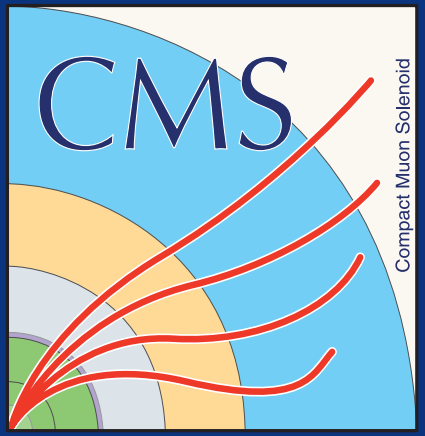
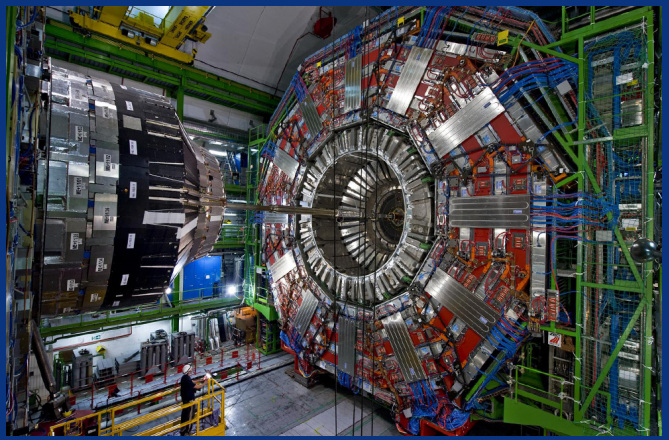
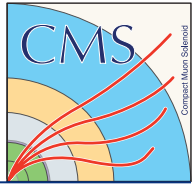
CMS Status and Outlook



Talk Presented to USLUA-2017
Roberto Carlin
Nov. 2, 2017



Outline

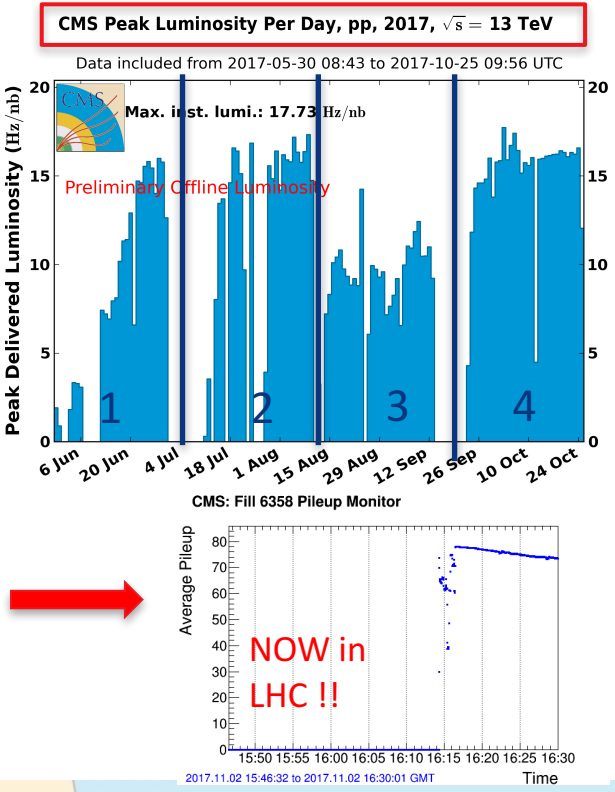


- CMS Status
  - Run in 2017, performances of upgraded detectors, computing
- Challenges ahead
  - 2018 Run and LS2
- Some Recent Physics Highlights
- CMS HL-LHC upgrades: TDRs, LHCC/UCG Reviews, and Schedules
- Summary

Run 2 Status
2017

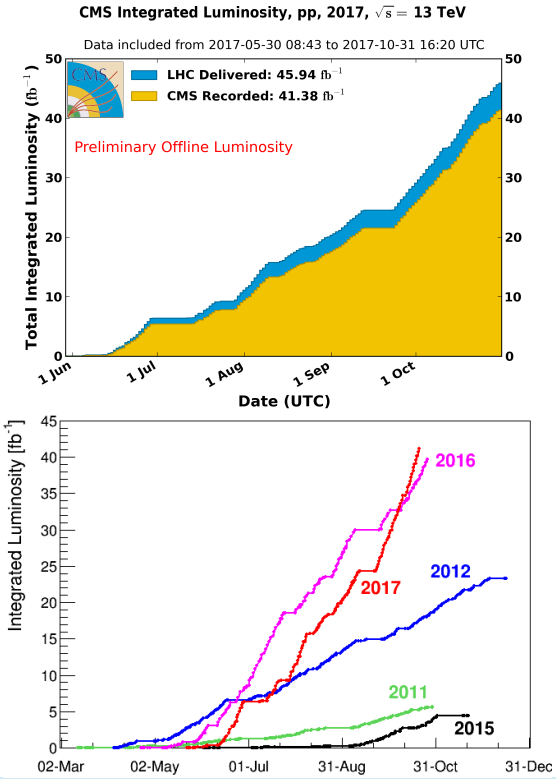
Four "luminosity" phases during the year 2017

1. Luminosity ramp-up
2. Run at 25ns bunch spacing, 1.75 10^{34} Hz/cm^2 peak instantaneous luminosity
3. LHC Problems with 16L2 and reduced intensity-luminosity
4. Problem solved by 8b4e injection scheme, run with reduced number of bunches and high pile-up: **luminosity levelled at 1.5 10^{34} Hz/cm^2 in CMS (and Atlas), PU ~ 56**
   - **Without levelling, PU would be ~ 80**

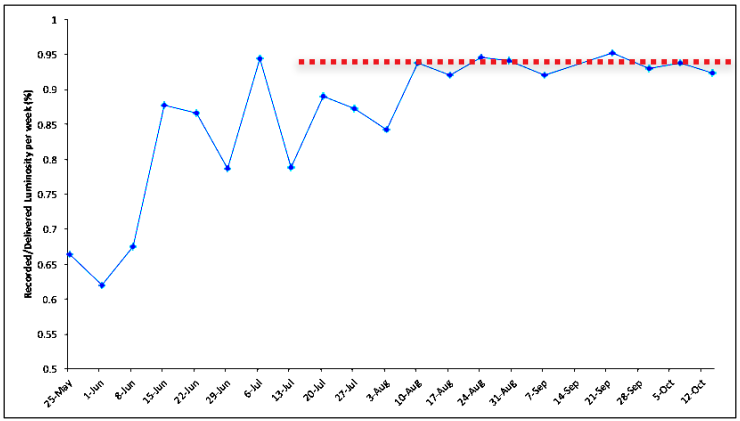


Good harvest of integrated luminosity in 2017

- Luminosity levelling does not impact too much (few %) the luminosity integrated in a fill
- LHC is working with very high efficiency
- Steep rise of the delivered luminosity in the last month
- Despite problems, in 2017 LHC reached the aggressively planned goals

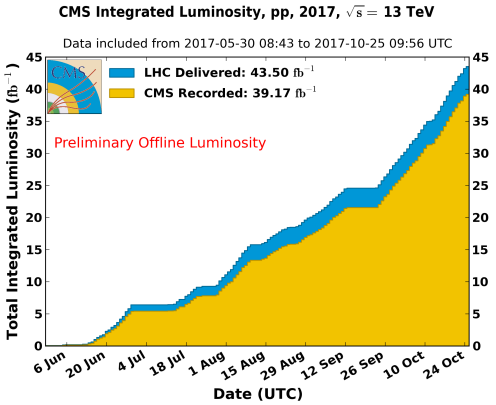


Data Recording Efficiency

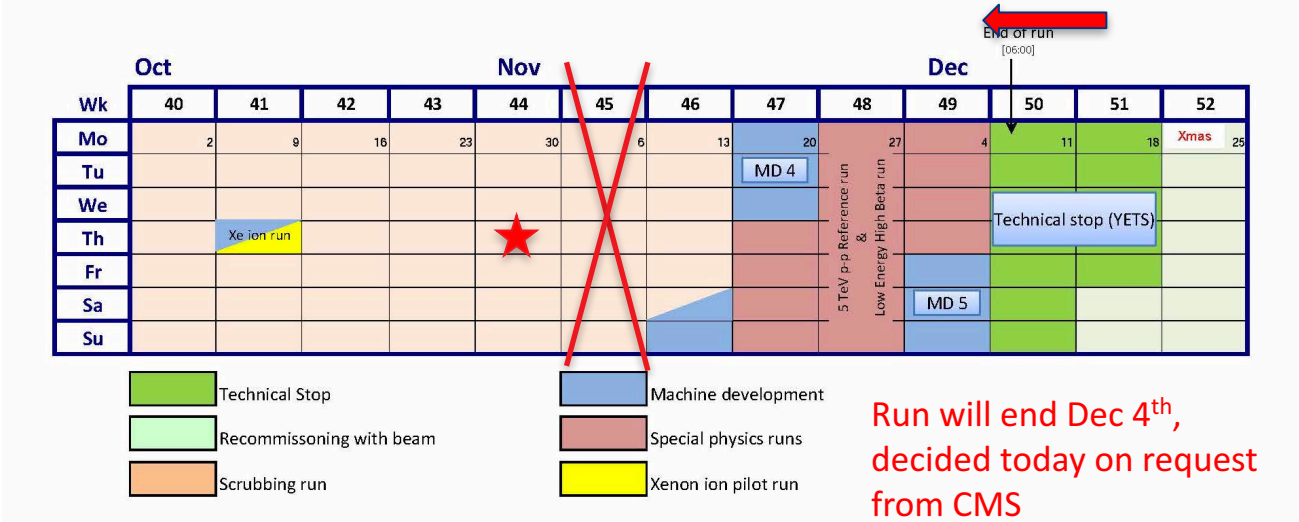


- The loss because of the pixel commissioning has been ~1 fb^{-1}, quite less than expected despite the somewhat longer commissioning time
- And is by far offset by the improvement in performances

- The overall recording efficiency in 2017 is around 90% as compared to 92.5% for 2016.
- This has improved lately, to mid 90's, even in very high luminosity running, so better than in 2016



Calendar for the remaining part of 2017

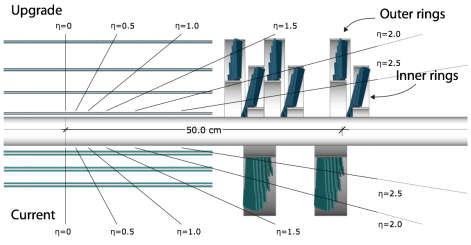


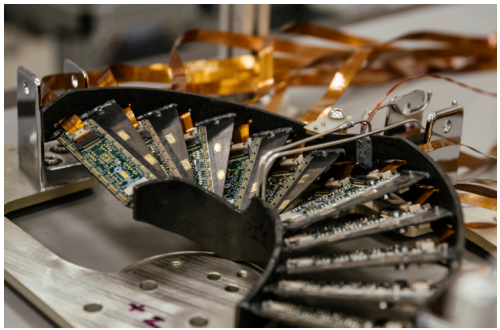
Run will end Dec 4th, decided today on request from CMS

- Still planned for 2017
  - The 5 TeV pp run, reference for the 2018 PbPb run
  - A short run at low energy (900 GeV) for the "Roman Pots" spectrometer experiments (Totem, Atlas-Alfa)

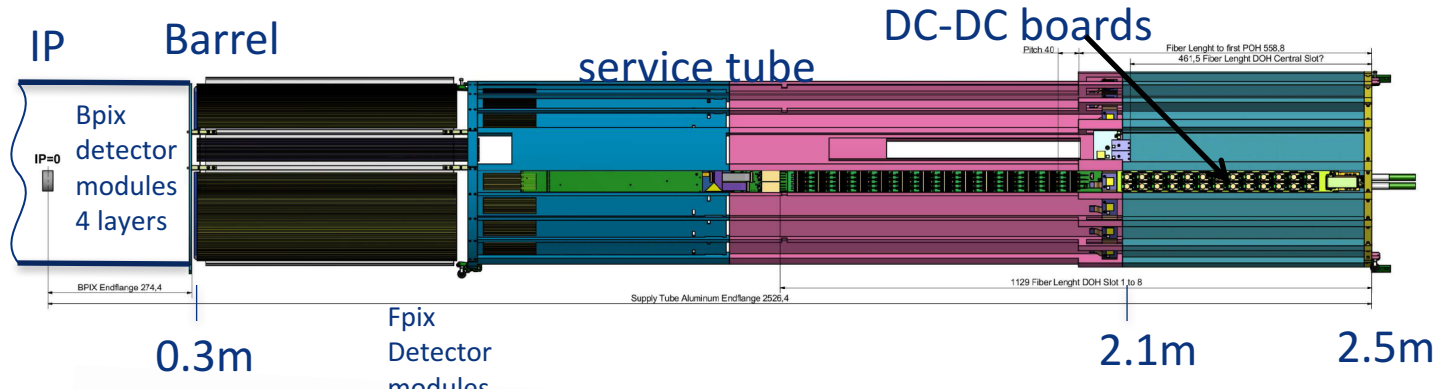
New Pixel Detector Commissioning

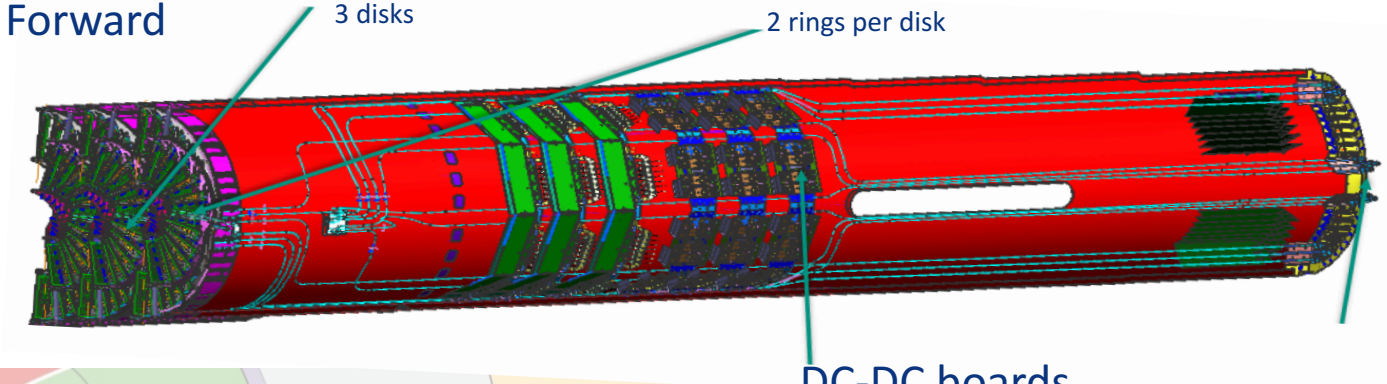
- Commissioning took longer than expected
  - Difficult tuning of timing between layer1 and layer2
  - Unexpected SEU sensitivity on a control chip, induced inefficiency improved with automatic reset procedure
  - Operational efficiency now recovered also at the highest luminosities and PU
  - Recently (from after TS2) we are observing some loss of DC/DC power converters related to LV on/off operations
    - Presently at the level of 5% of the detector
    - Actively investigating the source
    - Asked to start the winter stop one week ahead, to be able to access to the failing modules before the end of the year





Location of DC-DC Converters





CMS Pixel Tracker: powering system

DC-DC converters

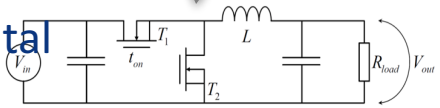
1 PS channel serves 4 converters (Bpix)
6-7 converters (Fpix)

of converters delivers
ue
& digital voltages to 1 to 4 modules

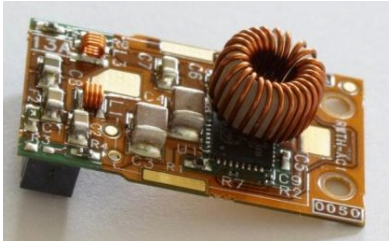
CAEN
digital
analog
+
sense
-
50m supply cable
X2F36/37
protection fuses
enable
Modules
DC-DC converters
800 Bpix
384 Fpix
CCU
Control of
1 DC-DC pair (Bpix)
2 DC-DC pairs(Fpix)

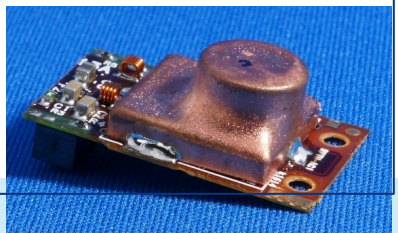
Inside Tracker environment bulkhead

CAEN PS in racks inside experimental cavern



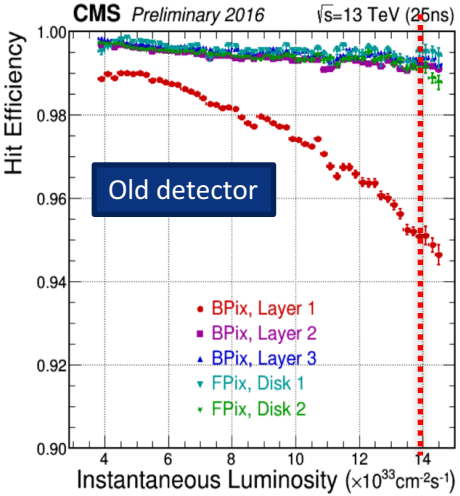
- A = 2.8 x 1.7cm^2
- m = 3.0g
- FEAST 2 ASIC (CERN-EP-ESE)
- Enable feature
- Status bit "Power good"
- Protection features
- Rad tolerant to:
  500Mrad (Si)
  5 x10^{14} n/cm^2 (1MeV eq)
  30MeVcm^{2}mg^{-1} (destr SEE)



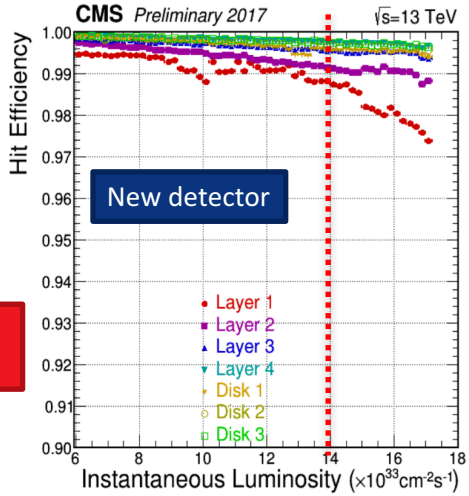


Buck converters based on CERN FEAST2 ASIC Pairs supply digital + analog

Pixel Hit Efficiency

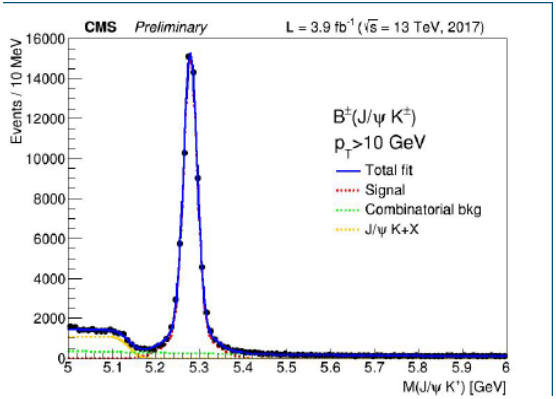


Note: the x scales are different!!

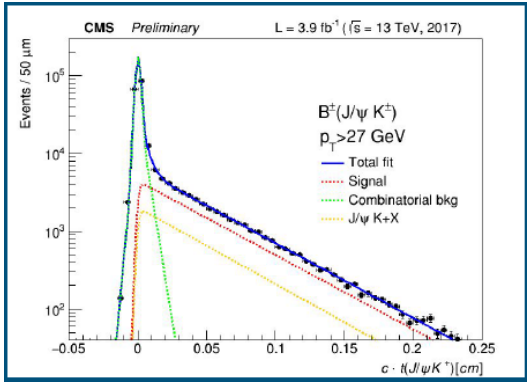


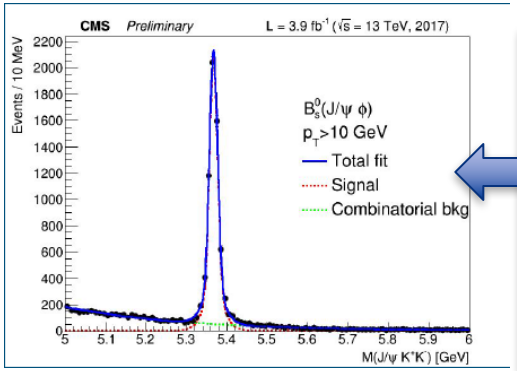
- Dynamic inefficiency is **much** smaller than in the old detector
- Also data throughput (not shown) much better
- Old Pixel detector would have hardly allowed CMS to run at present high PU conditions

Some B Physics Plots (from early in the run, ~ July 20)



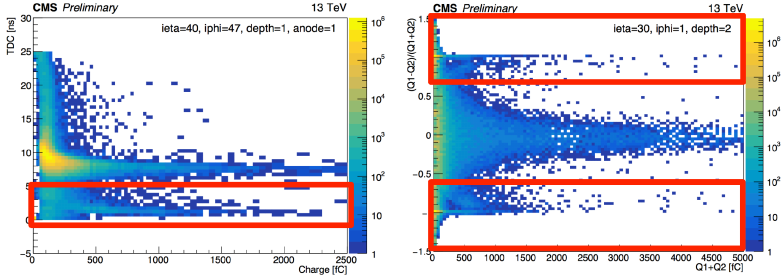
DP-17-029

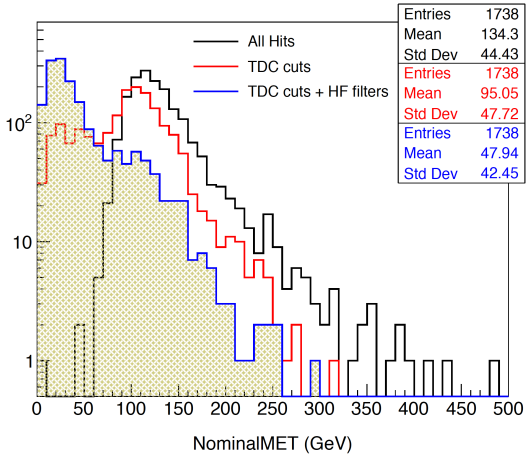




- Trigger conditions: opposite-sign muon pair with invariant mass in range 2.9-3.3 GeV, p_T > 6.9 GeV, single muons p_T > 4 GeV, displaced vertex-fit probability > 10%, plus a track with p_T > 1.2 GeV
- The J/ψ has p_T > 8 GeV and the B^0 has p_T > 10 GeV
- The J/ψ K^{*0} system has a vertex-fit probability > 10%
- The B^0 has flight length significance > 3 and cosine of pointing angle > 0.99
- Fit method: unbinned extended maximum likelihood
  - Signal: two Gaussians with common mean
  - Background: exponential

Phase 1 upgrades: HF (Forward Hadron Calorimeter)



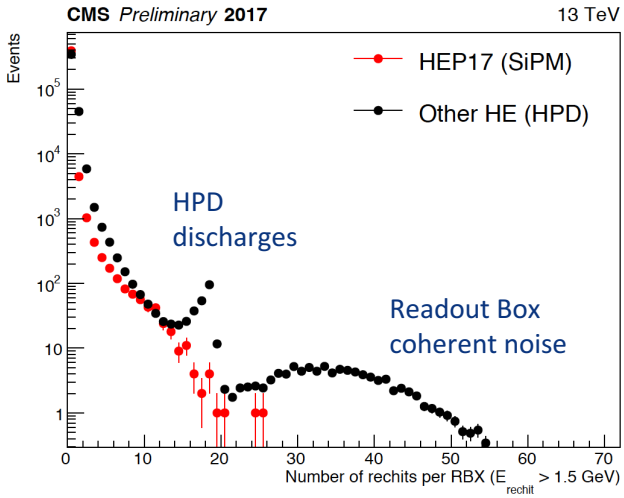


- New handles to achieve noise reduction are in use:
  - PMT with dual- anode readout and TDC information
- **Smooth installation and operation**
  - All 3456 channels, ADC&TDC, working
- **Substantial rate reduction for MET paths achieved**

Upgrade complete

Phase 1 Upgrade
Hadron Endcap Calorimeter (HE)

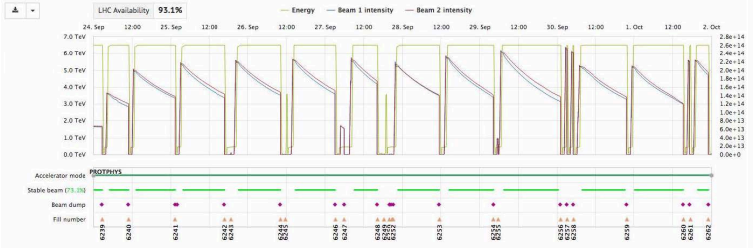
- We did install one Readout Box (HEP17) out of 36.
  - It uses SiPMs, new technology that provides superior performance than the Hybrid Photodiodes (HPDs) used in barrel (HB) and Endcap
  - Flawless performances of HEP17 in 2017, significantly reduced the noise
  - Allowed to measure that a significant part of the radiation damage is on HPDs and not on scintillator.
    - Important for Phase 2 upgrade



Computing

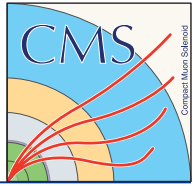
- CMS adapted well to the unexpectedly large data harvest in 2016
  - And is producing rich 2016 results with a computing budget rising less than the data volume
- In the last month, the huge increase of LHC performance had impact on computing too
  - PU well over 40, and levelled to 56 for long periods
  - LHC turnaround time as low as 2 hours

- Weekly LHC availability close to 95% with stable beam time close to 75% have been seen



- All of this has put pressure on the Tier-0 system – load depends on ~ PU * LHC Efficiency * HLT rate

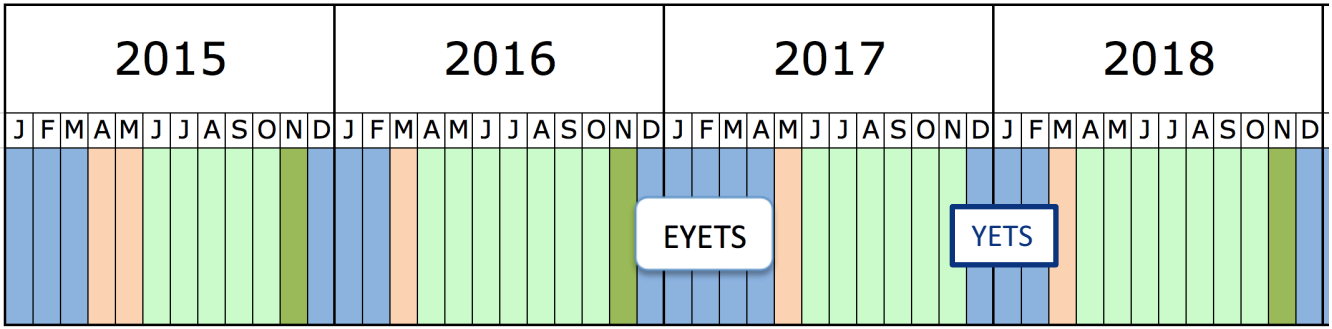
Tier-0 status



- "Too Much Data" is the best problem to have
  - CMS actively pursuing improvements in its computing model
  - Report from internal ECOM17 study group has been received and implementation has started
    - Further optimize the use of disks with more aggressive cleaning
    - Implement upfront "lifetime model" for all datasets
    - Design a new data tier, smaller than the present, already very successful "MiniAOD"
    - Improve the use of opportunistic resources (e.g. ready to go low priority MC samples)
    - …

Run 2,
Plans for 2018

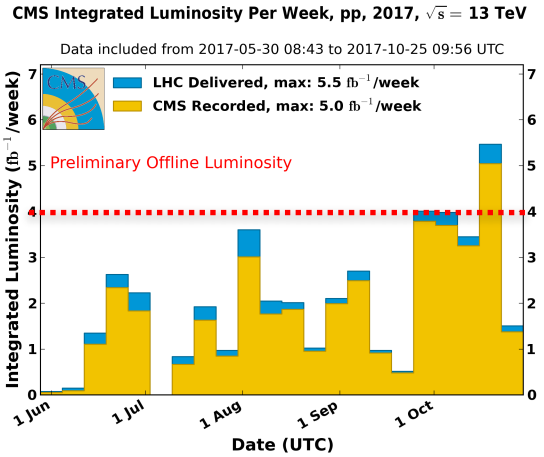
Run 2 Schedule



- What are the conditions we expect from LHC in 2018?
  - Problem in 16L2 is going to be solved
  - 25ns bx injection mode, full machine (2556 bunches with BCMS scheme) and currents up to nominal
  - Already gone to 30cm β*, optics may not change in 2018, very fast startup possible

Run 2 Schedule

- Already now LHC is providing about 4 fb^{-1} per week
  - Profiting from a very good system efficiency, but with limitations in the machine
- Sustained luminosity will be limited in LHC just above 2 10^{34} Hz/cm^2 by cooling problems
  - Can level there, if peak is higher
  - Would correspond to present levelled PU, with more bunches
- Even considering two months of ramp-up, there are 21 weeks from June to October



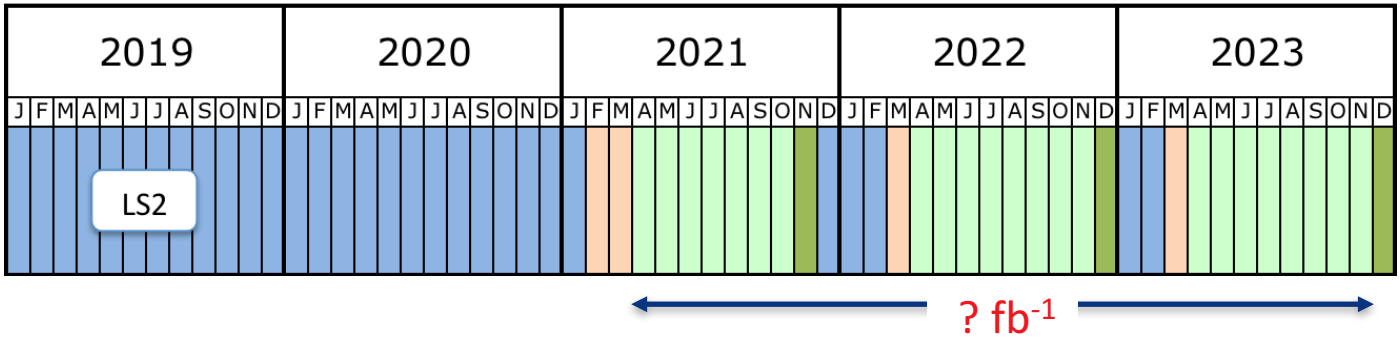
- Nothing is guaranteed, but a very strong 2018 seems possible

2018

- Even more than in 2017, CMS has to come up "physics ready" from the 17/18 YETS
- At the end of 2017, we will be above 90 fb^{-1} integrated at 13 Tev
  - We have already passed (and celebrated) the 100 fb^{-1} overall from LHC
- And at the end of 2018 likely above 150 fb^{-1} at 13 TeV
  - We are getting close to the 300-500 fb^{-1} of expected radiation dose lifetime of some of our detectors (and LHC too)
  - And at the same time need the best from our detectors to exploit the statistics with precision measurements

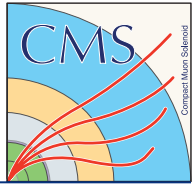
- New challenges ahead of us
- And we will be only at about 5% of the expected luminosity of our program, including HL-LHC

And then Run 3



- Then there is the LS2 followed by 3 years of run before LS3 and the big step to HL-HLC
  - LHC plans to go to 14 TeV
  - The LHC limit on the sustained luminosity will not be lifted, but new injector will be commissioned that may be able to provide higher head-on peak lumi, hence longer levelling periods
  - At least double the Run 2 statistics, quite unlikely a factor 4
  - The period of very fast luminosity doubling time is over

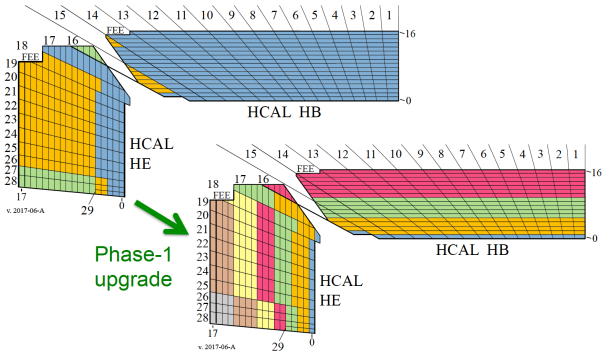
CMS in YETS 17/18 and LS2



- Short Technical Stop 17/18
  - HE Phase 1 full upgrade installation proposed
  - Some normal repair and maintenance
  - Will access to the Pixel detector to investigate/solve the power line problem
- LS2 (partial list)
  - Replace Layer 1 of Pixel detector
    - Would not stand the radiation from full Run2 + Run3
    - May profit to improve the Layer1 chip
  - Only Phase 1 upgrade left: HCAL Barrel (HB), replace HPDs with SiPMs as in HE
  - Plus activities already related to Phase 2 upgrade
    - Muon GEM chambers GE1/1 installation (Phase 2 Muons)
    - Forward CSC work (Phase 2 Muons)
    - Phase 2 infrastructure upgrades

Phase 1 upgrade

- Full HCAL upgrade is the last of a large Phase 1 program in CMS, mostly already implemented, highlights are:
  - The new Pixel detector
  - New, much more powerful architecture and processors for L1 trigger (essential to stand PU 60, remember that CMS was designed for PU 25)
  - New luminosity detectors (BRIL)
  - HCAL upgrade already partially implemented
    - HF, possibly HE in 17/18 , FE electronics
  - will bring CMS not only much better noise performance, light yield and radiation tolerance from replacing HPDs with SiPMs
  - But also longitudinal segmentation that can be exploited in trigger (possibly even in L1) and particle flow algorithms

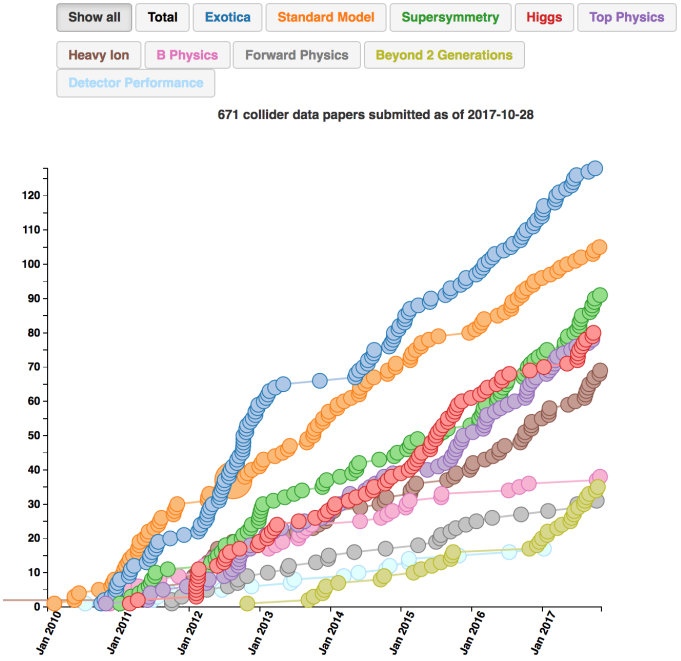


Some word on Physics Results

An overview will be given by
Joe Pastika later today

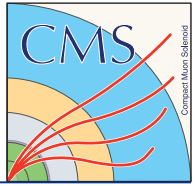
Publication Status

- 671 physics papers submitted
  - It was 536 at last US-LUA
- Passed the threshold of 700 CMS publications
  - Including no-collisions
- Most of the new publications exploiting the full 2016 dataset
- 44 new results were presented in summer conferences



http://cms-results.web.cern.ch/cms-results/public-results/publications-vs-time/

Observation of H → $\tau^+\tau^-$

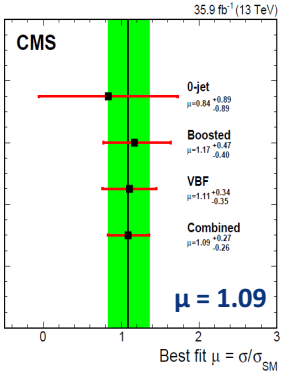


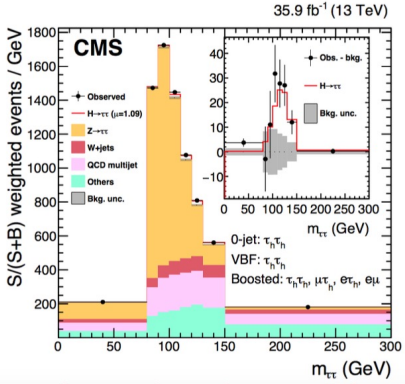
- Branching ratio = 6.3%, best channel to establish coupling of Higgs boson to fermions
- Final states: $\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$, $e\mu$ → Significance of 4.9σ observed (4.7σ expected) using 13 TeV data
- Combination with 7 and 8 TeV data: **5.9σ obs. (5.9σ exp.)** and **μ = 0.98 ± 0.18**

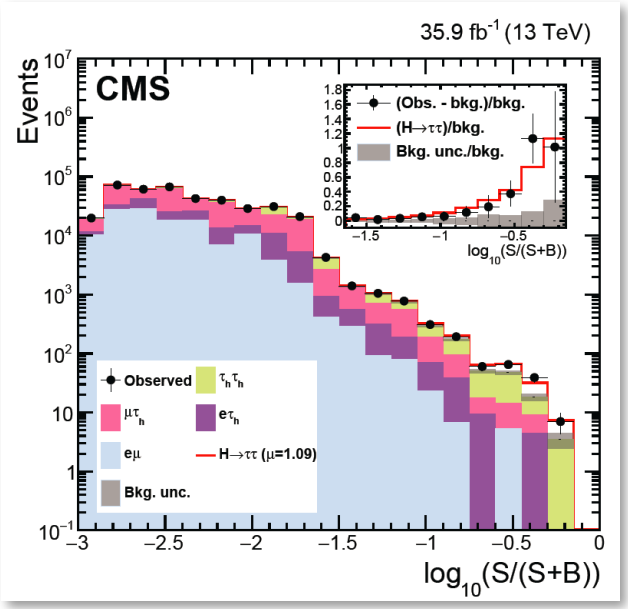
First direct observation by a single experiment of H coupling to fermions!

– Observed before in CMS+ATLAS combination

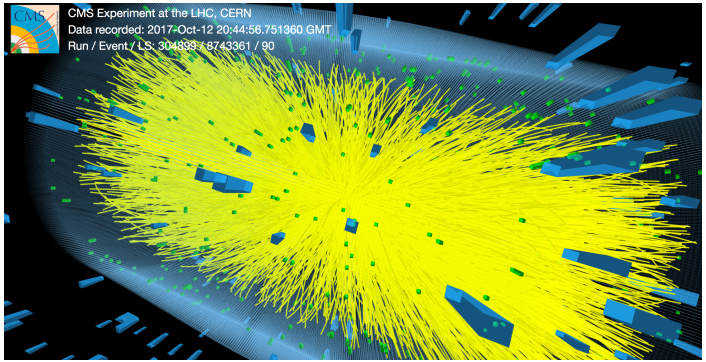
First direct observation of H coupling to leptons and to fermions of the 3rd generation!

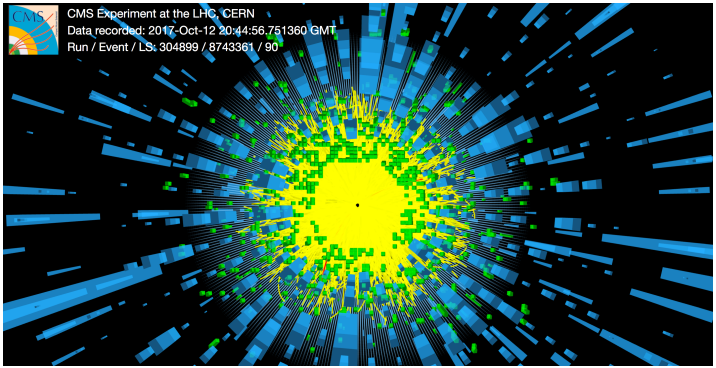






Xenon- Xenon Collisions

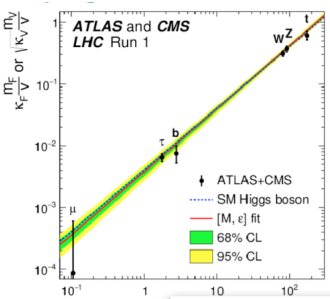


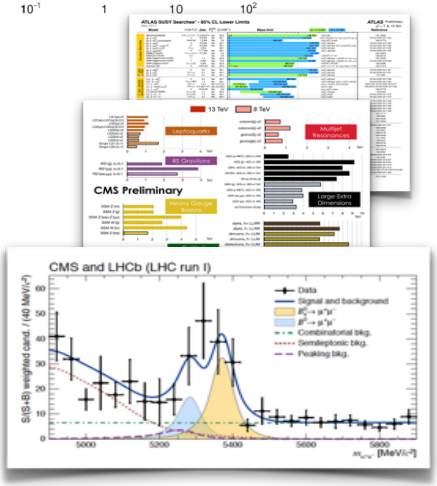


- As Xe ions were present in the accelerator chain, and LHC was interested in the enterprise, the LHC experiments took one fill of Xe Xe run
- About 4.6 ub^{-1} of integrated luminosity in one fill (plus setup)
  - Almost ½ of the Pb Pb data of 2010 taken in two weeks
- Exceptional response of all CMS groups involved in the preparation

Where are we now ?

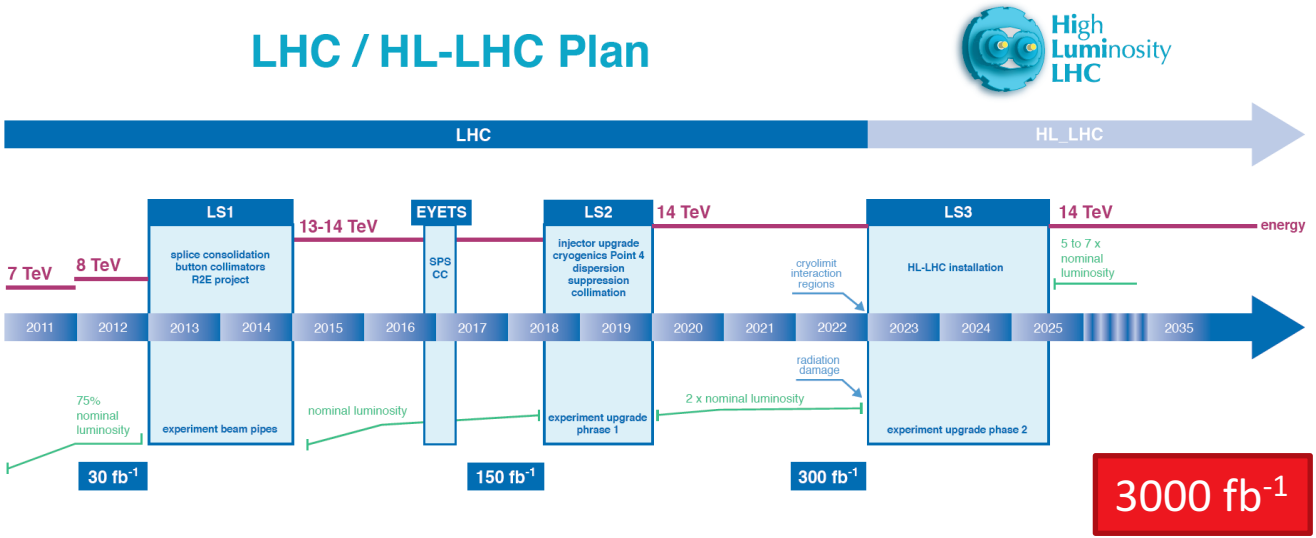
- **The Higgs boson**
  - Couplings to **vector bosons** measured at the **~20% level**
  - **Observation** of coupling to **tau leptons**
  - **Evidence** for coupling to **b- and top quarks**
- **Searches for new Physics**
  - **SUSY** particles probed (and not found) up to **~2 TeV**
  - **Heavy Vector Bosons** excluded up to **3-4 TeV**
  - and many (!) other limits….
- **Closed-in on some very rare processes**
  - eg. $B_s \rightarrow \mu\mu$ (at 10^{-9} level)
- **Some anomalies in the flavour sector? coupled to LFV?**



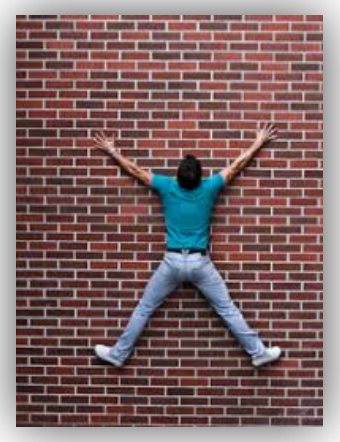


Heading to the future

- So far, recorded <3% of the total expected dataset !



Heading to the future



Already now, we are often hitting the systematics wall; some examples:

overall ATLAS-CMS Higgs combination

$$\mu = 1.09^{+0.11}_{-0.10} = 1.09^{+0.07}_{-0.07}\,(\text{stat})\,^{+0.04}_{-0.04}\,(\text{expt})\,^{+0.03}_{-0.03}\,(\text{thbgd})^{+0.07}_{-0.06}\,(\text{thsig})$$

Higgs to tau tau:

$$1.09^{+0.15}_{-0.15}\,(\text{stat})^{+0.16}_{-0.15}\,(\text{syst})^{+0.10}_{-0.08}\,(\text{theo})^{+0.13}_{-0.12}\,(\text{bin-by-bin})$$

- Need a new detector not only able to "stand" the 3000 fb^{-1} and the high PU, but also able to provide very high quality data to exploit it
  - Not only hunt for the very rare but also attack difficult corner of the phase space
  - **Need performant and flexible detector**

CMS HL-LHC upgrades

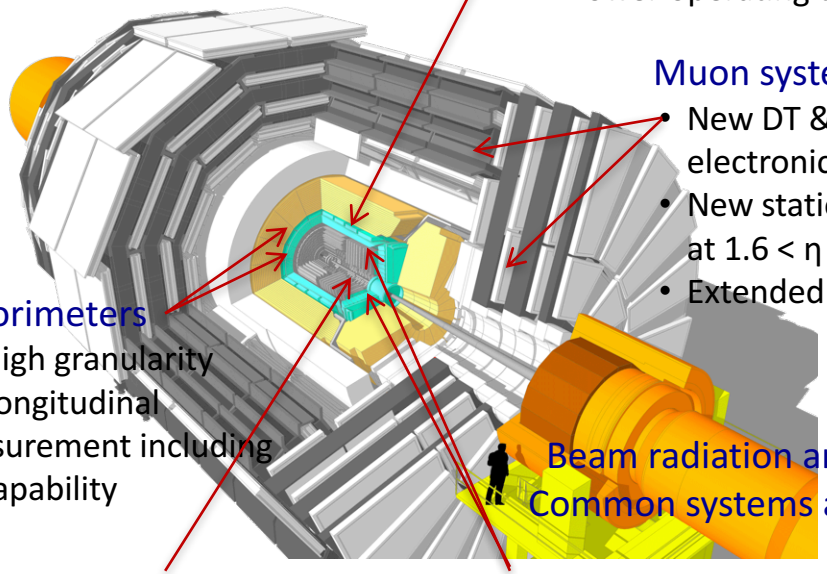
HL-LHC: CMS Phase-2 upgrades

Trigger/HLT/DAQ

- Track information in trigger at 40 MHz
- 12.5 μs latency
- HLT input/output 750/7.5 kHz

Barrel EM calorimeter

- New FE/BE electronics for full granularity readout at 40 MHz - with improved time resolution
- Lower operating temperature (8◦)



Muon systems

- New DT & CSC FE/BE electronics
- New station to complete CSC at $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$

New Endcap Calorimeters

- Rad. tolerant - High granularity transverse and longitudinal
- 4D shower measurement including precise timing capability

Beam radiation and luminosity

Common systems and infrastructure

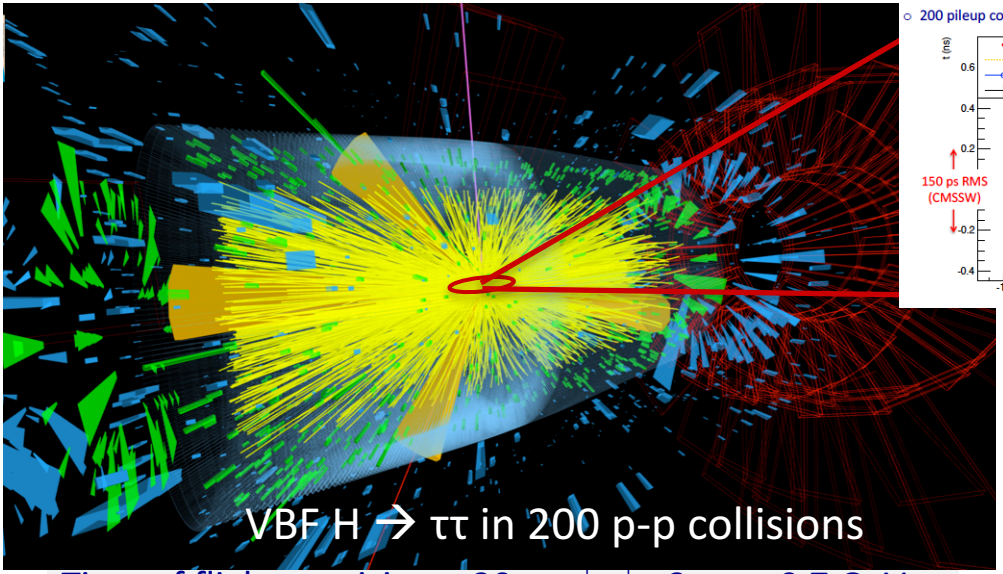
New Tracker

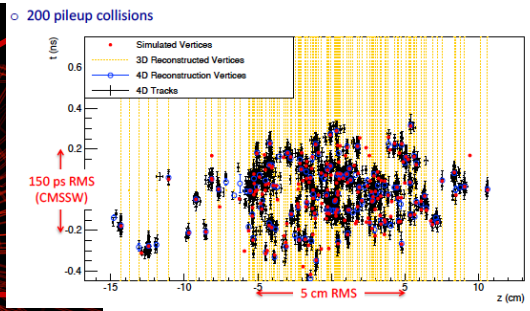
- Rad. tolerant - increased granularity - lighter
- 40 MHz selective readout (strips) for Trigger
- Extended coverage to $\eta \simeq 3.8$

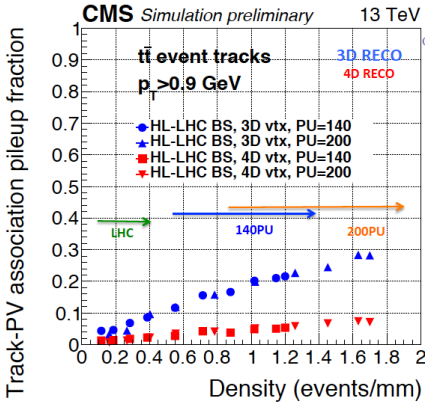
MIP precision Timing Detector

- Barrel layer: Crystal + SiPM
- Endcap layer: Low Gain Avalanche Diodes

MIP Precision Timing Detector Advantages





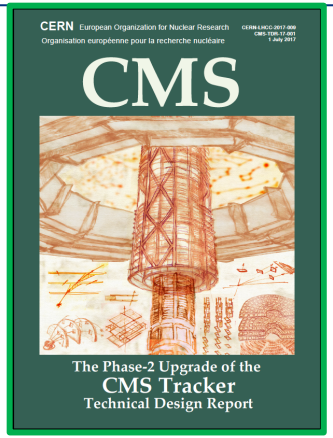


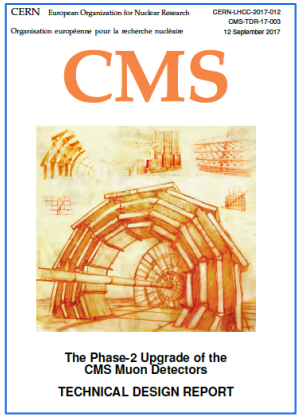
Time of flight precision ≃ 30 ps, $|\eta| < 3$, $p_T > 0.7$ GeV

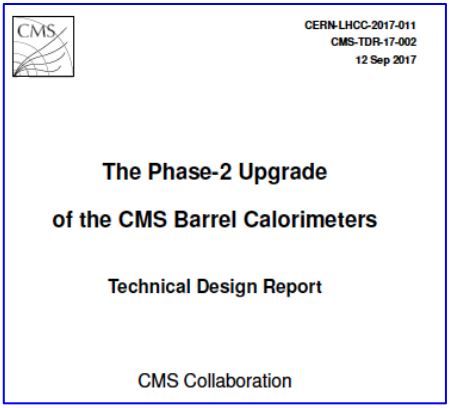
"Provide a factor 4-5 effective pile-up reduction"

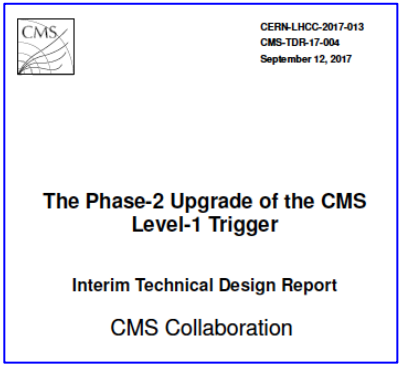
- ≃ 15% merged vertices reduce to ≃ 1.5%
- Low pileup track purity of vertices recovered

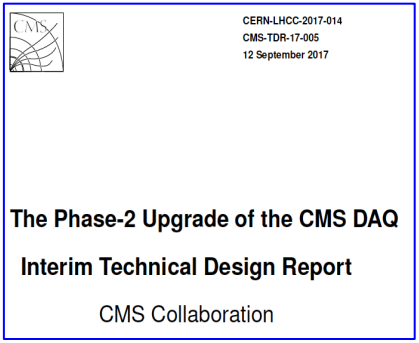
HL-LHC TDRs and ITDRs submitted so far









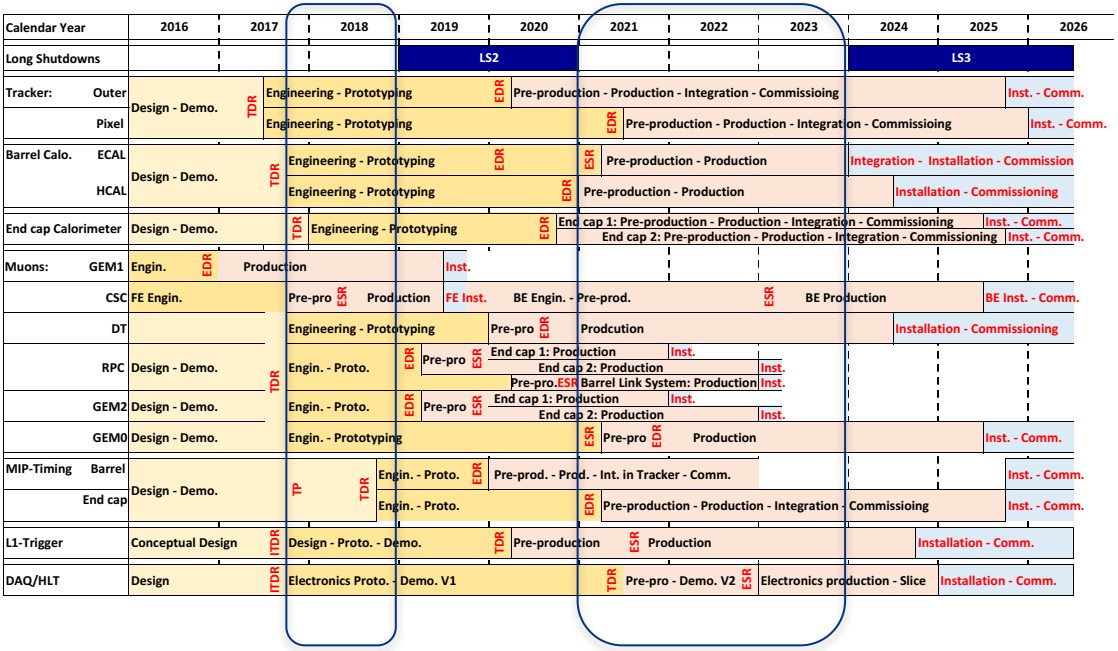


Endcap Calorimeter TDR and MIP Timing Detector Technical Proposal will be submitted to the LHCC at the end of November.

Tracker HL-LHC Upgrade

- Tracker TDR scientific review by LHCC is completed very positively:
  - "In summary, **the Tracker Upgrade Project pushes tracker designs into a new paradigm with a scope that is justified in terms of technical realization as well as physics performance**. The design is bold, but no technical showstoppers have been identified. It is critical that the remaining R&D be supported as strongly as possible and that appropriate funding for the R&D efforts be provided. Strong oversight is required to keep the schedule. Based on the technical and scientific review, approval is given for the project to proceed with the UCG review."

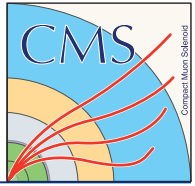
Task PU in the coming years



- Prototyping and review of results in parallel to Run2 and LS2
- Pre-production and productions in parallel with Run3

Summary

Summary and Outlook

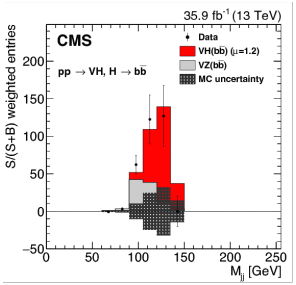


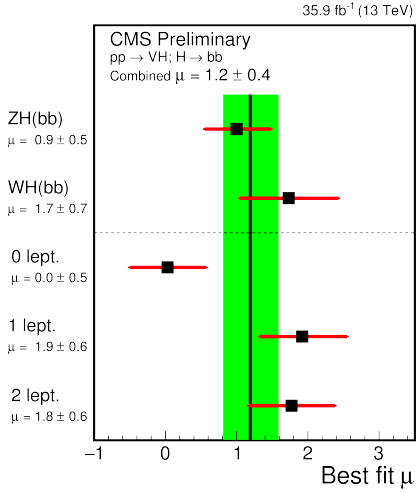
- The EYETS went well
  - We encountered problems with the new pixel detector but are taking excellent data with it
- **Physics results continue to be excellent with much exciting analyses ahead for 2016 data and with an equal or greater amount of new data from 2017**
- Computing navigated the challenges of the larger than expected 2016 data set and performed very successfully in the campaign for the winter/spring conferences and so far in 2017
  - Plans are in place for the next few years.
- **2018, the following LS2 and then three years of high luminosity running present many challenges and opportunities**
- In parallel, CMS is getting ready for HL-LHC
  - The Upgrade Document preparation is on track and has acquired a new element in the MIP Precision Timing Detector
  - The Tracker (inner and outer) received scientific and technical approval from the LHCC, now moving to the others

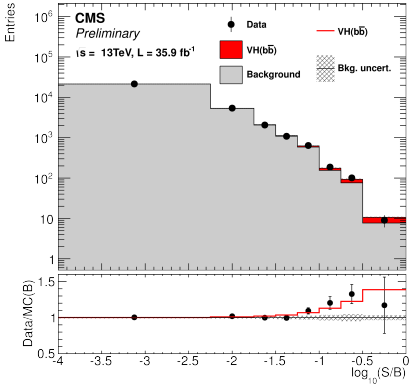
Backup

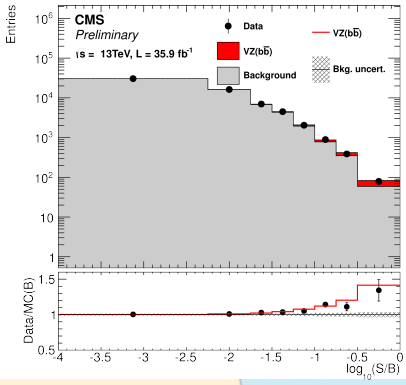
Evidence for Higgs →VH(bb)

- BR of Higgs to bb ~58%(expected)
  - Huge QCD backgrounds
- Most sensitive channel is associated production with W or Z, H→bb
  - 0L: Z(νν)
  - 1L: W(μ ν) W(e ν),
  - 2L : Z(μ μ), Z(ee)
- Mass resolution of M_{bb} is ~10%
- Based in several BDTs **Validated using di-boson production VZ(bb)**

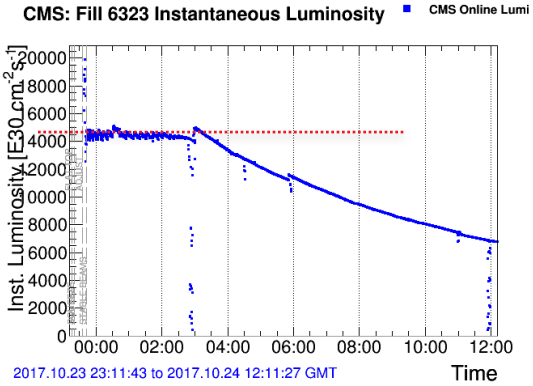








Levelling at 1.5 10^{34} Hz/cm^2

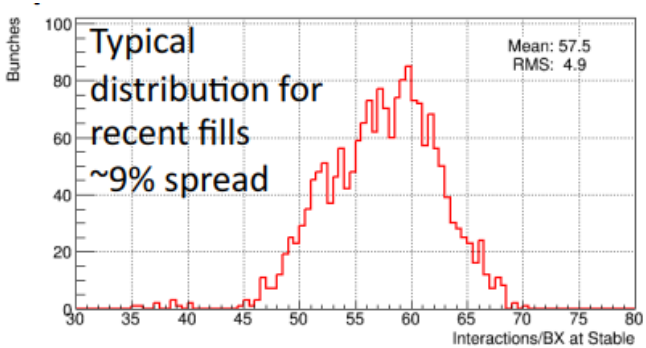


Present beam settings allow very high specific luminosity

- Beta* 30 cm, with small crossing angles
- Bunch intensities up to 1.25 10^{11} p/bunch
- Very small emittances (1.5 um)

Head-on luminosity with 1864 colliding bunches went up to **2.2 10^{34} Hz/cm^2**

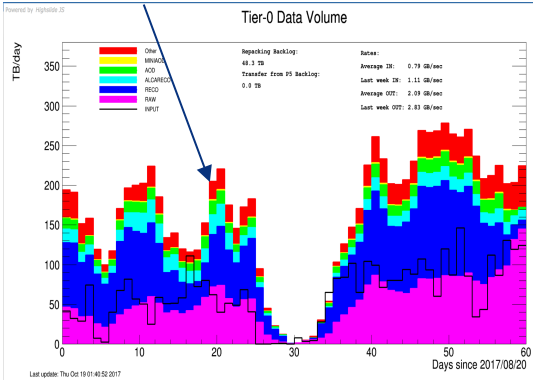
- This comes with very high PU (85 at 2.2 10^{34})
  - Level1 trigger rates have highly non-linear increase at high PU
- **Experiments decided to level at 1.5 10^{34}, corresponding to PU around 57**



Tier-0 status

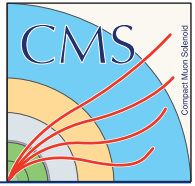
- Tier-0 under pressure after the LHC TS2
  - Change in daily produced output evident
- CPUs are holding up – up to 1 day of prompt delay over the 48h at times
- Disk buffers and transfers at the limit (systems provisioned for lower PU)
- Still, all ok with increased human effort

Daily Tier-0 output; clear change of pace after TS2



- "too much data" is the best problem to have
  - CMS actively pursuing improvements in its computing model
  - Report from internal ECOM17 study group has been received and implementation has started

Status of TDRs



- Tracker TDR scientific review by LHCC is completed very positively
  - Now reviewing the package costs (UCG)
- Reviews of Barrel Calorimeter and Muons TDRs, and of Trigger and DAQ interim design reports has started a couple of weeks ago
- Endcap Calorimeter TDR is expected by LHC by the end of November
- MIP timing detector Technical Proposals is expected at the same time
  - Followed by a joint Atlas-CMS review on the timing detectors on Dec 1st

- Lot of work done and expected in the coming months, to arrive to full approvals in Spring 2018
  - In parallel with running the detector with unprecedented luminosity and PU, commissioning the Phase1 and producing a rich wealth of physics results
- CMS is planning ahead the management of the next phases of the Phase 2 upgrade, that has to start swiftly
  - Time to 2025 is not that much, many lesson learned from Phase 1 upgrade