	-	7.1 ± 8.1	-	-
8 TeV	t-channel	$89.6_{-6.3}^{+7.1}$	83.6 ± 7.8	87.7 ± 5.8	13%
	tW	$23.0_{-3.9}^{+3.6}$	23.4 ± 5.4	23.1 ± 3.6	4%
	s-channel	$4.8_{-1.5}^{+1.8}$	13.4 ± 7.3	4.9 ± 1.4	15%

Observation of Single Top with associated Z boson

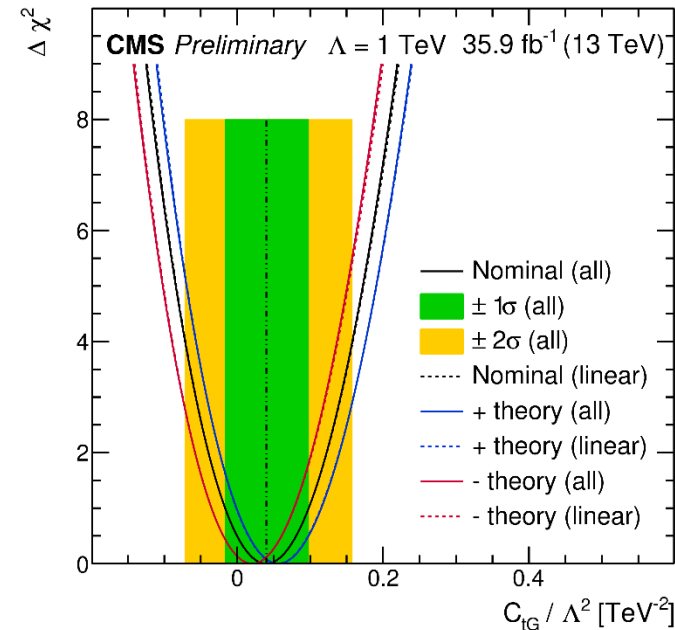
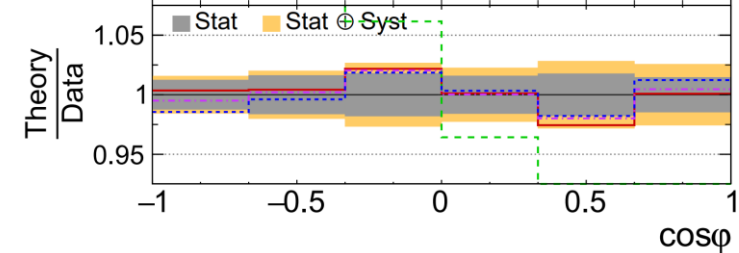
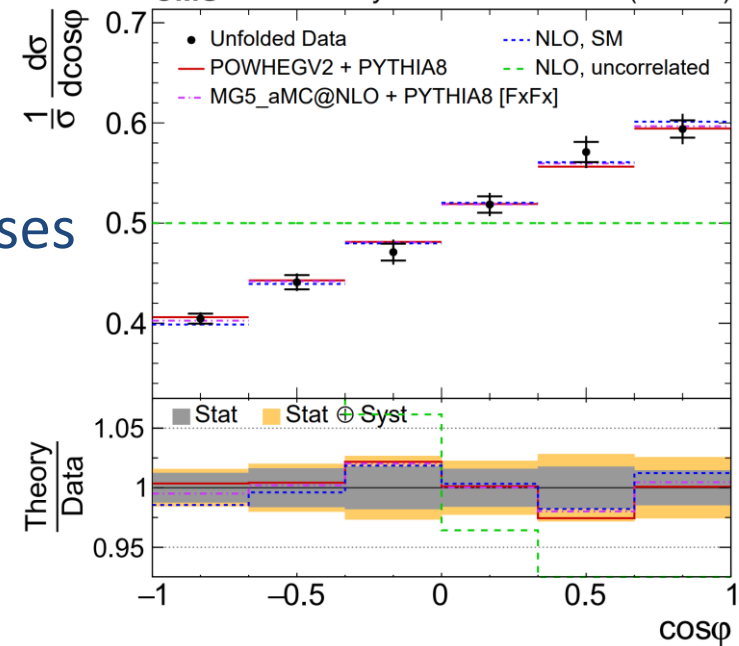
- due to unitary cancellations in SM tZq production, new physics can show up here and *not* inclusive single top or ttZ
 - important complementary measurement!
 - additionally sensitive to flavor changing neutral currents
- **observed with significance well over 5σ**
- analysis done in the leptonic channel
 - events require 3 charged light leptons, ≥ 2 jets (with at least one b-tagged)
- $\sigma(pp \rightarrow tZq \rightarrow tllq)$:
 - $111 \pm 13(stat)^{+11}/_{-9}(syst)$ fb
- compatible with SM prediction



not shown: ≥ 4 jets + 1 b-tag, 2 b-tag channels

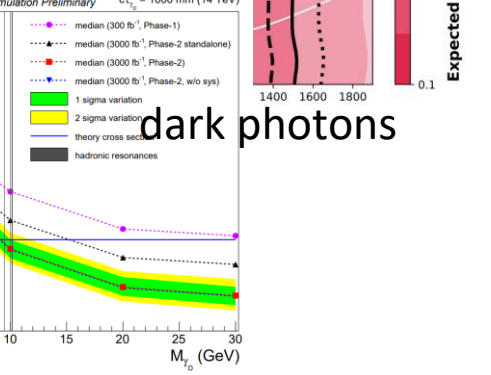
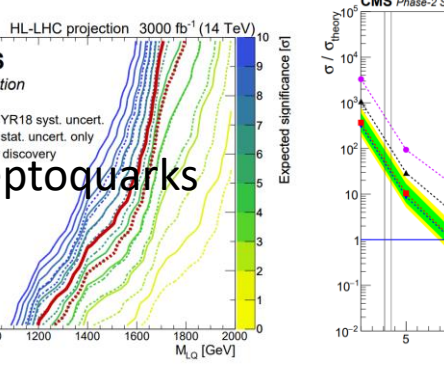
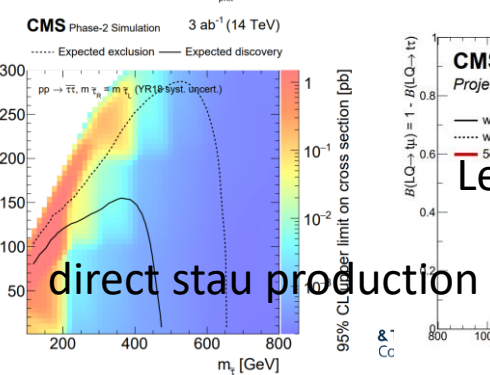
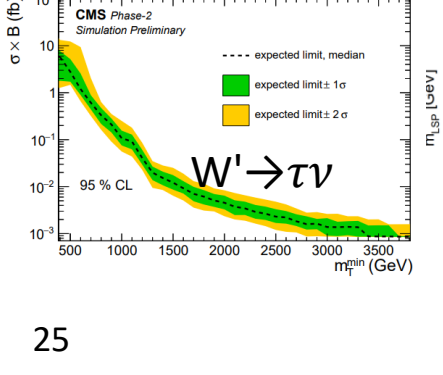
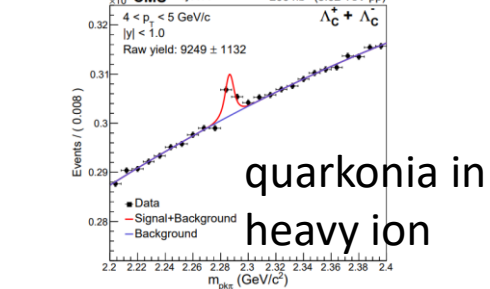
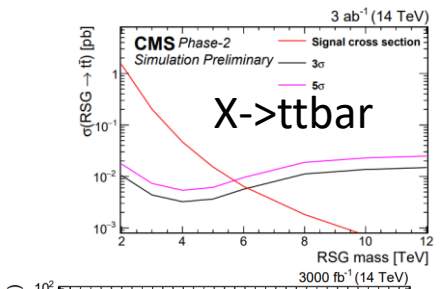
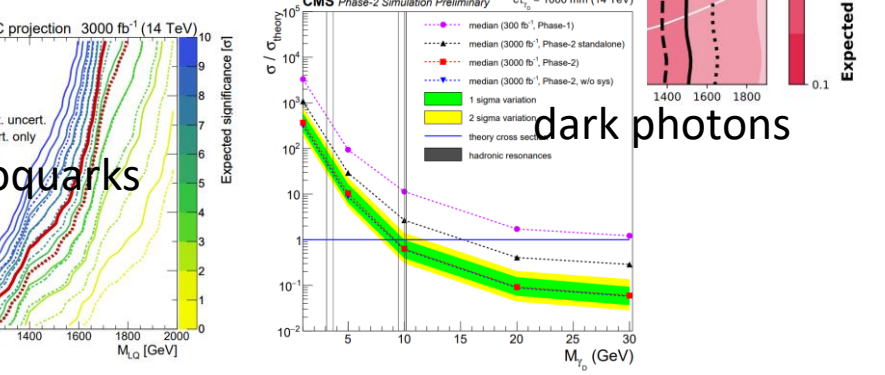
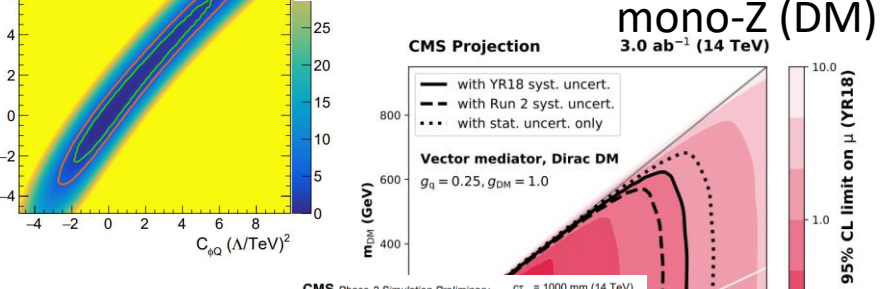
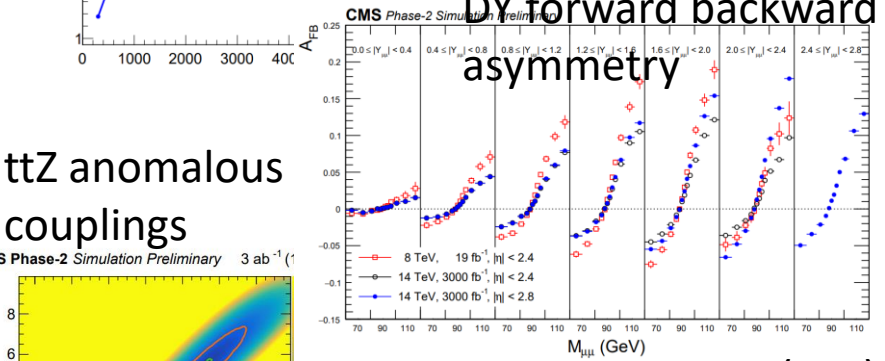
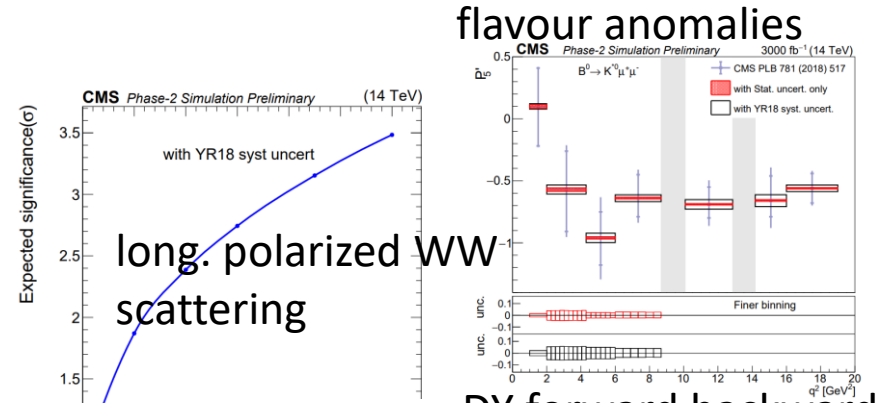
Top spin correlation

- fast decay of top quark allows unique probing of their spin structure
- spin structure sensitive to tt prod processes
 - powerful tool to probe new physics not accessible at the LHC
- measures all 15 coefficients of the spin density matrix
 - first time done at 13 TeV!
 - compatible with SM (with latest theory calcs)
- constrains anomalous chromomagnetic dipole moment of t quark
- strongest direct constraint to date!
 - factor 2 improvement w.r.t previous CMS result
 - more interpretations and Rivet data on release of the paper



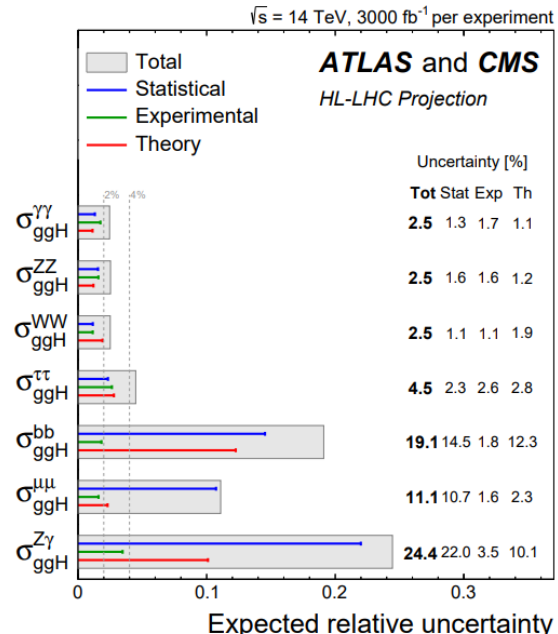
HL-LHC Yellow report

- HL/HE-LHC workshop now concluded
- ~40 CMS physics analyses contributed across all topic areas
 - precision standard model, Higgs physics, BSM models, flavour physics, heavy ion
 - displayed results only a fraction of total
- wrap up session on Friday: <https://indico.cern.ch/event/783141>

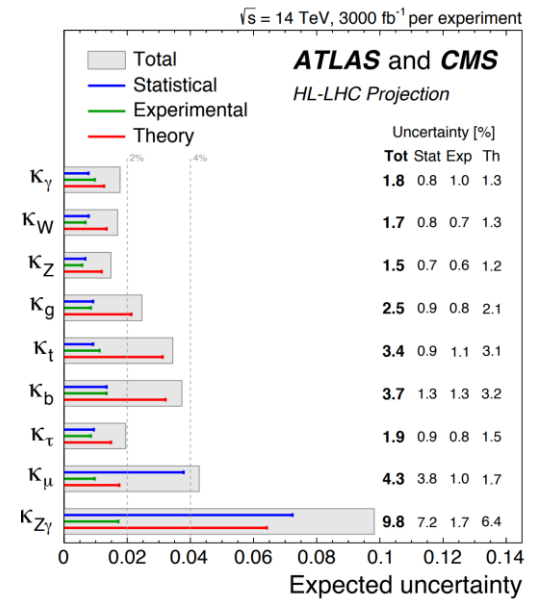


HL-LHC Yellow Report: Higgs couplings

- key goal of HL-LHC program, determine the Higgs properties to a high precision
 - important constraints to new physics, expressed using the κ framework
- goal is to measure the Higgs x-sec in each production & observable decay mode
 - HL-LHC gives us access to the rare decays to $\mu\mu$ and $Z\gamma$ not yet observed
 - also Higgs self-couplings (see ATLAS talk)
- expect % level accuracy on main couplings
 - constrains $\text{Br}(H \rightarrow \text{inv})$ to 2.5% at 95% CL
 - Γ_H constrained with 20% precision
 - 5% precision with assumption the new vector bosons couplings < SM vector boson couplings



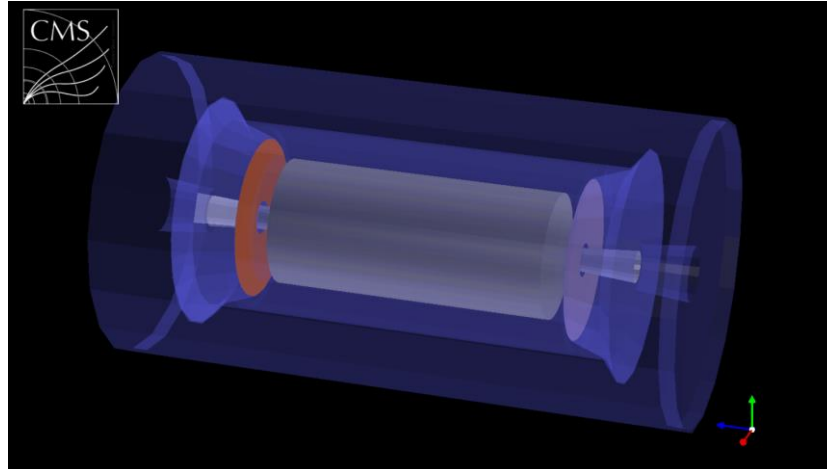
<https://cds.cern.ch/record/2650162/>



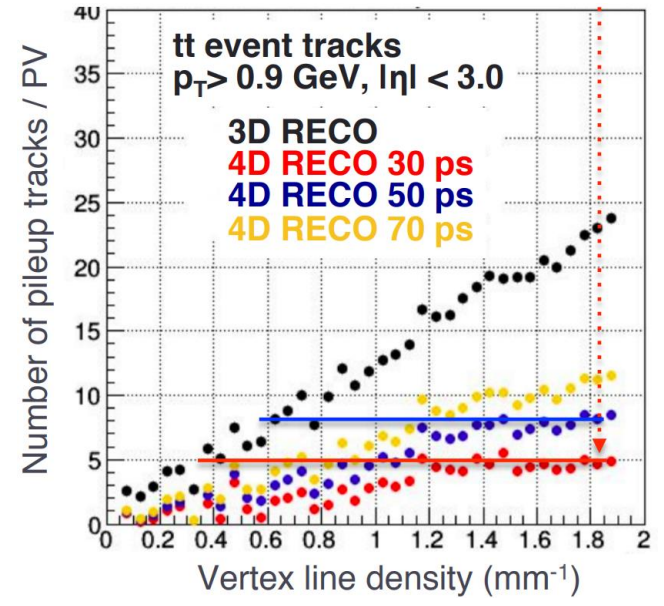
Phase-2 TDRs

remaining Phase-2 TDRs progressing as expected

- MTD TDR due end of March
- L1 TDR due in Q1 2020
- DAQ/ HLT TDR due in Q2 2021

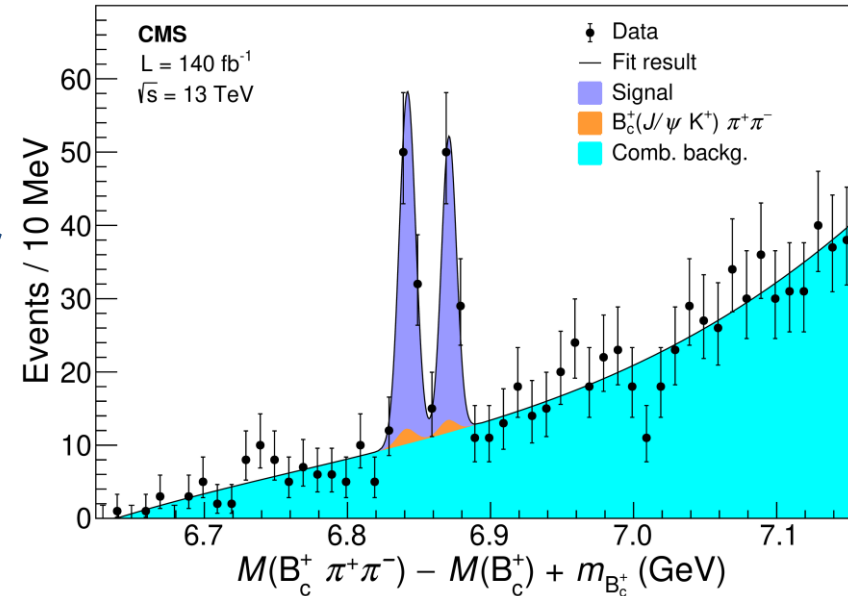


MIP Timing detector + performance



Summary

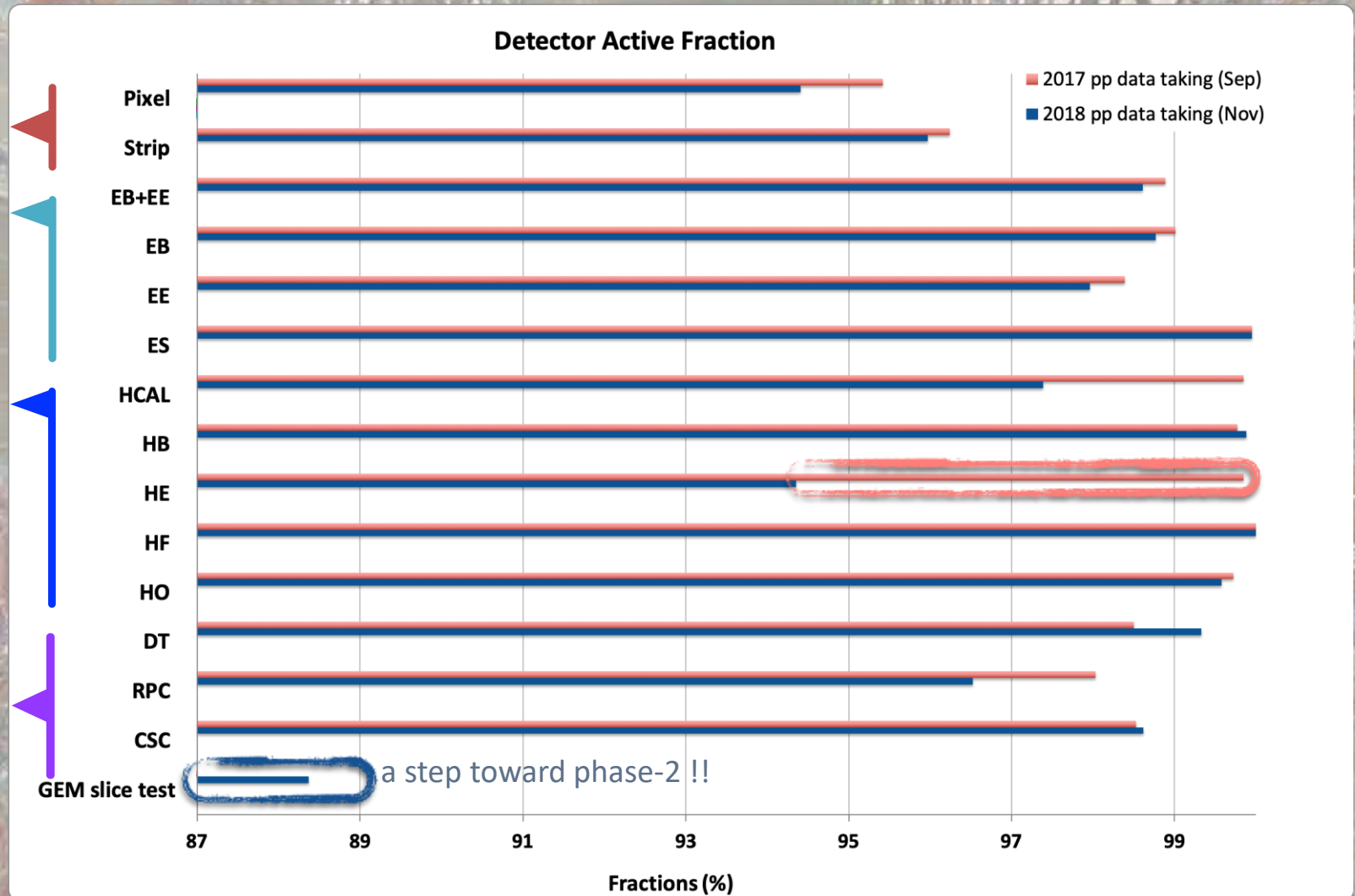
- Run2 is over, highly successful!
 - thank you LHC for all the data!
- CMS operations were extremely smooth in 2018
 - publication quality data & MC available to analysis teams around the winter break
 - analysers are eagerly studying the data, expect a significant number of new results for upcoming conferences
- LS2 is now fully underway
 - proceeding on schedule, upgrades for muons & HCAL, definitive fixes for the CMS pixels



backups

2018 pp Summary: CMS Detector Status

Excellent and stable performance of all sub detectors



Top Spin: $\Delta\phi_{ll}$

	Measured	POWHEGV2	MG5_aMC@NLO	NLO calculation
$A_{ \Delta\phi_{ll} }$	0.103 ± 0.008	$0.125^{+0.004}_{-0.005}$	0.115 ± 0.001	$0.112^{+0.009}_{-0.012}$

- result is compatible with ATLAS measurement
 - ATLAS-CONF-2018-027, <http://cds.cern.ch/record/2628770>
 - note CMS analysis optimised for coefficient measurements not $A_{|\Delta\phi_{ll}|}$ measurement
- since the ATLAS measurement, there have been found to be significant NNLO corrections to $A_{|\Delta\phi_{ll}|}$
 - <https://arxiv.org/pdf/1901.05407.pdf>
- at this time we consider the results to be compatible with the SM prediction

HL-LHC & HE-LHC Studies: Higgs self couplings

- key goal of HL program, constrains Higgs potential close to minimum, verification of EWK SB of SM
 - κ_λ : ratio of observed Higgs self couplings to SM prediction
- $3ab^{-1}$ at 14 TeV, CMS + ATLAS
 - observe able at 4σ
 - κ_λ precision $\sim 50\%$
- $15ab^{-1}$ at 27 TeV, CMS + ATLAS
 - $b\bar{b}\gamma\gamma, b\bar{b}\tau\tau$ only
 - κ_λ precision $\sim 10\text{-}20\%$
 - no sys considered and with caveats that this assumes a given experimental performance with 800-1000 pileup events

