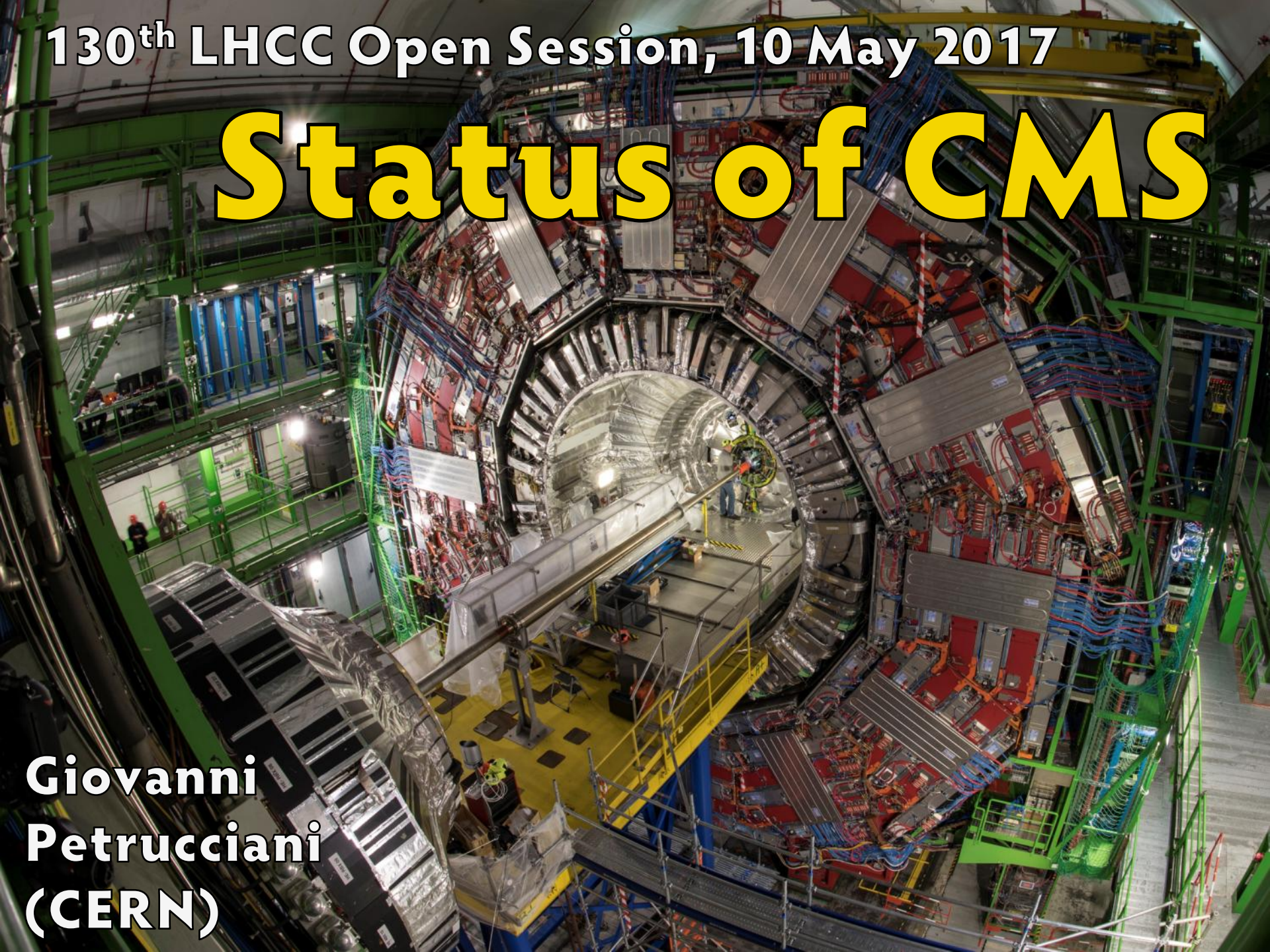
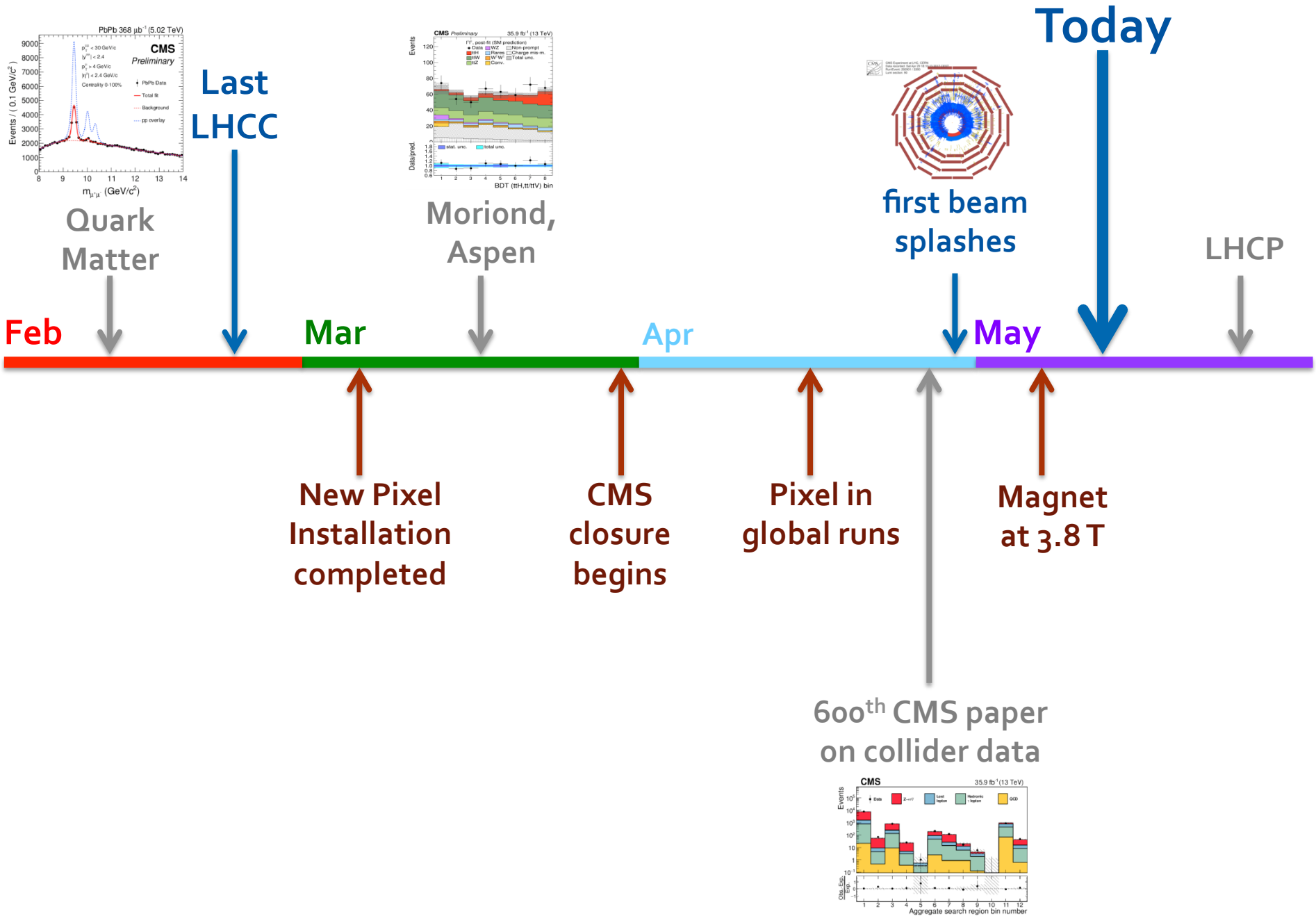
130th LHCC Open Session, 10 May 2017

Status of CMS



Giovanni Petrucciani (CERN)

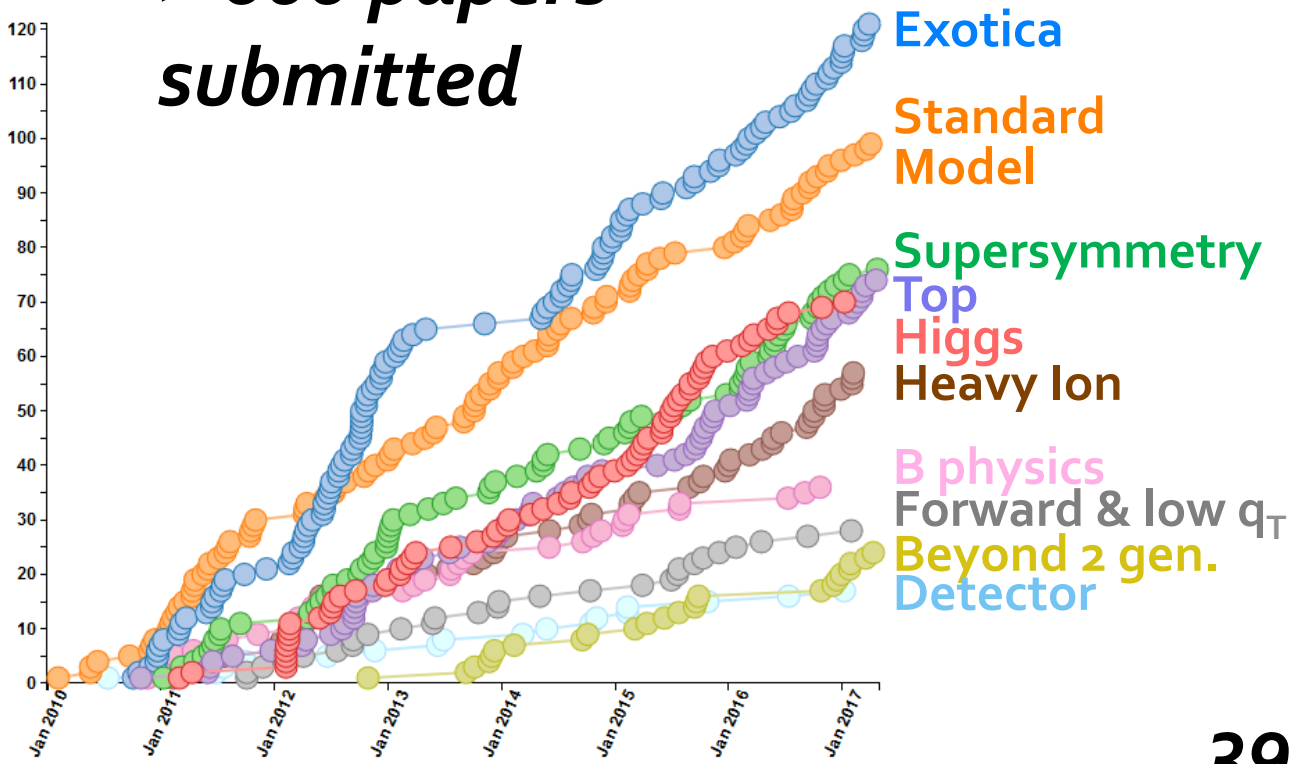

Today
Last LHCC
Quark Matter
Moriond, Aspen
first beam splashes
LHCP
Feb
Mar
Apr
May
New Pixel Installation completed
CMS closure begins
Pixel in global runs
Magnet at 3.8 T
600th CMS paper on collider data

Outline

Focusing on what's new since last LHCC:

- Harvesting 2016 data: highlights of CMS physics results from winter conferences
- 2017 CMS detector startup
- Preparation for 2017 running at higher instantaneous luminosity

> 600 papers submitted

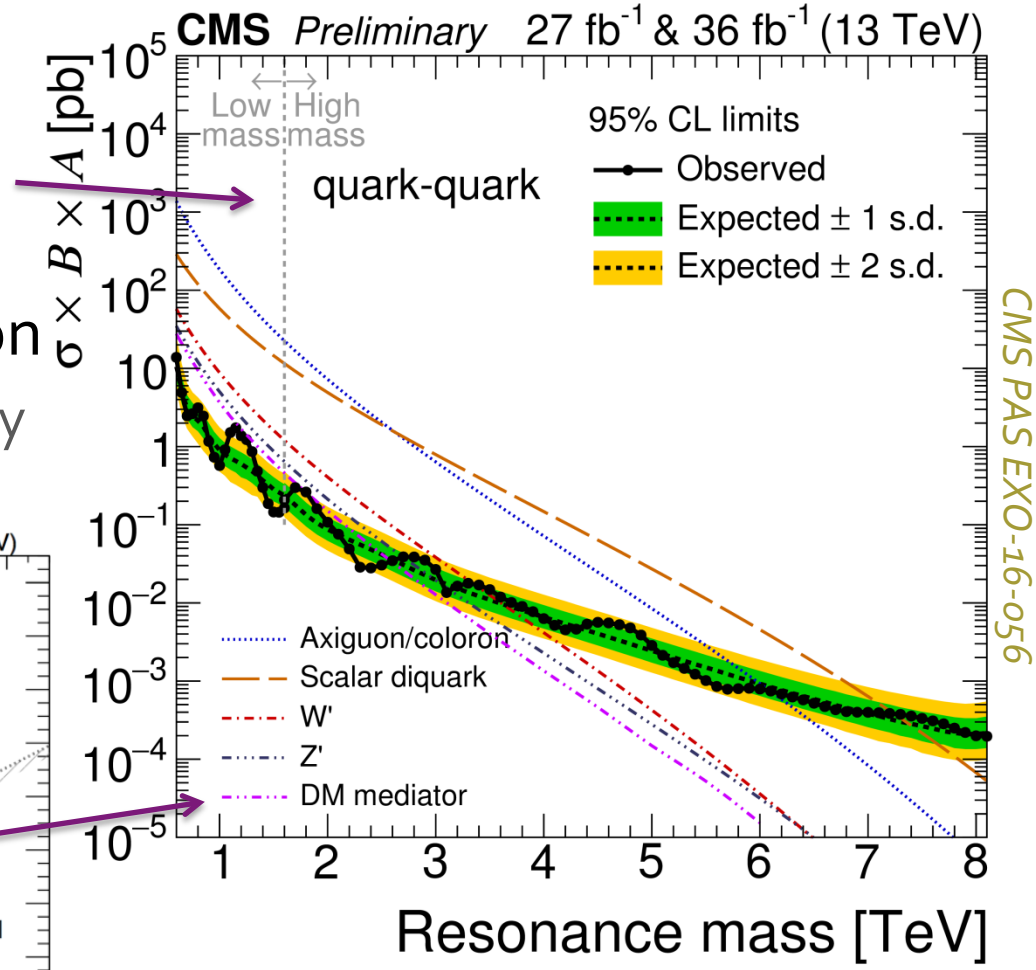


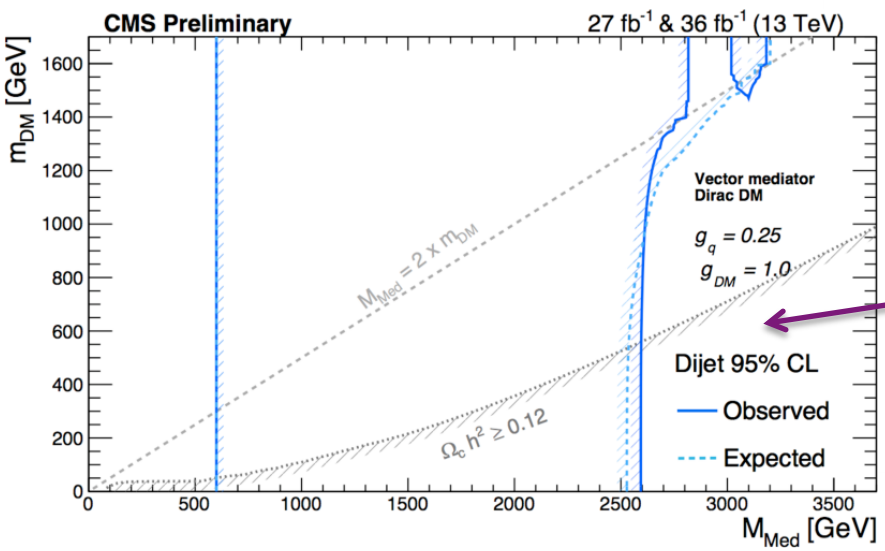
PHYSICS HIGHLIGHTS

39 new results released for Moriond 2017 conferences

Searches for new physics in di-jets

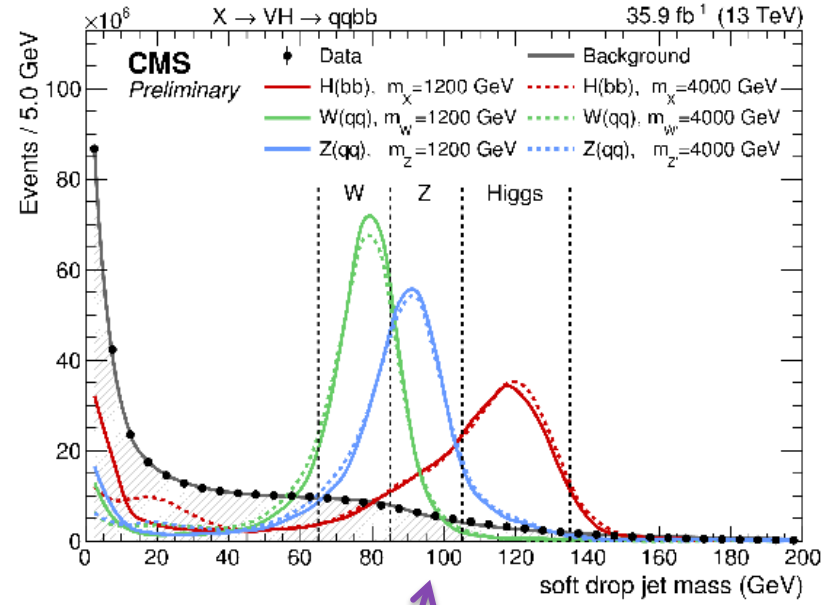
- Event reconstruction in High Level Trigger allows to cover low mass range (*data scouting*)
- Dark Matter interpretation
  - completmentary sensitivity to direct searches



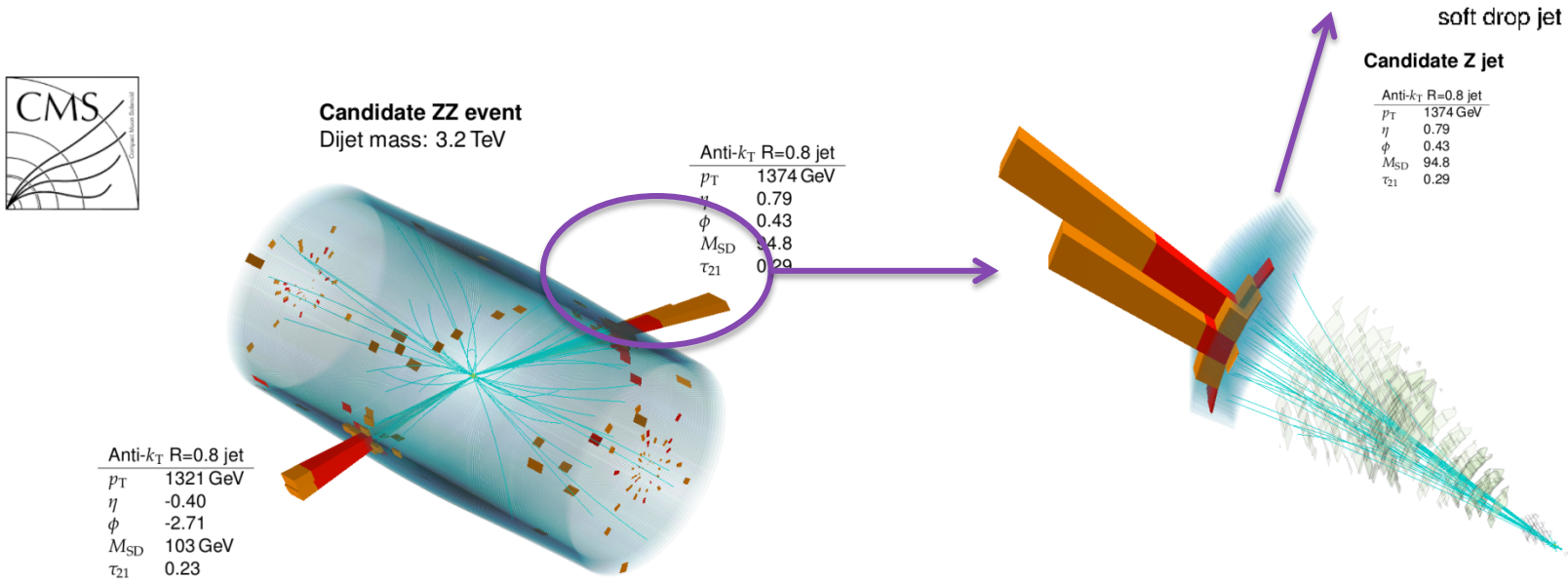


Searches with boosted objects

- Search for resonances that decay into heavy bosons: X → VV, VH, qV
  - Use jet substructure & boosted double-b tag

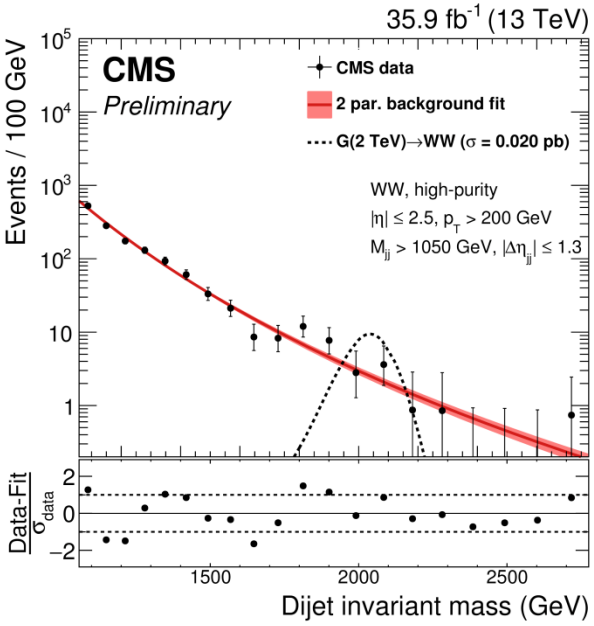


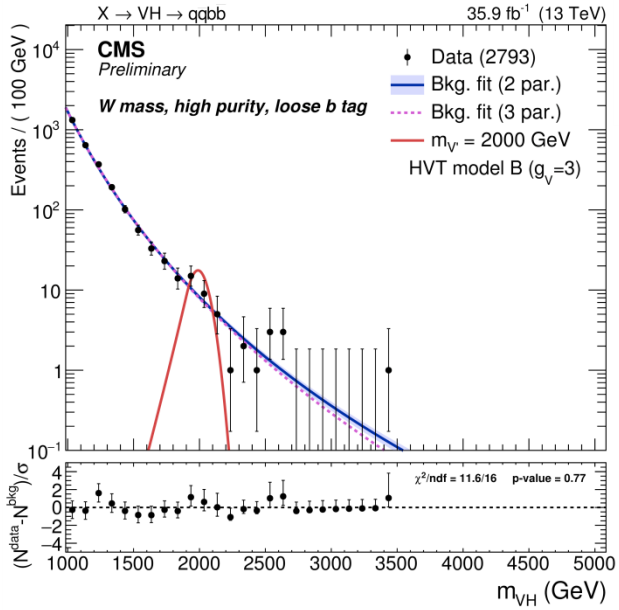
CMS PAS B2G-17-001, 17-002

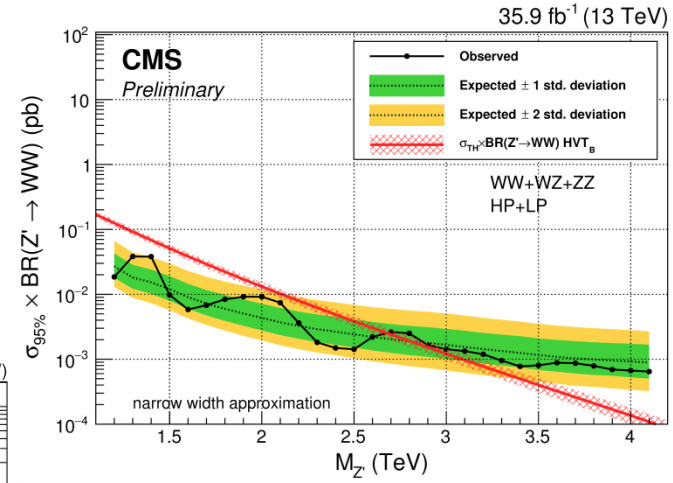


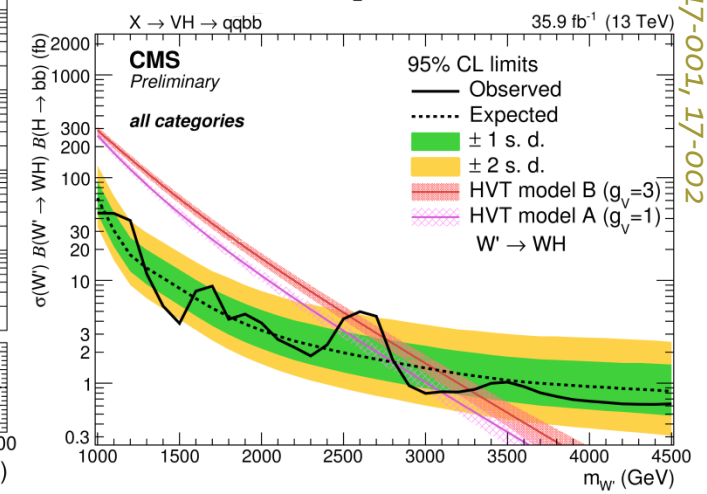
Searches with boosted objects

- Background fitted directly from data using analytic funtions
- Sensitivity to diboson resonances up to ~3 TeV









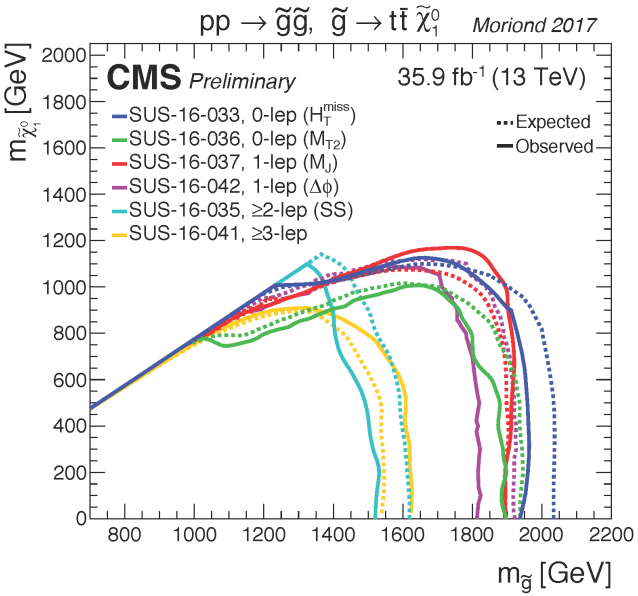
CMS PAS B2G-17-001, 17-002

Supersymmetry searches

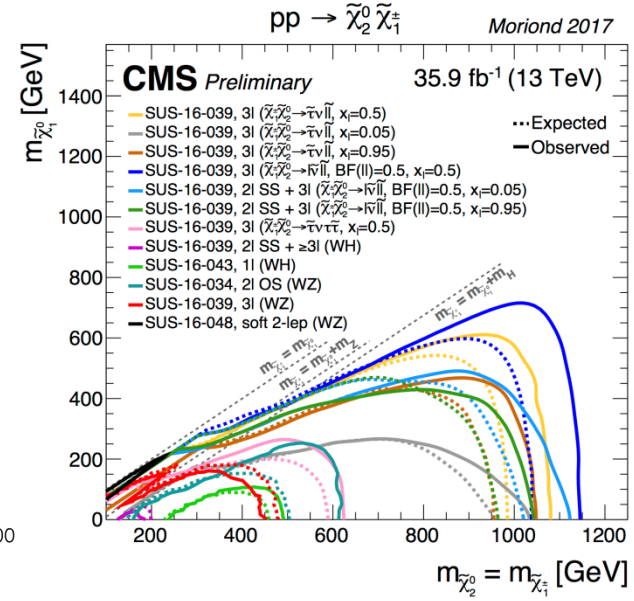
Broad program: 19 searches completed with full 2016 CMS data, several already submitted to journals for publication:

- probing different models (inclusive production, electoweak production, 3rd generation sparticles)
- relying on different final states (e.g. leptonic or hadronic) and analysis methods (generic or more model specific)

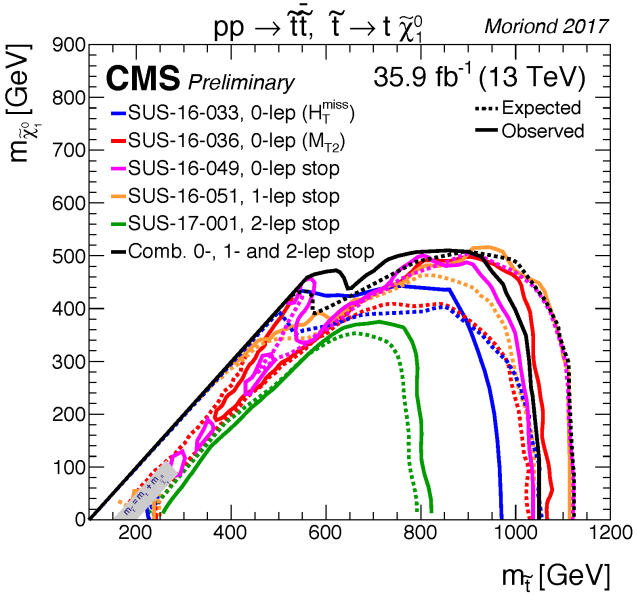
gluinos (inclusive)



electroweakinos

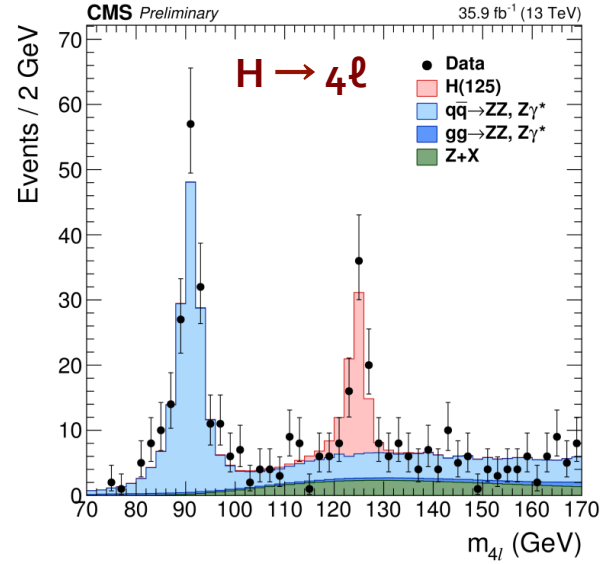


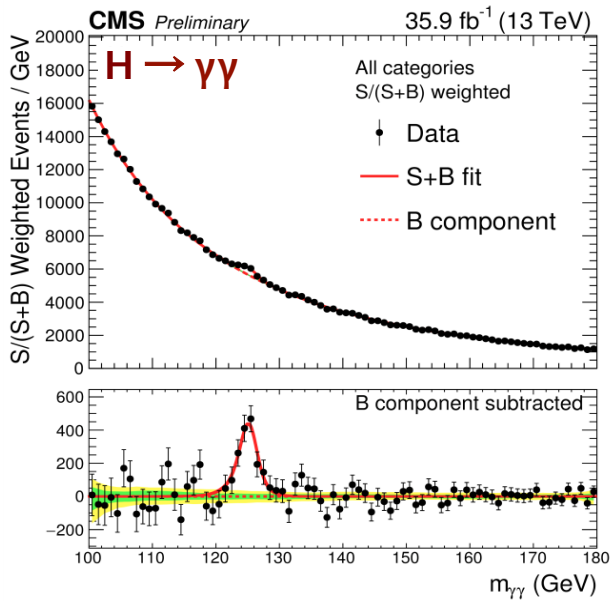
stops (3rd gen)



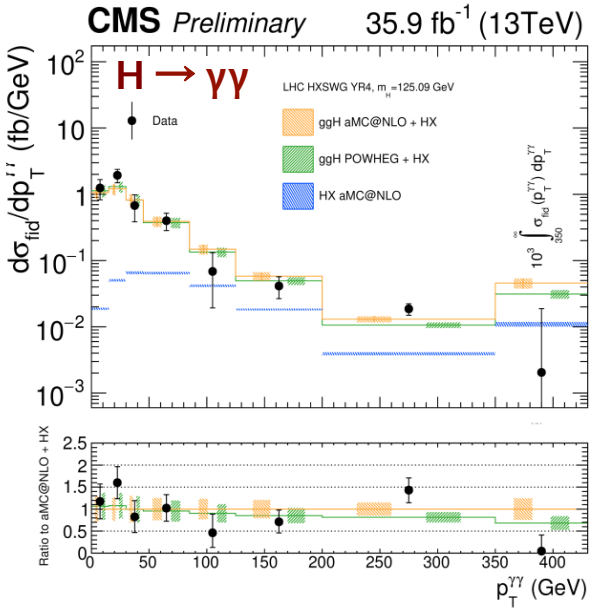
Higgs boson measurements

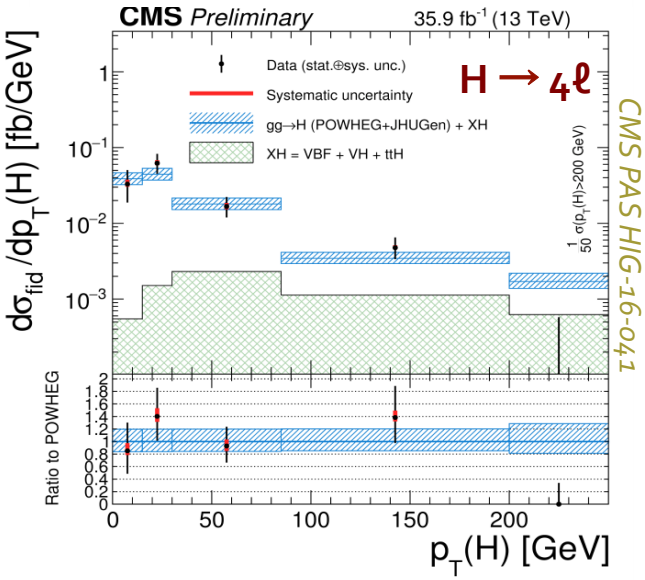
- Fiducial and differential cross sections from $H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ on full 2016 data
  - $\Delta\sigma_{fid}/\sigma_{fid}$ = 18% (4ℓ), 15% (γγ), good agreement with theory predictions (YR4, NLO MC) also on $p_T(H)$ and N(jet) distribution
- Mass measurement: 125.26 ± 0.21 GeV (4ℓ)
  - More precise than LHC Run 1 combination





CMS PAS HIG-17-015

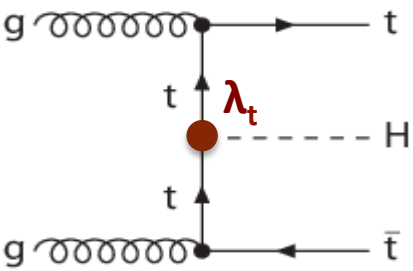




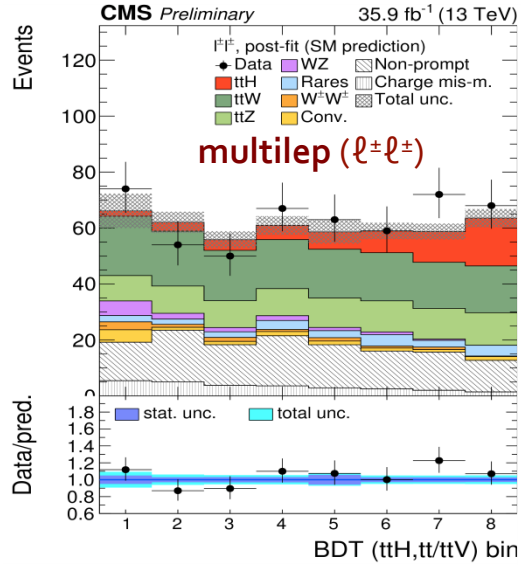
CMS PAS HIG-16-041

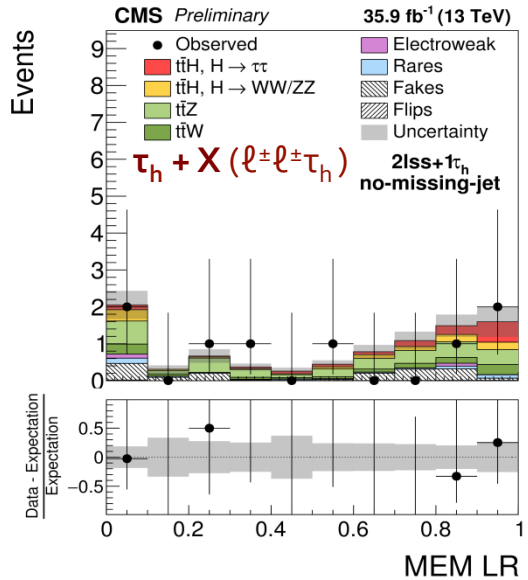
Higgs boson measurements

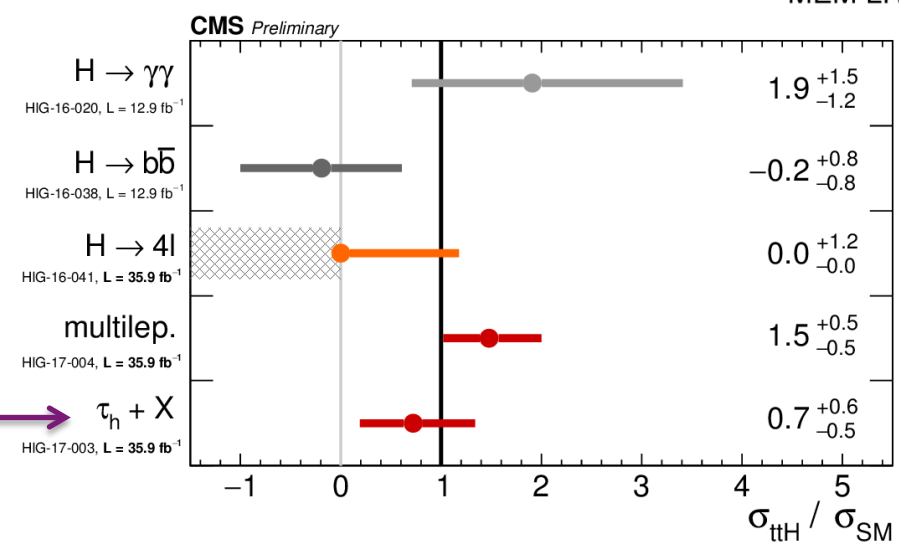
- ttH searches in leptonic final states
  - direct probe of top Yukawa coupling



- reoptimized analyses on full 2016 dataset
  - **3.3σ** evidence for ttH (2.5σ expected)
  - also dedicated effort for H → ττ decays



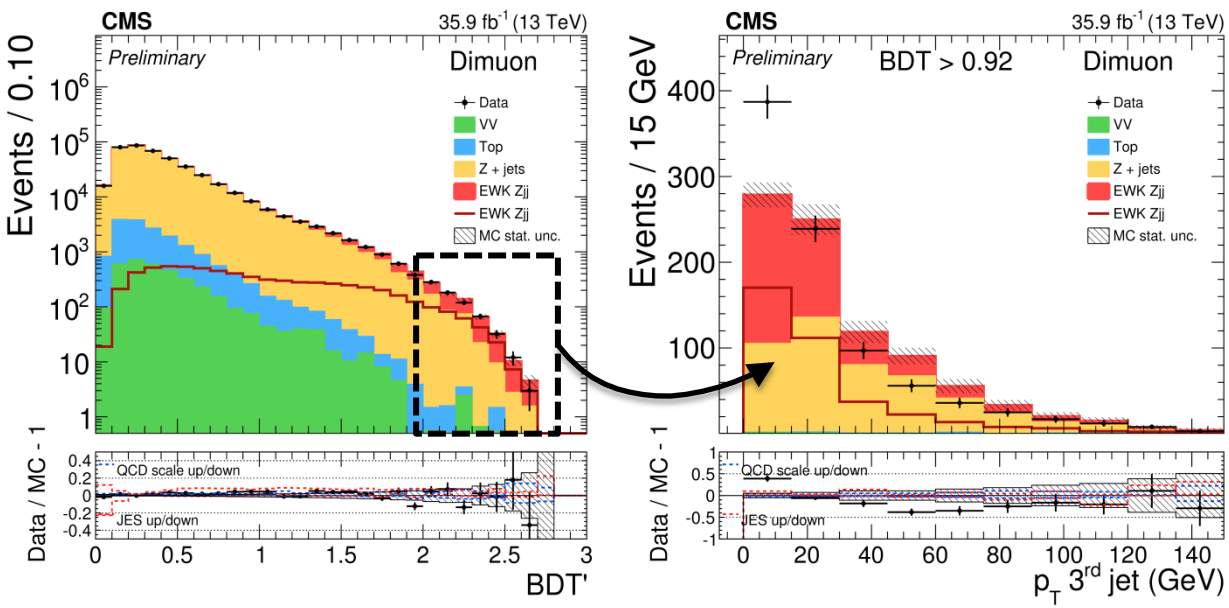




SM measurements at 13 TeV

Electroweak Z+jj production study with full 2016 data:

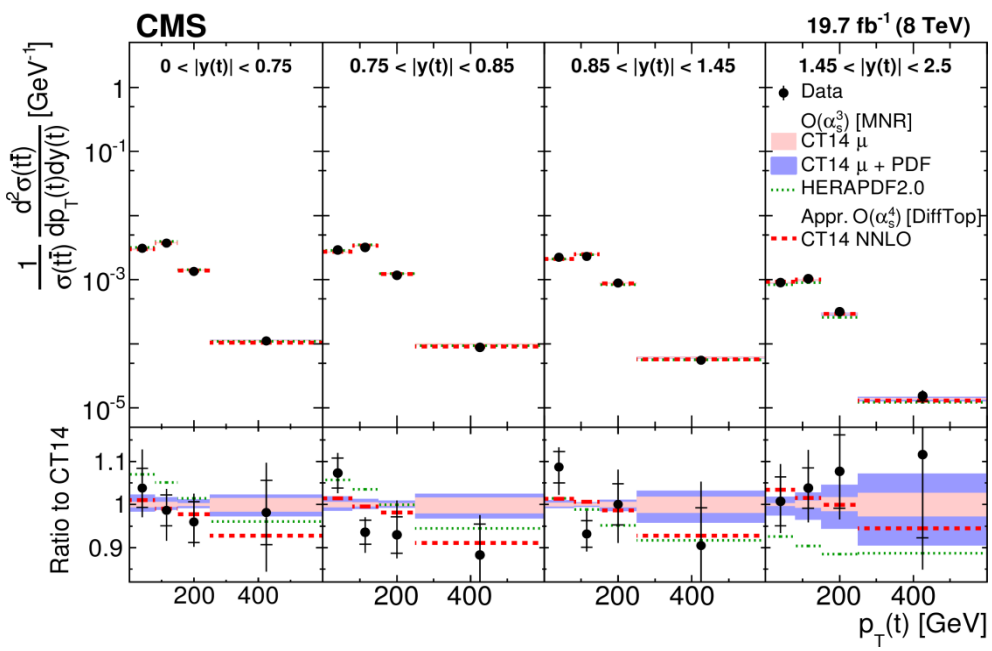
- Main QCD Z+jets background suppressed with a BDT using jet quark-gluon likelihood and event kinematics
- Measured $\sigma_{EW}(\ell\ell jj) = 552 \pm 58$ fb (SM pred.: 543 ± 24 fb)
- Validate MC modelling of VBF variables (e.g. 3rd jet p_T)

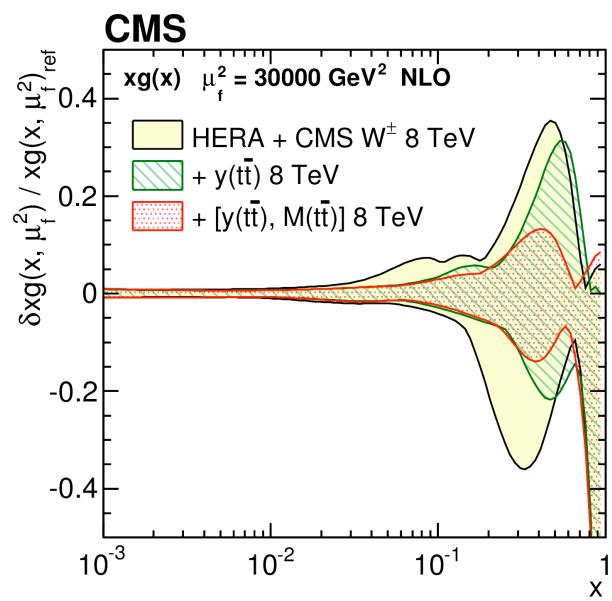


CMS PAS SMP-16-018

Run 1 measurements: dσ(tt̄)

- double-differential measurement of tt̄ production vs $p_T(t)$, $y(t)$, $p_T(t\bar{t})$, $y(t\bar{t})$, $M(t\bar{t})$, $\Delta\eta(t,\bar{t})$, $\Delta\phi(t,\bar{t})$
  - eμ final state, reconstruct ν kinematic imposing m_t value
  - approx NNLO predictions with latest PDFs show improved agreement with [$p_T(t)$, $y(t)$] data wrt existing NLO MCs
  - measurement yields improved constraints on gluon PDF

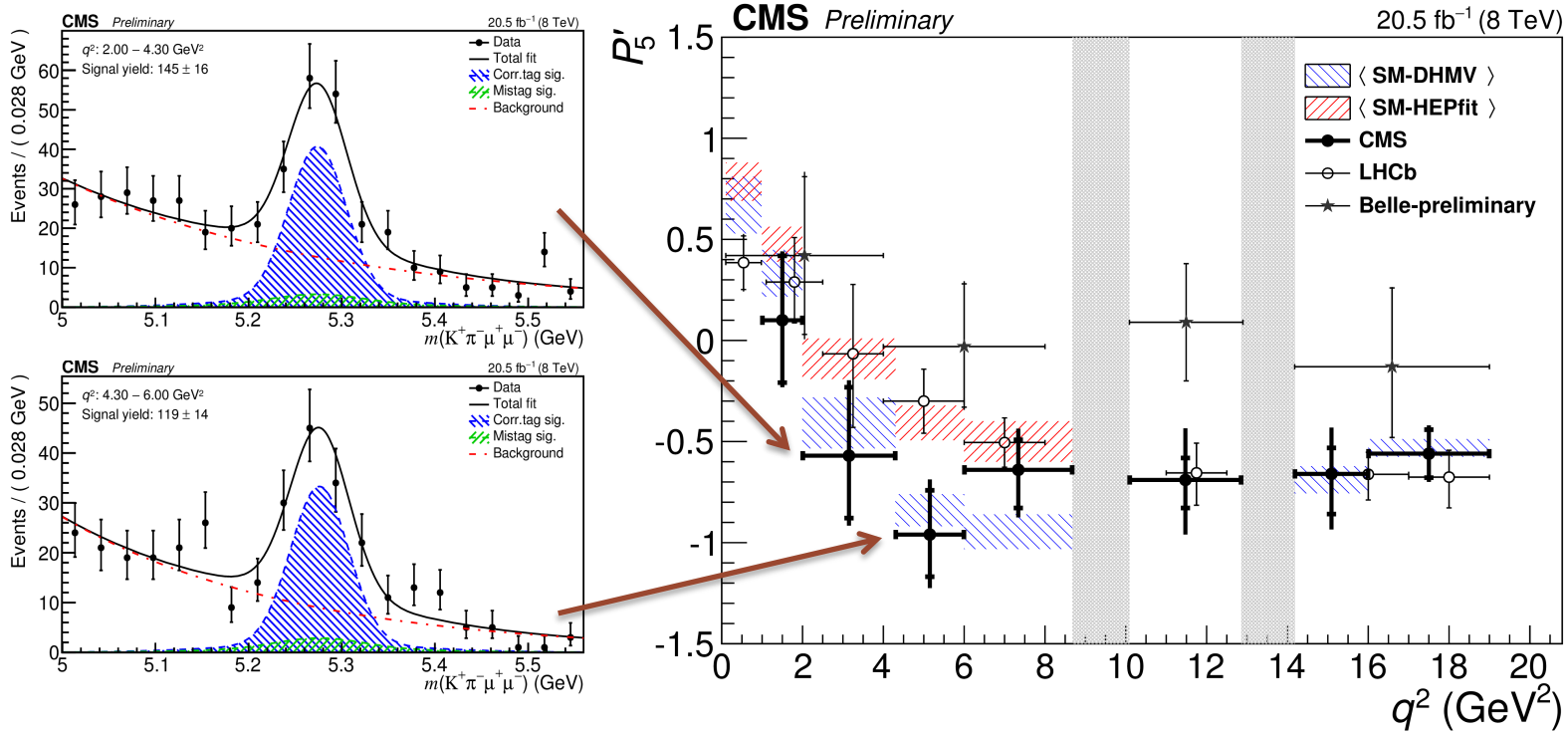




arXiv:1703.01630, Sub. to EPJC

Run 1 measurements: $B^0 \rightarrow K^{*0} \mu^+\mu^-$

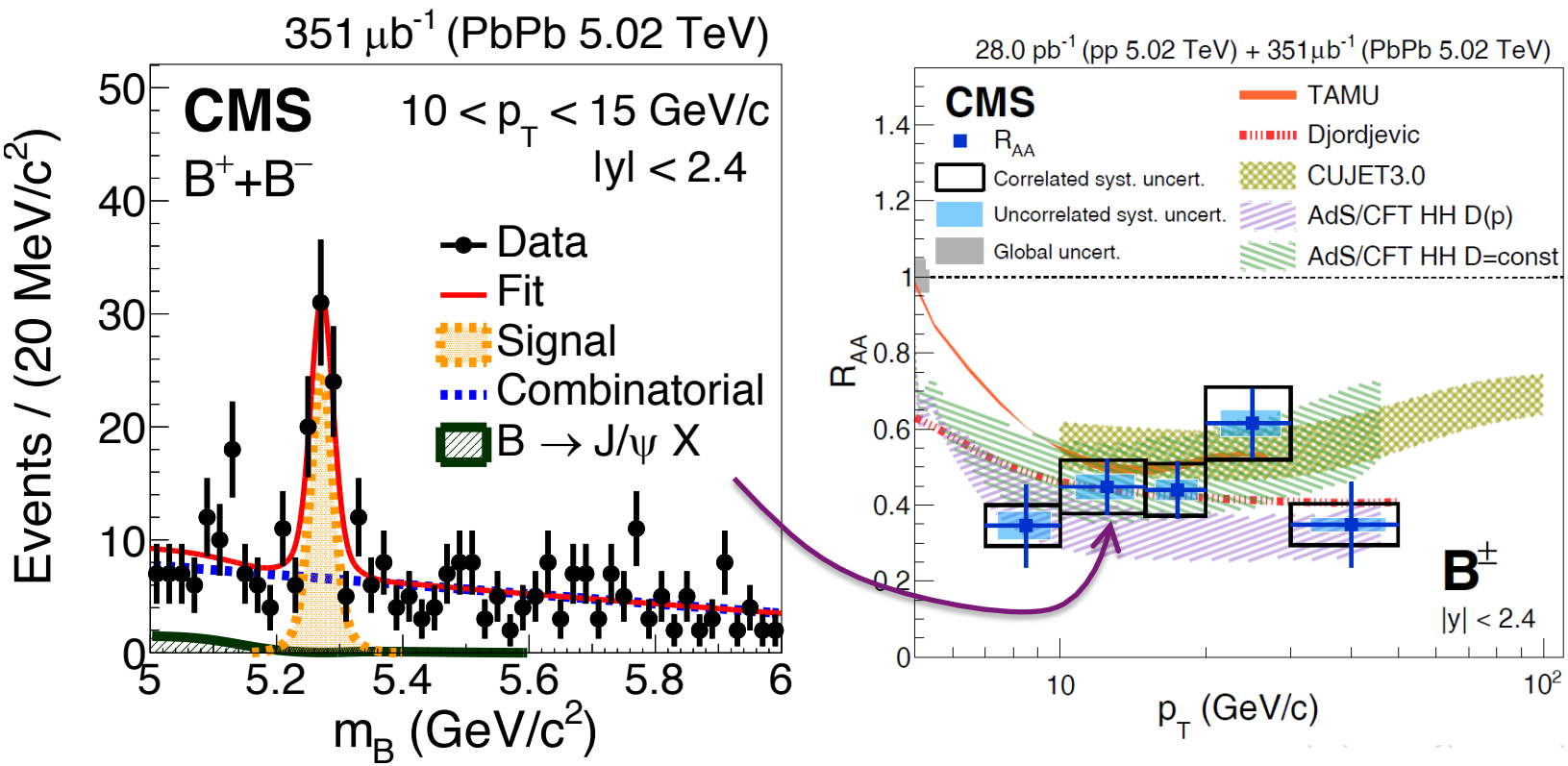
- 4D unbinned fit for angular parameters in B^0 decay
  - Try to address the tension between P5′ measurements in LHCb & Belle and the a-priori SM predictions (DHMV)
  - CMS result more SM-like, but compatible with both

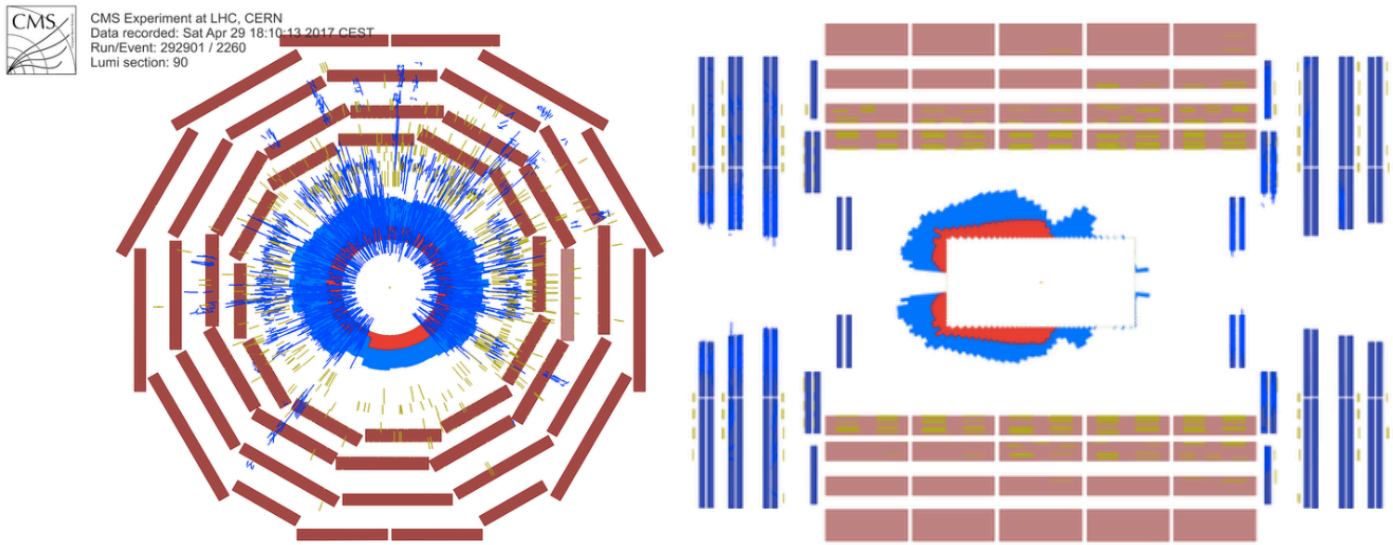


CMS PAS BPH-15-008

Heavy Ion physics: B mesons

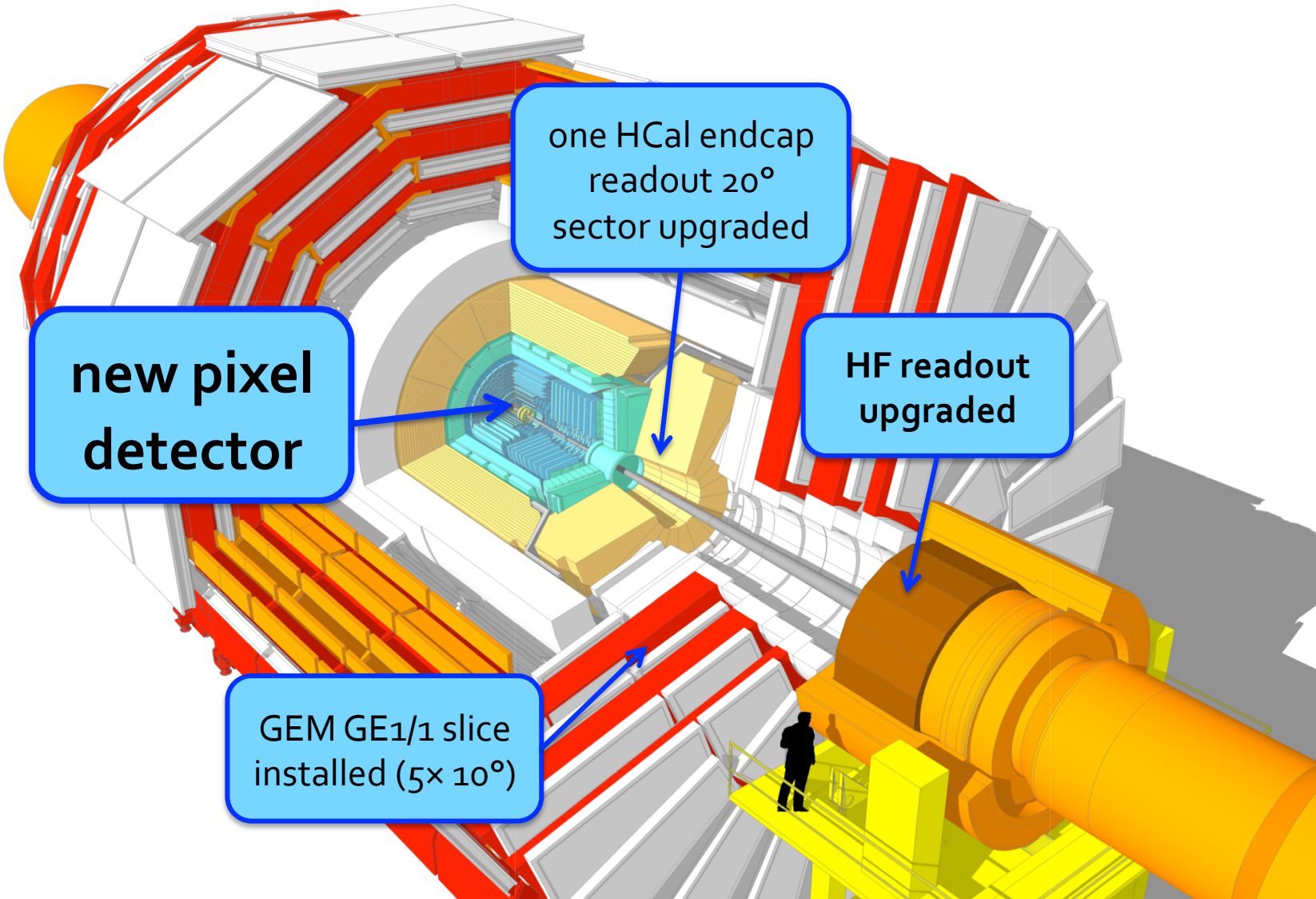
- First measurement of B mesons in Pb Pb collisions
  - suppression by a factor ~2 with respect to pp collisions
  - updated result w/ improved uncertainties and comparison to more theoretical models





2017 CMS DETECTOR STARTUP

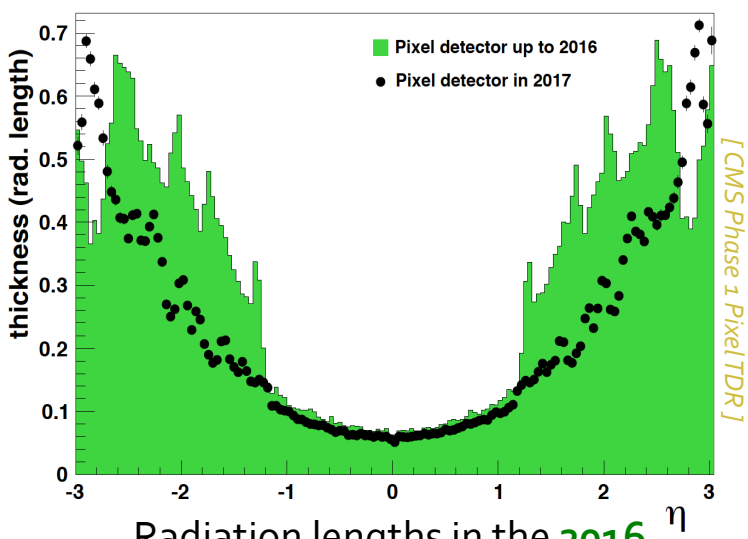
CMS detector: what's new in 2017



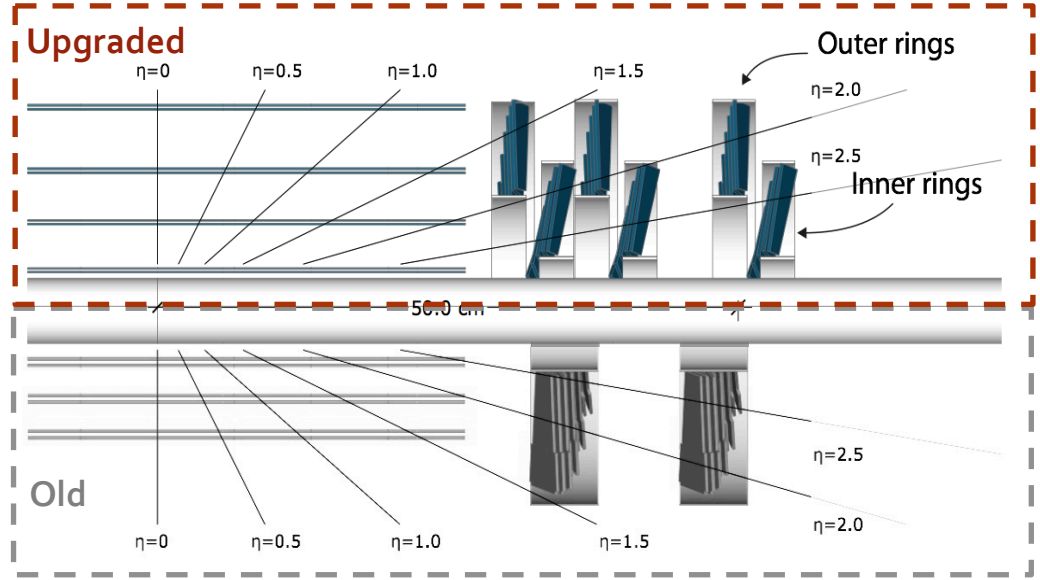
CMS Phase I Pixel Detector

- **4 layers / 3 disks**
- CO_2 cooling
- DCDC converters

→ reduced material budget



Radiation lengths in the **2016** and **2017** pixel detectors



- New readout ASIC & back-end electronics (µTCA)
  - Fully digital read out (400 MHz)

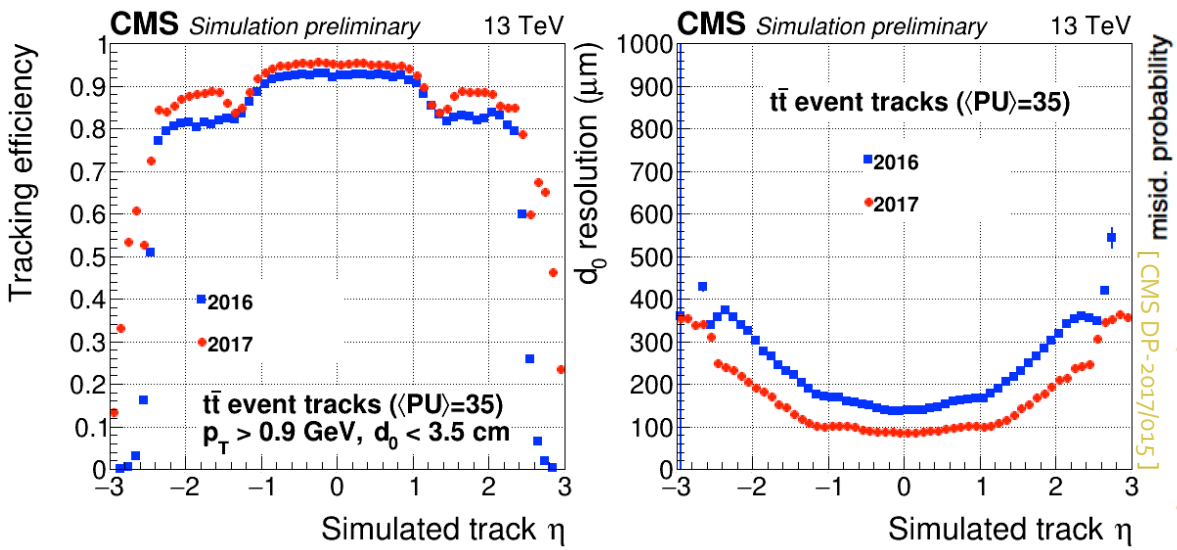
→ **Readout inefficiency negligible up to PU 100 at 100 kHz L1 rate**

  - Old detector had ~5% inefficiency in Barrel Layer 1 at PU ~ 40

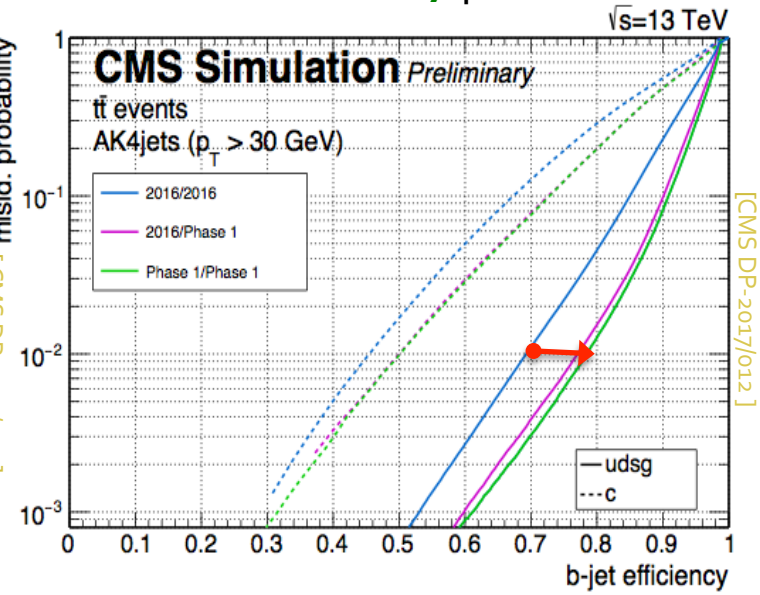
CMS Phase I Pixel Detector

- Increased tracking efficiency, especially at high |η|, and reduction of fake rate
- Improvement in impact parameter resolution and, consequently, b-tagging performance

Performance of tracking on simulated $t\bar{t}$ events at <PU> = 35, for **2016** and **2017** detector



Performance of b-jet identification with **2016** and **2017** pixel detector



Pixel detector: installation

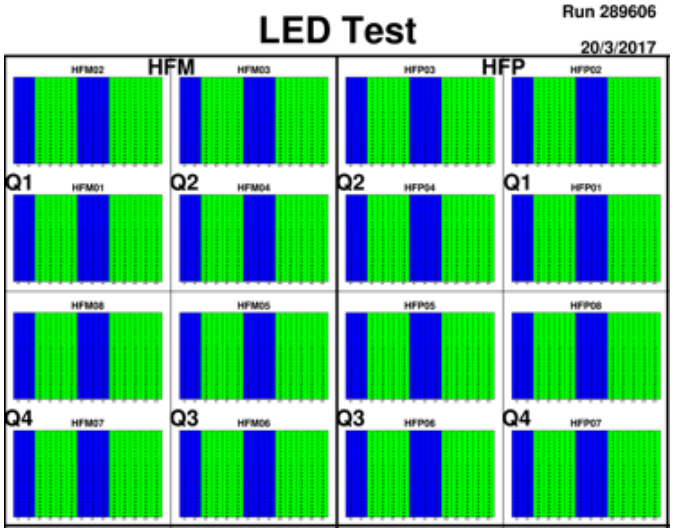
Started Feb 28th
Completed Mar 9th

Following commissioning steps:

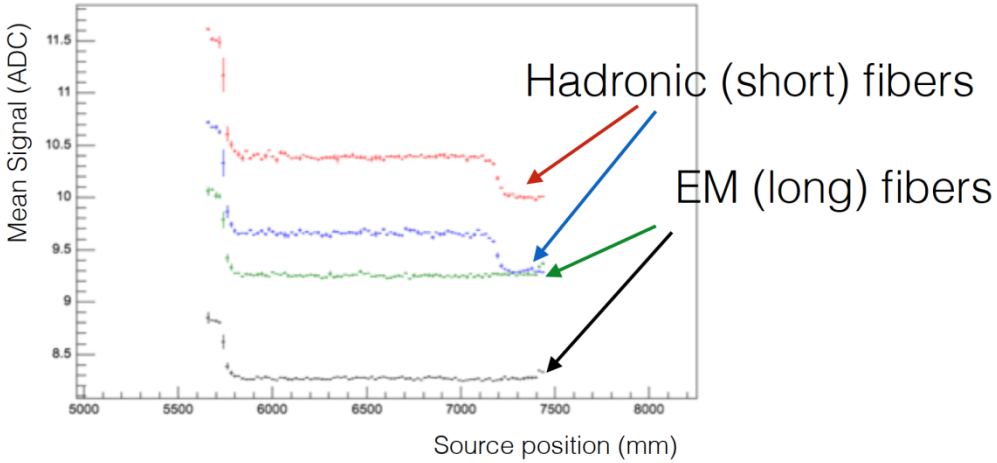
- Connection checkout Mar 5th-12th
- Sealed & running cold Mar 18th
- Ready to close CMS Mar 24th

HF Phase-I upgrade completed

- Completed the upgrade program to discriminate good physics signals from anomalous ones (particles hitting PMT windows)
- EYETS 16/17: PMT boxes reworked and Front-end upgraded:
  - Add TDC to improve PMT hit discrimination
  - Dual-anode readout for further discrimination & hit recovery
- Detector fully re-commissioned using laser/LED/pedestal runs, ^{60}Co source and beam splash events



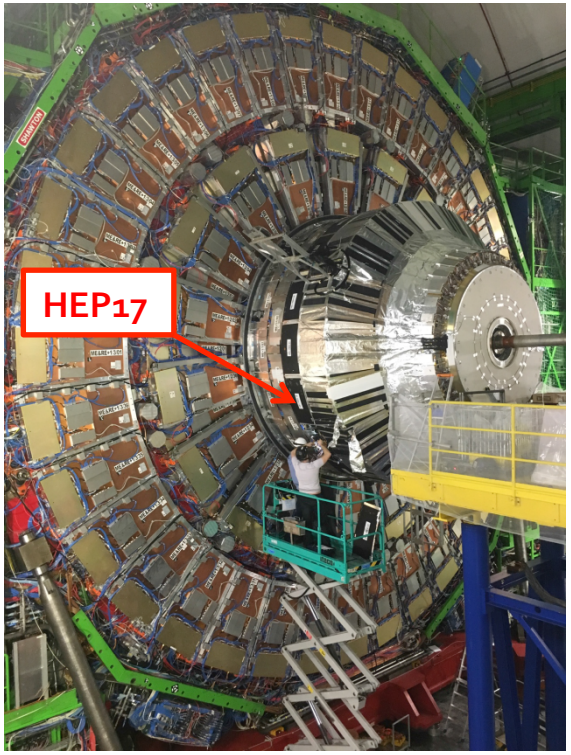
All HF channels are working
Green: good channel (blue: unused slot)



Example of ^{60}Co source signals for 4 readout channels in one HF tower
- Long and Short fibers
- Each with dual anode readout

Phase-I Upgrade of an HE Sector

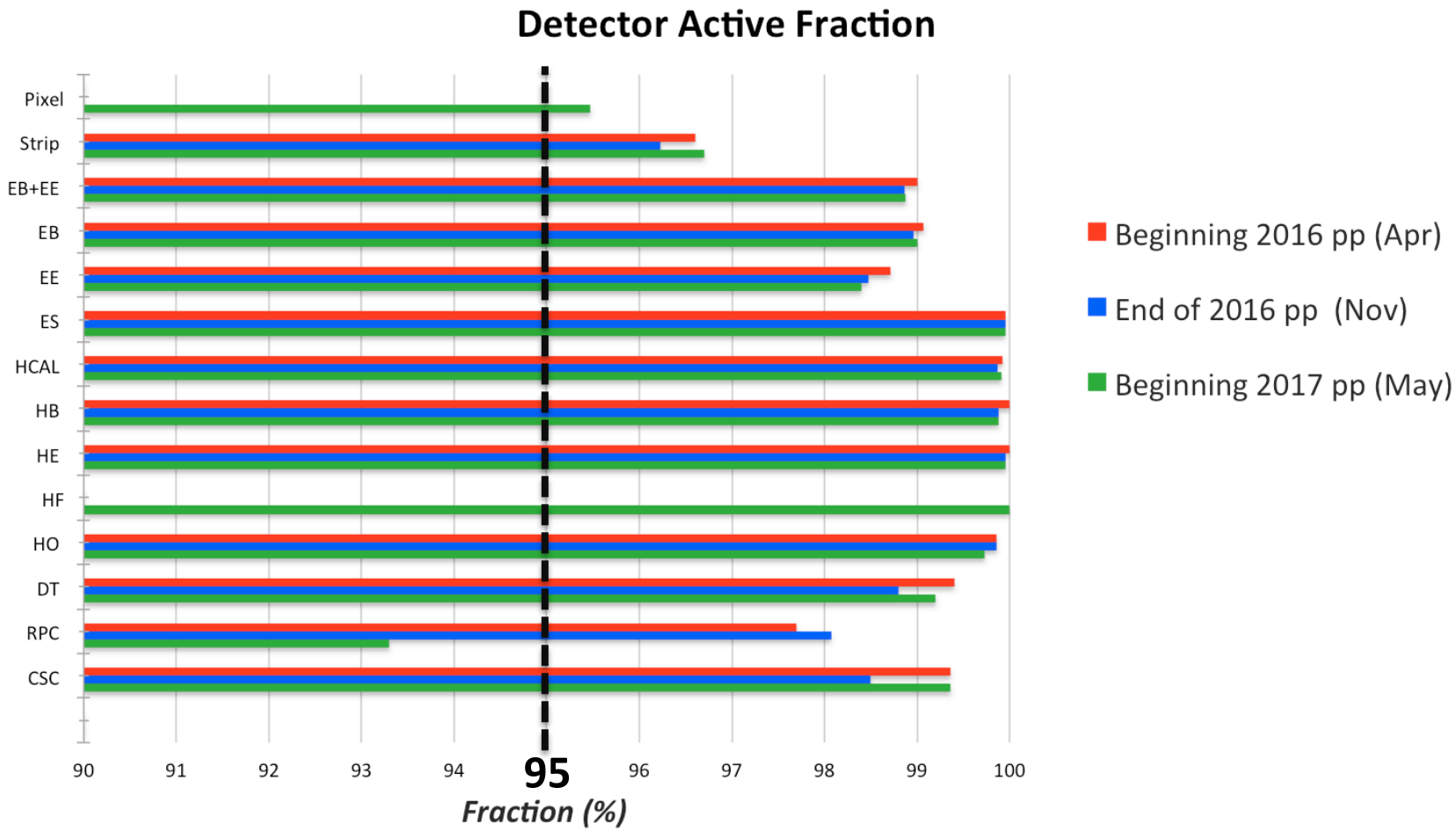
- A 20° ϕ sector (HEP17) of HCAL Endcap has been upgraded as demonstrator:
  - Replaced Hybrid Photo-Detectors (HPD) with Silicon Photo-Multipliers (SiPM)
    - Eliminate high amplitude noise and drifting response of HPDs
    - Mitigate effects of radiation damage
    - Increased longitudinal segmentation of readout
- Provides important feedback for upgrades of full HCal Endcap (likely in YETS17/18) and Barrel (scheduled for LS2)
  - Upgrade procedure validated
  - Commissioning: LED/Laser, ^{60}Co source, cosmic
- Phase 1 depth segmentation collapsed in software to emulate legacy system readout



Commissioning: other detectors

- **Strips:** standard calibration and alignment done with cosmics, stable and high signal/noise
- **ECal & ES:** stably running after refurbishment of LV power supplies, laser monitoring hardware and full recalibration of 1224 Ecal Barrel HV channels
- **Muons:** various repairs & updates to chambers and services, commissioning of GEM GE1/1 5×10° ϕ slice

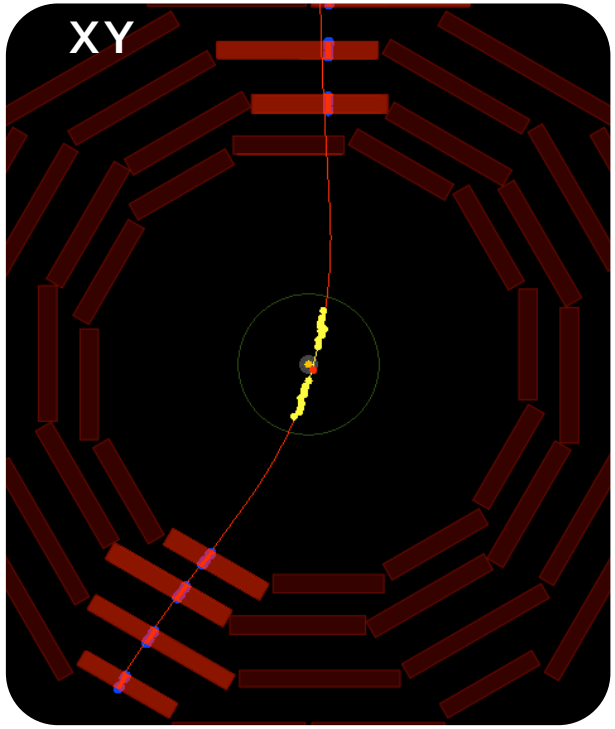
Commissioning: active channels

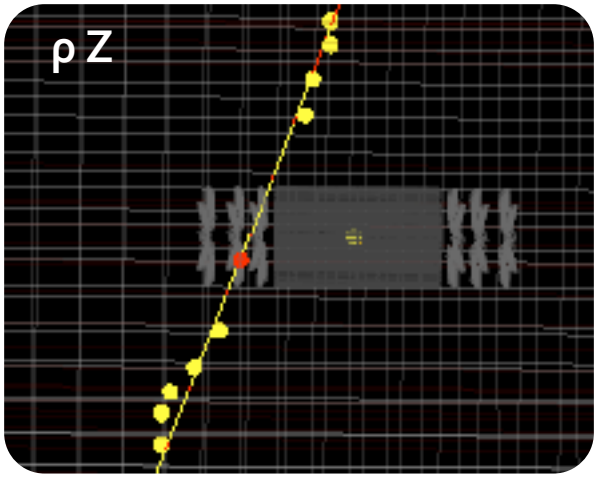


- Upgraded Pixel detector has ~twice the number of channels of the old one.
- Endcap RPC being brought back to HV on after flushing Argon gas from EYETS, expect to have all restored in 1-2 weeks

Cosmics: pixel

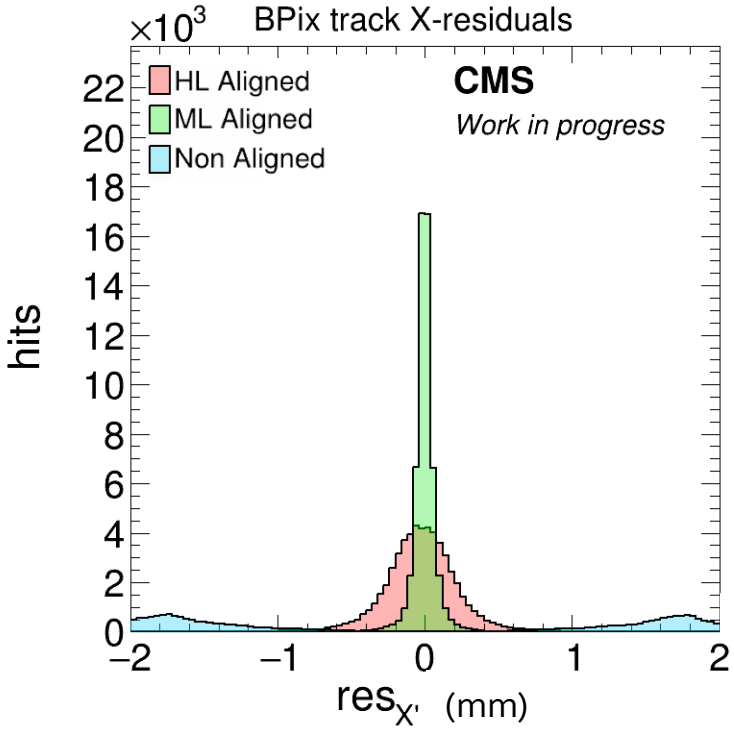
- Pixel detector in global runs for cosmic data taking since mid-April.
- The thresholds are already comparable (or better) to the ones of the previous detector
- Coarse time alignment achieved: **±12 ns**
  - to be completed with collisions.

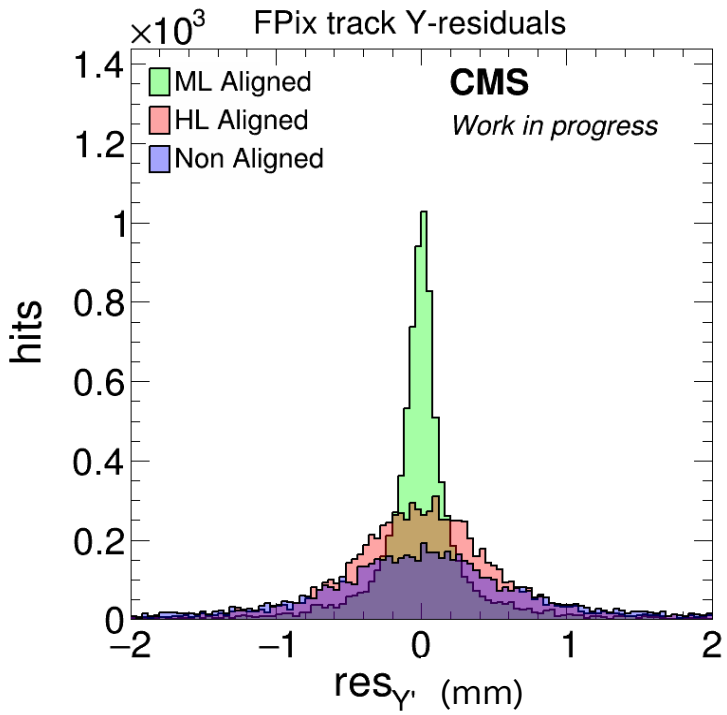




Cosmics: Pixel alignment

- Pixel detector aligned at module level using cosmics:
  - Barrel and Forward pixel aligned at 50-100μm precision
  - Very good starting point for alignment with collisions



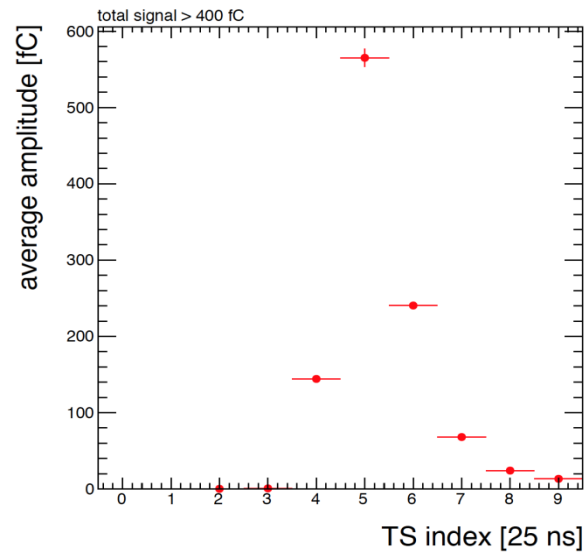


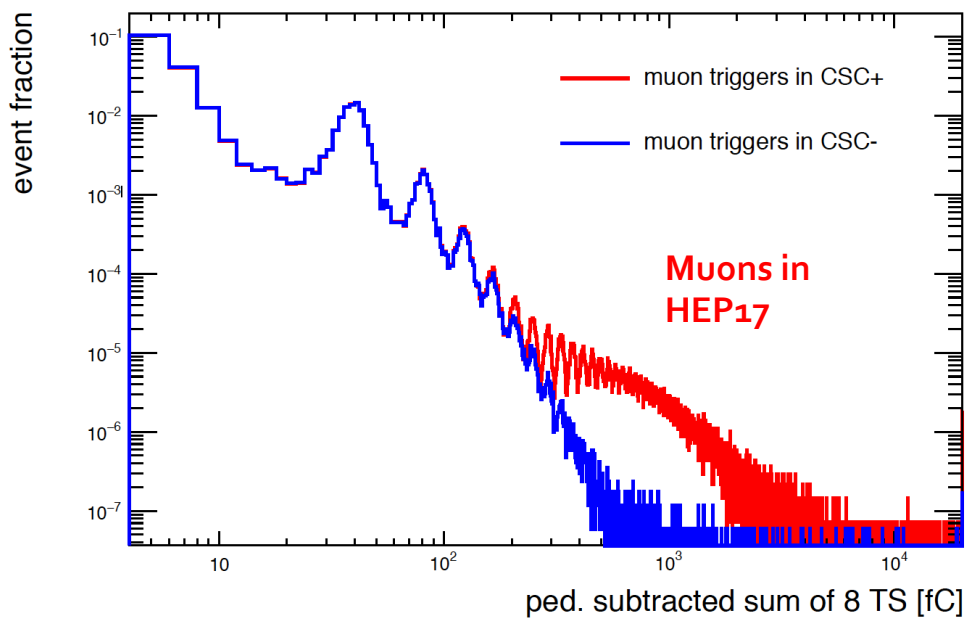
HL = alignment of high level structures only; ML = module-level aligment

Cosmics: HCAL HEP17

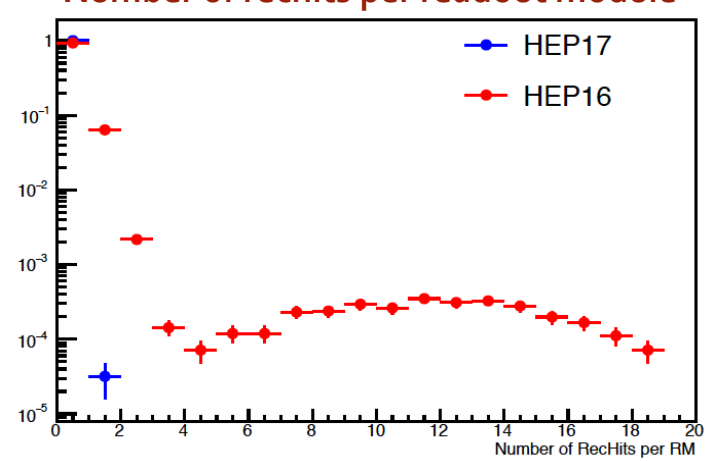
- Analysis of cosmic events confirms beautiful performance of HE Phase1
  - muon signals clearly seen in HEP17
  - timing also correctly measured
  - substantial reduction of coherent noise compared to old readout

Muon signal timing in HEP17





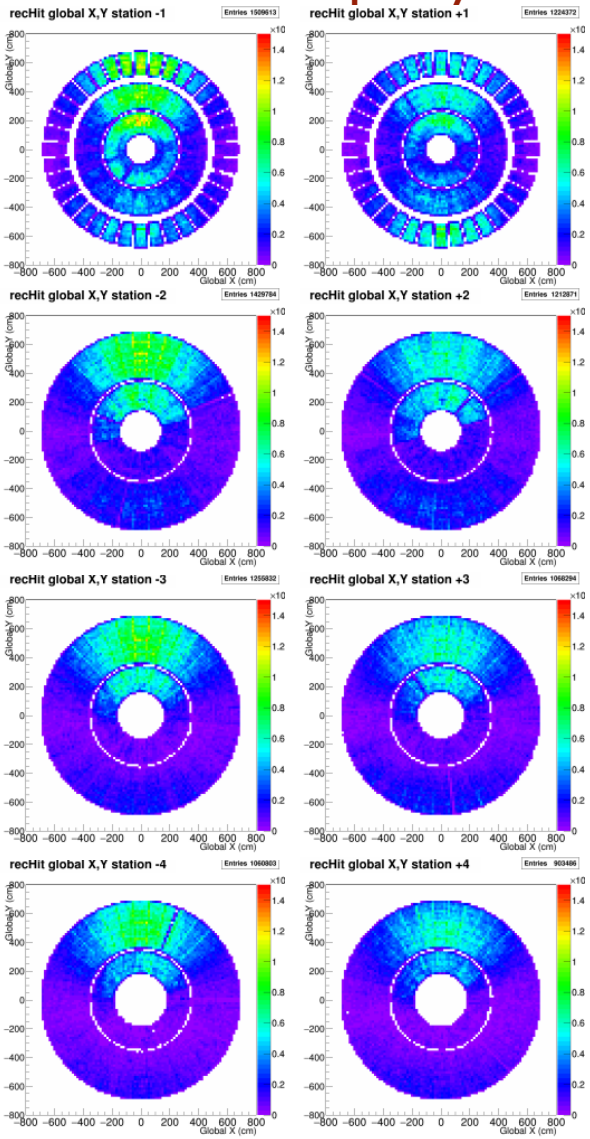
Number of rechits per readout module



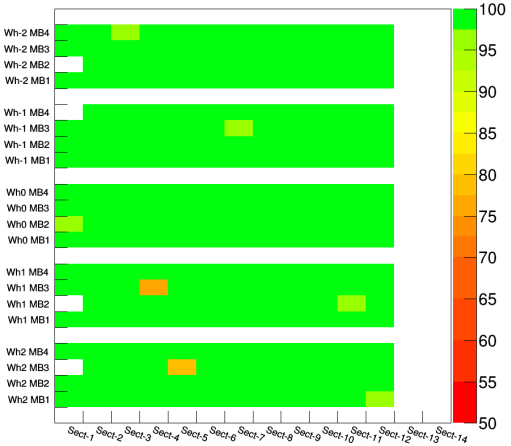
Cosmics: Muon detectors

- Overall, good state of muon systems demonstrated in first cosmic running:
  - DT, CSC & Barrel RPC fully ready for data
  - Endcap RPC HV being brought back on after flushing Argon gas from EYETS

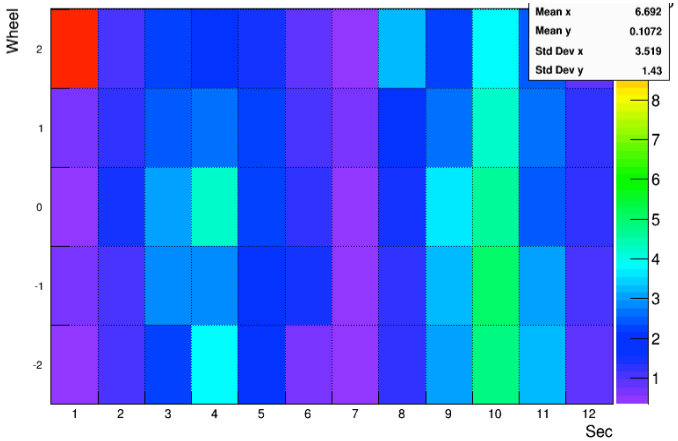
CSC occupancy



DT trigger efficiency



RPC barrel occupancy



Beam Splashes: ECAL

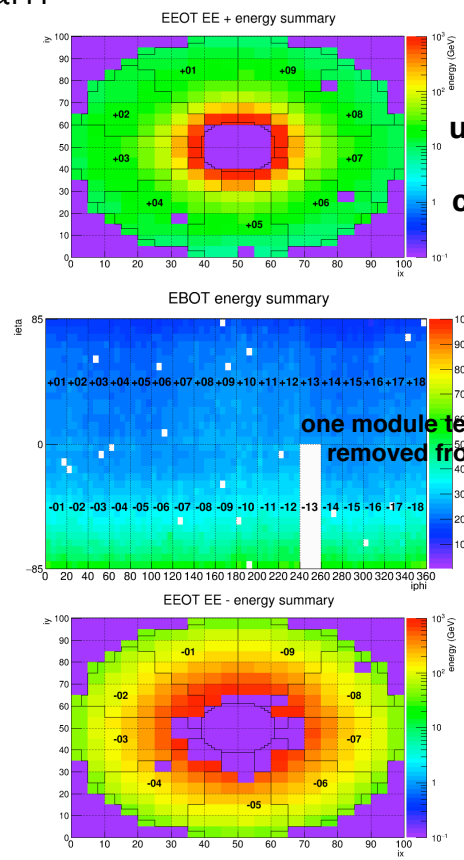
Energy

Timing

Upstream

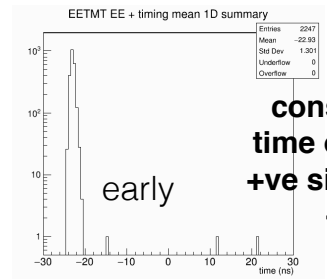
Direction of splash

Downstream

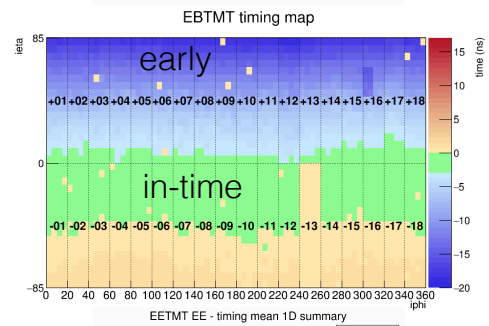


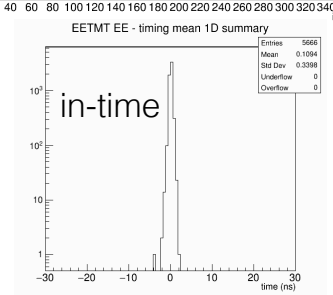
up to 1 TeV energy deposited per crystal in endcaps

one module temporarily removed from DAQ



consistent with time of flight from +ve side of CMS to -ve side



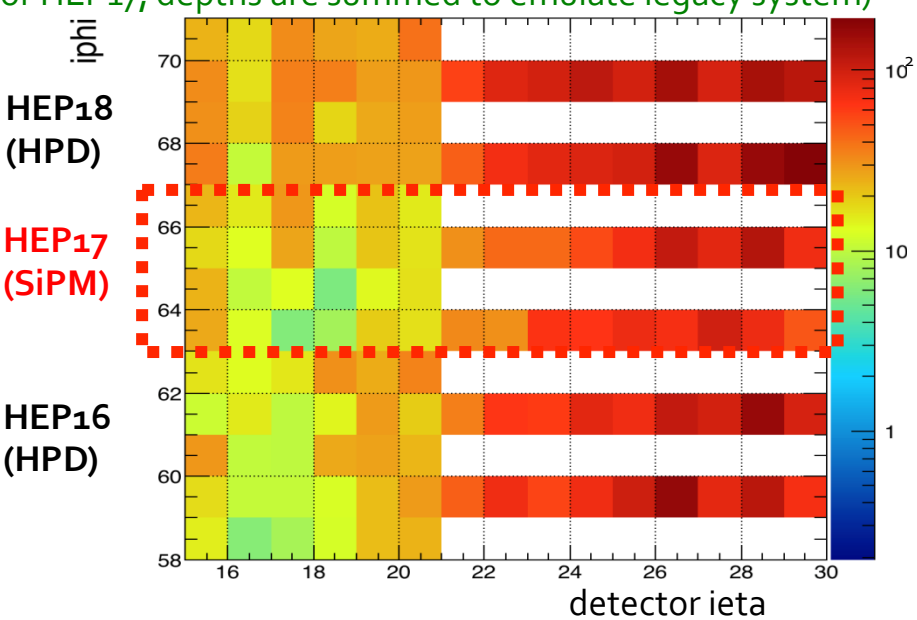


Splash events used to successfully validate ECAL readout/trigger status and timing synchronisation

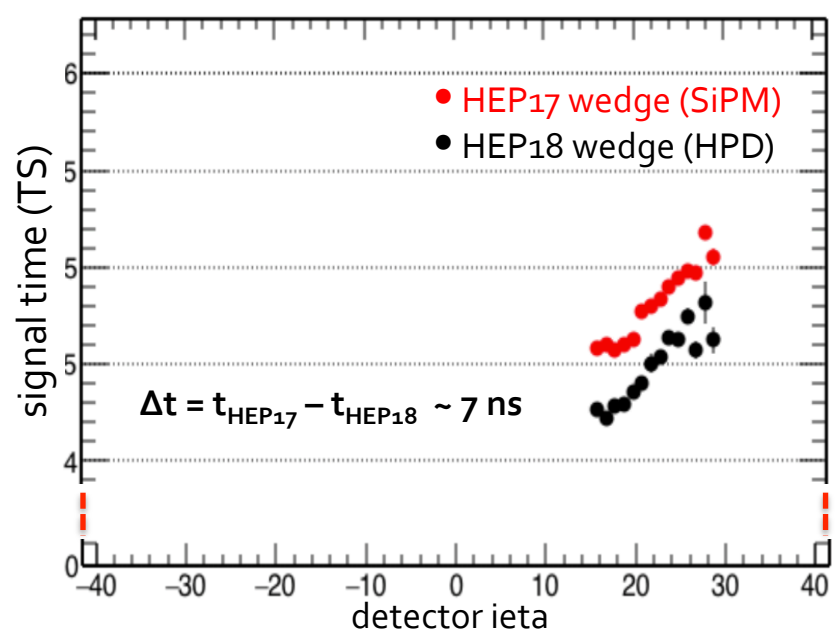
Beam Splashes: HCAL

- Validate energy response of the upgraded HEP17 (SiPMs) w.r.t legacy detector (HPDs), readout and trigger timing
- Reconstructed energy in HEP17 consistent with measurement in neighboring legacy system
  - NB: phi-symmetry not expected to be perfect for splash events due to 'LHC floor shadow'

Energy (GeV) in HE (legacy) depth1 vs iphi/ieta
(for HEP17, depths are summed to emulate legacy system)



Signal Time for a Beam2 splash event
(from –z to +z)



PREPARATION FOR 2017 RUN AT HIGHER LUMINOSITY

2017 detector re-tuning

Preparation for high luminosity & high rate running:

- **Pixel:** increased bandwidth from detectors to FEDs, new 10 Gb/s links allowing 100 kHz L1 rate at PU 100
- **Ecal:** optimized readout settings (zero suppression), DAQ improvements to reduce downtime.
- **DAQ/HLT:** increased number of sub-detector channels (esp. for new Pixel) and event building throughput. Planning for increased HLT processing capability.

All CMS subsystems ready for 2017 luminosity

Level 1 Trigger development

- Data from 2016 high pile-up run being used in preparation for 2017 running
  - Improvements in algorithms and calibrations, to better cope with PU (sizeable gains esp. for E_T^{miss} & H_T)
- Extended L1 trigger menu allowing for more complex algorithms *a la* HLT:
  - e.g. 2 jets w/ VBF cuts + 2 central jets or taus, or di-muon triggers in exclusive mass bins for b-physics
  - can have up to 512 different L1 seeds
- Good progress in integrating RPC data into the endcap muon track finder (last step of L1 trigger Phase 1 upgrade)
  - should increase efficiency in CSC ring gaps
- Operational improvements on automatic data quality monitoring, validation & shifter tools.

High Level Trigger development

- HLT preparation for 2017 running:
  - reconstruction updated to 2017 detector: upgraded pixel detector, HCal HEP17, HF
  - improvements to bring HLT objects closer to offline ones: higher purity & plateau efficiency
  - code and algorithm optimizations to reduce CPU usage, to allow running at higher PU
- HLT menu being defined for 2017 luminosity
  - main goal of ~1 kHz average physics rate for LHC fills with peak instantaneous luminosity of ~2E34

Software & Computing

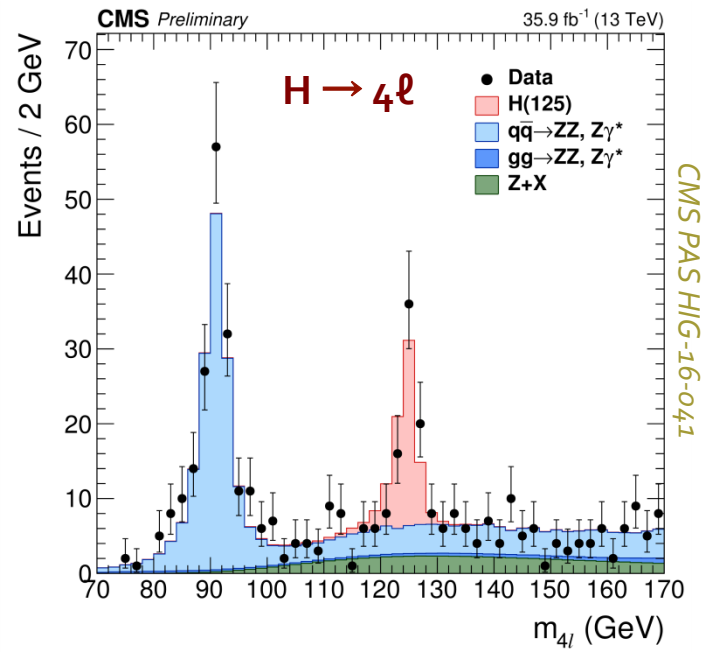
- MC production & 2016 data processing for 2017 winter conferences successfully completed (~20B events)
  - Resources now mainly devoted to MC for 2017 run preparation and phase 2 upgrade TDRs
  - Also, final 2016 data re-reco. with best calibrations and consolidation of analysis object developments for precision measurements and future 2016+2017 analyses
- Working to review and optimize overall computing model for Run 2 & Run 3
  - First outcome are strategies now being put in place to improve disk usage efficiency:
    - Improved MiniAOD (~40 kb/evt): larger analysis coverage, to reduce amount of AOD (~300 kb/ev) needed on T2 disks
    - Improving dynamic data management policies

Conclusions

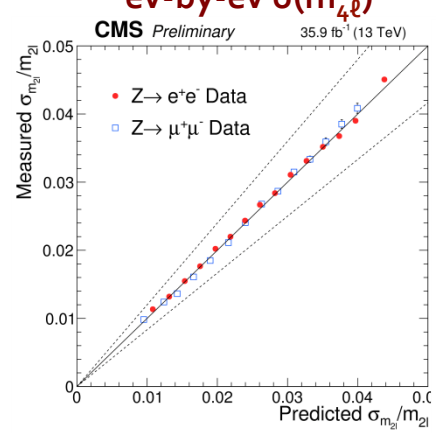
- Following up successful 2016 datataking with impressive set of new physics results.
  - and more precision physics measurements on earlier run 1 and run 2 datasets
- Upgraded Pixel detector and Hcal readout installed and integrated
- Successful 2017 detector commissioning, cosmics and beam splash data taking
- Completing preparations for 2017 running at higher luminosity and pileup

Higgs boson measurements

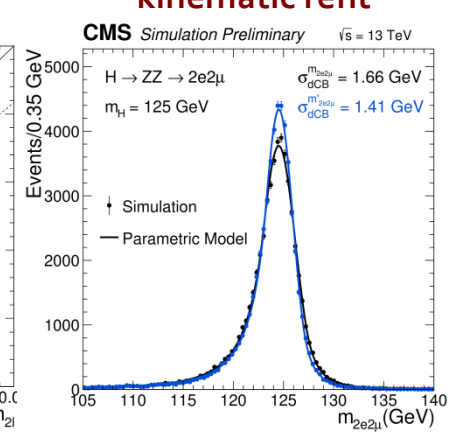
- Mass measurement in H→ZZ* → 4ℓ decays:
  - New technique combining event-by-event errors, Matrix Element and kinematic refit of the Z→ℓℓ decay
  - Full 2016 data analyzed
- m_H = 125.26 ± 0.21 GeV
  - better obs precision than LHC run 1 combination



ev-by-ev σ($m_{4\ell}$)



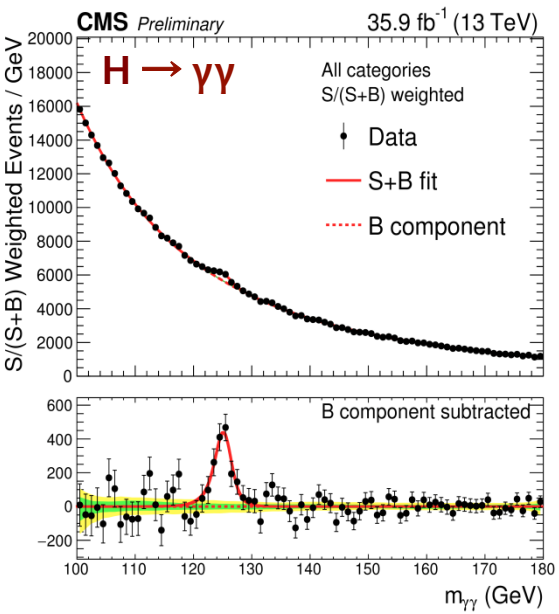
kinematic refit

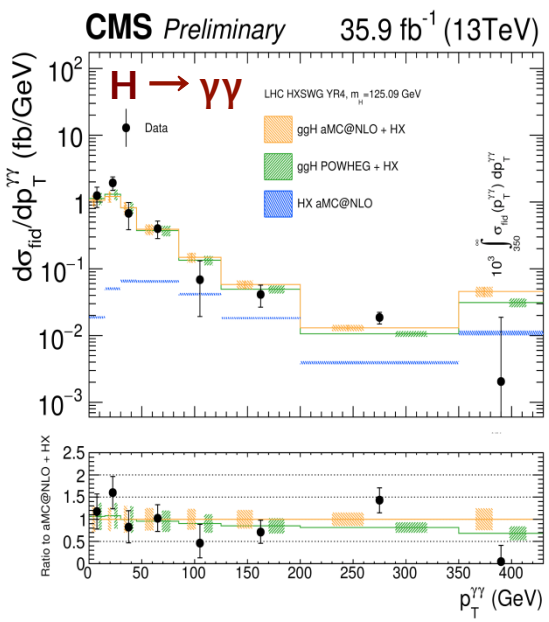


Higgs boson measurements

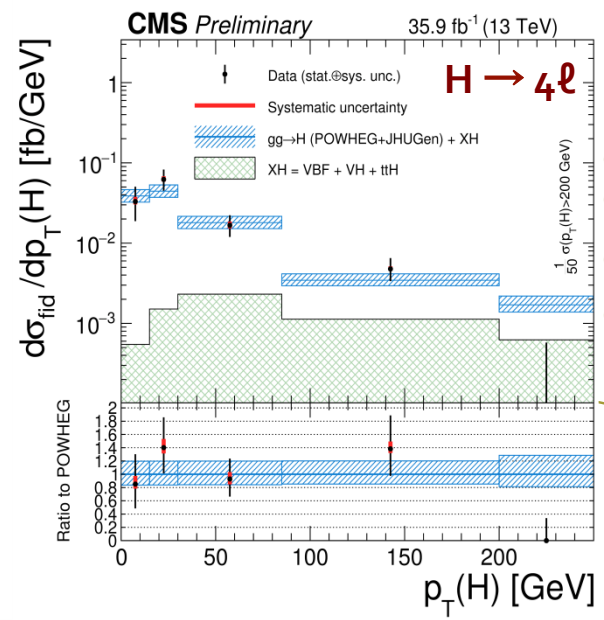
- Fiducial and differential cross sections from $H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ on full 2016 data
  - $\Delta\sigma_{fid}/\sigma_{fid}$ = 18% (4ℓ), 15% (γγ), good agreement with theory predictions (YR4, NLO MC)

CMS PAS HIG-17-015





CMS PAS HIG-16-041



Pixel detector: commissioning

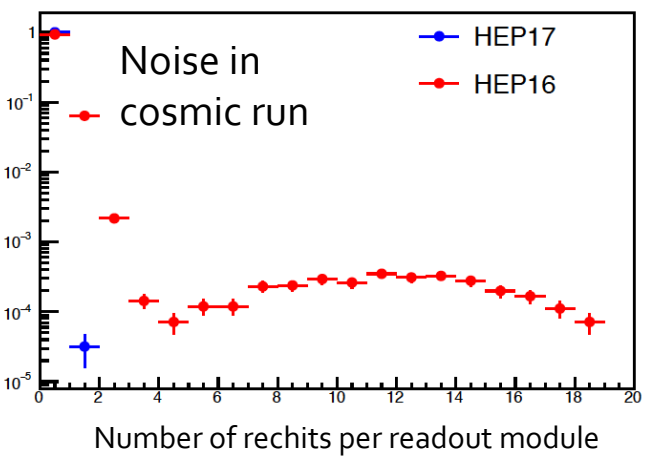
- Pixel detector integration timeline:
  - Installation in CMS: Feb 28th-Mar 9th
  - Connection checkout: Mar 5th-Mar 12th
    - cooling, power, control, readout
  - Sealing and start of cold operations: Mar 18th
  - Green light to close CMS: Mar 24th
  - In cosmic global runs since mid April
    - Coarse time alignment achieved: ± 12 ns

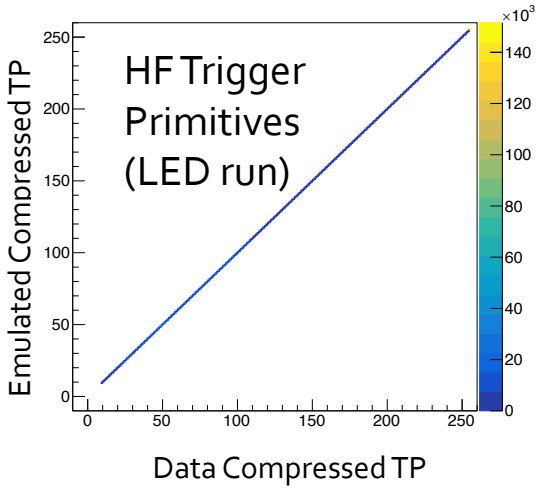
HCal Commissioning and Calibration

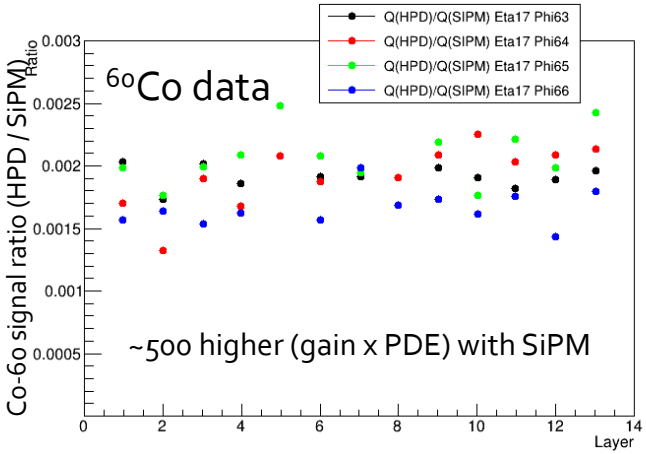
- The fraction of active channels is ~99.9% overall
- Coherent noise
  - The rate is much reduced in the upgraded wedge as expected (monitored in cosmic data taking)
- Trigger primitives
  - commissioned for the upgraded HF
  - finalizing those for HEP17 (the upgraded HE wedge)

HB (%)	HE (%)	HF (%)	HO (%)
99.88	99.96	100	99.72

- Initial gains for the upgrade wedge HEP17
  - are being set using the ^{60}Co source data taken before & after the HEP17 upgrade (HPD→SiPM)
  - To be further refined using phi symmetry and isolated tracks in collision data

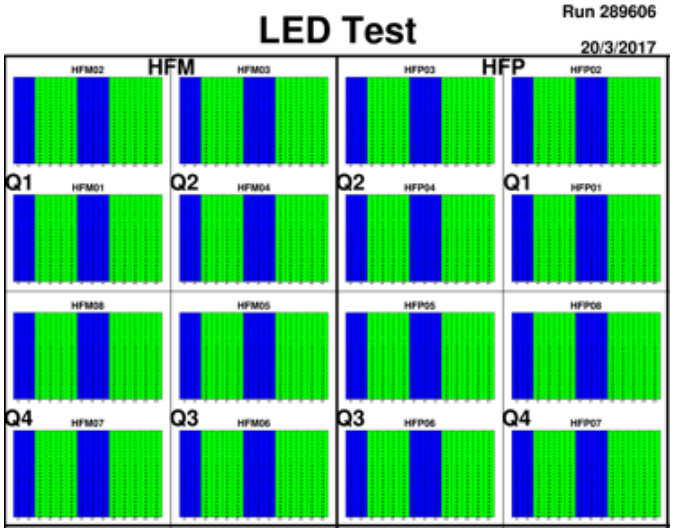




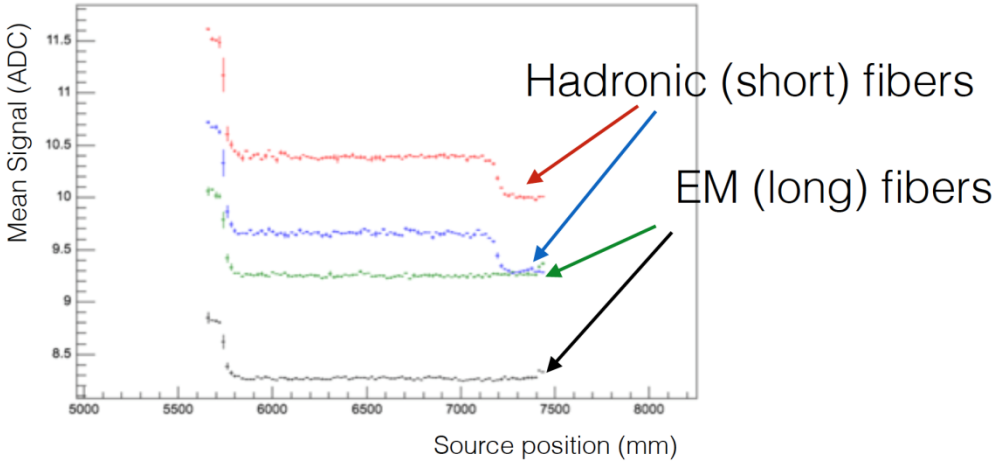


HF Phase-I upgrade completed

- Completed the upgrade program to further discriminate physics signals from 'PMT hits'
  - Beam-induced anomalous signals are due to particles directly hitting PMT windows
  - New, thin-window PMTs installed during LS1 are less sensitive to anomalous hits
- EYETS 16/17: PMT boxes reworked and Front-end upgraded in order to:
  - Add TDC to improve PMT hit discrimination (anomalous signals arise 2-7 ns earlier)
  - Implement dual-anode readout as further discrimination, as spurious signals often affect one anode only, enabling recovering the energy measurement from the other anode
- Detector recommissioned using laser/LED/pedestal runs, and ^{60}Co source
  - Also, splash events being used to adjust HF readout and trigger timing



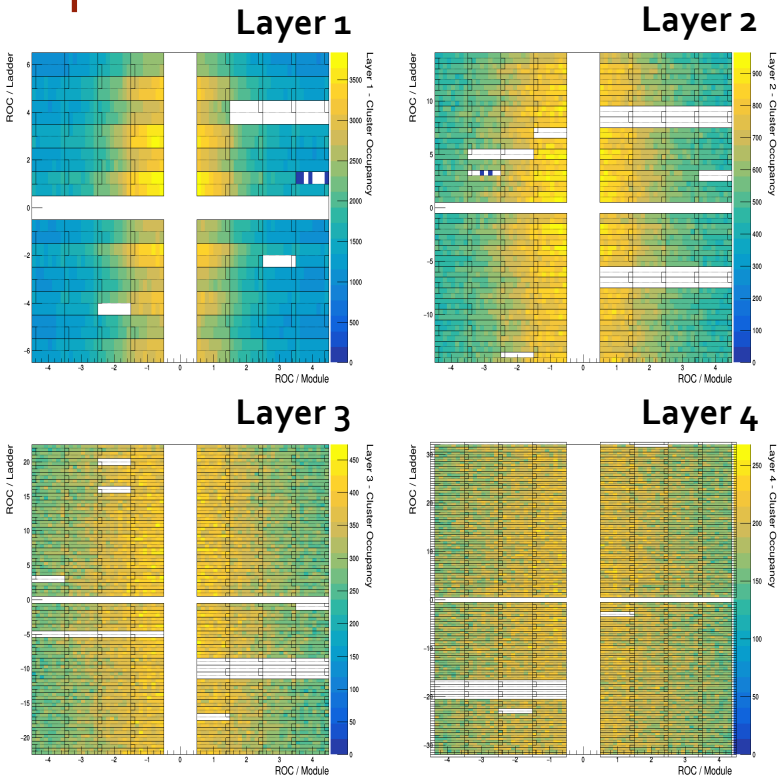
All HF channels are working
Green: good channel (blue: unused slot)

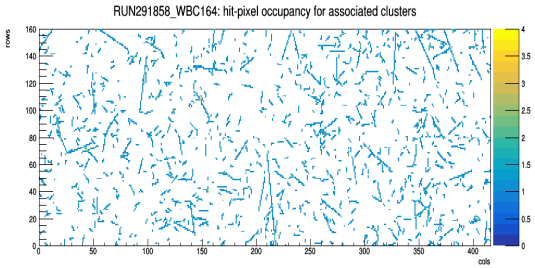


Example of ^{60}Co source signals for 4 readout channels in one HF tower
- Long and Short fibers
- Each with dual anode readout

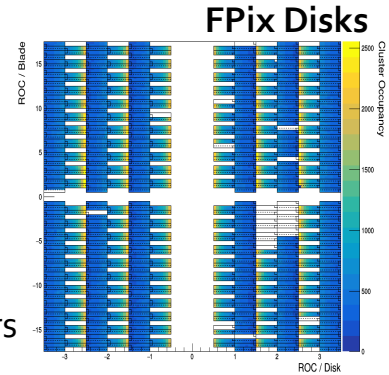
Pixel reconstruction and performance

- Trigger timing of the pixel detector was successfully adjusted to the Strip tracker and the Muon system
  - Subsequently, efficient data-taking in CMS global runs
- Observed uniform data-taking efficiency accross the whole detector
  - Inefficient regions expected from detector calibration is confirmed by data
  - No observable signs of relative misalignment in time or space for any partition of the detector
- Reconstruction geometry and online-to-offline cabling map has been verified





Pixel hits in associated muon clusters

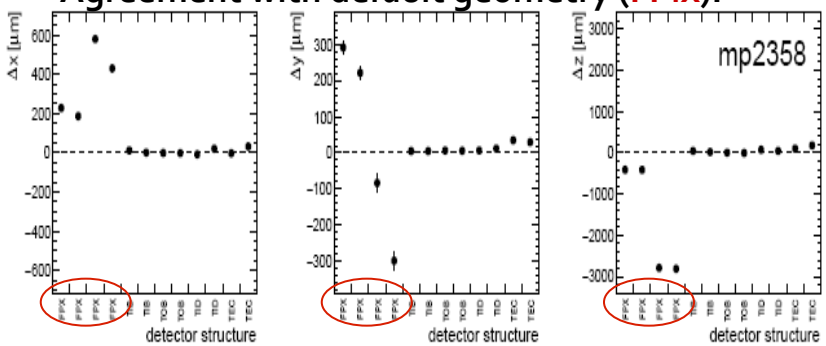


- Gain calibration for first collisions being processed
  - Cluster properties already look reasonable, final confirmation needed with magnetic field
- Ready for first collisions

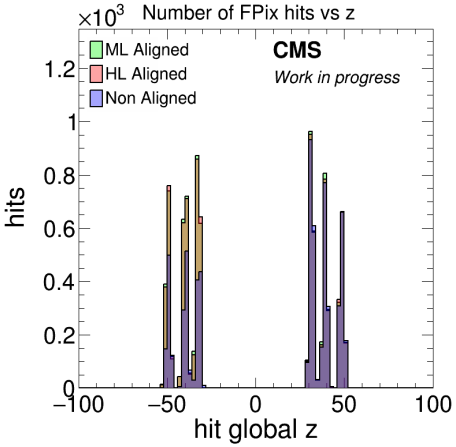
Tracker alignment of the pixel in 0T cosmics

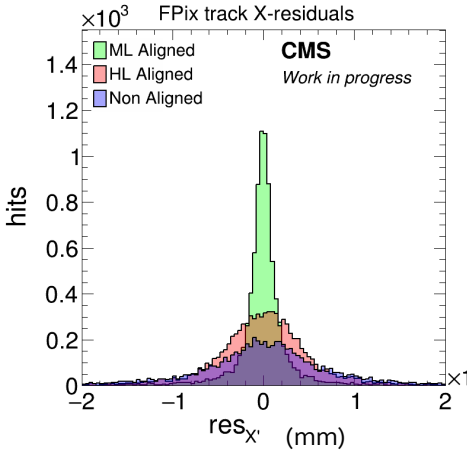
- Processed ~2M CRUZET events (more is available)
- FPix detector was timed earlier → good alignment available
  - ~3 mm difference of Z-minus side w.r.t ideal geometry
  - few 100 microns in transverse plane
- Monte Carlo with estimated misaligment was prepared earlier this year
  - Observed misalignment is consistent with expectations
  - Observed cosmics tracks rate dead-on with expectations
- Expected average accuracy of module-level alignment from available cosmics:
  BPix ~15-30 um, FPix ~150-200 um

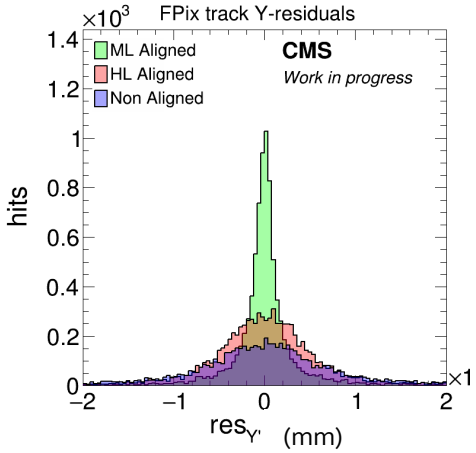
Agreement with default geometry (FPix):



Track-rate improvement after applying alignment (3 mm correction of Z-minus in global Z)

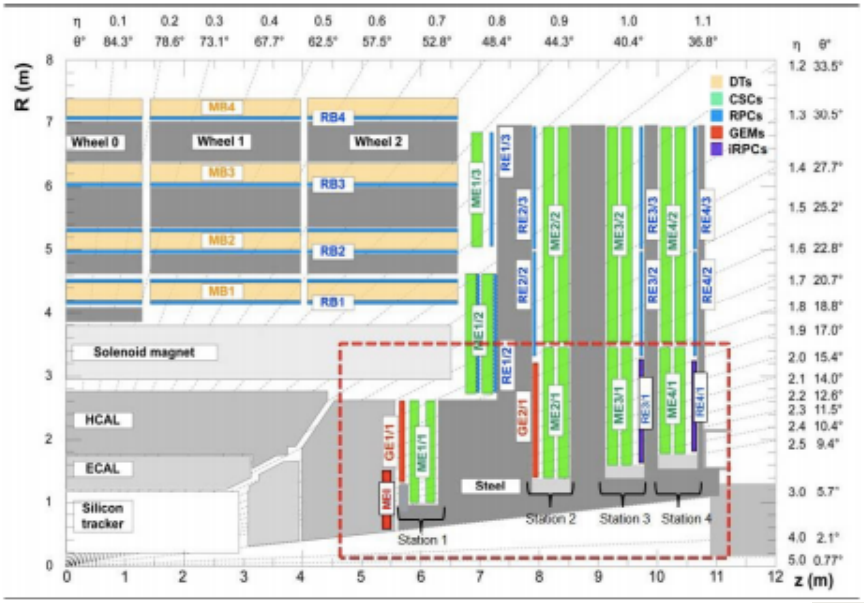


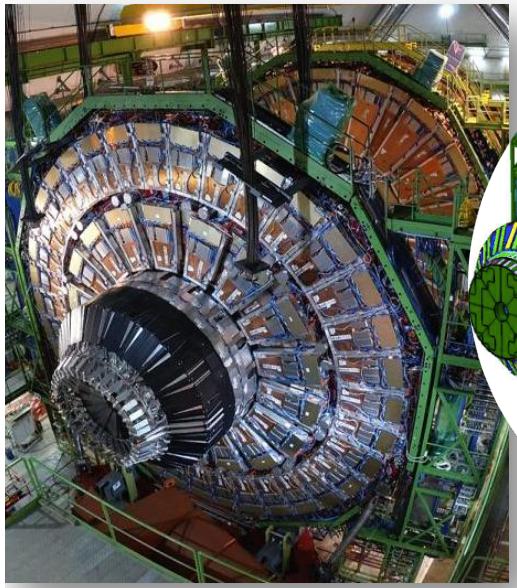


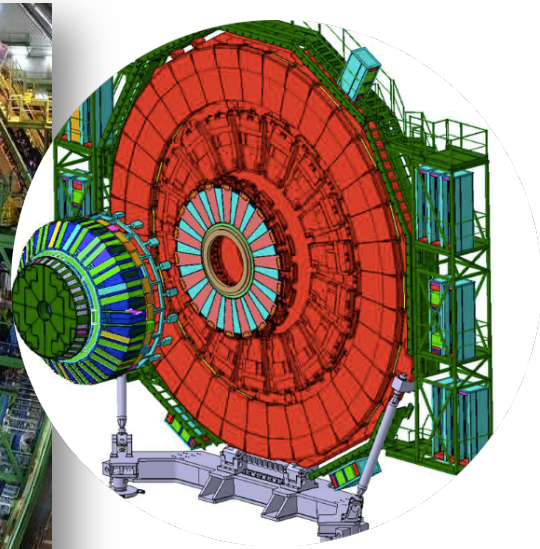


- Observed pulls in FPix suggests better alignment than expected
- 3.8T cosmics are still going to be useful
- Ready for alignment in collisions starting with smaller misalignment than expected!

GEM Muon Upgrade R&D to Demonstrator Slice







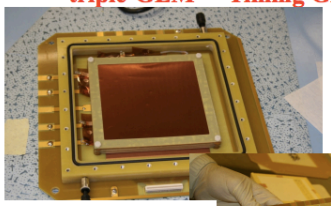
Small Prototypes

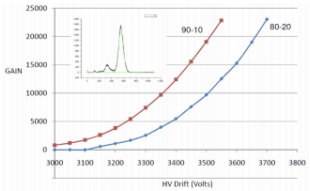
10x10 cm² triple-GEMs,

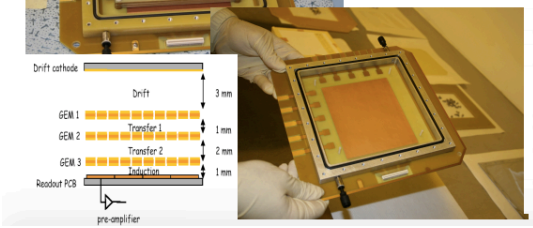
1D or 2D readout, 128 or 256 channels :

Standard double-mask

triple-GEM - "Timing GEM







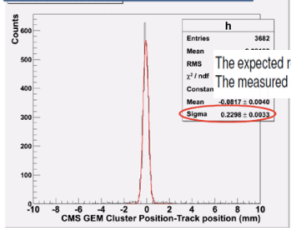
- Triple GEM Detector
- 10x10 cm² active area
- Gas Mixtures used: Ar/CO_2 90%/10% and 70%/30%
- 1D Readout Strip (X-direction) and 1 VFAT connected to the only one connector
- Strip pitch = 0.8 mm; 1 connector → 128 strips

http://indico.cern.ch/event/159247/

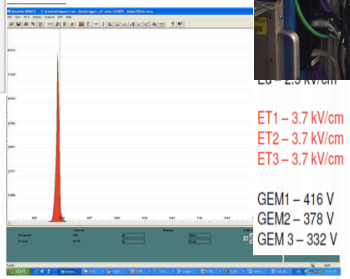
Detector Seminar: 16.12.2011

Small Prototypes II

CMS GEM SPACE RESOLUTION



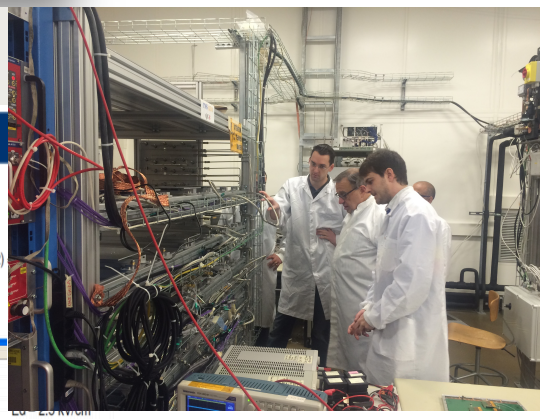
The expected resolution due to a digital readout is pitch/sqrt(12)
The measured space resolution is ~ 230 μm



S. Colafranceschi
A. Marinov

FWHM – 10.89 ns
RMS – 4.25 ns

Noise to be reduced



From 904 to TIF

Micro-pattern gaseous detectors for Upgrade of the CMS Muon System

https://indico.cern.ch/event/484223

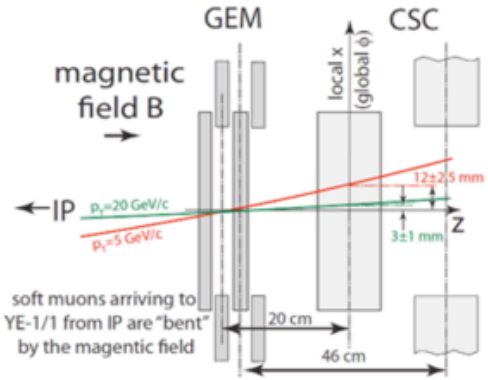
Archana Sharma Detector Seminar CERN Feb 5, 2016

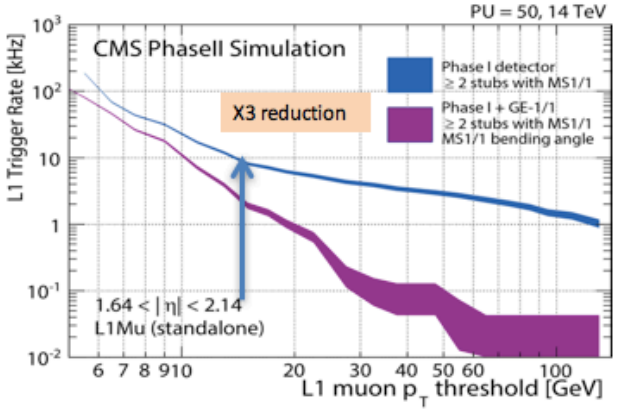
New handle: bending angle

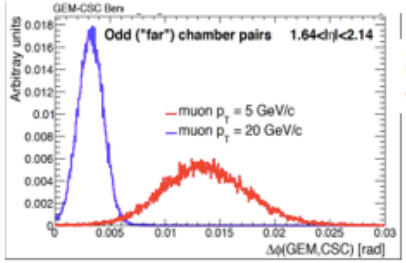
Forward trigger for |η|>1.6 relies entirely on the CSC system:

- Measurement driven by internal chambers: least scattering, strong B field.

GEM detector in front of CSC can measure muon bending angle in magnetic field and add redundancy

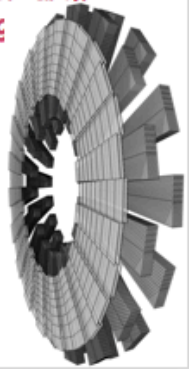




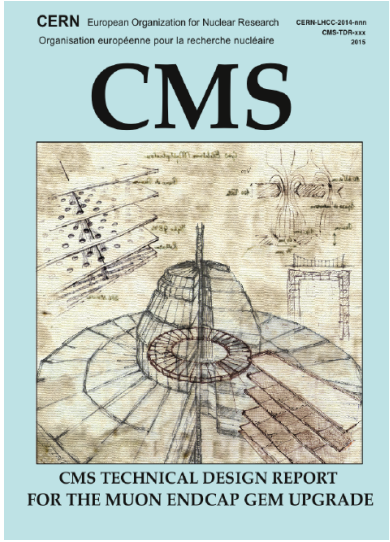


maintain 15 GeV online threshold, keep < 5 kHz rate, high efficiency

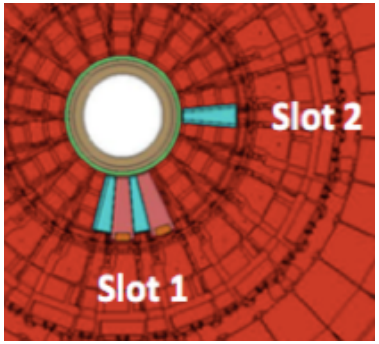
Lever arm - trigg



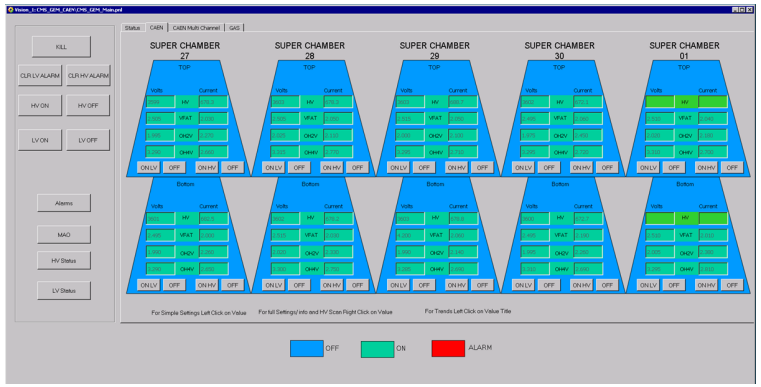
GE11 TDR approved 30.9.2015



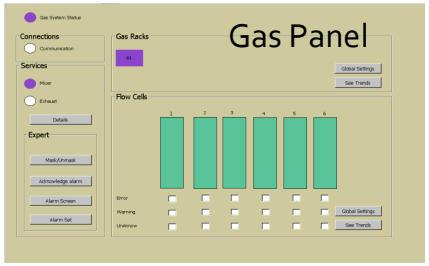
MUON GEM GE11 SLICE at P5



Overview of Standard HV and LV



DCS Operational Trending HV, I_{mon}, Gas parameters continuously monitored



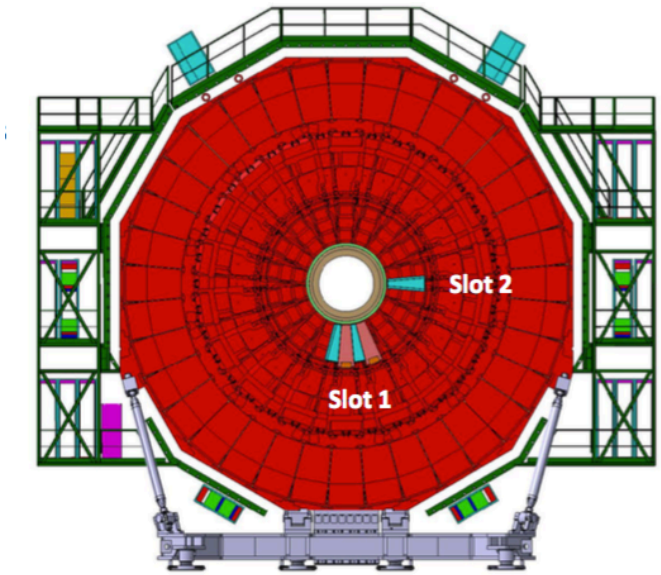
Further DCS, DB work on going for monitoring
DPG just starting work on real data!
DQM needs to be set up

First report in CMS Run Meeting – 14.3.2017

Good progress in DSS h/w
Insert in Action Matrix Plan 10.4

Planning for combined run with CSC for latency scan
Eventually muon detection with GEM soon

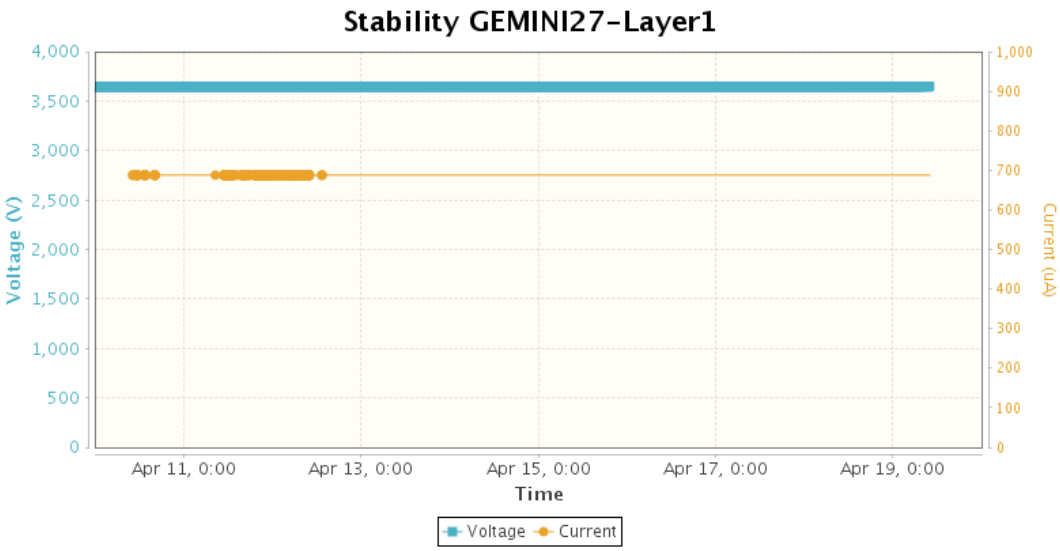
Detectors installation status



5 GEMINIs (2 layers ea.) were installed on the YE-1 endcap disk during this EYETS:

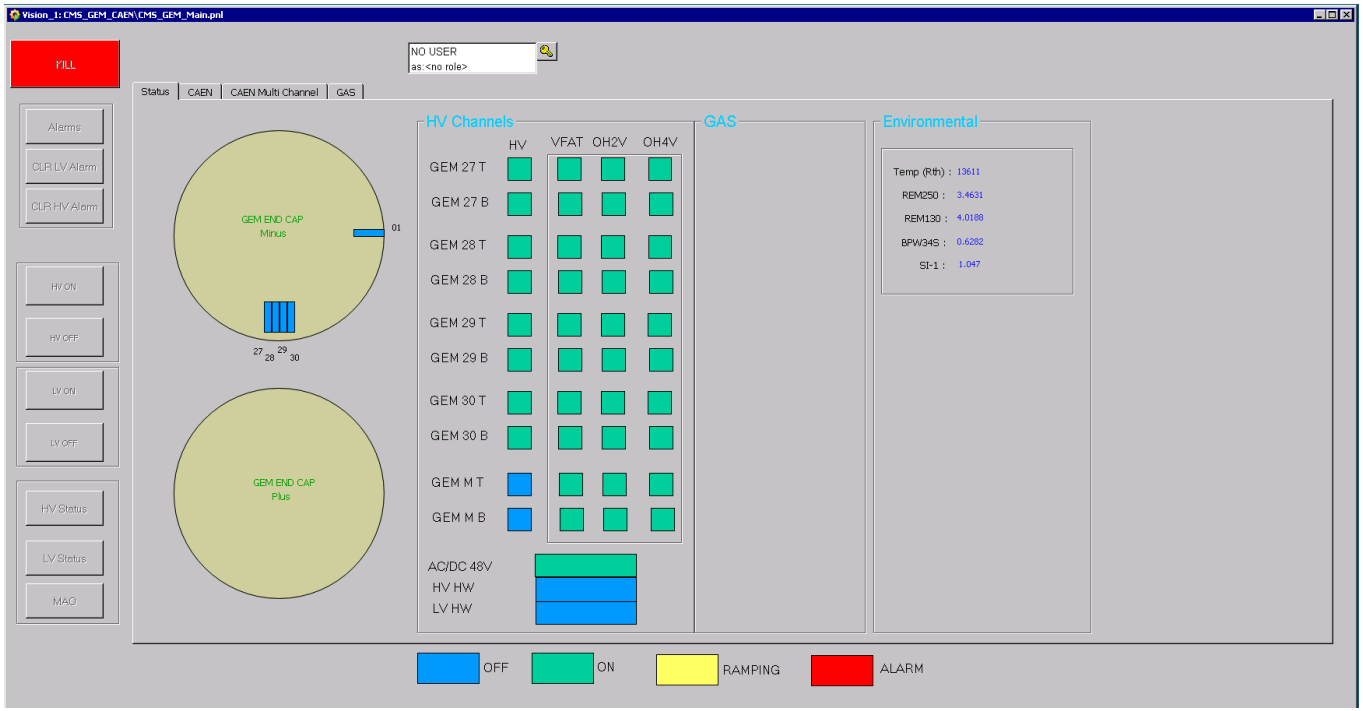
•4 GEMINIs are powered with the standard HV divider, the 5th one with the multichannel power supply

The HV and LV system has been commissioned and is operational. The gas system and the cooling system have been completed and are running as expected.



Stability tests are ongoing for HV, LV and gas to verify the performance of the detectors before the first beam.

DCS status

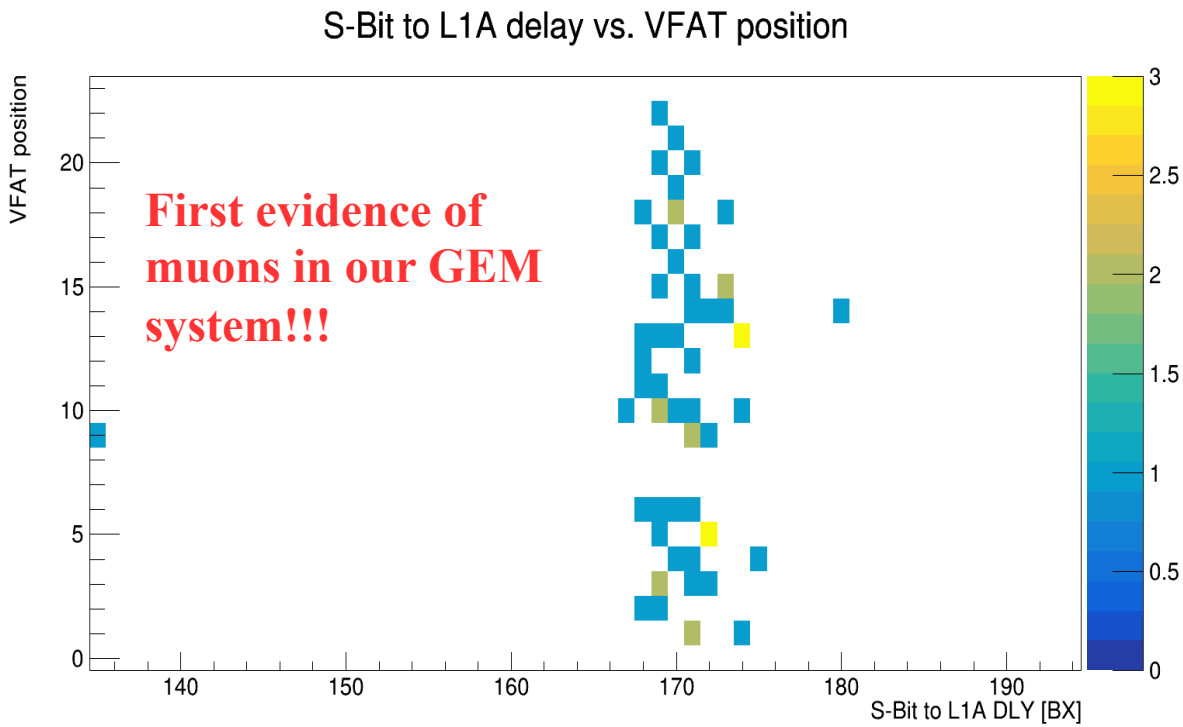


The GEM DCS is running locally and actually allows the shifter to:

- Control/Monitor the standard HV
- Control/Monitor the multichannel HV
- Control/Monitor the LV
- Monitor the gas system and the environmental parameters
- Monitor the RadMon sensors

The development of the GEM Finite State Machine, which is the first step towards the inclusion on the GEM DCS in Central, is ongoing

DAQ status



λAlready deployed and tested scan scripts that allow to configure the system and perform noise studies. (S-curves, threshold scan, latency scan.

λGood understanding of noise in our system. Currently optimizing the system to lower down the noise.

λDeploying XDAQ infrastructure at P5.

λDeveloping the Function Manager to be able to have miniDAQ for DOC shifter and to enter global CMS DAQ.

λDOC#1 already started in March. We are filling the shiftlist

Waiting for internal review on readiness of DQM, DCS (central), Global DAQ