Development of the μRWELL detector for large area application

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- **Novel solutions to large area μRWELL**
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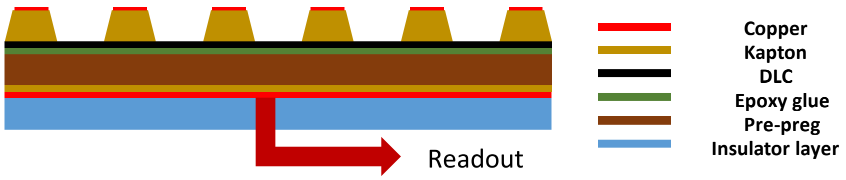
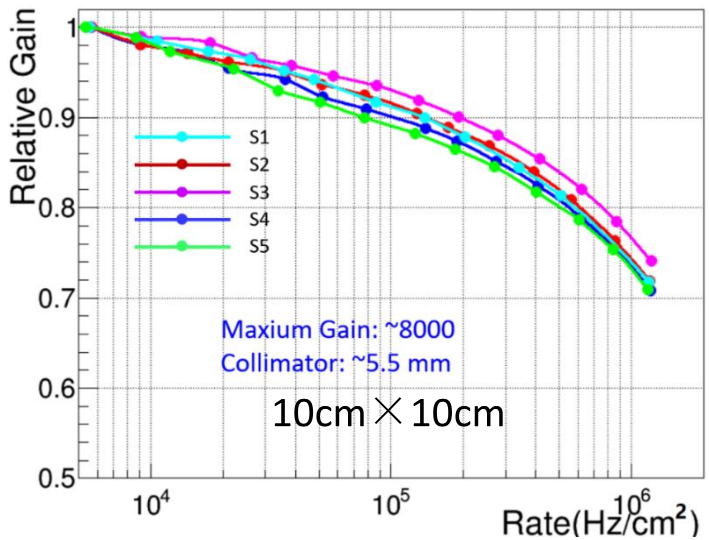
μRWELL detector

μRWELL: A Novel MPGD with resistive electrode and a single stage of well-type gas amplification.
Architecture: Compact, No gluing, No stretching, Easy handling.



μRWELL PCB



Rate capability of μRWELL

DLC resistive electrode:

1. A drop of the amplifying voltage on the DLC resistive layer caused by radiation, reducing the capability to stand high particle fluxes.
2. Higher the radiation rate, larger current drawn through the resistive layer, larger the voltage and gain drop.

For larger area detector, the gain drop caused by the radiation is more seriously.

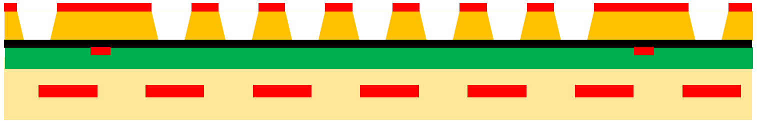
Large area and high-rate: key performance to the application

The fast-grounding technique is presented to solve the problem of gain drop in μRWELL with large area.

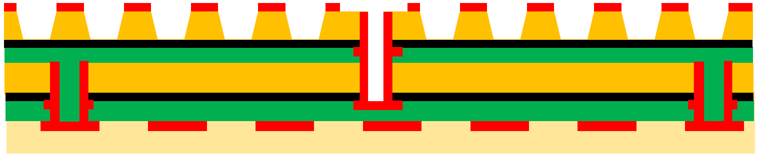
Fast-grounding μRWELL (SG2++ & SBU)

1. SG2++ type (Cu grid): The copper clad on the DLC is etched to conductive grounding lines by photo-lithography.

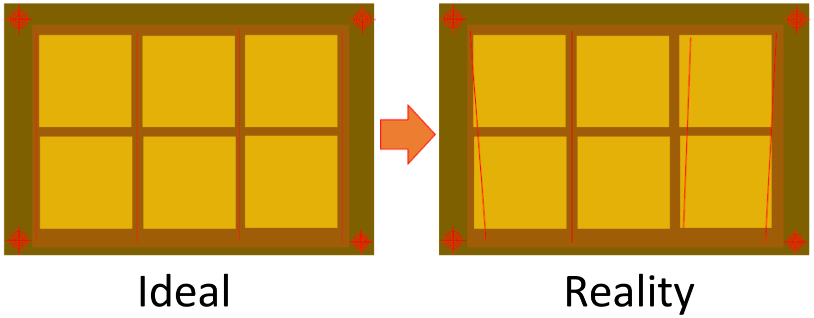
2. SBU type (Sequential Build Up): Current evacuation achieved by two stacked DLC layers.
Matrix of conductive vias manufactured with SBU technology are used to connect DLC layer to grounding.



SG2++ type



SBU type



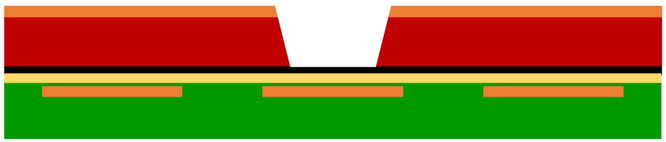
Problems to large area:

- For SG2++, after gluing the APICAL substrate onto the readout PCB, it is impossible to see the fast grounding lines, so it is impossible to align the mask for APICAL etching.
- For SBU, still have same alignment problems when making the conductive vias.

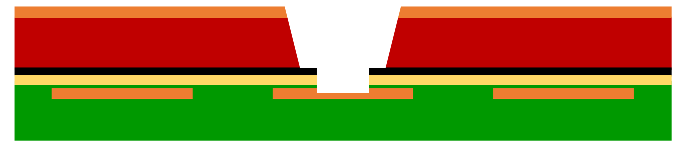
- Motivation
- **Novel solutions to large area μRWELL**
- Characterization of the detectors with X-rays
- Summary

Novel idea to large area

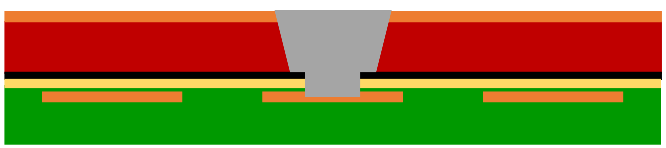
PEDF: Patterning , Etching , Drilling & Filling



Step1: Copper & APICAL etching, to make a big hole, with DLC on bottom.



Step2: Drill a small hole, the copper of the readout pad expose to air.



Step3: Use silver glue to connect the DLC to readout pad.

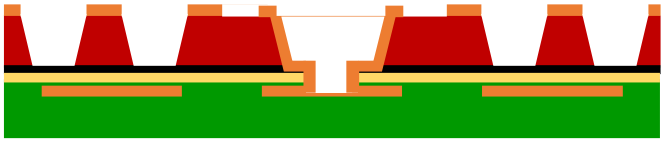
Step4: Make μRWELL structure and remove the copper around silver glue.

Advantages:

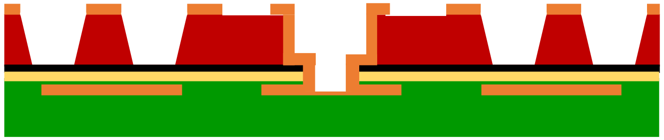
1. **No alignment problems even goes to large area;**
2. **No copper-coated DLC needed, better resistivity control;**
3. **Larger contact area between DLC and silver glue, improving the connection.**

PEDP,DEF,DEP μRWELL

Different options of large area μRWELL close to PEDF from Rui.



PEDP: Patterning , Etching , Drilling & Plating



DEP: Drilling , Etching & Plating

DEF: Drilling , Etching & Filling

Four different types (PEDF , DEF , PDEF , DEP) of μRWELL PCB with sensitive area of 5cm × 5cm have been produced at CERN and transferred to USTC .

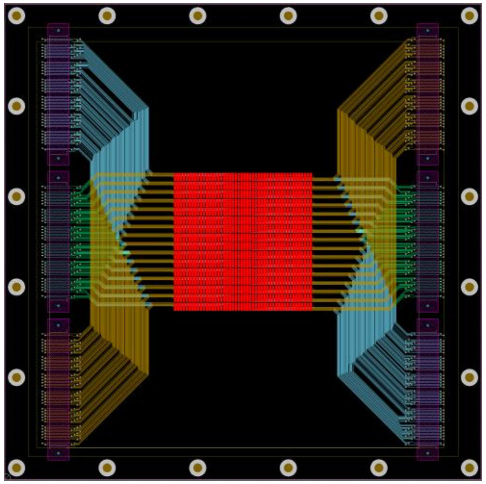
Thanks to Rui De Oliveira and CERN PCB workshop for supplying the technique support on μRWELL PCB.

µRWELL prototypes

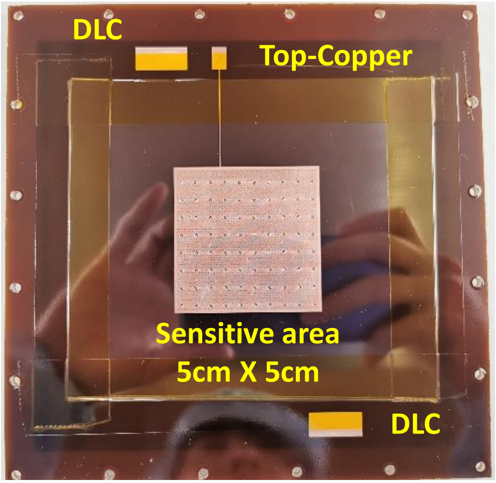
- Small-pad readout applied to the µRWELL prototypes.
- The parameters of readout pads almost same as small-pad readout MM.

Pad parameters
Size: 0.85mm @X & 2.85mm @Y
Pitch: 1mm @X @ 3mm @Y
Channel: 48(X) by 16(Y) = 768

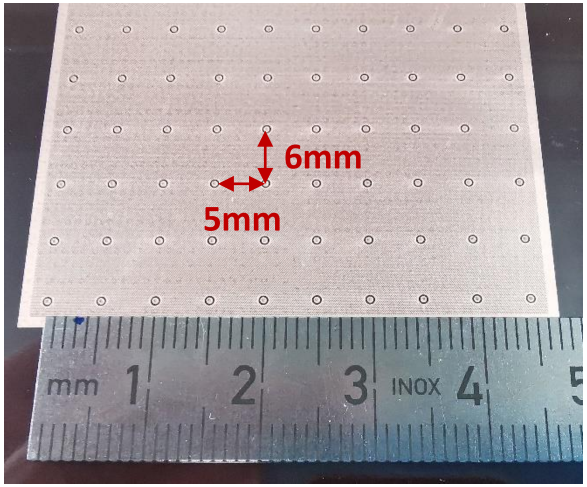
C. Di Donato., et al. Small-pads resistive Micromegas prototype. NIM A. Volume 958, 2020.



Small-pad readout



µRWELL PCB



Fast-grounding holes

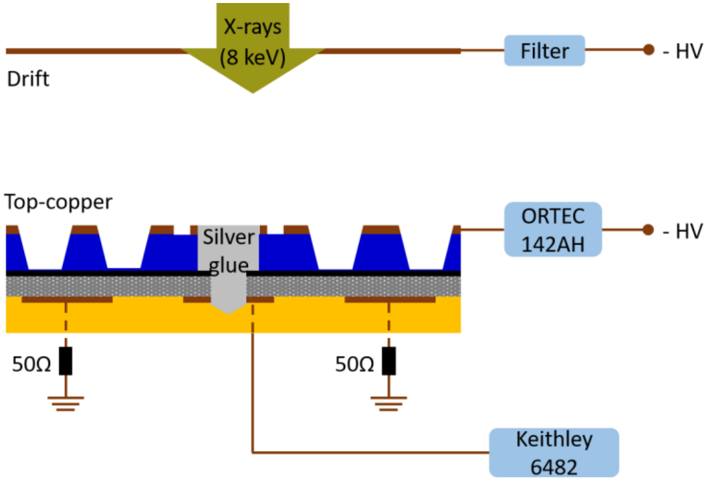
Fast-grounding hole: 1mm diameter, total 80 holes with a geometry acceptance of 97.5 %.

- These µRWELL PCBs (PEDF,PEDP,DEF,DEP) are assembled to µRWELL prototypes.
- The performance of these detectors are tested with X-rays.

- Motivation
- Novel solutions to high rate µRWELL
- **Characterization of the detectors with X-rays**
- Summary

Test setup

Work gas: Ar/iC_4H_{10} = 95/5
Hirose adapter: 128 readout pad → 1 channel → grounded by 50Ω terminator or Keithley 6482 Picoammeter.



DLC resistive electrode: grounded via a 50 Ω terminator or 6482 Picoammeter.

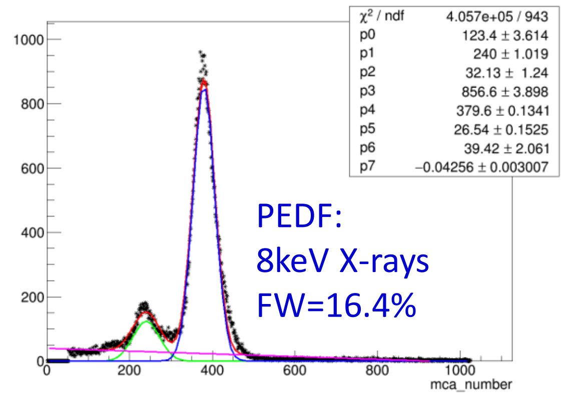
Induced signal: picked up from the top-copper or readout-pad.

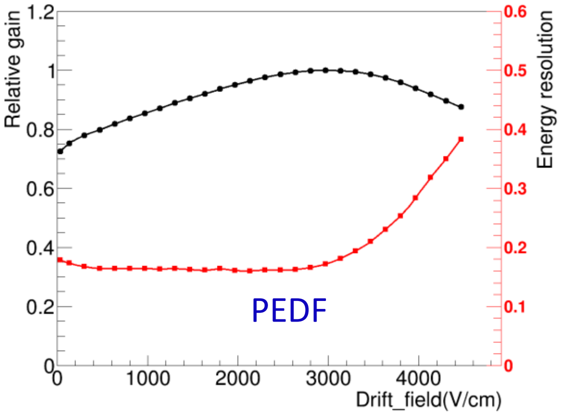
Current signal: picked up from readout-pad monitored by Keithley 6482.

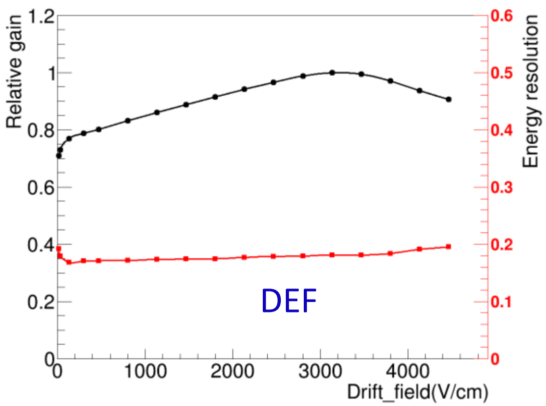
Gain vs drift field

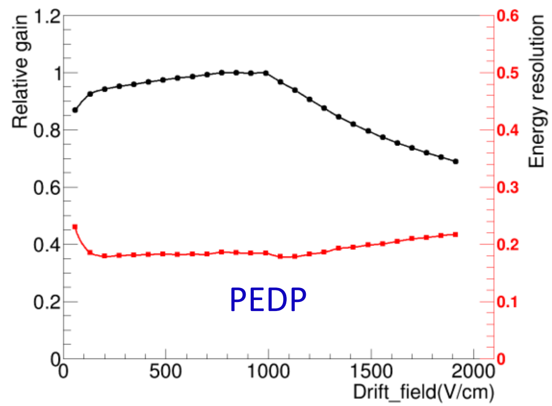
Normalized gain, fixed the avalanche electric field.

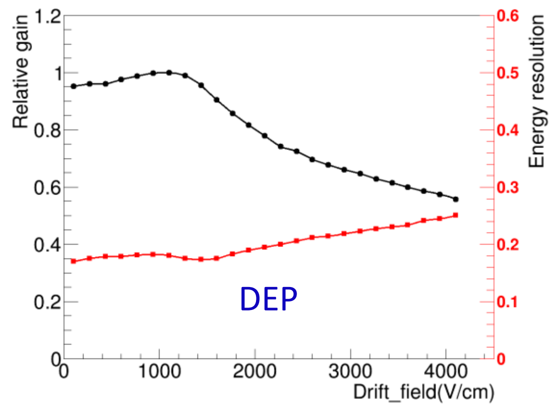
- PEDF&DEF: Maximum gain (~ 3kV/cm).
- PEDP&DEP: Maximum gain (~ 1kV/cm).











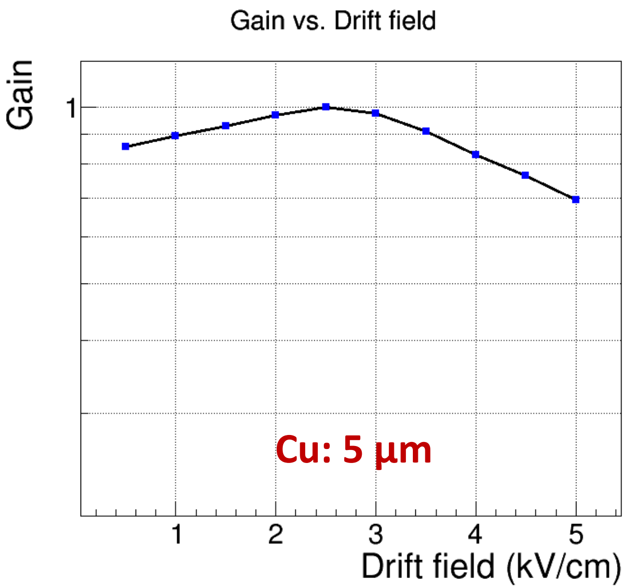
- The thickness of copper cladded on the APICAL is **5 μm** (PEDF&DEF).
- The plating process make the thickness of copper up to **15 μm** (PEDP&DEP). This is the reason to the different behavior between PEDF and PEDP.

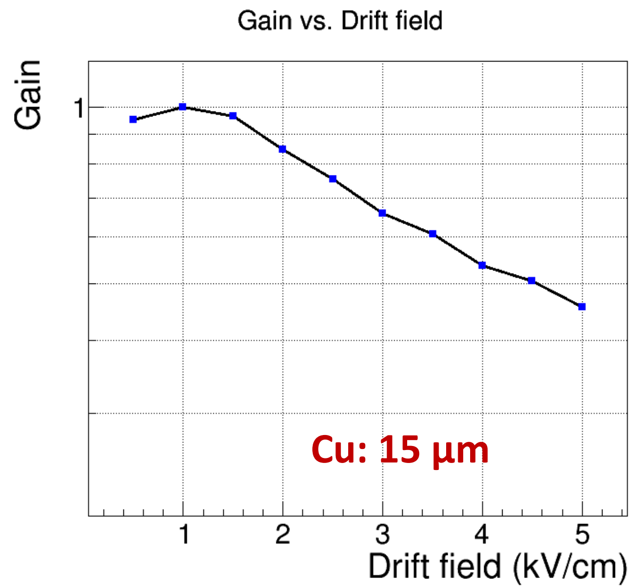
Simulation of the gain vs. drift field

A simulation was carried out to understand the influence on the gain caused by the thickness of copper electrode.

Detector geometry: ANSYS

Electron avalanche and the efficient gain: Garfield++





The simulation result is qualitative consistent with the test result.

The work gas set to Ar/CO_2 (70/30) in this simulation, the Ar/iC_4H_{10} (95/5) gas mixture will be simulated in the next step.

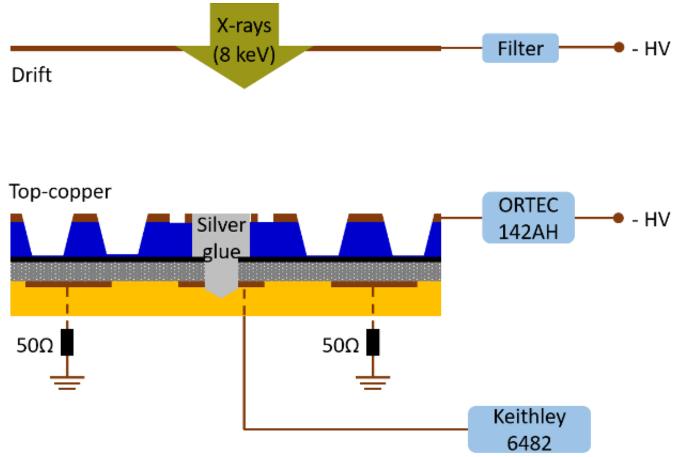
Definition of gas gain

Two different definition of gas gain presented: **Current gain** and **Induced signal gain**

1. Current gain: absolute gain, current signal exported from readout pad and recorded by Keithley 6482 Picoammeter.

$$G = \frac{I}{R \bullet \frac{8keV}{E} \bullet q_e}$$

I: current R: rate E: average ionization energy



2. Induced signal gain: induced signal exported from readout pad or copper electrode, it was amplified by a pre-amplifier followed by a main amplifier, the signal finally recorded by MCA.

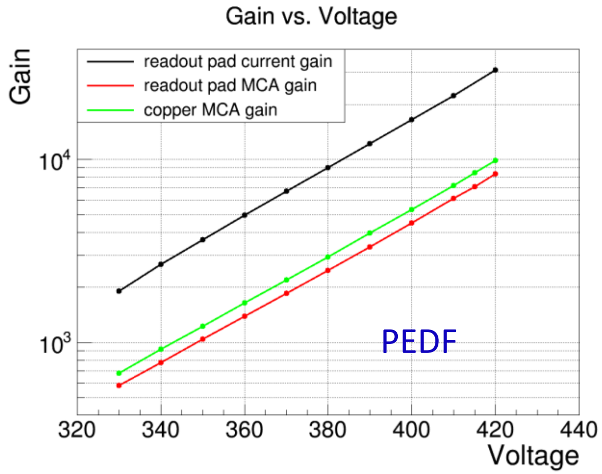
A pulse generate a signal , and it was input to the test port of Pre-Amp to calibrate the test system (pre-amplifier, main amplifier, MCA).

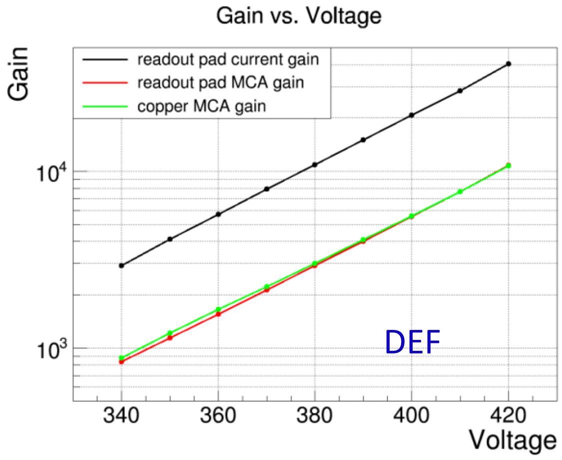
$$G = \frac{C \bullet U}{\frac{8keV}{E} \bullet q_e}$$

C: capacitance of pre-AMP U: effective voltage

The induced signal gain is the effective gain, it is influenced by the weighting field.
For DAQ system, it always receive induced signal, the induced signal gain is more accurate than current gain.

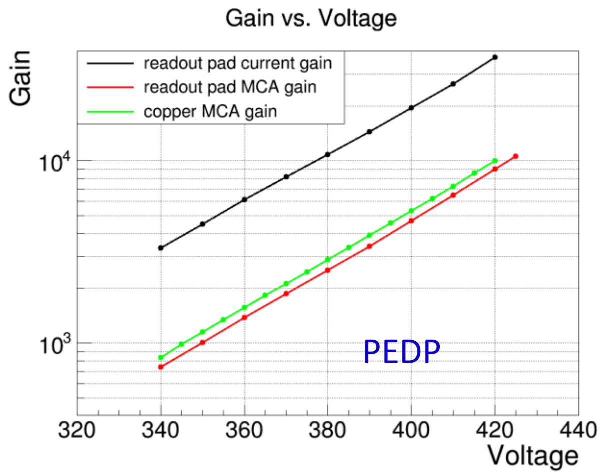
Gain vs avalanche electric field





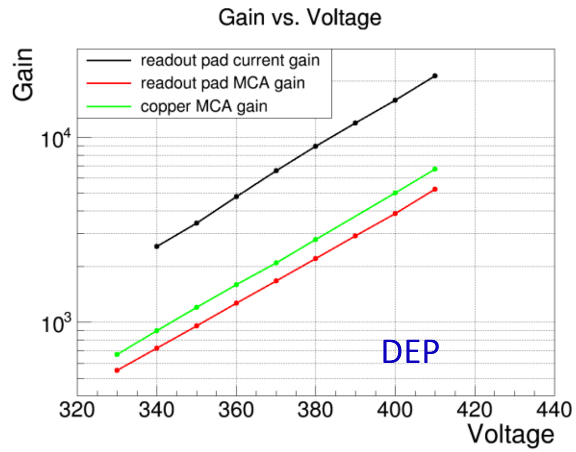
Current gain:
~30000 @420V

Induced signal gain:
~10000 @420V



The current gain is about 3 times bigger than induced signal gain.

It is due to that the effective weighting field smaller than 1.



Weighting field in μRWELL

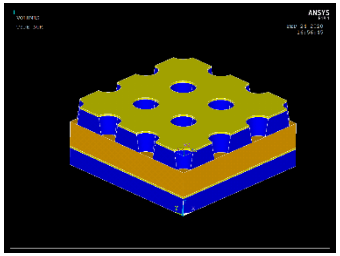
1. Ramo Theorem: induced signal :

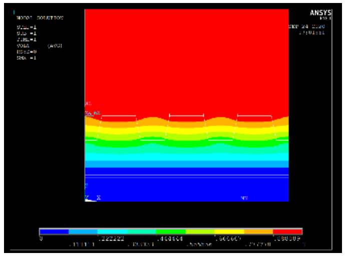
$$I_n^{ind}(t) = -\frac{Q_n^{ind}(\mathbf{x}(t))}{dt} = \frac{q}{V_w}\nabla\psi_n(\mathbf{x}(t))\dot{\mathbf{x}}(t) = -\frac{q}{V_w}\mathbf{E}_n(\mathbf{x}(t))\dot{\mathbf{x}}(t)$$

Induced charge: proportional to weighting potential.

2. Weighting field $\mathbf{E}_n(\mathbf{x})$: setting the voltage of interested electrode to 1, and other electrode to 0.

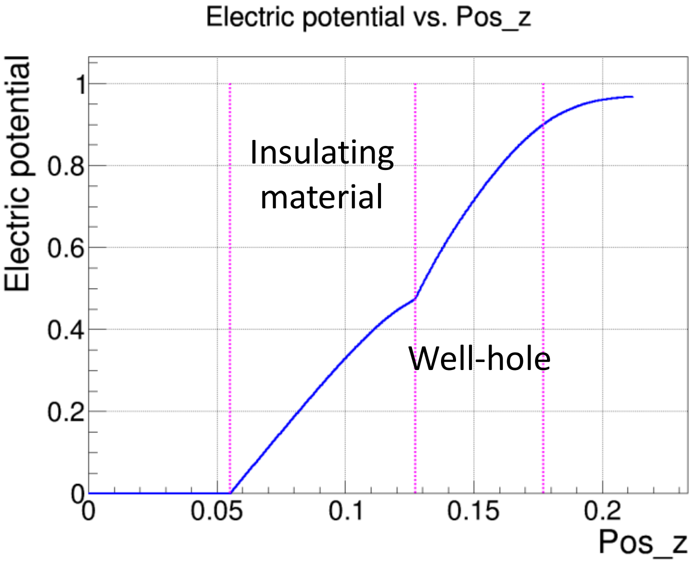
$$\mathbf{E}_n(\mathbf{x}) = -\nabla\psi_n(\mathbf{x})$$





μRWELL detector:

1. The second electron only drift in the well-hole.
2. 70 μm insulating material (50um Prepreg+12um Kapton+10um epoxy glue) between readout pad and DLC electrode, reduce the effective weighting field in well-hole.
3. Weighting potential: about 0.42 (0.48 to 0.9) in the well-hole.
4. Induced signal gain is smaller than current gain.



Rate capability (PEDP)

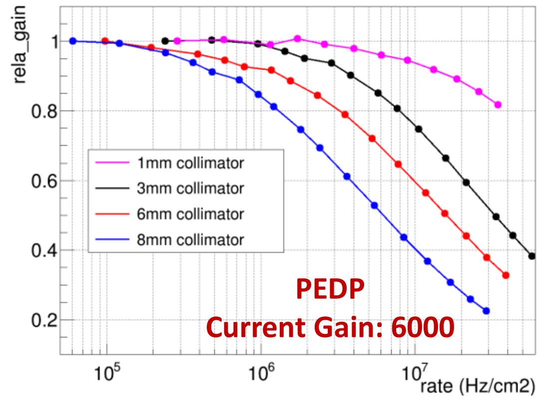
Rate capability: assessed by detector gain as a function of counting rate per unit area.

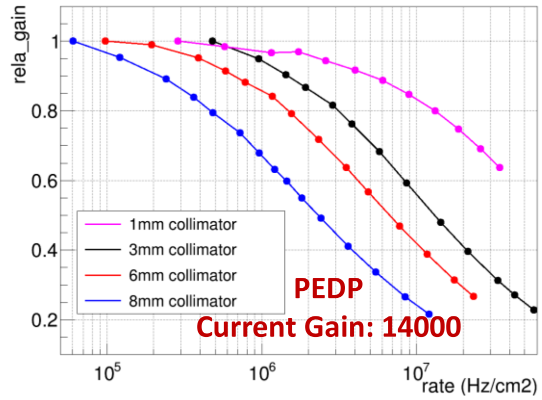
Different collimator diameters: 8 mm, 6 mm, 3 mm, 1 mm are used.

Rate: (1MHz/cm^2),

Gain (6000): 1 @1mm, 1 @ 3mm, 0.9 @6mm, 0.85 @ 8mm.

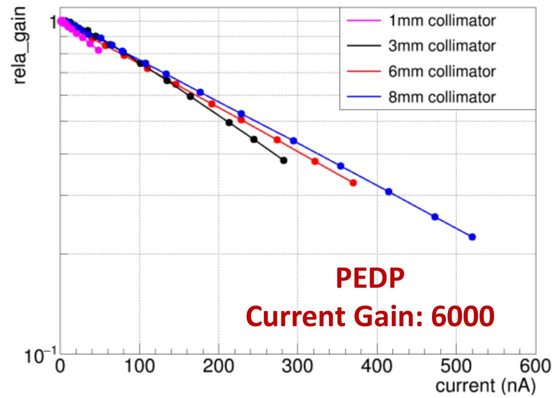
Gain (14000): 0.97 @1mm, 0.95 @ 3mm, 0.85 @6mm, 0.68 @8mm.

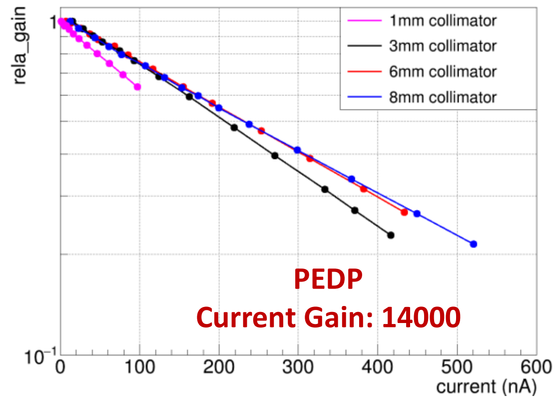




For a m.i.p. the primary ionization is 10 times smaller than 8 keV X-rays with a drift gas gap of 3mm.

Gain vs. current: Study the ohm effect of DLC resistive electrode in μRWELL.

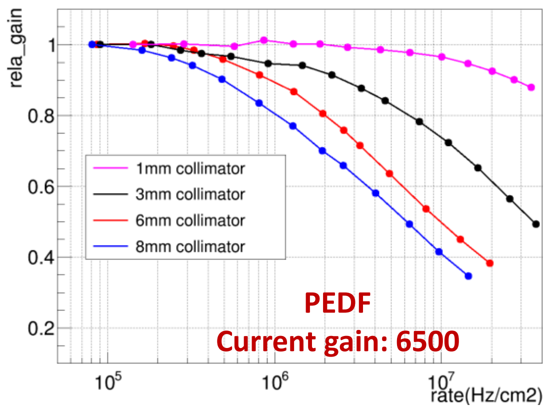


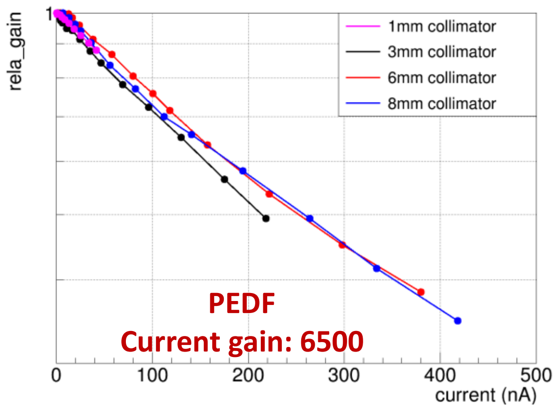


The log of the relative gain drops linearly with current

- Same current with different gain, same gain drop. The ohm effect result in the gain drop.
- Same current with different collimator diameters, different gain drop. The radiation area changes, the effective resistivity changes, the gain drop changes.

Rate capability (PEDF & DEF)

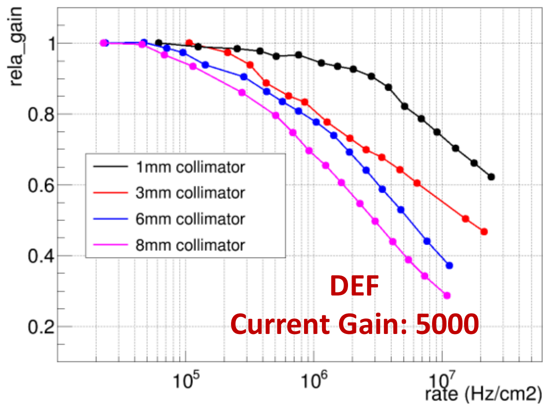


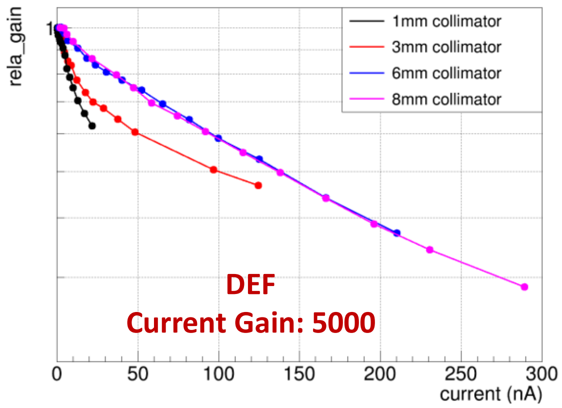


Rate: (1MHz/cm2)，

PEDF gain: 1 @1mm, 0.95 @ 3mm, 0.9 @6mm, 0.8 @ 8mm.

DEF gain: 0.95 @1mm, 0.85 @ 3mm, 0.8 @6mm, 0.7 @8mm.



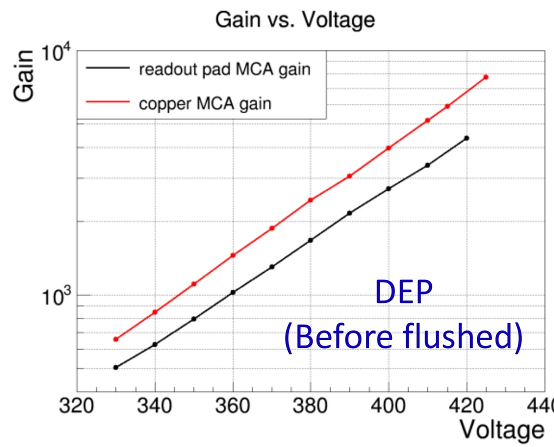


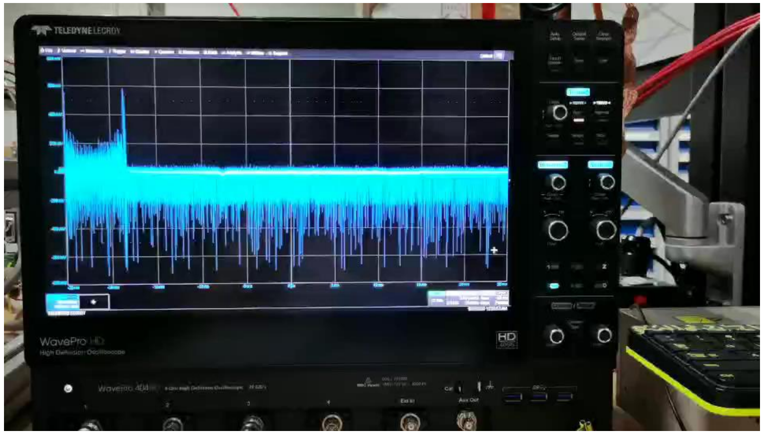
The DEF detector don't have pattering during the etching process. It may make the hole irregularly, and a poor performance.

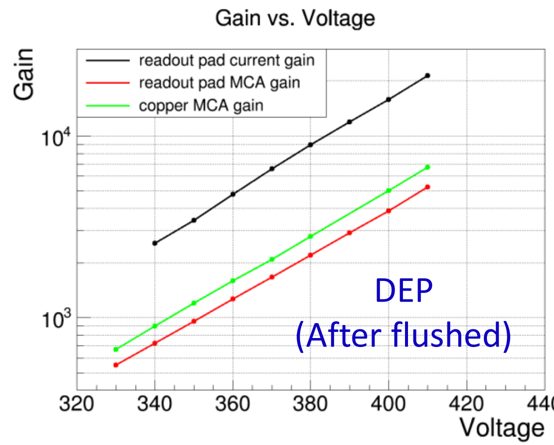
For PEDF and DEF: The filling process is not a standard process. The fast-grounding hole would be damaged when removing the excess silver glue.
The rate capability of PEDP is better than PEDF.

Problems of DEP μRWELL

1. When voltage applied to 425V, discharge occurs (~ 1 μA), then short circuit happened between the DLC and copper.
2. The PCB was flushed by high pressure water gun, then baked in oven with 70 degree.
3. The DEP detector work well in low rate.
4. A ripple signal occurs in high rate. The current exported from readout-pad shows larger fluctuation that make it impossible to have a rate capability result.



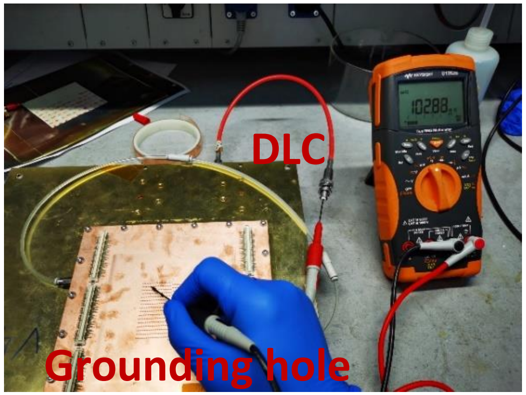




When test the highest gain, the PEDF and PEDP also occurs discharge (~ 1μA), but PEDF and PEDP can back to the good work condition.

Resistivity measurement

Measuring the resistivity between DLC and fast-grounding holes.



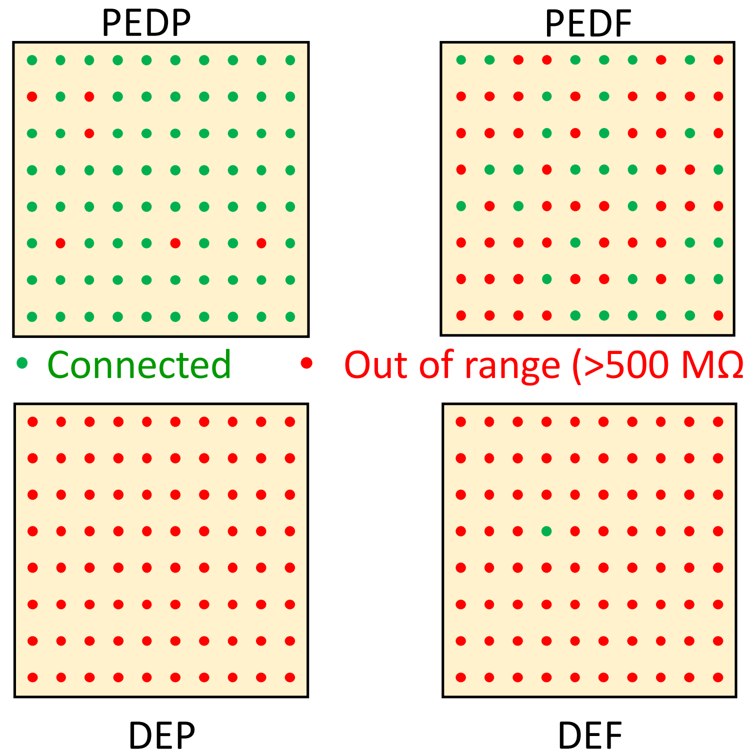
Measurement

PEDP: 6 holes out of range.
Resistivity: 90 to 110 MΩ

PEDF: 32 holes connected.
Resistivity: 350 to 450 MΩ

DEP: All holes disconnected.

DEF: 1 holes connected.
Resistivity: 380 MΩ

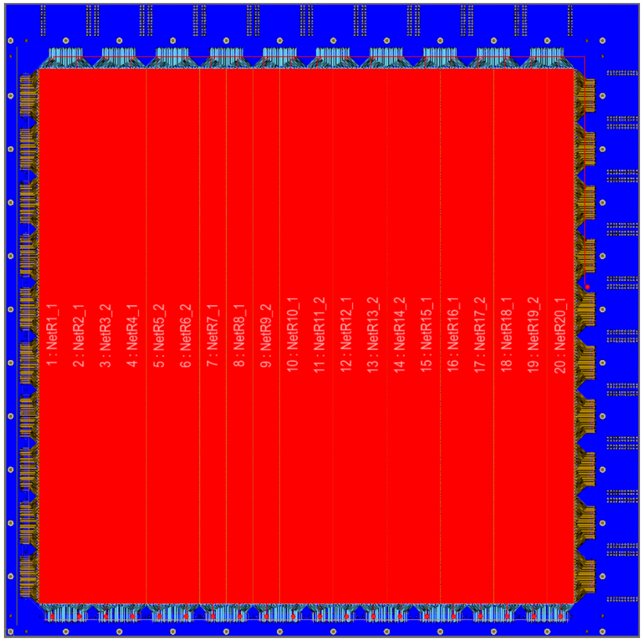


For DEP and DEF, it is uncontrollable when etching the grounding holes due to that no pattering during etching process. Bad connection between DLC and grounding holes.

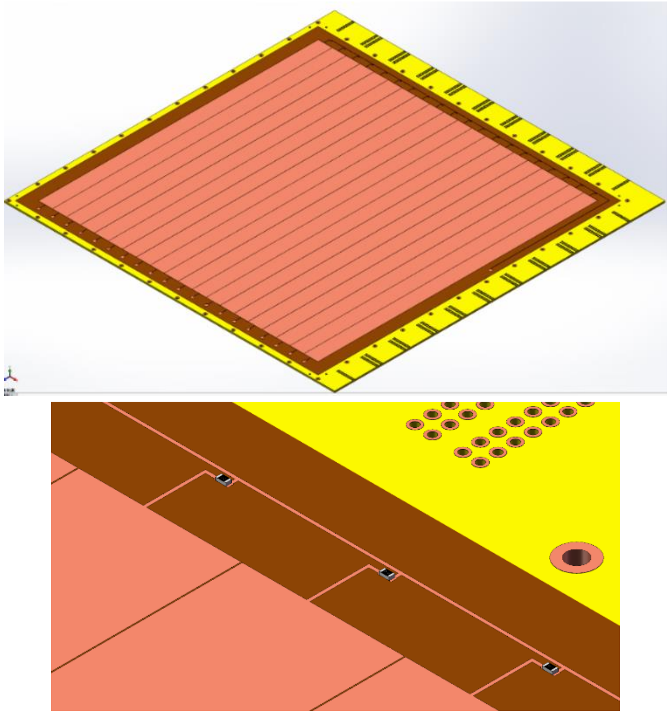
For PEDF, some of the grounding holes would be damaged when removing the excess silver glue.
The PEDP shows the best connection between DLC and grounding holes.

Large area high-rate μRWELL detector

A 50cmX50cm μRWELL have been designed, the PEDP technique will be used for the large area high-rate μRWELL.



The layout of the μRWELL-NT-50cmX50cm



The active area is divided into 20 sectors

Summary

1. Four different technique of high-rate μRWELL was presented. The current gain can be larger than 30000, with a induced signal gain larger than 10000. The rate capability of these detectors was tested, and the best performance is achieved with PEDP technique.

2. The performance (rate capability with larger irradiation area, efficiency, position resolution, dead area) will be tested in next step. A larger area μRWELL with PEDP technique have been designed.

- Thank Lanzhou Institute of Chemical Physics for support on DLC coating.
- Thank Rui De Oliveira and CERN PCB workshop for supplying the technique support on μRWELL PCB.
- Thanks to Giovanni Bencivenni, Eraldo Oliveri and CERN GDD for helpful suggestions and discussions.

Thank You

BACKUP

ATLAS geometry

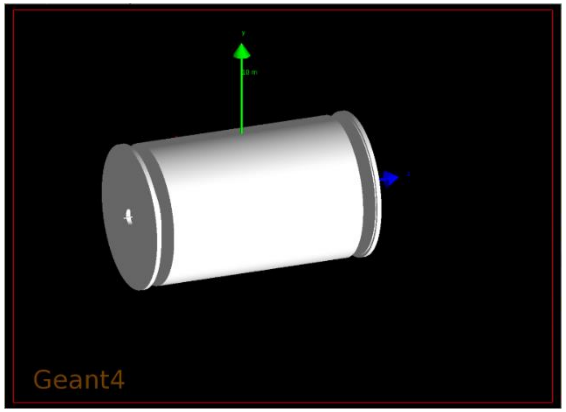
1. ATLAS geometry

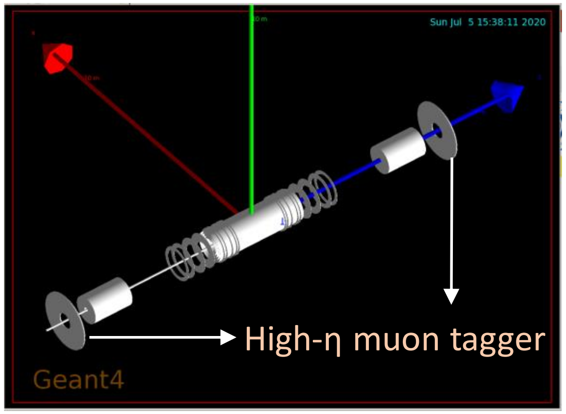
Beam-pipe: 4mm AEROGEL + 1mm BERYLLIUM

Inner detector
- Pixel detector: (10% Si+90% Cu)
- SCT detector (silicon-microstrip): (10% Si+20% Cu+60%C)
- TRT detector (transition radiation tracker): (70% Xe,+27% CO2 + 3% O2)

Calorimetry
- EM calorimetry
  - Barrel 4.2mm L_Ar + 1.1mm Pb + 1mm [Cu(50) +Stainless(50)]
  - Endcap 6mm L_Ar + 2mm Pb + 1mm [Cu(50) +Stainless(50)]
- Hadronic calometry
  - Tile 370mm Scti +1600mm Fe
  - Hadronic end-cap Cu + L_Ar
  - Forward Type1: Cu + L_Ar
Type2: W+L_Ar + Cu

JD shielding disk: Iron





2. High-η muon tagger

- Materials: 2mm PCB + 3mm gas + 2mm PCB
- Total ten detectors with a distance of 10mm each.

Pythia8 generate p-p collide events.

Physical process: SoftQCD:nonDiffractive (minimum-bias component)

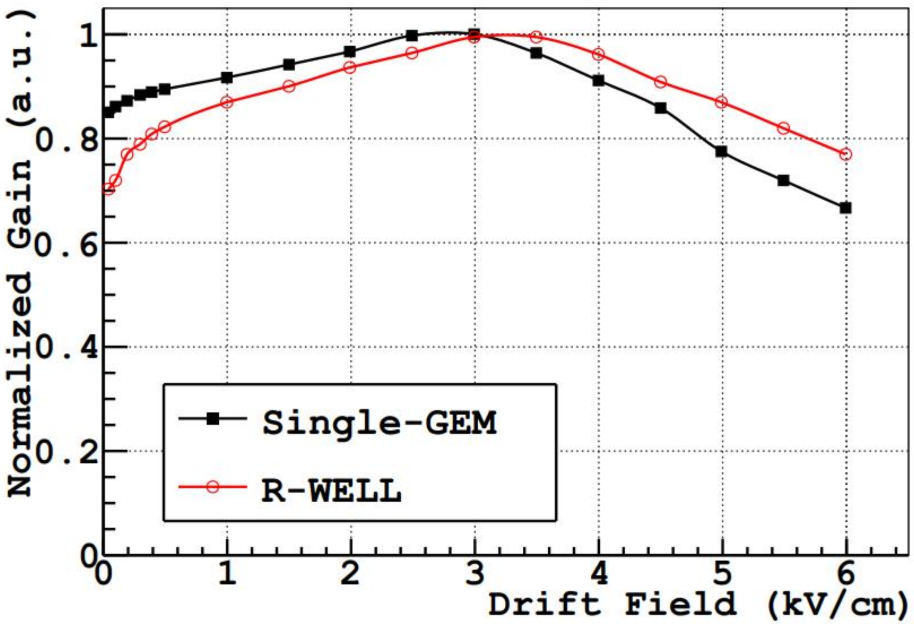


Figure 7. Relative charge collection efficiency as a function of the drift field.

ORTEC 142AH刻度

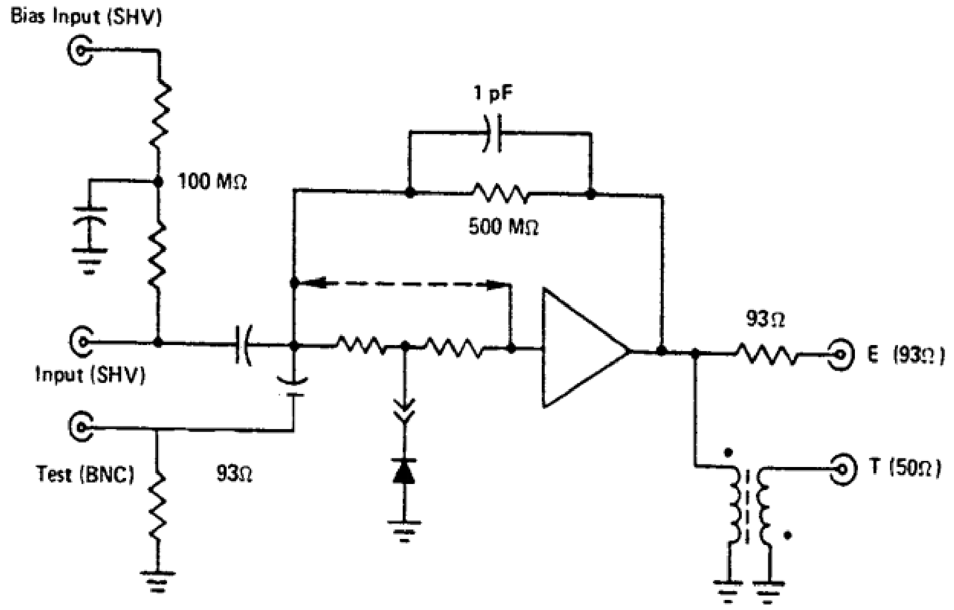
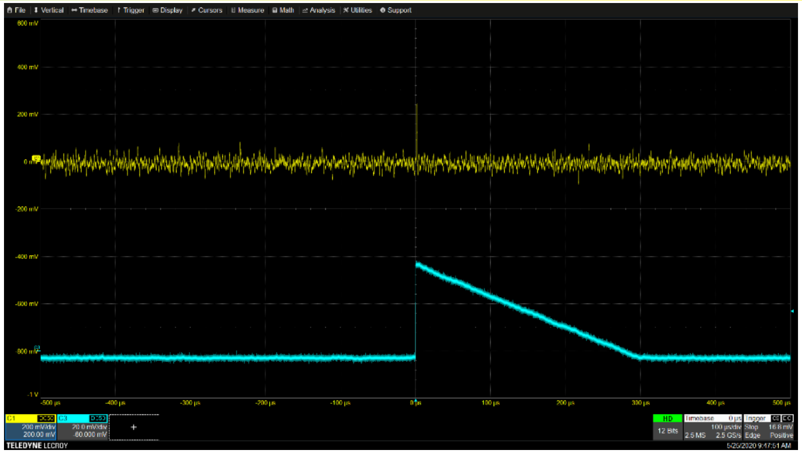


Fig. 4.1. Simplified Block Diagram of the ORTEC 142AH Preamplifier.



信号产生器的刻度信号以及响应

Leading: 10 ns　　1 KHz

Trailing: 240 µs　　Duty=15%

- Test input: A fast rise time (less than 40 ns) followed by a slow exponential decay (200 to 400 µs).
- Energy Output: The charge-sensitive loop is essentially an operational amplifier with a 1-pF capacitive feedback.
- While test pulses are being furnished to the Test input, connect either the detector (with bias applied).