Development of Carbonless MRPC for MARQ Experiment in Japan

Ming-Lee Chu[1], Wen-Chen Chang[1], Chia-Yu Hsieh (presenter)[1],

Natsuki Tomida[2], Ryotaro Koike[2], Masayuki Niiyama [3]

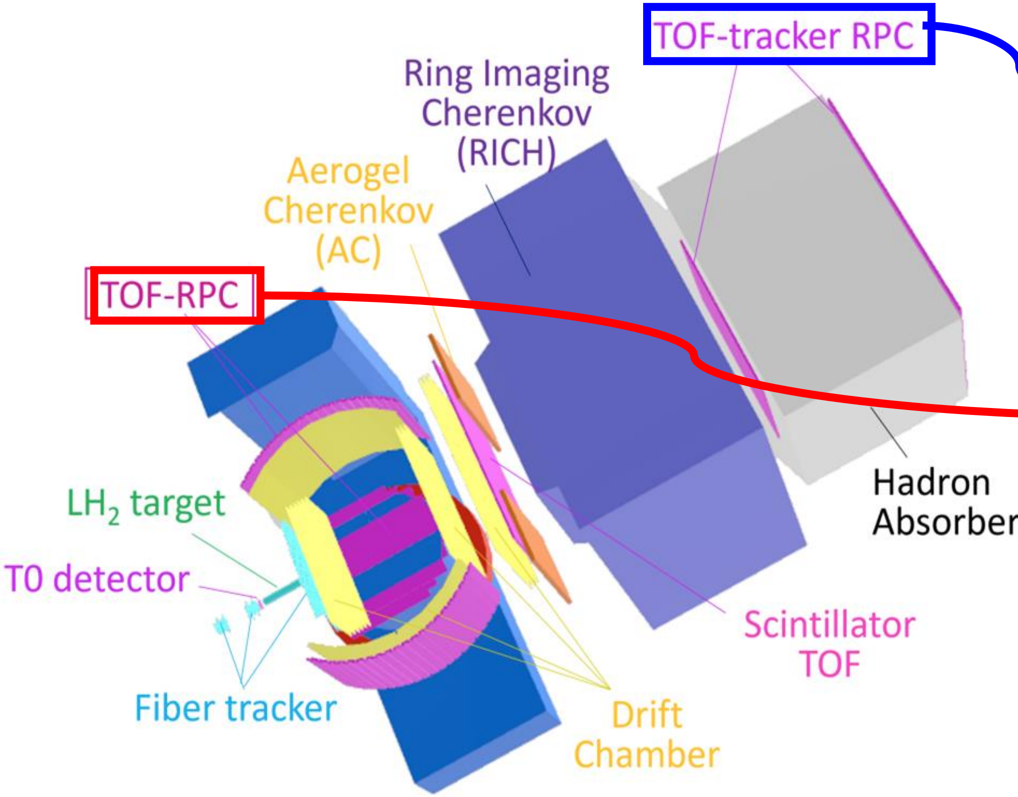
Po-Ju Lin [4], Yen-Jen Wu [4]

[1] Institute of Physics, Academia Sinica, Taiwan
[2] Graduate School of Science Division of Physics and Astronomy, Kyoto University, Japan
[3] Physics Department, Kyoto Sangyo University, Japan
[4] National Central University, Taiwan

Outline

- Requirement of MARQ RPC
- Carbonless RPC prototype
- Beam test results
- Summary and to do

Requirement of MARQ RPC



Tracker RPC (Muon-ID wall)
① >99% Eff
② 100ps time resolution
③ 1mm position resolution

TOF-RPC
① >99% Eff.
② 60ps time resolution

- MARQ (**M**ulti-purpose **A**nalyzer for **R**esonance and **Q**uark dynamics Spectrometer)
- Study **charmed-baryon spectroscopy** and **proton GPD.**
- Experimental site is located at **J-PARC in Tokai, Japan.**
- **RPC will be used as TOF wall and Muon wall.**

Development and Issues

NOW

BGO-egg TOF	→	LEPS2 TOF	→	MARQ TOF
2.5cm* 1m long strip		**2.5cm* 1.8m long strip**		**2.5cm* 1.8m long strip**
>99% eff.		**>99% eff.**		**>99% eff.**
50ps time resolution		**70ps time resolution**		**60ps time resolution**

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

- **Design of Carbonless RPC prototype for MARQ :**

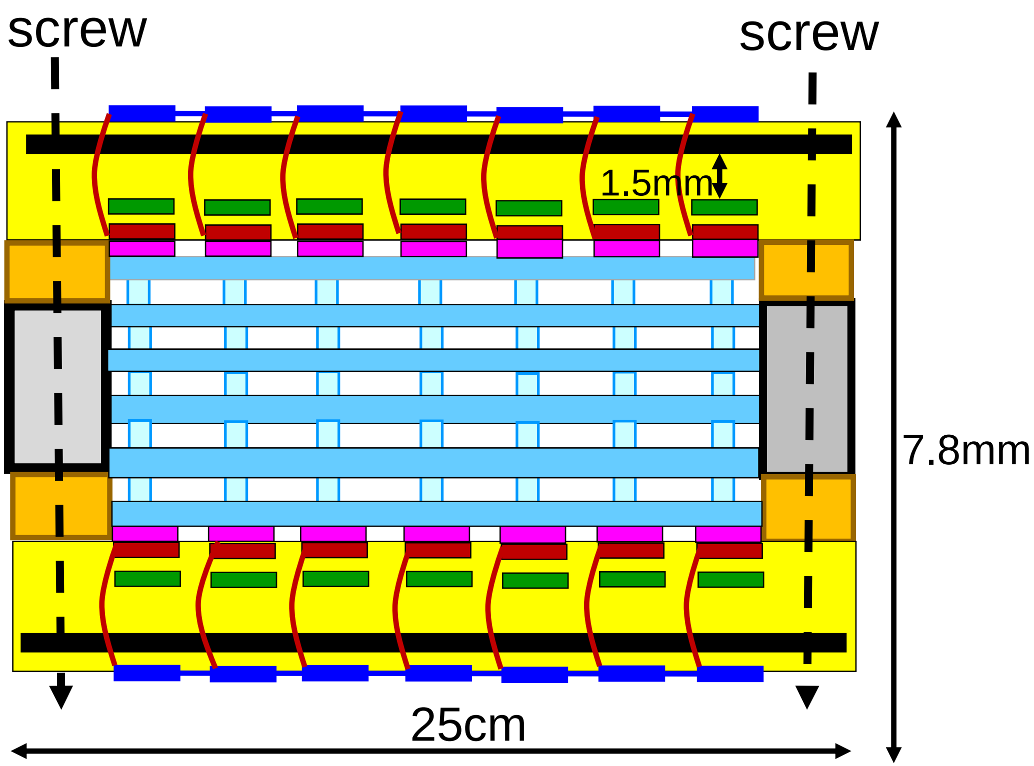
① **Carbonless electrode** : The supply of carbon tape used for BGO-egg RPC and LEPS2 RPC is no longer available. We tested **different material for electrode** and also develop **carbonless RPC** (this talk).

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 (1)



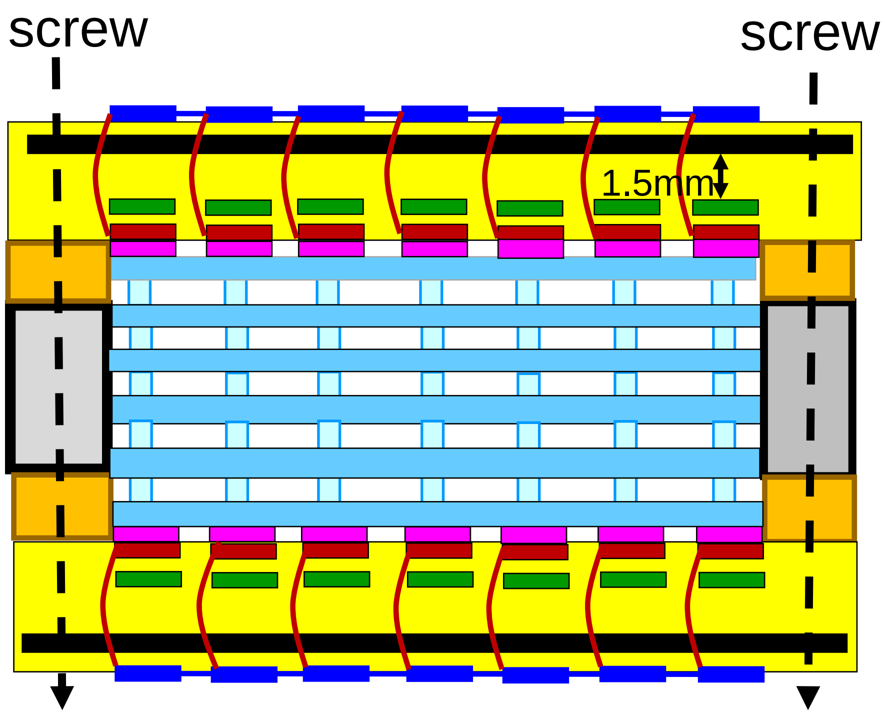
Structure

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

- **RPC specification**
- **Size of chamber 25cm * 25cm * 7.8mm**
- **1 stack * 5gaps * 260um gap * 400um glass**
- Active area 20cm*20cm
- Gas : R134a/iso-Butane/SF6 = 90/5/5
- 16ch thin readout strip with 4mm*20cm

- **Features :**
- Carbonless electrode
- Solid silicon gasket
- Multilayer PCB
- Mylar spacer
- **Self-seal MRPC**
- **Simple production procedure**
- **Read both positive and negative signals.**

Carbonless MRPC Prototype (2)



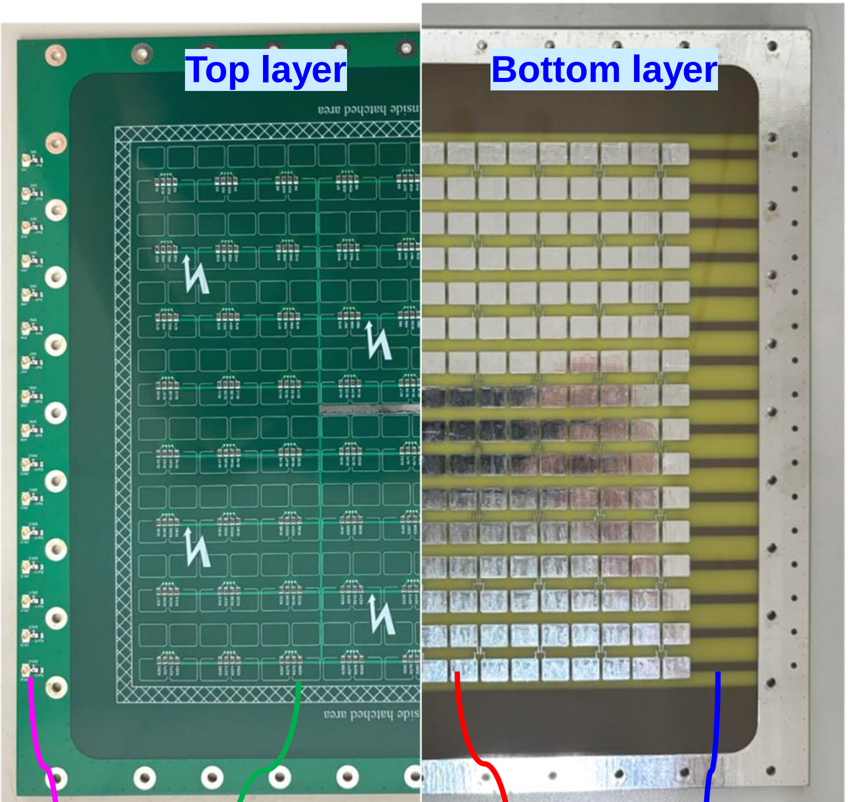
Multilayer PCB (~2 mm)			
Layer	**Name**	**Material**	**Thickness**
	Resistor solder	**copper**	**0.018 mm**
	Dielectric	FR4	**0.203 mm**
	GND	**copper**	**0.018 mm**
	Dielectric	FR-4	**1.500 mm**
	Readout strip	**copper**	**0.018 mm**
	Dielectric	FR-4	**0.203 mm**
	HV pad	**copper**	**0.018 mm**

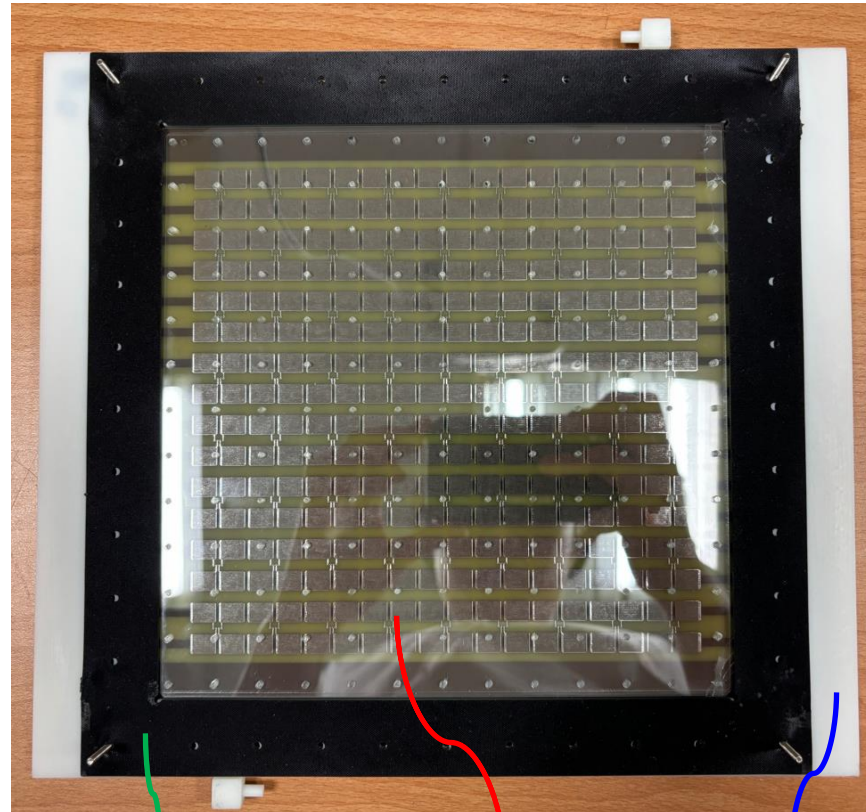
- **Through hold from top layer to bottom layer.**
- **Conductive tape required to have proper connection between glass and PCB.**

- **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.

Carbonless MRPC Prototype (3)





Readout connector

100 kOhm quenching resistor

HV pad

Readout strip

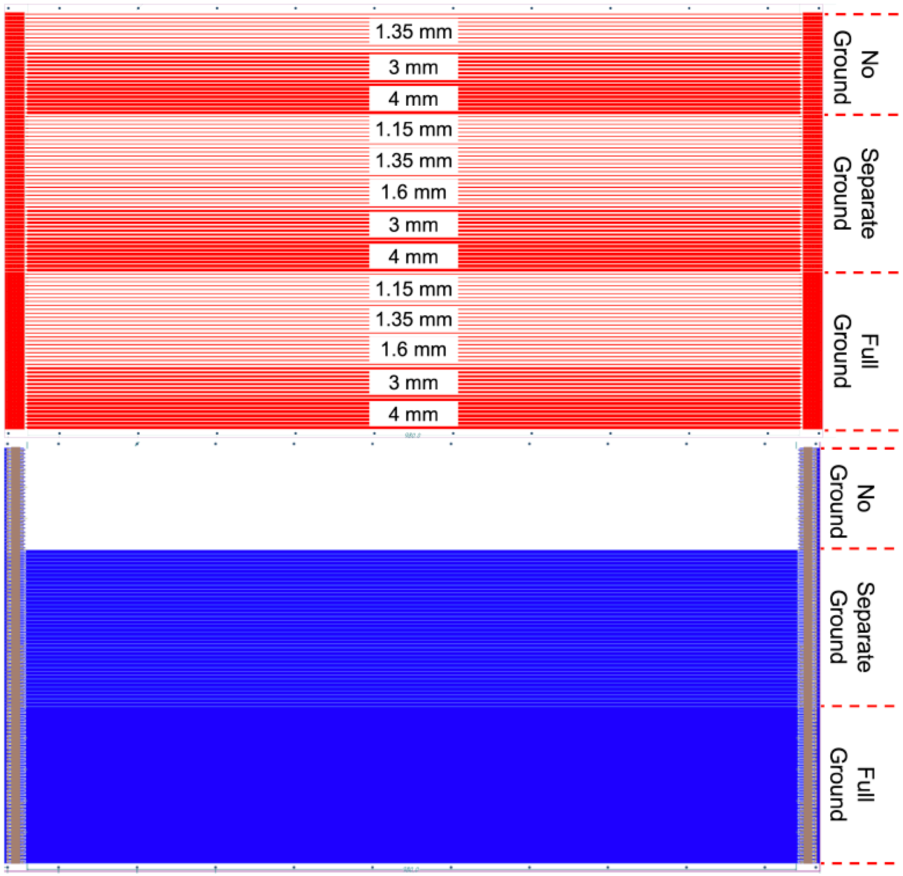
Silicon gasket (same hardness as O-ring)

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

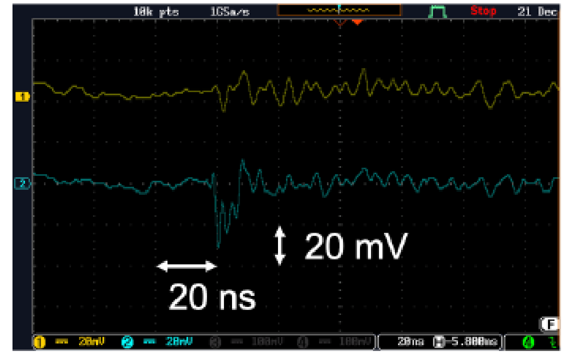
Frame by 3D printer

GND Layer to Reduce Signal Reflection

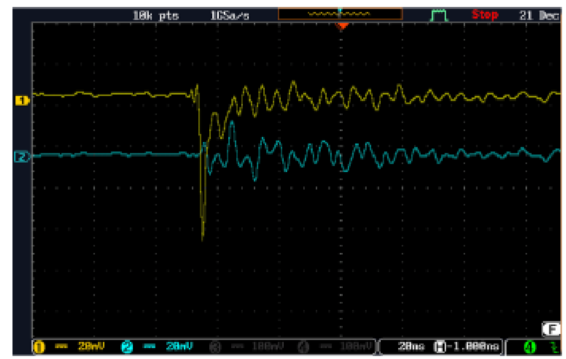
MARQ Tracker prototype



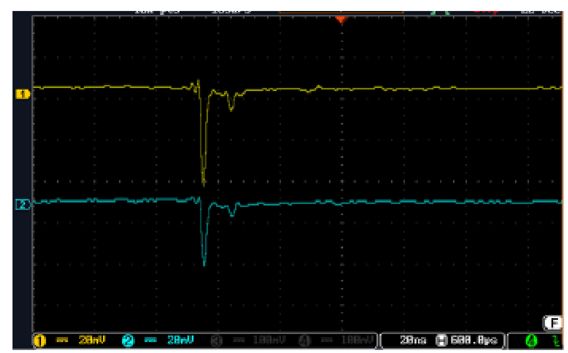
4mm strip width



No ground



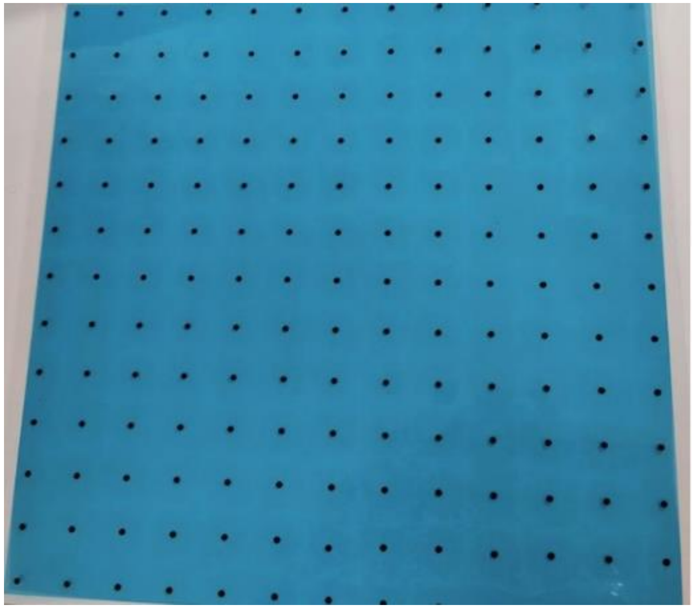
Separated ground

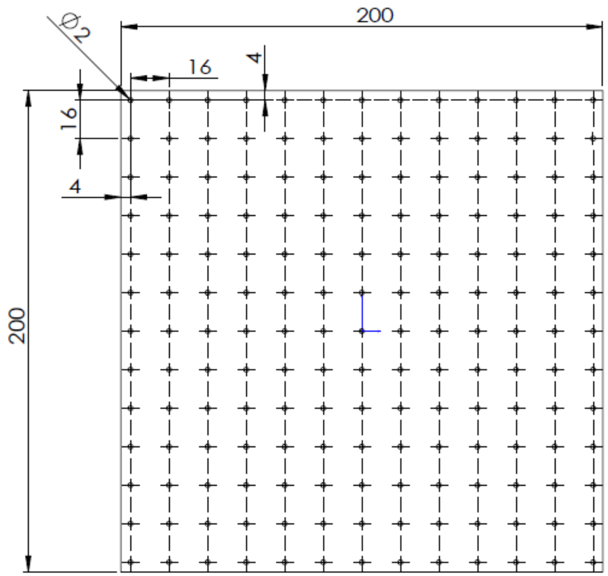


Full ground

Smaller reflection w/ full ground.

Mylar Spacer/Sticker



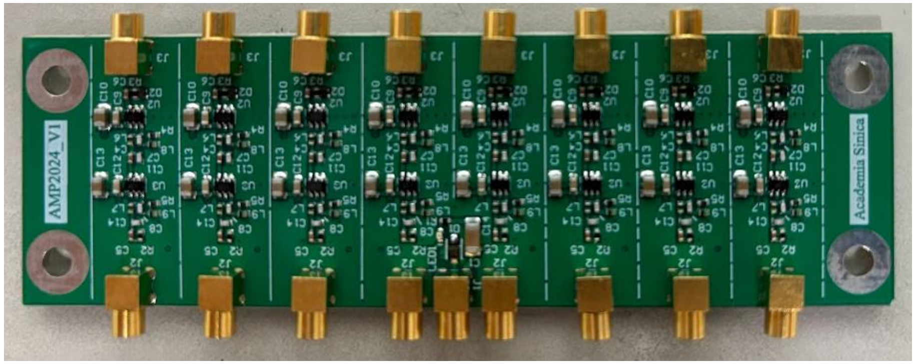


- Mylar spacer/sticker is **factory produced from Panel Group, Taiwan.**
- Size of one mylar spacer is 2mm-diameter dot with 0.26mm thickness.
- **It can be customized to different thickness, shape, and material.**

- thickness : min = 0.07mm, max = 1.5mm
- diameter : min = 1mm
- distance : min = 1mm
- **Teflon, Mylar, Kapton are all possible.**

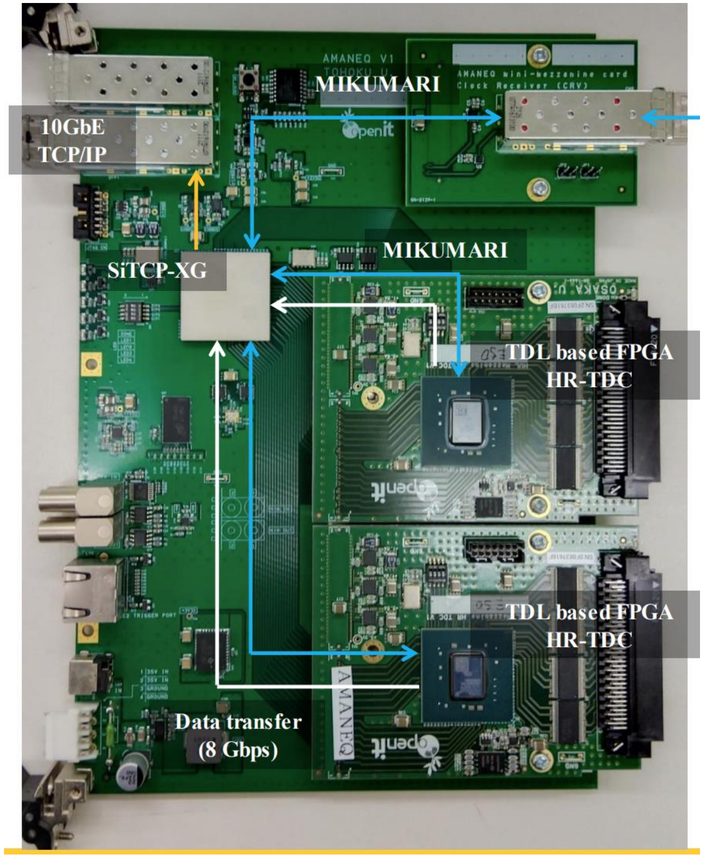
Electronics

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



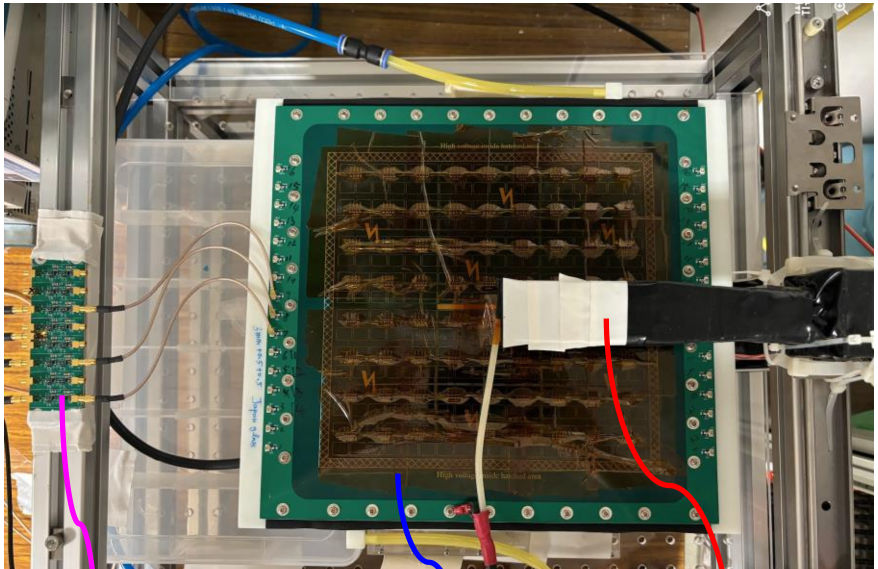
Dis : ADCMP572 / TOT / 10ps jitter / TW

HRTDC / 25ps jitter / JP



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

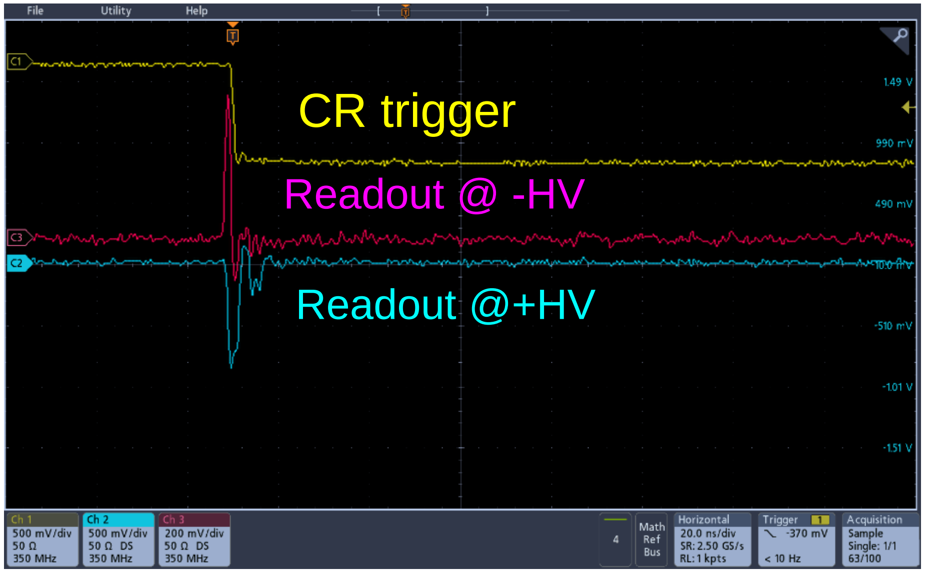
Cosmic Ray Signals



Amp

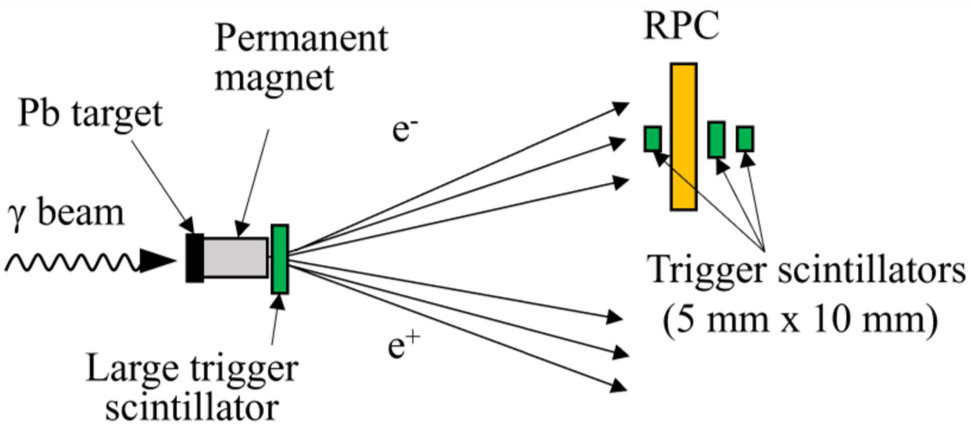
Carbonless prototype

Trigger



- Reasonable cosmic ray signals observed.
- Both positive and negative signals are sharp and fast.

Beam Test @ SPring-8

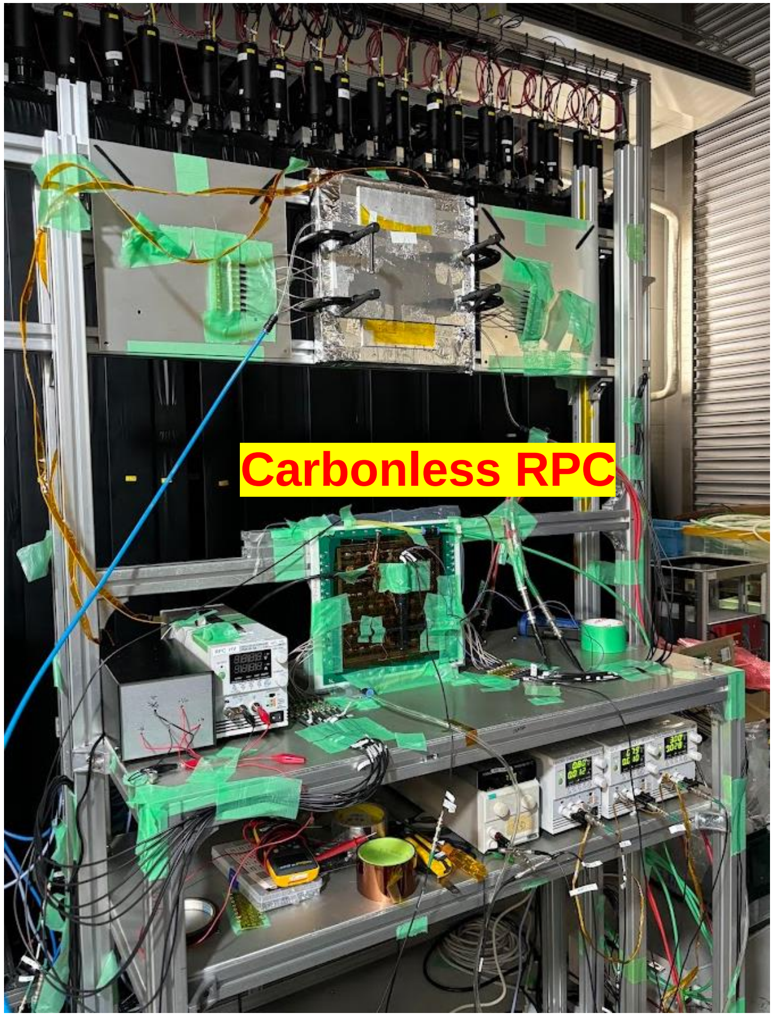


$$Efficiency = \frac{RPC \,\&\&\, trigger}{trigger}$$

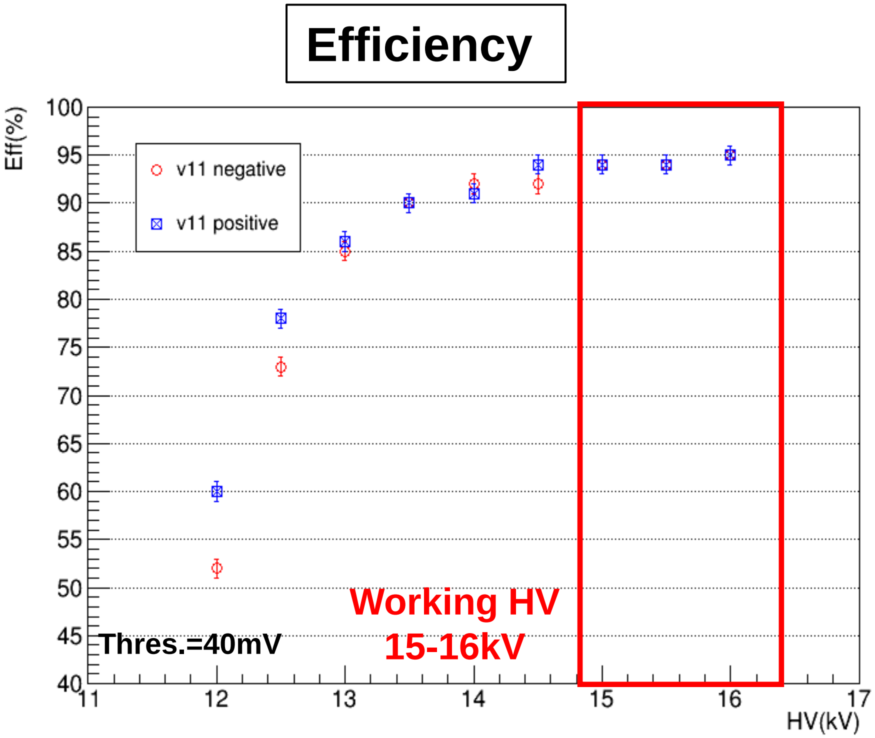
$$TOF = RPC - T0 = \frac{R + L}{2} - T0$$

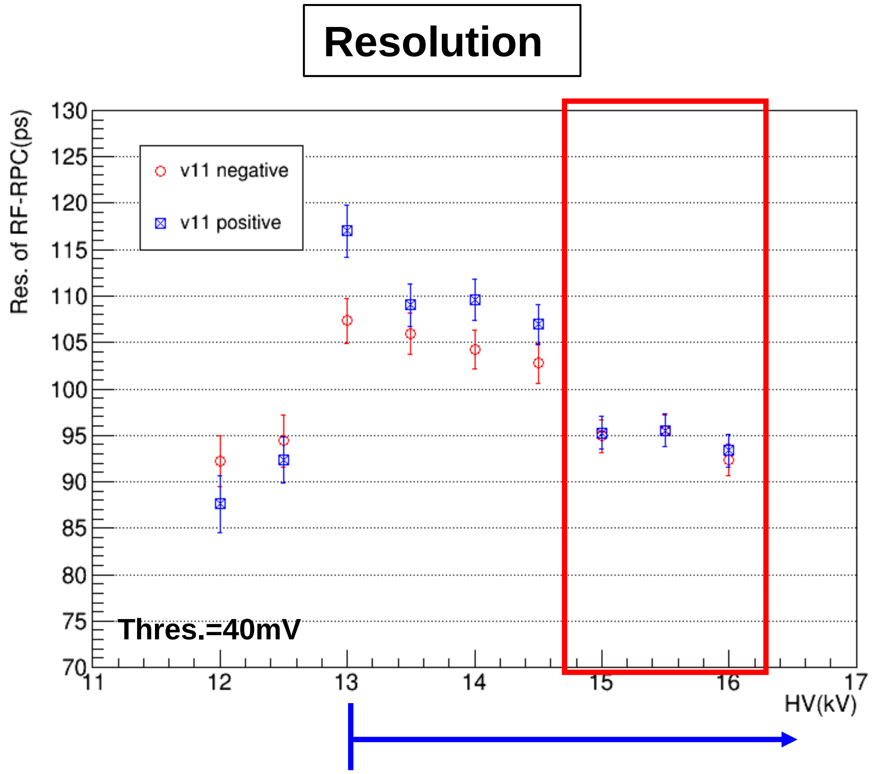
$$\sigma_{all}^2 = \sqrt{\sigma_{RPC}^2 + \sigma_{T0}^2}$$

- 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





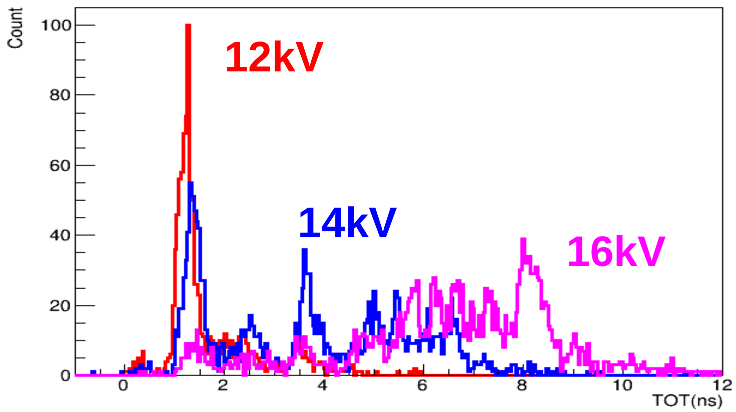
>13kV, Poor slewing correction

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

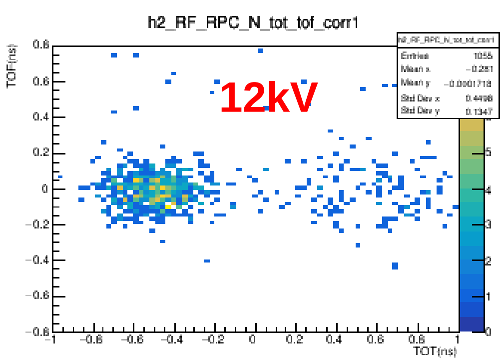
  (Goal : >99% efficiency and 70 ps time resolution)

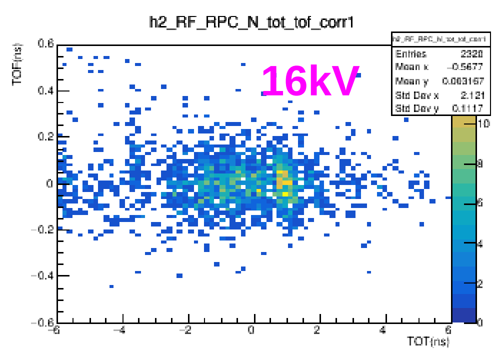
Best Test Results : HV Scan

TOT distribution



TOT VS TOF (after correction)





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

- **Why only 95% efficiency?**

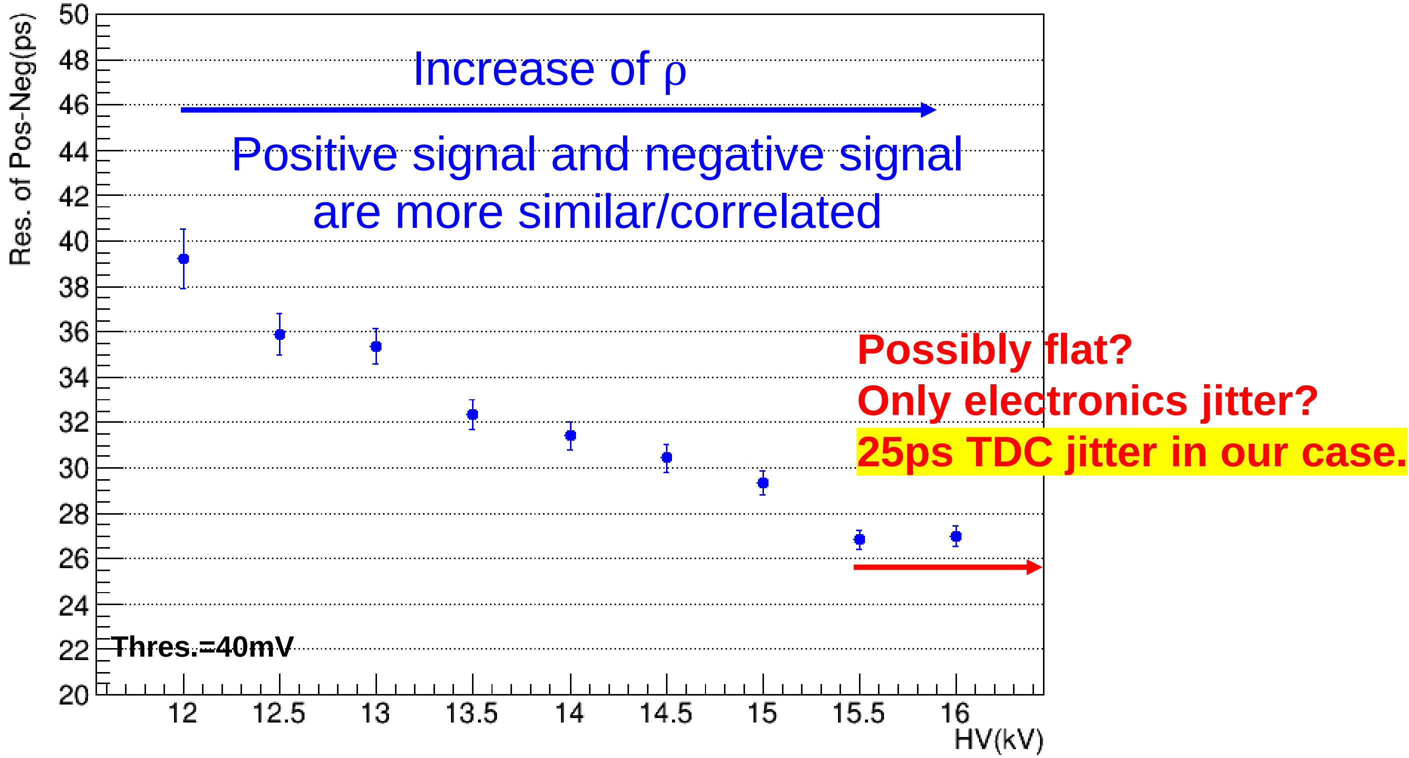
Due to TDC limitation, the narrow signals from the Resistive Plate Chamber (RPC) can't be detected effectively. The plan is to upgrade the discriminator to ensure that the logic signals it produces are always longer than 1 ns, which would allow the TDC to detect these signals properly.

- **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.

Beam Test Results : Intrinsic Resolution of Electronics

Time resolution of "Positive-Negative"



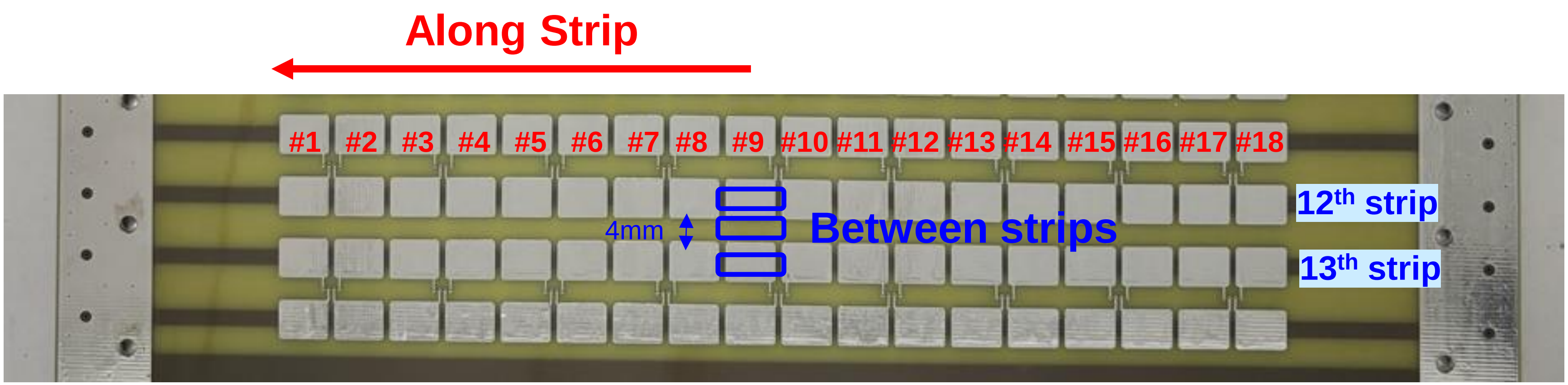
- $\sigma^2_{[Pos-Neg]} = 2 * [\,\sigma^2_{Eletro} + (1 - C)\sigma^2_{RPC}]$

C is the correlation between positive and negative signals.

If $C = 1$, $\sigma_{Electro} = \sigma_{[Pos-Neg]}/\sqrt{2}$ (if positive signal and negative signal are identical.)

- One could possibly access the intrinsic jitter of FEE from this method.

Best Test Results : Position Scan



Along Strip.

- #1 pad : 92%, 102.78 $\pm$ 2.16 ps
- #4 pad : 96%, 112.36 $\pm$ 2.15 ps
- #9 pad : 94%, 100.68 $\pm$ 2.10 ps
- #9 & #10 : 94%, 97.18 $\pm$ 1.85 ps

➔ **No trend observed.**

➔ **1mm gap between HV pad is fine.**

Between Strips

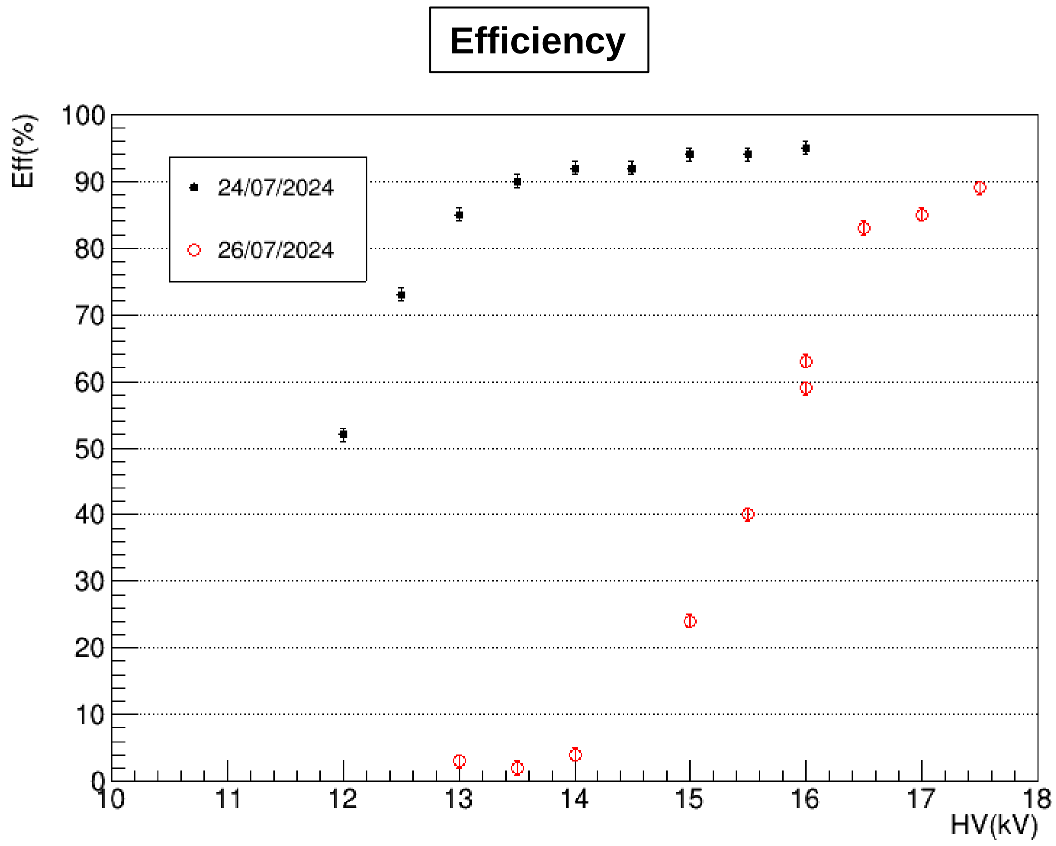
- 12^{th} strip : 94%, 93.82 $\pm$ 1.87 ps
- **Between : 80%, 135.33 $\pm$ 3.52 ps**
- 13^{th} strip : 92%, 105.23 $\pm$ 2.27 ps

➔ **Eff. Drops between strips.**

➔ **Gap size of HV pads between strips is 4mm.**

➔ **4mm gas is too large. We will reduce the gap between HV pad.**

Best Test Results : Stability



- Efficiency drops after two days operation in hall.
- We suspect there might be **current leakage in the multilayer PCB**. To address this, **we plan to increase the PCB thickness to 5mm (PCB production limitation is 7mm).**

Summary and To Do

- We have developed a carbonless RPC (Resistive Plate Chamber) prototype for the future MARQ project at J-PARC since the carbon tape supply is no-longer available. Our efforts have focused on addressing several issues: finding alternative electrode materials, preventing gas leaks from glue seals, and mitigating the aging effects of fishing line. To tackle these challenges, we experimented with various innovations, including multilayer PCBs, solid silicon gaskets, and mylar spacers.

- The prototype has demonstrated around 95% efficiency and a time resolution of approximately 95 ps. However, some challenges remain that need further investigation.

- Concerning the stability issue, there is a suspicion of current leakage in the multilayer PCB. To address this, we plan to increase the PCB thickness and conduct a beam test in November.
- To enhance efficiency, we will upgrade the discriminator design to ensure that the Time-Over-Threshold (TOT) exceeds 1 ns. Additionally, to improve time resolution, we will work on better noise control to enhance the quality of slewing correction.

Backup

Options of Electrode Material

Candidates and Milestones

As of 2024/08/23 2

Candidate Name	Composition	in hand	Assembly	HV test	CR test	Endurance test	Beam test
① (Lyon)	Carbon ink	Mylar			○		
② CS-6301	Nanocarbon dispersed polysiloxane	Glass			○	72 hours ○	
		Mylar			△		
③ KP-8348-1 Black	Fluoropolymer-base conductive coating	Glass			○	72 hours ○	
④ SEPLEGYDA	Polythiophene-base conductive polymer	Mylar		× No dark current			
⑤ (Portugal)		Mylar		× No dark current			
⑥ Tanimura	Carbon tape						

newly done

done before

considering 2 additional candidates (Fluoropolymer-base conductive coating).

GND Layer To Have Better Transmission Line Calaultion

Typical RPC is designed to be like Transmission Line (TL), However not in typical PCB Planar TL structure.

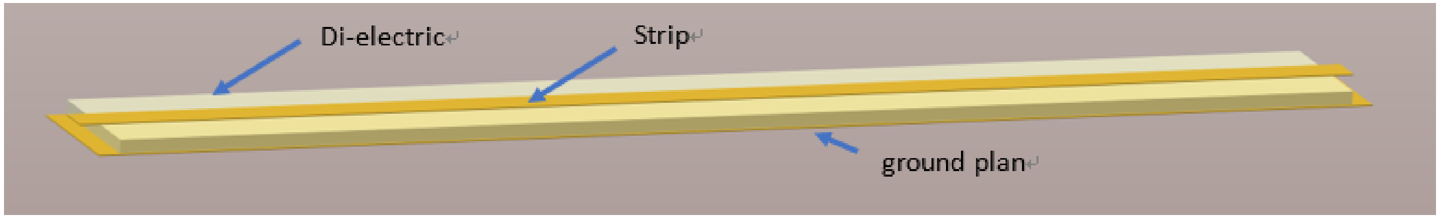
A. No metal ground plan along with signal strip,

B. Two signal strips in parallel, one strip for +HV Carbon signal induction, the other for -HV carbon signal induction.

Not so easy to practice “Impedance match” like most of strip type TL.

Multiple reflected signals often overlap with original signal, degrades timing measurement quality.

Basic Transmission Line: Microstrip as example



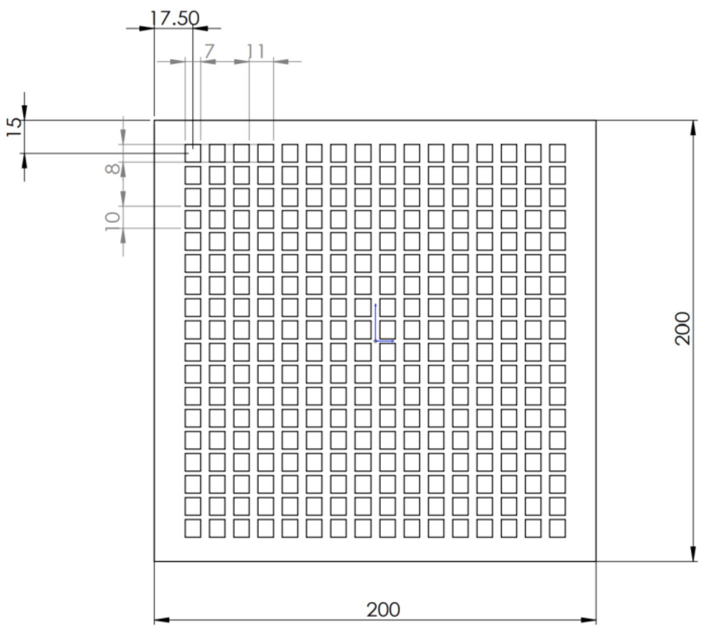
Characteristic Impedance = R=V/I

Matched Load

Matched condition: TL’s characteristic impedance = Load resistance ➔No reflection.

Within 10% mismatched is considered to be usable (10% V reflection)

3M Conductive Tape



3M

3M™ XYZ-Axis Electrically Conductive Acrylic Double Side Coated Tape 9850

Product Description

3M™ XYZ-Axis Electrically Conductive Acrylic Double Side Coated Tape (e-Conductive DC Tape) 9850 is an isotropically and electrically conductive tape. It consists of conductive acrylic Pressure Sensitive Adhesive (PSA) loaded with conductive nonwoven. This Electrically Conductive Acrylic Double Side Coated Tape 9850 offers both high adhesion and very good electrical conductivity. The conductive nonwoven in 3M™ e-Conductive DC Tape 9850 also provides better handling characteristics and prevents oozing issue. 3M e-Conductive DC Tape 9850 conducts electricity (current) flowing through the thickness (Z-axis) and the bone-line of the adhesive (X-Y axis), it is an ideal PSA designed to most desired surface for grounding, EMI shielding and EMI gasket attachment... etc. in electronics or electrical devices application. It can be also used for many types of metal foils laminated to provide customized shielding, grounding or e-Conductive purpose reinforcing solutions. This tape may be used for attaching conductive fabric/foam core EMI gaskets to electronic cabinetry as well.

3M™ XYZ-Axis Electrically Conductive Acrylic Double Side Coated Tape 9850

Properties	Typical Value
Type of carrier	Conductive nonwoven
Type of Adhesive	Conductive acrylic adhesive
Release Liner	White Polycoated Kraft Paper printed with 3M logo in red color.
Thickness	
Carrier plus Adhesive	50 um
Liner	150 um
Adhesion strength [1]	1500 gf/inch
Surface Resistance of Adhesive [2]	< 0.1 Ω/□
Electrical resistance through adhesive [3]	< 0.5 Ω
Electrical resistance through adhesive [4]	< 0.05 Ω/inch^2

* Foot note 1. Test method ref. to ASTM D 1000 peeling force section
2.

Factory produced

Specification of Amplifier Chip

RFMD
rfmd.com

停產

RF3376
General Purpose Amplifier

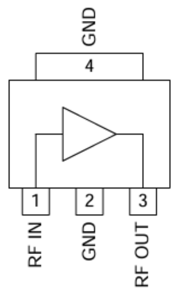
Package Style: SOT8

Features

- DC to >6000MHz Operation
- Internally Matched Input and Output
- 22dB Small Signal Gain
- +2.0dB Noise Figure
- +11dBm Output P1dB
- Useable with 5V Supply

Applications

- Basestation Applications
- Broadband, Low-Noise Gain Blocks
- IF or RF Buffer Amplifiers
- Driver Stage for Power Amplifiers
- Final PA for Low-Power Applications
- High Reliability Applications



Functional Block Diagram

Product Description

The RF3376 is a general purpose, low-cost RF amplifier IC. The device is manufactured on an advanced Gallium Arsenide Heterojunction Bipolar Transistor (HBT) process, and has been designed for use as an easily-cascadable 50Ω gain block. Applications include IF and RF amplification in wireless voice and data communication products operating in frequency bands up to 6000MHz. The device is self-contained with 50Ω input and output impedances and requires only two external DC-biasing elements to operate as specified.

BGA2866
MMIC wideband amplifier

Rev. 4 — 13 July 2015 Product data sheet

1.1 General description

Silicon Monolithic Microwave Integrated Circuit (MMIC) wideband amplifier with internal matching circuit in a 6-pin SOT363 plastic SMD package.

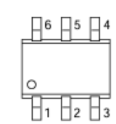
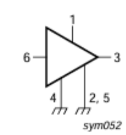
1.2 Features and benefits

- Input internally matched to 50 Ω
- A gain of 23.2 dB at 250 MHz increasing to 24.3 dB at 2150 MHz
- Output power at 1 dB gain compression = 4 dBm
- Supply current = 17.4 mA at a supply voltage of 5 V
- Reverse isolation > 32 dB up to 2150 MHz
- Good linearity with low second order and third order products
- Noise figure = 3.8 dB at 950 MHz
- Unconditionally stable (K > 1)
- No output inductor required

1.3 Applications

- LNB IF amplifiers
- General purpose low noise wideband amplifier for frequencies between DC and 2.2 GHz

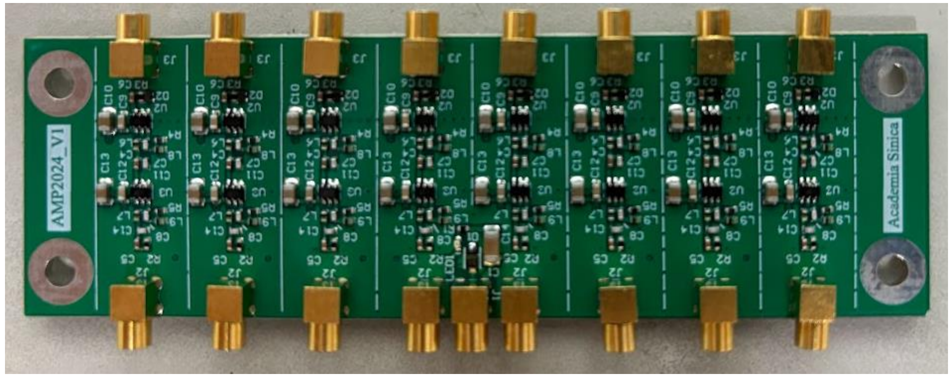
Table 1. Pinning

Pin	Description	Simplified outline	Graphic symbol
1	V_{CC}		
2, 5	GND2		
3	RF_OUT		
4	GND1		
6	RF_IN		

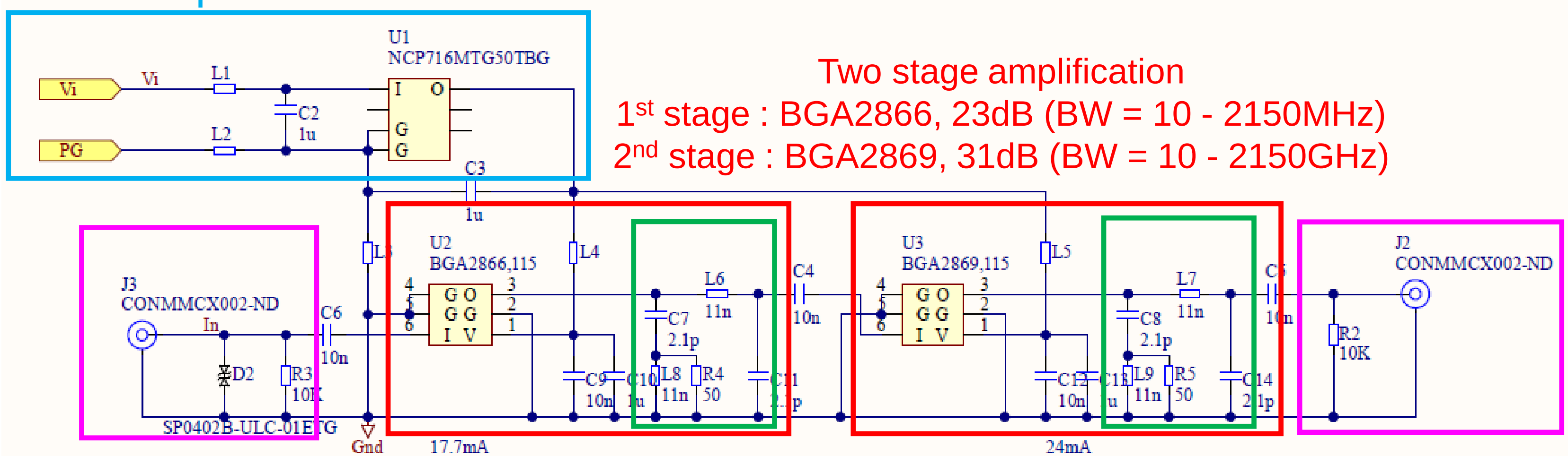
https://www.mouser.com/datasheet/2/412/f3376_data_sheet-973800.pdf

https://www.nxp.com/docs/en/data-sheet/BGA2866.pdf

Design of Amp w/ LP Filter



power



Two stage amplification

1st stage : BGA2866, 23dB (BW = 10 - 2150MHz)

2nd stage : BGA2869, 31dB (BW = 10 - 2150GHz)

Input

output

Filter for noise reduction

RPC signal < 1GeV

Radio/Phone/Wifi signals > 1GeV

Chip of Discriminator

ANALOG DEVICES

Ultrafast 3.3 V/5 V Single-Supply SiGe Comparators

Data Sheet **ADCMP572/ADCMP573**

FEATURES

- 3.3 V/5.2 V single-supply operation
- 150 ps propagation delay
- 15 ps overdrive and slew rate dispersion
- 8 GHz equivalent input rise time bandwidth
- 80 ps minimum pulse width
- 35 ps typical output rise/fall
- 10 ps deterministic jitter (DJ)
- 200 fs random jitter (RJ)
- On-chip terminations at both input pins
- Robust inputs with no output phase reversal
- Resistor-programmable hysteresis
- Differential latch control
- Extended industrial −40°C to +125°C temperature range

FUNCTIONAL BLOCK DIAGRAM

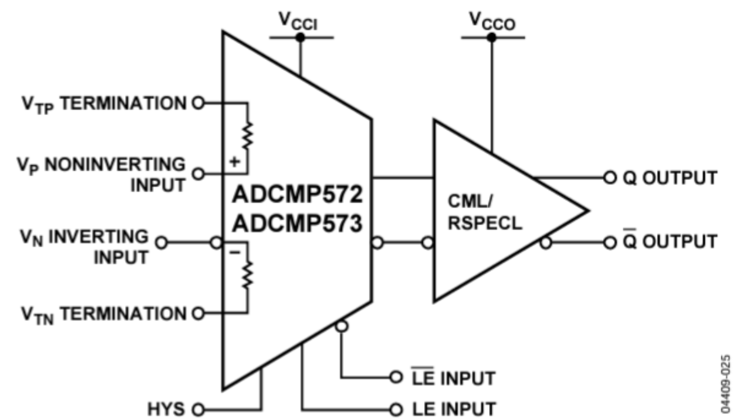
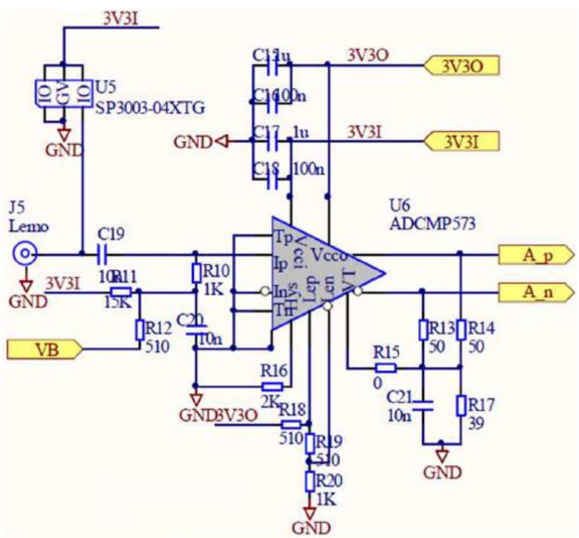


Figure 1.

https://www.analog.com/media/en/technical-documentation/data-sheets/ADCMP572_573.pdf

Design of Discriminator



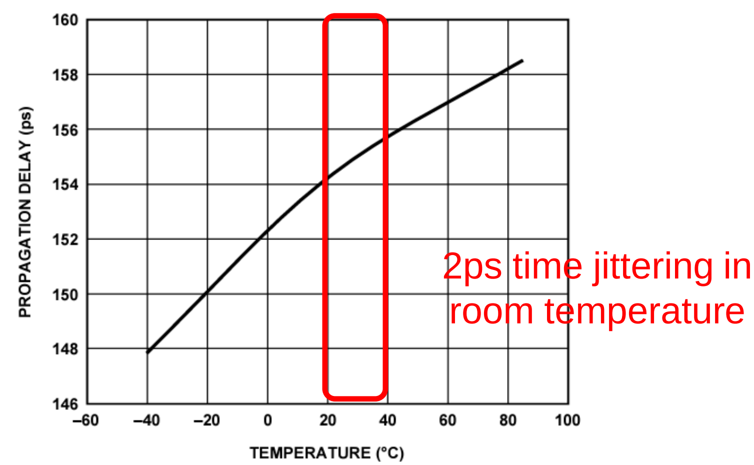
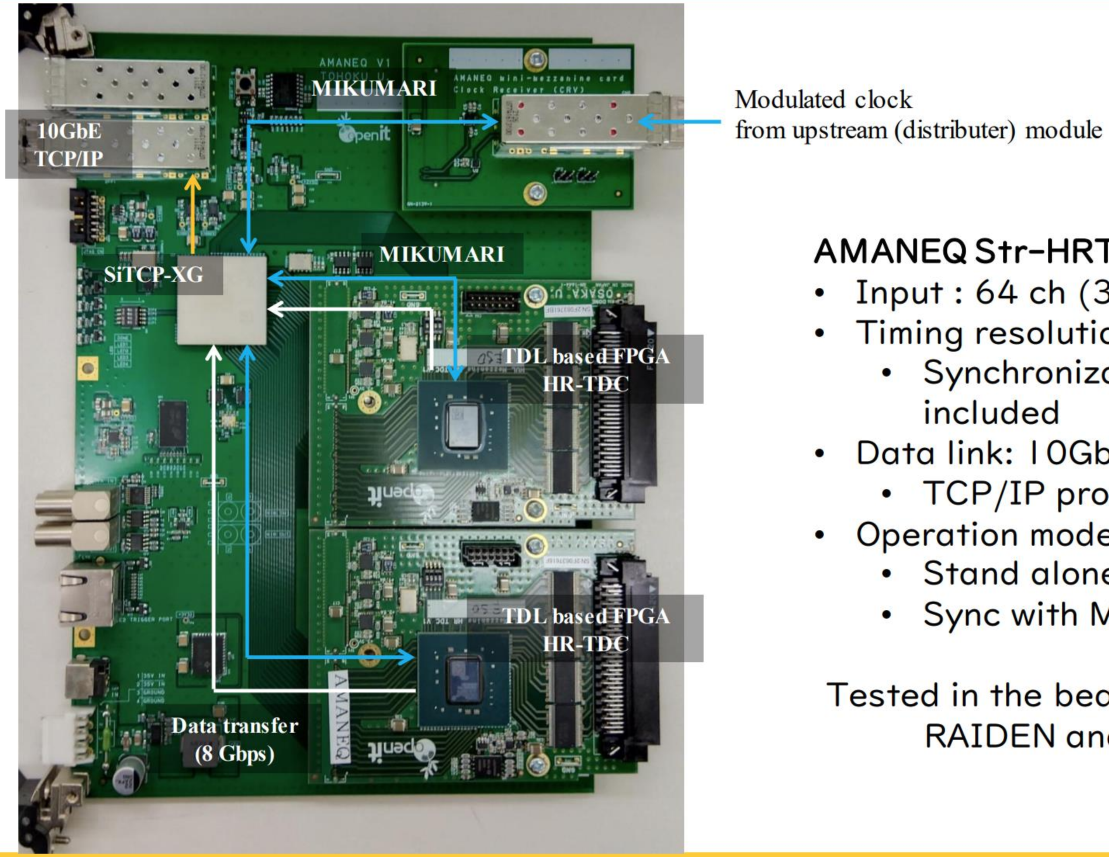


Figure 5. Propagation Delay vs. Temperature

HRTDC

Streaming HR-TDC on AMANEQ



AMANEQ Str-HRTDC

- Input : 64 ch (32+32)
- Timing resolution: ～25 ps (σ)
  - Synchronization precision of MIKUMARI is included
- Data link: 10GbE
  - TCP/IP provided by SiTCP-XG
- Operation mode
  - Stand alone mode
  - Sync with MIKUMARI system

Tested in the beam experiments at RCNP Grand RAIDEN and J-PARC hadron facility

https://openit.kek.jp/workshop/2023/dsys/presentation/honda.pdf

$\boldsymbol{\sigma^2_{[Pos-Neg]} = 2 * [\, \sigma^2_{Eletro} + (1-\rho)\sigma^2_{RPC}]}$

- $\boldsymbol{\sigma^2_{positive}} = \boldsymbol{\sigma^2_{RPCP}} + \boldsymbol{\sigma^2_{EletroP}} + \boldsymbol{\sigma^2_{Scin\mathrm{P}}}$
- $\boldsymbol{\sigma^2_{negative}} = \boldsymbol{\sigma^2_{RPCN}} + \boldsymbol{\sigma^2_{EletroN}} + \boldsymbol{\sigma^2_{Scin\mathrm{N}}}$
- $\boldsymbol{\sigma^2_{PosSubNeg}} = \boldsymbol{?}$

① σ_{scinP} and σ_{scinN} are fully correlated (same source).
② electronics of positive and negative are independent, but the same size.
③ signal of positive and negative are partially correlated/uncorrelated, not sure.

$$\boldsymbol{\sigma^2_{PosSubNeg} = 2 * \sigma^2_{Eletro} + [\, \sigma^2_{RPCP} + \sigma^2_{RPCN} - 2\rho * \sigma_{RPCN} * \sigma_{RPCP}]}$$

where ρ gives the correlation between σ_{RPCN} and σ_{RPCP}

If σ_{RPCN} and σ_{RPCP} are fully correlated

➔ $\boldsymbol{\sigma^2_{PosSubNeg} = 2 * \sigma^2_{Eletro}}$

We can potential know the jitter of electronics if σ_{RPCN} and σ_{RPCP} are fully correlated.

If σ_{RPCN} and σ_{RPCP} are partially correlated with the same size.

➔ $\boldsymbol{\sigma^2_{PosSubNeg} = 2 * [\, \sigma^2_{Eletro} + (1-\rho)\sigma^2_{RPC}]}$