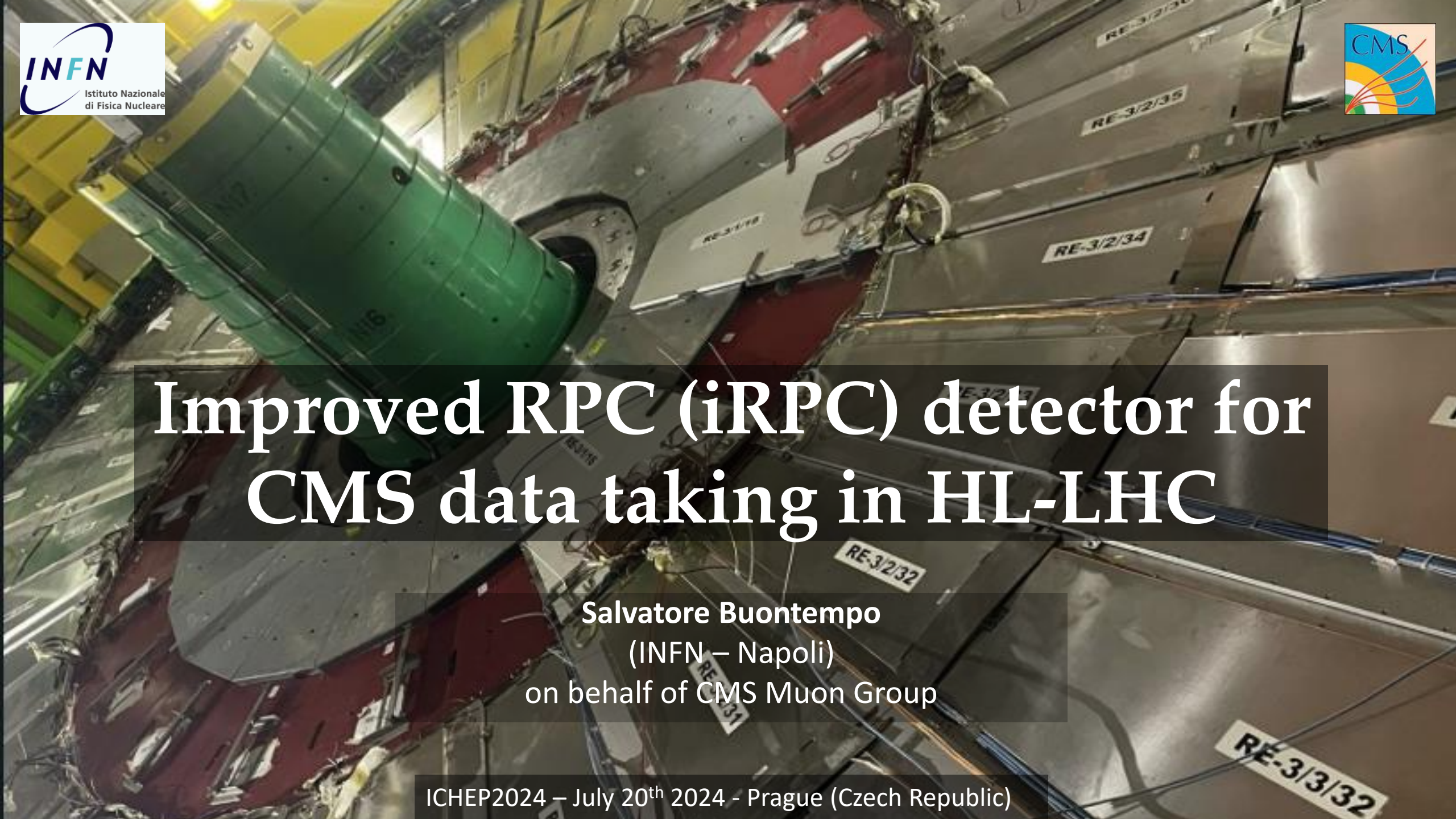


Improved RPC (iRPC) detector for CMS data taking in HL-LHC

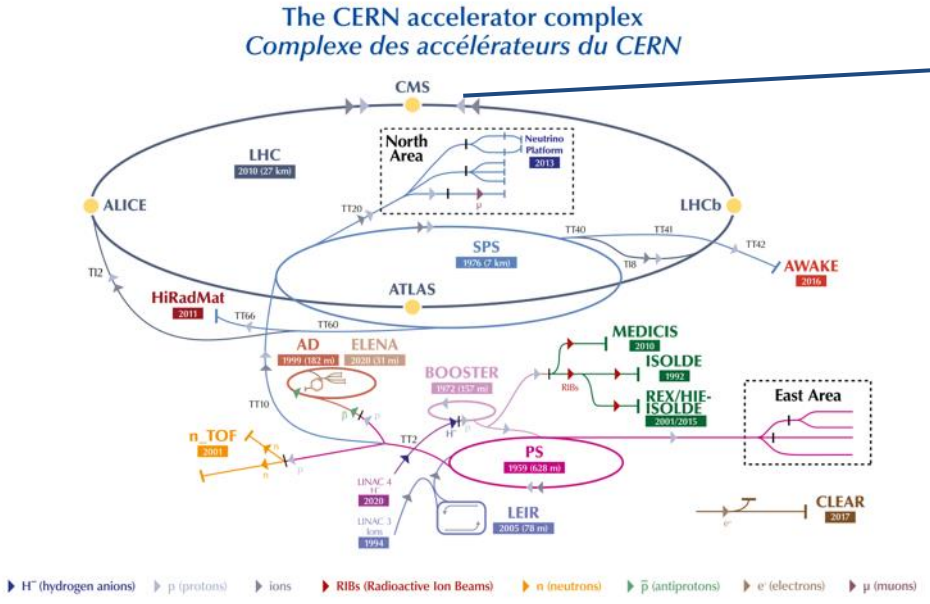
Salvatore Buontempo
(INFN – Napoli)
on behalf of CMS Muon Group

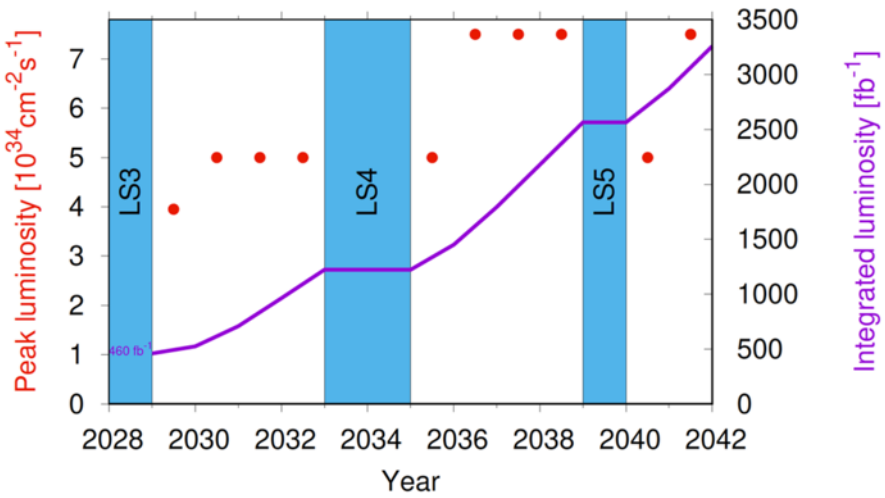
ICHEP2024 – July 20th 2024 - Prague (Czech Republic)

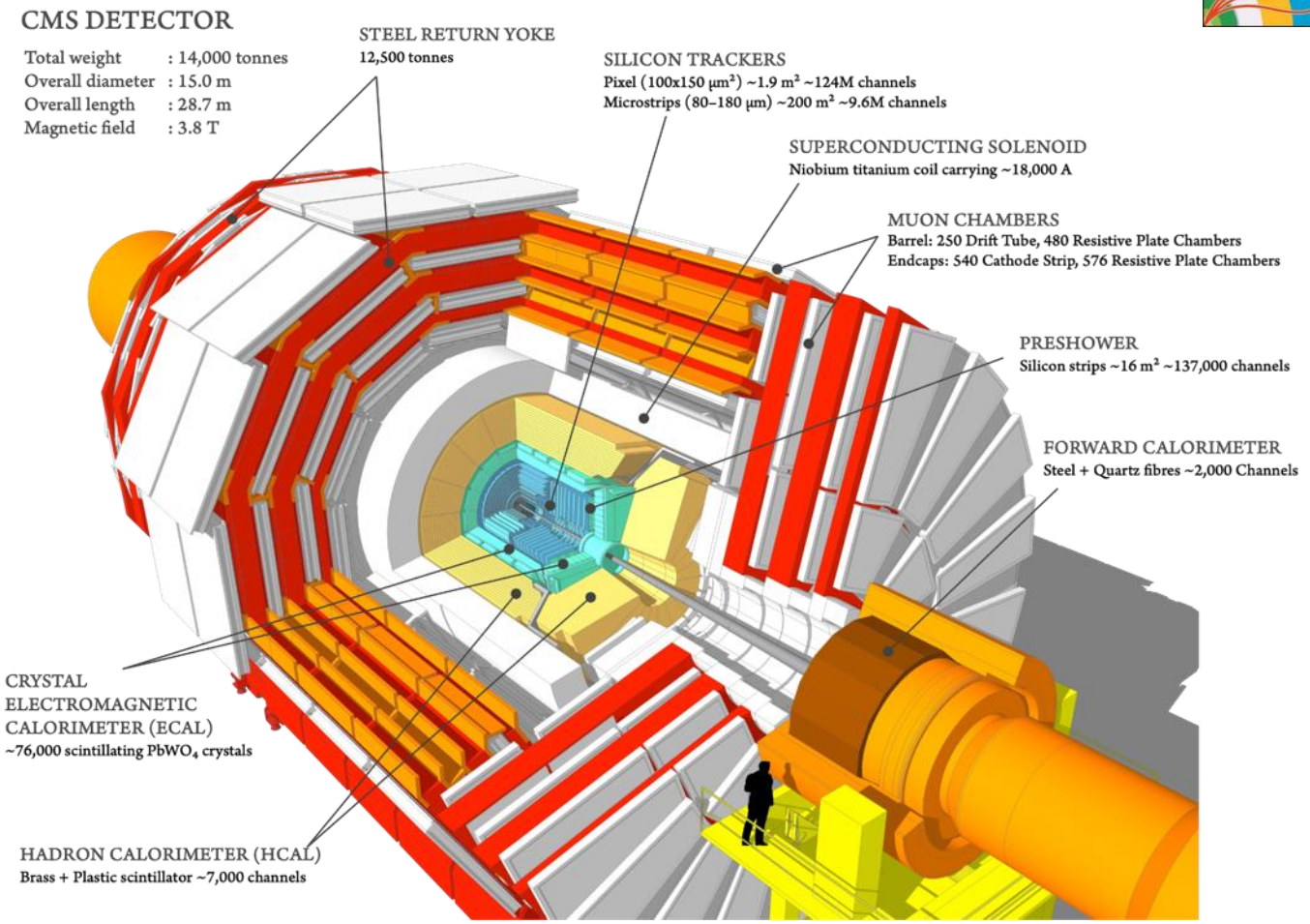
Outline

- The Compact Muon Solenoid (CMS) for the HL-LHC
- The improved Resistive Plate Chambers (iRPCs) in CMS
- iRPC production and quality control
- Time and space resolution
- Performance of iRPCs under gamma background
- Installation in CMS
- Conclusions and Perspectives

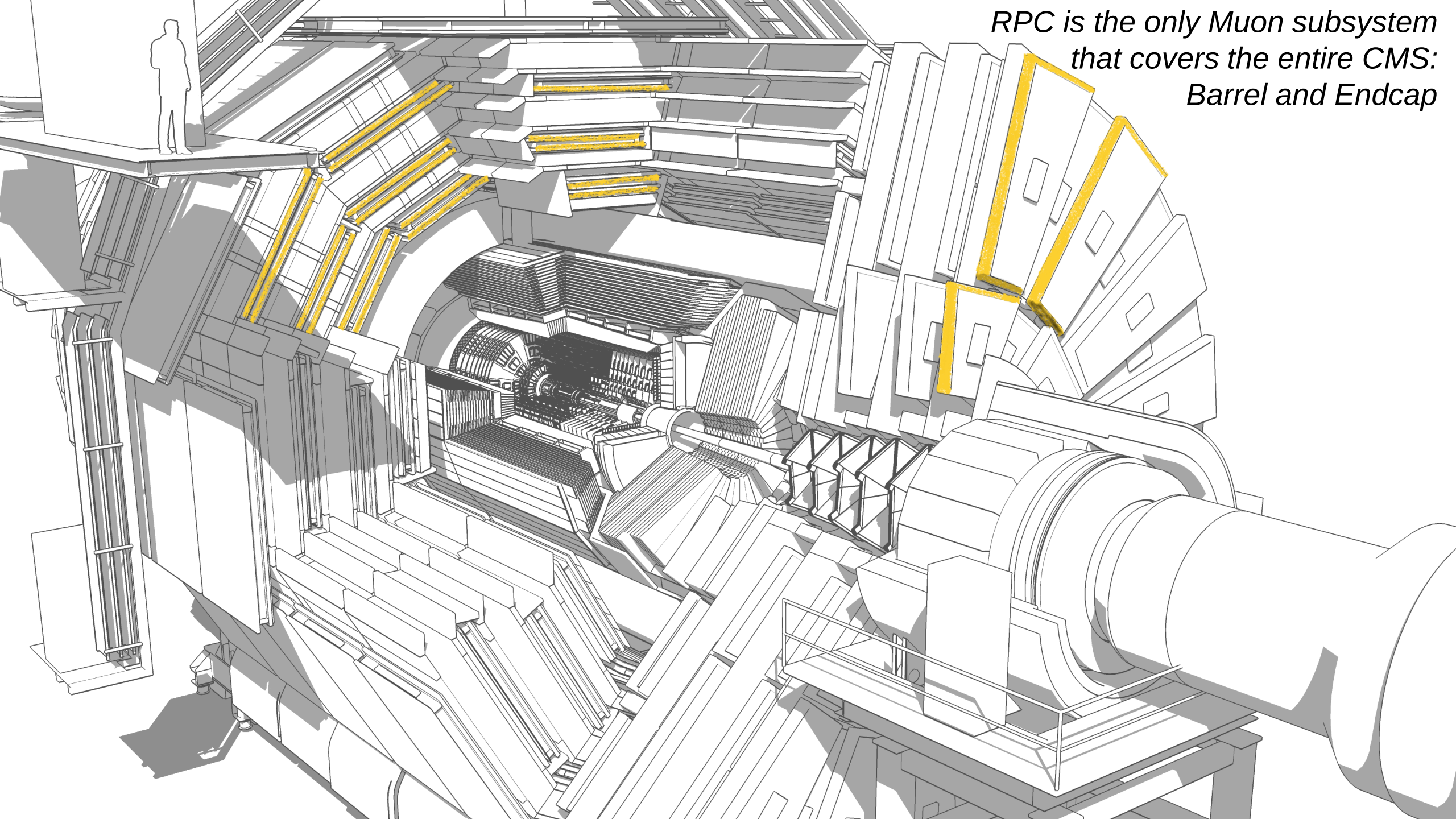
The Compact Muon Solenoid for HL-LHC





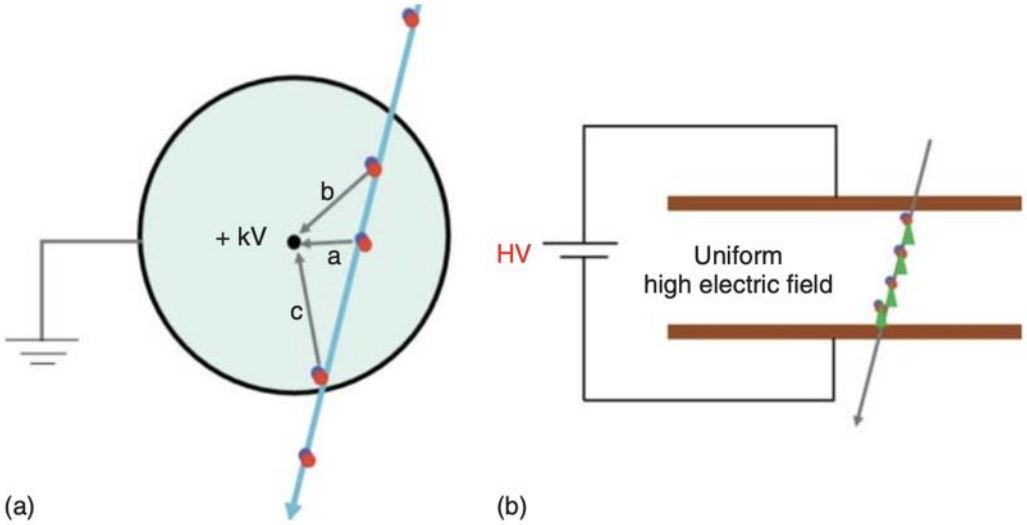


CMS is under Run III data taking and in the process of preparation to extend its sensitivity to new physics searches for the High-Luminosity LHC period starting in 2029, anticipated to feature a higher Instantaneous Luminosity to around 3000 fb^{-1}.

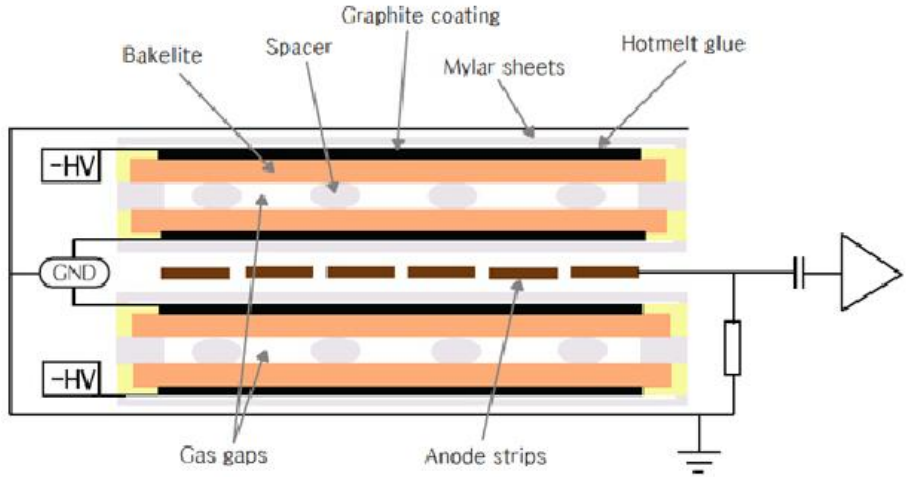

RPC is the only Muon subsystem that covers the entire CMS: Barrel and Endcap

International CMS RPC

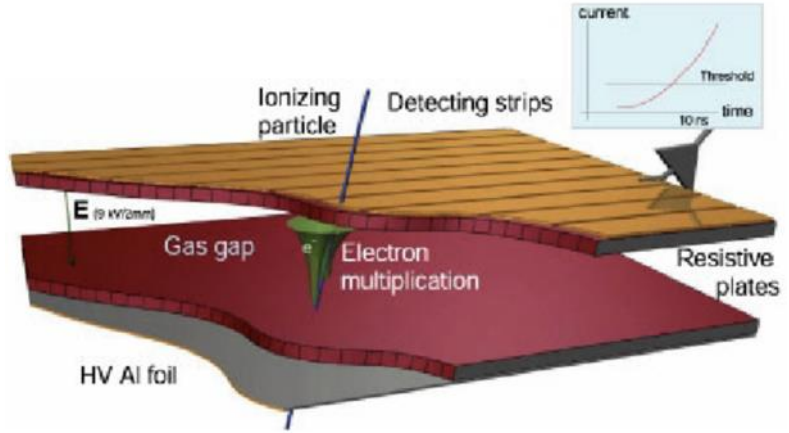
The Resistive-plate Chambers in CMS



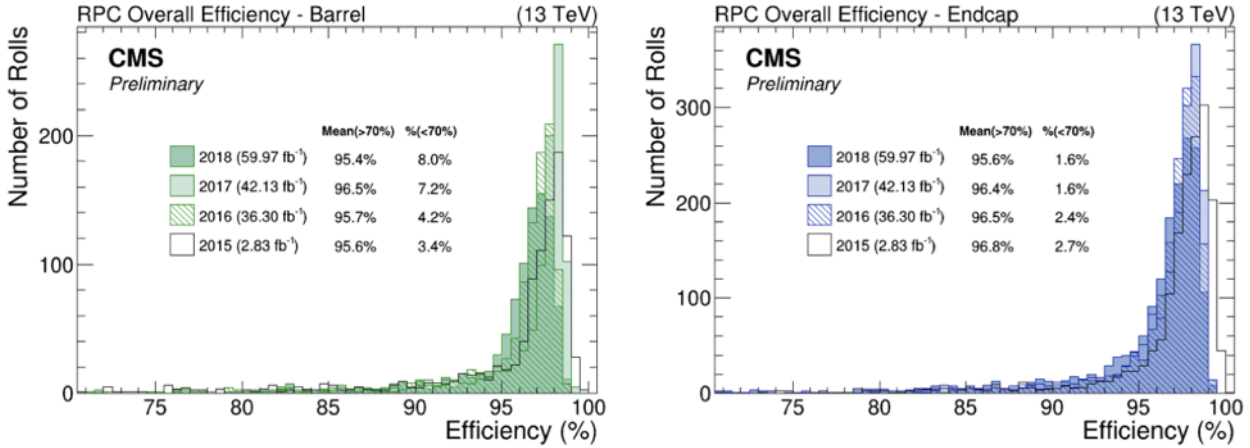
Abbrescia et al, 2018



Park, S et al (2012). CMS endcap RPC gas gap production for upgrade. Journal of Instrumentation. 7. P11013.



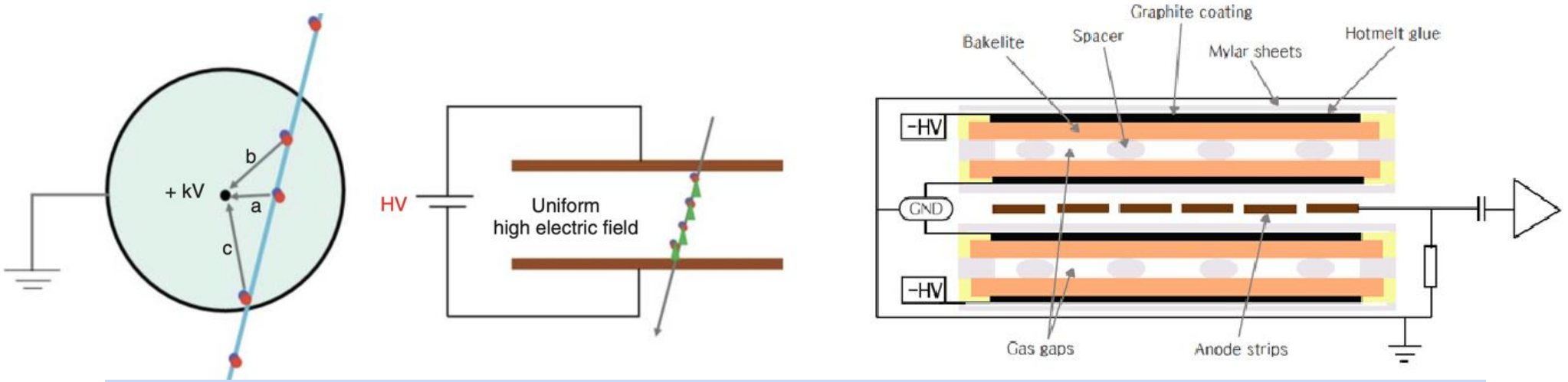
Guiducci, Luigi & Montanari, Alessandro & Odorici, Fabrizio & Rossi, Antonio. (2006). Design and Test of the Off-Detector Electronics for the CMS Barrel Muon Trigger



RPC barrel and end cap efficiency during Run II (2015-2018)

Gas mixture used in CMS/RPC: 95.2 % $C_2H_2F_4$ + 4.5 % i-C_4H_{10} + 0.3 % SF_6

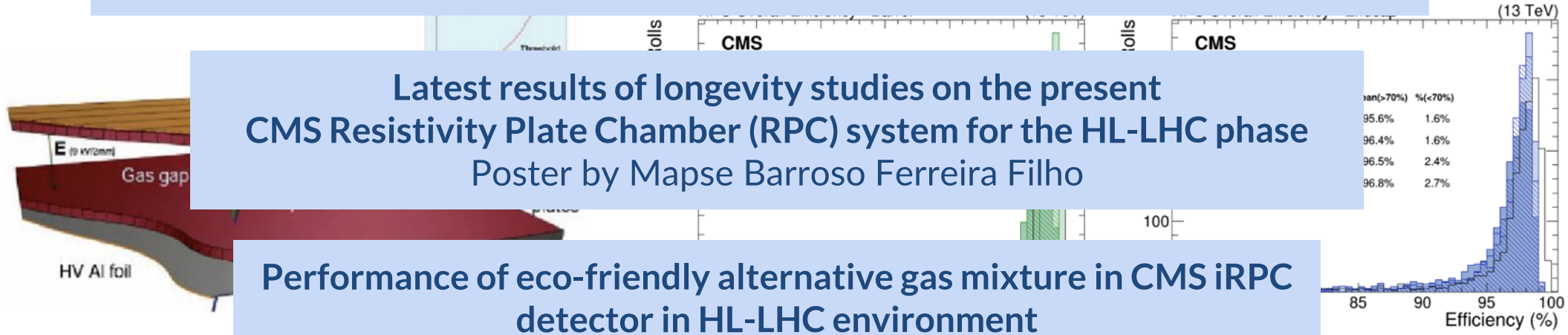
The Resistive-plate Chambers in CMS



(a)

Abbrescia

Operations and Performance Summary of CMS Muon System for LHC Run 3
Talk by Gabriella Pugliese



Latest results of longevity studies on the present CMS Resistivity Plate Chamber (RPC) system for the HL-LHC phase
Poster by Mapse Barroso Ferreira Filho

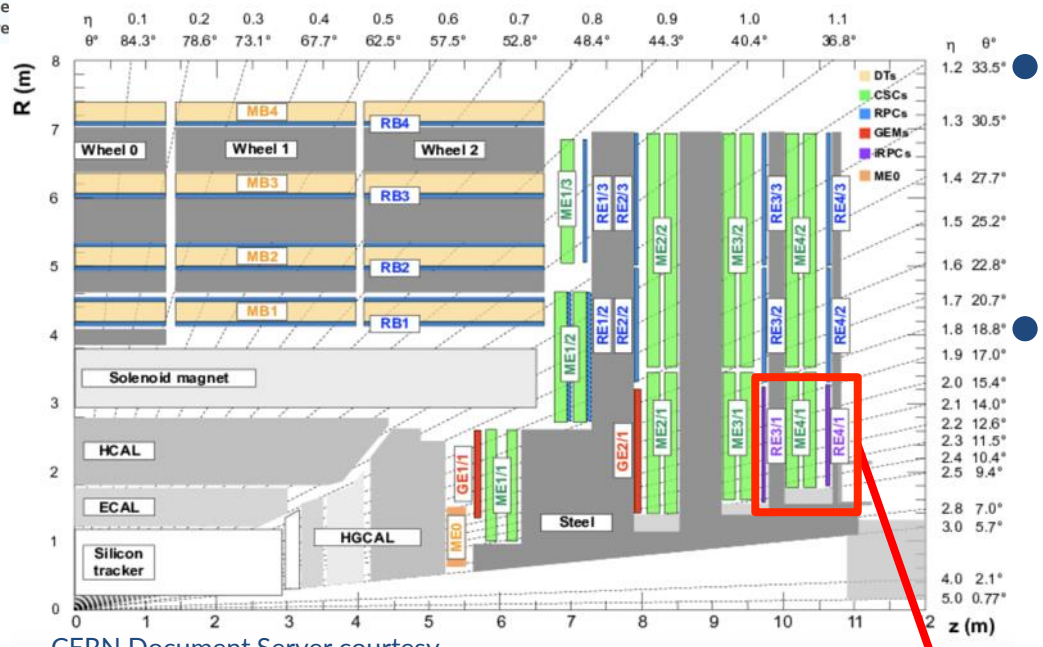
Performance of eco-friendly alternative gas mixture in CMS iRPC detector in HL-LHC environment
Poster by Joao Pinheiro

Guiduccı, Luigi & Montanari, Alessand
and Test of the Off-Detector Electroni

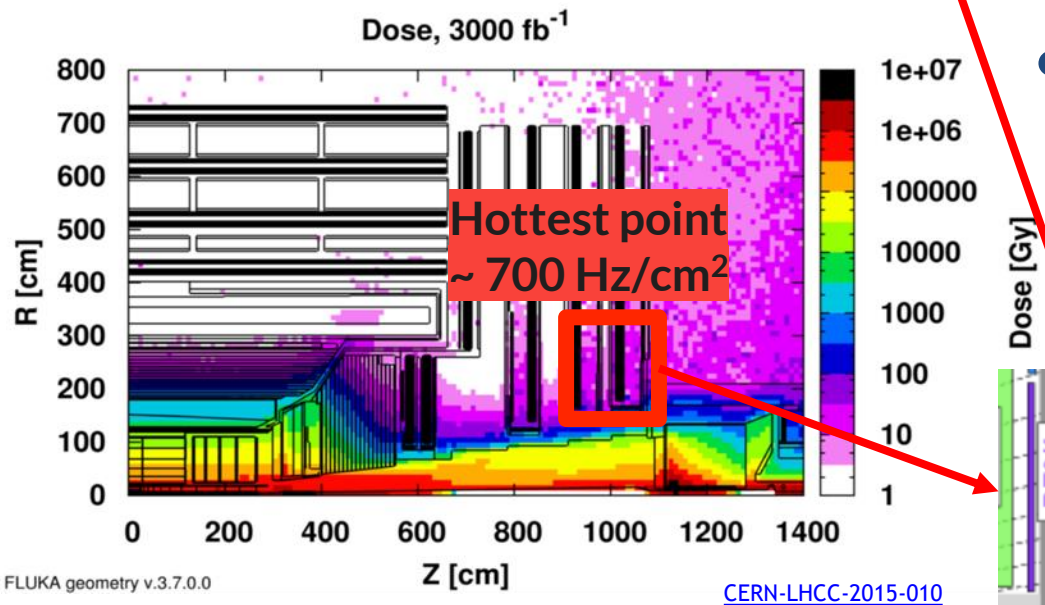
Run II (2015-2018)

Gas mixture used in CMS/RPC: 95.2 % $C_2H_2F_4$ + 4.5 % i-C_4H_{10} + 0.3 % SF_6

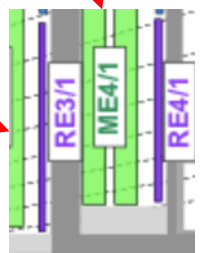
CMS Muon LHC Phase-II Upgrade



CERN Document Server courtesy



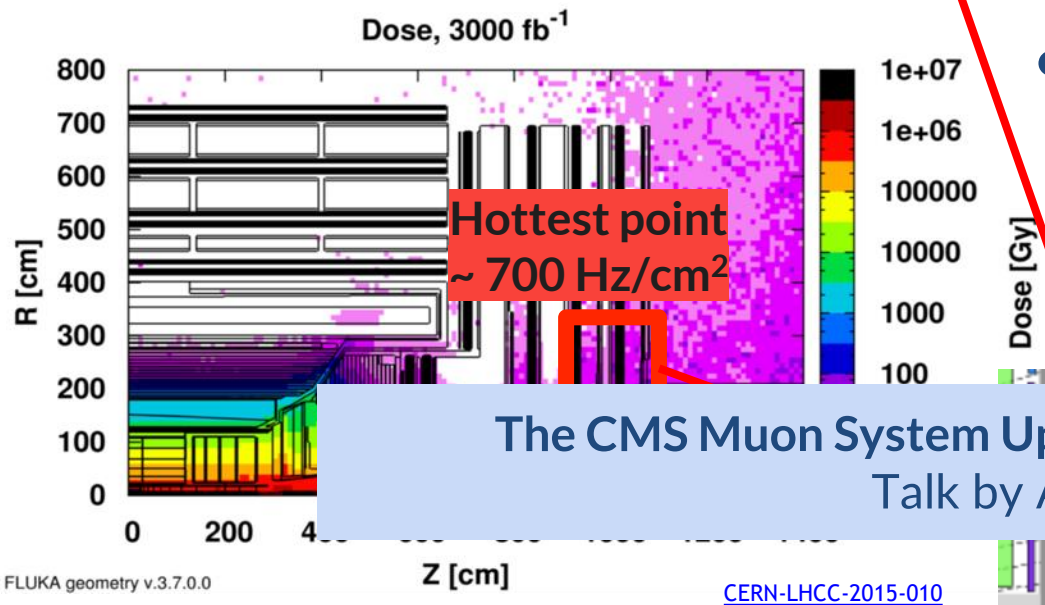
CERN-LHCC-2015-010



- To cope with the high particle rate and high pileup environment due to increased luminosity in HL-LHC, the CMS forward region demands
  → **improved trigger and reconstruction performance !**
- Interesting **Physics** in the forward region (CERN-LHCC-2017-012):
  - long-lived particles decaying leptonically;
  - final states with low *p*T muons;
  - heavy slowly moving charged particles;
  - highly boosted di-muons;
- Muon System Upgrade for HL-LHC (|η| < 2.8):
  - Existing DTs, CSCs and RPCs:
    → **Upgrade the Electronics!**
  - Installation of new detectors in the forward region:
    - **Gas Electron Multipliers:** ME0 and GE21
    - **Improved Resistive Plate-Chambers (iRPC) :** RE31 and RE41

CMS Muon LHC Phase-II Upgrade

CERN Document Server courtesy



CMS FLUKA geometry v.3.7.0.0

CERN-LHCC-2015-010

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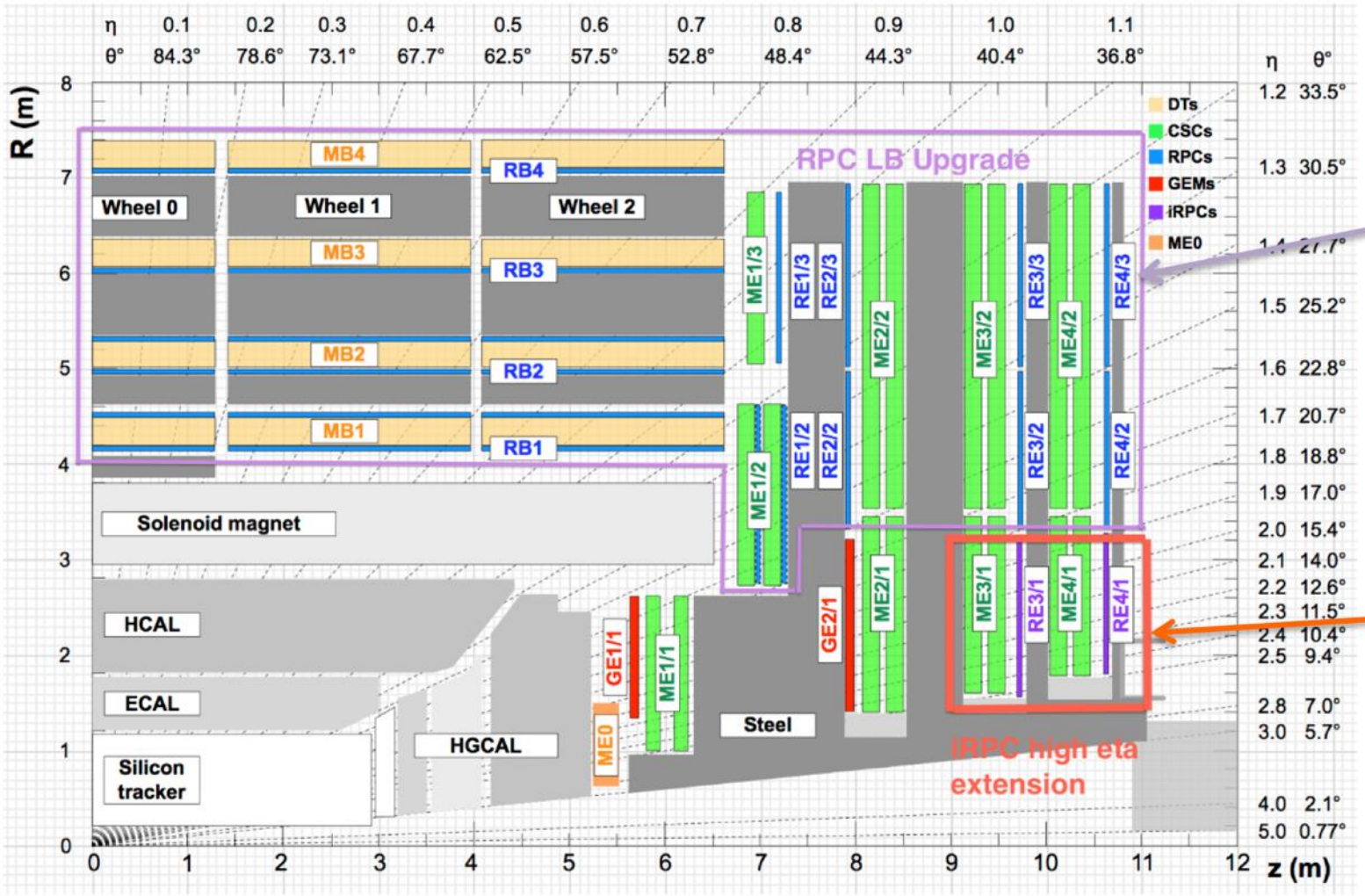
The CMS Muon System Upgrade for High Luminosity LHC
Talk by Archie Sharma

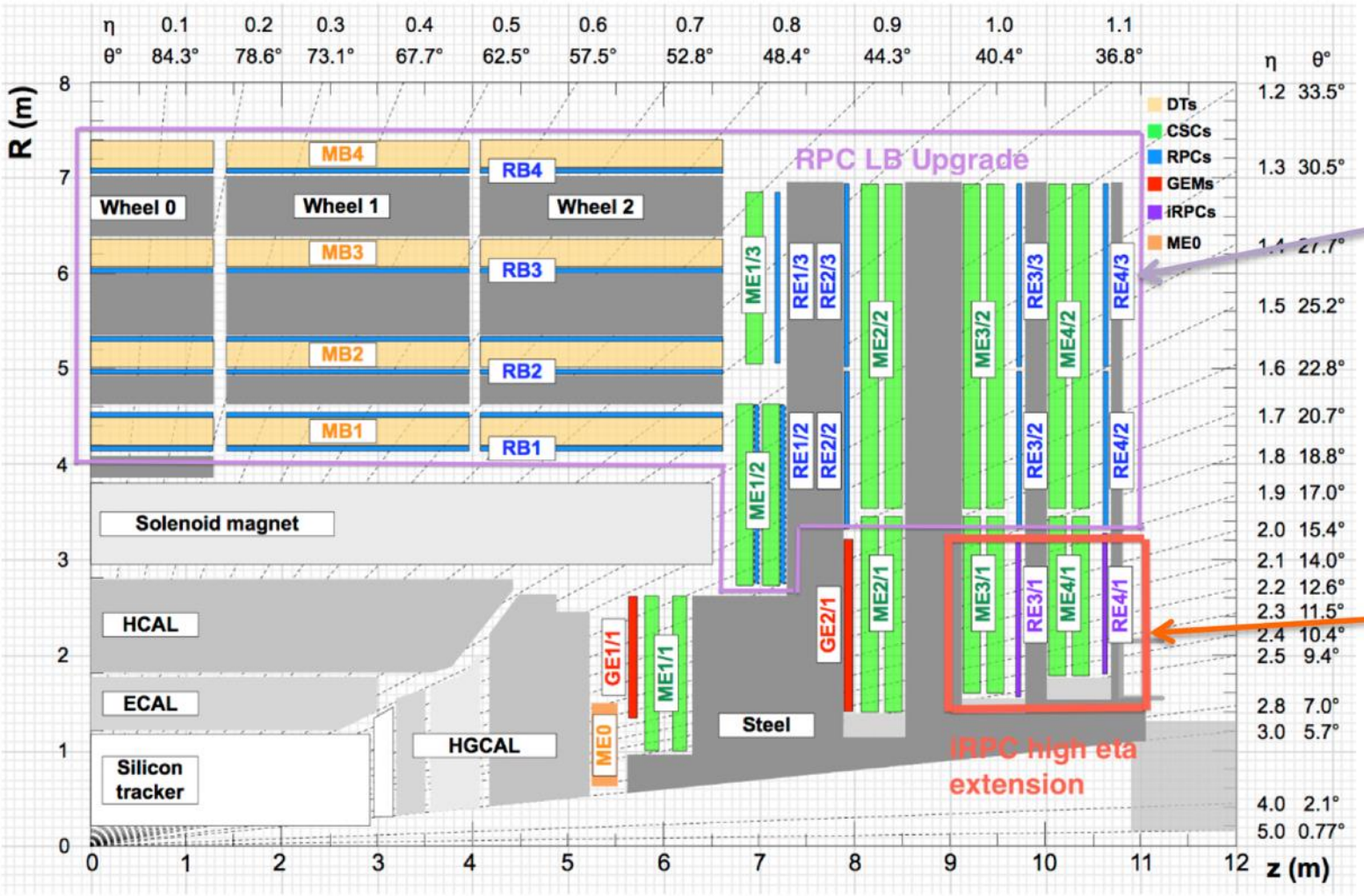
CMS RPC Upgrade Project

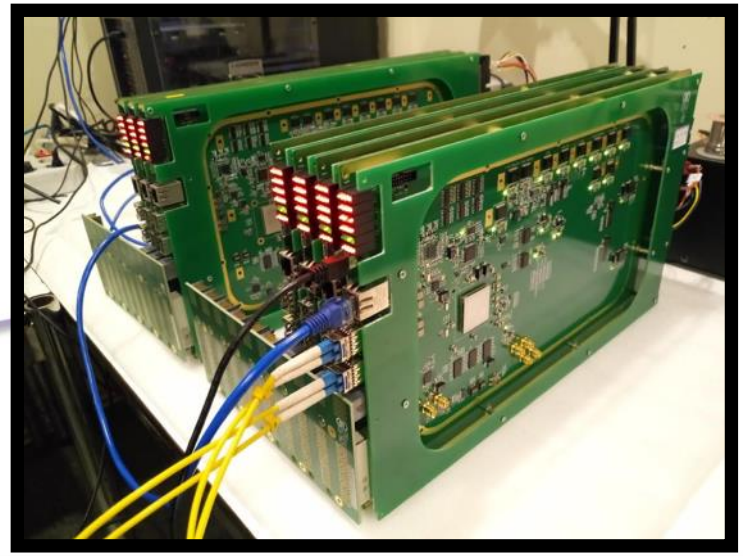


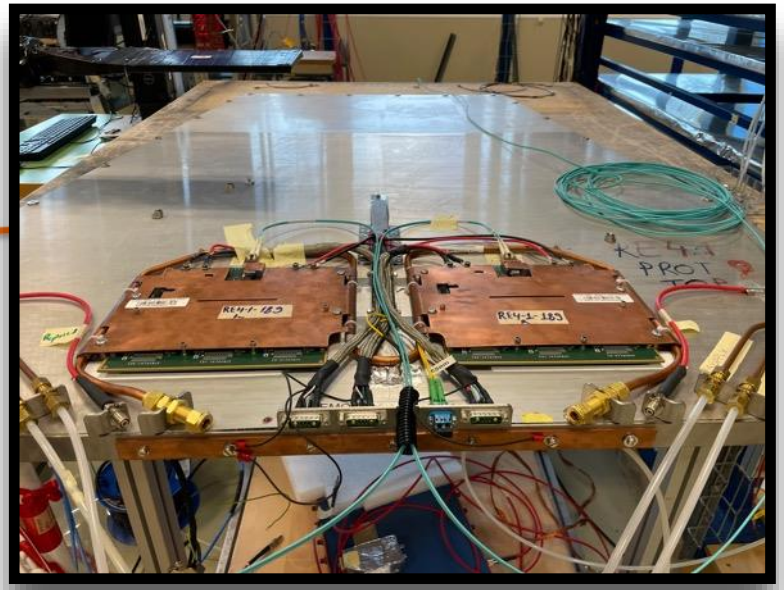
Upgrade of Link System to improve timing resolution for existing RPC system ($|\eta|<1.9$) Replace all off-chamber electronics.

iRPC: Extend the RPC coverage up to $|\eta|=2.4$ in high eta region in stations 3 and 4

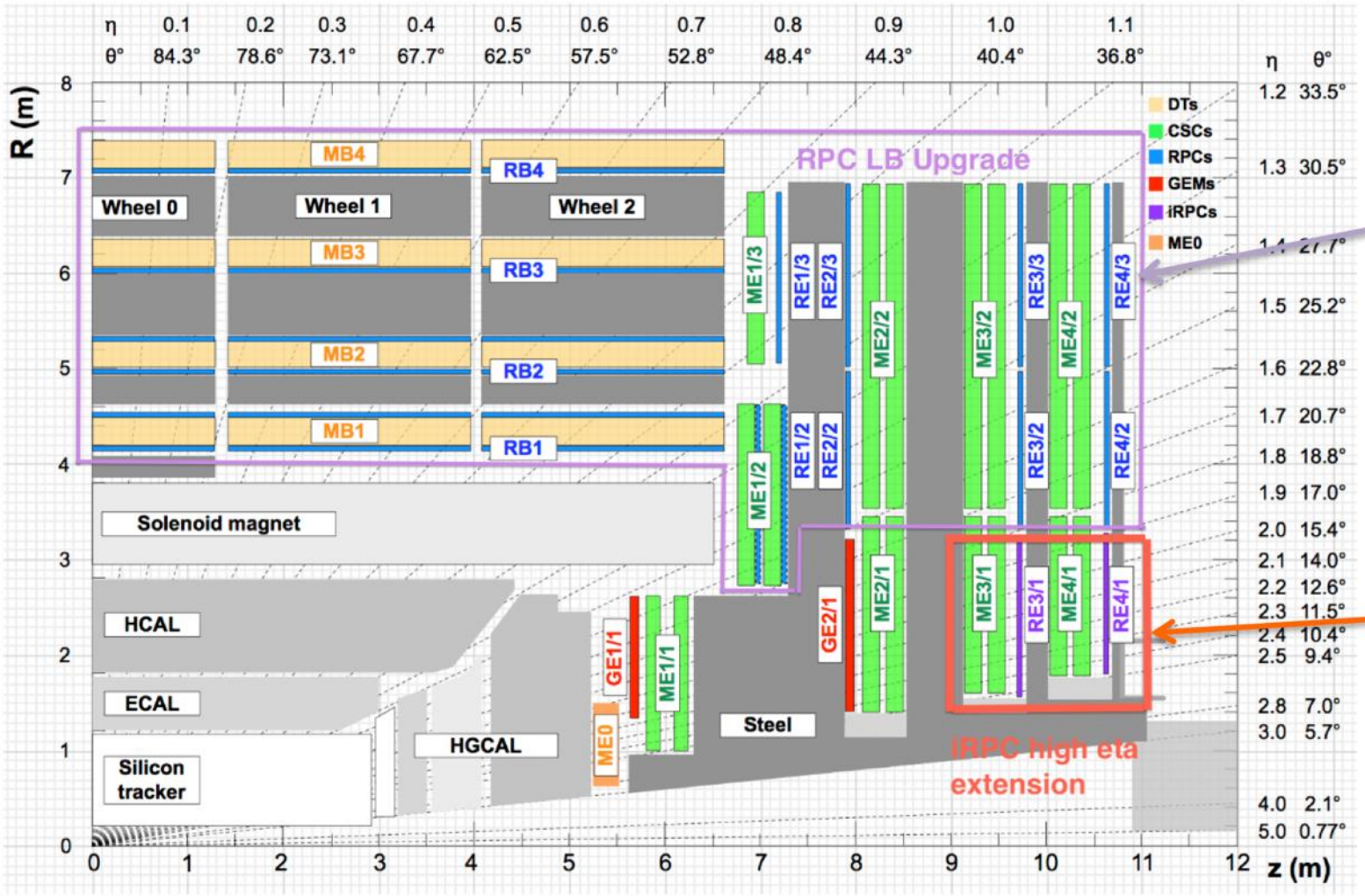
CMS RPC Upgrade Project

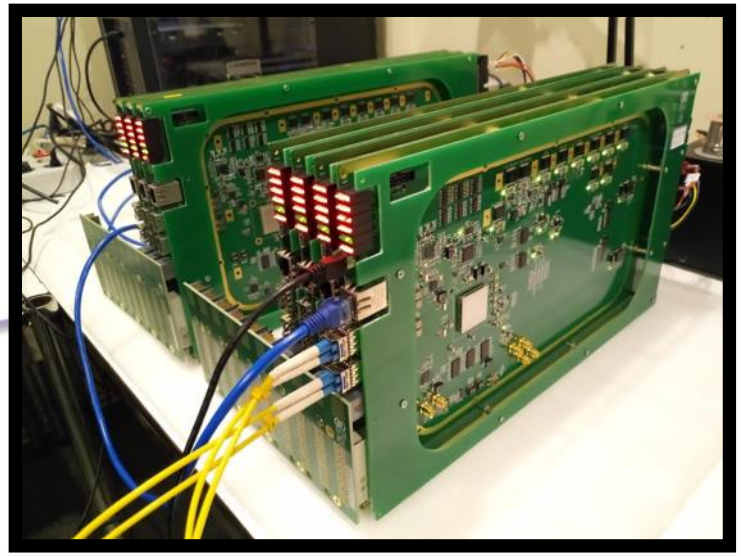


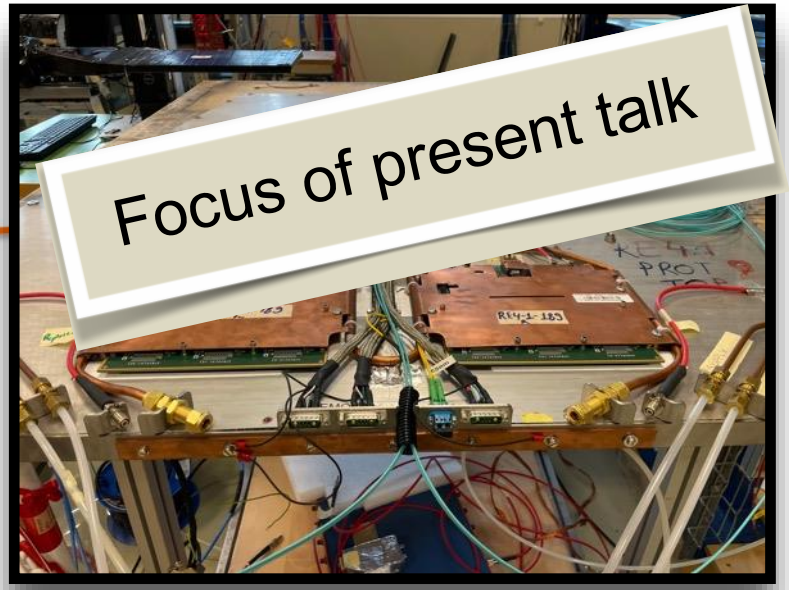




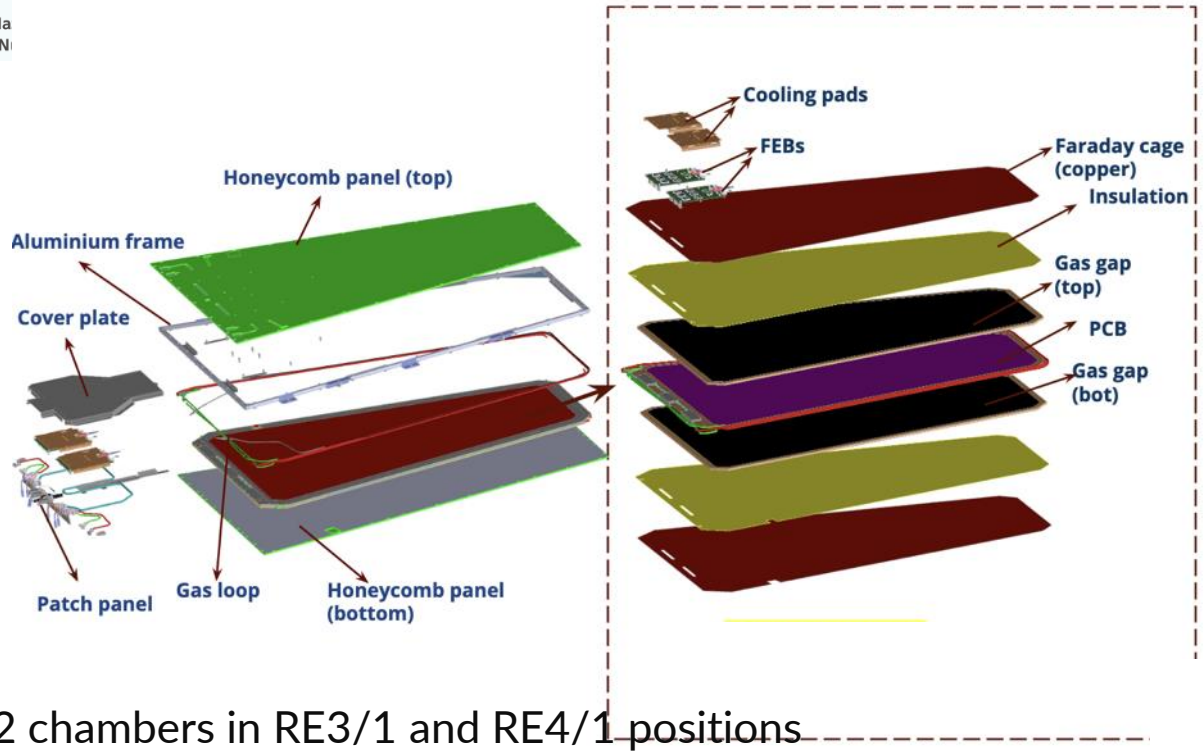
CMS RPC Upgrade Project





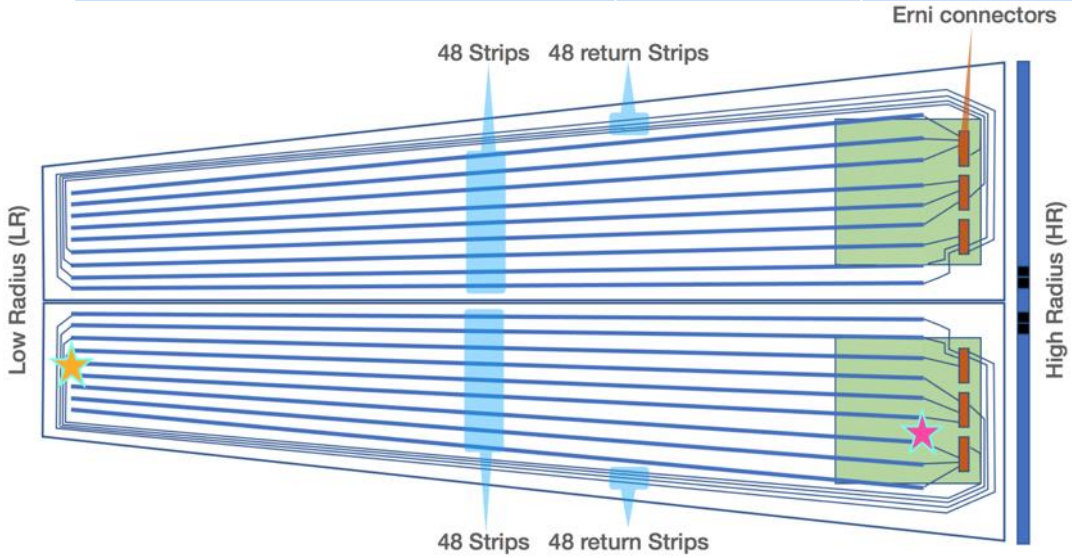


iRPC: improved Resistive Plate Chambers



	RPC	iRPC
HPL thickness (mm)	2	1.4
Number of gas gaps	2	2
Gas gap thickness (mm)	2	1.4
Resistivity (Ωcm)	1 - 6 x 10^{10}	0.9 - 3 x 10^{10}
Charge threshold (fC)	150	30 - 40
Space resolution in η (cm)	20 - 28	1.5
Space resolution in ϕ (cm)	0.8 - 1.9	0.3 - 0.6
Intrinsic timing resolution (ns)	1.5	0.5

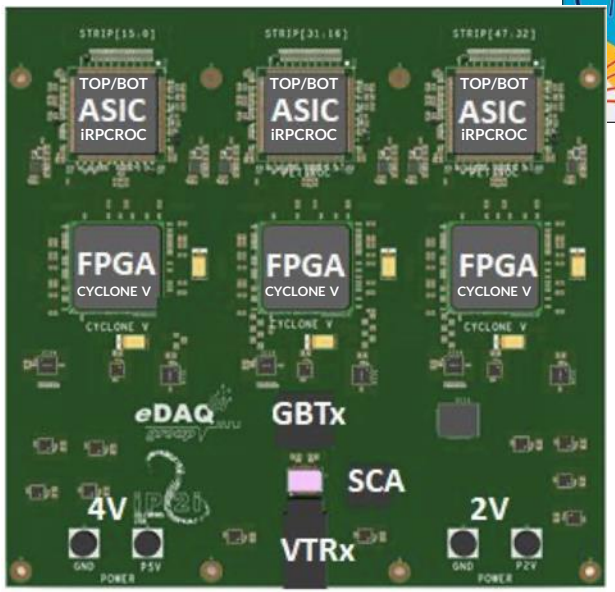
- + 72 chambers in RE3/1 and RE4/1 positions
  - 20 ° coverage in **ϕ** per chamber
  - Variable strip width from 0.6 cm to 1.23 cm
  - trapezoidal geometry ~1.2 x 1.6(3) m^2 for RE 3(4)/1
- Double readout in the strips high and low radius
- Charge threshold between 30 and 40 fC

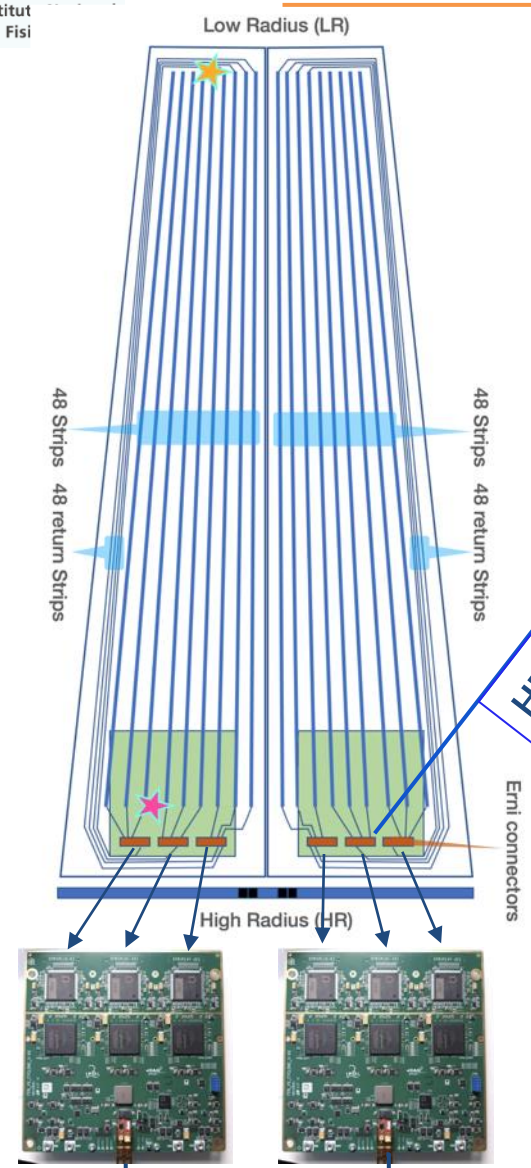


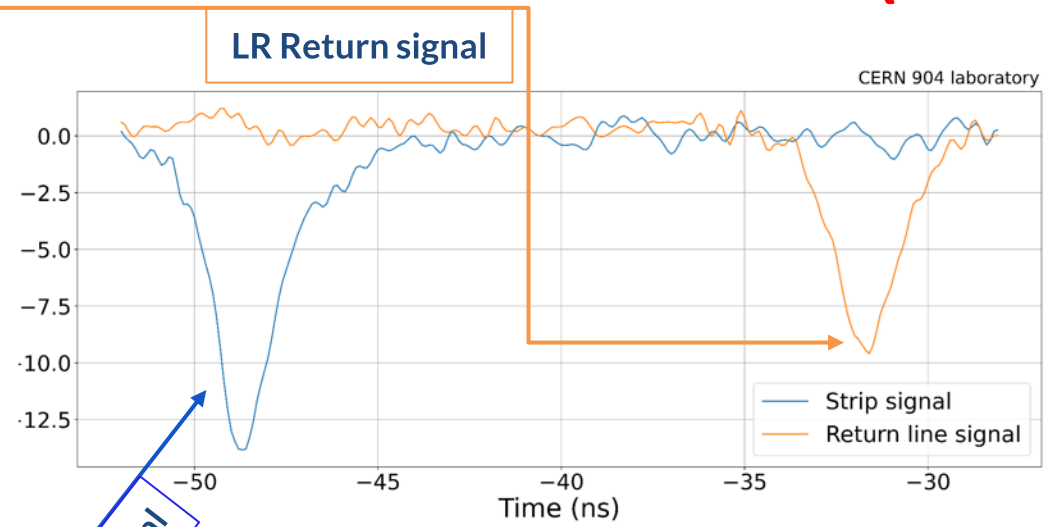
Strip PCB allow Return line ➡ FEB positioned external and @ HR (lowest dose

iRPC Front-end electronics (FEB)

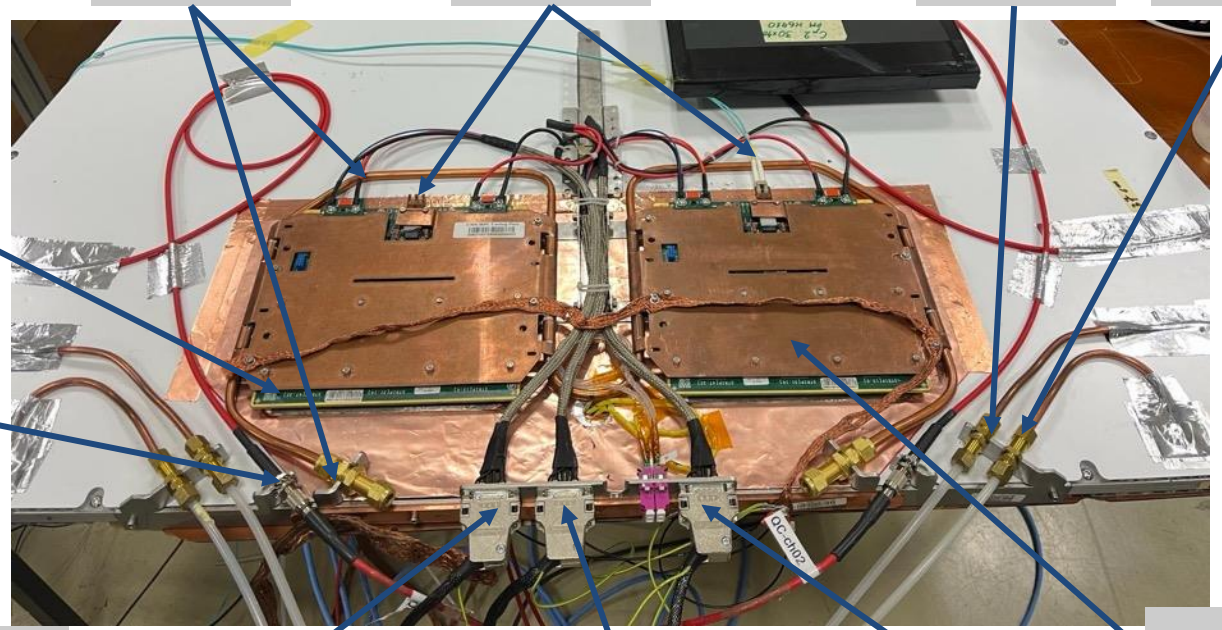
Front-end Electronics for iRPC



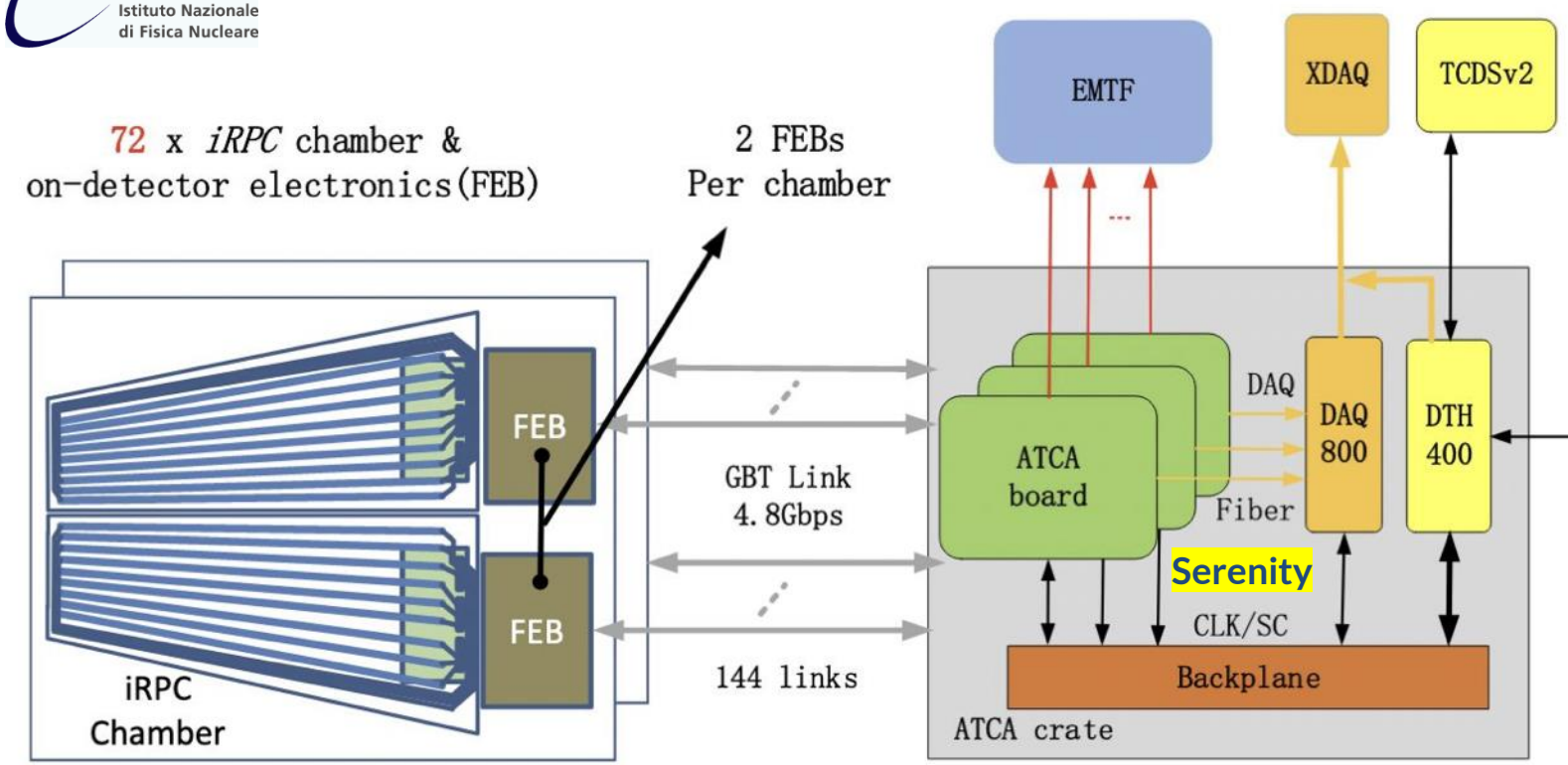




HR Direct signal



The iRPC back-end electronics



Back-end functions include:

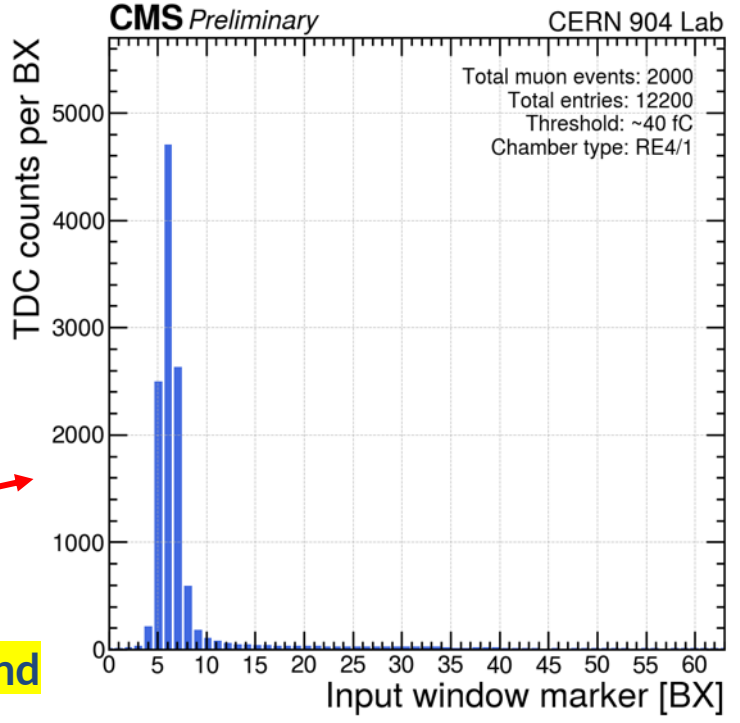
- Fast/slow control and monitor
- Cluster finding and trigger primitive generation
- Timing reference adjustment
- Data acquisition

Set up in CMS Underground Service Cavern

At present, microTCA-based with custom back-end board by IHEP is in use

FEB TDC data recorded in few BX, well inside the 20 BX trigger latency

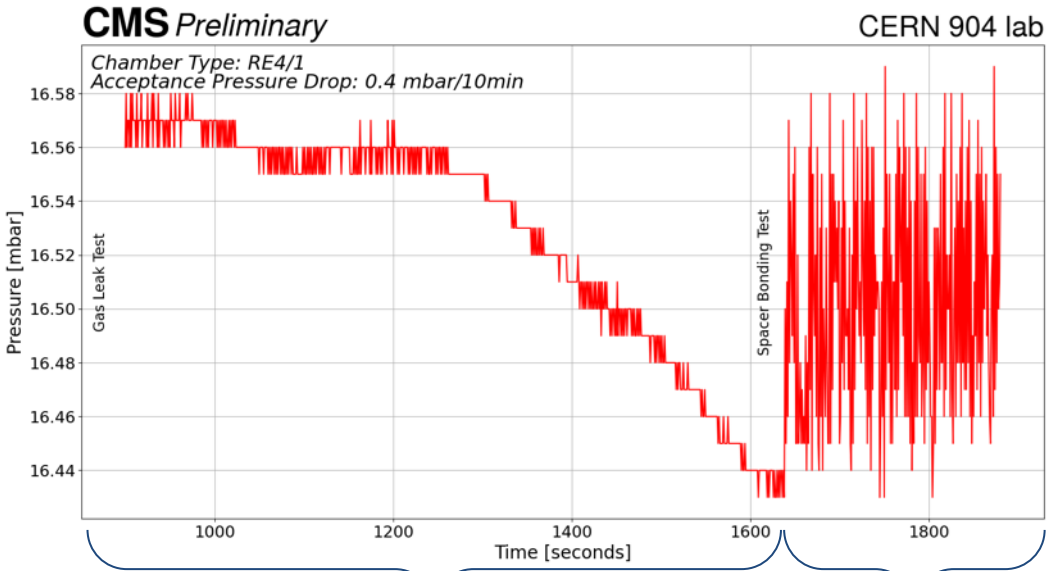
Data transmission delay properly adjusted by Back-end



iRPC production and Quality Control@

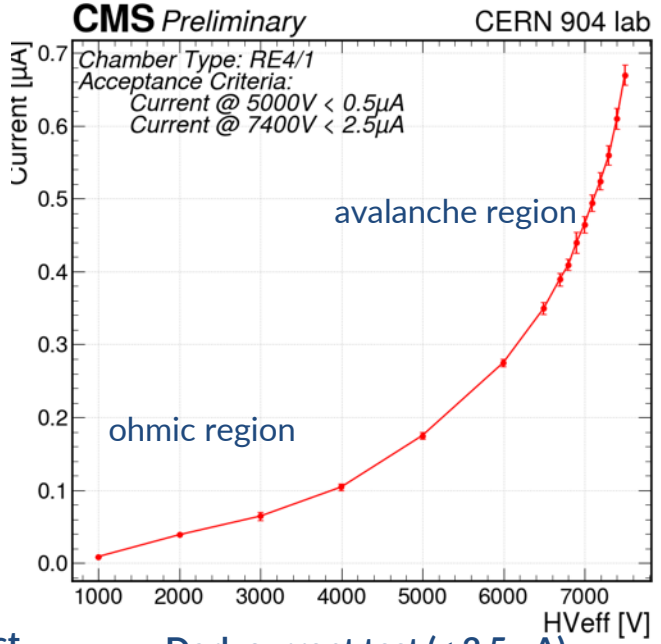
- First QC step performed in the **original sites** of components manufacturing
- Second QC step is again on component level, but in the chamber **assembly sites** (CERN and Ghent University) to check component quality & stability after transport

Cosmic stand for gaps validation



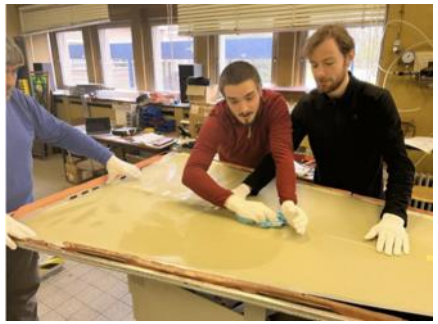
Leak test (drop < 0.4 mbar/10 min)

Spacer bonding test



Dark current test (< 2.5 uA)

Chamber assembly with validated components:

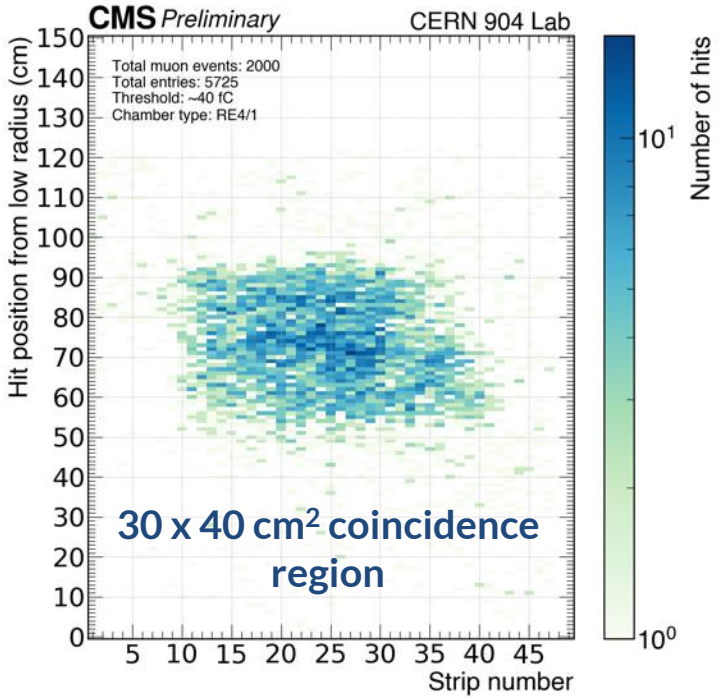


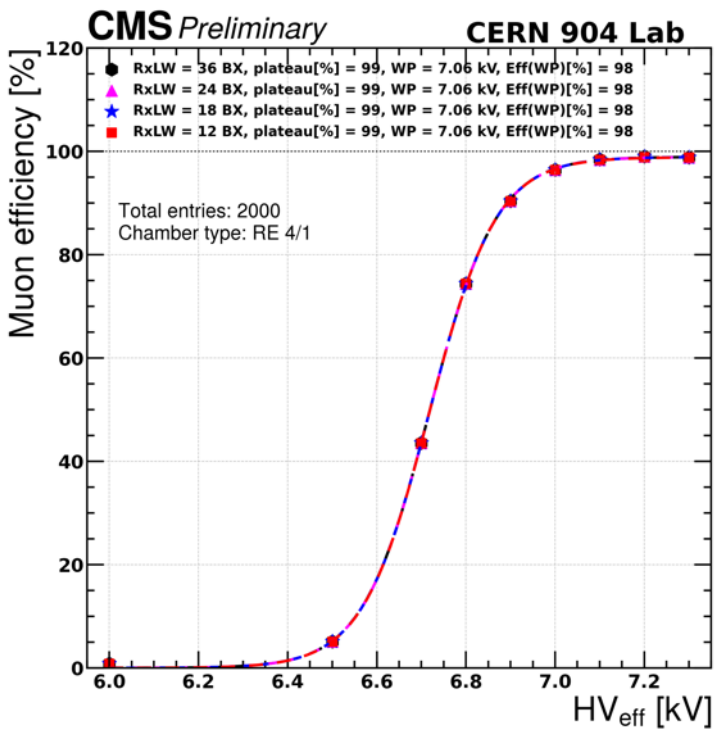
- 62/72 chambers manufactured so far, completion **expected by end of August 2024**

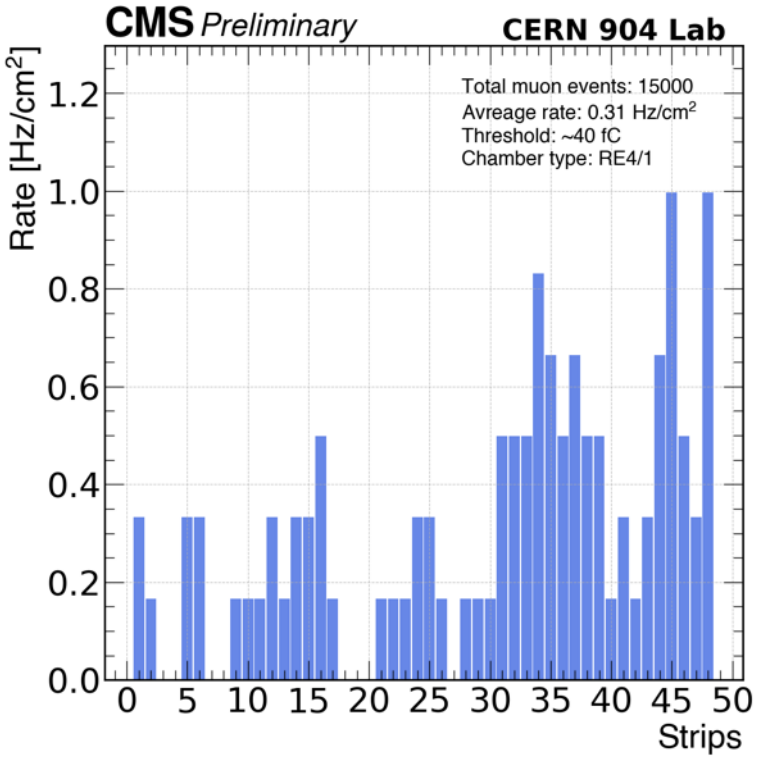
iRPC production and Quality Control@

3rd step: Cosmic efficiency with portable FEB v2.3

3 scintillators for coincidence + veto







After TDC channel mapping, the hit position along the strips are obtained by the arrival time between LR and HR signals:

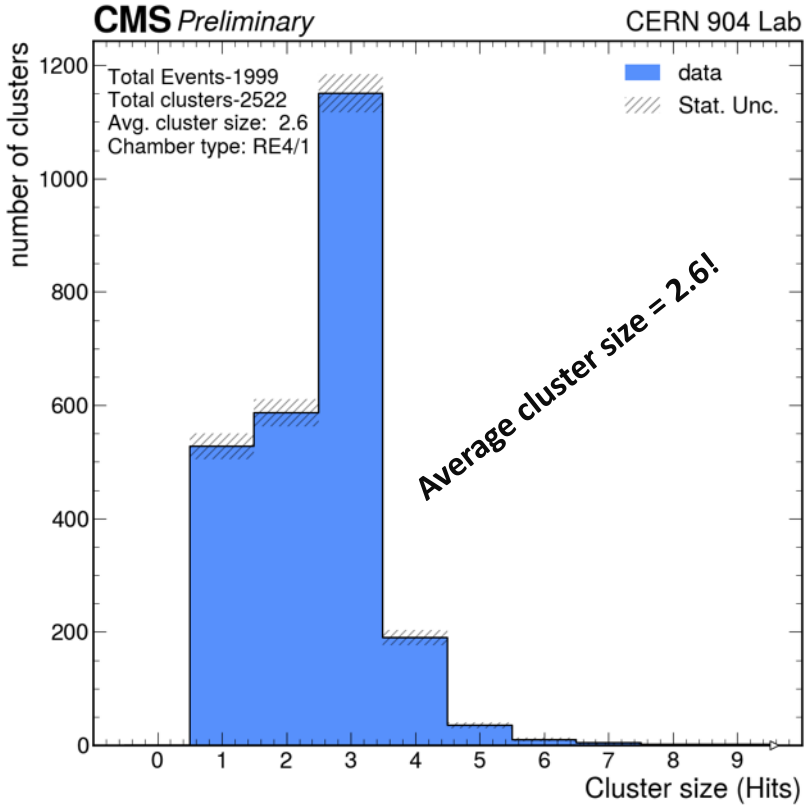
$$r = \frac{1}{2}L - \frac{(t2 - t1)}{2} * v$$

Efficiency of 98% and working point around 7050 V is stable up to 12 BX readout window!

Average noise < 1 Hz/cm² measured in dedicate random scans

iRPC production and Quality Control@

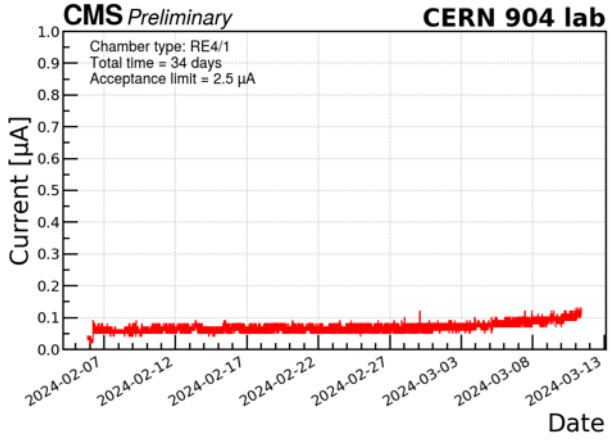
Cluster size in cosmic test with FEB v2.3



- Cluster size is defined as **the number of adjacent strips fired** when a muon crosses the detector
- The strips pitch in the coincidence region is **~1 cm**

Step 4: Final chambers with final FEBs (v2.3)

→ **Long stability test:** current monitoring @ WP for 1

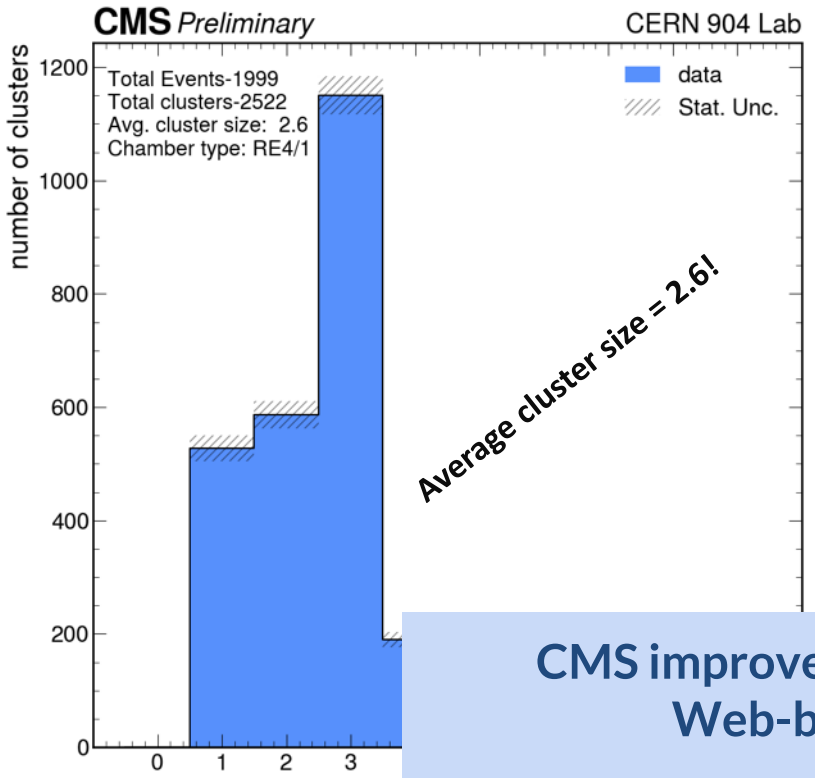


→ **Final cosmic test** with final FEB v2.3 + cooling system

+ cover (not shown in the picture)

iRPC production and Quality Control@

Cluster size in cosmic test with FEB v2.3



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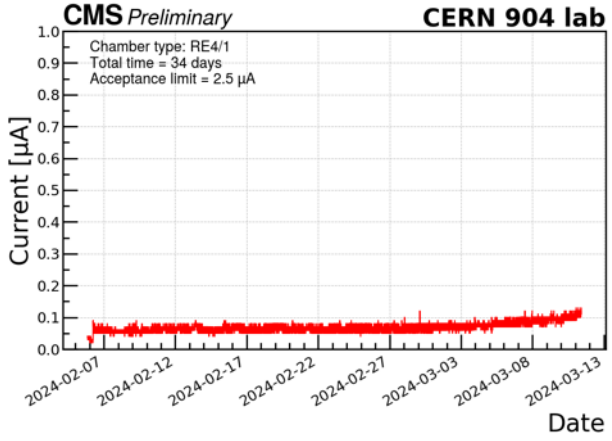


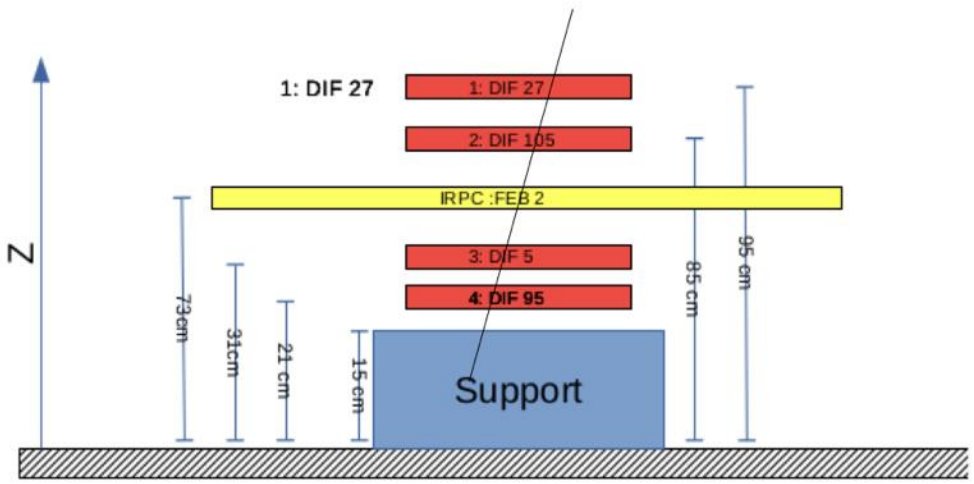
→ **Final cosmic test** with final FEB v2.3 + cooling system

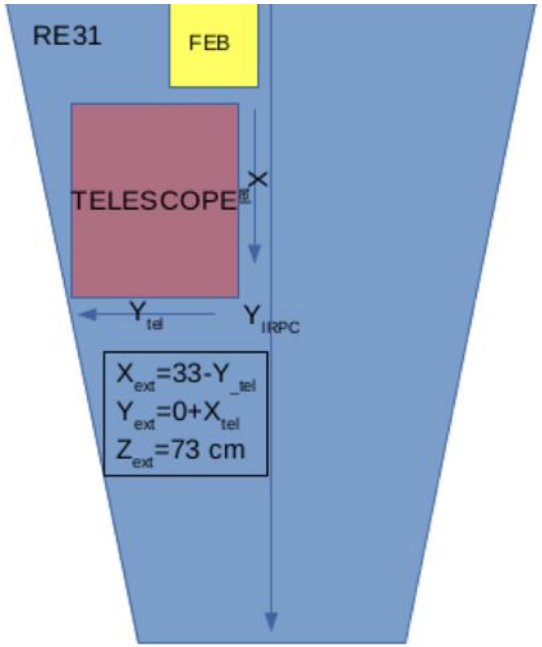
CMS improved Resistive Plate Chamber (iRPC) upgrade: Web-based automation for Quality Control
Poster by Ece Asilar

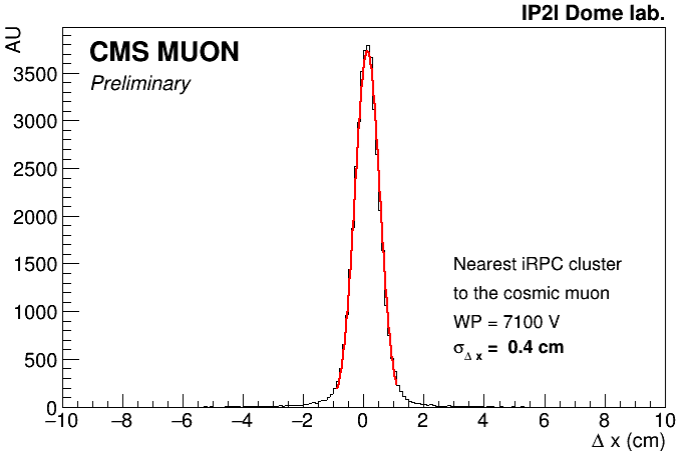
Production and quality control for CMS iRPC
Poster by Dilson De Jesus Damiao

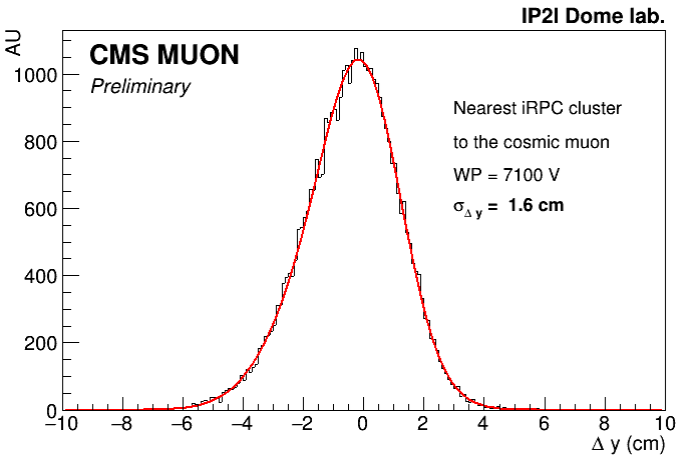
\+ cover (not shown in the picture)

Space resolution









- Telescope in Lyon University IP2I made up with **4 RPC chambers** (2 mm double gap 30 x 50 cm²)

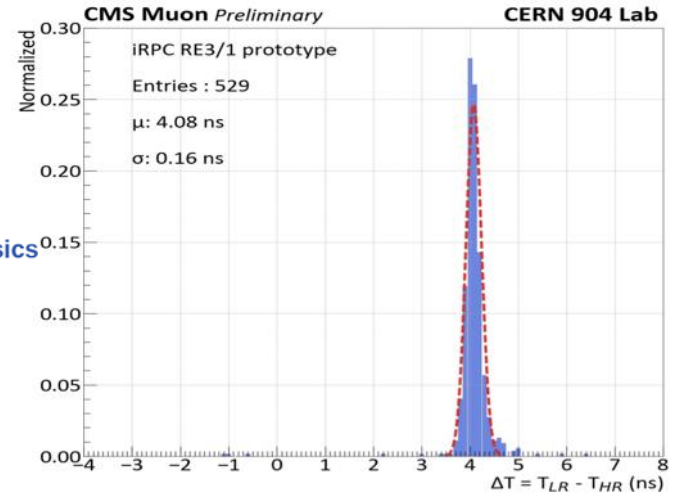
- X-axis resolution depends on **strip pitch** in the telescope region:
  - 0.8 - 0.9 cm

$$\rightarrow \quad \sigma_x = 0.4 \text{ cm}$$

- In y-axis, resolution depends on $\Delta T = T_{HR} - T_{LR}$

$$\sigma_{\Delta T} \approx 150 \text{ ps} \rightarrow \sigma_y \approx 1.6 \text{ cm}$$

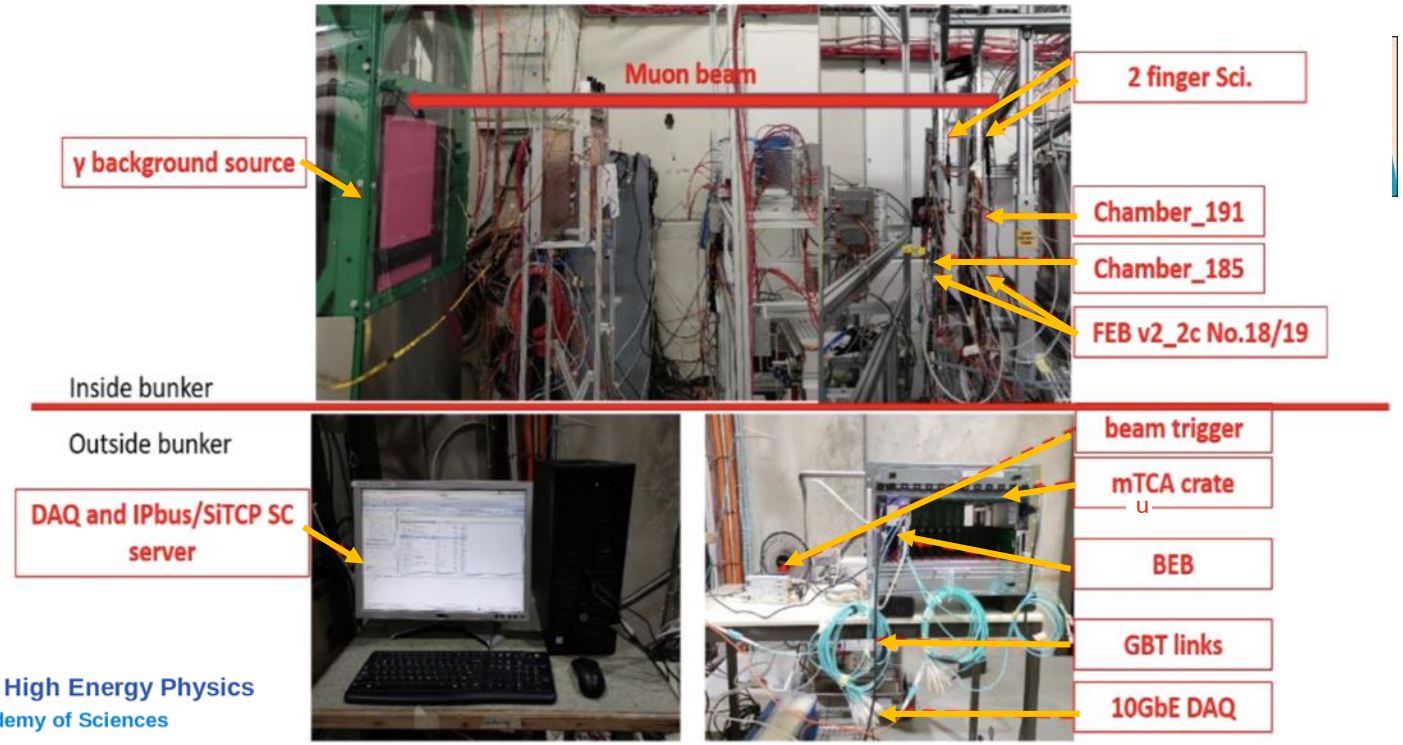
Institute of High Energy Physics
Chinese Academy of Sciences



Time resolution

- Timing resolution performed with 2 identical chambers and a muon beam
- Absolute timing resolution of the system after alignment by back-end:

$$\frac{780}{\sqrt{2}} \approx 550 \text{ ps}$$



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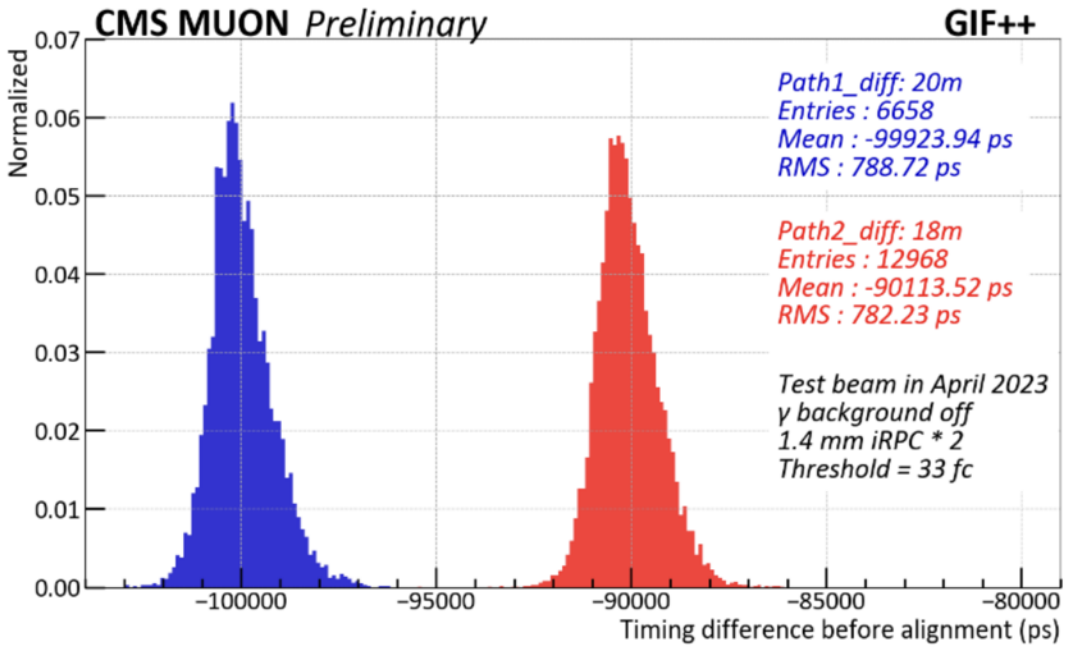
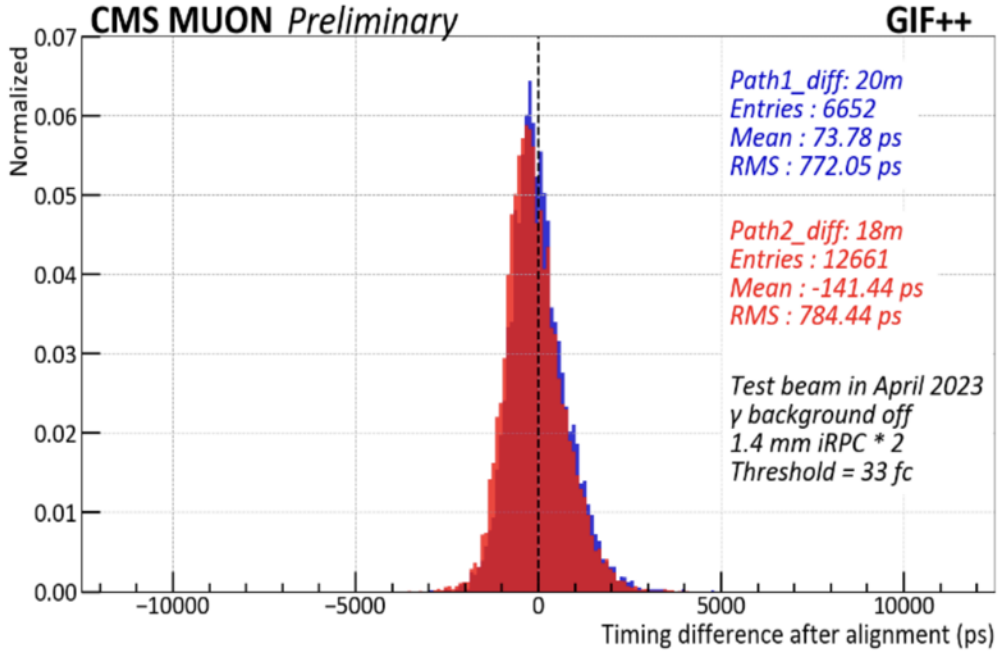


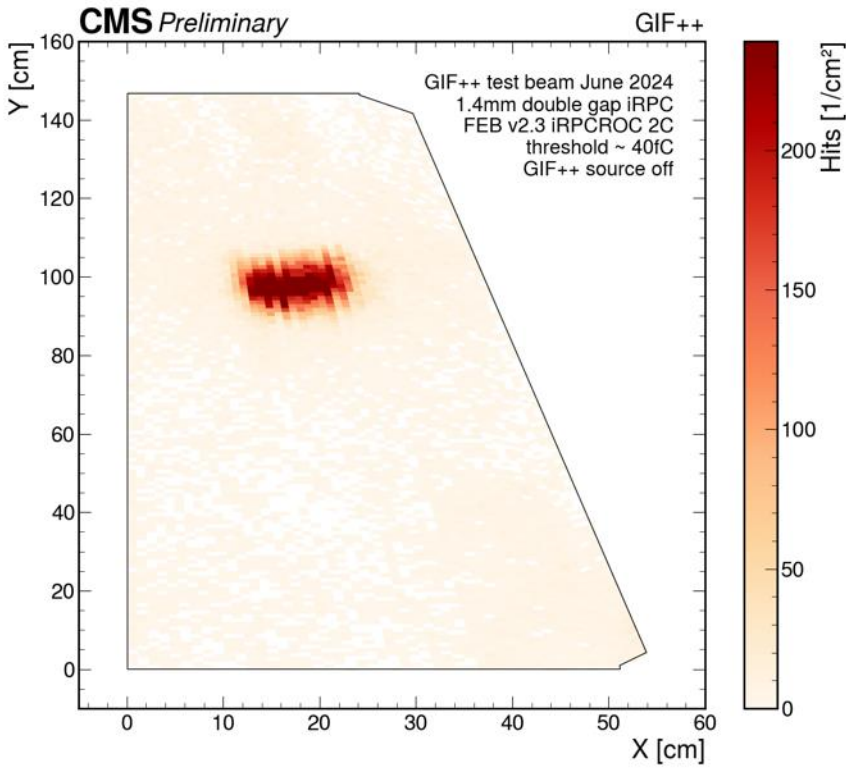


Performance of iRPC under gamma bkg

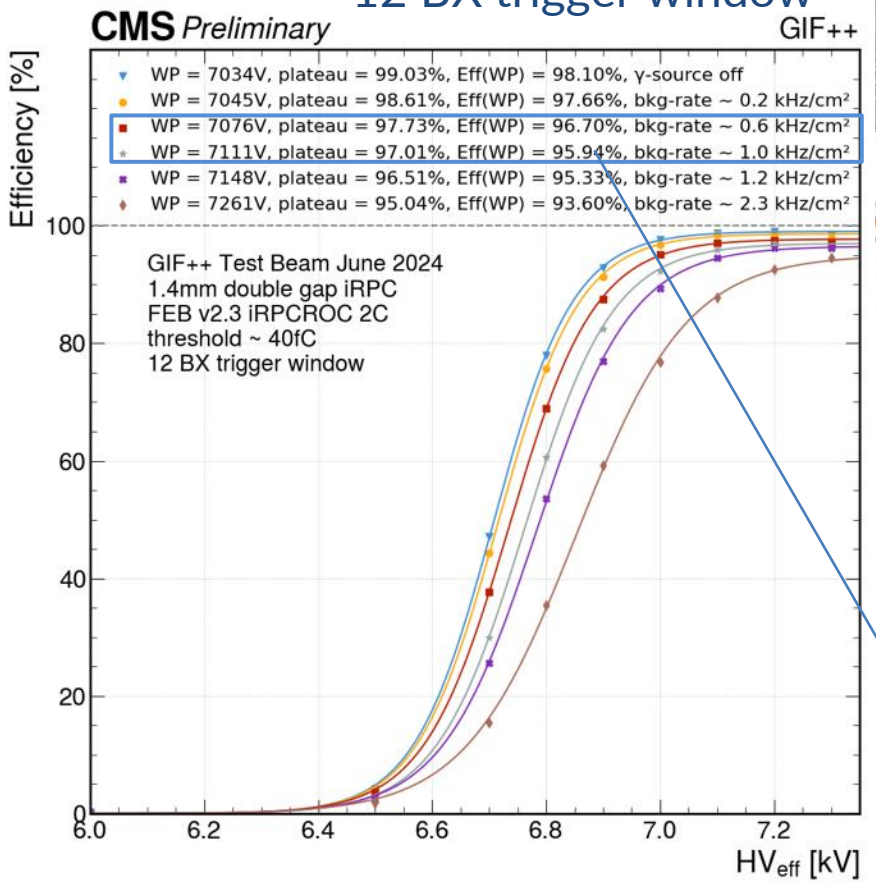
Performance of a iRPC chamber in Gamma Irradiation Facility (GIF++) at CERN

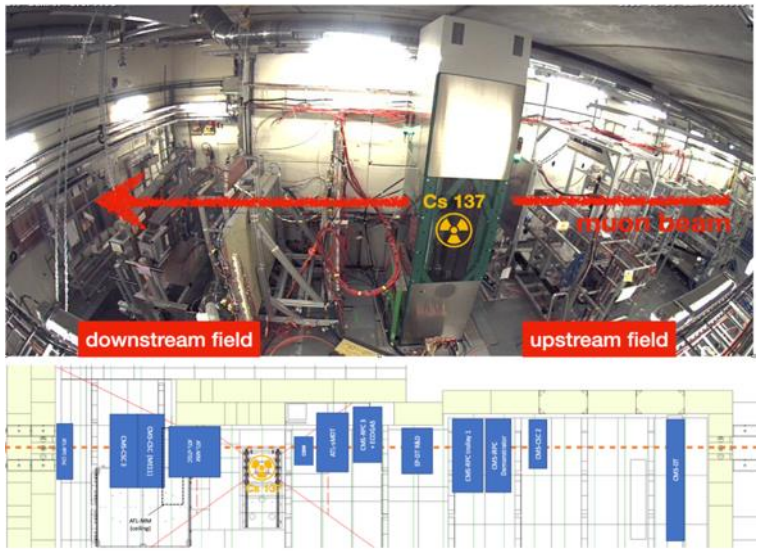
→ 12 TBq ^{137}Cs gamma source 662 KeV
→ Muon beam ~ 150 Gev/c

Event display @ GIF++



Efficiency curves
- threshold @ ~ 40 fC
- 12 BX trigger window





Gamma Irradiation Facility ++

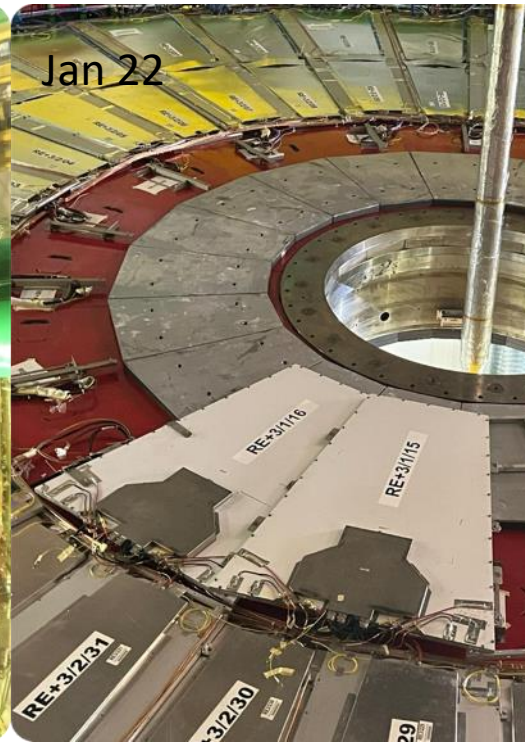
iRPC performance validated under background gamma rate within a safety factor of 3!

@ bkg-rate = 600-1000 Hz/cm^2:

→ Efficiency = 96 - 96.7 %
→ Working Point = 7.07 - 7.11 kV

Data analysis ongoing with fine-tuned threshold and further optimised FEB configuration

Installation in CMS



4 demonstrator chambers (RE+4/1/15,16 and RE+3/1/15,16) were installed in CMS in the end of the Long Shutdown 2 (2021-22), 4 FEBs v2.1 and 4 FEBs v2.2:

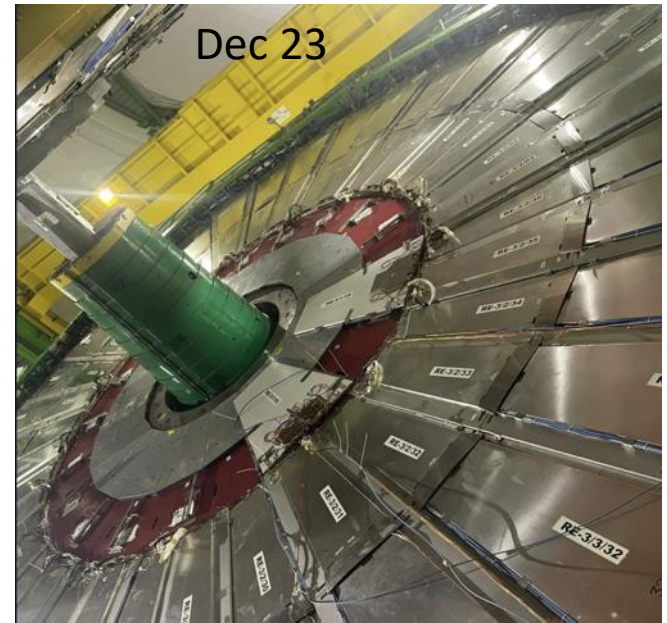
- **Noise < 1Hz/cm²** with final end cap disk grounding
- FEB **temperature stable** in CMS endcap closed mode with water cooling
- HV currents showing **smooth operation** during LHC Run III
- **Normal operation** in 3.8 T magnetic field

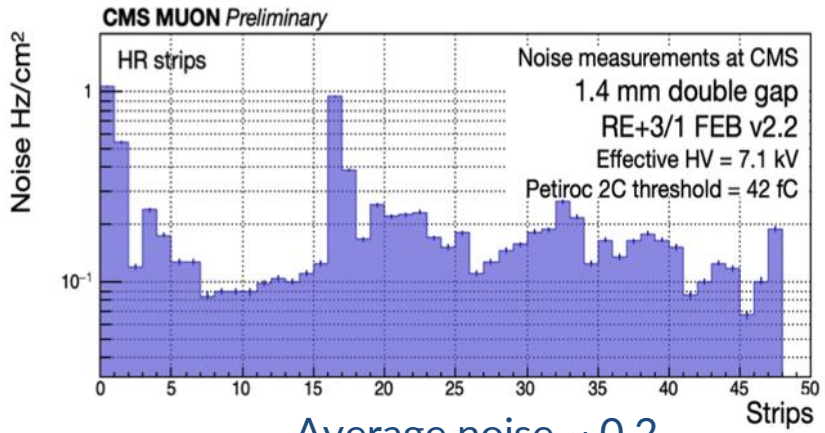
2 mass production final chambers with final FEBs installed in CMS last YETS (2023):

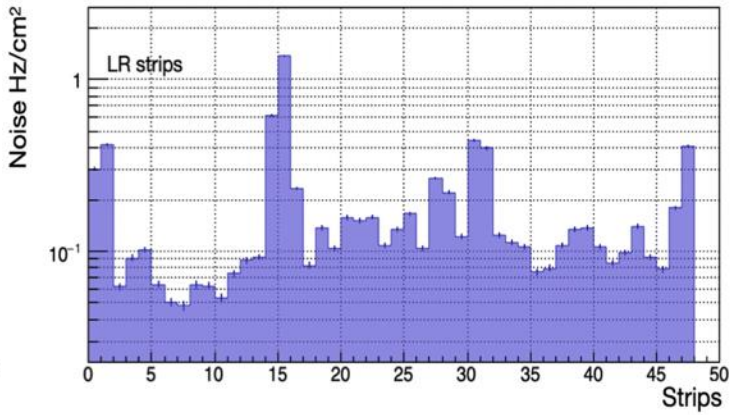
- RE-3/1/16 and RE-3/1/18

All **services are already installed** since LS2 waiting for all 72 chambers

All 70 remaining chambers are expected to be installed next YETS 2024-2025 access time

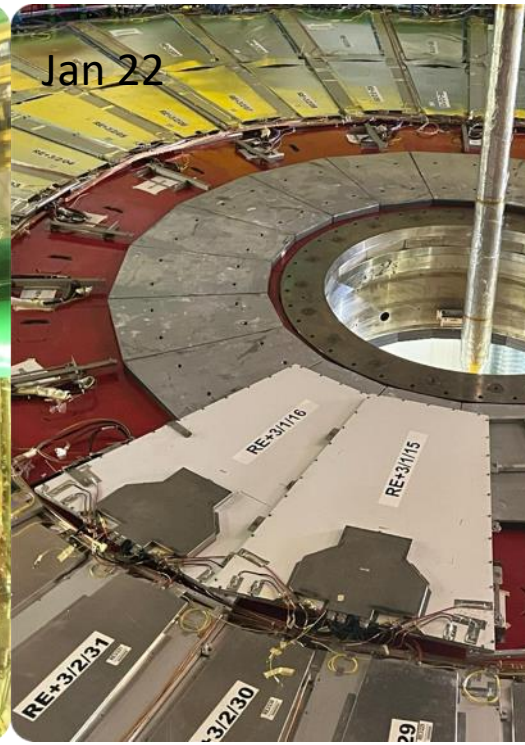






Average noise ~ 0.2 Hz/cm²

Installation in CMS



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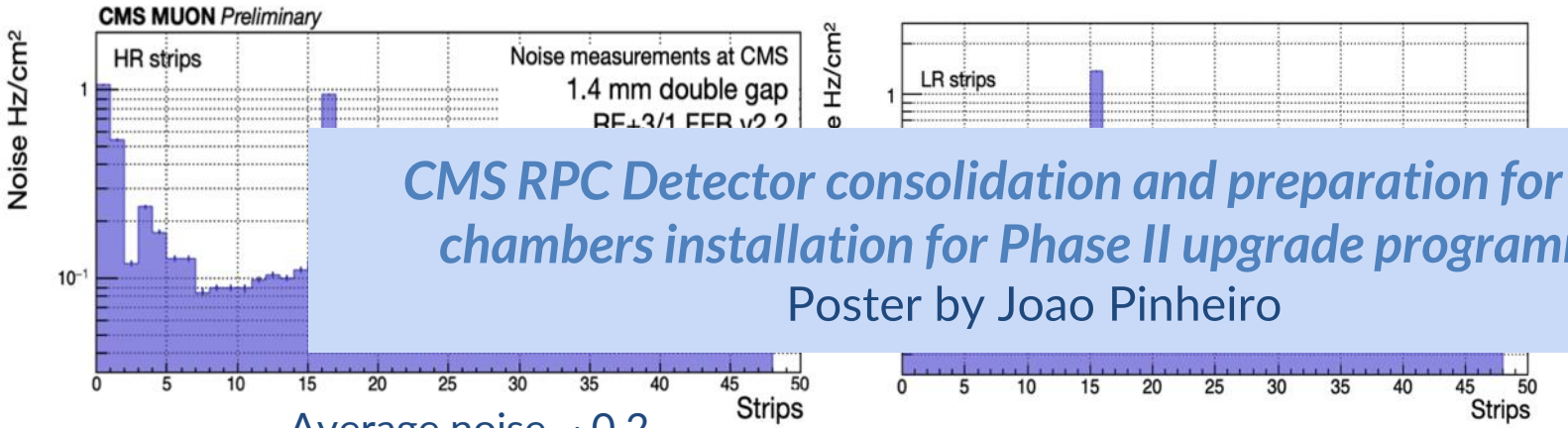
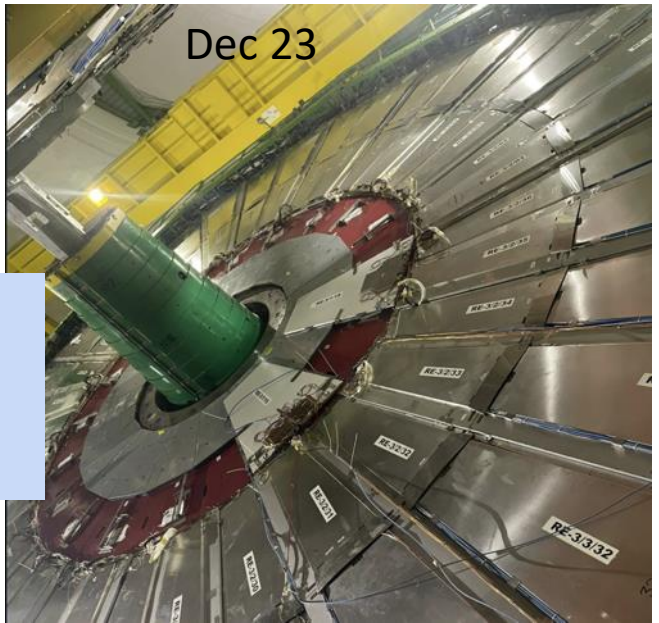


Average noise ~ 0.2 Hz/cm²

CMS RPC Detector consolidation and preparation for new chambers installation for Phase II upgrade programme

Poster by Joao Pinheiro



Conclusions and perspectives

- iRPC chamber is an **innovative design detector** to operate in CMS at High Eta region with HL-LHC
- iRPCs production and quality control for installation in CMS **are ongoing** in 2 assembly sites: 62/72 chambers manufactured and QC (with portable FEB) so far. Completion **expected by end of August 2024**
- iRPC **space resolution** is Δx = 0.4 cm and Δy = 1.6 cm, improved wrt to present Δx = 1-2 cm and Δy = 20-30 cm
- iRPC **timing resolution** is Δt ~ 0.5 ns, improved wrt to present Δt ~ 1.5 ns
- At 600 Hz/cm^2 and with a threshold of ~40 fC, the iRPC chambers have a performance of:
  - **96.7 % muon efficiency**
  - **Working point ~ 7076 V**

  (further improvements recorded in last June/July test beam with FEB optimised threshold and configuration modes)
- Demonstrators in P5 have already shown **less than 1Hz/cm^2 of noise** and **stable operation** with CMS yoke grounding, water cooling, 3.8T magnetic field and no interference with nearby subdetectors
- First 2 final chambers **successfully completed, installed and commissioned** last December 2023 in CMS
- Chamber construction (with FEB) **expected to be completed by the November 2024**, installation planned


INFN
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di Fisica Nucleare
CMS
Thank you
for your attention
ICHEP2024 – July 20th 2024 - Prague (Czech Republic)