Development of large area μRWELL detector

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Outline

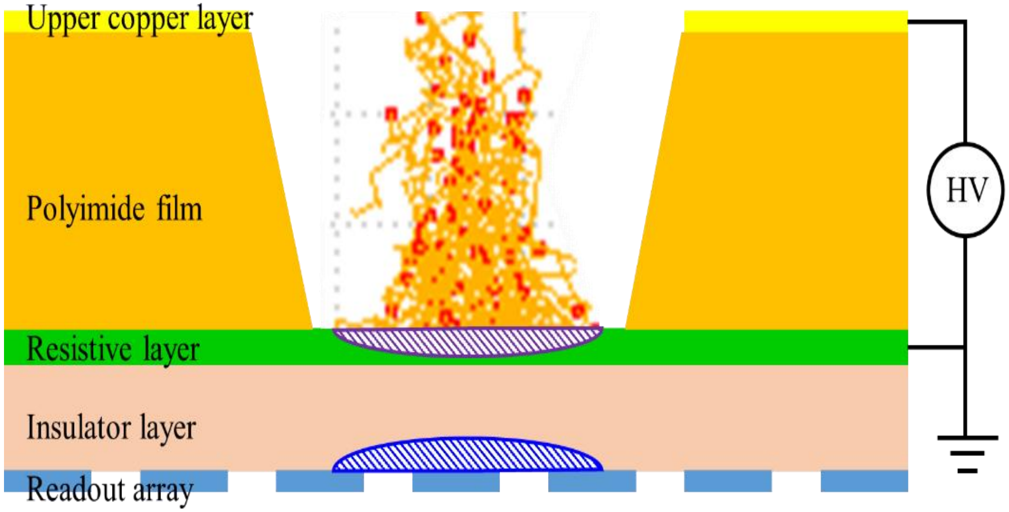
1. **Motivation**
2. Fast grounding research
3. Detector performance optimization:

   magnetic field
4. Summary

µRWELL detector

µRWELL detector

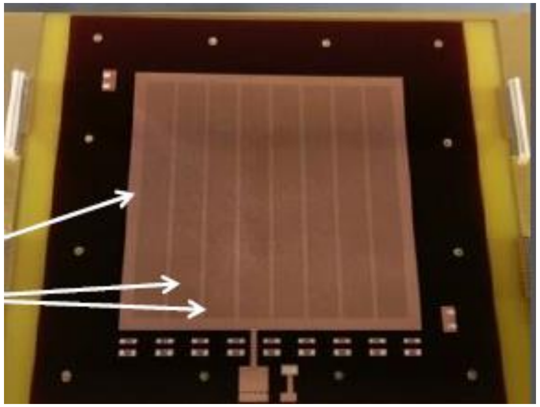
- Suppressiveness of sparks
- Large gain
- Simple structure



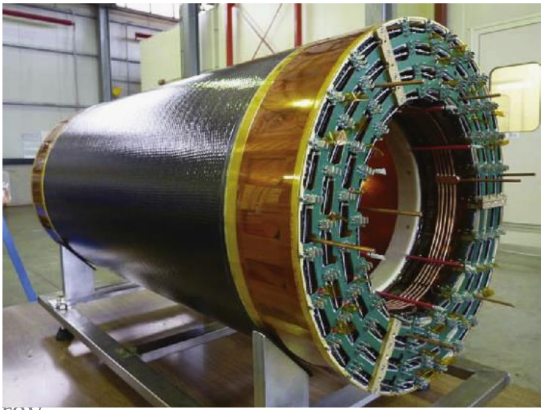
Several developments of µRWELL detector:

Large area

High rate capability

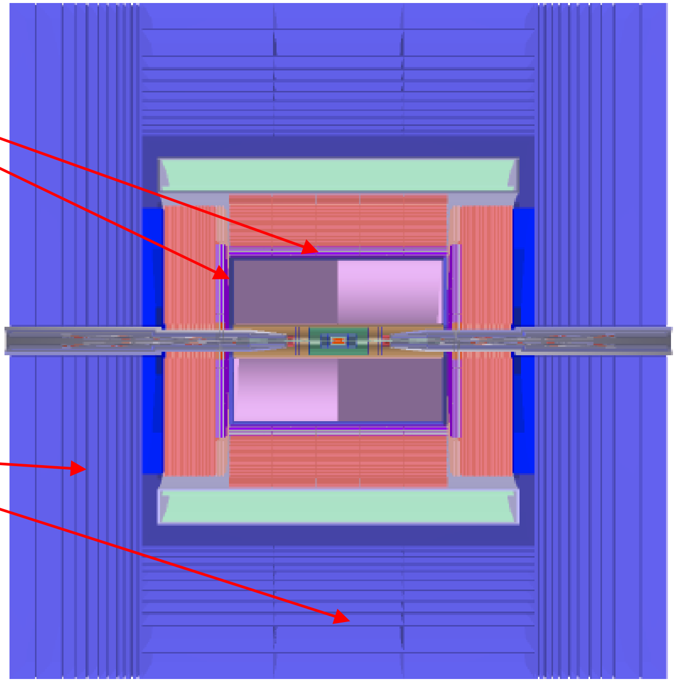


Customization for applications



Overview: μRWELL in CEPC

Alternative applications of μRWELL in CEPC



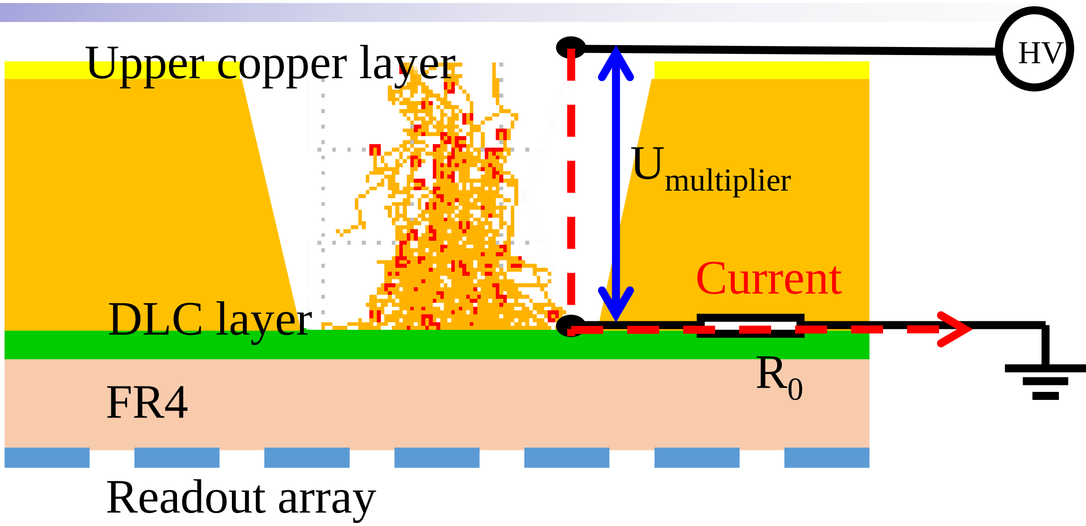
1. Preshower detector

2. Muon detector system

Requirements:

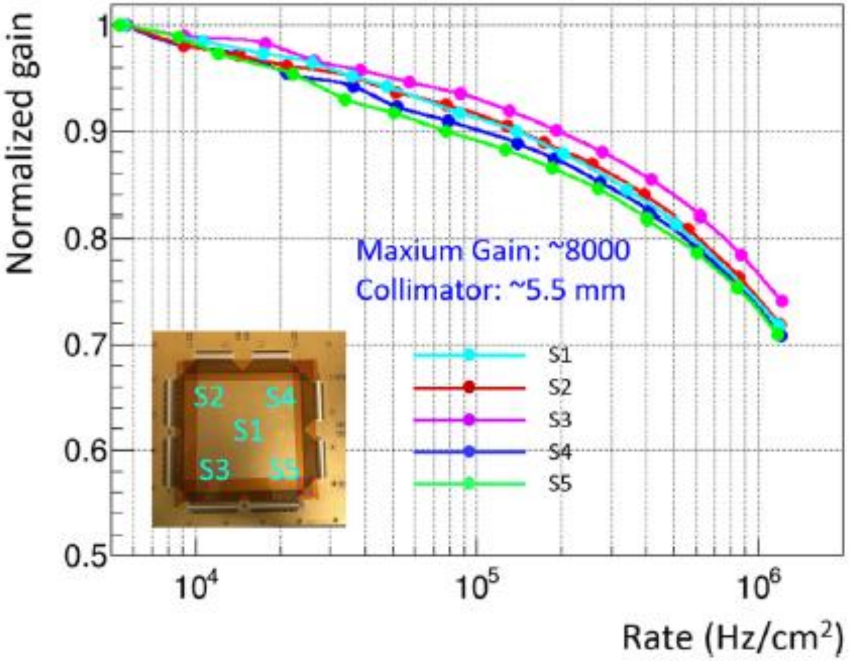
- Large area
- High robustness
- Good rate capability
- Stable performance under different working conditions

μRWELL rate capability



For traditional μRWELL:

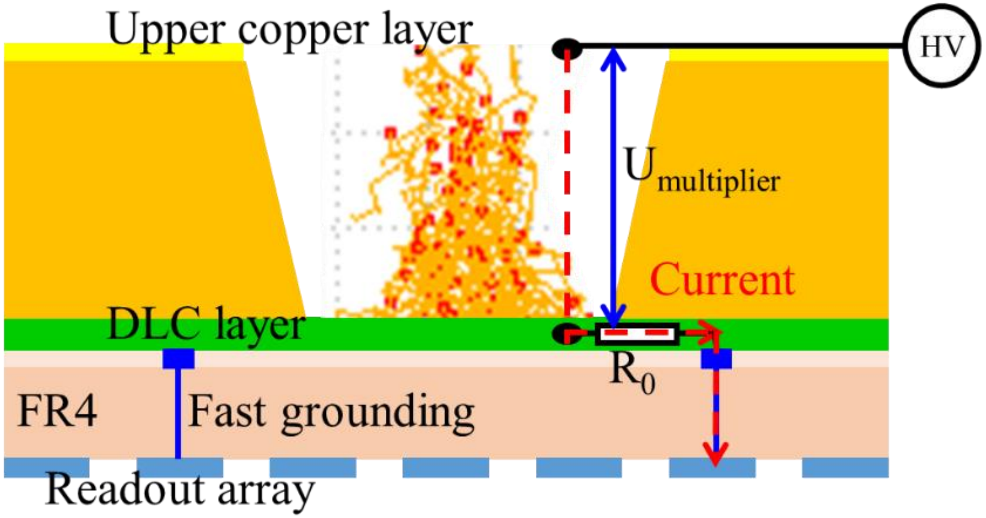
- Decreased gain under high rate
- Caused by the introduction of resistive layer
- Harmful to performance, especially with large area



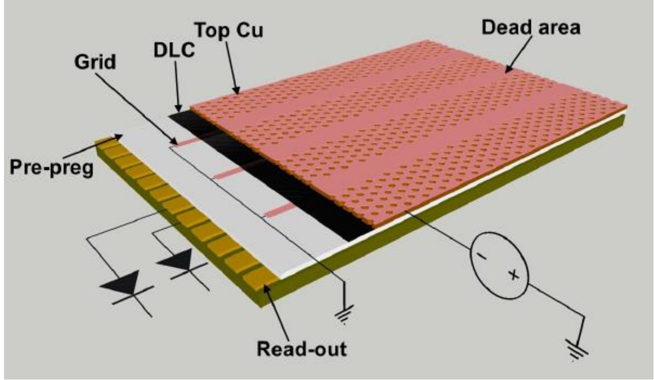
Fast grounding μRWELL

Fast grounding:

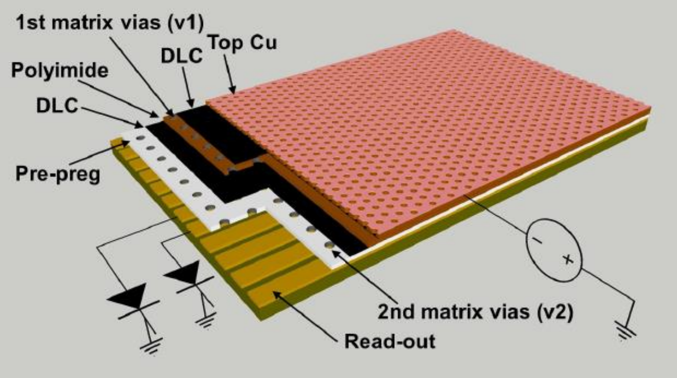
- Setting grounded conductor array
- Decreasing equivalent grounding resistance of DLC
- Remaining detector gain



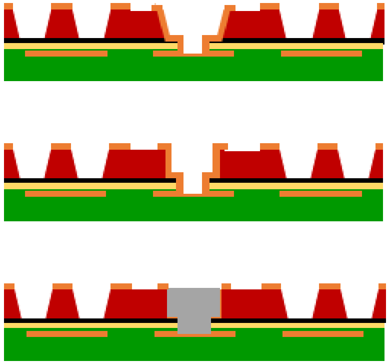
1D strip-grounded



Double layer point-grounded



Point-grounded



Research direction

Two effects：

- (U) Voltage drop effect by DLC flowing current
- (Q) Electrostatic field effect of accumulated charge

Principle:

- Contributions of the two effects
- Optimization of μRWELL fast grounding for large area

Manufacturing technologies：

- Performance evaluation of existing technologies
- Acceptable manufacturing deviation

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2. **Fast grounding research**
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   magnetic field
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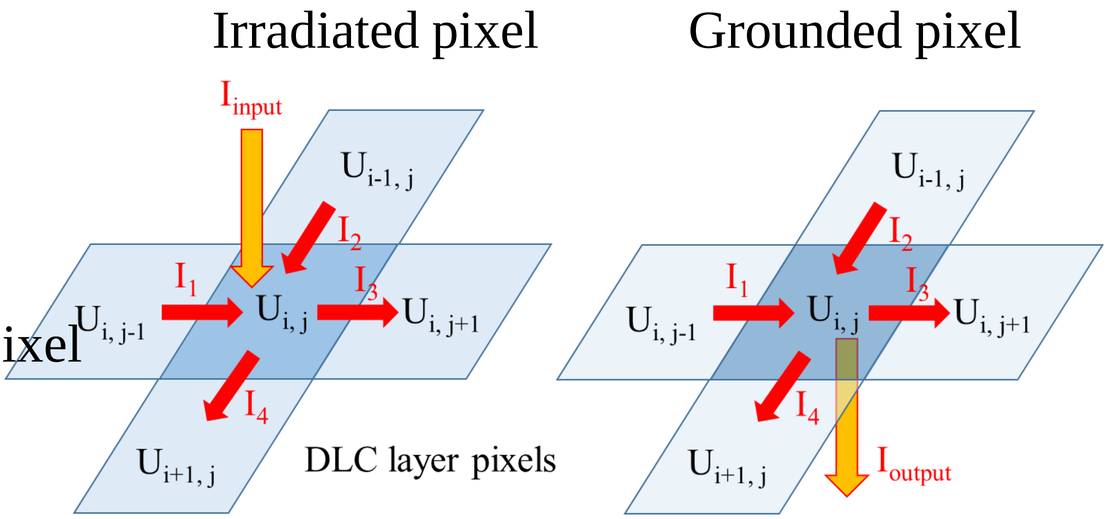
Voltage drop effect

Simulation 1: Kirchhoff-equation-method

Key points:

- Dividing DLC into 2-D grid
- I_{in} equals I_{out} in each pixel
- Potential equals 0 in grounded pixel
- Kirchhoff equations
- Solving voltage drop distribution on DLC, and flowing out current distribution on grounded-pixels



Advantages

- Accurate solutions

Disadvantages:

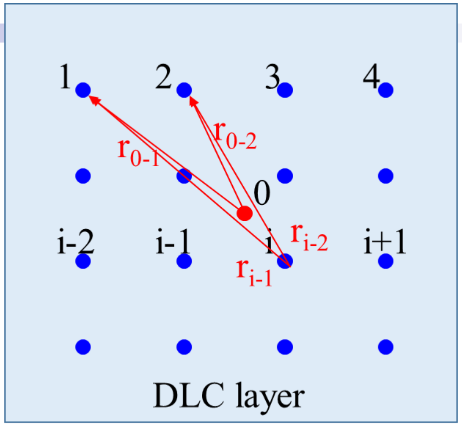
- Low calculation speed
- Cannot get DLC equivalent resistance effectively

Voltage drop effect

Simulation 2: Ideal-formula method

Key point:

- Dividing DLC and irradiation area into 2-D grid
- Solving flowing out current distribution on grounded-pixels
- Calculating voltage distributions by each I_{in} I_{out} pair
- Summing weighted
- Traversing all the irradiated pixels and getting the total effect



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

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

Advantages:

- Fast calculation speed
- Getting DLC equivalent resistance simultaneously

Disadvantage:

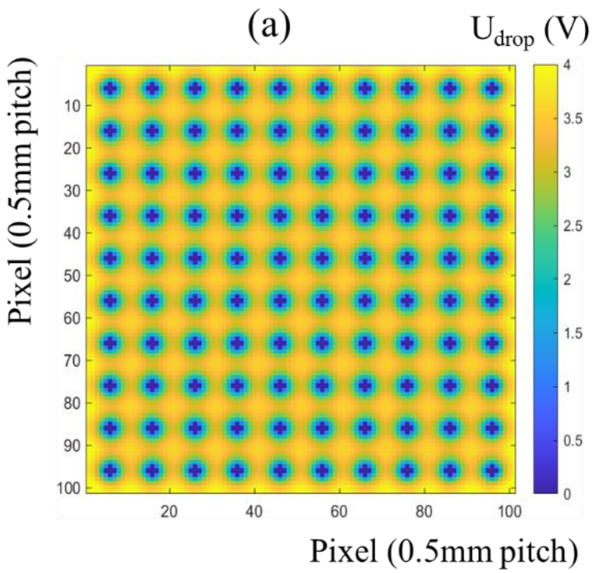
- Distortion at the DLC boundary

Voltage drop effect

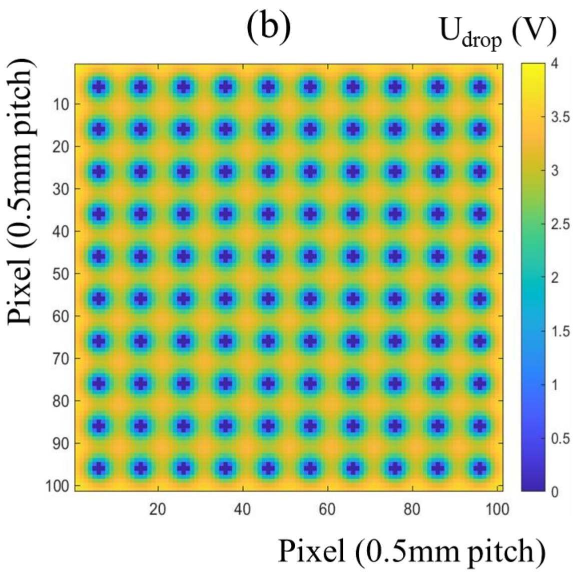
Simulation results:

- 1 MHz/cm^2 8.1 keV X ray, $G_0 = 24000$
- Main area of DLC: voltage drop 2.8 V ±5%
- **$G/G_0 = 91.8\% \pm 0.3\%$**

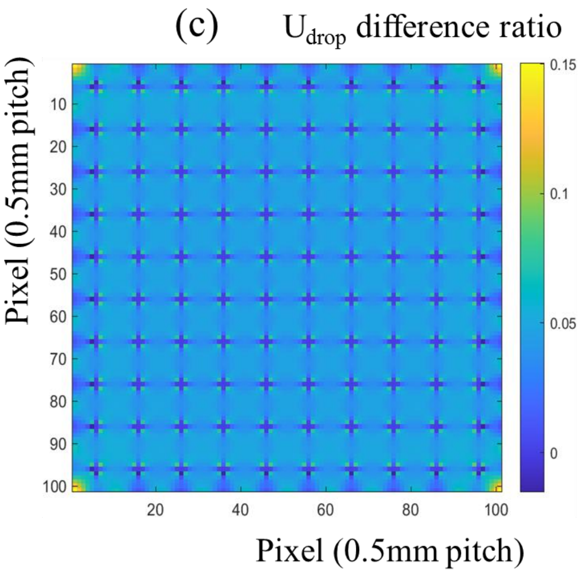
Kirchhoff-equation-method



Ideal-formula method



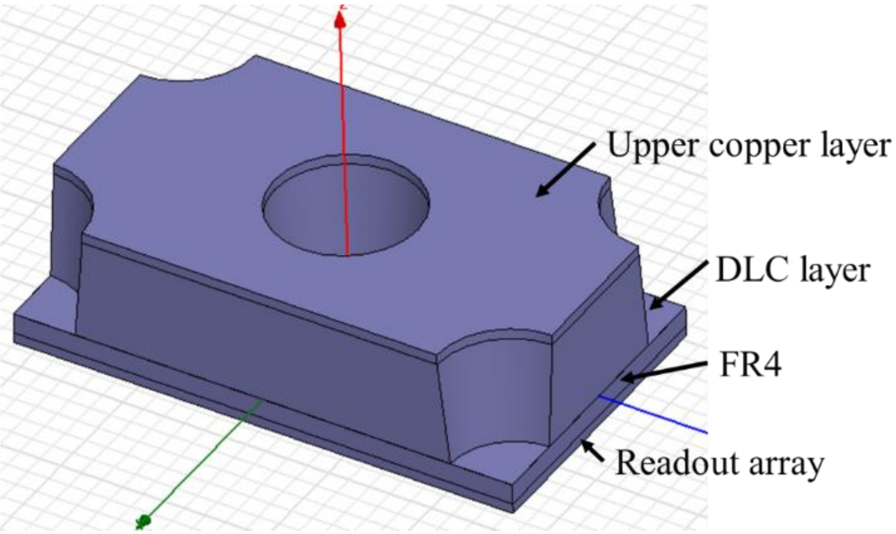
ΔU ratio



Charge accumulation effect

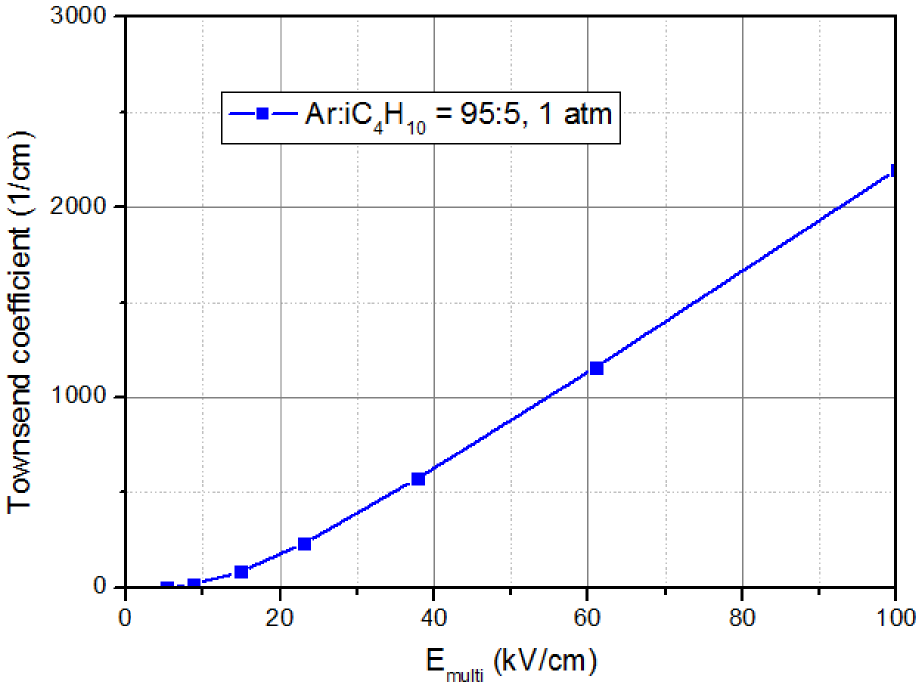
1. Maxwell simulation

- Electric field with charge areal density



2. Garfield database

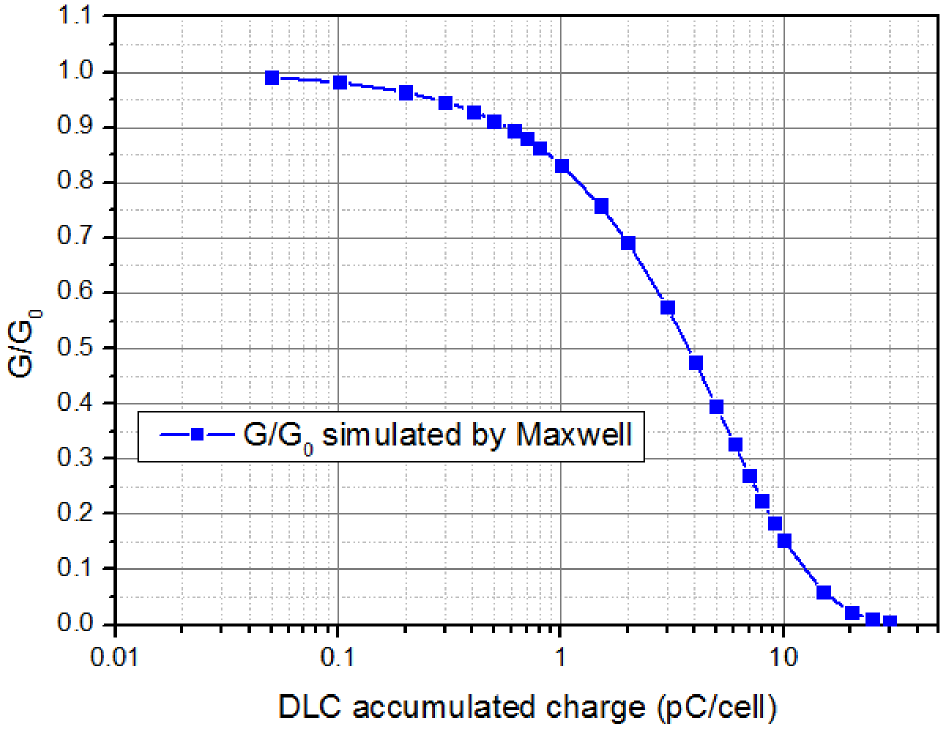
- Townsend -electric field relationships



Charge accumulation effect

3. Accumulation in the μWELL

- Charge accumulation effect



In the steady state:

$$\Delta Q = \frac{\Delta E}{W} \cdot G \cdot Rate \cdot S_{rad}$$

$$dt \cdot \Delta Q = \sigma_0 \cdot S_{rad} \cdot \left(1 - e^{-\frac{dt}{\tau}}\right)$$

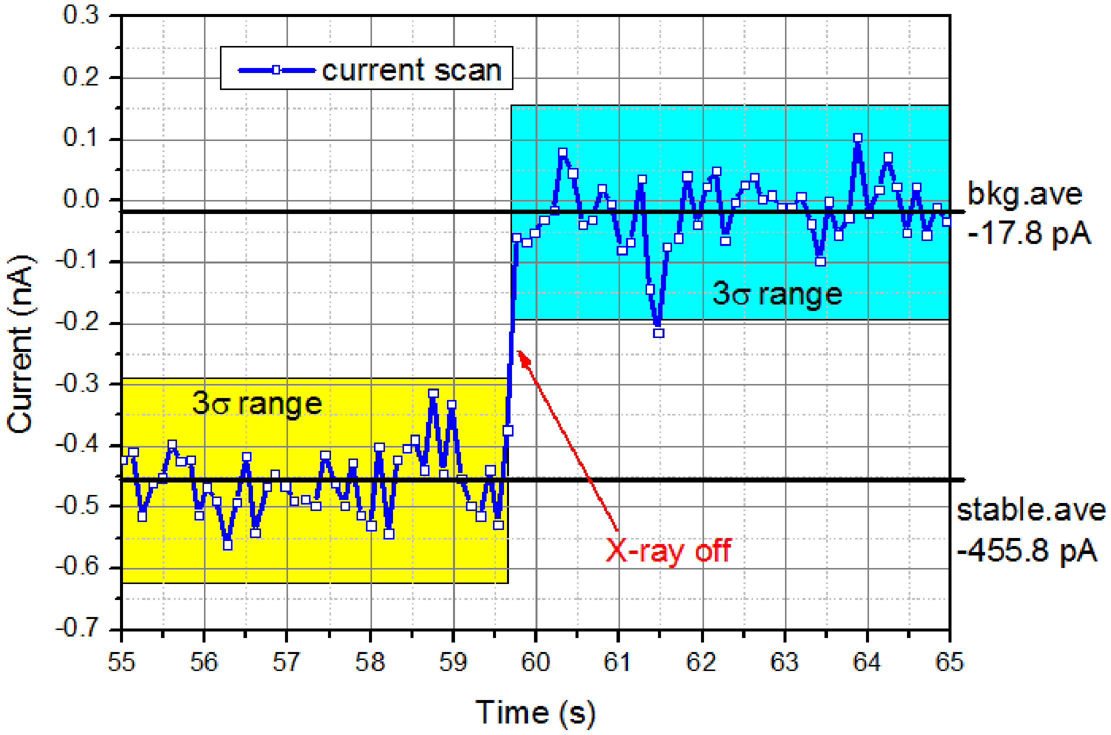
$$\therefore \sigma_0 = \frac{dt \cdot \Delta Q}{S_{rad} \cdot \left(1 - e^{-\frac{dt}{\tau}}\right)} = \frac{dt \cdot \frac{\Delta E}{W} \cdot G \cdot Rate \cdot S_{rad}}{S_{rad} \cdot \frac{dt}{\tau}}$$

$$= \tau \cdot \frac{\Delta E}{W} \cdot G \cdot Rate$$

Charge accumulation effect

The accumulated charge areal density is proportional to the time constant of DLC-ground circuit.

- PEDF μRWELL:

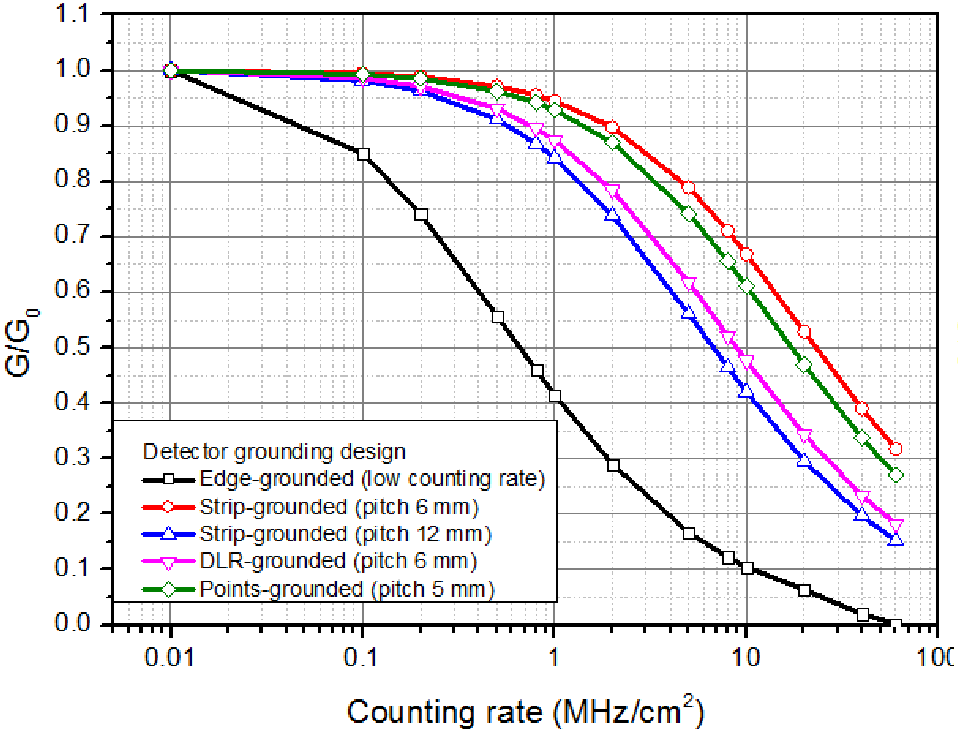


- **Measured:** DLC cuurent drops to bkg-level within 111 ms, $e^{-t/\tau}$=1.8%, t=4τ, **τ<28 ms**

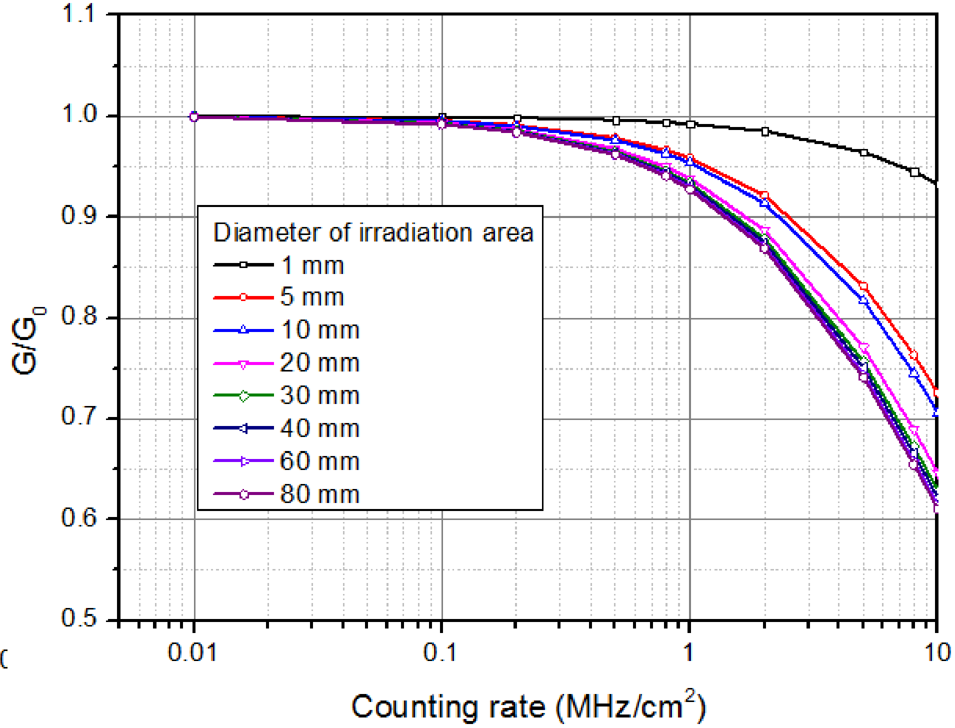
Simulation result

Combining the two effects:

Many fast grounding designs performance



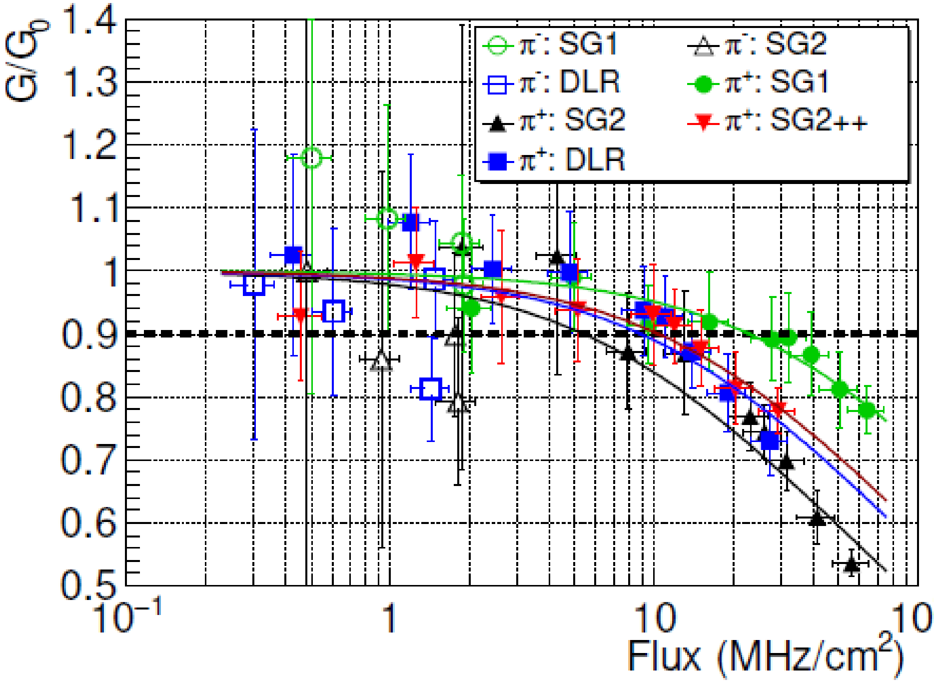
Rate capability with various irradiation area



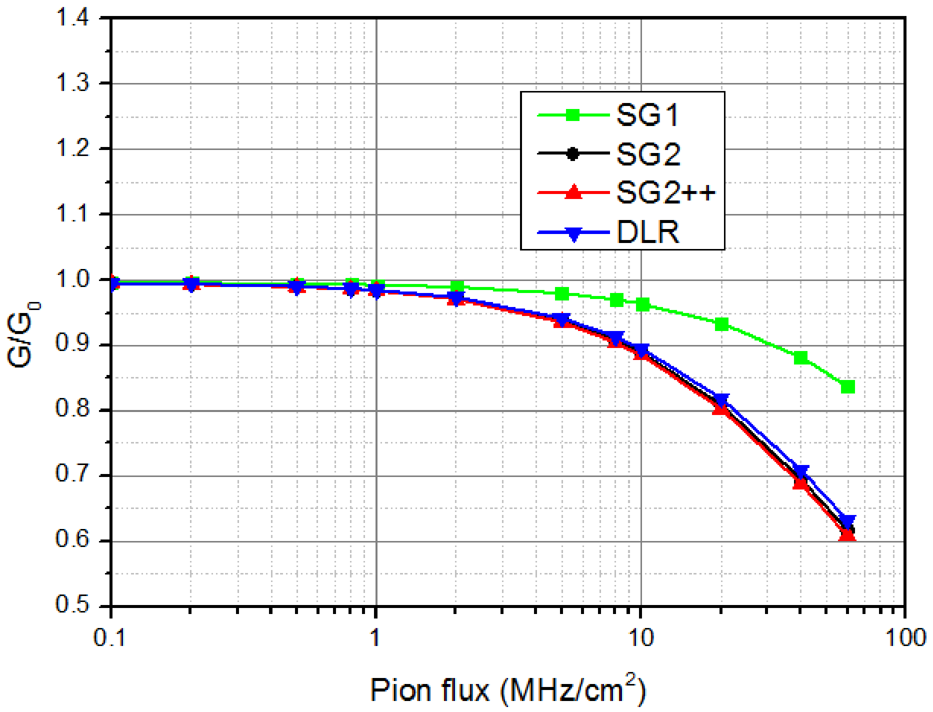
Experimental evaluations

INFN proposed strip-grounded and double layer point-grounded design

experiments

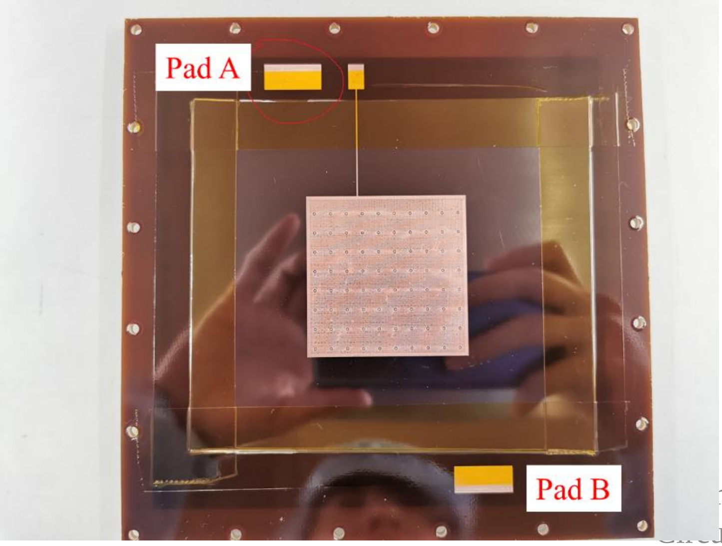


simulations

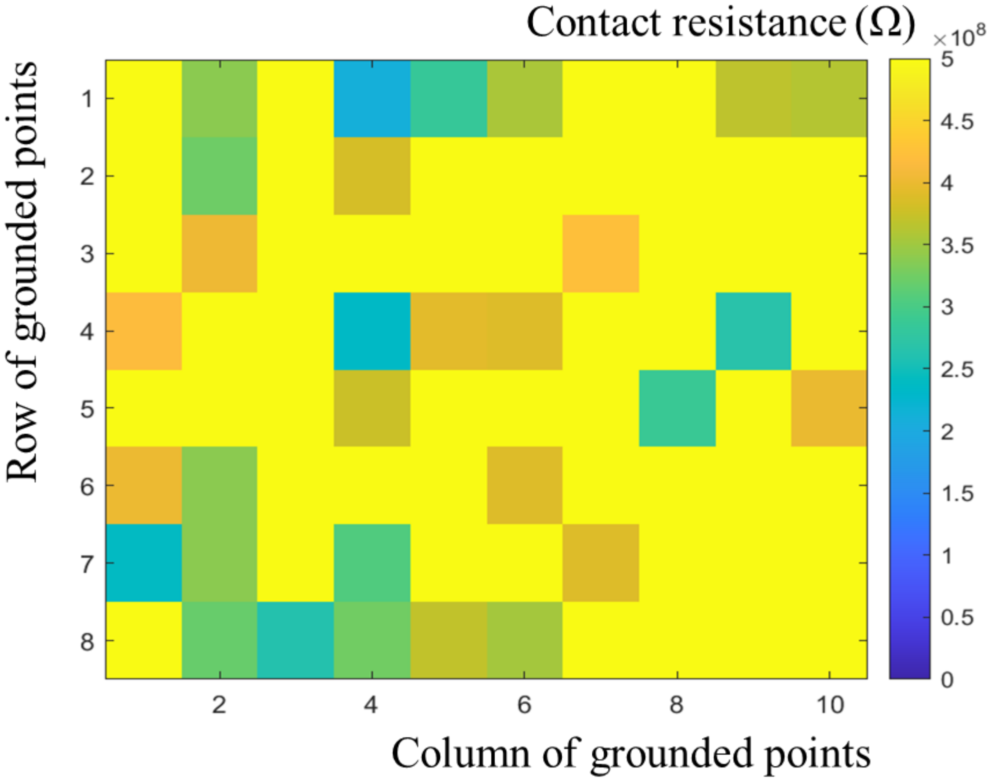


Experimental evaluations

- The grounded point has a contact resistance, may influence the rate capability.
- PEDF contact resistance:
  200-500 MΩ
- PEDP contact resistance:
  15-35 MΩ



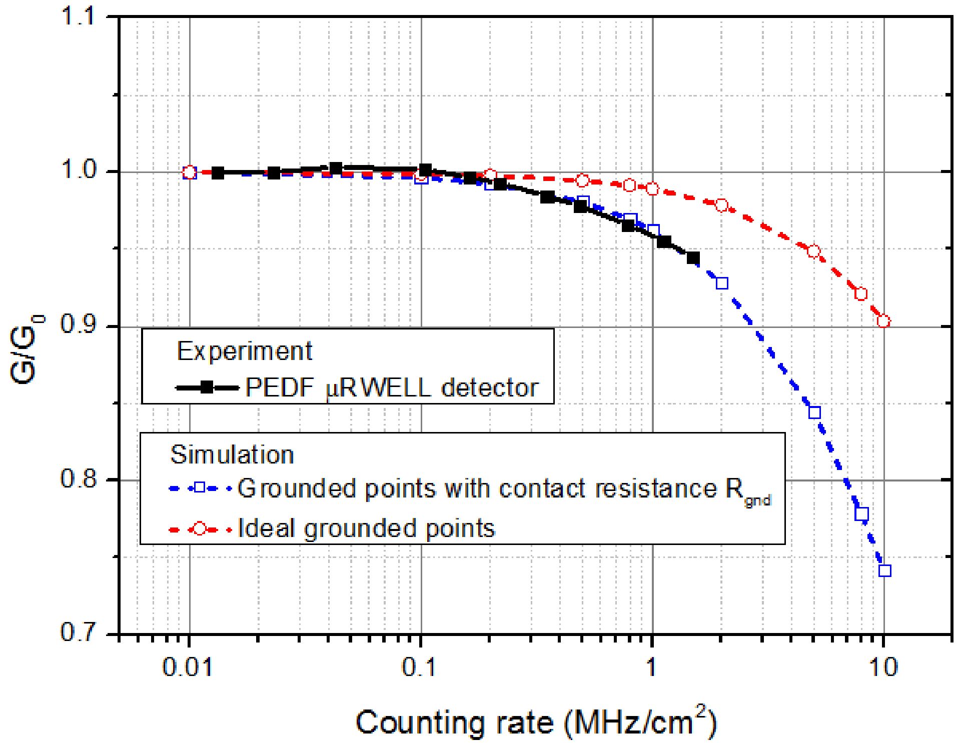
Measured contact resistance in PEDF grounded-points array



Experimental evaluations

- Good match between simulation and experimental data
- Suppressing the contact resistance in grounded points is very important for large area fast grounding μRWELL

PEDF, Φ 8 mm 8.1 keV X ray irradiated



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3. **Detector performance optimization: magnetic field**
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μRWELL under magnetic field

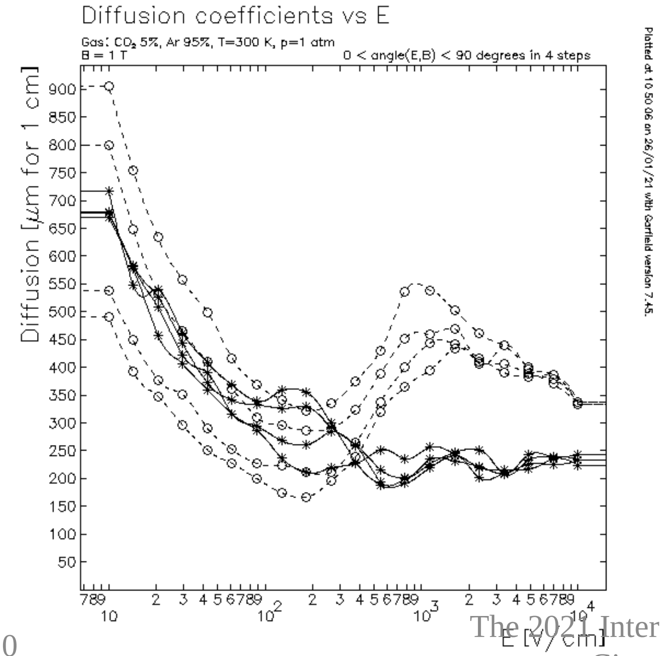
Due to the magnetic field in Z direction, situations are different：

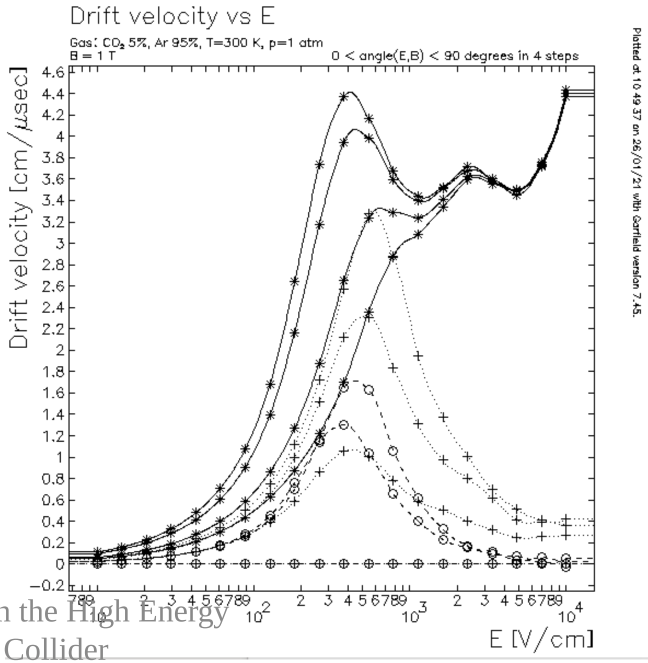
- Electron drift velocity
- Transverse & longitude diffusion coefficients
- Lorenz angle
- …

Gas volume width

Gas component

Drift electric field strength





Ideal parameters simulation

1 T magnetic field

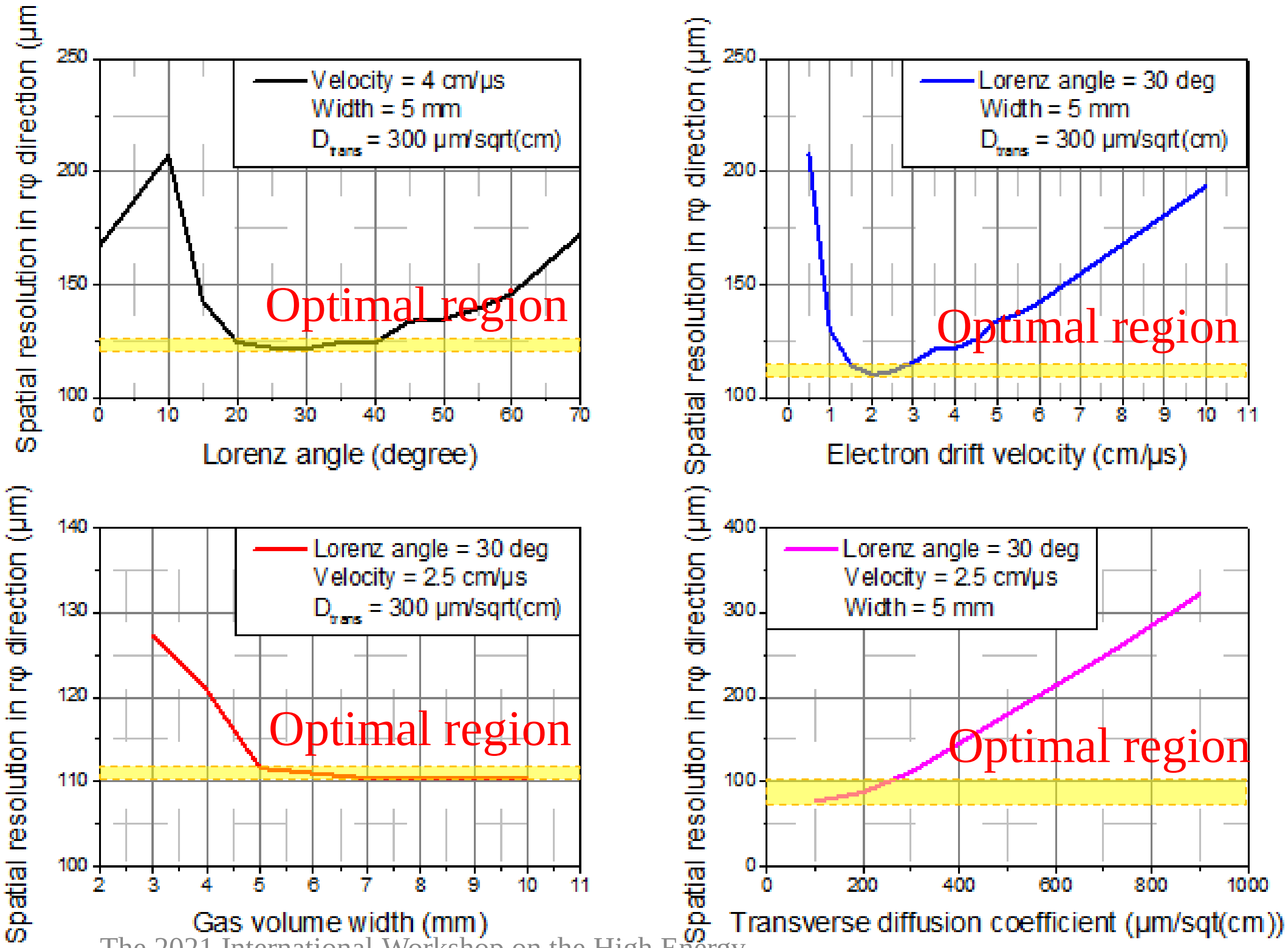
Gradient descent method in multi-dimensions

Optimal region:

- Gas width: 5 mm
- Lorenz angle:

  20-40 deg
- V_{drift}: ~2 cm/μs
- $\sigma_{Transverse}$ < 100

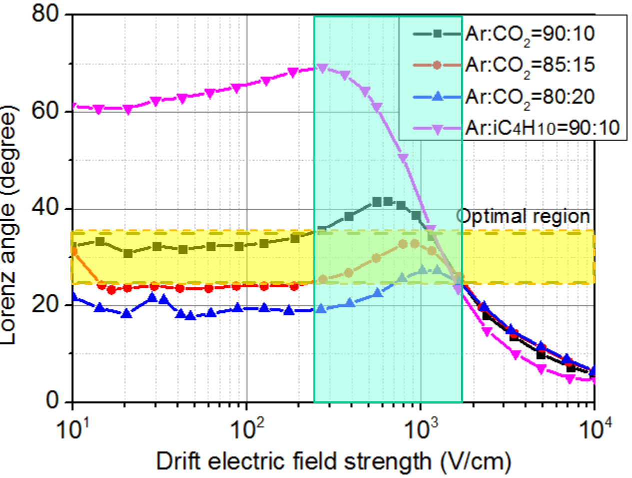
  μm/sqrt(cm)



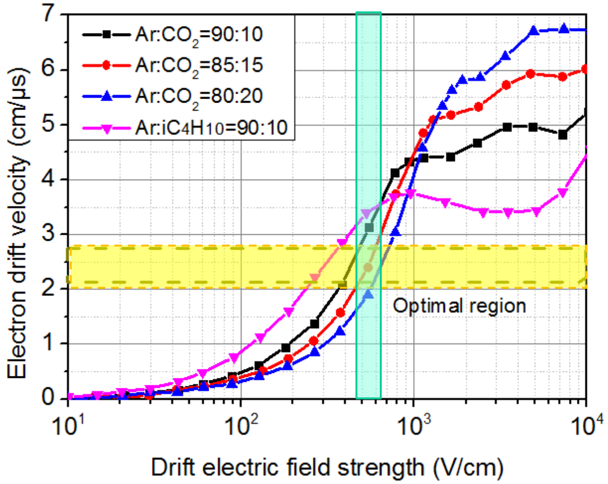
Real situation optimization

Target: tens of gas components from Garfield database

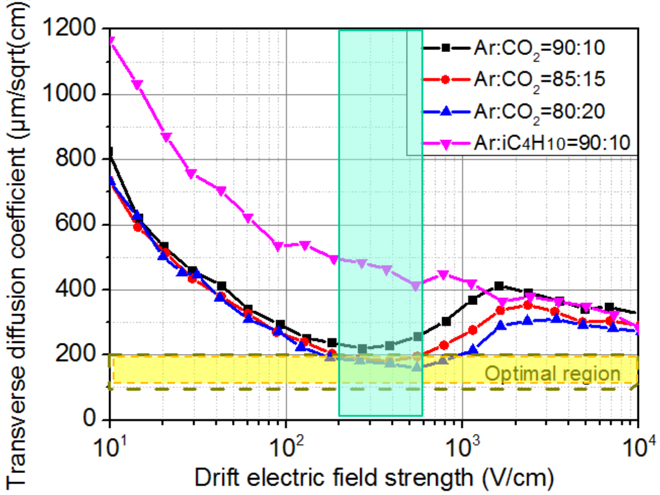
Lorenz angle



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)

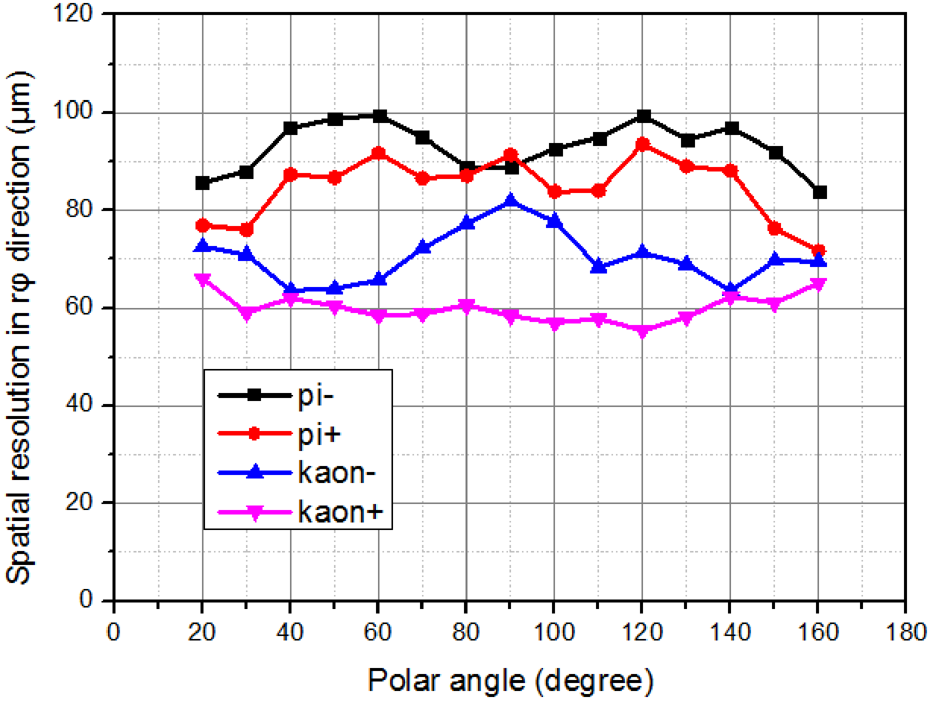
Optimal electric drift field strength: 500 V/cm

µRWELL under magnetic field

Many parameters influences the spatial resolution:

- p_T of charged particle
- Polar angle of particle
- Negative/positive charged
- **Gas component & working point**

Spatial resolution in rφ direction



By optimizing the gas component and working point, a good performance of µRWELL under magnetic field can be obtained.

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Summary

1. Large area μRWELL is an alternative detector choice in CEPC.
2. We proposed a full-simulation method of fast grounding, contributing to the μRWELL detector design, parameter optimization, and performance expectations.
3. Suppressing the grounded point contact resistance is very important for the large area μRWELL manufacturing process.
4. By Geant4 & Garfield++ simulation, the optimal gas component and working point of μRWELL under magnetic field can be obtained. (i.e. Ar:CO_2=85:15, E_{drift} = 500 V/cm for 1 T)

THANKS FOR YOUR ATTENTION