Development of MRPC

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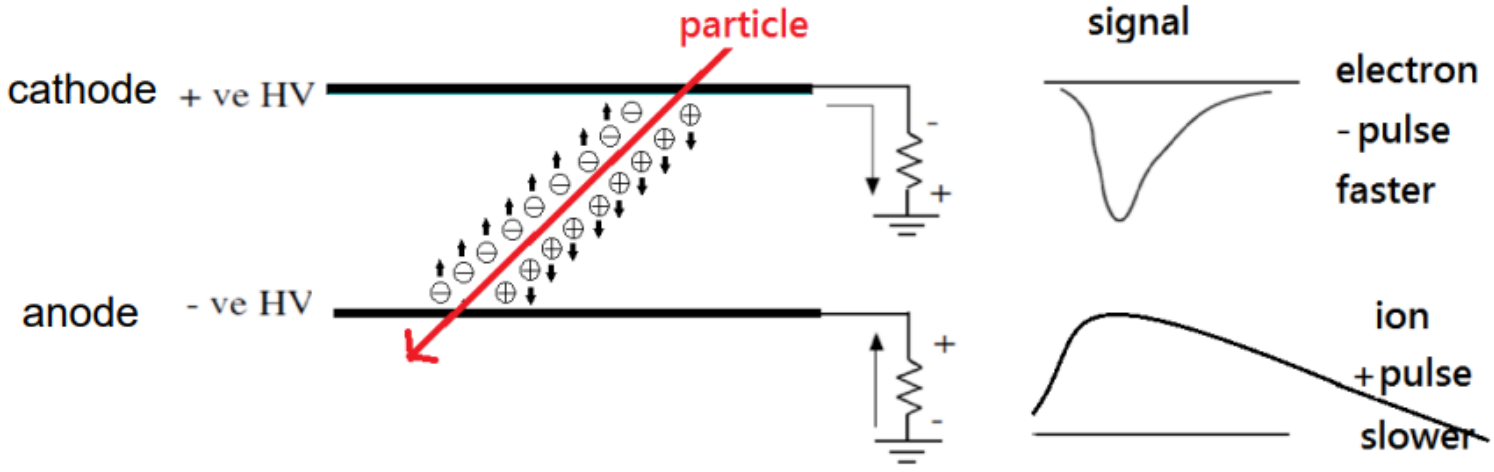
Outline

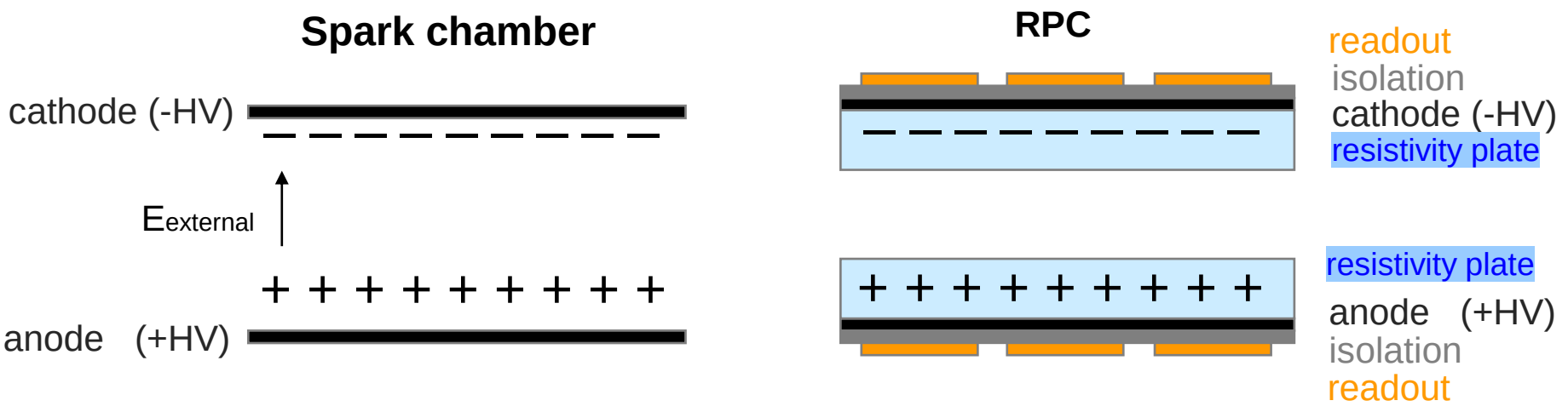
- Basic of MRPC
- Development of MRPC in Taiwan
- Carbonless MRPC

Gas Ionization Chamber

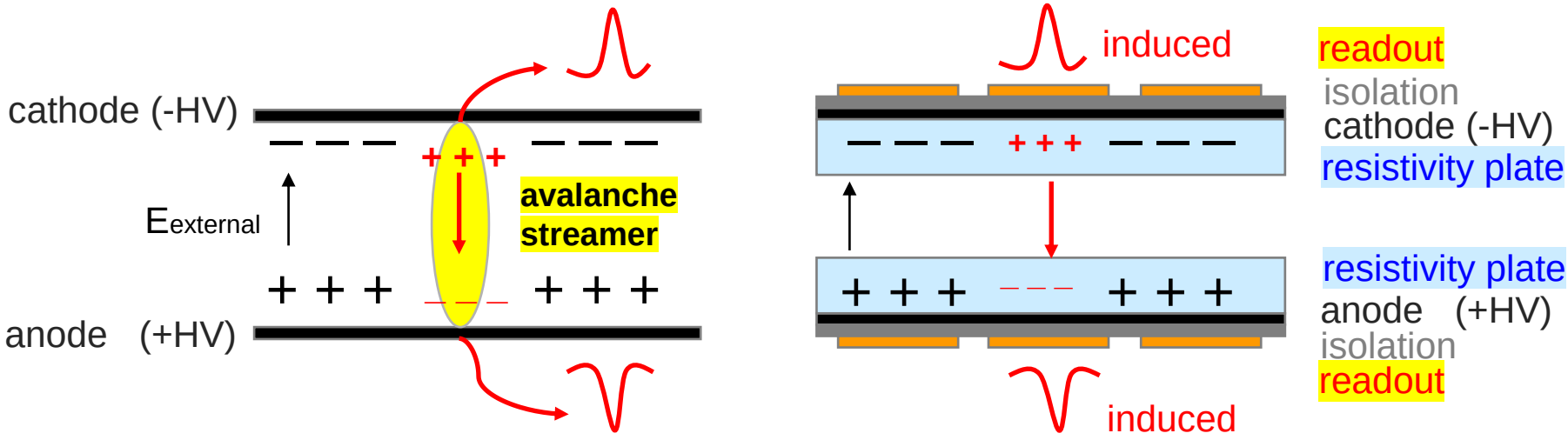


Incoming particles ionizes gas molecules.
➔The resulting ions and electrons drift in an applied electric field.
➔ Generating a measurable electric signals.

Resistivity Plate Chamber (RPC)

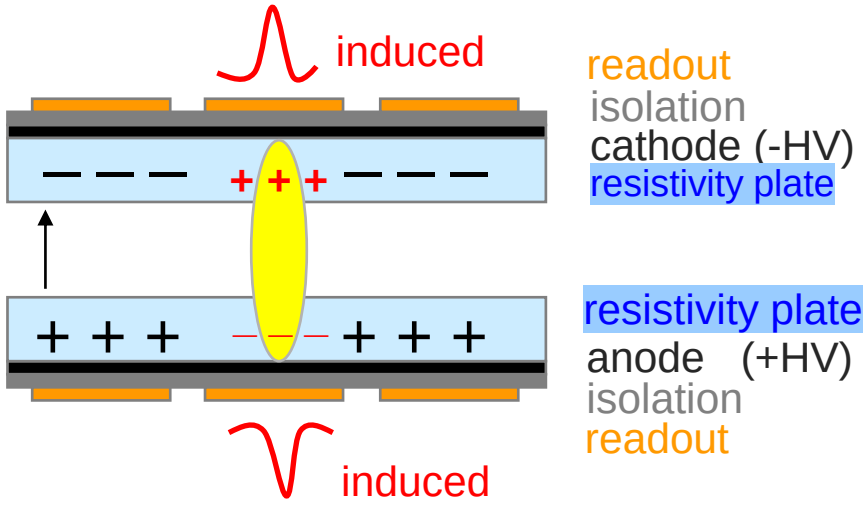


Resistivity plates are added in between electrodes ➔as quencher to prevent spark.



Induced signals readout for RPC

Feature of Resistivity Plate

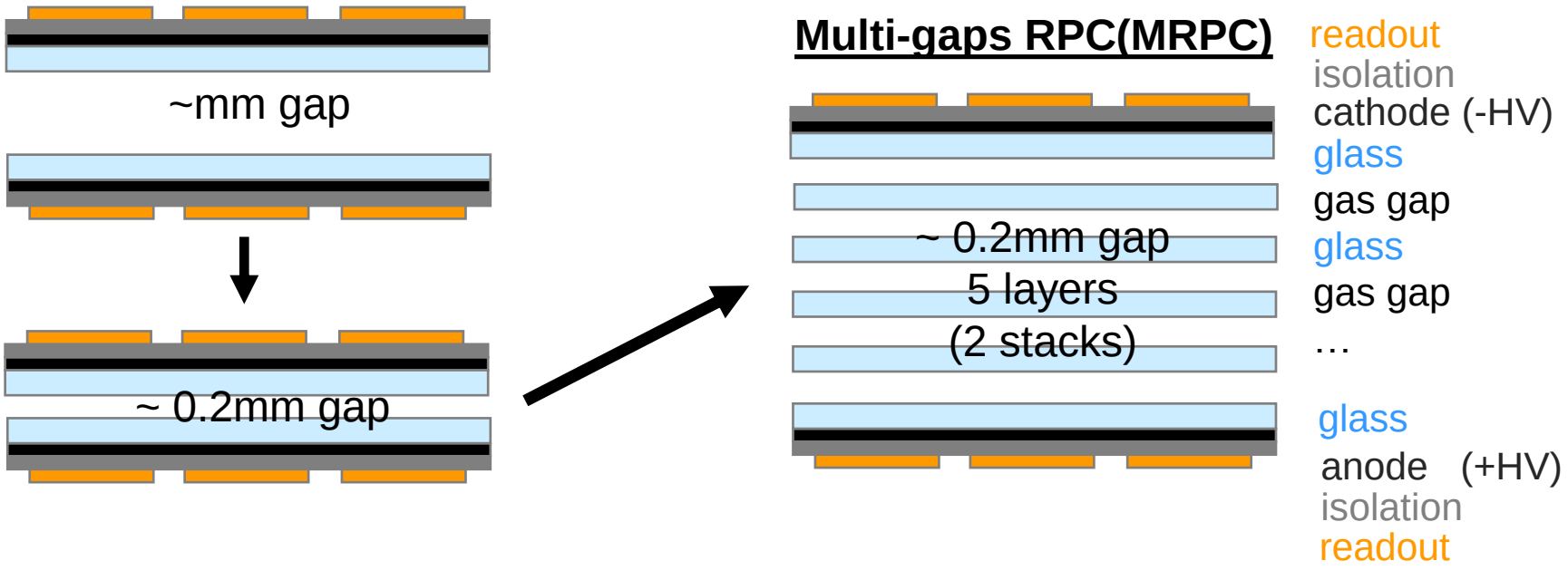


- **Resistivity plate**

Resistivity plate plays a role as quencher to prevent the spark and the spread of discharge. It localizes the voltage drop and decrease the size of avalanche cluster. Due to the small-size cluster, the signals is usually small and sharp.

- **Advantage** : A good time resolution is achieved.
- **Disadvantage** **:** Low-rate capability due to slower response to the electric field.
- **Choice of resistivity plate :** glass(~ 10^{10} Ohm/cm^2– 10^{12} Ohm/cm^2), Bakelite (~ 10^{10} Ohm/cm^2)

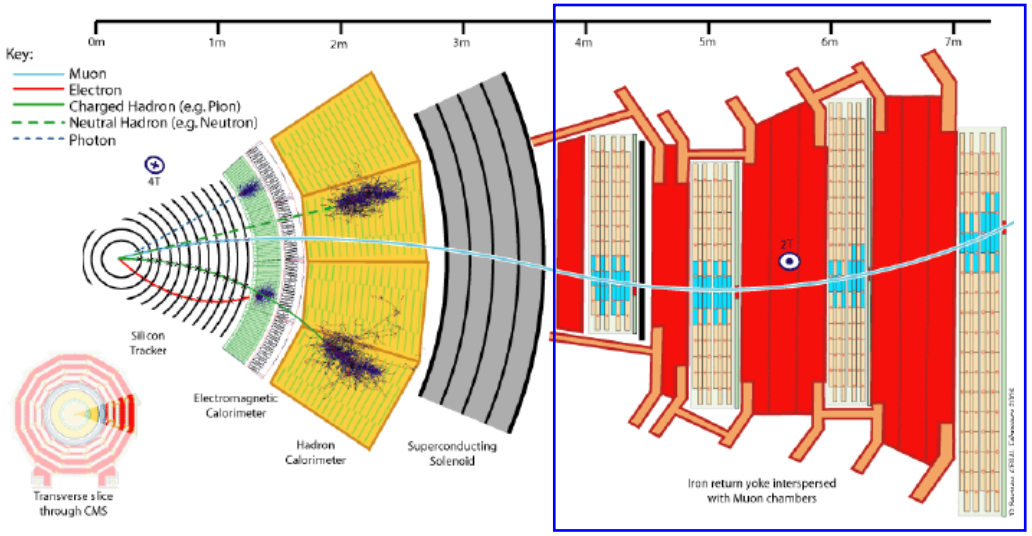
Multiple-Gap RPC (MRPC)

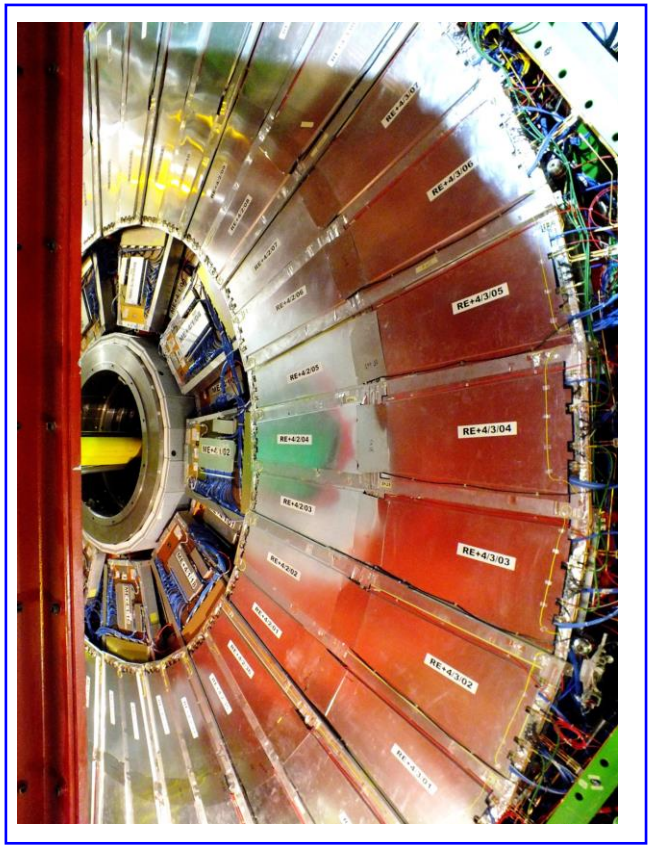


- **Single-gap RPC** : gap size ~ mm, single gap, ns time resolution
- **A thin gap improves time resolution** because it reduces the spread in the avalanche development time, leading to sharper and faster signals.
- However, the **signal amplitude becomes too small** to be reliably detected by the electronics.
- **Multi-gap RPC** : gap size ~ 0.2 mm, multiple-gaps, ~100 ps time resolution
- **To overcome the small signal issue, multiple thin gaps are stacked together**.
- This design **enhances the signal strength (from multiple avalanches) while retaining good time resolution.**

Suitable Condition for RPC

CMS : use RPC as muon wall





- **Advantages**

① Good time resolution<100ps ➔ Time-of-Flight (TOF) (similar to scintillator counter)

② Cheap and easy to build into large area

- **Disadvantage**

① Low rate capability <100kHz ➔ Cosmic ray exp.

② Small induced signal ➔ require low noise amplifier

RPC could be a good candidate to substitute scintillator counter if the experimental environment is in low-rate condition. It is a much cheaper choice. Normally it is used as TOF in HEP experiment or tracker in cosmic ray experiment.

MRPC Development
Collaboration between Japan and Taiwan

10 yrs ago..

BGO-egg TOF
2.5cm* 1m long strip
>99% eff.
50ps time resolution

→

LEPS2 TOF
2.5cm* 1.8m long strip
>99% eff.
70ps time resolution

→

Now

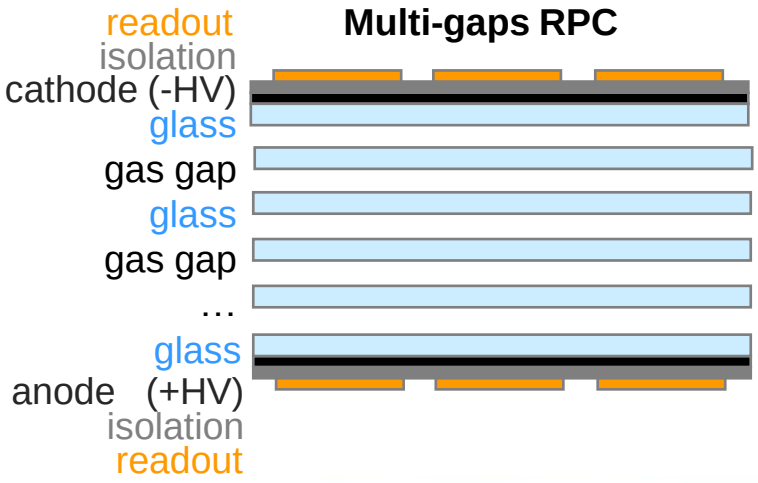
MARQ TOF
2.5cm* 1.8m long strip
>99% eff.
60ps time resolution

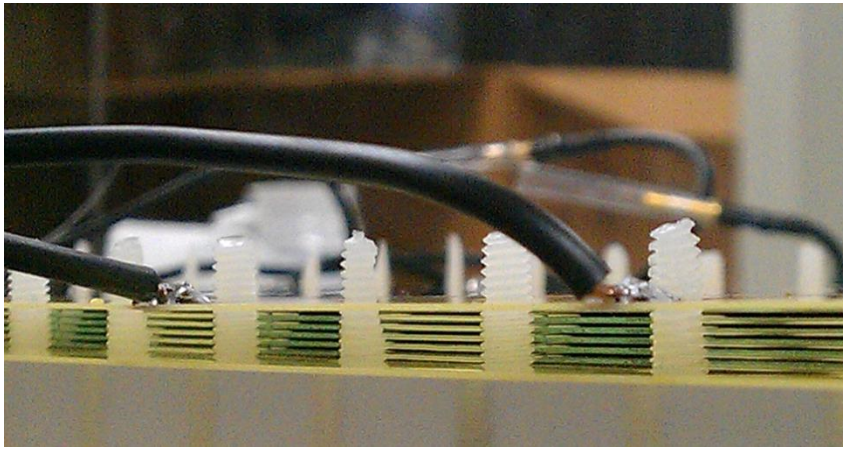
MARQ Tracker
1mm*3.5m strip
>99% eff.
1mm position resolution

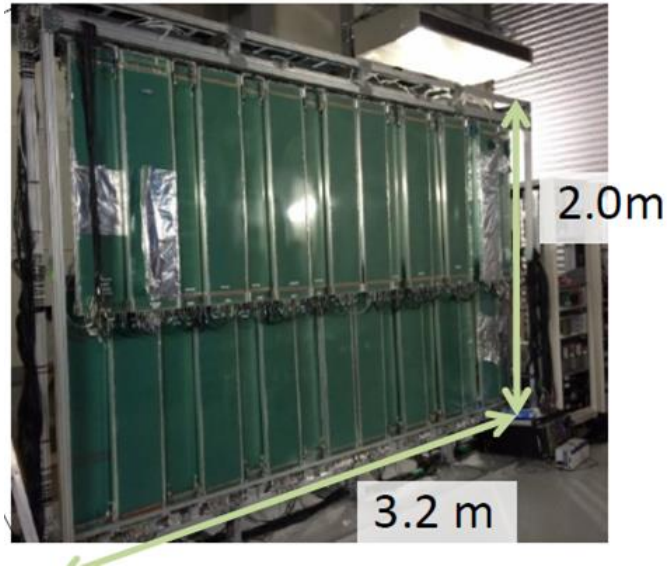
In 2012, a team led by Prof. Wen-Chen Chang and Dr. Ming-Lee Chu at Academia Sinica collaborated with a Japanese group led by Prof. M. Niiyama from Osaka University and Prof. Natuki Tomida from Kyoto University to develop RPC technology. **Taiwan's primary contribution to BGO-egg TOF and LEPS TOF was on the development of electronics.**

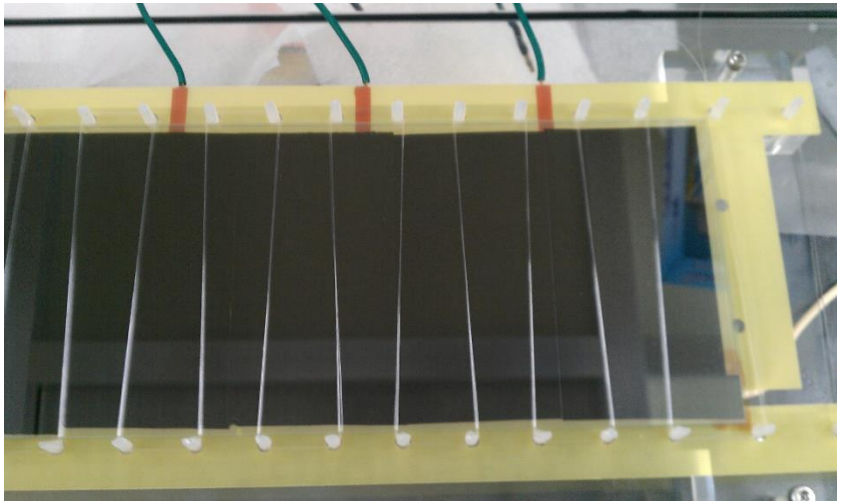
The carbon tape previously used is no longer available. For the development of MARQ MRPC, **we initiated a carbonless MRPC starting from 2022 in Taiwan. Academia Sinica and NCU start to work together for this project.**

BGO-Egg MRPC





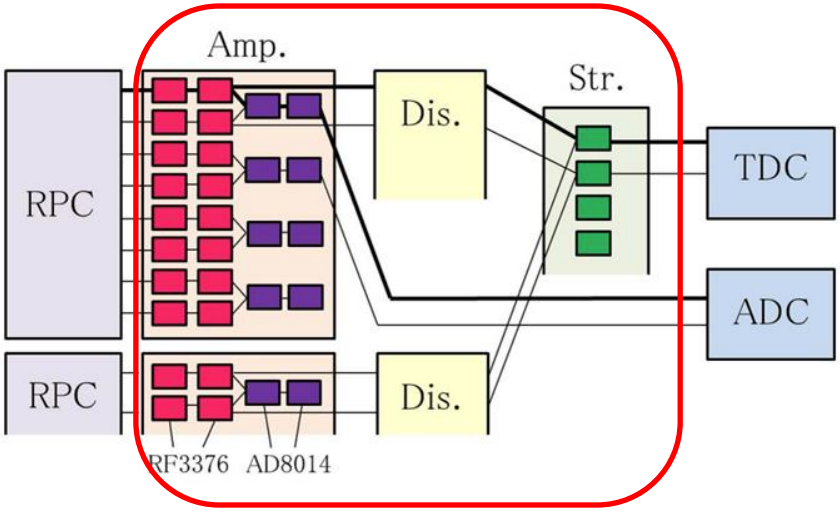




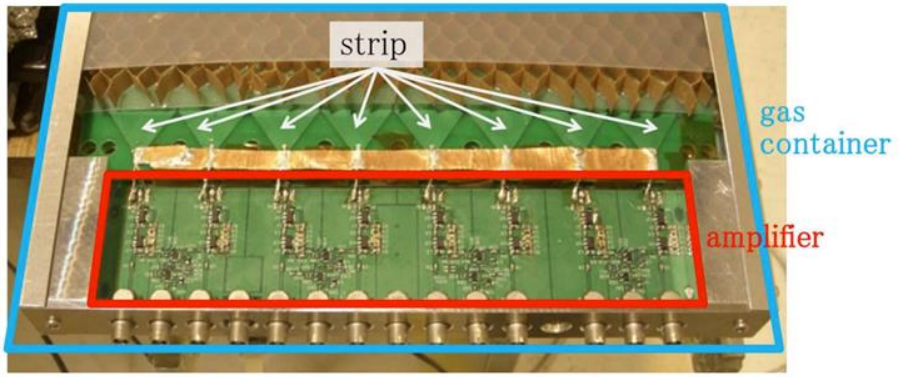
stably running from 2014

>95% Eff. and ~50ps time resolution

Electronics of BGO-egg MRPC

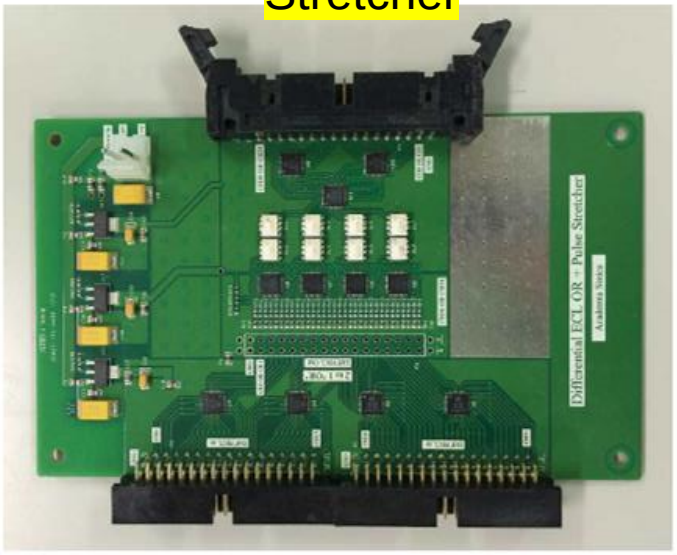


Amplifier



Discriminator

Stretcher



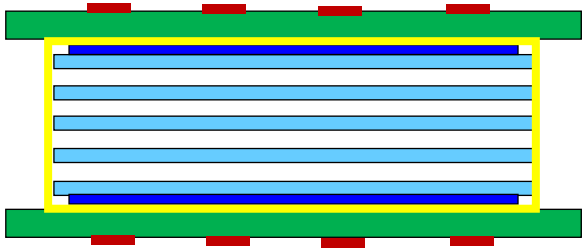
Carbonless MRPC

Traditional MRPC

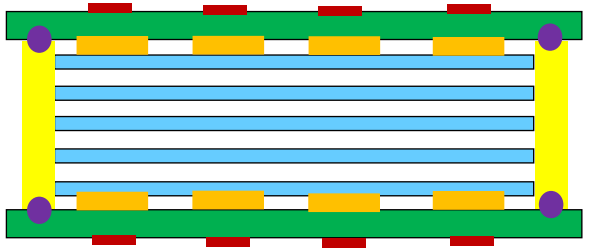
Carbon electrode

Gap by fishing line

Acryl case Glue sealed



New : Carbonless MRPC



Copper-pad electrode

Gap by Mylar spacer

Silicon gasket sealed

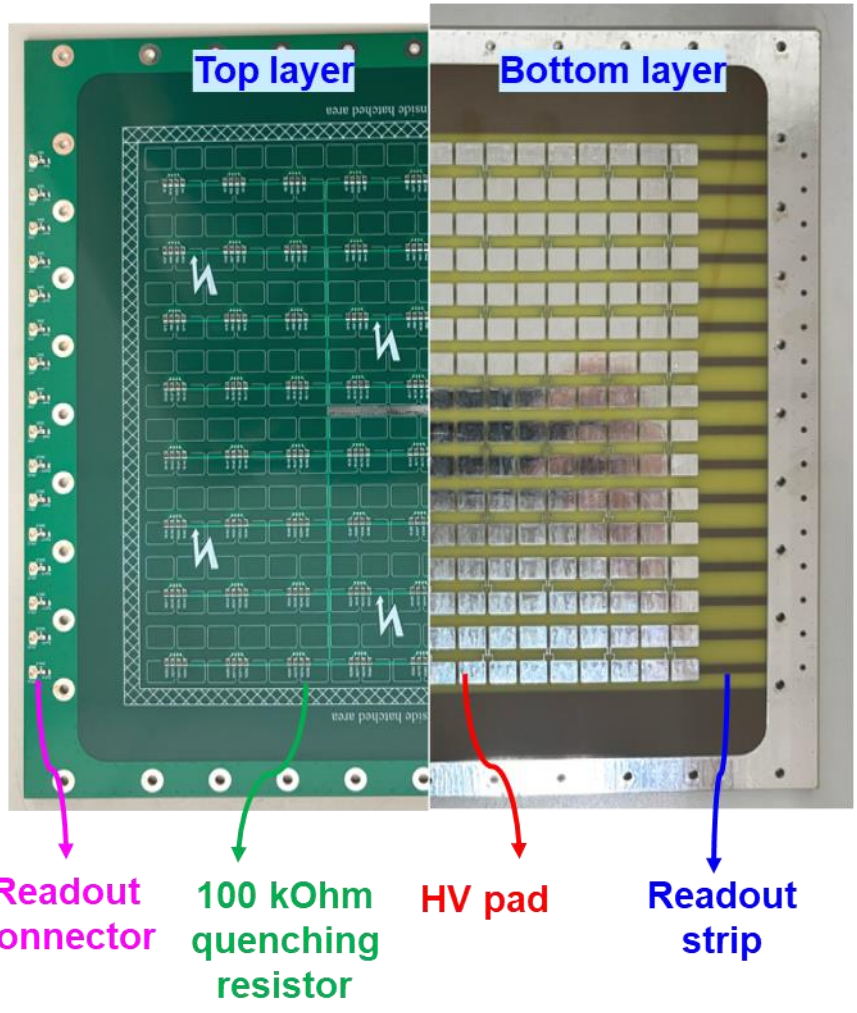
- **Carbonless RPC**
- Carbon paint/spray/tapes (MOhm) ➔ “copper pads” with resistors (~MOhm) connected in between.
- It is easily manufactured by PCB technique. Assembling of RPC becomes more standardized.

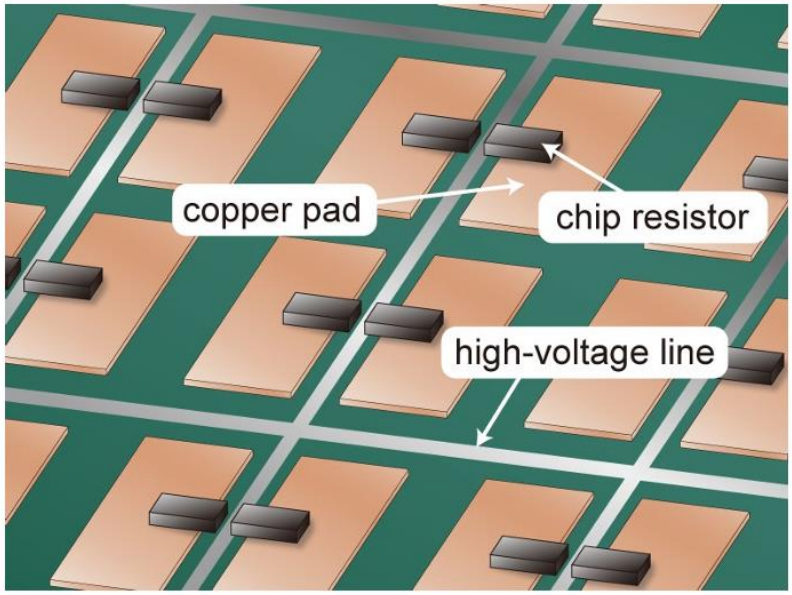
- **Gas gap by Mylar sticker**
- Reduce ageing effect
- Easy for assembling.

- **New gas sealing**
- Glue is easily be damaged during the transportation.
- Solid-silicon gasket sealed is used for the new chamber.

Carbonless Electrode w/ PCB Technique

PCB = Electrode + Read-out Strip

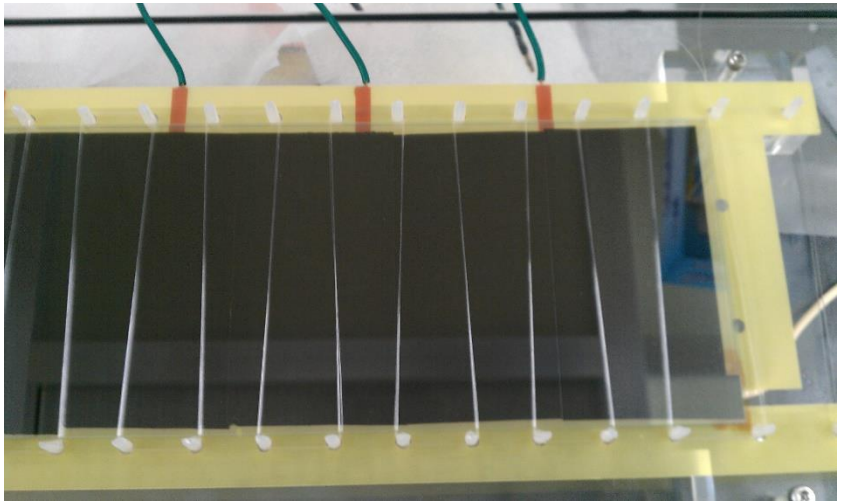


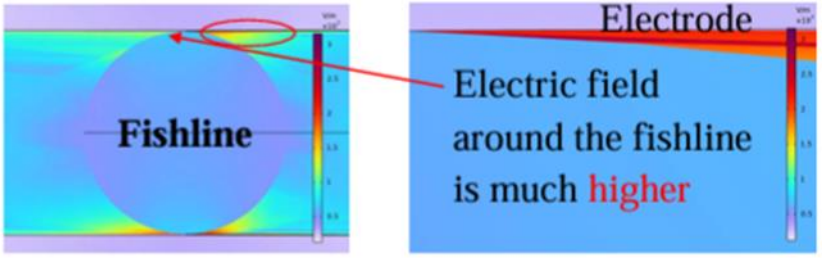


The electrodes of gas detectors are typically coated with carbon. In contrast, **carbonless electrodes use high-voltage electrodes that combine copper pads and MOhm resistors to mimic carbon electrode.** The high voltage is supplied to the copper pads through the resistors, creating an equipotential, while the resistors help reduce the current drawn by the electrode. **A single PCB can be used for both the electrode and the readout to simplify the structure of RPC.**

Mylar Spacer

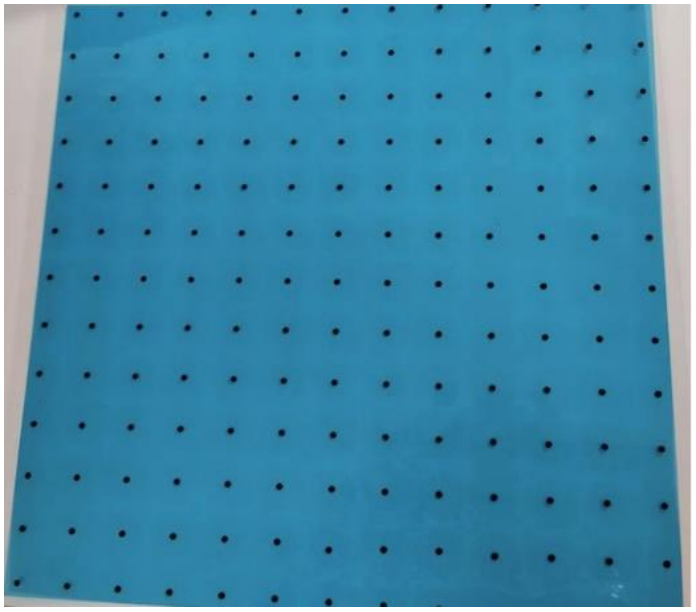
Fishing line





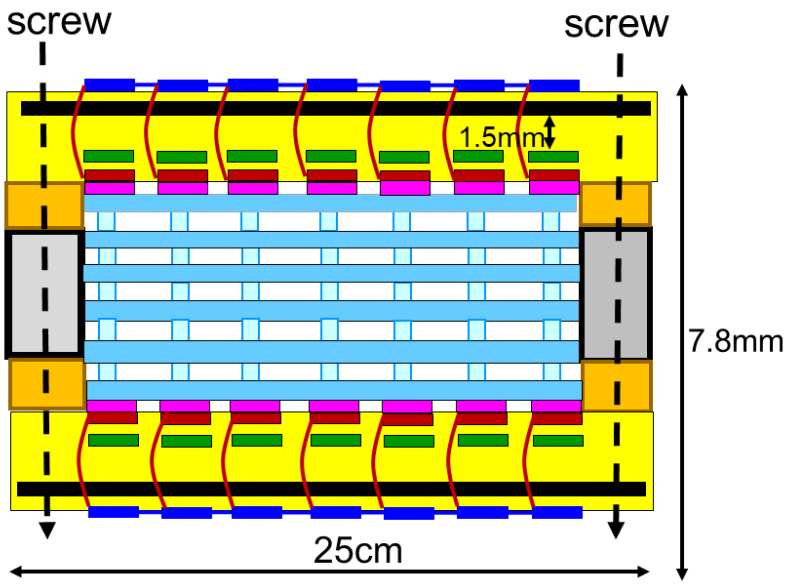
Traditionally, the gas gap in MRPCs is maintained using fishing line. However, **fishing line suffers from significant aging effects due to the fluoride.**

Mylar spacer



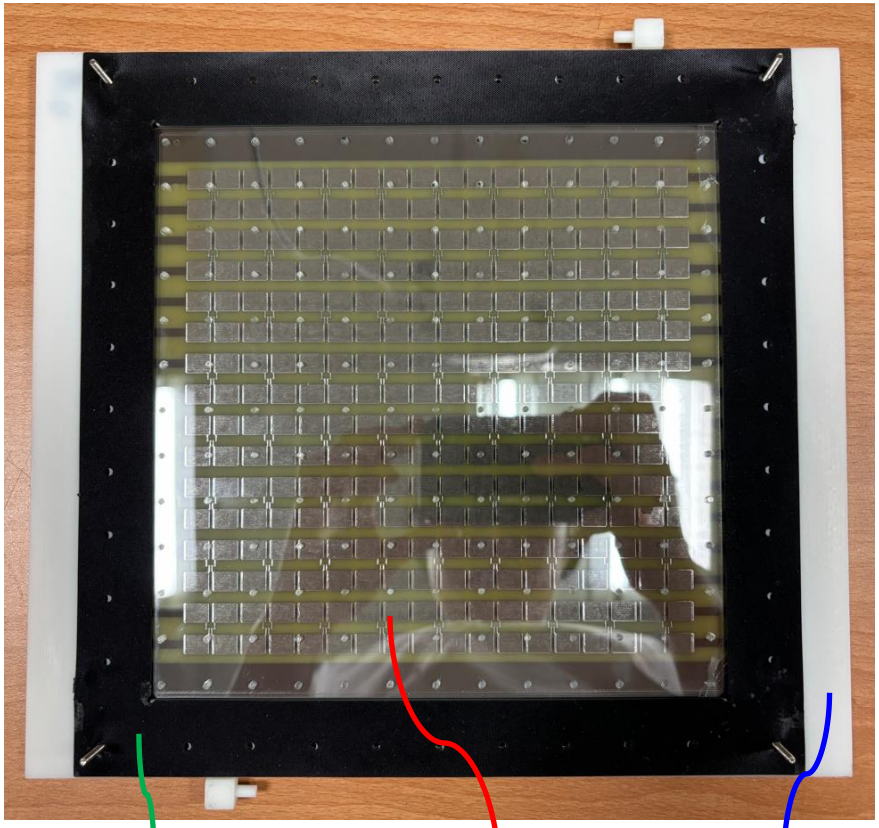
Recently, **Mylar/Kapton spacers have been proposed as an alternative.** Producing Mylar spacers with a thickness of around 0.2mm has been a challenge for research groups worldwide. **A Taiwanese company now provides a stable and reliable supply of these spacers.**

Carbonless MRPC



Structure ~ 8mm thickness

Multilayer PCB (2mm)
Silicon gasket (0.5mm)
Frame (glass+gap)(2.8mm)
Silicon gasket (0.5mm)
Multilayer PCB (2mm)

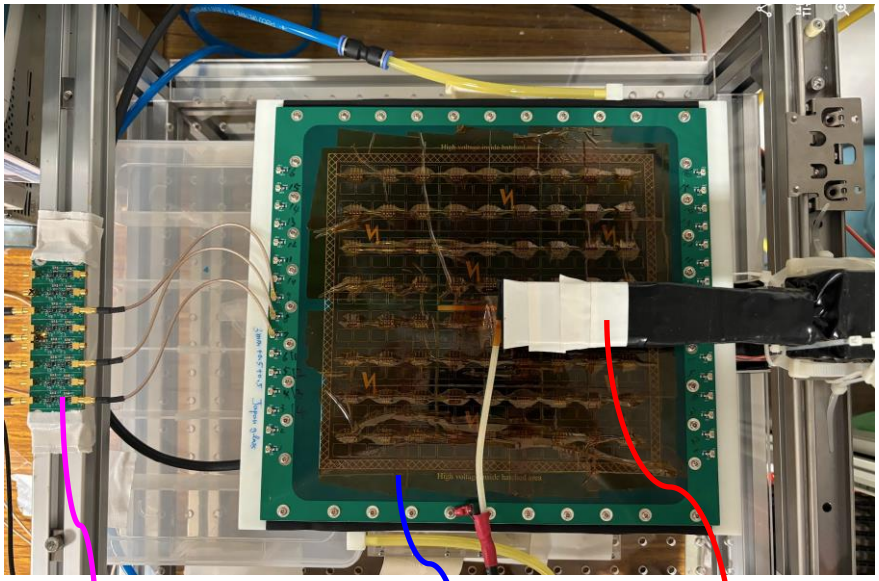


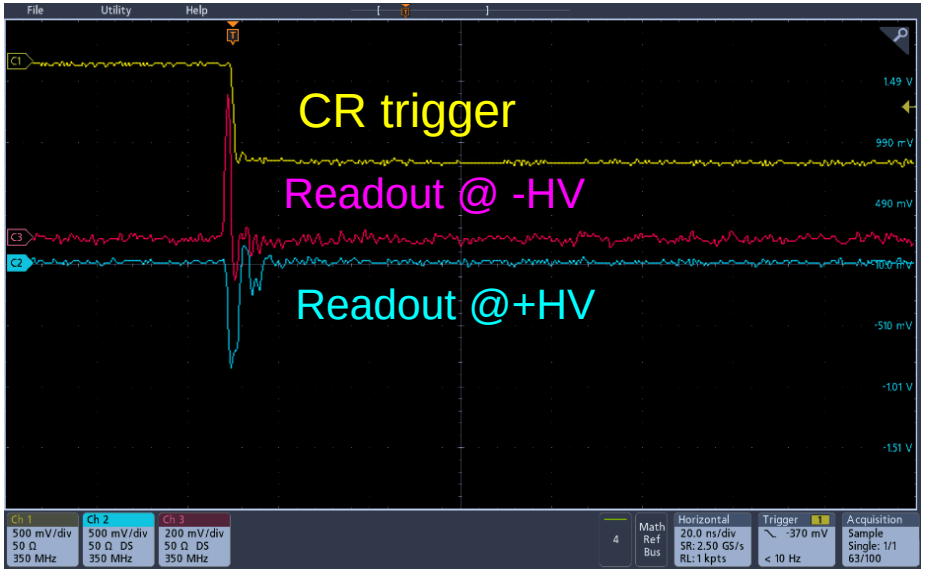
Silicon gasket (same hardness as O-ring)

PCB
+ Glass
+ Mylar sticker
+ Glass
+ Mylar sticker
…

Frame by 3D printer

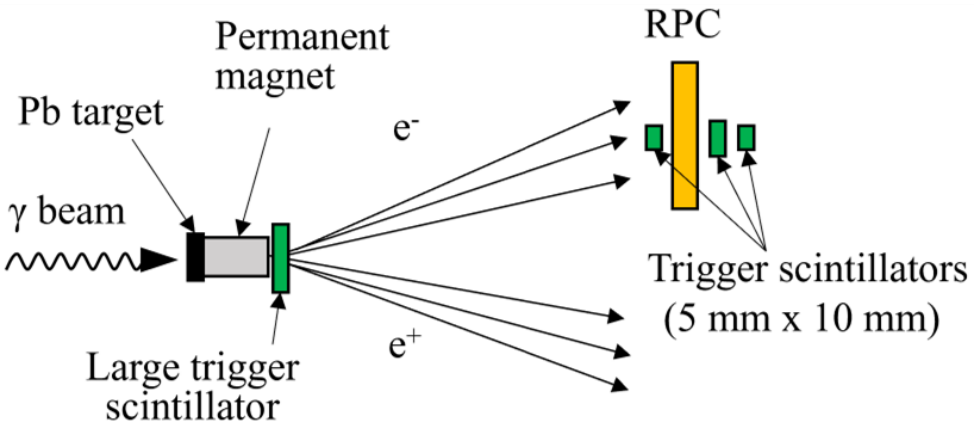
Cosmic Ray Signals





- Reasonable cosmic ray signals observed, ~ 1ns raising time.
- Both positive and negative signals are sharp and fast.
- Stable running w/ cosmic ray > 2 weeks.

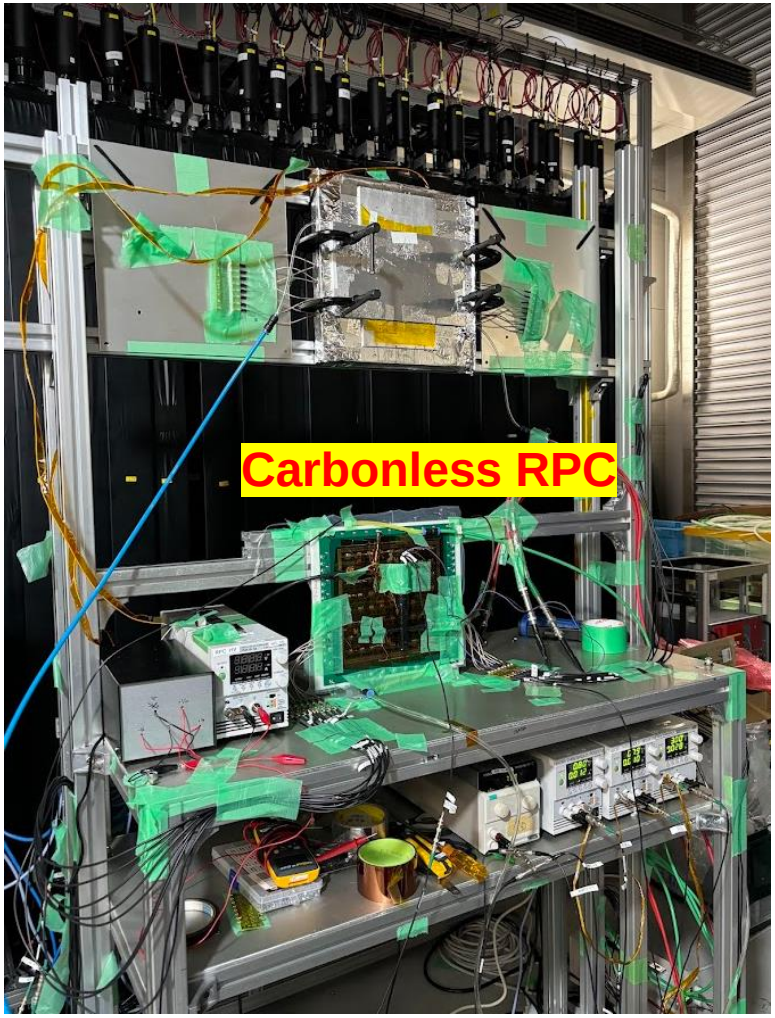
Beam Test @ SPring-8



$$Efficiency = \frac{RPC \;\&\&\; trigger}{trigger}$$

$$TOF = RPC - T0 = \frac{R + L}{2} - T0$$

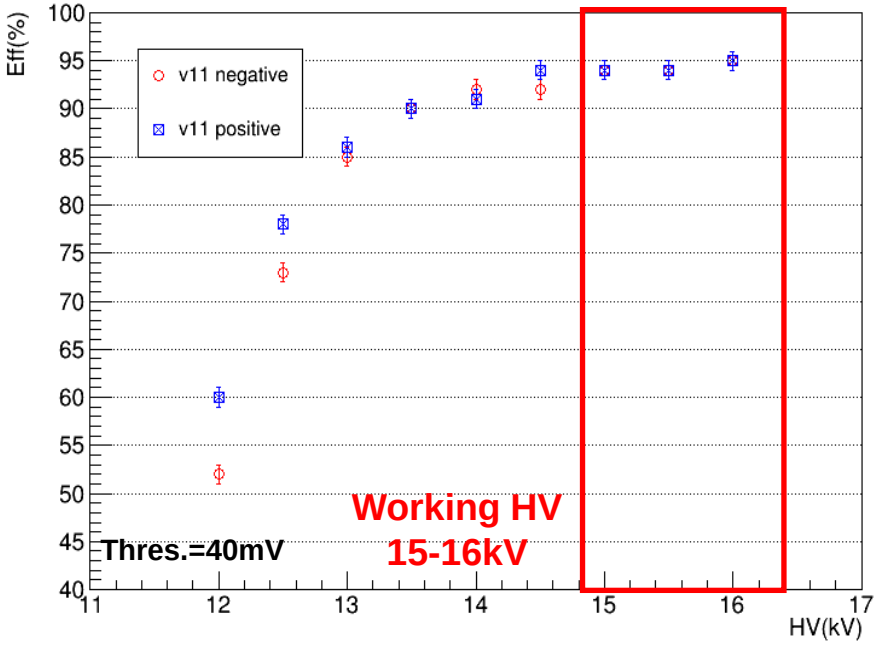
$$\sigma_{all}^2 = \sqrt{\sigma_{RPC}^2 + \sigma_{T0}^2}$$



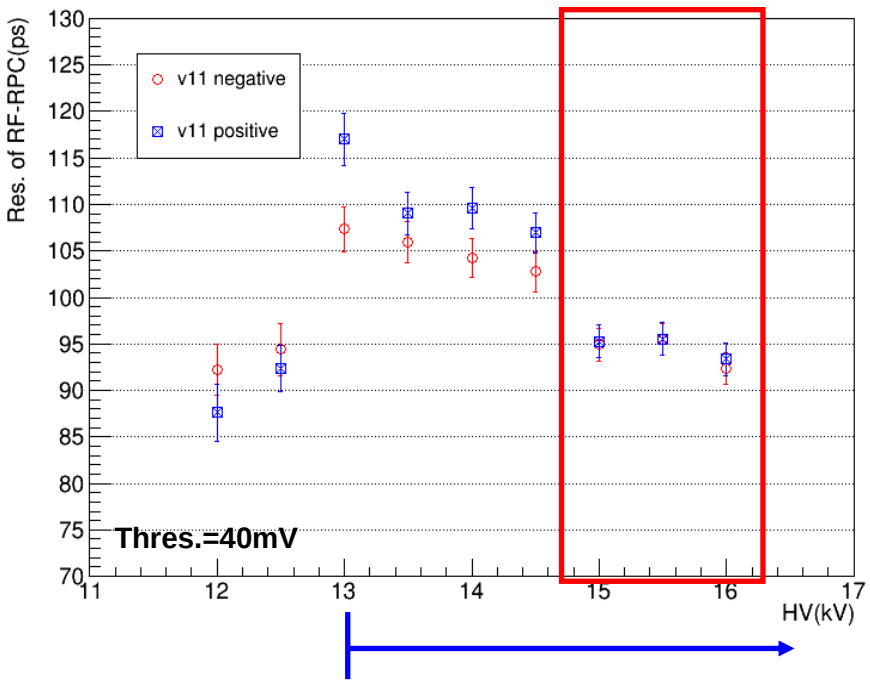
- Beam test was performed with electron beam with low rate < $3kHz/cm^2$.
- **Time resolution includes jitter of T0 ~ 15ps.**

Best Test Results : HV Scan

Efficiency



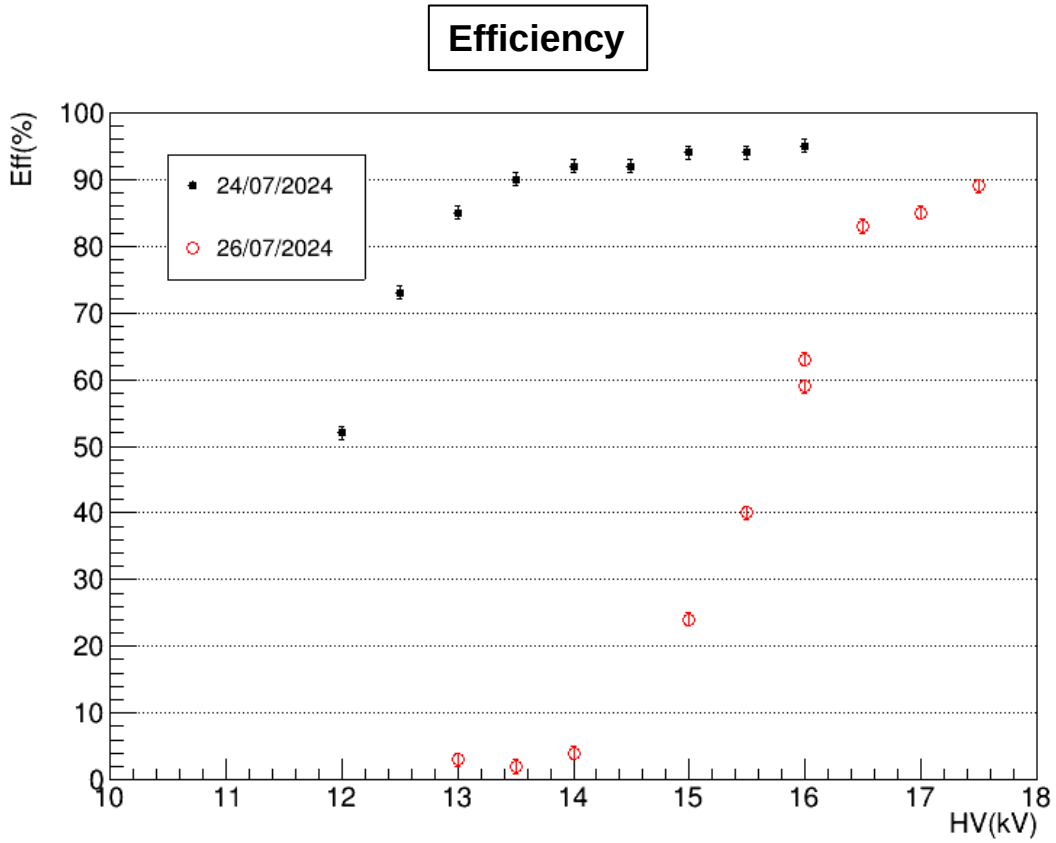
Resolution



>13kV, Poor slewing correction

- Positive ang negative signals have the same performance.
- **95% efficiency and 95 ps time resolution**.

Best Test Results : Stability



- Efficiency drops after two days operation in hall.
- We suspect there might be current leakage in the multilayer PCB.
- We will try thicker PCB from 2mm to 5mm.

Summary and To Do

- RPC is a gas chamber made with a high-resistivity plate, known for its excellent time resolution, making it ideal for time-of-flight detection. It is also inexpensive and easy to construct, which makes it a potential alternative to scintillator counters. However, RPCs have a limitation in their low-rate capability.

- Academia Sinica and NCU collaborates with a Japanese group to develop RPCs for the BGO-eg, LEPS2, and MARQ experiments. The TOF RPCs for BGO-eg and LEPS2 have been successfully operational since 2014, achieving 99% efficiency and a time resolution of 60ps.

- We are currently developing a carbonless RPC prototype for the future MARQ project at J-PARC, as the carbon tape supply is no longer available. Several new ideas are also tested, such as Myler spacer, silicon gasket, etc. The prototype has demonstrated around 95% efficiency and a time resolution of approximately 95ps. However, challenges such as stability remain and require further investigation.

Backup

Carbonless MRPC

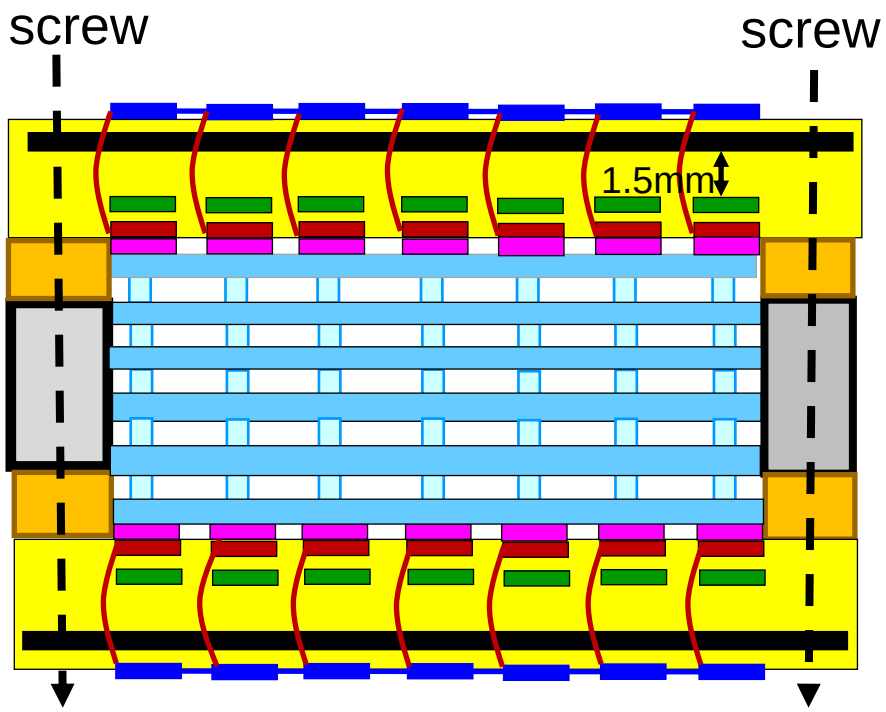
① **Carbonless electrode** : The supply of carbon tape used for BGO-egg RPC is no longer available. We tested **different material for electrode** and also develop **carbonless RPC** (this talk).

② **Solid silicon gasket** : The **glue seal** was used for BGO-egg RPC and LEPS2 RPC. However, we suffered from the **gas leak due to the damage of transportation** of MRPC. New design adopts **mechanical seal with solid silicon gasket which allows us to have more reliable gas seal. Furthermore, a thinner chamber with thickness less than 10mm is possible with silicon gasket.**

③ **Multilayer PCB : Multilayer PCB serve as part/cover of gas chamber, so-called self-seal MRPC. It consists of both HV copper array and readout strip.**

④ **Mylar spacer** : The aging effect of MRPC is caused by the chemical deposition of the gas along the fishing line. **Mylar spacer** is employed and tested.

Carbonless MRPC Prototype



Multilayer PCB (~2 mm)			
Layer	Name	Material	Thickness
	Resistor solder	copper	0.018 mm
	Dielectric	FR4	0.203 mm
	GND	copper	0.018 mm
	Dielectric	FR-4	1.500 mm
	Readout strip	copper	0.018 mm
	Dielectric	FR-4	0.203 mm
	HV pad	copper	0.018 mm

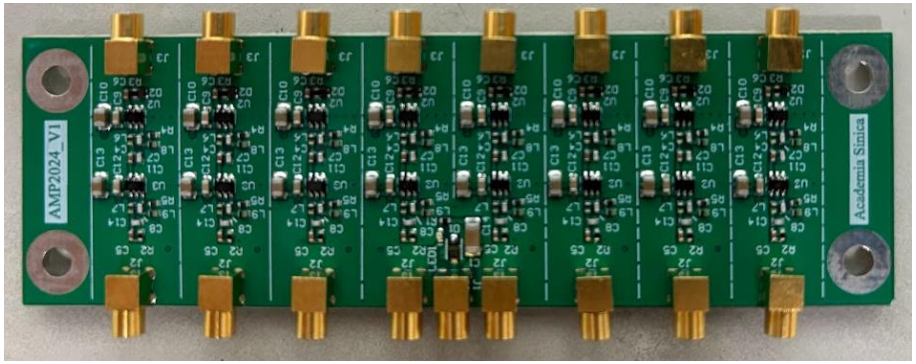
- **Through hold from top layer to bottom layer.**
- **Conductive tape required to have proper connection between glass and PCB.**

- **2mm thickness multilayer PCB** includes

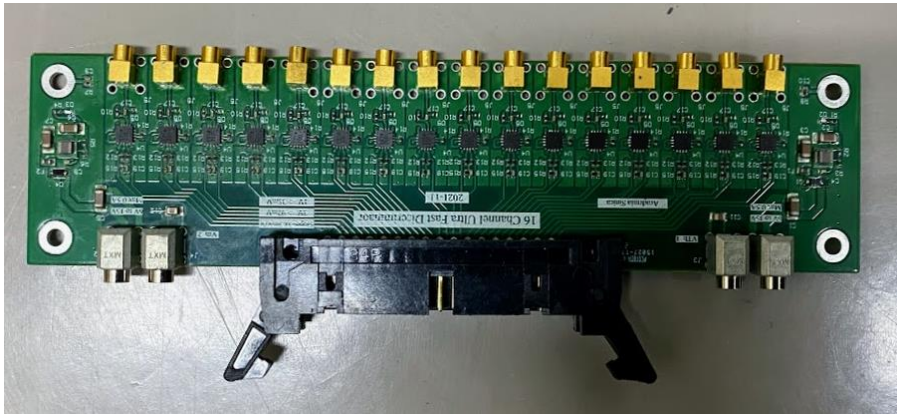
(1) Carbonless = HV copper pad array with 100kOhm resistor connected to reduce current draw.
(2) Though holes connect the top later and bottom layer to apply HV from outside to inside.
(3) 3M conductive tape is required between PCB and glass to have HV properly applied.
(4) Readout strips is 1.5mm away from GND to have larger induced signal.
(5) GND is designed to have better transmission line calculation for impedance match.
(6) Thick PCB to avoid HV breakdown inside PCB.

Electronics

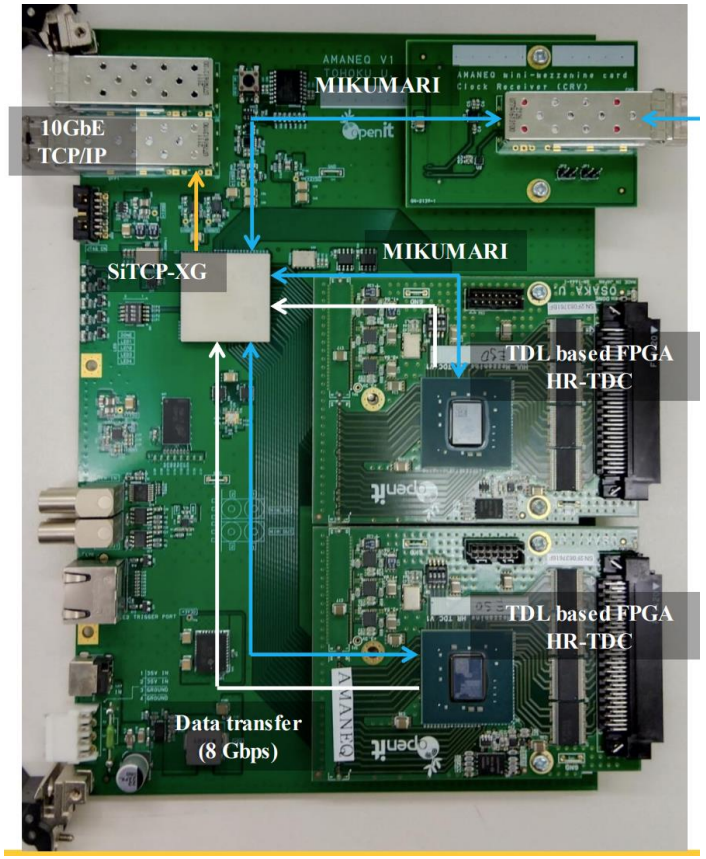
Amp : BAG2866/ 2 stages / BW up to 2G / TW



Dis : ADCMP572 / TOT / 10ps jitter / TW



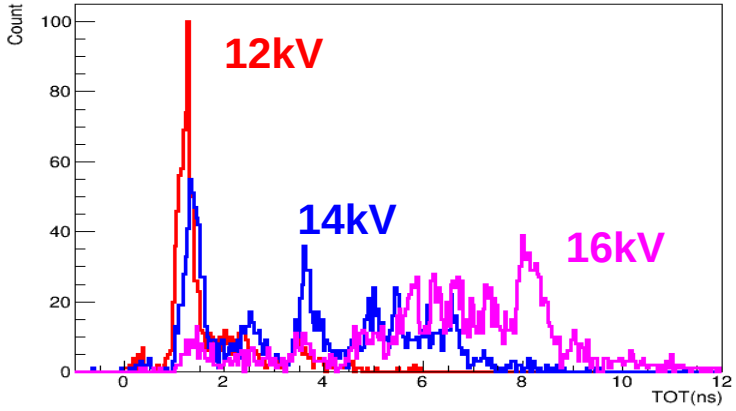
HRTDC / 25ps jitter / JP



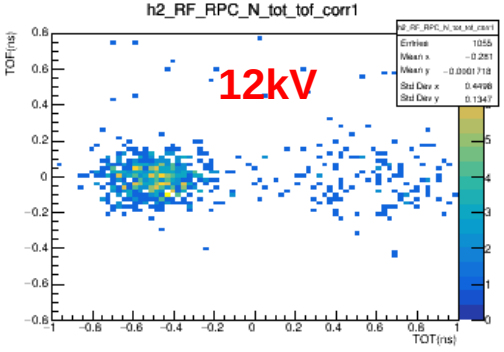
Commercial chips are used for Amp and discriminator. HRTDC is newly developed and testing.

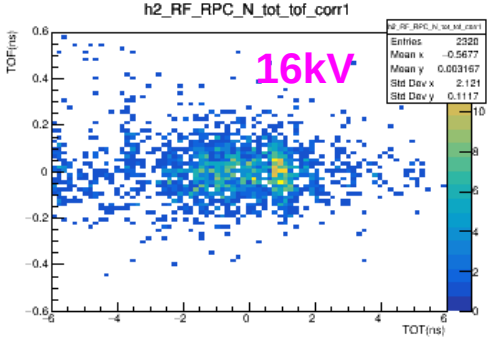
Best Test Results : HV Scan

TOT distribution



TOT VS TOF (after correction)





- **Time-over-threshold (TOT) is used to perform the slewing correction.**

- **Why only 95% efficiency?**

Due to TDC limitation, the narrow signals from the Resistive Plate Chamber (RPC) can't be detected effectively. The plan is to upgrade the discriminator to ensure that the logic signals it produces are always longer than 1 ns, which would allow the TDC to detect these signals properly.

- **Why only 95ps time resolution?**

The presence of multiple peak TOT signals suggests that noise, possibly from a ground loop, is affecting the measurements. To improve the time resolution, we will address this noise issue.