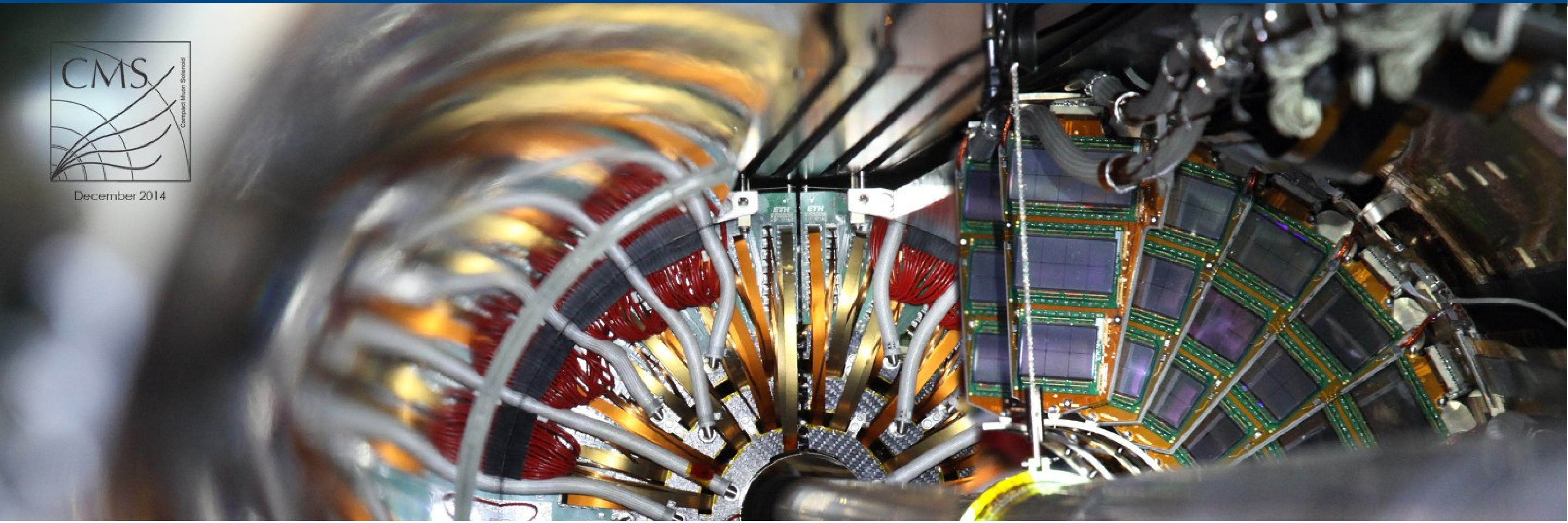
LHC: the adventure continues



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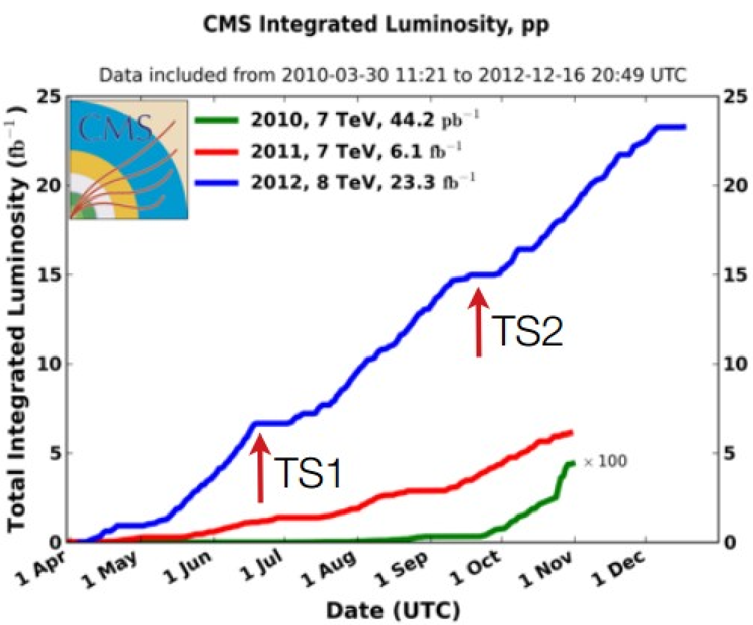
Friday, 02 October 2015

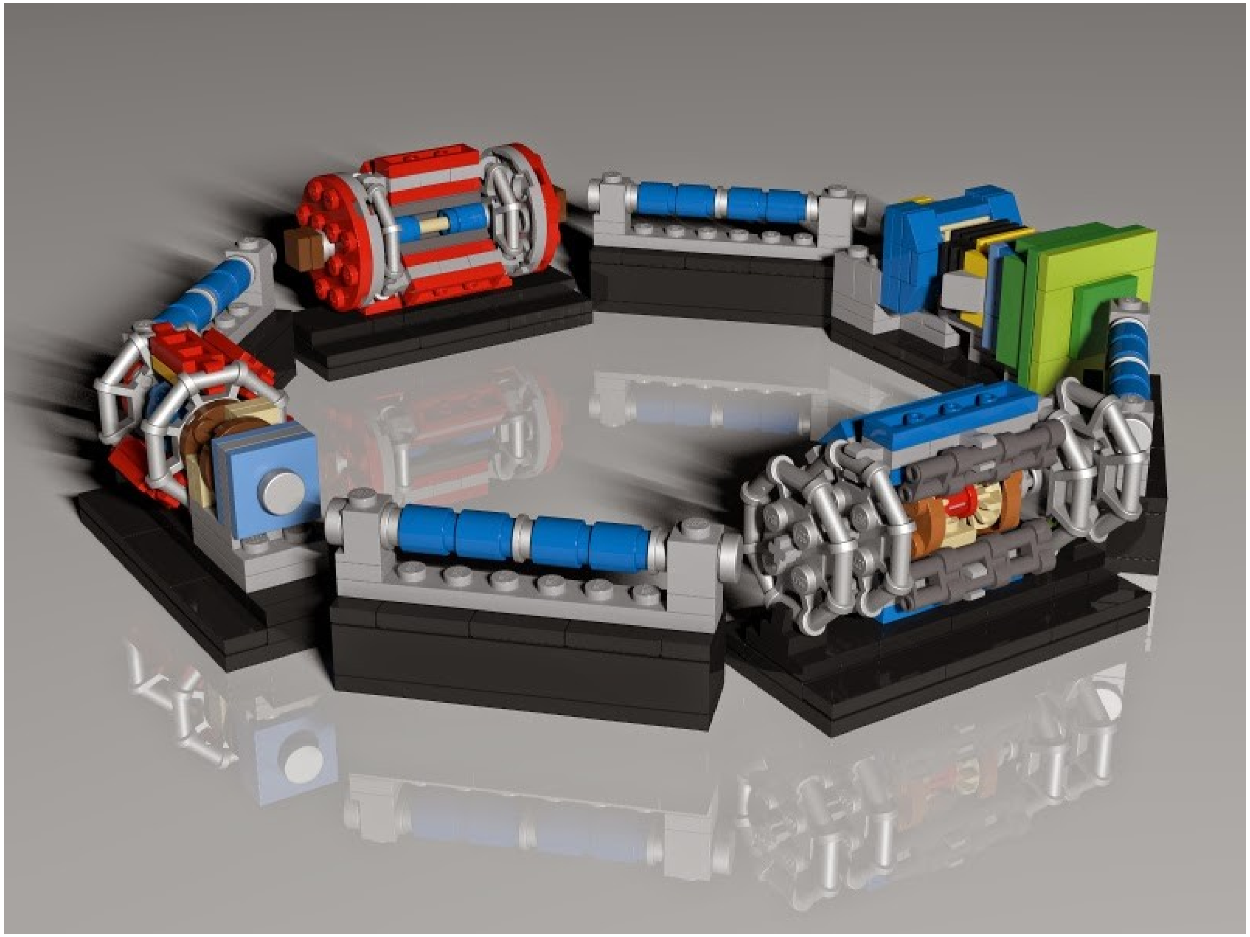
On the menu today

- Introduction
- LHC status
- CMS status
- Some physics highlights

The LHC...

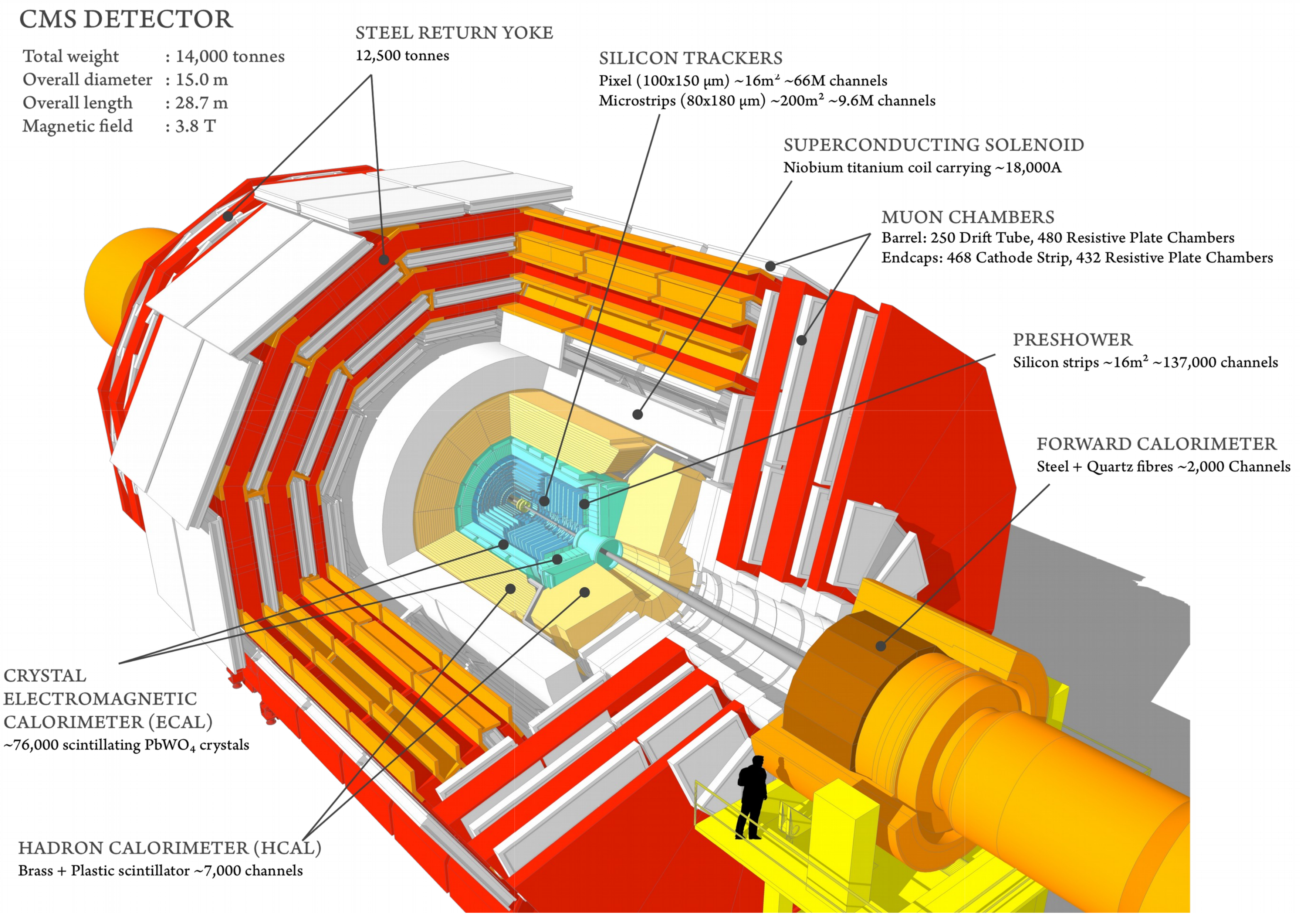
- LHC started to deliver p-p collision in 2010
  - √s =7/8 TeV
  - Peak instantaneous luminosity: ~7.7 x 10^{33} cm^{-2} s^{-1}
  - 50 ns bunch crossing (BX) spacing
  - Up to 21 average pile up interactions





- Data taking interrupted by Technical Stops (TS)
  - Time used for detector calibrations
- Long shutdown (LS1) started in 2013
  - Run 2 started in spring 2015

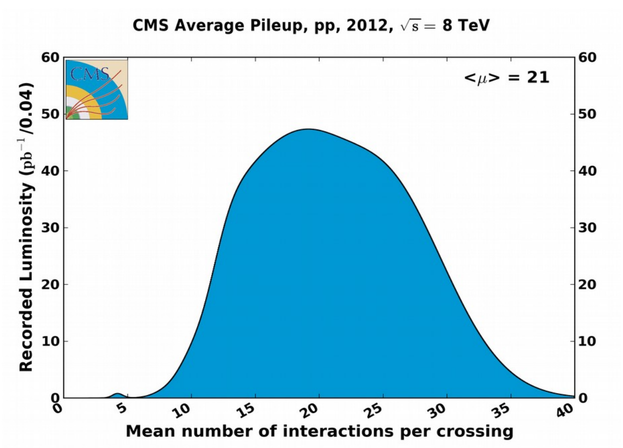
The CMS detector

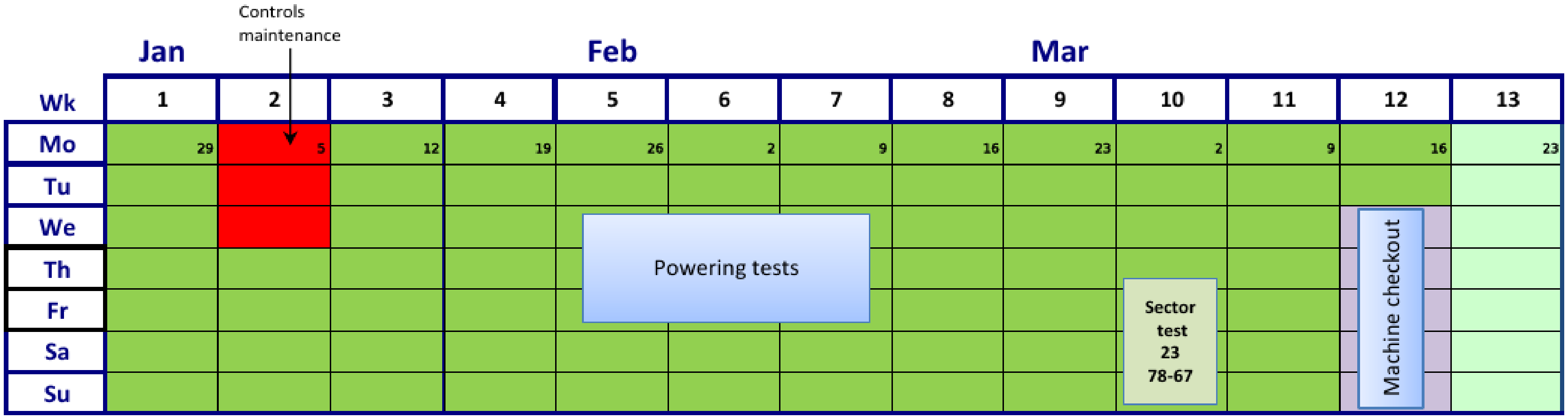


Challenges

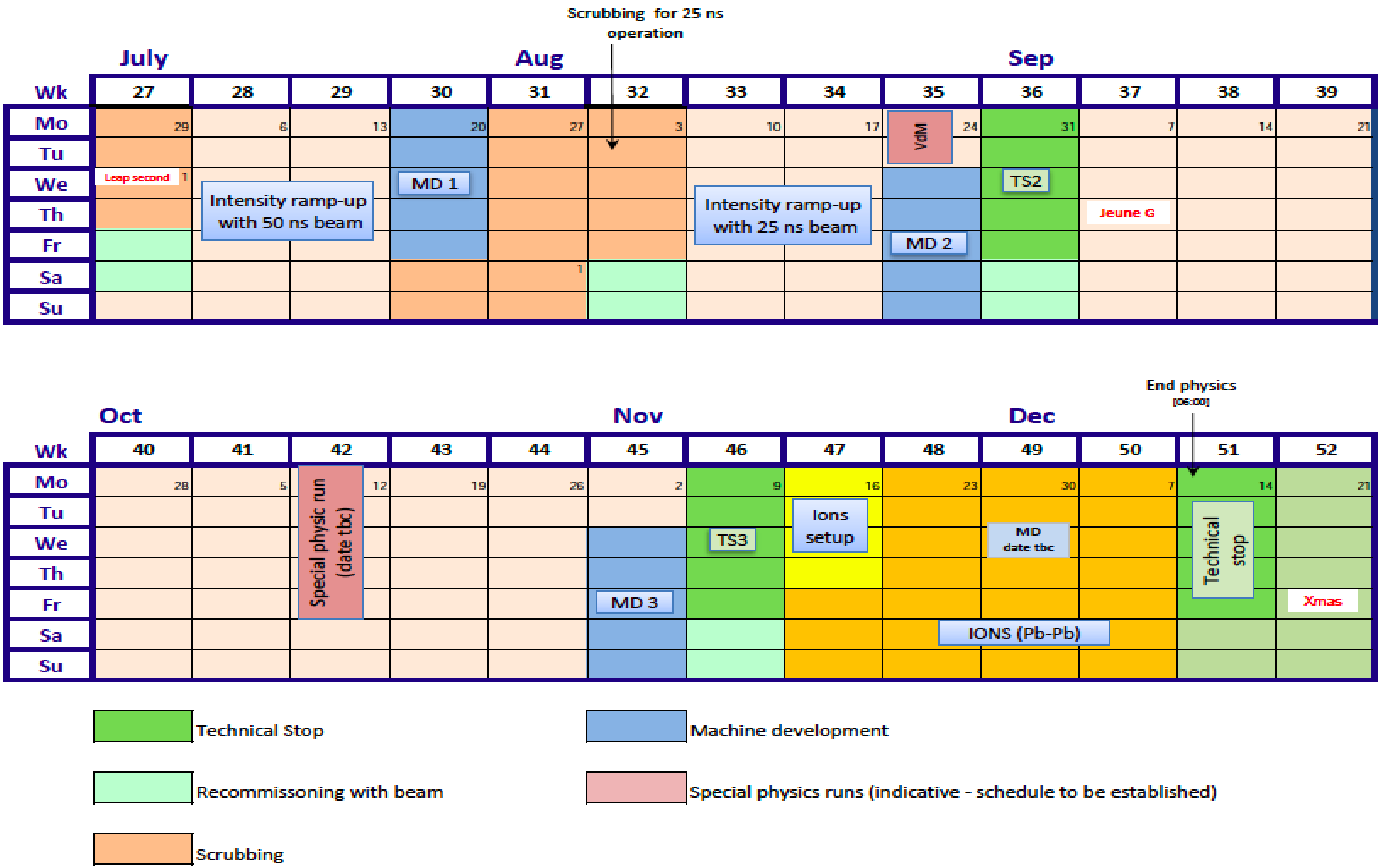
- During run 2, detectors will face unprecedented conditions
  - 25ns **bunch spacing** (instead of 50ns)
  - Higher **luminosity**
    (1.3E34$cm^{-2}s^{-1}$ in 2015, up to 1.7E34$cm^{-2}s^{-1}$ by LS2)
  - Higher **energy** (13TeV, compared to 8TeV so far)
    - Higher cross-sections
    - Heavier resonances
    - More boosted objects
- The **early days** of run 2 are challenging in many ways
  - Recommissioning of the detectors after (more than) two years
  - Machine conditions do change on a daily basis
  - Physics expectations are high

} up to $<\mu> \sim 50$
(factor ~2 higher than Run 1)





Machine schedule



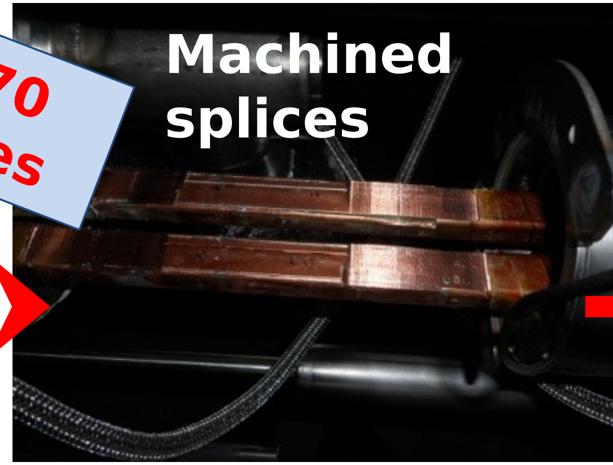
Machine status

Before looking where we are, let's glance at where we come from…

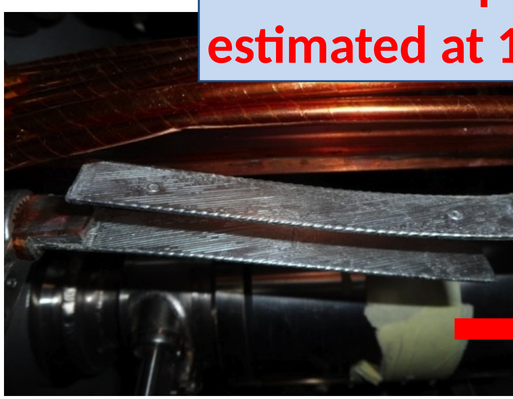
Once upon a time, was the “LS1”.

- Main motivation for LS1:
  - Consolidation of the Large Hadron Collider to enable the operation at the design energy of 7 TeV.
- This goal had to be achieved through (among others...):
  - Consolidation of superconducting splices (10170 splices, 27000 shunts!);
  - Installation of 5000 new electrical insulation systems;
  - 612 new relief valves installed.
- Timeline: Feb. 2013 - Dec. 2014, followed by hardware commissioning.
  - Other important activities took place in the 2 year stop!

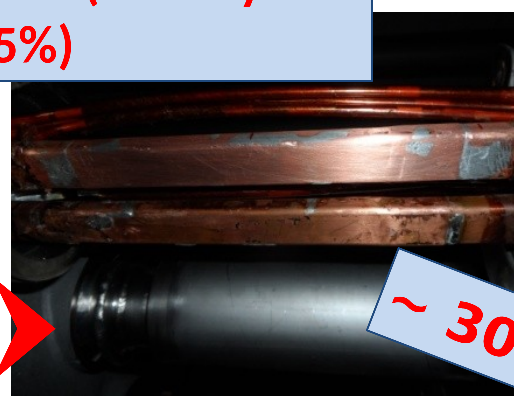
Splices consolidation process



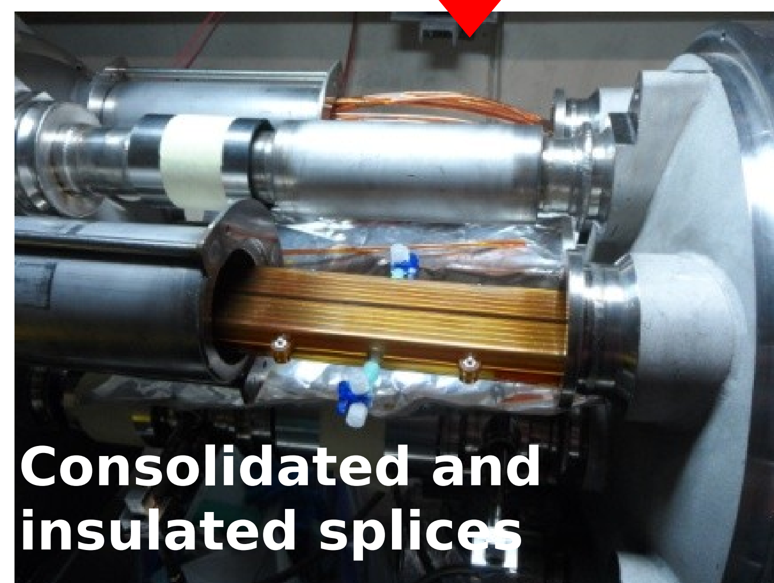
30% of the splices (initially estimated at 15%)



Unsoldering of splice and superconducting cables

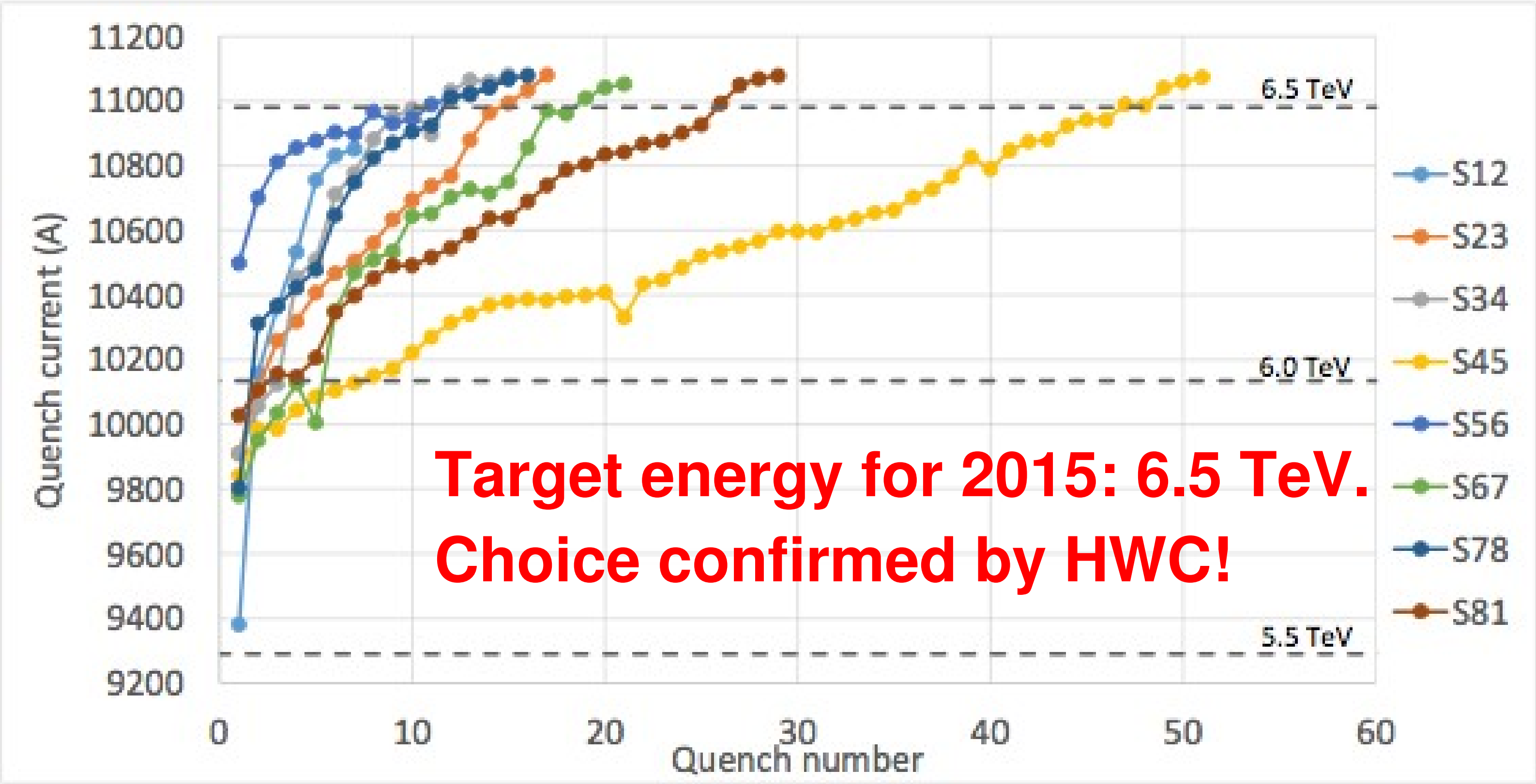


Reconstruction and soldering of splice and superconducting cables



Total interconnects: 1695 (**10170** high current splices). Number of splices redone: ~3000

Dipole training



Sector	# Training quench	Flattop quenches
S12	7	0
S23	17	0
S34	15	1
S45	51	0
S56	18	3
S67	22	1
S78	19	3
S81	29	0
Total	171	8

All LHC dipoles were trained above nominal current *before* installation.

Training stopped after the 2008 incident: safe operation < 4TeV.

After removing HW limitations, training started for all sectors.

Machine parameters

Phase	Days	Physics efficiency	Integrated luminosity	Comment
Initial low luminosity run	7	20%	Few pb-1	low number of bunches
50 ns intensity ramp-up	21	20%	0.5 fb-1	short fills plus stepped increases in number of bunches
25 ns phase 1, beta*=80 cm	44	30%	4 fb-1	includes ramp-up and bedding in of 25 ns
25 ns phase 2, beta*=40 cm	44	35%	8 fb-1	ramp-up after reduction in beta* - should be quicker

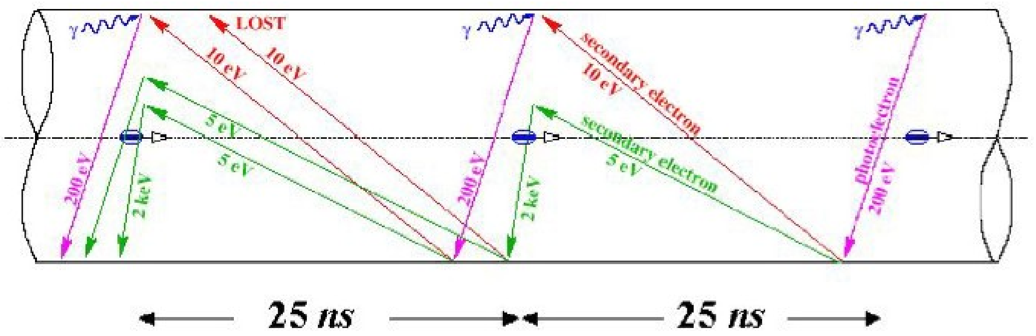
Parameter	50 ns	25ns phase 1	25ns phase 2
Energy [TeV]	6.5 TeV	6.5 TeV	6.5 TeV
β* (1/2/5/8) [m]	0.8 / 10 / 0.8 / 3	0.8 / 10 / 0.8 / 3	0.4 / 10 / 0.4 / 3
Half X-angle (1/2/5/8) [μrad]	-145 / 120 / 145 / -250	-145 / 120 / 145 / -250	-155 / 120 / 155 / -150
Number of colliding bunches (1/5)	1368	2592	2592
Bunch population	1.2E11	1.2E11	1.1E11
Emittance into Stable Beams [μm]	2.5	2.5	2.5
Bunch length [ns] - 4 sigma	1.25	1.25	1.25
Peak Luminosity	4.88e33	9e33	1.2e34
Peak mean pile-up (visible xsection 85 mb)	26	26	36

Priorities for 2015

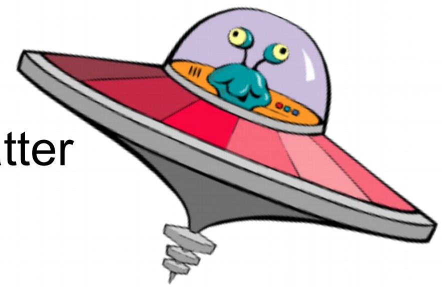
- The main goal of 2015 is to prepare 2016 as a physics “production run” at 25ns.
  - Aim at an integrated luminosity of 3/fb. (updated value)
- Preparation for 2016:
  1) Establish proton-proton collisions at 13TeV with 25 ns bunch spacing.
  2) Establish the operation at low β*
     - Start with β* = 80 cm (conservative).
     - Estimated ultimate reach in Run 2: ~ 40 cm
     - Determine optimum running conditions for 2016
- Heavy ions: 1 month of Pb-Pb physics at the end of 2015

Limiting factors

- Electron cloud
  - Reduced in dedicated "scrubbing runs" with high intensity, low energy beams
  - Impacts the beam stability



- UFOs
  - Sudden local loss triggering a preventive dump
  - Possible explanation: dust particles falling into beam creating scatter
  - 2011: Decrease from ≈10 UFOs/hour to ≈2 UFOs/hour.
  - 2012: Initially, about 2.5 times higher UFO rate than in October 2011.



- Heating and collective effects (driven by impedance, electron cloud, beam-beam)
  - TDI: heating, mechanical deformation, increase in tune shift with intensity (impedance). **This is an essential component of machine protection at injection**.
  - QPS: issues with radiation hardness of some components of the QPS boards. **Fixed during the last technical stop.**

Now running with ~1465 bunches, about 50% of nominal

Performance improvements

$$L = \frac{N_b^2 \, M \, f_{rev} \, \gamma_r}{4 \pi \, \varepsilon_n \, \beta^*} F$$

$$F = 1/\sqrt{1 + \left(\frac{\theta_c \sigma_z}{2\sigma^*}\right)^2}$$

Different strategies to improve LHC performance:

- Reduce β*
  - Implies available beam aperture (larger beam size in the triplets, larger crossing angle for beam-beam separation)
  - Implies good control of the optics (linear and nonlinear)
  - Implies good control of orbit stability for collimator system
- Increase beam intensity
  - Number of bunches -> control of e-cloud and collective effects (instabilities and beam-beam), removal of limitations by TDI
  - Intensity/bunch -> control of collective effects and beam losses
- Increase beam brightness. This implies
  - better performance at the level of the LHC injectors
  - removal of limitations at the level of the TDIs
  - good control of emittance over the LHC cycle

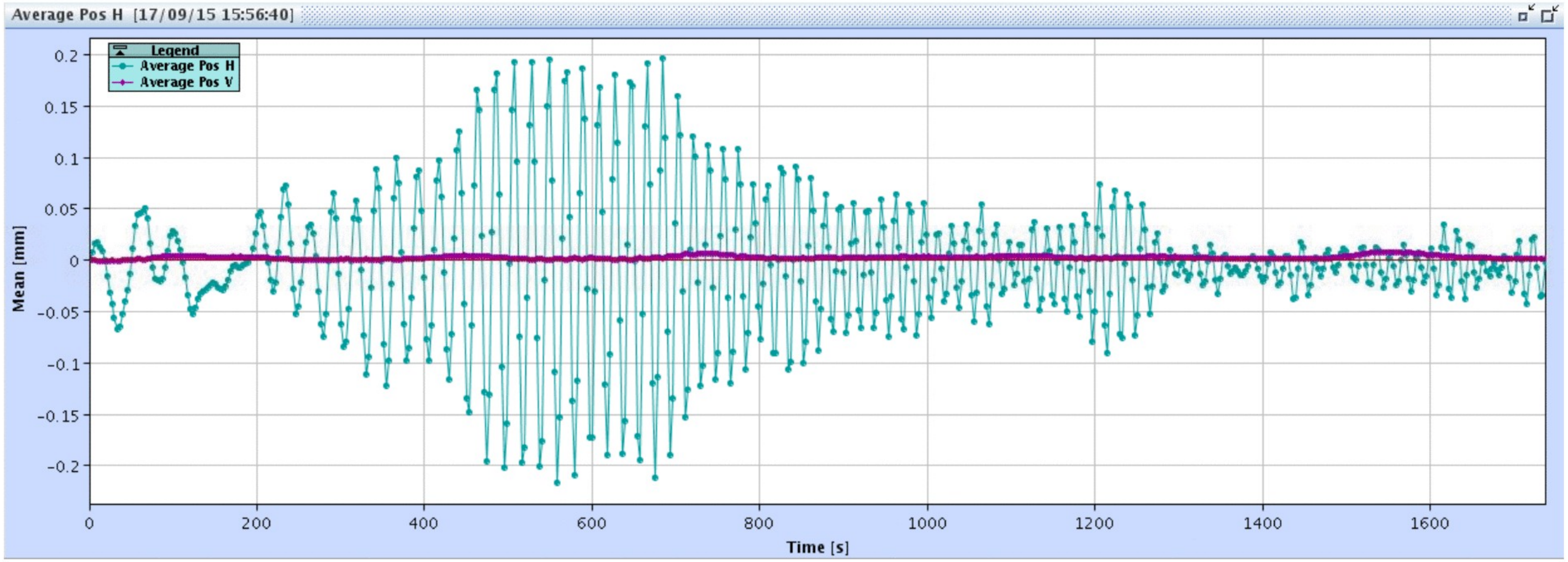
In the meanwhile,

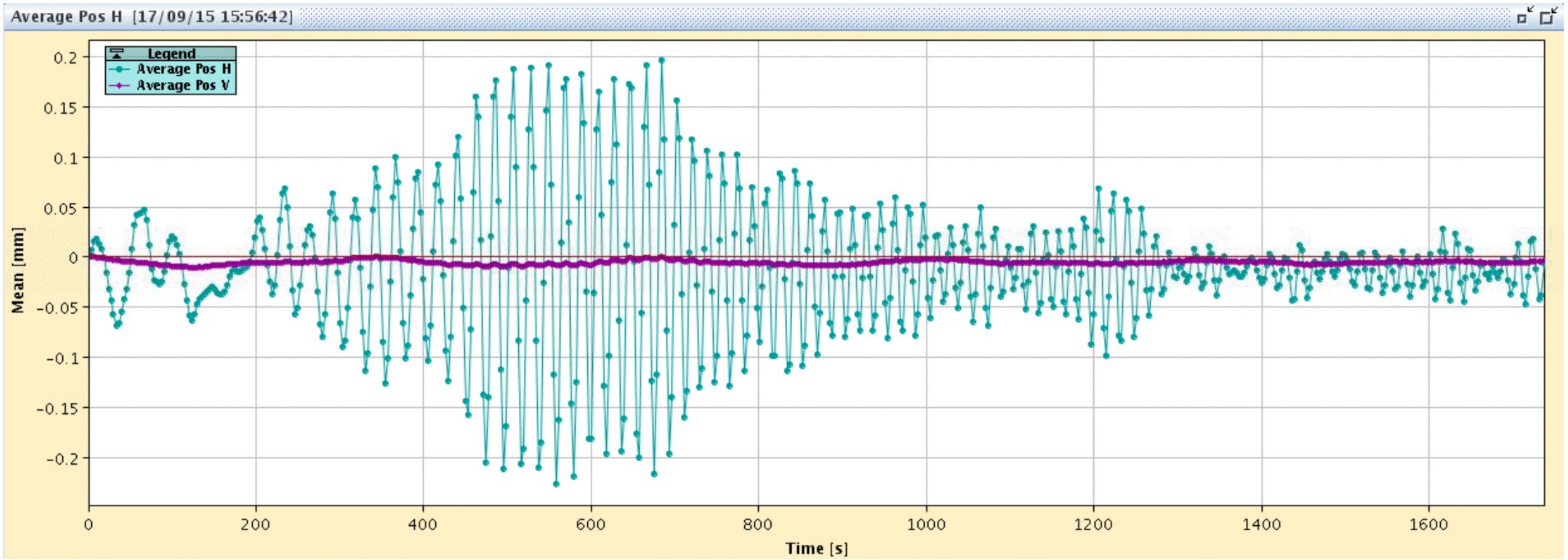
LHC is still a precision machine...

Earthquake in Chili

1 hour after
Chile earthquake
(17/9/2015)

Radial orbit changes
200um amplitude
25s period





CMS status

Operations

- Extensive commissioning needed before data-taking
  - Many changes in subdetectors
  - Fundamental changes to core infrastructure:
    - New DAQ system
    - New Trigger Control and Distribution System
    - New Calorimeter trigger
    - New luminosity detectors
- A lot could be tested prior to collisions, with cosmics, beam “splashes”, circulating beams, …
  - Initial synchronization, etc.
- Collision data needed as well
  - Fine-tuning of the timing, gain calibration, alignment, ...

For illustration: list of commissioning activities

2015 commisioning with stable beams

https://twiki.cern.ch/twiki/bin/view/CMS/CollisionsJun2015 (B=0T)
https://twiki.cern.ch/twiki/bin/view/CMS/CollisionsJuly2015 (B=0T, 2.8T, 3.8T)

1. 3 Fills 3x3 bunches (2 colliding)
   - Align CMS BX1 to LHC BX1
   - Confirm initial timing settings
   - Timing scan for pixel (ZeroBias)
   - Timing scan for HF (ZeroBias)
   - Add ECAL contributions into jets at L1
   - Strip bias scan
   - Enable bits at L1
   - Pixel begins bias scan
   - CSC begins HV scan
2. Fill 12x12 (6 colliding)
   - Pixel begins bias scan
3. Fills 50x50 (39 colliding)
   - Pixel finishes bias scan
   - HF timing scan
   - Enable L1 bits and passthrough for HLT studies
   - Strip timing scans

1. Fills 50x50 (39 colliding) B=0T
   - HF timing scan
5. Fills 152x152 (110 colliding) B=3.8T
   - L1 passthrough for HLT studies
   - Pixel timing scan
   - CSC timing scan
6. Fill 296x296 (254 colliding) B=2.8T
   - HF timing scan
7. Fill 476x476 (414 colliding) B=3.8T
   - Stage-1 test

- Basic commissioning phase with dedicated data-taking is over for this year
  - Apart from upgrades
- Lumi used for commissioning in 2015 very similar to 2012 (~ 40/pb)

Ischia Physics Upgrade Week Silvia Goy Lopez, 7th Sep 2015

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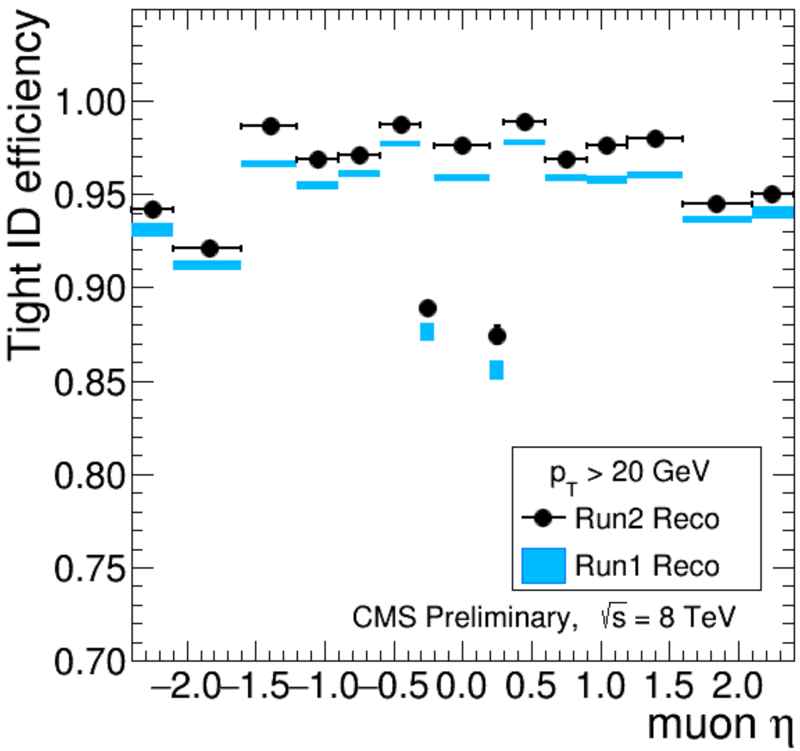
Sylvia Goy Lopez, CMS plenary in Ischia

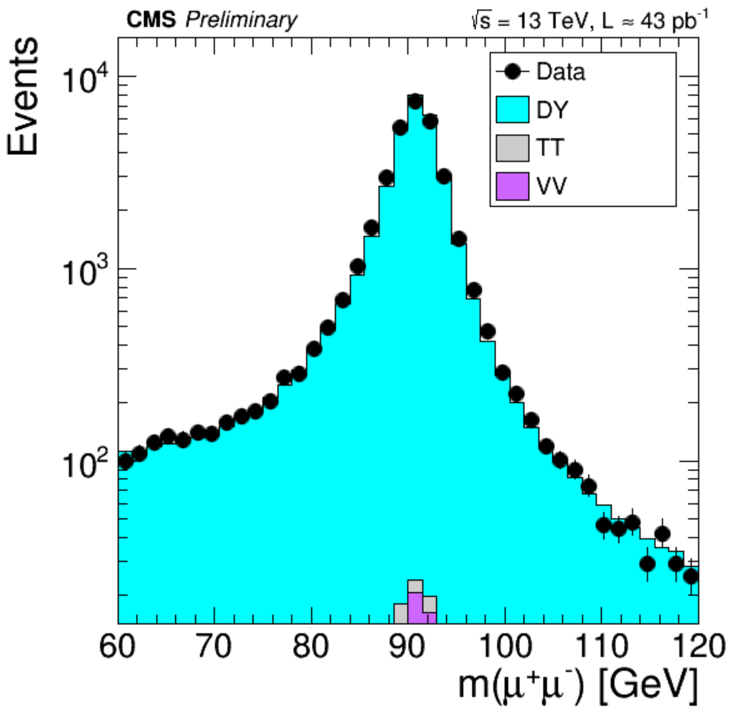
Muons performance

Muon Efficiency



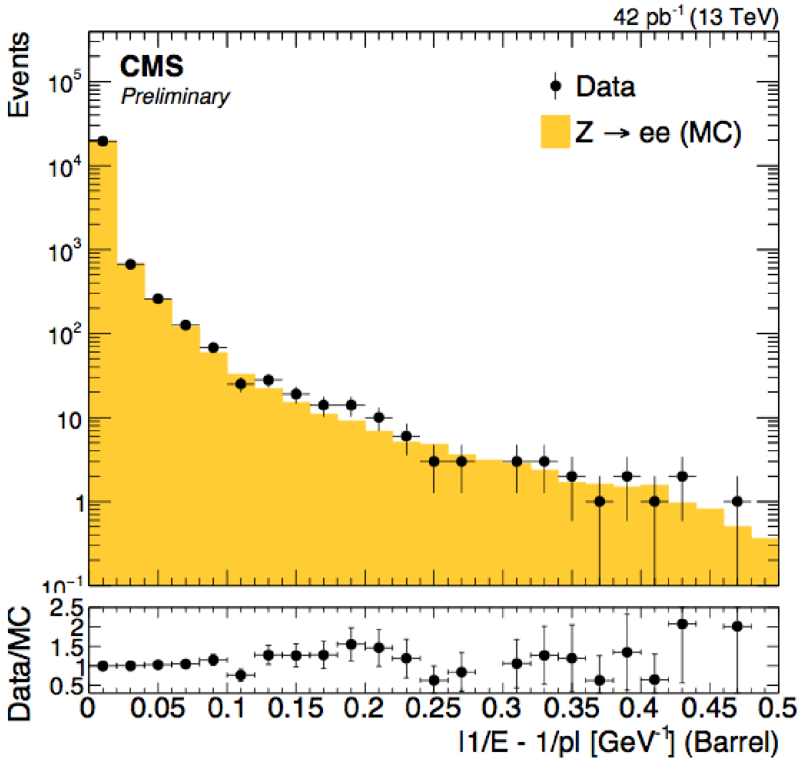
The Z is still there!…

… good sign for the H

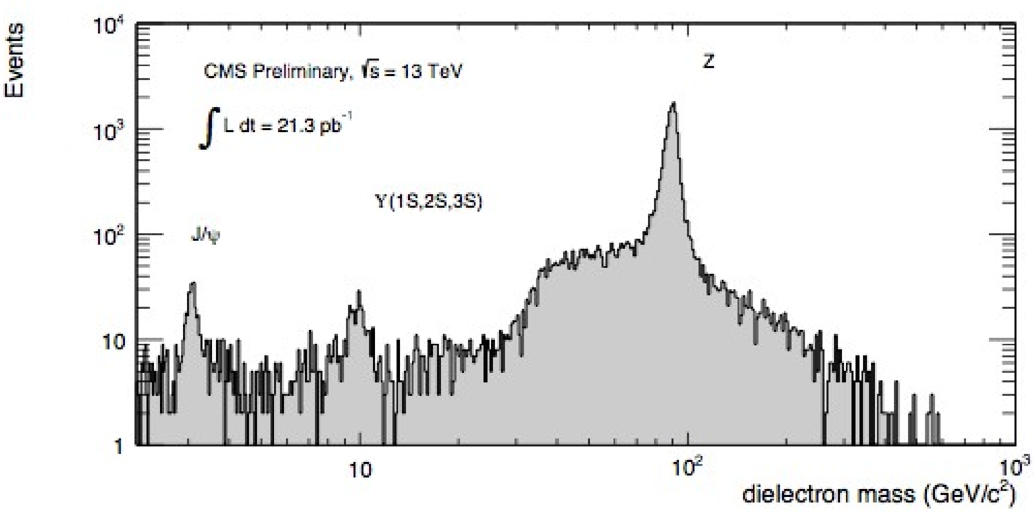


Electrons performance

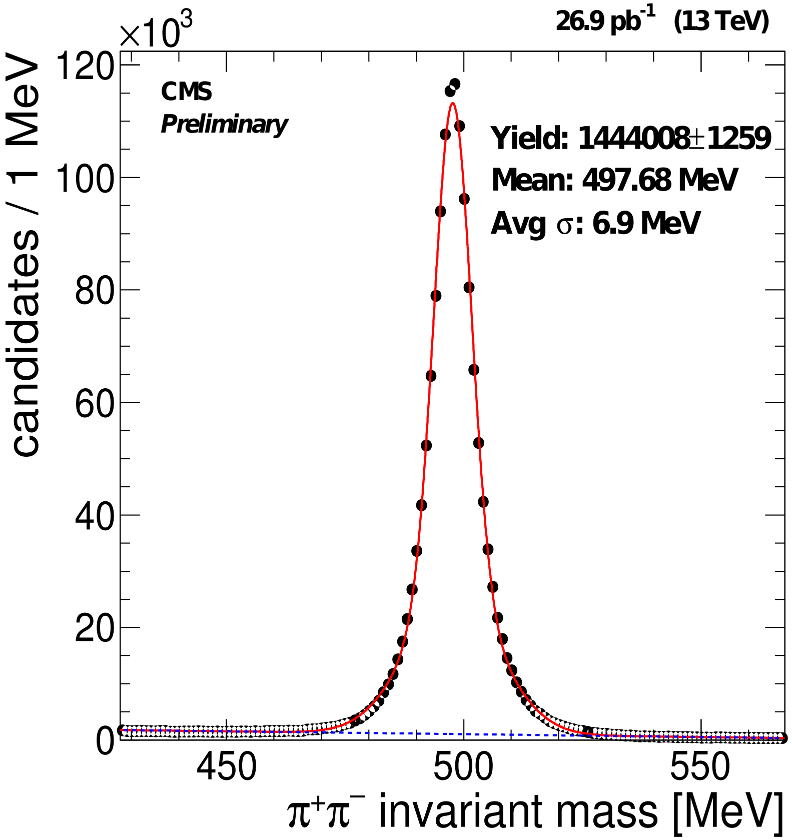
Electrons calibration: tracker vs calorimeter



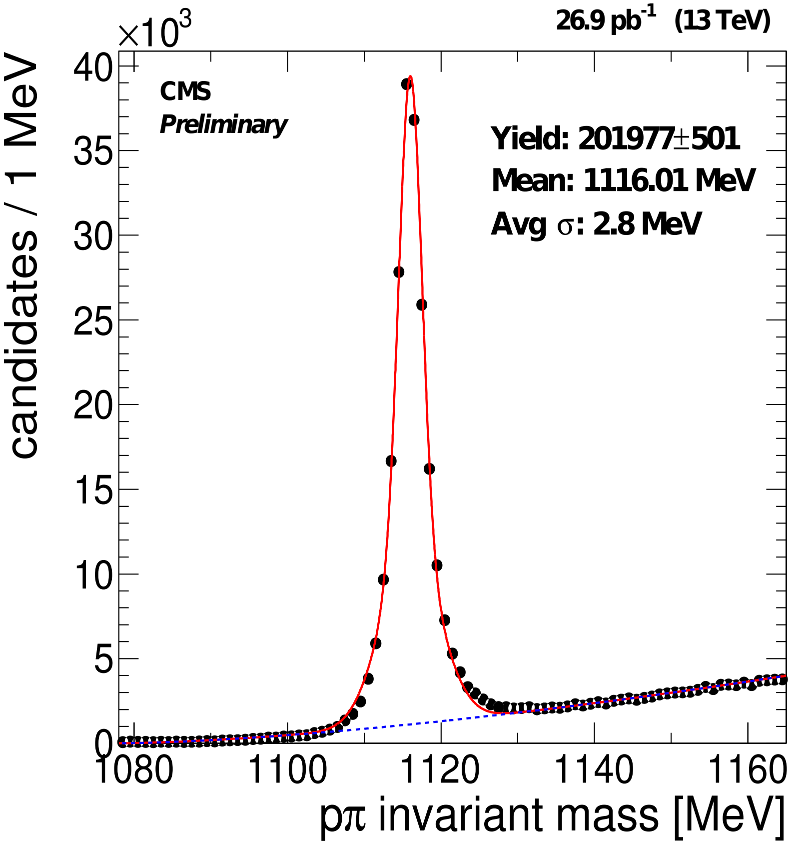
… and the Z is still there!



Reconstruction of K^0_s and Λ^0



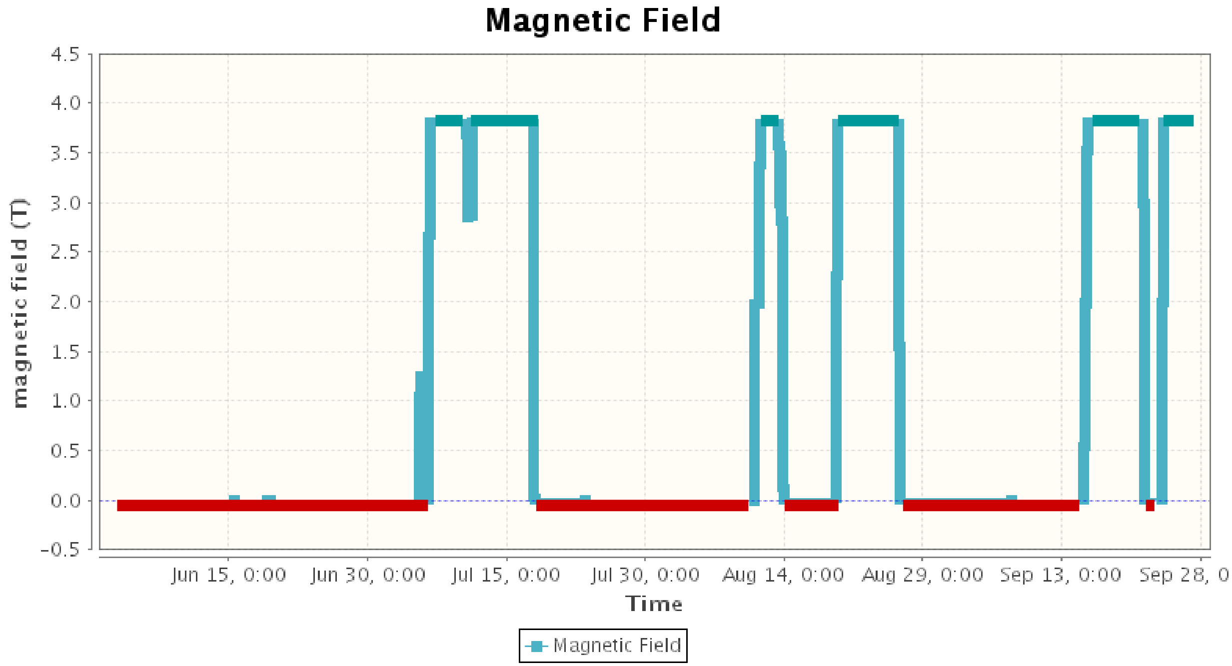
Invariant mass of the pion pairs fitted with a double gaussian and a first order polynomial for the background



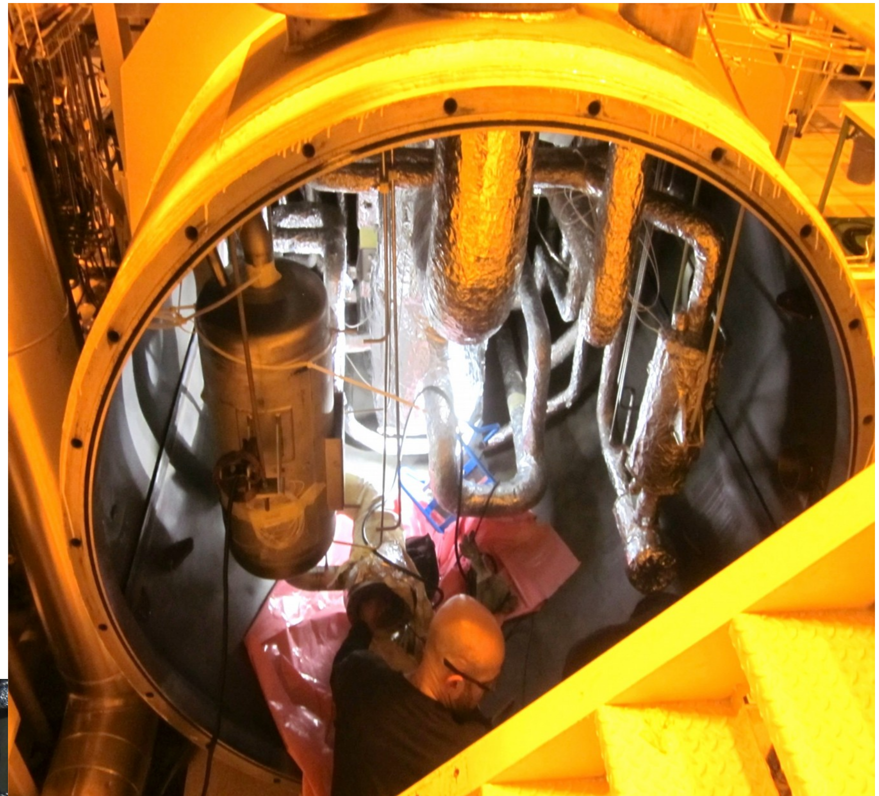
Invariant mass of the proton-pion pairs fitted with a double gaussian and a first order polynomial for the background

Tracks selected with p_T>350 MeV. Selection requires displaced vertex wrt the primary vertex by 10σ and cosθ>0.9998

CMSolenoid status

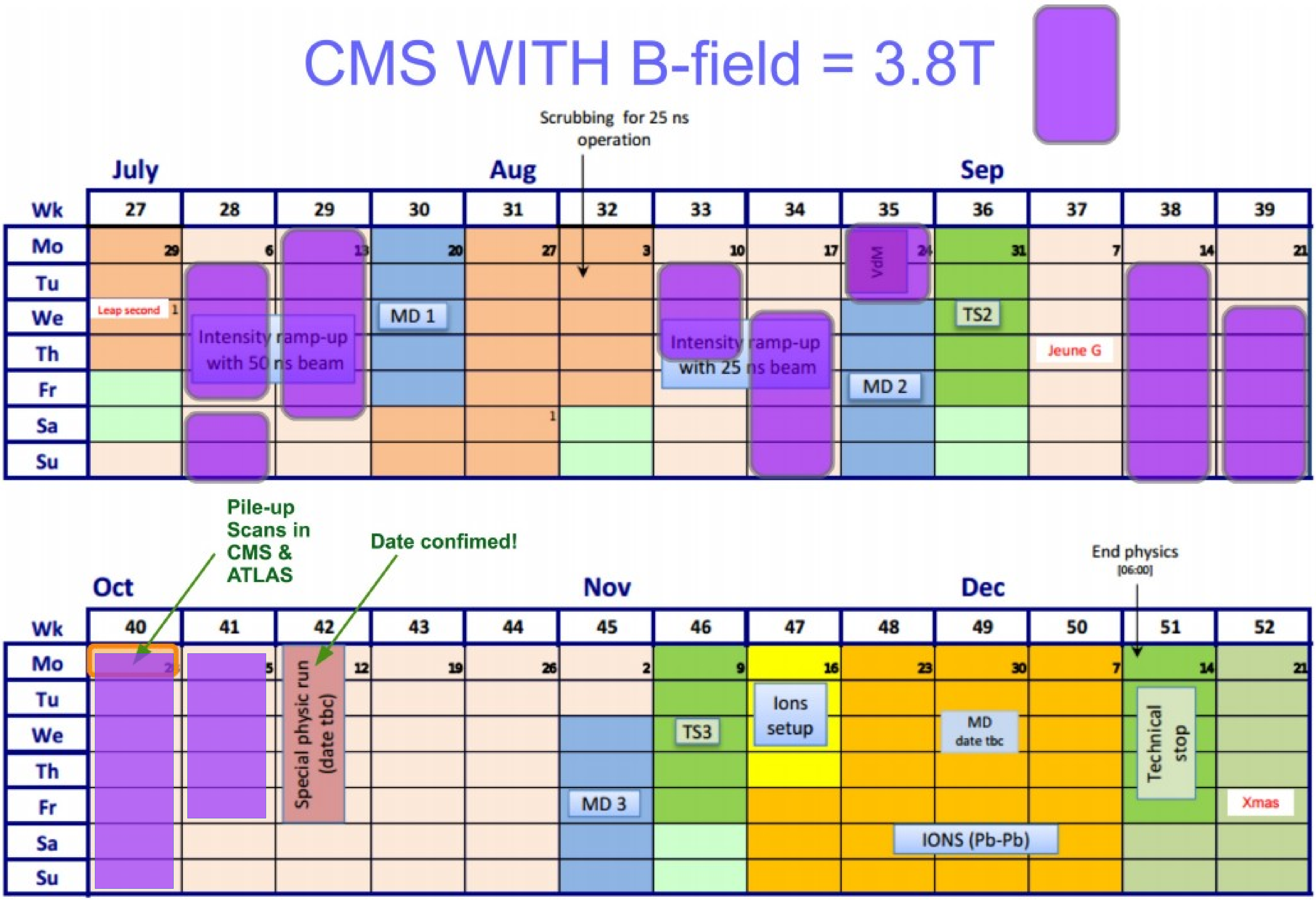


- What happened to the CMS magnet?
  - **Nothing!**
- What then?
  - The "cryo box", i.e. the system that liquefies helium and absorbs the thermal load got contaminated by oil in the end of 2014, following a routine maintenance.
  - Since then, we are suffering from the consequences of that contamination
    - Clogging filters
    - Reduced performance of heat exchangers
- This forces us to do regular interventions on the system
  - "regeneration" of filters (magnet on)
  - Reheating of heat exchangers (magnet off)
  - Installation of larger filters at the last Technical Stop (all off - see next slides)
  - Long term: planing a thorough cleaning for the end of the year



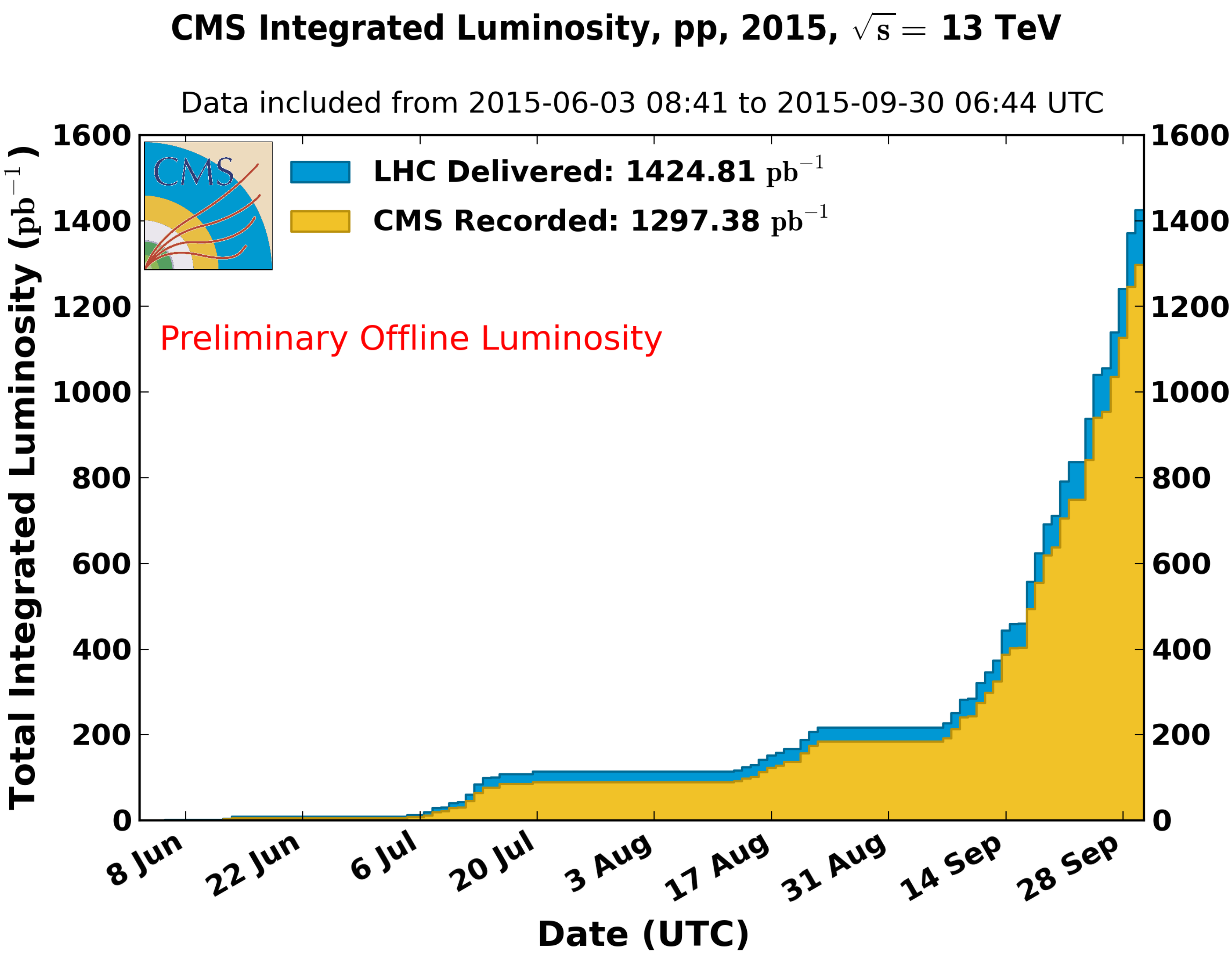


Run 2 so far...



CMS WITH B-field = 3.8T
Scrubbing for 25 ns operation
July
Aug
Sep
Wk
27
28
29
30
31
32
33
34
35
36
37
38
39
Mo
Tu
We
Th
Fr
Sa
Su
29
6
13
20
27
3
10
17
24
31
7
14
21
1
1
Leap second
Intensity ramp-up with 50 ns beam
MD 1
Intensity ramp-up with 25 ns beam
VdM
MD 2
TS2
Jeune G
Pile-up Scans in CMS & ATLAS
Date confimed!
End physics [06:00]
Oct
Nov
Dec
Wk
40
41
42
43
44
45
46
47
48
49
50
51
52
28
5
12
19
26
2
9
16
23
30
7
14
21
Special physic run (date tbc)
MD 3
TS3
Ions setup
MD date tbc
IONS (Pb-Pb)
Technical stop
Xmas

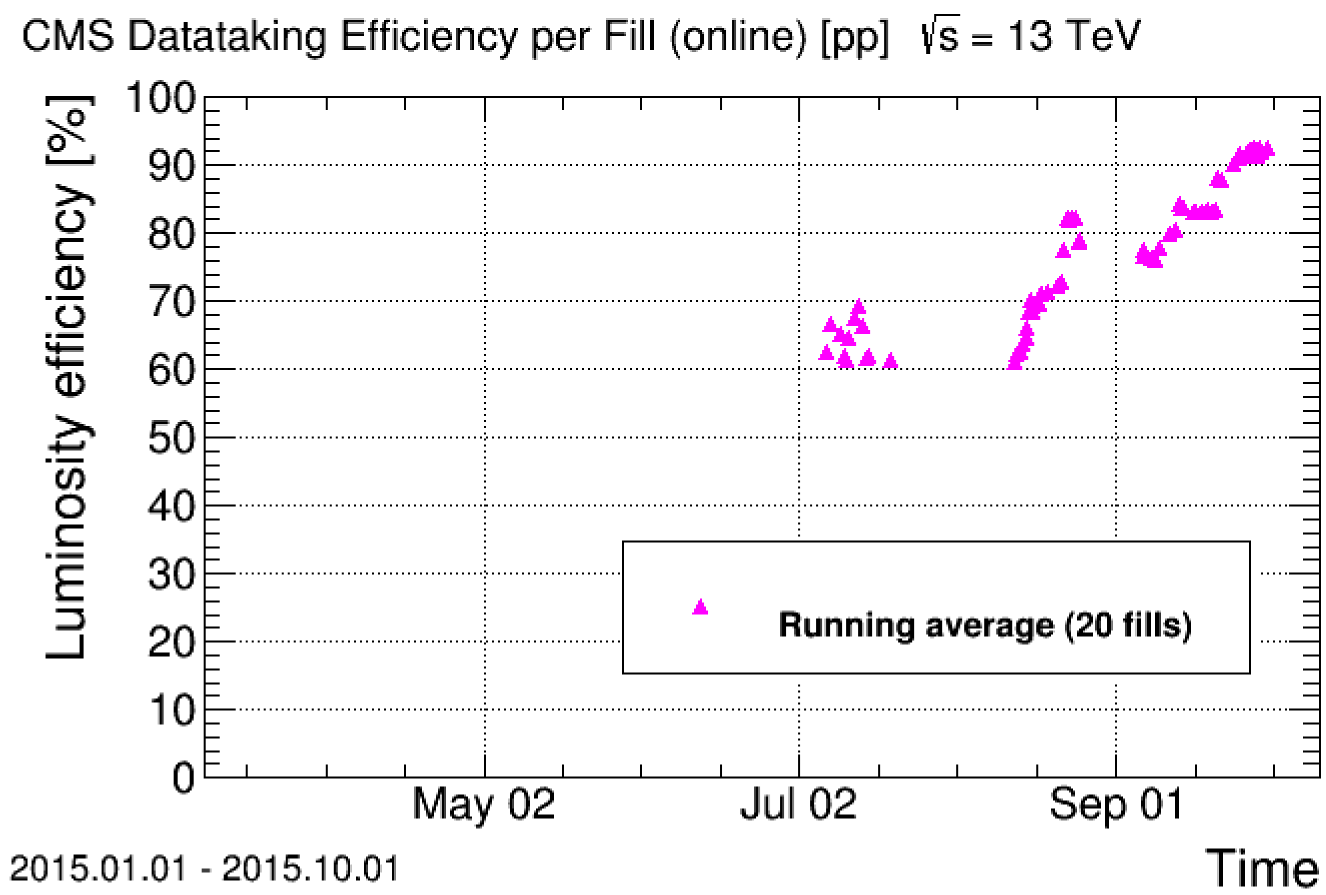
Run 2 so far...



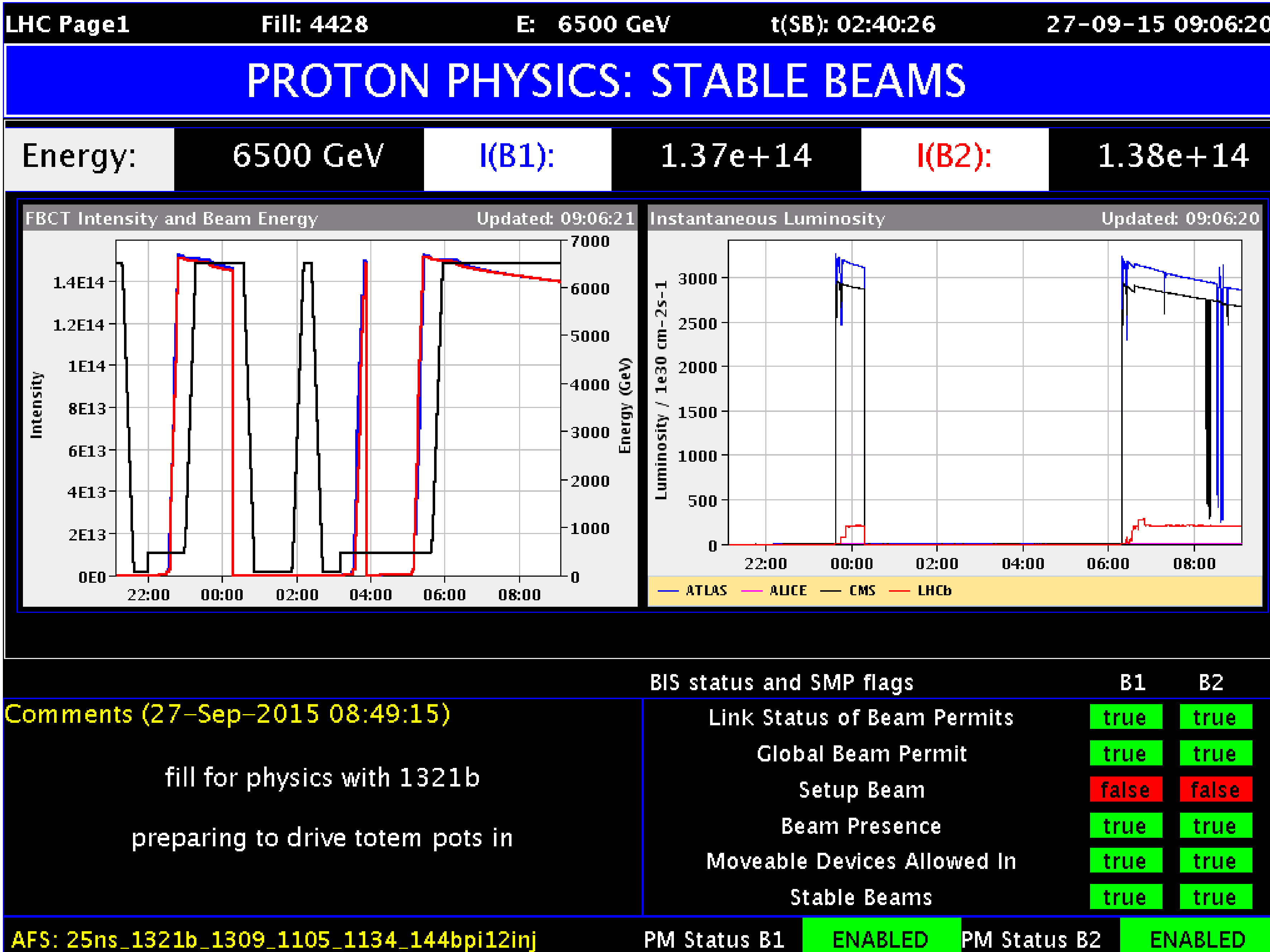
CMS Integrated Luminosity, pp, 2015, $\sqrt{s} = $ 13 TeV
Data included from 2015-06-03 08:41 to 2015-09-30 06:44 UTC
LHC Delivered: 1424.81 pb^{-1}
CMS Recorded: 1297.38 pb^{-1}
Preliminary Offline Luminosity
Total Integrated Luminosity (pb^{-1})
1600
1400
1200
1000
800
600
400
200
0
8 Jun
22 Jun
6 Jul
20 Jul
3 Aug
17 Aug
31 Aug
14 Sep
28 Sep
Date (UTC)

Run 2 so far...

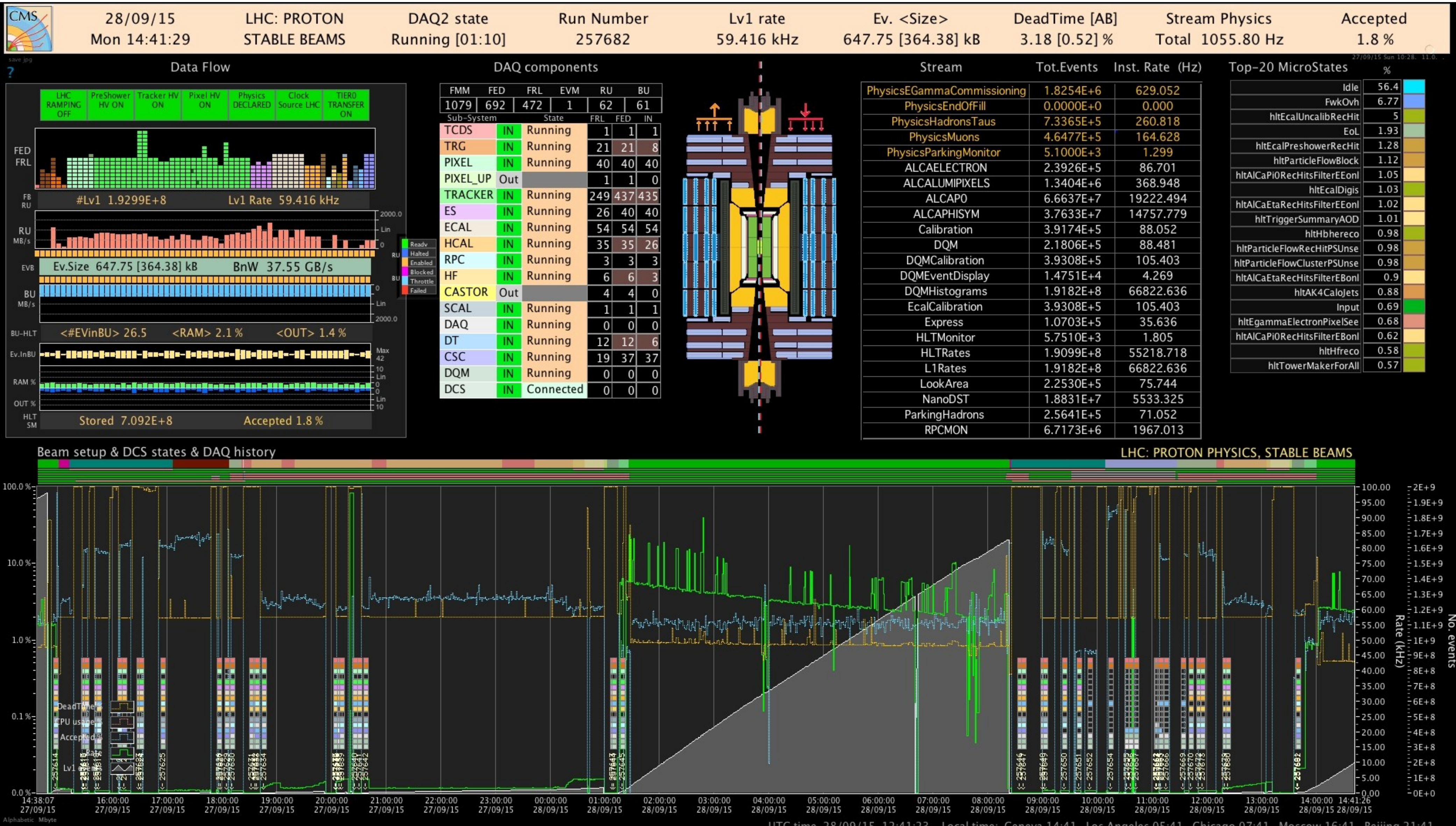
- CMS data taking efficiency has been steadily increasing.
- Now reached values similar to run 1 (>90%, approaching 95%)



Understanding the LHC and CMS screens

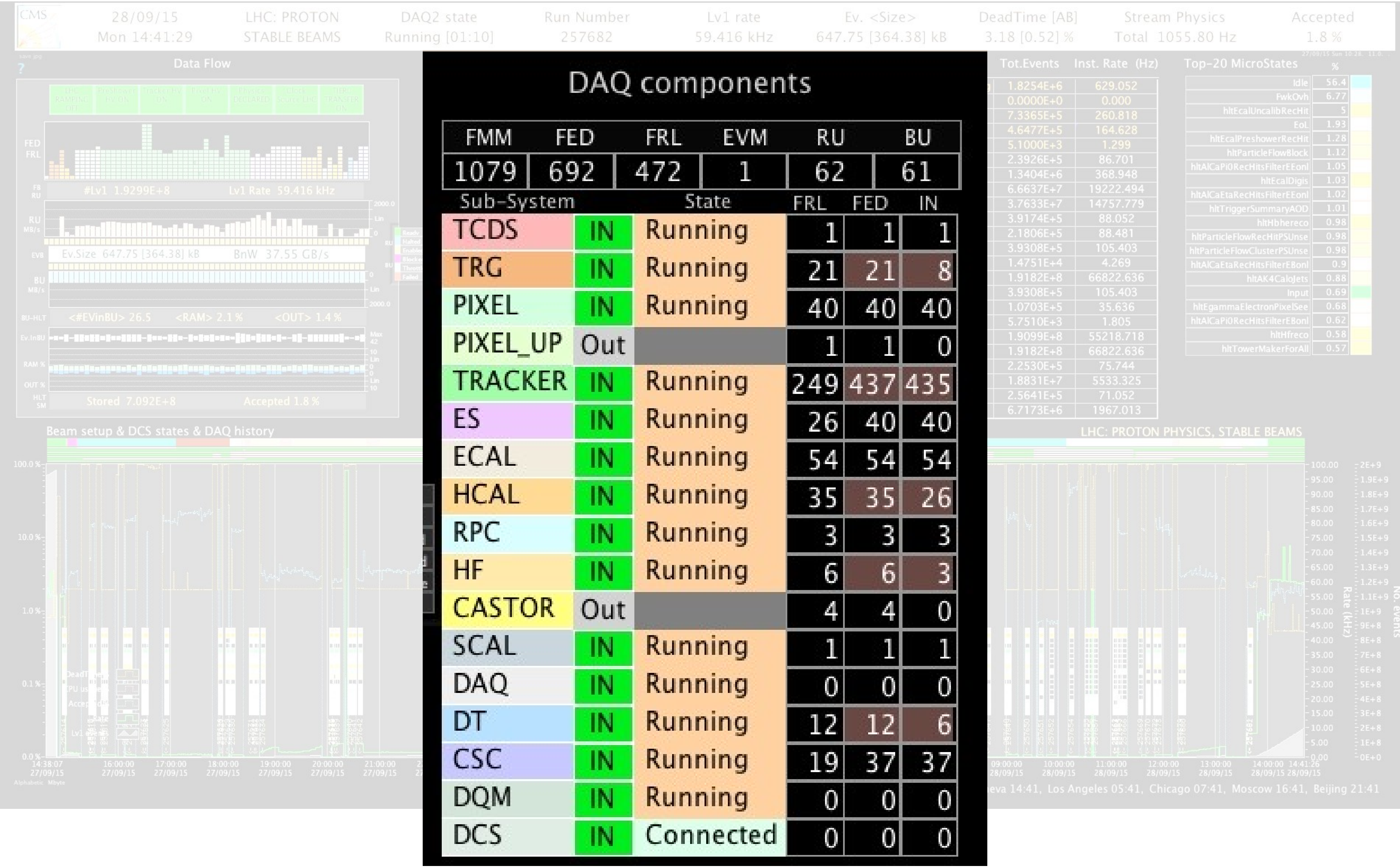


CMS summary screen

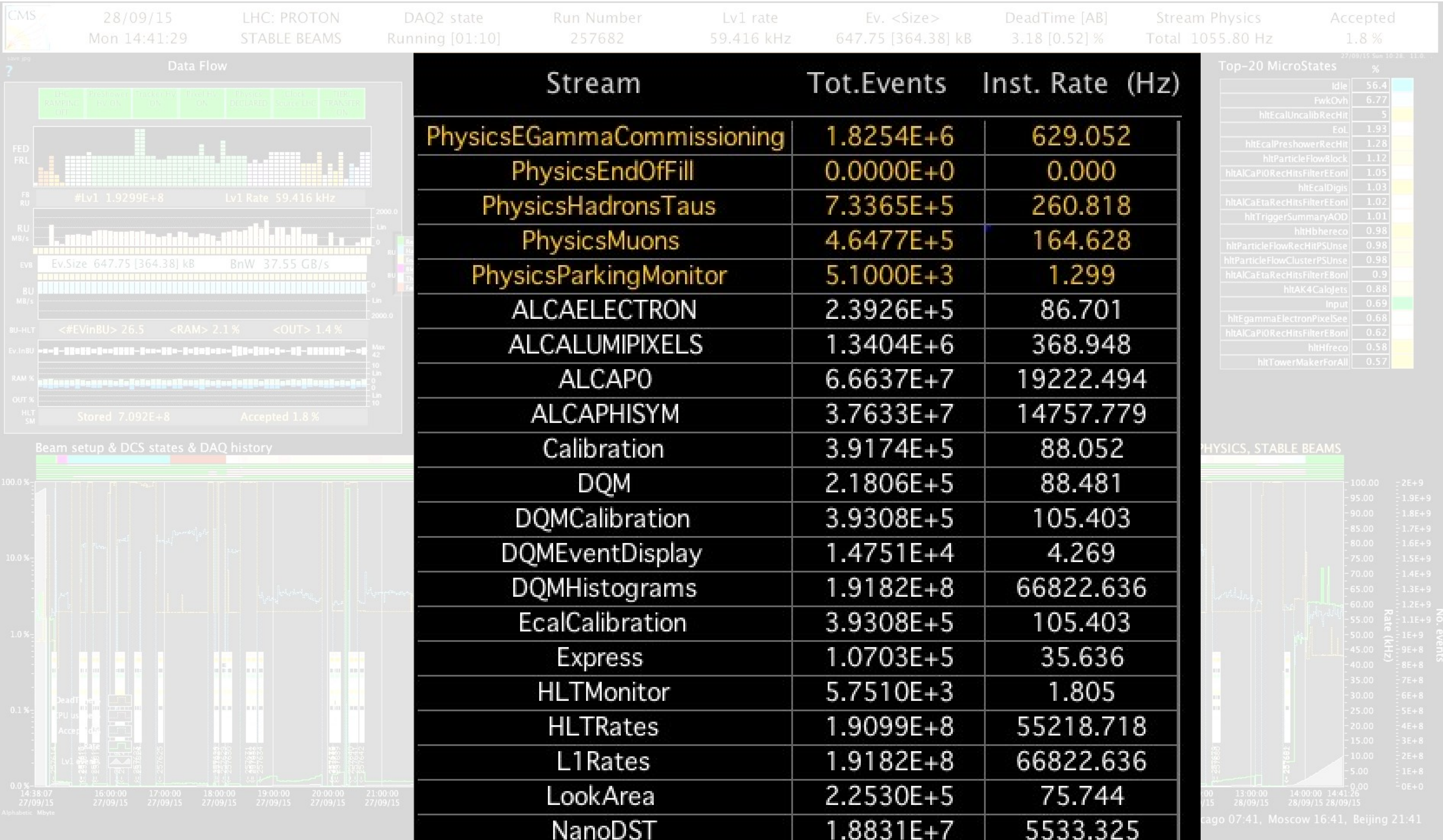


CMS summary screen

CMS summary screen



CMS summary screen



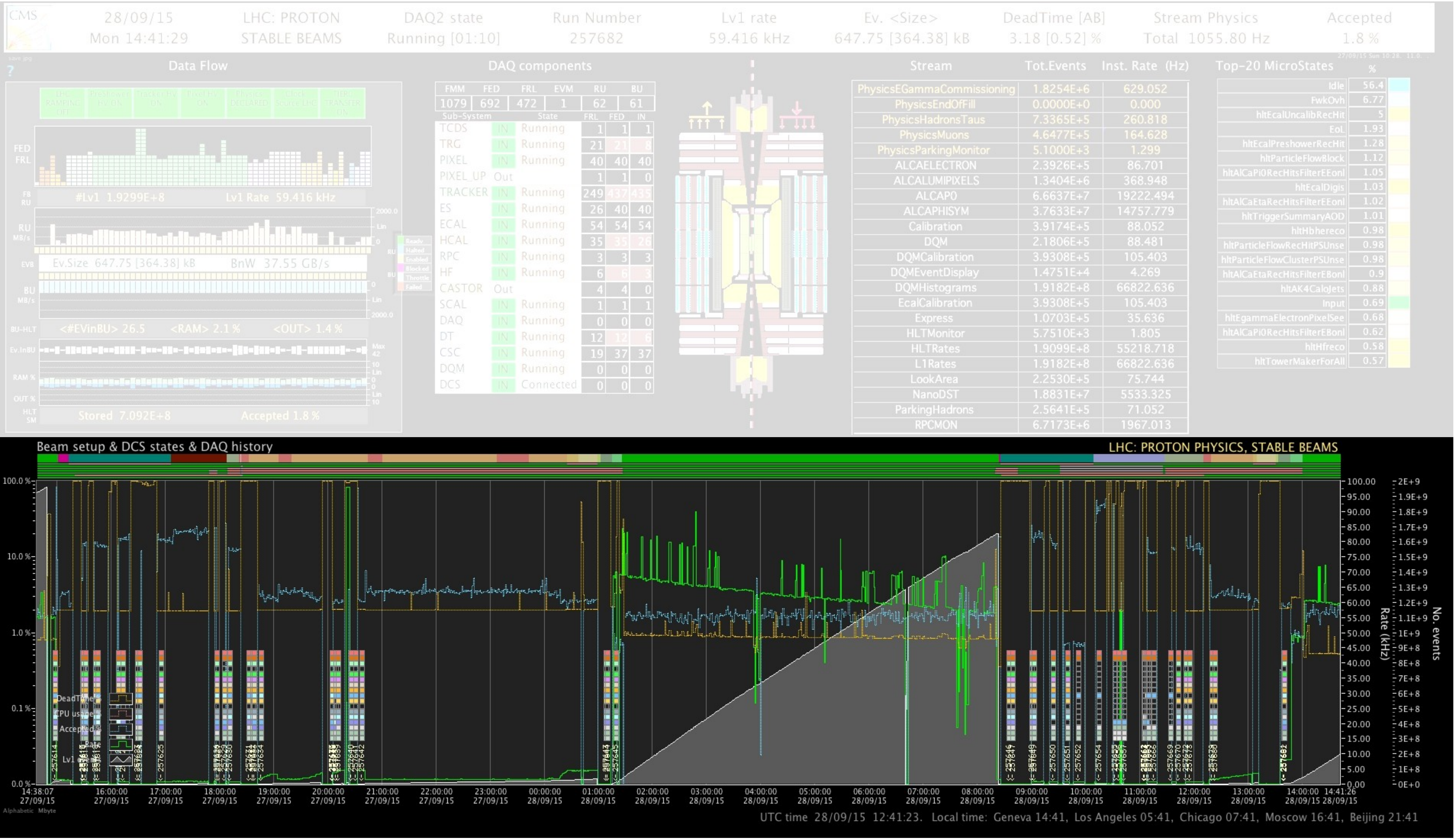
Stream	Tot.Events	Inst. Rate (Hz)
PhysicsEGammaCommissioning	1.8254E+6	629.052
PhysicsEndOfFill	0.0000E+0	0.000
PhysicsHadronsTaus	7.3365E+5	260.818
PhysicsMuons	4.6477E+5	164.628
PhysicsParkingMonitor	5.1000E+3	1.299
ALCAELECTRON	2.3926E+5	86.701
ALCALUMIPIXELS	1.3404E+6	368.948
ALCAP0	6.6637E+7	19222.494
ALCAPHISYM	3.7633E+7	14757.779
Calibration	3.9174E+5	88.052
DQM	2.1806E+5	88.481
DQMCalibration	3.9308E+5	105.403
DQMEventDisplay	1.4751E+4	4.269
DQMHistograms	1.9182E+8	66822.636
EcalCalibration	3.9308E+5	105.403
Express	1.0703E+5	35.636
HLTMonitor	5.7510E+3	1.805
HLTRates	1.9099E+8	55218.718
L1Rates	1.9182E+8	66822.636
LookArea	2.2530E+5	75.744
NanoDST	1.8831E+7	5533.325
ParkingHadrons	2.5641E+5	71.052
RPCMON	6.7173E+6	1967.013

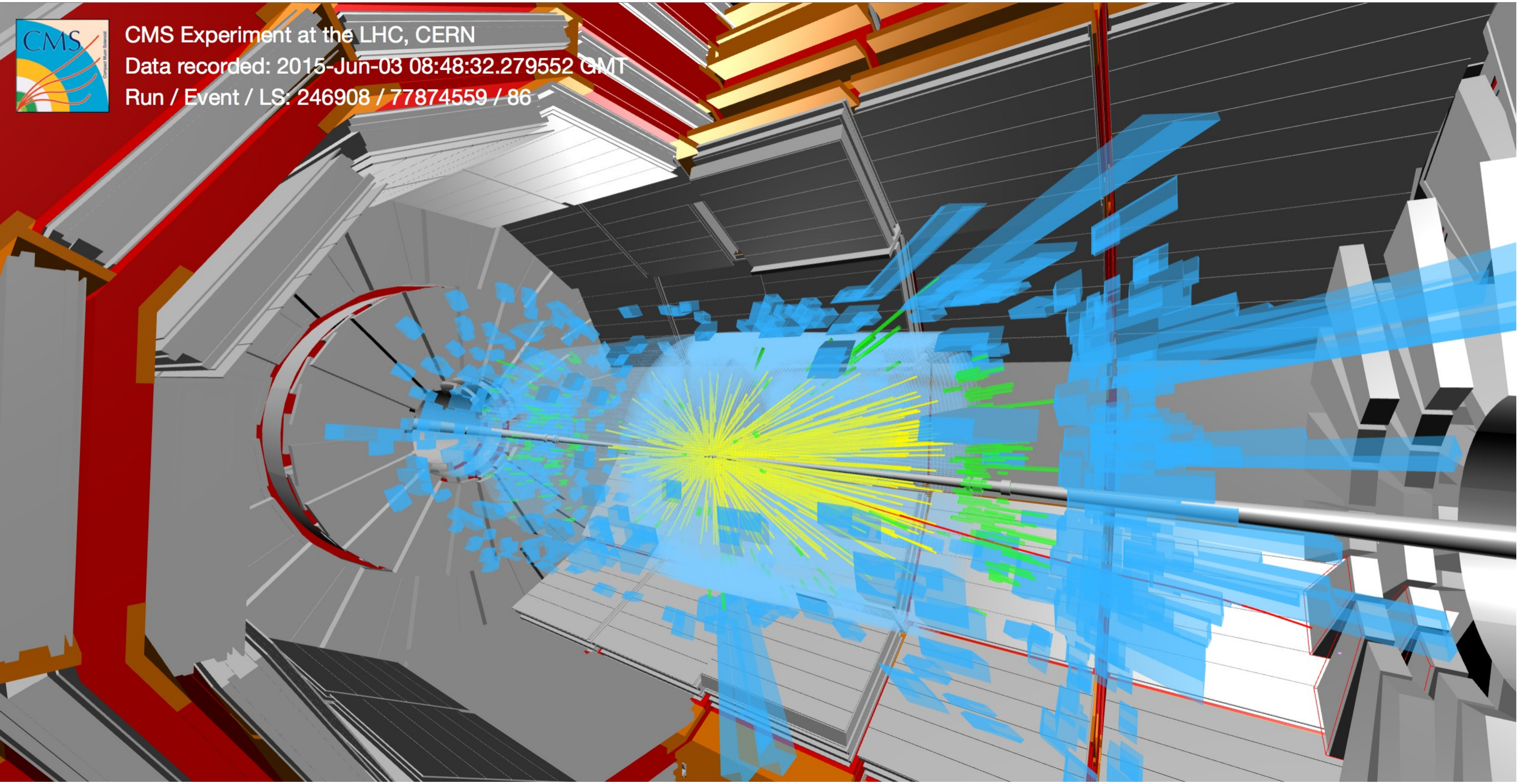
CMS summary screen

27/09/15 Sun 10:28. 11.0.

Top-20 MicroStates	%	
Idle	56.4	
FwkOvh	6.77	
hltEcalUncalibRecHit	5	
EoL	1.93	
hltEcalPreshowerRecHit	1.28	
hltParticleFlowBlock	1.12	
hltAlCaPi0RecHitsFilterEEonl	1.05	
hltEcalDigis	1.03	
hltAlCaEtaRecHitsFilterEEonl	1.02	
hltTriggerSummaryAOD	1.01	
hltHbhereco	0.98	
hltParticleFlowRecHitPSUnse	0.98	
hltParticleFlowClusterPSUnse	0.98	
hltAlCaEtaRecHitsFilterEBonl	0.9	
hltAK4CaloJets	0.88	
Input	0.69	
hltEgammaElectronPixelSee	0.68	
hltAlCaPi0RecHitsFilterEBonl	0.62	
hltHfreco	0.58	
hltTowerMakerForAll	0.57	

CMS summary screen



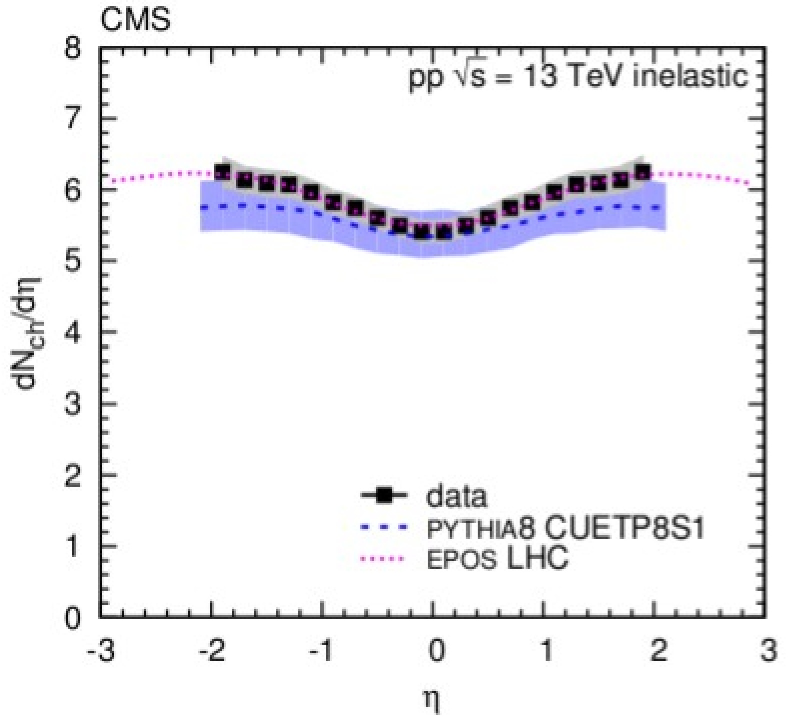


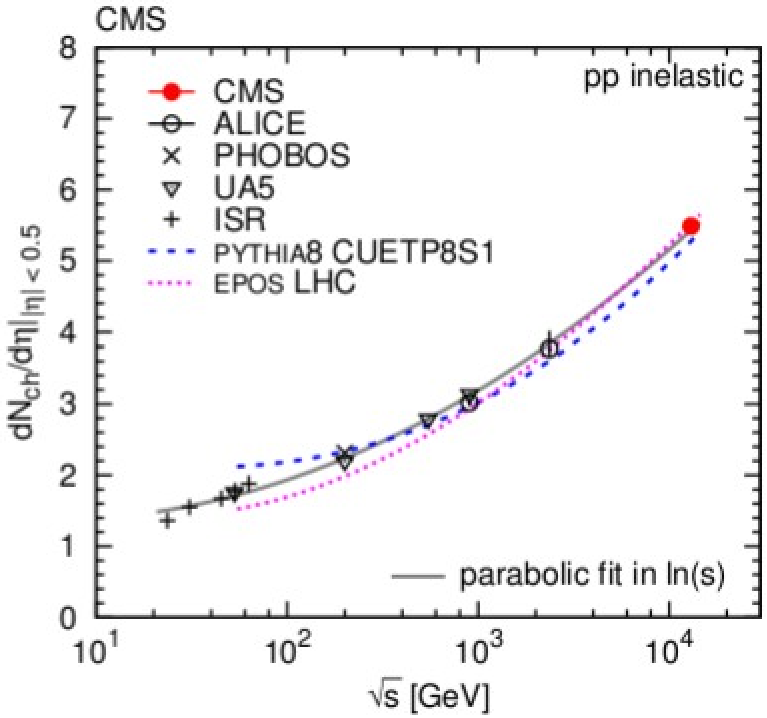
Some highlights from 13TeV data

Dn/deta: first publication at 13TeV

FSQ-15-001

Analysis performed without magnetic field and with the pixel detector. Two methods used and combined (tracklets and 3-hit tracks)





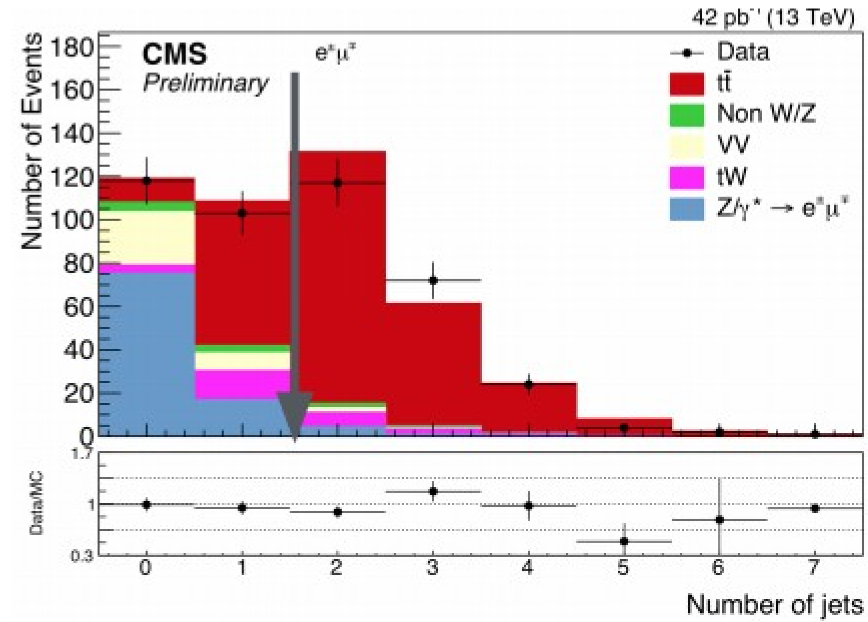
- Results in agreement with MC predictions within systematic uncertainties. At 13 TeV EPOS LHC is slightly favored.

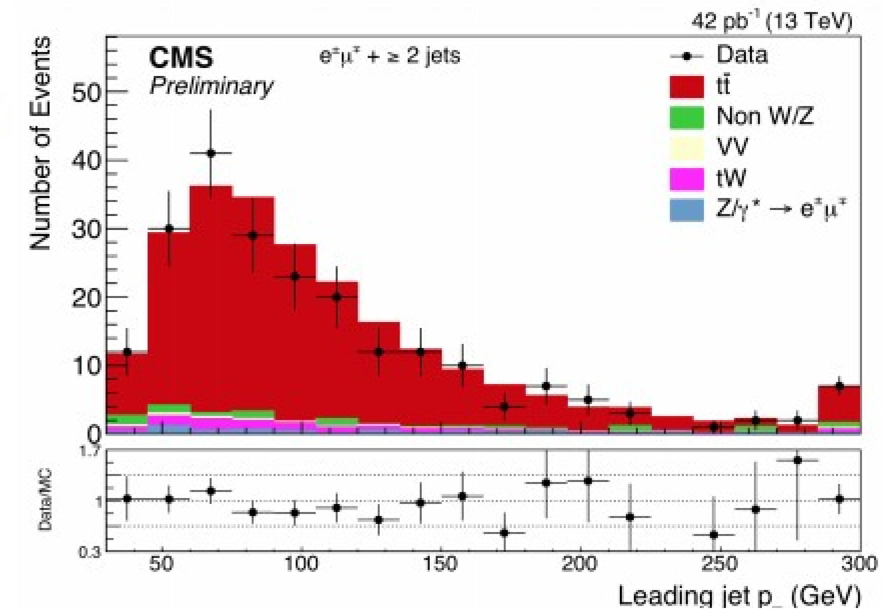
Ttbar inclusive cross-section

TOP-15-003

First time presented at Lepton Photon 2015
ATLAS presented at EPS 2015

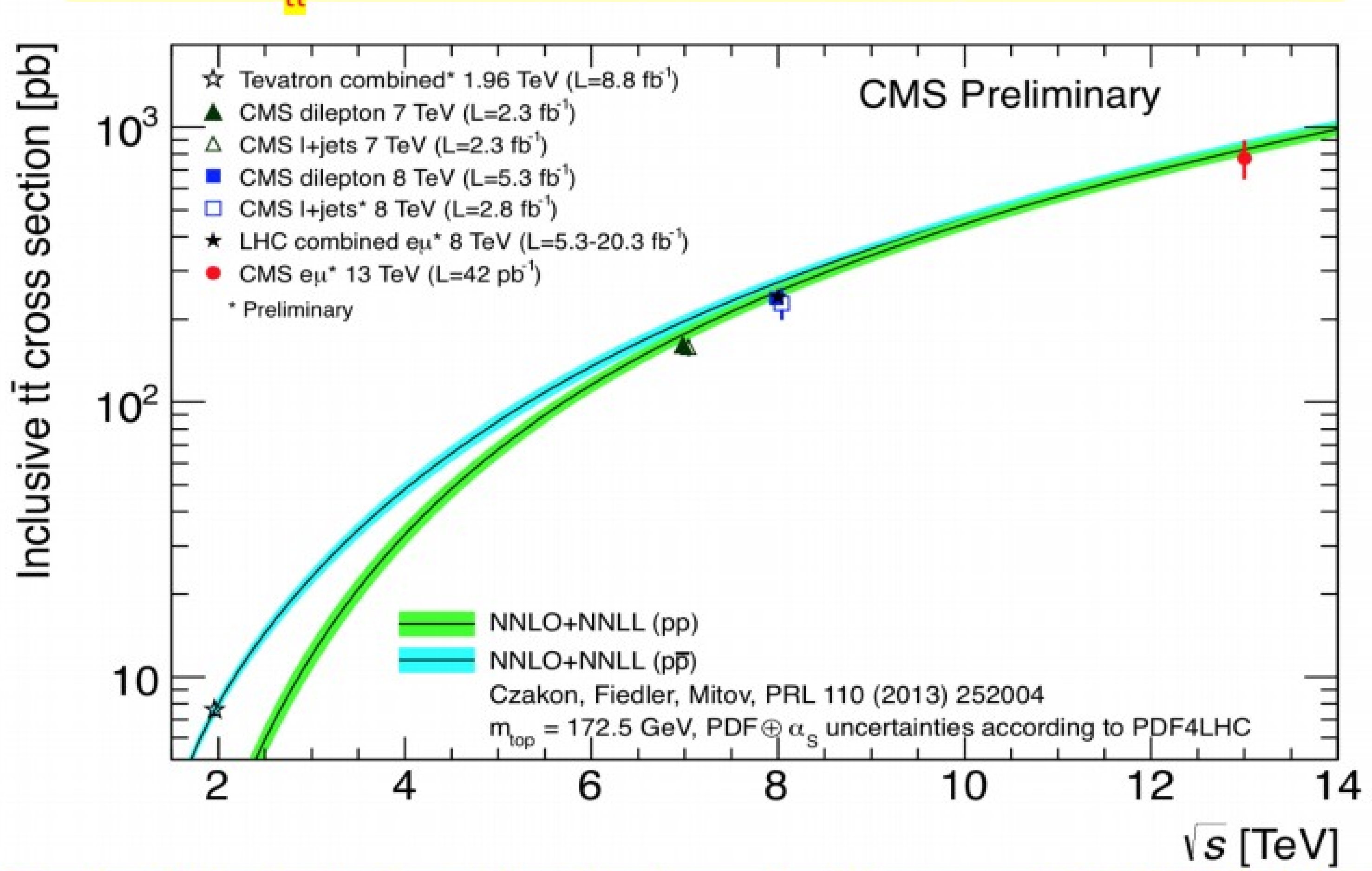
- Integrated lumi= 42 pb^{-1}
  - all validated data from 50ns run
- Signal tt MC reference sample:
  - PowhegV2+Pythia8, normalized to NNLO+NNLL
- Selection
  - At least 2 good (OS) leptons (1e and 1μ)
  - pt(lept)> 20 GeV and $|\eta|$< 2.4
  - If more than 2 good leptons, the two with highest pt are retained
  - Di-lepton invariant mass > 20 GeV
  - At least 2 jets (anti-kT R = 0.4)
  - pt(jets)> 30 GeV and $|\eta|$< 2.4





Ttbar inclusive cross-section

Inclusive σ_{tt}(13TeV)= 772 ± 60 (stat.) ± 62 (syst.) ± 93 (lumi.) pb



Results derived also in a fiducial volume: both leptons pT > 20 GeV, |η|<2.4:

Fiducial σ_{tt} =12.9 ± 1.0 (stat.) ± 1.1 (syst.) ± 1.5 (lumi.) pb

Ttbar differential cross-section

TOP-15-010

Analysis performed in three possible final states:

- ee, μμ, eμ

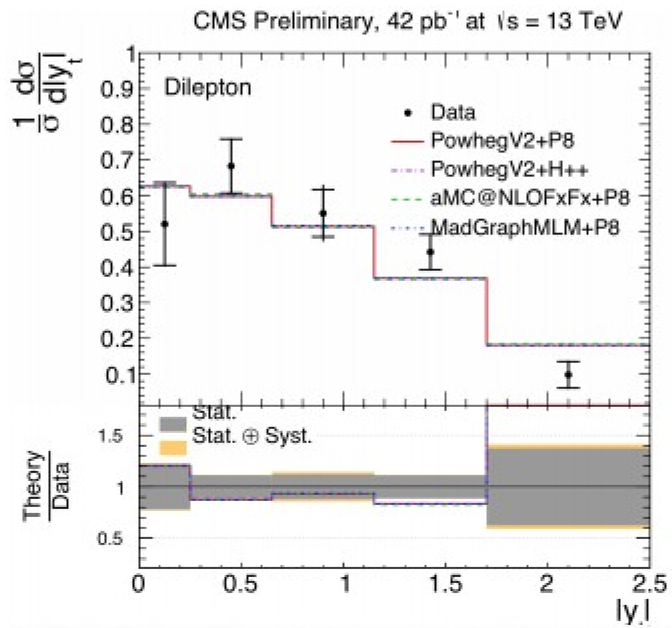
Selection similar to the inclusive cross section adding:

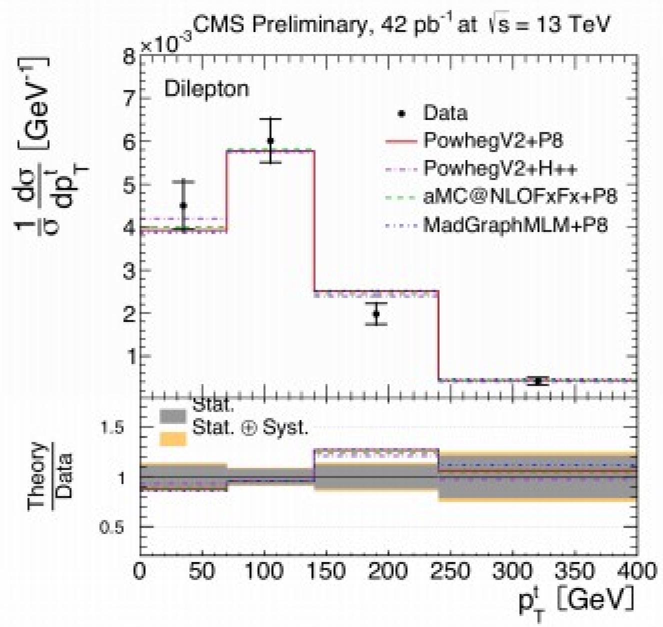
- at least 1 b-tagged jet
- for ee, μμ reject DY background by applying MET and invariant mass cuts

Regularized unfolding used to go to parton level

Shown for the first time at LHCP 2015

PC report - CMS Week - 07/09/2015



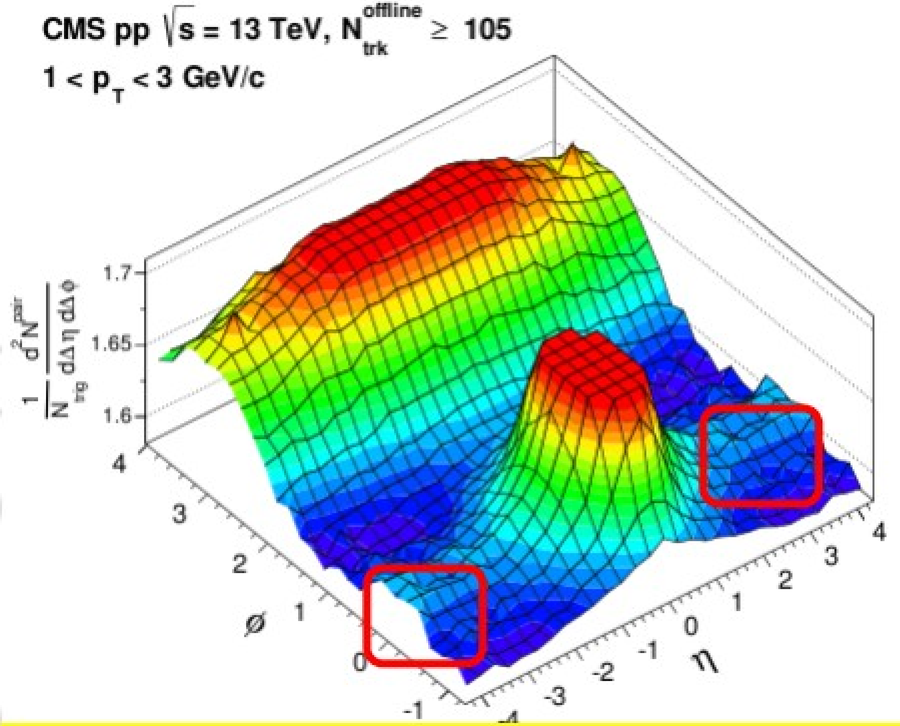


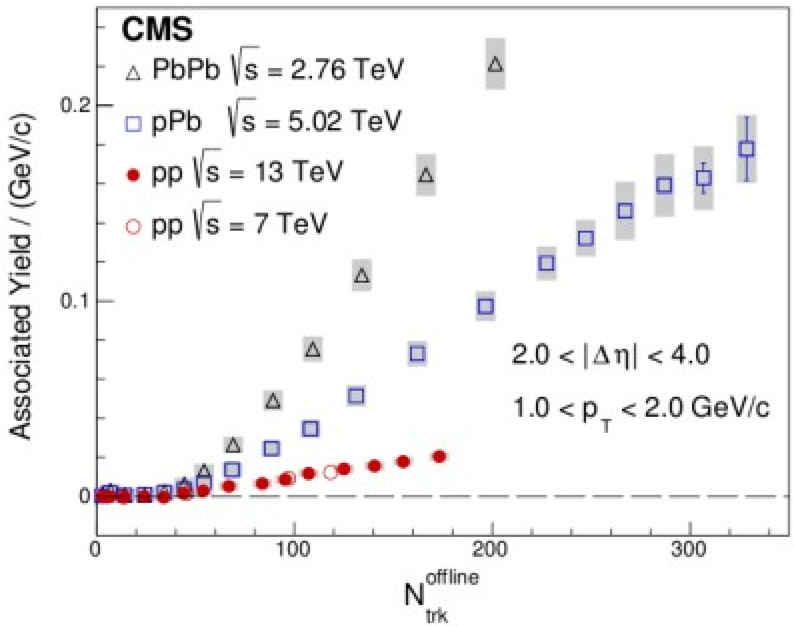
15

"The ridge" @ 13TeV

Analysis very similar to the one already performed at lower center-of-mass energies:

- New treatment of pileup, N trigger threshold slightly different, zero-yield-at-minimum subtraction procedure





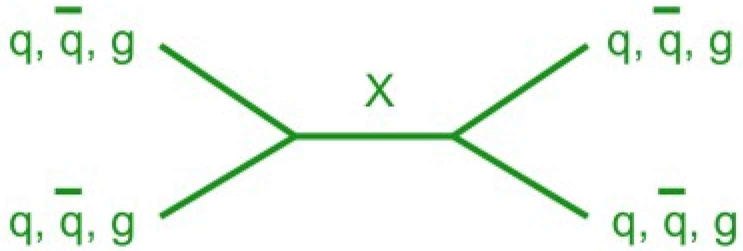
Effect confirmed at different energies and for different colliding beams

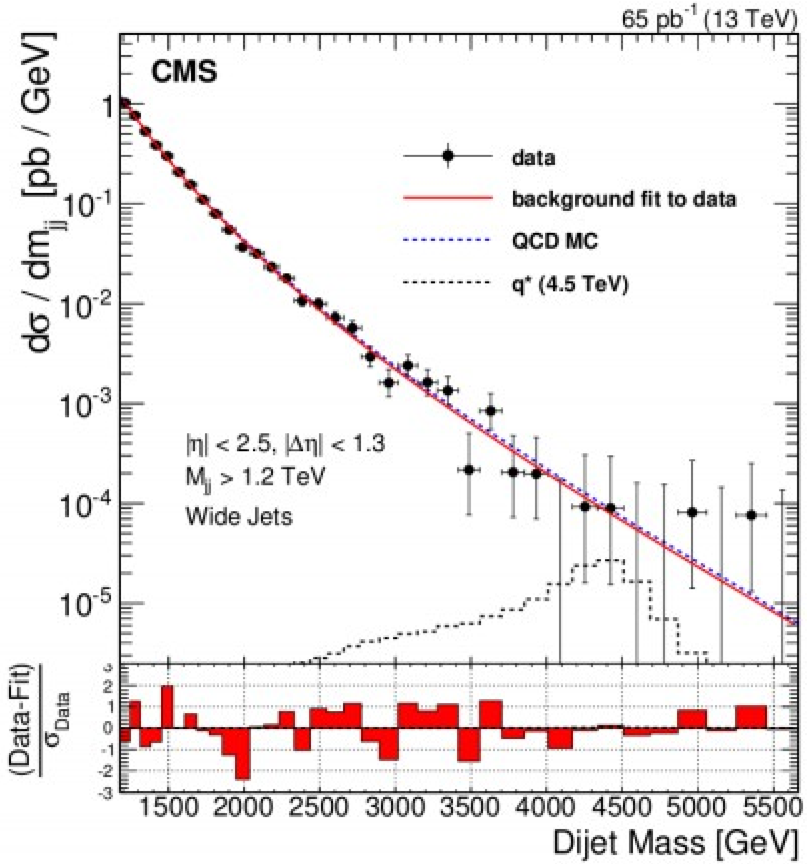
Di-jets: first limits

EXO-15-010

- Classical resonance search decaying in jet pairs
- Model Independent: Search results are applicable to any model of narrow qq, qg, or gg resonances.
- Already 65 pb^{-1} are sufficient to surpass Run 1 limits for string models and resonances above 5 TeV in general. Two events observed with mass ≳ 5 TeV.
- Results with 42 pb^{-1} already shown at LHCP. Fast publication planned with 65 pb^{-1}.
- Similar approach used for Run 1 with a fit parametrization inspired by QCD:

$$\frac{d\sigma}{dm_{jj}} = p_0 \frac{(1-x)^{p_1}}{x^{p_2}}, \qquad x = \frac{m_{jj}}{\sqrt{s}}$$





Di-jets: first limits

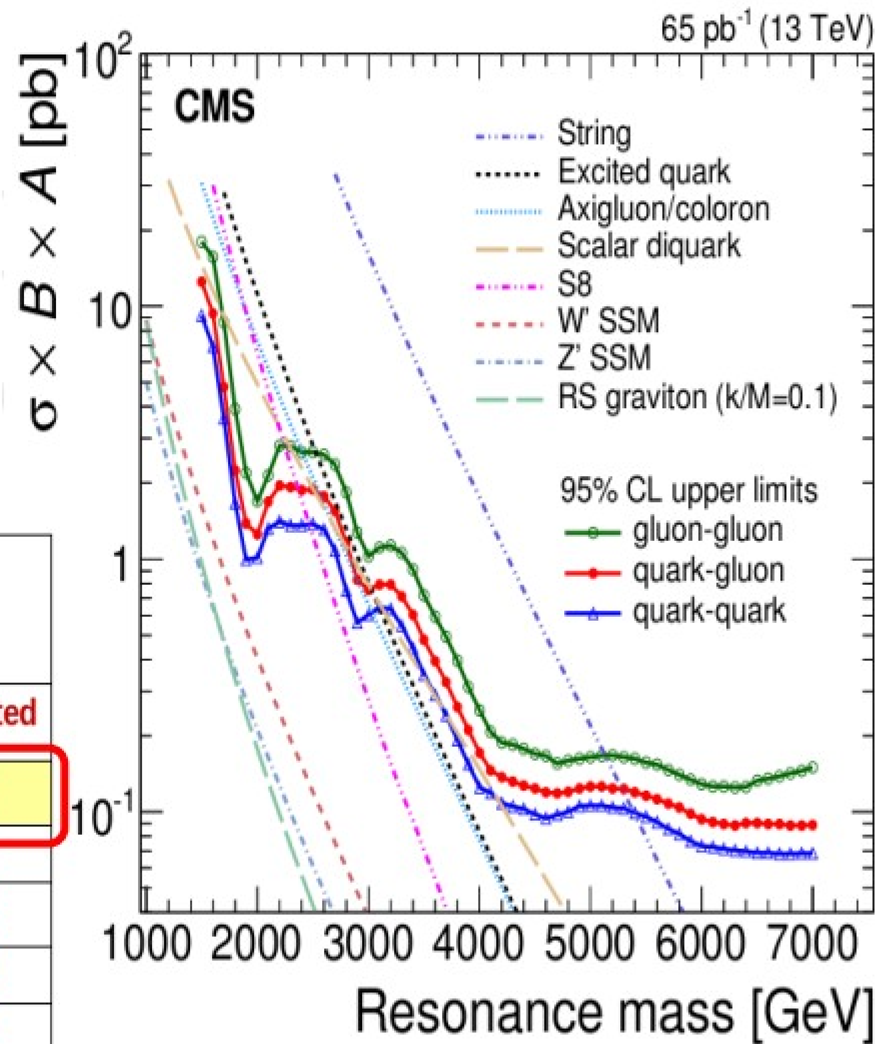
EXO-15-010

We exclude string resonances with masses below 5.3 TeV.

This is beyond the CMS Run 1 limit of 5.0 TeV

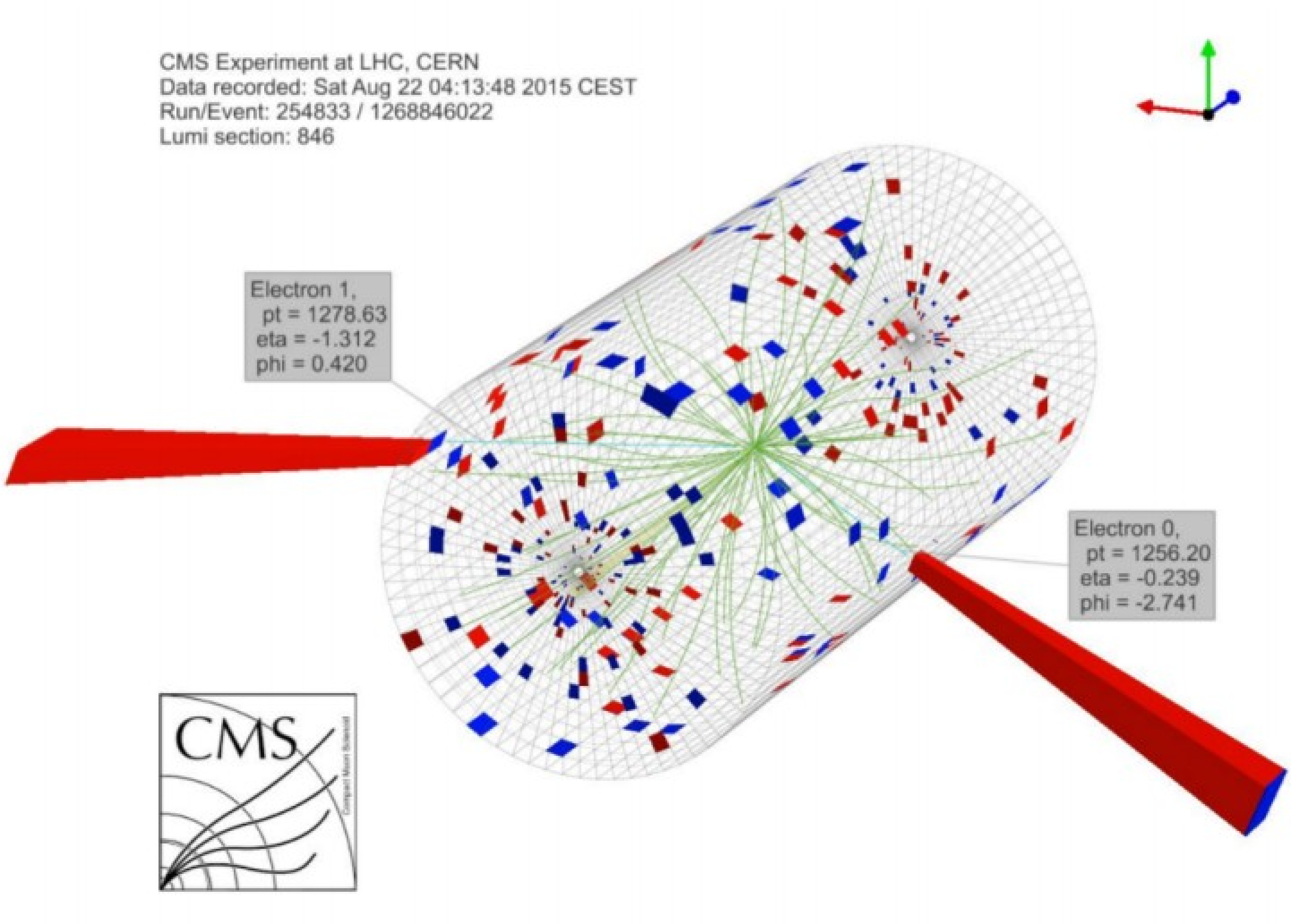
Limits on other models of NP also set but are not yet competitive with Run 1 results with the present luminosity.

Model	Mass Limits (TeV)			
	Run 1 (20 fb^{-1})		Run 2 (65 pb^{-1})	
	Observed	Expected	Observed	Expected
String Resonance (S)	5.0	4.9	5.3	5.4
Excited Quark (q*)	3.5	3.7	3.0	3.2
Axigluon (A) / Coloron (C)	3.7	3.9	3.0	3.3
Scalar Diquark (D)	4.7	4.7	3.1,3.7-4.1	3.7
Color Octet Scalar (S8)	2.7	2.6	2.2	2.2



And a beautiful event...

A beautiful di-electron event with a 2.9 TeV invariant mass!



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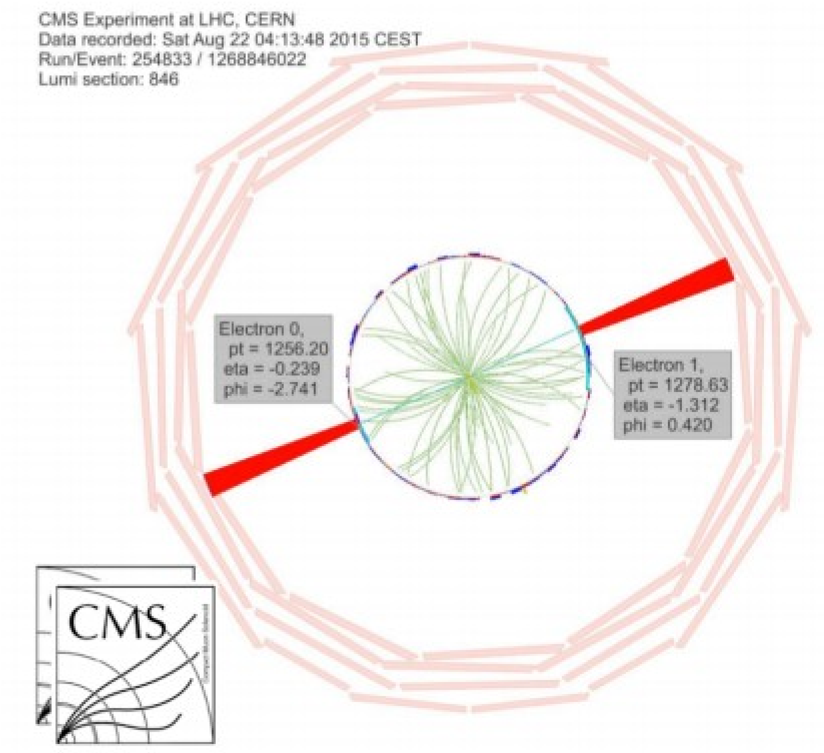
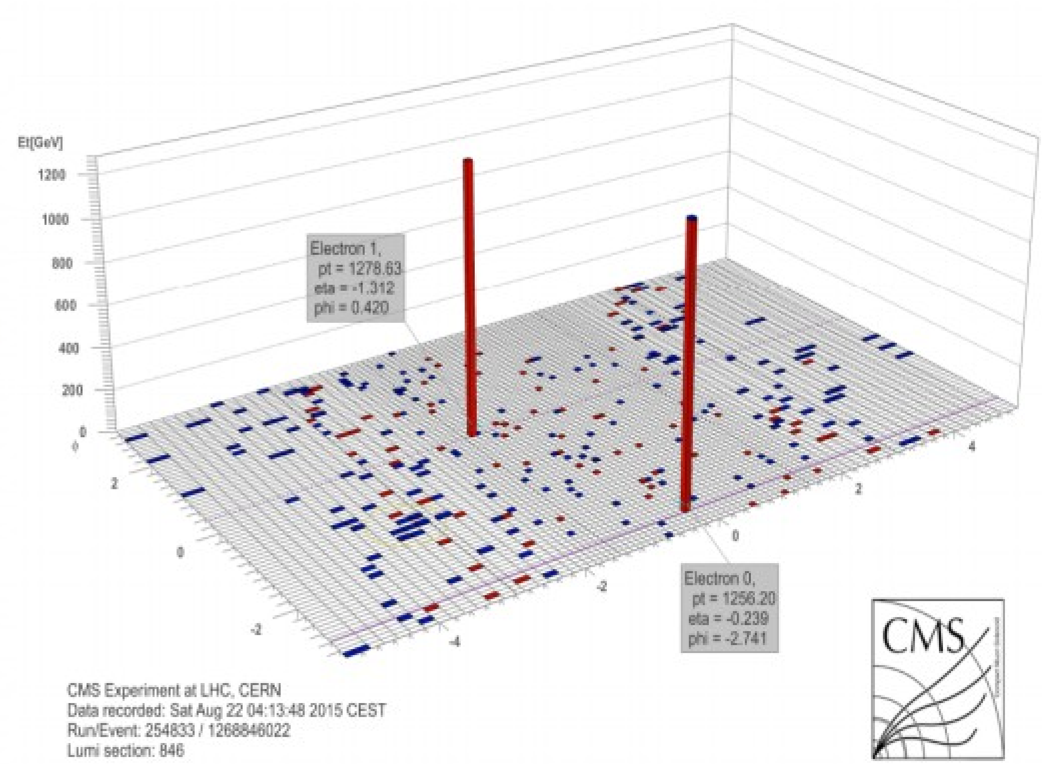
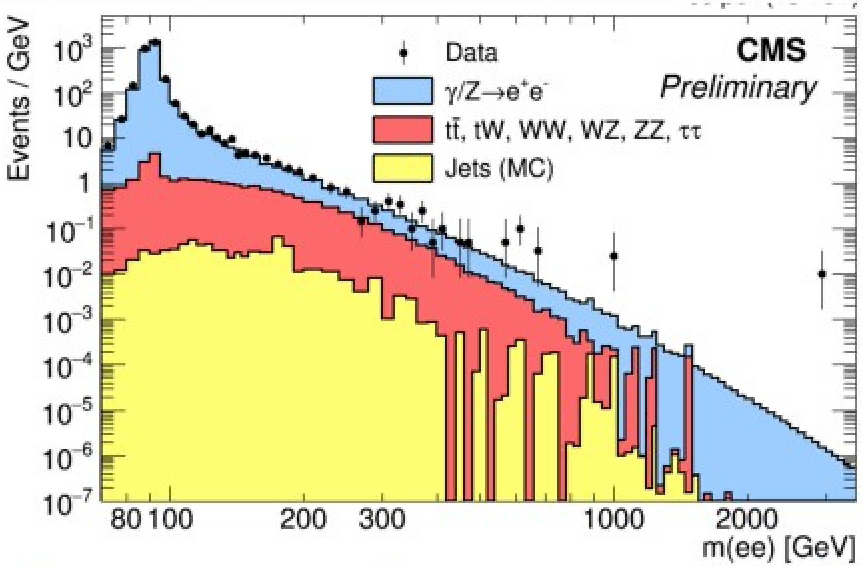




Run1 largest masses observed: 1.8 TeV (ee), 1.9 TeV ($\mu\mu$)

And a beautiful event...

	electron 0	electron 1
E_T	1260 GeV	1280 GeV
η	-0.24	-1.31
φ	-2.74 rad	0.42 rad
charge	-1	+1
mass	2.91 TeV	
cos θ^*_{CS}	-0.49	
y	-0.78	

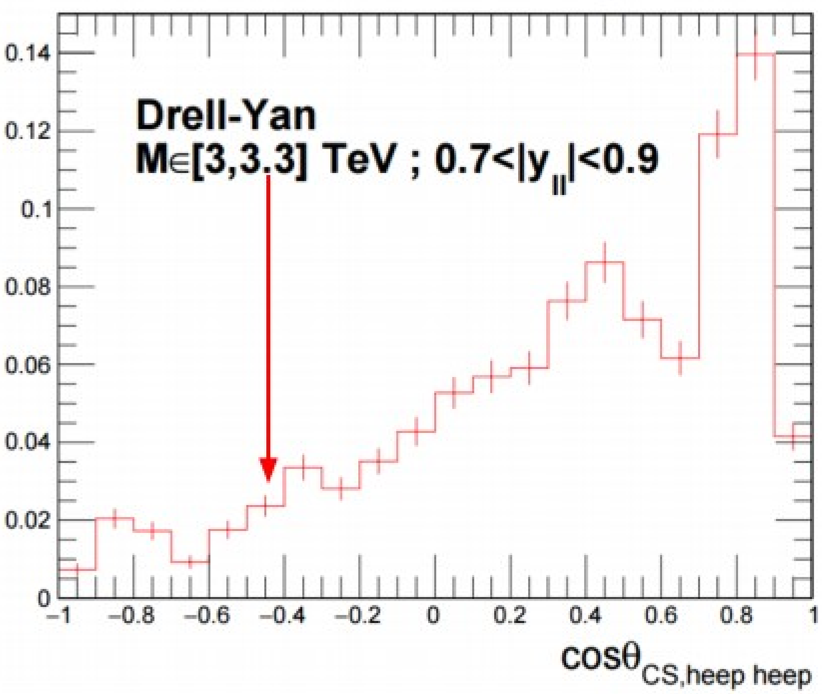


mass range	SM Bkg Expection
>1 TeV	0.21
> 2 TeV	0.007
> 2.5 TeV	0.002

Assuming the right direction for the q (inferred from the boost of the system):

$\cos\theta_{CS}$= -0.49

(DY events with similar kinematics present a positive FB asymmetry)



Not to conclude...

There is still a long way to go...

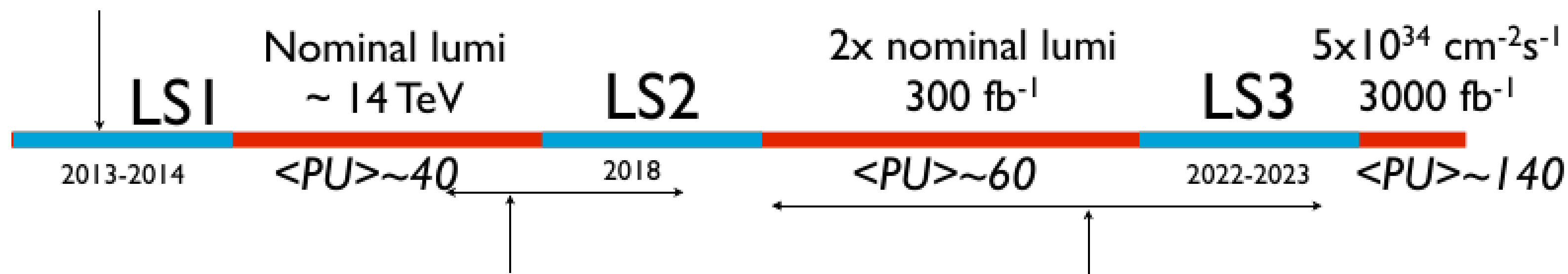
… lets start today.

Backup

Challenges

- In the case of CMS, several hardware changes are foreseen **during** Run 2
  - L1 Trigger upgrade
  - HCAL upgrade (photo-detectors, electronics)
  - Pixel upgrade (EYETS 2016-2017)

Reparations and LS1 projects: in production
- **Completion of muon coverage (ME4)**
- **Improve muon operations: ME1, DT electronics**
- Replace HF (PMTs) and HO (SiPM) photodetectors

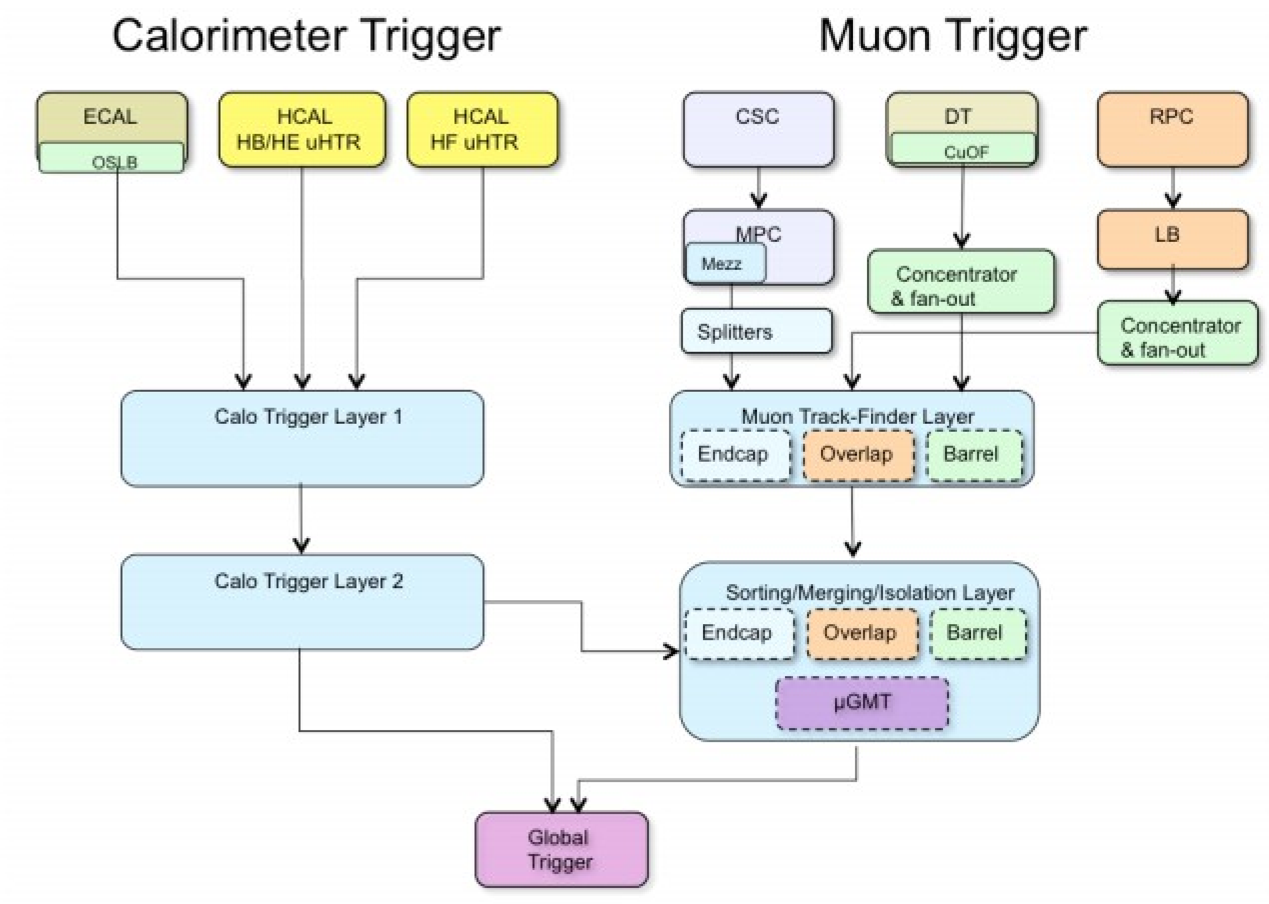


Phase 1: production
- Pixel detector replacement
- HCAL electronics upgrade
- **L1-Trigger upgrade**

Phase 2: Tecnical Proposal 2014
- Tracker replacement, **Track Trigger**
- Forward region: Calorimetry, **Muons**, Pixels
  - **GEMs in first two endcap stations**
  - **New RPCs in 3rd and 4th station**
  - **$|\eta|>2.4$: "ME0" GEM, up to $\eta=4$?**
  - **New CSC and DT electronics**
- Further Trigger and DAQ upgrade: **10us, 1MHz**

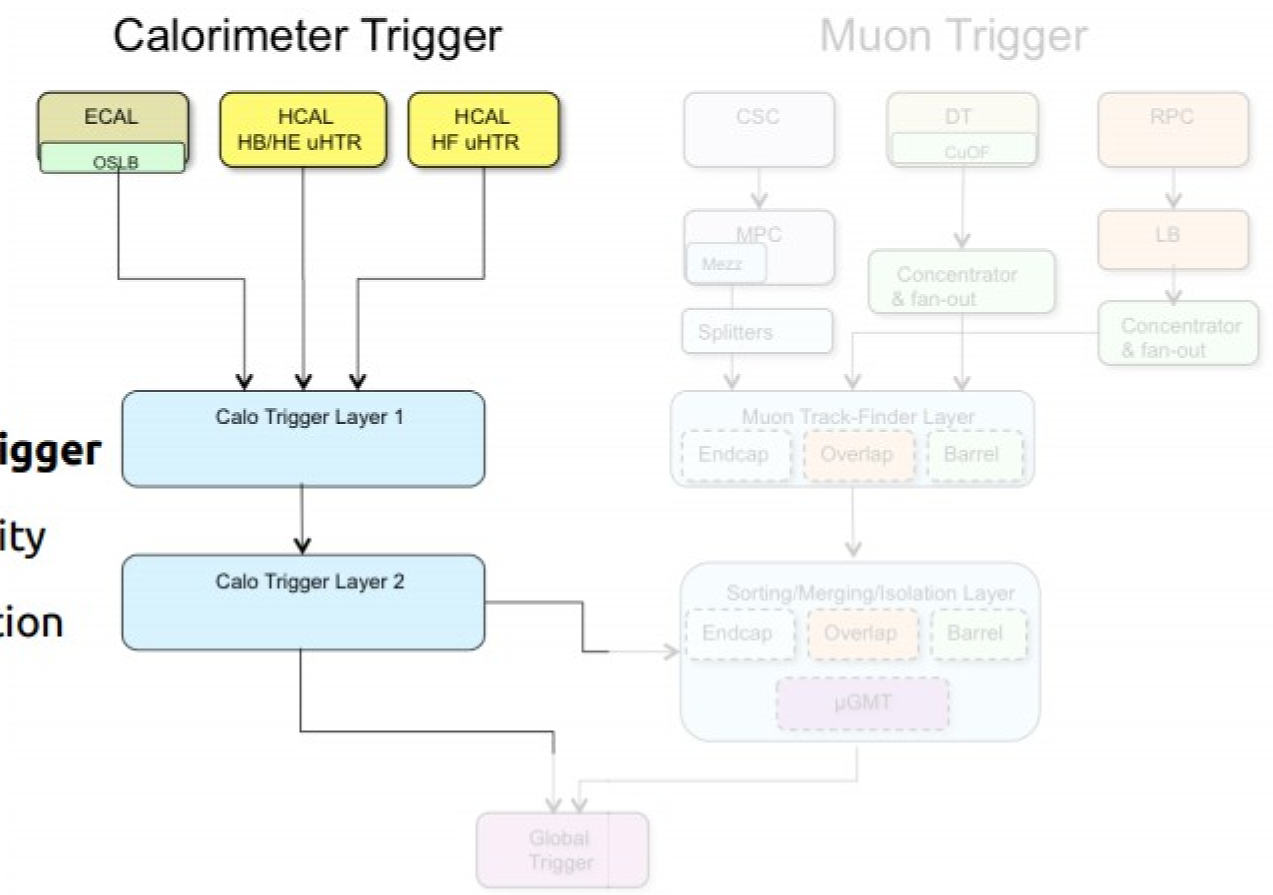
Trigger

L1 trigger in 2016

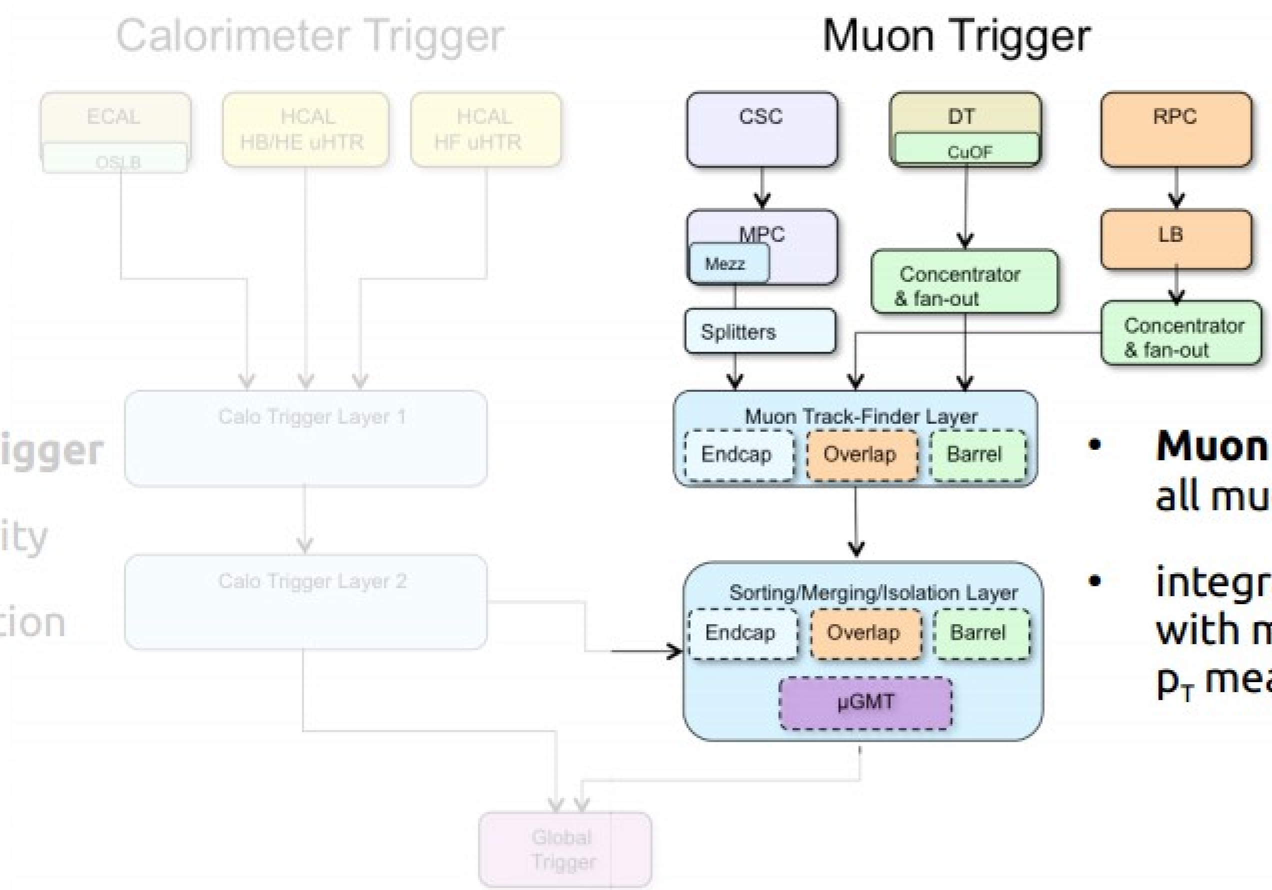


L1 trigger in 2016

- two-layer **Calorimeter Trigger**
- higher granularity
- pile-up subtraction



L1 trigger in 2016



- two-layer **Calorimeter Trigger**
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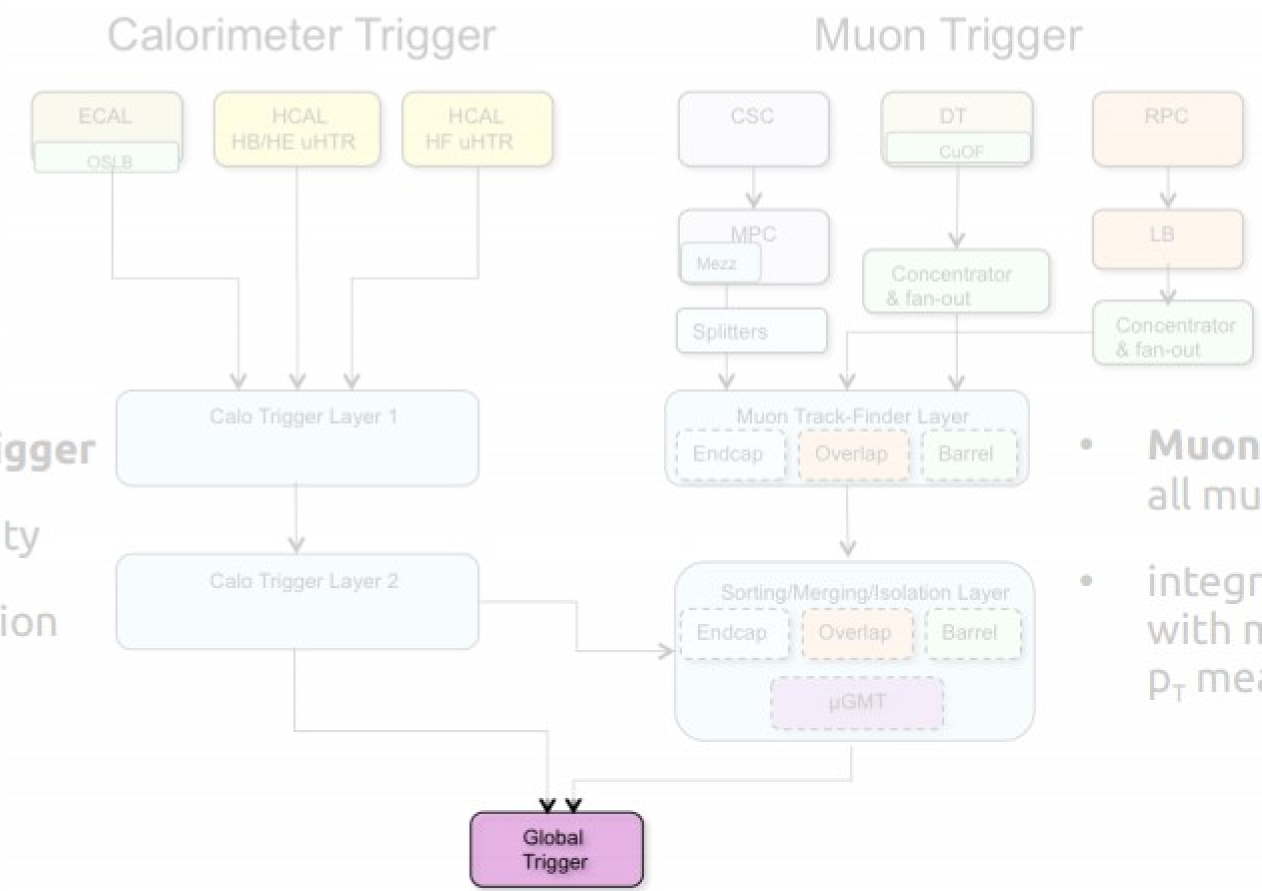
- **Muon Trigger** combining all muon systems
- integrated track-finding with more sophisticated p_T measurement

L1 trigger in 2016



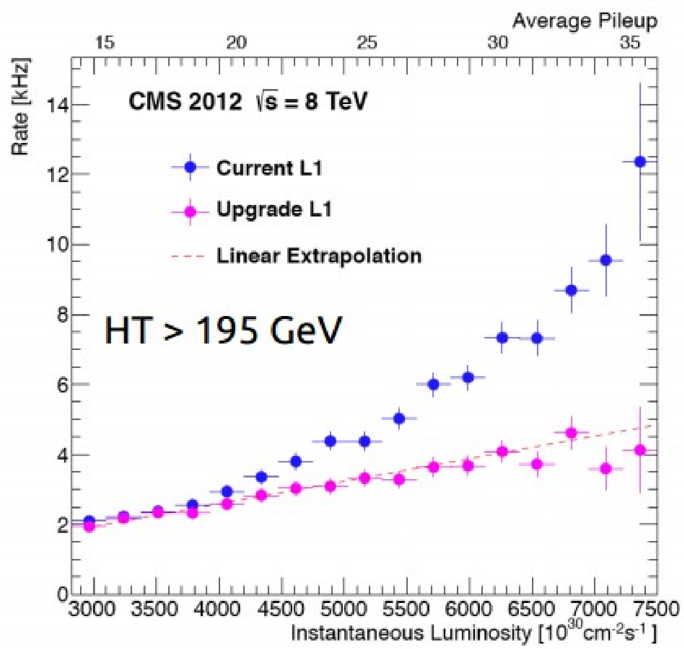
- two-layer **Calorimeter Trigger**
- higher granularity
- pile-up subtraction

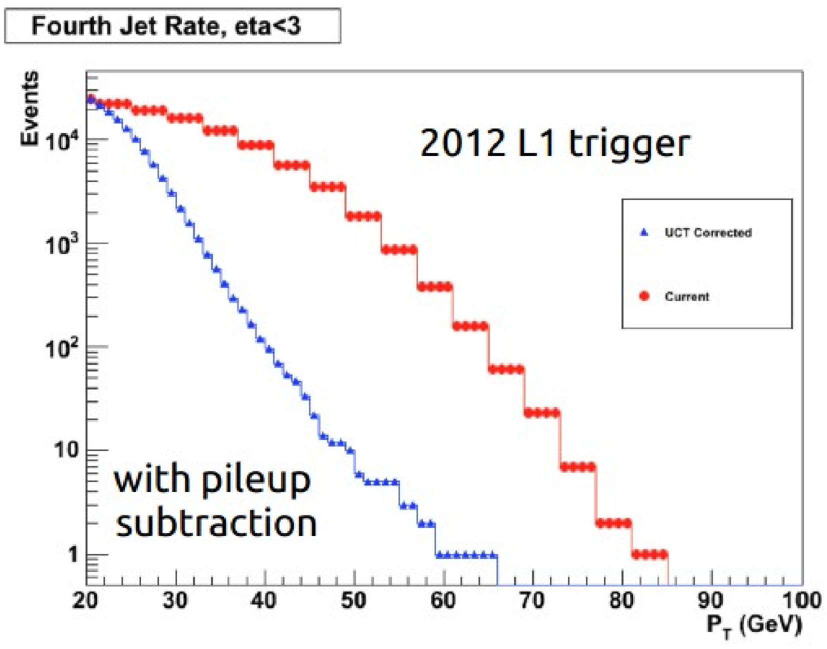
- **Muon Trigger** combining all muon systems
- integrated track-finding with more sophisticated p_T measurement

- more powerful Global Trigger
  - topology cuts, invariant mass cuts, …
  - larger number of triggers

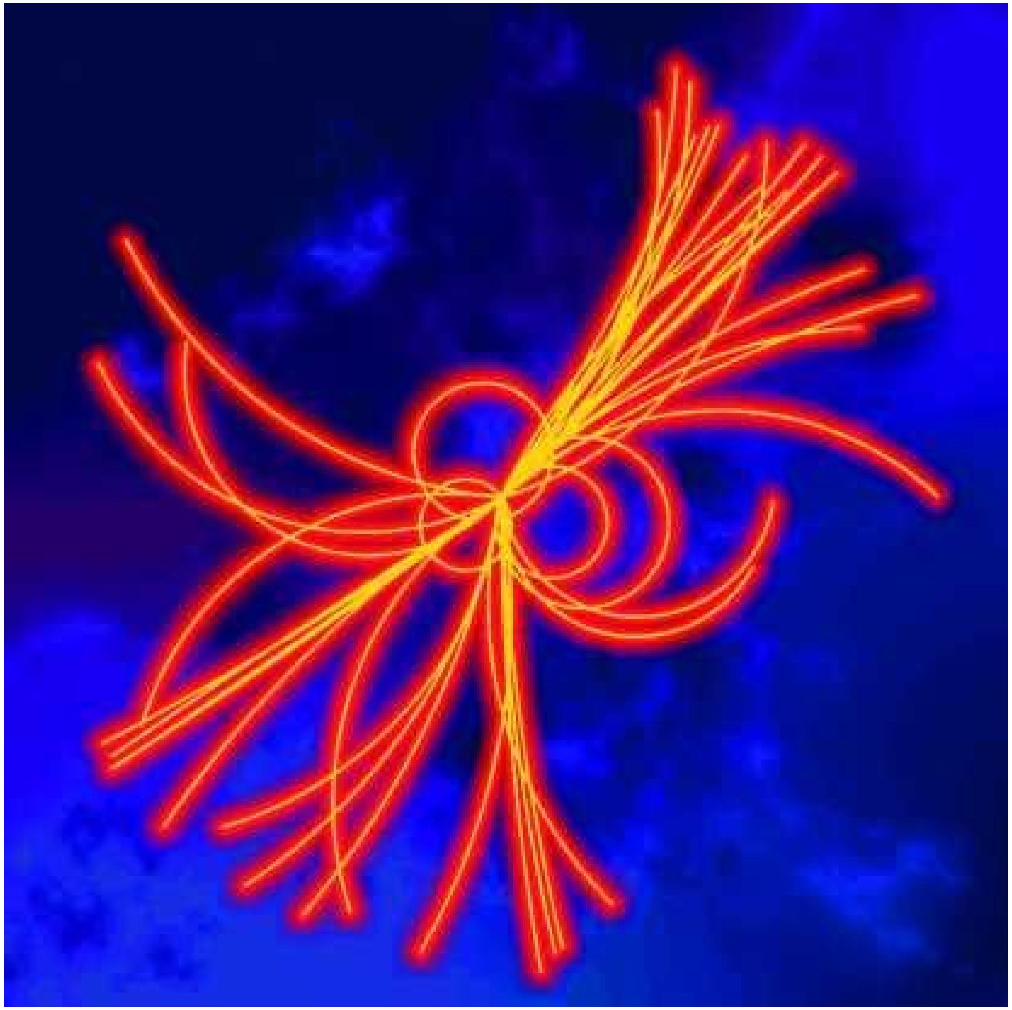
Stage 1: L1 trigger in 2015

- replace the Global Calorimetric Trigger with a a prototype of the "Layer 2"
  - improved calorimetric trigger
    - pile-up subtraction for jets and energy sums
    - dedicated tau trigger candidates
- improvements to the Muon Trigger
  - make use of new muon chambers
  - increased granularity of the CSC readout
  - improve the LUTs used for track building and matching

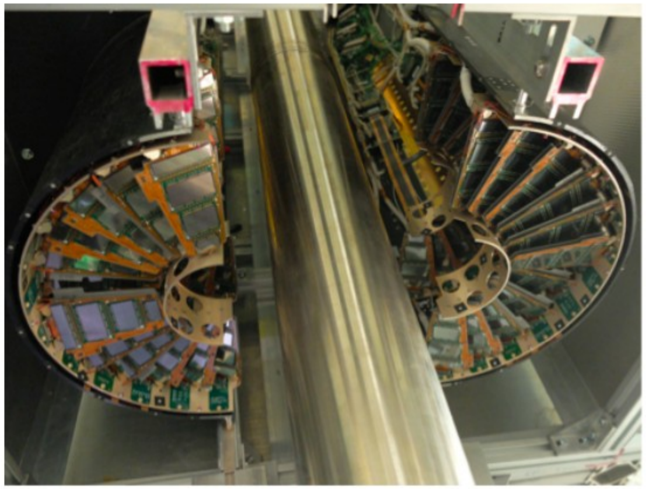




Tracker & tracking

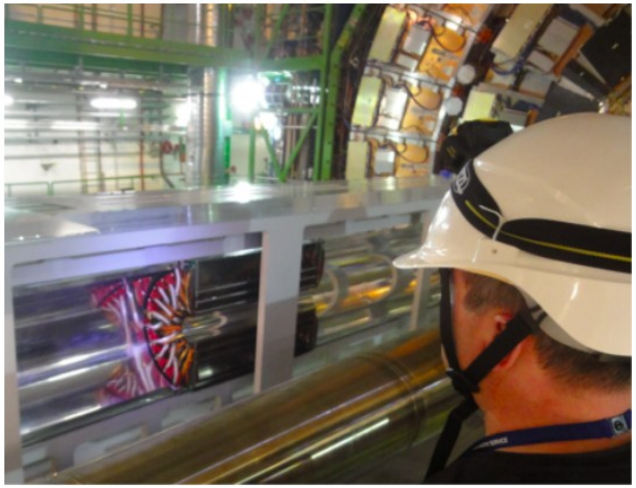


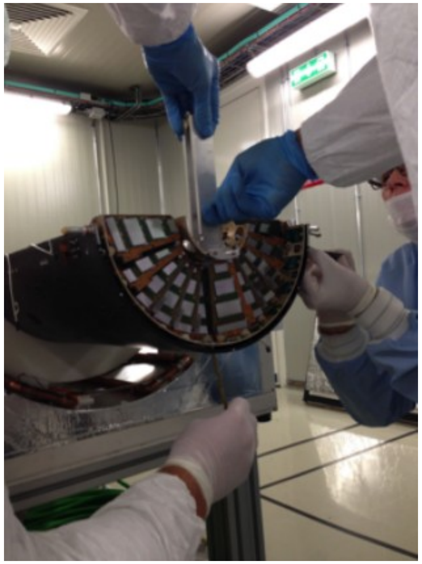
Pixel detector extraction & repairs

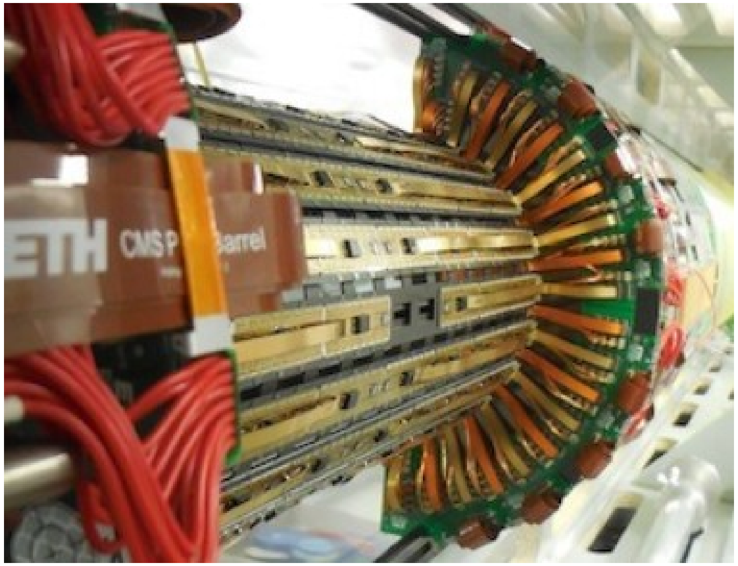


FPix

BPix







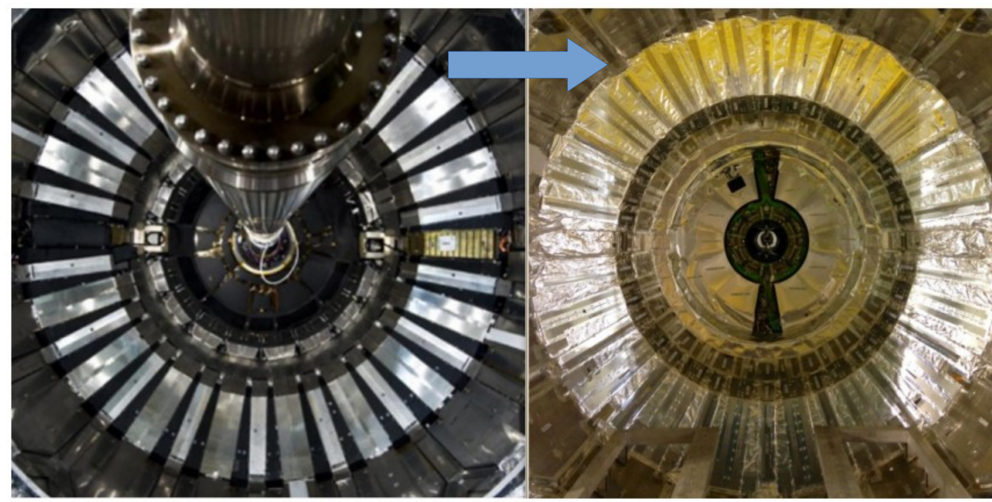
- About 2.3% of BPix channels inoperative at the end of Run 1
  - 1.2%: modules located on outer shell of Layer 3
  - 1.1%: modules placed on Layers 1 and 2 or inner shell of Layer 3
    - removal/substitution operation considered too risky to plan a replacement
  - 2 AOHs not fully operative (workaround allowed proper data taking)
- Repairs performed during LS1:
  - almost 100% of faulty modules on Layer 3 outer shell replaced (1.1% of BPix channels)
  - AOHs successfully replaced

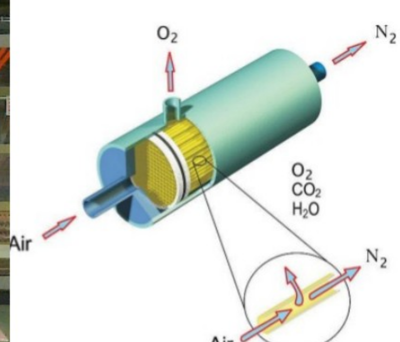
- At the end of Run 1 ~ 7.8% of FPix channels was not operational
  - **3.6%**: failing digitization of the analog signal due to distortion of the signal ("slow channels") caused by misaligned flex cables
  - **3.1%**: unplugged analog electrical-to-optical converters (AOHs)
  - **1.1%**: problematic panels
- Repairs performed during LS1
  - **99.9%** of FPix channel is now operational

CMS Tracker

- In order to sustain the increased radiation levels in run 2, the tracker has to be operated at lower temperatures.
  - Run 1 operating point: +4°C
  - Run 2 operating point: -15°C
- This implied an effort to prevent humidity in the "bulkhead" region in between the tracker volume and the ECAL endcap.

Complete sealing of the region

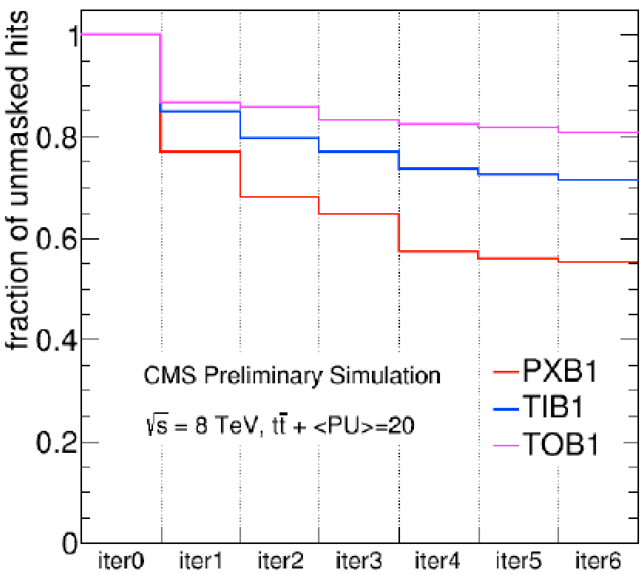


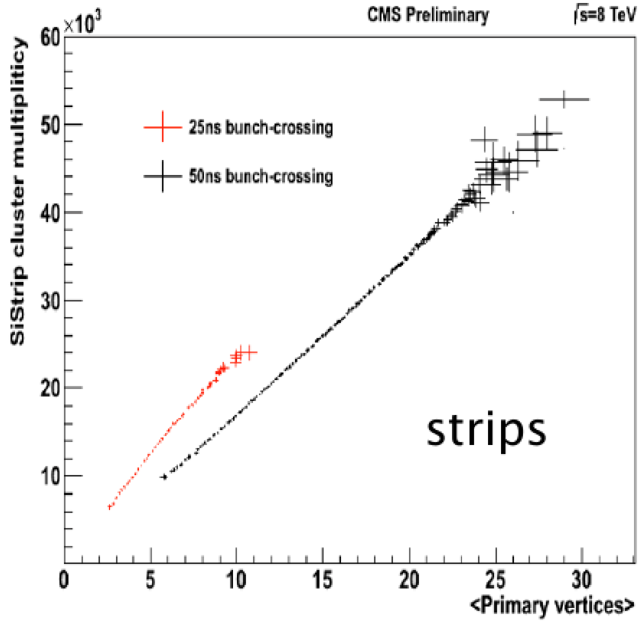


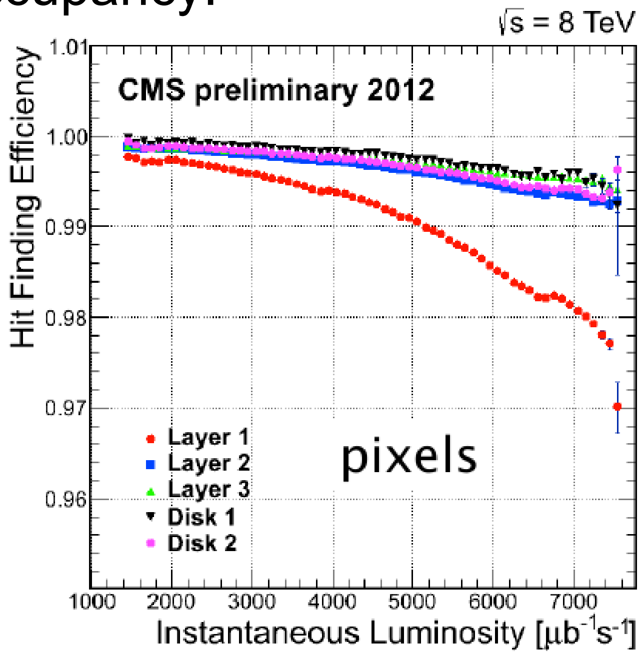
Brand new dry gas (membrane) plant

Tracking challenges at high pile-up

Tracking in run 2 is a challenge due to increasing tracker occupancy:







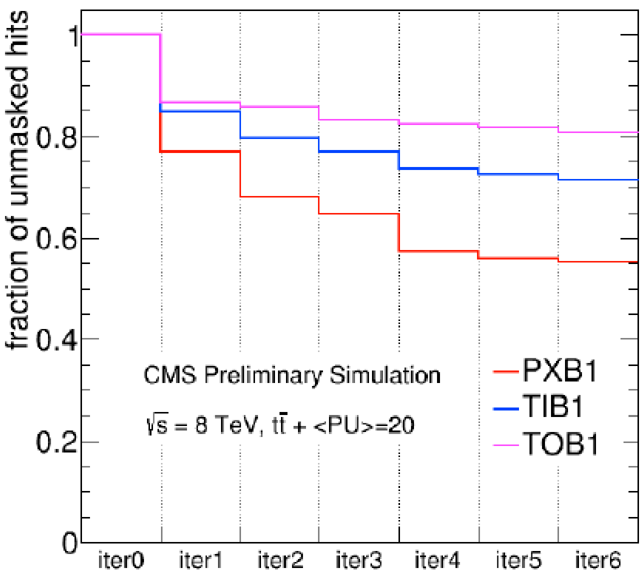
- Pixels are affected by a dynamic inefficiency, mainly due to saturation of chip readout buffers.

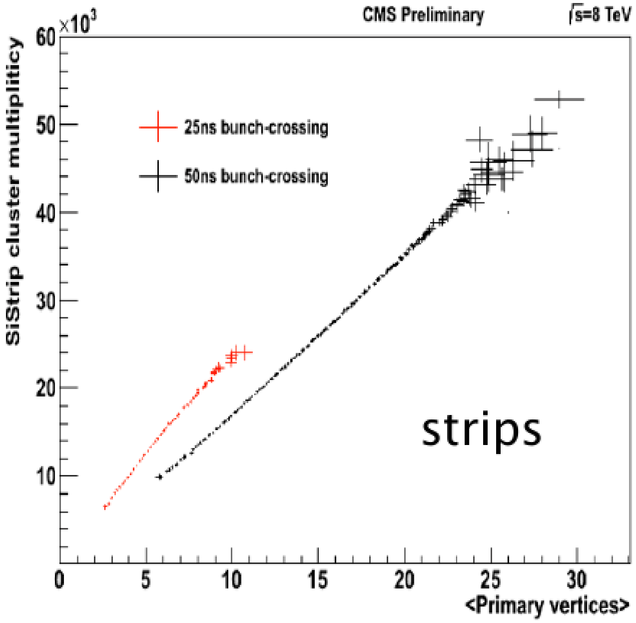
- Out of time pile-up increases the occupancy of the strip detector by ~45% (only ~5% for pixels)

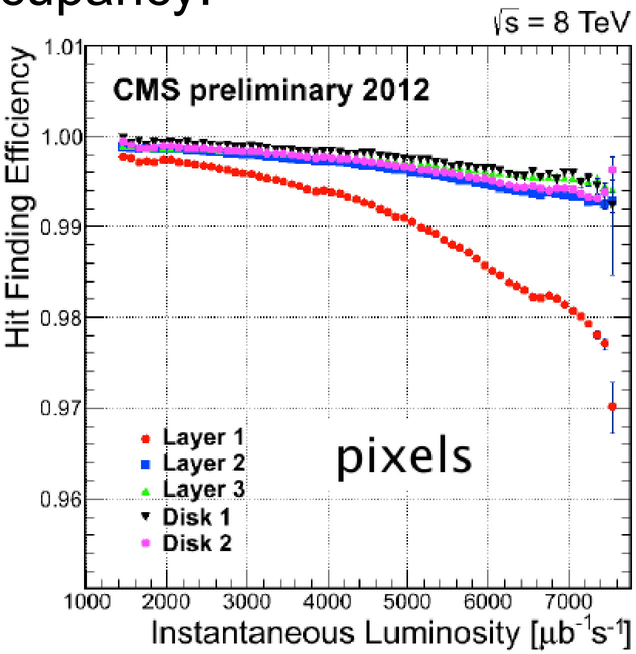
- Iterative tracking is not the definitive solution, tracker is far from being empty after all iterations

Tracking challenges at high pile-up

Tracking in run 2 is a challenge due to increasing tracker occupancy:







New Pixel detector by the end of 2016

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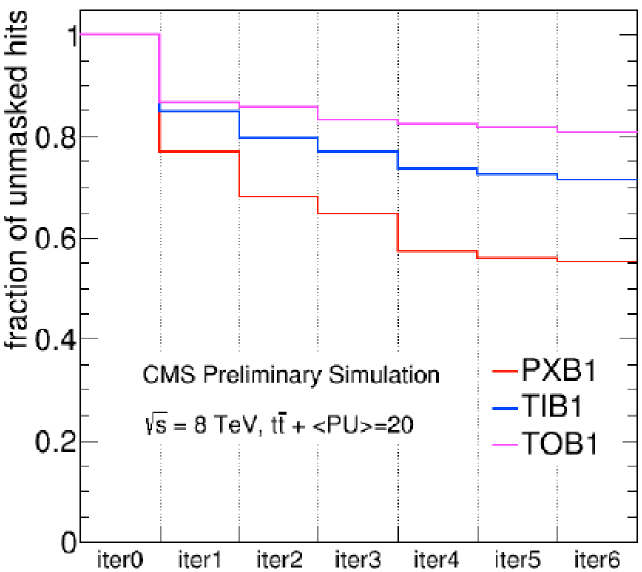
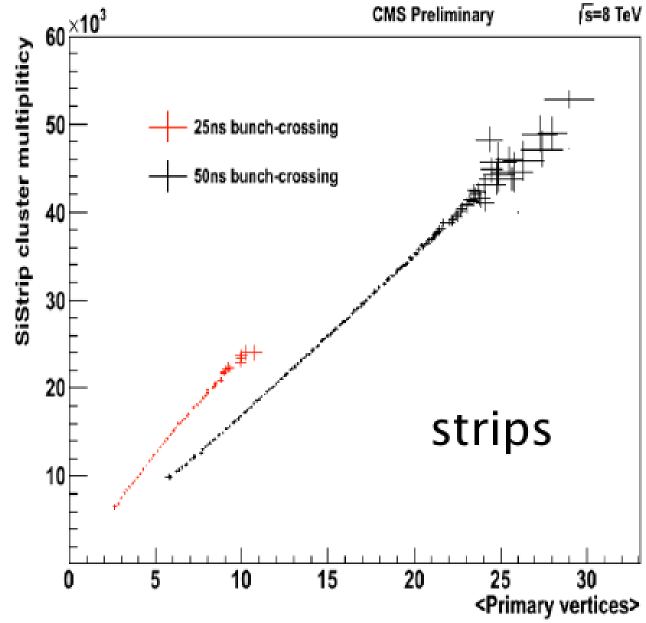
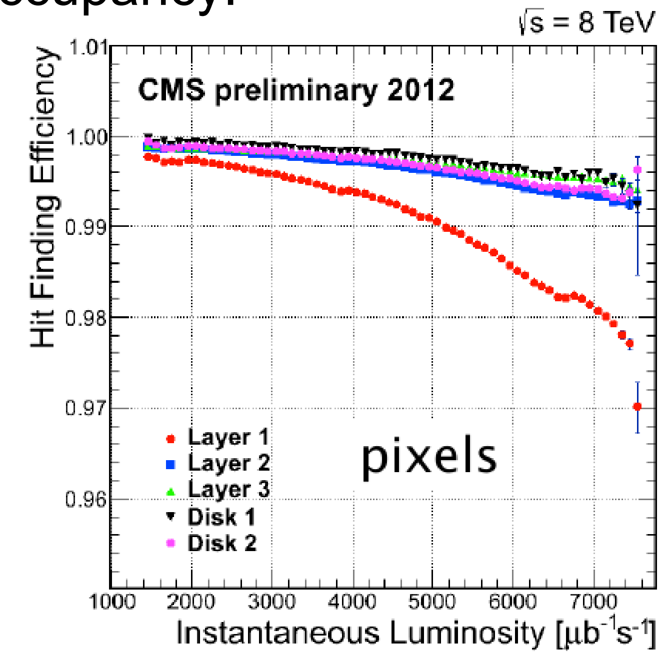






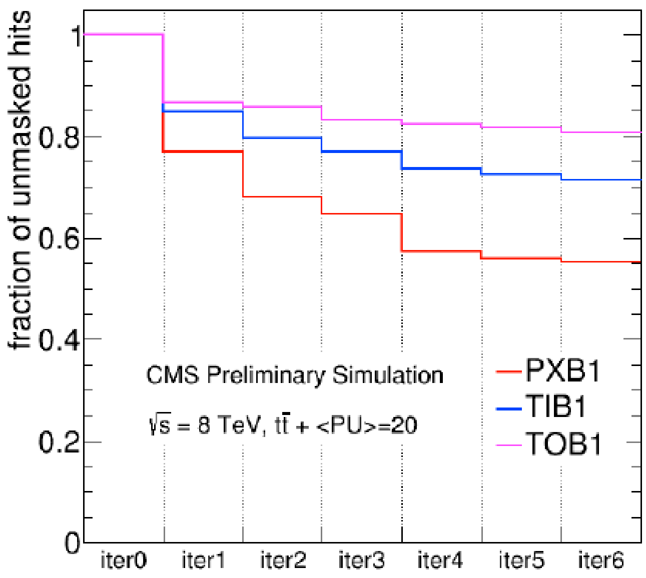
New Pixel detector by the end of 2016

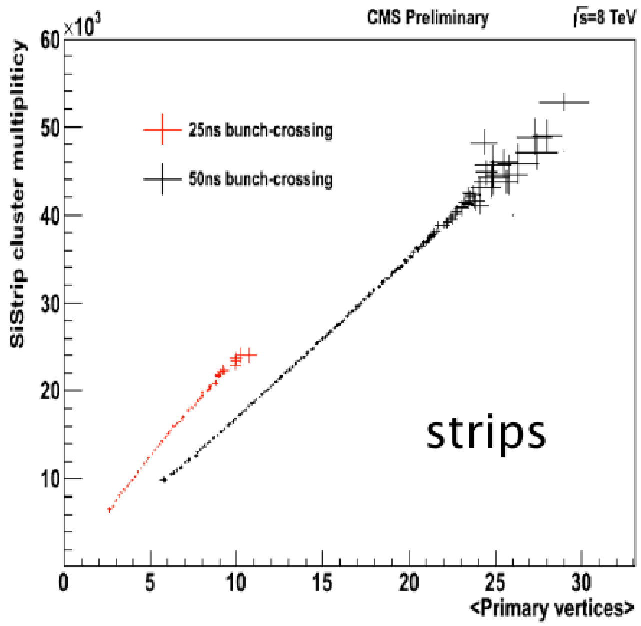
Introduction of a cluster charge cut

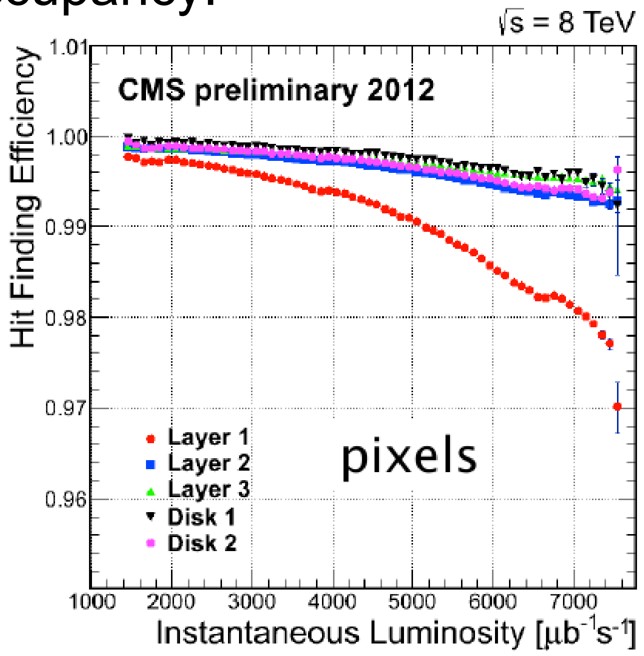
- Iterative tracking is not the definitive solution, tracker is far from being empty after all iterations

Tracking challenges at high pile-up

Tracking in run 2 is a challenge due to increasing tracker occupancy:







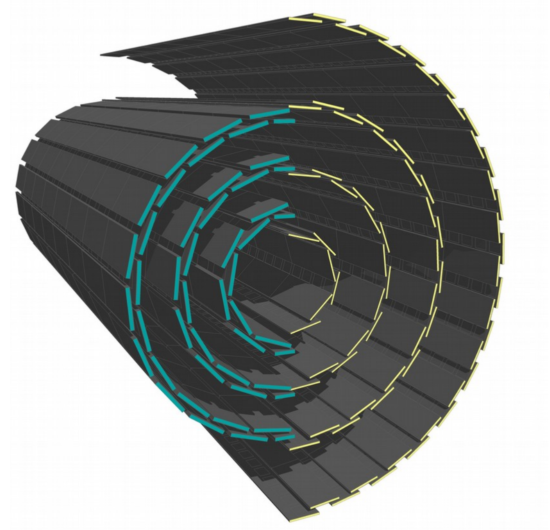
New Pixel detector by the end of 2016

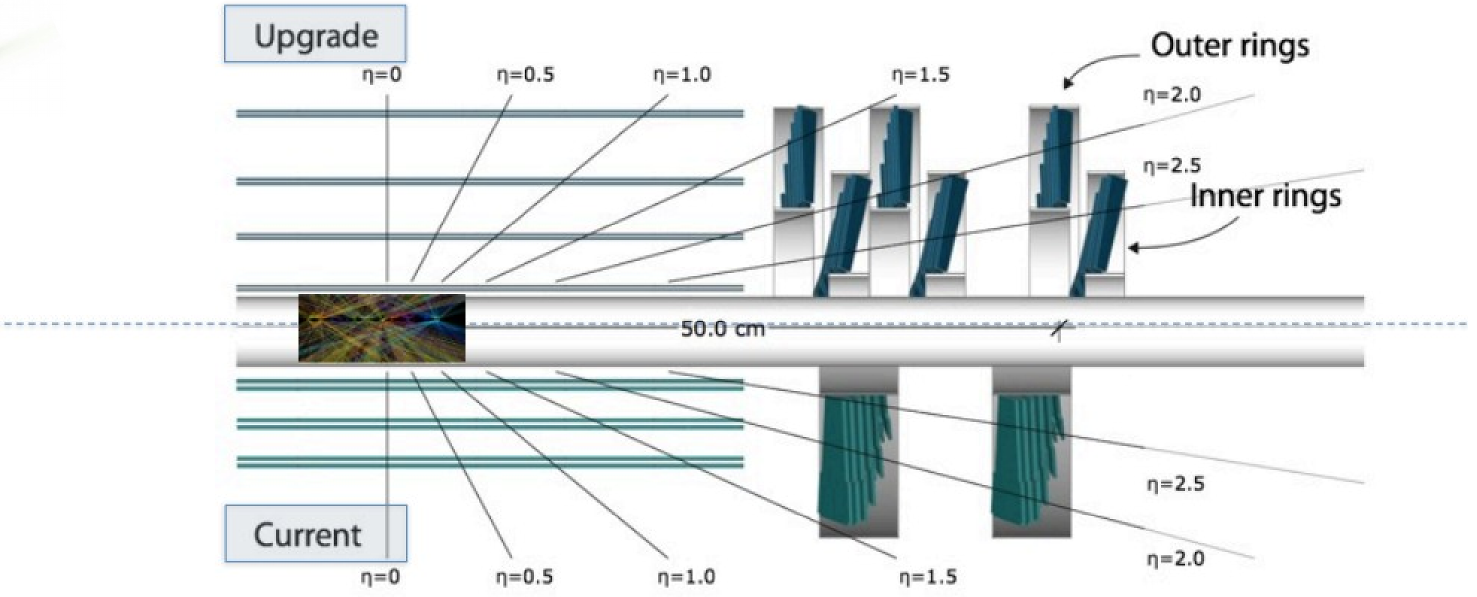
Introduction of a cluster charge cut

Global re-optimization of the tracking sequence

From 2017: pixel phase 1 upgrade

Depends on the installation of a new beam pipe during LS1



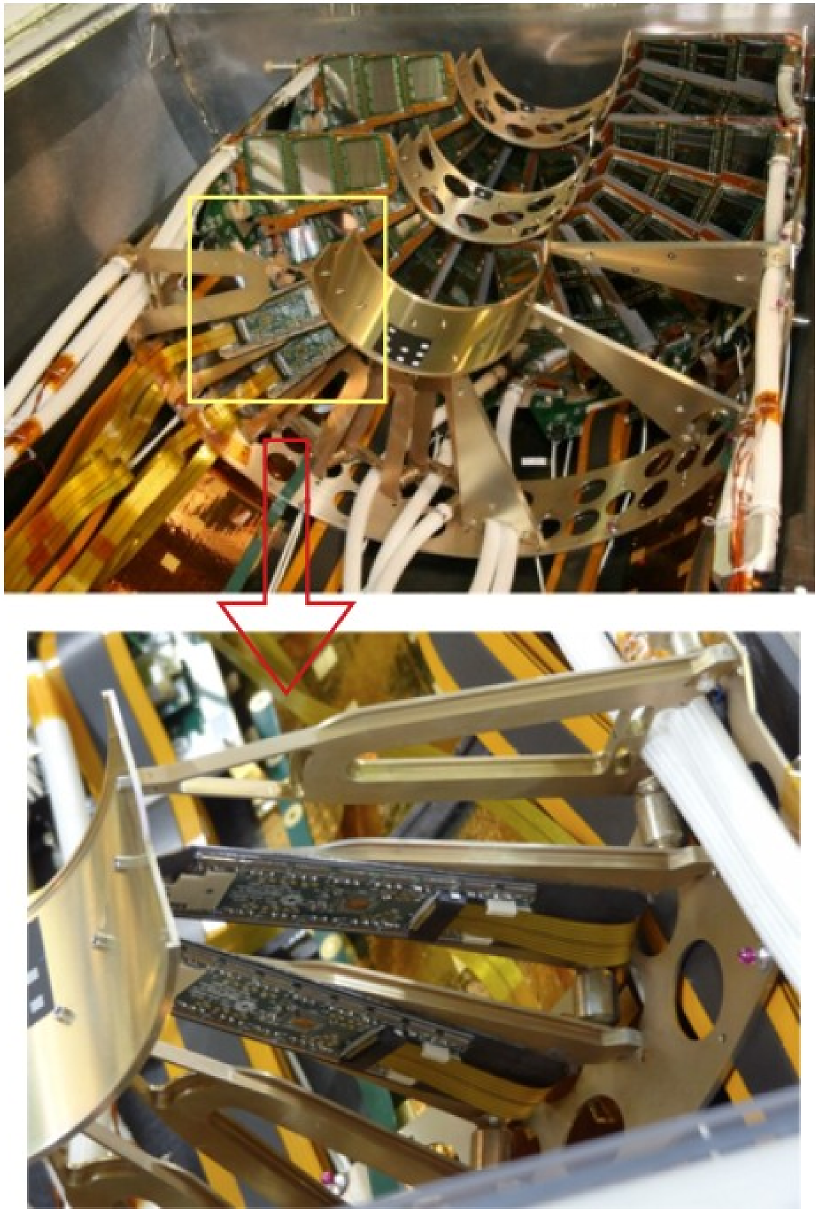


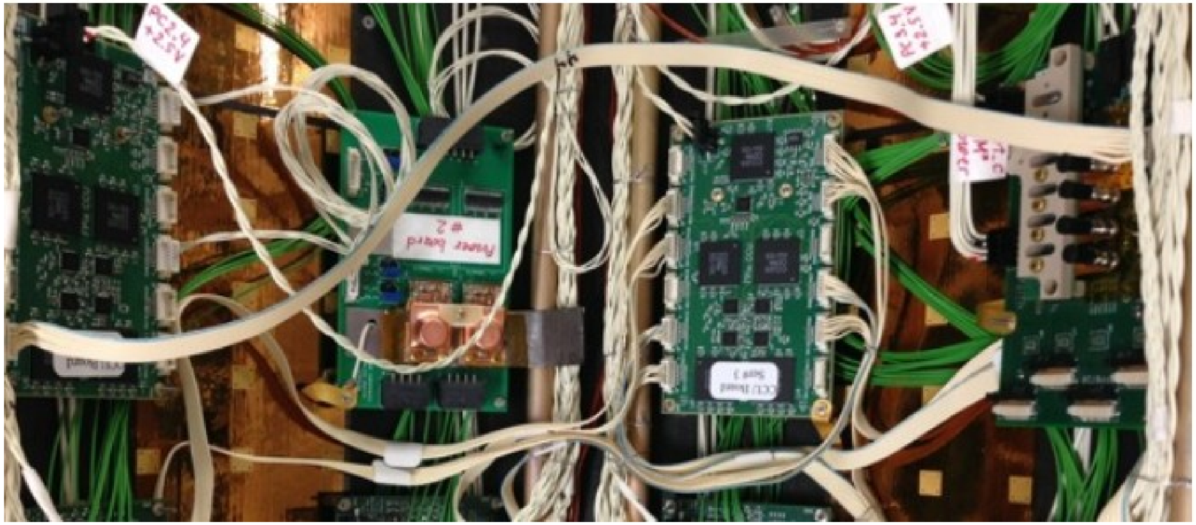
<u>Pixel Upgrade</u>

Baseline L = $2x10^{34}$ $cm^{-2}s^{-1}$ & 25ns **(50PU)**
Tolerate L = $2x10^{34}$ $cm^{-2}s^{-1}$ & 50ns **(100PU)**
Survive Integrated Luminosity of $500fb^{-1}$
(Evolutionary upgrade with) **minimal disruption of data taking**
Same detector concept: higher rate readout, data link & DAQ w/ less material forward
Robust tracking: 4 hit coverage

Pixel pilot blades

- New prototype modules installed in two forward half disk added to the present detector
  - New **digital** ROCs
  - New auxiliary electronics
  - Everything in place to test Upgrade of Pixel detector before its insertion

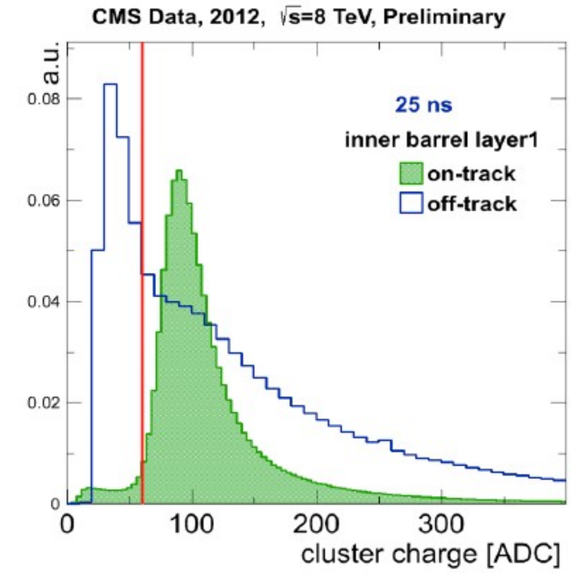




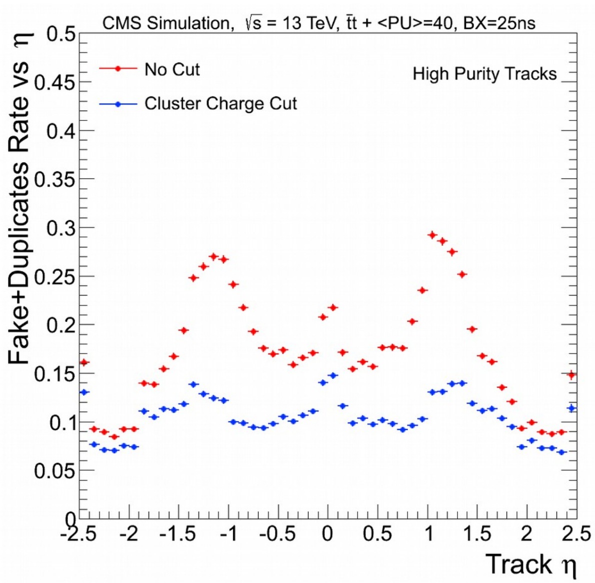
Cluster charge cut for OOTPU mitigation

- Clusters from out of time pile-up are characterized by low collected charge

Due to out-of-time PU, there is a factor of 2 increase
- in fake rate
- in timing



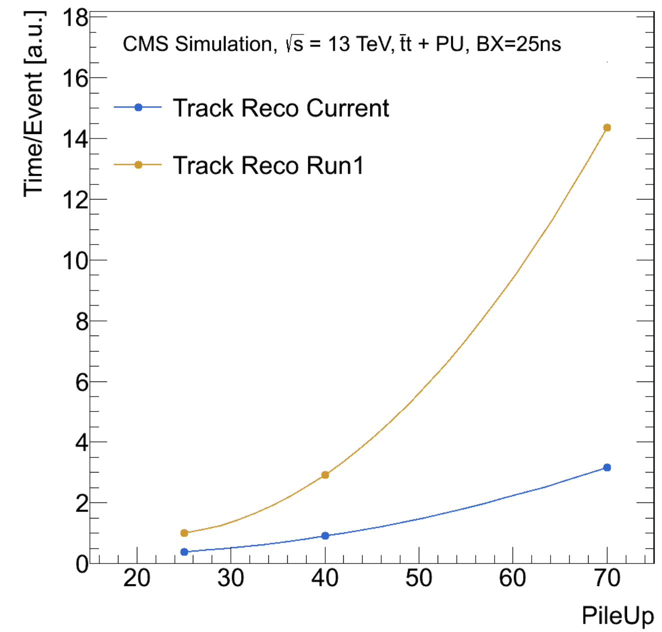
- Cutting on the cluster charge suppresses the effect
  - accounts for sensor thickness and trajectory crossing angle
  - pT dependent cut to preserve potential signal from fractional charge particles
- Stable performance ensured by gain calibration in quasi-real time
  - The regular gain monitoring will be critical

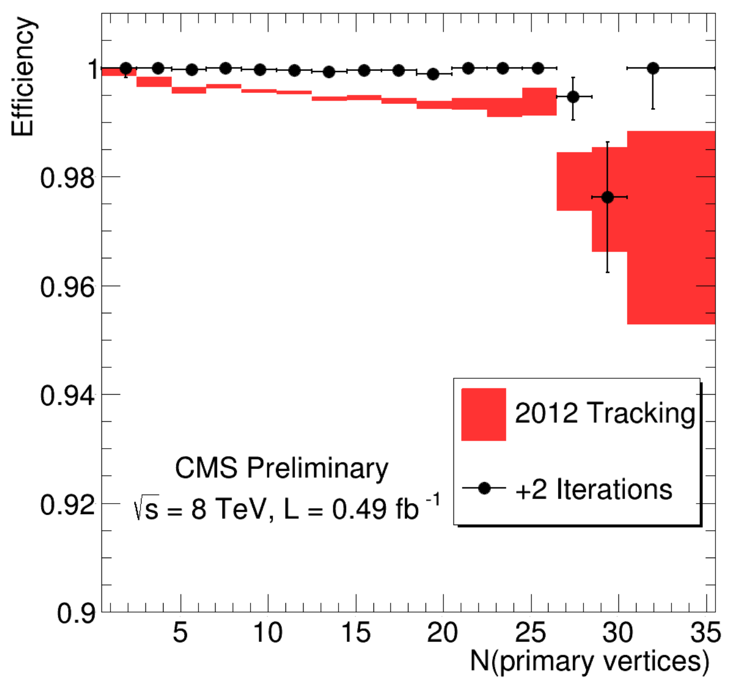


The cluster charge cut effectively restores Run 1 performance.

Tracking optimization

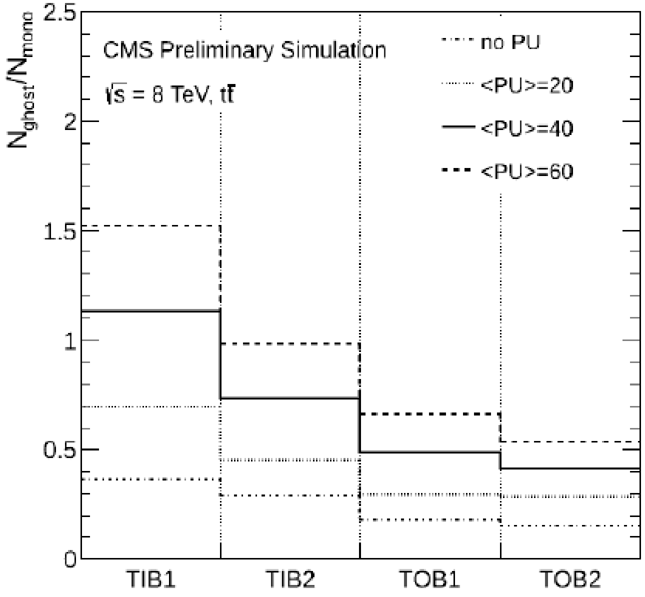
- Lots of efforts put in reshuffling and optimizing the iterative tracking steps
  - Factor ~5 gain in performance in run 2 conditions
  - Maintained physics performance similar to run 1

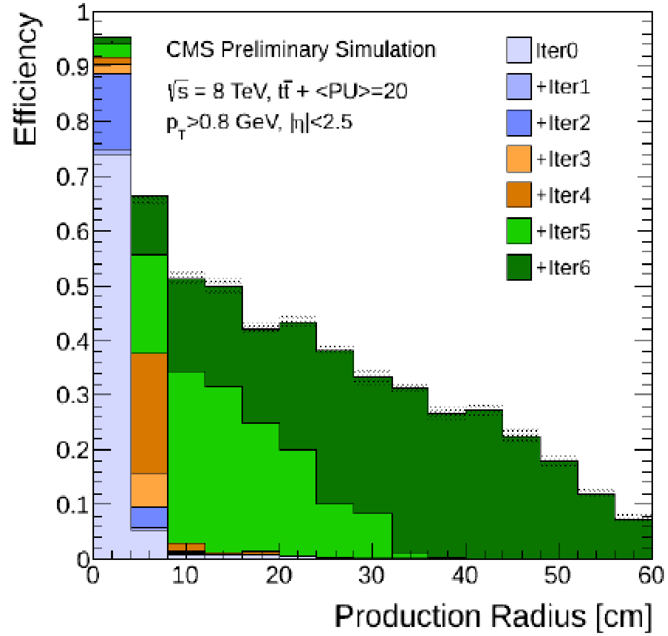


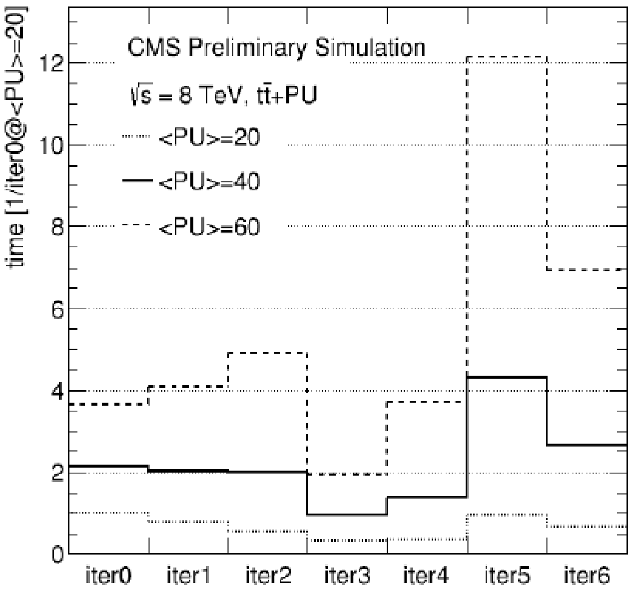


- 2 additional iterations have been designed to recover the efficiency loss seen in 2012 for muons:
  - an Outside-in iteration, seeded from the muon system, designed to recover the missing muon-track in the tracker
  - an Inside-Out iteration designed to re-reconstruct muon-tagged tracks with looser requirements to improve the hit-collection efficiency.
- The new iterations are clearly much less sensitive to the underlying PU conditions.

Tracking challenges at high pile-up (2)

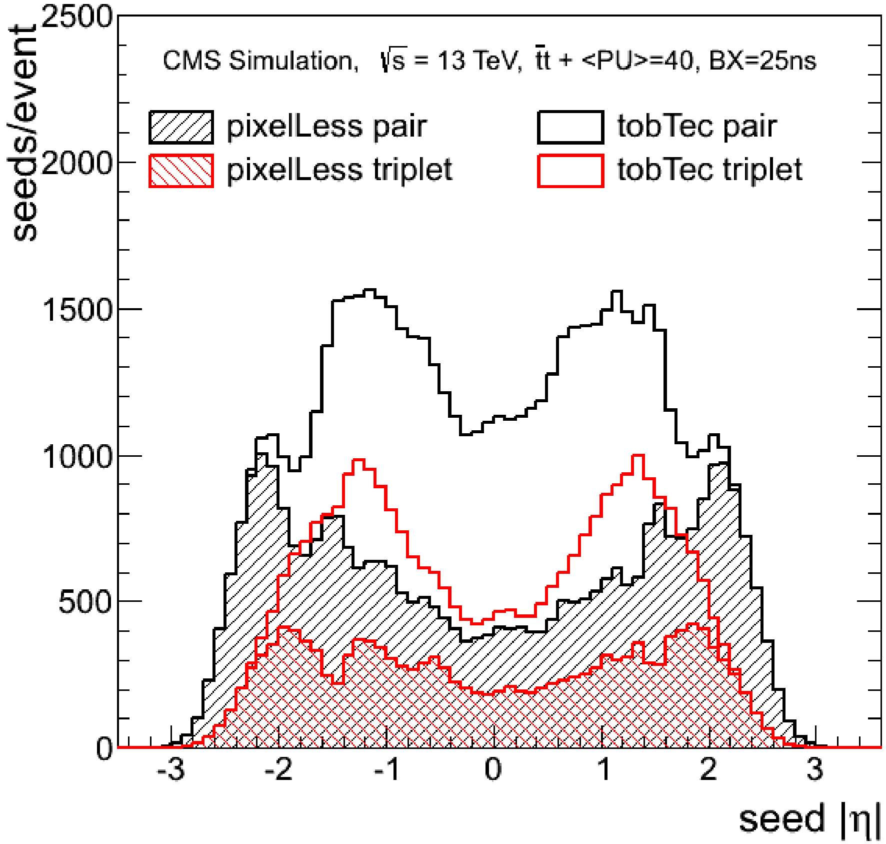


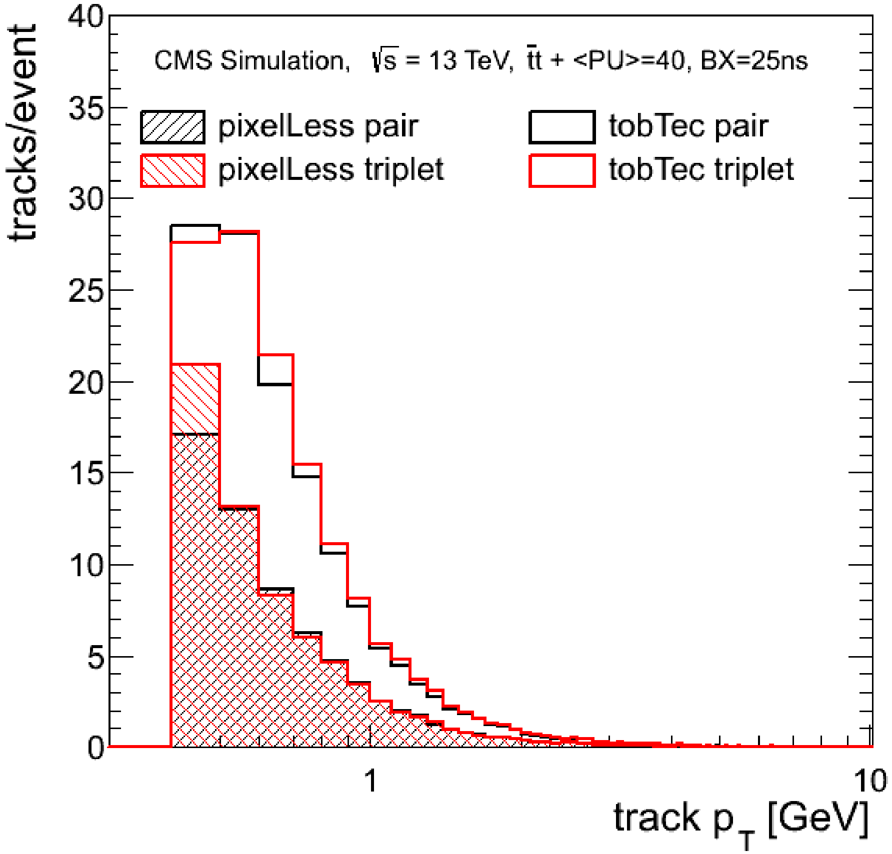




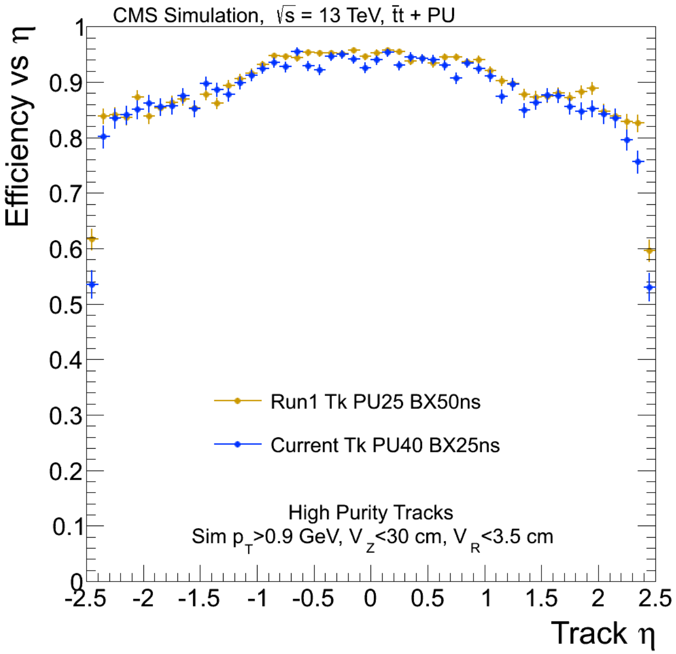
- On double-sided strip layers the number of ghost hits increases and in TIB1 becomes larger than true hits at <PU>=40
  - ghost hits are due to ambiguities when more than one track crosses a glued detector
- As a consequence, the effect of pile-up is dramatic on iterations seeded by pairs of strip matched hits (iter5 and 6)
  - still problematic for steps seeded by pixel pairs (iter2) and mixed triplets (iter4)
  - pixel triplet seeded steps are linear (iter0) or close to linear (iter1 and 3) with respect to pile-up

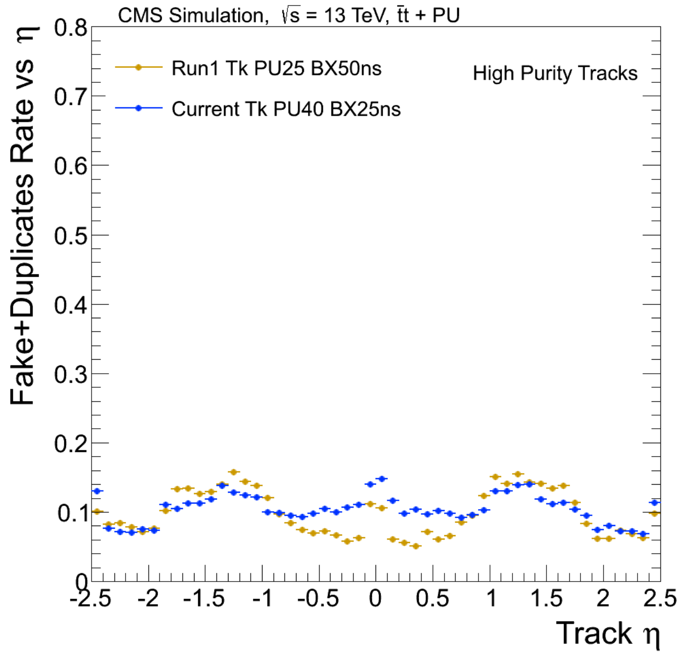
Pileup mitigation: from pairs to triplets

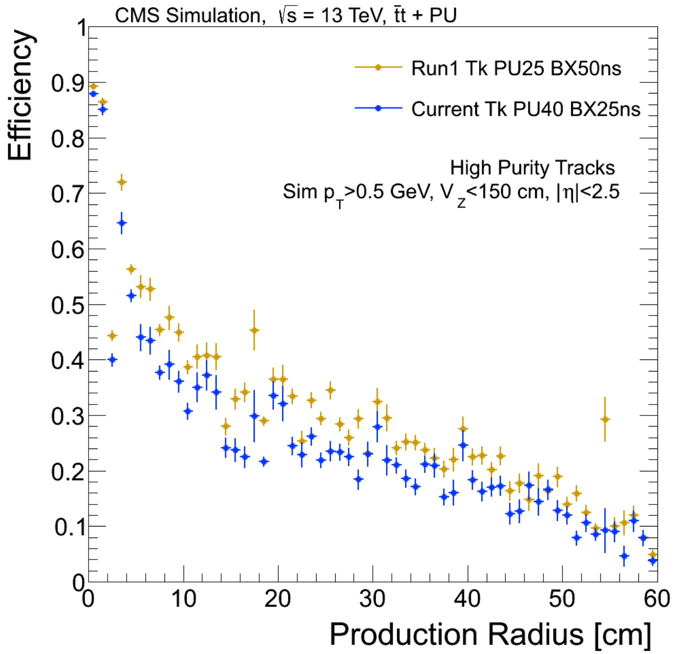




Performance after optimization

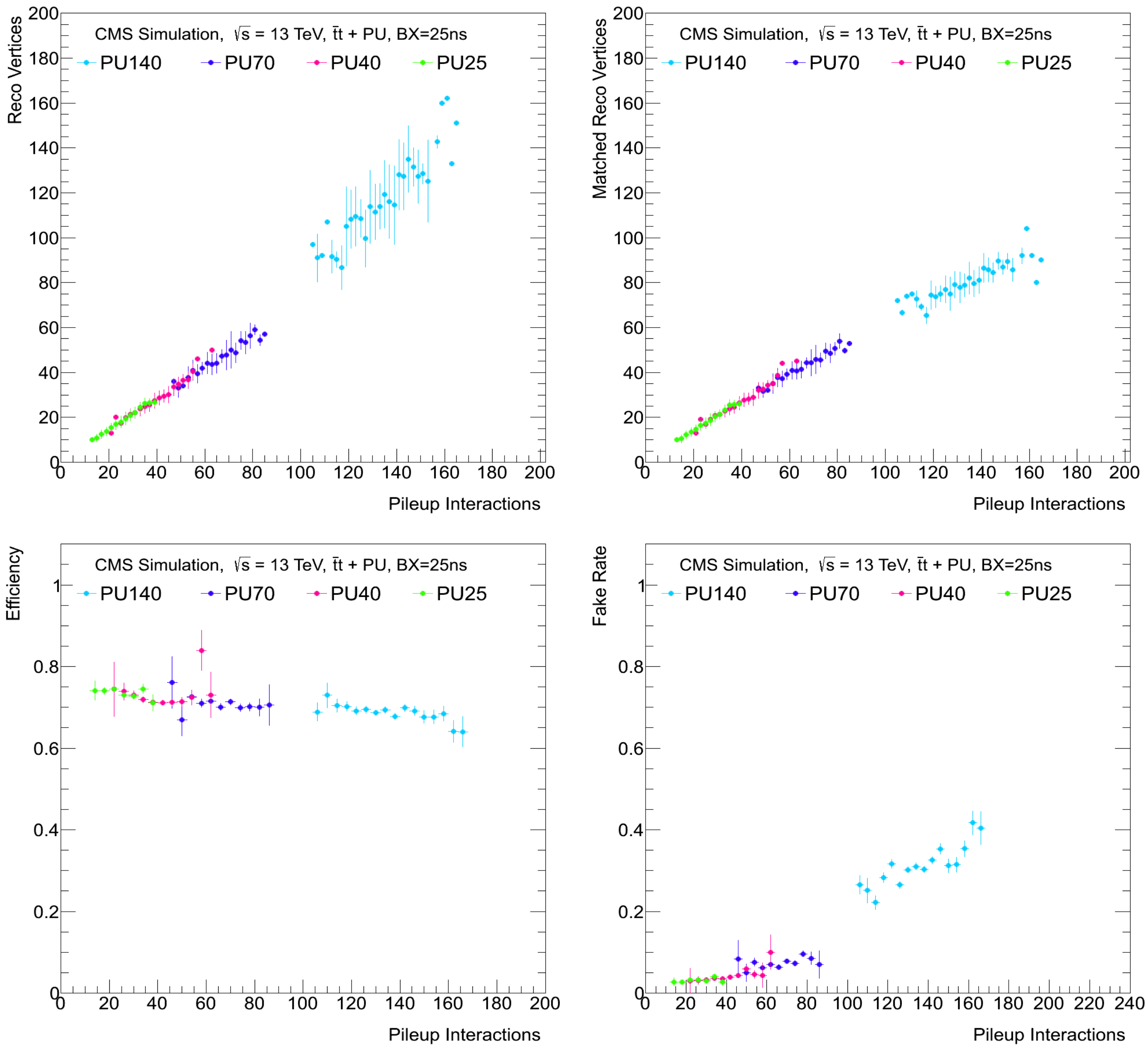






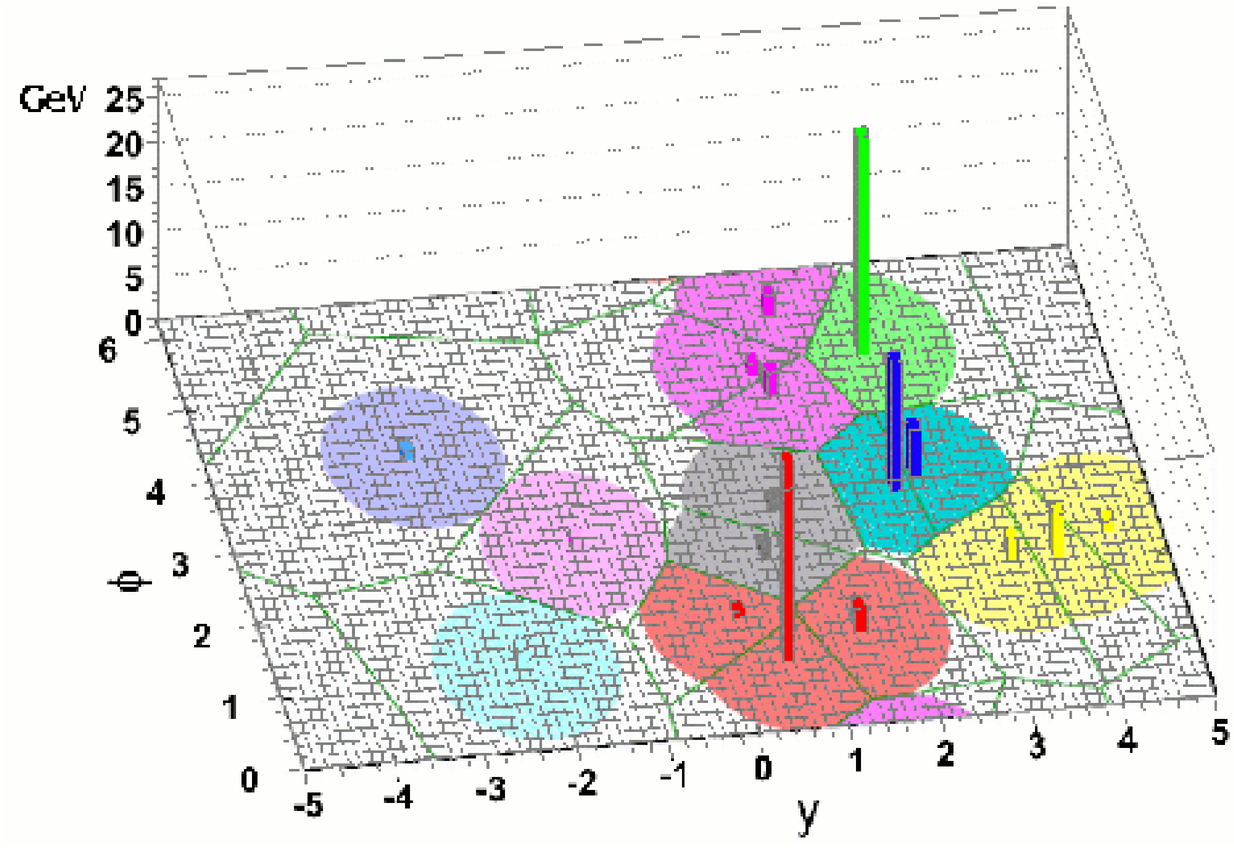
- Performance after optimization are very similar to those in run 1.
  - Track reconstruction efficiency vs eta
  - Fake and Duplicate rate vs eta
  - Track reconstruction efficiency vs track production radius
- With the modifications presented above, pileup is under control for run2

Vertexing



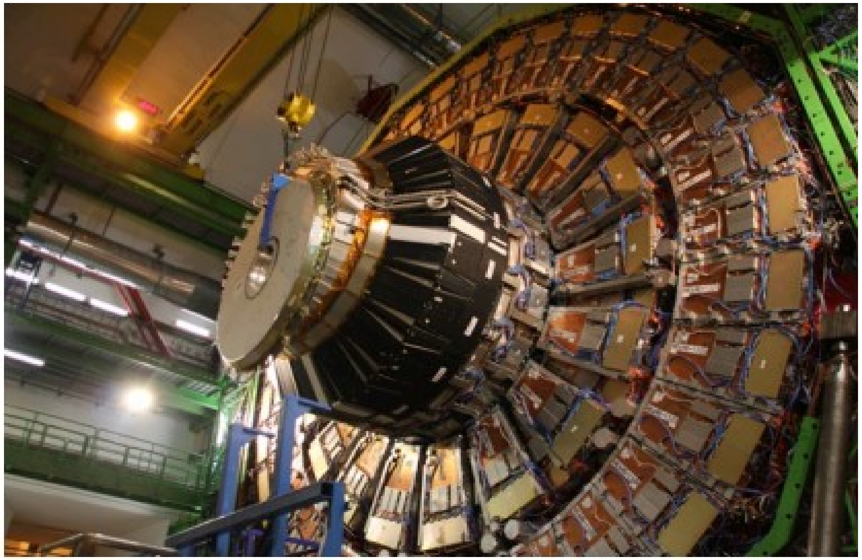
- Vertexing performance are good up to pileup of O(100)
- No special action needed for run2
- A new approach will be needed for HL-LHC

Calorimeters



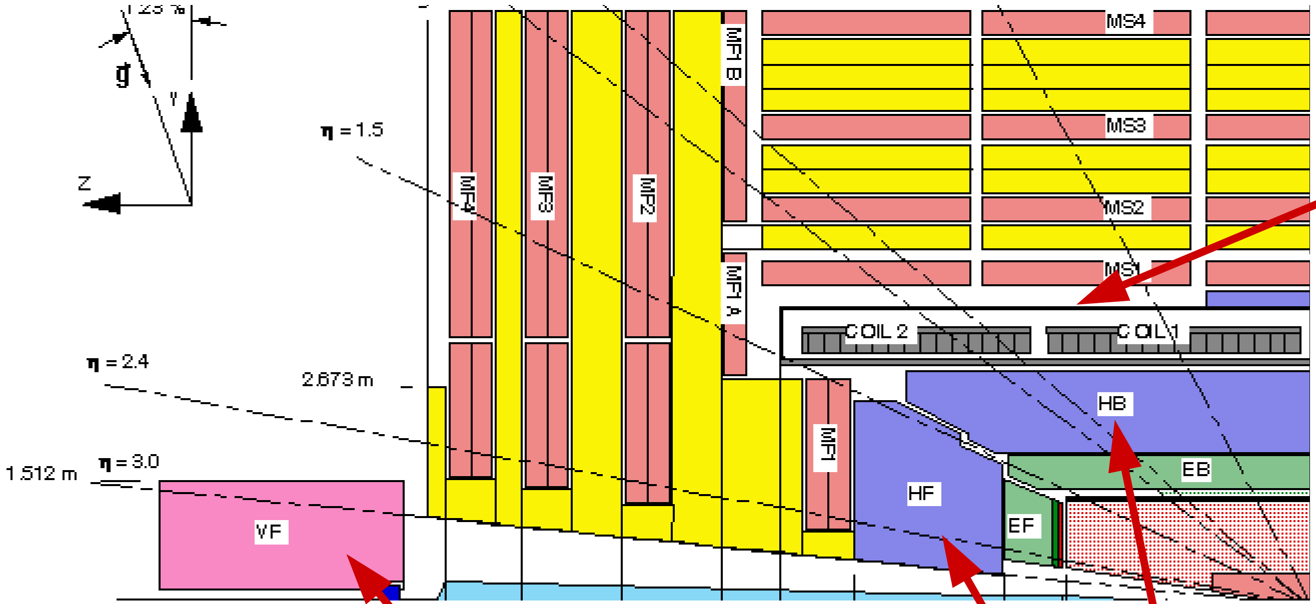
Preshower repairs during LS1

- In November 2013 a problem was detected with connectors at the exterior of the ES− disc. It was promptly decided to replace the four connectors of this type.
  - This implied the removal of preshower for repair on the surface



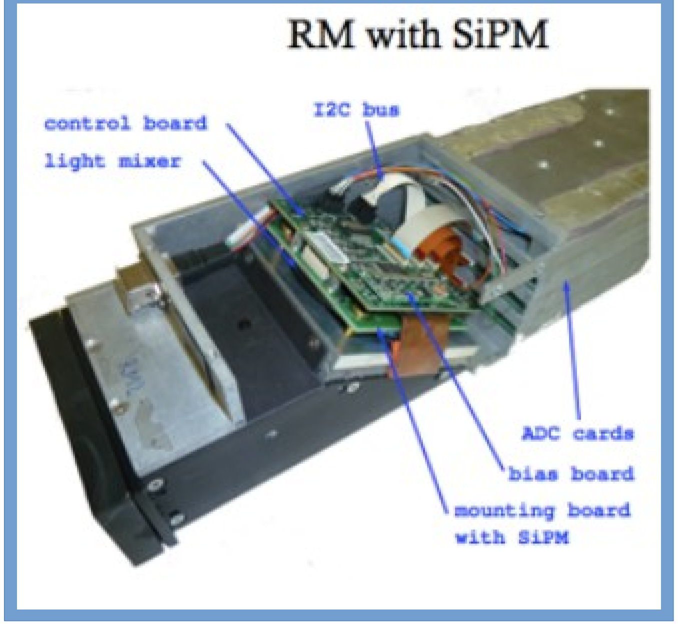
  - At the same time, we recovered non-operational channels
    - **96.8% operational in 2012 → 99.95% in 2014**
- Both disks were re-installed and recommissioned.

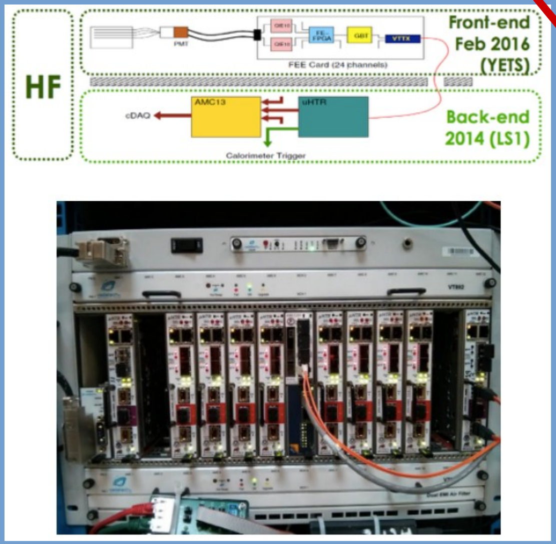
Interventions on HCAL during LS1



HO: replacement of HPDs by SiPMs

(HPDs were not behaving well because of the magnetic field)



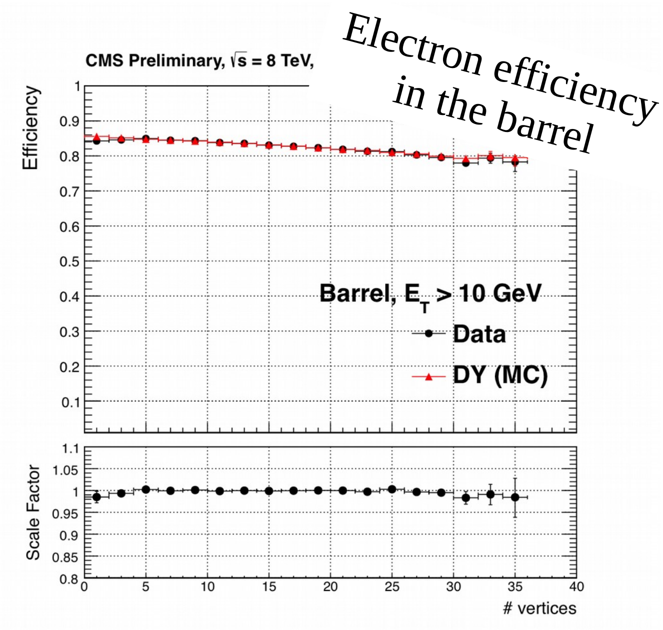


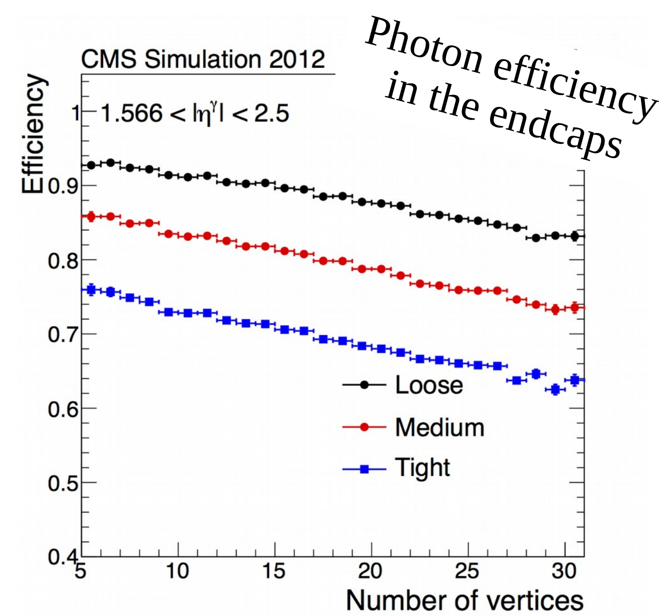
HF: switch to multi-anode PMTs and uTCA BE electronics

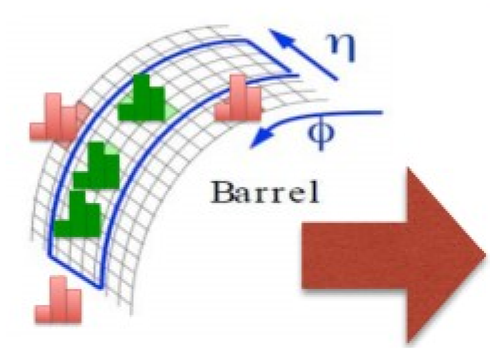
HBHE:
control modules replacement
and misc. repairs

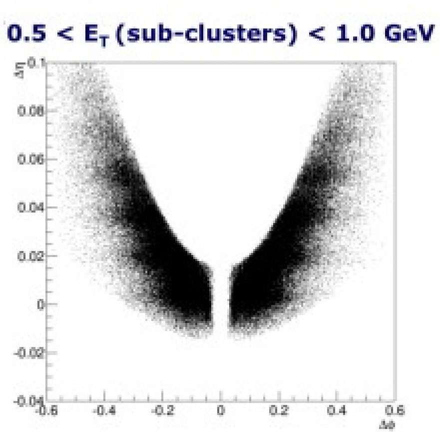
Electrons/photons reconstruction: PU effect

Electron and photon reconstruction is moderately affected by pileup.









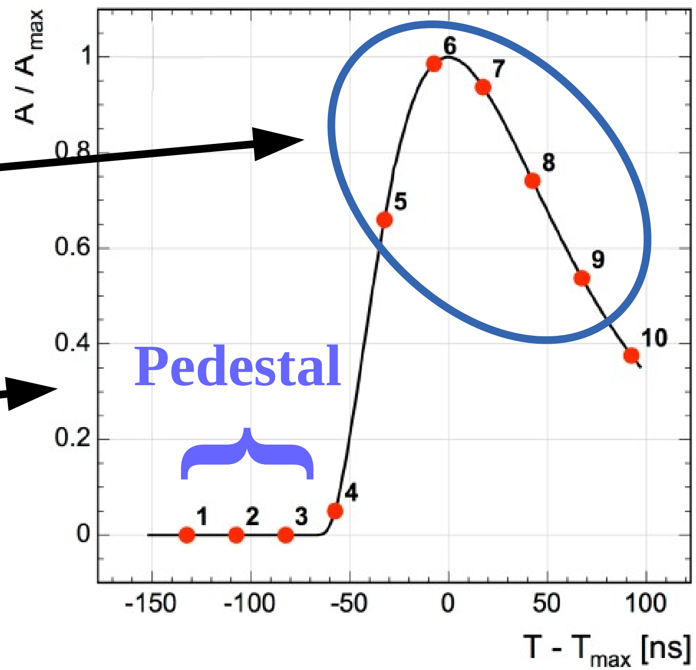
New clustering method using the precise shape of the expected deposit from photons from bremstrahlung.

Allows to maintain the established performance for electron reconstruction

Electrons/photons reconstruction: OOTPU

- Lead tungstate has fast scintillation response.
  - about 80% of the light emitted in 25 ns
  - **excellent time resolution** maintained through the signal processing
- Each pulse shape made of 10 samples

- **CMS is developing reconstruction methods resilient to out-of-time pileup.**
  - Different set of samples
    - Either shift by one sample
    - Either go from 5 to 1 sample
  - Alternative determination of the pedestal



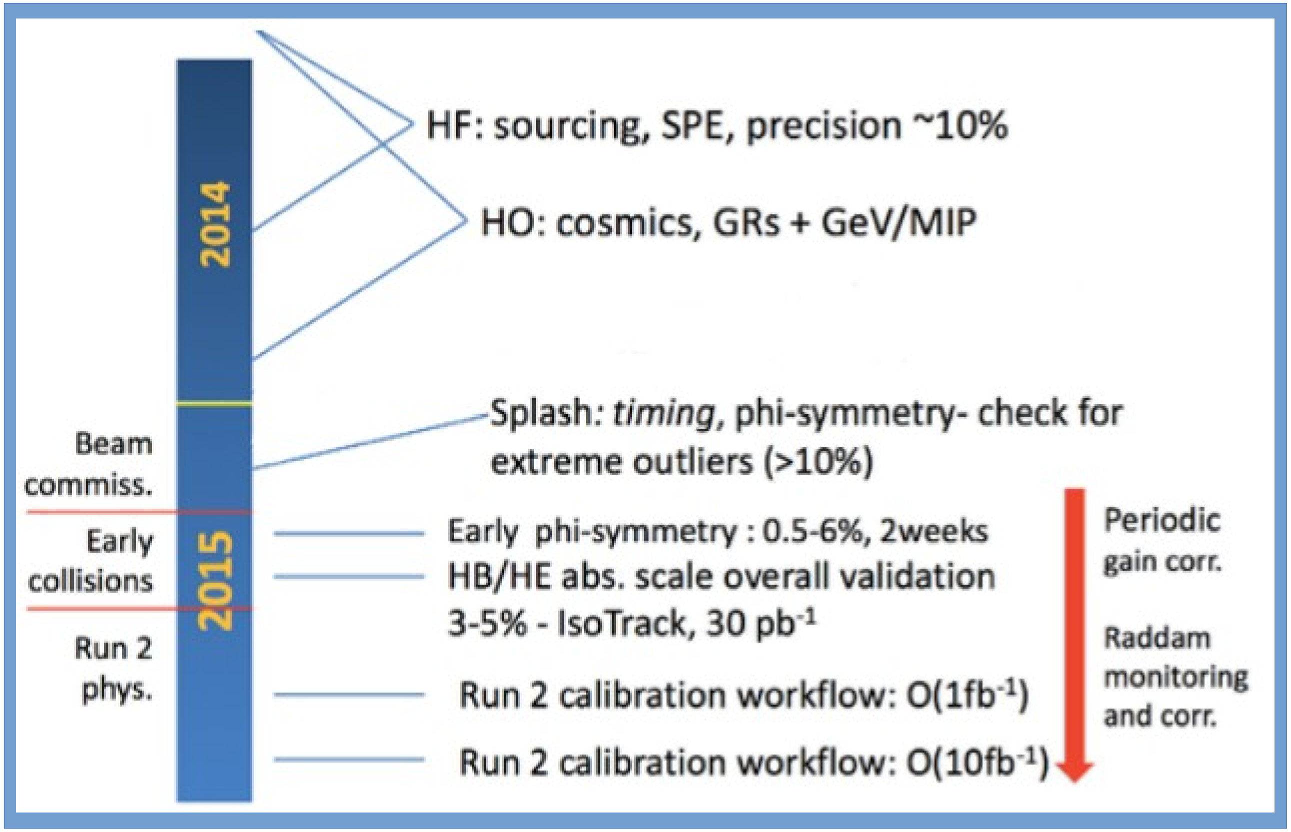
- Situation of HCAL is similar.

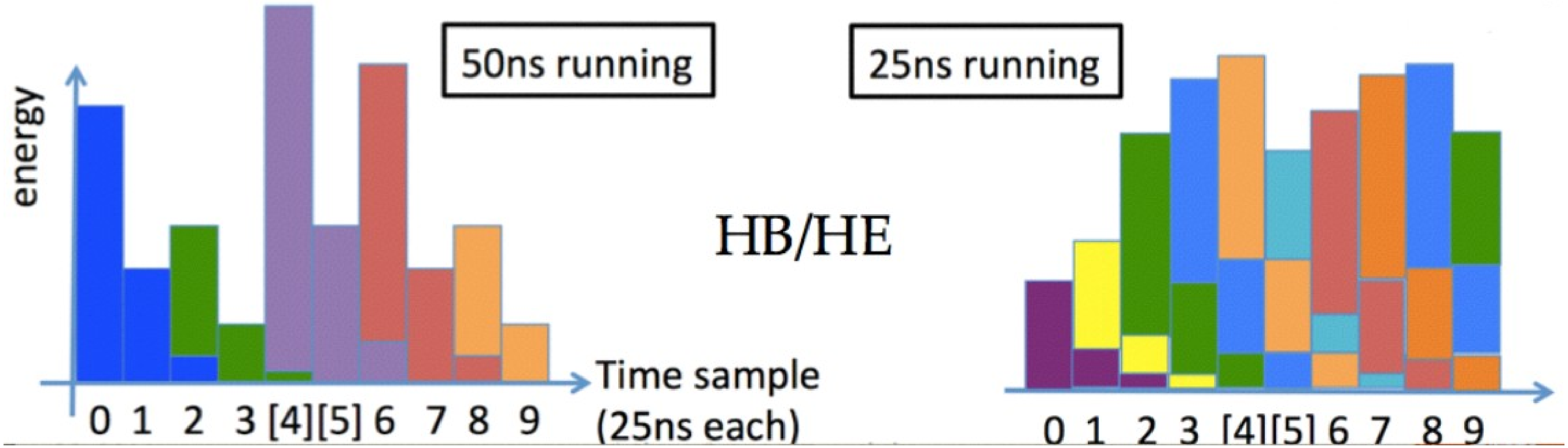
HCAL reconstruction

At 25 ns there is **significant leakage between adjacent Bxs,** resulting in additional neutral energy which can affect jet/MET reconstruction.

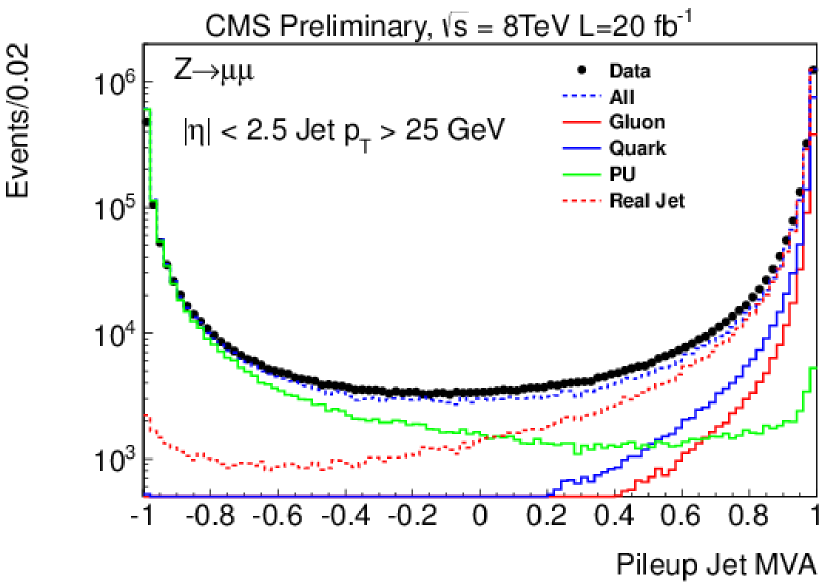
Strategy is to use a **parametrization of the pulse shape** to remove OOT PU energy.

Noise filtering needs to be updated as well to use OOT PU robust quantities.

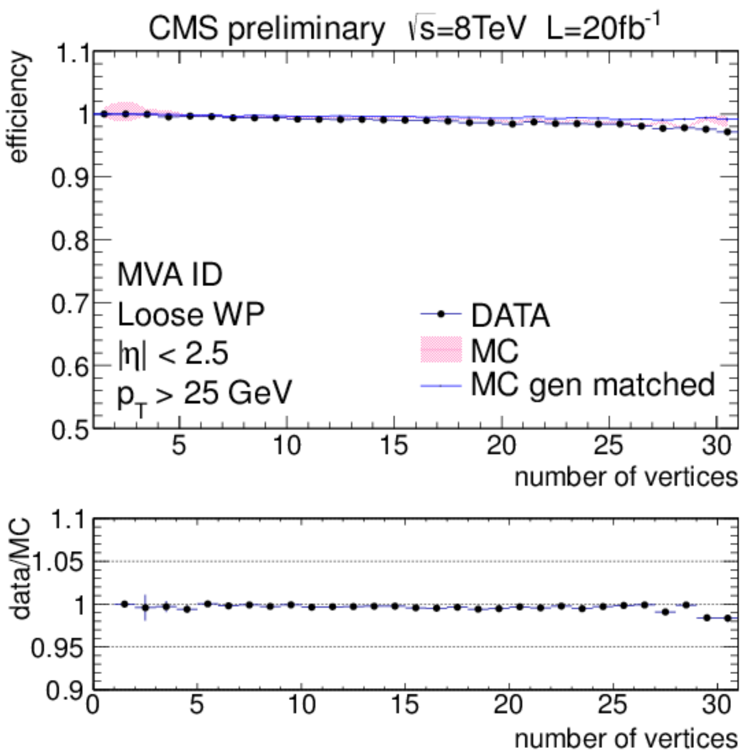


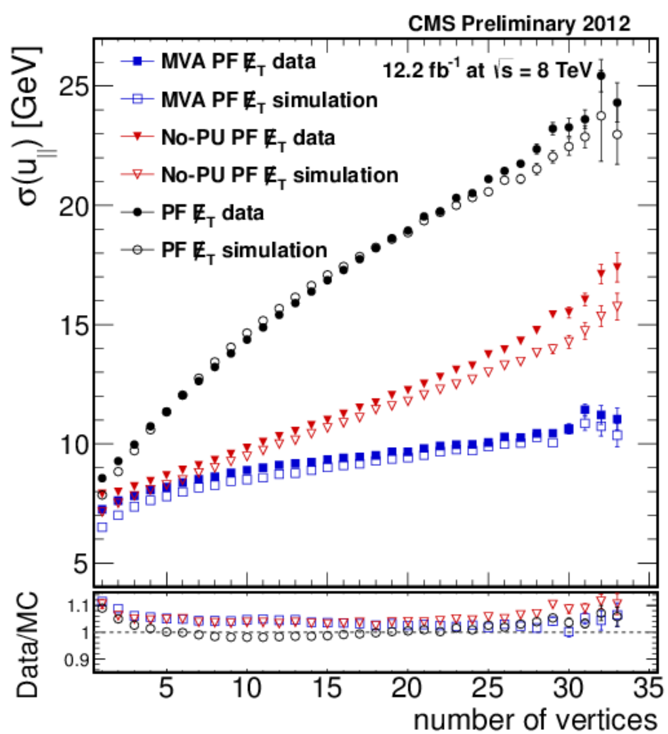


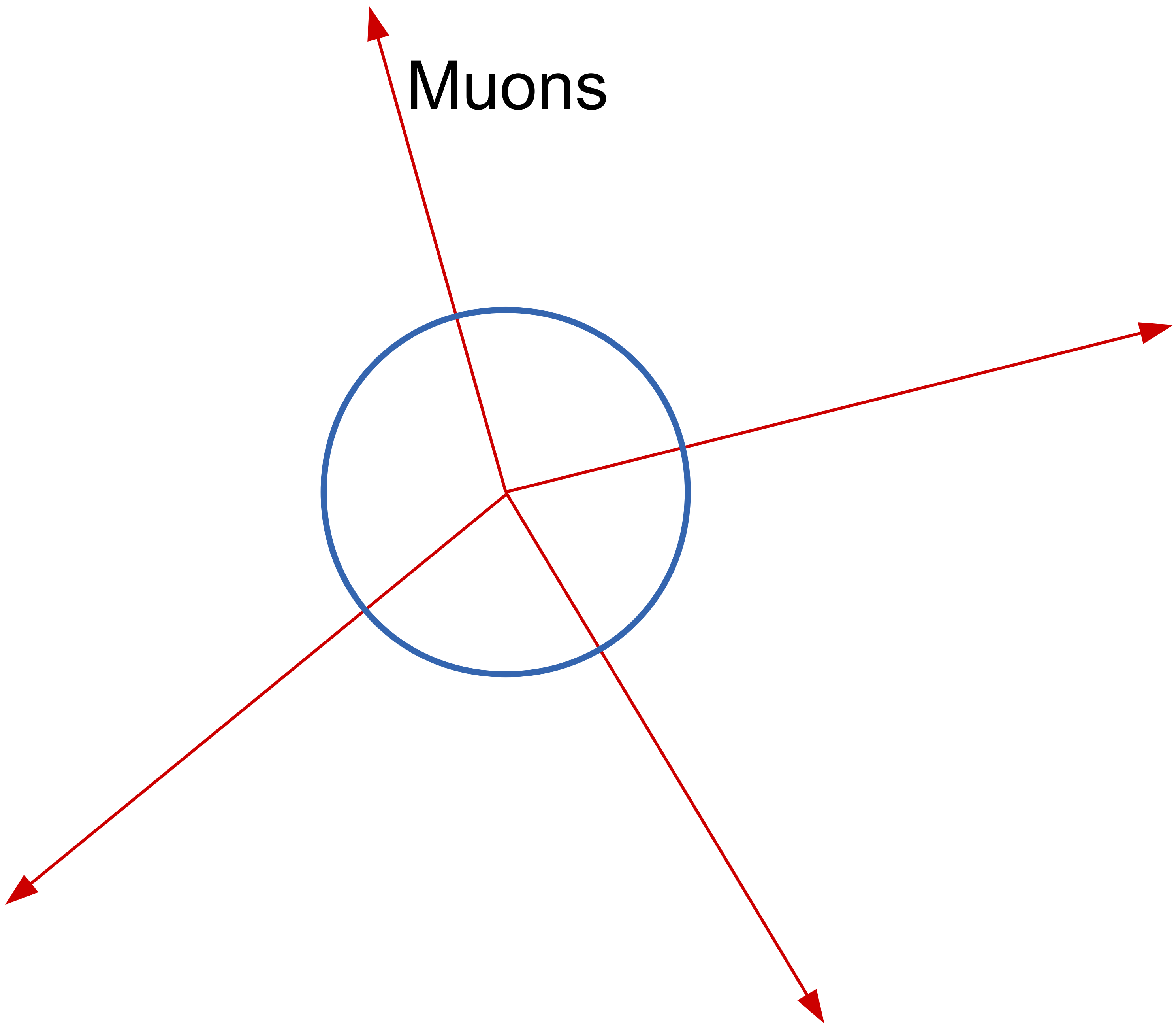
Jet/MET Performance



- Pileup identification is based on a MVA method already used during run 1
- Pileup-jet identification efficiency remains constant at high pileup
- MET resolution is only slightly affected by pileup when using the most advanced reconstruction method.



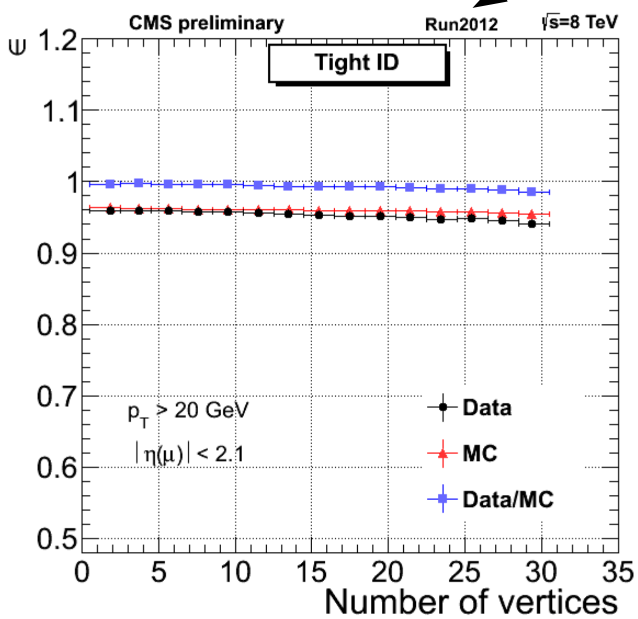


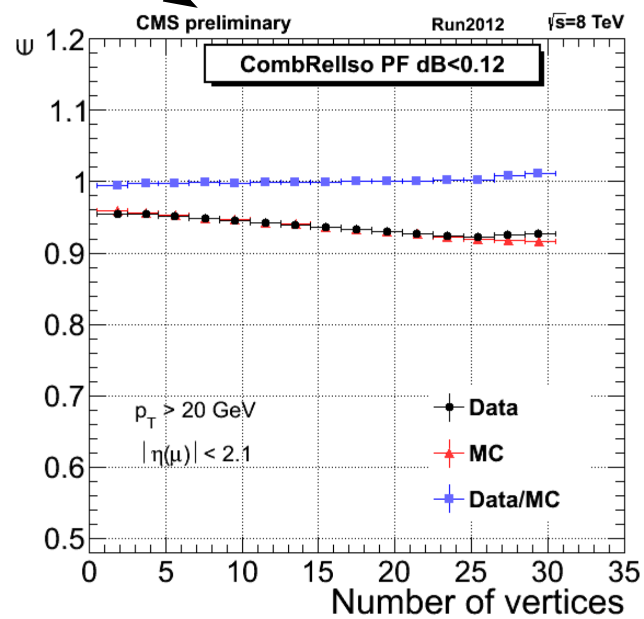

Muons

Pileup and muon efficiency

- Muon efficiency does not suffer significantly from pile-up

Muon Identification & Isolation efficiency

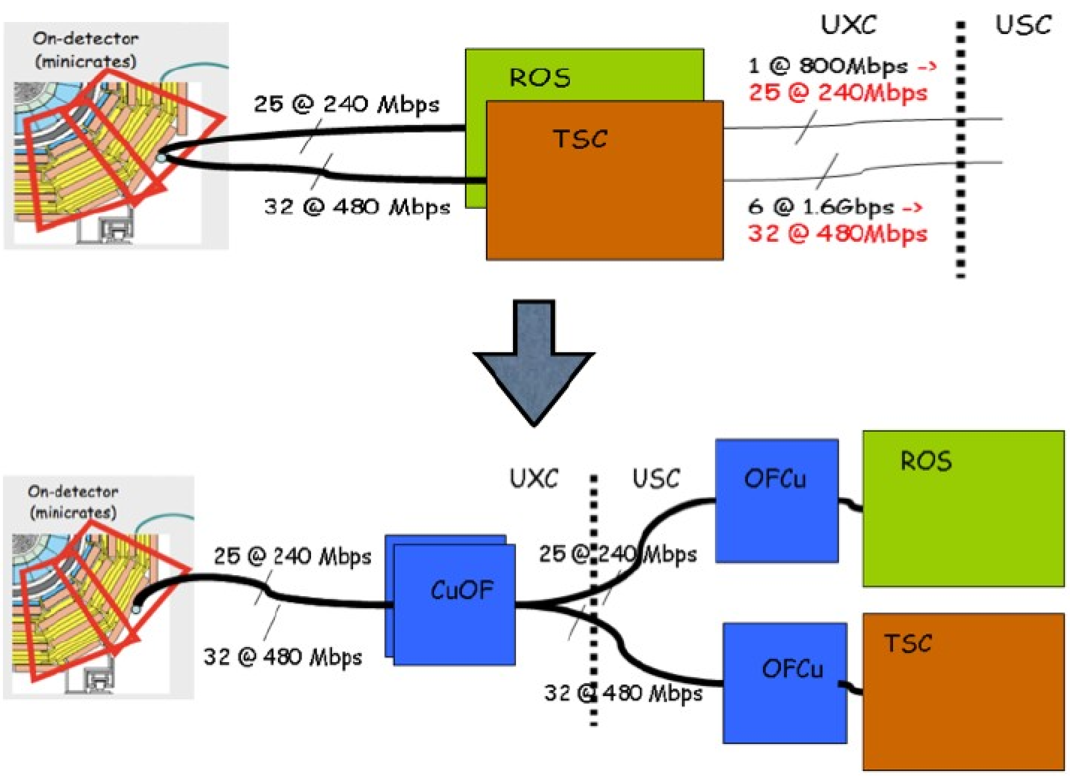




- Instead, the focus during LS1 has been on repairs to improve performance
  - Improvements targeting the trigger system
    - Implies a full recommissioning of the system in early 2015.

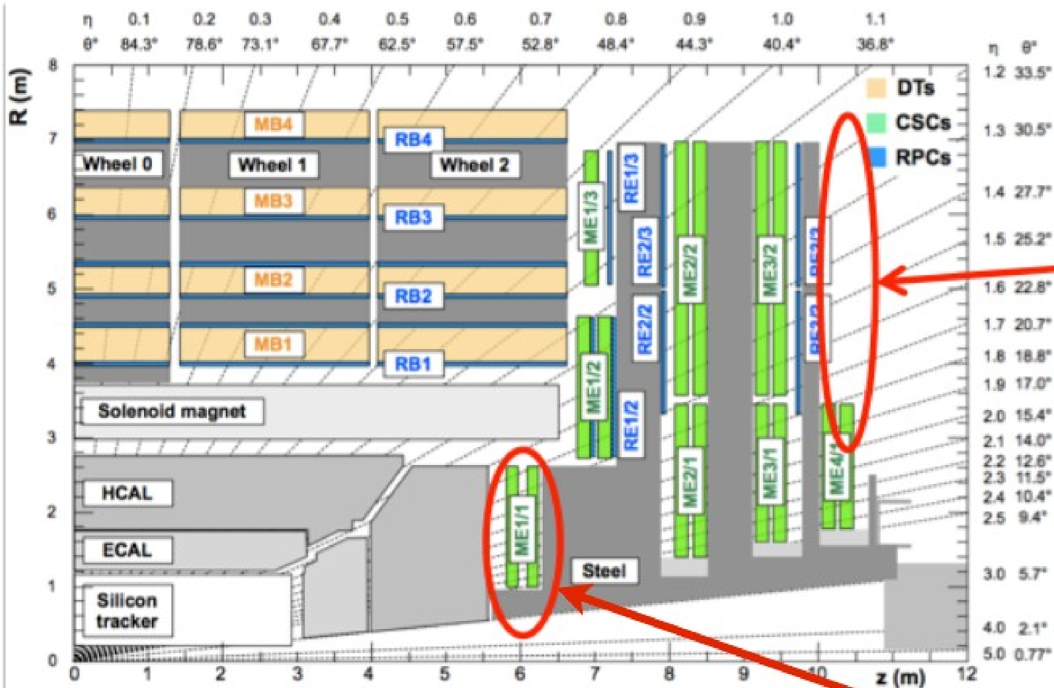
DT interventions during LS1

- Sector Collector relocation: move DT trigger & readout concentrator from UXC to USC
  - 20 new electronic crates, ~400 boards installed
  - New fibers from UXC to USC, full trigger information available in USC
  - In preparation for the Level-1 trigger upgrade in 2016 (TwinMux, new DT/RPC/HO concentrator)



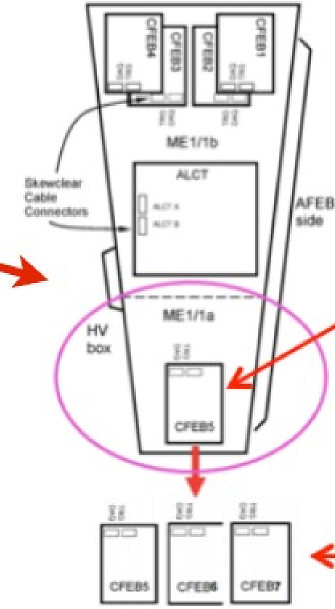
- Install FPGA version of theta-trigger-board in external wheels
  - Refurbish stock of Bunch-and-Track-Identifier ASIC spares
- Reparations on electronics/HV: ~3.5k channels recovered (178k channels total)

CSC interventions during LS1



ME42

ME11



Run 1

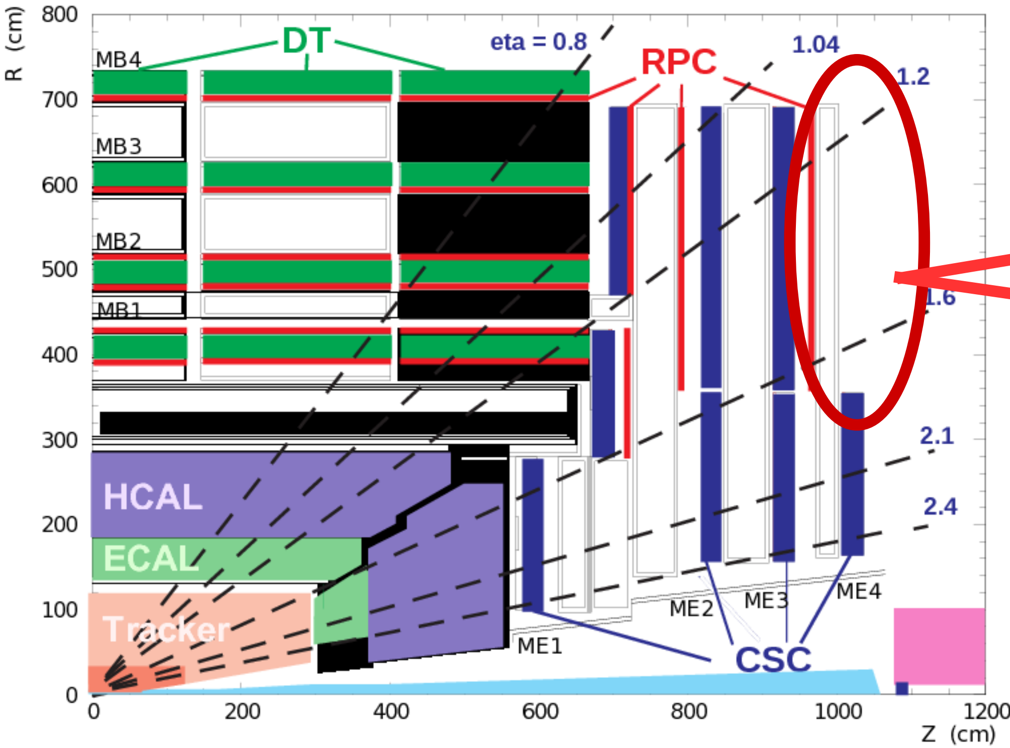
Run 2

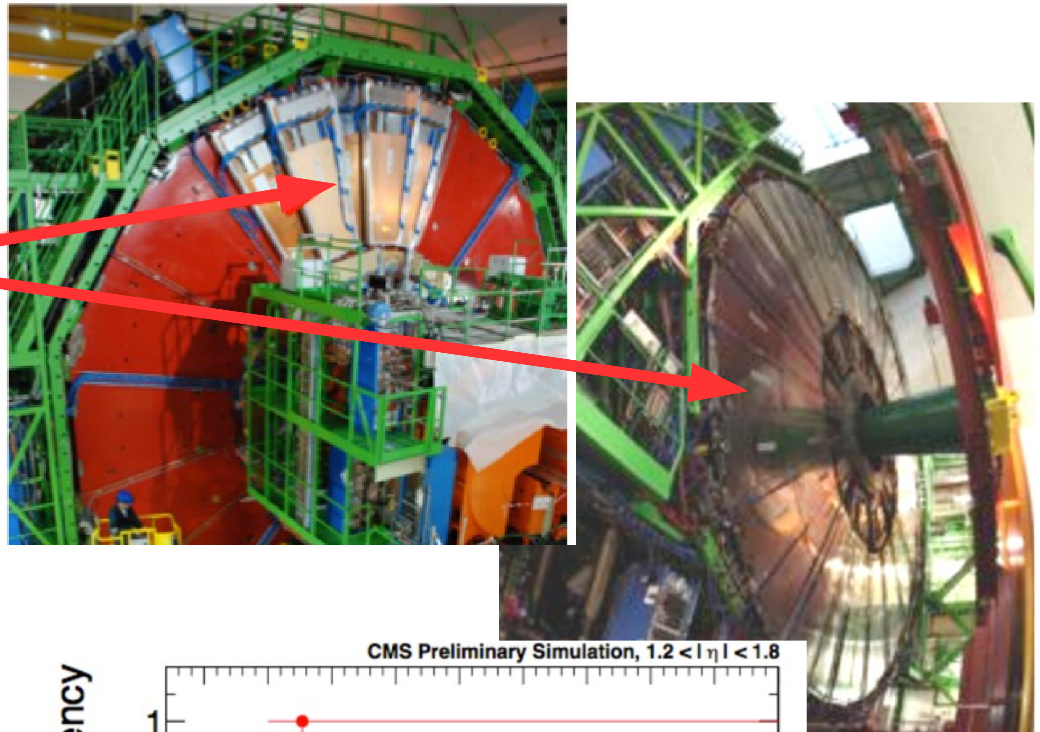
- Replacement of ME11 FE electronics
  - Improve trigger and pattern recognition in 2.1<|η|<2.4 (fine strip granularity of ME11a)
- ME42 construction and installation
  - Improve trigger performance of endcap muon system at L>1034 cm-2s-1 (better Pt resolution, fewer fakes)
- CSC reparations

RPC interventions during LS1

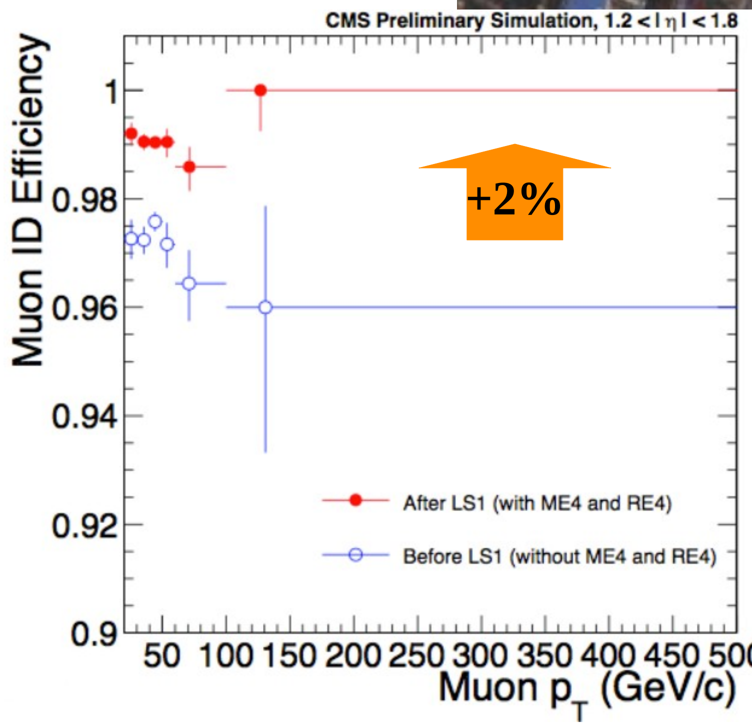
- Reparation campain (HV, LV, electronics): 99.5% working channels today
- Installation of RE4 chambers
  - 686 gaps produced in 22 months
  - Installation completed and commissioned

Completion of the forward muon system



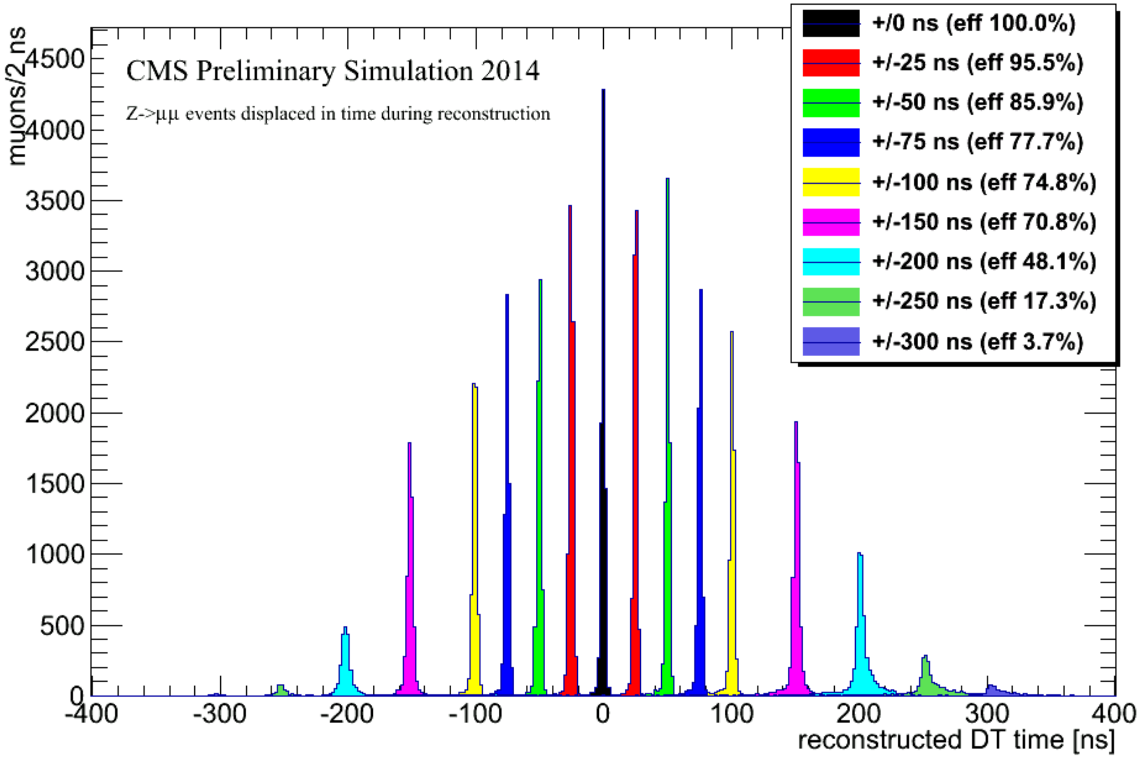


- The completion of the muon system in the forward region increases the muon id efficiency by ~2%.
- Redundancy also improves the fake rate.
- **Performance in run 2 will be better than in run 1.**



Impact of out-of-time pileup on muons

- The CMS muon detectors have an excellent time resolution.
- This makes the system very robust against out-of-time pileup.



<u>Example:</u>
Reconstructed time in the DT system (Barrel muon system)

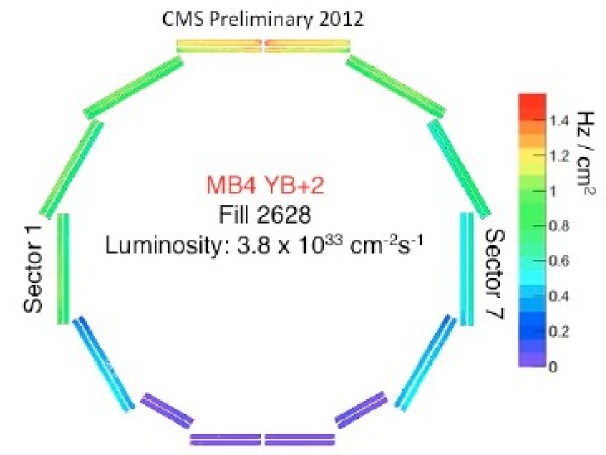
This does not use information from RPCs.

Muon time is considered as a free parameter in the track fit, as time impacts the position of reconstructed segments in the DT system.

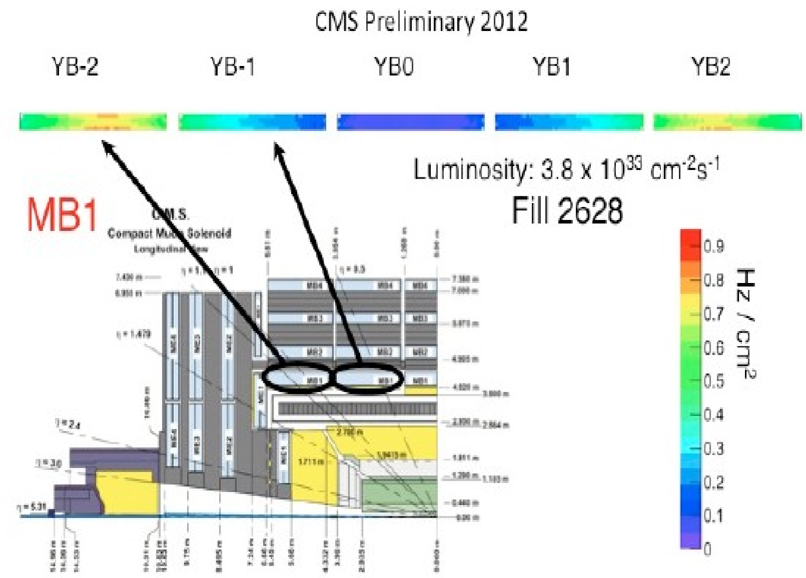
Until now: method used in pattern recognition
From 2015: method extended to final determination of track parameters.

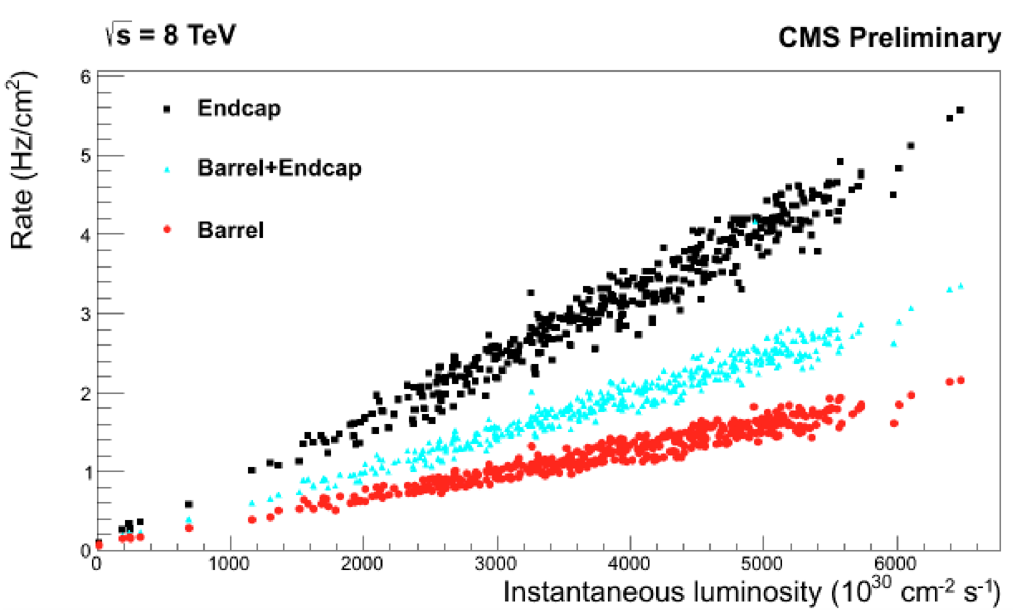
Background in the muon system

- The main sources of background in the muon system are:
  - **Photon-like background (neutron capture)**: neutrons populating the caverns
    - Highest rates in outer chambers and in top sectors (no shielding, far from the concrete floor)
  - **Prompt background**: mostly punchthrough/flythrough
    - Inner chambers, forward region
- Rate measurements in 2011 and 2012 show linear behavior
  - Extrapolation + safety factor + cross-check with simulations to prepare for higher luminosity runs



DT background rates



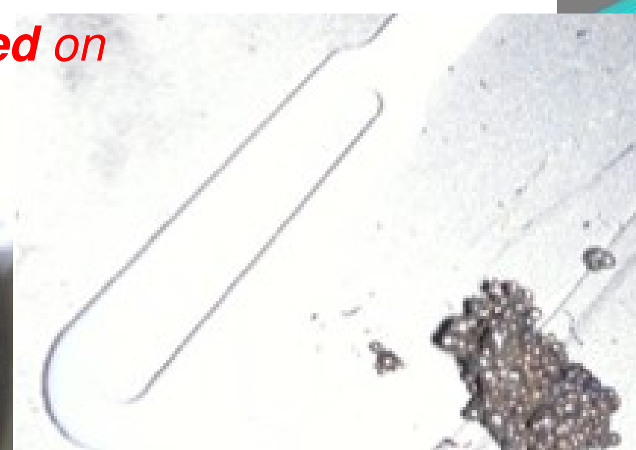


RPC backgroound rates vs luminosity

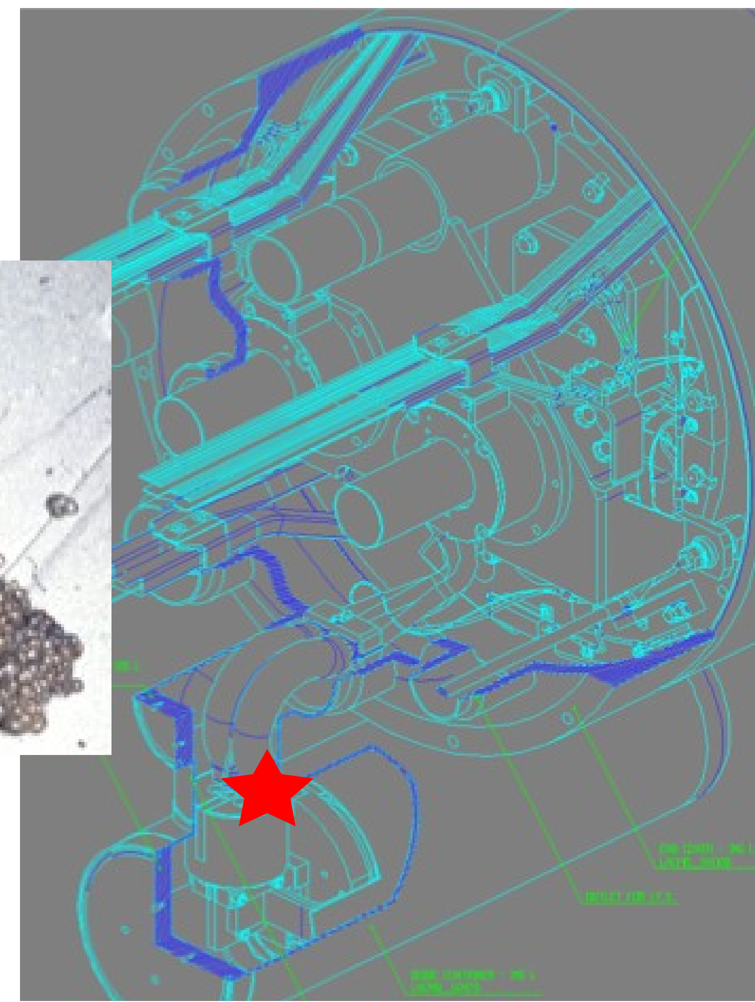
The first hurdle

A **short to ground** developed in sector 34 on March 21st, during current decay following a training quench.

- *Fault location identified on March 24th: R < 0.2 Ω at the anode diode lead of a main dipole: suspect a metallic debris.*
- *After tests in the lab, it was decided to try and vaporize/displace the debris through a capacitive discharge through the short.*
- *The short was successfully **removed** on*
- *March 30th, later confirmed by*
- *re-qualification.*



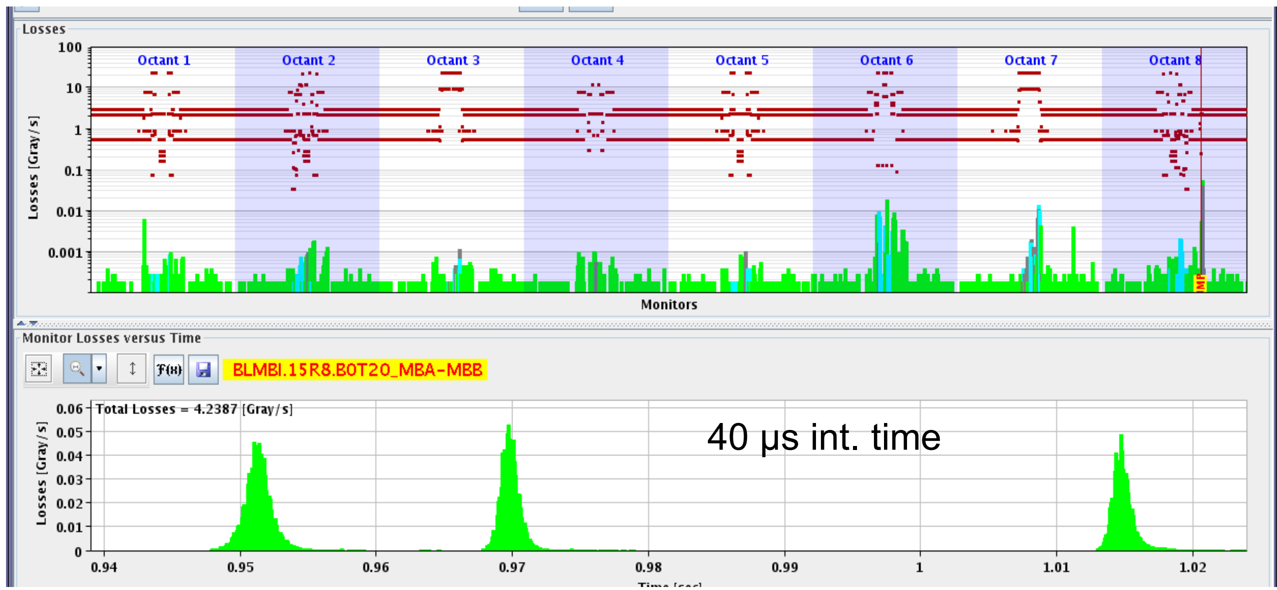
Courtesy A. Siemko



The second hurdle

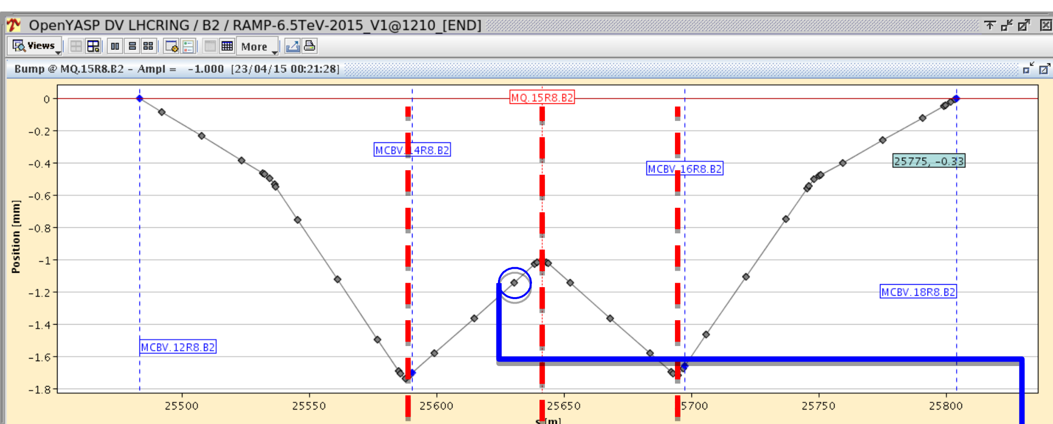
Various dump of **B2** triggered after ~10-15 min at flat top by BLMBI.15R8.B0T20_MBA-MBB. Suspected multiple **UFO** events.

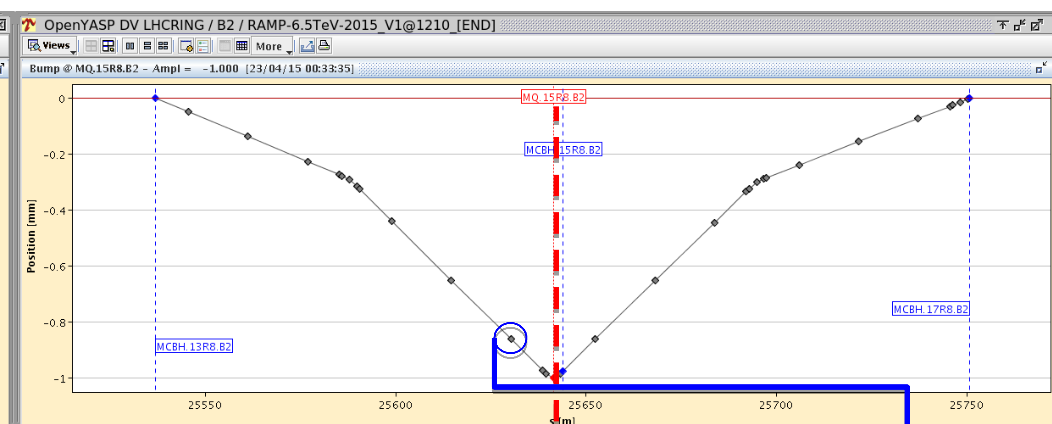
- Initially, aperture scans did not identified any apparent reduction.
- After the local warm up of the beam screen a reduction of aperture has been observed corresponding to an obstacle lying on the beam screen (**ULO**).



4-corrector bump in V plane

3-corrector bump in H plane





Q14 Q15 Q16

B15=1.14*Q15

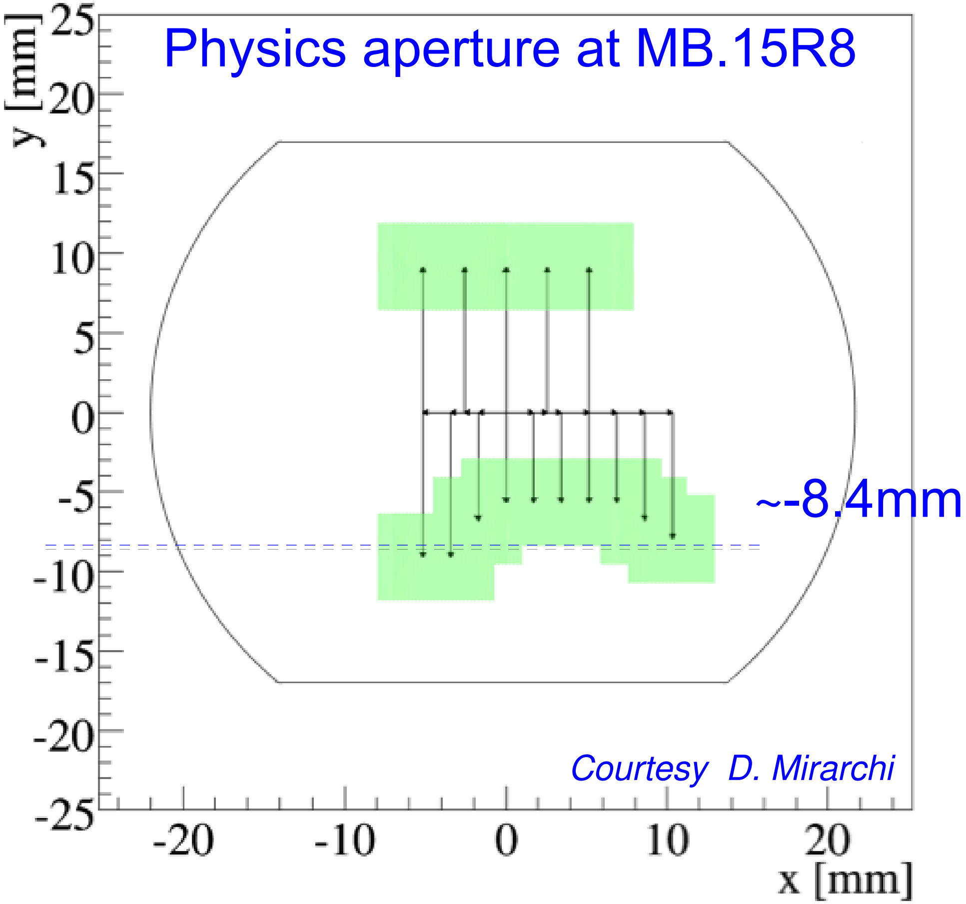
Q15

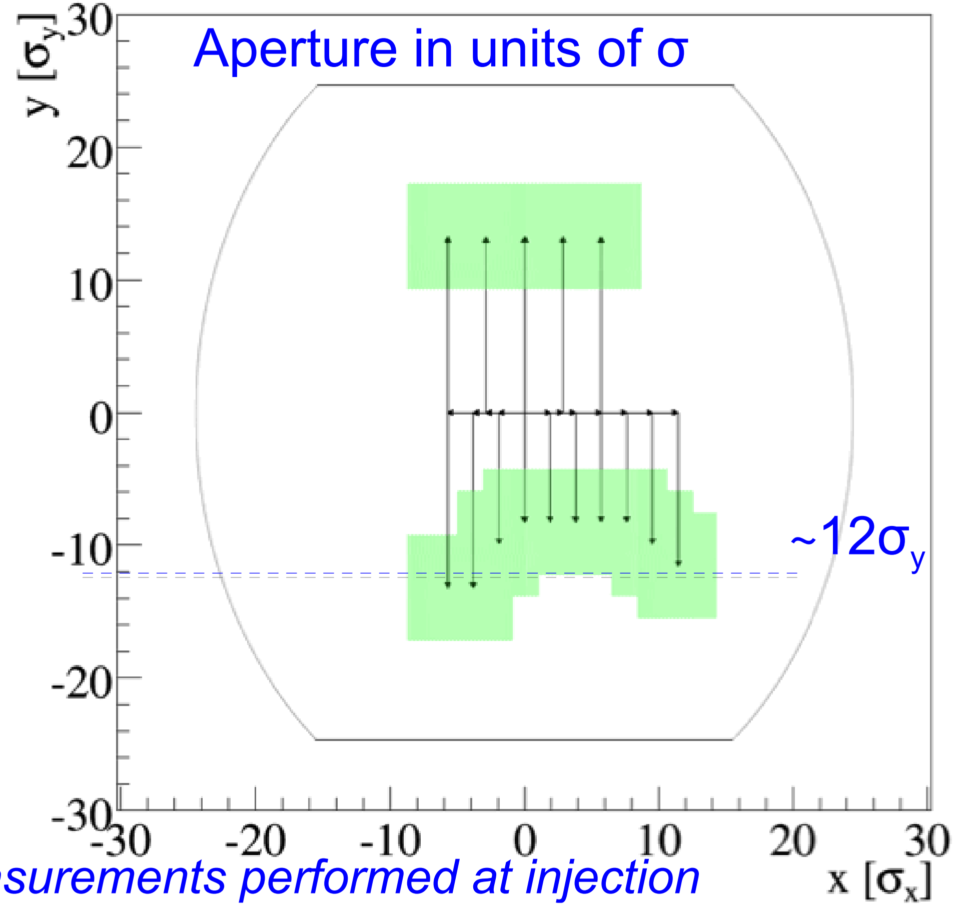
B15=0.86*Q15

Aperture measurements in 15R8.B2

- **Cut applied** with IR7-TCPs: $\mathbf{4\sigma_y}$ **and** $\mathbf{3\sigma_x}$
- **Step of 2-3mm** for **H** bumps, **1mm** for **V** bumps (~1.4σ_y at MB15R8)

Safe aperture (last step before losses on MB15R8)



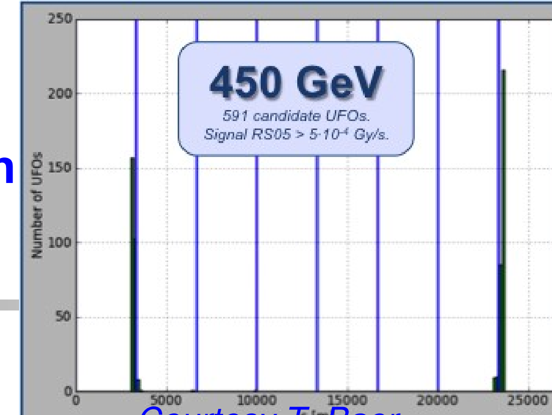


Measurements performed at injection

The aperture restriction seems to get worse between injection and top energy (and sometimes even at injection)! Current strategy: continue beam commissioning, monitor the behaviour of the ULO, and check with higher intensity beams.

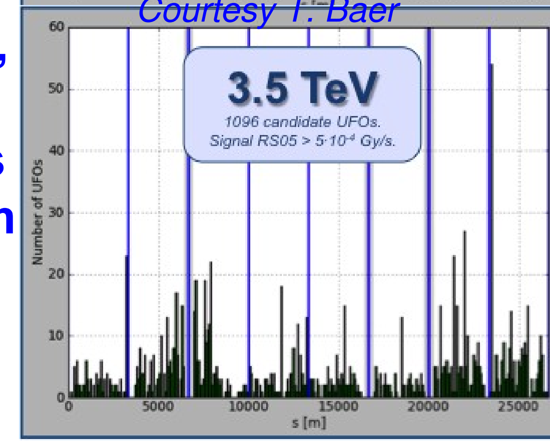
UFOs

At injection energy UFOs concentrate in MKI region.



Courtesy T. Baer

At top energy, the UFOs distribution is rather uniform



- Sudden local losses recorded
- No quench, but preventive dumps
- Rise time around of the order 1 ms.
- Possible explanation: dust particles falling into beam creating scatter losses and showers propagating downstream
- Distributed around the ring – arcs, inner triplets, IRs