The CMS RPC Detector Operation, Performance & Stability

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On behalf of CMS Collaboration

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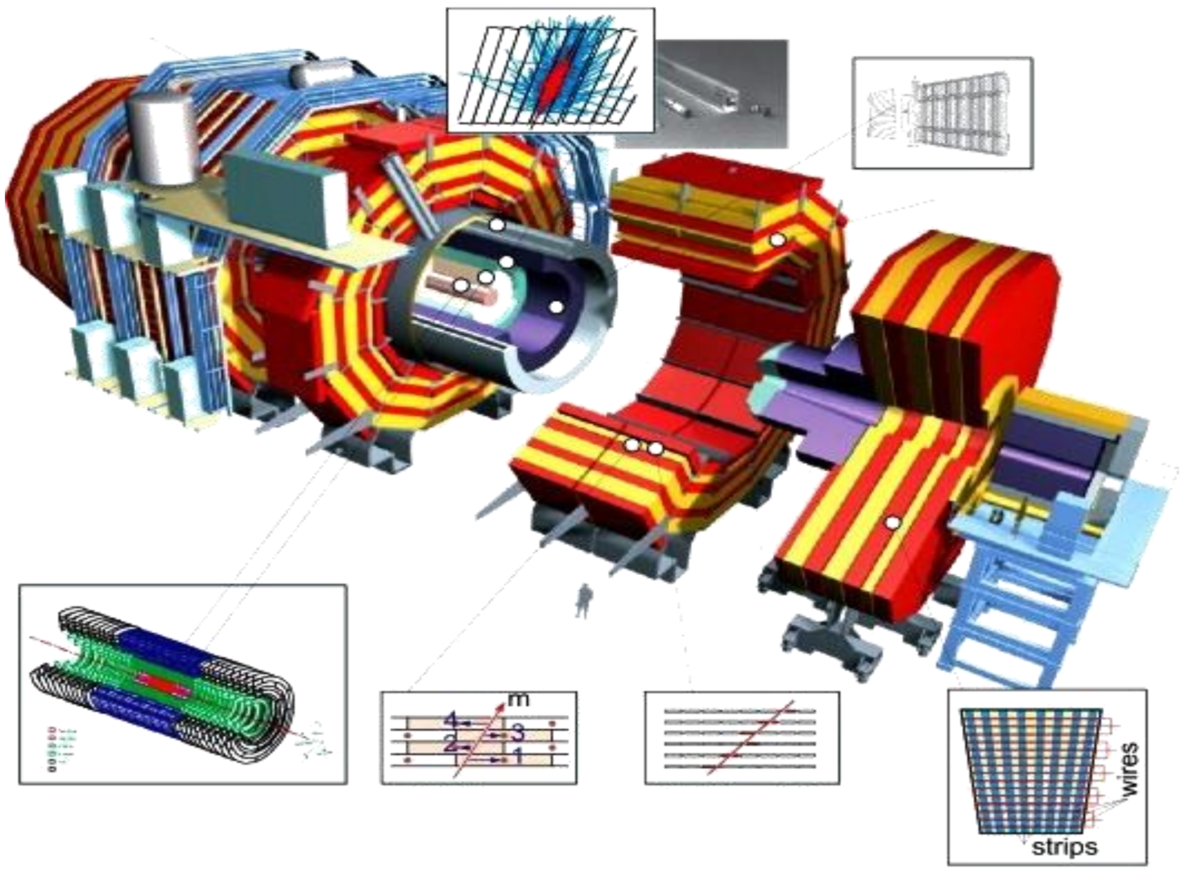
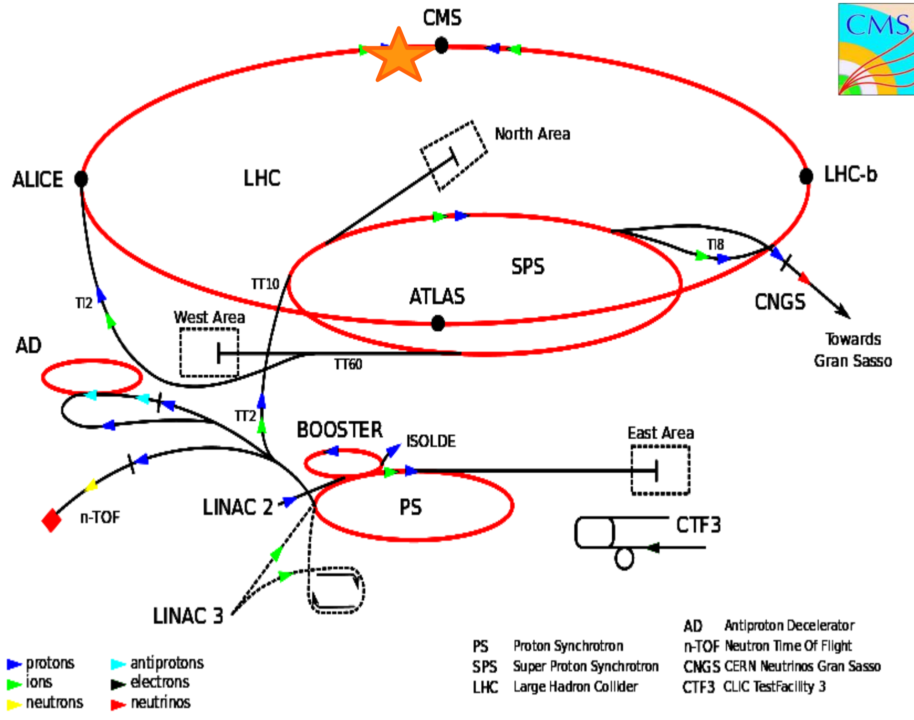
XIV Workshop on Resistive Plate Chambers and related detectors

Puerto Vallarta, México

The Large Hadron Collider LHC and CMS (Compact Muon Solenoid) Experiment





General purpose detector – looking for new physics phenomena in all the available energy ranges.

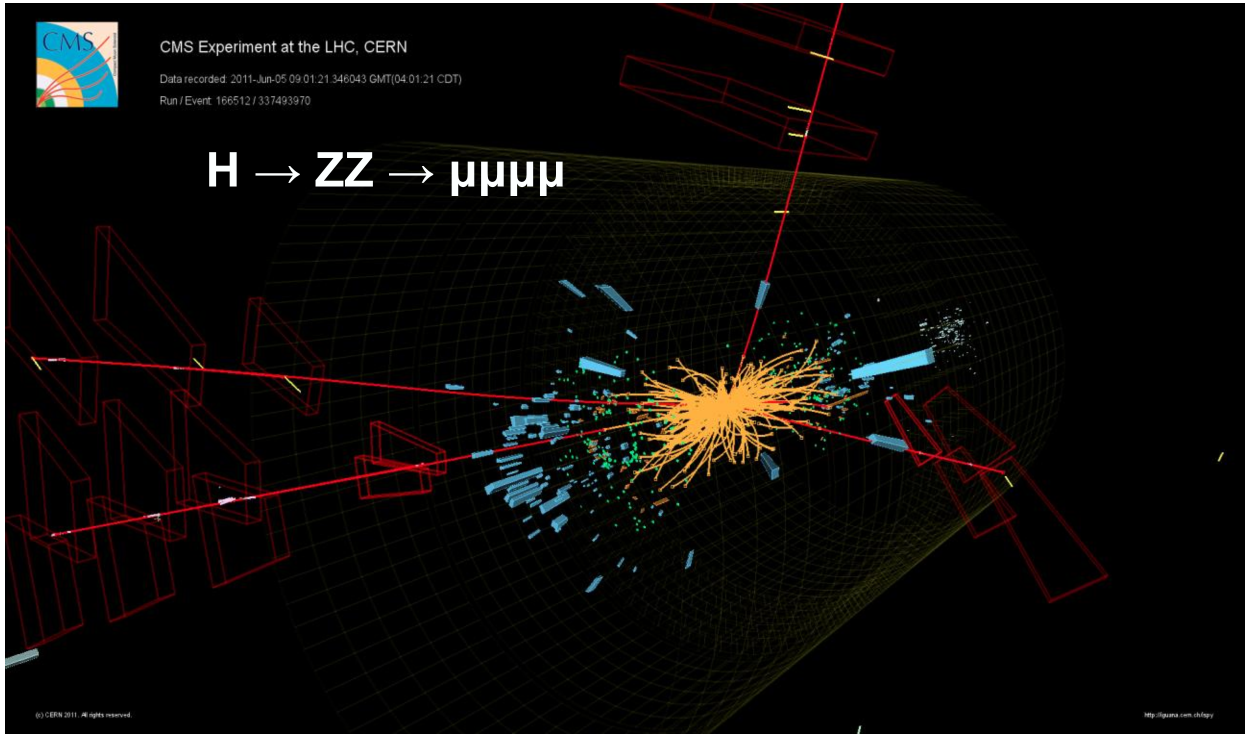
2012 - Higgs boson observation!

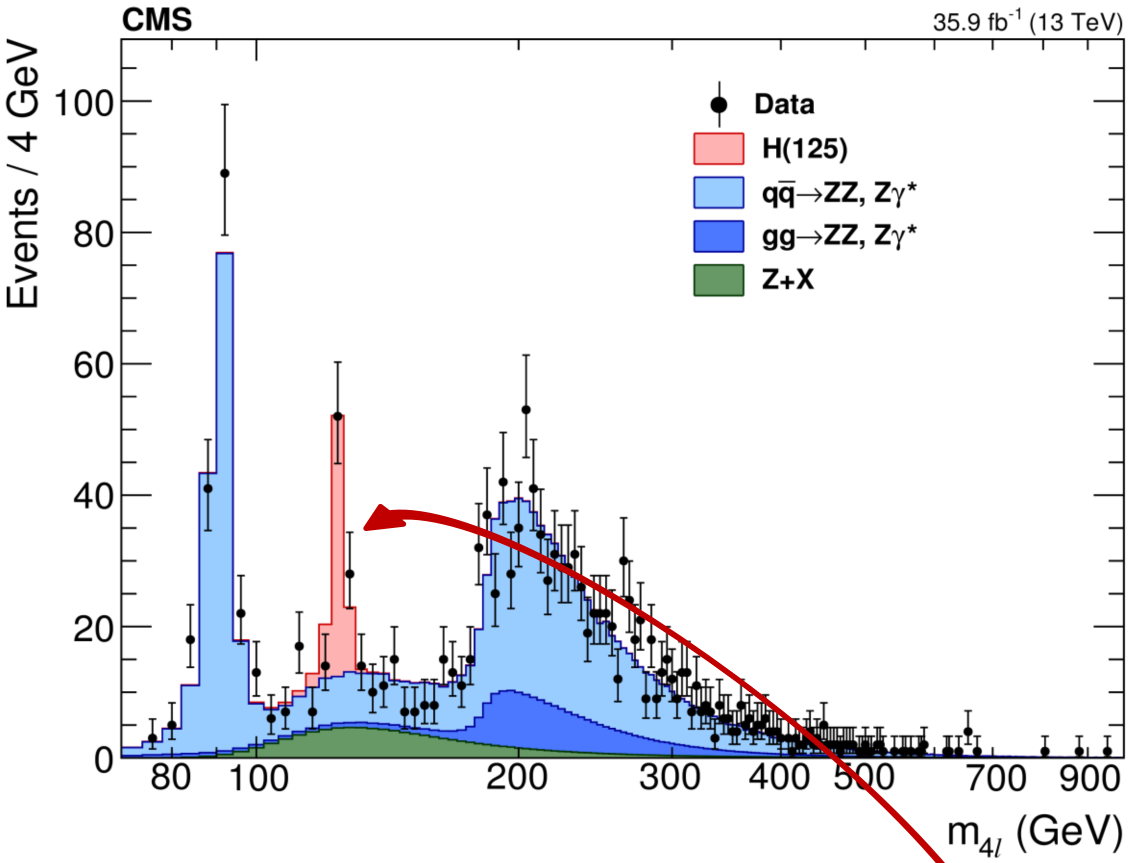
CMS

- Cylindrical barrel region (Drift Tube & RPC)
- 4 coaxial stations interleaved with the iron return yoke plates, grouped into 5 wheels around the beam line.
- Planar endcap region (Cathode Strips Chambers & RPC). 4 planar stations (disks) interleaved with the iron return yoke plates.

CMS Higgs (→4*l*) Measurement

Ref: HIG-16-041





A 4 lepton event in CMS, showing the 4 muons with tracks in red. **RPC hits** are shown in yellow.

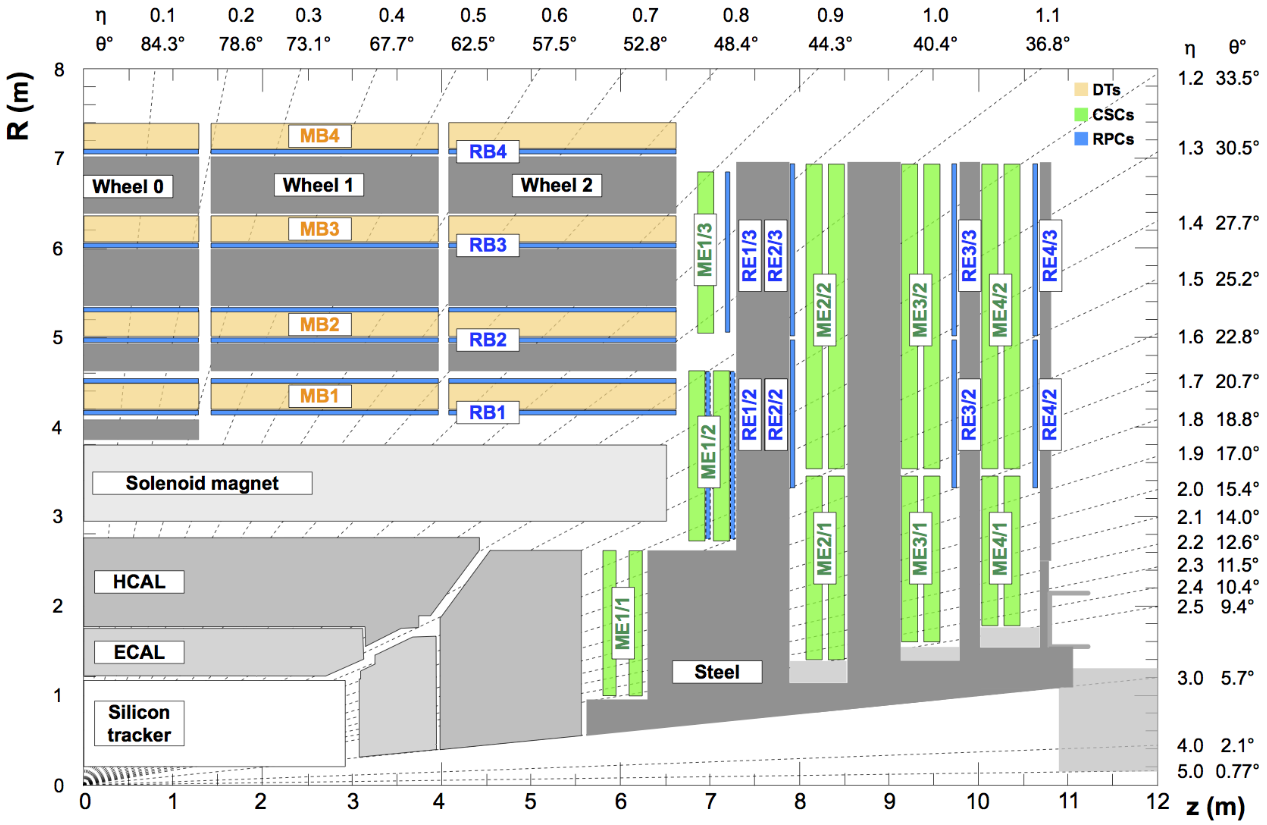
Four-lepton mass spectrum:
clean Higgs boson signal peak at ~125 GeV

CMS Muon System

Robust, efficient and redundant muon system

Muon system requirements:

- muon identification
- muon p_T and charge measurment
- triggering and bunch crossing (**BX**) association



Three different gaseous detector technologies are used to trigger and reconstruct muons:

Barel: DT & RPC $|\eta| < 0.8$

Overlap: DT & RPC & CSC $0.8 < |\eta| < 1.2$

EndCap: CSC $(1.2 < |\eta| < 2.4)$ & RPC $(1.2 < |\eta| < 1.9)$

- DT – Drift Tubes;
- CSC – Cathode Strip Chambers;
- RPC – Resistive Plate Chambers

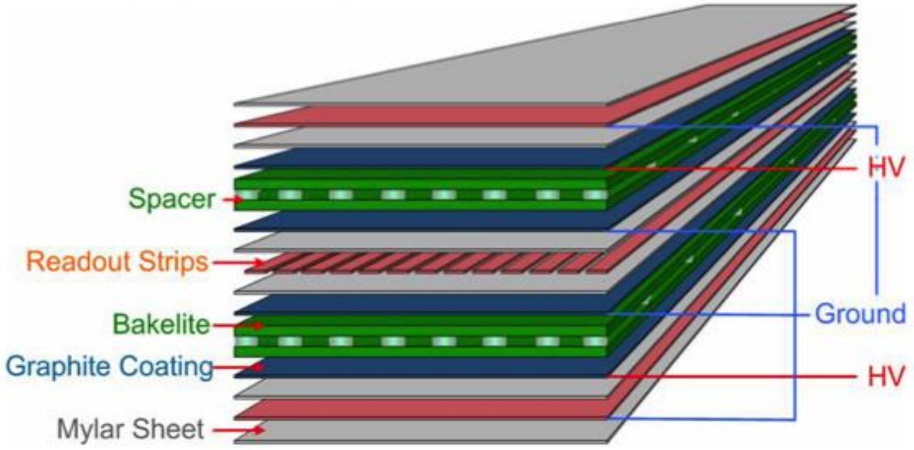
$$\eta = -\ln \tan(\theta/2)$$

Drift tubes in the barrel region and **Cathode strip chambers** in the endcaps provide "Tracks Stubs" (a vector in space) . This information is supplemented by **Resistive Plate Chambers** that provide precise **time information** and coarse **position** measurement.

The CMS Resistive Plate Chambers

RPC present system

- Covers $0 < |\eta| < 1.9$
- **1056 chambers** (480 in barrel and 576 in endcap)
- **More than** 110000 **electronic channels**
- **Double gaps gas chamber:** 2 mm gas width
- **Bakelite** bulk resistivity: $\rho = 1 - 6 \times 10^{10}\ \Omega$cm
- **Strip width:** 1 – 4 cm.
- **Gas mixture:** $C_2H_2F_4$ + isoC_4H_{10} + SF_6
- 95.2% 4.5% 0.3%
- Operated in **avalanche mode**



Requirement of RPC system:

- High rate capability (~**300** Hz/cm^2)
- High detection efficiency > 95% & plateau more than **300 V** long
- Intrinsic time resolution < **1.6 ns** (BX identification)
- Intrinsic Noise < 5 Hz/cm^2
- Average cluster size ~**2** strips
- Spatial resolution ≈ 10 mm
- **Ability to withstand** in long term operation and high
- background radiation

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How to Judge the RPC Muon System ?

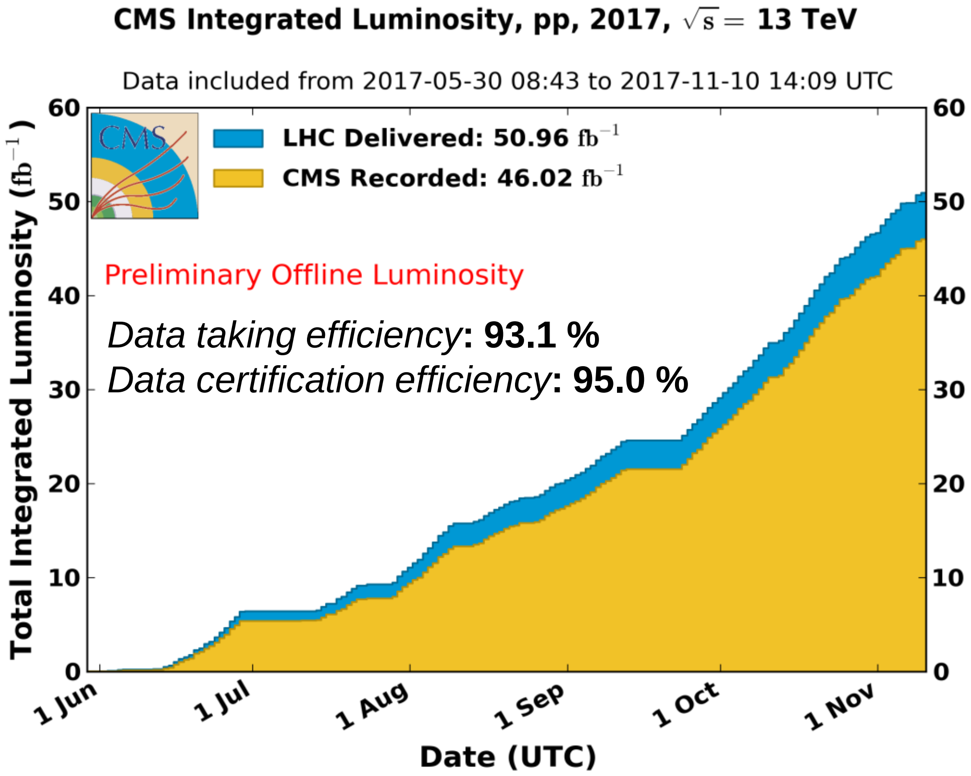
- ❖ Data taking efficiency
- ❖ Trigger rate, efficiency and cluster size stability
- ❖ Detection efficiency and stability
  - Overall efficiency
  - Plateau curves
- ❖ Background
  - Noise rate
- ❖ Aging effects
  - Efficiency uniformity and stability
  - Plateau position (HV at 50% of efficiency)

- High luminosity $2*10^{34}$ $cm^{-2}s^{-1}$
- Millions of muons
- Many runs (time)

- High luminosity
- High beam intensity
- Time
- Sophisticated analysis

CMS & RPC over RUN II

RUN II
Total delivered L ~ 96 fb^{-1}
Total recorded L ~ 86.6 fb^{-1}



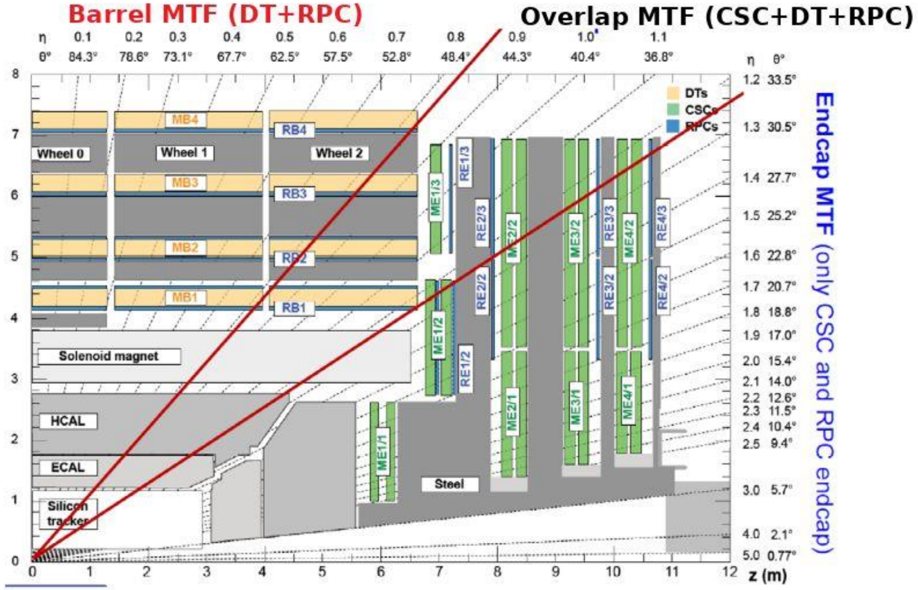
- ➢ The RPC contribution to the **CMS downtime in 2017** has been **0.03** %.
- ➢ **For run validation, the fraction of luminosity lost** due to RPC was **0.1** % in 2017, mostly concentrated in two events (electronic (LV) failure)

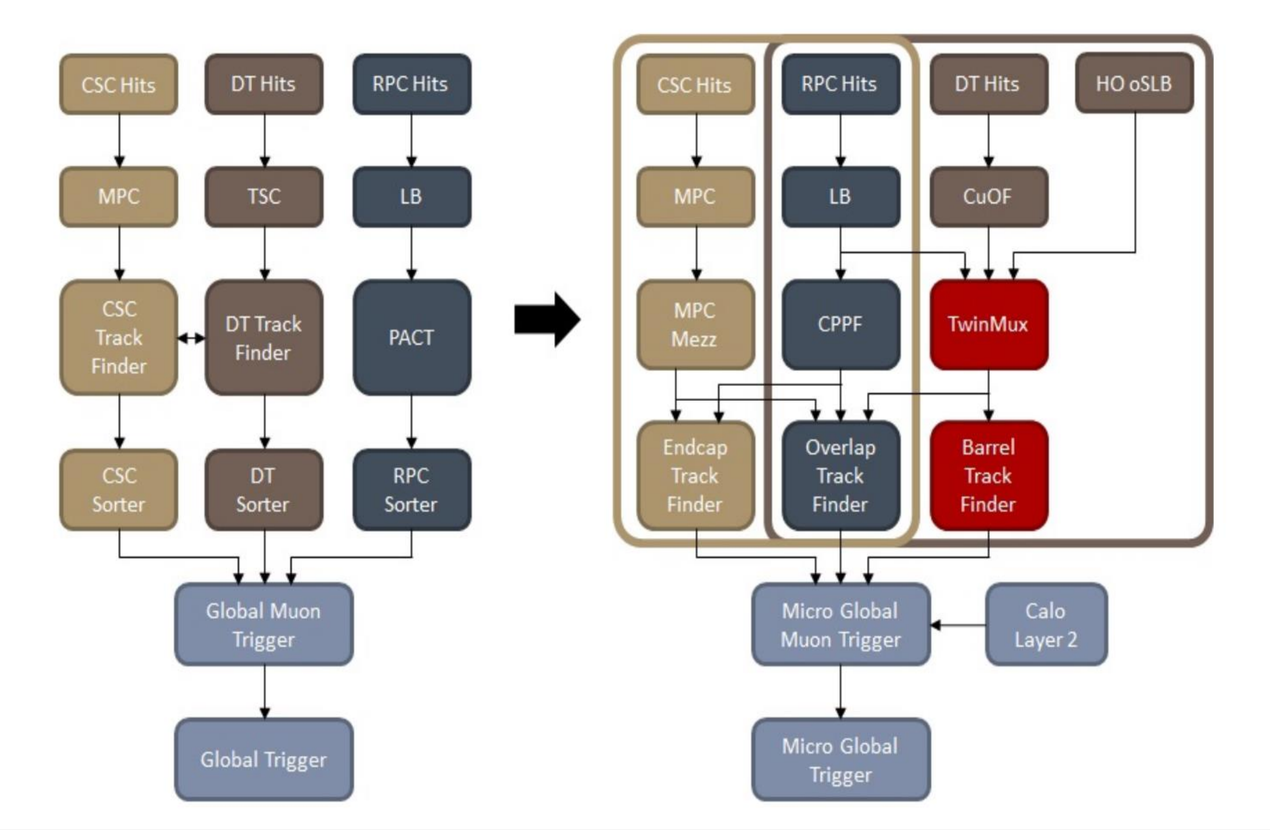
Key of success: Robust hardware and clear procedures for a prompt intervention during all beam-off and technical access time.

RUN2 experience crucial:
Study the **longevity** of the system in the view of **phase 2** operations by monitoring the stability of the performance (efficiency, cluster size,..) and of the intrinsic noise and current.

CMS Muon Trigger

Legacy regional triggers → Combined measurements from the three muon system (*)





- CMS Muon Trigger is divided in **3 regions.**
  - **Barrel Muon Track Finder (BMTF)**
  - **Overall Muon Track Finder (OMTF)**
  - **Endcap Muon Track Finder (EMTF)**
- In 2017, RPC provide hits to in the all **η coverage** (3 muon track finders)

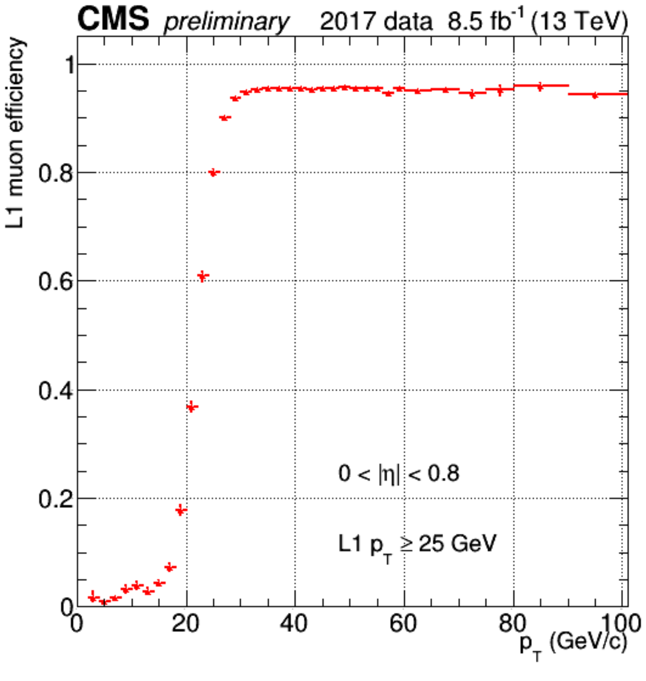
* *2017 JINST* **12** C01095

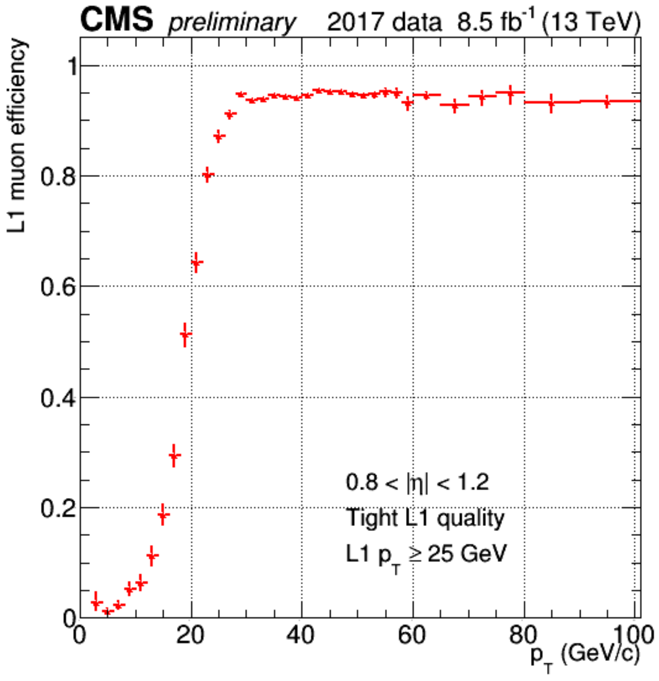
Muon Trigger Performance

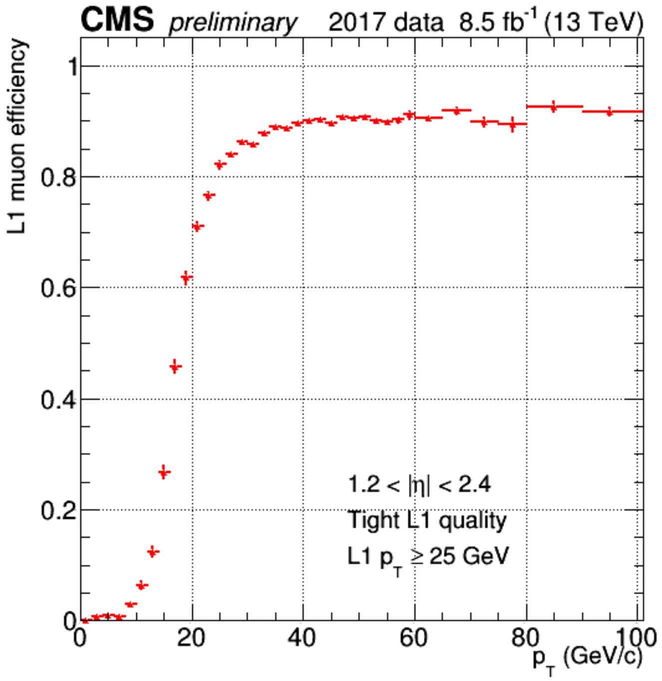
- All three track finders are independent hardware trigger systems that build tracks and assign transverse momentum (**pT**) for different **η** regions using trigger primitives from the CMS muon detectors (**DT, RPC and CSC**).

L1 efficiency vs p_T curves for the barrel, overlap & endcap track finders.

Ref: CMS DP -2017/041

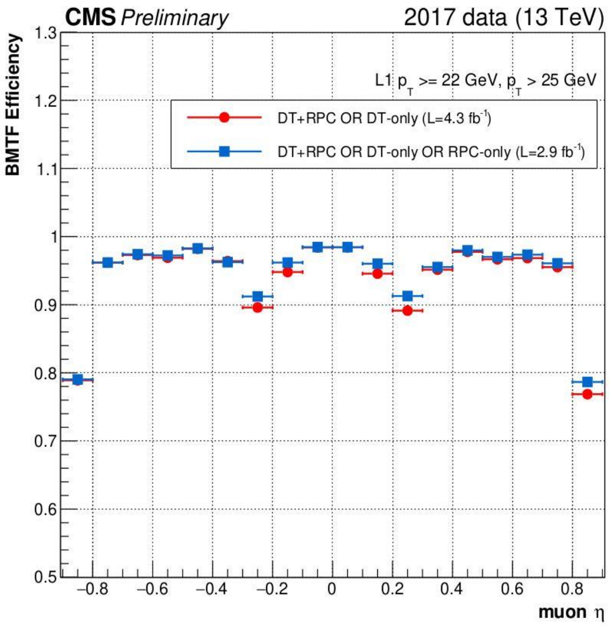


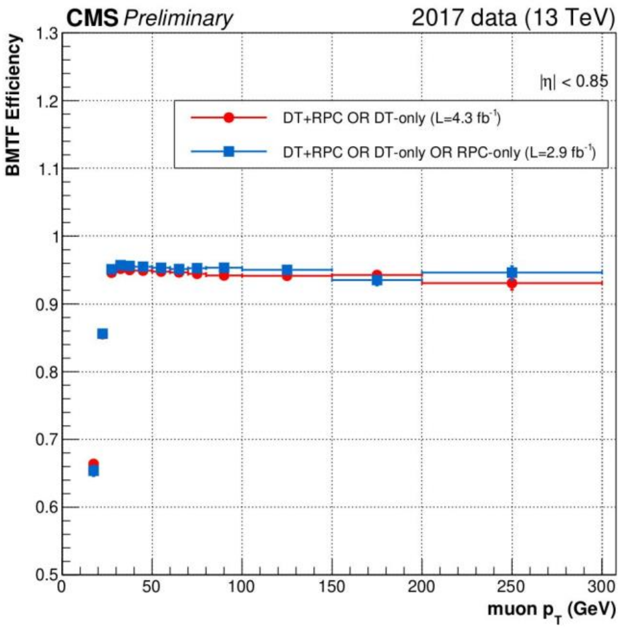


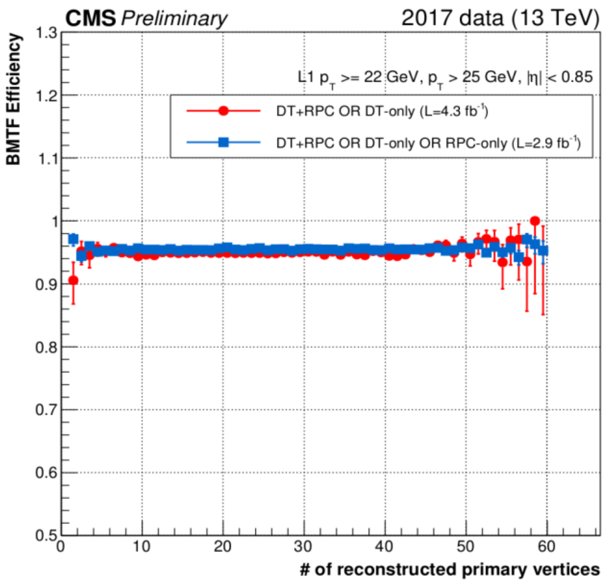


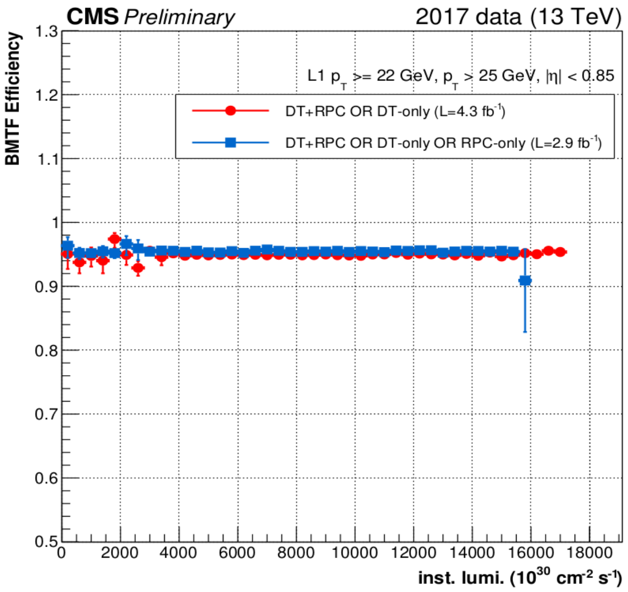
Plots show the efficiency for the most common **single muon** trigger threshold (**25 GeV**) used in CMS analyses in 2017.

RPC Contribution to the Muon Trigger









- **3 types** of trigger primitives seeding the L1 Barrel Muon Track Finder
  - **DT+RPC** segments (in all 4 stations, RPCs are used to complement low quality DT segments)
  - **DT**-only segments
  - **RPC-only segments** (in MB1 and MB2)

The RPC-only segments were included in the Barrel Trigger primitive algorithm in 2017.

- Overall BMTF efficiency improves by ≈ **0.7%**.
- Reduced the trigger rate for barrel muons with **pT > 25** GeV by **3%**, by improving the BMTF pT assignment.
- No degradation in the high pT region is observed.

No dependence on luminosity is observed for either algorithm and the inclusion of the RPC-only segments.

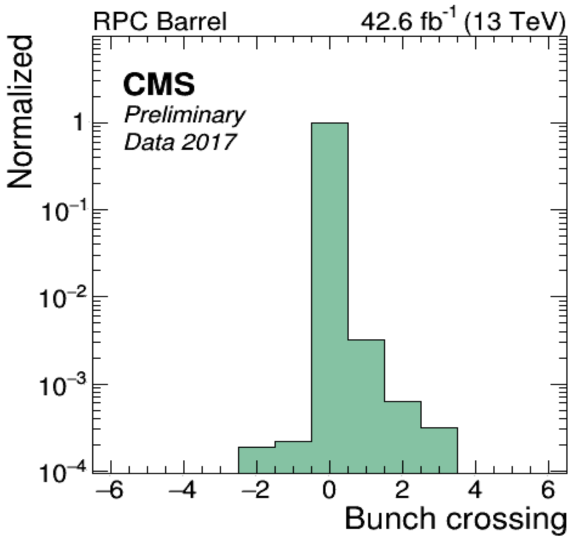
RPC Performance

Trigger requirements

- Good time resolution & BX assignment
- Bending angle evaluation depends on transversal spacial resolution (CLS and residual)

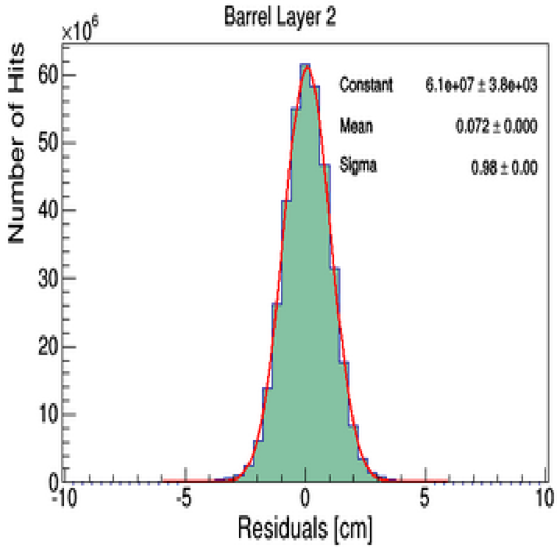
- Two methods are used to study performance
  - Segment extrapolation(*) (Extrapolating CSC/DT segments into RPC plane)
  - Track extrapolation Details of method can be found in John's poster

Synchronization of RPC Data

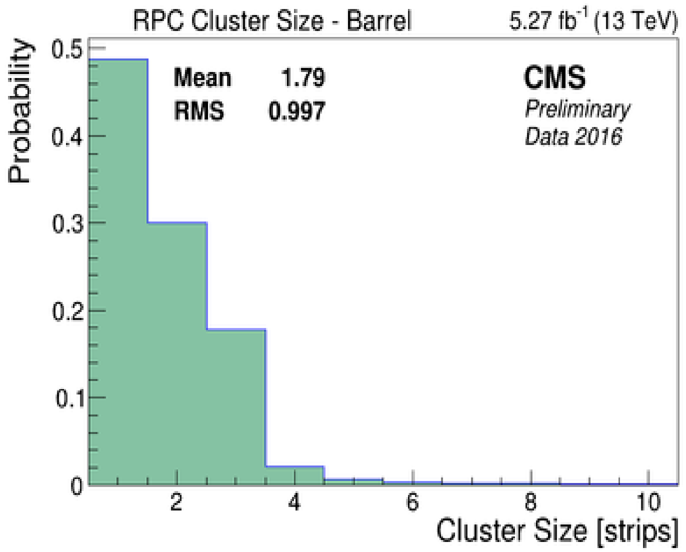


- Bunch crossing of RPC reconstructed hits associated with global muons in the barrel.
- New link system (to be installed during LS3) will improve timing resolution from 25 ns to 1. 6 ns

RPC Hit Resolutions



Resolutions range from sigma = 0.9 cm in the inner to 1.4 cm in the outer station. Strip widths range from 2.3 cm to 4.1 cm. In agreement with the expectations and less than one strip pitch of the strip for a given layer.



Stable Cluster size ~2 strips. Within CMS requirement for trigger unambiguity.

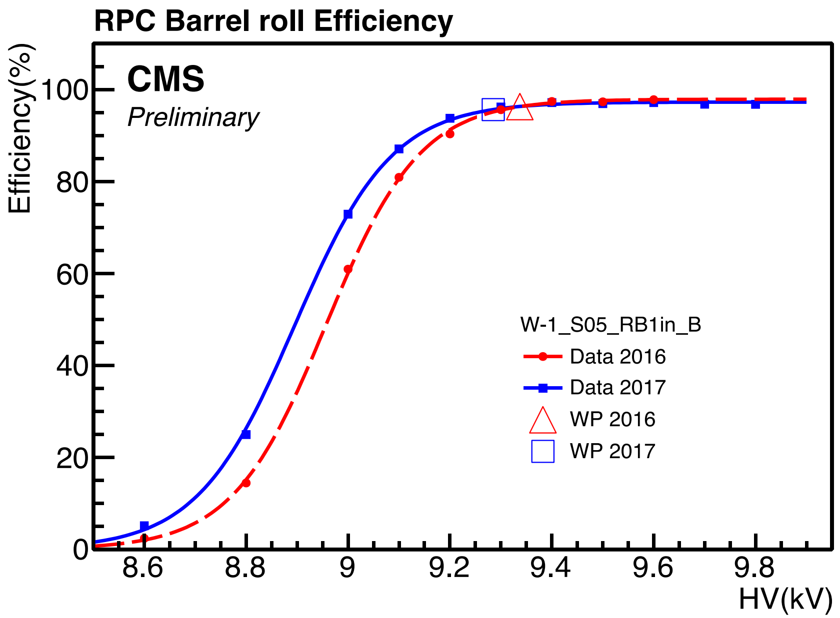
* CMS-MUO-11-001, 2013 JINST 8 P11002.

RPC Working Point Calibration

- Three **HV scans** have been done every year with a dedicated collision runs.
- **Main goals:** optimize chamber Working Point (WP) and monitor in time the performance.

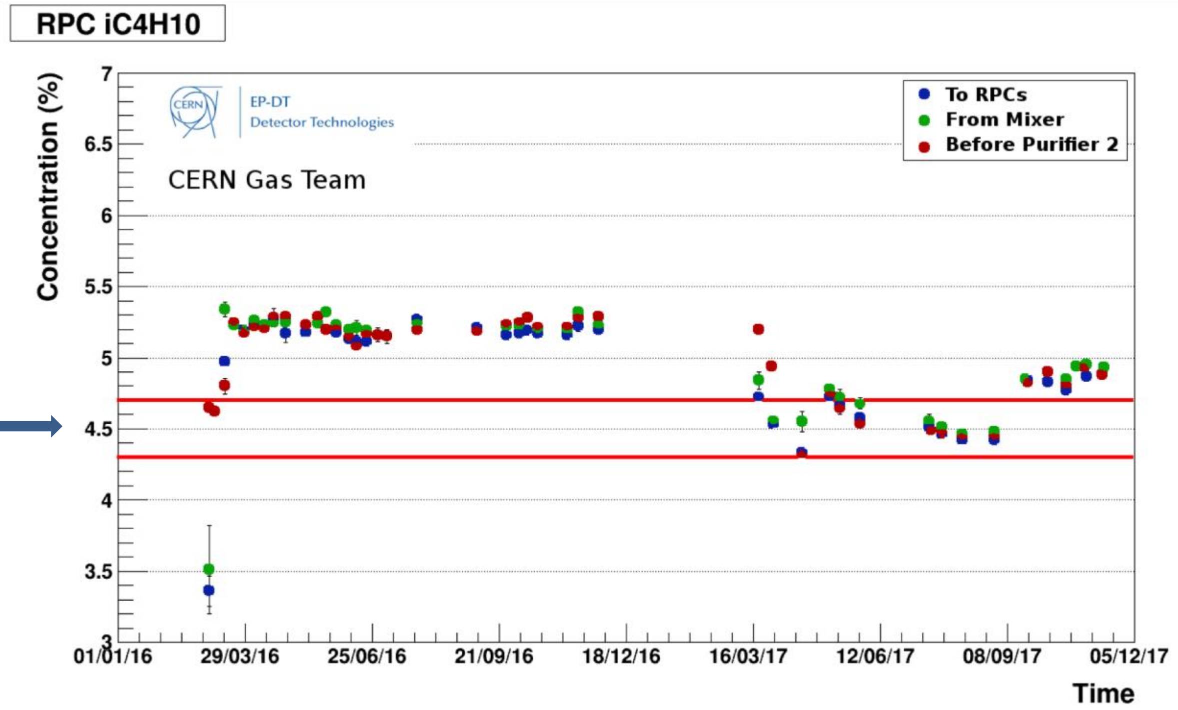
Working Point Definition

$$HV_{WP} = HV_{knee} + \begin{cases} 100\text{ V (Barrel)} \\ 120\text{ V (Endcap)} \end{cases}$$



Efficiency vs HV with different isobutane concentration in 2016 and 2017

Required level

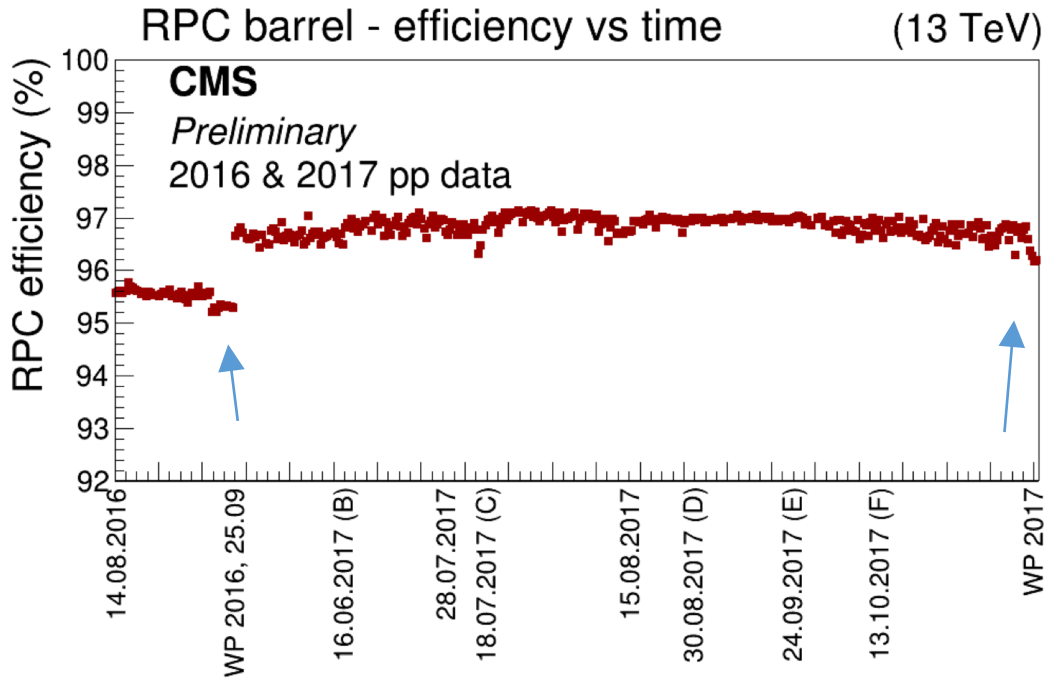


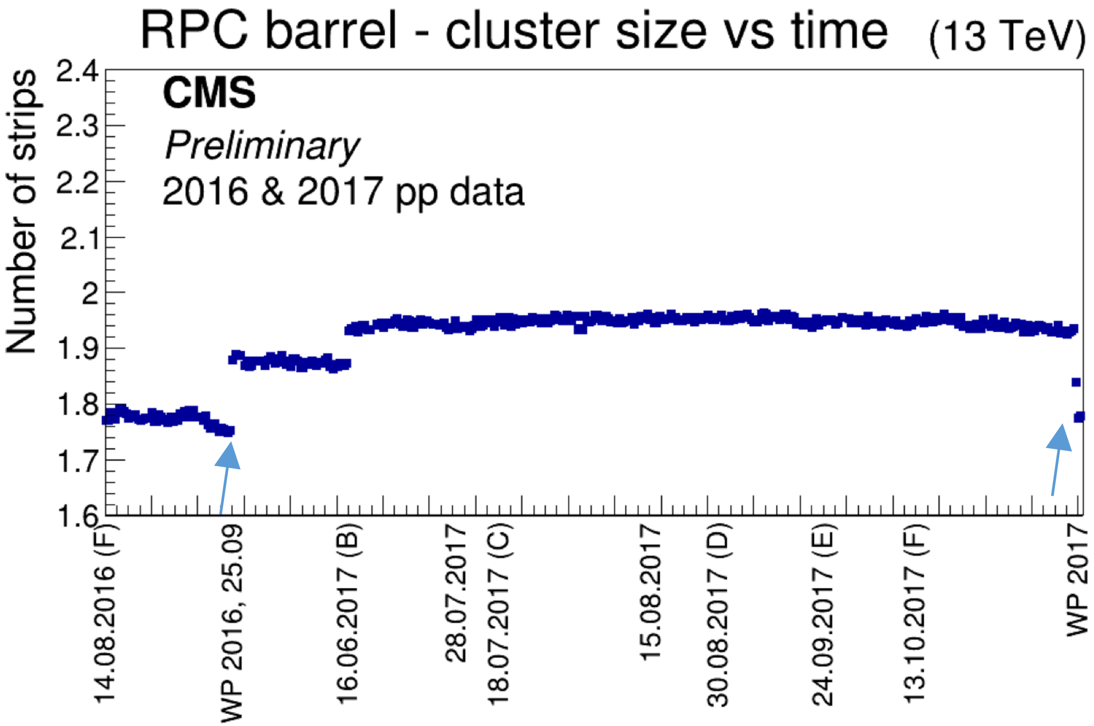
Isobutane concentration in 2016 and 2017. In 2016 concentration was higher because of mass flow cell controller problem.

Details of HV scan and results can be found in Rogelio's poster

RPC Performance During 2016/2017

After years of LHC collisions, very stable performance





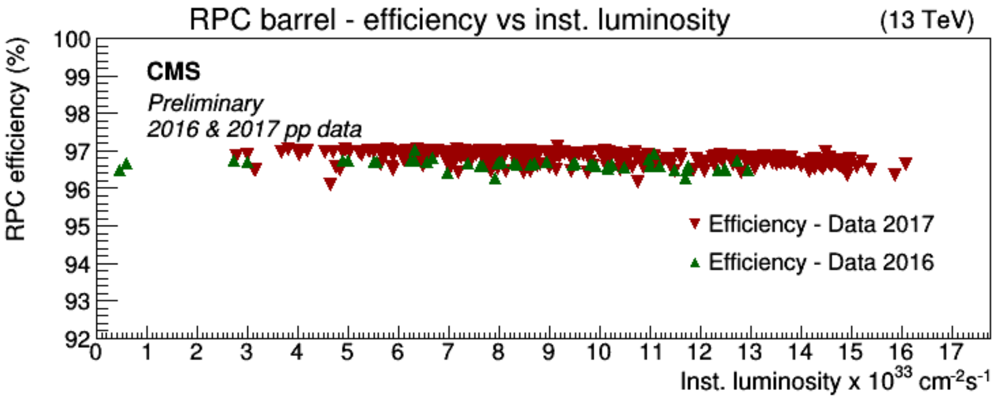
RPC efficiency and cluster size history for the barrel in 2016 and 2017 is shown on the plots. In 2016 because of higher isobutane concentration (5.3%), efficiency was lower as the WPs were not changed to compensate the wrong gas mixture. After the deployment of the new HV working points in September 2016, the efficiency increased by ~1% and cluster size increased sharply. Gas concentration was back at 4.5 % in 2017 but the WP were not changed. New WP deployed by end of 2017.

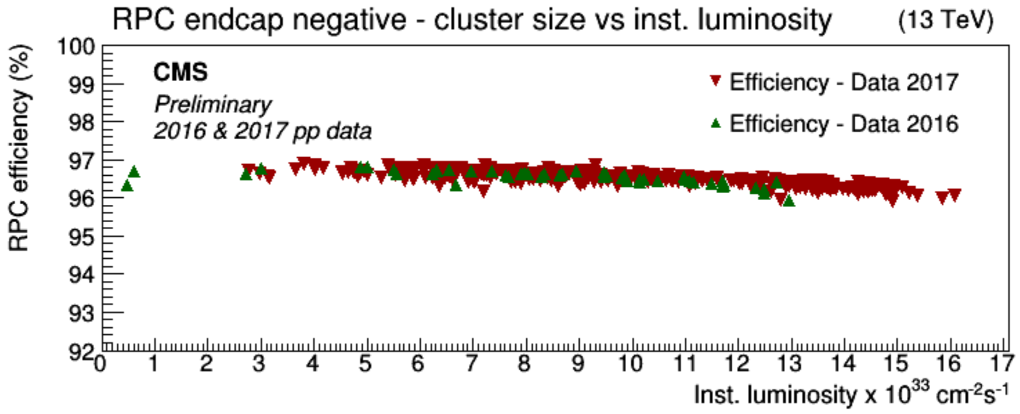
Barrel/Endcap Efficiency & Cluster Size vs Luminosity

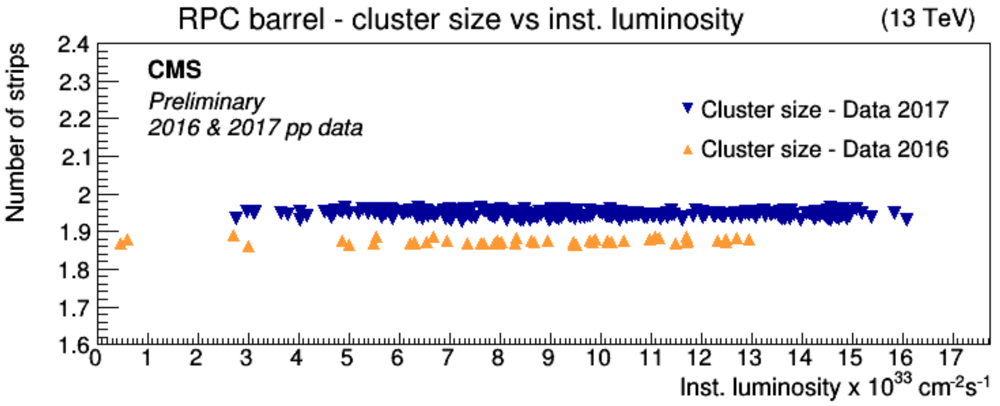
At L = 5×10^{34} cm^{-2}s^{-1} (HL-LHC)

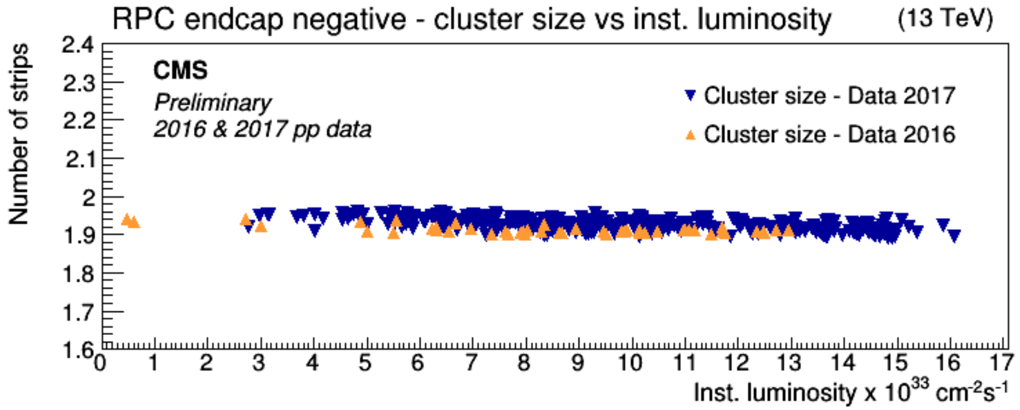
Extrapolated efficiency reduction

~ 0.8 % in barrel **& ~ 2 % in** endcap









Stable cluster size with increasing luminosity

Conclusion

- The CMS RPC system operated successfully in extreme conditions (8 TeV & 13 TeV & L ~ 2 x 10^{34} $cm^{-2}s^{-1}$) during RUN-I & RUN-II and detector performance is within CMS specifications and stable.
    - Average efficiency ~ **96%**
    - Average cluster size ~ **2 strips**

- The RPC performance is stable and fulfill the requirements for the trigger and reconstruction capabilities necessary for the CMS physics program.

- No major degradation has been observed to participate in the hadron collisions of HL-LHC at higher energy (14 TeV) and luminosity (5 x 10^{34} $cm^{-2}s^{-1}$).


BONUS
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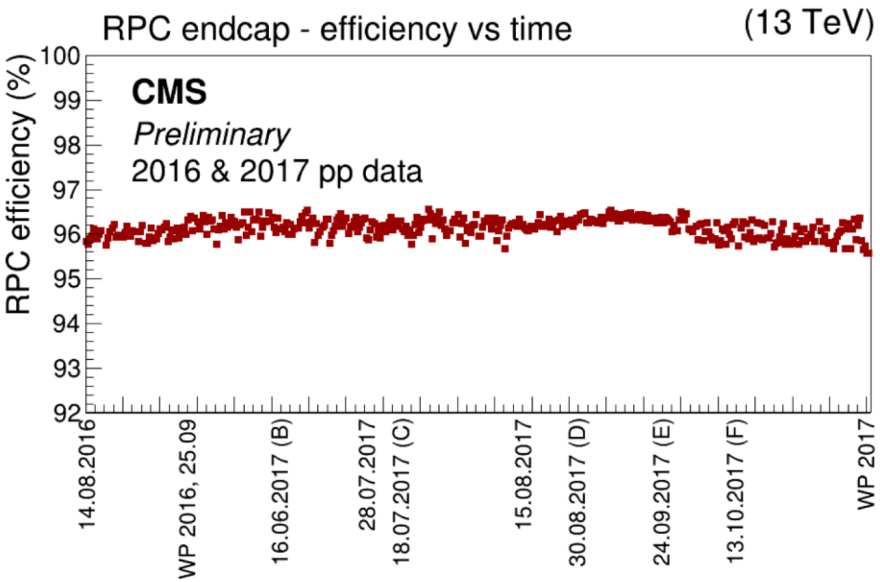
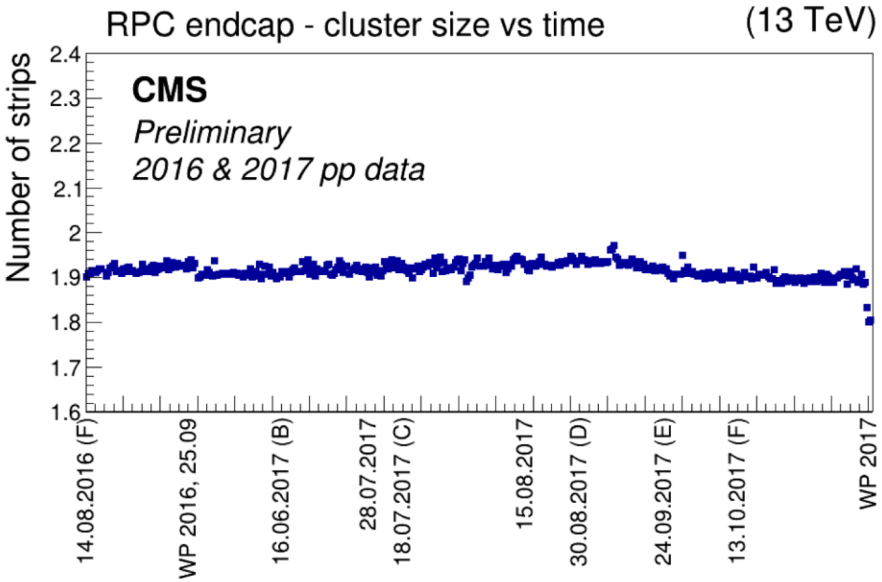
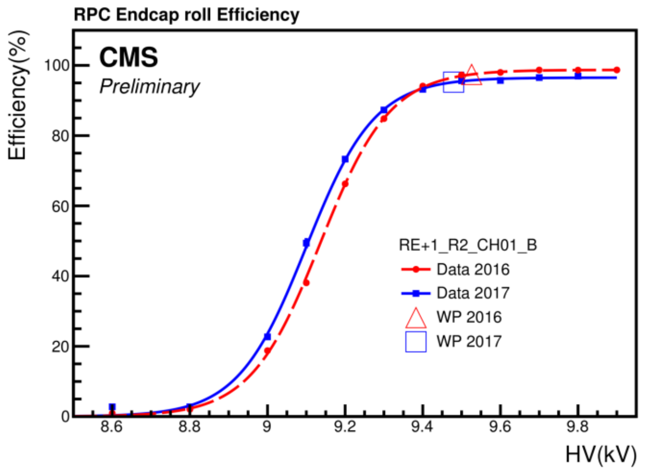
Endcap Efficiency and Cluster Size during 2016/2017





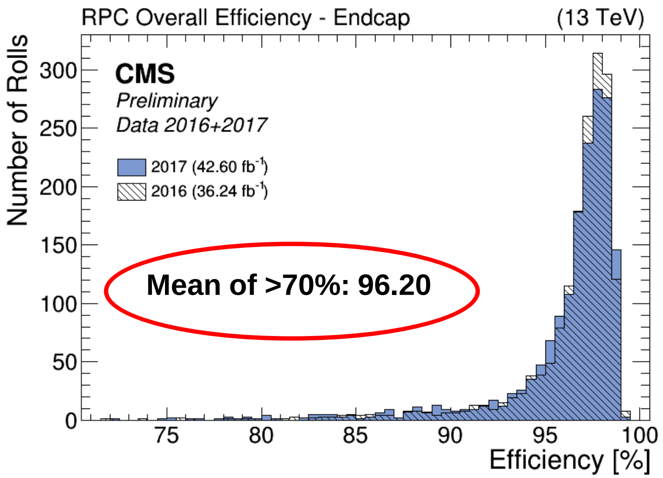


Eff vs HV with different isobutane concentration in 2016 and 2017

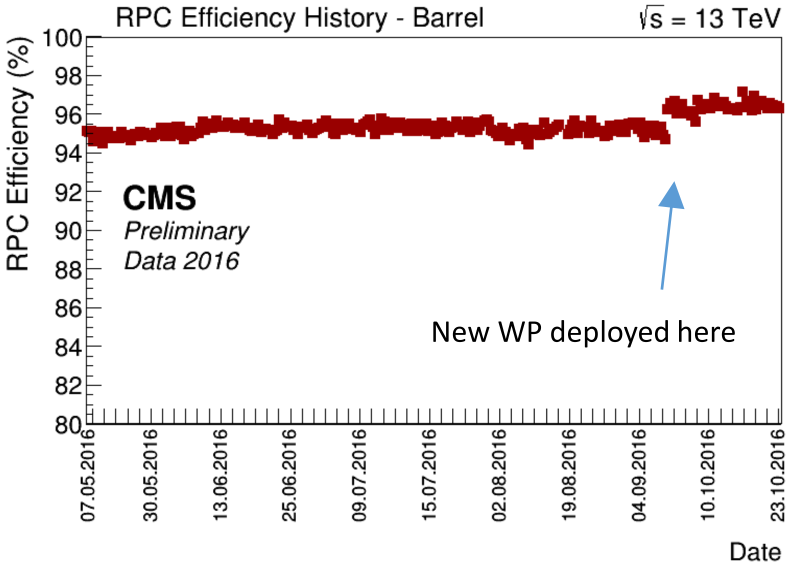
RPC efficiency and cluster size history for the endcap in 2016 and 2017 is shown on the plots. In 2016 higher isobutane concentration (5.3) did not really effect the efficiency and cluster size because of different WP definition (~200 V more on the plateau) in the endcap. Average cluster size remains stable below 2 strips as specified in the CMS requirements for trigger unambiguity

Barrel Efficiency and Cluster Size during 2016

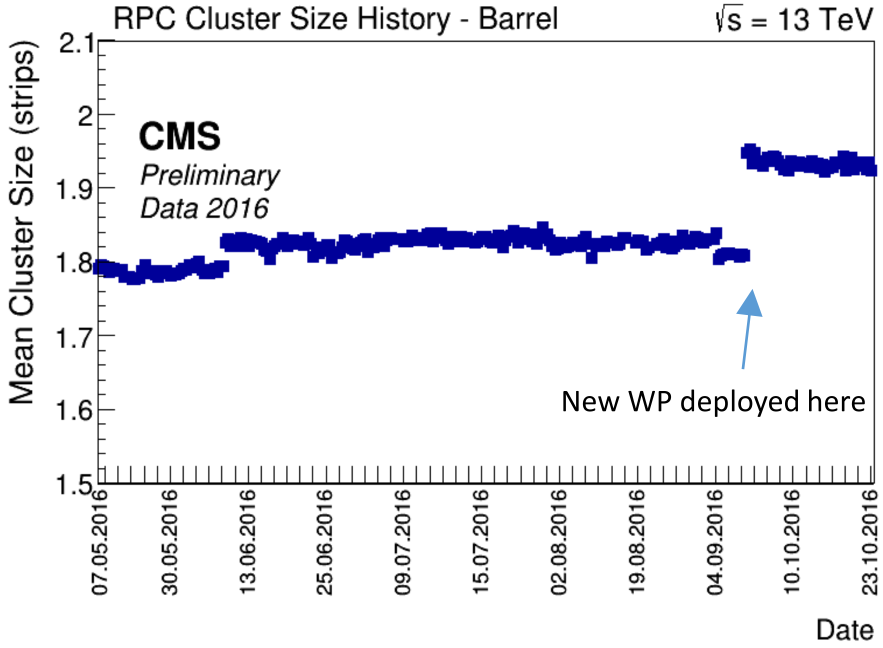
- 2017 Data: Track extrapolation method



2016 Barrel average efficiency vs. time



2016 Barrel average cluster size vs. time



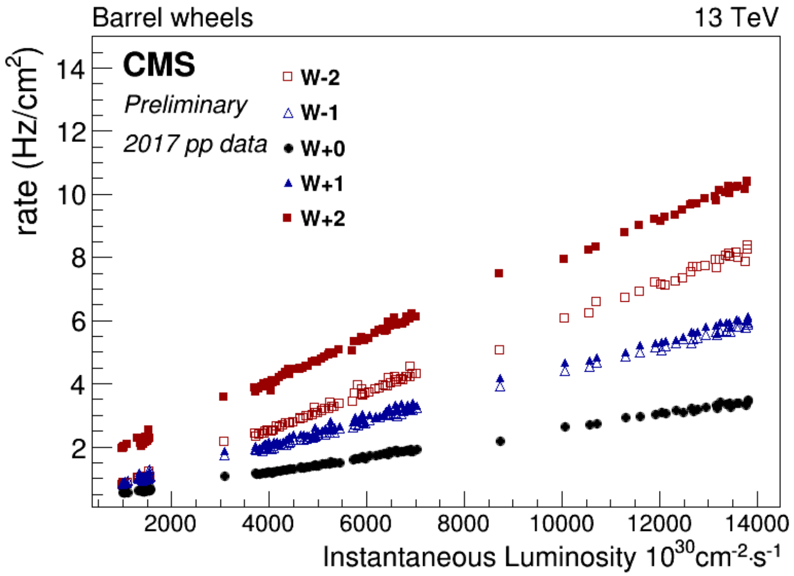
Excluding chamber with efficiency < **70%**

Average efficiency **96.2%** both barrel and endcap

Stable Cluster size ~2 strips. Within CMS requirement for trigger unambiguity.

RPC Rate/Current vs Instantaneous Luminosity

2017 RPC Barrel average rate vs luminosity

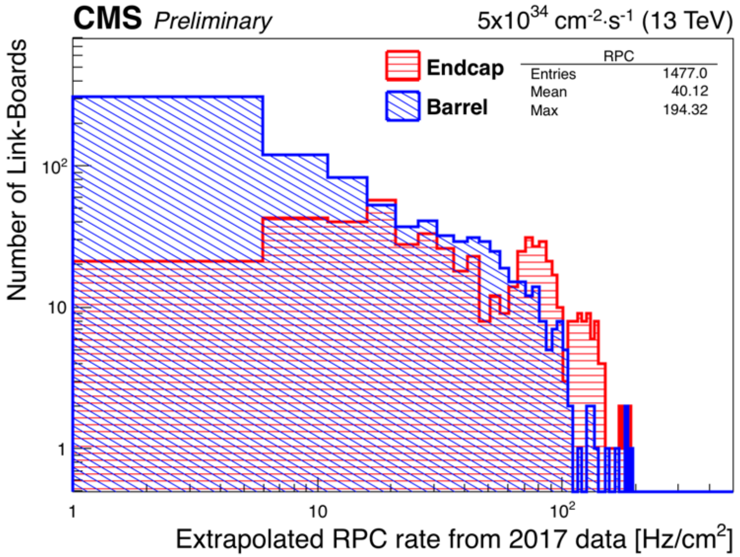


Linear dependence between the RPC rate (measured from LB) and instantaneous luminosity.

Rate and currents in the endcap are twice as that of barrel.

RPC expected rate at HL-LHC luminosity

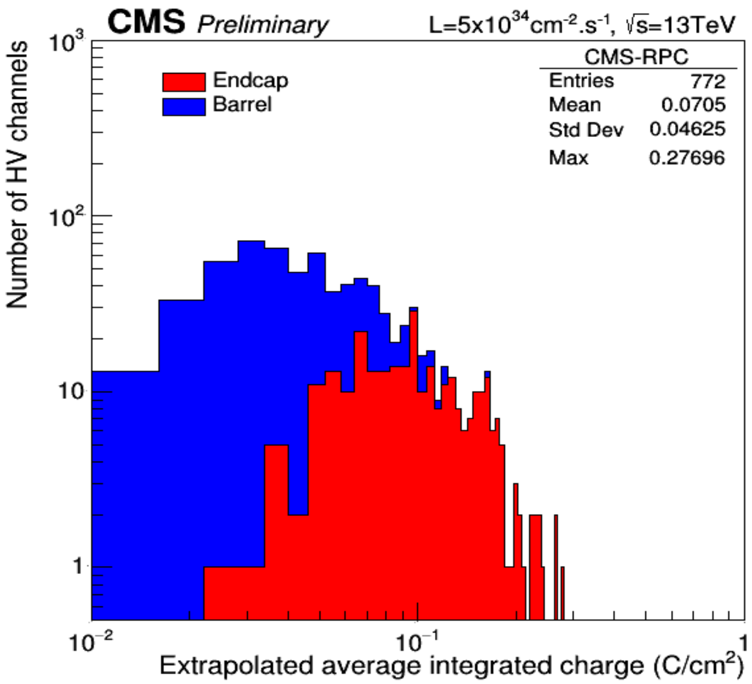
- The linear dependence of the RPC hit rates on the instantaneous luminosity for every RPC chamber have been extrapolated to the HL-LHC instantaneous luminosity of 5×10) $cm^{-2}s^{-1}$ using 2017 data.
- The expected mean and maximum rate for the entire RPC system are **40 Hz/cm²** and **194 Hz/cm²**, respectively.

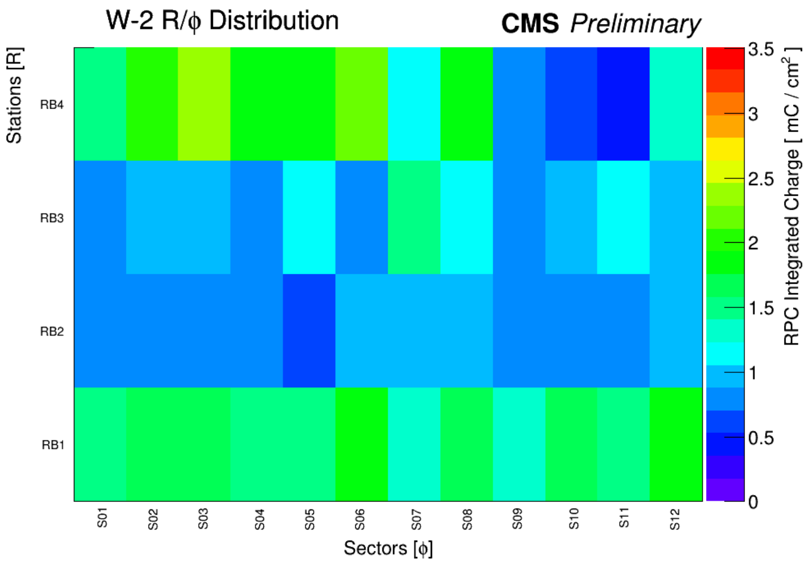


Details of background studies can be found in Raul's talk

Expected conditions at HL LHC integrated charge

The charge integrated at LHC collisions used to estimate the expected **integrated charge** at HL-LHC assuming a total integrated luminosity of 3000 fb^{-1}





Integrated charge in W-2 for an integrated luminosity of 75 fb^{-1}

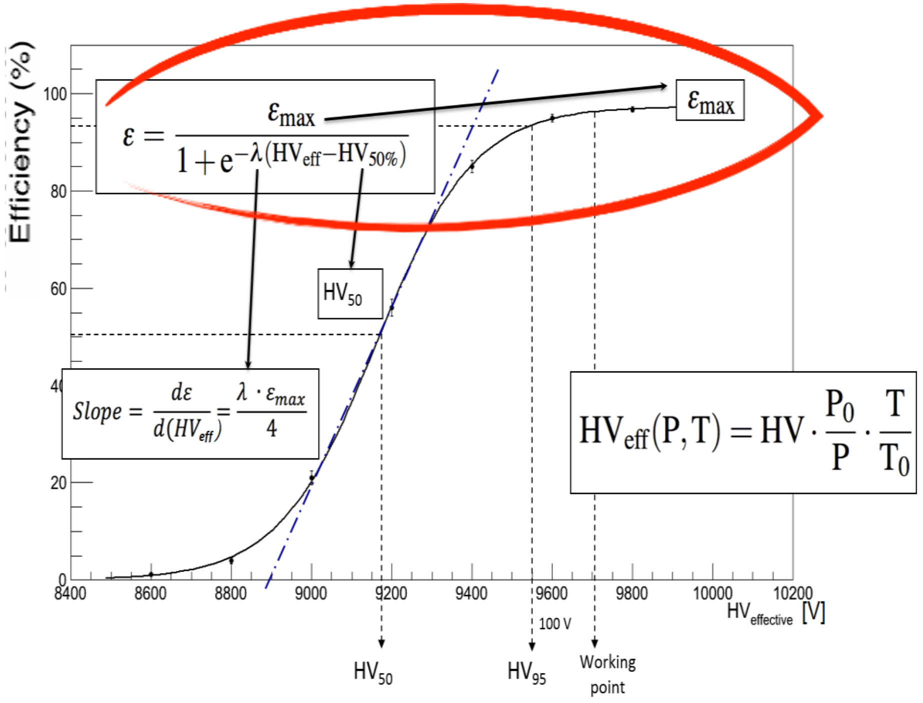
Maximum expected integrated charge ≈ 272 mC/cm²

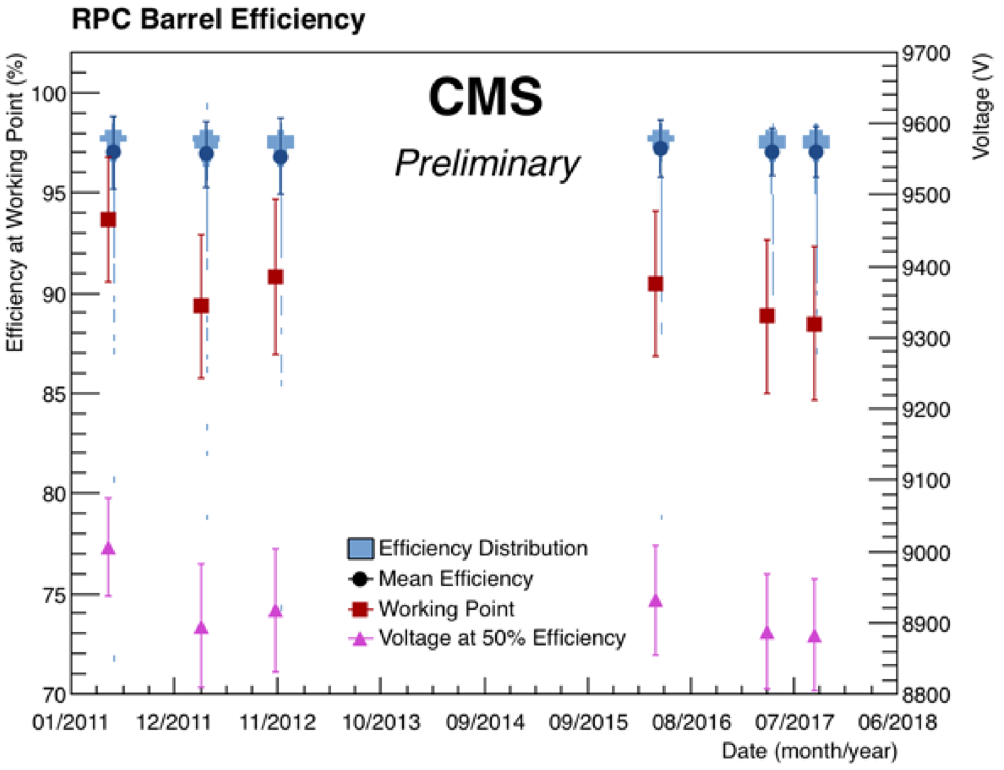
➢ Barrel chambers factor 2 less

The system will be certified for int. charge of ≈ 816 mC/cm² (safety margin of 3)

HV Scan Parameters

RPC WP, Efficiency and HV50 history over the years





Upgraded L1 Muon Trigger