



Automating the CMS DAQ

A review of automation features added to CMS during Run 1 of the LHC

20th International Conference on Computing in High Energy and Nuclear Physics (CHEP)

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on behalf of the CMS DAQ group



Overview

- Automation Features added to CMS DAQ over Run 1 of the LHC added gradually
 - as we learned from operation
 - as new requirements emerged
 - as new failure scenarios became apparent

- These features were needed
 - to operate CMS with high data taking efficiency
 - to operate CMS with a non-expert crew
 - to reduce the work load for on-call experts



Definition: Automation

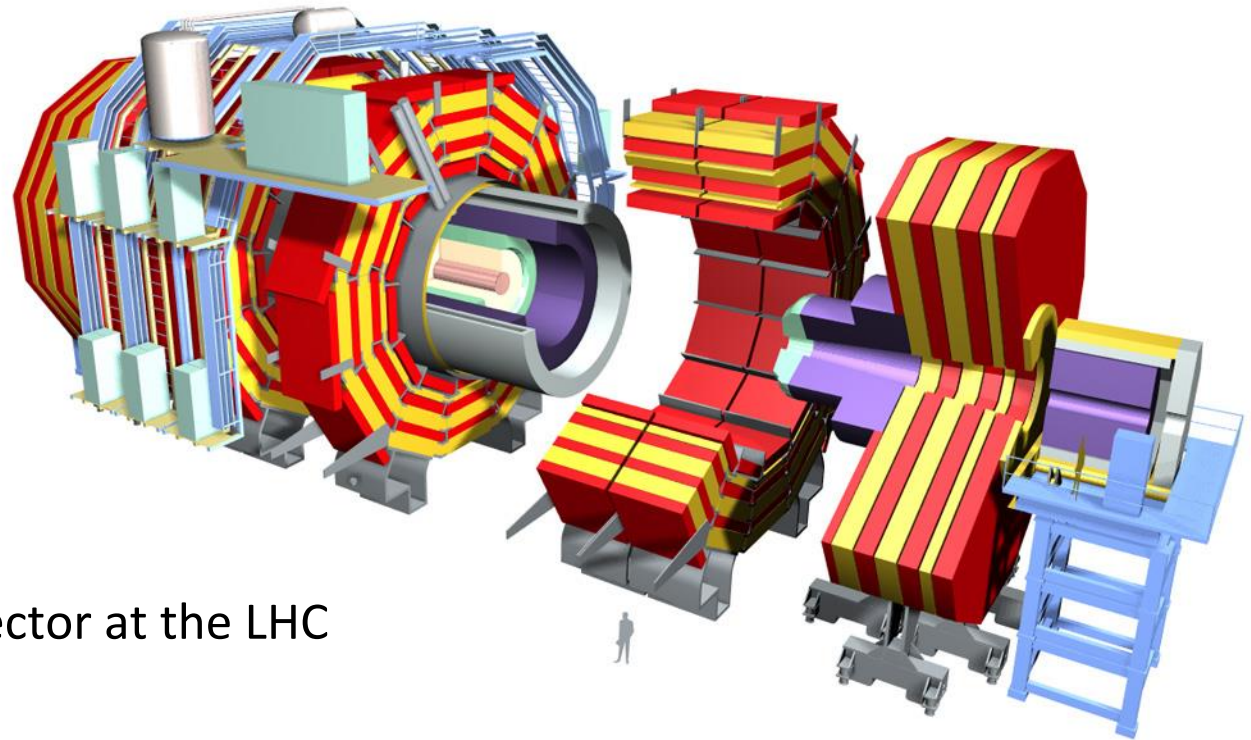
- In principle, anything done by the experiment's online software ultimately falls into the domain of automation

- For this talk we define **automation** to be
 - The automation of routine tasks that otherwise would be performed by the operator or on-call expert (or which were initially performed by the operator)
 - Automatic diagnosis
 - Automatic recovery from known error conditions



System Overview

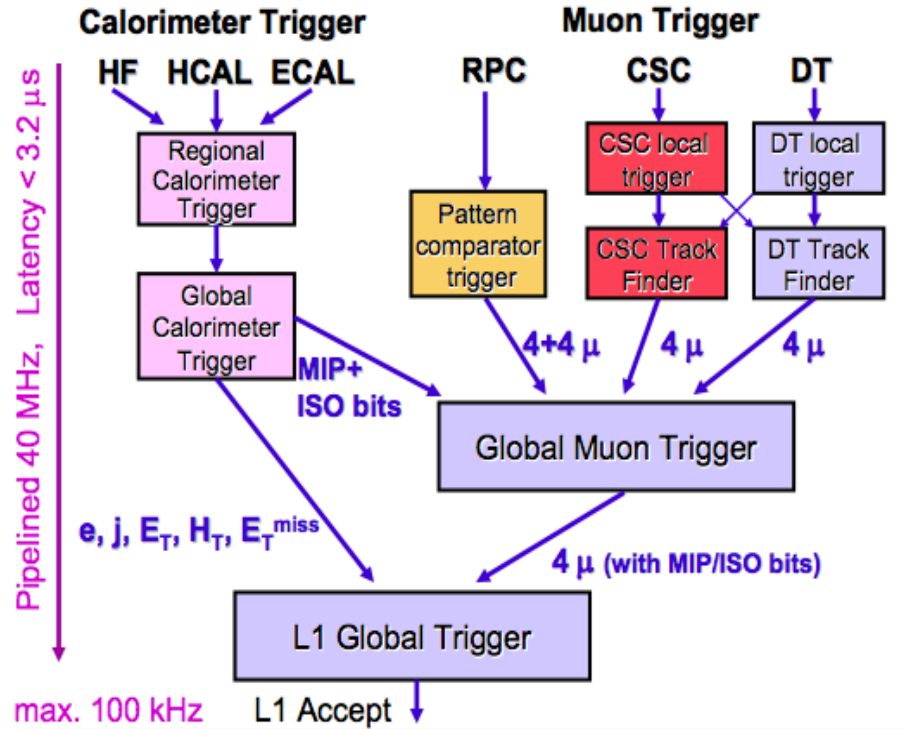
The Compact Muon Solenoid Experiment



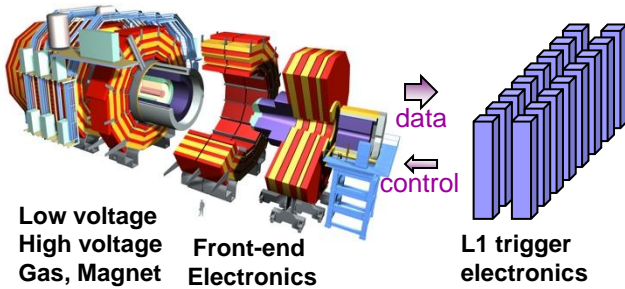
- General-purpose detector at the LHC
- 12 sub-systems
- 55 million readout channels



The first-level trigger



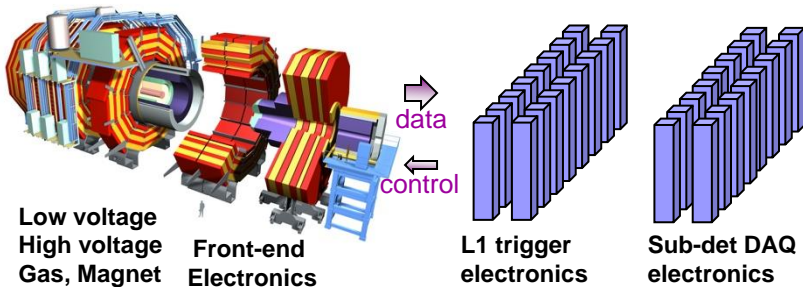
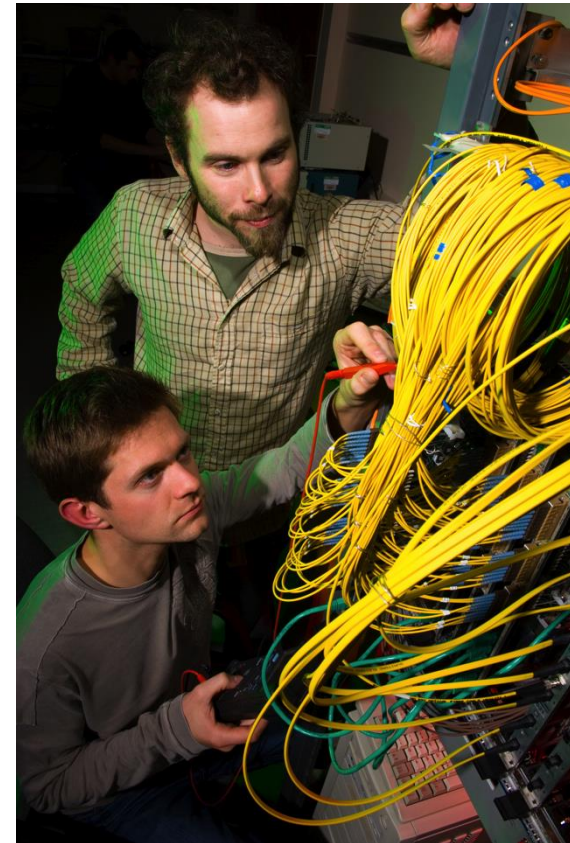
40 racks of custom electronics





Sub-detector DAQ electronics

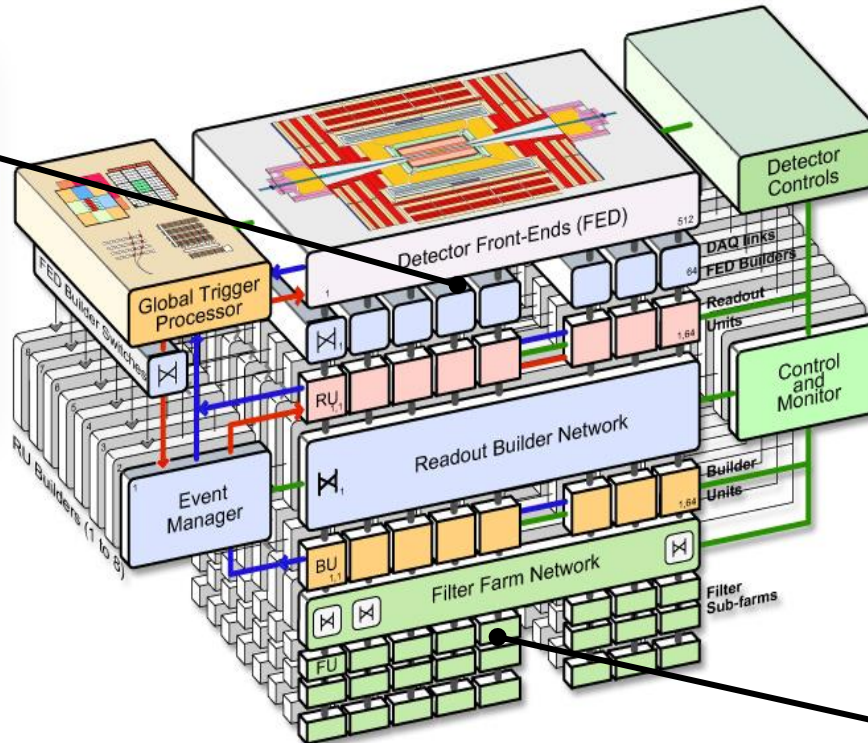
- Front-end Controllers
- Front-end Drivers
 - Delivering data to the central DAQ
 - 700 links



The central DAQ



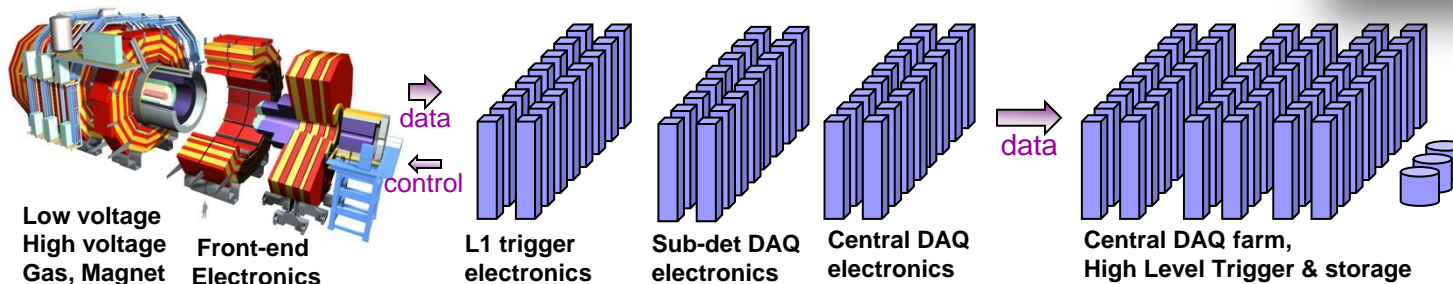
Frontend
Readout Links



- Builds events at 100 kHz, 100 GB/s
 - 2 stages: Myrinet
 - Gigabit Ethernet
 - 8 independent event builder / filter slices
- High level trigger running on filter farm
 - ~1200 PCs
 - ~13000 cores (2012)



Filter farm





The online software

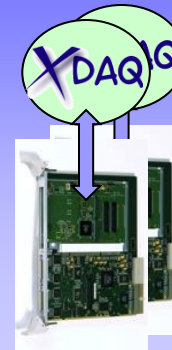
XDAQ Framework – C++

XDAQ applications control **hardware** and handle **data flow**

Hardware Access, Transport Protocols,
XML configuration, SOAP communication,
HyperDAQ web server

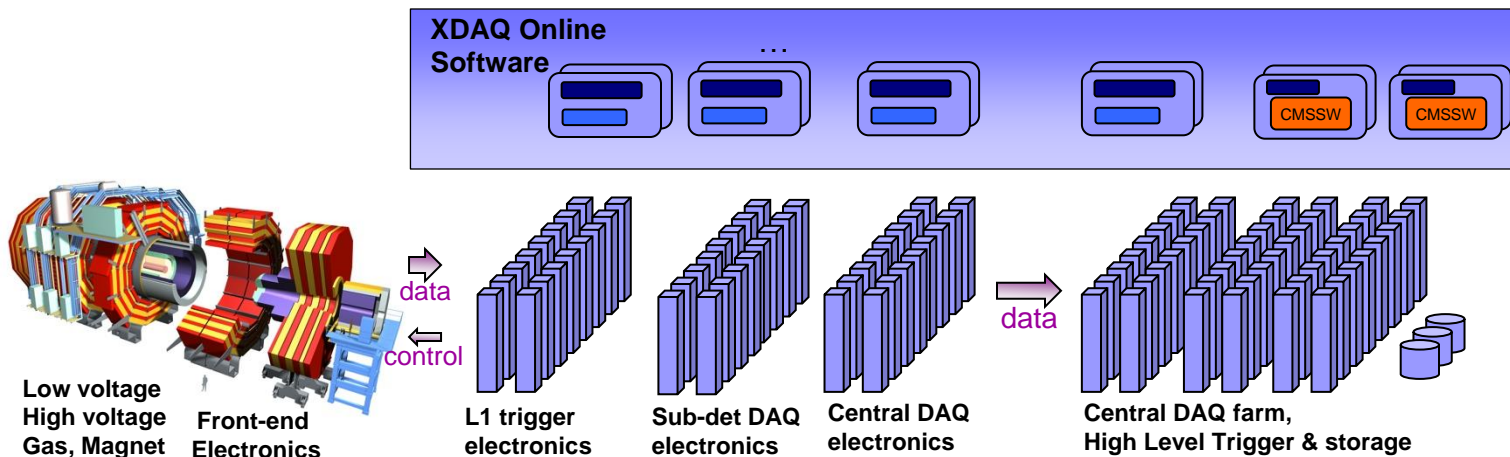


XDAQ Application



data

~20000 applications to control





The online software

Run Control System – Java, Web Technologies

Defines the control structure



GUI in a web browser

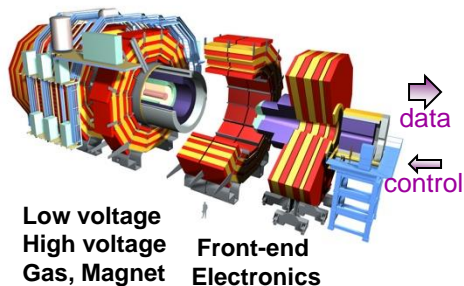
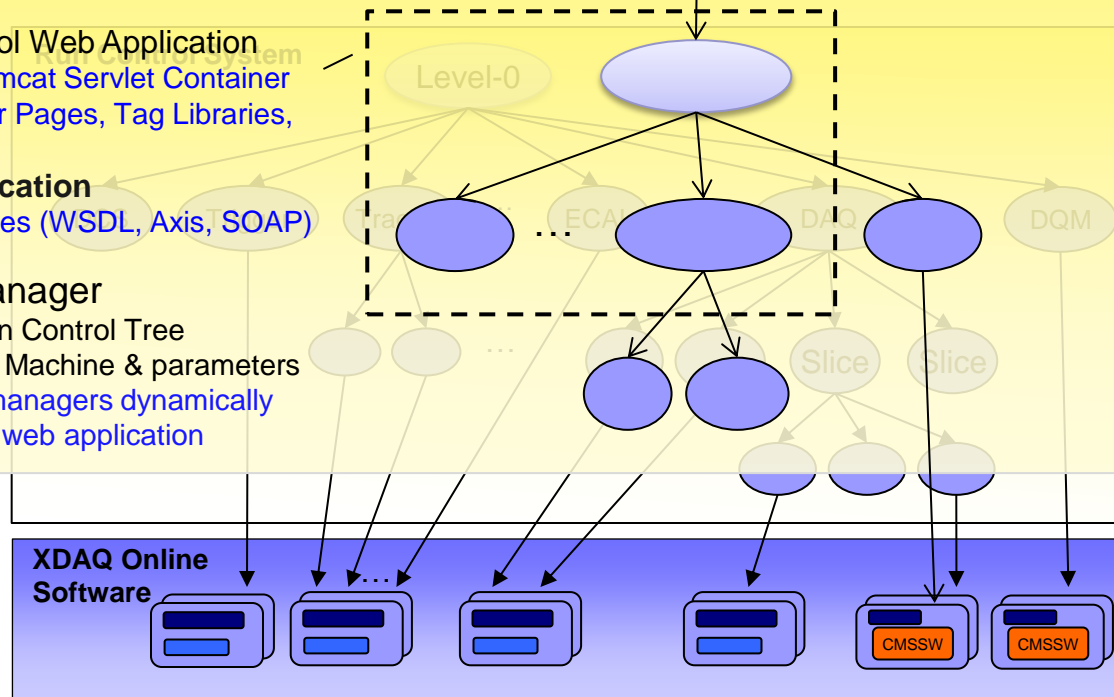
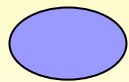
HTML, CSS, JavaScript, AJAX

Run Control Web Application
 Apache Tomcat Servlet Container
 Java Server Pages, Tag Libraries,

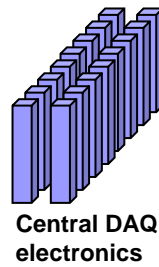
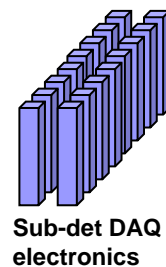
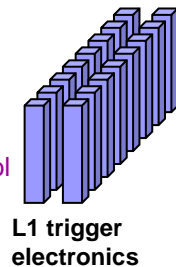
Communication
 Web Services (WSDL, Axis, SOAP)

Function Manager

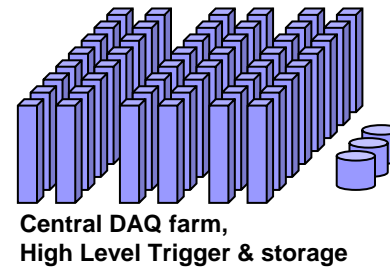
Node in the Run Control Tree
 defines a State Machine & parameters
 User function managers dynamically
 loaded into the web application



data
 control

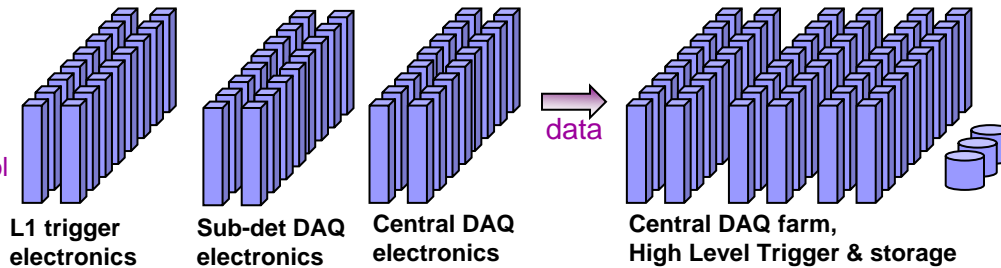
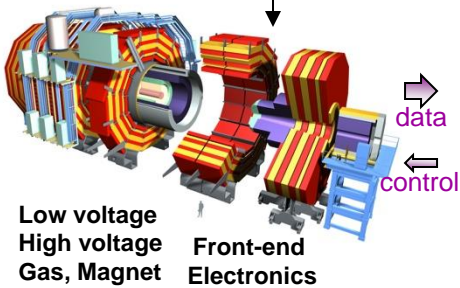
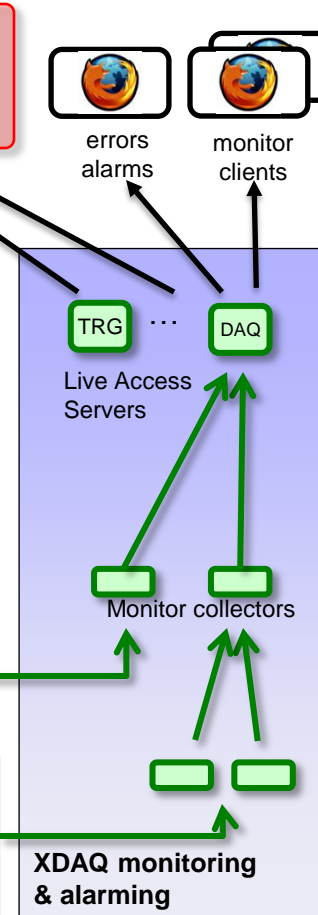
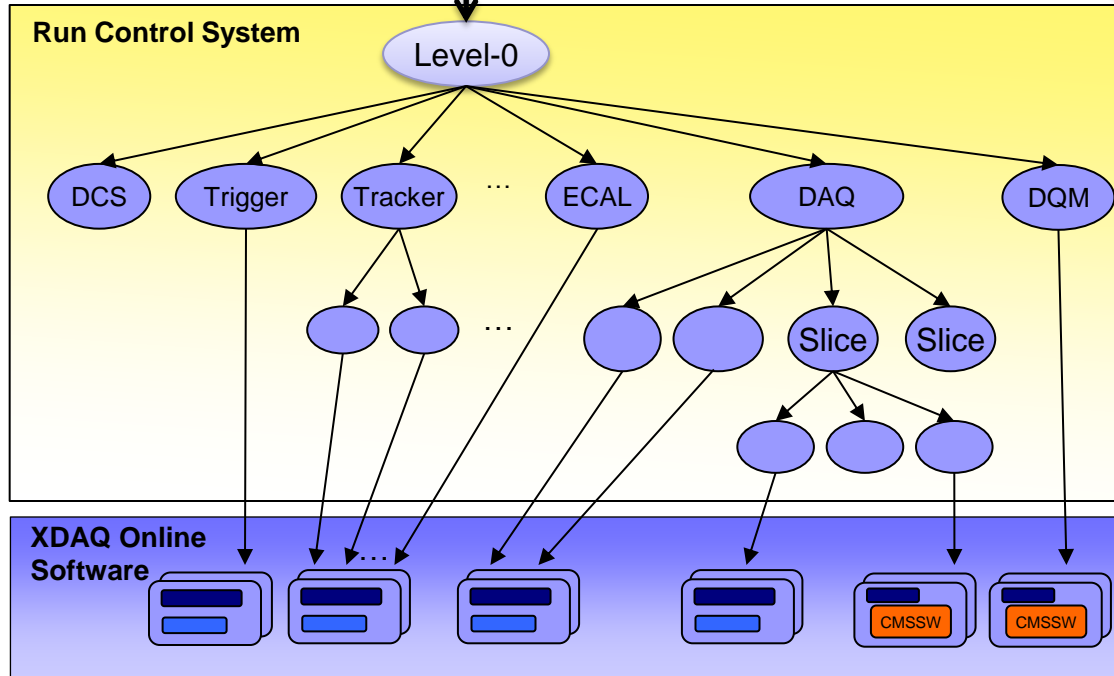
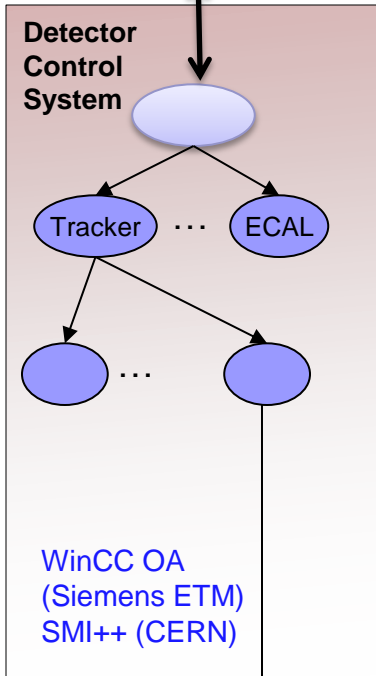
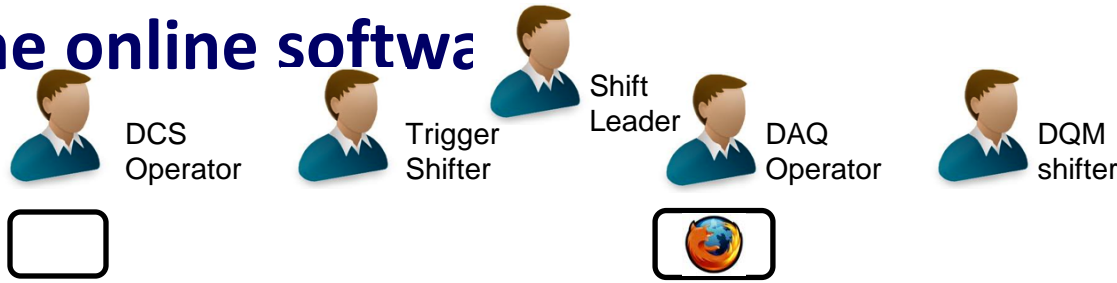


data





The online software





Adding automation



Principles of Automation in CMS

- Integrated into the control tree
 - As **local** as possible
 - Control nodes react to state of their child nodes
 - Detailed knowledge stays encapsulated
 - Propagate information only as far up as necessary
 - Implemented in the Run Control & XDAQ frameworks
 - Distributed
 - Parallel

- In addition – external automation
 - For recovery that changes the system structure
 - E.g. re-computation of the configuration after hardware failure

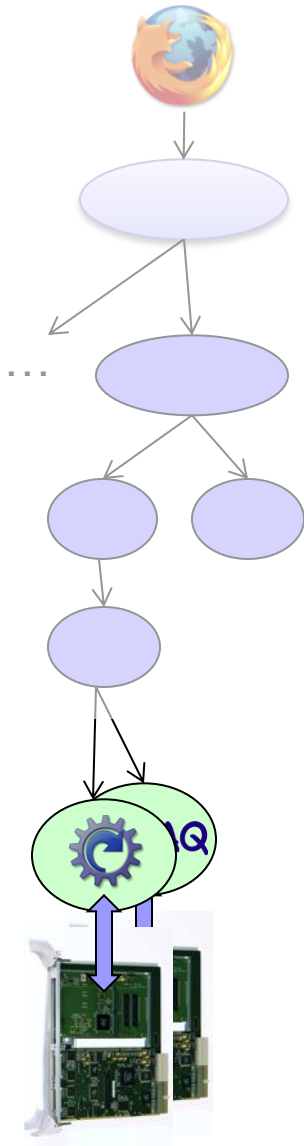


Integrated Automation

a) at the XDAQ layer



Automation in the XDAQ layer



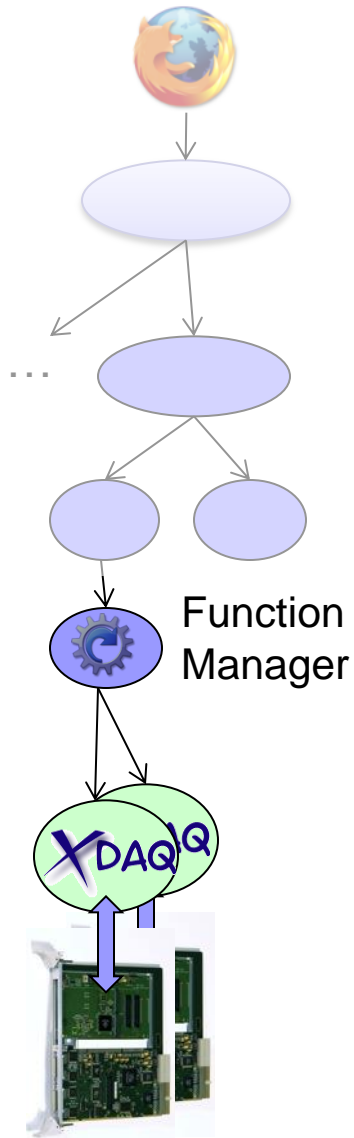
- XDAQ application detects problem and takes corrective action
- How
 - Using framework functionality (work loops ...)
 - Full flexibility of C++ (e.g. Unix signals)
- Example
 - Event Processors (High-Level Trigger)
 - Child processes are forked to process in parallel
 - reduces memory footprint (Copy-On-Write)
 - Reduces configuration time
 - In case a child processes crashes, a new one is created



Integrated Automation b) at the Run Control layer



Automation in Run Control



■ How

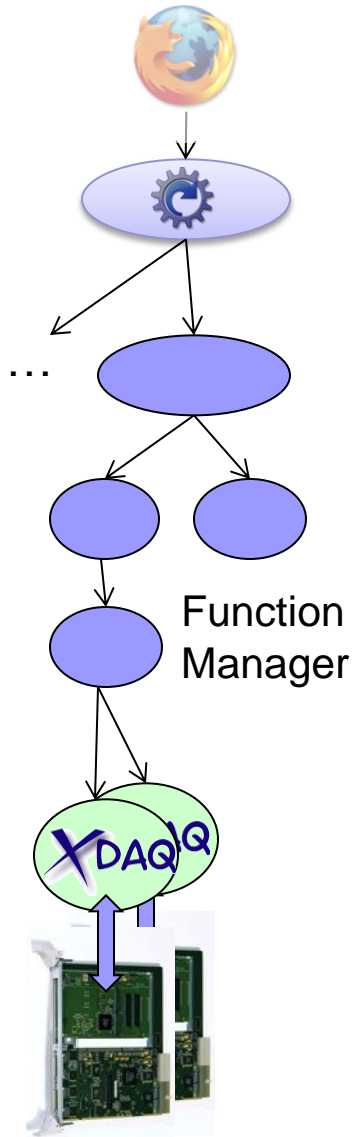
- Function Managers receive **asynchronous updates** from their children
 - State updates
 - Monitoring data
- Function Managers define **event handlers** (Java) reacting to these notifications
- Full flexibility of Java

■ Examples

- Exclude crashed resources from control
- Recover flush failure
 - When stopping a run, sometimes a DAQ slice cannot be flushed
 - The corresponding function manager detects this and locally recovers this slice



Automation in the Run Control Top-level Node



- For actions that need coordination between multiple sub-systems
 - Example 1: Automatic actions in the DAQ in response to condition changes in the DCS and the LHC
 - Example 2: Synchronized error recovery
 - Example 3: Automatic configuration selection based on LHC mode

see following slides ...

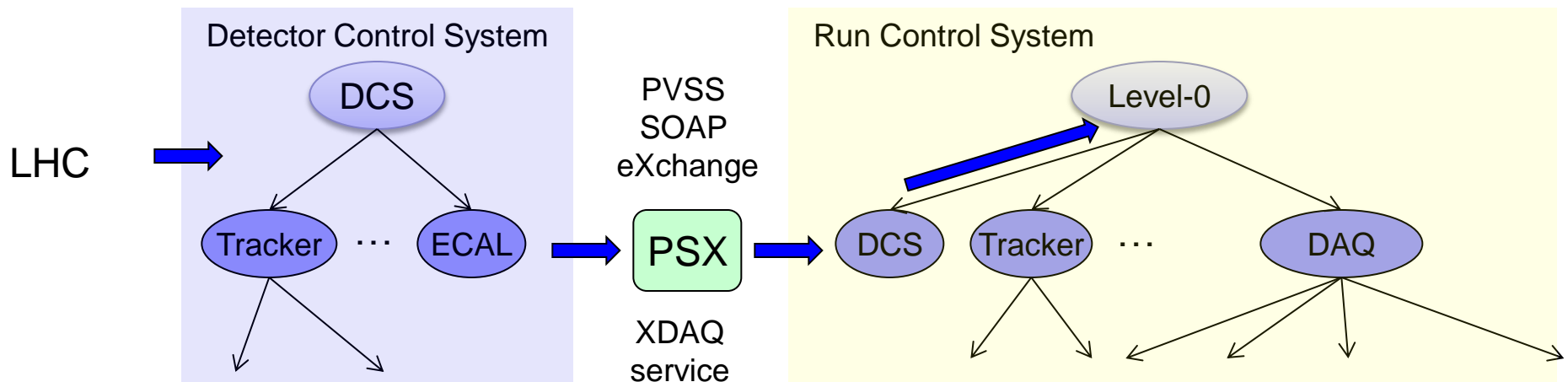


Automation Example 1: Automatic reaction to LHC and DCS



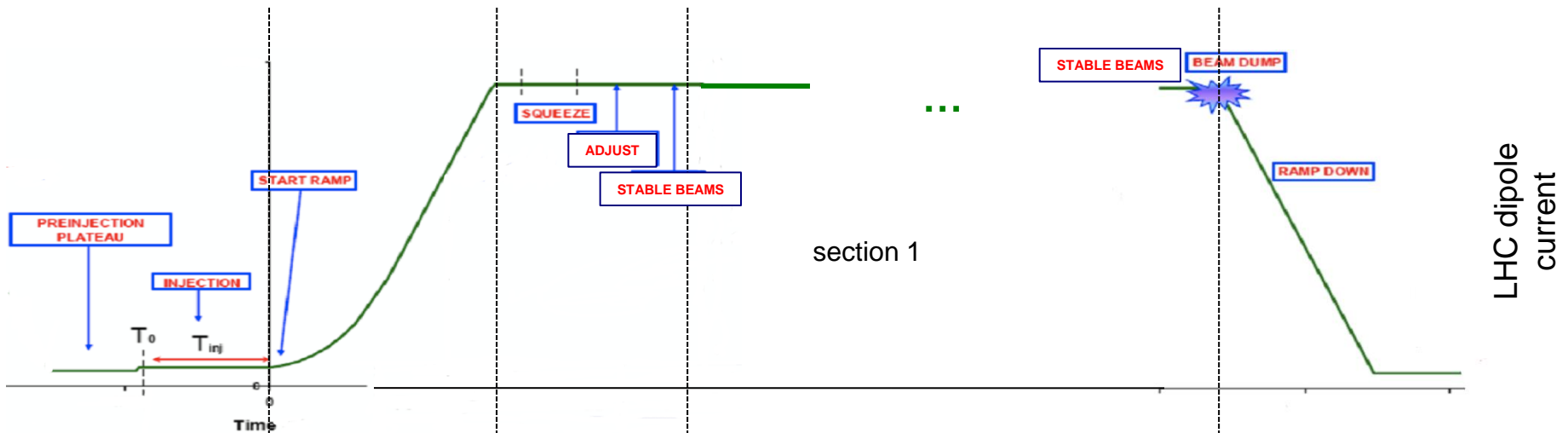
DAQ actions on LHC and DCS state changes

- Extensive automation has been added to DCS
 - Automatic handshake with the LHC
 - Automatic ramping of high voltages (HV) driven by LHC machine and beam mode
- Some DAQ settings depend on the LHC and DCS states
 - Suppress payload while HV is off (noise)
 - Reduce gain while HV is off
 - Mask sensitive channels while LHC ramps ...
- Initially needed to start new run with new settings – *very error prone*
- Since 2010: automatic new **run sections** driven by asynchronous state notifications from DCS/LHC

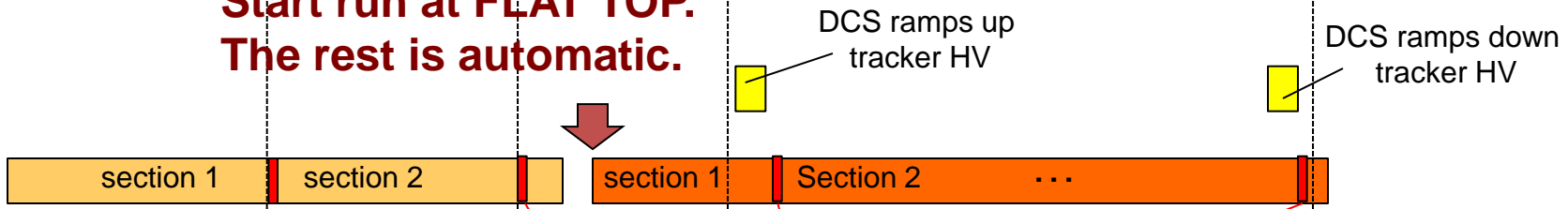




Now everything is driven by the LHC ...



**Start run at FLAT TOP.
The rest is automatic.**



Automatic actions in DAQ :

ramp start
Mask sensitive trigger channels

ramp done
Unmask sensitive trigger channels

Tracker HV on
Enable payload (Tk)
raise gains (Pixel)

Tracker HV off
Disable payload (Tk)
reduce gains (Pixel)



Example 2: Automatic recovery from Soft Errors



Automatic soft error recovery

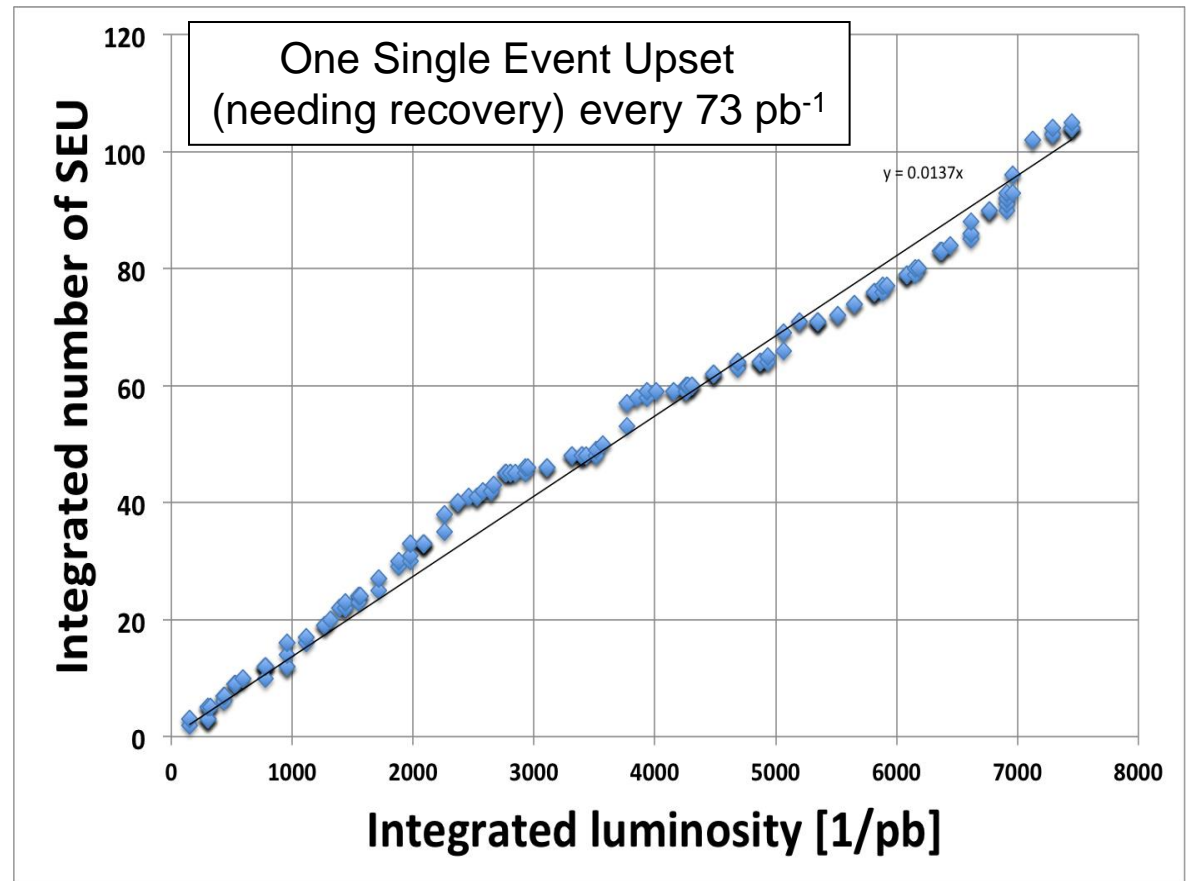
- With higher instantaneous luminosity in 2011 more and more frequent “soft errors” causing the run to get stuck

- Proportional to integrated luminosity
- Believed to be due to single event upsets

- Recovery procedure

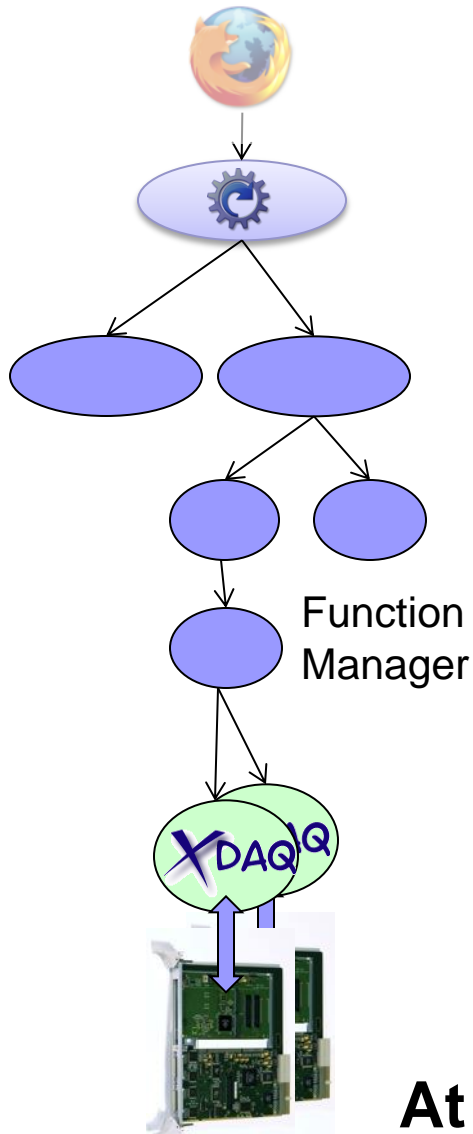
- Stop run (30 sec)
- Re-configure a sub-detector (2-3 min)
- Start new run (20 sec)

3-10 min down-time



Single-event upsets in the electronics of the Si-Pixel detector. Proportional to integrated luminosity.

Automatic soft error recovery



- From 2012, new automatic recovery procedure in top-level control node

1. Sub-system detects soft error and signals by changing its state
2. Top-level control node invokes recovery procedure
 - a) Pause Triggers
 - b) Invoke newly defined selective recovery transition on requesting detector
 - c) In parallel perform preventive recovery of other detectors
 - d) Resynchronize
 - e) Resume

12 seconds down-time

At least 46 hours of down-time avoided in 2012



Example 3: Automatic Configuration Handling



Lots of options to parameterize the configuration

Level0-FM (RCMS_3_5_3_LEVELZEROFM_v6) - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://rcms/gui/servlet/FMPilotServlet?PAGE=/gui/jsp/controlPanel.jsp

Most Visited Red Hat, Inc. Red Hat Network Support Shop Products http://cmsrc-trigger.39... Training

Status Table PCMonitor FED & TTS **HLT Keys** Lock save Refresh Detect Destroy

Running 00:24.1

Connect Configure Get Ready Start

Pause Resume Stop Halt ColdReset

ForceStop ForceHalt Recover Interrupt

TTCResync TTCHadReset TTTestMode TestTTS

DCS/LHC flag	state	force
PIX_HV_ON	N/A	FROM DCS
TK_HV_ON	N/A	FROM DCS
PHYSICS_DECLARED	false	FROM DCS
LHC_RAMPING	false	FROM DCS

LHC machine mode: ACCESS
 LHC beam mode: NO BEAM
 LHC clock stable: false
 Next clock source: LOCAL force_LOCAL
 Current clock source: LOCAL

Configuration: /appro:PublicGlobal/levelZeroFM

Run Number: **134746**

SID: 133644
 Seq Name: GLOBAL-RUN
 Global Key: /GLOBAL_CONFIGURATION_MAP/CMS/CENTRALGLOBAL_RUN
 HLT Config Name: /cdq/physics/firstCollisions10v5.1/HLT_CosmicsV1
 L1 Trigger Key: L1_20100508_144832_997 => TSC_20100501_002208_cosmics_BASE made current 22 minutes and 25 seconds ago.
 Clock type: LOCAL => MIL_KEY_boneInternal-manual
 /cmseq_100308_RUN_201010_all_rev100420
 /cp_8slice_5TC_BUF0_848UTMasterFU_16SM_NR_brev74.0
 Tasks completed.

Subsystem	ECAL	ES	HCAL	[LUM]	TRG	DT	CSC	RPC	DAQ	DOM	SCAL	CASTOR	DCS
State	Running	Running	Running	Running	Running	Running	Running	Running	Running	Running	Running	Running	Connected
Time:	00:04.0	00:02.3	00:11.6		00:06.7	00:10.3	00:09.0	00:00.1	00:16.3	00:00.5	00:00.8	00:00.5	00:06.7

Enabled Slices: [checked] [checked] [checked] [checked] [checked] [checked] [checked]

Run Key: SelectiveReadout HighGain 25 HF AND LUM FOLLOW HCAL Automatic TERO_TRANSFER ON

Commander: [select] [select] [select] [select] [select] [select] [select] [select] [select] [select] [select] [select] [select] [select]

ECAL
 ES
 HCAL

TRACKER Configured

TRG TRG NR=900487 Rate: 898.8 Hz orbit=1267855 (prev=985891.5113990487)

DT
 CSC
 RPC Starting
 DAQ
 DOM running
 PIXEL
 SCAL
 CASTOR running like hell ...

COW
 DCS DCS_LHC_FLAGS at 2010-05-03 14:02:30 CEST: LHC_RAMPING:false TK_HV_ON:N/A PIX_HV_ON:N/A PHYSICS_DECLARED:false

Run History 2010-05-03 16:52:45 CEST: LS=1.00 Trg=0 Evts=0 Start Run 134746 TK_HV_ON:N/A PIX_HV_ON:N/A LHC_RAMPING:false PHYSICS_DECLARED:false

Done

Top level Run Control GUI
 Initially flexibility needed – many manual settings



First added shifter guidance

TRG	DT	CSC	RPC	
Running	Running	Running	Running	
00:03.8	00:11.0	00:05.6	00:00.2	

Automatic [dropdown] [dropdown] [dropdown] [dropdown] TERP...

select [dropdown] select [dropdown] select [dropdown] select [dropdown] select

[Recycle icon] [Recycle icon] [Recycle icon] [Recycle icon] [Recycle icon] [Recycle icon] [Recycle icon] [Recycle icon]

Reconfiguration needed for subsystem TRG

L1: The L1 trigger configuration has changed:
new L1 key: L1_20100429_172021_908
old L1 key: L1_20100429_094604_907

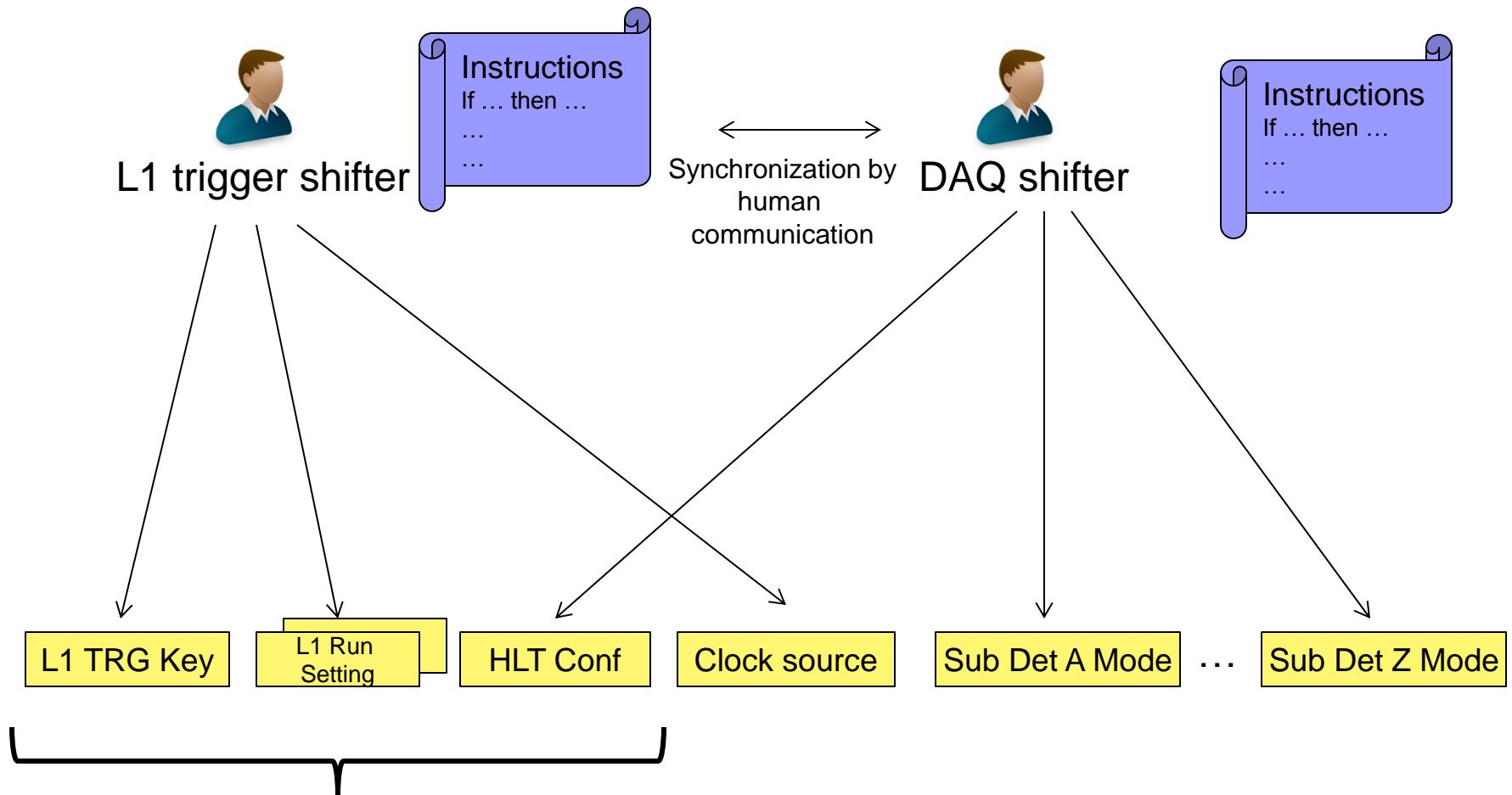
The following sub-keys / ...
ECAL_KEY: BEAMV1 ...
TSC_KEY: TSC_201004 ...

- Added cross-checks and reminders
 - When sub-systems need to be re-configured
 - Because of clock instabilities
 - Because (External) configuration changes ..
 - Correct order of operations enforced
- Then simplified and automated ...



Configuration Handling (initial)

■ 2009/2010

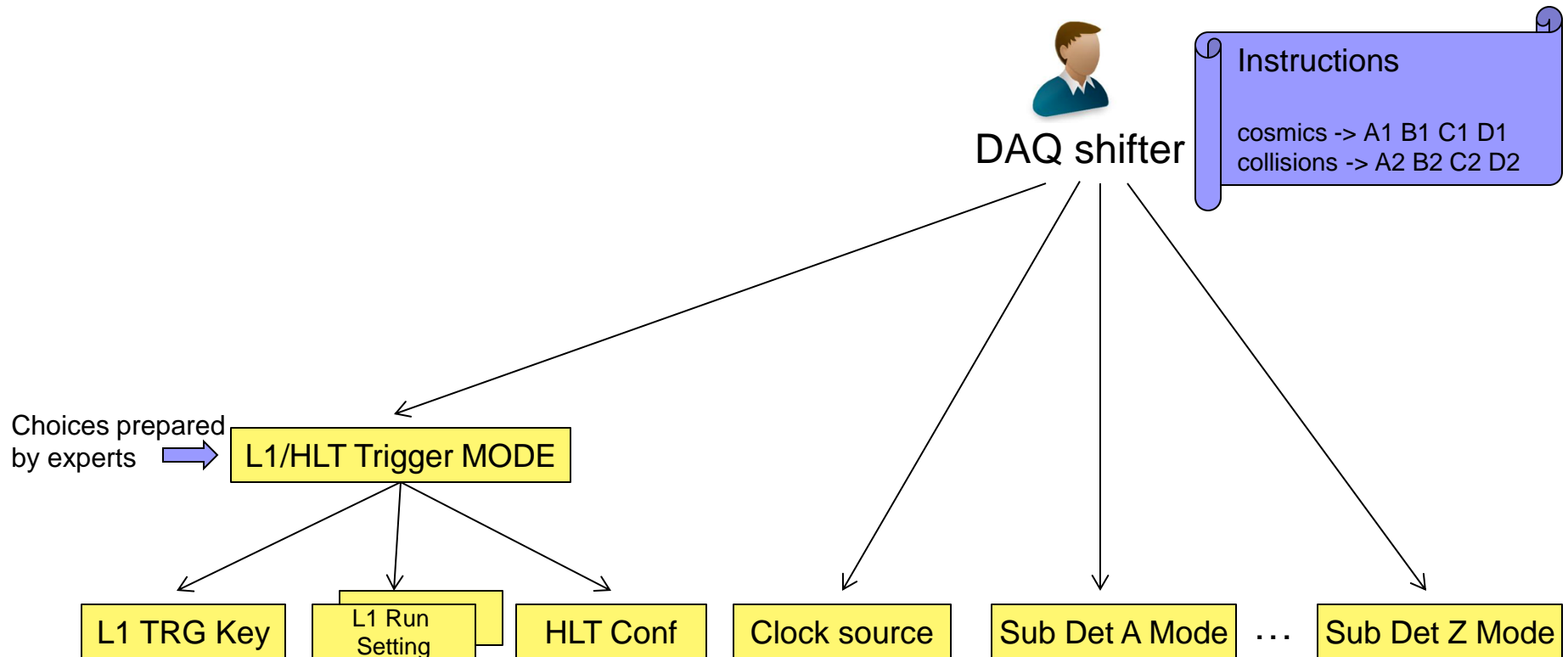


Trigger configuration needs to be consistent



Configuration Handling (simplified)

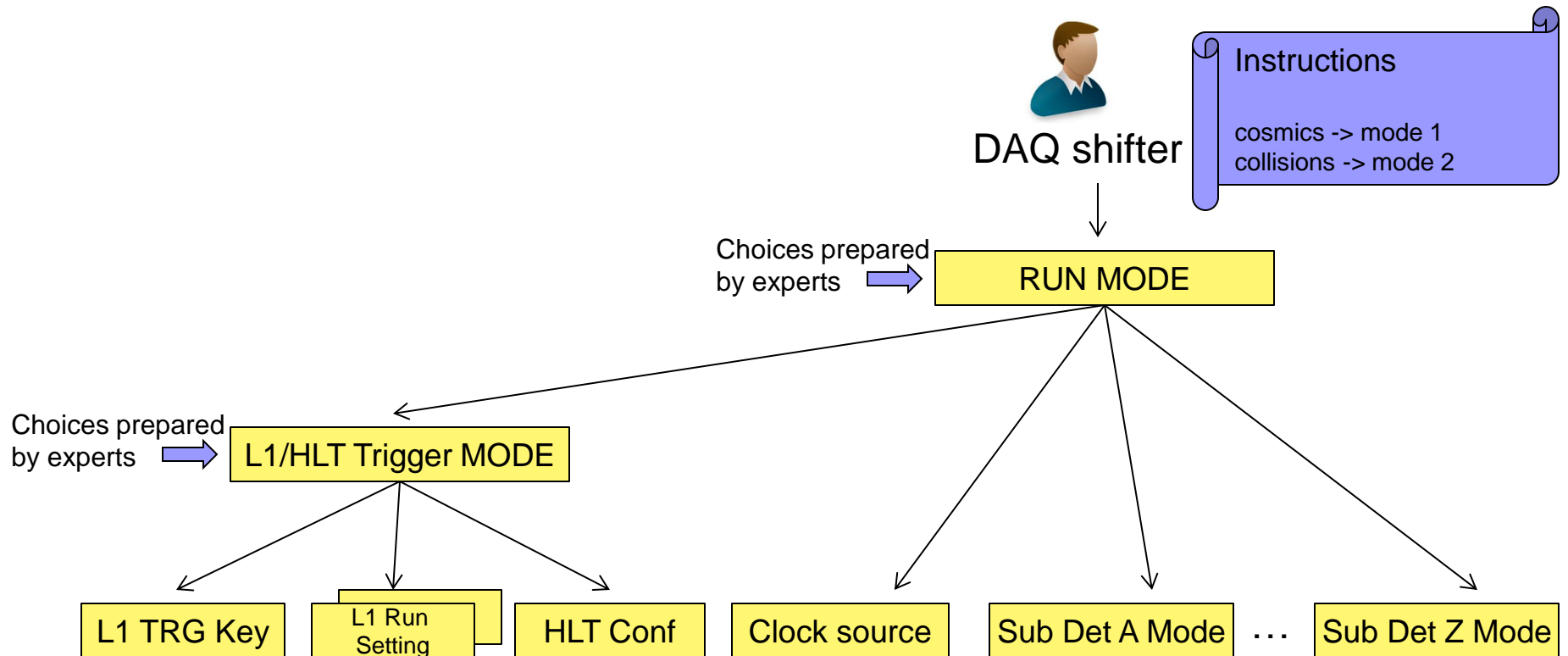
■ 2010





Configuration Handling (Run Mode)

■ 2012



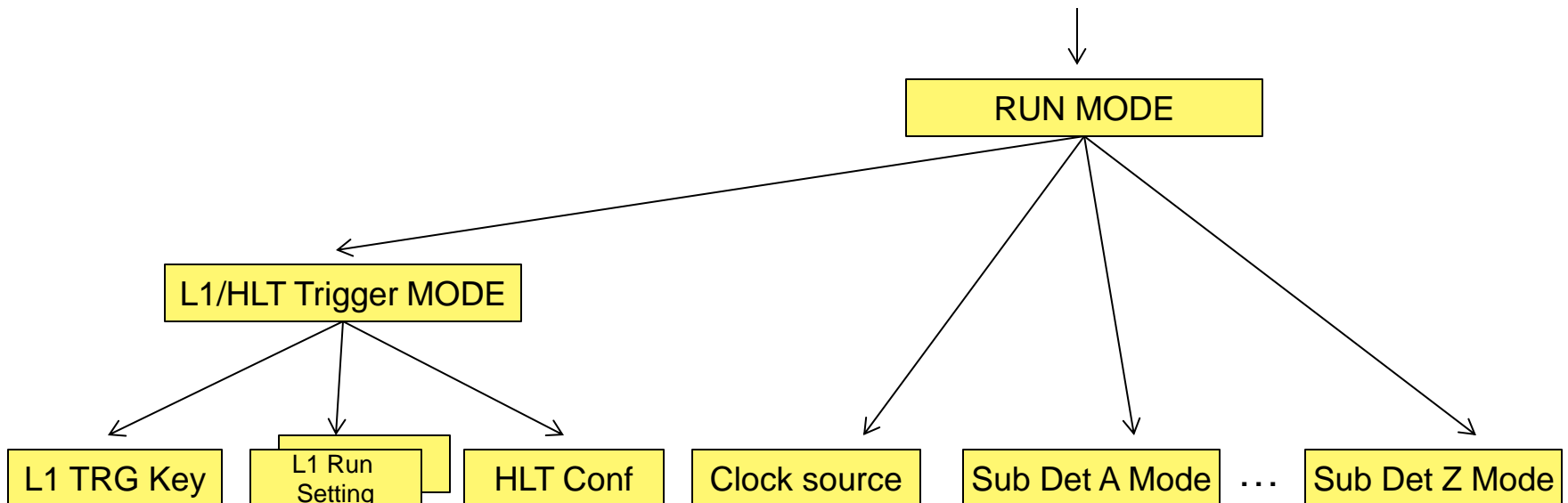
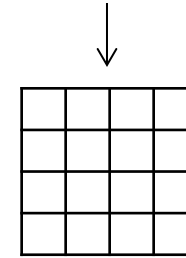


Configuration Handling (automatic)

■ 2012

KEY TYPE	CURRENTLY APPLIED VALUE	NEXT VALUE	from LHC
CMS Run Mode	collisions	collisions	autoselect <input checked="" type="checkbox"/>

LHC
machine / beam mode

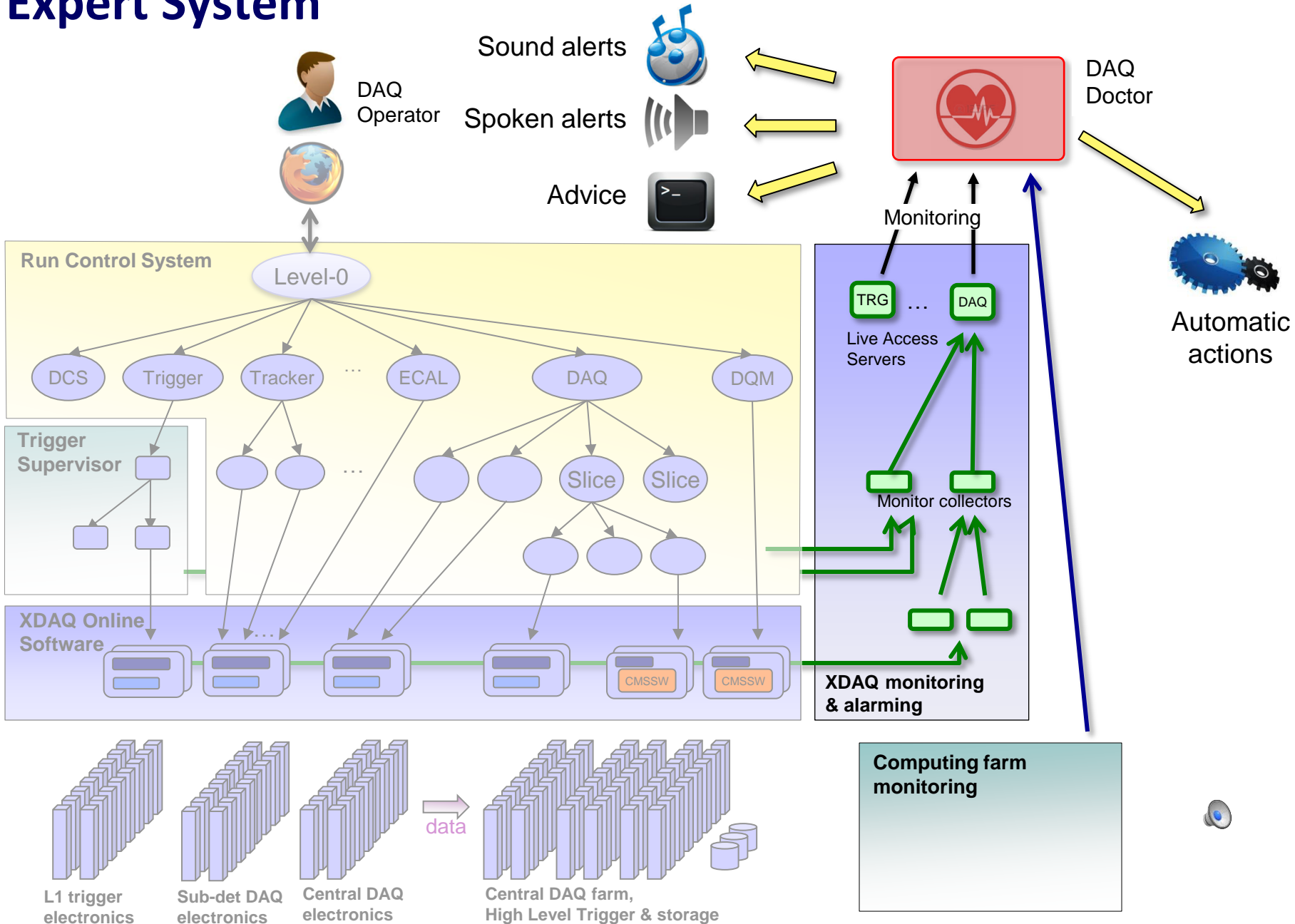




Central Expert System

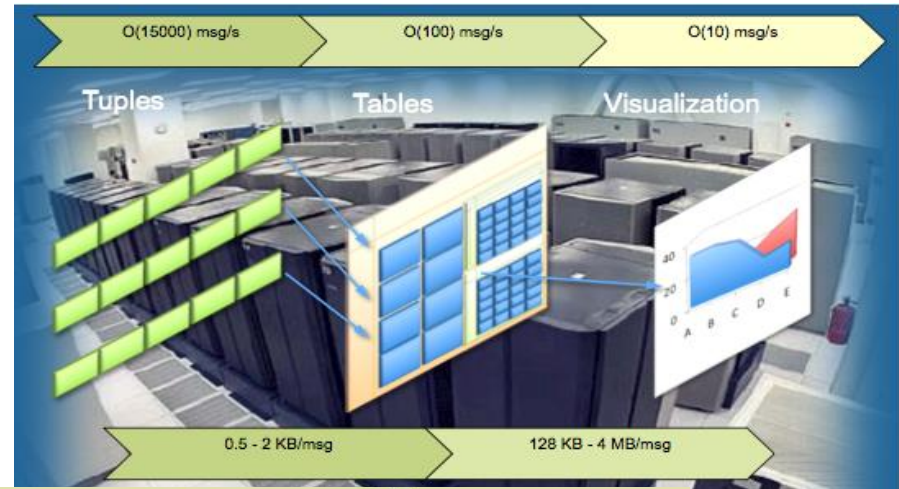


Expert System



The DAQ Doctor

- Expert tool based on the same technology as **Booking.com**
 - High level scripting language (Perl)
- Generic framework & pluggable modules
- Detection of high level anomaly triggers further investigation
- Archive (web based)
 - All Notes
 - Sub-system errors
 - CRC errors
- Dumps (of all monitoring data) for expert analysis in case of anomalies



Notes of the DaqDoctor

2012 - may - 7 - 2012 - may - 7 - go search (perl regex)

An extract of the DaqDoctors Notes for the year 2012

Note that not all subsystem errors are contained in this list. For a full error list browse the [archive of the DaqDoctor!](#)

Date	LHC State	System	Error	Remarks
2012-05-18 18:18:26	STABLE BEAMS	PIXEL	FMSStateError	oldstate: Faulty
2012-05-17 17:48:28	SETUP	PIXEL	FMSStateError	oldstate: Initializing
2012-05-17 03:39:08	STABLE BEAMS	PIXEL	FMSStateError	oldstate: FixingSoftware
2012-05-17 03:41:25	STABLE BEAMS	PIXEL	FMSStateError	oldstate: FixingSoftware
2012-05-14 13:52:02	SETUP	PIXEL	FMSStateError	oldstate: Configuring
2012-05-14 13:50:20	SETUP	PIXEL	FMSStateError	oldstate: Configuring
2012-05-14 13:48:32	RAMP DOWN	PIXEL	FMSStateError	oldstate: Initializing
2012-05-14 13:47:37	RAMP DOWN	PIXEL	FMSStateError	oldstate: Halted
2012-05-08 14:31:41	SETUP	PIXEL	SyncLostDraining	37, 37, 38, 33, 39, 32, 35, 36, 26, 29, 25, 23, 20, 30, 17, 18, 24, 31, 28, 16, 19, 27, 5, 9, 14, 15, 3, 0, 10, 13, 7, 4, 1, 2, 8, 12, 6, 11
2012-05-07 01:39:50	SETUP	PIXEL	FMSStateError	oldstate: Initializing
2012-05-06 23:17:12	PREPARE RAMP	PIXEL	FMSStateError	oldstate: Pausing
2012-05-02 18:04:37	INJECTION PHYSICS BEAM	PIXEL	FMSStateError	oldstate: Initializing
2012-04-28 00:32:32	NO BEAM	PIXEL	FMSStateError	oldstate: Initializing
2012-04-27 15:23:59	NO BEAM	PIXEL	FMSStateError	oldstate: Starting
2012-04-27 15:19:38	NO BEAM	PIXEL	FMSStateError	oldstate: Initializing
2012-04-20 15:22:08	SETUP	PIXEL	FMSStateError	oldstate: Initializing
2012-04-19 16:09:52	SETUP	PIXEL	FMSStateError	oldstate: Initializing
2012-04-19 12:56:32	SETUP	PIXEL	FMSStateError	oldstate: Initializing
2012-04-19 00:49:53	STABLE BEAMS	BPX	ITSNvcs	1,20
2012-04-19 00:48:30	STABLE BEAMS	BPX	ITSNvcs	1,20
2012-04-19 00:48:06	STABLE BEAMS	BPX	ITSNvcs	1,20
2012-04-19 00:46:36	STABLE BEAMS	BPX	ITSNvcs	1,20
2012-04-18 00:30:42	STABLE BEAMS	PIXEL	SyncLostDraining	5, 37, 34, 39, 32, 35
2012-04-15 12:54:52	SETUP	PIXEL	FMSStateError	oldstate: Initializing
2012-04-15 09:44:28	SETUP	PIXEL	FMSStateError	oldstate: Initializing
2012-04-12 23:36:13	SETUP	PIXEL	FMSStateError	oldstate: Initializing



The DAQ Doctor

■ Diagnoses Anomalies in

- L1 rate
- HLT physics stream rate
- Dead time
- Backpressure
- Resynchronization rate
- Farm health
- Event builder and HLT farm data flow
- HLT farm CPU utilization
- ...

2013-02-02 00:02:31	ADJUST	The average event size is suspiciously SMALL: 237 kB. Normally around 700kB are expected during a Physics run with all subdetectors in and at the beginning of a fill. Check with the shiftleader and the DQM shifter if something is going wrong. (Check the Radar plot of event sizes, DQM, Detectors which are missing in the readout, ...) (...I could do this also ... but I am too lazy and something also YOU have to do...)
2013-02-02 00:05:27	ADJUST	The total datarate written by the StorageManagers to disk has changed by 932.471560311376%. It is now 114.9 MB/s.
2013-02-02 00:05:35	ADJUST	sTTS of TIBTID is in Out-Of-Sync. Please follow the instructions in the DAQ Shifter Action Matrix (in the bulletin board)!
2013-02-02 00:05:41	ADJUST	Number of resyncs in this run now: 4
2013-02-02 00:05:43	ADJUST	sTTS of TIBTID is not anymore in Out-Of-Sync.
2013-02-02 00:05:51	ADJUST	TTS Alarm for partition CSC+: FMM fmmpc-s1d12-07.cms slot 3 is 9.25% in busy!

■ Automatic actions

- Triggers computation of a new central DAQ configuration in case of PC hardware failure(great help for on-call experts since 2012)

2013-02-02 01:48:32	INJ PROBE BEAM	I did not find a reason yet why the DAQ is in ERROR... may be the monitoring system is slow and I need more up to date data. I try again in 10 seconds. (try no: 2/3)
2013-02-02 01:48:47	INJ PROBE BEAM	====> !!! Trouble ahead !!! <==== The machine ru-c2a05-15.cms does not respond to ssh connections. It is probably crashed.
2013-02-02 01:48:47	INJ PROBE BEAM	I am now trying to generate and register a new configuration without the offending host ru-c2a05-15.cms in slice 1... some patience please...
2013-02-02 01:49:27	INJ PROBE BEAM	The new configuration has been generated and created. Probably stopping the run will fail. When you recycle the DAQ the new configuration without the broken computer will be picked up and you should be able to continue. But remember: if you are happily taking data at the moment defer the recycling of the DAQ as much as possible! Only interrupt this run when really necessary!



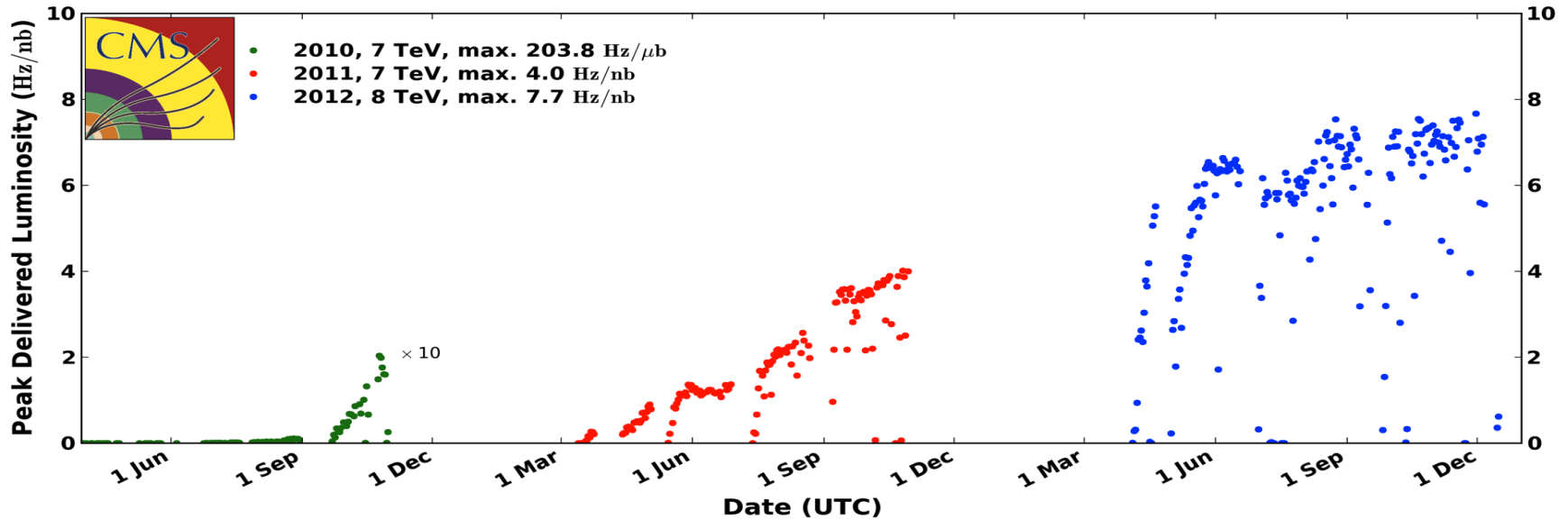
Operational Efficiency

CMS control room, Cessy, France ...



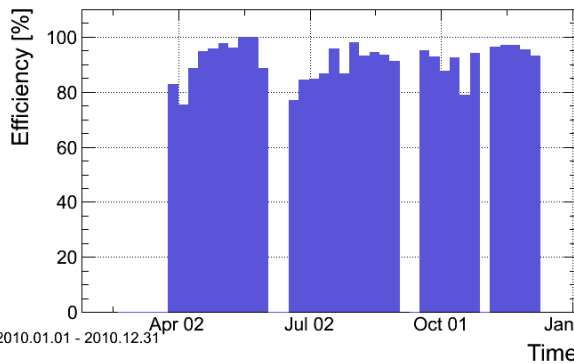
CMS Peak Luminosity Per Day, pp

Data included from 2010-03-30 11:21 to 2012-12-16 20:49 UTC

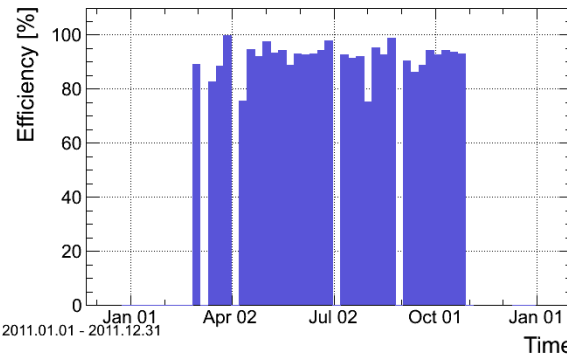


CMS data taking efficiency:

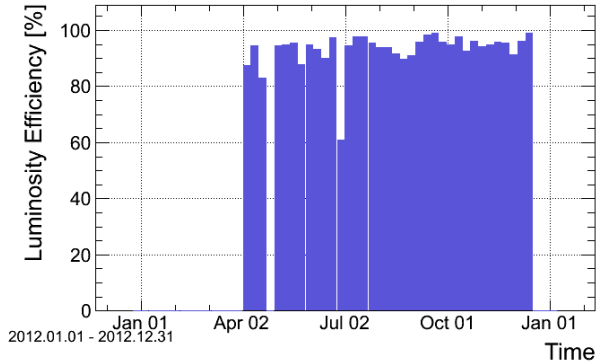
CMS Weekly Efficiency (online) [pp] $\sqrt{s} = 7$ TeV



CMS Weekly Efficiency (online) [pp] $\sqrt{s} = 7$ TeV



CMS Weekly Efficiency (online) [pp] $\sqrt{s} = 8$ TeV



CMS data taking efficiency (stable beams):

Central DAQ availability > 99.6% in all three years

2010: 90.7%

2011: 93.1%

2012 : 94.8%



Summary & Outlook



Summary

- During Run 1 of the LHC, routine actions and error recovery have largely been automated in the CMS DAQ

- Two approaches were followed
 - Integrated into the control tree
 - **Local**, distributed
 - Central expert system
 - For diagnosis, advice &
 - automation that changes the system structure

- Automation allowed us to
 - Run CMS with a non-expert crew
 - Increase data taking efficiency despite frequent single-event upsets at high luminosity
 - Significantly ease the load on the on-call experts



Outlook

- Automation integrated into the DAQ control tree served us well
 - Knowledge encapsulated (rather than centralized)
 - Fast & reliable
 - Plan to cover more error scenarios using this approach
- Expert analysis of the central DAQ system will change significantly due to the DAQ & Filter Farm upgrade

- Planning to include more information sources in analysis: errors, alarms ...
- We are currently investigating the use of a complex event processing engine (Esper)
 - Powerful query language
 - Rather steep learning curve

#87: P. Zejdl: 10 Gbps TCP/IP streams from FPGA for HEP

#72: R. Mommsen: Prototype of a file-based high level trigger in CMS

#139: A. Holzner: The new CMS DAQ system for LHC operation after 2014

- On our wish list
 - Completely automated operation: start of collision, cosmic and calibration runs
 - Correlation of errors: root cause finding

... stay tuned for CHEP 2015



Thank You