Detector performance and stability of the CMS RPC system during Run-2

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On behalf of the CMS collaboration

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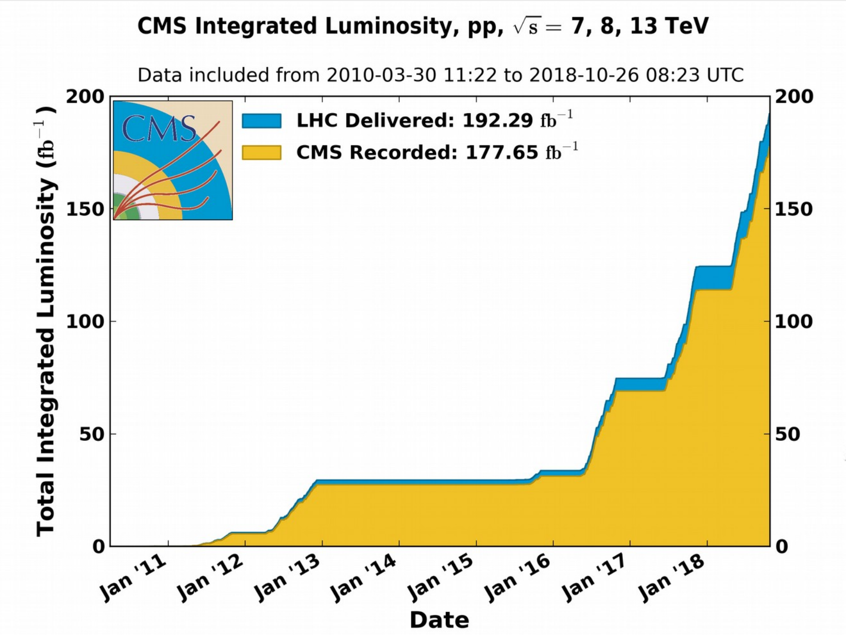
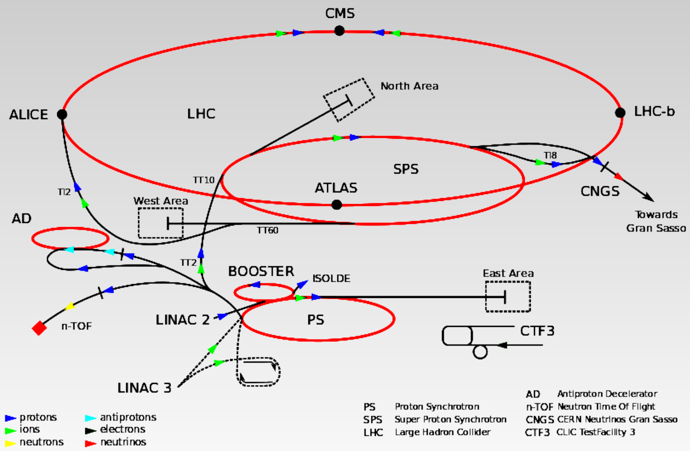
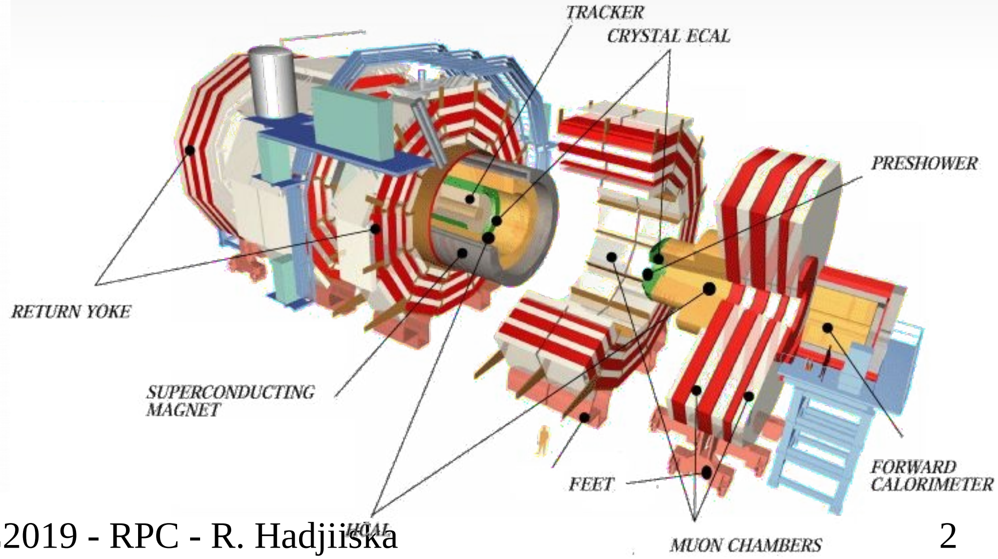
Run-2 of LHC (2015 - 2018)
$\sqrt{s}$ = 13 TeV
Inst. luminosity ~ 10^{34} $cm^{-2}s^{-1}$
Integrated luminosity (Run-1 and Run-2) - 177.65 fb^{-1}



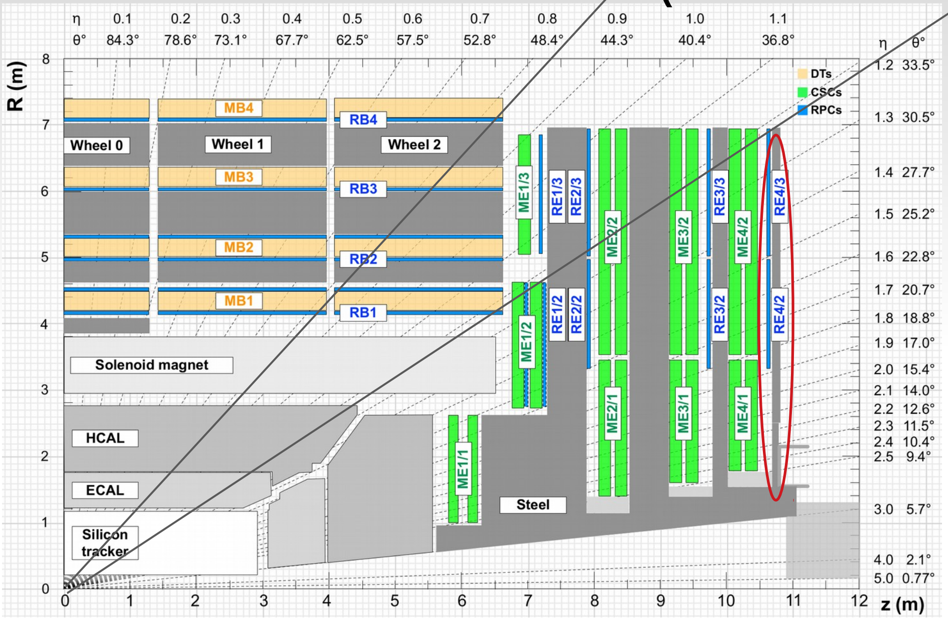




CMS Muon System during Run2 and the place of RPCs

Barrel MTF (DT & RPC)

Overlap MTF (DT & RPC & CSC)



Endcap MTF (RPC & CSC)

η = -ln tg(θ/2);
θ - polar angle;
z – along the beam line;
φ – azimuthal angle in the plane (x, y)

CMS quadrant plot:

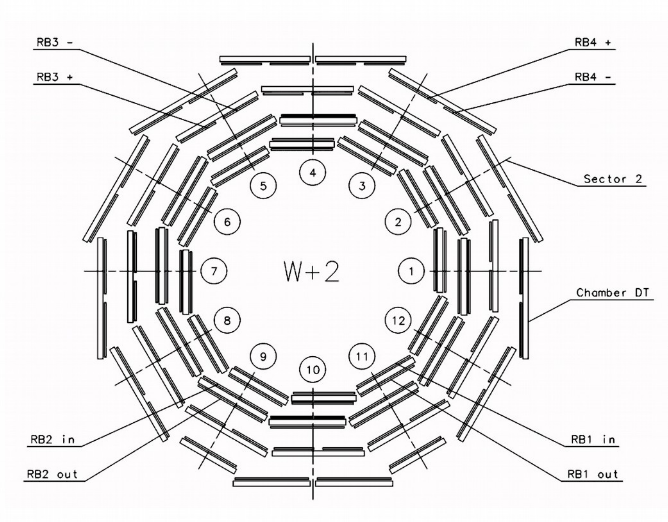
3 different gaseous detector technologies
- **Drift Tubes (DT)**
- **Cathode Strip Chambers (CSC)**
- **Resistive Plate Chambers (RPC)**

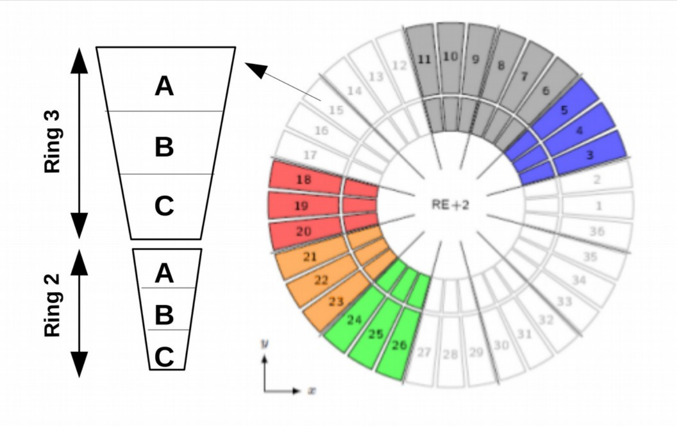
4 stations in the central barrel part
- **6 RPC layers – 2 layers on the 1st and 2nd stations**

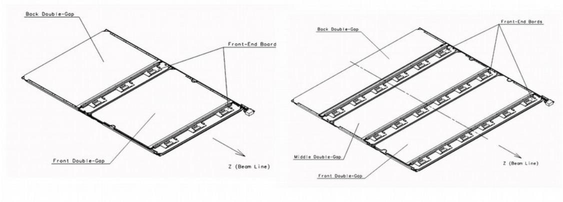
4 stations in every of the endcap parts
- **4th RPC stations installed during the LS1 in order to enhance the trigger performance**

L1 trigger upgrade in Run 2
- **RPCs contributing to three different L1 muon trigger sections and track finders**

CMS Muon System during Run2 and the place of RPCs







φ
12 sectors in every barrel wheel – every sector covers 30º
36 chambers on the 2nd and 3rd ring of every endcap station – every chamber covers 10º;

η
Barrel RPCs are subdivided in 2 or 3 η partitions, called rolls
- **Every barrel roll is connected to one link board**

Endcap RPCs are subdivided in 3 η partitions
- **The three rolls are connected to only one link board**

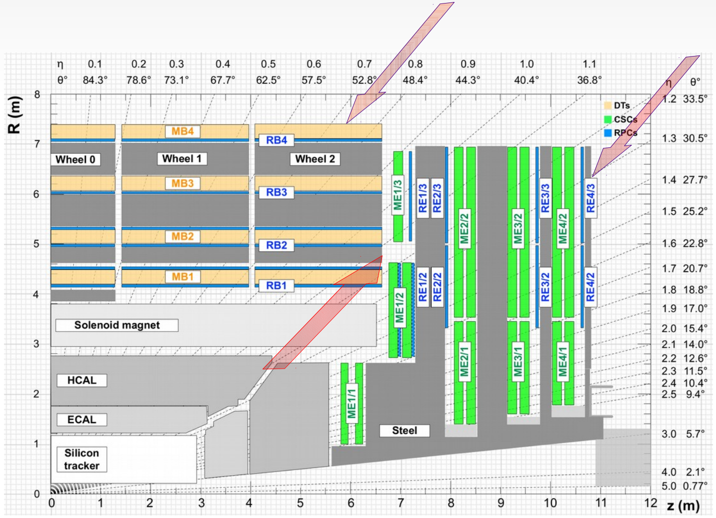
RPC – operating in harsh radiation conditions

RPC hit rates measurements – Link Board counts integrated over the run and normalized to the run duration time and active area of the strips.

- **Three main contributions:**
  - **hits from collisions**
  - **hits, caused by the radiation background**
  - **cosmics and fake hits caused by the electronics**
- **Main contribution is from the background particles**

Two main components of the background:

- **from collision and radiation leak from the HCAL gap - Affects mainly the first station of external barrel wheels**
- **neutron induced background from the cavern - Affects mainly the outermost endcap stations and the chambers from the 4th barrel station**

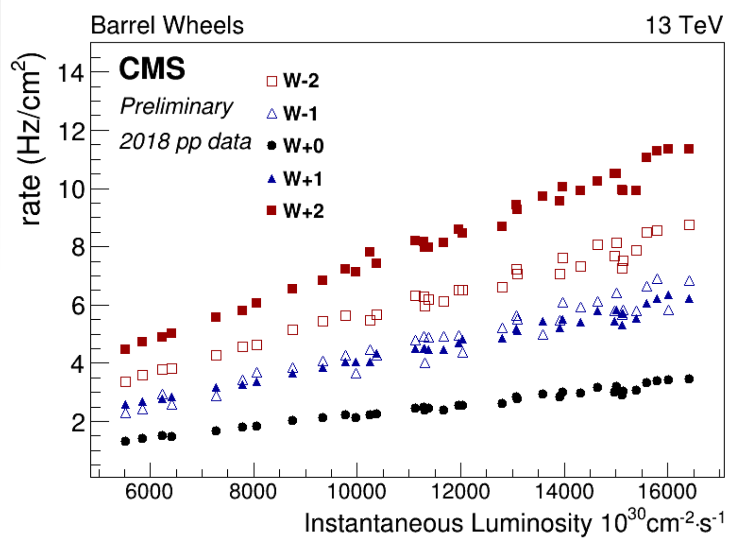


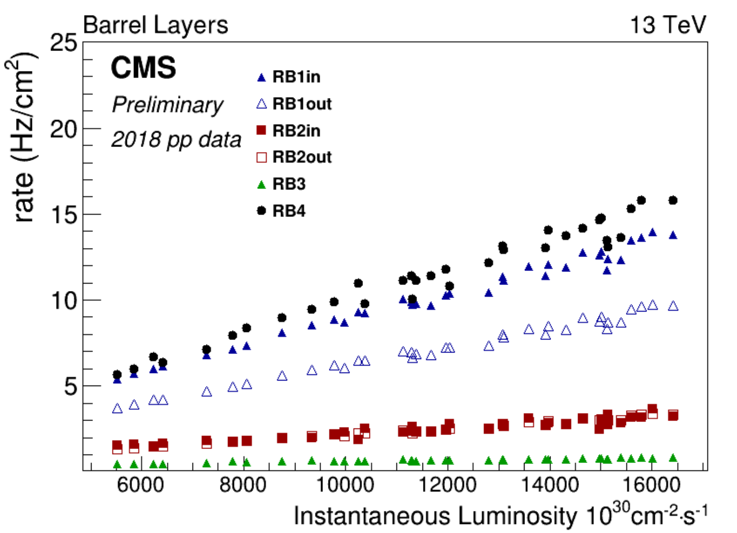
RPC – single hit rate - Barrel

Linear dependence on the instantaneous luminosity – already known from previous studies

Though the slopes may depend on the run conditions – pileup events, number of colliding bunches, LHC bunch crossing schema etc.

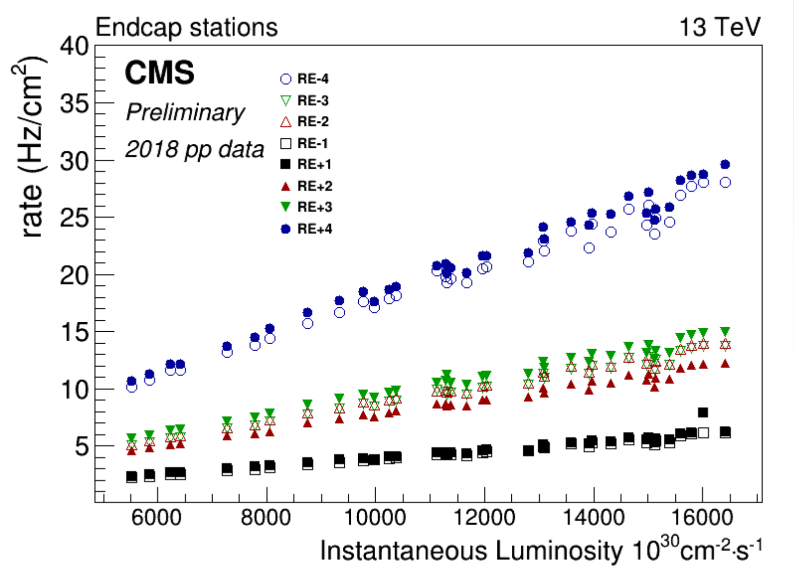
Linear dependence is kept within particular LHC fills

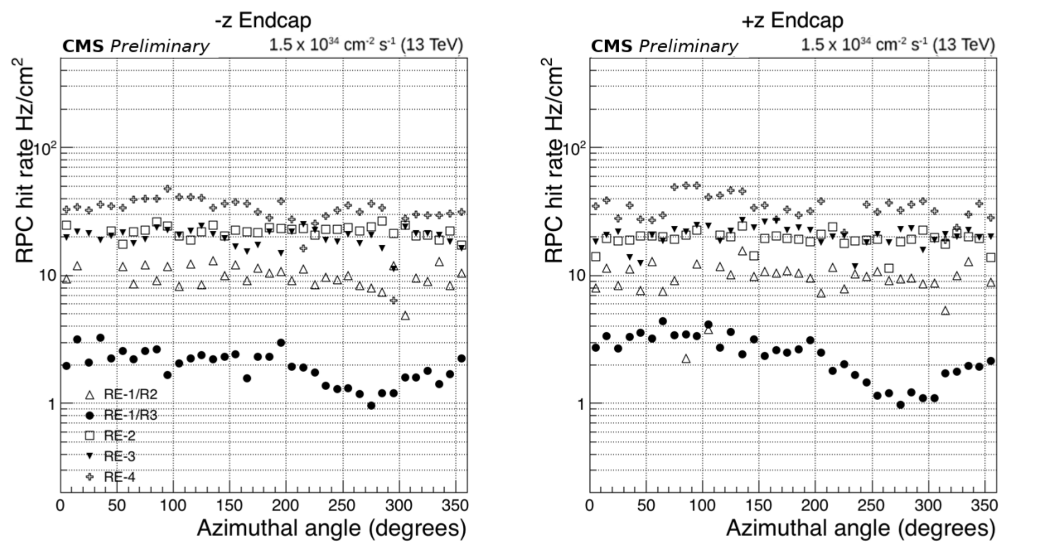




RPC hit rate as a function of the instantaneous luminosity, measured in proton-proton collision runs in 2018. Plot on the left, represents five barrel wheels (at different Z positions along the beam pipe). Highest rate is measured for the outermost wheels W+2 and W-2. Plot on the right represents barrel layers (different radii with respect to the beam pipe), where RB1in is at clossest one to the collisions. Highest rates are measured in RB4 (caused by the cavern background) and RB1 (caused by the collisions)

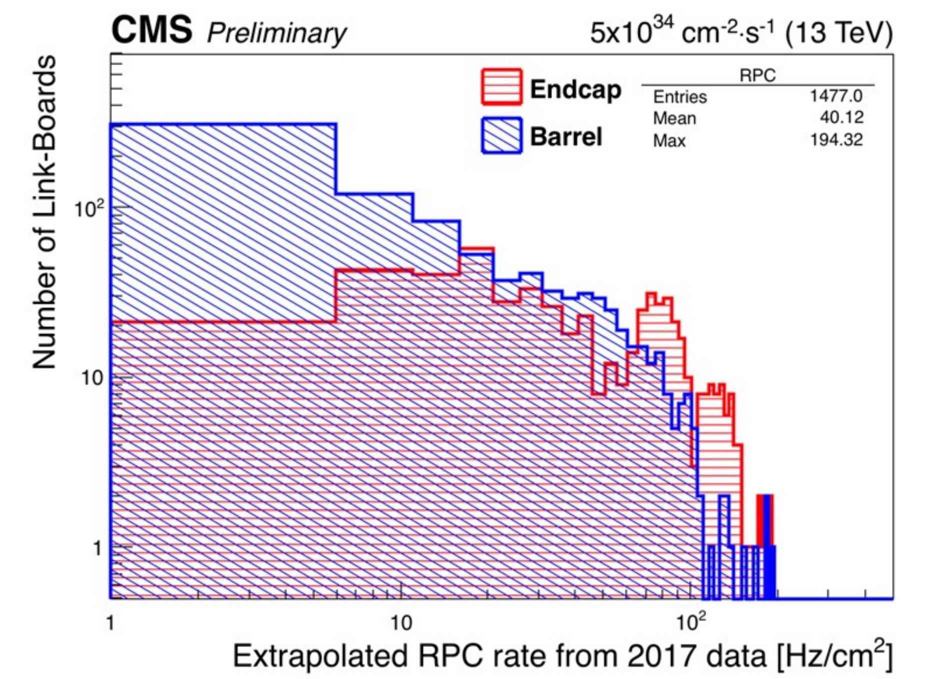
RPC – single hit rate - Endcap





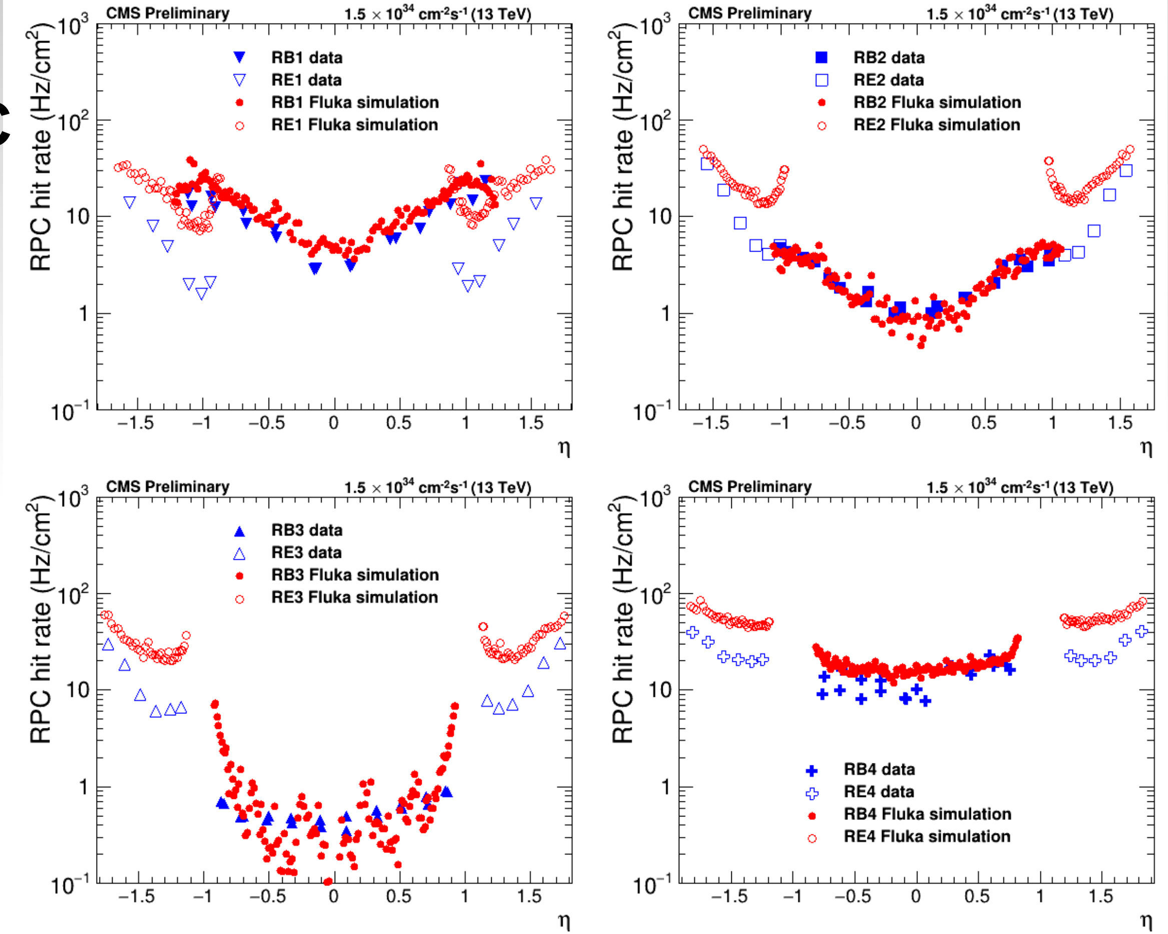
RPC hit rate as a function of the instantaneous luminosity, measured in proton-proton collision runs in 2018. Plot on the left, represents endcap stations (at different Z positions along the beam pipe). Highest rate is measured for the outermost 4th stations – RE+4 and RE-4, caused by the cavern background.
The two plots on the right represent rate measured in the edncap stations as a function of φ at fixed instantaneous luminosity. A clear asymmetry is obvious. Highest rate is measured in the top sectors (~ 90^{o}), caused by the radiation leak from the gap in the rotating shielding of the beam pipe on the entrance of it in the cavern.

RPC single hit rate – predictions to HL-LHC



Linear dependence on the instantaneous luminosity has been used to extrapolate the RPC rates to the HL-LHC conditions and luminosity of $5x10^{34}$ $cm^{-2}s^{-1}$.
The highest expected rate is ~ 200 Hz/cm^2.

RPC hits vs η and comparison to MC



The plots represent a comparison between the experimentally measured RPC hit rates (in blue) and the rates predicted by FLUKA (in red). The full markers correspond to the barrel part, while the empty ones - to the endcap. The plots show a good agreement between the experimentally obtained results and MC predicted ones.

RPC Performance – main objects and quantities

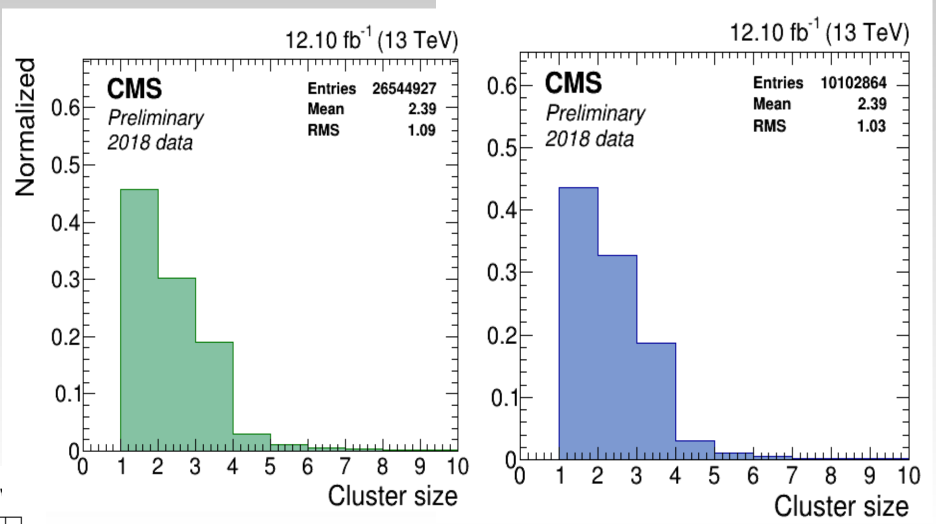
- CMS RPCs: Double gap design with a common readout of 32 – 92 strips per roll depending on the chamber position
- Cluster size – number of adjacent fired strips - Clusters are output of the local reconstruction and are associated to the so called RPC rechits (reconstructed hits).
  - Average cluster size is ~2 strips and depends on the strip pitch. Spatial resolution is around 1 cm.
  - Having two RPC layers in the 1st and 2nd barrel stations allows to build RPC segments and thus to improve bending angle evaluation

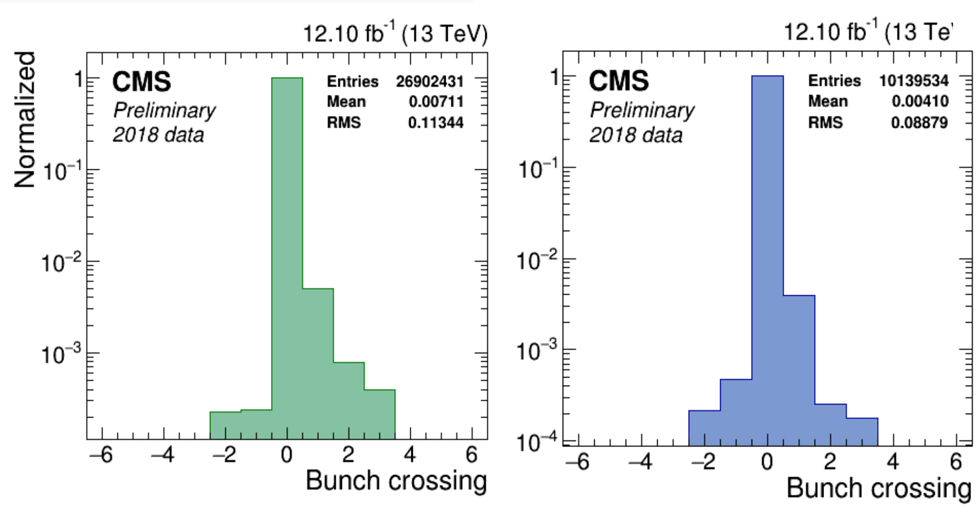
- Hit registration efficiency - two main methods used in Run1 and Run2
  - Segment extrapolation method – segments from the nearest DT or CSC chambers are extrapolated to the RPC. Extrapolated points are matched to the RPC hits in a close area of +- 4 strips.
    - The method was in use during Run1 and Run2 and it is main method used for RPC HV working point calibrations
  - Tag & Probe (T&P) method – explores two independent muon Id algorithms – Tracker muon (Tracker track, tagged by the DT/CSC segments) and RPCMuon (Tracker track tagged to the RPC hit). The muons from the two samples have been checked to pass the criteria and form Z->μμ resonance
    - The method was accepted as a main one in the end of Run2

- Time resolution ~2ns, however it is limited by the 25ns time window of the readout electronics – BX association of the measured hits and clusters.

Cluster size and BX association

Average cluster size (CLS) for RPC rechits is kept ~2. The plot on the left represents barrel, while the one on the right – endcap.

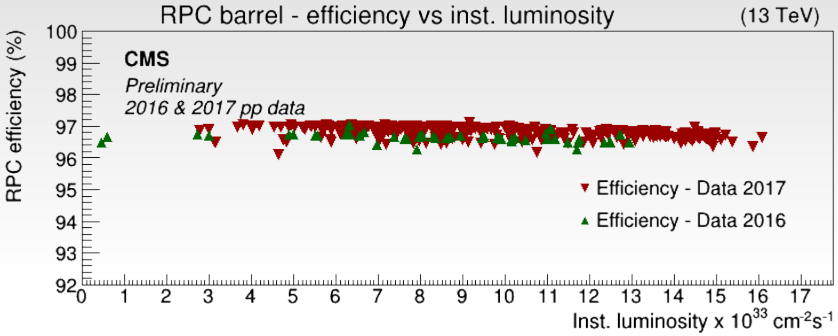


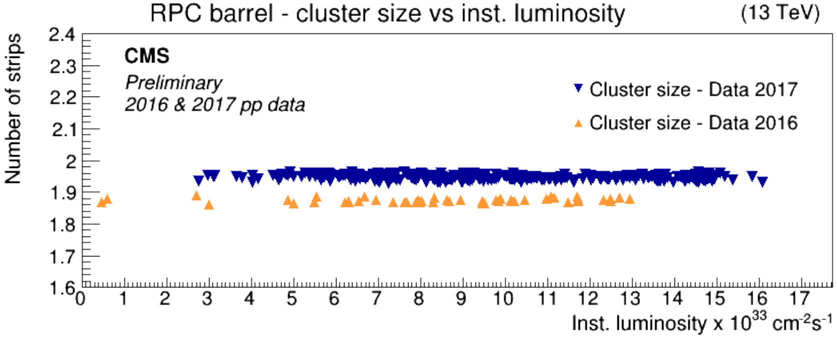


RPC BX distributions for the rechits from muons. Y axis id given in a logarithmic scale. More than 99% of muons hits are associated in the central BX window. The left plot represents barrel, while the on eon the right – endcap.

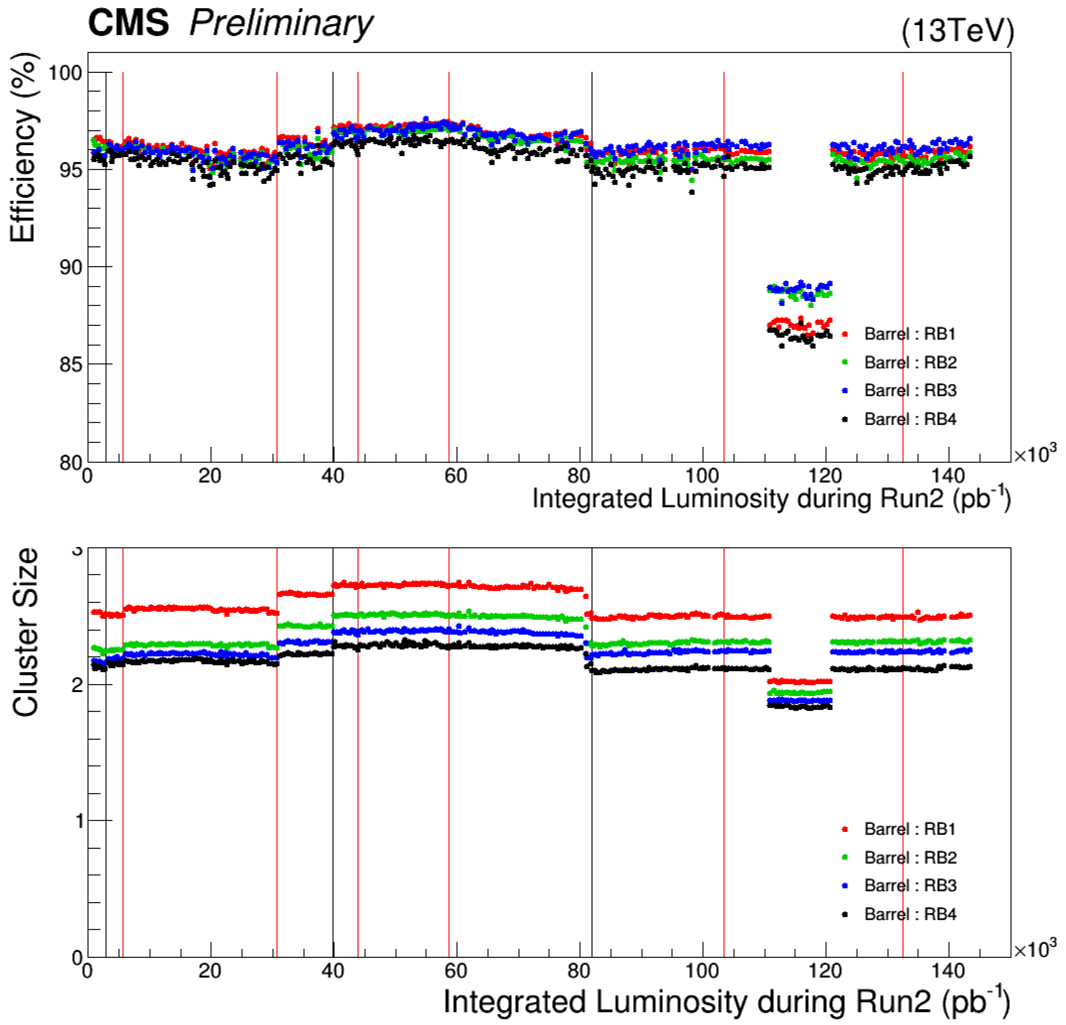
Isobutane concetration and HV WP

CMS RPC – Working gas mixture: 95,2% $C_2H_2F_4$(Freon), 4,5% iC_4H_{10} (Isobutane), 0,3 % SF_6





- *Higher Isobutane concentration in 2016 because of the problem with mass flow controller*
- *HV working points (WP) were not changed to compensate the wrong gas mixture.*
- *After the deployment of the new WP 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*
- *The efficiency of the system remained unchanged (running in the plateau of the sigmoid curve), however a new increase of the cluster size have been observed.*
- *New WP have been deployed by end of 2017, which lead to a slight decrease of the efficiency but sensible reduction of the cluster size*



RPC efficiency and cluster size history vs integrated luminosity for the four barrel stations:

The plots represent Run-2 history. (Run-1 integrated luminosity is 27 fb-1). Each point corresponds to an average efficiency or cluster size per station in a given LHC fill.

The x-axis shows the integrated luminosity a date and the y-axis - average efficiency or cluster size for the detector part under study.

Red lines are the planned technical stops (TS) and the grey ones - year end technical stops (YETS).

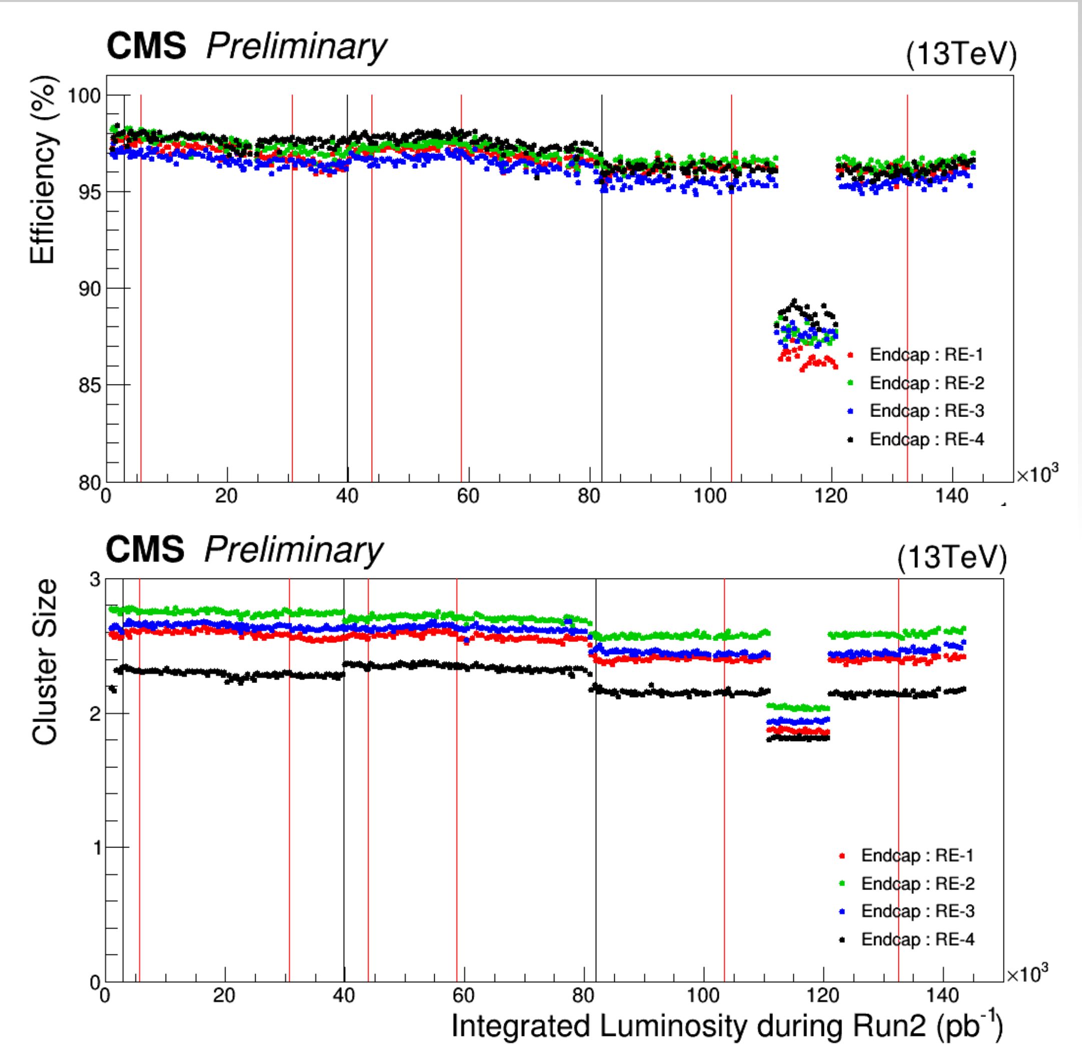
The trend of the curves follows the changes of the applied high voltage working points and changes of the Isobutane concentration in the working gas mixture. The drop of the efficiency during 01. Aug. 2018 - 19. Aug.2018 is caused by a known configuration setting problem.

RPC efficiency and cluster size history vs integrated luminosity for the four stations in the negative endcap:

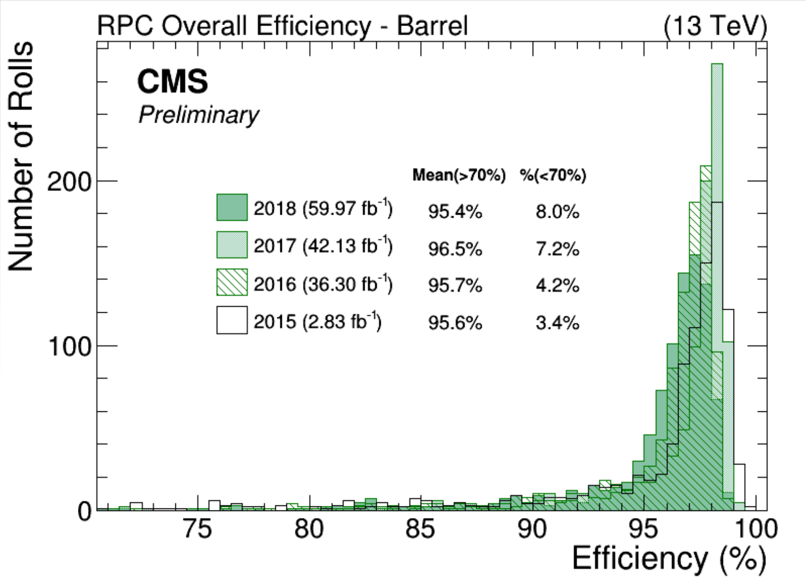
The plots represent Run-2 history. (Run-1 integrated luminosity is 27 fb-1). Each point corresponds to an average efficiency or cluster size per station in a given LHC fill.

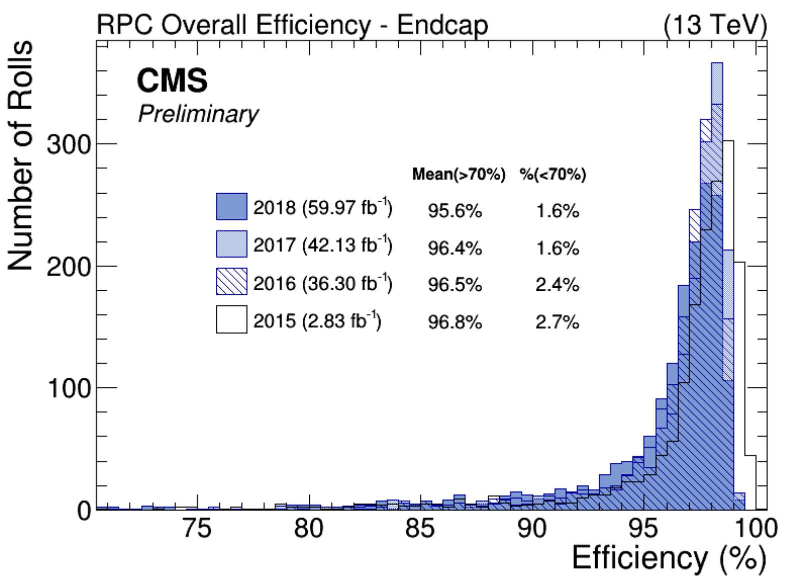
The x-axis shows the integrated luminosity a date and the y-axis - average efficiency or cluster size for the detector part under study. Red lines are the planned technical stops (TS) and the grey ones - year end technical stops (YETS).

The trend of the curves follows the changes of the applied high voltage working points and changes of the Isobutane concentration in the working gas mixture and are well understood. The drop of the efficiency and cluster size during 01. Aug. 2018 - 19. Aug.2018 is caused by a known configuration setting problem



RPC overall efficiency in the years of Run-2





Overall efficiency distribution of RPC rolls during the LHC Run-2 (2015-2018) for barrel (left) and endcap (right) region. The underflow entries are from rolls with efficiency lower than 70%, caused by known hardware problems - threshold control, chambers switched off because of the gas leak problems. The numbers given on the plots show the average efficiency for the well performing and the fraction of the problematic RPC rolls. The RPC efficiencies measured in 2015-2018 are comparable and in agreement with the expectations

Summary

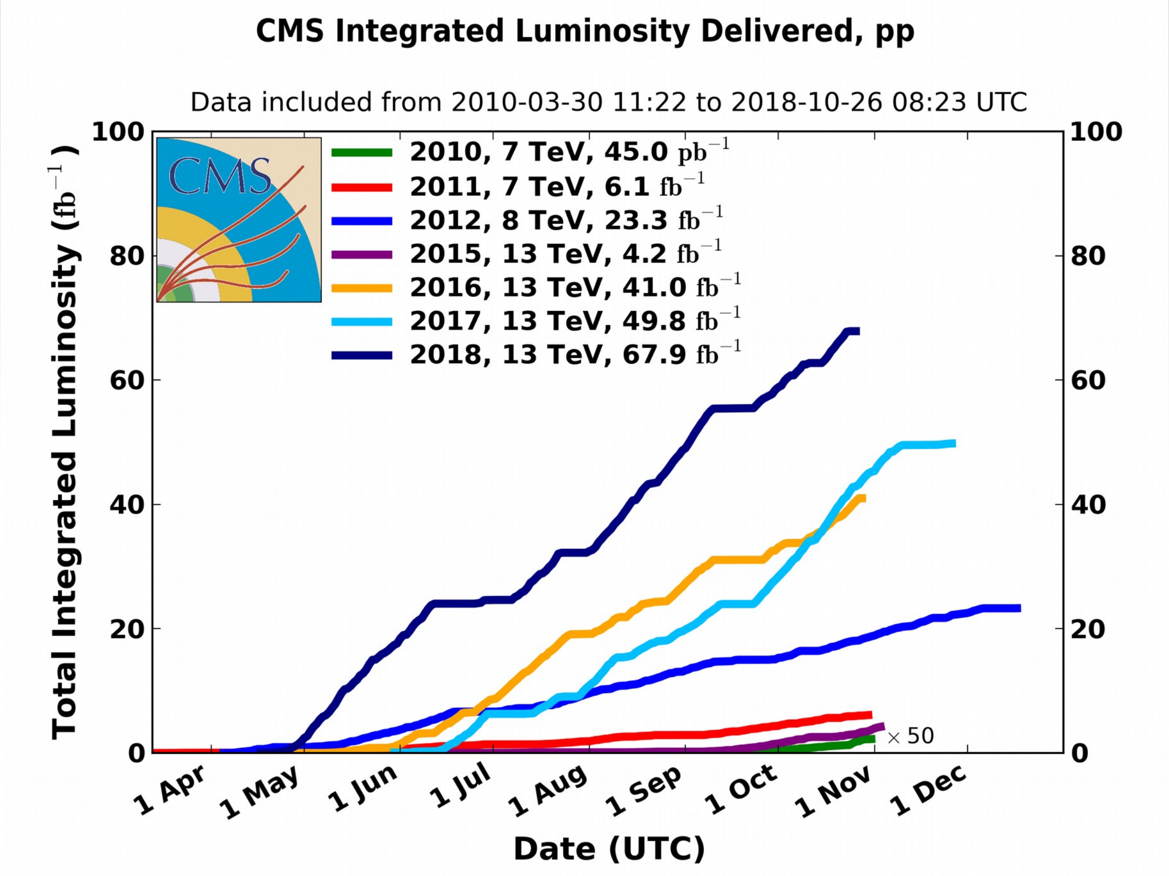
- **Main detector parameters of the CMS RPC system have been studied with proton-proton collision data at $\sqrt{s}$ = 13 TeV and instantaneous luminosity> 1.5×10^{34} $cm^{-2}s^{-1}$ during Run-2 of LHC;**

- **Detector performance is stable, facing the designed requirements**

- **The operational problems were well understood and compensated with the proper calibrations;**

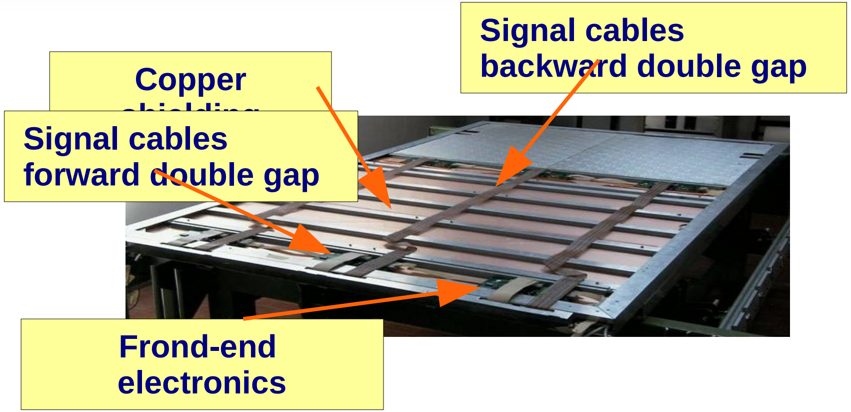
- **Thanks to the stable performance of the RPC system and the entire CMS detector more than 177 fb^{-1} have been collected only during RUN-1 & Run-2, providing valuable data for physics analyses and searches.**

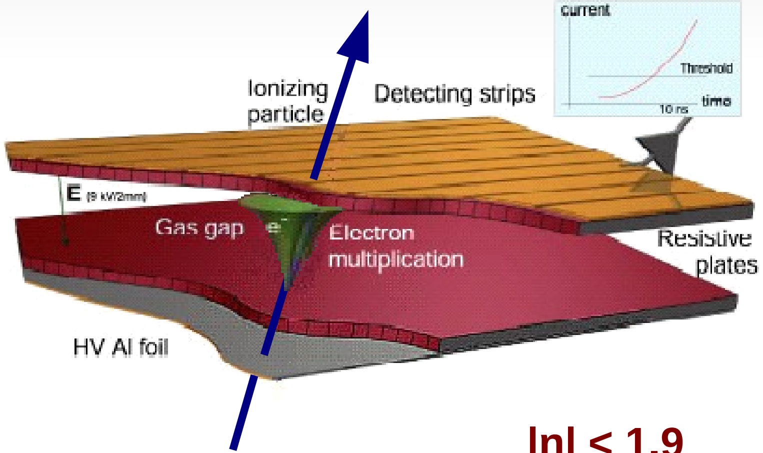
Spare Slides


CMS Integrated Luminosity Delivered, pp
Data included from 2010-03-30 11:22 to 2018-10-26 08:23 UTC
2010, 7 TeV, 45.0 pb^{-1}
2011, 7 TeV, 6.1 fb^{-1}
2012, 8 TeV, 23.3 fb^{-1}
2015, 13 TeV, 4.2 fb^{-1}
2016, 13 TeV, 41.0 fb^{-1}
2017, 13 TeV, 49.8 fb^{-1}
2018, 13 TeV, 67.9 fb^{-1}
CMS
$\times$ 50
Total Integrated Luminosity (fb^{-1})
Date (UTC)
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
0
20
40
60
80
100

Resistive Plate Chambers – RPC

Resistive Plates	Bakelite with bulk resistivity 10^{10} - 10^{11} Ω.cm
Gas gap	2 mm ± 20 μm wide
Gas mixture	95,2% $C_2H_2F_4$(Freon), 4,5 % iC_4H_{10} (Isobutan), 0,3 % SF_6
Insulating PET film	0.3 mm thick
Detecting copper strips	pitch 2.3 – 4.1 cm (barrel); 1.7 – 3.6 cm (endcap)
Avalanche mode	ability to work at a high rate of ionizing particles ~ 1 kHz/cm²
Trigger	time resolution < 2 ns – bunch crossing assignment





|η| < 1.9