Muon Background Studies in RunII and RunIII at the CMS Experiment

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On behalf of the CMS Naples Group

Gruppo1 - INFN@Napoli: Riunione Annuale

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Introduction

- Muons constitute an important signature of new physics and their detection, triggering, reconstruction and identification at CMS experiment is guaranteed by various sub-detectors.

- The quality triggering/identification/reconstruction of muon could be degraded by background particles in the muon system.

- The background rate increases linearly with the Instantaneous Luminosity.

- Understanding and analysing the background is a key point for maintaining robust operation and future upgrade choices.

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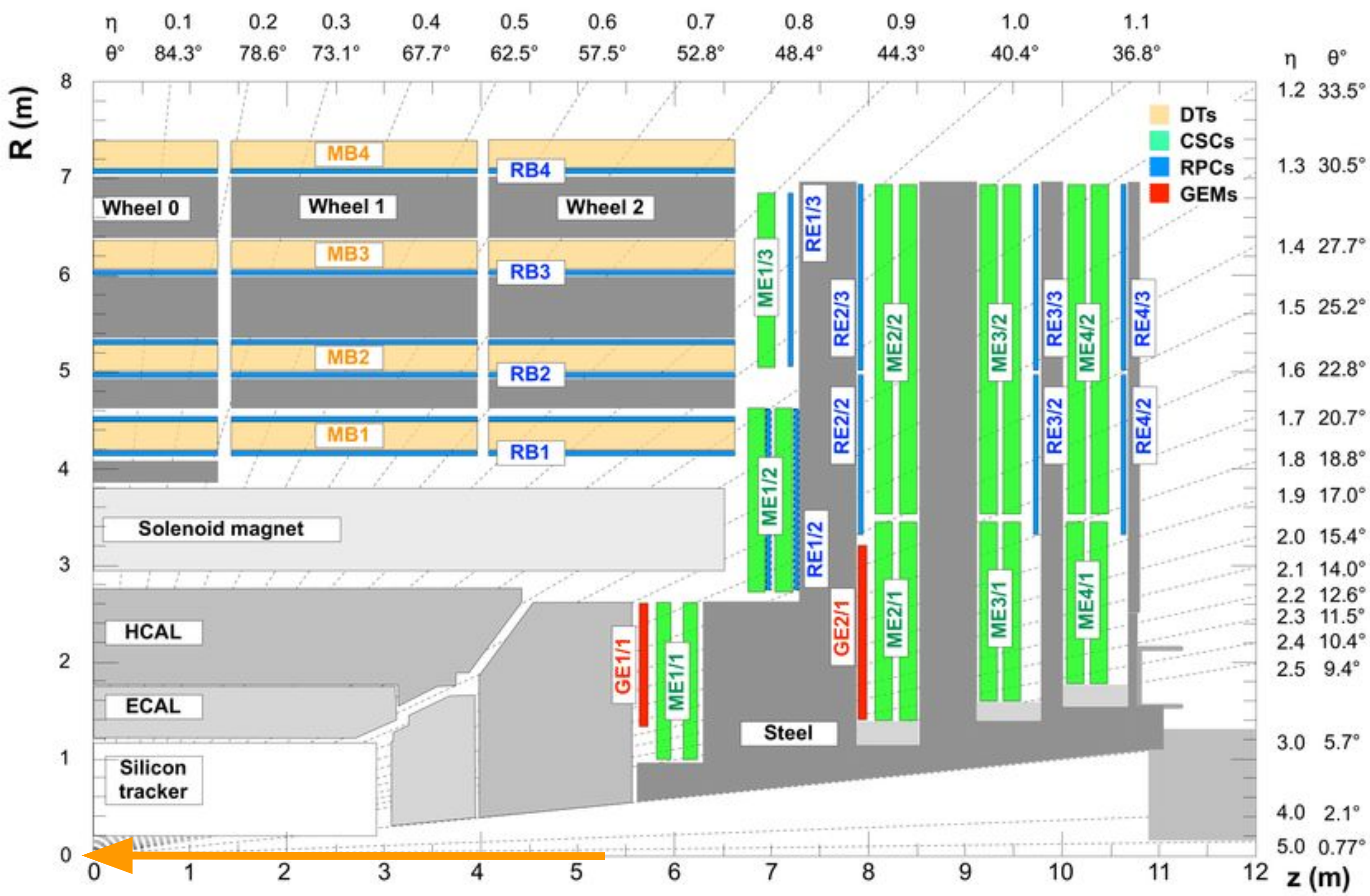
CMS Muon System

The CMS Muon System is made by different sub-detectors:

- Drift Tubes (DT)
- Resistive Plate Chambers (RPC)
- Cathode Strip Chambers (CSC)
- Gas Electron Multiplier (GEM)



Proton beam axis

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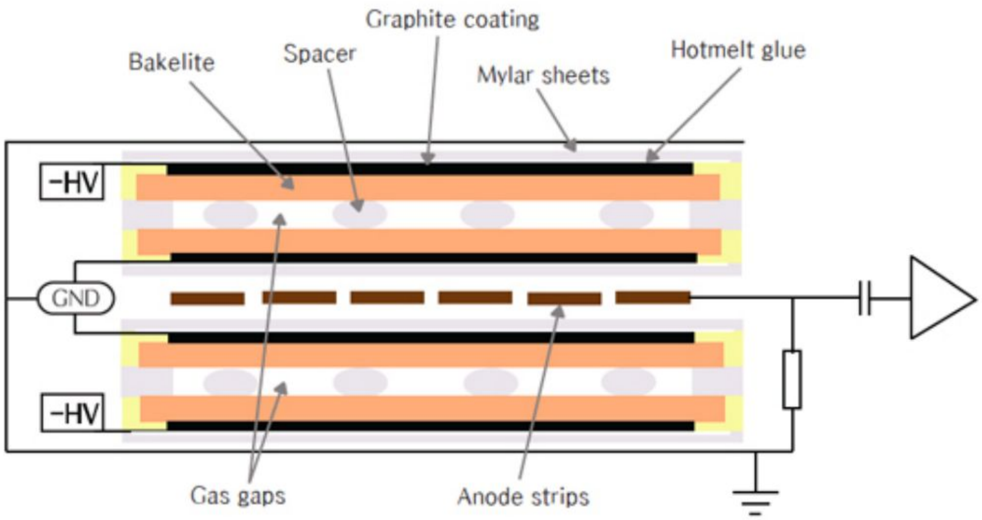
RPC Detectors

- RPC: double-gap chambers operated in avalanche mode, at both the barrel and endcap, very fast response time for trigger.



RB = RPCs in the barrel

RE = RPCs in the Endcap

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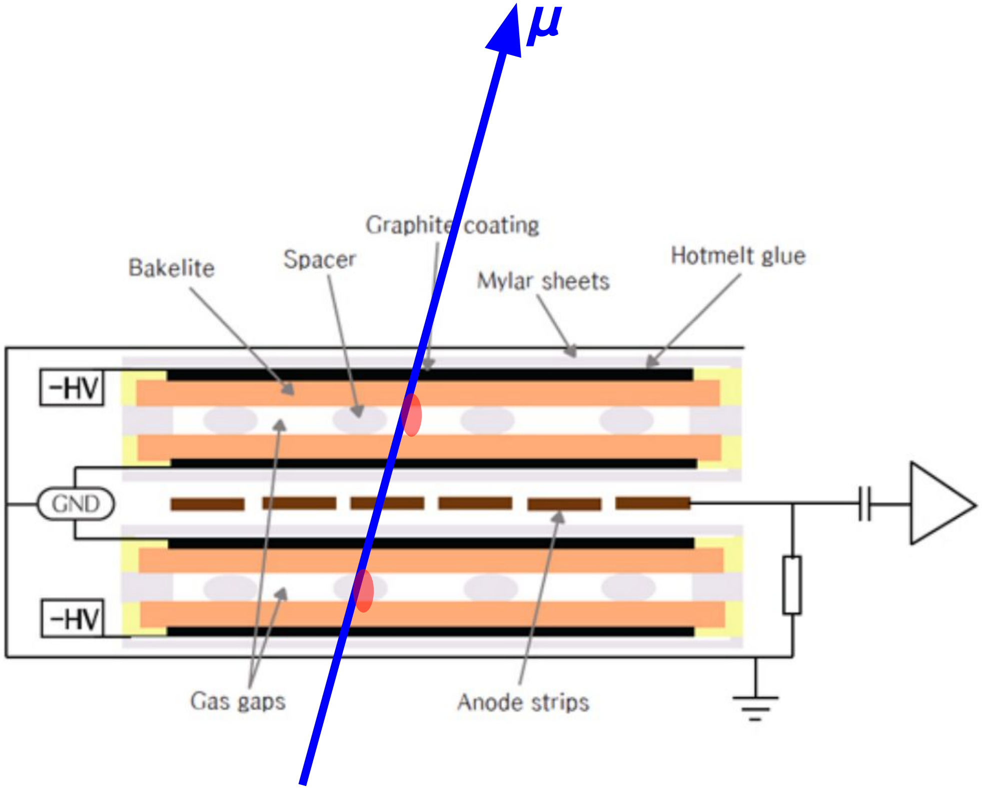
RPC Detectors

- RPC: double-gap chambers operated in avalanche mode, at both the barrel and endcap, very fast response time for trigger.
- When a muon passes through the chamber, electrons are knocked out of the atoms of the gas.
- The electrons hit other atoms causing an avalanche of electrons, these ones are then picked up by the anode strips.



RB = RPCs in the barrel

RE = RPCs in the Endcap

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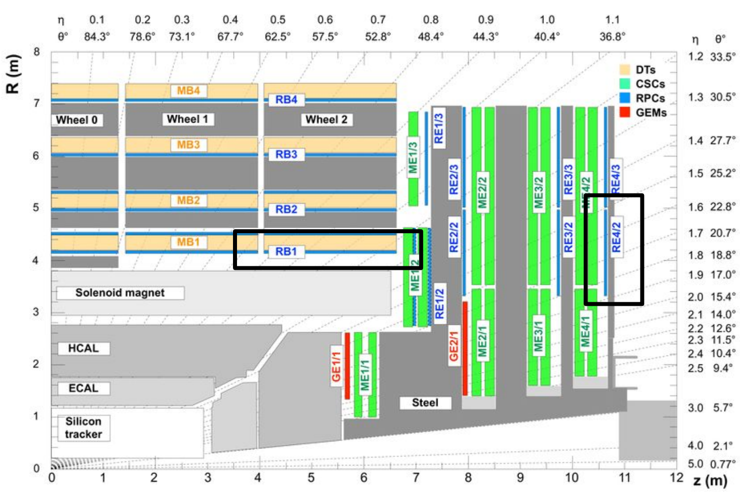
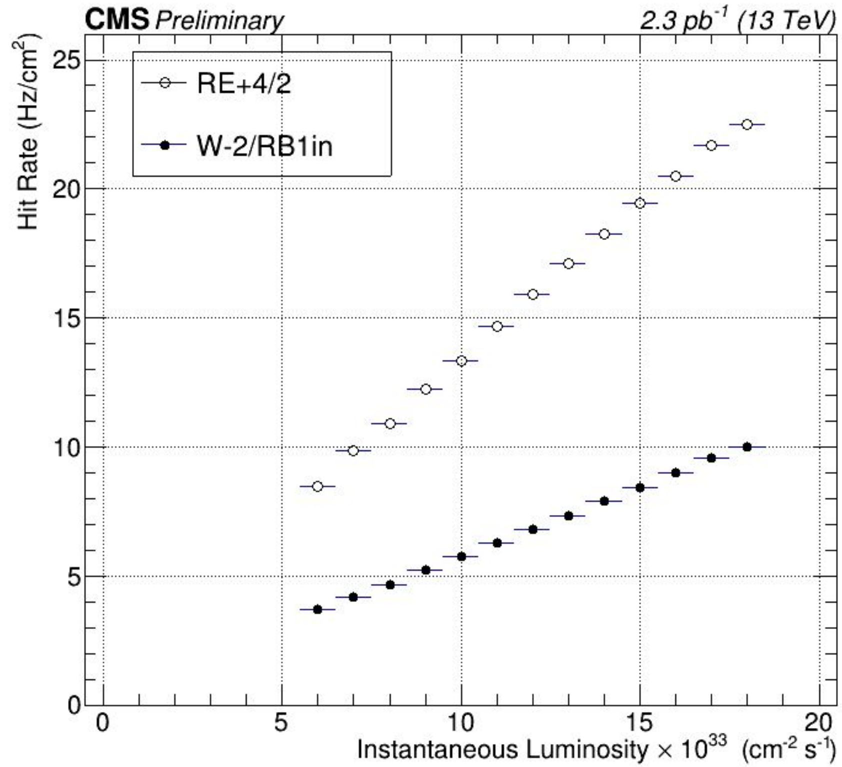
RPC Hit Rate vs Luminosity

- The background Hit Rate as a function of the Instantaneous Luminosity shows a linear trend.

- In this plot two examples for a region in the barrel and in the endcap.



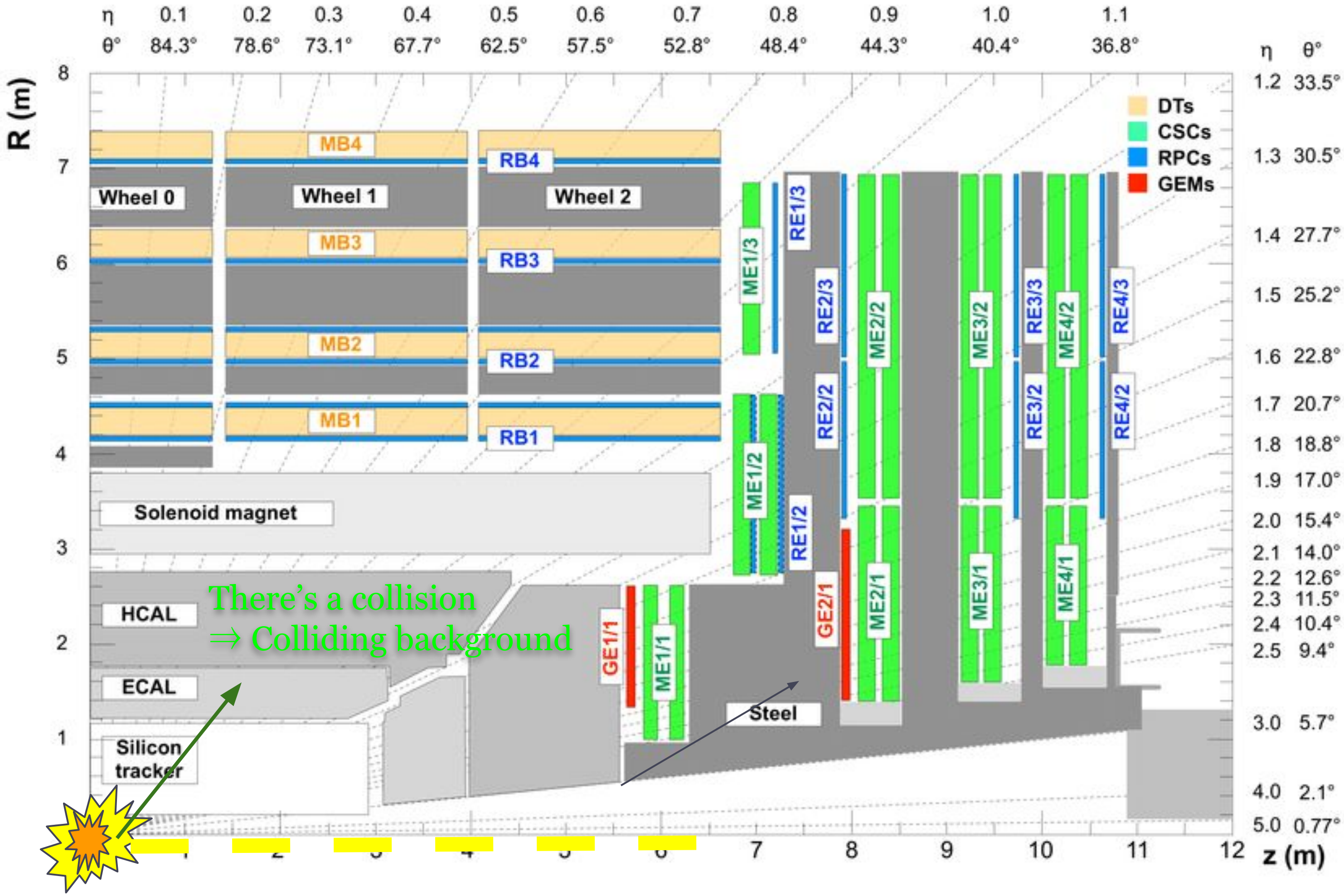


Instantaneous luminosity (L) corresponds to the potential number of collisions per second.

$$L = \frac{N_b^2 n_b f_{rev} \gamma}{4\pi \epsilon \beta^*} F$$

LHC Fill Scheme

LHC proton beams are trains of proton bunches
→ Events are divided depending on whether a “bunch” of protons is passing through the interaction point



Proton train

LHC Fill Scheme

LHC proton beams are trains of proton bunches
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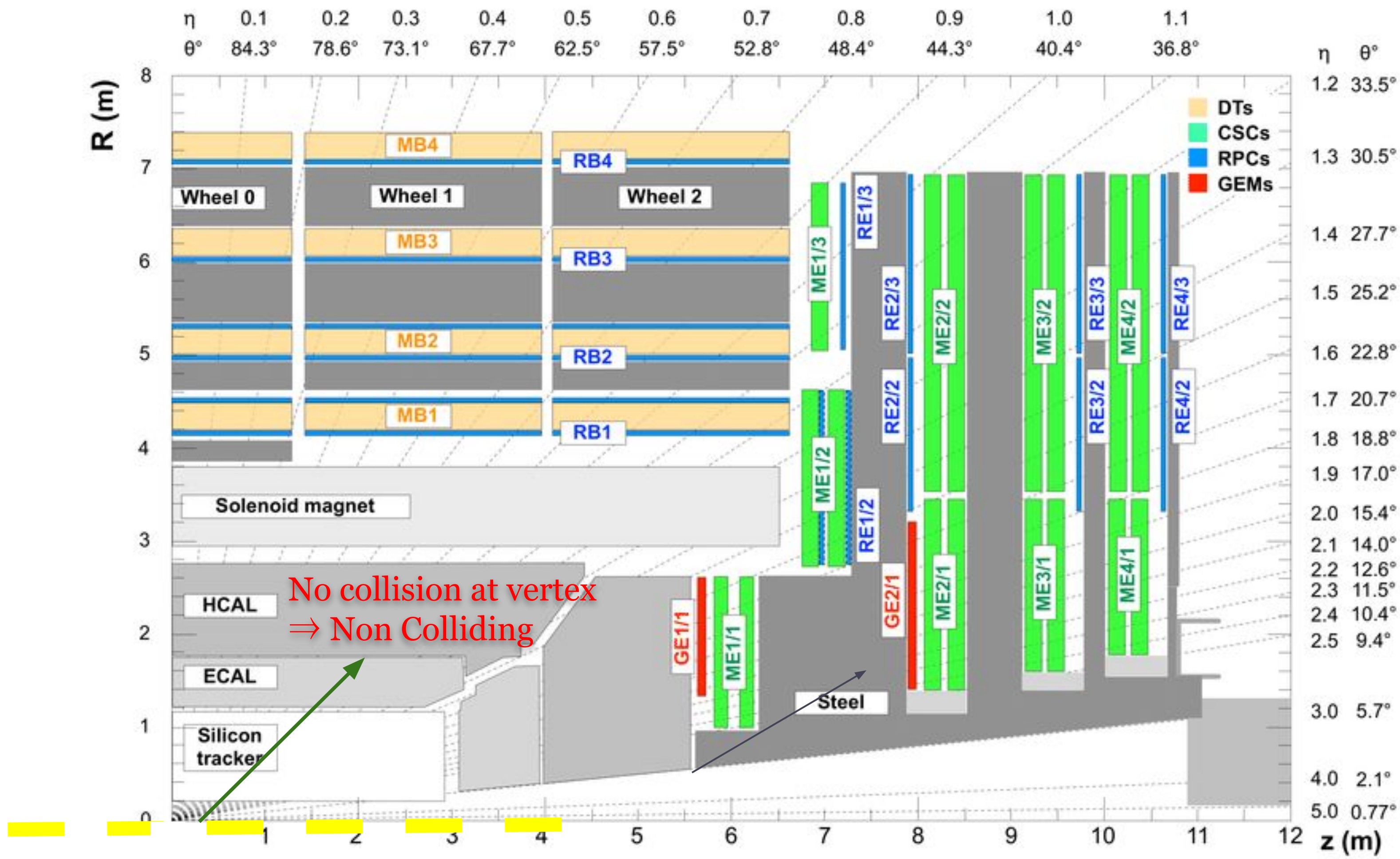

Proton train

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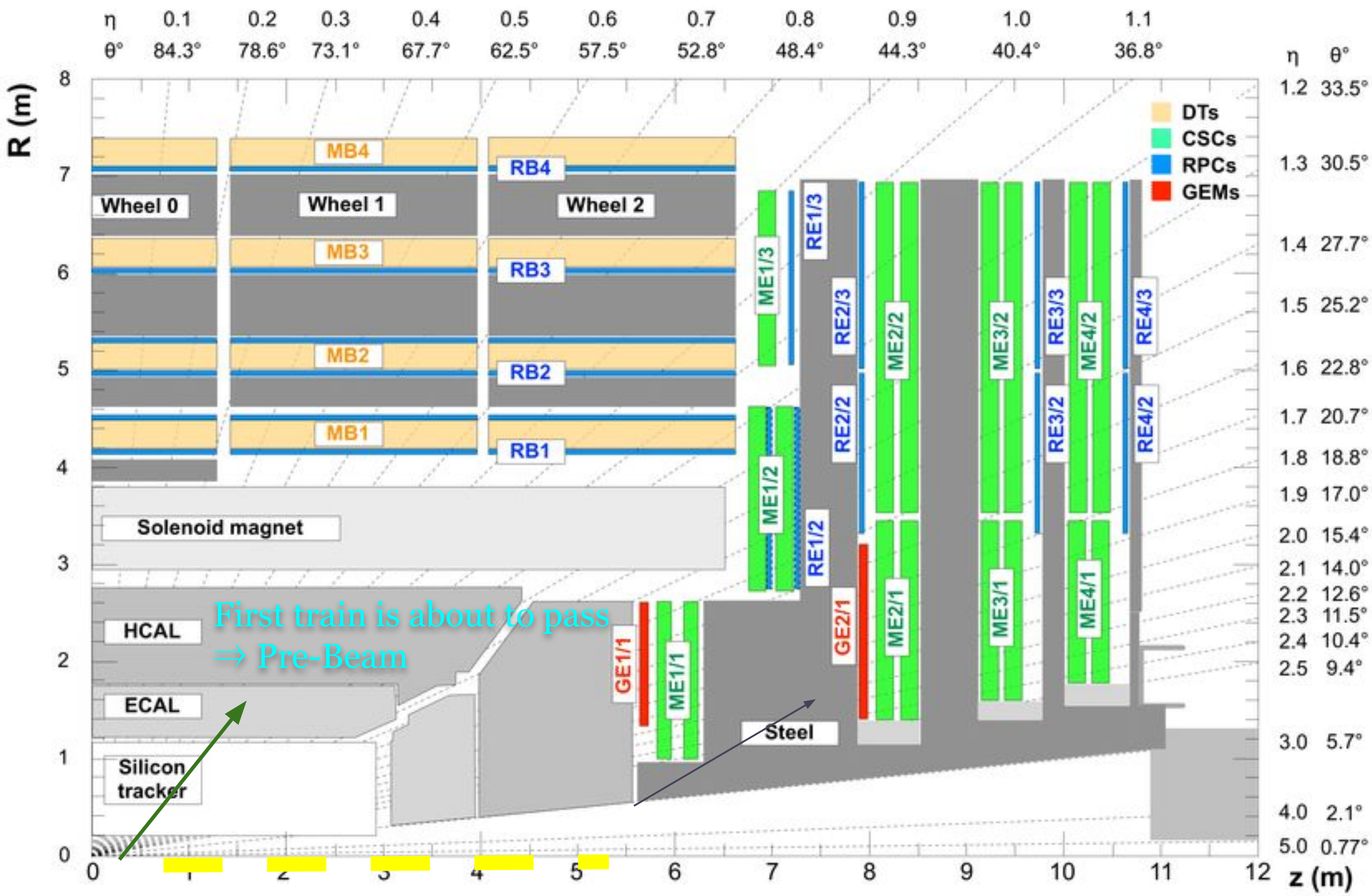

Proton train

LHC Fill Scheme

LHC proton beams are trains of proton bunches
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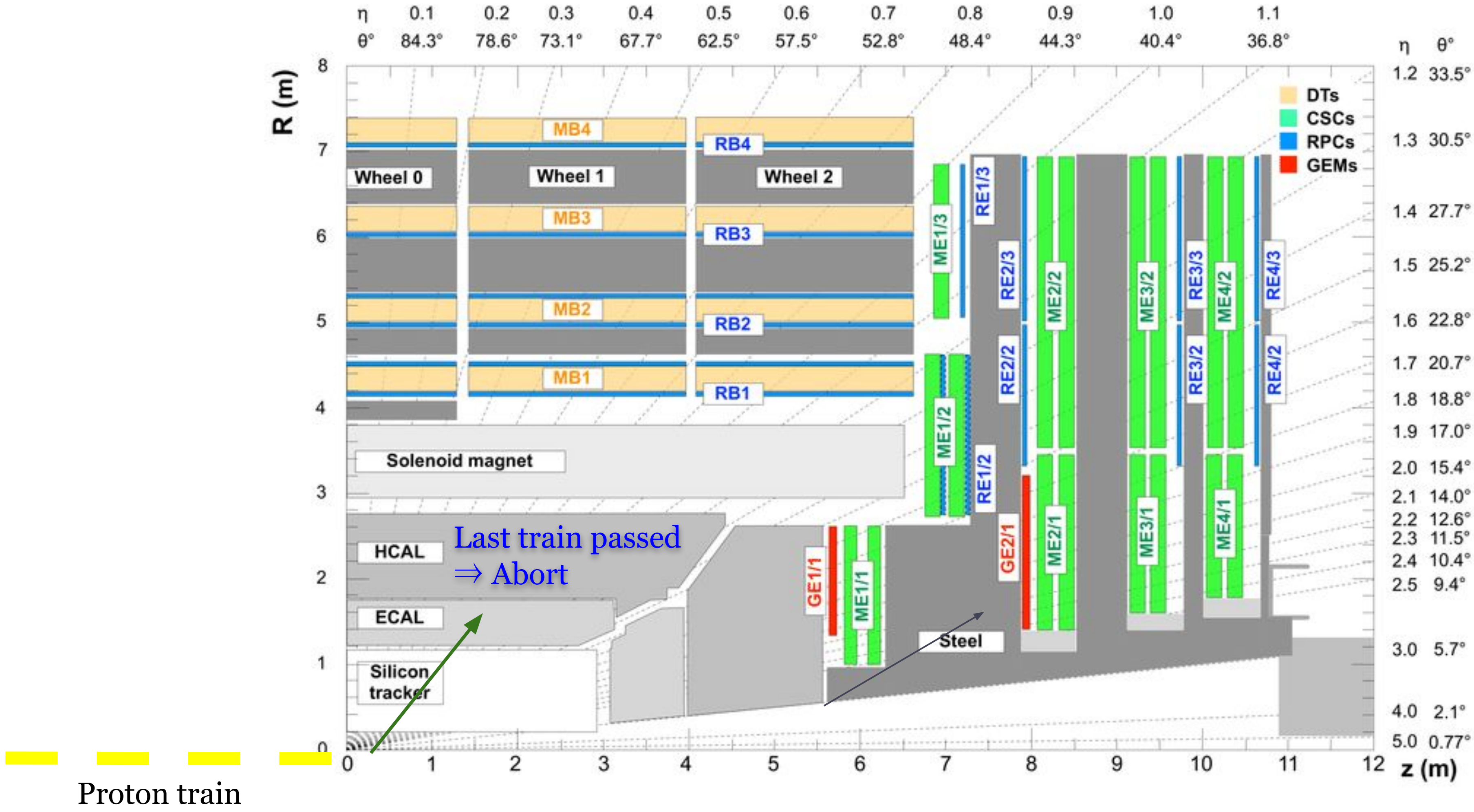

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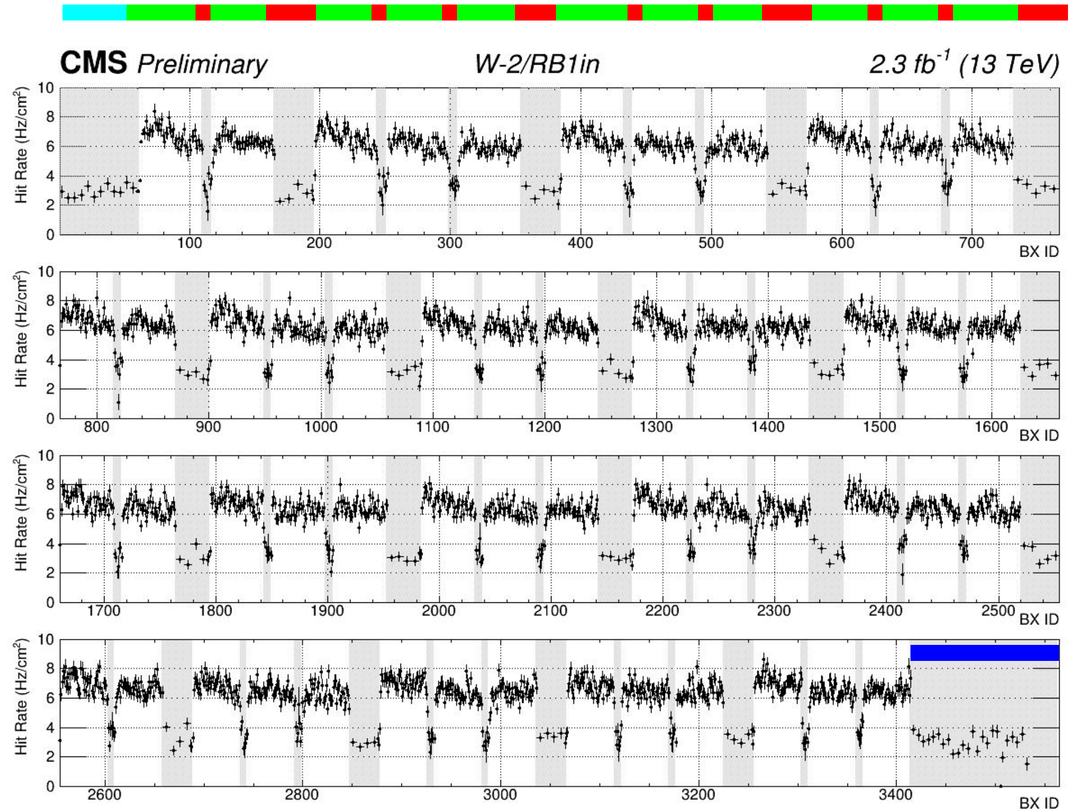
RPC Hit Rate vs BX ID

- Analysed data collected in 2018 with triggers in any bunches in order to estimate slow neutron background in non colliding bunches.

- The background rate is studied separately in Colliding, Non Colliding, PreBeam, and Abort regions.



No collisions

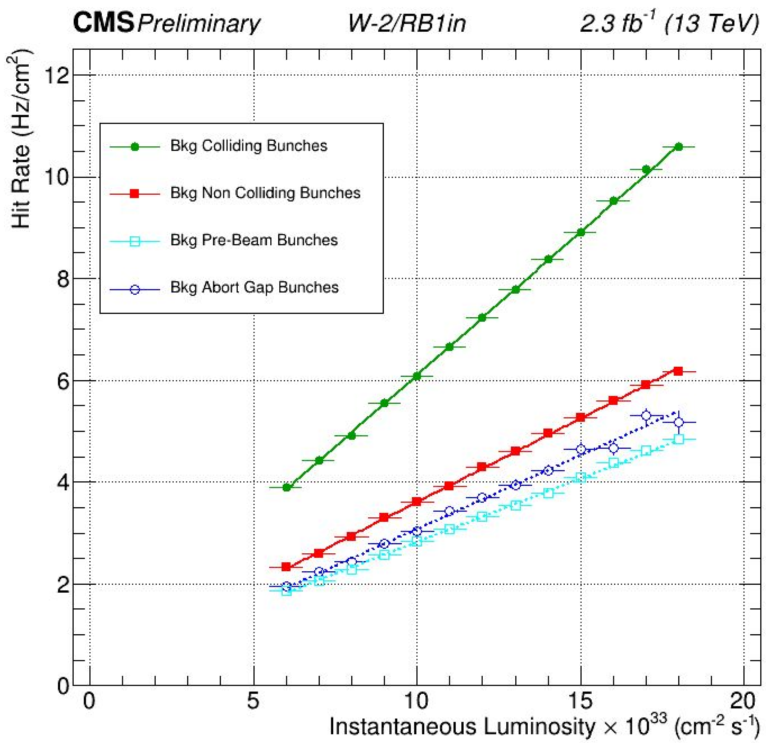
$W-2/RB1in\ Cluster\ Rate\ at\ 10^{34}\ Inst.\ Lumi\ (cm^{-2}s^{-1})$

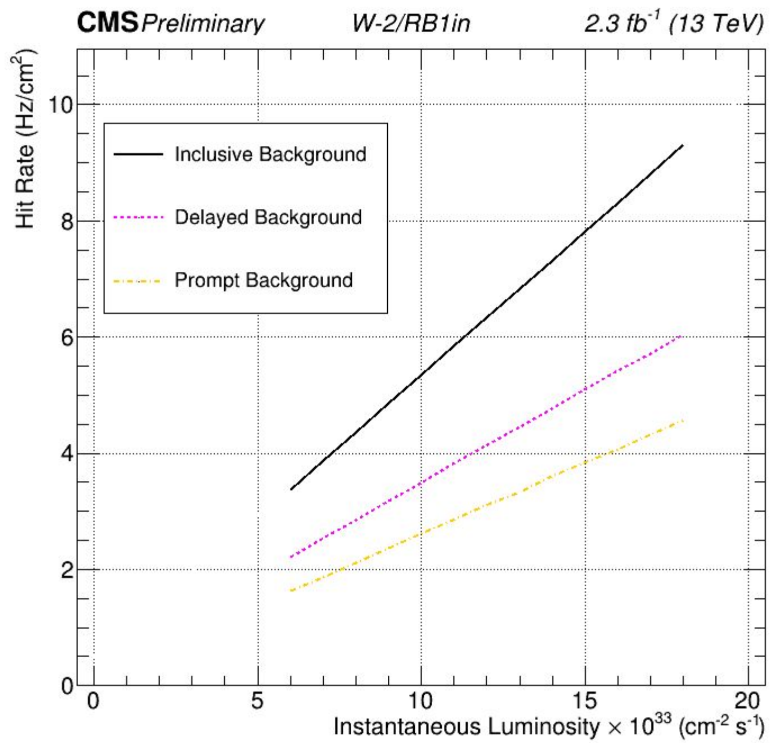
RPC Hit Rate vs Luminosity

- To take into account the LHC fill scheme it was studied separately for the Colliding, Non Colliding, PreBeam, and Abort regions.

N_C=2544, N_{NC} = 808, N_{PB} = 62, N_{BA} = 150, N_{Tot}=3564

- Inclusive Background: $B_{Tot} = \dfrac{N_C B_C + N_{NC} B_{NC} + N_{PB} B_{PB} + N_{BA} B_{BA}}{N_{Tot}}$
- Delayed: $B_{Sec} = \dfrac{N_{NC} B_{NC} + N_{PB} B_{PB} + N_{BA} B_{BA}}{N_{Tot} - N_C}$
- Prompt: $B_{Pr} = B_C - B_{Sec}$



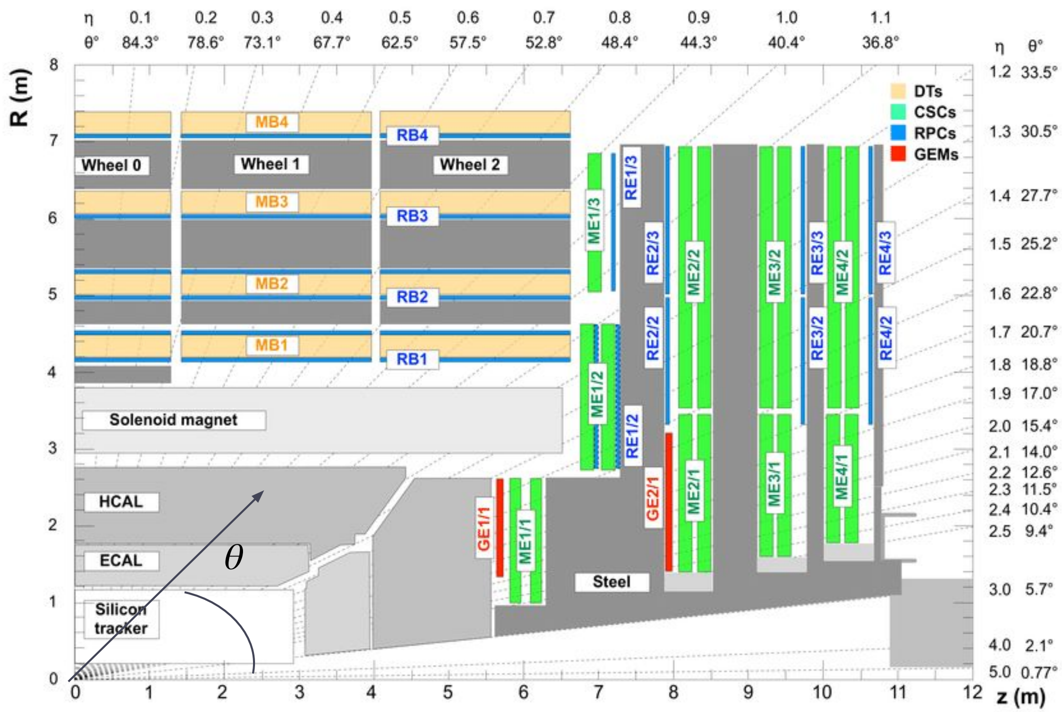


RPC Hit Rate vs η

- The total (inclusive), prompt, and delayed background rate is shown as function of pseudorapidity ***η*** :

$$\eta = -ln\left[tan\left(\frac{\theta}{2}\right)\right]$$

where ***θ*** is the azimuthal angle



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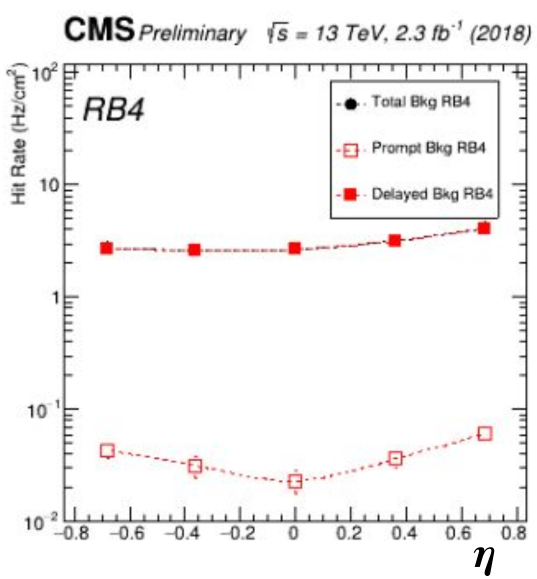
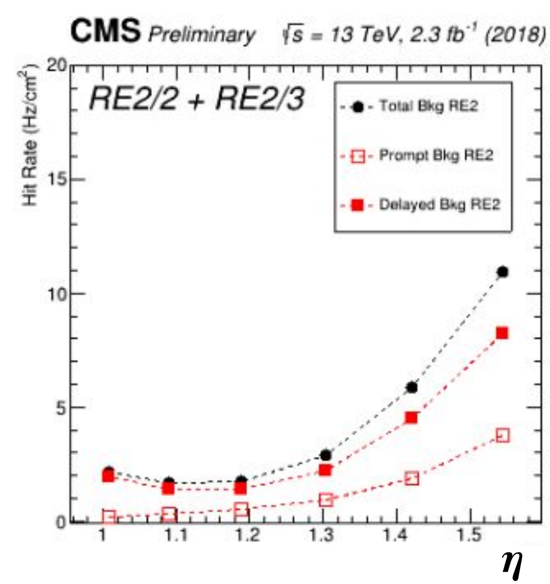
RPC Hit Rate vs η

- The “Delayed background”, associated to the slow neutron background of the cavern dominates in the outermost barrel station (RB4).
- Prompt background is associated to collisions
- Both prompt and delayed components contribute to the total background rate in the endcap station shown.

Background rate at fixed value of 10^{34} cm^{-2} s^{-1} instantaneous luminosity

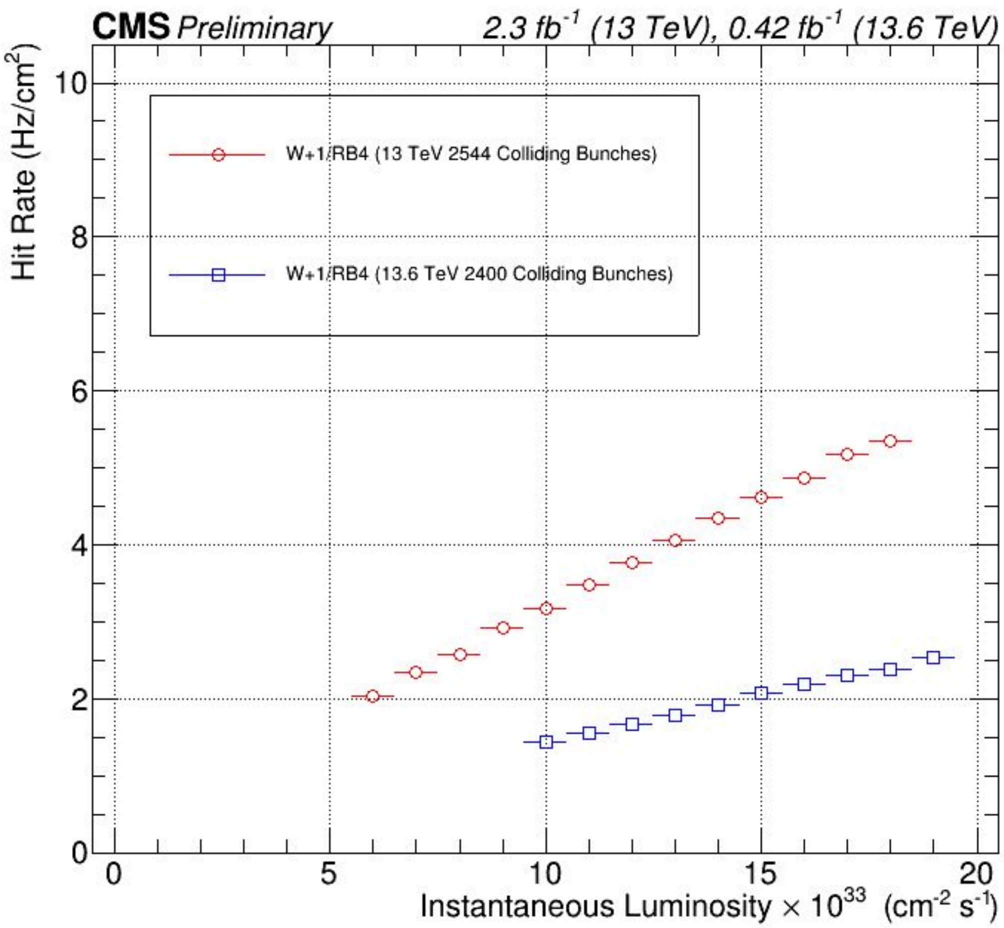




Run2 vs Run3

• First comparison between Run2 data (13 TeV) and Run3 data (13.6 TeV).

•Shielding added between Run2 and Run3 in the outermost region of the barrel.

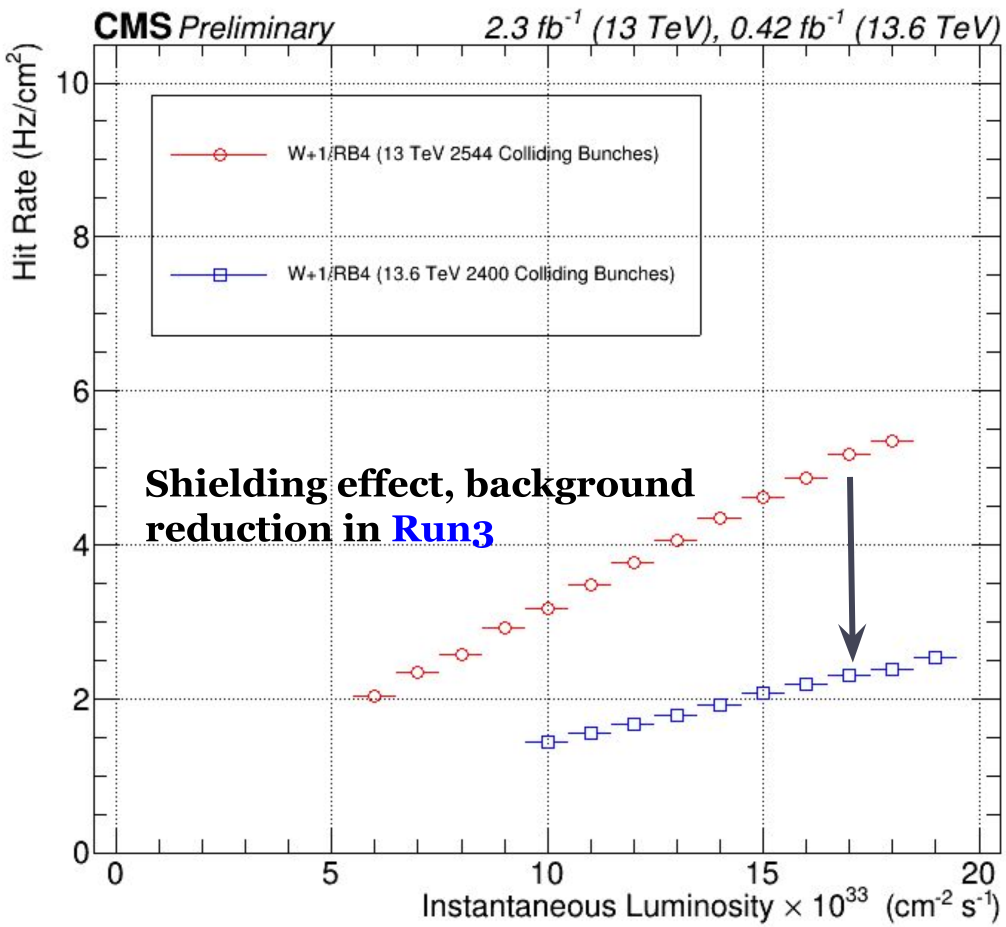


Run2 vs Run3

- First comparison between Run2 data (13 TeV) and Run3 data (13.6 TeV).

- Shielding added between Run2 and Run3 in the outermost region of the barrel.

- The background rate is much lower in Run3 than the Run2 rate.



Conclusions

- Understanding and analysing the background is a key point for maintaining robust operation and future upgrade choices.

- The background rate increases with the increasing of instantaneous luminosity, the LHC filling scheme affects the background rate.

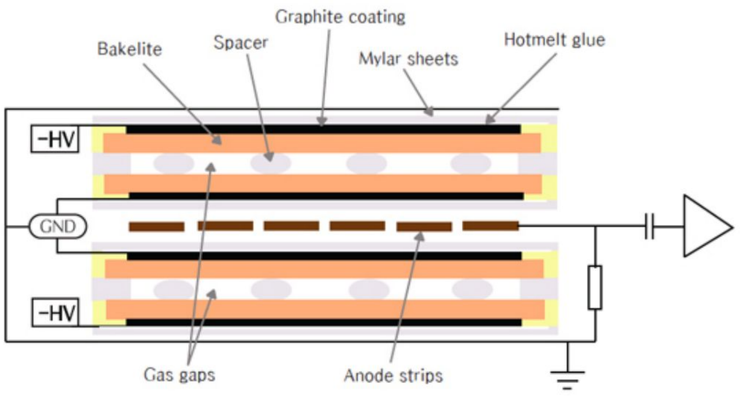
- Prompt background rate increases with the absolute value of pseudorapidity, while the delayed background rate dominates in the barrel outermost region.

- Multiple mitigation actions, the most prominent being the installation of set of shields during the LS2, show big reduction of background in the outermost barrel region, improving the longevity and stability of the chambers.

Thank you!

RPC Hit Rate

- **Hit Rate =** $$\frac{\sum_{i=1}^{n} nCluster_i(\Delta t)}{n \times \Delta t \times area}$$
  - $nCluster_i(\Delta t)$: number of cluster in the Δt window related to the *i* RPC BX.
  - n: number of RPC BX considered.
  - area: effective area, computed excluding the "off or noisy chambers"



Readout window -> n=6 RPC BX

From -2 up to 3.

In each RPC BX is counted the numbers of Clusters.

Cluster: a set of 1 or more contiguous strips producing a signal. The number of strips is the cluster size. CMSSW object-> "RecHit"

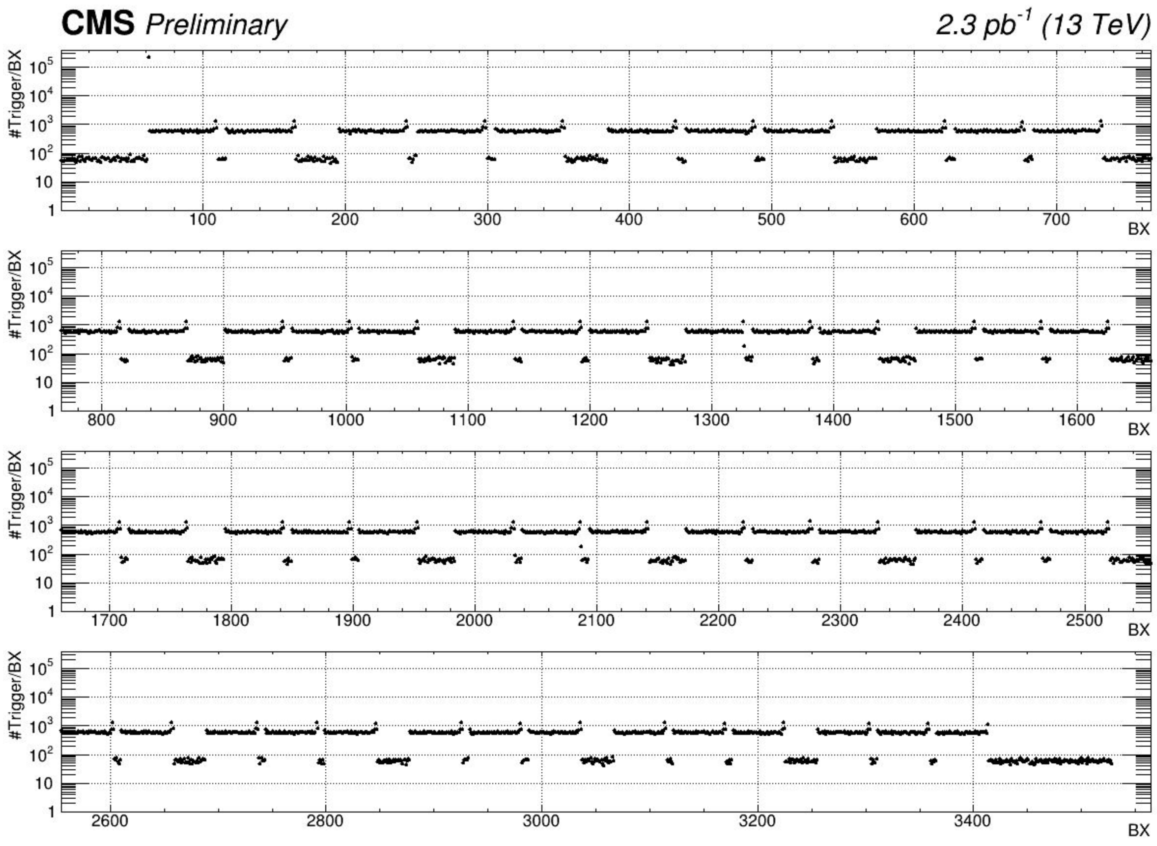
LHC Fill Scheme

- LHC fill scheme can affect the background rate in the CMS Muon System.

- Rate is dominated by the one measured in collisions, the number of events (triggers) in **colliding bunches** is greater than in **Non Colliding ones.**

LHC Fill Scheme

- Each entry correspond to an L1A from CMS
- Dedicated trigger in the ZeroBias dataset:
    - for the first colliding bunch (BX 62)
    - for the last colliding bunch of each train
    - Good statistics in Colliding BX and triggers also in empty gaps



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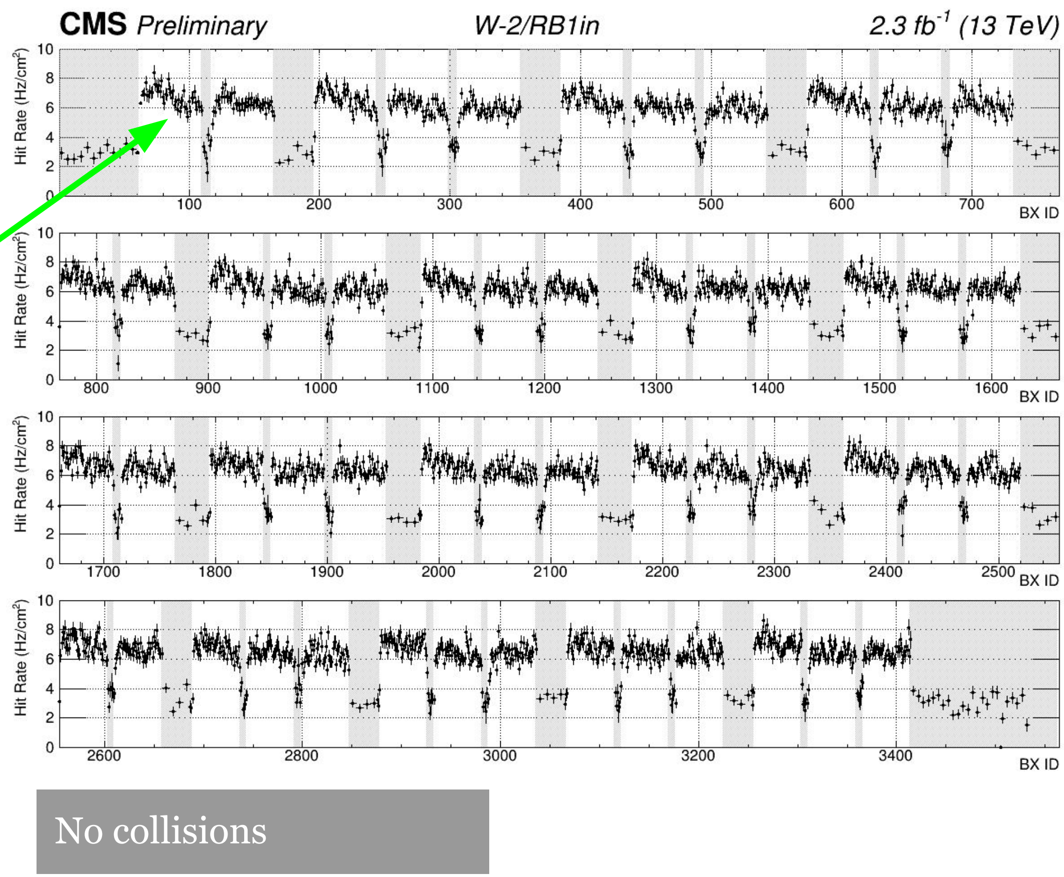
RPC Hit Rate vs BX ID

- Analysed data collected in 2018 with triggers in any bunches in order to estimate slow neutron background in non colliding bunches.

- The background rate is studied separately in Colliding, Non Colliding, PreBeam, and Abort regions.



$W - 2/RB1in\ Cluster\ Rate\ at\ 10^{34}\ Inst.\ Lumi\ (cm^{-2}s^{-1})$

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RPC Hit Rate vs BX ID

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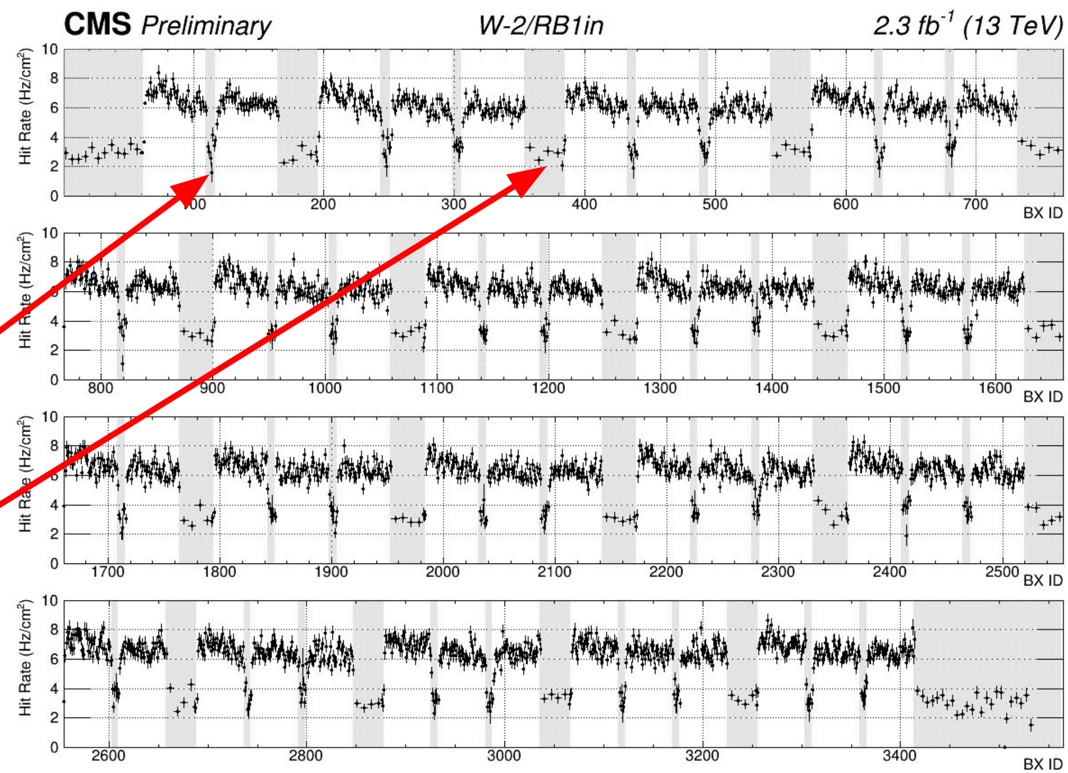

No collisions

$W-2/RB1in\ Cluster\ Rate\ at\ 10^{34}\ Inst.\ Lumi\ (cm^{-2}s^{-1})$

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RPC Hit Rate vs BX ID

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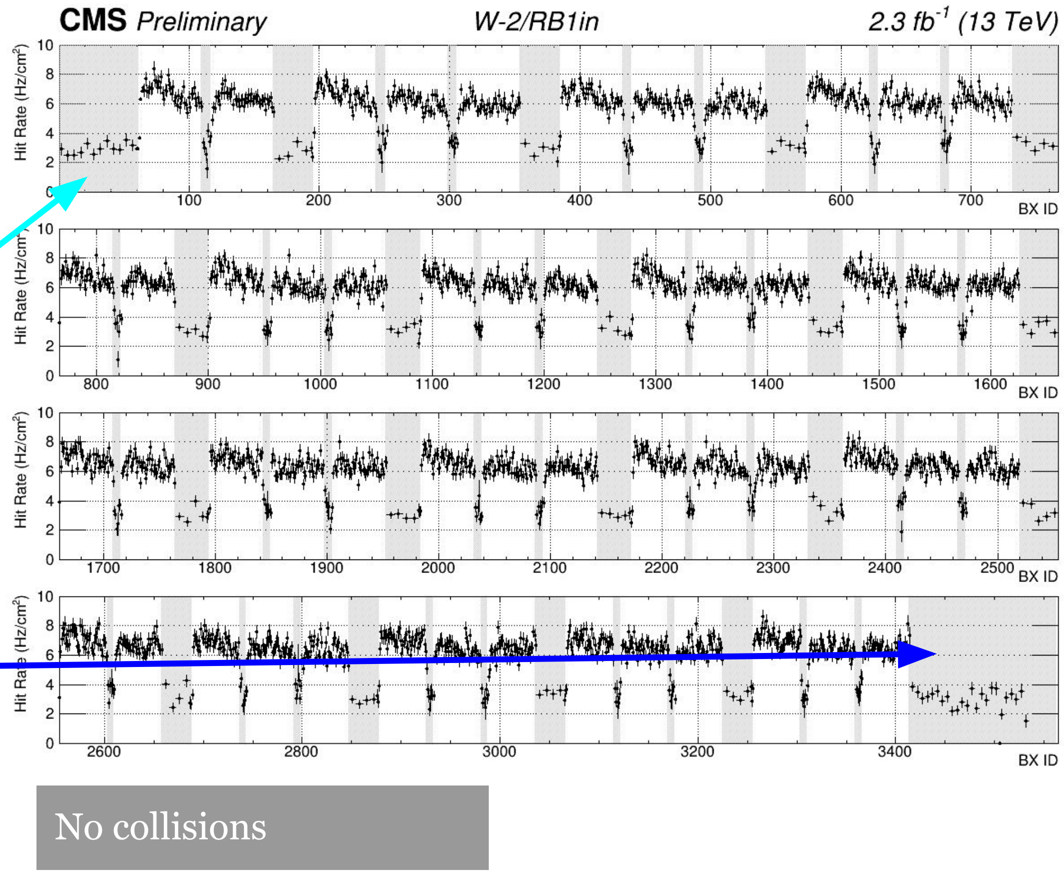
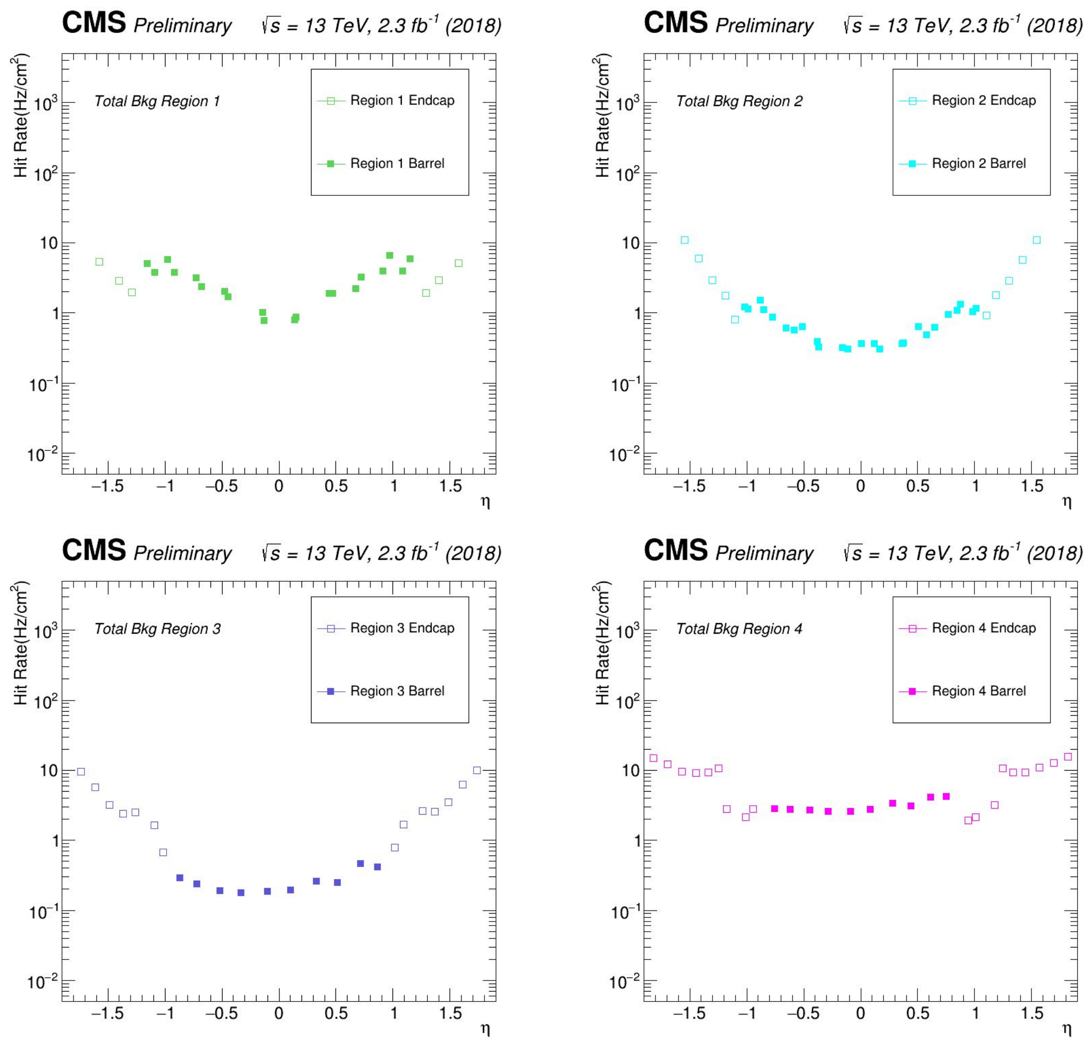


$W-2/RB1in\ Cluster\ Rate\ at\ 10^{34}\ Inst.\ Lumi\ (cm^{-2}s^{-1})$

RPC Total Hit Rate vs η

- From the linear fit, the 10^{34} cm^{-2} s^{-1} instantaneous luminosity total background rate for different regions was obtained and its trend was evaluated as a function of the pseudorapidity.

- Total background rate increases with the absolute value of pseudorapidity in the endcap, while in the barrel it decreases with the increasing of the distance to the beam until the not shielded region (RB4).



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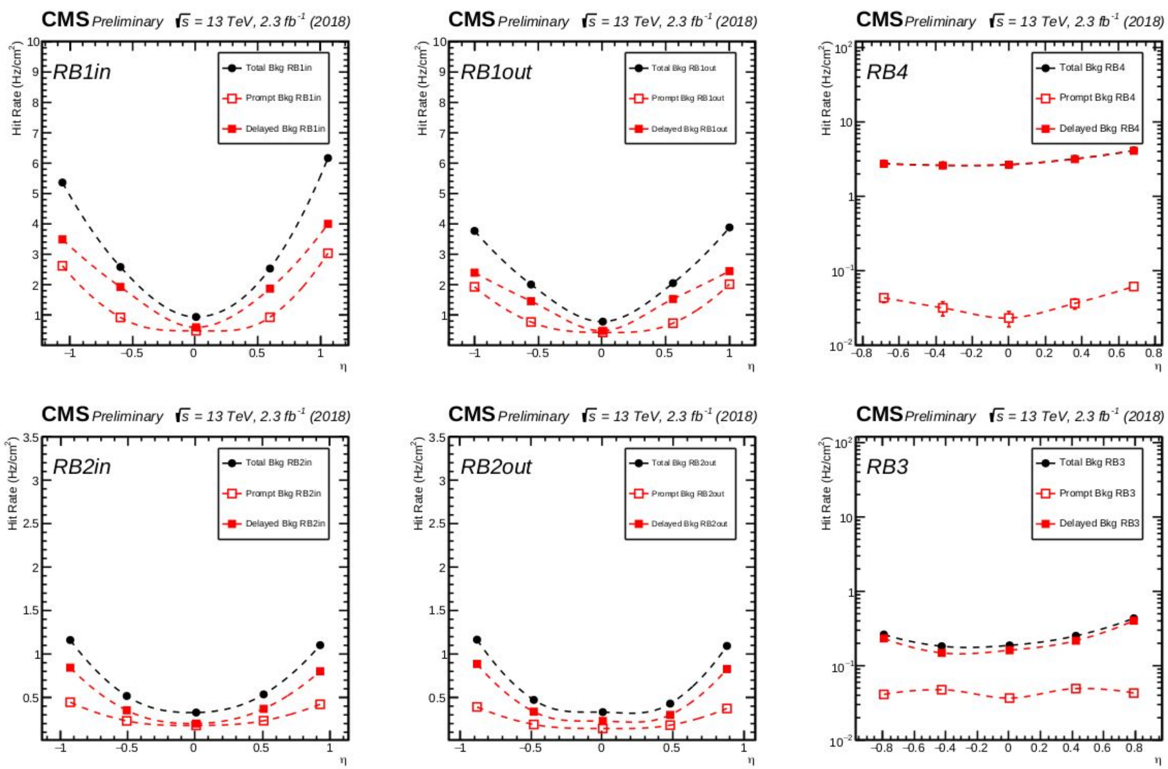
RPC Hit Rate vs η (Barrel)



Inclusive (black circle), Prompt (red open box) and Delayed (red filled box) hit rate at instantaneous luminosity of 10^{34} cm^{-2} s^{-1} in the RPC chambers in the Barrel as function of the pseudo-rapidity.

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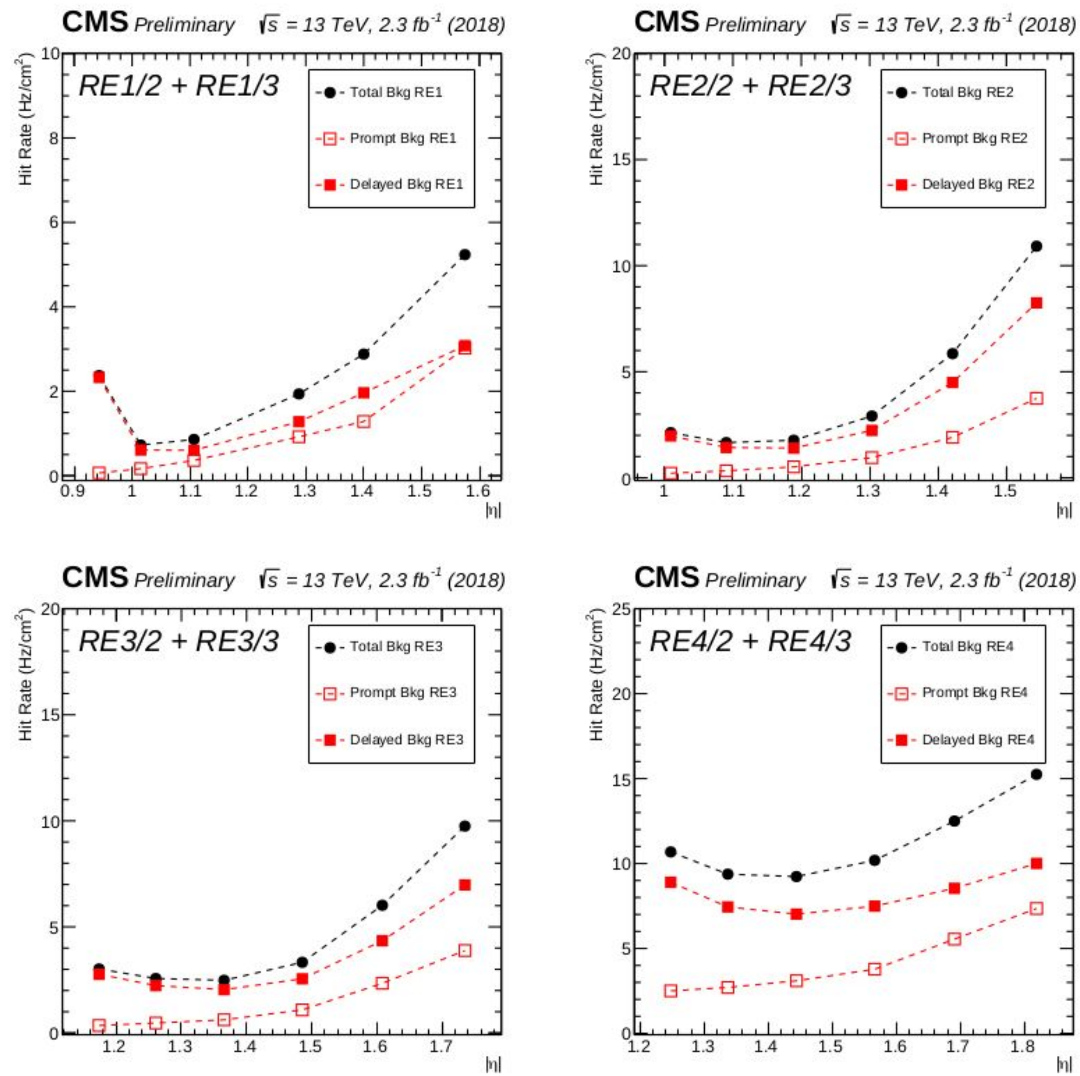
RPC Hit Rate vs η (Endcap)

Inclusive (black circle), Prompt (red open box) and Delayed (red filled box) hit rate at instantaneous luminosity of 10^{34} cm^{-2} s^{-1} in the RPC chambers in the Endcap as function of the pseudo-rapidity.



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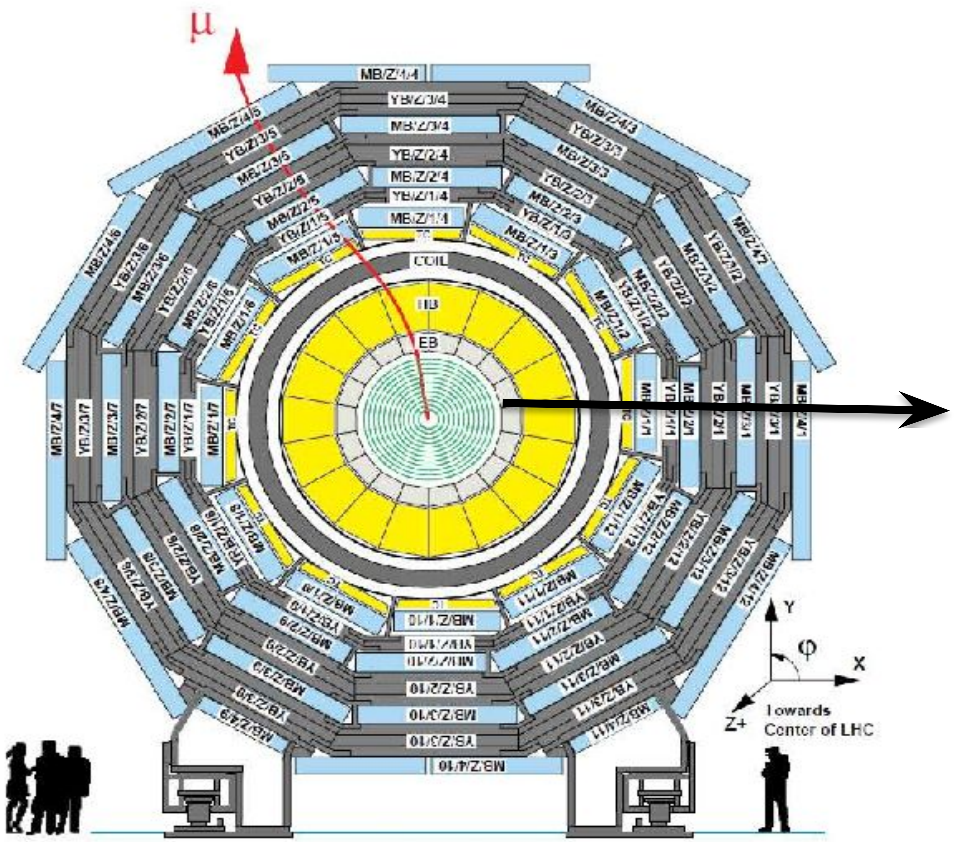
RPC Hit Rate vs Φ (Barrel)



φ = 0

- From the linear fit, the 1e34 instantaneous luminosity rate for different regions was obtained and its trend was evaluated as a function of the φ angle.

- Each sector has a granularity of 30 degrees (points in the next slides represent the middle of the barrel sector). The value φ = 0 is related to the first sector.

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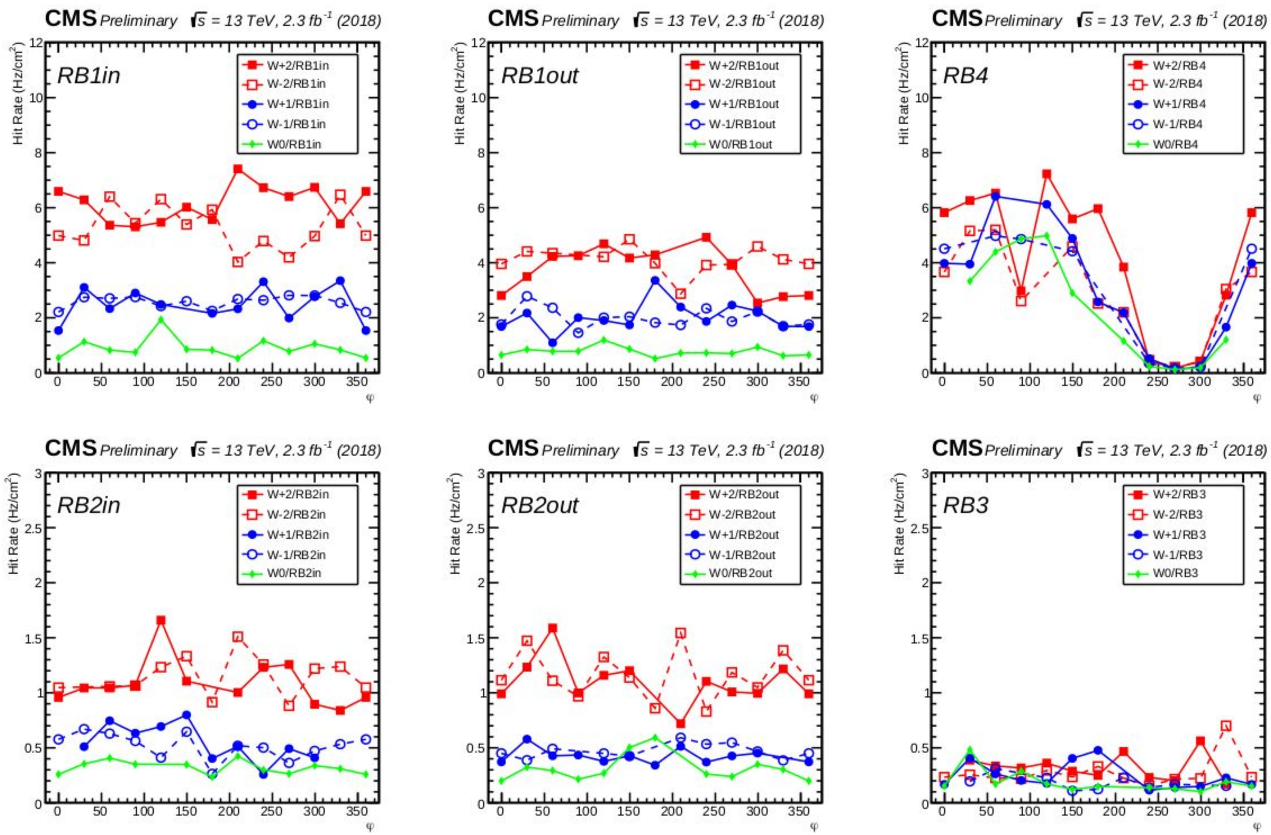
RPC Total Hit Rate vs Φ (Barrel)



The total background per layer is shown for individual RPC chambers, as a function of the azimuthal angle Φ, at the reference LHC Instantaneous Luminosity of L = 10^{34} cm^{-2} s^{-1}.

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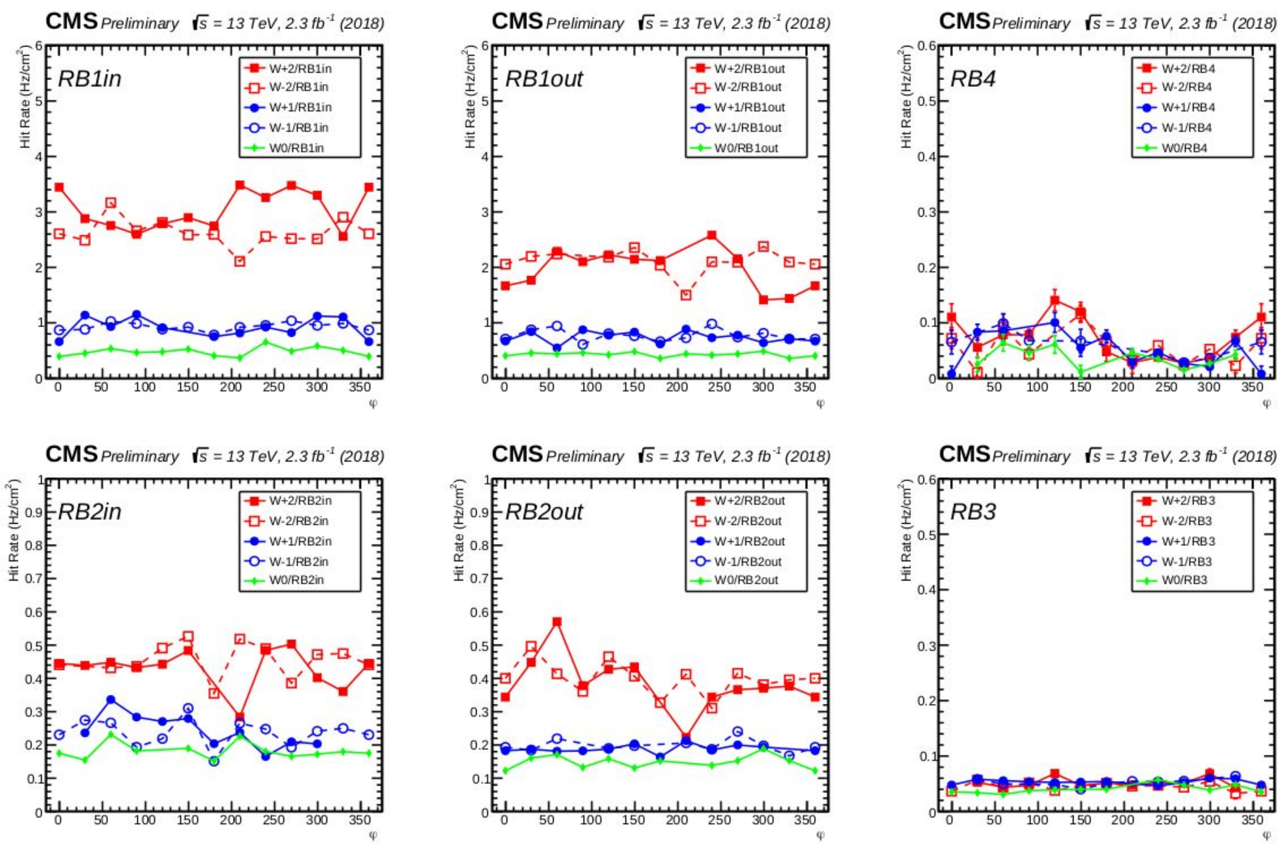
RPC Prompt Hit Rate vs Φ (Barrel)



The prompt component of the background per layer is shown for individual RPC chambers, as a function of the azimuthal angle Φ, at the reference LHC Instantaneous Luminosity of $L = 10^{34}$ cm^{-2} s^{-1}.

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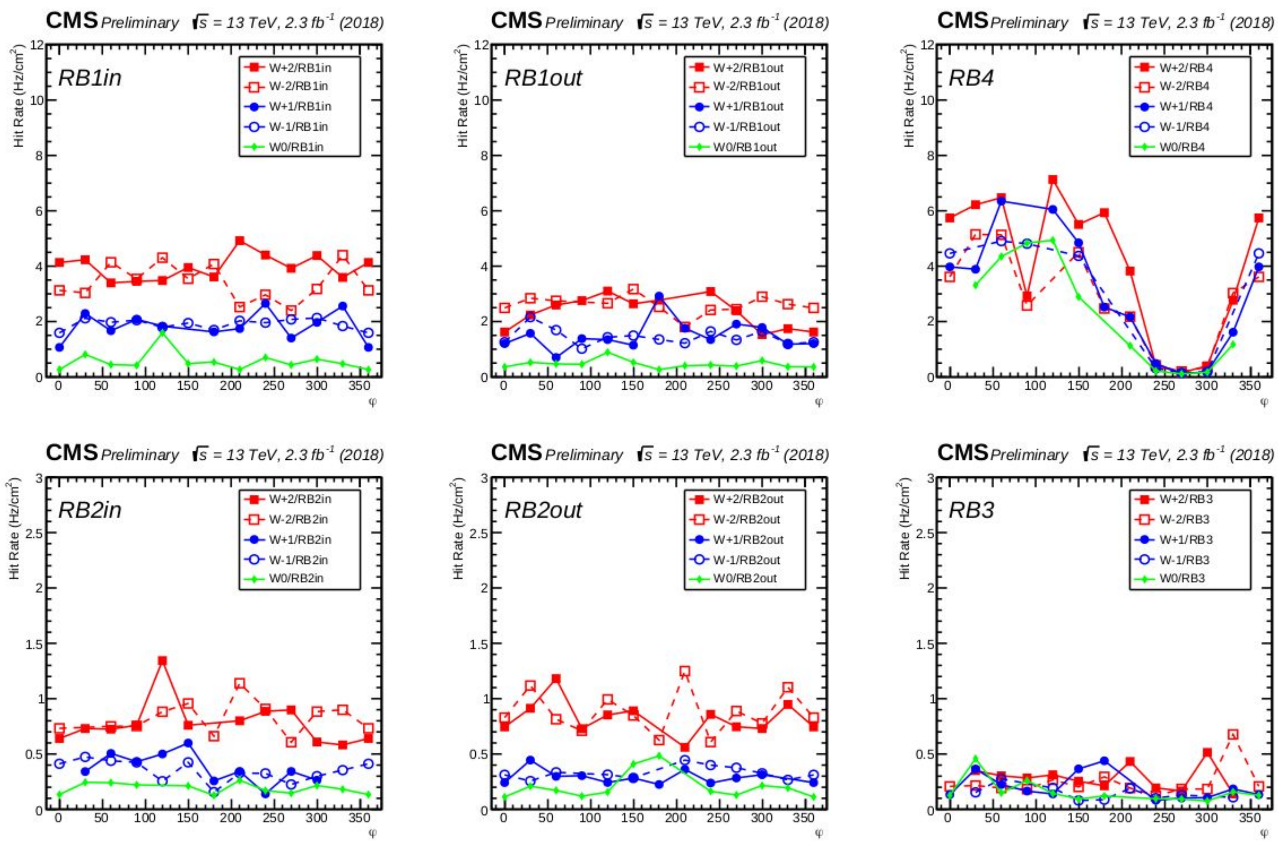
RPC Delayed Hit Rate vs Φ (Barrel)



The delayed component of the background per layer is shown for individual RPC chambers, as a function of the azimuthal angle Φ, at the reference LHC Instantaneous Luminosity of L = 10^{34} cm^{-2} s^{-1}.

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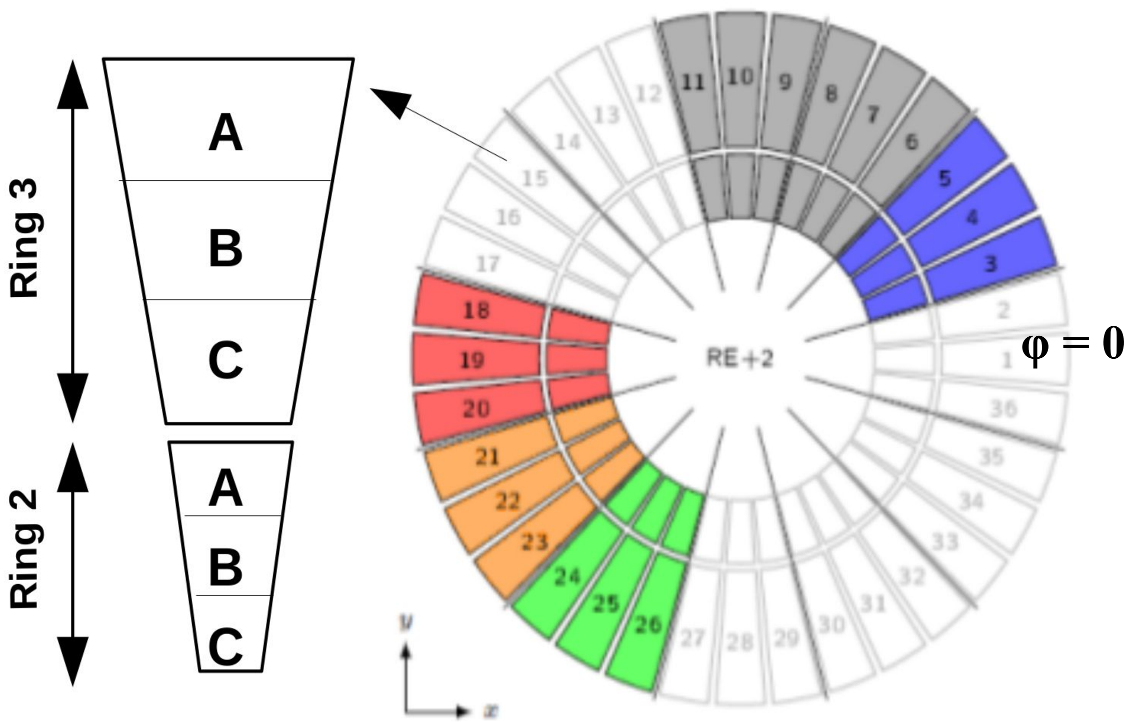
RPC Hit Rate vs Φ (Endcap)

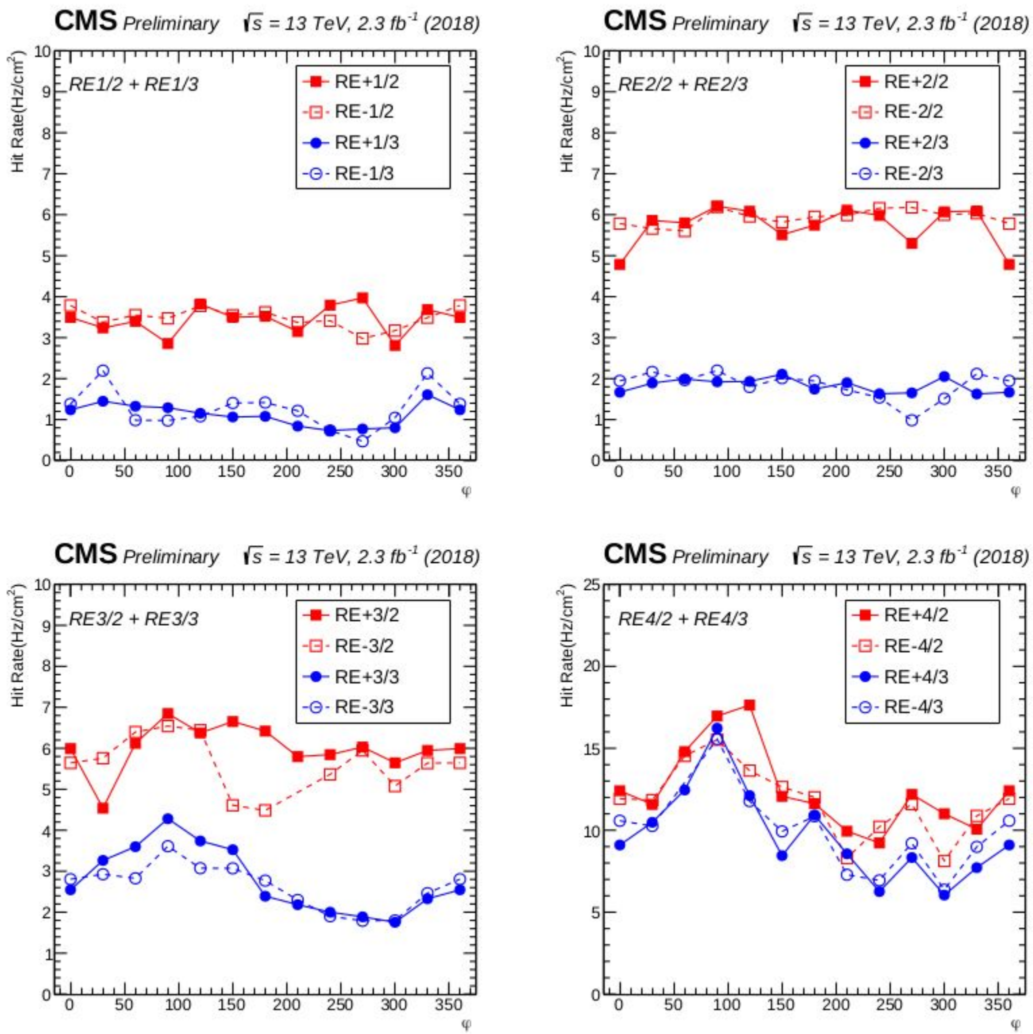
•From the linear fit, the 1e34 instantaneous luminosity rate for different regions was obtained and its trend was evaluated as a function of the φ angle.

• Granularity of 30 degrees, which are three chambers (of 10 degree each) has been considered. The value φ = 0 is related to the three chambers 36,1,2.



RPC Total Hit Rate vs Φ (Endcap)

The rate of background and noise hits per layer is shown for individual RPC chambers, as a function of the azimuthal angle Φ, at the reference LHC Instantaneous Luminosity of L = 10^{34} cm^{-2} s^{-1}.



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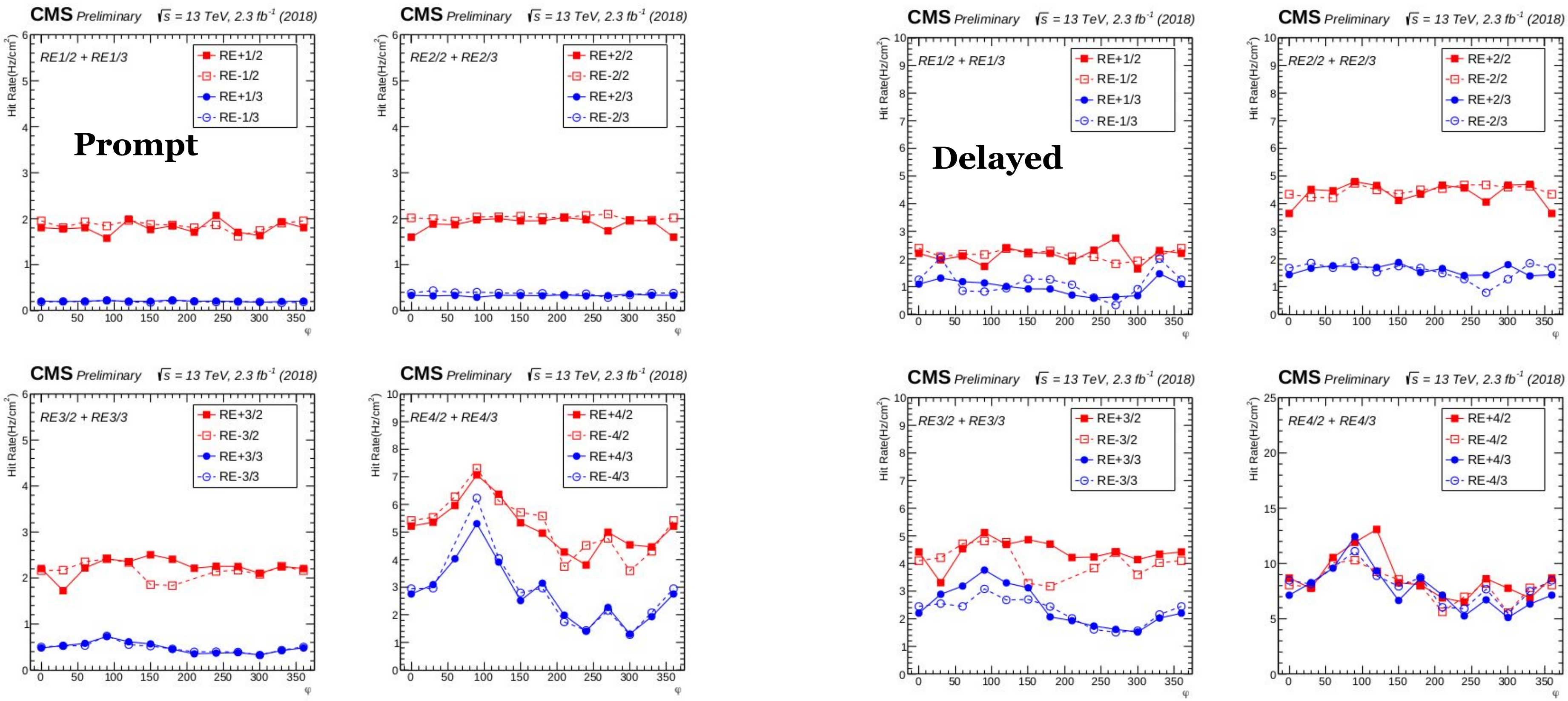
RPC Hit Rate vs Φ (Endcap)



The rate of background and noise hits per layer is shown for individual RPC chambers, as a function of the azimuthal angle Φ, at the reference LHC Instantaneous Luminosity of L = 10^{34} cm^{-2} s^{-1} , split by the prompt component and the delayed component.

RPC Hit Rate vs η

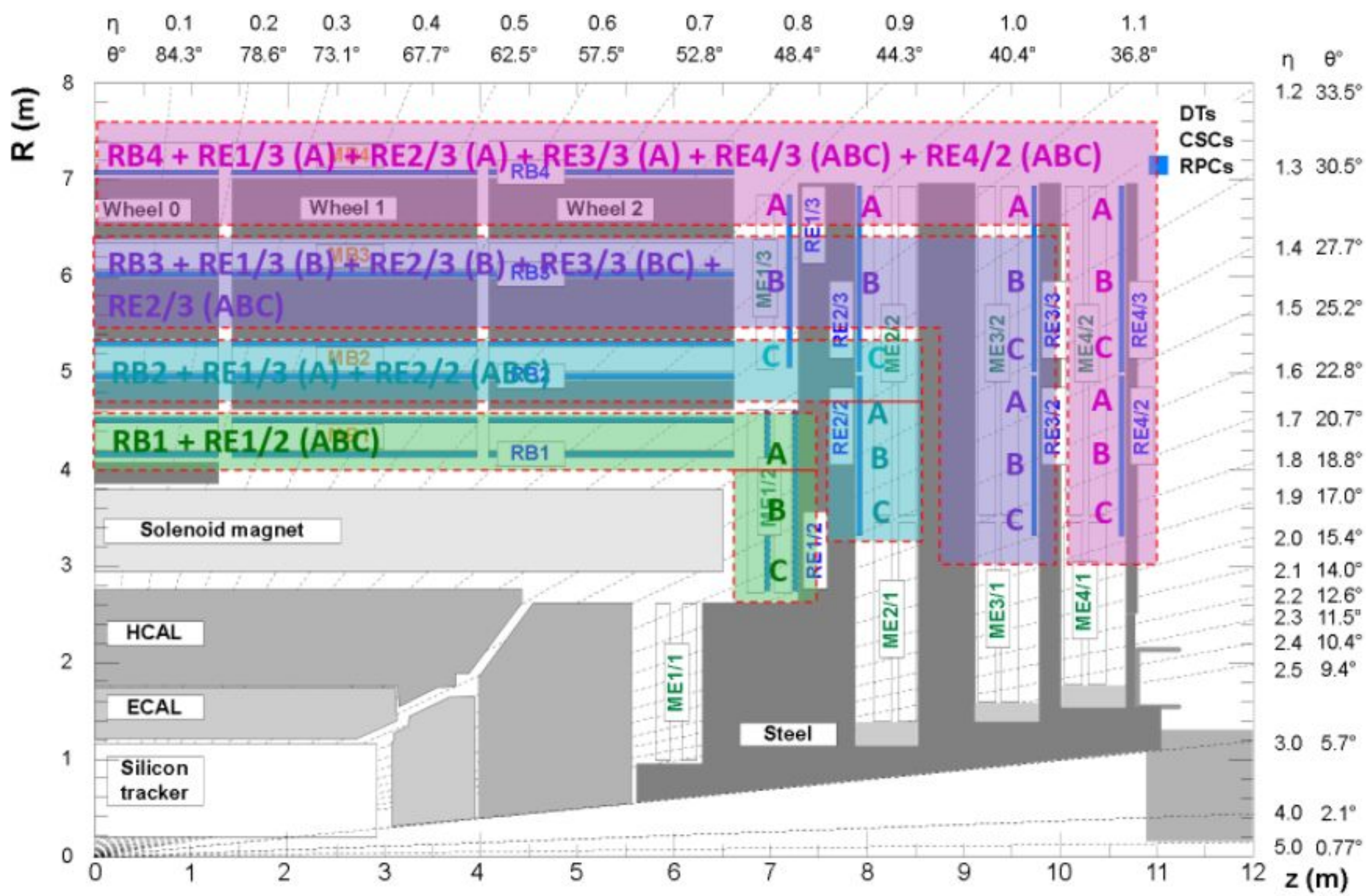
Region splitting to evaluate the background rate as a function of the pseudorapidity both in the barrel and endcap region:

Region 1

Region 2

Region 3

Region 4



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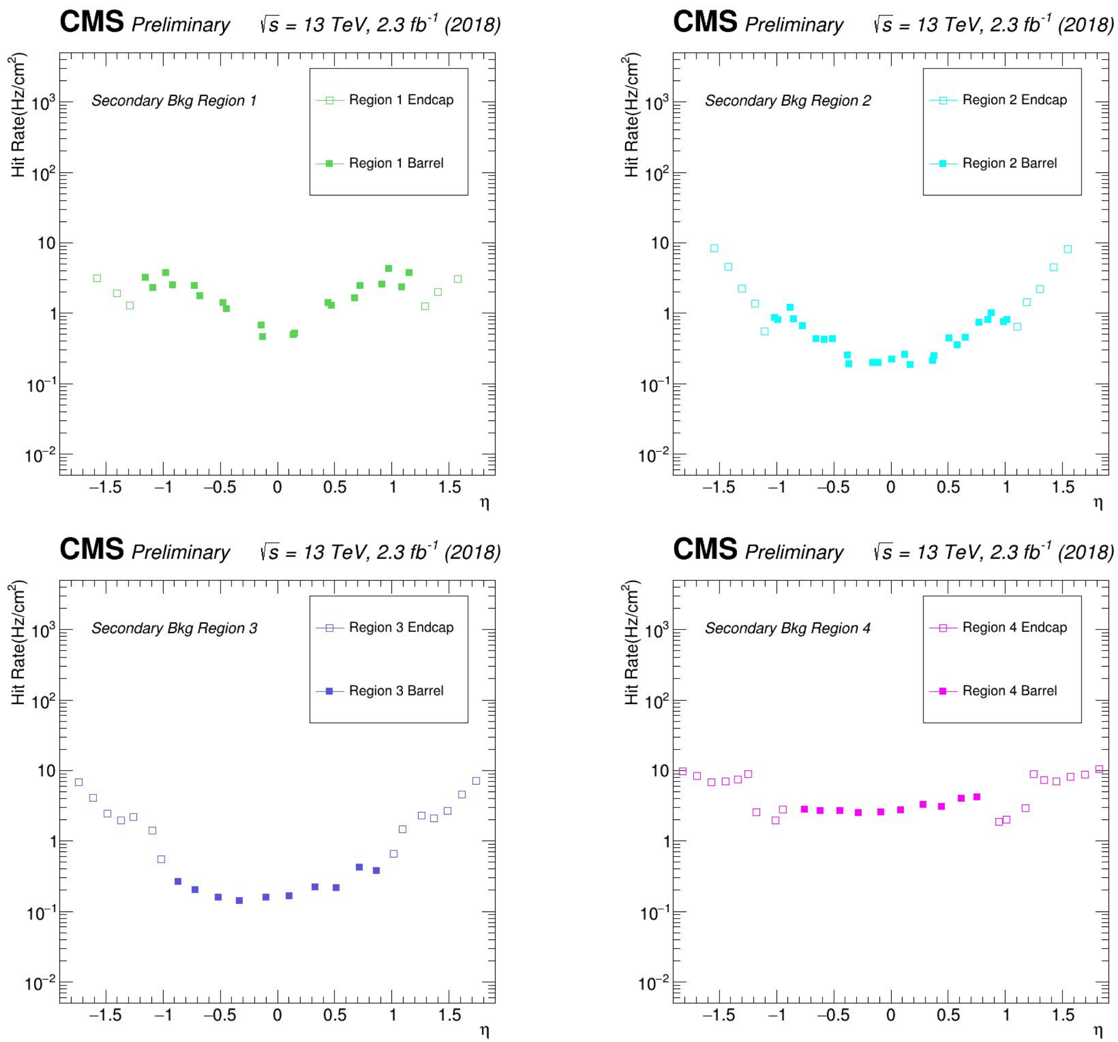
RPC Delayed Hit Rate vs η

- From the linear fit, the 10^{34} cm^{-2} s^{-1} instantaneous luminosity secondary (delayed) background rate for different regions was obtained and its trend was evaluated as a function of the pseudorapidity.

- Delayed background decreases from the innermost station to the 3rd station, in the outermost barrel station it increases again, due to not shielding effect.



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RPC Prompt Hit Rate vs η

- From the linear fit, the 10^{34} cm^{-2} s^{-1} instantaneous luminosity primary (prompt) background rate for different regions was obtained and its trend was evaluated as a function of the pseudorapidity.

- Prompt background rate increases with the absolute value of pseudorapidity in the endcap, while in the barrel it decreases with the increasing of the distance to the beam.