Multi-gap RPCs

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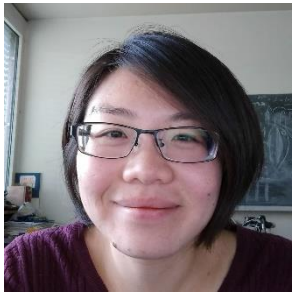
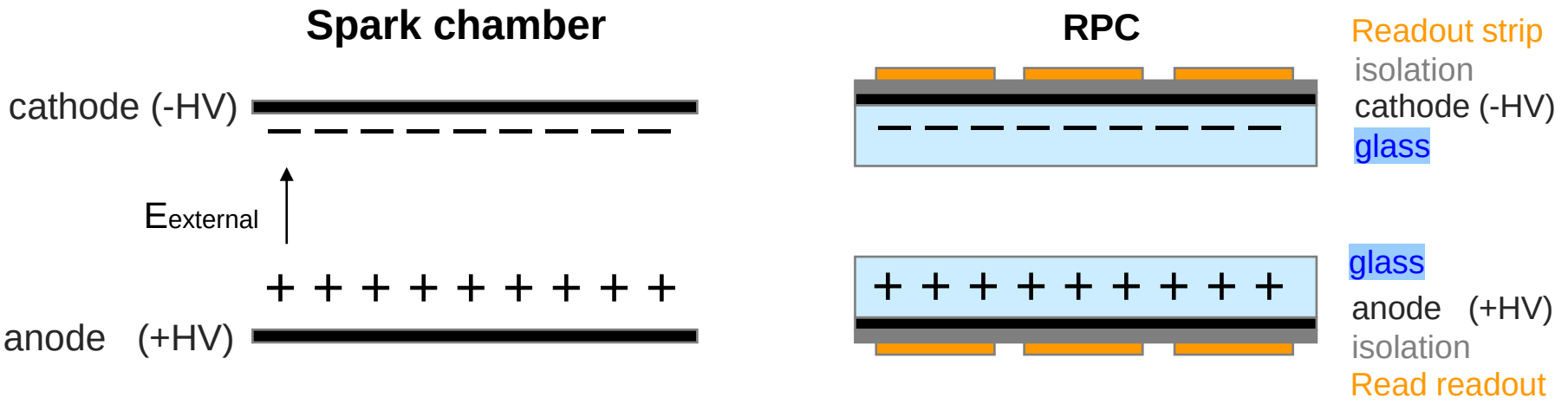


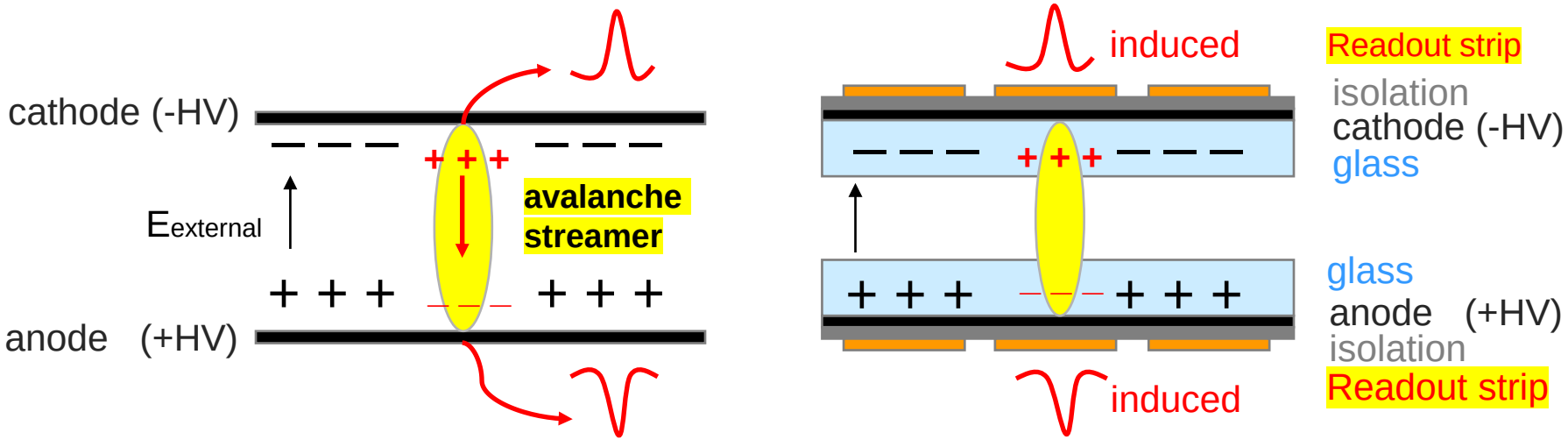
Outline

- Brief introduction of Multi-gap RPCs (MRPC)
- MRPC projects (2012 -)
- MRPC development (2022 -)
- Outlook

Resistivity Plate Chamber (RPC)



Glass between electrodes serves as an internal quencher of discharging.

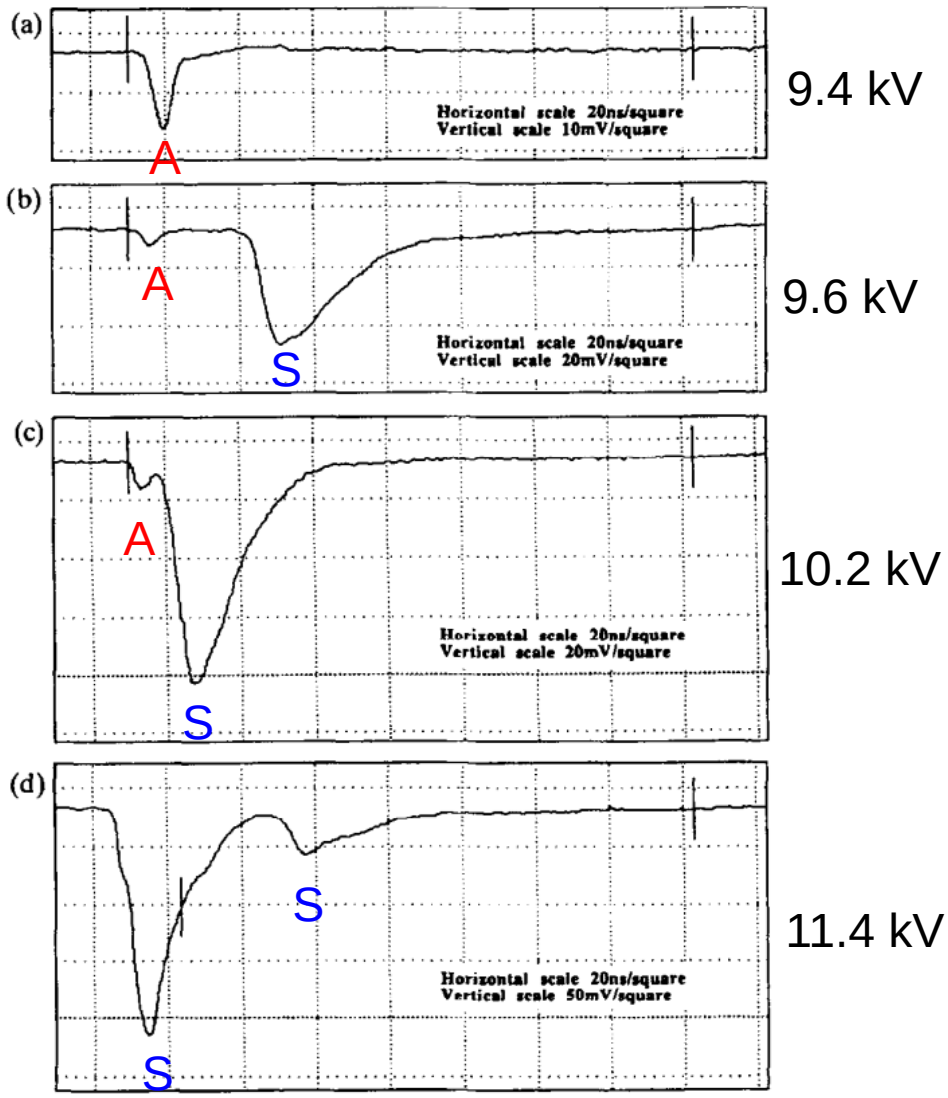


Fast and large signals.

Large detection areas

Santonico and Cardarellis (1981)

Avalanche and Streamer Modes



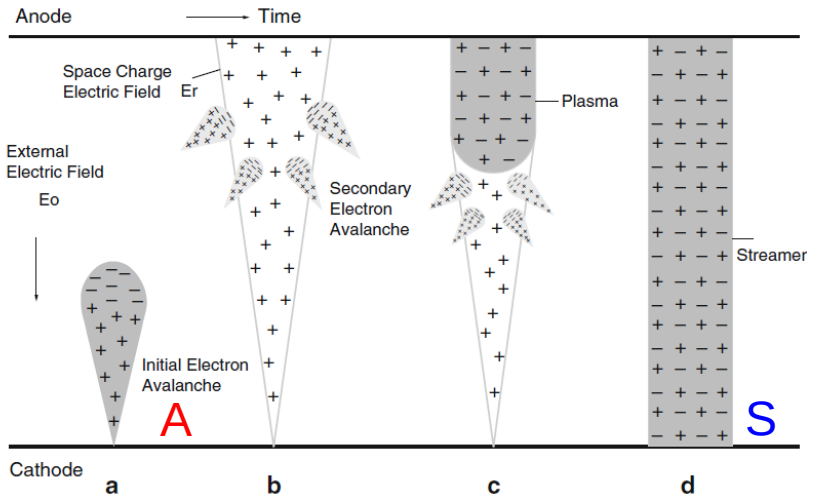
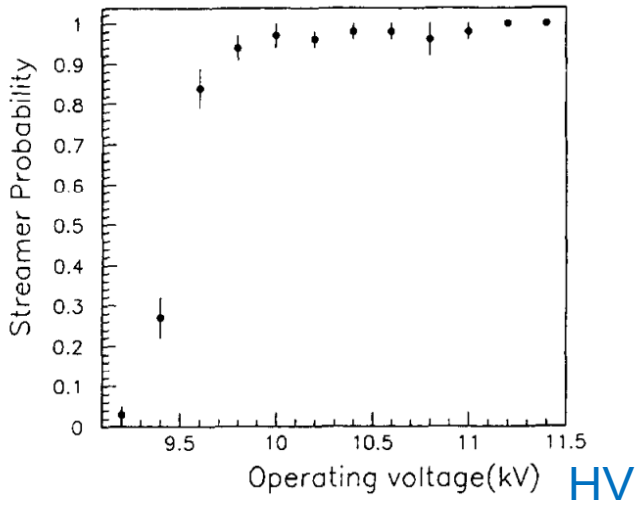


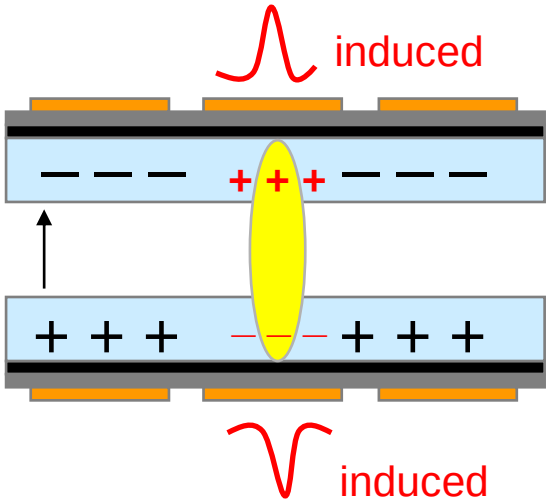
Fig. 4.7 Formation and development of positive flow: (**a**) Initial electron avalanche, (**b**) secondary electron avalanche, (**c**) appearance of plasma, (**d**) formation of streamer

https://link.springer.com/chapter/10.1007/978-3-662-48041-0_4



https://www.sciencedirect.com/science/article/pii/S016890029600811X

Resistivity Plate



readout
isolation
cathode (-HV)
glass

glass
anode (+HV)
isolation
readout

higher resistivity		***lower resistivity***
slower responce to E field	↔	***faster responce to E field***
lower rate capability	↔	***larger rate capability***
smaller avalanch cluster	↔	***larger avalanch cluster***
better time resoltion	↔	***worse time resolution***

Choice of resistivity plate is a balance between rate capability and time resolution.

- **Advantage**

Good time resolution: ~1-2 ns

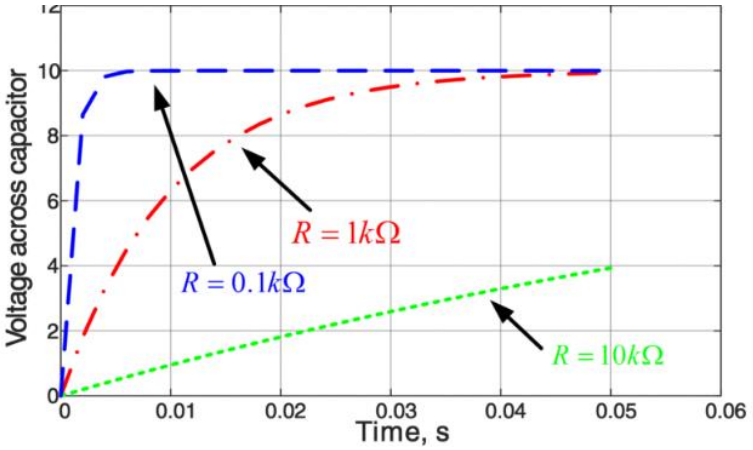
- **Limitation**

Low-rate capability: ~1kHz/cm^2

- **Resistivity plate**
  - glass (~ 10^{10}–10^{12} Ohm/cm^2)
  - bakelite (~ 10^{10} Ohm/cm^2)
  - ceramics (~ 10^9 Ohm/cm^2).

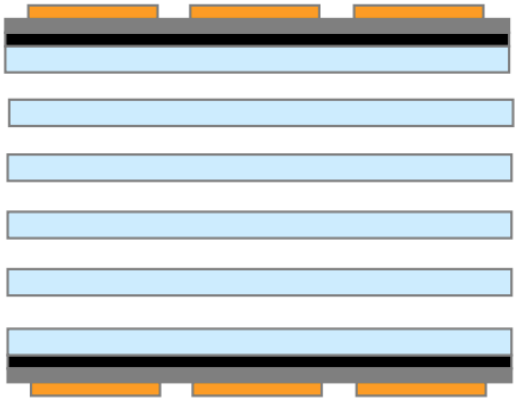
Common choice is glass.

RC circuit, time constant $\tau = RC$



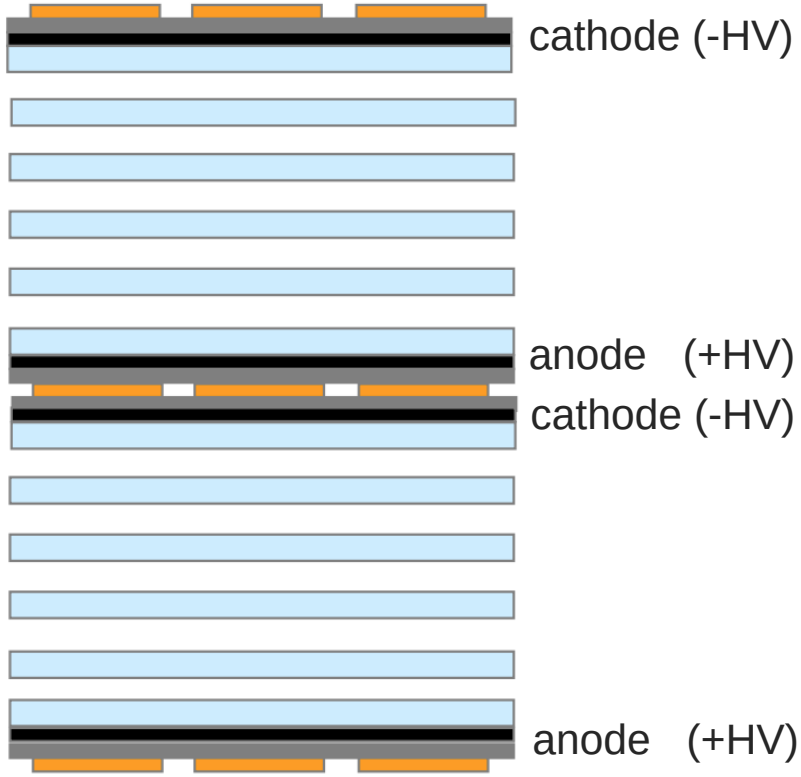
Multi-gap and Multi-stack

Multi-gaps RPC(MRPC)



Extend the concept to have small-size cluster inside chamber, one could decrease the gap size between glasses. However, if the cluster is too small, the induced signal in the read-out is too small to observe. To increase the induced signal but keep the small gap size(good time resolution), multiple-gaps RPC was invented. Currently, the structure of time-of-flight detector is usually in this shape.

Double-stack MRPC



To combine the signal from both top and bottom stacks of MRPC could also give the same effect – enlarge the induced signal but keep the cluster small, keep good time resolution.

Enhance the induced signal and keep a good time resolution.

MRPC projects

- Since 2012, we collaborate w/ Prof. Tomida Natsuki (Kyoto) in developing MRPC and the readout electronics (amplifier, discriminator, & stretcher) for the SPring-8 LEPS2, FNAL EMPHATIC, J-PARC E88 and E50 fixed-target experiments.
- Starting from 2022, we do R&D on
  - Noise reduction
  - Signal reflection
  - Carbonless
  - Mylar spacer
  - PCB-sealed

MRPC projects

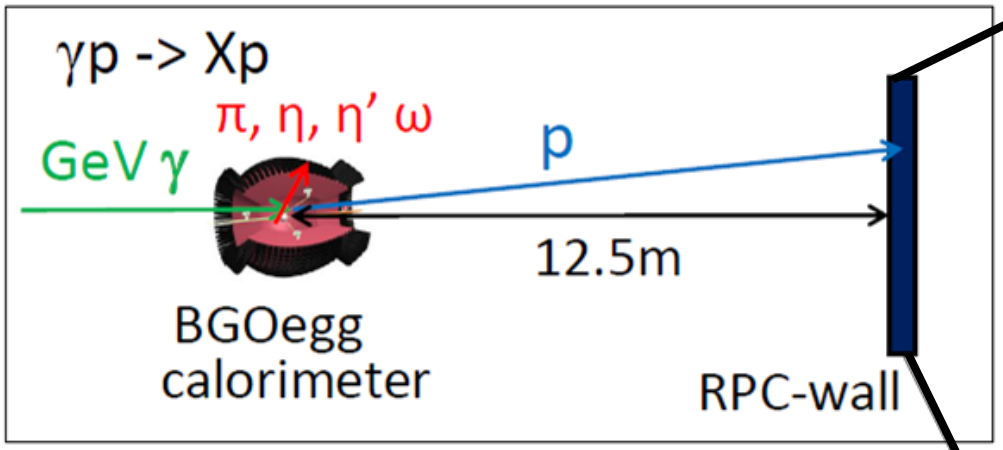
commissioning

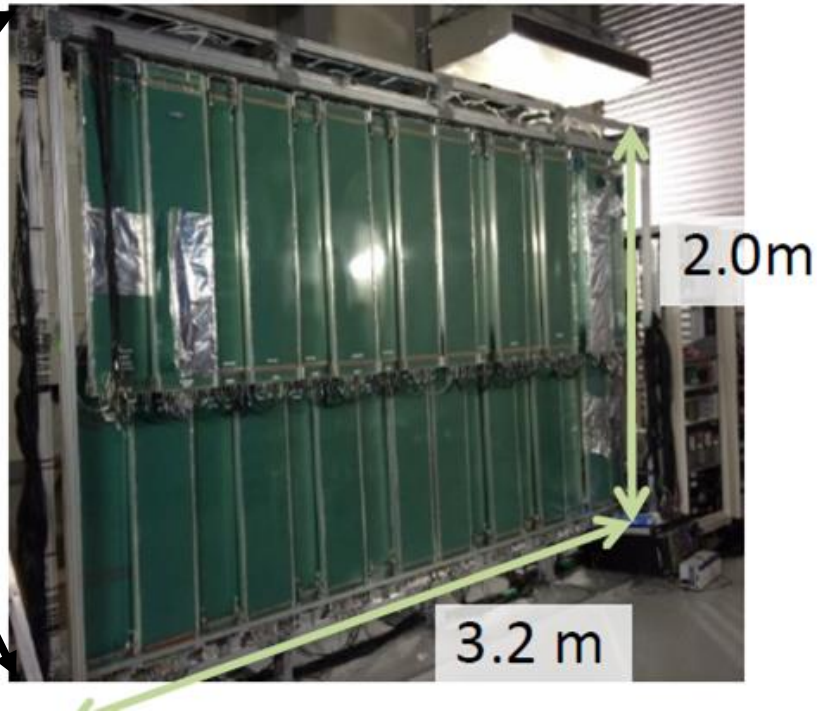
Purpose	Experiment		Goal	RPC structure	Readout strip
TOF	BGO-egg	SPring-8	time res. <60ps	5 gaps * 260um gaps 2 stack	2.5cm * 1.0m strip
	LEPS2	SPring-8	time res. <60ps		2.5cm * 1.8m strip
	EMPHATIC	FNAL	time res. <60ps		2.5cm * 1.0m strip
	E88	J-PARC	time res. <60ps (high rate, heat chamber)		2.5cm * 0.75m strip
	E50	J-PARC	time res. <60ps		2.5cm * 1.8m strip
Tracker	E50	J-PARC	Tracker (time res.<100ps, pos. res. <1mm)	5 gaps * 260um gaps 1 stack	1mm * 1.8/2.4m strip

under development

- Publications:
  - K. Watanabe et al., NIM A 925, 188 (2019).
  - R. Uda et al., NIM A 1056, 168580 (2023).
  - N. Tomida et al., NIM A 1056, 168581 (2023).
- **BGO-egg MRPC was the first MRPC used in experiment in Japan.** MRPC of LEPS2, EMPHATIC, E88 follow a similar structure as MRPC of BGO-egg with small modifications. All of them are in operation.
- We are now developing **TOF and tracker for E50 experiment**. MRPC will be used for both TOF and tracking for the first time.

BGO-egg TOF MRPC

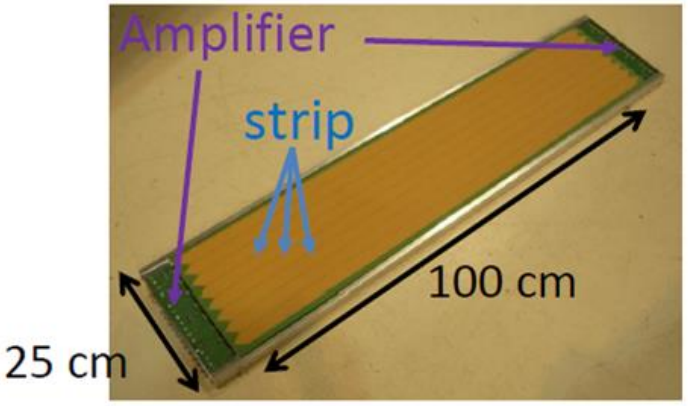




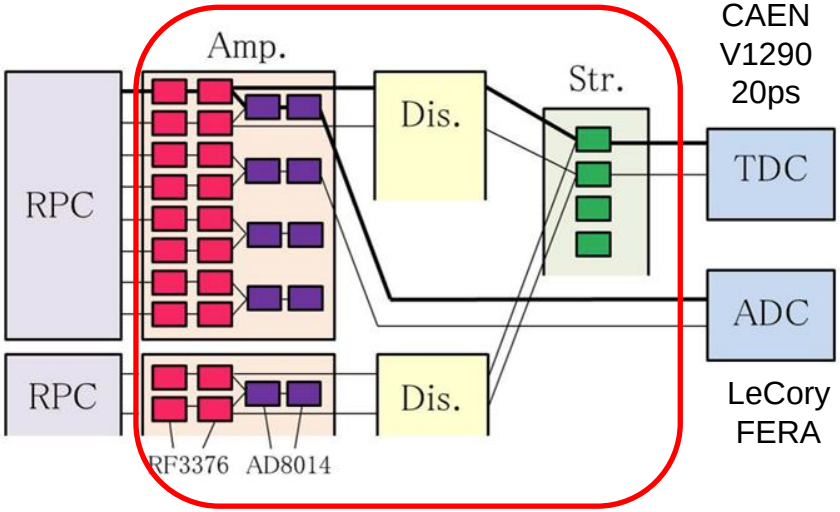
- MRPC

1. Measure proton energy (away from collision)
2. MRPC : 2 stacks * 5 gaps* 265 um gap size
3. Read-out : 2.5 cm *1 m long
4. Cover 3.2 m * 2.0 m
5. >95% Eff. and ~50 ps time resolution

- Detector ran since 2014. We contribute to the FEEs of BGO-egg MRPCs.

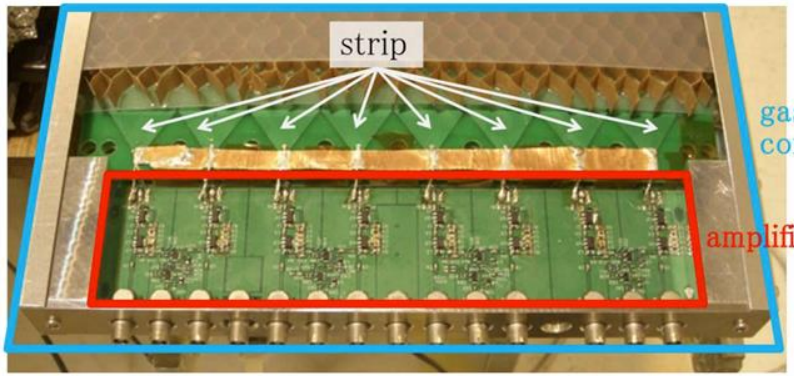


FEEs of BGO-egg MRPC



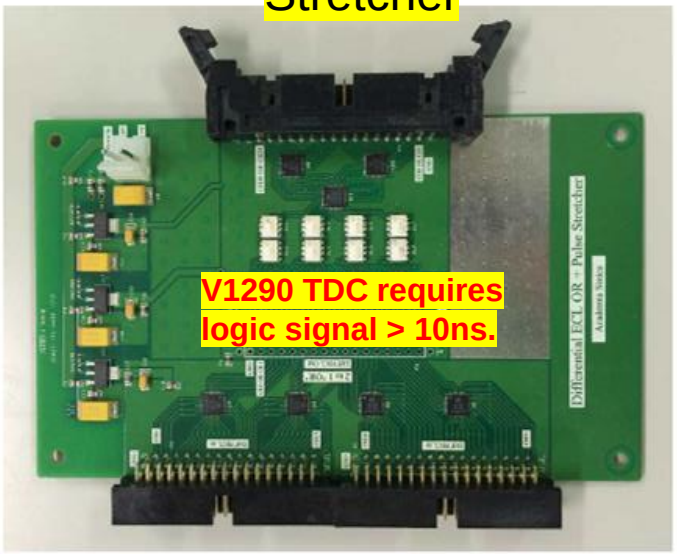
Dr. Ming-Lee Chu

Amplifier



Discriminator

Stretcher



MRPC projects

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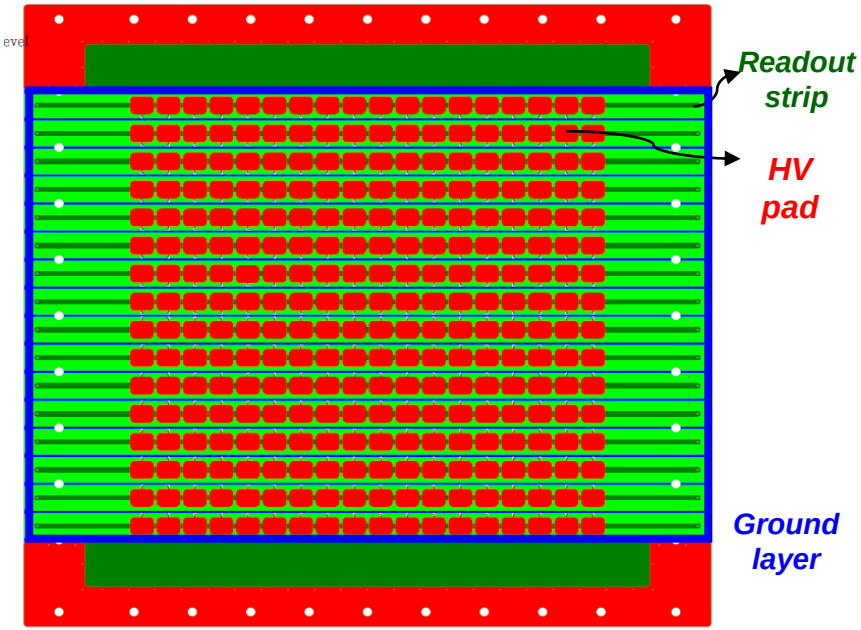
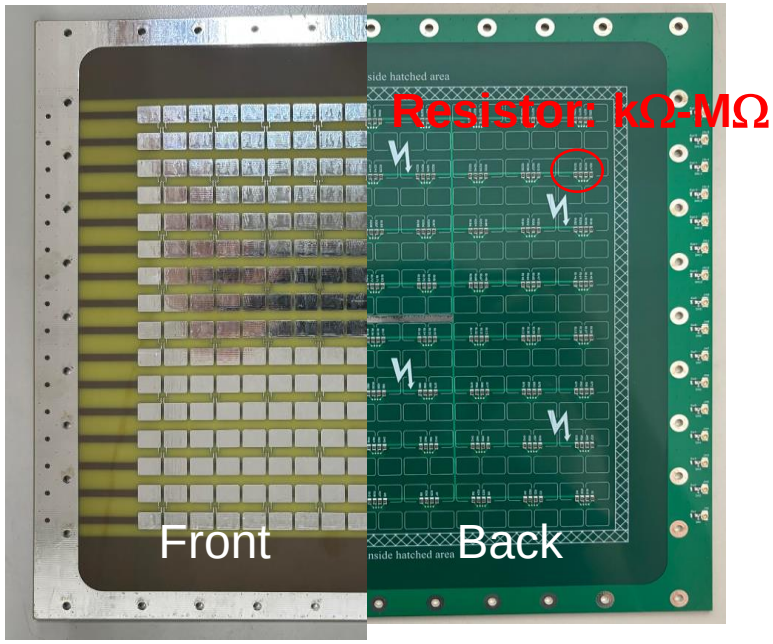
- Starting from 2022, we do R&D of MRPC about
  - Carbonless
  - Mylar spacer
  - Gas seal
  - Noise reduction
  - Signal reflection

Carbonless Electrode

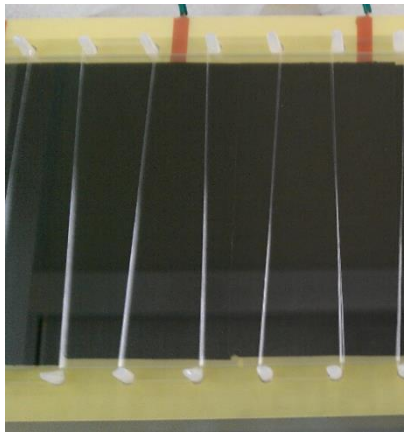


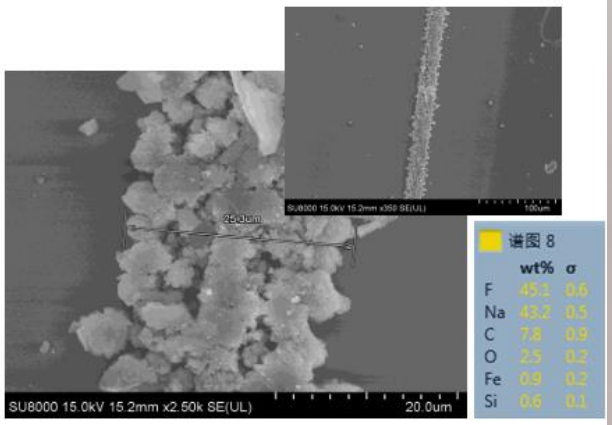


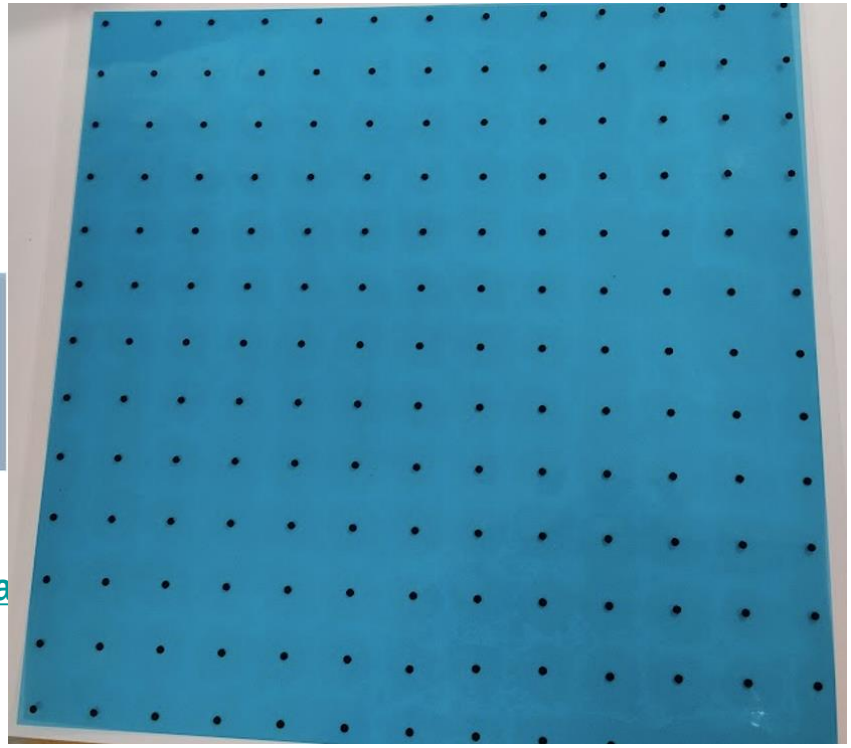
- Supply of carbon tape from Japanese company no longer existed. Carbonless MRPC is inspired by CBM experiment (https://www.sciencedirect.com/science/article/pii/S0168900222009135?via%3Dihub).
- Carbonless electrode : Replace the **carbon electrode** by an array of **copper pads** (PCB ready) connected by kΩ-MΩ resistors. The resistors helps reduce the current drawn when the chamber discharges.
- **PCB**:

(1) **Narrow readout strip** (~ 4mm), reducing the signal propagation modes with slower speeds for a better time solution
(2) **HV copper electrodes** (carbonless electrode)
(3) **Ground layer** for the impedance match through transmission line calculation

Mylar Spacer





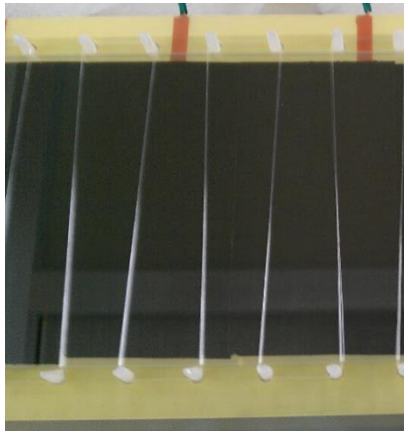


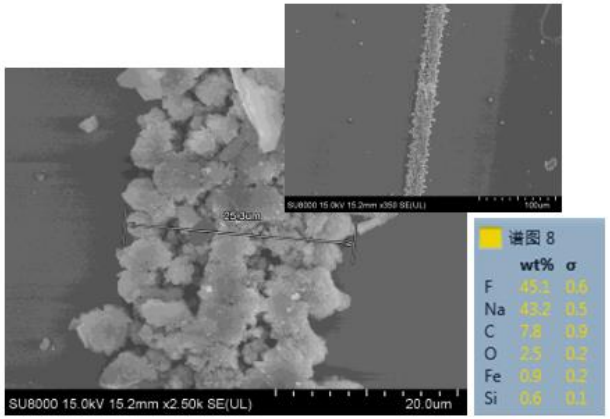
Aging effect of fishing line
(https://indico.gsi.de/event/13648/contributions/58177/attachments/37930/50957/botan_MRPC2_20211123.pdf).

- Long-term operation of MRPC with gas mixtures based on C2H2F4 and SF6 leads to **aging effects**, observed as **depositions on the surface of the resistive electrodes and fishing line**. This results in a higher dark current rate. (https://arxiv.org/pdf/2105.12214)

- **We replace the fishing rod by the sheet of Mylar spacer.** Usage of the Mylar spacers (~0.25 mm thickness) highly industrializes the assembly work.

Mylar Spacer





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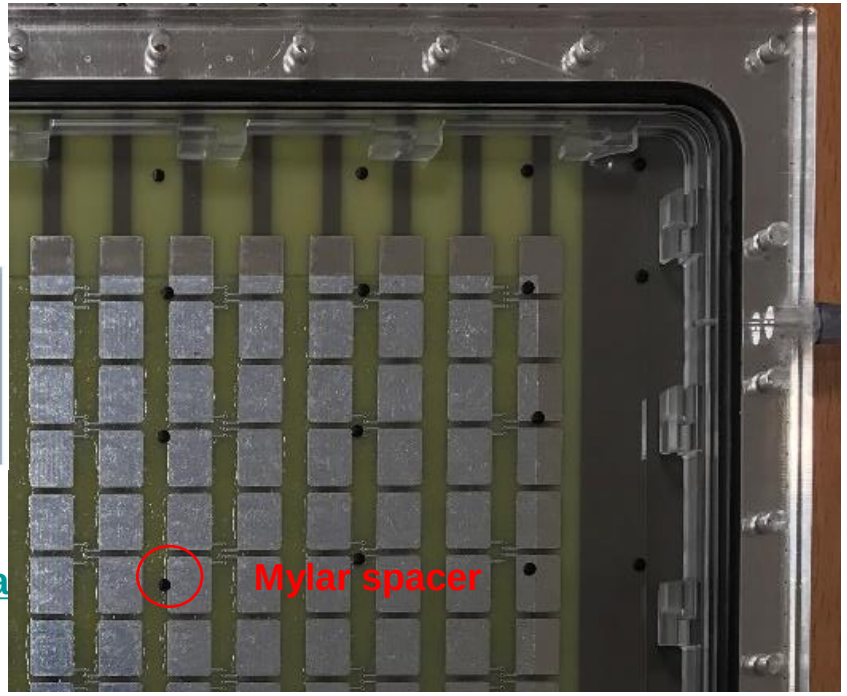

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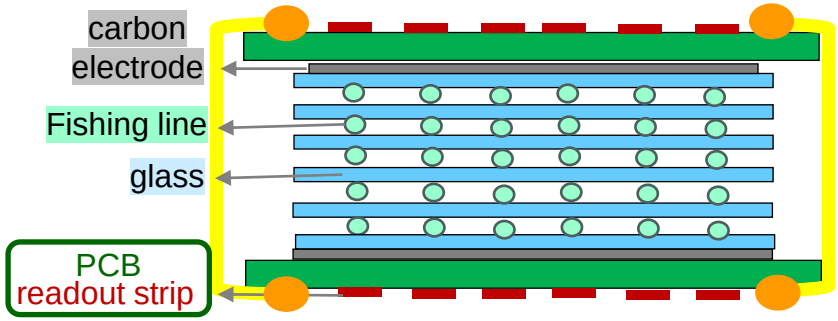
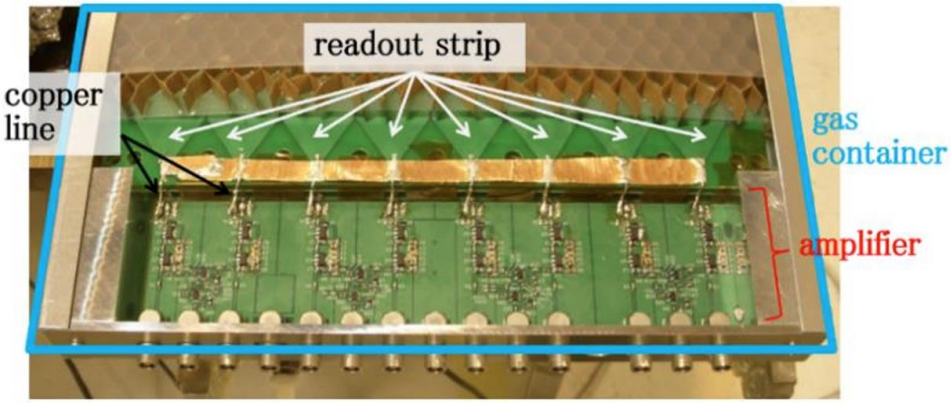
Gas Seal - Glue

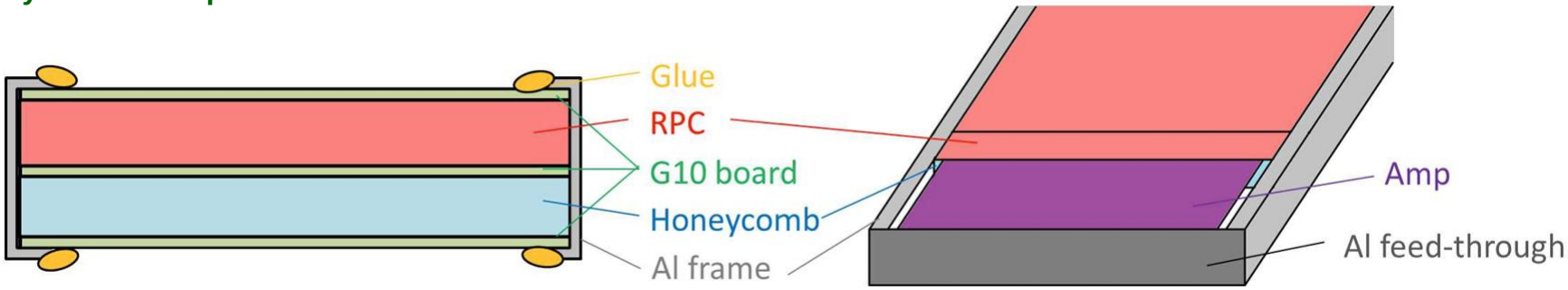
BGO-egg MRPC

Al case + Glue sealed





Only readout strip on PCB



- We used glue to seal the gas chamber, but the **seal was easily broken during transportation.**
- **For the glue-sealed chamber, amplifier needs to be placed very close to the readout strip inside the chamber. This makes it difficult to maintain the electronics if any issues arise.**

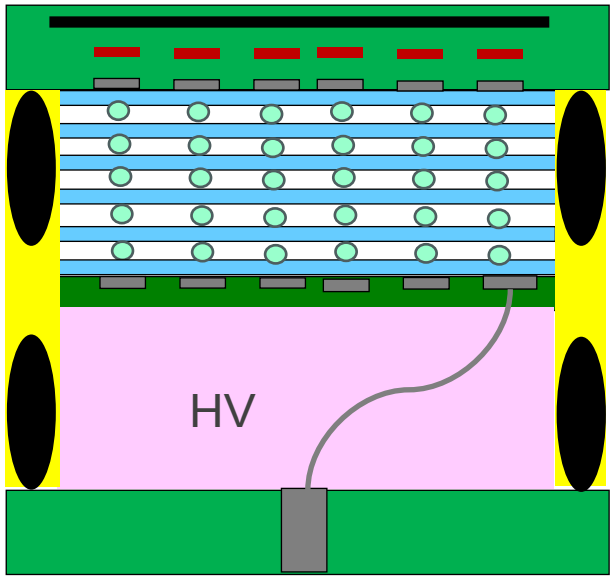
Gas Seal - Mechanical way with O-ring

AS MRPC : 1st prototype with O-ring

PCB ground layer
readout strip
copper pad electrode

Oring
Acryl frame
Buffer material

PCB
copper pad electrode



One **PCB includes ground layer, the readout strip, and electrodes**, and is used as the **cover of the chamber, creating a so-called self-sealing chamber**. The PCB must be **as thick as possible** to provide strong support for the gas chamber (1.5 mm in our case).
The amplifier can be connected outside the gas chamber in this configuration.

It requires the minimum height of the frame to be larger than 7 mm due to the usage of O-ring, which is almost twice the needed space of the chamber. Consequently, **a buffer material had to be placed inside**, and **one of the HV connections was not directly applied to the electrode. Only positive or negative signals can be read.**

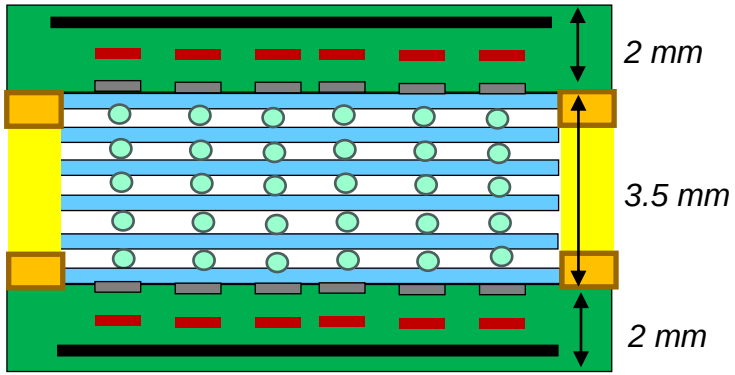
Gas Seal - Mechanical way with Solid Silicon Gasket

AS MRPC 2nd prototype#2 : Silicon Gasket

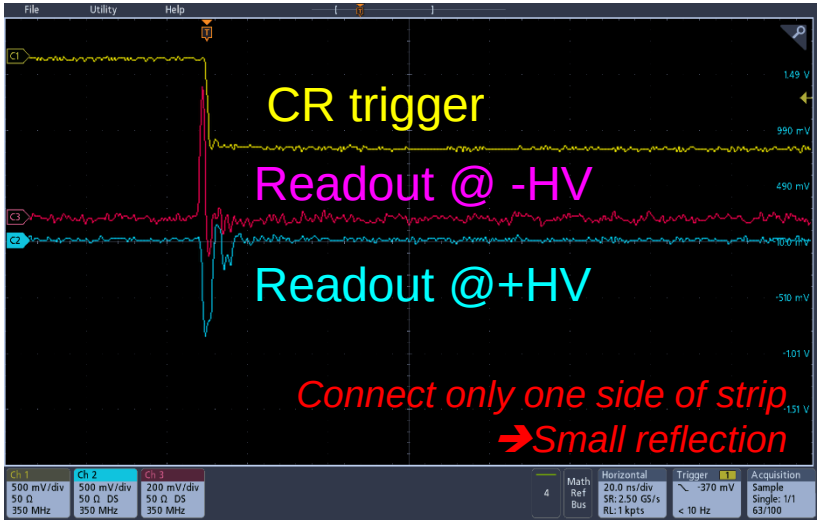
PCB ground layer
readout strip
copper pad electrode

Acryl frame
Silicon sheet

PCB ground layer
readout strip
copper pad electrode

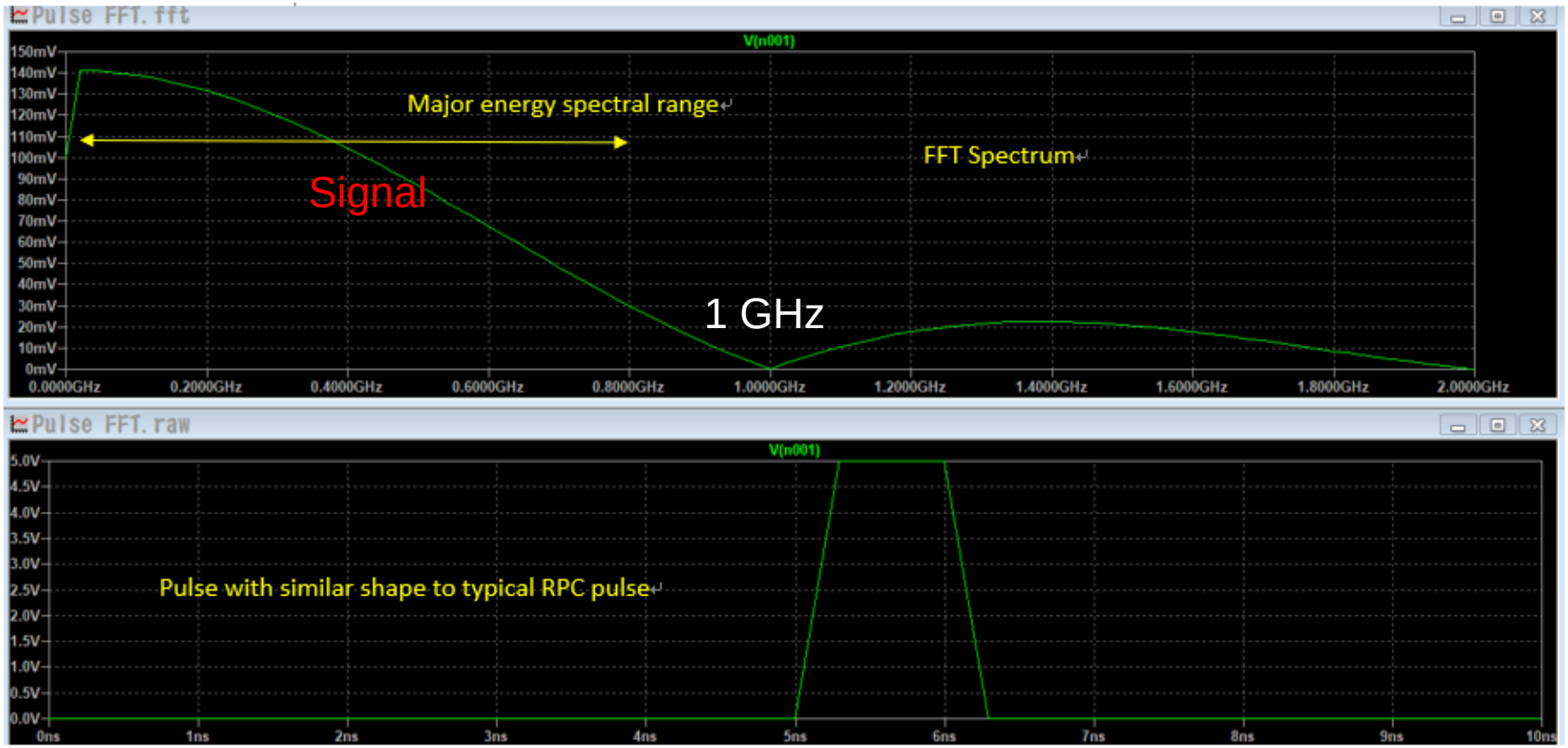


Solid Silicon Gasket : Various thickness and hardness. Shape can be optimized.



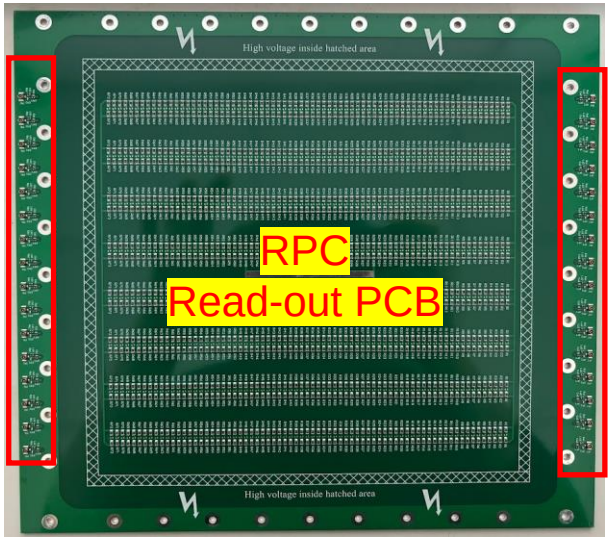
- The thickness of the solid silicon gasket varies from 0.1 mm to 1 mm. **This allows us to have a very thin chamber without the need for any buffer material inside the chamber.**
- This design reduced the material budget. In addition, **both positive and negative signals are read.**
- **Cosmic ray test has been performed, >90% Eff. @ 14kV. Beam test will be performed soon in July 2024.**

RPC signal vs. [Noise & RF interference]



- Typical RPC pulse energy is practically within 1GHz
- The amplifier we used have bandwidth of 10MHz to 2GHz
- Environmental RF is practically full the 1MHz to way over 2GHz.
- We are suffering noise from RFI, does RFI degrades our timing measurement (We can see noise, how bad it is?)
- => add filter to the output of each element

Noise Reduction with 3-Stage Low-Pass Filters



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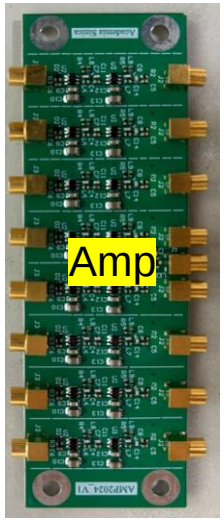


Low-pass filter on read-out side

1st stage

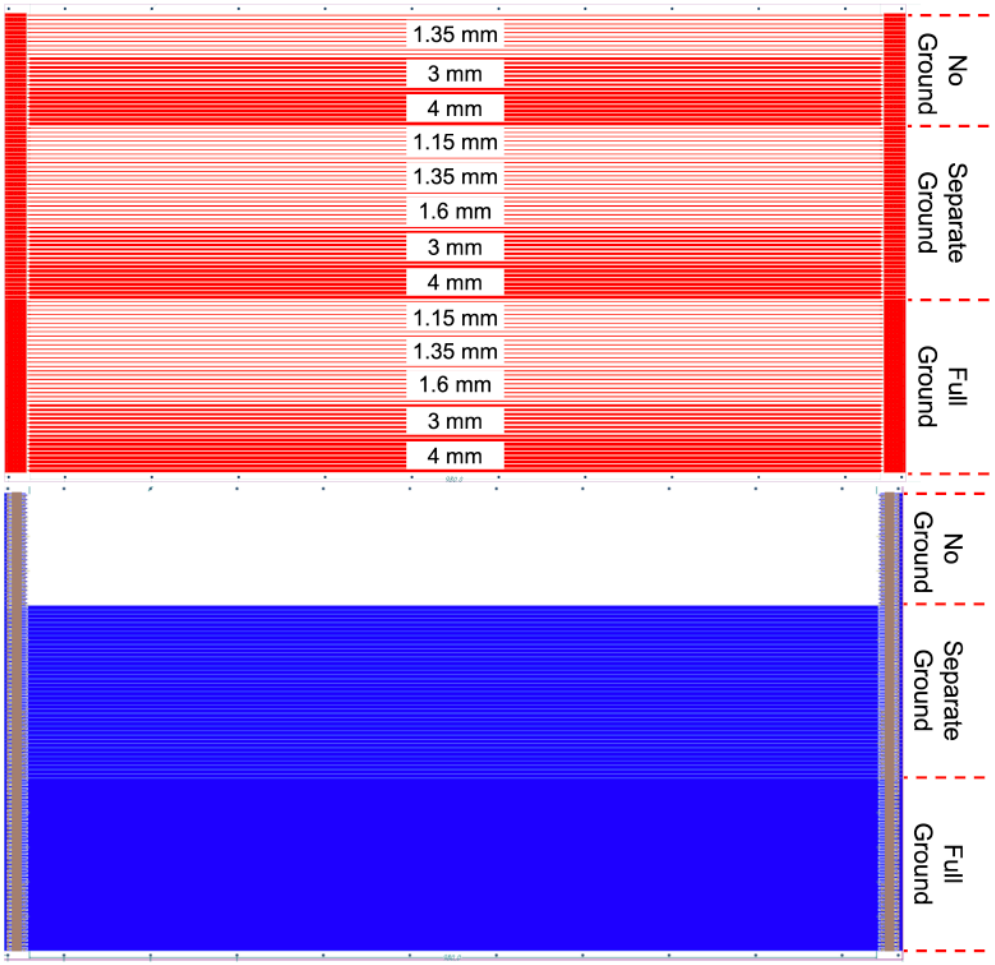
Low-pass filter on Amp side

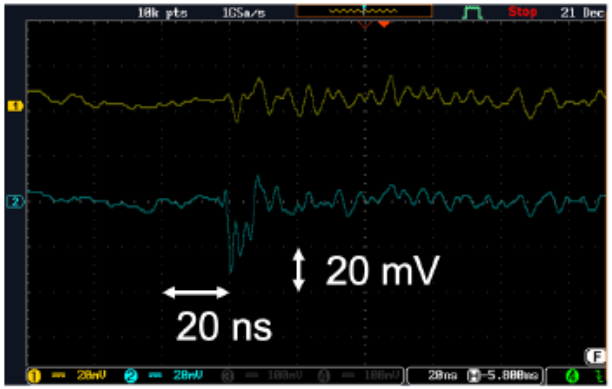
2nd and 3rd stages

- Two-stage low pass filters will be implemented, one on read-out PCB (one stage) and another on the side of amplifier (two stages).
- RPC signals are < 1 GHz and the environments signals from the radio or cell phones are usually > 1 GHz. Low pass filters are designed to amplify the major component of signals.

Improvement of Signal Reflection

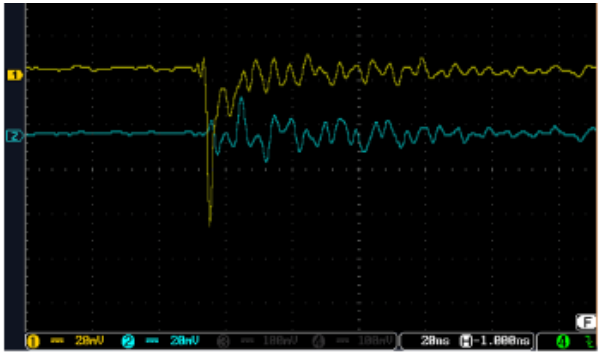
MARQ Tracker prototype



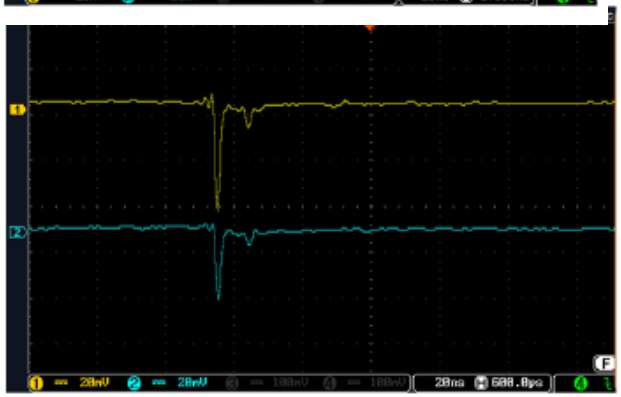


4mm

No Ground



Separated Ground



Full Ground

Reduced reflection w/ full Ground.

Outlook

- Future R&D:
  - Double-stack MRPC
  - Large size (~1m long) ➔ Series chain of chambers
  - Stability of operation
- Our group, together with NCU group, join the CERN DRD1 (gaseous detectors) Collaboration. Look forward to more international collaborations on MRPC development.