Towards a two-dimensional readout of the improved CMS Resistive Plate Chamber with a new Front-End electronics

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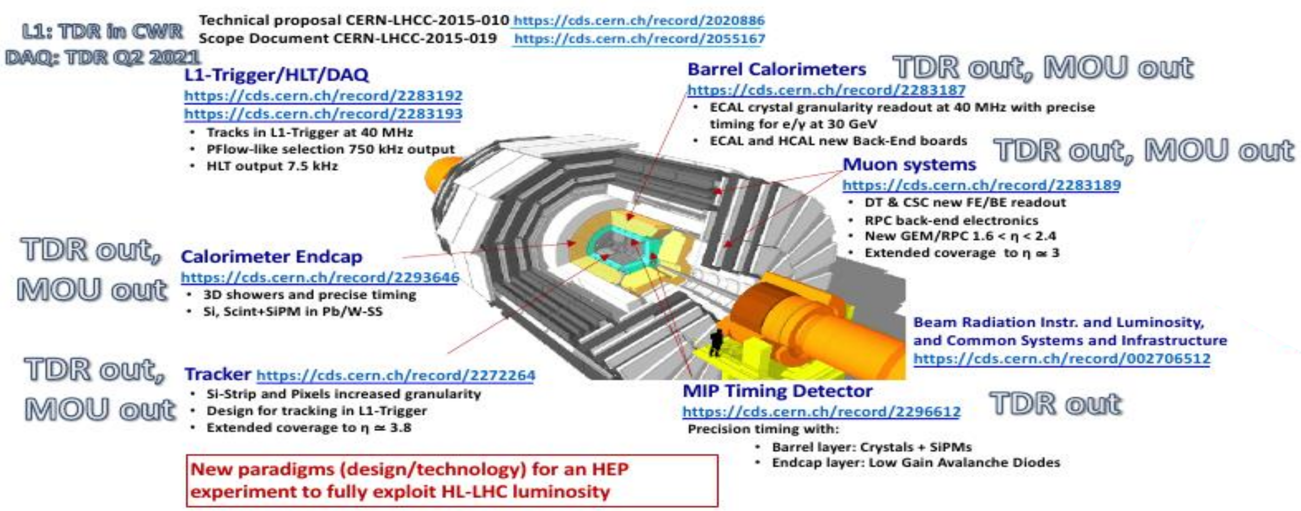
Outline

- Improved RPC design and test setup
- Analysis method
- Results of 2D measurements on real-size chamber

Improved RPC design and test setup

Improved RPC: Alternative Solution

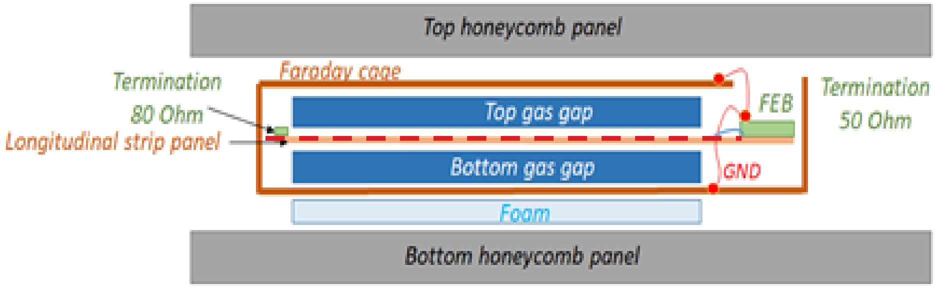
- As part of the CMS Phase-II program, new iRPC will be installed
  - Higher rate capability and better time resolution, required by HL-LHC
- **iRPC and electronics should sustain a background rate up to 2 kHz/cm^2**
  - Efficiency > 95 % at high rate
  - Reasonable cluster size
  - Aging: limit operational currents
  - Time resolution: naturally lower due to reduction of gap thickness (~ 800 ps)
- In addition to the R&D ongoing with the new electronics, an alternative solution based on Electronic developed at Roma Tor Vergata is being considered
  - Alternative solution has a design more similar to the present RPC design

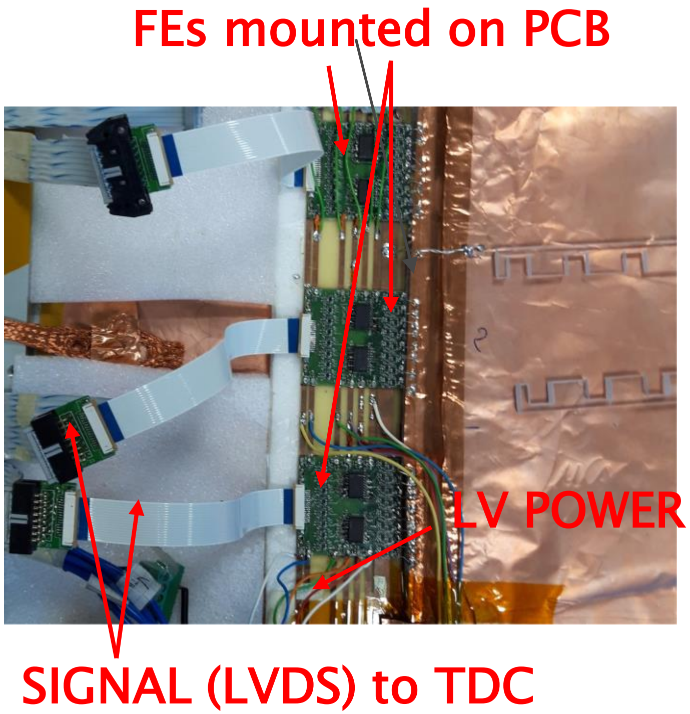


- **iRPC**
  - Double gap, top and bottom gaps
  - 1.4 mm electrode and gap thickness
  - Resistivity 0.9 - $3x10^{10}$ Ωcm
  - PCB strip plane (terminated), pitch ~ 4-8 mm, length ~ 1.6 m
  - Position resolution of the order of cm in both dimensions

  - RPC real size dimensions
    - Bases 58x100 cm
    - Lenght 167 cm

→ Integration of electronics with chamber needed with low threshold and noise reduction

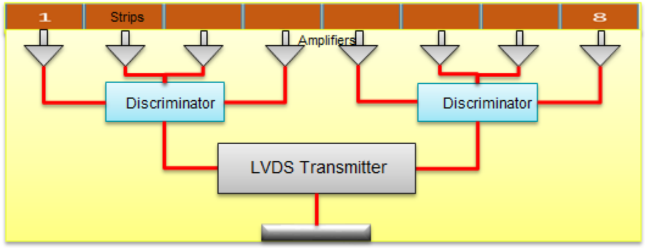


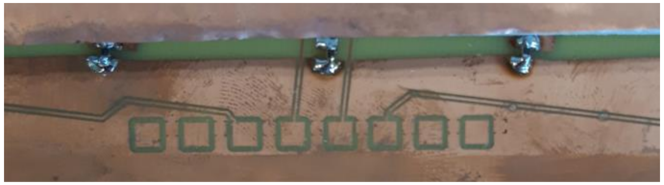


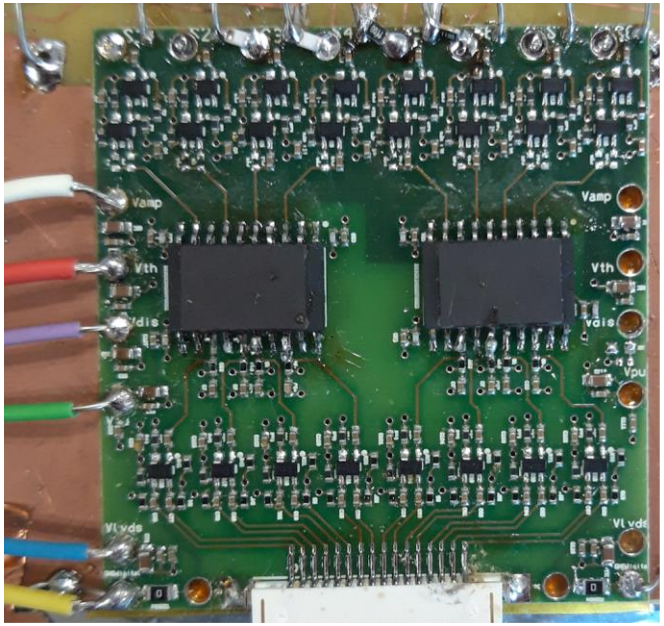
Front–End Electronics

More info: https://arxiv.org/pdf/1806.04113.pdf

- **Front-End Electronics developed at Rome Tor Vergata**
  - Front-End: 8 pre-amps + 2 custom ASIC discriminators
  - Directly mounted on the PCB
  - PullUp and LVDS transmitters integrated
  - Typical achievable thresholds: ~ 1-20 fC
  - 5 LV adjustables: *TH/DISC/AMP/PU/LVDS*







Amplifier	**Discriminator**
Si Bipolar Junction Transistor (BJT) technology	Si-Ge Hetero Junction bipolar Transistor (HJT) technology
Sensitivity: 0.2-0.4 mV/fC	Minimum threshold 0.5 mV
Low intr. noise: 1000 e- RMS	Regulation within order of mV
Possibility to match input impedance to strip	Time Over Threshold

Radiation Hardness: 1 Mrad, 10^{13} n/cm^2

Analysis method

Efficiency Calculation

Muon efficiency ε_μ: $\varepsilon_\mu = \frac{(\varepsilon_{raw} - \varepsilon_{fake})}{1 - \varepsilon_{fake}}$ → Gamma/fake subtraction

- ε_{raw} = efficiency evaluated in the muon time window
- ε_{fake} = efficiency evaluated in a *reduced* noise window with length equal to the muon time window

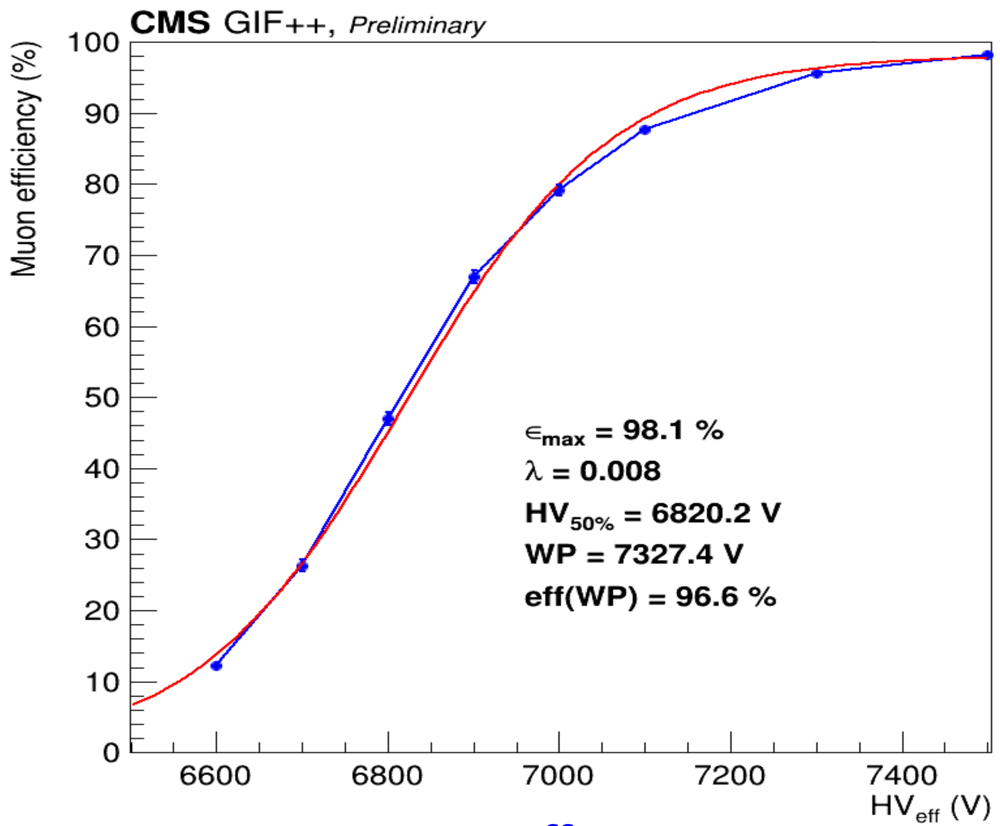
Sigmoid fit:

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

Working point:

WP = ln(19)/λ + HV(50%) + 150 V

[λ and HV(50%) obtained from fit]



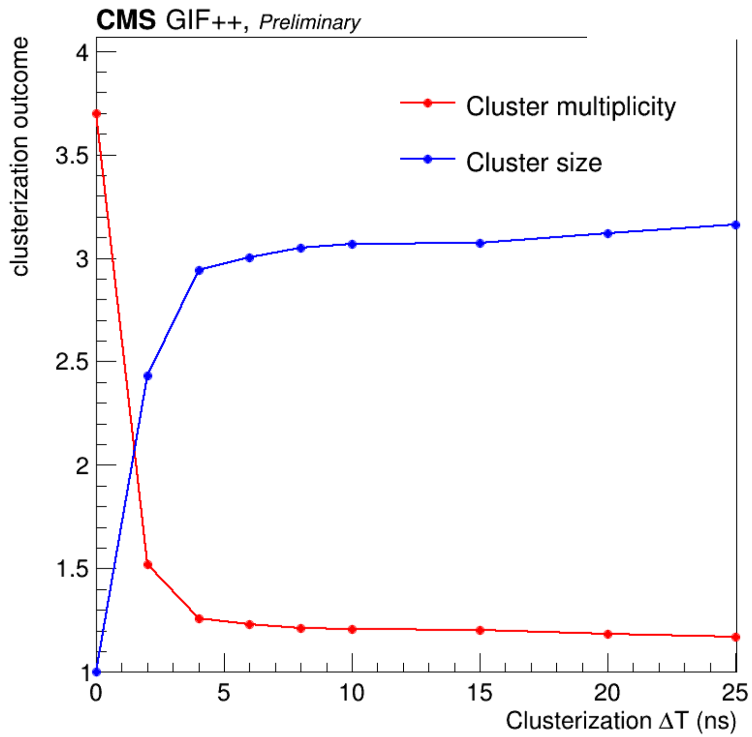
Muon efficiency

Clusterization

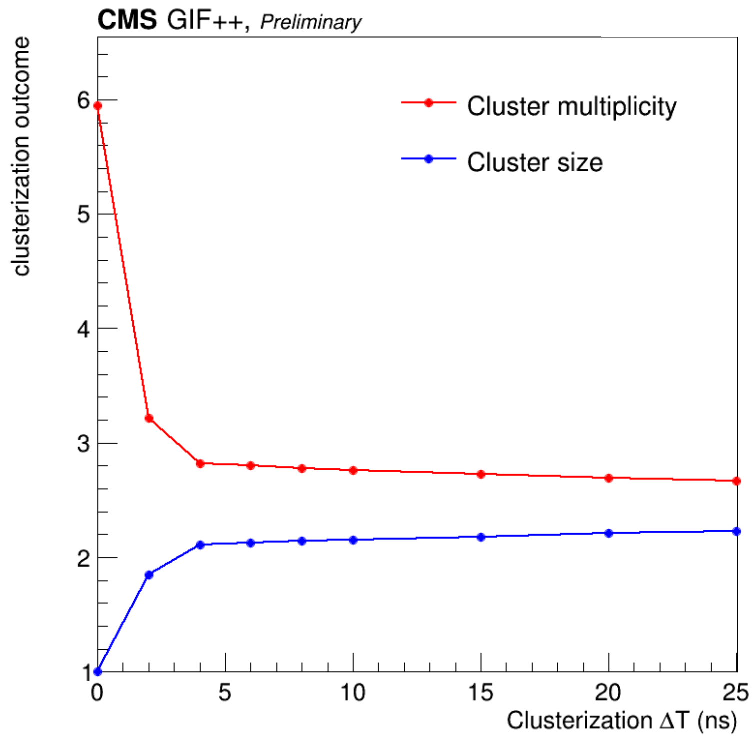
Muon or gamma hits are clustered under two conditions:

1) Adjacent strips (presence of dead strip neglected)
2) Within a time interval of 10 ns → *obtained by scanning the time and re-calculating the clusters till plateau is reached*

Systematic uncertainty derived by varying the time interval with +/- 6 ns



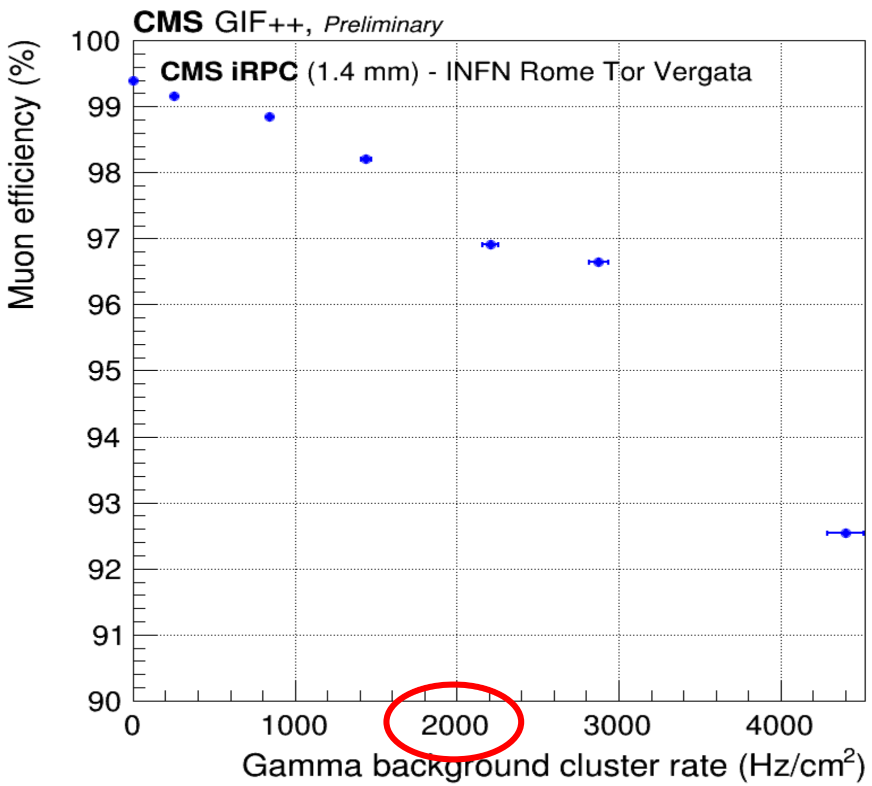
Muon CLS/CMP, source OFF

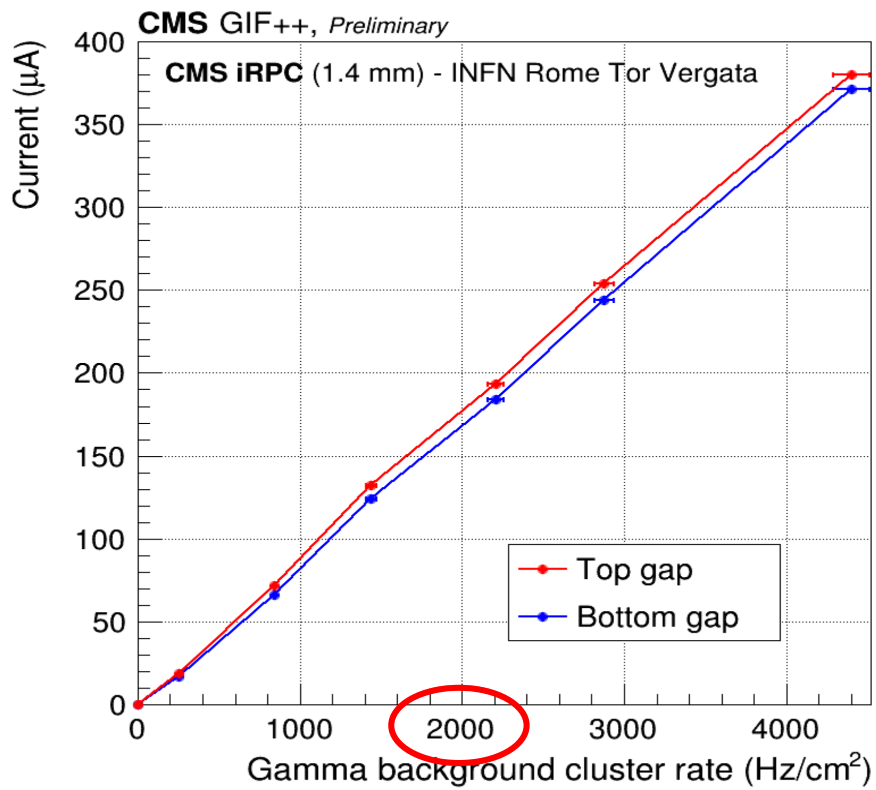


Gamma CLS/CMP, source ON ~ 2 kHz/cm^2

Previous Studies

- Extensive efficiency measurement with 1D readout in 904 and in GIF++.
- Results presented at the EPS 2019 conference.
  - See “*R&D campaign on the improved CMS RPC with a new Front End Electronics*” by Jan Eysermans

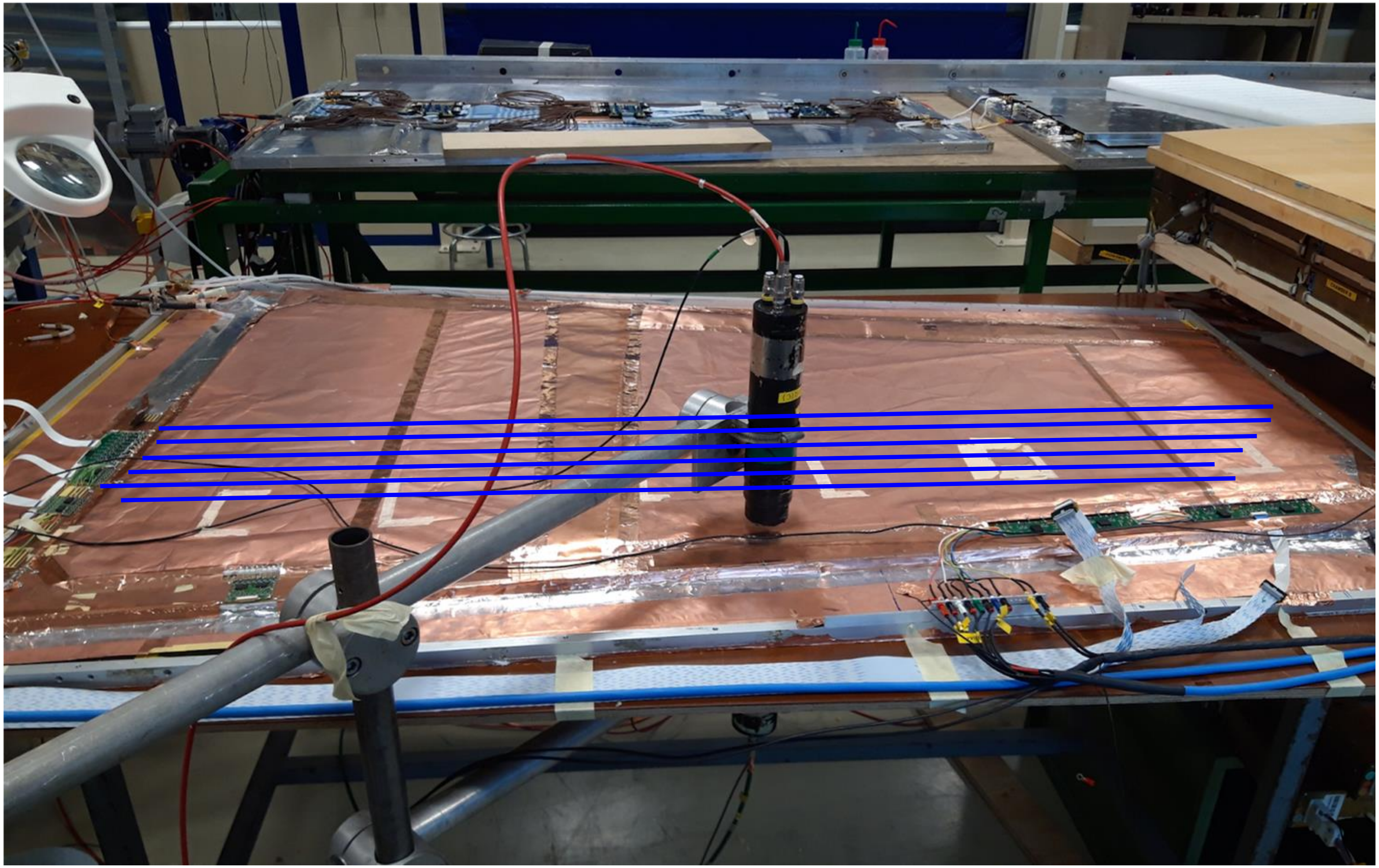




Results of 2D measurements on real-size chamber

Longitudinal (X)

Strip pitch 1.5-0.5 cm



HW Setup and Methodology

16 longitudinal strips connected

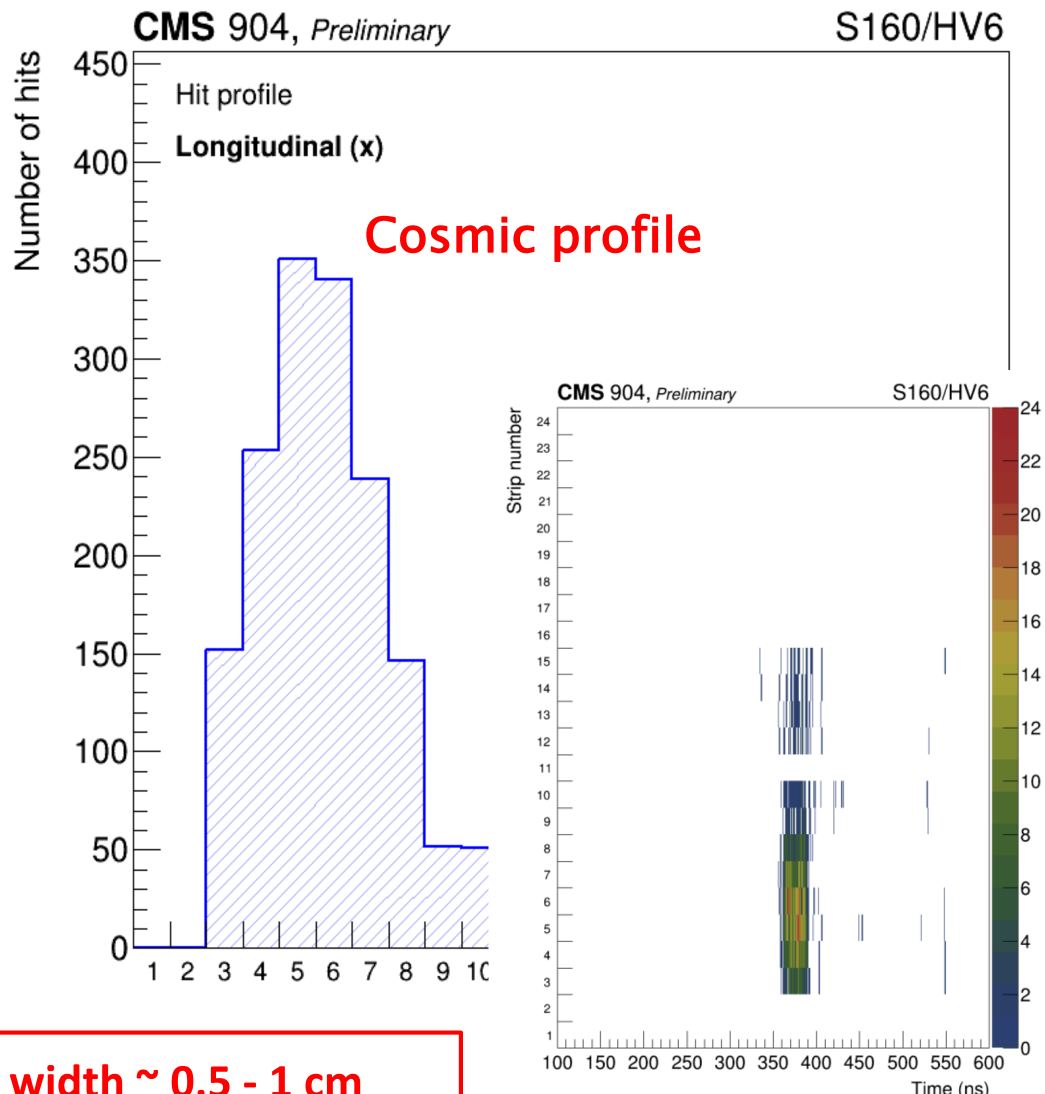
- Noisy strips 1 and 2
- Dead strip 11
- Focus on strips 3-10

Data taken in DOUBLE GAP TOP mode:

- Measurements in 3 different position along the strips
- Trigger positioned in middle of active strips (3-10)
- FEB parameters identical to previous orthogonal runs

FEB parameters:

v_thrs	= 1.6 V
v_amp	= 1.6 V
v_lvds	= 2.6 V
v_disc	= 2.5 V
v_pu	= 0.3 V



Strip width ~ 0.5 - 1 cm

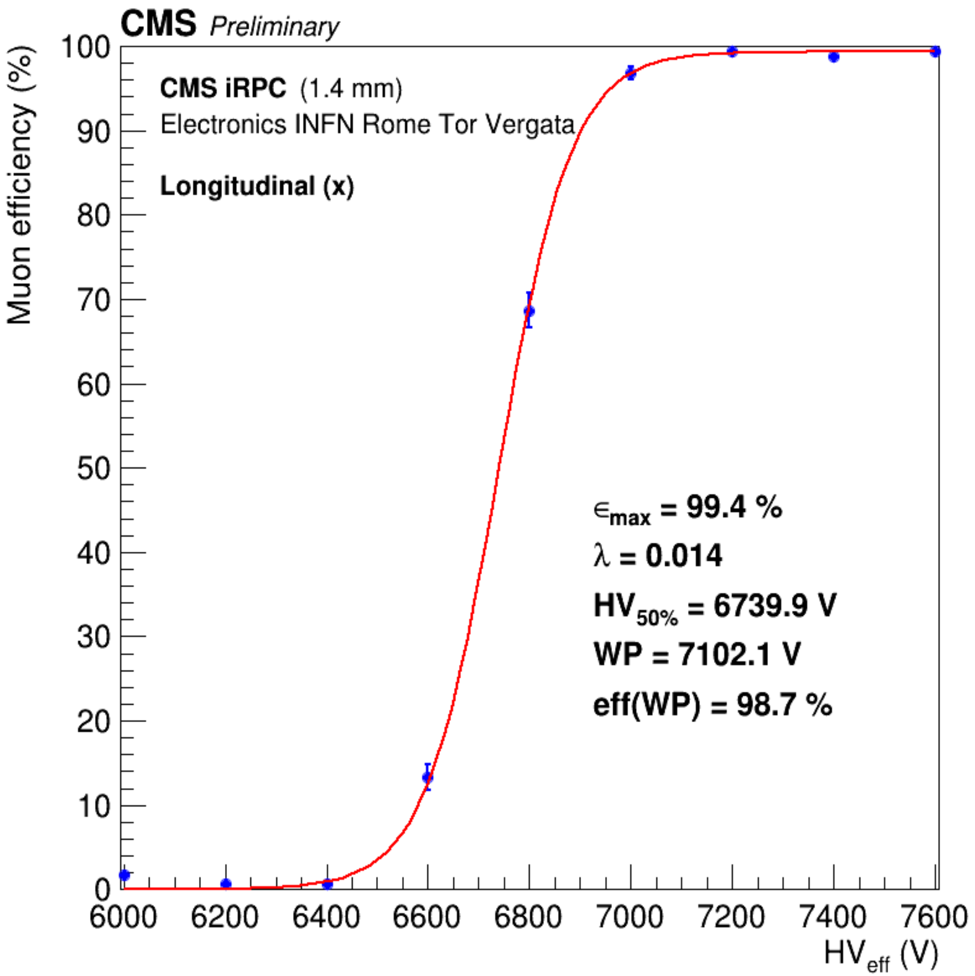
Muon Efficiency: Longitudinal Direction (x)

Muon efficiency for the longitudinal strips as function of high voltage.

WP defined by fitting the efficiency curve.

A working point of 7.1 kV is measured with an efficiency of 98.7%.

The WP is slightly higher than the expected WP for a 1.4 mm chamber, as the measurement is performed at the high radius at a long distance from the electronics (~1.5 m), causing a small signal propagation loss along the strip.

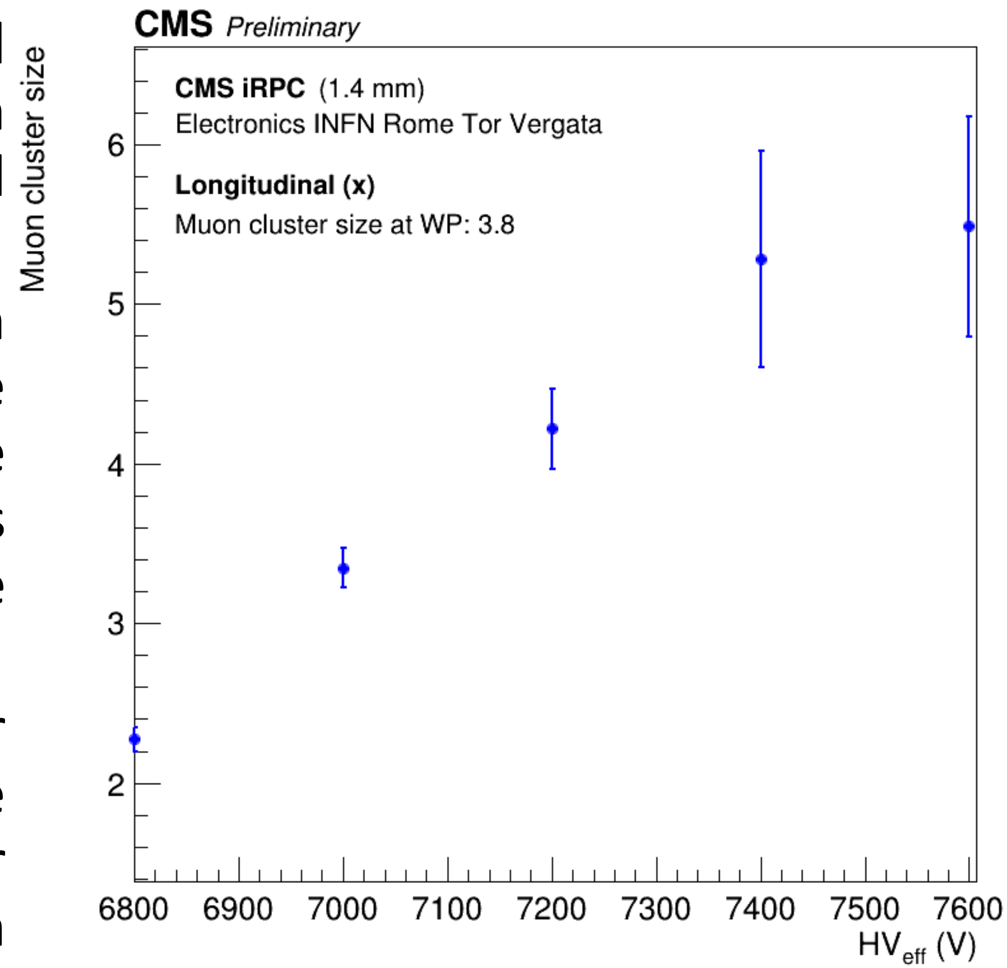


Muon Cluster Size: Longitudinal Direction (x)

Muon cluster size as function of high voltage, for the longitudinal direction, measured in region where the strip pitch is around 0.5 cm.

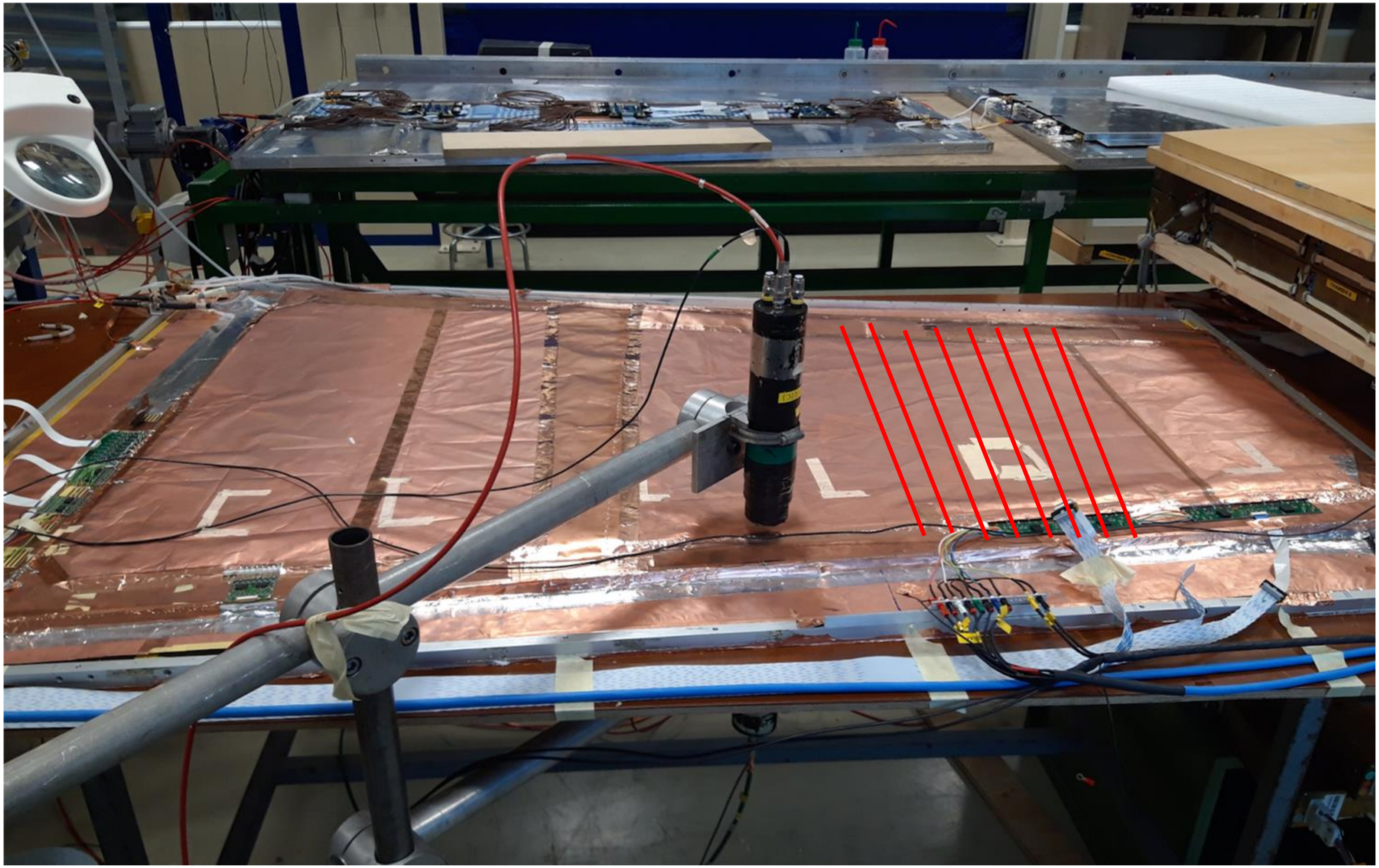
Muon clusters are formed when adjacent strips within a time interval of 10 ns are fired. The error on the cluster size is estimated by altering the time interval with 10 +/- 4 ns.

The defined error becomes larger at higher voltages as more streamers are present at higher voltages, leading to more muon clusters due to separated fired strips in time.



Orthogonal (Y)

Strip pitch 5 cm



HW Setup and Methodology

10 orthogonal strips connected

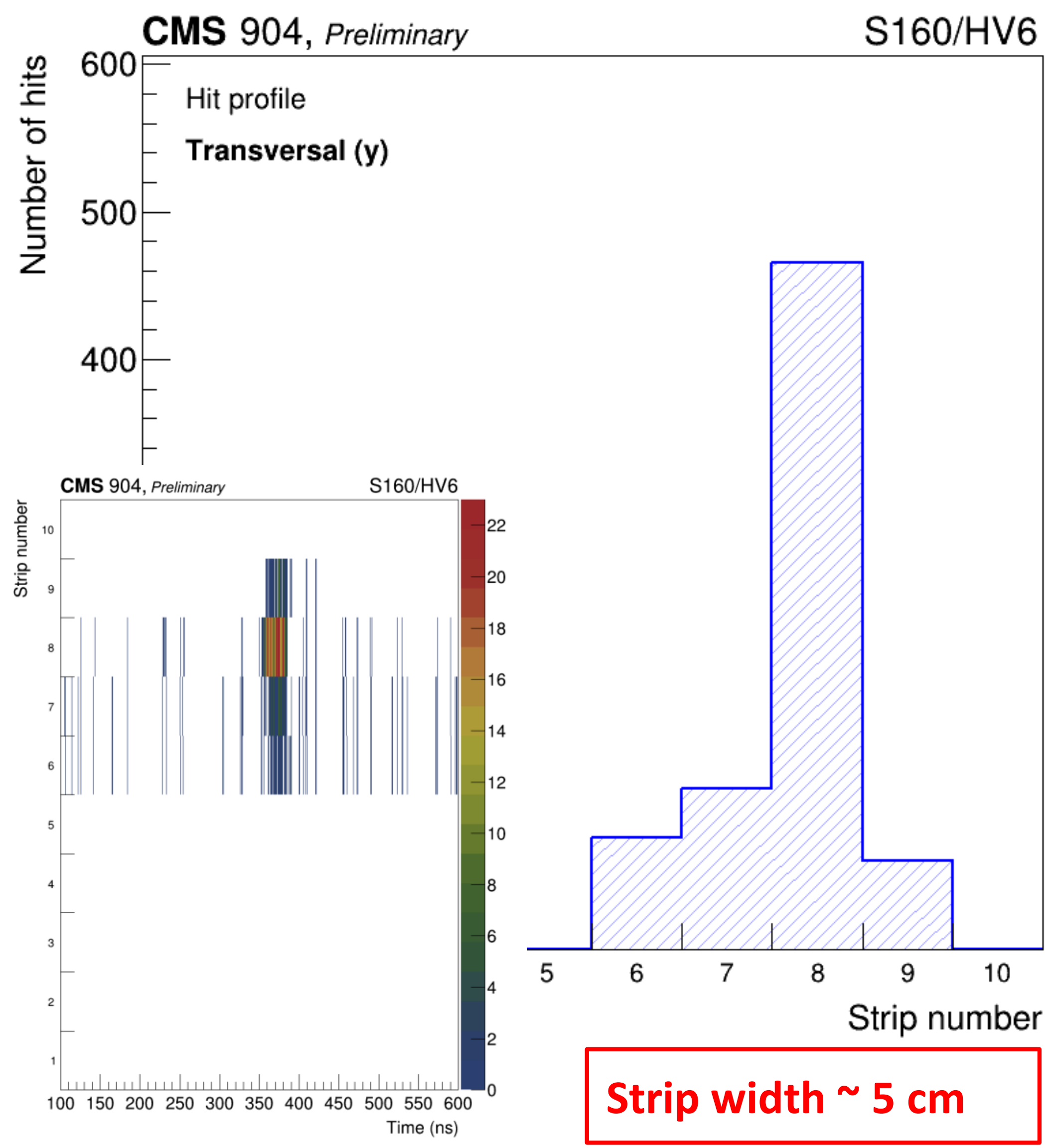
- Strip #5 and #10: noisy
- Focus on 4 strips only (#6, 7, 8, 9)

Data taken in SINGLE GAP TOP mode

- Trigger exactly positioned at strip #8
- profily should be symmetric around strip #8

FEB parameters:

v_thrs	= 1.6 V
v_amp	= 1.6 V
v_lvds	= 2.6 V
v_disc	= 2.5 V
v_pu	= 0.3 V



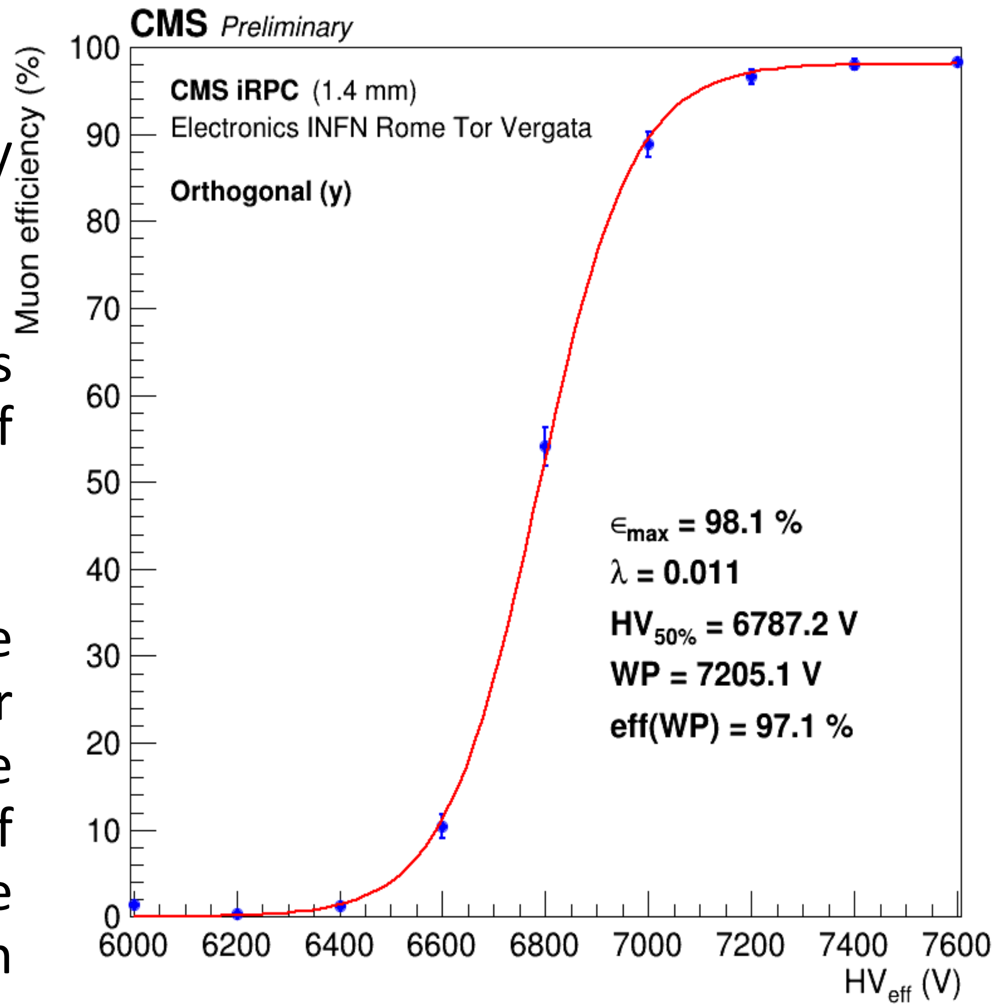
Muon Efficiency: Orthogonal direction (y)

Muon efficiency for the orthogonal strips as function of high voltage.

WP defined by fitting the efficiency curve.

A working point of 7.2 kV is measured with an efficiency of 97.1%.

A higher WP is expected as the orthogonal strips are on the outer plane of the double gap, therefore sensitive to the induction of charges in one gap. Hence the orthogonal strips are effectively in single gap mode.



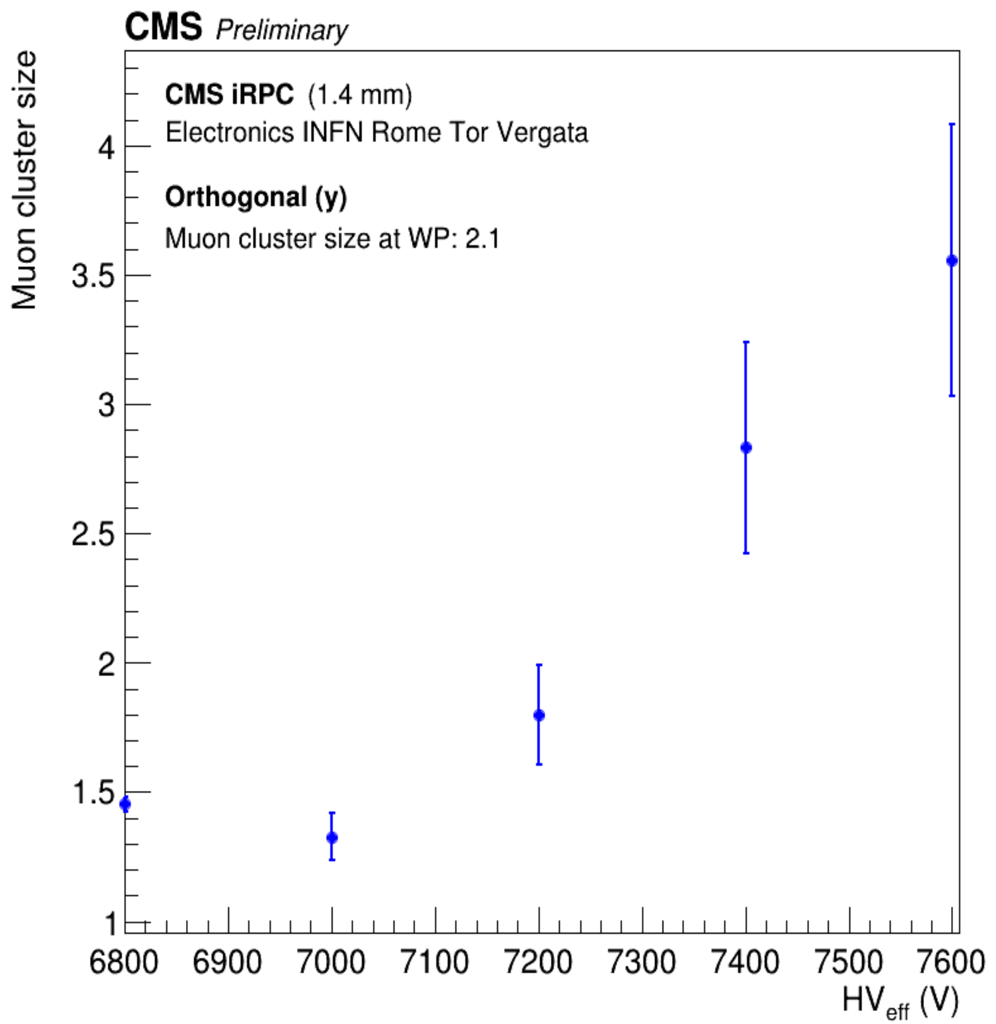
Muon Cluster Size: Orthogonal direction (y)

Muon cluster size as function of high voltage, for the orthogonal direction. The strip pitch is 5 cm.

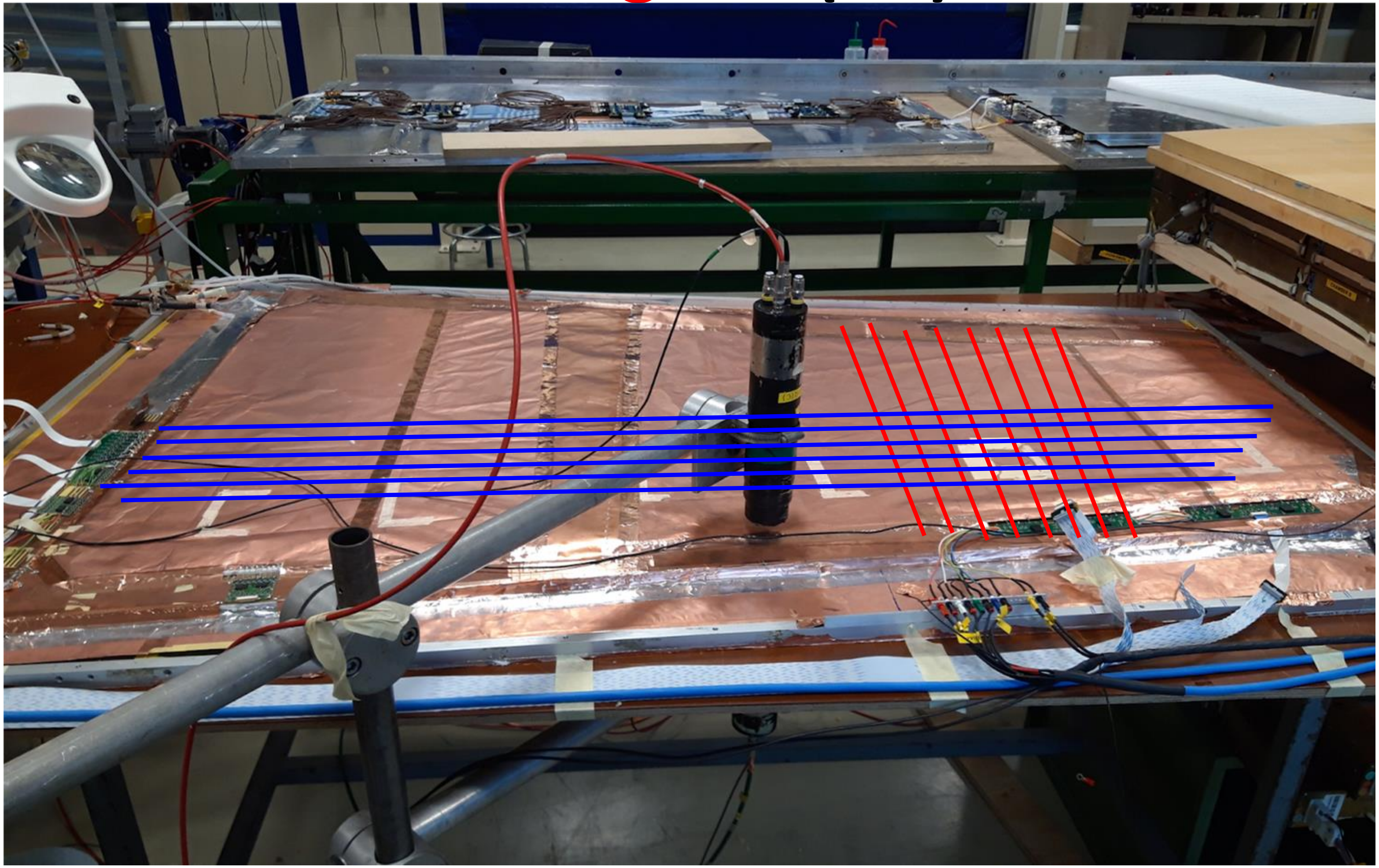
Muon clusters are formed when adjacent strips within a time interval of 10 ns are fired. The error on the cluster size is estimated by altering the time interval with 10 +/- 4 ns.

At the working point, on average 2 strips are fired due to cross-talk between both strips.

The defined error becomes larger at higher voltages as more streamers are present at higher voltages, leading to more muon clusters due to separated fired strips in time.



Simultaneous longitudinal and orthogonal(XY)



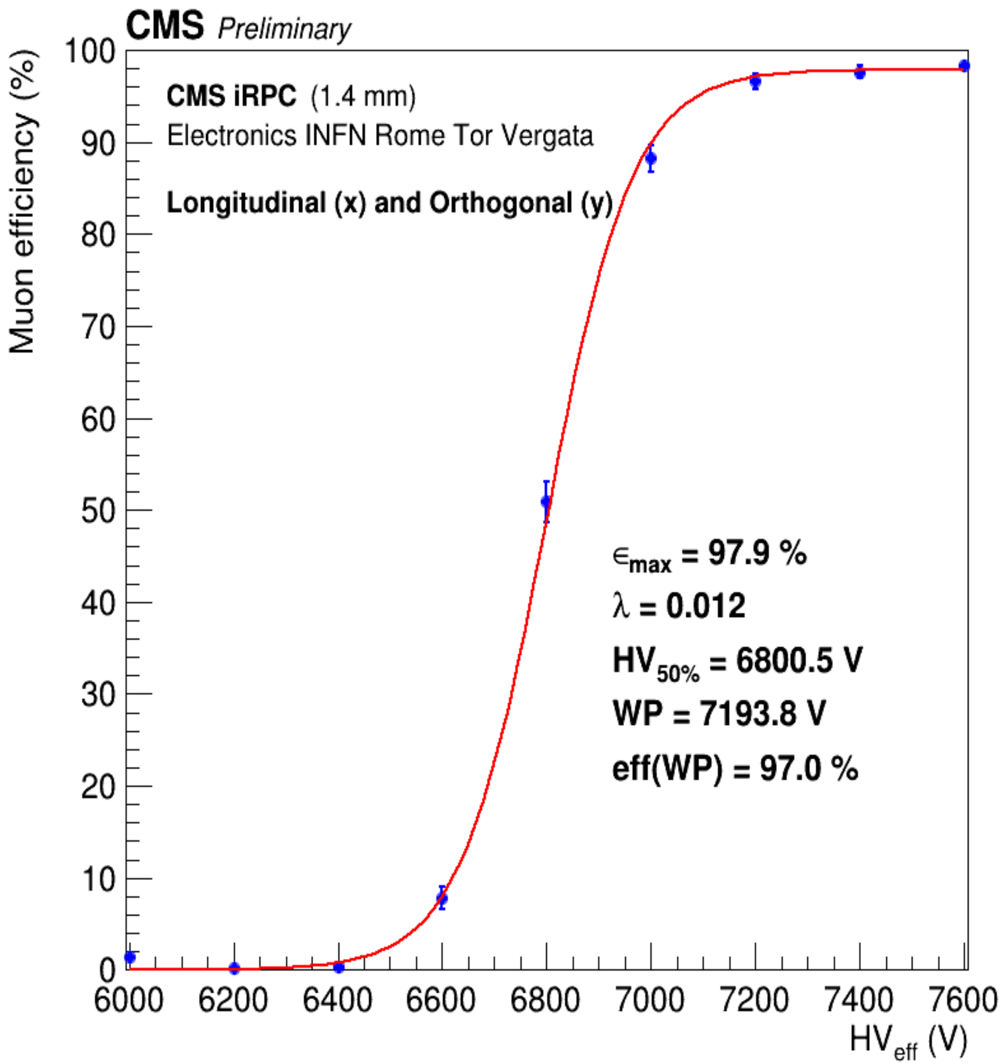
Muon Efficiency: Longitudinal and Orthogonal Direction (y)

Muon efficiency for the longitudinal AND orthogonal strips as function of high voltage.

A hit in AND configuration requires at least one strip fired simultaneously on both longitudinal and orthogonal directions.

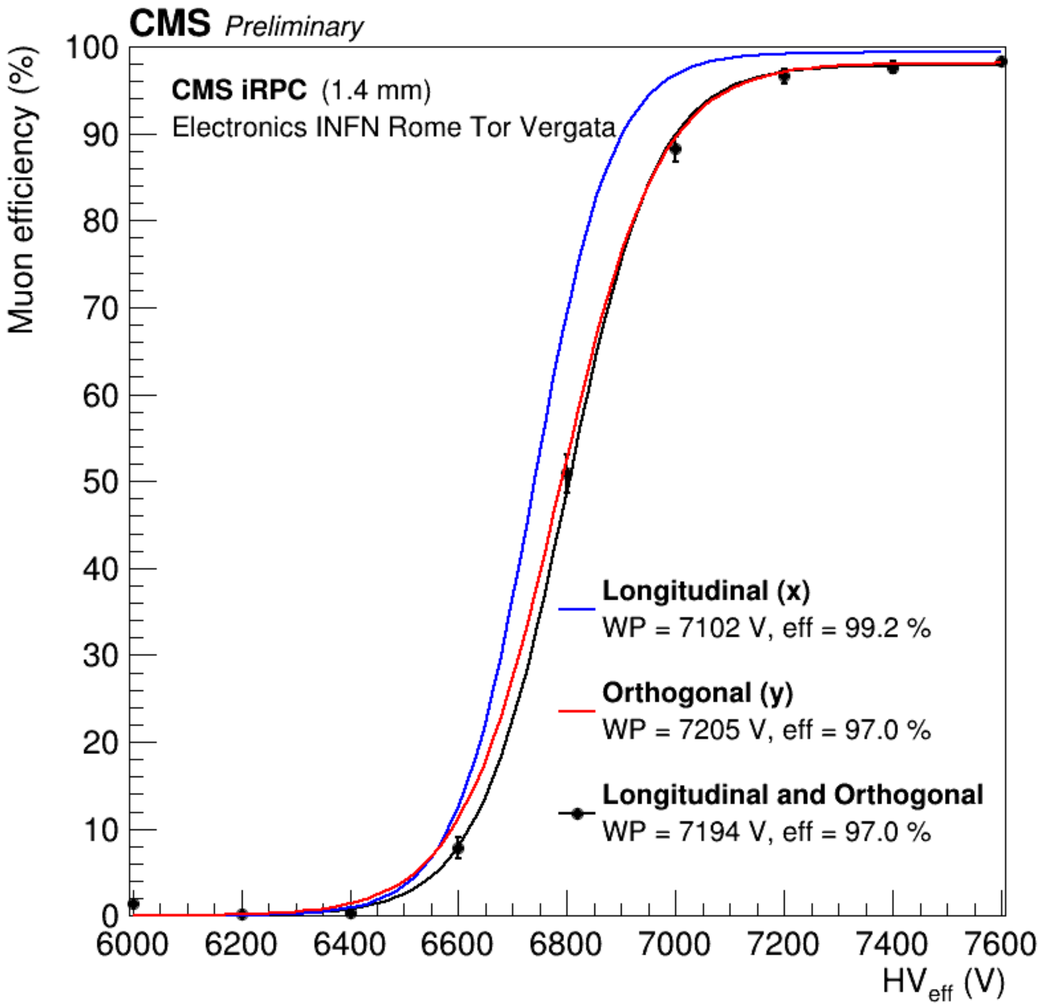
WP defined by fitting the efficiency curve.

The maximum efficiency and working point are driven by the orthogonal strips parameters.



Muon Efficiency: Combined Efficiencies

Combined Muon Efficiency curves for the longitudinal (blue), orthogonal (red) and combined AND efficiency (black).



Conclusions

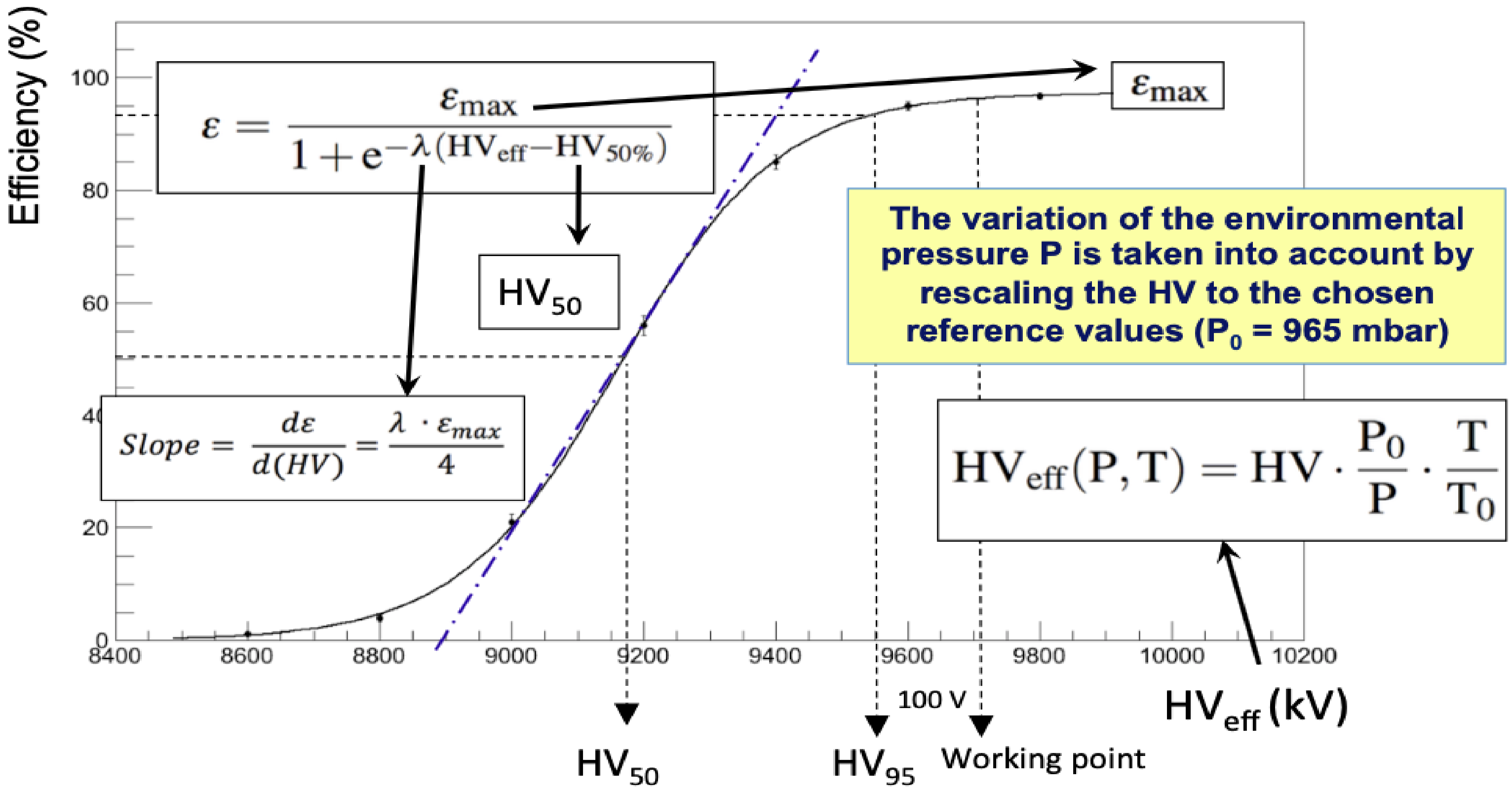
- A real size iRPC 1.4 mm with new Tor Vergata front-end electronics has been tested with cosmics.
  - Muon performance (efficiency and cluster size) measured for longitudinal and orthogonal strips separately
  - Combined Longitudinal+Orthogonal measurements driven by the orthogonal strips
  - Combined maximum efficiency not deteriorating in Longitudinal+Orthogonal configuration
- Results so far show that the considered solution is a suitable alternative for the RPC CMS detector.

Backup

Thank you

High Voltage Scan Parameters.

Typical HV SCAN with fit parameters [1, 2]

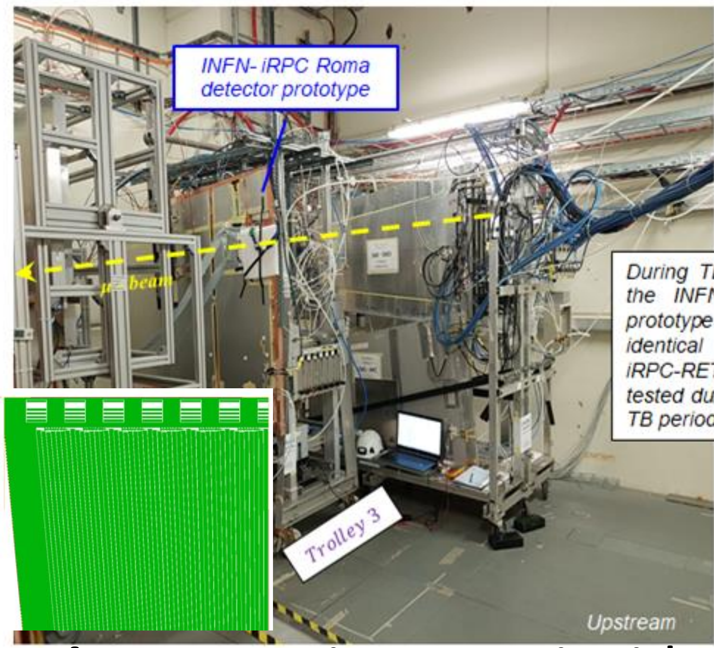


[1] Resistive Plate Chambers commissioning and performance results for 2011-2013, CMS Performance Note, CMS DP -2014/003

[2] M.Abbrescia et al., "Cosmic ray test of double-gap resistive plate chambers for the CMS experiment", Nucl. Instr. Meth. A550 (2005) 116

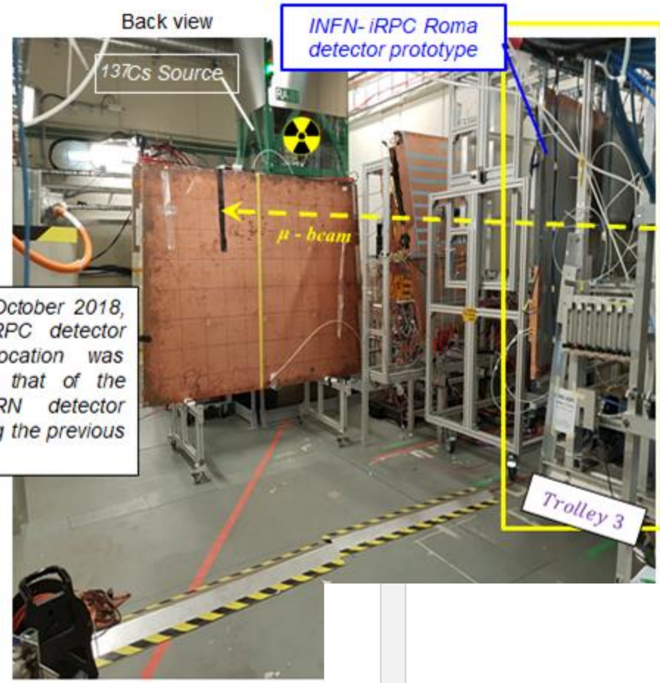
GIF++ setup and DAQ

Front view



During TB October 2018, the INFN-iRPC detector prototype location was identical to that of the iRPC-RETURN detector tested during the previous TB period.

Back view



Parameters of Longitudinal strip panel:

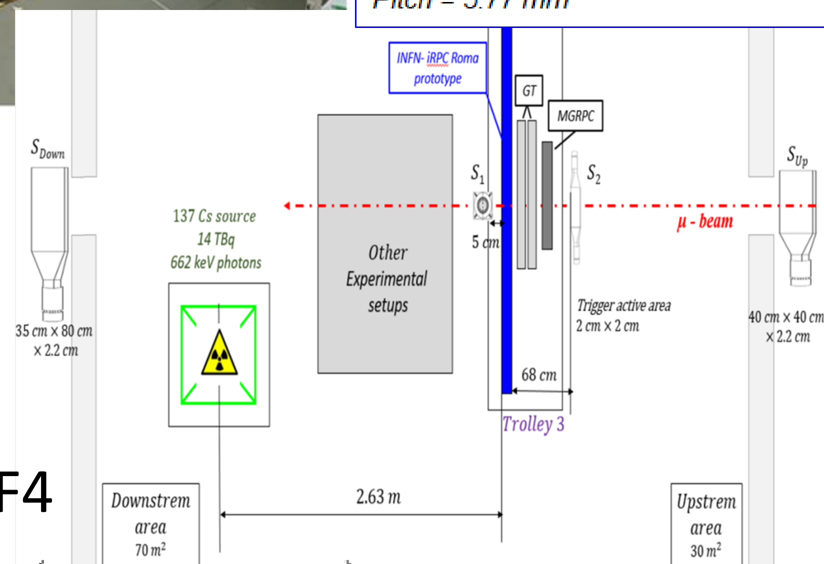
Length: 167.185 cm
Small base: 49.35 cm
Big base: 28.127 cm

Total number of strips: 48

Parameters of strips:

High radius:
d=1.5 mm
strip width = 8.71 mm
Pitch = 10.21 mm

Low radius:
d=1.5 mm
strip width = 4.086 mm
Pitch = 5.77 mm



Trigger: 4 Triggers coincidence (2 external, 2 internal)

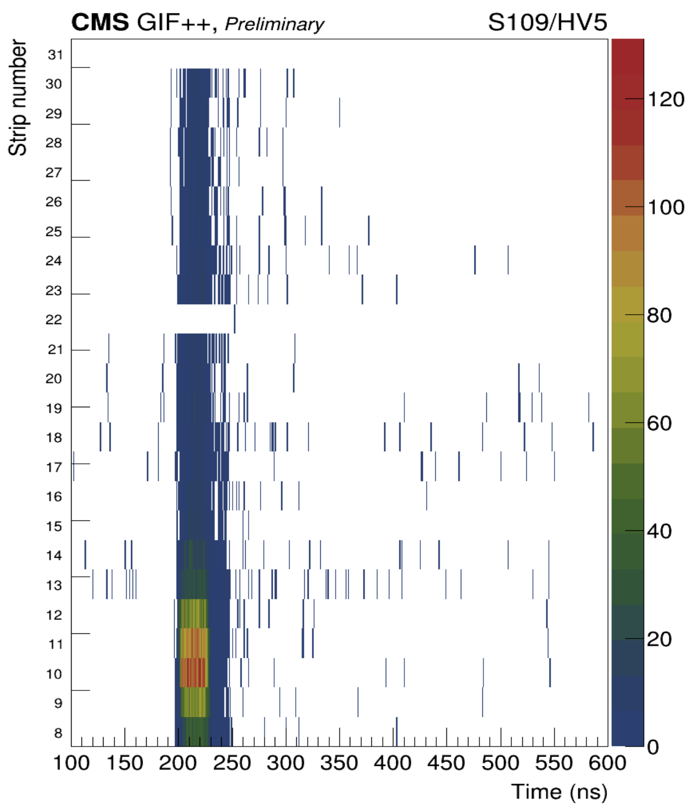
DAQ: TDC DAQ with 100 ps resolution, connected to 3 FEBs = 24 channels

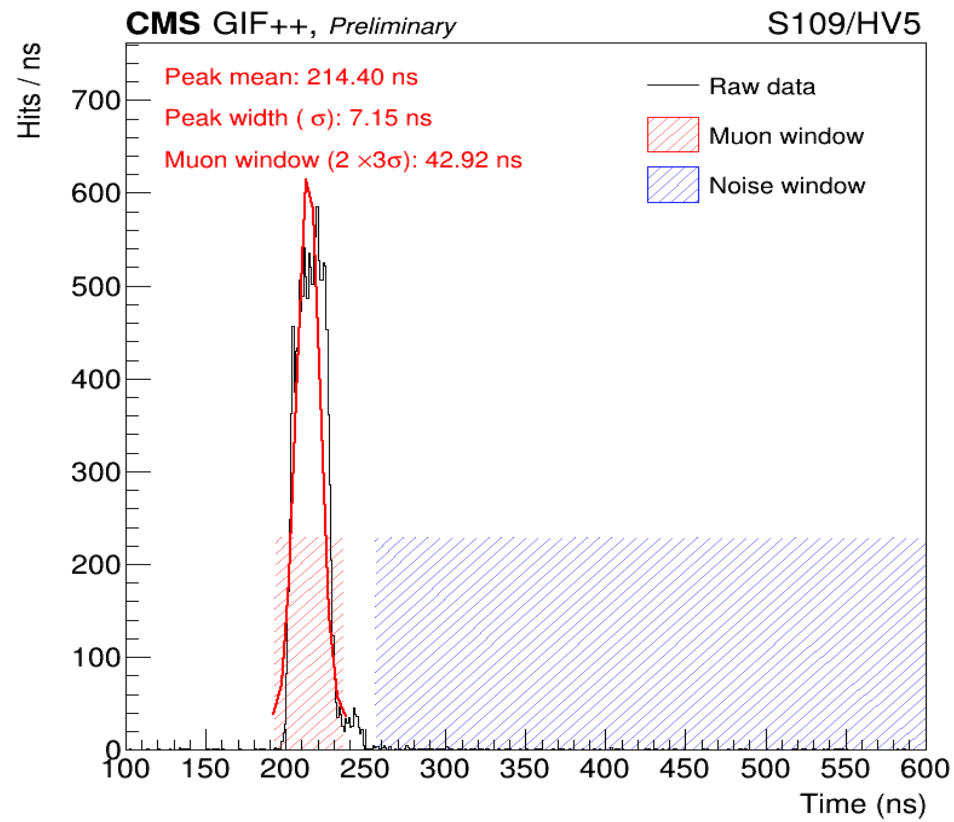
Gas: iC4H10 4.5 %, 0.3 % SF6, rest C2H2F4

PT correction for HV: $HV_{app} = \beta HV_{eff} = HV_{eff}\left((1-\alpha)+\alpha\frac{P}{P_0}\frac{T_0}{T}\right)$

Raw data and timing

- Channels are read by the TDCs at beam trigger (4 scintillators in coincidence), for 600 ns window
- For each trigger: strip and timestamp are collected → raw data for analysis

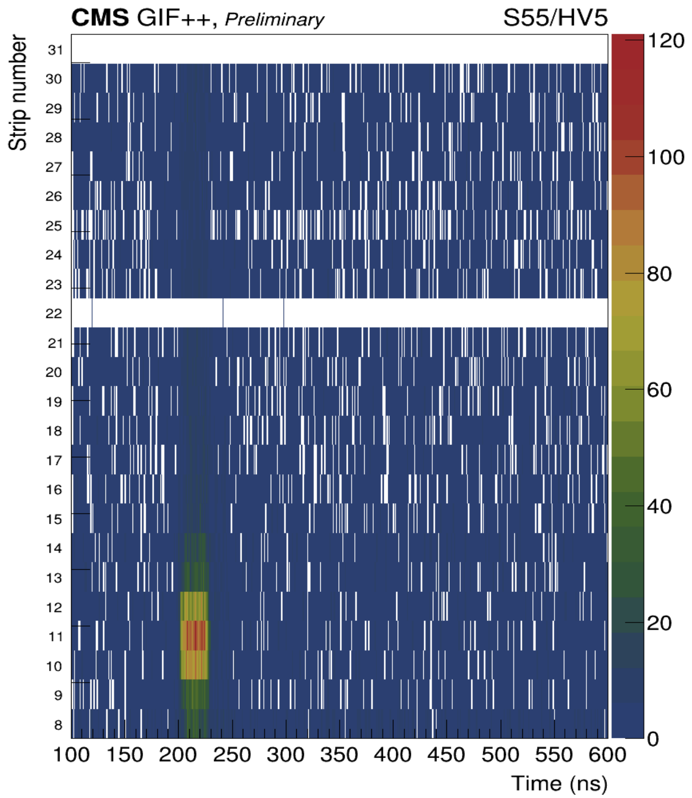


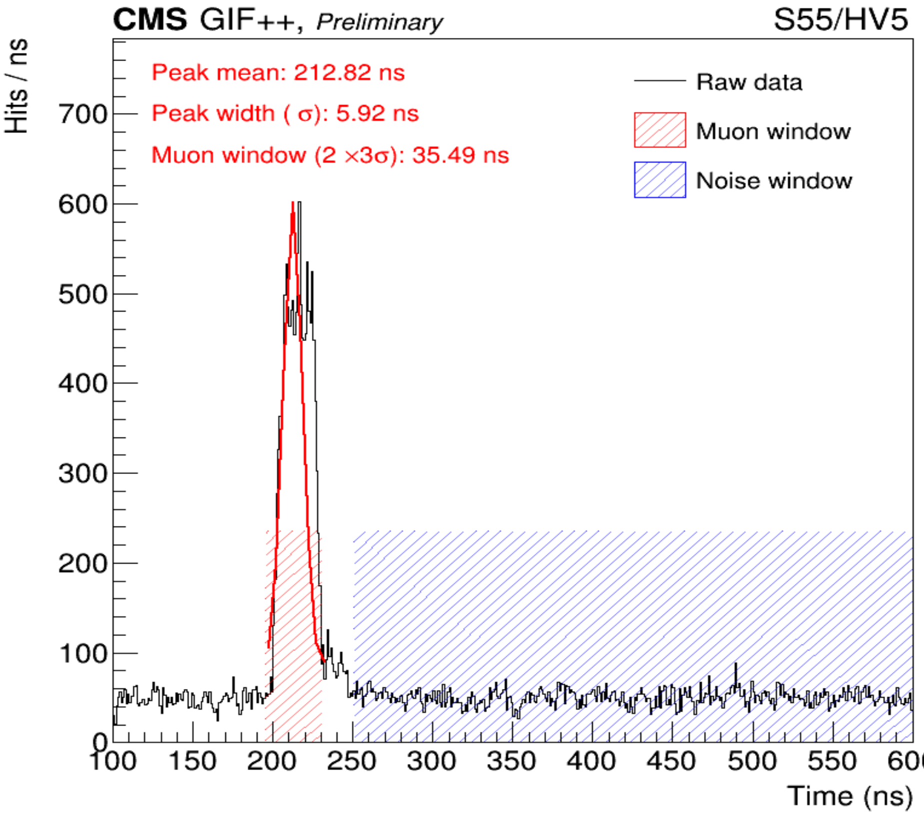


EXAMPLE SOURCE OFF

Raw data and timing

- Channels are read by the TDCs at beam trigger (4 scintillators in coincidence), for 600 ns window
- For each trigger: strip and timestamp are stored → raw data for analysis



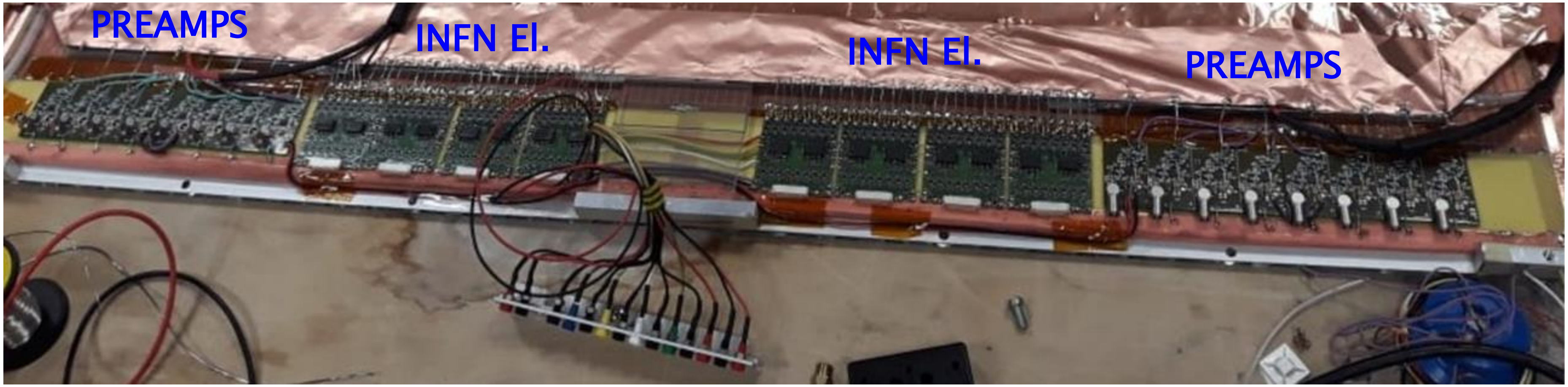


EXAMPLE SOURCE ON ~ 2 kHz/cm^2 gamma rate

Electrode Surface Resistivity

Measurement overview: The graphite chamber

- **1.4 mm chamber with two graphite resistivity regions: 600 and 50 kΩ (*)**
  - → Study effect on cluster size with cosmics
- **Chamber equipped with PCB strip plane in both graphite resistivity regions   (5 mm strip width)**
- **Tests performed with INFN Tor Vergata electronics (using conventional CAEN TDC) and analog pre-amplifiers**



(*) Our present system: RE4 ~ 150 kOhm, RE2/3 ~ 100 kOhm

Muon efficiency: high resistivity graphite

Muon efficiency for the **high** resistivity graphite region, as a function of high voltage.

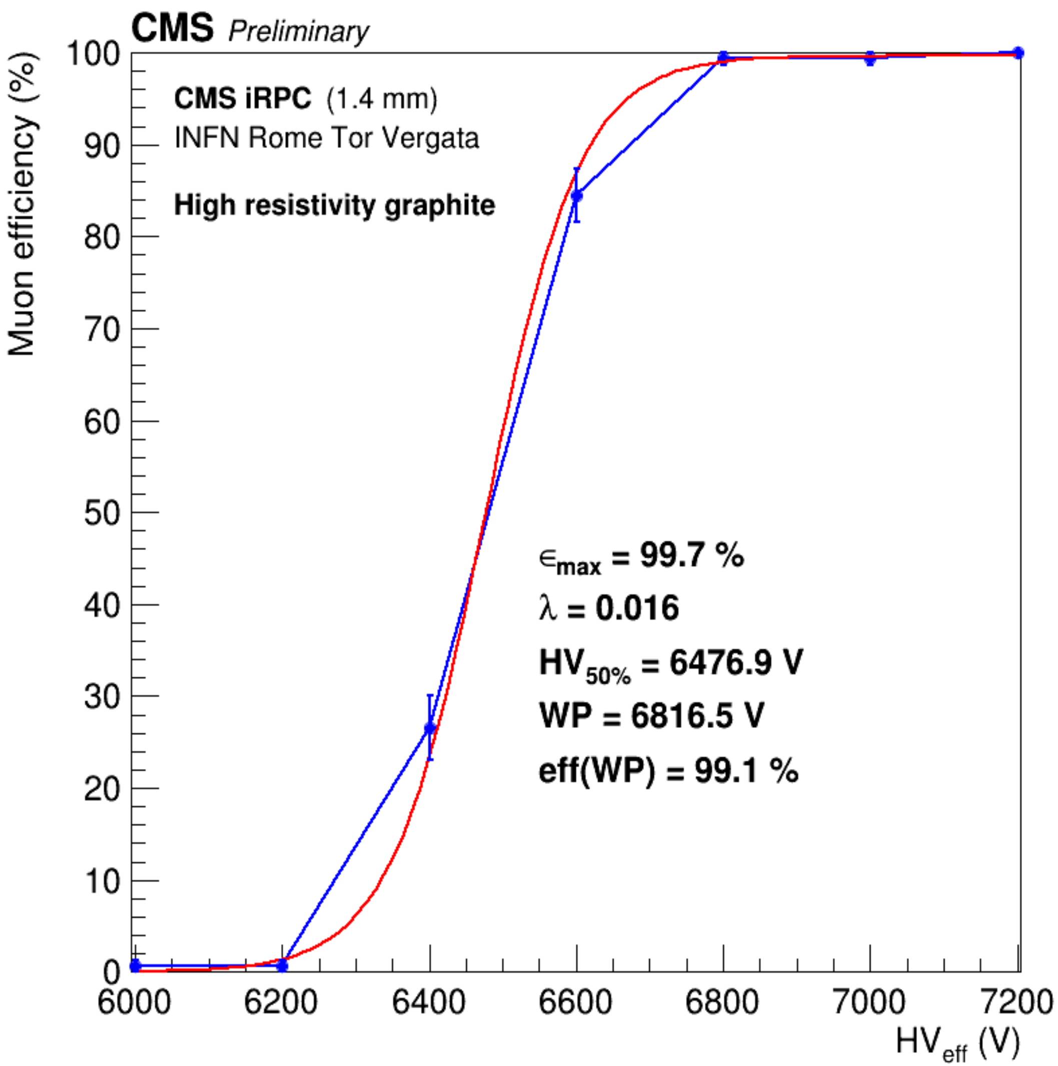
WP defined by fitting the efficiency curve with the sigmoid formula:

$$E = \frac{E_{max}}{1 + e^{-\lambda\,(HV_{eff} - HV_{50\%})}}$$

The working point voltage is then defined as:

WP = ln(19)/λ + HV(50%) + 150 V

A working point of 6.82 kV is obtained with an efficiency of 99.1 %.



Muon efficiency: low resistivity graphite

Muon efficiency for the **low** resistivity graphite region, as a function of high voltage.

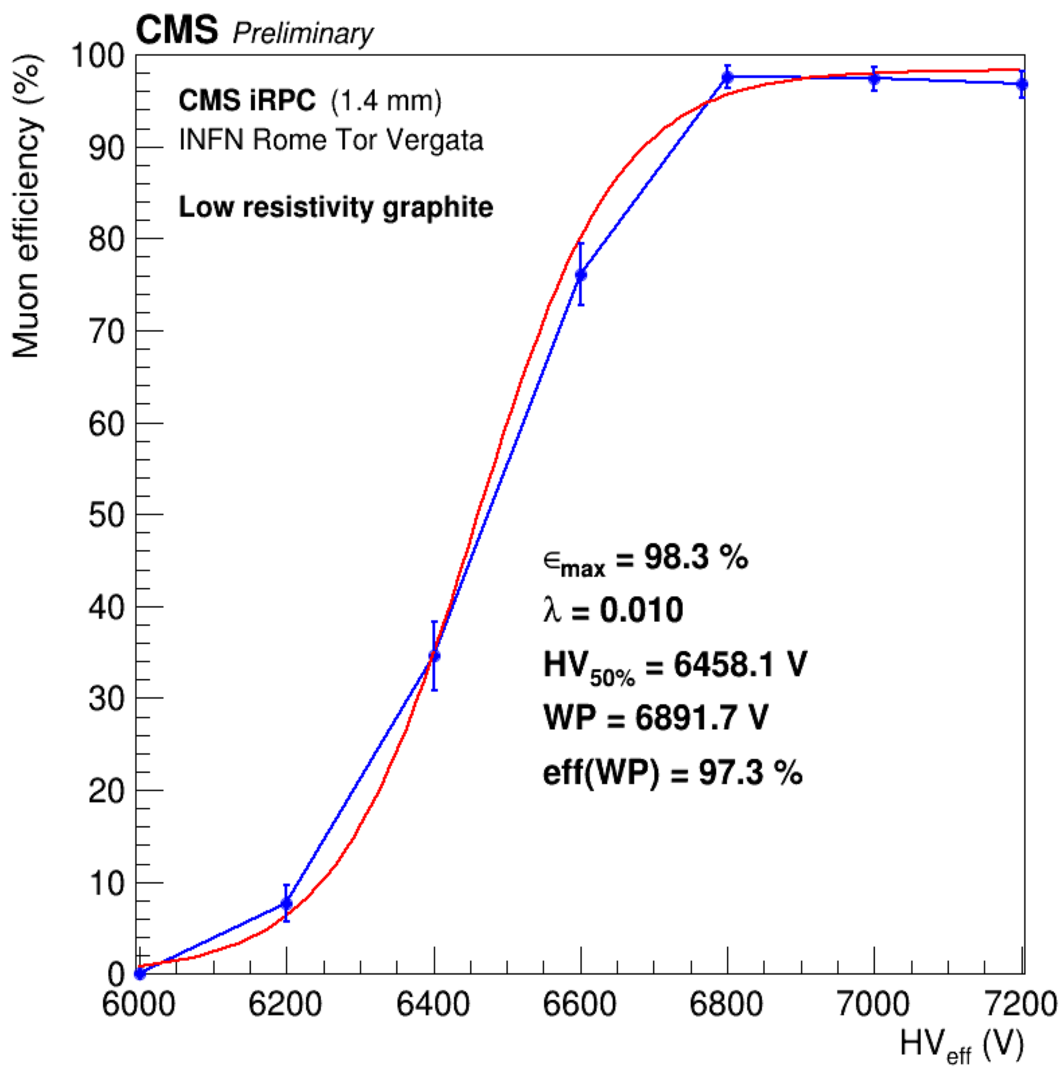
WP defined by fitting the efficiency curve with the sigmoid formula:

$$E = \frac{E_{max}}{1 + e^{-\lambda\,(HV_{eff} - HV_{50\%})}}$$

The working point voltage is then defined as:

WP = ln(19)/λ + HV(50%) + 150 V

A working point of 6.89 kV is obtained with an efficiency of 97.3 %.

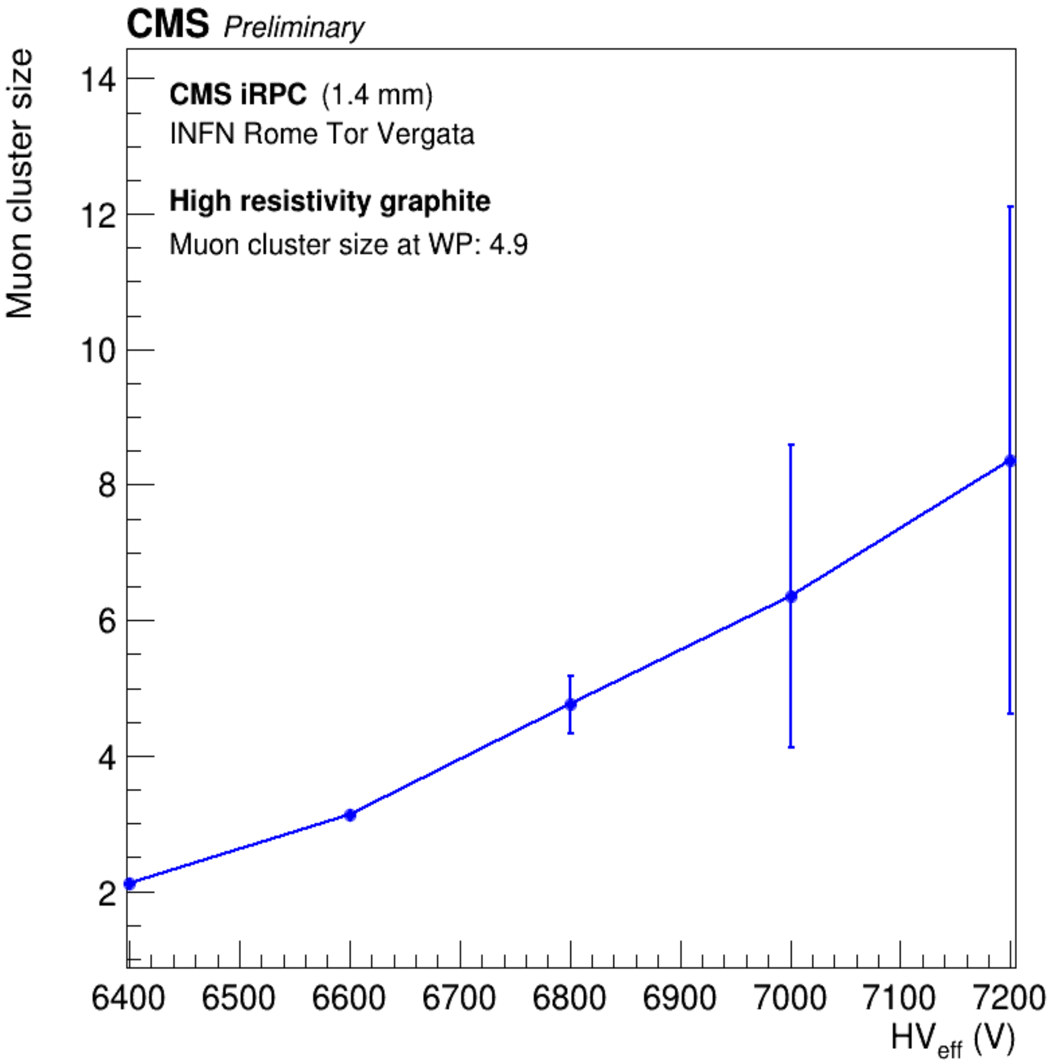


Muon cluster size: high resistivity graphite

Muon cluster size as function of high voltage, for the **high** resistivity graphite region. At working point, typically 4.9 strips are fired.

Muon clusters are formed when adjacent strips within a time interval of 10 ns are fired. The error on the cluster size is estimated by altering the time interval with 10 +/- 4 ns.

The defined error becomes larger at higher voltages as more streamers are present at higher voltages, leading to more muon clusters due to separated fired strips in time.

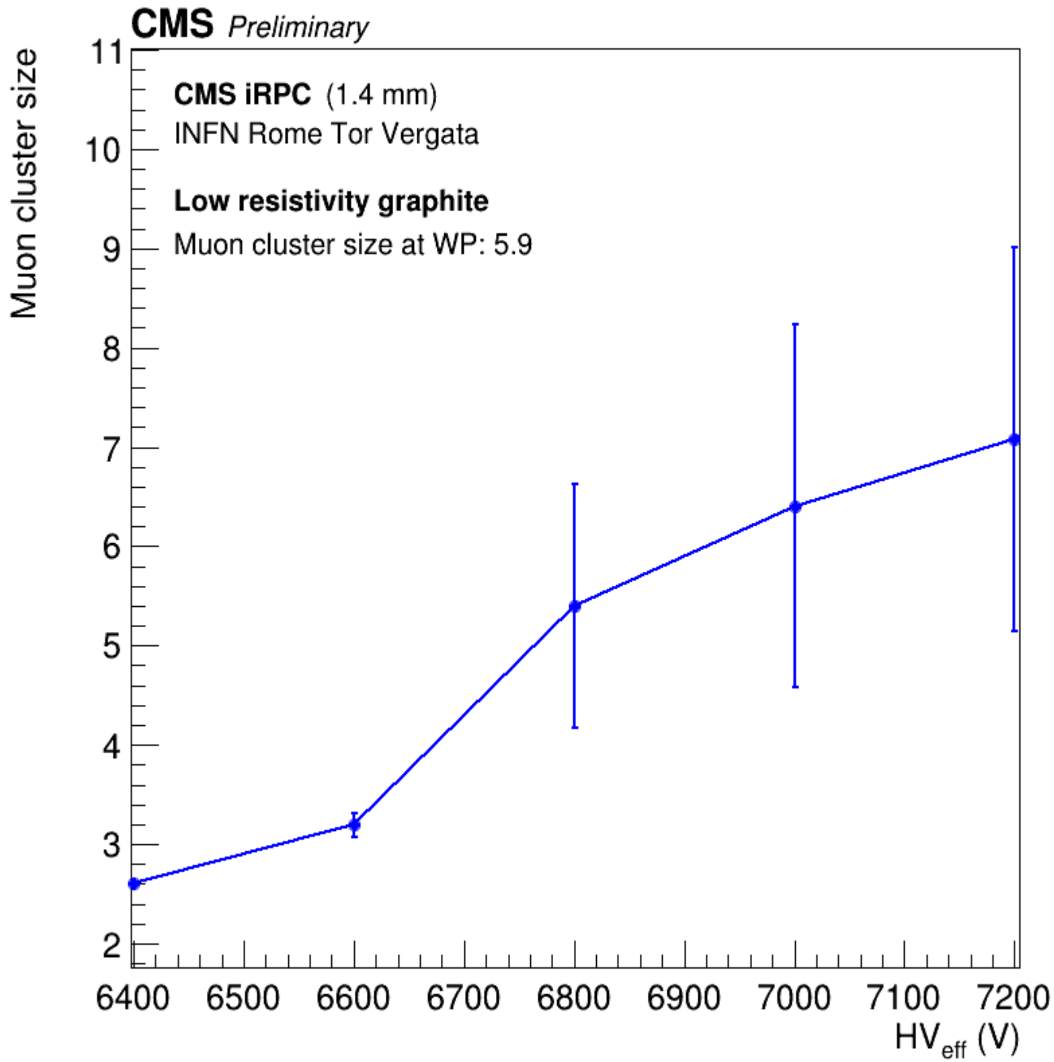


Muon cluster size: low resistivity graphite

Muon cluster size as function of high voltage, for the **low** resistivity graphite region. At working point, typically 5.9 strips are fired.

Muon clusters are formed when adjacent strips within a time interval of 10 ns are fired. The error on the cluster size is estimated by altering the time interval with 10 +/- 4 ns.

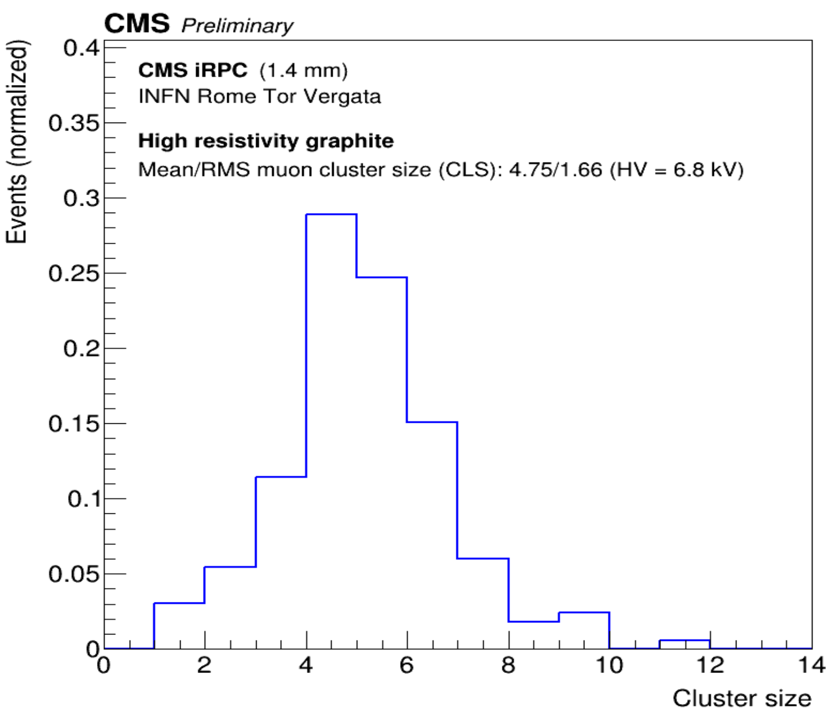
The defined error becomes larger at higher voltages as more streamers are present at higher voltages, leading to more muon clusters due to separated fired strips in time.

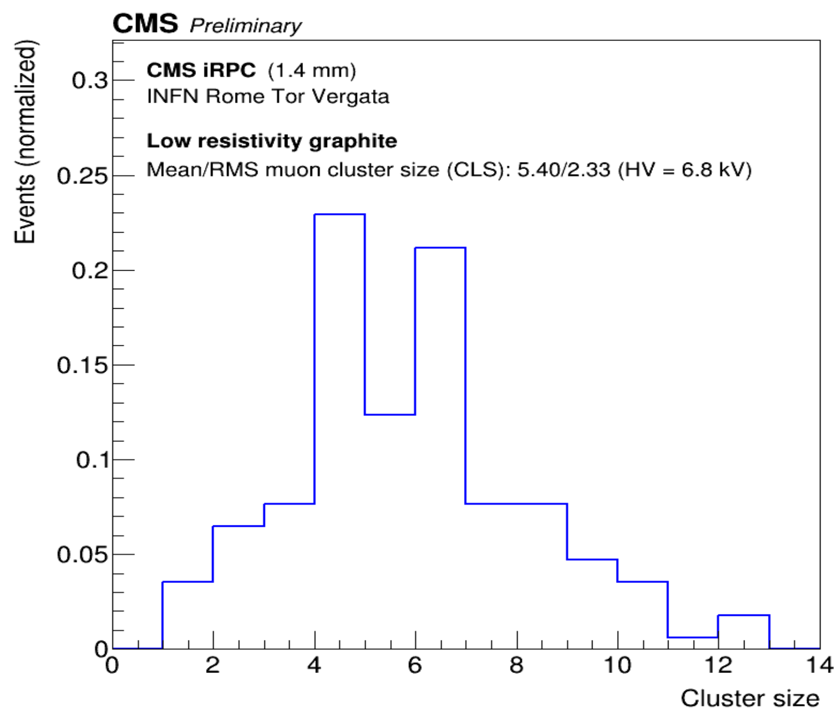


Muon cluster size distribution

Muon cluster size distribution at a fixed high voltage of 6.8 kV, close to the working point. Compared to the low graphite resistivity, the high resistivity graphite region exhibit narrower distribution (RMS from 2.33 to 1.66), shifted towards a lower cluster size (from 5.40 to 4.75). This effect is ascribed due to the difference in graphite resistivity, directly influencing cluster size through cross talk by the capacitive coupling of the strips.

This behavior was also confirmed using analog pre-amplifiers.





Part I: Summary and conclusions

- Data taken with both pre-amplifiers and INFN electronics
  - showing similar behavior for efficiency (very low WP for both regions)

- Studied effect on graphite resistivity
  - Measurements performed on dedicated chamber with low and high graphite resistivity region
  - High graphite resistivity shows a lower muon cluster size with a narrower cluster size distribution
  - motivation of usage of higher graphite resistivity, now new gaps produced with 450 kOhm /