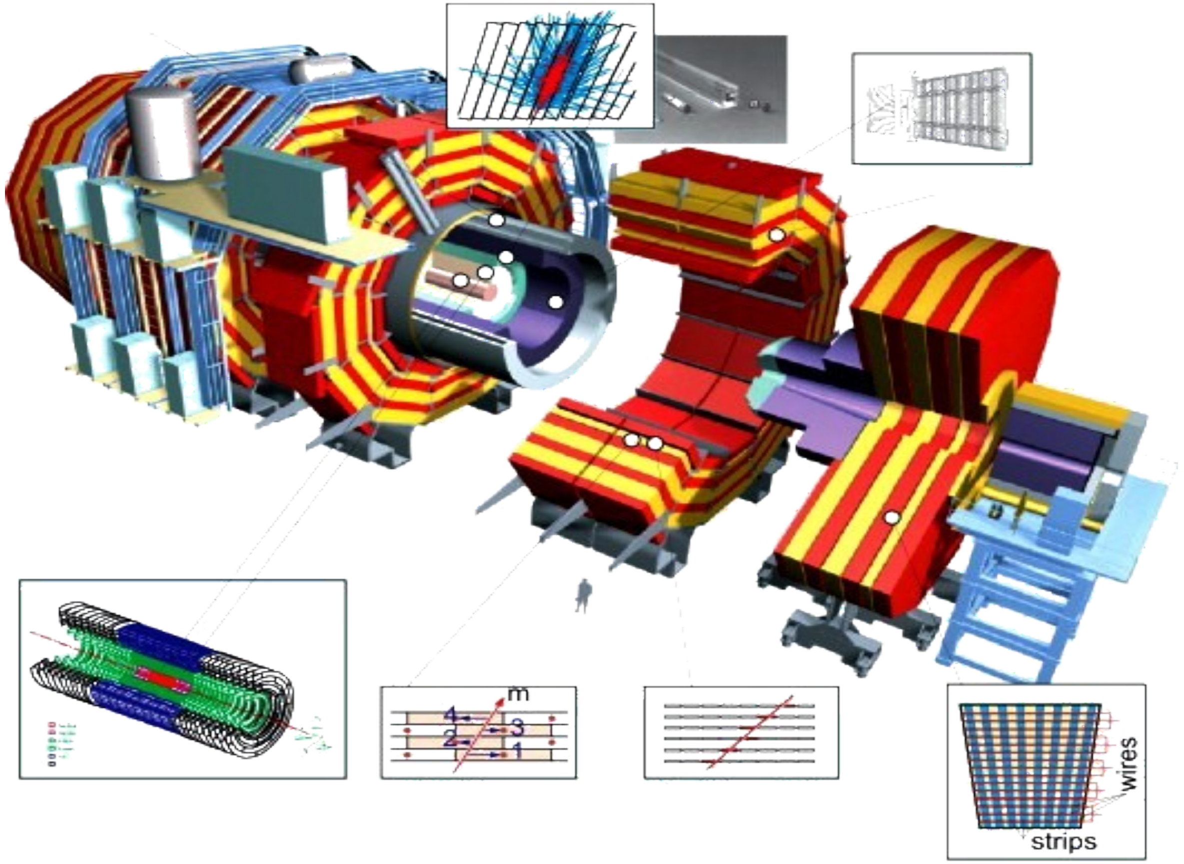
Experiences from the RPC data taking during the LHC RUN-2

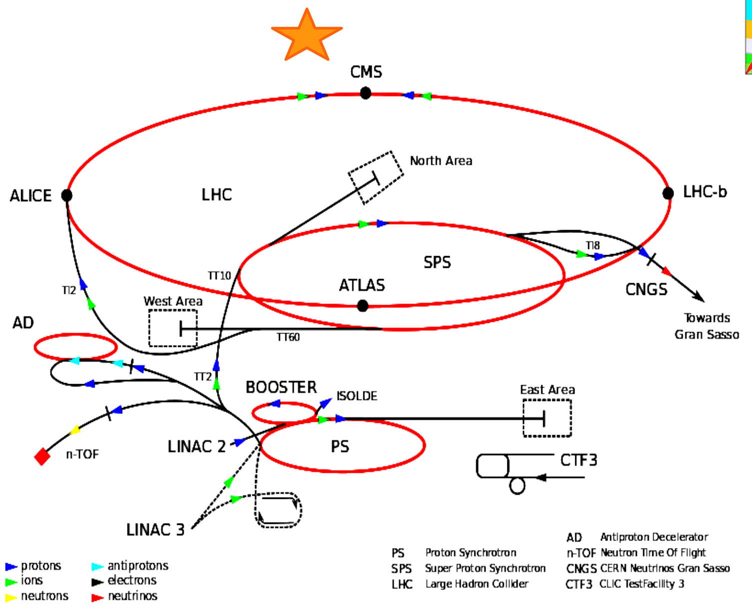
Mehar Ali Shah
on behalf of the CMS collaboration

RPC2020, Roma

National Centre for Physics, Pakistan

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.

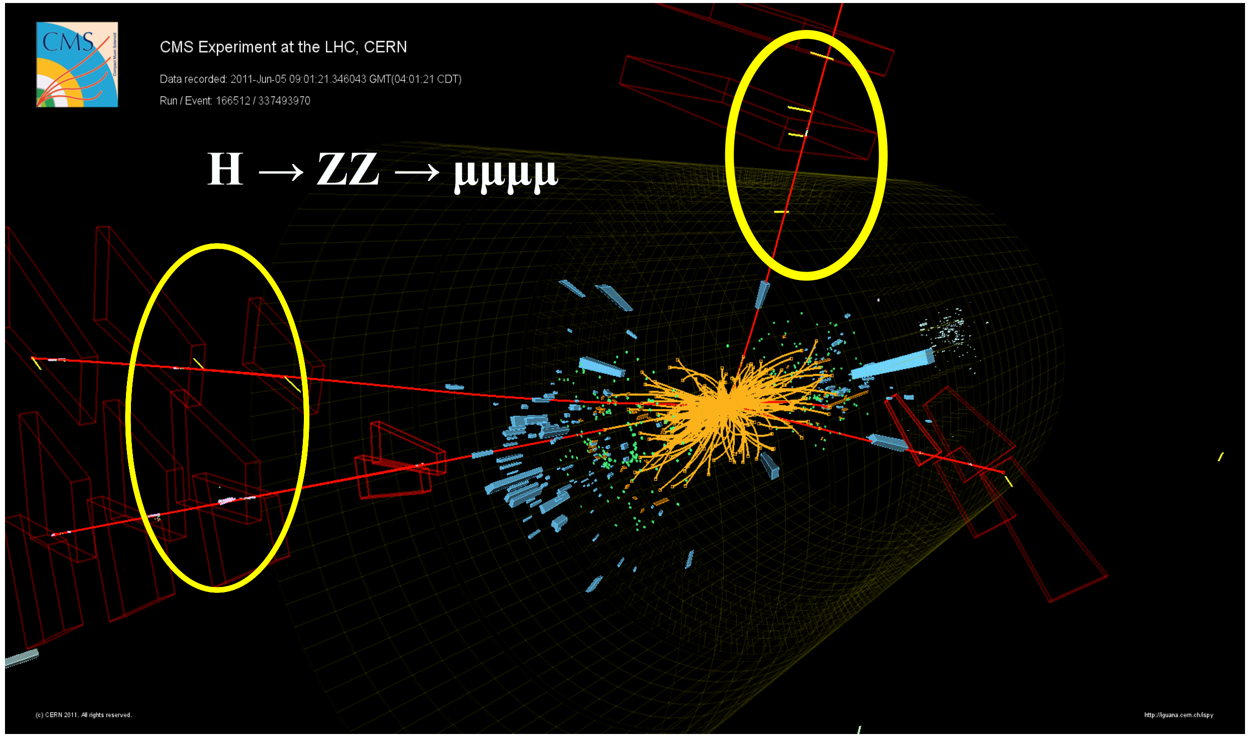
2012 - Higgs boson observation!

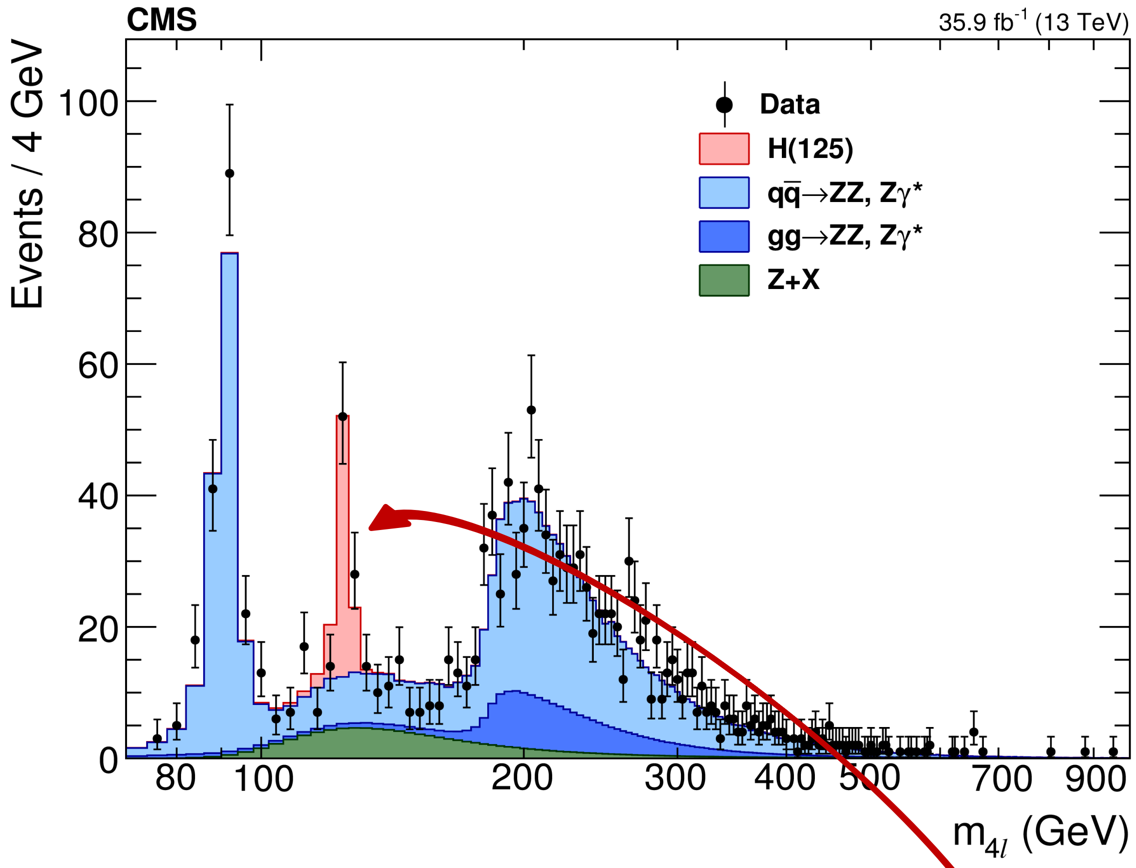
CMS

- 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 (→ *4l*) Measurement

Ref: HIG-16-041





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

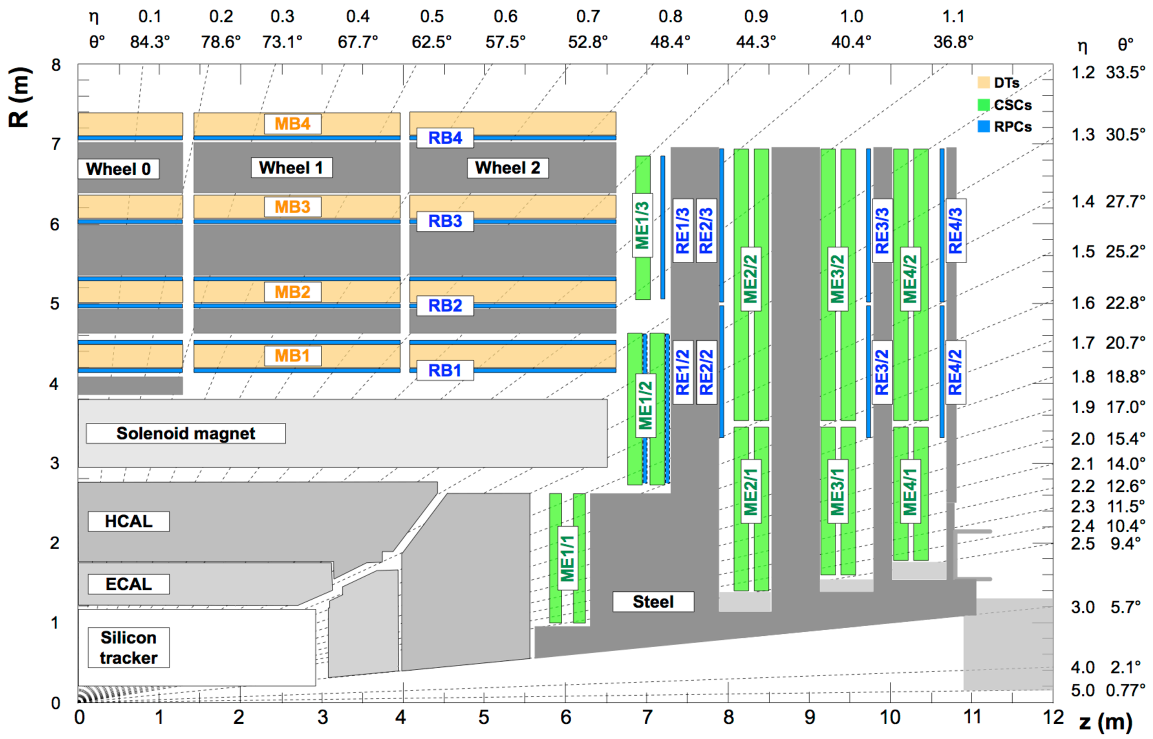
Four-lepton mass spectrum: clean Higgs boson signal peak at ~125 GeV

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:

Barrel: 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

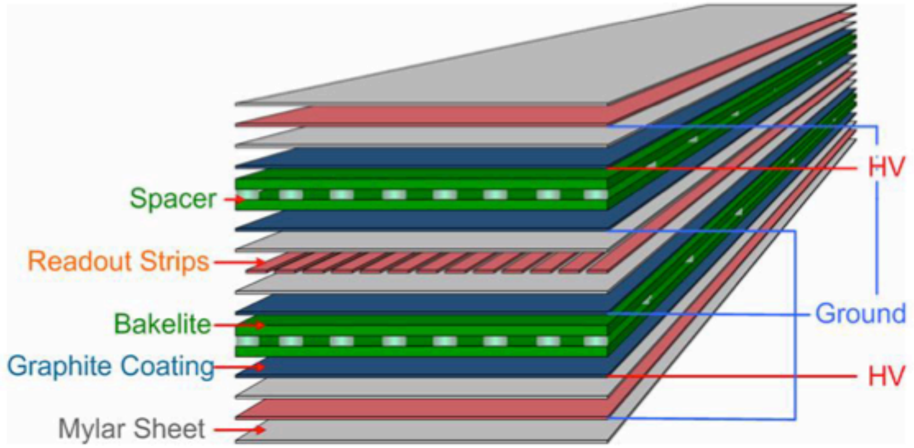
Drift tubes in the barrel region and **Cathode strip chambers** in the endcaps provide “Tracks Stubs” (a vector in space) . This information is supplemented by **Resistive Plate Chambers** that provide precise **time information** and coarse **position** measurement.

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

The CMS Resistive Plate Chambers

RPC present system

- **Covers $|\eta| < 1.9$**
- **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**



Details of eco friendly gas mixture in Andrea's talk: "Characterization of new RPC eco-friendly gas mixtures at GIF++".

Requirement of RPC system:

- High rate capability (~**300** Hz/cm^2)
- High detection efficiency > 95% &
- 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

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

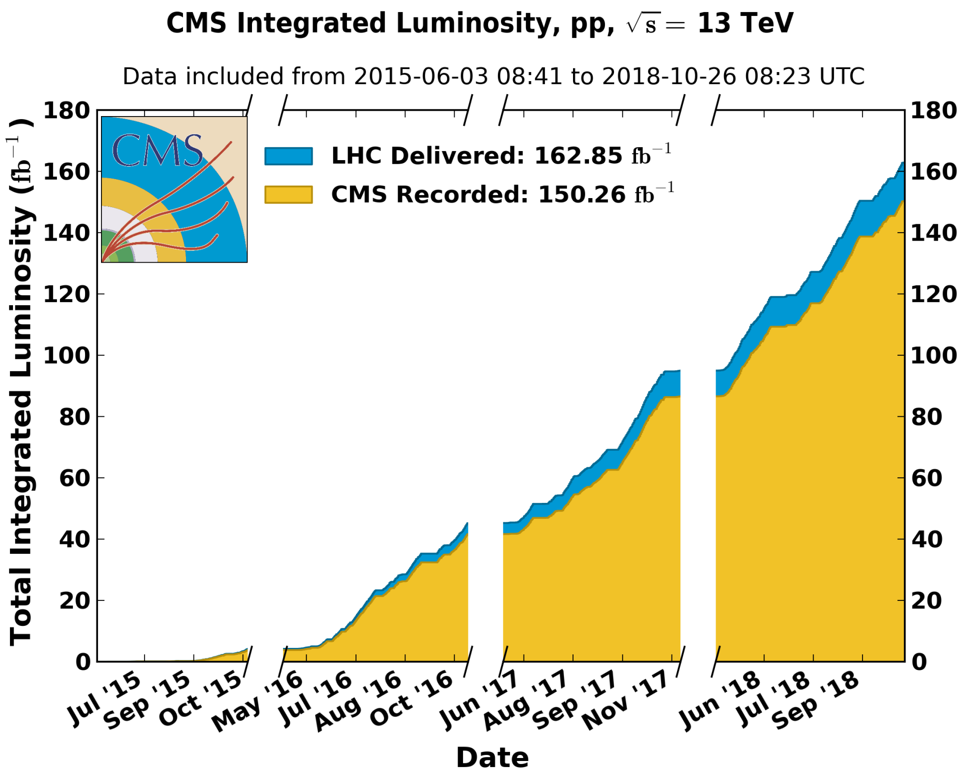
- High luminosity $2*10^{34}$ $cm^{-2}s^{-1}$
- Millions of muons
- Many runs (time)

- ❖ Aging effects
  - Efficiency uniformity and stability
  - Plateau position (HV at 50% of efficiency)

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

CMS & RPC over RUN II

RUN II
CMS recorded $L_{int} \sim 150\ fb^{-1}$



- ➢ CMS RPC **Run effectiveness** of **~99.97 % in RUN-2**
  →The RPC contribution to the **CMS downtime**

RUN-1	RUN-2
1.2 %	0.03 %

- ➢ **For run validation, the fraction of luminosity lost** due to RPC during RUN-2 was **~231 /pb**, concentrated mainly in 6 events (electronic failures and software configuration errors.

RUN-1	RUN-2
~ 0.6 %	~ 0.15 %

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

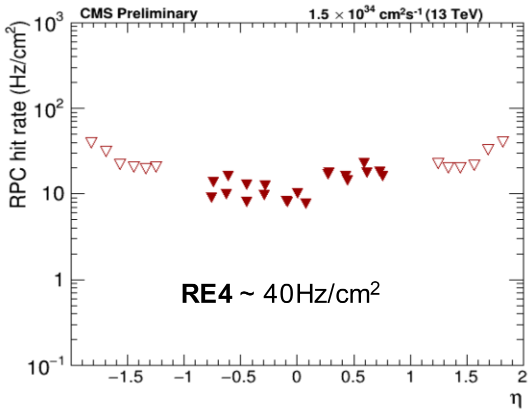
RUN2 experience crucial:
Study the **longevity** of the system in the view of **phase 2** operations by monitoring the stability of the performance (efficiency, cluster size,..) and currents.

RPC Background/Integrated Charge

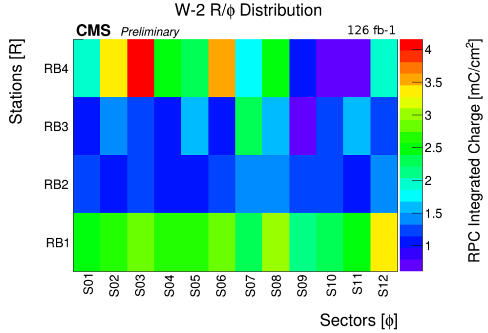
After ~ 9 years operation → ~ **185 fb^{-1}** integrated luminosity
~ **2.3 mC/cm^2** for Barrel
~**7.5 mC/cm^2** for Endcap

RPC Hit Rates - φ distribution in endcaps at
$L=1.5\times10^{34}cm^{-2}s^{-1}$

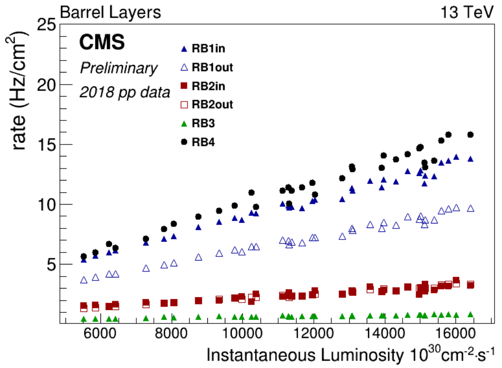
→ RE4 are most exposed stations.



Higher contribution in layer RB1 and RB4
→ higher background contribution



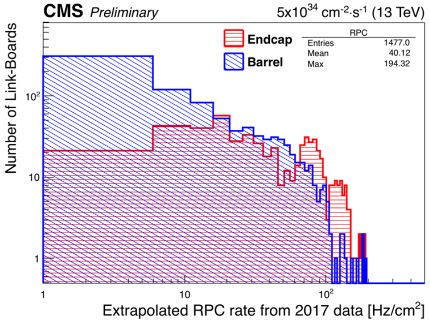
RPC barrel hit rate and current vs instantaneous luminosity
→ **RB1** and **RB4** are most exposed layers.

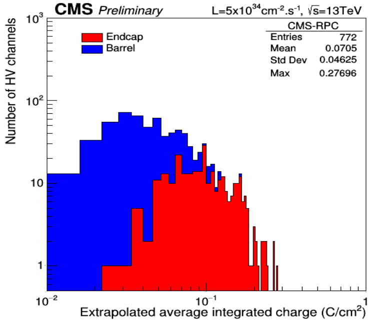


→ Complete background details can be found in Roumyana's poster "CMS RPC background studies and measurements".

RPC expected rate & charge at HL-LHC conditions

The charge integrated at LHC collisions and linear trend of rate vs luminosity is used to estimate the expected integrated charge and rate at HL-LHC assuming a total integrated luminosity of 3000 fb^{-1} and instantaneous luminosity of 5×10^{34} $cm^{-2}\cdot s^{-1}$

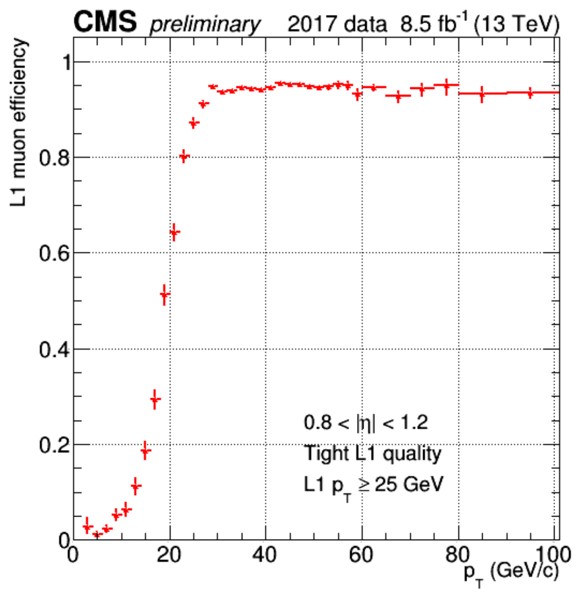




→ Maximum expected integrated charge **≈ 272 mC/cm^2**
→ The expected mean and maximum rate for barrel and endcap are **40 Hz/cm^2** and **194 Hz/cm^2**.

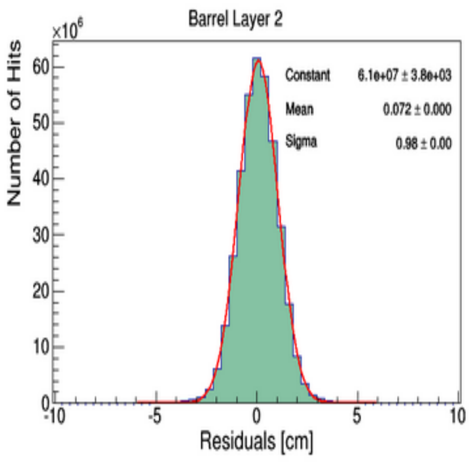
RPC Performance

→ RPC system is present both in the barrel and the endcap, contributing to all 3 **Muon track finders** (Barrel, overlap, endcap)



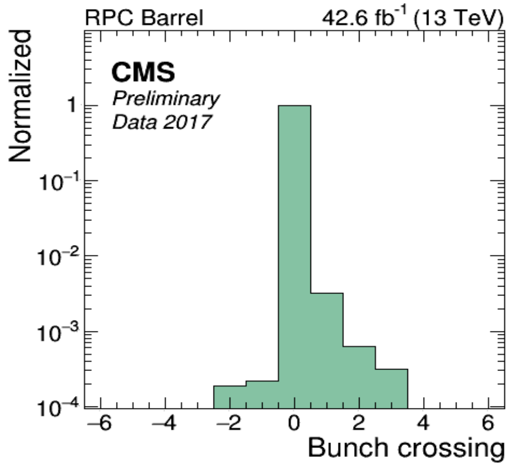
L1 efficiency vs p_T curve for the overlap track finder.

RPC Hit Resolutions



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

Synchronization of RPC Data



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** and provides higher bandwidth.

→ Details in Behzad talk "CMS RPC upgrade phase-II of new Link system ".

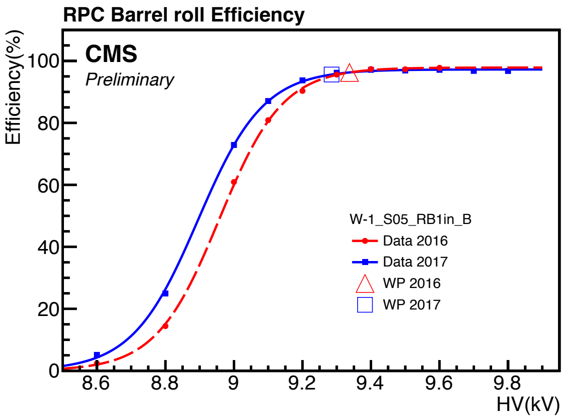
→ Full details of RPC and L1 trigger in Brieuc's talk "RPC System in the CMS Level-1Muon Trigger".

→ Details of RPC cluster size in slide 12.

RPC Working Point Calibration

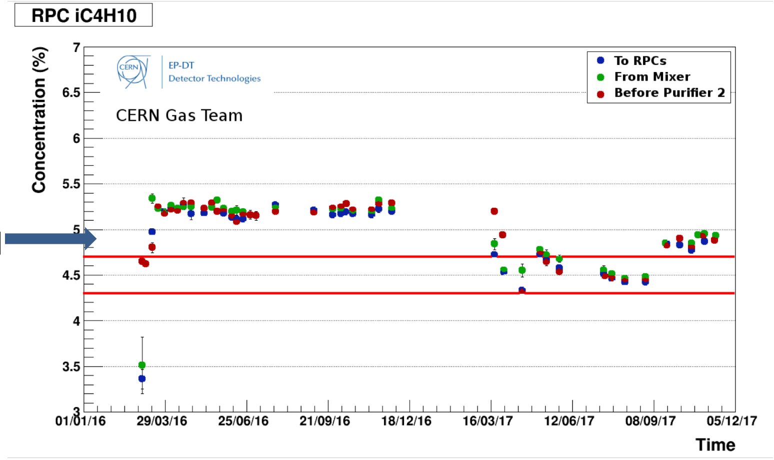
- **HV scans** have been done every year with a dedicated collision runs.
- **Main goals:** optimize chamber Working Point (WP) and monitor in time the performance.

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

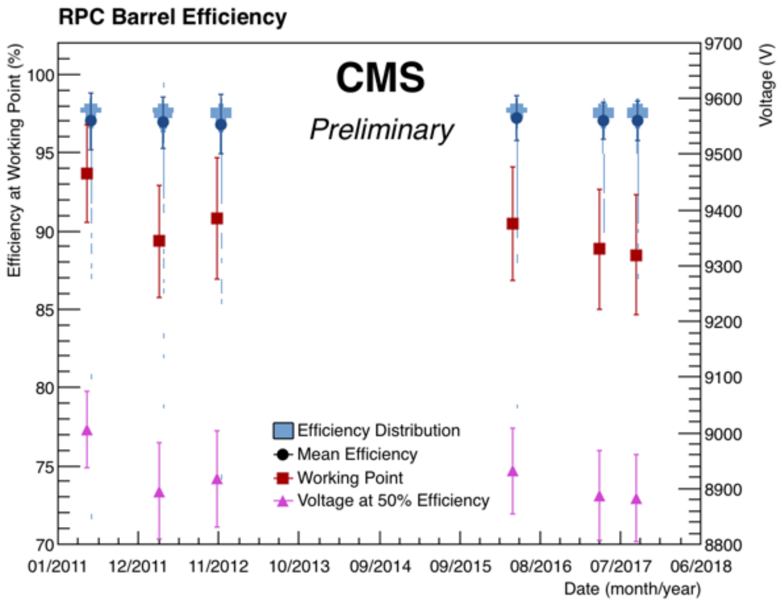


Efficiency vs **HV** with different isobutane concentration in 2016 and 2017.

Required level



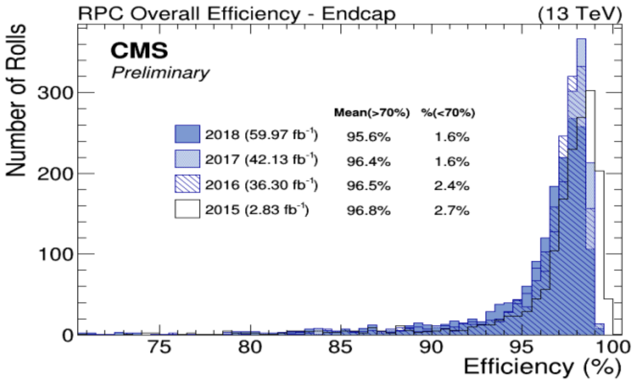
Isobutane concentration in 2016 and 2017. In 2016 concentration was higher because of mass flow cell controller problem.

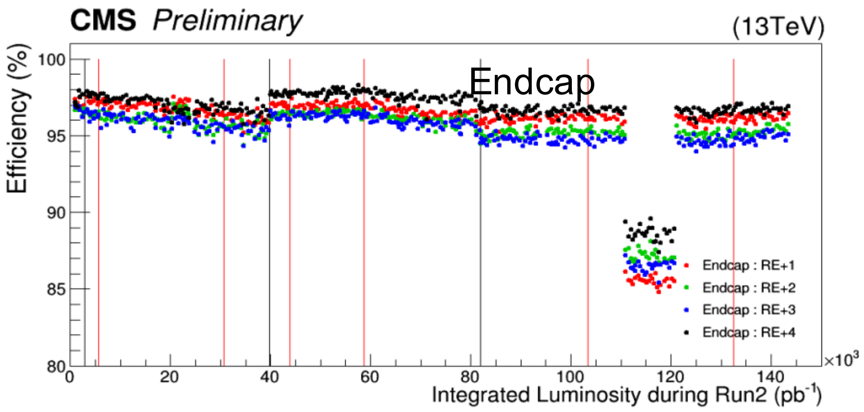


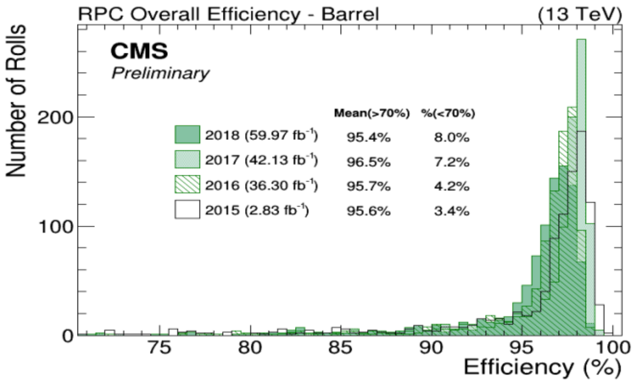
RPC **WP, Efficiency** and **HV50** history over the years.

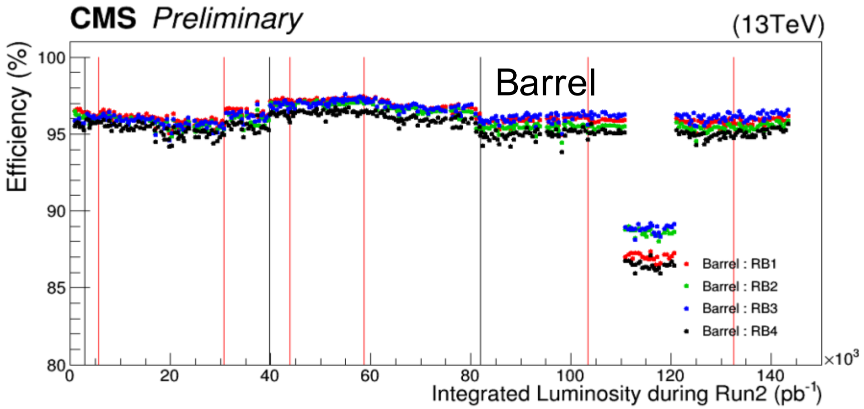
CMS RPC Performance during RUN-2

After ~ 9 years operation → ~ 185 fb^{-1} integrated luminosity (~150 fb^{-1} only Run 2)
CMS-RPC **performance is high, efficiency > 95 % and stable.**







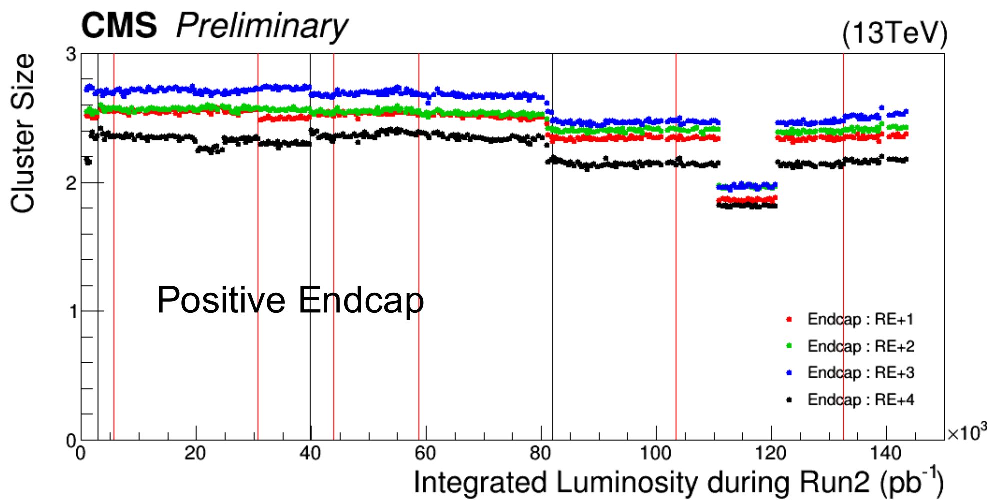


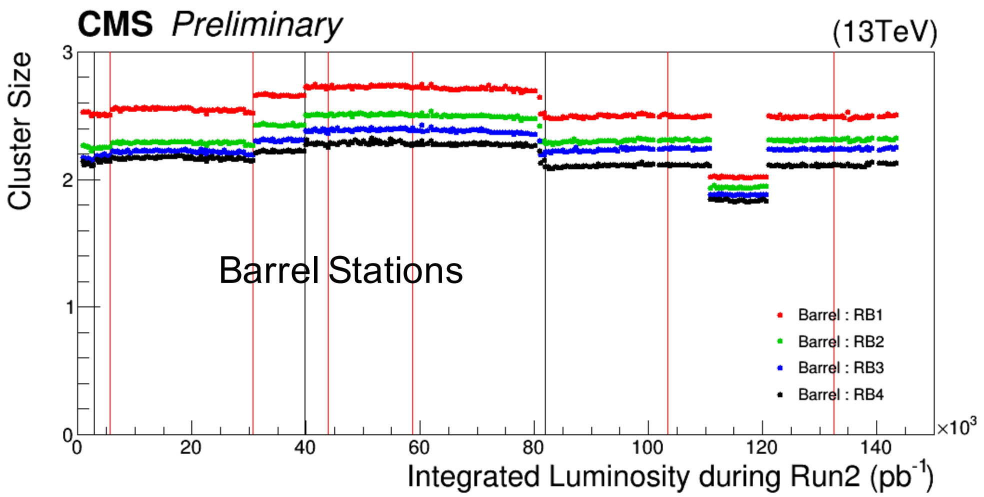
The drop of the efficiency during August is caused by a known configuration setting problem.

RPC Cluster Size during RUN-2

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

→ RPC Strips width range from 1.4 cm to 4.1 cm.

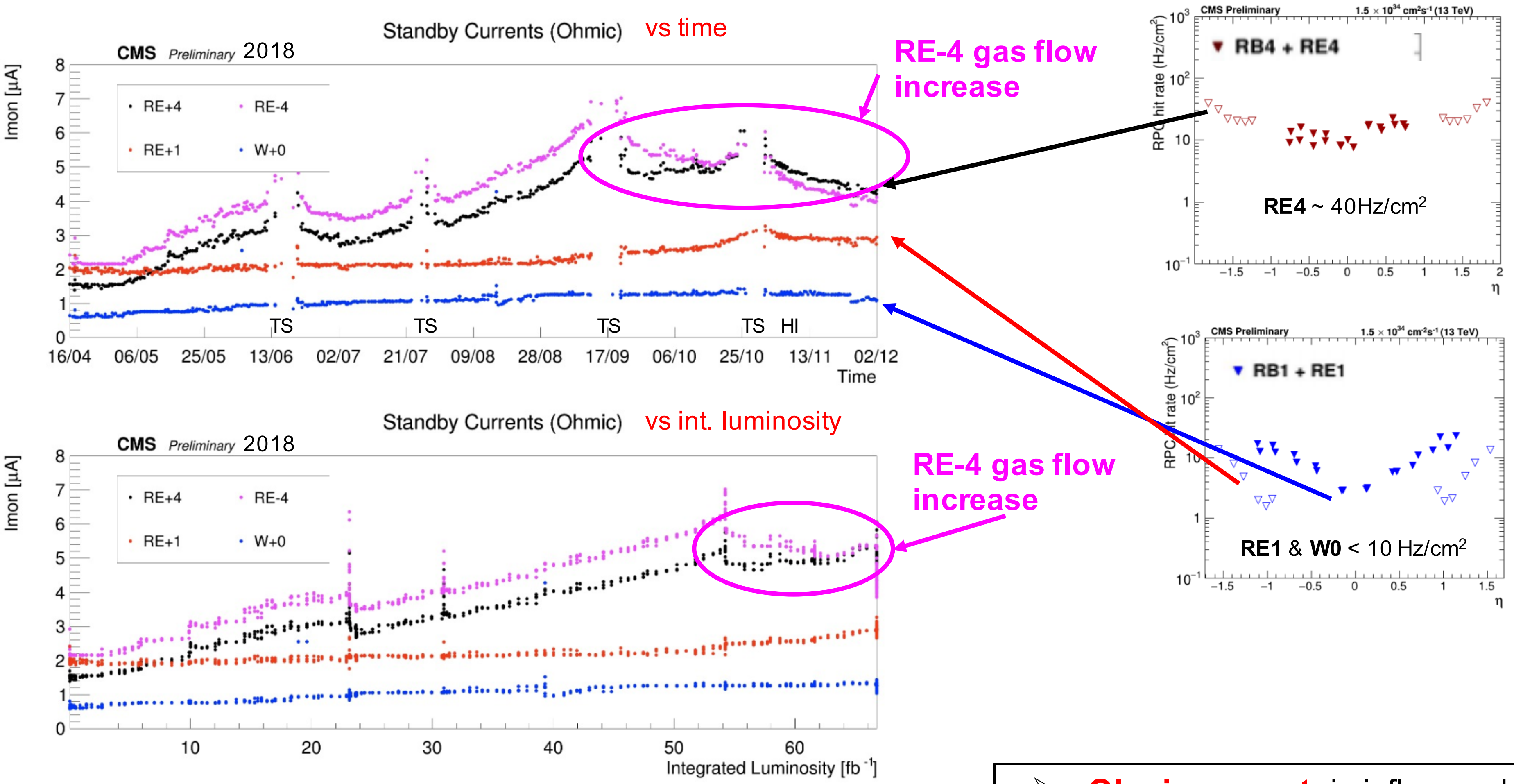




- In 2016 because of **higher isobutene concentration** (**5.3%**), efficiency was lower as the WPs were not changed to compensate the wrong gas mixture. After the deployment of the new HV working points in September 2016, the efficiency increased by **~1%** and cluster size increased sharply.
- Gas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

Ohmic Current Monitoring

- ➢ **Ohmic current increase** was observed in regions of higher background: In endcap **RE4s** & in Barrel **RB1 & RB4** stations.
- ➢ **Ohmic current decrease** when there is no beam (TS) or the luminosity is very low (HI)

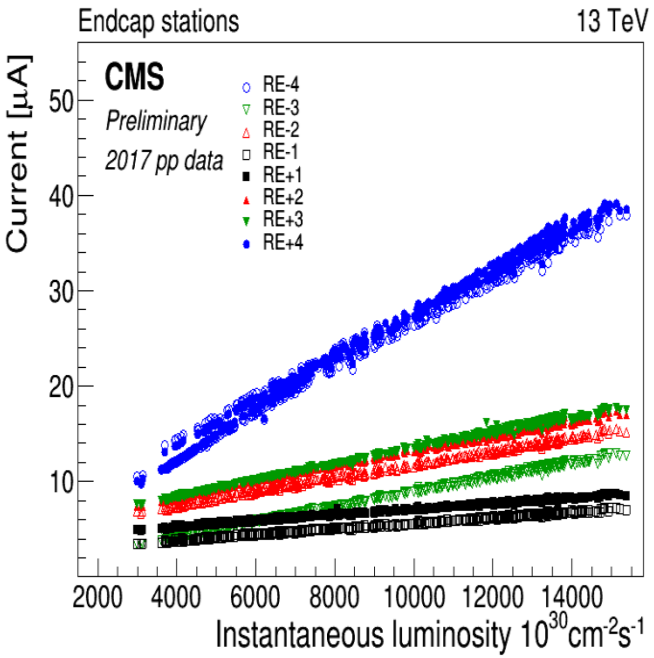


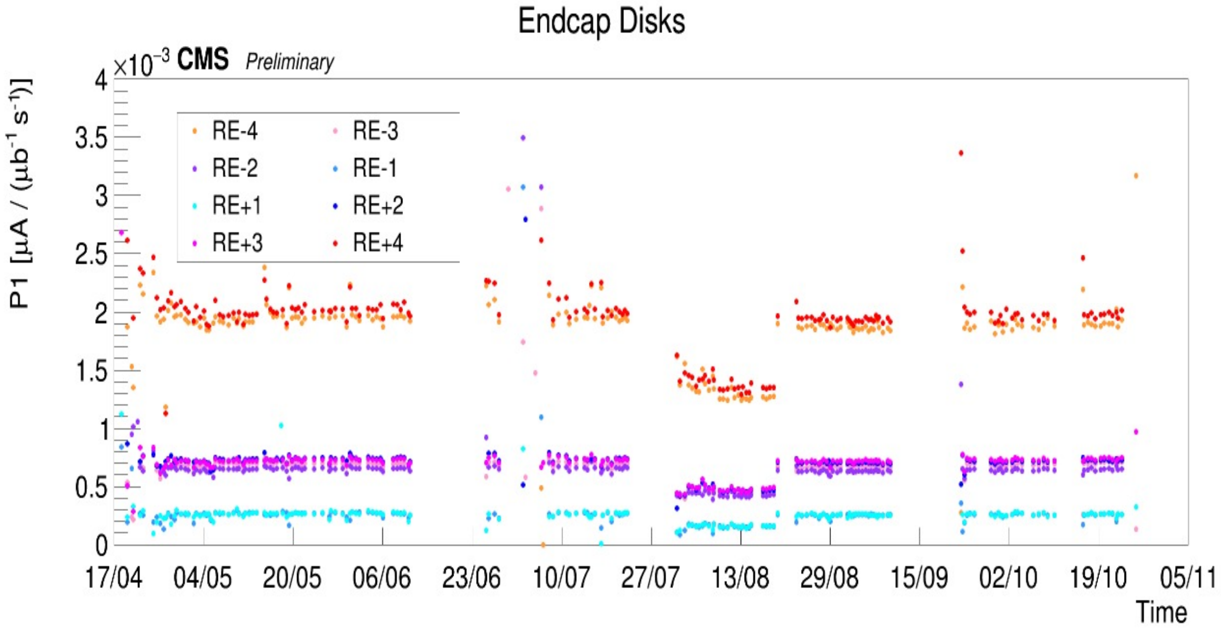
- ➢ **Ohmic current decay** is observed when there is no beam (TS) or the luminosity is very low (HI)
- → Details of machine learning approach to spot abnormal currents can be found in Piecho's talk "A new approach for CMS RPC current monitoring using Machine Learning techniques"

- ➢ **Ohmic current** is influenced by the **background** and **gas flow**
- ➢ **Ohmic current** is **linear** as a function of the integrated luminosity

Total Current Monitoring

Total current can be evaluated by the linear dependence of current vs luminosity, subtracting the offset, leaving: i = p1 * L



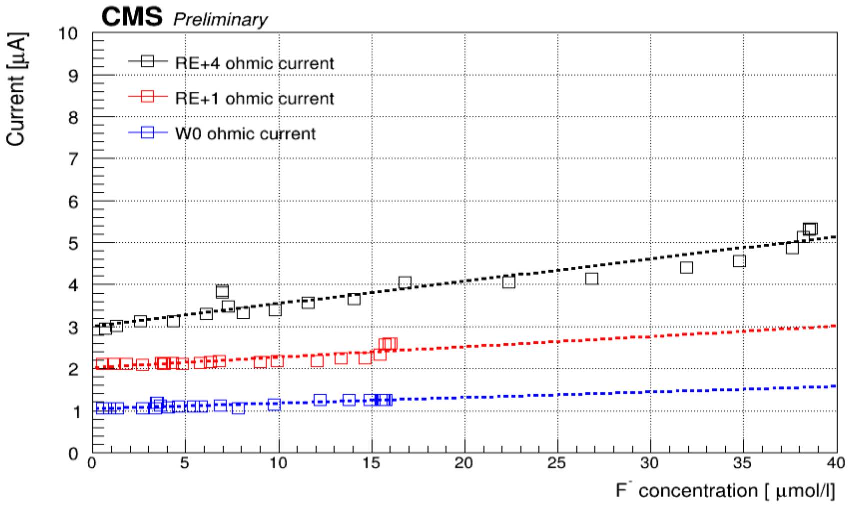


Physics current is stable and not affected by the ohmic current increase.

HF & Ohmic Currents @ CMS

- RPC gas mixture is manly composed of F-gas. The decomposition of F-gas under electrical disharge produces Fluorine ions (F^-) which can produce HF.
- Both the ohmic current and the HF concentration have a linear correlation with respect to the integrated luminosity.

→ HF studies done I collaboration with CERN EP DT gas group



- The ohmic current and the HF concentration are linearly dependent
- W0 & RE+1: lower background → lower HF production → lower ohmic current increase
- RE+4: higher background → higher HF production → higher ohmic current increase

HF trapped in the gap may form a thin conductive layer that increase the ohmic current → it is necessary to fine tune the gas flow as a function of the background rate so that the HF is efficiently removed

→ Full details of Hf analysis at CMS and GIF++ can be found in Roberto's talk "Gas mixture quality studies for the CMS RPC detectors during LHC Run 2"

Conclusion

- After ~ 9 years of operation **(~ 185 fb-1**) and operating successfully in extreme conditions (8 TeV & 13 TeV & L ~ 2 x 10^{34} $cm^{-2}s^{-1}$) during RUN-1 & RUN-2, RPC performance is stable and fulfill the requirements for the trigger and reconstruction capabilities necessary for the CMS physics program.

  - **Average efficiency ~ 96%**
  - **Average cluster size ~ 2 strips**

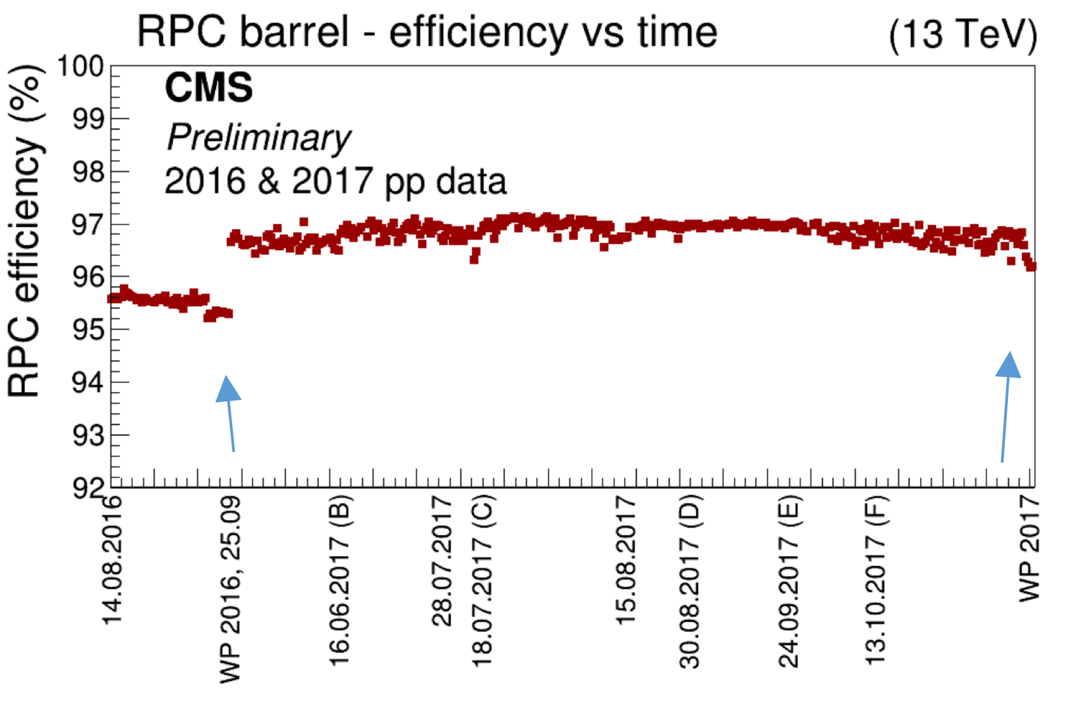
- A reversible **ohmic current** increase was observed in the most exposed regions. Fine tuning of the gas is mandatory.

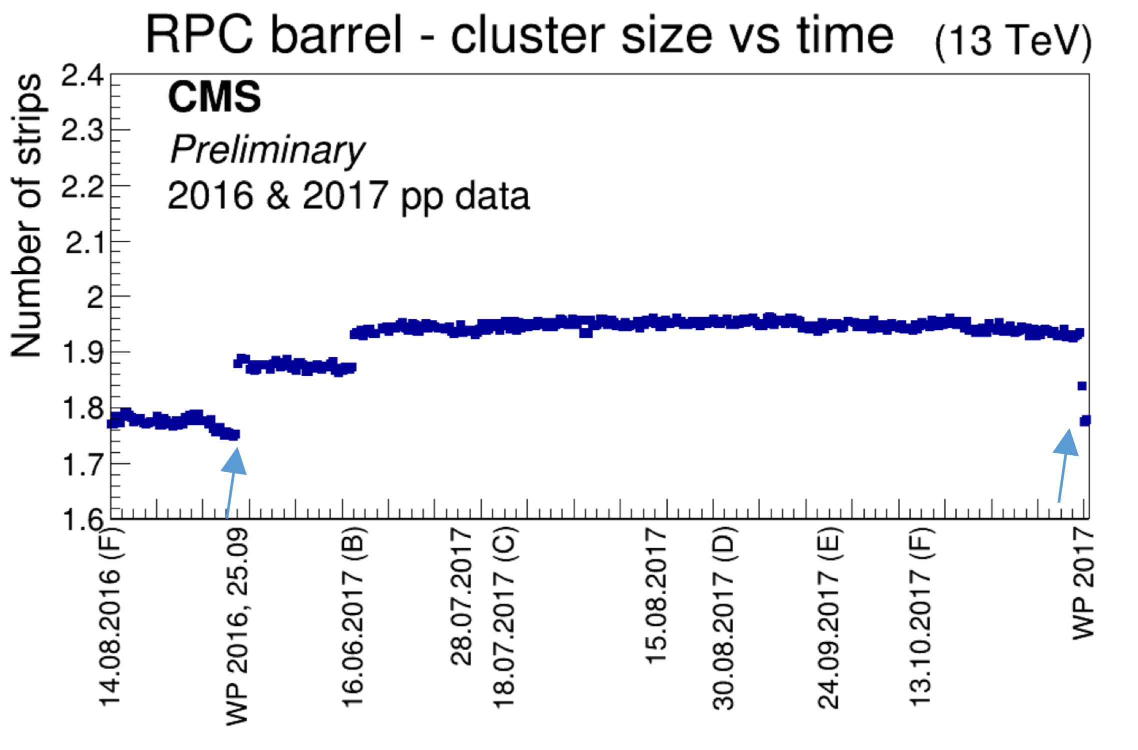
- No degradation has been observed to participate in the hadron collisions of **LHC Run-3.**


BONUS
slides

RPC Performance During 2016/2017

After years of LHC collisions, very stable performance

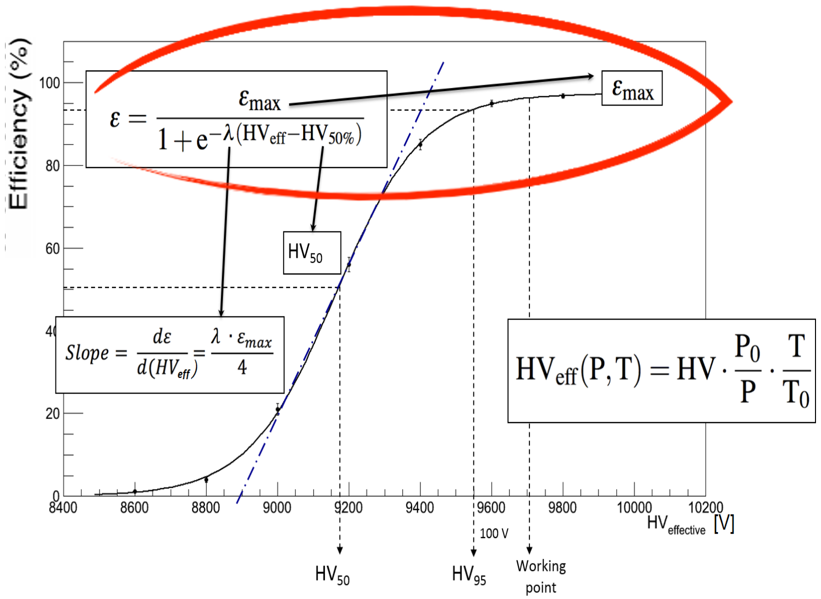




RPC efficiency and cluster size history for the barrel in 2016 and 2017 is shown on the plots. In 2016 because of higher isobutane concentration (5.3%), efficiency was lower as the WPs were not changed to compensate the wrong gas mixture. After the deployment of the new HV working points in September 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.

HV Calibration Scan Parameters

RPC ENDCAP WP, Efficiency and HV50 history



Efficiency vs **HV** with different isobutane concentration in 2016 and 2017.