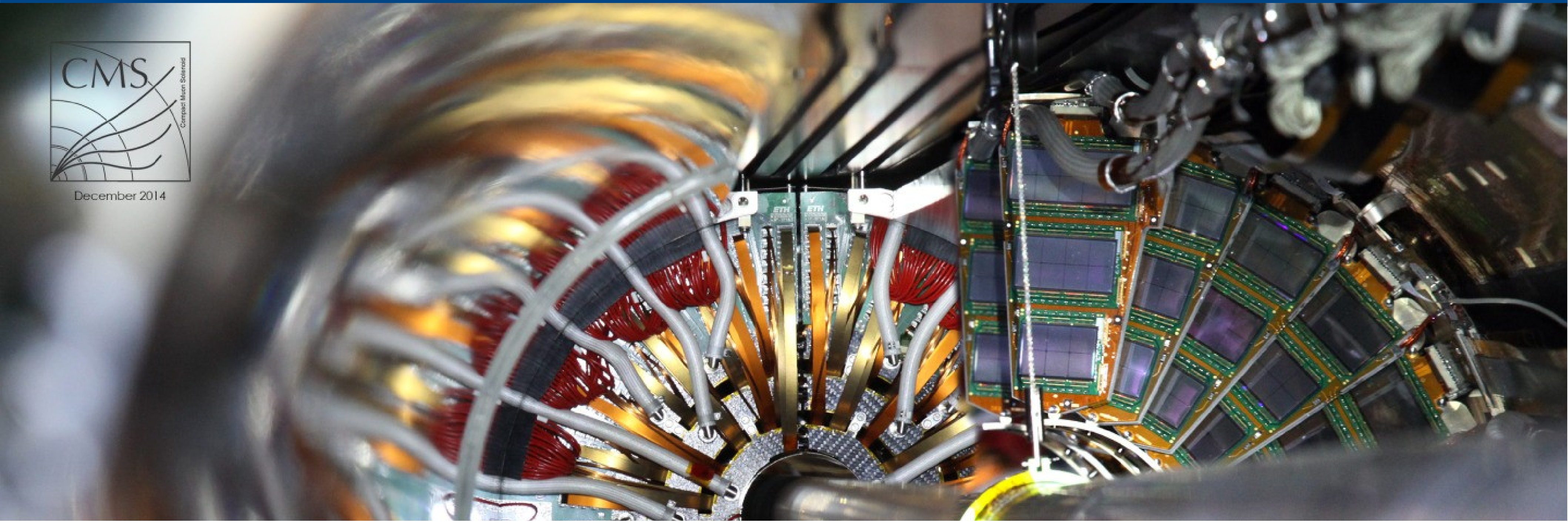
CMS: en route for Run2



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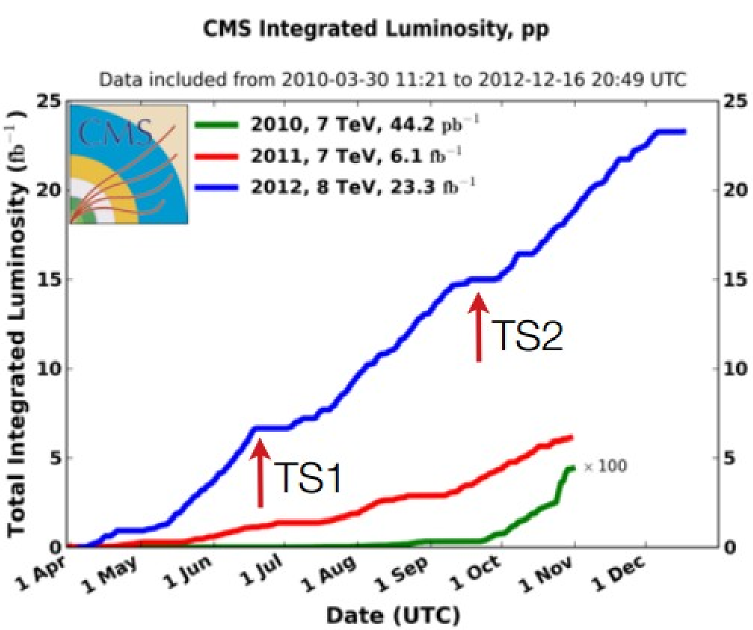
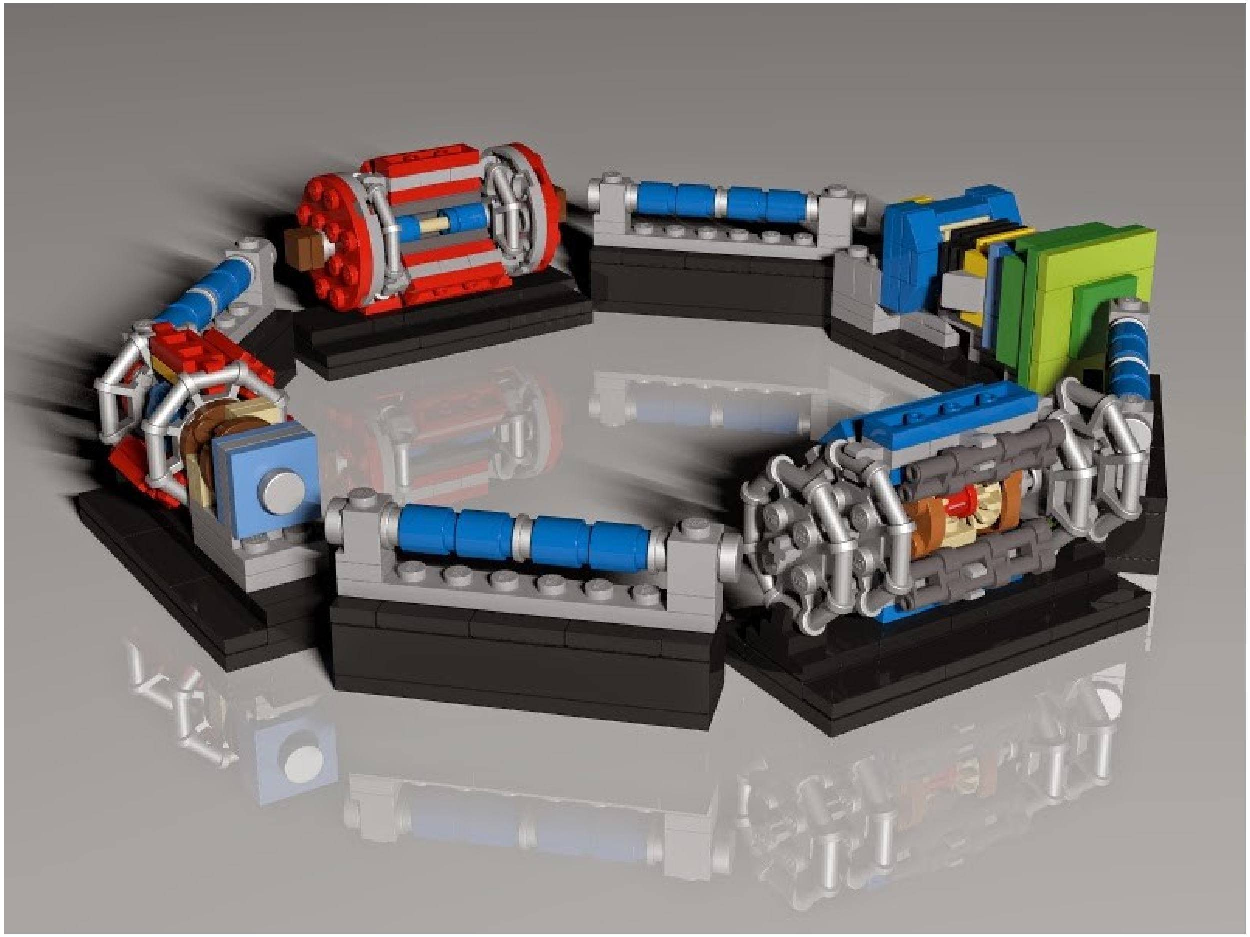
Université catholique de Louvain
Center for Cosmology, Particle Physics
and Phenomenology (CP3)

Friday, 13 March 2015

The LHC...

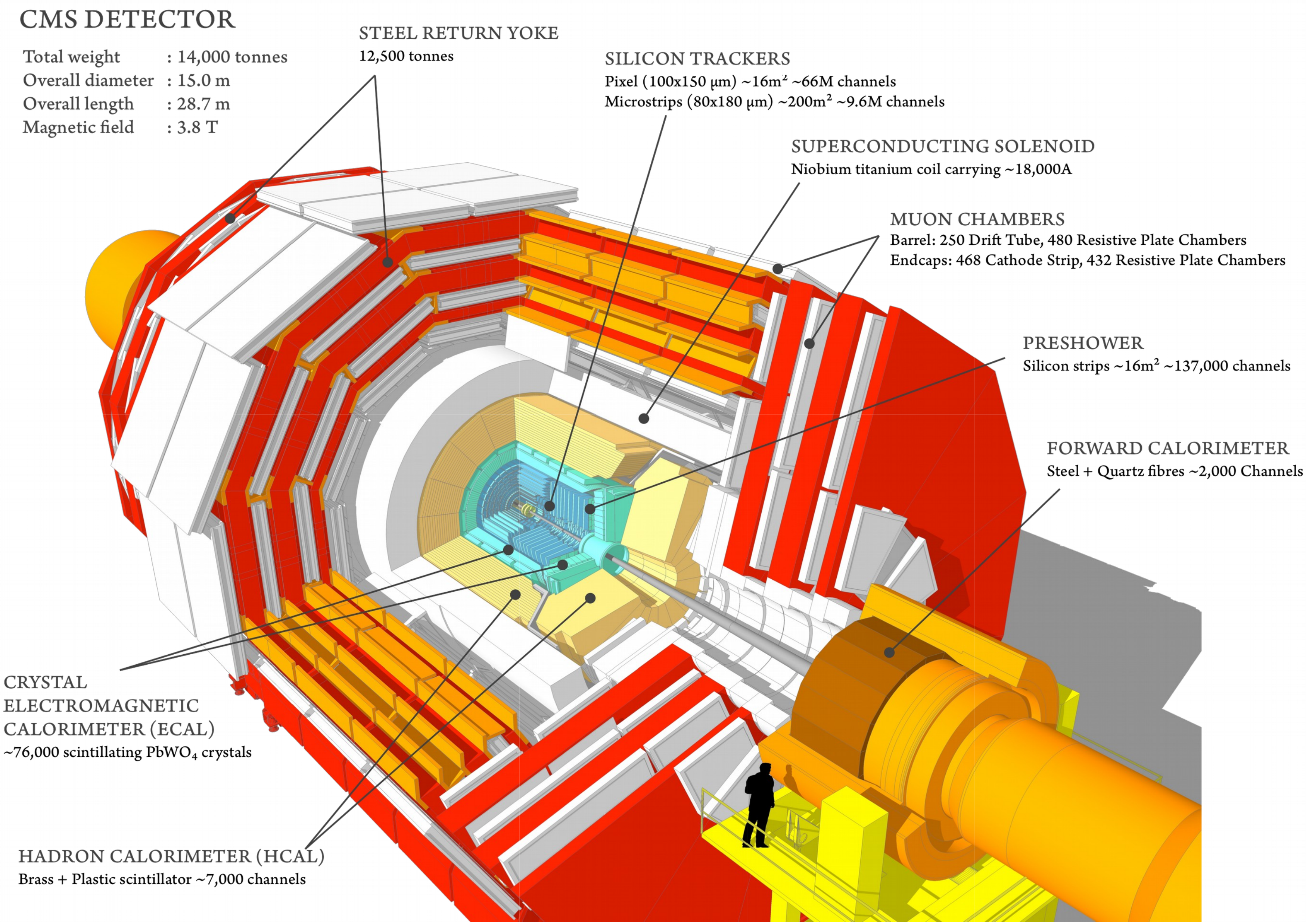
- LHC started to deliver p-p collision in 2010
  - √s =7/8 TeV
  - Peak instantaneous luminosity: ~7.7 x 1033 cm-2 s-1
  - 50 ns bunch crossing (BX) spacing
  - Up to 21 average pile up interactions





- Data taking interrupted by Technical Stops (TS)
  - Time used for detector calibrations
- Long shutdown (LS1) started in 2013
  - Run 2 planned to start in the coming weeks

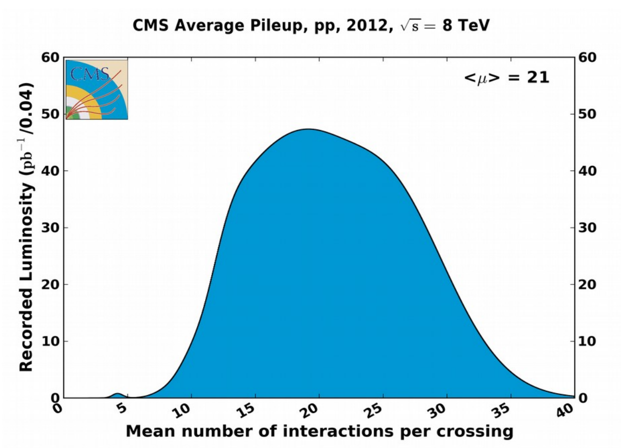
The CMS detector



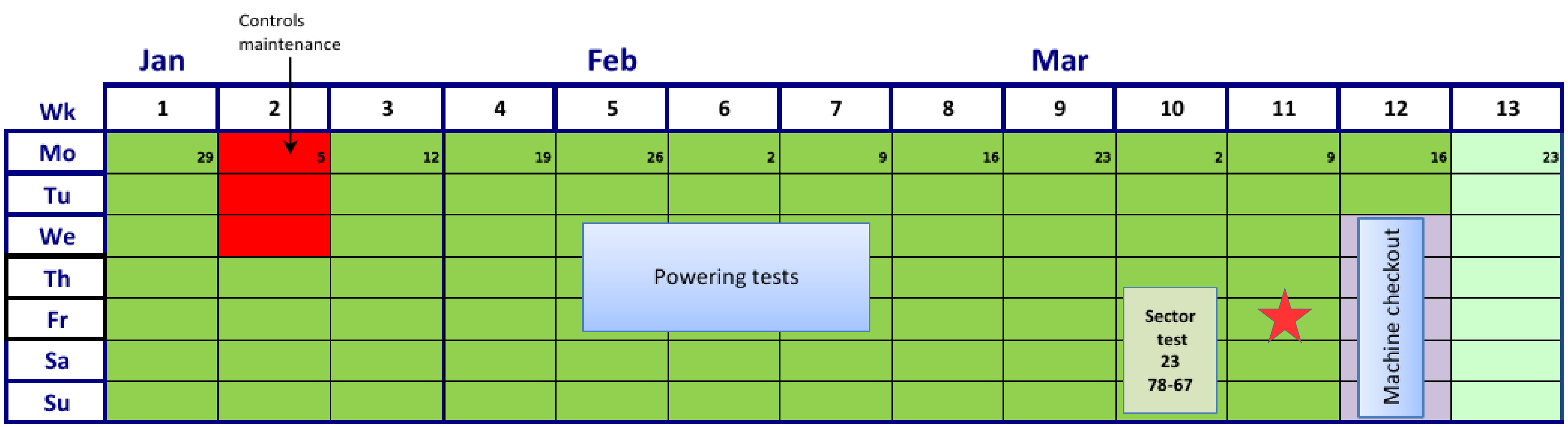
Challenges

- 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

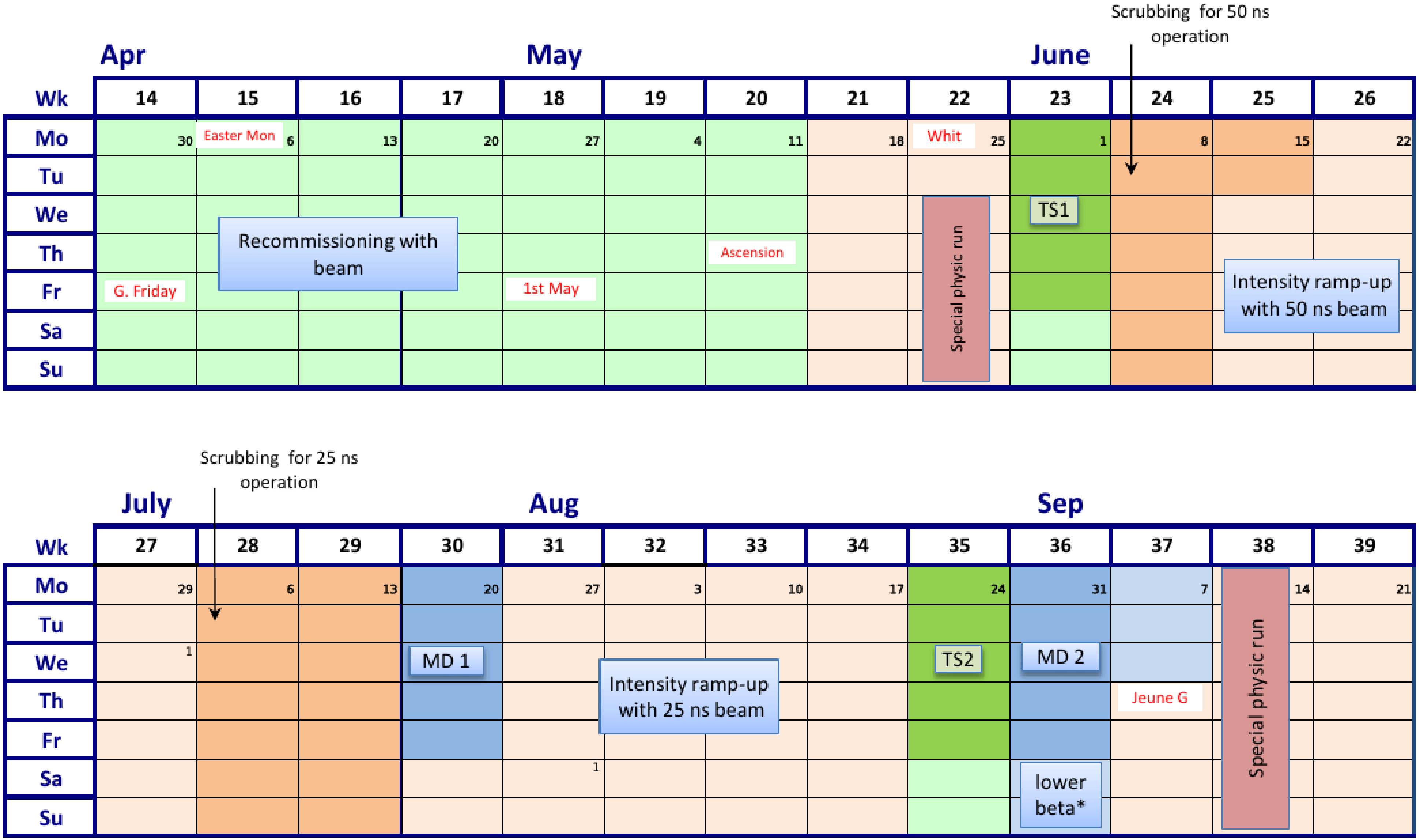
} up to <μ> ~ 50 (factor ~2 higher than Run 1)



- The **early days** of run 2 will be challenging in many ways
  - Recommissioning of the detectors after (more than) two years
  - Machine conditions will change on a daily basis
  - Physics expectations will be high

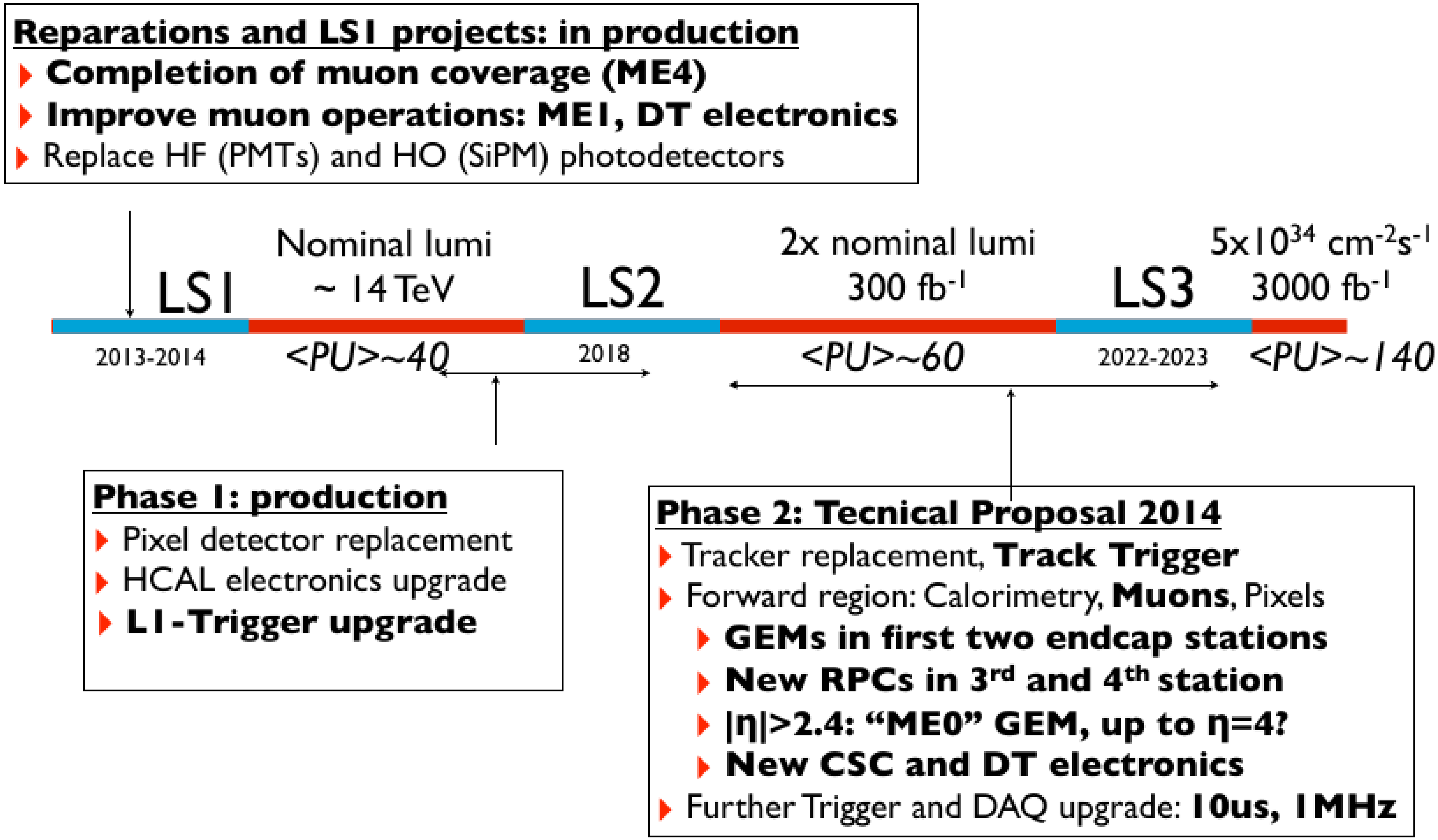


Machine schedule

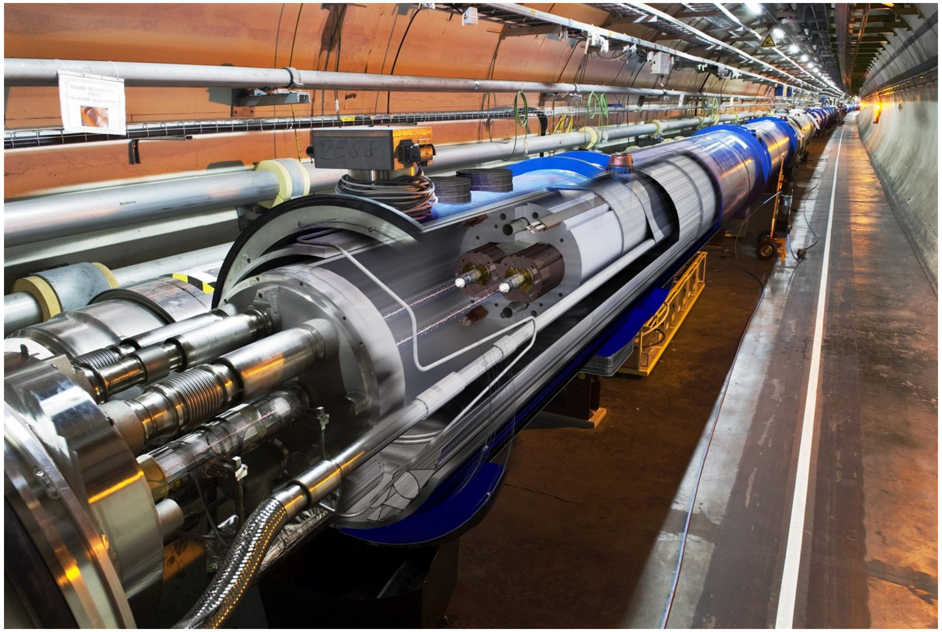


Challenges

- 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)



LHC

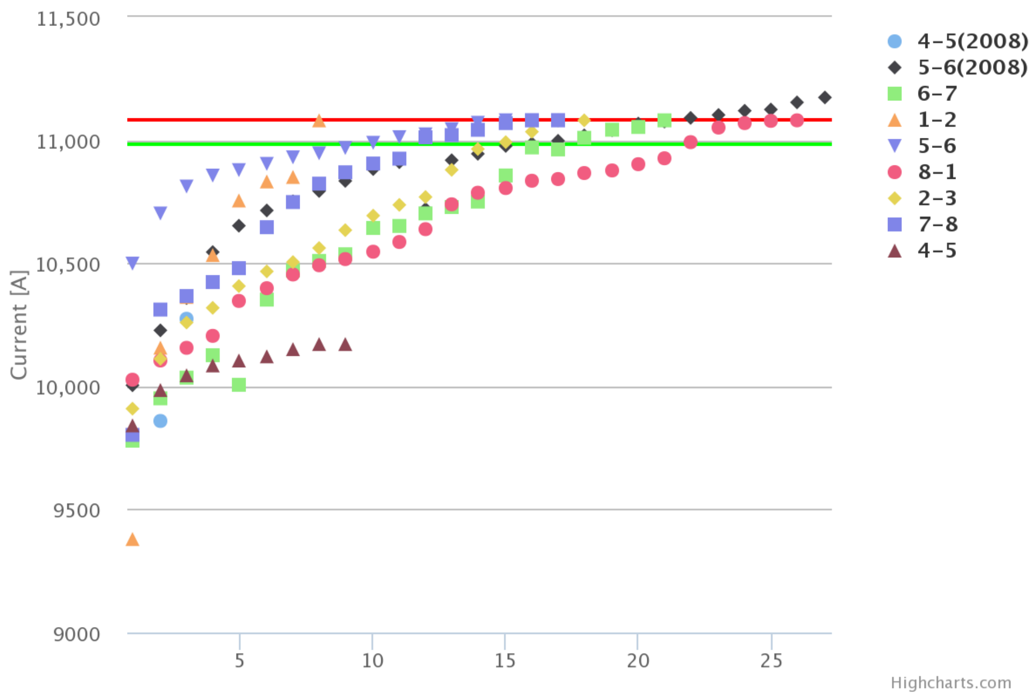


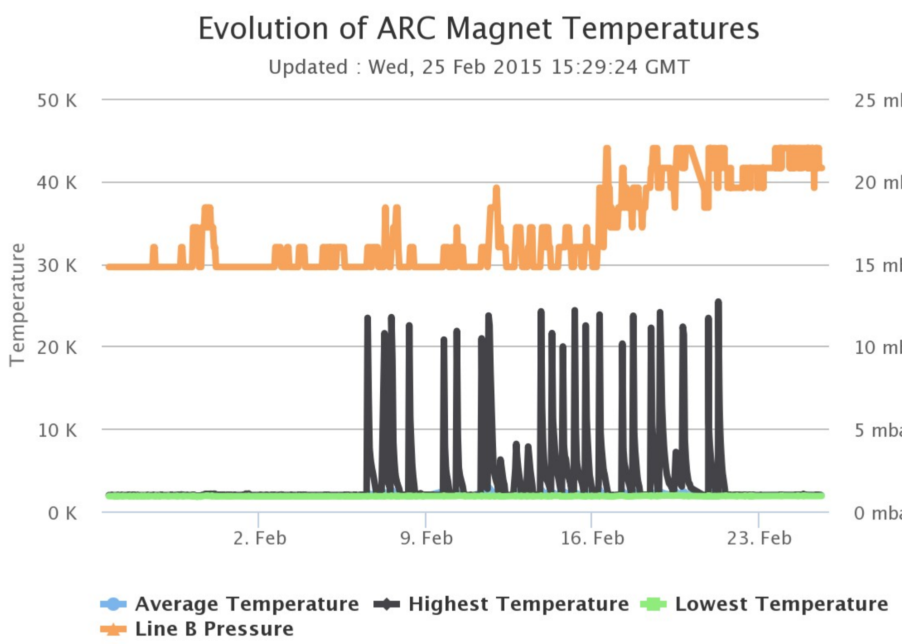
Machine parameters

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

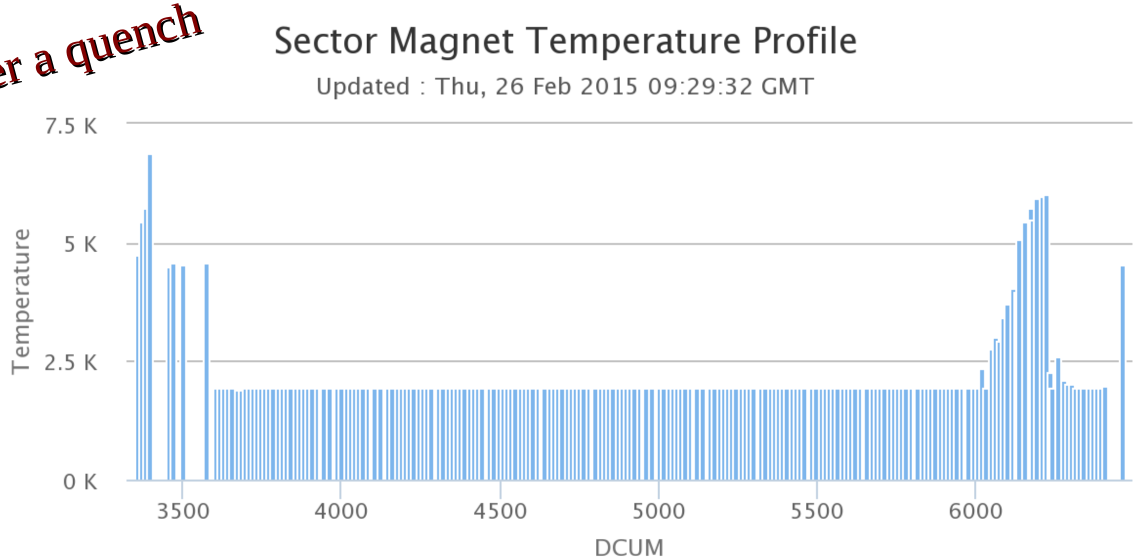
Parameter	50 ns	25ns phase 1	25ns phase 2
Energy [TeV]	6.5 TeV	6.5 TeV	6.5 TeV
β* (1/2/5/8) [m]	0.8 / 10 / 0.8 / 3	0.8 / 10 / 0.8 / 3	0.4 / 10 / 0.4 / 3
Half X-angle (1/2/5/8) [μrad]	-145 / 120 / 145 / -250	-145 / 120 / 145 / -250	-155 / 120 / 155 / -150
Number of colliding bunches (1/5)	1368	2592	2592
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

Power tests



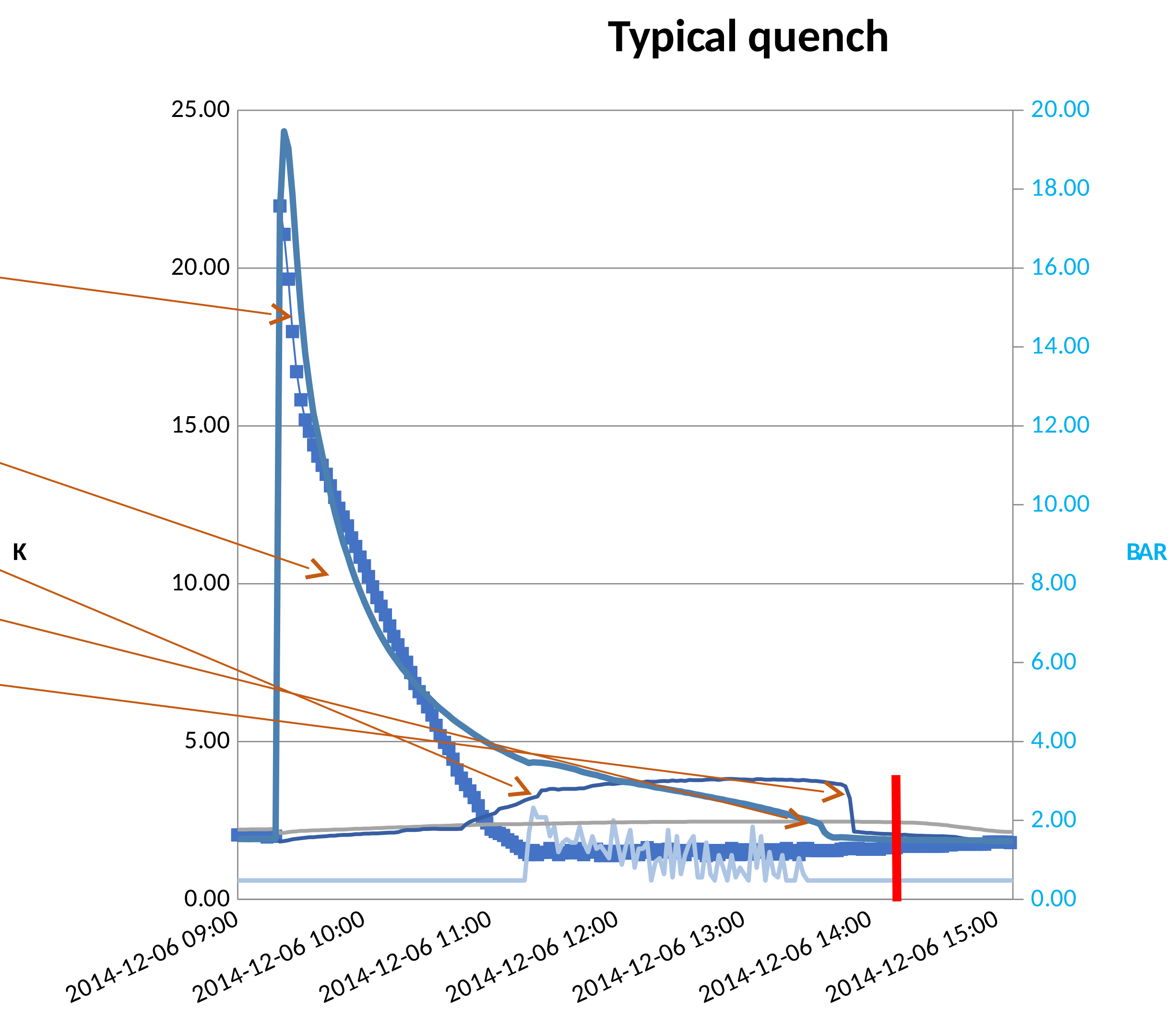


Example...
a couple of hours after a quench

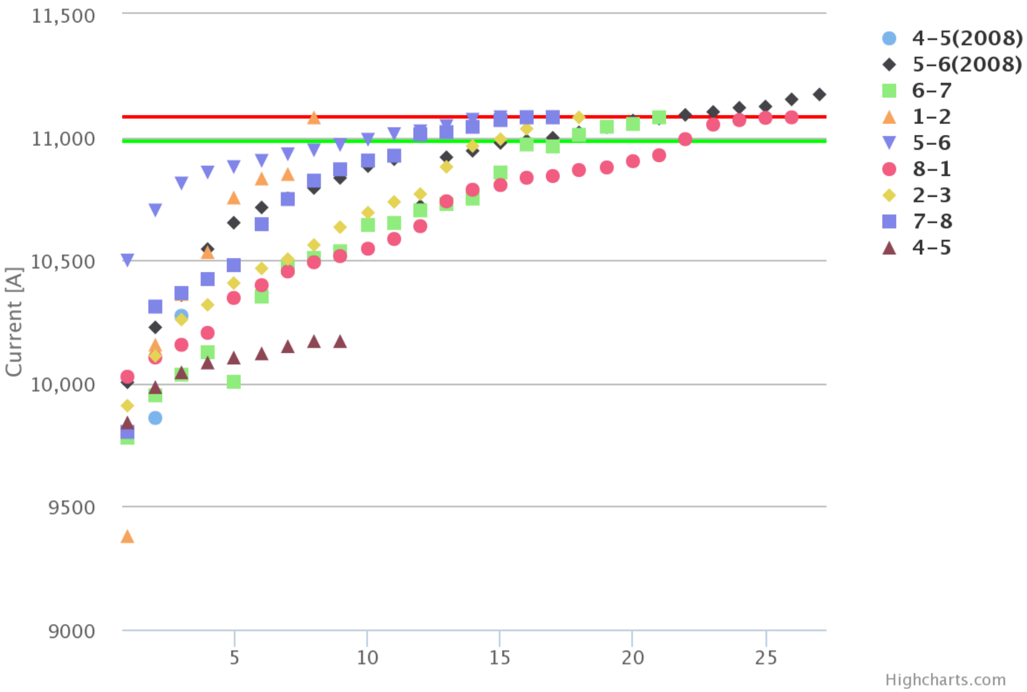


MB training from the cryogenic point of view

- Temperature And Pressure increase
- Pressurised Helium release
- Cell cooling down and pressure decrease
- Refilling of the cell with 5 K supercritical Helium
- Magnets temperature <= 2.17 K
- Line N temperature <= 2.17
- Cryo ok for next Quench



Power tests



Latest Quenches

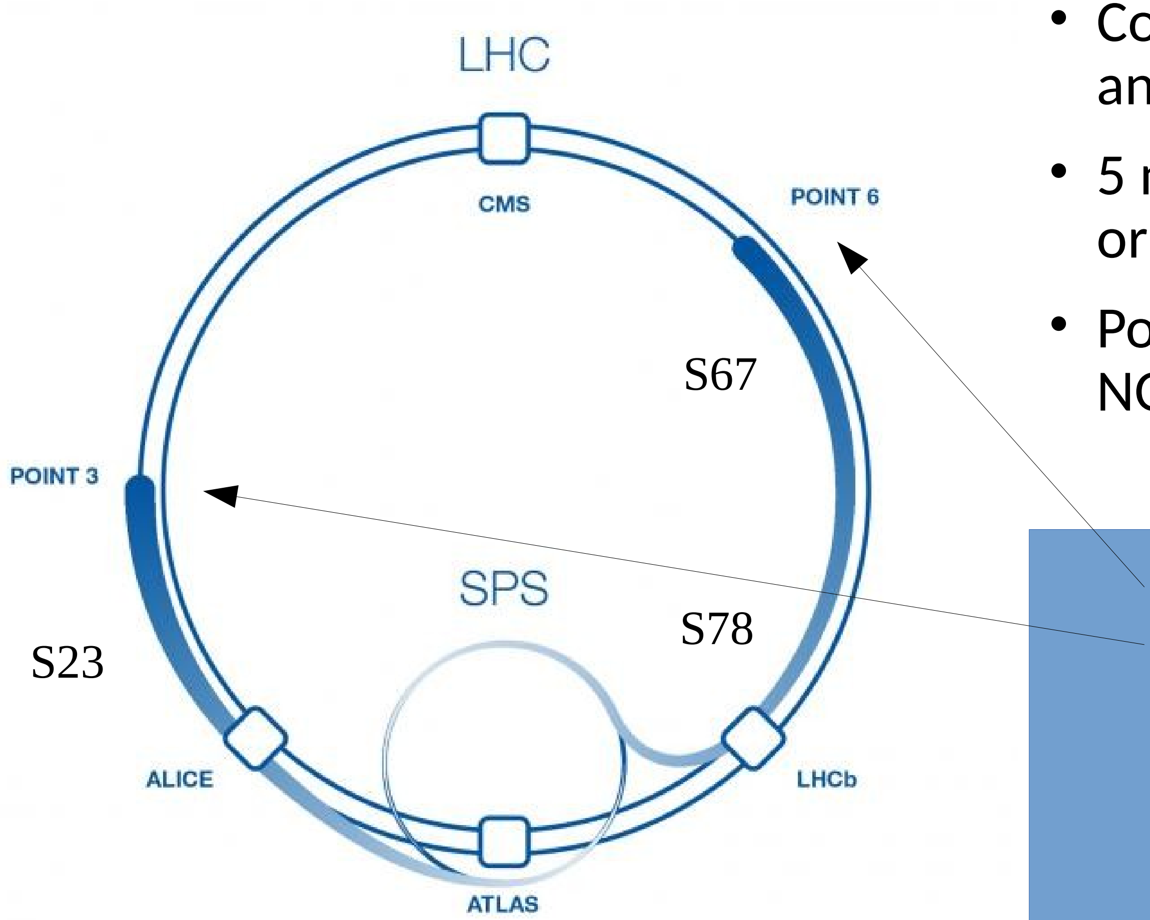
Sector	MAX I [A]	MAX E [TeV]	Date	N of Quenches
1-2	11080	6.55	19-01-2015	7
2-3	11080	6.55	28-02-2015	17
3-4	0	-	-	0
4-5	10171	6.02	13-03-2015	9
5-6	11080	6.55	08-02-2015	16
6-7	11080	6.55	10-12-2014	20
7-8	11080	6.55	12-03-2015	16
8-1	11080	6.55	22-02-2015	25

The target for 2015 is 10980 A <=> 6.5 TeV, with 100 A of margin for stable operation. Once the circuit has reached 11080 A, the training quench campaign is closed in the concerned sector.

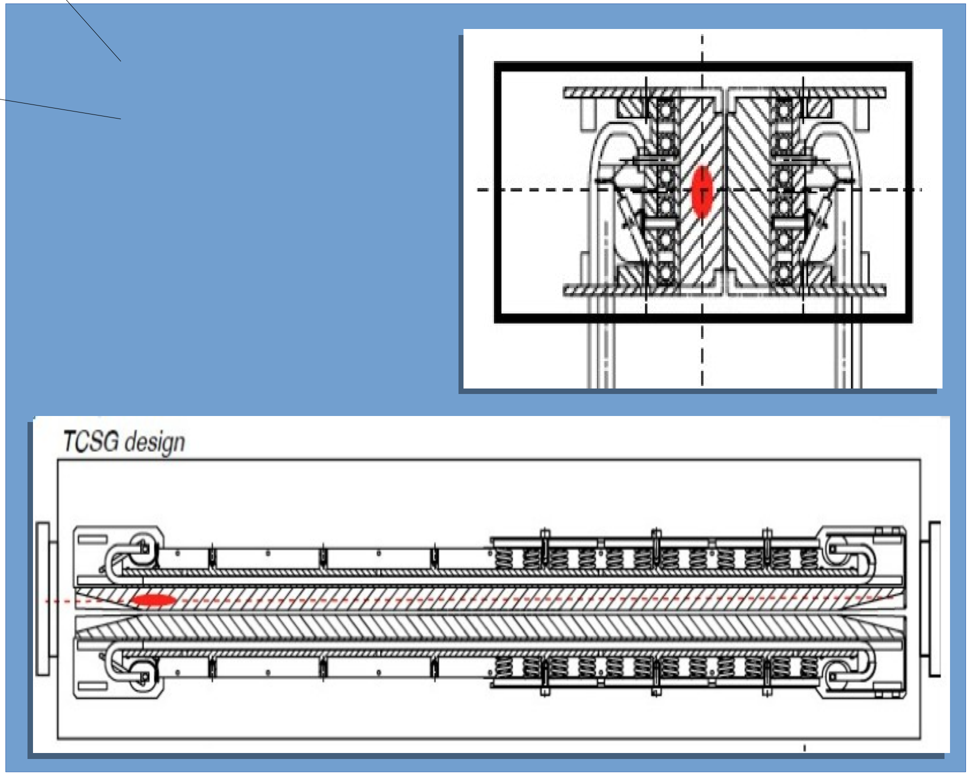
Circuit	Status	#M Firm 1	#M Firm 2	#M Firm 3	#MQ Firm 1	#MQ Firm 2	#MQ Firm 3	#MQ total	#CQ total	Estimate
RB.A12	11080 A reached	50	95	9	2	1	4	7	7	-
RB.A23	11080 A reached	56	58	40	0	2	15	17	17	16
RB.A34	not started	44	81	29	-	-	-	-	-	13
RB.A45	not started	48	44	62	-	-	-	-	-	24
RB.A56	11080 A reached	28	42	84	0	0	17	17	16	-
RB.A67	11080 A reached	57	36	61	0	1	19	20	20	-
RB.A78	in progress	53	40	61	1	5	3	9	8	23
RB.A81	11080 A reached	64	24	66	0	3	25	28	26	-

On track for 13 TeV

The March sector test



- Collimators with minimum gap on anti-collision switches = 0.5 mm
- 5 mm overshoot across nominal orbit
- Possible to tilt collimator to leave NO clearance



And on March 8th ...

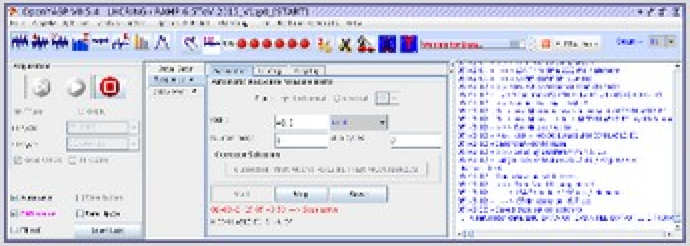
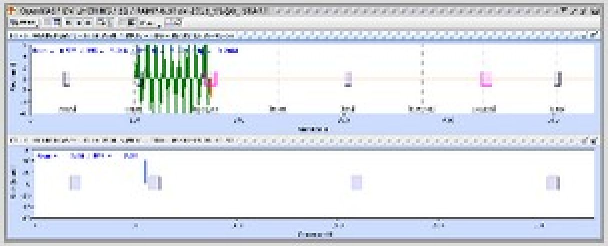
Activity seen in LHCb

Beam in S67 & S78

Feeling too short!

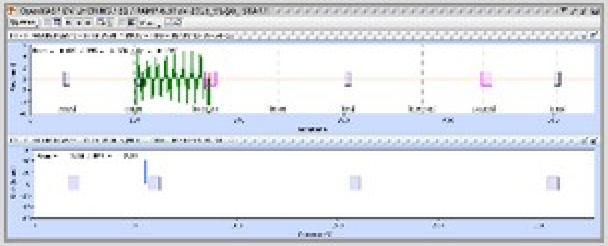
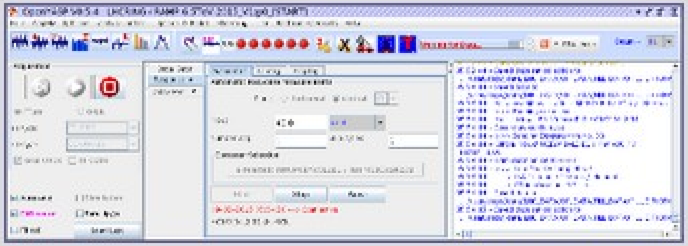
05:43

Kick response measurements for B1 in LHC - horizontal

05:51

Kick response measurements for B1 in LHC - Vertical

05:59

Measurements completed (all we could do), we stop the beam

;-(((

06:03

LHC SEQ: injection handshake closed; LHC=STANBY, EXP=VETO

06:04

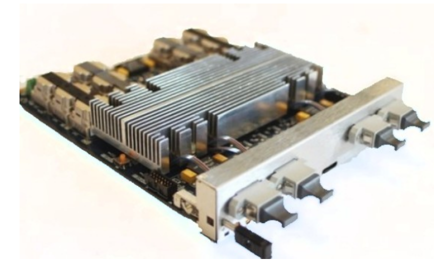
LHC RUN CTRL: BEAM MODE changed to NO_BEAM

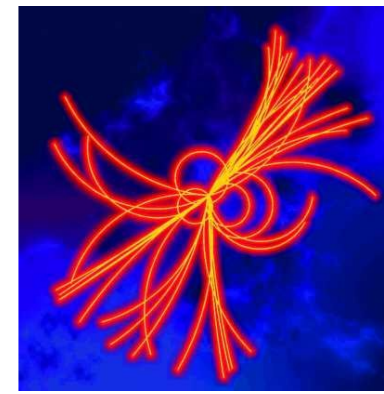
06:04

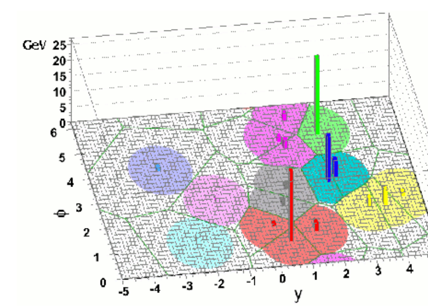
LHC RUN CTRL: ACCELERATOR MODE changed to SHUTDOWN

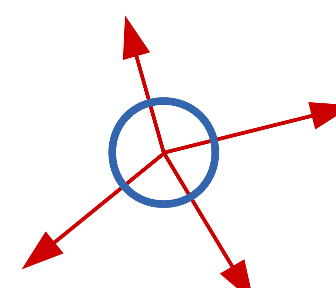
LHC OP elog. 9/3/2015

CMS



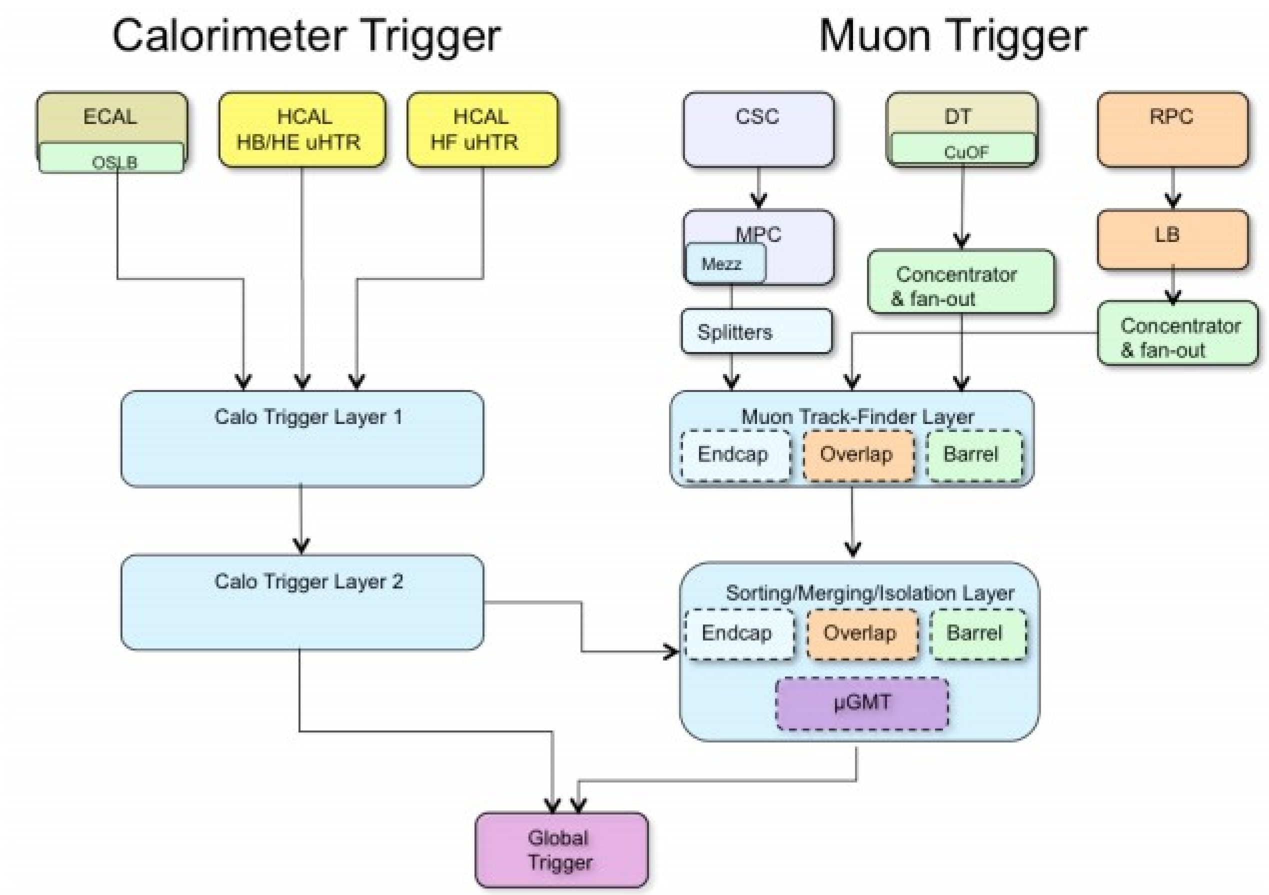






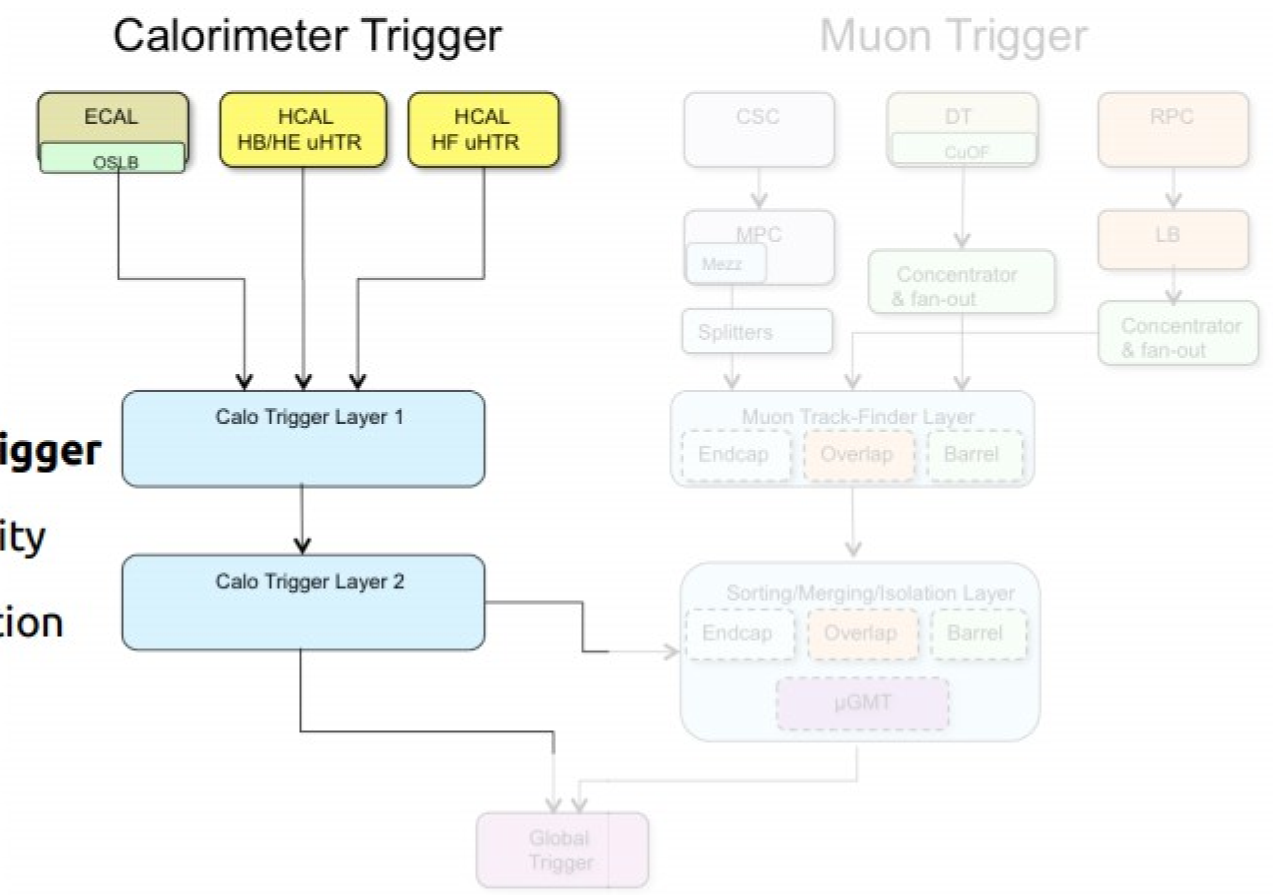
Trigger

L1 trigger in 2016

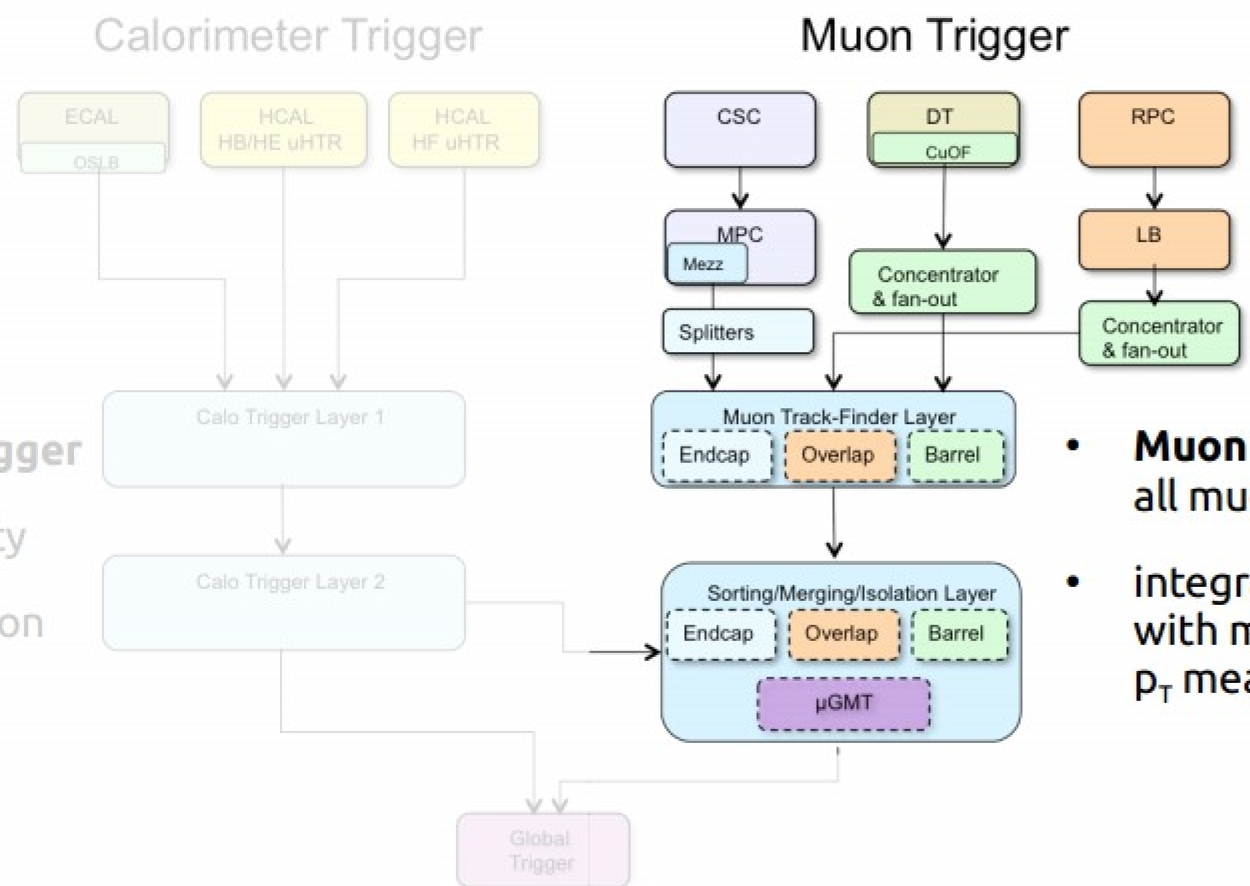


L1 trigger in 2016

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



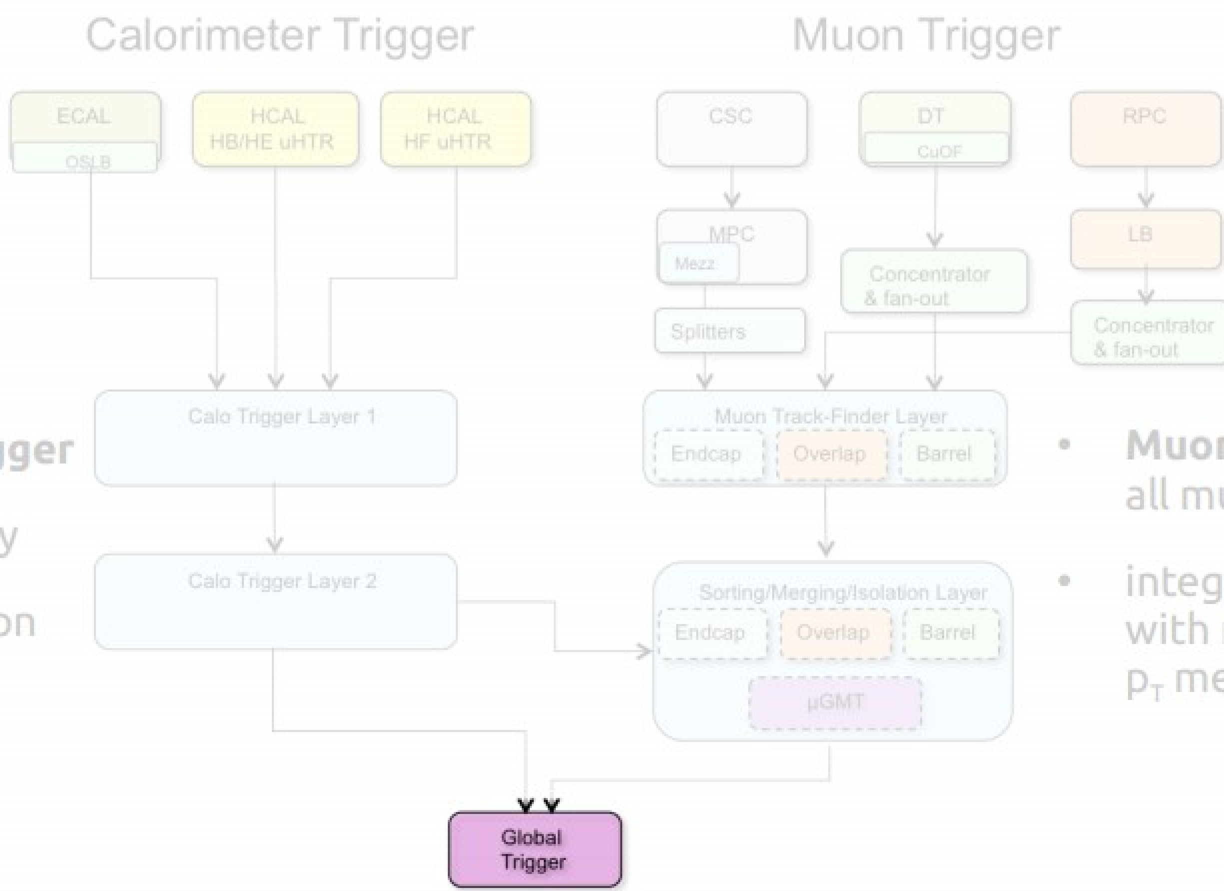
L1 trigger in 2016



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

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

L1 trigger in 2016



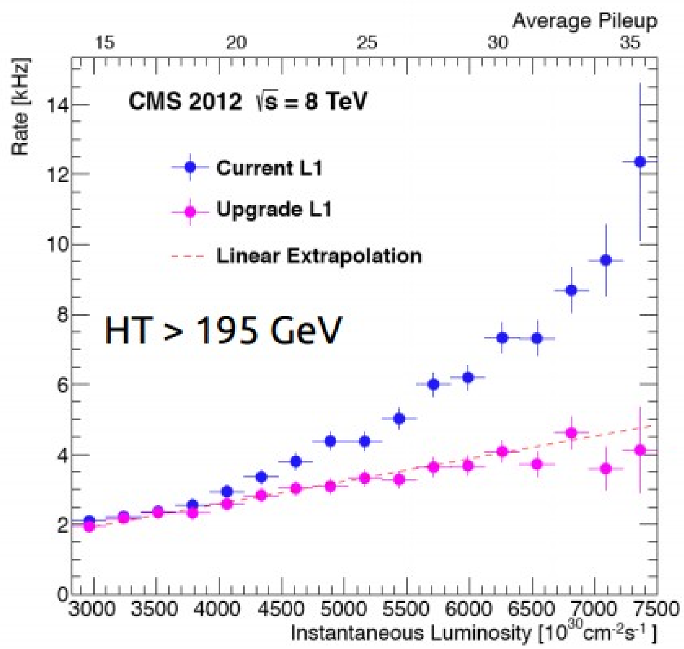
- two-layer **Calorimeter Trigger**
- higher granularity
- pile-up subtraction

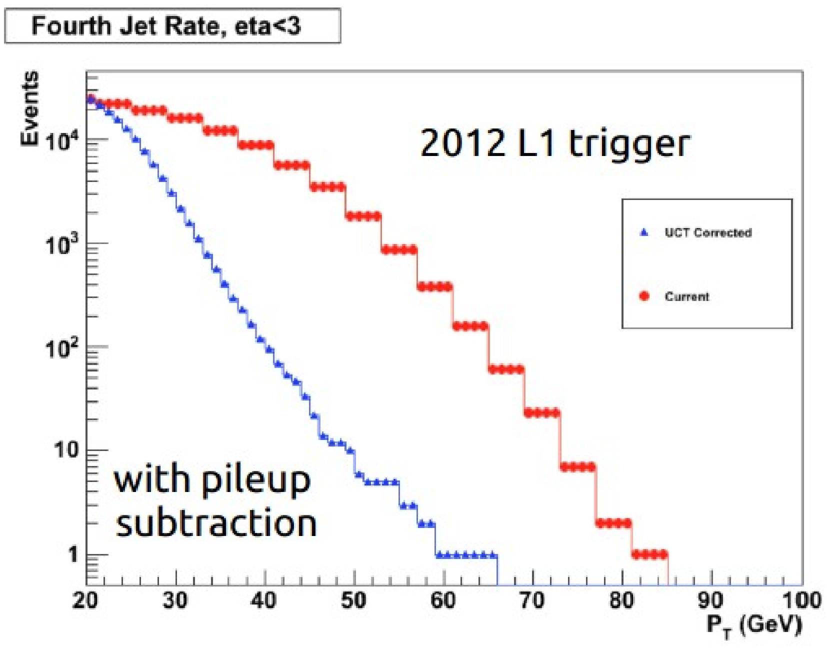
- **Muon Trigger** combining all muon systems
- integrated track-finding with more sophisticated p_T measurement

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

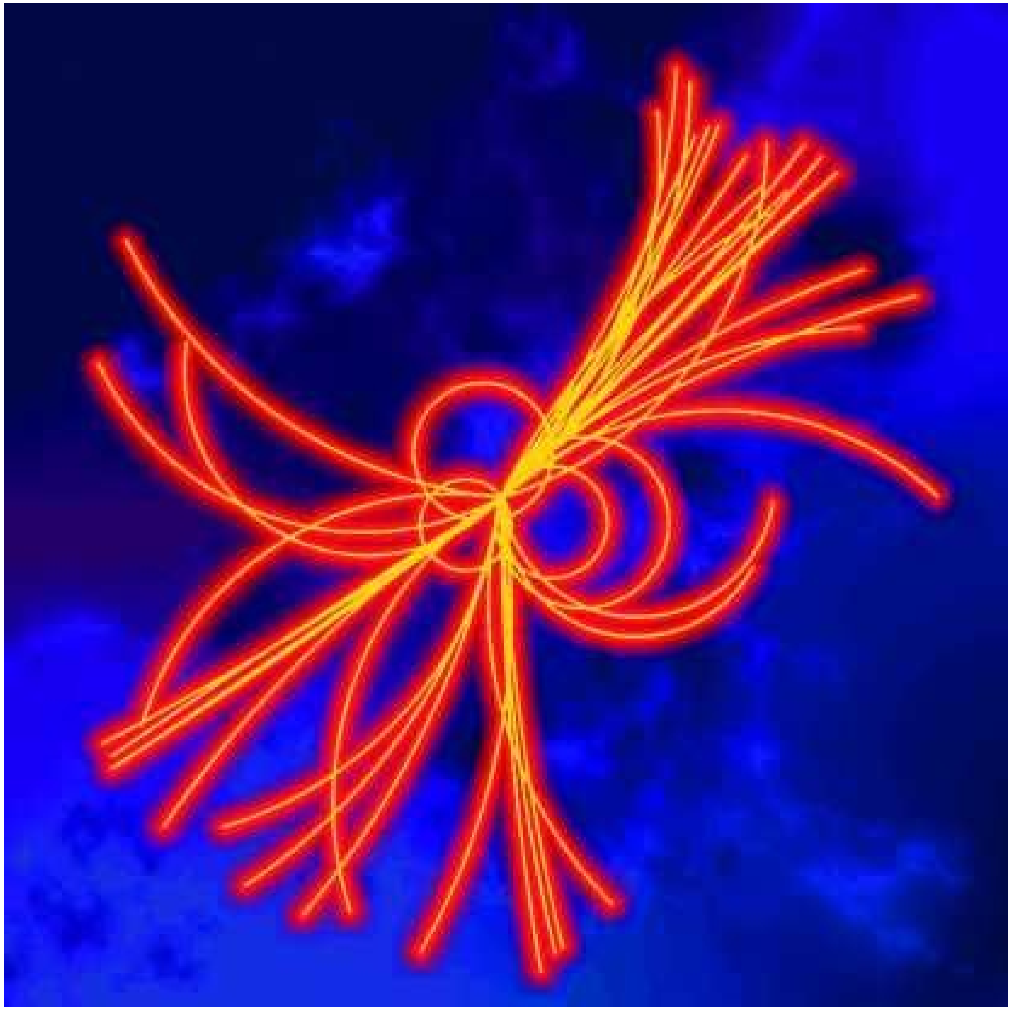
Stage 1: L1 trigger in 2015

- 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

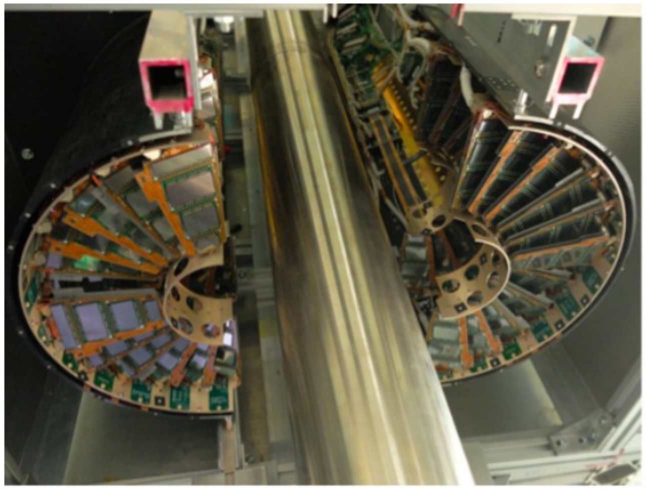




Tracker & tracking

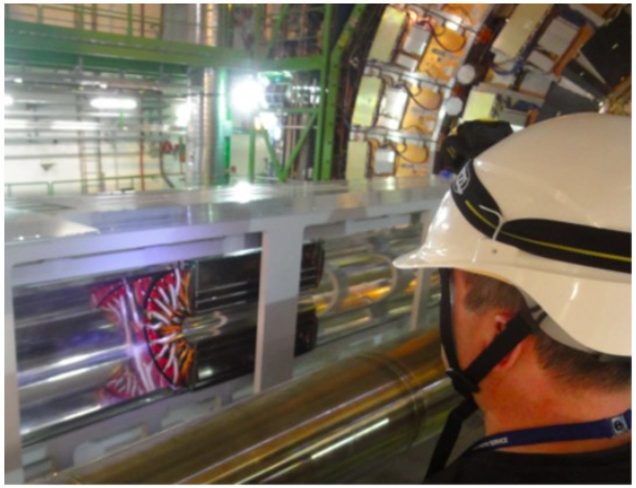


Pixel detector extraction & repairs

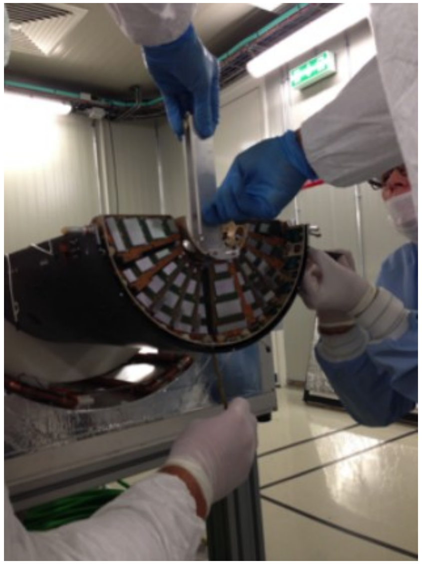


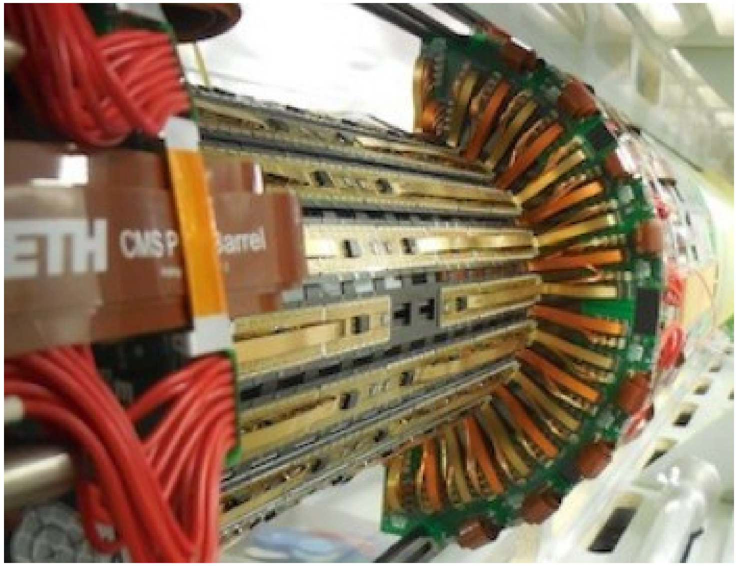
FPix

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



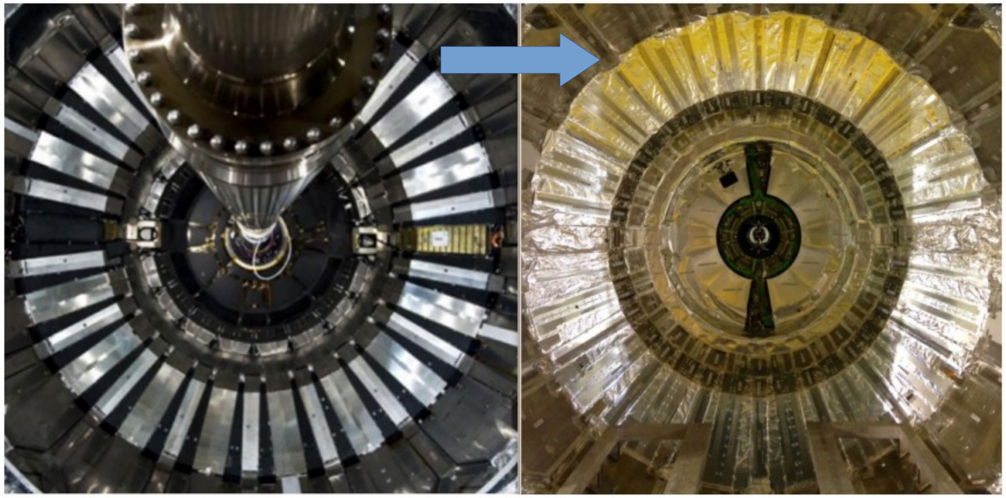


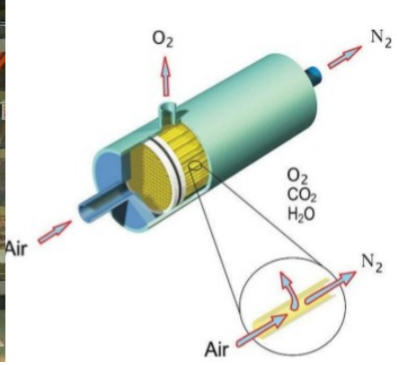
- At the end of Run 1 ~ 7.8% of FPix channels was not operational
  - **3.6%**: failing digitization of the analog signal due to distortion of the signal ("slow channels") caused by misaligned flex cables
  - **3.1%**: unplugged analog electrical-to-optical converters (AOHs)
  - **1.1%**: problematic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

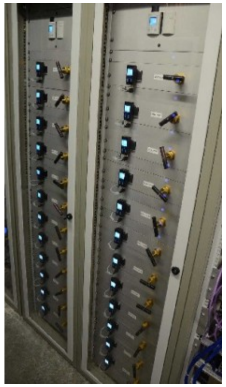
CMS Tracker

- 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



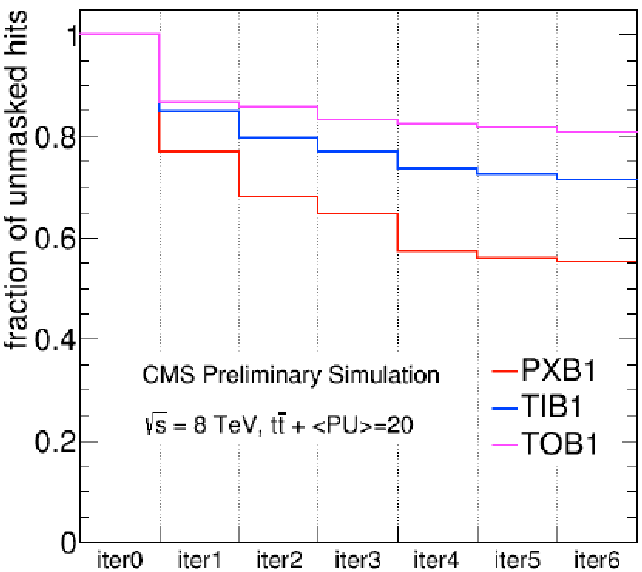


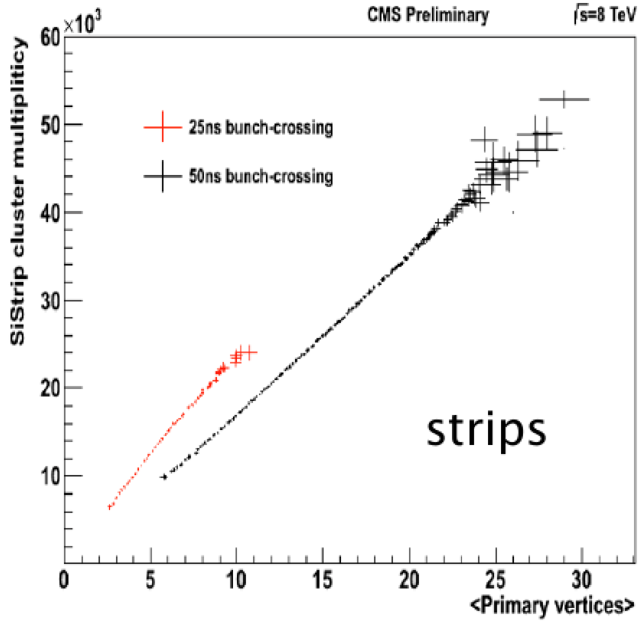


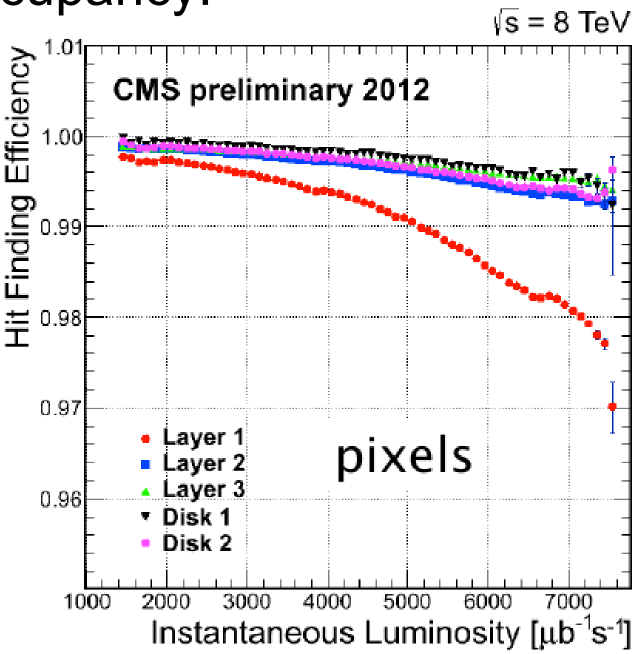
Brand new dry gas (membrane) plant

Tracking challenges at high pile-up

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



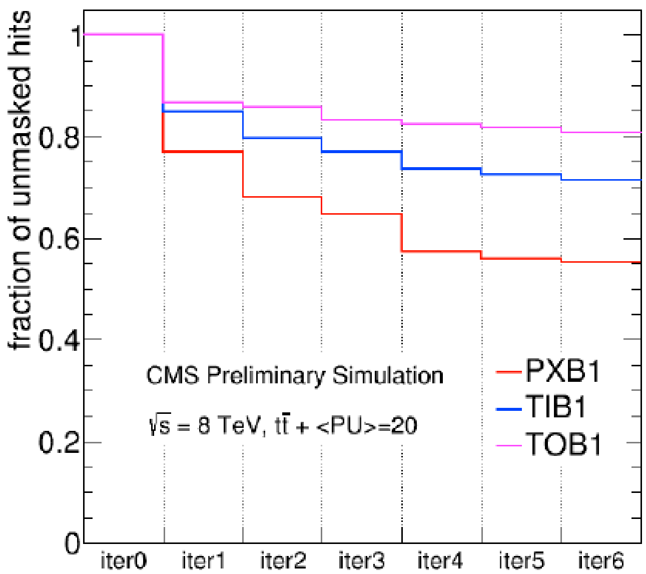


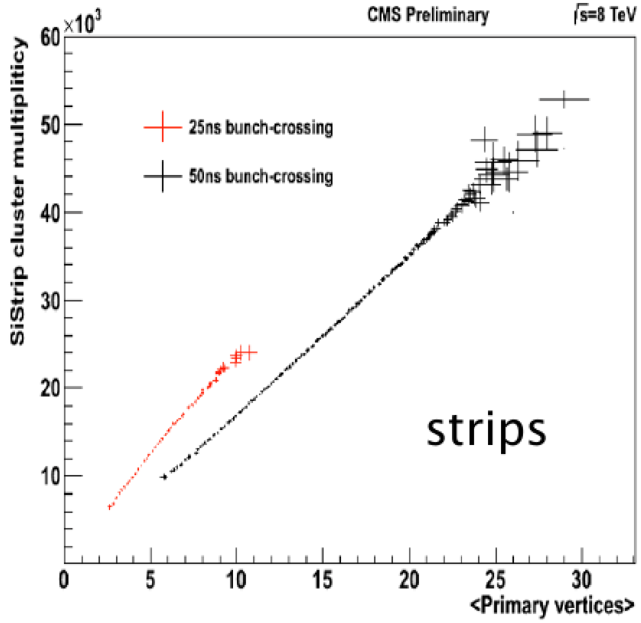


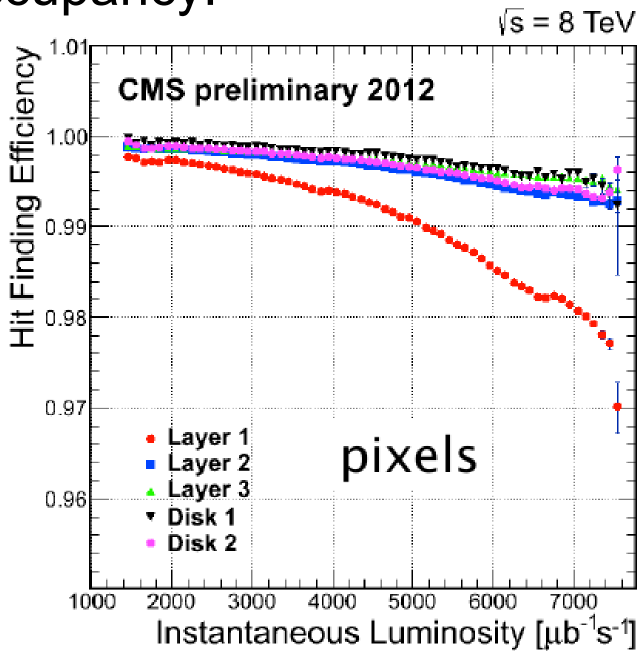
- Pixels are affected by a dynamic inefficiency, mainly due to saturation of chip readout buffers.
- Out of time pile-up increases the occupancy of the strip detector by ~45% (only ~5% for pixels)
- Iterative tracking is not the definitive solution, tracker is far from being empty after all iterations

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

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

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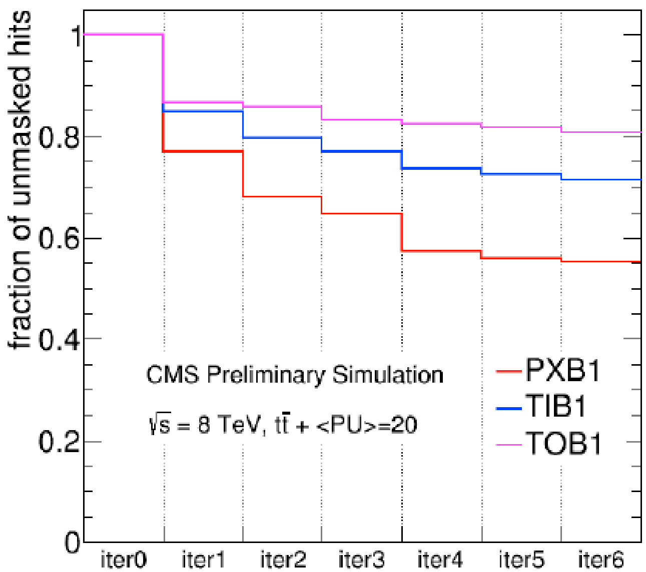
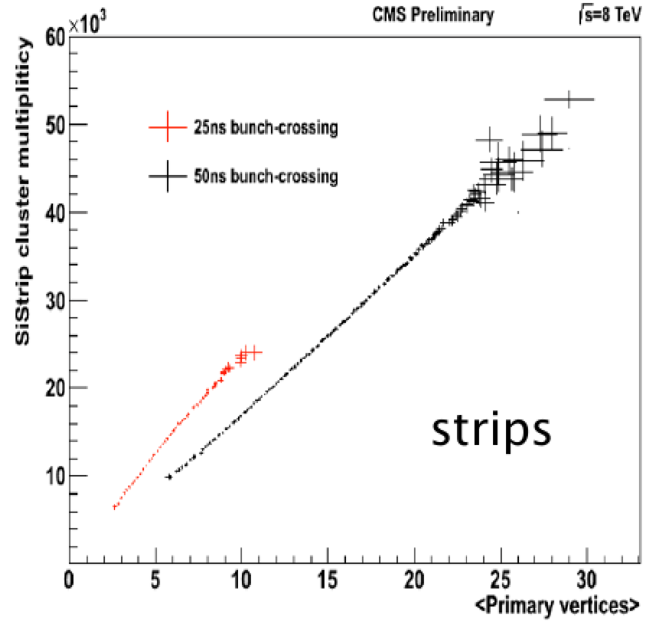
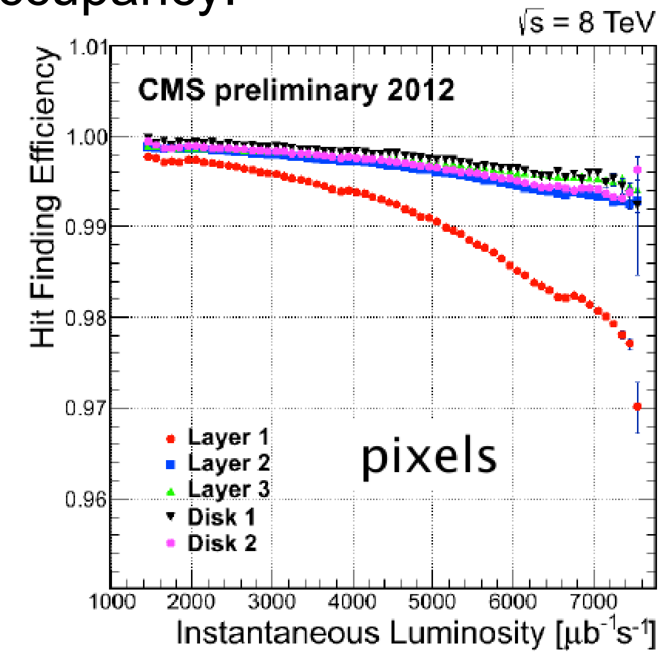
Tracking challenges at high pile-up

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







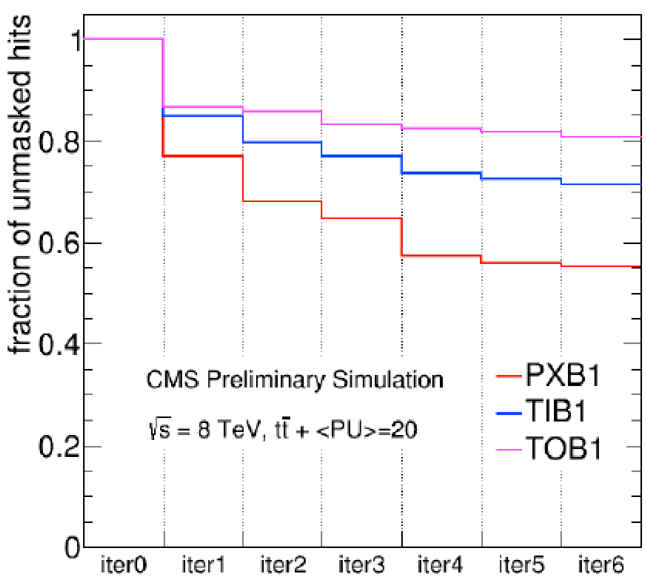
New Pixel detector by the end of 2016

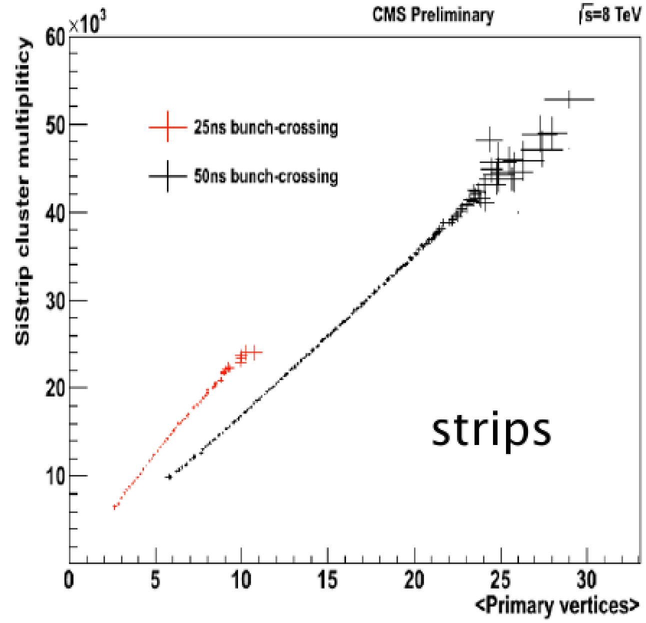
Introduction of a cluster charge cut

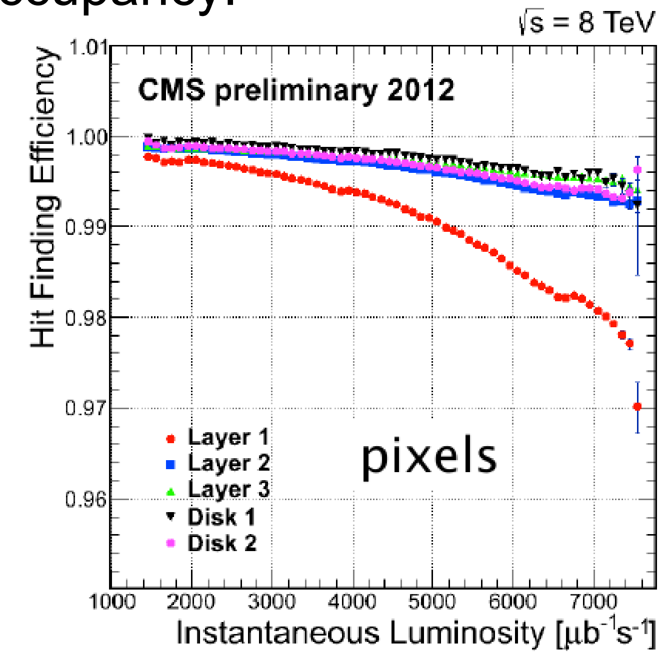
- Iterative tracking is not the definitive solution, tracker is far from being empty after all iterations

Tracking challenges at high pile-up

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







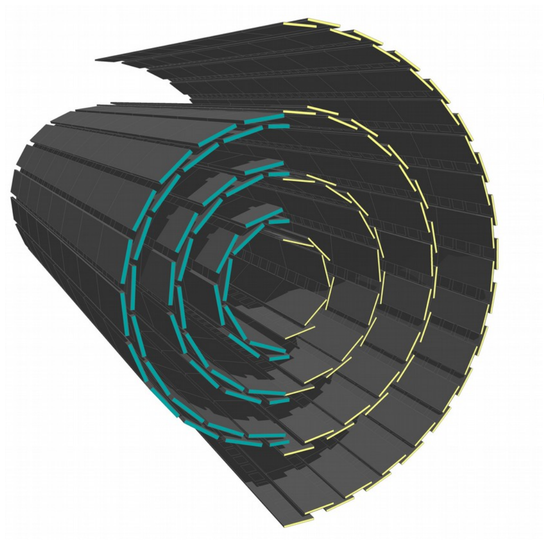
New Pixel detector by the end of 2016

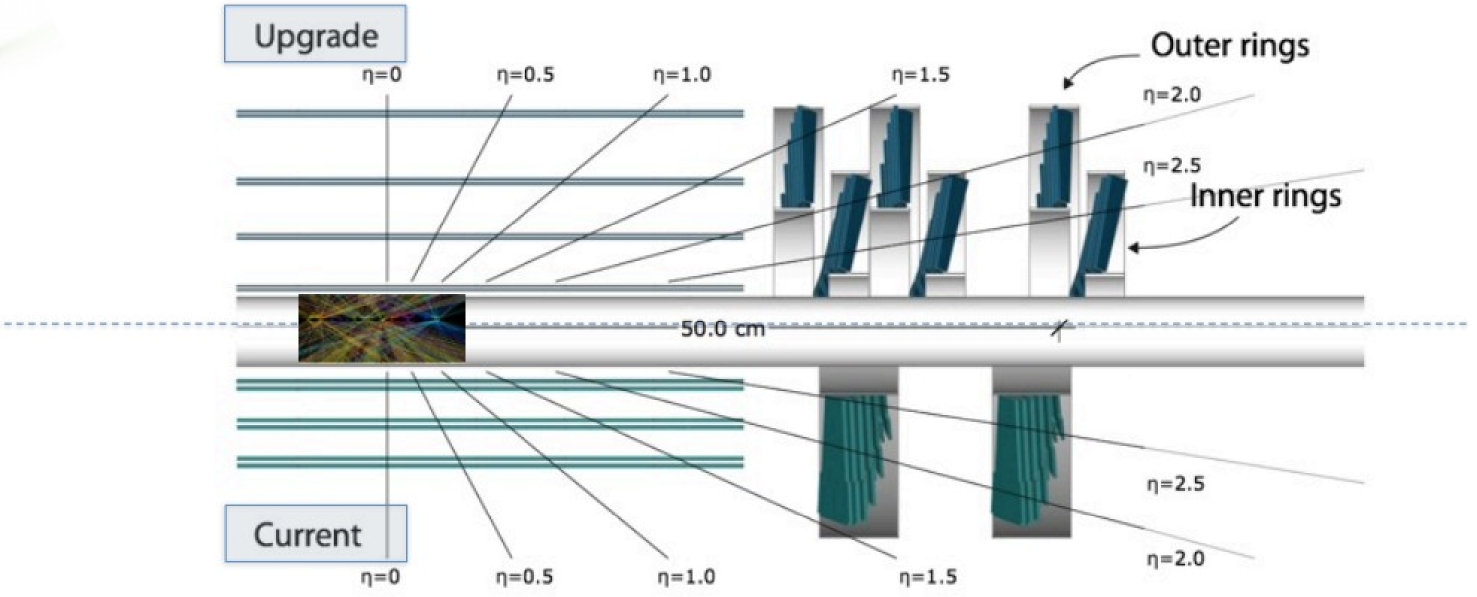
Introduction of a cluster charge cut

Global re-optimization of the tracking sequence

From 2017: pixel phase 1 upgrade

Depends on the installation of a new beam pipe during LS1 ✓



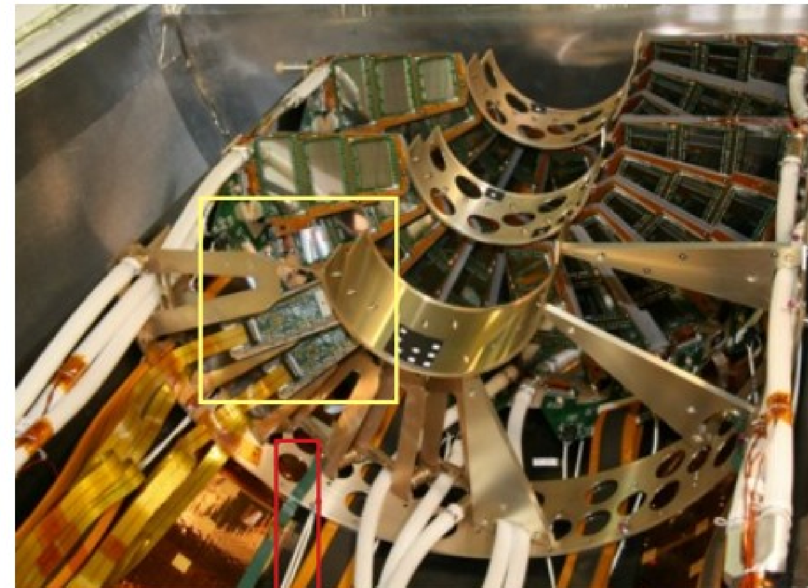


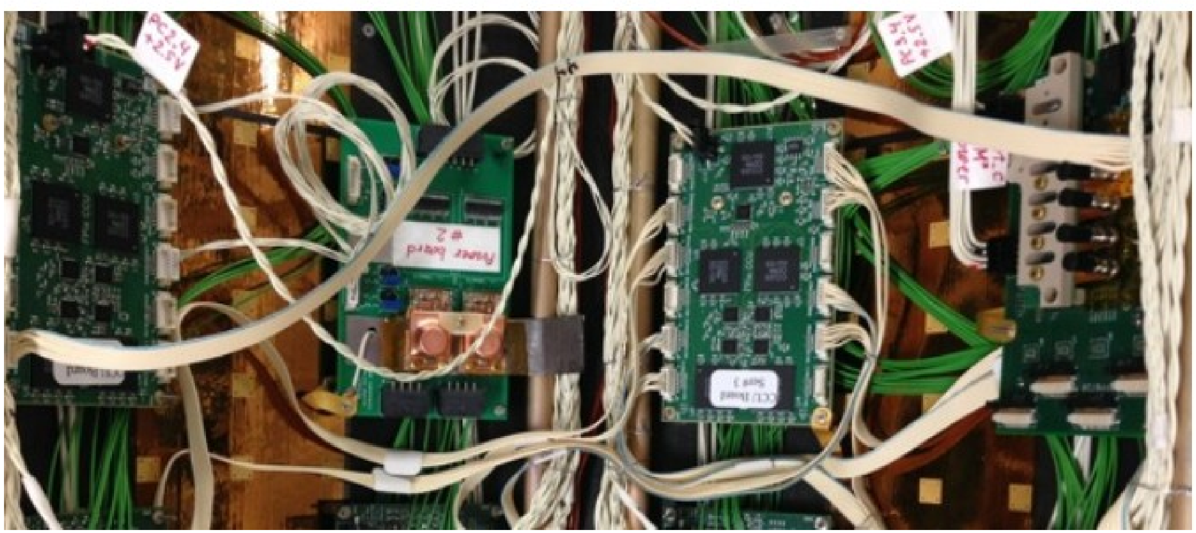
<u>Pixel Upgrade</u>

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

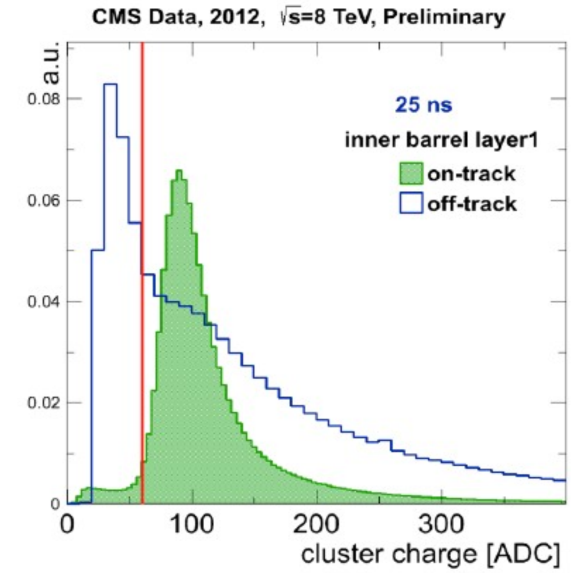




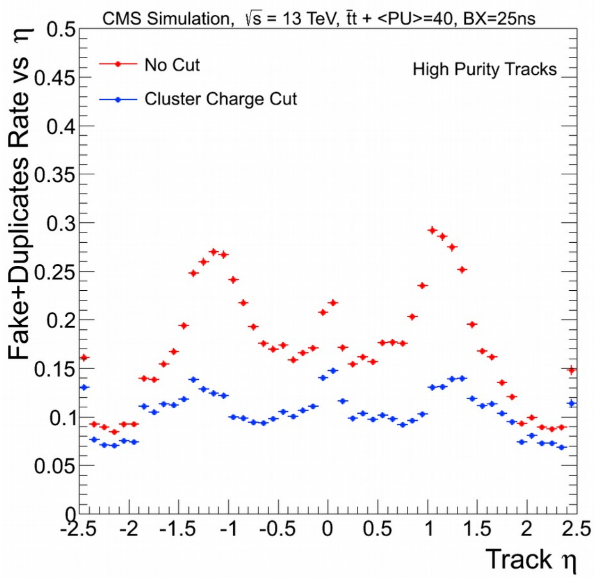
Cluster charge cut for OOTPU mitigation

- 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



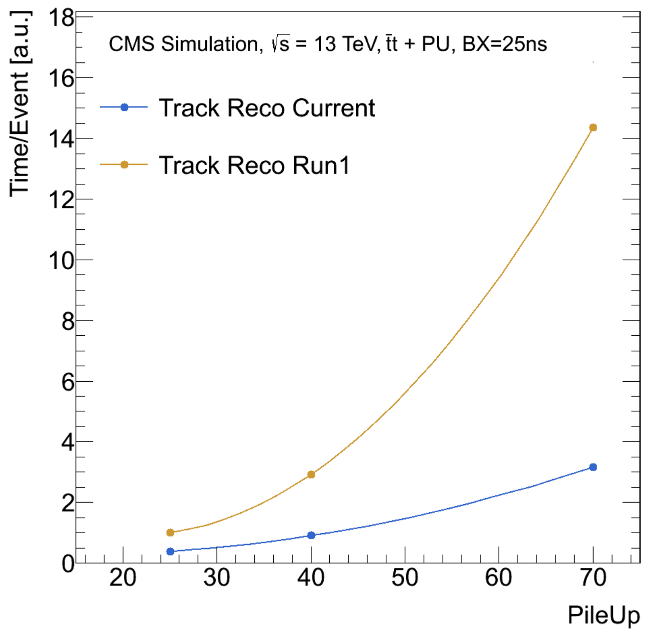
- Cutting on the cluster charge suppresses the effect
  - accounts for sensor thickness and trajectory crossing angle
  - pT dependent cut to preserve potential signal from fractional charge particles
- Stable performance ensured by gain calibration in quasi-real time
  - The regular gain monitoring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

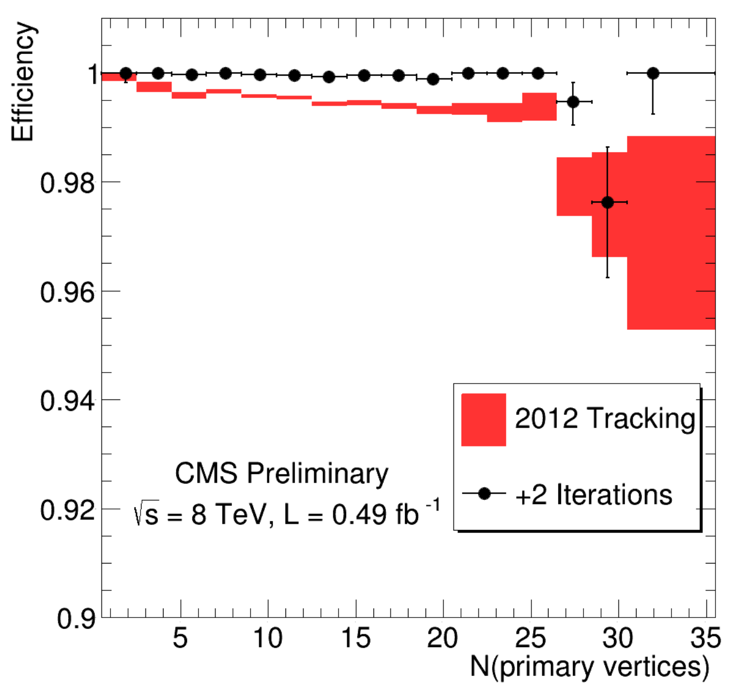


The cluster charge cut effectively restores Run 1 performance.

Tracking optimization

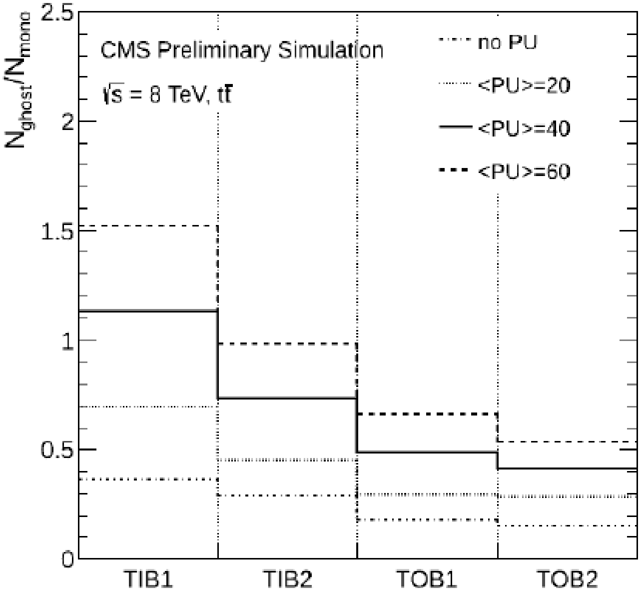
- Lots of efforts put in reshuffling and optimizing the iterative tracking steps
  - Factor ~5 gain in performance in run 2 conditions
  - Maintained physics performance similar to run 1

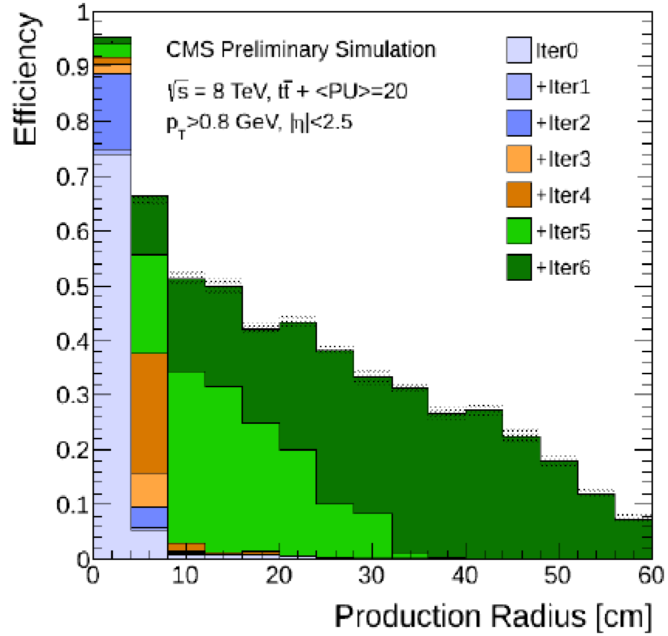


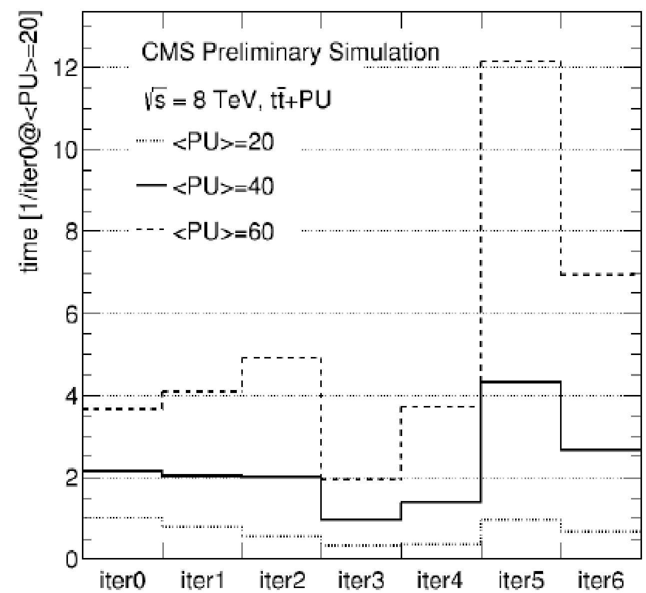


- 2 additional iterations have been designed to recover the efficiency loss seen in 2012 for muons:
  - an Outside-in iteration, seeded from the muon system, designed to recover the missing muon-track in the tracker
  - an Inside-Out iteration designed to re-reconstruct muon-tagged tracks with looser 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)

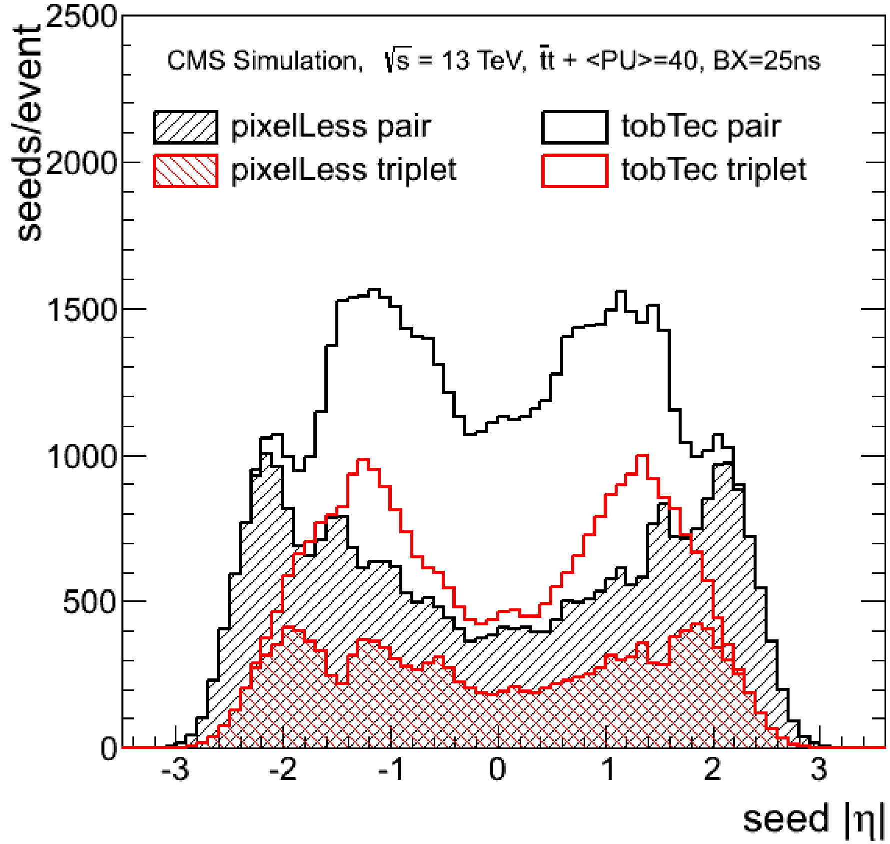


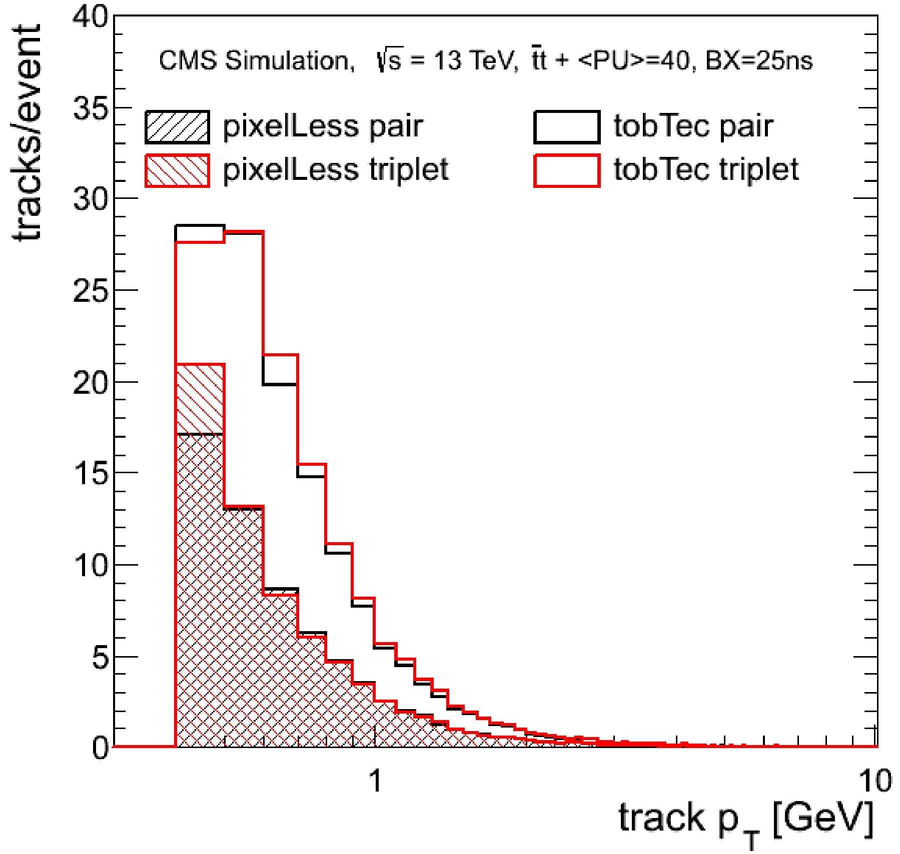




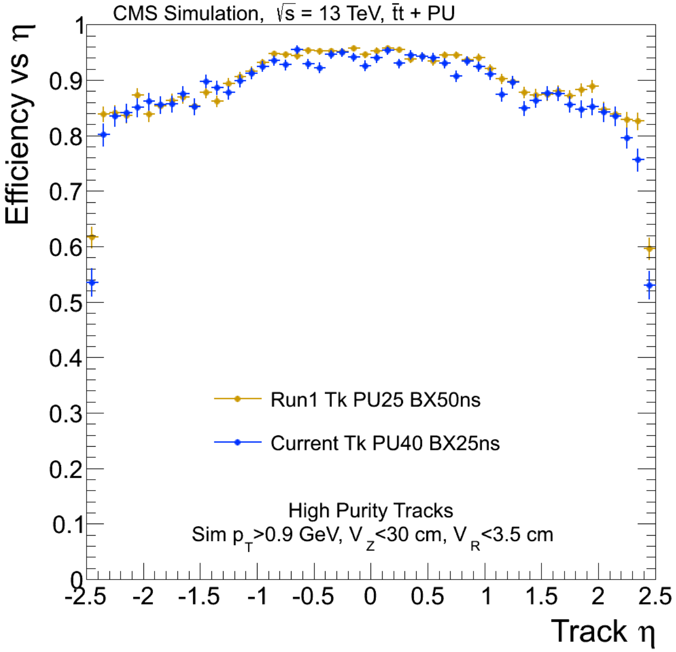
- On double-sided strip layers the number of ghost hits increases and in TIB1 becomes larger than true hits at <PU>=40
  - ghost hits are due to ambiguities when more than one track crosses a glued detector
- As a consequence, the effect of pile-up is dramatic on iterations seeded by pairs of strip matched 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

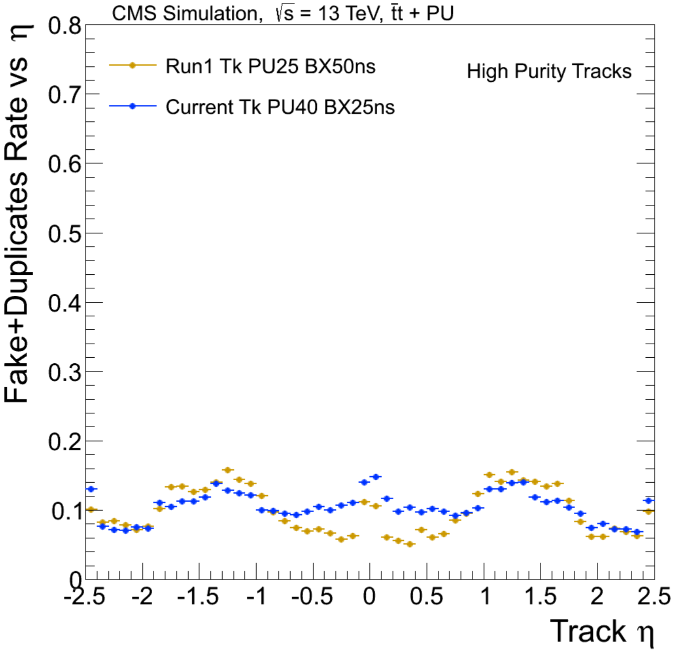
Pileup mitigation: from pairs to triplets

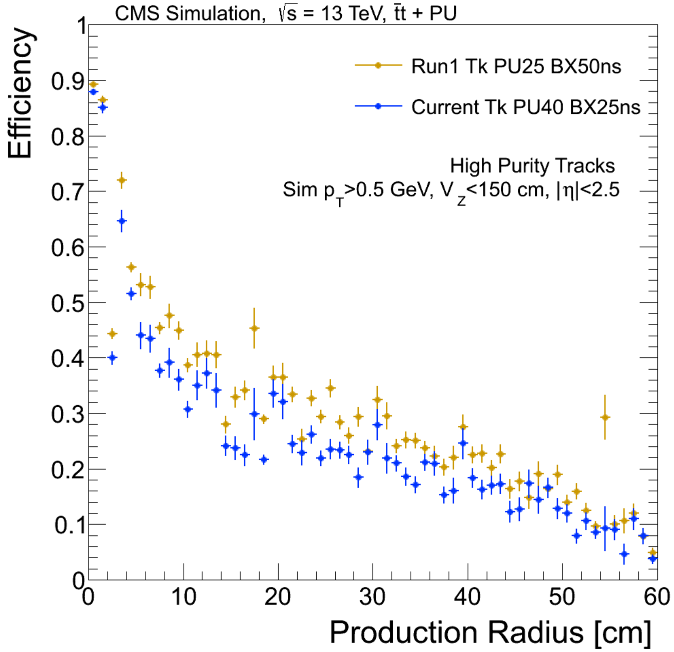




Performance after optimization

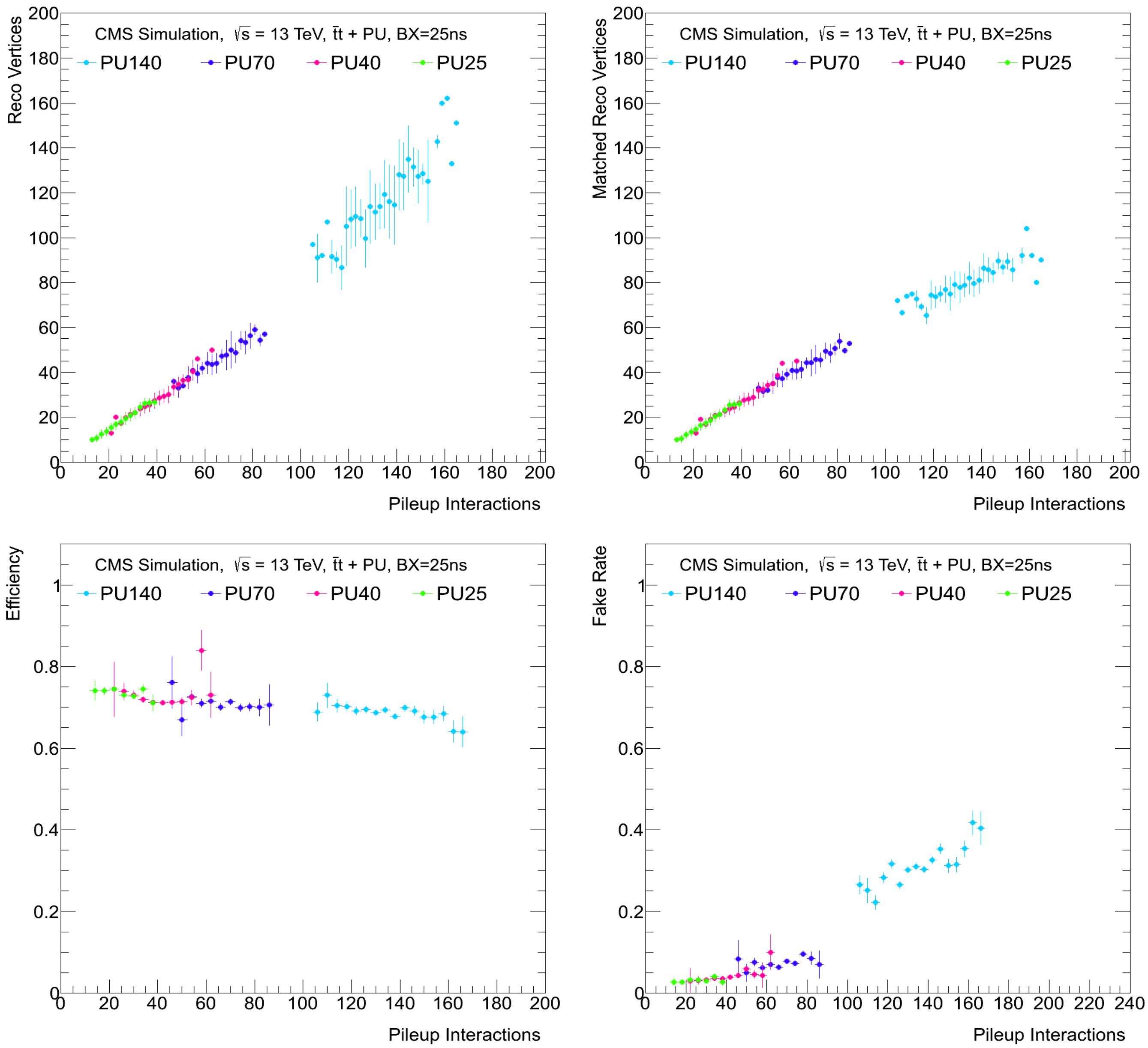






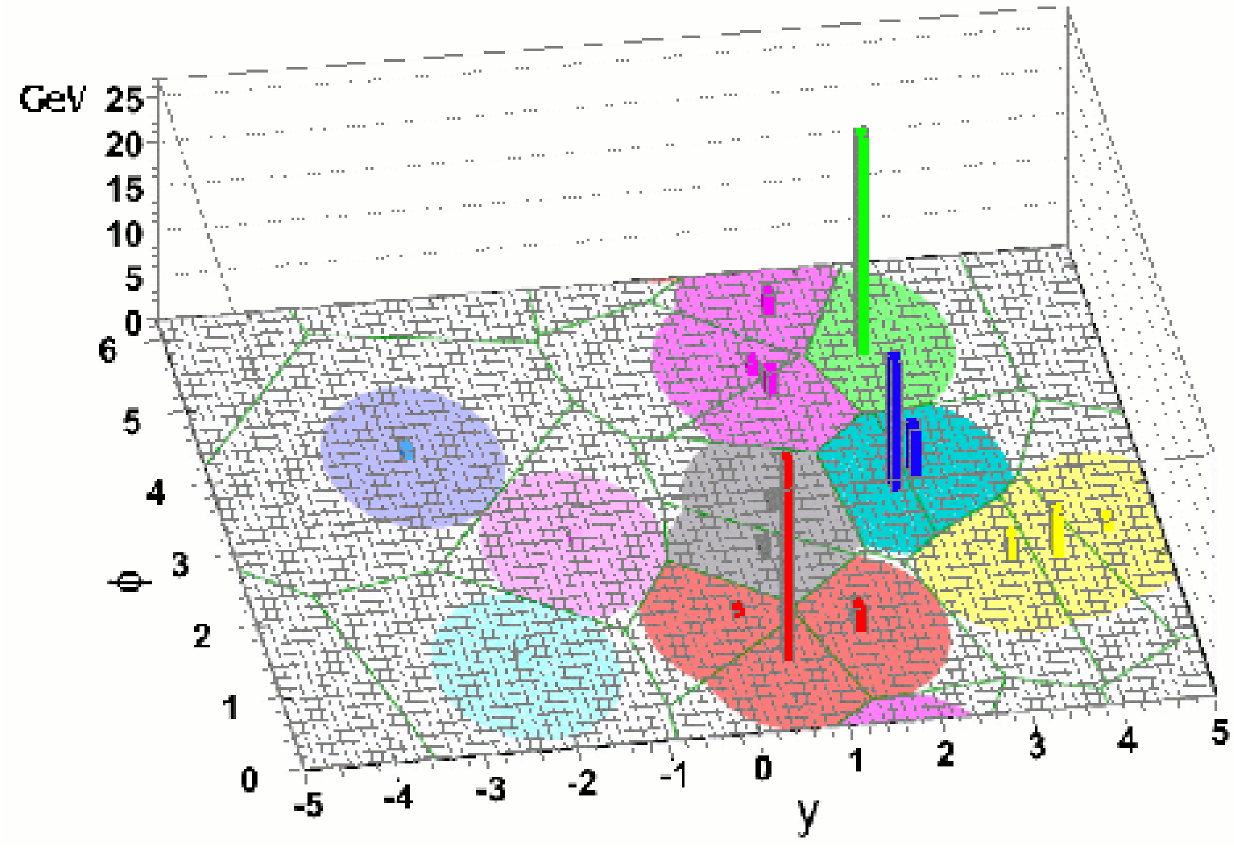
- Performance after optimization are very similar to those in run 1.
  - Track reconstruction efficiency vs eta
  - Fake and Duplicate rate vs eta
  - Track reconstruction efficiency vs track production radius
- With the modifications presented above, pileup is under control for run2

Vertexing



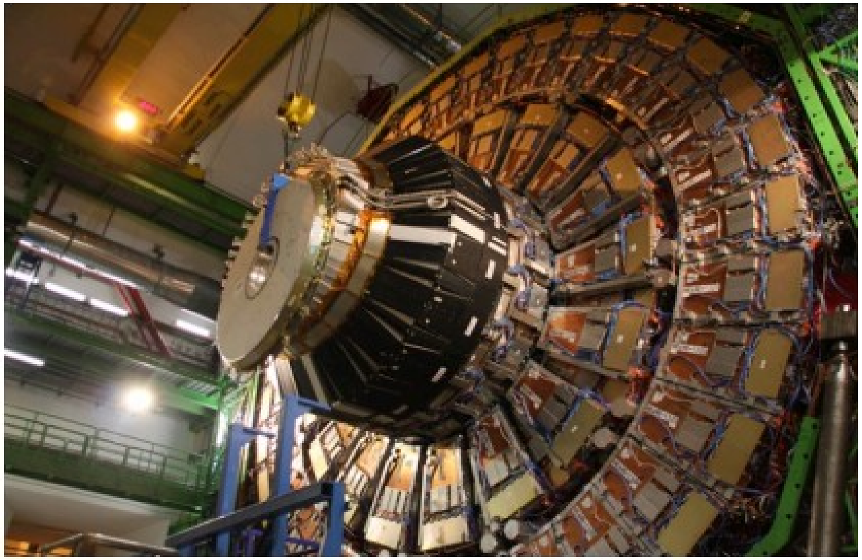
- Vertexing performance are good up to pileup of O(100)
- No special action needed for run2
- A new approach will be needed for HL-LHC

Calorimeters



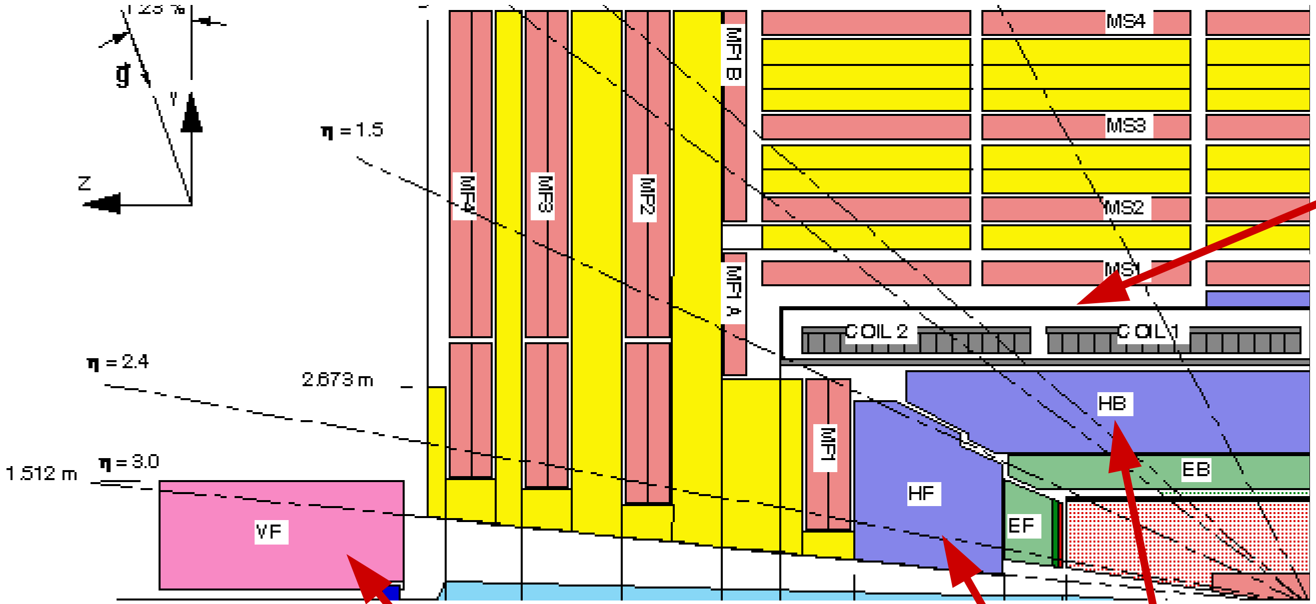
Preshower repairs during LS1

- 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



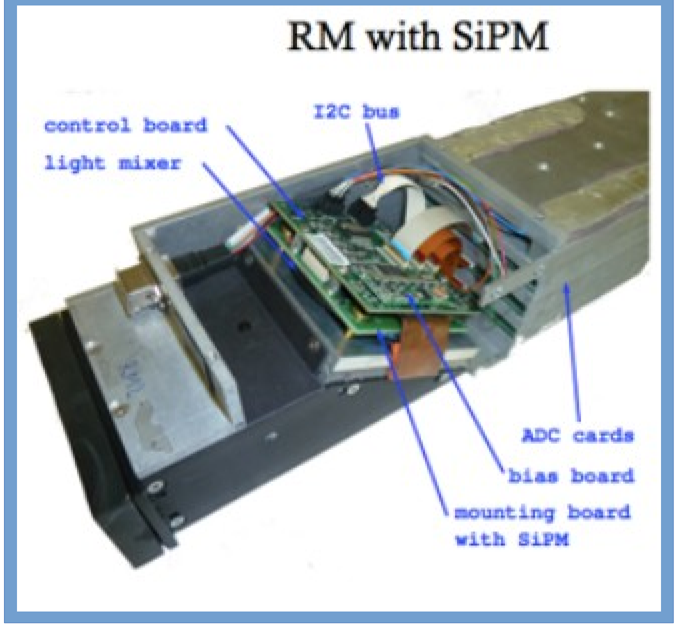
  - At the same time, we recovered non-operational channels
    - **96.8% operational in 2012 → 99.95% in 2014**
- Both disks were re-installed and recommissioned.

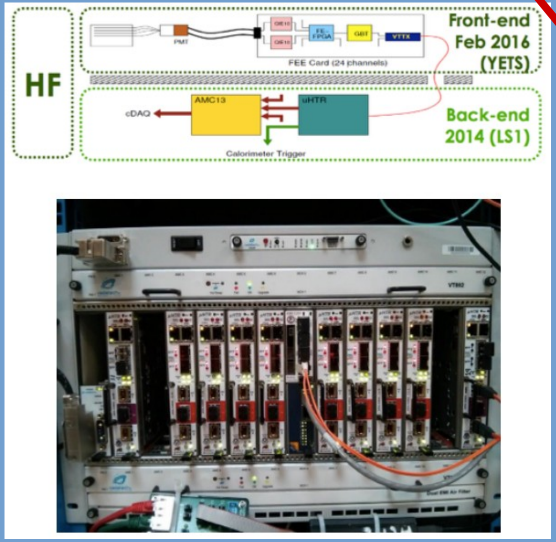
Interventions on HCAL during LS1



HO: replacement of HPDs by SiPMs

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



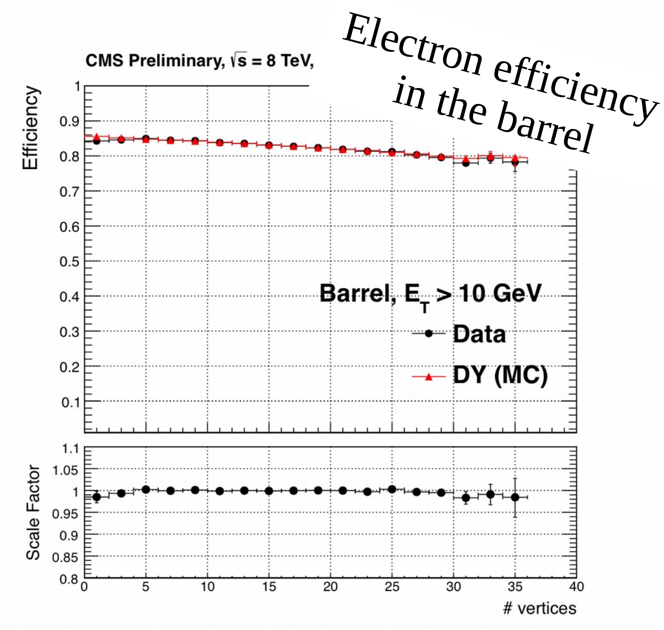


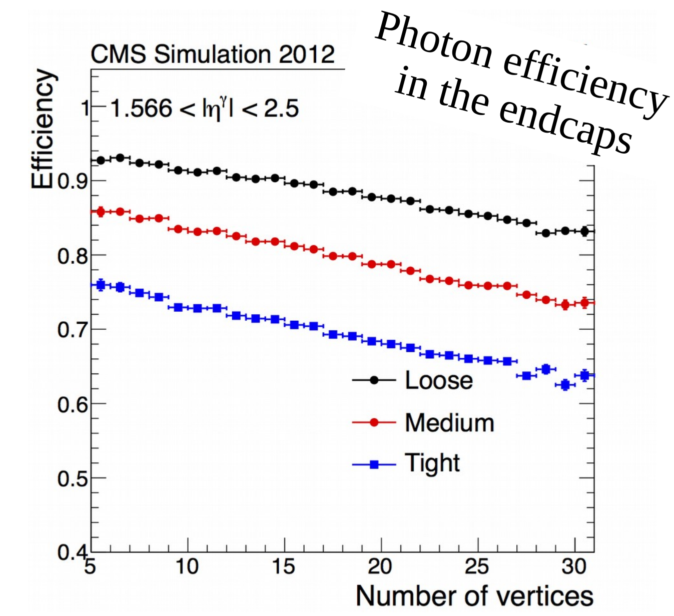
HF: switch to multi-anode PMTs and uTCA BE electronics

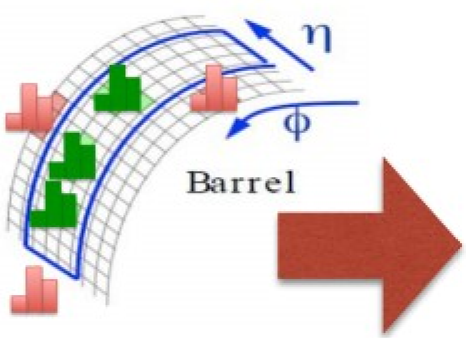
HBHE:
control modules replacement
and misc. repairs

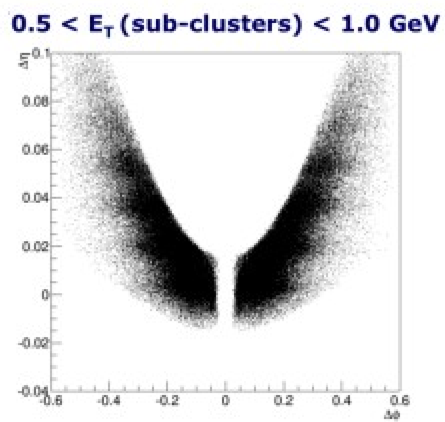
Electrons/photons reconstruction: PU effect

Electron and photon reconstruction is moderately affected by pileup.









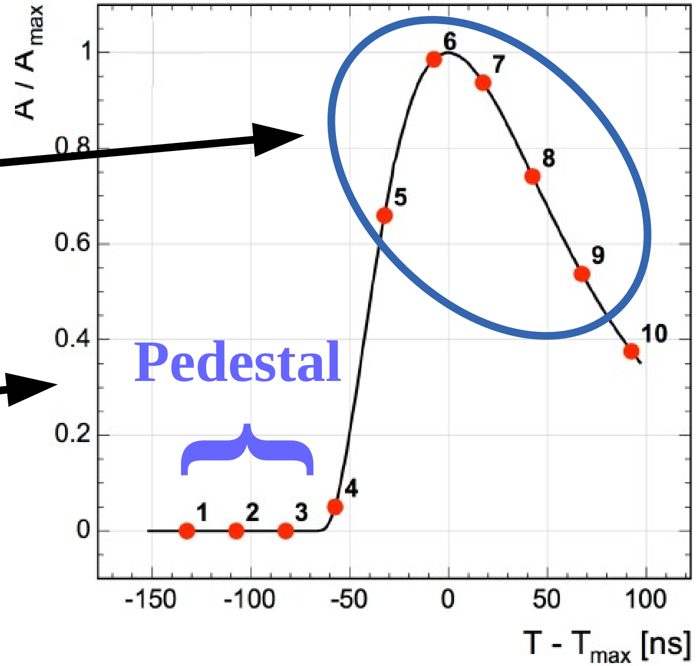
New clustering method using the precise shape of the expected deposit from photons from bremstrahlung.

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

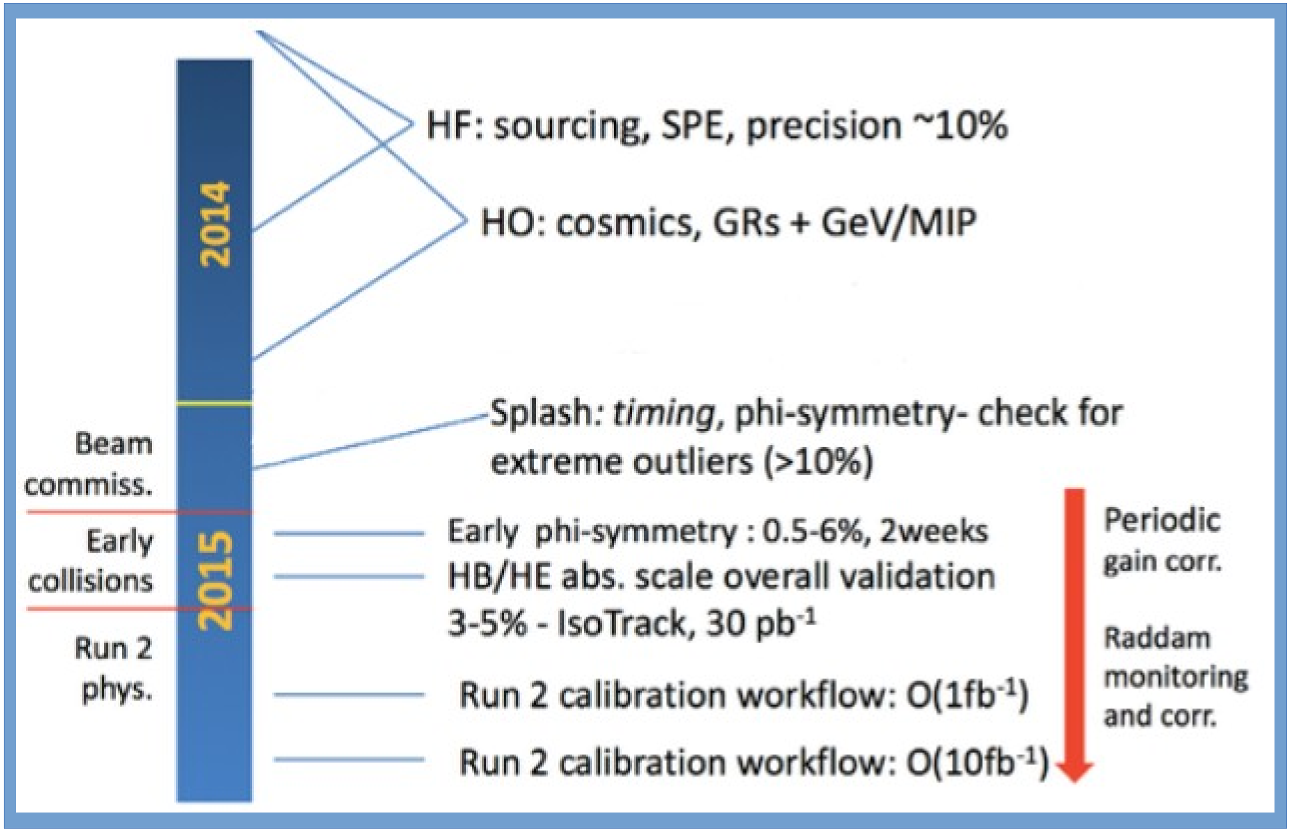


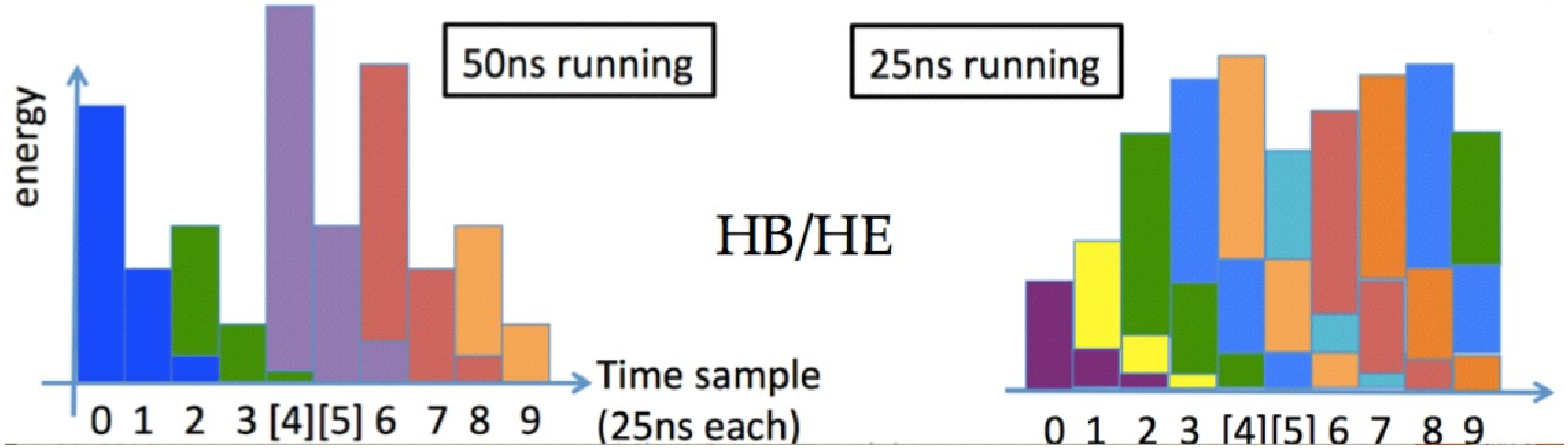
- Situation of HCAL is similar.

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

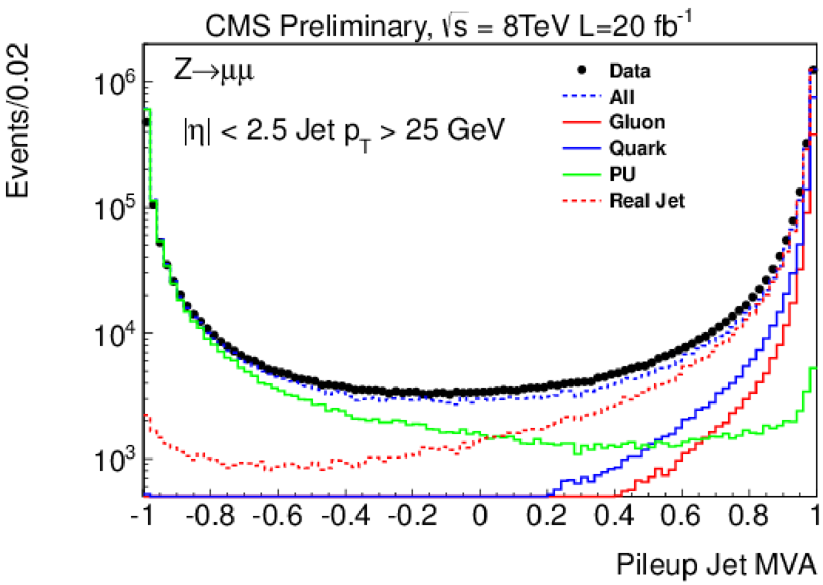
Strategy is to use a **parametrization of the pulse shape** to remove OOT PU energy.

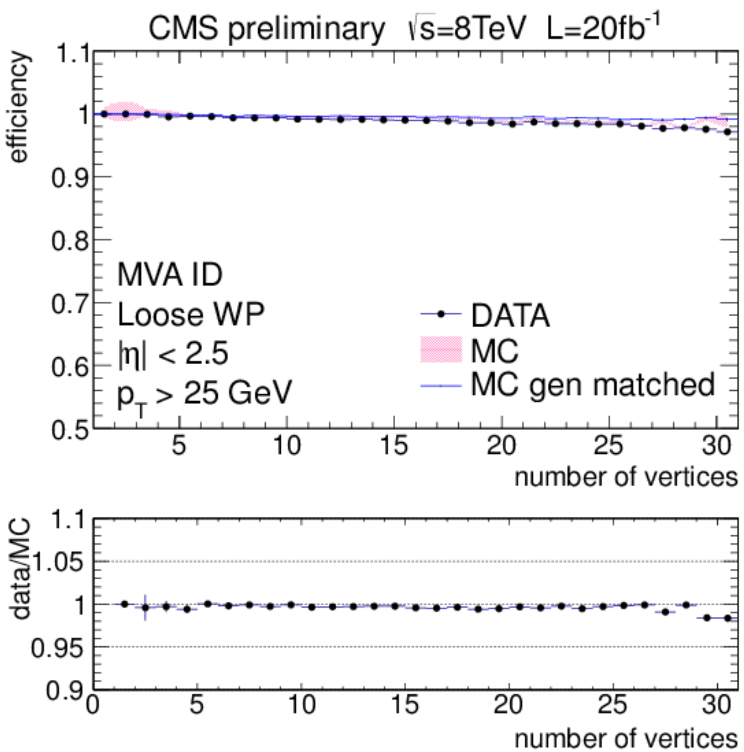
Noise filtering needs to be updated as well to use OOT PU robust quantities.



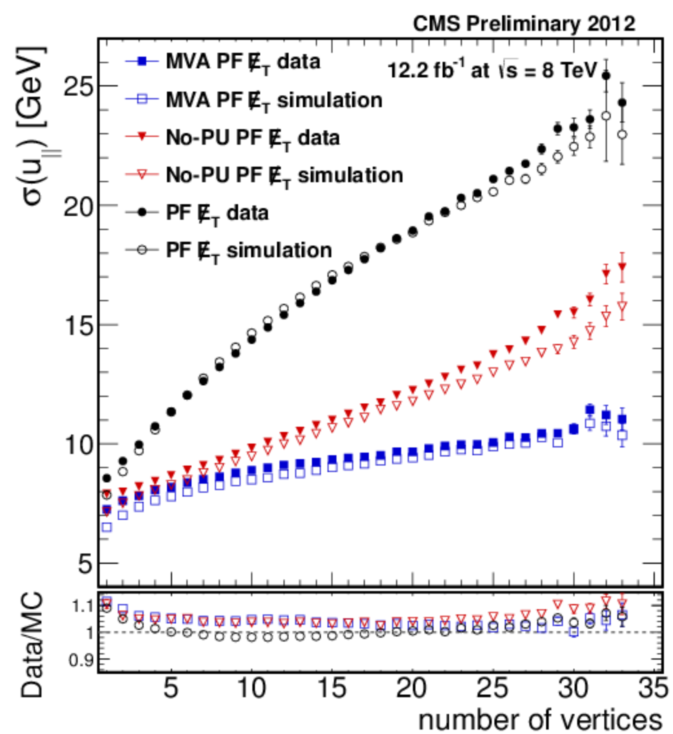


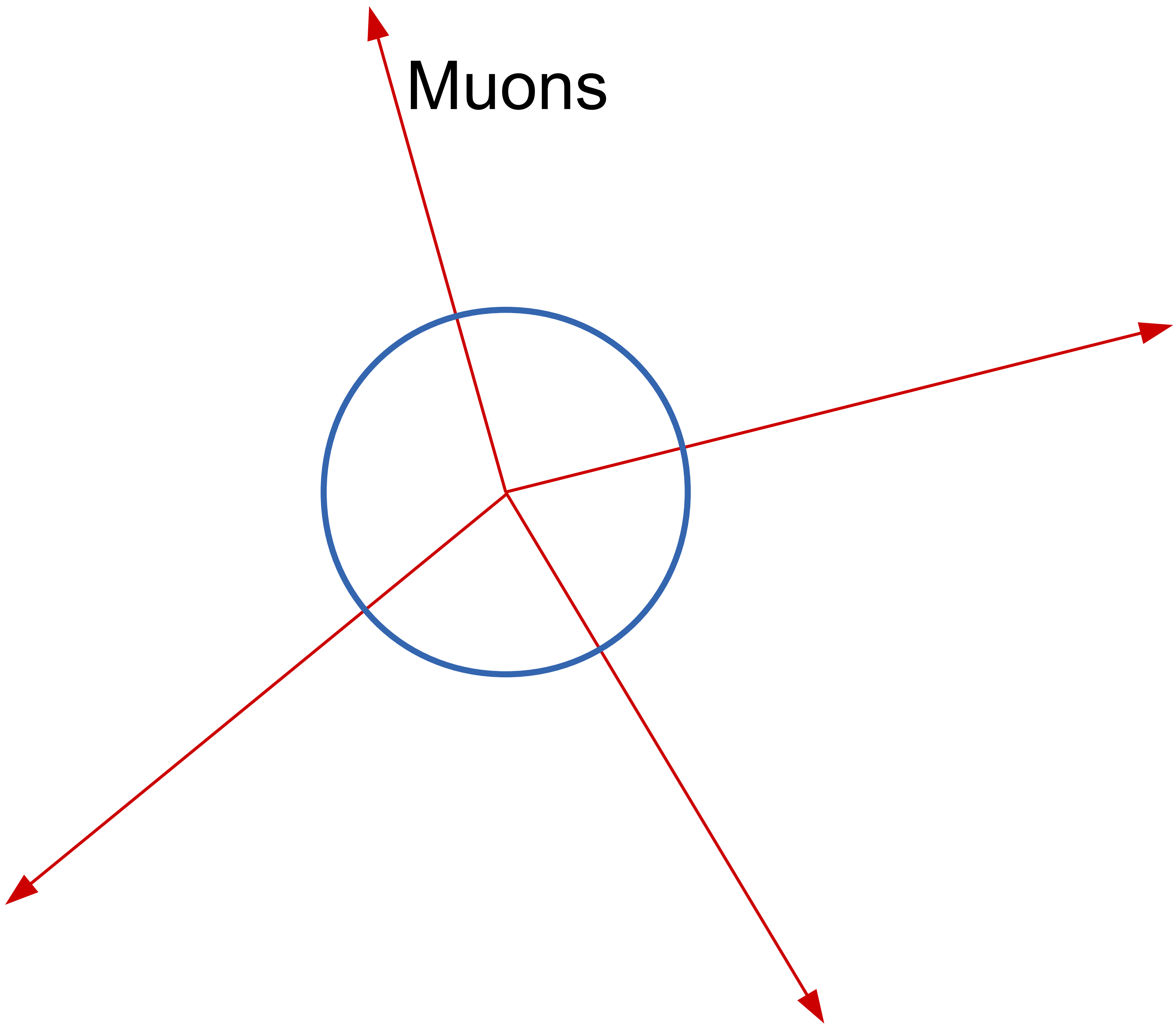
Jet/MET Performance





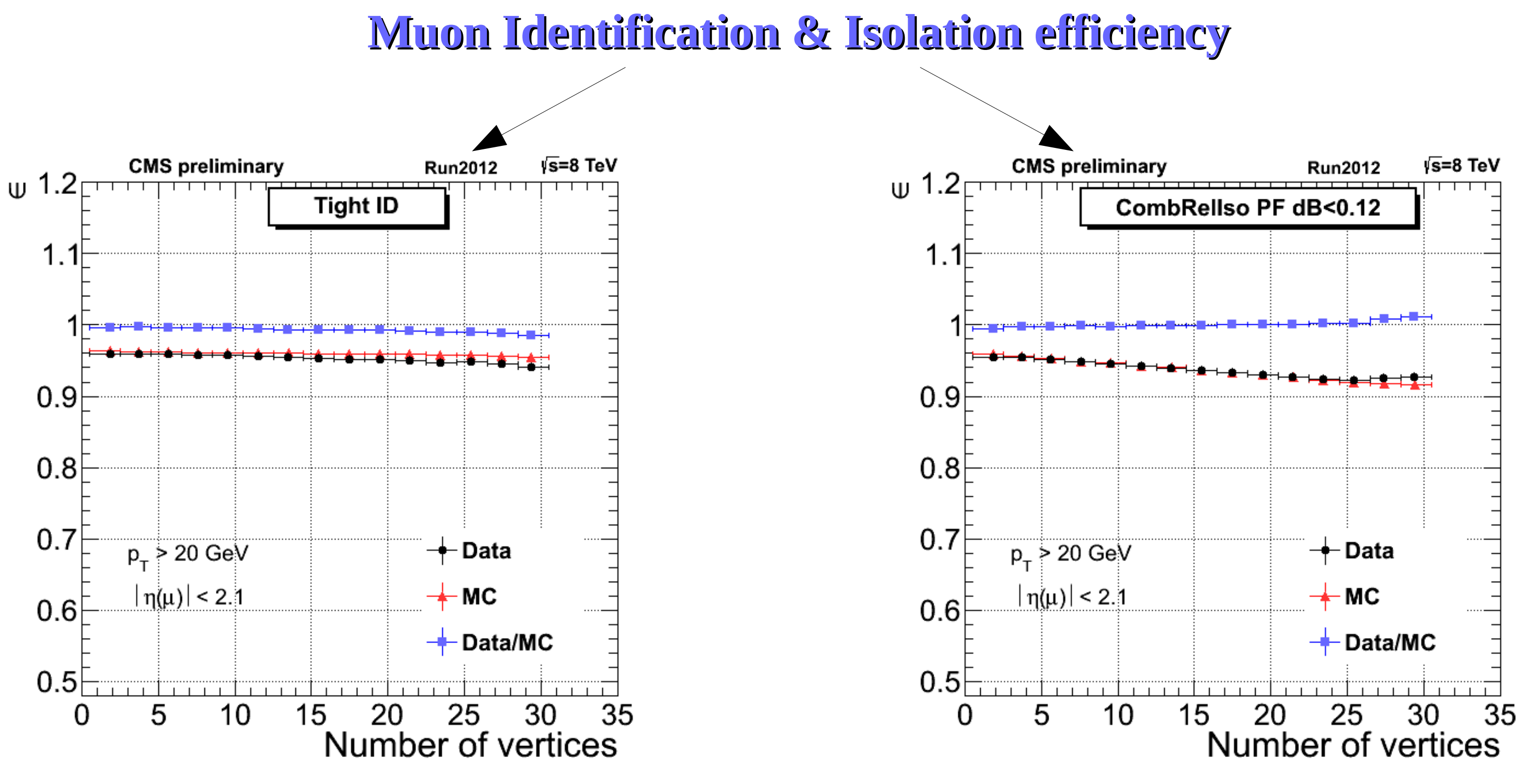
- Pileup identification is based on a MVA method already used during run 1
- Pileup-jet identification efficiency remains constant at high pileup
- MET resolution is only slightly affected by pileup when using the most advanced reconstruction method.




Muons

Pileup and muon efficiency

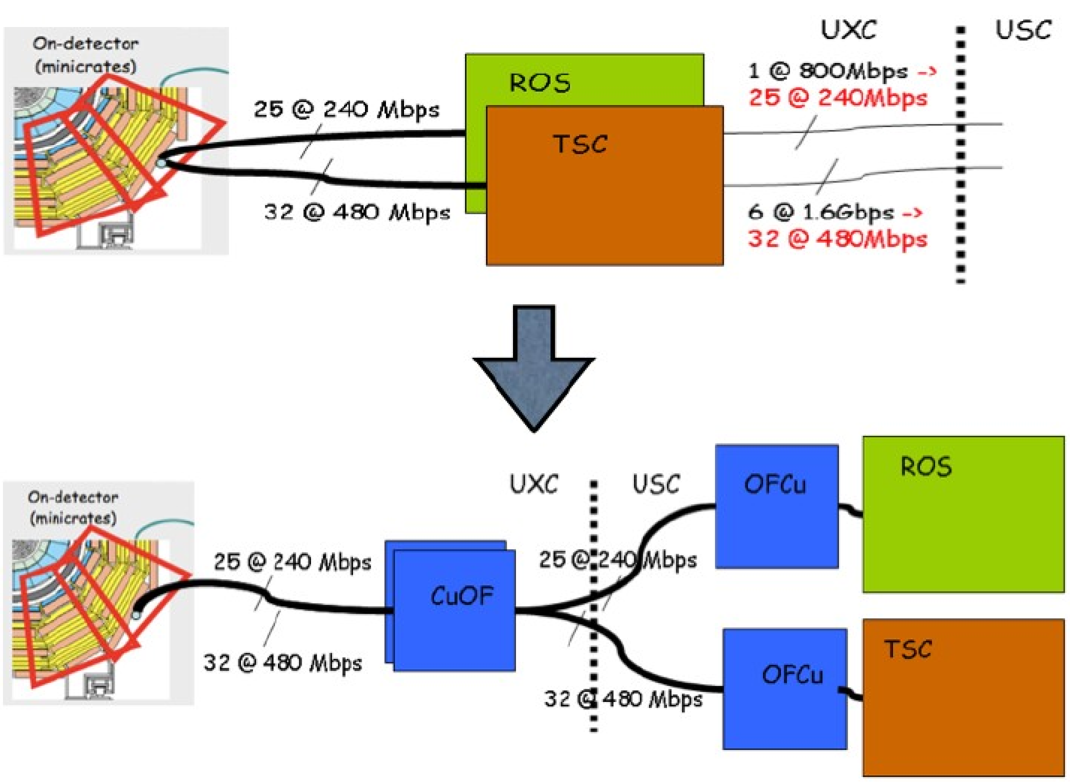
- Muon efficiency does not suffer significantly from pile-up



- 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.

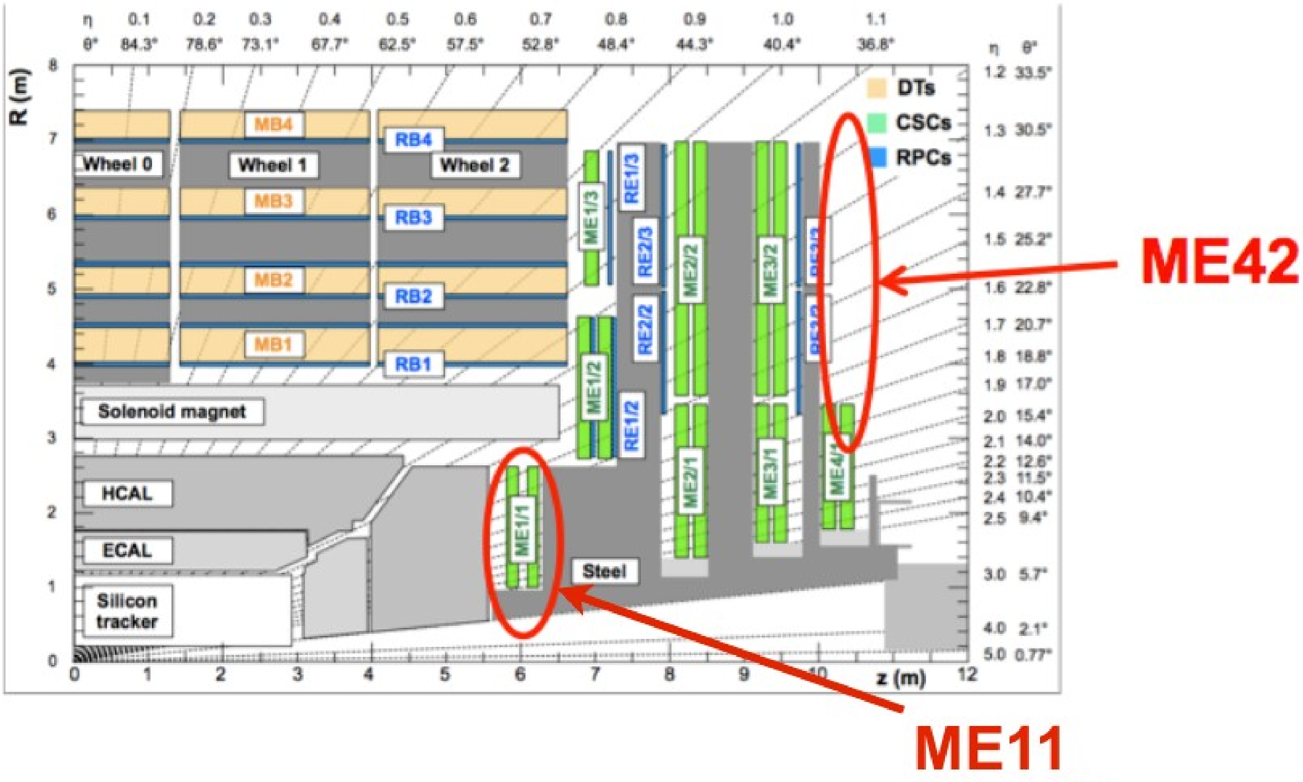
DT interventions during LS1

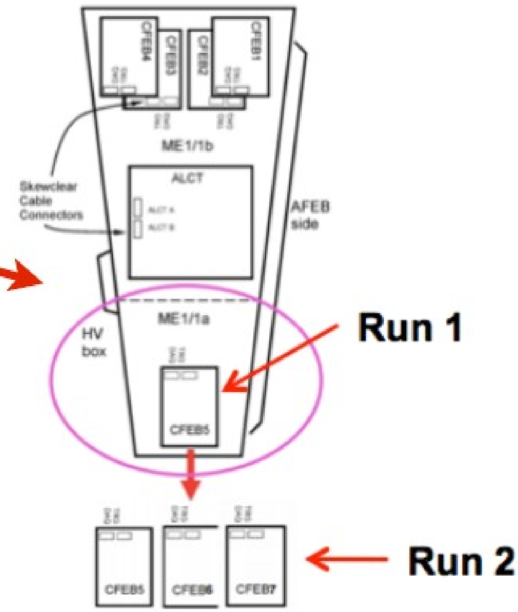
- Sector Collector relocation: move DT trigger & readout concentrator from UXC to USC
  - 20 new electronic crates, ~400 boards installed
  - New fibers from UXC to USC, full trigger information available in USC
  - In preparation for the Level-1 trigger upgrade in 2016 (TwinMux, new DT/RPC/HO concentrator)



- 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



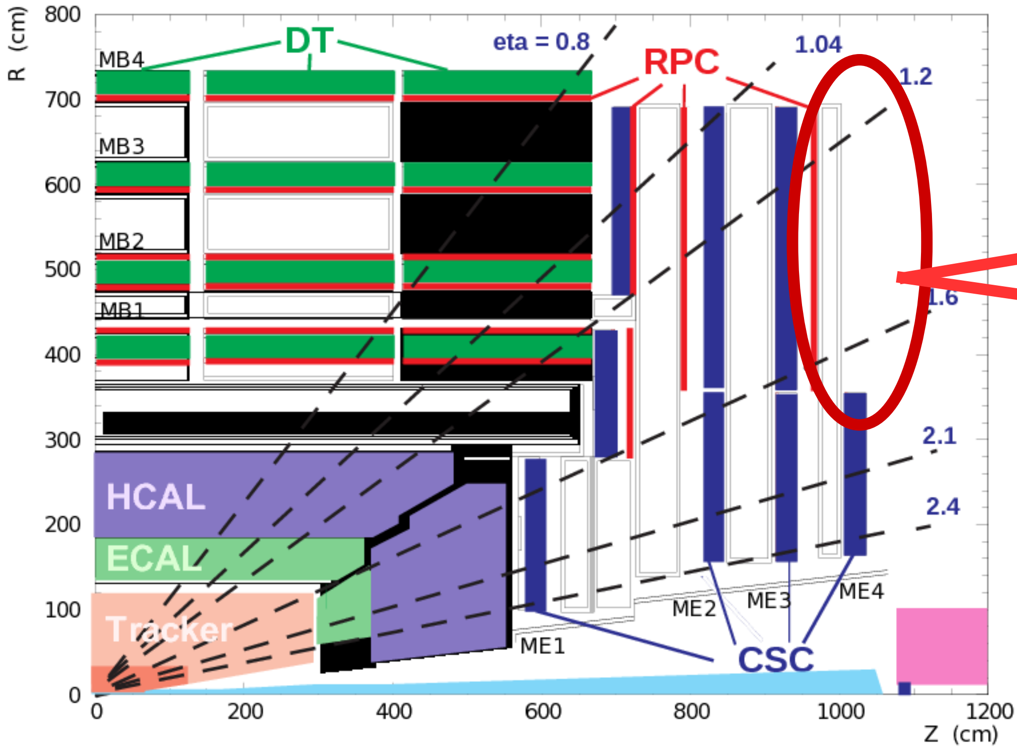


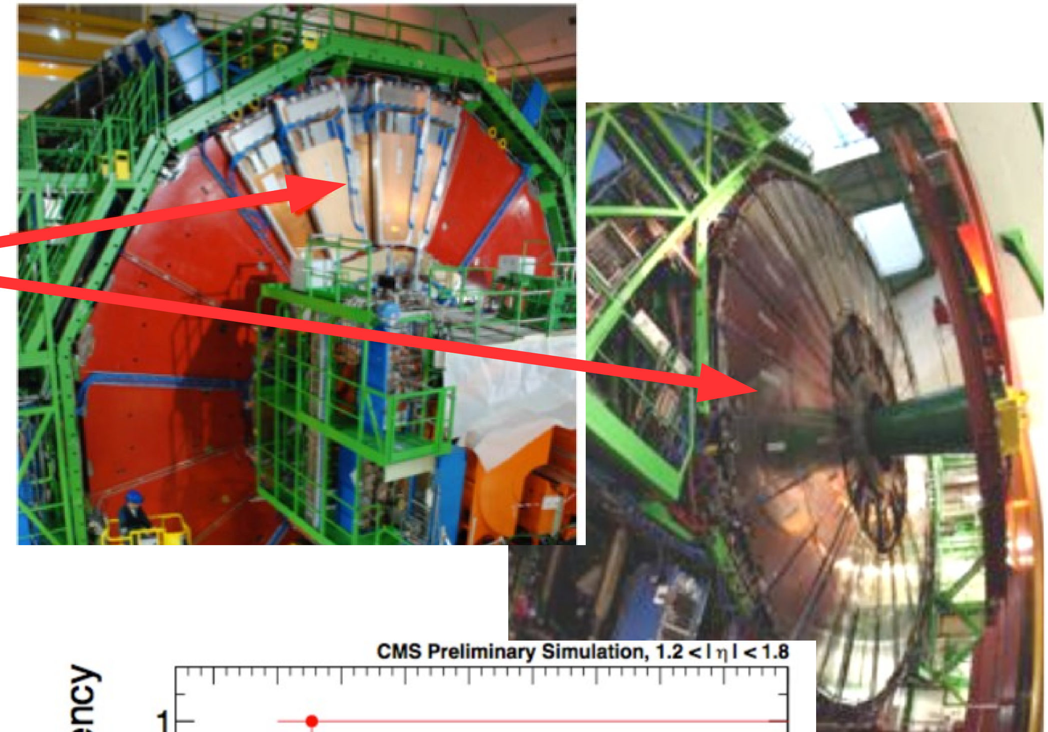
- Replacement of ME11 FE electronics
  - Improve trigger and pattern recognition in 2.1<|η|<2.4 (fine strip granularity of ME11a)
- ME42 construction and installation
  - Improve trigger performance of endcap muon system at L>1034 cm-2s-1 (better Pt resolution, fewer fakes)
- CSC reparations

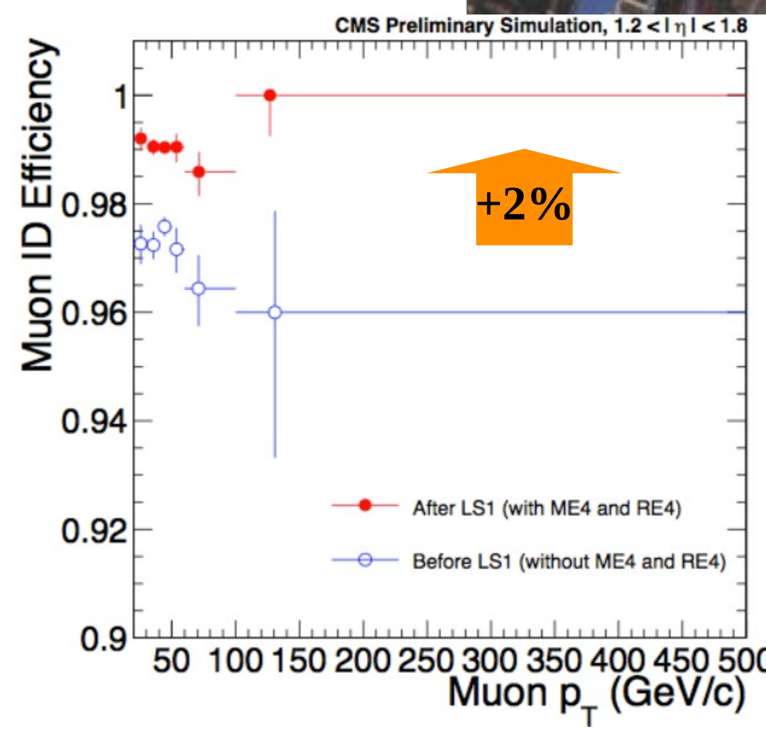
RPC interventions during LS1

- 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



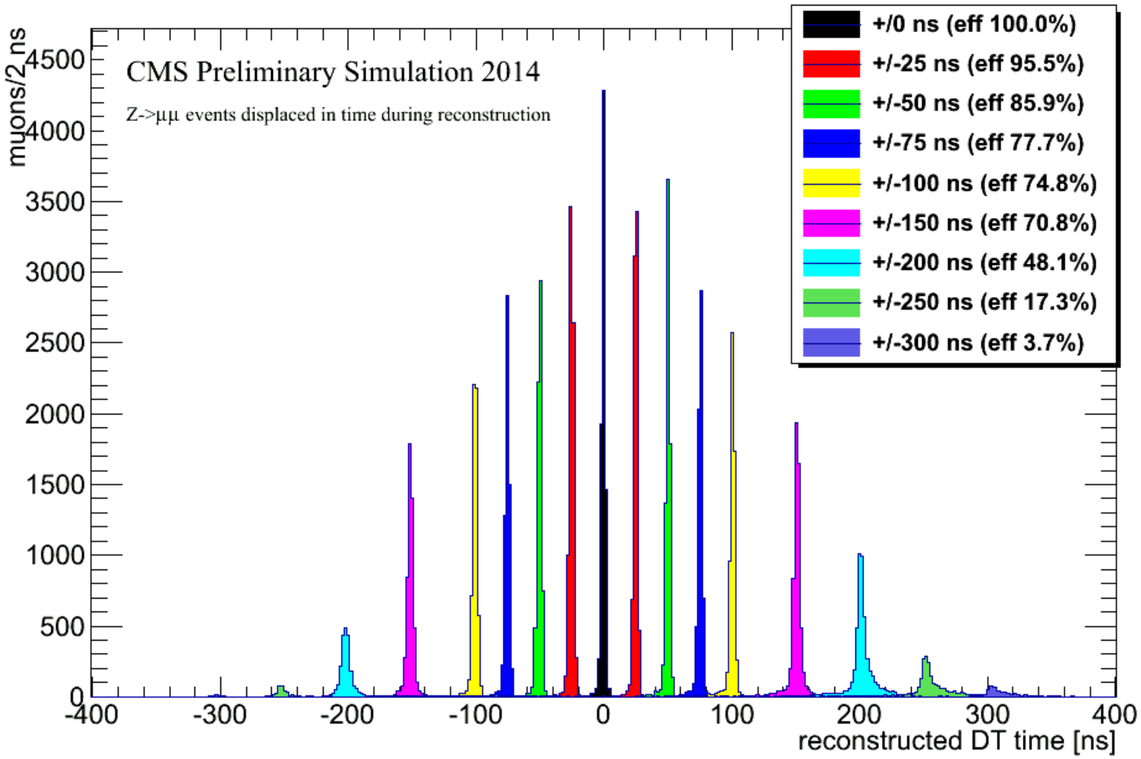




- The completion of the muon system in the forward region increases the muon id efficiency by ~2%.
- Redundancy also improves the fake rate.
- **Performance in run 2 will be better than in run 1.**

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)

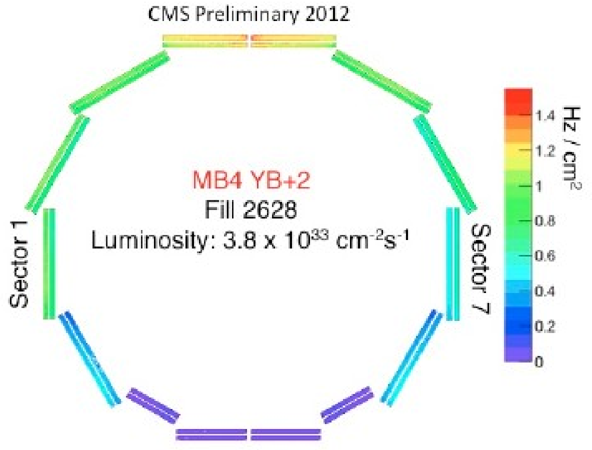
This does not use information from RPCs.

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

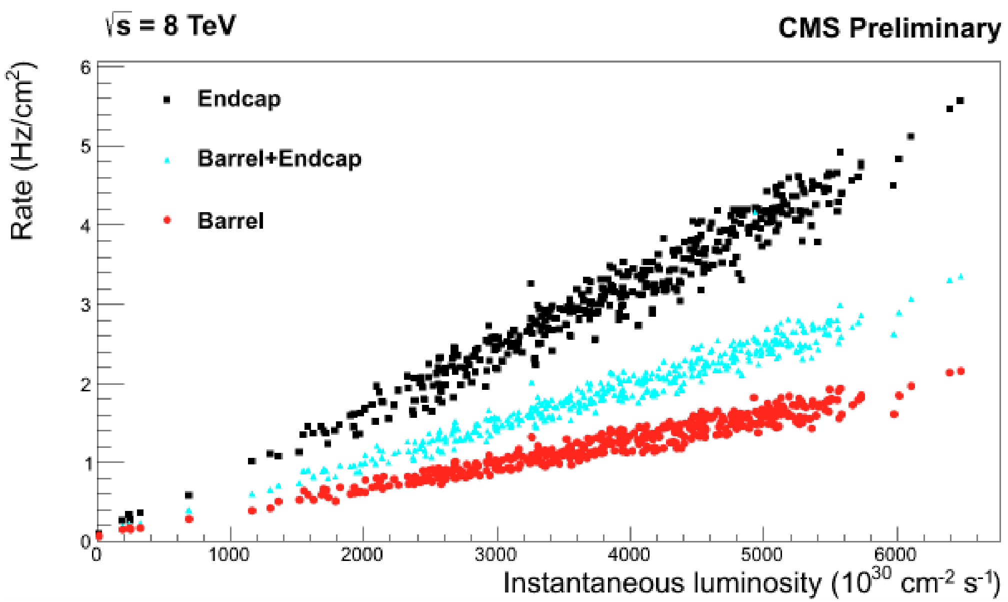
Until now: method used in pattern recognition
From 2015: method extended to final determination of track parameters.

Background in the muon system

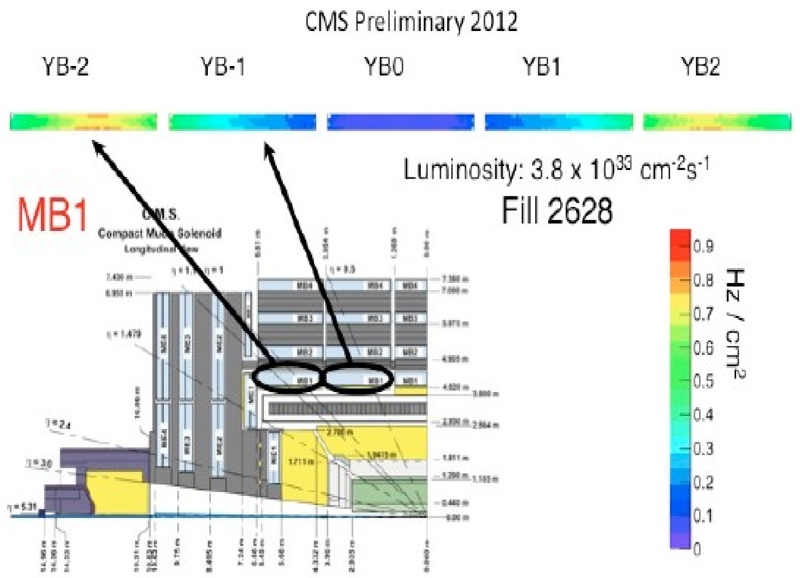
- The main sources of background in the muon system are:
  - **Photon-like background (neutron capture)**: neutrons populating the caverns
    - Highest rates in outer chambers and in top sectors (no shielding, far from the concrete floor)
  - **Prompt background**: mostly punchthrough/flythrough
    - 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



To Conclude...

- During run 2, detectors will face unprecedented conditions
  - Higher pileup
  - Higher integrated dose
  - Higher out-of-time pileup
  - Higher Energy
- At the same time, new or repaired detectors will have to be commissioned.
  - Already started with cosmic rays, will be finalized with first collisions
- Despite all that, performance is expected to equal or even surpass run I.

Backup

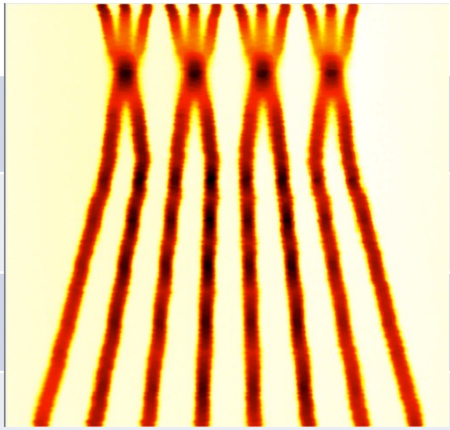
2015 strategy overview

- 2015 will be a re-commissioning, re-conditioning year.
  - Following initial commissioning with beam, **the intensity and performance ramp-up will take longer** than it did in 2011 and 2012.
- 2015 starts with system tests in parallel with hardware commissioning. **Dry runs** of operations functionality also in parallel.
- This is followed by the **Machine Checkout** with particular attention to machine protection commissioning.
- **Low intensity commissioning** with beam of the full operational cycle will last about 2 months.
  - This will include first pass machine protection commissioning and validation in parallel with system commissioning.
  - An exit condition of the beam commissioning phase is **first stable beams** with a low number of bunches and low luminosity.
- **Scrubbing** for around 9 days will be required early on (partially with 25 ns beam) paving the way for 50 ns operation.
- **Intensity ramp-up with 50 ns** is the foreseen. This will take 3 weeks or so.
  - During this stage system commissioning with higher intensity continues (instrumentation, RF, TFB, injection, beam dumps, machine protection, vacuum...).
  - Physics fills can be kept reasonable short during this phase given the experiments lack of interest in accumulating too much 50 ns data.
  - We would image less than, or up to, 1 fb-1 being delivered during the 50 ns ramp-up/running-in phase.
- Thereafter 14 days **scrubbing will be required for 25 ns operation**, followed by a **gentle intensity ramp up with 25 ns** dictated by electron cloud conditions with further scrubbing as required.
- Initial performance with 25 ns: in the 25 ns run at the end of 2012, 25 ns physics was delivered with up to 400 bunches. An 800 bunch attempt was dumped by ALICE going into collision. The beam was made up of batches of 96 bunches (2 injections of 48 from the PS to the SPS). Electron cloud was manageable because of the reduced batch length (nominal would be 5*48 = 240). If we imagine being able to get reasonable quickly up to 800 bunches we should be able to deliver something like 0.5 fb-1 per week during initial 25 ns operation.
- **50 ns is held in reserve as a long term operational option only in case of serious problems with 25 ns.**

Plans for 2015

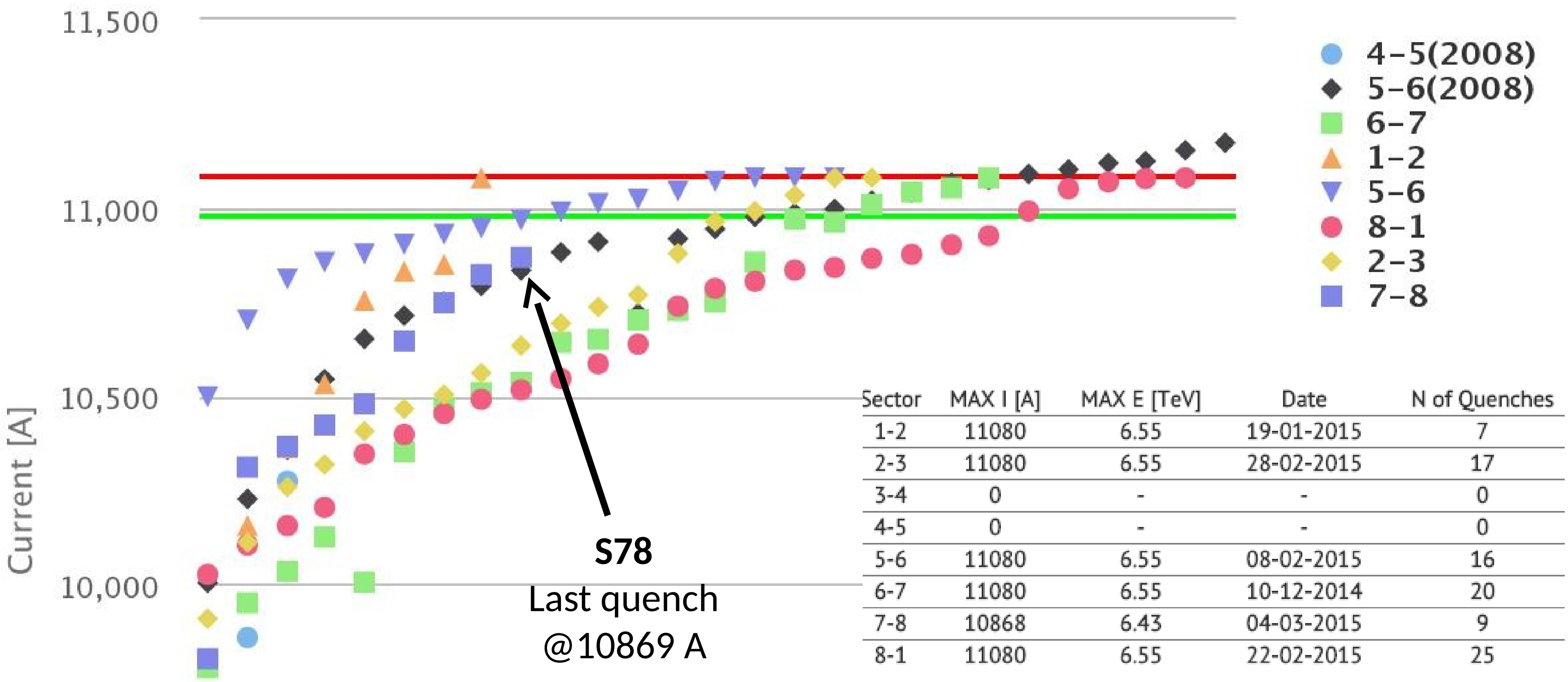
Phase	Days
Initial Commissioning	56
Scrubbing	24
Early LHCf/VdM	5
Proton physics phase 1 (including 50 ns & ramp-ups)	**94**
Change in beta*	**5**
Proton physics phase 2 (including ramp-ups)	**46**
TOTEM/VdM (Note: TOTEM request ~ 2 weeks) Intermediate energy run – to be scheduled	7
MD	22
Technical stops	15
Technical stop recovery	6
Ion setup/Ion run	4 + 24
Total	308 (44 weeks)

Beam conditions for Run 2



Energy	**6.5 TeV maximum**
Bunch spacing	25 ns (but start with 50 ns)
Injection tunes	0.31/0.32
Injection beta*	11-10-11-10
Optics	ATS compatible pending validation
Initial beta*	**>= 65 cm**
Beta beating	At least as good as 2012
Chromaticity	High – acceptable (but lower in stable beams)
Collimators	2012 settings in mm (intermediate)
Octupoles	LOF < 0 (negative detuning)
Bunch length	**~1.25 ns**

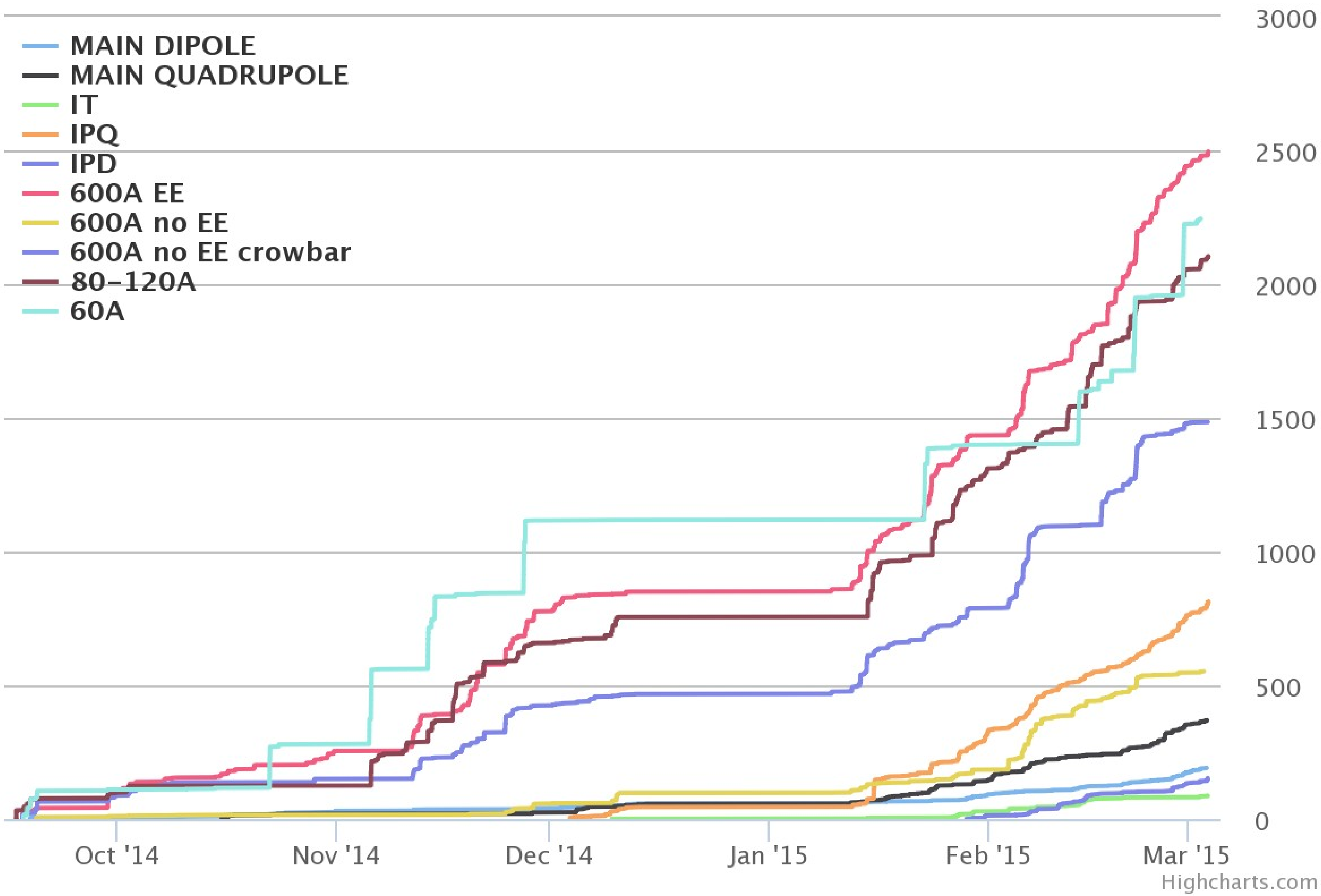
TRAINING QUENCH PLOT



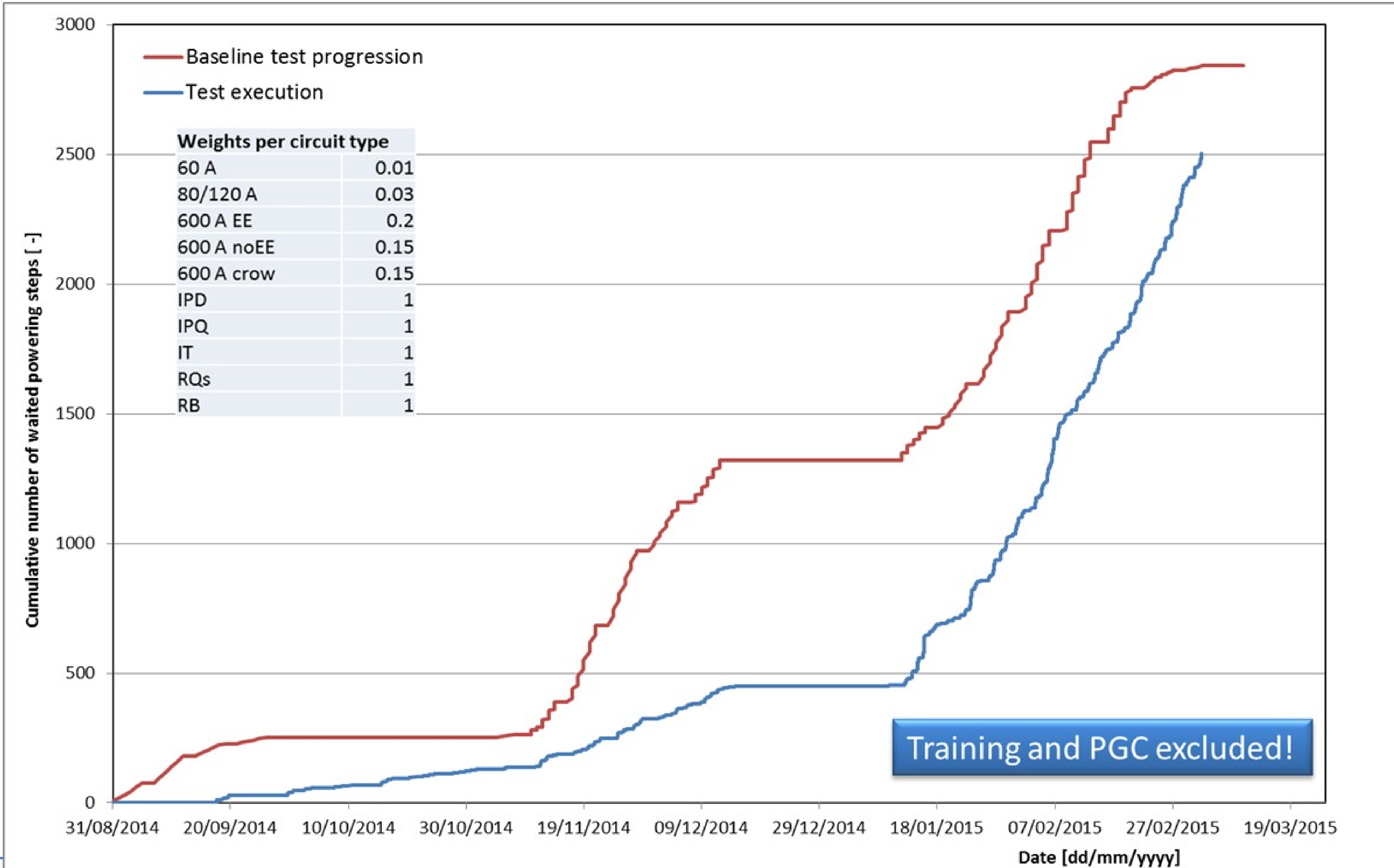
Sector	MAX I [A]	MAX E [TeV]	Date	N of Quenches
1-2	11080	6.55	19-01-2015	7
2-3	11080	6.55	28-02-2015	17
3-4	0	-	-	0
4-5	0	-	-	0
5-6	11080	6.55	08-02-2015	16
6-7	11080	6.55	10-12-2014	20
7-8	10868	6.43	04-03-2015	9
8-1	11080	6.55	22-02-2015	25

Circuit	Status	#M Firm 1	#M Firm 2	#M Firm 3	#MQ Firm 1	#MQ Firm 2	#MQ Firm 3	#MQ total	#CQ total	Estimate
RB.A12	11080 A reached	50	95	9	2	1	4	7	7	-
RB.A23	11080 A reached	56	58	40	0	2	15	17	17	16
RB.A34	not started	44	81	29	-	-	-	-	-	13
RB.A45	not started	48	44	62	-	-	-	-	-	24
RB.A56	11080 A reached	28	42	84	0	0	17	17	16	-
RB.A67	11080 A reached	57	36	61	0	1	19	20	20	-
RB.A78	in progress	53	40	61	1	5	3	9	8	23
RB.A81	11080 A reached	64	24	66	0	3	25	28	26	-

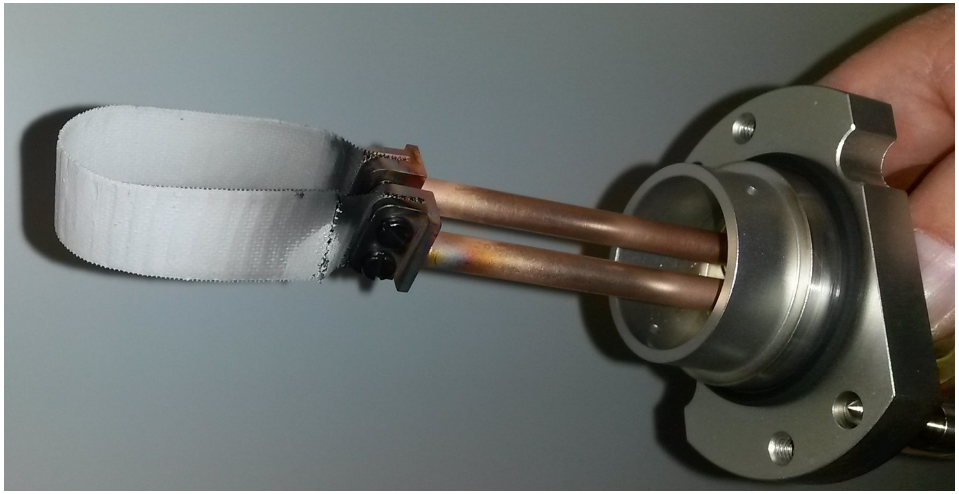
POWERING TESTS GLOBAL ADVANCEMENT

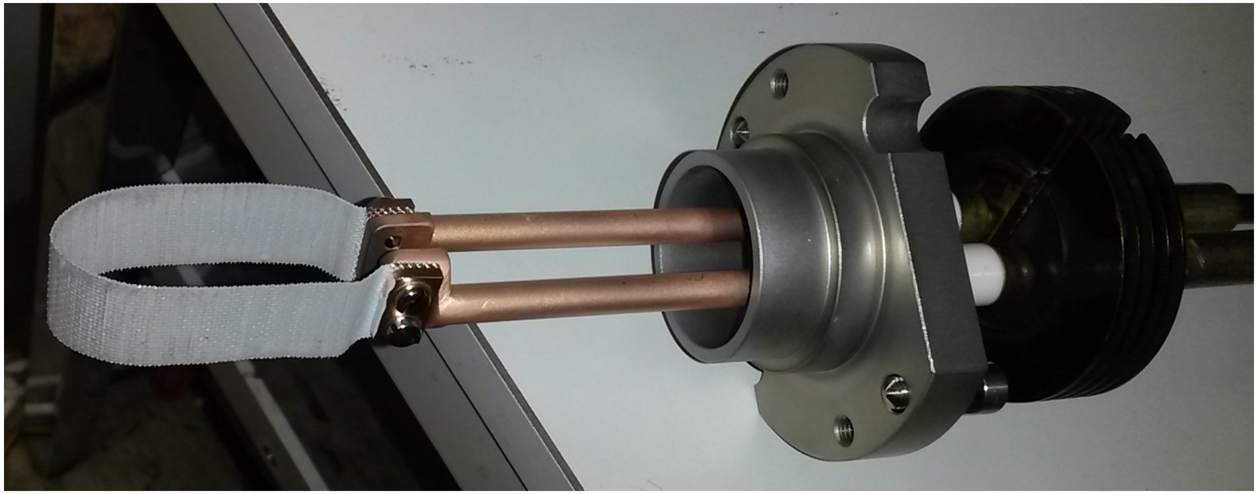


“WEIGHTED” ADVANCEMENT



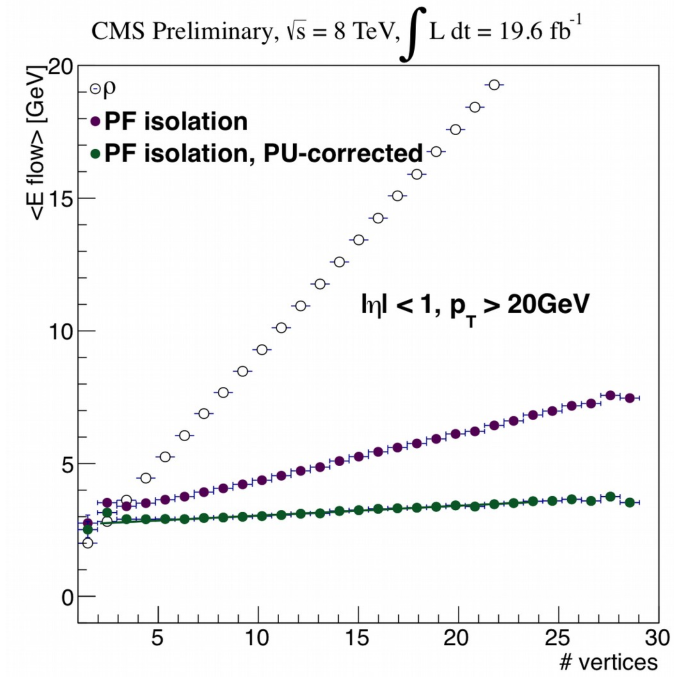
Weights per circuit type	
60 A	0.01
80/120 A	0.03
600 A EE	0.2
600 A noEE	0.15
600 A crow	0.15
IPD	1
IPQ	1
IT	1
RQs	1
RB	1



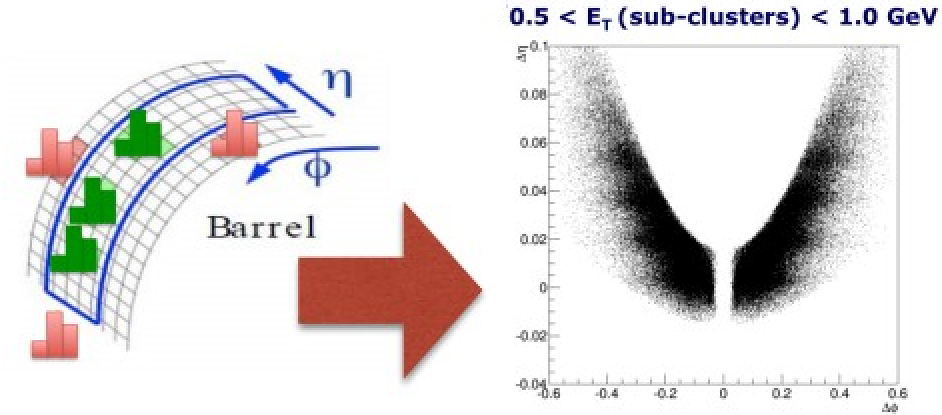


ECAL reconstruction

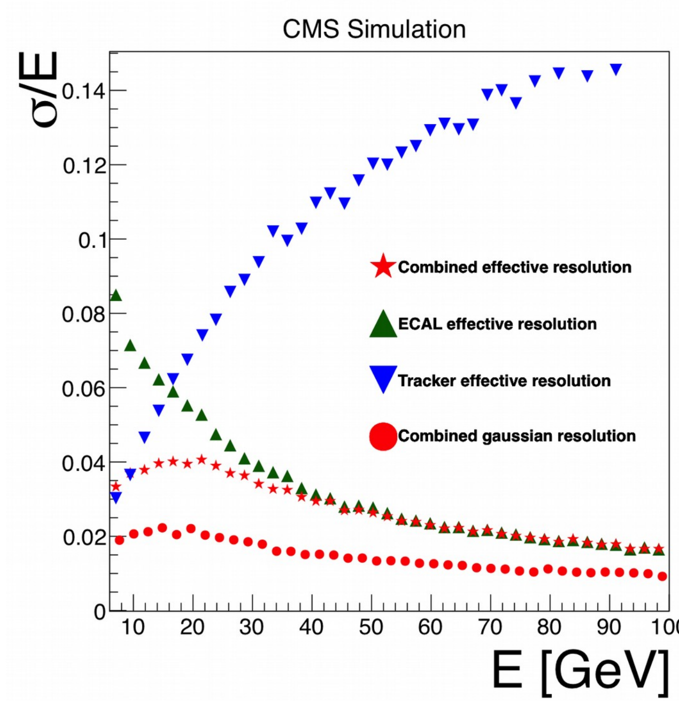
- Pile-up subtraction performed using
  - Vertex association for charged particles
  - Rho correction for neutrals



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

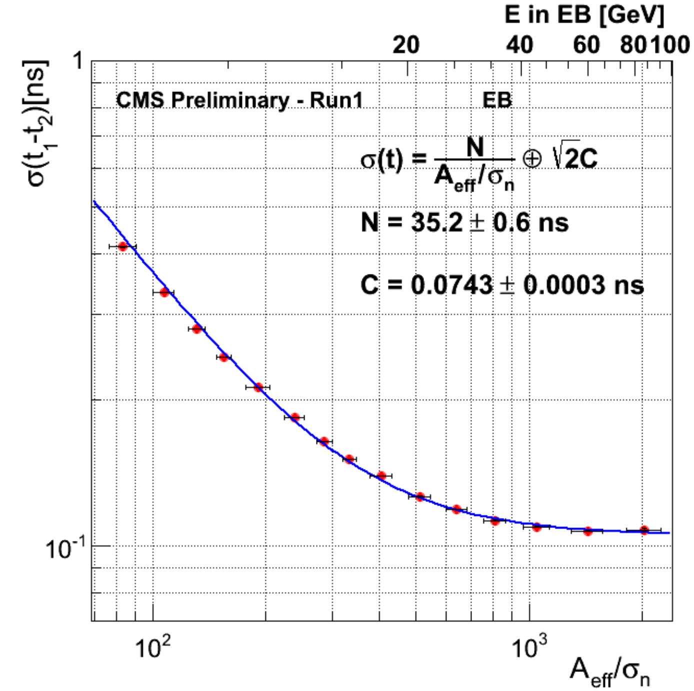


- Allows to maintain the established performance for electron reconstruction

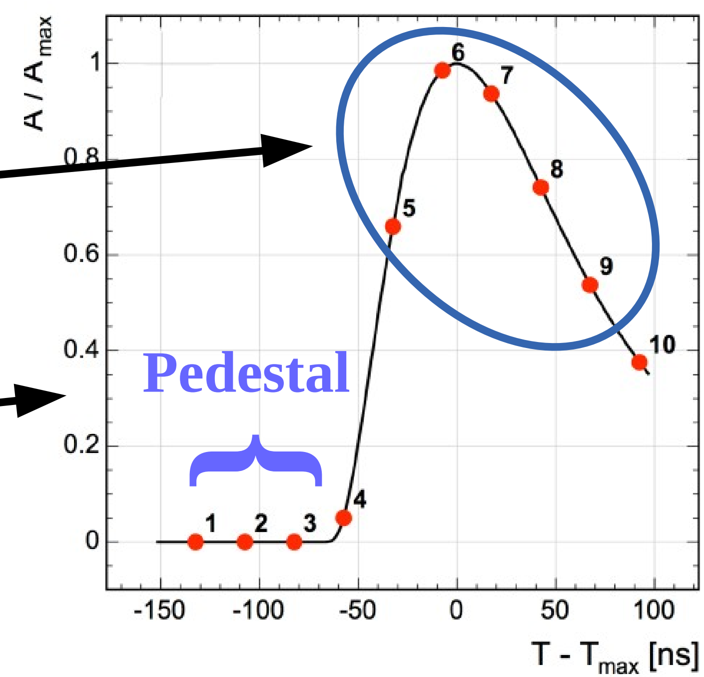


Electrons/photons reconstruction: OOTPU

- 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
  - Time extracted from ratios of consecutive 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



- In run I the strip tracker operated at a cooling plant set point of +4°C because of problems with too high humidity levels in the tracker service channels and bulkhead
- After LS1 the operating temperature will be significantly lower to avoid problems due to
- Too high leakage current
- Long-term effects on the depletion voltage
- During LS1 the Tracker Humidity Improvement Project successfully addressed the humidity problems