Cylindrical and flat MPGD trackers

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On behalf of

eRD108

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Micro Pattern Gaseous Detector (MPGD) overview

Gas Electron Multiplier (GEM)

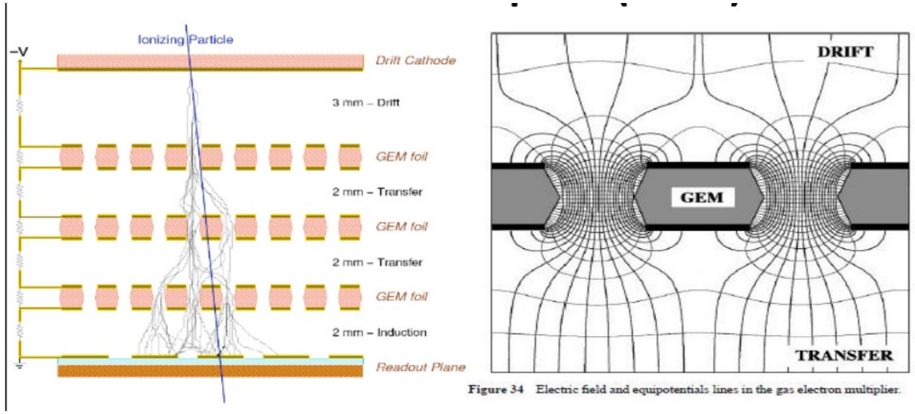
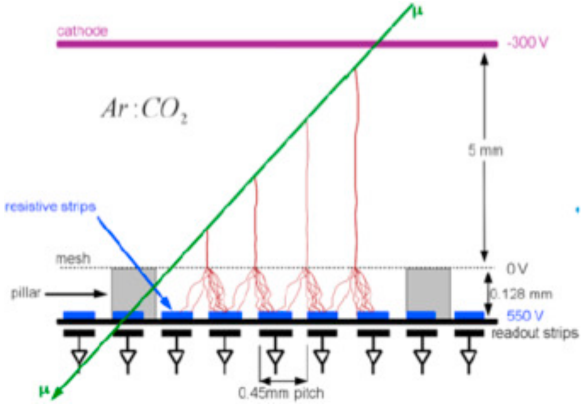


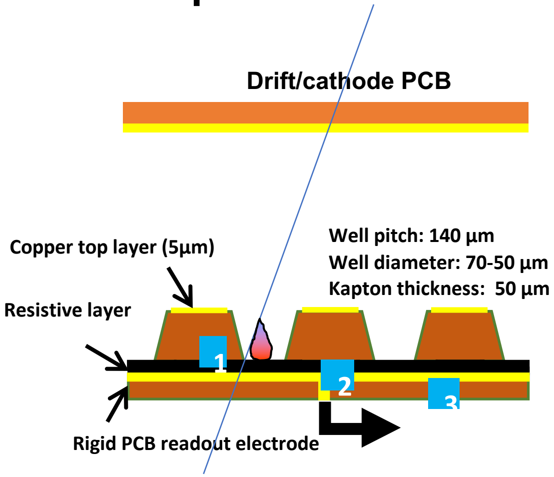
Figure 34 Electric field and equipotentials lines in the gas electron multiplier.

F.Sauli, Nucl. Intr. And Meth. A386(1997)531

Micromegas

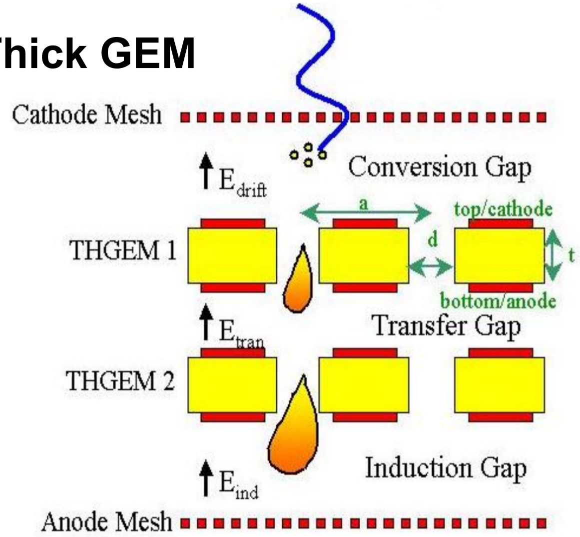


μ-RWELL PCB



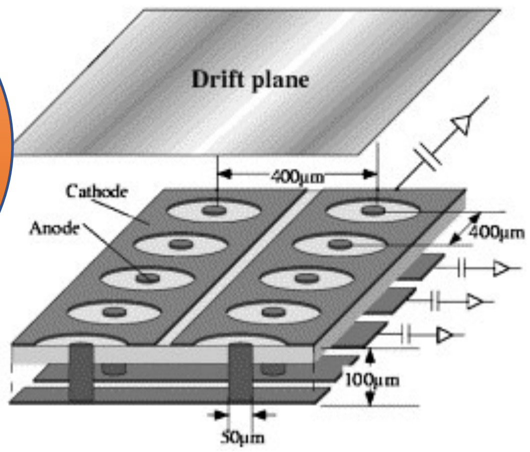
G. Bencivenni et al., 2015_JINST_10_P02008

Thick GEM



- Many more variant of MPGDs are available.
- All of them are based on same basic principle of amplification of ionized electrons in gaseous medium under the passage of charge particle.

μ-PIC

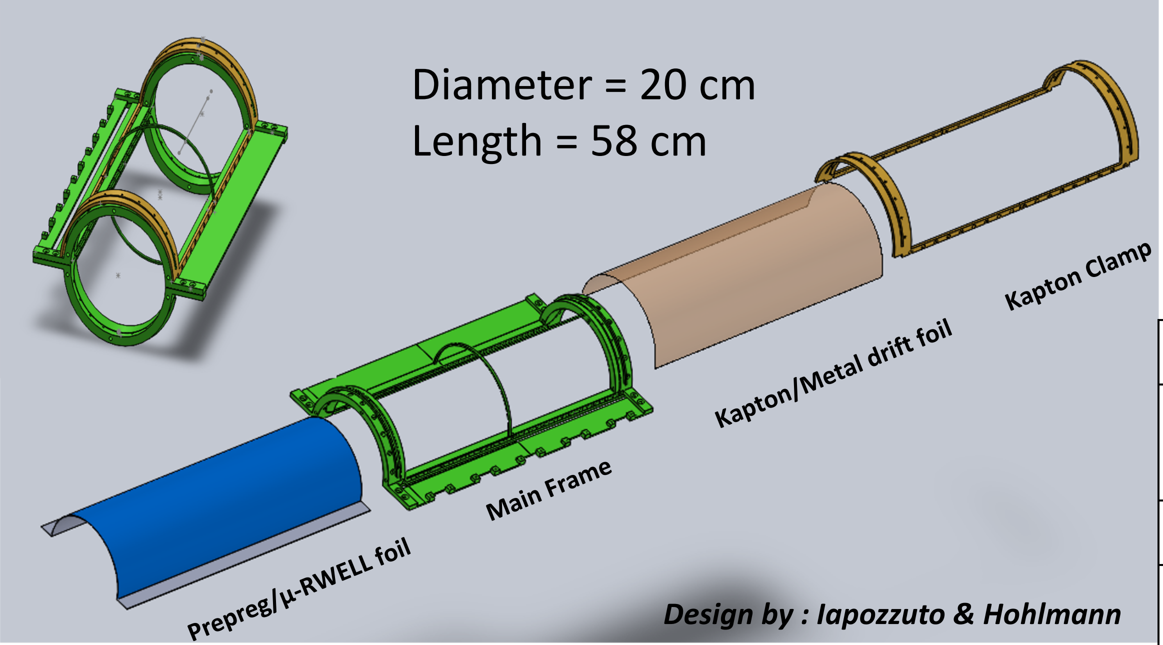


eRD108 program for EIC

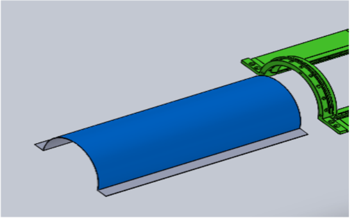
- **Goals of eRD108 for EIC detector-1 :**

1. **MPGD tracking layer inside 1.4 T magnet:**
   - Development of low mass large size detector in barrel region (R < 70 cm) which is critical for meeting Physics requirement.
   - Development of tracking layer (either cylindrical tiles or planar tiles) outside DIRC (R > 70 cm) to provide directional information to help reconstruct Cherenkov ring reconstruction. Low material budget less critical. Can be either **μ-RWELL or Micromegas.**
   - Challenging R&D for satisfying both low mass and also cylindrical geometry .
2. **MPGD tracking layer behind dRICH (low priority):**
   - Planar MPGD layer to provide additional space point for reconstructing Cherenkov rings in dRICH.
   - Low material budget is less critical and easier to construct.
3. **Both the above R&D has the common goal of developing/optimizing various 2D readout patterns for MPGD which can provide requisite spatial resolution to satisfy EIC Physics requirement.**
4. **Not only hardware but also simulation studies on detector performance (both standalone and after complete integration in EIC detector-1).**

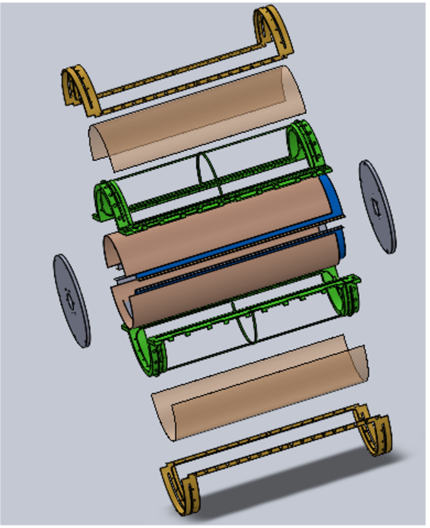
Mechanical structure of cylindrical μ-RWELL



Material considerations for μ-RWELL foil support base



Base Material	Thickness (mm)	Radiation Length (cm)	% of Radiation Length
Epoxy Resin...	0.3	41.6	0.07
Prepreg Fiberglass	0.2	25.0	0.08
Carbon Fiber	0.1	42.7	0.02
PETG Thermo	0.5	28.5	0.17
PETG Thermo	1.0	28.5	0.35
Styrofoam	5.0	1,375.0	0.04
Styrofoam	2.6	1,375.0	0.02
Styrofoam	1.3	1,375.0	0.01



PETG

Currently preferred candidate

Capacitive-sharing (CapaSh) with various readout structure

Jefferson Lab

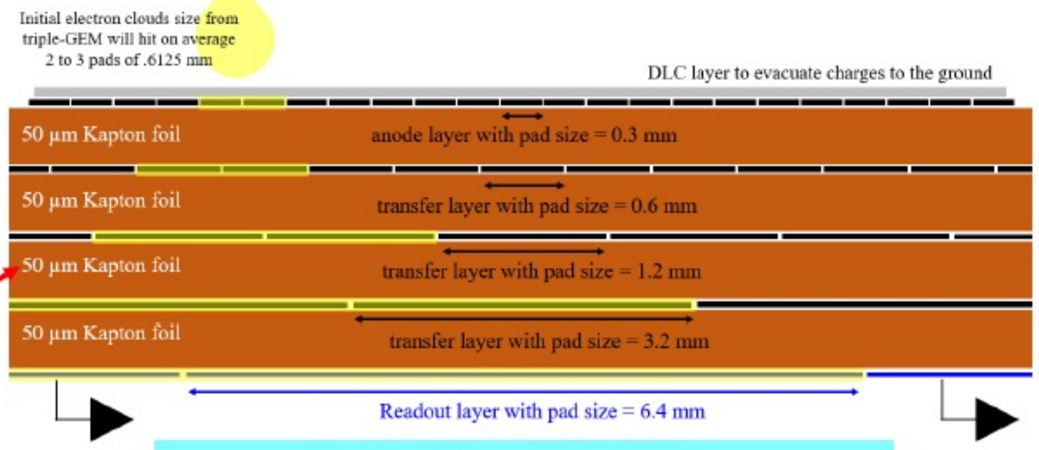
Principe of capacitive-sharing readout structures:

- Vertical stack of pads layers ⇨ Transfer of charge from MPGD via **capacitive coupling**
- A given arrangement of the pads position from one layer to the layer underneath as well as the doubling in size of the pad pitch allows:
  - Transverse sharing of the charges between neighboring pads of the layer (i+1) from vertical charged transfer from layer (i) through capacitive coupling
  - Principle of transverse charge-sharing through capacitive coupling i.e., **capacitive-sharing** is illustrated on the cross-section sketch on the left
- The scheme preserves of the position information i.e. spatial resolution with large readout strips or pads ➔ Goal 50 µm for 1-mm strip r/o and 150 µm for 1 cm^2 pad r/o
- Basic proof of concept established with **800 µm** X-Y strip and ***1 cm²*** pad readout

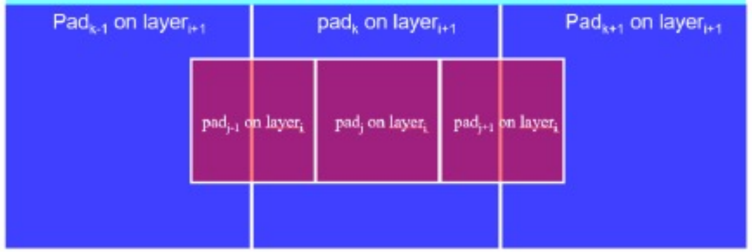
Motivation & some key facts of capacitive-sharing readout:

- Develop high performance & low channel count readout structures for MPGDs:
  - Reduce the number of readout electronic channels for large area MPGDs
  - Low-cost technology for large area ➔ standard PCB fabrication techniques
  - Application for future colliders and NP experiments
- Capacitive-sharing concept is **simple, versatile and flexible**:
  - Compatible with all MPGD technologies ➔ GEM, uRWELL, Micromegas, THGEM …
  - Compatible with all type of readouts ➔ pads, 2D-strips, zigzag, 3-axis X-Y-U etc …

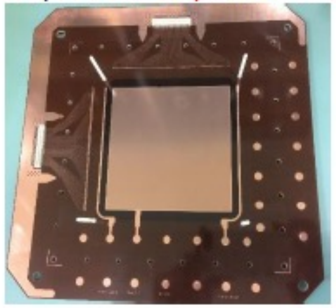
Cross section of capacitive-sharing pad readout with 6.4 mm × 6.4 mm pads



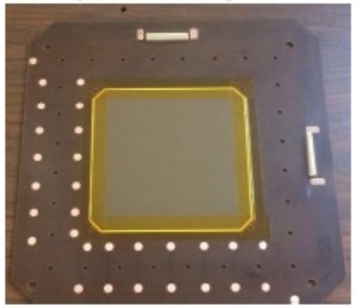
Top view of two pad-sharing layers



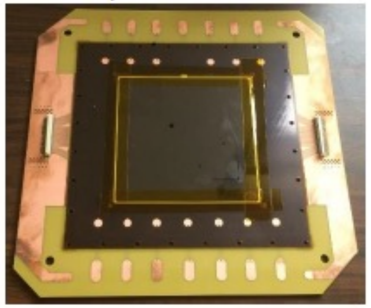
capaSh-XY-Strip uRWELL



capaSh-XY-Strip GEM



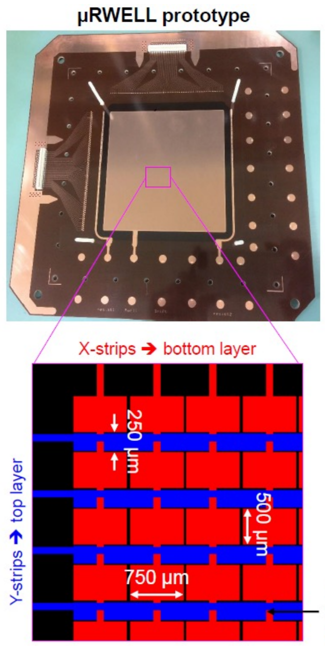
capaSh-Pad GEM

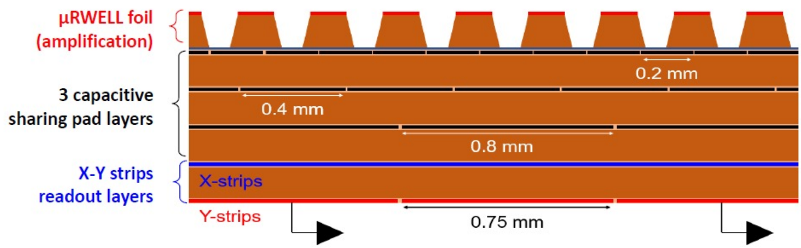


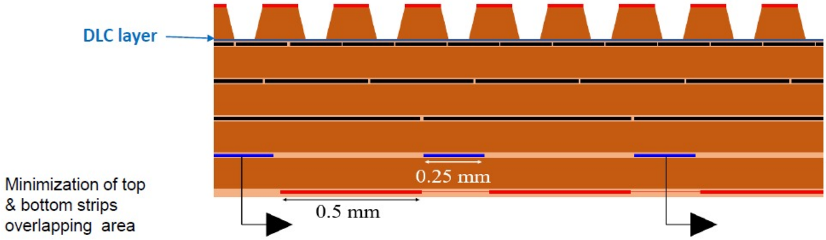
µRWELL prototype with capaSh 2D strip readout anode

Jefferson Lab

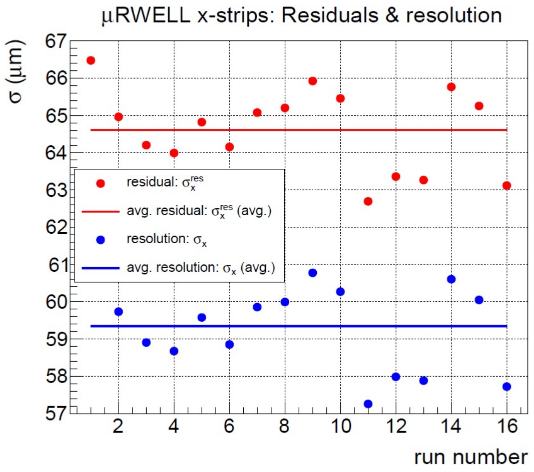
- 3-layer stack capacitive sharing strip readout ➔ black pads on the cross-section view
- X-strips and X-strips on different layers separated by 50 µm. Kapton foil is not etched out between top and bottom strips ➔ Signal on top and bottom strip collected through capacitive coupling: strip pitch = 800 µm
- Beam test in Hall D @ JLab with 3 – 6 GeV electron beam at normal incidence.
- Spatial resolution performances
  - Red dots: widths $\sigma_{X(Y)}$ of the Gaussian fit to tracking residuals in x and y before track fit correction. Average $\sigma_{X(Y)}$ over 16 independent runs ~64 µm
  - Blue dots: spatial resolution after before track fit corrections . The average resolution in both x and y over 16 independent runs is ~ 59 µm

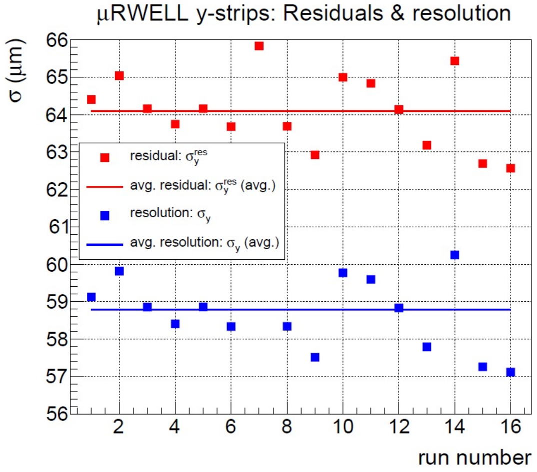




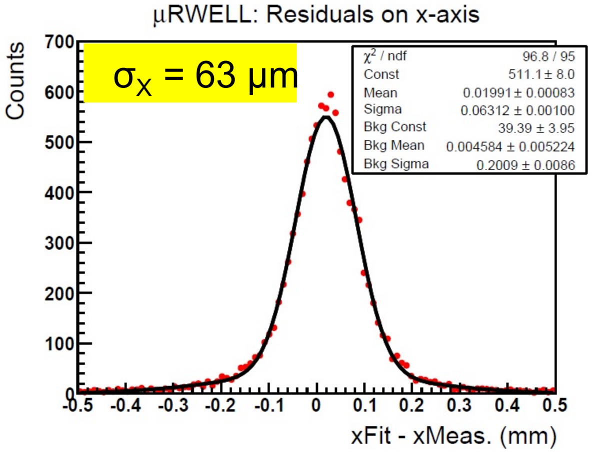


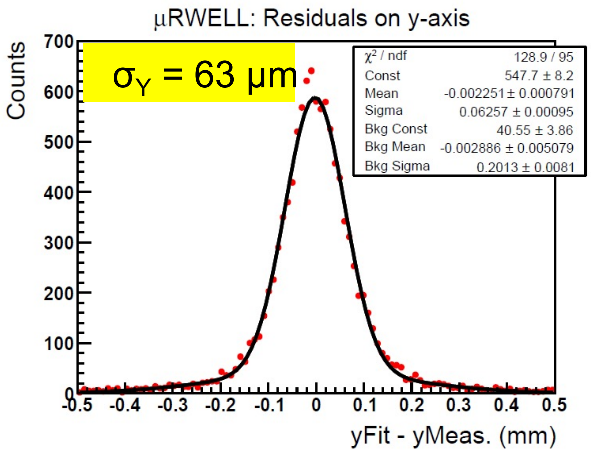
Residual width (red dots) & spatial resolution (blue dots) in x and y





Tracking residual distribution plots in x and y before track fit correction



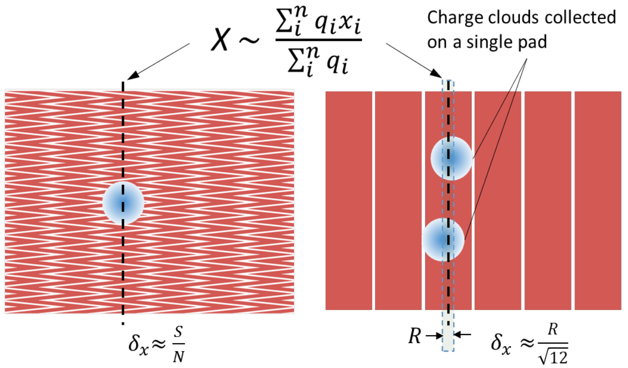


Note : Normal incidence of track

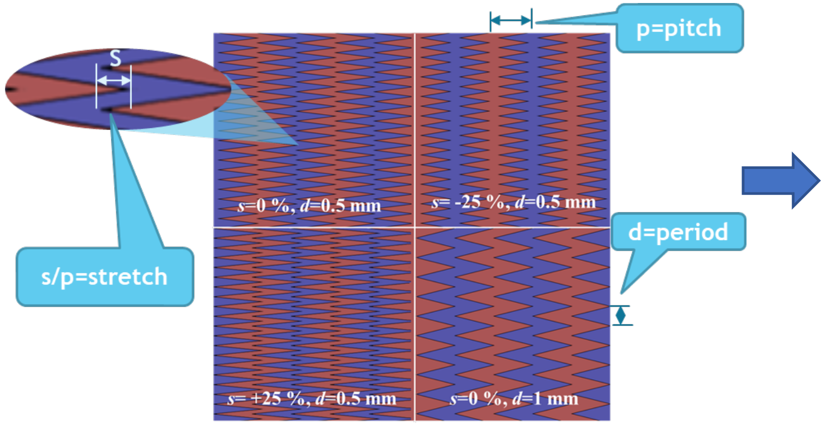
2D Interleaved Readouts for MPGDs

Objective: Once the geometric parameters of interleaved anodes (such as zigzags) are precisely tuned for a specific detector application, coarsely segmented (pitch > 1 mm) strip arrays maintain high position resolution, a uniform detector response, do not necessarily require correction functions, and minimize the readout channel count.

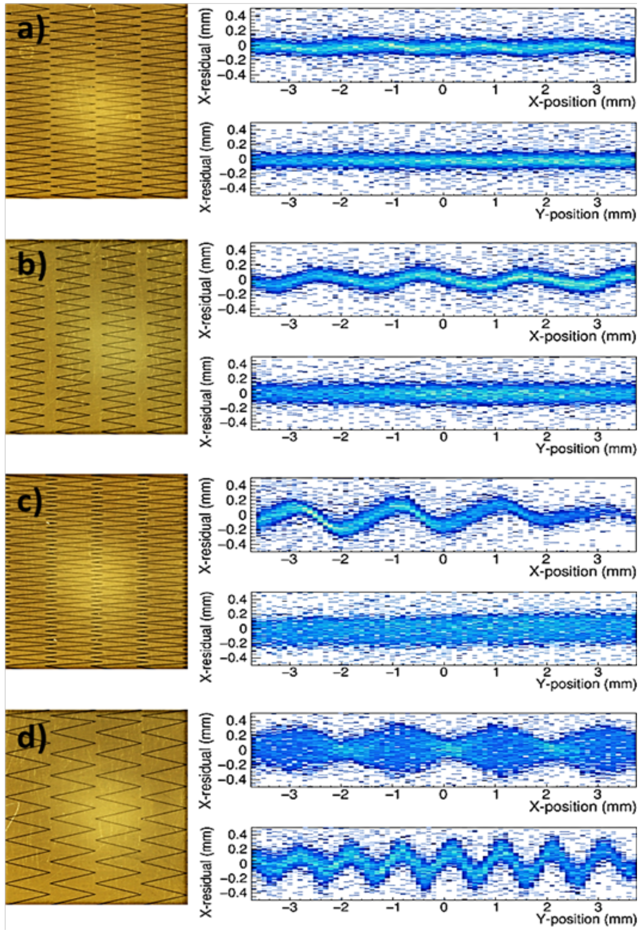
Advantage of Interleaved anodes



Can Optimize 1D ZZ patterns

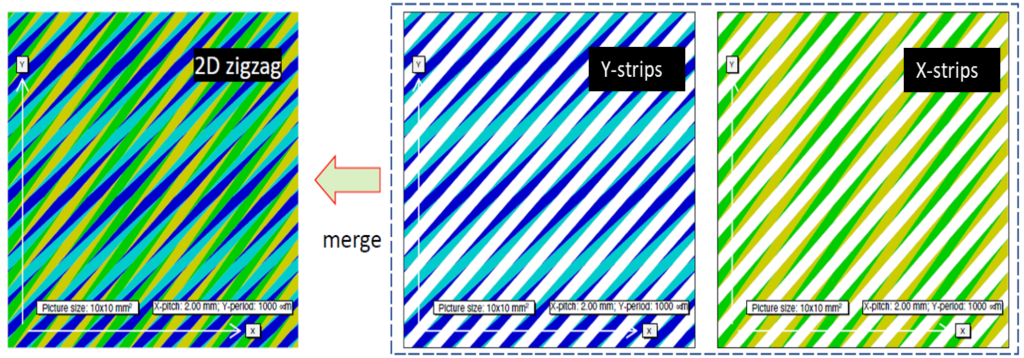


Tune Detector Response



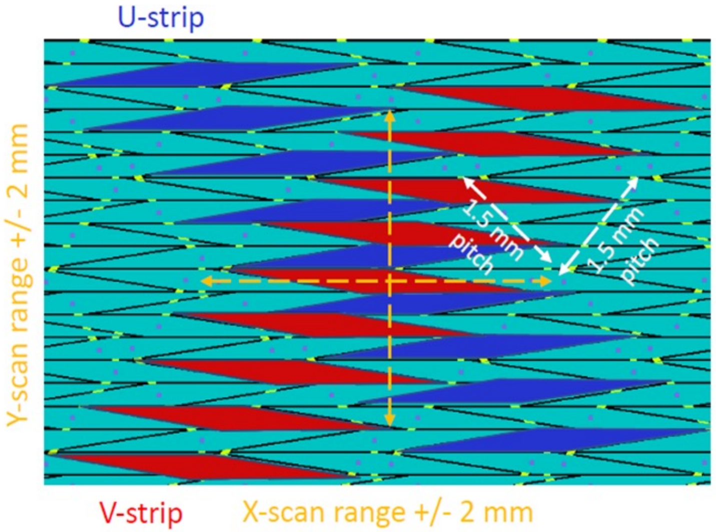
Organize 2D Interleaved Anode Strips

- 2D interleaved anode structures can be constructed by a relatively simple rearrangement of the 1D zigzag diamond-shaped elements
- The geometric parameters of the anode can be tuned to achieve the desired performance with linear charge sharing and a uniform response



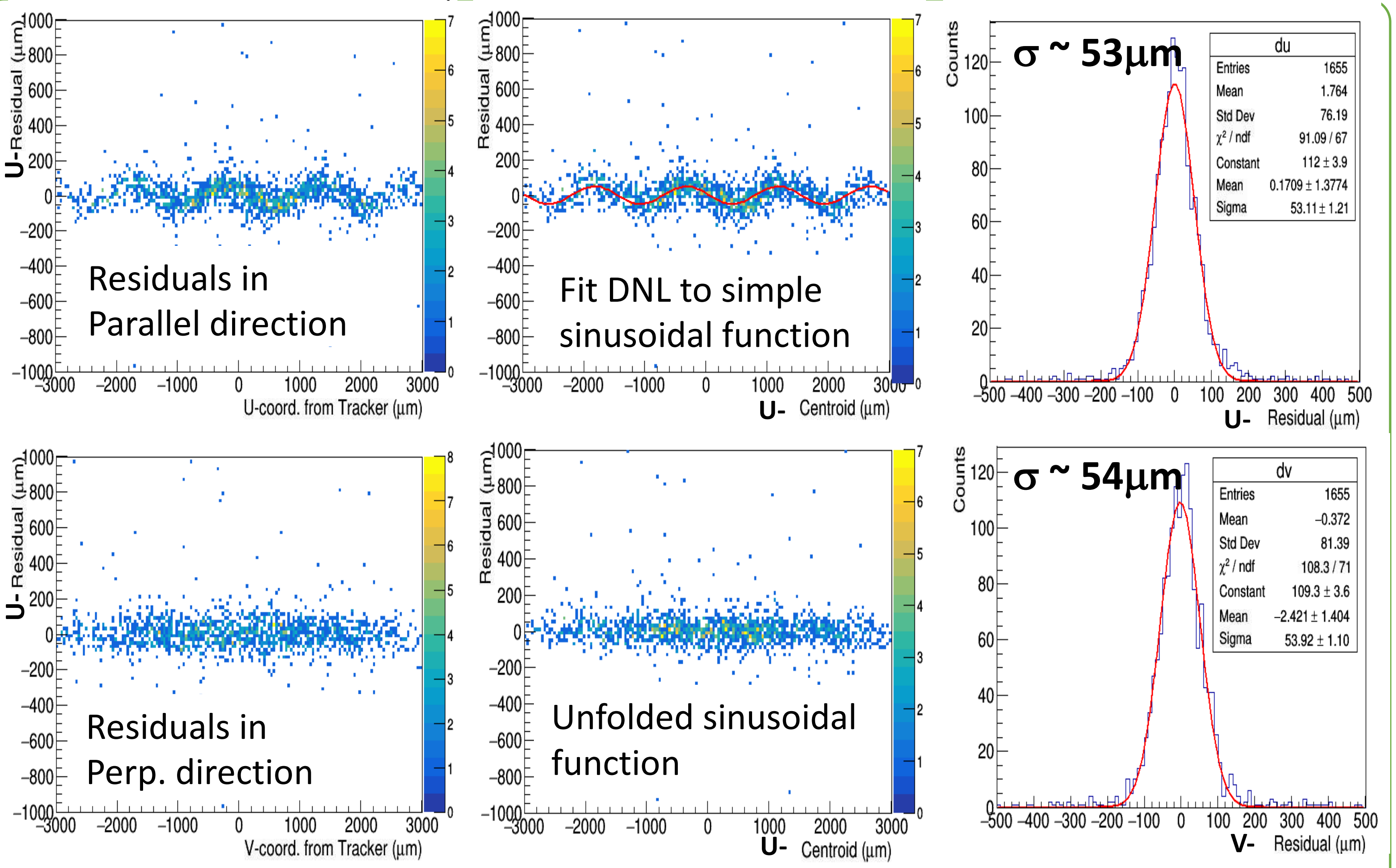
2D Zigzag Performance for normal track incidence

Example of 2D ZZ pattern



- Organize arbitrary U-V Strips
- The readout is realized on a simple 2- layer flex Kapton PCB to accommodate non-planar configurations
- Achieve uniform response in direction orthogonal to strip coord. axis
- Slight (<50μm) DNL in parallel direction
- The DNL-corrected resolution along the U- and V-plane is <54μm
- The correction is small (i.e., reduces the resolution by about 5μm)
- The slight DNL may be removed via anode shape optimization

Results from μ–RWELL with 3mm drift gap



Note: Normal incidence, 120GeV proton beam at FTBF

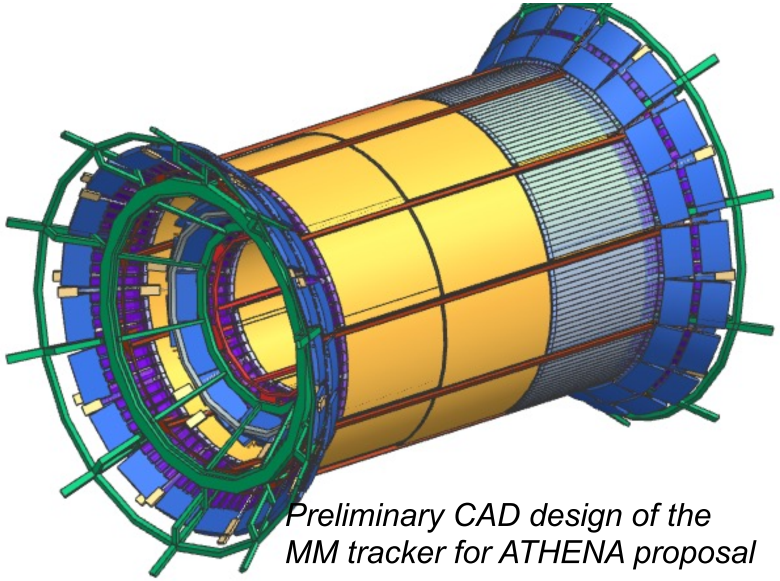
Summary: 2D interleaved anode patterns with relatively coarse pitch are capable of producing excellent position resolution and a relatively uniform detector response with relatively minimal instrumentation

R&D on cylindrical Micromegas tracker

Motivation
- Build a full (no acceptance gaps) light-weight modular Micromegas barrel tracker to complement the silicon vertex detector

CLAS12 MM Technology
- Compact cylindrical tracker in a B=5T solenoid, total active area ~4m^2
- Light cylindrical tiles (~0.4% X0 per layer)
- 1D readout per tile (either phi or z coord)
- Taking data since 2017

Upgrades to fit the EIC needs:
- **Simpler construction:**
  - about one module size bent at different radii,
  - overlap tiles for no acceptance gaps
- **2D readout**
  - Resolutions 50 – 100 μm, on both directions
  - Keeping the channel count as low as possible



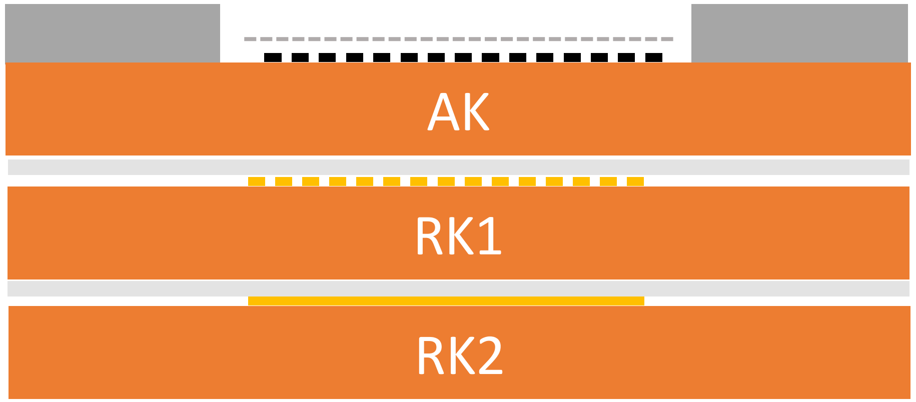
Preliminary CAD design of the MM tracker for ATHENA proposal

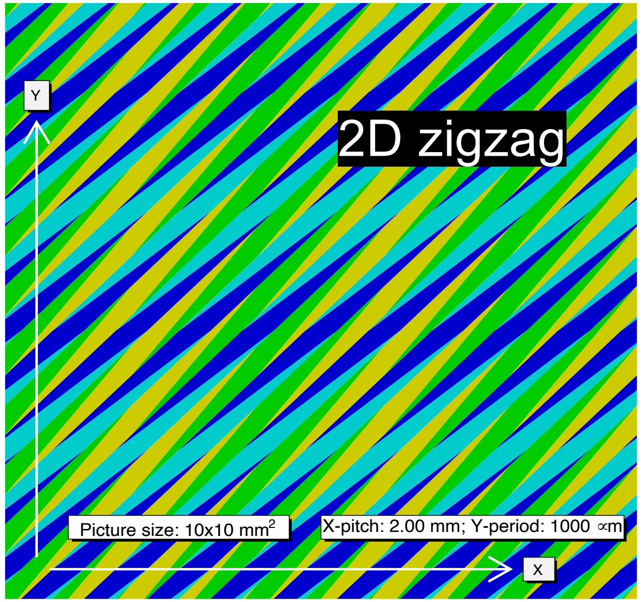
Objectives
- FY22:
  - Optimization of the 2D readout for low number of channels on small prototypes
  - CAD design of the full-scale prototype
- FY23:
  - Build a full-scale prototype of a Micromegas tile (50x70cm^2) with the chosen 2D readout

R&D on cylindrical Micromegas tracker

R&D 2D readout

- Several small prototypes ~12x12 cm^2
- Multi stack for easy combination of different options:
  - AK: Amplification Kapton
    - Vary the resistivity, the shape, …
  - RK: Readout Kapton
    - Different strip pitch (1, 1.5, 2 mm)
    - Vary strip type (straight, zigzag, pixel,..)
    - 2D zigzag from BNL
- Assembly in house
  - Pressing
  - 3D printed mechanics





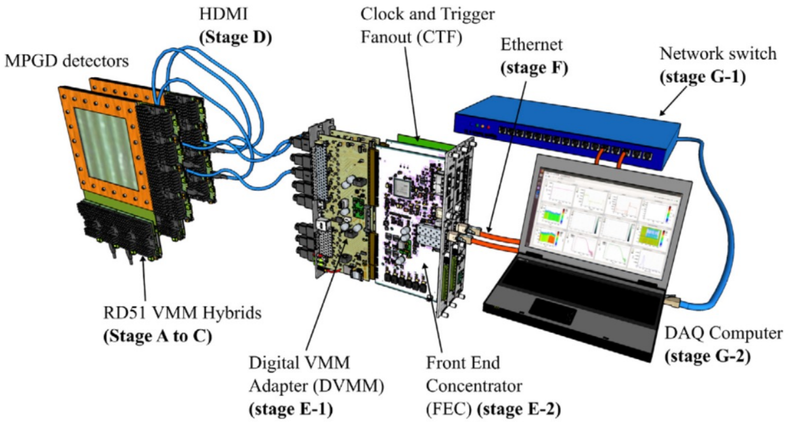
Testing

- ^{55}Fe Cosmic rays test bench in Saclay
- X-rays gun tests in BNL
- Beam test in 2023

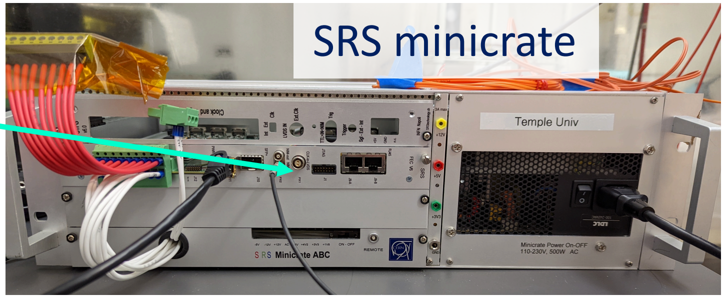
Electronics and DAQ system

Small scale VMM-SRS electronics and DAQ system

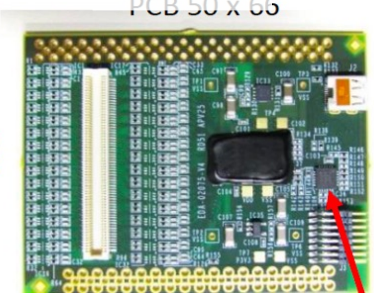
- **Goal**: In collaboration with BNL, FIT, and JLab to commission a small-scale VMM-SRS system to equip and readout a portion of the μ-RWELL cylindrical prototype tracker with VMM3a ASICs [*ref : D.Pfeiffer et. al. , NIMA 1031 (2022) 166548*].
  - APV25 has been an MPGD ASIC workhorse, but no longer produced
  - Assess the use of VMM3a as potential replacement ASIC for APV25
  - Attractive characteristics of VMM
    - Self trigger ability
    - Digital instead of analogue
    - Higher trigger rate of 1 MHz/channel as compared to 5 kHz/128 channels in case of APV25
    - Variable preamp gains (0.5-16 mV/fC) compared to fixed 65 mV/fC gain in case of APV 25
    - Less intrinsic noise along with better timing resolution (< 1ns)



FECv6 Card



APV 25



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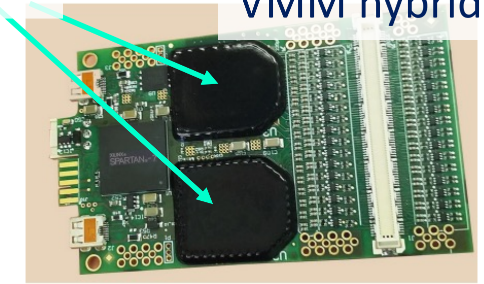
VMMs

VMM hybrid card



Summary and Outlook

- Substantial R&D is in progress related to design of mechanical structure of large size cylindrical **μ-RWELL .**
- Promising R&D results from cylindrical large size Micromegas.
- Encouraging results from preliminary R&D with various types of MPGD readout board structure (2D zigzag and capacitive sharing).
- Upgrading of traditional APV25 based MPGD electronics to latest VMM based MPGD electronics is ongoing
- Ongoing studies to implement effect of track angle and Magnetic field on spatial resolution in EIC-detector1 simulation framework.
- Upcoming test beam during Fall 2022 at Jefferson Lab will provide more answers to the effect of track angle with respect to detector R/0 surface on spatial resolution.
- Standalone simulation studies will provide answers to the effect of magnetic field on spatial resolution of cylindrical MPGD trackers.