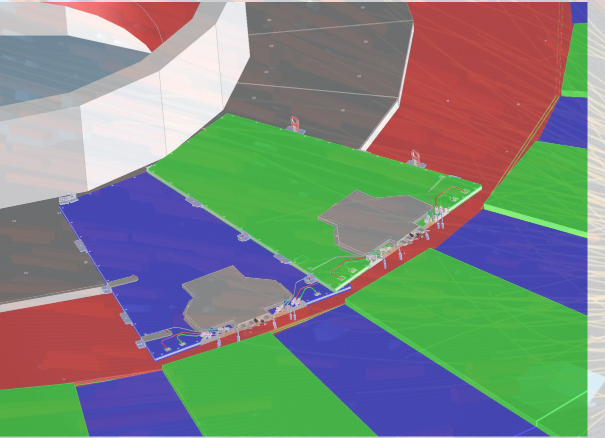


Improved Resistive Plate Chambers for Phase 2 Upgrade of CMS

Amrutha Samalan[1], Mauricio Thiel[2]

1. Ghent University, Belgium
2. Universidade do Estado do Rio de Janeiro, Brazil

On behalf of the CMS MUON Group

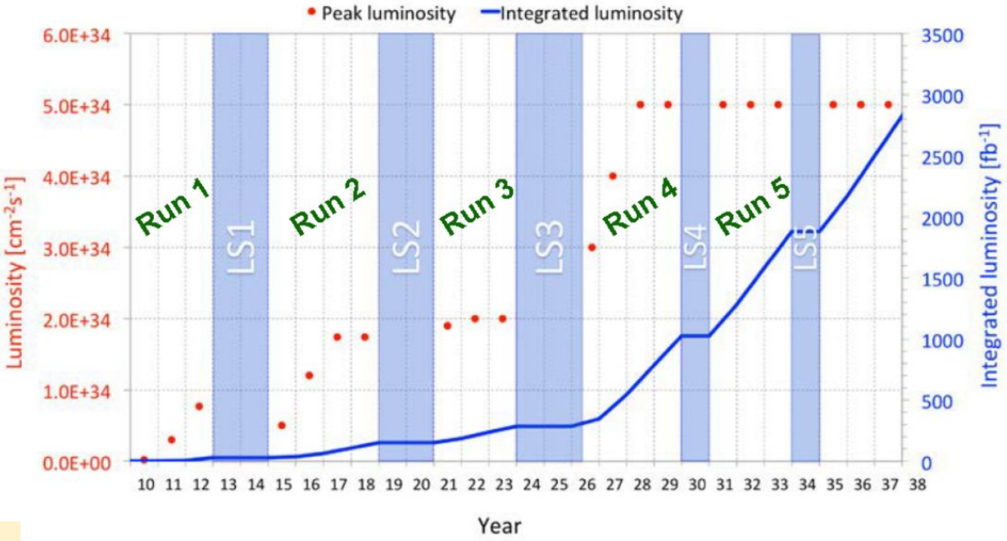
RPC 2022

XVI Workshop on Resistive Plate Chambers and Related Detectors

Motivation

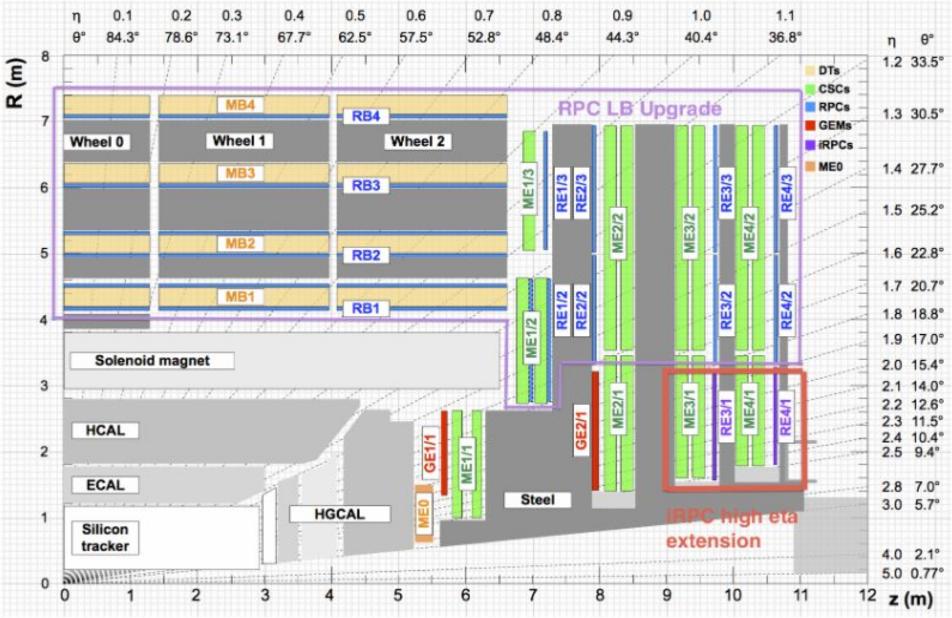
- During High Luminosity LHC (HL-LHC) operation, the instantaneous luminosity will be increased to 5×10^{34} cm^{-2} s^{-1}
- Increase in the average pileup will result in
  - Worse background conditions
  - Higher trigger rates
  - Accelerated aging effects
  - Complex event reconstruction

To cope with these challenges CMS is implementing different upgrades of the present systems, including the extensions of the muon endcaps with new chambers

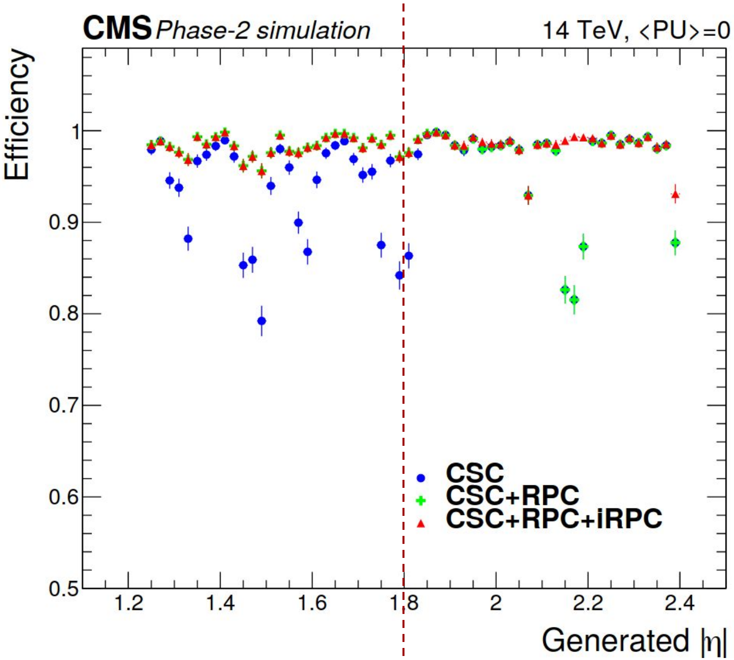


The LHC schedule and the design values for instantaneous and integrated luminosity

Motivation

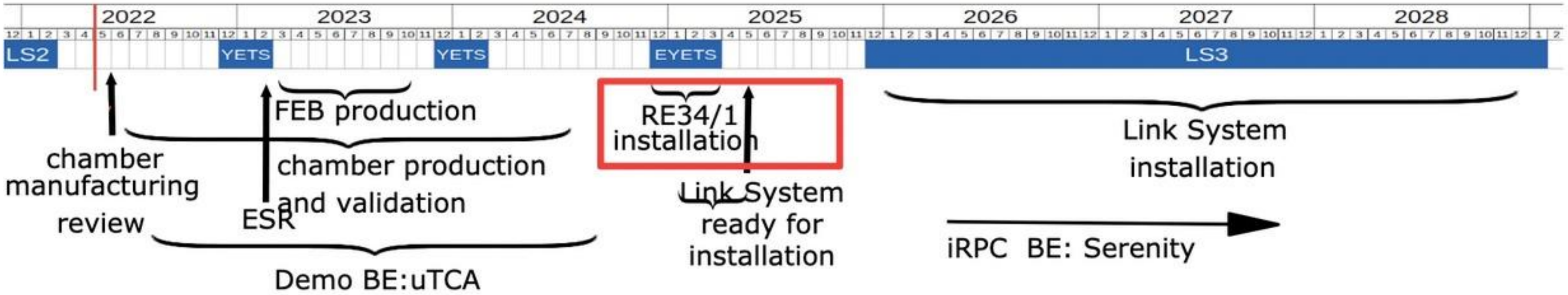


An improved version of the already existing RPCs (iRPCs), will be installed in the forward region on the 3rd and 4th endcap disk-> 72 chambers in-total

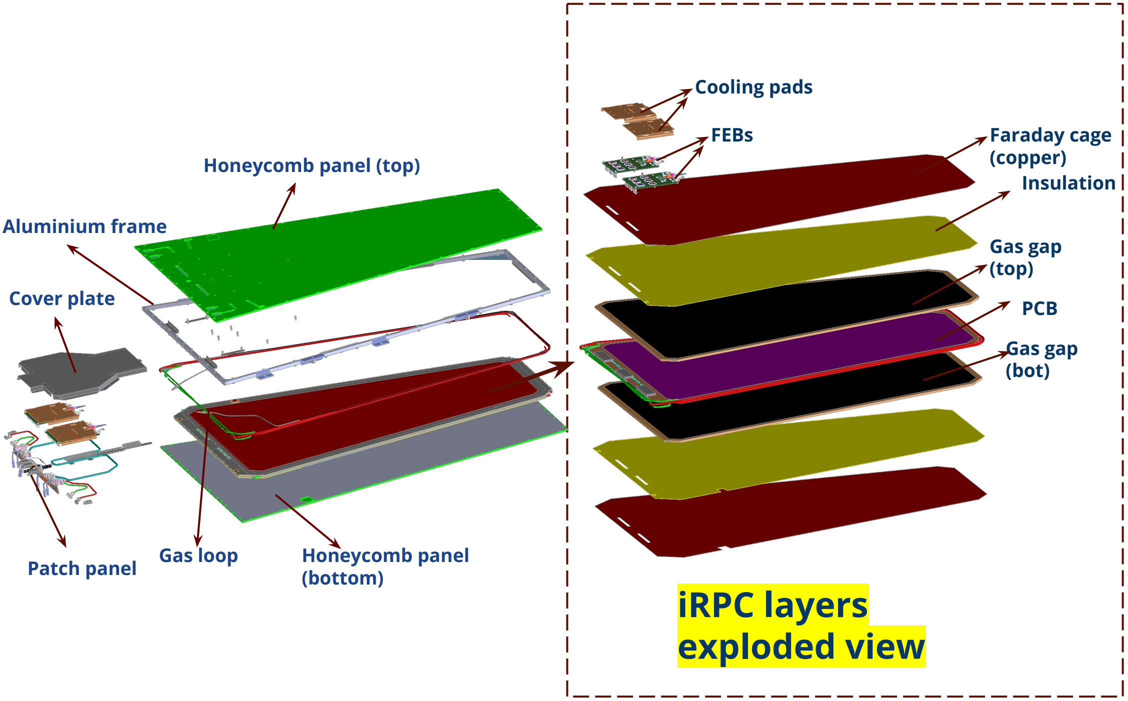


Extension of the RPC coverage in the high η region (1.8<|η|<2.4) with L1 single muon trigger efficiencies > 95%

iRPC Project: timeline



iRPC technical layout



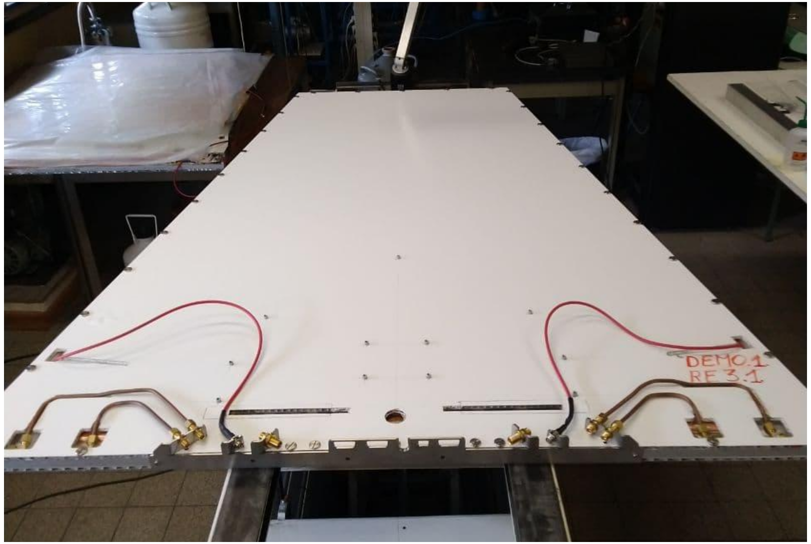
	RPC	iRPC
High Pressure Laminate (HPL) thickness (mm)	2	1.4
Num. of Gas Gap	2	2
Gas Gap width (mm)	2	1.4
Resistivity (Ωcm)	1 - 6 x 10^{10}	0.9 - 3 x 10^{10}
Charge threshold (fC)	150	50
Strip pitch (cm)	2.0-4.0	0.6-1.2
η segmentation	3 η partitions	2D readout

The technical layout of RE3/1 and RE4/1 chambers are exactly same except the geometry

iRPC demonstrator project

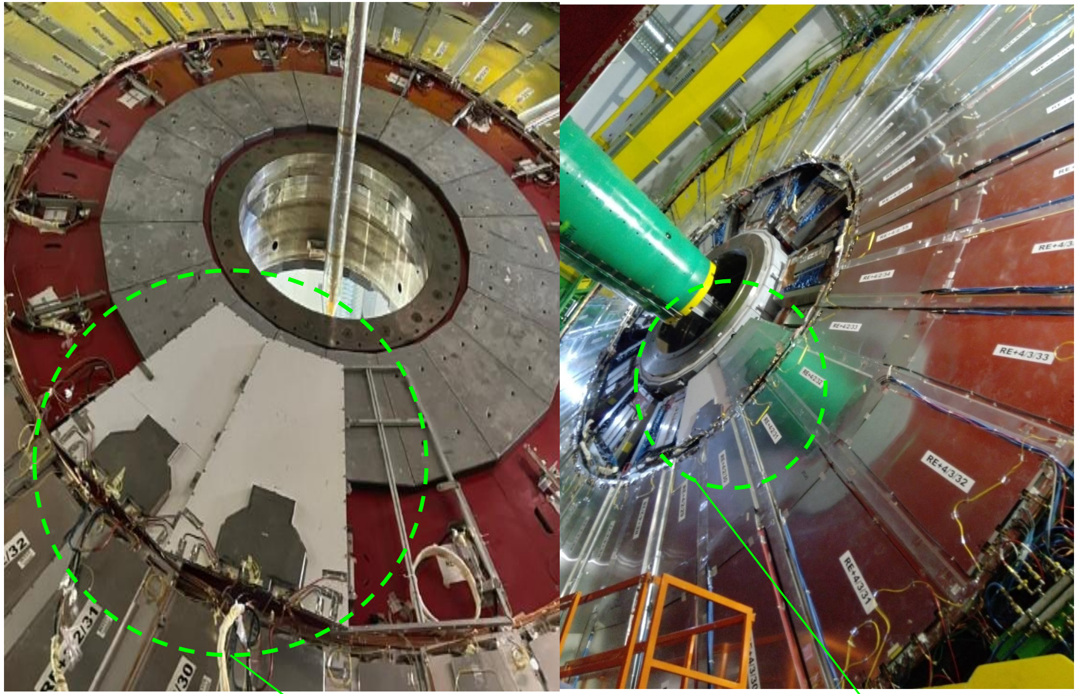
Assembled four RE3/1 and four RE4/1 demonstrator chambers at Gent on July 2021 in order to validate the:

- Technical design
- New construction protocols, QC and AC
- Readiness of construction and test sites
- The CMS DCS and DAQ system with new RPC stations
- Detector behavior in real CMS conditions
- Chamber integration into CMS endcaps



iRPC demonstrator chamber assembled at Ghent University, Belgium

iRPC demonstrator installation at P5



RE+4/1/15,16

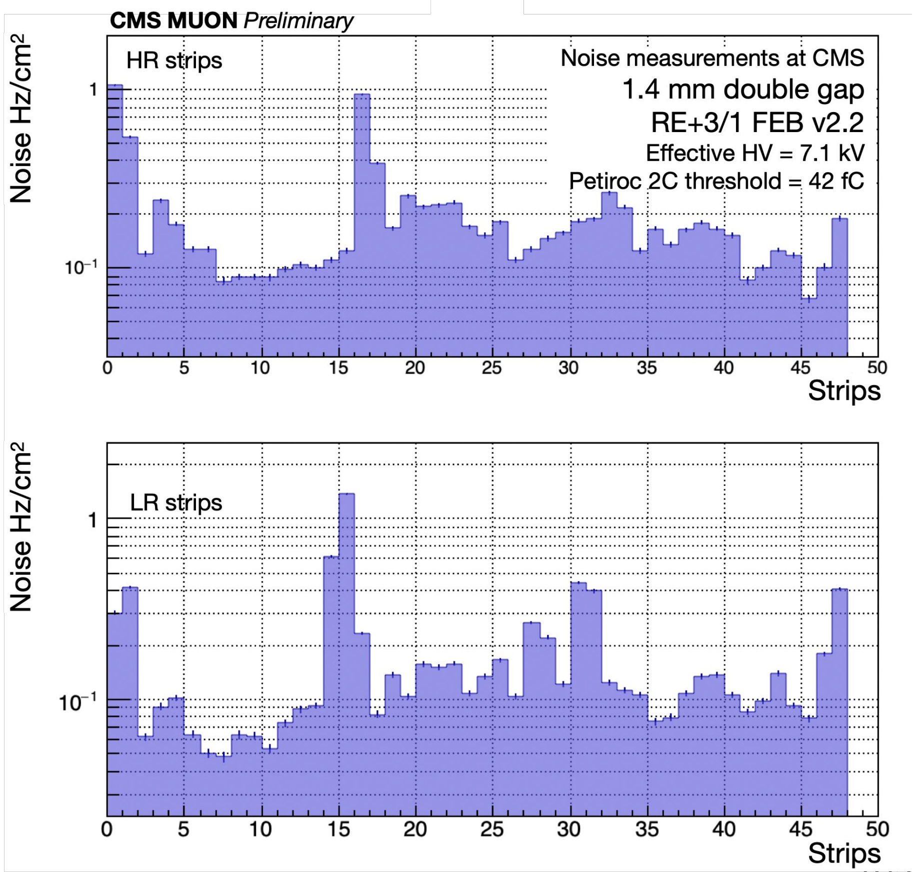
RE+3/1/15,16

02 December 2021	• RE 4.1 demonstrator successfully installed and commissioned in P5
28 January 2022	• RE 3.1 demonstrator successfully installed and commissioned in P5

iRPC demonstrator commissioning at P5

Recent commissioning of demonstrator chambers at CMS Cavern showed/confirmed:

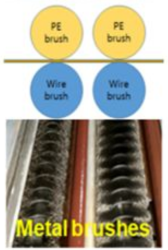
- Low noise (max 1 Hz/cm^2) with final CMS endcap disk grounding
- Normal/stable operation temperature in CMS endcap closed mode and CMS endcap water cooling
- Normal operation in 3.8T magnetic field



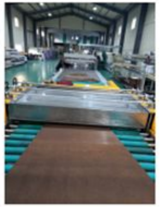
iRPC mass production: Gap manufacturing

Washing procedure for HPL panel:

MEK washing



+

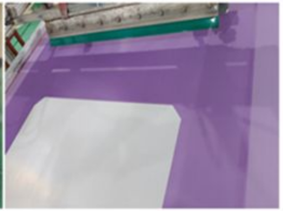


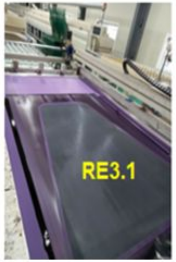
Water washing + drying

Two-step washing procedure (3 mins/panel, 1000 rpm)

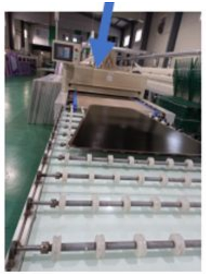
Quick water washing and drying (10s)

Graphite coating:



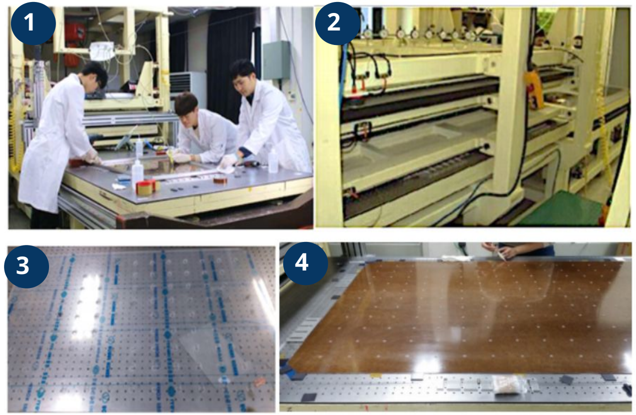


Drying



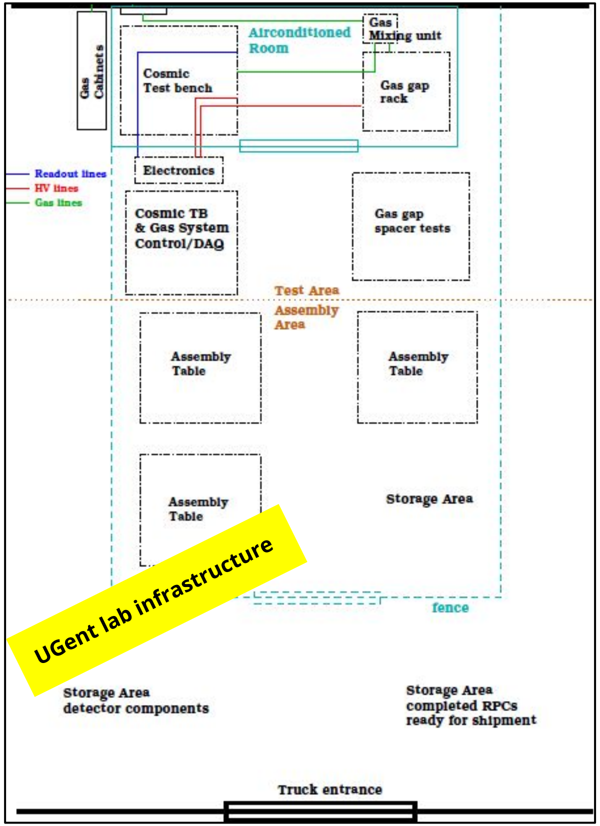
Surface resistivity: 350-700 kΩ/□ with a mean of 500 kΩ/□

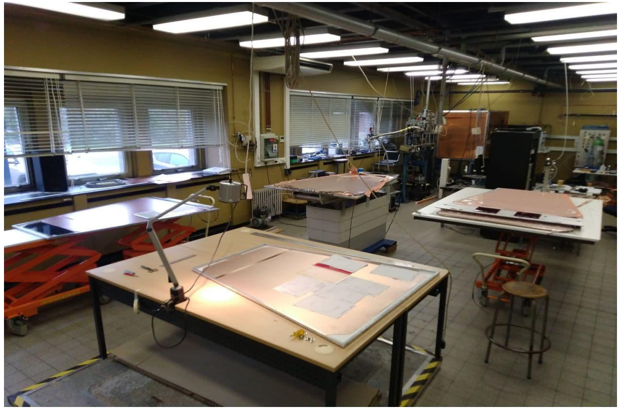
Gap production:



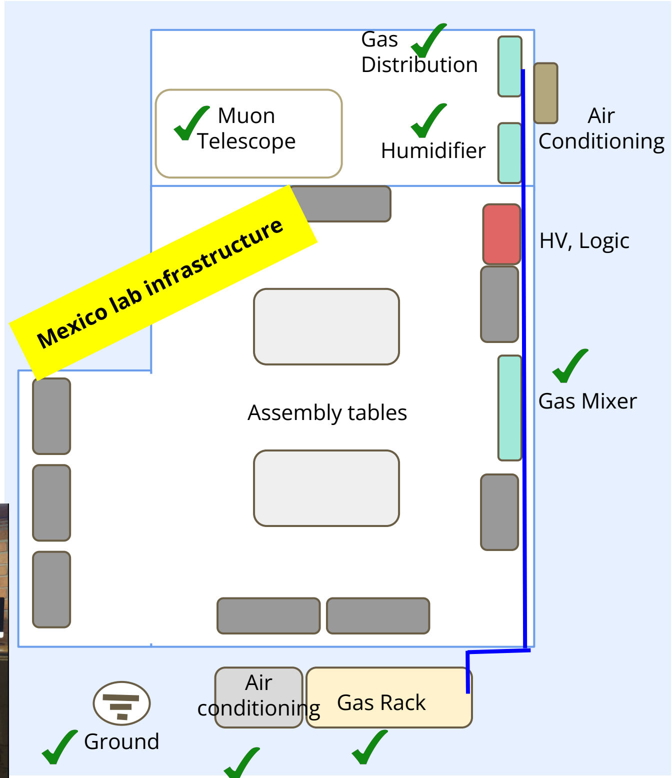
1. Gluing tables and pressure devices
2. Matric tables and multi-layer pouche for gluing and glue hardening for gaps
3. Spacer jig
4. Spacer gluing

iRPC mass production: Production sites





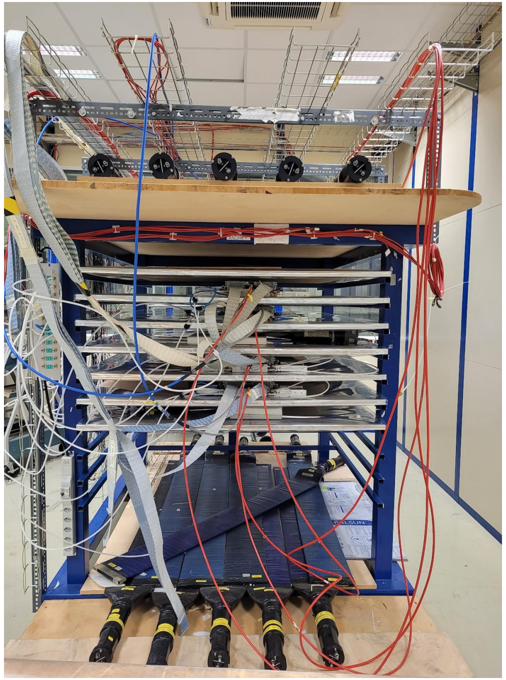
Assembly lab @ UGent, Belgium



Assembly lab @ Ibero-American University, Mexico

iRPC mass production: QC procedures

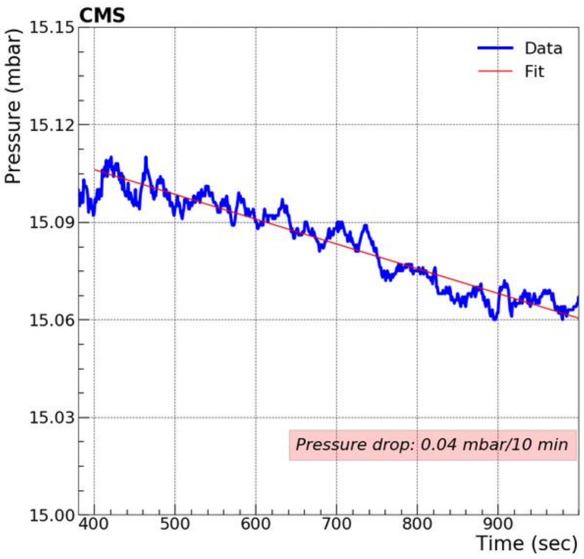
QC Protocols		Location	Validation (during demonstrator assembly)
QC 1	**Applied to basic chamber components:** on-detector electronics, PCB and connectors, HPL electrodes, pipes, unions, HV/LV/signal connectors/cables, cooling pipes/elements	Pavia, Italy (HPL) Lyon (PCB, electronics), 904 lab at CERN	✓
QC2	**Applied to chamber elements:** gas gaps, PCB and cooling circuit For gas gaps: visual inspection (flatness, surface quality etc.), gas leak test (@ 15 mbar), resistivity measurements,spacer gluing, popped spacer test, dark current tests	KODEL laboratory at Korea University, Production labs (Gent, Mexico)	✓
QC 3	**Applied to chambers after production:** gas leak test (@ 5 mbar), electronics tests, PCB test, cooling circuit tightness, dark current tests, chamber performance tests with cosmics	Production labs (Gent, Mexico)	✓
QC 4	**Applied to chambers after shipment to CERN (final validation tests):** Repetition of QC3, cosmic validation with final FEB, beam tests (background up to 2 KHz/cm^2)	904 lab at CERN GIF++ at CERN	✓



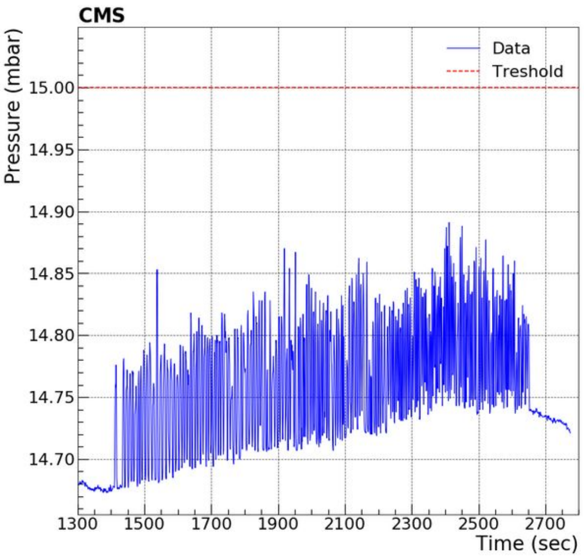
Cosmic test bench at 904 (CERN)

iRPC mass production:QC procedures

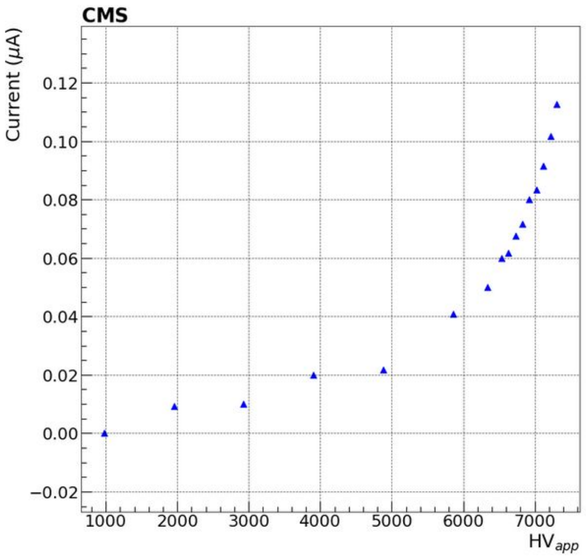
Few results of the QC2 performed for the iRPC demonstrator HPL gaps:



Leak test

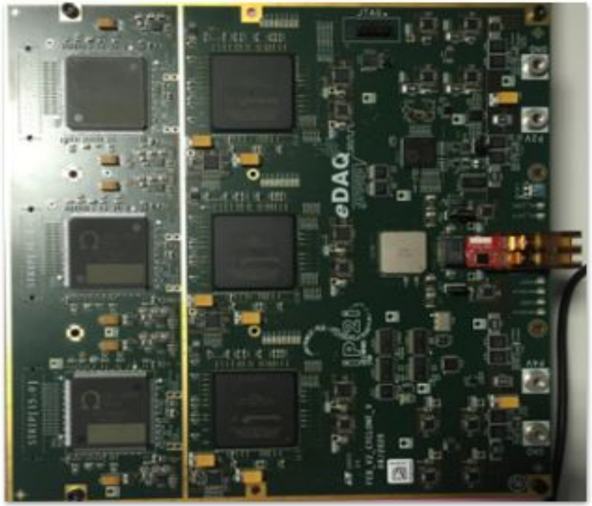


Popped spacer test



HV test

iRPC front-end electronics

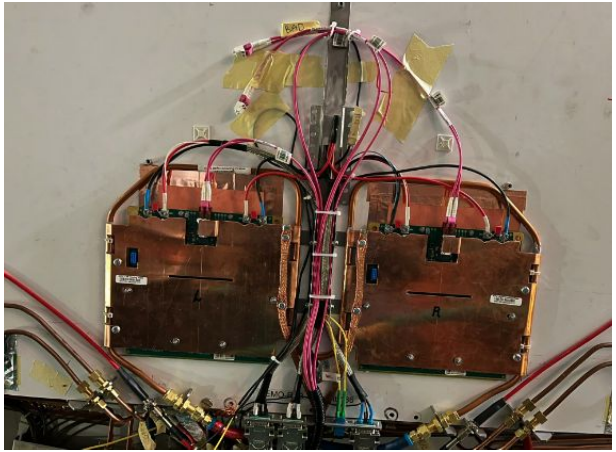


Feb v2.2; PETIROC 2C

iRPC FEB is equipped with low noise front-end electronics that can detect signals with a charge as low as ~50 fC (present RPC system ~150 fC)

The FEB is composed of:

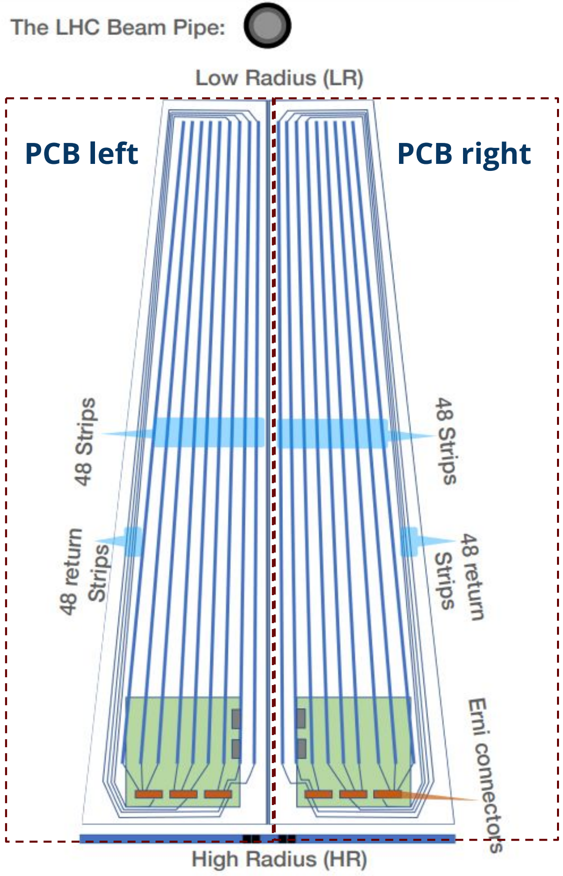
- 3 ERNI connectors of 32 channels each
- 6 ASICs PETIROC 2C
- 3 FPGAs Cyclone V
- GBTx/GBT-SCA/VTRx



Feb v2.2 integrated on iRPC demonstrator chamber

CMS iRPC FEB development and validation https://indi.to/5PR9F

Readout principle



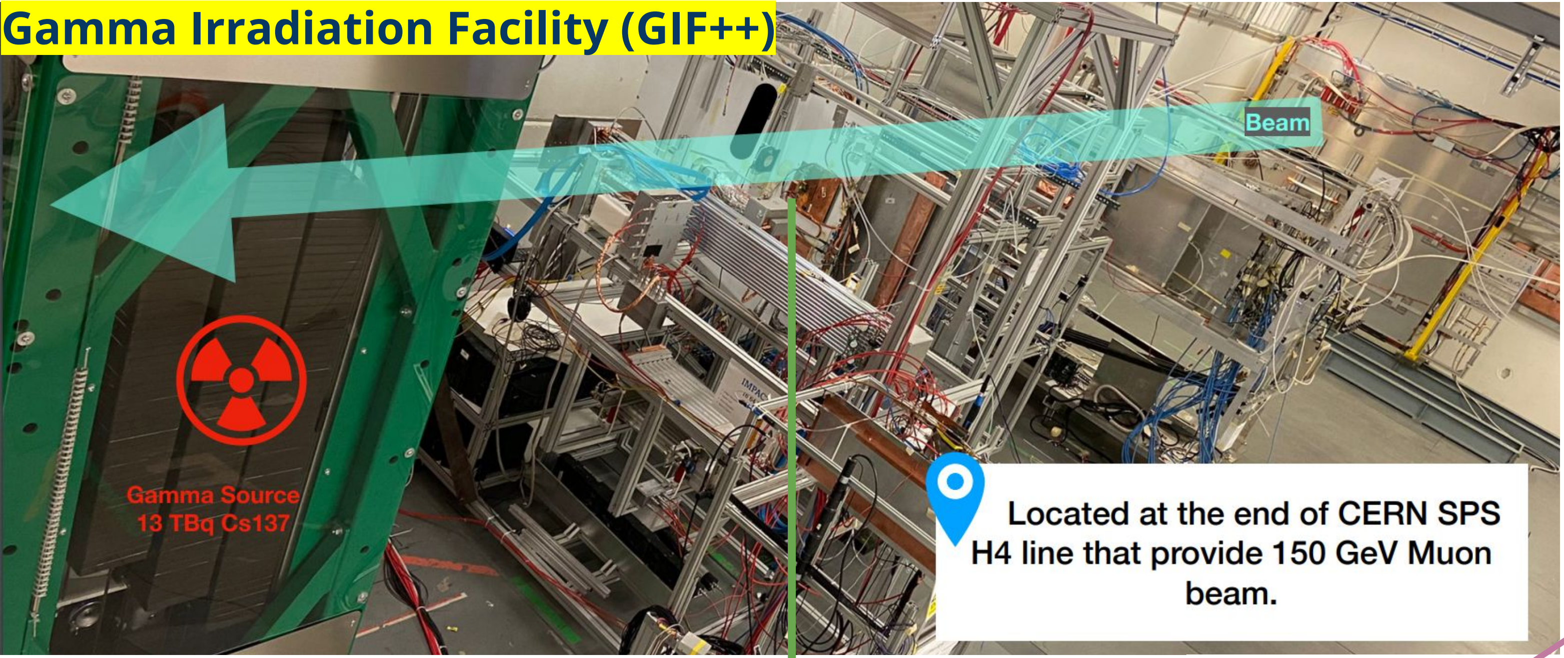
iRPCs are equipped with 2 readout panels (PCBs): **0.6 mm** thin, embedded with **48 strips**, and equipped with a FEB

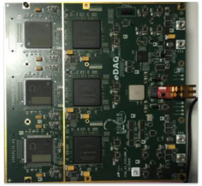
Three ERNI connectors of each FEB reads **96 channels**
Each of the two ends of a strip is connected to a different PETIROC

If amplitude of the signal > channel threshold -> PETIROC sends an output signal to the associated TDC channel

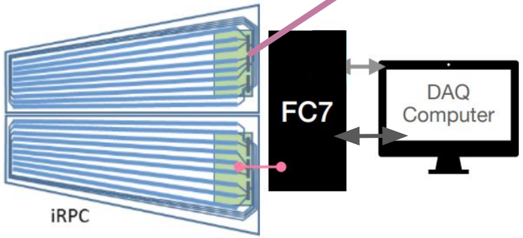
The 2D position information is obtained by **reading out the strips from both ends** (Low Radius (LR) and High Radius (HR)) and then measuring **ΔT**

FEB validation at GIF++

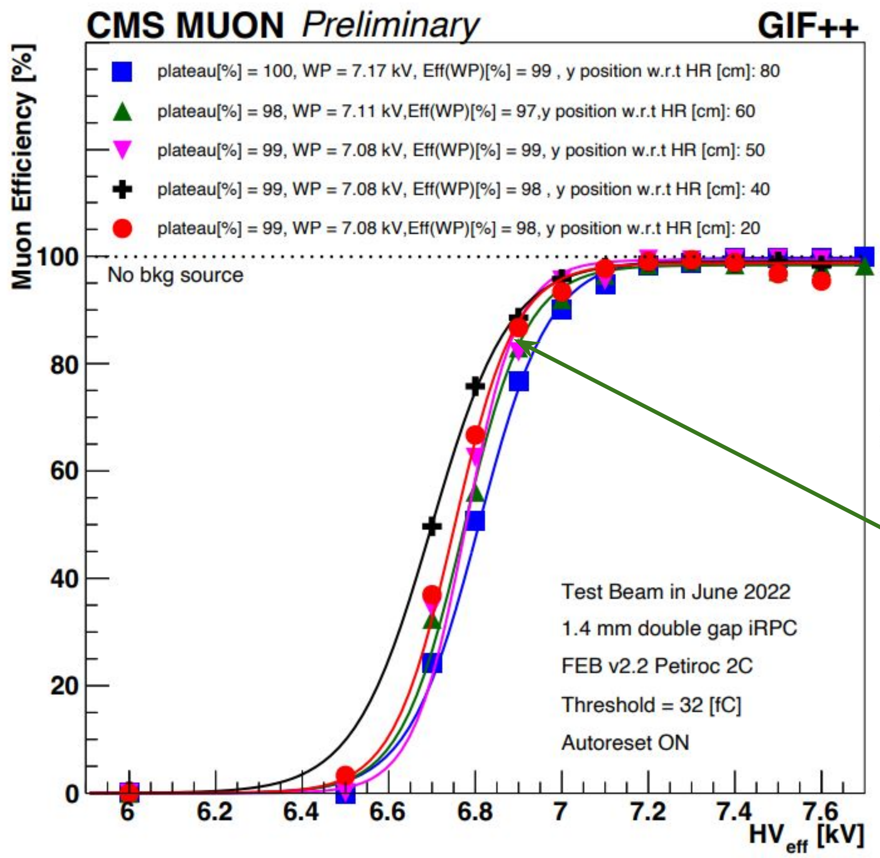




Feb v2.2

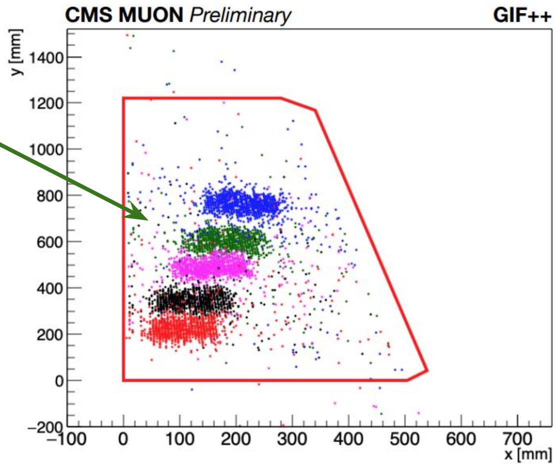


FEB validation results



iRPC efficiency at different y regions

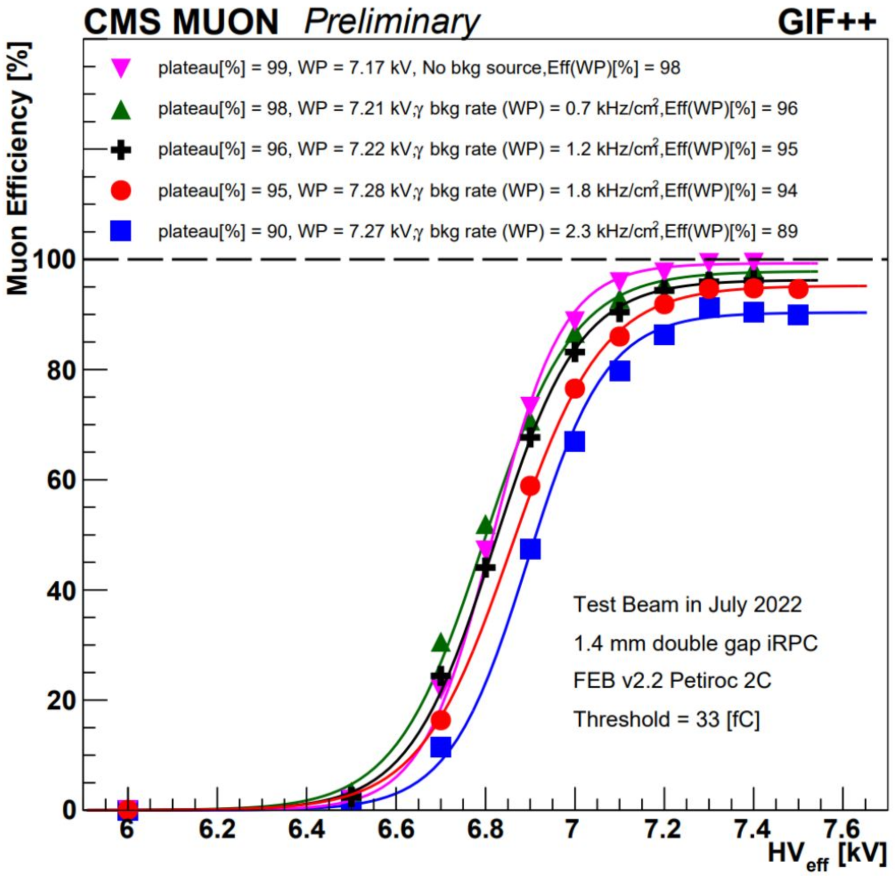
- The efficiency at WP is 98±1%.
- The WP is defined as HVknee +120 V.
- The data is collected at the GIF++ facility during the June 2022 test beams



- Cluster hits from different regions of the chamber
- The effective high voltage is working point (WP) in the absence of background source

.

FEB validation results

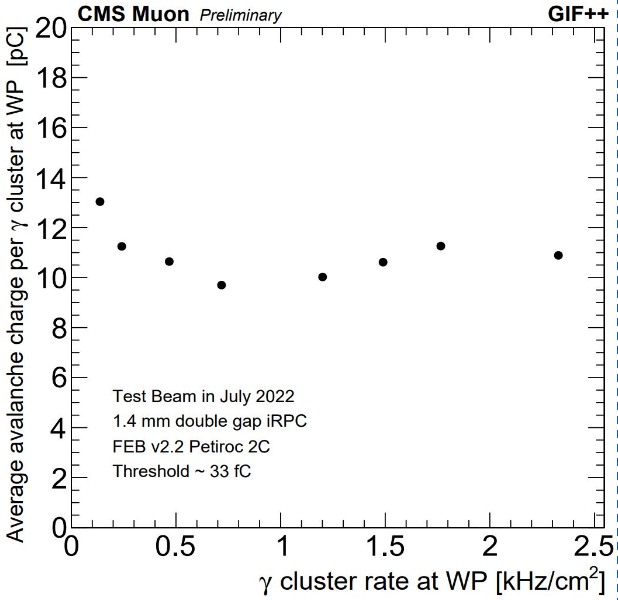


At **0.7 kHz/cm²** (the expected background rate of Phase II) the efficiency at WP ~ **96%**

At **2.3 kHz/cm²** (above the 3 times safe factor of background radiation), the efficiency at WP ~ **89%**

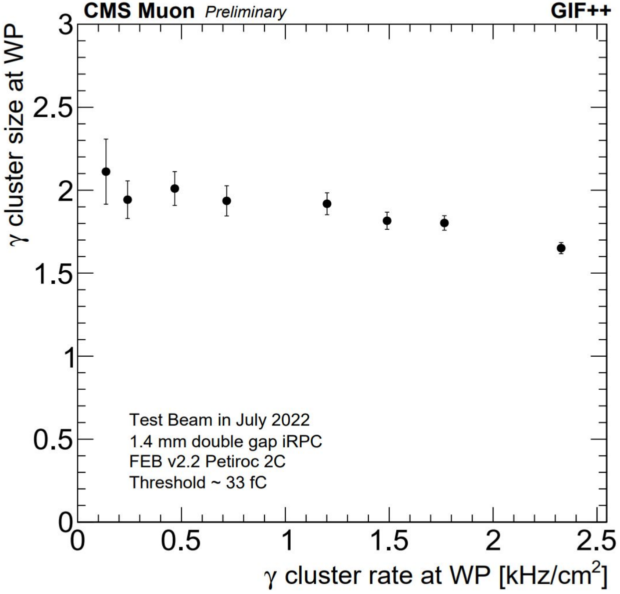
The WP is defined as HV_{knee} +120 V

FEB validation results

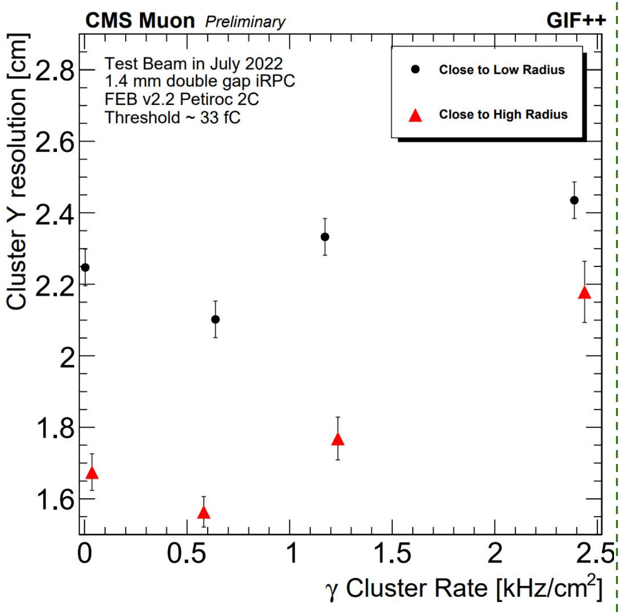


Charge is calculated from the average current measured from both gaps:

$$< q >= \frac{(I_{TOP} + I_{BOT})/2}{rate_{\gamma CLS} \cdot A_{GAP}}$$



Statistical fluctuations are observed in the case of gamma cluster size

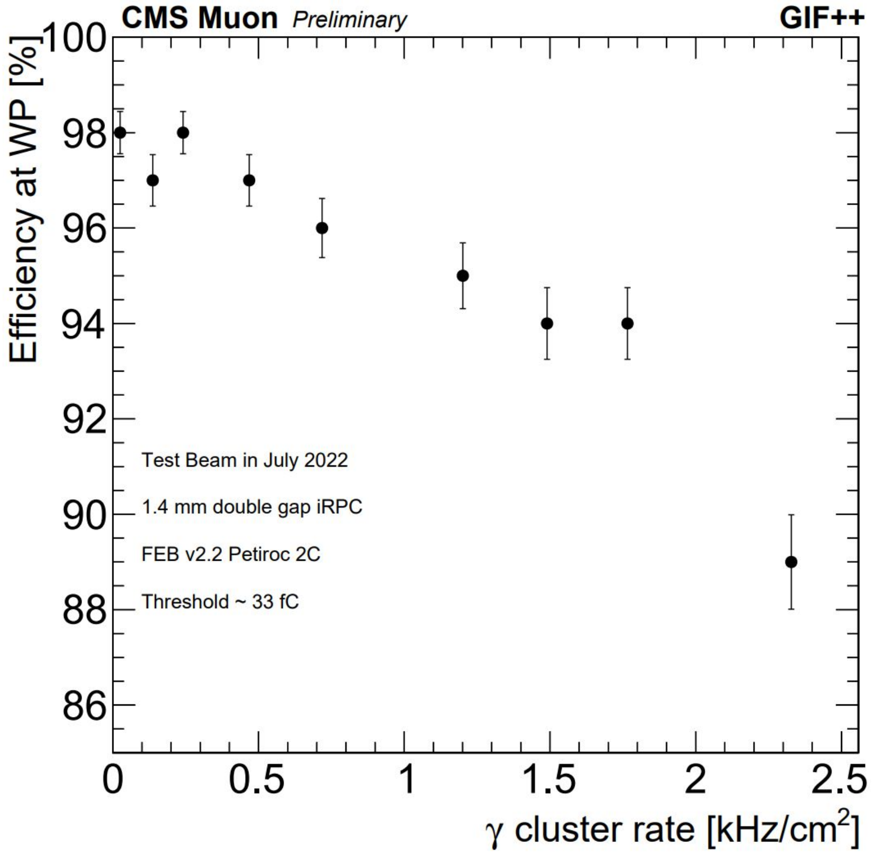


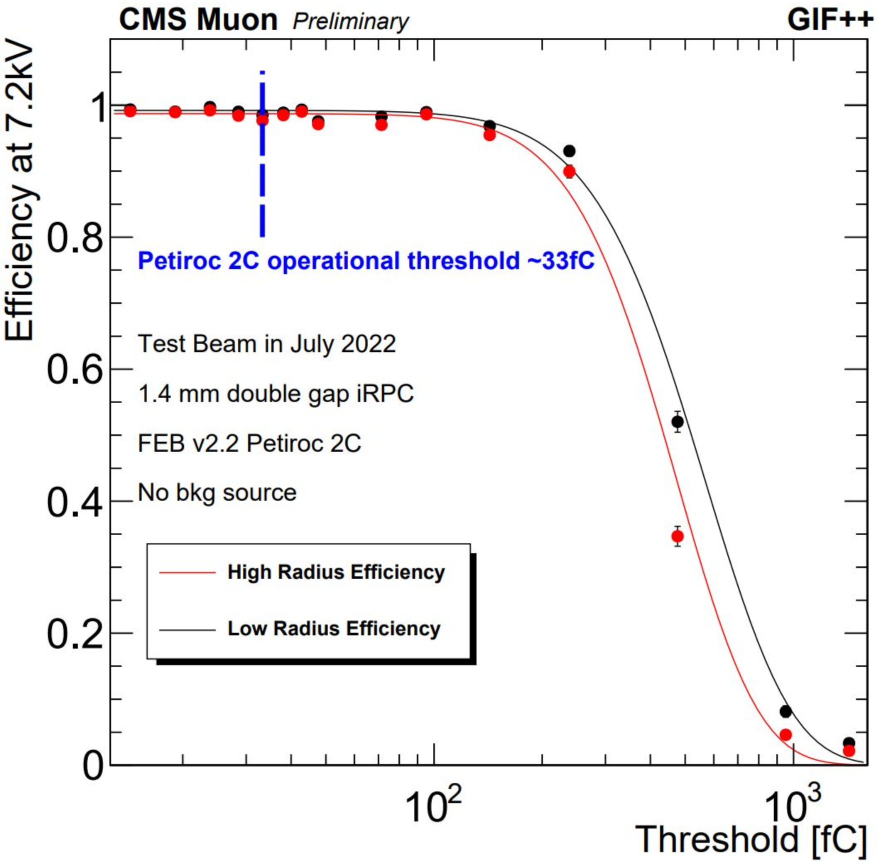
Y resolution<2.6cm @ 2.5 kHz/cm^2

Cluster Y resolution:

$$\Delta y = (v \times \Delta T)/2$$

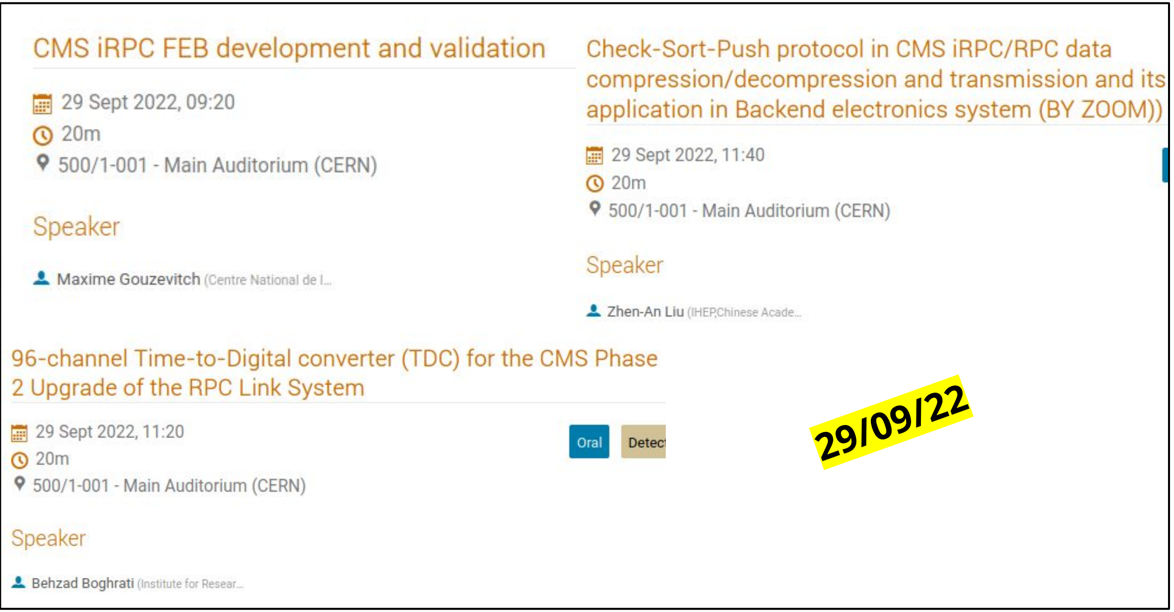
FEB validation results

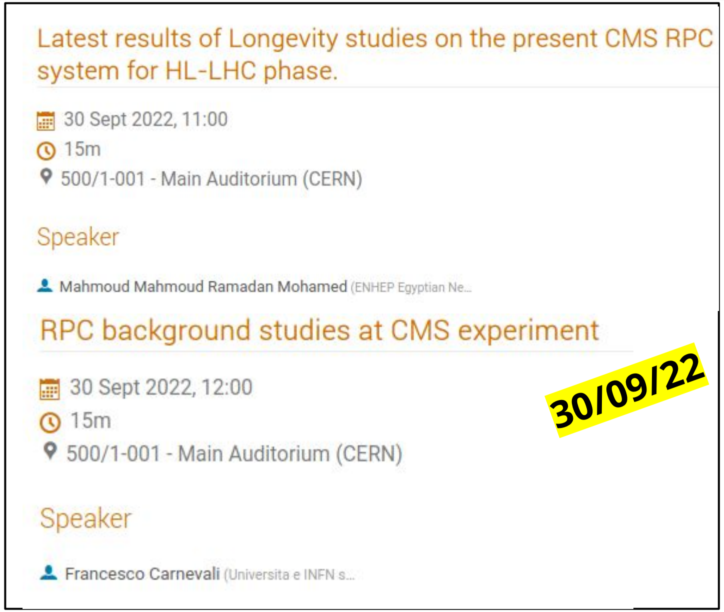




Summary

- To cope with the HL-LHC conditions, RPC coverage will be extended to $|\eta| = 2.4$ by installing iRPCs
- An updated technical layout is proposed for the iRPCs
- As part of the iRPC demonstrator project, eight iRPC chambers were developed and successfully validated
- Four demonstrator chambers were installed and commissioned at p5 and they showed low noise, stable operation under p5 conditions and 3.8T magnetic field
- The first phase of iRPC mass production will launch on November 2022
- All steps of the QC procedures were performed and finalized during the iRPC demonstrator assembly and commissioning
- The performance of the new front-end electronics was validated at the Gamma Irradiation Facility at CERN


CMS iRPC FEB development and validation
29 Sept 2022, 09:20
20m
500/1-001 - Main Auditorium (CERN)
Speaker
Maxime Gouzevitch (Centre National de l...
Check-Sort-Push protocol in CMS iRPC/RPC data compression/decompression and transmission and its application in Backend electronics system (BY ZOOM))
29 Sept 2022, 11:40
20m
500/1-001 - Main Auditorium (CERN)
Speaker
Zhen-An Liu (IHEP,Chinese Acade...
96-channel Time-to-Digital converter (TDC) for the CMS Phase 2 Upgrade of the RPC Link System
29 Sept 2022, 11:20
20m
500/1-001 - Main Auditorium (CERN)
Oral
Speaker
Behzad Boghrati (Institute for Resear...
29/09/22


Latest results of Longevity studies on the present CMS RPC system for HL-LHC phase.
30 Sept 2022, 11:00
15m
500/1-001 - Main Auditorium (CERN)
Speaker
Mahmoud Mahmoud Ramadan Mohamed (ENHEP Egyptian Ne...
RPC background studies at CMS experiment
30 Sept 2022, 12:00
15m
500/1-001 - Main Auditorium (CERN)
Speaker
Francesco Carnevali (Universita e INFN s...
30/09/22

Thank You

Backup Slides

First proto

2017

proof of principle for CMS-MUON-TDR-016

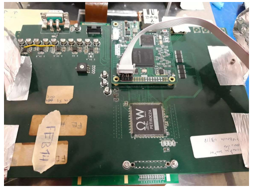
2 PetiROC2A
+ FPGA Cyclone II
+ ETHERNET
directly on strip PCB
(50 cm)

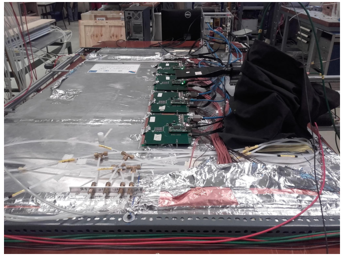
Feb V0

2018

First FEB (Conf. note)

1 PetiROC2A +
MEZZANINE with
FPGA Cyclone II
+ ETHERNET





Feb V1

2019

FEB without mezzanine

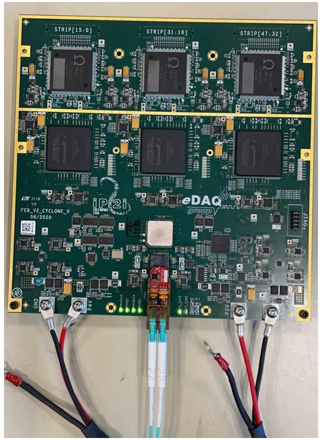
2 PetiROC2B
+ FPGA Cyclone V
+ ETHERNET

Feb V2

2021

Non-rad hard for iRPC Demo

6 PETIROC2C
+ 3 FPGA Cyclone V
+ Optical GBT

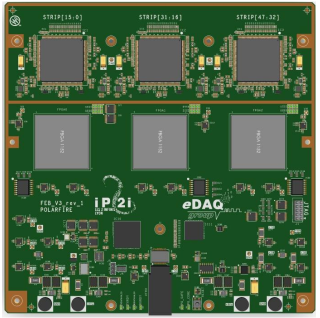


Feb V3

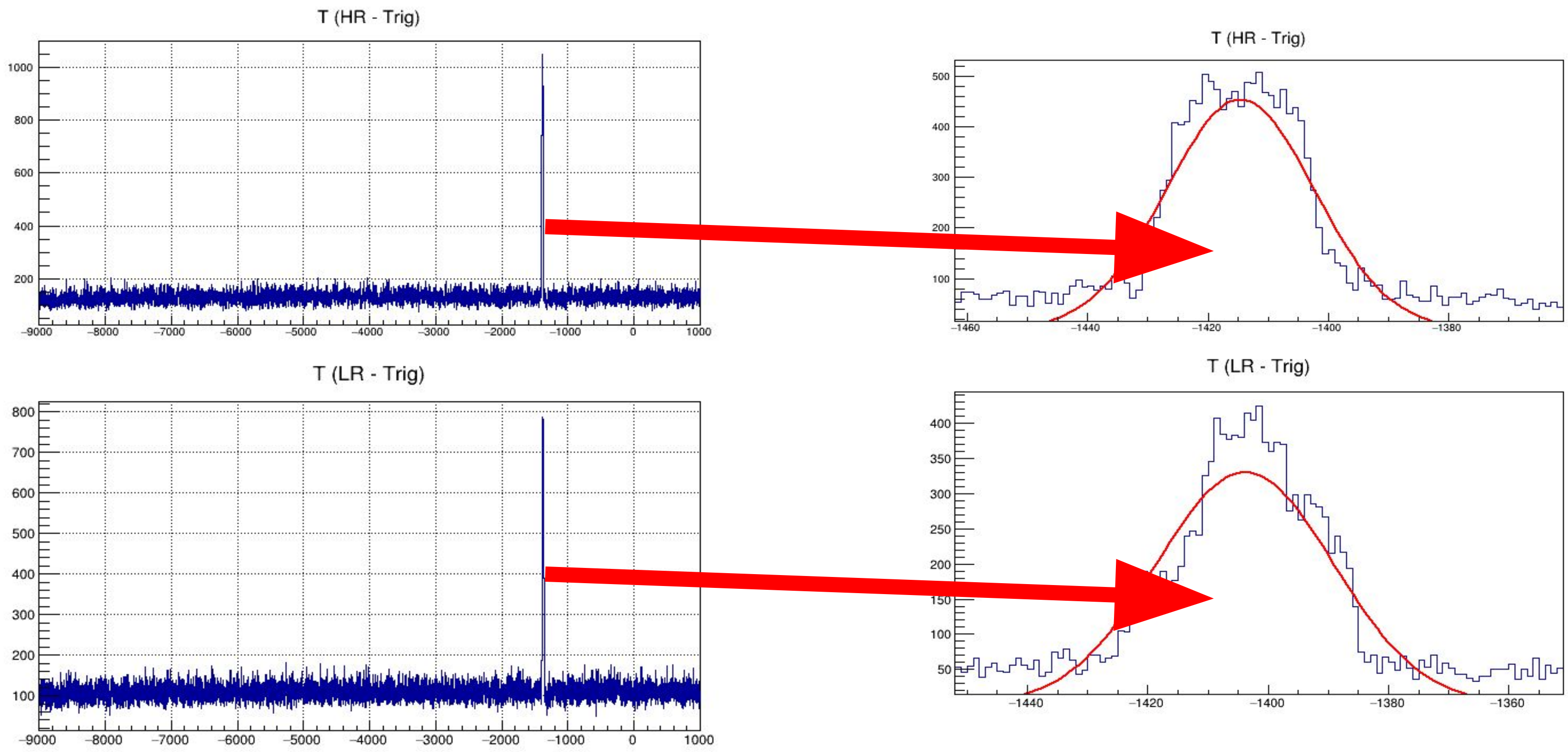
→ 2023

Rad hard final

6 PETIROC2C
+ 3 FPGA PolarFire
+ Optical GBT



Data taking and analysis overview

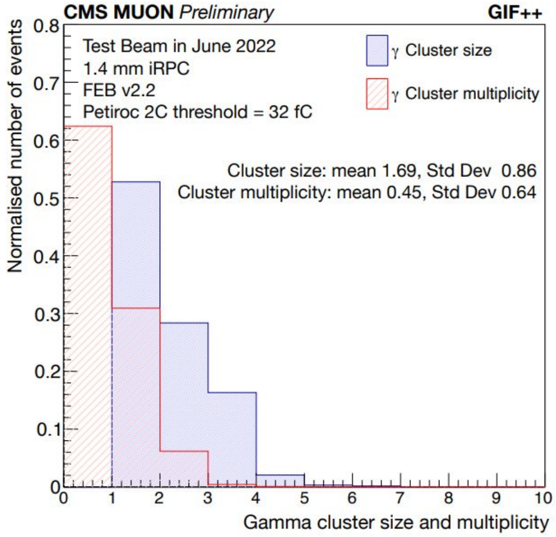


(trigger delay of ~1.5 μs comes from the cables length - scintillator -> FC7)

Data taking and analysis overview

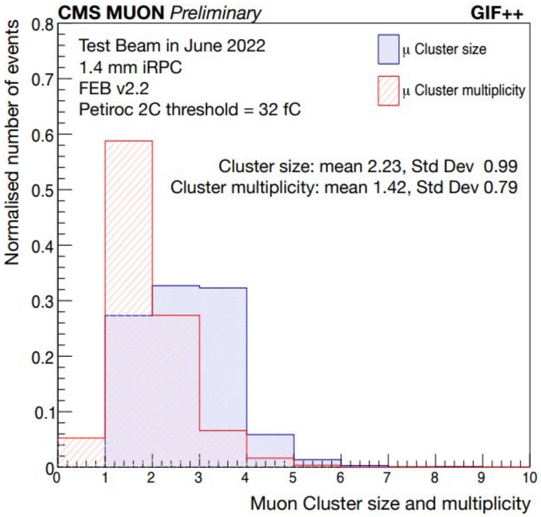
- Then we count the events:
  - **Events with HR AND LR inside the muon window -> to evaluate "AND" efficiency**
  - Events with at least one cluster -> to evaluate "cluster" efficiency
- The efficiency is evaluated in the correct muon window and in a shifted (by 1000 ns) window - to evaluate the efficiency due to the background and perform the bkg subtraction
- Final efficiency:

$$\text{Efficiency} = (\text{Eff}_{muon\_window} - \text{Eff}_{bkg\_window})/(1 - \text{Eff}_{bkg\_window})$$



CAPTION:

Figure shows distributions of the cluster size and the number of clusters for the collected gamma events that are out side muon window close to the working point (HV_{eff} = 7.2 kV) with the back ground radiation of ~1 kHz/cm^2.
The data is collected at the GIF++ facility during the June 2022 test beams. The 13 Tbq Cs^{137} is used as gamma source to mimic the back ground.



CAPTION:

Figure shows distributions of the cluster size and the number of clusters for the collected muon events close to the working point (HV_{eff} = 7.2 kV) with the back ground radiation of ~1 kHz/cm^2.
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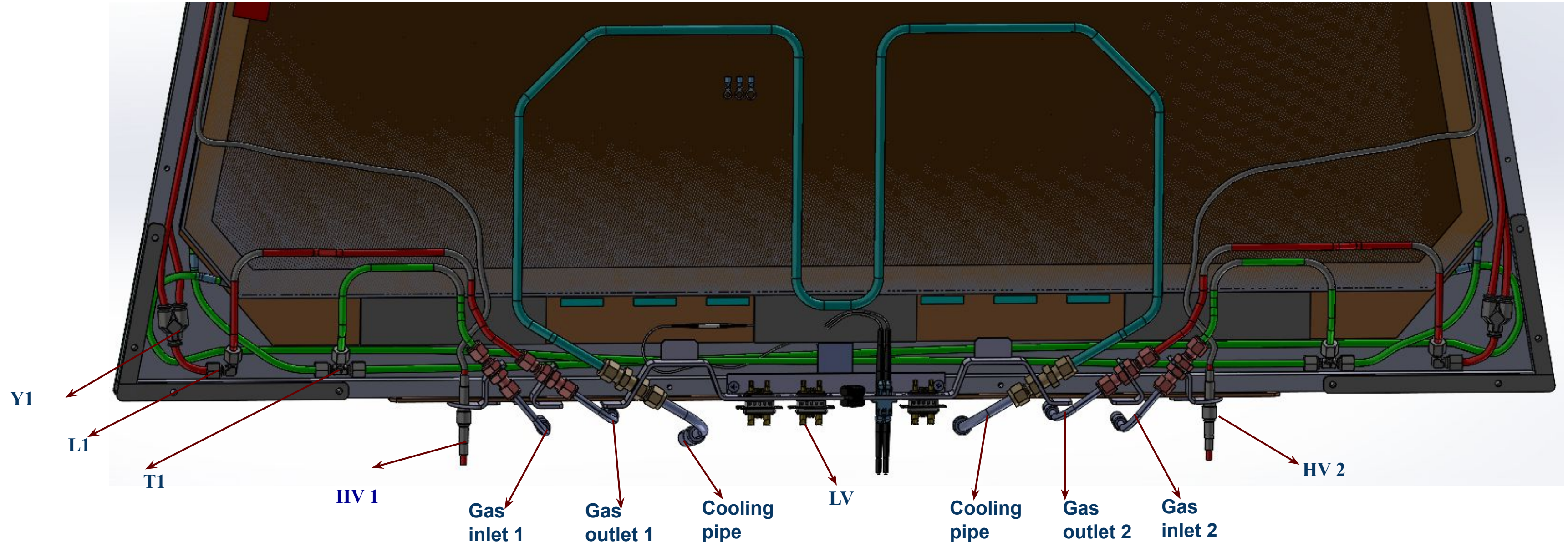
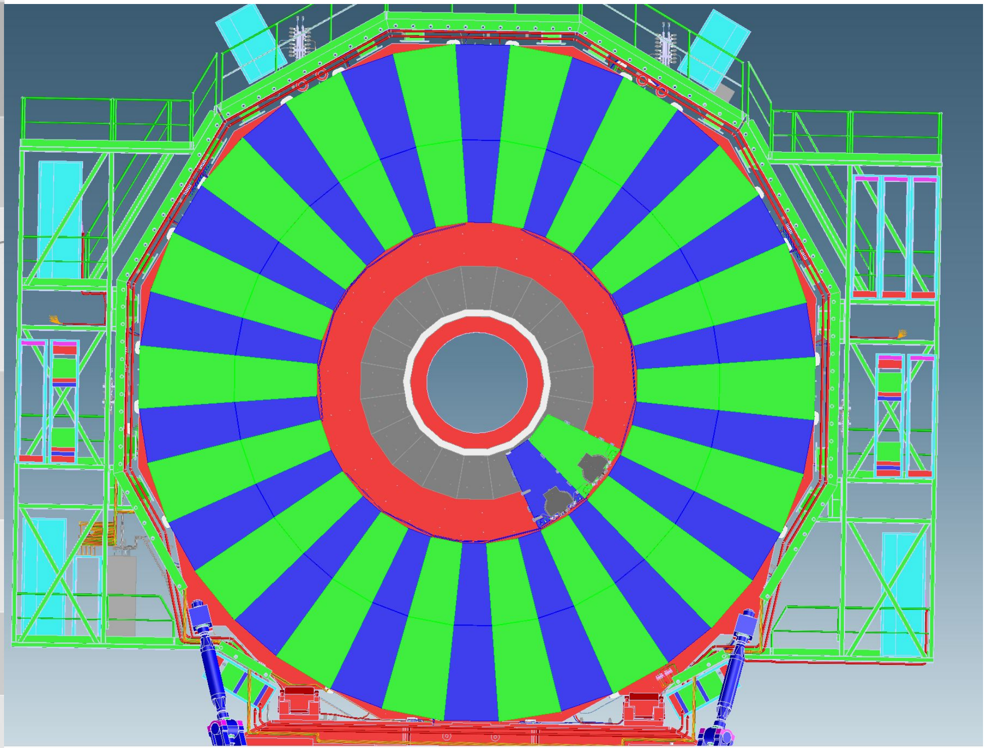
iRPC technical layout



Improved mechanical layout by adding patch panel to hold all the mechanics in position and separate gas loops for top and bottom gaps

Motivation

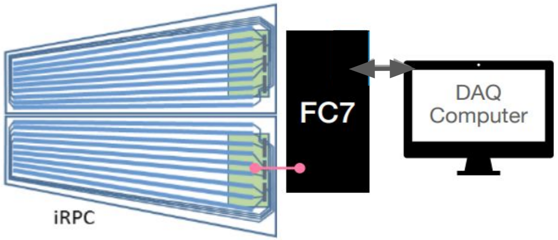
	Present system	iRPC
|η| coverage	0 – 1.9	1.8 – 2.4
Max expected rate (Safety factor SF = 3 included)	600 Hz/cm^2	2 kHz/cm^2
Max integrated charge at 3 ab^{-1} (SF = 3 included)	~ 0.8 C/cm^2	~ 1.0 C / cm^2
ϕ granularity	~ 0.3 °	~ 0.2°
η resolution	~ 20 cm	~ 2 cm
T resolution	1.5 ns	< 1 ns



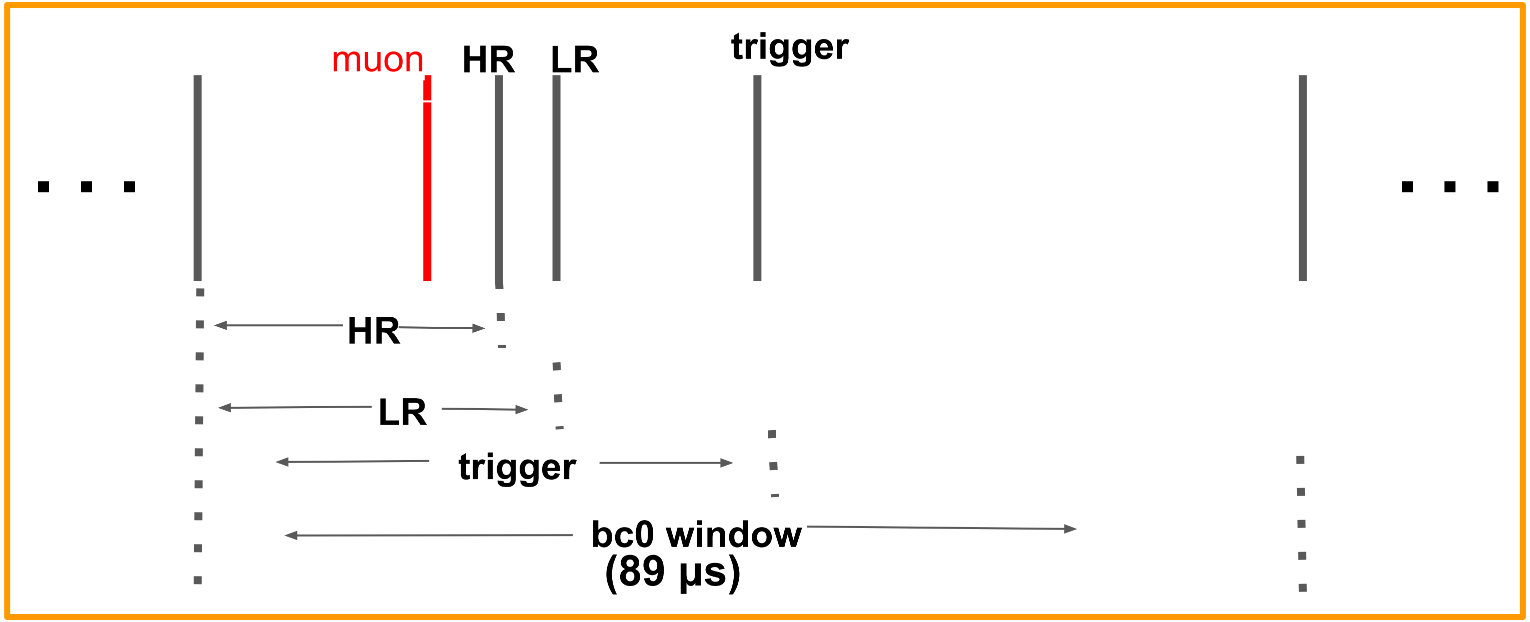
MEK solvent

Methyl Ethyl Ketone is a liquid solvent that is found in adhesives, printing inks, and surface coatings. MEK cleaner contains lube oil dewaxing agents and is used as a medium to extract waxes, oils, fats, and resins. Its effectiveness has made it one of the most popular liquid solvent today

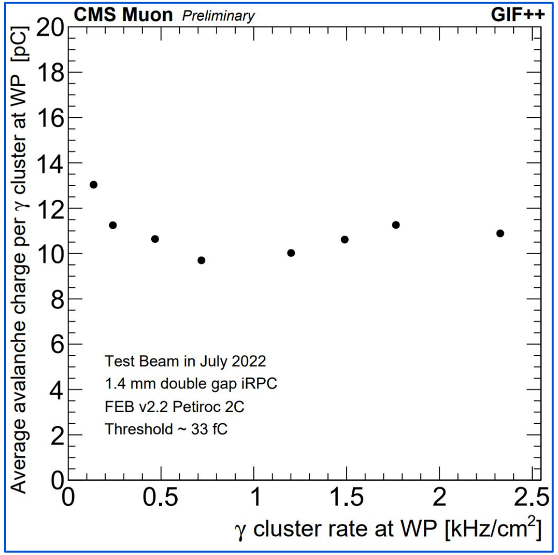
Data taking and analysis overview



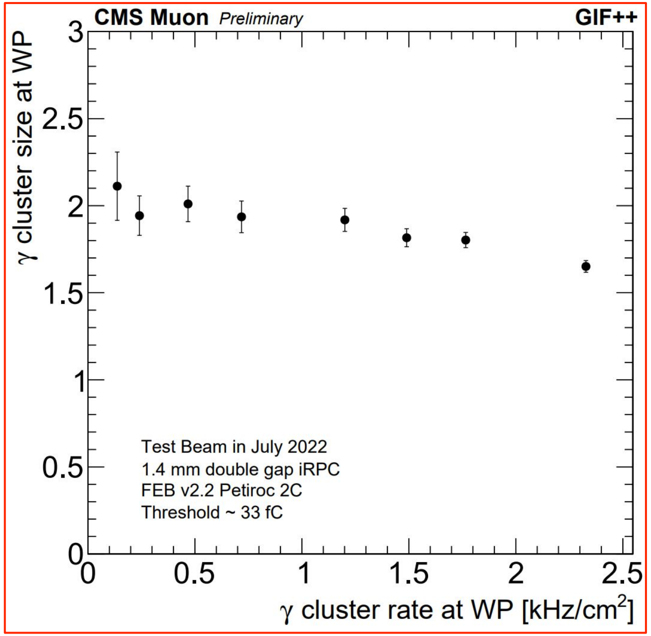
One event



Performance studies



The figure shows the gamma cluster size for the collected gamma events that are outside muon window at working point as a function of gamma background rates. The statistical uncertainty is present for the gamma cluster size. The data is collected at the GIF++ facility during the July 2022 test beams. The 13 TBq Cs^{137} is used as gamma source to mimic the background, and the new front-end electronics (FEB v2.2) with Petiroc 2C ASIC was used.

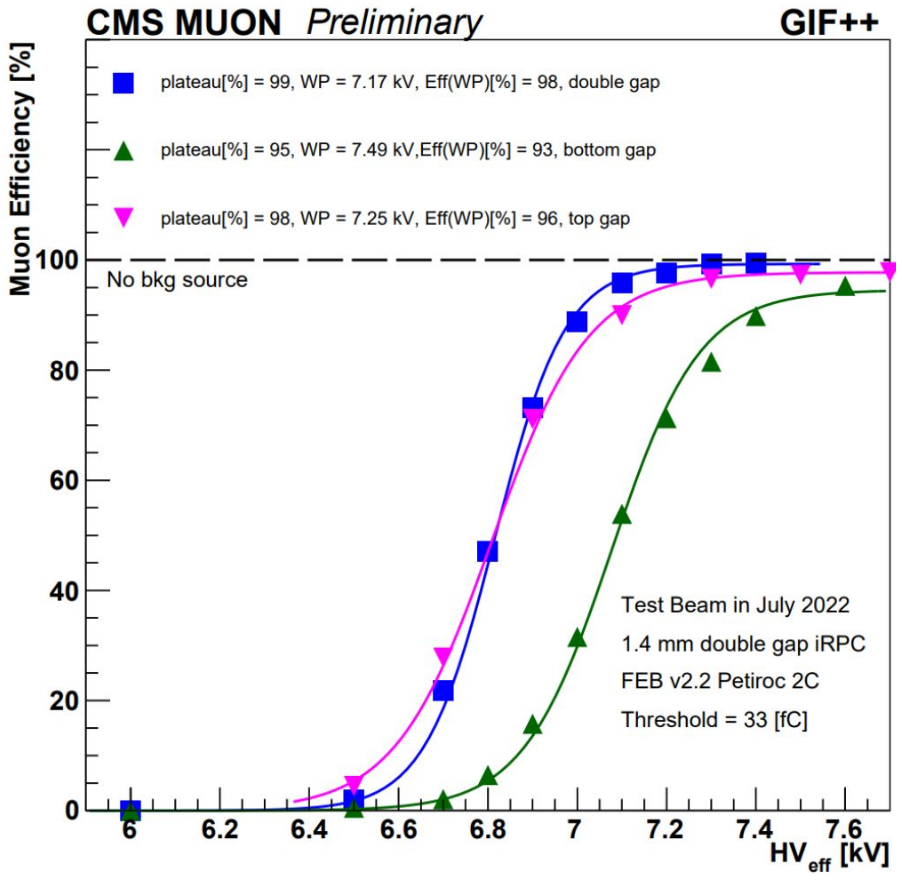


The figure shows the average avalanche charge per gamma cluster at the working point (WP) versus gamma background rates at the associated WP. The charge is calculated using the average of the currents measured for two gaps. The charge is calculated as follows:

$$<Q>=\frac{(I_{TOP}+I_{BOT})/2}{rate_{\gamma CLS}\cdot A_{GAP}}$$

Where I_{TOP}(I_{BOT}) is the current of the top (bottom) gap, $rate_{\gamma CLS}$ is the rate of gamma clusters and A_{GAP} is the area of the gap.

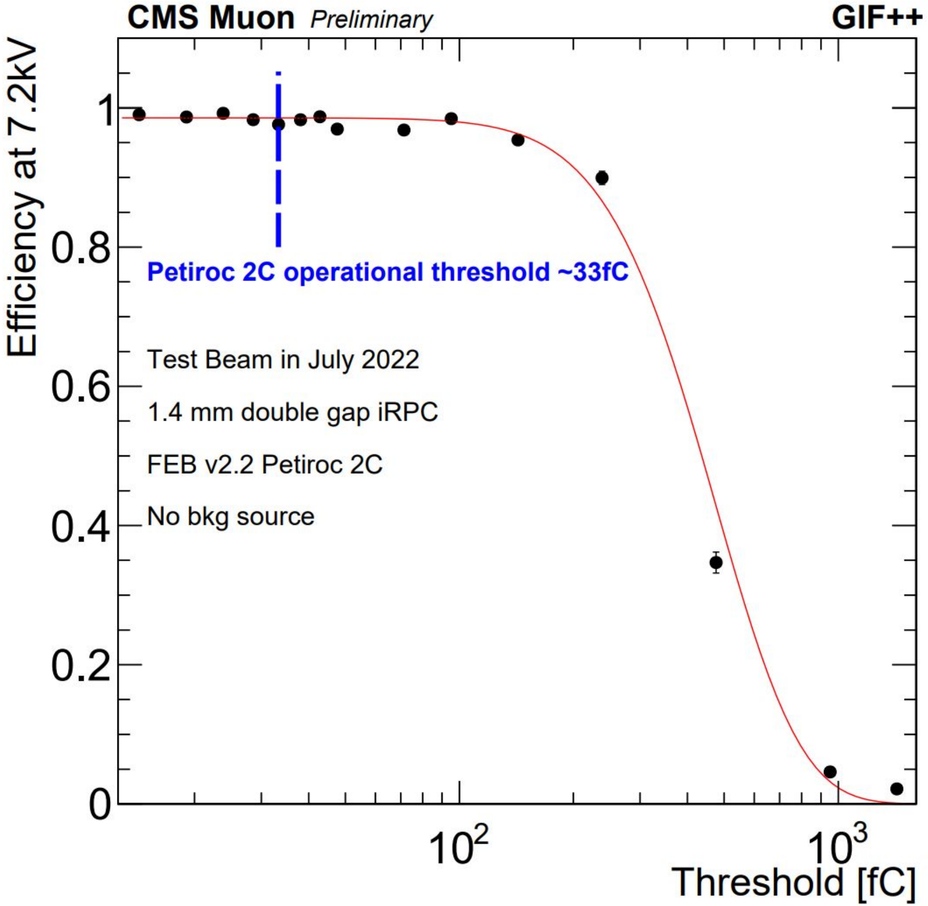
Performance studies



The figure shows efficiency versus effective high voltage without background source for different configuration for the gaps: double gap, only bottom gap, and only top gap on. The WP is defined as HV_{knee} +120 V. The efficiency shown is calculated after subtraction of the estimated gamma background using events falling outside the muon window.

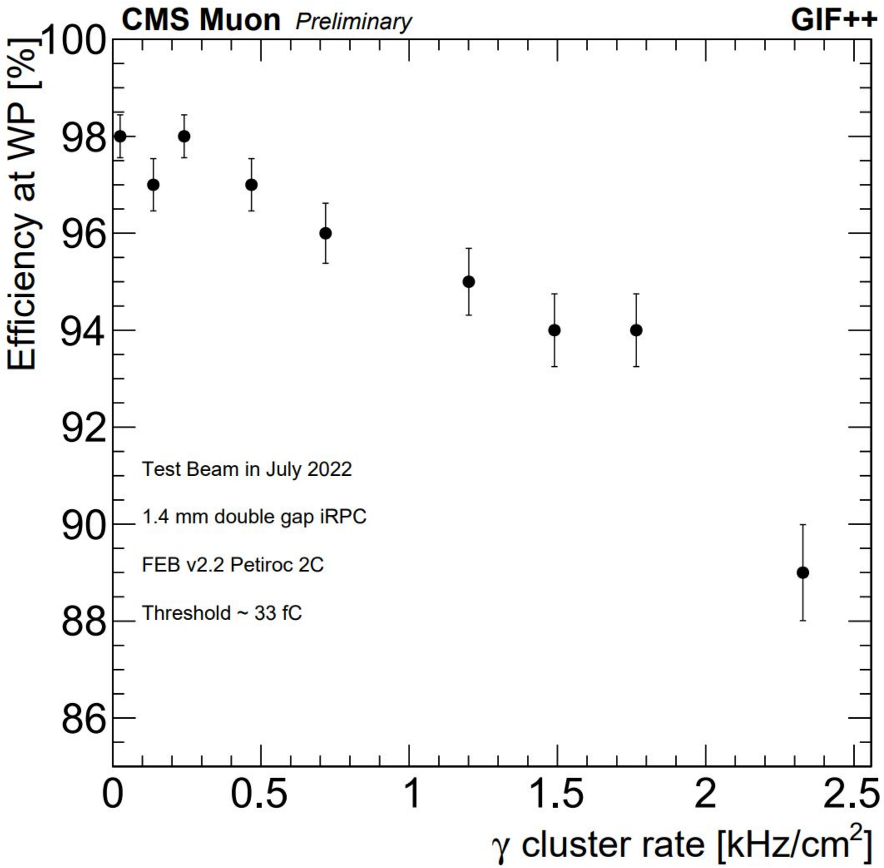
The dashed line is placed at the 100% efficiency. The data is collected at the GIF++ facility during the July 2022 test beams. The 13 TBq Cs^{137} is used as gamma source to simulate the LHC background, and the new front-end electronics (FEB v2.2) with Petiroc 2C ASIC was used. When the statistical uncertainty is smaller than 2%, the associated error bars disappear behind the data points.

Performance studies



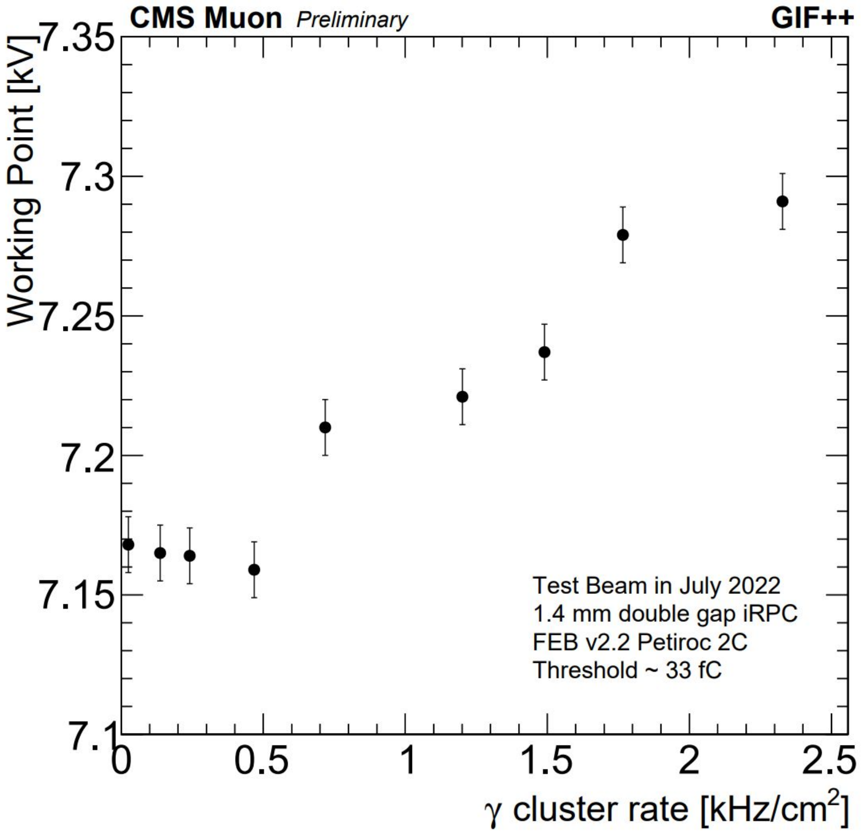
The figure shows AND efficiency at HV=7.2kV as a function of threshold. The AND efficiency is evaluated with the events that have signal in both HR and LR sides. The efficiency shown is calculated after subtraction of the estimated gamma background using events falling outside the muon window. A Cumulative Distribution Functions is used to fit the curve. When the statistical uncertainty is smaller than 2%, the associated error bars disappear behind the data points. The data is collected at the GIF++ facility during the July 2022 test beams. The 13 TBq Cs^{137} is used as gamma source to mimic the background, and the new front-end electronics (FEB v2.2) with Petiroc 2C ASIC was used.

Performance studies



The figure shows efficiency at working point high voltage as a function of gamma background rates at the associated WP. At 0.7 kHz/cm^2 (the expected background rate of Phase II), the efficiency at WP is measured as 96%. If we take the average between the last 2 points, at 2 kHz/cm^2 (the 3 times safe factor of background radiation), the efficiency at WP is expected as 94%. The WP is defined as HV_{knee} +120 V. The efficiency shown is calculated after subtraction of the estimated gamma background using events falling outside the muon window. The statistical uncertainty is present for the efficiency. The data is collected at the GIF++ facility during the July 2022 test beams. The 13 TBq Cs^{137} is used as gamma source to mimic the background, and the new front-end electronics (FEB v2.2) with Petiroc 2C ASIC was used.

Performance studies



The figure shows the working points as a function of gamma background rates at the WP. The WP is defined as HV_{knee} +120 V. The HV uncertainty was set as 10V as recommended in previous studies. The data is collected at the GIF++ facility during the July 2022 test beams. The 13 TBq Cs^{137} is used as gamma source to mimic the background, and the new front-end electronics (FEB v2.2) with Petiroc 2C ASIC was used.