

# Modernising CERN CMS Rate Monitoring tools

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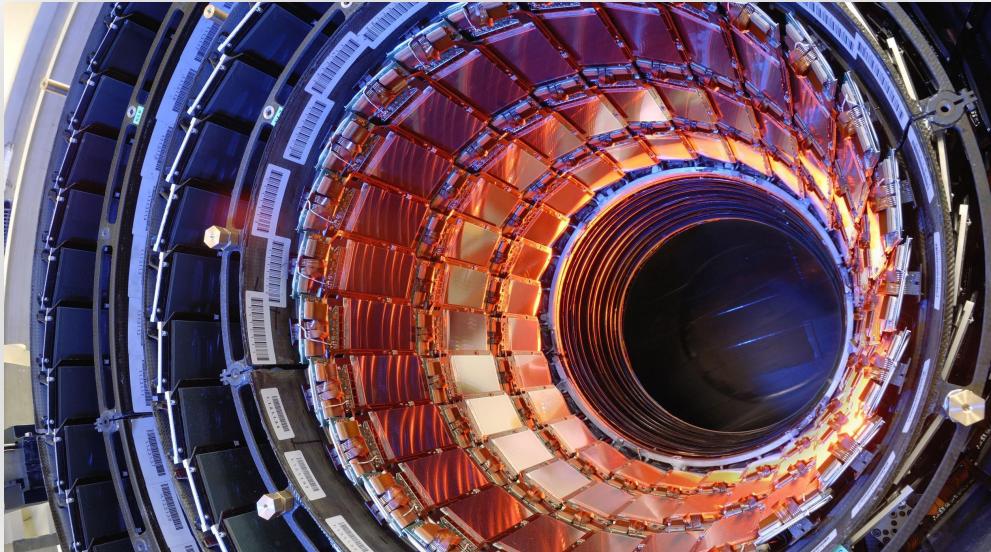
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Co-relatori: Simone Gennai (INFN), Glenn Dirkx (CERN)



# Overview

- The *Compact Muon Solenoid* experiment at CERN
- **Trigger System** and Trigger Rates
- Monitoring anomalies from Trigger Rates
- Rate Monitoring software features
- **Modernising the Rate Monitoring software:**
  - Mainteinance, bug fixing
  - Packaging,
  - CI/CD, Cactus
  - API, final deployment
  - New UI
- **Integrating Trigger Rates data with the Run Registry**



# Compact Muon Solenoid, Monitoring

## CMS DETECTOR

Total weight : 14,000 tonnes  
Overall diameter : 15.0 m  
Overall length : 28.7 m  
Magnetic field : 3.8 T

STEEL RETURN YOKE  
12,500 tonnes

SILICON TRACKERS  
Pixel ( $100 \times 50 \mu\text{m}^2$ ) ~ $1.9 \text{ m}^2$  ~124M channels  
Microstrips (80–180  $\mu\text{m}$ ) ~ $200 \text{ m}^2$  ~9.6M channels

SUPERCONDUCTING SOLENOID  
Niobium titanium coil carrying ~18,000 A

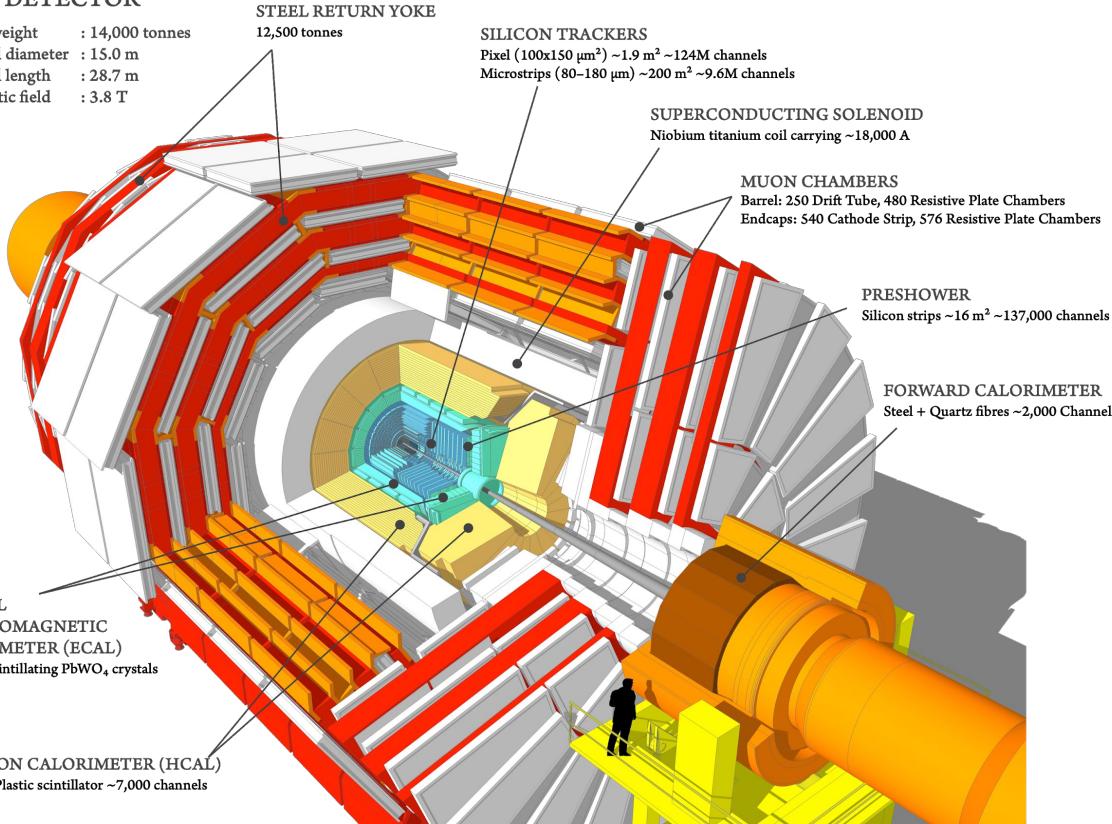
MUON CHAMBERS  
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers  
Endcaps: 540 Cathode Strip, 576 Resistive Plate Chambers

PRESHOWER  
Silicon strips ~ $16 \text{ m}^2$  ~137,000 channels

FORWARD CALORIMETER  
Steel + Quartz fibres ~2,000 Channels

CRYSTAL  
ELECTROMAGNETIC  
CALORIMETER (ECAL)  
~76,000 scintillating PbWO<sub>4</sub> crystals

HADRON CALORIMETER (HCAL)  
Brass + Plastic scintillator ~7,000 channels



CMS is a complex system which needs fast and reliable monitoring. Quick feedback on each of the subsystems is essential to spot and solve problems or the data taken might be unusable or not interesting for physics analysis. Experts from different systems need to correlate information to investigate underlying problems.

The high level monitoring software is being migrated to a new stack, its sources need to be updated and plugged into the new Data Aggregation Layer.

We'll focus on the Trigger System monitoring software.

# Trigger System

Hardware and Software filters, retaining only interesting events.

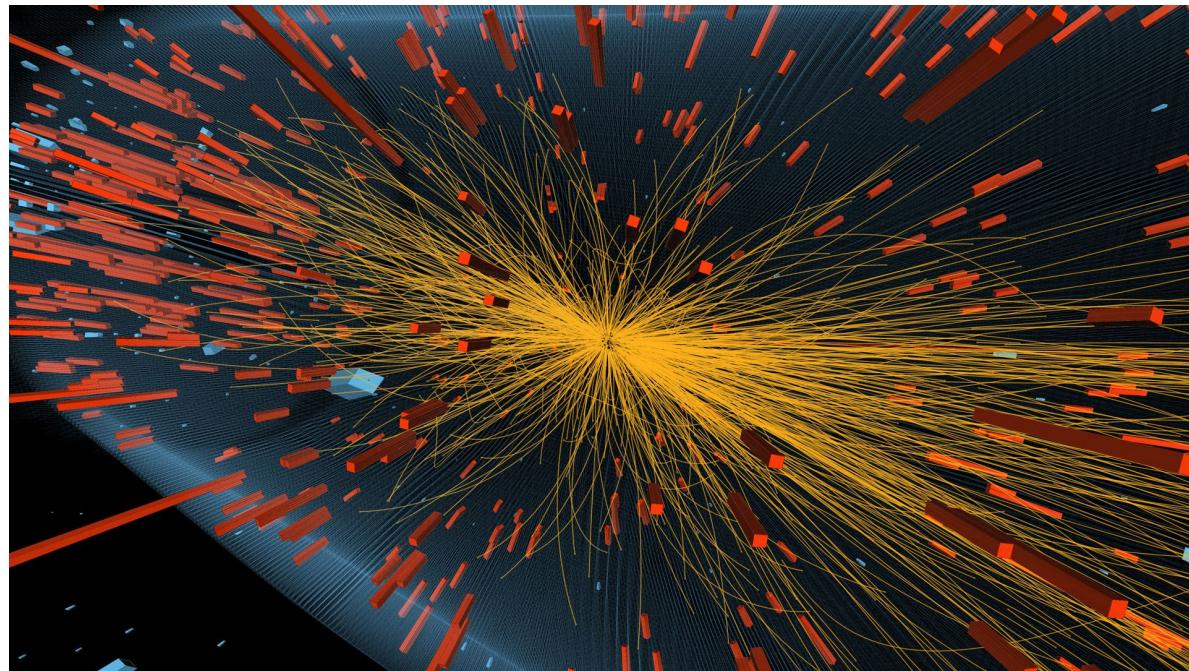
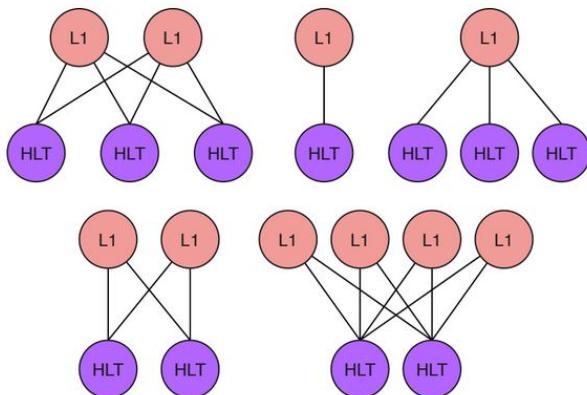
2 layers:

**L1** 40 MHz to 100 kHz

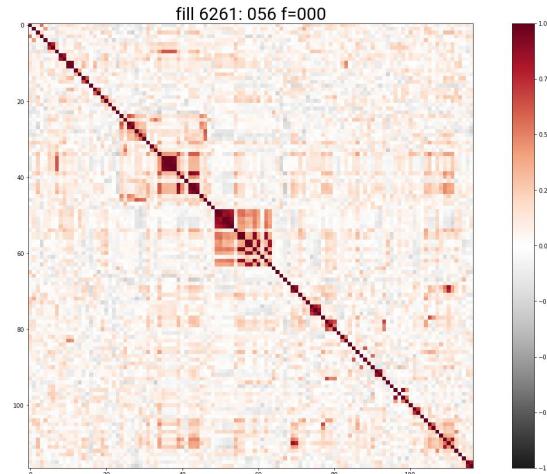
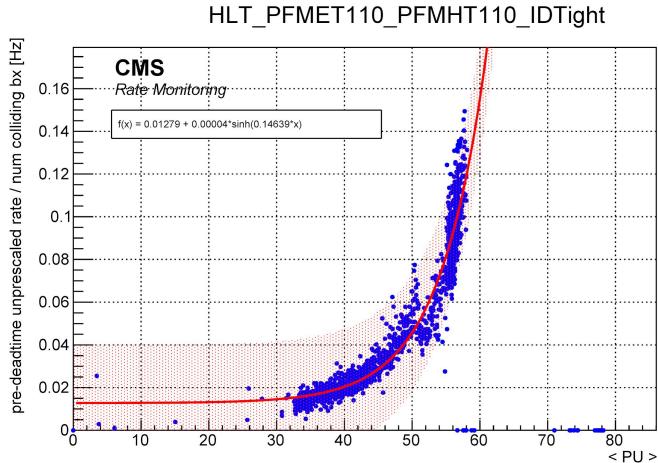
**HLT** final average rate of **400 Hz**

Average payload is 1.5 MB

Hundreds of "paths", looking for specific physics signatures.



# RateMon software features



- Query, preprocess, normalise and correct rate data
- Corrections for deadtime, prescale, number of colliding bunches
- Time series over Lumi Section or Luminosity
- Alerting
- Fitting
- Plot + export
- Used to spot malfunctions, misconfigurations and anomalies in CMS sub detectors

# Spotting subdetector issues from anomalies in rates

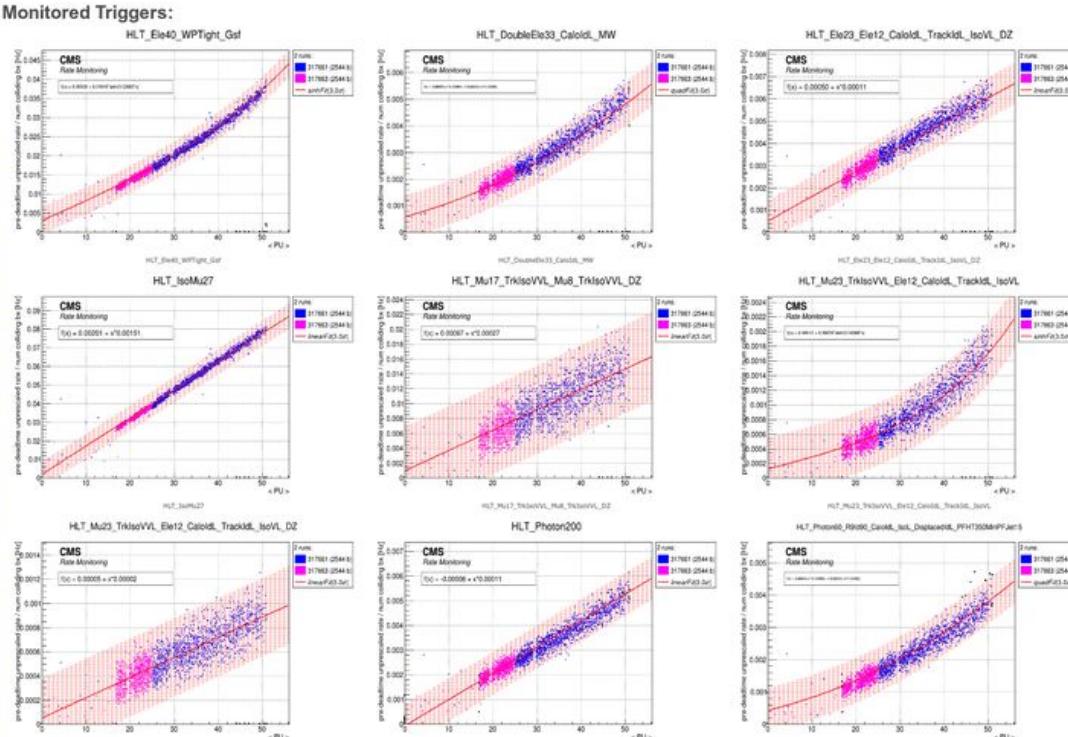
Runs used to produce fits:

317182

Rate Collections  
Stream Rates  
Dataset Rates  
L1 Rates  
L1 Trigger Rates  
HLT Trigger Rates

Triggers by Dataset  
AlCaLumiPixels  
AlCaP0  
AlCaPhiSym  
AlCaLumiPixelsE...

BTagMu  
Charmonium  
Commissioning  
DQMOnlineBeamspot  
DisplacedJet  
DoubleMuon  
DoubleMuonLowMass  
EGamma  
EcalLaser  
EmptyBX  
EphemeralHTPhy...  
EphemeralHTPhy...  
EphemeralHTPhy...  
EphemeralHTPhy...  
EphemeralHTPhy...  
EphemeralHTPhy...  
EphemeralHTPhy...  
EphemeralHTPhy...  
EphemeralHTPhy...  
EphemeralZeroBias1  
EphemeralZeroBias2  
EphemeralZeroBias3  
EphemeralZeroBias4  
EphemeralZeroBias5  
EphemeralZeroBias6



Trigger shifters spot anomalies, malfunctions and misconfigurations in the CMS sub systems by looking at and comparing specific trigger paths (and their deviations from the fits)

Fits and rates are dependent on PU and many other factors. Risk of bad fitting and a lot of false positive (RateMon alerts on  $>3\sigma$ )

Dimensionality reduction needed: hundreds of rates and plots to look at!

Naturally related blocks of triggers (because tracking similar events)

# Status and upgrades

- **Very old documentation (first twiki revision in 2011, last updated 2018)**

Updating documentation, deployment instructions, more verbose output on errors and database connection issues

- **Runs only on LXPLUS, needs cx\_Oracle and access to cms\_omds\_lb oracle db**

Now runs on every CC7/C8 machine. There's a provided command to proxy the database connection through LXPLUS with a SSH SOCKS5 proxy (when not on CERN network).

Defined reproducible environments. Decouple the software from CERN internal setups

- **Fits are ROOT objects, serialised with pickle**

Fits are now exported as readable and parse-able functions. Each value available separately. Consistent schema.

```
"linear": "-0.00581 + x*0.00018"
```

- **Output are static image renders of the plots**

Implemented SVG, JSON and ROOT exports.

JSON exports with consisted schema:

X Values, Y Values, X Label, Y Label,  
fit function, Trigger Name, Run/Fill number  
pre/post deadtime  
prescaled/unprescaled

```
40.7754/100/CMS
"fit":
{
  "linear": "-0.00581 + x*0.00018",
  "xvar": "< PU >",
  "plotname": "HLT_DoublePhoton70_< PU >_vs_pre-deadtime unprescaled rate",
  "yvar": "pre-deadtime unprescaled rate",
  "yVals": [0.00289909983985126, 0.0026693413965404034, 0.003336422611027956, 0.0021802419796586037, 0.002595725702121854, 0.0020407323502004147, 0.002743976889178157]
```

# Status

- **Python2**  
Migration to Python3
- **Configuration “hardcoded” is a python class**  
Configuration is now a YAML file with a defined **schema**. Easily portable
- **No packaging**  
RPM Packaging streamlined. Easily **produce** a package installable in every CC7 machine with “make rpm”. No more git clones: just rpm install the distributed packages.
- **No CI/CD (Continuos Integration/Continuos Deployment)**  
Now, on each new pushed commit on git:
  - A gitlab-ci job using docker images for the dependencies automatically builds an RPM package.
  - Tagged commits trigger different filenames (develop vs tagged version packages).
  - Packages are automatically uploaded on a public CERNBox folder (accessible also on /eos/).
- **Must be restarted manually**  
Now comes with a proper systemd service
- Final migration to Cactus CI/CD tools
- P5 deployment

# OMS Integration

Migration to OMS: Data needs to be plugged into an OMS panel (WBM imported the PNGs) and readable by its plot engine (HighCharts)

- Investigation of the new stack, its limitations and constraints
- Migration to the new, monitoring system. Must expose plots using a restricted set of tools
- Data aggregation layer
- Drawing library limits (HighCharts not supporting function plotting)
- DB Quota issues
- Deployment was complex and poor documented
- Solution: **new API**, ratemon as python “import-able” module, ratemon as a service

# New API

The screenshot shows the RateMon API documentation on the Swagger UI. At the top, there's a navigation bar with the Swagger logo, the URL '/api/v1/openapi.json', and a green 'Explore' button. Below the header, the title 'RateMon API 0.0.2 OAS3' is displayed, along with a link to '/api/v1/openapi.json'. A sub-header states 'API exposing CMS Trigger Rates exported by the RateMon tools'. On the left, a 'Servers' dropdown is set to '/api/v1'. The main content area is titled 'Trigger Rates' and contains two 'GET' requests: '/ratesJSON' and '/ratesROOT'. Below these, a description says 'Get ROOT plot of the Rates of the specified Trigger Path and LHC Run Number'. Under the 'Parameters' section, there are two fields: 'runNumber \* required' (integer, query) with an example value '305112' and 'triggerKey \* required' (string). A note at the bottom specifies that trigger name key must be part of the monitorlist\_COLLISIONS list.

Trigger Rates plotting and exporting functionalities are now exposed as a “service” with a new RESTful API, formally defined with an OpenAPI 3.0 schema.

Can export rates for any run as raw JSON files or ROOT binary files.

Cache has been setup and we started to populate it (NGINX).

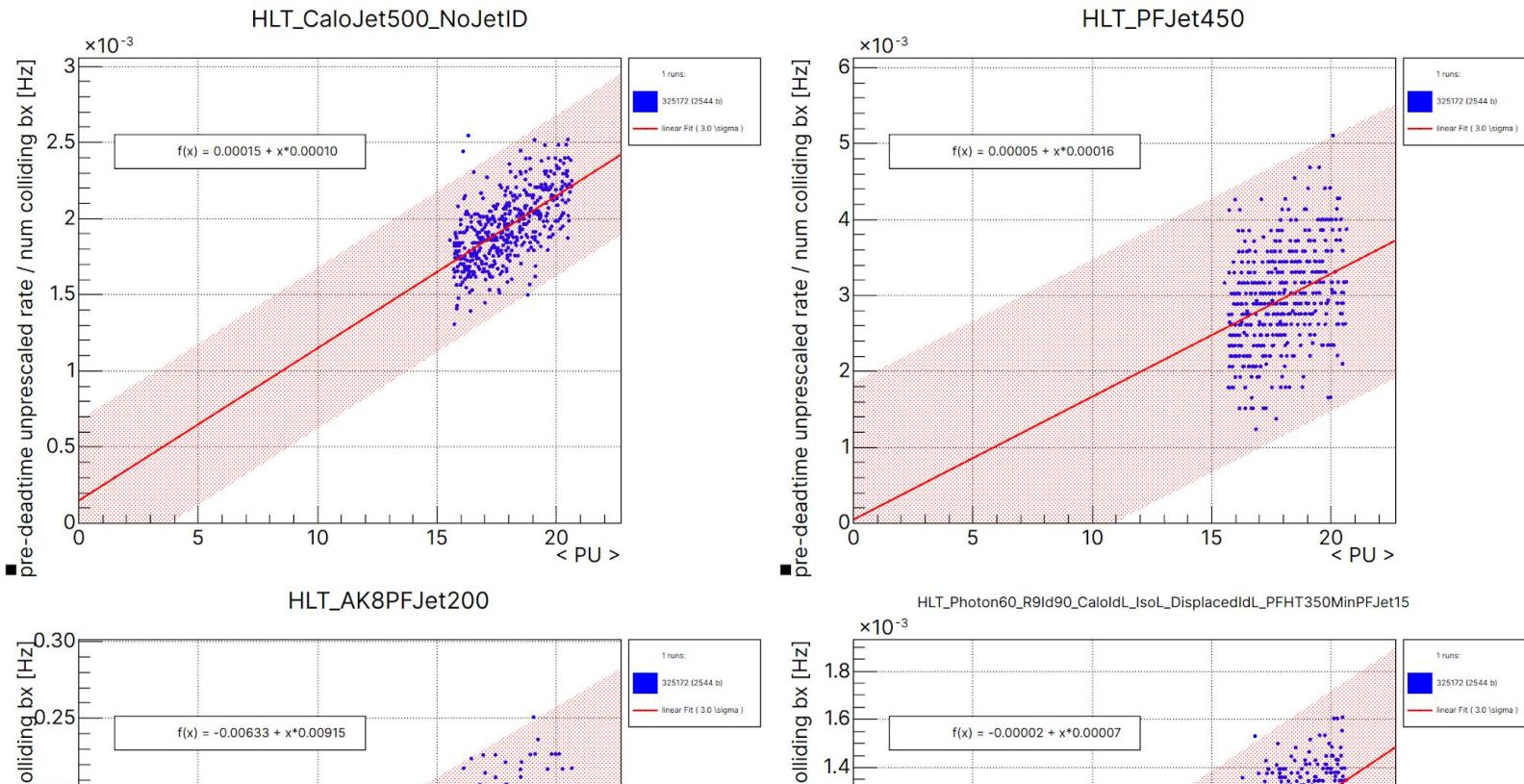
# Experimental UI

- VueJS web application consuming the new RateMon API.
- Features Trigger Selection and direct drawing of ROOT plots in the browser (using **JSROOT**).
- Can show tens of plots without slowing down the browser
- No problem with the fit functions: we're plotting in a interactive ROOT canvas what we were previously exporting as PNG files
- Can still export PNG, SVG files when requested

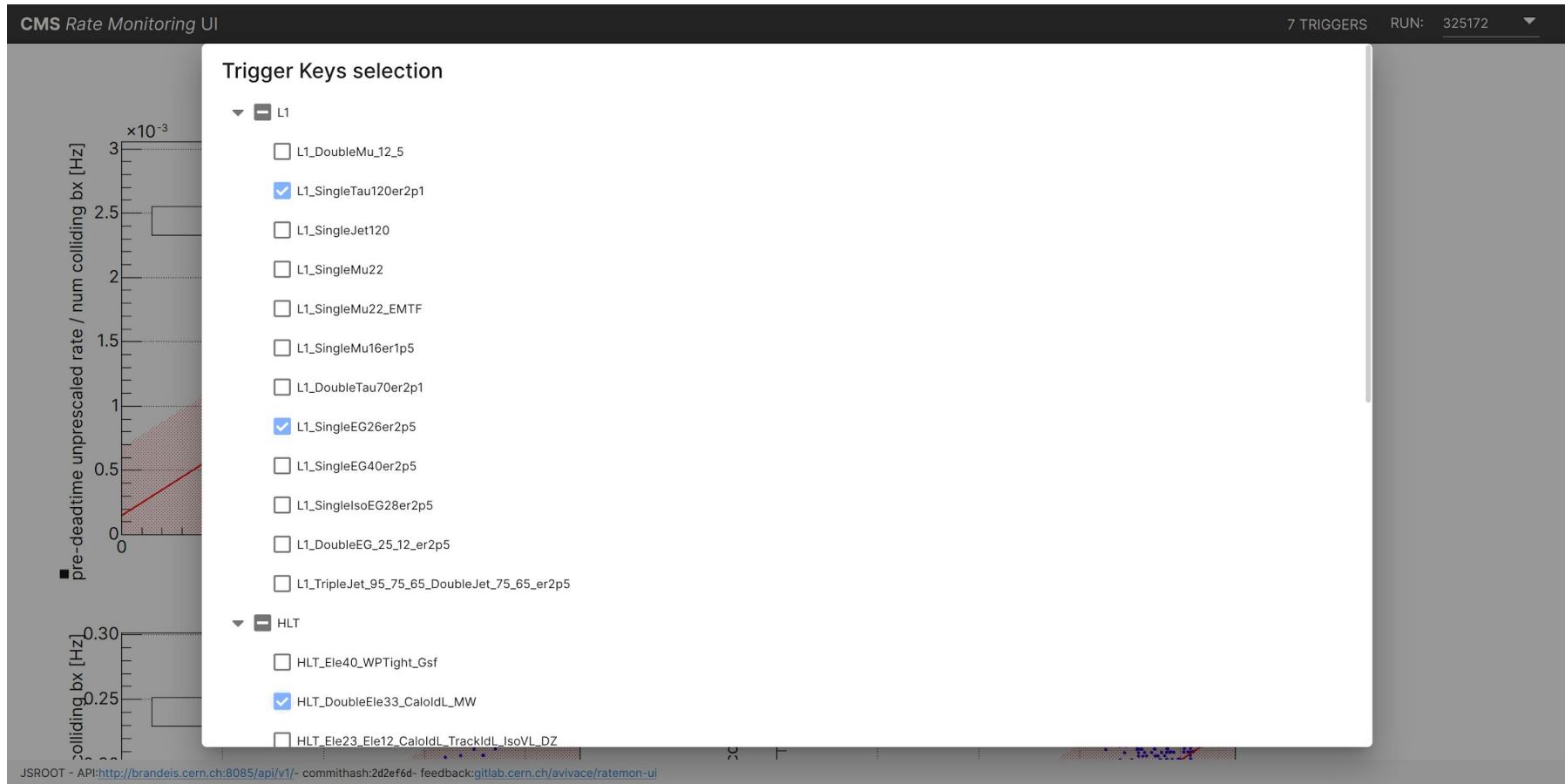
# Experimental UI: main view

CMS Rate Monitoring UI

6 TRIGGERS RUN: 325172



# Experimental UI: trigger key selection



# New integrated dataset for Anomaly Detection

Ground truth for what's happening on CMS sub detectors in the same time scale of Trigger Rates: DQM databases, exposed by a new, WIP, software: CMS Run Registry.

Run Number	Dataset Name	Class	Manage / LS	GUI Link	OMS	global State	LS Duration	btag	castor	cms	csc	ctpps	lowlumi	dt
327744	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	723	GOOD	EXCLUDED	BAD	EXCLUDED	BAD	BAD	GOOD
327743	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	812	GOOD	EXCLUDED	BAD	EXCLUDED	BAD	BAD	GOOD
327740	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	353	GOOD	EXCLUDED	BAD	EXCLUDED	BAD	BAD	GOOD
327696	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	70	GOOD	EXCLUDED	BAD	EXCLUDED	BAD	BAD	GOOD
327693	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	480	GOOD	EXCLUDED	BAD	EXCLUDED	BAD	BAD	GOOD
327692	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	163	GOOD	EXCLUDED	BAD	EXCLUDED	BAD	BAD	GOOD
327692	/TestRun/HICos...	Cosmics18	Manage / LS	Not in GUI yet	OMS	COMPLETED / move	163	GOOD	EXCLUDED	BAD	EXCLUDED	BAD	BAD	GOOD
327676	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	23	GOOD	EXCLUDED	BAD	EXCLUDED	BAD	BAD	GOOD
327618	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	666	GOOD	EXCLUDED	BAD	GOOD	BAD	BAD	GOOD
327604	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	219	GOOD	EXCLUDED	BAD	GOOD	BAD	BAD	GOOD
327601	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	29	GOOD	EXCLUDED	BAD	GOOD	BAD	BAD	GOOD
327600	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	39	GOOD	GOOD	BAD	GOOD	BAD	BAD	GOOD
327596	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	140	GOOD	GOOD	BAD	GOOD	BAD	BAD	GOOD
327593	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	12	GOOD	GOOD	BAD	GOOD	BAD	BAD	GOOD
327592	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	30	GOOD	GOOD	BAD	GOOD	BAD	BAD	GOOD
327590	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	91	GOOD	GOOD	BAD	GOOD	BAD	BAD	GOOD
327589	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	44	GOOD	GOOD	BAD	GOOD	BAD	BAD	GOOD
327588	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	62	GOOD	GOOD	BAD	GOOD	BAD	BAD	GOOD
327587	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	476	GOOD	GOOD	BAD	GOOD	BAD	BAD	GOOD
327565	/PromptReco/Hl...	Cosmics18	Manage / LS	GUI Link✓	OMS	COMPLETED / move	7	GOOD	GOOD	BAD	GOOD	BAD	BAD	GOOD

# Conclusions

Results:

- Reproducible environments to run (and build) the software
- Now runs on supported version of Python/oracle\_db module and ROOT bindings
- New export features
- New API, exposing functionalities as a service
- New UI, offering new features requested by the trigger shifters
- New development and deployment pipelines easing workflows for everyone involved, exploiting a general CI/CD setup and an auto DevOps template by CMS
- Enabled new ways to get and process raw rates data to do data analysis

Next steps:

- Error handling, introduce testing
- Further UI development, polishing and bugfixing
- OMS integration
- Possibly enable new Anomaly Detection approaches on the new integrated dataset

# Backup

\*\*\*\*\*  
**INFORMATION:**  
Run Number: 256936  
LS Range: 0 - 714  
Last LHC Status: Cycling  
Number of colliding bunches: 1165  
Trigger Mode: l1\_hlt\_collisions2015/v247 (collisions)  
Number of HLT Triggers: 451  
Number of L1 Triggers: 116  
Number of streams: 14  
\*\*\*\*\*  
\* TRIGGER NAME \* ACTUAL [Hz] \* EXPECTED \* % DIFF \* DEVIATION  
\*\*\*\*\*  
Predictable HLT Triggers (ones we have a fit for)  
\*\*\*\*\*  
\* **HLT\_PFMET120\_PFMHT120\_IDTight** \* **10.73** \* **1.63** \* **558.98** \* **44.84**  
\* **HLT\_PFMET170\_NoiseCleaned** \* **6.06** \* **1.92** \* **215.08** \* **15.35**  
\* **HLT\_Ele27\_WPLoose\_Gsf** \* **53.62** \* **58.76** \* **-8.76** \* **-2.20**  
\* **HLT\_IsoMu27** \* **17.62** \* **19.07** \* **-7.59** \* **-1.72**  
\* **HLT\_DoubleMediumIsoPFTau35\_Trk1\_eta2p1\_Reg** \* **6.15** \* **6.73** \* **-8.62** \* **-1.28**  
\* **HLT\_Mu45\_eta2p1** \* **7.68** \* **8.30** \* **-7.38** \* **-1.22**  
\* **HLT\_AK8D1PFJet250\_200\_TrimMass30\_BTagCSV0p45** \* **8.67** \* **9.34** \* **-7.18** \* **-1.17**  
\* **HLT\_Ele105\_CaloIdVT\_GsfTrkIdT** \* **3.30** \* **3.60** \* **-8.42** \* **-0.95**  
\* **HLT\_DoubleEle33\_CaloIdL\_GsfTrkIdVL** \* **2.29** \* **2.48** \* **-7.73** \* **-0.77**  
\* **HLT\_Mu17\_TrkIsoVVL\_Mu8\_TrkIsoVVL\_DZ** \* **3.08** \* **3.29** \* **-6.39** \* **-0.71**  
\* **HLT\_HT650** \* **16.08** \* **16.58** \* **-3.04** \* **-0.64**  
\* **HLT\_PFT800** \* **5.77** \* **6.04** \* **-4.45** \* **-0.59**  
\* **HLT\_PFJet450** \* **2.26** \* **2.36** \* **-4.23** \* **-0.36**  
\* **HLT\_Mu23\_TrkIsoVVL\_Ele12\_CaloIdL\_TrackIdL\_IsoVL** \* **0.48** \* **0.52** \* **-7.35** \* **-0.36**  
\* **HLT\_Photon36\_R9Id85\_OR\_CaloId24b40e\_Iso50T80L\_Photon22\_AND\_HE10\_R9Id65\_Eta2\_Mass15** \* **3.92** \* **4.00** \* **-1.88** \* **-0.23**  
\* **HLT\_Photon175** \* **2.22** \* **2.27** \* **-1.95** \* **-0.19**  
\* **HLT\_CaloJet500\_NoJetID** \* **1.94** \* **1.99** \* **-2.37** \* **-0.18**  
\* **HLT\_MET250** \* **2.45** \* **2.40** \* **2.06** \* **0.17**  
\* **HLT\_QuadJet45\_TripleBTagCSV0p67** \* **1.20** \* **1.17** \* **2.63** \* **0.17**  
\*\*\*\*\*

**SUMMARY:**

Triggers in Normal Range: 533 | Triggers outside Normal Range: 3

Prescale column index: 5

Average inst. lumi:  $2007.90734991 \times 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$ 

\*\*\*\*\*  
All triggers deviating past thresholds from fit and/or L1 rate > 30000 Hz, HLT rate > 200 Hz: L1\_SingleEG2\_BptxAND, HLT\_PFMET120\_PFMHT120\_IDTight, HLT\_L1\_SingleEG2\_BptxAND has been out of line for more than 1 minutes  
Trigger HLT\_PFMET120\_PFMHT120\_IDTight has been out of line for more than 1 minutes  
Trigger HLT\_PFMET170\_NoiseCleaned has been out of line for more than 1 minutes