# CMS Status Report

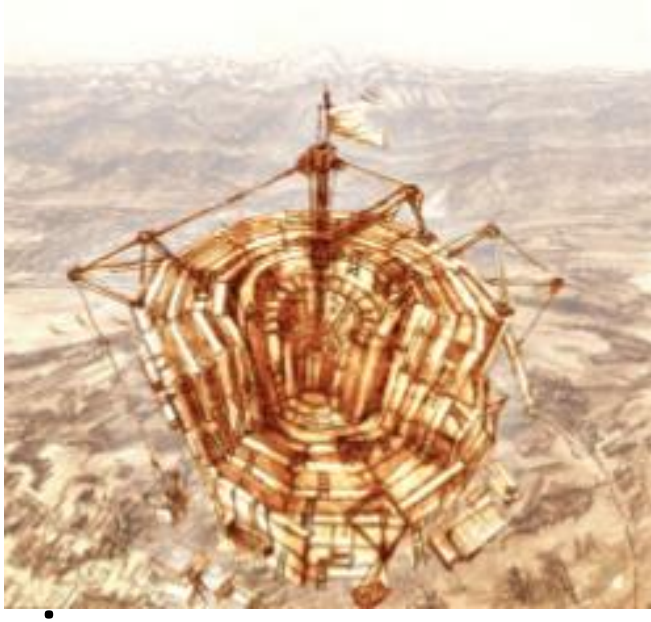
LHCC Open Session

24 Sept 2014

Jay Hauser, UCLA

# Outline of the talk

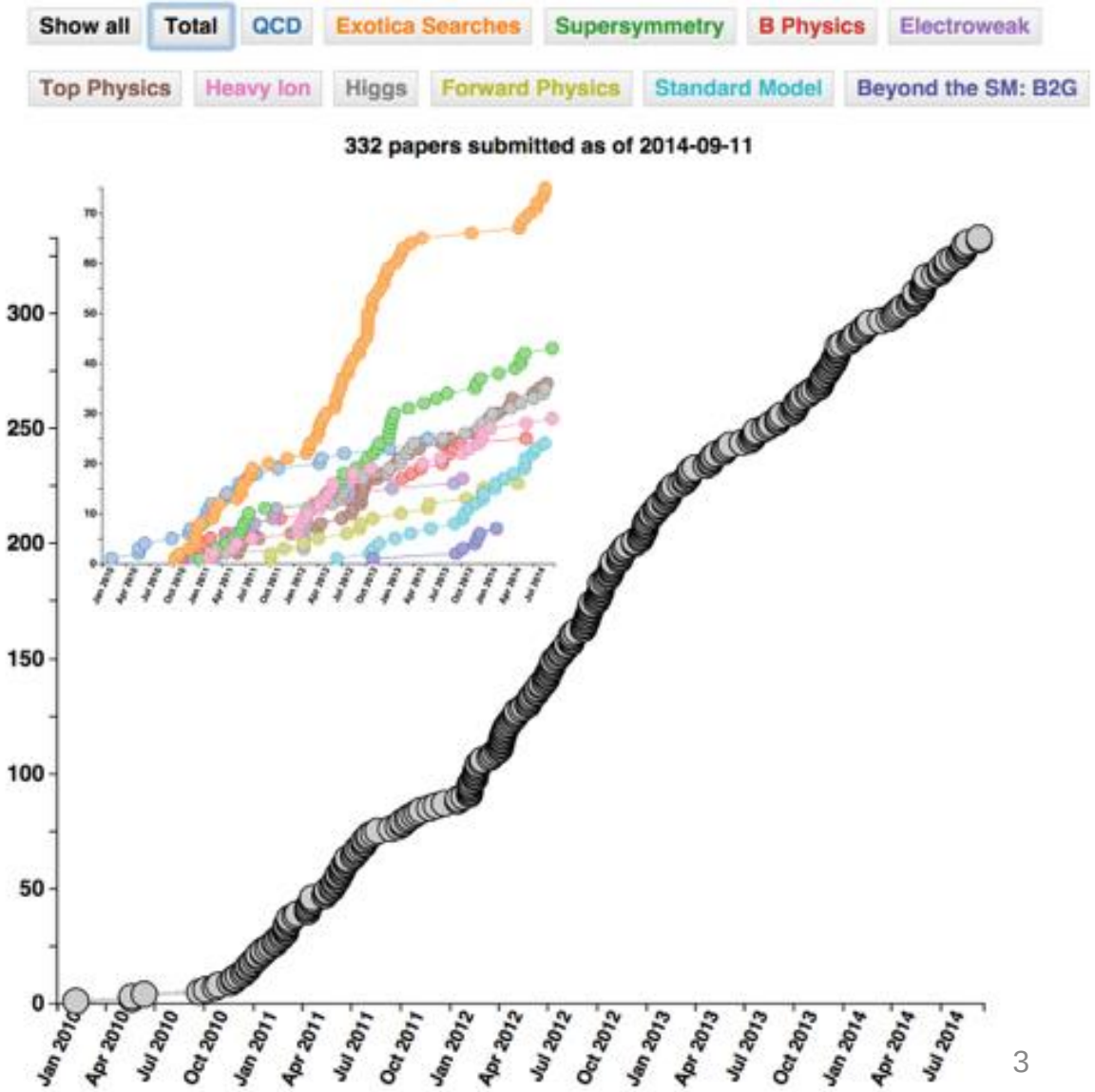
- Context: past, present, and future activities
- Recent physics highlights from Run 1
  - Higgs, b, SUSY, top, SM
- CMS readiness for Run 2
  - Detector upgrades
  - Pixel detector
  - Software & computing, CSA14 exercise
  - Priority physics (PHY14) exercise
- Upgrades: the Phase 2 Technical Proposal for HL-LHC



# Context – the past – legacy analyses

- Run 1 in 2010-2012: 7+8 TeV and 5+20 $fb^{-1}$ pp collisions
  - Up to 0.7E34 @ 50 ns
  - Also HI pPb, PbPb

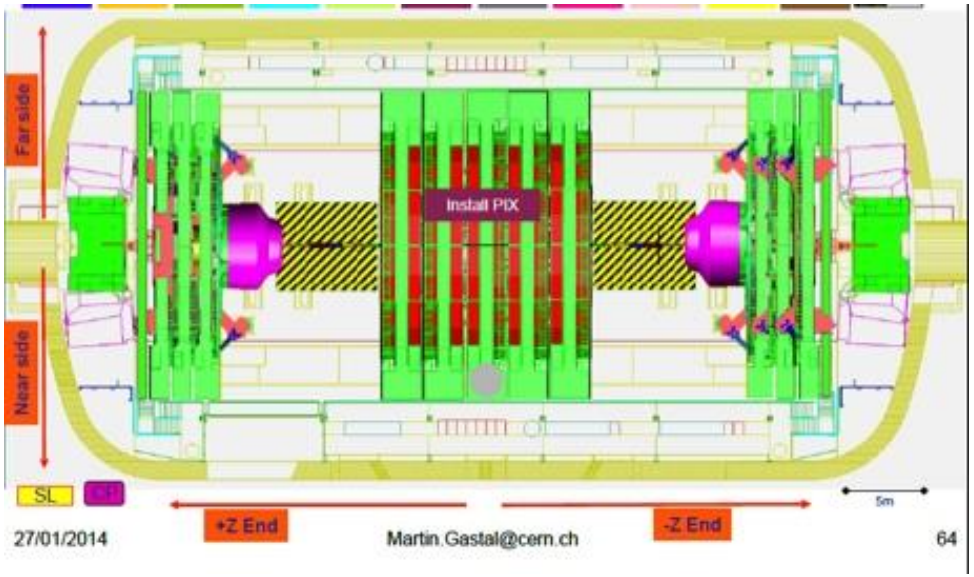
- 332 physics publications
  - 30 since last LHCC
  - Wrap this up soon to concentrate on Run 2



# Context – the present – LS1 work

- Prepare for 1.5E34 luminosity @ 25ns, for example:
  - Tracker and preshower going cold for longevity to 500 $fb^{-1}$
  - Muon system upgrades for better L1 trigger
  - New DAQ2 with modern hardware
  - New timing/control system
  - Infrastructure: new beam pipe for Phase 1 pixel upgrade, muon shielding
  - Maintenance and repairs

LS1: many detector configs in SX5…

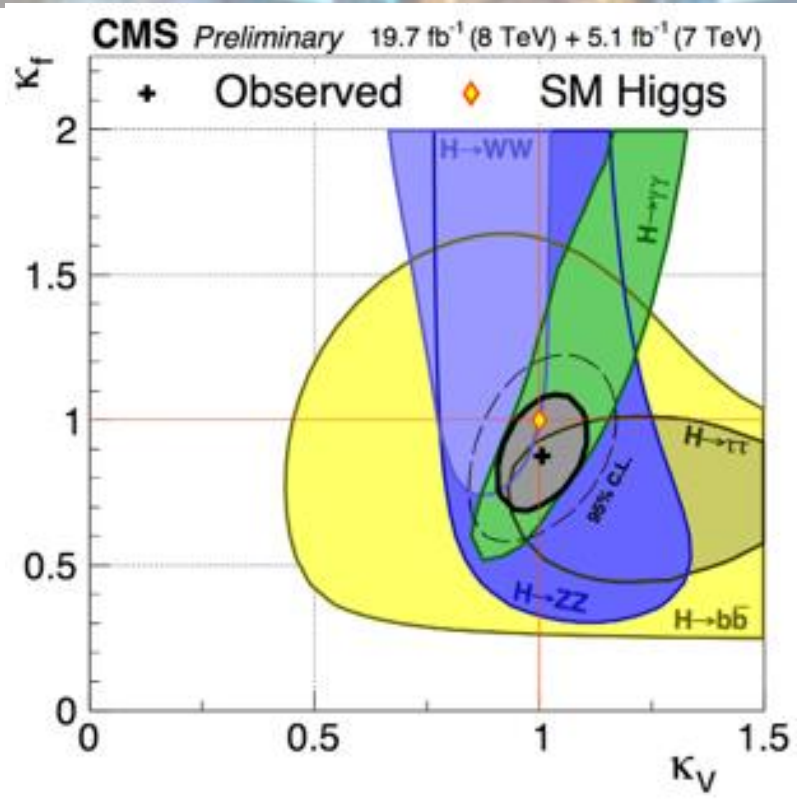


# Context – the future

- HL-LHC presents challenges for the CMS detector
  - Nominally 5x the luminosity
  - Implies 5x pile-up and many trigger rates and CPU times increase even faster (non-linear)
  - 6x the integrated radiation doses
- Upgrades now focus on the Phase 2 Technical Proposal
- Major detector components needed:
    - New rad-hard Si tracker with L1 track trigger
    - New rad-hard endcap calorimeters
    - Various trigger, barrel ECAL electronics, muon upgrades, infrastructure improvements

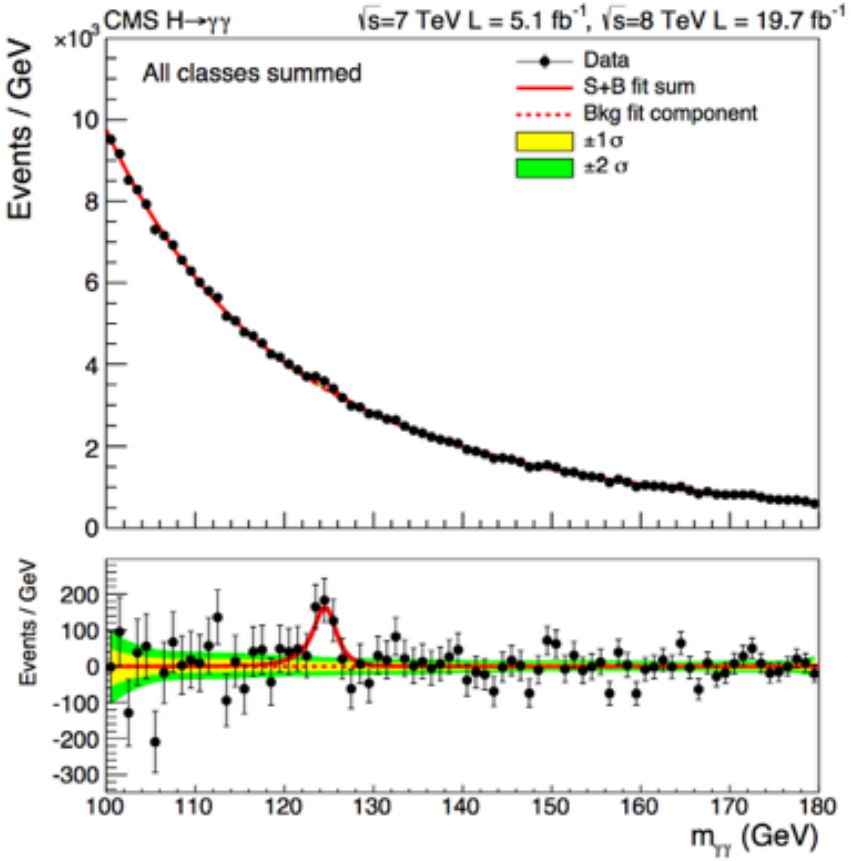
# Selected recent physics highlights

- Higgs
  - Last major analysis on $H \to \gamma\gamma$ accepted for pub
  - Combination of all results presented at ICHEP
- b physics
  - $B_s + B_d \to \mu\mu$ "analysis level" combination with LHCb now public, Nature article being finalized
- SUSY
  - Combination EW chargino+neutralino search (WZ, ZZ, hW+MET, hZ, hh+MET)
  - "Dilepton edge" fully investigated
- Top mass
  - Hadronic and dilepton channels complement the previous l+jets measurements
- Standard Model
  - Dijet differential cross-sections to 5.5 TeV!



# H→γγ and Higgs combination

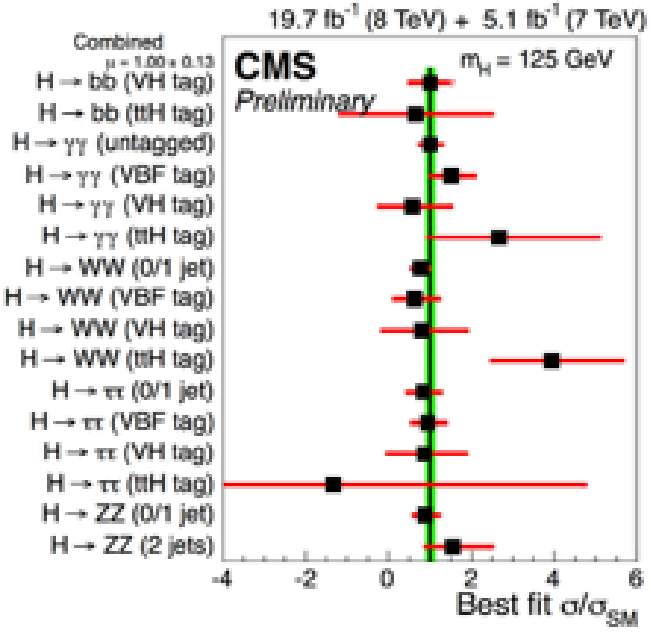
- Final γγ mass plot

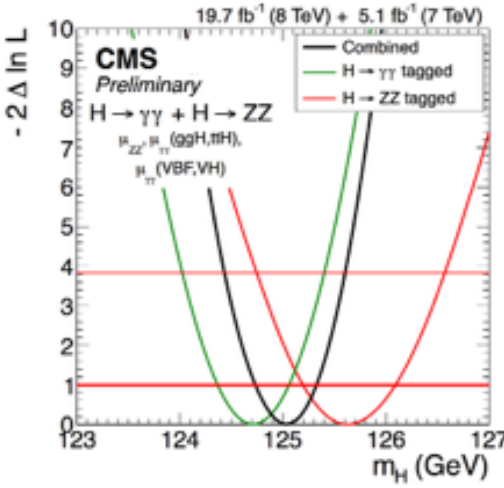



- Combine H→(γγ , ZZ, WW, ττ), VH→bb, and ttH→(ττ, bb)

$$m = 1.00 \pm 0.13$$

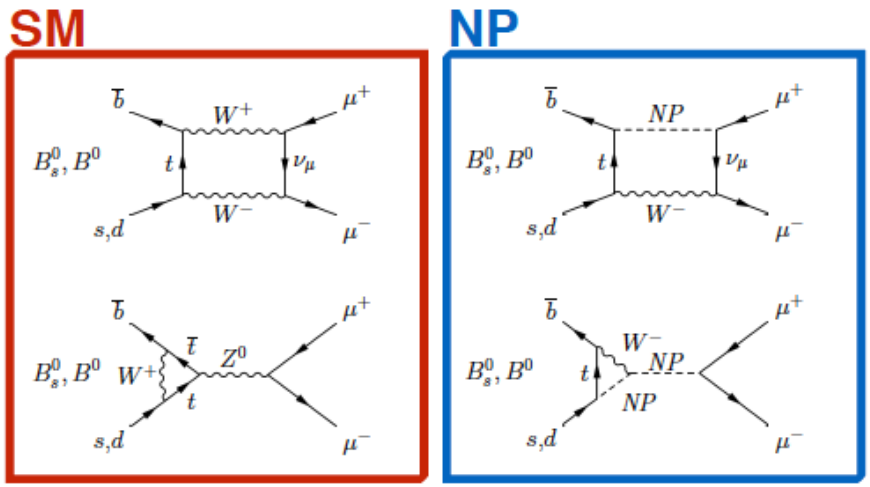
$$m_H = 125.03^{+0.26}_{-0.27}(stat)^{+0.13}_{-0.15}(syst)GeV$$

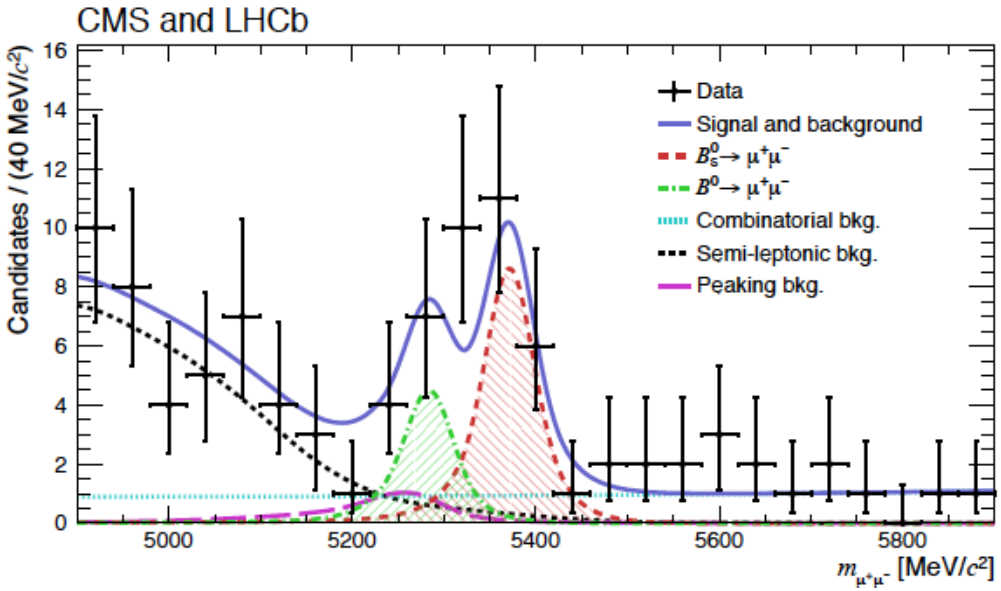


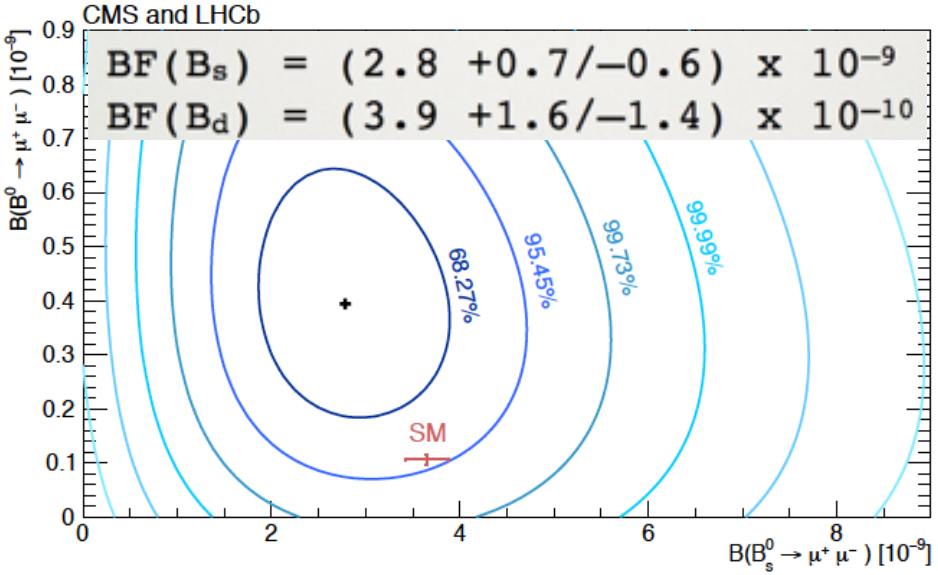



# LHCb-CMS $B^0 \to \mu\mu$ combination

- FCNC physics is sensitive to certain BSM contributions such as extra Higgs doublets
- The first likelihood-level combination between the experiments: simultaneous fit for both $B_d$ and $B_s$ hypotheses
- Result is public, paper is in the final stages of joint review for submission to Nature

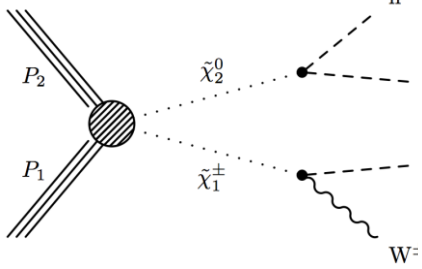


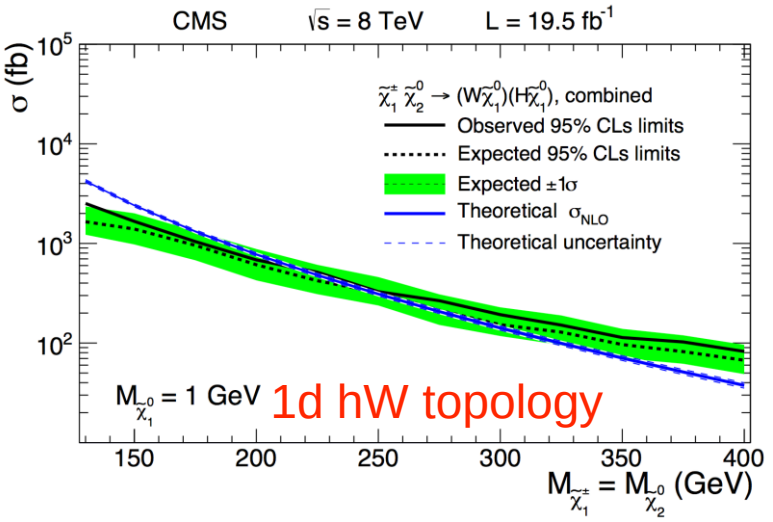



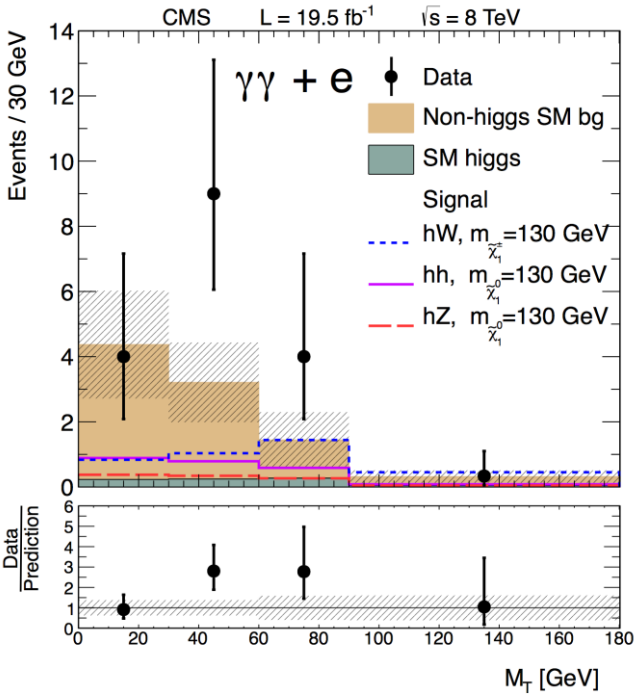



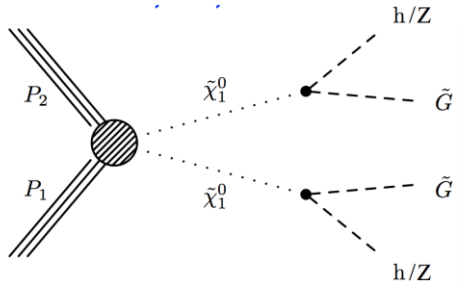
# Expansion of SUSY EW $\chi^+_1\chi^0_2$ search

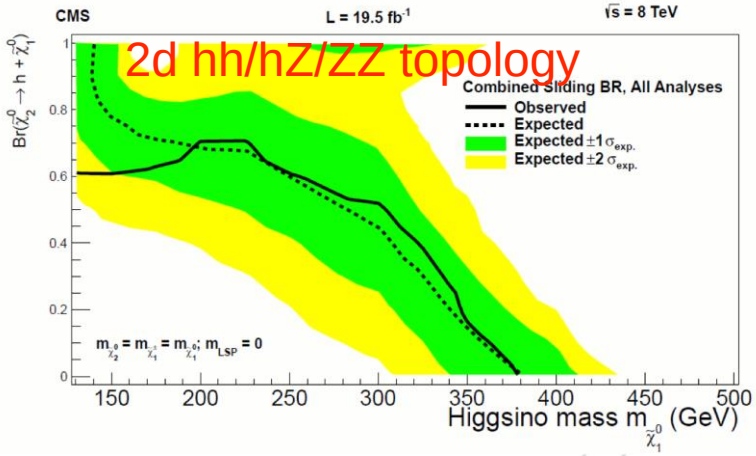
- Previous searches used WZ, ZZ, hW+MET
- Add channels hZ, and hh+MET, including $h \rightarrow \gamma\gamma$
- Simplified models for limits



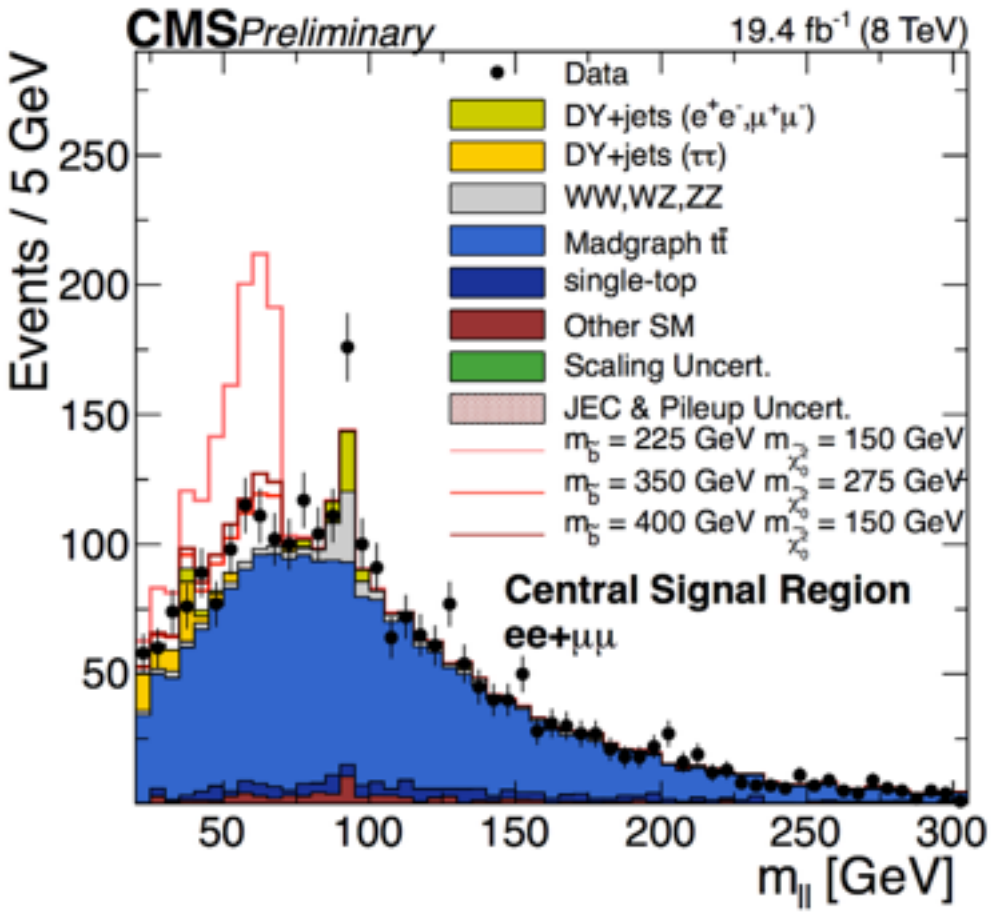

Slight excess in the γγ+e channel:
18 events observed
10.0±2.3 SM expected
in Higgs tag window

# SUSY dilepton edge search

- Dilepton+jets+MET channel
- An excess was observed below 70 GeV in dilepton mass already in 2011 data
  - Example SUSY decay channel

$$\tilde{b}\tilde{b}^{\star} \rightarrow \tilde{\chi}_2^0 b \tilde{\chi}_2^0 \bar{b}$$
$$\tilde{\chi}_2^0 \rightarrow \ell\tilde{\ell} \rightarrow \tilde{\chi}_1^0 \ell^+\ell^-$$
$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 Z^{\star} \rightarrow \tilde{\chi}_1^0 \ell^+\ell^-$$

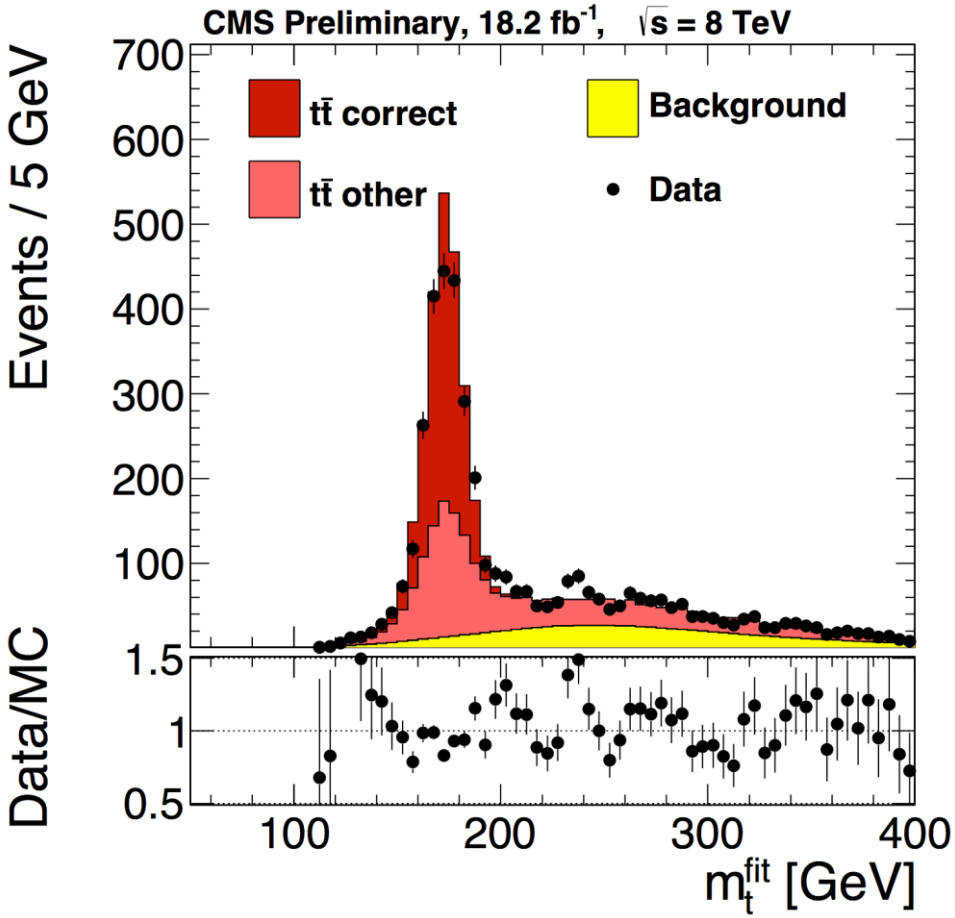
  - In both cases it would show up as a kinematic edge at $m(\chi^0_2)$-$m(\chi^0_1)$
  - Wrap-up: the excess is at the 2.6σ level, but no corroboration from other channels is seen
  - Clearly a channel to watch in Run2



# Top mass: new measurements

- All-hadronic and dilepton channels complement the existing single lepton measurement
- The fully leptonic analysis is the first “blind” top mass measurement in CMS

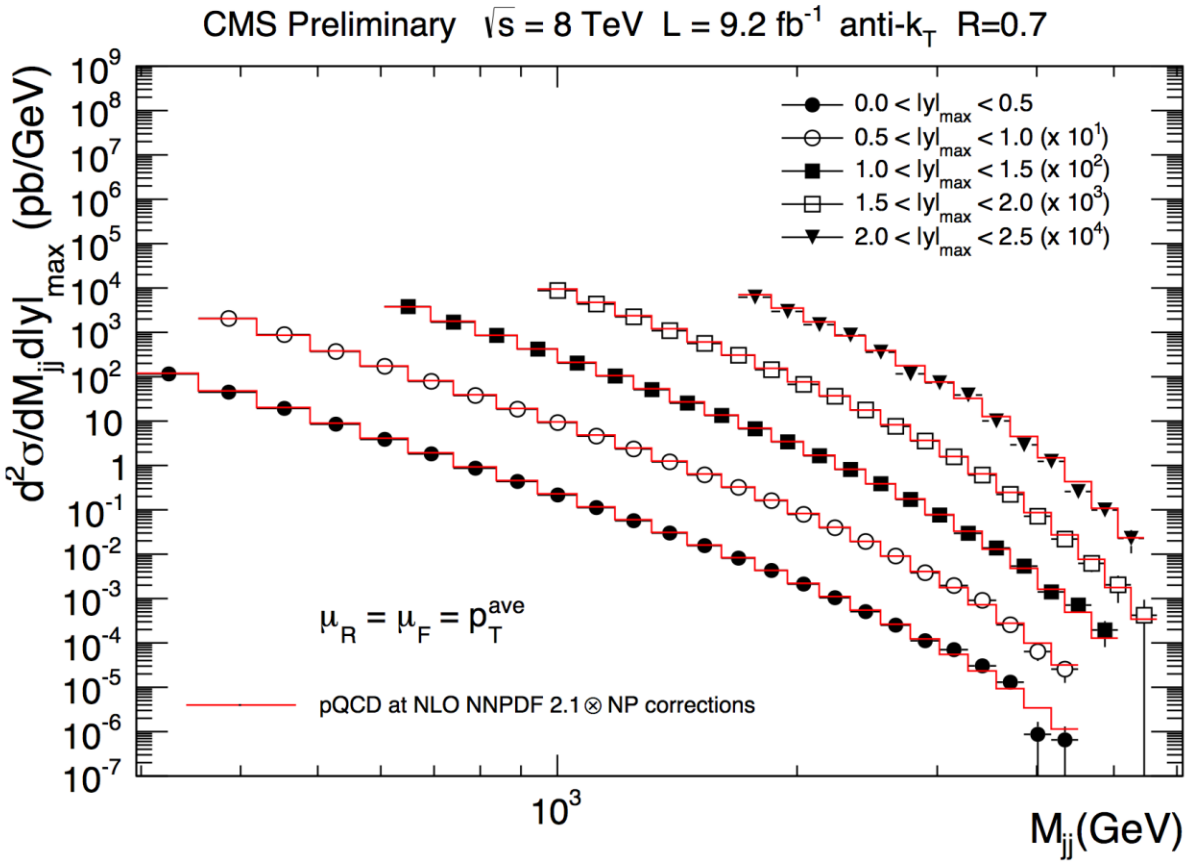
*Fully hadronic*

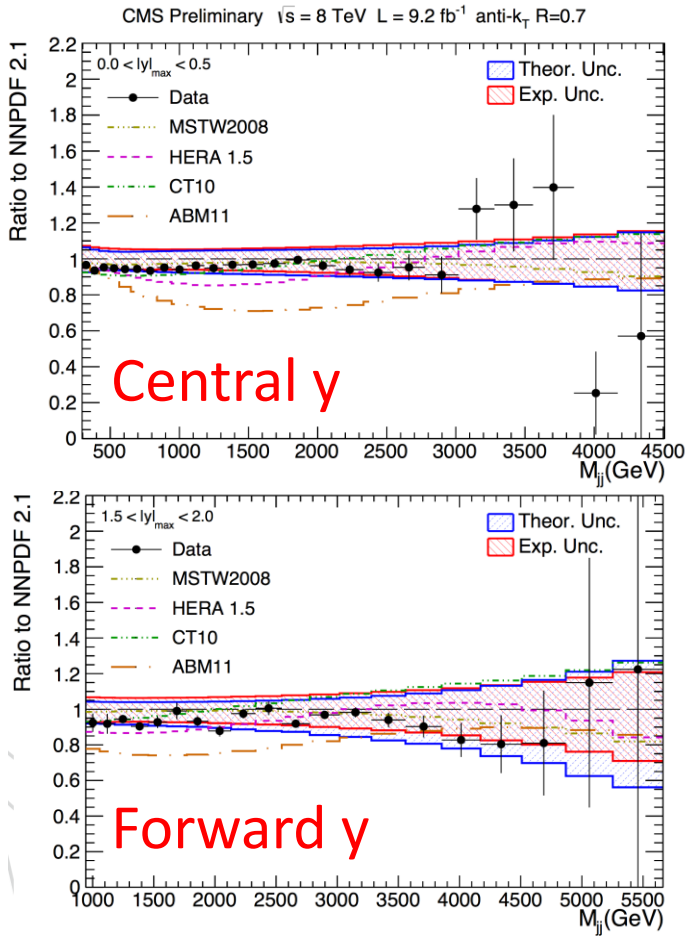



$m_t(0\ell)$= 172.08±0.36 (stat.+JSF) ± 0.83 (syst.) GeV
$m_t(1\ell)$ = 172.04±0.19 (stat.+JSF) ± 0.75 (syst.) GeV
$m_t(2\ell)$ = 172.47±0.17 (stat. ) ± 1.40 (syst.) GeV

# SM physics: jet cross sections

- Dijet differential cross sections as function of $|y_{max}|$ and $M_{jj}$ to 5.5 TeV(!), to test PDFs and NLO pQCD



# CMS readiness for Run 2: summary

- Detector: numerous LS1 upgrades and repairs done
- Recent ‘surprise’ with barrel pixels:
  - One quarter with 47 modules (7% of total BPIX) not responding – repair is ongoing
- DAQ2 and new Timing and Control system (TCDS) are being deployed and exercised
- Software, Computing: various improvements, CSA14 summer challenge exercise just finished successfully
- Analysis: PHY14 exercise aims to prepare high priority analyses for speedy results on first 1-5 $fb^{-1}$

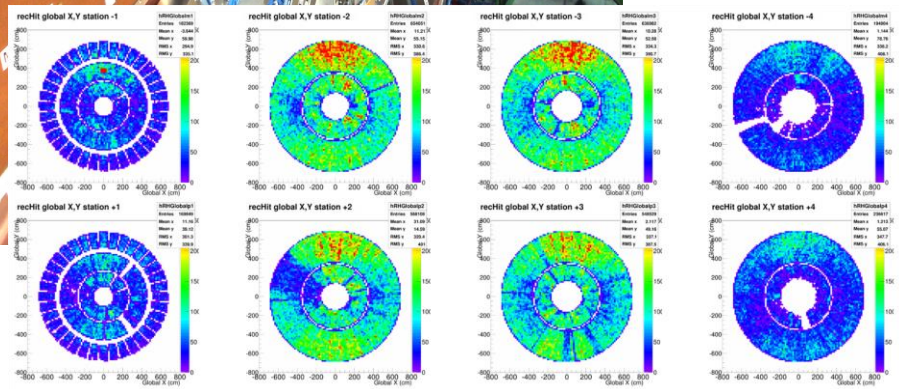
# LS1 upgrade: Tracker running cold (-15°)

Si tracker commissioned at -15° C (tested to -20° C) for required longevity to 500 $fb^{-1}$


Bulkhead with insulation

New molds ready; **last** thing to be placed

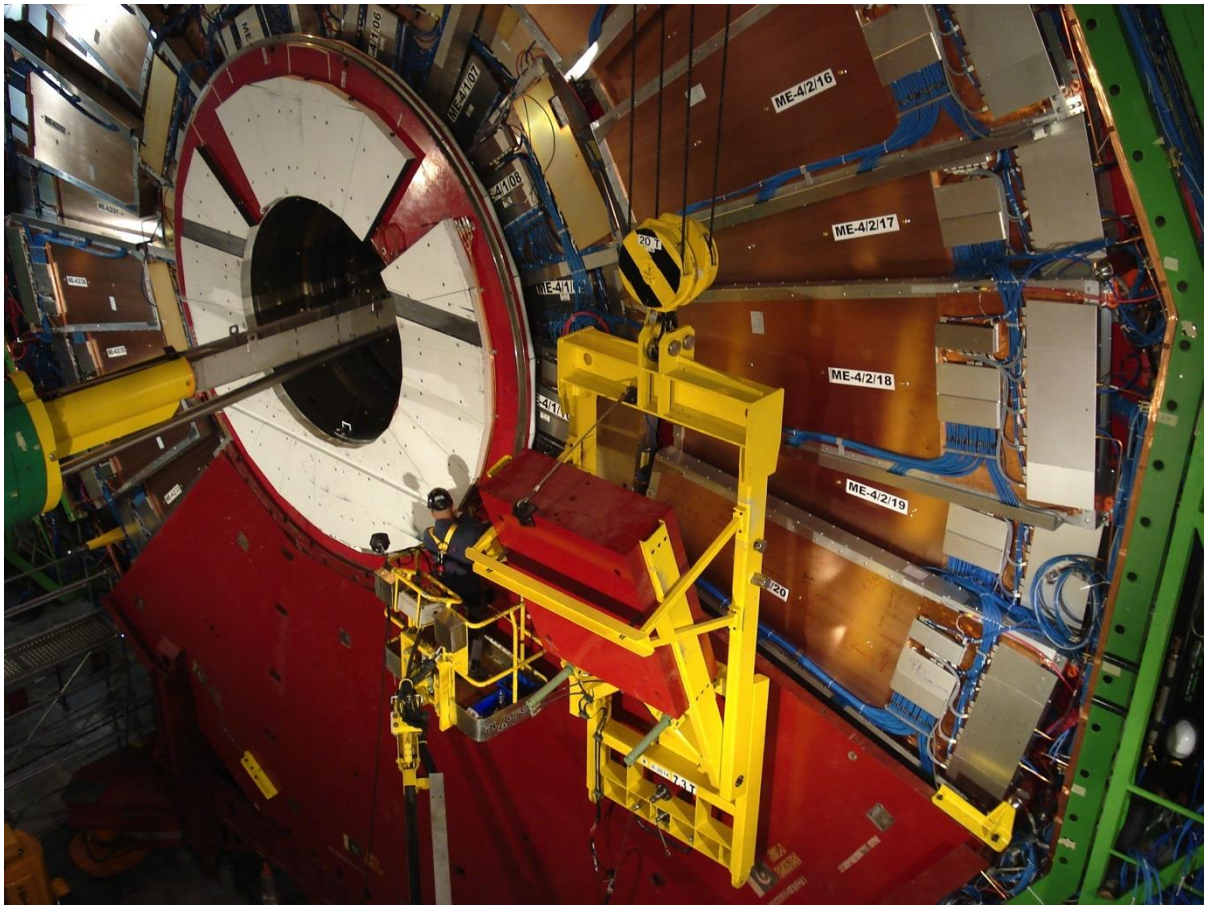
# LS1 upgrade: CSC and RPC new detectors


CSC cosmic ray hits in July

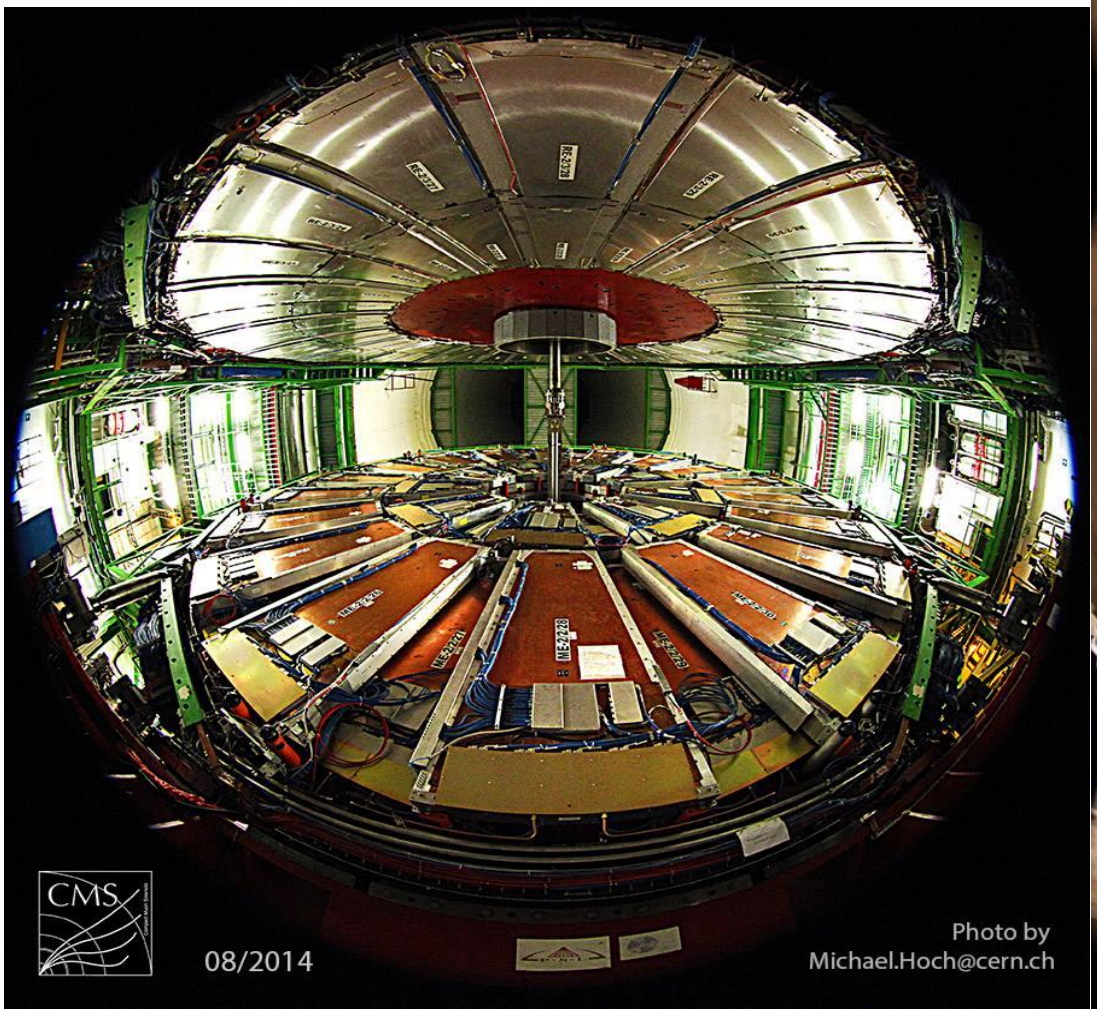

+DT muon: insert optical links and move trigger electronics to service cavern

# LS1 upgrade: shielding walls (YE4) constructed in both endcaps




# LS1 upgrade: new beampipe

New reduced-diameter pipe ready for upgraded pixel installation YETS 2016

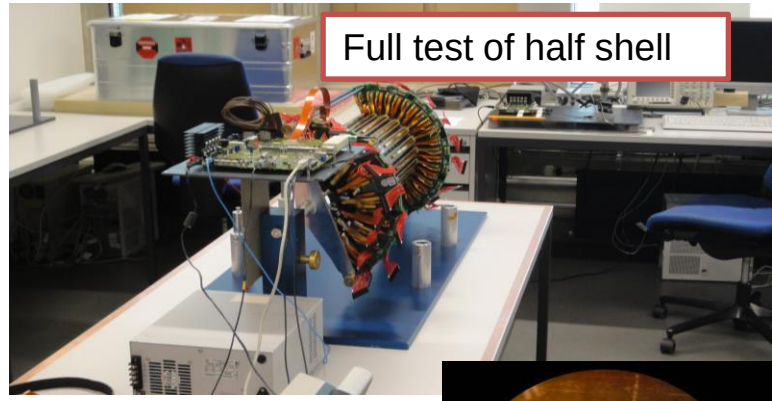


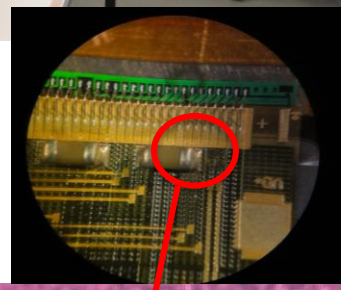

# And more detector work …

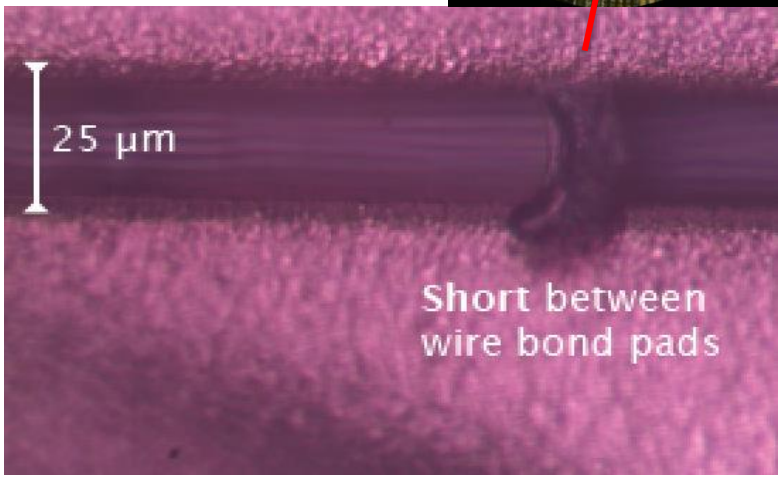
- New SiPM photodetectors in outer HCAL (done)
- New thin-window, multianode PMT in HF (done)
- New μTCA readout for HF (being deployed)
- New beam monitoring (e.g. new silicon pixel based lumi monitor ,PLT) in progress
- Phase 1 trigger upgrade (e.g. optical splitting) (ongoing)
- Beam instrumentation (Pixel Lum Telescope, Beam Conditions Monitor, Beam Loss Monitor) (ongoing)

# Pixel (BPIX) status

- Discovery:
  - ~25% (47/192) of BPIX modules in one half-shell were found unresponsive at final checkout, 2 weeks before insertion date
  - The half-shell was transported to PSI for diagnosis and repair; the other three have been re-checked and are working fine
- The problem:
  - Ohmic shorts between wire-bond pads on the High Density Interconnect (HDI). Most of the shorts look like “dendrites”
- Repair:
  - The shorts can be removed in a controlled way thus repairing the module - “scratching”. Also, production of new modules is underway, allowing to completely replace modules with multiple shorts. **Layers 1 and 2 repairs are almost finished**
- Prevention:
  - Chemical analysis is underway; investigating conditions that create the shorts, and longevity of repair
- A plan has been developed to advance other tasks and install the pixel detector in December/January. **No significant change to overall CMS schedule.**

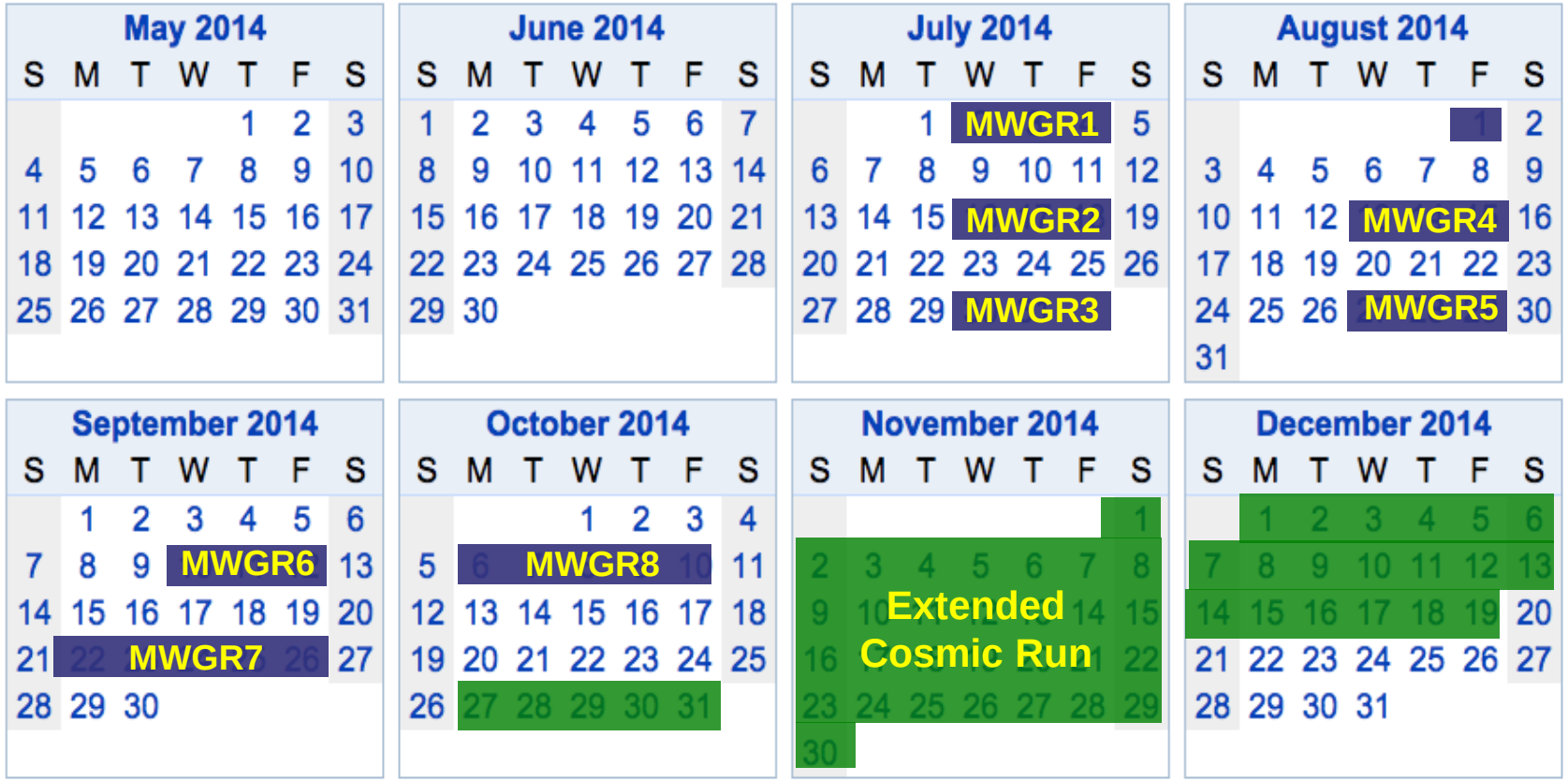




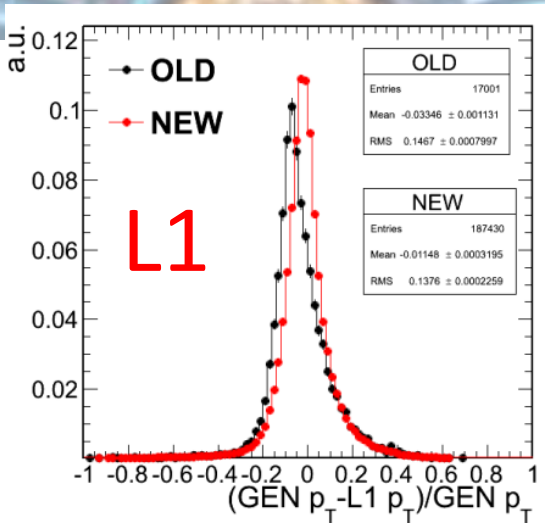
# Commissioning at Point 5 in 2014

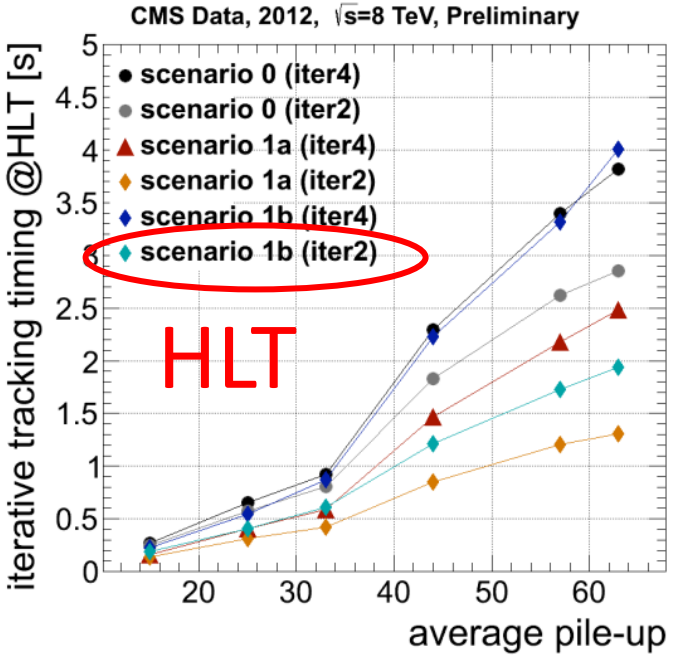
- Eight Mid-Week Global Runs (MWGR) to commission new detectors, followed by an Extended Cosmic Run to verify operational stability



# L1 and HLT Trigger

- Need to cope with factor of 2 luminosity, factor 2 in cross sections due to energy boost
- Goal is to keep the same physics sensitivity
  - Trigger has to select more wisely
  - Calorimeter: PU subtraction, better e isolation, tau ID
  - Muons: take advantage of LS1 detector upgrades
- HLT higher PU leads to larger reconstruction times – improve tracking algorithms
- Phase 1 calorimeter trigger upgrade is crucial for HI physics in late 2015 (jet trigger needs PU subtraction)
- First full menu aimed at PU=40, $\Delta T$=25 ns is now implemented in CMS simulation

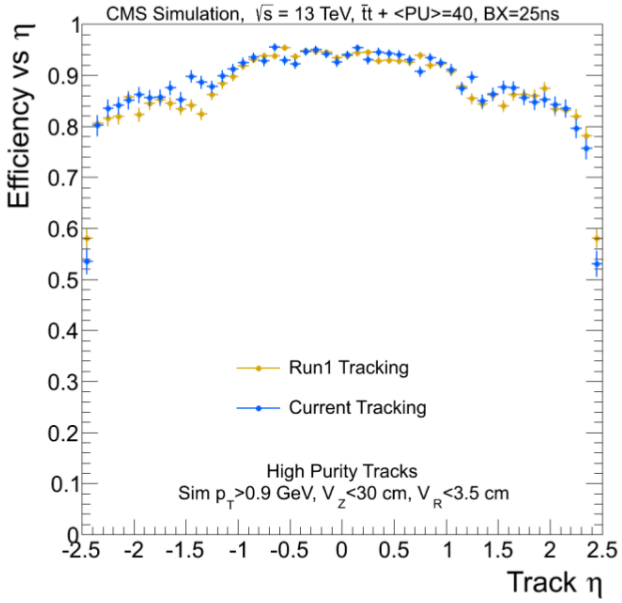


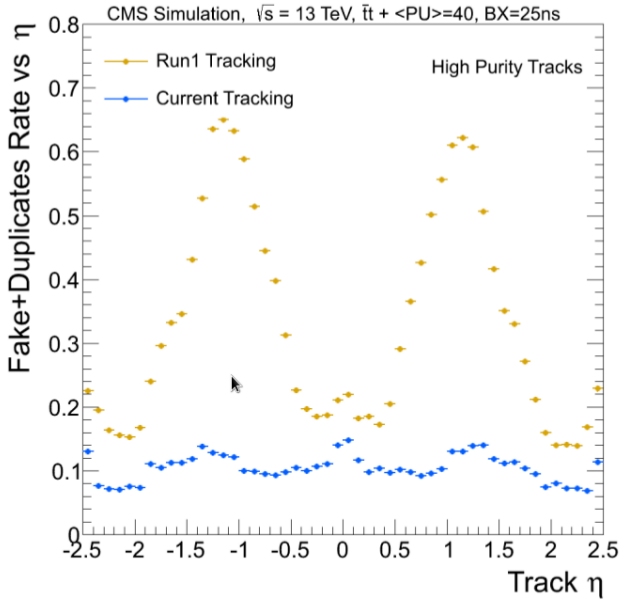
# Software and computing summary

- New improved algorithms
  - For tracking, ECAL, muons, boosted jets, MET
- Readiness exercise CSA14 successfully concluded
  - Allows assessment of workflows/computing, reconstruction of physics objects
- Follow-on analysis exercise PHY14 will target a few high-priority analyses
  - Re-reco the GEN-SIM samples from CSA14
  - Test new reconstruction developments @ 25 ns
  - Include trigger menu and simulation
  - Define analysis strategies in case of new physics

# Run 2 improved algorithms: Tracking



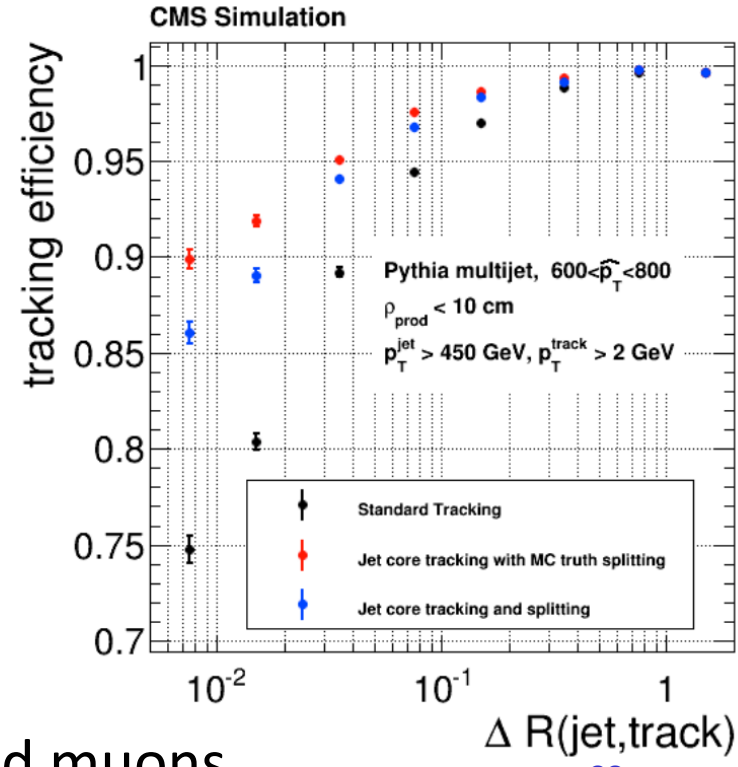

high $p_T$ prompt tracks




all tracks

- Large improvements in fake rejection
  - Improved seeding from triplets
  - Cluster charge cut to reduce out-of-time PU

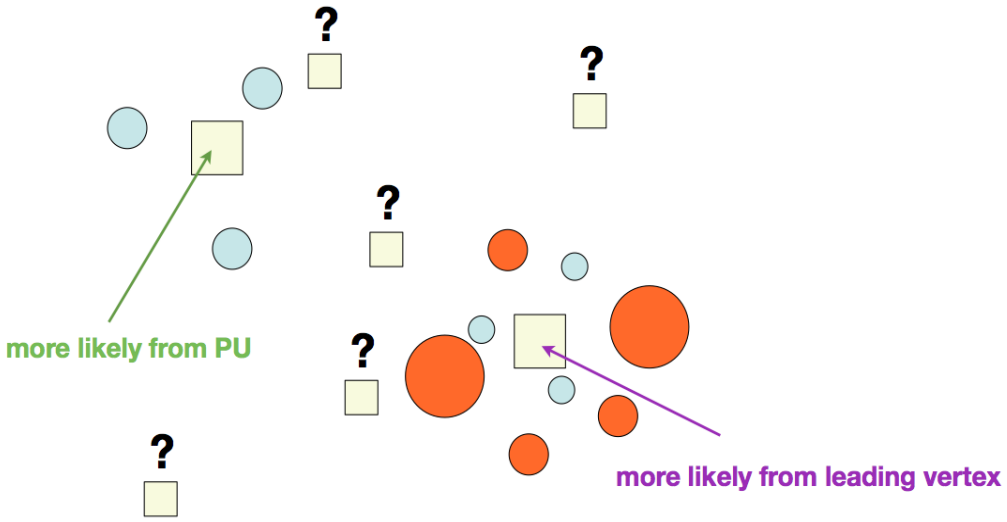
- Boosted jet tracking
  - Esp for b, t ID
  - Use cluster splitting regionally around high pT calo-jets
  - Improves efficiency at low $\Delta R$




- Now validating improved algorithms for ECAL and muons

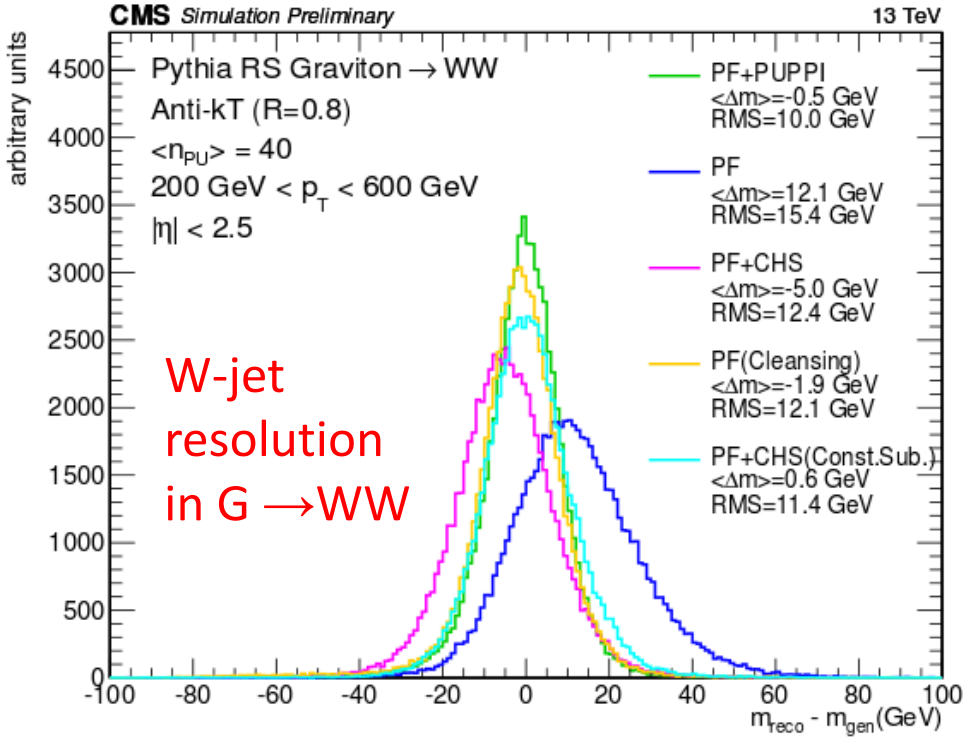
# Jets and MET

- PUPPI* technique uses per-particle PU subtraction. First results based on full reconstruction look promising
  - Can also be used on lepton isolation




$$\alpha_i = \log \sum_{j \in \text{event}} \frac{p_{Tj}}{\Delta R_{ij}}$$

$$R_{\min} \leq \Delta R_{ij} \leq R_0$$




*Pile-Up Per Particle Id, http://arxiv.org/abs/1407.6013

# Outcome of CSA14 exercise

- July-September 2014: simulation, digitization, reconstruction were robust in processing ~1.5 billion events
- Integrated and deployed a new analysis data format "MiniAOD"
  - 10x reduction in size relative to AOD (~40 kB at PU=20) that was used in Run 1
  - Plan to centrally produce the MiniAOD for 2015

- Beyond CSA14, begin production of Monte Carlo samples with 2015 startup geometry, GEANT4.10, and improved sim code:
  - October for GEN-SIM, February 2015 for DIGI-RECO
  - Factor of 2 speed improvement over the last year

# Phase1 upgrade in LS1→LS2 period

- Major milestone
- System comes into operation


**L1-Trigger** http://cds.cern.ch/record/1556311

Installation of parallel paths Calo Trigger — May 2014
Interim Calo Trigger operational
Slice of TDR Trigger (Calo, Muon, Global) operating
Full TDR Trigger commissioned

**PIXELS**

Start sensor prod, submit final ROC — Oct 2013
Install pilot blades
Start module production — May 2014
DAQ operational at P5
Ready for Installation

**HCAL**

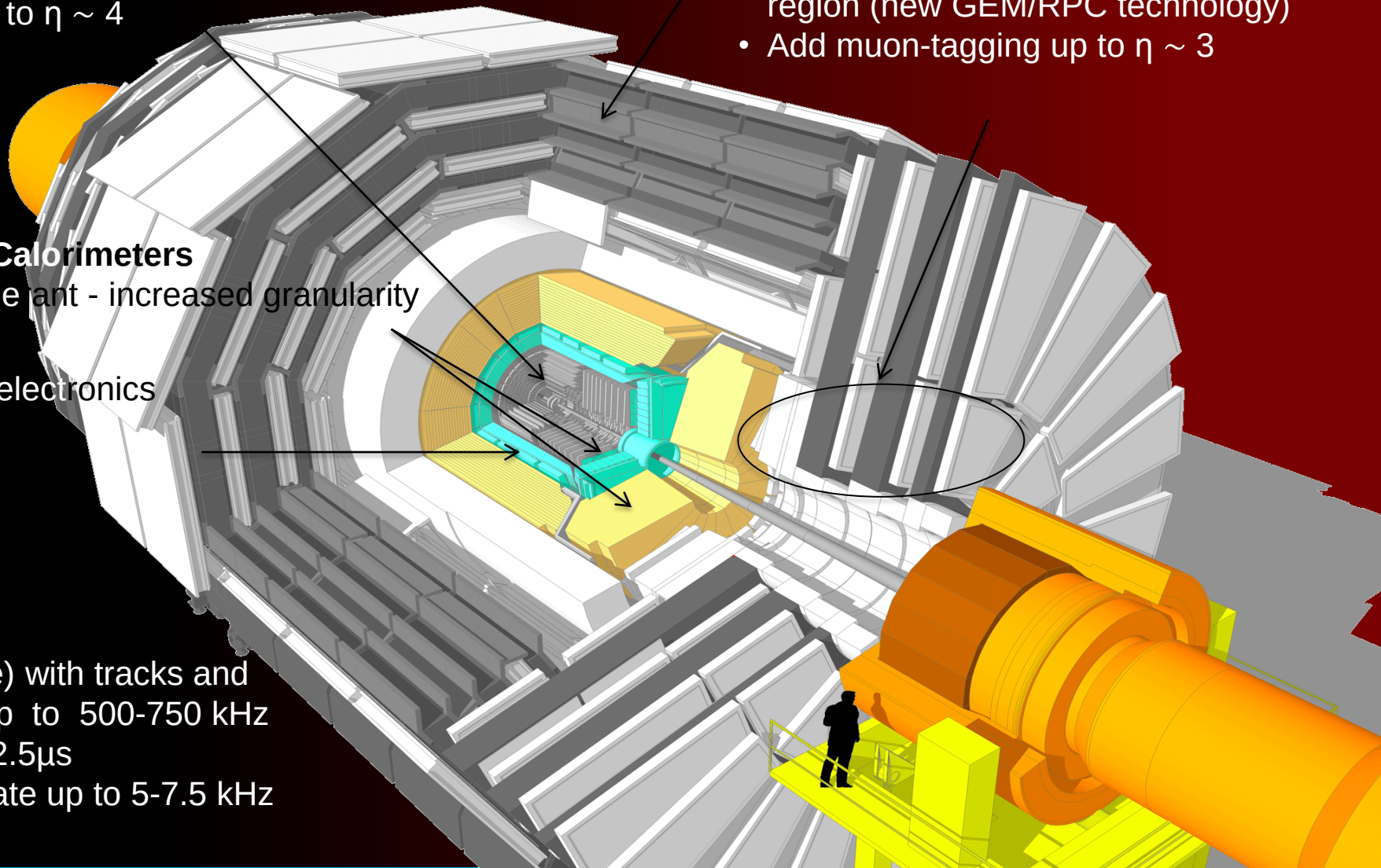
HF BE upgraded to µTCA — Aug 2014
HF FE upgraded (2-channels per PMT, TDC)
HBHE BE upgraded to µTCA
HBHE FE upgraded (SiPM and depth segmentation)

LS2

# CMS Phase-II Upgrades

**New Tracker**
- Radiation tolerant - high granularity - less material
- Tracks in hardware trigger (L1)
- Coverage up to η ~ 4

**Muons**
- Replace FE electronics in barrel DT and endcap CSC inner rings
- Complete CSC system in forward region (new GEM/RPC technology)
- Add muon-tagging up to η ~ 3

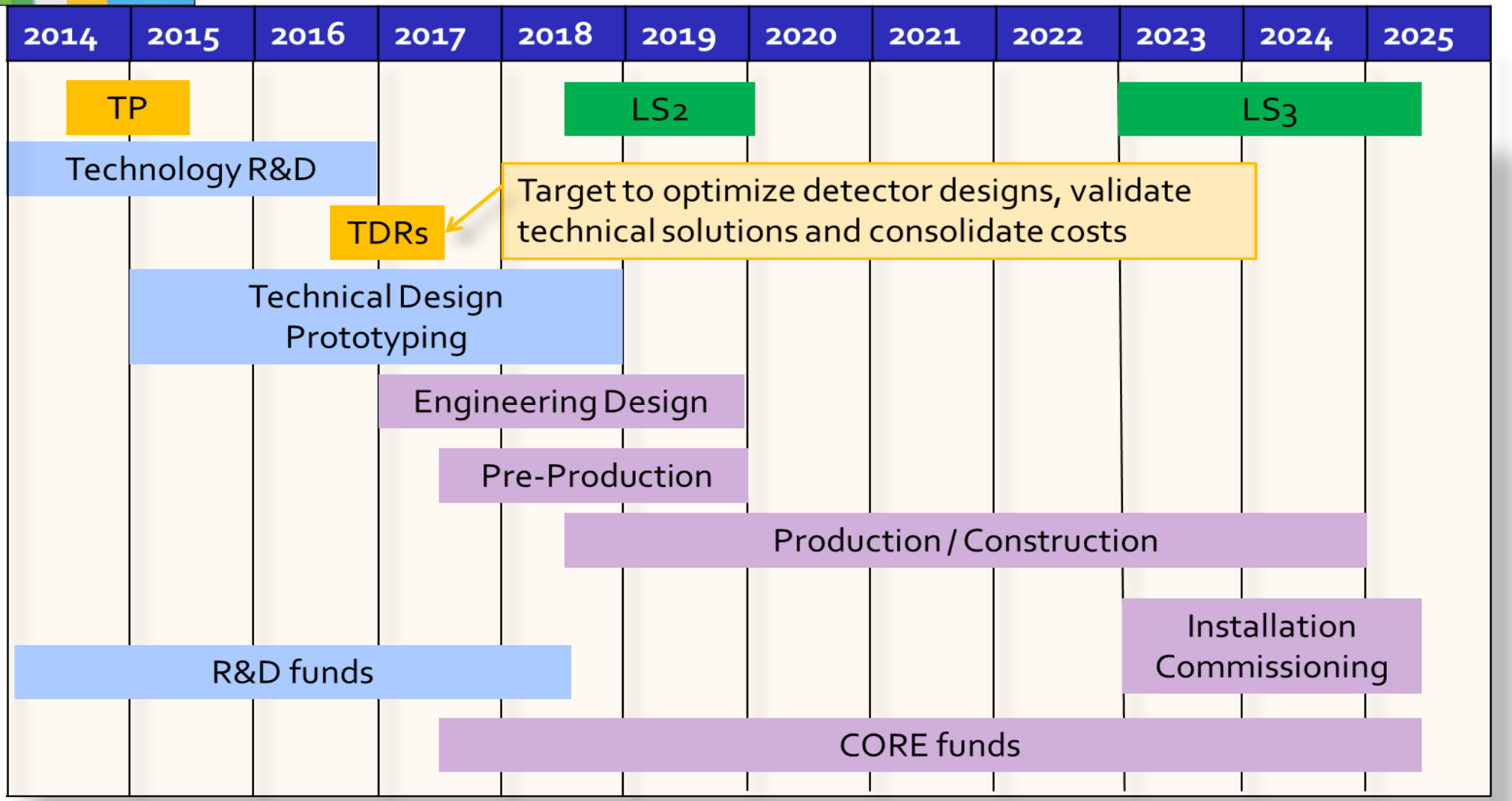


**New Endcap Calorimeters**
- Radiation tolerant - increased granularity

**Barrel ECAL**
- Replace FE electronics

**Trigger/DAQ**
- L1 (hardware) with tracks and output rate up to 500-750 kHz
- Latency of 12.5μs
- HLT output rate up to 5-7.5 kHz

# Phase 2 upgrade planning



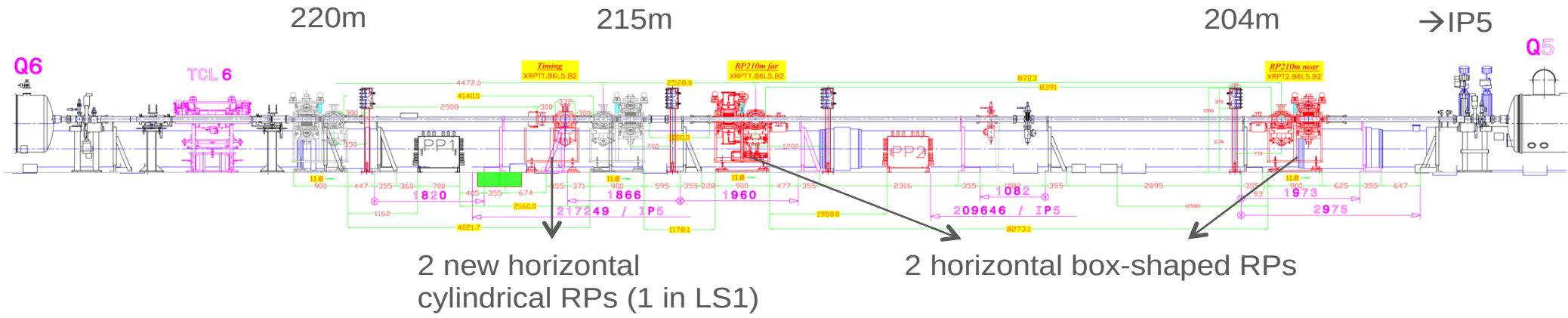
# Summary for CMS

- Many Run 1 physics final results still in progress
- It has been a highly successful shutdown, with numerous improvements
  - The BPIX problem was recognized late, but looks to be solvable within the time remaining
  - CMS is in full recommissioning mode at Point 5 now
  - Trigger, software, computing, physics coordination are preparing to exploit fully the Run 2 data
- The CMS Phase 2 Technical Proposal is being prepared
  - Expect a decision on endcap technology early next year
  - TDRs to follow during the following two years

# Backup slides follow

# CT-PPS TDR

- CMS-TOTEM Precision Proton Spectrometer:
  - Central exclusive production at high luminosity:
    - quartic gauge couplings, QCD, search for new resonances
  - Project scale ~ 1 MCHF
  - Issues:
    - Detector operation close to the beam (RPs and MBPs)
    - Synergy with Phase 2 R&D (pixel and timing detectors)
- TDR was released:
  - https://cds.cern.ch/record/1753795



# Beam Radiation Instrumentation and Luminosity (BRIL) Hardware

Z=+/- 14.4 m, R=5 cm; R=28cm

**BCM2L:**

- 4 pCVD diamond (inner) – beam abort
- 8 pCVD diamond (outer) - monitoring

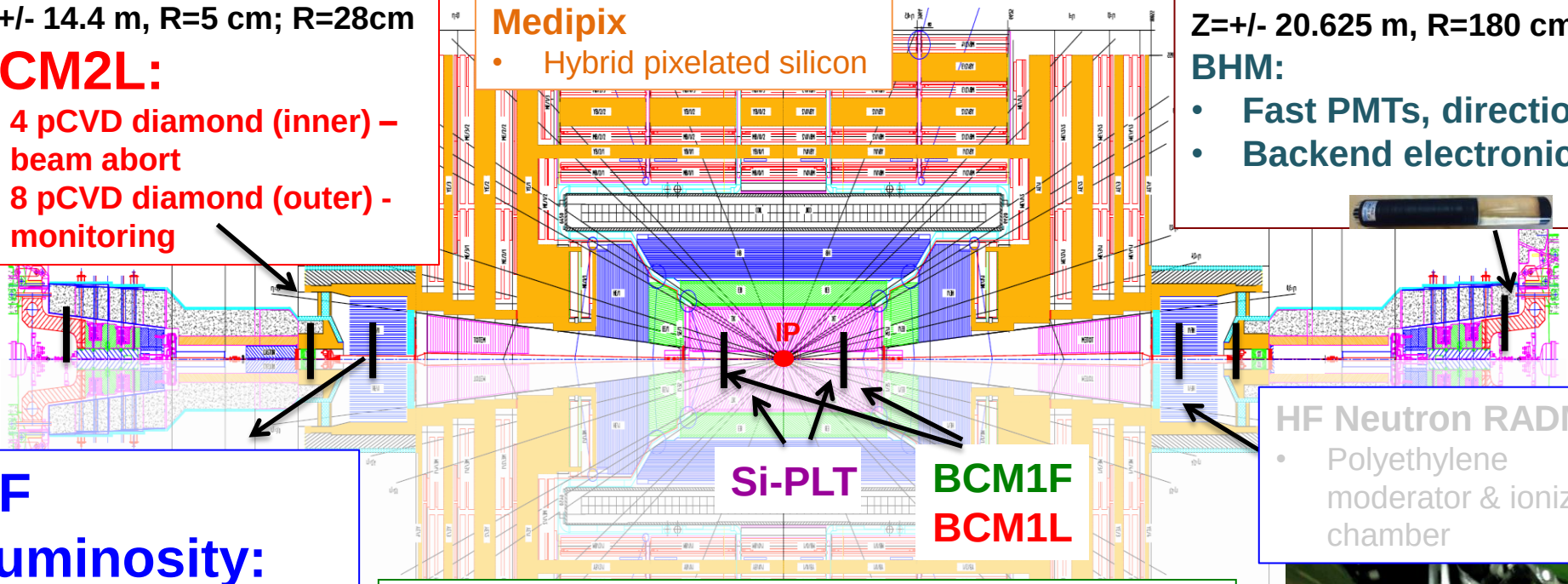
**Medipix**

- Hybrid pixelated silicon

Z=+/- 20.625 m, R=180 cm

**BHM:**

- Fast PMTs, directionality
- Backend electronics




**HF Neutron RADMON:**

- Polyethylene moderator & ionization chamber

**HF Luminosity:**

- Photo-detectors
- backend electronics

Z=+/- 1.8 m, R=5-6 cm

**si-PLT:**

- 48 si-pixel sensors
- special 40 MHz readout

**BCM1F:**

- 48 single crystal diamond sensors
- fast MIP counter, triggerless readout

**BCM1L:**

- 4 pCVD diamond – beam abort