μRWELL-based cylindrical tracker for the next generation colliders

USTC

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On behalf of the STCF detector working groups

Outline

1. μRWELL researched for experiments
2. μRWELL-based cylindrical inner tracker studies
3. Conclusion

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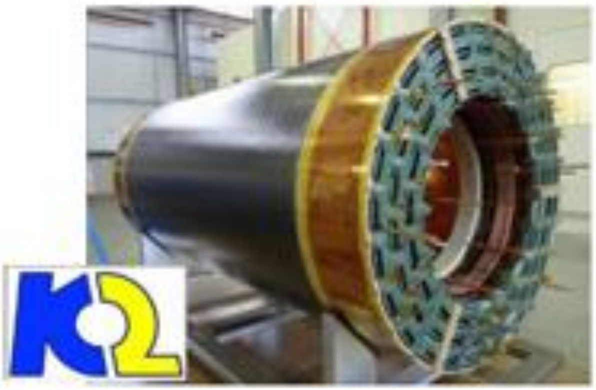
MPGD used in experiments



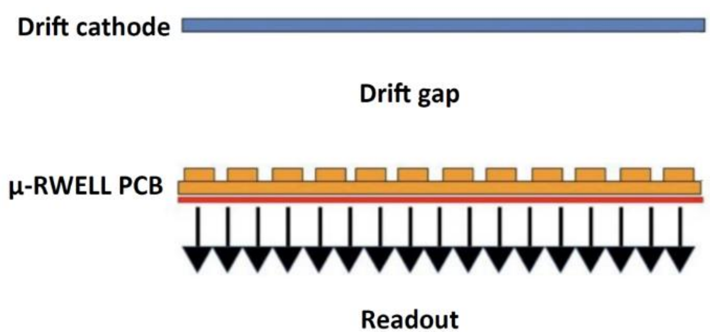
KLOE CGEM inner tracker

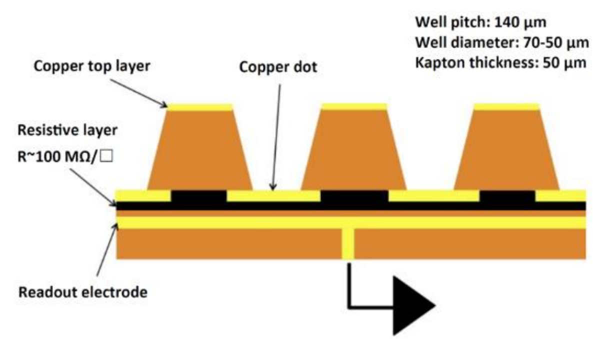
BESIII (upgrade) CGEM inner tracker

A bit complicated structure…?

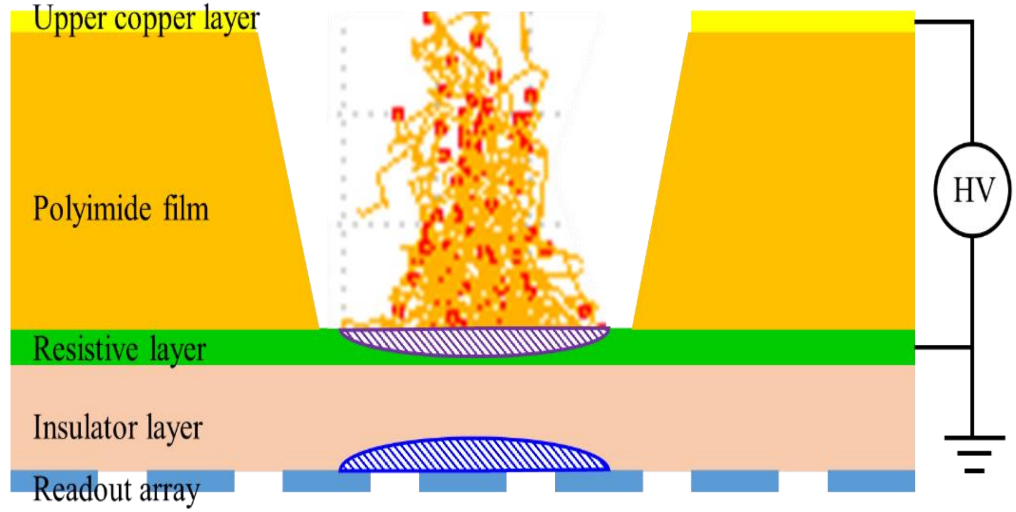
μRWELL detector

- Micromachining Technology
- WELL
- Resistive layer





Advantages of μRWELL



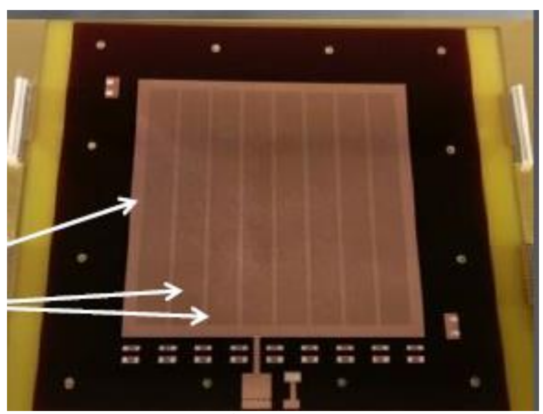
Advantages of μRWELL:

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

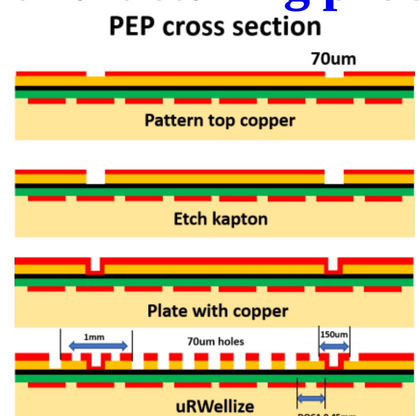
Many research directions of μRWELL:

Large detection area

High counting rate



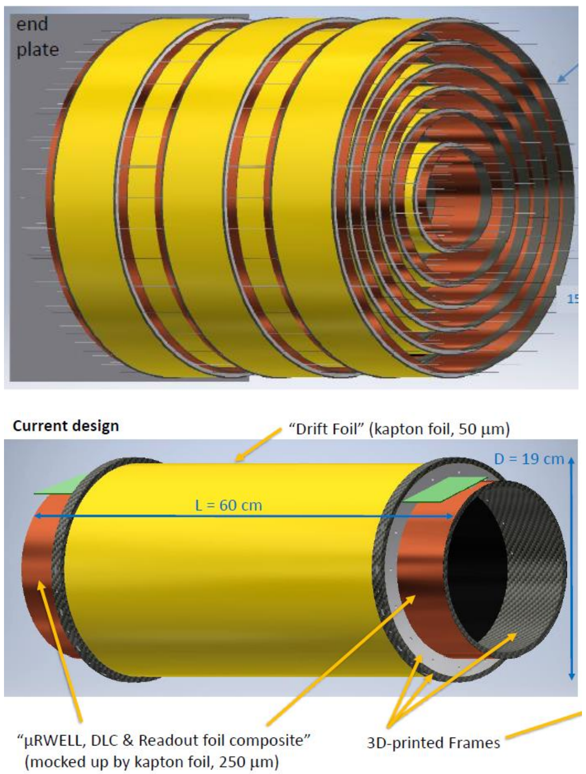
Manufacturing process

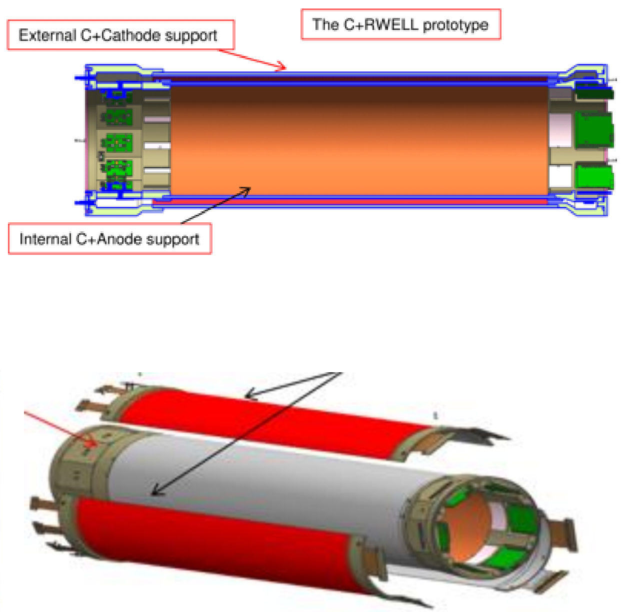


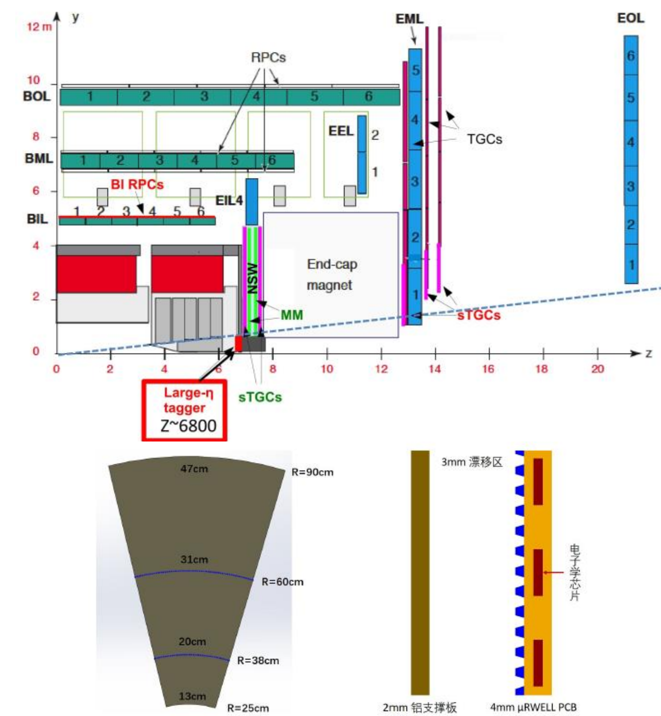
μRWELL researched for experiments

Cylindrical μRWELL | **Planar μRWELL**

EIC central tracking | SCTF C+RWELL inner tracker | ATLAS High η muon tagger







μRWELL designed for STCF

Super Tau-Charm Facility:

- Newly designed e^-e^+ collider
- Luminosity: 0.5×10^{35} /cm^2/s
- Center of mass energy region: 2-7 GeV/c

Inner tracker requirements:

Low budget

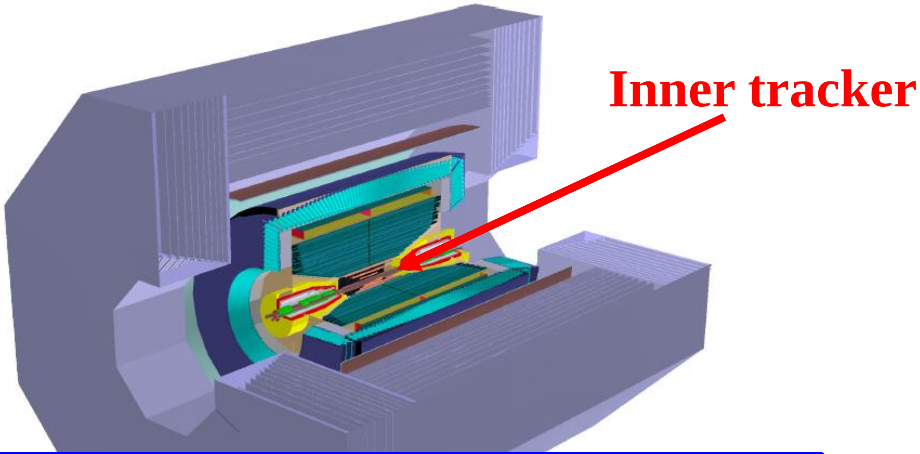
- 0.15% X/X_0 for silicon pixel detector
- 0.5% X/X_0 for CGEM and silicon strips

Detection area

- ~1 m^2

Counting rate

- <100 kHz/cm^2



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

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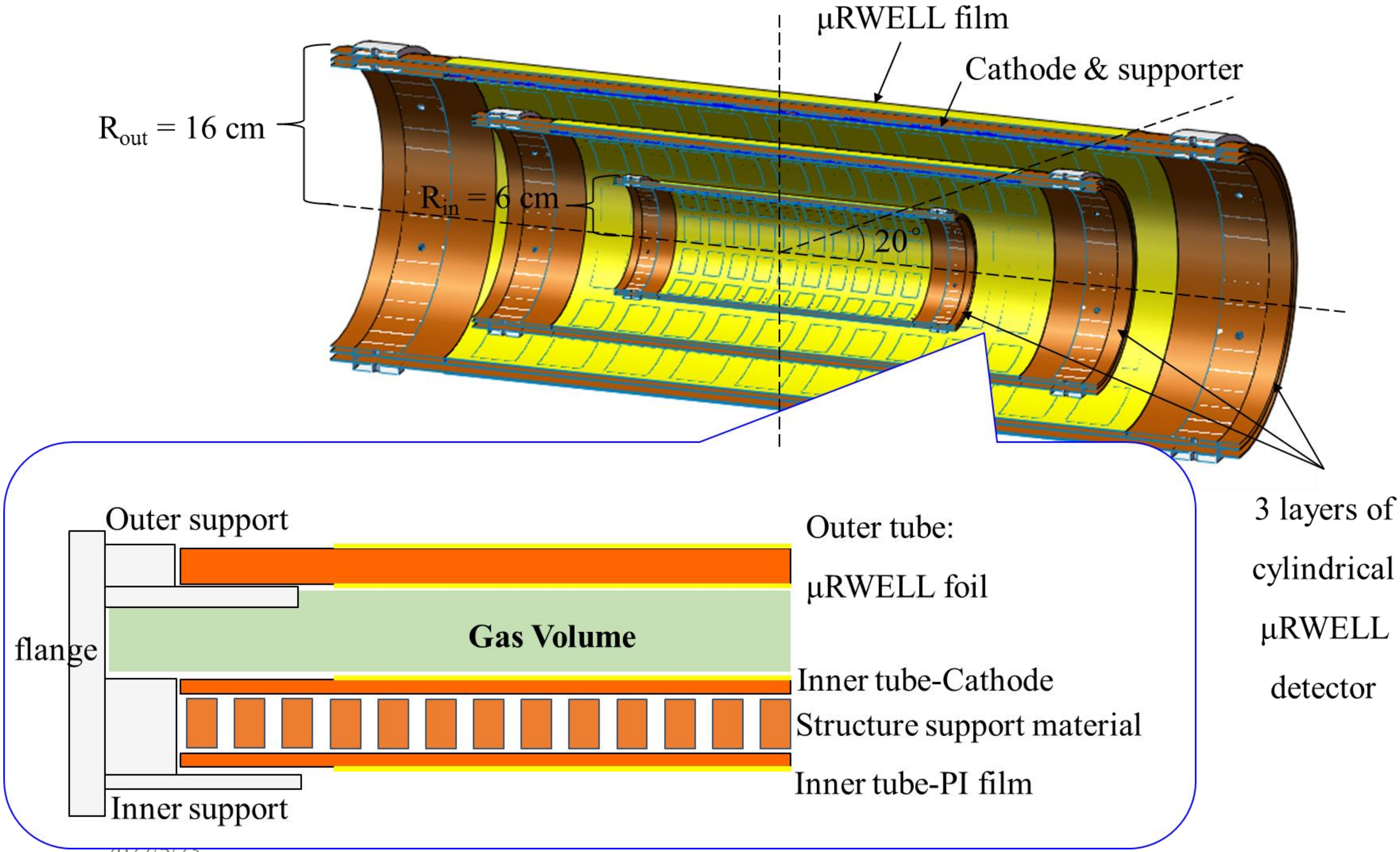
Cylindrical μRWELL design



μRWELL detector studies

- Low material budget realization
- Mechanical structure optimization
- μRWELL film optimization
- Counting rate capability optimization
- Spatial resolution performance
- …

Low material budget realization

Inner tube: tradeoff between material budget and structural strength

(Key point: adhesion, substrate, manufacturing technologies)

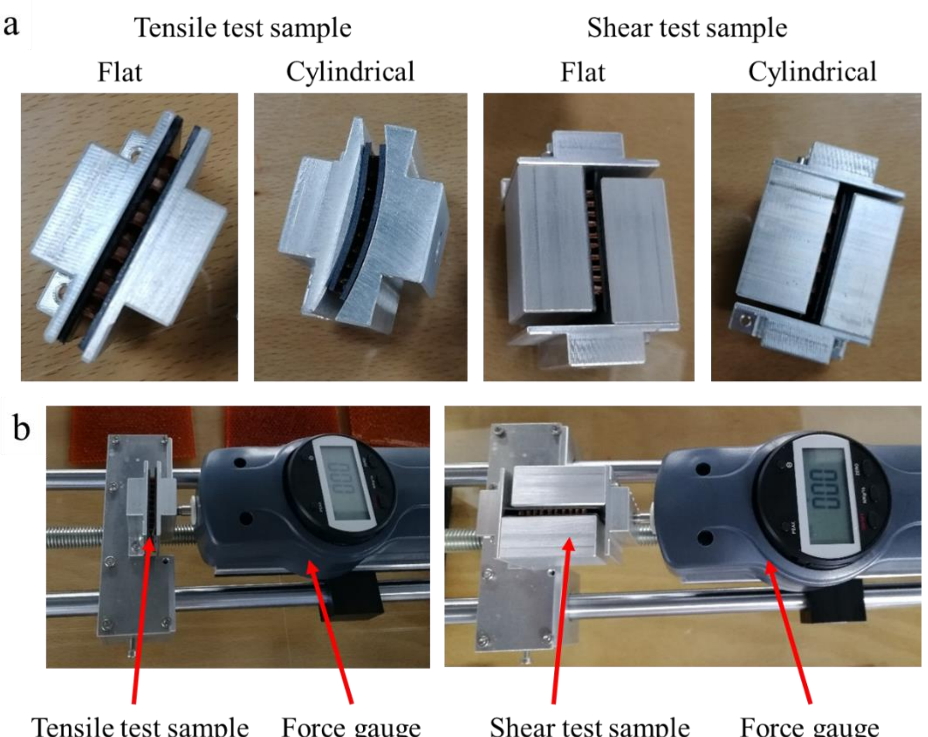
μRWELL film: FPCB technologies

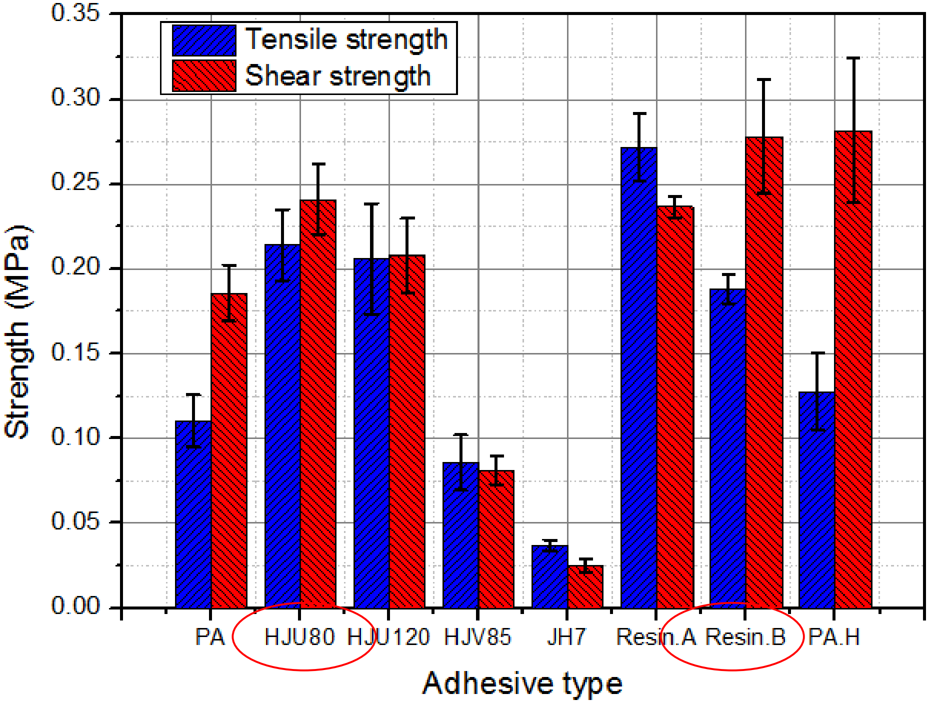
Structure	Material	Thickness (cm)	Material budget (X/X_0)
Inner tube	Aluminum (X_0=8.897 cm)	0.001	**0.011%**
	Polyimide (X_0=28.57 cm)	0.01	**0.035%**
	Aramid honeycomb/Rohacell foam (X_0≈267 cm)	0.2	**0.075%**
Gas Volume	Argon-based gas mixture (X_0=11760 cm)	0.5	0.0043%
Outer tube (μRWELL film)	Aluminum (X_0=8.897 cm)	0.0015	0.017%
	Polyimide (X_0=28.57 cm)	0.03	0.106%
	DLC (X_0=12.13 cm)	0.0001	0.00082%
Total			**0.249%**

Adhesion 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



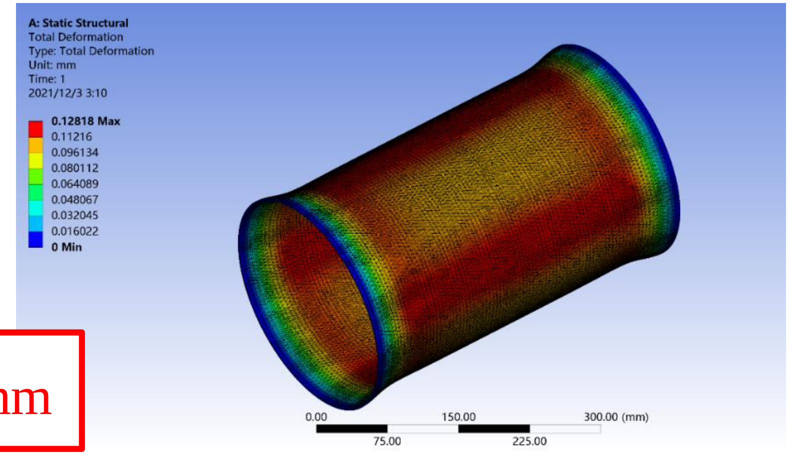


Substrate and manufacturing studies

ANSYS simulation:

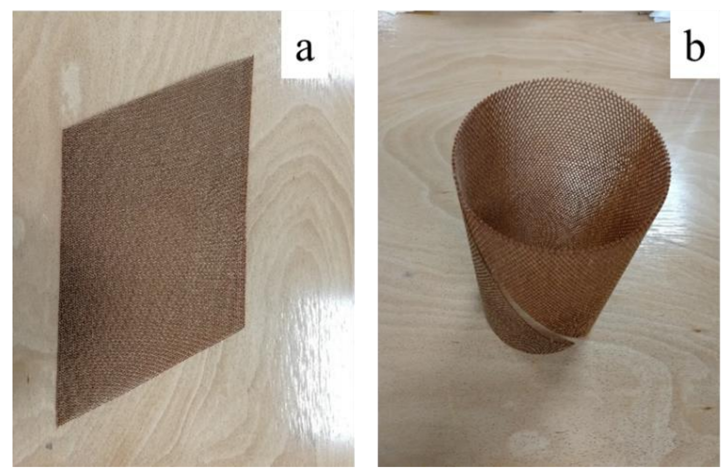
- Structural support material choice
- Distortion under pressure

Thickness of honeycomb/Rohacell foam: 2 mm



Manufacturing method development:

- Honeycomb/Rohacell foam high-temperature reshaping
- Uniform coating of epoxy resin



Budget & strength performance

Tolerate 1.1 bar

for 30 mins

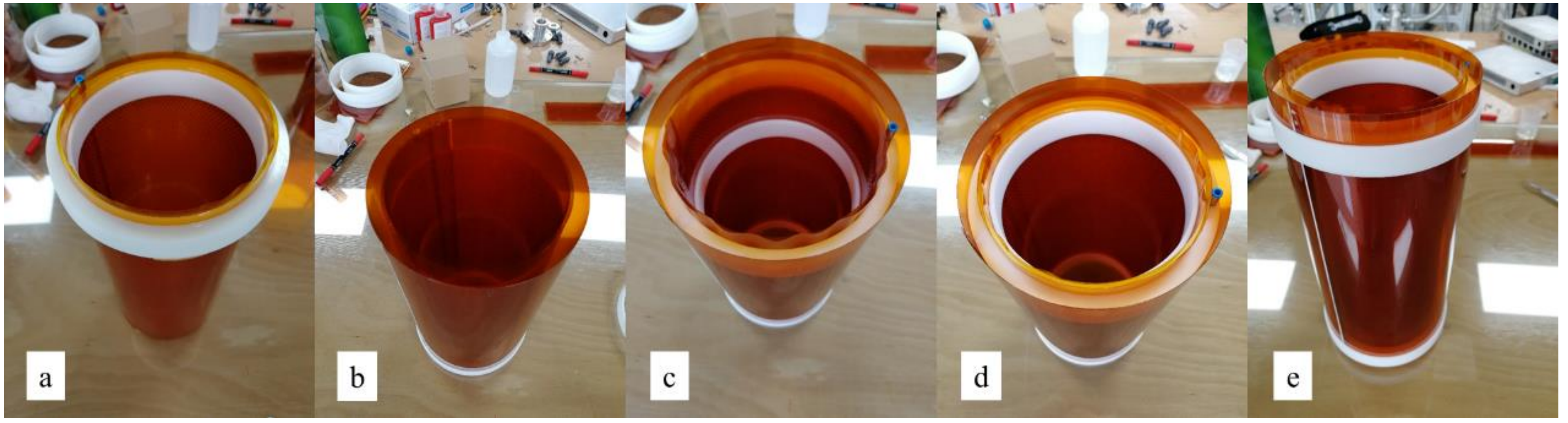
Material budget of sandwich-like cylindrical support layer

Structural support material	Polyimide film	Adhesive layer	Support layer	Adhesive layer	Polyimide film	Total
Honeycomb-based	0.028%	0.009%	0.033% (2 mm)	0.009%	0.030%	**0.105%**
Rohacell-based	0.028%	0.009%	0.010% (1 mm)	0.008%	0.029%	**0.084%**

- Adding the μRWELL film and cathode, the total material budget of the detector is approximately **0.25%** X/X_0

Mechanical structure optimization

1st design: cylindrical detector with sealing rings



a) Installing three sets of rings on one side of the inner tube.

b) Assembling outer tube and take the detector up and down.

c) Installing the innermost and sub-outer rings to the reserved position.

d) Installing the sub-inner ring.

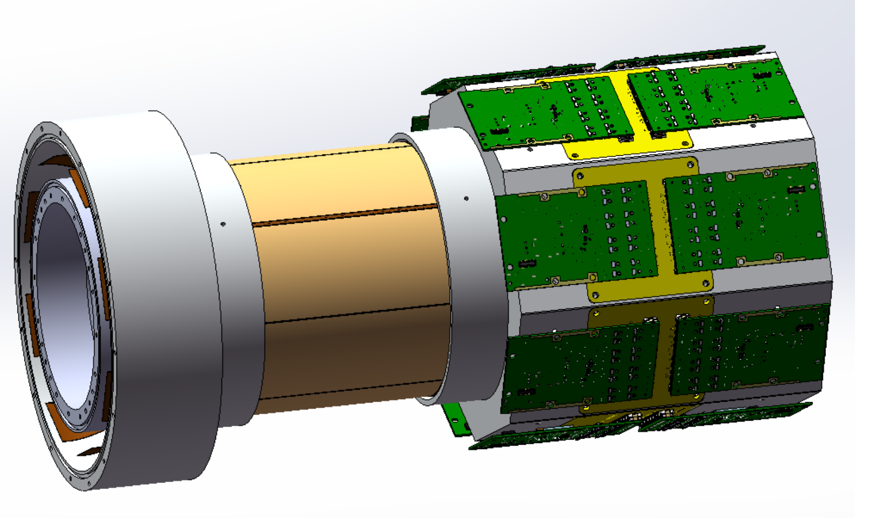
e) Installing the outermost ring.

A little complex

Easy to damage the polyimide film

Mechanical structure optimization

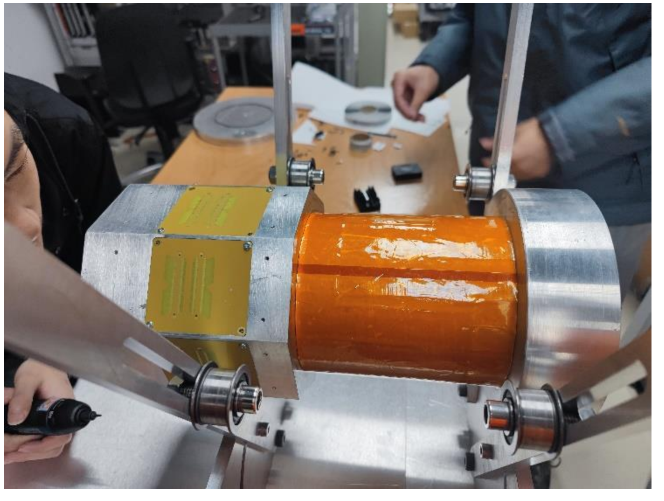
Sealing rings → Flange system

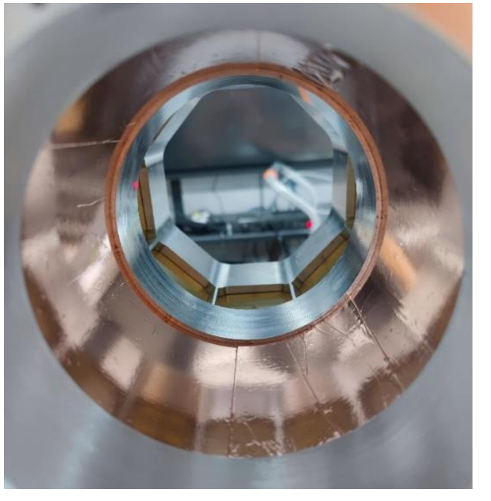


- Better mechanical strength
- Easier assembling process

1st test:

Drift tube assembling



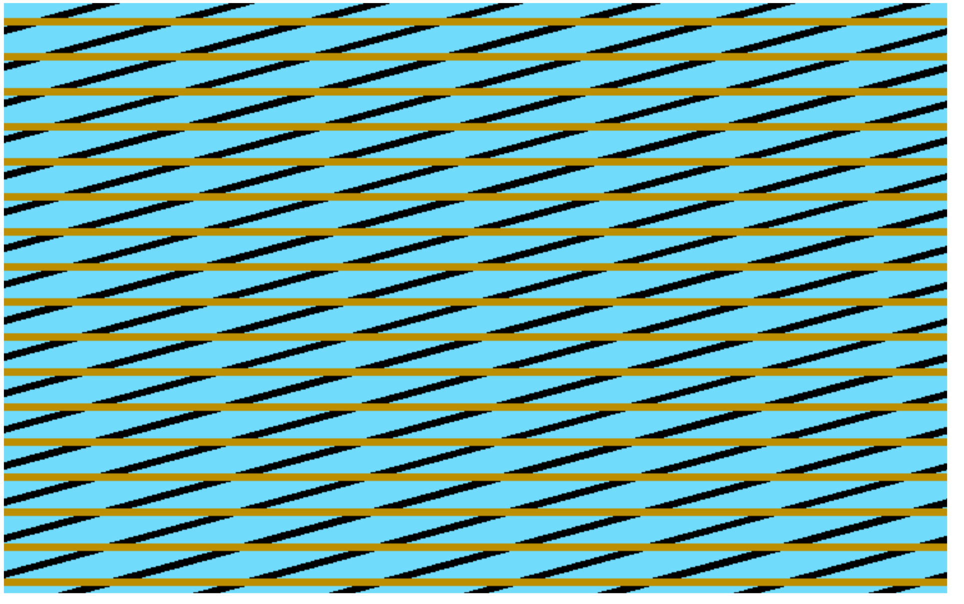


μRWELL film optimization

XV readout strips layout with **rectangle** μRWELL film:

- Some of the V strips are separated into 2 sub-strips
- More electronic channels
- Complex assembling process

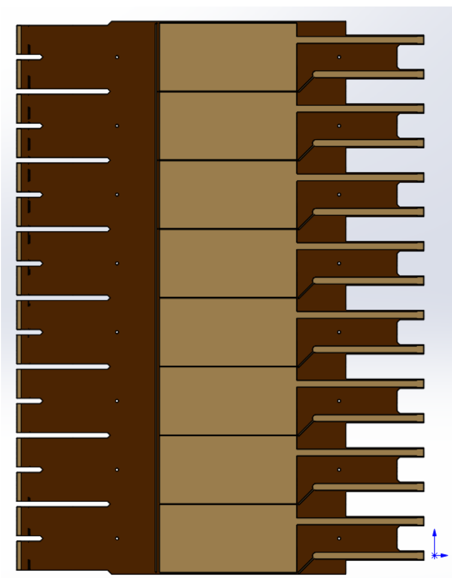
Brown: X strips Light blue: V strips



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



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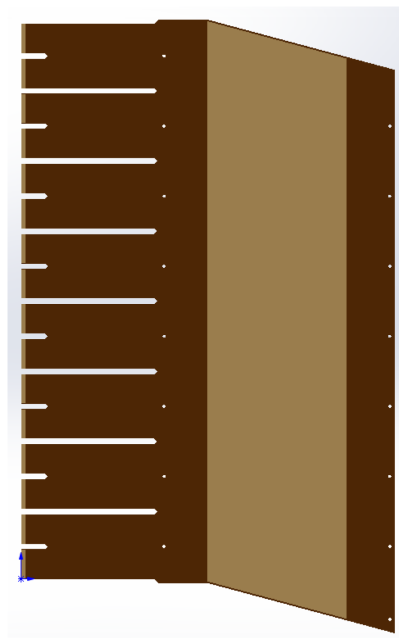
Parallelogram V strip array



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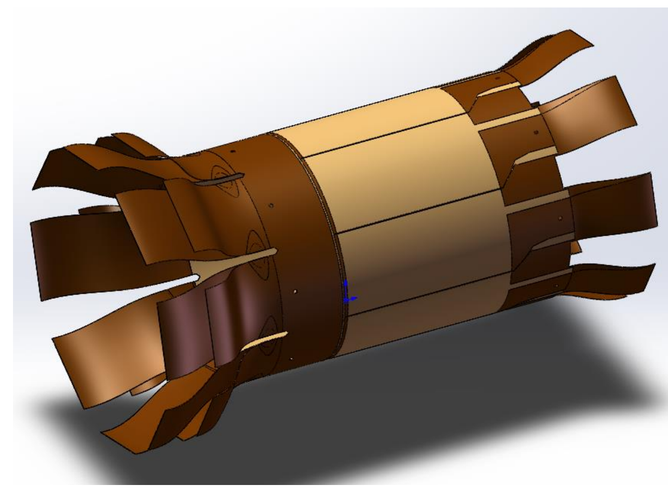
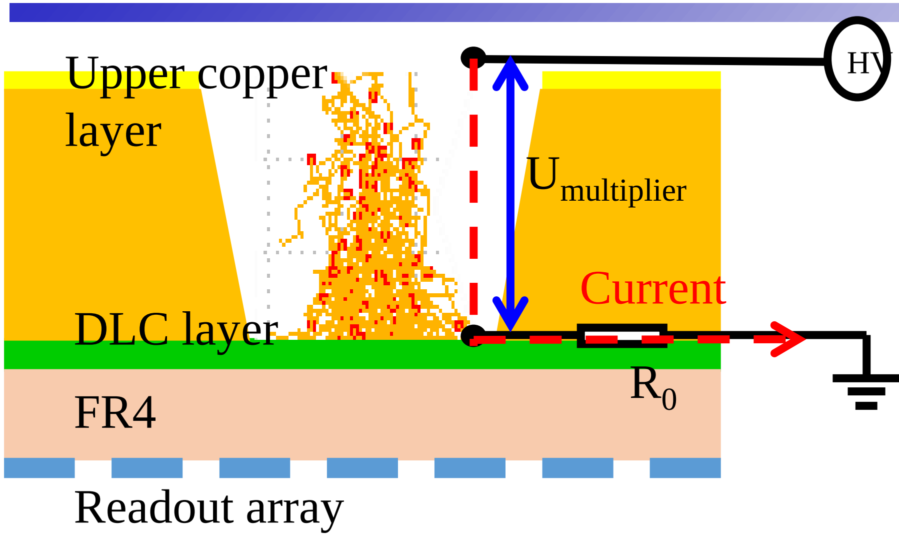
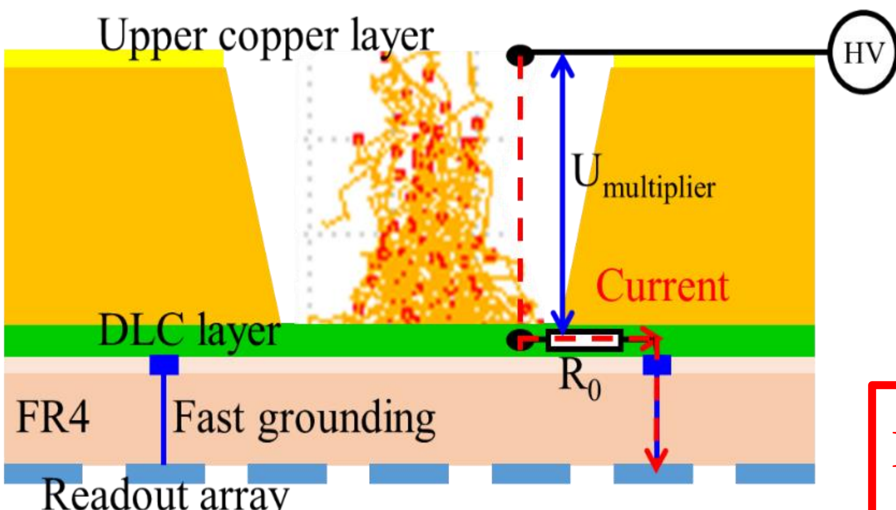


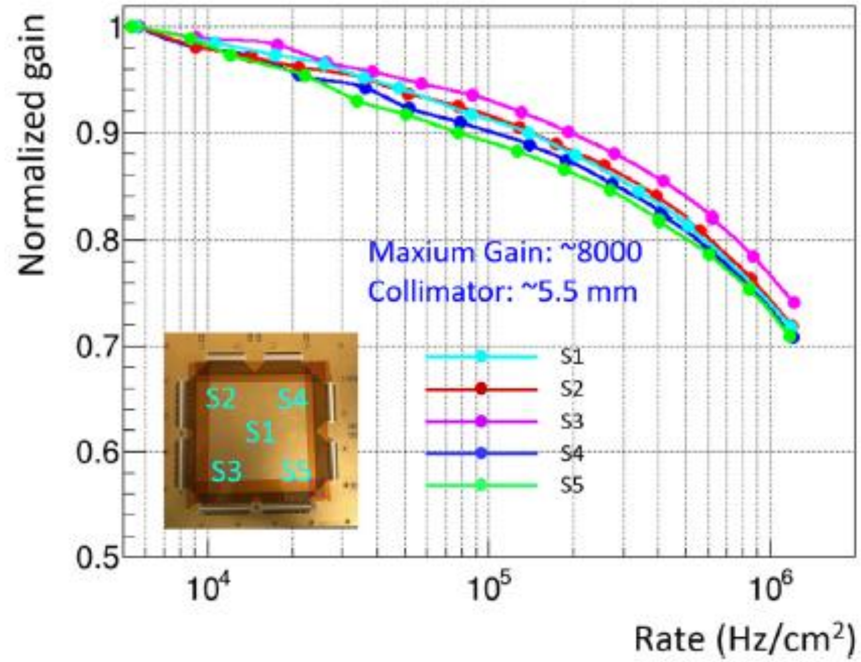
Undivided V strip array

Better deformation control

High counting rate capability







- Detector gain decreases under high counting rate.
- Fast grounding design is required.

How to evaluate the detector gain?

How to optimize the fast grounding design?

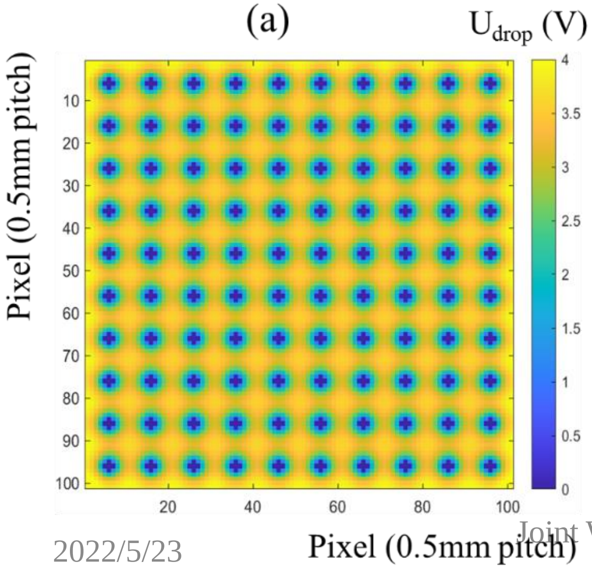
Counting rate capability simulation

Gain decrease comes from:

- **Flowing current effect** on the resistive layer
- **Charge accumulation effect** on the resistive layer

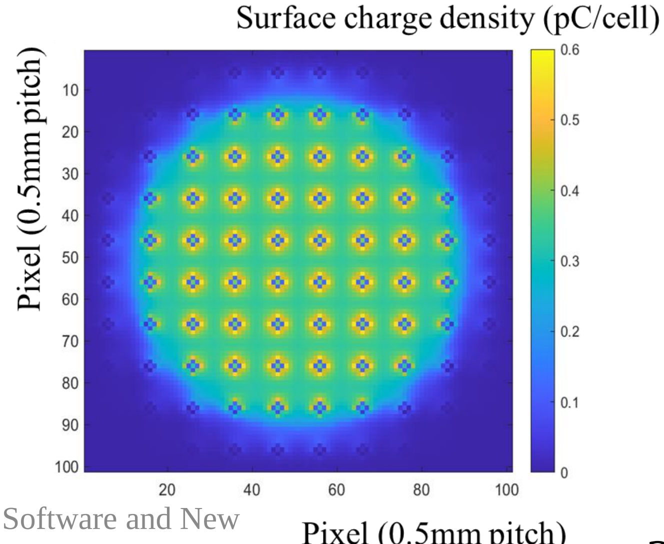
Flowing current effect:

- Kirchhoff equation-based method
- Ohm's law-based method



Charge accumulation effect:

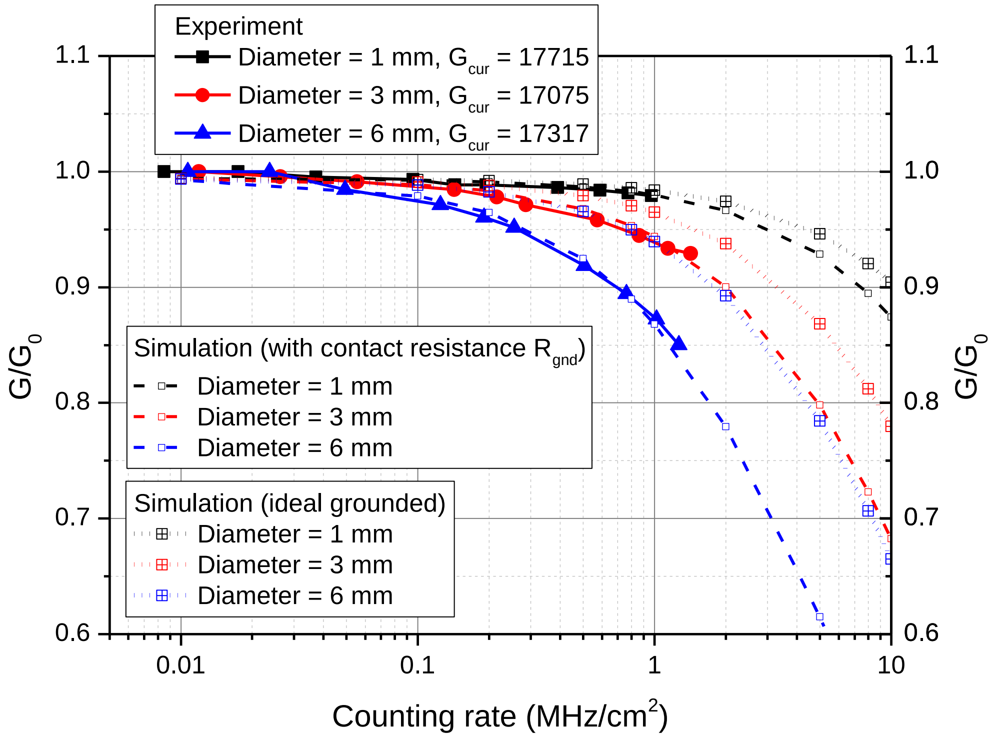
- Maxwell + Garfieldpp

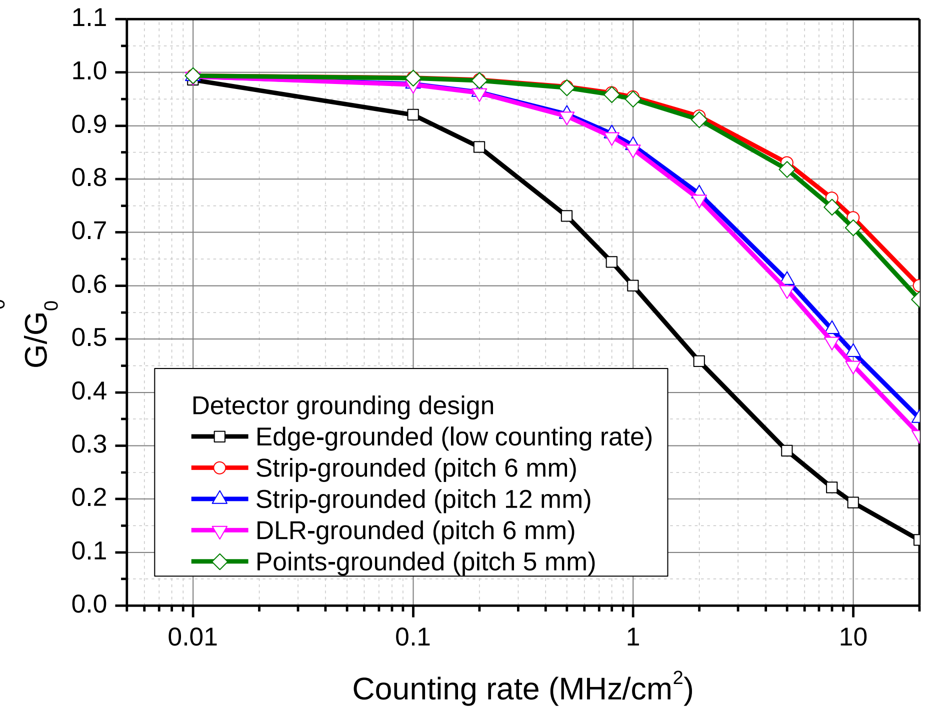


Counting rate capability simulation

Experiments show a good match with the simulation result

Optimize the fast grounding design of μRWELL, for better counting rate capability





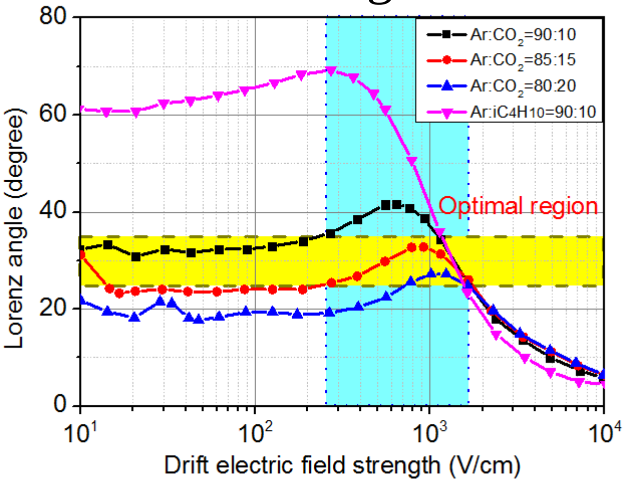
Z. Fang, *et al.*, Simulation and optimization of a fast grounding design for micro-pattern gas detectors with a resistive layer, *NIMA*, 2022

Spatial resolution performance

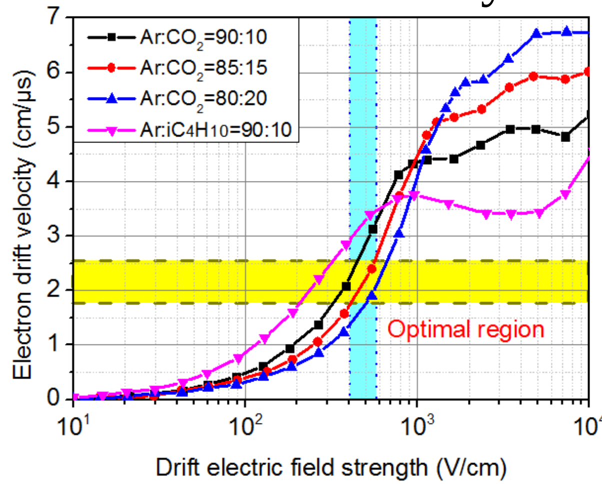
With the Z direction magnetic field:

- The working gas and drift electric field setting get optimized

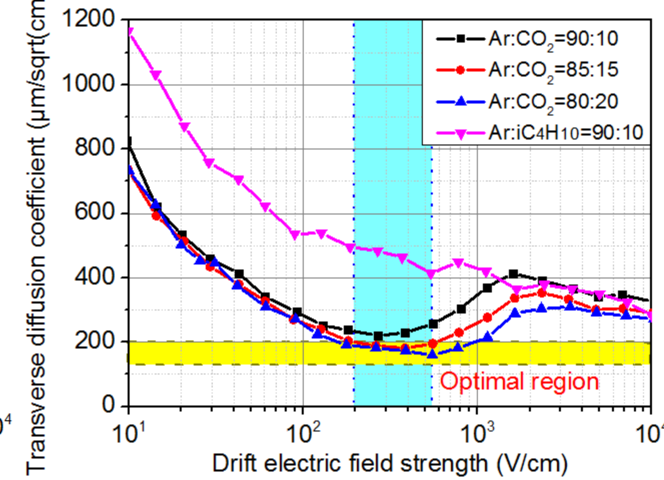
Lorenz angle



Electron drift velocity



Transverse diffusion coefficient



Gas volume width in this step: 5 mm

Optimal gas component: **Ar:CO_2=85:15** (or Ar:DME=90:10)

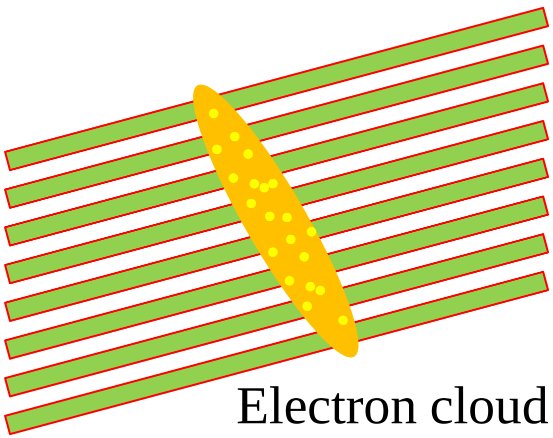
Optimal electric drift field strength: **500 V/cm**

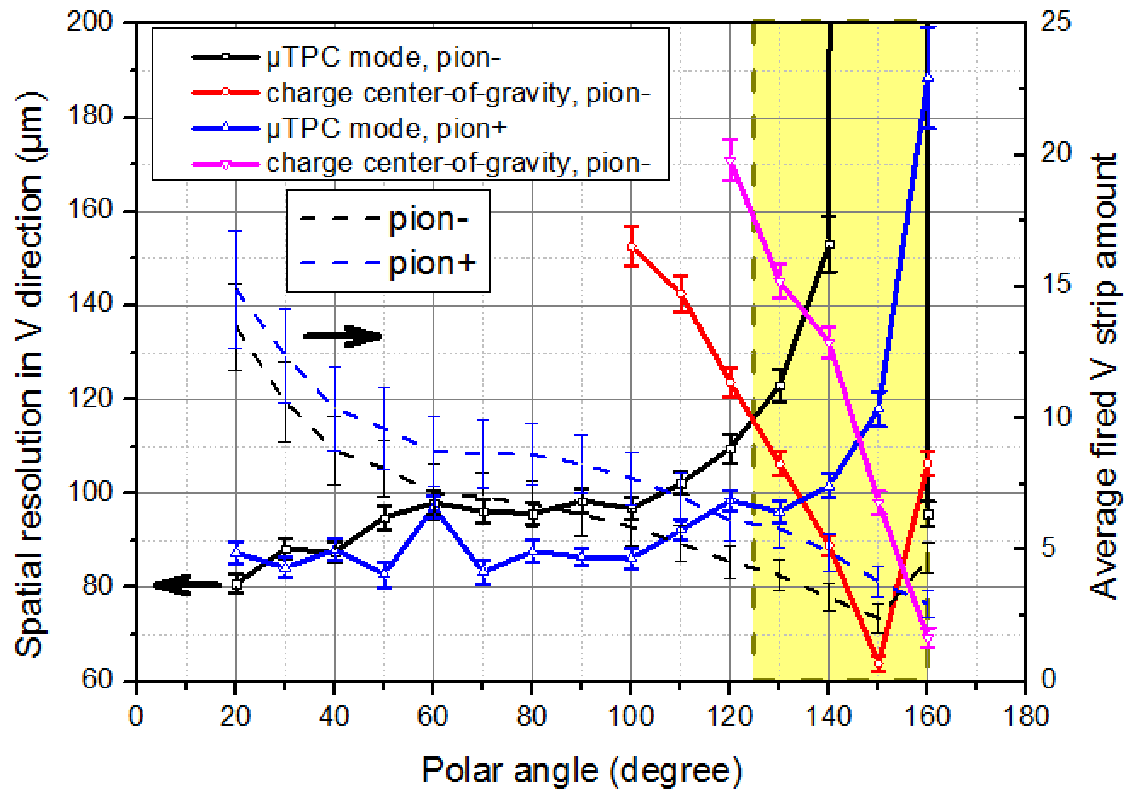
Hit reconstruction method

Hybrid hit reconstruction method:

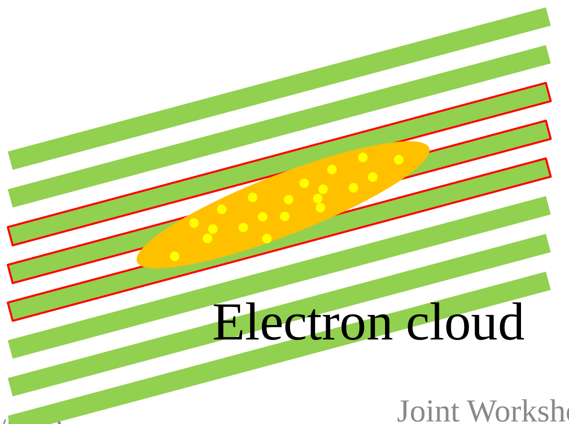
- μTPC mode (for most cases)
- Charge center-of-gravity method (when electron cloud parallels to V strips)

Readout strips





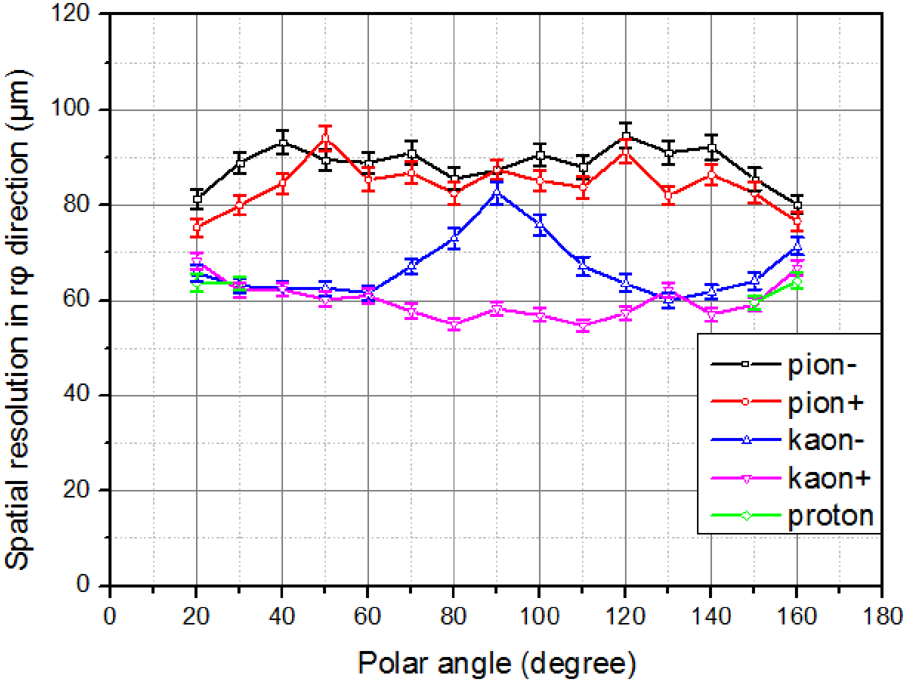
Readout strips



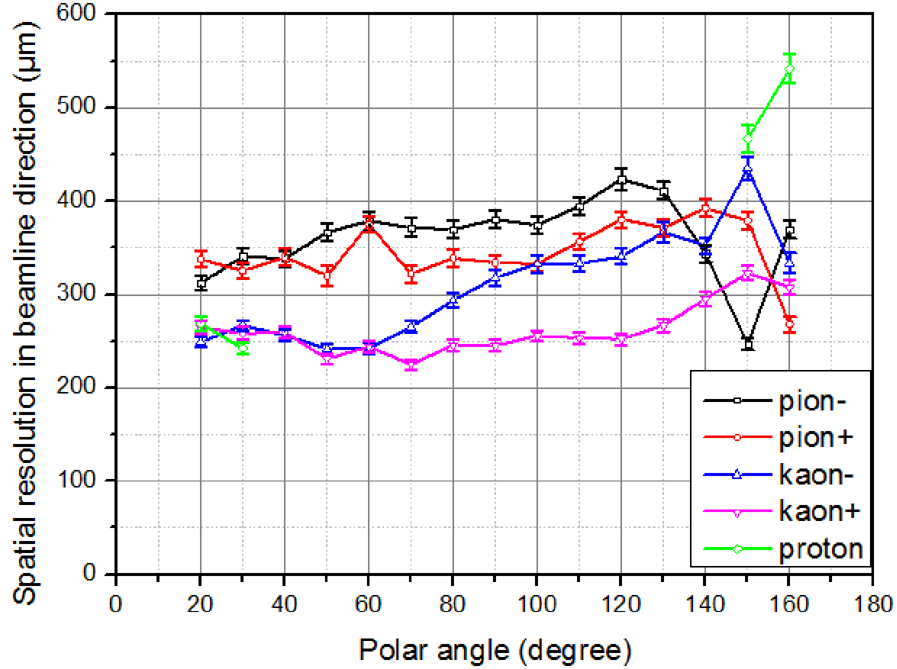
Spatial resolution performance

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

Spatial resolution in rφ direction



Spatial resolution in z direction



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Conclusion

μRWELL detector

Low material budget	High counting rate capability	Large detection area with acceptable cost

1. μRWELL-based detector could used in the next generation colliders.
2. A cylindrical detector is studied:
   - Suppressing budget to approximately 0.25% X/X_0 per layer.
   - Optimizing mechanical structure and μRWELL film designs.
   - Promoting counting rate capability and spatial resolution.
3. In this step, the simulated spatial resolution of approximately 100 μm and 400 μm in rφ and z direction, respectively.

THANKS