R&D Results for RE3/1 and RE4/1 RPCs at KODEL

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1st small prototype 1.6-mm double-gap RPC

For the last 6 months, performed basic RPC R&Ds for RE3/1 and RE4/1 RPCs

Thin double-gap RPCs: reduced the gap thickness from **2.0 mm → 1.6 mm**

→ Manufactured four trapezoidal-shape small RPC gaps (55 cm long, 40-cm wide)

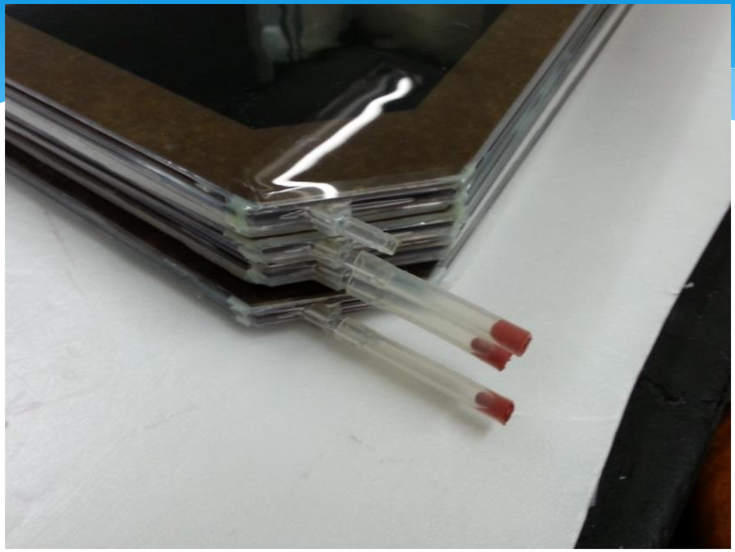
HPL: Bakelite previous used for the R&D of RE11 RPCs, $\rho = 3.7 \times 10^{10}\ \Omega\text{cm}$

Gaps:

- Spacers (accepted 1,58 & 1,59 mm, **σ ~ 6 μm**): Nicemold, Seoul, Korea
- Gas blocks for gas feeding: 1.60 mm: Nicemold, Soul, Korea
- Edge strips (1.60 mm ±20 μm, **σ ~ 10 μm**) for gas sealing : Atrix, Inchon, Korea

Chamber: one of the chamber frames used for previous 4-gap RPCs

- Thickness of the detector only = 26 mm
- Uses one 32-ch CMS RPC FEB: threshold at 210 mV (150 fC).
- Gas = 95.2% $C_2H_2F_4$ + 4.5% isobutene + 0.3% SF_6
- Working HV = 8.1 ~ 8.8 kV with Th = 220 mV (170 fC)
- Read signals only from the narrower side of the strips.

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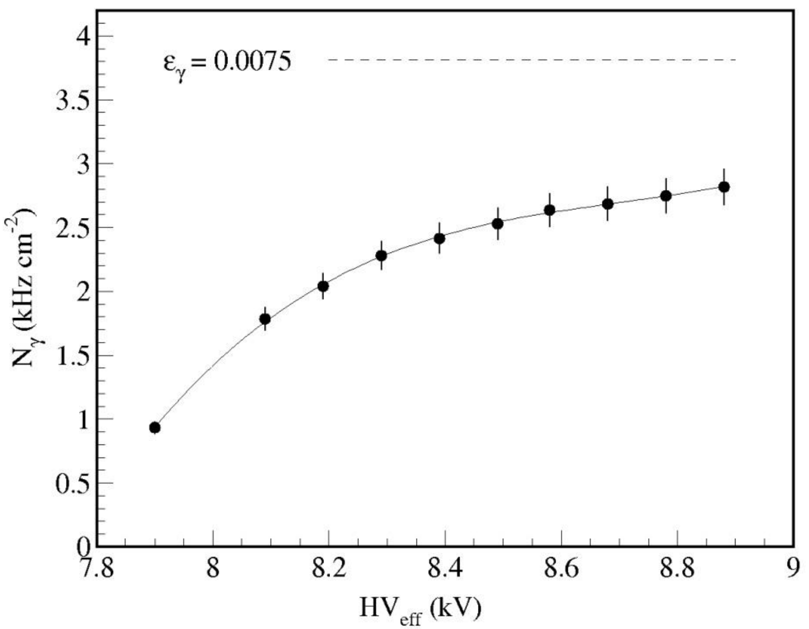
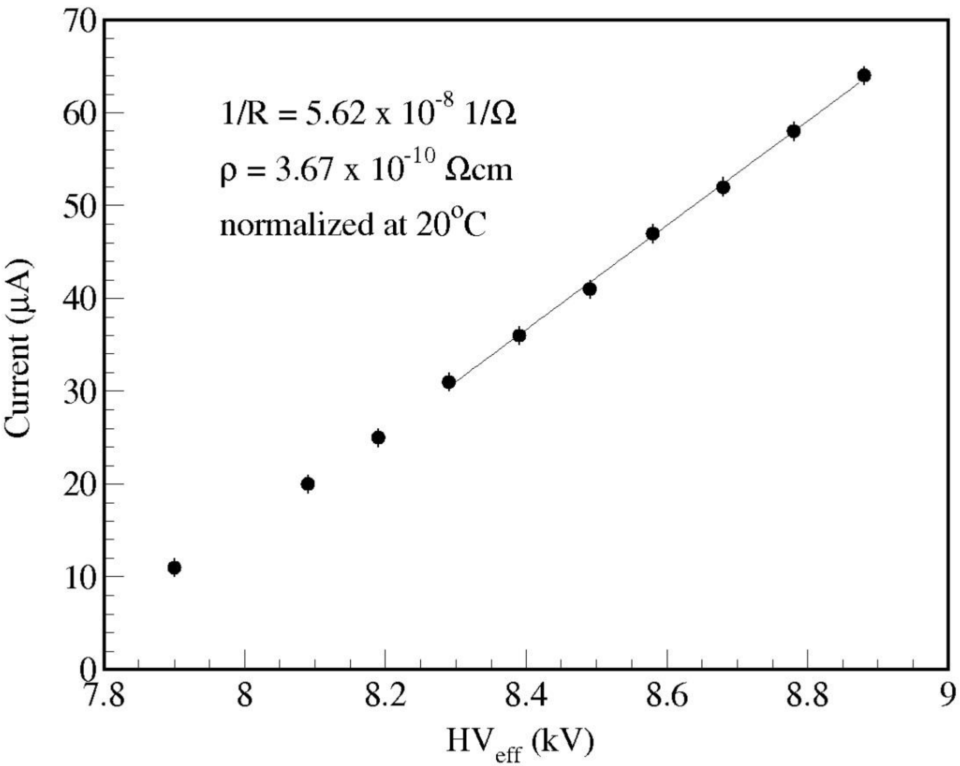
Gamma rates

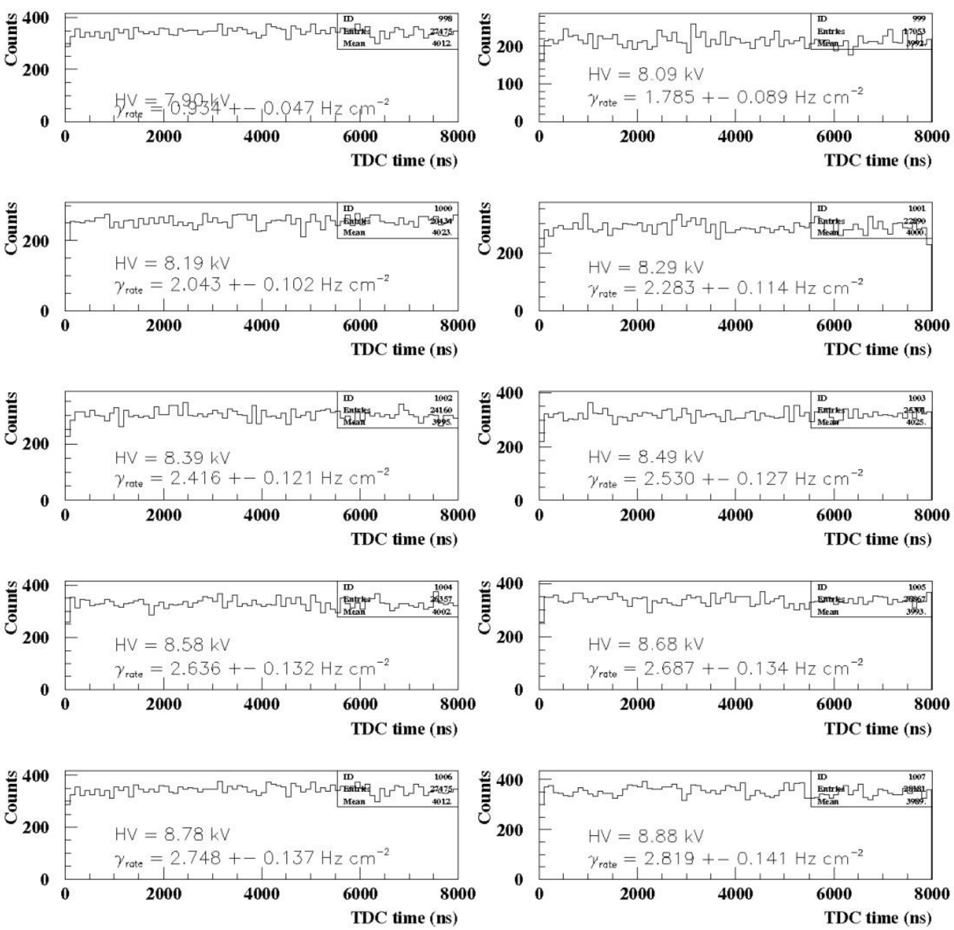


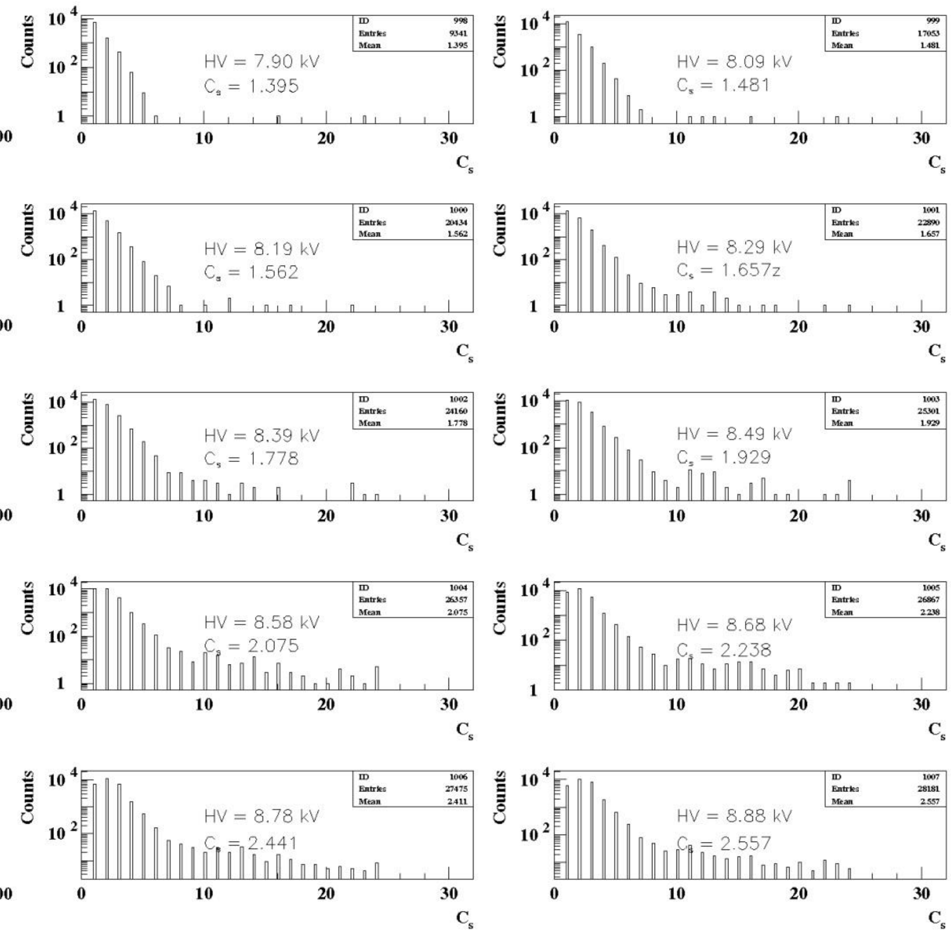
Measurement of resistivity of HPL



Gamma hits

Mean cluster sizes of gammas





Muons were triggered using 10-cm thick plastic scintillators

- Time resolution of triggers ~ 300 ps
- Muon tagging area = 20 cm × 10 cm

DAQ: common-start mode

- Twist-pair Cable delay ~ 200 ns

VME-mode multi-hit TDC

- 16 hits per channel
- Time window = 64 μs
- Time resolution ~ 1 ns

32-ch CMS-RPC FEB

- Threshold = 220 mV (170 fC)
- VBIAS = 2.50 V
- LVDS width = 100 ns

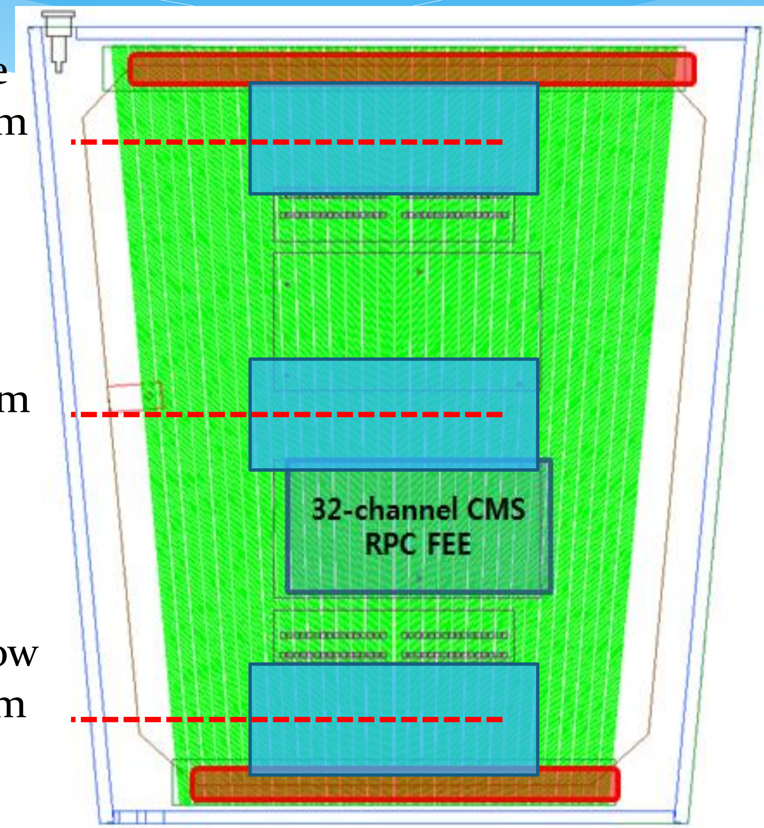
Then, we tested three sections

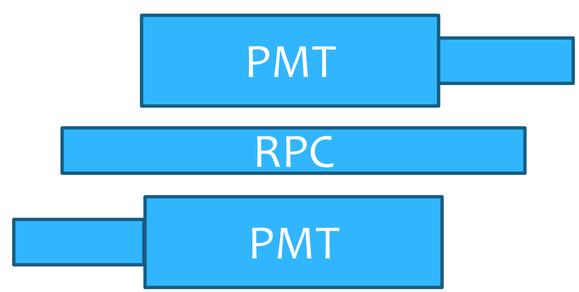
- Efficiencies
- Time responses
- Cluster sizes
- Noise rates

Low eta, wide
Pitch = 13.0 mm
r = + 20 cm

Central
Pitch = 12.0 mm
r = 0 cm

High eta, narrow
Pitch = 11.0 mm
r = -20 cm





Basic tests for a 1.6-mm 2-gap RPC

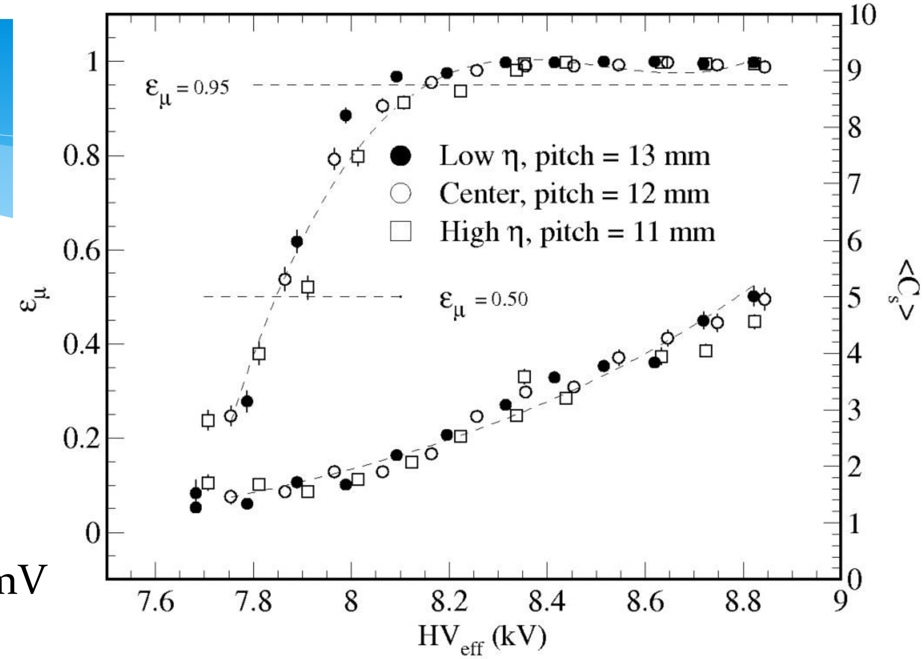
(400 events per a HV point)

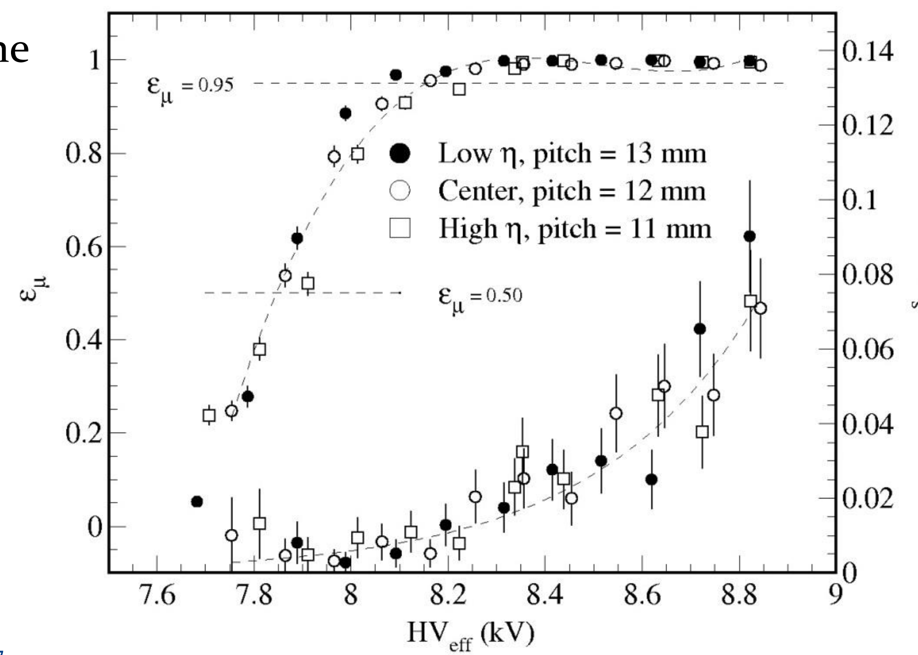
The gap uniformity is fairly good.

→ RE11-size small detector

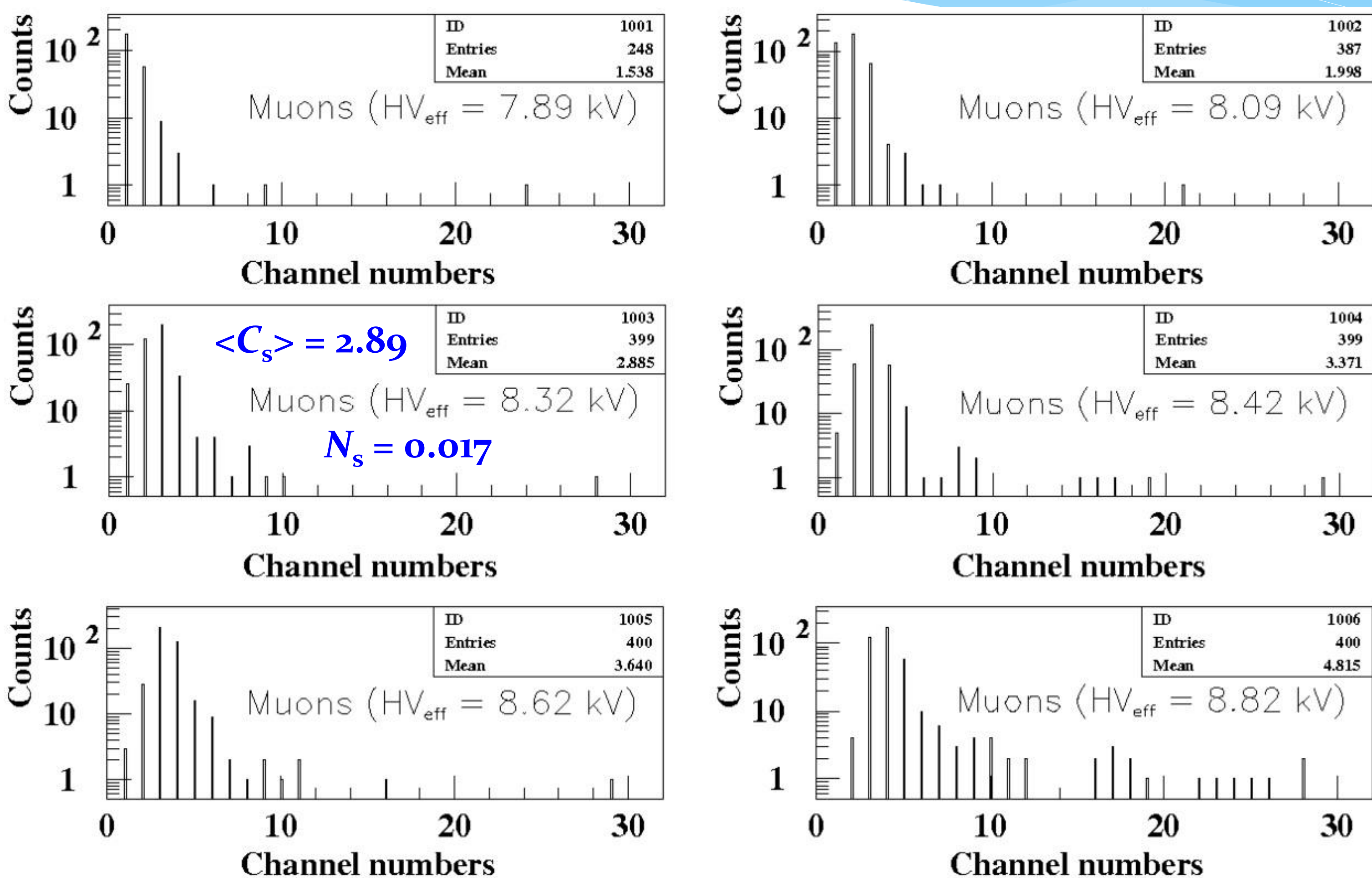
The difference of detector properties for three sections is insignificant.

- $HV_{\varepsilon=0.95}$ = 8.10 ~ 8.15 kV
- Efficiency plateau size ~ 700 V with Th = 220 mV
- Differences in $HV_{\varepsilon=0.5}$ ~ 50 V
- $\varepsilon > 0.99$ at 8.3 kV (mid of the plateau) for all the sections
- $<C_s>$ ~ 2.0 at $HV_{\varepsilon=0.95}$ (8.10 ~ 8.15 kV)
- $<C_s>$ ~ 3.2 at $HV_{\varepsilon ff}$ at mid of ε plateau (8.4 kV)
- Streamer probability $N_s < 0.1$ at 8.8 kV
- $N_s < 0.03$ at ~ 8.4 kV





Muon cluster-size distributions measured at wide-strip region (low eta)



Longer-period data

1.6 k events at wide at 8.42 kV

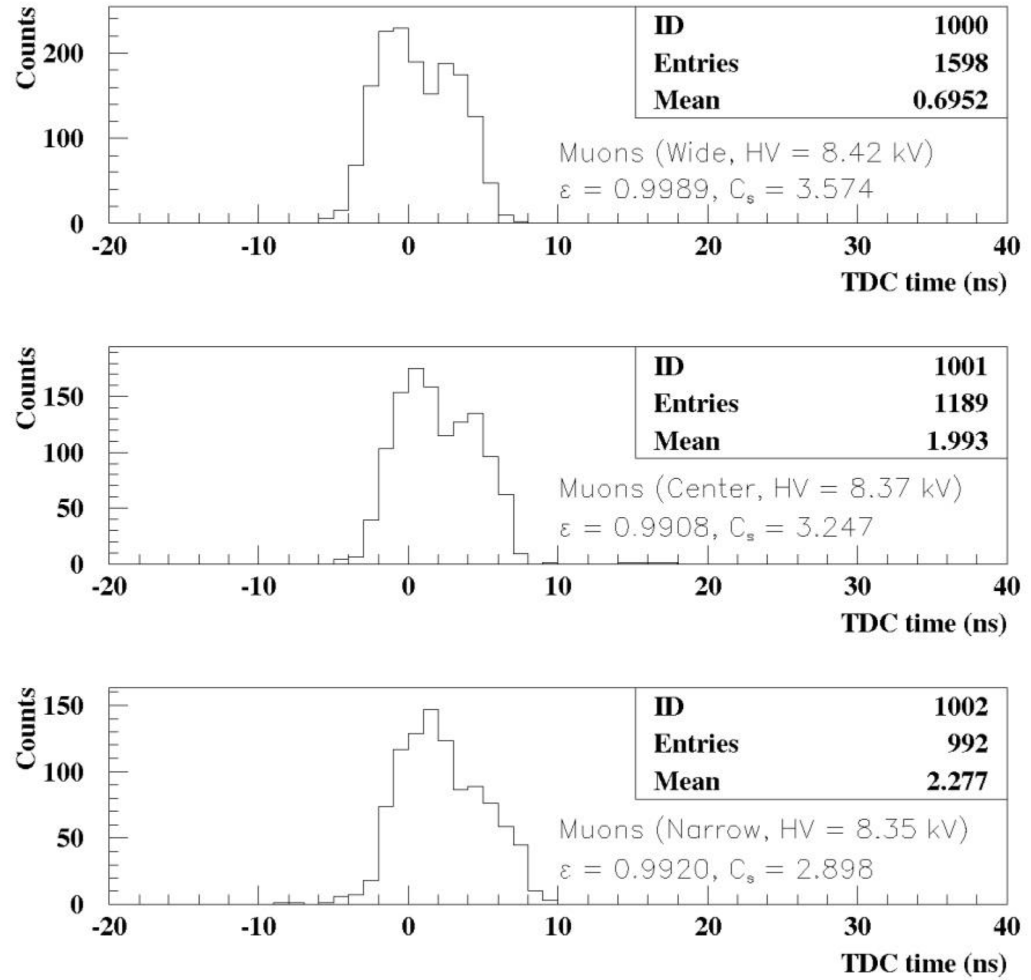
1.2 k events at center at 8. 37 kV

1.0 k events at narrow at 8.35 kV

TDC problem: Two channel-time responses of the TDC are splitting by ~ 4 ns.

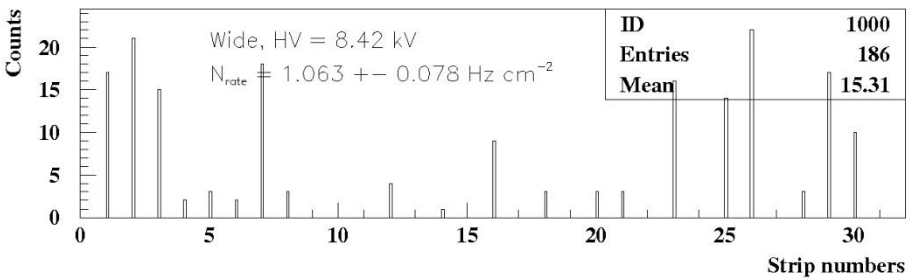
→ was not solved.

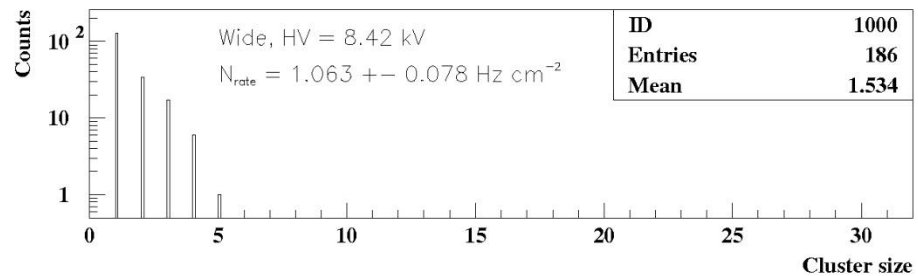
- Nevertheless, the time resolution of the detector + current CMS-RPC FEE seems to be ~ 1.5 ns.
- Electronics noises are severe at digitization threshold < 210 mV (150 fC).

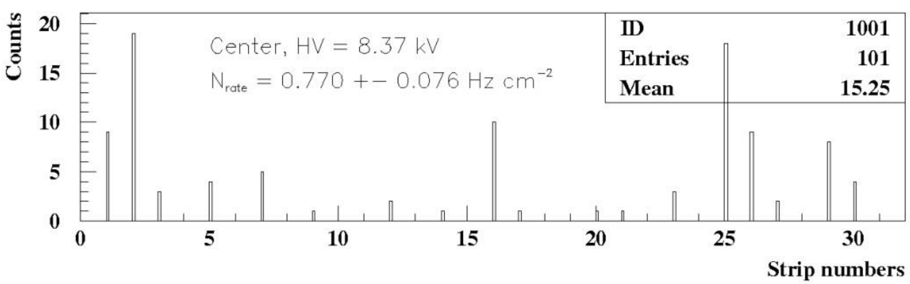


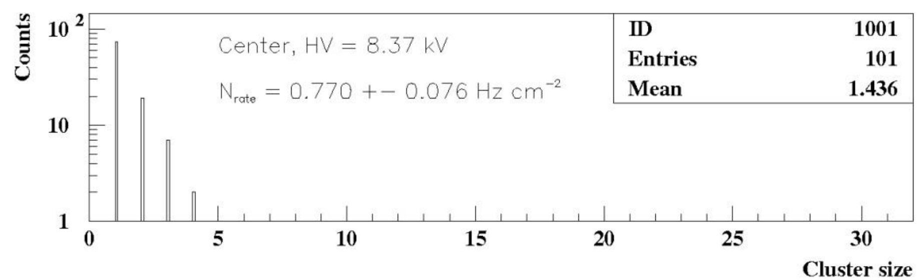
Positions of noises

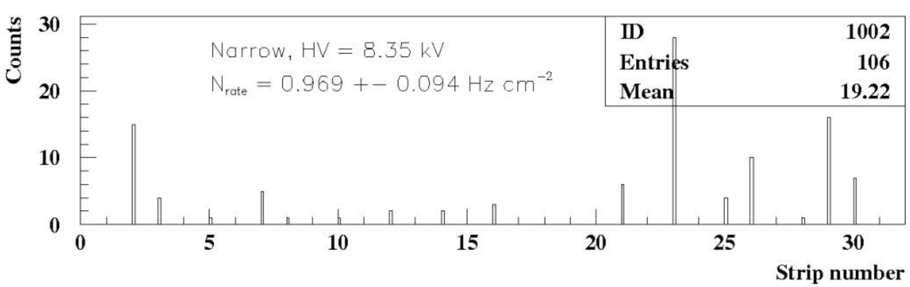
- Noise rates at the mid of efficiency plateaus = 0.77 ~ 1.06 Hz cm^{-2}
- $\langle C_s \rangle_{\text{noises}} \sim 1.4$
- Still expect some contamination of electronics noises in the data.

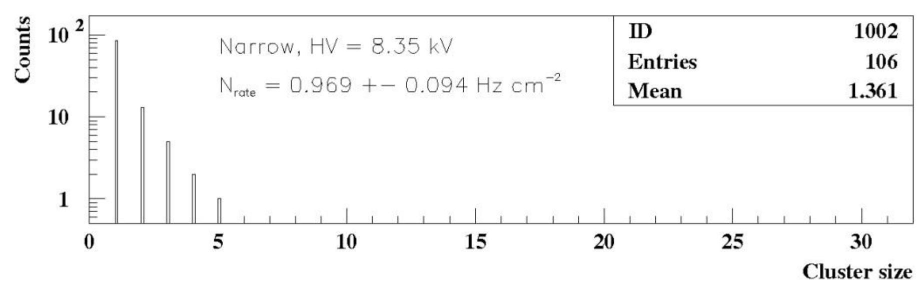






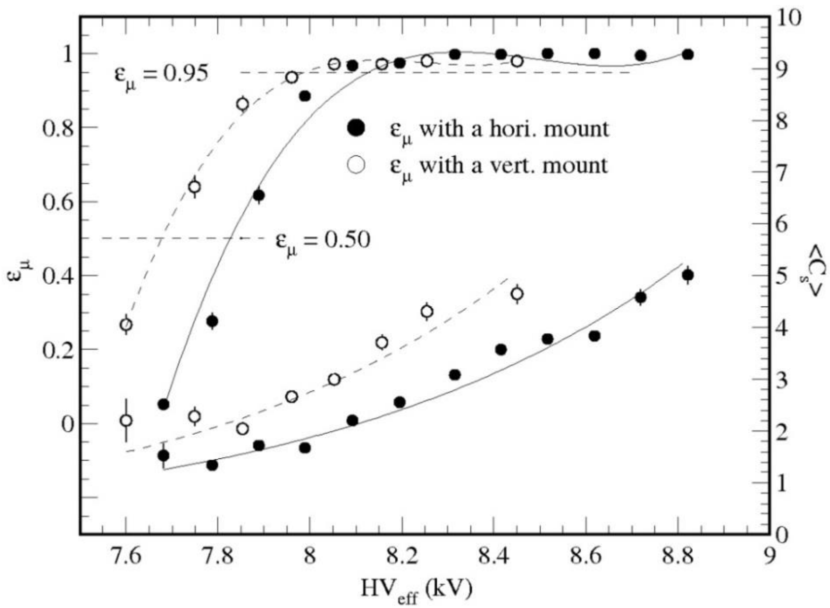


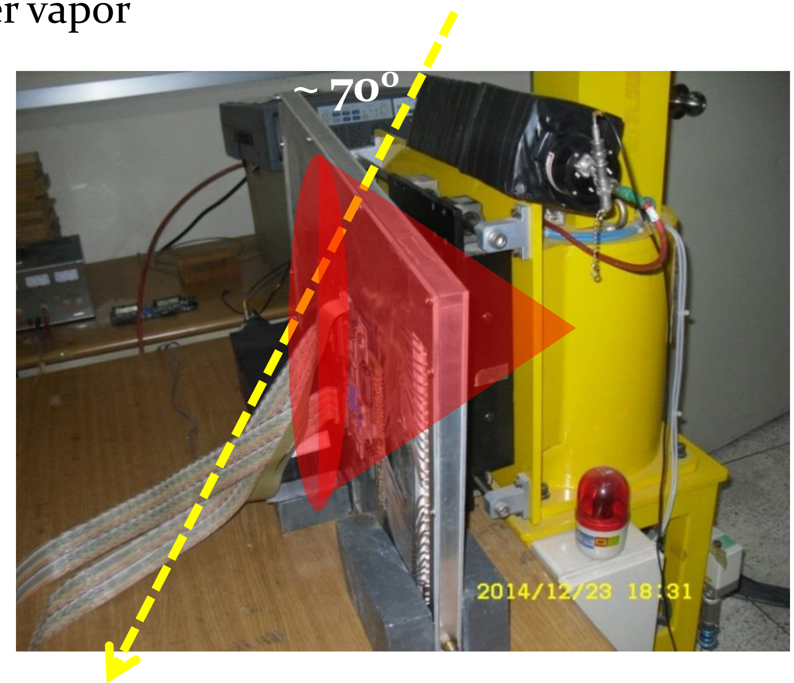




Test of a 1.6-mm 2-gap RPC with a 150 mCi ^{137}Cs source

- The RPC installed at 35 cm from the source
  → Incident gamma flux on the RPC = 360 kHz cm^{-2}
- Active gamma-irradiation area on the RPC ~ 800 cm^2
- Drawback: Incident angle of cosmic muons to the detector ~ 70°
  - ✓ Strip cluster sizes are overestimated due to the large track length in the detector
  - ✓ Cause a shift in the working HV ~ 130 V toward the low HV side
- Digitization threshold = 170 fC (220 mV)
- Gas = 95.2% $C_2H_2F_4$ + 4.5% i-C_4H_{10} + 0.3% SF_6 + water vapor





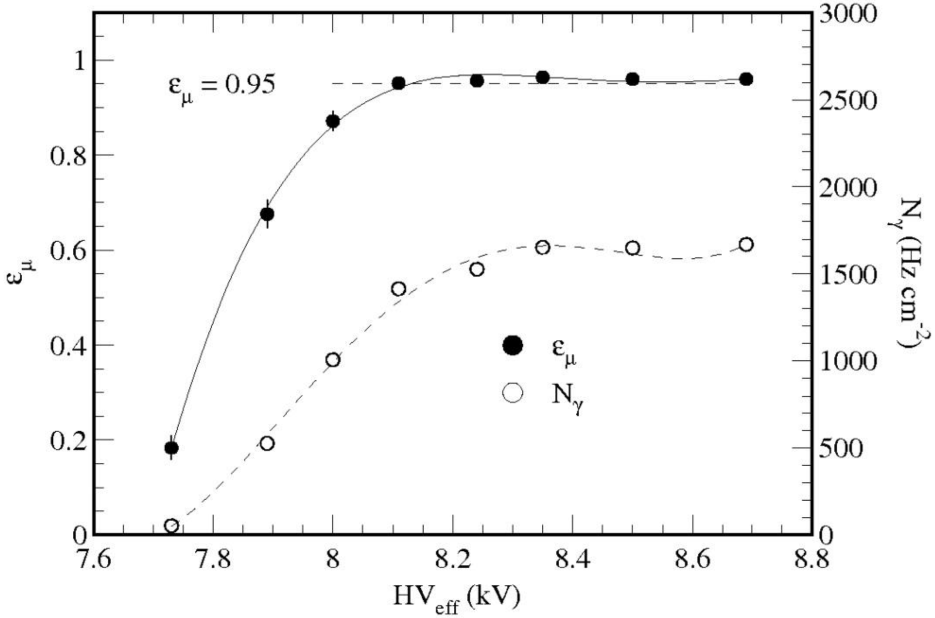
Incident gamma flux on the RPC = 360 kHz cm⁻²

Gamma rate saturated to 1.67 kHz cm^{-2} at HV_{eff} = 8.35 kV (~ 250 V above the HV_{eff} yielding $\varepsilon_\mu = 0.5$)

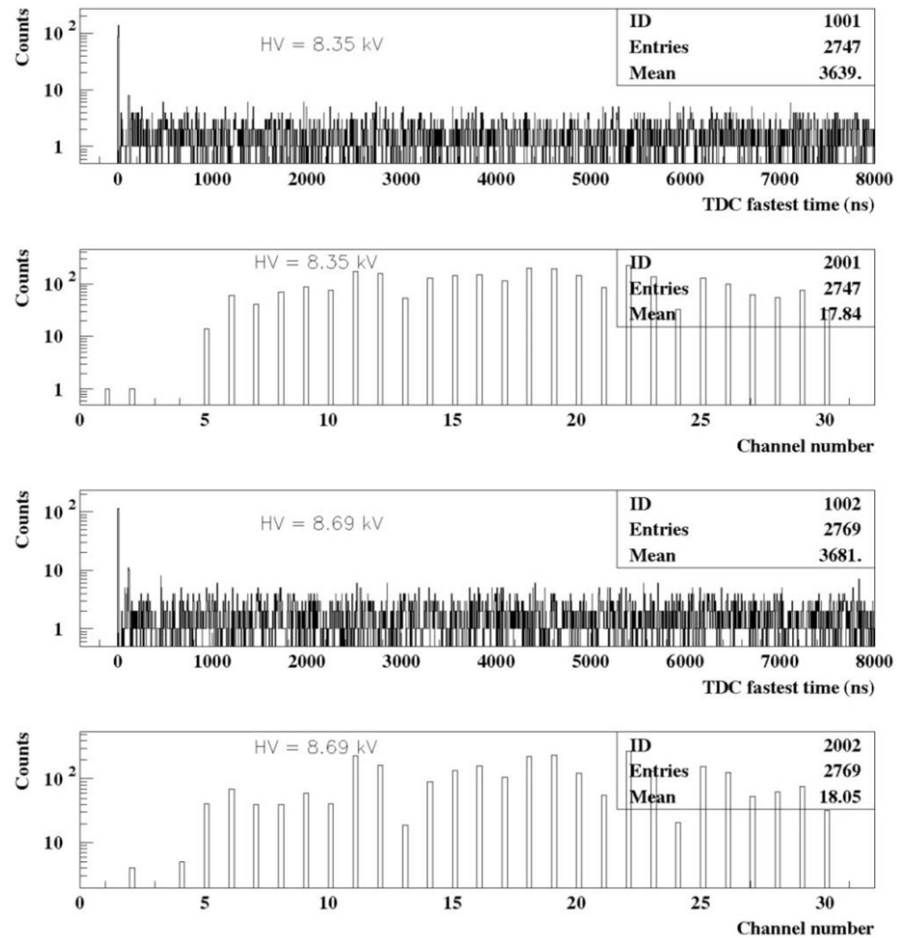
Q.E. for 661.7 keV gammas (estimated using GEANT4) = 0.0075

- ✓ Gamma rate predicted by GEANT4 ~ 2.7 kHz cm^{-2}
- ✓ The actual detected rate ~ 1.67 kHz cm^{-2}

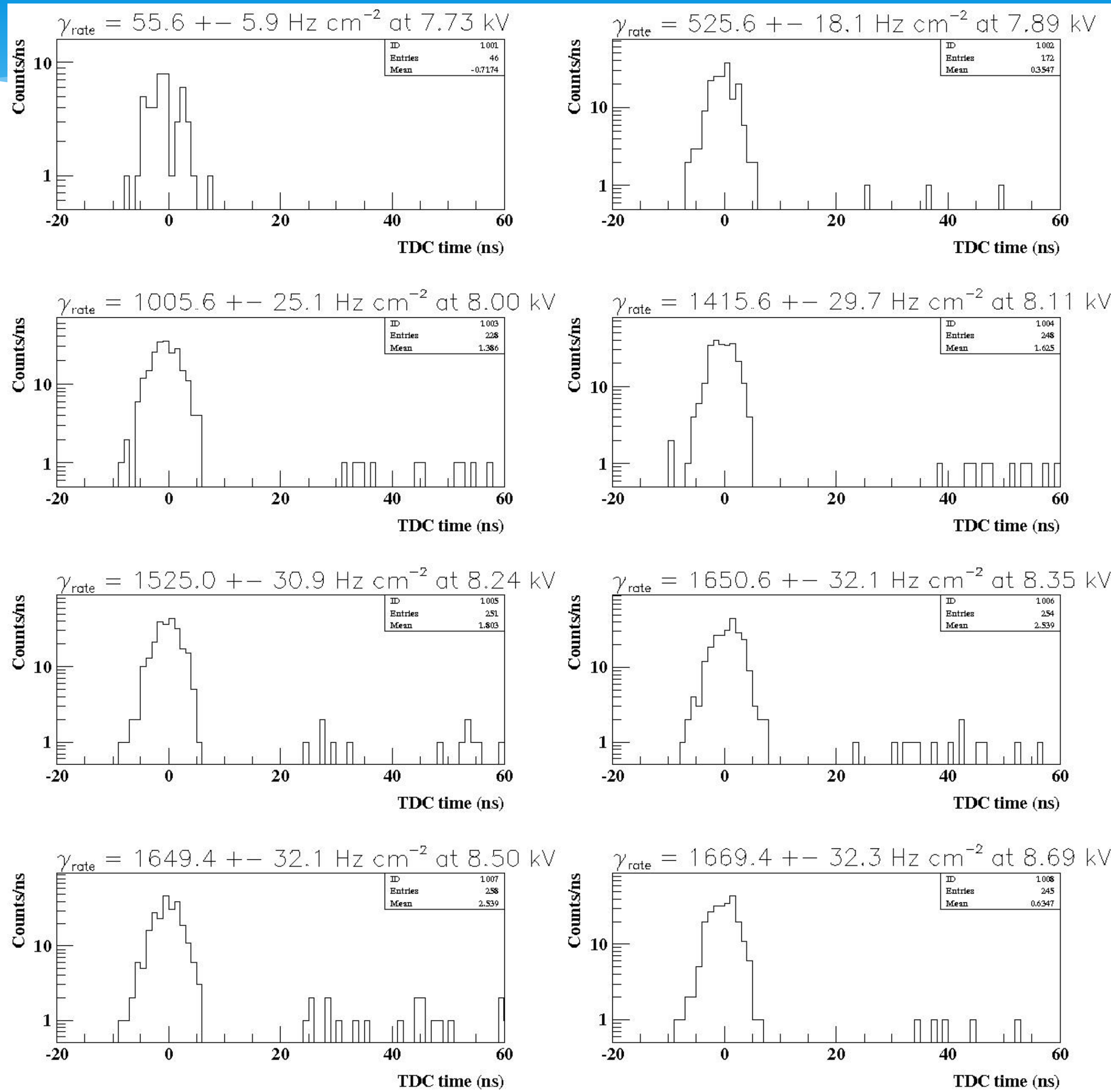
Thus, the ratio: detector efficiency /Q.E. ~ 0.62



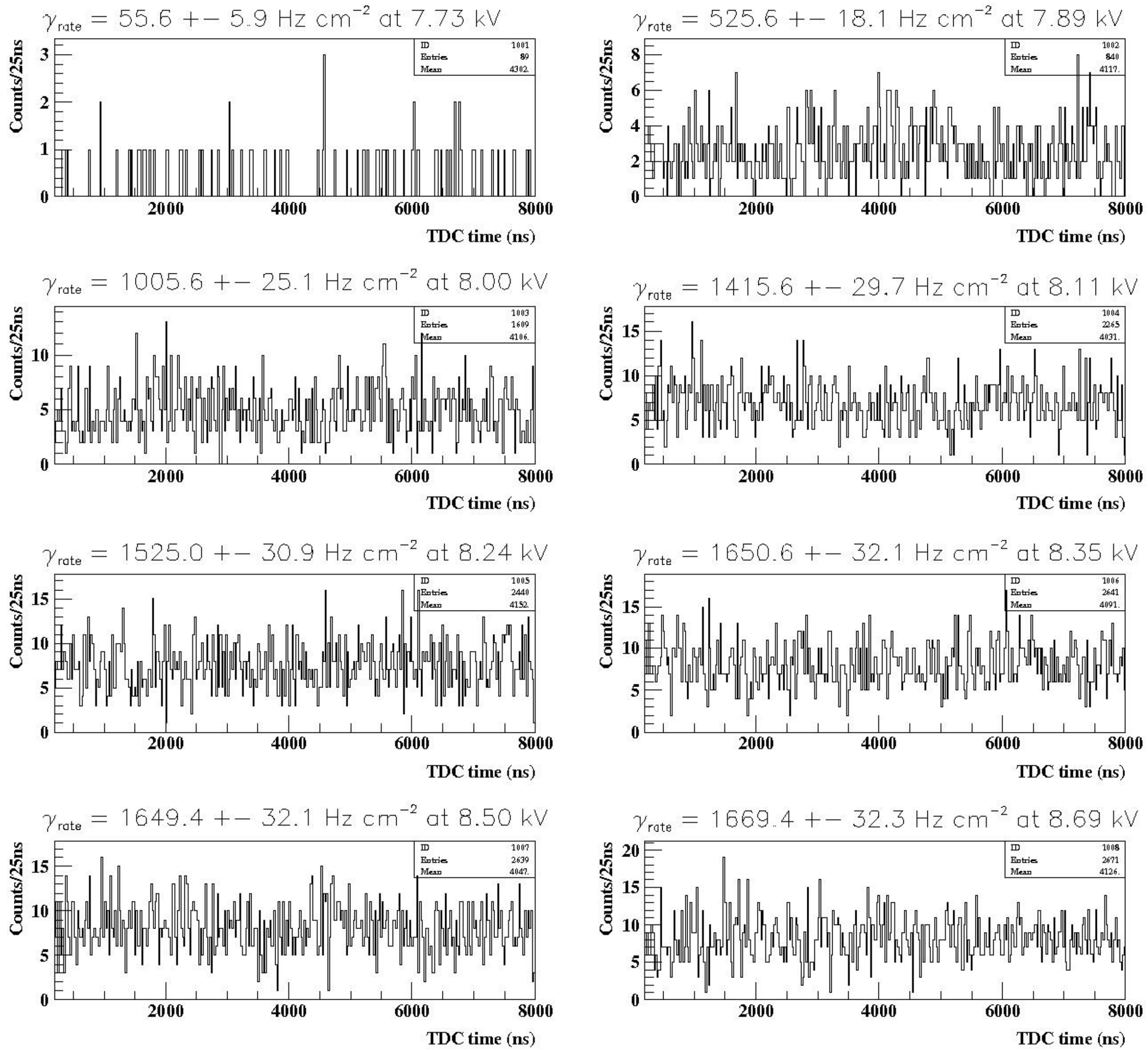
TDC fastest hits in 8 μs trigger windows



Fastest hits for muons and gammas



Fastest hits gammas

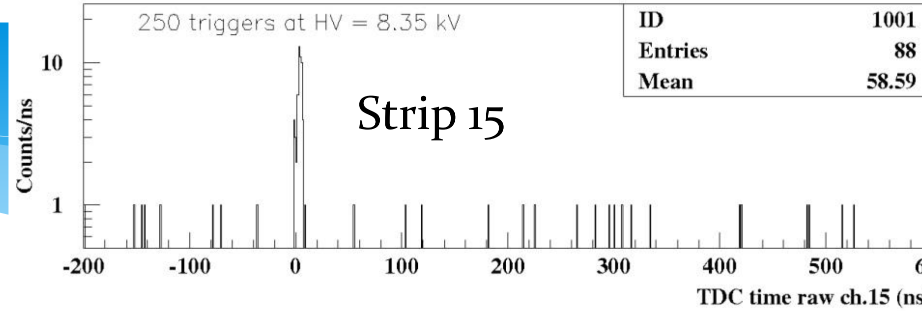


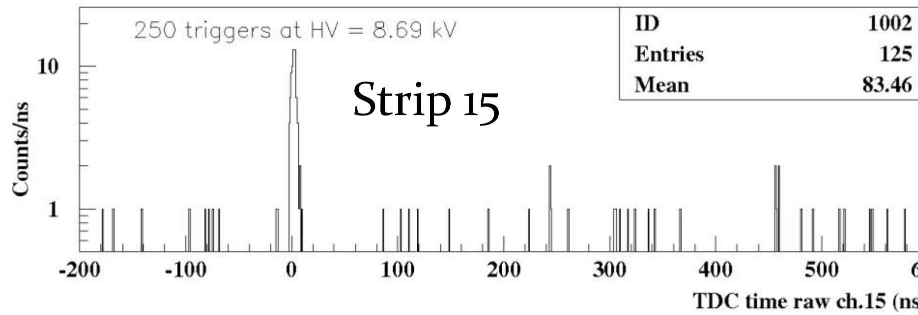
1. Probability of losing muon signals due to the gamma hits lying in or in front of the muon time window for each strip ~ 2%

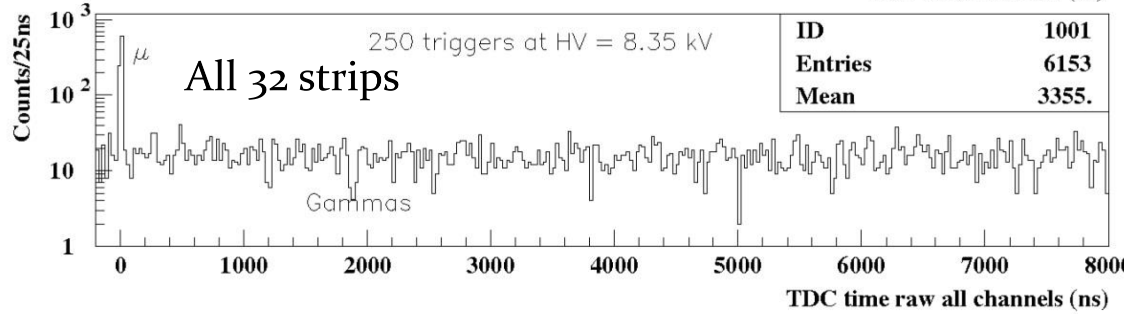
2. Probability of having gamma background hits in each muon time window (25 ns): ~ 8 %

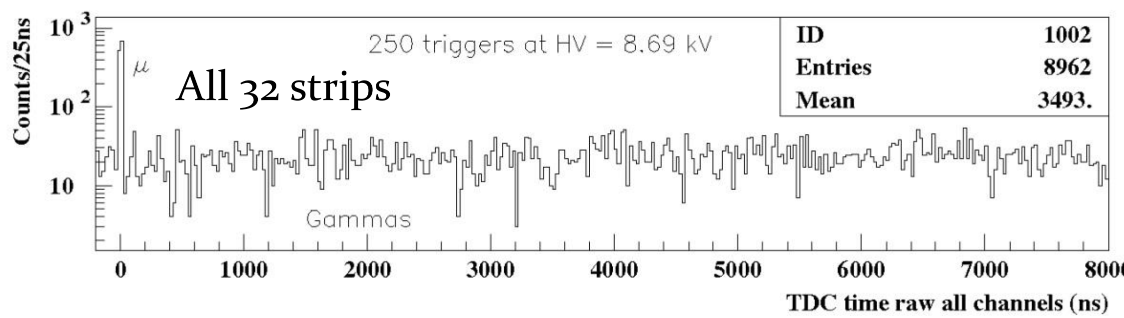
Mean strip length illuminated by gamma rays

~ 28 cm (gamma irradiation area ~ 800 cm^{-2})





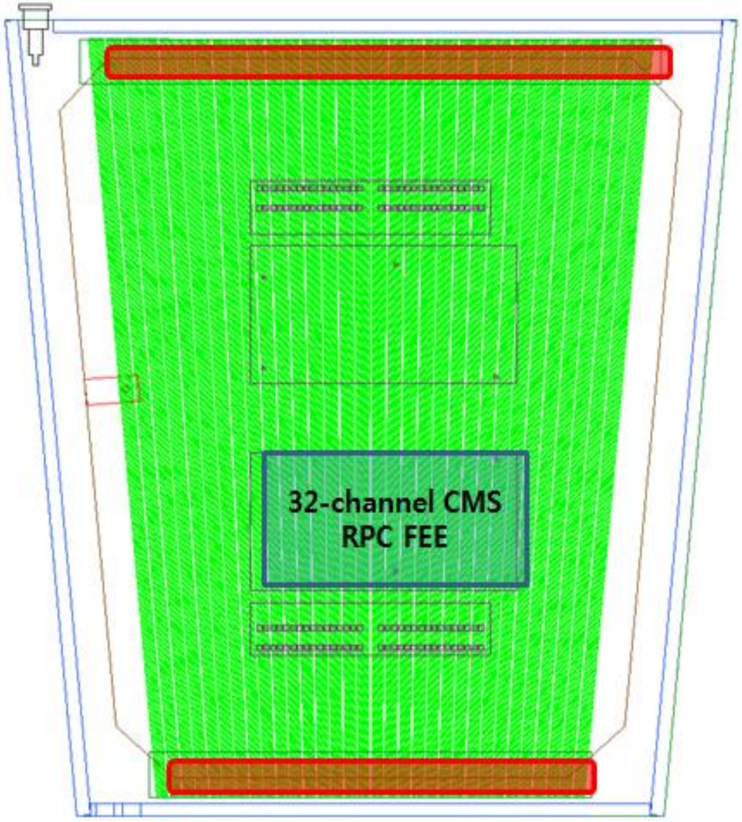




Small prototype 0.8-mm four-gap RPC (multi-gap RPCs)

Thickness of a single gap = 0.80 mm
→ Trapezoidal-shape with 55-cm long strips

HPL: Bakelite previous used for the R&D of RE11 RPCs,
$\rho \sim 4 \times 10^{10}\ \Omega\text{cm}$



Gaps:

- Spacers (accepted 0.78 & 0.79 mm, **$\sigma \sim 6\ \mu m$**): Nicemold, Seoul, Korea
- Edge strips (3.60 mm ±20 μm, **$\sigma \sim 10\ \mu m$**) for gas sealing : Atrix, Inchon, Korea

Chamber:

- Thickness of the detector only = 29 mm (26 mm for current 2-gap RPCs)
- Uses one 32-ch CMS RPC FEB: threshold at 213 mV (160 fC).
- Gas = 95.2% $C_2H_2F_4$ + 4.5% isobutene + 0.3% SF_6
- Working HV = 9.6 ~ 10.4 kV with Th = 213 mV (160 fC)
- Read signals only from the narrower side of the strips.

Triggered using 10-cm thick plastic scintillators

- Time resolution of triggers ~ 300 ps
- Muon tagging area = 20 cm × 10 cm

DAQ: common-start mode

- Twist-pair Cable delay ~ 200 ns

VME-mode multi-hit TDC

- 16 hits per channel
- Time window = 64 μs
- Time resolution ~ 1 ns

32-ch CMS-RPC FEB

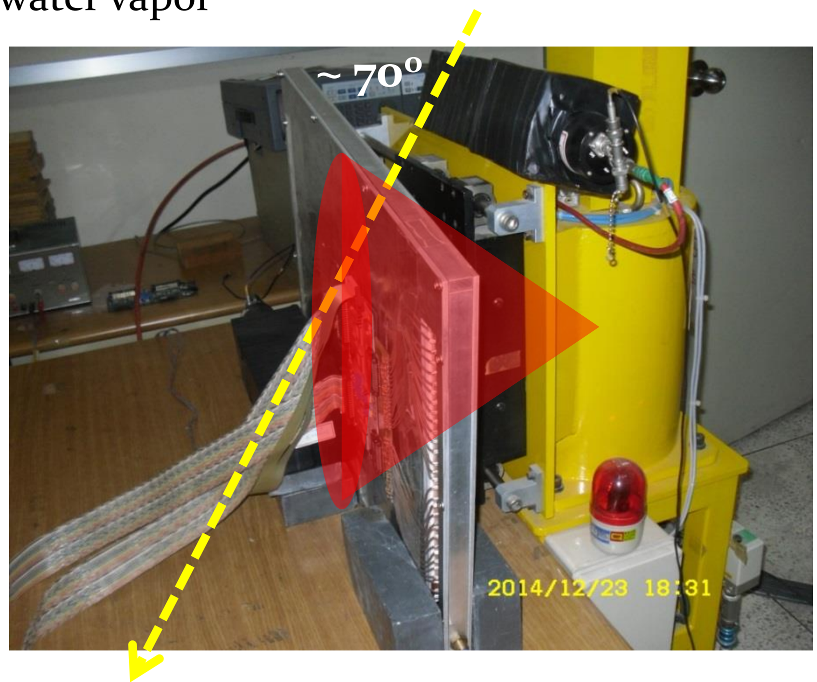
- Threshold = 213 mV (160 fC)
- VBIAS = 2.50 V
- LVDS width = 100 ns

Tested three sections

- Efficiencies
- Time responses
- Cluster sizes
- Noise rates

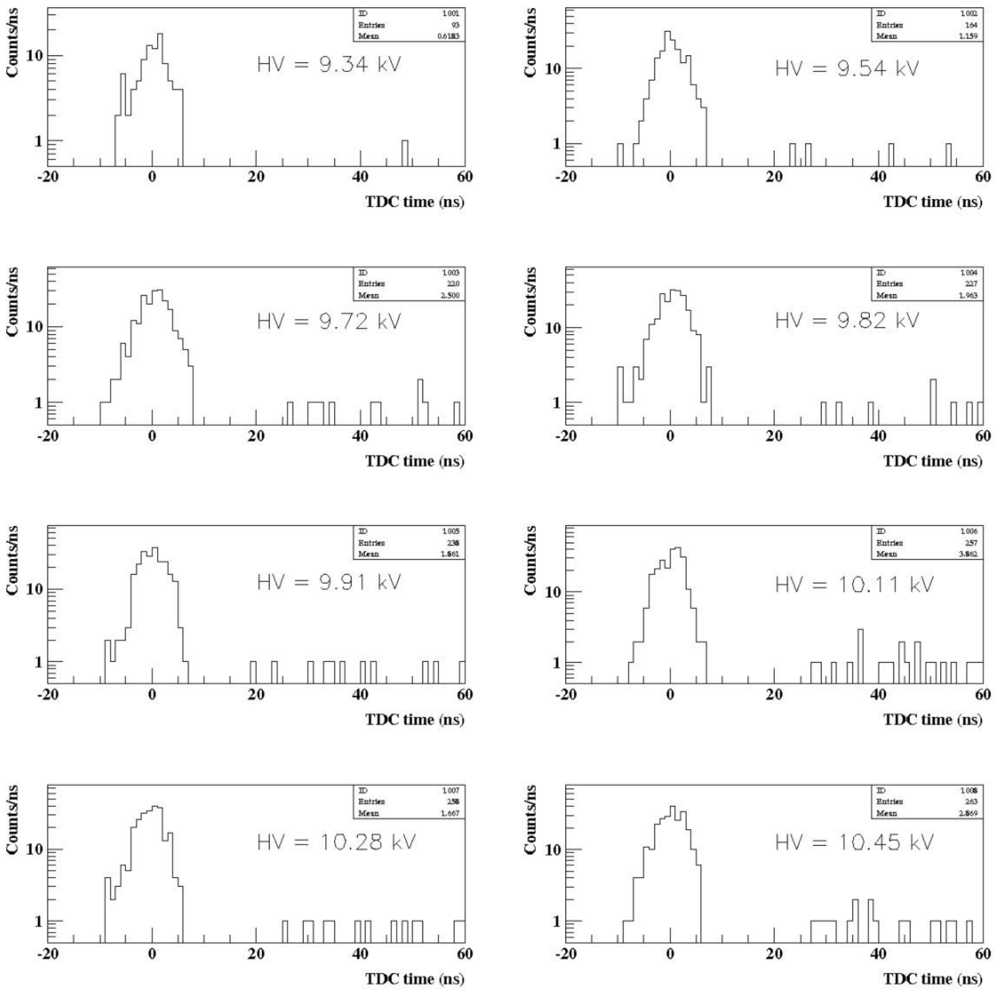
Test of a 4-gap RPC with a 150 mCi ^{137}Cs source

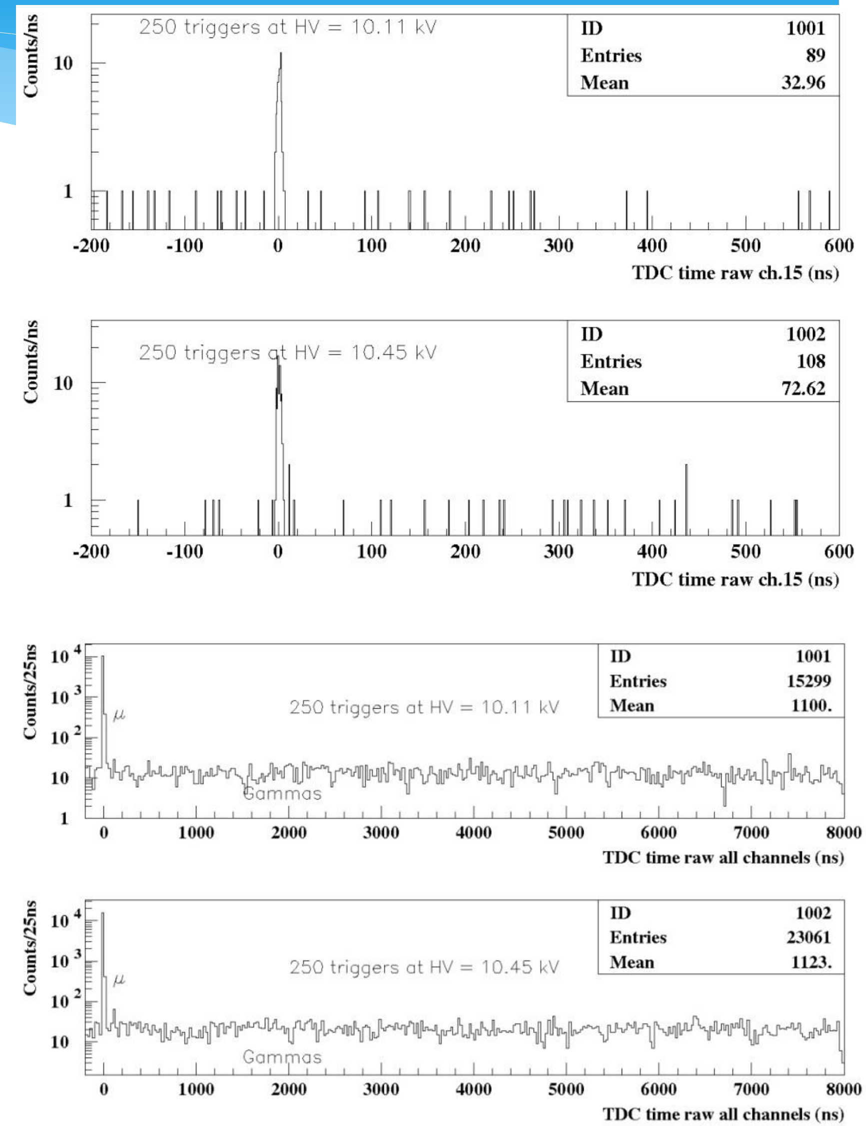
- The RPC installed at 35 cm from the source
  → Incident gamma flux on the RPC = 360 kHz cm^{-2}
- Active gamma-irradiation area on the RPC ~ 800 cm^2
- Incident angle of cosmic muons to detector ~ 70°
- Digitization threshold = 160 fC (213 mV)
- Gas = 95.2% $C_2H_2F_4$ + 4.5% *i*-C_4H_{10} + 0.3% SF_6 + water vapor



0.8-mm 4-gap RPC

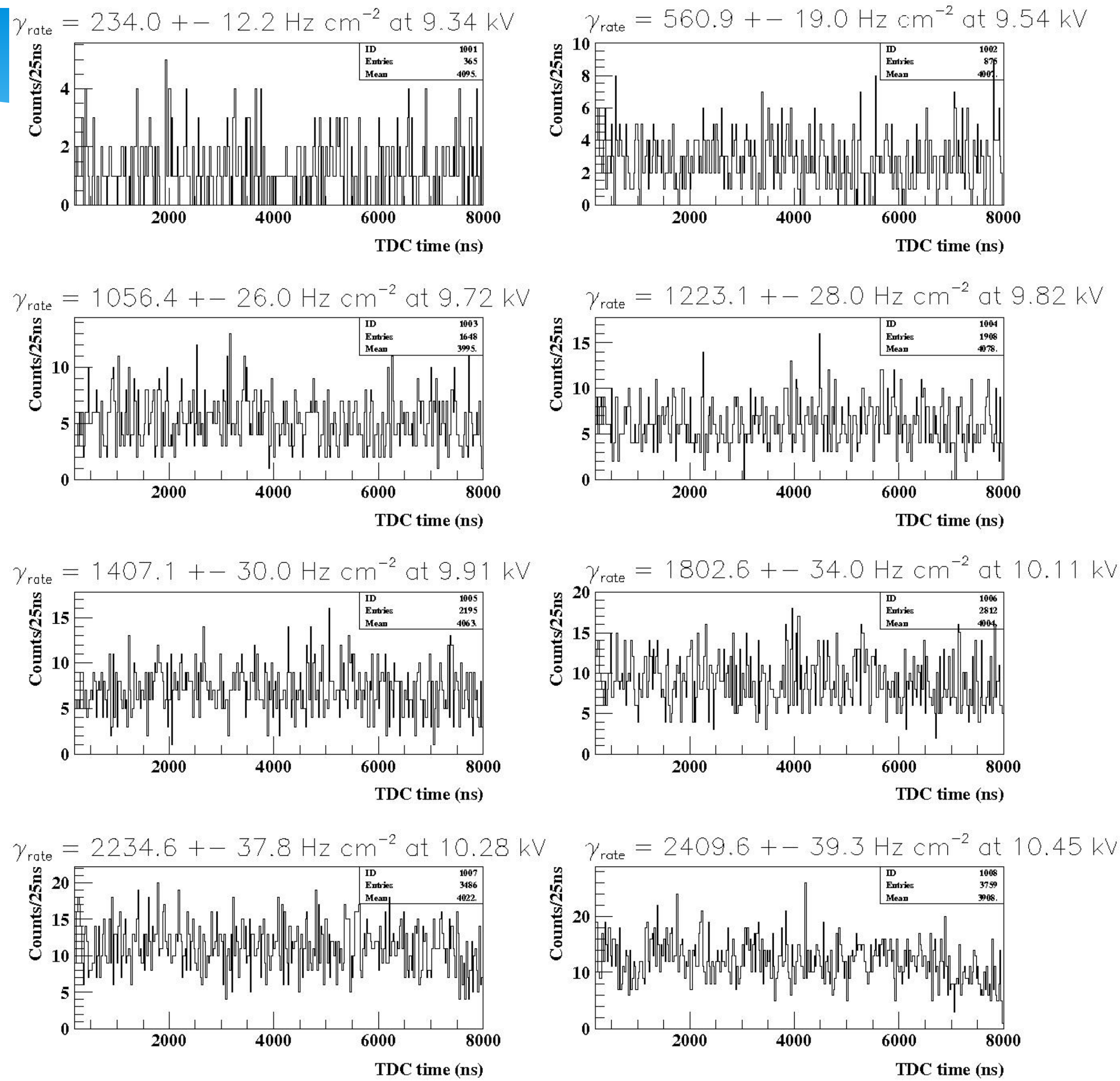
Muon/gamma time distributions





0.8-mm 4-gap RPC

Gamma time distributions



0.8-mm 4-gap RPC

Thr = 160 fC

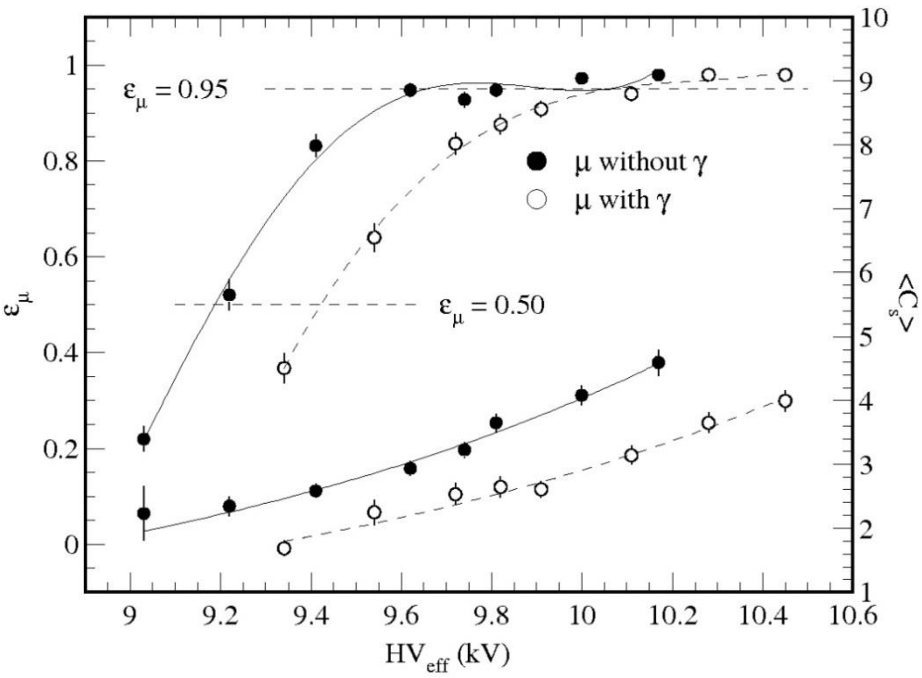
Shifts in HV_{eff} due to a γ-flux of 360 kHz cm^{-2}

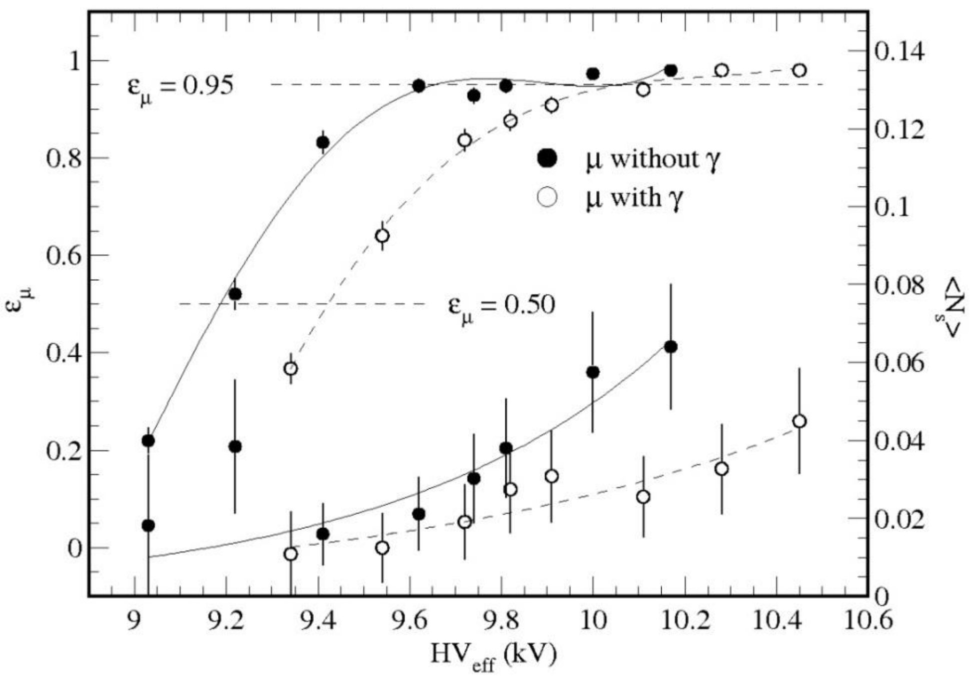
γ- signal rate reaching (ε_μ = 0.5) ~ 1.8 kHz cm^{-2}

✓ ~ 200 V at ε_μ = 0.5

✓ ~ 400 V at ε_μ = 0.95

Thus, the shift ~ 220 V / (kHz cm^{-2})





1.6-mm 2-gap RPC

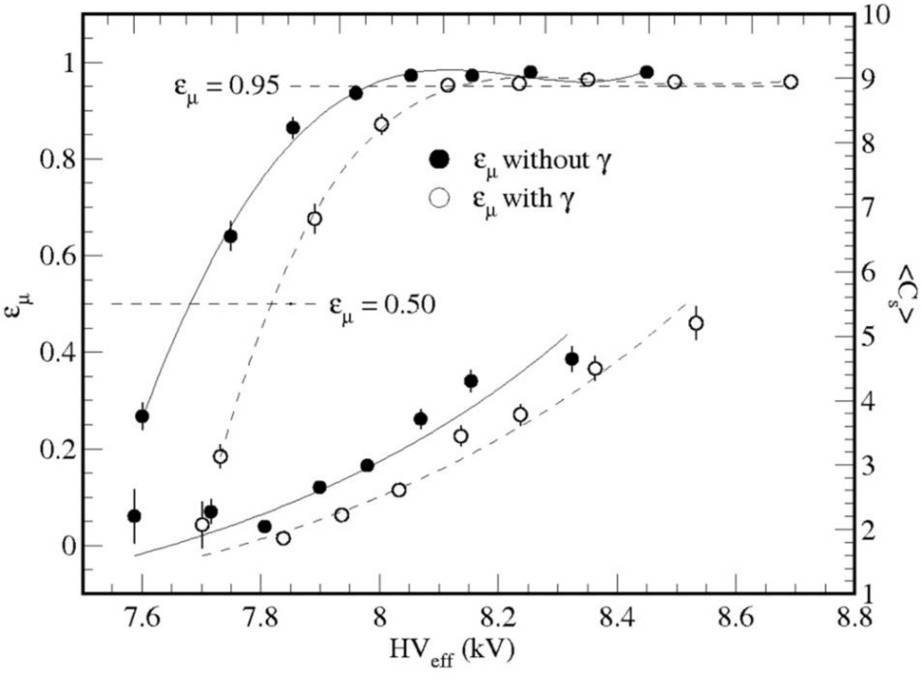
Thr = 170 fC

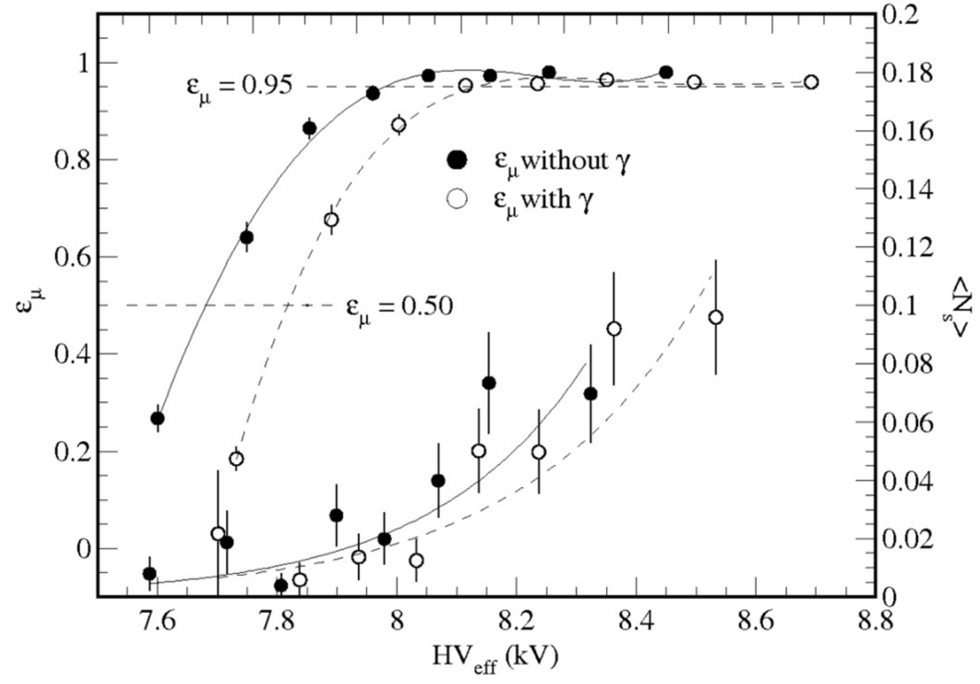
Shifts in HV_{eff} due to a γ-flux of 360 kHz cm^{-2}

γ- signal rate reaching (ε_μ = 0.5) ~ 1.4 kHz cm^{-2}

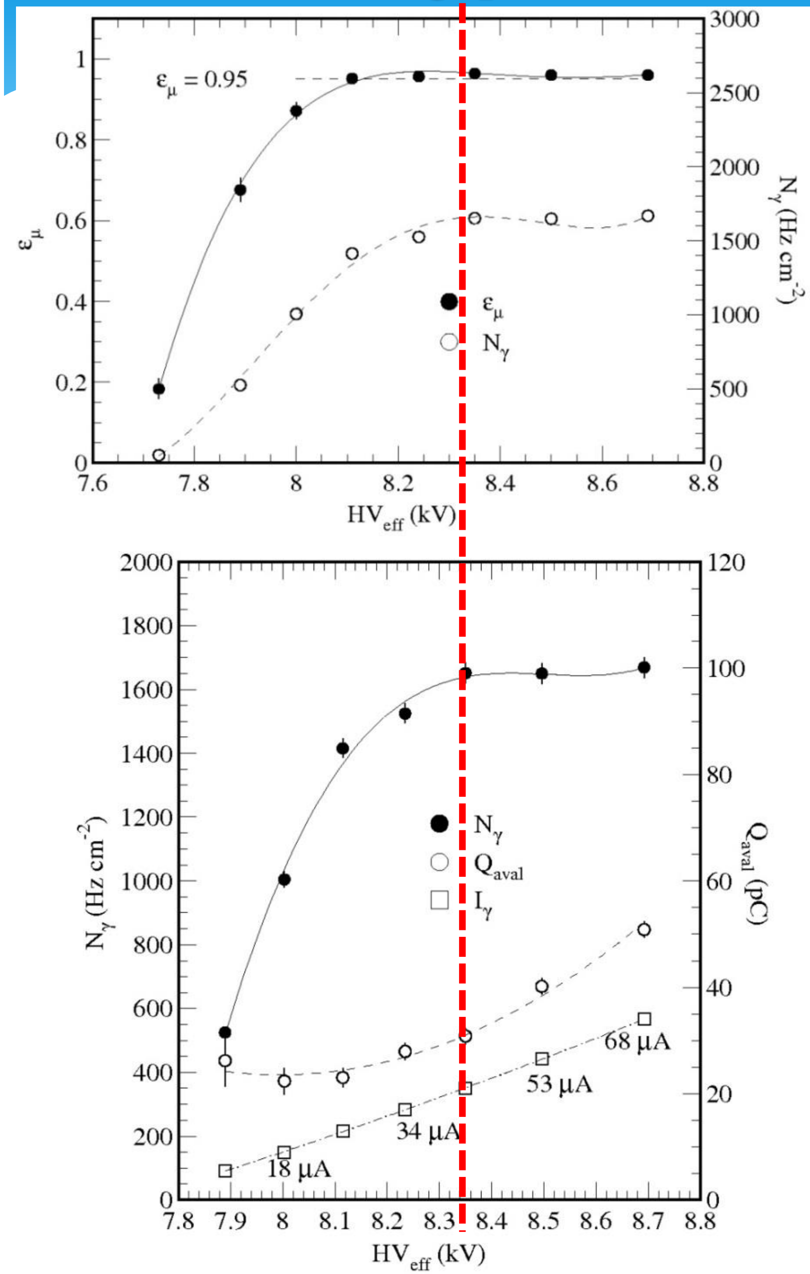
- ✓ ~ 120 V at ε_μ = 0.5
- ✓ ~ 150 V at ε_μ = 0.95

Thus, the shift ~ 110 V / (kHz cm^{-2})

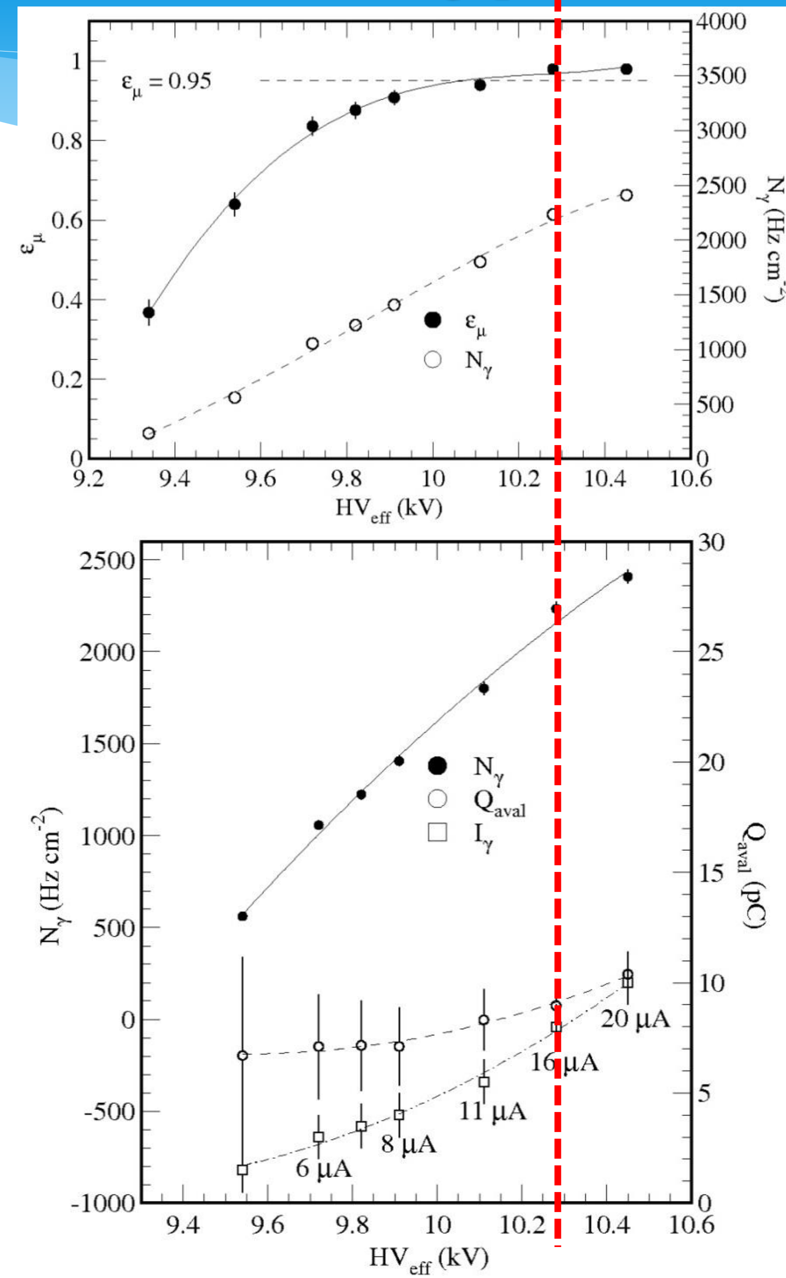




1.6-mm 2-gap RPC



0.8-mm 4-gap RPC



Incident gamma flux on the RPC = 360 kHz cm^{-2} at d = 35 cm
Active gamma-irradiation area on the RPC ~ 800 cm^2

1.6-mm 2-gap RPC

- At the mid of muon efficiency plateau,
  - ✓ N_γ = 1.67 kHz cm^{-2}
  - ✓ i_γ = 42 μA
  - ✓ i_{ohmic} < 1 μA
  - ✓ $Q_{aval,\gamma}$ ~ 30 pC
  - ✓ Shift ~ 110 V / (kHz cm^{-2})
- The avalanche charge $Q_{aval,\gamma}$ keeps increasing with HV at N_γ ~ 1.7 kHz cm^{-2}.

→ The rate capability exceeds 2 kHz cm^{-2}.

- The avalanche charge induced by neutral particles (gammas, single-gap events) is the same for both 1.6-mm and 2.0-mm double-gap RPCs. But, the operational voltage for muons in 1.6-mm double gaps RPC starts at HV = 8.1 kV.
- 1 kHz cm^{-2} → i_γ ~ 300 μA in a 1-m^2 detector

→ Better to reduce the threshold to reduce the detector current per unit rate.

0.8-mm 4-gap RPC

- At the mid of muon efficiency plateau,
  - ✓ N_γ = 2.28 kHz cm^{-2}
  - ✓ i_γ = 16 μA
  - ✓ i_{ohmic} < 1 μA
  - ✓ $Q_{aval,\gamma}$ ~ 10 pC
  - ✓ Shift ~ 220 V / (kHz cm^{-2})
- The avalanche charge $Q_{aval,\gamma}$ keeps increasing with HV at N_γ ~ 2.3 kHz cm^{-2}.

→ The rate capability exceeds 3 kHz cm^{-2}.

- The avalanche charge induced by neutral particles (gammas, single-gap events) is about 1/3 of that of 2.0-mm double-gap RPCs.
- 1 kHz cm^{-2} → i_γ ~ 100 μA in a 1-m^2 detector

→ Batter to far reduce the threshold to reduce the detector current per unit rate.

6. Plans

Gap production at KODEL

- 1.6-mm double-gap RPCs

→ Produce ~ 4 sets of gaps for 1.6-mm thick double-gap RPCs with the RE4/2 size using the HPL used for RE4 production remained at KODEL **and** newly manufactured HPL (lower resistive).

- 0.8-mm 4-gap RPCs

→ Produce ~ 4 sets of gaps for 0.8-mm-thick 4-gap RPCs with the RE1/1 size using the old HPL used for the previous RE1/1 R&D remained at 904/CERN **or** newly manufactured HPL.

Further test plans at KODEL

- For both 1.6-mm double-gap & 0.8-mm 4-gap RPCs (small prototype)
  - ✓ Precision charge measurement using FADC (two 4-channel modules)
  - ✓ High-rate tests with new more sensitive digitization electronics (thresholds < 100 fC)

GIF++ test at CERN

- The amount of HPL at KODEL

→ 1 ~ 2 RPC modules (to be assembles at 904/CERN)

- New HPL with RE1/1 sizes

→ ~ 1 RPC module (to be assembled at KODEL)