eRD6 Progress Report

EIC GENERIC DETECTOR R&D ADVISORY COMMITTEE MEETING

January 30, 2020

Kondo Gnanvo on Behalf of the eRD6 Consortium

The eRD6 Progress Report

The eRD6 Member Institutes

- Brookhaven National Laboratory (BNL)
- Florida Institute Of Technology (FIT)
- INFN Trieste (INFN)
- Stony Brook University (SBU)
- Temple University (TU)
- University Of Virginia (UVa)
- Yale University (Yale U.)

Contents

- Progress on Central Tracker
  - R&D on TPC.
  - R&D on Cylindrical uRWELL.
- Progress on End Cap Tracker
  - R&D on Large-area & Low-mass GEM Prototypes.
  - Development of Commercial GEMs.
- Progress on 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.

The eRD6 Consortium

- **Brookhaven National Laboratory (BNL)**
  - **People**: E.C Aschenauer, B. Azmoun, A. Kiselev, M. L. Purschke, C. Woody.
  - **Central Tracker:** TPC and TPC/Cherenkov prototypes; zigzag pad readout, Avalanche structure readout.
- **Florida Institute Of Technology (FIT)**
  - **People**: M. Bomberger, J. Collins, M. Hohlmann.
  - **Central Tracker:** Cylindrical µRWELL; **End Cap Tracker:** Large area & low mass GEM with zig-zag readout.
- **INFN Trieste**
  - **People**: 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)**
  - **People**: K. Dehmelt, A. Deshpande, P. Garg, T. Hemmick.
  - **Central Tracker:** TPC-IBF; **Particle ID:** Short radiator length RICH, Large mirror coating, Meta Materials.
- **Temple University (TU)**
  - **People**: M. Posik, B. Surrow, N. Lukow, A. Quintero.
  - **Central Tracker:** Cylindrical µRWELL; **End Cap Tracker:** Commercial GEMs.
- **University Of Virginia (UVa)**
  - **People**: J. Boyd, M. Dao, K. Gnanvo, N. Liyanage, H. Nguyen.
  - **Central Tracker:** Cylindrical µRWELL; **End Cap Tracker:** Large area & low mass GEM with U-V readout.
- **Yale University**
  - **People**: D. Majka, N. Smirnov.
  - **Central Tracker:** Avalanche structure readout.

Progress on Central Tracker

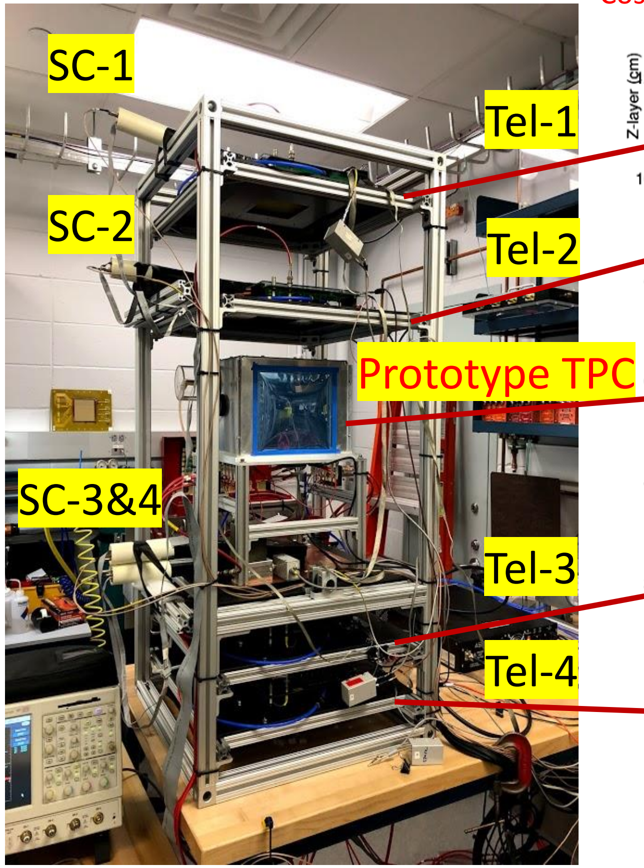
Central Tracker: TPC R&Ds Overview

- TPC R&D Studies: (BNL, Yale U, SBU)
  - MPGD based avalanche structure with zigzag pad readout for a TPC (BNL & Yale U)
  - Tests of new FE electronics (SAMPA & DREAM) for a TPC readout (BNL)
  - Investigation of Ion Back Flow (IBF) structures for MPGD based readout for a TPC (SBU)

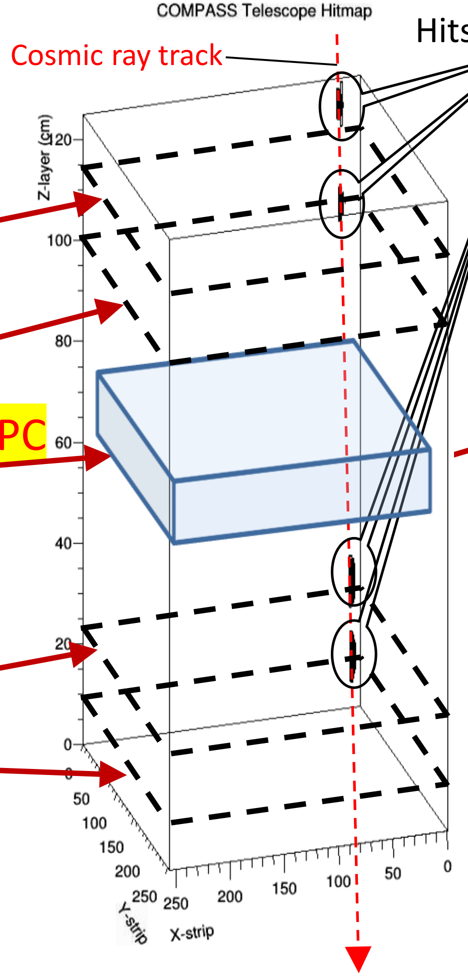
Central Tracker: TPC R&D @ BNL

Cosmic Ray Measurements with TPC Prototype

- Cosmic ray telescope re-assembled at BNL after used at FTBF to measure reference tracks from particle beam
- Cosmic ray telescope reconstructed using 4-layer telescope w/ SRS + APV25
- Cosmics also reconstructed in prototype TPC using zigzag readout plane and SAMPA front end electronics
- Cosmic rays will be used to characterize TPC response to high energy particles
- **Expect the cosmic ray telescope to provide a low rate/ low statistics verification of results obtained w/ the laser system described below**

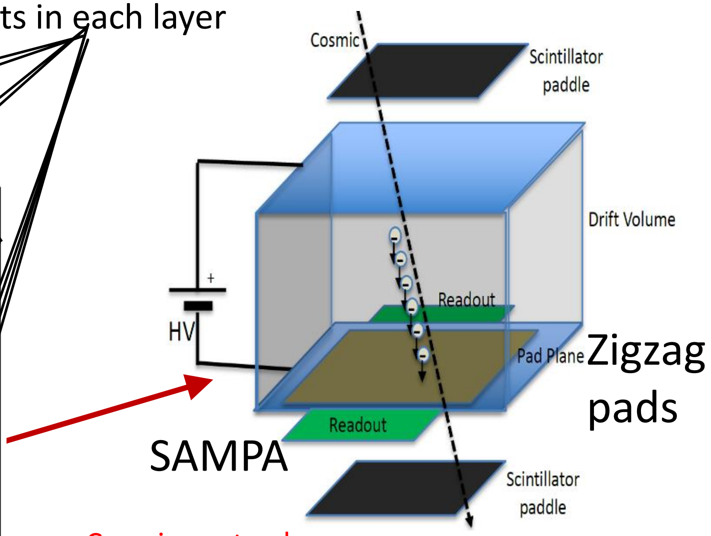


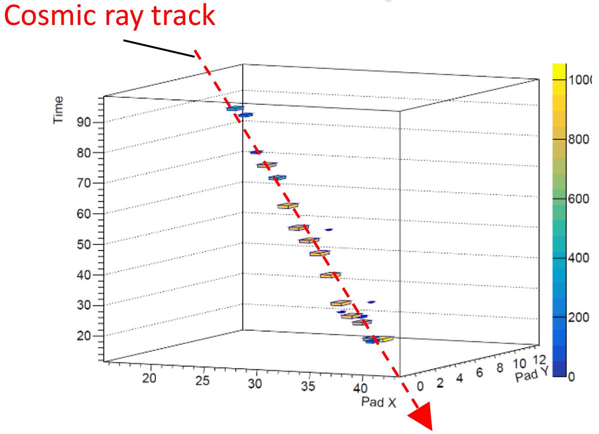
Active Area/Volume



(Aspect ratio not to scale)

Field Cage: **10cm x 10cm x 10cm**

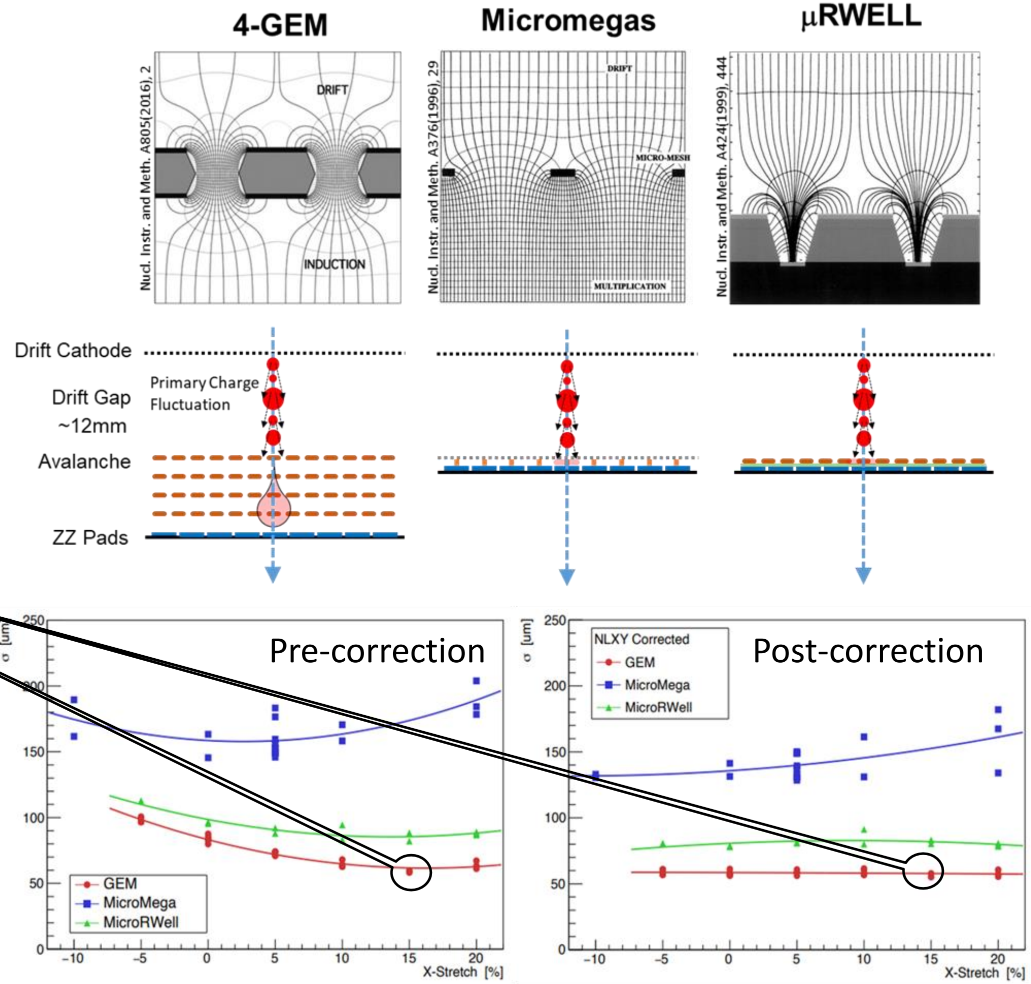




Central Tracker: TPC R&D @ BNL

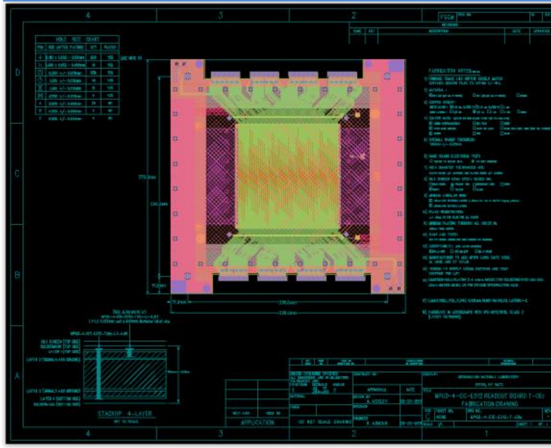
New Zigzag readout PCB for TPC Prototype

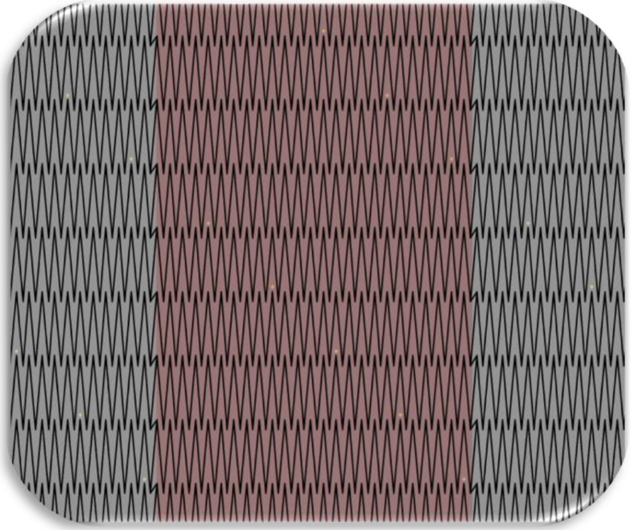
- New zigzag PCB design for TPC based on *preliminary* beam test studies with various MPGD avalanche schemes
- The minima of the resolution trend plots indicate the optical zigzag parameter set for a 4GEM: 2mm pitch, 0.5mm period, 50mm gap, and 15% interleaving (ie “stretch”)
  - Also, pre and post correction values are the same, so no DNL correction is needed!
- The new zigzag-based TPC PCB is being produced by the CERN PCB shop and will utilize a high precision chemical etch technique
- **NB: the resolution comparison is for particular detector operating parameters; more extensive testing is required for more general conclusions**



MM and μRWELL were not tested using optimal gas mixtures and for MM, no resistive layer is used

Engineering drawing of ZZ PCB



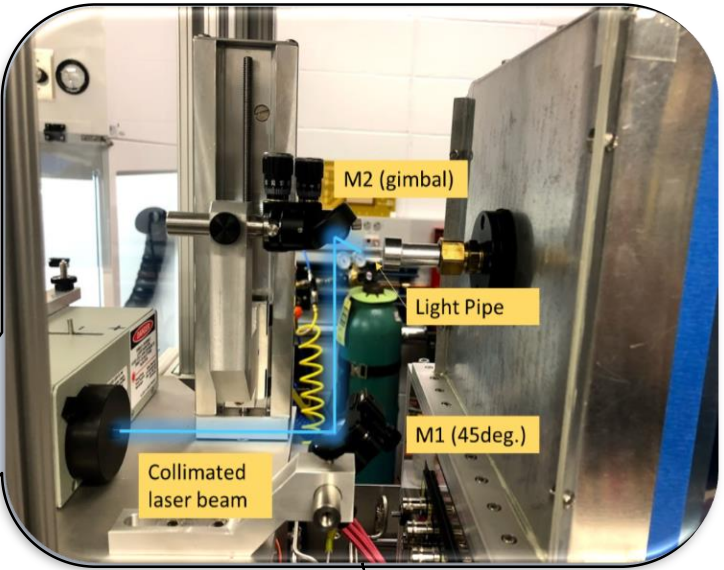


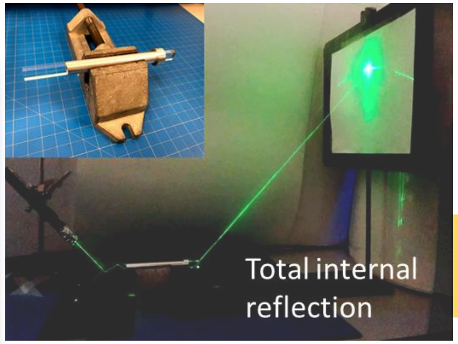
Zigzag pattern w/ highlighted pad rows
Pitch=2mm, period=0.5mm, stretch=15%, gap=50μm

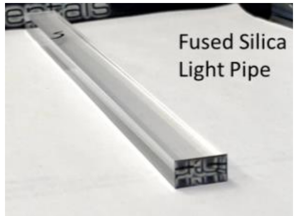
Central Tracker: TPC R&D @ BNL

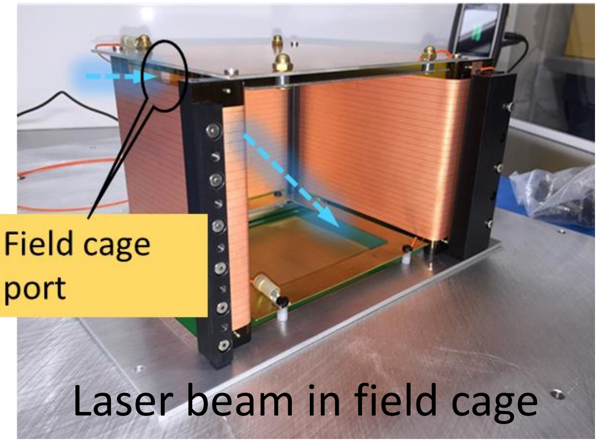
Laser Line Reference Tracks

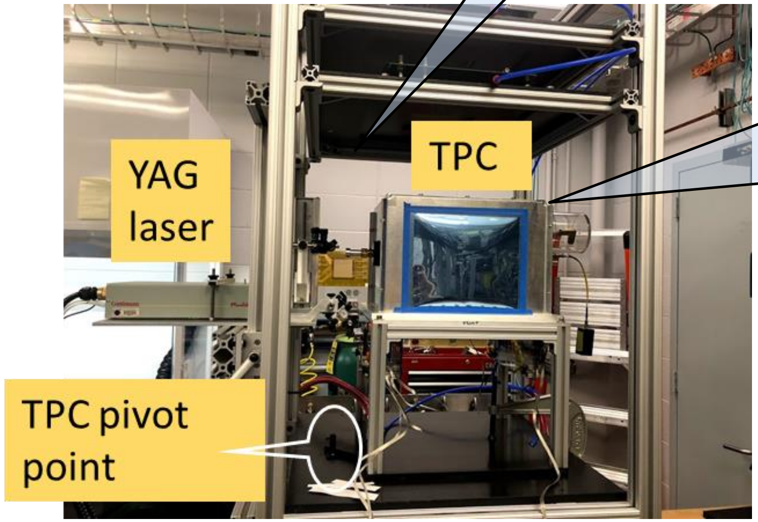
- Use laser beam to create straight lines of ionization to mimic particle tracks
- Tool for characterizing the TPC response with “lines” of ionization that can be controlled, at a relatively high rate in a lab setting
- Laser beams are delivered to TPC drift volume for virtually any polar angle (θ_x , θ_y), controlled externally

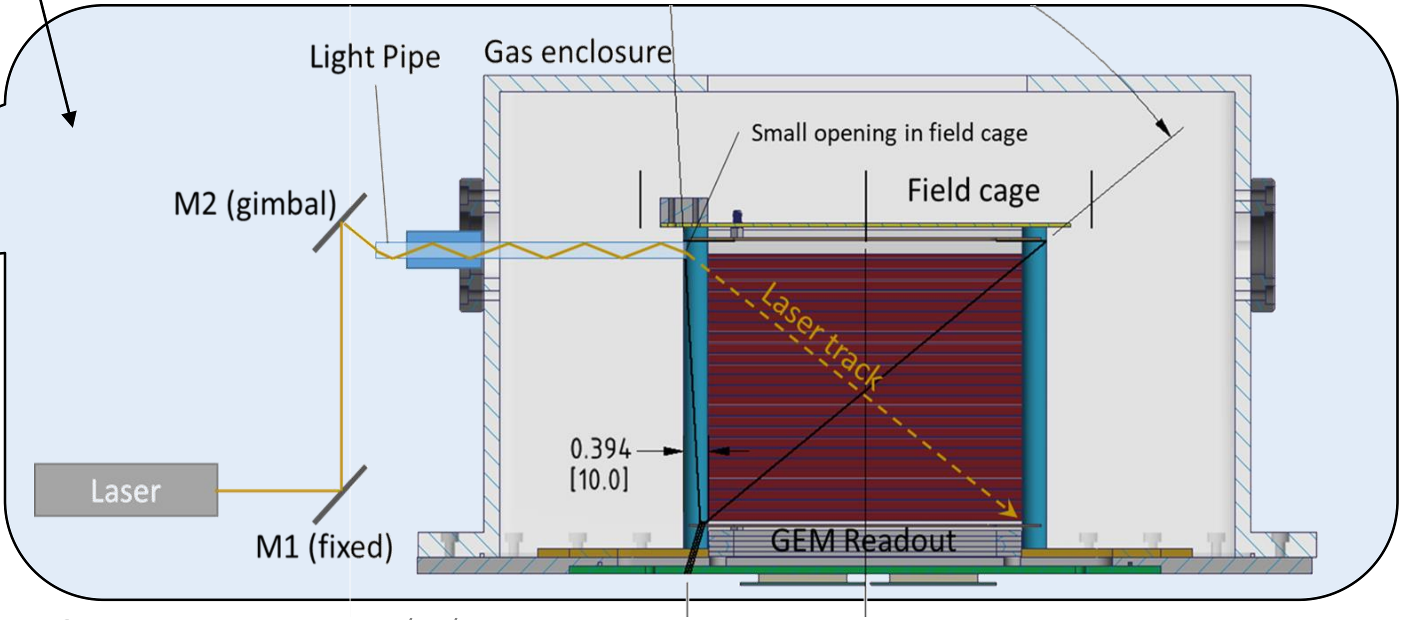










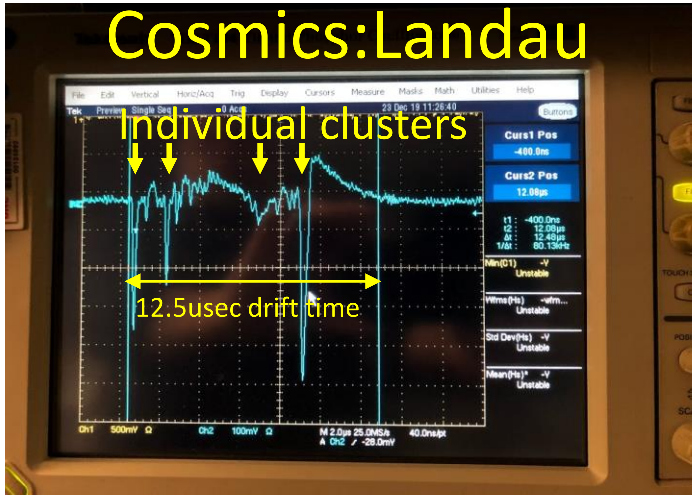


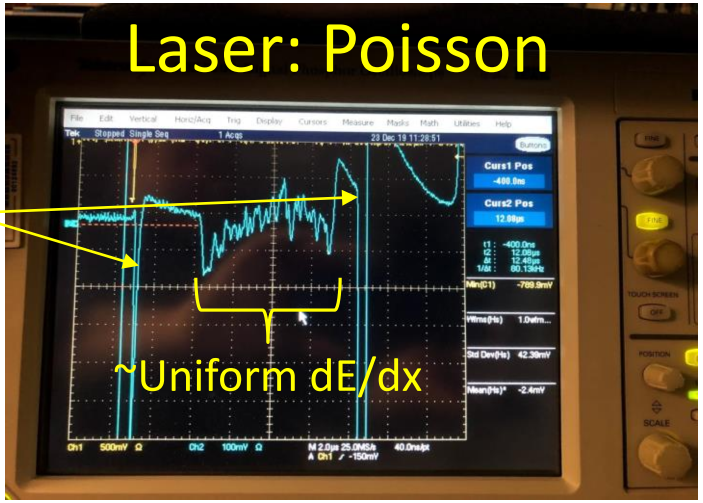
Central Tracker: TPC R&D @ BNL

Laser Line Reference Tracks

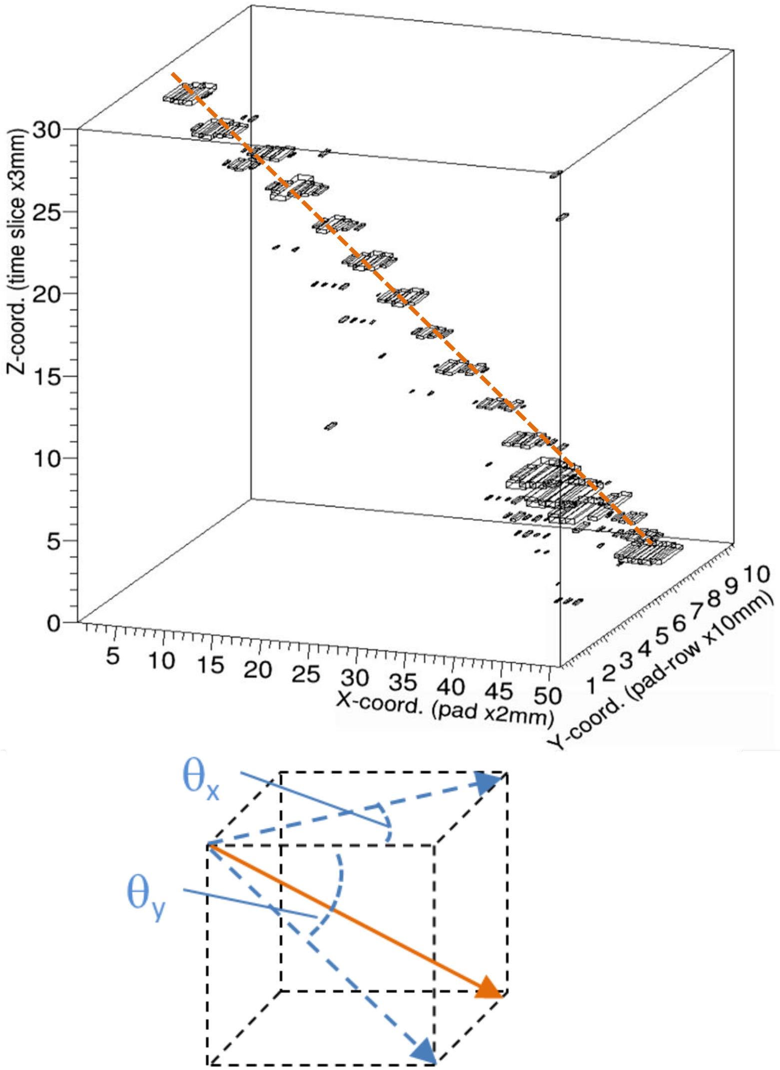
- Used in conjunction with cosmic ray tel. to characterize TPC
- The resulting lines of ionization are easily detectable in the TPC field cage (must greatly attenuate beam)
- Trace molecular impurities in the gas are ionized by a 2-photon absorption process of 266nm/4.7eV photons
- Unlike a Landau process which generates sporadic clusters, ionization via high intensity light produces a more uniform distribution of charge (dE/dx~Poisson)
- Signal from top and bottom plates of the field cage produce large signals at either end of drift volume
- **Advantages of lasers**: controllable beam position, relatively high rate (acceptance not an issue), triggerable pulse, no external detectors necessary

Time profile of preamp/shaper pulse from bottom GEM electrode





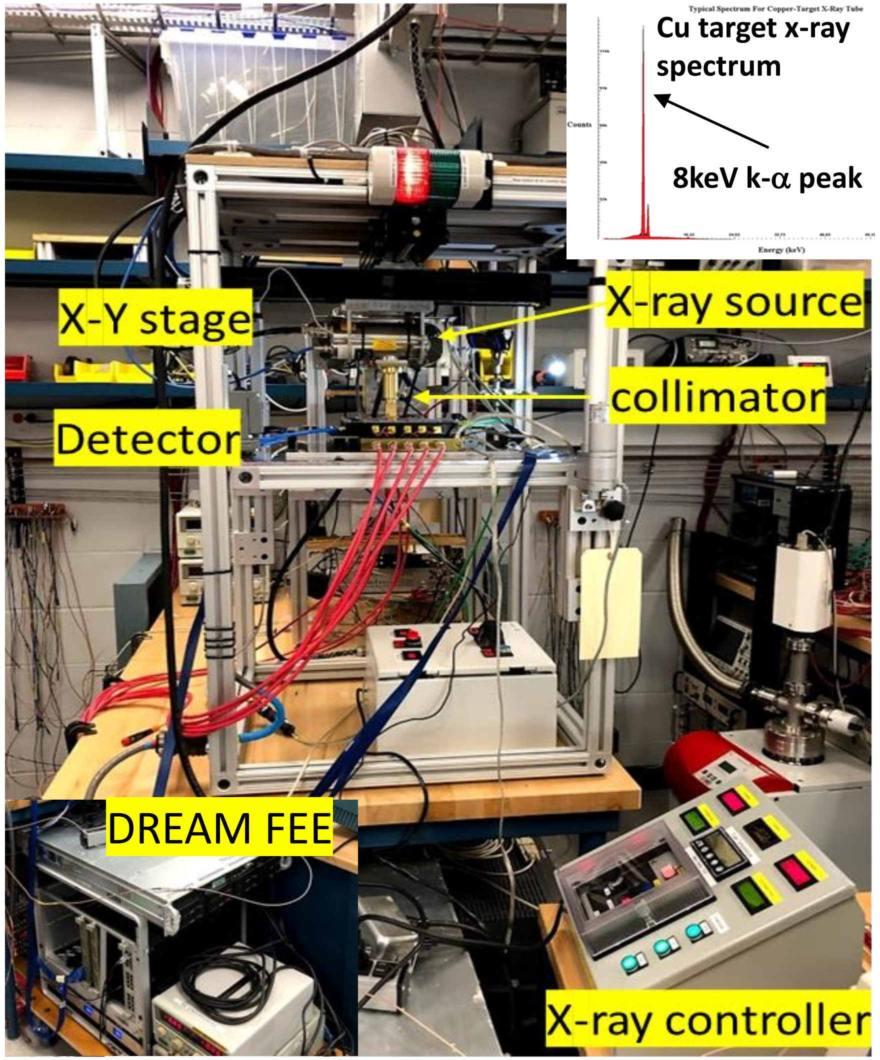
TPC hit map of fired pads on the GEM readout plane for successive time slices, weighted by charge



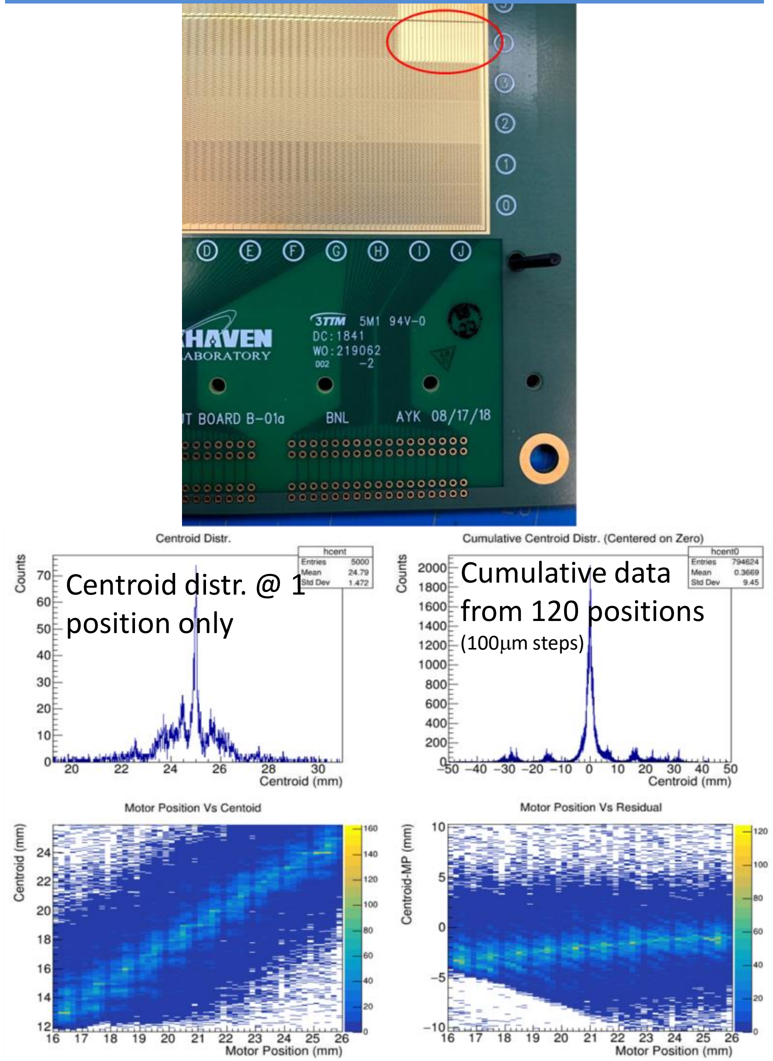
Central Tracker: TPC R&D @ BNL

High Rate, Narrow Beam X-ray Scanner

- Highly collimated & narrow beam: 1mm x 25μm beam spot
- High intensity: 50W x-ray tube (14kHz counting rate @ 50% power)
- Compared to older, 3W x-ray tube w/ ~60Hz rate (secondary beam) w/ 100μm x 4mm beam spot @ 100% power
- Monochromaticity: Primary beam is highly peaked at ~8keV (Cu target)
- Precision XY stage with $\mathcal{O}$(1μm) resolution
- DREAM FEE
  - High channel count (512 ch./FEU)
  - High dynamic range >200fC/12 bit ADC
  - Large memory depth: 256 samples (>10μm sec charge collection time)
  - High rate capable (~10kHz)



Initial scan results of straight pad r/o

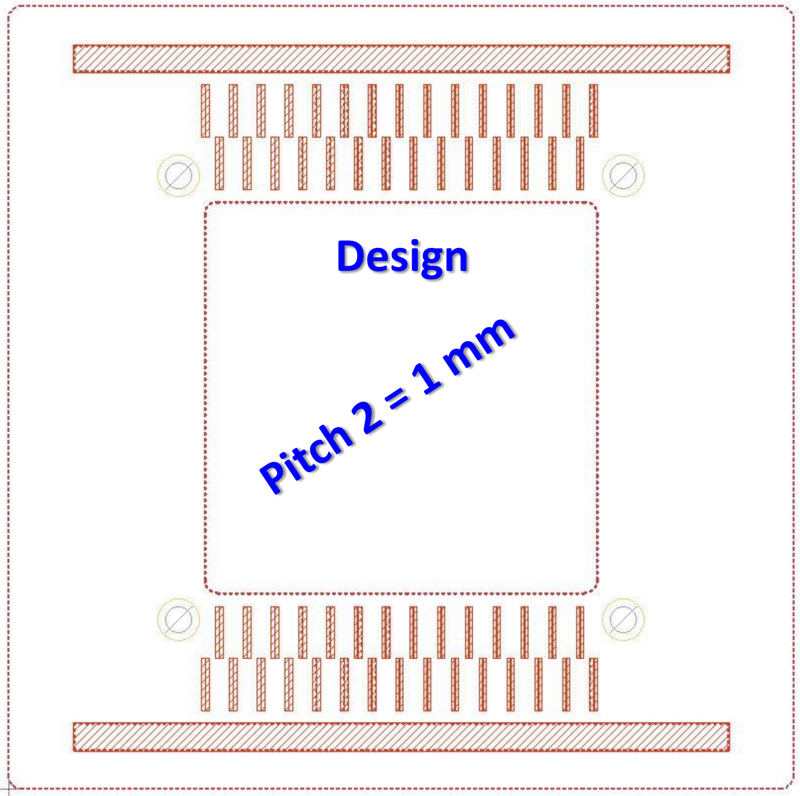


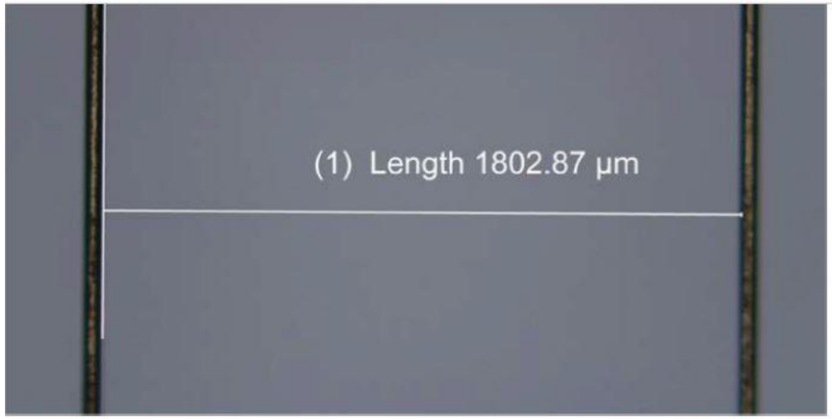
Top: Residual distributions
Bottom: Motor position vs Centroid Correlation

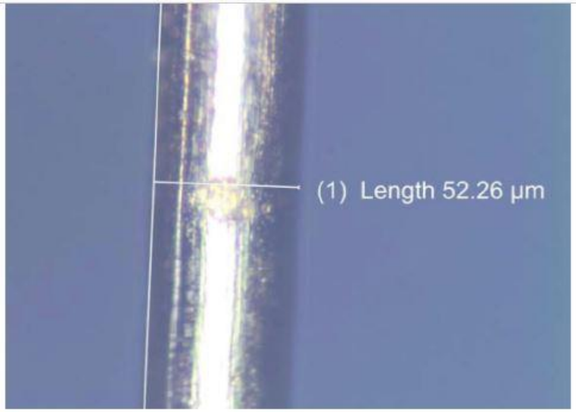
Central Tracker: TPC @ SBU

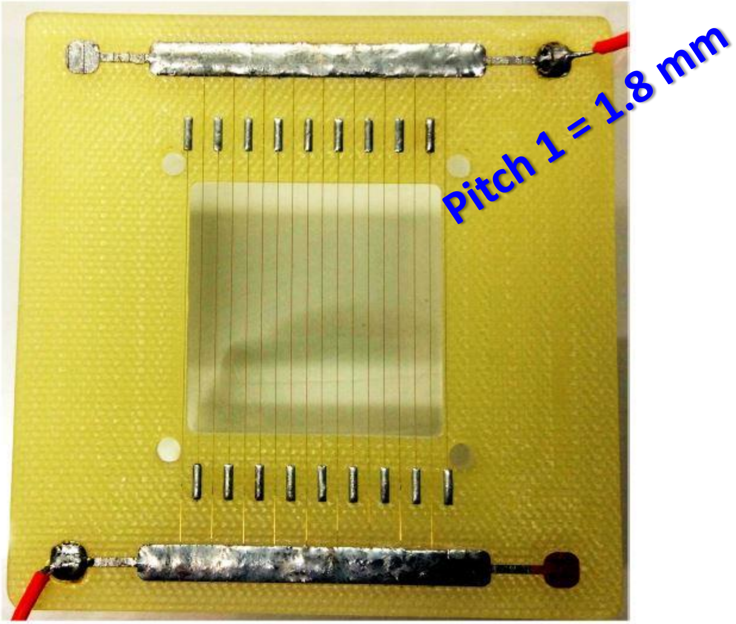
Passive IBF Grid

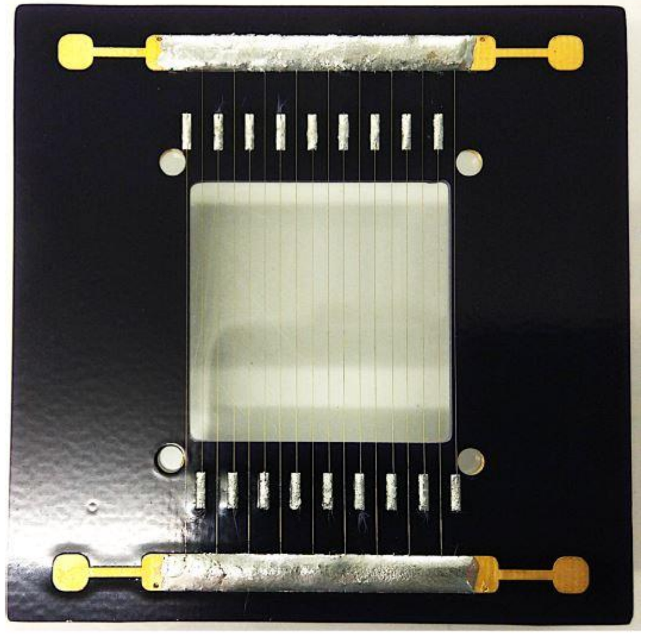
- Small prototype for feasibility studies 30 *x* 30 mm^2
  - Compare different gas choices
  - Effect of wire pitch









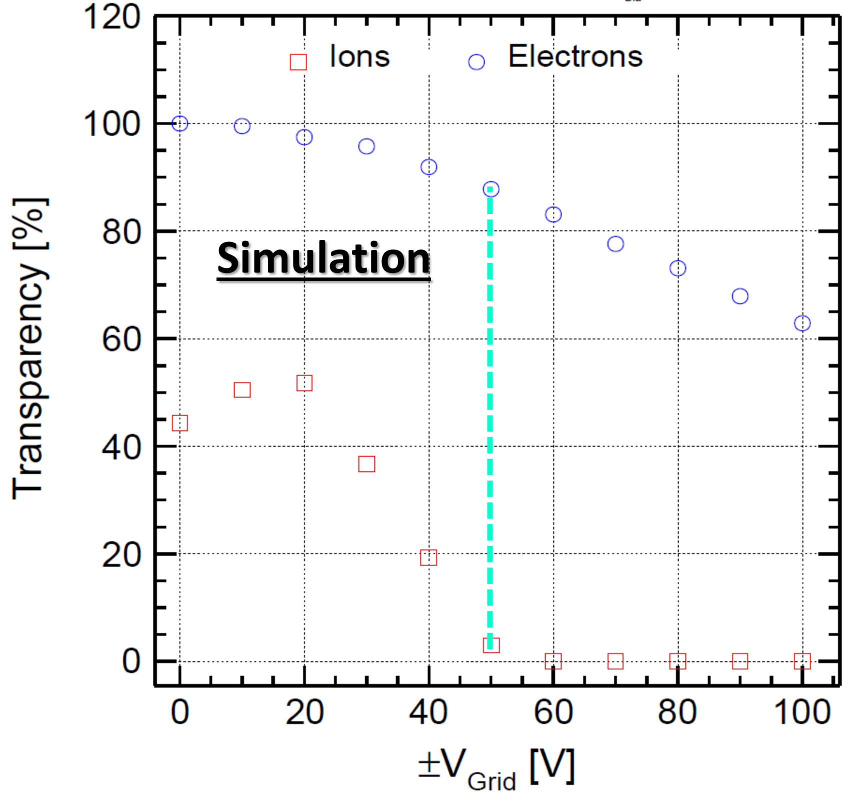


Central Tracker: TPC @ SBU

Passive IBF Grid

- Plan to extend to real size "R2" module (ePHENIX)
  - Test at ANL with MRI device → B = 1.4 T / cosmics
  - Promising simulation results, serve as guidance for test procedure

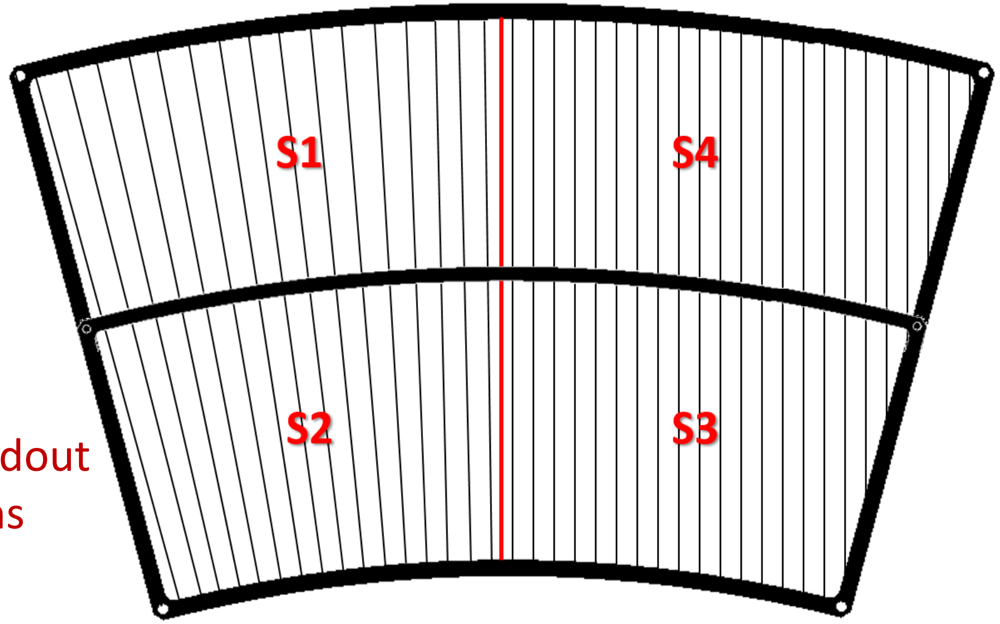
$Ar+CF_4$ (90:10); B = 1.4 T; TF = 700 V/cm; DF = 300 V/cm; W_{dia} = 50 um; Pitch = 1mm

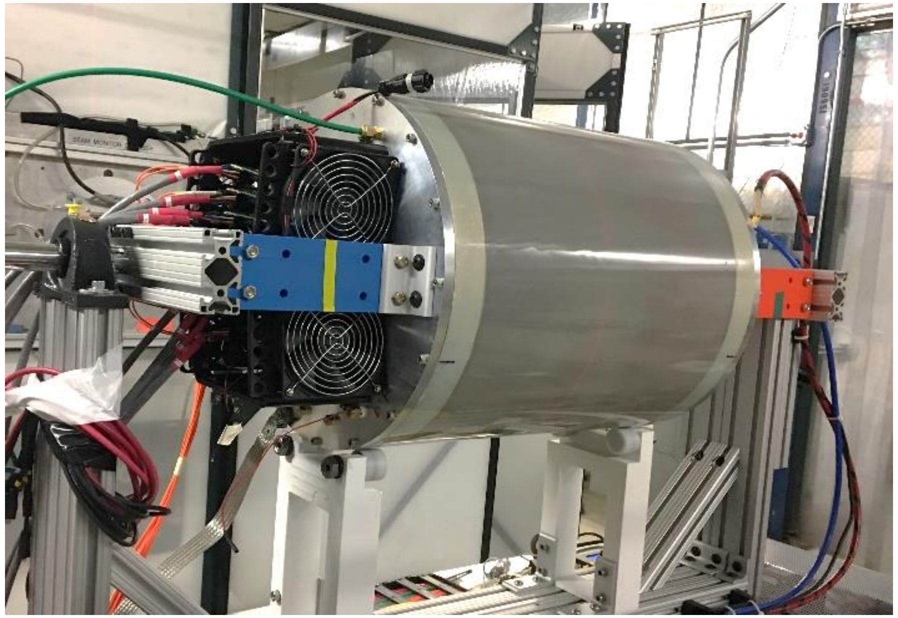


~ 90% e^- transparency vs < 5% ion transparency

S1 / S2: radial
S3 / S4: cartesian

with different readout pad-configurations



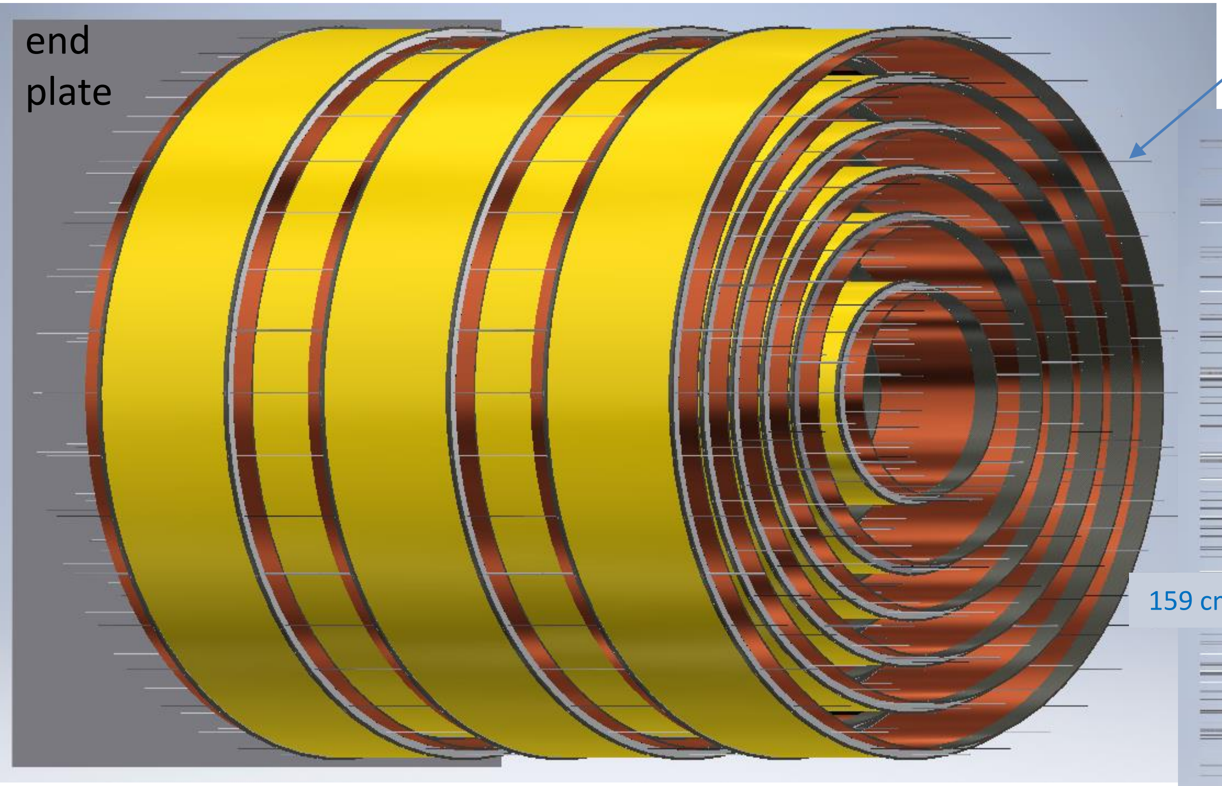


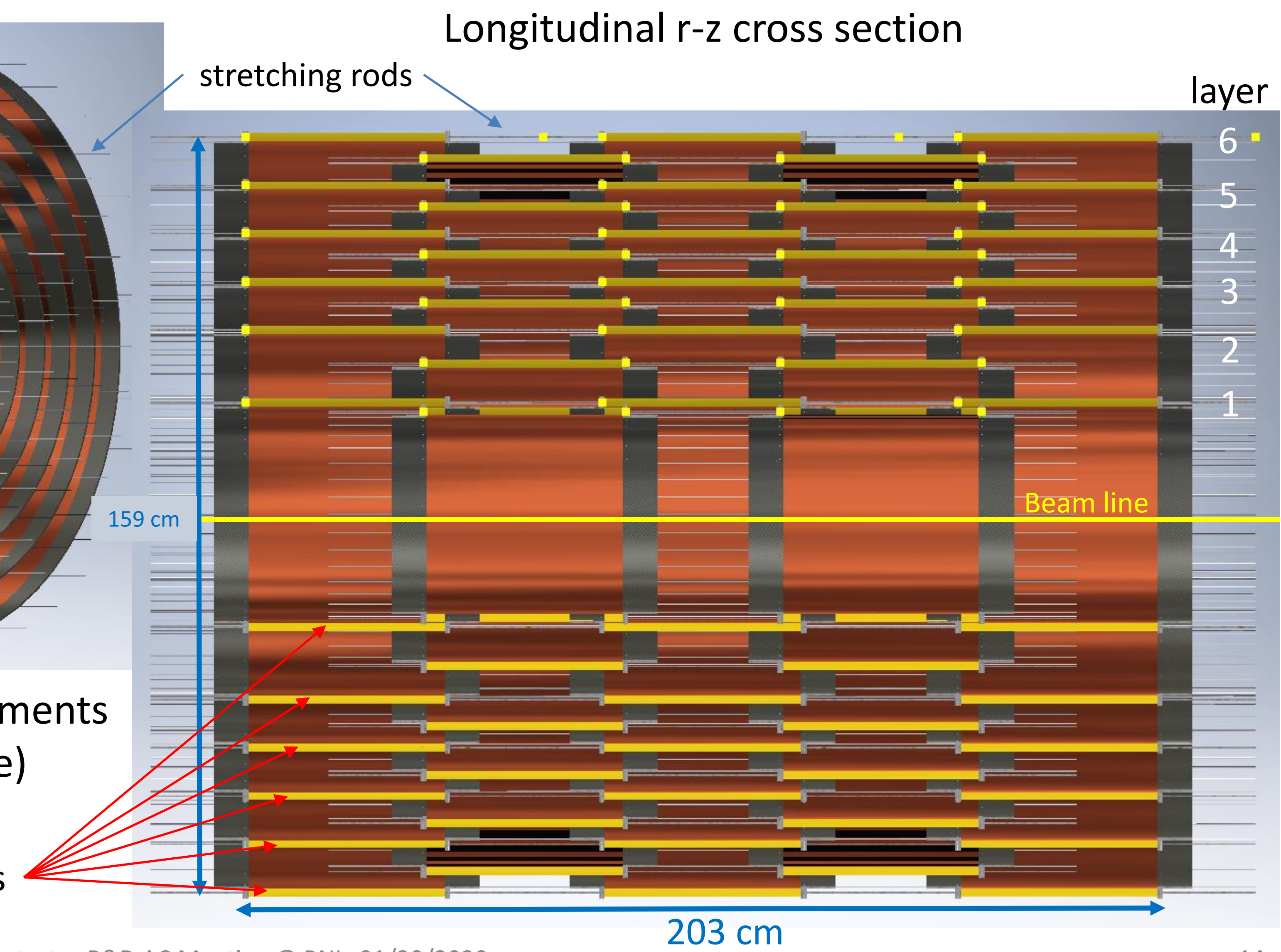
Central Tracker: Cylindrical µRWELL R&Ds Overview

- Cylindrical µRWELL R&Ds Studies (FIT, TU, UVa)
  - Design of cylindrical µRWELL for EIC Central Tracking (FIT)
  - Prototyping of a small mock up cylindrical µRWELL detector (FIT)
  - Simulation of cylindrical µRWELL operating in µTPC mode (TU)
  - Characterization of small planar µRWELL with 2D XY readout strips (UVa)
  - Design of new µRWELL prototype with large drift for µTPC operation mode (UVa)
  - Investigation of new FE electronics (VMM3-SRS) for MPGD tracking detectors (UVa)

Central Tracker: Cylindrical µRWELL @ FIT

Design

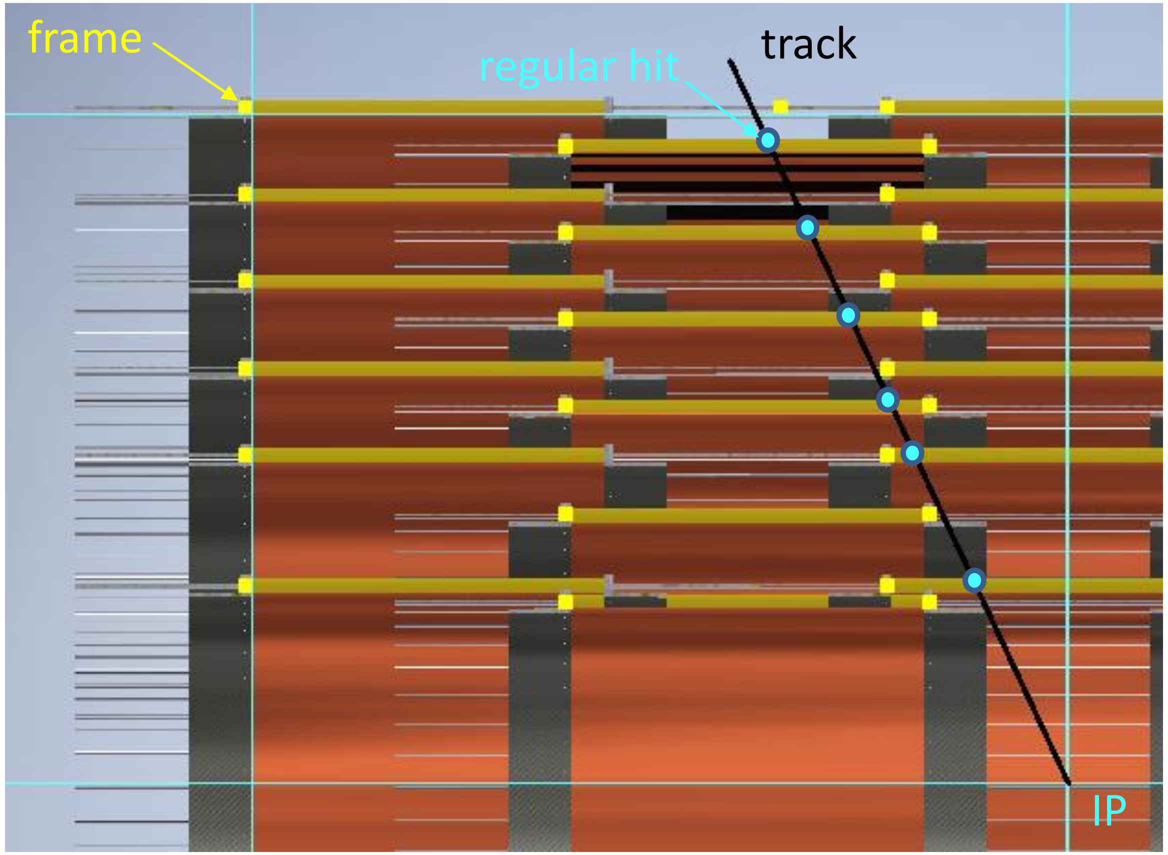




Design update with 5 overlapping barrel segments (was 3 non-overlapping segments before)

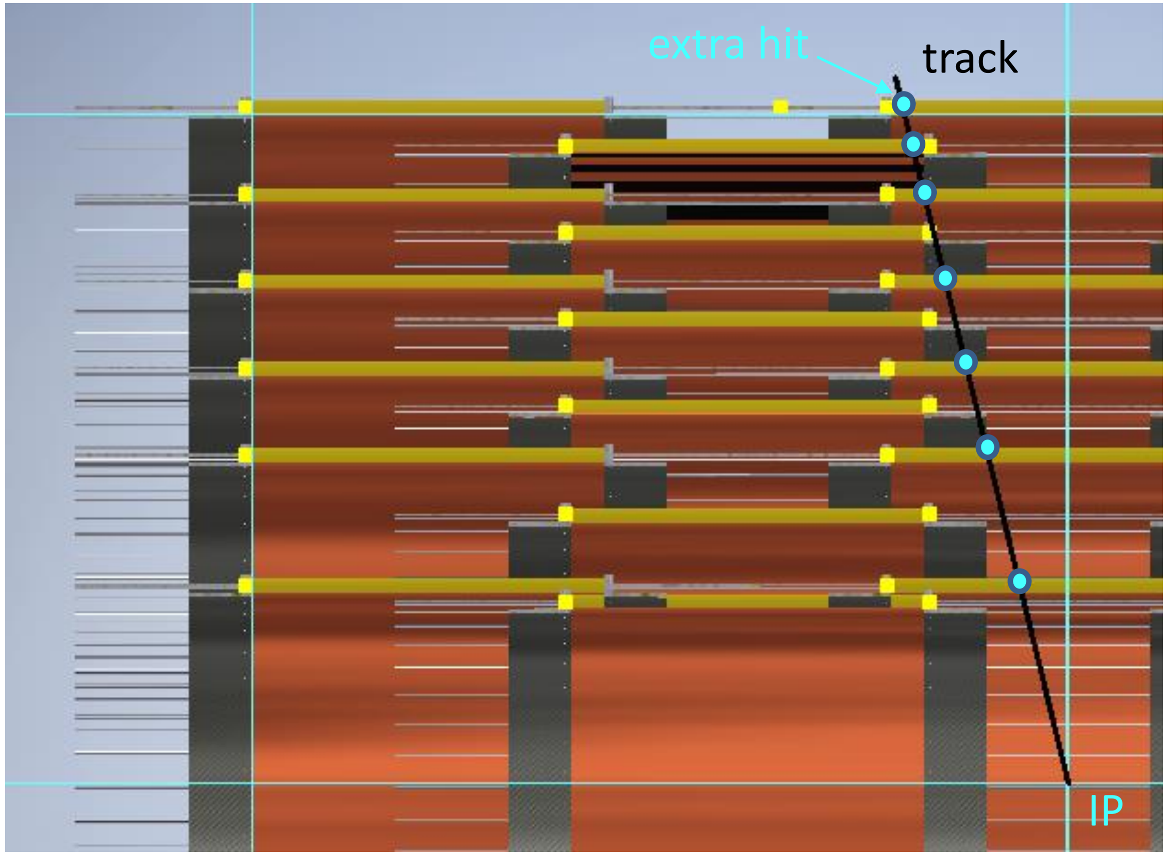
Central Tracker: Cylindrical µRWELL @ FIT

of Hits on Tracks



Six detectors being hit by the track

[Each "hit" is actually a track stub (track-let, sub-track) with directional information in a mini-drift ("µTPC") configuration]

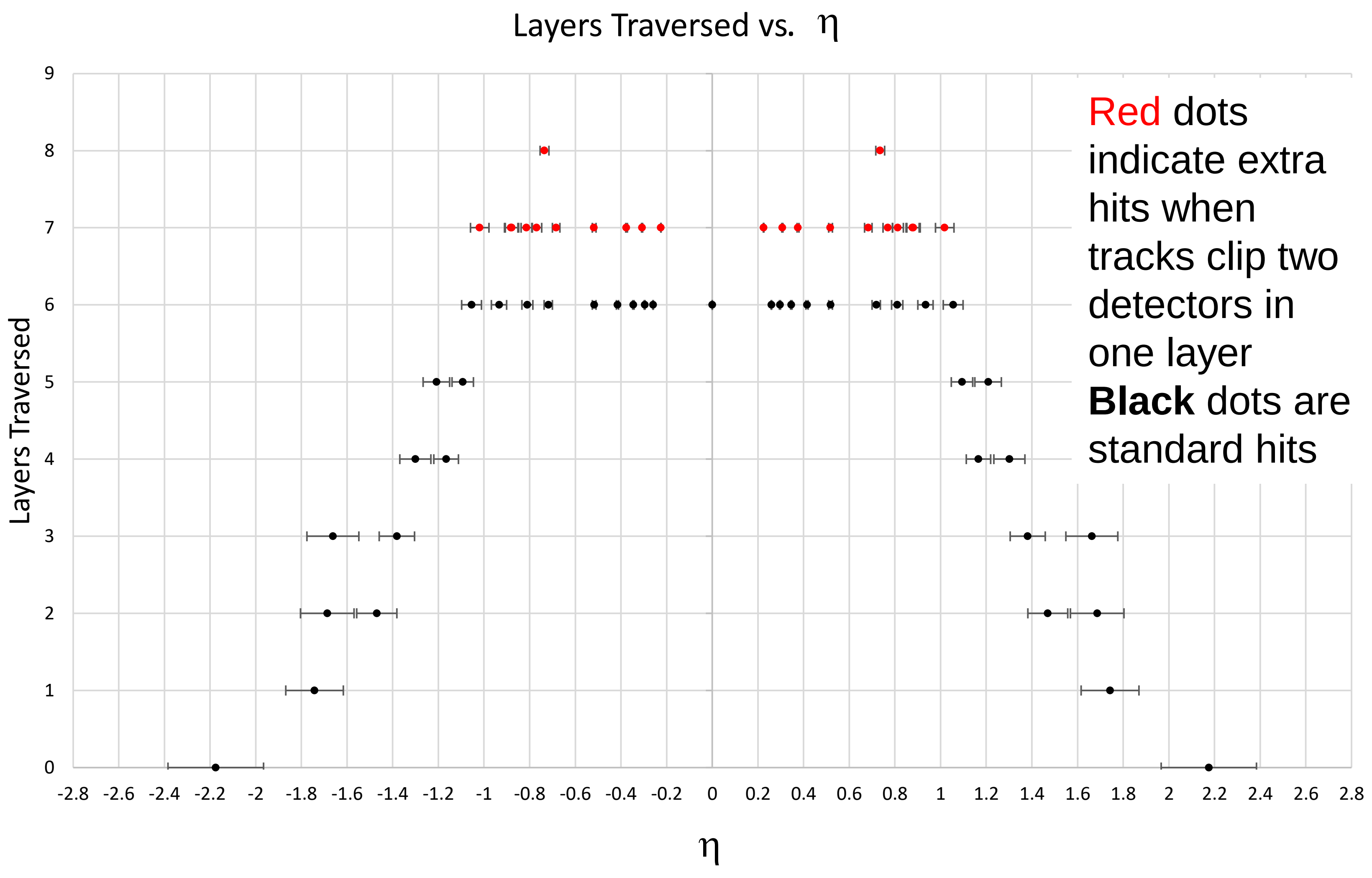


Extra detector hits occur at certain η-values, e.g. seven hits on this particular track

Central Tracker: Cylindrical µRWELL @ FIT

Geometric Acceptance

- In previous designs, there were η-values where the number of detectors hit dropped down as low as two due to gaps in the coverage.
- We have updated the design such that detectors partially overlap to create continuous coverage in the z-direction.
- This improves the coverage greatly, with tracks now hitting at least six detectors at all times through $|\eta_{det}| < 1$, sometimes even eight.
- The price to pay is that the detectors within one layer have to be radially staggered (see previous slide) making the design more complex.



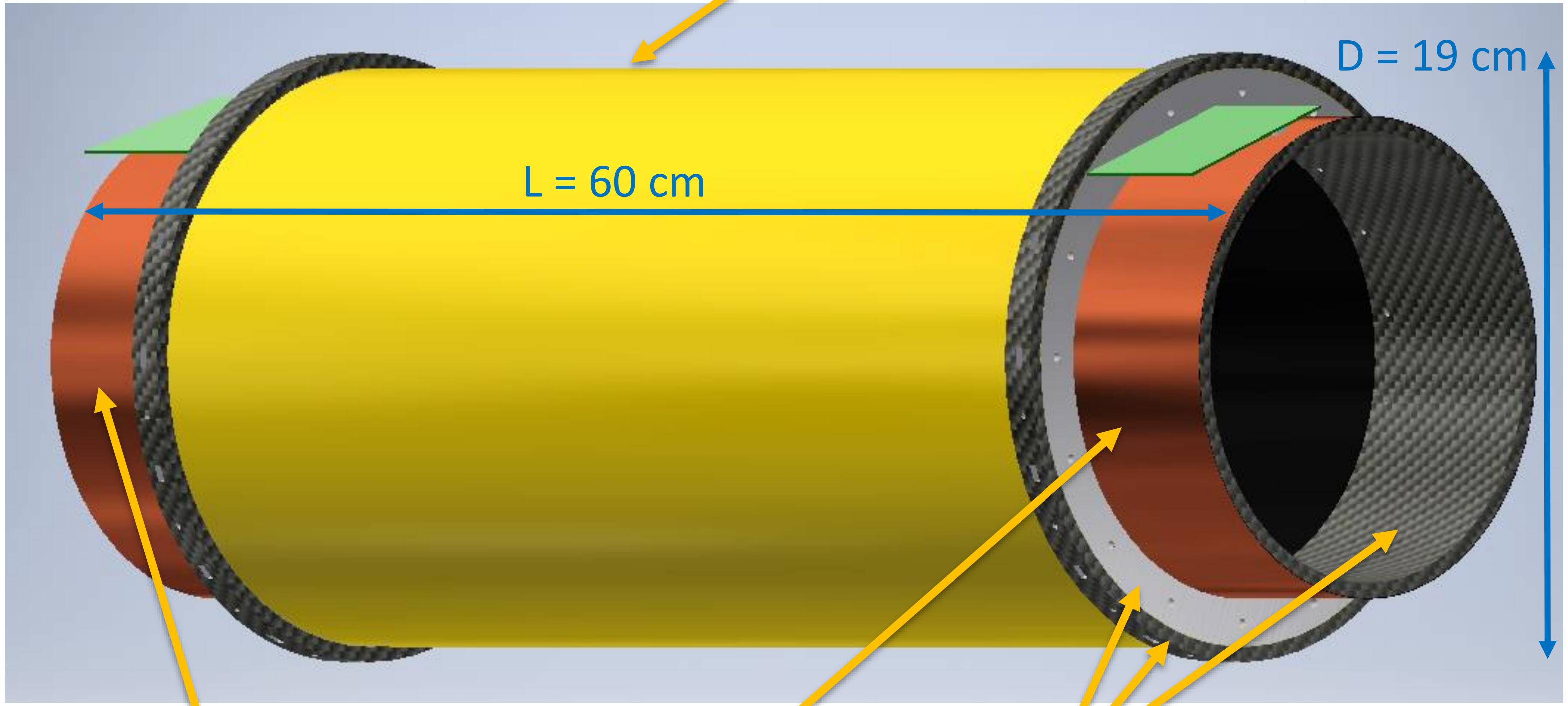
FLORIDA TECH

Central Tracker: Cylindrical µRWELL @ FIT

Mechanical Mock-up

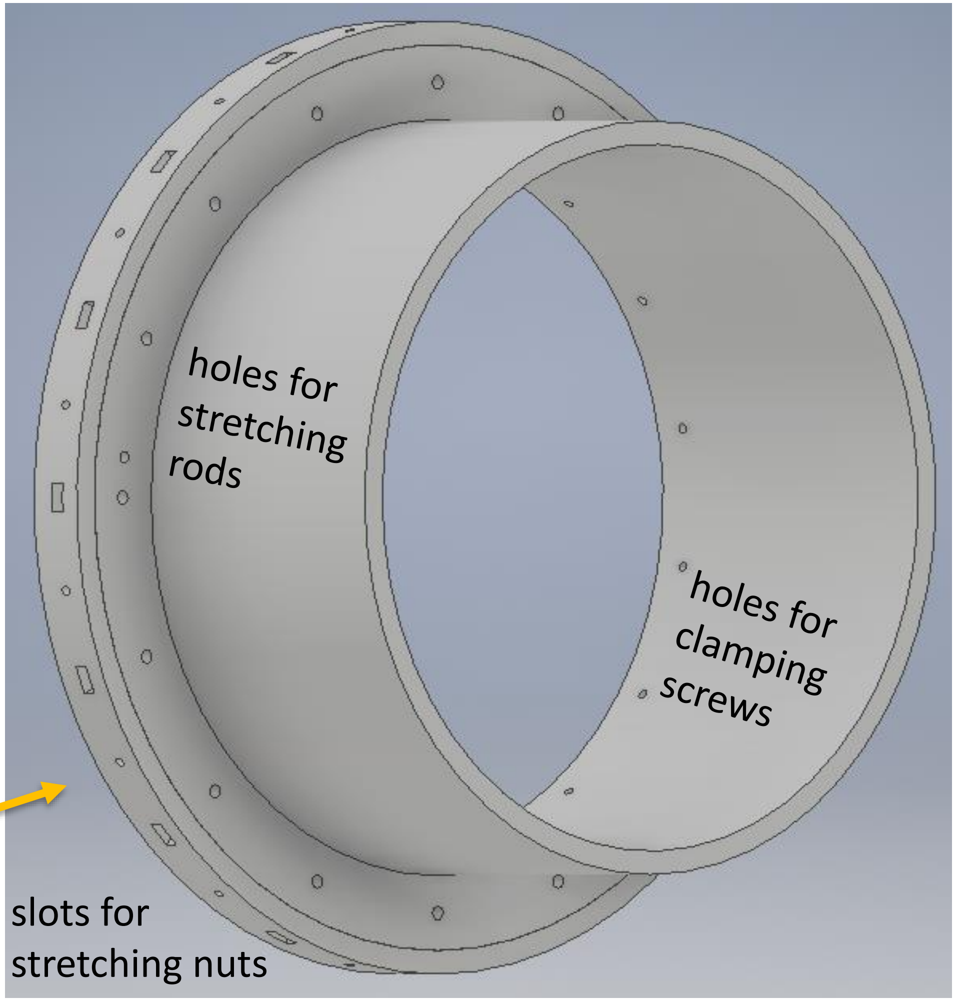
Current design

“Drift Foil” (kapton foil, 50 μm)



“µRWELL, DLC & Readout foil composite”
(mocked up by kapton foil, 250 μm)

3D-printed Frames



FLORIDA TECH

Central Tracker: Cylindrical μRWELL @ FIT

Procurement for Mock-up

- ❖ Components in hand:
  - both Kapton foils
  - adhesive Kapton tape for splicing flat foils into cylinders
  - threaded nylon stretching rods and nuts
- ❖ Working on 3D-printing the frames at the university maker-space
- ❖ Also investigating 3D-printing the frames at BNL

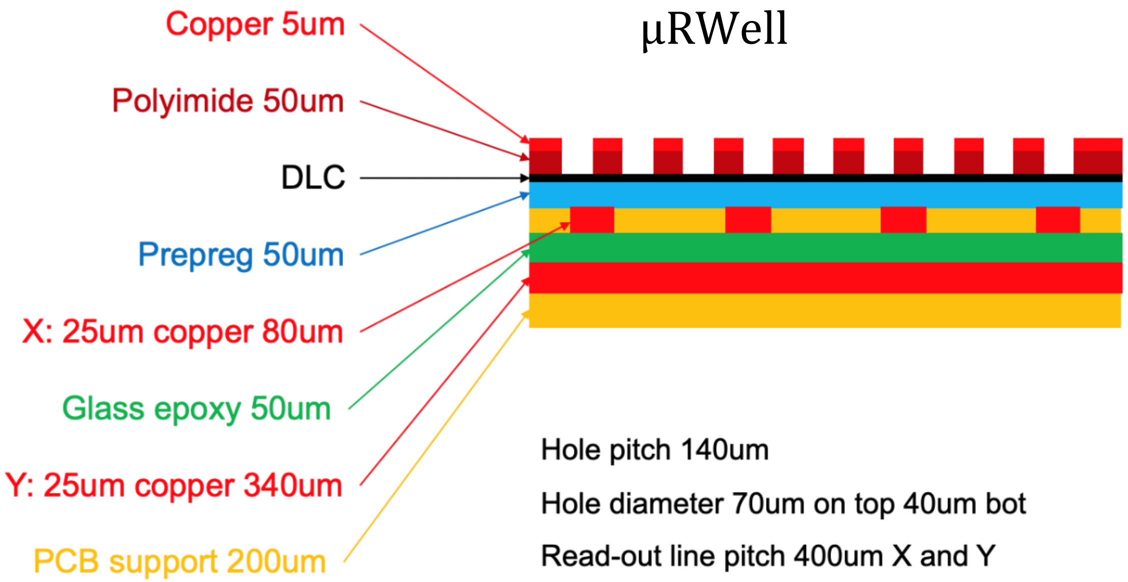
Plans

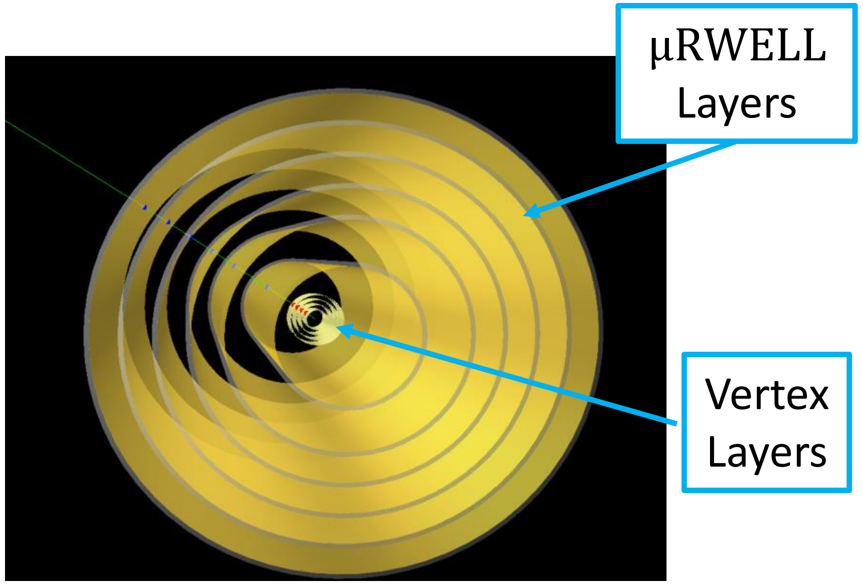
- ❖ Jan – April 2020
  - Build and test mechanical mock-up for single cylinder
- ❖ May – July 2020
  - If successful,
    - Build and test mechanical mock-up for multiple cylinders connected along z-direction
    - Begin design of components for <u>active</u> single-cylinder detector

Central Tracker: Cylindrical µRWELL @ TU

Current Simulation Studies

- Cylindrical µRWell simulation overview
  - TU graduate student Nick Lukow has taken over the bulk of the simulation work.
  - Investigate central tracking performance with silicon vertex detector and cylindrical µRWell layers in a 1.5 T field.
- Detectors
  - **Silicon vertex detector**
    - 4 layers each with X-Y pixel resolution of 20 µm - 20 µm
  - **Cylindrical µRWell Barrel Tracker**
    - Consists of six 2m long cylindrical layers covering radii from 22.5 cm - 77.5 cm
    - For each layer
      - One hit point with resolution of ~100 µm x ~100 µm
      - Detector material , $\chi\ /\chi_0 = 0.64\%$
      - Additional 15 mm of $ArCO_2$ implemented as drift gap
    - No support structures are included
    - µTPC mode is not yet implemented in the simulation

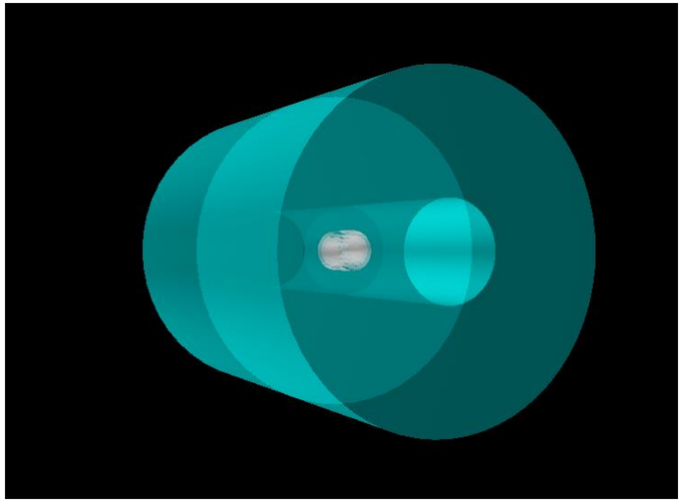


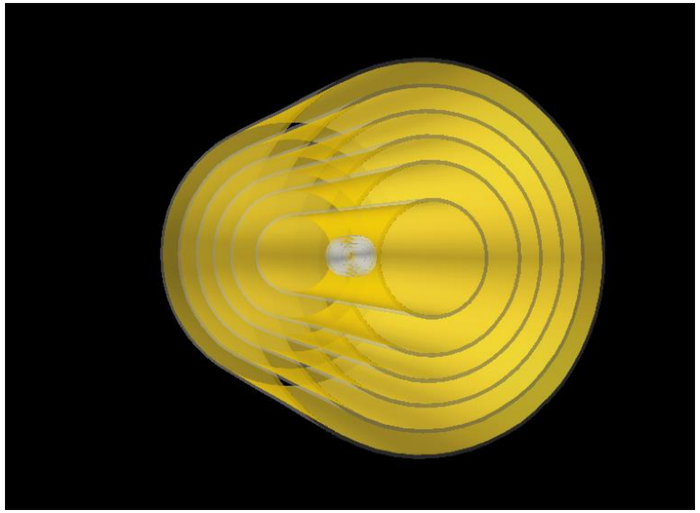


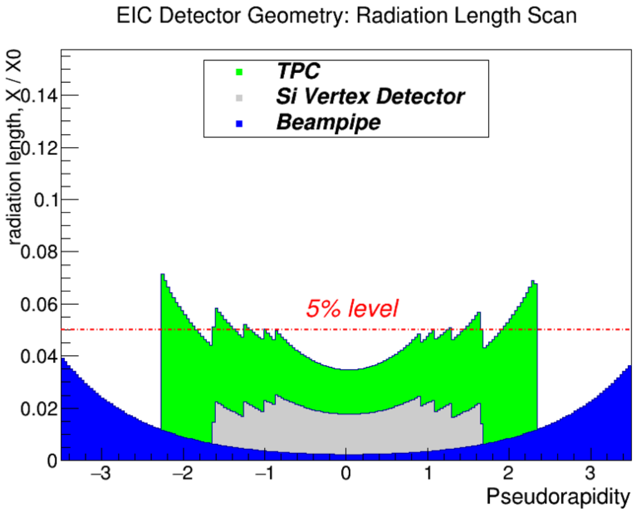
Central Tracker: Cylindrical μRWELL @ TU

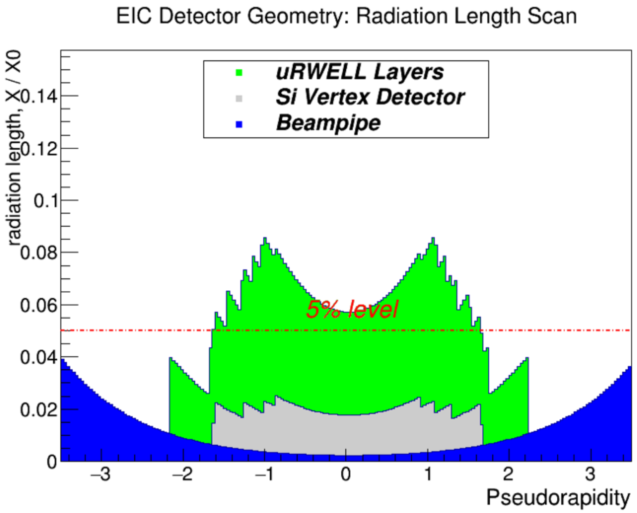
Current Simulation Studies

- Comparison to TPC performance
  - Implemented a TPC into simulation based on sPHENIX TPC
  - TPC parameters
    - Radial length: 80 cm
    - Dispersion (longitudinal, transverse)
      - ($1\ \mu\mathrm{m}/\sqrt{\mathrm{D}}$, $15\ \mu\mathrm{m}/\sqrt{\mathrm{D}}$)
    - Resolution (longitudinal, transverse)
      - ($500\ \mu\mathrm{m}$, $200\ \mu\mathrm{m}$)
  - Material budget for TPC and 6 barrel μRWell tracker (ongoing, **not final**) used in upcoming preliminary results.







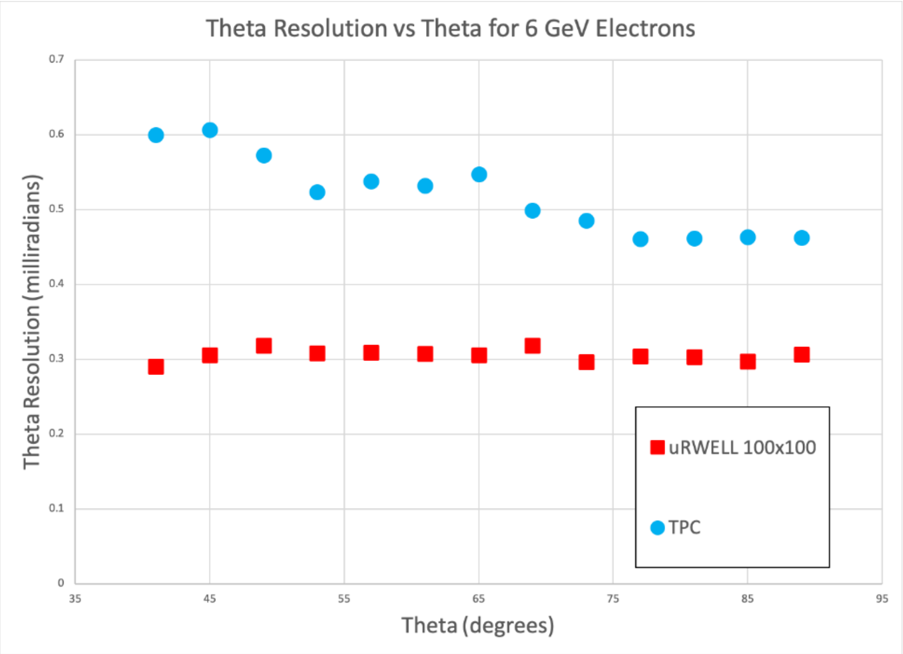


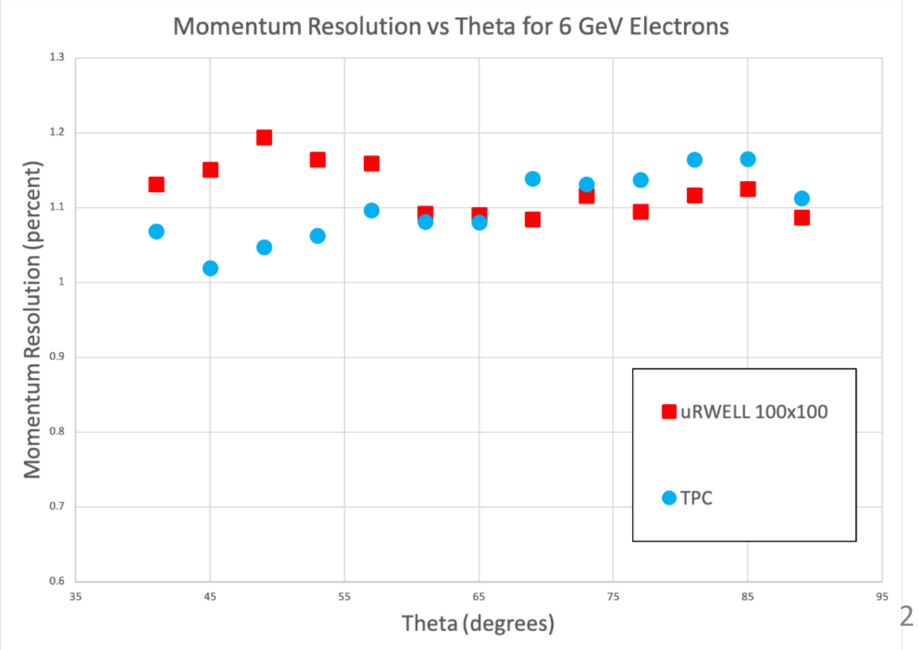
Central Tracker: Cylindrical μRWELL @ TU

Current Simulation Studies

- Comparison of μRWell and TPC performance
  - Using the stated detector simulation conditions, 6 GeV electrons were simulated in a 1.5 T magnetic field
  - Theta resolution vs. theta
    - μRWell appears to have a better angular resolution than the TPC, particularly at smaller angle ($\sim 45^{o}$).
  - Momentum resolution vs. theta
    - TPC has better momentum resolution at small angle ($\sim 45^{o}$).
    - Momentum resolution of the μRWell (100 μm, 100 μm) becomes comparable to the TPC at moderate angles ($> 55^{o}$)

These results include the vertex detector

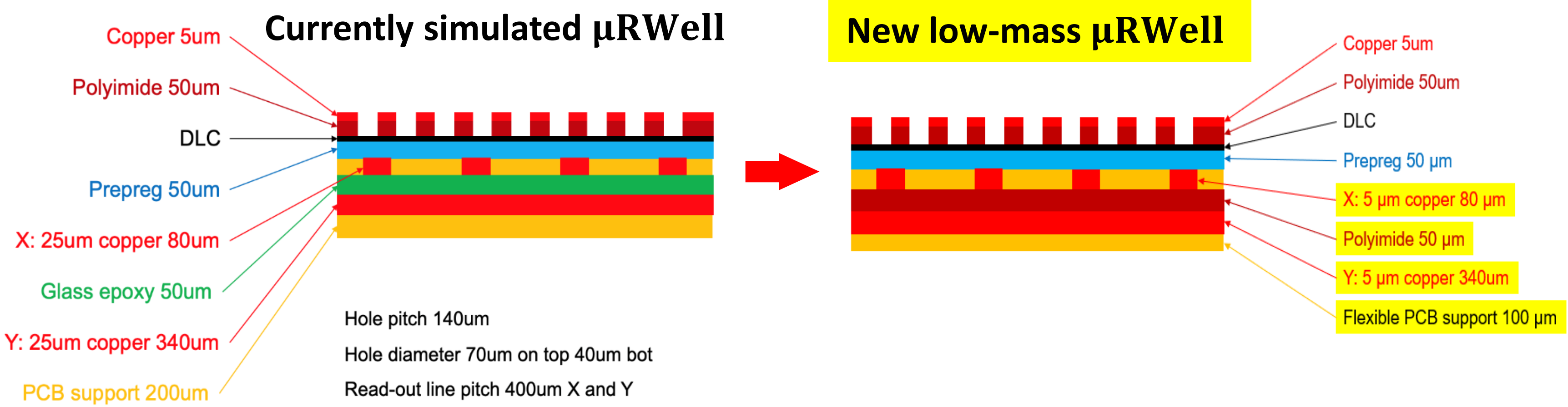


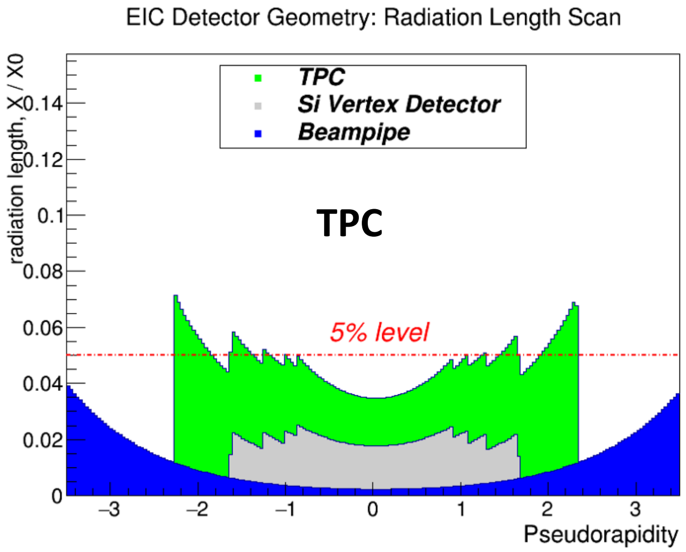


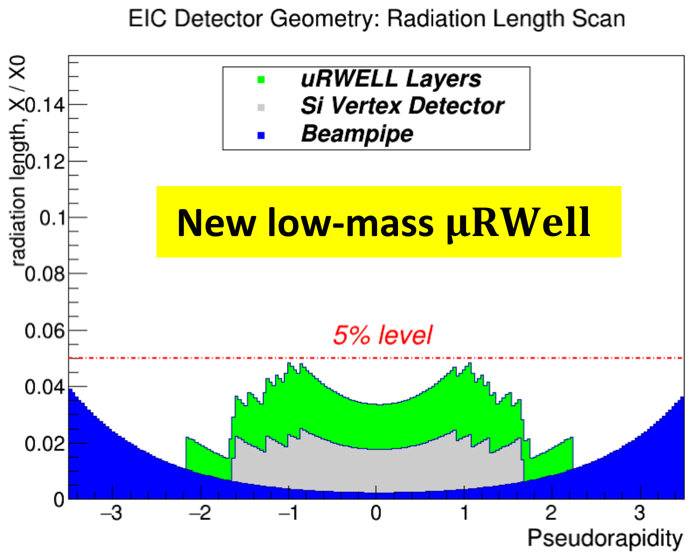
Central Tracking: Cylindrical µRWELL @ TU

Next Simulation Steps: Investigating the performances of low-mass µRWELL

- New low-mass µRWELL
  - Material budget for TPC and 6 barrel µRWELL tracker (**ongoing, not final**)
  - Will be implementing a new low mass µRWell which is comparable to TPC material in the central region.
    - Follows UVa low mass µRWELL design for reducing overall material budget.
  - Will update our simulation



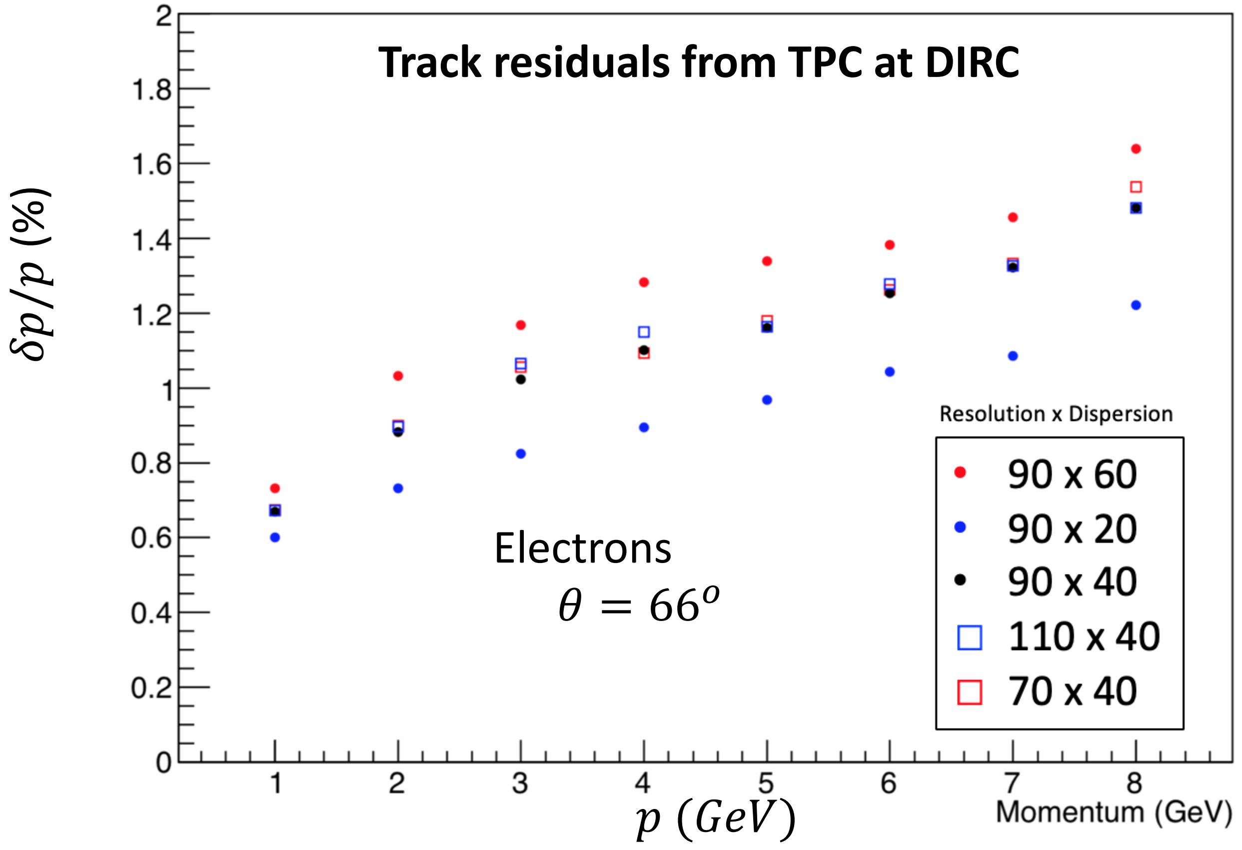




Central Tracking: Cylindrical µRWELL @ TU

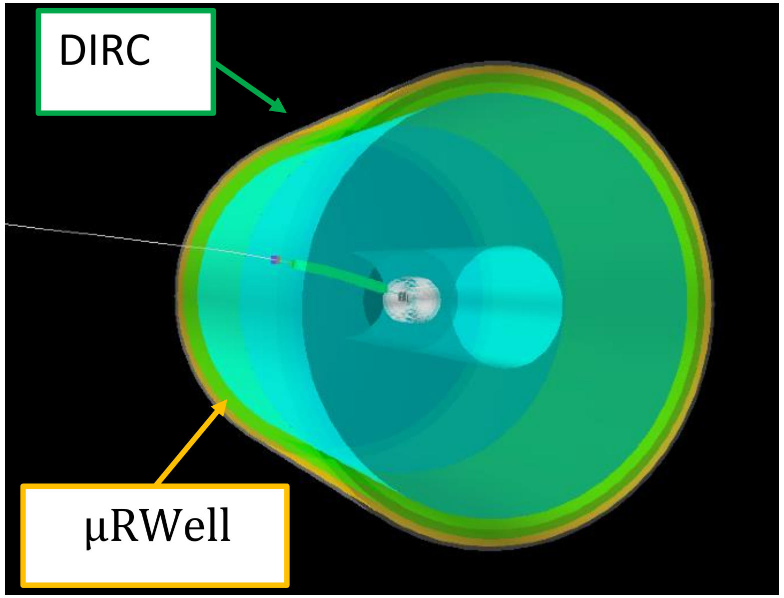
Next Simulation Steps: Update with the latest more realistic TPC parameters

- Update TPC performance
  - Current TPC parameters
    - Radial length: 80 cm
    - Dispersion (longitudinal, transverse)
      - ($1\ \mu m/\sqrt{D}$, $15\ \mu m/\sqrt{D}$)
    - Resolution (longitudinal, transverse)
      - ($500\ \mu m$, $200\ \mu m$)
  - Transverse dispersion and resolution need to be updated with the latest sPHENIX results **measured from beam test results** (**$40\ \mu m/\sqrt{D}$, $90\ \mu m$**)
    - Particular sensitivity to the transverse dispersion



Central Tracker: Cylindrical µRWELL @ TU

Next Simulation Steps: Investigate impact of fast tracker µRWELL on DIRC performances



- **Recent Progress**
  - In addition to our base simulations, we have started investigating the tracking performance with additional uRWELL layer surrounding the TPC and a DIRC detector
  - The additional uRWELL layer basically serve two purposes:
    - Used as fast tracking layer to complement the slow electronics of the TPC and MAPS
    - Provide high precision position information to the DIRC because track residuals at the DIRC show large sensitivity to TPC transverse dispersion.
  - We have had several conversations with DIRC representatives from the PID consortium to better understand their tracking needs.
  - Added dead material representing the DIRC: length = 80 cm, thickness = 6 cm, $\chi\ /\chi_0 = 17.5\%$

Future Goals

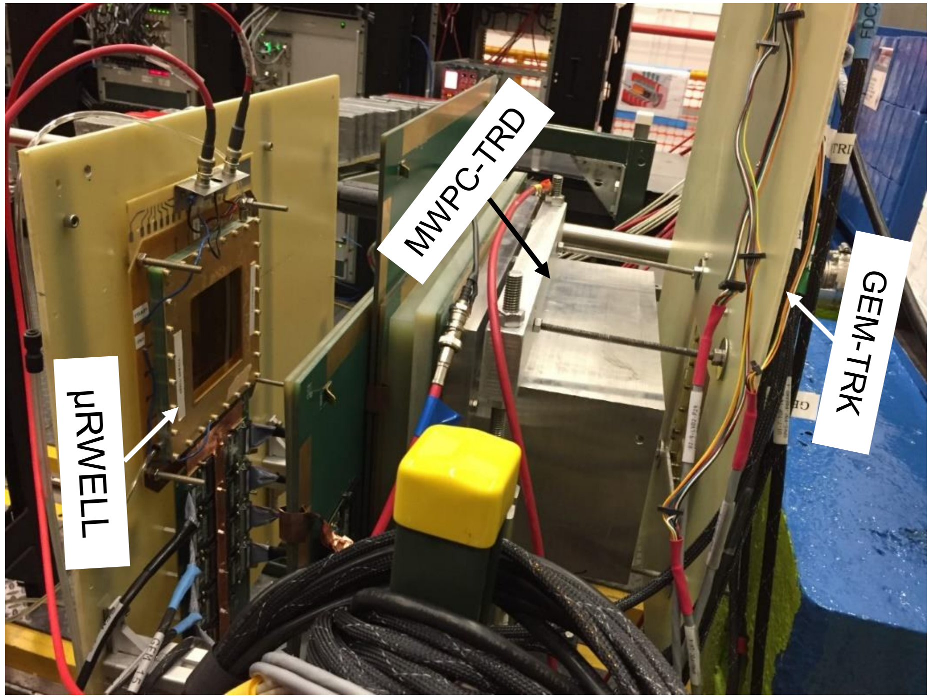
- **µRWELL**
  - Reduce detector material to mimic UVa low mass prototype – comparable/better to simulated TPC material (in central region)
  - Include multiple hit points and μTPC (mini-drift) mode
  - Implement FIT design structure & Optimize number of cylindrical layers and their spacing
- **TPC**
  - Update simulations using measured sPHENIX transverse resolution
  - Investigate the impact of the material budget of the TPC readout and uRWELL FE electronics in the end cap region
  - Investigate performance with fast signal µRWELL layer surrounding TPC
- **DIRC**
  - Continue discussions with PID consortium (DIRC) to understand needed tracking performance
  - Implement realistic budget material

Central Tracker: Cylindrical µRWELL @ UVa

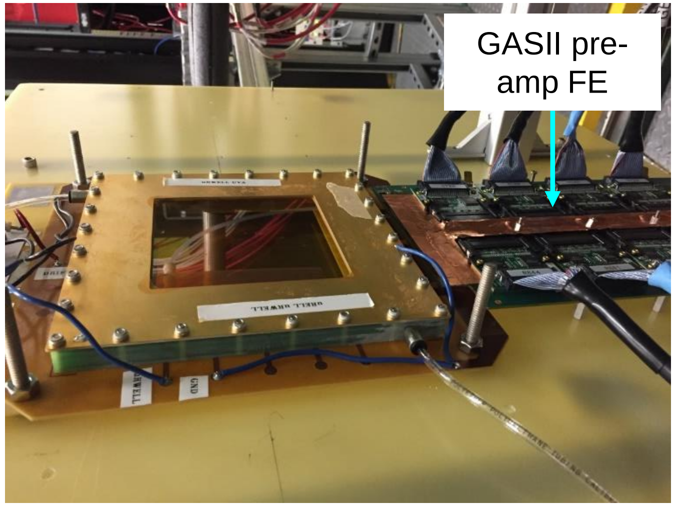
Characterization UVa µRWELL prototype with 2D strip readout

- µRWELL prototype was installed in Hall D @ JLab since Nov. 2019
  - Initial attempt of data taking for a joint test beam campaign with JLab DIRC detector commission with GEM-TRD and smaller GEM trackers was unsuccessful
- New test beam setup after January 6th with one GEM tracker (GEM-TRK) and one MWPC-TRD
- All 3 detectors are been read out with **JLab flash ADC electronics (fADC125)** with GASII chip
  - HV scan of drift field and uRWELL device performed last week (6M triggered events)
  - Efficiency analysis using GEM and Wire-TRD as reference trackers is ongoing
- Preliminary results of uRWELL and GEM-TRK performances with fADC125 electronics

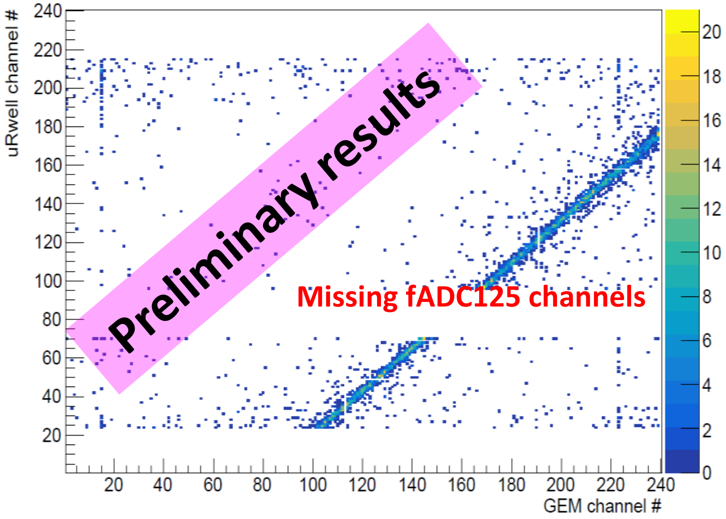
µRWELL prototype in a test beam setup in Hall D @ JLab



µRWELL with fADC125 Electronics



µRWELL vs. GEM-TRK: Hit correlation



Preliminary results to check how the detectors performed with the fADC125 readout electronics

Plans for future tests

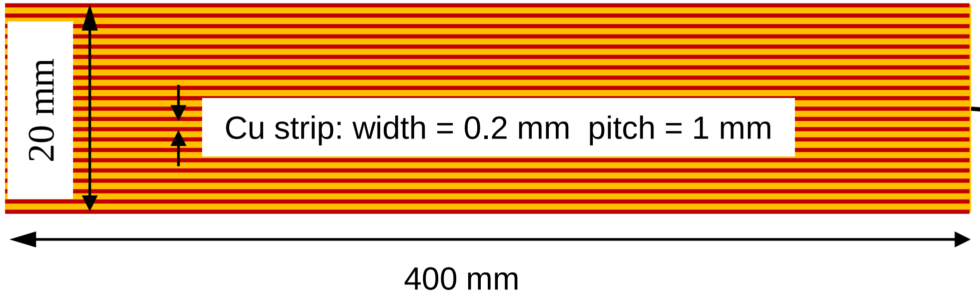
- Study the prototype in test beam at FNAL in April 2020 to study:
  - Spatial resolution
  - performances in high rate environment
- Study spatial uniformity of gain and stability of the detector in a cosmic setup with GEM trackers and in the X-ray box at UVa

Central Tracker: Cylindrical µRWELL @ UVa

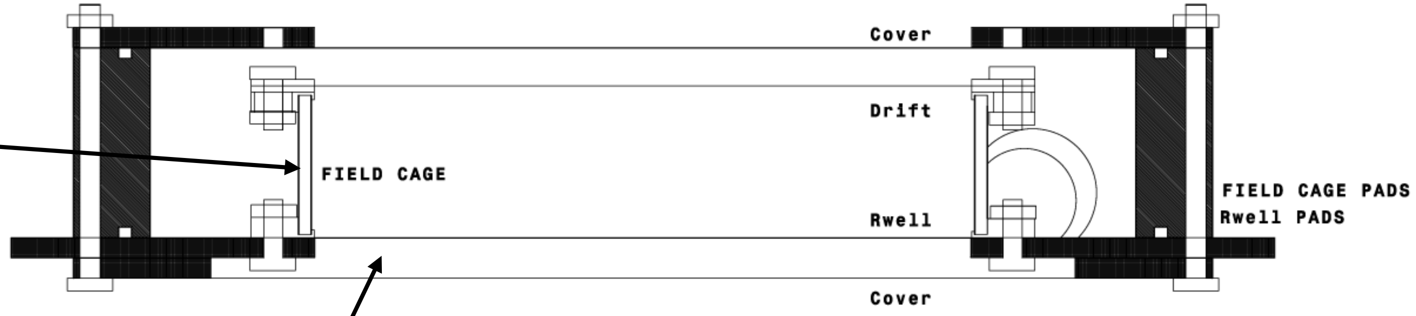
Design & Prototyping of Low-mass µRWELL- µTPC with built-in Field Cage

- Investigating the feasibility of **Low-mass µRWELL-µTPC** prototype: Discussion with CERN experts to optimize the design
- µRWELL- µTPC Prototype will operate in mini-drift (or micro TPC) mode with a large drift of 20 mm instead of 3 mm
- Built-in Field Cage (FC) for a better control of drift field uniformity
- Minimization of the material of the µRWELL- µTPC (compared to the current prototype)

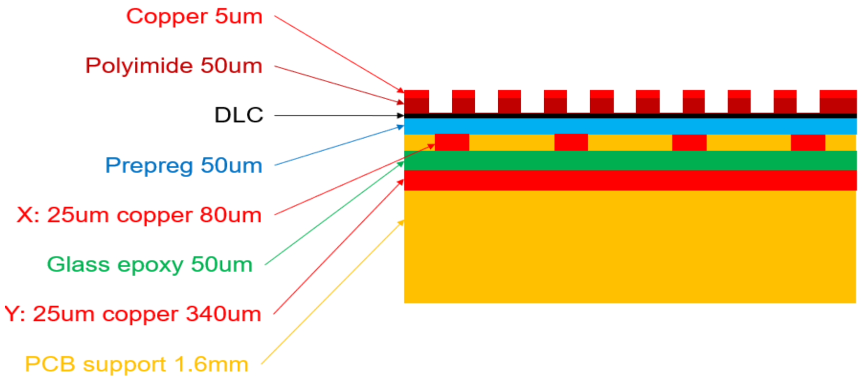
Field Cage:3 µm Cu electrode 50 µm Kapton foil



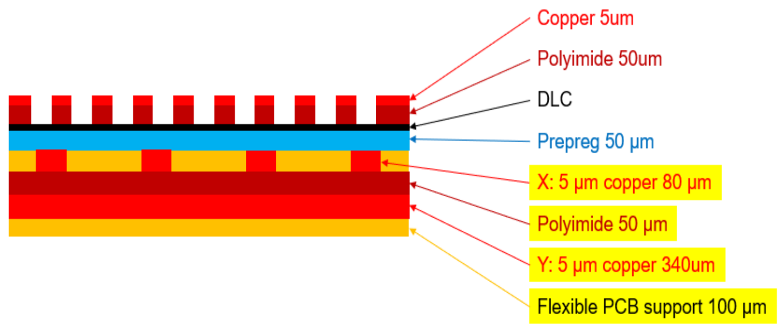
Cross section view of the Low Mass µRWELL- µTPC prototype



Current UVa µRWELL with XY strips: Bulky



Low mass µRWELL device with XY strips



How to get to low mass µRWELL prototype:

⇨ Make a few changes w.r.t the existing UVa µRWELL prototype

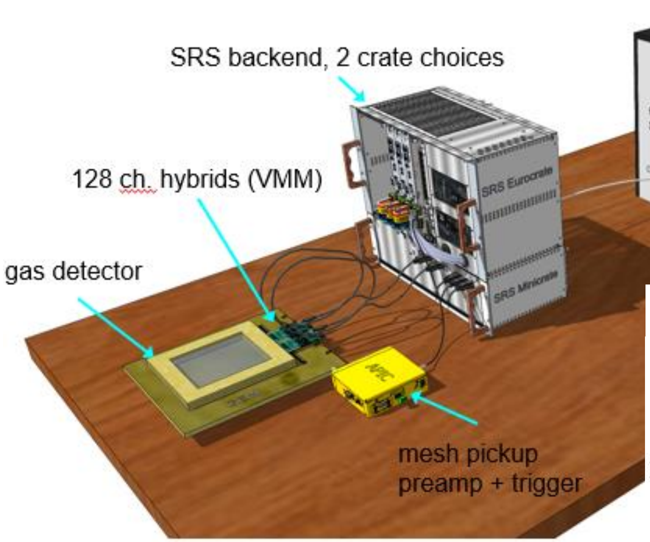
- Reduce R/O Cu strips from 25 µm to 5 µm
- 1.6 mm PCB support ⇨ 100 µm Kapton
- Drift foil: Al-Kapton (5 / 25 µm)
- Entrance window foil: Al-Kapton (5 / 25 µm)
- Exit window foil: Kapton (5 / 25 µm)

Central Tracker: Cylindrical µRWELL @ UVa

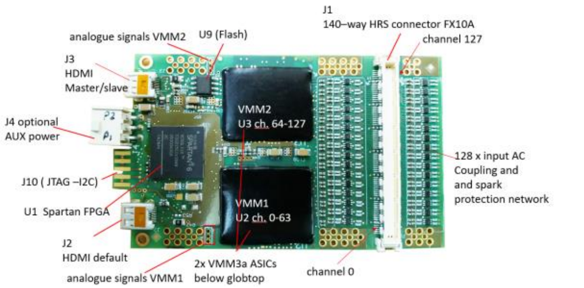
SRS-VMM3 Readout Electronics for MPGD tracking

- ❖ VMM chips developed at BNL for ATLAS Muon Detector Upgrade
- ❖ SRS-VMM3 readout electronics by the RD51 coll. as a replacement of the SRS-APV25
- ❖ Ideal candidate for both GEM tracker and µRWELL-µTPC detector
- ❖ We have received most parts of the small scale SRS-VMM3 electronics:
- ❖ 4 FE hybrids card (SRS-VMM3, 512 chs),
- ❖ data processor with FPGA board (SRS-FECv6) and digital adapter board (SRS-DVM), Panasonic-to-Hirose adapter card
- ❖ We are still waiting for the Euro power supply crate and a few other small items
- ❖ Basic DAQ & analysis software available to start with SRS-VMM3
- ❖ Later, we will work with **M. Purshke (BNL) to integrate the SRS-VMM3 into RCDAQ**

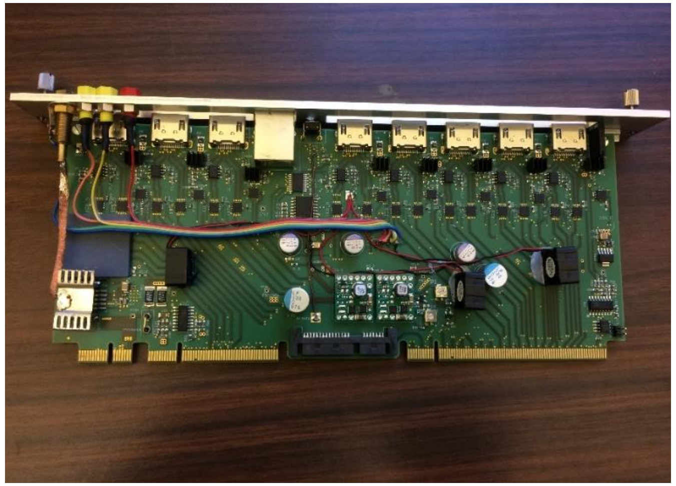
SRS-VMM3 Readout System developed by the RD51 collaboration



SRS-VMM3 hybrid card



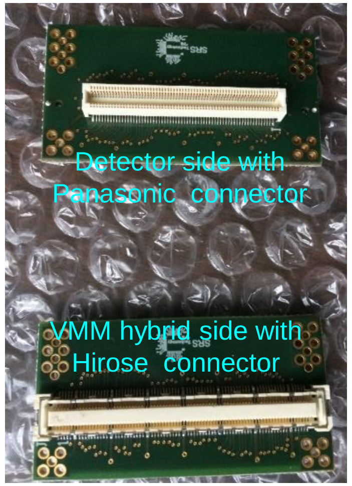
SRS-DVM board



SRS-FECv6 board

SRS-VMM3 with cooling structure

Adapter cards

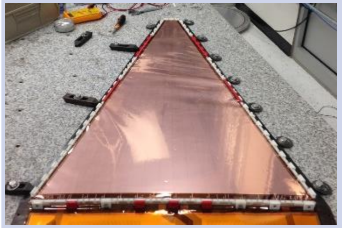
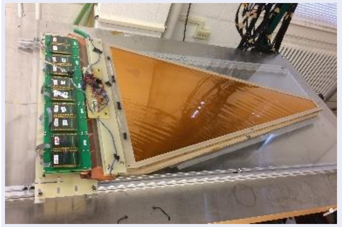


Progress on End Cap Tracker

End Cap Tracker: Large area GEM R&D Overview

- ❖ Large-area & Low-mass GEM Prototypes (FIT, UVa)
  - ➢ Refurbishment of Florida Tech Large Carbon Fiber GEM Prototype with zigzag readout (FIT)
  - ➢ Characterization of UVa Large GEM Prototype with 2D U-V readout (UVa)
- ❖ Commercial GEMs and GEM CCD Scanners (TU)
  - ➢ Scan of µRWELL and Low Temperature Co-fired Ceramic GEM (LTCC GEM) foils

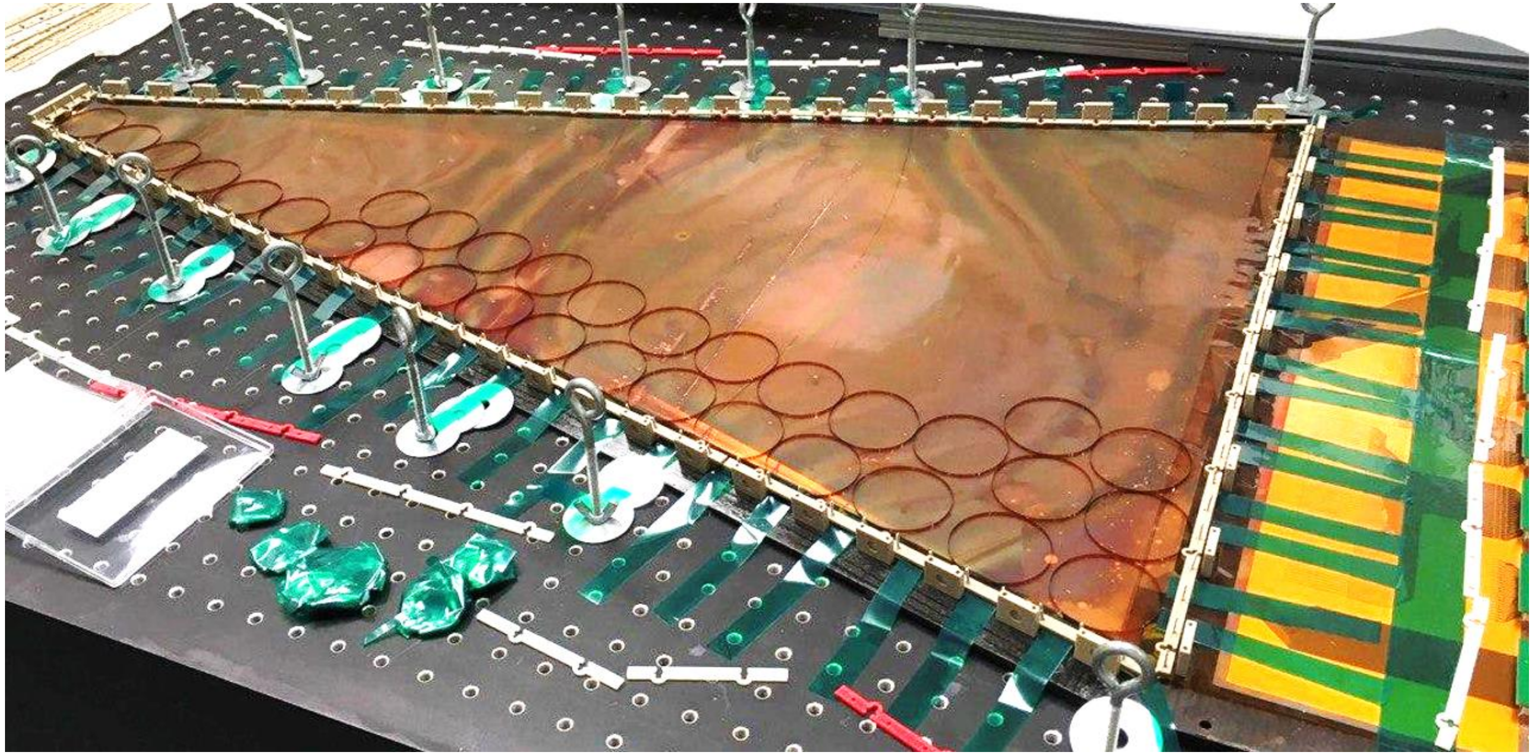
End Cap Tracker: R&D on Large-area & Low-mass GEMs

	Status of the prototype	Assembly technique	Readout technology	spatial resol (phi × Rphi)	Low mass	Dead area from support frames	Dead area in active area	FE cards connection
FIT FT-GEM 	Assembled – Technical issues – Fixes underway X	**Mech. Stretching technique - chamber can be reopened √**	1D Zigzag strips X	100 µm √ **but 1D only**	**Yes √**	Carbon Fiber, G10 Fiber glass, metallic piece X	**No spacers √**	Standard - Outside active area √
UVa FT-GEM 	**Assembled – Tested in beam at FNAL √**	Glued frames - chamber can't be reopened X	**2D U-V stereo-angle strips √**	100 µm × 500 µm √	**Yes √**	**Fiber glass (G10) 15 mm √**	300 µm straight spacers grid X	**Zebra - Outside active area √**
TU FT-GEM 	STAR FGT Technical issues – Fixes underway X	Glued frames - chamber can't be reopened X	**2D radial-Azimuth strips √**	**100 µm × 100 µm √**	**Yes √**	(G10) 15 mm but FE cards on the side X	50 µm Kapton rings X	Outside active area But FE on side X ?

End Cap Tracker: Large-area & Low-mass GEM @ FIT

FIT Large Carbon Fiber GEM Prototype

- Continue to struggle with short between GEM foil and readout in induction gap
- Partially filled induction gap with **Kapton rings** as spacers obtained from Temple U.
- Currently reassembling
- Graduate student working on detector had to take leave of absence; forced to train a new graduate student

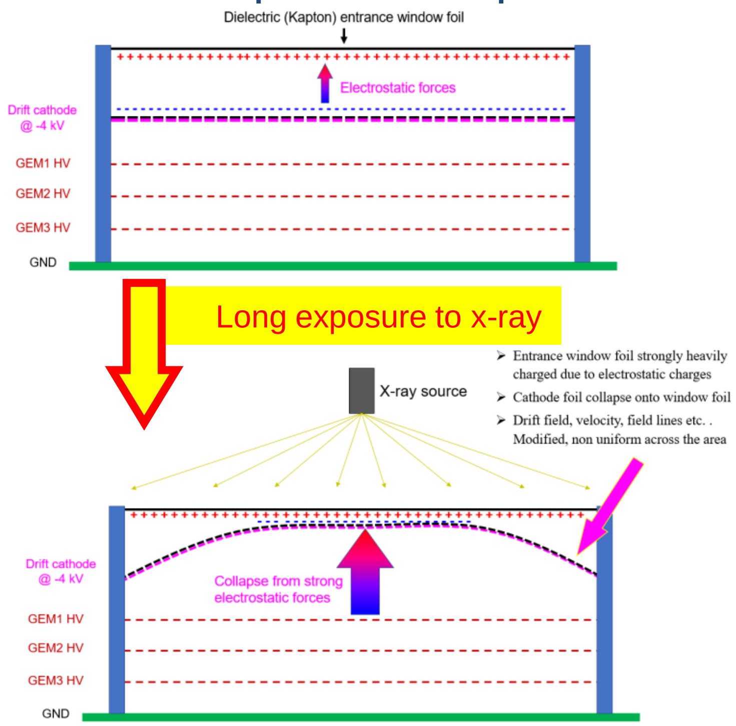


End Cap Tracker: Large-area & Low-mass GEM @ UVa

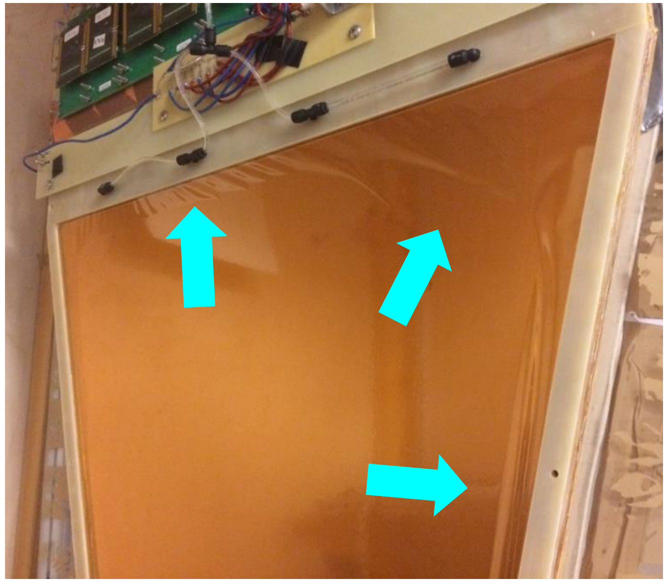
Characterization of UVa Large GEM prototype

- Low-mass GEM prototype ⇨ all foils no rigid part in active area of the detector: Entrance window and top side of the cathode foil of UVa prototype are both Kapton foils
- Electrostatic charging up **of large area foils** in high particle rate ⇨ electrostatic force triggers the collapse of the foils onto each other.
- Strong deformation of the drift volume that leads to **significant efficiency drop in large portion** of the detector active area
- Wrinkles on the entrance foil collapse of the foils shows evidence of the collapse of the foils during long exposure to x-ray
- 2D hit map shows low hit occupancy in a large portion of the detector active area correlated to the collapsing of the foils
- After the total collapse, the drift volume increases significantly ⇨ HV on the divider need to increase accordingly to compensate ⇨ **Not a safe way to operate triple-GEMs**
- Degradation of the detector spatial resolutions ⇨ **explains our challenges extracting expected resolution from FNAL 2018 test beam data**

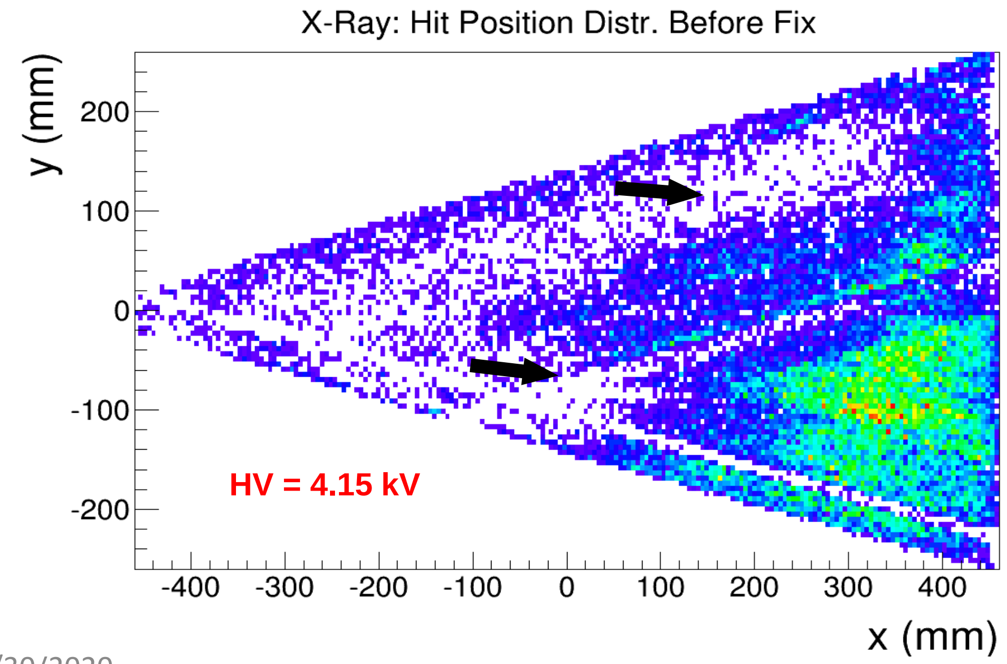
Principle of foils collapse



Evidence of collapse: apparition of wrinkles shown on entrance window foil



Dead area (efficiency lost caused by the foils collapse

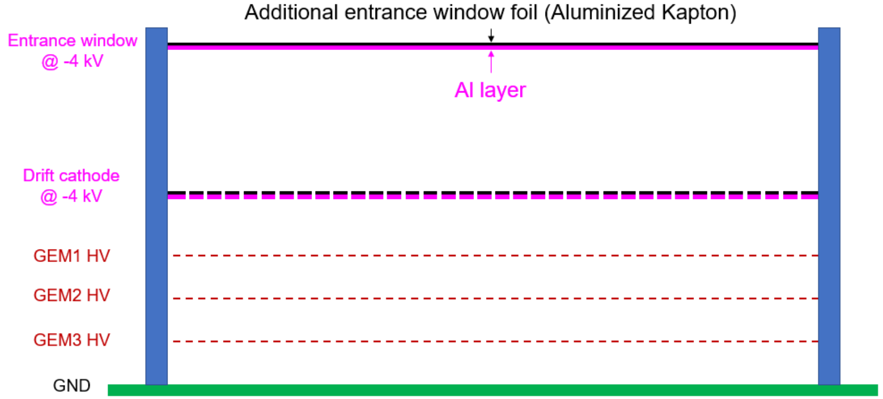


End Cap Tracker: Large-area & Low-mass GEM @ UVa

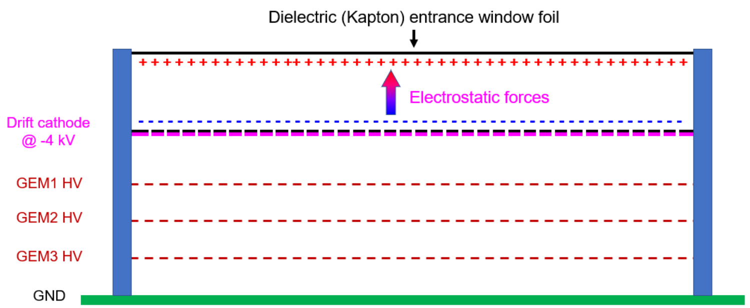
Fix to collapse of drift cathode

- Additional Al-Kapton foil glued on top of the window foil
- Al-Kapton at same potential as drift cathode (-4 kV) ⇨ Create a Faraday cage that suppress the charging of inner window foil
- Effect on the performance shown on the two hit map plots
  - **without the fix:** HV = 4.15 kV largely above the operating voltage of triple-GEM with x-ray ⇨ low efficiency on large section of the detector area and strong non uniformity
  - **With the fix:** HV = 3.9 kV which is the normal operating voltage for triple-GEM for x-ray data ⇨ good and uniform hit reconstruction across the entire active area of the detector
- For the future: Al-Kapton used for entrance window foil the same voltage as the drift cathode

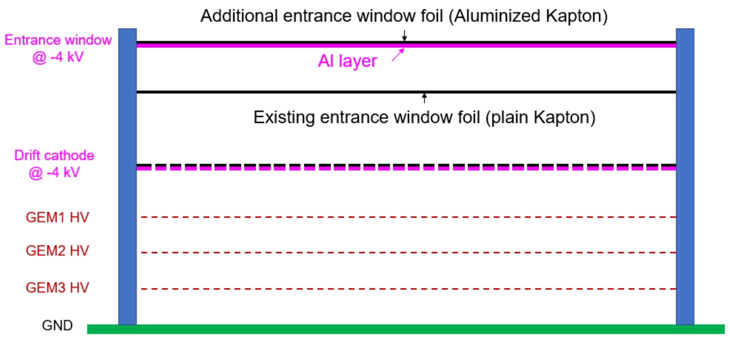
Future prototype

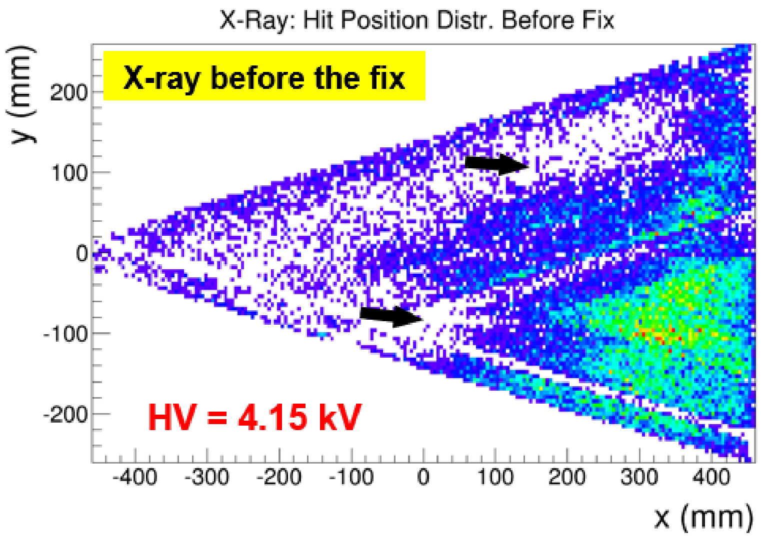


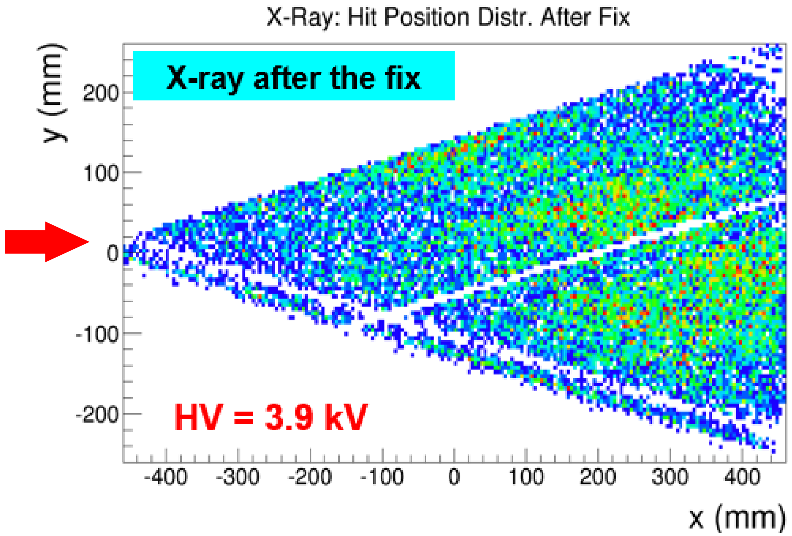
Without the fix



With the fix



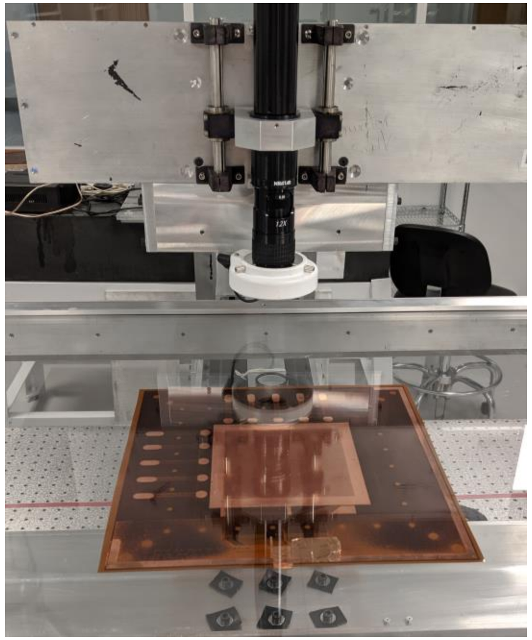


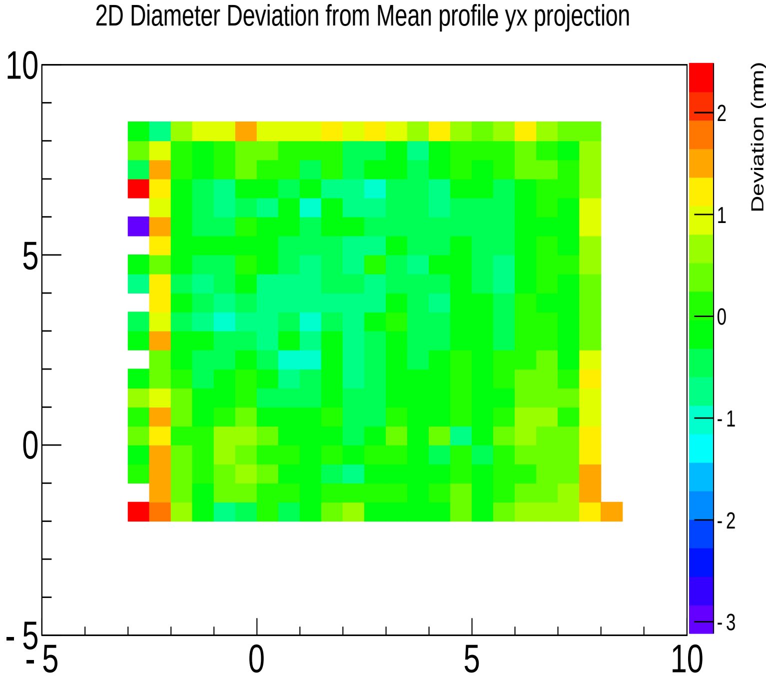


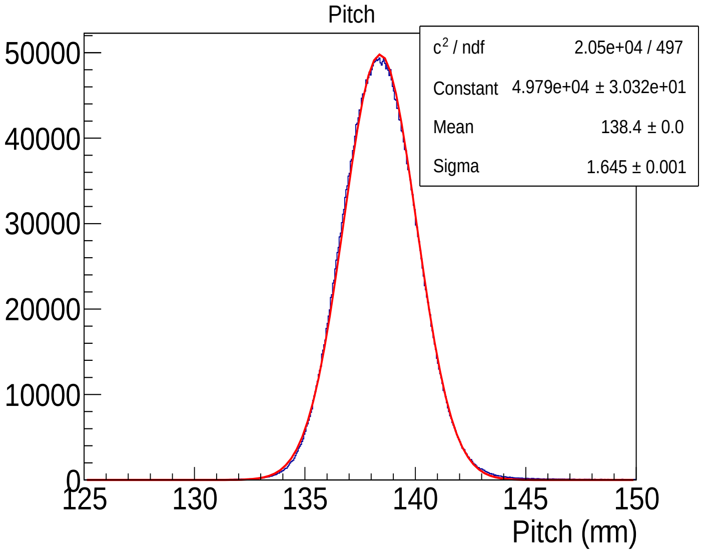
End Cap Tracking Detector: Commercial GEMs @ TU

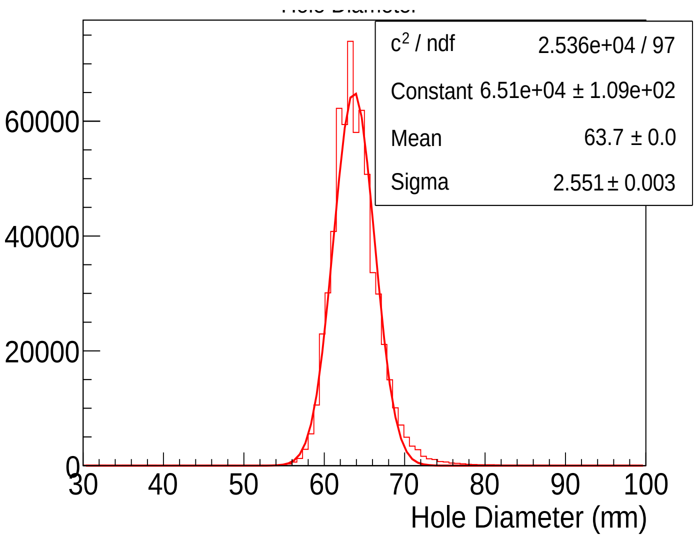
- **GEM CCD Scanner**
  - Continues to serve the MPGD community
  - Recently completed or upcoming scans
    - µRWELL foil (completed last summer)
    - Low Temperature Co-fired Ceramic GEM (to start soon)
  - This past summer, we completed scans of an FIT µRWell foil that was deemed "bad" by CERN.

- **uRWELL foil Scan**
  - Investigate hole (well) pitch and diameter uniformity of a µRWELL.
  - FIT sent us a bare foil not mounted to a substrate that CERN determined to be "bad".
  - Measurements of the pitch and outer hole (well) diameters were found to be uniform.
    - Pitch: ~ 138 µm
    - Outer well diameter deviation: ~ 3µm









Progress on Particle ID

Particle ID: Hybrid MPGDs for RICH @ INFN

Main test beam results reported in July 2019

- good electrical stability
- high gain (~30 k) achieved in stable conditions
- time resolution (14 ns)
- capability to operate in pure methane atmosphere

Assessment to further results, in particular <u>space resolution</u>, prevented by the <u>noise level</u>

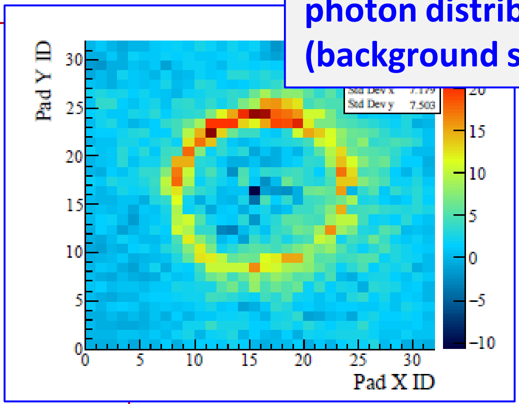
- 3σ threshold at ~10 k electrons eq.

→ limited single photoelectron detection efficiency (~70%)

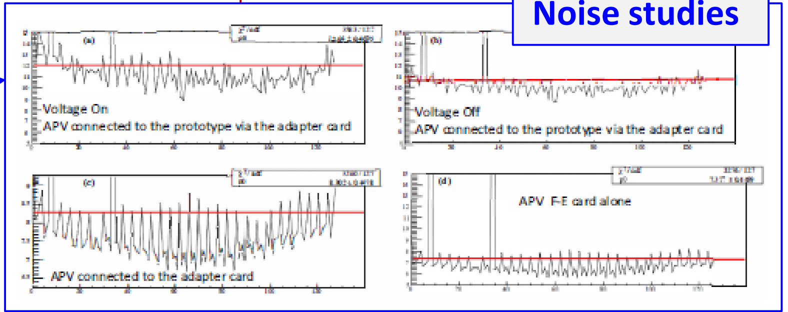
→ no reliable cluster analysis possible (space resolution cannot be determined)

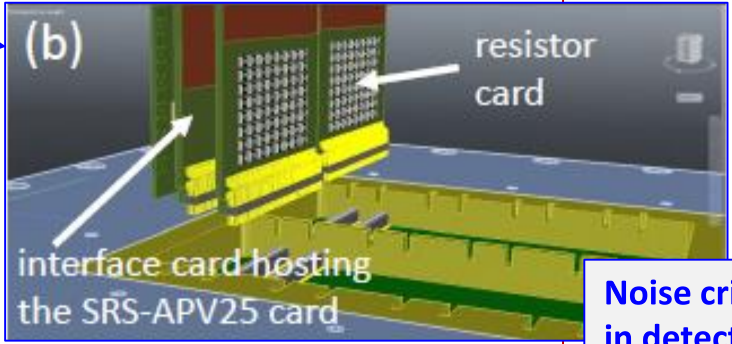
- <u>Noise source analysis</u>:
  1. From SRS architecture
  2. From detector architecture

2-D Cherenkov photon distribution (background subtracted)



Noise studies





Noise critical aspect in detector architecture: Resistor cards providing HV to the individual pads near and parallel to the FE cards

ACTIONS

1. **Get organized for testing different, most promising (noise figure) FE**
2. **Detector version 2 designed following prescriptions for lower noise level**

Deviation from previous planning due to the too high noise level

Particle ID: Hybrid MPGDs for RICH @ INFN

MORE ABOUT ACTIONS

1. Get organize for testing different, most promising (noise) FE: VMM3

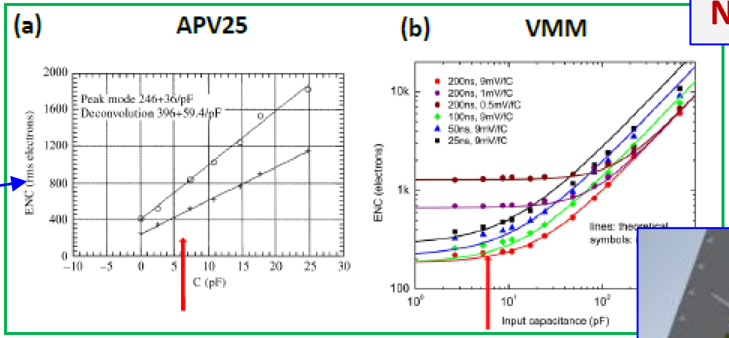
- the <u>low noise figure</u>, also for high C detector
- Moreover, architecture designed also for <u>trigger-less operation</u> (perspective for streaming r-o at EIC)

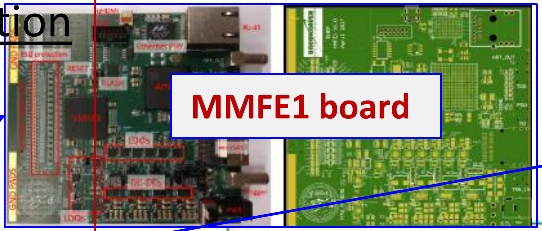
→ 2 stand-alone VMM read-out board MMFE1 (ATLAS NSW project) ordered

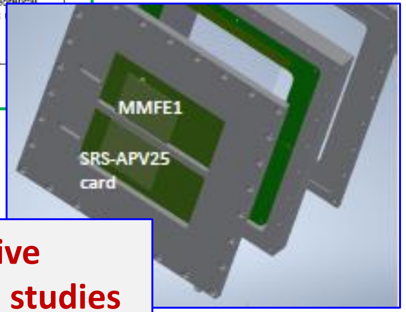
→ Dedicated micromegas stage for comparative evaluation designed

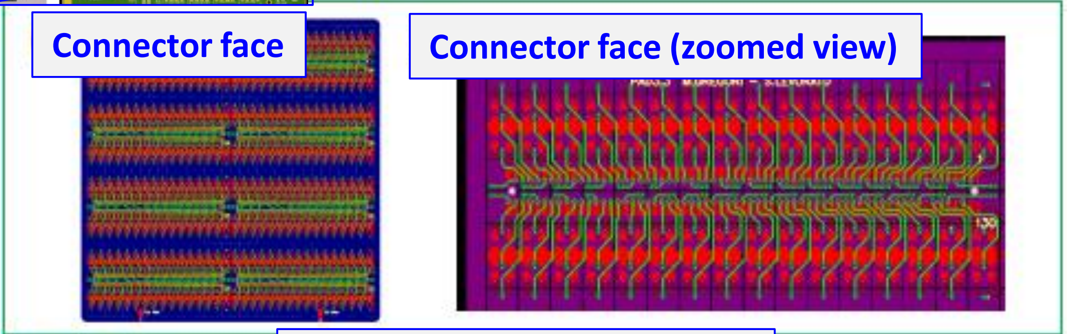
2. Detector "version 2" designed following prescriptions for lower noise level:

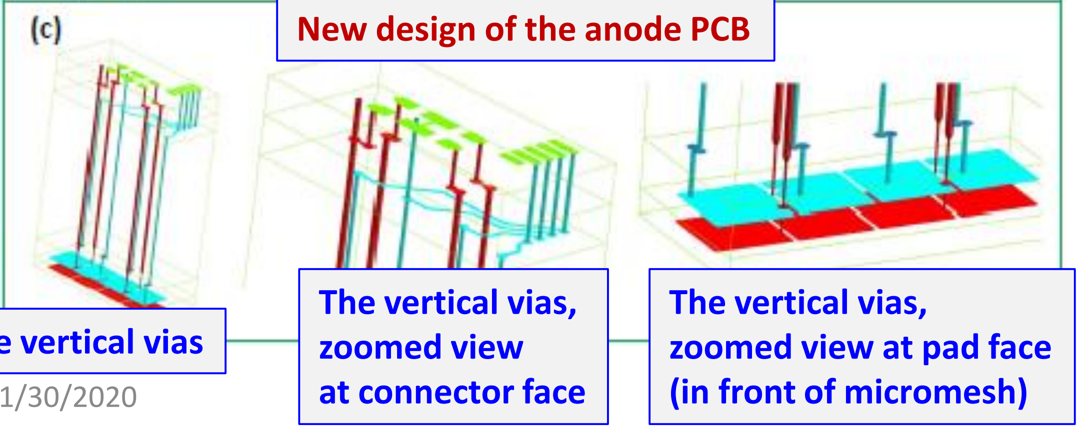
- <u>No longer a resistor card</u>: SMD resistors directly soldered on the anode PCB; each resistor is mounted over its pad;
- <u>Vertical vias</u> to minimize "crossing" signal lines (before: crossing even if lines running in different PCB layers);
- <u>Another improvement:</u> improving the equalization of the signal line length in order to have the same input capacitance, therefore avoiding different effective pad gains











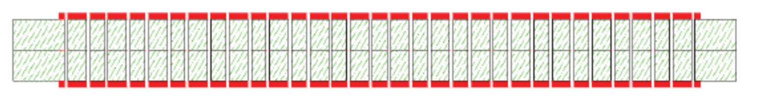
Particle ID: New Photocathodes for RICH @ INFN

Novel set of samples realized and coated (spray technique)

- **THGEM for photocathode-THGEM coupling studies**
- **PCB disk for studies of general photocathode properties**

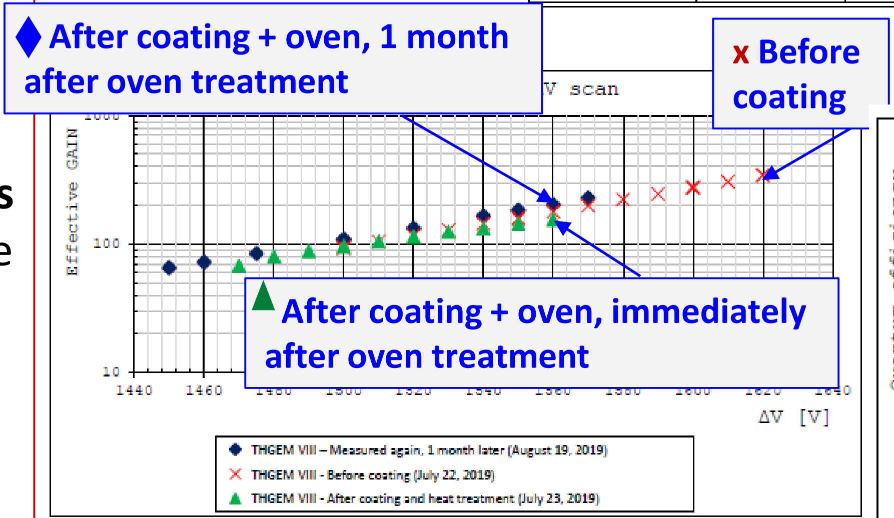
substrate type	sample label	coating material	number of spray shots
THGEM	TB IX	ND	300
THGEM	TB VIII	HND	140
THGEM	TB III	HND	43
THGEM	TB VII	HND	55
THGEM	TB XIX	HND	59
THGEM	TB XI	HND	250
disc	PBC1	ND	100
disc	PBC2	ND	100
disc	PBC3	ND	200
disc	PBC4	ND	200
disc	PBC5	ND	50
disc	PBC6	HND	50
disc	PBC9	HND	25
disc	PBC7	HND	50
disc	PBC10	HND	100
disc	PBC11	HND	200
disc	PBC8	HND	400

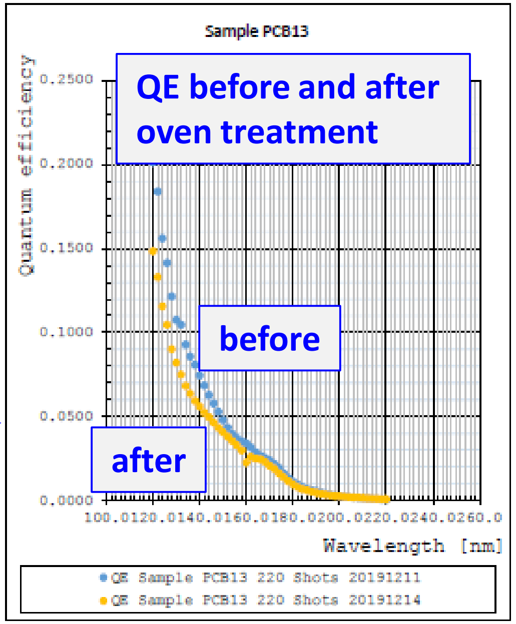
About poor electrical rigidity of H-ND coated THGEMS (observed since the beginning)



- **THGEMS by 2 layers attempted**
  - Too large gain evolution with time due to hole misalignments→ **abandoned**
- **H-ND is hydroscopic**
  - Recovery by **oven treatment** attempted → **it works**
  - Demonstrated comparing amplitude spectra before coating and after coating + oven
  - Good performance preserved in time
  - **IMPORTANT:** Is the oven treatment compromising QE?
  - **Positive outcome**: some QE reduction only below 160 nm (oxidation due to heating in air?)

→ Heating in dry atmosphere to be tried in the future

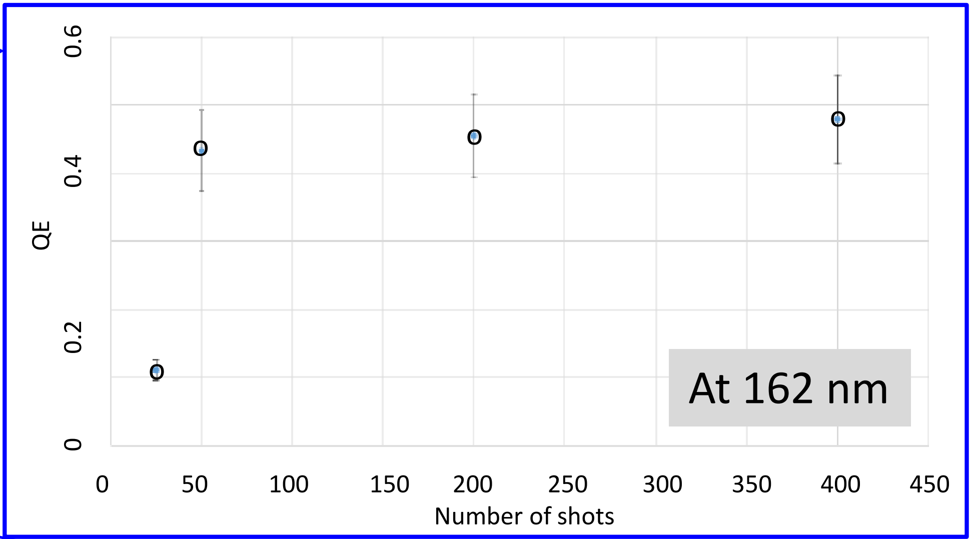




Particle ID: New Photocathodes for RICH @ INFN, MORE

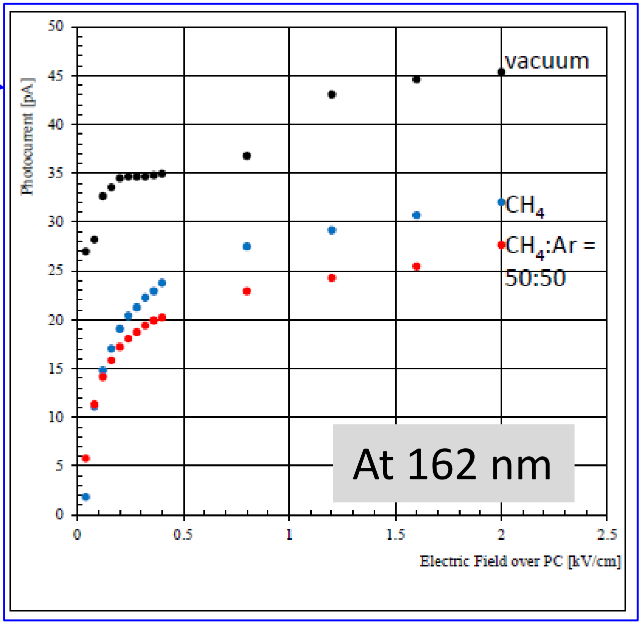
QE versus number of spray shots

- **Understanding the potentiality of the spray approach**
- **Saturation above 50 shots**

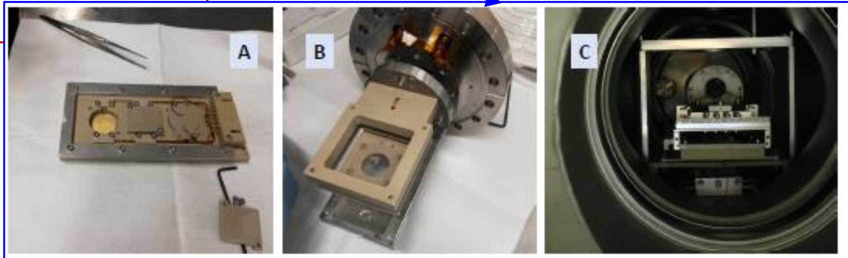


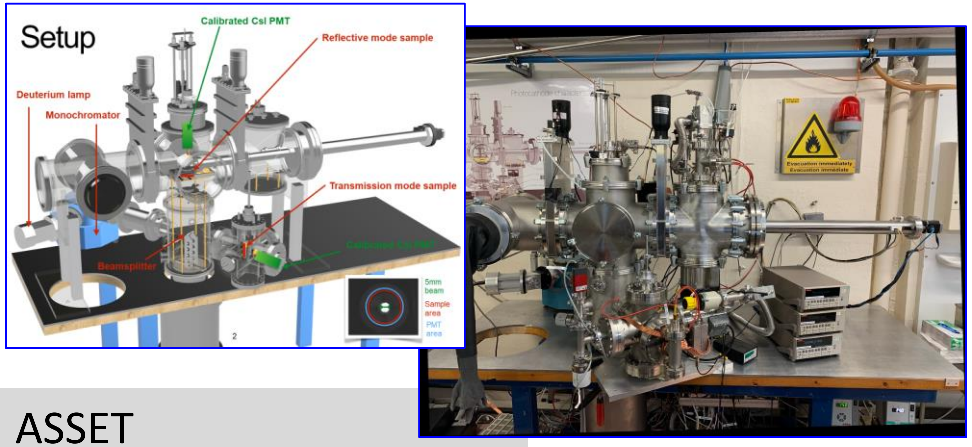
QE in gas atmosphere

- **First set of measurements**



- **Prepare mechanical supports for our samples in view of QE studies with ASSET (new CERN-RD51 facility for QE measurements)**





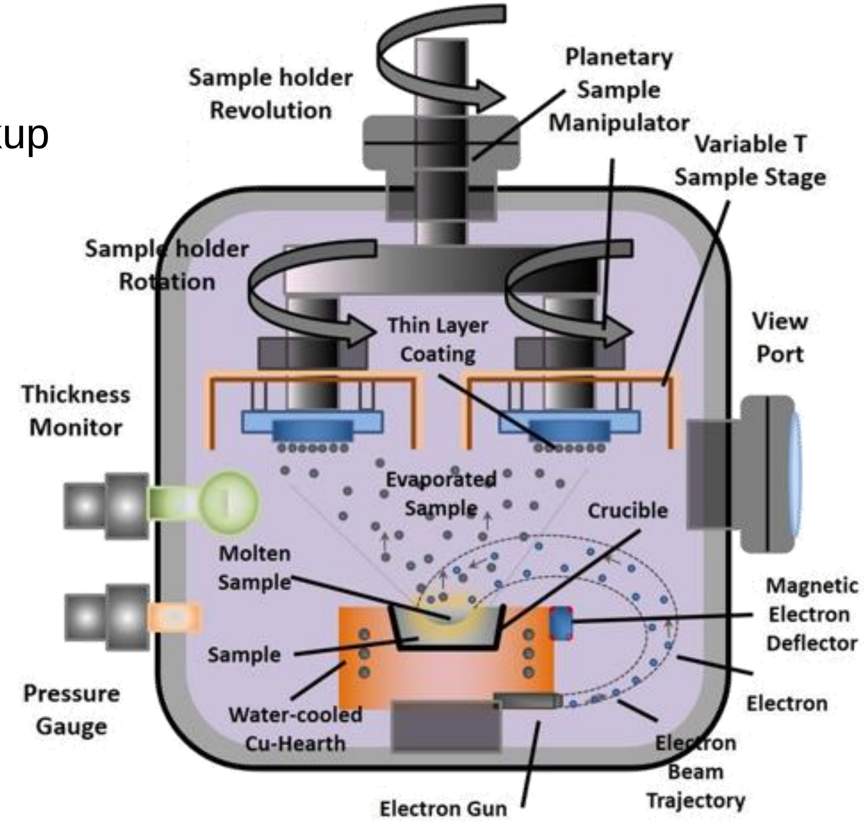
ASSET
Courtesy by F. Brunbauer

Stony Brook University

Particle ID: Large Mirrors for RICH @ SBU

Evaporator Readiness

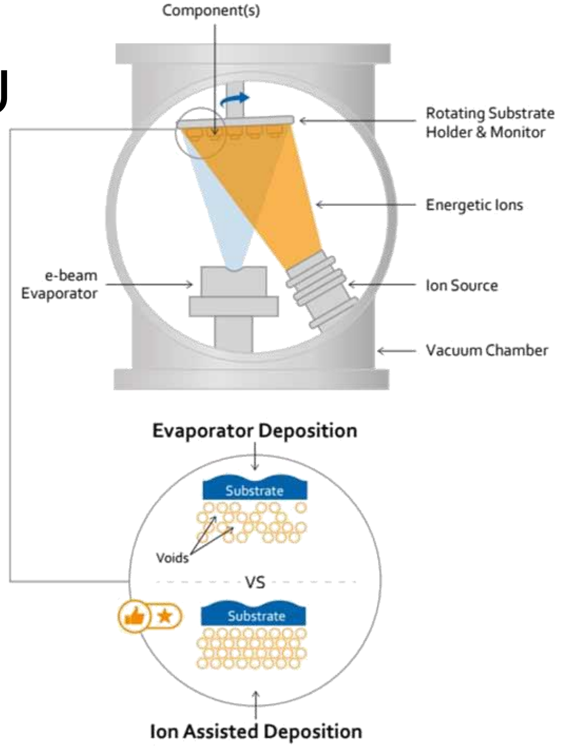
- ➢ Installation complete
  - ➢ Vacuum equipment
  - ➢ E-beam, ion-gun, motor rotating shaft, mirror mockup

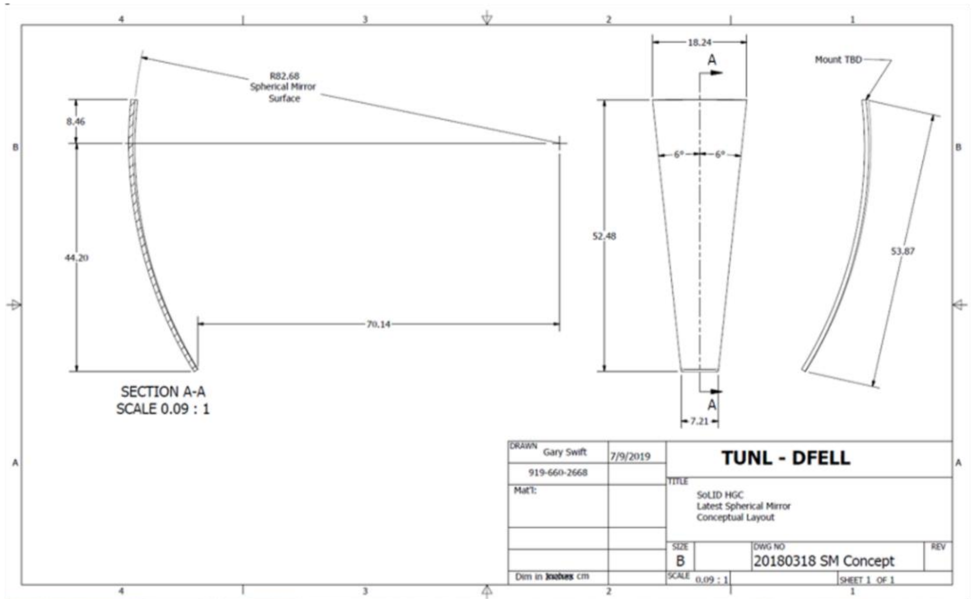


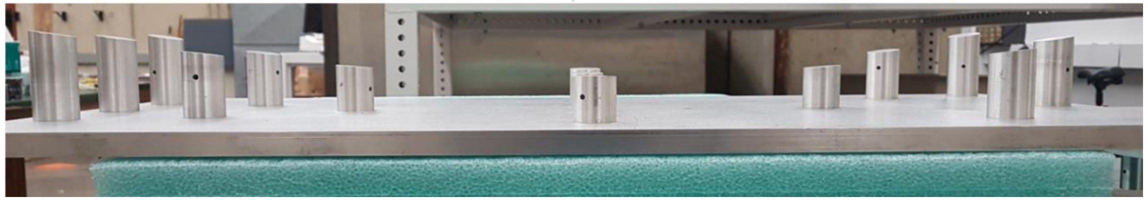
Particle ID: Large Mirrors for RICH @ SBU

Evaporator Readiness

- Installation complete
  - Vacuum equipment
  - E-beam, ion-gun, motor rotating shaft, mirror mockup





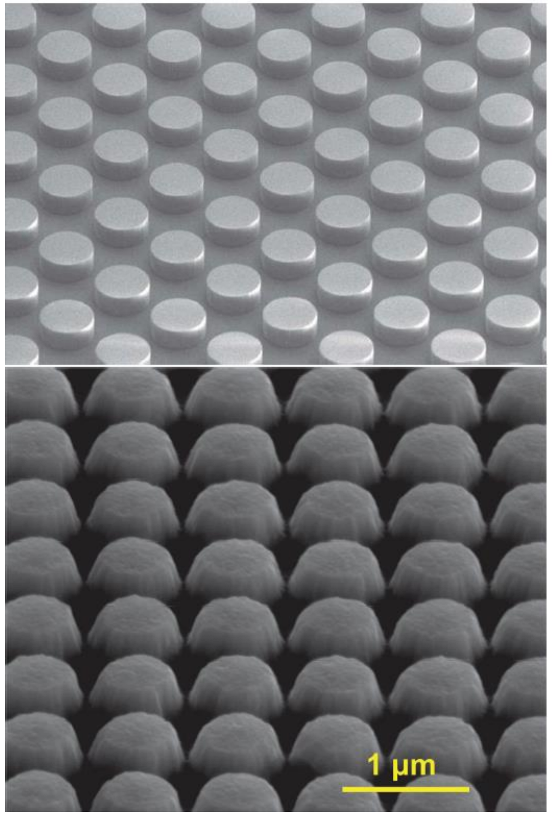


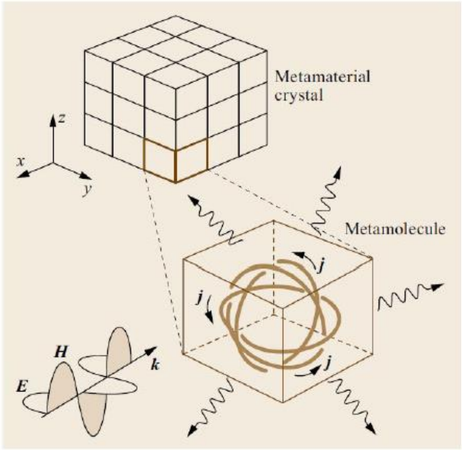
Particle ID: Investigation of Meta Materials @ SBU

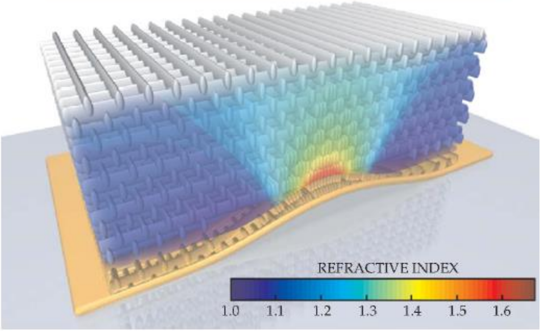
Looking into condensed matter problems

- Use of alkali metals → transparent in the UV
- Plasmons
- Design of metal-like materials using unconventional materials
- Carrier concentration manipulation
- Local variation in rod structure regarding
  - filling fraction
  - thickness
  - pitch
- Arrangement of shells of spherical nano-particles
- Nanowires
- Sub-wavelength hole arrays
- ...

... and a combination thereof.







Lets get A.I. involved→ Deploy Neural Networks

- Vast number of possible configurations
  - Impossible to simulate via trial and error
  - Need to narrow the configuration space

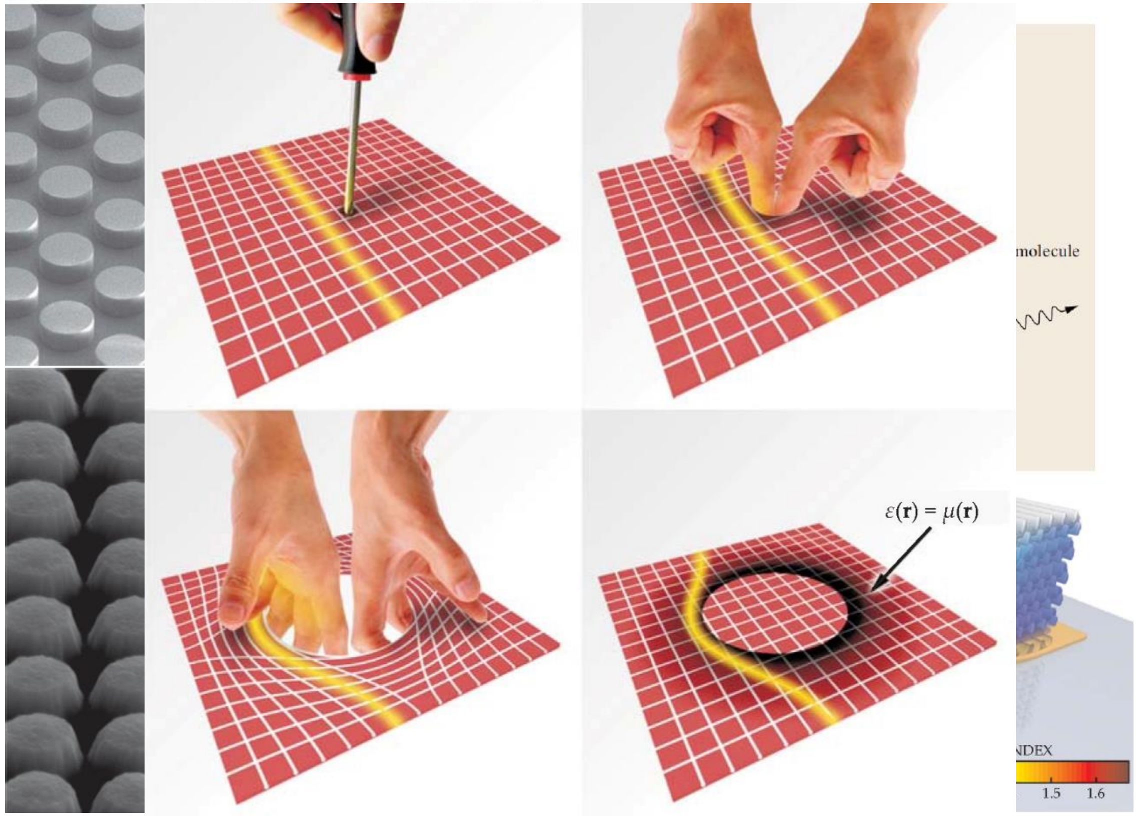
Particle ID: Investigation of Meta Materials @ SBU

Stony Brook University

Looking into condensed matter problems

- ◇ Use of alkali metals → transparent in the UV
- ◇ Plasmons
- ◇ Design of metal-like materials using unconventional materials
- ◇ Carrier concentration manipulation
- ◇ Local variation in rod structure regarding
  - ▶ filling fraction
  - ▶ thickness
  - ▶ pitch
- ◇ Arrangement of shells of spherical nano-particles
- ◇ Nanowires
- ◇ Sub-wavelength hole arrays
- ◇ ...

... and a combination thereof.

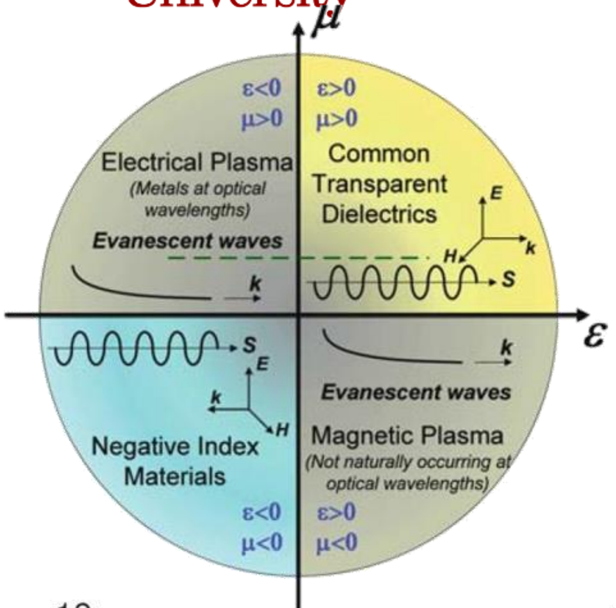


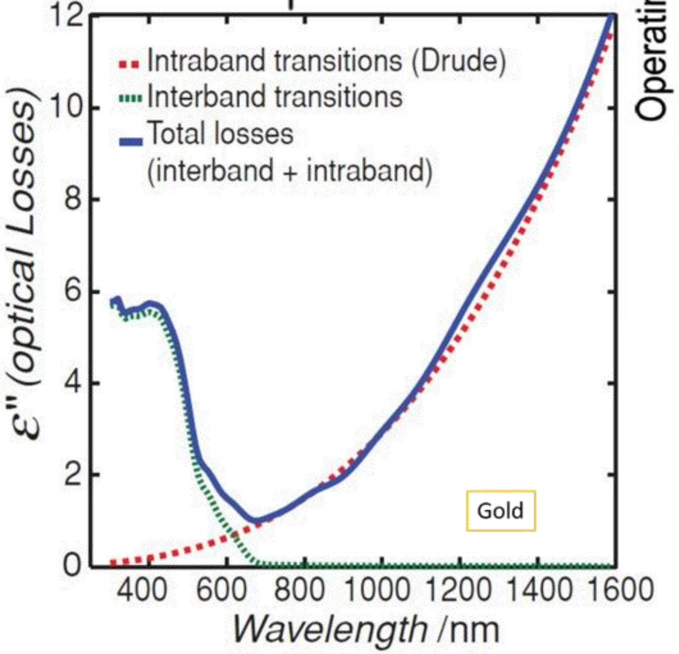
Lets get A.I. involved→ Deploy Neural Networks

- ➢ Vast number of possible configurations
  - ➢ Impossible to simulate via trial and error
  - ➢ Need to narrow the configuration space

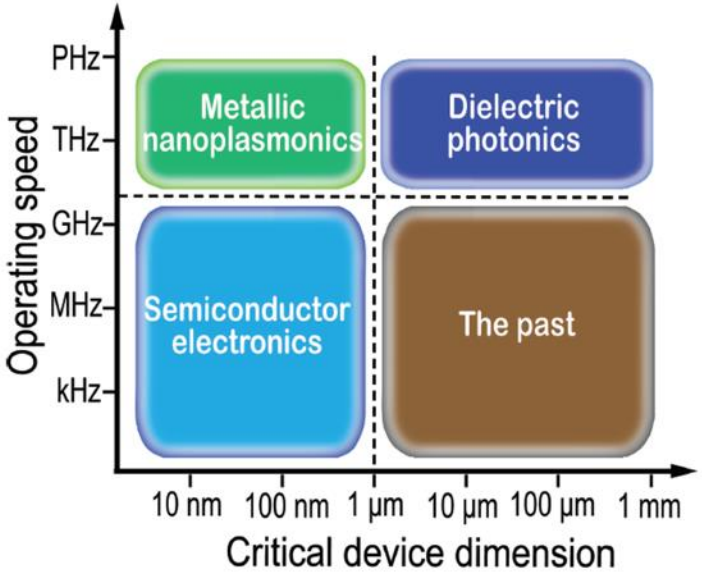
Particle ID: Investigation of Meta Materials @ SBU

Stony Brook University



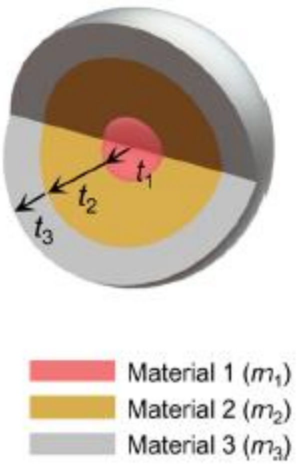


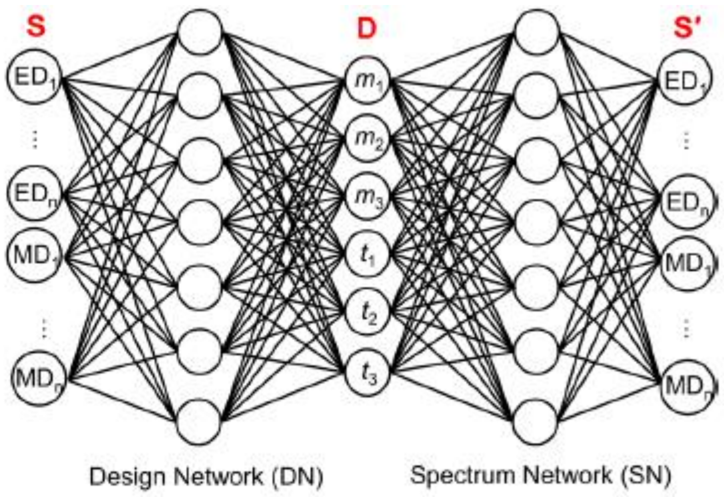
Challenges



Strategy of NN-Deployment

- Create a series of simulations based on different materials/sizes/configurations
- T-Matrix formalism to generalize desired spectrum
- Produce a NN and train/validate
- Create an inverse design problem





eRD6 Projects Completion Milestone & Timeline for Readiness for a TDR in 2023

eRD6 Projects Completion Milestone & Timeline for Readiness for a TDR in 2023

❖ Central Tracker - TPC

1. **Novel charge collection anode geometries (BNL):** Our investigations into novel charge collection anode geometries to provide enhanced charge sharing for various MPGD based detectors **was completed in 2018**. However, this work was not fully developed at that time and we are now pursing this under a BNL sponsored LDRD which **will be completed in 2021.**
2. **Readout structures and gas amplification schemes (BNL, Yale U):** We are now investigating various readout structures and gas amplification schemes for use in a TPC for EIC under the eRD6 program which **we hope to complete by 2022**.
3. **TPC IBF (SBU):** to be finished by **mid-2021**

➢ These combined efforts will provide several options which can be implemented in a variety of EIC detector specific designs for a TDR in 2023.

❖ Central Tracker - Cylindrical μRWELL

1. **Single Cylindrical μRWELL prototype:** Our goal is to build and characterize in test beam one full size (smallest EIC detector diameter) single Cylindrical uRWELL prototype operating in micro-TPC mode **by December 2022.**
2. **Simulation of central tracker detector:** Complete the study of material budget and performances of uRWELL vs. TPC in a realistic EIC detector including impact of the material budget of the central detector choice in the endcap region **by December 2022**

⇨ See milestone breakdown in back-up slides

➢ These combined efforts will provide several options which can be implemented in a variety of EIC detector specific designs for a TDR in 2023.

eRD6 Projects Completion Milestone & Timeline for Readiness for a TDR in 2023

❖ **End Cap Tracker – Large-area & Low-mass GEMs**

1. **Large GEM prototypes:** Our plan is to complete characterization of the two current UVa & FIT large GEM prototypes **by December 2021.**
2. **Simulation of End Cap GEM trackers:** Conduct full simulation study of material budget and performances of realistic large area GEMs in the end cap region of a EIC detector **by December 2022** including impact of the material budget of the central detector choice.
   - ⇨ See milestone breakdown in back-up slides

➢ These combined efforts will provide several options which can be implemented in a variety of EIC detector specific designs for a TDR in 2023.

❖ **PID detectors (RICH)**

1. **Gaseous photon detector with miniaturized pad-size (INFN):** (INFN) R&D completed by the end of 2022
2. **Photocathode by nano diamond powder (INFN):** blue-sky R&D --> the time of completion cannot be predicted in a solid way; Our attitude is to **see where we are at the end of 2022** and decide completion within one more year if mature enough:
   - ⇨ See milestone breakdown in back-up slides
3. **Large Mirrors (SBU):** to be finished **by end-2020**
4. **Meta Materials (SBU):** to be finished **by TBD**!

➢ These combined efforts will provide several options which can be implemented in a variety of EIC detector specific designs for a TDR in 2023.

BROOKHAVEN NATIONAL LABORATORY | FLORIDA TECH | INFN TRIESTE | Stony Brook University | TEMPLE UNIVERSITY | UNIVERSITY of VIRGINIA | Yale University

eRD6 Publications

eRD6 Publications

- **BNL**

1. B. Azmoun et al. “Results From a Prototype Combination TPC Cherenkov Detector With GEM Readout”. In: IEEE Transactions on Nuclear Science 66.8 (Aug. 2019), pp. 1984–1992. issn: 1558- 1578. doi: 10.1109/TNS.2019.2928269.
2. Maxence Vandenbroucke et al. “A Study of “Zigzag” Strip Readout for Micromegas Detectors”. In: 2018 IEEE Nuclear Science Symposium and Medical Imaging Conference (2018 NSS/MIC). Nov. 2018, pp. 1–4. doi: 10.1109/NSSMIC.2018.8824702.
3. 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.
4. B. Azmoun et al. “A Study of a Mini-Drift GEM Tracking Detector”. In: IEEE Transactions on Nuclear Science 63.3 (June 2016), pp. 1768–1776. issn: 0018-9499. doi: 10.1109/TNS.2016.2550503.
5. Craig Woody et al. “A Prototype Combination TPC Cherenkov Detector with GEM Readout for Tracking and Particle Identification and its Potential Use at an Electron Ion Collider”. In: 2015. arXiv: 1512.05309 [physics.ins-det]. url: https://inspirehep.net/record/1409973/files/arXiv: 1512.05309.pdf.
6. 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, pp. 1–2. doi: 10.1109/ NSSMIC.2014.7431059.
7. 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, pp. 1–4. doi: 10.1109/NSSMIC.2013.6829463.

- **INFN**

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 .
2. J. Agarwala et al. *“Study of MicroPattern Gaseous detectors with novel nanodiamond based photocathodes for single photon detection in EIC RICH*". In: Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment (2019). issn : 0168-9002. doi : https://doi.org/10.1016/j.nima.2019.03.022 . url : http://www.sciencedirect.com/science/article/pii/S0168900219303213 .

eRD6 Publications

❖ **FIT**

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.
2. Aiwu Zhang et al. *“A GEM readout with radial zigzag strips and linear charge-sharing response"*. In:Nucl. Instrum. Meth. A887 (2018), pp. 184. arXiv: 1708.07931 [physics.ins-det].
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.
5. Aiwu Zhang et al. *“Performance of a Large-area GEM Detector Read Out with Wide Radial Zigzag Strips"*. In: Nucl. Instrum. Meth. A811 (2016), pp. 30. doi: 10.1016/j.nima.2015.11.157. arXiv:1508.07046 [physics.ins-det].

❖ **SBU**

1. M. Blatnik et al. *“Performance of a Quintuple-GEM Based RICH Detector Prototype"*. In: IEEE Trans. Nucl. Sci. 62.6 (2015), pp. 3256. doi :10.1109/TNS.2015.2487999 . arXiv: 1501.03530[physics.ins-det] .

eRD6 Publications

- **TU**

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. 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: 511.08693 [physics.ins-det].
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]. [physics.ins-det].

- **UVa**

1. Kondo Gnanvo et al. “*Large Size GEM for Super Bigbite Spectrometer (SBS) Polarimeter for Hall A 12 GeV program at JLab*". In: Nucl. Instrum. Meth. A782 (2015), pp. 77. doi : 10.1016/j.nima.2015.02.017 . arXiv: 1409.5393 [physics.ins-det] .
2. Kondo Gnanvo et al. *“Performance in test beam of a large-area and light-weight GEM detector with 2D stereo-angle (UV) strip readout"*. In: Nucl. Instrum. Meth. A808 (2016), pp. 83. doi : 10.1016/j.nima.2015.11.071 . arXiv: 1509.03875 [physics.ins-det] .

- **Yale**

1. S. Aiola et al. *“Combination of two Gas Electron Multipliers and a Micromegas as gain elements for a time projection chamber"*. In :Nucl. Instrum. Meth. A834 (2016), pp. 149. doi: 10.1016/j.nima.2016.08.007. arXiv: 1603.08473 [physics.ins-det].

BROOKHAVEN NATIONAL LABORATORY · FLORIDA TECH · INFN TRIESTE · Stony Brook University · TEMPLE UNIVERSITY · UNIVERSITY of VIRGINIA · Yale University

Thank You

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

Number of institutions/labs
7

Number of People
35

Number of publications
21

Backup Slides

eRD6 Projects Completion Milestone Breakdown

❖ **Central Tracker - Cylindrical µRWELL**

1. **Single Cylindrical µRWELL prototype:** Our plan is to build and characterize in test beam one full size (smallest EIC detector diameter) single Cylindrical uRWELL prototype operating in micro-TPC mode **by December 2022.**
   - ⇨ **January 2020 – July 2020:** Complete the Mock-up design – Pursue the characterization of planar low-mass µRWELL prototypes
   - ⇨ **July 2020 – July 2021 :** Complete the design of the prototype and procurement of the parts
   - ⇨ **July 2021 – July 2022:** Complete the assembly of the prototype & investigation of the best FE electronics
   - ⇨ **July 2022 – December 2022:** Characterization of the prototype in test beam at Fermilab followed by the data analysis effort and submission of the results to a peer-reviewed journal.

2. **Complete the simulation of central tracker detector:** Study of material budget and performances of uRWELL vs. TPC in a realistic EIC detector including impact of the material budget of the central detector choice in the endcap region **by December 2022**
   - ⇨ **January 2020 – July 2020:** Start the implementation of realistic detectors (currents parameters – geometries & material budget)
   - ⇨ **July 2020 – July 2021:** Complete the implementation of realistic detectors
   - ⇨ **July 2021 – July 2022:** Full simulation of the End Cap GEMs including the impact of the material budget of the barrel detector on the performances of the end cap tracker.
   - ⇨ **July 2022 – December 2022:** Complete the full simulation of the central tracker detectors and submission of the results to a peer-reviewed journal.

BROOKHAVEN NATIONAL LABORATORY | FLORIDA TECH | INFN TRIESTE | Stony Brook University | TEMPLE UNIVERSITY | UNIVERSITY of VIRGINIA | Yale University

eRD6 Projects Completion Milestone Breakdown

❖ **End Cap Tracker – Large-area & Low-mass GEMs**

1. Large GEM prototypes: Our plan is to complete characterization of the two current UVa & FIT large GEM prototypes **by December 2021.**
   - ⇨ **January 2020 – July 2021:** Pursue the characterization of UVa prototypes with cosmic and x-ray setups at UVa; Complete the refurbishment of FIT prototype and upon successful outcome, characterize the detector in cosmics and x-ray setup at Florida Tech
   - ⇨ **July 2021 – December 2021:** Characterization of the two prototypes in test beam at Fermilab followed by the data analysis effort and submission of the results to a peer-reviewed journal.

2. Complete the simulation of End Cap tracker detectors: Full study of material budget and performances of **realistic** large area GEM in the end cap region of a EIC detector by **December 2022** including impact of the material budget of the central detector choice.
   - ⇨ **July 2020 – July 2021:** Complete the implementation of realistic detectors (currents parameters – geometries & material budget …)
   - ⇨ **July 2021 – July 2022:** Full and comparative simulation of TPC and Cylindrical uRWELL options
   - ⇨ **July 2022 – December 2022:** Complete the full simulation of the central tracker detectors and submission of the results to a peer-reviewed journal.

eRD6 Projects Completion Milestone Breakdown

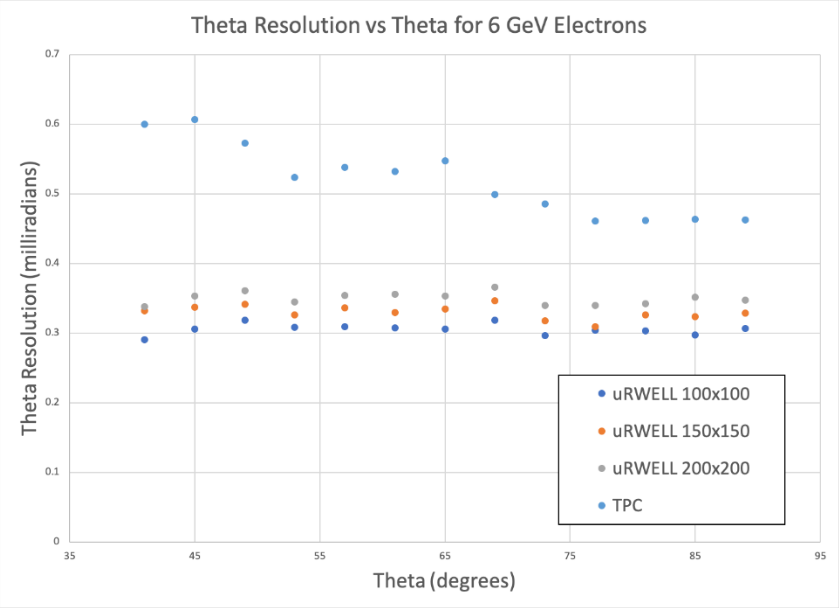
- **Hybrid MPGDs with fine space resolution for RICHs**
  - Construction of the upgraded version of the prototype: **2020**
  - Characterization of the upgraded version of the prototype: **first quarter 2021**
  - Test of VMM3 FE chip coupled to Hybrid MPGDs for RICH : **second quarter 2021**
  - Validation of the upgraded version of the prototype with CF4 : **end 2021**

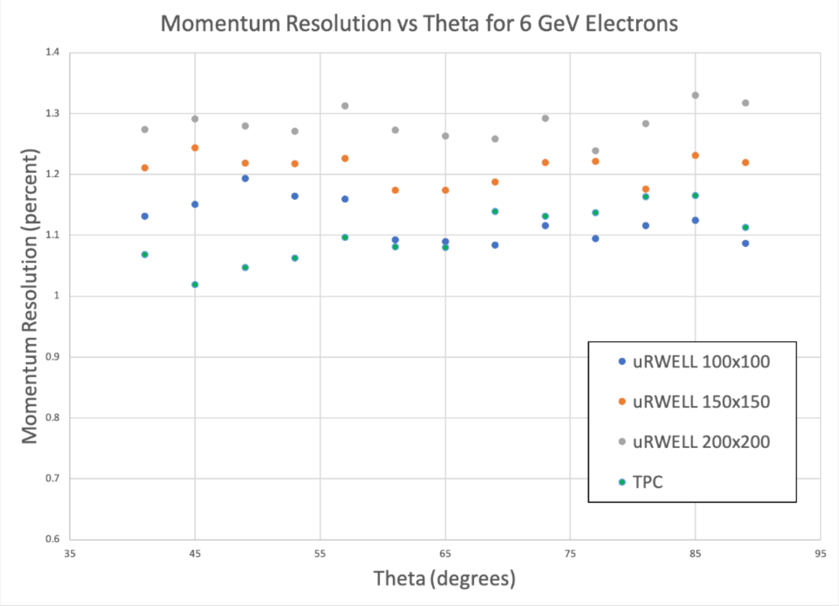
- **New Photocathodes by Hydrogenated NanoDiamond (H-ND) powder for RICHs**
  - Confirmation that the H-ND QE remains unchanged after the heating treatment
  - That recovers the electrical stability of coated THGEMs: 2020
  - Absolute measurements of H-ND qe in the CERN facility ASSET : first quarter 2021
  - Identify in the industrially produced powders those characteristics that favor high QE: end 2021

Central Tracking: Cylindrical μRWELL @ TU (Backup)

- Comparison of $\mu RWell$ and TPC performance
  - Performance of cylindrical $\mu RWell$ barrel was done using three (longitudinal, transverse) spatial resolution values
    - (100 μm, 100 μm), (150 μm, 150 μm), and (200 μm, 200 μm)
  - Using the stated detector simulation conditions, 6 GeV electrons were simulated in a 1.5 T magnetic field
  - Theta resolution vs. theta
    - $\mu RWell$ appears to have a better angular resolution than the TPC, particularly at smaller angle ($\sim 45^o$).
  - Momentum resolution vs. theta
    - TPC appears to have a better momentum resolution at small angle ($\sim 45^o$).
    - Momentum resolution of the $\mu RWell$ with resolution (100 μm, 100 μm) becomes comparable to the TPC at moderate angles ($> 55^o$)

Results include the vertex detector





Central Tracking: Cylindrical μRWELL @ TU

- Comparison to TPC performance
  - Implemented a TPC into simulation based on sPHENIX TPC
  - TPC parameters
    - Radial length: 80 cm
    - Dispersion (longitudinal, transverse)
      - ($1\ \mu m/\sqrt{D}$, $15\ \mu m/\sqrt{D}$)
    - Resolution (longitudinal, transverse)
      - ($500\ \mu m$, $200\ \mu m$)
  - Transverse dispersion and resolution need to be updated to match sPHENIX transverse (dispersion, resolution) **beam test results** ($\mathbf{40\ \mu m/\sqrt{D}}$**,** $\mathbf{90\ \mu m}$)
    - We do find particular sensitivity to the transverse dispersion
  - Material budget for TPC and 6 barrel $\mu RWell$ tracker (ongoing, **not final**)
    - Reducing readout strip thickness ($25\ \mu m \rightarrow \sim 10\ \mu m$) would yield comparable results to central TPC material
    - Investigating performance of 5 $\mu RWell$ layer barrel