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CMS Status

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on behalf of the CMS Collaboration

LHCC Open Session
25th May 2016

Outline

- **Preparing for 2016 startup**
  - Magnet status
  - Phase 1 Level 1 trigger commissioning
  - DAQ and High-Level trigger developments
- **Commissioning and data taking with stable beams**
  - Commissioning activities with cosmics, beam splash, first collisions
  - Detector status and performance
- **Physics status and plans for Summer Conferences**
- **Phase I upgrades status: Pixel and HCAL**
- **Summary and outlook**

Magnet: recommissioned and stable at 3.8T

- **Intense programme of work during YETS to refurbish magnet system for 3.8T operation in 2016**
  - **Cold box cleaning** to remove traces of Breox contaminant - **successful**
  - **Replacement of primary oil removal system (PORS) - successful**
- **Magnet cool down commenced on 9th April**
  - **28th April: declared magnet + cryo ready -> ramp to 3.8T**
  - **reached full field at 12:30 on 28/4 -> ready for physics**
  - **Operational parameters of cryogenic system are stable (see backup slide)**
- **Great thanks to:**
  - Colleagues from CERN-TE dept, technical support from across other CERN depts, CERN-EN,EP, CERN Management, CMS Magnet team and integration office, contractors (particularly Altead, ZEC service), CMS members for support and advice

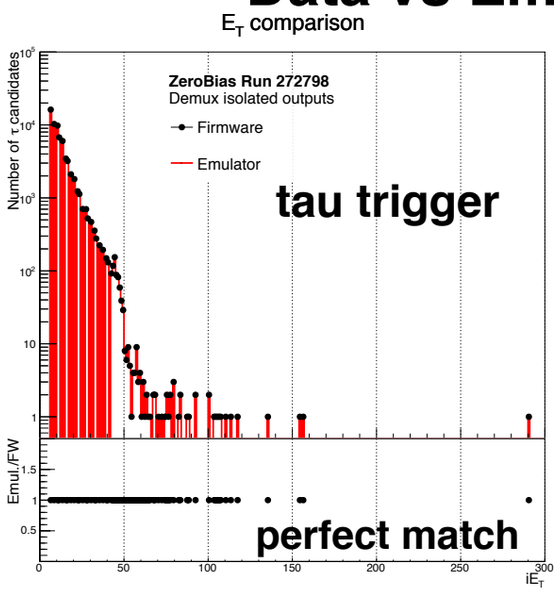
Phase 1 L1 trigger

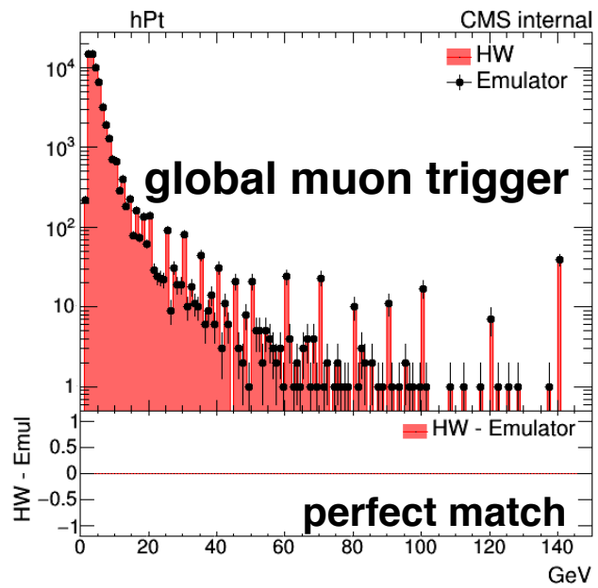
- **<u>Phase 1 Upgrade L1 trigger commissioned with first data</u>**
  - New calorimeter and muon trigger systems deployed, with improved granularity and more advanced algorithms:
    - improved efficiencies, PU rejection, object ID and resolution compared to 2015
  - Huge effort in developing firmware, emulators, online software
    - close to 100% matching between data and emulator in first collisions
    - Algorithm performance appears as expected with first data

Calorimeter trigger granularity improved

2015 2016

Data vs Emulator E_T matching





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DAQ and HLT

- **<u>DAQ: planned updates and consolidation</u>**
  - Integration of several new uTCA-based systems in readout
  - Scheduled replacement of obsolete CPU nodes
  - HLT cloud routinely used for MC generation, commissioning inter-fill dynamic usage
- **<u>HLT: menu development ongoing for new L1 inputs</u>**
  - Significant effort during the last few months to adapt and HLT menus to the upgraded Phase 1 Level-1 trigger algorithms
    - targeting a range of peak luminosities: $5x10^{33}$-$1x10^{34}$ $cm^{-2}s^{-1}$ (PU ~25–35)
  - Also collecting data for detector calibration/alignment & commissioning
  - Deployed special menus: VDM scan (lumi) and low pileup runs for FSQ/HIN

First performance studies using recent data are encouraging; no major surprises

Algorithms and menus are being fine-tuned with data and updated menus will be used for large-scale MC production

CMS commissioning

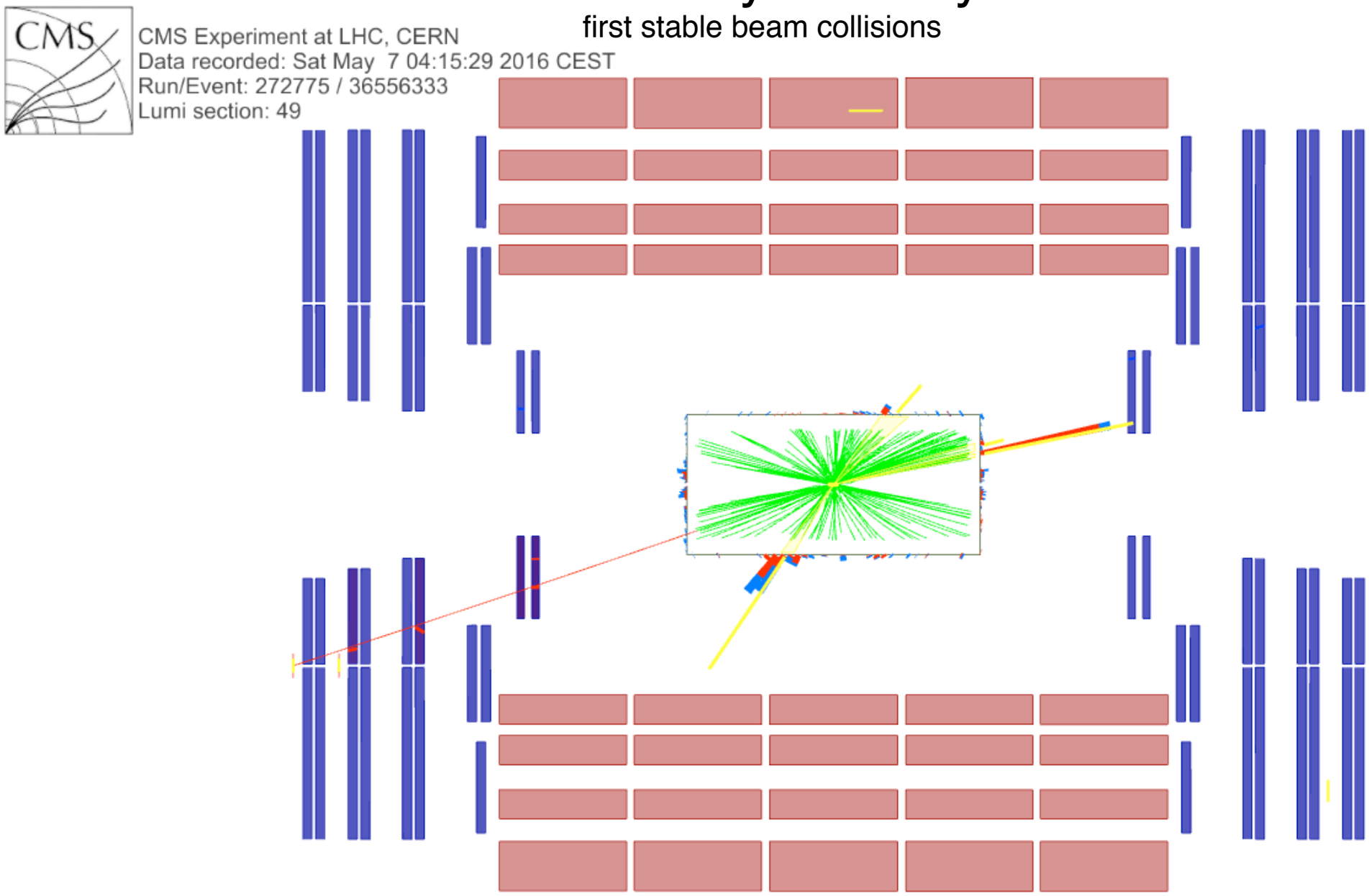
Commissioning status

- **Commissioning before beams**
  - Re-establish global runs with all subdetectors following YETS
  - Commission Phase 1 upgrade trigger
  - Record cosmic muons for tracker alignment
- **Beam splash and non-stable collisions**
  - Establish BX synchronisation with LHC, check subdetector readout and trigger timing, subdetector timing scans
- **First stable beams (0T/3.8T)**
  - Complete subdetector timing and bias scans
  - Time-in and enable L1 algorithm bits, test L1 and HLT menus
- **Special runs**
  - Van der Meer scans on 17/18 May (data good, but cryo lost during scan)
    - important to propagate our 2015 luminosity uncertainty (2.7%) to ICHEP

Stable beams

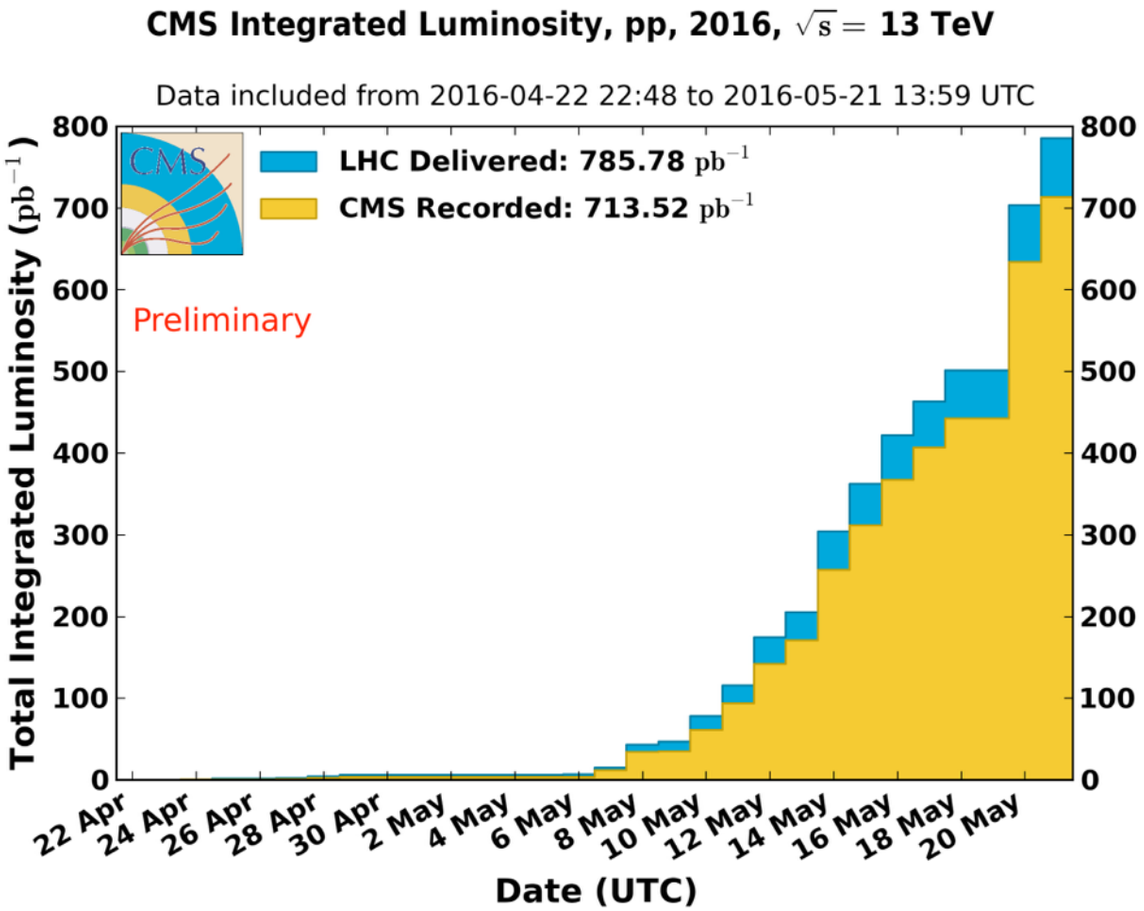
Saturday 7th May

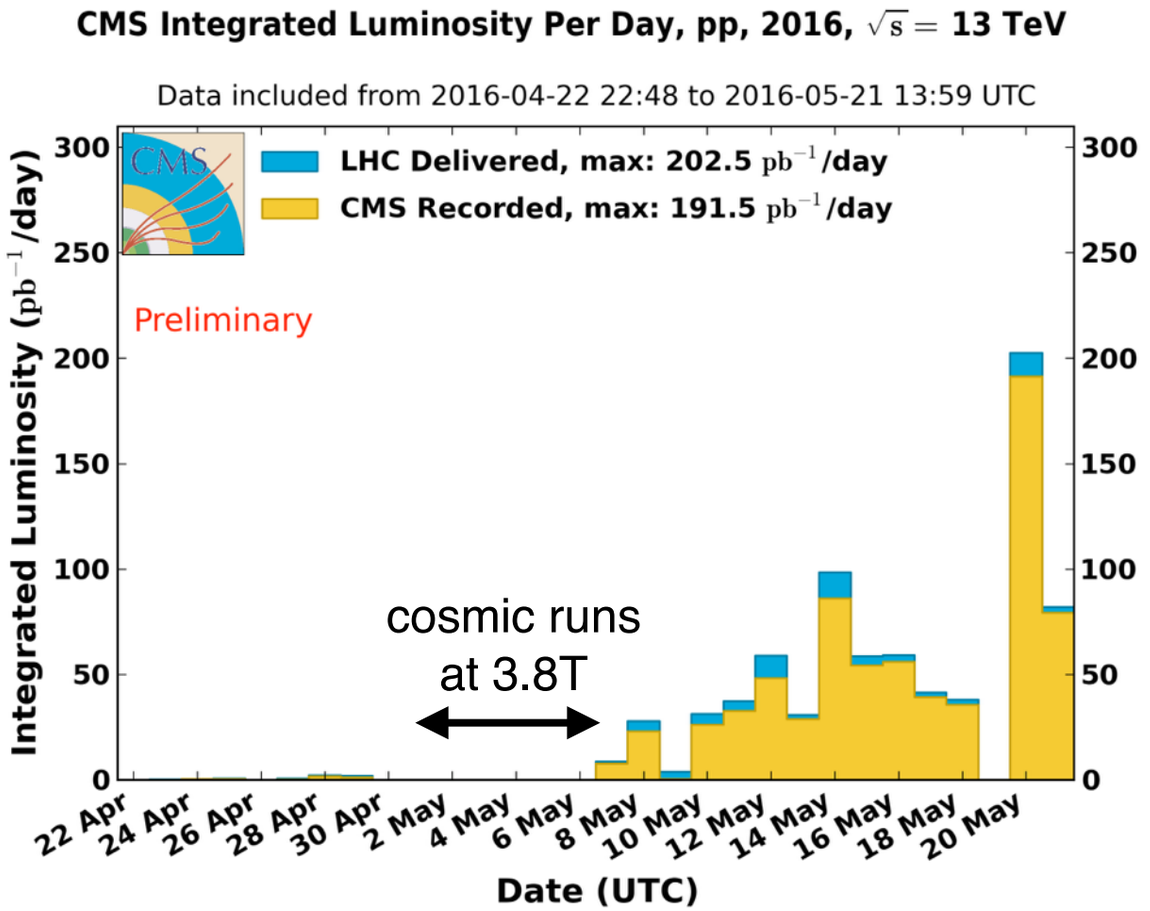
first stable beam collisions



All subdetectors in the run, and fully operational

CMS data taking efficiency





- 60 pb^{-1} devoted to detector commissioning, special runs
- Data taking efficiency for remaining 725 pb^{-1} sample: **92%**
  - Work ongoing to minimise downtime (firmware improvements for new readout systems)
  - 1.5M cosmic muons (for tracker alignment) were recorded at 3.8T during recent LHC outages

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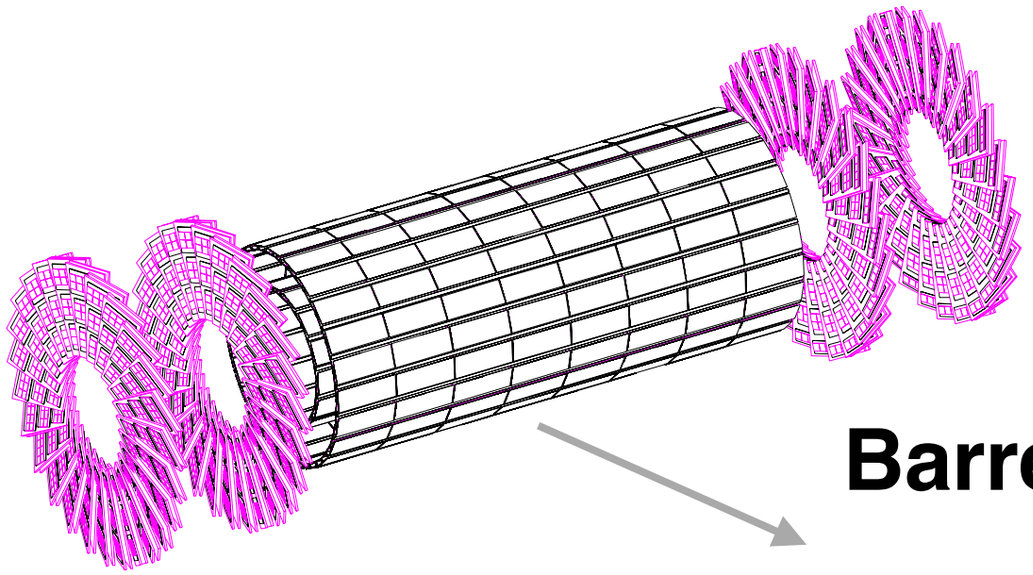
Tracker readiness

- **<u>Pixel and Strip Tracker detectors ready for Physics</u>**
  - Fraction of active channels as high as in 2015: **Pixel: 98.8% Strip 96.6%**
  - Pixel thresholds and Strip noise as low as in 2015
  - Detector re-tuning completed, timing optimized using initial collisions
  - Sufficient collision and cosmic data collected to update alignment
- **<u>Data quality from first collisions runs is good</u>**
  - Tracking performance now being assessed with first data
  - Tracking reconstruction algorithms are stable wrt 2015 run
- **<u>Beam spot determined routinely in 2016 data</u>**
  - x,y positions are close to 2015 - barrel pixel position has remained ~constant
  - follows coherently any modification of beam conditions from LHC (see backup)

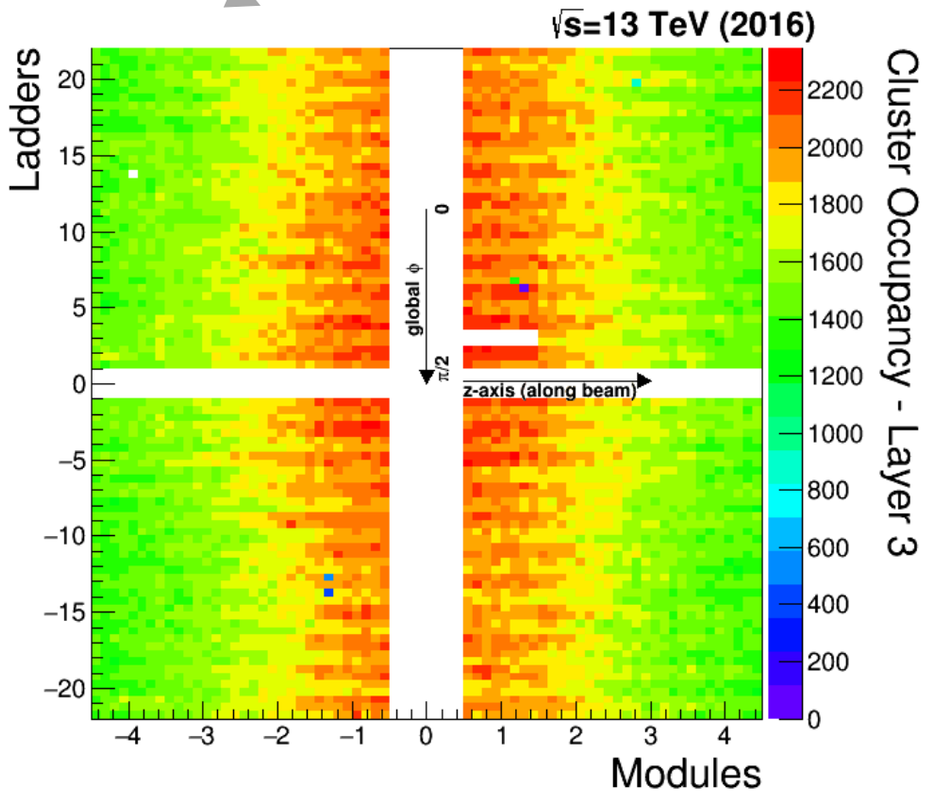
Parameter	x [cm]	y [cm]	z [cm]	σ_z [cm]
2015 Data (50ns)	0.077	0.097	-1.61	4.2
2016 3.8T Data	0.065	0.093	0.40	3.6
2016 0T Data	0.053	0.096	1.07	4.2

Pixel occupancy

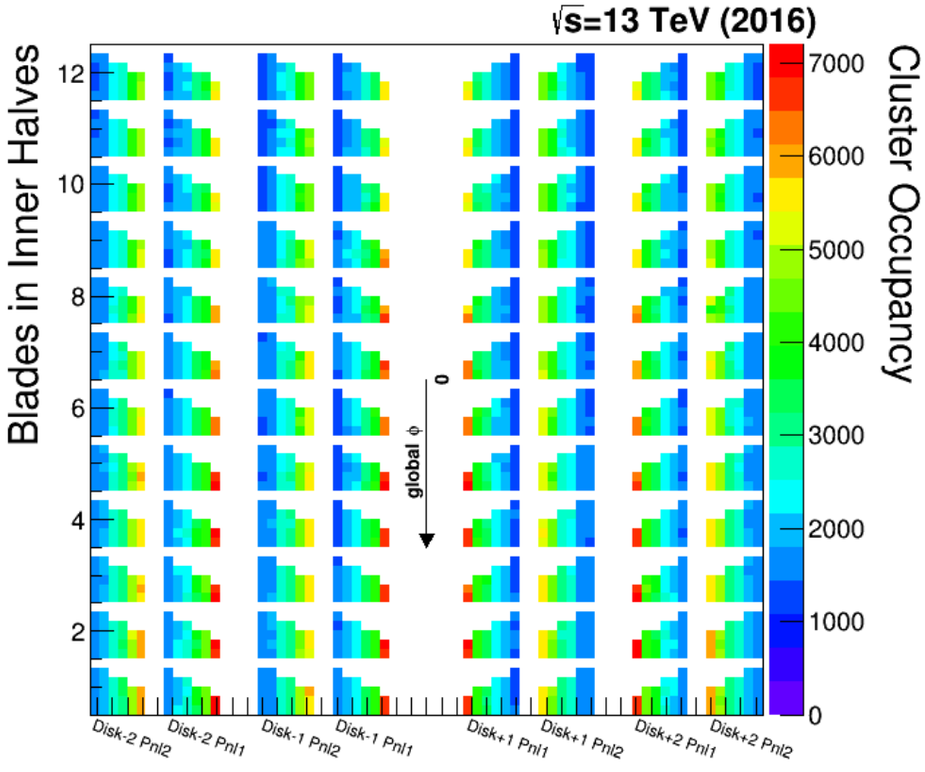


>98% of pixel reading out

Barrel



Endcaps



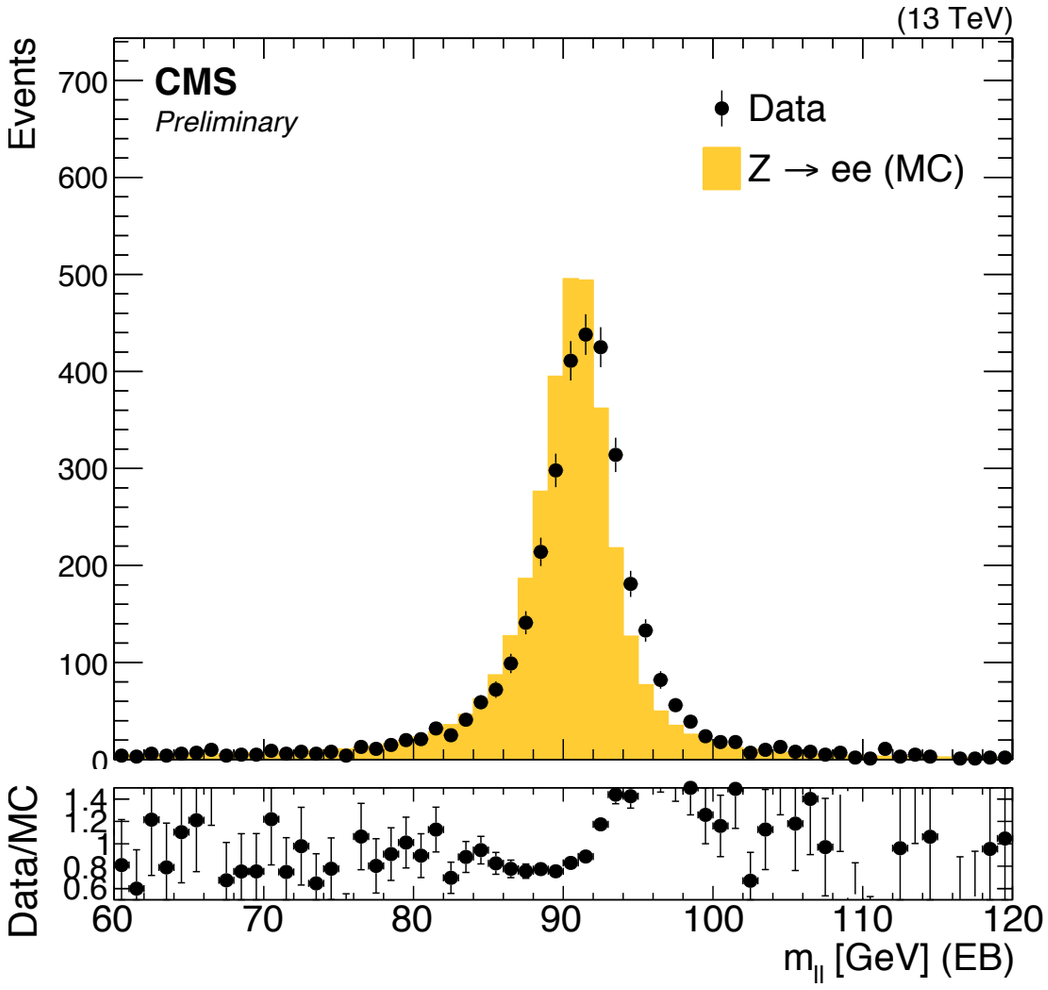
ECAL readiness

- **Detector status (active channel fraction)**
  - **Barrel: 99.1%, Endcaps: 98.7%, Preshower: 99.9%**
    - **preshower active channels increased by 3%** (on-detector repair during YETS)
- **Commissioning with beam**
  - **Deployed new readout settings for 2016** - to cope with higher pileup in 2016
  - Restarted **regular calibration sequence data taking**
    - Recorded $10pb^{-1}$ with **preshower** in high gain for **MIP calibration**
    - Validated **trigger and readout timing**
      - **measured per-channel pulse shapes** using special lone colliding bunch triggers to optimise amplitude reconstruction performance
    - **Calibration streams deployed** and first data being analysed. Updates to alignment and intercalibration foreseen prior to ICHEP

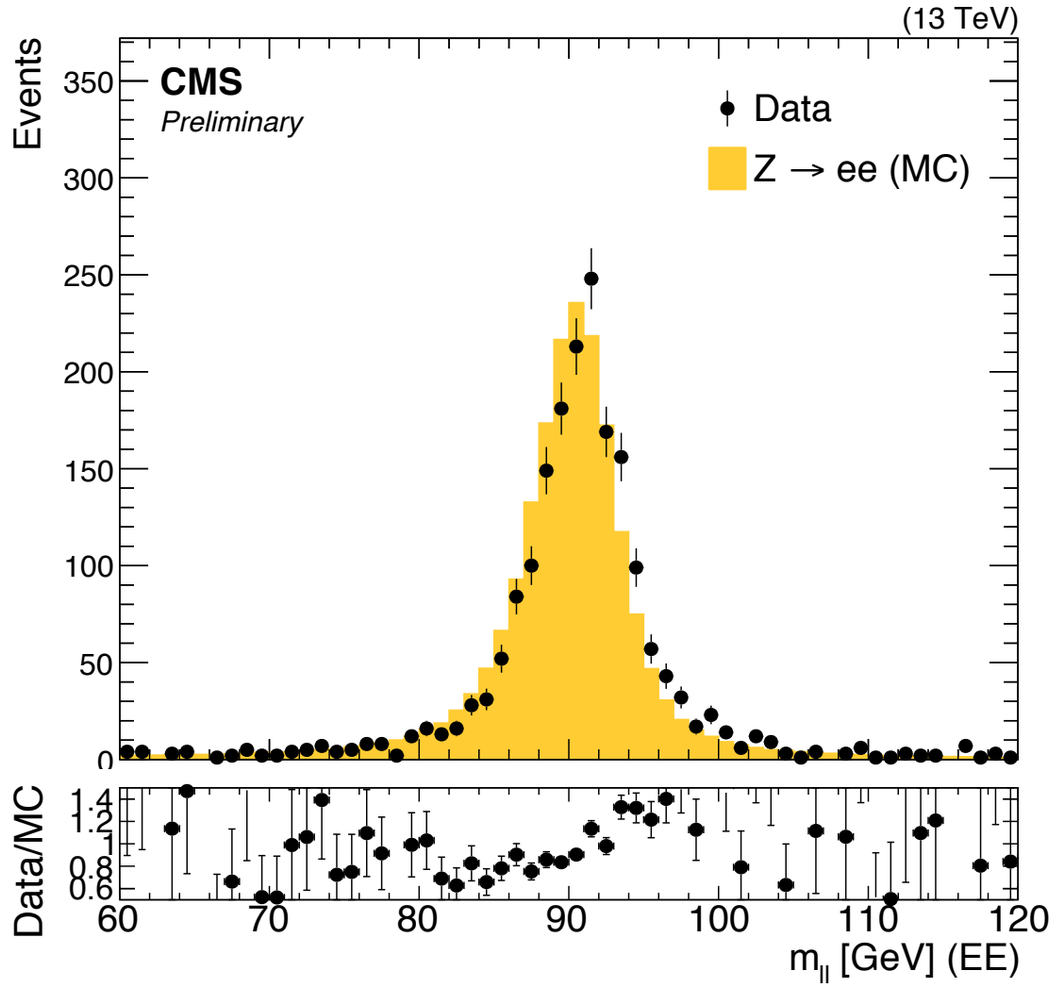
Egamma performance

- Promising performance “out-of-the-box”

Z-> ee mass, both electrons in Barrel



Z-> ee mass, at least one electron in Endcaps

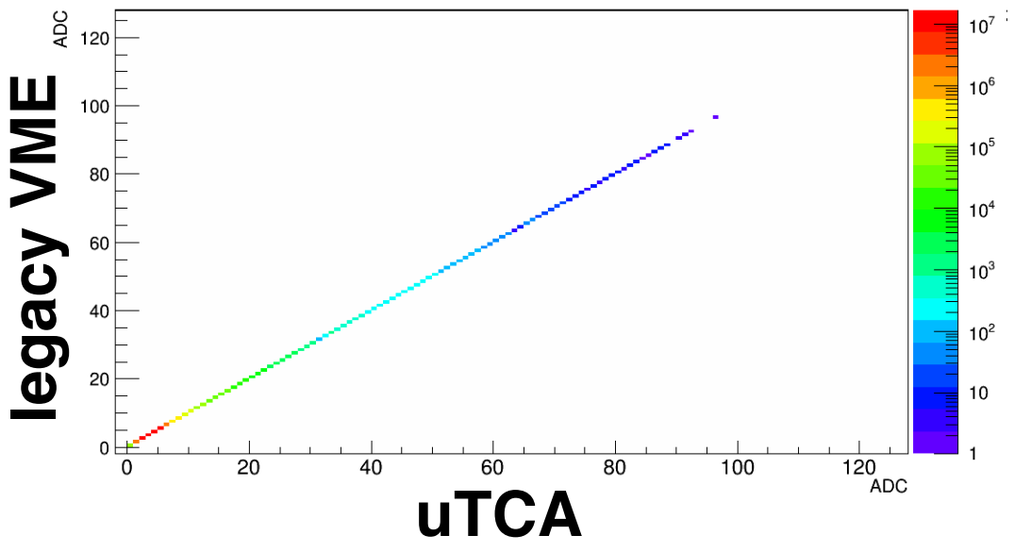


- Resolution in data comparable to MC using 2015 calibration
  - re-calibration of energy scale from 2016 data yet to be applied

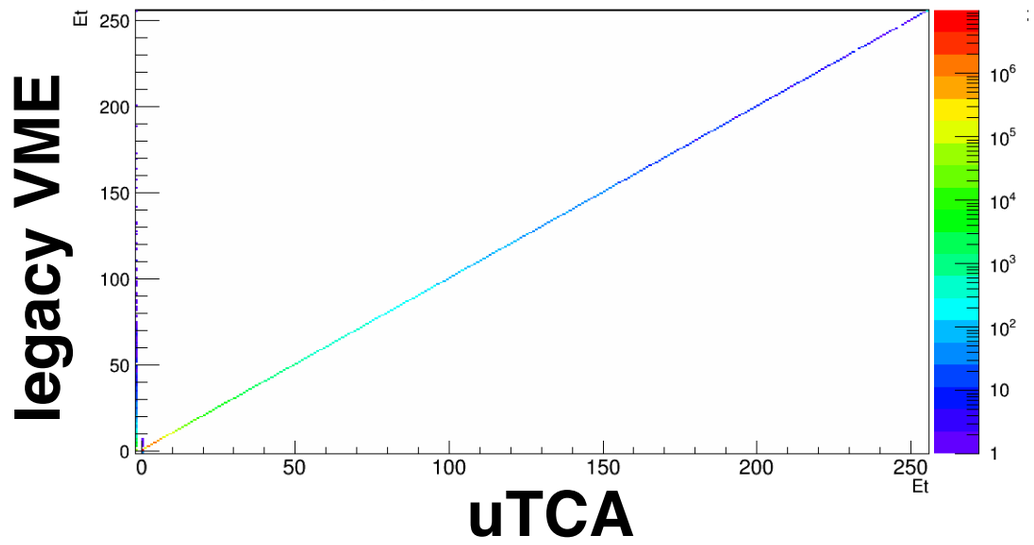
HCAL readiness

- **Detector status: >99.8% of channels operational**
- **Many updates deployed during YETS**
  - New uTCA-based readout for HB and HE (10Gb/s links)
  - Switched to Phase 1 L1 trigger (uTCA inputs from HB,HE,HF)
  - Completely new DQM framework to improve detection of data integrity problems
- **Data checks with beam splash and first stable beams**
  - HCAL timing synchronisation confirmed. HF timing scan performed.
  - Verified matching of data and trigger primitives from new uTCA and legacy VME readout

Readout



Trigger Primitives

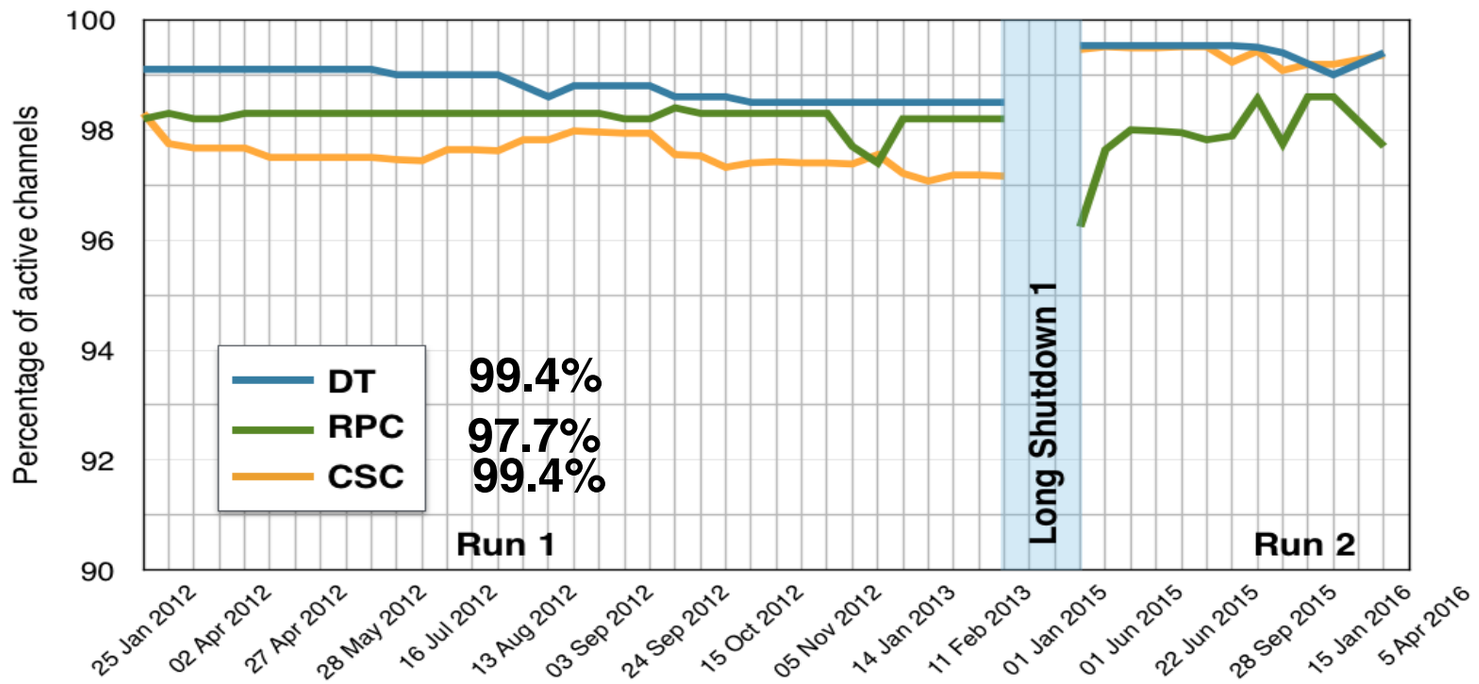


Muon system readiness

- **Muon detectors (DT, CSC, RPC) have performed well during the first collisions of 2016**
  - Efficiencies and timing are very good for all detectors (see next slides)
- **DT accomplished a major goal with the installation of TwinMux**
  - Trigger data concentrator for new L1 muon trigger
- **Inclusion of RPC information in the upgraded Level 1 muon trigger expected soon**
- **Longevity tests ongoing at the gamma irradiation facility GIF++**
- **Upgrade GEM GE1/1 Slice Test (8 out of 144 chambers) being prepared for installation early next year**
  - All chambers built, and electronics are in the production stage

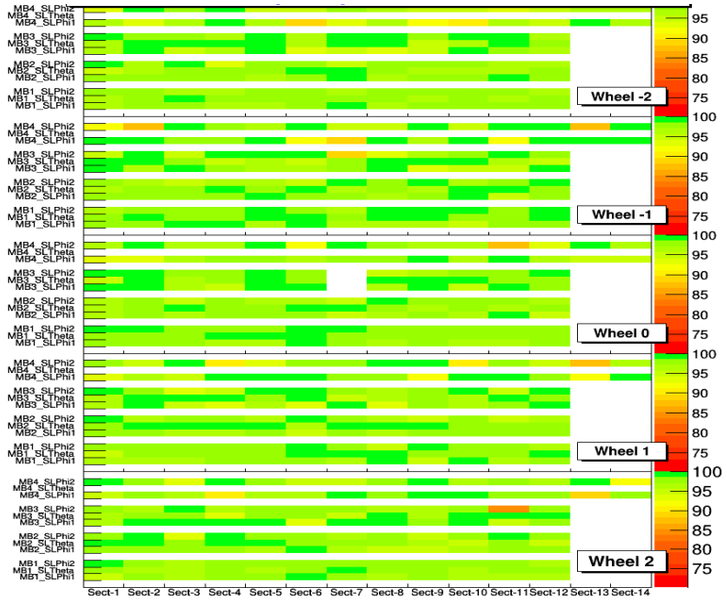
Muon system efficiency and timing

Muon detector active channel fraction vs time

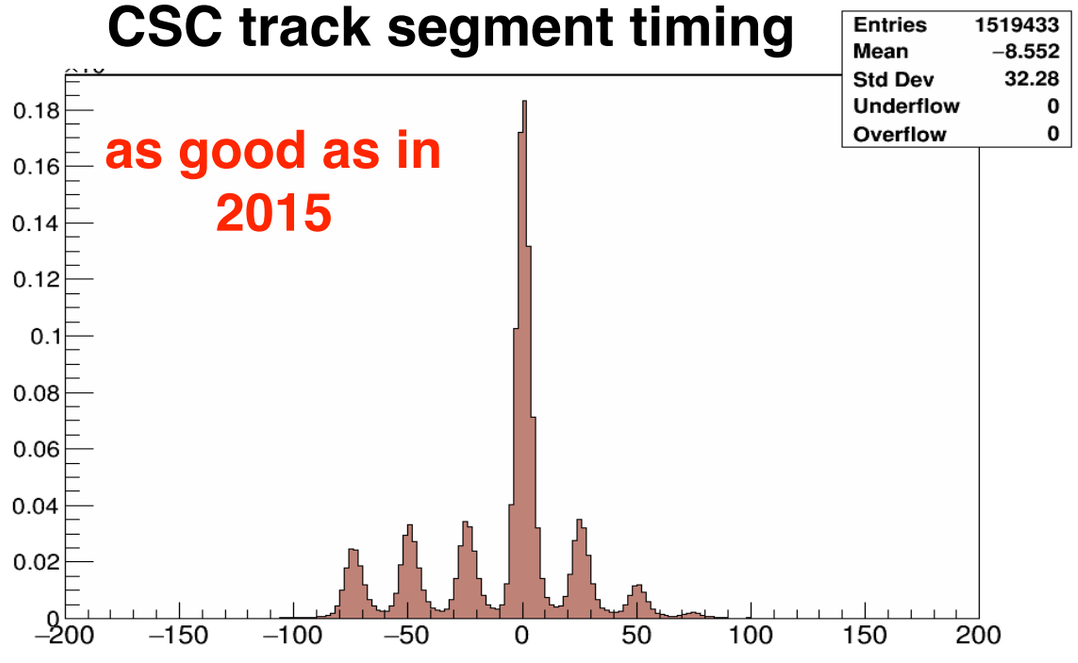


Muon efficiency close to 100%

DT efficiency



CSC track segment timing



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CT-PPS status

CMS-TOTEM Precision Proton Spectrometer

- **Accelerated program, given potential sensitivity to X(750)->γγ**
  - Via central exclusive production of X(750), with protons detected by CT-PPS
- **Huge amount of work to achieve full integration of proton tracking and timing detectors in CMS on a short time scale**
  - TOTEM Strips integrated in CMS for proton tracking. Now part of CMS normal data taking
  - Diamonds (as tracking and timing detector) should be installed during June TS
  - Offline track reconstruction code is now available in latest CMS software release
- **Sensitivity depends crucially on minimising detector/beam separation**
  - **LHC orbit configuration:**
    - Several bump designs studied to increase dispersion at Roman Pot (RP) locations.
    - "Mild" orbit configuration was approved by LMC -> 2/3 RP stations within target acceptance
  - **Many thanks to LHC for their important efforts to increase CT-PPS acceptance**
  - **Roman Pots insertion validation:**
    - Insertion tests to 15σ (with tolerance) in all intensity steps were successful until now.
    - Insertion at 15σ (without tolerance) was successful with 49 and 600 bunches.

Physics status and plans

see M. Sani presentation at March LHCC for details of physics object tuning/improvements for 2016

(small changes and optimisations, including tuning for higher PU)

Physics

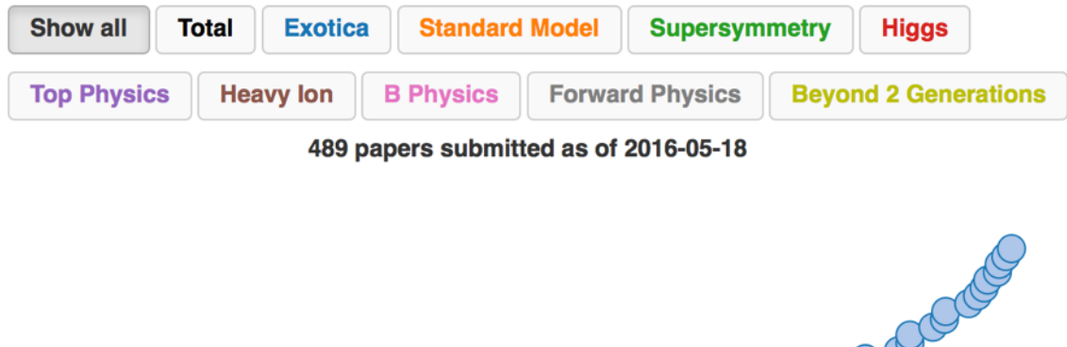
Rich physics output from 2015 data so far:

- 82 public results from 2015 data (most released for Moriond series)
- Many more being released soon, targeting Blois, Initial Stages (HIN conference)

Current plans:

- Push publication of results from 2015 data (most achieved before 2016 pp run started)
- **Target first round of 2016 results with up to 5-10 fb^{-1}**
  - Targeting LHCP for first performance studies
  - Stay on the lookout for signs of new physics until ICHEP

489 papers submitted



Plan for 2016: Data & MC

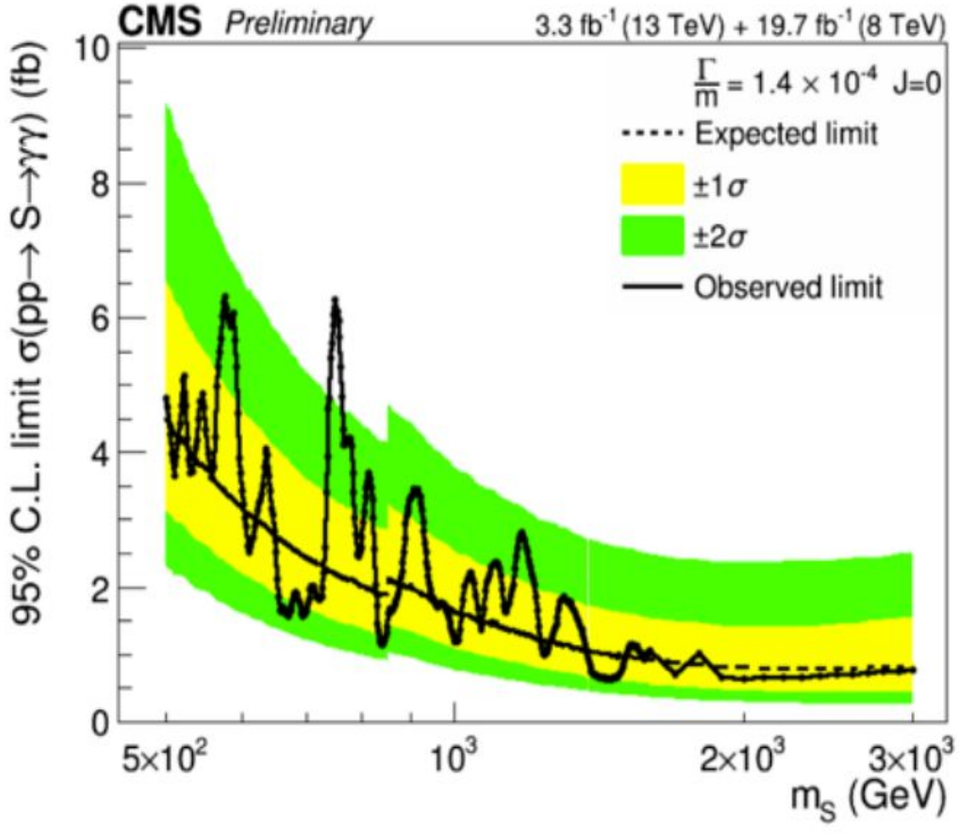
- **Data calibration and alignment to be updated prior to ICHEP:**
  - **<u>Alignment must be reassessed due to opening of endcaps during YETS</u>**
    - Tracker alignment being derived now
    - Followed by dependent workflows (ECAL, Muon alignment)
  - **<u>Energy intercalibration to be checked/updated</u>**
    - Verify performance of existing calibrations using physics events (Z,W, minbias)
    - Re-derivation of ECAL intercalibrations requires about $1fb^{-1}$
    - HCAL response corrections to be assessed using laser calibration data
  - **<u>Target is to deploy updates online mid-June</u>**
    - Plan to reprocess earlier data with these updated conditions prior to ICHEP
- **Production of MC for ICHEP analyses well underway:**
  - More than 3B events (of 5B total) already produced

Selected Physics highlights

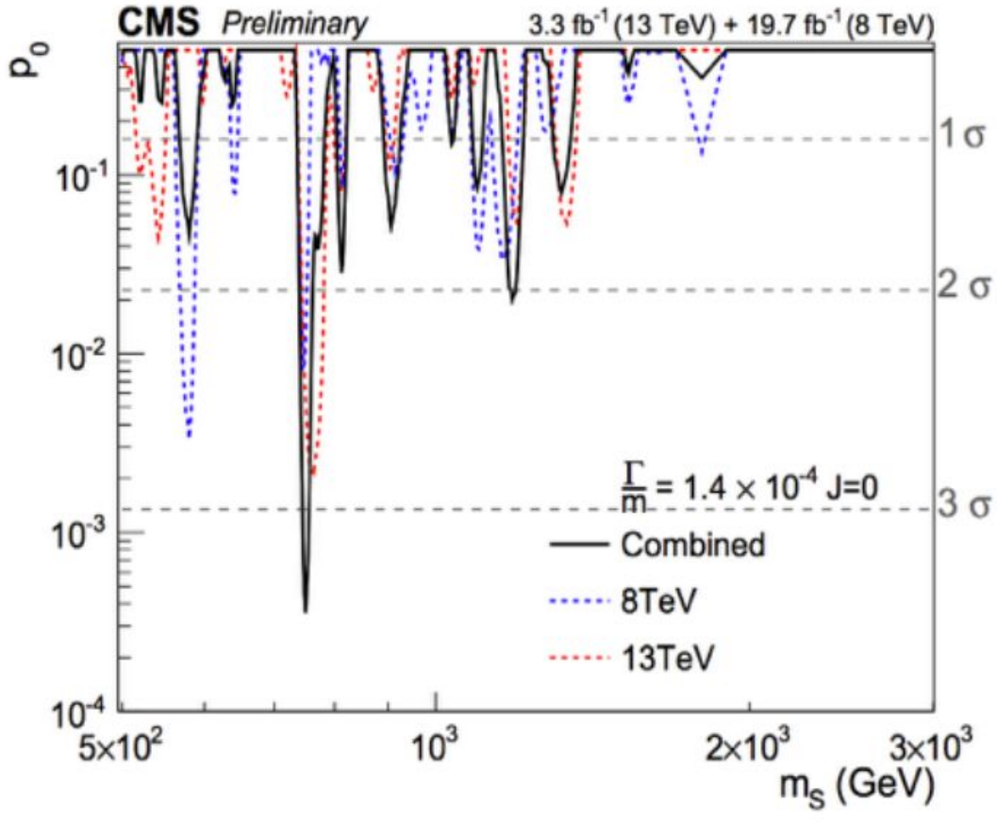
X(750)→γγ analysis

- Presented at Moriond EW
  - **Sensitivity improvements: new calibration (10%) + 0.6fb^{-1} of 0T data (10%)**

8 TeV/13 TeV Combined Cross section limit
(assuming narrow width spin 0 resonance decaying to γγ)



8 TeV/13 TeV Combined p-value
(assuming narrow width spin 0 resonance decaying to γγ)
Maximum local significance: 3.4 sigma @ 750 GeV

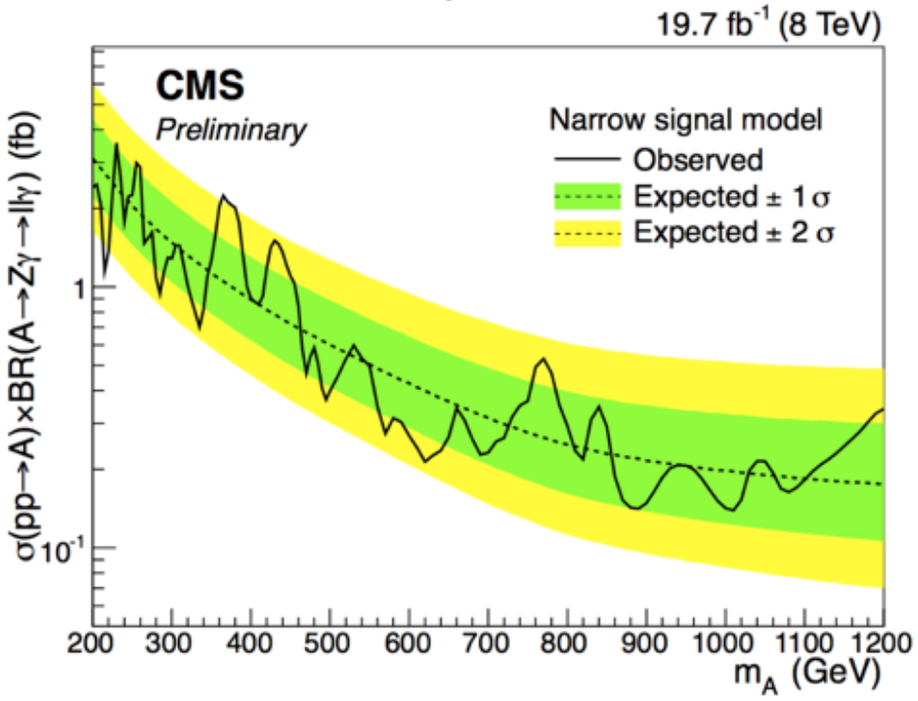


In focus from now up to and including ICHEP

X→Zγ search around 750 GeV

- <u>Presented at Moriond QCD</u>

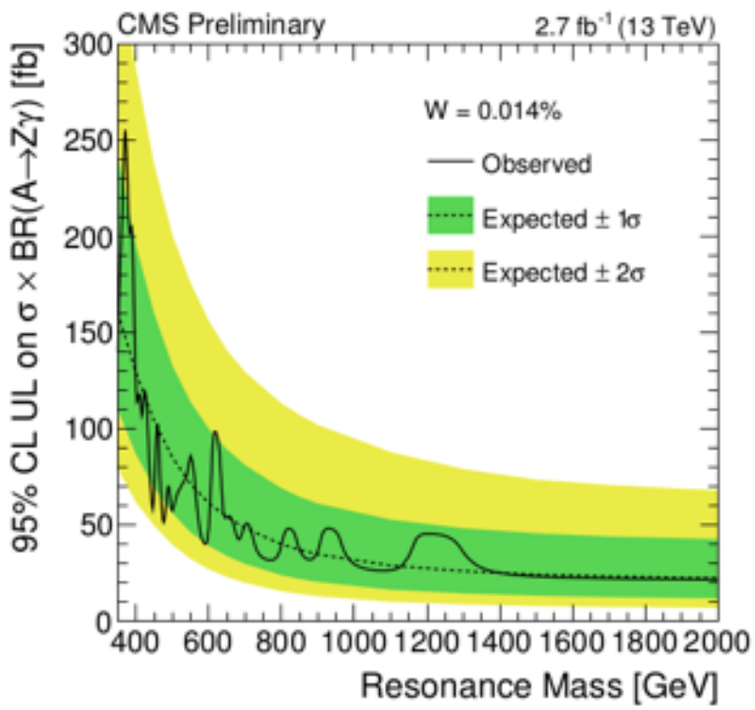
8 TeV
narrow signal model



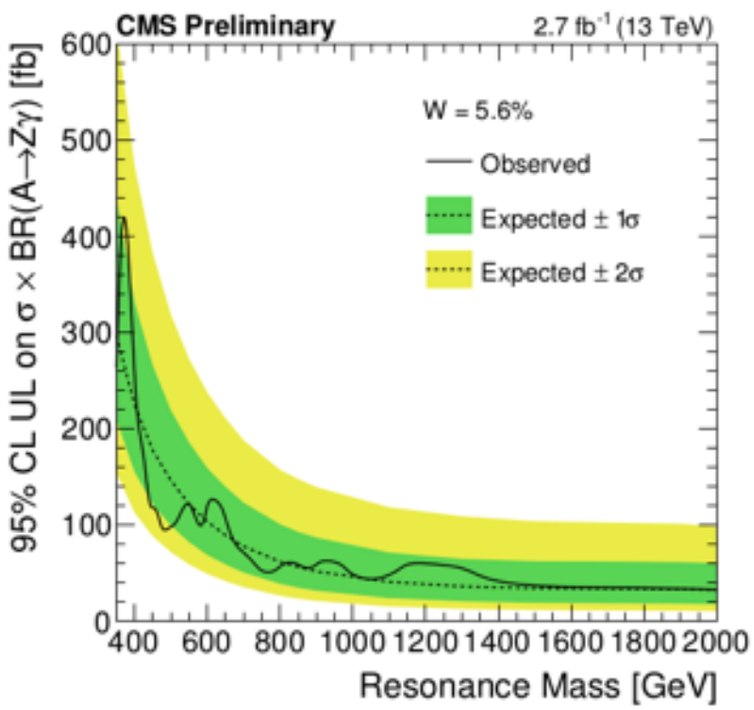
Small excess (<2σ) in the 750-800 GeV interval

σ Br ≲ 6 fb at 95% CL

13 TeV
narrow signal model



13 TeV
broad signal model



No excess in the 750-800 GeV interval

σ Br ≲ 30 fb at 95% CL

(narrow width assumption)

Equivalent to ~7 fb cross-section at 8 TeV

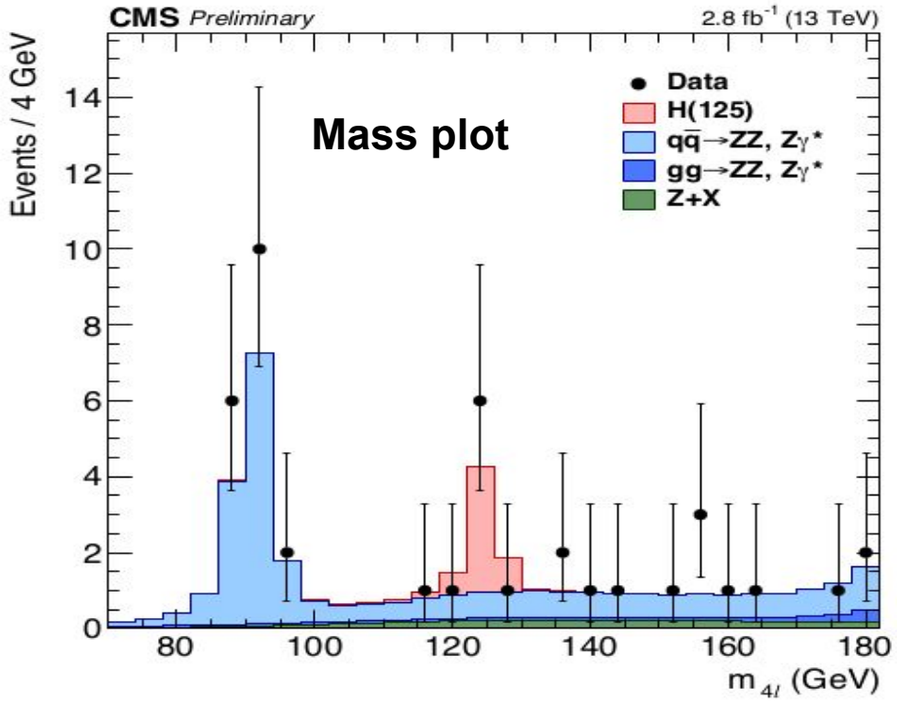
(assuming gg production mechanism)

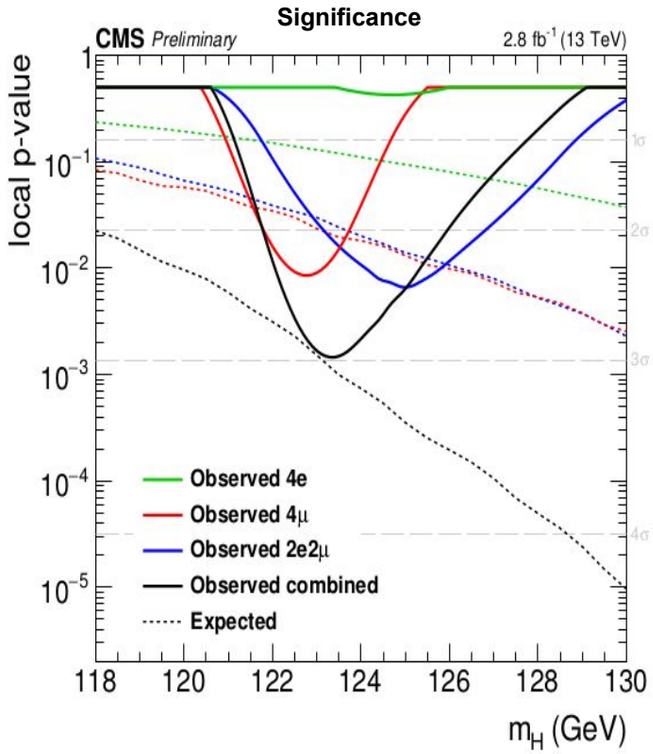
Larger statistics: expand to dijet, ll, ZZ, WW, HH, ZH final states

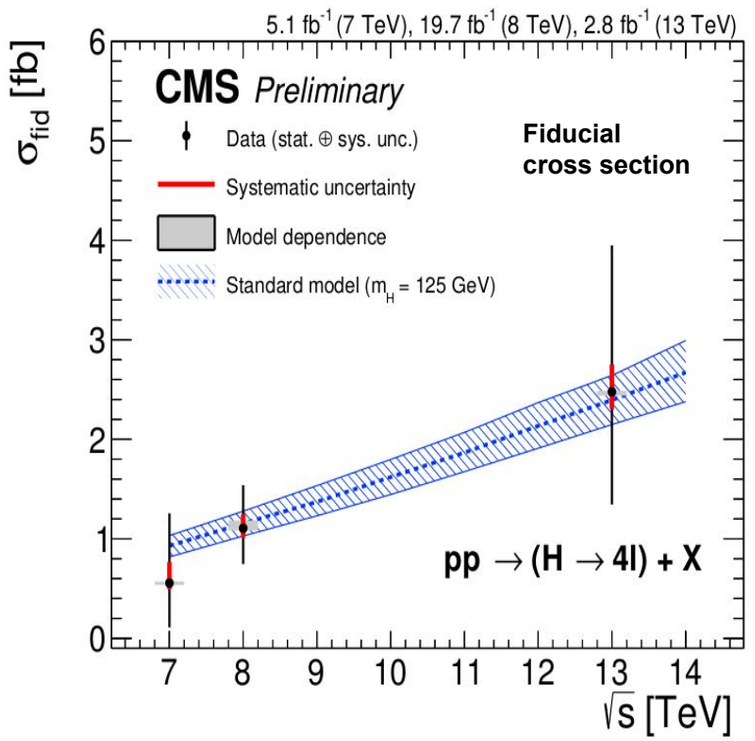
Higgs rediscovery @ 13 TeV

- Presented at Moriond EW

H→ZZ→4l







Clear excess in the m_{4l} mass plot @ 125 GeV

Observed (expected) significance: **2.5σ** (3.4σ)

Fiducial cross-section measurement: $\sigma_{fid}=2.66^{+1.58}_{-1.22}$ **fb^{-1}**

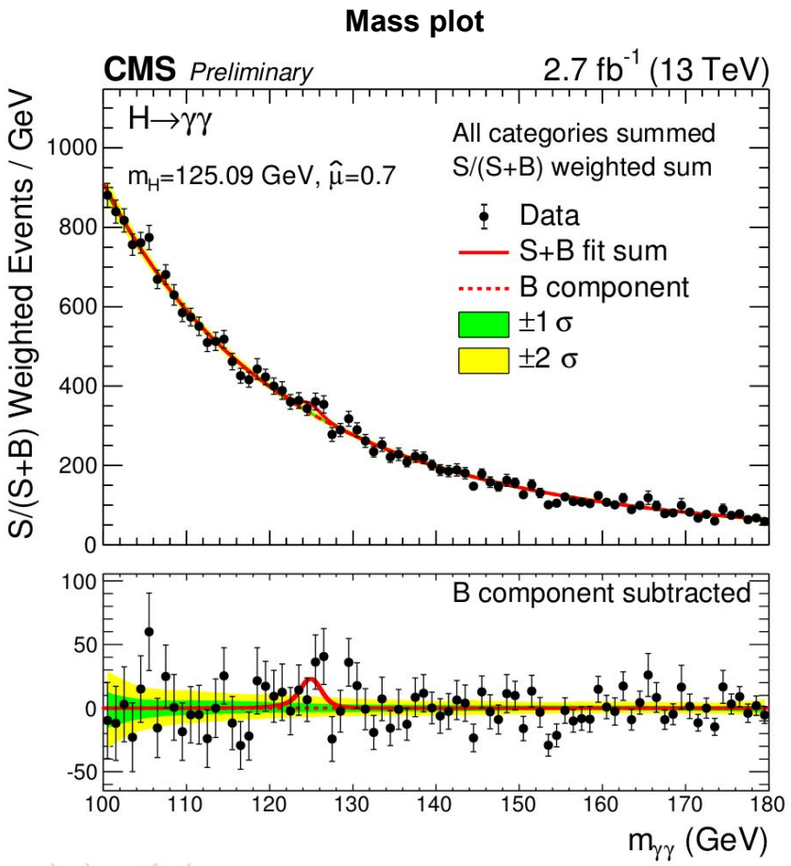
$\sigma_{SM}=2.50$ fb^{-1}

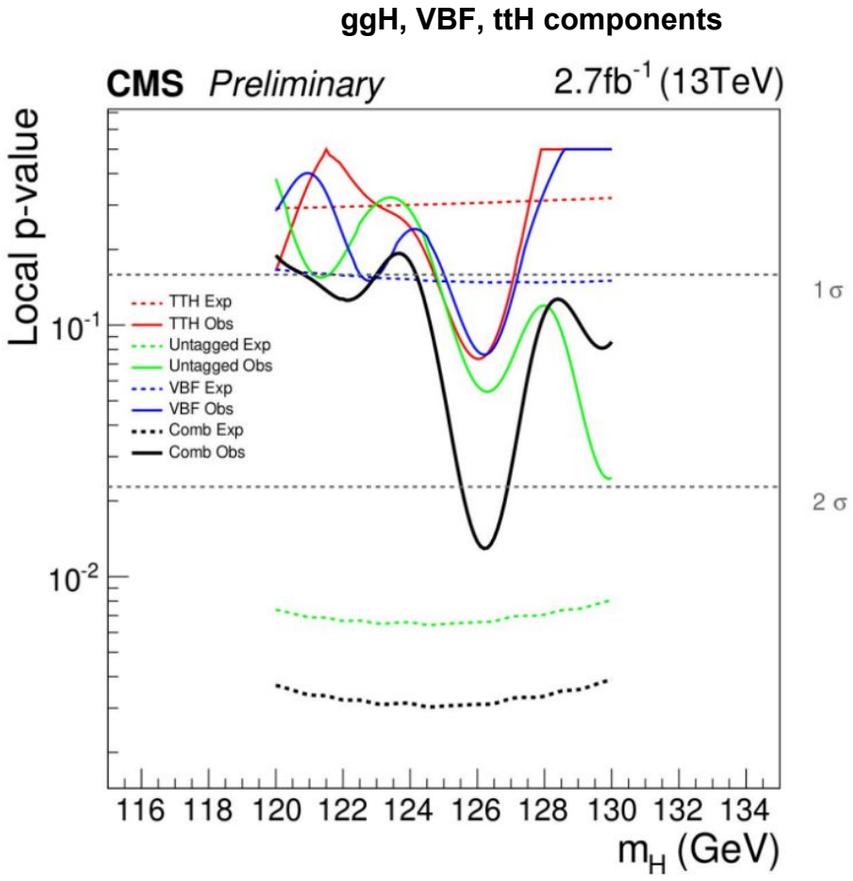
Next steps: expand to measuring properties and high mass search

Higgs rediscovery @ 13 TeV

- Presented at Moriond EW

H→γγ





gg->H, VBF, ttH categories analysed

Observed (expected) significance @ 125 GeV: **1.7σ** (2.7σ)

small deficit driven by untagged category (gg->H)

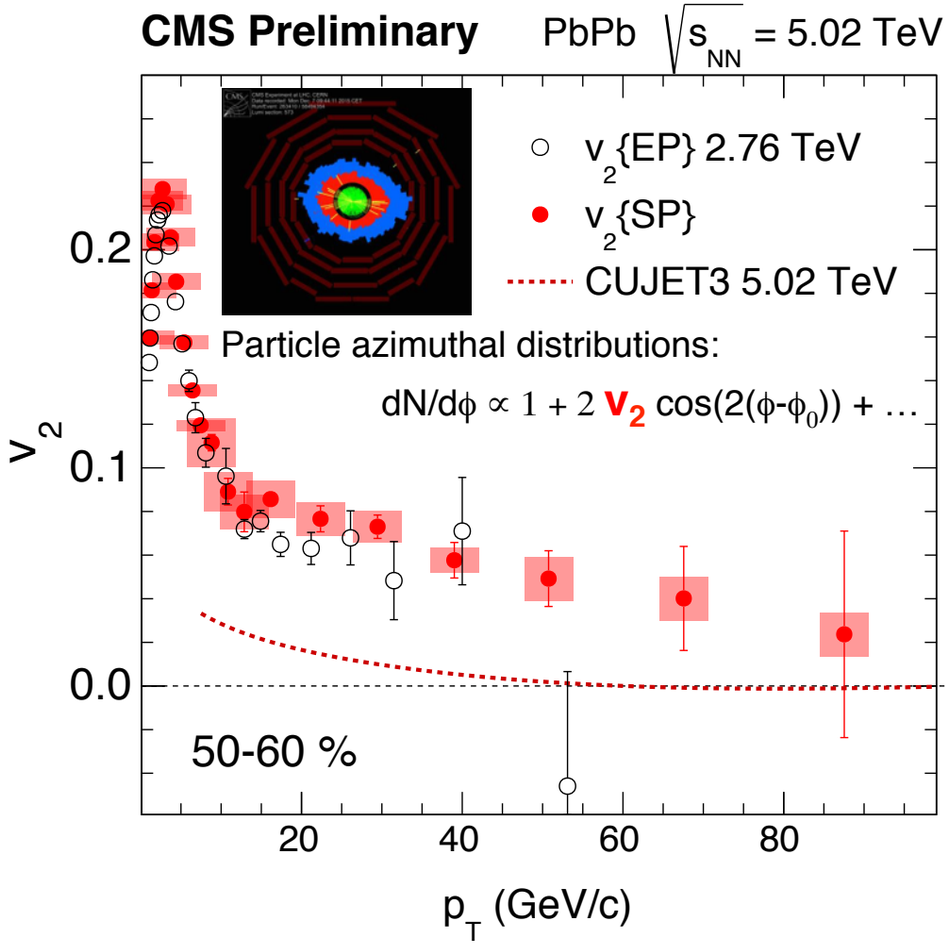
Consistent with SM expectation: **μ=0.69** $^{+0.47}_{-0.42}$

For ICHEP: reoptimise categories, properties (mass, couplings)

HI results (2015 PbPb run)

- Presented at Initial Stages this week

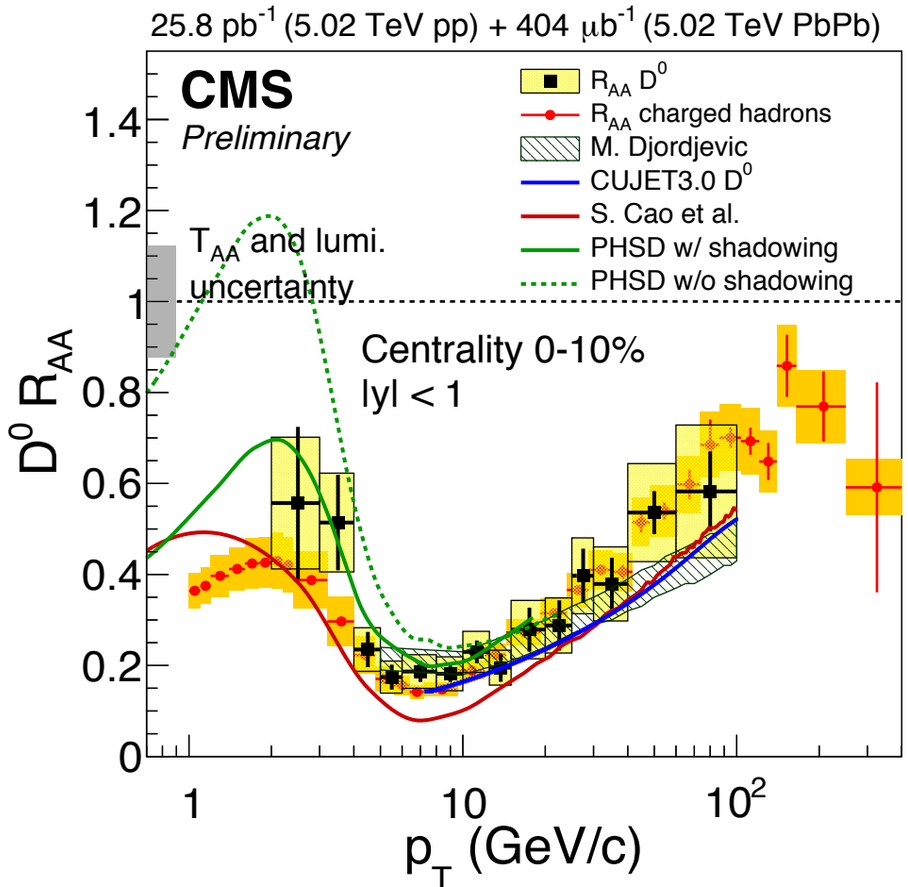
Elliptic anisotropy at very high p_T



v2 at high p_T sensitive to path length of hard parton in QGP

5.02 TeV results: extend to much higher p_T range with significant non-zero v2

Suppression of light and heavy flavours

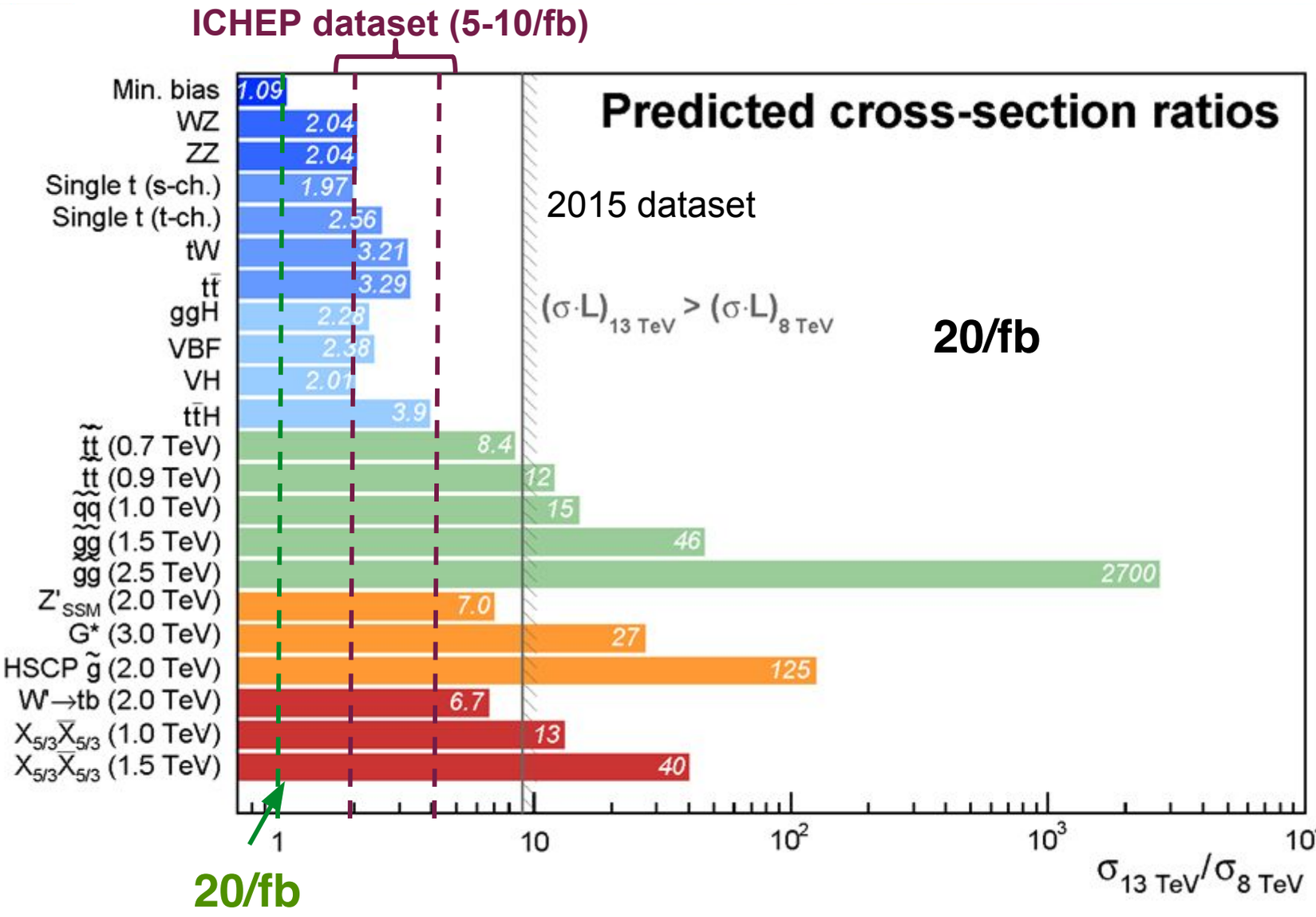


R_{AA} : nuclear modification factor

Strong suppression of light and heavy flavors with comparable magnitude over a wide p_T range

Physics plans for Summer conferences

Searches for masses/scales around or above 1 TeV should improve over Run1 results for L > 5 fb^{-1}.



Examples include

- Dark Matter searches
- X(750) searches
- High-mass Higgs searches, ttH
- Searches for X->VV
- New vector-like quarks singly-produced
- SUSY searches
- Z', W' searches

Precision studies (SMP, TOP, BPH, …) continue:

- Fully differential studies (W +jets, multijet studies...)
- High-mass final states: ttW, ttZ, tttt, multibosons

Phase 1 upgrade status

Pixel/HCAL upgrades during EYETS 2016/17

Pixel upgrade:

Maintain high efficiency, low fake rates at L=2e34, PU~50

Longevity up to 500fb^{-1}

New Readout chip to reduce data losses

4-hit coverage up to |η|=2.5

Reduced material budget

HCAL upgrade:

Improve performance at high lumi, PU by increasing depth segmentation of calorimeter

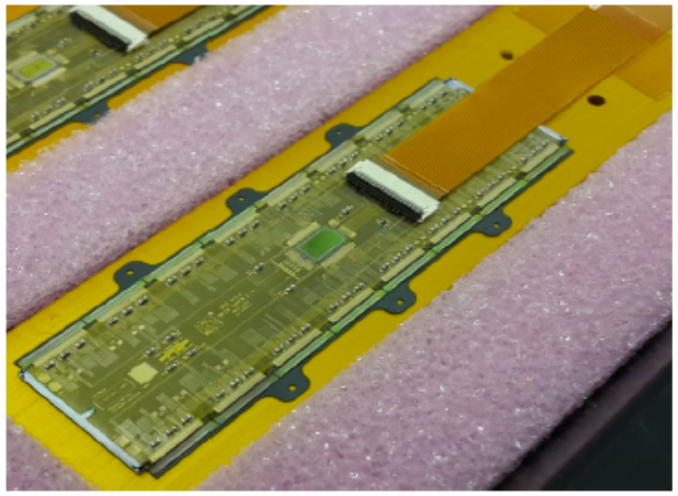
New photodetectors in Barrel/Endcaps (HB/HE) with higher QE

New multi-anode PMTs in Forward calorimeter (HF)

New on- and off-detector readout with higher output bandwidth

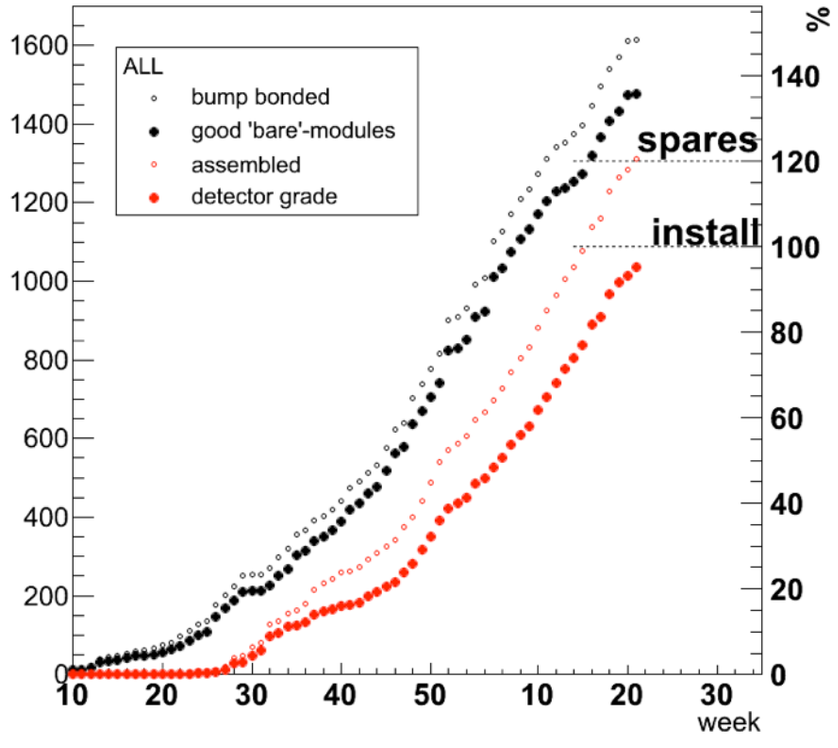
Phase 1 status: Pixel

- Detector construction progressing well
  - **Barrel:**
    - Modules for Layers 2-4 completed by end of June
    - ASIC for layer 1 (PROC600) submitted
    - Layer 1 module production in Aug-Sep: ~100 units
  - **Endcaps:**
    - Progressing steadily: 40 modules/week

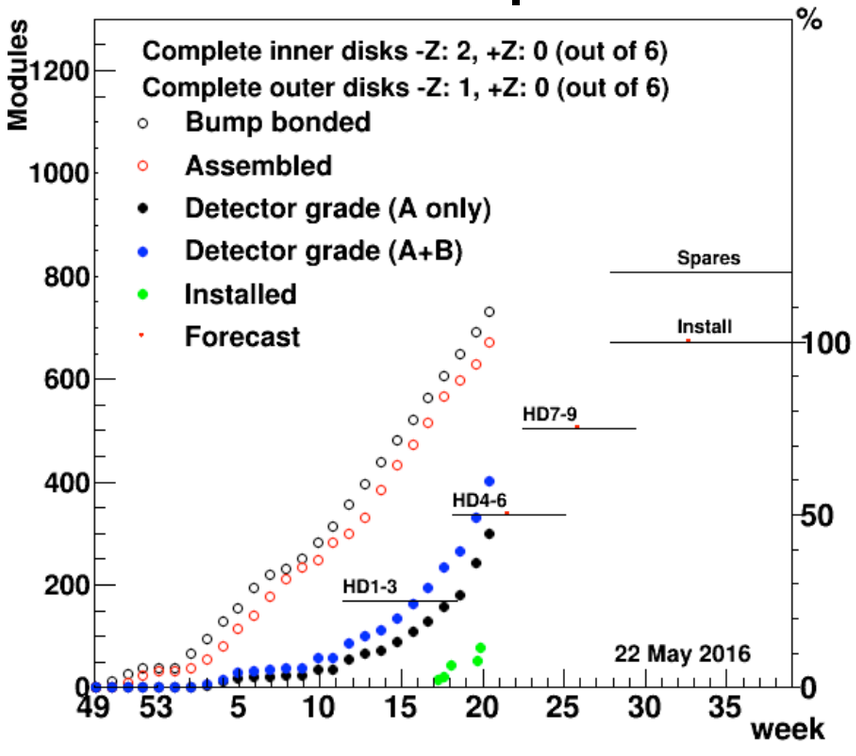


Barrel pixel module

Barrel: Layers 2-4



Endcaps

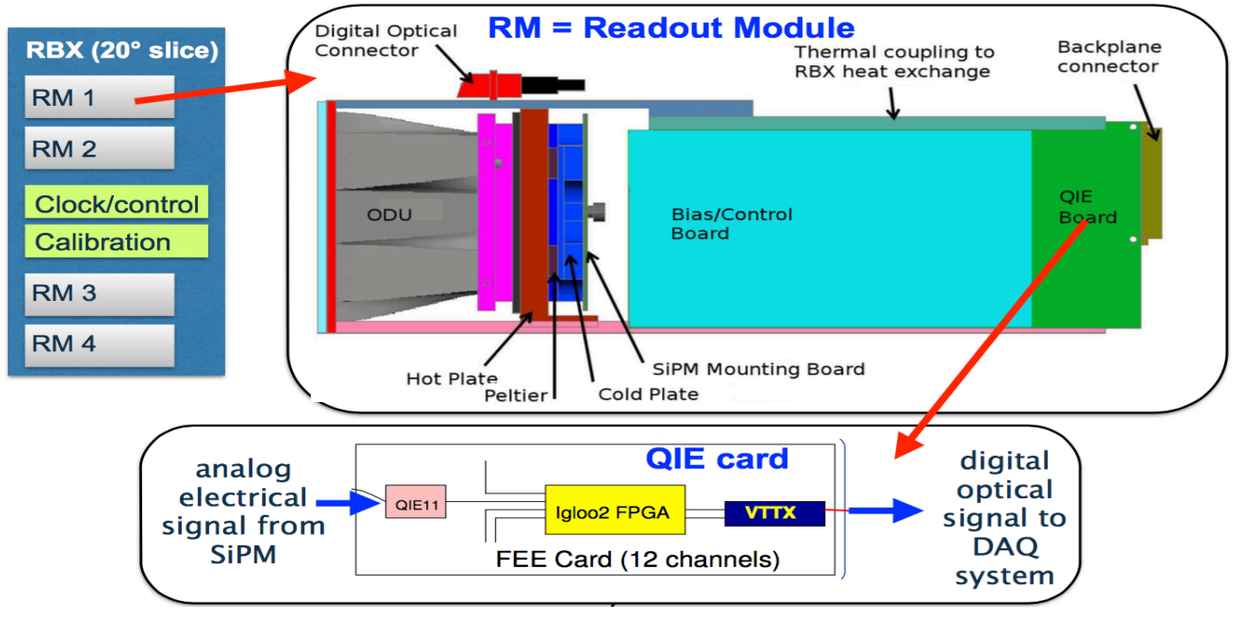


Phase 1 status: HCAL

- **<u>HF upgrade during EYETS 16/17:</u>**
  - installation of new FE electronics to implement dual-anode readout and TDC measurement for each PMT (to improve discrimination of anomalous signals)
- **<u>Replacement of HE FE electronics also in focus for EYETS 16/17</u>**

Phase1 HE FE Electronics:

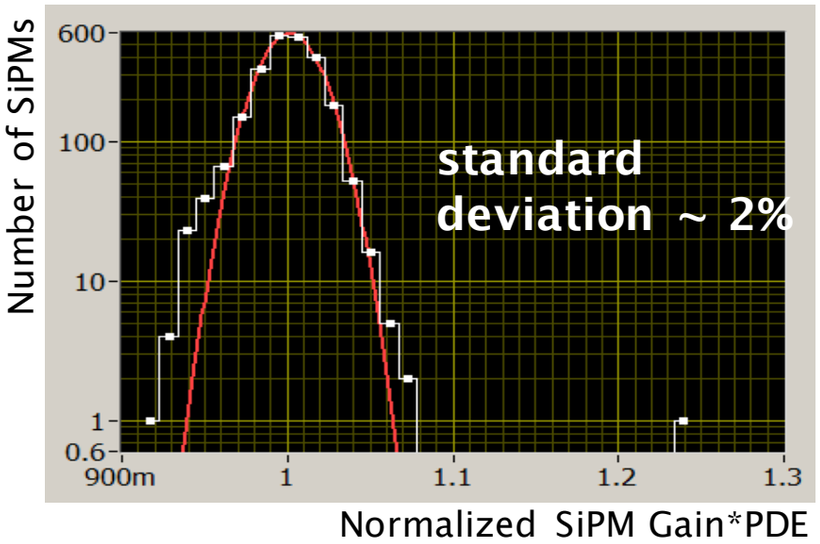
- produce 144 (+spares) Readout Modules
- produce 36 (+spares) of Clock/Control Modules and 36 (+spares) of Calibration Units



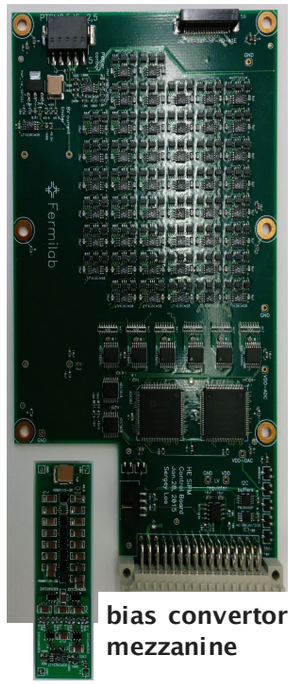
- Installation brought forwards from LS2. Higher PDE of SiPMs mitigates impact of response loss of HE scintillator/fibre.

Phase 1 status: HCAL

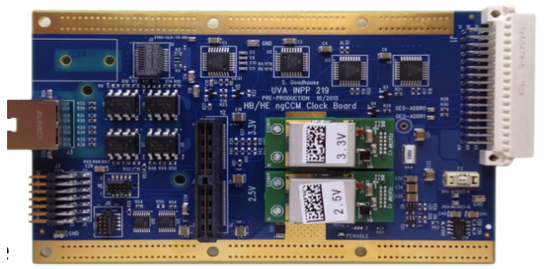
- Production and testing of necessary components for HE FE electronics progressing on track.



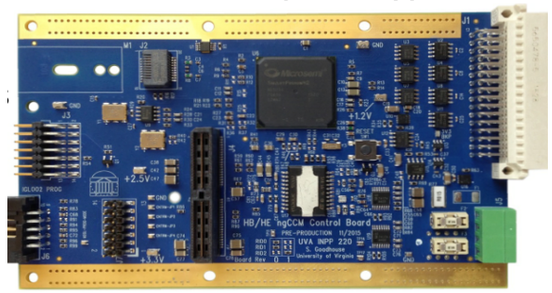
SiPM Control card

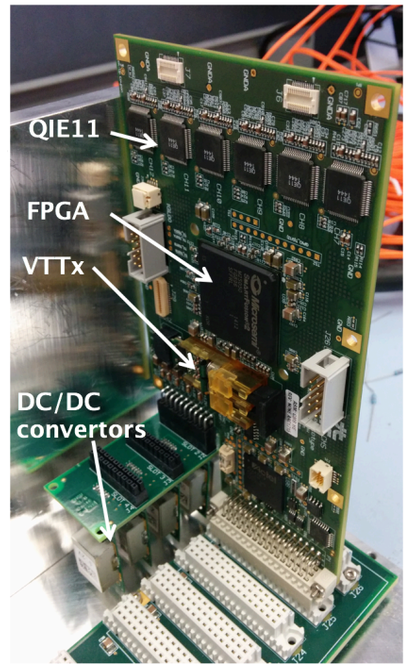


Clock card prototype



Control card prototype





SIPMs: 100% in hand, 90% tested (enough to populate HE)

QIE11 board:
20 produced, being tested at FNAL. Ship 16 to CERN in June to assemble 4 RMs
All other pieces to equip 1 RBX scheduled to be available at CERN in June

Key Milestone: Manufacturing Progress Review (MPR) scheduled for early July

expect to have one full RBX with production version of four Readout Modules, clock and control module and calibration unit, assembled and tested for functionality

Science & Technology Facilities Council

CERN RD contributions (limited to main CMS current priorities)

- RD50 - Radiation hard semi-conductor devices
  - CMS sensors R&D work for OT, Pixel and HGC moves on from the knowledge accumulated over years by RD50 (ex. Selection of p-type sensors) - large community of CMS experts is active in RD50. Main current interests are in:
    - Planar and 3D Pixel sensors (some common submissions in the latter case)
    - Evaluation of neutron damaged for HGC
    - TCAD simulation and parameterization of radiation damage models
    - Developments of sensors for precise timing measurement: low gain sensors with thin gain layer at surface (LGAD) and deep-depleted APDs with high gain
- RD51 - Micro-Pattern Gas Detectors
  - CMS MPGD work benefit from the worldwide and longstanding knowledge accumulated in RD51 - CMS experts contribute to several areas:
    - Large area detectors (GE1/1 self-stretching, without spacers technique)
    - New developments such as m-R-well & Fast-Timing MPGD (FTM).
    - Detector simulation (Garfield, Comsol, ANSYS, Geant4) and electronics
    - Transfer to industrial partners(ELTOS, MACARO..) for mass production
- RD53 - Large scale Front-End ASIC prototype for Pixel Phase-II detectors
  - Common development with ATLAS, several CMS Institutes are active in RD53
  - Crucial work on 65 nm radiation tolerance validation
  - Important submission of RD53A full size chip early 2016
- Several other common developments rely on CERN support groups, external programs (AIDA…), synergies with other experiments (CALICE…)…

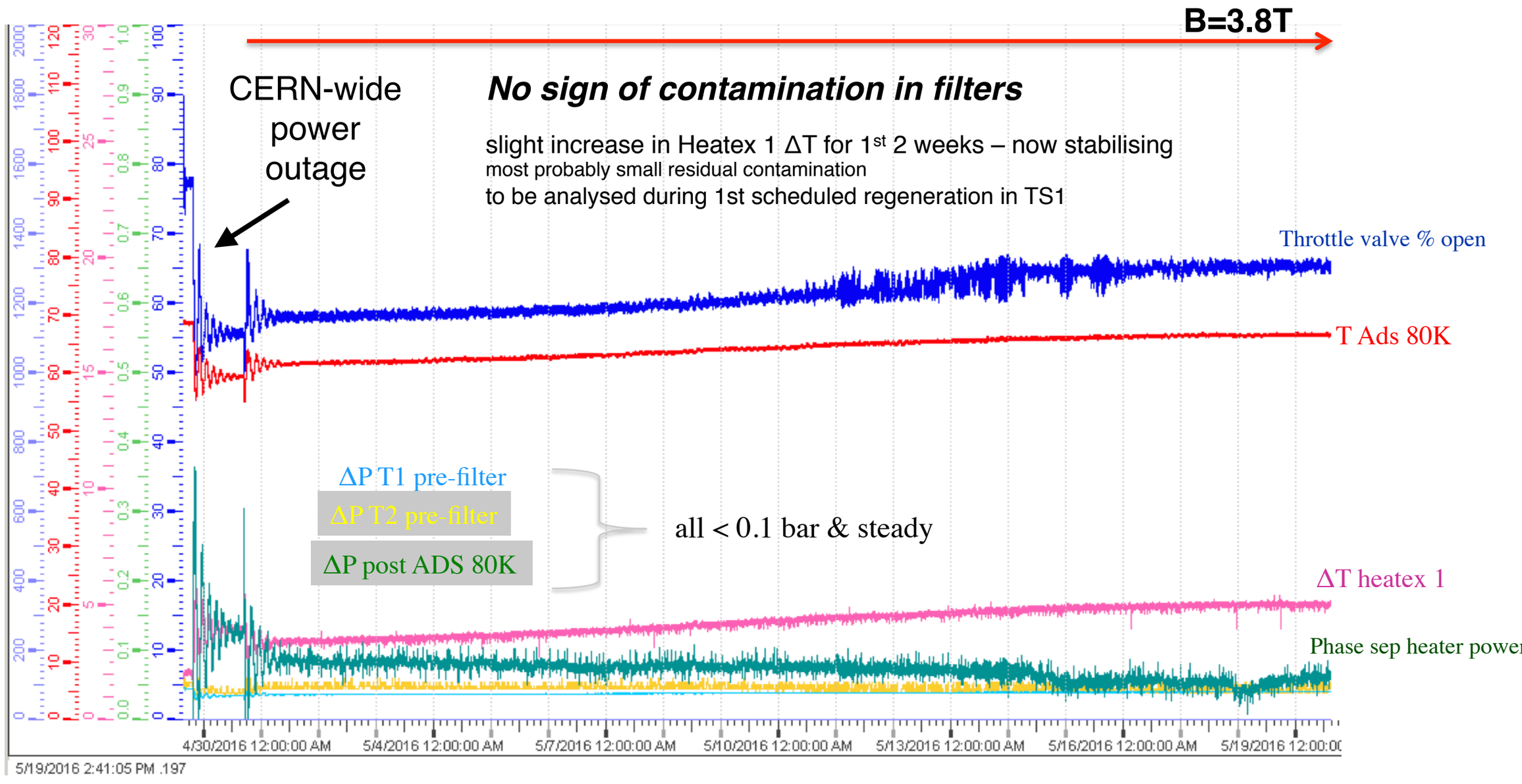
Summary and conclusions

- **CMS has emerged from the year-end stop in excellent shape**
  - Magnet cold box cleaning and cryo system refurbishment a major success
  - Now running stably at 3.8T with good cryo performance
  - All subdetectors are performing well, new systems incorporated into DAQ
  - New Level-1 trigger system deployed, with improved performance
  - Data taking efficiency: better than 90% and improving
- **Rich physics programme defined for the next several months**
  - Many new results presented@Moriond. Targeting ICHEP for major update
  - First HI results from 2015 run presented
- **CMS is ready to fully exploit the large datasets provided by the LHC in 2016**
  - Many thanks to our collaborators within CMS and our colleagues at the LHC for their dedication and hard work.
  - We hope it will be rewarded by exciting new discoveries!

Spares

Magnet: recent performance of cryo system

Magnet cryo system parameters stable over past 3 weeks



System parameters in a completely different regime from 2015
Much improved stability

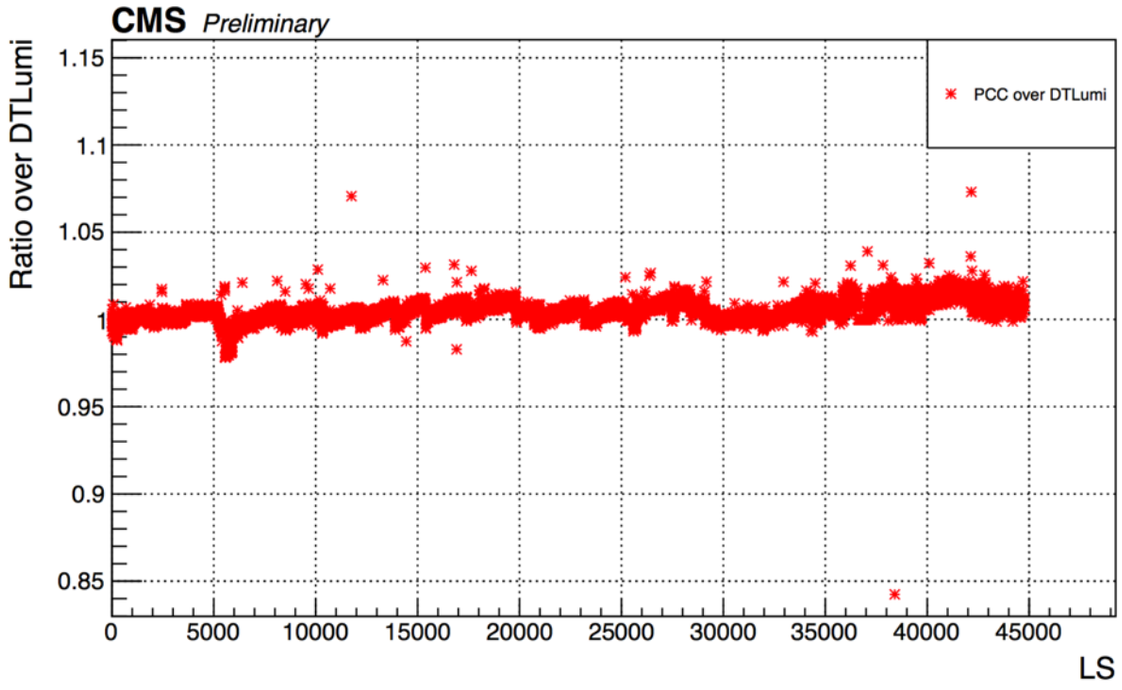
Luminosity measurement

Primary measurement:
Pixel cluster counting

$$\mathcal{L} = \frac{\langle N_{\text{cluster}} \rangle f}{\sigma_{\text{vis}}^{\text{PCC}}}.$$

	Systematic	correction (%)	uncertainty (%)
Integration	Stability	-	1
	type 1	$7-9$	0.6
	type 2	$0-4$	0.7
	CMS deadtime	-	0.5
	Dynamic Inefficiency	-	0.4
Normalization	XY-Correlations	1.1	1.5
	Beam current calibration	-	0.3
	Ghosts and satellites	-	0.2
	Length scale	-3.2	1.5
	Orbit Drift	-	0.4
	Beam-beam deflection	1.8	0.4
	Dynamic-β	-	0.5
	Total		2.7

Sources of systematic uncertainty



Comparison with DT lumi for entire 2015 run

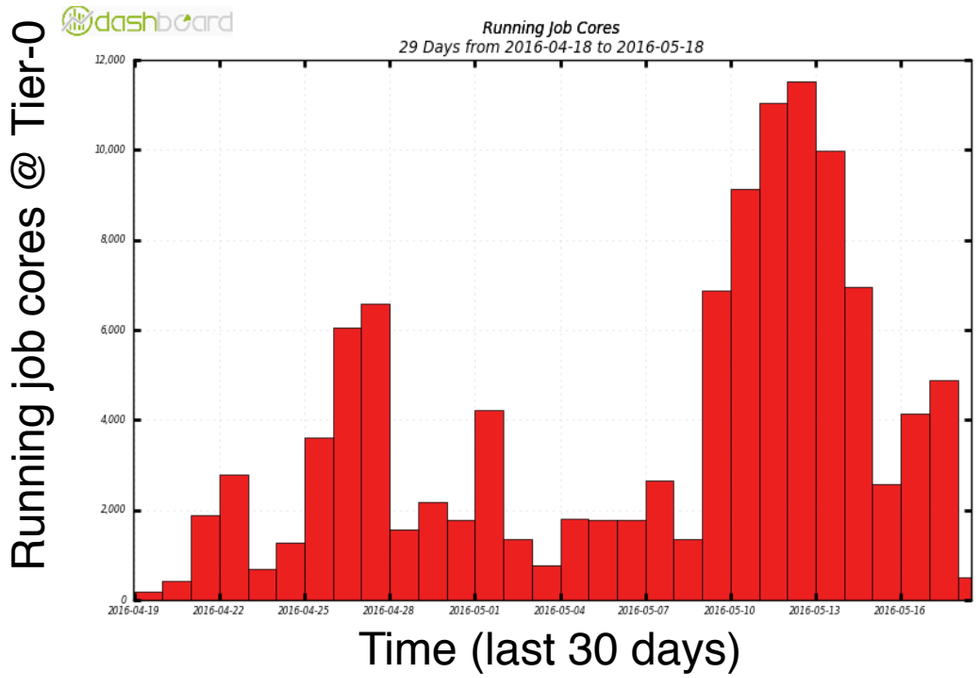
Total systematic uncertainty for 2015 analyses: 2.7%

Plan to propagate this uncertainty to 2016 ICHEP analyses
re-derive PCC corrections using early 2016 data + VdM scan results

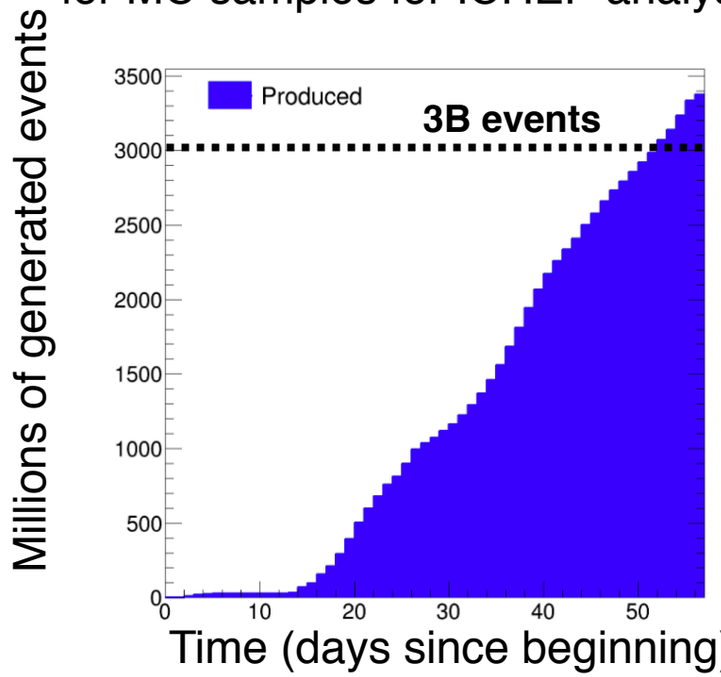
Plan for 2016: Offline/computing

2016 MC production well underway

Tier-0 working well:
fully busy with initial data samples and MC

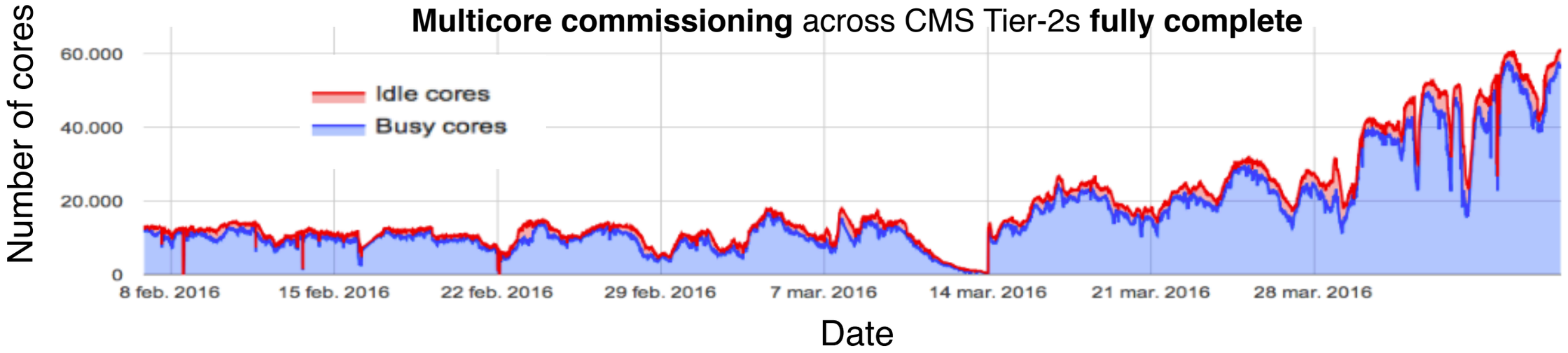


Surpassed CMS goals
for MC samples for ICHEP analysis



Initial tranche of **3B events** complete. Now preparing second set of **2B events**

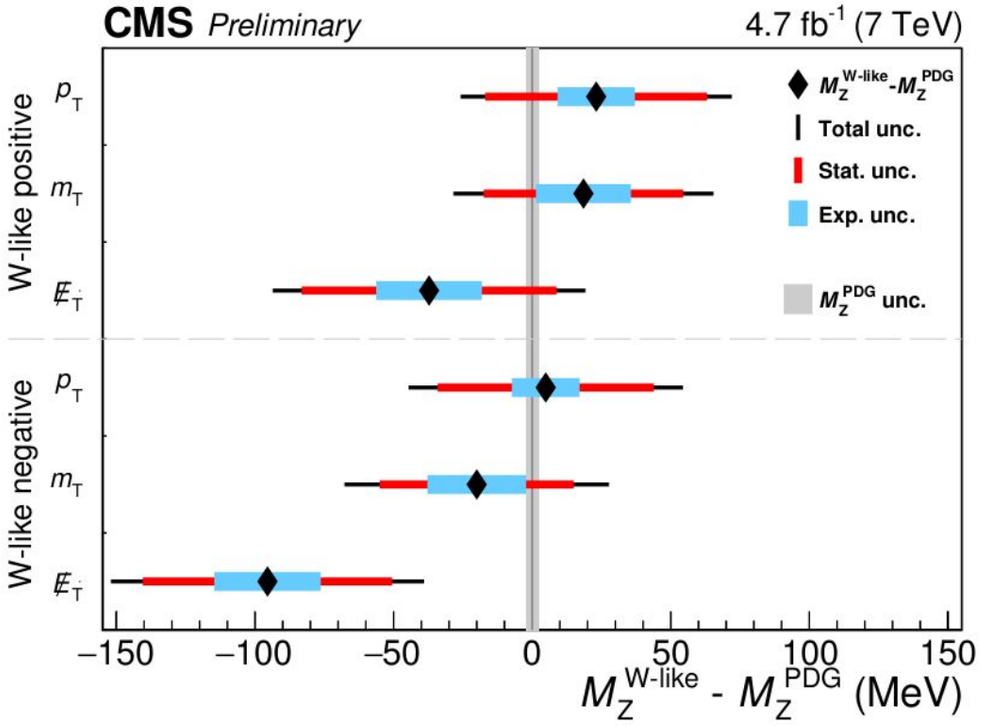
Multicore commissioning across CMS Tier-2s **fully complete**



Other selected highlights

- Presented at Moriond EW

W-like mass measurement from Z->μμ



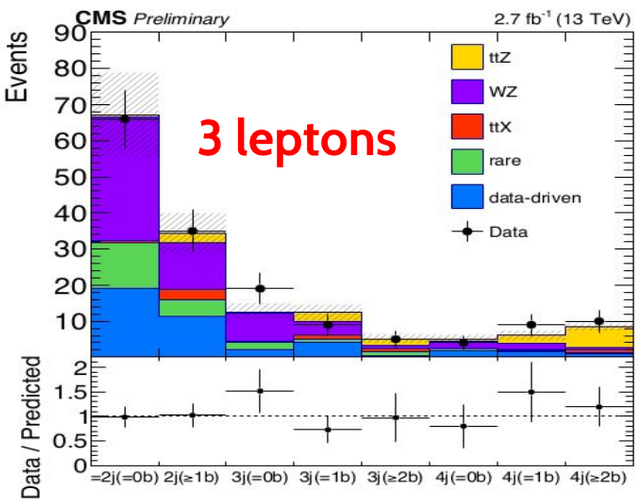
Validates our understanding of:

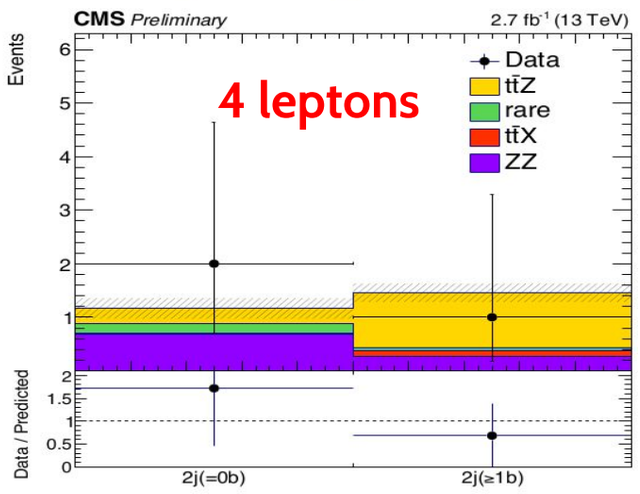
muon momentum scale and resolution

MET resolution

Experimental uncertainty better than 20 MeV

ttZ production at 13 TeV





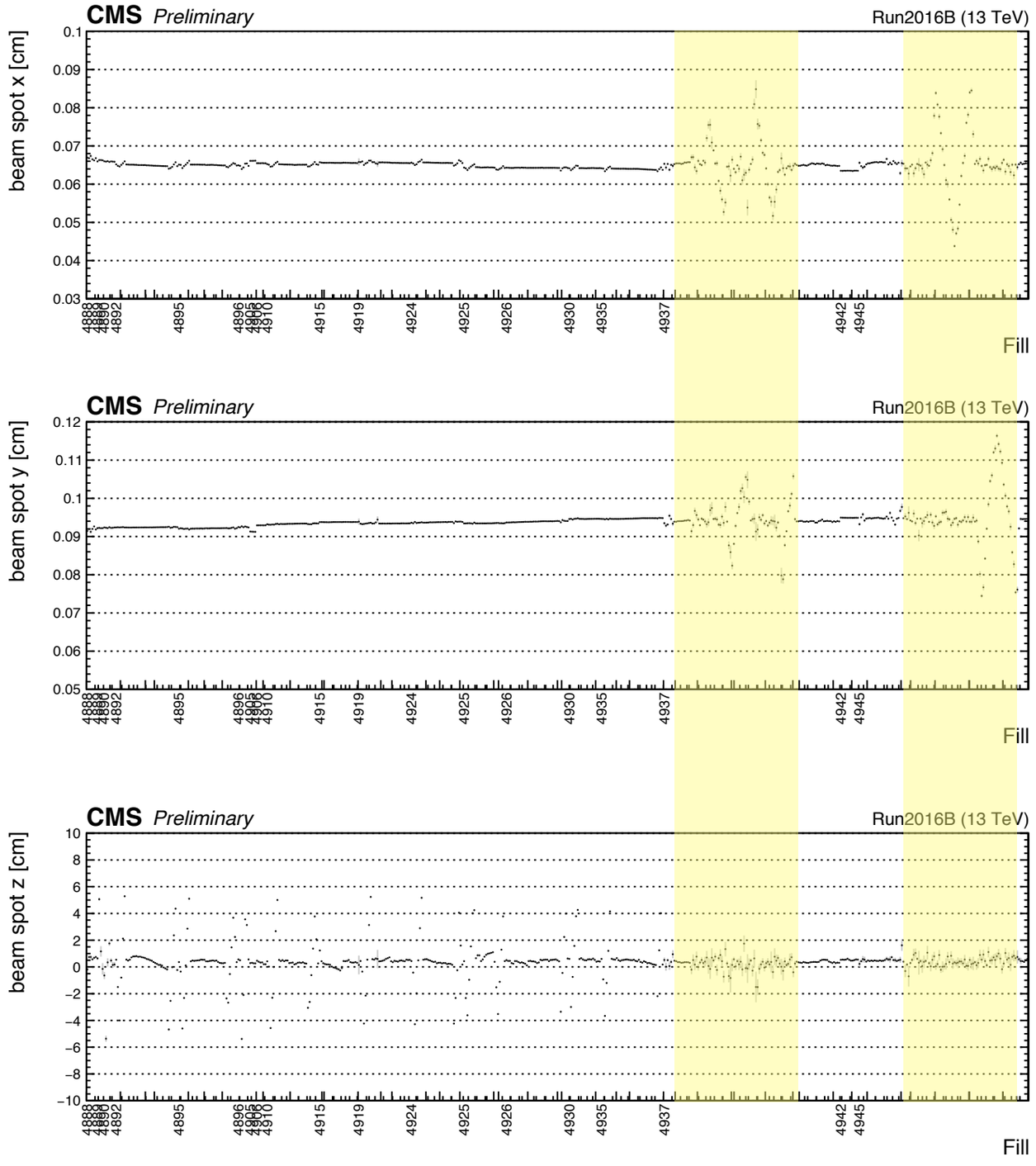
Channel	Expected significance	Observed significance
3ℓ analysis	2.9	3.5
4ℓ analysis	1.2	0.9
3ℓ and 4ℓ combined	3.1	3.6

$$\sigma(\mathrm{pp} \to \mathrm{t\bar{t}Z}) = 1065\ ^{+352}_{-313}(\mathrm{stat.})\ ^{+168}_{-142}(\mathrm{sys.})\ \mathrm{fb}$$

Consistent with SM

$$\mu = 1.27\ ^{+0.42}_{-0.37}(\mathrm{stat.})\ ^{+0.20}_{-0.17}(\mathrm{sys})$$

Beam spot determination



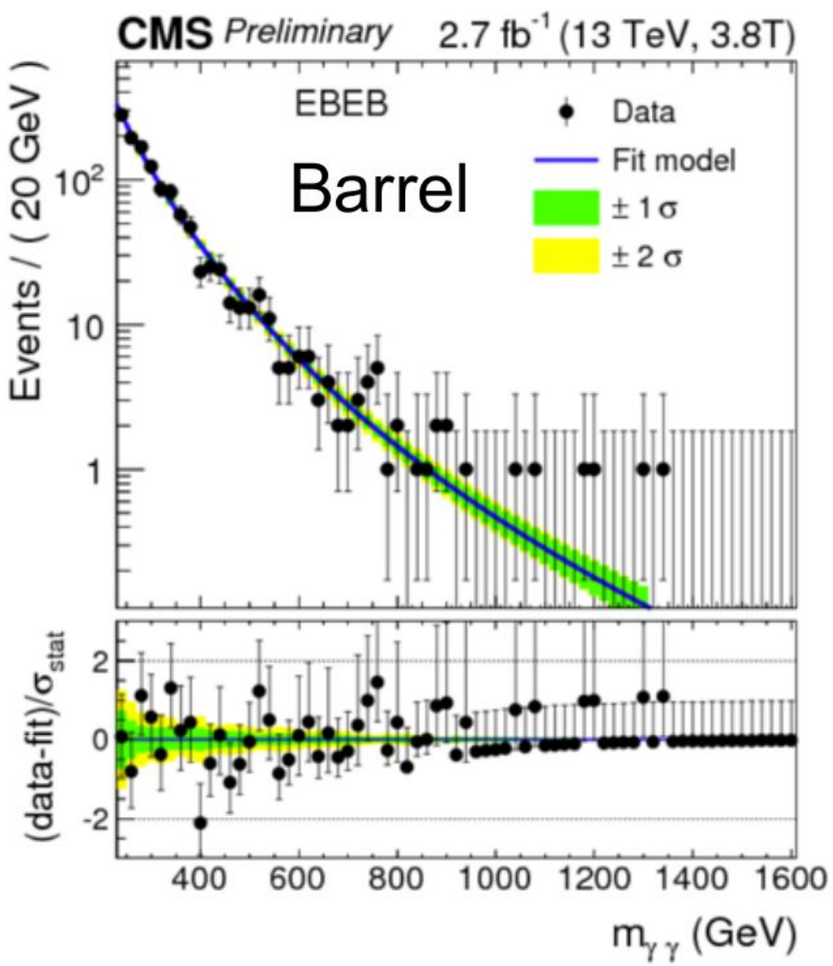
low PU/VdM scan

X(750)→γγ analysis

- Presented at Moriond EW

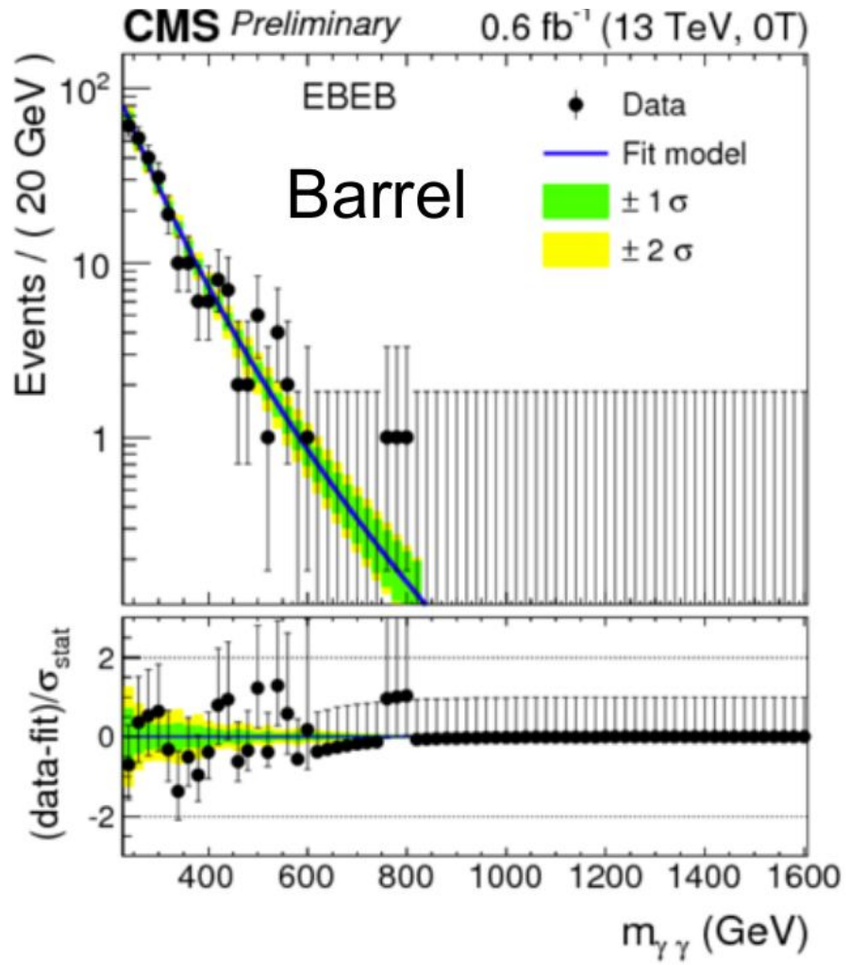
3.8T data

with updated ECAL calibration
(~10% sensitivity improvement)



added 0T data

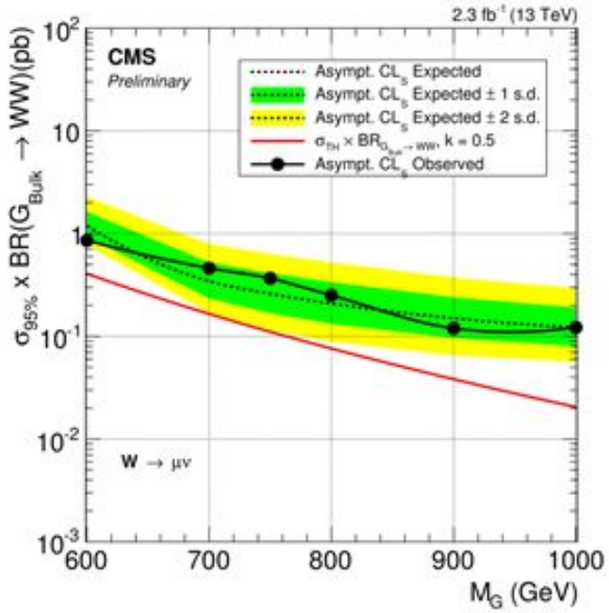
with dedicated 0T calibration
(additional 10% sensitivity improvement)

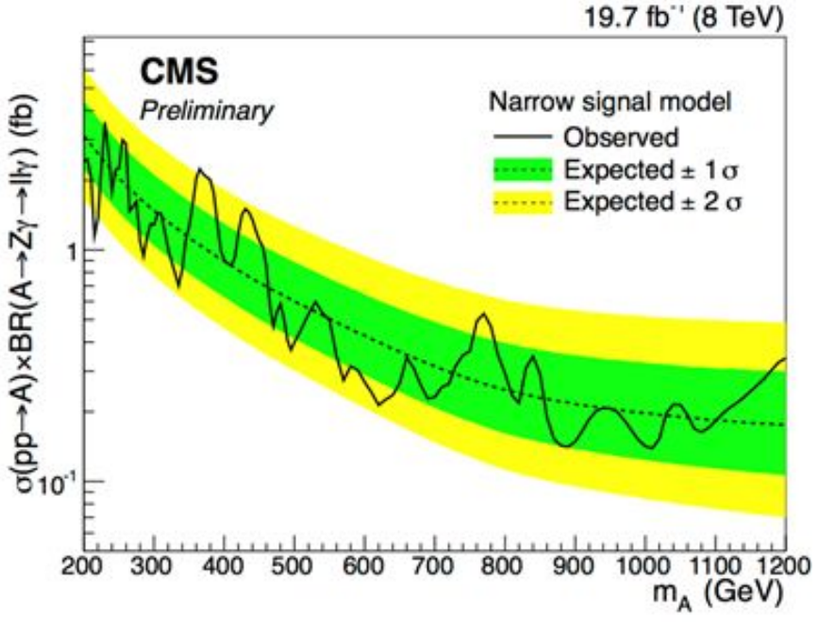


X(750) analyses

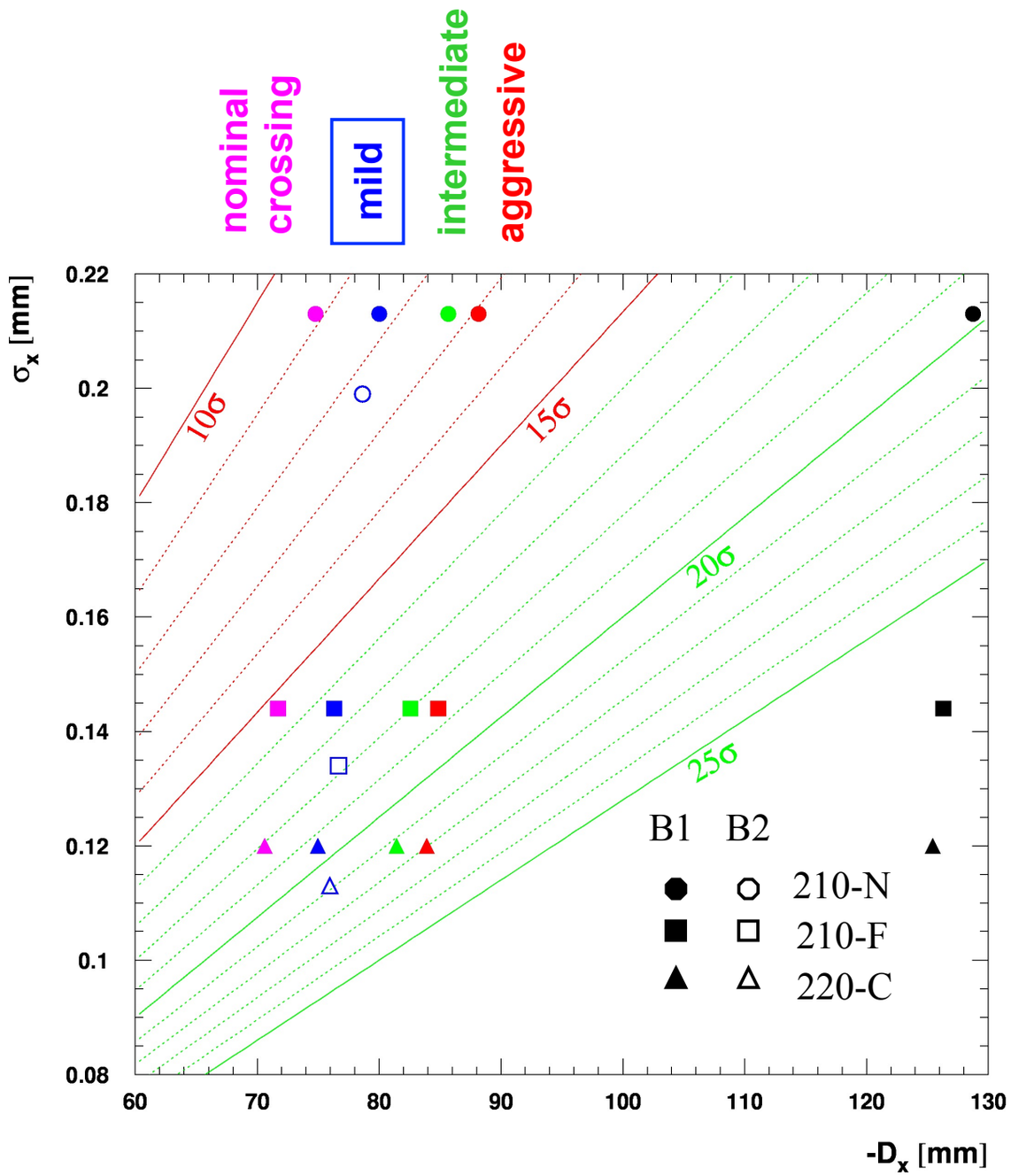
X(750): no stone unturned

- **pp → X → Zγ → (μμ, ee)γ**
  - EXO-16-010 (13 TeV), HIG-16-014 (8 TeV)
- **pp → X → ZZ**
  - 4 lepton: HIG-15-004
  - 2l 2ν: HIG-16-001
- **pp → X → ZH(125)**
  - H(125) → bb: B2G-16-003
- **pp → X → HH**
  - bbbb: HIG-16-002
  - bbττ: HIG-16-013 (13 TeV), HIG-15-013 (8 TeV)
  - WWbb: HIG-16-011
- **pp → X → WW**
  - lνqq: B2G-16-004
- **pp → X → $t\bar{t}$**
  - B2G-15-002





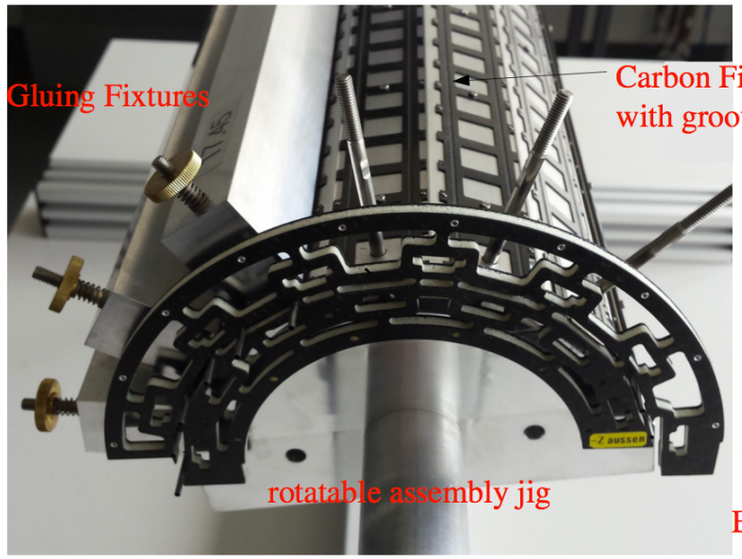
CT-PPS acceptance

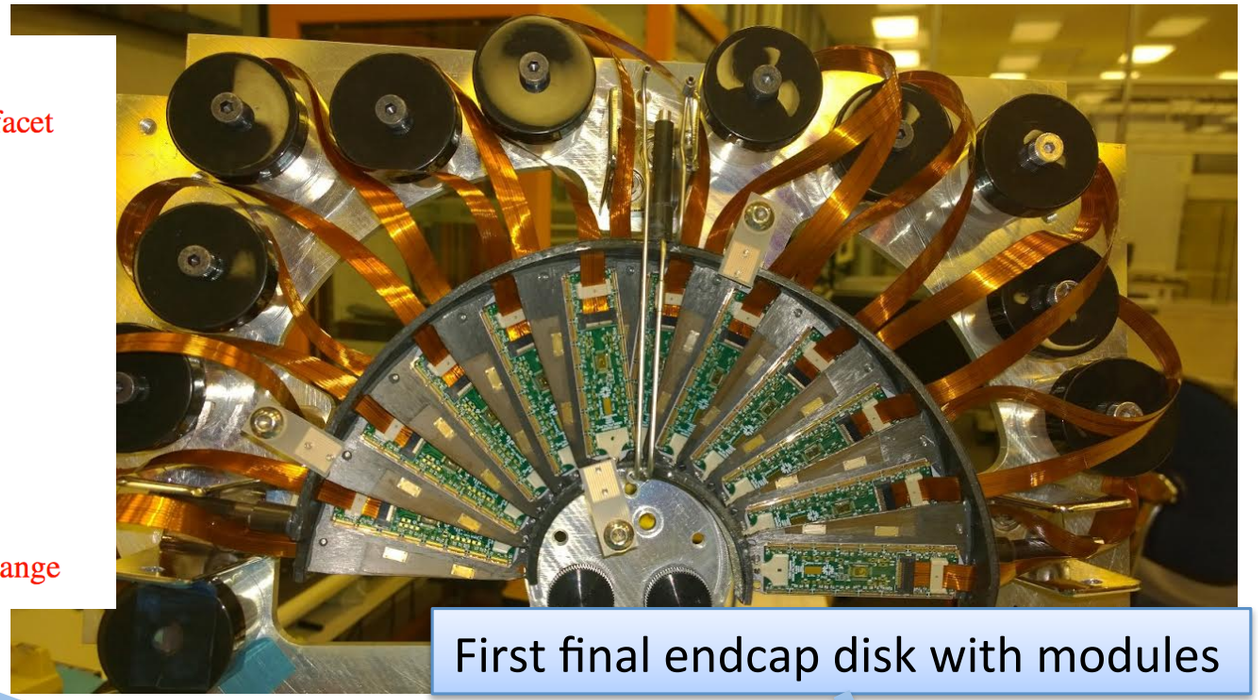


Distance of RP approach to beam required for acceptance y<0.5 at 750 GeV mass

Science & Technology Facilities Council

Phase 1 status: Pixel

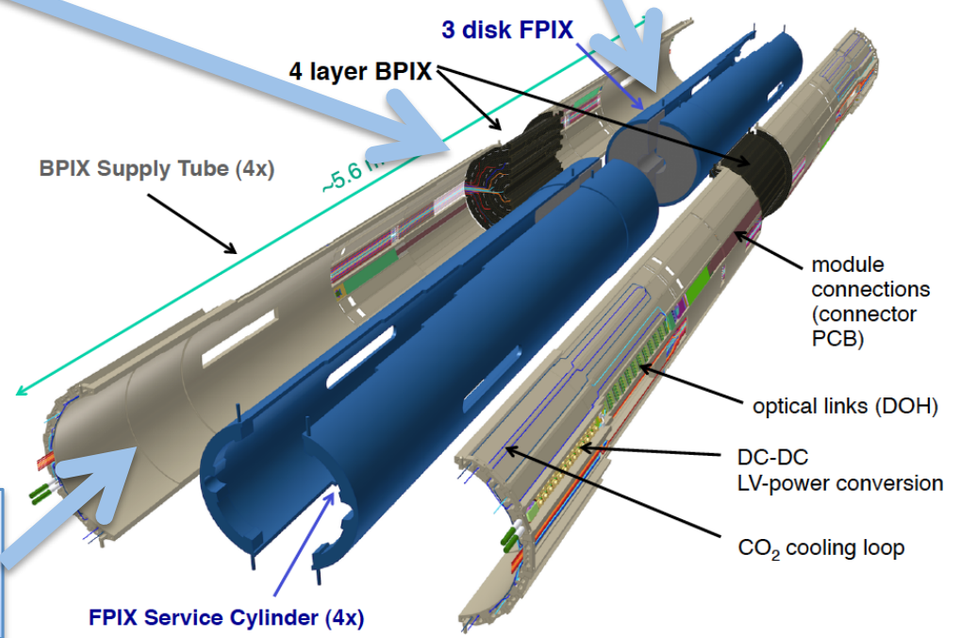




Final barrel detector mechanics
cooling pipes to be embedded

First final endcap disk with modules

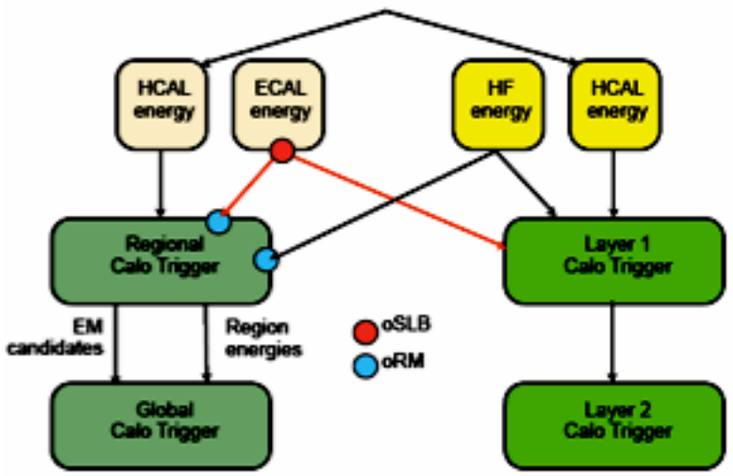
Final barrel Supply Tube
being dressed with electronics



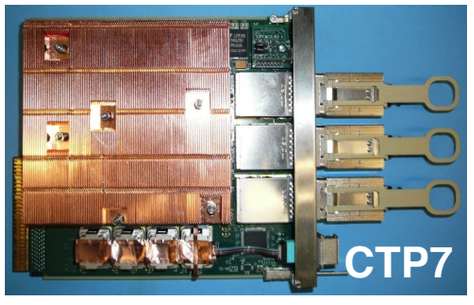
New L1 trigger commissioning

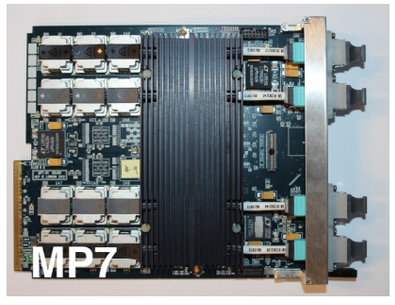
- Phase 1 L1 calorimeter trigger commissioned with data
  - **New trigger exploits full granularity of detector, with advanced algorithms:**
    - **improved efficiencies, PU rejection, object ID and resolution compared to 2015**
  - Successfully triggered on beam splash events with upgraded EG/Jet triggers
  - Huge effort in developing firmware, emulators, online software
    - **100% matching between data and emulator in first collisions**
    - **Algorithm performance appears as expected with first data**

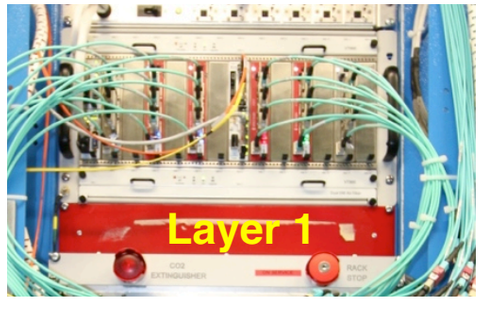
Level-1 Calorimeter trigger

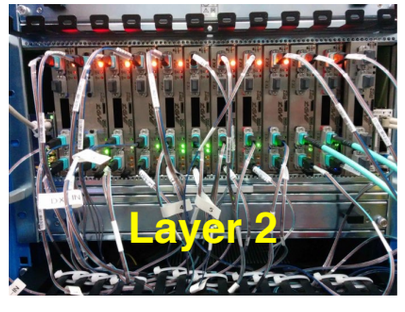


Legacy **Upgrade**





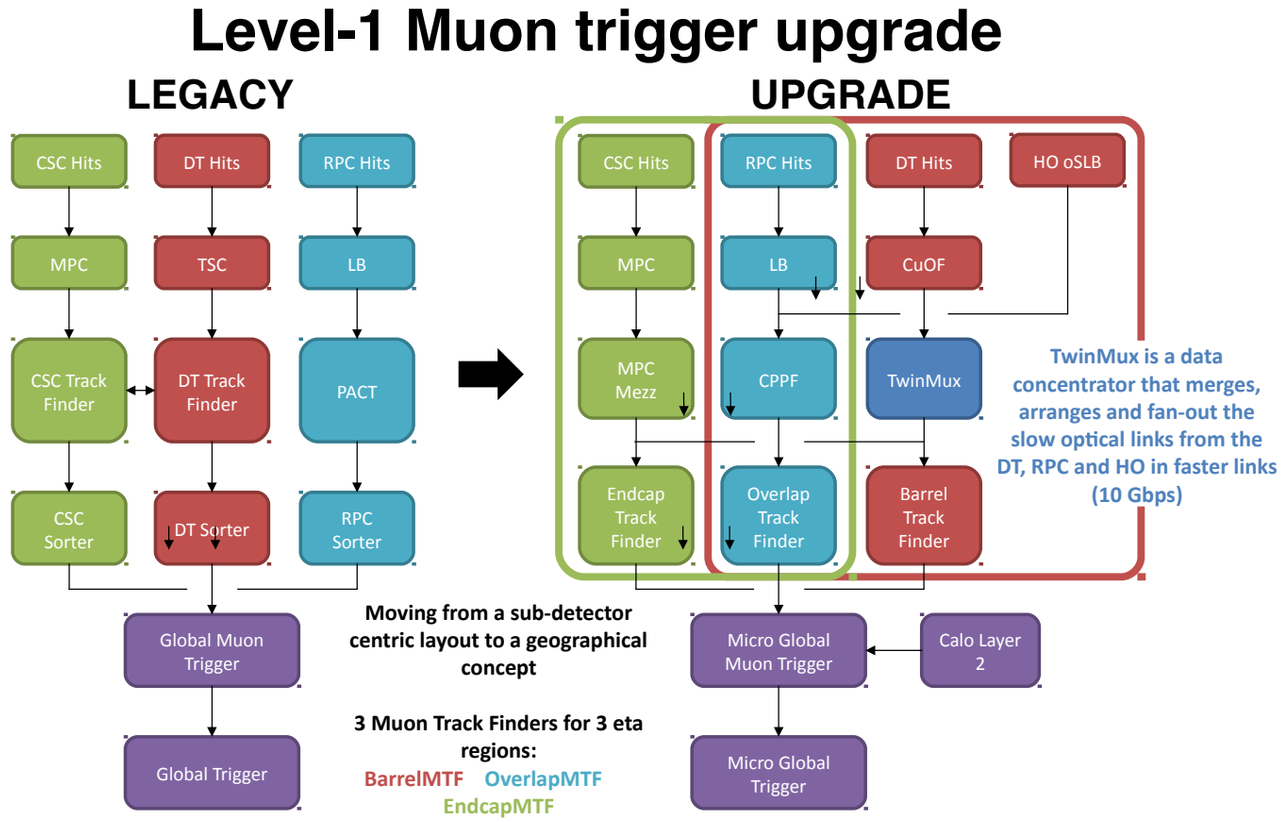


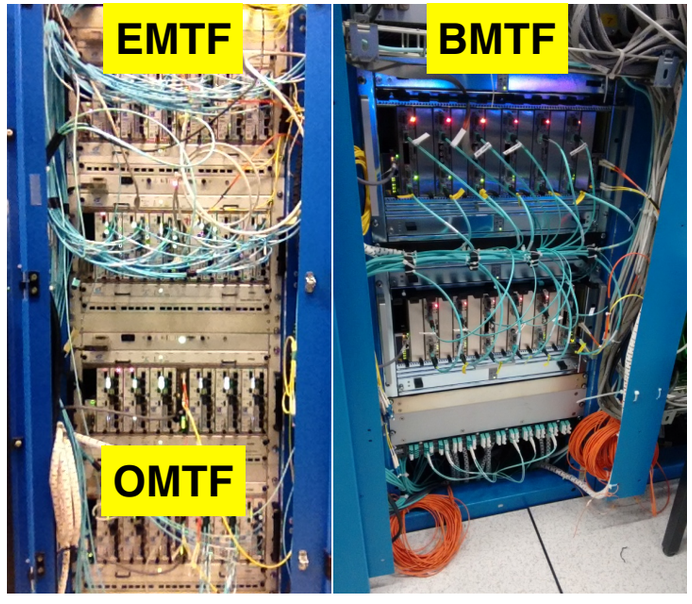


Layer 1: 18x CTP7 cards **Layer 2: 10x MP7 cards**

New L1 trigger commissioning

- <u>New L1 muon trigger running at P5</u>
  - **Improved algorithms due to more capable hardware - keep thresholds low at higher PU**
  - significant progress being made in understanding performance compared to legacy system
  - **TwinMux**: installation of data concentrator (replacement of second layer of DT trigger electronics) completed
    - input and output (to new Barrel Track finder) connected and operational



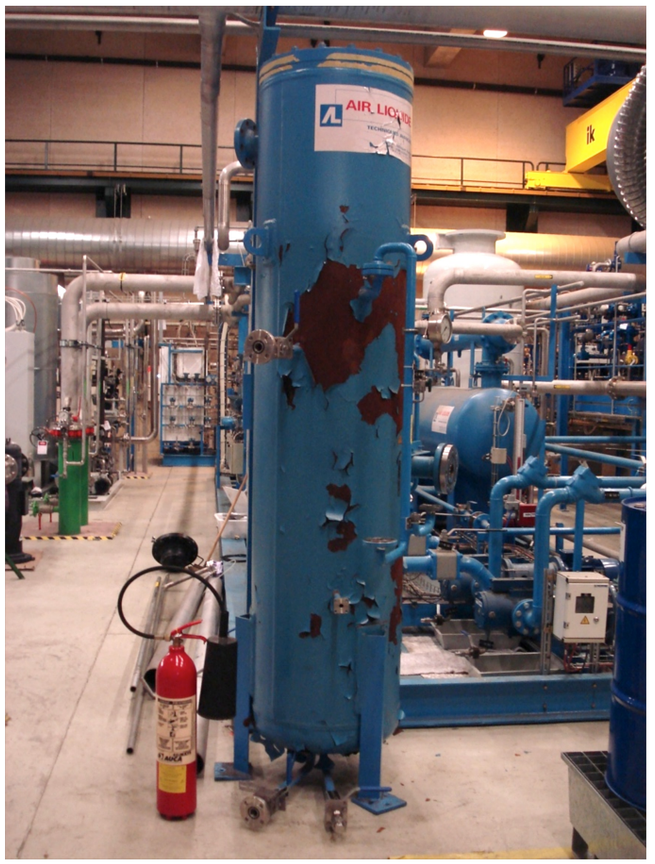


Magnet cryogenics

excellent performance of new system (more effective than old system in removing Breox contaminant)

NEW Primary Oil Removal System

NEW Oil Coalescers

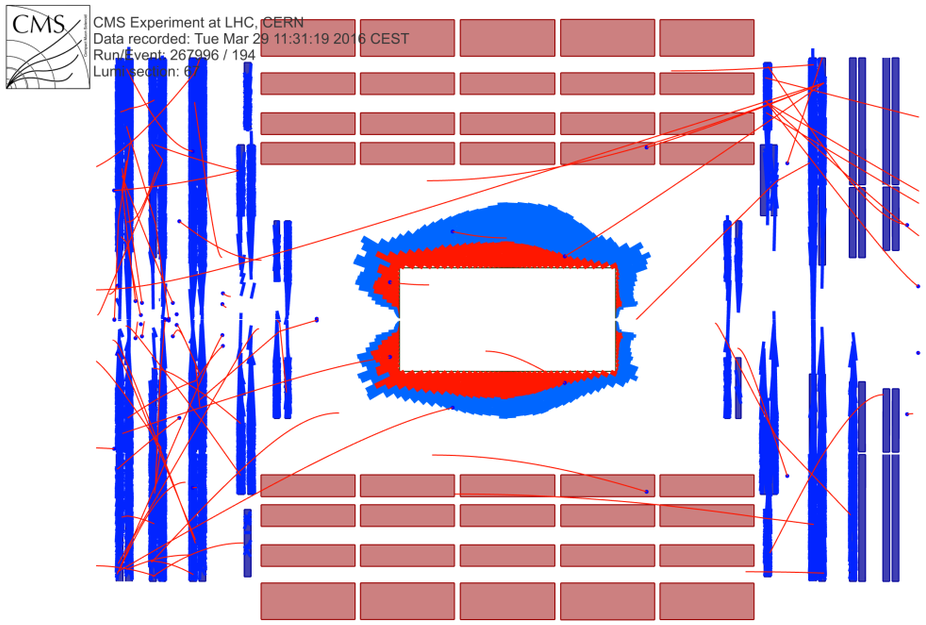


OLD system

Splash and non-stable beams

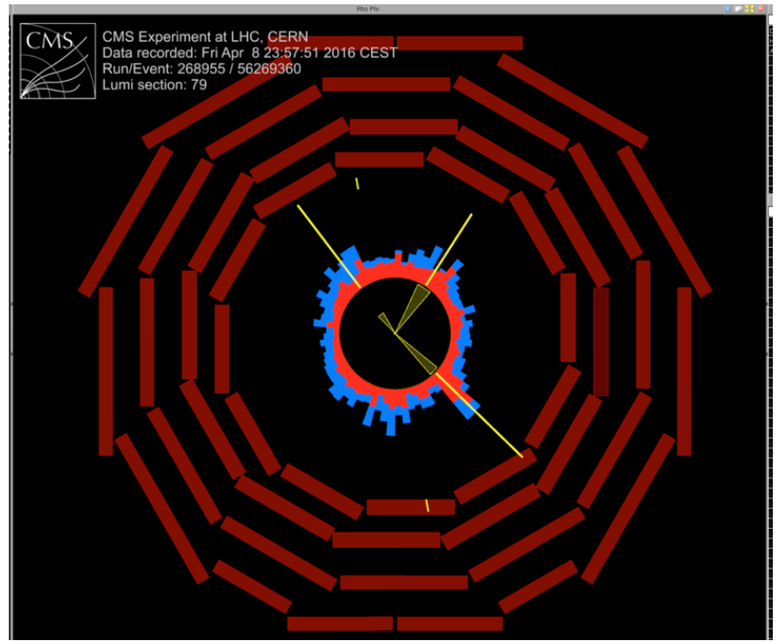
Tuesday 29th March

successful triggering of beam splash



Friday 8th April

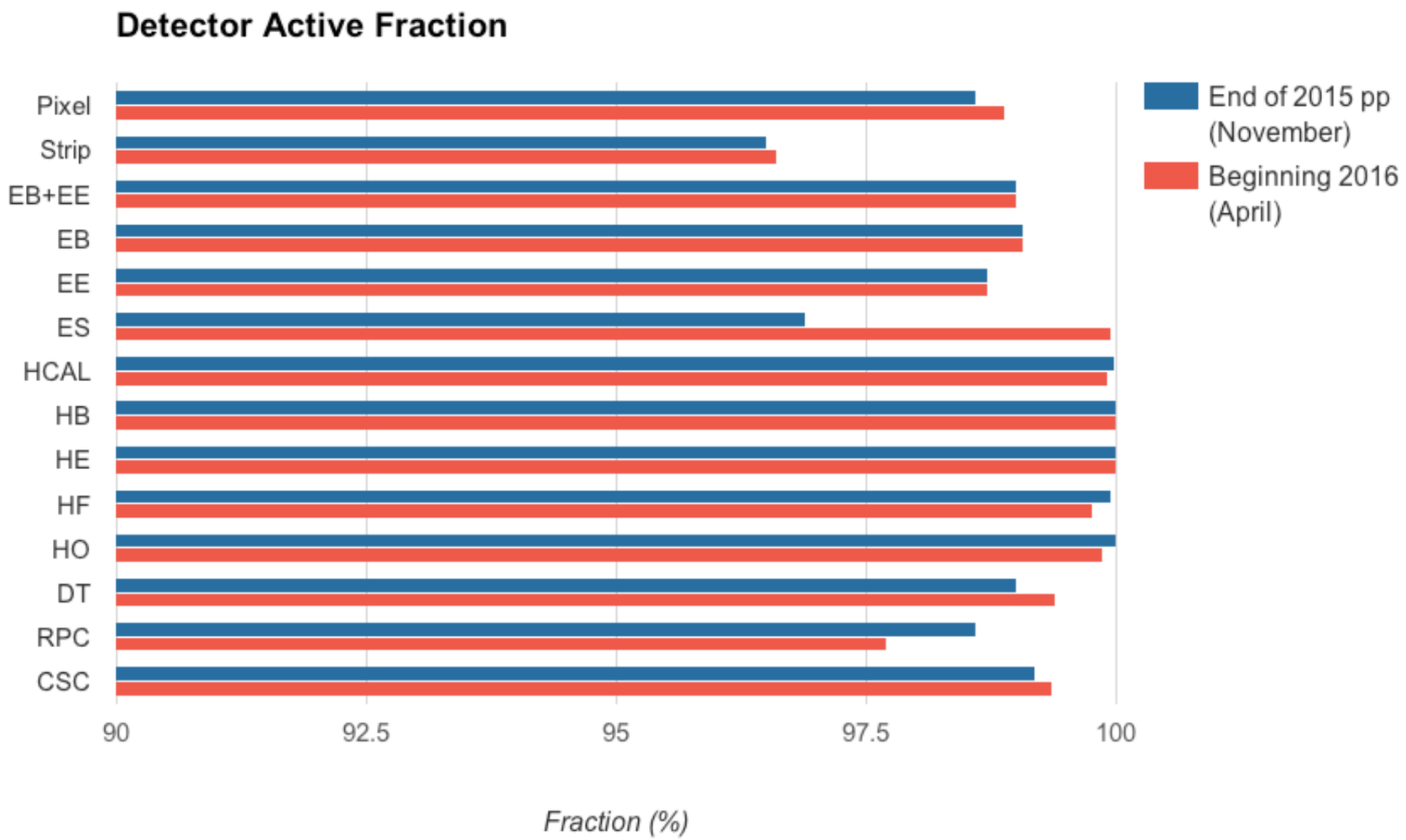
first non-stable beam collisions



- <u>Successfully recorded data from beam splash and first collisions data</u>
  - beam splash triggered with new Stage 2 EG algorithms (using special configuration)
  - both sets of data used to verify detector status, readout and trigger timing alignment

Detector status

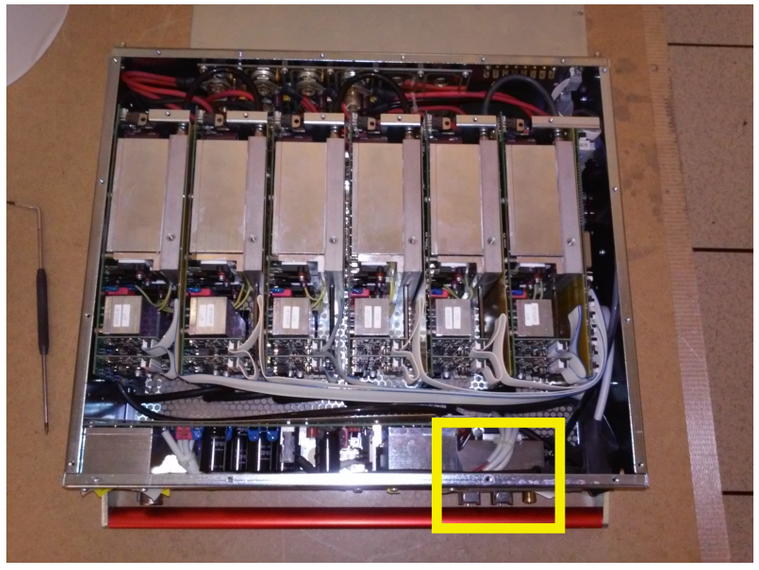
- **<u>Percentage of operational channels at beam startup typically >99%</u>**



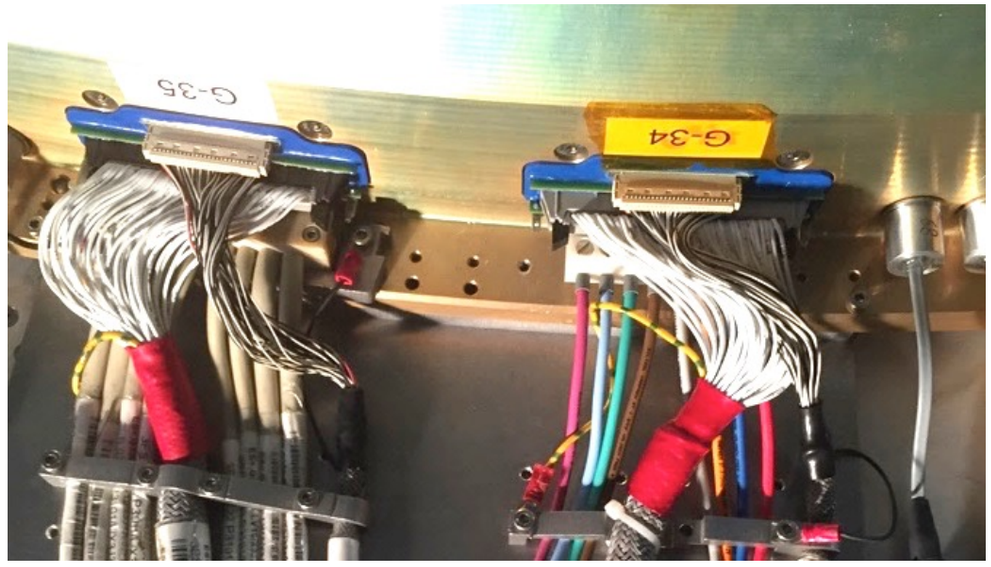
- **<u>Stable relative to end-2015</u>**
  - recovery of dead regions corresponding to 3% of Preshower (ES) following on-detector repairs during YETS

ECAL detector status

- Two significant refurbishment campaigns completed
  - **MARATON refurbishment (EB/EE LV power supplies)**
    - Preventative maintenance of 136 units + spares carried out in USC
  - **ES LV connector rework (at detector patch panel)**
    - Replaced problematic “Phoenix” connectors - ES active channels now >99.9%



View of opened MARATON
cooling block visible at bottom right



ES Low voltage feedthroughs
Left: before rework; Right: after rework