eRD6 Progress Report

EIC GENERIC DETECTOR R&D ADVISORY COMMITTEE MEETING

March 24, 2021

The eRD6 Consortium

❖ **Brookhaven National Laboratory (BNL) -** E.C Aschenauer, B. Azmoun, A. Kiselev, M. L. Purschke, C. Woody.
  ▪ Barrel TPC Tracker: TPC and TPC/Cherenkov; zigzag pad readout, Avalanche structure readout.

❖ **CEA Saclay -** F. Bossu,, M. Vandenbroucke.
  ▪ Barrel MPGD Tracker: Cylindrical Micromegas Tracker;

❖ **Florida Institute Of Technology (FIT) -** J. Collins, J. Hadley, M. Hohlmann, M. Lavinsky
  ▪ Barrel MPGD Tracker: Fast µRWELL Tracking Layer;
  ▪ End Cap GEM Tracker: Large area & low mass GEM with zig-zag readout.

❖ **INFN Trieste -** C. Chatterjee, D. D'Ago , S. Dalla Torre, S. Dasgupta, S. Levorato, F. Tessarotto, Triloki.
  ▪ Particle ID: Hybrid MPGDs for RICH applications; New photocathode materials for RICH detectors.

❖ **Stony Brook University (SBU) -** K. Dehmelt, A. Deshpande. P. Garg, T. K. Hemmick, S. Park, V. Zakharov, A.Zhang.
  ▪ Particle ID: Short radiator length RICH, Large Mirror, Meta Materials;
  ▪ Barrel TPC Tracker: TPC-IBF

❖ **Temple University (TU) -** M. Posik, B. Surrow, N. Lukow, A. Quintero.
  ▪ Barrel MPGD Tracker: Fast µRWELL Tracking Layer;
  ▪ End Cap GEM Tracker: Commercial GEMs.

❖ **University Of Virginia (UVa) -** K. Gnanvo, N. Liyanage.
  ▪ Barrel MPGD Tracker: Fast µRWELL Tracking Layer
  ▪ End Cap GEM Tracker: Large area GEM with U-V readout.

❖ **Vanderbilt University (VU) –** J. Velkovska, V. Greene, S. Tarafdar. **(new eRD6 member)**
  ▪ Barrel TPC Tracker: TPC studies, including FEA of IBF and a hybrid MMG+2GEM gain element

❖ **Yale University -** D. Majka (deceased), N. Smirnov.
  ▪ Barrel TPC Tracker: : Avalanche structure readout

Outline

❖ **End Cap Tracker:** GEMs

❖ **Barrel Fast Layer:** Cylindrical uRWELL

❖ **Barrel Tracker:** Cylindrical Micromegas

❖ **Barrel Tracker:** TPC

❖ **Particle ID**
  ▪ R&D on Hybrid MPGDs for RICH.
  ▪ Studies of New Photocathodes for RICH.
  ▪ Development on Large Mirror for RICH.
  ▪ Studies of Meta Materials.

❖ **eRD6 Future Plans**

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eRD6 Progress Report: Contribution to the Yellow Report

The eRD6 consortium is playing an important role in the elaboration of the EIC Yellow Report (YR)document with contributions to several YR Working Groups (WGs), in particular Tracking and PID WGs. The developments performed within eRD6 activities are injected as input material in the relevant WGs, often accompanied by a dedicated effort to shape the information in a form adequate for the Yellow Report initiative. This core effort is accompanied by some specific personal contributions by eRD6 members:

- **Silvia Dalla Torre** (*INFN Trieste*) is one of the **conveners of the YR Detector Working Group (YR-DWG)** overlooking the broad discussions related to the various EIC detector options under consideration including the detector integration and the complementarity aspects of different detector options. Her role as convener is complemented by her contribution to the discussions in WGs: PID, DAQ and electronics, integration and central magnet.
- **Kondo Gnanvo** (*University of Virginia*) is one of **conveners of the Tracking WG**, one of the subgroups of the YR-DWG. He is specifically looking at all the aspect of gaseous detectors options including MPGDs technologies for EIC central tracking detector which include both the barrel and both end cap trackers.
- **Thomas Hemmick** (*Stony Brook University*) is one of the **conveners of the PID WG**, one of the subgroups of the YR-DWG. He is dedicating specific effort to the comparative analysis of the several technologies proposed in order to perform PID from the low momenta (∼1 GeV/c) up to the high ones (∼50 GeV/c).
- **Alexander Kiselev** (*Brookhaven National Lab*) is one of the **conveners of the integration and central magnet WG**, one of the subgroups of the YR-DWG. Among other efforts, he has built a software tool for fast modelling and generation of EIC Central Detector templates.
- **Matt Posik** (*Temple University*) is the **liaison between eRD6 groups and the YR WGs** including physics working group (PWG), detector working group (DWG) and software group (SWG).

Barrel Tracker: TPC

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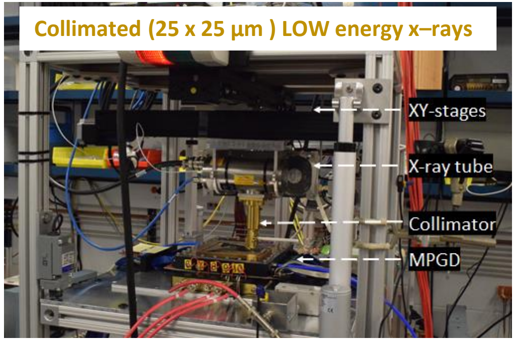
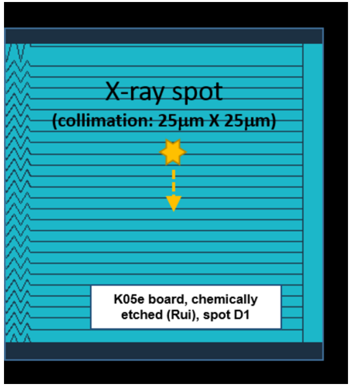
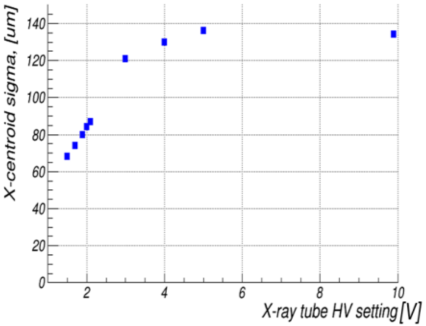
Barrel Tracker: High Spatial Resolution Measurements with X-ray Scanner

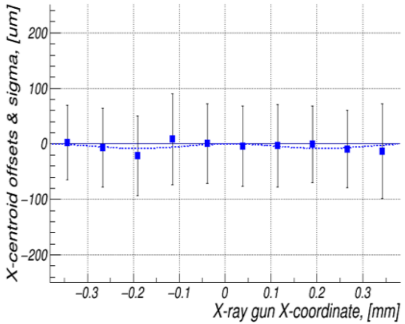


- X-ray energy reduced to below excitation energy of Cu target
- This results in low energy pe conversions with small range in gas (estimated to be <<100µm for very soft x-rays)
- The resulting extent of the charge cloud is no longer expected to dominate the position residual distr. width
- Clearly see effect with straight strips as x-ray tube potential is increased
- **2D Zigzags also tested and verified for the first time to operate with excellent performance**
- A newly designed TPC ZZ PCB was also tested and verified to perform well
- Similar PCBs were sent to CERN for µRWELL and MMG application, for future tests
- NEXT STEPS: test optimized 1D and 2D ZZ pattern readouts in TPC prototype

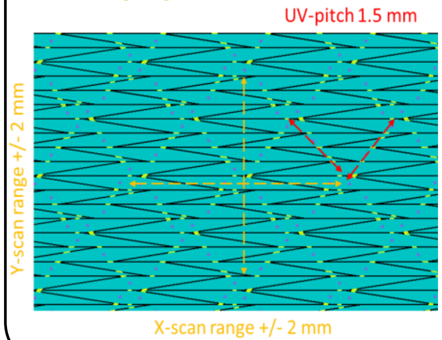
COMPASS-style 400µm pitch strips

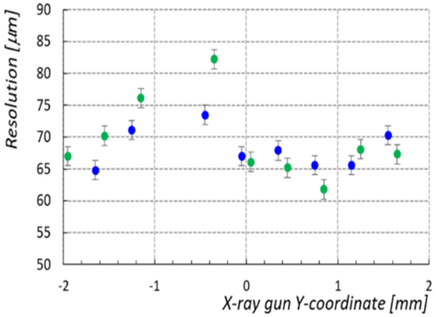


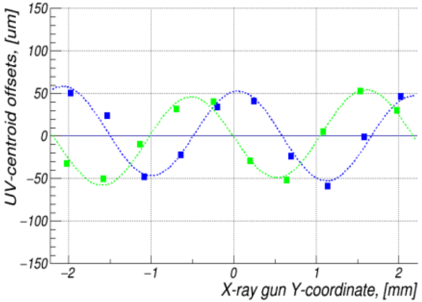




2D Zigzag







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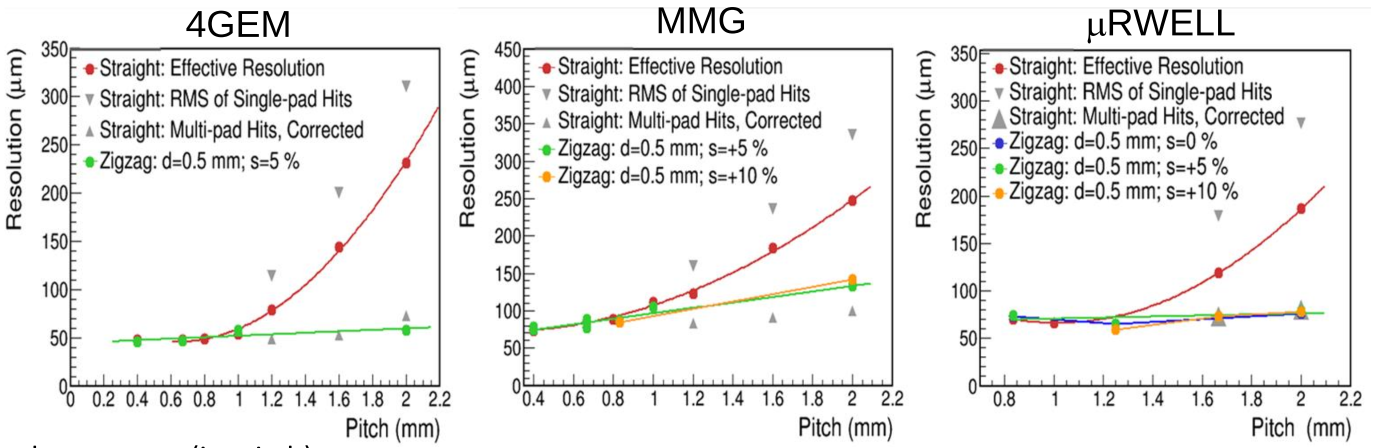
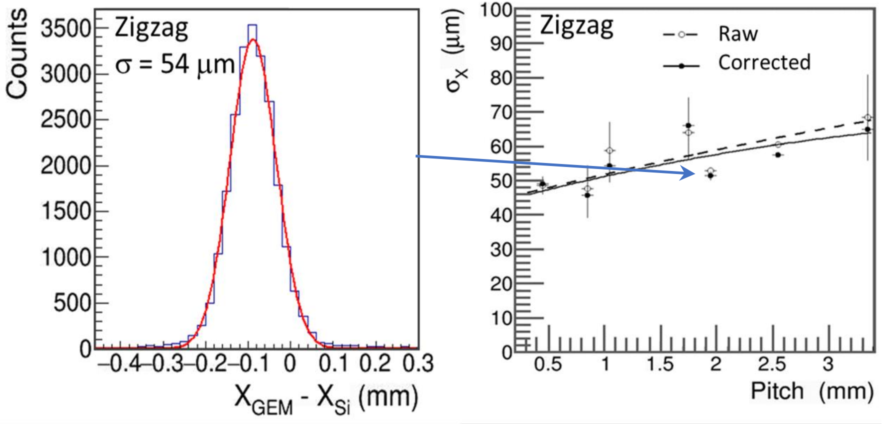
Barrel Tracker: Zigzag Vs Straight Strip R/O Performance

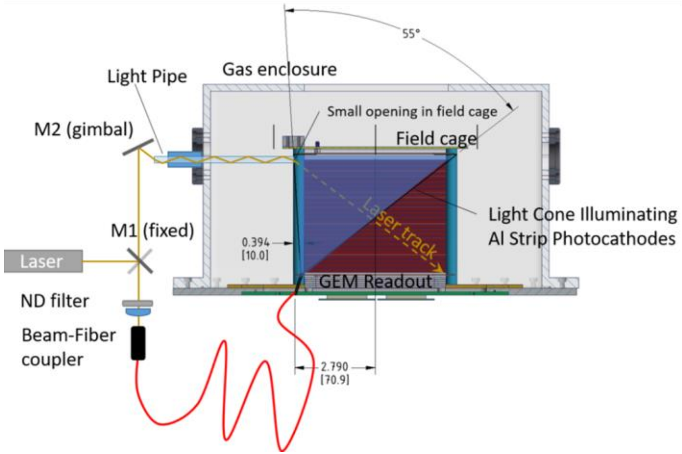
- A direct performance comparison of a zigzag (ZZ) and straight (SS) anode pad readout was made at a beam test using 3 different MPGD technologies.



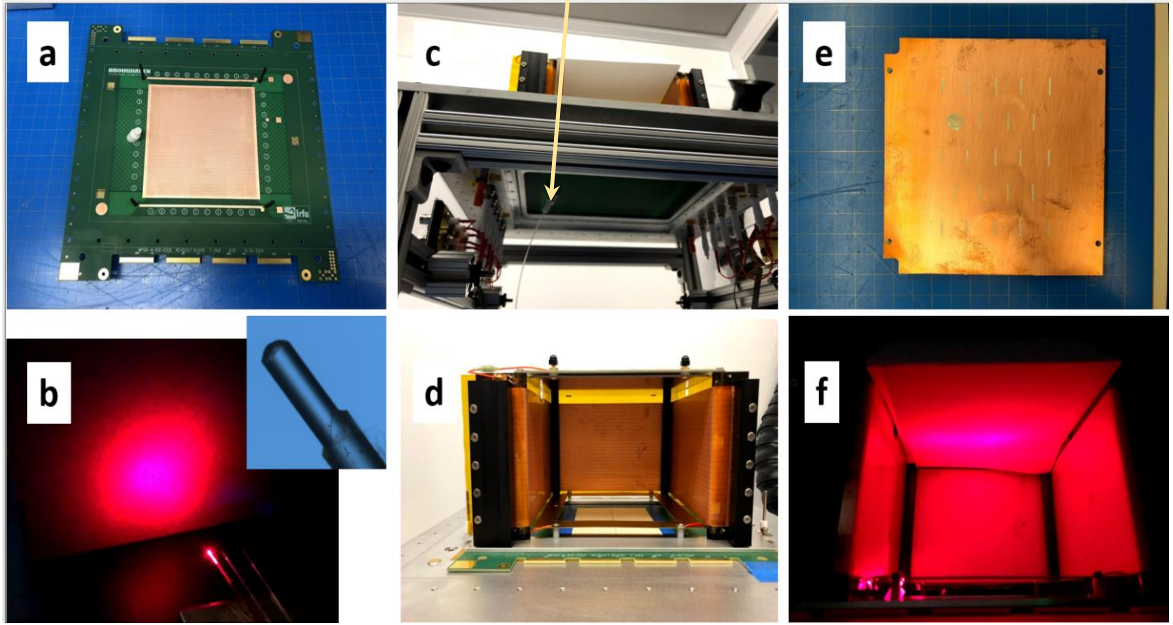
- SS readouts have a single operational parameter (ie, pitch), whereas ZZs have three (ie, pitch, stretch, period), allowing a larger parameter space for the optimization process
- Optimized ZZ patterns have a virtually uniform detector response with excellent position resolution and do not require pad response functions (PRFs)
- At larger pitch (>1mm), the resolution of SS patterns deteriorates significantly, even if a PRF is employed
- In contrast, *optimized* ZZs maintain a highly uniform response at large pitch and present a viable, LOW channel count alternative (assuming occupancy is not an issue)
- NEXT STEPS: This study is complete



Barrel Tracker: Laser Calibration Prototype



TPC R/O ZZ PCB | Fiber entering TPC volume through r/o PCB | Al photocathodes on Field Cage Cathode

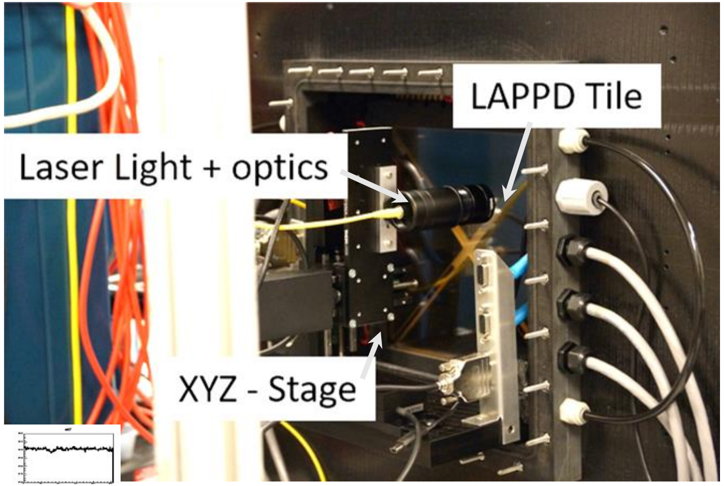


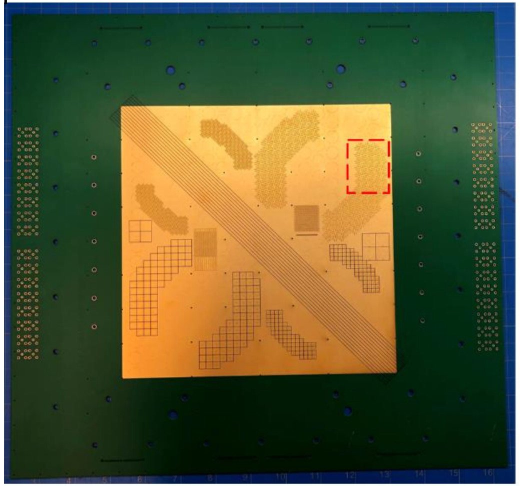
Sculpted tip fiber helps to de-focus light | Field Cage | Illuminated Field Cage Cathode

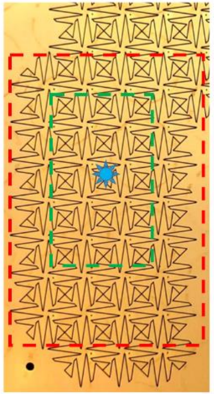
- Progress made testing **two** Laser-based calibration methods for a TPC in our mini-TPC setup
- Meant to correct distortions in TPC drift volume due to space charge buildup
  - Diffuse Laser illumination of Al photocathode pattern on field cage cathode (e)
  - Tested fiber-based source of diffuse laser light to illumination cathode (b, f)
  - Can redirect laser upward to deliver laser beams into the TPC to create ionization tracks
  - NEXT STEPS: Fully assemble TPC prototype and test both calibration schemes

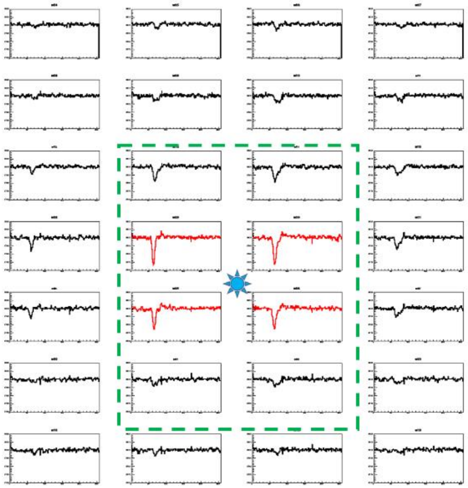
Barrel Tracker: Application of MPGD-style Interleaved Readouts for LAPPDs

- **L**arge **A**rea **P**icosecond **P**hoto-**D**etectors (LAPPDs): Micro-channel-based, Large Area (400cm^2), Low profile (~2cm), High gain ($10^{7,}$ single photons), High QE (25% @ 365nm), Fast (~10ps transit time spread), High spatial resolution (Few 100µm(?))
- Suited for high performance ToF and RICH applications for PID
- May also be used to extract high resolution space points from energetic particles generating Cherenkov radiation in the entrance window
- We mechanically coupled a highly interleaved, MPGD-style anode readout pattern to the back of the LAPPD tile to measure capacitively induced charge on our readout plane
- Initial goal is to measure high spatial resolution (<<pitch/sqrt(12)) from single photons









Initial results:

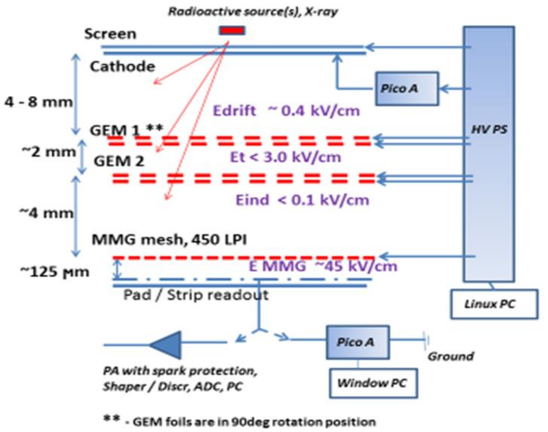
- Focused 420nm laser light to a 20µm diam. point
- Initial results show signals with good S/N ratio
- Many more pads fire than expected → investigating
- Recently managed to see single photon response (analysis pending)

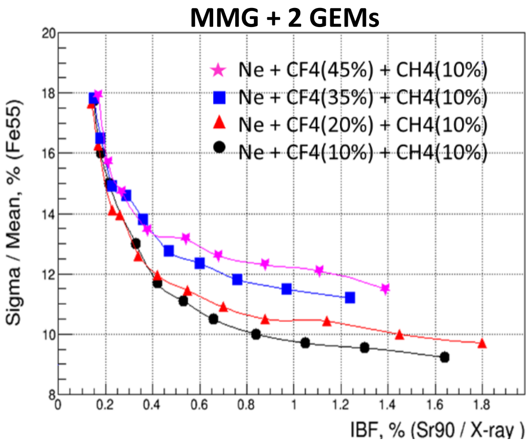
NEXT STEPS: finalize res. measurements, followed by beam test w/ mRICH

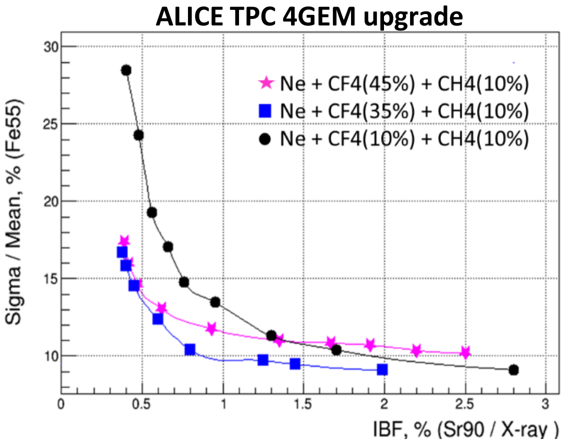
Yale University

Barrel Tracker: IBF w/ MMG + 2GEM Hybrid MPGD

- MPGD-based readout options for a high rate TPC at EIC
  - Ne+CF_4 gas mixtures and two gain elements studied: 4GEM (ALICE-style w/ specialized foils) & 2GEM+MMG (hybrid)
  - Gain structures exploit large gap field ratios to suppress IBF





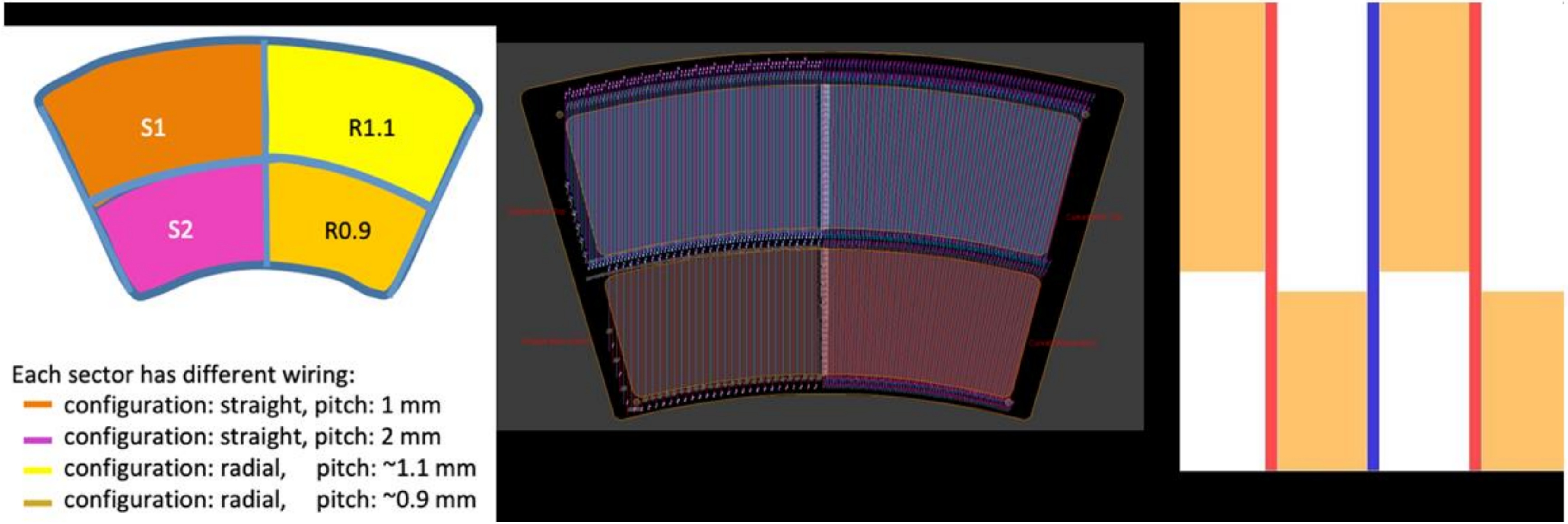


- Excellent IBF performance for both MPGD options, though the hybrid option excelled and requires a smaller max operating voltage:
  - Best IBF results for 12% E. Res: 0.40% (MMG + 2 GEMs) and 0.60% (4 GEMs)
  - Best IBF results for 16% E. Res: 0.18% (MMG + 2 GEMs) and 0.40% (4 GEMs)
  - The hybrid option also was subject to a stability test and did not spark after 7hrs of operation
  - In the event of a spark, a resistive layer on the readout reduces the gain drop from sparking to negligible levels

NEXT STEPS: perform beam test of TPC prototype with hybrid gain option, configured for min. IBF

Barrel Tracker: TPC R&D @ SBU

- Static bi-polar gating grid
  - Simulations for large parameter space
    - Wire diameter, pitch, potential across wires, various gas mixtures …
  - Test in magnetic field environment → planning test at ANL magnet facility with B up to 5 T
  - PCB based frame with attached wires + providing appropriate potentials



Stony Brook University

Barrel Tracker: TPC R&D @ SBU

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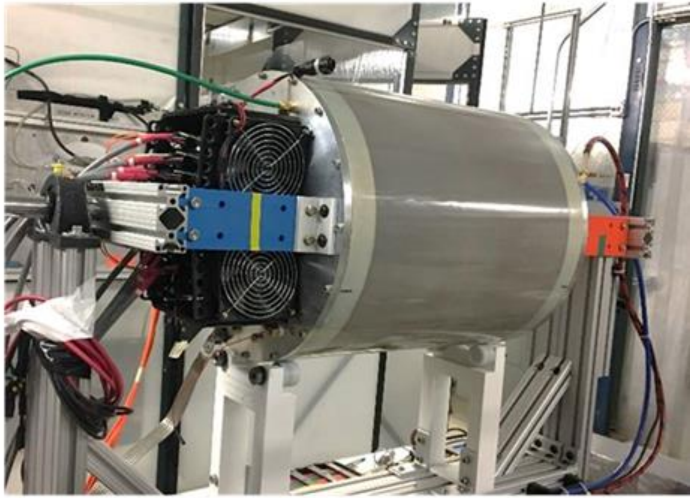
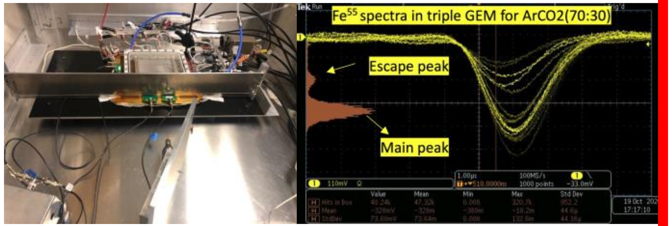


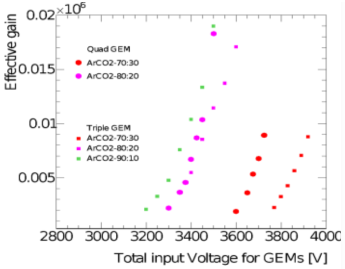
Barrel Tracker: TPC R&D @ VU

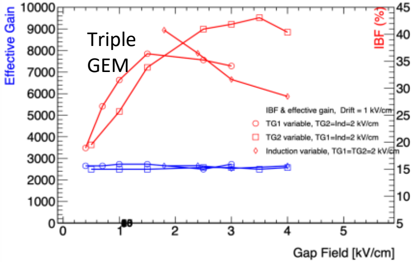
VANDERBILT UNIVERSITY

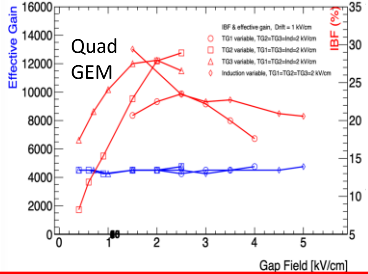
- Completion of MPGD R&D bench set up.
- Preliminary studies for IBF , effective gain scan for both triple and quad gem detector with Argon based gas mixture was done.



- Effective gain scanning for triple and quad gem with ArCO2 (70:30, 80:20, 90:10) was done.
- IBF suppression for both triple and quad gem with standard 10x10 cm^2 was done using ArCO2(70-30) gas mixture.
- More studies on IBF suppression, energy resolution for potential use in PID will be performed using varying pitch GEM layers, along with GEM + MMG hybrid detector for both Ar and Ne based gas mixtures .

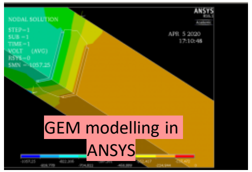


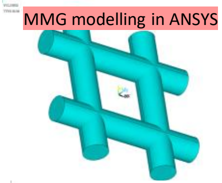


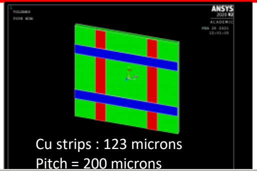


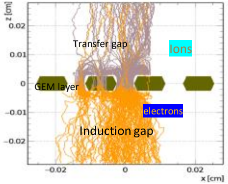
Simulation studies :

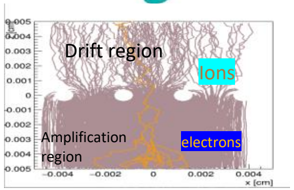
- Initial study of gas avalanche for GEMs and MMG using Finite Element Analysis (FEA) and Garfield++ was done.
- Modelling of standard MPGD readout board is complete and effort is ongoing to implement it to standard pitch GEM and Micromega within FEA+GARFIELD++ simulation framework.
- In future more simulation studies on different readout patterns will be carried out in collaboration with BNL.
- Effort is also ongoing for tracking performance in Fun4All simulation framework using TPC as the main barrel tracker.

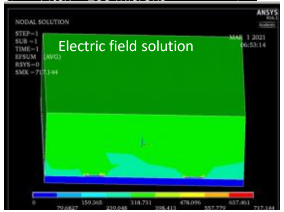












SUMMARY of Barrel Tracker: TPC

SUMMARY

Development Goals

- A Time Projection Chamber (TPC) is one of the preferred central detector options at EIC for its tracking and dE/dx measurement capabilities. However, we focus mainly on developing the endcap readout options only, including the gain element, the anode plane, and optimizations intent on minimizing IBF.

Accomplishments to Date

- Progress on a) identifying an optimized readout plane with zigzag-shaped pads, b) operating a Micromegas + 2GEM gain element with an appropriately chosen gas mixture to minimize IBF, and c) investigating a *passive* bi-polar gating grid to provide additional IBF suppression

Technological Readiness

- Experience developing sPHENIX TPC, including the production of prototype with 40cm drift (w/ beam test results)
- Demonstrated the ability of coarsely segmented zigzag pads to deliver excellent position resolution with a very uniform response
- Developed a hybrid MPGD option, once paired with the appropriate gas mixture is capable of reducing IBF to acceptable levels, while maintaining very good energy resolution
- A passive gating grid option has been shown through simulation to provide additional IBF suppression

Work remaining for a TDR

- The work to generate a TDR for a full TPC is extensive and beyond the purview of this group. However, the major work required to fully develop a TPC endcap readout includes more detailed studies of these readout options integrated with a long (~1m) drift volume and investigations into ways of minimizing material at the endcaps

Cost estimate and timelines

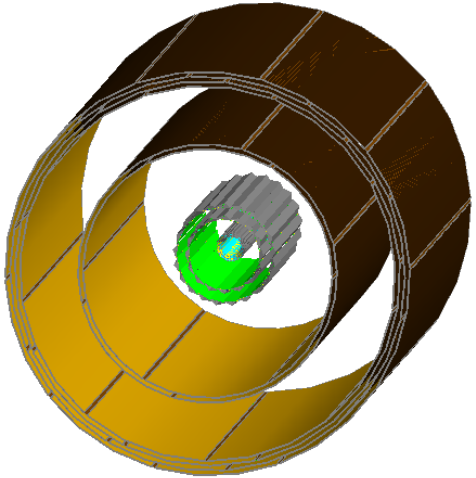
- Because the development of a full TPC is outside the scope of this group, we cannot provide a fully informed cost estimate, however based on our experience with the sPHENIX TPC, the needed cost to develop a viable design for a TDR is likely of the order of a few $100K and would require several years to complete.

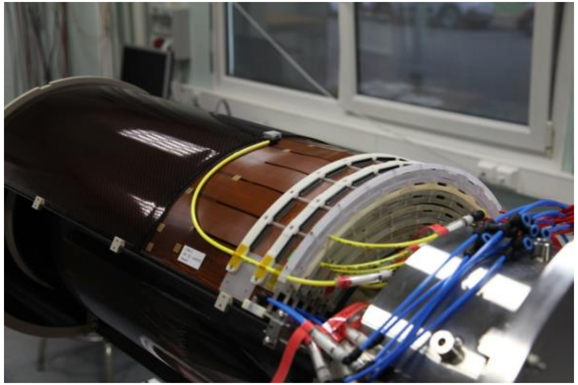
Barrel Tracker: Cylindrical Micromegas

Barrel Tracker: Cylindrical Micromegas @ CEA Saclay

Simulation studies:

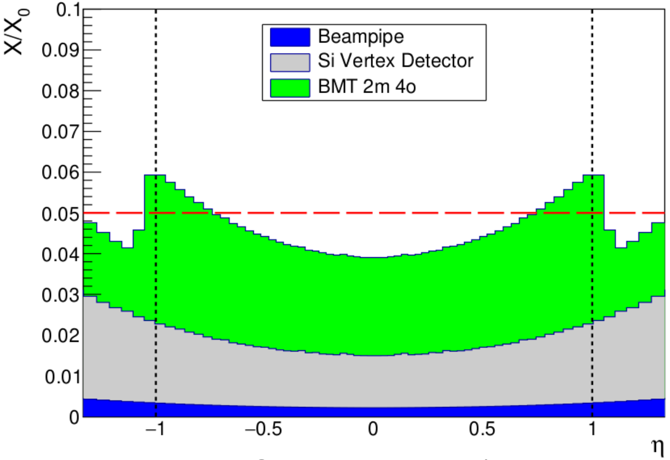
- Hybrid detector: silicon vertex detector + gaseous barrel tracker
- Micromegas tiles arranged in concentric cylindrical layers
- Each tile is about 50cm wide
- Technology based on CLAS12 Micromegas, with 2D readout
- Assumed resolutions: 150µm both in rφ and z directions
- Six layers tracker well within material budget requirements
- Several layer geometries tested

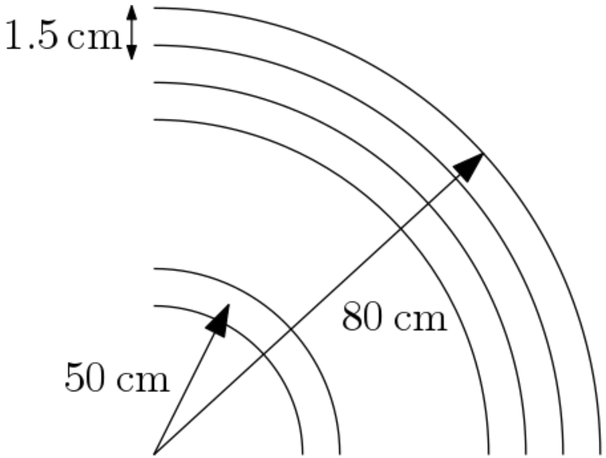




CLAS12 BMT

Material budget from Geant4





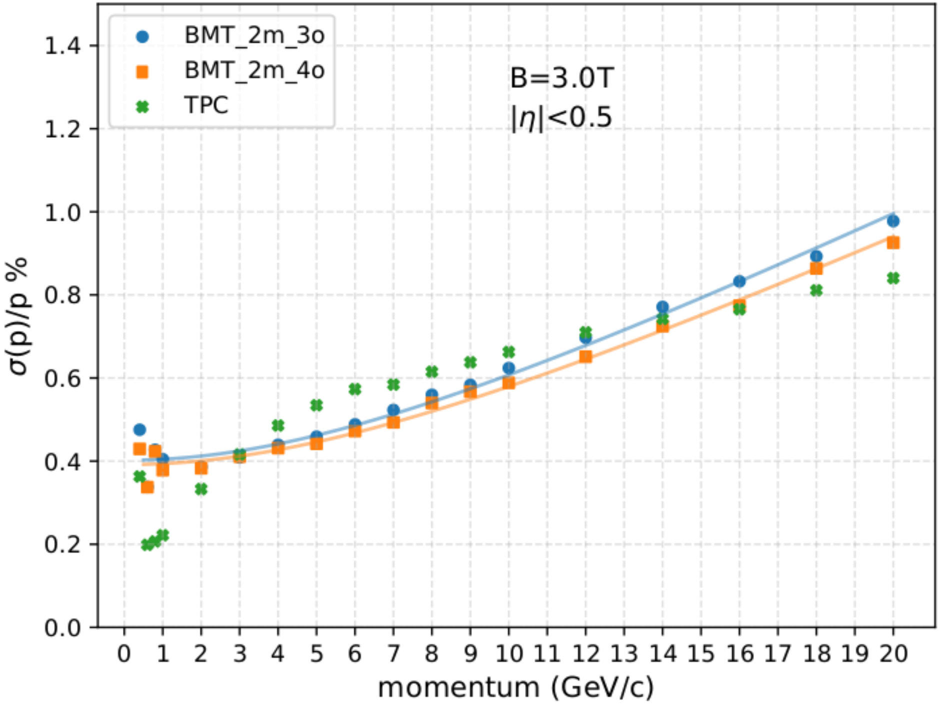
Barrel Tracker: Cylindrical Micromegas @ CEA Saclay

Simulation studies:

- Results published in the YR
- The Micromegas hybrid detector momentum resolution is similar to the TPC hybrid detector
- The momentum resolution at B=3T is compatible with physics requirements

Next steps:

- The goal is to reduce the material budget even further and to simplify the production and installation
- Implement a new detector geometry, with flat detector modules
- A flat light prototype is begin designed and it will be built in Saclay this year
- Optimization of the readout pattern for 2D readout ongoing



SUMMARY of Barrel Tracker: Cylindrical Micromegas @ CEA Saclay

SUMMARY

Development Goals

- Design and optimisation of a cylindrical MPGD tracker for a hybrid EIC detector

Accomplishments to Date

- Simulations studies using the CLAS12 detector technology

Technological Readiness

- Simulation results at B=3T are compatible with the physics requirements
- The material budget is within the limits of 5% X/X0

Work remaining for a TDR

- Optimise the 2D readout patterns to achieve the design resolutions
- Explore a ultra light technology, with modular flat design, that will simplify the production and the detector installation

Cost estimate and timelines

- A small demonstrator for ultra light technology will be built this year
- A small batch of prototypes is foreseen for the 2D readout optimisation

Barrel Fast Tracking Layer: Cylindrical µRWELL

FLORIDA TECH

TEMPLE UNIVERSITY

UNIVERSITY of VIRGINIA

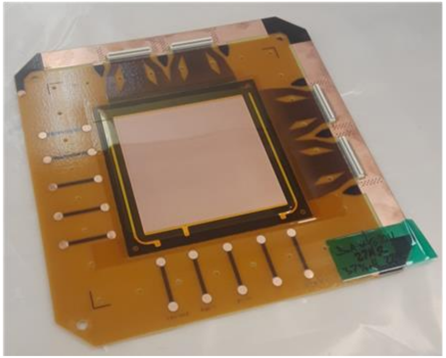
Barrel Fast Tracking Layer: Cylindrical µRWELL @ Temple

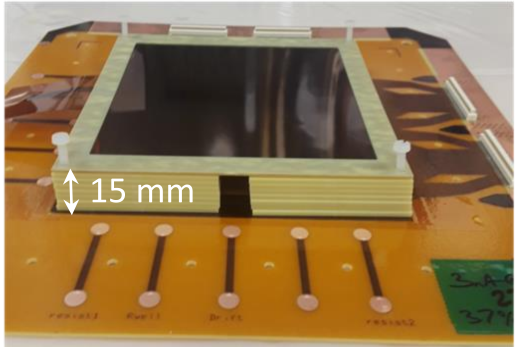
Impact of cylindrical µRWELL

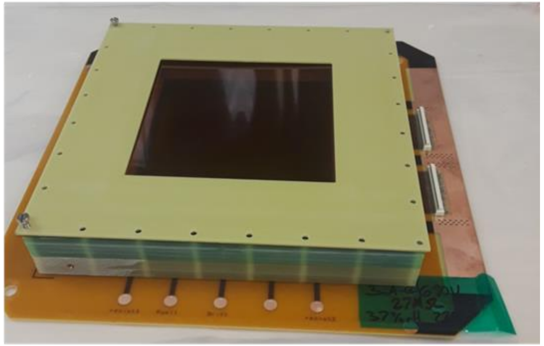
- Simulation shows two cylindrical µRWELLs located before and after a DIRC detector can improve momentum and angular reconstruction resolutions.
- These layers can help seed particle identification in a DIRC by providing tracking information.
- Write-up of the study is included in the EIC Yellow Report.

µRWELL µTPC

- Build and test a 10 cm x 10 cm planar µRWELL detector operating in µTPC mode to study performance and aid in simulation detector response.
- Detector is designed to have a drift gap of 15 mm without the use of a field cage.
- After several delays, the detector has now been acquired from CERN.





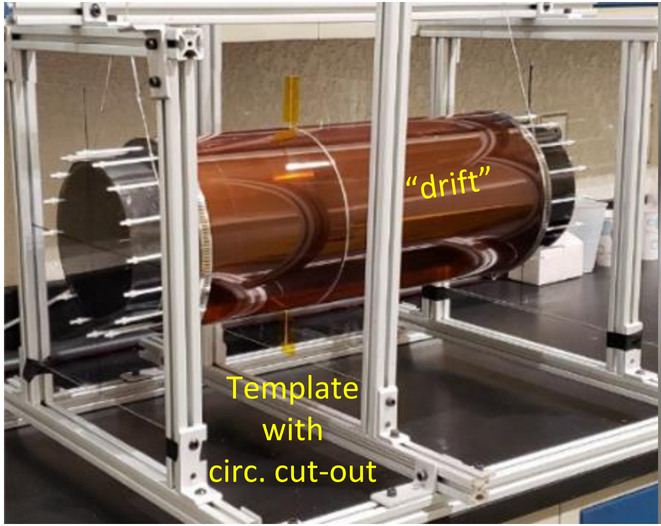


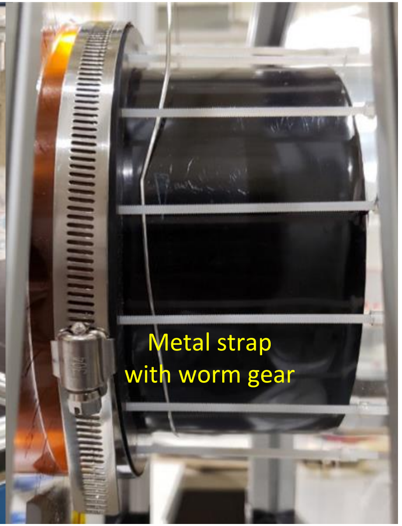
FLORIDA TECH

Barrel Fast Tracking Layer: Cylindrical µRWELL @ FIT

Further Development of Mechanical Mock-up:

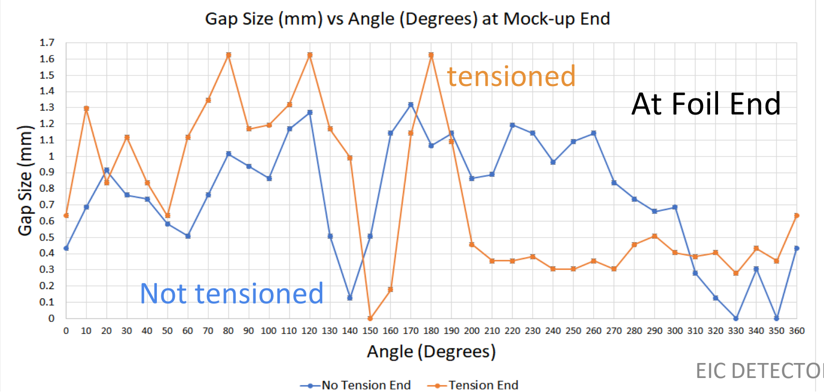
- Increase thickness of “drift” foil: 2 mil → 5 mil
- Splice together foil ends w/ 2 mil adhes. kapton tape
- Replace closing ring with metal strap tightened via worm gear to improve tension & seal for drift foil
  ⇒ *Results now in a visually smooth foil cylinder*

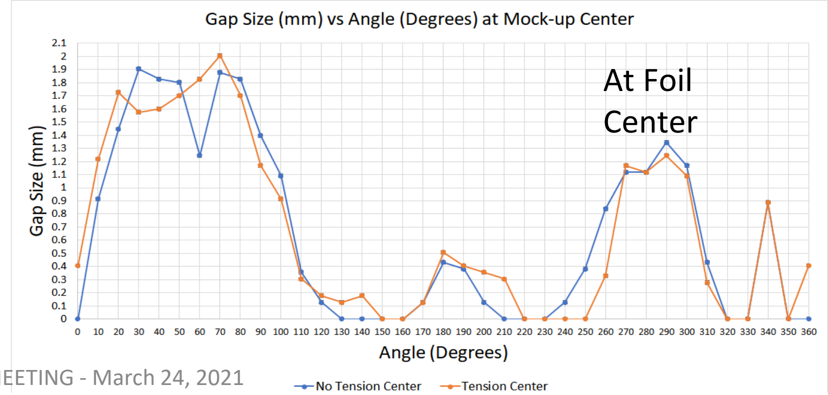




Per reviewer’s suggestion at last review, performed QC:

- Measure gap size between drift foil and a template with “perfect” circular cut-out
- Max. meas. deviation from circle is 2 mm (1% of diam.)
- Corresponds to max. variation in drift gap size of 13%. Tolerable if $v_{drift}(E)$ is on plateau. Will work to minimize.

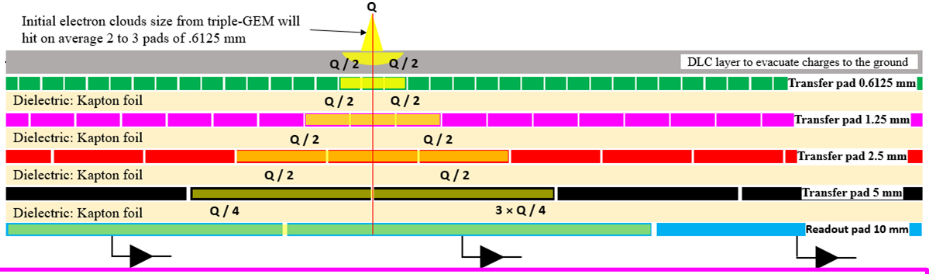




Capacitive-Sharing Readout for MPGDs: Performance of the prototype

Principle of capacitive-sharing large-pad Readout

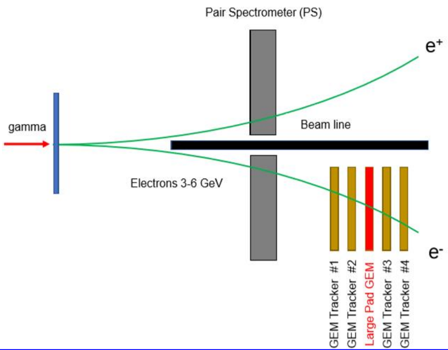
- Vertical stack of pads layers ⇨ charges transfer from layer to layer via capacitive coupling
- The arrangement of pad geometry and size from layer to layer ensures:
  - **Excellent spatial resolution expected for 1 cm^2 pad: < 150 µm**
- Concept easily expanded with strip readout (X-Y, U-V, X-U-V …)
  - significant reduction of number of electronic channels
- Low cost technology, large area capability and high degree of flexibility
  - Application: R/O planes for MPGDs, GEM-RICH, LAPPD …
- 1 cm^2 pad prototype ⇨ **a resolution better than 190 µm was achieved**

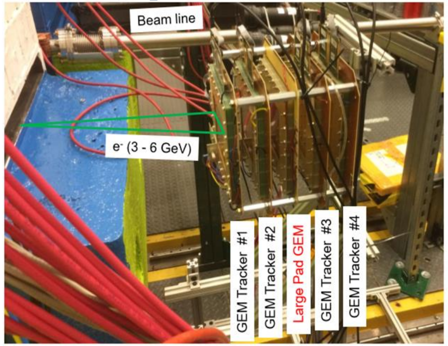


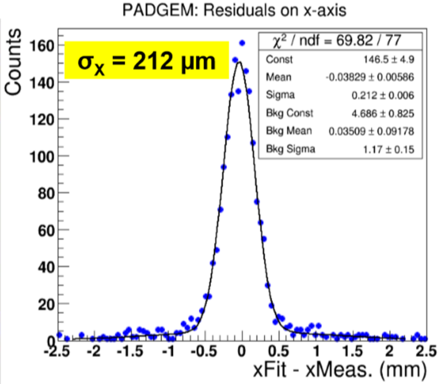
Beam test in Hall D @ JLab (2020): Spatial resolution performances

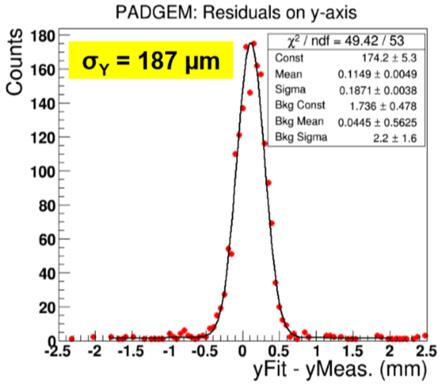
- 1 cm × 1 cm pad capacitive-sharing prototype + 3 X-Y COMPASS GEMs
- 3 – 6 GeV electron beam, e- tracks angle: 7 degree in x and 2 degree in y
- Spatial resolution **212 µm and 187** µm in x and y respectively, slightly worse result in x due to large incoming track angle effect

Beam test setup in Hall D @ JLab (Sept. 2020)









Capacitive-Sharing Readout for MPGDs: Ongoing R&D plans

Prototype #2: Capacitive-Sharing Pad readout

- ❑ 4 capacitive sharing layers with pad readout: 9 mm × 9 mm pad pitch
- ❑ Several improvements implemented w.r.t prototype #1:
  - ⇨ R/O split in 4 quadrants to study effect of inter pad gap (40 μm, 45 μm, 50 μm, 60 μm)
  - ⇨ Pad trace to connectors: width from 200 um in first proto to 50 um to reduce noise
  - ⇨ Better shielding of pad trace layers to reduce cross talk and noise
- ❑ **Prototype will be tested at FNAL June 2021**

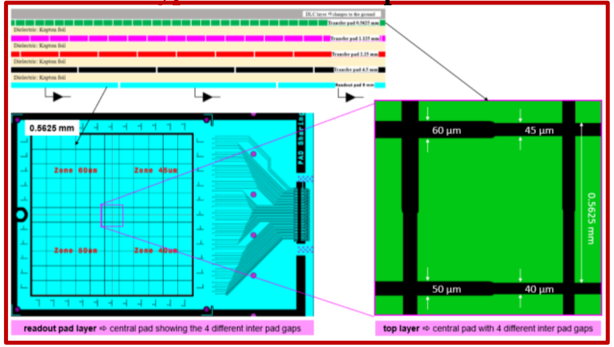
Prototype #3: Capacitive-sharing X-Y Strips readout

- ❑ Same concept as pad R/O with less channel to read out and less pad sharing layers (low mass)
- ❑ Less pad sharing layers and channel counts for similar spatial resolution performances
- ❑ 2 capacitive sharing layers + 2D straight strip / pad-like strip readout with **800 μm pitch**
- ❑ **Prototypes with GEM & μRWELL amplification will be tested at FNAL June 2021**

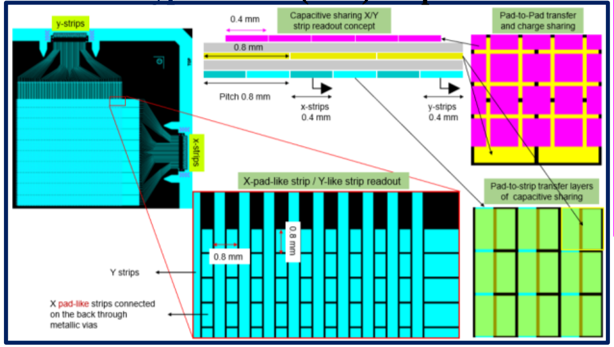
Application for MPGD tracking and PID for EIC

- ❑ Cylindrical μRWELL Tracker: Large capacitive-sharing (U-V) strip readout with angle: 90°, pitch: 2 to 4 mm, (rφ,z) resolution: 100 μm
- ❑ Forward / Backward MPGD Tracker: capacitive-sharing U-V strip readout with 30° degree stereo anngle, pitch: 2 to 4 mm, (rφ, r) resolution: 100 μm × 400 μm
- ❑ GEM-TRD readout: Large capacitive-sharing radial (r,φ) strip readout, pitch: 2 to 4 mm, (rφ, r) resolution: 100 μm × 100 μm
- ❑ TPC MPGD readout: Capacitive-sharing pad readout: pad pitch up to 4 mm × 20 mm, expected space points resolution better ~50 to 100 μm
- ❑ GEM-RICH readout: Capacitive-sharing pad readout: pad pitch up to 5 mm × 5 mm, with < 200 μm space points resolution achievable
- ❑ LAPPD, mRICH readout: Possible applications?

Prototype #2: 9 m x 9 m pad readout



Prototype #3: 2D (X-Y) strip readout

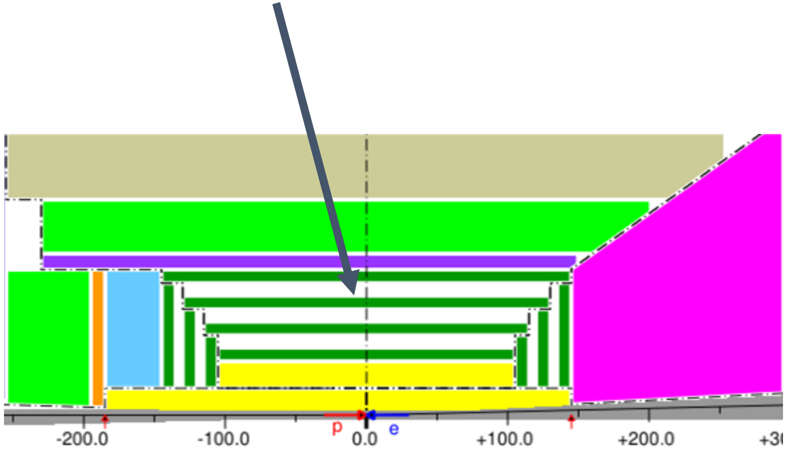


Barrel Fast Tracking Layer: Cylindrical µRWELL – NEXT STEPS

Objective: Focus the R&D on a full-size *µ*RWELL tracker with multiple layers for Dec proposal

Corresponding next R&D Tasks:

1) Functional small µRWELL prototype
   - FIT: Develop mechanics based on experience with mock-up
   - Temple U: Develop Electronics and DAQ
   - UVa: Design µRWELL foil & capacitive-sharing U/V strip R/O
   - All: Performance testing including a beam test



SiMPLE: **Si**+**MP**GD in **L**arge **E**xp. Design

2) Full-size mechanical mock-up (FIT)
   - Design & build metallic end-ring structure with ca. 2m diameter and ca. 2m length
   - Splice multiple foils together to form cylinders
   - Quality control & Evaluation

3) Simulation:
   - Optimize "SiMPLE" design for tracking, dE/dx, and material allocation
   - Implement µTPC mode for cylindrical µRWELL detectors to allow reconstruction of tracklets
   - Study the impact of µRWELL tracking on DIRC PID

SiMPLE @ IP6: Silicon and Micro Pattern Gaseous Detector for Large Experiment

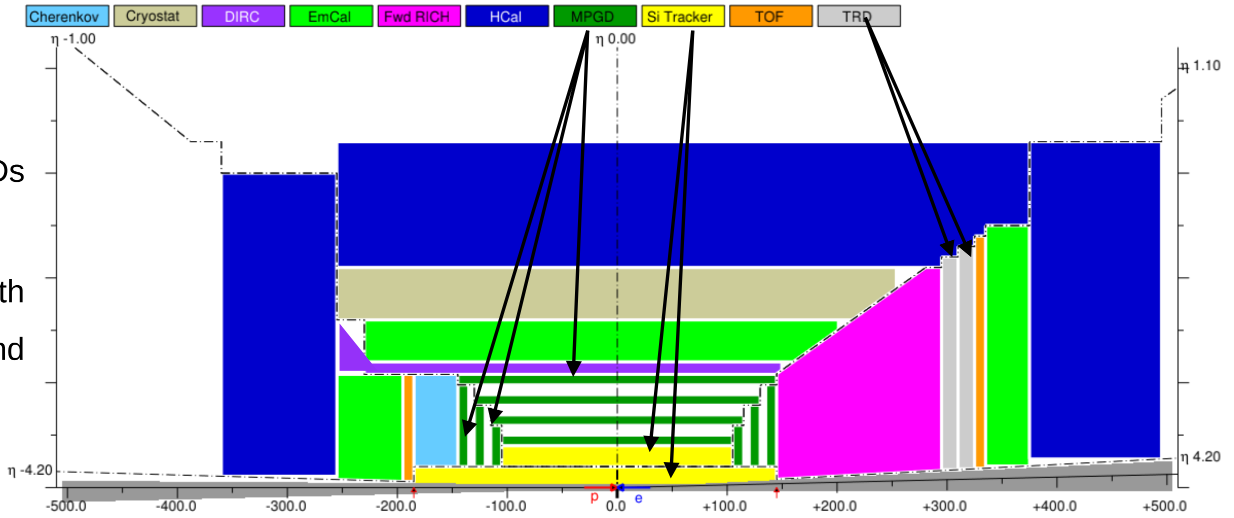
We are the tracking detector collaboration Yulia's is looking for for the EIC@IP6 Collaboration! It is as **SiMPLE** as that

SiMPLE: The collaboration for hybrid Si+MPGD tracking detector for EIC @ IP6

See Yulia's talk at the IP2@EIC workshop 17-19 March 2021

https://indico.bnl.gov/event/10677/contributions/46855/attachments/33157/53166/EICatIP6_v2.pptx

- SiMPLE is a starting point deriving from a ToyModel cartoon describing the idea we want to coalesce around
- Not a frozen configuration, MAPS + MPGDs configuration is not finalized
- Already an international collaboration with big France, UK and China institutions and universities as major players
- Open to and expect new members
- Several US institutions



SiMPLE @ IP6: a detector design

SUMMARY of Barrel Fast Tracking Layer: Cylindrical µRWELL

SUMMARY

Development Goals

- Design and optimization of cylindrical µRWELL for tracking and PID for a hybrid EIC detector

Accomplishments to Date

- Simulations in progress and small mechanical mockup built

Technological Readiness

- Planar µRWELL detectors have been shown to be a viable MPGD technology with good performance characteristics for tracking applications
- A fully functional cylindrical µRWELL detector is yet to be demonstrated

Work remaining for a TDR

- Build and test a small (20 cm diam. and 55 cm long) functional cylindrical µRWELL tracking layer that operates in µTPC mode
- Build a full-size mock-up of the mechanics
- Assess for mechanical stability and tracking performance

Cost estimate and timelines

- ~2 years (includes building prototype, beam test campaign, and analysis of results)
- ~$140k over two years

End Cap GEM Tracker

TEMPLE UNIVERSITY

FLORIDA TECH

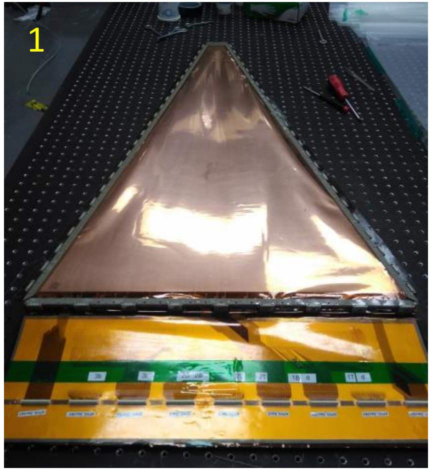
UNIVERSITY of VIRGINIA

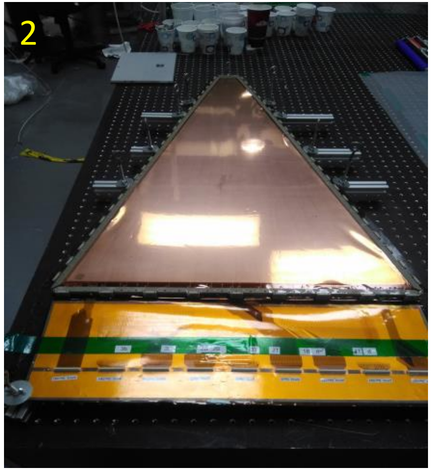
End Cap Tracker: GEM with Carbon Fiber Frame @ FIT

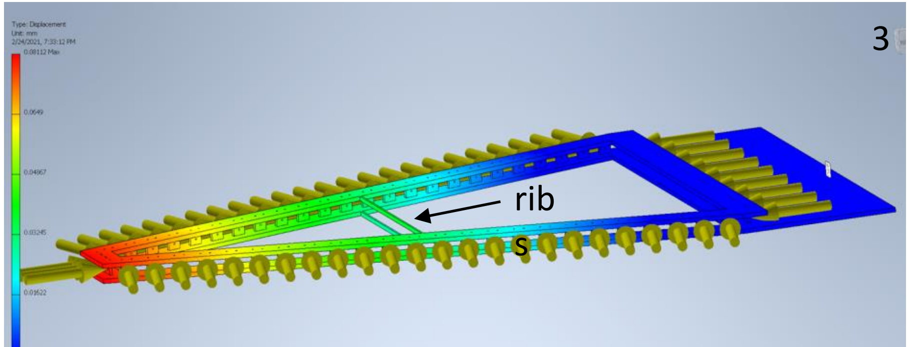
- **Rebuilt detector** using new PEEK inner frames; assembled detector did not have any shorts between foils as long as the lower carbon fiber frame was fixed to the optical table
- Once released from the optical table, shorts reappeared (fig.1); we attempted to make a mobile external support structure (fig.2) to remove the shorts, which had a clear positive effect on the tension of the foils, but ultimately we could not permanently remove shorts reliably
- **We believe we have singled out the *material and geometry of the carbon fiber frames* as the main point of failure.**

- Currently designing a new frame assembly with thicker commercial carbon fiber and modeling the forces on this frame and the resulting deformation (fig.3)
- Adding a single 3 mm wide central support "rib" to the region of greatest deformation reduces the simulated deformation in the frame from 2.886 mm to 0.226 mm.
- Material for new CF frame is already procured

- **NEXT STEPS for Dec proposal:**
  - Final rebuild of prototype and commissioning
  - Beam test at FNAL if detector works
  - If successful, incorporate detailed design and material specifications into fun4all simulations for performance





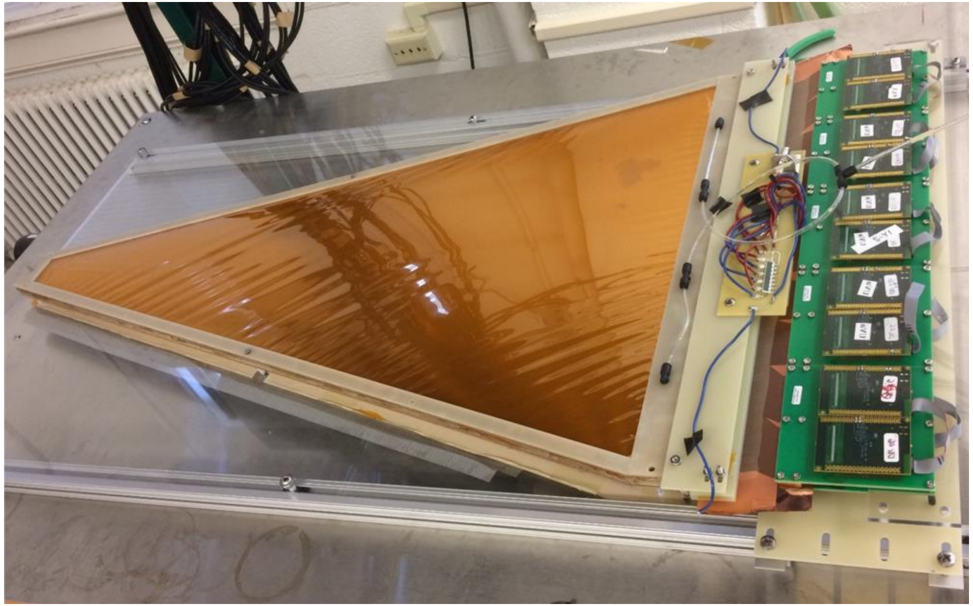


Finite element analysis of new CF frame design

University of Virginia

End Cap Tracker: Large GEM @ UVa

Large size & low mass GEM with U-V Strip readout



What was achieved and status of the R&D

- ❑ Ultra low mass triple GEM detector 0.4% X/X_0
- ❑ 2D U-V strip readout with zebra connectors ⇨ All electronics channels on one side (outer edge)
- ❑ Prototype tested in beam test at Fermilab in 2018

  ⇨ Measured spatial resolution 115 μm

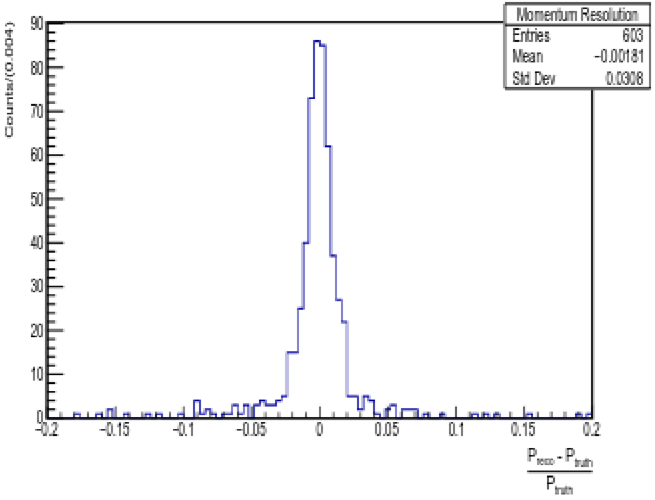
To complete the R&D program

- ❑ Test different zebra connectors for optimization of the prototype and fix gas window / drift foils.
- ❑ second beam test at FTBF Fermilab (Summer 2021
  - Complete the spatial resolution studies
- ❑ Plan is to complete the R&D on large GEM by January 2022

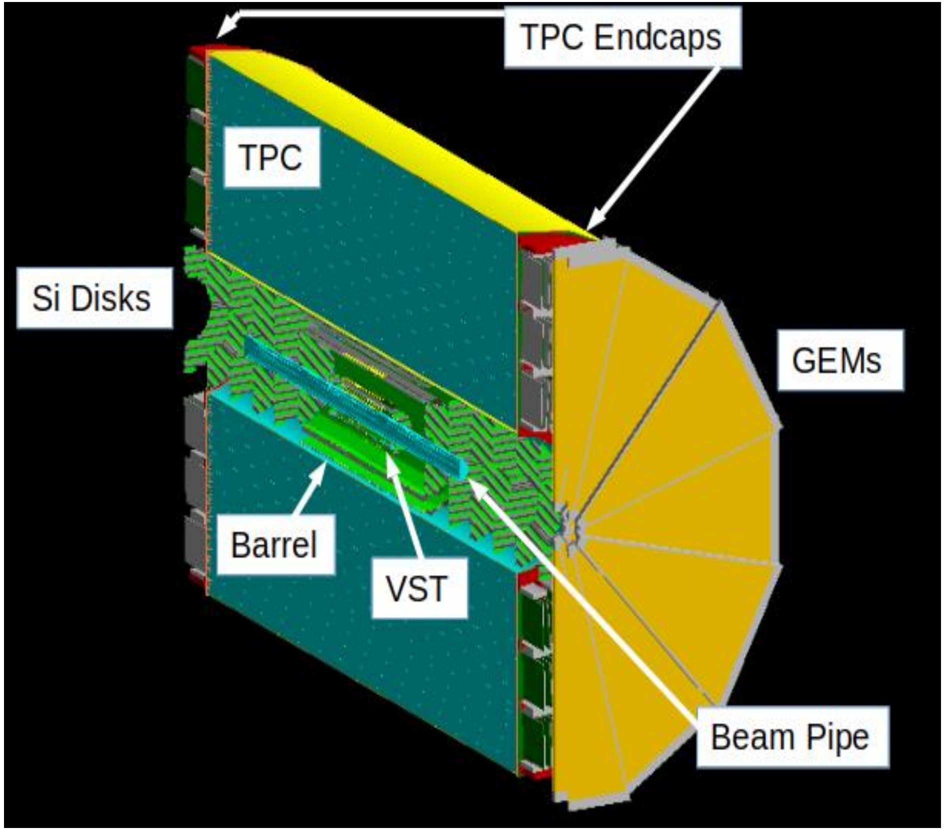
End Cap Tracker: Simulation @ FIT & Temple

MPGD Endcap Simulation Progress

- Students are **integrating multiple detector elements into Fun4All environment.** Including TPC, vertex detector, Si disks, and endcap GEMs.
- Very preliminary first results from resolution study: For 10 GeV pions, the momentum resolution averaged over $0 < \eta < 4$ is found to be 3.1%
- Some difficulty with overlaps in Si geometry



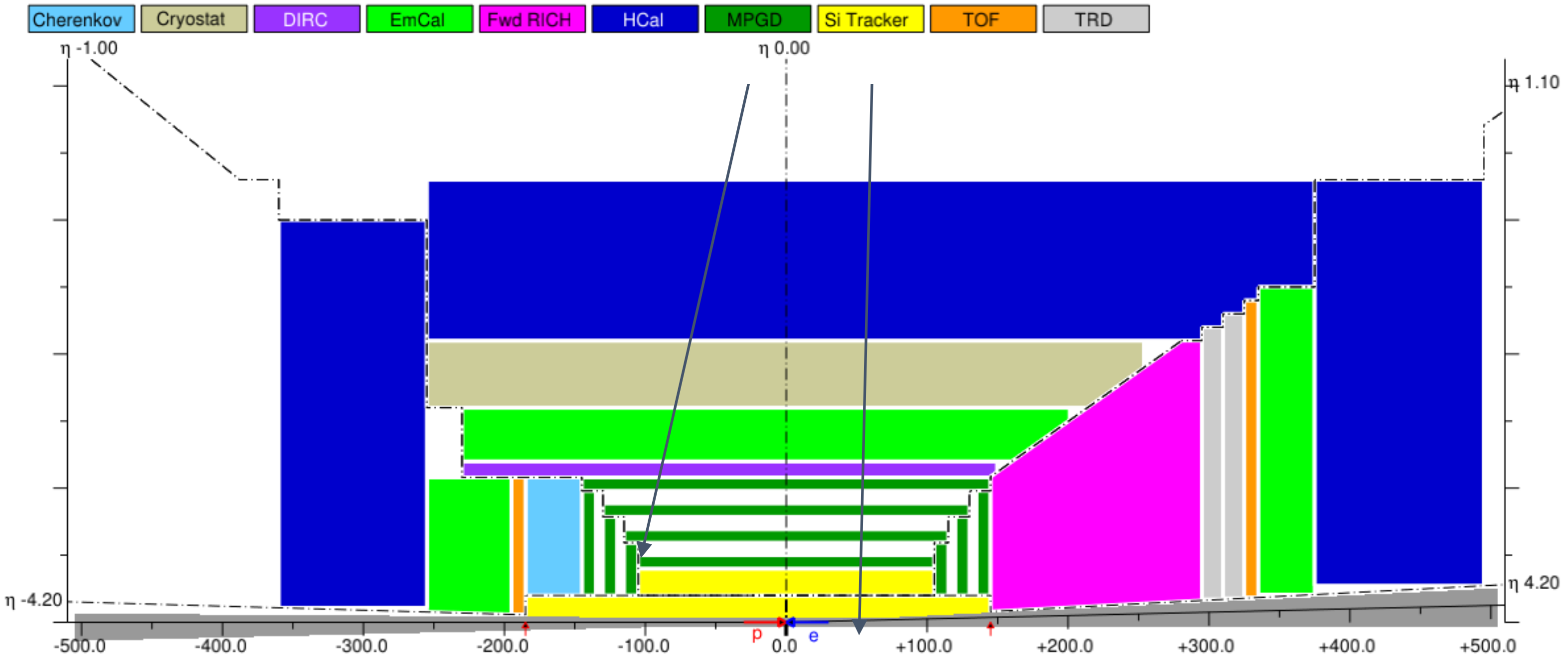
Fun4All Geometry of EIC Hybrid Model



End Cap Tracker: Simulation @ FIT & Temple - NEXT STEPS

- Replace TPC with cylindrical MPGD trackers (μRWELL) plus several planar endcap layers (GEM or μRWELL) of varying size
- Study resolutions and impact of material on tracking performance

Proposed simulation geometry for Silicon and MPGD hybrid tracking detector



SUMMARY of End Cap Tracker

SUMMARY

Development Goals

- Design and optimization of large-area and low-mass MPGD trackers

Accomplishments to Date

- Two large-area (~60 cm x 100 cm) triple-GEM prototypes built using different assembly techniques and readout patterns
- One triple-GEM prototype successfully tested in beam, the other is being refurbished for potential beam test
- Small area planar µRWELL detectors were built and successfully tested in beam

Technological Readiness

- GEM technology is mature with performance and limitations well known
- µRWELLs have been demonstrated to be a viable tracking detector

Work remaining for a TDR

- A final triple-GEM tracker design needs to be chosen based on prototype results
- Large-area µRWELL needs additional development
- Standard µRWELL material budget needs to be reduced

Cost estimate and timelines

- Triple-GEM prototype trackers do not need additional funds
- Jefferson Lab has recently dedicated R&D to large-area µRWELLs, expected to be completed within a year. We will reassess then if further R&D is needed for use at the EIC.

Particle ID

Particle ID: MPGD-based Photon Detectors for RICH @ INFN

INTRODUCTION

MPGD-based Photon Detectors for RICH

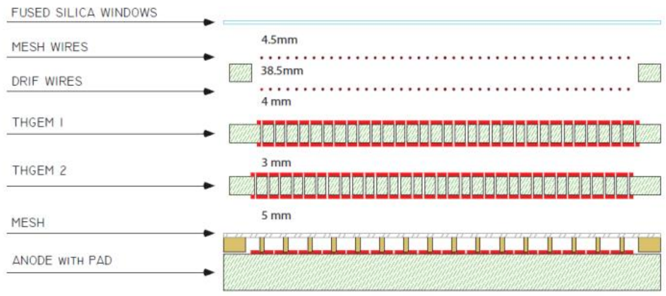
- **Technology demonstrated** with the application in COMPASS RICH upgrade, in operation since 2016
- @EIC, the application in a collider environment, imposes the design of a **compact RICH for high momentum h-PID** (possible by the windowless-RICH approach to detect very far UV photons (~120nm) to increase the Cherenkov photon rate) → **2 DEVELOPMENT LINES**

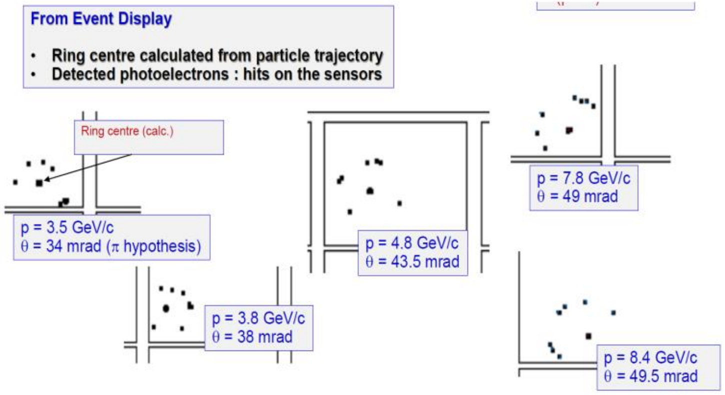
  i. **upgrade detector architecture and operation**
  ii. **Introduce new photocathode material for gas detectors**

RELEVANT IMPACT OF THE PANDEMIC EMERGENCY

- "random" impact on activities
- activity (i) more heavily affected than activity (ii)

Starting point: COMPASS experience





Particle ID: MPGD-based Photon Detectors for RICH @ INFN

SUMMARY, 1/2

i. Upgrade detector architecture and operation

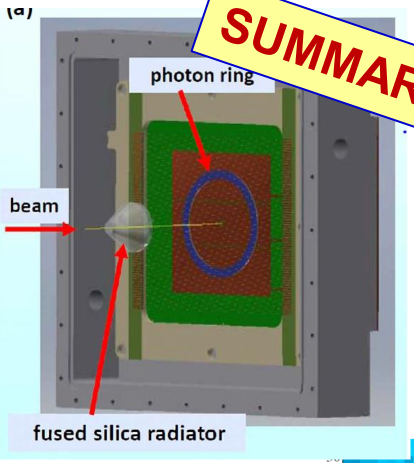
Development Goals
- miniaturization of the read-out pads because of reduced lever arm in compact RICH
- validation of the read-out with the VMM3 front-end chip (streaming read-out compatible) for single photon detection.

Accomplishments to Date
- First version prototype realized, tested in lab and on beam
- Second version under construction (*)
- Tests of read-out with VMM3 in preparation (procurements completed) (*)

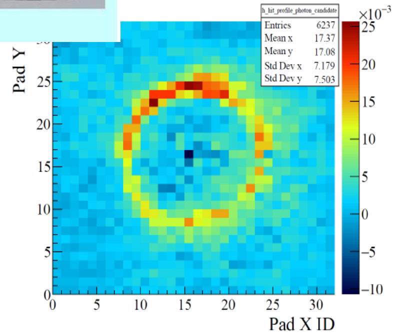
Technological Readiness
- prototype demonstrated in a test beam environment

Work remaining for a TDR
- Construction and test of prototype version 2 and test of read-out with VMM3

Cost estimate and timelines
- 24 months required (**)
- 1 y cover by available resources not used (pandemic), 40k$ for the second y



Prototype, version 1



(*) severely delayed by pandemic emergency
(**) assuming no further delay due to emergency

ii. new photocathode material for gas detectors

SUMMARY, 2/2

Development Goals

- CsI (so far, the only photoconverter for gaseous detectors) is fragile (water vapor, ion bombardment) → Hydrogenated NanoDiamond (H-ND) expected more robust
- establishing the use of H-ND in gaseous detectors
- determine the key parameter of ND powders to obtain maximum and reproducible QE

Accomplishments to Date

- assessment of the compatibility of the novel photoconverter with gaseous detectors is well advanced
- Study of ND powder characteristics in an initial stage

Technological Readiness

- Prototypes demonstrated in laboratory environment

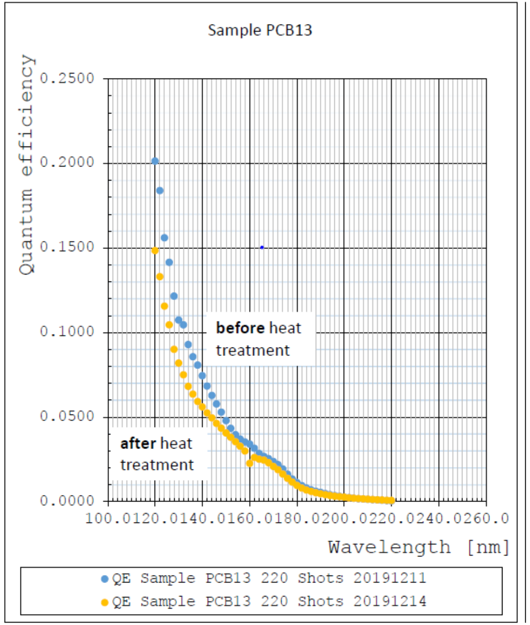
Work remaining for a TDR

- Not expected ready for TDR: option for upgrade that can be selected later

Cost estimate and timelines

- 3-4 y to completion
- ~ 100k$ in total over the 4 y

Studies of H-ND QE



Particle ID: MPGD-based Photon Detectors for RICH @ INFN

PERIOD REPORT, 1/2

i. Upgrade detector architecture and operation (*)

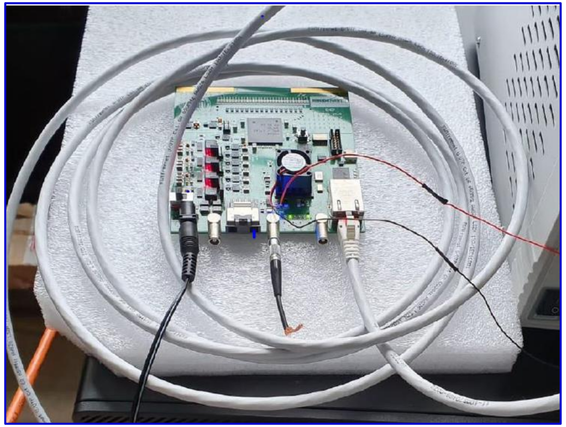
On-going activities

- Second version under construction, severely delayed by pandemic effects
- Tests of read-out with VMM3 in preparation:
  - new prototype designed so to make possible read-out with SRS and APV25 front-end (old approach) and with the MMFE1 board by ATLAS and VMM3 front-end in comparative way
  - VMM3 preparatory exercises performed to gain experience in using the MMFE1 board and the accompanying control software:
    - threshold calibration,
    - on-board pulse signal calibration (both polarities)
    - acquisition of the digital output signals.

Next coming activities:

- Completion and test of the second version prototype
- Detector read-out with VMM3

MMFE1 board with VMM3 chip used for preparatory exercises



(*) severely delayed by pandemic emergency

Particle ID: MPGD-based Photon Detectors for RICH @ INFN

PERIOD REPORT, 2/2

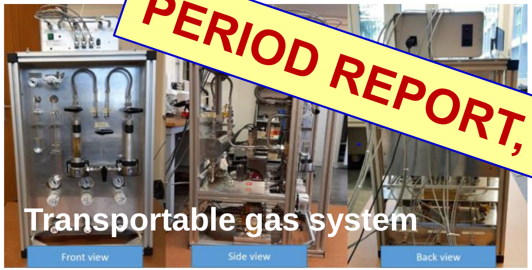
ii. new photocathode material for gas detectors

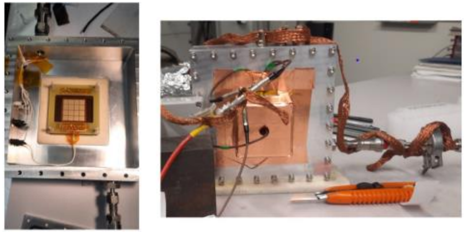
On-going activities

- Substantial preparatory activity to restart at full speed when traveling (Trieste-Bari, to CERN) made possible again; **it includes:**
- New transportable gas mixing system (ATEX-compliant mass flowmeters) built and tested
- 20 new THGEM samples, complete polishing procedure, exhaustive test for a complete set of reference parameters; yield of good pieces : 90%
- Construction of a new dedicated prototype of a complete detector with 3 multiplication layer for tests of photocathodes by H-ND in a realistic detector; the detector has been successfully tested in laboratory and it is ready to host H-ND photocathodes
- Set of new substrate samples to be coated at CERN with CsI for comparative studies, mounted on support and ready for coating

Next coming activities:

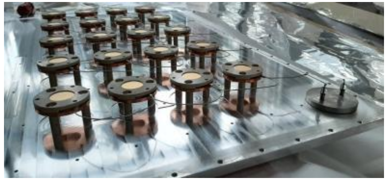
- Improving the heat treatment with test in inert gas
- Further investigation of ND powder parameters affecting the QE
- First measurements of H-ND radiation hardness at the ASSET setup at CERN





New detector prototype for H-ND photocathode tests

New set of substrate ready for CsI coating



Particle ID: Large Mirrors for RICH @ SBU

- Evaporator installation complete
  - Commissioning completed
  - First evaporation performed




Particle ID: Large Mirrors for RICH @ SBU

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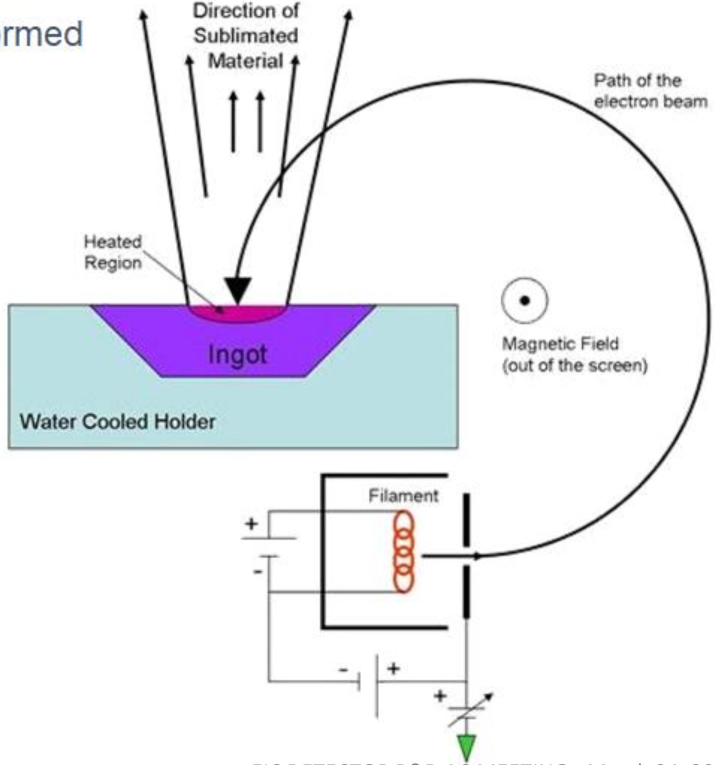
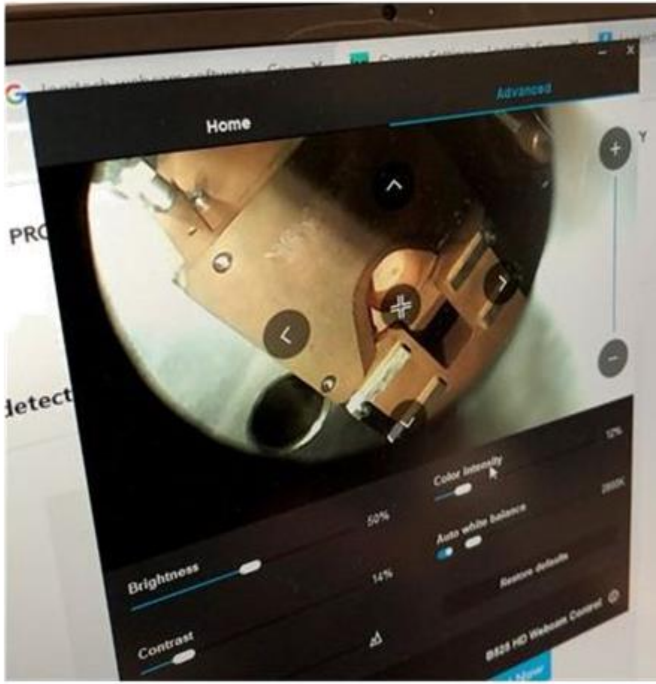
  - First evaporation performed





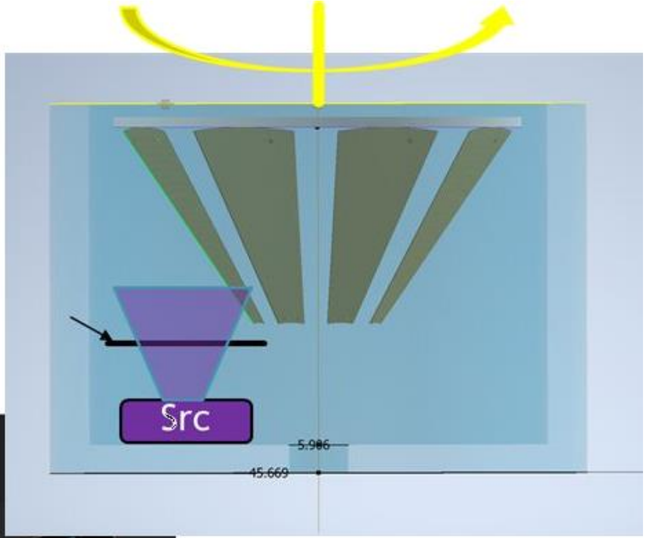
Particle ID: Large Mirrors for RICH @ SBU

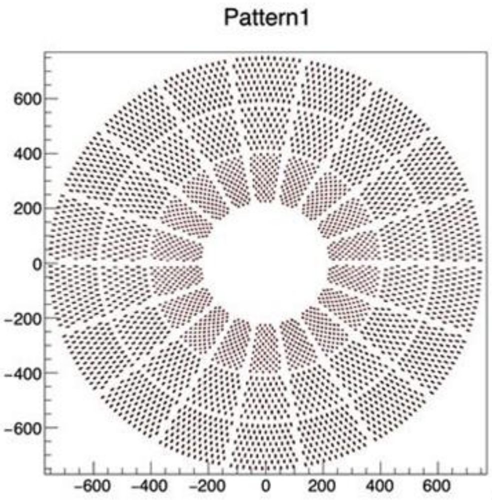
- Evaporator installation complete
  - Commissioning completed
  - First evaporation performed

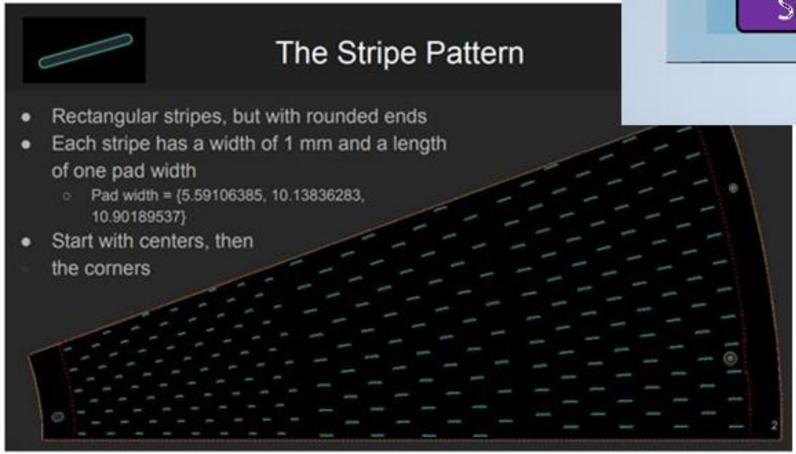
Project finalized and available for the community

Particle ID: Large Mirrors for RICH @ SBU

- First real application in progress
  - TPC central membrane evaporation → IBF calibration pattern







eRD6 Project Future Plans

- TPC Central Tracker
  - In-lab characterizations of 2D zigzag PCBs and LAPPDs
  - Confirm performance of laser-based calibration methods for TPC using mini-TPC prototype
  - Test hybrid MPGD IBF suppression in mini-TPC prototype (10cm drift), test static bi-polar gating grid
  - Test resolution performance in beam: 2D ZZ r/o, LAPPD + Interleaved r/o, mini-TPC with MMG+2GEM r/o optimized for min. IBF
- Cylindrical MMG Barrel Tracker
  - Optimize the 2D readout patterns for the curved detectors
  - Design and build a demonstrator for the ultra light modular technology
- Cylindrical µRWELL Barrel Tracker
  - Design, build, and test a functional small prototype
  - Construct a full-size mechanical mock-up
  - Simulations for SiMPLE hybrid design
- GEM Endcap Tracker
  - Refurbish second GEM prototype
  - Beam test with both prototypes
  - Simulations for SiMPLE hybrid design
- Particle ID
  - September 2021: “The completion of the laboratory characterization of the second version of the photon detector with miniaturized pad-size.”
    STATUS: it will not be fully met because of pandemic limitations
  - September 2021: Complete small size prototype of a MPGD-based photon detector with hydrogenated nanodiamond power photocathode.
    STATUS: expected to be fully met

BROOKHAVEN NATIONAL LABORATORY · cea · FLORIDA TECH · INFN TRIESTE · Stony Brook University · TEMPLE UNIVERSITY · University of Virginia · Vanderbilt University · Yale University

Thank You

Number of institutions/labs: 9

Number of People: 36

Number of publications: 30 + 2 pending

We would like to thank the EIC R&D Program for all their support in making this a successful program!

Backup

eRD6 Publications

BNL publications:

[1] C. Perez-Lara et al. "A Comparative Study of Straight-Strip and Zigzag-Interleaved Anode Patterns for MPGD Readouts". In: *IEEE Transactions on Nuclear Science* [Submitted for publication Jan. 2021] (2021).

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[5] B. Azmoun et al. "Design Studies for a TPC Readout Plane Using Zigzag Patterns with Multistage GEM Detectors". In: *IEEE Transactions on Nuclear Science* (July 2018), pp. 1–1. ISSN: 0018-9499. DOI: 10.1109/TNS.2018.2846403.

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Florida Tech publications:

[1] Marcus Hohlmann et al. "Low-mass GEM detector with radial zigzag readout strips for forward tracking at the EIC". In: *2017 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC 2017) Atlanta, Georgia, USA, October 21-28, 2017*. 2017. arXiv: 1711.05333 [physics.ins-det]. URL: http://inspirehep.net/record/1636290/files/arXiv:1711.05333.pdf.

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[3] Aiwu Zhang and Marcus Hohlmann. "Accuracy of the geometric-mean method for determining spatial resolutions of tracking detectors in the presence of multiple Coulomb scattering". In: *JINST* 11.06 (2016), P06012. DOI: 10.1088/1748-0221/11/06/P06012. arXiv: 1604.06130 [physics.data-an].

[4] Aiwu Zhang et al. "R&D on GEM detectors for forward tracking at a future Electron-Ion Collider". In: *Proceedings, 2015 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC 2015): San Diego, California, United States*. 2016, p. 7581965. DOI: 10.1109/NSSMIC.2015.7581965. arXiv: 1511.07913 [physics.ins-det]. URL: http://inspirehep.net/record/1406551/files/arXiv:1511.07913.pdf.

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[1] J. Agarwala et al. "The MPGD-based photon detectors for the upgrade of COMPASS RICH-1 and beyond". In: *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* (2018). ISSN: 0168-9002. DOI: https://doi.org/10.1016/j.nima.2018.10.092. URL: http://www.sciencedirect.com/science/article/pii/S0168900218314062.

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TU publications:

[1] M. Posik and B. Surrow. "Construction of a Triple-GEM Detector Using Commercially Manufactured Large GEM Foils". In: 2018. arXiv: 1806.01892 [physics.ins-det].

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[2] Nikolai Smirnov et al. "Options for gain elements and gas mixtures in a high rate EIC Time Projection Chamber". In: *IEEE Transactions on Nuclear Science* [Submitted for publication Dec.2020] (2021).