R&D results of iRPC tested at GIF++ for CMS Phase II upgrade

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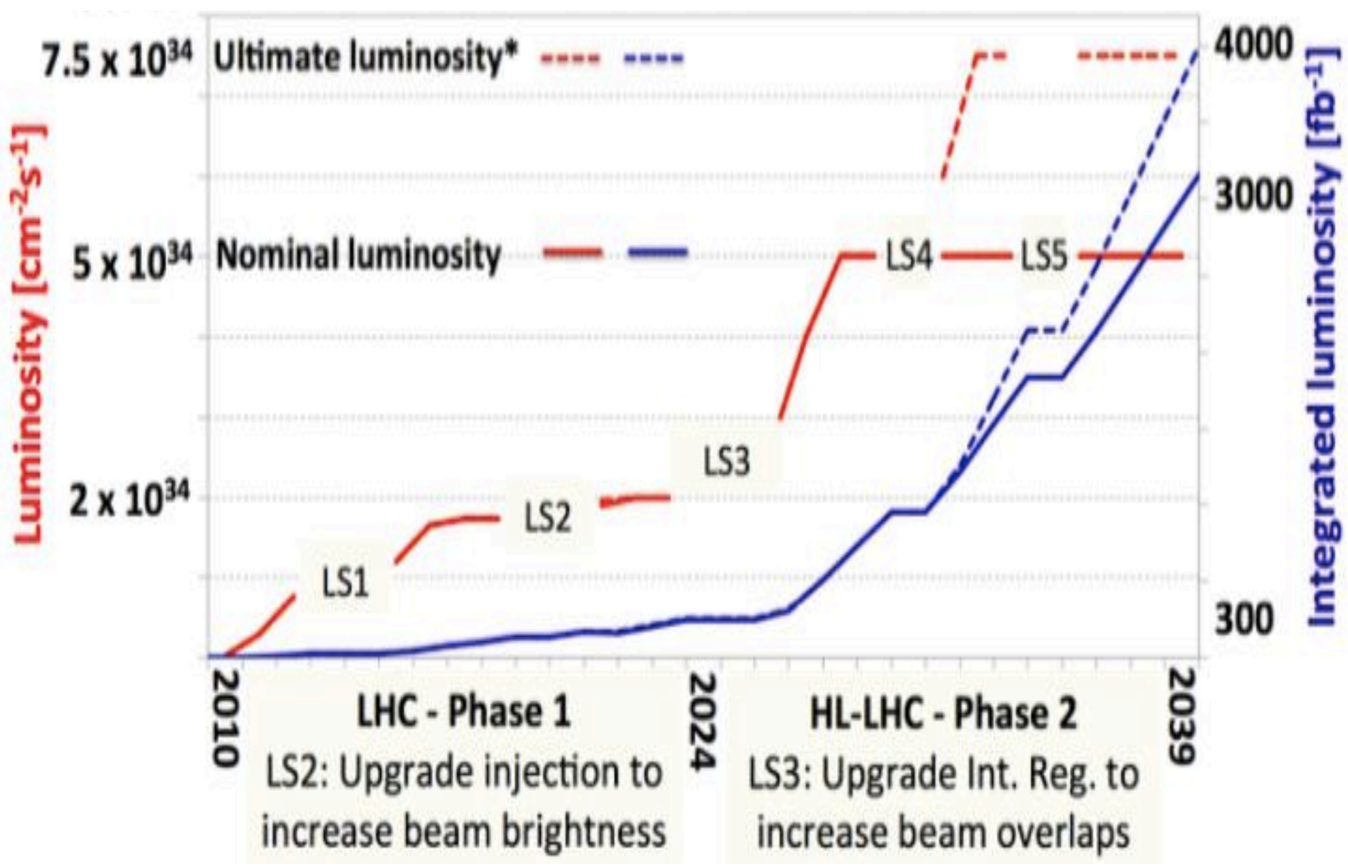
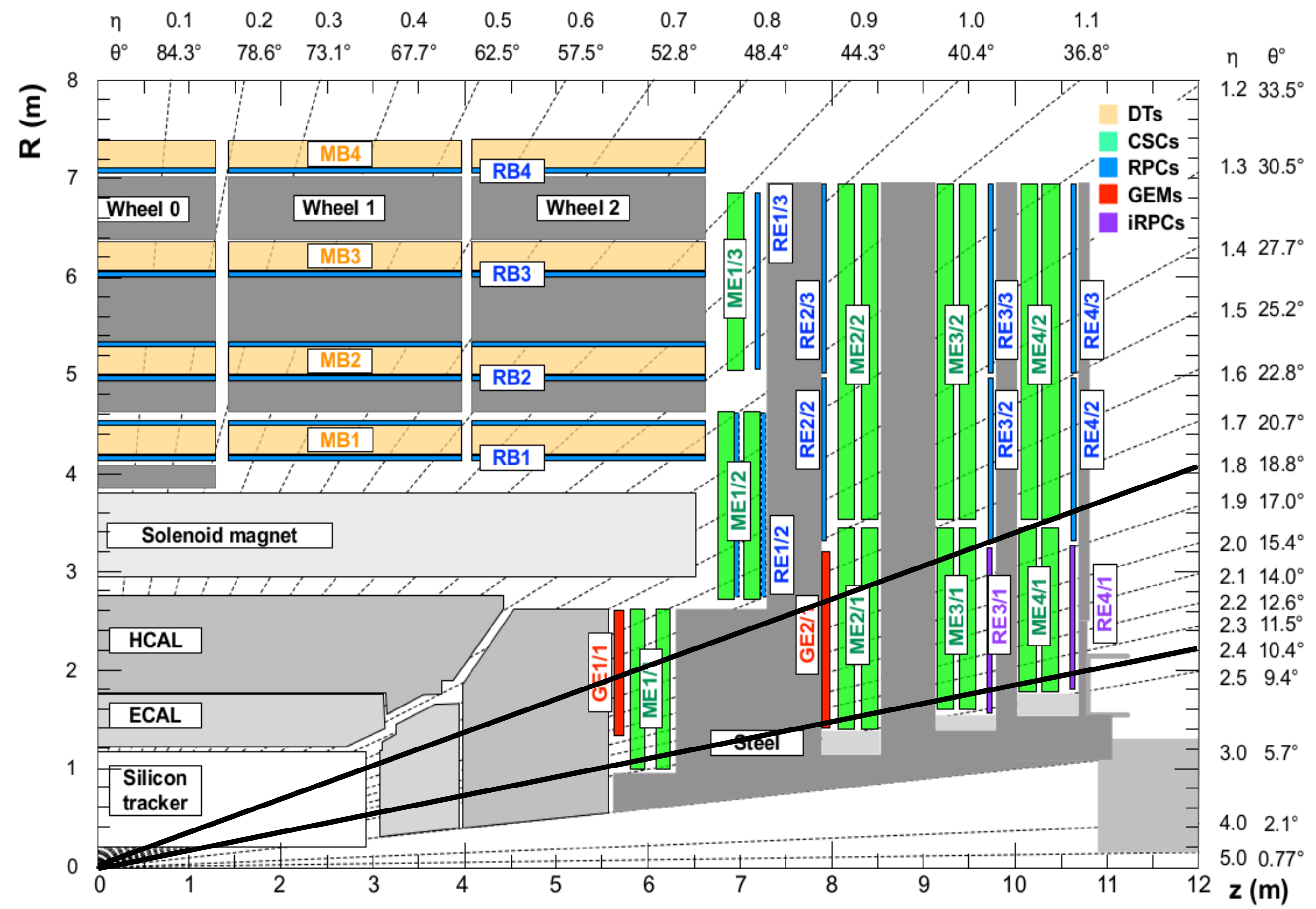
On behalf of the CMS muon group

The XIV Workshop on Resistive Plate Chambers and Related Detectors

Phase II upgrade & improved RPC



High Luminosity (HL)



High η (pseudo rapidity) region

Extend |η| of 2.4

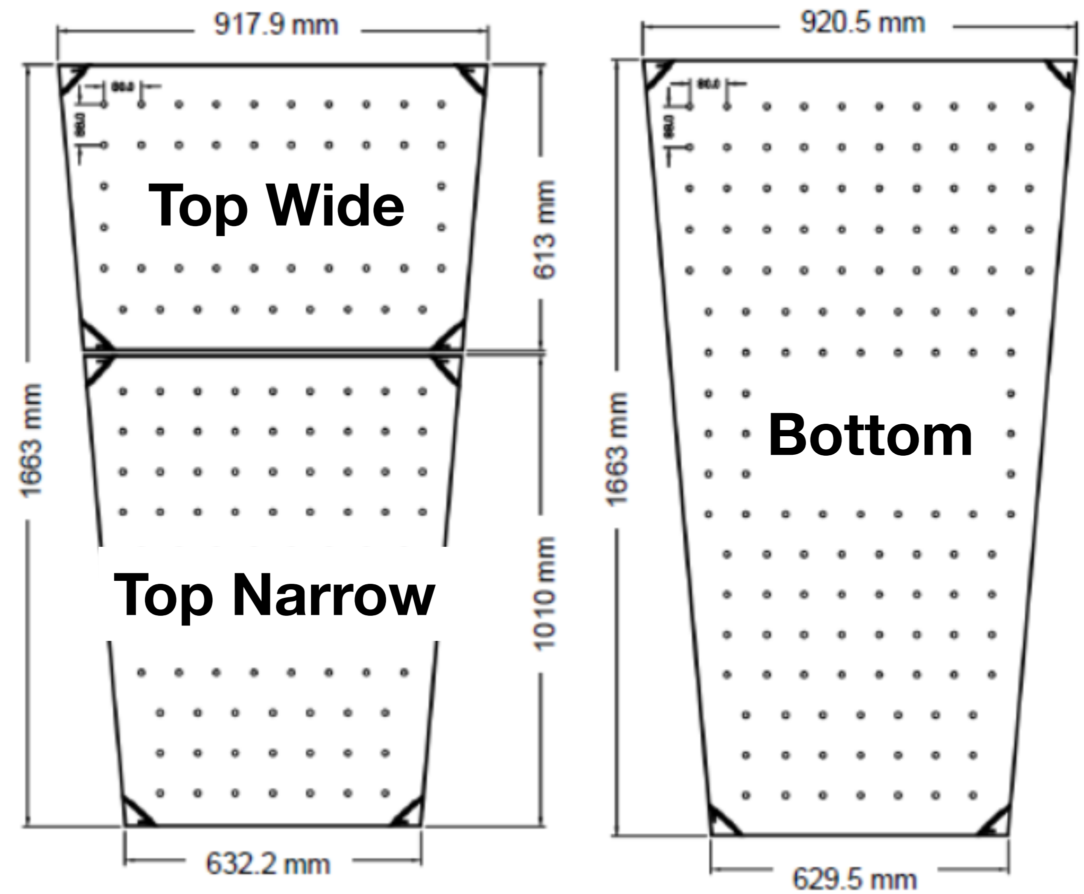
HL-LHC : maximum rate of 2 kHz/cm² (safety factor of 3)

→ improved RPC (iRPC) : better detector performance ensuring higher rate capability

Details on RPC upgrade project for CMS Phase II in Isabel Pedraza's presentation

iRPC developed by KODEL

iRPC Baseline design	
High Pressure Laminate Thickness	1.4 mm
The Number of Gas Gaps	2
Gas Gap & Electrode width	1.4 mm
Resistivity (Ω·cm)	0.9~3 x 10^{10}
Strip pitch	0.7~1.2 cm
Electronics Threshold	< 50 fC



Large Size double-gap iRPC

- **two cut gaps (top) and a full gap (bottom)**
- **96 strips (strip pitch : 1.5~2.8 cm)**

Three Front-end electronics

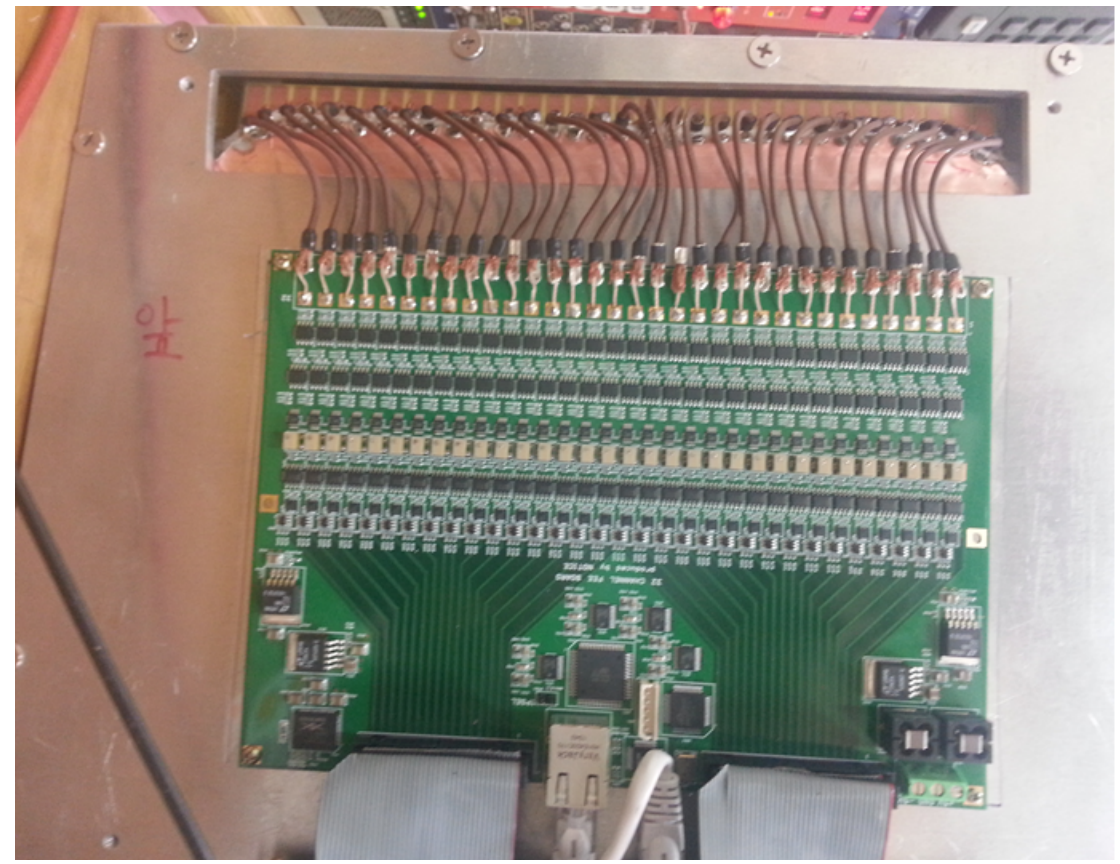
- **32 channel**
- **voltage-sensitive mode (KODEL customized)**

Gas : humidified CMS mixture

- **95.2 % C_2F_4 + 4.5 % iC_4H_{10} + 0.3 % SF_6 (humidity 50%)**

KODEL FEBs

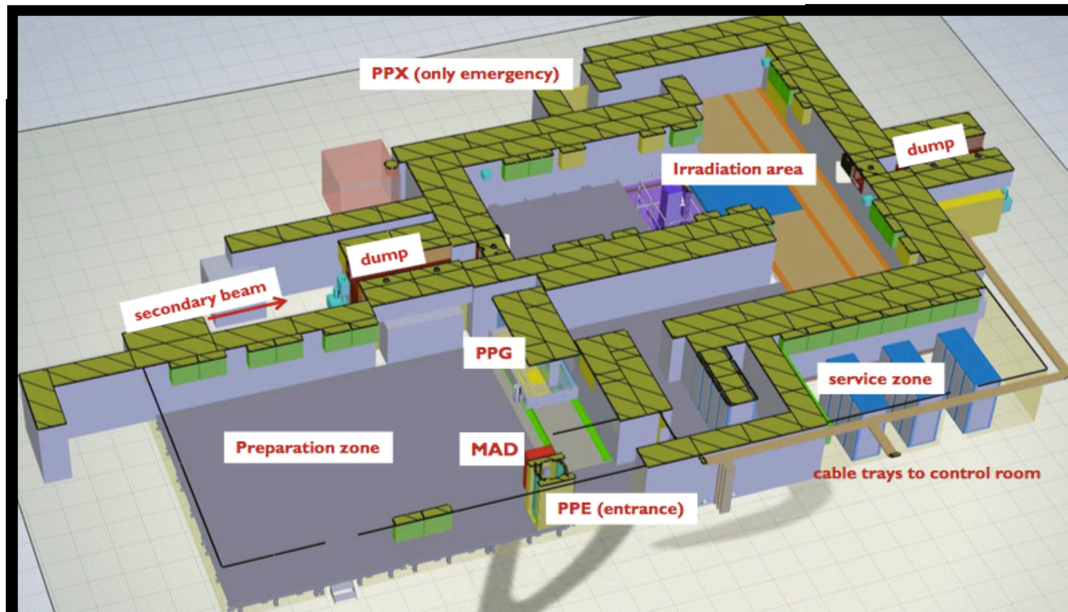
Input impedance	20 Ω
Gain	200 mV/mV
LVDS output pulse width	20 ~ 100 ns
Time resolution	~100 ps (for typical 1 pC signals)
RMS electronics noises (board only)	~20 μV (3 fC)
Minimum threshold (with coaxial cable readout)	~250 μV (40 fC)

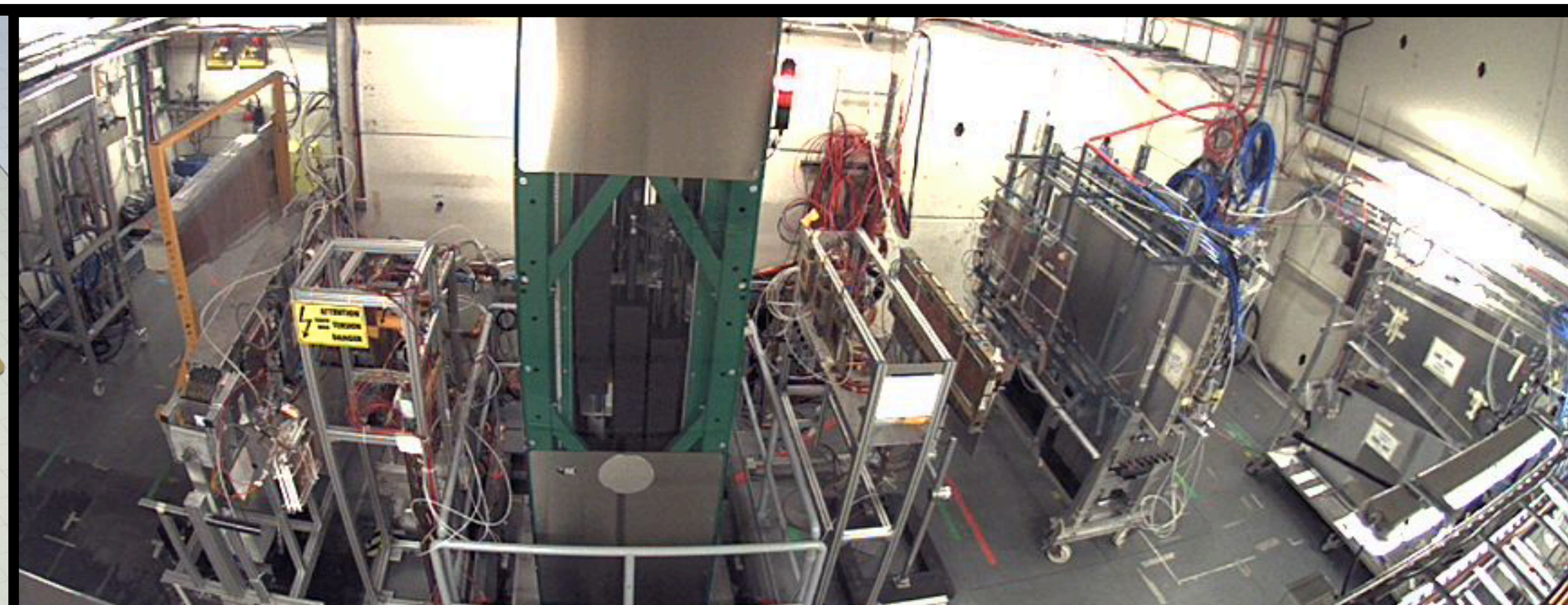


Voltage sensitive-mode FEBs manufactured with commercial preamplifiers

- **developed only for fundamental R&Ds for CMS iRPCs**
- **Ethernet communication for adjusting thresholds**

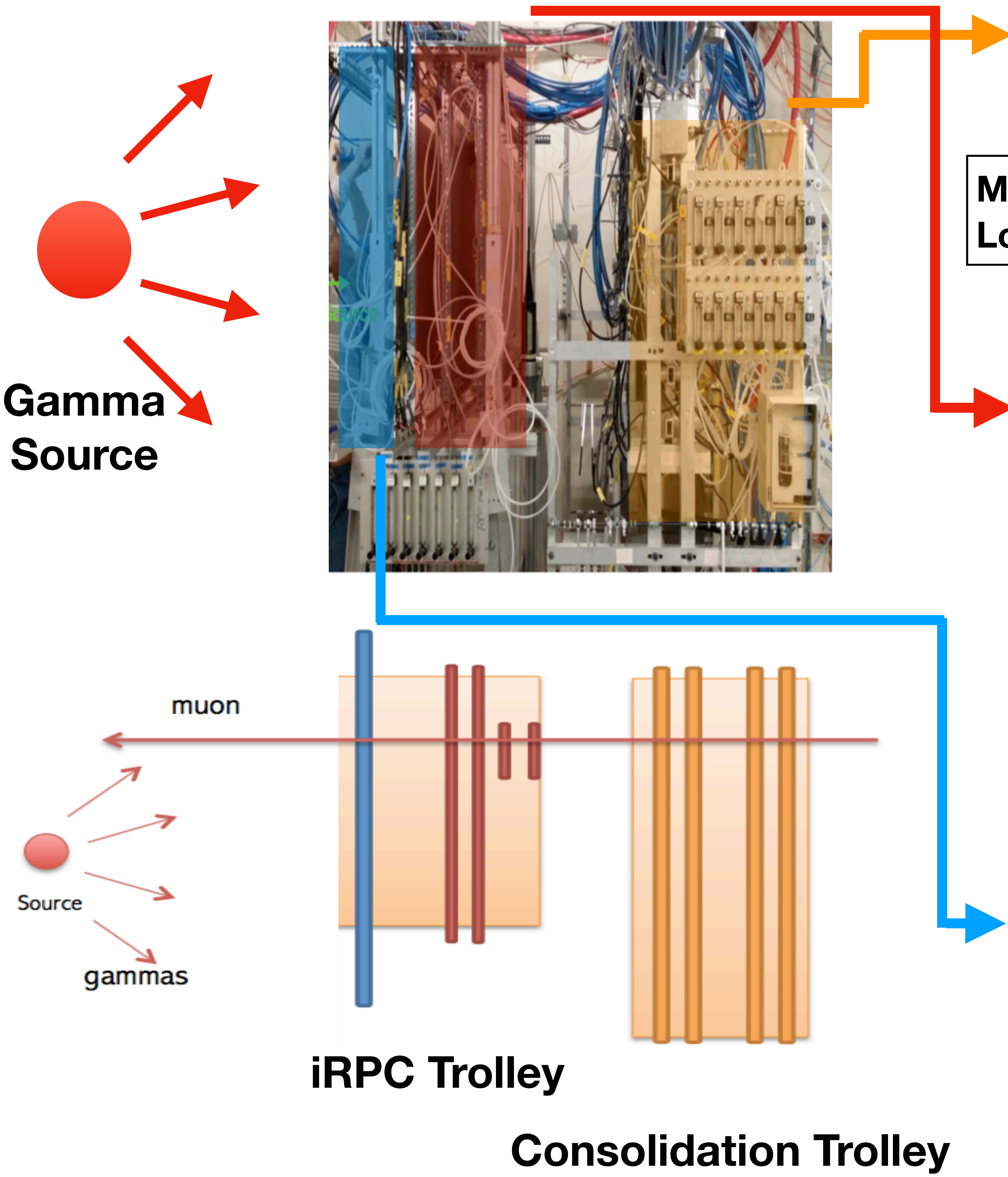
Gamma Irradiation Facility (GIF) ++





- **Locates in CERN Prevessin Site**
- **100 GeV Muon beam from Super Proton Synchrotron (SPS)**
  & ~13 TBq ^{137}Cs gamma radiation source

2017 May Test Beam



Current CMS RPC

- Longevity test

More details on next talk
Longevity studies for the CMS-RPC system, Andrea Gelmi

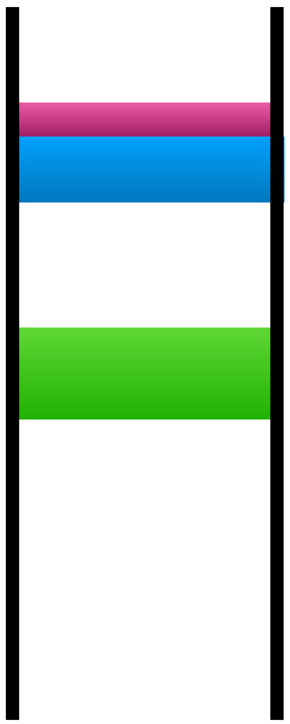
Tracking Chamber

- Two 100 cm x 70 cm 2-mm double-gap RPCs from General Tecnica (GT), Italy & Two 10 cm x 10 cm RPCs from BARI
- Fixed $HV_{eff.}$ at Working Point
- Additional trigger for muon tracking

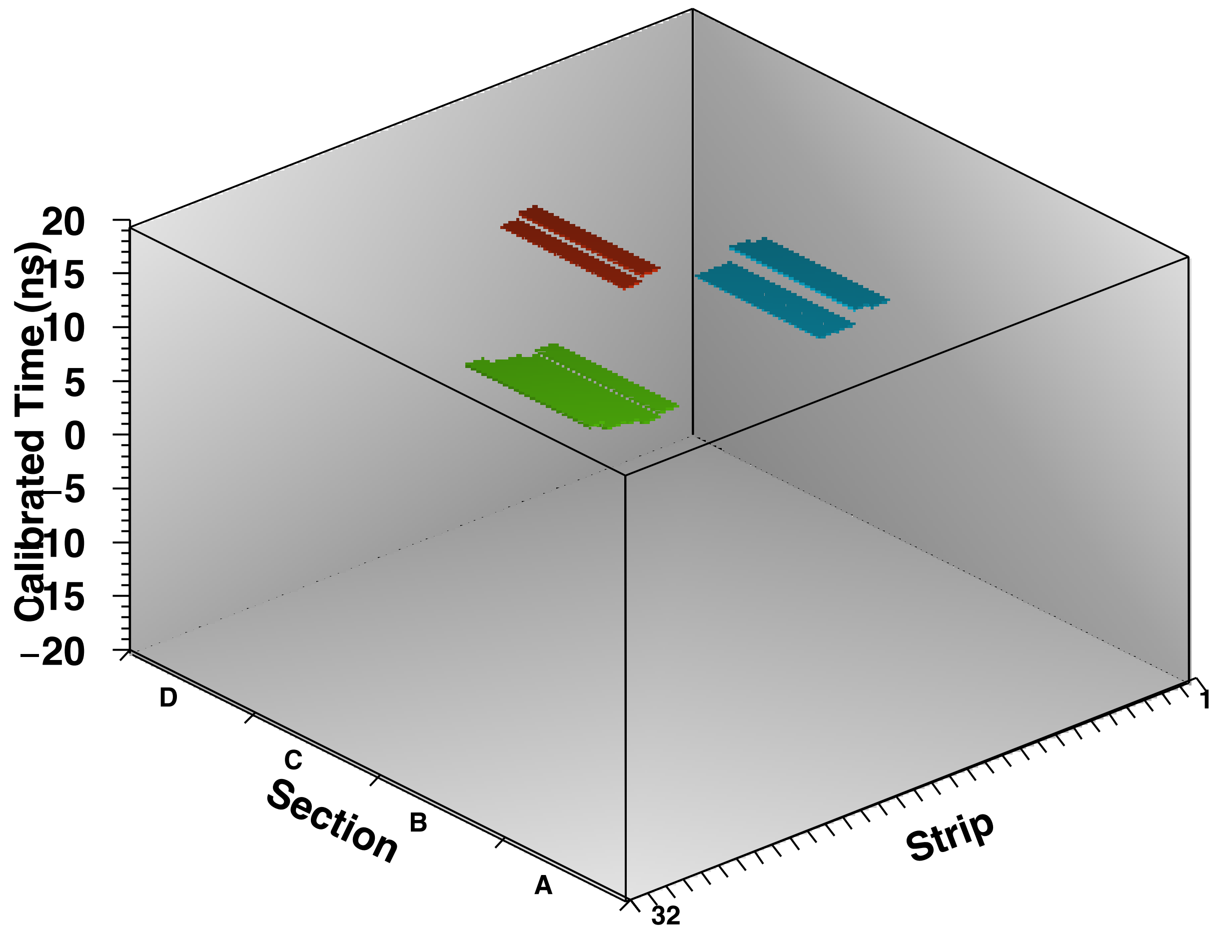
iRPC from KODEL

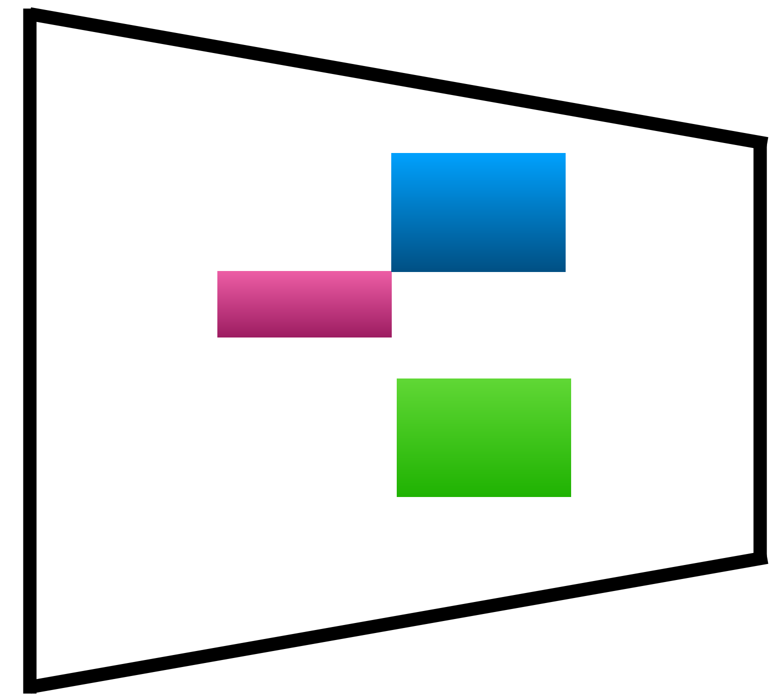
- Measure efficiency at different gamma rates by using dedicated clustering & tracking algorithm

Clustering



Time





Position

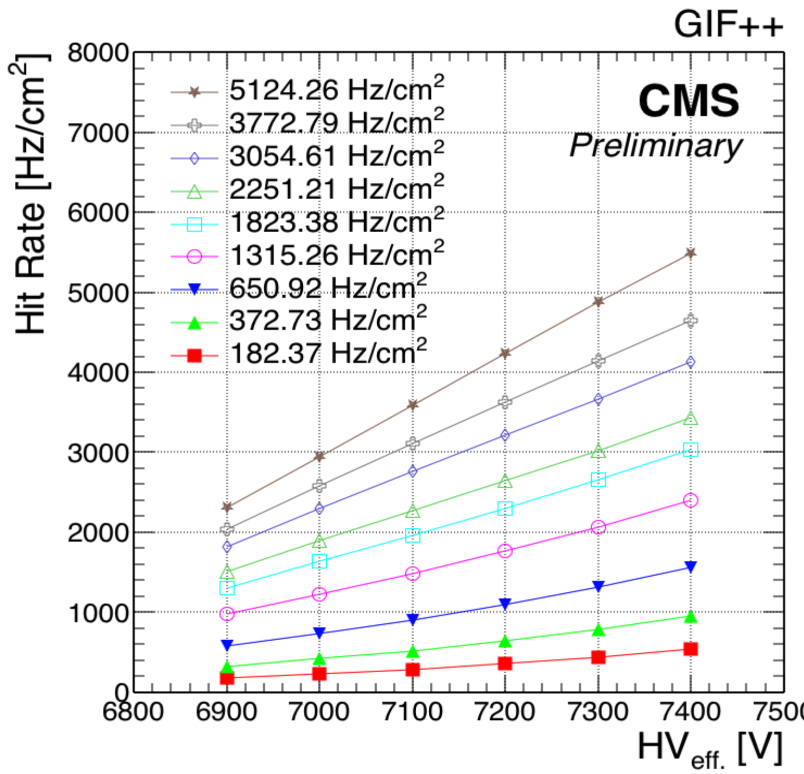
Clustering

- **Using hit position & calibrated time information**
- **Cluster adjacent hits in position and in time**

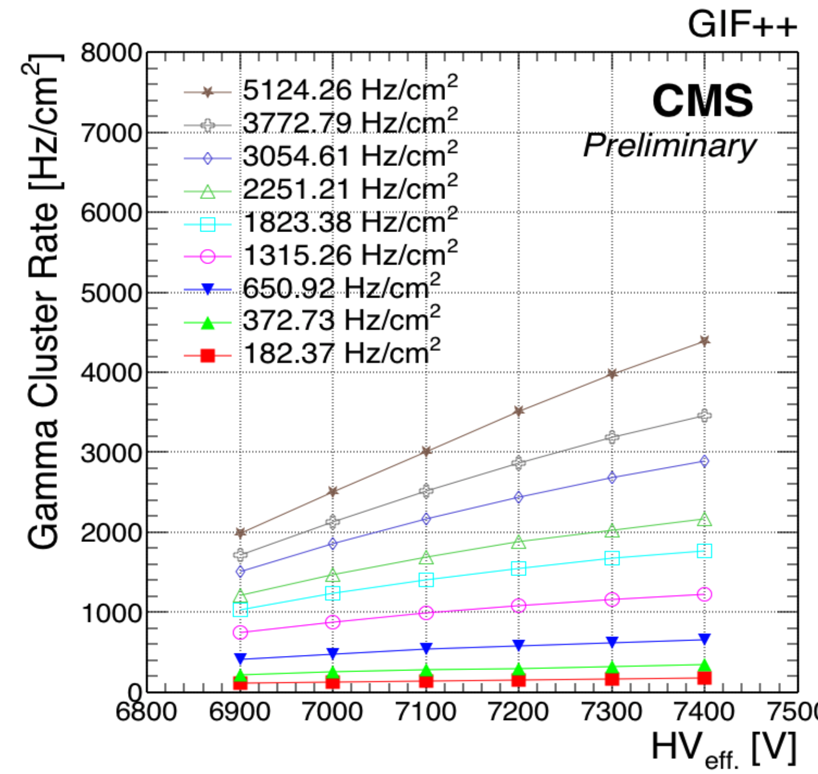
only Time Information : Green // Blue + Red

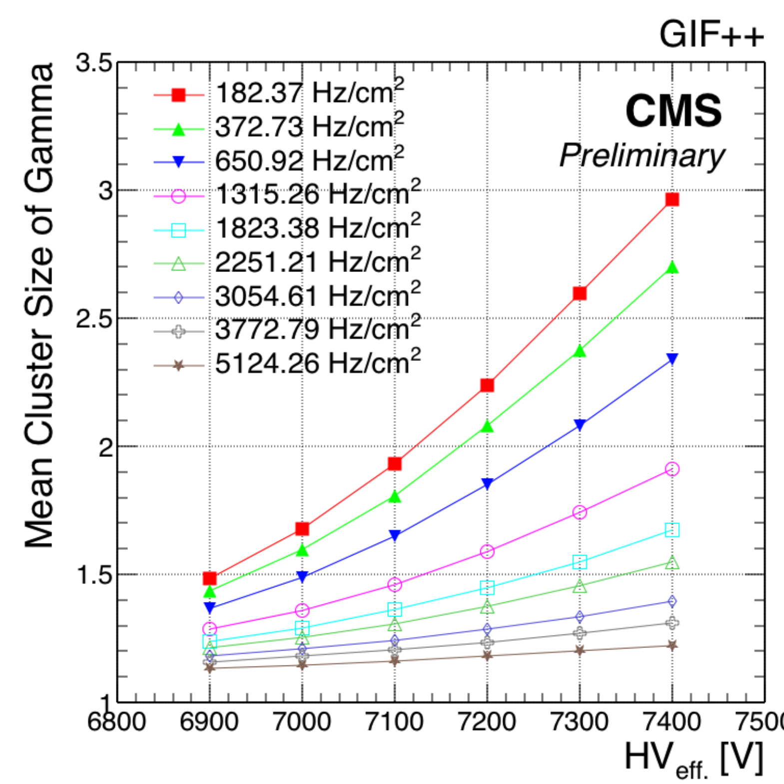
→ Time + Position Information : Green // Blue // Red

Gamma Cluster



Clustering Algorithm →





Gamma Cluster

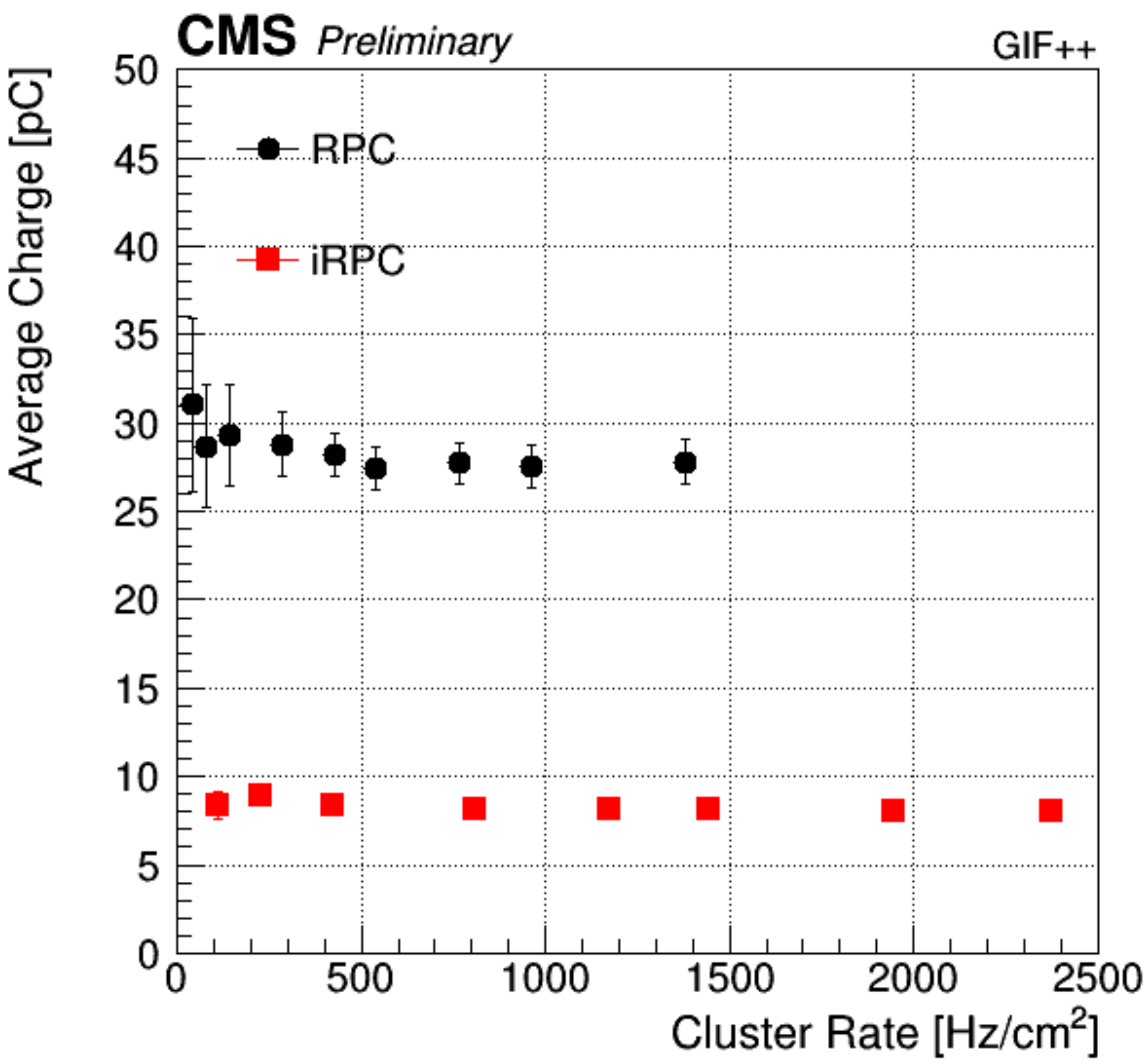
- **At different gamma source rates**
- **Without muon beam**

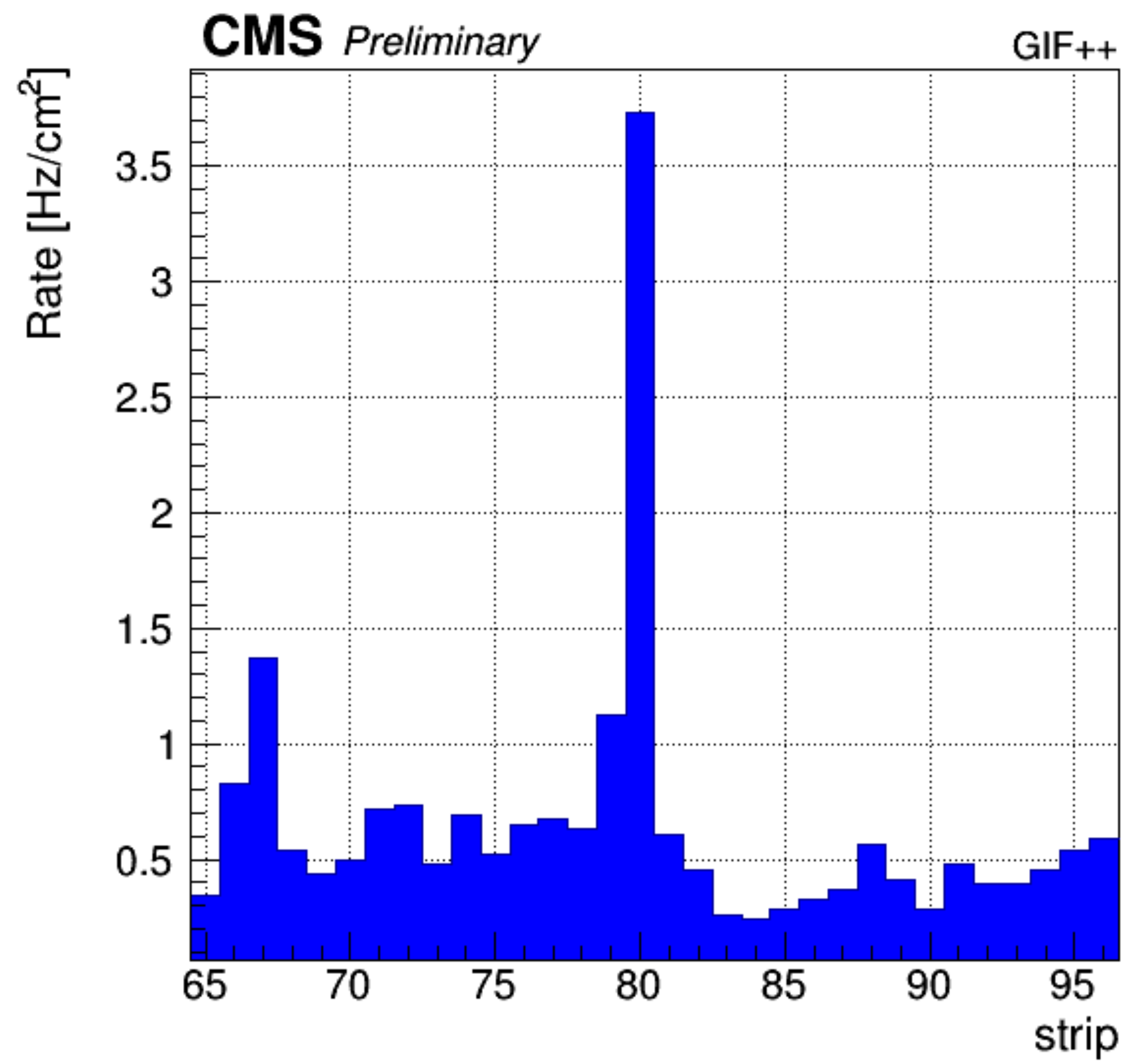
Effective High Voltage (HV_{eff})

- $HV_{eff} = \dfrac{HV_{app}}{1 - \alpha + \alpha \cdot \frac{T_0 P}{T P_0}}$

α : 0.8
T_0 : 293.15 K
P_0 : 990 mbar

Charge & Noise Rate



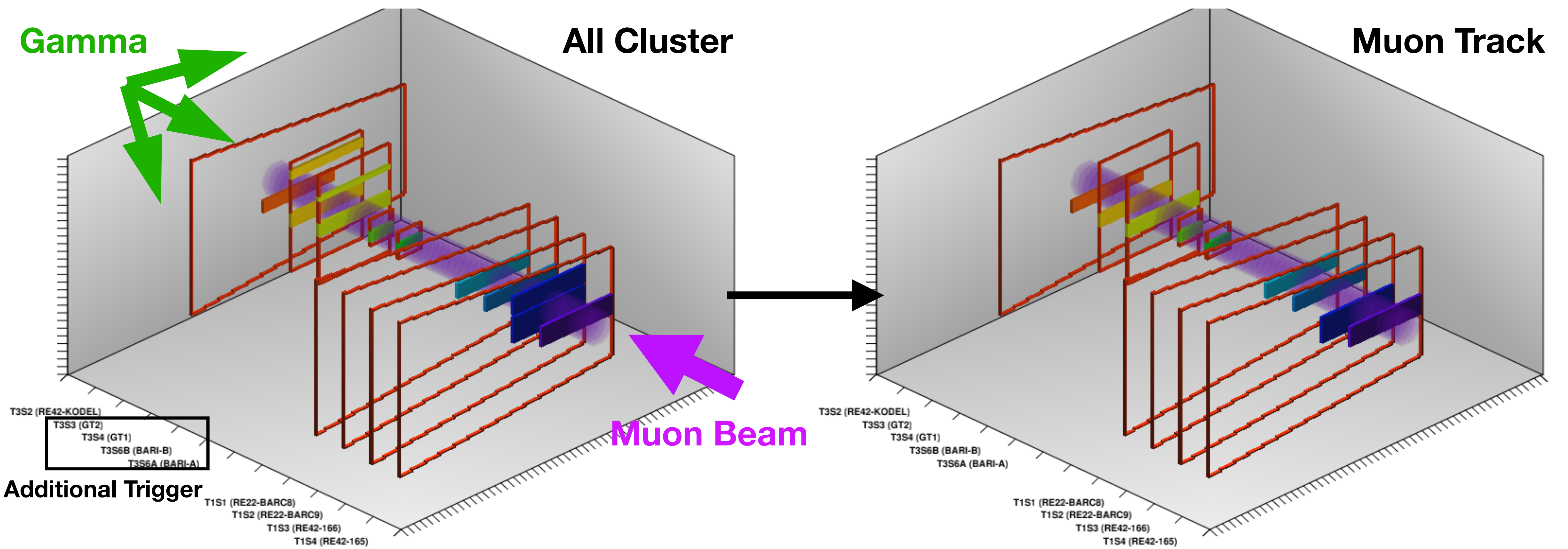


Charge = $\frac{\textbf{Detector Current}}{\textbf{Gamma Cluster Rate}}$ **= ~8 pC at threshold 50 fC (HV$_{\text{eff.}}$ of 6900 ~ 7400 V)**

→ 3.5 times smaller than that of 2.0-mm double-gap RPCs at threshold 150 fC

Details on Longevity studies for the CMS-RPC system in Andrea Gelmi's presentation

Tracking



github.com/JaehoonLim/GIFAnalysis

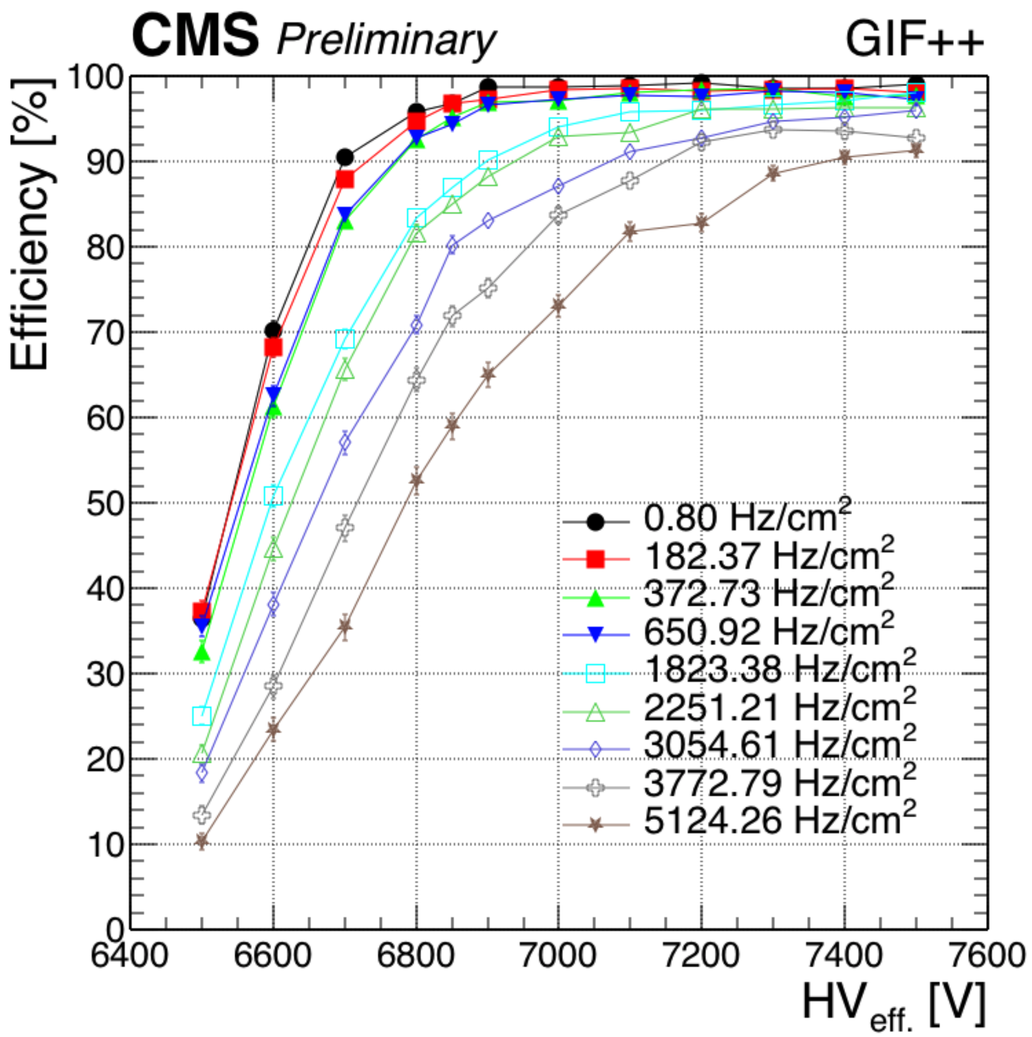
Tracking

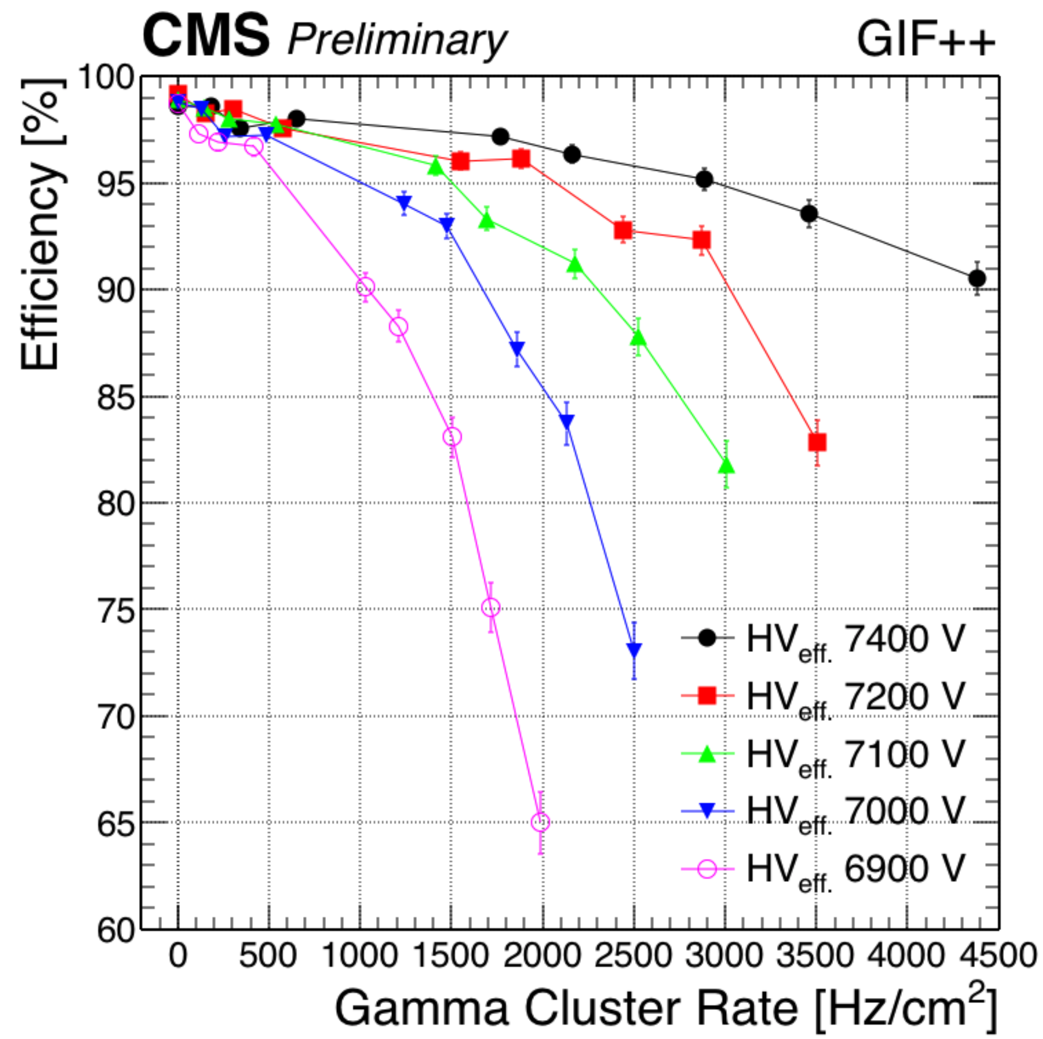
- Using cluster position & calibrated time information
- Track adjacent clusters in position and in time

Distinguish Muon Track

- Muon beam position and timing cut on reconstructed Track
- Additional Trigger : (GT1 || GT2) && (BARI-A || BARI-B)

Muon Efficiency





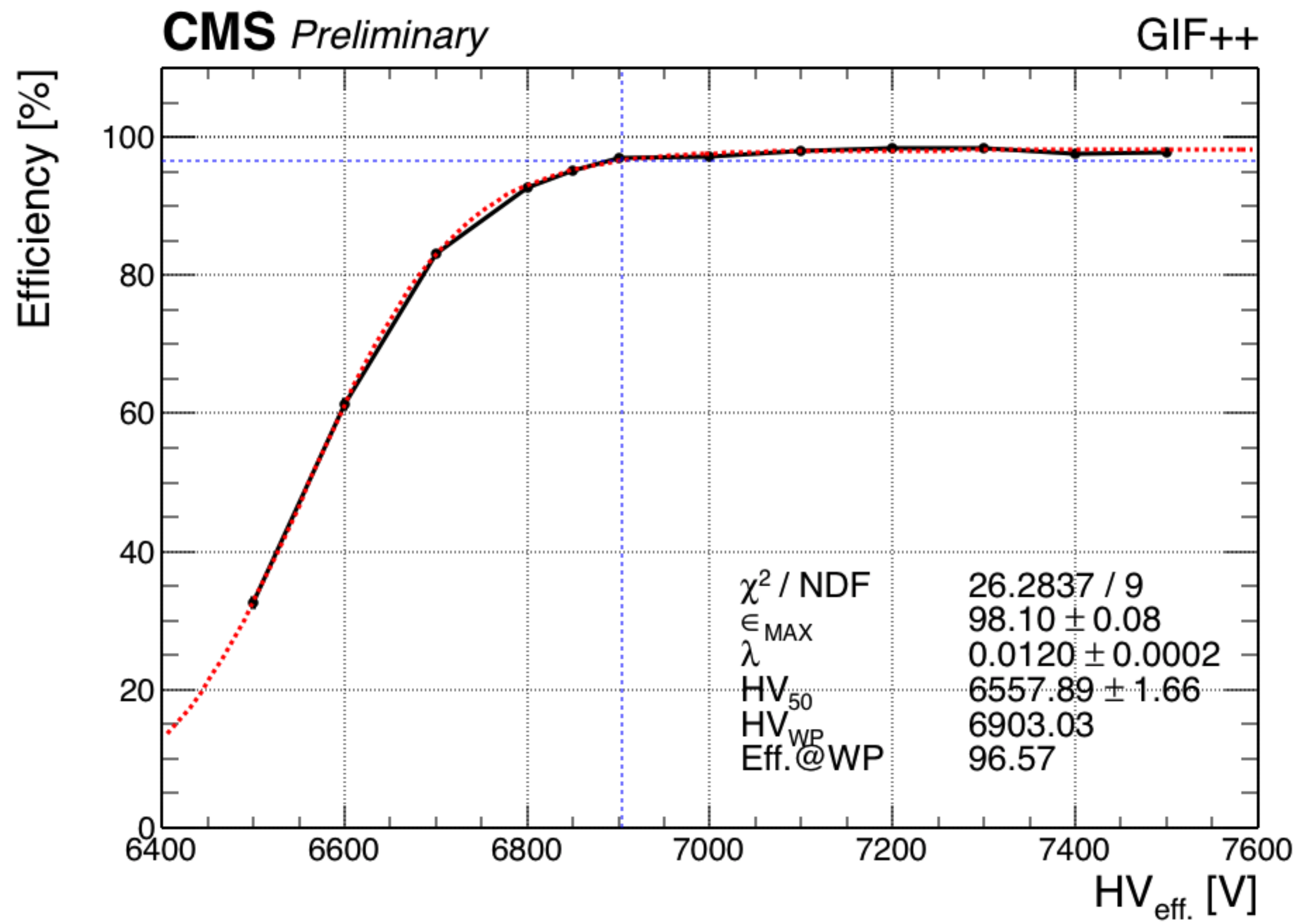
$$\textbf{Muon Efficiency} = \frac{\textbf{Number of Muon Track (Additional Trigger \&\& iRPC)}}{\textbf{Number of Muon Track (Additional Trigger)}}$$

Additional Trigger : (GT1 || GT2) && (BARI-A || BARI-B)

HV$_{eff.}$ 6900 V : Efficiency >95 % at <500 Hz/cm^2
Efficiency ~65 % at ~2 kHz/cm^2
HV$_{eff.}$ 7200 V : Efficiency >95 % at ~2 kHz/cm^2

~300 V to recover efficiency

Sigmoid Functional Fit



Gamma Source Rate : 372.73 Hz/cm²

Sigmoid functional fit

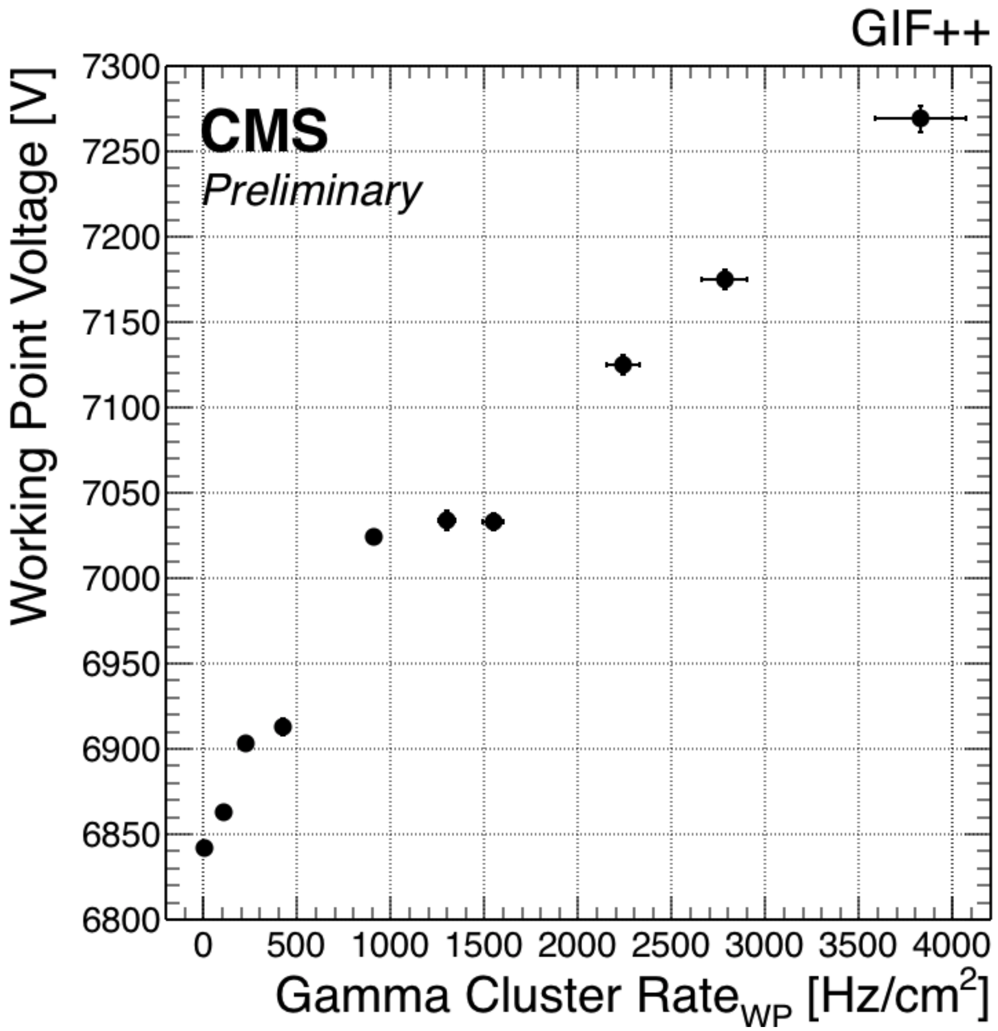
$$\varepsilon = \frac{\varepsilon_{max}}{1 + e^{-\lambda(HV_{eff.} - HV_{50})}}$$

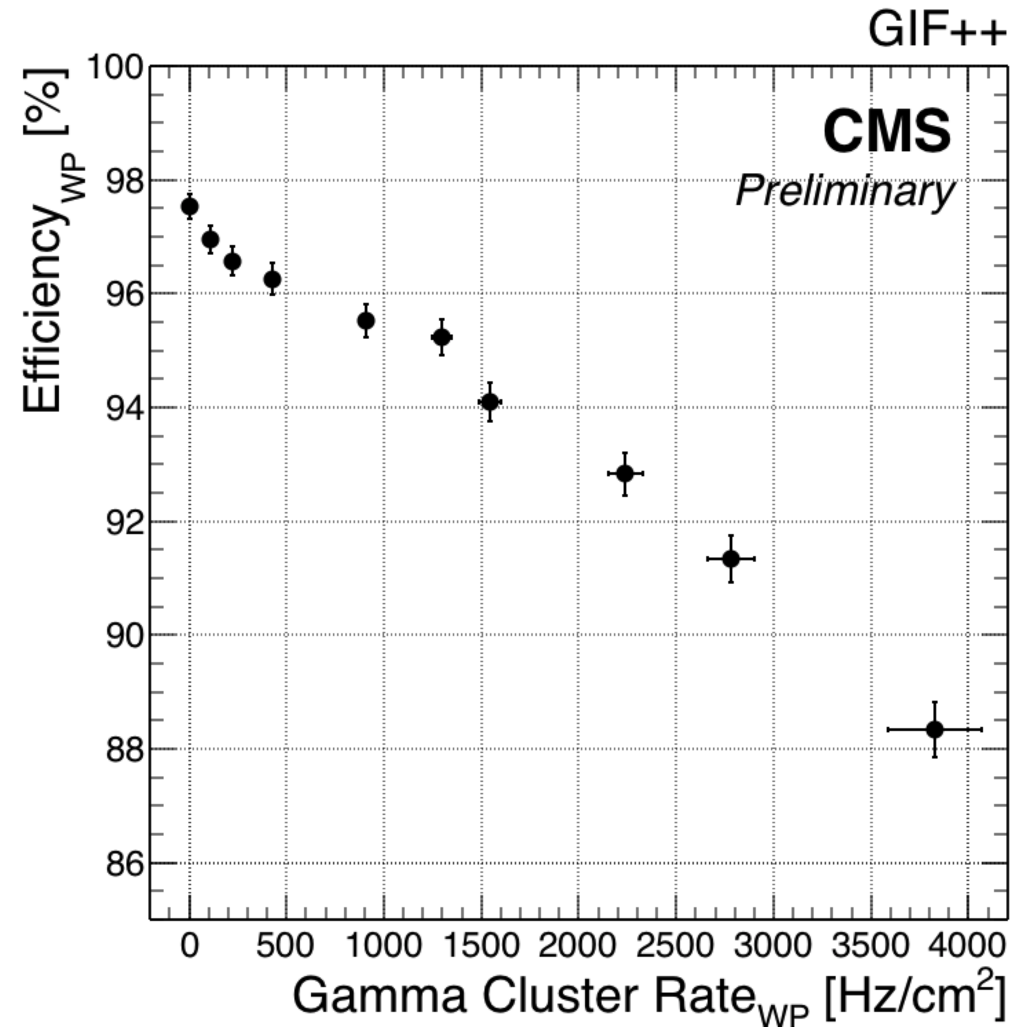
$HV_{eff.}$: Effective high voltage
ε_{max} : Maximum efficiency of detection
HV_{50} : $HV_{eff.}$ where the ε is 50% of ε_{max}
λ : Slope parameter at HV_{50}

Working point voltage (WP)

WP = HV_{95} + 100V (HV_{95} : $HV_{eff.}$ where the ε is 95% of ε_{max})

Working Point & Effciency$_{WP}$





at < 500 Hz/cm^2

- **WP ~6850 V : Efficiency$_{WP}$ >95 %**

at 2 kHz/cm^2

- **WP ~7100 V : Efficiency$_{WP}$ ~93 %**

The shift of WP is also ~300 V

Summary

The large-size prototype iRPC developed by KODEL has been successfully tested at GIF++ and 100-GeV SPS H4 muon beams at CERN:

1. **The performance of iRPC was tested by using dedicated algorithm for clustering and tracking**

2. **Mean avalanche charge of gamma background particle is ~8 pC when digitized at threshold 50 fC (300 uV)**
   → **3.5 times smaller than that of 2.0-mm double-gap RPCs at threshold 150 fC**
   → **better rate capability and longevity**

3. **The prototype iRPC well satisfies the rate capability of 2 kHz/cm^2 that is required in the future Phase-2 LHC runs**

$HV_{eff.}$ 6900 V :	**Efficiency >95 % at <500 Hz/cm^2**
	Efficiency ~65 % at ~2 kHz/cm^2
$HV_{eff.}$ 7200 V :	**Efficiency >95 % at ~2 kHz/cm^2**

We need ~300 V to recover the 95% efficiency
The shift of WP at ~2 kHz/cm^2 is also ~300 V

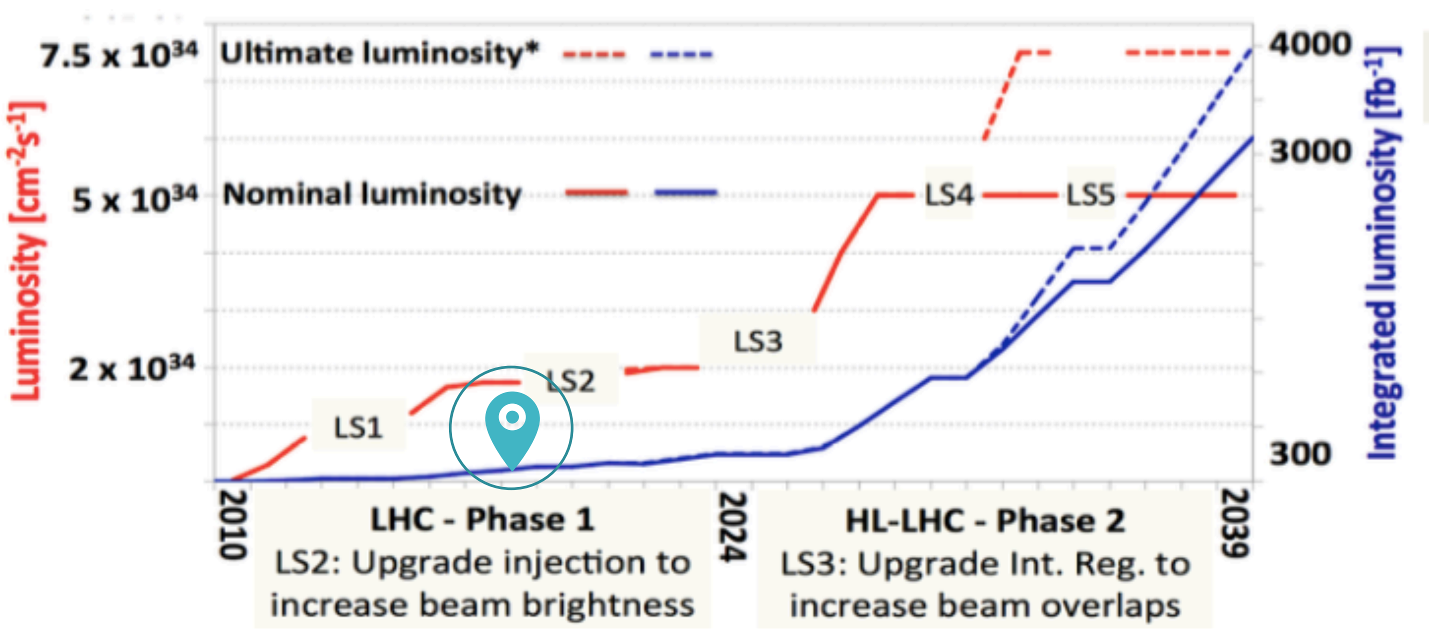
Thank you!

HL-LHC

RPC upgrade project for CMS Phase II, Isabel Pedraza - page 6

LHC specs

		LHC	Earlier HL-LHC	Ultimate HL-LHC
Collider	instantaneous luminosity ($cm^{-2}s^{-1}$)	10^{34}	5×10^{34}	7.5×10^{34}
	pileup collisions	30	150	200
	integrated luminosity (fb^{-1})	500	3000	4000
CMS	L1 trigger (kHz)	100	500	750
	L1 trigger latency (μs)	3.6	12.5	



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All LHC experiments were designed for the LHC specs.

New specs require detector upgrades.

iRPC

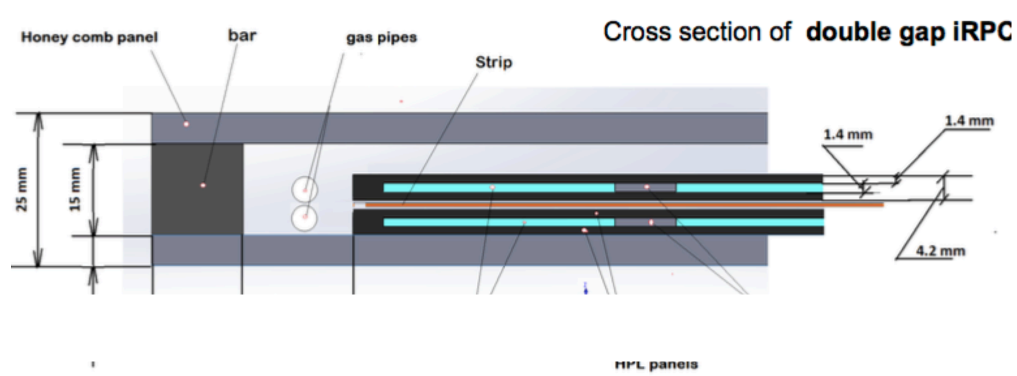
RPC upgrade project for CMS Phase II, Isabel Pedraza - page 8

Research and development done

All relevant detector improvement factors have been investigated:

- Reduced electrode resistivity
- Different technologies : Glass[+] and HPL electrodes[++].
- New detector geometry[*]
- New Front-End electronics design[**]

*Schematic design of a Double-Gap iRPC**



\+ see François Lagarde talk on *High rate, high time precision RPC detector for LHC*
++ see *R&D results of iRPC tested at GIF++ for CMS Phase II upgrade*
*see Elena Voevodina's poster on *RE3/1 and RE4/1 chambers integration in the inner region of the Forward Muon Spectrometer of the CMS experiment*
** see Christophe Combaret's talk on *Fast timing measurement for CMS Phase II upgrade*

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iRPC detector design

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iRPC: detector design

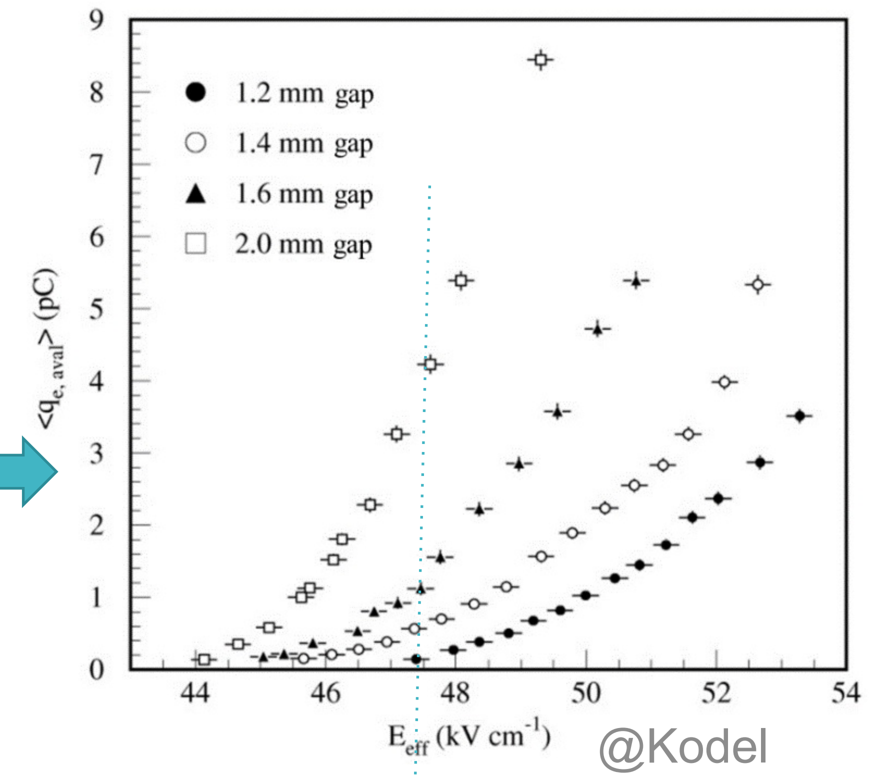
- **Resistivity of the HPL**

From 1-6 x 10^10 -> 0.9-2 x 10^10 Ohm-cm -> **Enhance the rate capability by a factor 2**

- **Gap thickness:** 1.4 mm instead of 2.0 mm: retards the fast growth of the pick up charge.

- **Electrode thickness:** 1.4 mm instead of 2.0 mm:

1) Recovery time reduced by factor 30%.
2) Efficiency of extracting the pickup charge from the avalanche charge increases by 70%.
Totally an **enhancement of a factor 2 in the rate capability**.



- **Smaller avalanche charges obtained by the lowering threshold: 150 fC -> 50 fC or less**

Lowing the threshold + gap thickness can lower the avalanche charge by a factor 3 in the rate capability.

The thinner gas gaps will be more sensitivity to non uniformity.
1.4 mm is consider as a safe compromise for CMS.

*(*see Jae Hoon Lim's talk on R&D results of iRPC tested at GIF++ for CMS Phase II upgrade)*

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RPC & iRPC

RPC upgrade project for CMS Phase II, Isabel Pedraza - page 10

RE3/1 and RE4/1 requirements at HL-LHC

	Present system	RE3/1-RE4/1
|η| coverage	0 - 1.9	1.8 - 2.4
Max expected rate (Safety Factor = 3 included)	600 Hz/cm^2	2 kHz/cm^2
Max integrated charge (SF = 3 included)	~ 0.8 C/cm^2	~ 1.0 C/cm^2
ϕ resolution	~ 0.3^0	~ 0.2^0
η resolution	~ 20 cm	~ 2 cm

To match CSC granularity

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

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GIF++ details

Longevity studies for the CMS-RPC system, Andrea Gelmi - page 5

Gamma Irradiation Facility (GIF++)

To certify the RPC system at HL-LHC conditions a new LONGEVITY STUDY started @ ***Gamma Irradiation Facility (GIF++) CERN*** *in 2016***:**

- ***^{137}Cs source***
  - → *~13 TBq*
  - → *Photons Energy spectrum 0-662 KeV*
  - → *Filter system (ABS source attenuation)*
- ***Muon beam***
  - → *Energy up to 100 GeV, 10^4 muons/spill*
  - → *3-4 times per year*
- ***Main parameters under control***
  - ***Environmental parameters***
  - → *Temperature, Humidity, Pressure*
  - ***Gas parameters***
  - → *gas composition*
  - → *gas flow*
  - → *gas Temperature, Pressure, Humidity*

GIF++ allows to test real size detectors in a similar background condition as in CMS

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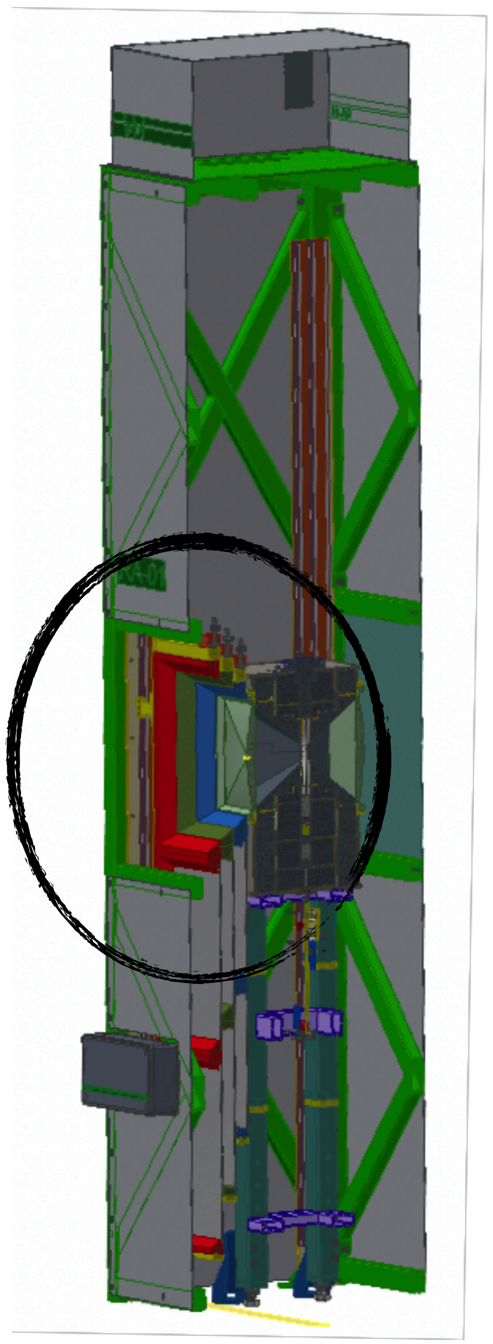
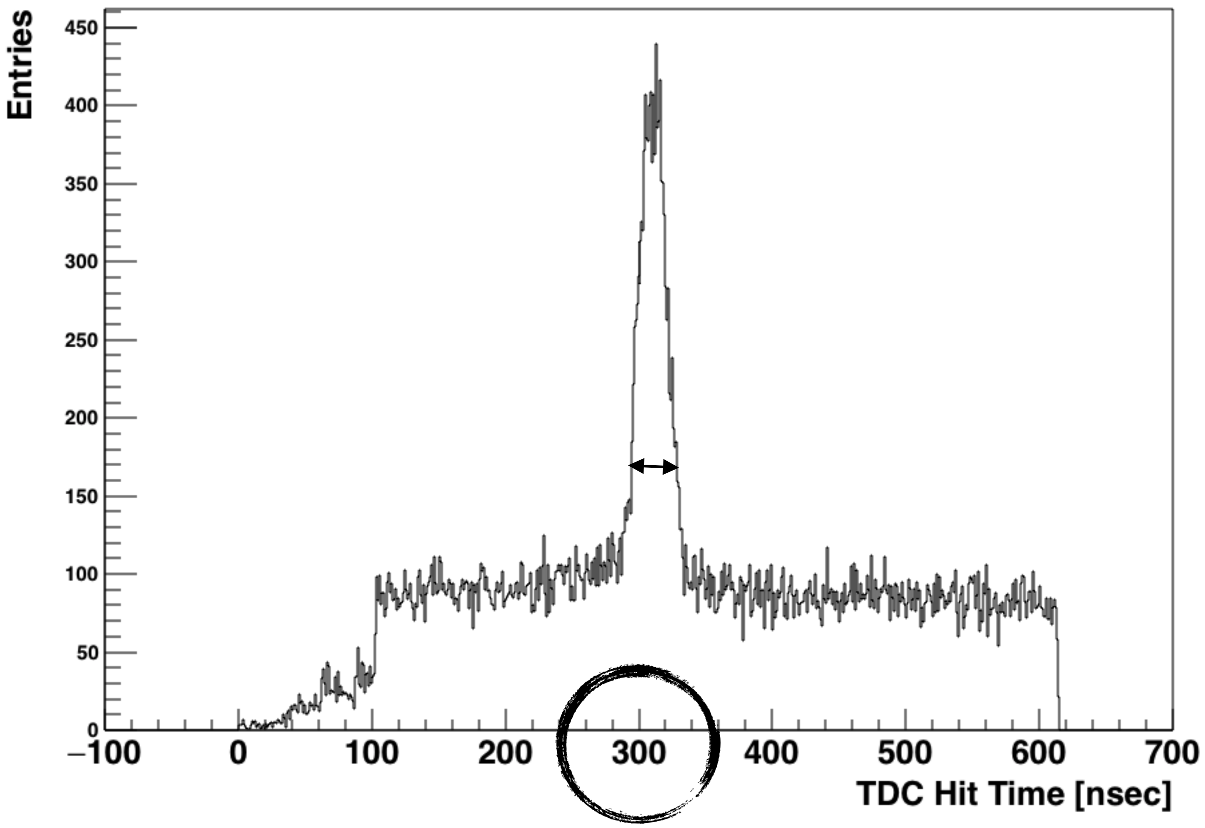
Gamma Source Rate

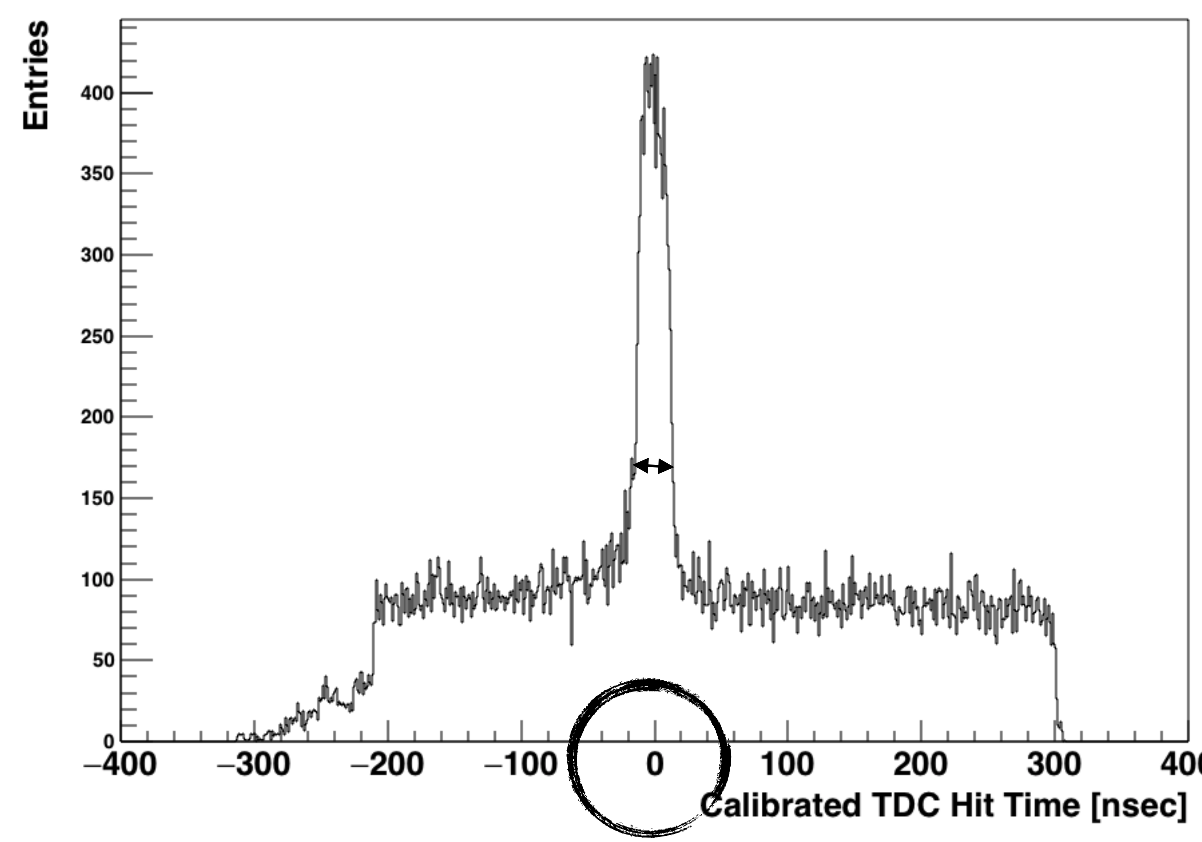


Gamma Source Rate at WP	Absorption Factor
5124.26 Hz/cm^2	3.2
3772.79 Hz/cm^2	4.6
3054.61 Hz/cm^2	6.8
2251.21 Hz/cm^2	10
1823.38 Hz/cm^2	15
1315.26 Hz/cm^2	21.5
650.92 Hz/cm^2	46
372.73 Hz/cm^2	100
182.37 Hz/cm^2	215

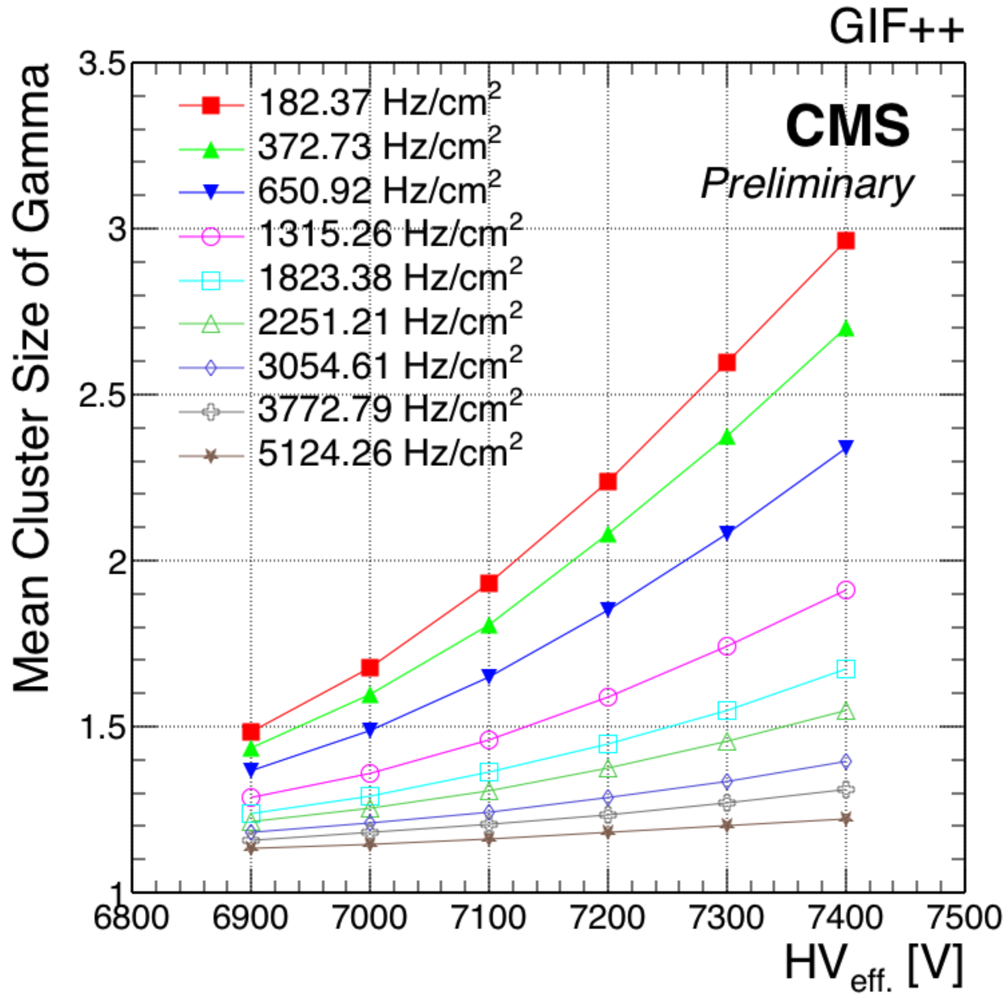
Time Calibration



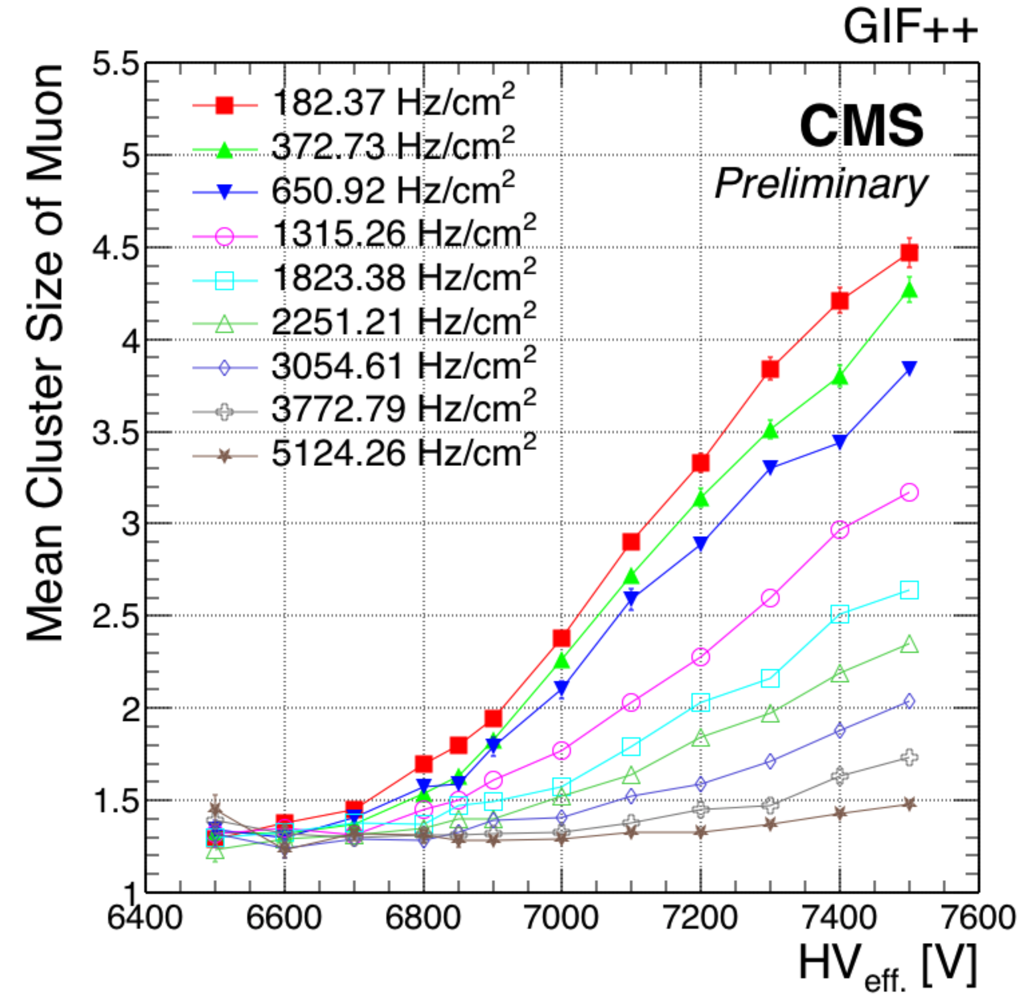
With muon sample
calibrate channel by channel (strip by strip)



Cluster Size



Gamma



Muon