Design and performance of the gaseous beam monitor for the CSR external-target experiment

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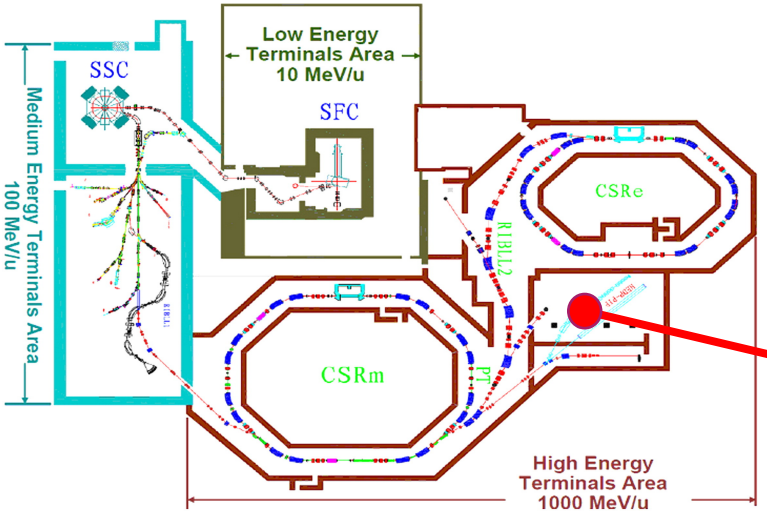
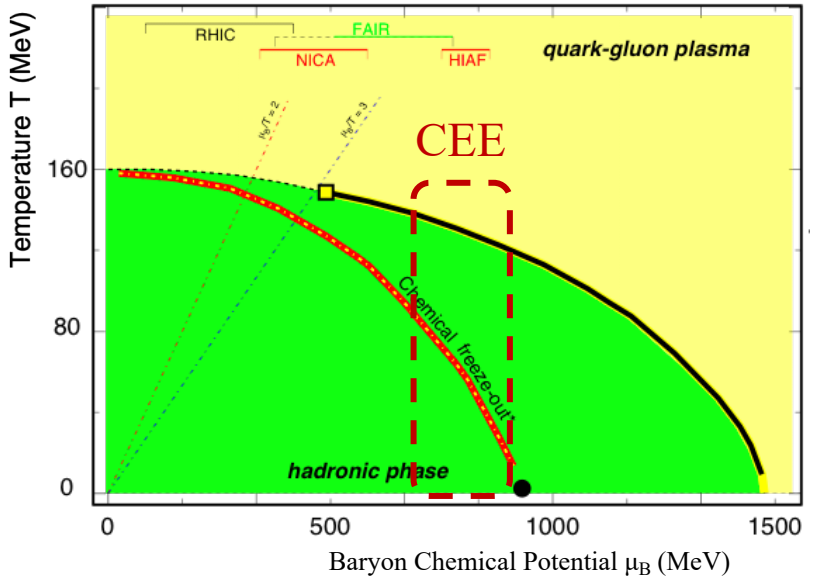
Outline

- Introduction
- Beam Monitor of CEE
- Topmetal-CEEv1/v2 chips
- Summary and Outlook

CEE at HIFRL-CSR

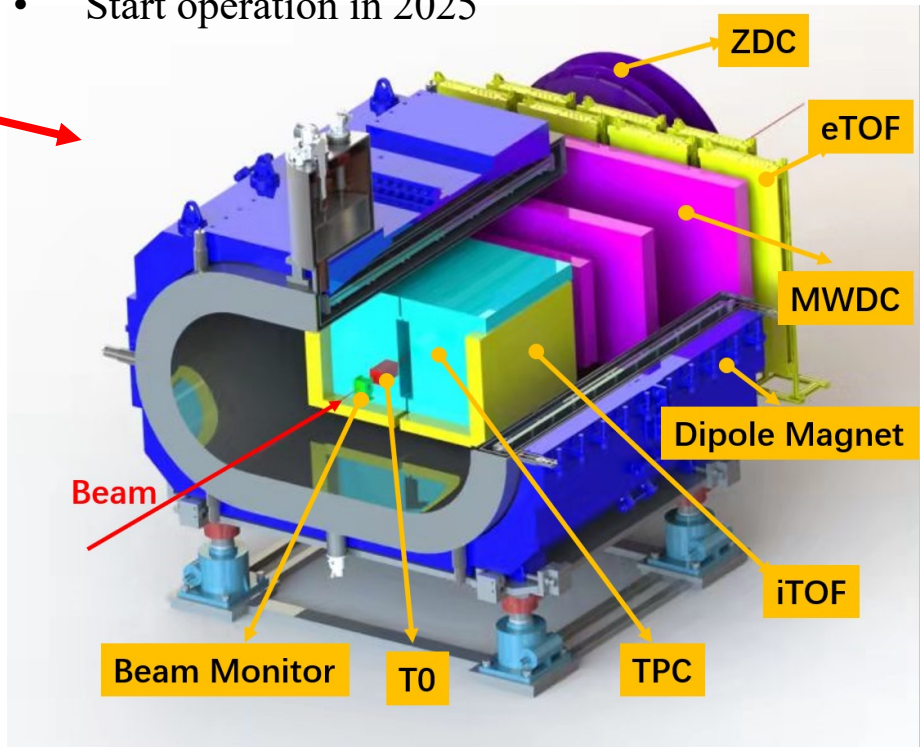
Heavy Ion Research Facility in Lanzhou
Cooling-Storage-Ring system





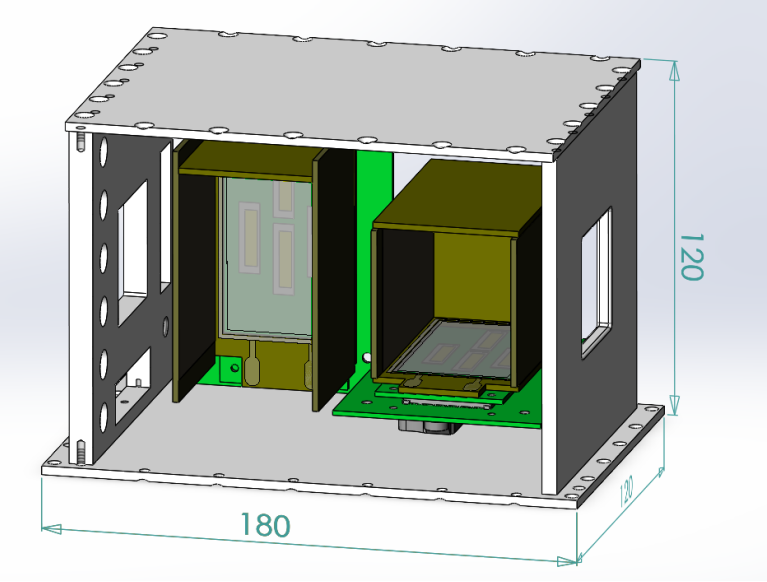
CSR External-target Experiment

- Study the properties of nuclear matter at high baryonic density
- Fixed target, with heavy-ion (up to U) beam energy: ~0.4 - 1.1 GeV/u
- Maximum event rate: 10^4 s^{-1}
- Start operation in 2025

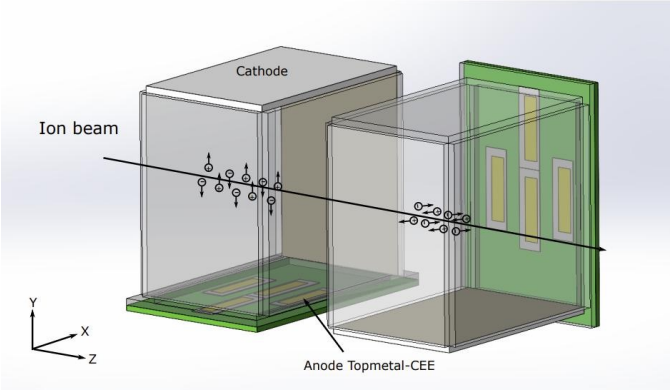


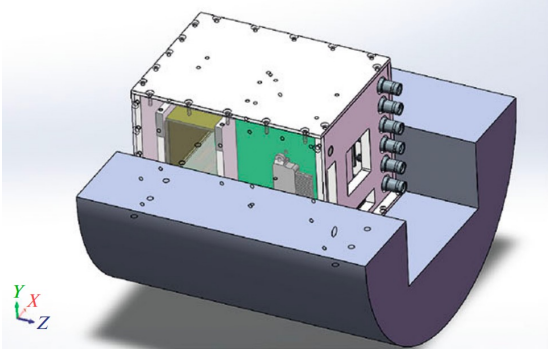
Beam Monitor of CEE

- Placed upstream of the fixed target in a magnetic shield
- Measure the position of each beam particle
- Offline: vertex reconstruction (combined with TPC and MWDC)
- Online: monitor the beam status
- Main design parameters:
  - Position resolution : 50 μm
  - Time resolution: 1 μs
  - Maximum event rate: ~1 MHz
  - Sensitive area: 30×30 mm^2

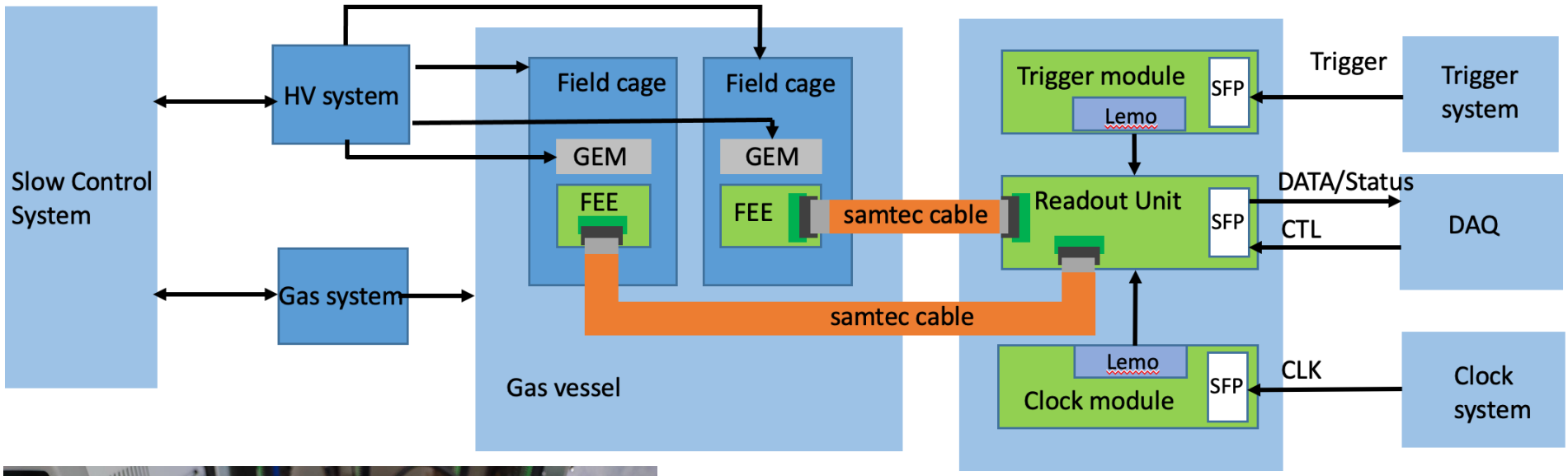


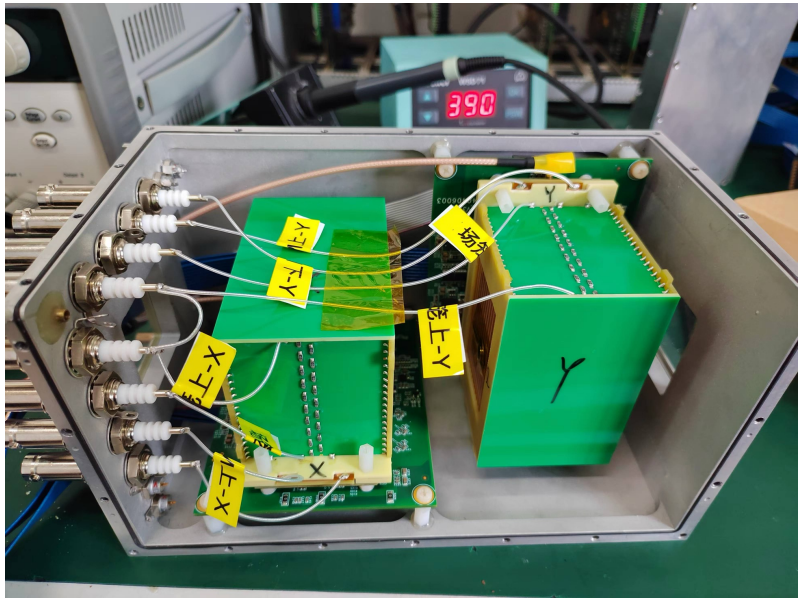
- Two micro-TPCs in a gas vessel, with electric field orthogonal to each other
- Position measured in two readout planes; arrival time used for track matching between two mico-TPCs
- Custom-designed Topmetal-CEE chip as anode for charge sensing and readout
- Amplification with GEM

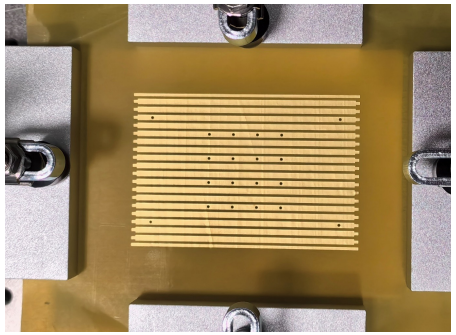




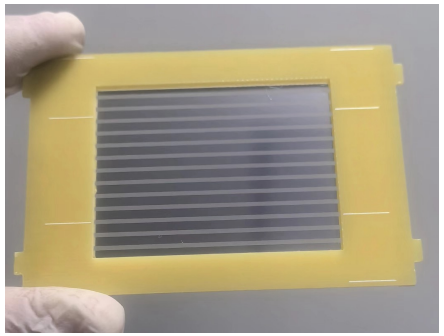
Detector system





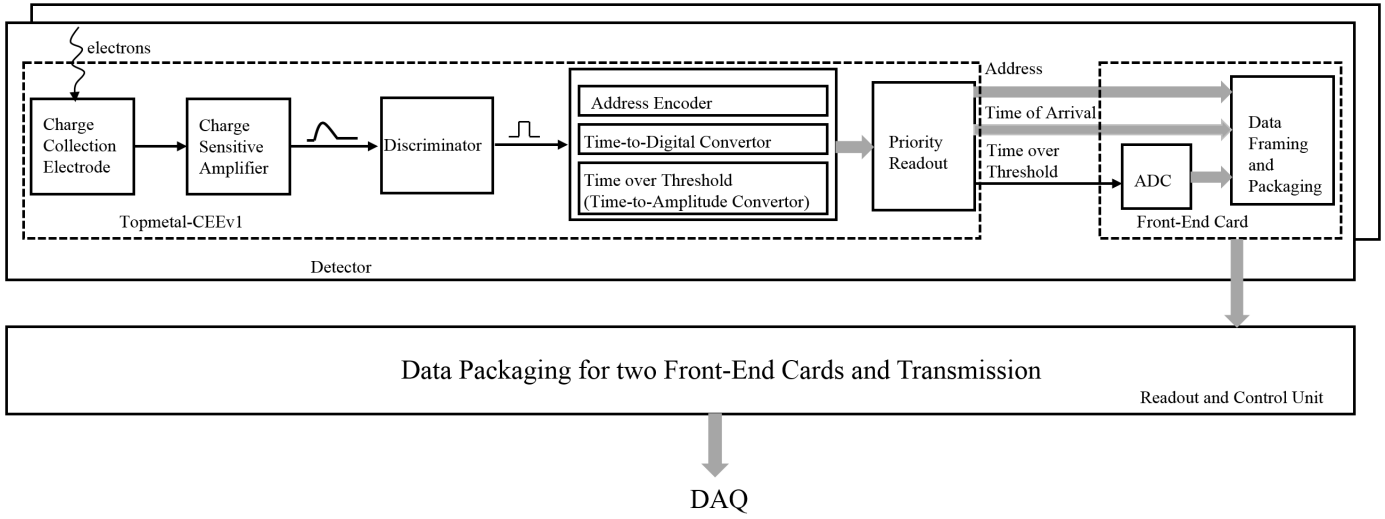


Field cage v1 :
25 μm Kapton+5 μm Au



Field cage v2 :
2 μm Mylar+100 nm Al

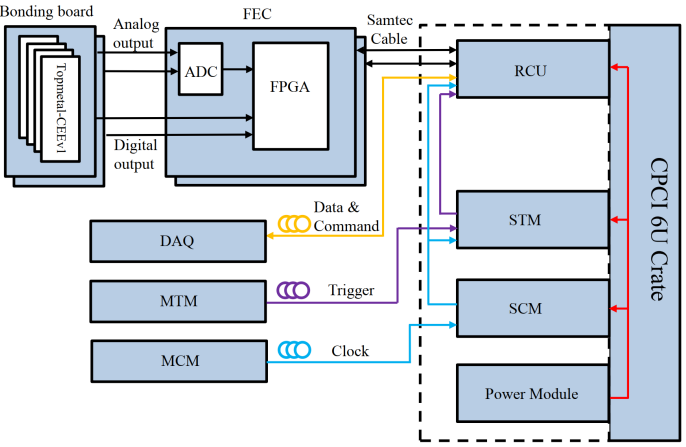
Electronics

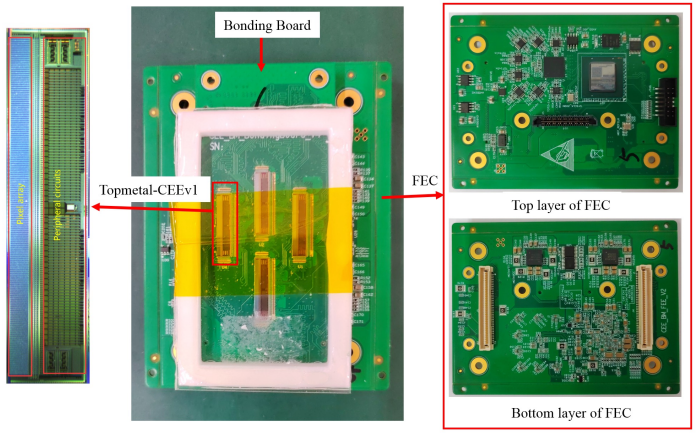


One chip: max. 40 MPixel/s
FEE (8 chips) : max. 1.92 Gbps
FEE to RCU: max. 3.2 Gbps

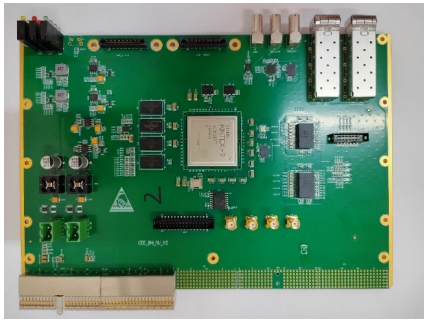
Typical data rate (10^6 pps):

- Chip: 10 MPixel/s
- FEE: 0.36 Gbps



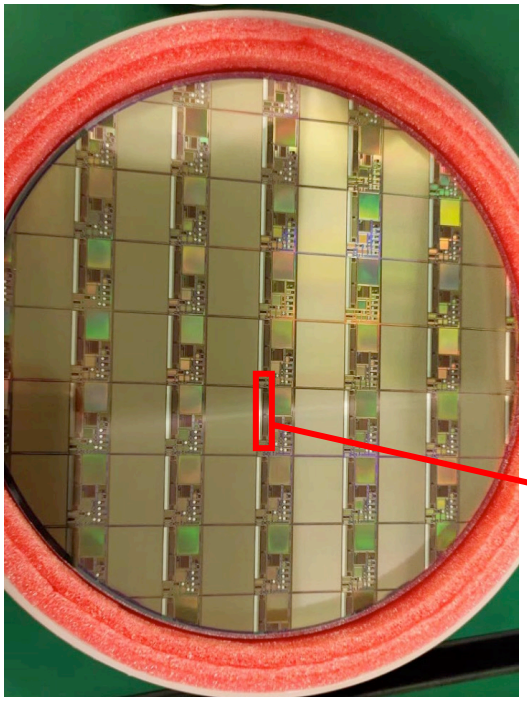


Front-end electronics



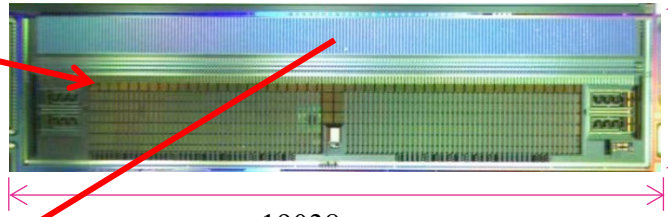
Readout and control unit

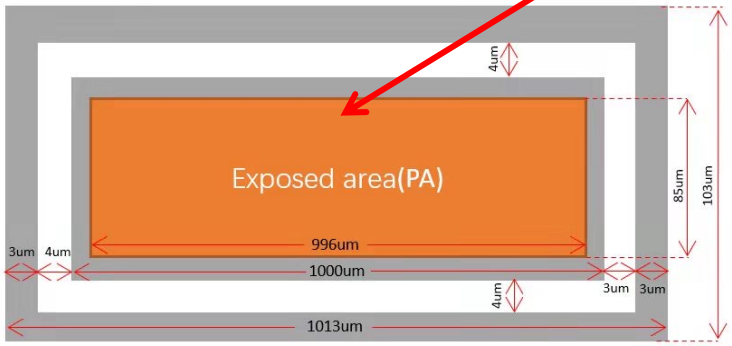
Topmetal-CEEv1 chip

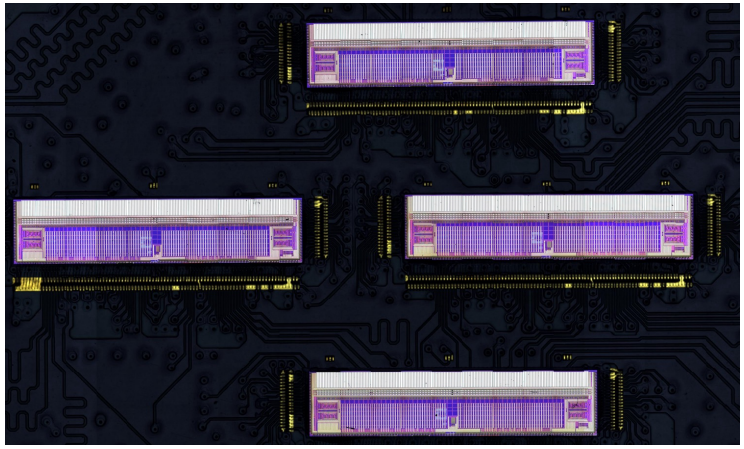


The main features of the Topmetal-CEEv1 chip.

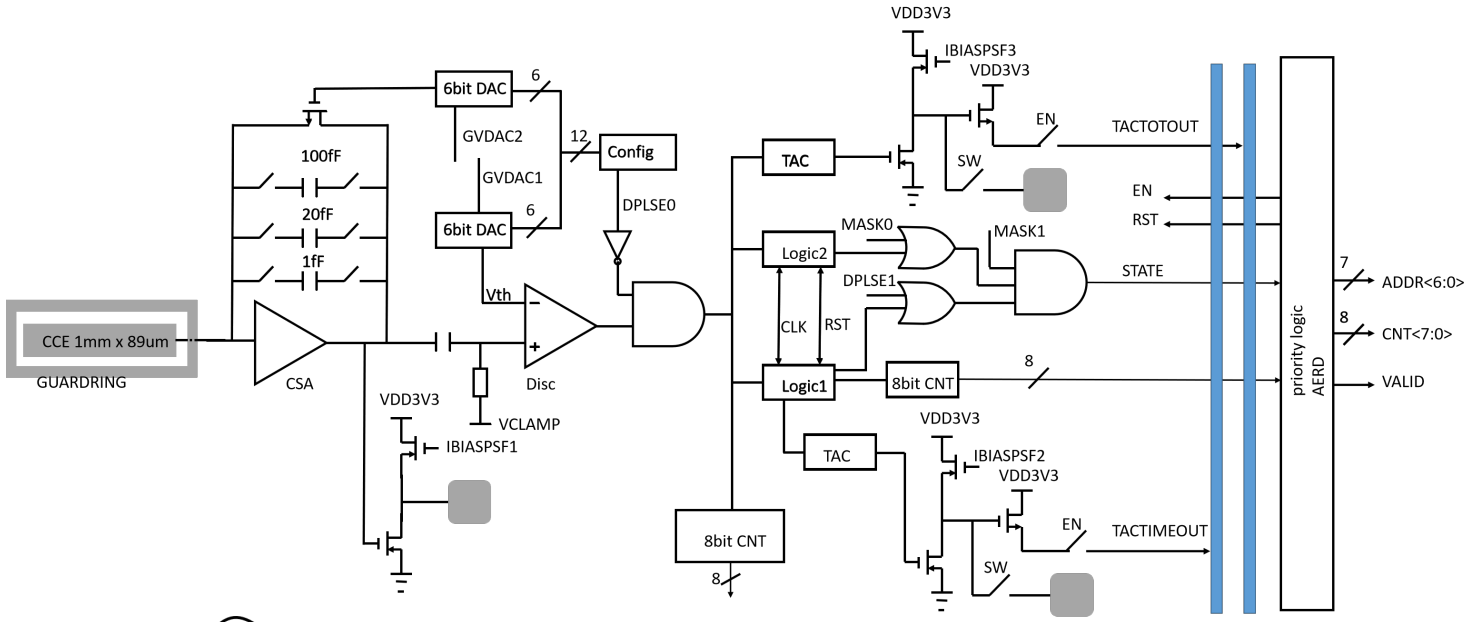
Feature size	130 nm
Chip area	4.2 mm ×19 mm
Number of pixels	1 × 180
Pixel pitch	100 μm
CCE size	1 mm ×89 μm
Shaping time (tunable)	~ 0.5 μs to 2 ms
Peaking time	~ 100 ns
Readout scheme	Data-driven readout
Readout time	25 ns/pixel
Amplitude measurement	TOT method

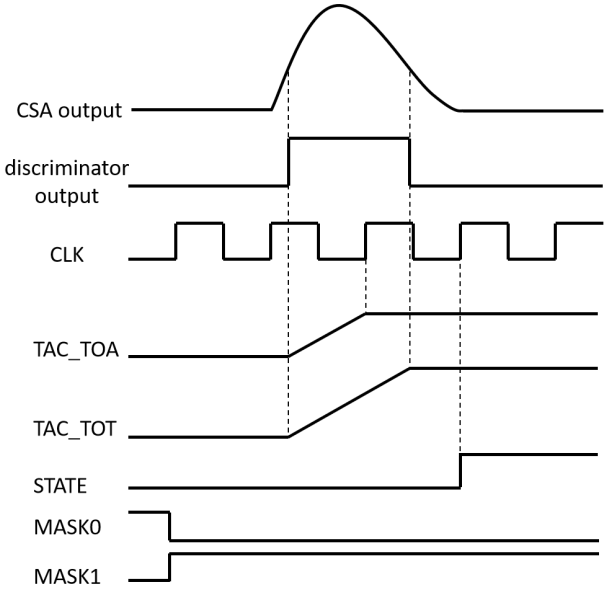






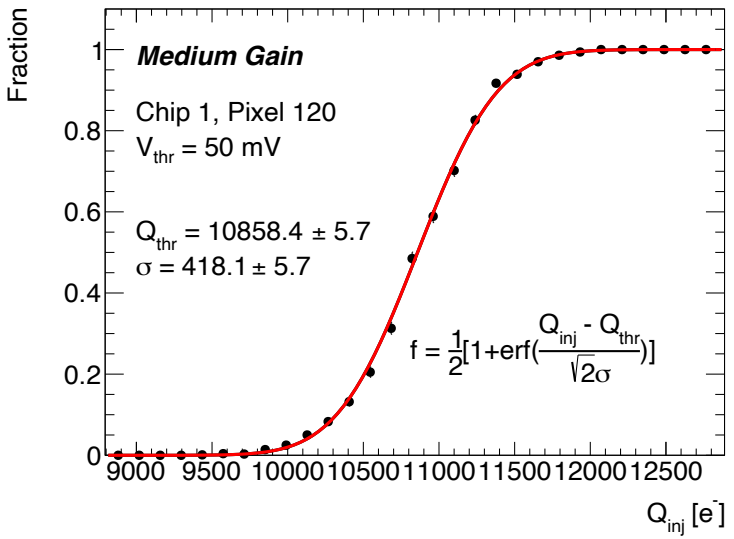
Topmetal-CEEv1 chip

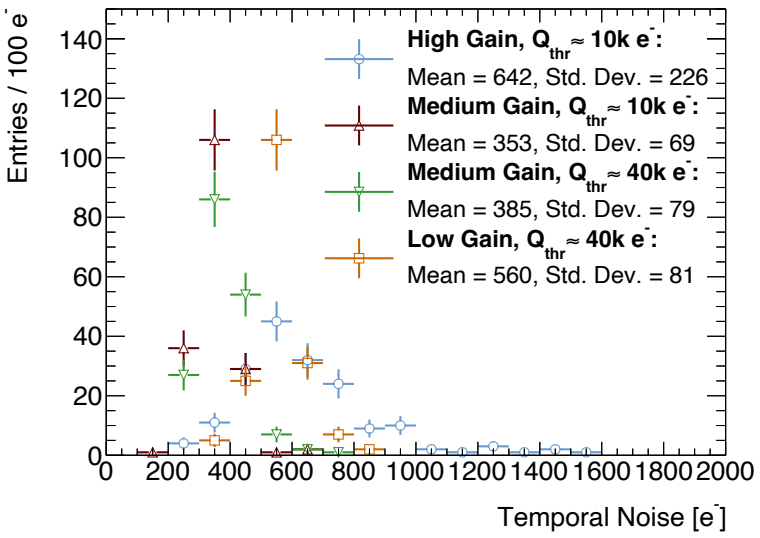


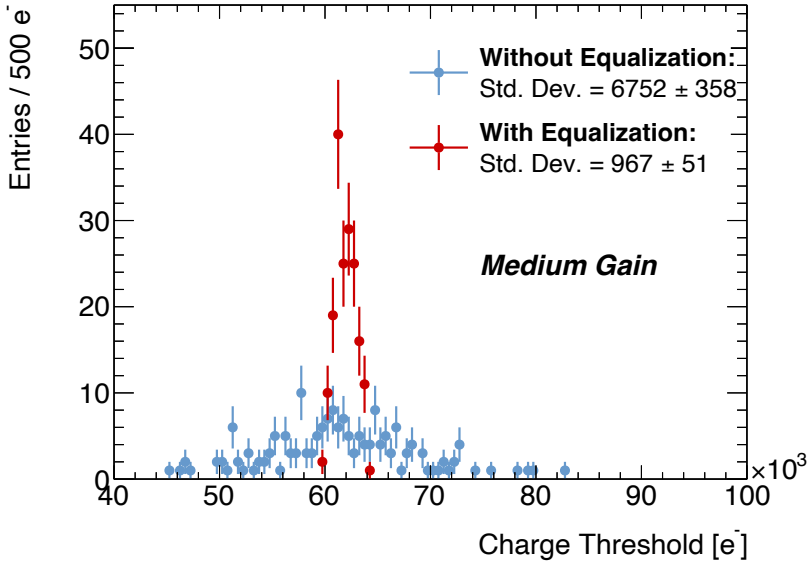


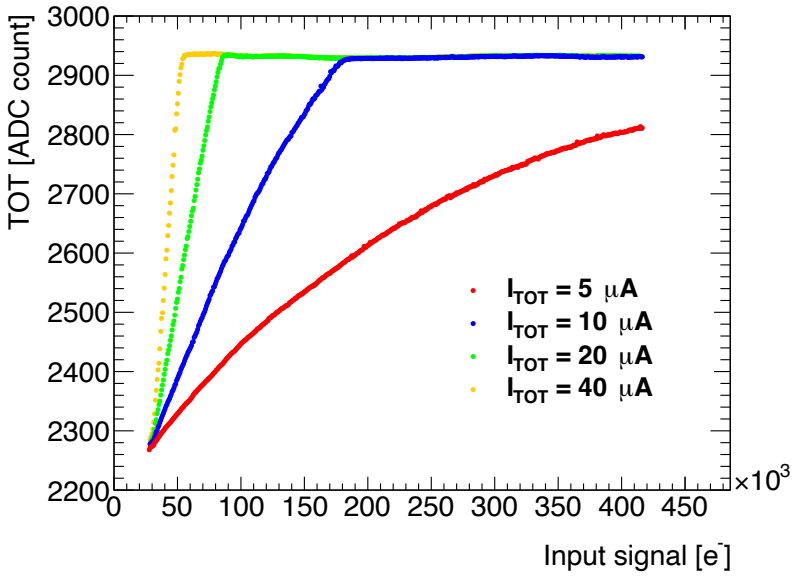
- Exposed metal (CCE): sense the drifting charge carriers in the gas
- Three feedback capacitors: low to high gains
- Time measurement:
  - Coarse: 8-bit counter with 25 ns precision
  - Fine: TAC for TOA (not used)
- Amplitude measurement: TAC for TOT
- Two on-chip ADCs for analog signals of TOA and TOT (not used)
- High speed serial readout module (not used)

Topmetal-CEEv1 chip: basic test



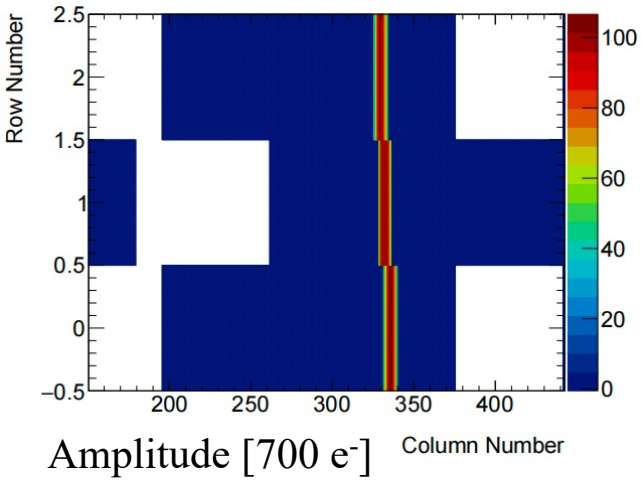


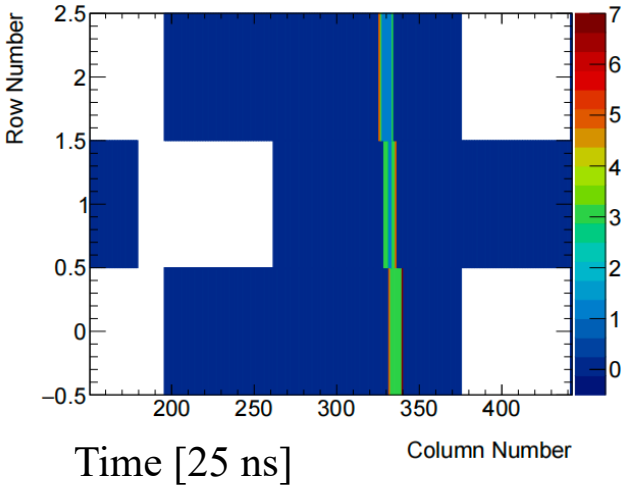


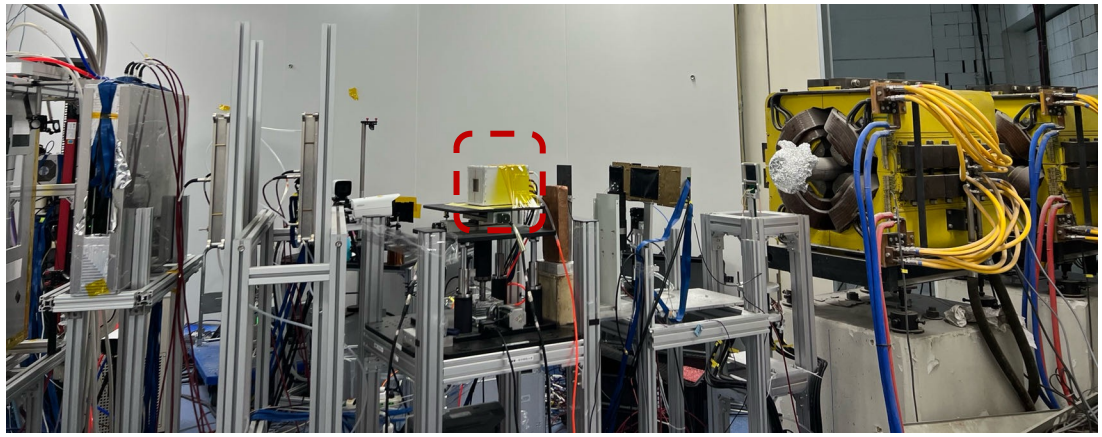


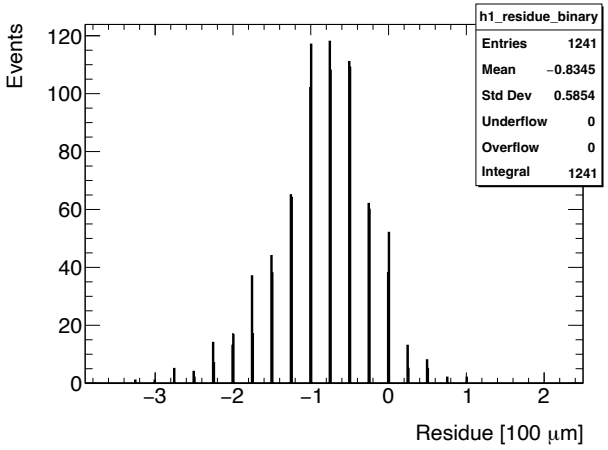
Topmetal-CEEv1 chip: heavy-ion beam test

- Kr at ~320 MeV/u
- Rate: ~10^4 – 10^6 s^{-1}

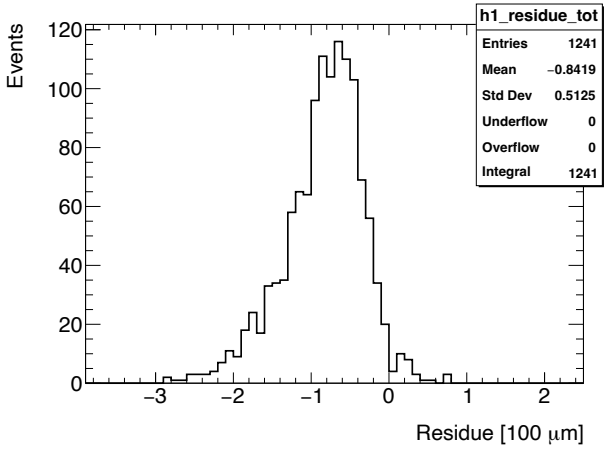








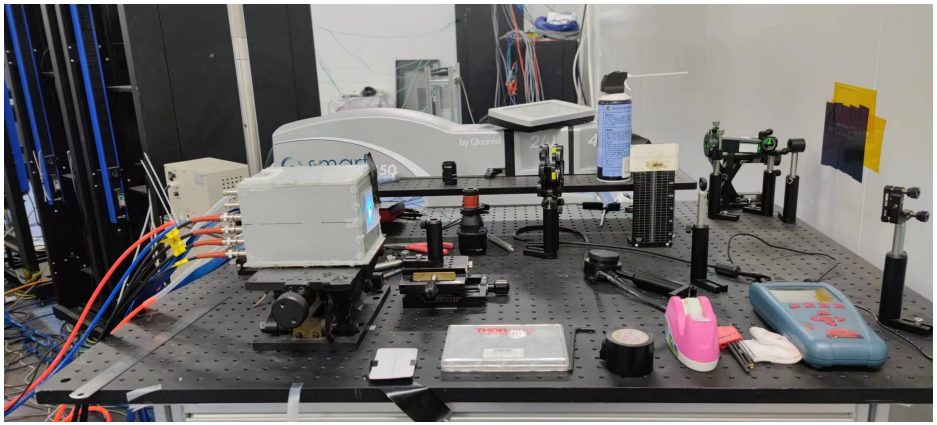
Center of geometry
Resolution (one row):
47.80 μm

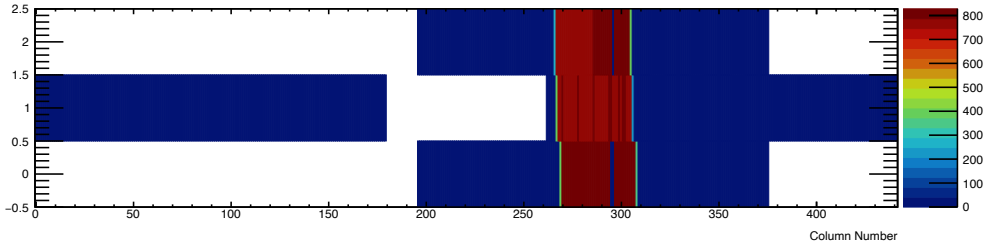


Center of gravity
Resolution (one row):
41.85 μm

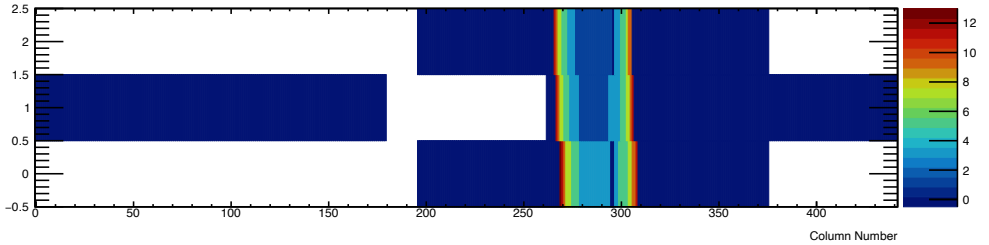
Topmetal-CEEv1 chip: laser test

- 266 nm pulsed laser

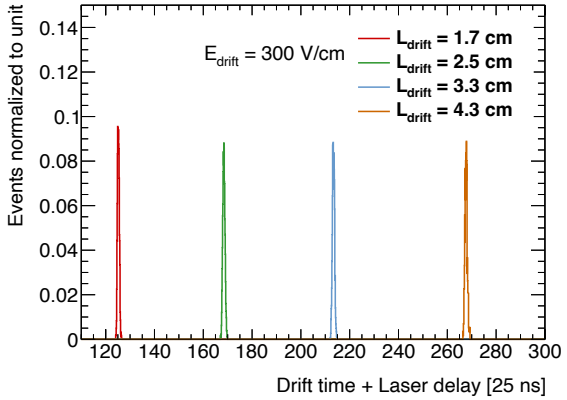


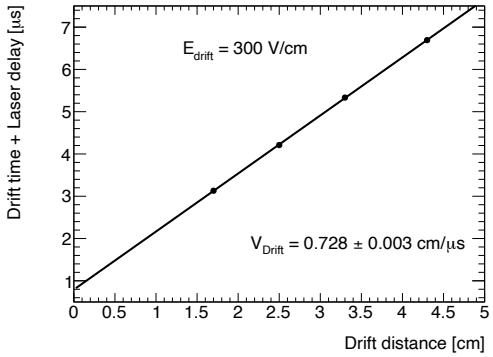


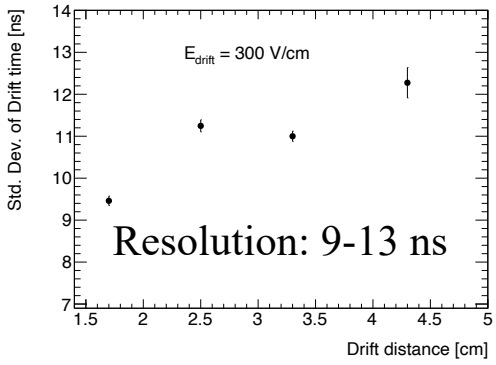
Amplitude [700 e$^-$]



Time [25 ns]







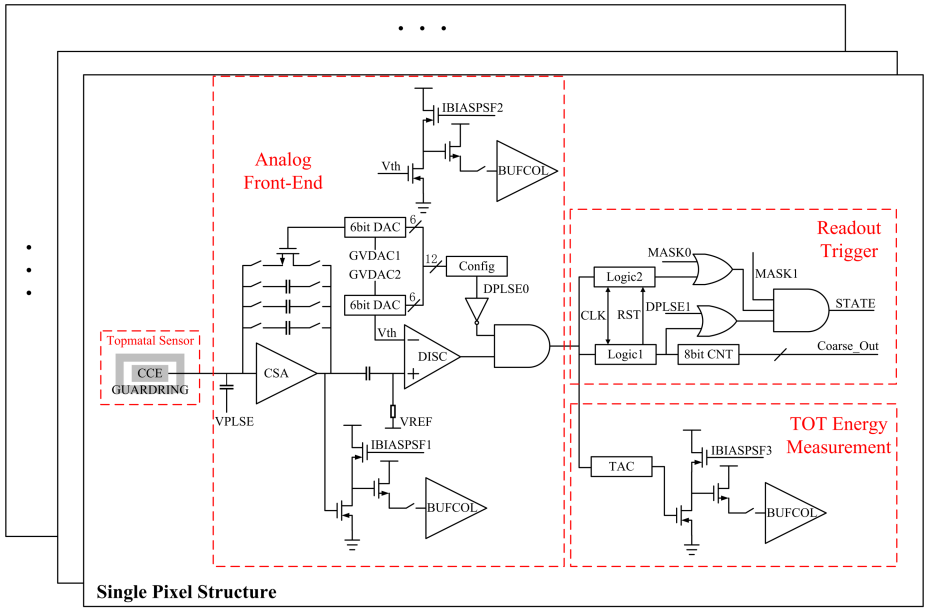
Topmetal-CEEv2 chip

Main issues in Topmetal-CEEv1 chip:

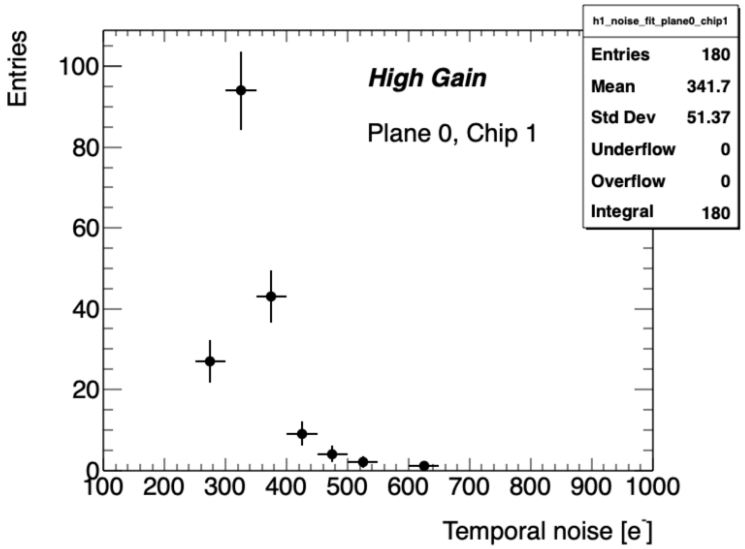
1. Disturbance of digital circuit to the analog circuit : large pixel threshold ~ 20 ke$^-$
2. Large noise for high gain (custom-designed 1 fb feedback capacitor) : use medium gain as default setting: shaping time ~ 1 μs
3. Large fixed-pattern noise without threshold equalization

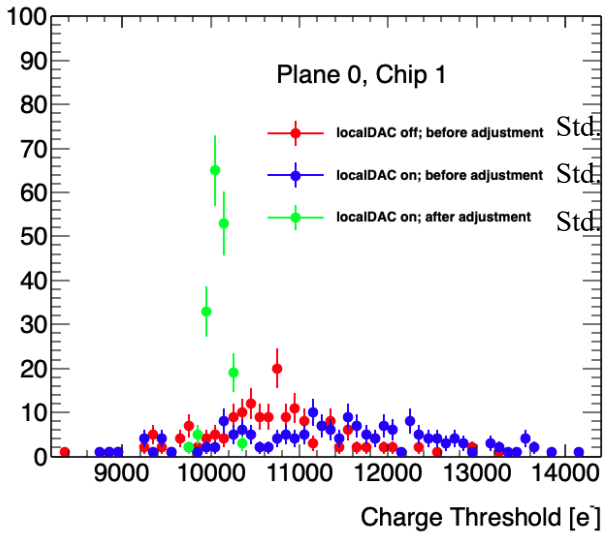
Changes in Topmetal-CEEv2 chip:

1. Careful isolation of digital and analog circuits; remove pads inside pixels; remove TAC for TOA, on-chip ADCs, and high-speed serial readout module: pixel threshold ~ 5ke$^-$
2. Use 5 fb capacitor in the foundry device library for high gain : shaping time ~0.5 μs
3. Option to disable the local DAC for tuning



Topmetal-CEEv2 chip





Std. dev. = 769 e-

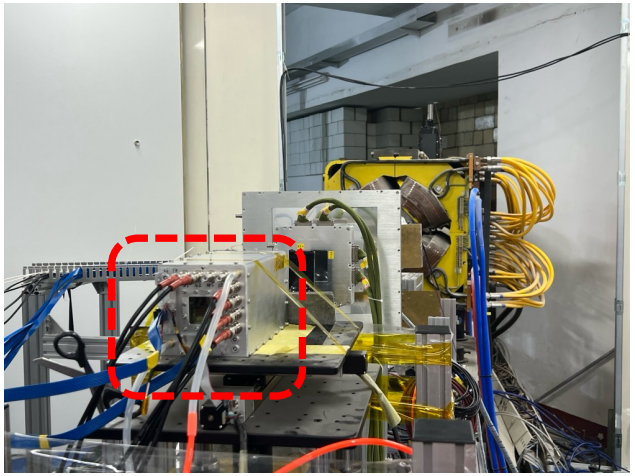
Std. dev. = 1173 e-

Std. dev. = 104 e-

Heavy-ion beam test: Topmetal-CEEv1 VS Topmetal-CEEv2 :

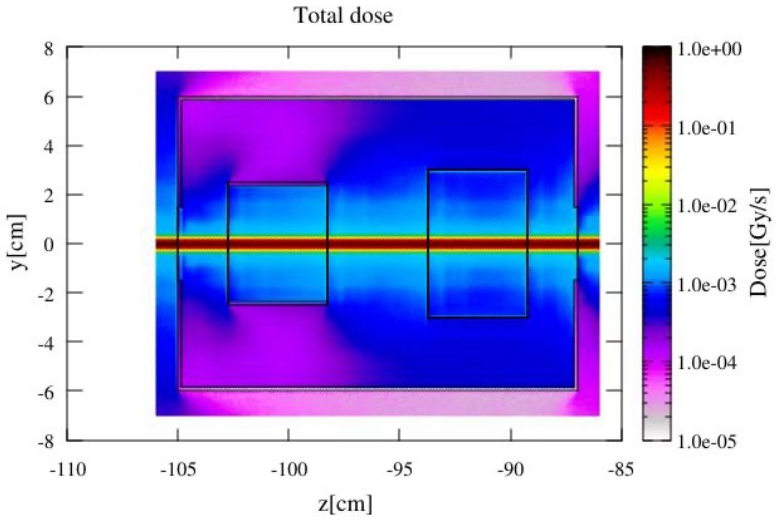
- Pixel threshold: ~20ke$^-$ => ~5ke$^-$
- GEM voltage: 350V => 230 V
- Maximum particle rate before GEM sparks: ~10^4 Hz=> ~10^6 Hz

- Position resolution: similar (dominated by detector calibration, electric field uniformity, space charge effect …)



Summary and Outlook

- Gaseous beam monitor, part of the CEE experiment, is under development. It features Topmetal-CEE chips for charge sensing and readout in the gas, with GEM for amplification.
- Complete detector system, including the gas detector, front-end electronics, and readout and control electronics, have been developed.
- Preliminary results from heavy-ion beam and laser tests showed a spatial resolution better than 50 μm and a time resolution better than 15 ns.
- Ongoing work on the radiation tolerance study of the chip, detector calibration, track reconstruction and matching with other sub-detectors of CEE.



Thank you