Operational Experience at 7 TeV

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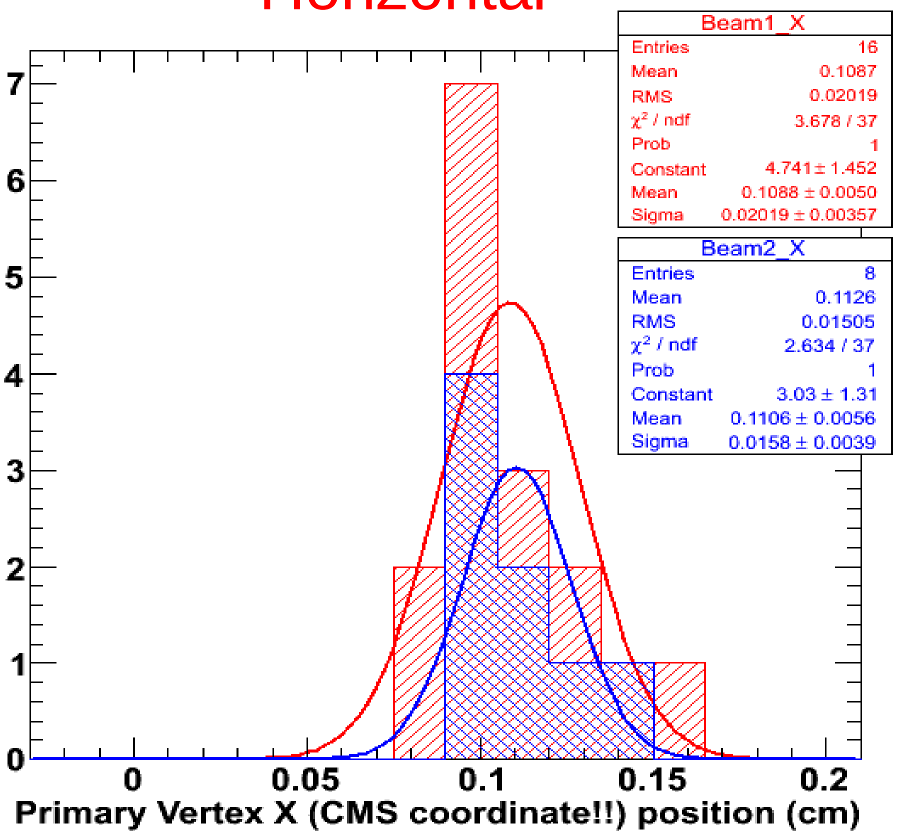
Outline:

- First 7 TeV collisions
- Delay scan and trigger commissioning
- Detector performance
- Some recent operational issues
- LHC plans
- Summary

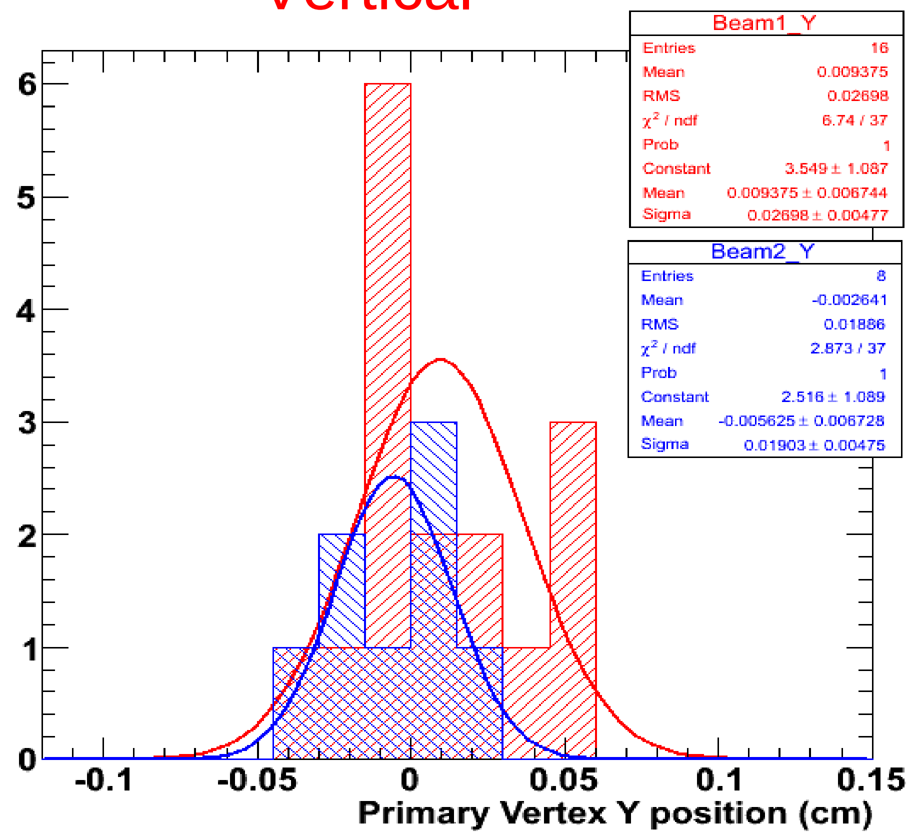
CERN Media Event – March 30, 2010

- Before the first 7 TeV stable beams for the 'The CERN Media Event', we took data with non-colliding beams to reconstruct beam-gas interactions to determine the beam positions to verify that we would have collisions in CMS.
  - First time we had stable beam since Dec. 2009 was at 01:00 on March 30.

Horizontal

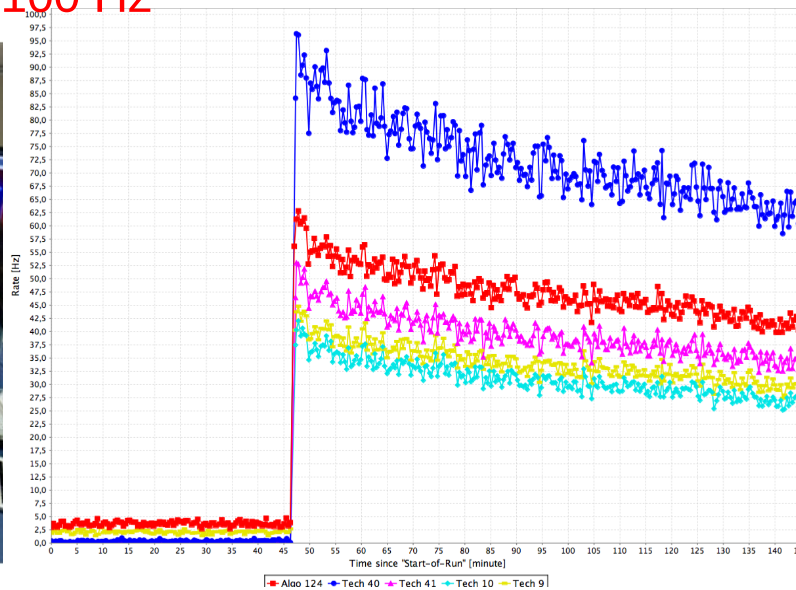


Vertical

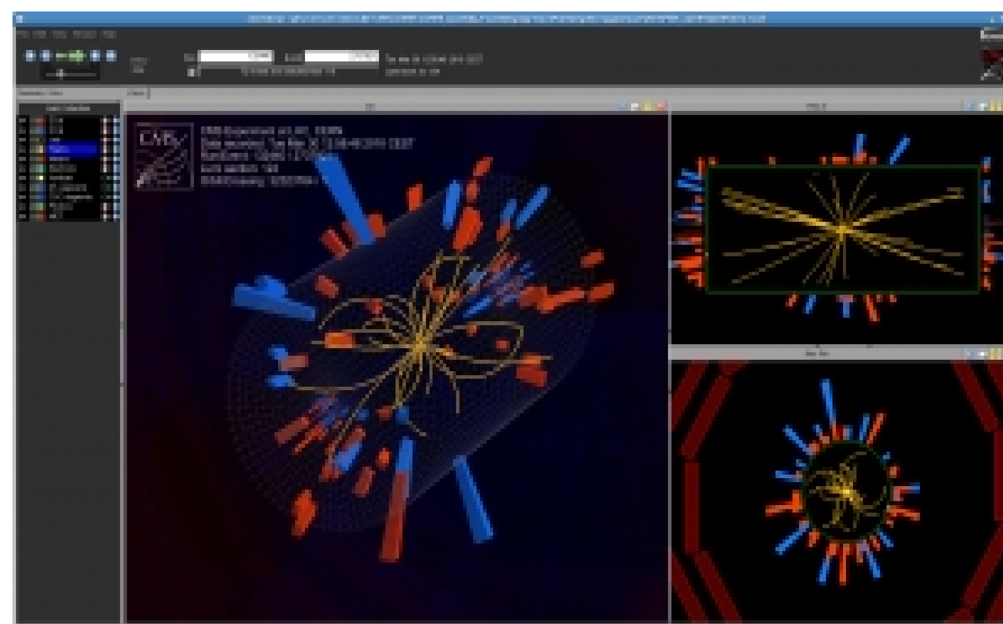


March 30: First 7 TeV Collisions

100 Hz



12:58

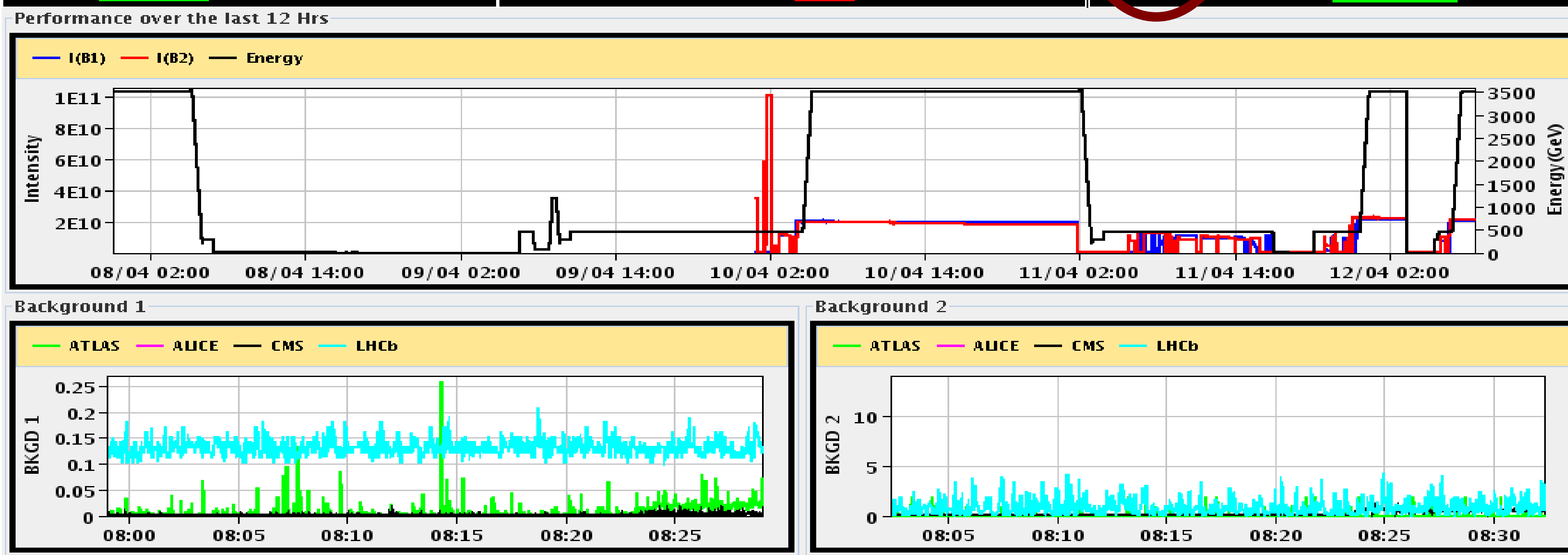


Live Luminosity and Backgrounds

12-Apr-2010 08:32:54 Fill #: 1034 Energy: 3500.3 GeV I(B1): 2.0[illegible]e+10 I(B2): 2.15e+10

	ATLAS	ALICE	CMS	LHCb
Experiment Status	STANDBY	No Info	STANDBY	STANDBY
Instantaneous Luminosity	1.266e-03	--	1.214e-03	0.000e+00
BRAN Count Rate	--	0.000e+00	3.025e+01	1.385e+00
BKGD 1	0.013	--	0.002	0.141
BKGD 2	0.000	--	0.468	0.968
BKGD 3	0.000	--	0.003	0.031

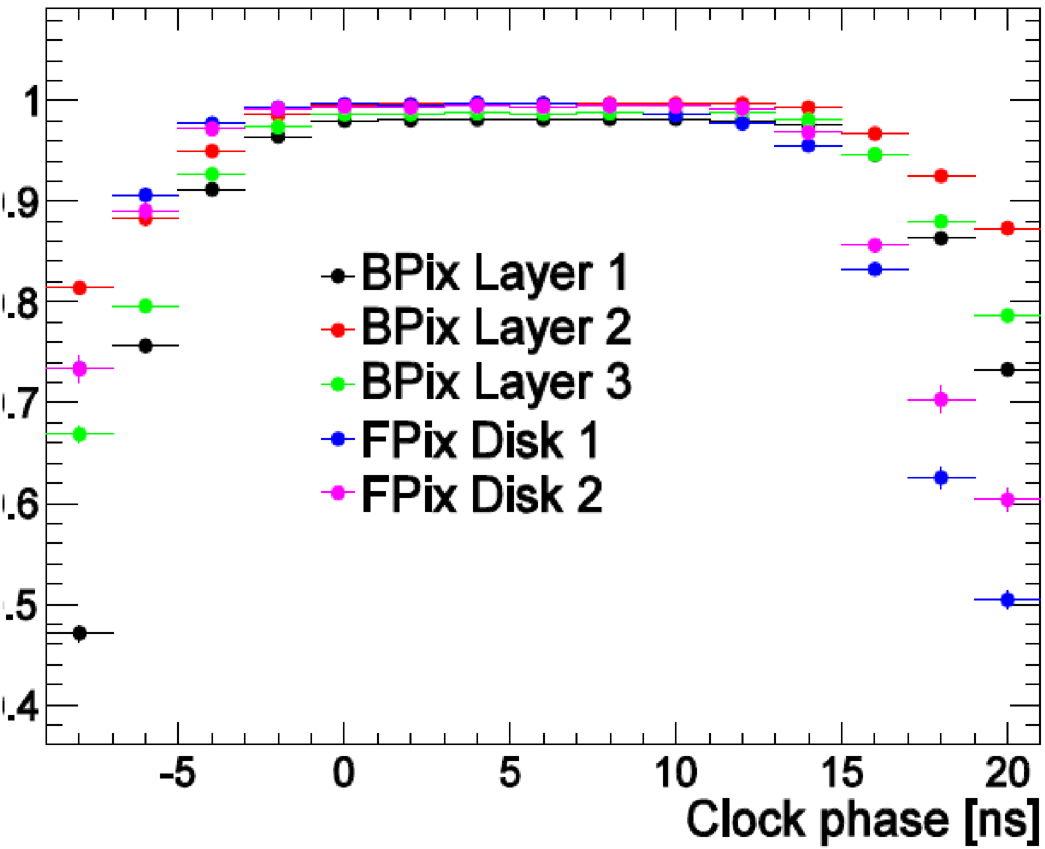
LHCf STANDBY Count(Hz): 0.000 | LHCb VELO Position OUT Gap: 58.0 mm | TOTEM: STANDBY



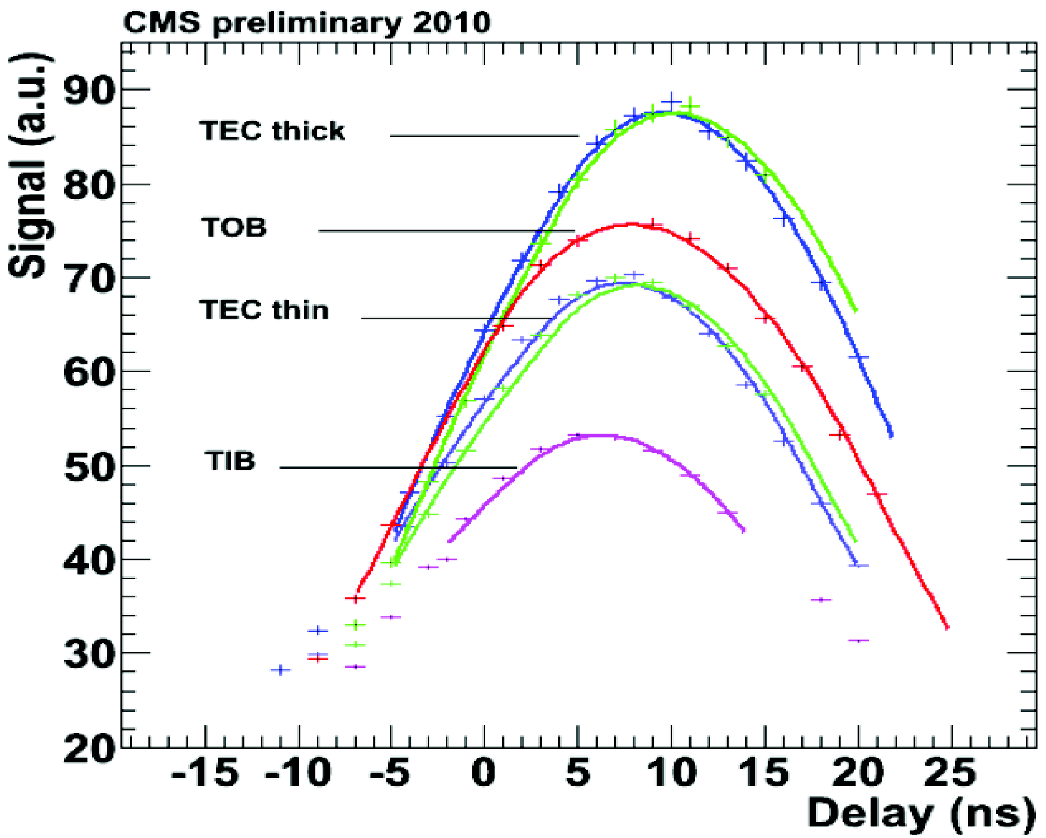
Some issues with delivering luminosity all the time – still being worked on...

Pixel and Strip Time Alignment

Pixel



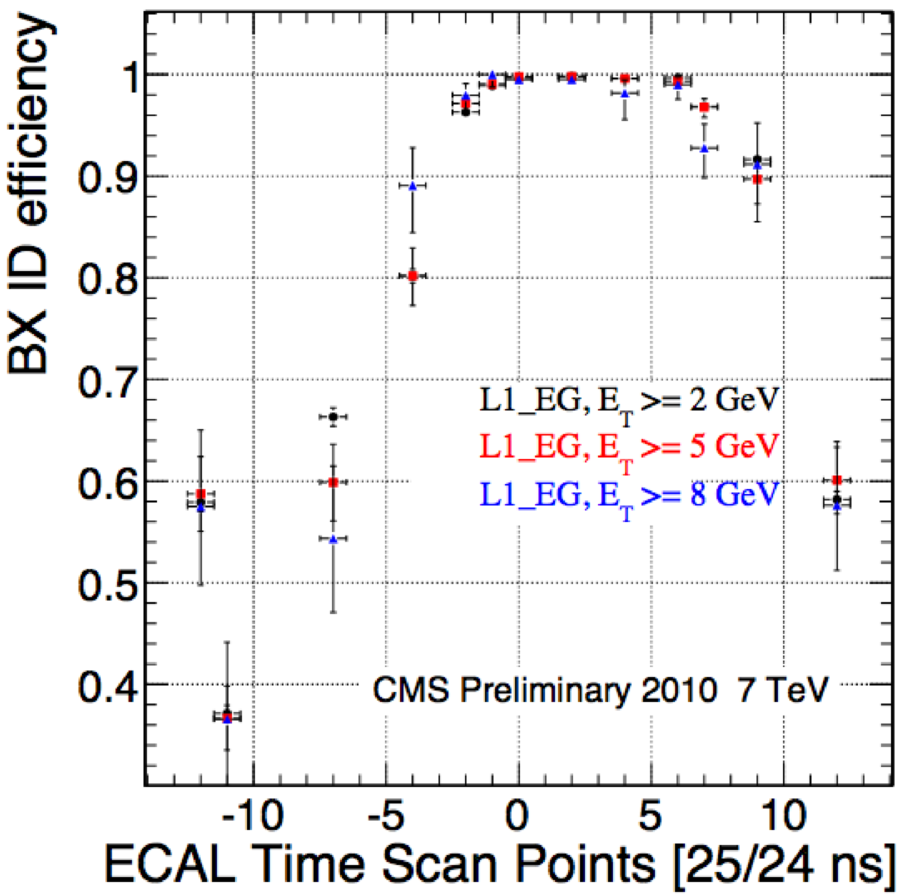
Strips



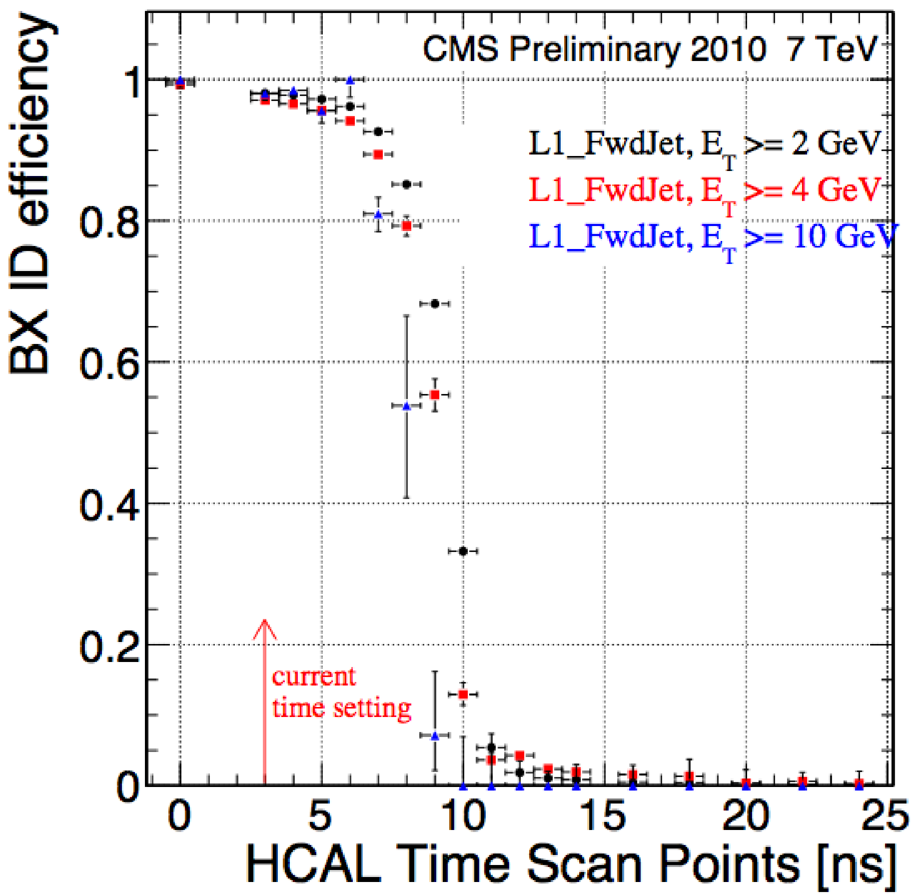
- Fine delay scans – in steps of ~2ns – taken to time align tracking detectors with respect to the LHC beam.
- Optimal time alignment important to measure small charge deposits – important for positions resolutions in pixels via charge sharing.

ECAL and HCAL Time Alignment

ECAL

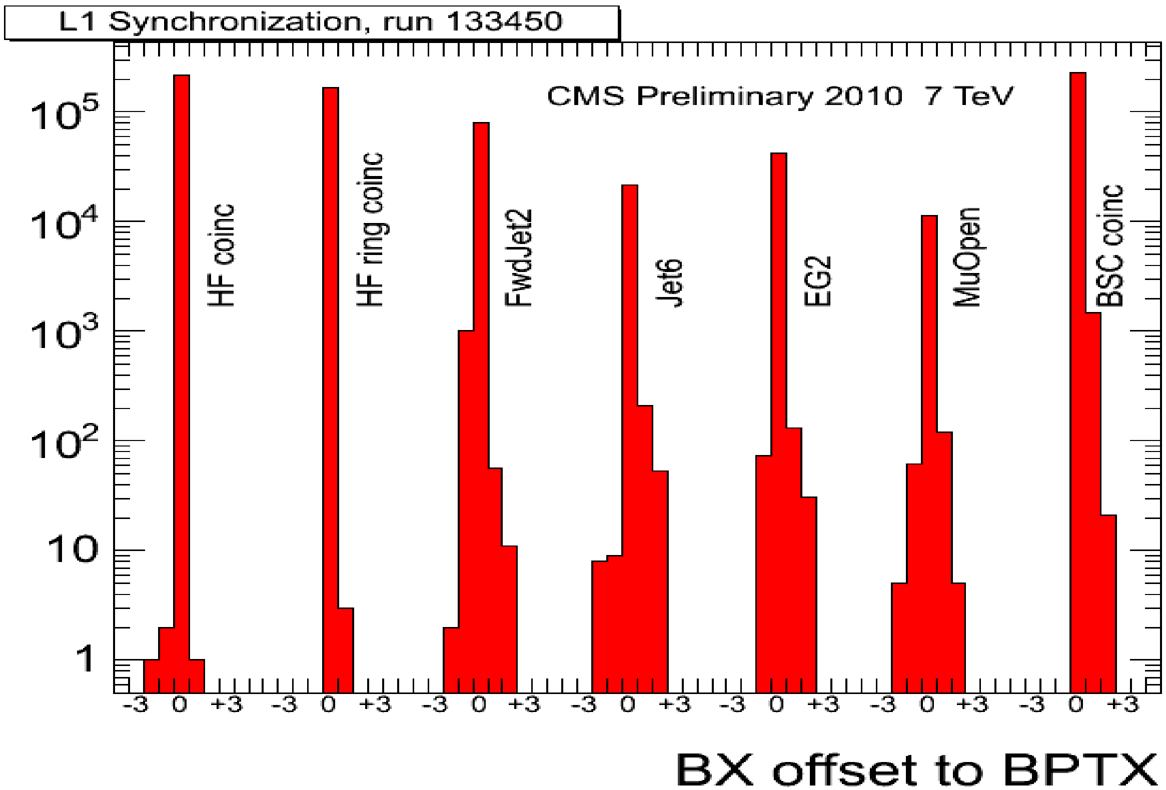


HCAL



- Fine phase adjusted to ensure precise timing of L1 trigger

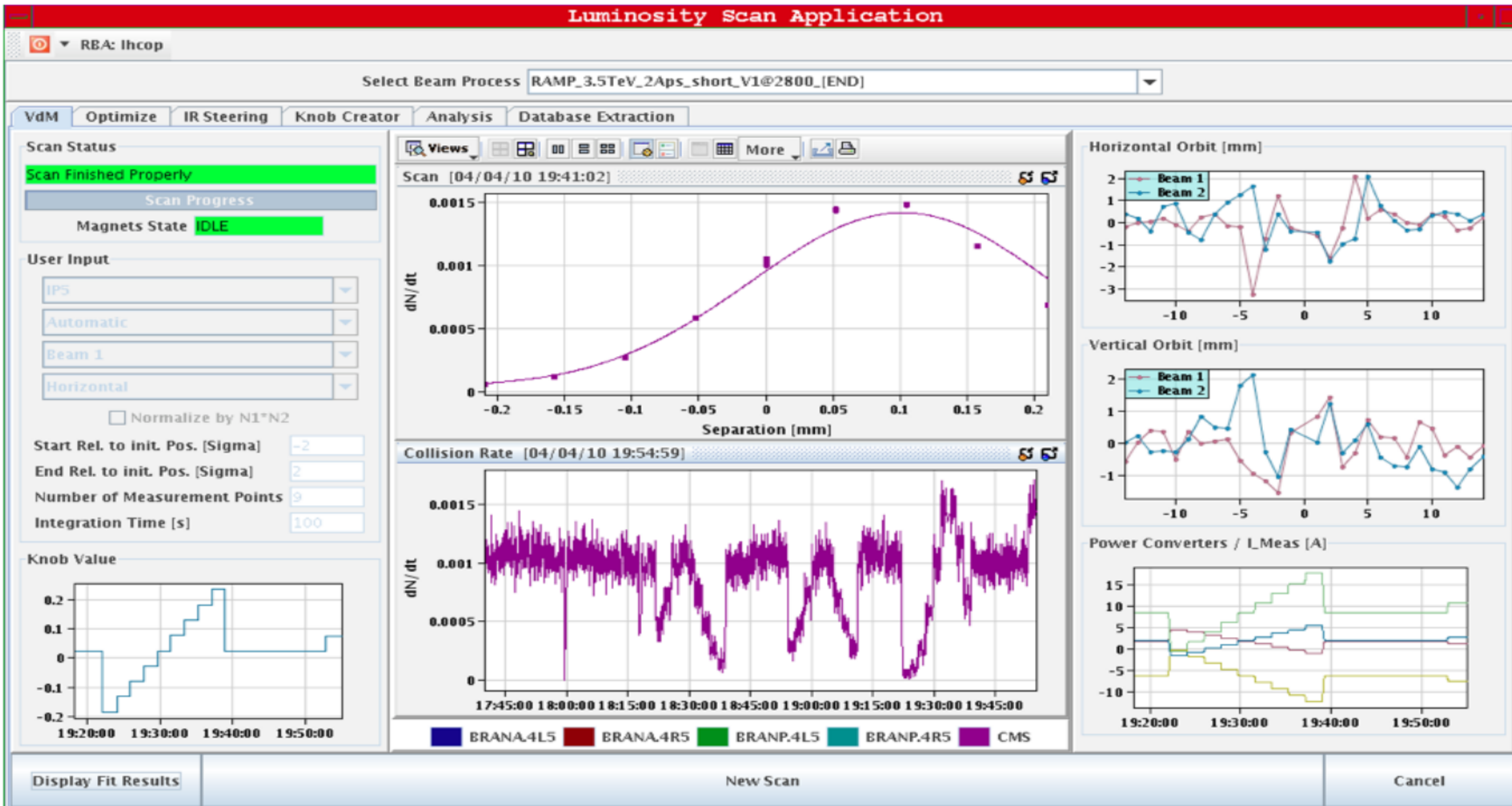
L1 Time Alignment



- With timed in L1 algorithms we deployed them in the trigger.
- These studies has continued, with over 1/pb of data we now have most of the muon timing updated.

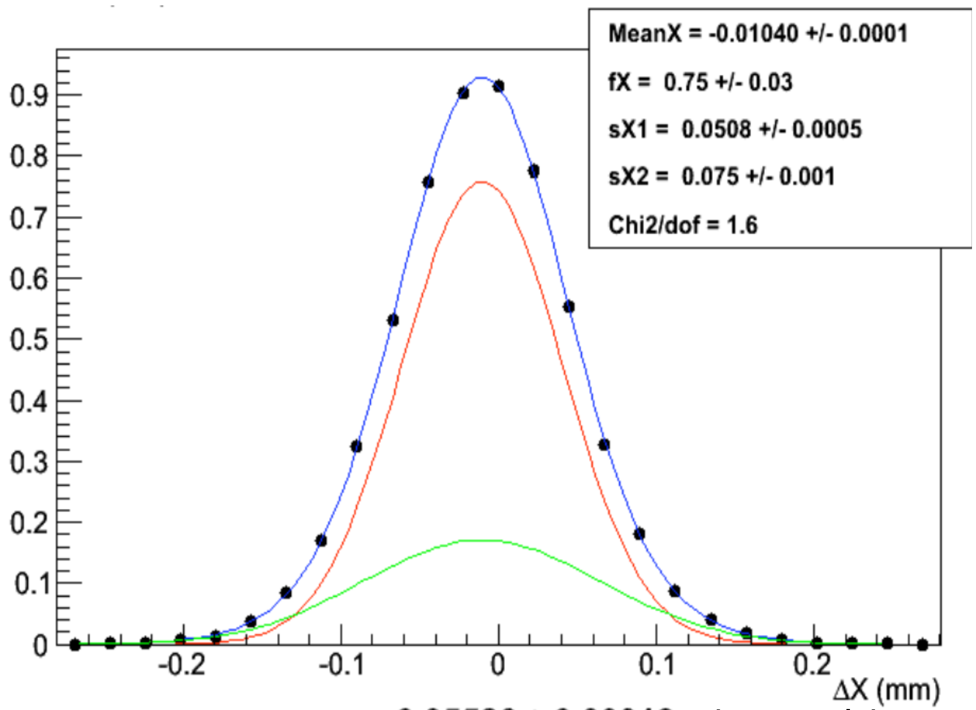
'Mini' Lumi Scans - Optimization

- Though we saw a reasonable collision rate in the first fill, in many fills the initial interaction rate were lower than expected.
- Performing 'mini' lumi scans to optimize the luminosity is now routine.

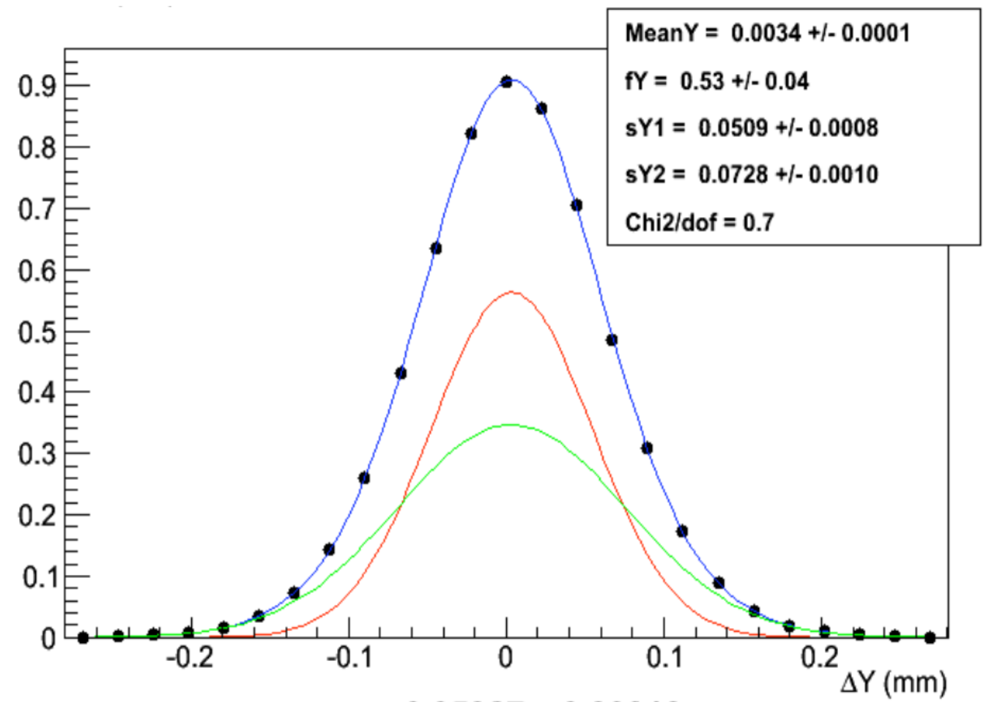


Van der Meer Scans

- We have also performed full van der Meer scans to measure the beam size and combined with the measured bunch currents it allows us to determine the absolute luminosity.



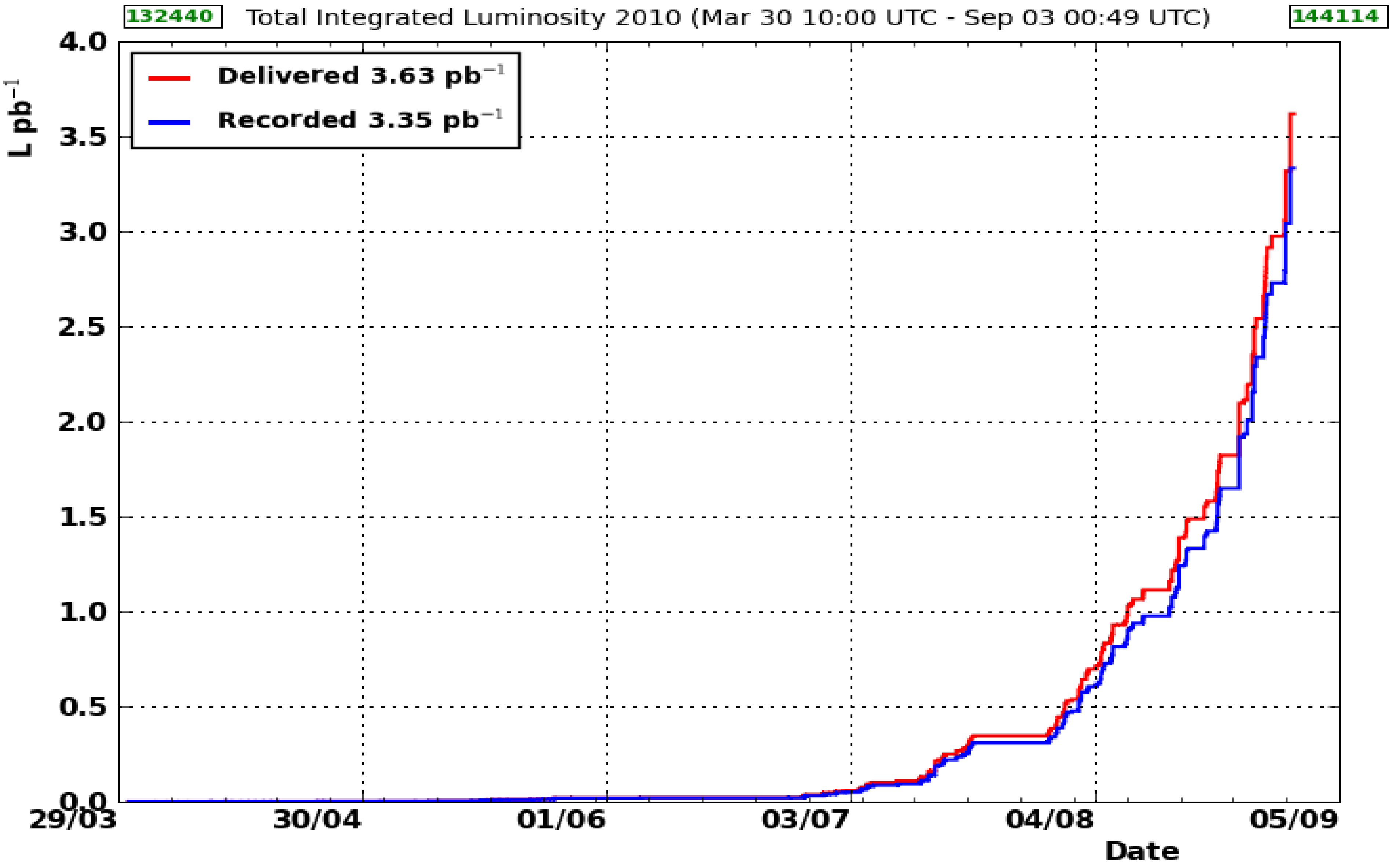
σ_{eff} = 0.05526 ± 0.00012 (stat. only)



σ_{eff} = 0.05927 ± 0.00012 (stat. only)

- Absolute luminosity known to ~11% now, dominated by 10% uncertainty from beam current.

Integrated Luminosity

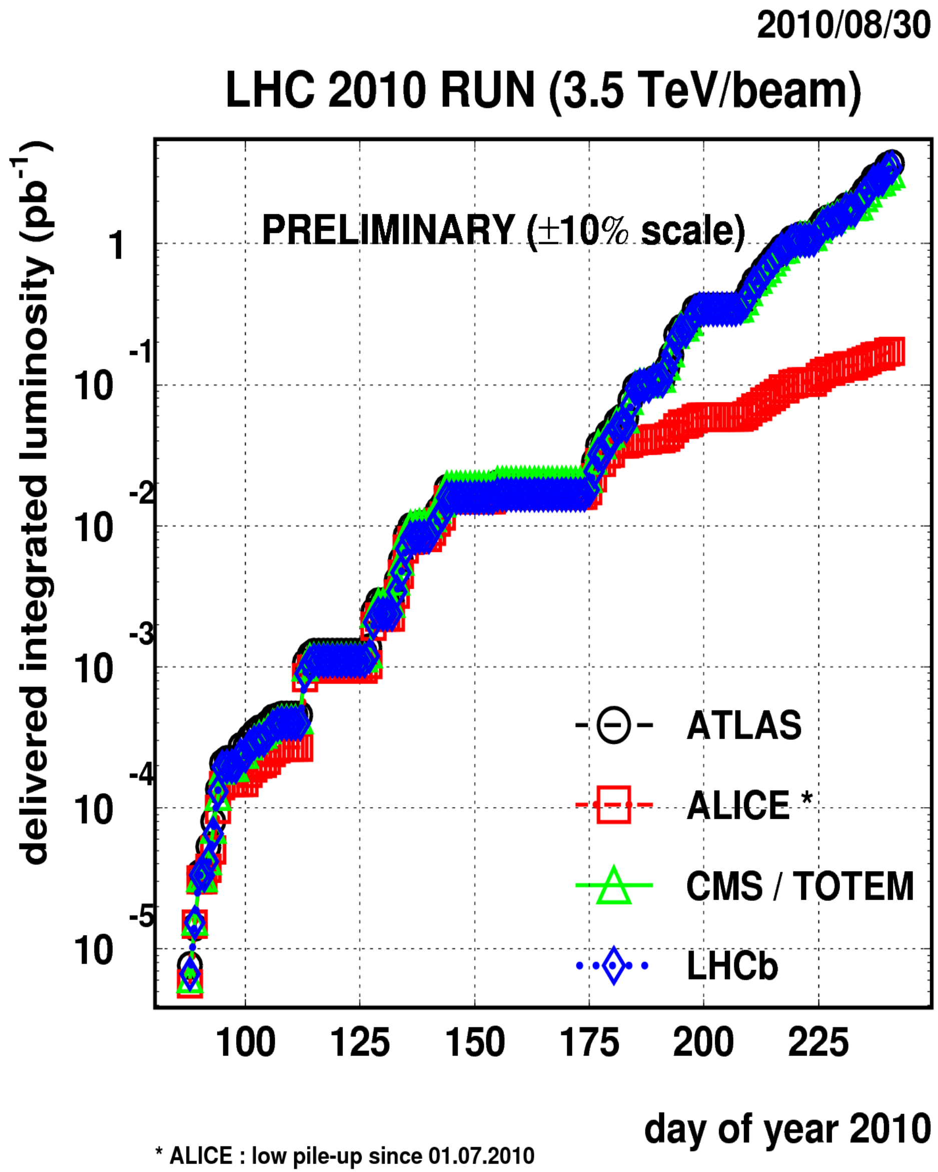


Luminosity Evolution

Luminosity 'knobs' for the LHC:

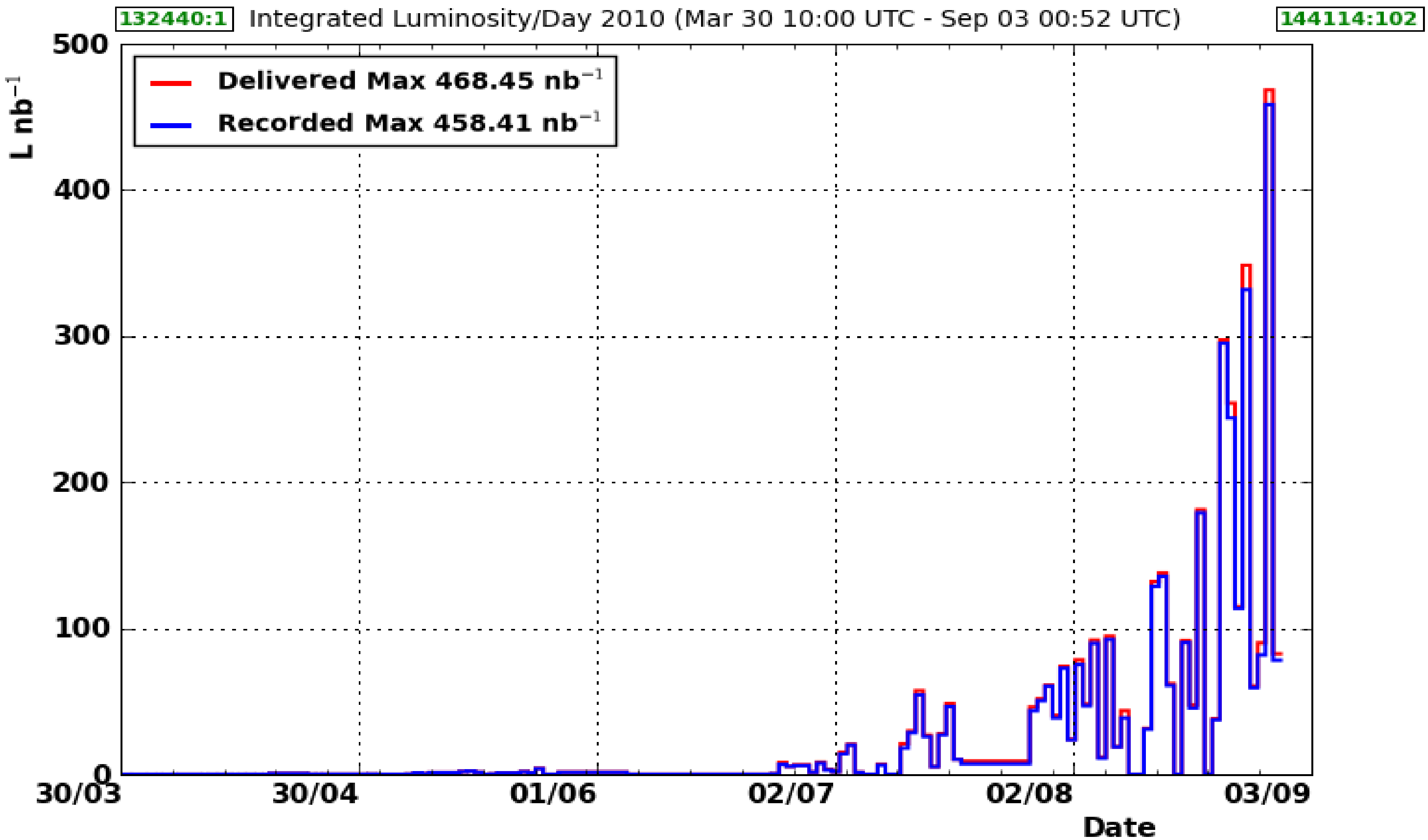
- Bunch charge, nominal 1.15×10^{11}
- Focus, β*, ultimate 0.55m.
- Colliding bunches

Date	Bunch chg.	β* m	#colliding bunches	L inst.
10-03-30	1×10^{10}	10	1	5×10^{27}
10-04-10	1×10^{10}	2	2	3×10^{28}
10-04-20	1×10^{10}	2	4	6×10^{28}
10-05-15	2×10^{10}	2	8	2×10^{29}
10-06-27	1×10^{11}	3.5	2	5×10^{29}
10-07-02	1×10^{11}	3.5	4	1×10^{30}
10-07-10	1×10^{11}	3.5	8	2×10^{30}
10-07-28	1×10^{11}	3.5	16	4×10^{30}
10-08-15	1×10^{11}	3.5	35	1×10^{31}



The goal for the rest of the pp operation is to
Increase the number of colliding bunches to ~400
In order to reach a luminosity of 10^{32} this year

Daily Luminosity



Rapid progress: On Aug. 29 LHC delivered 450/nb – more than we had recorded before ICHEP!

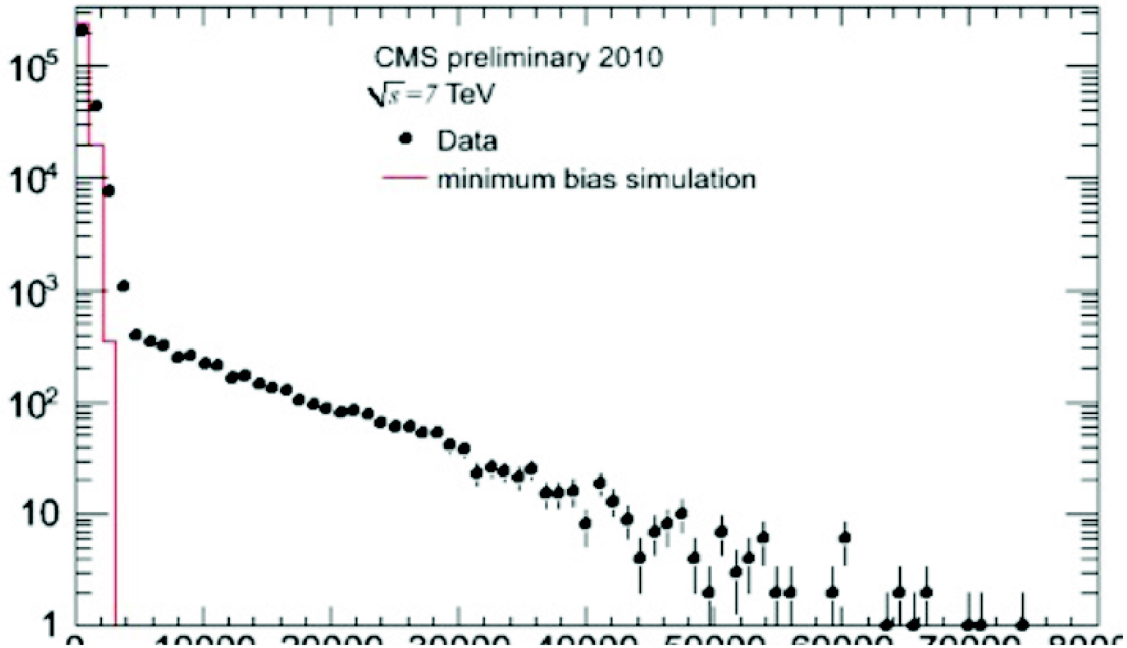
Trigger Operation

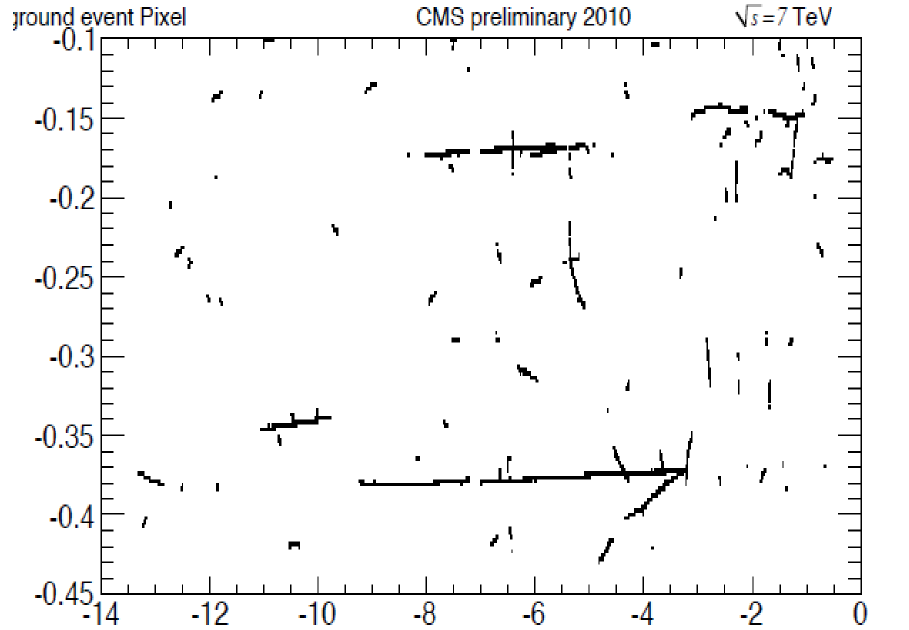
- As we have seen the luminosity increased by more than a factor of 10^3 since the start of beam operation in late March.
- A large number of changes to the trigger configurations, both L1 and HLT, has been required:
  - Starting with pass through menues for all min bias triggers
  - Min bias triggers or zero bias in L1 and selection in HLT
  - Now increasing thresholds in L1 to keep L1 rate at around 50 kHz
- The challenge as we increase the luminosity in the next two months by another factor of 10 is not only to keep the rate in control, but we are currently utilizing about 50% of the CPU in the HLT farm.

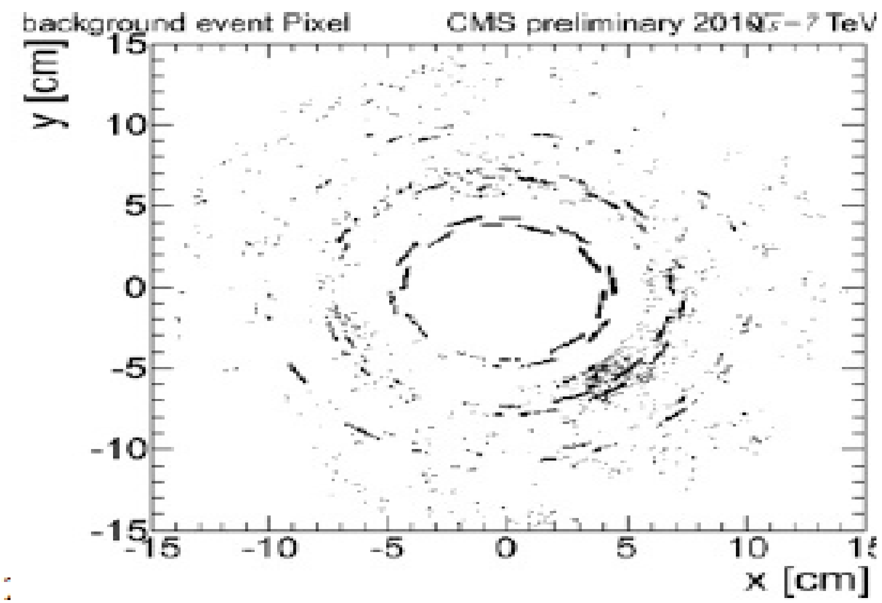
Operational Issues

- There are many issues that has come up over the last few months of operation that have – or still are – requiring attention.
  - Pixel PKAM – and busy firmware issues
  - CSC out-of-synch with beam halo triggers
  - What a re-synch means in CMS
  - Turbine failures
  - Magnet cryo filter regeneration
  - Strip 'clock offset'
  - RPC out-of-synch
  - DB overload from storage manager
  - ...
- On the next few slides I will say a few words about the issues in blue above.

High Pixel Occupancy Events



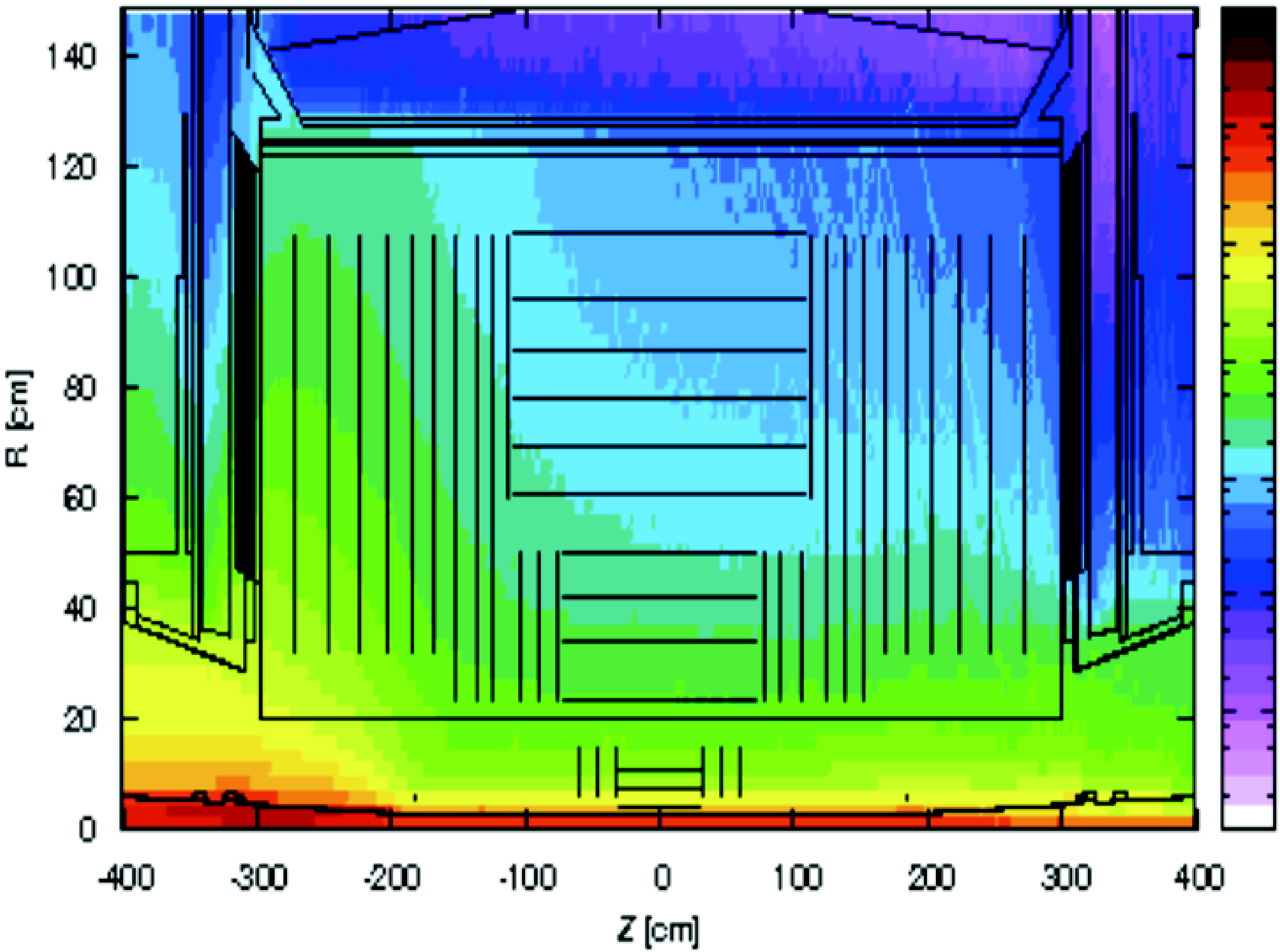




- Events with occupancy much larger than expected from minbias events seen in the pixel detector.
  - Tracks parallel to the barrel pixel modules – source along beam line.
- Readout of these high occupancy events in the pixels takes long time.
  - Readout and recovery modified in frontend readout firmware.

Beam-Gas Interactions
(PKAM='Previously Known As Monsters')

- The source of these large pixel events is beam-gas interaction outside detector area.



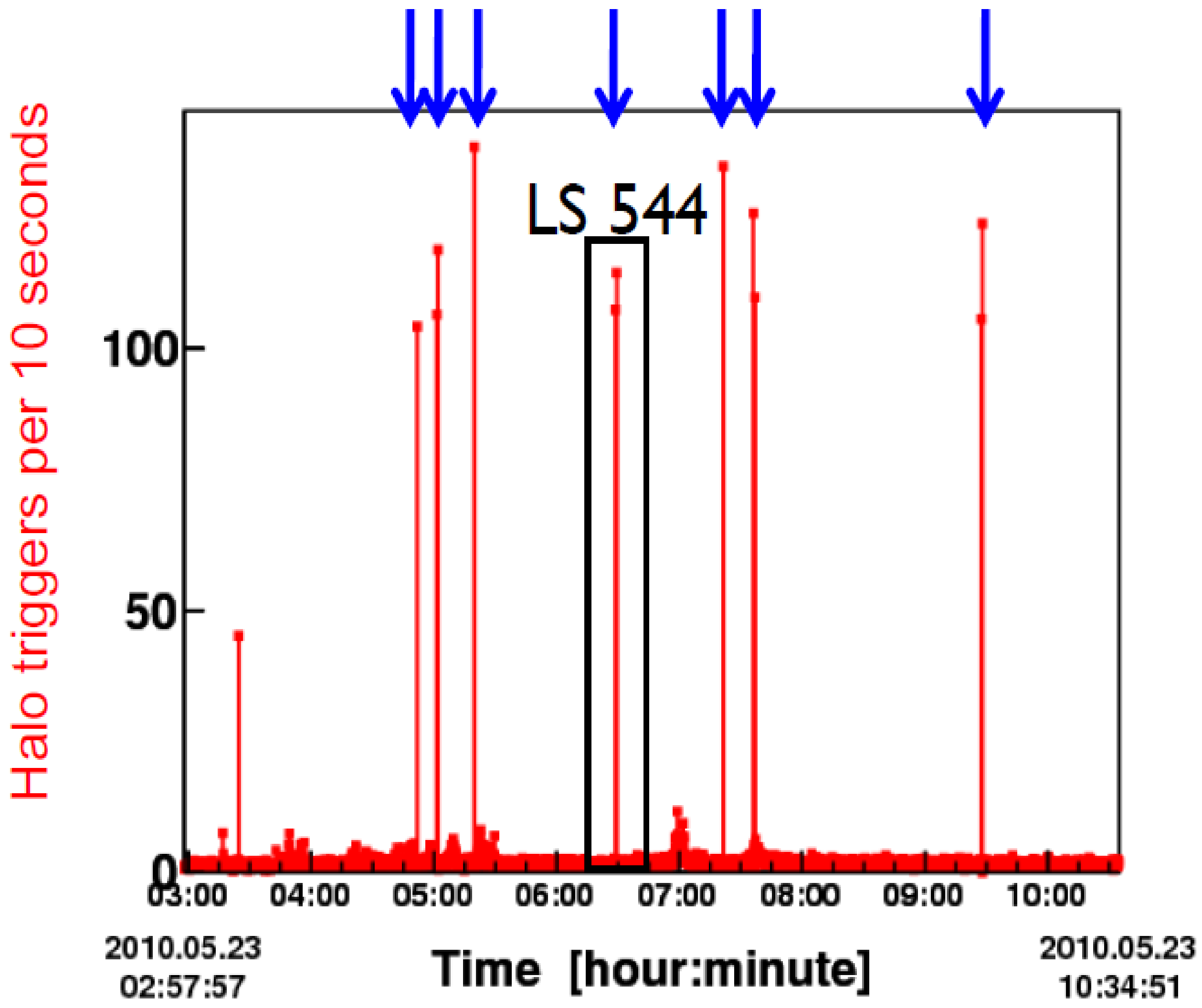
- Simulation of beam-gas interactions shows that the rate and radial distributions of particles are qualitatively in agreement with the observations.

Pixel 'Busy' Firmware

- In order to avoid the out-of-sync problems when large events arrive in the pixels a mechanism where the pixel FED raise busy to stop triggers was introduced.
- This mechanism worked fine, but a few feds (out of 40) started to generate sync-lost-draining in the FRLs.
  - This means that a FED sent either more or less events than other FEDs – something that the central DAQ can not handle.
- After ~1½ months of hard work from the pixel group a solution was finaly found – reducing the slew rate of the FPGAs eliminated this problem.
  - This points to some noise source, but this has not yet been understood.
- However, now we can again operate the pixels without it causing the DAQ to fail.
- The busy mechanism is causing a small deadtime (<<1%).

CSC Halo Triggers

From Lindsey Gray (CSC):



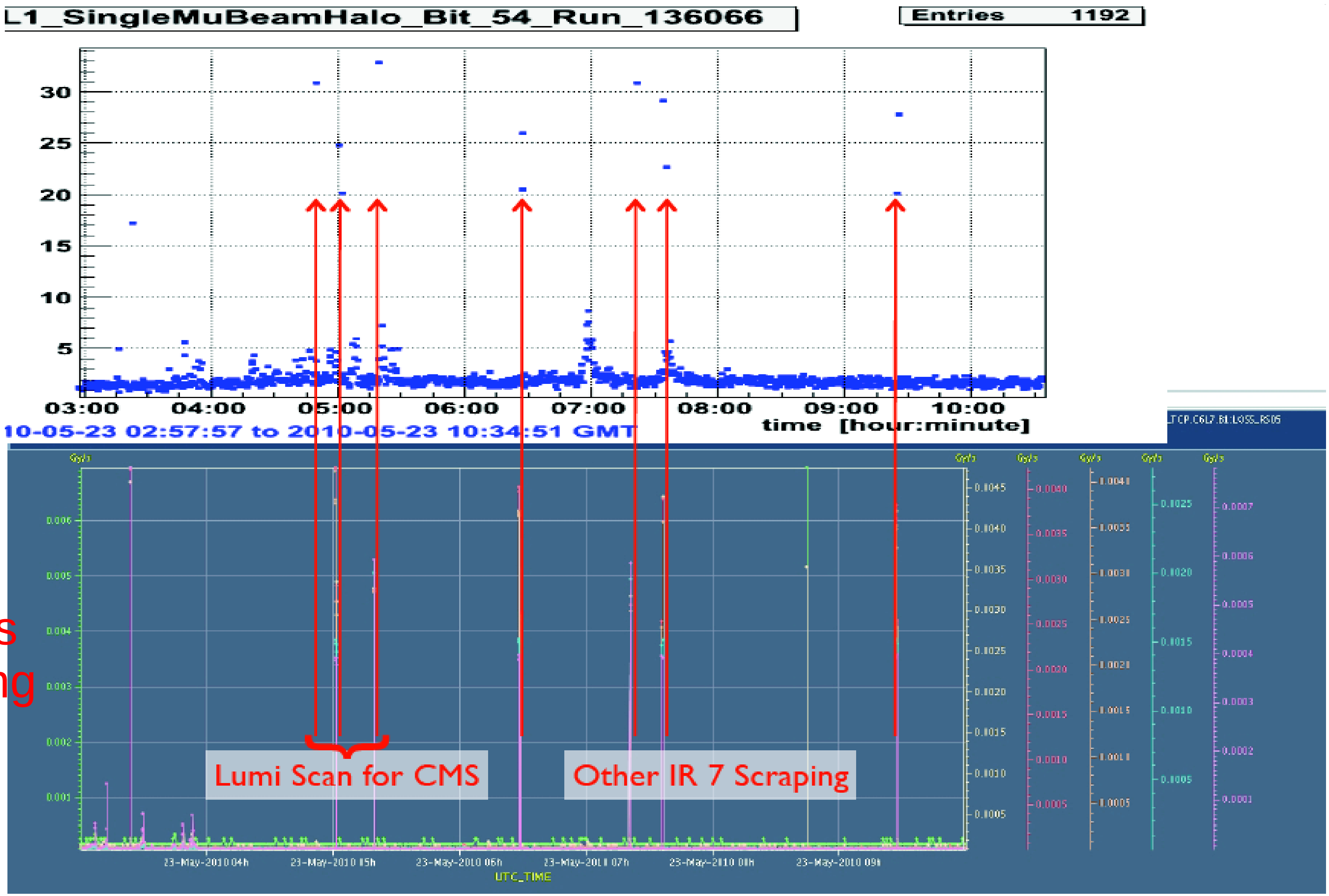
Looking at one of these events (8:28:38), the FED crate monitoring logfiles, the ME+ DCC FIFO's are filling up, backpressuring to DDU's...

7 spikes in 3.5 hours, with "bursts" of trouble…

Note: this plot is UTC (i.e. 5:00 = 7:00GVA time)

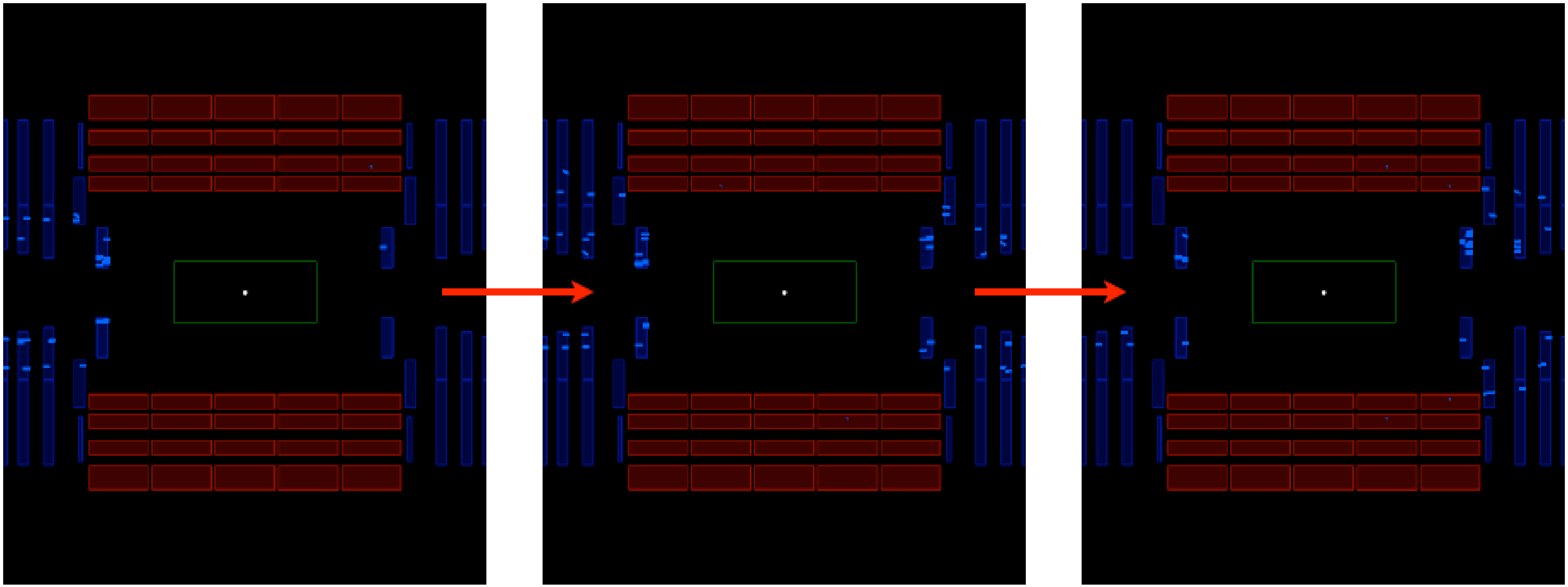
It was kind of harrowing to be i the control room during this time…

Correlation to LHC Beam Losses



LHC beamloss monitoring from Timber

CSC Halo Event



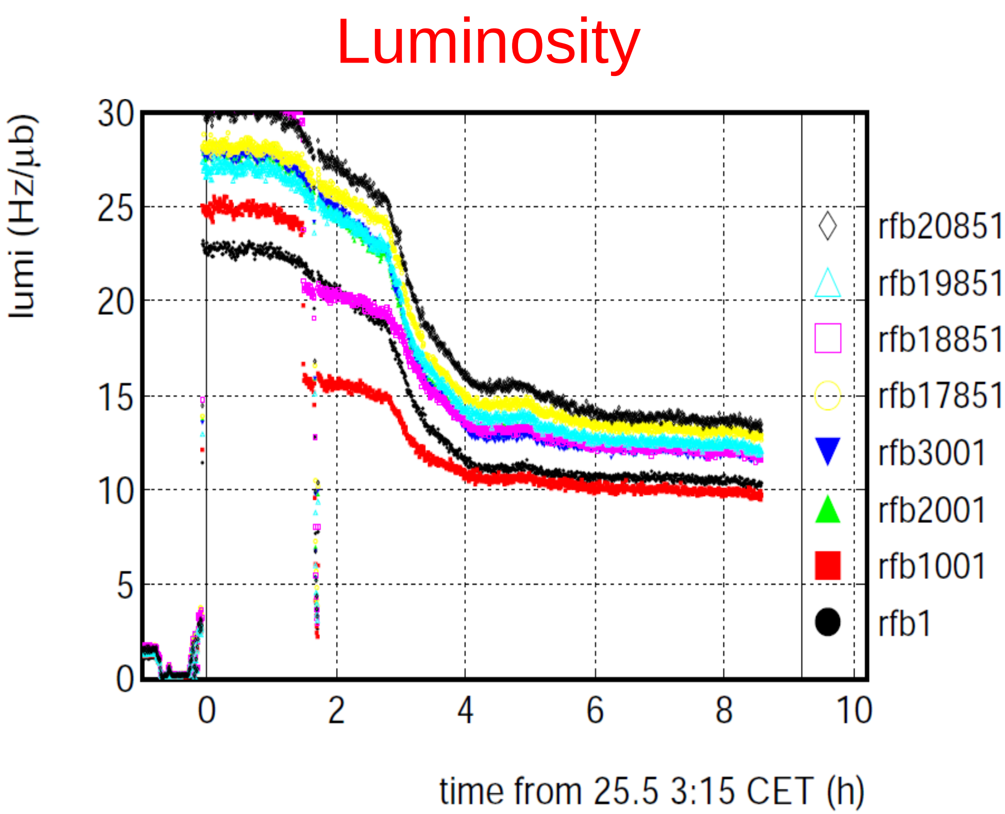
BX 3 BX 201 BX 401

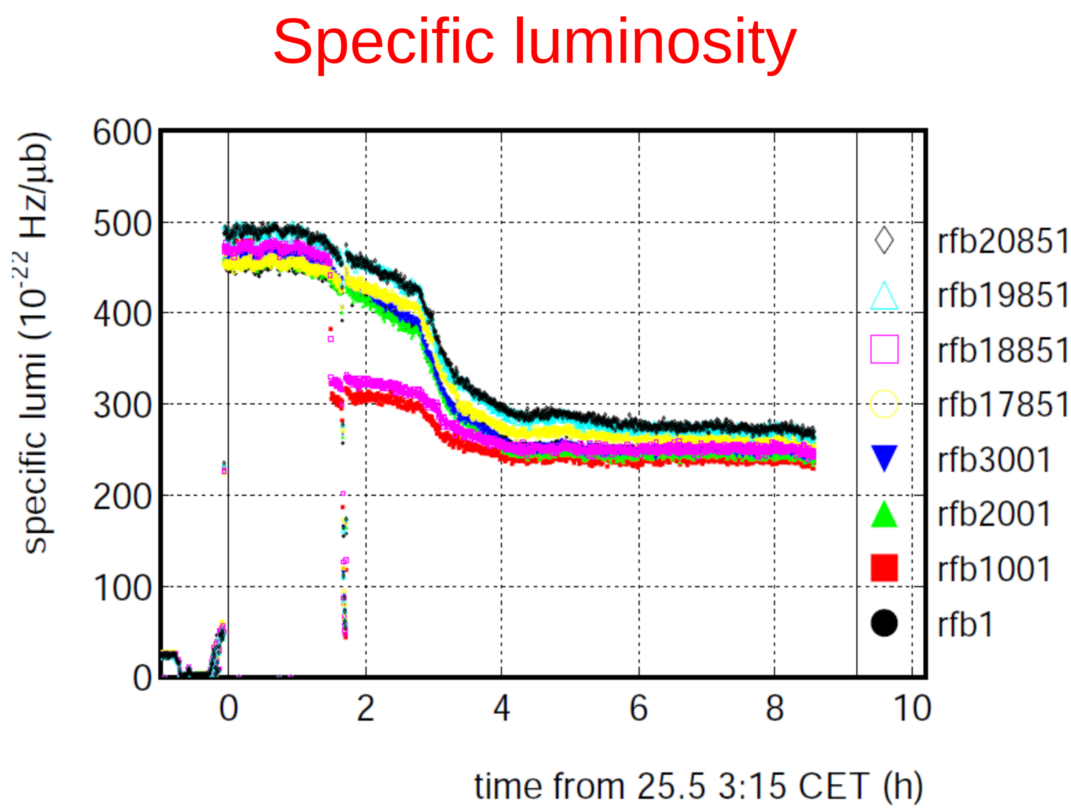
Should have generated a busy when getting large events. At first this mechanism did not look like it was working. But busy was just raised too late – one single large event could overflow the buffers. Fixed.

Problem with Configuration Failures

- In early May we started seeing some sporadic problems with configurations.
  - Pixel configuration timed out a few times – had noted longer time for some DB queries.
  - Failures to configure trigger.
- Over the next few weeks this problem became more severe. On several occasions we failed to configure – once at a start of a physics fill and we lost data.
- Was this a DB problem? Software problem (TStore)? Network instabilities? We did not really have the tools to tell some of these problems apart.
- Lots of finger pointing until we brought all relevant experts to P5 at the same time one afternoon (without beam) to debug.
  - Very productive afternoon that found overload of DB from the storage manager trying to keep track of what files to delete. We also found a problem in our network configuration.

Need to Provide Machine Feedback



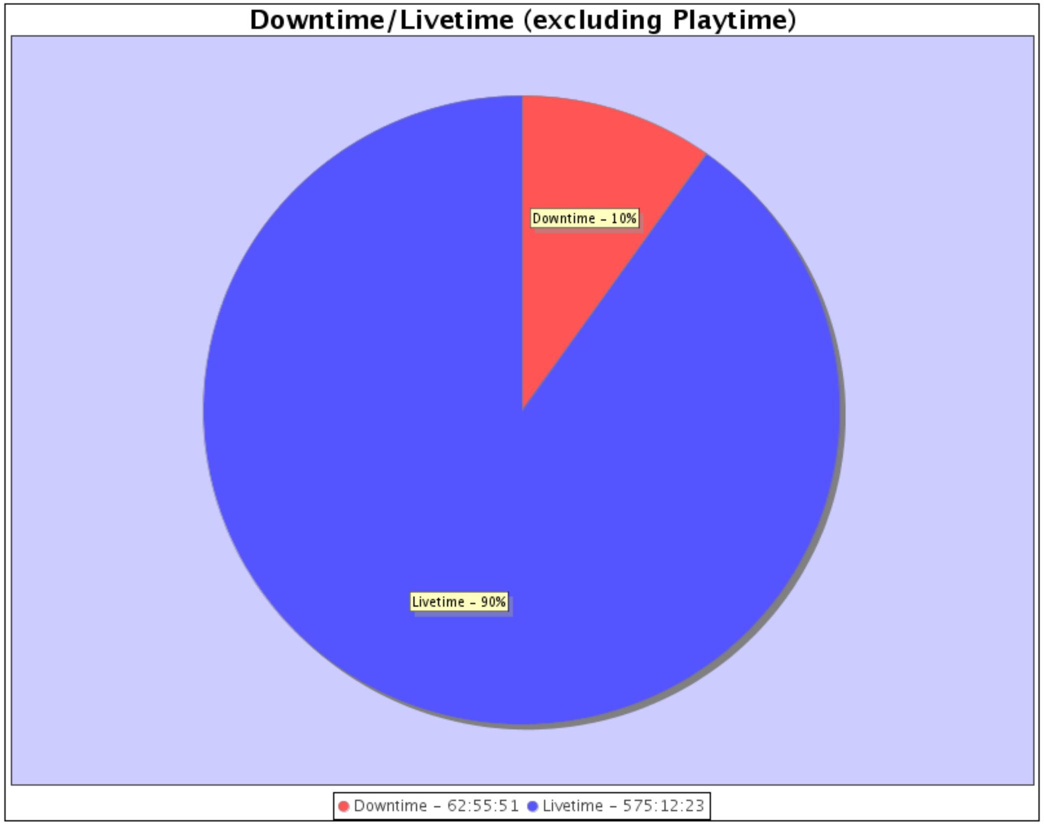


- Sudden drop in luminosity for 2 (out of 8) colliding bunches.
  - This was never understood.
- LHC still has limited bunch-by-bunch minitoring. They rely on feedback from experiements e.g. on beamspot sizes and movements.
  - In CMS we are now (re)organizing a team for online monitroing of the beamspot.

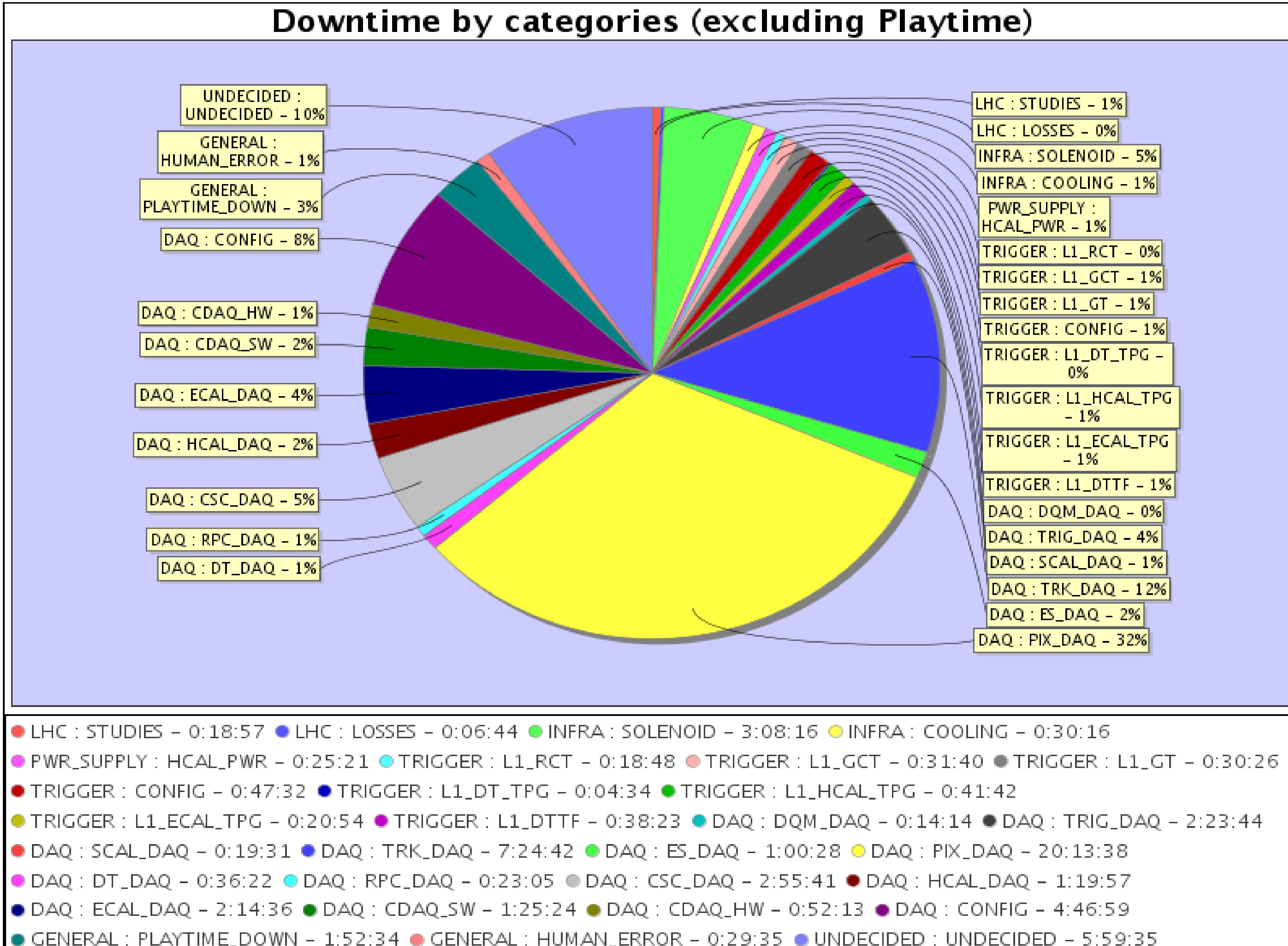
Run Time Logger (RTL)

- The run time logger is our main tool for tracking data taking inefficiencies.
  - Any stops to the data taking is automatically recorded and the shift leader enters the reason for the stop.
- The tool automatically generates summaries of the outages per fill, per run, or over a given time interval.
  - Some examples from these summaries on the next slides.

Data taking efficiency in 2010

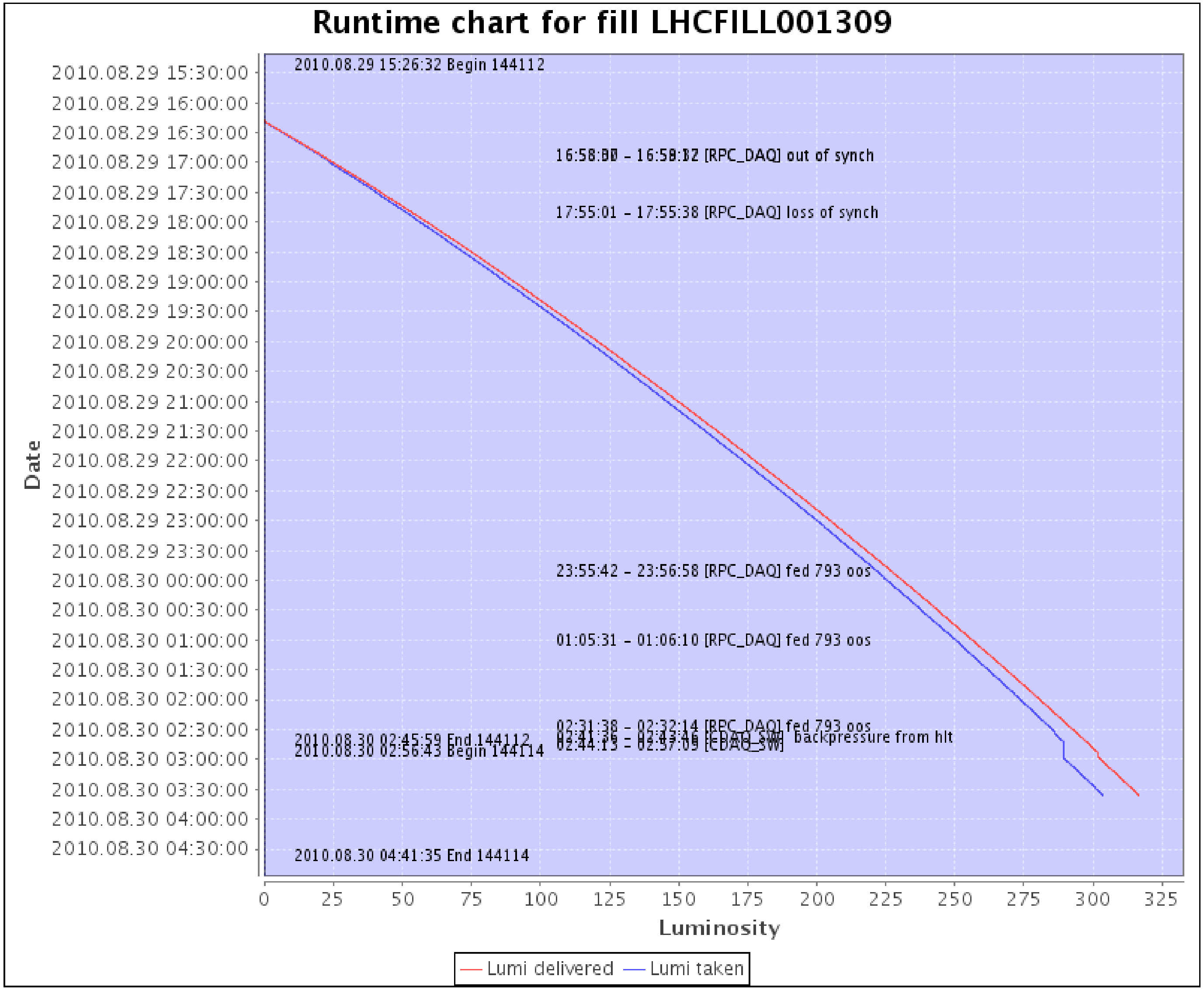


Breakdown of Downtimes in 2010



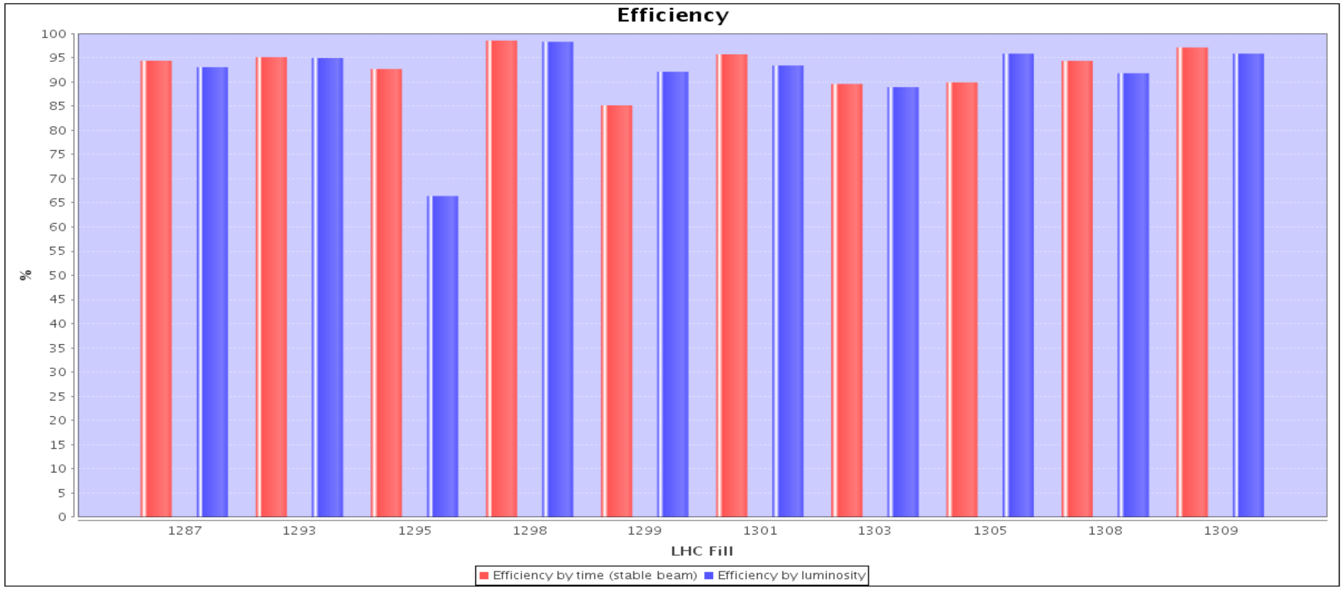
Lumi Collection

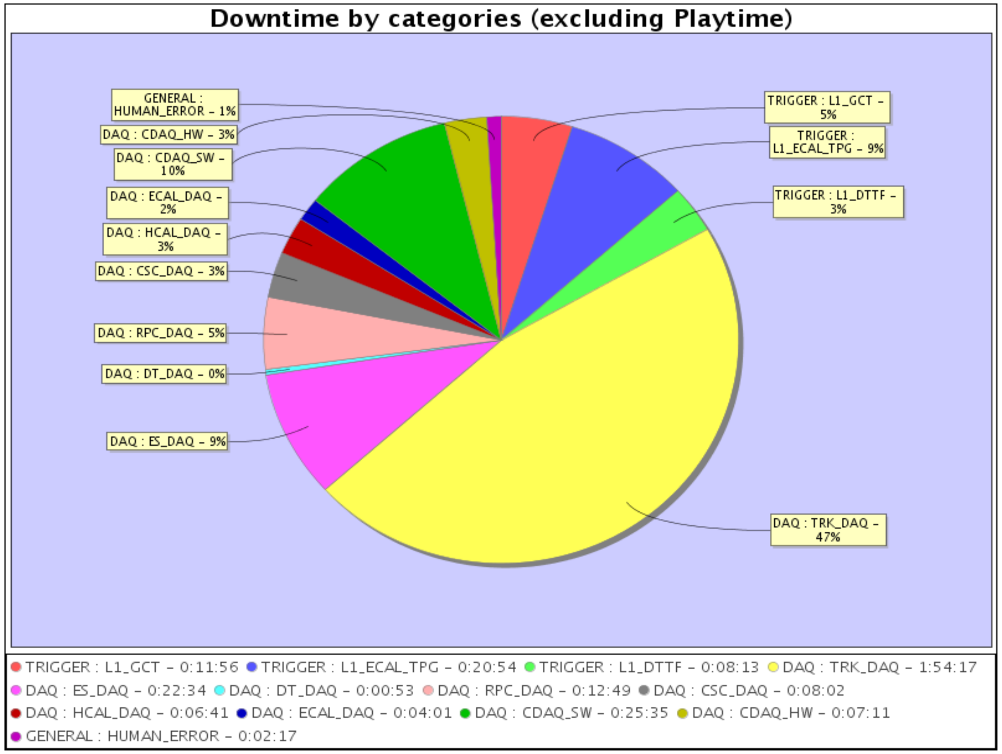
RTL also provides a timeline for the accumulation of luminosity



Performance last 2 Weeks

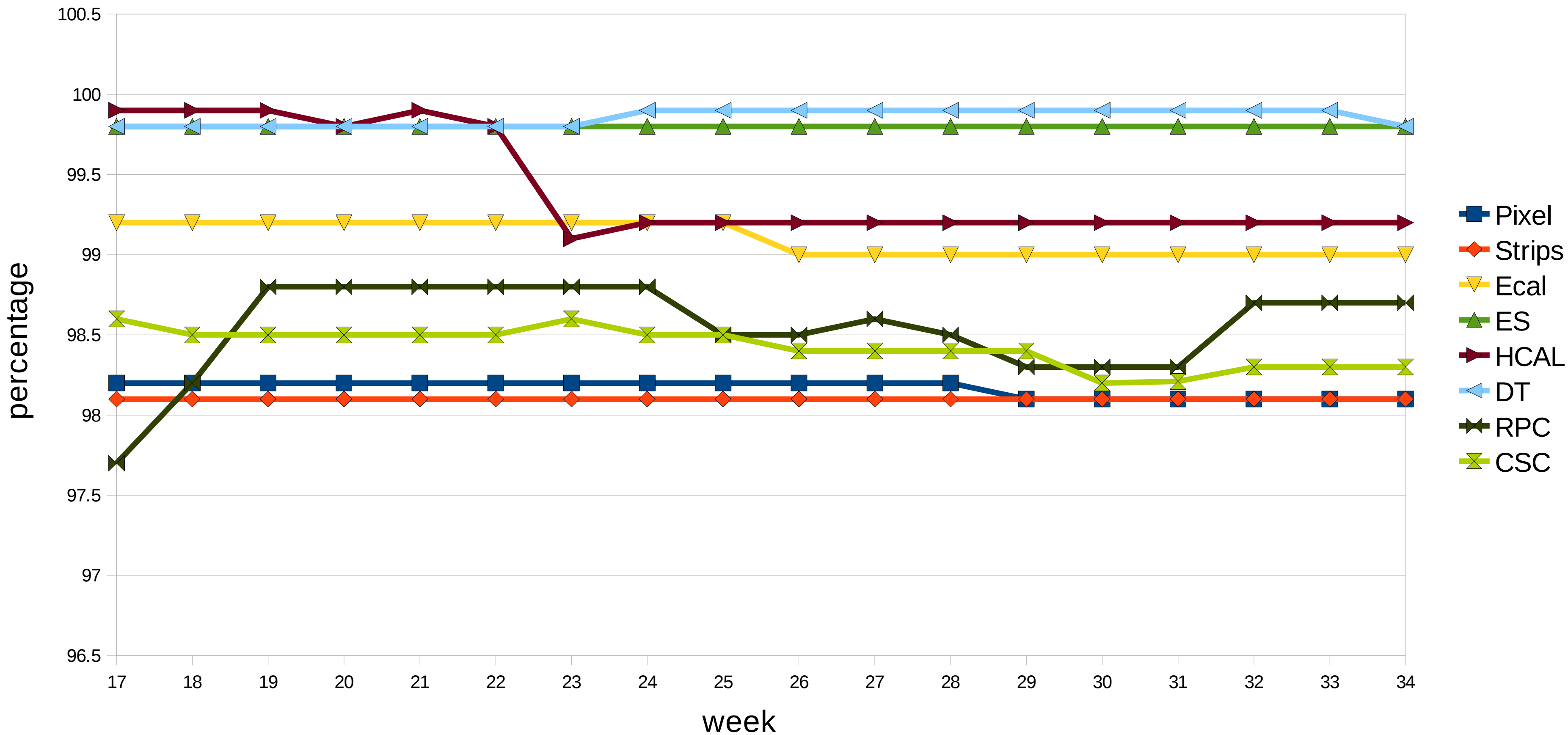
Data taking efficiency by LHC fill.





Downtimes in the last ten fills

Active Detector Channels



All subsystems over 98% functional.

'Unattended' Operation

- Technical coordination held a review of subdetectors readiness for unattended operation, i.e. that the detector can be operated by the central DCS shifter without a subdetector shifter in the control room.
  - Most subsystems now without shifters at P5
  - Made lots of progress in automatizing DCS
- In general the experience to operate without subsystem shifters at P5 has been good.
  - Mostly subsystem shifters had to call experts if something unusual happened. Now this is done by the central shift crew.
- Centrally we have five shifters at P5:
  - Shift leader
  - DAQ
  - DCS
  - Trigger
  - DQM

Shift Organization

- We have a system with shift blocks with different credits for the different shifts (day, evening, owl).
- We have asked that people take a minimum number of credits in a short period – however has not always happened and sometimes we have shifters that are not familiar with the current operation.
- As the shift block system is enforced when you sign up for shifts this works; however we are not getting people to take the required number of shifts within a short time period.
  - e.g. we are asking shiftleaders to take 24 shift credits within 3 months.
- We are considering ways of operating with a more experienced shift crew next year.

Heavy Ion Running

- There will be a ~4 week long Heavy Ion run in November.
- Will readout Strips, ECAL, HCAL, non-zero suppressed.
  - Leads to very large events (~12 MB, compared to 230 kB now).
- We will take about 1 hour of data in this mode next week to test this configuration and data processing.

- Otherwise we are trying to keep the operation during HI data taking as similar as posible to the pp data taking.

LHC Performance Numbers Week 34

Peak luminosity – stable beams	1.07×10^{31} $cm^{-2}s^{-1}$
Average luminosity – stable beams	7.10×10^{30} $cm^{-2}s^{-1}$
Total stable beam time	67.6 hours (40.2%)
Delivered luminosity	1750 nb^{-1}
Luminosity lifetime	~25 hours

Hübner factor ≈ 0.29

Including some dedicated bunch train commissioning

	Availability	Physics
W33	47.3%	22%
W34	~85%	40.2%

- **Remarkable machine availability**: impressive performance of cryogenics, QPS, converters, RF, instrumentation, collimators, injectors…
- **Very effective** use of available time

Slide from Mike Lamont LMC 67

LHC Plans

- The goal for 2010 is to reach an instantaneous luminosity of 10^{32} – a factor of 10 beyond what has currently been achieved.

Parameter	Achieved	Nominal
Energy C.o.M	7 TeV	14 TeV
Bunch charge	$1.15{\times}10^{11}$	$1.15{\times}10^{11}$
β^*	2 m (currently 3.5 m)	0.55 m
Colliding bunches	35	2808

- This will be achived by increasing, to almost 400, the number of colliding bunches.
- The plan is to increase by 48 bunches/week
- To do this LHC needs to inject bunch trains – i.e. closely spaced (150 ns apart) bunches injected in one shot.
- This requires about 10 days of commissioning – this work is currently underway.
  - Increasing the number of bunches is straight forward. Should get at least 30/pb by end of pp operation.

Detailed LHC Plan for This Week

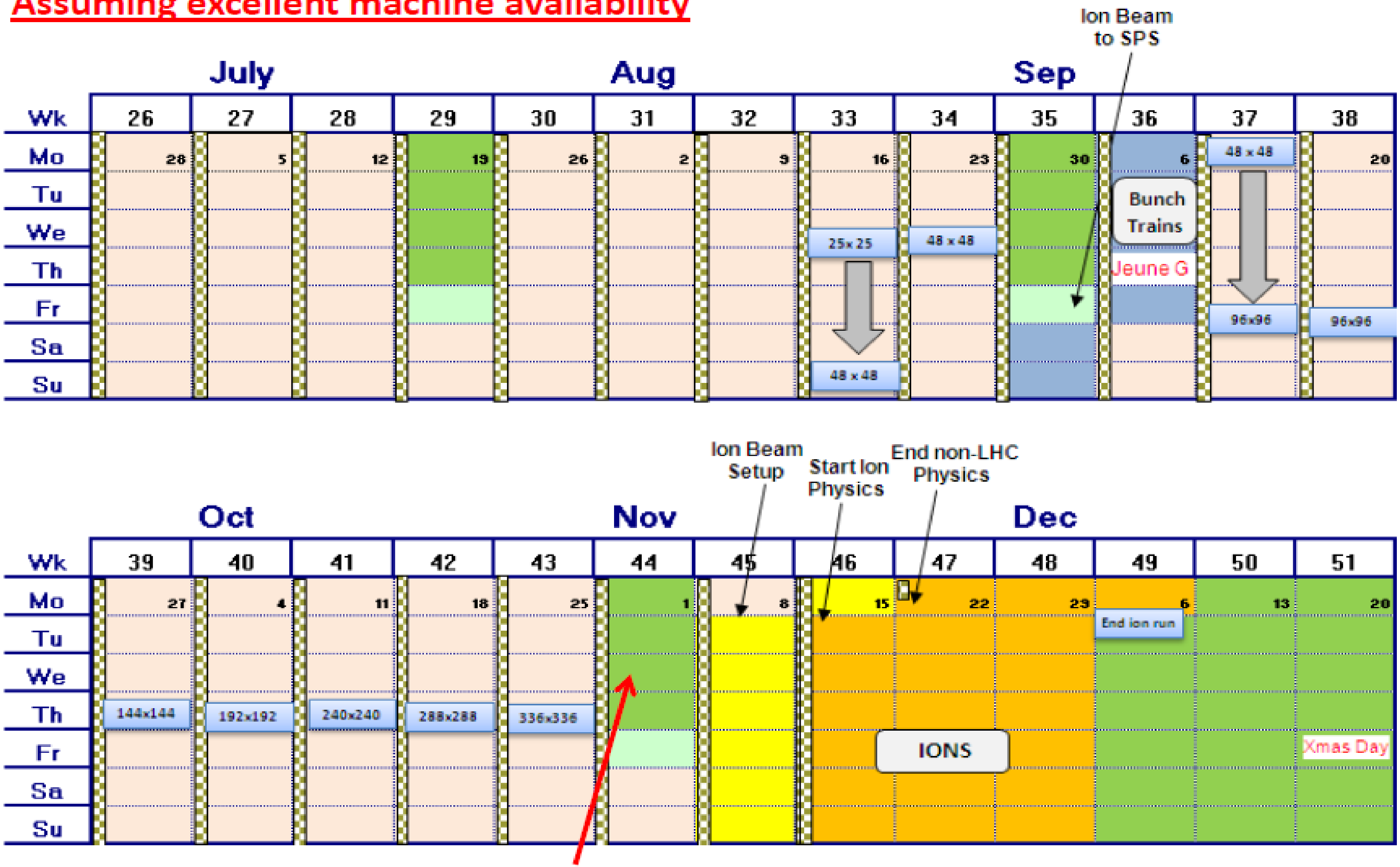
	Day	Start	Time (h)	Activity	Comments	Beam type
5	Sun	M	4	Transverse feedback setting up: noise reduction (450 GeV - single nominal bunch)		INDIV
5	Sun	A	1	Closed oorbit at 450 GeV with crossing angle ON	Non-closuire correction based on measurement done on 4/9/2010	PROBE, INDIV
5	Sun	A	7	Injection / injection protection: crossing angles ON	TDI/TCLI setup in LHC and protection validation (pilot bunch)	PROBE, INDIV
5	Sun	A	1	Splash events for CMS	Beam 1 only	PROBE
5	Sun	N	7	ramp at 10 A/s with single bunch/beam 1e10 + squeeze and crossing angles ON during the ramp - measurement of non closure during the squeeze	Feedforward from previous measurements should be implemented Chromaticity measurement during the ramp - collimators open. Crossing angles on during the ramp	PROBE
6	Mon	M	8	Injection / injection protection - crossing angles ON	Steering of trajectory in TLs and adjustment of TCDIs	PROBE, INDIV
6	Mon	A	8	Collimation set-up at 450 GeV/c		INDIV
6	Mon	N	8	Transverse feedback setting up: noise reduction (450 GeV - single nominal bunch) - crossing angle ON		INDIV
7	Tue	M	2	RF set-up with 4 bunches spaced of 150 ns and cavity configuration with all caivites ON		LHC3
7	Tue	M	8	Injection / injection protection - crossing angles ON	Steering of trajectory in TLs and adjustment of TCDIs	PROBE, LHC3
7	Tue	A	8	Loss maps at 450 GeV/asynch beam dump	Single nominal bunch	INDIV
7	Tue	N	8	PLL setting-up		PROBE, INDIV
8	Wed	M	8	ramp at 10 A/s with single bunch/beam 1e11 - Collimation set-up at 3.5 TeV crossing angle ON -preceed through squeeze according to progress - reference orbit set-up - Transverse ffedback checks during the ramp	Longitudinal blow-up ON? BLM monitor factor reduction at TCTs before ramp	INDIV
8	Wed	A	6	Collimation set-up at 3.5 TeV - ramp as required - up to 2 nominal bunches / beam	Longitudinal blow-up ON? BLM monitor factor reduction at TCTs before ramp	INDIV
8	Wed	A	2	RF set-up with 4 bunches spaced of 150 ns and cavity configuration with all caivites ON		LHC3
8	Wed	N	8	Injection / injection protection: crossing angles ON	Study and quantify losses at injection due to RF system	PROBE, LHC3
9	Thu	M	8	Collimation set-up at 3.5 TeV - ramp as required - up to 2 nominal bunches / beam	Longitudinal blow-up ON? BLM monitor factor reduction at TCTs before ramp - Stefano on shift	INDIV
9	Thu	A	8	Collimation set-up at 3.5 TeV - ramp as required - up to 2 nominal bunches / beam	Longitudinal blow-up ON? BLM monitor factor reduction at TCTs before ramp	INDIV
9	Thu	N	8	PLL setting-up		PROBE, INDIV
10	Fri	M	8	Injection / injection protection: crossing angles ON	Validation checks of TCDI system (pilot bunch)	PROBE, LHC3
10	Fri	A	8	Loss maps in collision + asynch dump - 2 nominal bunches/beam		INDIV
10	Fri	N	8	PLL setting-up		PROBE, INDIV
11	Sat	M	8	Reserve		
11	Sat	A	8	Loss maps in collision + asynch dump - 2 nominal bunches/beam		INDIV
11	Sat	N	8	Reserve		
12	Sun	M	8	Injection / injection protection: bunch trains up to 4x12 bunches (150 ns spacing) - crossing angles ON	Validation checks of TCDI system (pilot bunch) CAN INJECT 8 and 12b ONLY AFTER THIS STEP	PROBE, LHC3
12	Sun	A	8	Reserve	No TFB expert available	LHC3
12	Sun	N	8	Reserve		
13	Mon	M	8	Injection / injection protection: bunch trains up to nx4x12 bunches (150 ns spacing) - crossing angles ON	Inject trains of 8 and 12 bunches (150 ns) to LHC	PROBE, LHC3
13	Mon	A	8	RF set–up with more batches at injection		PROBE, LHC3
13	Mon	N	8	Test of new collimator functions - without beam?		
14	Tue	M	8	Collisions - ramp with new functions		LHC3
				Collisions and progressive increase of number of batches		LHC3

Very compact schedule – basically no contingency built in – to be ready by Sept. 14

LHC Schedule

Very AGGRESSIVE schedule!

Assuming excellent machine availability



Tech stop postponed from week 42 to week 44

LHC Goals for 2011

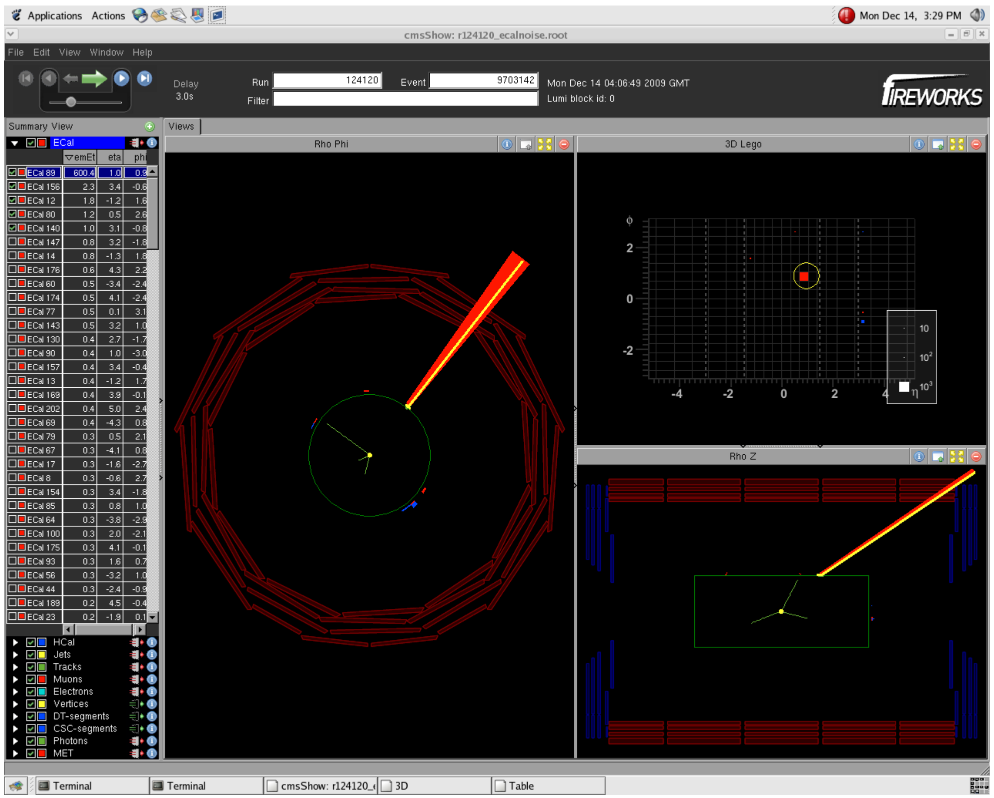
- Should start with recovering $L=10^{32}$
- With nine months running, a Hubner factor of 0.2 and 10^{32} we would get 0.5 fb^{-1}.
- Can we do better than this? There are several areas where we probably could gain:
  - Better than 0.2 for Hubner factor.
  - Reduce β^* to 2m (instead of 3.5m).
  - Inject more bunches – could gain factor of 2.
  - Inject more than 1.15×10^{11} protons per bunch.
- It seems likely that one, or more, of these options should work and would take us safely to 1 fb^{-1} or more next year.
  - But the first step is to get to $L=10^{32}$ this year!

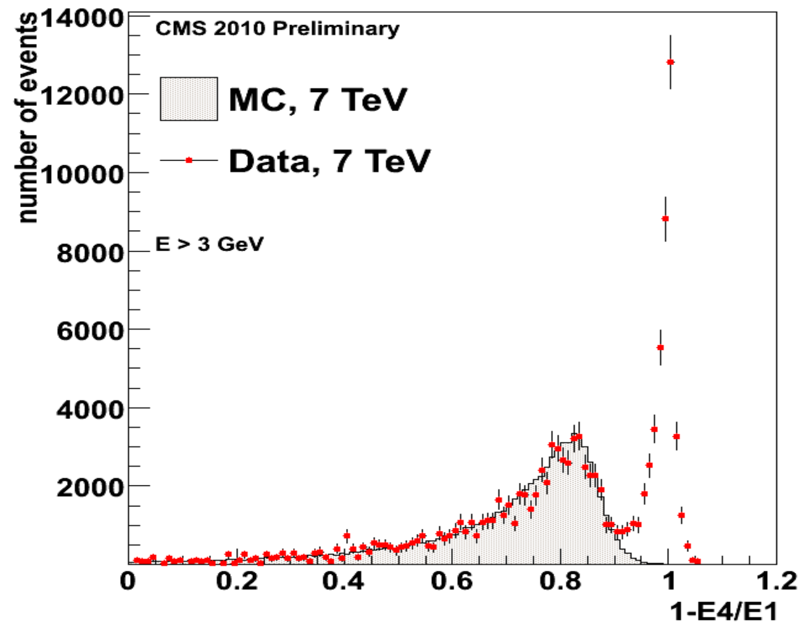
Conclusions

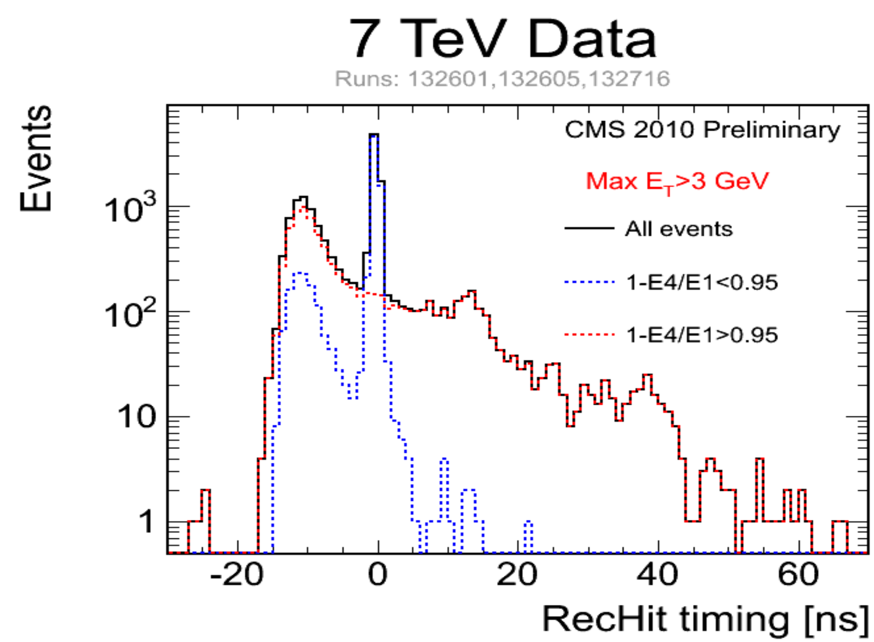
- CMS has operated with high efficiency since the start of 7 TeV operations on March 30, 2010.
  - We have recorded 90% of the luminosity delivered by the LHC in stable beam conditions.
- All subdetectors operating with an active channel fraction greater than 98%.
- The detectors have been timed in to the LHC beam
  - L1 physics triggers have been deployed.
  - The high level trigger is now actively selecting events for storage.
- Have addressed several issues in the operations that has come up:
  - Pixel firmware, CSC out-of-synch, DB overloads, magnet cryo filters,...
- Next step is a factor of 10 increase in luminosity over the next 8 weeks.

BACKUP

ECAL Anomalous Energy Deposits







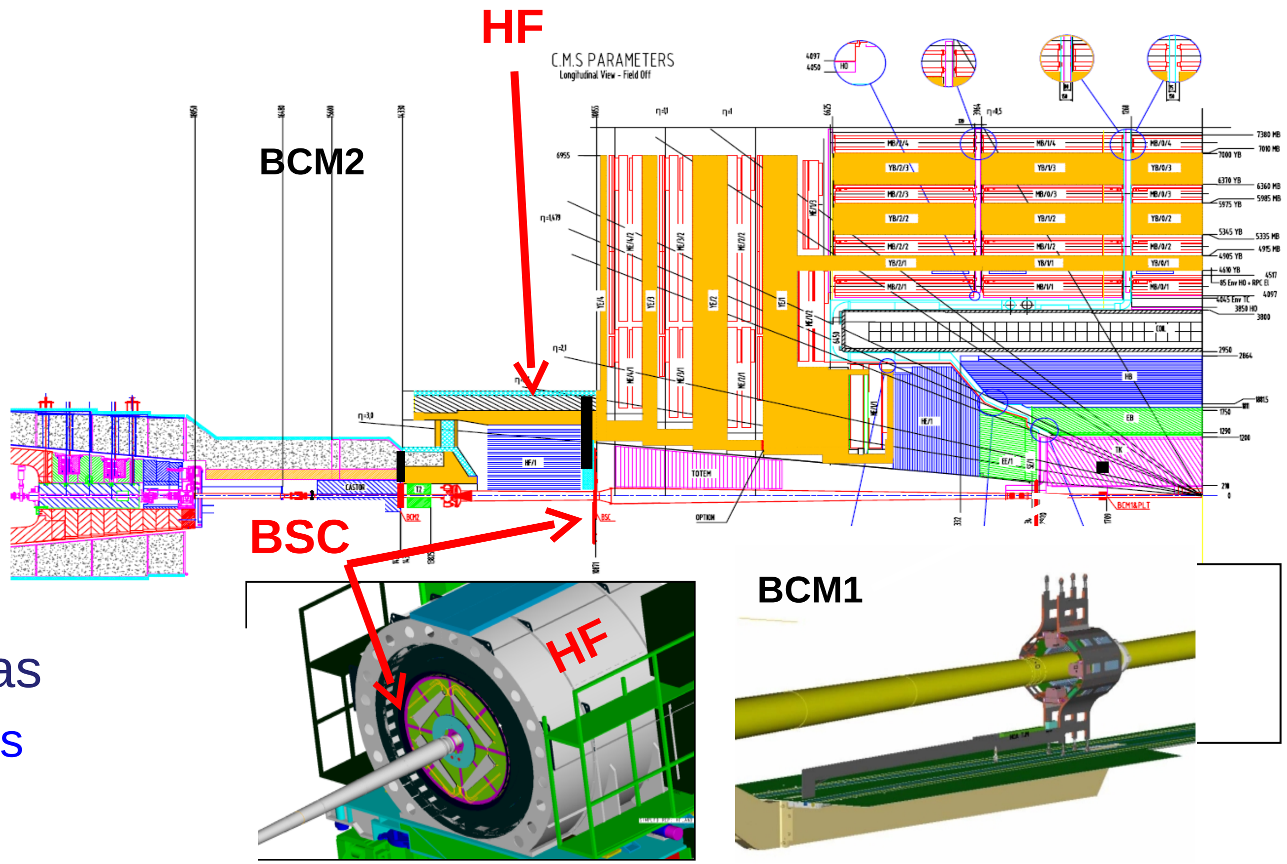
- Large energy deposits in single crystal in barrel. Barrel uses avalanche photodiodes (APD). Not seen in endcap which use vacuum phototriodes (VPT).
- Source: Energy deposited in APD by heavy ionizing particles.
- Can be rejected based on 'shower shape' and timing.

Commissioning Triggers

7 TeV Start up:

Minimum bias triggers

- Hadronic Forward
  - HF: $2.5 < |\eta| < 5.0$
- Beam Scintillator Counter
  - BSC: 10.5 m from

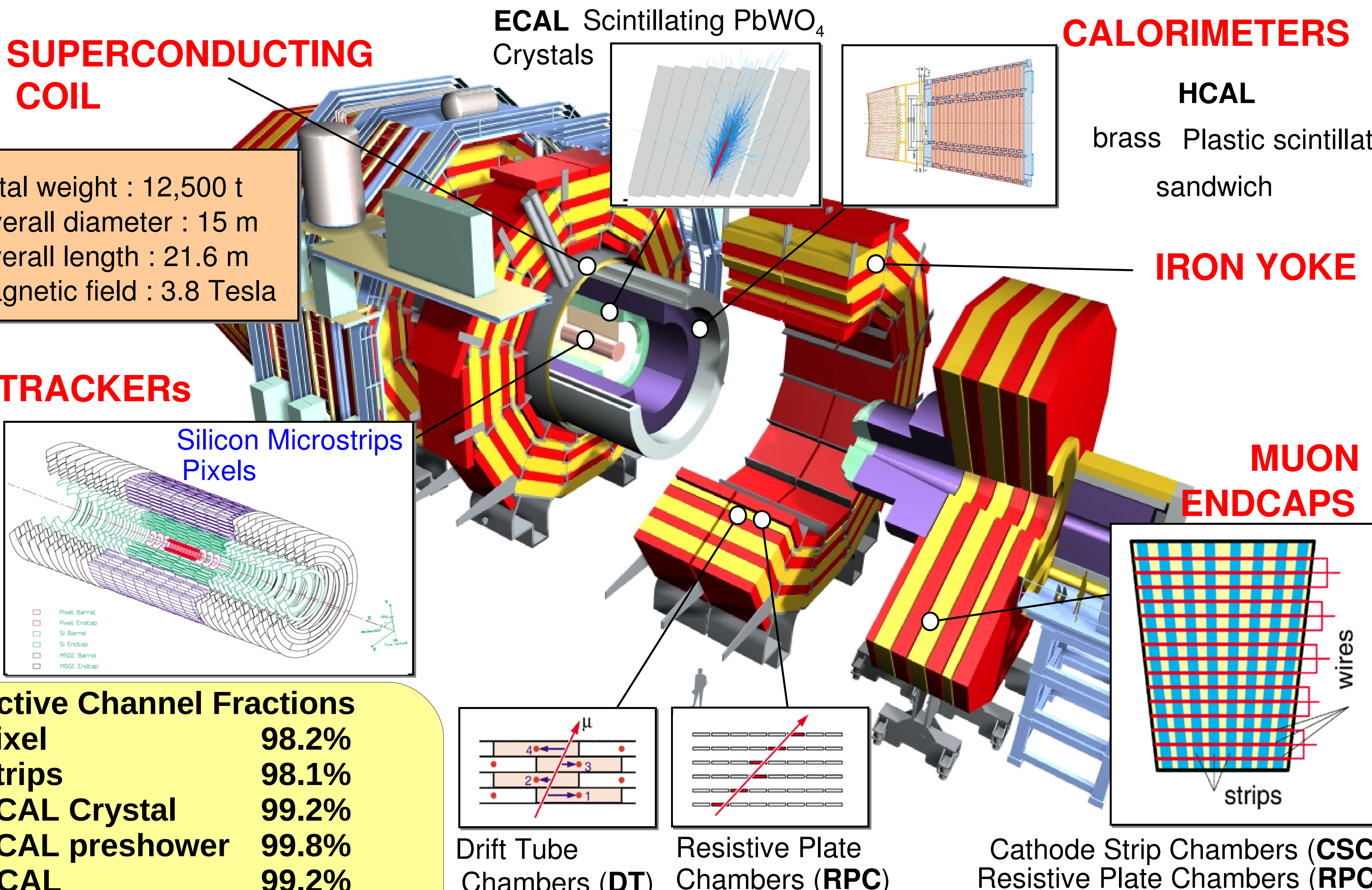


- Trigger: Min Bias & Zero Bias
  - L1 Beam Scintillator Counters
  - L1 Trigger "BPTX" prescaled
- Minimum Bias selection:
  - BSC (OR 2 planes): $\epsilon \sim 90\%$
  - HF (E > 3 GeV both sides): $\epsilon \sim 90\%$
    - Combined high efficiency

Physics triggers are now deployed based on calorimetry and muons

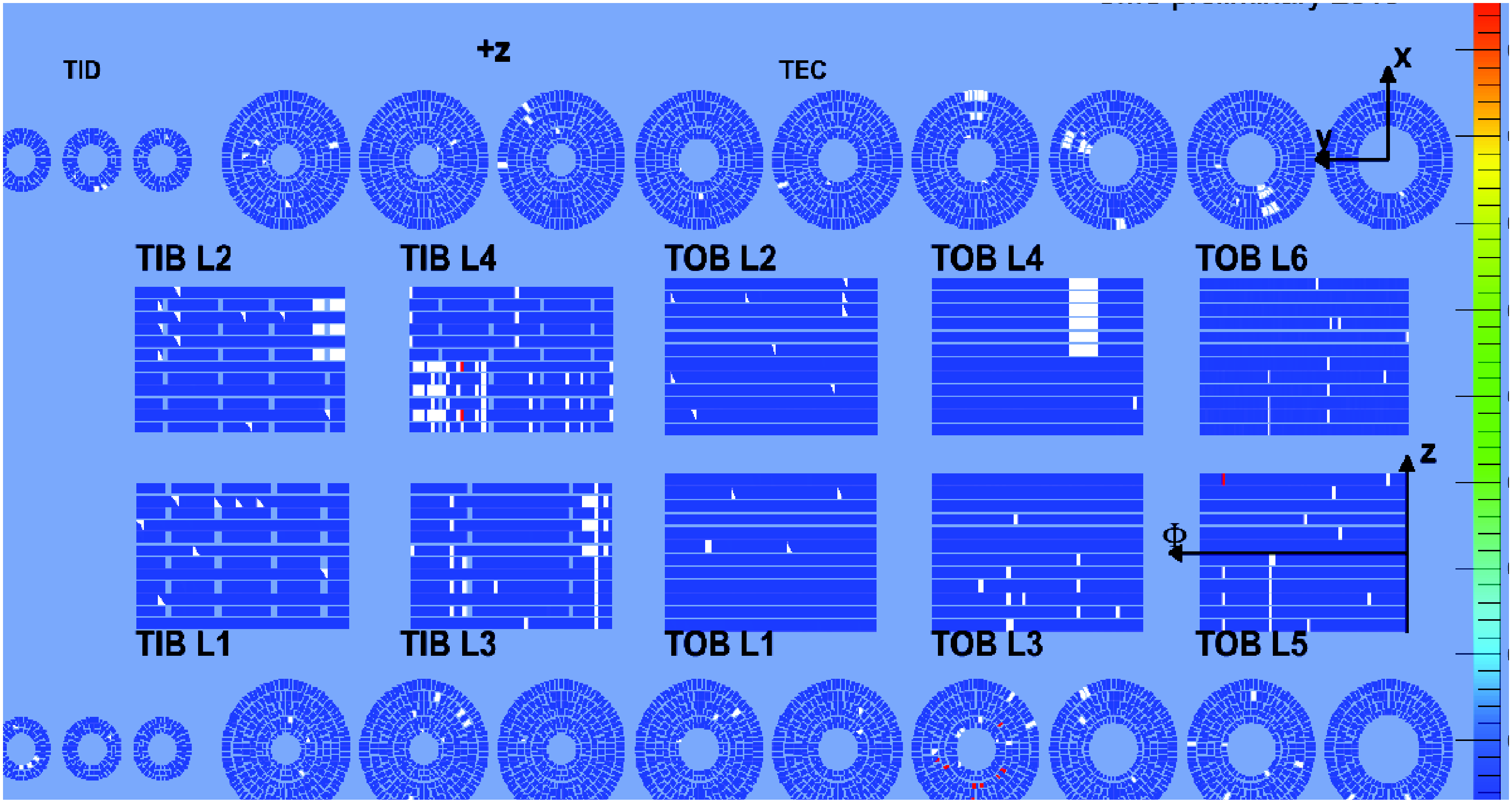
The Compact Muon Solenoid Detector

Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 3.8 Tesla



Active Channel Fractions	
Pixel	98.2%
Strips	98.1%
ECAL Crystal	99.2%
ECAL preshower	99.8%
HCAL	99.2%
DT	99.8%
RPC	98.8%
CSC	98.9%

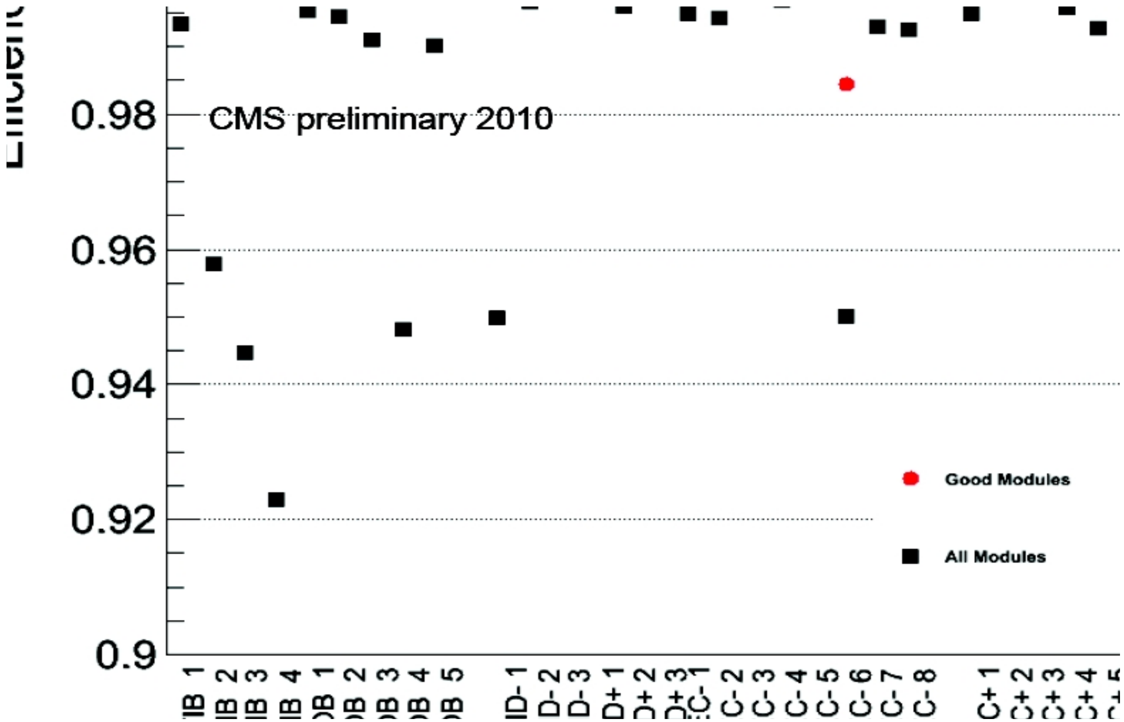
Strip Tracker Efficiency Map



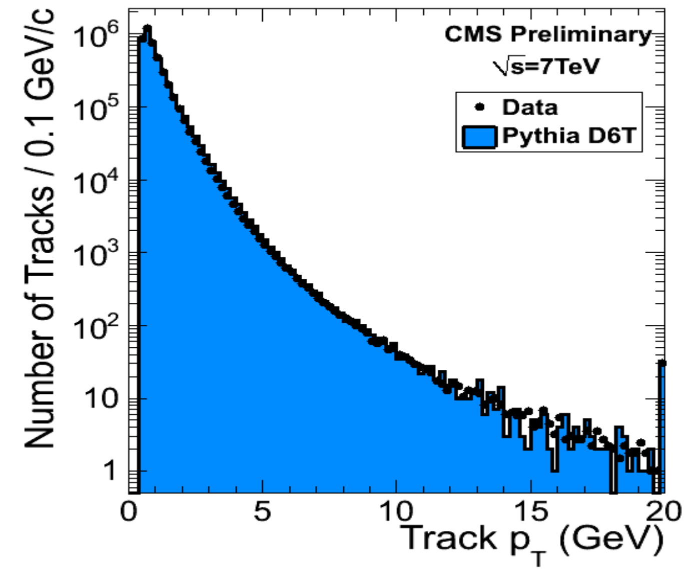
- Overall 98.2% of detector is working

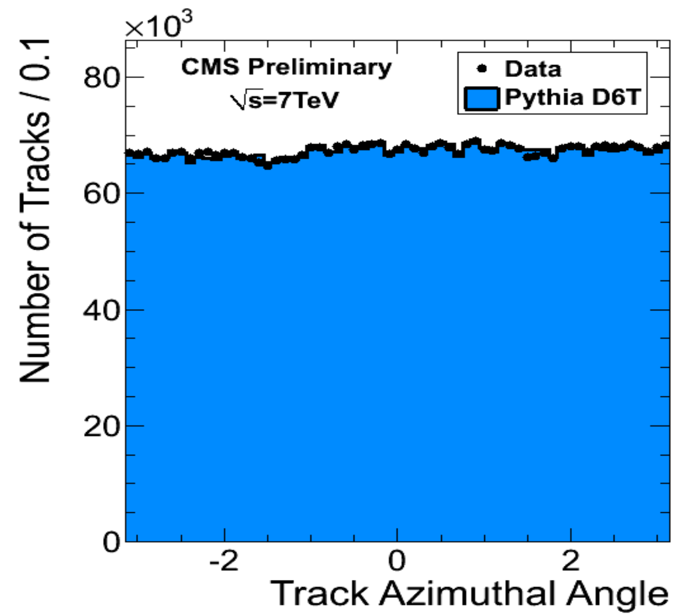
Tracking Performance

Strip Tracker Hit Efficiency



Track Distributions

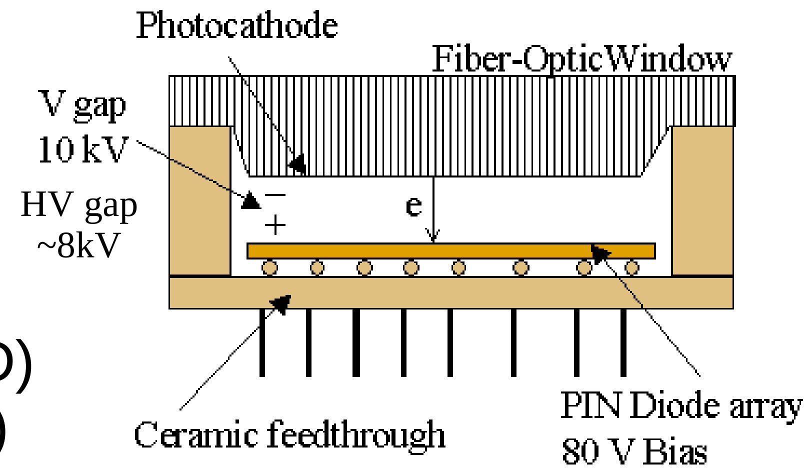


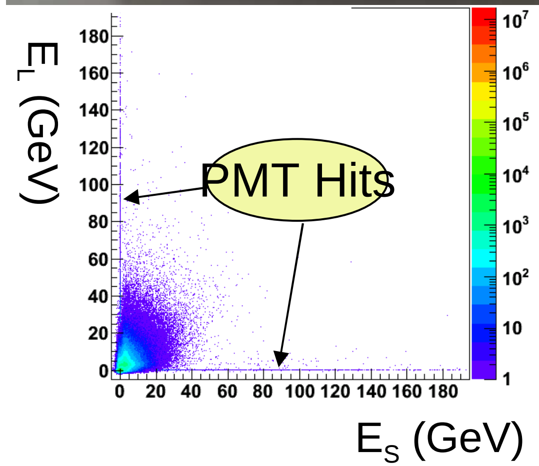


- With 98.1% of channels active in the strips and 98.2% active in the pixels the tracking performance is excellent.

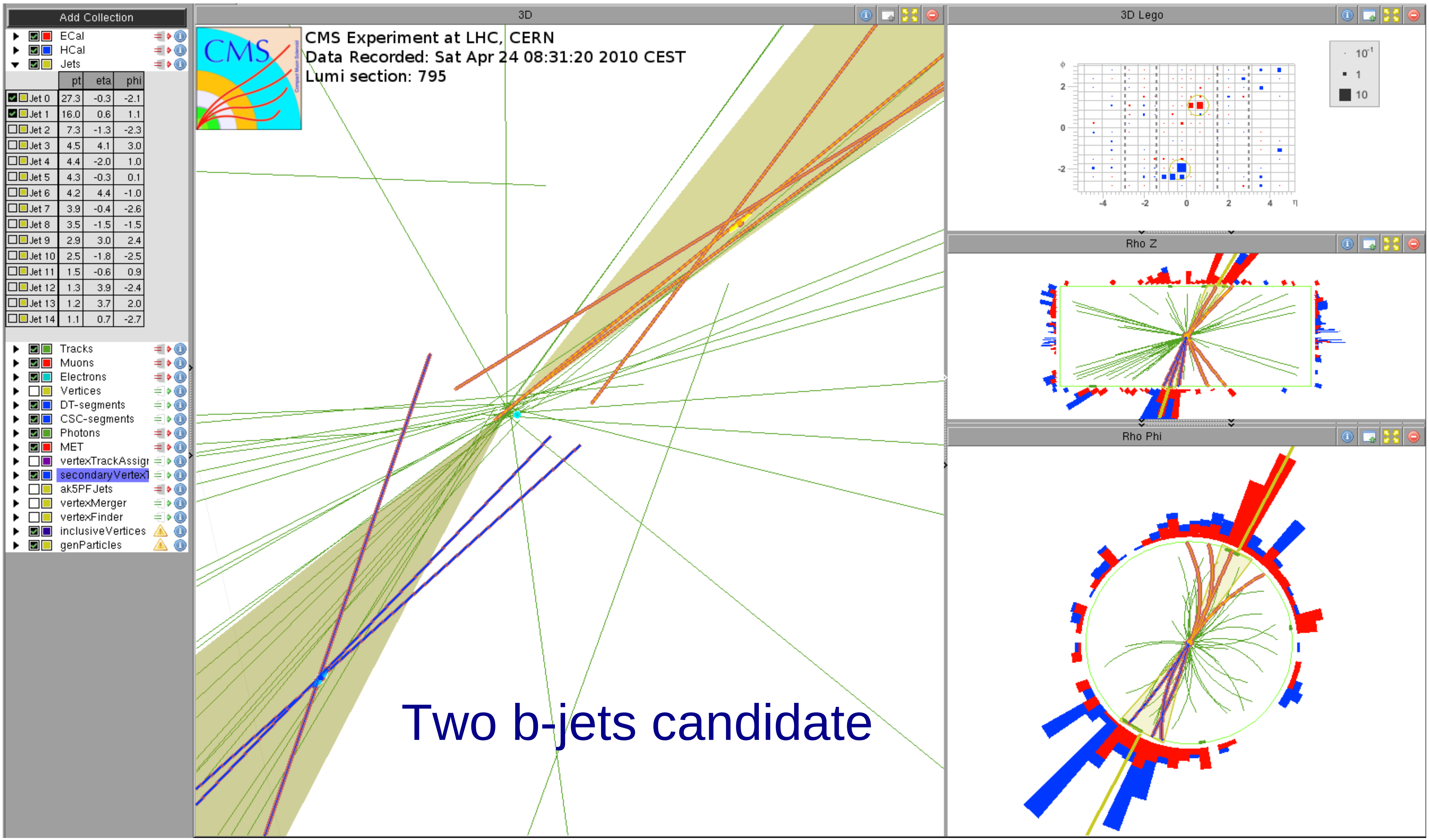
HCAL Anomalous Signals

- Electronic noise from Hybrid Photo Diodes (HPD), used in Barrel, Endcap, and Outer HCAL
  - HPD Ion Feedback (1 channel)
  - HPD Discharge (up to 18 channels = 1 HPD)
  - Readout Box Noise (up to 72 ch. = 4 HPDs)
- 10-20 Hz for E>20 GeV from all 288 barrel and endcap HPDs.
- Noise is random and very small overlap with physics.
- Filters developed to remove this noise based on timing, pulse shape, and EM fraction. (*JINST 5 T03014*)
- Cherenkov light produced by interactions in the window of the Forward Calorimeter PMTs, can also be filtered out based on energy asymmetry in long vs. short fibers. (*Eur. Phys. J. C53, 139-166, 2008*)



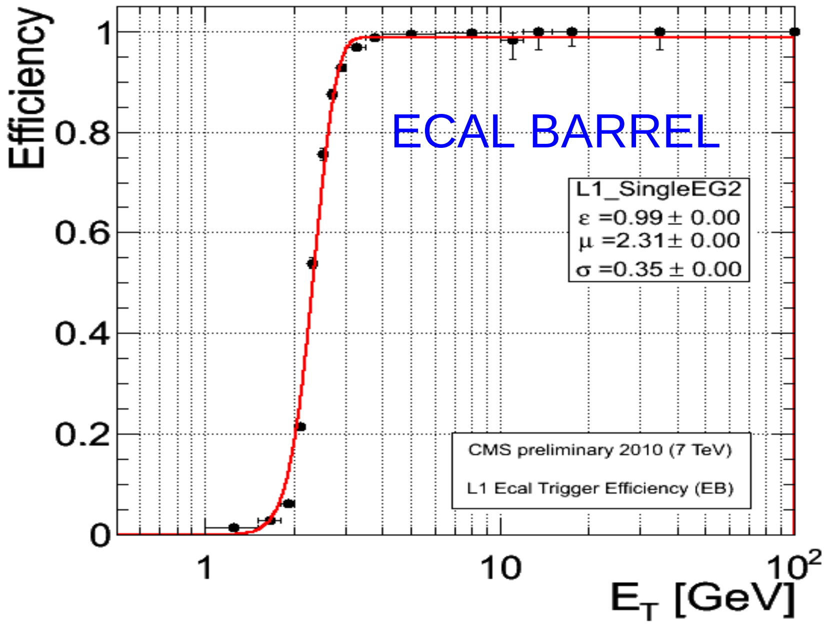


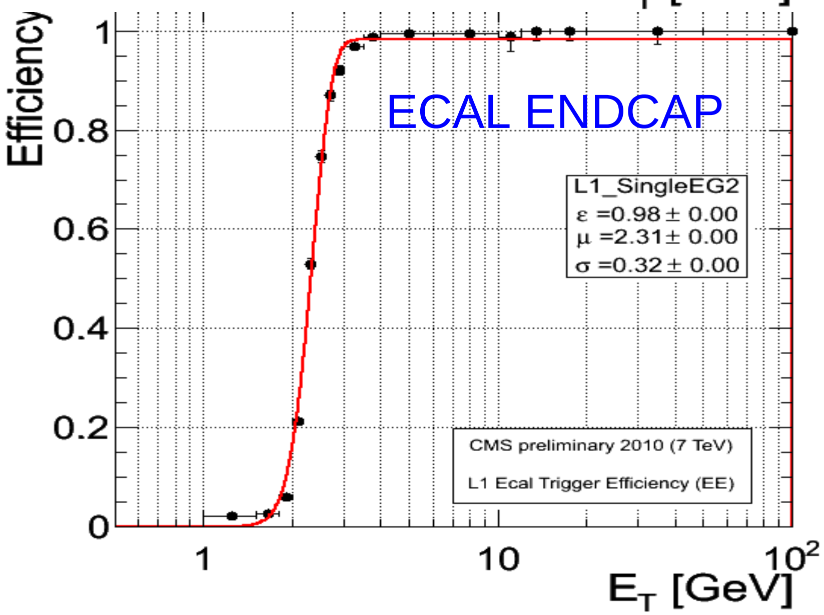
Vertexing: b-tagging



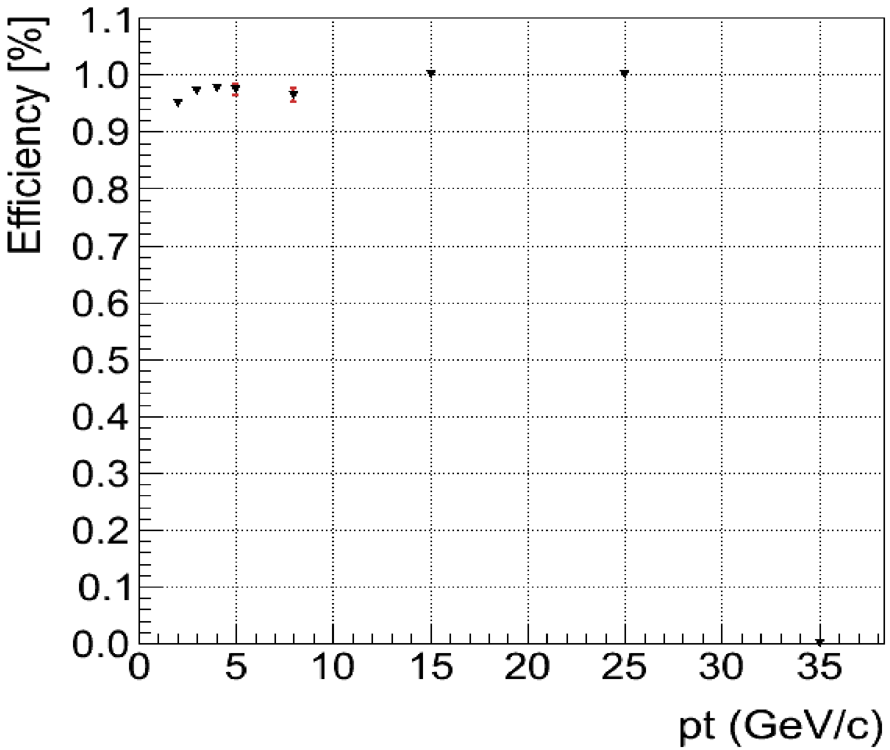
Examples of Trigger Performance

Turn-on curves for 2 GeV threshold



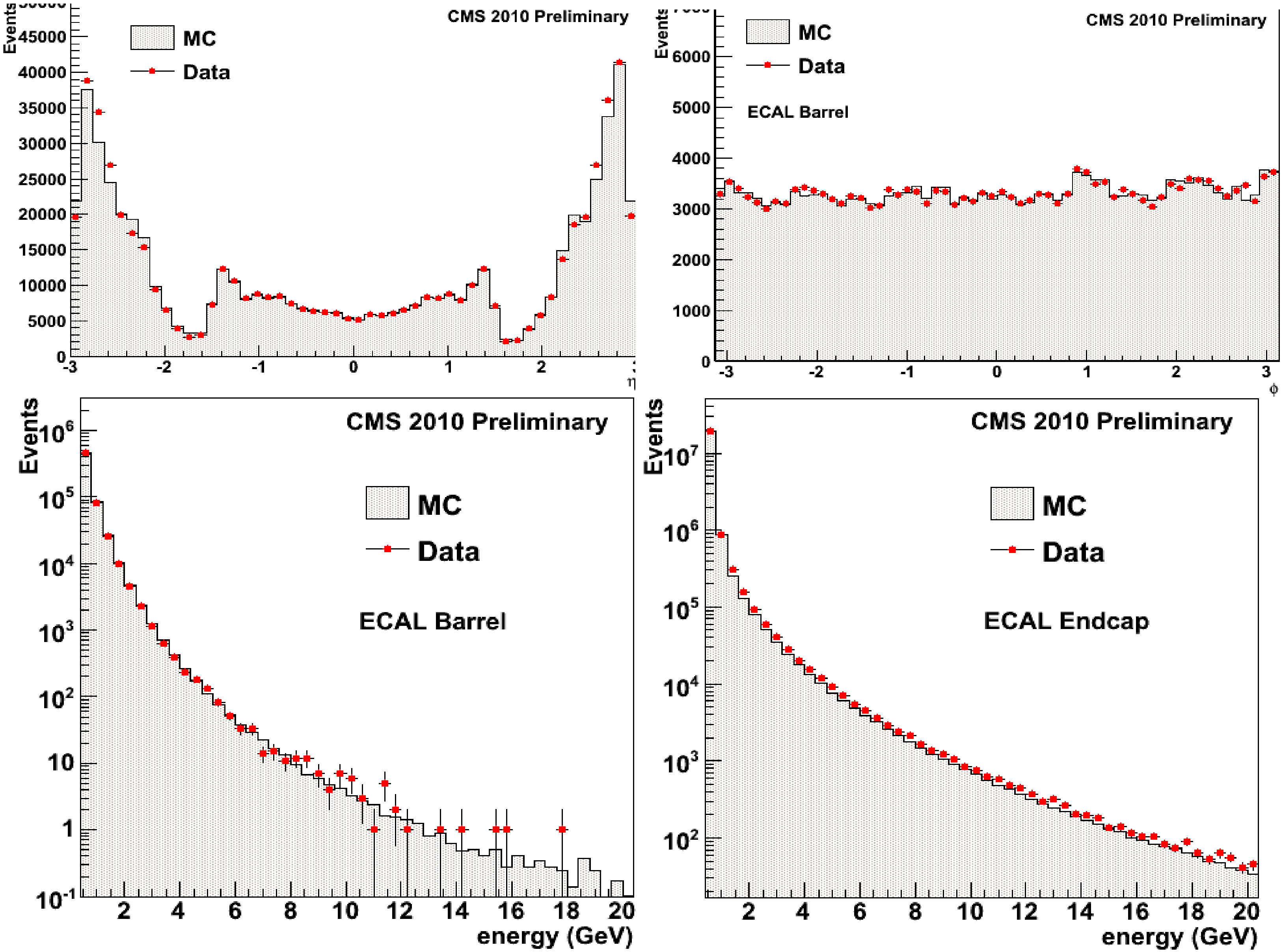


CSC Forward Muon Trigger Efficiency



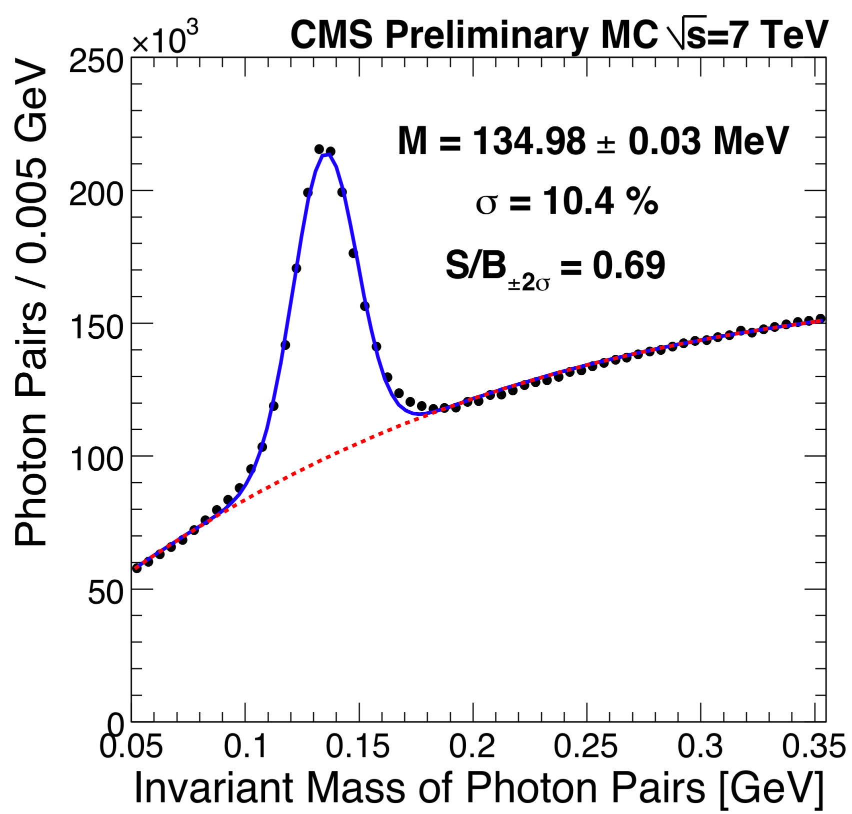
- Triggers first deployed in flagging mode; after validating timing to ensure low pre-firing the triggers are now deployed.

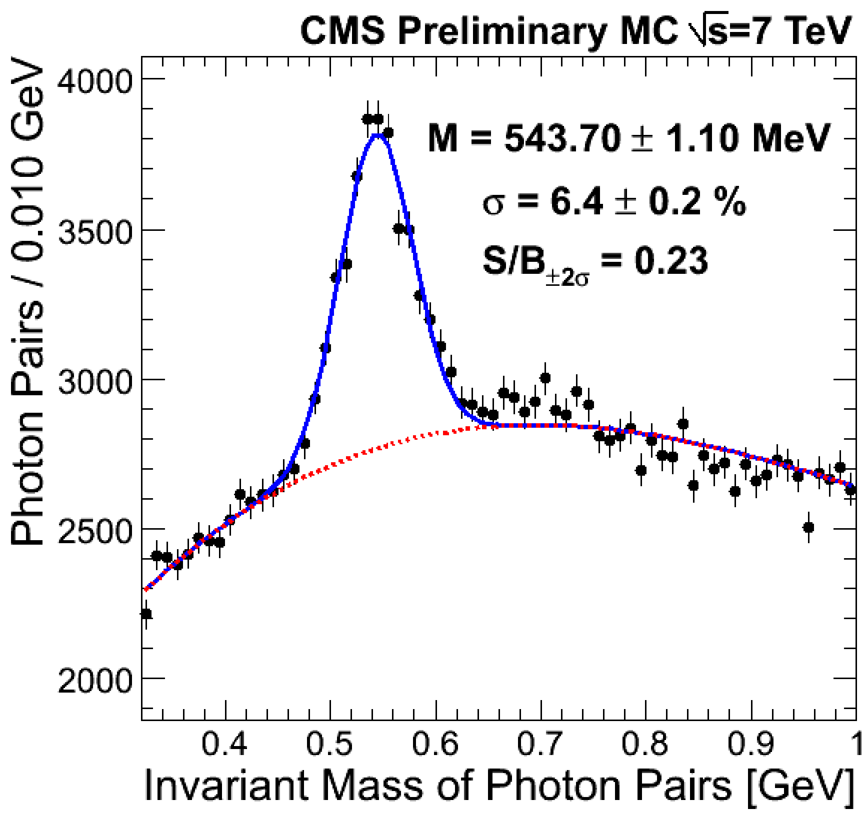
MC vs. Data Distributions for ECAL



Overall very good agreement between data and MC

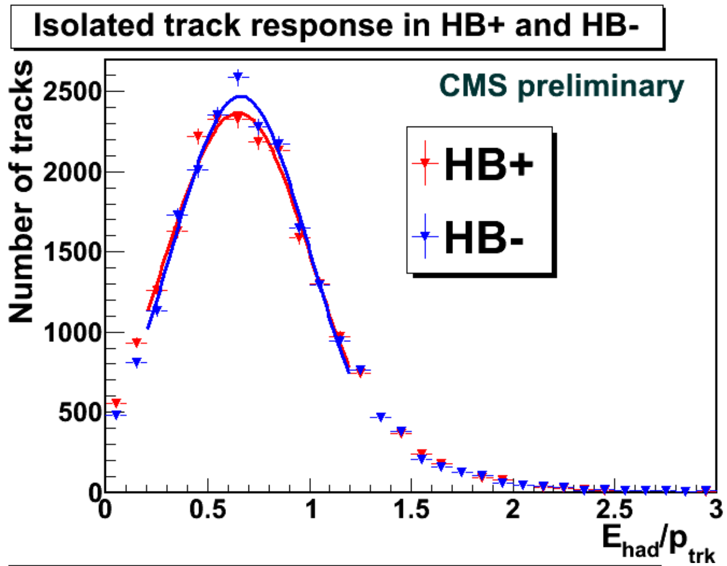
π^0 and η Reconstruction

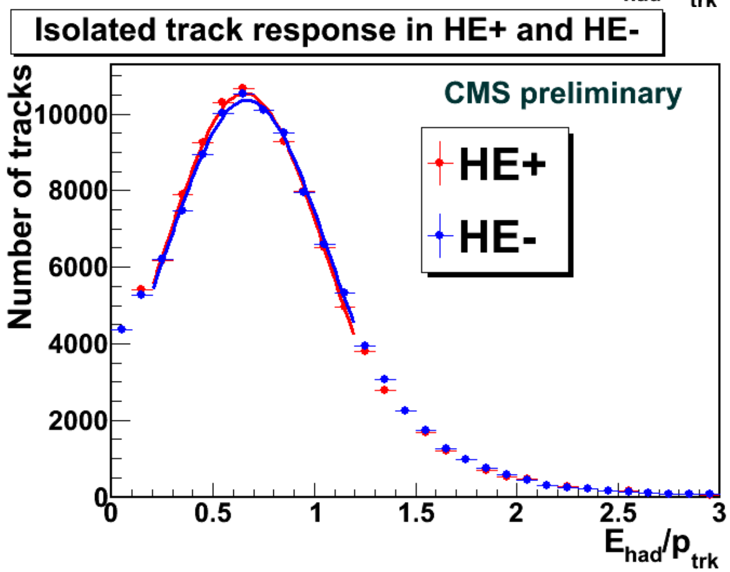




- The excellent ECAL performance allow the clean reconstruction of π^0 and η signals

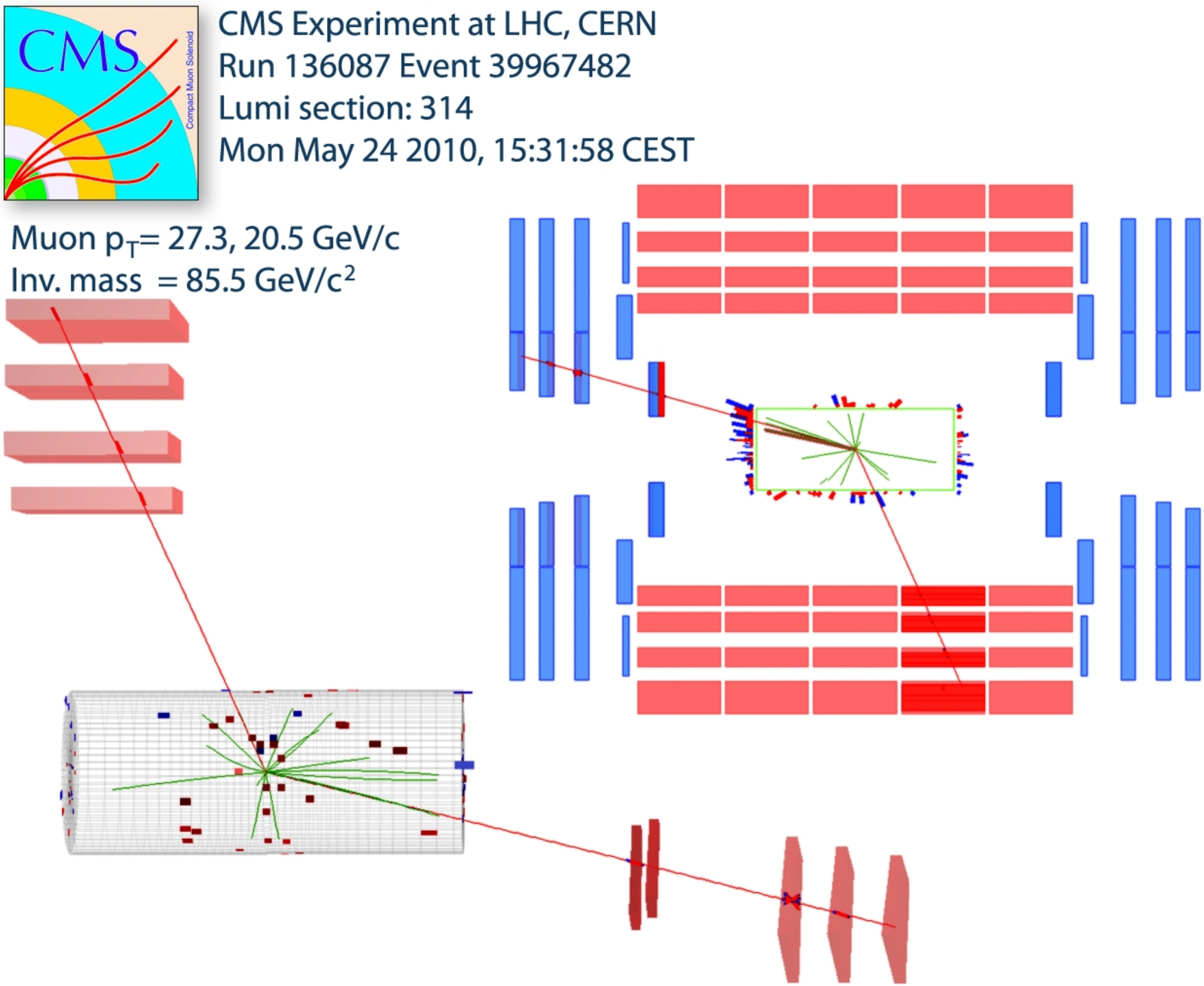
HCAL Calibration with Isolated Tracks





- An important calibration of the HCAL will be done with high pT (pT>60 GeV?) isolated tracks.
- Isolated tracks with pT>5 GeV has been used to study the algorithm.
- Good agreement is seen between the plus and minus side of the detector.

Muon Reconstruction: $Z \rightarrow \mu\mu$



Beyond the Media Event

- Within two hours after the first collisions we started our program of delay scans:
  - We had collected several hundred thousand min bias events, enough for the $dN/d\eta$ analysis at 7 TeV.
  - Pixels and strips (in the deconvolution mode) are read out only for one 25 ns clock cycle. Important to adjust the timing with respect to the LHC clock and the time of collisions.
  - Calorimeters and muon systems need to be timed properly in order to deploy the physics triggers.
    - Only the CSC from the muon subsystems had enough statistics at this early stage to perform a delay scan.
- This program was carried out in the first ~two weeks.
  - Some results from these scans are shown next.

Network Reconfiguration Cont.

- A Team of experts were assembled to tackle this problem
  - DAQ experts
  - DB experts
  - Network monitoring experts
- During an afternoon without beams a series of tests were performed that revealed a number of issues:
  - Very high load on the DB from storage manager process responsible for keeping track of files deleted. This problem has been addressed, but makes it clear that we have to be able to monitor the DB performance.
  - High (CPU) load on network switch. Tried to upgrade software version, but made problem even worse. Have now reconfigured the network to not use ARP (Address Resolution Protocol)
  - There were some failures also in TStore. These are still being addressed.
- The network reconfiguration seems to successfully have addressed the timeouts seen. It also exposed a number of computer systems that was not compliant and made the reconfiguration a bit tricky.