

Tracking/PID R&D for EIC

Selected results from eRD6 & eRD14

AGS/RHIC User's Meeting

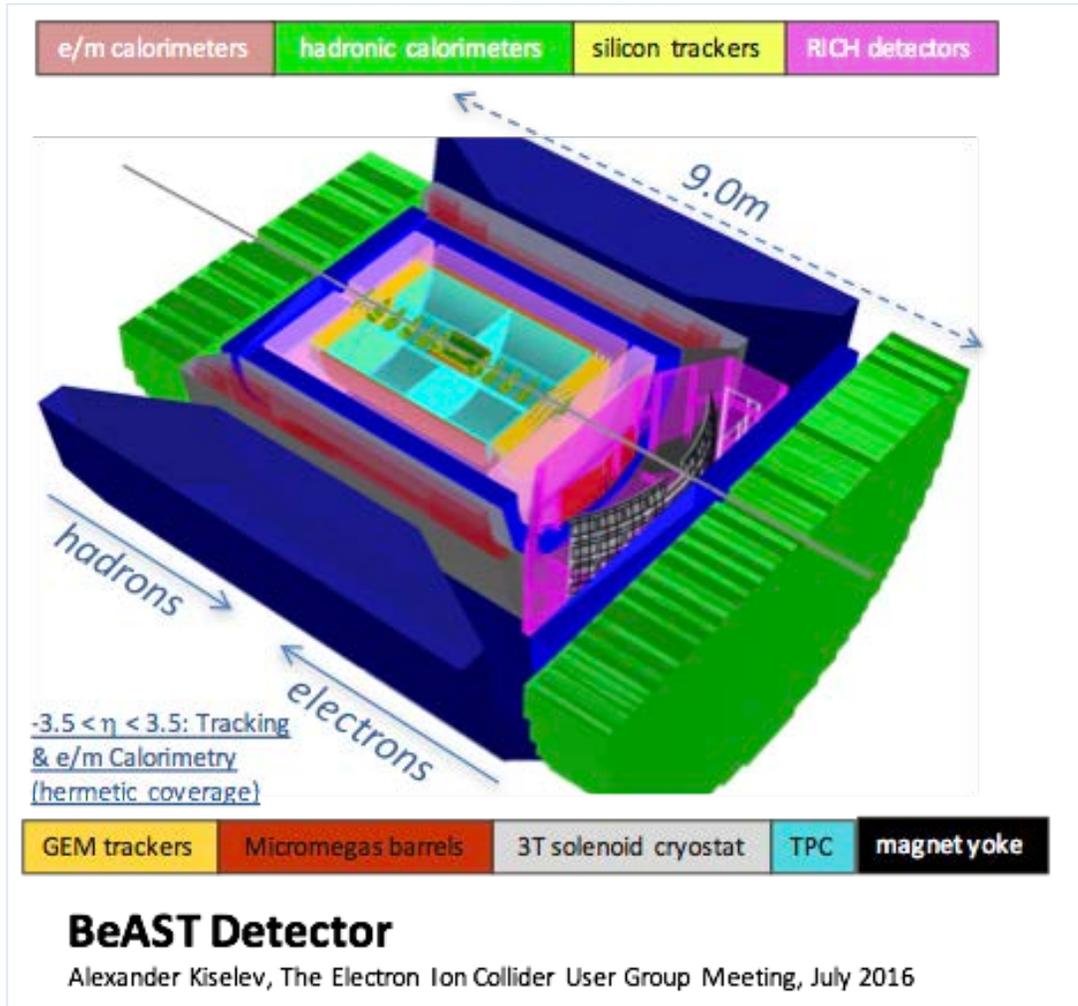
June 5, 2019

TK Hemmick*

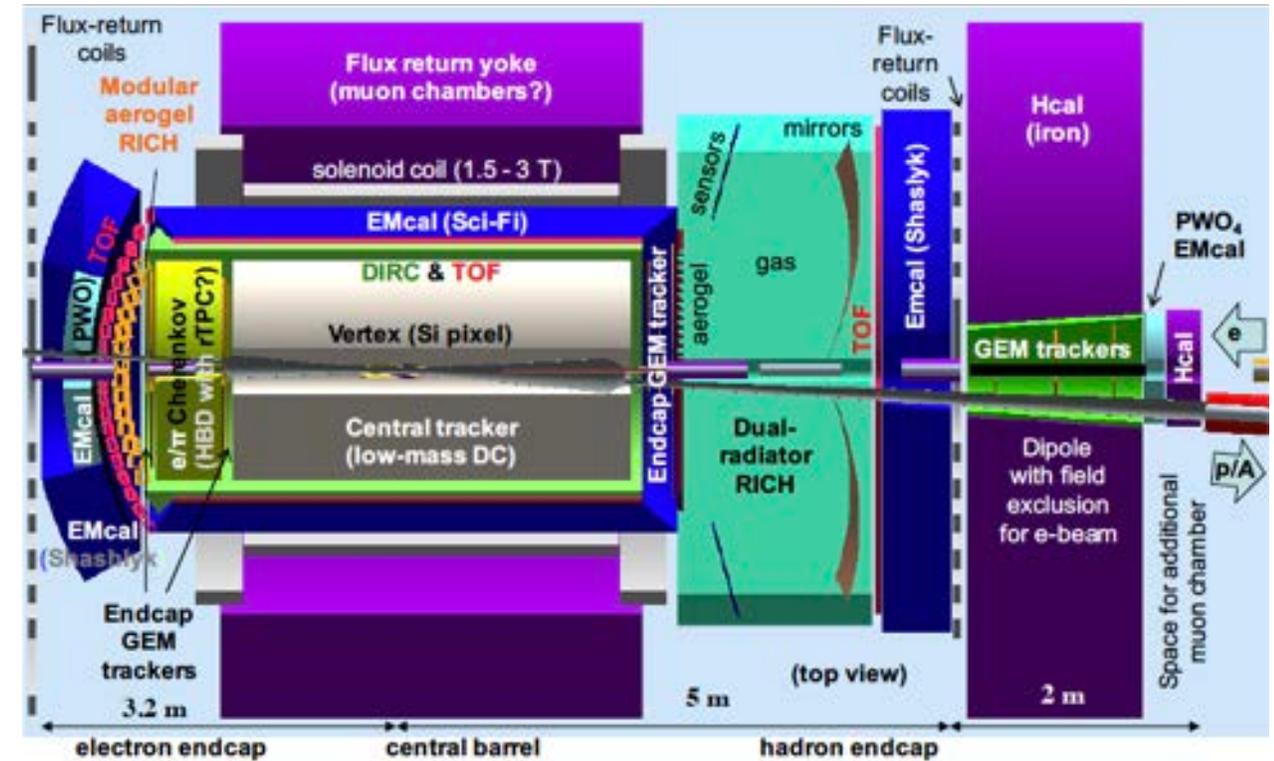
*Thanks to B Azmoun and X He for generous sharing of material

Two EIC Detector Design Concepts

BNL Version



JLab Version



Electron end cap

Central barrel

Hadron end cap

Progress @ SBU: TPC Beam Test Results

sPHENIX TPC → envisioned to serve as central tracker in day-1 EIC detector

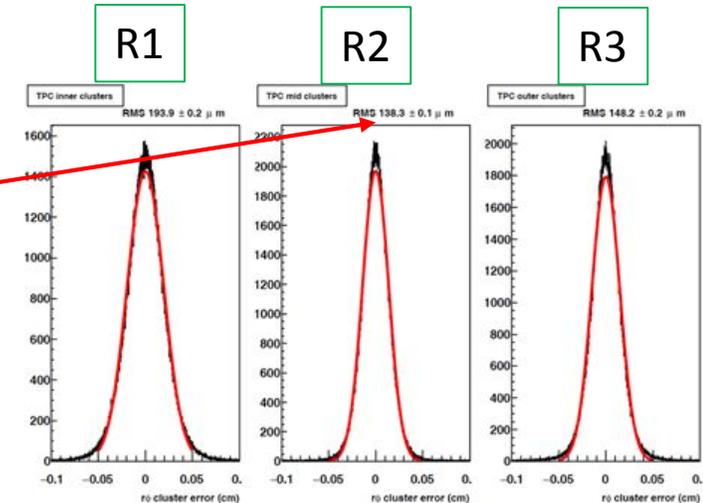
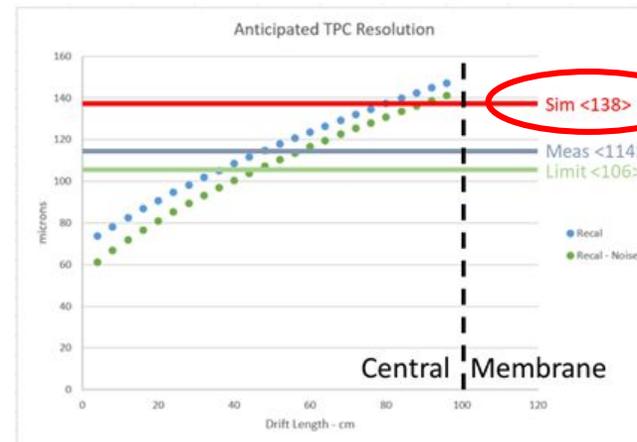
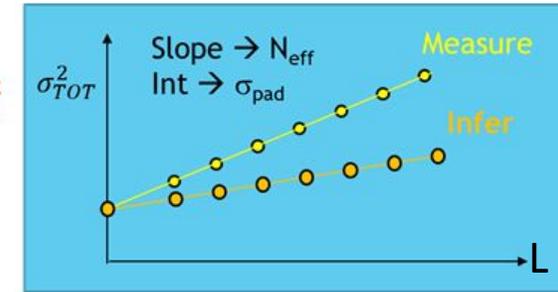
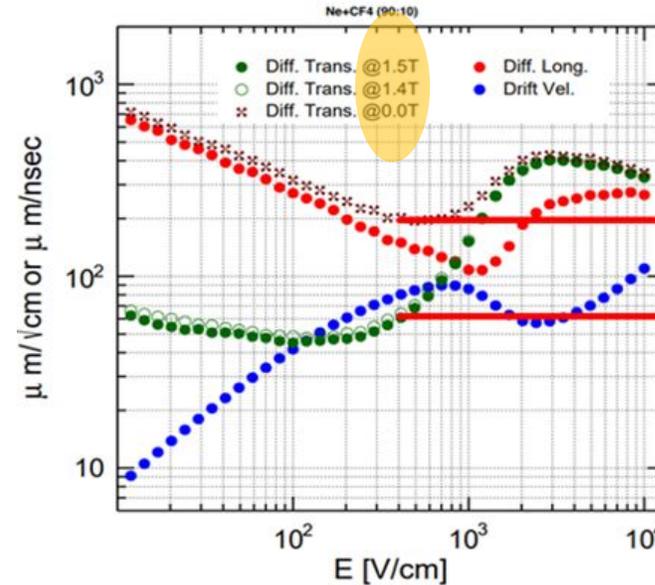
Readout with three radial subdivisions: R1, R2, R3

TPC prototype at FTBF: Determination of working parameters with R2 module

- 120 GeV proton beam
- 4 drift-lengths
- B = 0 T, extrapolation to B = 1.4 T
- Compare to realistic GEANT4 simulation

$$\sigma_{total}^2 = \sigma_{int}^2 + \frac{D_T^2 L}{N_{eff}} + \sigma_{sc}^2$$

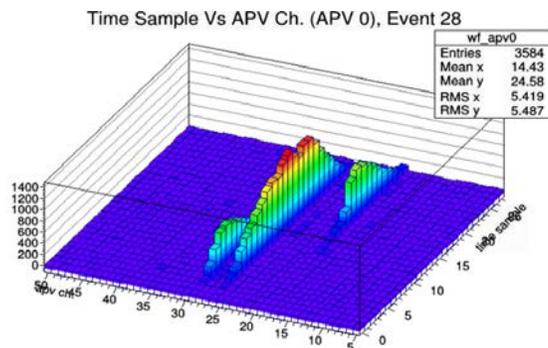
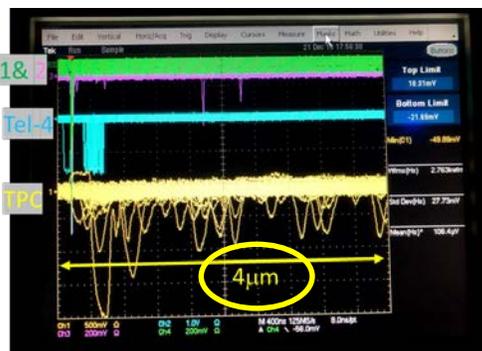
irrelevant due to small track density



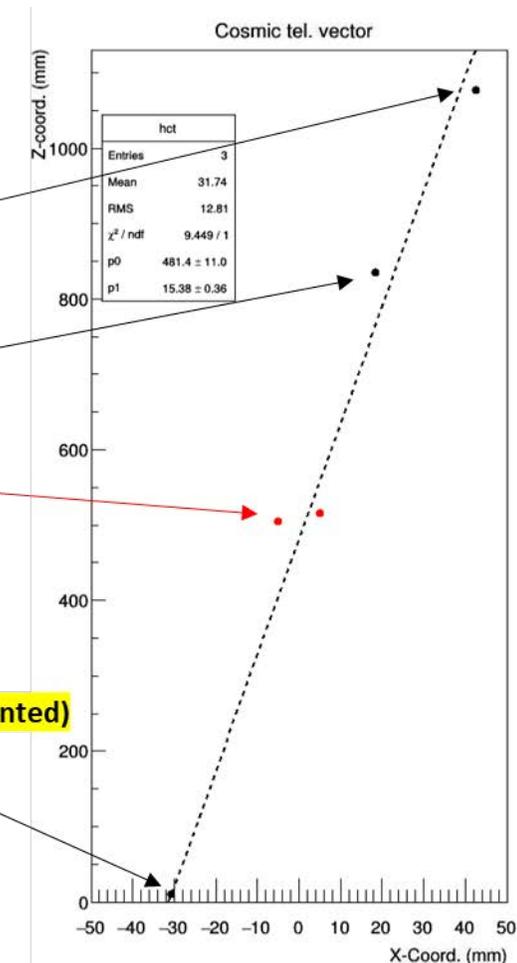
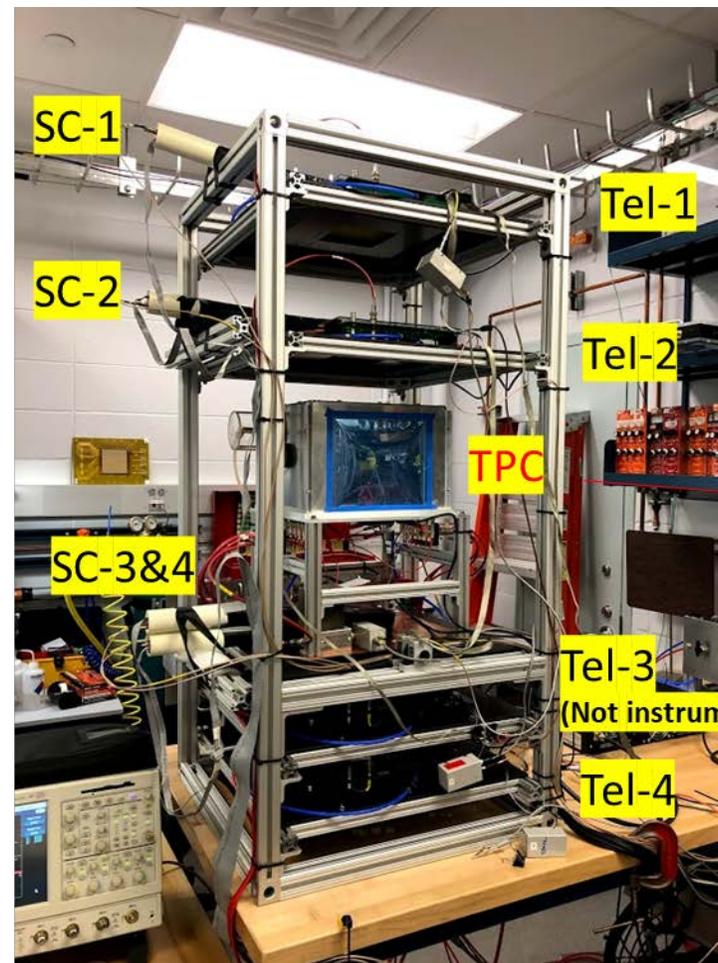
Progress @ BNL: Cosmic-ray telescope & Small TPC

- 4-layers of 3-GEM with COMPASS X-Y r/o
- Commissioned at beam test by UVA
- Coincident signal from 4 scintillator counters provides prompt trigger
- TPC prototype as Det. Under test (for position resolution measurements)
- Expect $40\text{-}50\mu\text{m}$ per telescope layer and $40\text{-}50\mu\text{m}/\sqrt{4 \text{ points}} = 25\text{-}30\mu\text{m}$ track pos. resolution

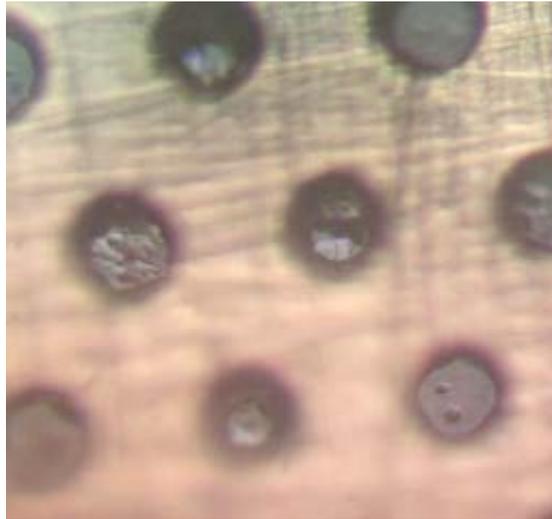
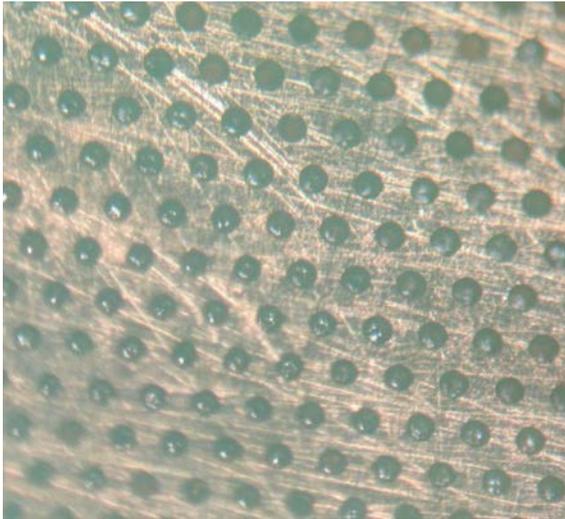
Measured TPC signals span the expected drift time



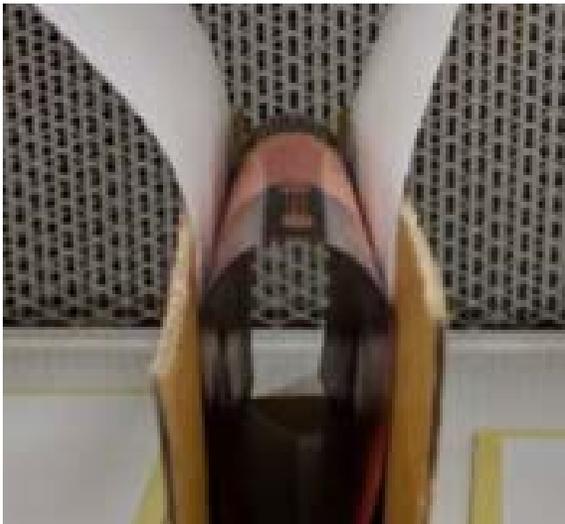
Example of a single reconstructed track



Progress @ FIT: μ RWELL prototype – basic studies



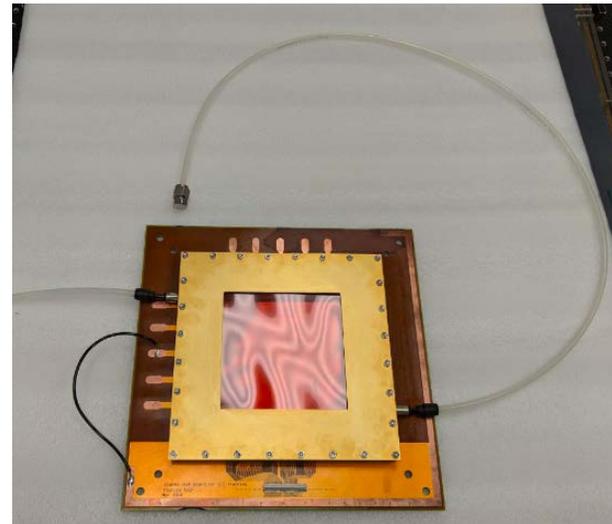
Observe non-uniformity of DLC layer at bottom of wells (bumps, divets)



convex bending



concave bending

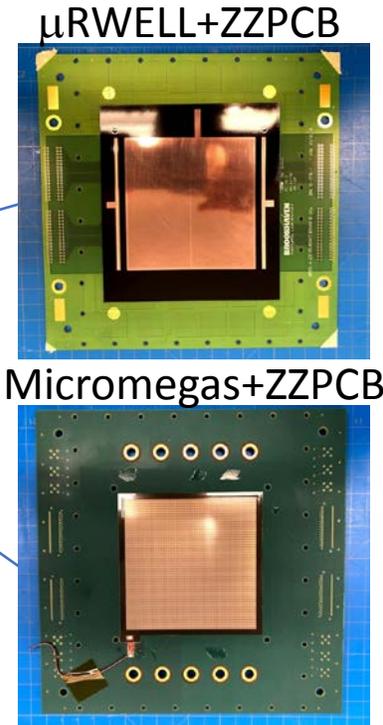
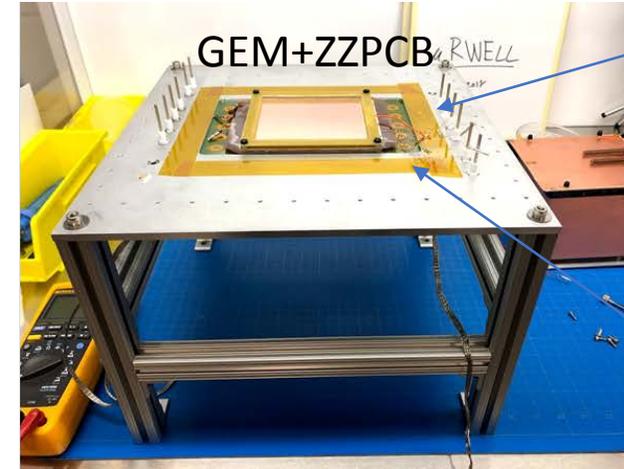
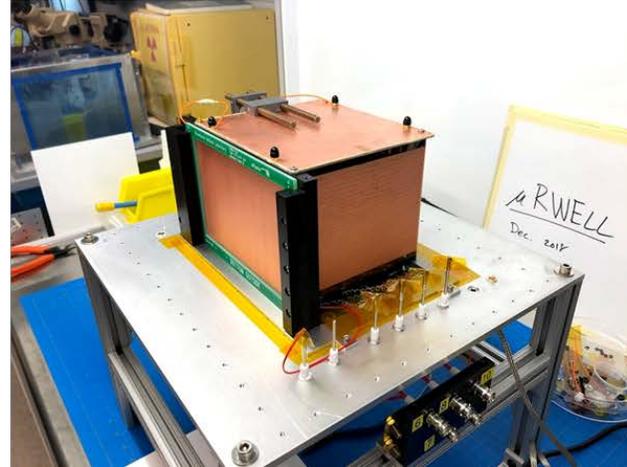
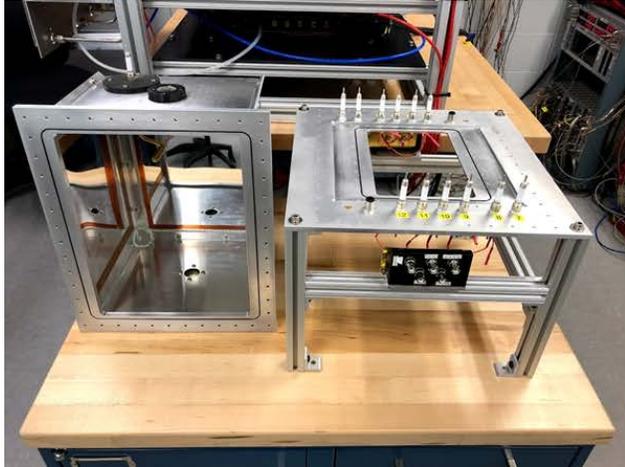


assembled 10 × 10 cm planar μ RWELL detector with zigzag r/o

μ RWELL foil can be easily bent into cylindrical shape down to a radius of a few centimeter

No degradation of hole shape in bent foil observed under microscope

Progress @ BNL:TPC prototype



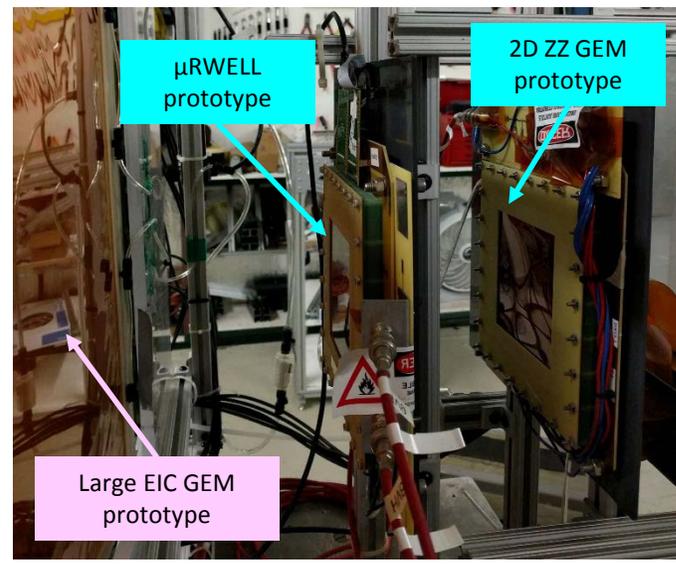
- Assembly and commissioning of new TPC prototype completed (gas tightness, HV tests, etc)
- Re-used TPCC field cage
- 4GEM with optimized zigzag readout
- New flexible and compact design with three large windows
- Tested successfully with cosmics using SRS/APV25 readout FEE (700ns DAQ frame → only measure fraction of charge in TPC)
- For initial tests: Ar-CO₂ (70-30) with drift field of 0.75kV/cm → drift velocity = 25μm/ns
- Eventually will test with μRWELL and MM (initially will test each in a simple planar det. config.)

Progress @ UVA: Small μ RWELL Prototype w/ 2D r/o

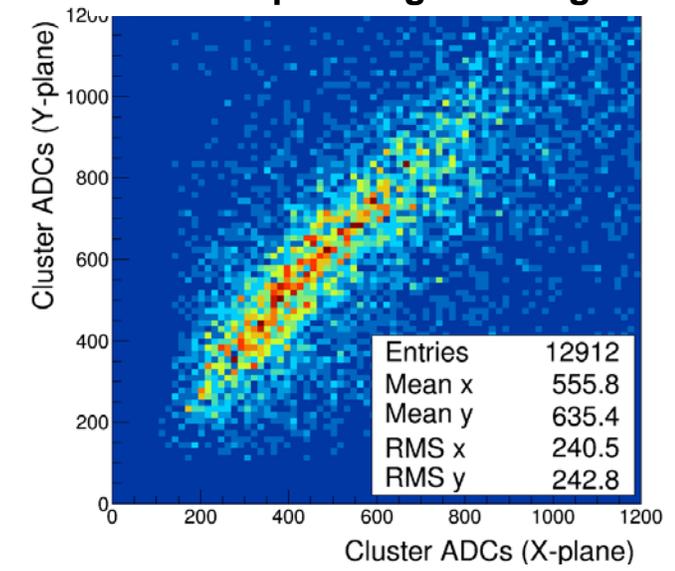
Characteristics of the $10 \times 10 \text{ cm}^2$ μ RWELL prototype

- ❖ **2D (X-Y) strips readout**
 - ⇒ Strips: same pitch (400 μm) as for COMPASS 2D readout
 - ⇒ **X vs. Y charge sharing via capacitive coupling**
 - ⇒ X and Y strip layers are separate by 50 μm glass epoxy layer
- ❖ **μ RWELL prototype in FNAL test beam**
 - ⇒ Operated with standard Ar-CO₂ (70/30)
 - ⇒ Charge sharing correlation between x and y strips
 - ⇒ Width of track fit residual: 50 μm in x and 43 μm in y
 - ⇒ **Expect even better resolution after track fit correction**

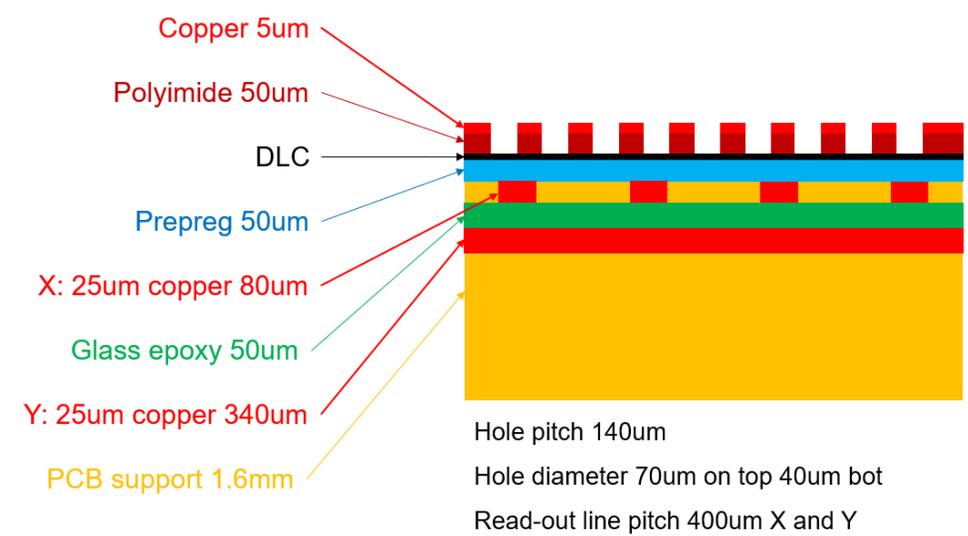
μ RWELL at FTBF beam test 2018)



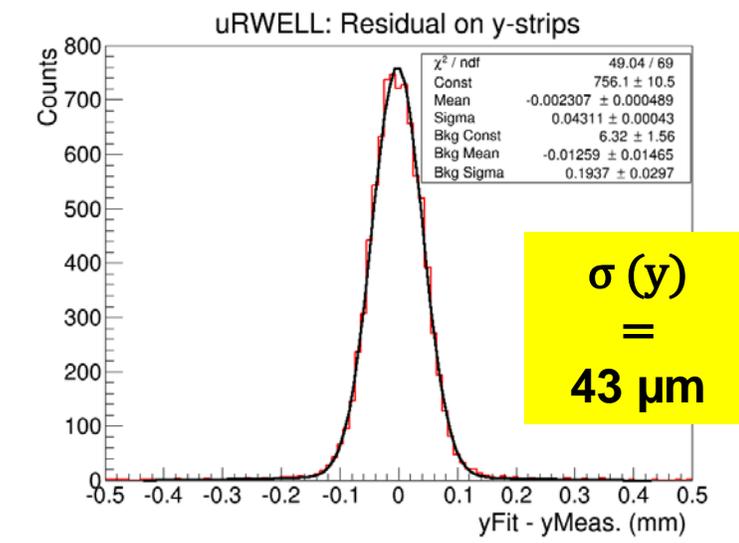
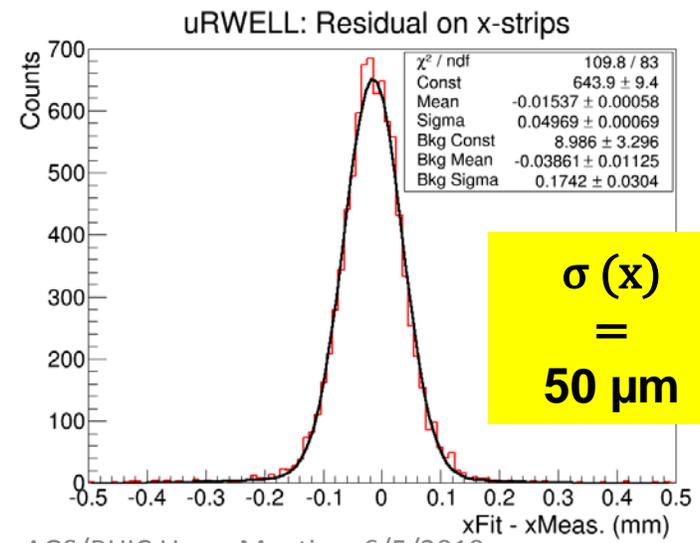
X-Y strips charge sharing



Cross section of μ RWELL X-Y readout

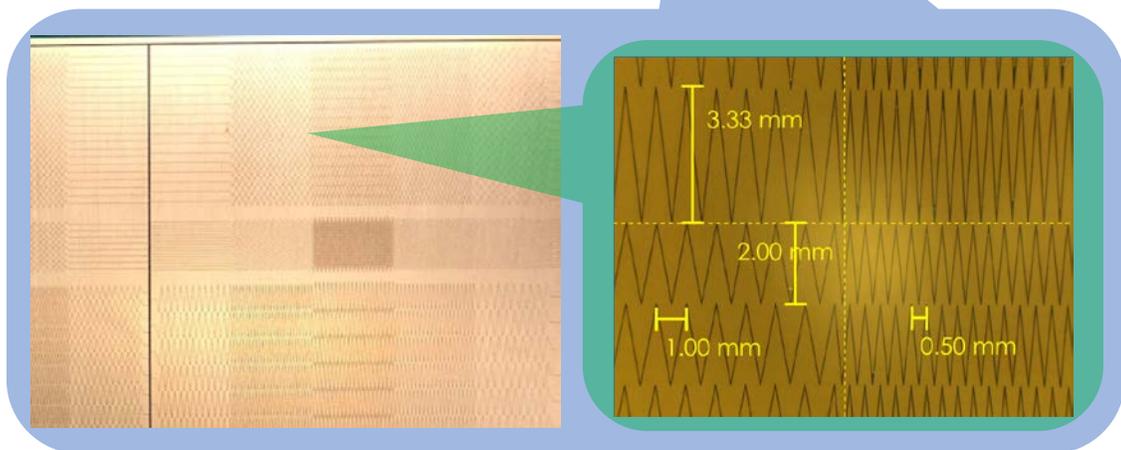
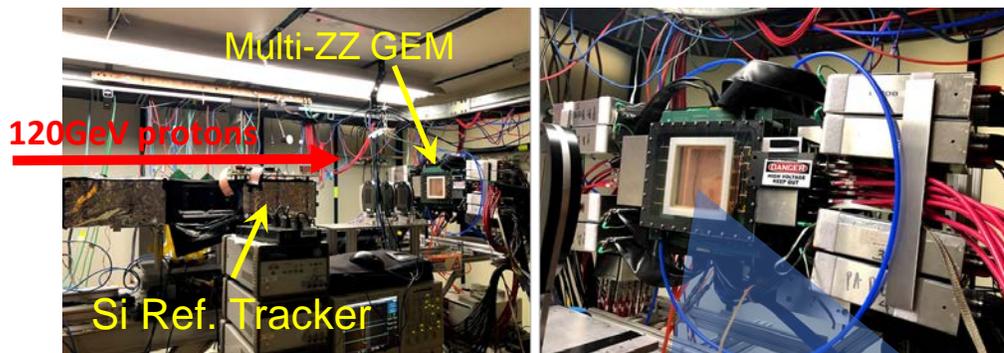


Track fit residual distributions from FNAL test beam data



Progress @ BNL: ZZ Beam Test

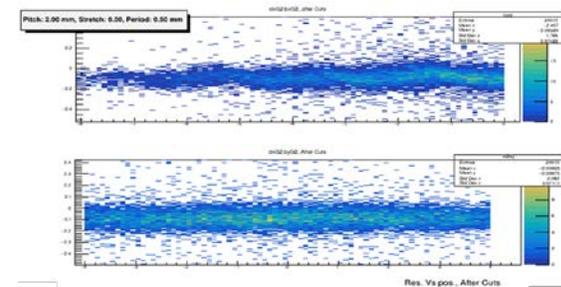
- ZZ R&D now funded by BNL LDRD, but mentioned here since it is a related effort



- “Multi-ZZ PCB: 10 x 10 array of 1cm x 1cm cells
Laser-etched, gap fixed at $\sim 24\mu\text{m}$ ”
- ZZ parameters varied broadly:
Pitch: 0.4 - 3.33mm, Stretch: -25% - +25%, Period: 0.2 - 1mm

All 2mm pitch

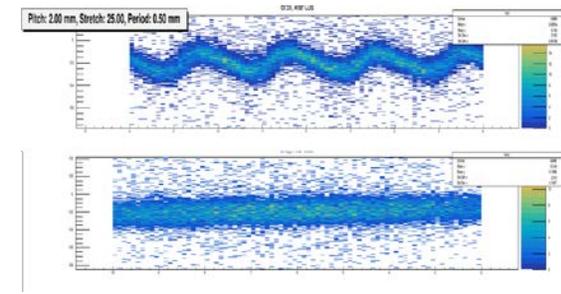
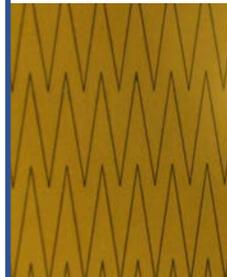
Stretch=0



DNL vs x

DNL vs y

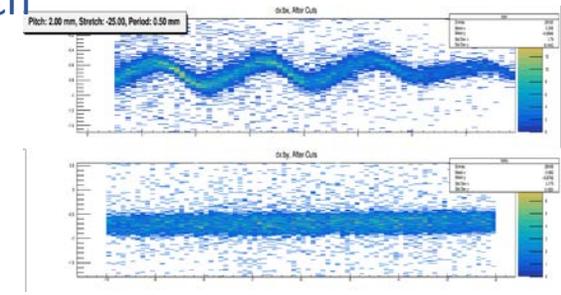
Over-Stretch



DNL vs x

DNL vs y

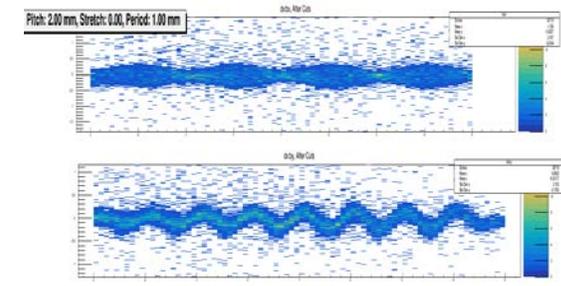
Under-Stretch



DNL vs x

DNL vs y

Large Period

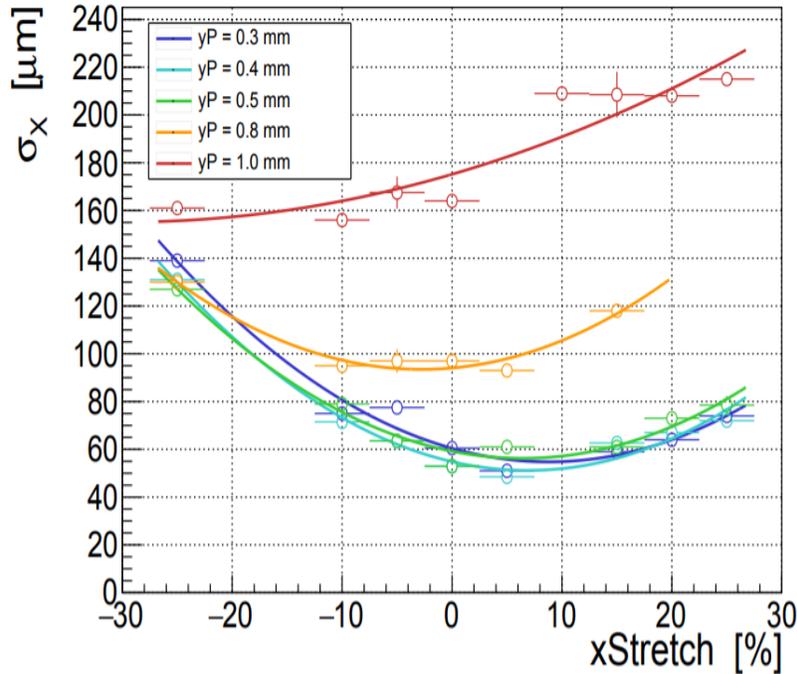


DNL vs x

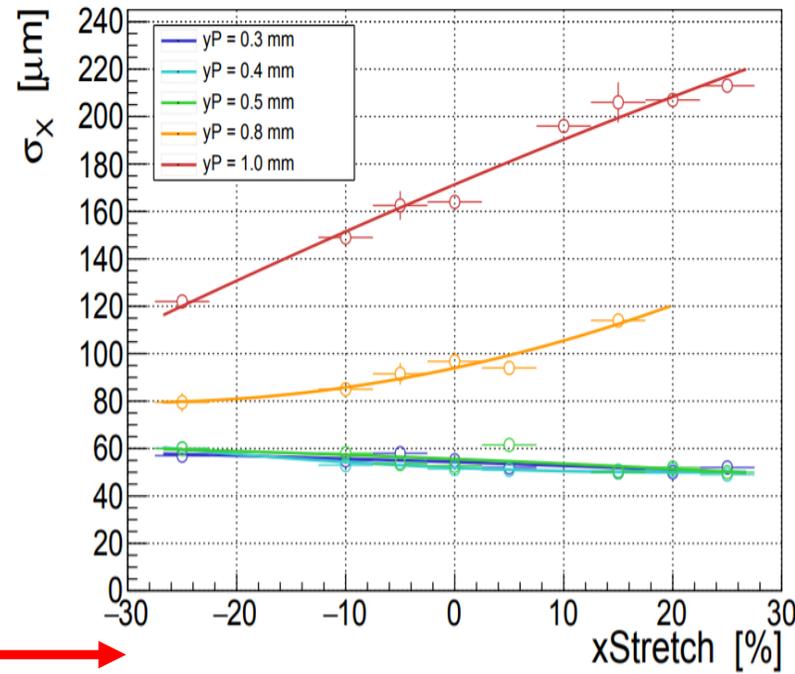
DNL vs y

Progress @ BNL: ZZ Beam Test Results

Pitch = 2mm, No DNL correction

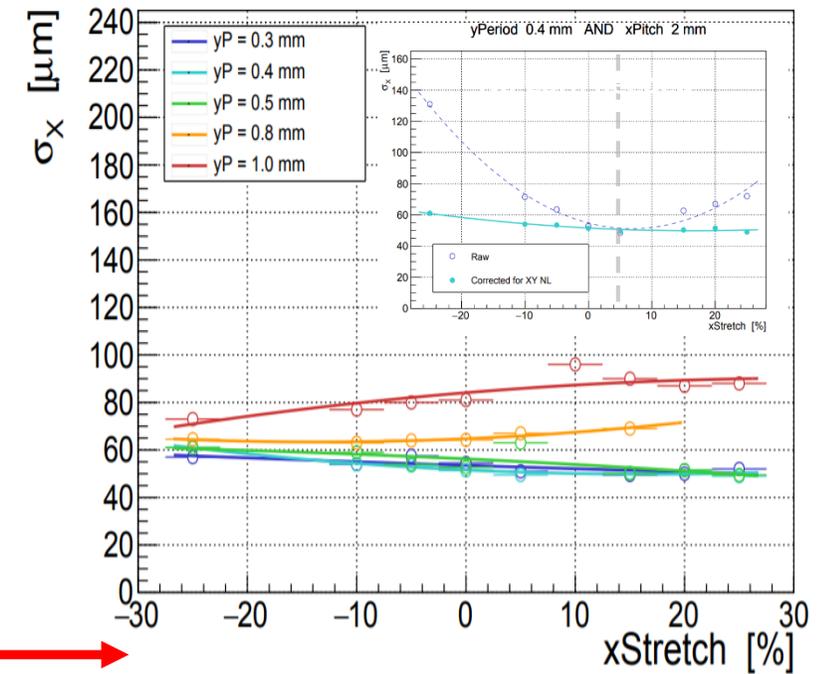


Pitch = 2mm, DNL-x correction



→
xStretch
Correction

Pitch = 2mm, DNL-xy correction

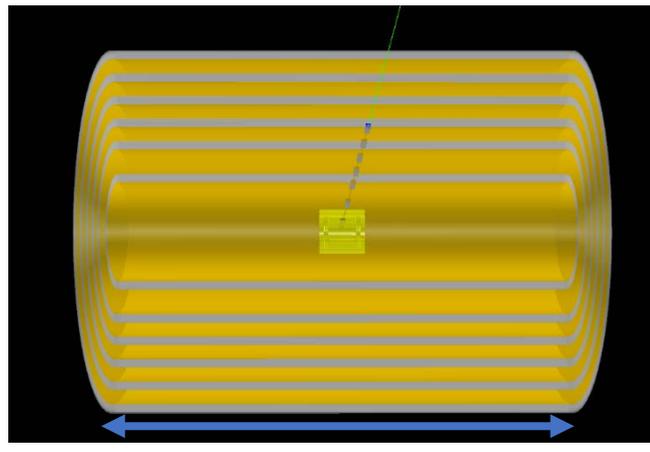
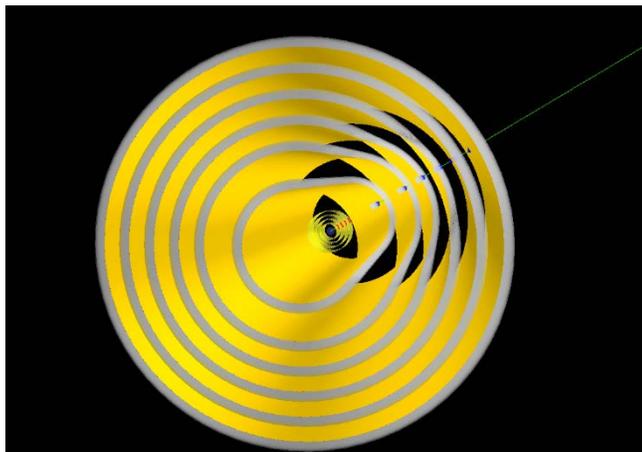


→
yPeriod
Correction

- Recover systematic offset in residuals using DNL-y correction followed by DNL-x correction
- Use centroid for correction, so process is limited by resolution of centroid itself
- At small periods, the impact of this parameter on performance becomes saturated
- **Inset plot identifies the point where no DNL correction is required and 50 μm resolution is obtained for a pitch as large as 2mm!**

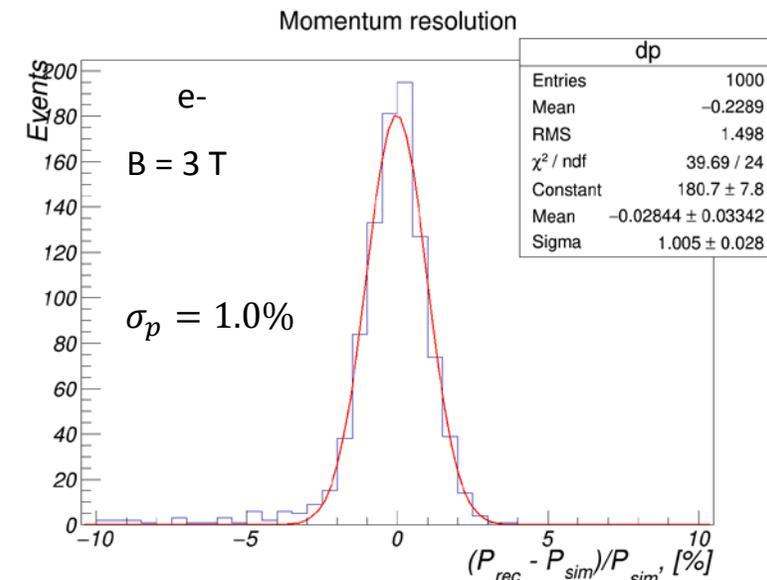
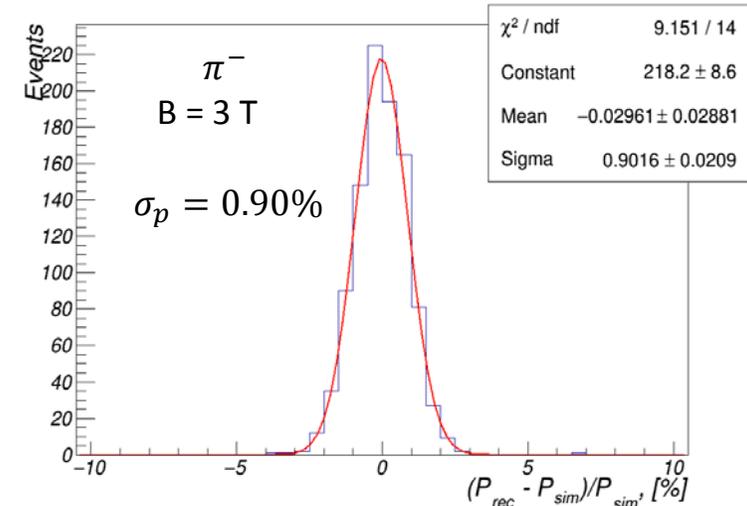
Progress @ TU: μ Rwell μ TPC Barrel Simulation

- Machinery to simulate low-mass μ RWell μ TPC barrel has been setup within EICRoot framework.
- Consists of 6 barrel layers ($r = 225 \text{ mm} - 775 \text{ mm}$) with each layer having
 - $\chi_{o,foil} = 0.172\%$ (detector and readout foil)
 - $\chi_{o,gas} = 4 \text{ cm}$ (ArCO2:70,30 – defined in EICRoot)
- To simulate the multiple hit points within a TPC, each barrel layer contains 10 4 mm sensitive layers with $50 \mu\text{m}$ resolution in ϕ and z .
- Simulation also consists of 4 silicon detectors with $20 \mu\text{m}$ resolution.



2m

AGS/RHIC Users Meeting, 6/5/2019



Progress @ UVA: Large Area Triple-GEM with U-V r/o

Three novel ideas tested with this large prototype

❖ Low Mass Detector:

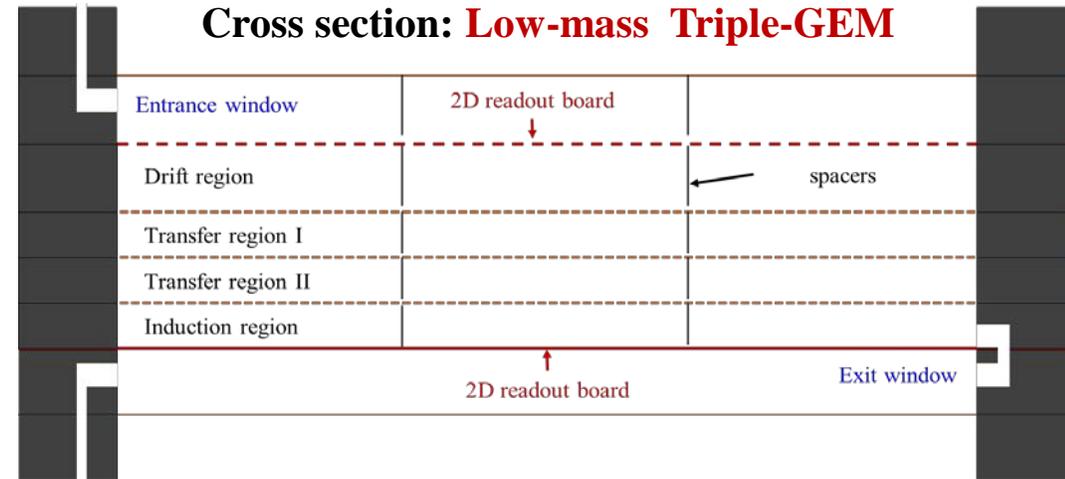
- ⇒ GEMs, cathode & U-V r/o are all Kapton foils
- ⇒ No rigid PCB or honeycomb support in active area
- ⇒ Entrance and exit window ⇒ uniform gap b/w layers
- ⇒ **Detector radiation length = 0.41%**

❖ Low Cost Support Frames:

- ⇒ Four inner frames with spacers for GEMs & drift foils
 - ⇒ by RESARM (Belgium) ⇒ higher cost
- ⇒ Four outer frames for gas window & top frames
 - ⇒ locally produced at lower cost standard G10
- ⇒ **Saving: ~ 30% in overall production cost (\$)**

❖ U-V readout with double-sided zebra connection:

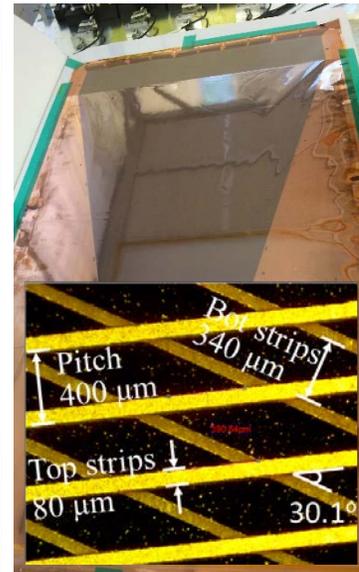
- ⇒ All e- channels read out at the outer radius ⇒ No FE cards on the back or side of the detector
- ⇒ No vias necessary on the readout foil ⇒ minimize Cu layer thickness for U and V strips



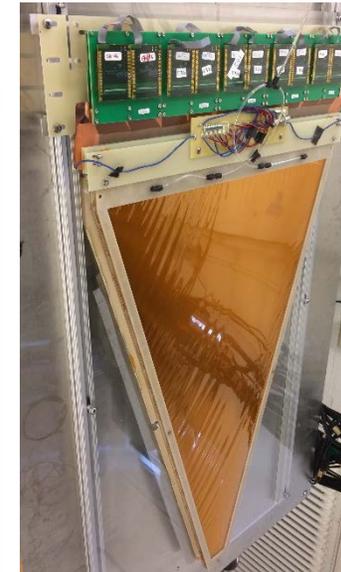
Common GEM Foil



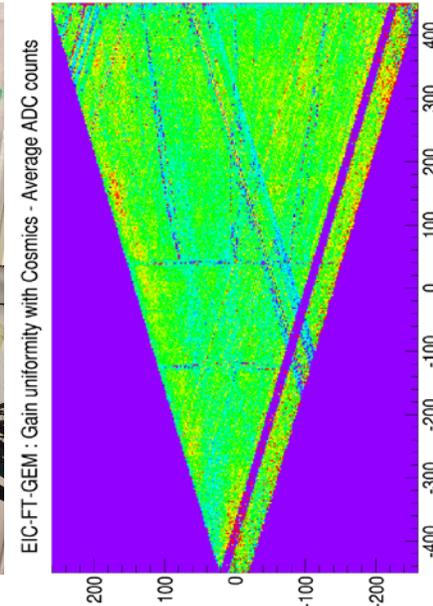
U-V strips readout foil



Large GEM Prototype



Response uniformity

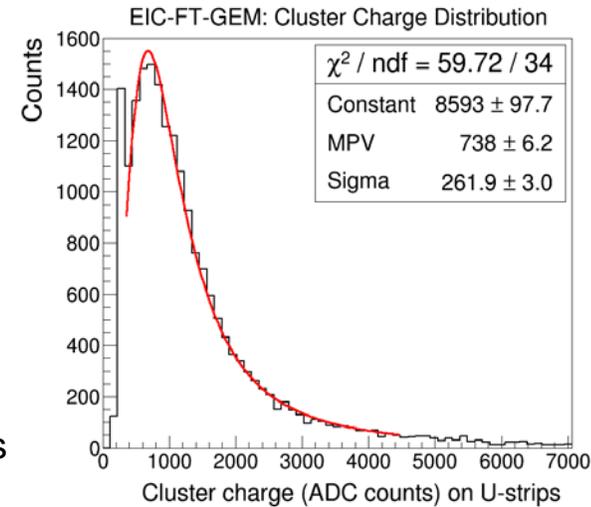


Progress @ UVA: Beam test results

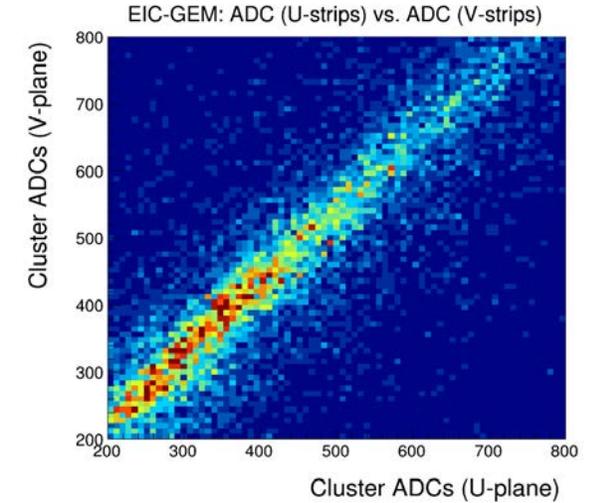
Characterization of the prototype in test beam at FNAL

- ❖ FTBF 120 GeV primary proton beam
 - ⇒ APV25-based SRS Readout at 0.5 kHz trigger rate
 - ⇒ Very good overall performance of the prototype
- ❖ Performance of the U-V strip readout:
 - ⇒ ADC distribution ⇒ Characterization of zebra connection
 - ⇒ Excellent charge sharing between U and V strip layers
 - ⇒ Spatial resolution in x & y direction ⇒ close to expected performances

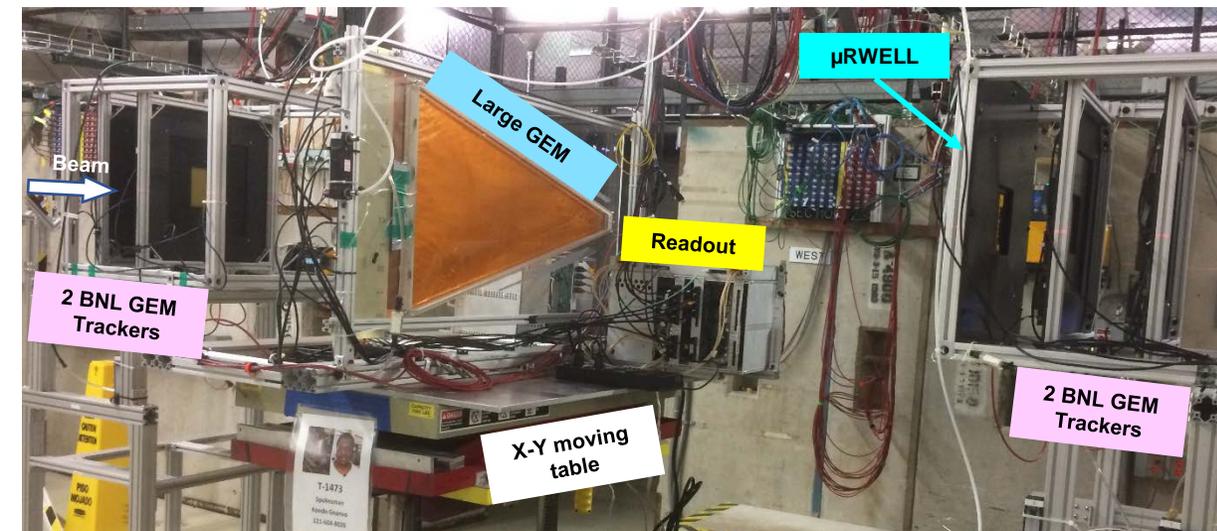
ADC Distribution on U-strips



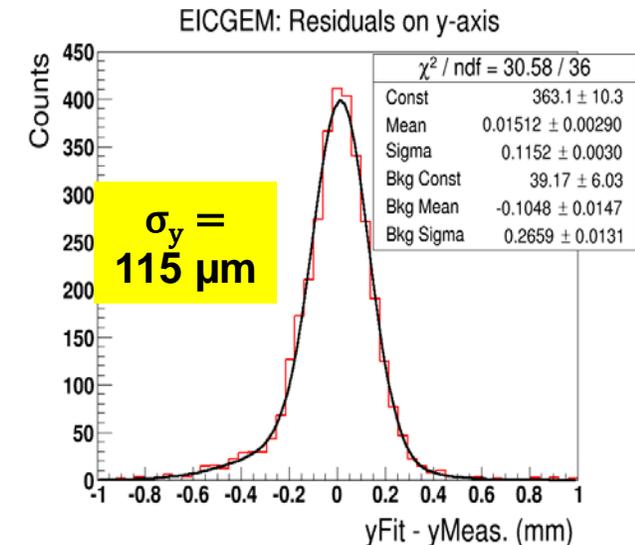
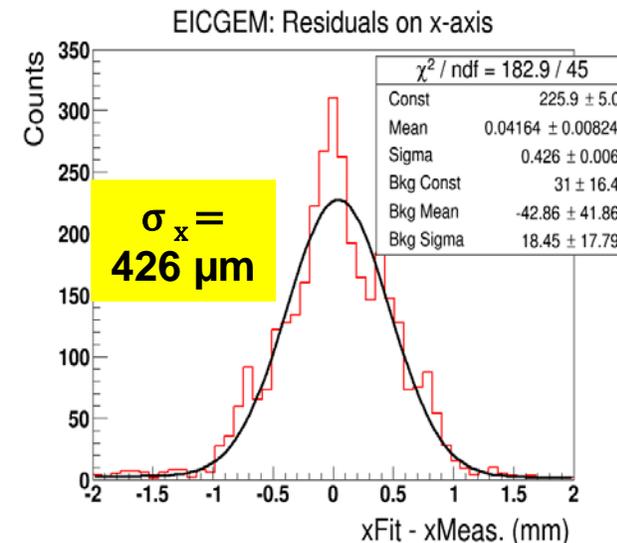
U-V strips charge sharing



Large GEM Setup in MT6.2b Area at the FTBF (June-July 2018)

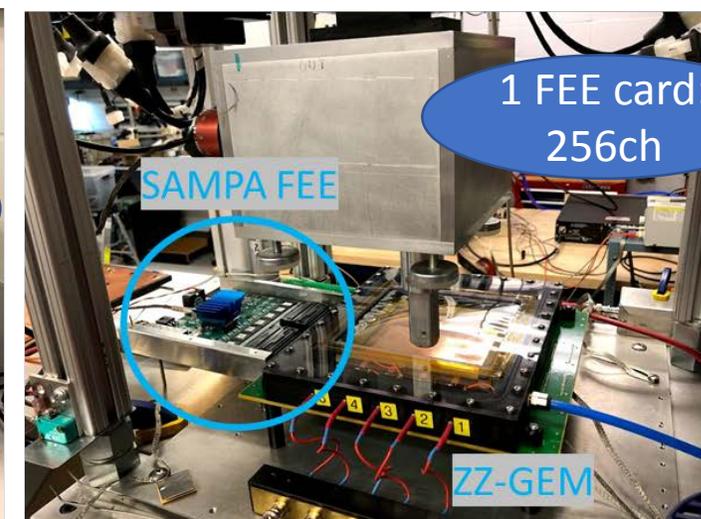
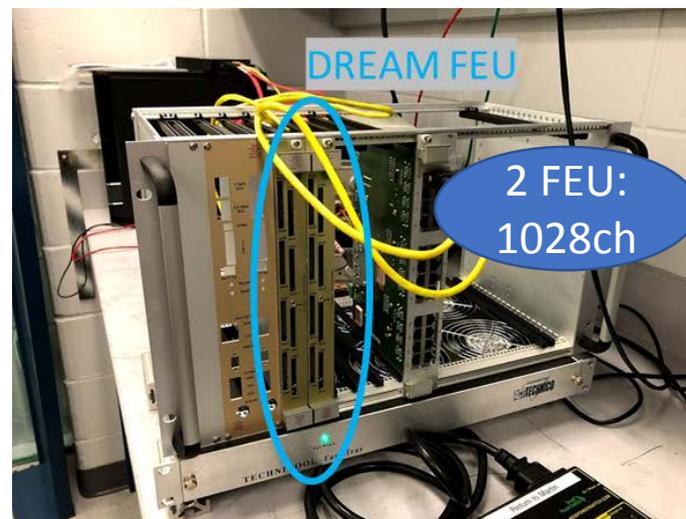


Spatial resolution of the detector with U-V strip readout

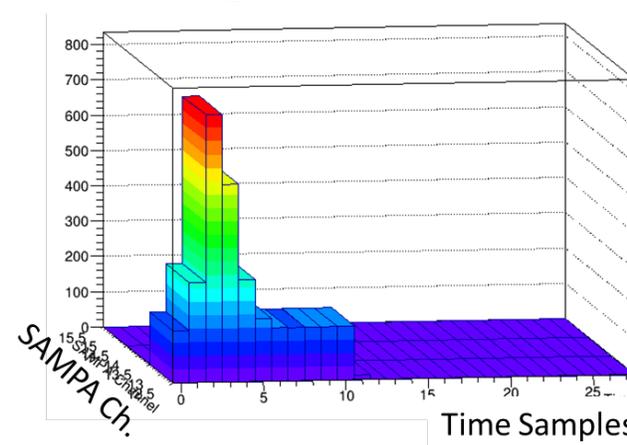


Progress @ BNL: Electronics for TPC r/o

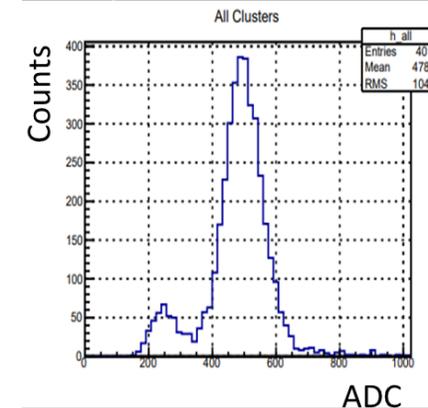
- **SAMPA** electronics under development: multi-SAMPA chip ASIC + data module card + firmware (continuous and trigger mode)
- Being tested in the lab using a 4GEM w/ ZZ r/o with very positive results (1024 samples @ 10-20MHz ADC)
- **DREAM** electronics also available: used successfully at beam test last year for measuring ZZ r/o (512 samples @ 1-50MHz ADC)



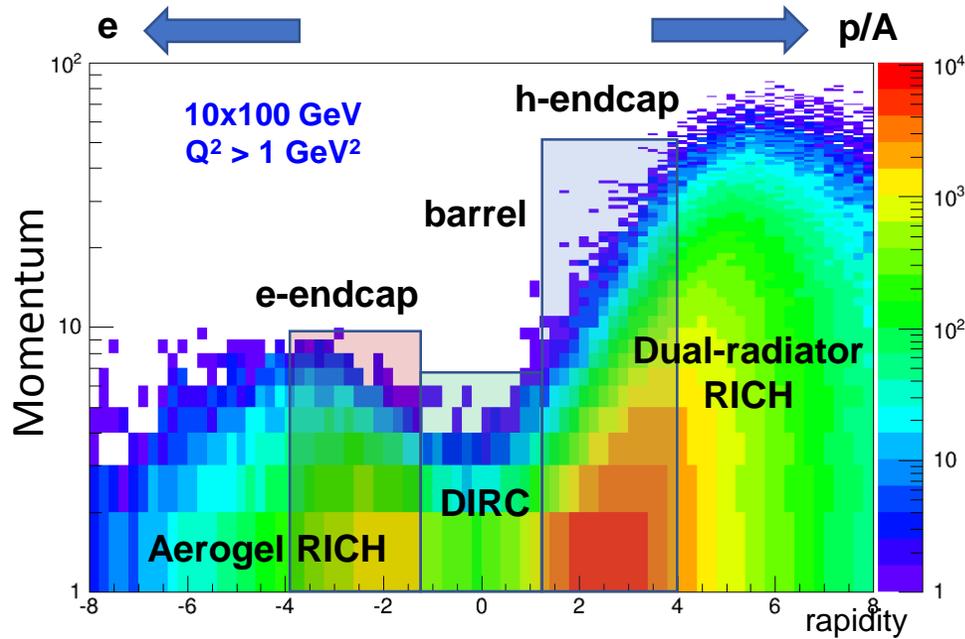
SAMPA Single event waveforms



Fe55 spectrum w/ SAMPA

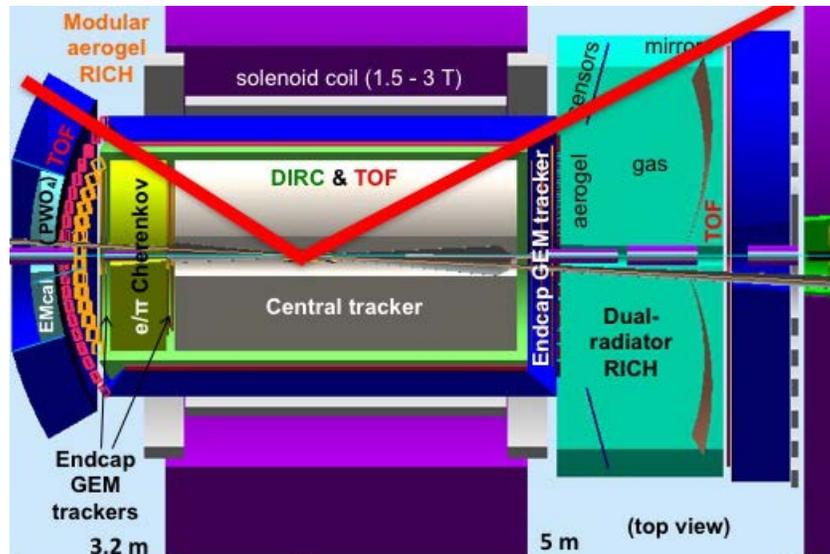


EIC PID Strategies for EIC



- **h-endcap:** A RICH with two radiators (gas + aerogel) is needed for
 π/K separation up to ~ 50 GeV/c **dRICH**
- **e-endcap:** A compact aerogel RICH which can be projective
 π/K separation up to ~ 10 GeV/c **mRICH**
- **barrel:** A high-performance DIRC provides a compact and cost-effective way to cover the area.
 π/K separation up to $\sim 6-7$ GeV/c **DIRC**

- **TOF (and/or dE/dx in TPC):** can cover lower momenta.
- **Photosensors and electronics:** need to match the requirements of the new generation devices being developed – both for the final system and during the R&D phase

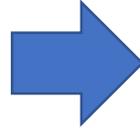


EIC DIRC Evolution

- First DIRC detector
- Successfully operated (1998-2008)
- Used for 98% of publications
- Discovered many mesons



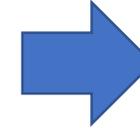
BABAR
DIRC



- Lens based Focusing DIRC detector
- Compact design
- Advanced R&D program

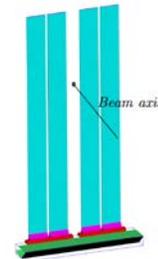


PANDA
BARREL DIRC

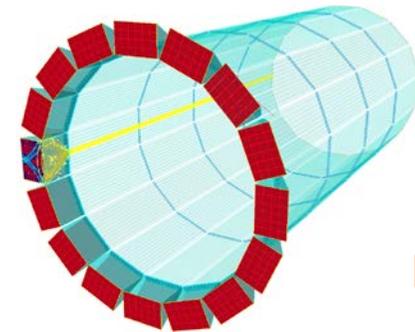


- Mirror based Focusing DIRC detector
- Reusing BaBar DIRC radiators

GlueX
DIRC



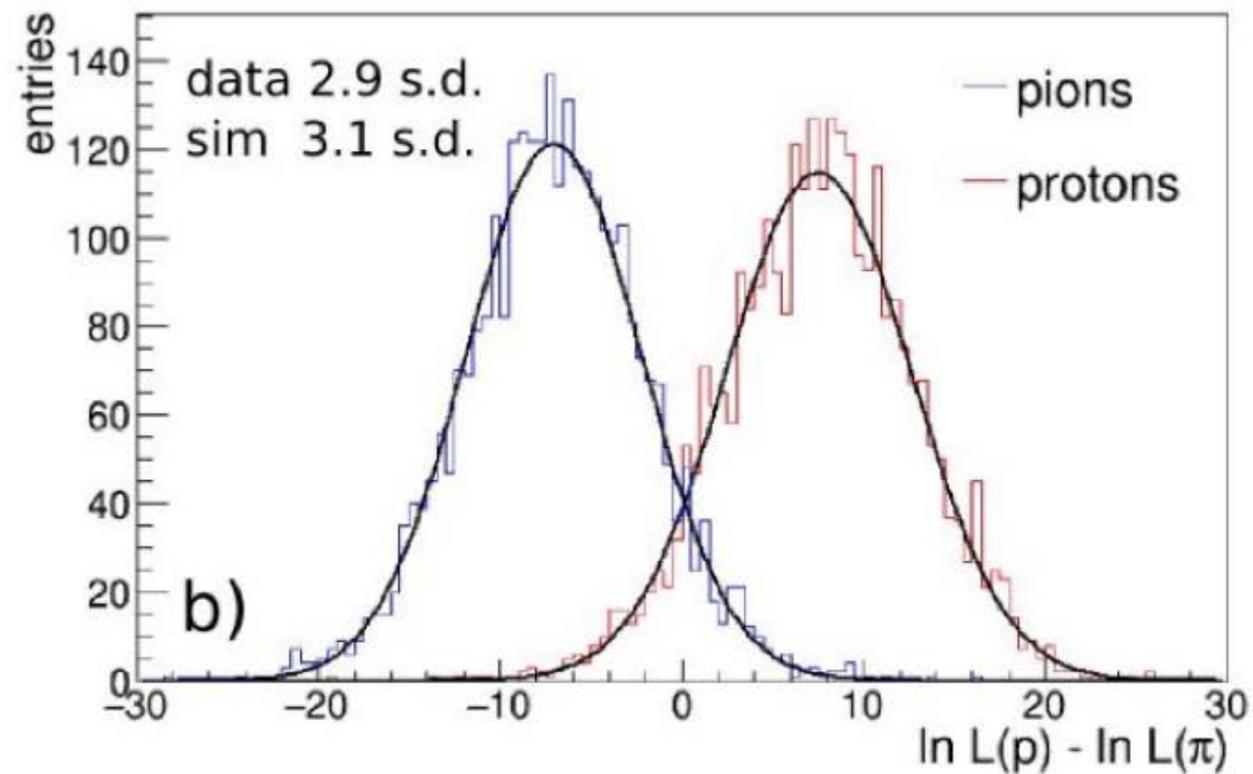
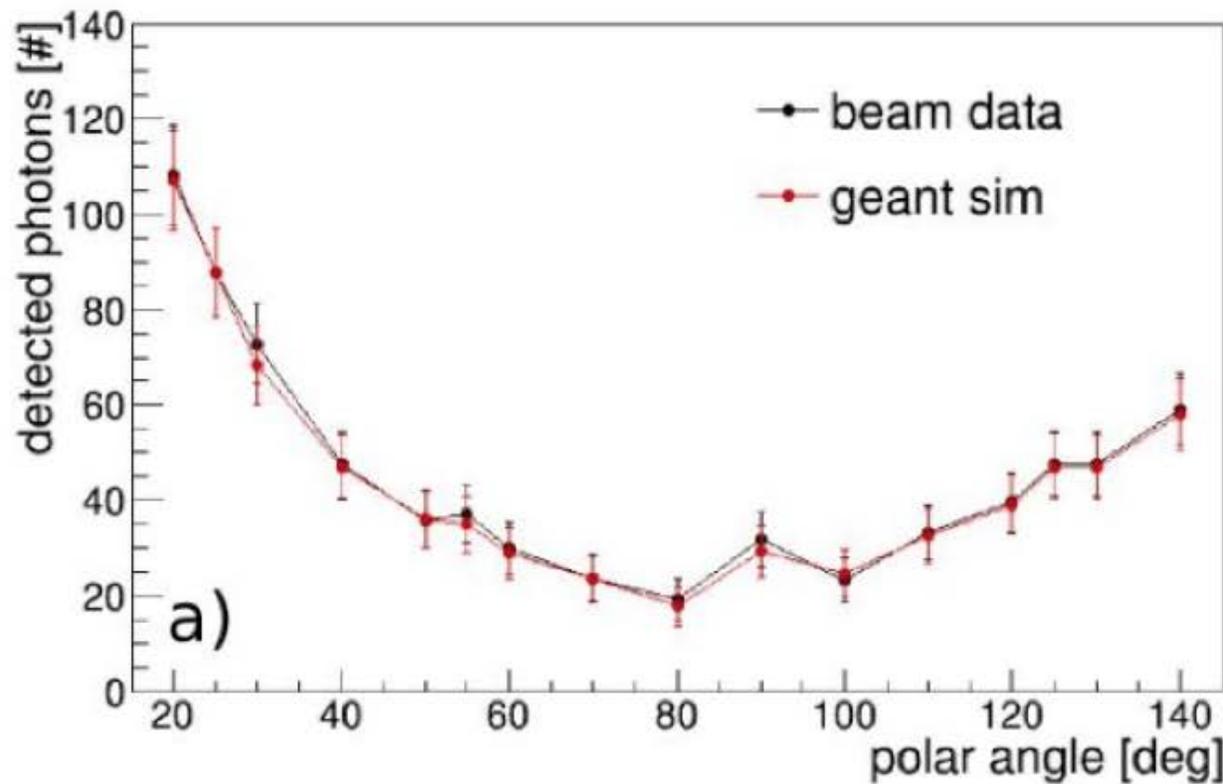
- High Performance DIRC detector
- New innovative components
- First DIRC aiming to utilize high-resolution 3D (x,y,t) reconstruction



EIC
DIRC

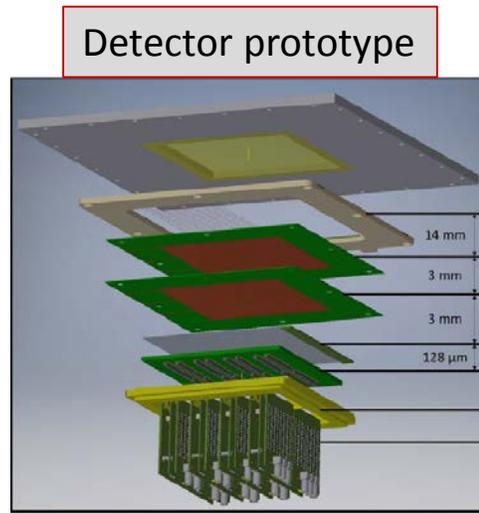
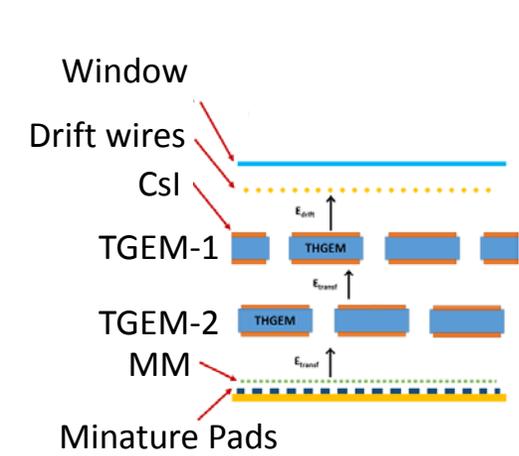
EIC DIRC Beam Test Results at CERN in 2017

Prototype with MCP-PMTs and electronics designed for PID validation at 3.5 GeV/c



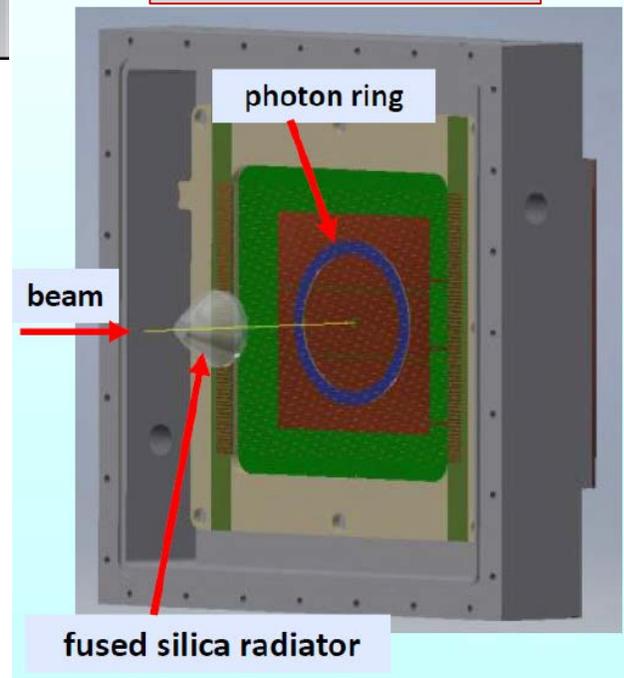
Very good agreement between prototype Geant4 simulation and beam data
Performance of cost-saving wide plate with 3-layer cylindrical lens promising

Progress @ INFN: Photosensitive TGEM+Resistive MICROMEAS prototype with miniaturized pads

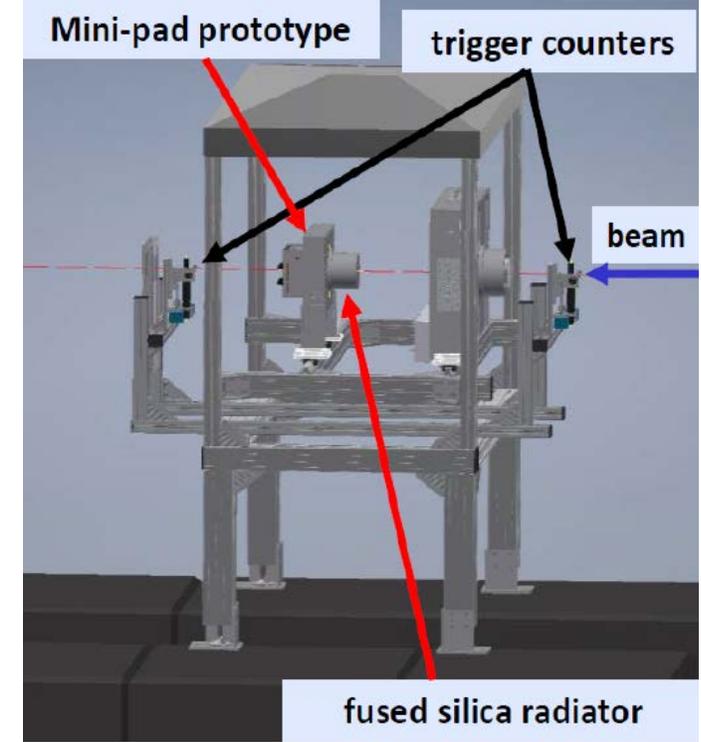


After completing the laboratory studies, the prototype equipped with a fused silica radiator was studied at a **test-beam** @ CERN (Oct-Nov 2018)

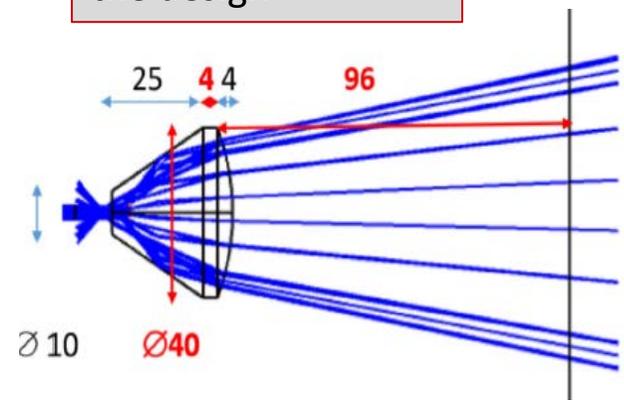
Fused silica radiator, the principle



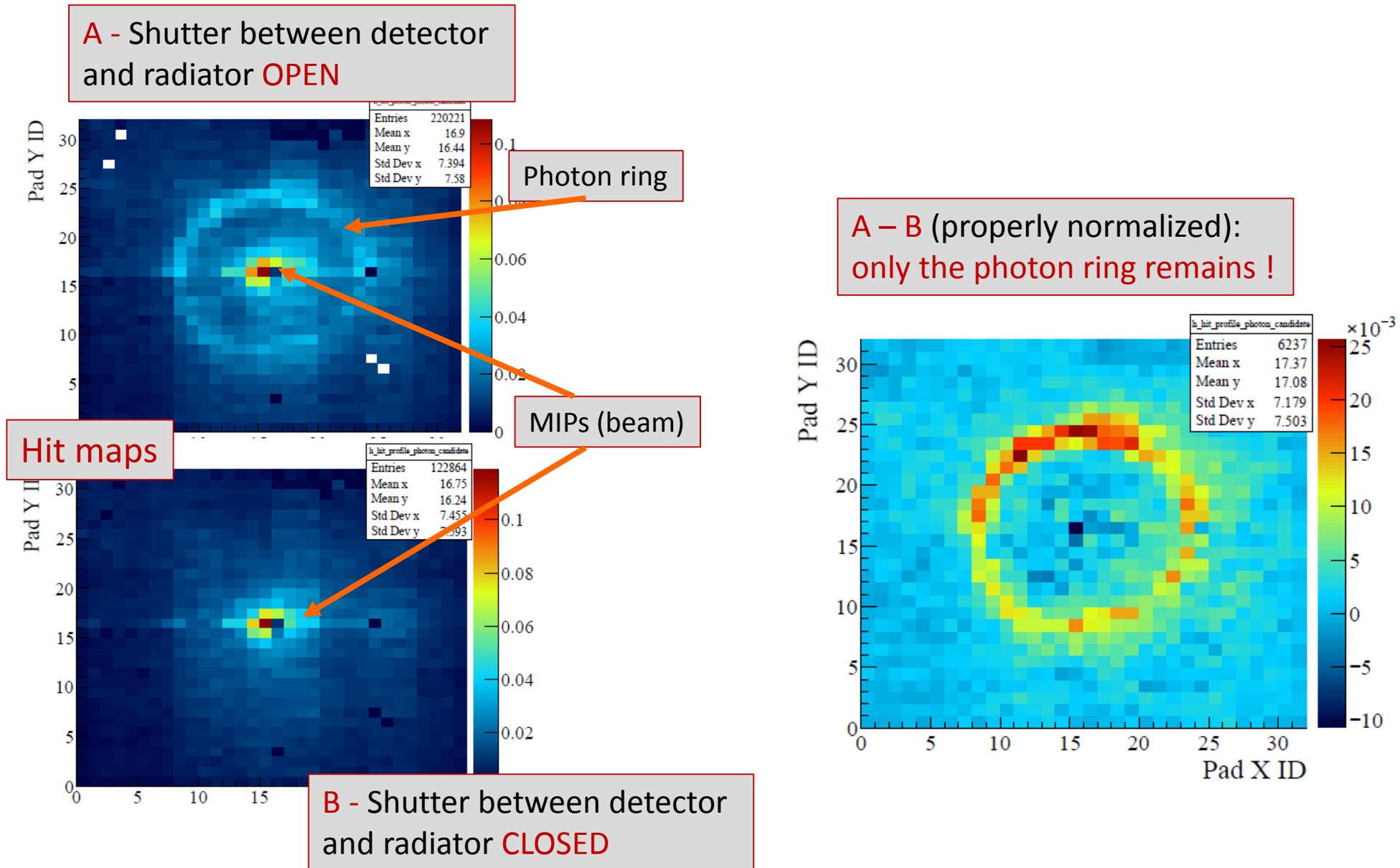
test-beam setup



Fused silica radiator, the design



Progress @ INFN: First hints from the test beam



Progress @ INFN: NanoDiamond (ND) photocathode

Initial studies of the compatibility of an innovative photocathode based on NanoDiamond (ND) particles with the operation in MPGD-based photon detectors

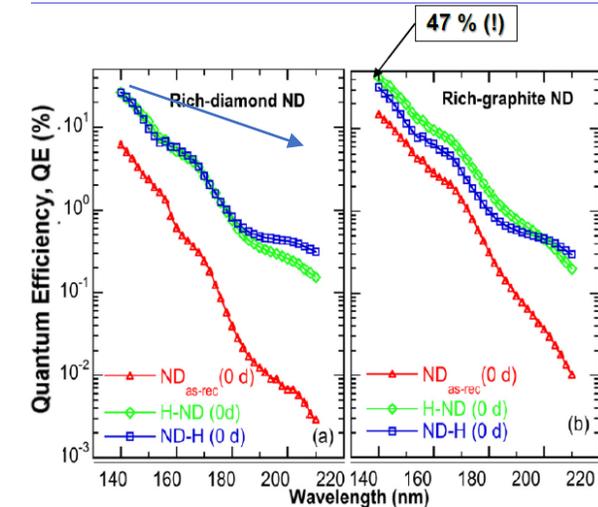
- Preliminary exercises reported in July 2018

Unexpected feature:

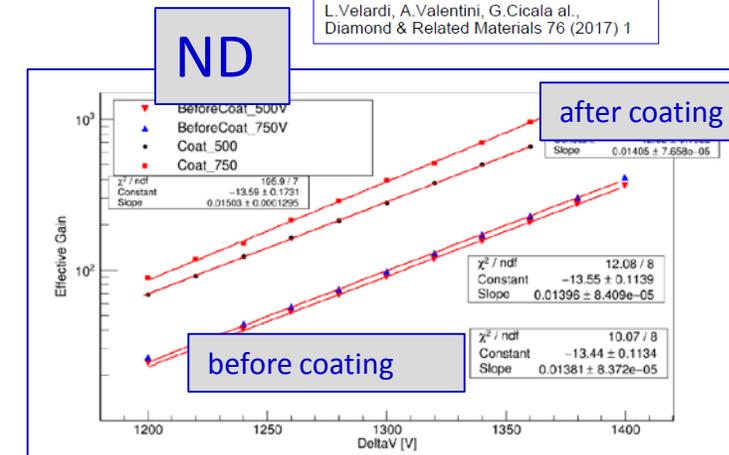
Gain increase in coated samples

- *A possible explanation emerging from repeated measurements:*
- The coating with the resistive material prevents charging-up phenomena in THGEMs
 - An observation of interest beyond this specific application

Reminder: the starting point

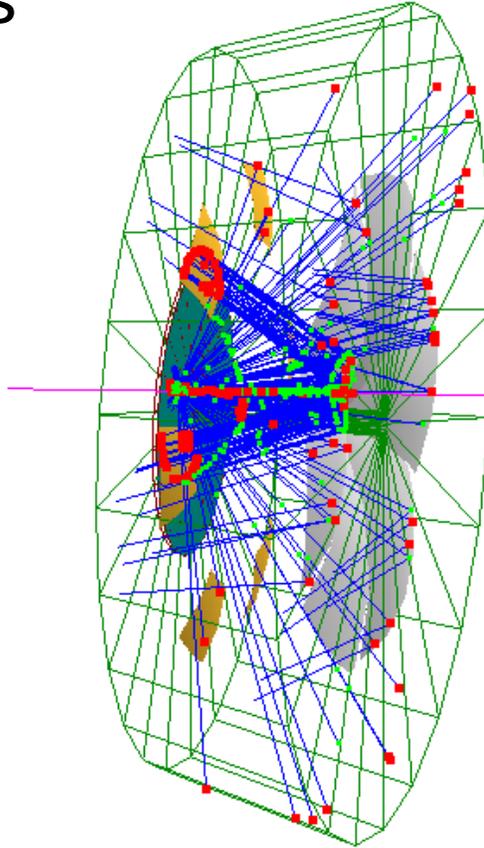


L. Velardi, A. Valentini, G. Cicala et al.,
Diamond & Related Materials 76 (2017) 1

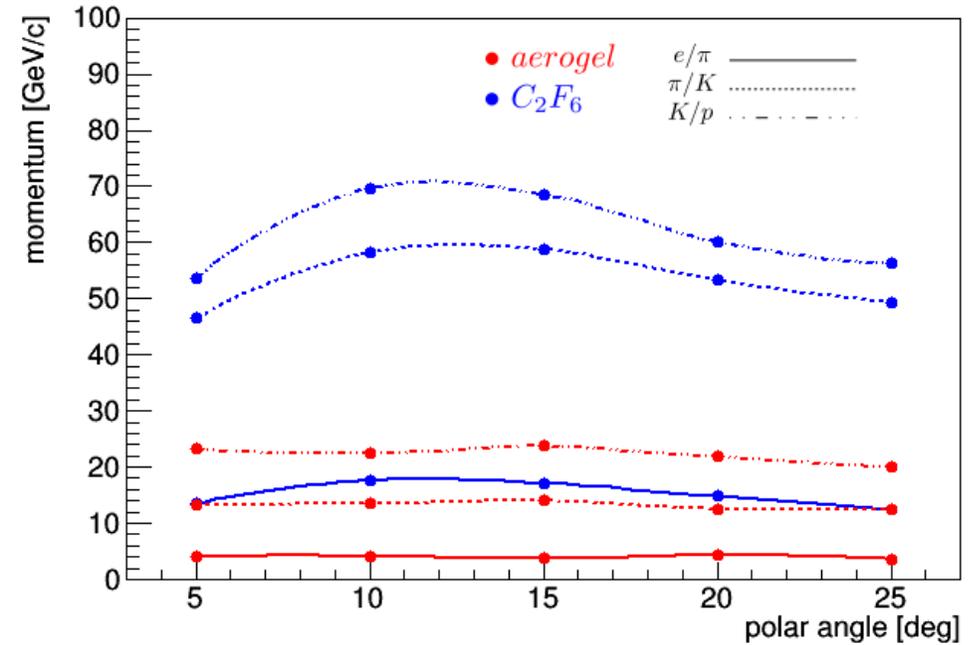


EIC dRICH (JLab Geometry)

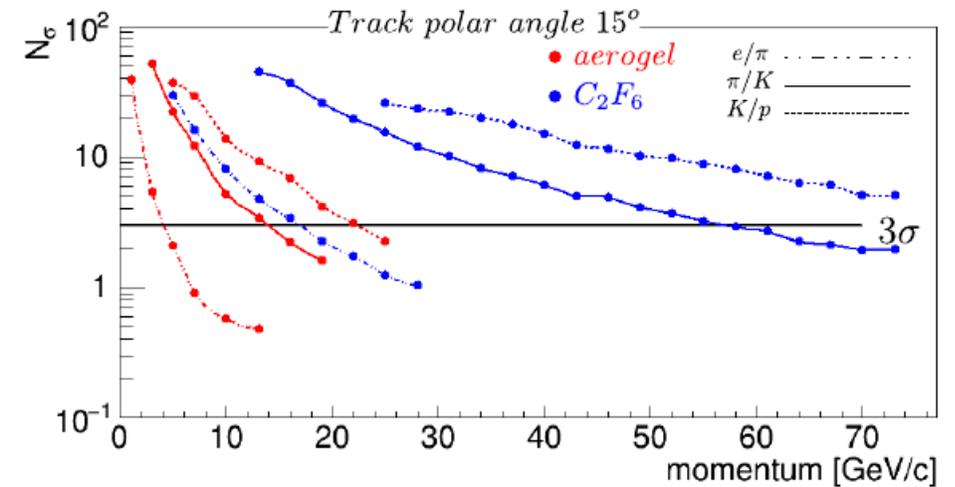
- Aerogel ($n=1.02$) & C_2F_6 gas
 - Continuous coverage
- Outward reflecting mirrors
 - Sensors away from the beam
 - No scattering in aerogel
- Sector-based 3D focusing
 - Reduced photosensor area



Isolines at 3σ (the $K/p(\text{gas})$ curve is given at 6σ)



Geant4 simulation includes magnetic field



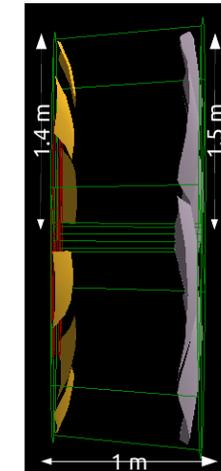
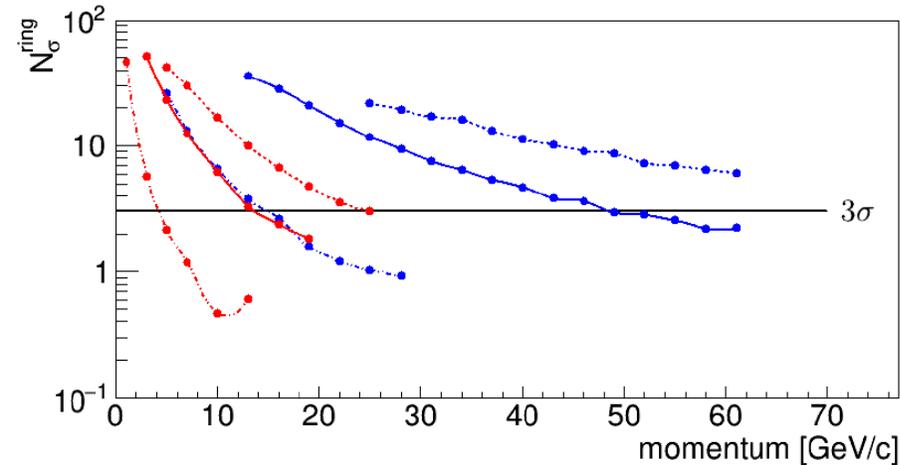
dRICH and eRD6 Gas RICH (BNL Geometry)

dRICH (ePHENIX)

dRICH (From GEMC simulation)

- aerogel + C_2F_6
- outward reflecting mirrors
- six azimuthal sectors
- SiPM or LAPPD sensors

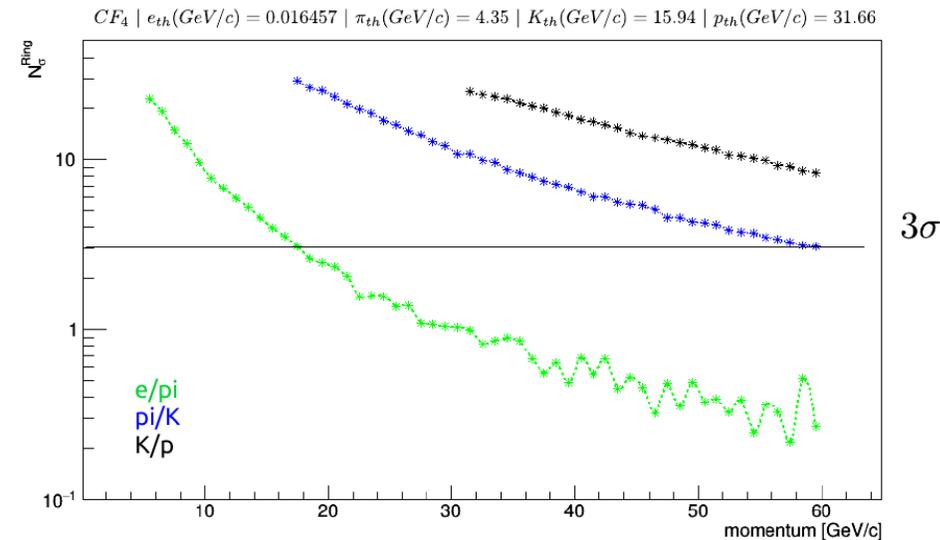
Aerogel ($n = 1.015$) | $e_{th}(GeV/c) = 0.0029$ | $\pi_{th}(GeV/c) = 0.80$ | $K_{th}(GeV/c) = 2.84$ | $p_{th}(GeV/c) = 5.40$
C₂F₆ ($n = 1.00082$) | $e_{th}(GeV/c) = 0.0123$ | $\pi_{th}(GeV/c) = 3.48$ | $K_{th}(GeV/c) = 12.3$ | $p_{th}(GeV/c) = 23.4$



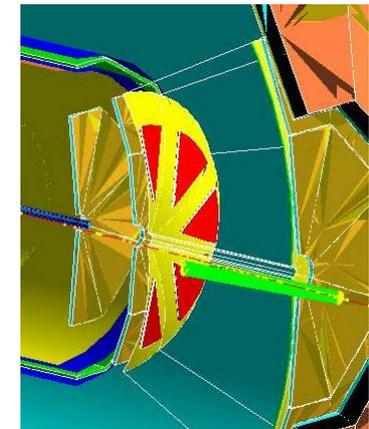
Spherical detector plane

eRD6 RICH (From Fun4All simulation)

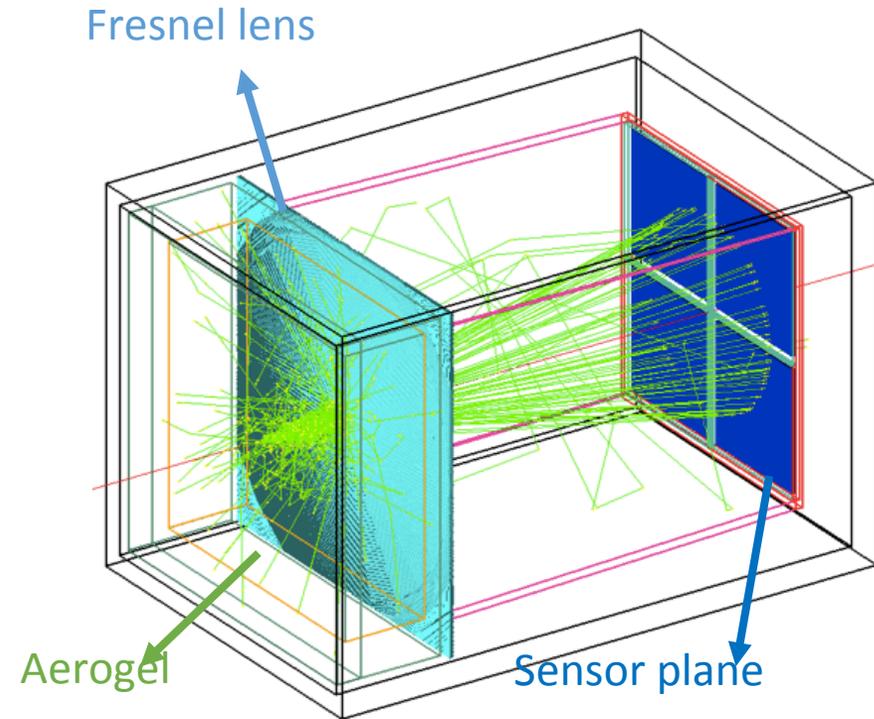
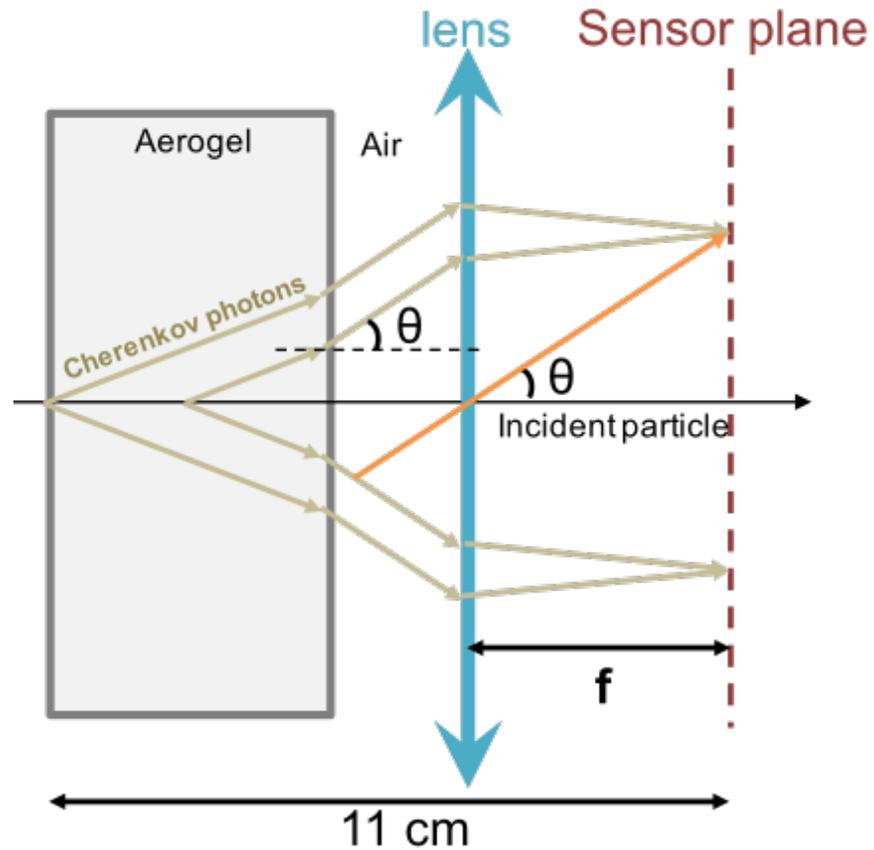
- CF_4 gas only
- inward reflecting mirrors
- eight azimuthal sectors
- GEM photosensors (sensitive in the UV)



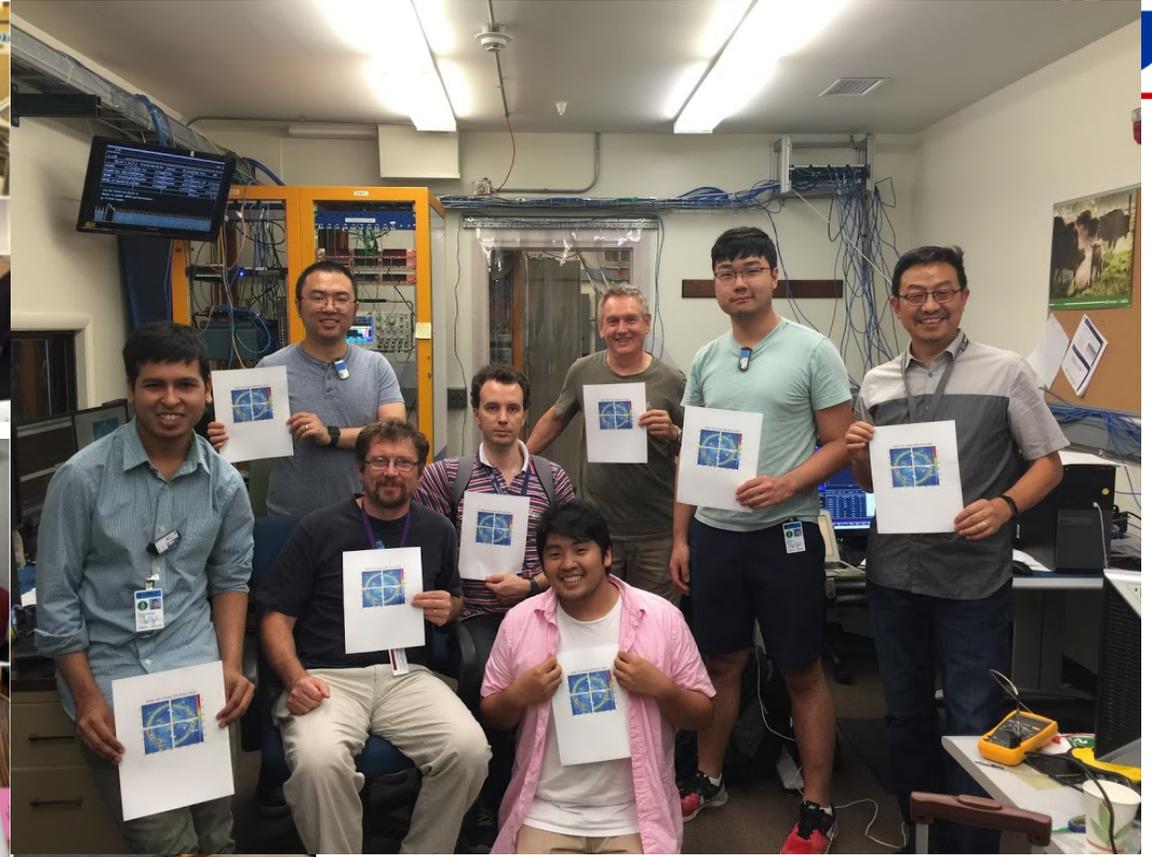
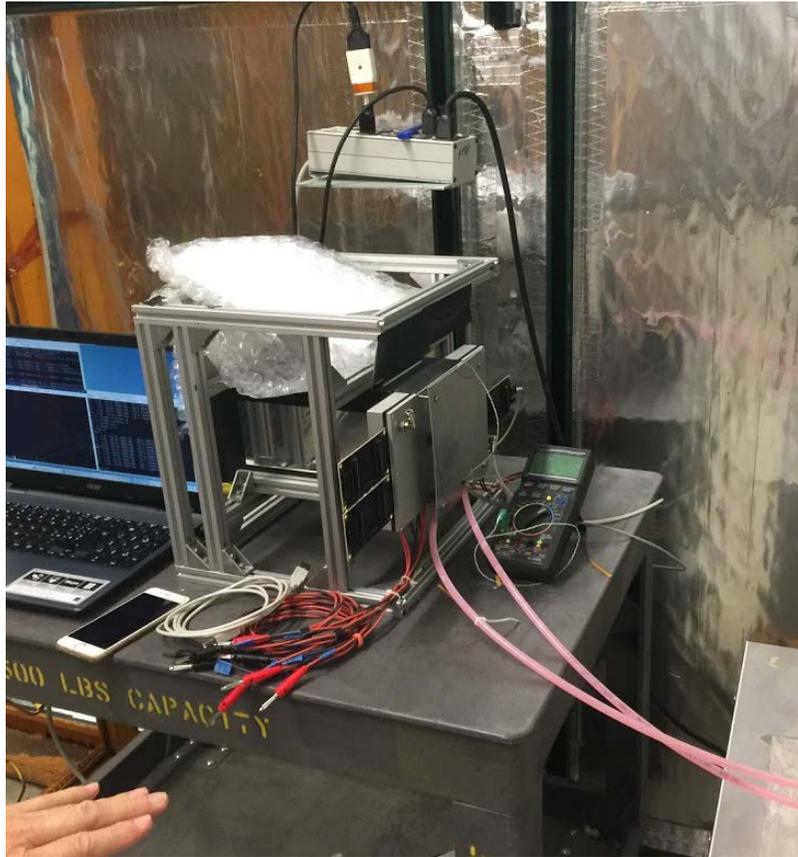
CF_4 gas RICH (ePHENIX)



EIC mRICH – Working Principle



Geant4 Simulation



Recent mRICH Beam Test at Fermilab

June 25 – July 6, 2018

1st mRICH Beam Test Results

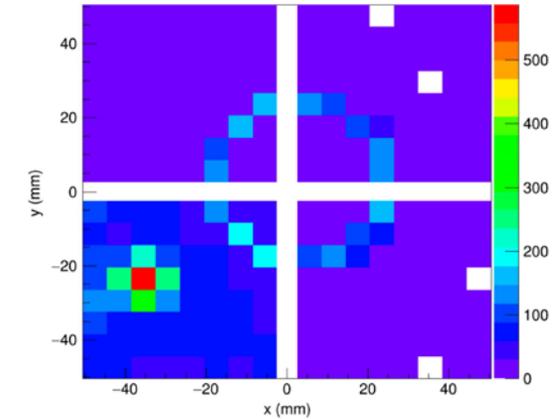
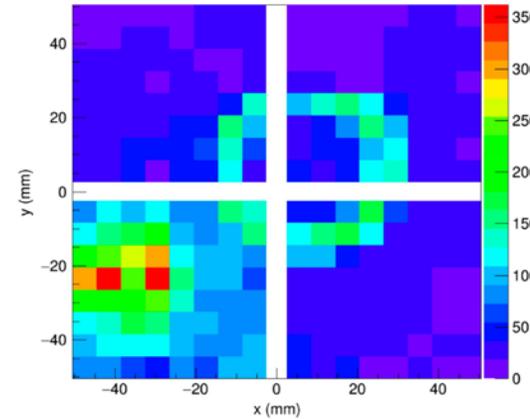
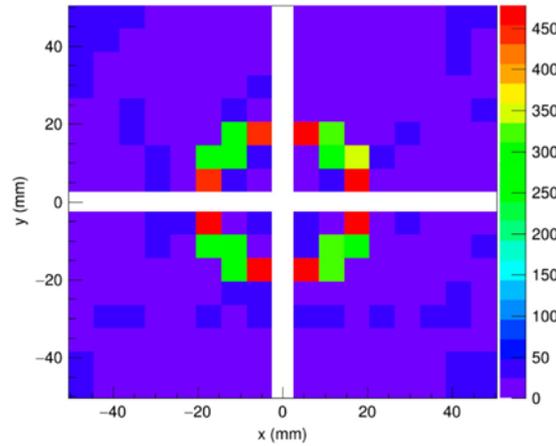
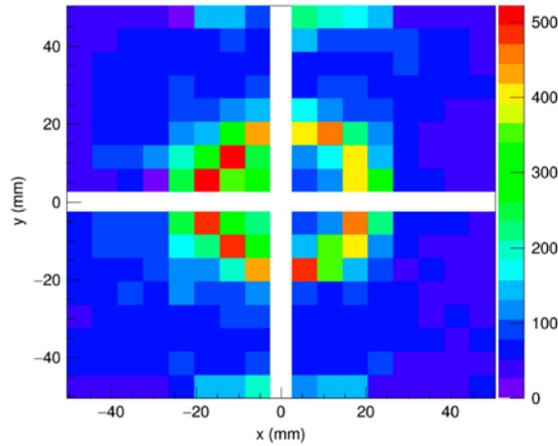


Beam Data

Geant4 Simulation

Beam Data

Geant4 Simulation



Analytical Calculation

Test Beam Data

Simulation

Radius (mm)

19.4

19.0 ± 1.3

18.9 ± 1.0

Number of
detected photons
per event

10.4

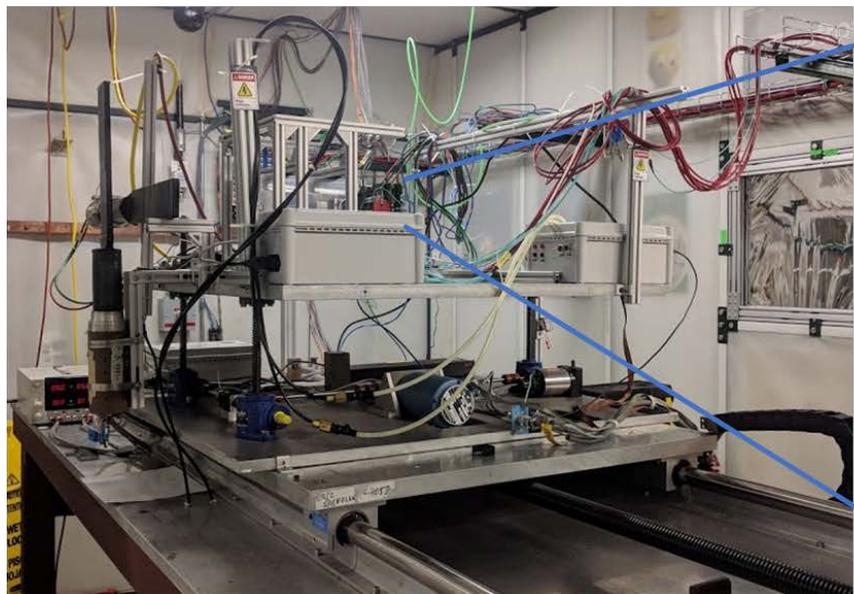
11.0 ± 2.9

11.1 ± 2.9

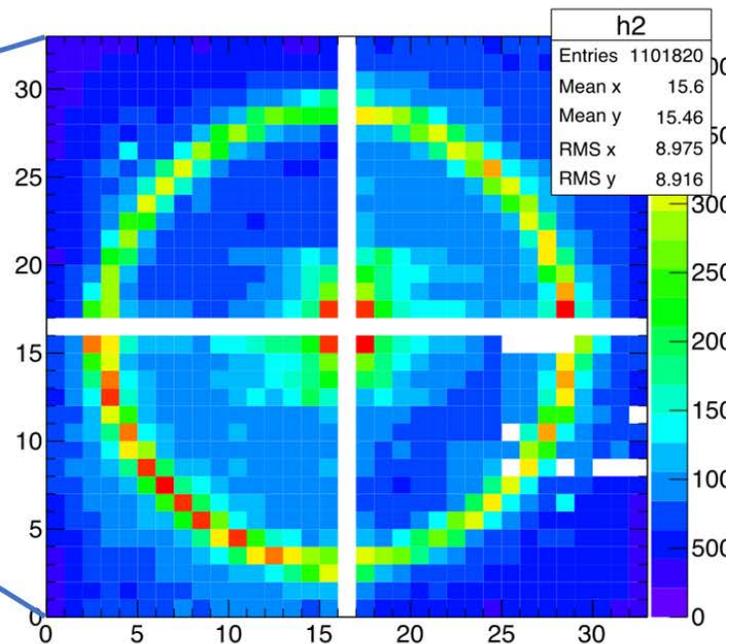
Beam incident in the lower quadrant
Ring image from Cherenkov radiation is
shifted toward central region on the
sensor plane.

C.P. Wong et. al. NIM A871 (2017) 13-19

Ring Image from 120 GeV/c primary proton beam incident at the center (Preliminary)

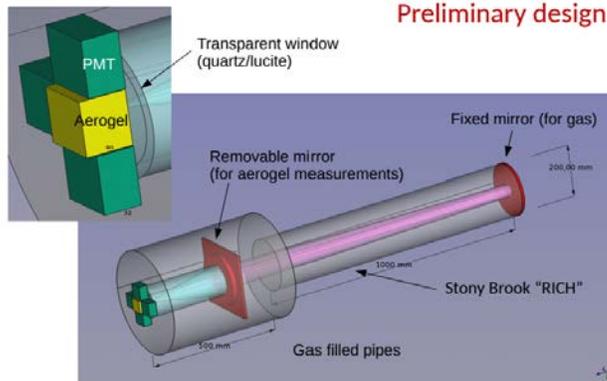


120 GeV/c
proton



dRICH Prototype

Preliminary design



Cross-over possible?

Progress @ SBU: Evaluated Optical Metamaterials

Transformation optics procedures applied on directional permittivities/permeabilities
 → dispersion relation

$$\frac{\epsilon_{x,x}}{\epsilon_0\epsilon_b} = \frac{\mu_{x,x}}{\mu_0} = \frac{g'(y)h'(z)}{f'(x)}$$

$$\frac{\epsilon_{y,y}}{\epsilon_0\epsilon_b} = \frac{\mu_{y,y}}{\mu_0} = \frac{f'(x)h'(z)}{g'(y)}$$

$$\frac{\epsilon_{z,z}}{\epsilon_0\epsilon_b} = \frac{\mu_{z,z}}{\mu_0} = \frac{f'(x)g'(y)}{h'(z)} \quad f'(x) = F \left(= \frac{\partial x}{\partial x'} \right), \quad g'(y) = G \left(= \frac{\partial y}{\partial y'} \right), \quad h'(z) = H \left(= \frac{\partial z}{\partial z'} \right)$$

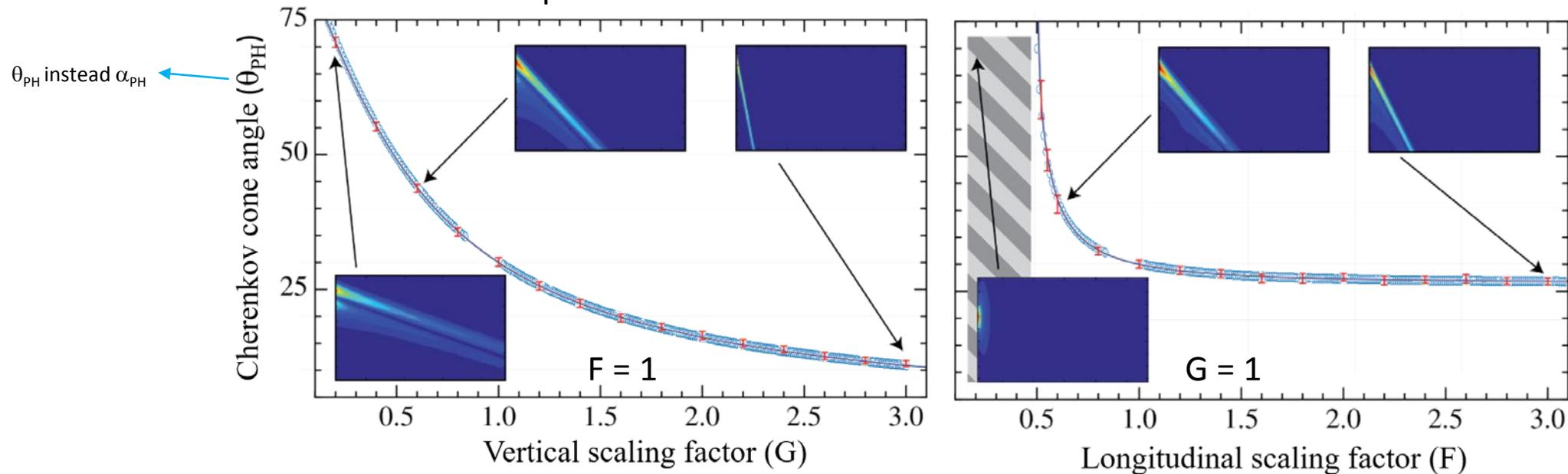
Dispersion relation:

$$\frac{k_x^2}{f'^2(x)} + \frac{k_y^2}{g'^2(y)} + \frac{k_z^2}{h'^2(z)} = \epsilon_b \frac{\omega^2}{c^2}$$

and

$$\tan(\alpha_{PH}) = \frac{k_y}{k_x} = \frac{G}{F} \frac{\sqrt{F^2 \epsilon_b \omega^2 / c^2 - k_x^2}}{k_x} = \frac{G}{F} \tan(\theta_{Ch,n_b})$$

Blue open circles overlaid on full-wave numerical simulations



Science Fiction?

- Angles like low n material
- Light yield like high n material

Summary

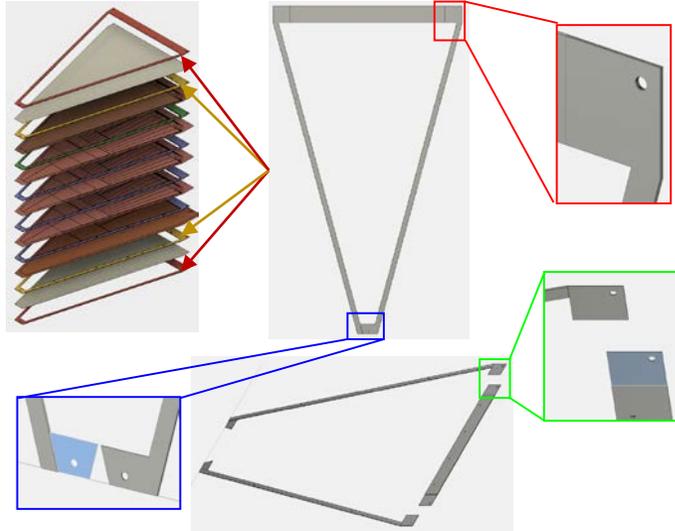
- EIC Tracking & PID R&D is active and growing.
- Multiple cutting edge technologies are being tested.
- Much success.
- Look forward to EIC CD-0 which will drive the process of narrowing the options to final detector designs.

Backup

Progress @ UVA: Low Cost Support Frames

Outer Frames without spacer grids: Low cost

- **Four Outer Frames** for gas window foils without spacers grid
- Each frame made of four **G10** pieces cut out in local machine shop
- **Low material and production cost**



Set of G10 pieces for all 4 frames

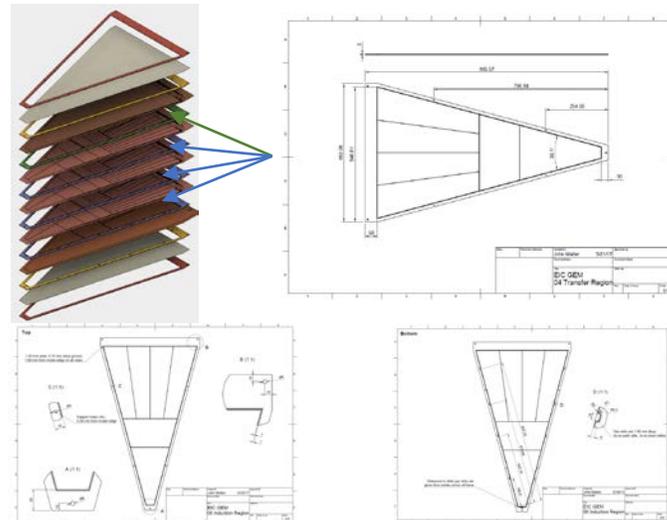


Set for one frame



Inner Frames for GEMs with spacer grids: High cost

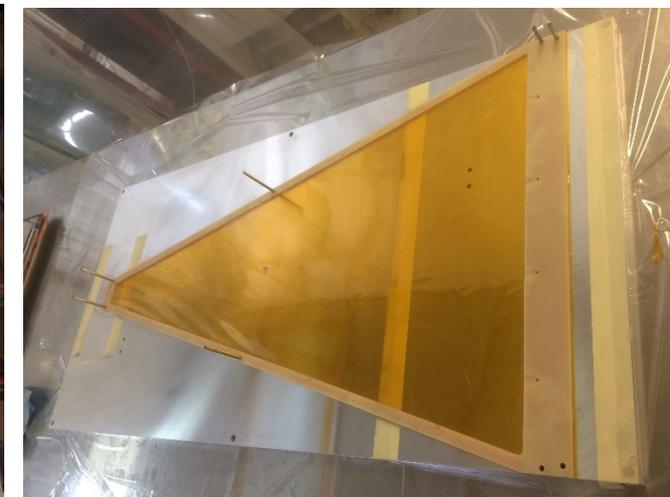
- **Four Inner Frames** with 300 μm spacers grid for GEM foils
- Precision machining of **PERMAGLAS** by RESARM (Belgium)
- **High material and machining cost**



Gluing of one frame



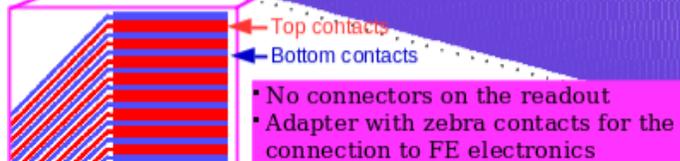
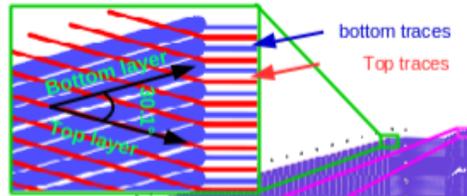
Window foil glued to low cost frames



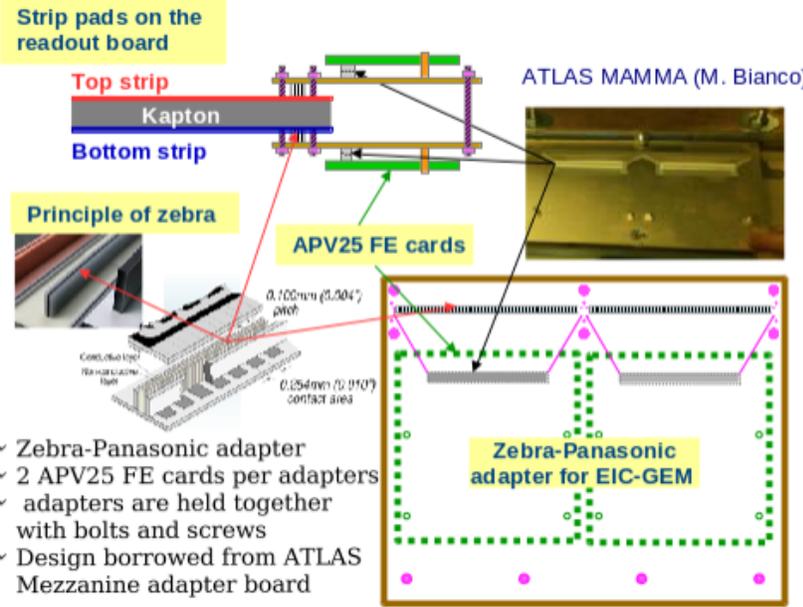
Progress @ UVA: U-V Readout with Zebra Connection

Design of EIC-Proto II 2D U-V strips readout board

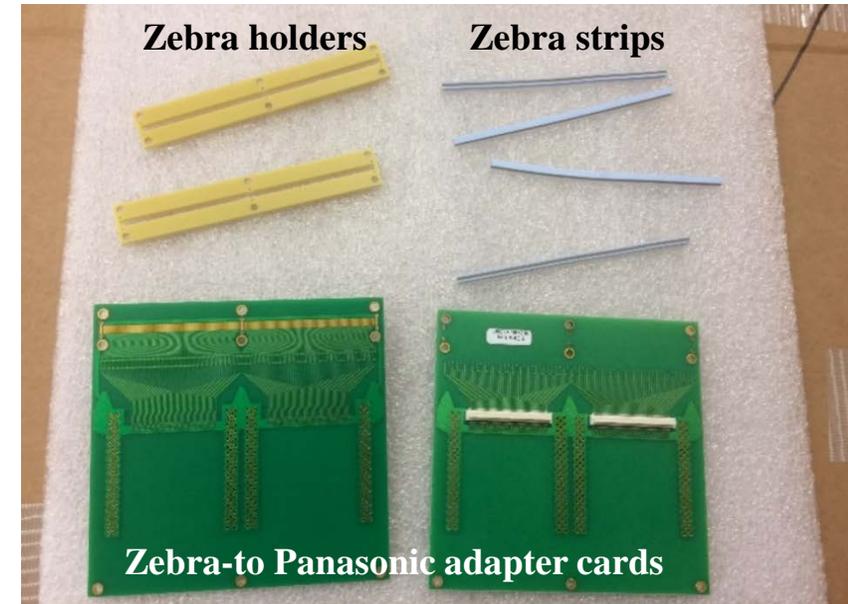
- 2d U-V strips (5 μm Cu) readout on board, 50 μm Kapton; Pitch: 400 μm
- Top layer: 80 μm U-strips parallel to one radial side
- Bottom layer: 350 μm V-strips parallel to other radial side.



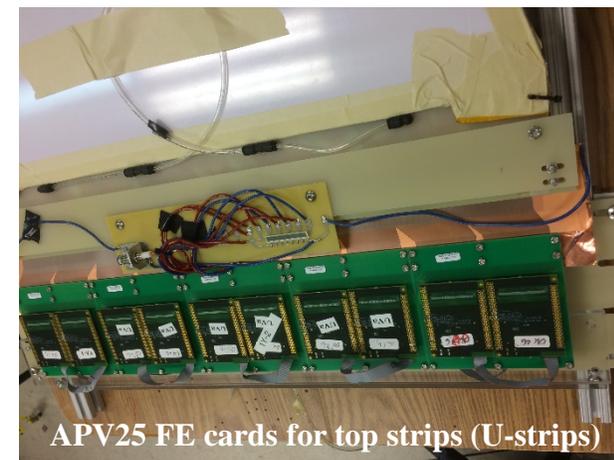
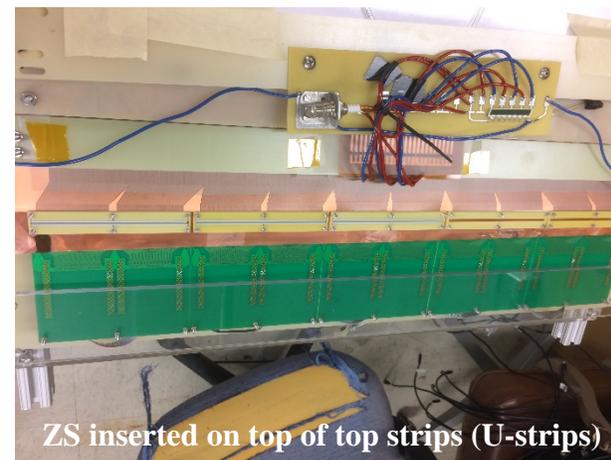
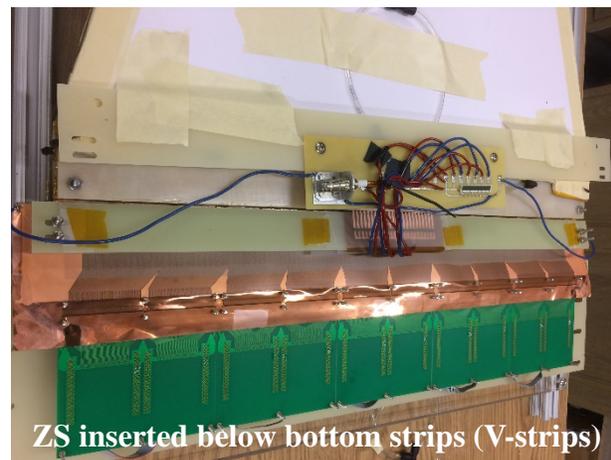
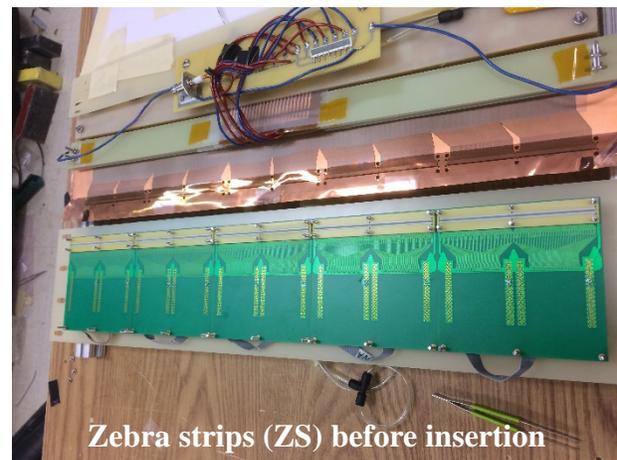
Drawings of the Zebra-Panasonic adapter board



Components of the double-sided zebra connection



Assembly steps of the double-sided zebra connection scheme on the large GEM prototype



The eRD6 Consortium

➤ EIC detector R&D for the development of tracking and pID capabilities beyond the present state of the art

❖ Brookhaven National Laboratory (BNL)

People: E.C Aschenauer, B. Azmoun, A. Kiselev, J. Kuczewski, M. L. Purschke, C. Woody

R&D: Mini-Drift detector; TPC/Cherenkov prototype (TPC-C); MPGD-based TPC; Zigzag pad development (*not funded under eRD6, but relevant for eRD6 R&D*)

❖ Florida Institute Of Technology (FIT)

People: M. Bomberger, M. Hohlmann

R&D: Large & low mass GEM with zig-zag readout structures; Cylindrical μ RWELL

❖ INFN Trieste

People: S. Dalla Torre, S. Levorato, F. Tassarotto

R&D: Development of hybrid MPGDs for single photon detection, synergistic to TPC read-out sensors (in particular, high momentum RICHes)

The eRD6 Consortium

- ❖ Stony Brook University (SBU)

People: K. Dehmelt, A. Deshpande, P. Garg, T.K. Hemmick

R&D: Short radiator length RICH; Large mirror coating, TPC-IBF studies

- ❖ Temple University (eRD3 merger with eRD6)

People: B. Surrow, M. Posik, A. Quintero

R&D: Commercial GEMs, MPGD-based trackers, tracking simulations; Cylindrical μ RWELL

- ❖ University Of Virginia (UVa)

People: K. Gnanvo, N. Liyanage

R&D: Large GEM with U-V readout; Chromium-GEM (Cr-GEM); Cylindrical μ RWELL

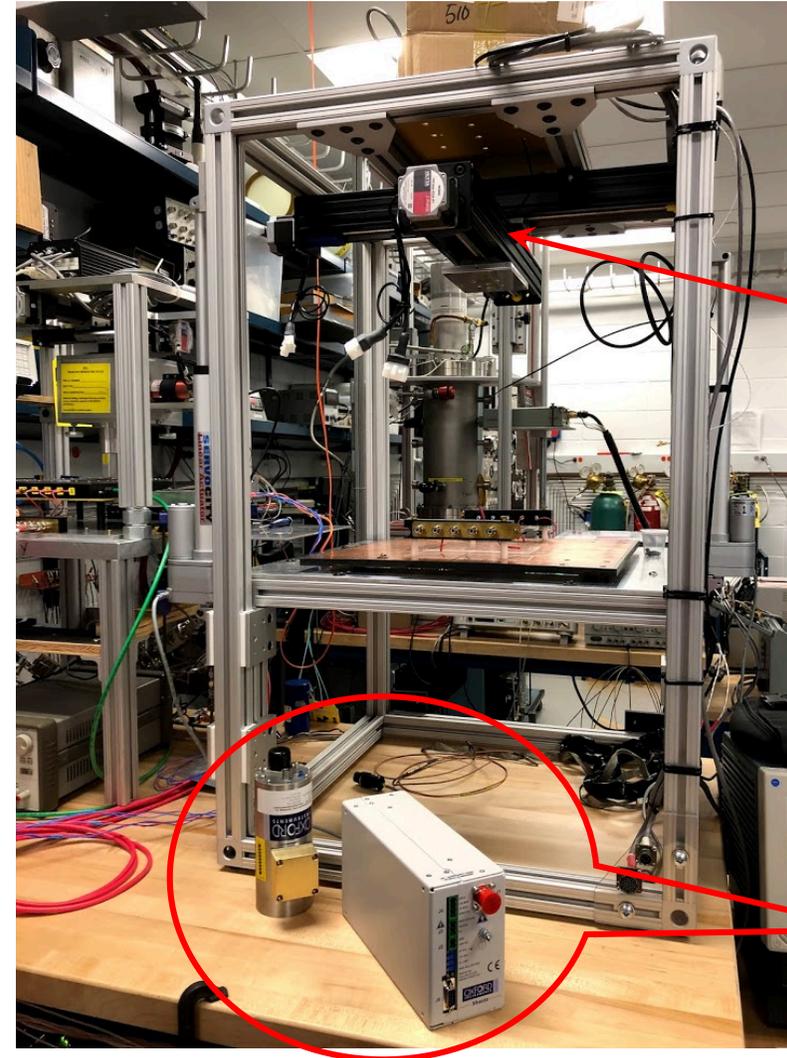
- ❖ Yale University

People: D. Majka, N. Smirnov

R&D: TPC characterization studies

Progress @ BNL: High Intensity X-ray scanner

- High intensity, highly collimated x-ray beam ($\sim 20\mu\text{m}$ wide) for in-lab characterization of detectors under test
- Initially we were sold an x-ray source that was later determined to be inadequate for our needs (ie, equipped with a window which severely truncated the x-ray intensity spectrum)
- After much back and forth with manufacturer, we were able to exchange the source for one with a Be window, with virtually no cut-off
- We are now working to integrate the new source into the existing setup (XY-scanning stage and infrastructure already in place)



X-Y slides
mounted to
stand

New X-ray
source &
power supply

Progress @ BNL: Plans and Milestones

- January - March: Complete tracking software for the cosmic ray telescope, tune operating parameters, implement all the necessary calibrations
- January - June: Study track reconstruction in the TPC prototype using the cosmic ray telescope and attempt to get a first measure of the position resolution **in the lab**
- February - June: Read out the TPC with different electronics (ie, SAMPA and DREAM) and attempt to evaluate the performance for each case
- March - April: Study Micromegas and μ RWELL with zigzag readout in a planar detector configuration (ie, short drift gap)
- March - June: Continue work on optimizing the design and production of zigzag readouts (LDRD) in parallel with the eRD6 R&D program

Progress @ FIT: Plans and Milestones

□ Plans

- Forward Tracker Prototype:
 - Assemble the refurbished low-mass prototype and demonstrate that it can be operated
 - Characterize performance of the low-mass prototype with X-rays at Florida Tech
- EIC Simulations:
 - Extract hit residuals for tracks through the forward GEM chambers
 - Study how the reduction of material affects the spread of track position due to multiple scattering
 - Study precision of reconstructing track impact points on the RICH entrance window, i.e. seeds for ring reconstruction, with forward GEM trackers in front of and behind RICH
- RWELL detector:
 - Commission the $10 \times 10 \text{ cm}^2$ μ RWELL prototype with zigzag-strip readout
 - Characterize performance using X-rays.
 - Begin design for a small cylindrical RWELL detector together with UVa

□ Milestones

- Working low-mass prototype
- Working $10 \times 10 \text{ cm}^2$ μ RWELL prototype

Progress @ INFN: Plans and Milestones

- Future (2019), continuation of the on-going R&D activities:

1. MICROMEAS prototype with miniaturized pad-size

- Completion of the analysis of the 2018 test-beam data
- Construction of a second version of the prototype
- Characterization of this second version by laboratory exercises

2. Coupling of innovative photocathode based on NanoDiamond (ND) particles to MPGD photon detectors

- Production of a new set of small-size THGEM coated with ND and hydrogenated ND(HND)
- Progress in understanding of the THGEM performance and features when coated with ND and HND by laboratory studies

- 2019 Longer Term MILESTONES:

- September 2019: *The completion of the laboratory characterization of the second version of the photon detector with miniaturized pad-size.*
- September 2019: *The completion of the studies to understand the performance of THGEMs with ND*

Progress @ SBU: Mirror coating project

- Continuing installation effort
- Equipment installation into evaporator almost complete
- Connecting to external equipment under way
- Start-up expected at end of 1st quarter '19

Progress @ SBU: Plans and Milestones

- January – March '19

IBF studies (Abstract to MPGD2019 submitted)

- February – April '19

Simulation of meta-materials

- January – April '19

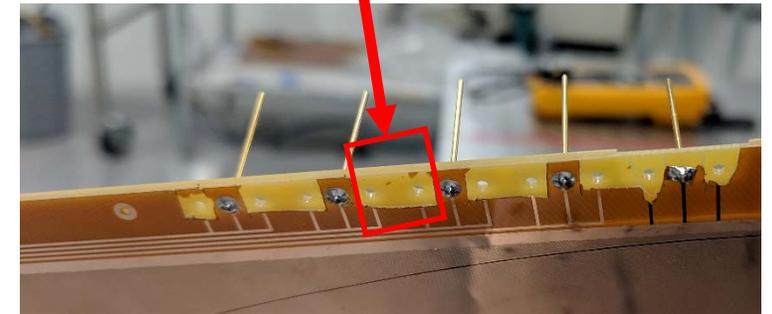
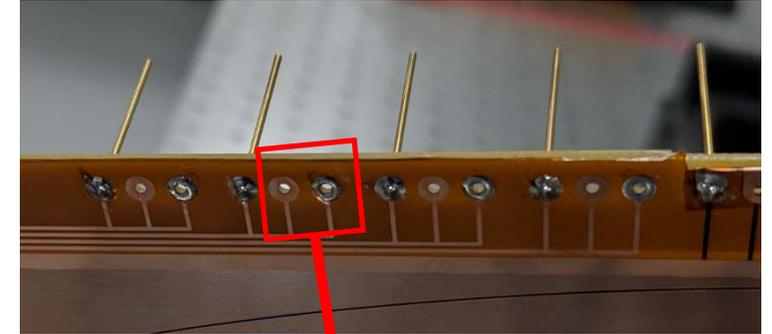
Finalizing installation of mirror coating equipment

- April – May '19

Commissioning evaporator

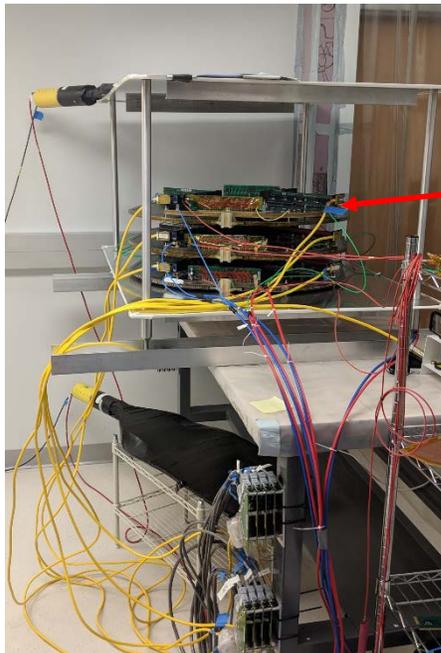
Progress @ TU: Commercial Triple GEM Detector

- **Goal** is to build and characterize triple-GEM detectors using **commercial foils** (Tech-Etch) and **Kapton spacer rings** rather than G10 spacer strips.
- Identified and corrected the shorting issue with first two triple-GEM detectors which rendered them useless.
- **Third triple-GEM detector** implemented shorting fix by removing unused HV pads.
- Foils have been stretched and glued to their respective frames for the **fourth triple-GEM detector**.

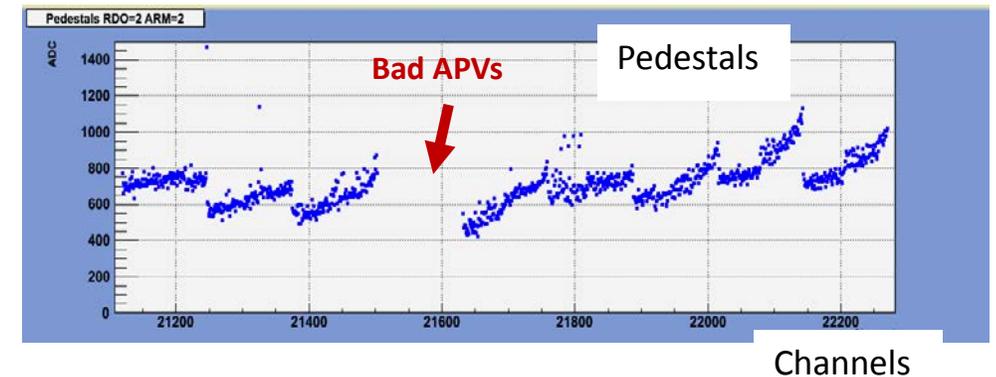
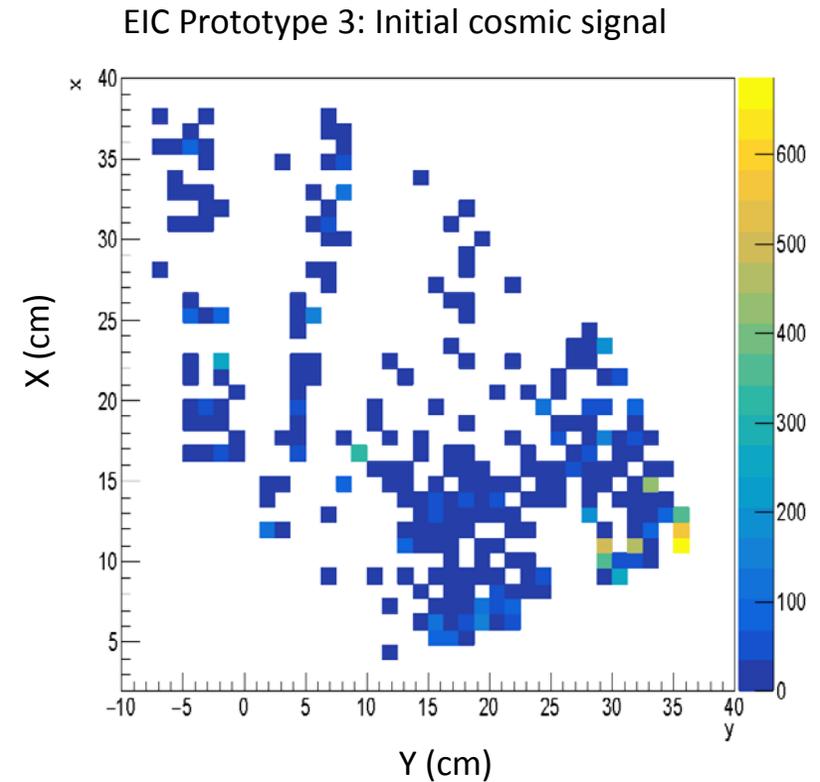


Progress @ TU: Commercial Triple GEM Detector

- We see signal from cosmics with the third triple-GEM detector, but some issues too → currently investigating
 - 2 APV chips are bad
 - Electronic mapping issues
- Characterization (cosmic/ ^{55}Fe) of third and fourth triple-GEM detector will complete the eRD3 carry over R&D



EIC Prototype



Progress @ TU: Plans and Milestones

□ Plans

- Commercial Triple-GEM Detectors
 - Test remaining APV cards (**March**)
 - Complete electronic mapping (**March**)
 - Complete cosmic and ^{55}Fe detector characterizations → completes eRD3 carry over R&D (**end of year**)
- μRWell μTPC barrel simulation
 - Implement more realistic hit point resolutions in to barrel μTPC based on radial TPCs and eRD6 μTPC prototypes, e.g. mini-drift detector (**April**).
 - Simulate track residuals and charge discrimination (**June**).

Progress @ UVA: Plans and Milestones

❖ Plans

- ⇒ Continue / Complete the FNAL test beam data analysis for large GEM and μ RWELL prototypes
- ⇒ Present the results at the coming MPGD2019 Conference in Paris
- ⇒ Characterization of the small μ RWELL prototype, the high rate capabilities and charge sharing of the readout structure
- ⇒ Start the draft of the paper on Chromium GEMs and on the large GEM R&D effort for submission to NIM A or IEEE TNS
- ⇒ Pursue the collaborative effort with FIT and TU on simulation and design of cylindrical μ RWELL

❖ Milestones for 2019

- ⇒ Jan - May: FNAL test beam data analysis
- ⇒ May – Dec : Draft of manuscripts and R&D on μ RWELL for EIC central tracker

eRD6 Publication List: Breakdown per institute

❖ Brookhaven National Lab

1. B. Azmoun et.al., "A Study of a Minidrift GEM Tracking Detector", IEEE Transactions on Nuclear Science, Vol. 63, No. 3 (2016) 1768-1776; <https://doi.org/10.1109/TNS.2016.2550503>.
2. C. Woody et.al., "A Prototype TPC/Cherenkov Detector with GEM Readout for Tracking and Particle Identification and its Potential Use at an Electron Ion Collider"; <https://inspirehep.net/record/1409973/files/arXiv:1512.05309.pdf>.
3. B. Azmoun et al.; "Initial studies of a short drift GEM tracking detector", In: 2014 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC). Nov. 2014; <https://doi.org/10.1109/NSSMIC.2014.7431059>
4. M. L. Purschke et al. "Test beam study of a short drift GEM tracking detector", In: 2013 IEEE Nuclear Science Symposium and Medical Imaging Conference (2013 NSS/MIC). Oct. 2013; <https://doi.org/10.1109/NSSMIC.2013.6829463>
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.
6. B. Azmoun, et al., "Results from a Prototype Combination TPC Cherenkov Detector with GEM Readout", submitted for publication in IEEE Transactions on Nuclear Science, Dec. 2018.

❖ Florida Tech

1. M. 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; <http://inspirehep.net/record/1636290/files/arXiv:1711.05333.pdf>
2. A. Zhang et al. "A GEM readout with radial zigzag strips and linear charge-sharing response"; In: Nucl. Instr. Meth. A, article in press (2017). arXiv: <https://arxiv.org/abs/1708.07931v1>
3. A. Zhang and M. Hohlmann, "Accuracy of the geometric-mean method for determining spatial resolutions of tracking detectors in the presence of multiple Coulomb scattering," JINST 11 P06012 (2016), June 21, 2016; <https://doi.org/10.1088/1748-0221/11/06/P06012>
4. A. 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; <https://doi.org/10.1109/NSSMIC.2015.7581965>
5. A. Zhang, et al., "Performance of a large-area GEM Detector read out with wide radial zigzag strips," Nucl. Inst. Meth. A 811 (2016) 30-41; <https://doi.org/10.1016/j.nima.2015.11.157> EIC Detector R&D AC Meeting @ BNL, 1/18/2018 32 eRD6 Publication List: Breakdown per institute

eRD6 Publication List: Breakdown per institute

❖ INFN Trieste

1. J. Agarwala et al. “Optimized MPGD-based Photon Detectors for high momentum particle identification at the Electron-Ion Collider”. 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.2018.10.185>. url: <http://www.sciencedirect.com/science/article/pii/S0168900218314992>.
2. J. Agarwala et al. “Novel NanoDiamond based photocathodes for gaseous detectors”. In: 2018. arXiv: 1812.04552 [physics.ins-det].

❖ Stony Brook University

1. M. Blatnik et al., “Performance of a Quintuple-GEM Based RICH Detector Prototype”, In: IEEE Trans. Nucl. Sci. 62.6 (2015), <https://doi.org/10.1109/TNS.2015.2487999>

❖ Temple University

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].
2. M. Posik and B. Surrow. “Construction of Triple-GEM Detectors Using Commercially Manufactured Large GEM Foils”. In: Proceedings, 2016 IEEE Nuclear Science Symposium and Medical Imaging Conference: NSS/MIC 2016: Strasbourg, France. 2016, p. 8069743. doi: 10.1109/NSSMIC.2016.8069743. arXiv: 1612.03776 [physics.ins-det].
3. M. Posik and B. Surrow. “Optical and electrical performance of commercially manufactured large GEM foils”. In: Nucl. Instrum. Meth. A802 (2015), pp. 10–15. doi: 10.1016/j.nima.2015.08.048. arXiv: 1506.03652 [physics.ins-det].
4. M. Posik and B. Surrow. “R&D of commercially manufactured large GEM foils”. In: Proceedings, 2015 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC 2015): San Diego, California, United States. 2016, p. 7581802. doi: 10.1109/NSSMIC.2015.7581802. arXiv: 1511.08693 [physics.ins-det]. 52
5. M. Posik and B. Surrow. “Research and Development of Commercially Manufactured Large GEM Foils”. In: Proceedings, 21st Symposium on Room-Temperature Semiconductor X-ray and Gamma-ray Detectors (RTSD 2014): Seattle, WA, USA, November 8-15, 2014. 2016, p. 7431060. doi: 10.1109/NSSMIC.2014.7431060. arXiv: 1411.7243 [physics.ins-det].

eRD6 Publication List: Breakdown per institute

❖ Univ. of Virginia

1. K. Gnanvo et al., “Performance in Test Beam of a Large-area and Light-weight GEM detector with 2D Stereo-Angle (U-V) Strip Readout”, Nucl. Inst. and Meth. A808 (2016); <https://doi.org/10.1016/j.nima.2015.11.071>
2. K. Gnanvo, et al. “Large Size GEM for Super Bigbite Spectrometer (SBS) Polarimeter for Hall A 12 GeV program at JLab”, Nucl. Inst. and Meth. A782, 77-86 (2015); <https://doi.org/10.1016/j.nima.2015.02.017>

❖ Yale University

1. S. Aiola et al., “Combination of two Gas Electron Multipliers and a Micromegas as gain elements for a time projection chamber”, Nucl. Inst. and Meth. A834 (2016); <https://doi.org/10.1016/j.nima.2016.08.007>

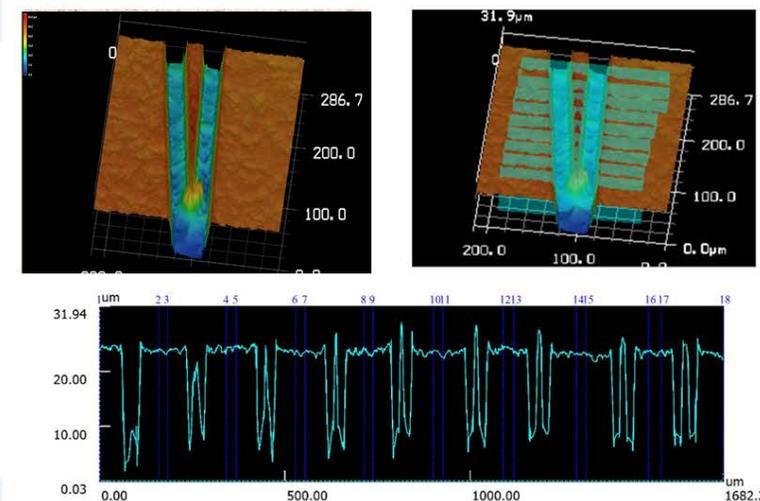
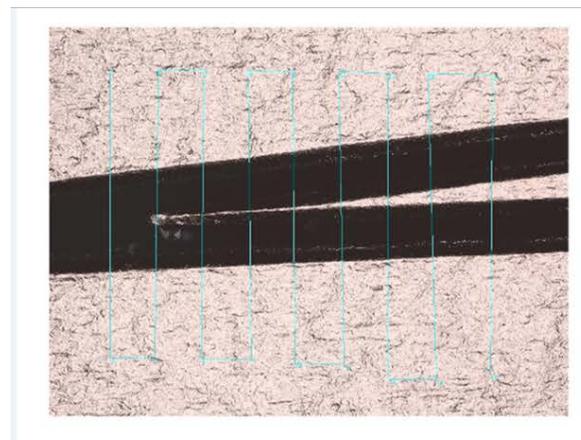
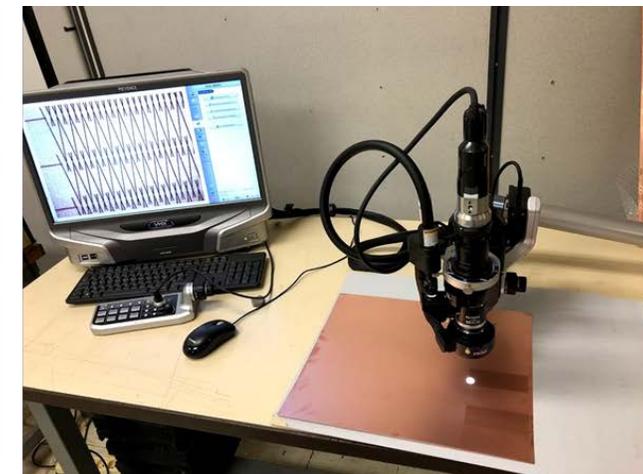
~22 eRD6 publications in all, with more to come!!

Thank you!

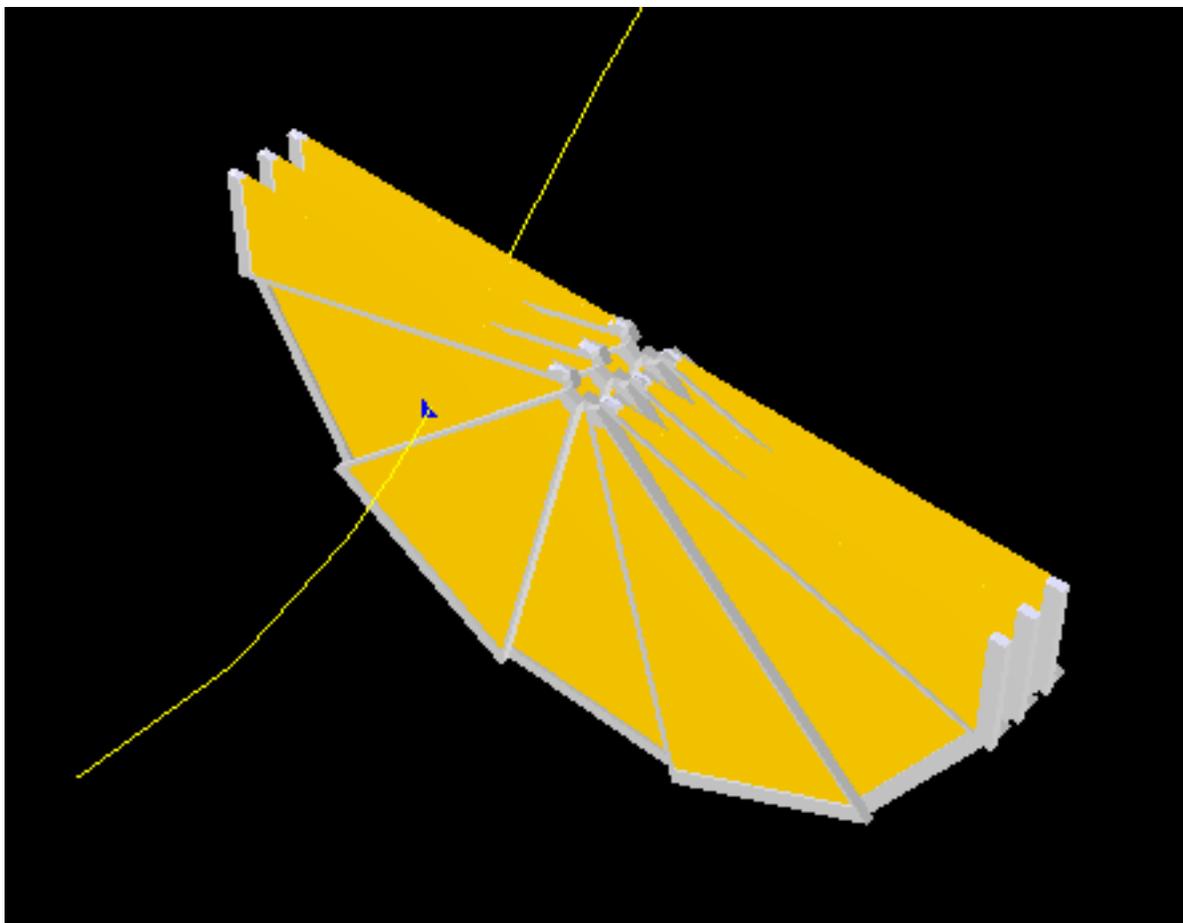
Progress @ BNL: Laser ablation

- Laser ablation is used in a novel way as the primary method to generate micropattern readout structure
- ~20mm wide trenches are able to be carved out of the copper+FR4 substrate, allowing the realization of unprecedented zigzag geometries
- **These new geometries are getting close to the ideal as suggested by simulation: ~40-50 μ m position resolution with NO differential non-linearity!!**
- Tuning the production parameters (eg, laser intensity, # of laser passes, machine instruction set) is informed by a rigorous QA routine
- Microscopic inspection of samples validates design specs and looks for damaging artifacts by examining the overall topology of the trenches

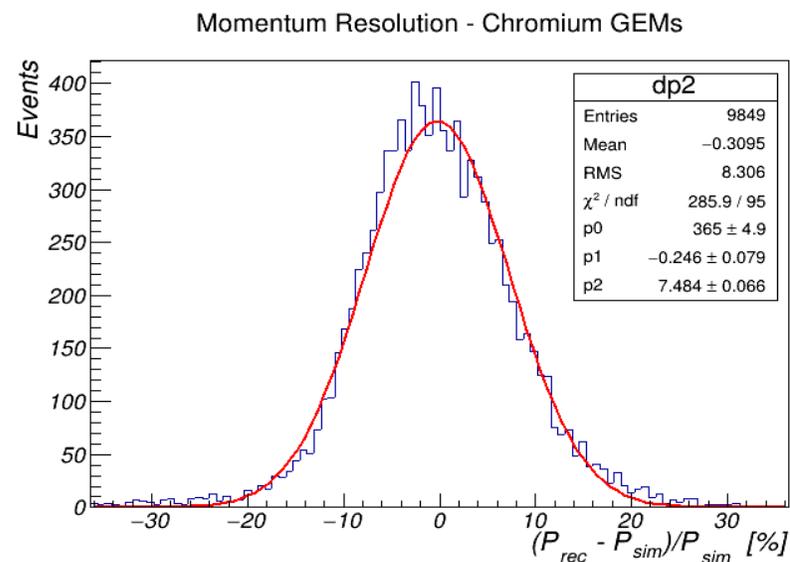
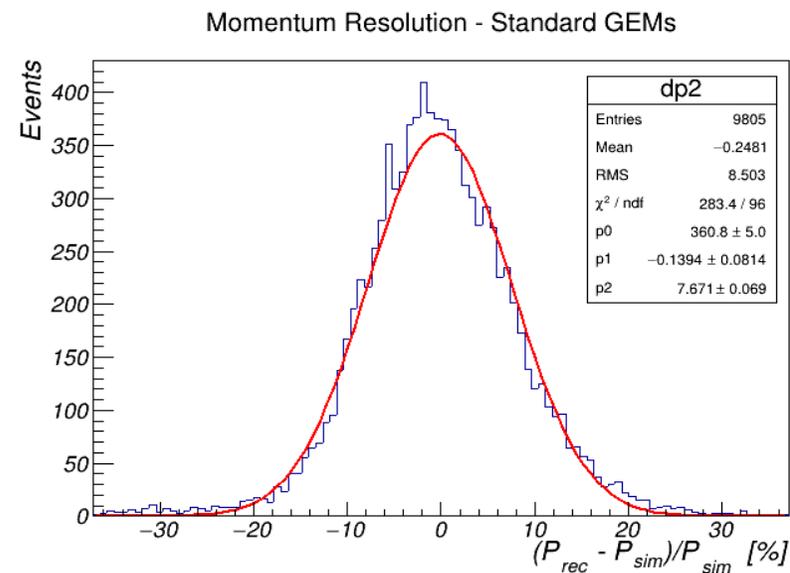
Laser ablation equipment at Elvia PCB manufacturing facility



Progress @ FIT: Simulation of Cr-GEM forward tracker



EicRoot simulation of a 1 GeV/c electron track reconstructed stand-alone in three GEM stations in forward tracker region



Progress @ UVA: Production Quality Issues

Production quality issues with the U-V readout

❖ Strange pattern in the reconstructed positions

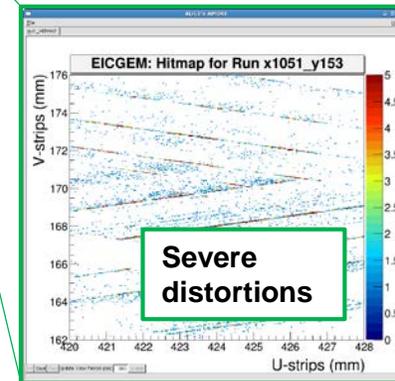
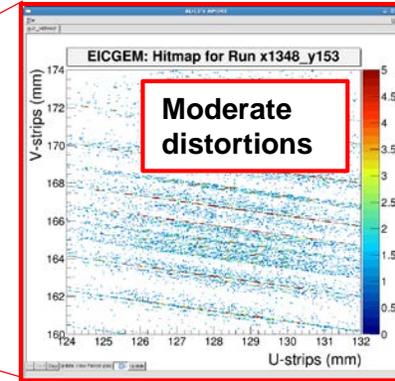
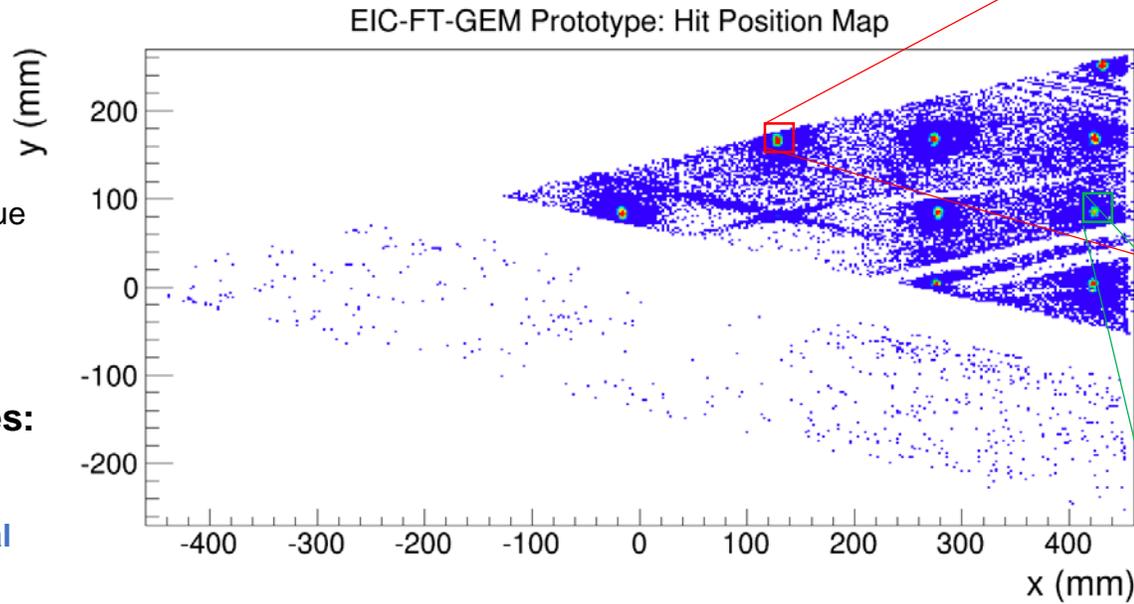
⇒ We normally expected uniform distribution of the position

❖ Cause of the problem still under investigation

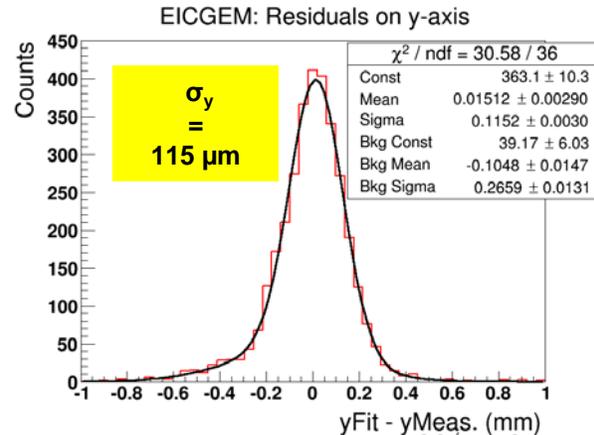
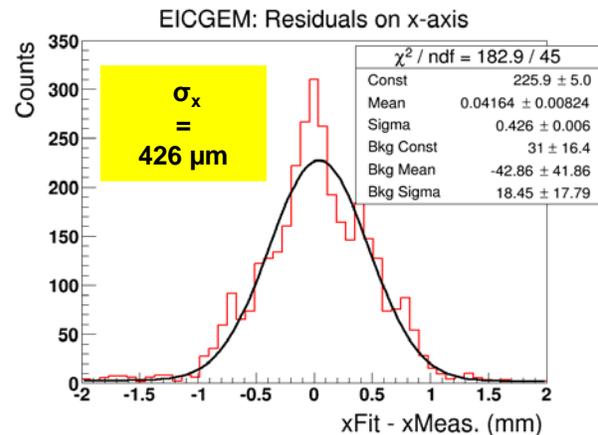
- ⇒ Looks like a lot of strips are shorted, but could also be an issue with the zebra connection or the quality of the zebra strips
- ⇒ Pattern effect more pronounced in some area than other

❖ Degradation of the spatial resolutions performances:

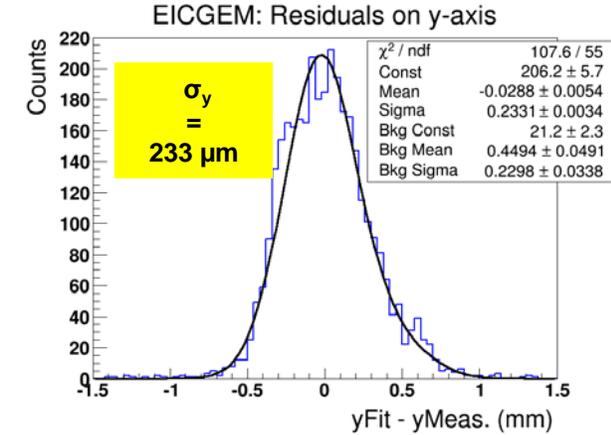
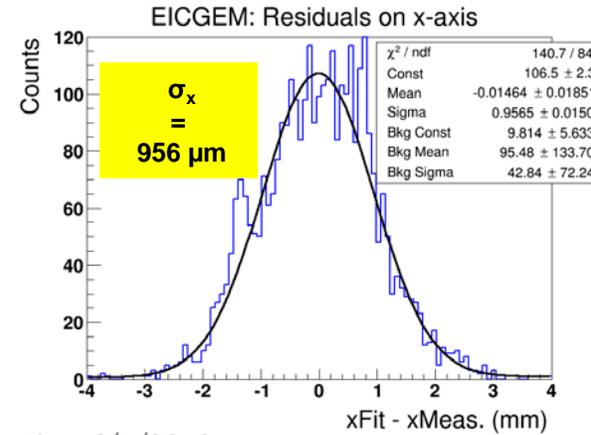
- ⇒ More pronounced where the distortions are severe
- ⇒ **But it is a production quality issue and not a fundamental issue with the U-V readout with double zebra connection**



Spatial resolution: moderate distortion area

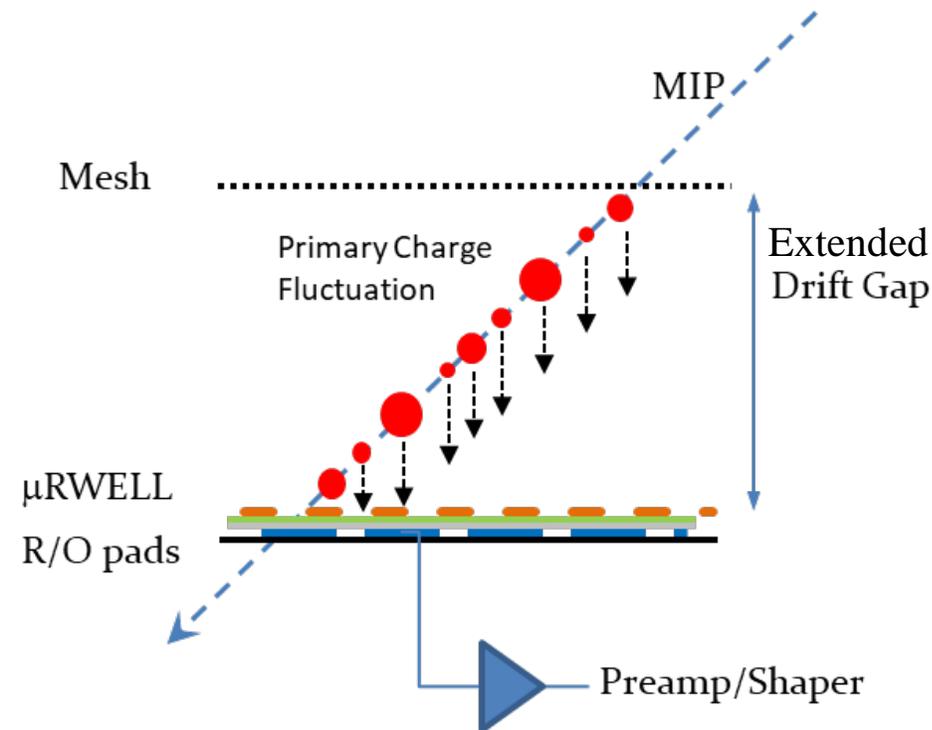


Spatial resolution: severe distortion area

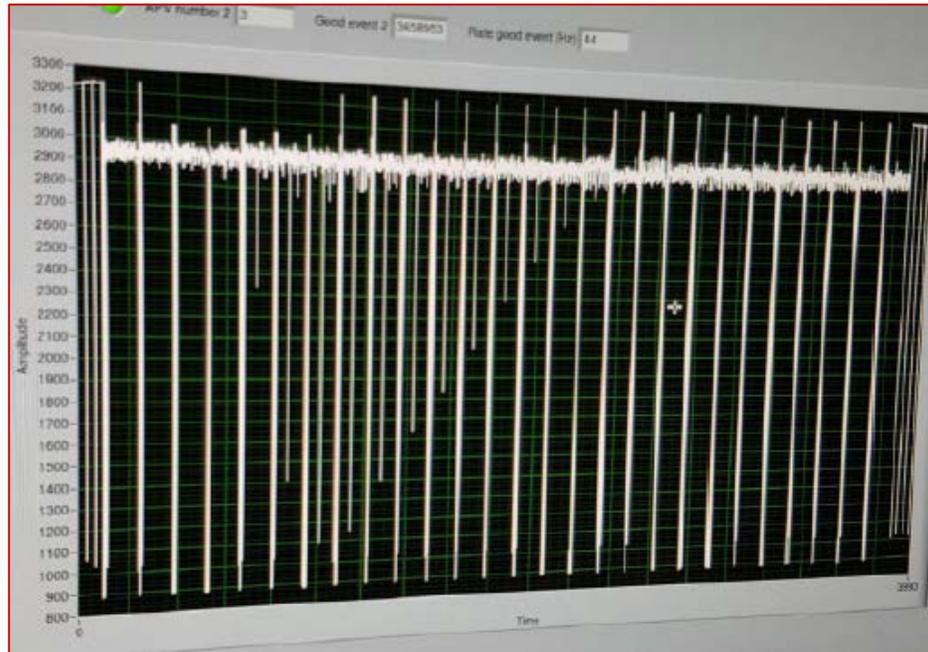


Progress @ TU: $\mu Rwell$ μTPC Barrel Simulation

- **Goal** is to simulate use of $\mu RWell$ operating in μTPC mode in the central rapidity region to study performance
 - May be useful option at a second EIC IR where TPC technology is not wanted.
 - $\mu RWell$ can also be used with silicon detectors to provide fast readout to distinguish particle bunches.

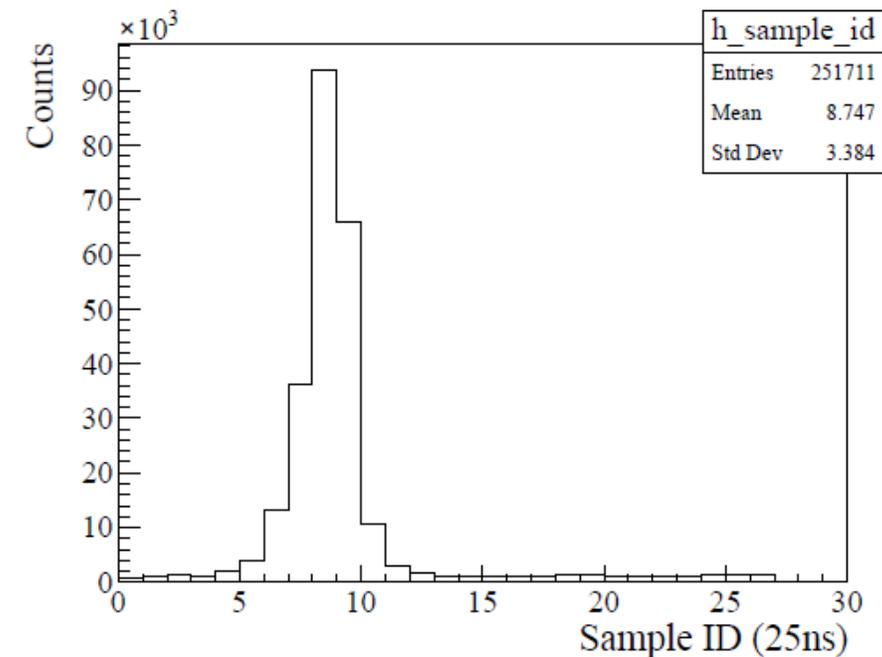


Progress @ INFN: First hints from the test beam

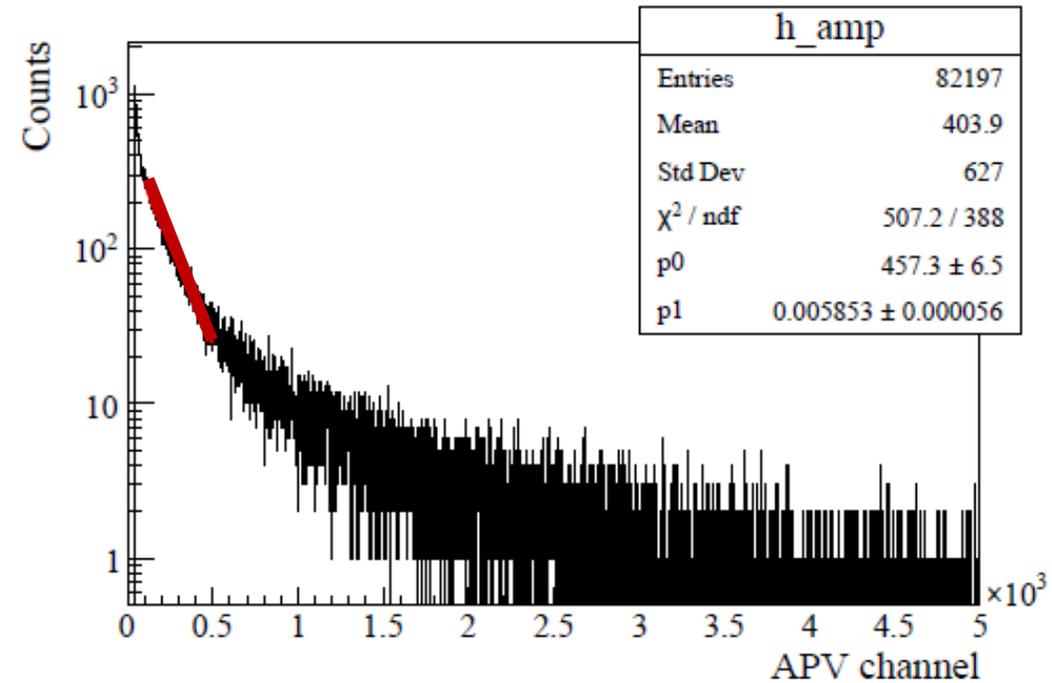
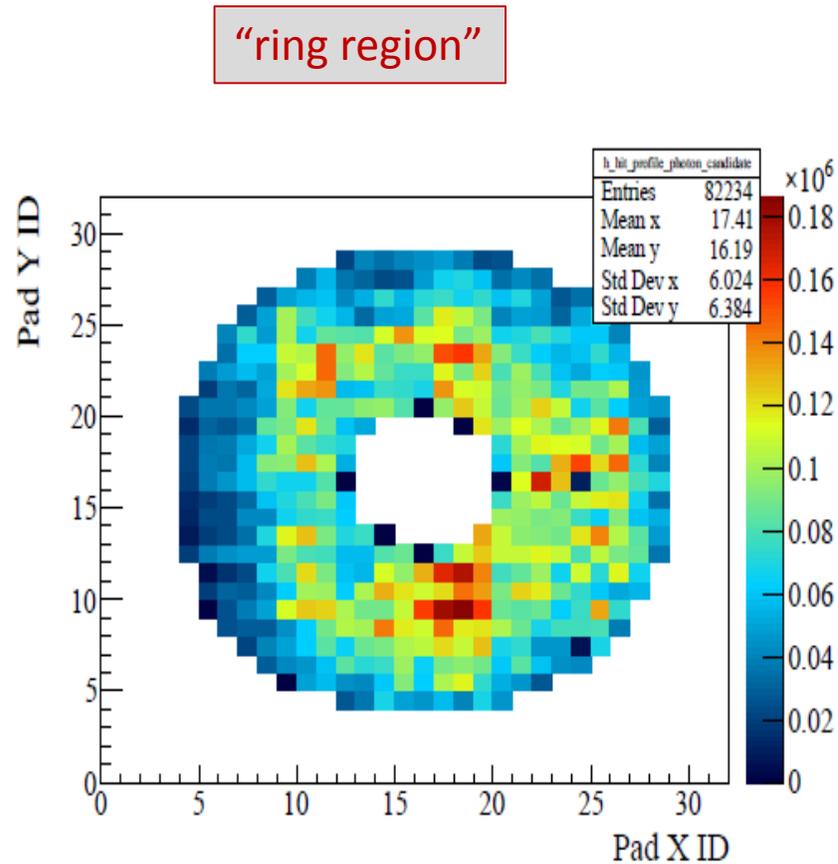


Time-development
of a single photon signal
(from on-line display)

Time distribution vs trigger time
of the Cherenkov photon signals



Progress @ INFN: First hints from the test beam



Signal amplitude in the ring region

Detector gain from the slope
of the exponential distribution (fitted):

Gain ~ 50 k !!!