MEG II実験感度向上へ向けた高レート耐性RPCでのパイルアップ抑制

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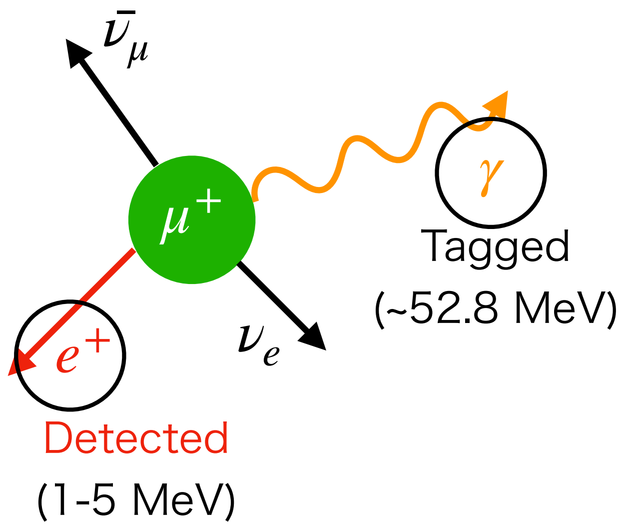
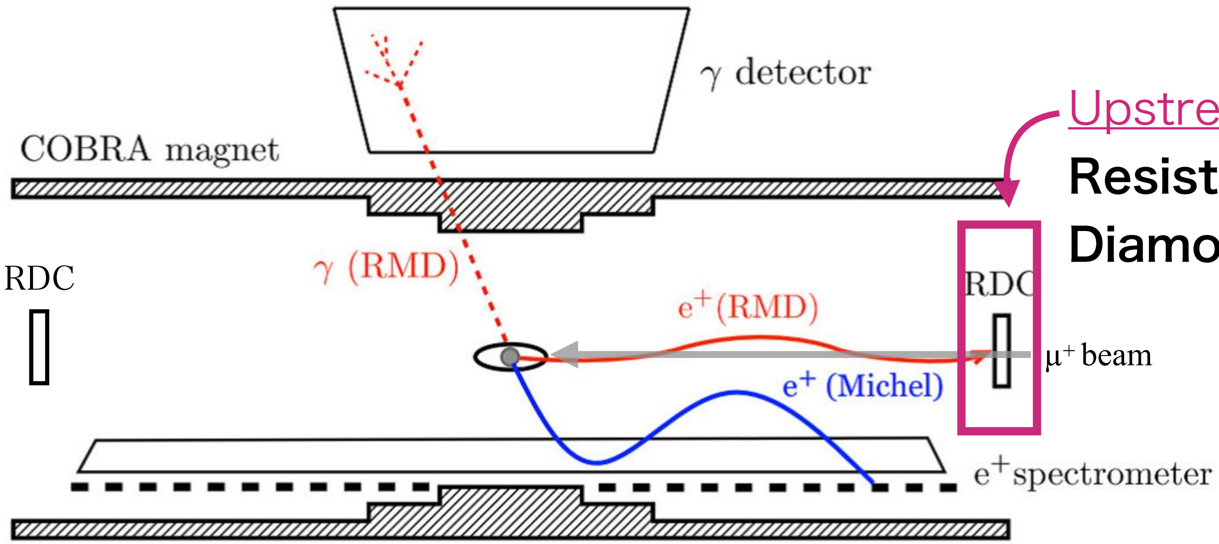
MEG II and RDC

- MEG II searches for $\mu \to e\gamma$ decay
- RDCs are detectors to tag BG-γ from Radiative Muon Decay (RMD)





Upstream RDC candidate:
Resistive Plate Chamber (RPC) with Diamond-Like Carbon (DLC) electrodes

Outline

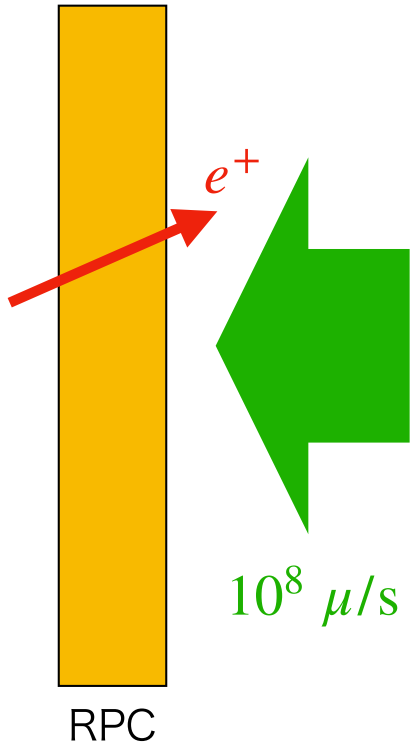
- Introduction
- Pileup suppression
  - Strategies for pileup suppression
  - Pileup probability calculation
  - Optimise strip configuration
  - Ringing suppression
- Summary

Detect e^+ in high-intensity μ^+

- The RPC detects e^+ in MEG II μ beam at 1×10^8 /s
- The RPC faces problems
  - Performance degradation ← referred in previous talk
  - **Pileup of e^+ and beam μ^+** ← this talk
- Goal of pileup suppression:
  - **1% level of RMD e^+ inefficiency**
    - Required efficiency of e^+ = 90%

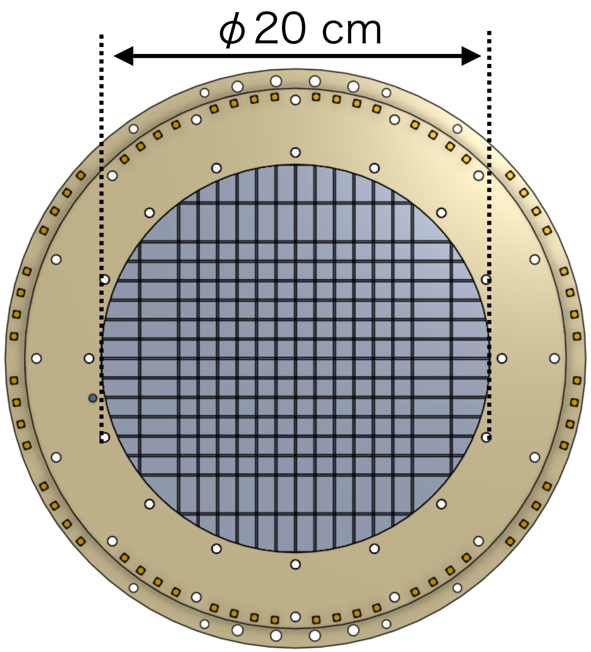
    $\updownarrow$

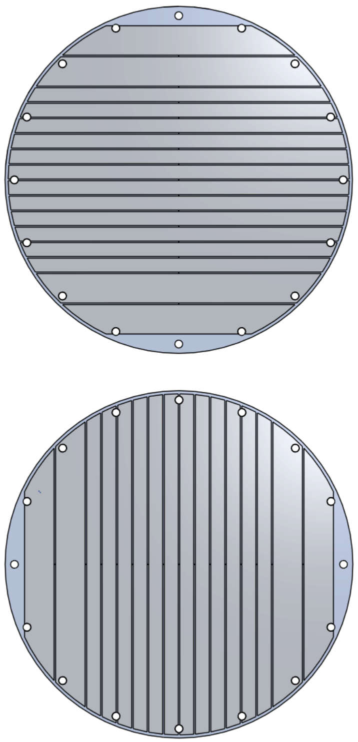
    - Inefficiency by inactive region = 4.1%
    - Expected detection efficiency ~ 94%



Strategies for pileup suppression

1 - Segment readout region

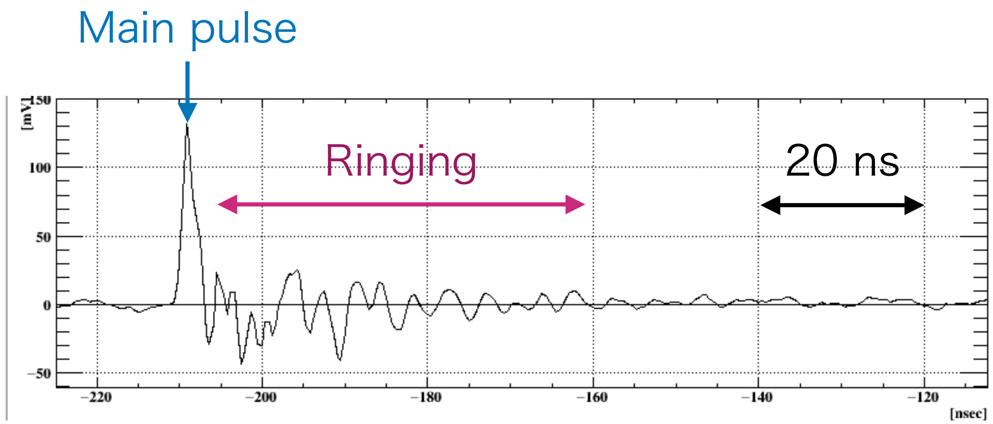




The configuration must be optimised

- Virtual cells by X, Y strips
  - X strips at the top side
  - Y strips at the bottom side

2 - Short signal duration



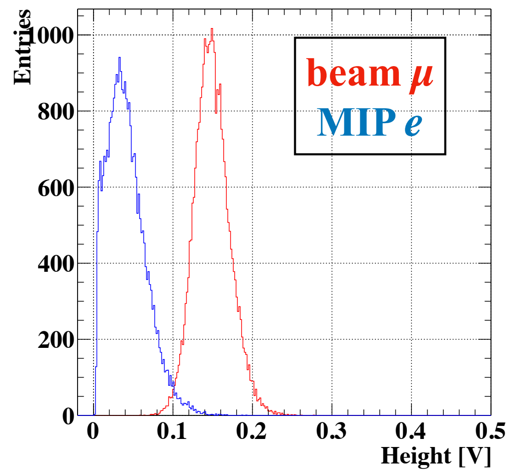
Ringing observed with prototype detector must be suppressed

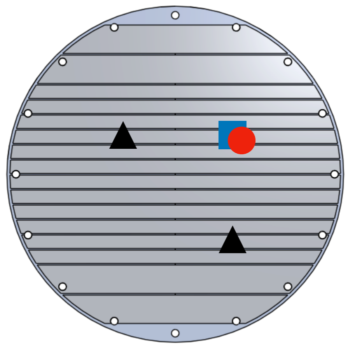
- Possible cause
  - Reflection
  - Resonance
- Time: ~50 ns
- Height: ~25% of main pulse height

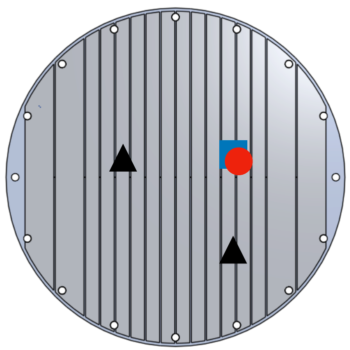
Calculation of pileup inefficiency

- μ and e can be separated
  - The responses at single layer were measured
- Pileup pattern
  - μ and e in the same cell (■ & ●)
  - μ, μ, and e in the same strip (■ & ▲)
- Pileup definition

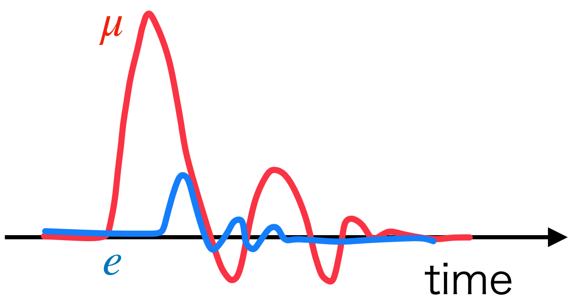
Expected pulse height spectra



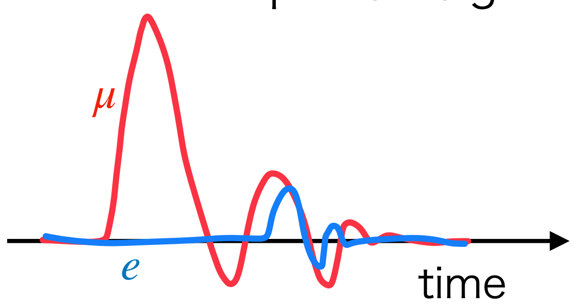




Within pulse width of μ hit

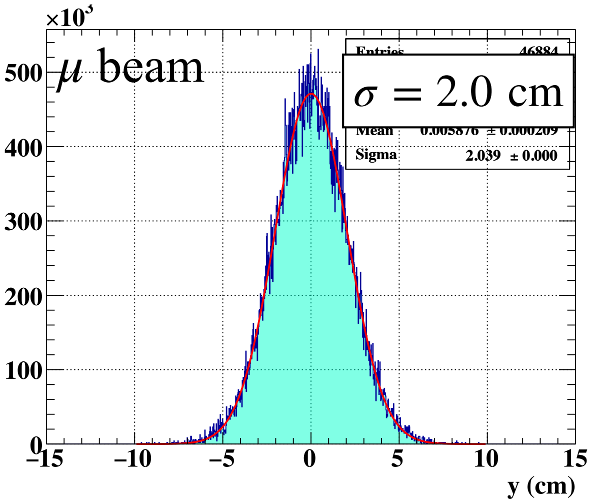


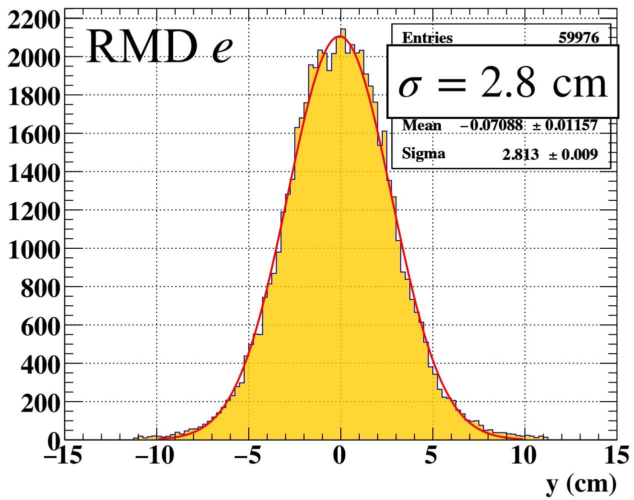
Within ringing time of μ hit with small pulse height

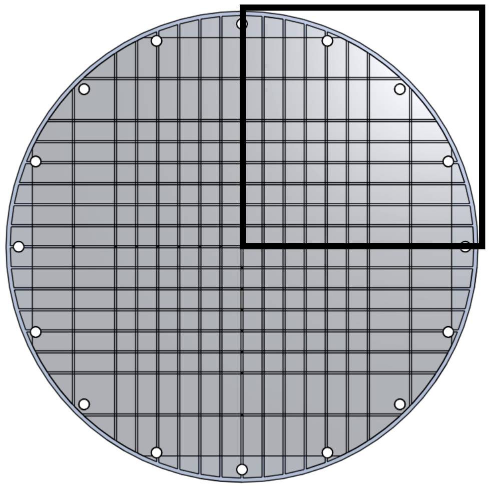


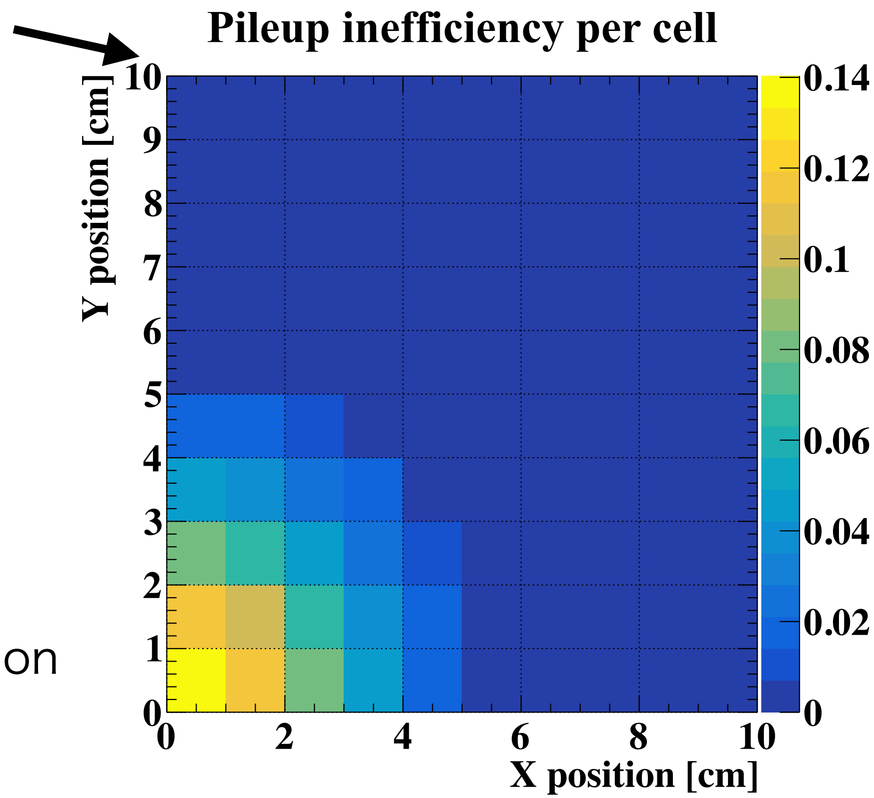
Calculation of pileup inefficiency

Beam μ and RMD e distribution









Parameters

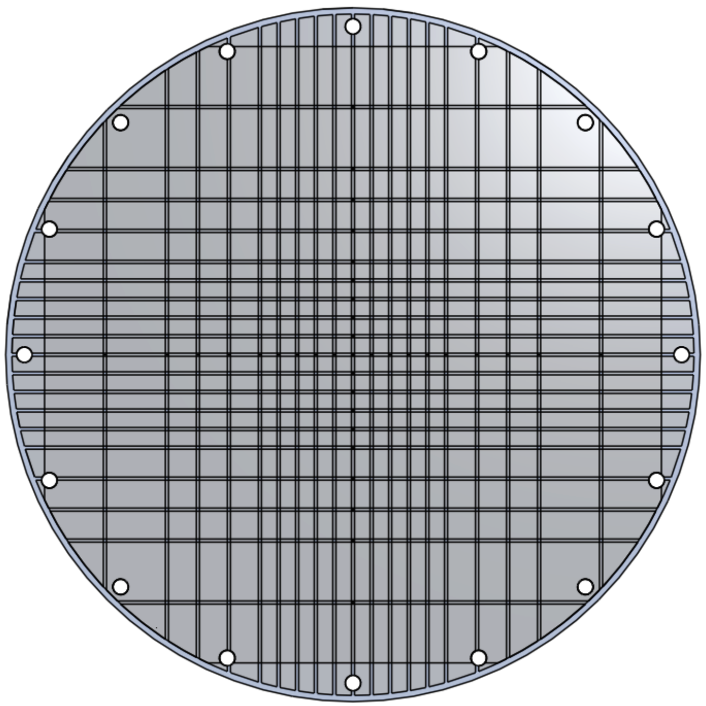
- 16 strips configuration
- Ringing time: 40 ns
- Ringing height: 25%

6.0% total pileup inefficiency with basic design

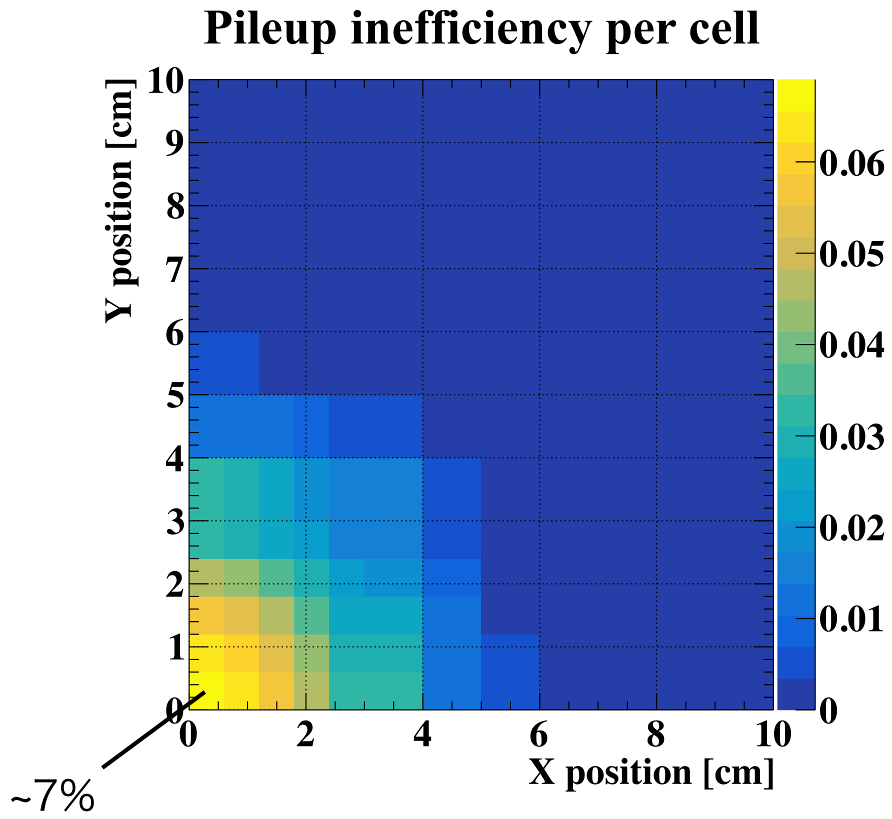
→ Pileup must be suppressed

Optimise strip configuration

Narrower as closer to the centre
to reduce the inefficiency around the centre

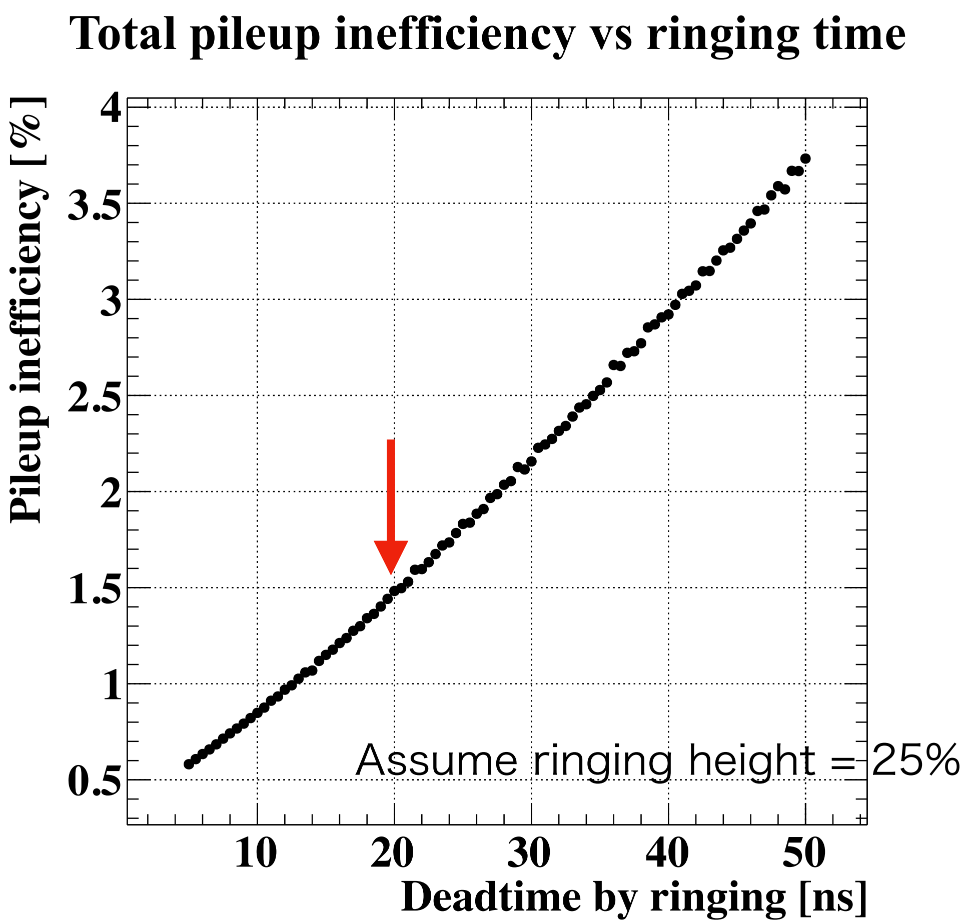


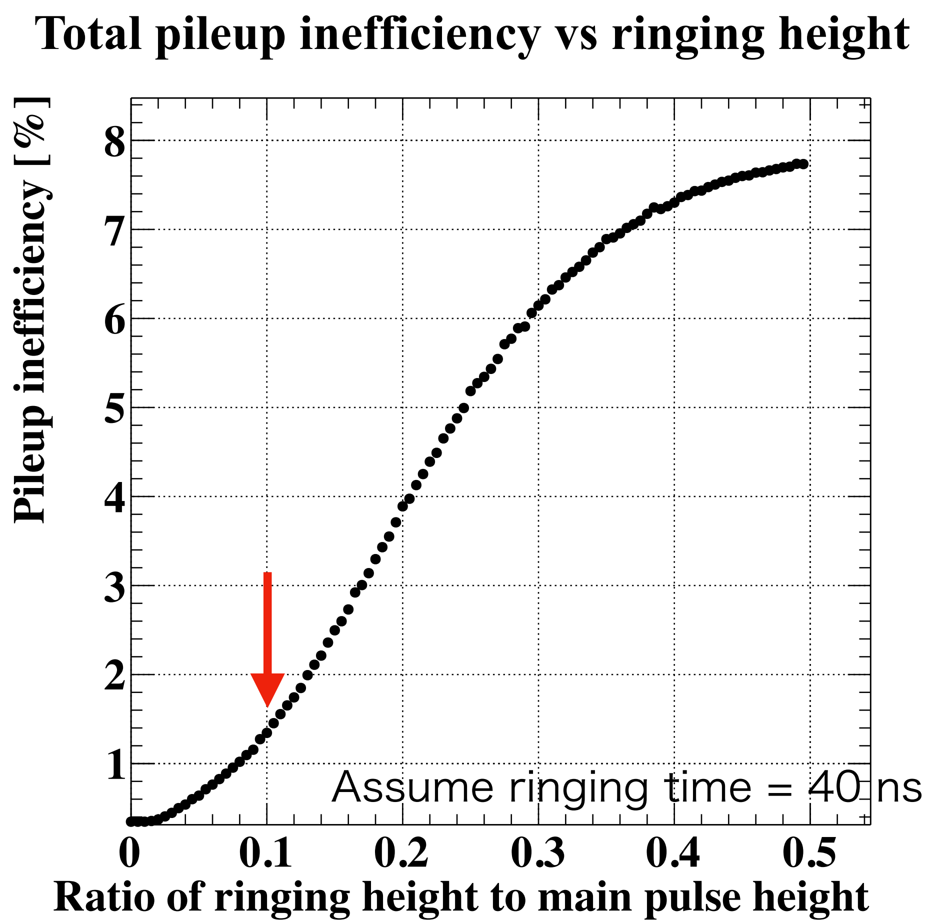
Strip configuration at a side
0.6 cm x 5 x 2
1.0 cm x 3 x 2
2.0 cm x 2 x 2



Total pileup inefficiency = 2.9%

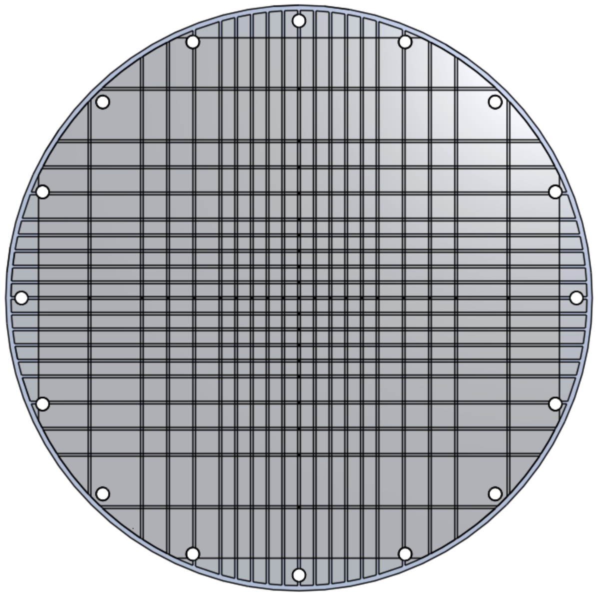
Ringing dependence

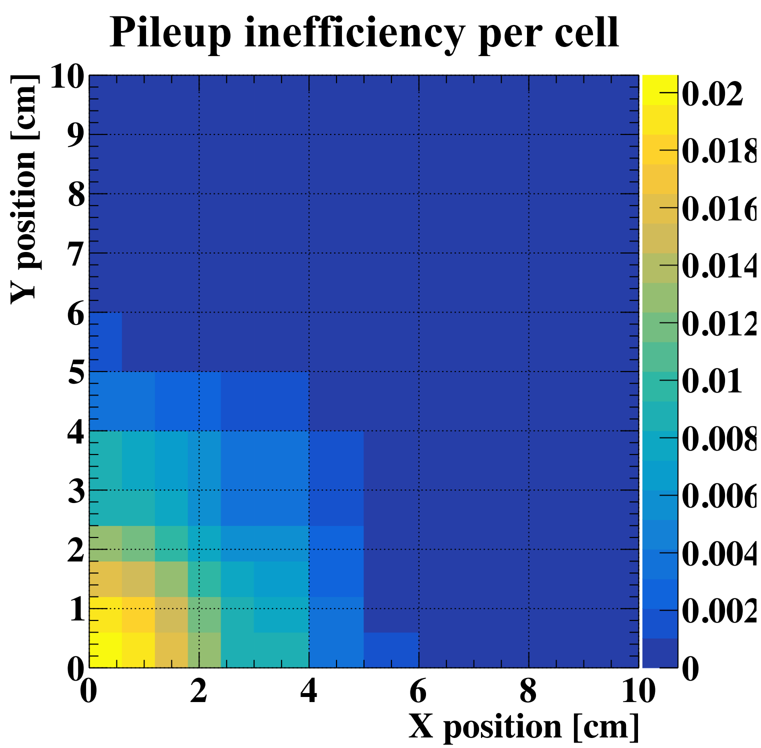




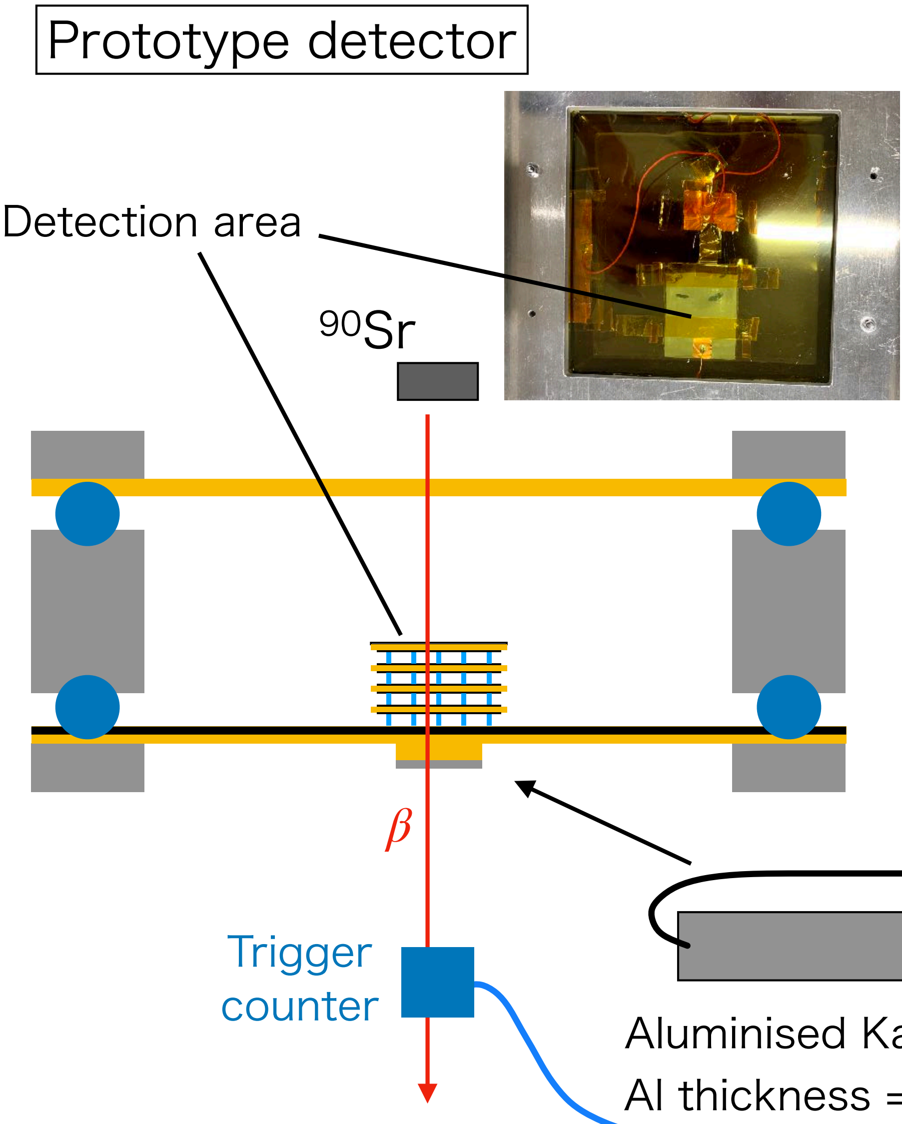
Suppressed pileup inefficiency

- **0.83% inefficiency will be achieved** under the conditions as follows:
  - Ringing time < 20 ns
  - Ringing height < 10% of pulse height
  - 20 strips configuration

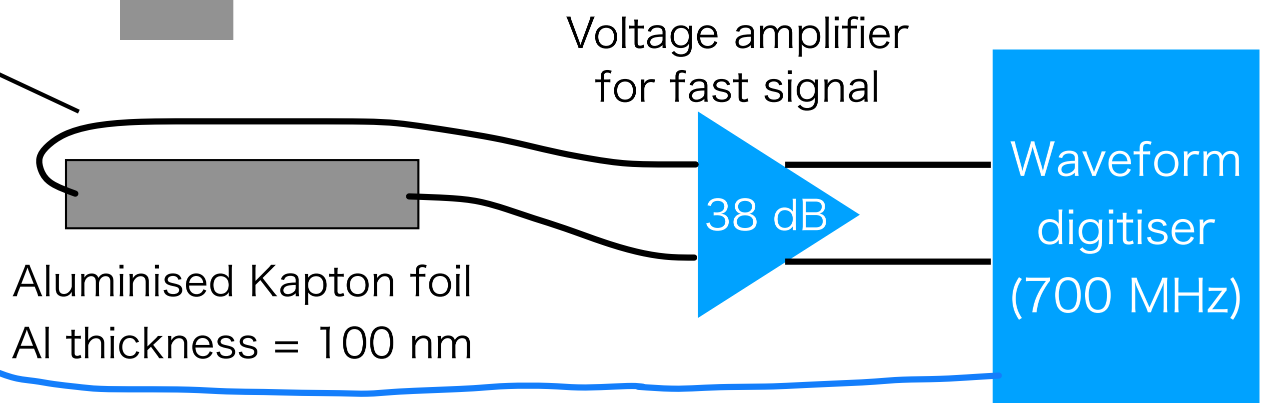




Ringing suppression test

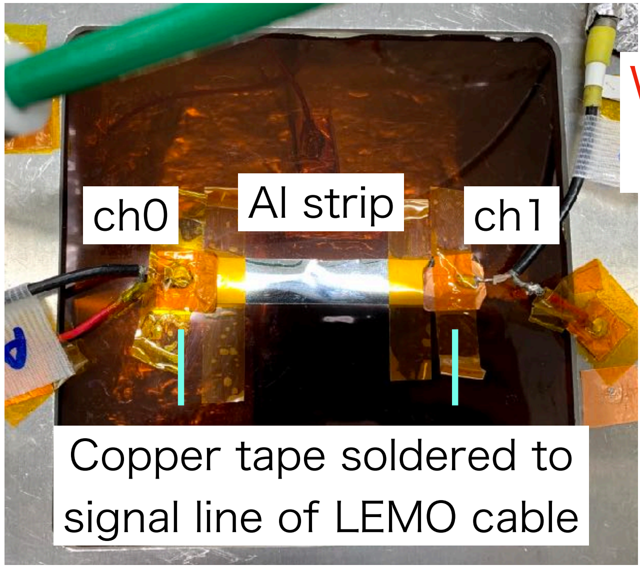


- Purpose:
  - Identify ringing cause
  - Suppress ringing
    - Time < 20 ns
    - Height < 10% of pulse height
- RPC basic information
  - Freon based gas
  - Single-layer or 4-layer config.



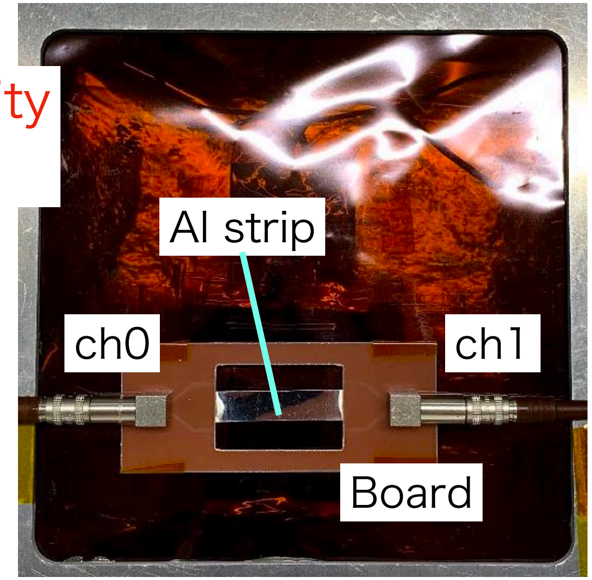
Readout strip setups

Copper tapes were on
the both ends of Al strip so far

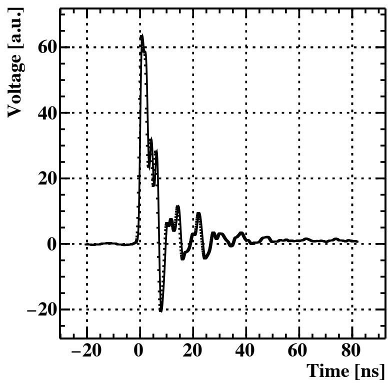


Waveform stability
is improved

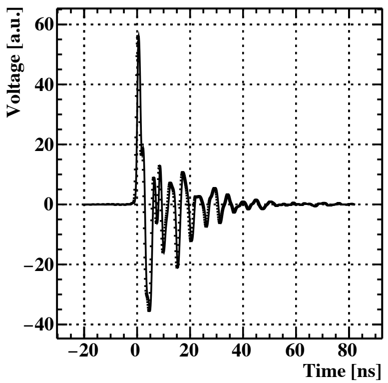
Al strip and board are connected
with conductive glue



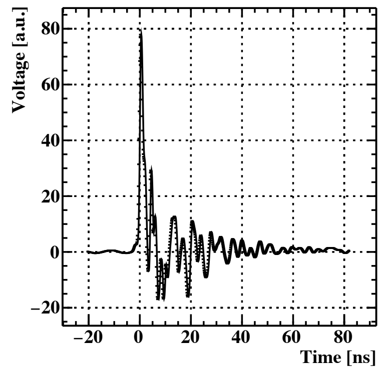
Average waveform at ch0



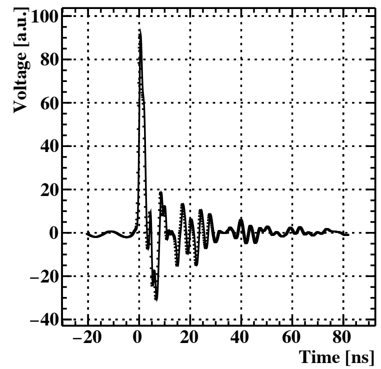
Average waveform at ch1



Average waveform at ch0

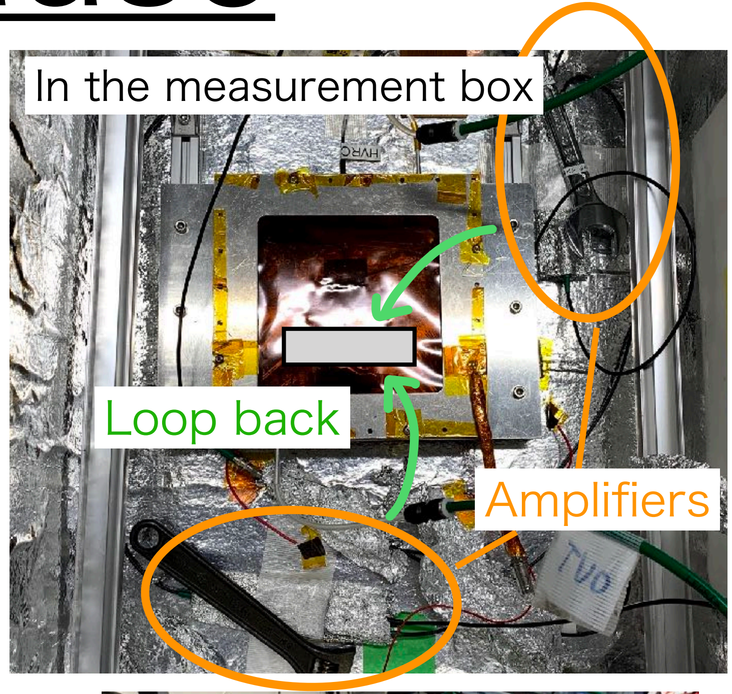


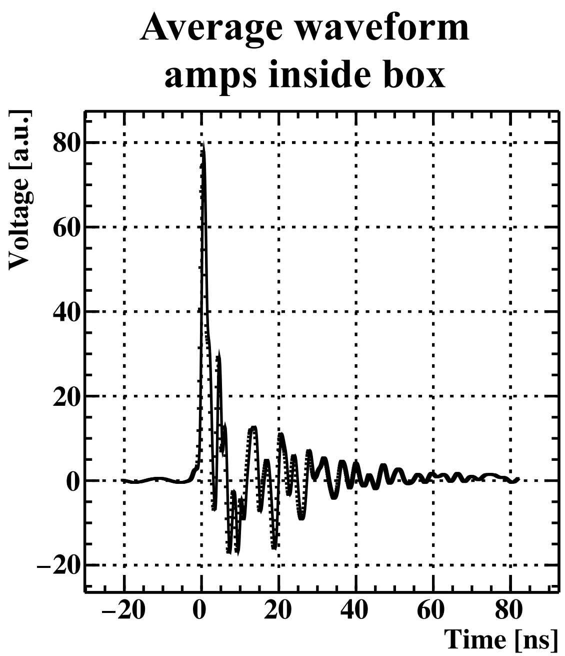
Average waveform at ch1

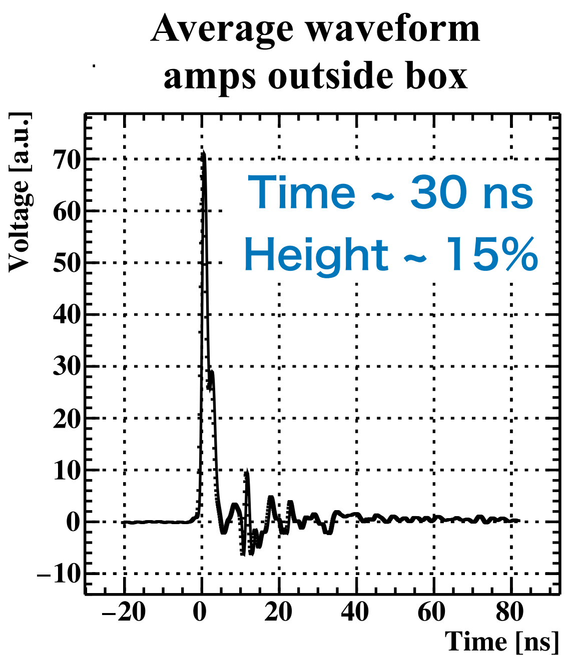


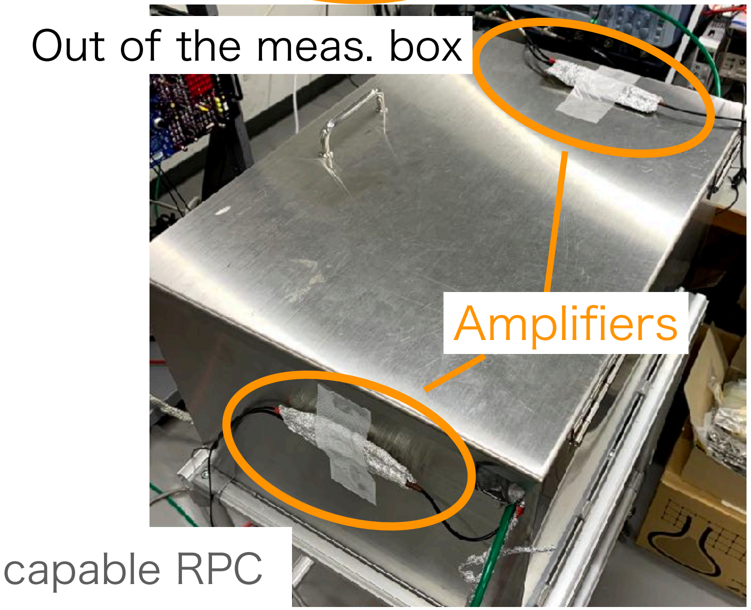
Ringing cause

- Loop back b/w readout strip and amplified RPC signal occurs
- Ringing was suppressed by getting amplifiers out



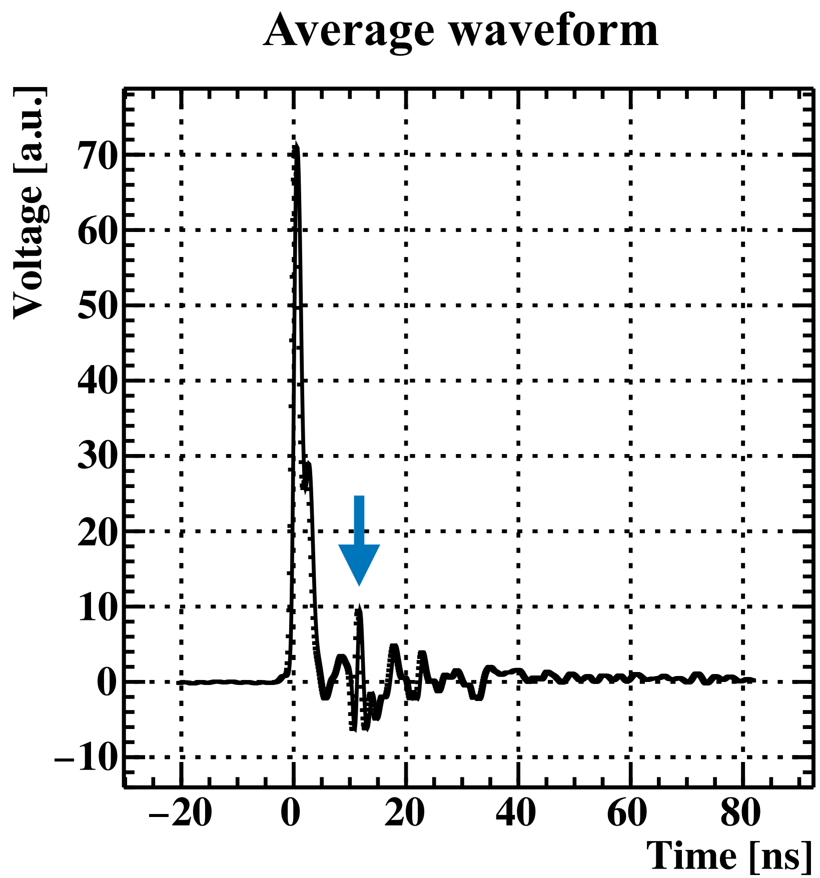






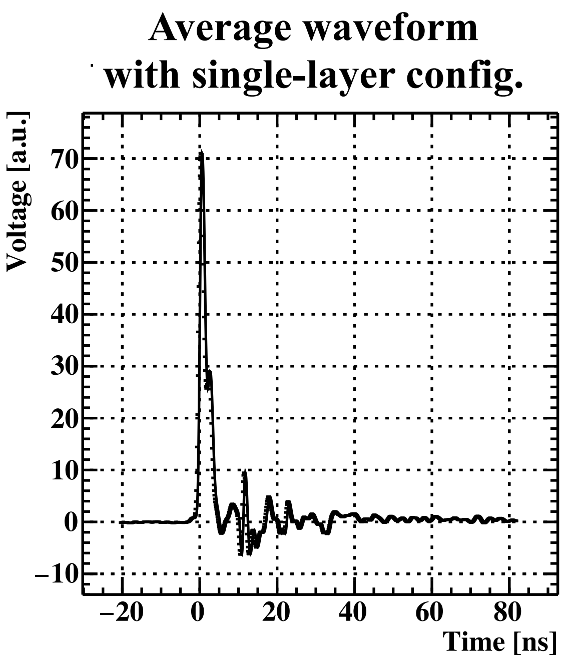
Other factors

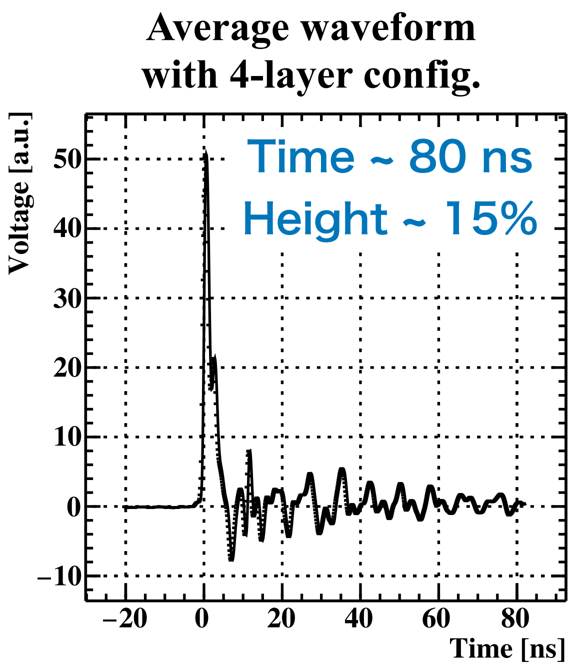
- Reflection at amplifier
  - Shape pulse at ~10 ns are caused by reflection at amplifier
- Characteristic impedance of readout strip
  - The impedance is determined by
    - Width of a strip
    - Distance b/w both sides of strips
  - Preferable for the impedance to be 50 Ω

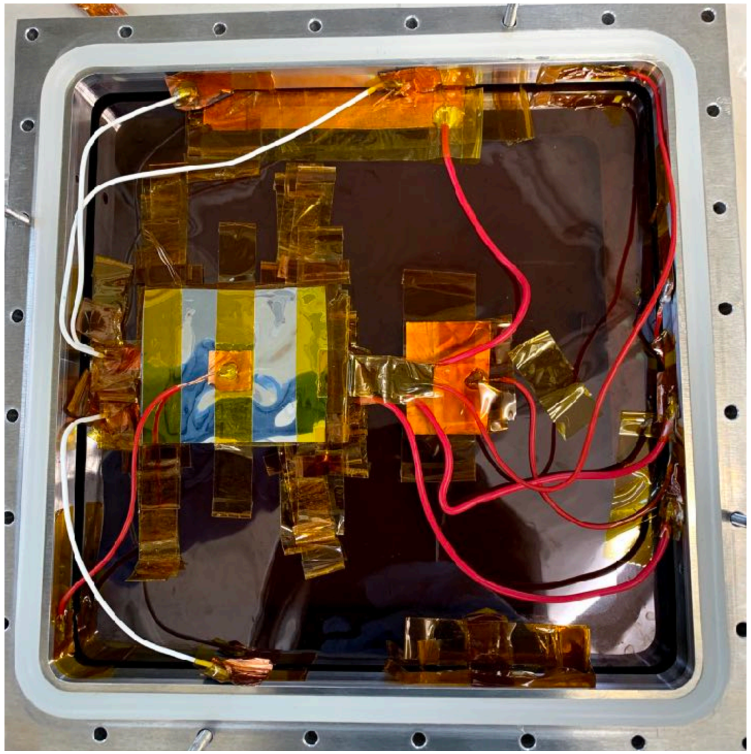


Comparison with layers

- The MEG II RPC will have 4 layers
- Longer ringing occurred with 4-layer configuration
  - Noise from other causes?
  - Complex wiring must be controlled
- Further suppression is needed







Outline

- Introduction
- Pileup suppression
  - Strategies for pileup suppression
  - Pileup probability calculation
  - Optimise strip configuration
  - Ringing suppression
- Summary

Summary & prospects

- High-rate capable RPC with DLC electrodes is under development for MEG II upstream RDC
- Pileup of beam μ^+ and RMD e^+ will be suppressed at 1% level of e inefficiency
  - Segment readout region by placing strips vertically with optimised strip configuration
  - Shorten signal duration by ringing suppression

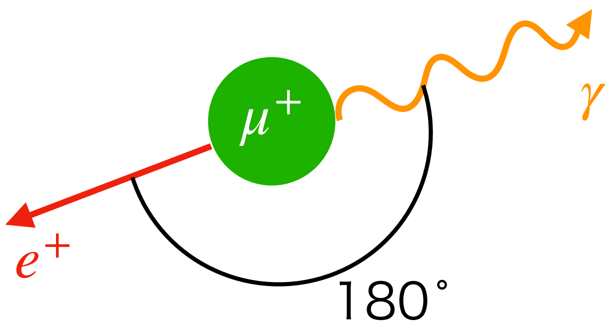
- Further ringing suppression will be studied with
  - 4-layer configuration
  - Multi strip configuration

Backup

MEG II signal and background

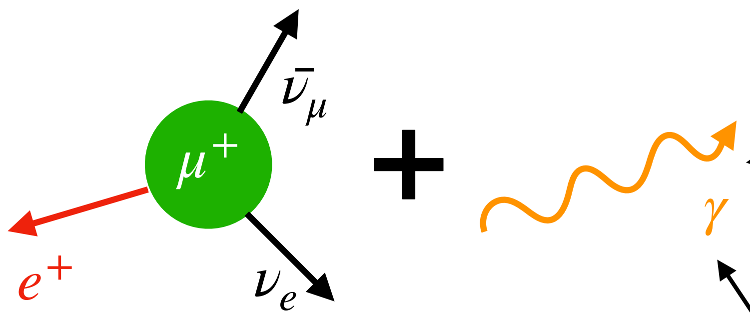
- MEG II searches for $\mu \to e\gamma$ decay, one of charged lepton flavour violation (cLFV) channels
- Dominant background is accidental coincidence of BG-e^+ and BG-γ

Signal

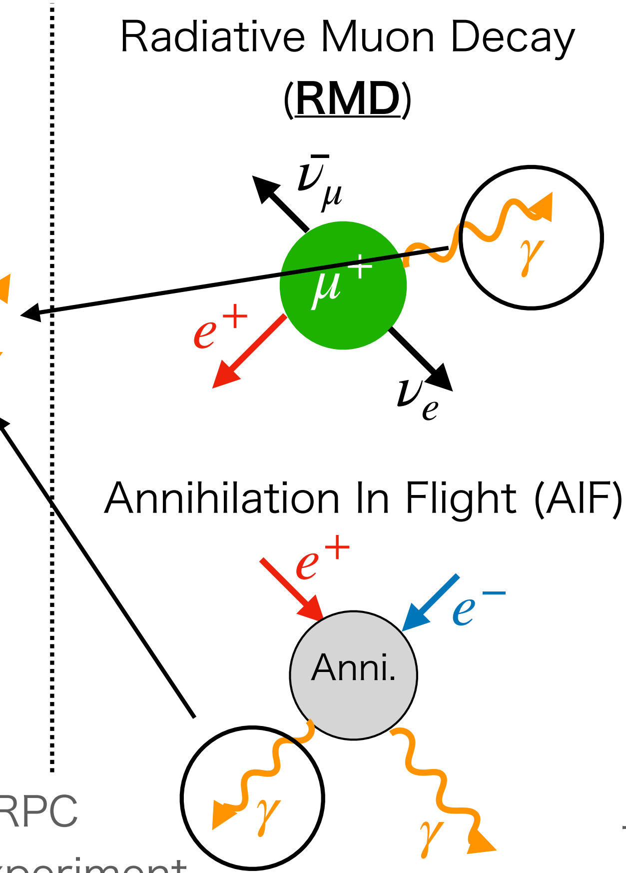


- The same energy of 52.8 MeV
- Opposite direction
- The same timing

Accidental BG

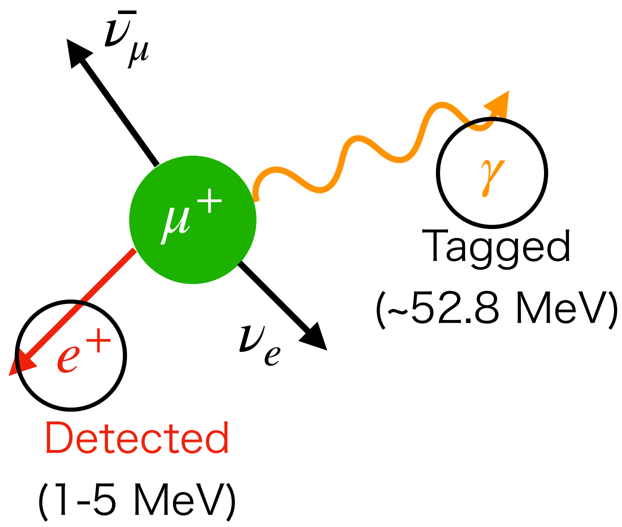


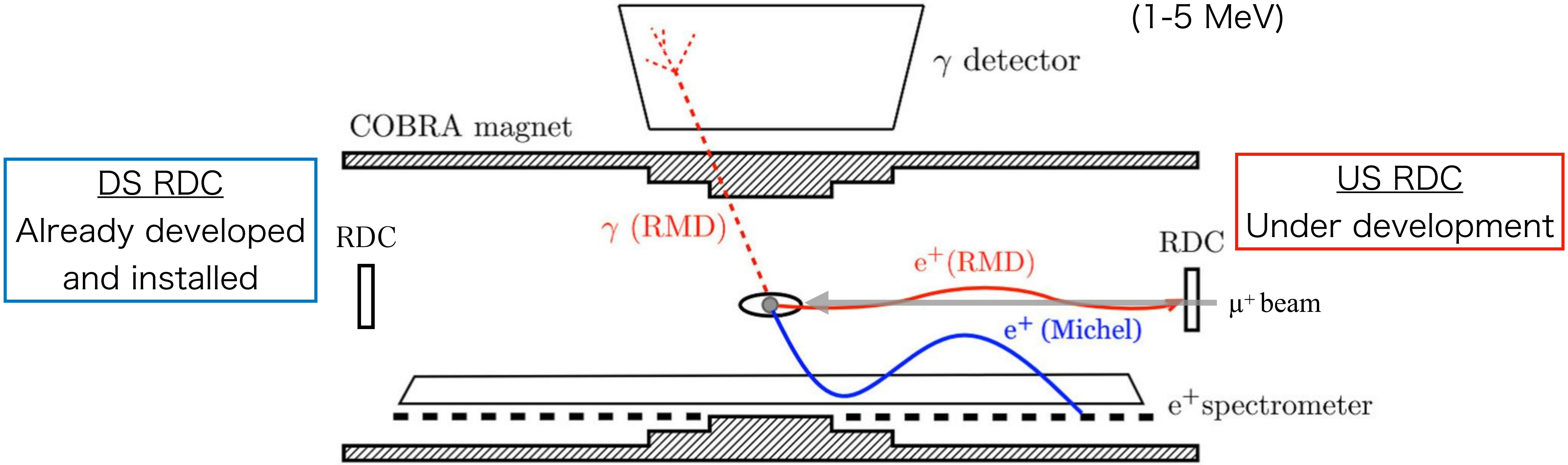
Signal-like accidental coincidence of e^+ and γ with ~52.8 MeV



Radiative Decay Counter

- Radiative Decay Counter (RDC) detects RMD e^+ with 1-5 MeV to tag BG-γ
- RDCs will be installed at both upstream and downstream of target
- Upstream RDC is under development





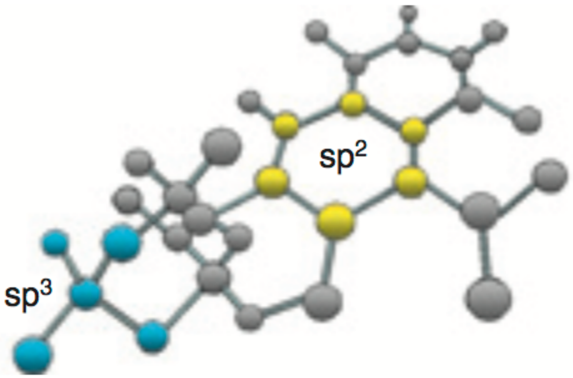
Requirements for upstream RDC

1. <0.1% X_0 material budget
   - μ beam with 28 MeV/c must pass through the detector
2. 90% efficiency for RMD e^+ with 1-5 MeV
3. 1 ns timing resolution
4. Rate capability and radiation hardness for 10^8 μ/s
5. 20-cm diameter detector size

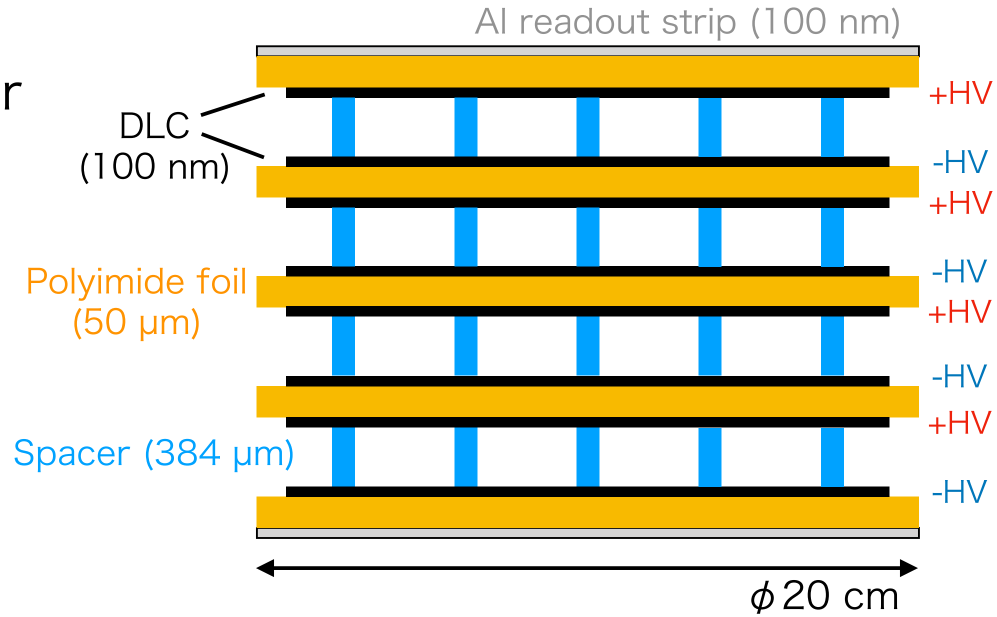
Candidate: Ultra-low mass Resistive Plate Chamber (RPC) with Diamond-Like Carbon (DLC) electrodes

RPC with DLC technology

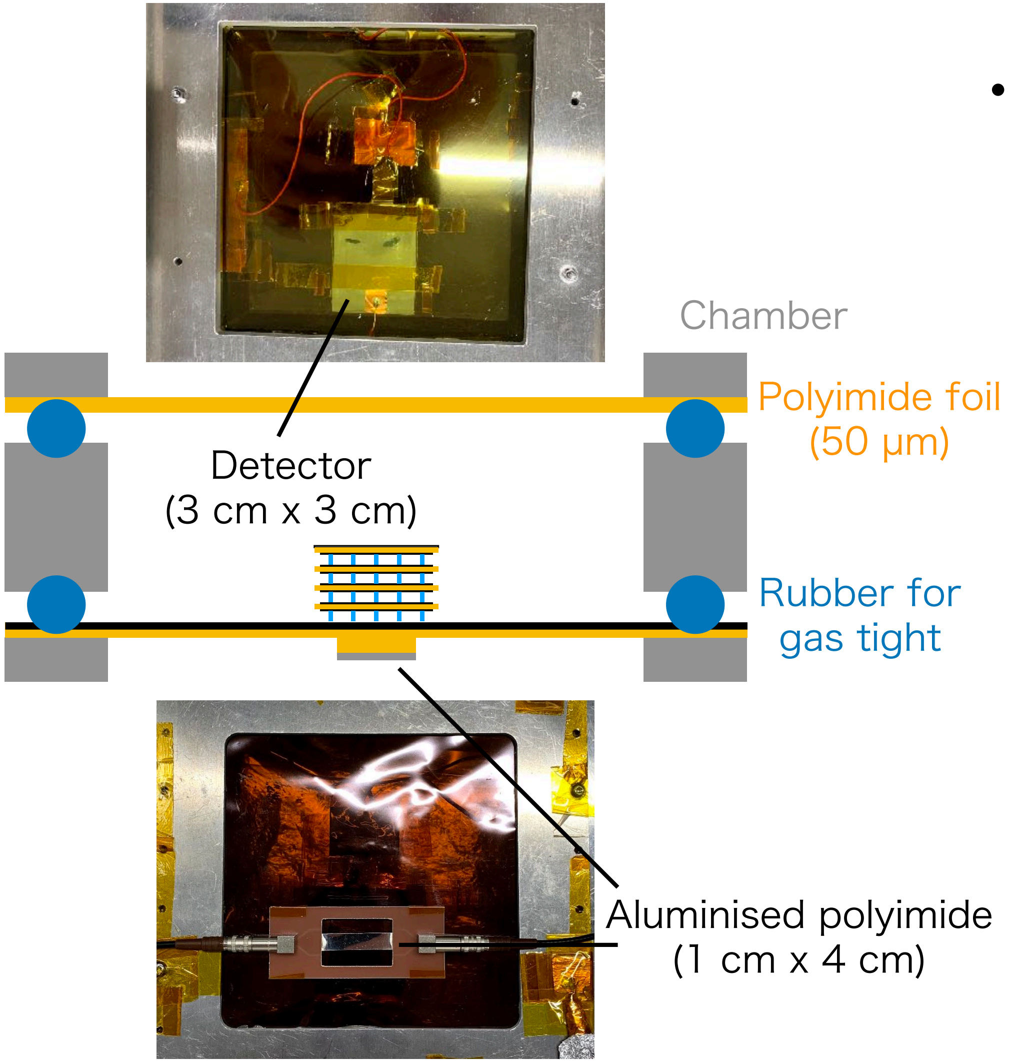
- Diamond-Like Carbon (DLC) is used as resistive electrodes
  - DLC is sputtered on polyimide foil
  - ➡ Small material budget can be achieved
  - DLC resistivity is adjustable
  - ➡ Small resistivity can be achieved, which is important for rate capability



- MEG II RPC design
  - 4 layers ← Higher efficiency
    - $\epsilon_n = 1 - (1 - \epsilon_1)^n$
  - <0.1% X_0 material budget
    - 50 μm Polyimide foil → 0.018% X_0
    - 100 nm aluminium → 0.0012% X_0



RPC prototype detector

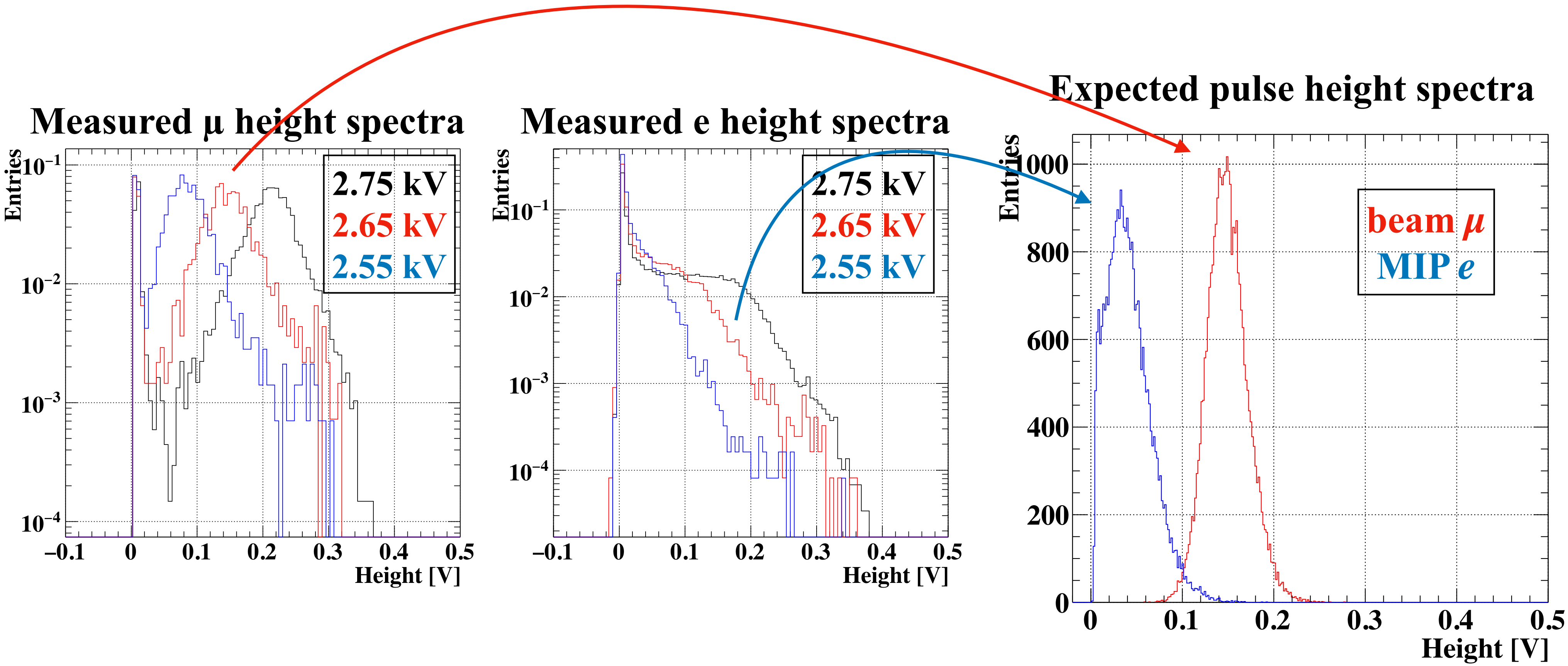


- Prototype detector performance for MIP
  - Operated with ultra-low mass design
  - Efficiency is dependent on applied HV
  - 60% efficiency is achieved with single-layer configuration
  - 90% efficiency is achievable with 4-layer configuration
  - 190 ps timing resolution

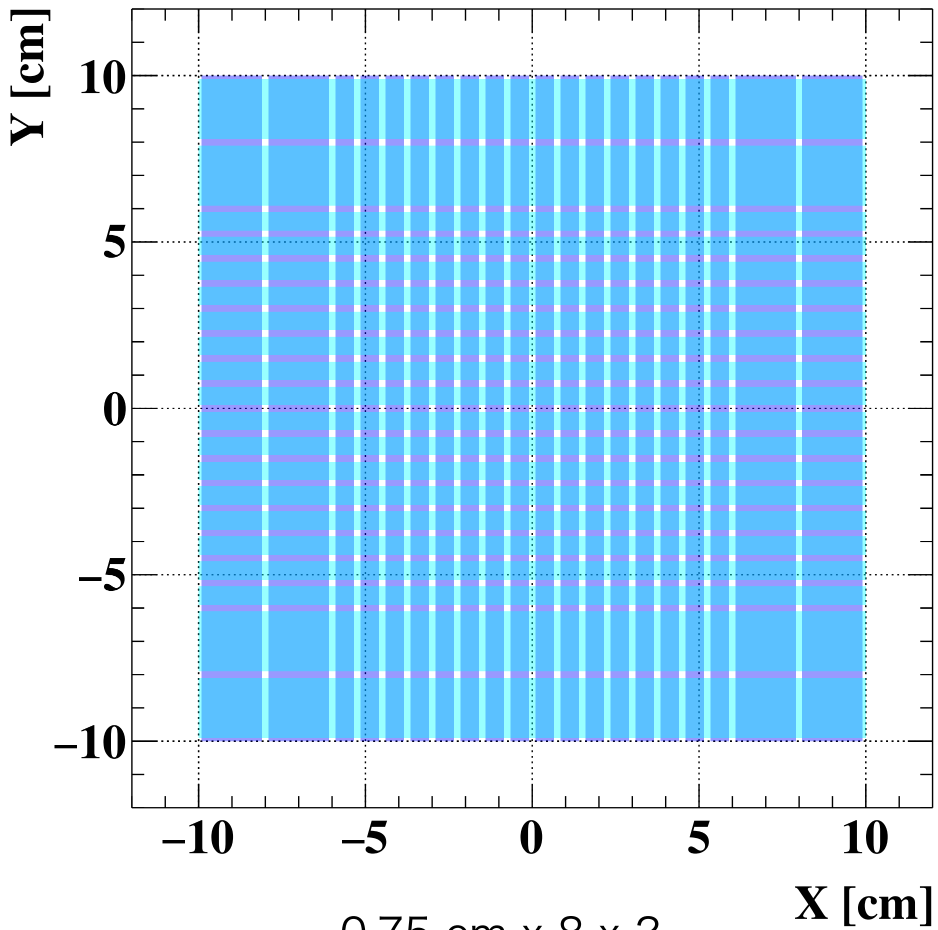
Pulse height spectra of μ and e

Measured with single layer

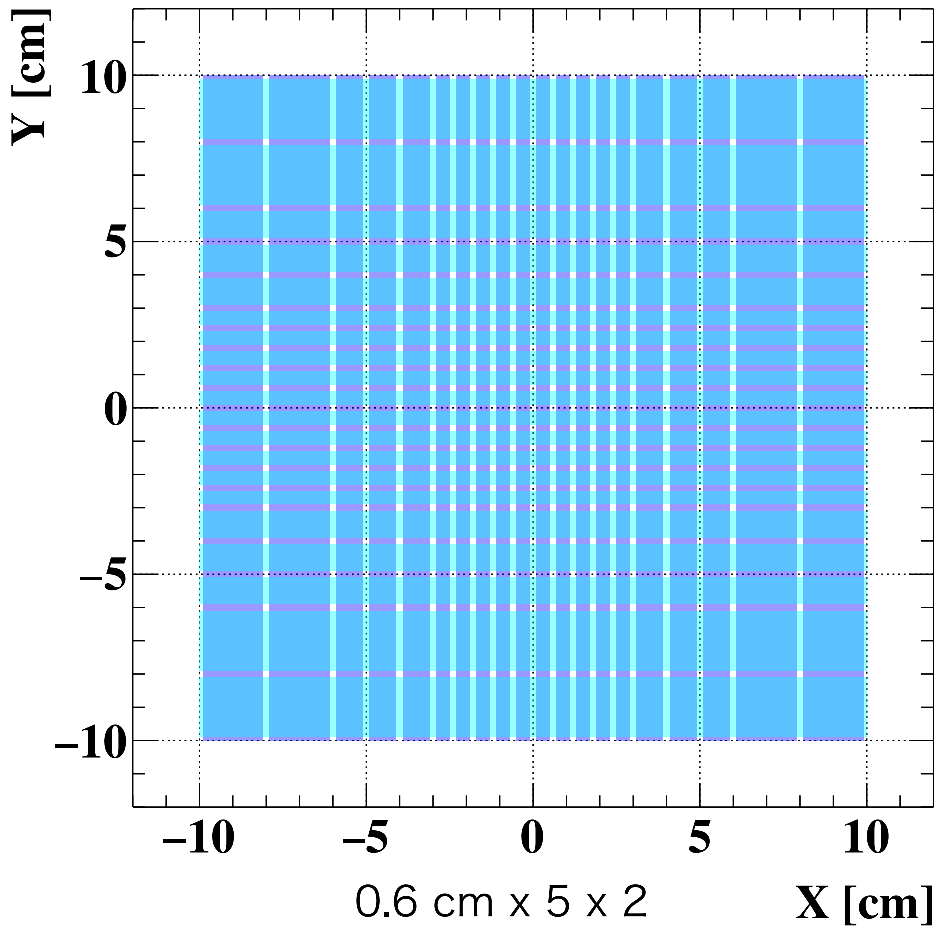
Expected with 4 layers



20 strips configuration

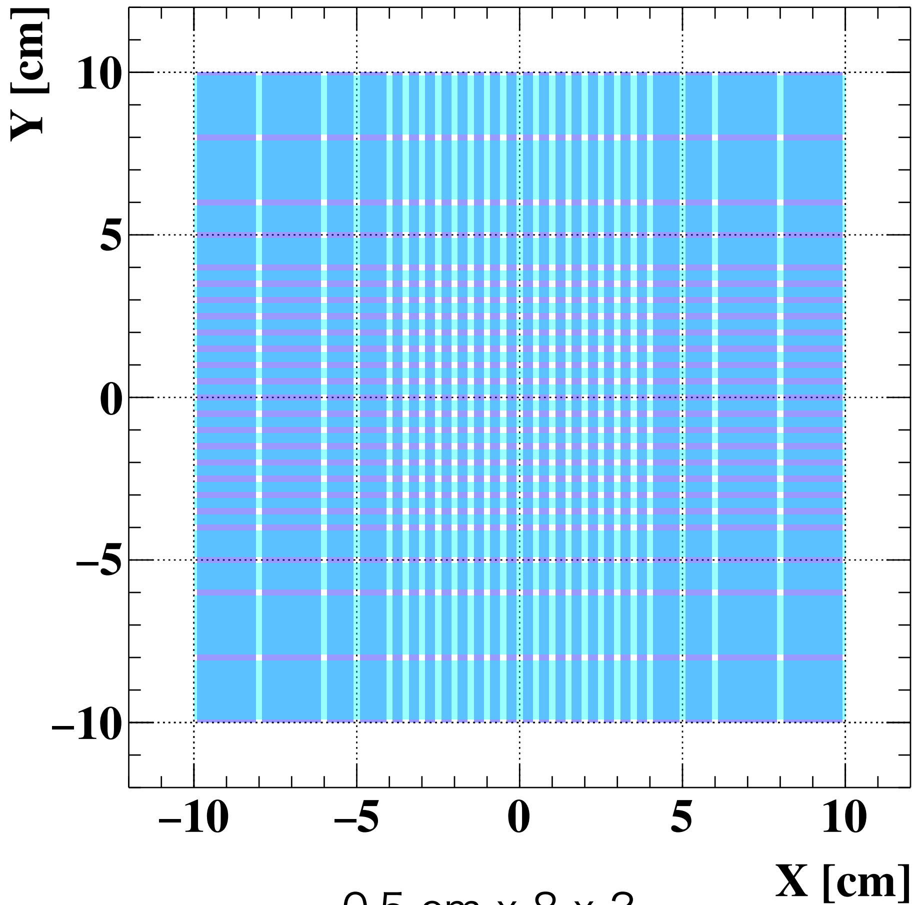


0.75 cm x 8 x 2
2.0 cm x 2 x 2
Total pileup prob. = 3.9%

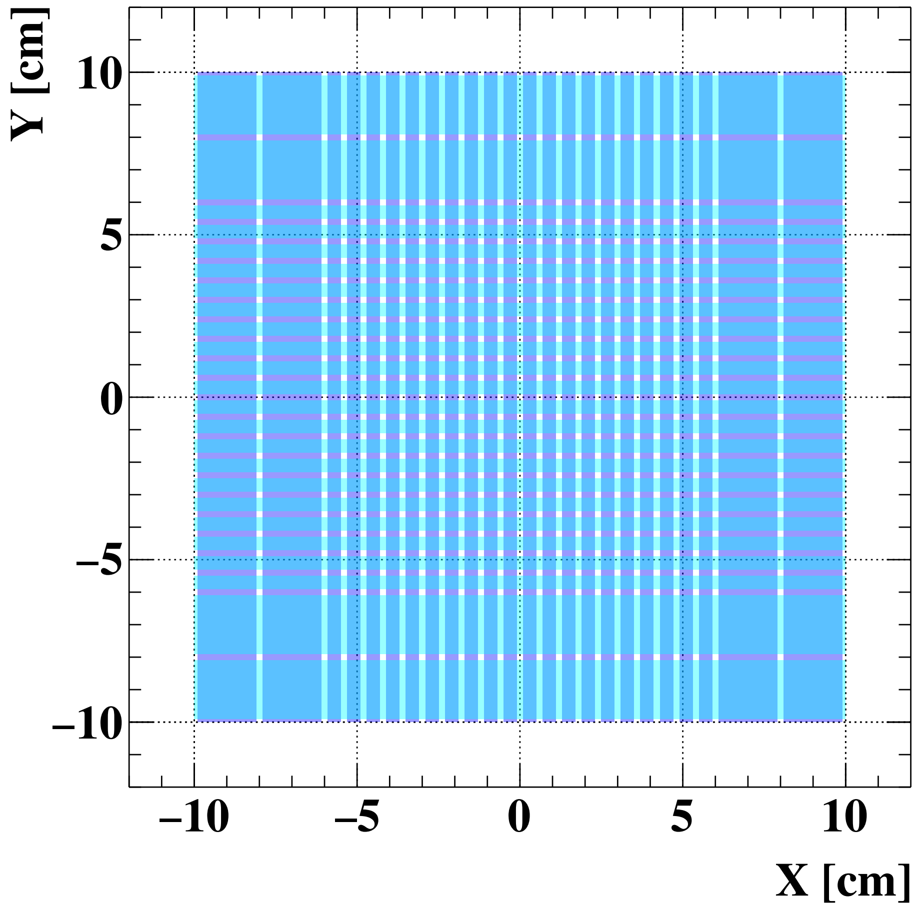


0.6 cm x 5 x 2
1.0 cm x 3 x 2
2.0 cm x 2 x 2
Total pileup prob. = 2.9%

24 strips configuration

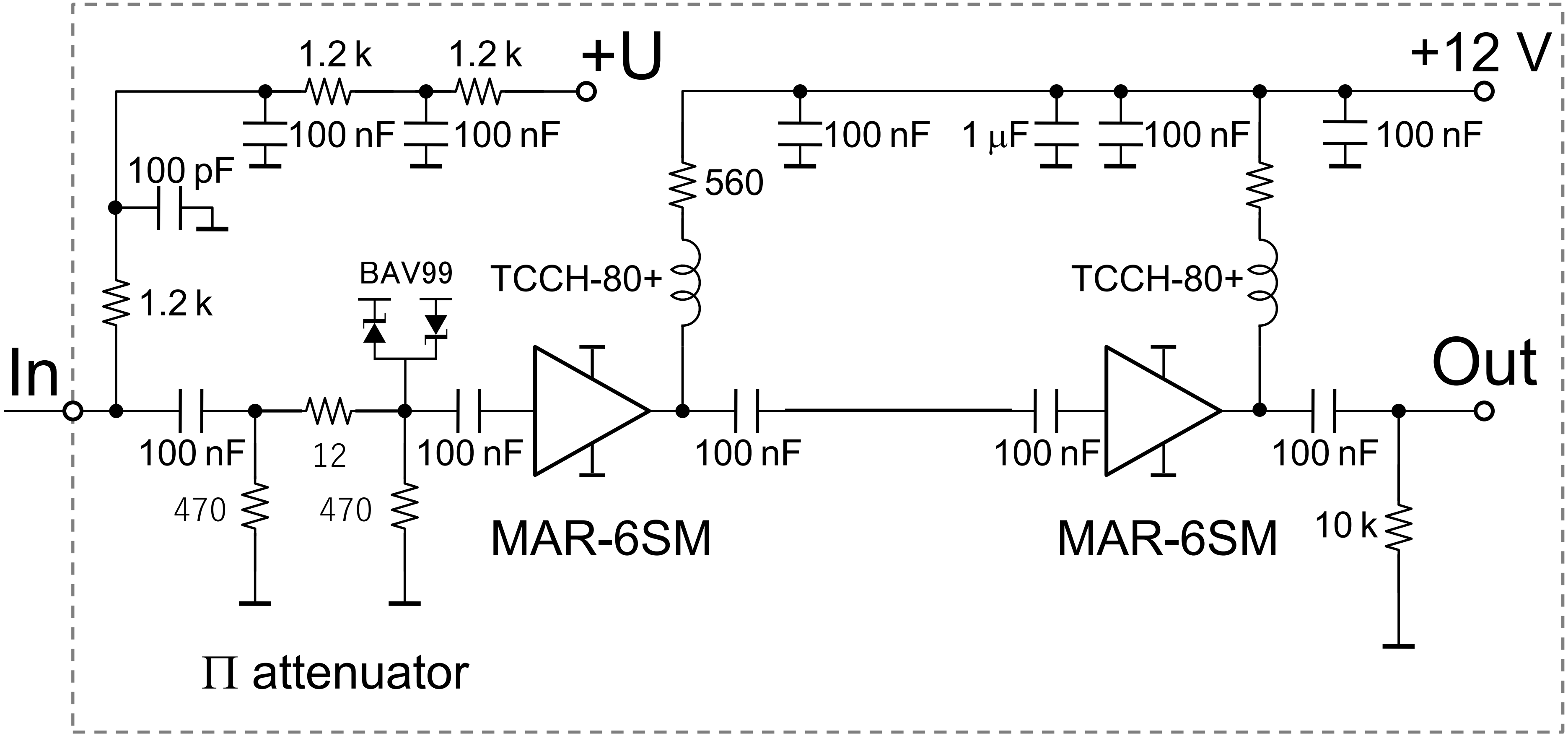


0.5 cm x 8 x 2
1.0 cm x 2 x 2
2.0 cm x 2 x 2
Total pileup prob. = 2.0%



0.6 cm x 10 x 2
2.0 cm x 2 x 2
Total pileup prob. = 2.3%

Amplifier



1.2 k
1.2 k
+U
+12 V
100 nF
100 nF
100 pF
100 nF
1 μF
100 nF
100 nF
560
BAV99
TCCH-80+
TCCH-80+
1.2 k
In
Out
100 nF
12
100 nF
100 nF
100 nF
100 nF
470
470
MAR-6SM
MAR-6SM
10 k
Π attenuator