# The μRWELL-based inner tracker research for Super Tau-Charm Facility

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On behalf of STCF group
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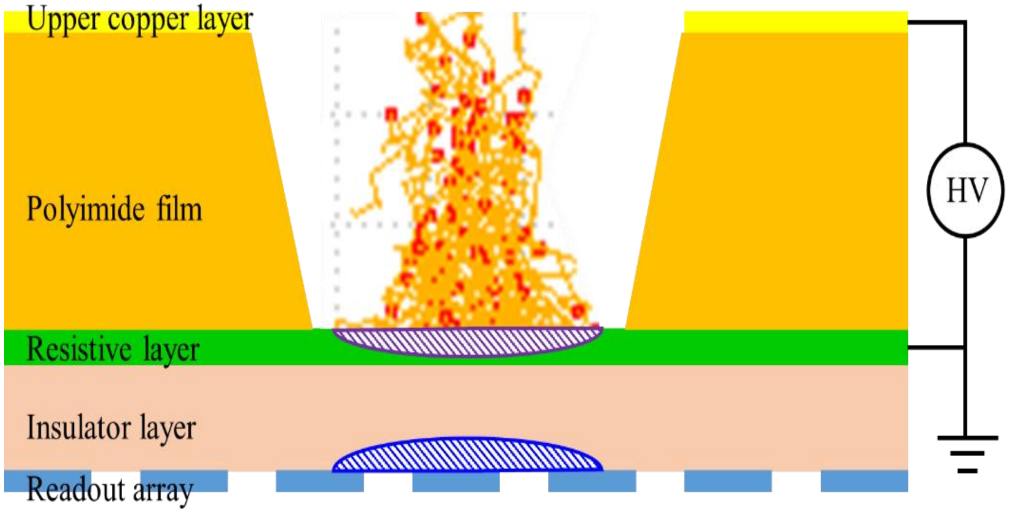
# Outline

1. **Introduction to μRWELL detector**
2. Research progress in μRWELL key technology
3. μRWELL inner tracker for STCF
4. Discussion: large planar μRWELL
5. Conclusion

# µRWELL detector design

**Advantages of µRWELL:**

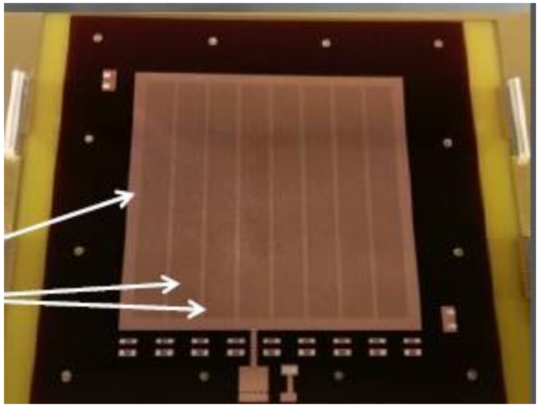
- **Resistive layer**
- High detector gain
- Simple structure
- **Low material budget**



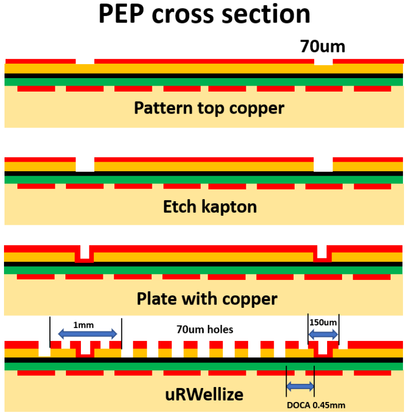

Many research directions of µRWELL:

**Large detection area**


**High counting rate**



**Manufacturing process**

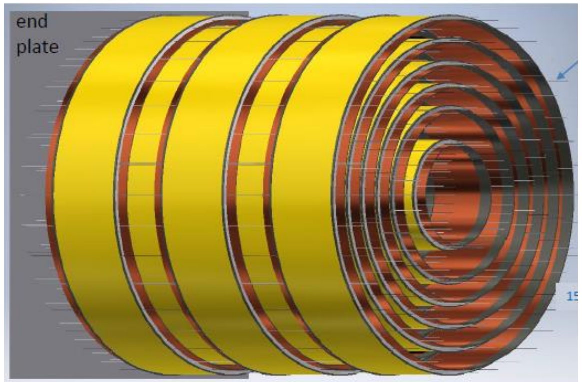


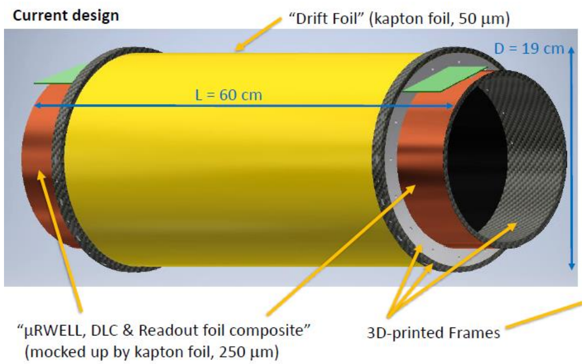
# µRWELL researched for experiments

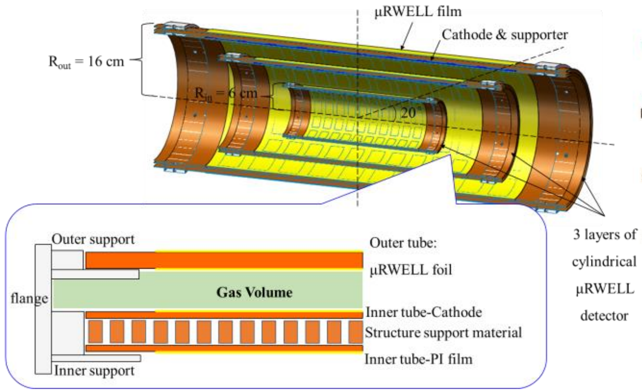
## Cylindrical µRWELL

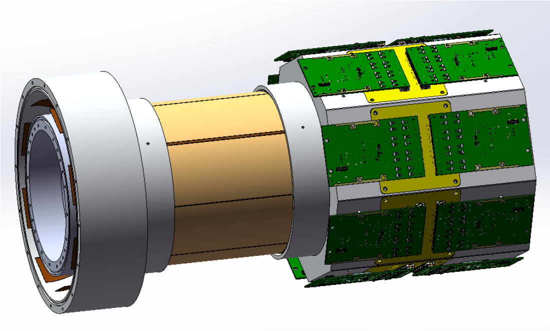
## Planar µRWELL

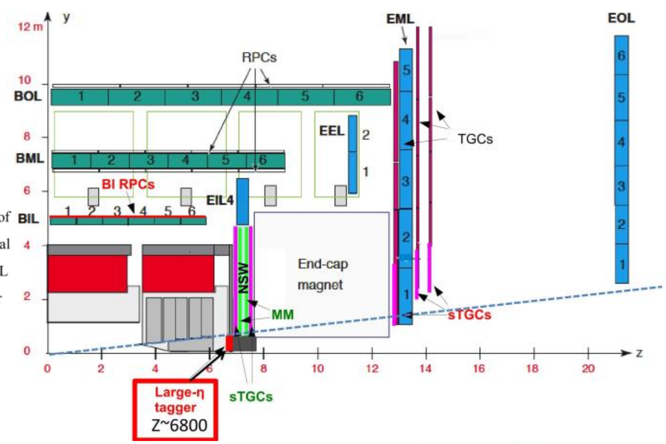
EIC central tracking    STCF C-µRWELL inner tracker    ATLAS High η muon tagger

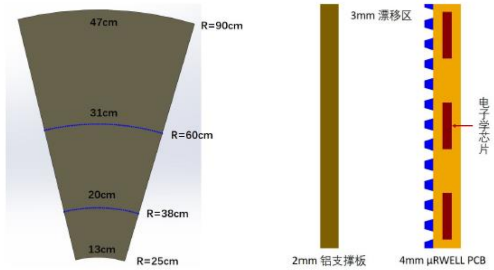




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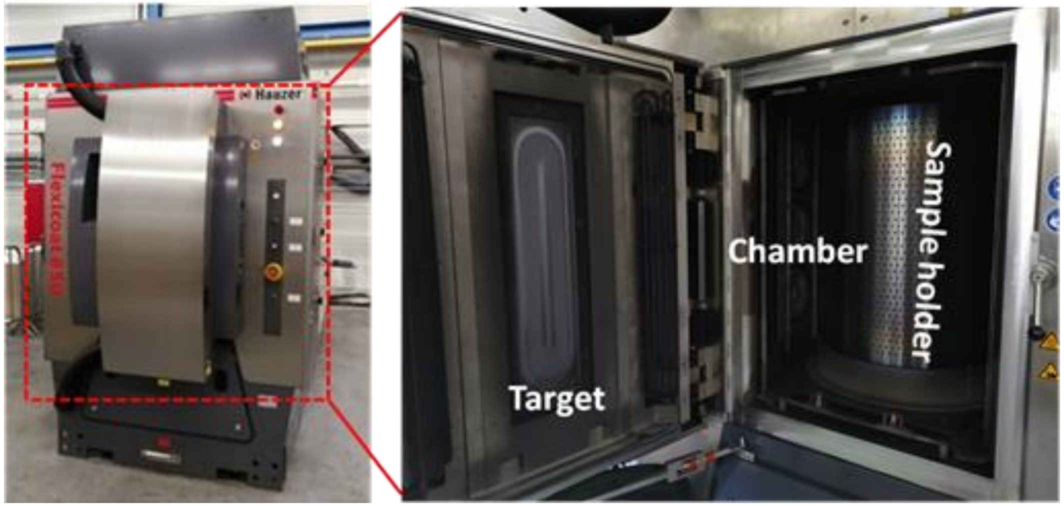
# Research progress of μRWELL

- Large area **resistive layer** manufacturing
- Different **μRWELL manufacturing** method for fast grounding
- New **fast grounding design** and performance simulation method
- **Material budget** control
- **Large area μRWELL** detector research
- **Electronic system** research

# Large area resistive layer study

- Large area resistive layer is the foundation of detector implementation

- **Uniformity** of the layer
- **Adhesion** to the substrate
- Surface resistance **control**
- **Consistency** of the manufacturing process

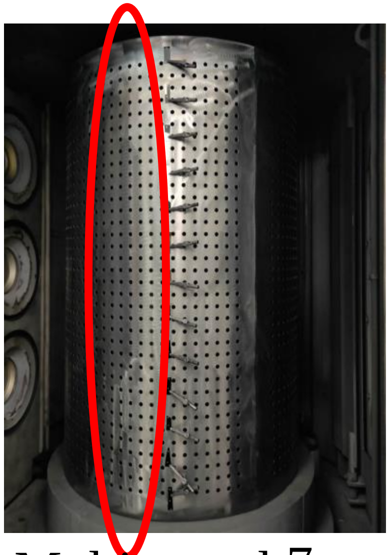




Apical before coating

Made Cu-DLC

Resistance measurement



Multi sample test

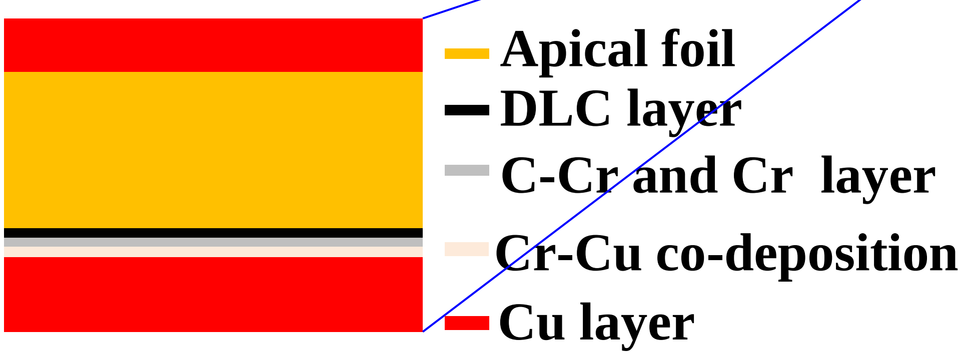
# Cu-DLC manufacturing

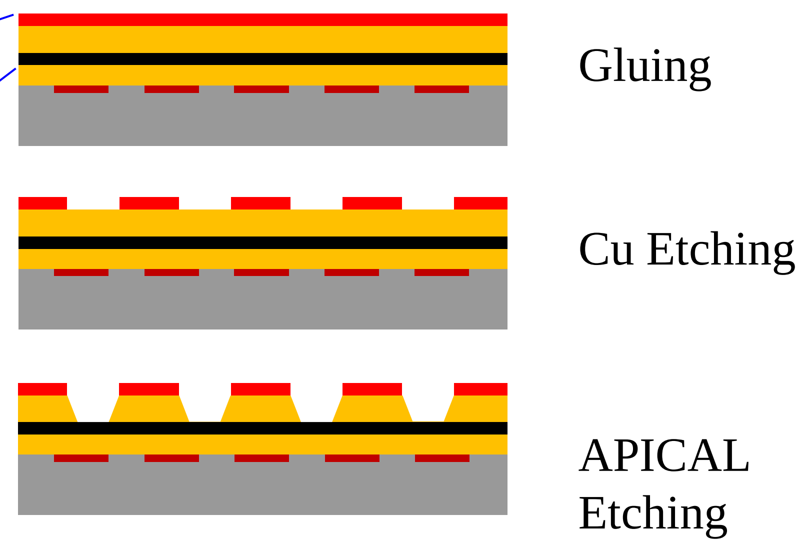
## Flow chart of the Cu+DLC by “One-batch” method

APICAL Clamping → Vacuum Pumping → DLC Deposition → C & Cr Co-deposition → Cr Deposition → Cr & Cu Co-Deposition → Cu Deposition → Cooling taking down

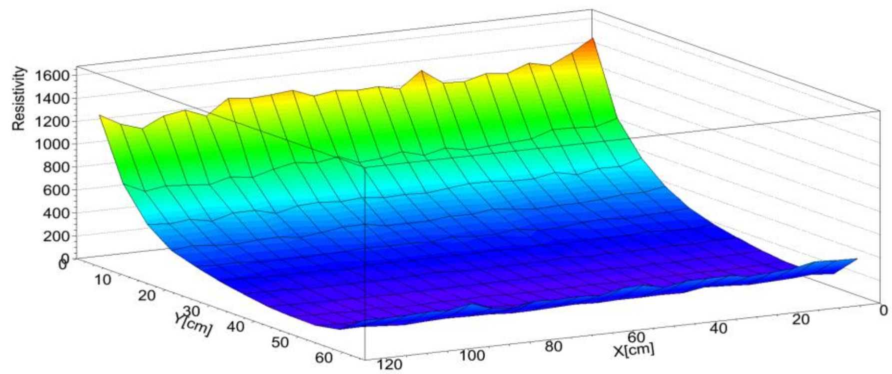
**Cu-DLC layer:**

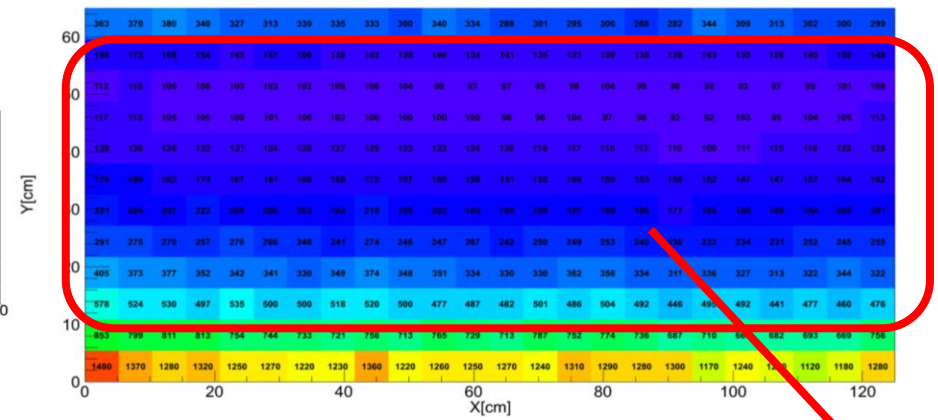
- Better resistance stability in long time
- One-batch manufacturing method
- Preparing well for fast grounding

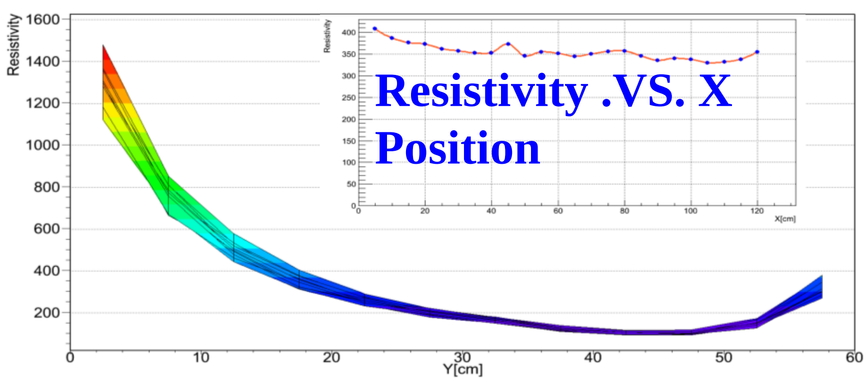


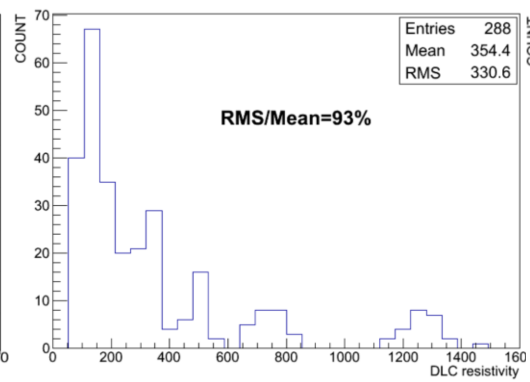



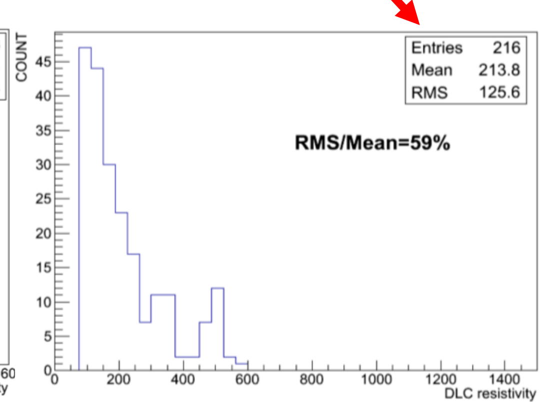
# Uniformity: Apical-C:H



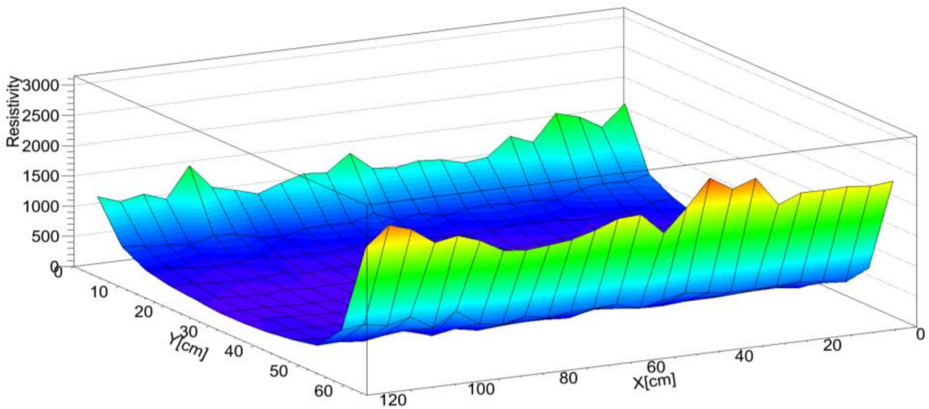



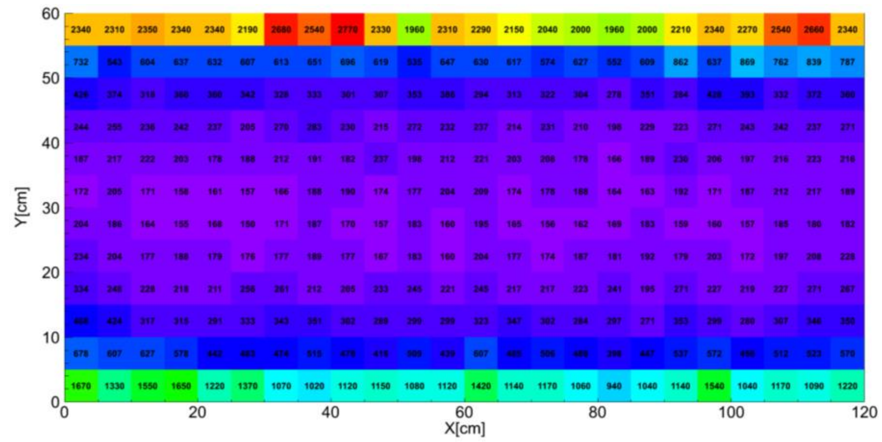



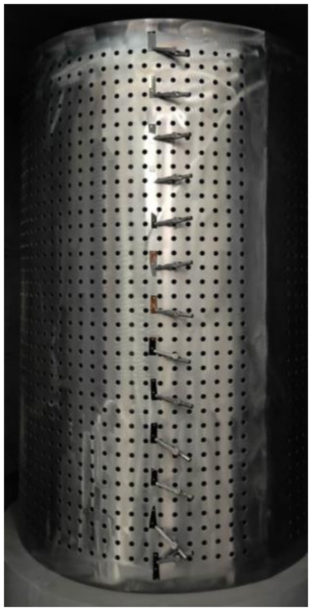

- The resistivity significantly decreasing when the height is increasing, which is caused by the $C_2H_2$ gas flow;

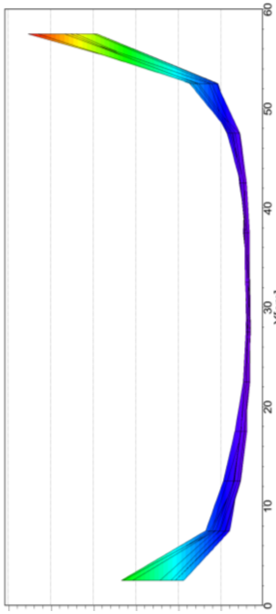
# Uniformity: Apical-C

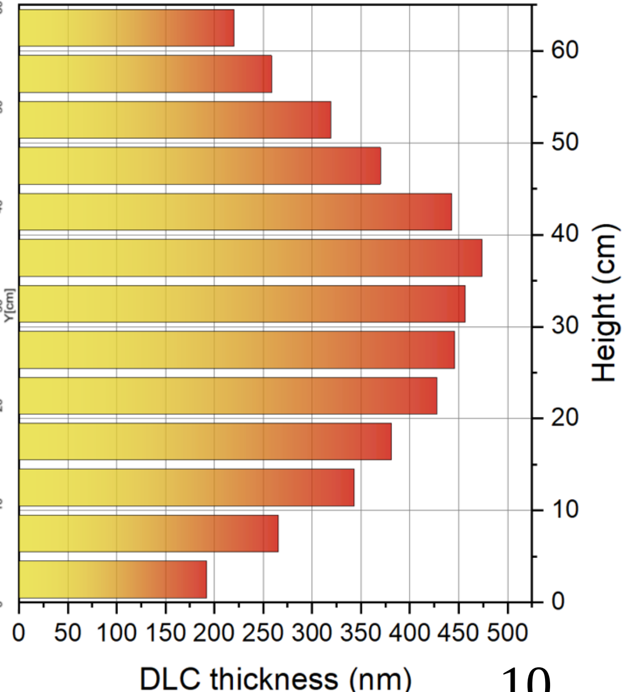



- **Two measurements show a similar trend of the Apical-DLC layer uniformity**

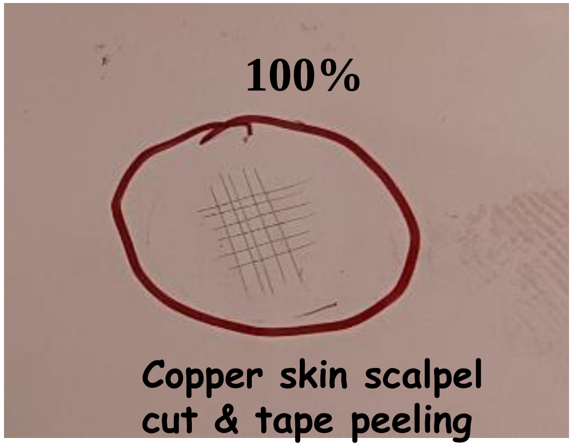




# Other tests

- **Adhesion test**
- Scalpel cut
- Tape peeling

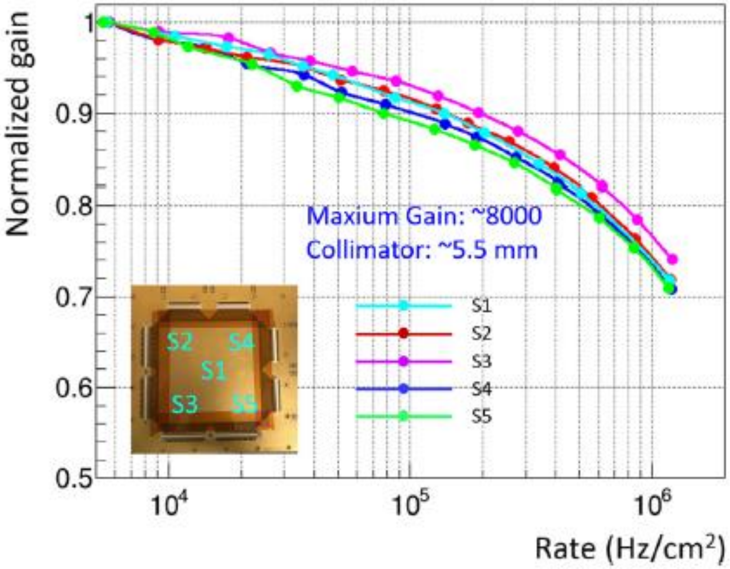



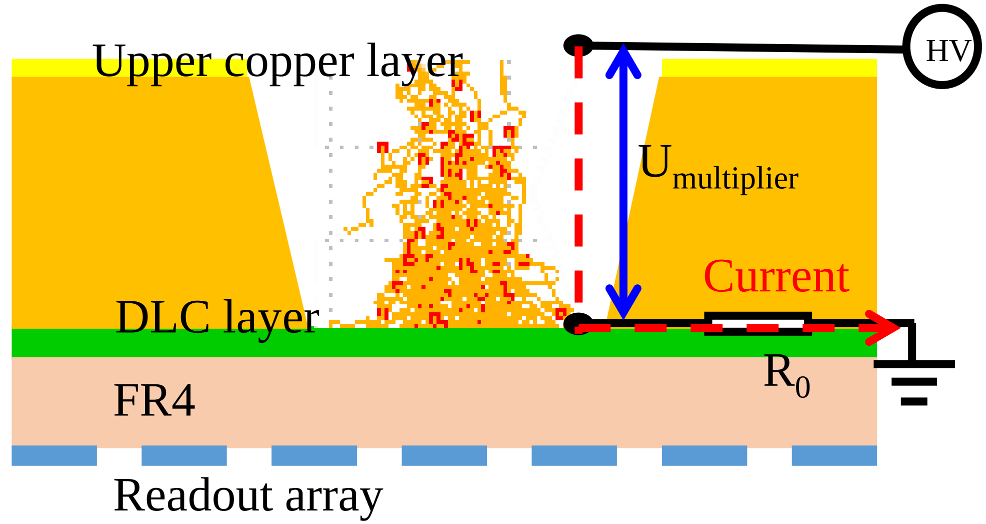

- **Surface resistance control:**
- Temperature
- $C_2H_2$ flow rate
- Coating time
- Bias setting

- **Consistency in different manufacturing process:**
- Calibrating the important parameters before coating

- **Manufactured maximum size of DLC samples is up to 1.4 m×0.65 m**

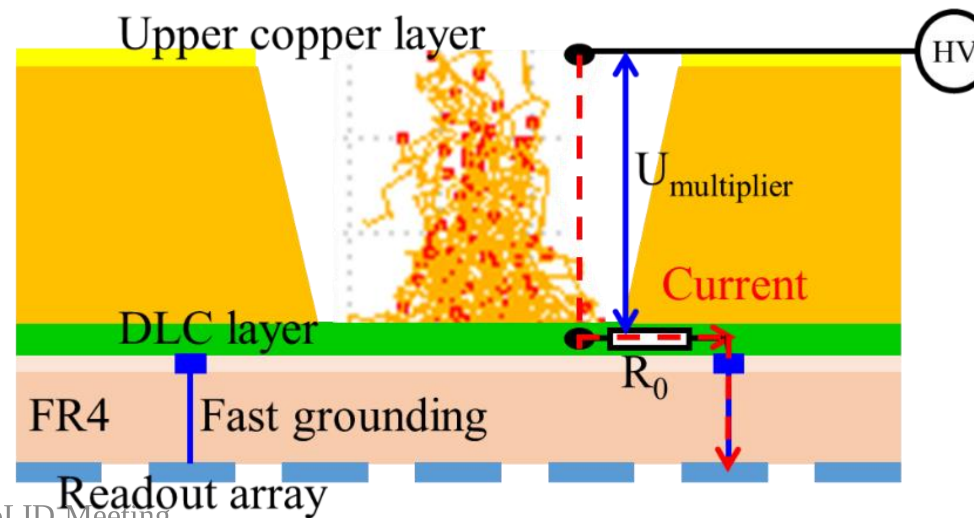
# Fast grounding μRWELL manufacturing



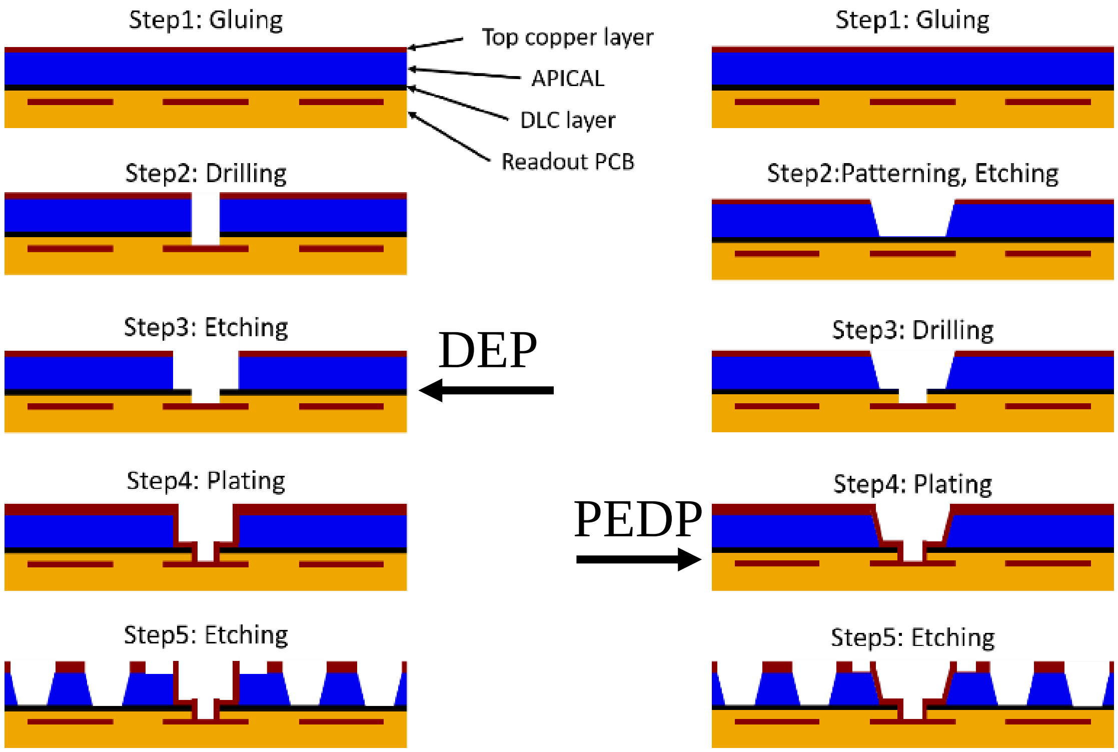



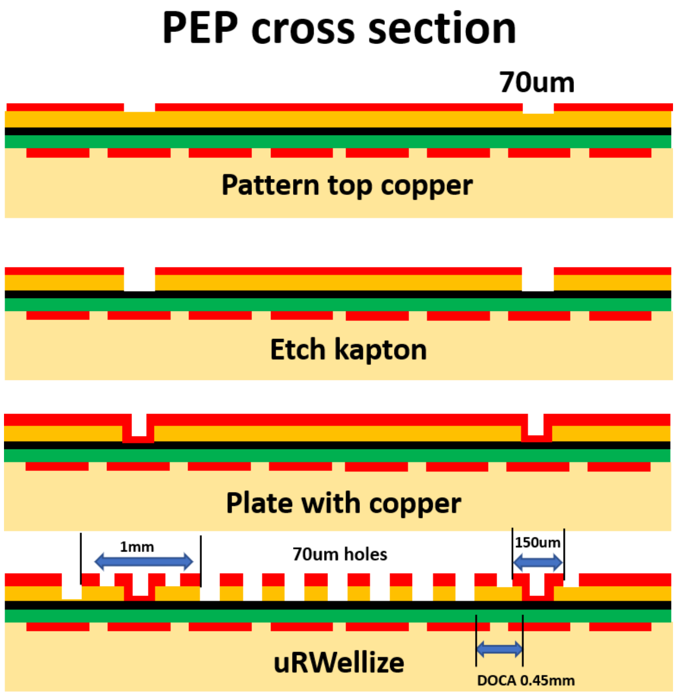

**Fast grounding:**

- Setting grounded conductor array
- Decreasing equivalent grounding resistance of DLC
- **Avoiding significant gain decrease under high rate**

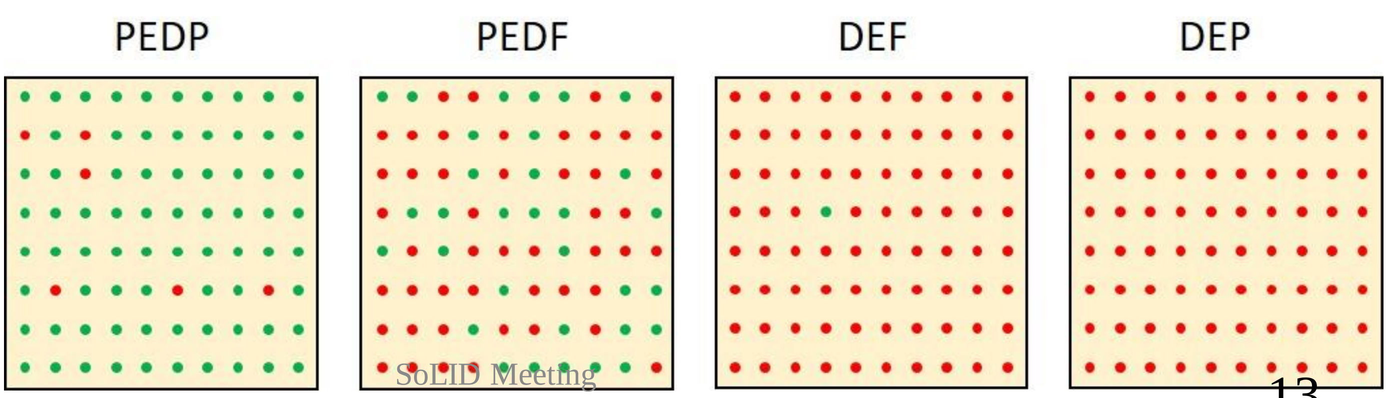


# Fast grounding μRWELL manufacturing




- P: patterning
- E: etching
- D: drilling
- F: filling



# Effects causing gain decrease

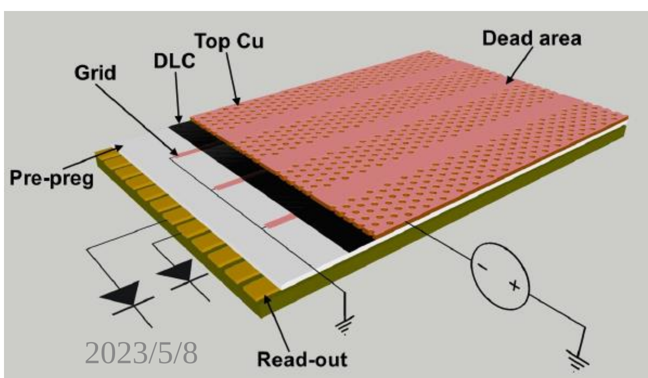
**For all kinds of fast grounding, effects should be concerned：**

- (U) Major: Voltage drop effect by DLC flowing current
- (Q) Major: Electrostatic field effect of accumulated charge
- (E) Minor: Protection resistor connects to the upper copper layer
- Key point: **follow the charge**

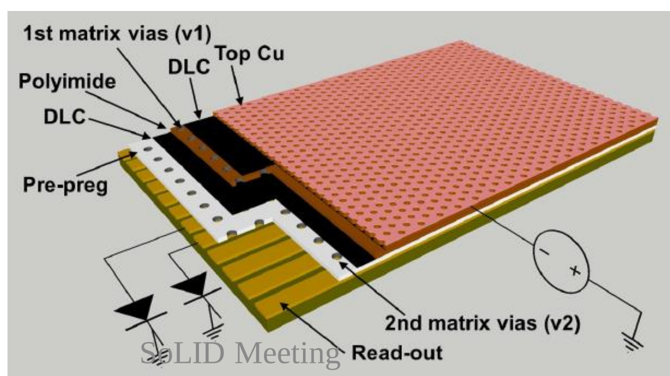
How to evaluate the detector gain?

How to optimize the fast grounding design?

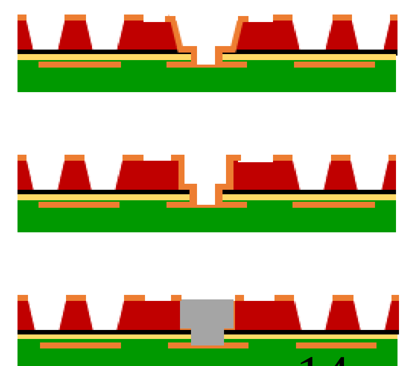
1D strip-grounded




Double layer point-grounded



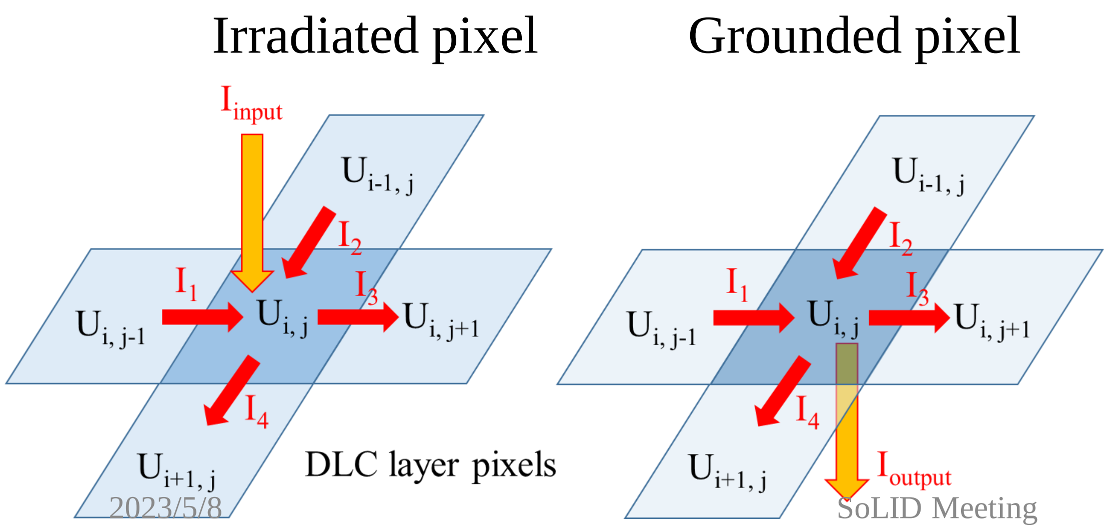

Point-grounded

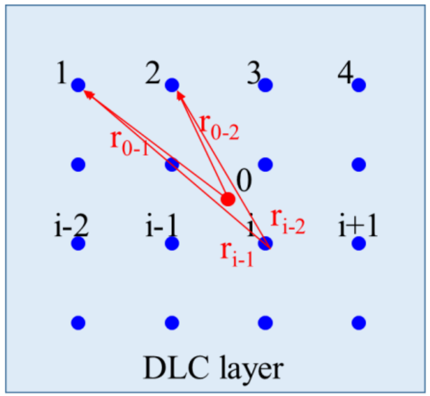


# Flowing current effect simulation

- **Simulation 1: Kirchhoff equation-based method**
  - Dividing surface into small pixel array
  - Setting V=0 in grounded pixels
  - Solving **voltage drop distribution** on DLC, and flowing out current distribution on grounded-pixels

- **Simulation 2: Ohm's law-based method**
  - Solving flowing out current distribution on grounded-pixels
  - Calculating **voltage drop distributions** by $I_{in}$ $I_{out}$ pair
  - Traversing all the irradiated pixels




Blue circle: grounded points
Red circle: current flowing in point

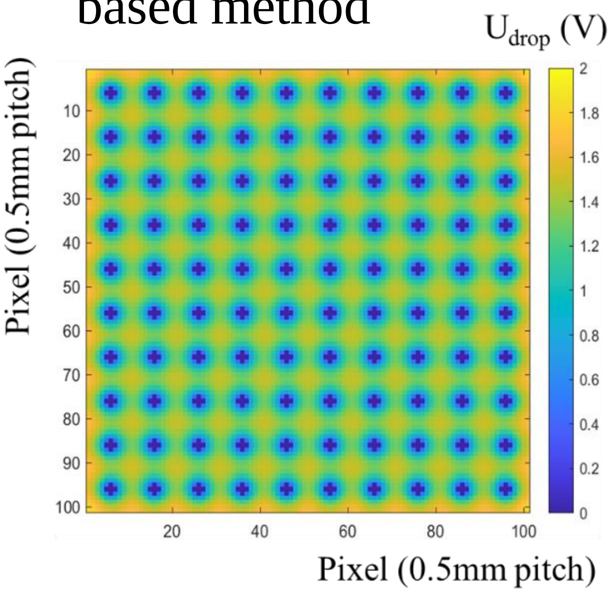
$$U_i - U_1 = \frac{I_0 \cdot R_s}{2\pi} \sum_{j=1}^{N} \omega_j \cdot ln\left(\frac{r_{j-i}}{r_{j-1}}\right) = 0$$

# Flowing current effect simulation

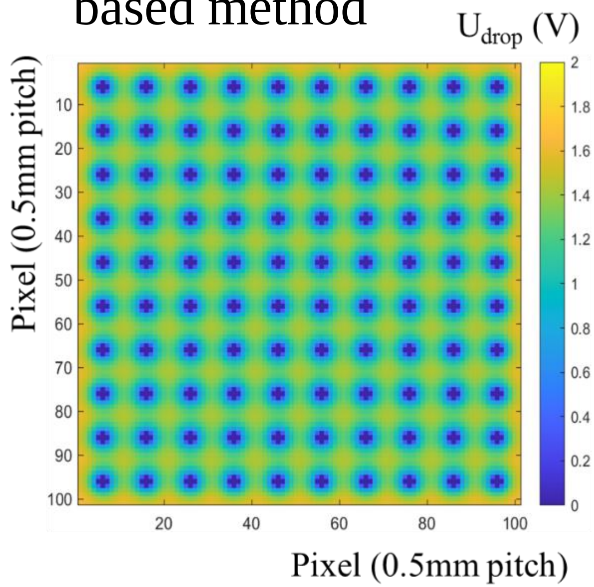
**Simulation results:**

- 1 $MHz/cm^2$ 8.1 keV X ray, $G_0 = 10000$
- Main area of DLC: **voltage drop 1.2 V±4%**

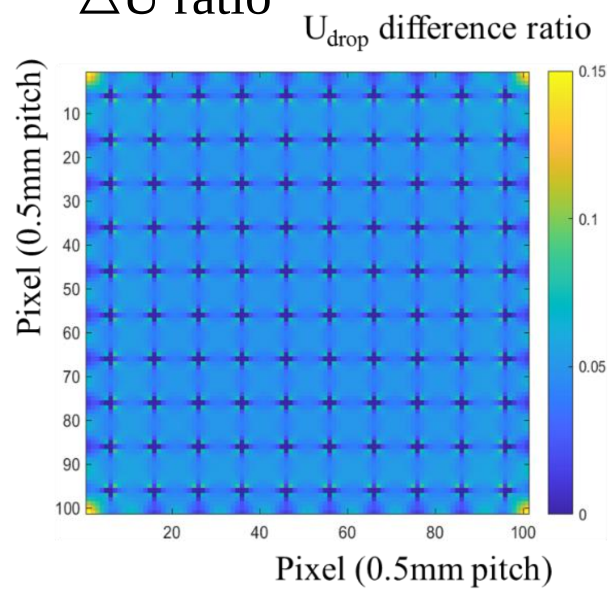
Kirchhoff equation-based method




Ohm’s law-based method

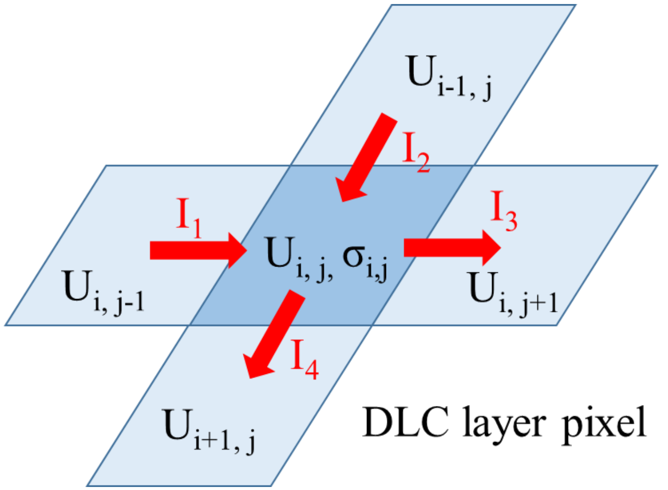


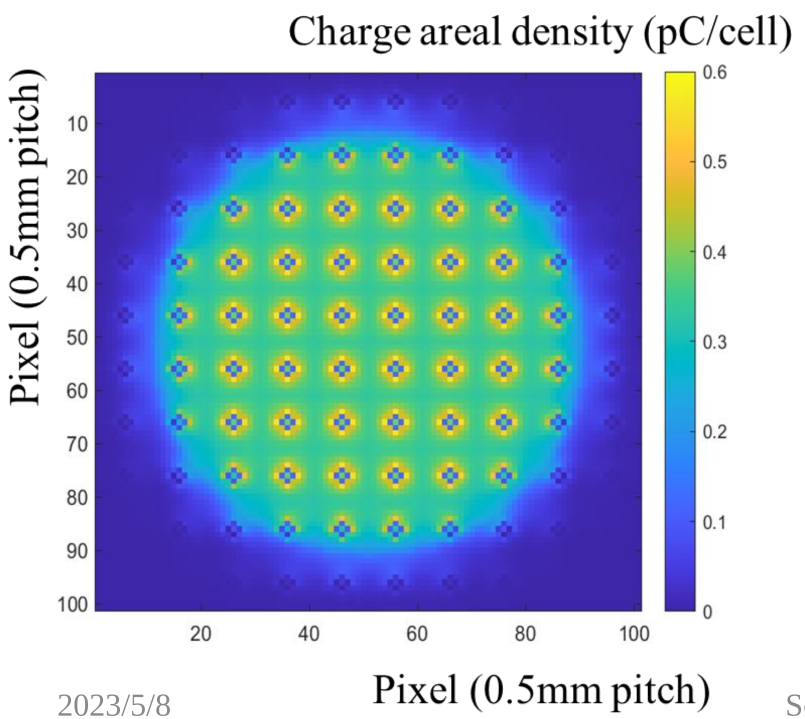

△U ratio



# Charge accumulation effect simulation

- Accumulated charge density is related to the **voltage drop distribution**.




$$\sum I_{out}\cdot dt = \sigma_{i,j}\cdot S\cdot\left(1-e^{-\frac{dt}{\tau_0}}\right)$$

$$\therefore \sigma_{i,j} = \frac{\sum I_{out}\cdot\tau_0}{S} = \frac{\tau_0}{S}\cdot\frac{\sum\left(U_{i,j}-U_{neighboring\ smaller\ than\ (i,j)}\right)}{R}$$

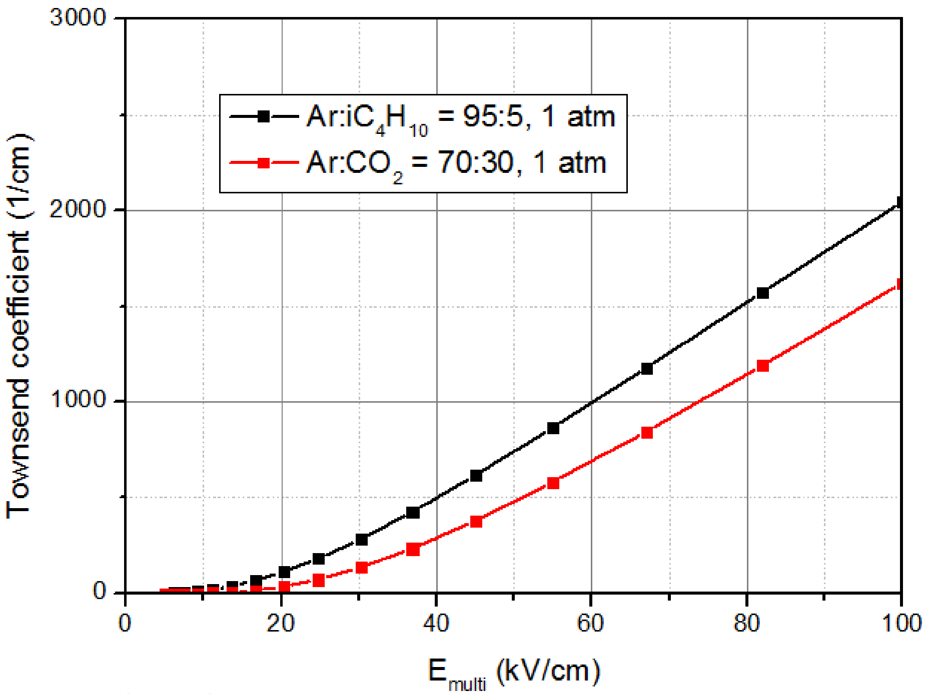
$$= \frac{\varepsilon\cdot\varepsilon_0\cdot S\cdot R}{S\cdot d}\cdot\frac{\sum\left(U_{i,j}-U_{neighboring\ smaller\ than\ (i,j)}\right)}{R}$$

$$= \frac{\varepsilon\cdot\varepsilon_0}{d}\cdot\sum\left(U_{i,j}-U_{neighboring\ smaller\ than\ (i,j)}\right)$$

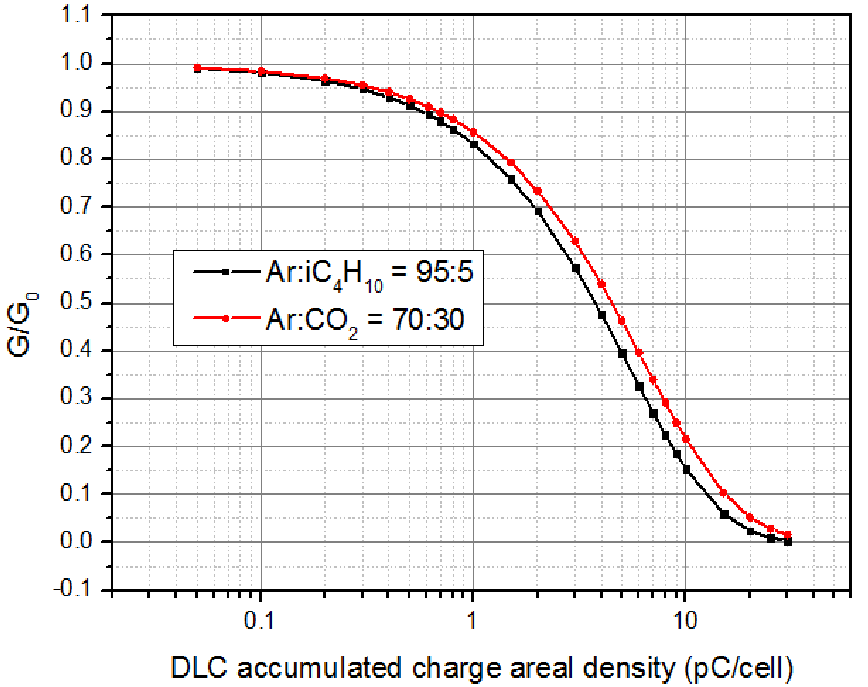
# Charge accumulation effect simulation

| Maxwell: Electric field strength V.S. charge density | Garfield: Electric field strength V.S. Townsend coefficient | MATLAB: Townsend coefficient V. S. detector gain |
|---|---|---|

- ➢ **Garfield database**
  - Townsend -electric field relationships

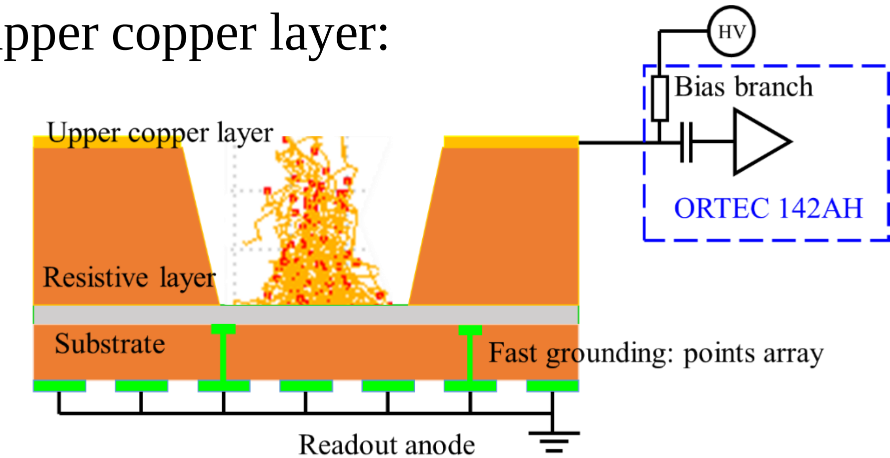



- ➢ **Final result**
  - Charge accumulation effect

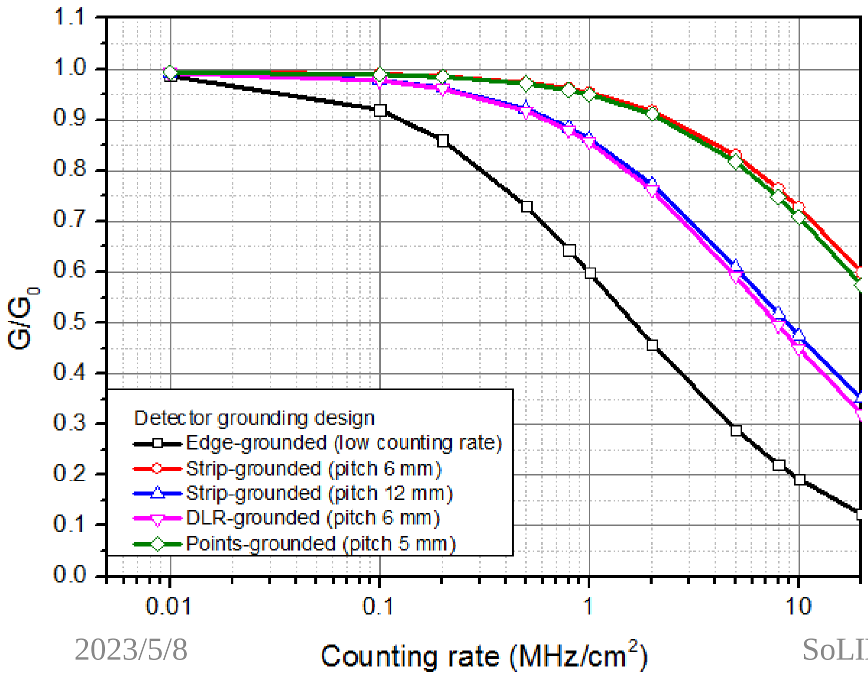


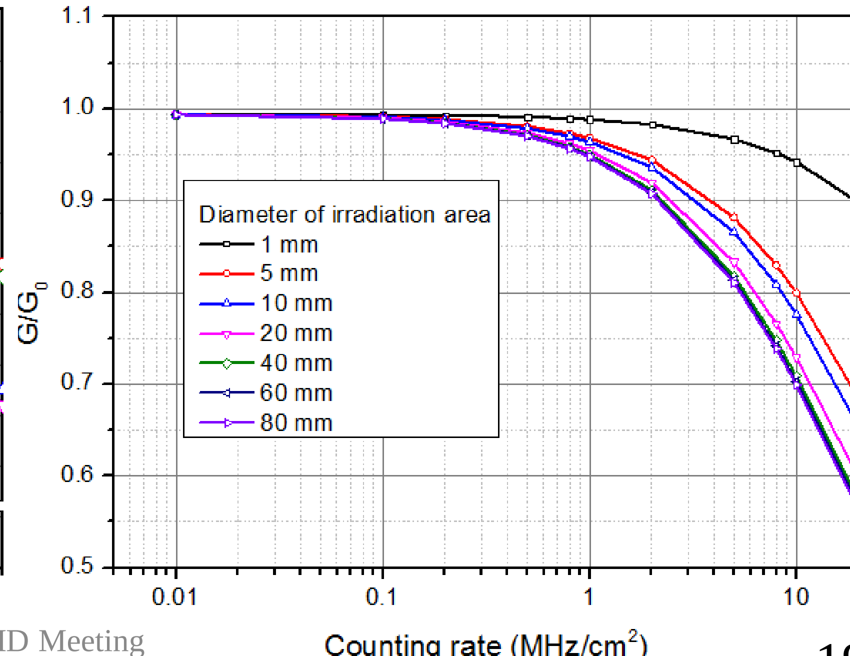
# Final effect simulation

➢ (Minor) Protection resistor connects to the upper copper layer: introducing 2rd flowing current effect



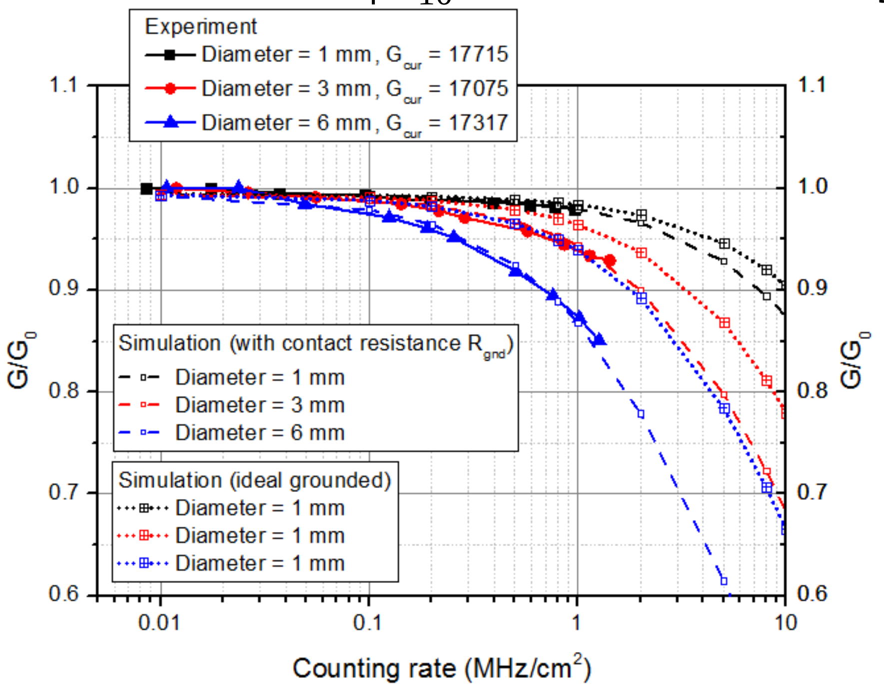

Comparison of various fast grounding design



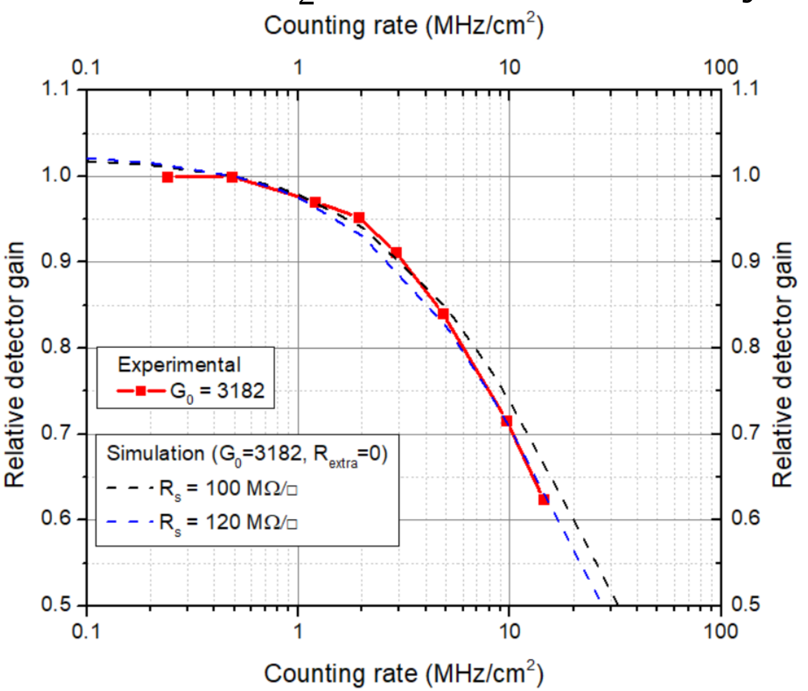



# Experimental evaluation

**μRWELL**, Ar:i$C_4H_{10}$=95:5, 8.1 keV X ray




**MM**, Ar:$CO_2$=93:7, 8.1 keV X ray




- Good match between simulation and experimental data
- This simulation method is suitable for other MPGD with resistive layer.

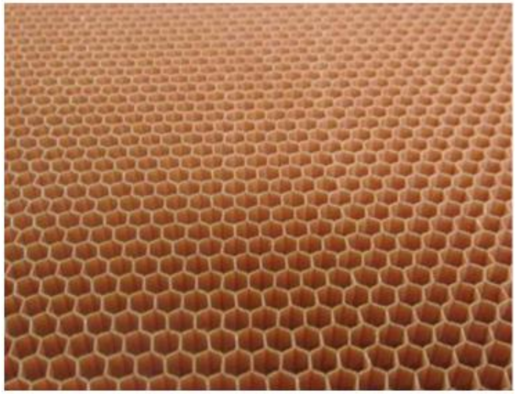
# Material budget control

Tradeoff: **structural strength** and **material budget**

- **Structure optimization:**
- PCB -> FPCB + support layer
- Adhesive type and uniformity
- Reinforcement rib (if necessary)
- Thinning copper layer
- New manufacturing technology (related to the detector design)

PMI foam

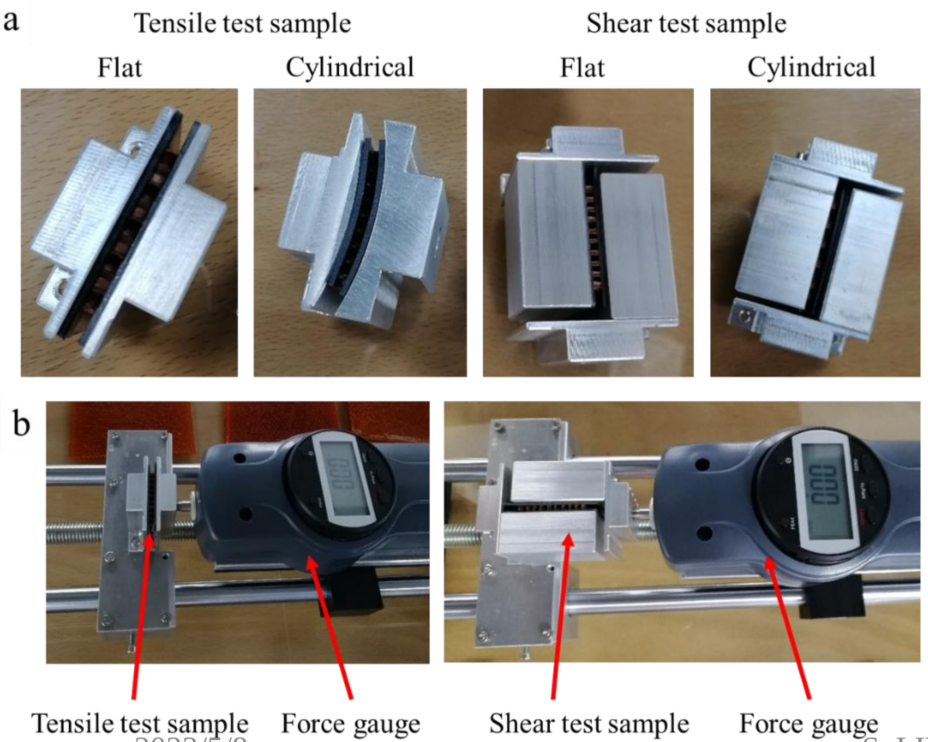
Aramid paper honeycomb

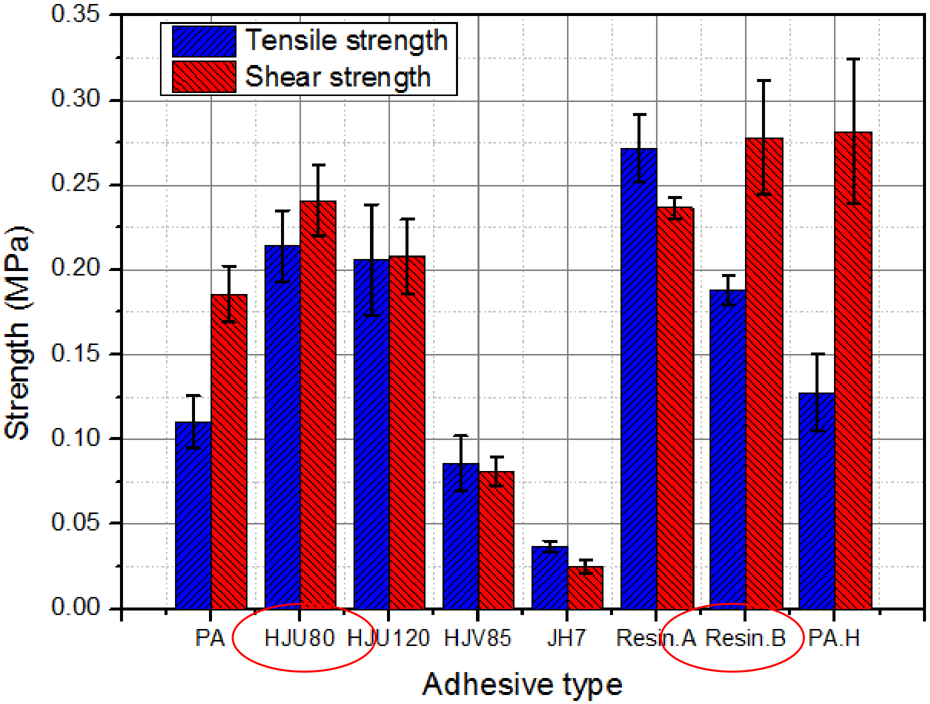


# Adhesive studies

More than 5 kinds of thermal lamination films and 2 kinds of epoxy resins are tested.

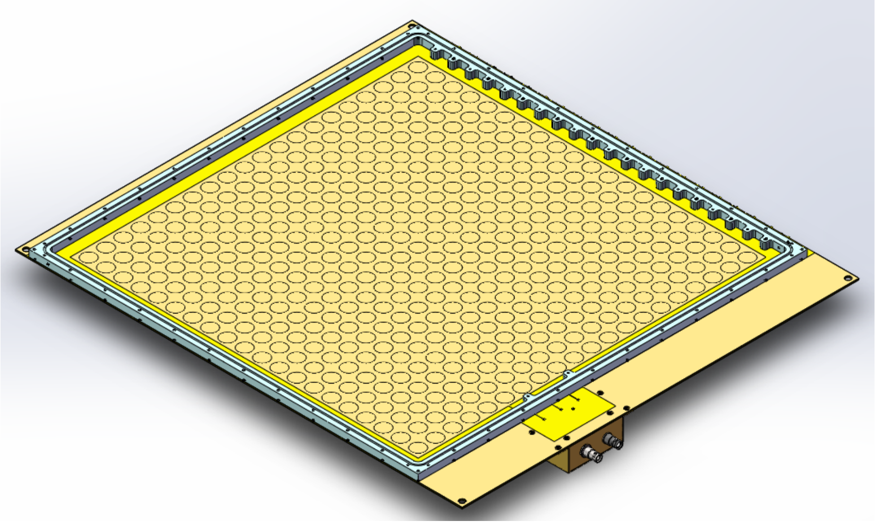
- **Tensile** and **shear** strength
- Material budget on a 10 cm ×10 cm sample
- Manufacturing difficulties

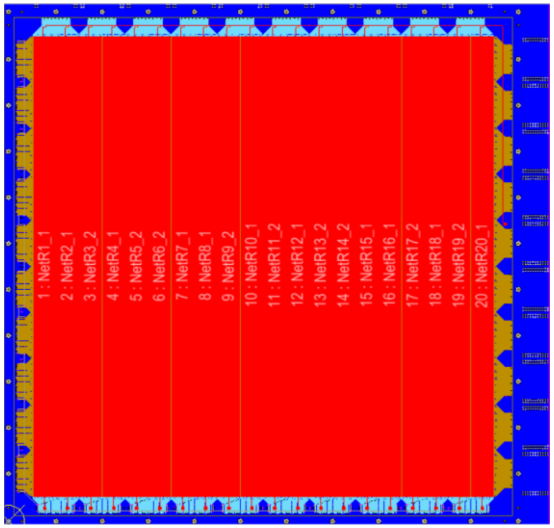


# Large area μRWELL research

- Under manufactured μRWELL detector (PEP method):
  - Detection area: 50 cm × 50 cm
  - μRWELL layer: strip-divided with 25 mm pitch
  - X strip: pitch = 400 μm, width = 60 μm
  - Y strip: pitch  = 400 μm, width  = 350 μm
  - Fast grounding: point array, pitch = 12.8 mm, diameter = 200 μm





# Conceptual Design of Readout Electronics

**Challenges:**

- High readout density of 32 channels/cm

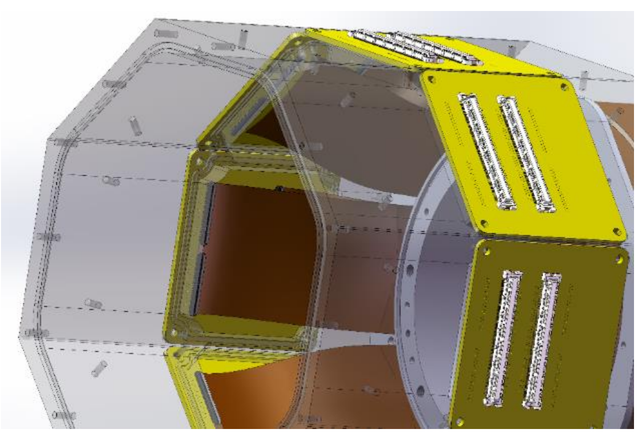
  → High integration and low power front-end ASIC

- High event rate of 367 kHz at average for single channel

  → Short dead time

- Time measurements accuracy of 10 ns RMS @ 4.5 fC

  → Low noise



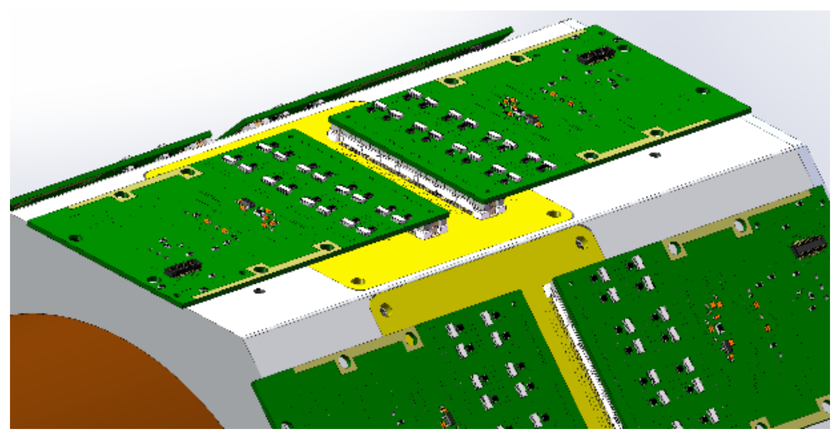
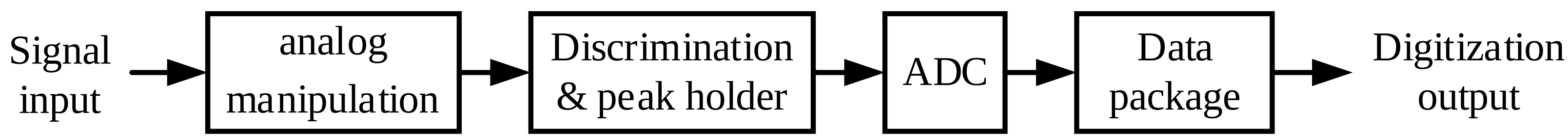


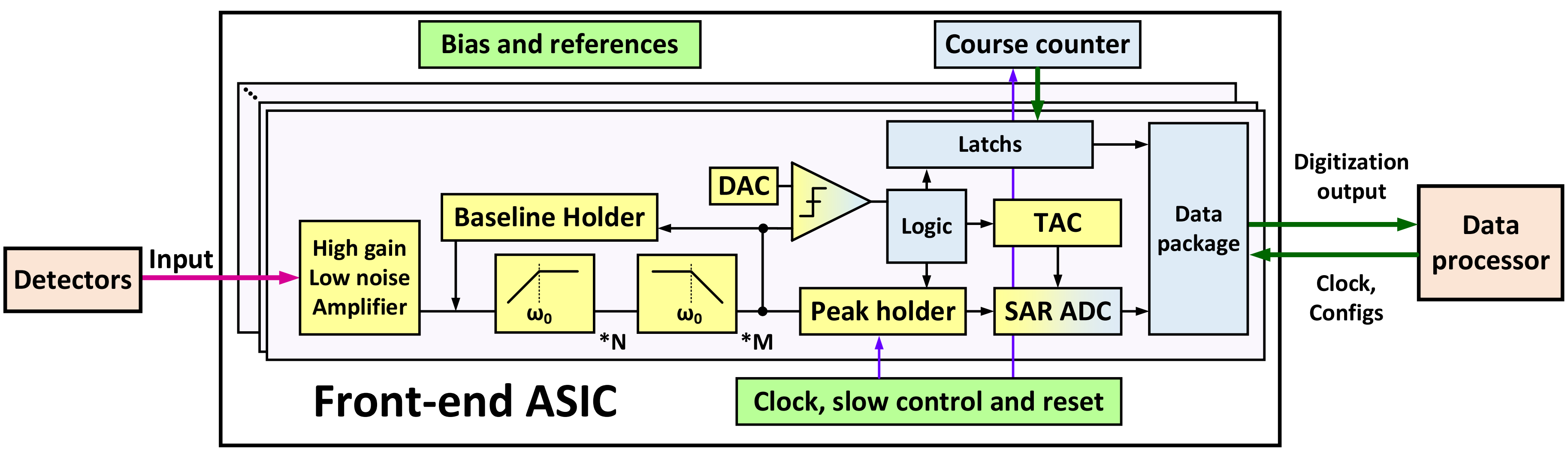
Diagram of possible readout connections from the µRWELL detectors

# Conceptual Design of Readout Electronics

In order to improve the system integration, it is planned to integrate front-end analog manipulation circuits, analog-to-digital conversion circuits of multiple channels in a self-developed ASIC.




Proposed signal flow of the front-end readout electronic




Proposed functional diagram of the self-developed ASIC

# Outline

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# μRWELL inner tracker for STCF

**Super Tau-Charm Facility:**

- Newly designed $e^-e^+$ collider
- Luminosity: $1\times10^{35}$ /cm$^2$/s
- Center of mass energy region: 2-7 GeV/c

**Inner tracker requirements:**

Low budget

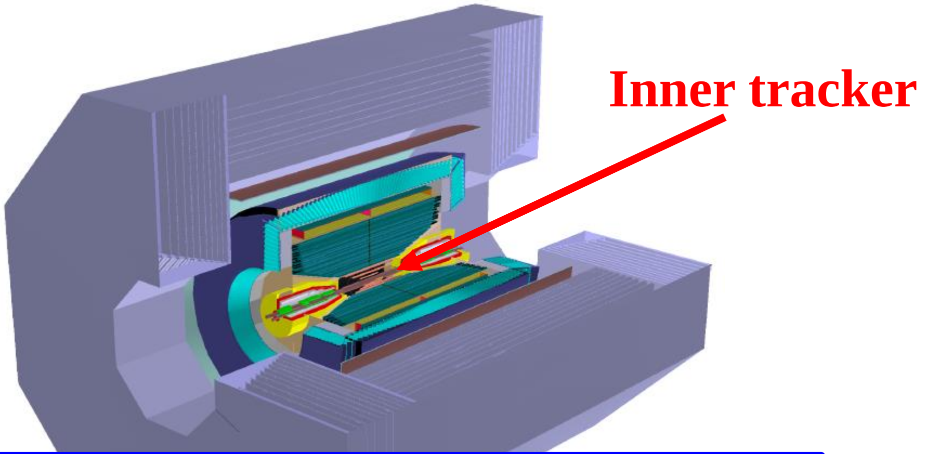
- ~0.3% $X_0$ for single layer of detector

Detection area

- ~1 m$^2$

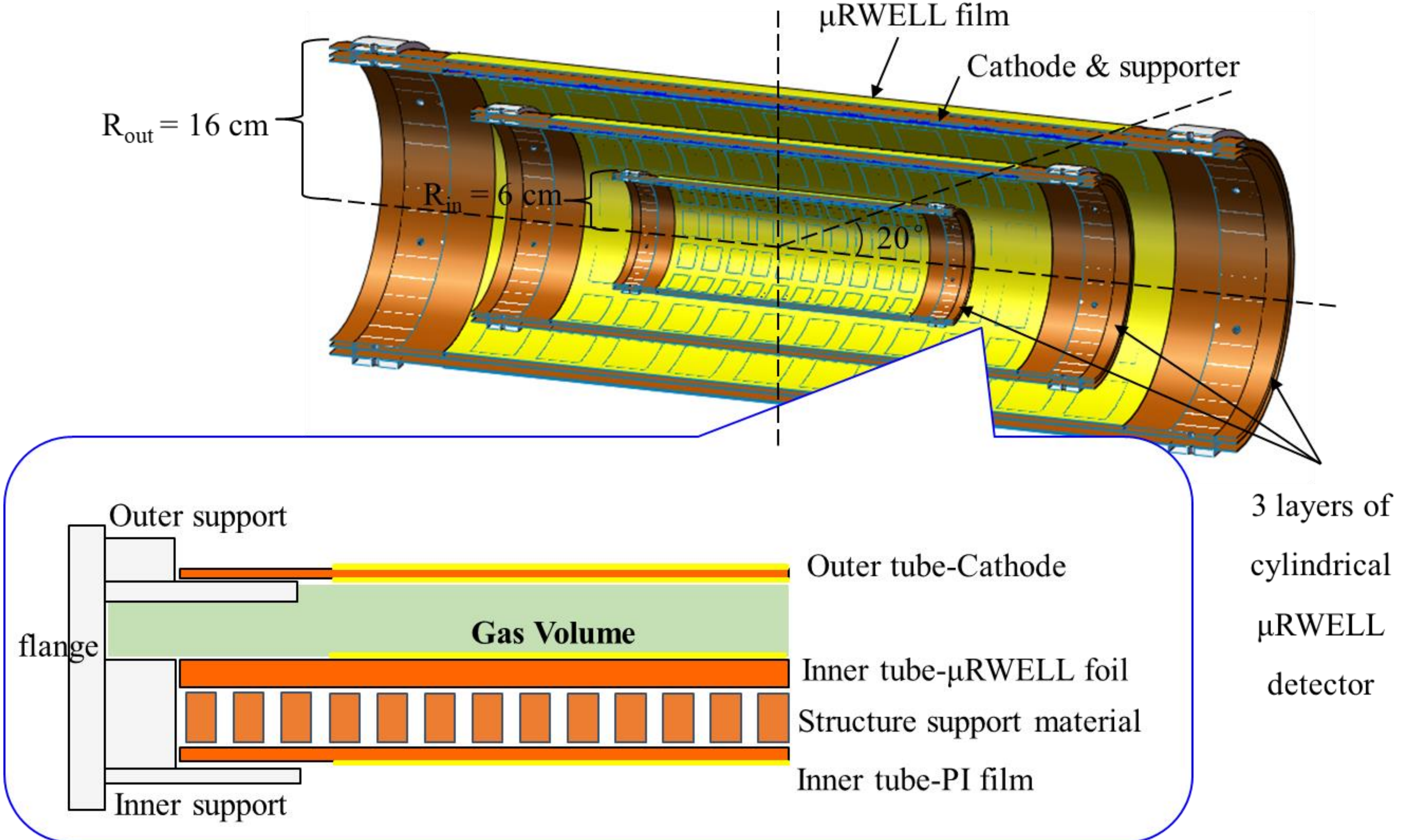
Counting rate

- Hundreds of kHz/cm$^2$




The μRWELL can meet these demands with simple structure and high robustness.

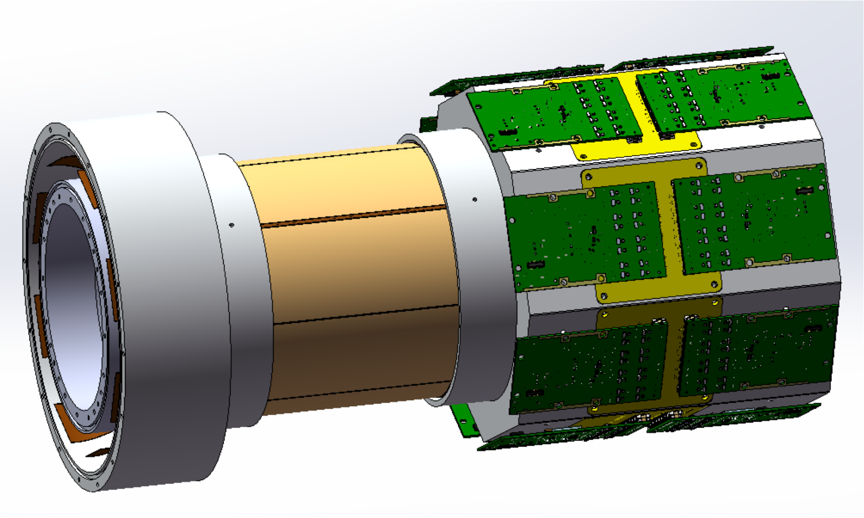
# Cylindrical μRWELL design



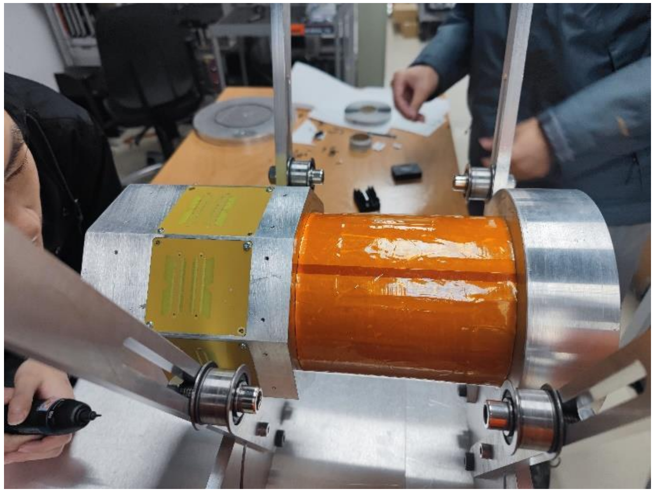
# Mechanical structure realization

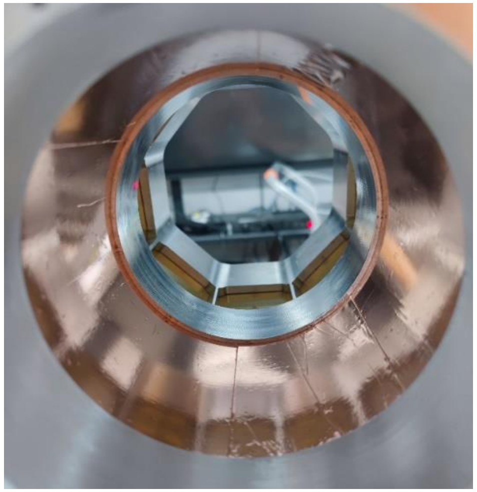
Sealing rings ⇨ Flange system

- Better mechanical strength
- Easier assembling process



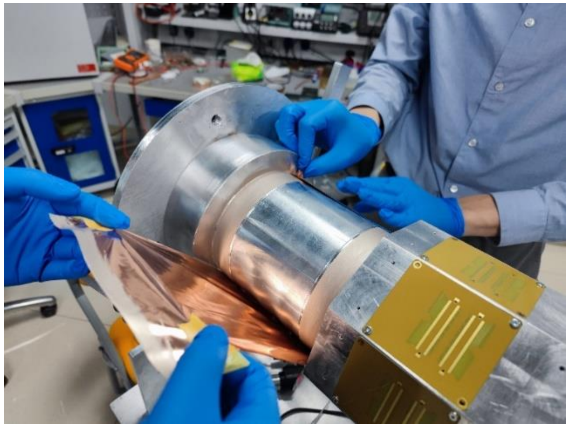
1st and 2nd test: Inner and outer tube assembling



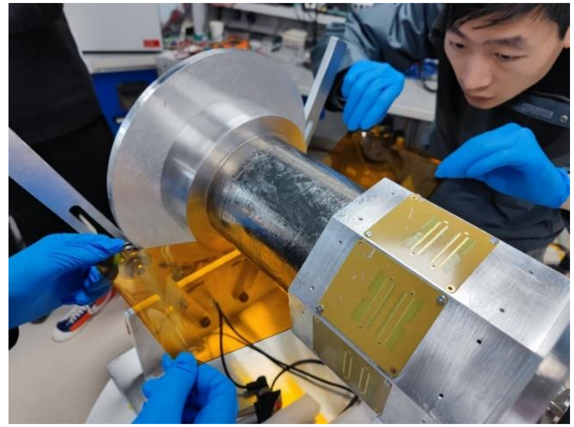


# Mechanical structure realization

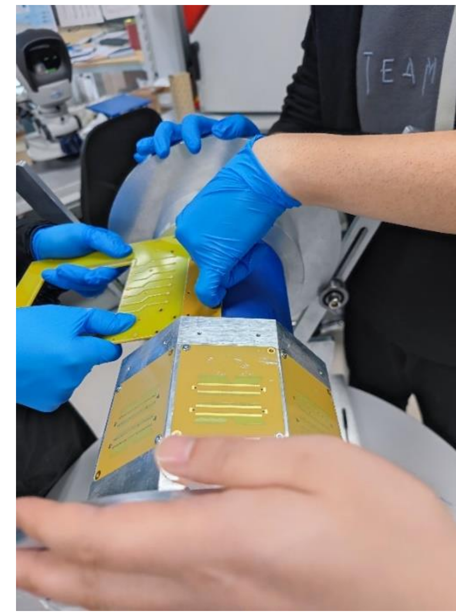
1. Gluing copper layer



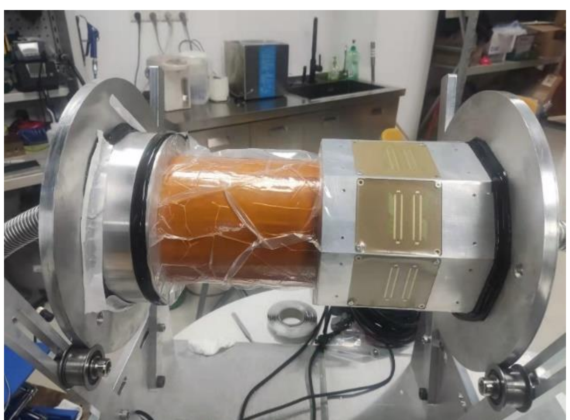
2. Gluing the apical layer

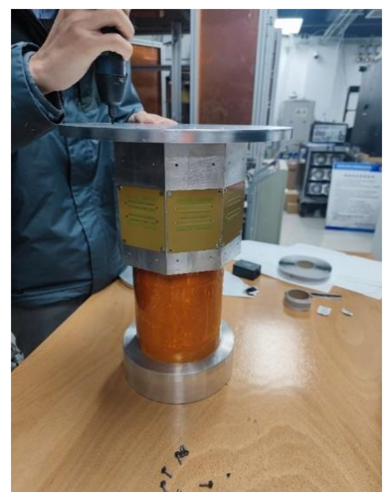


3. Assembling PMI foam



4. Gluing the 2nd apical layer





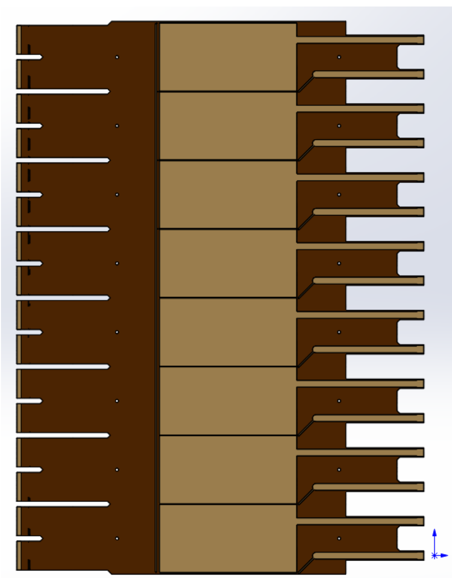
5. Removing the inner mold

# µRWELL film optimization

- Now that we need to bend the flat µRWELL into cylindrical shape…
- Maybe we can do more in the assembling process.

Rectangle X strip array

Parallelogram V strip array



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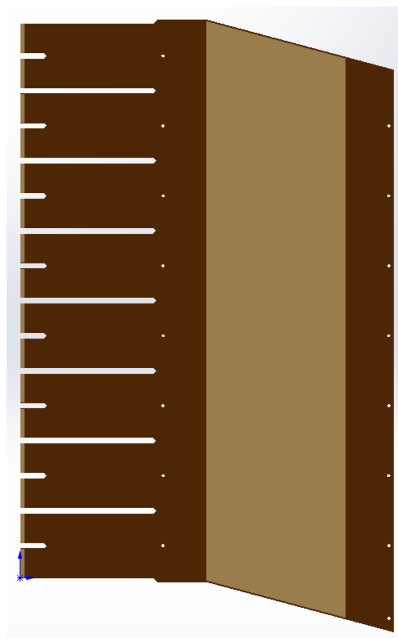

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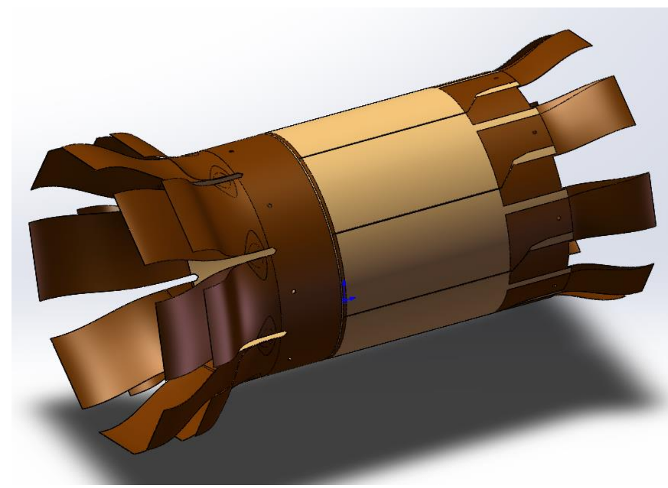


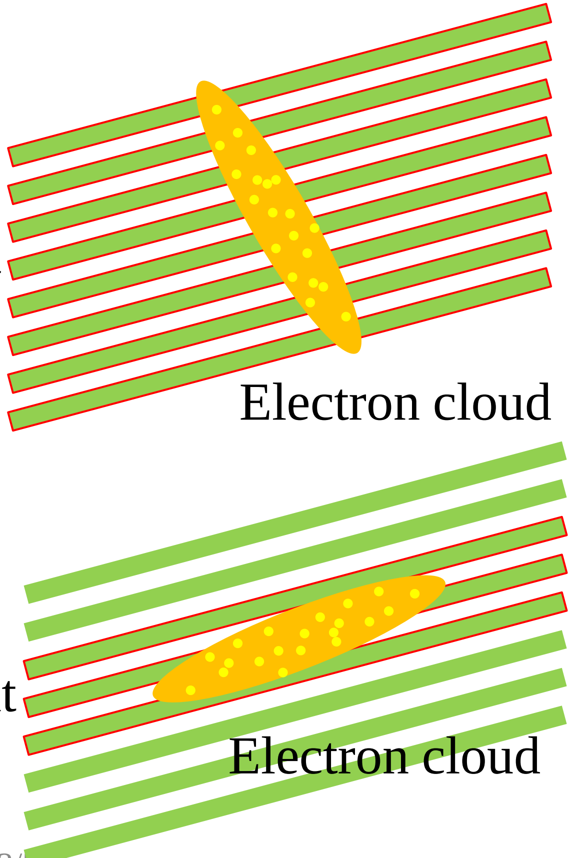
Undivided V strip array

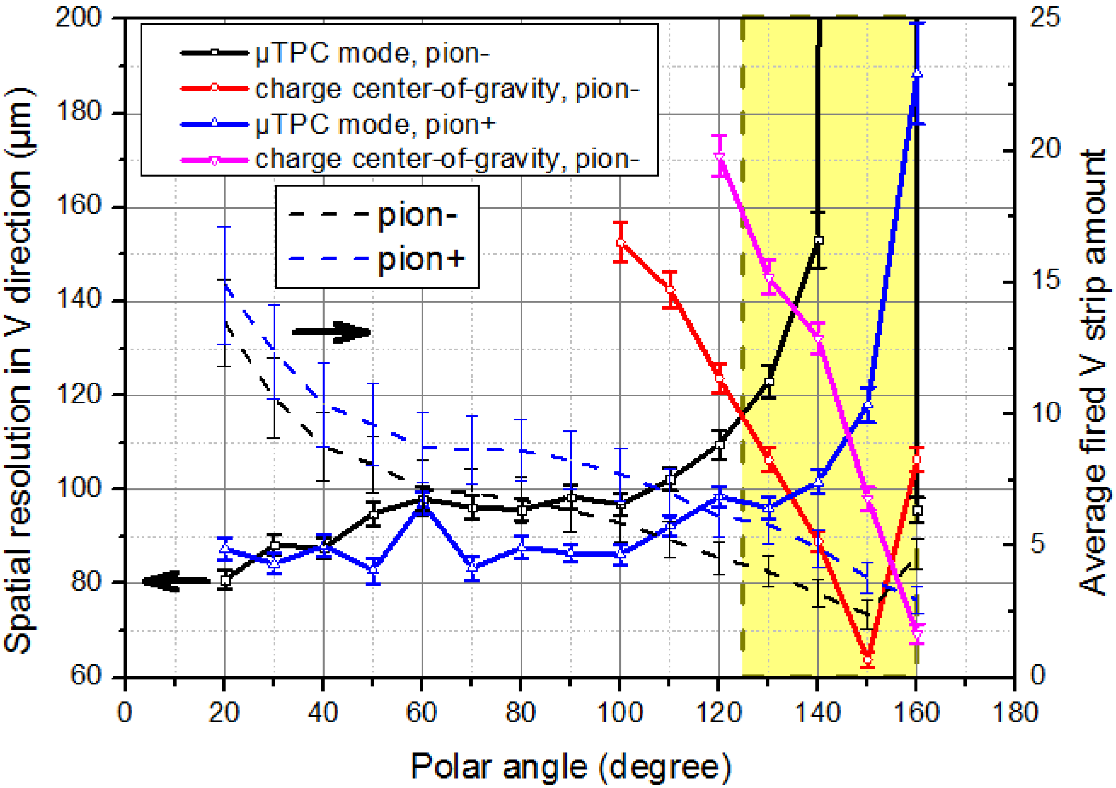
Better deformation control

# Hit reconstruction method

**Hybrid hit reconstruction method:**

- μTPC mode (for most cases)
- Charge center-of-gravity method (when electron cloud parallels to V strips)

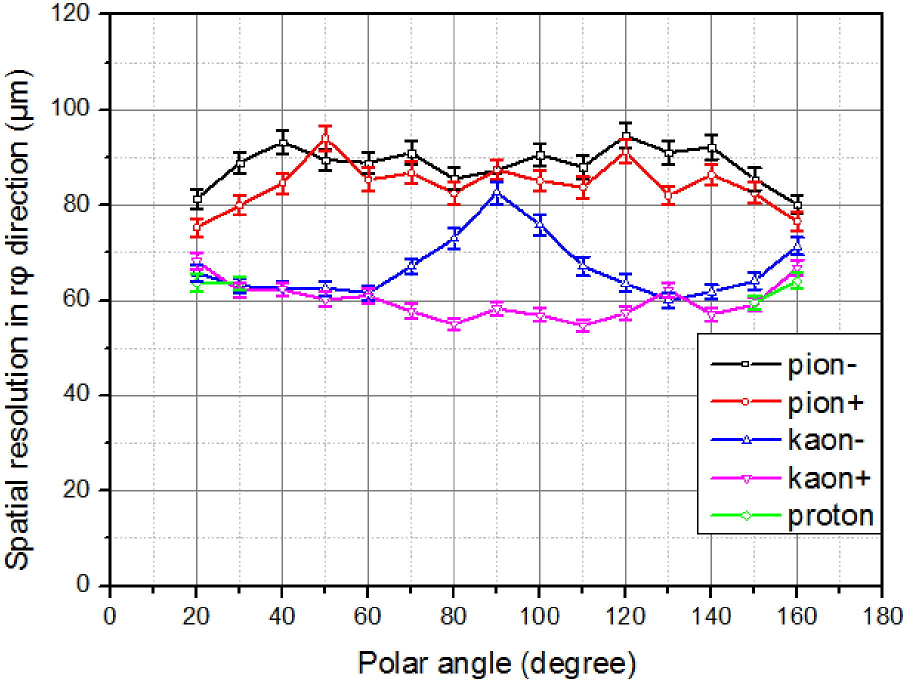


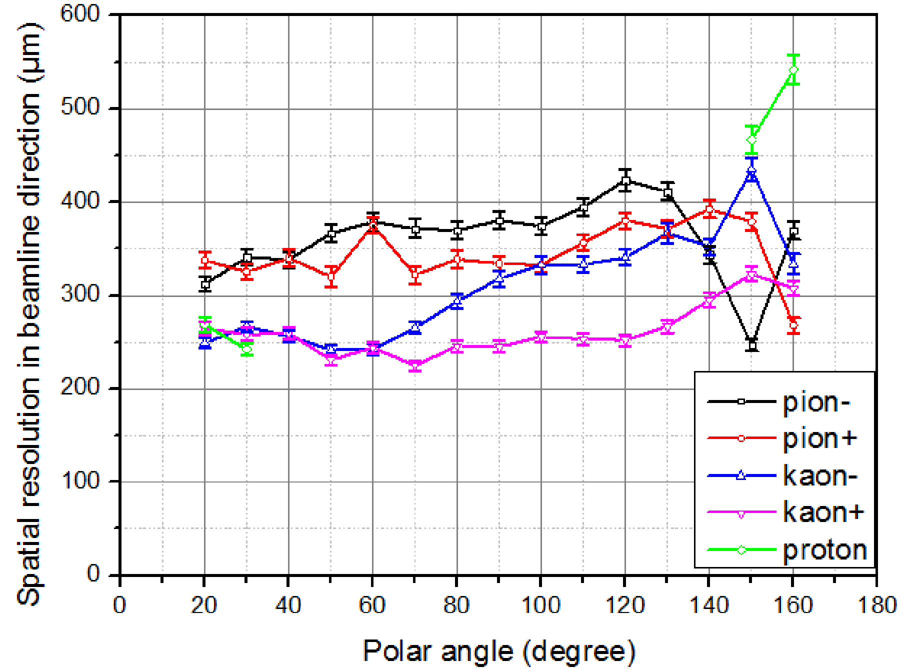
# Spatial resolution performance

**Spatial resolution: ~100 μm in rφ and 400 μm in z direction**

Spatial resolution in rφ direction




Spatial resolution in z direction



# Outline

1. Introduction to μRWELL detector
2. Research progress in μRWELL key technology
3. μRWELL inner tracker for STCF
4. **Discussion: large planar μRWELL**
5. Conclusion

# Discussion

- **Large planar μRWELL for HEP experiments:**
  - **Large area FPCB** manufacturing technology (1.9 m × 1.2 m)
  - **Large area resistive layer** coating technology (1.4 m×0.65 m)
  - **Low material budget** design and realization
  - **Fast grounding** design for high rate
  - **Special optimizations** for certain requirements

# Outline

1. Introduction to μRWELL detector
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# Conclusion

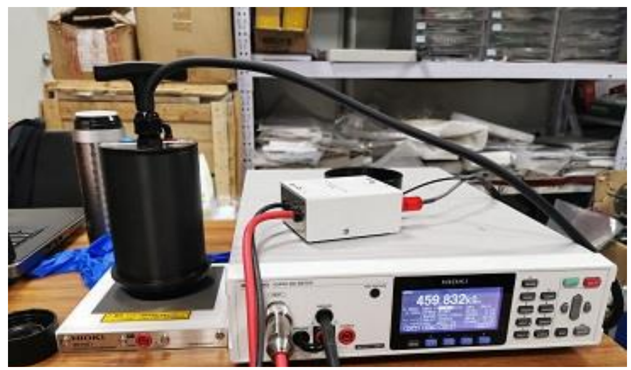
In the past several years, we focused on the μRWELL research:

- Realizing large area Cu-DLC layer coating on Apical, with an adjustable surface resistance.
- Proposing new manufacturing process for fast grounding point on the μRWELL.
- Performing the simulation method for fast grounding performance for resistive-MPGDs.
- Research on low budget C-μRWELL inner tracker is on going.
- Large area planar μRWELL detector is preparing.

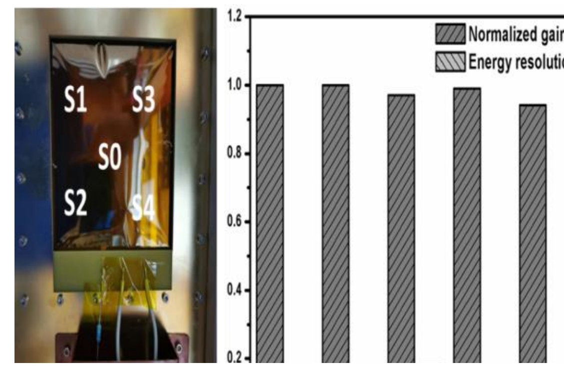
# THANKS~

# BACK UP

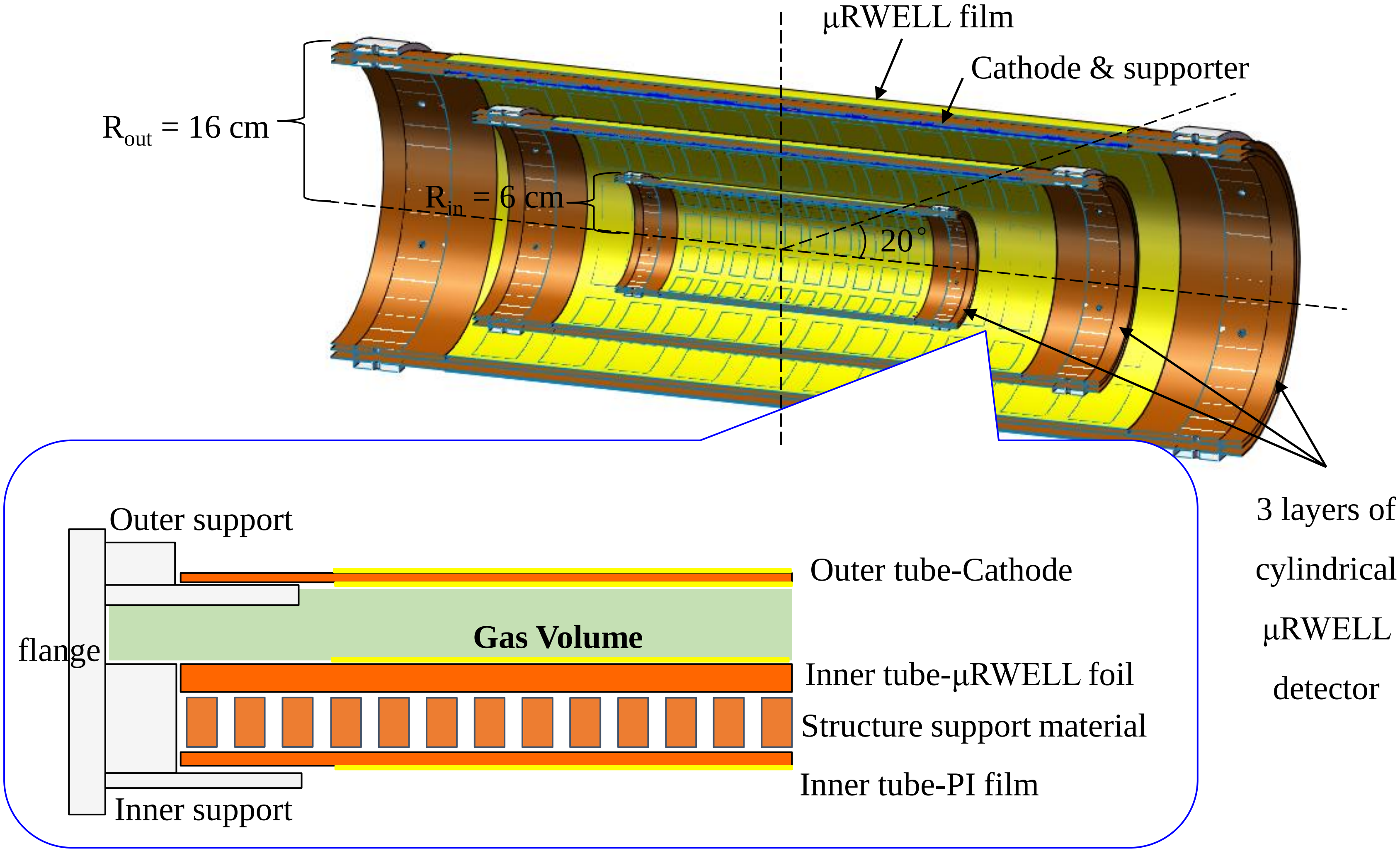
Different sample holders



Super Megohm meter




Experimental test


μRWELL film
Cathode & supporter
$R_{out}$ = 16 cm
$R_{in}$ = 6 cm
20°
3 layers of cylindrical μRWELL detector
Outer support
Outer tube-Cathode
flange
Gas Volume
Inner tube-μRWELL foil
Structure support material
Inner tube-PI film
Inner support