Development and performance of a pixel chip for the readout of GEM detectors for high-rate particle tracking

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On behalf of the CEE beam monitor group

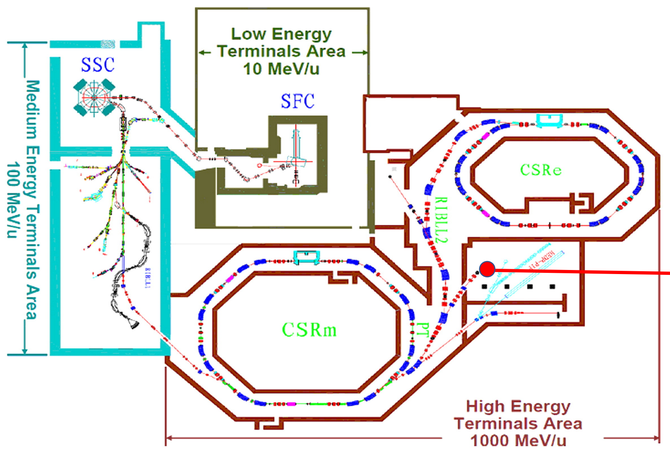
Abstract: We report the R&D program underway at CCNU to develop a pixel chip for the readout of GEM detectors appropriate for use in the CSR external-target experiment (CEE) at HIRFL for beam monitoring. The chip offers simultaneous Time over Threshold (ToT) and Time of Arrival (ToA) measurements, with an event-driven readout mode. The chips were tested with injected pulses, α particles from ^{241}Am, and a Fe-ion beam of 350 MeV/u, coupled with single GEM. The position resolution, rate capability and reconstruction efficiency for the beam particles were characterized.

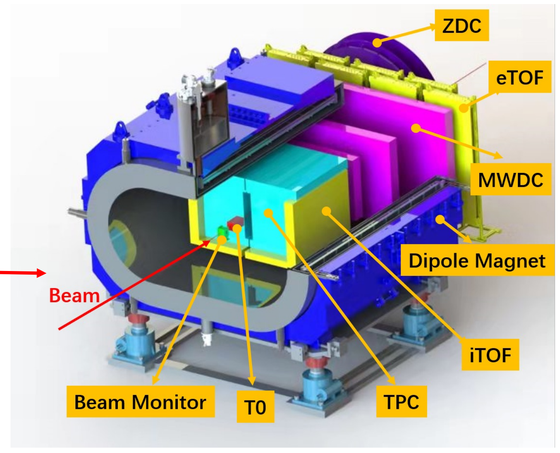
CEE at HIFRL-CSR

Heavy **I**on **R**esearch **F**acility in **L**anzhou
Cooler-**S**torage-**R**ing system

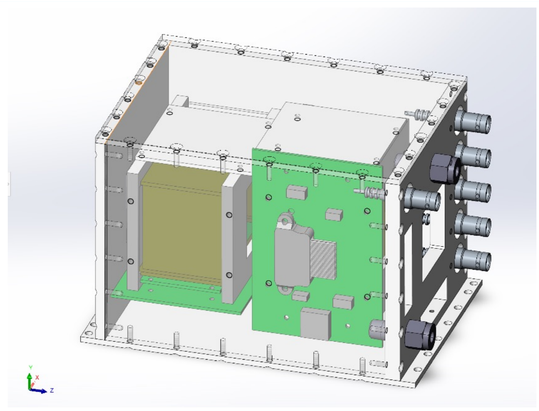
CSR **E**xternal-Target **E**xperiment

- Study the properties of cold nuclear matter at high baryonic density
- Construction time: 2020-01 to 2024-12
- Lowest (highest) beam energy: 0.3 (2.8) GeV/u
- Maximum system: U+U
- Maximum event rate: 10^4 s^{-1}

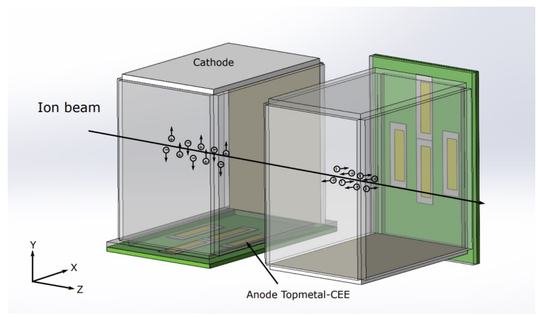




Beam Monitor of CEE

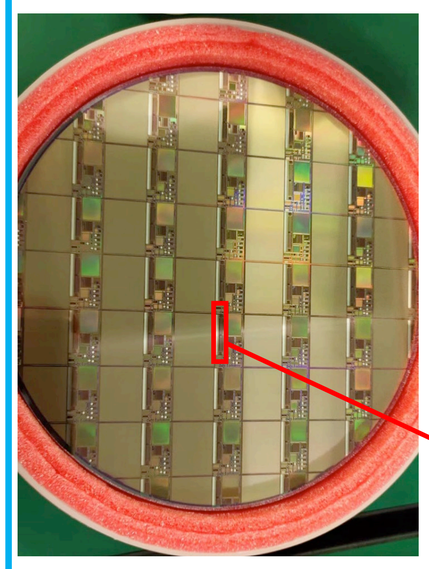


- Placed upstream of the fixed target
- Measure the position of each beam particle
- Used in vertex reconstruction (combined with TPC and MWDC)
- Main design parameters:
  - Position resolution : 50 μm
  - Minimum time separation of two particles: 1 μs
  - Sensitive area: 30×30 mm^2



- Two field cages in a gas vessel, each measuring 1-D transverse coordinate
- Custom-designed Topmetal chip as anode for charge sensing and readout
- Direct charge sensing for heavy ionizing particles e.g. U
- Single-layer GEM for less ionizing particle e.g. C

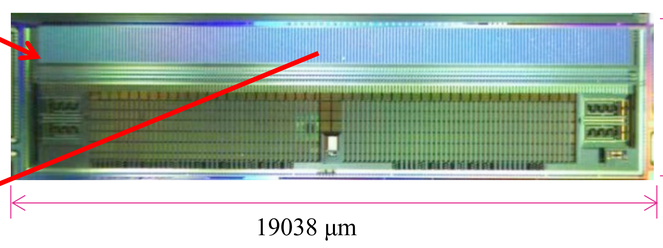
Topmetal-CEEv1 chip

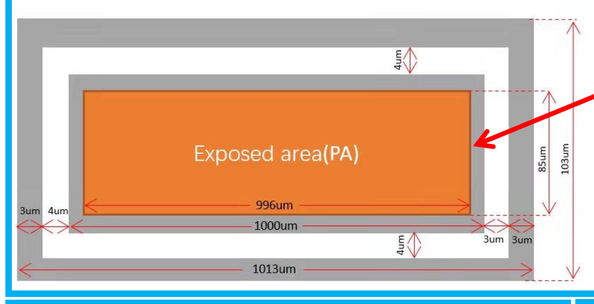


[NIMA 1047 (2023) 167786]

The main features of the Topmetal-CEEv1 chip.

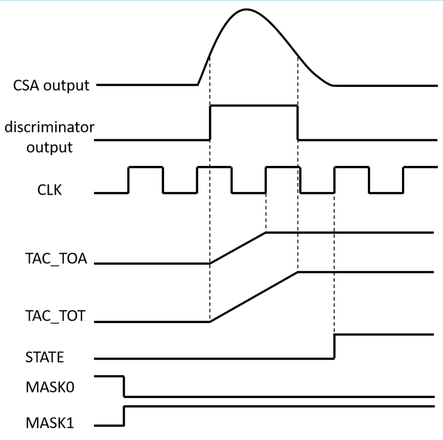
Feature size	130 nm
Chip area	4.2 mm ×19 mm
Number of pixels	1 × 180
Pixel pitch	100 μm
CCE size	1 mm ×89 μm
Shaping time (tunable)	~ 0.5 μs to 2 ms
Peaking time	~ 100 ns
Readout scheme	Data-driven readout
Readout time	25 ns/pixel
Amplitude measurement	TOT method

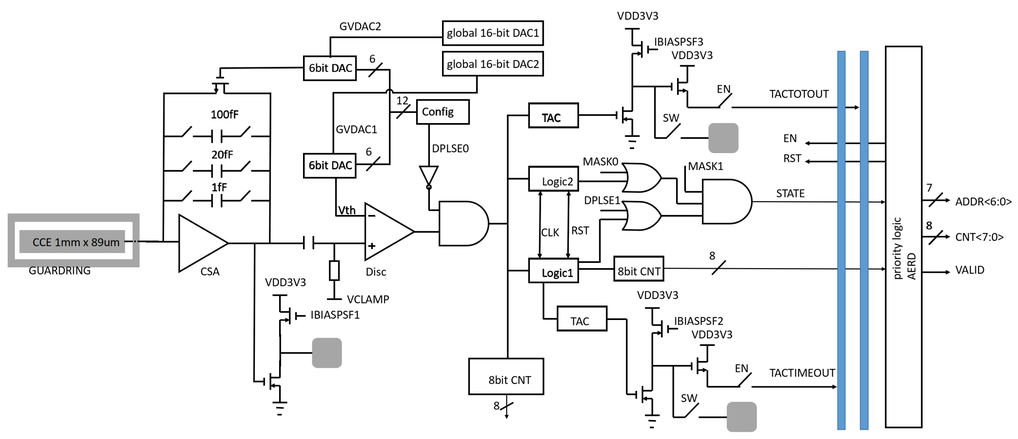




Front-end circuit:

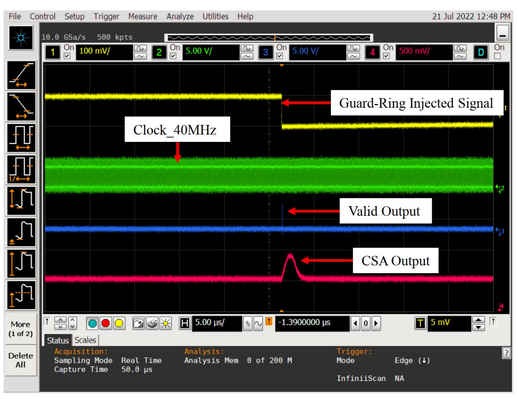
- Three gains for ions of different ionizing density
- Discriminator with local DAC for per-pixel adjustment
- Time-over-threshold signal for amplitude measurement
- Output signals sent to priority logical circuit for hit-driven readout

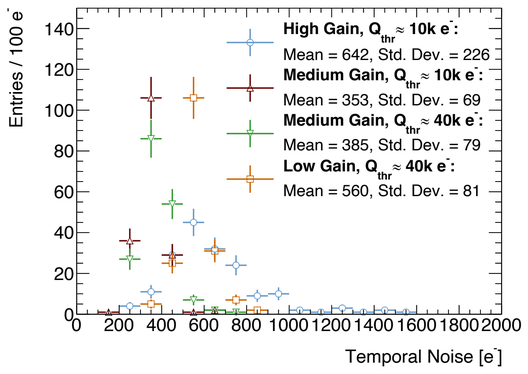




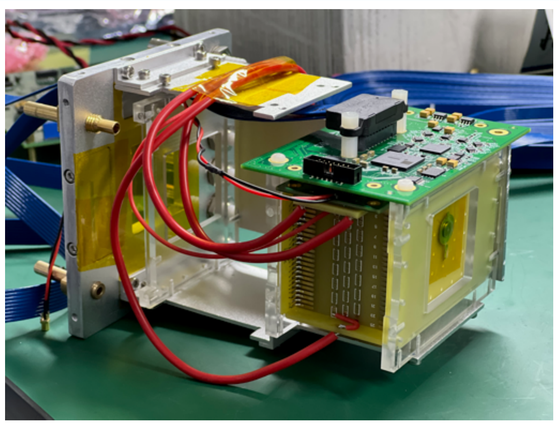
Tests with injected pulses

Key characteristics of the electronics, including the noise, threshold and gain of the CSA and the ToT output, are assessed by means of injected pulse signals through the guard-ring capacitance.



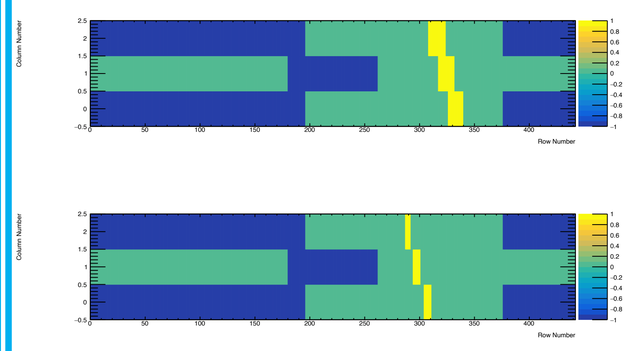


Tests with Fe-ion beam

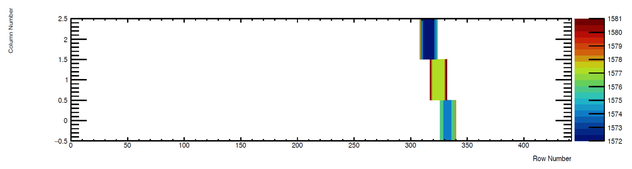


The photo of the detector. The bonding board is placed under single GEM, acting as the anode of the field cage.

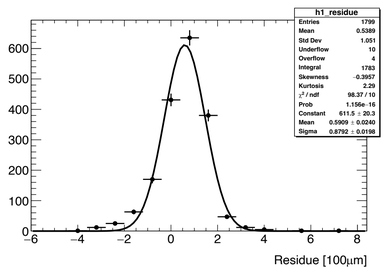
The setup of the beam test. The energy of the Fe-ion beam is 350 MeV/u, with the density varying between about 10^4 to 10^6 pps.



Typical event with ΔV_{GEM} = 450 V (top), 350 V (bottom), E_{Drift} = 300 V/cm, $E_{Induction}$ = 1000 V/cm and pixel threshold of about 28k e^-, in a gas mixture of Ar(70%) + CO_2(30%).



ToA of the pixels in a typical event. ΔV_{GEM} = 350 V . 1 count = 25 ns.

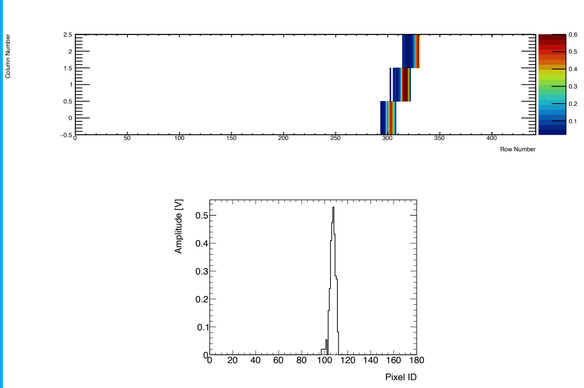


The residue distribution of the cluster position in the middle column, with the reference track determined by the other two columns of pixels. ΔV_{GEM} = 350 V.

Tests with ^{241}Am α particles

At the time of the beam test, the ToT function was not available in the readout system. The ToT was later tested with ^{241}Am α particles.

ToT of the pixels in a typical event with ΔV_{GEM} = 475 V, E_{Drift} = 300 V/cm, $E_{Induction}$ = 1000 V/cm and pixel threshold of about 10k e^-.
Amplitude 0.1 V = ~70k e^-.



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TWEPP-23 : Topical Workshop on Electronics for Particle Physics, Geremeas, Sardinia, Italy, 2 – 6 October 2023