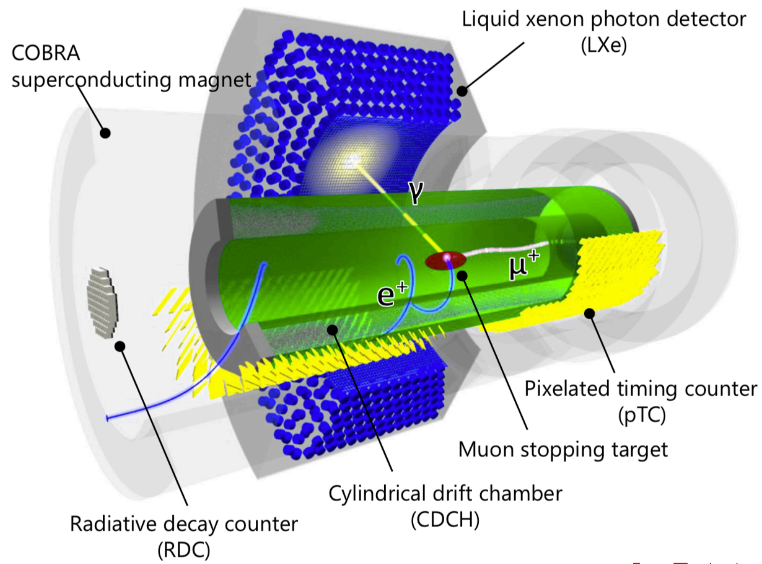
Study on the readout of the ultra-low material RPC for background suppression in the MEG II experiment

Kensuke Yamamoto
ICEPP, The University of Tokyo

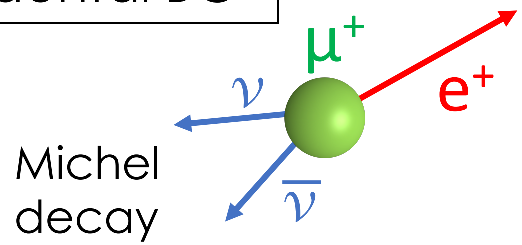
26th ICEPP Symposium on 16th February, 2020

MEG II & RPC



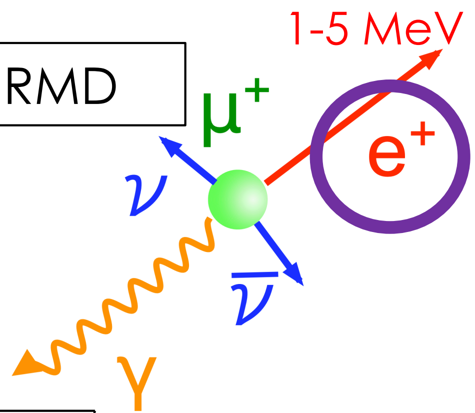
- MEG II searches for charged lepton flavour violating decay: $\mu^+ \rightarrow e^+\gamma$

Accidental BG

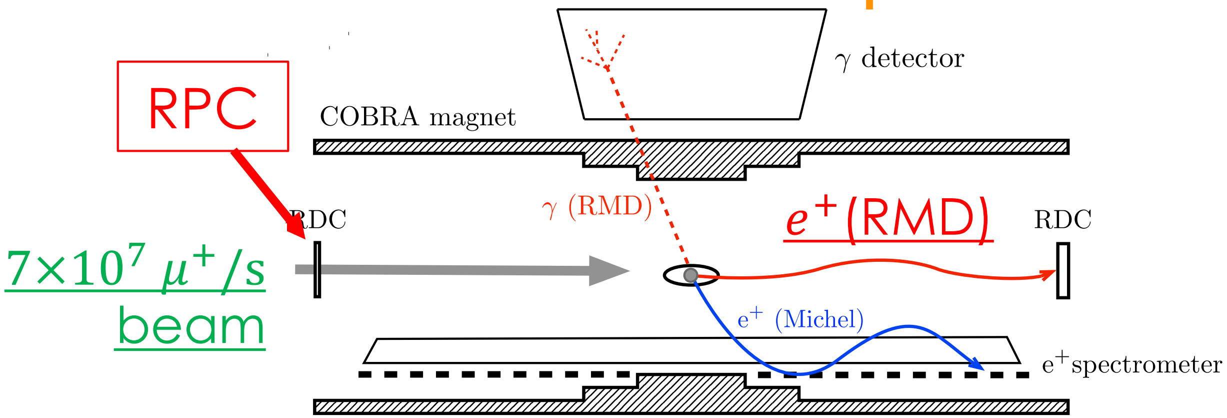


+

γ from RMD or Annihilation



- Resistive Plate Chamber (RPC) is one of gaseous detectors, uses high resistive electrodes placed face to face



Outline

- Introduction of RPC readout
  - Pileup probability
  - Prototype RPC readout
  - Impedance matching
- Lab test
- Summary & prospects

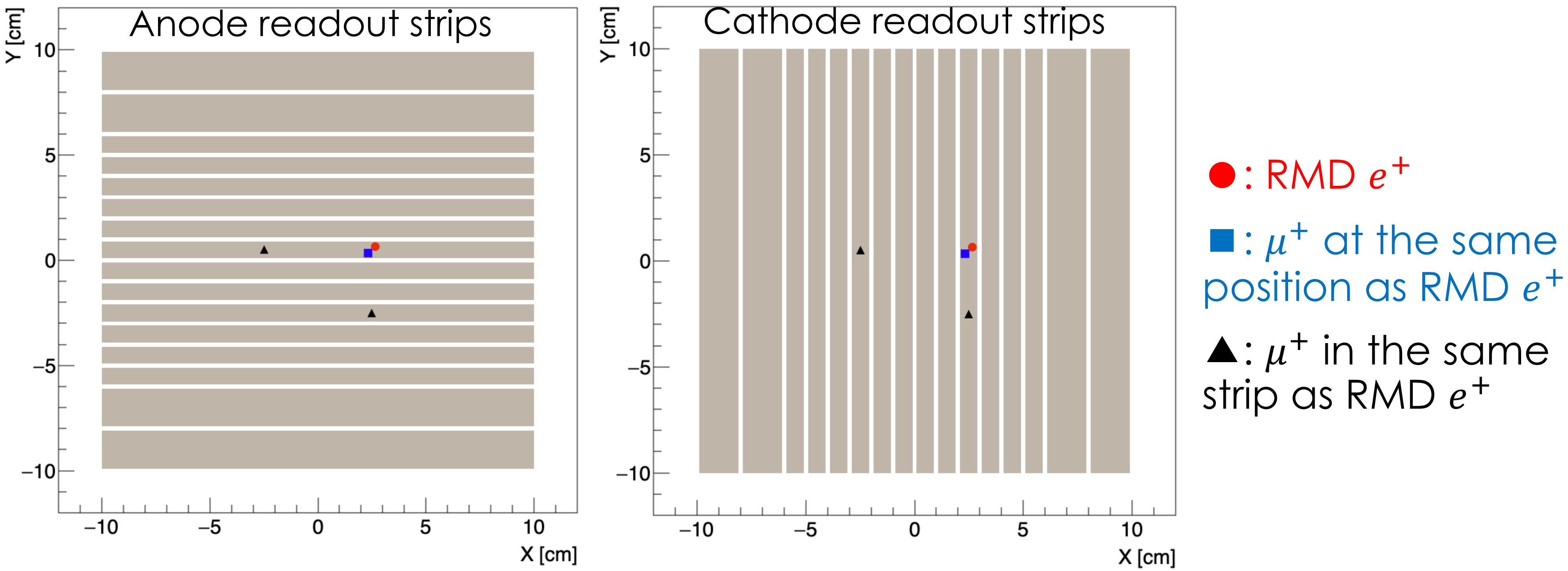
Pileup study

Requirements for RPC
- 90% efficiency for 1-5 MeV e^+
- Rate capability ($10^8 \mu/s$ with 21 MeV/c)

- Pileup of high-rate μ^+ beam & RMD e^+

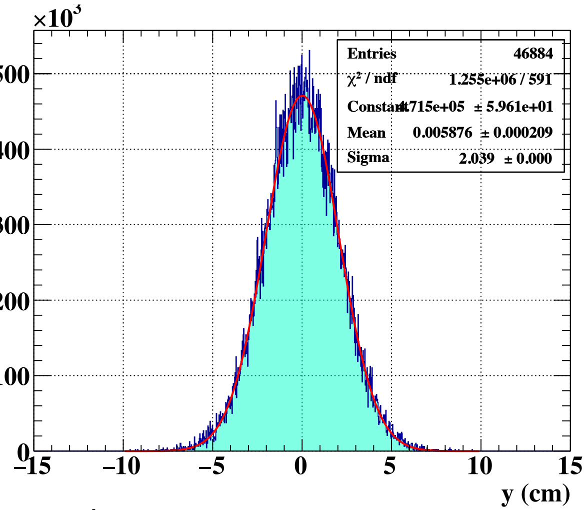
→ Inefficiency of RMD e^+

→ Readout strips should be segmented

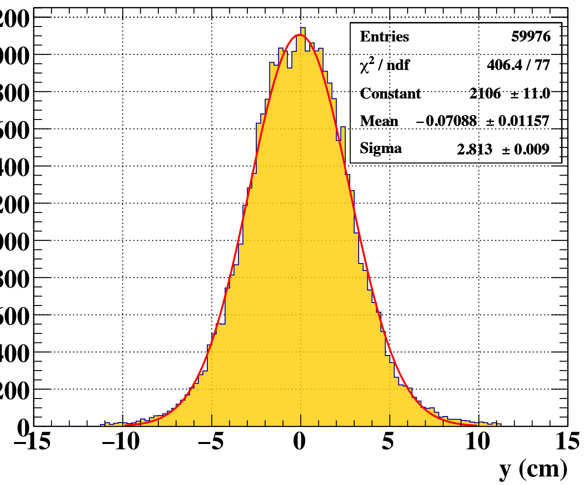


Pileup

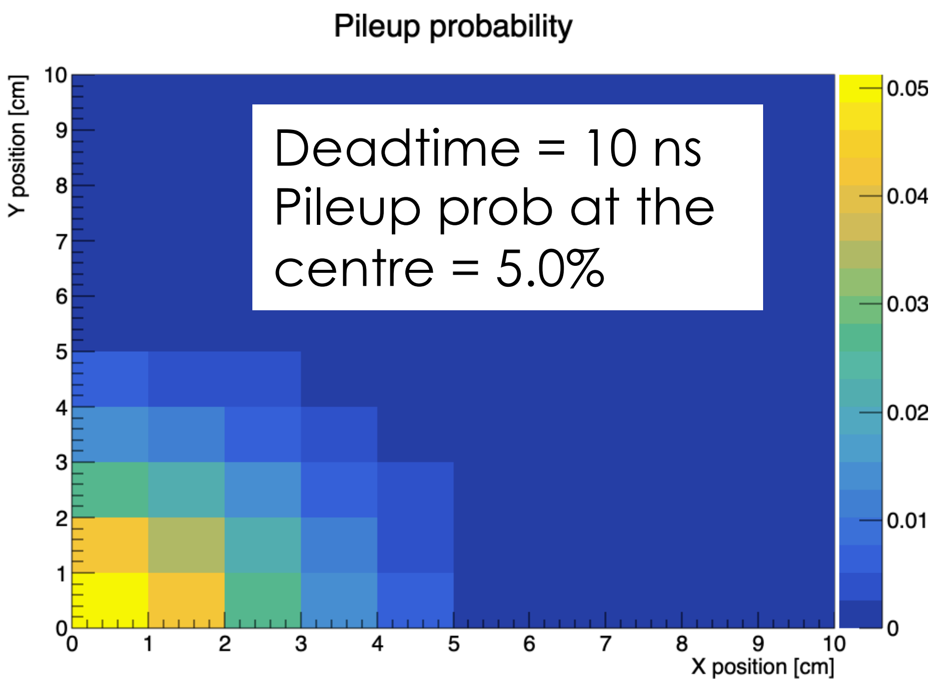
- Calculate pileup probability per readout segmented region

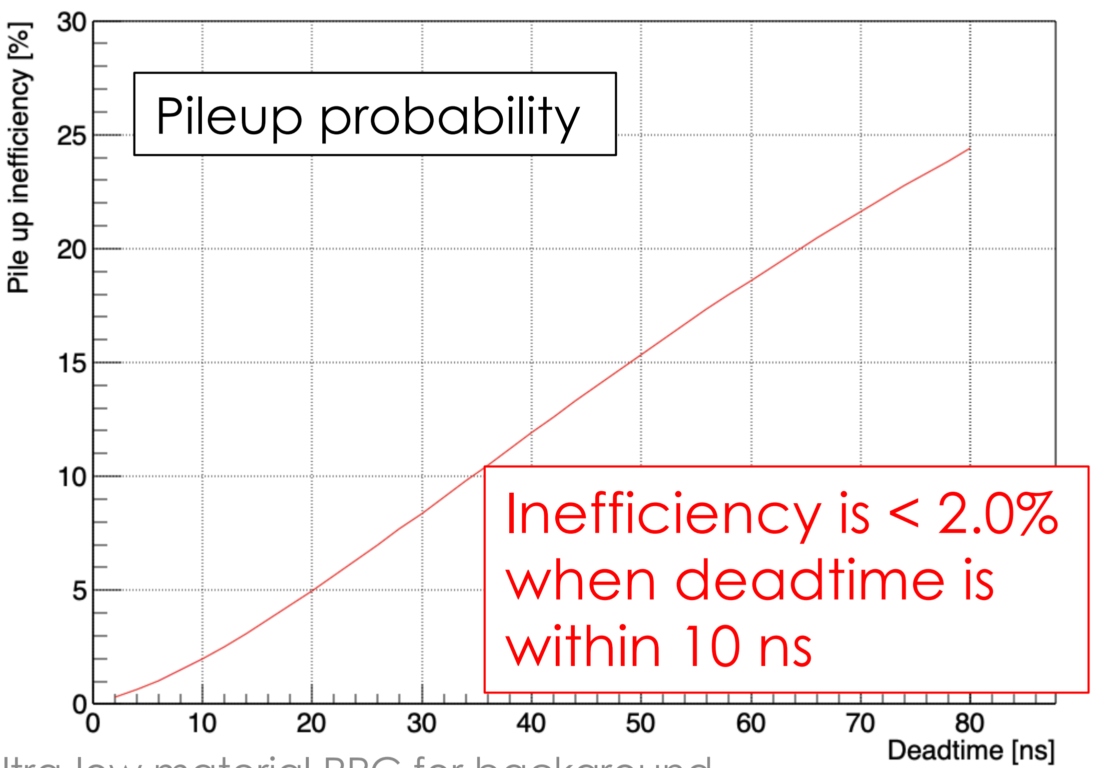


μ^+ beam divergence
$\sigma = 2.0$ cm

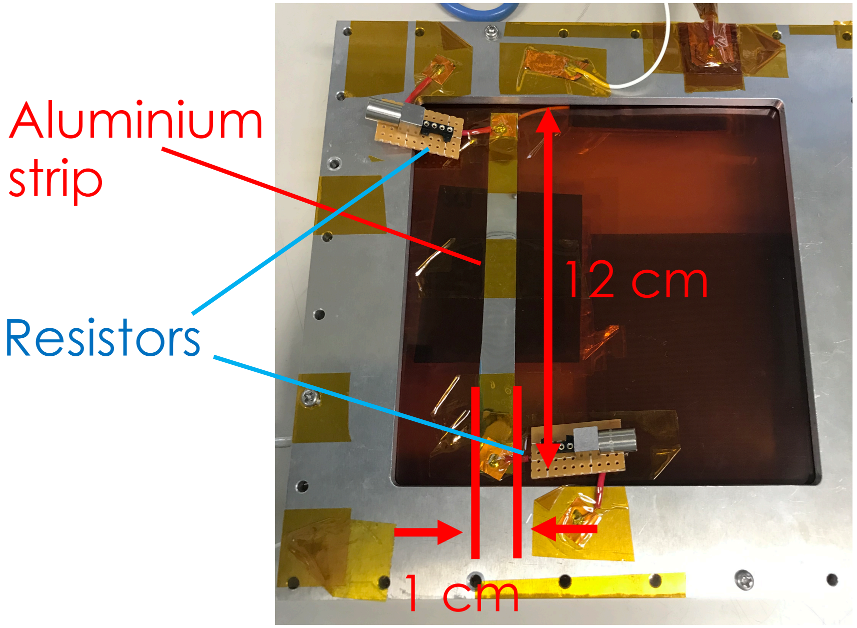


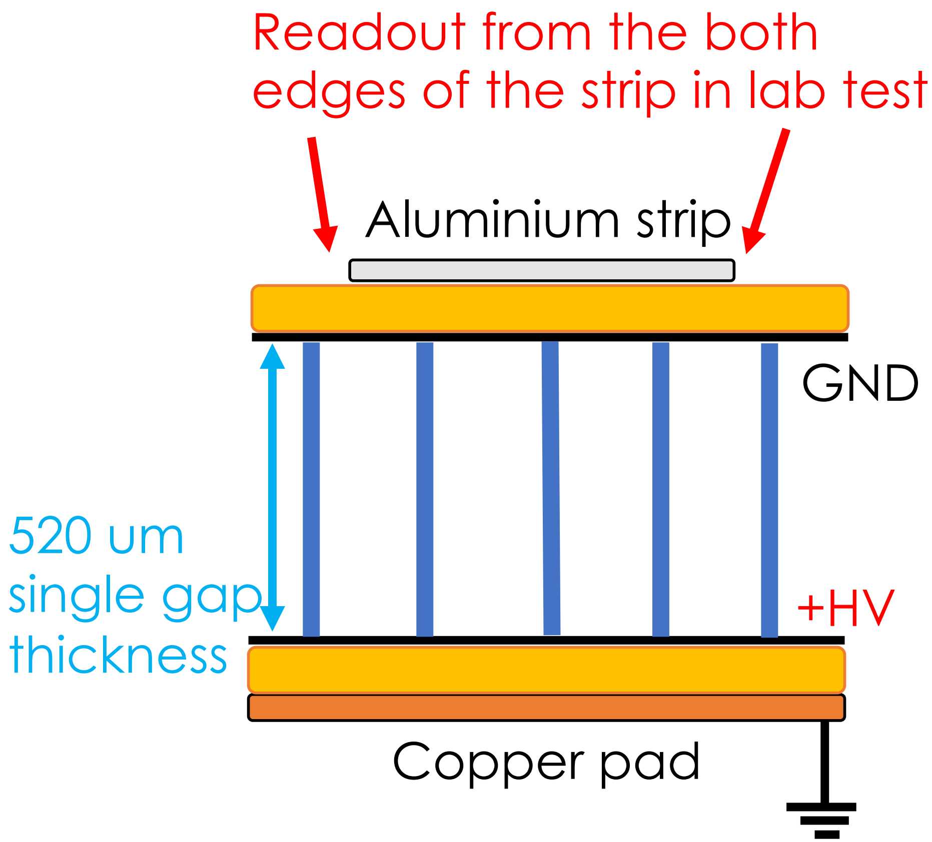
RMD e^+ divergence
$\sigma = 2.8$ cm

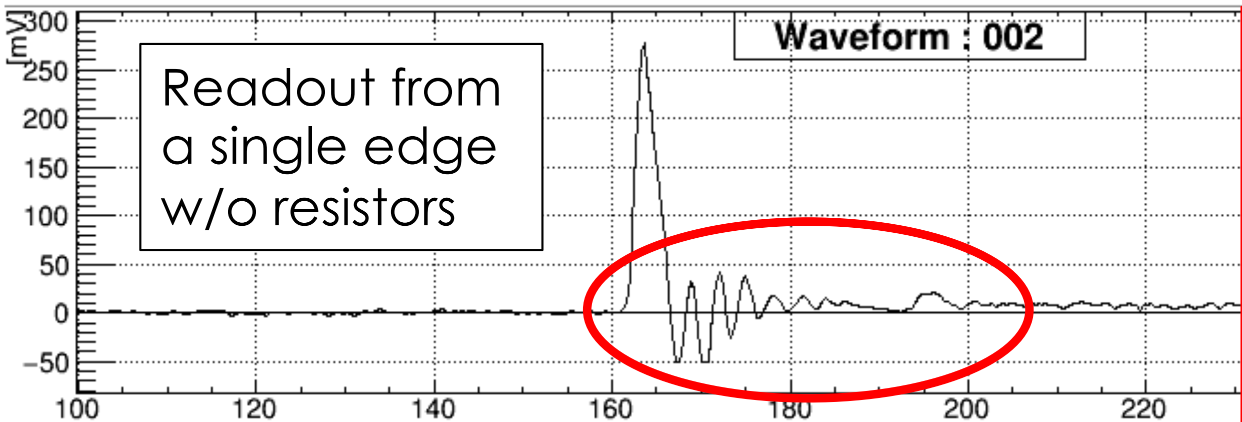




RPC readout

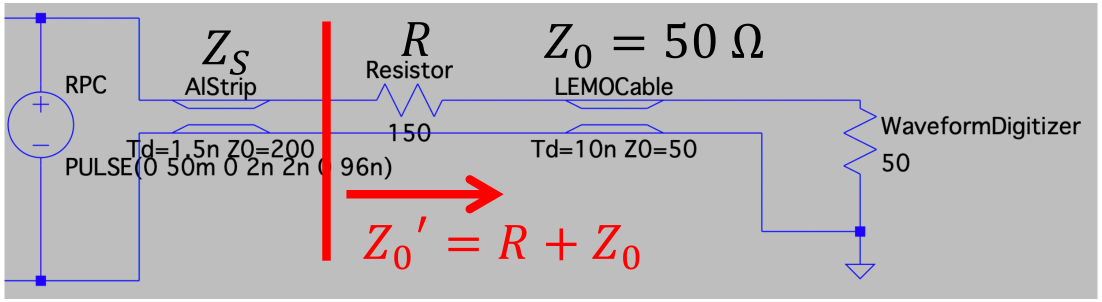






Reflection were observed due to <u>impedance mismatching</u>
→ It results in deadtime and bad effect on pileup inefficiency

Impedance



- Characteristic impedance of Al strip: Z_S
- Characteristic impedance of LEMO cable: $Z_0 = 50\ \Omega$
- Reflection coefficient $r = \frac{Z_0 - Z_S}{Z_0 + Z_S}$
- → $Z_0 = Z_S$ for no reflection ($r = 0$)
- Insert a resistor b/w Al strip & LEMO → $Z_0' = R + Z_0$
- Then $r = \frac{Z_0' - Z_S}{Z_0' + Z_S}$ → Find R which gives $r = 0$ in lab test
- RPC threshold in our lab test is 10 mV

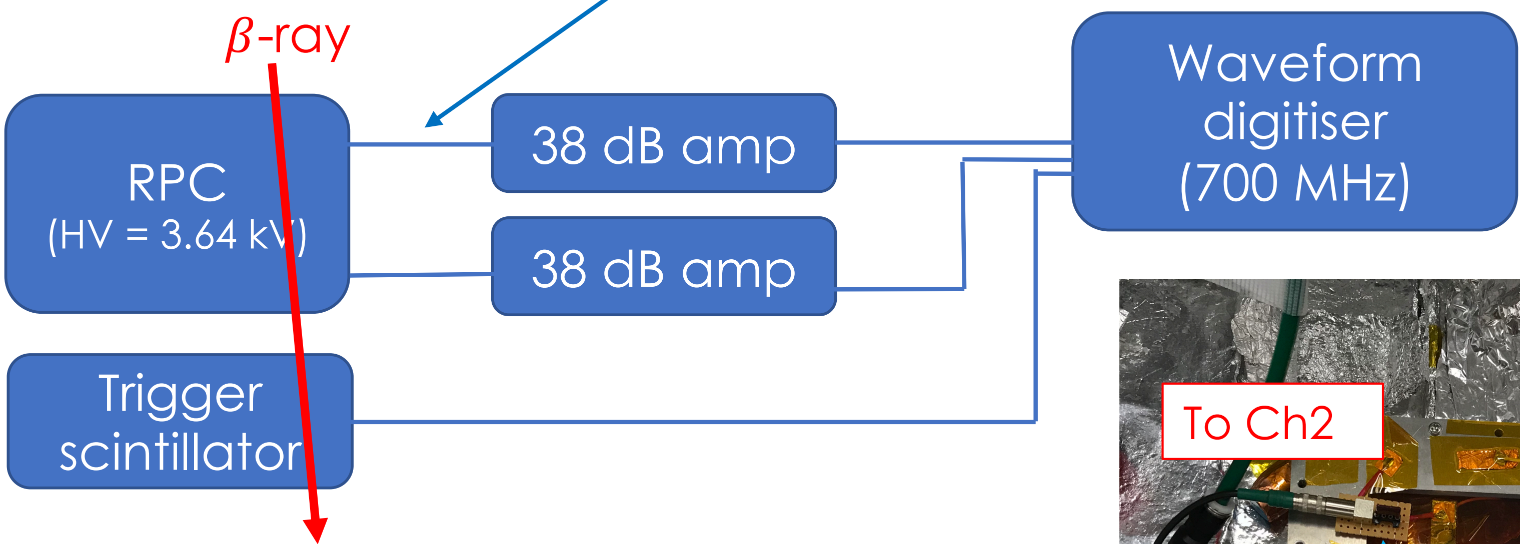
→ In lab test, find resistance which suppresses reflection to reduce deadtime

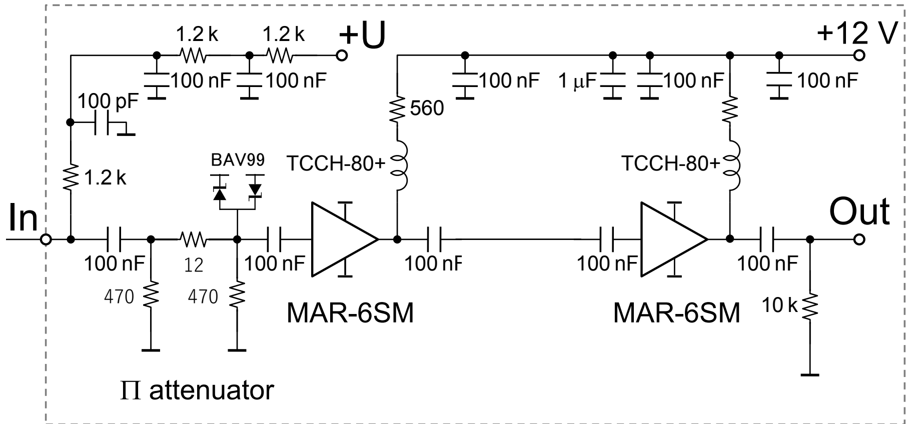
Outline

- Introduction of RPC readout
- Lab test
  - Setups
  - Waveform
  - Effect of resistors on RPC
- Summary & prospects

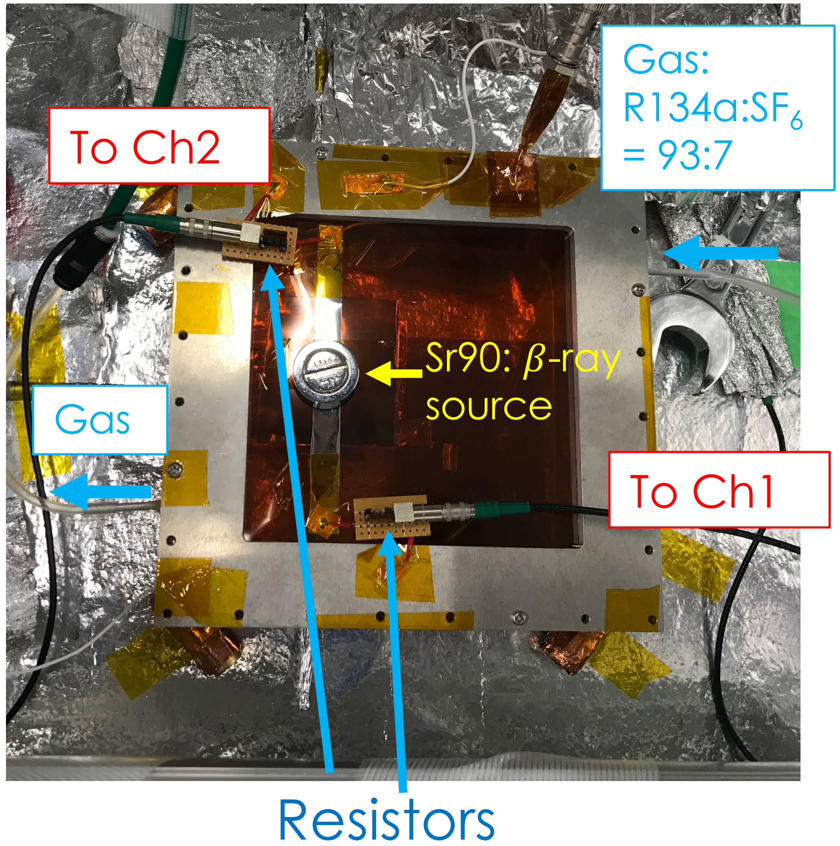
Setups

Resistors:
68 Ω, 82 Ω, 150 Ω



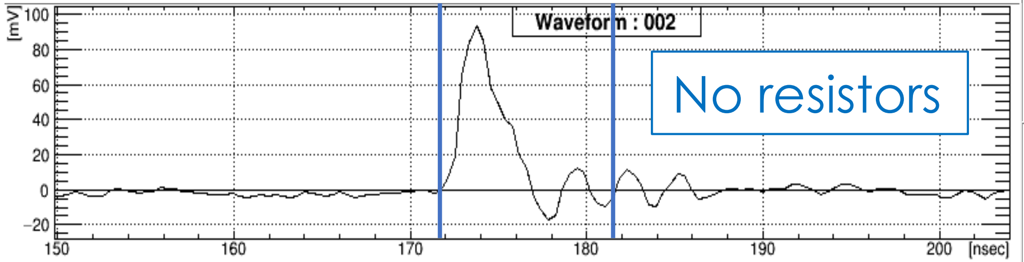


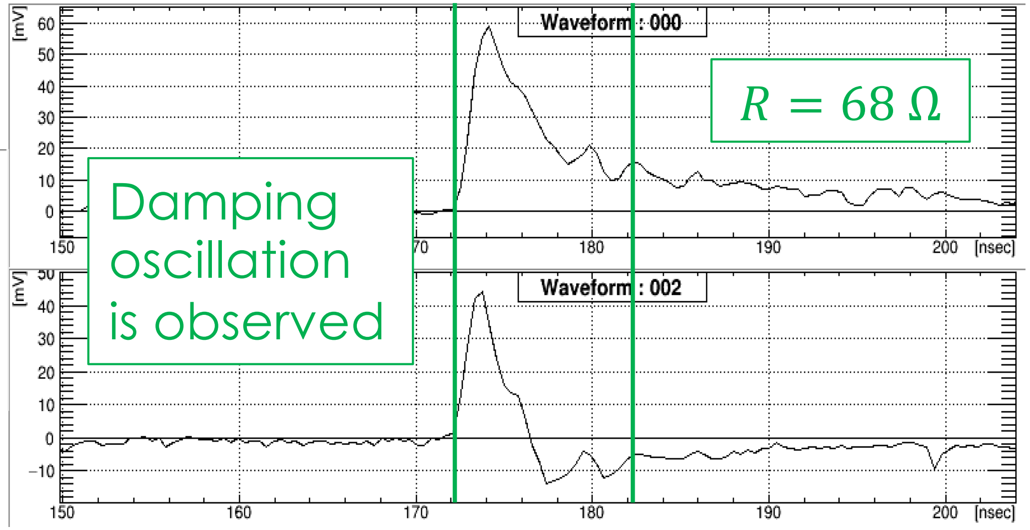
38 dB amplifier

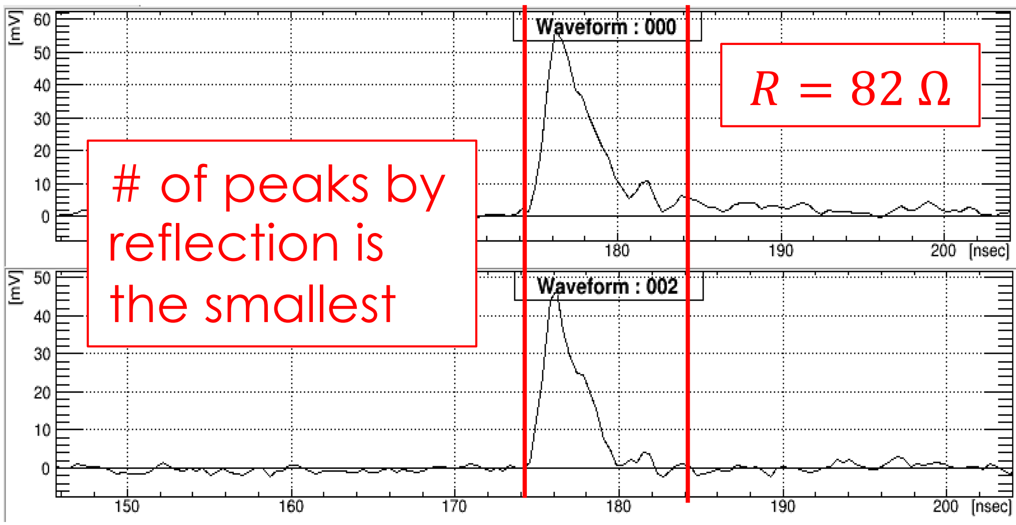


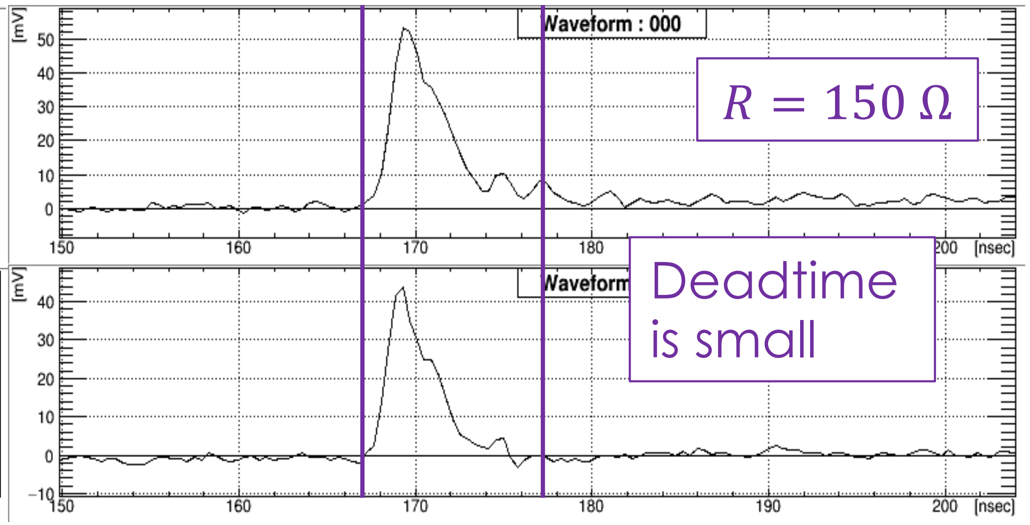
Waveform

Waveform changed.
But signals still reflected.





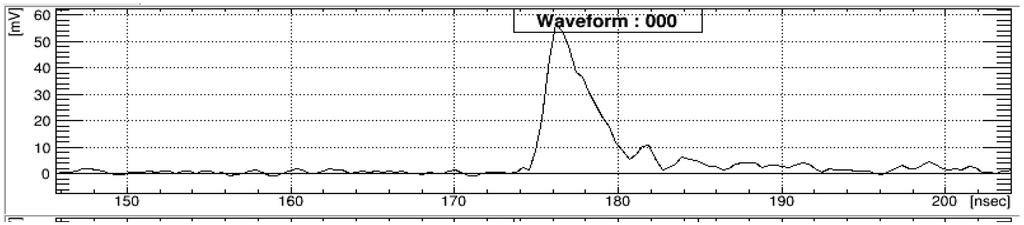


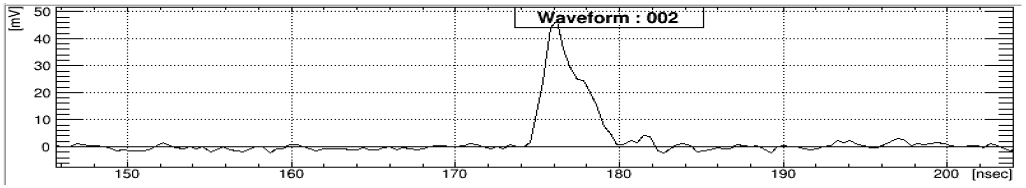


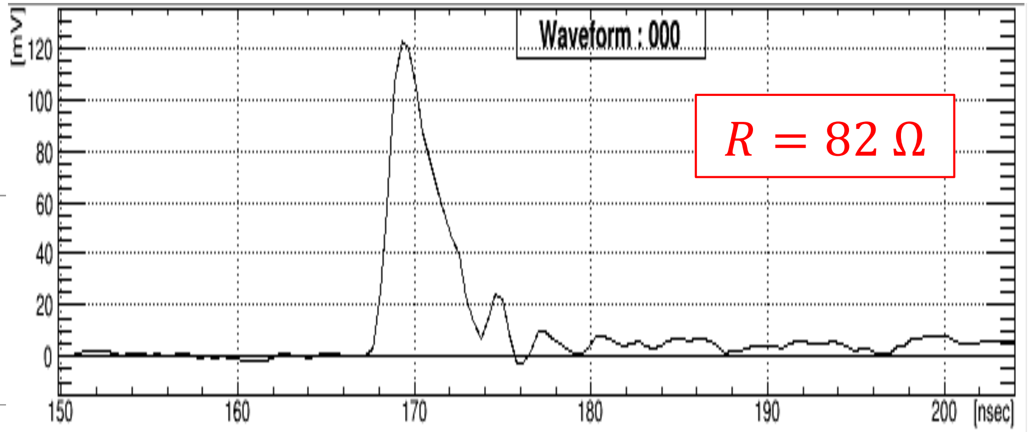
Waveform

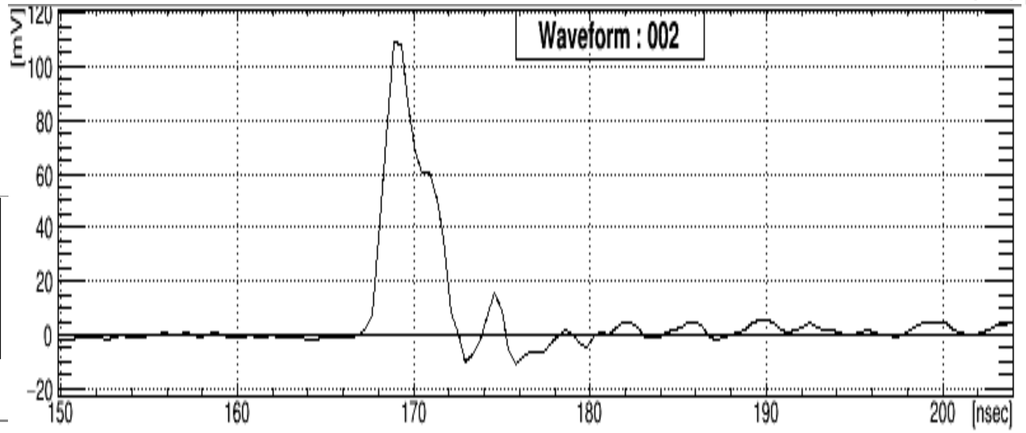
- Reflected height is dependent on signal height

- Reflection can be suppressed by inserting resistors
- Need to optimise resistance

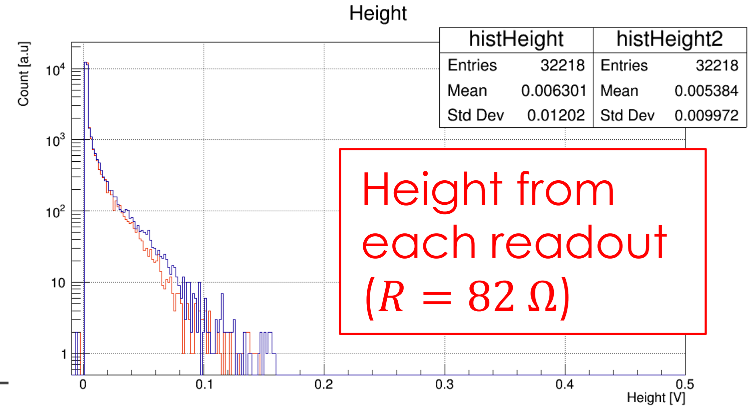






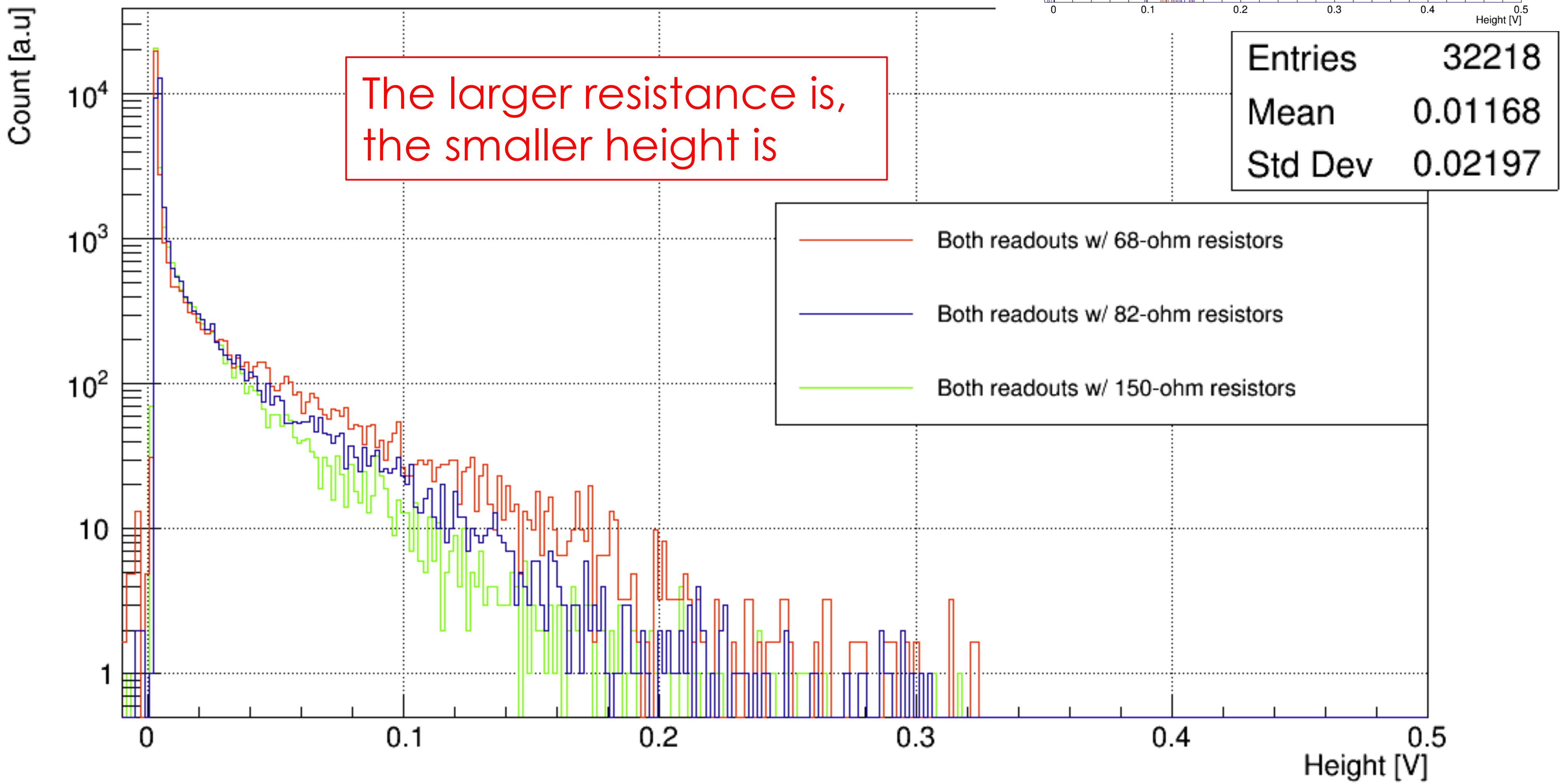


Height distribution



Height from each readout ($R = 82\ \Omega$)

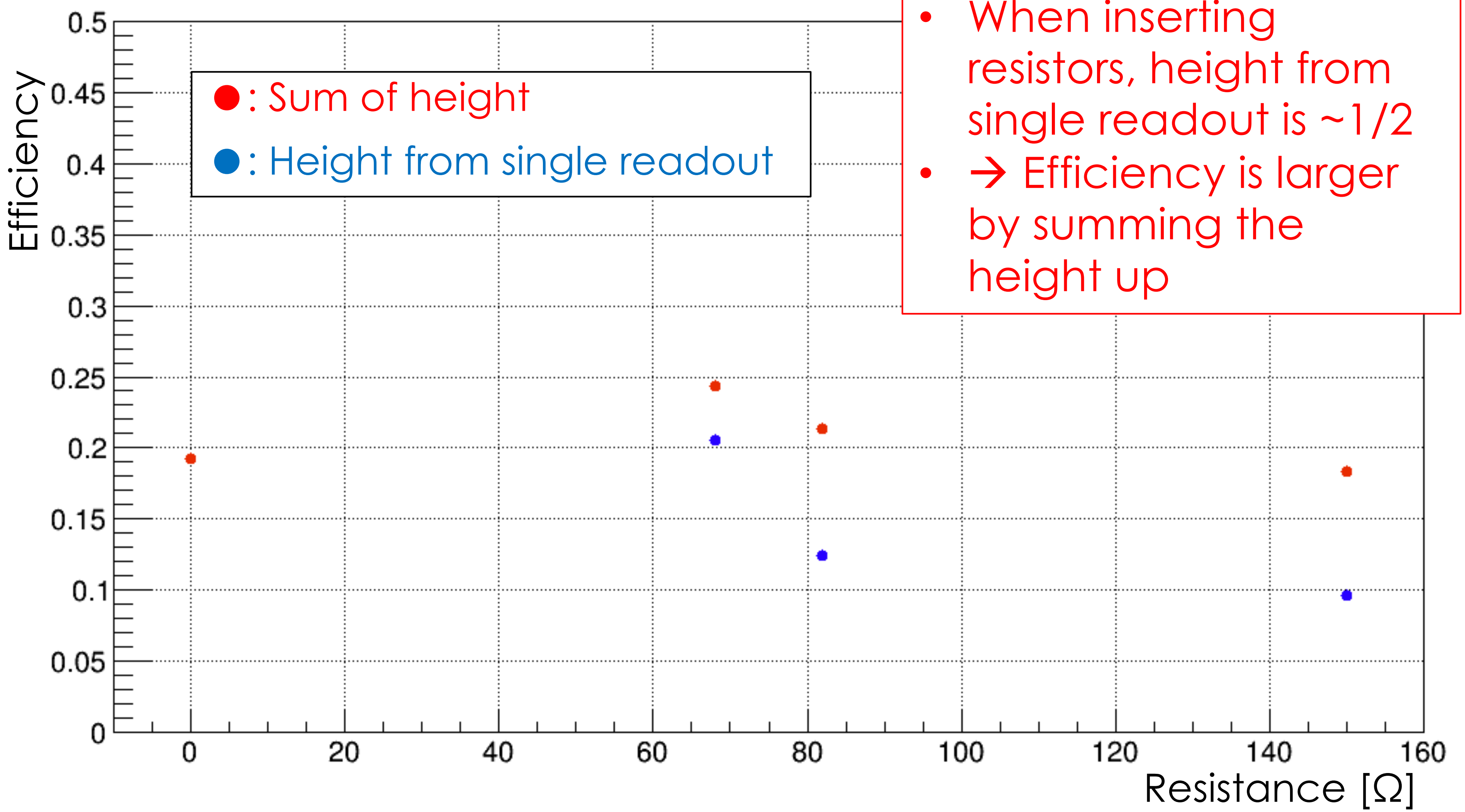
Height sum of both readouts



The larger resistance is, the smaller height is

Efficiency

- When R = 0 Ω, HV = 3.74 kV due to uncertainty of gap thickness
- Threshold = 10 mV



- When inserting resistors, height from single readout is ~1/2
- → Efficiency is larger by summing the height up

Outline

- Introduction of RPC readout
- Lab test
  - Setups
  - Waveform
  - Effect of resistors on RPC
- Summary & prospects

Summary & prospects

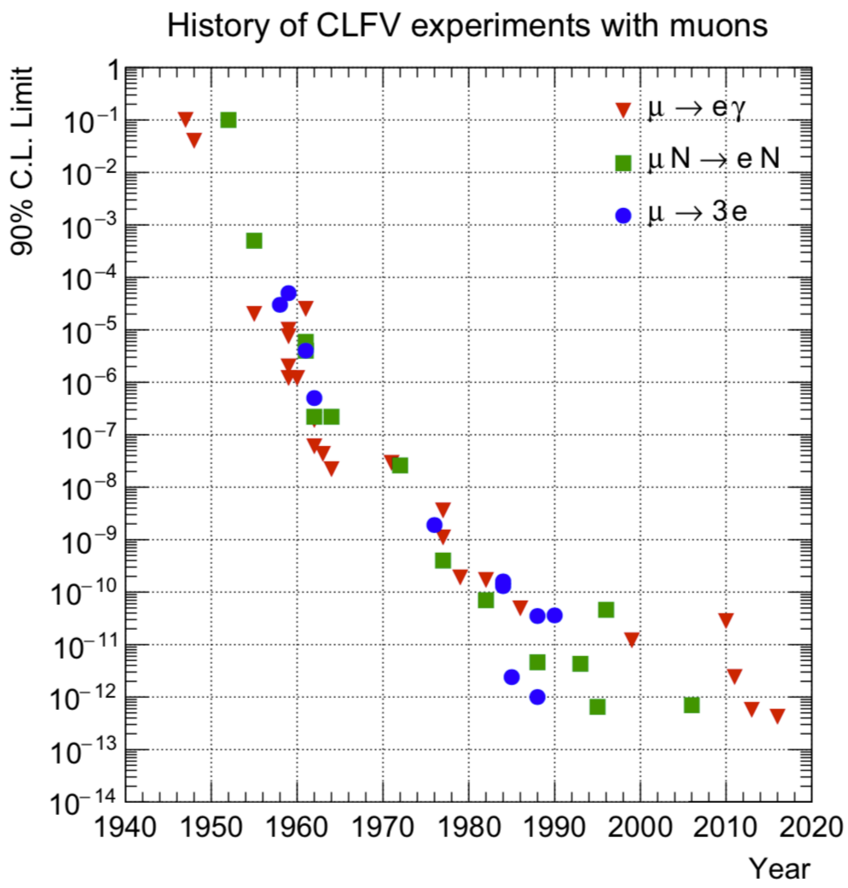
- Summary
  - Readout w/o resistors generated reflection
  - Resistors inserted b/w Al readout strip & LEMO cable can improve impedance matching

- Prospects
  - Compare w/ to w/o resistors in case of both readouts
  - Investigate reflected height quantitatively
  - Optimise readout and resistance

Backups

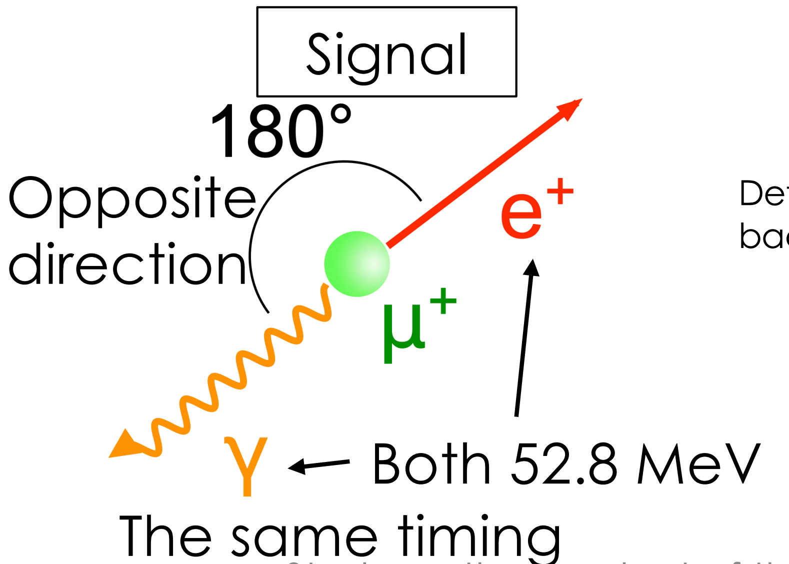
Physics of $\mu^+ \rightarrow e^+\gamma$

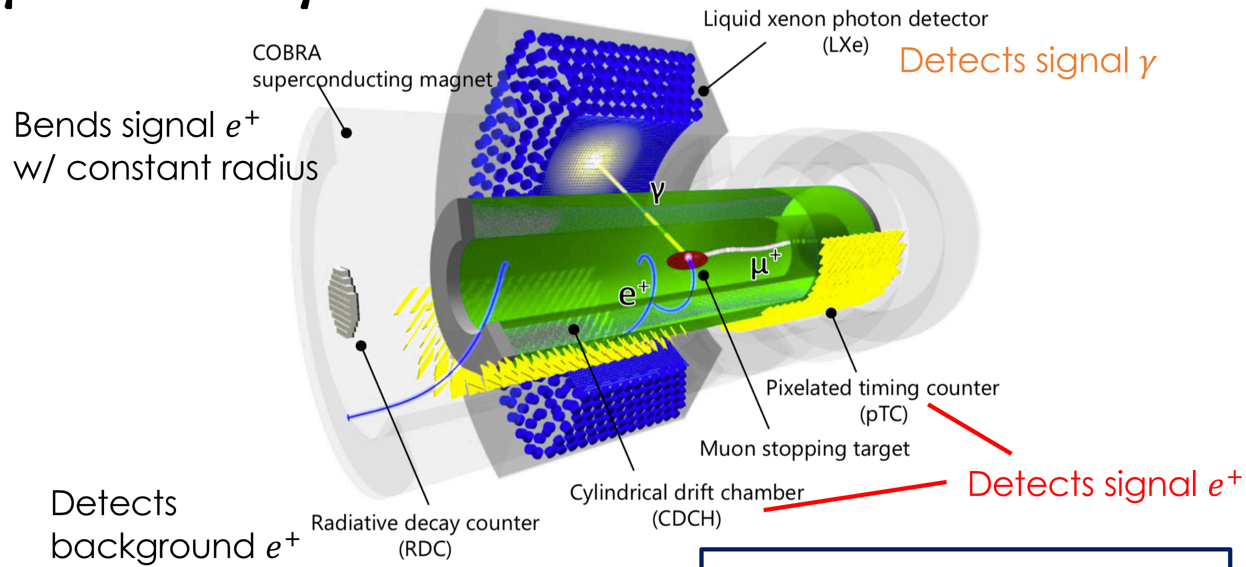
- Charged lepton flavour violation (cLFV) is forbidden in the standard model (SM)
  - In the SM, $\mathcal{B}(\mu \rightarrow e\gamma) < 10^{-50}$
- Some physics models beyond the SM (SUSY-GUT, SUSY-seesaw) say $\mathcal{B}(\mu \rightarrow e\gamma)$ is $10^{-11} - 10^{-14}$
- MEG experiment gave the upper limit of $\mu \rightarrow e\gamma$ 5.3×10^{-13} for the branching ratio
- $\mu \rightarrow e\gamma$ observation strengthen makes models beyond SM



MEG II signal

- MEG II searches for charged lepton flavour violating decay: $\mu^+ \to e^+\gamma$
- MEG II signal is identified by the kinematics

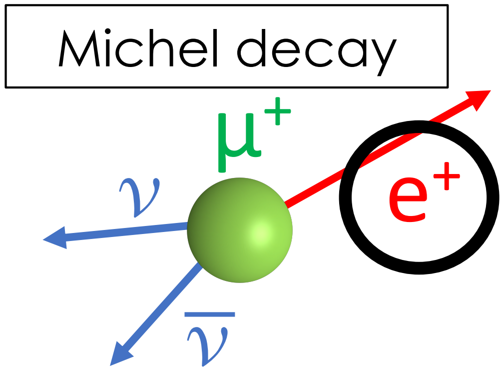


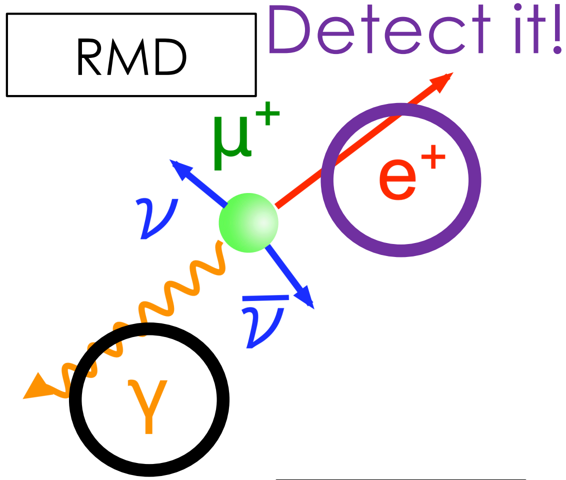


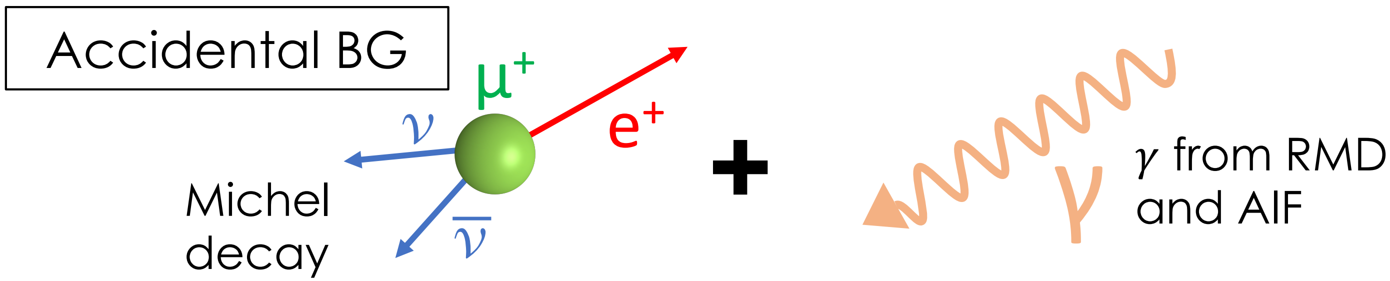
Use the most intense μ beam: DC and beam rate ~ $7{\times}10^7$ /s

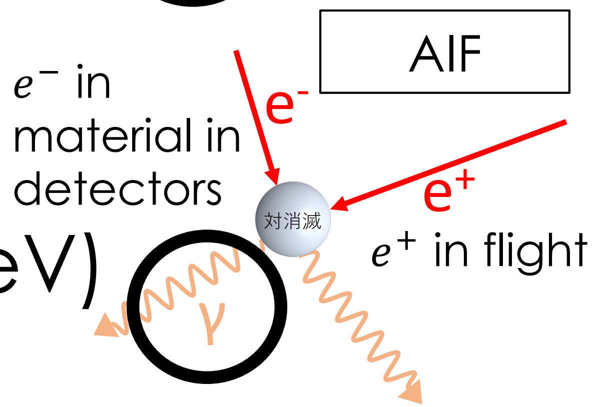
MEG II background

- Sources of e^+, γ of around 52.8 MeV are these 3 reactions:
  - Michel decay
  - Radiative muon decay (RMD)
  - Annihilation in flight (AIF)





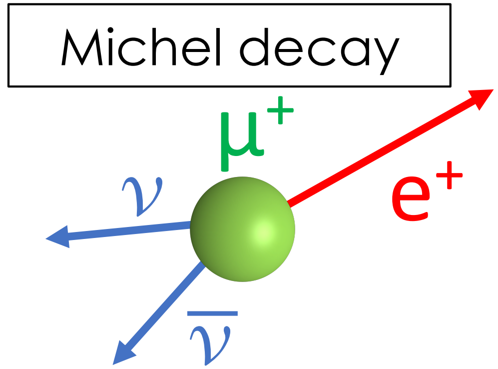


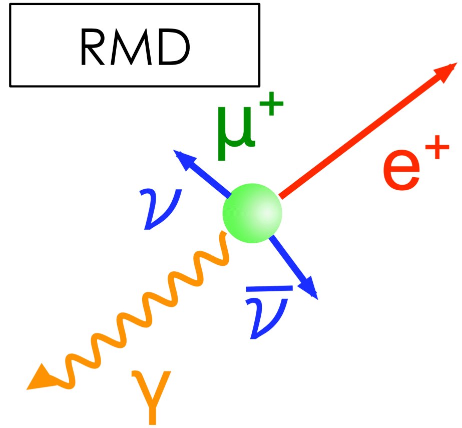


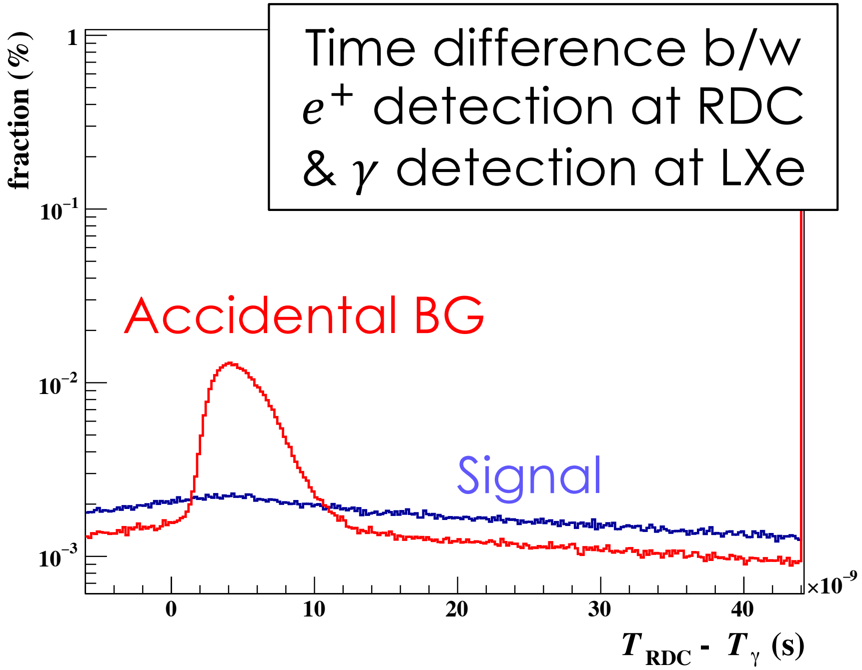
- Detect e^+ with low energy (1-5 MeV) from RMD to identify γ from RMD

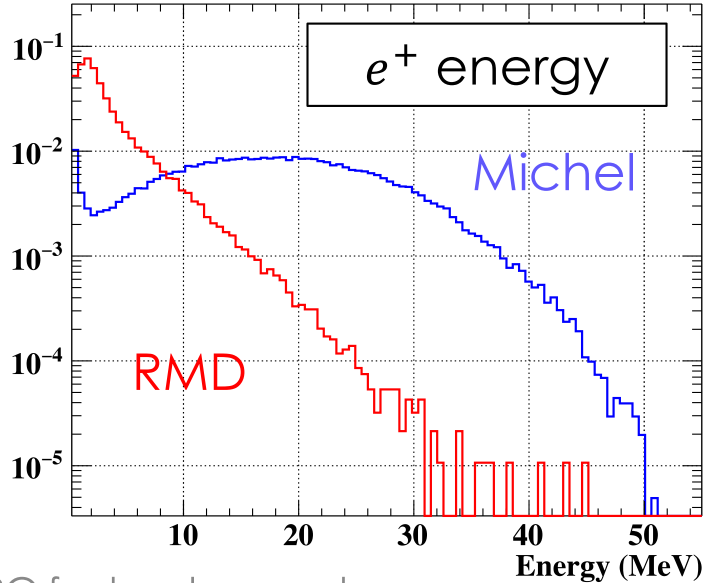
BG properties

- RMD γ is identified from
  - RMD e^+ energy
  - Time correlation b/w e^+ & γ



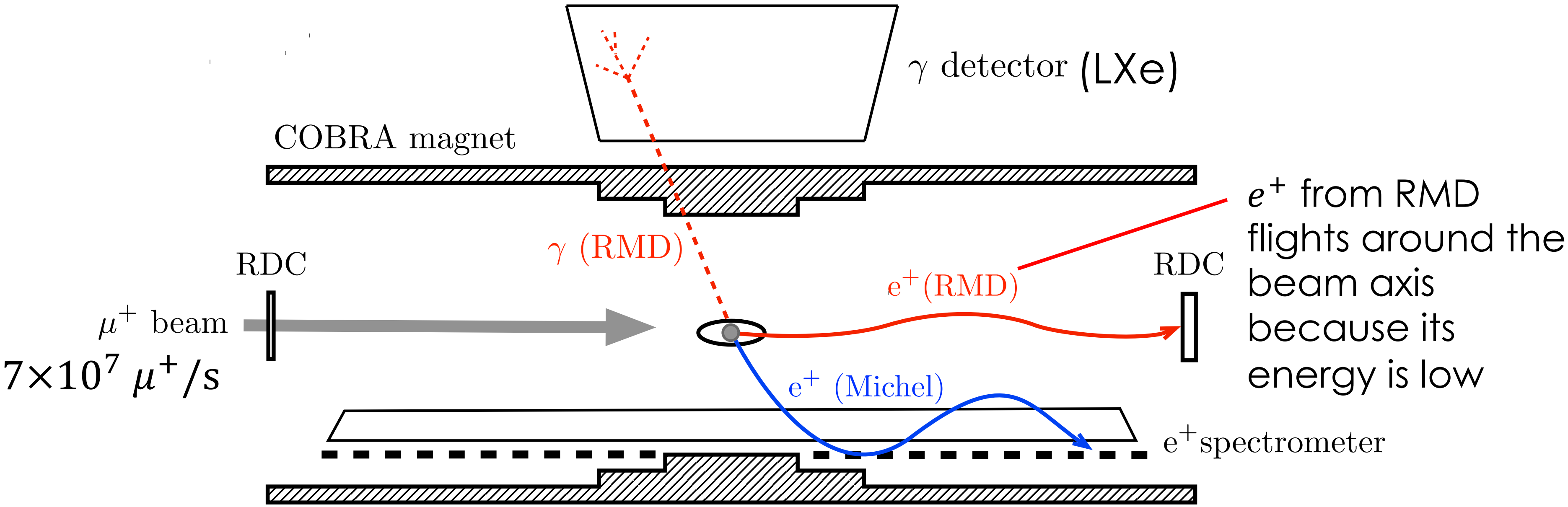






BG identification detectors

- Install radiative decay counters (RDCs) in both upstream and downstream



- High-intensity μ^+ beam passes through the upstream RDC

← Difficulty in developing it

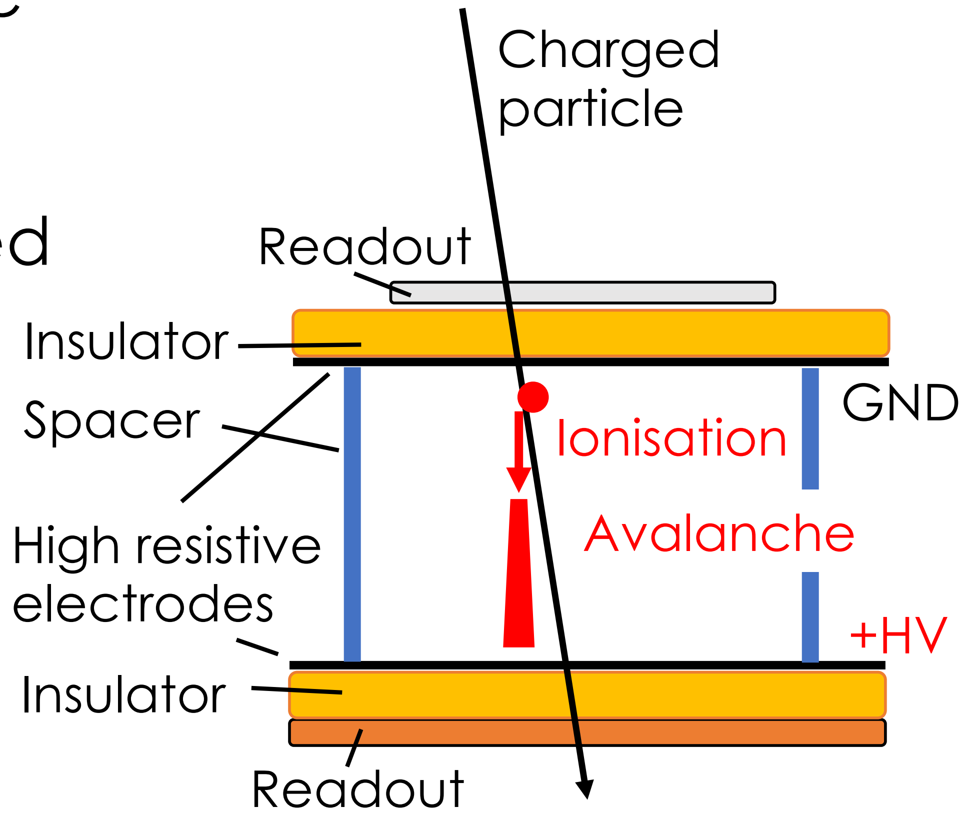
Upstream RDC requirements

1. Material budget: $< 0.1\% \ X_0$
   (← μ^+ beam passes through the detector)
2. 90% efficiency for e^+ with 1-5 MeV
3. 1 ns time resolution
   (← RMD ID with time difference b/w e^+ & γ)
4. Rate capability & radiation hardness
   (← $7\times10^7 \mu^+/s$ with 21 MeV/c & > 60 weeks run)
5. Detector size: 20-cm diameter
   (← 45% acceptance in the one RDC, 90% in total w/ DS)

→ Ultra-low material resistive plate chamber (RPC)

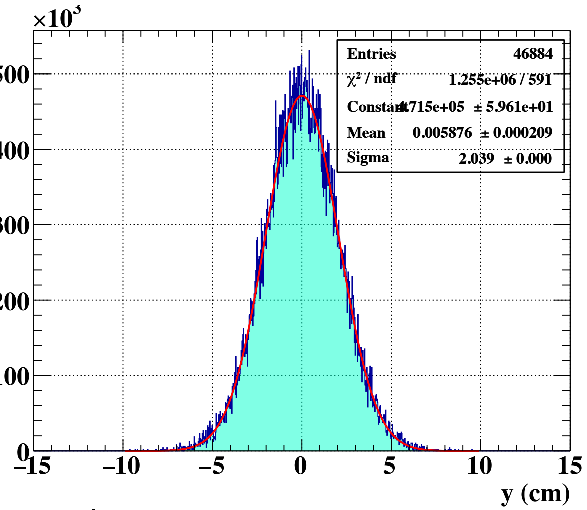
RPC: Resistive Plate Chamber

- RPC is one of gaseous detectors, uses high resistive electrodes placed face to face
- Gas is ionised when charged particles pass through RPC
- Ionised electron is accelerated by high voltage (HV)
- Avalanche occurs by accelerated electrons
- Avalanche signals are induced in readout

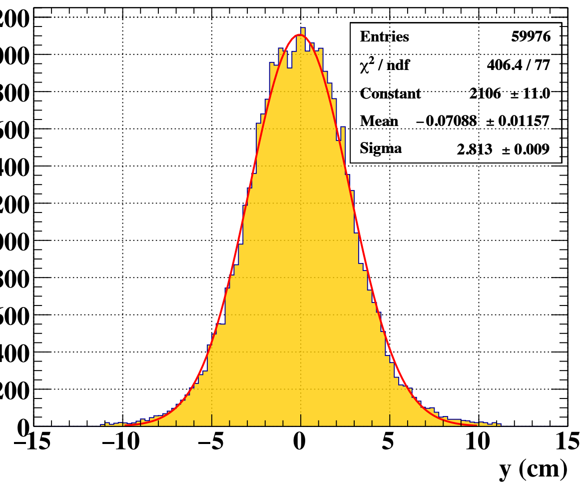


Pileup

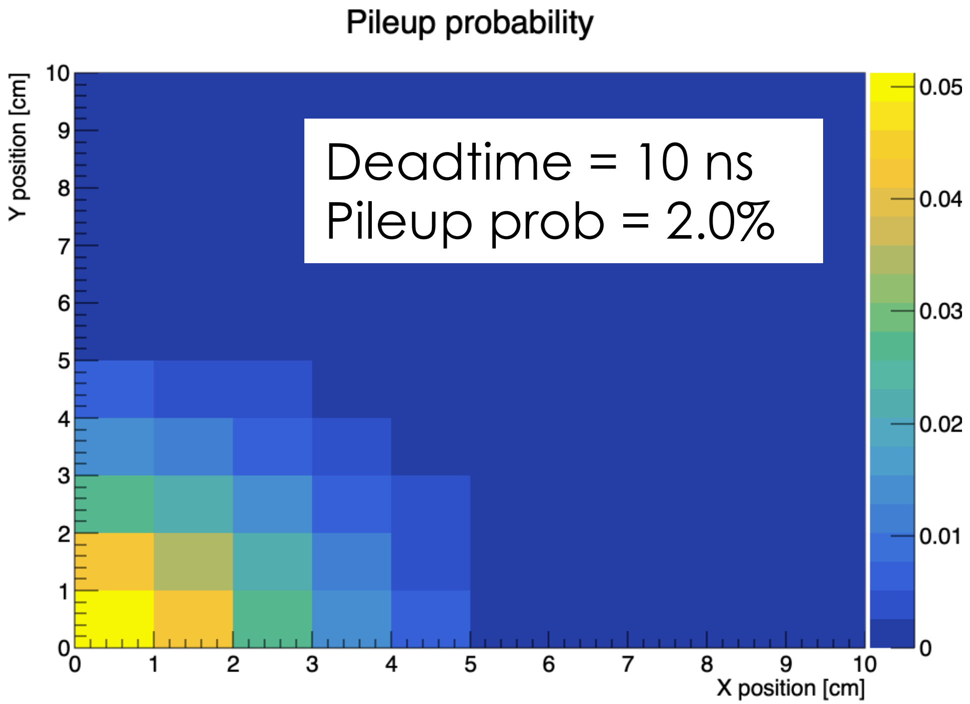
- Calculate pileup probability per readout region in which Al strips overlap

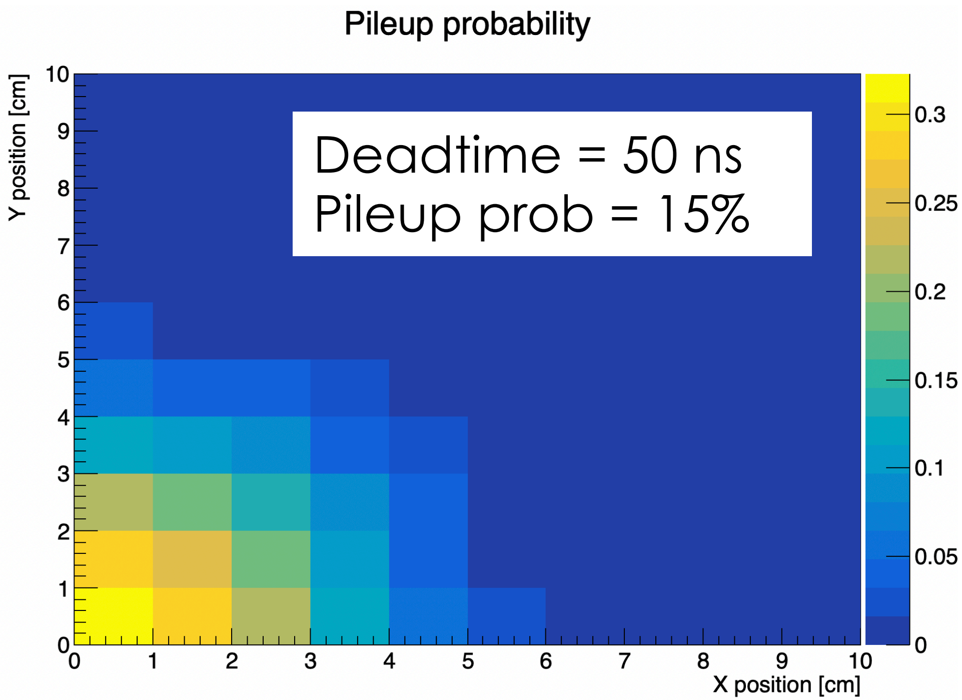


μ^+ beam divergence
$\sigma = 2.0$ cm



RMD e^+ divergence
$\sigma = 2.8$ cm



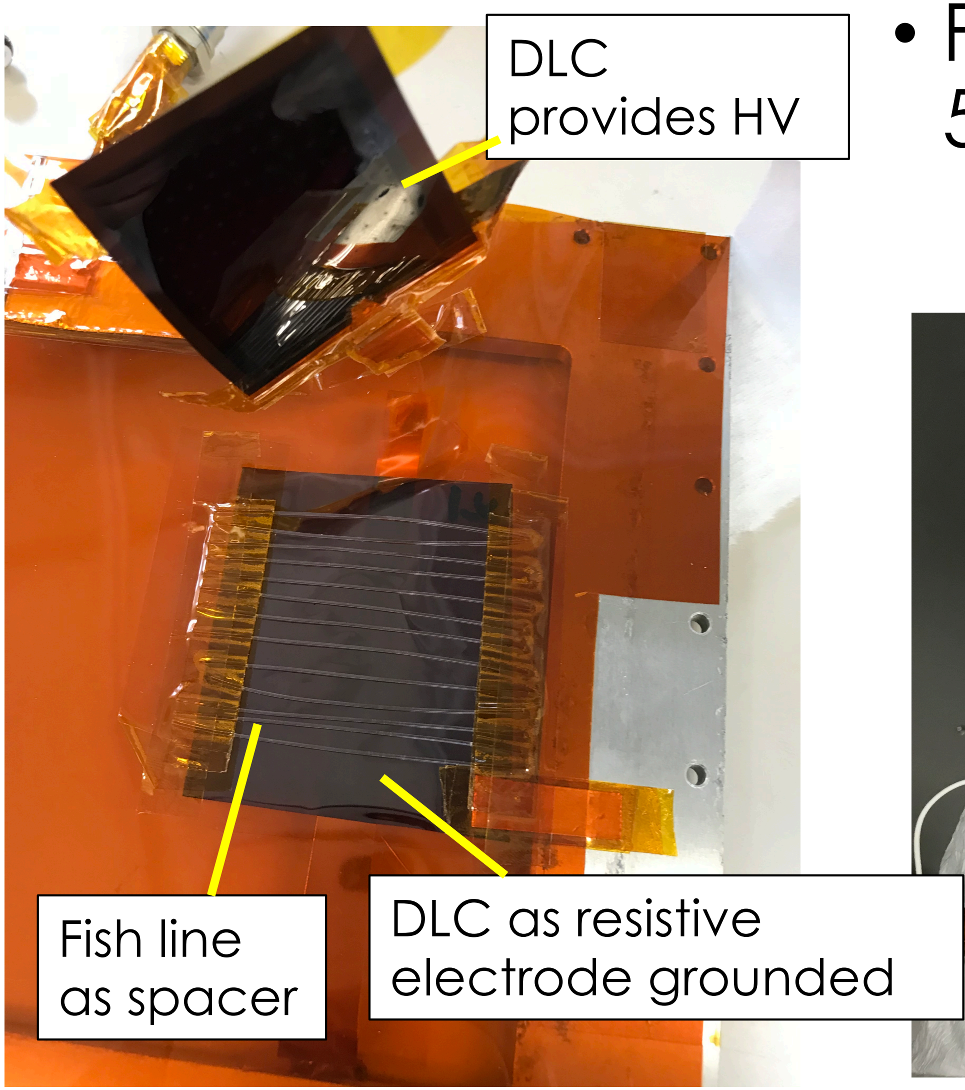


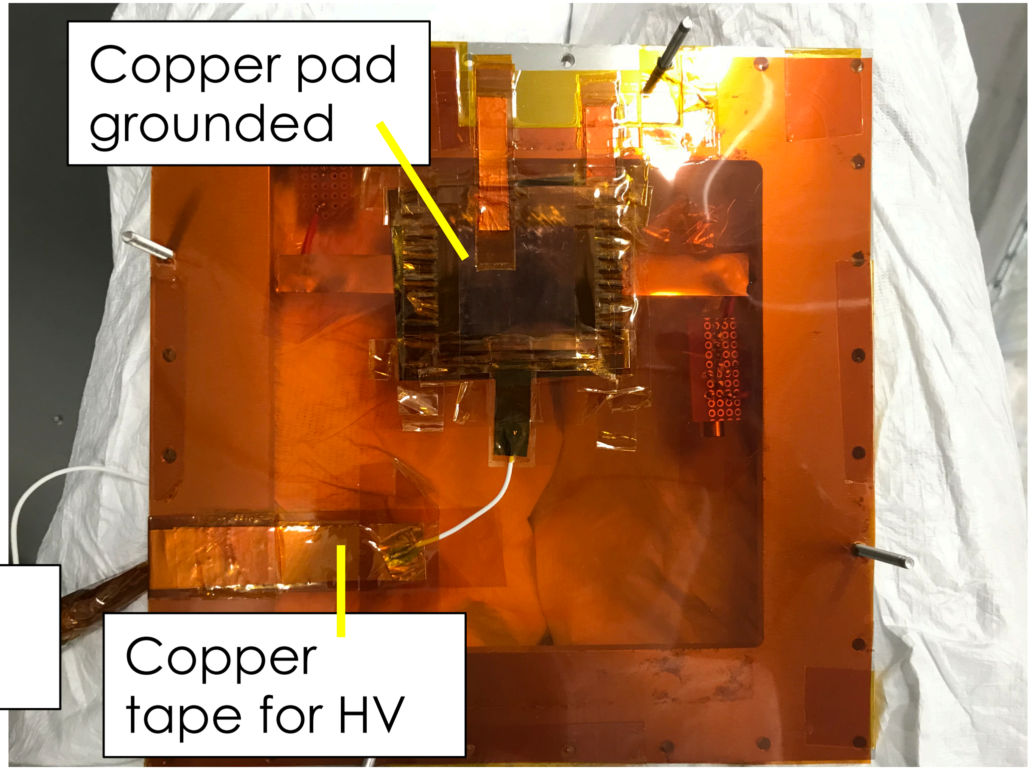
Pileup calculation

- P_i: pileup probability per readout segmented region
- ρ_i: probability to detect RMD e^+ in the segmented region (= 2.8 cm)
- Total pileup probability is given by
- $\sum_{strips=256} P_i \, \rho_i$
- Probability of time difference t b/w continuous μ^+:
- $p(t) = \frac{1}{\tau} \exp\left(-\frac{t}{\tau}\right)$, where $\frac{1}{\tau}$ is μ^+ rate in region i
- Probability of pileup of μ^+ beam & RMD e^+ in region i:
- $P_i = 1 - \exp\left(-\frac{t_{dead}}{\tau}\right)$, where t_{dead} is deadtime when we cannot distinguish μ^+ & RMD e^+

Prototype RPC

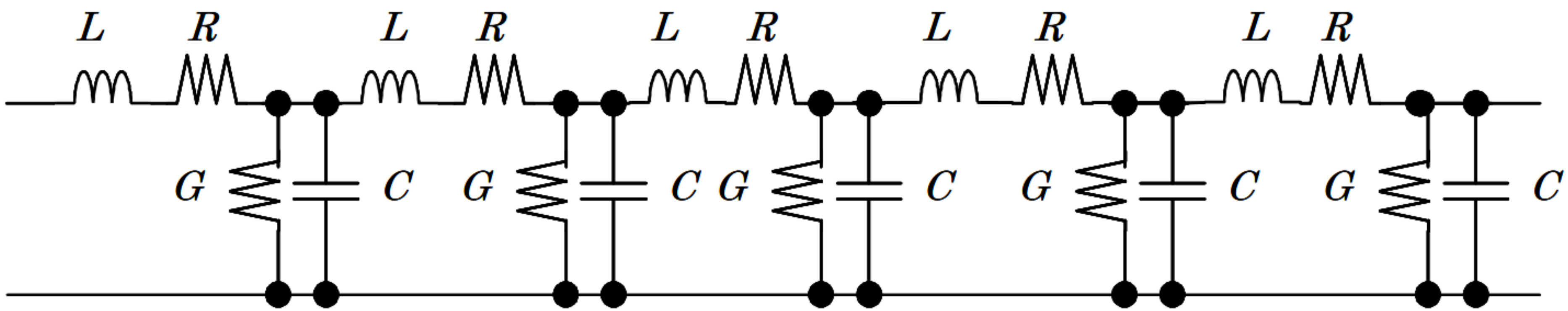
- Fish line (#10) gives 520-um gas thickness





Transmission line

- Assume Al strip is a transmission line with loss
- Conductance G is zero



R :単位長あたりの抵抗
L :単位長あたりのインダクタンス
G :単位長あたりのアドミッタンス
C:単位長あたりのキャパシタンス
（単位長は扱う波長に対して、充分、小さい値で考える）

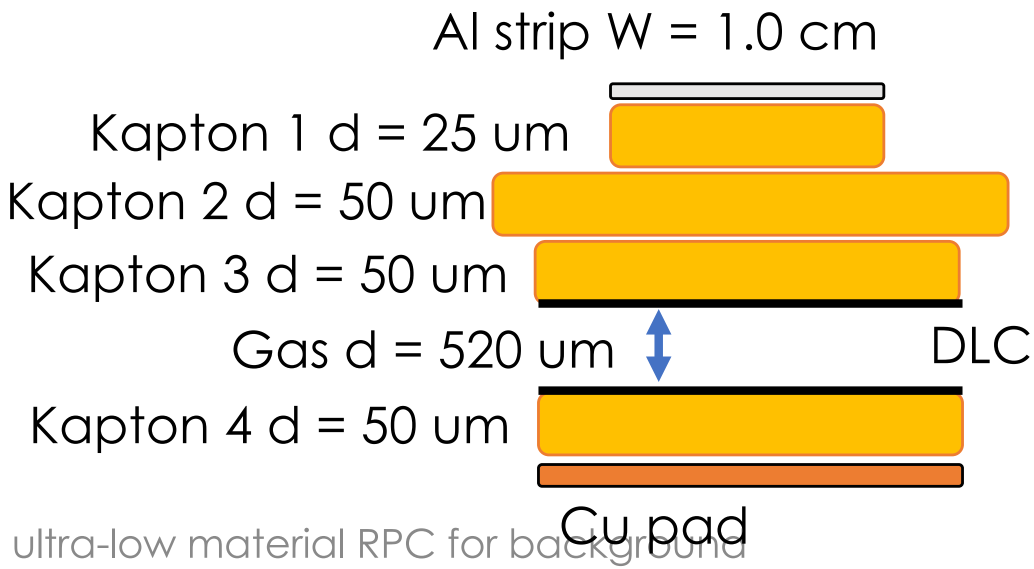
Resistance per length

- Surface resistivity $R_S = 1.1\ \Omega/\mathrm{sq}$
- → $R = \frac{R_S}{W} = 110\ \Omega/\mathrm{m}$
- where W is width of Al strip, that is 1 cm

Property		Units	Aluminum Metallized Polyimide Film Typical Value	
			LR-PI 100AM	LR-PI 200AM
Backing Thickness		μm	25	50
Aluminum Thickness		μm	0.2-0.5	0.2-0.5
Tensile Strength		MPa	≥140	≥130
Elongation		%	≥45	≥45
Shrinkage, at 150℃		%	0.20	0.20
Surface Resistivity	The side of PI Film	Ω	$\geq 1\text{X}10^{12}$	$\geq 1\text{X}10^{12}$
	The side of Aluminum	Ω	$<10^{3}$	$<10^{3}$

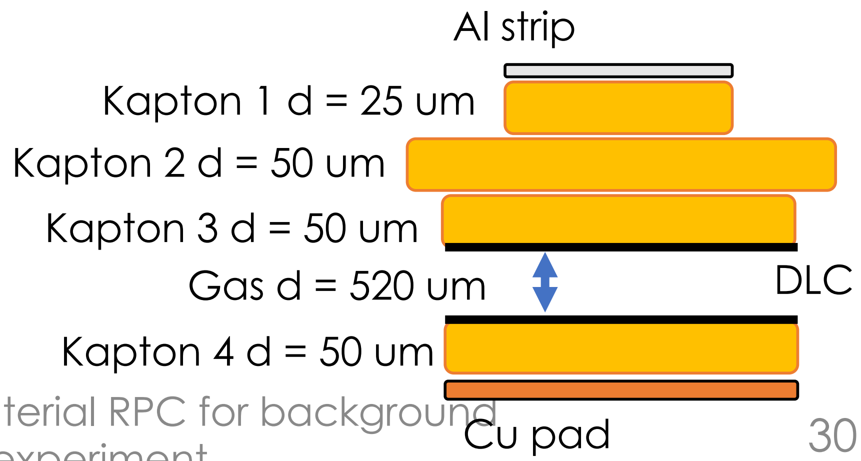
Capacitance per length

- Think of geometry like this figure
- Ignore DLC plate because DLCs are sputtered on kaptons
- Kapton's relative permittivity $\varepsilon_r = 3.3$



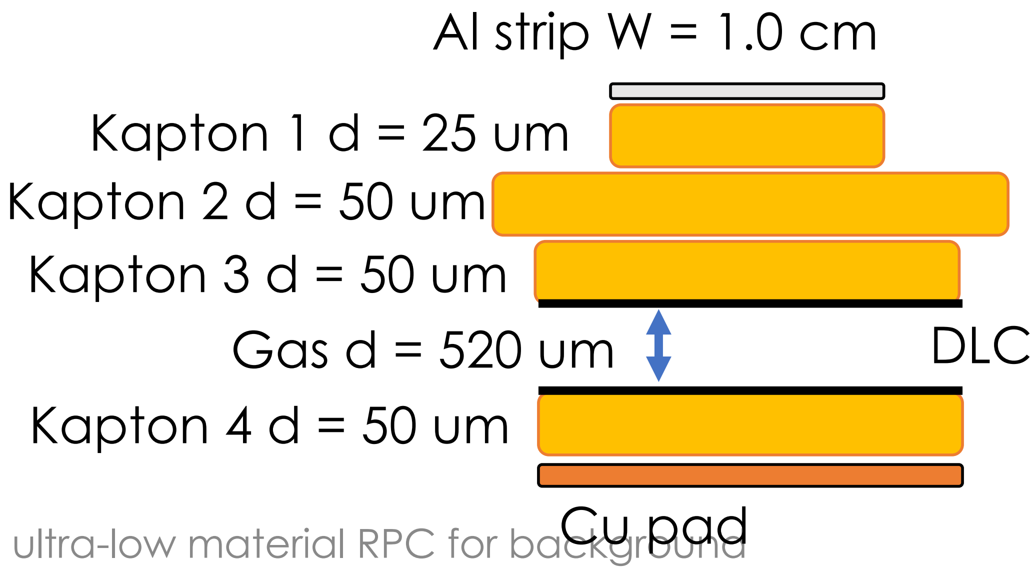
Capacitance per length

- Give strip charge per length q
- From Gauss's raw, electric field is
- $q = \varepsilon_0 \varepsilon_r E W \rightarrow E = \dfrac{q}{\varepsilon_0 \varepsilon_r W}$
- From the field, potential diff b/w Al strip and Cu pad is
- $V = \int_0^d \dfrac{q}{\varepsilon_0 \varepsilon_r W} dx = \dfrac{qd}{\varepsilon_0 \varepsilon_r W}$
- From $V = \dfrac{q}{C}$,
- $C_i = \dfrac{\varepsilon_0 \varepsilon_r W}{d}$



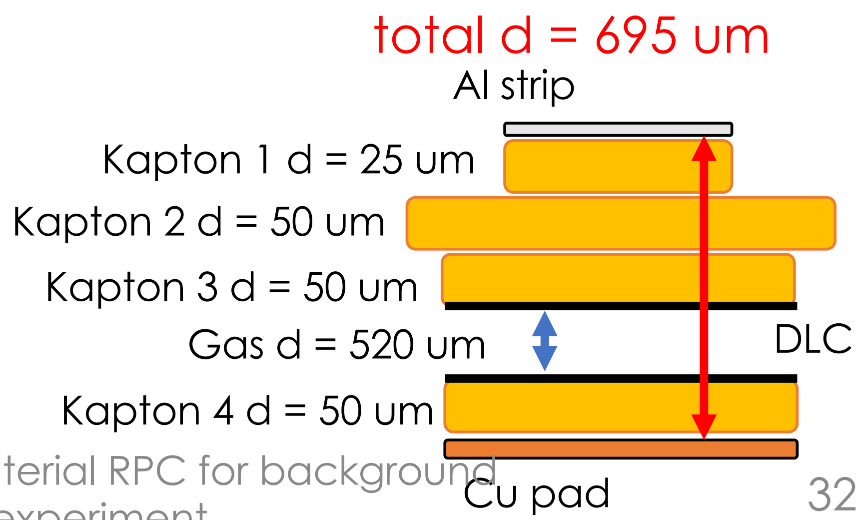
Capacitance per length

- From $C_i = \frac{\varepsilon_0 \varepsilon_r W}{d}$, where C_i is capacitance per length in layer i
- Total capacitance $C = 155\ \mathrm{pF/m}$



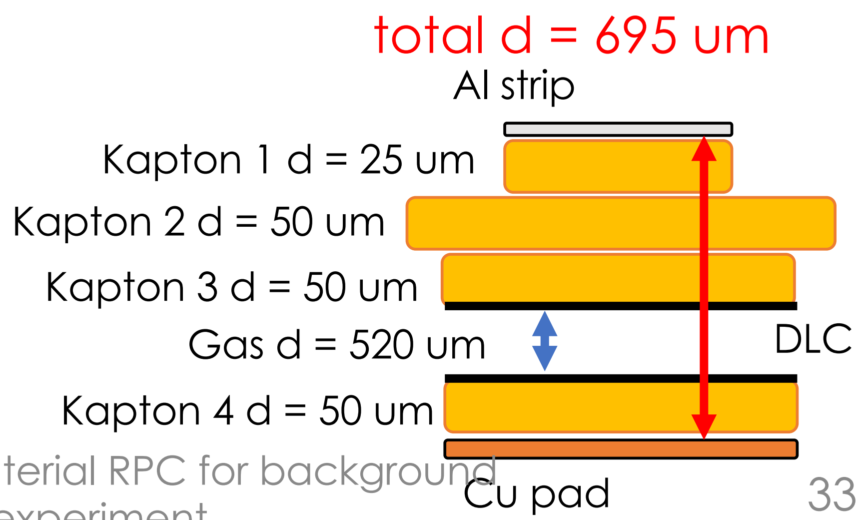
Inductance per length

- Think of geometry like this figure
- Assume current J flows only in Al strip (No current in Cu pad)
- From Ampere's raw, magnetic field is
- $2W\mu B = J \rightarrow B = \frac{\mu J}{2W}$
- Permeability $\mu = \mu_0$



Inductance per length

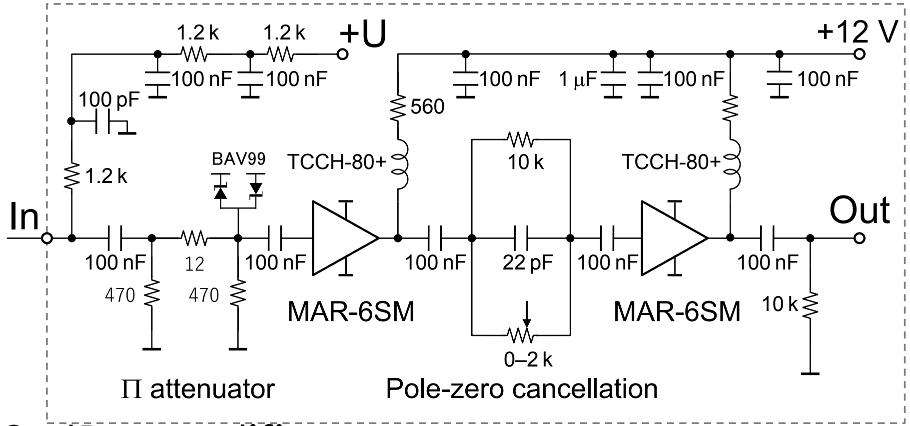
- Magnetic flux Φ is
- $\Phi = \int \frac{\mu_0 J}{2W} dS = \frac{\mu_0 J}{2W} d$
- From Φ, calculate V, L
- $V = -\frac{d\Phi}{dt} = -\frac{\mu_0 d}{2W}\frac{dJ}{dt} = -L\frac{dJ}{dt} \rightarrow L = \frac{\mu_0 d}{2W}$ H/m
- $L = 44$ nH/m



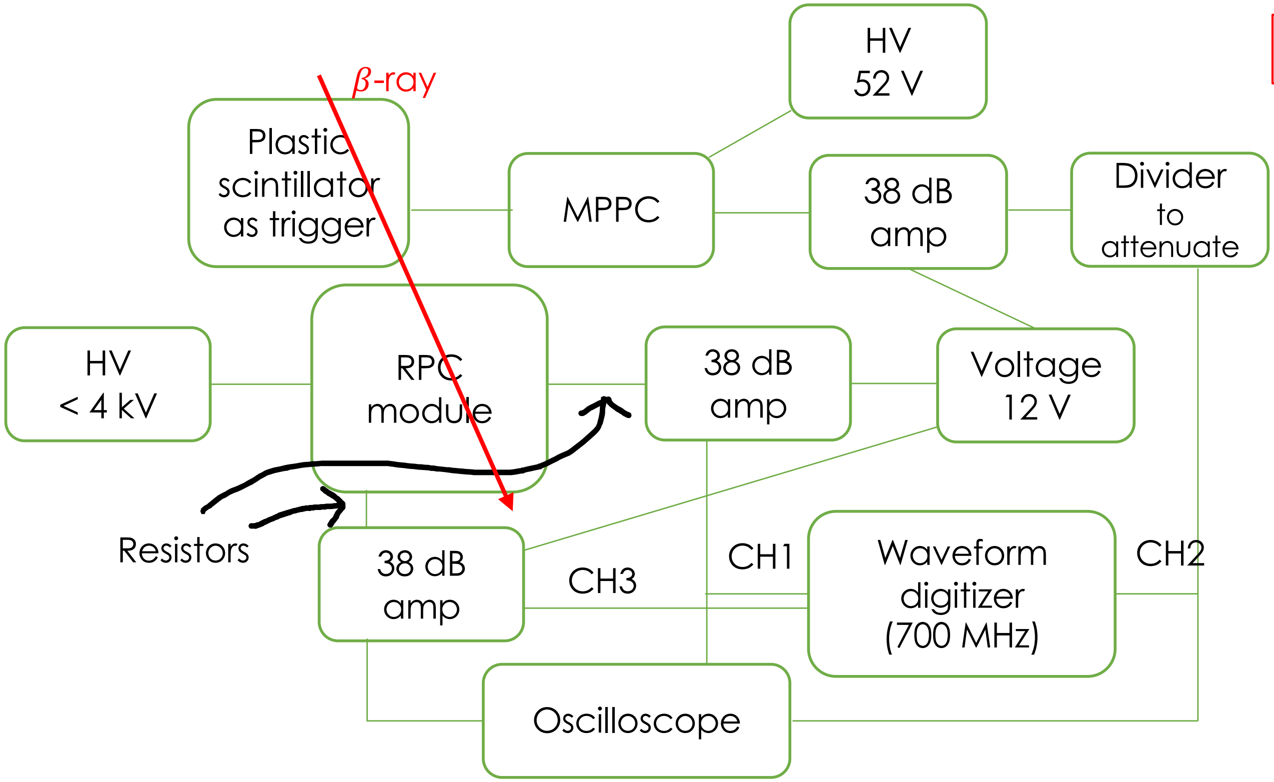
Characteristic impedance

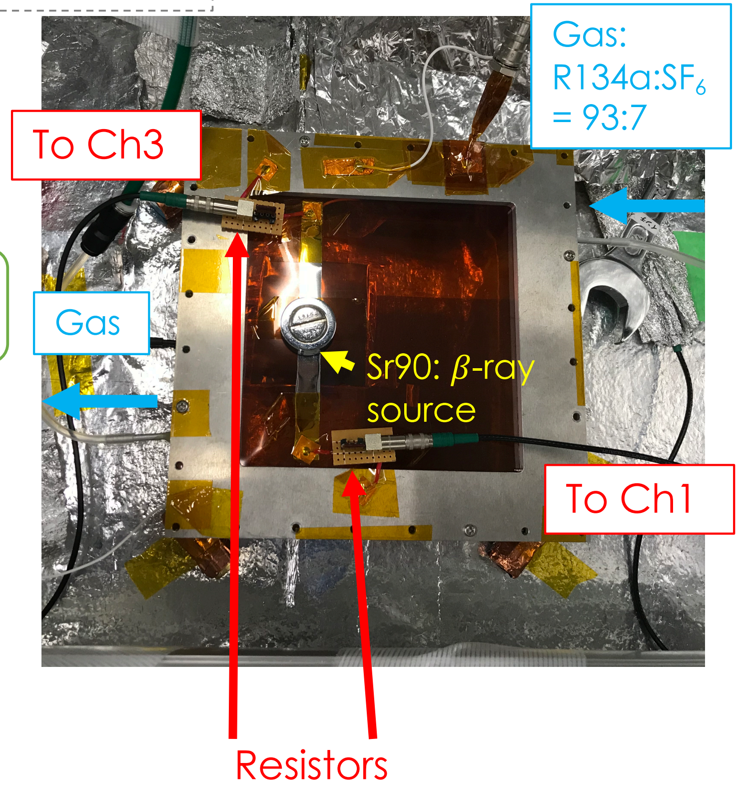
- Need to consider resistance R because we cannot ignore loss
- Characteristic impedance is
- $|Z_0| = \sqrt{\frac{R^2+(\omega L)^2}{(\omega C)^2}}$
- where ω is angular frequency
- Assume signals are triangle waves whose width is 5 ns
- In this case, assume $\omega = 628\ \mathrm{rad/\mu s}$
- → $|Z_0| = \sqrt{\frac{R^2+(\omega L)^2}{(\omega C)^2}} = 17\ \Omega$
- But I estimate $Z_0 > 50\ \Omega$ from observation of reflection

Setups



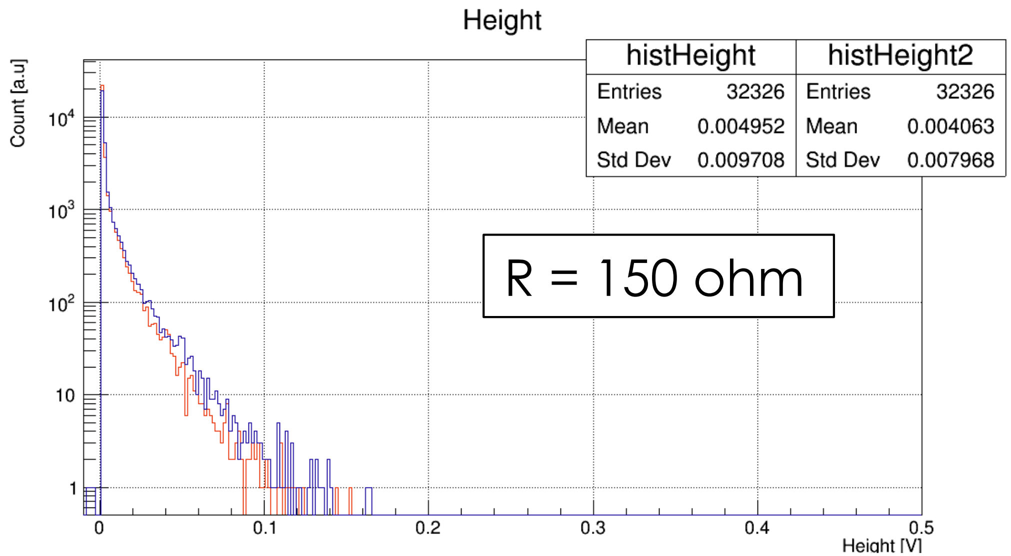
38 dB amplifier

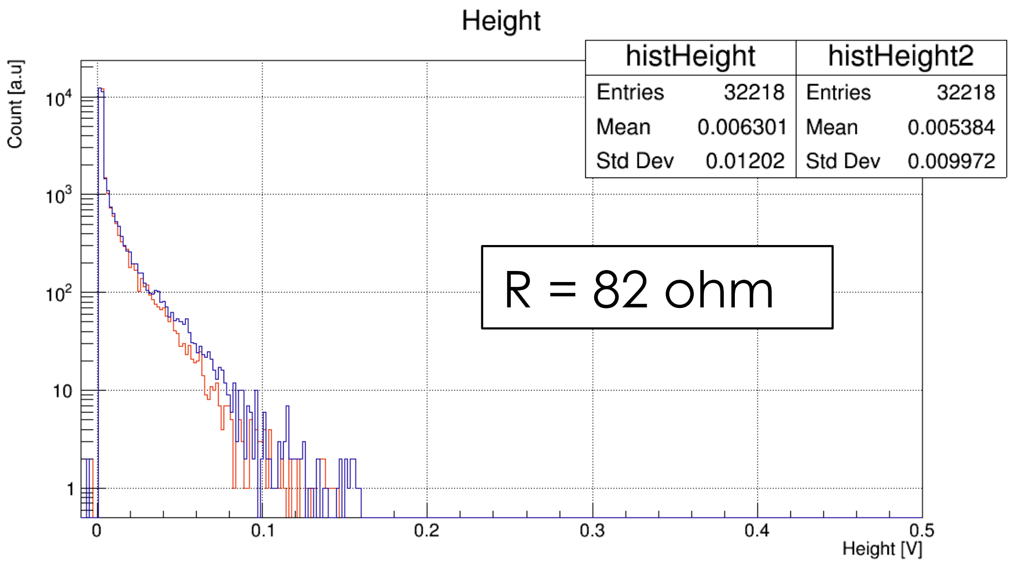


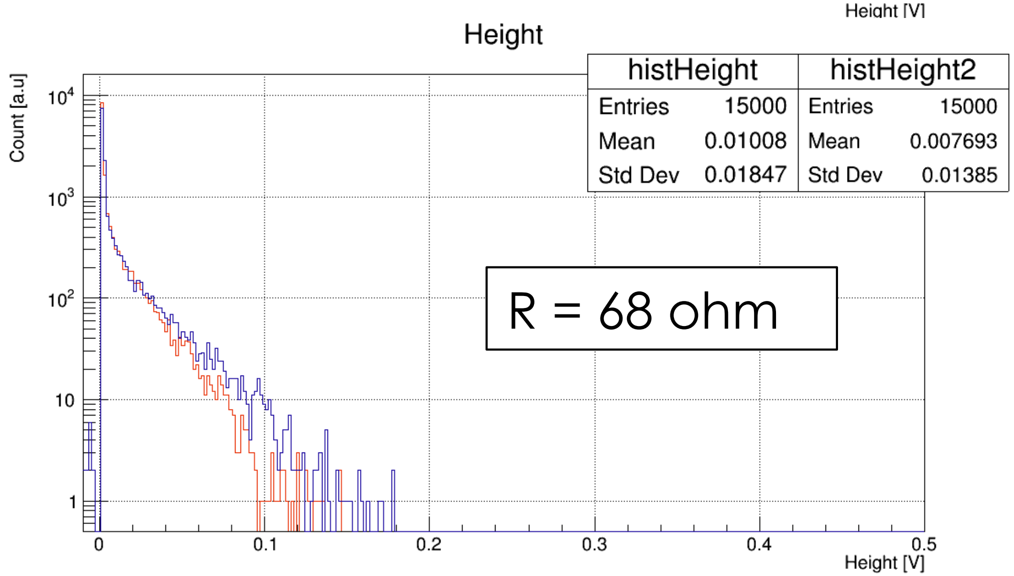


RPC performance w/ resistors

- Each histogram expresses voltage height induced in each side
- Height is dependent on resistance because voltage drop occurs at resistors







RPC performance w/ resistors

- These histograms express the sum of voltage at both sides of Al strip
- Height sum is dependent on resistance because voltage drop occurs at resistors as well as height from each side