Self Introduction

Ryotaro Koike (Kyoto University Nuclear Hadron Phys. Lab. M2)

- Hometown：Oita Prefecture
  Usuki (1y) → Oita(16y) → Fukuoka (1y) → Kyoto(~7y)
- Hobby：Tennis、Fishing、

@Goto Islands in Nagasaki

Development of
new High-Voltage Electrodes
for Multi-gap Resistive Plate Chambers
in the MARQ experiments

Ryotaro Koike
Kyoto University

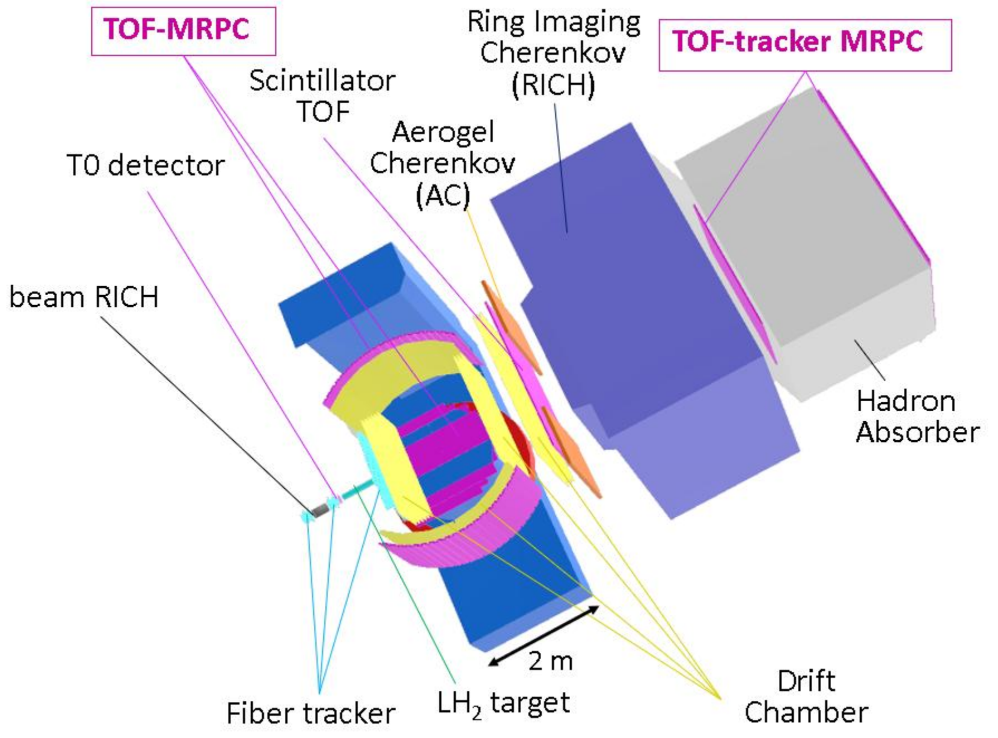
Introduction

- **MARQ experiments**

  Collection of experiments at the J-PARC $\pi 20$ beamline (π, K, p up to 20 GeV/c)
  such as Charmed baryon spectroscopy, Xi baryon spectroscopy, and $I = 3$ dibaryon search.

- **MARQ spectrometer**

  A versatile spectrometer which performs particle identification even at momenta of 20 GeV/c with a great momentum resolution in a high intensity situation



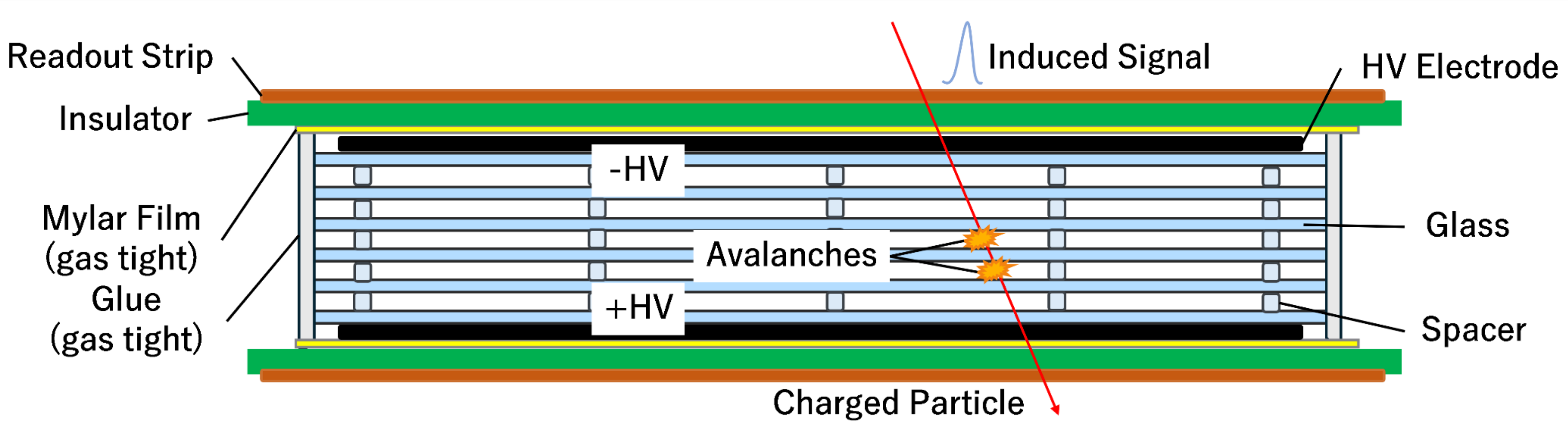
<u>Multi-gap Resistive Plate Chamber(MRPC)</u>
serves as a stop timing detector of TOF system in the MARQ spectrometer.

- **Desired Performance of MRPC**
  - Total Coverage: 11 m^2
  - Time Resolution: ~60 ps
  - Efficiency: 99 %

Multi-gap Resistive Plate Chamber (MRPC)

- **MRPC ⋯ gaseous detector for charged particles**

  Electron avalanches ⇒ Electric distortions in gas gaps ⇒ Induce signals on readout strips



- **Roles of HV electrode**
  - Creates a uniform electric field
  - Prevents the induced charge from dispersing

⇒ standard resistivity： $10^5 \sim 10^7\ \Omega/\mathrm{cm}^2$

if it’s too low ⋯ Low performance due to charge sharing between strips

too high ⋯ Voltage drop along the HV electrodes, causing non-uniform fields

Purpose of this work

- **Problems of former HV electrode (T-9188 from the EEEC company)**
  - Adhesive, high-resistivity tape
  - Different resistivities for different lots
  - Discontinued, causing MRPC developments in Japan difficult

⇒ **Purpose:**

To find alternative HV electrodes and make MRPC development possible

- **Requirements for HV electrodes**
  - Work as HV electrodes for MRPC (i.e., HV suppliable and signals readable)
  - Stable operation with large MRPC (MRPC for MARQ experiments will be 1.8 m long)
  - Uniform Resistivity

  - (mass-productivity)
  - (stable resistivity, resistivity reproducible, stable supply)

Search for new HV electrodes

No promising candidates so far

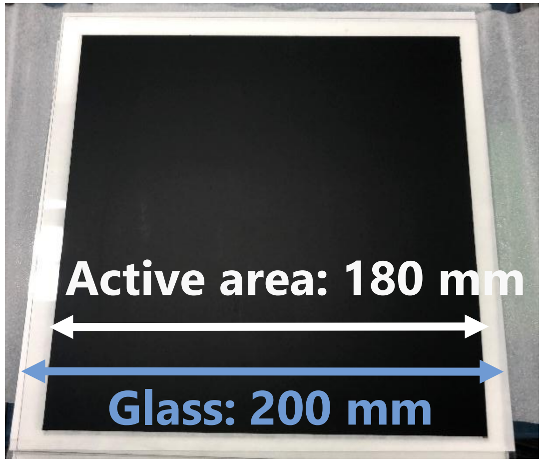
- First, we looked for high-resistivity adhesive tapes. (2020 Mater thesis from Tohoku Univ.) Found one candidate (MK-APT from Tanimura company), but stability issue.
- We also considered coatings which are used in foreign groups, but faced problems of imports, maximum size, coating methods, etc.

This work focused on new <u>conductive coatings</u>

Coatings on Glass

- HV electrode and Glass is well attached
- Simple assemble procedure

- Risk of damaging the glass while coating
- Varying quality due to hand coating



Coatings on Film

- Produce HV electrodes separately from glass

- Minimum risk of damage
- Great mass-producibility by machine coating
- Reproducible and even quality

List of new candidates

- **Seplegyda from Shinetsu Polymer (Japan)**
  - Polythiophene-base conductive polymer (intrinsically conductive polymer)
  - Applications: antistatic on packing sheet for IC, display
- **Air-Opaque from Badger Air-Brush**
  - Colloidal graphite gives conductivity
  - Water-based ink for illustrators
  - adopted in SHiP experiment
- **Graphit from Kontakt Chemie**
  - Colloidal graphite gives conductivity
  - Conductive coating used for electronics mainly in Europe
  - adopted in Lyon university
- **CS-6301 / CS-5302 from Colcoat (Japan)**
  - Nano carbon dispersed polysiloxane
  - Antistatic application
- **KP-8348-1 / KP-K2919-1 from Kansai-Polymer (Japan)**
  - Fluoropolymer-base carbon dispersed conductive coating
  - Applications: antistatic in semiconductor region

Workflow

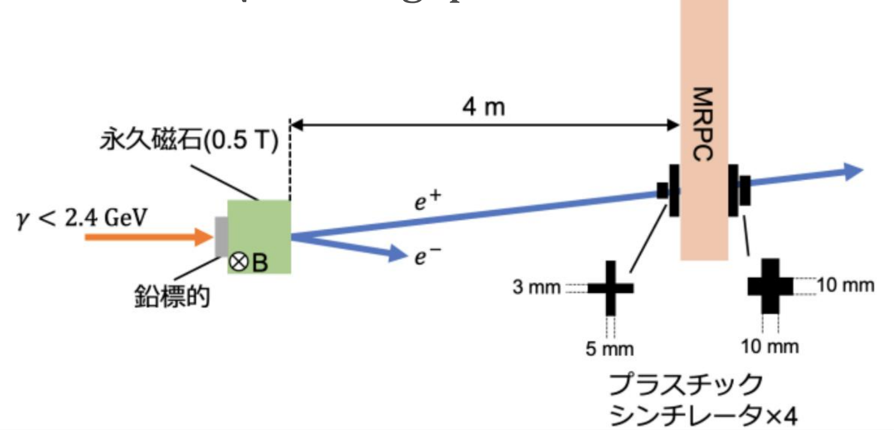
Assembled prototype MRPCs using new HV electrodes

- asked companies to apply the coatings
- fabricated prototypes in our laboratory
- started with small size(20 cm sq.),
  and then made the succussed ones larger (~1 m long)

Evaluated the performance using an electron beam

- SPring-8 LEPS2 beamline
- e^-/e^+ of $\sim 1\ \mathrm{GeV}/c$ momenta
- Checked whether the chamber is working
  based on efficiency and time resolution

Gas gap configuration :
$255\ \mu m \times 5$ gaps $\times\ 2$ stack



Evaluation method

- Efficiency: $(N_{\mathrm{MRPC\_hits}}\ /\ N_{\mathrm{trigger}})$
- Time Resolution: standard deviation of $(T_{\mathrm{MRPC}} - T_{RF})$,
  where T_{MRPC} is the mean timing of signals from the left end and right of a strip,
  and T_{RF} is the timing of RF signal, which is synchronized with the beam bunch.

Prototypes

Coating	substrate	technic	resistivity	CR test	1st beam test	2nd beam test
Seplegyda	Film	barcoater	$\sim 6 \times 10^5\ \Omega/cm^2$	×	-	-
Air-Opaque	Film	barcoater	$\sim 5 \times 10^{10}\ \Omega/cm^2$	×	-	-
① Graphit 33	Film	paint roller	$\sim 2 \times 10^6\ \Omega/cm^2$	○	conducted	-
② CS-6301 (1)	Glass	hand spray	$\sim 4 \times 10^6\ \Omega/cm^2$	○	conducted	-
③ CS-6301 (2)	Film	microgravure	$\sim 3 \times 10^6\ \Omega/cm^2$	○	conducted	conducted
④ CS-5302	Film	microgravure	$\sim 2 \times 10^4\ \Omega/cm^2$	○	-	conducted
⑤ KP-8348-1	Glass	hand spray	$\sim 2 \times 10^4\ \Omega/cm^2$	○	conducted	conducted
⑥ KP-K2919-1	Film	hand spray	$\sim 2 \times 10^8\ \Omega/cm^2$	○	-	conducted

- **Seplegyda：dark currents×**
  Due to intrinsically conductive coating?
- **Air-Opaque ：dark currents×**
  Difficulties in getting desired resistivity
- **Others: passed CR test in laboratory, and proceed to the beam tests**

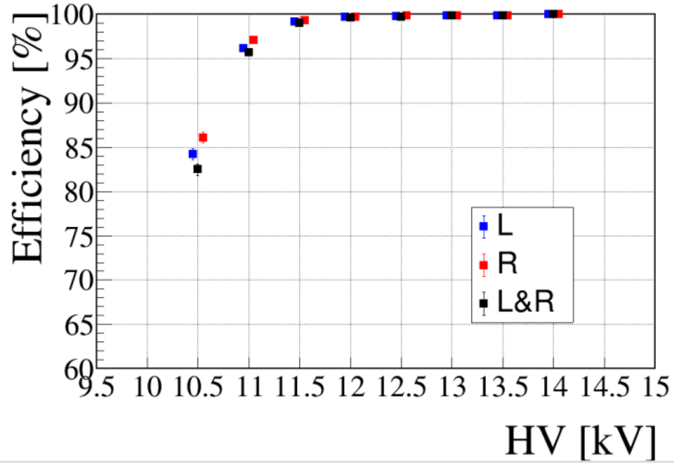
Prototypes

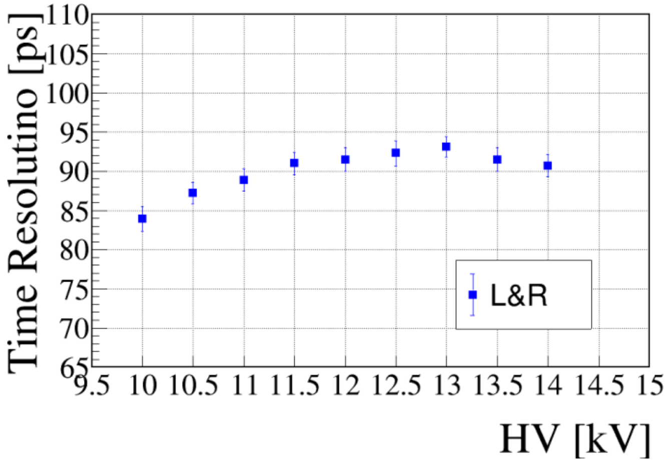
Coating	substrate	technic	resistivity	CR test	1st beam test	2nd beam test
Seplegyda	Film	barcoater	$\sim 6 \times 10^5\ \Omega/cm^2$	×	-	-
Air-Opaque	Film	barcoater	$\sim 5 \times 10^{10}\ \Omega/cm^2$	×	-	-
① Graphit 33	Film	paint roller	$\sim 2 \times 10^6\ \Omega/cm^2$	○	conducted	-
② CS-6301 (1)	Glass	hand spray	$\sim 4 \times 10^6\ \Omega/cm^2$	○	conducted	-
③ CS-6301 (2)	Film	microgravure	$\sim 3 \times 10^6\ \Omega/cm^2$	○	conducted	conducted
④ CS-5302	Film	microgravure	$\sim 2 \times 10^4\ \Omega/cm^2$	○	-	conducted
⑤ KP-8348-1	Glass	hand spray	$\sim 2 \times 10^4\ \Omega/cm^2$	○	conducted	conducted
⑥ KP-K2919-1	Film	hand spray	$\sim 2 \times 10^8\ \Omega/cm^2$	○	-	conducted

- **CS series (③ and ④) and KP series (⑤ and ⑥) were tested using large prototypes, based on the results of the first beam test**
- **Stopped trying ① Graphit 33 because it has a problem with import**
- **Only the results of ⑤ KP-8348-1 will be shown in this talk.**

Results

Performance on a strip (⑤KP-8348-1)

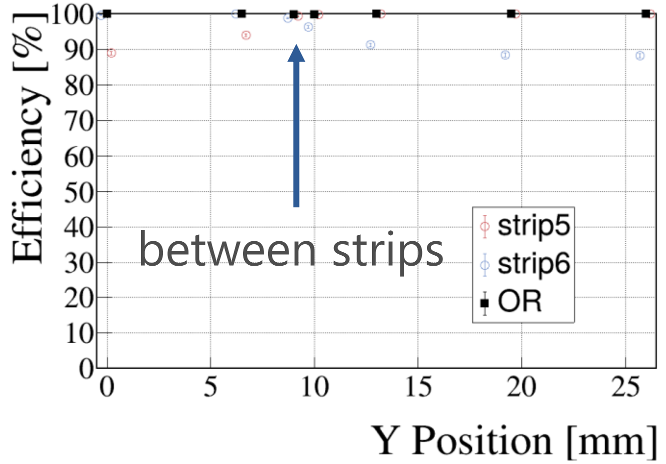


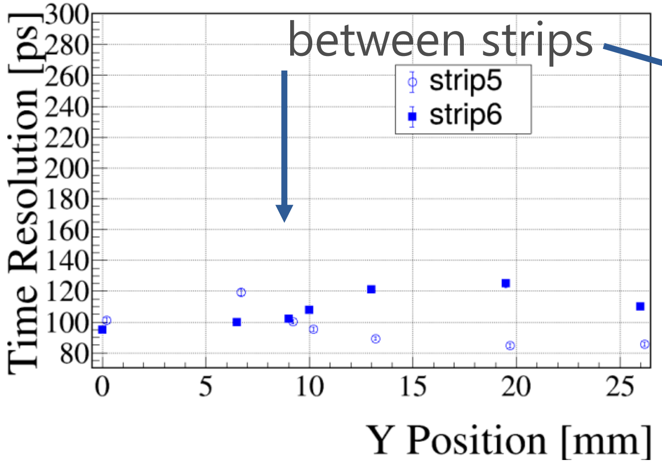


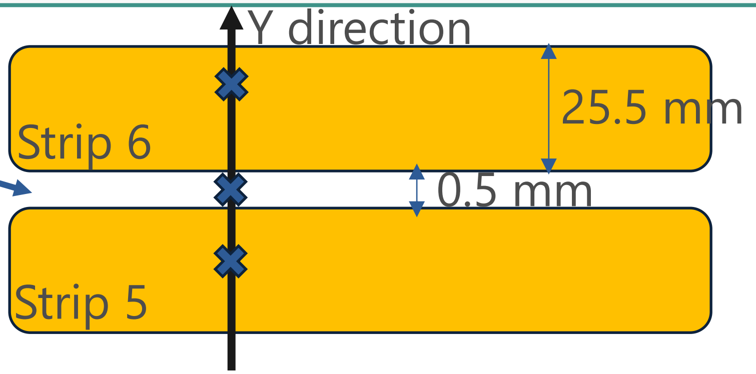
HV scan at the top of a strip

Efficiency: 99+ %
Time Resolution: ~ 90 ps

Performance between strips (⑤KP-8348-1)







Efficiency (OR): 99+ %
Time Resolution ~100 ps

- ⑤ KP-8348-1 showed reasonable performances even with a ~1 m prototype。

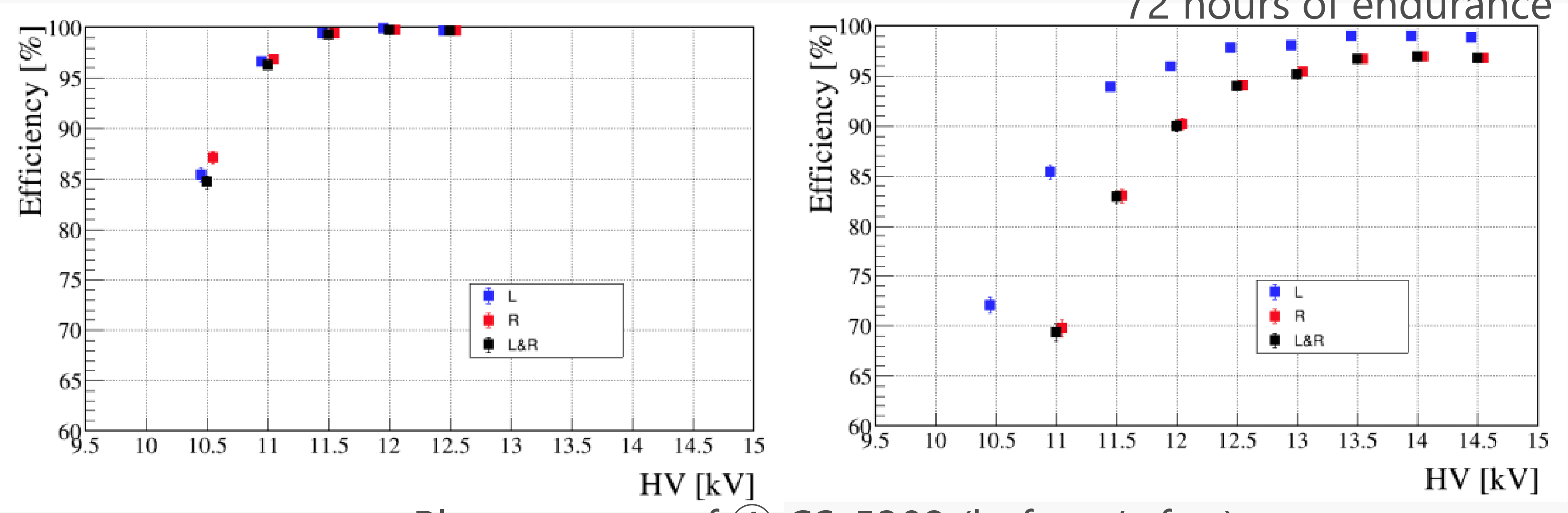
Results

- **Reasonable performances confirmed for all the other candidates too**

  However… shifts of plateau curve were seen for both CS series

  (probably 1 electrode among 4 was electrically detached)

  although there was no problem after 72 hours of endurance test in the lab.



Plateau curve of ④ CS-5302 (before / after)

Chamber	on a strip	between strips	stability	producibility	reproducibility
③ CS-6301 (on Film)	99.6 %, 77.8 ps	95+ %, 100 – 140 ps	△	○	○
④ CS-5302 (on Film)	99.4 %, 70 – 80 ps	99.1 %, 85.8 ps	△	○	○
⑤ KP-8348-1	99.9 %, ~100 ps	99.9 %, 101.0 ps	○	△	△
⑥ KP-K2919-1	~80 %, ~100 ps	~80 %, 120 – 180 ps	○	△	?

Summary

We explored an alternative new HV electrodes for MRPC detector

Multiple candidates eventually are found;

- ③ CS-6301 / ④ CS-5302

  99 % efficiency, ~70 ps time resolution at best.
  Coating on a film enables us to produce a large quantity with desired resistivity.
  Issues with stability, which may come from assembling process of MRPC.
- ⑤ KP-8348-1

  99 % efficiency, ~100 ps time resolution.
  Hand coating resulted in high risk of glass breaking, high cost of mass production, and low reproducibility in resistivity.
  The operation was very stable.

⇒ CS series if the stability issues are resolved

To do

- To find the reason why CS series broke and fix it.
- Optimization of resistivity.

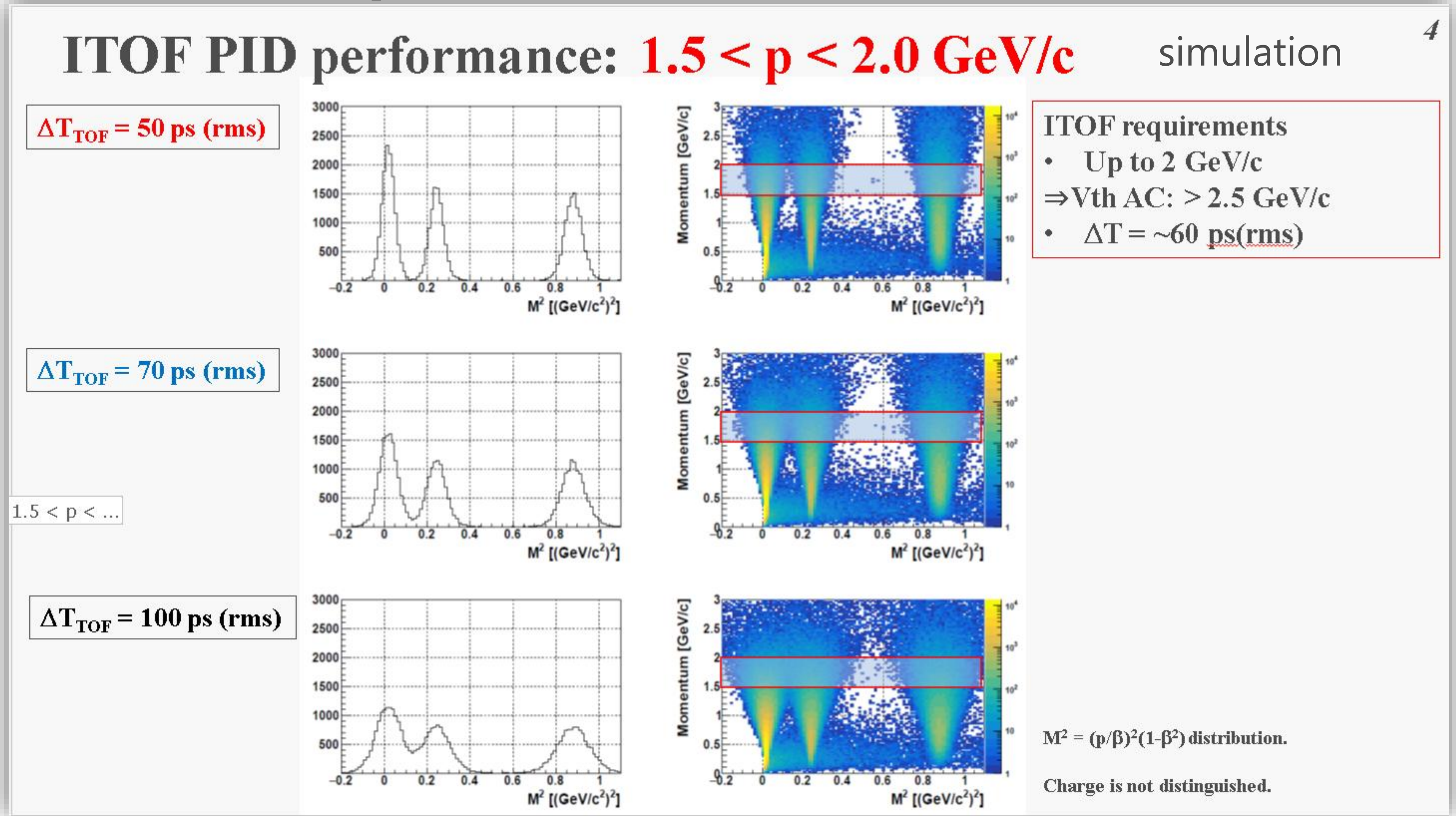
Backup

Effects of time resolution to PID

- **TOF time resolution affects the resolution of mass squared**
  → affects the fraction of events in which particles are identified
  - Start counter is already developed ($\Delta T \sim 40$ ps)

If $\Delta T_{\mathrm{MRPC}} \sim 60$ ps →

If $\Delta T_{\mathrm{MRPC}} \sim 90$ ps →



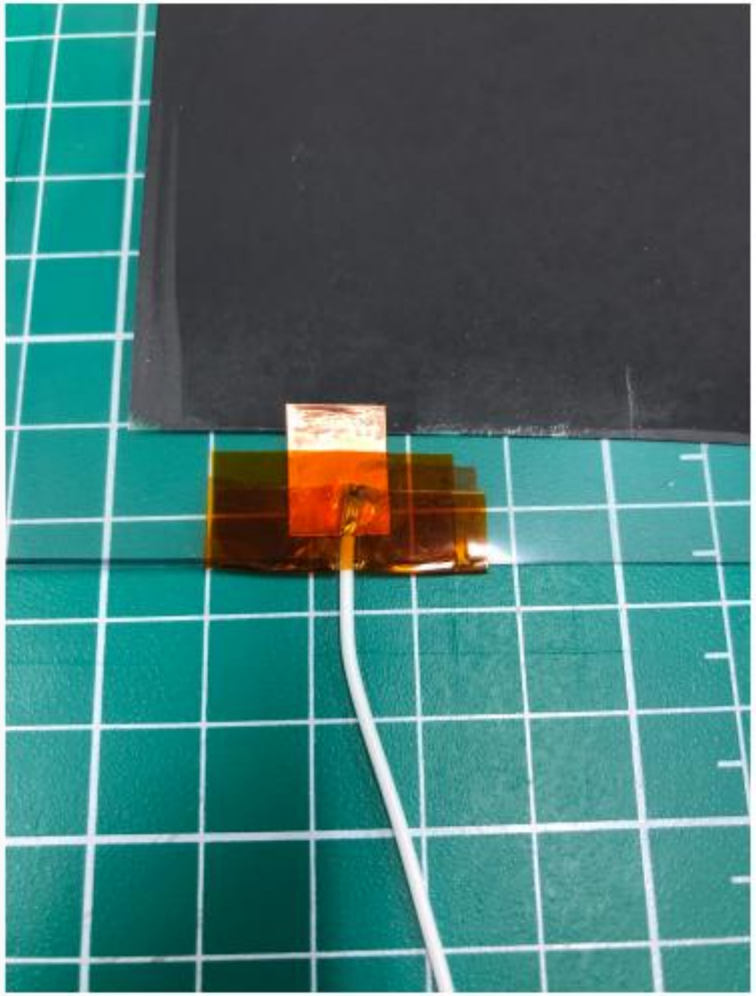
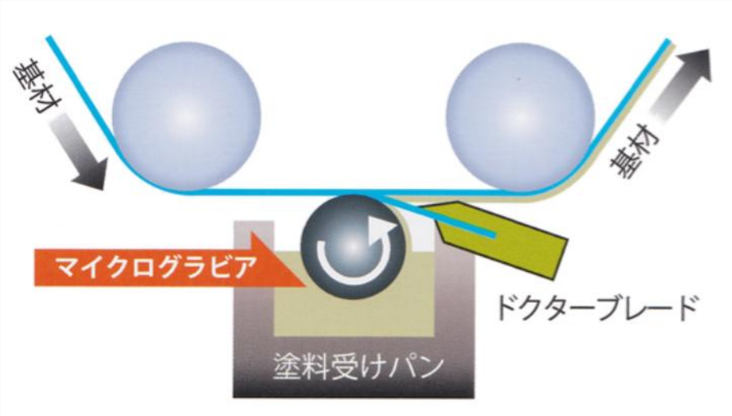


Image of HV connecting point

Coating methods

- **Microgravure**

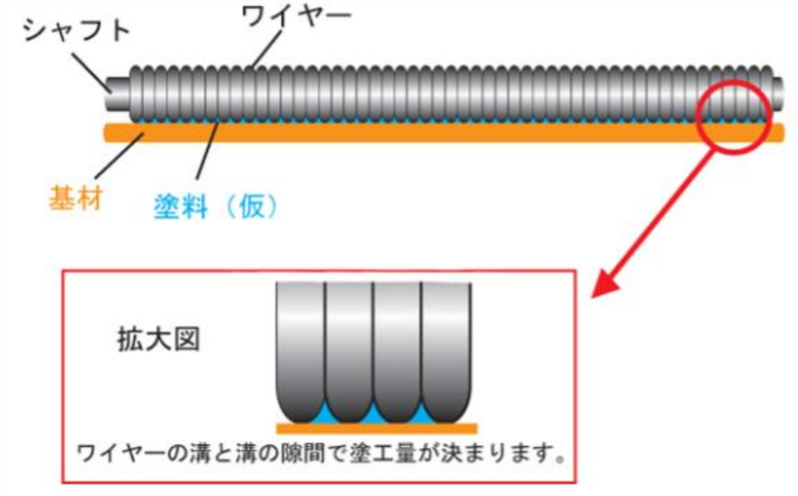


https://www.labojapan.co.jp/labotech/coating/#micro

- **Hand spray**

https://kansaipolymer.co.jp/strength/method

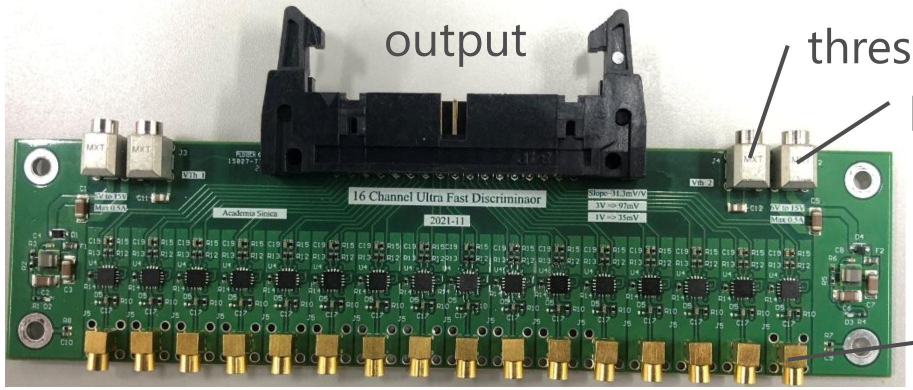
- **Barcoater**



https://www.mitsuiec.co.jp/Wirebar

Dedicated electronics and methods

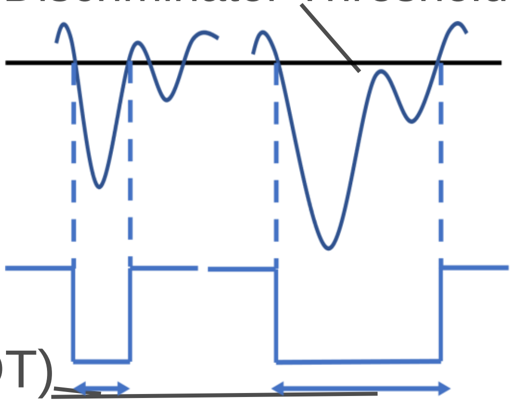
Discriminators (Academia Sinica)



Width-varying output depending on the input width

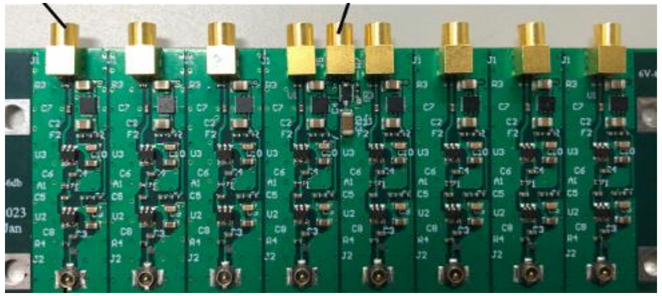
Time Over Threshold (TOT)

Width of the discriminator output.
A representative of charge.



Amplifiers (Academia Sinica)

fast.
gain : ×~300

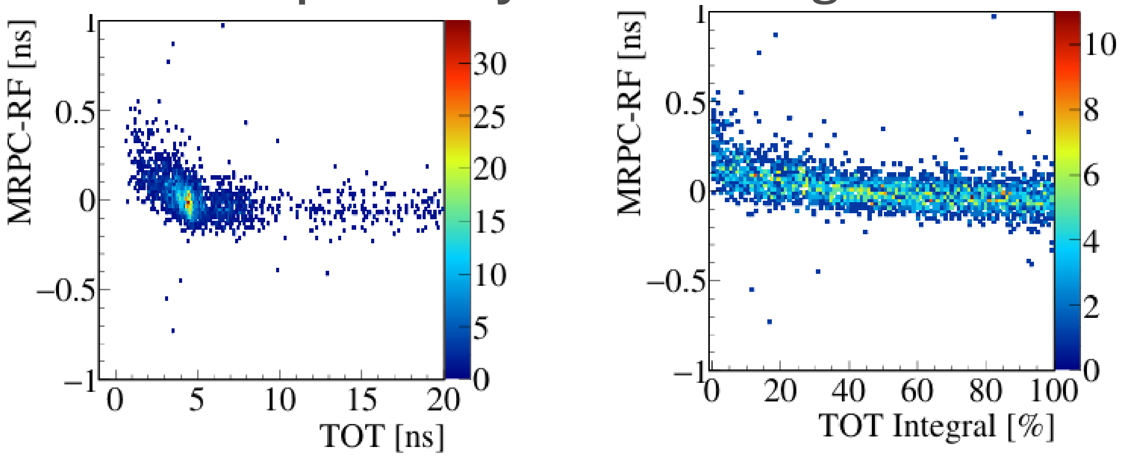


Slewing correction with TOT integral

A slew. corr. method that can be done only with TDC.

TOT integral = percentile of a tot in a tot distribution

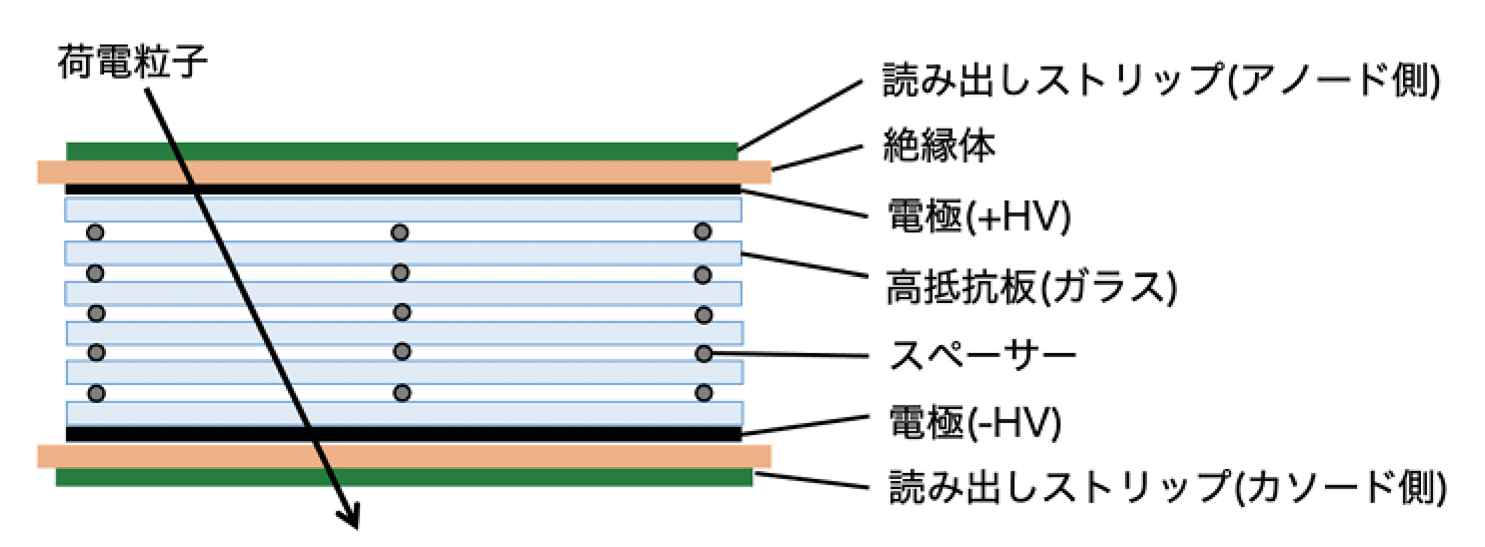
Subtract the dependency on TOT integral



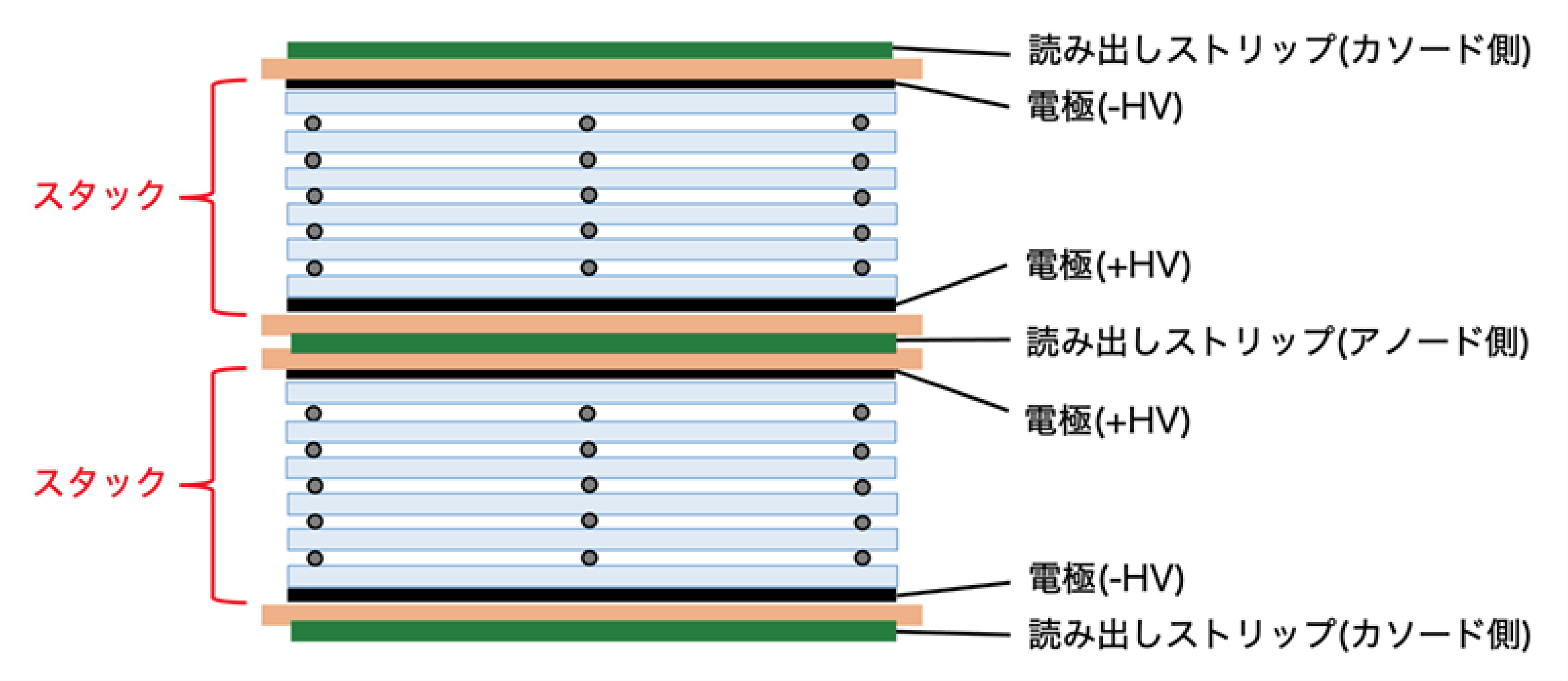
R. X. Yang, C. Li, Y. J. Sun et al., JINST 12 C01012 (2017).

1 stack MRPC と 2 stack MRPC

1 stack MRPC



2 stack MRPC



Small (200 mm × 200 mm) prototypes for 1st beamtest

塗料	塗布形態	抵抗率	Gas gap configuration
Air-Opaque	フィルム塗布	$5 \times 10^{10}\,\Omega/\mathrm{cm}^2$	$255\ \mu\mathrm{m} \times 5$ gap $\times 1$ stack
Graphit 33	フィルム塗布	$2 \times 10^{6}\,\Omega/\mathrm{cm}^2$	$255\ \mu\mathrm{m} \times 5$ gap $\times 1$ stack
KP-8348-1	ガラス塗布	$2 \times 10^{4}\,\Omega/\mathrm{cm}^2$	$255\ \mu\mathrm{m} \times 5$ gap $\times 1$ stack
CS-6301 (1)	ガラス塗布	$4 \times 10^{6}\,\Omega/\mathrm{cm}^2$	$255\ \mu\mathrm{m} \times 5$ gap $\times 1$ stack
CS-6301 (2)	フィルム塗布	$3 \times 10^{6}\,\Omega/\mathrm{cm}^2$	$255\ \mu\mathrm{m} \times 5$ gap $\times 1$ stack
セプルジーダ	フィルム塗布	$6 \times 10^{5}\,\Omega/\mathrm{cm}^2$	$255\ \mu\mathrm{m} \times 5$ gap $\times 1$ stack

Large (~1 m long) prototypes for 1st beamtest

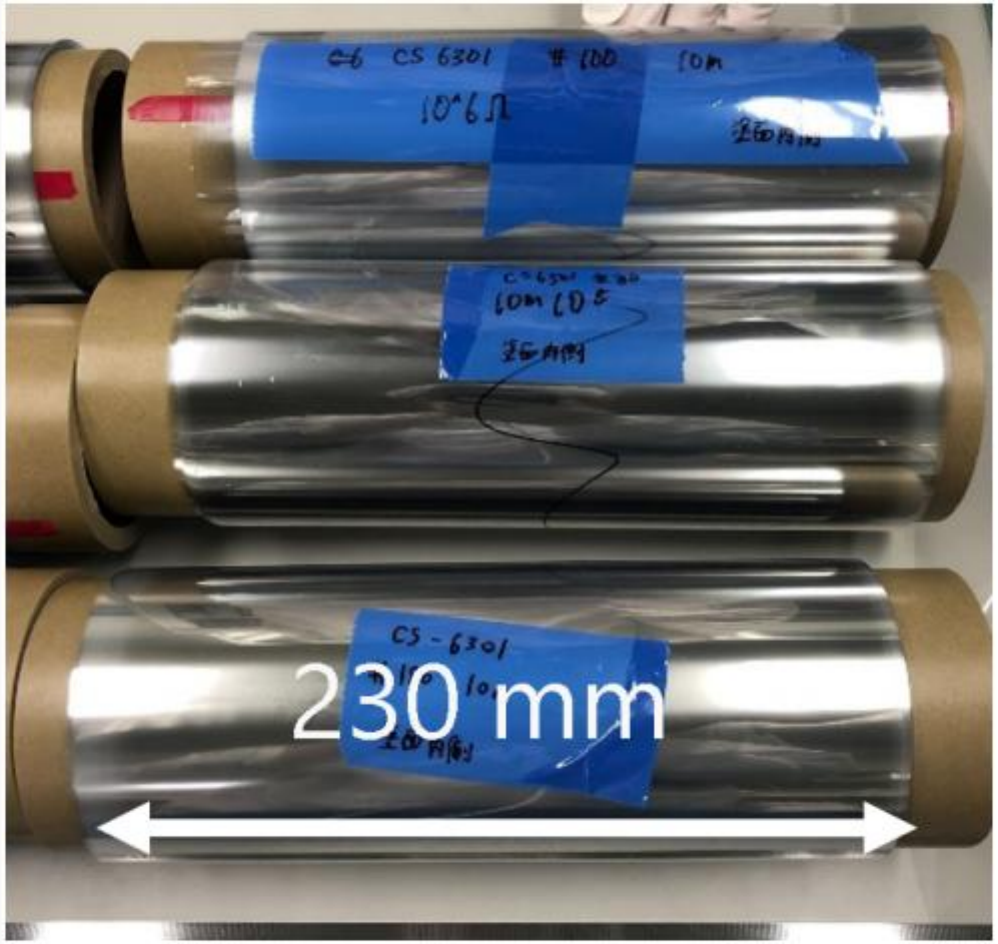
電極	塗布形態	塗布方法	Glass size	stack	率
CS-6301	フィルム塗布	マイクログラビア	940 mm × 230 mm	**2** stack	$\sim 1 \times 10^{6}\,\Omega/\mathrm{cm}^2$
CS-5302	フィルム塗布	マイクログラビア	870 mm × 230 mm	**2** stack	$\sim 2 \times 10^{4}\,\Omega/\mathrm{cm}^2$
KP-8348-1	ガラス塗布	スプレーガン	940 mm × 230 mm	**2** stack	$\sim 2 \times 10^{4}\,\Omega/\mathrm{cm}^2$
KP-K2919-1	フィルム塗布	スプレーガン	200 mm × 200 mm	**1** stack	$\sim 2 \times 10^{8}\,\Omega/\mathrm{cm}^2$

(Gas gap configuration per stack is **260 μm × 5 gaps** である。)

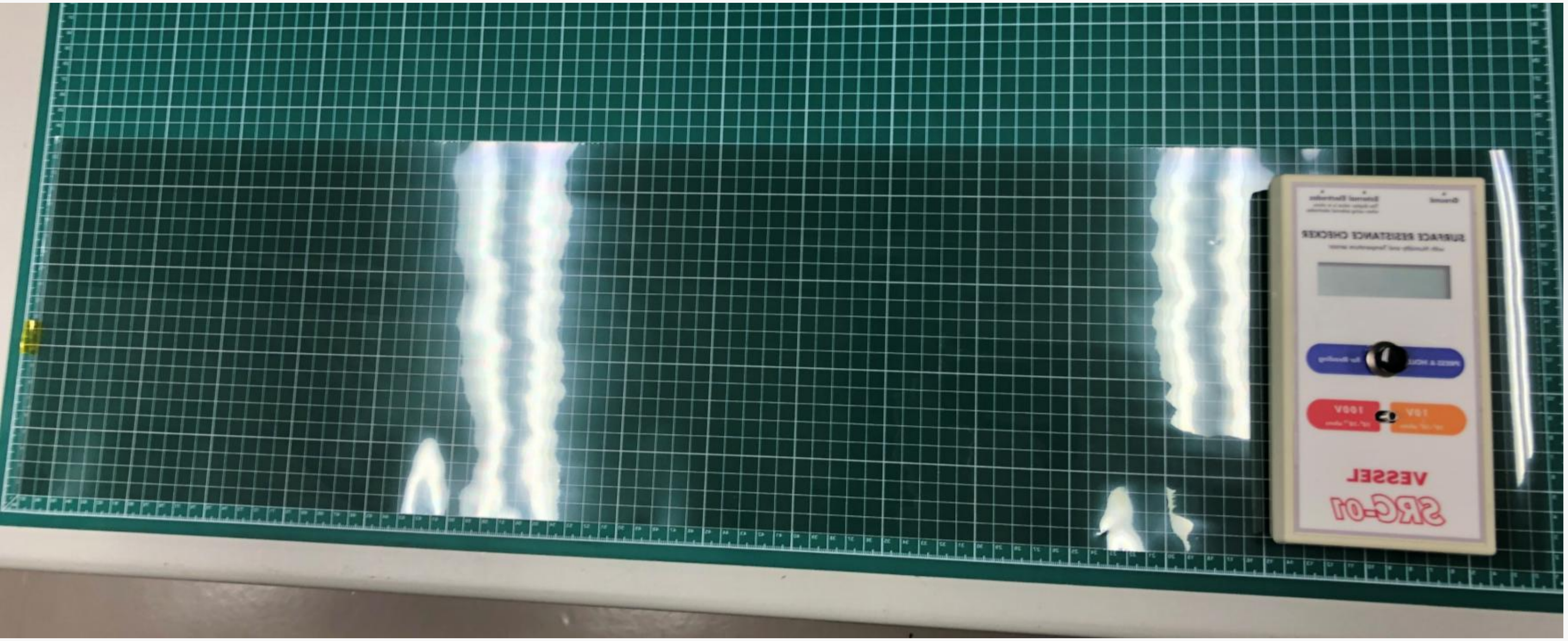
Adjustment of resistivity

We can adjust various resistivity using CS-6301 by changing the thickness of coating.
We made several sample and confirmed the resistivity shown below can be achieved.

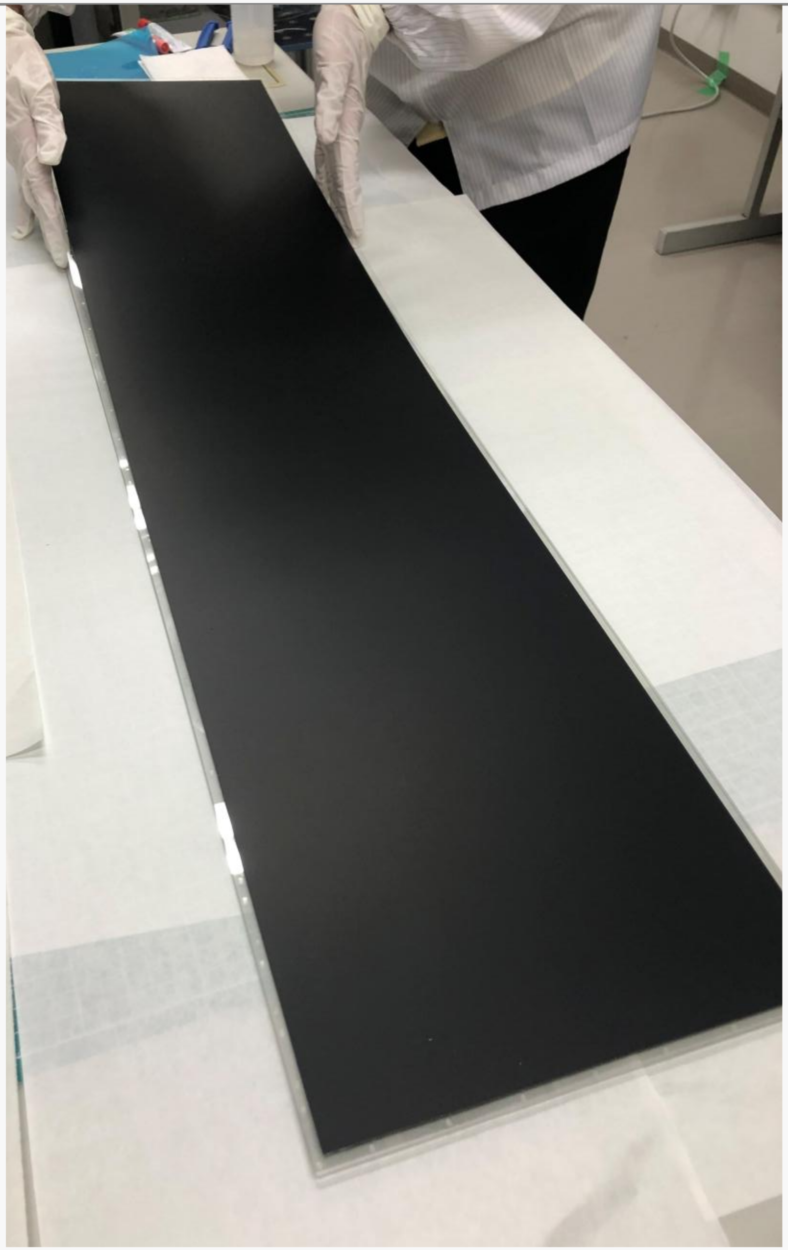
- CS-6301 : 10^5, $10^6, 10^7$ Ω/sq.
- CS-5302 : 10^4, $10^5, 10^8$ Ω/sq.



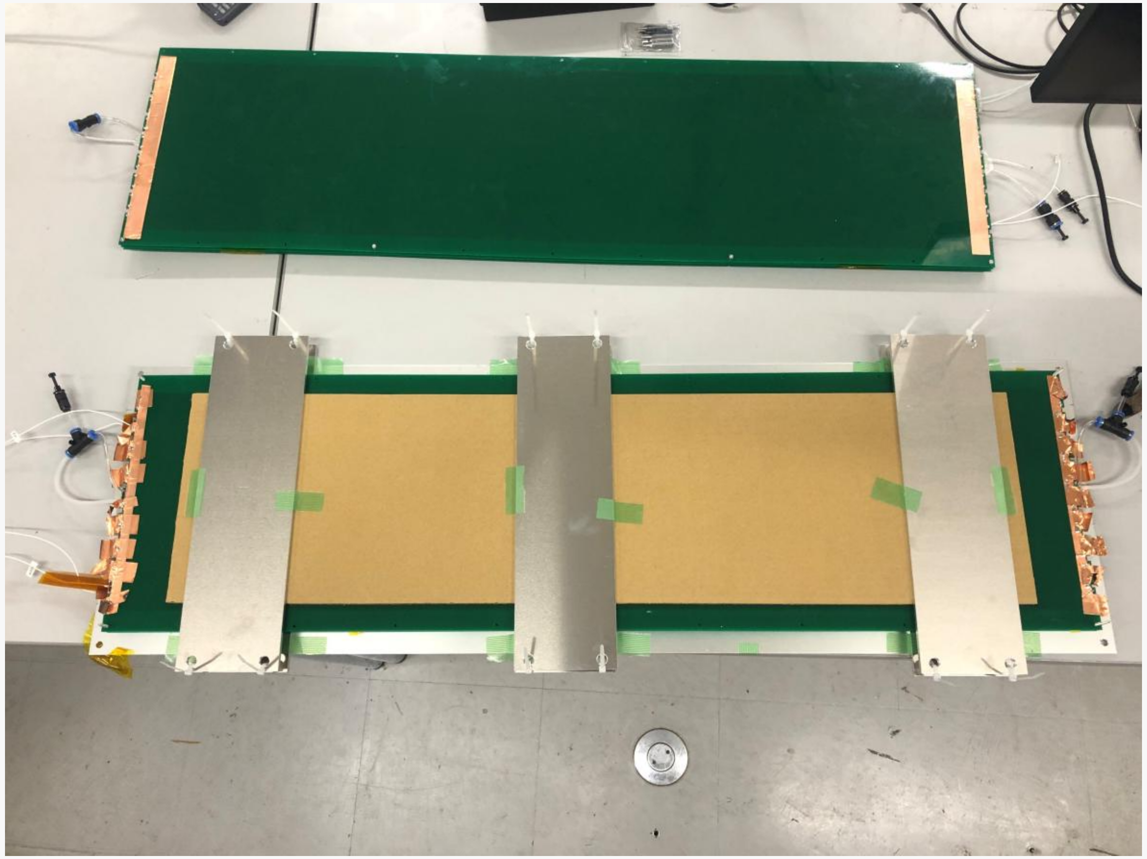
Rolls of film coated with CS-6301



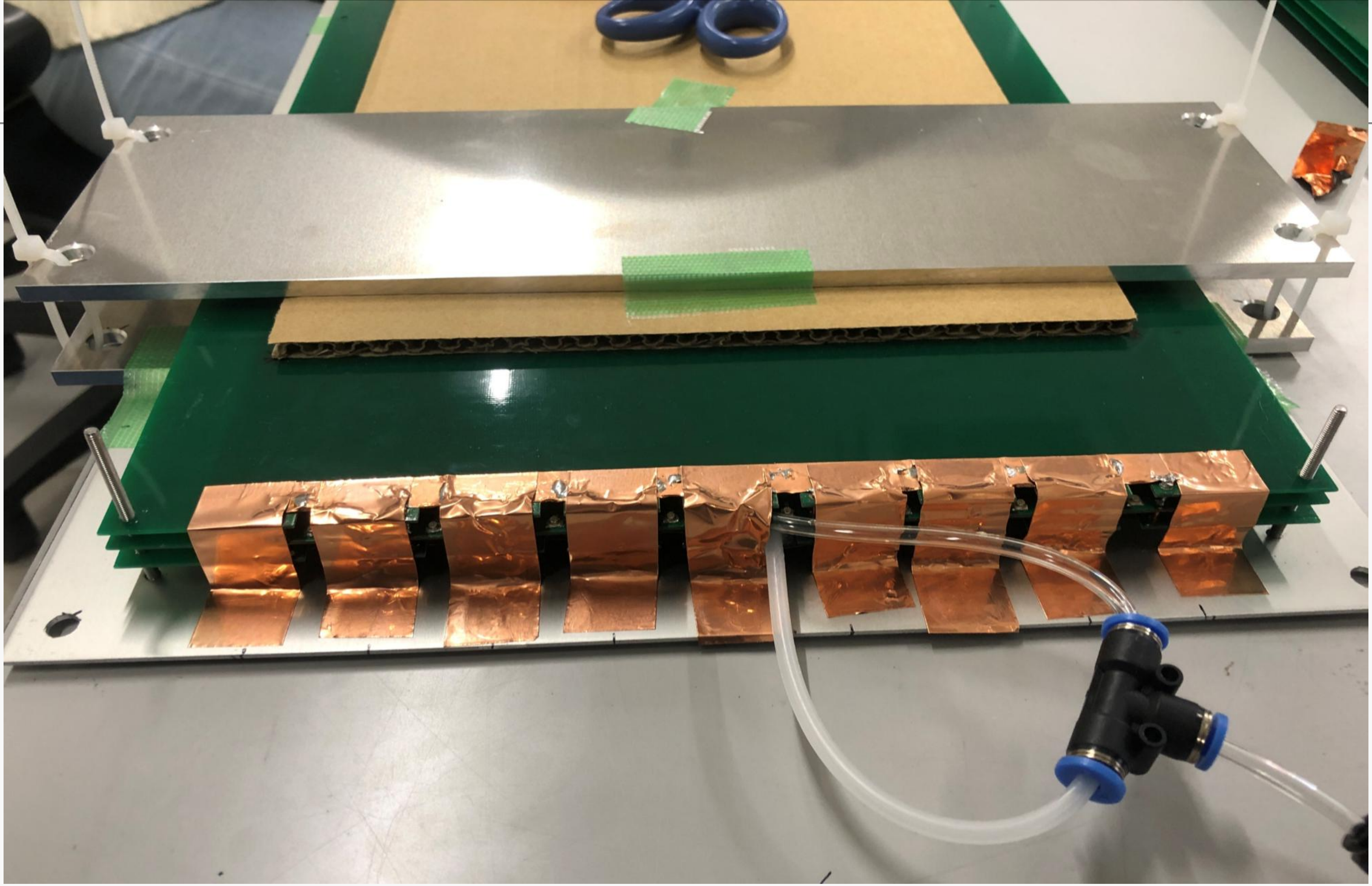
④CS-5302



⑤KP-8348-1



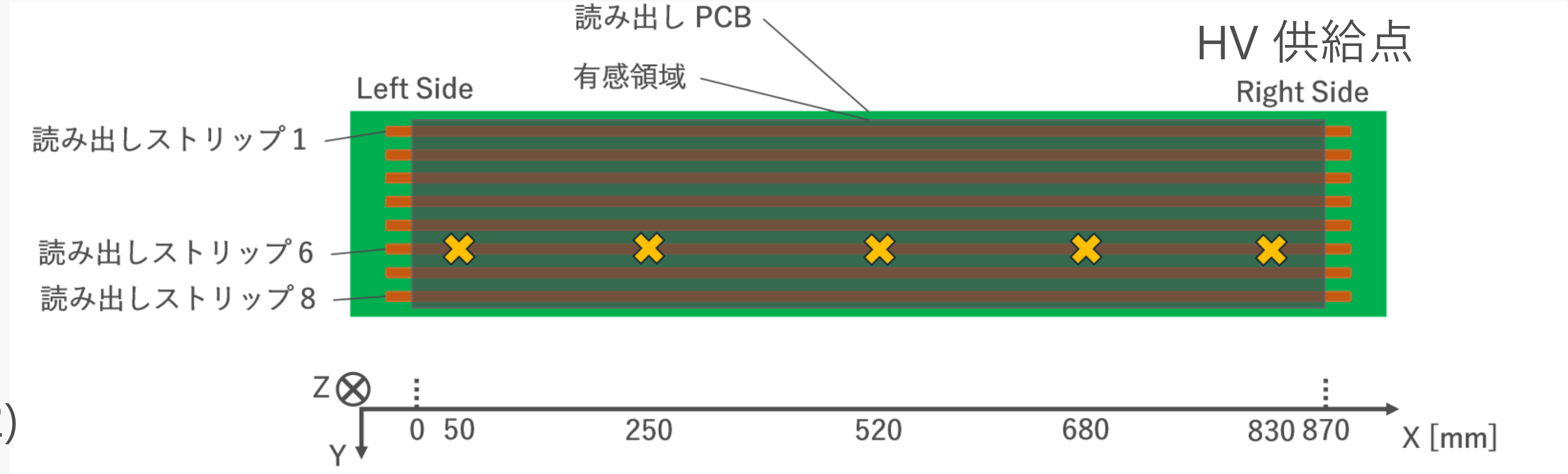
Electric contact was assured by pressing



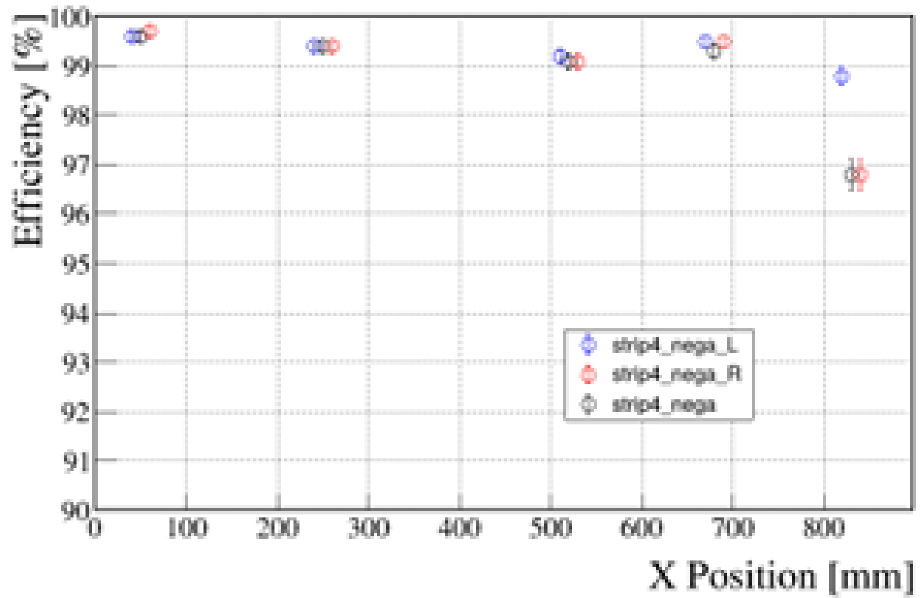
Grounding for noise reduction

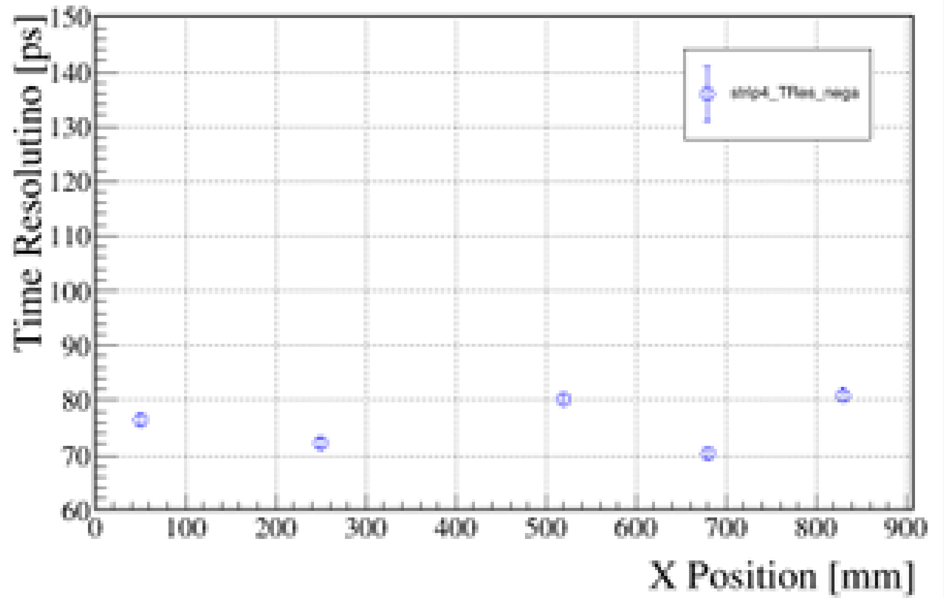
結果（第二弾）

- **電圧降下の兆候もなかった**



X position scan の結果 (④ CS-5302)





結果（第二弾）

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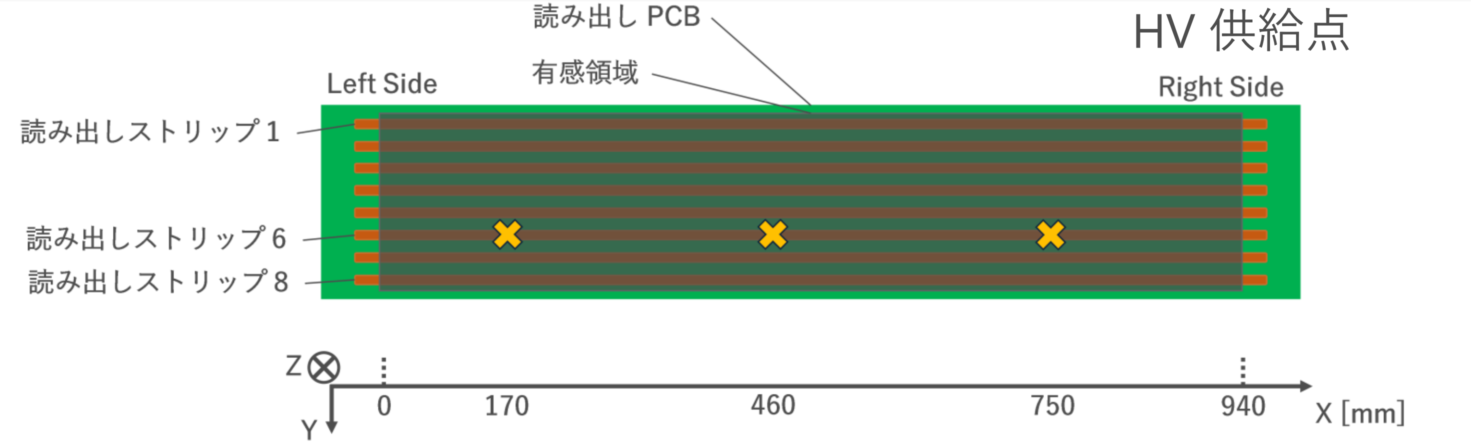
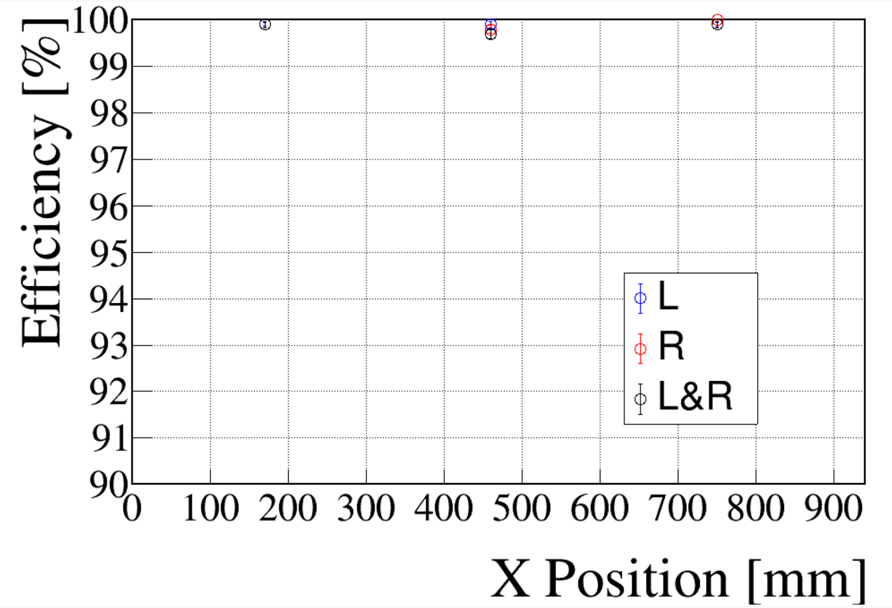
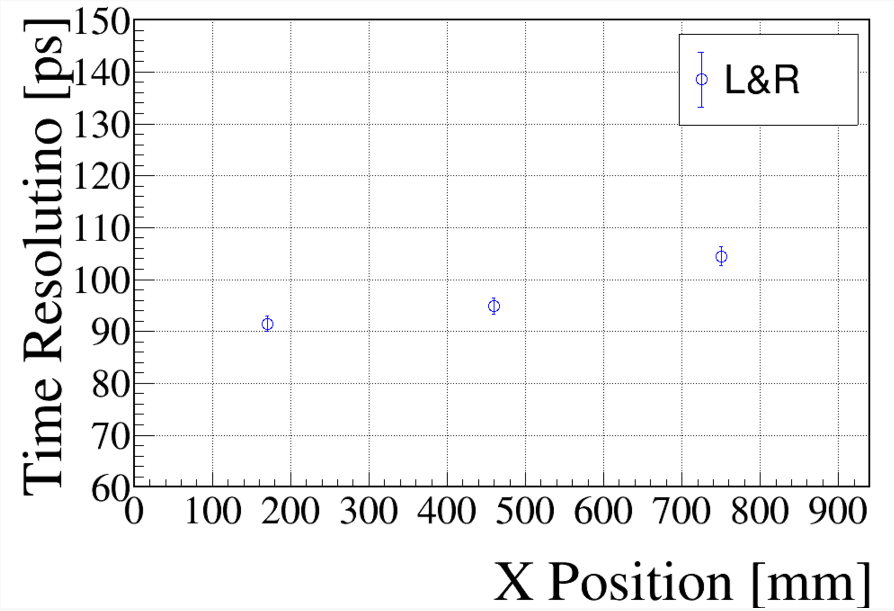
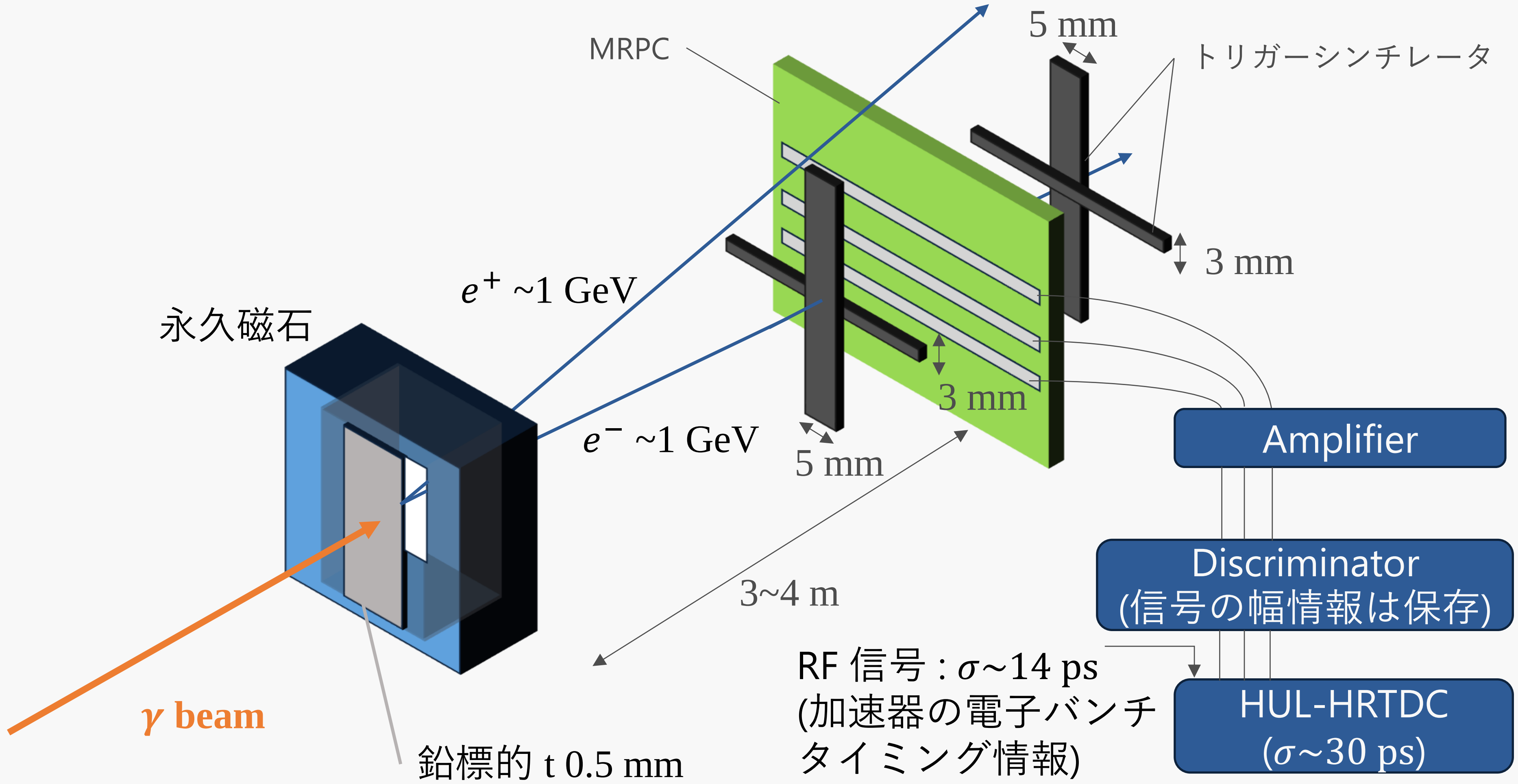


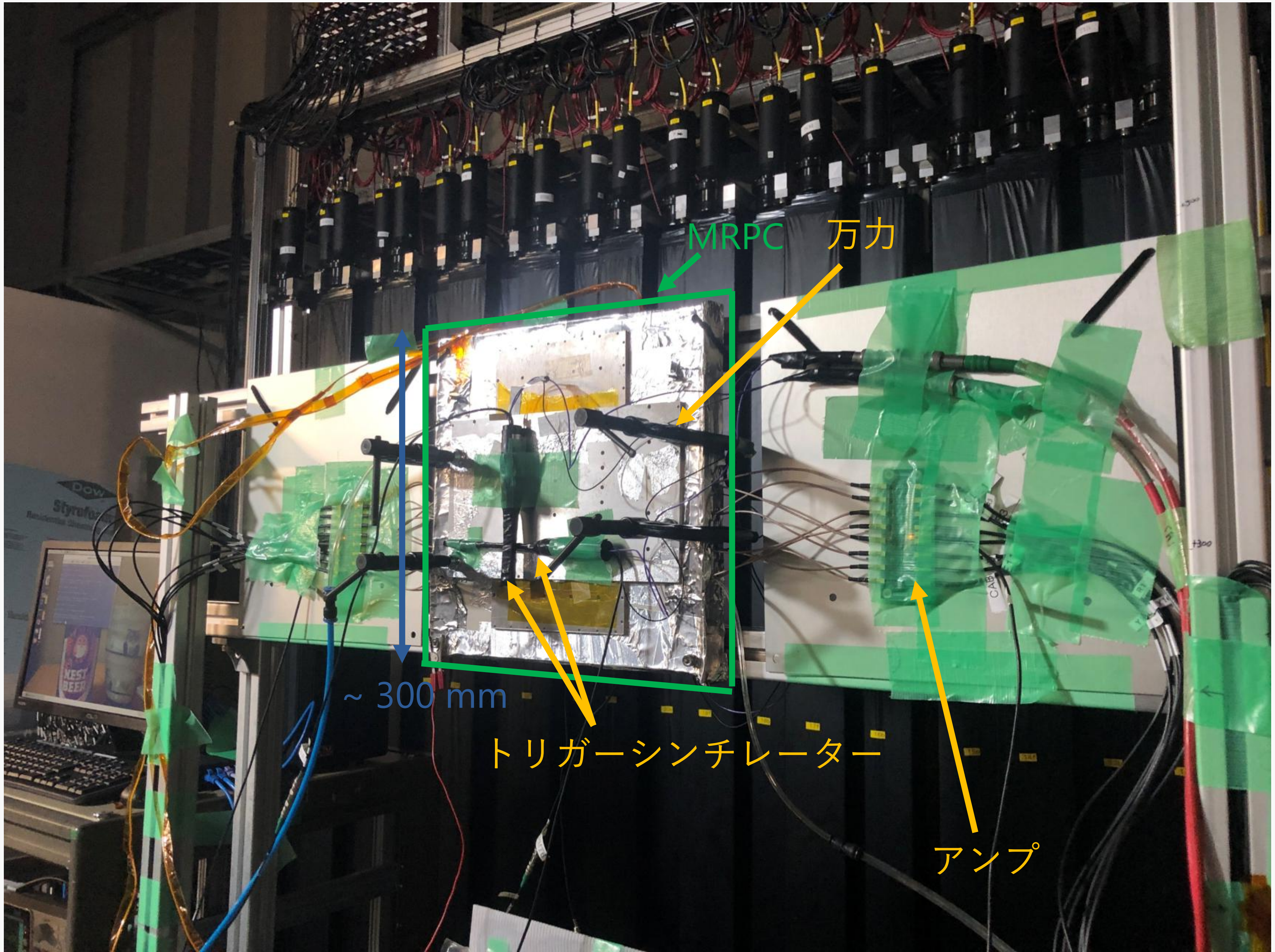
X position scan の結果 (⑤ KP-8348-1)



X position scan の結果 (⑤KP-8348-1)




MRPC
5 mm
トリガーシンチレータ
3 mm
e+ ~1 GeV
永久磁石
e− ~1 GeV
5 mm
3 mm
Amplifier
3~4 m
Discriminator
(信号の幅情報は保存)
RF 信号 : σ~14 ps
(加速器の電子バンチ
タイミング情報)
HUL-HRTDC
(σ~30 ps)
γ beam
鉛標的 t 0.5 mm


MRPC
万力
~ 300 mm
トリガーシンチレーター
アンプ


~ 1000 mm
MRPC
トリガーシンチレーター
アンプ

Design of film spacer

図 4.6: ポリエステルフィルムスペーサーの構造。市販のフィルムやテープを組み合わせている。