Athena Gaseous Technology Considerations

M. Posik

for eRD6 and eRD22

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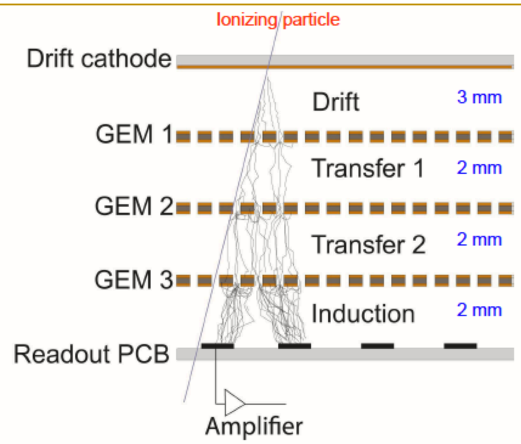
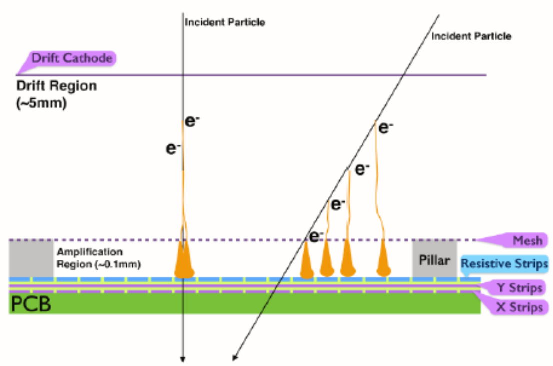
MPGD Technologies

- GEM and micromegas technologies are very mature
- $\mu RWell$ not as mature, but significant R&D has already been done
- All three technologies are well suited for EIC
- Several hybrid options looked at in YR

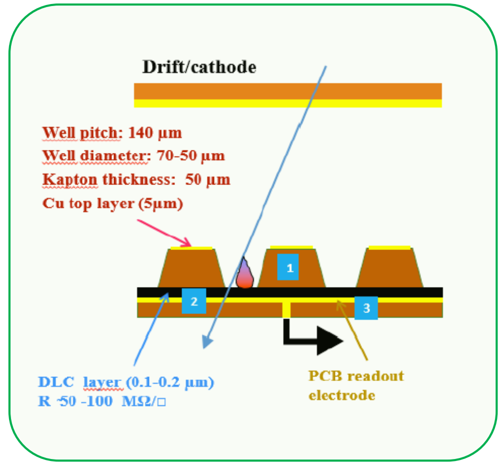
GEM



Micromegas



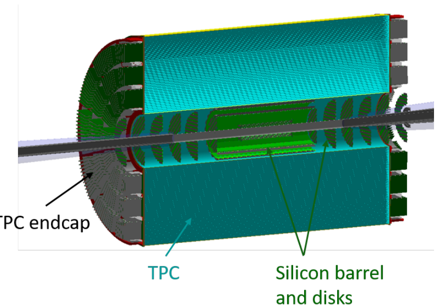
$\mu RWELL$



Yellow Report Studies

TPC + Si

- Meets PWG requirements at $\eta > \sim -2.0$
- Doesn't meet PWG requirements at $\eta < -2.0$
- Backward direction has similar situation in all designs so far
- help needed around $\eta < -1.0$
  → end cap tracker



η			Momentum res. Performance	Requirements
-3.5 to -3.0	Central Detector	Backward Detector	σp/p ~ 0.05%×p ⊕ 2%	σp/p ~ 0.1%×p ⊕ 0.5%
-3.0 to -2.5				
-2.5 to -2.0			σp/p ~ 0.11%×p ⊕ 0.4% (0-8 GeV/c) σp/p ~ 0.04%×p ⊕ 1% (8-30 GeV/c)	σp/p ~ 0.05%×p ⊕ 0.5%
-2.0 to -1.5				
-1.5 to -1.0				
-1.0 to -0.5		Barrel	σp/p ~ 0.11%×p ⊕ 0.2% (0-5 GeV/c) σp/p ~ 0.03%×p ⊕ 0.5% (5-30 GeV/c)	σp/p ~ 0.05%×p ⊕ 0.5%
-0.5 to 0				
0 to 0.5				
0.5 to 1.0				
1.0 to 1.5		Forward Detector	σp/p ~ 0.11%×p ⊕ 0.4% (0-8 GeV/c) σp/p ~ 0.04%×p ⊕ 1% (8-30 GeV/c)	σp/p ~ 0.05%×p ⊕ 1%
1.5 to 2.0				
2.0 to 2.5				
2.5 to 3.0			σp/p ~ 0.05%×p ⊕ 2%	σp/p ~ 0.1%×p ⊕ 2%
3.0 to 3.5				

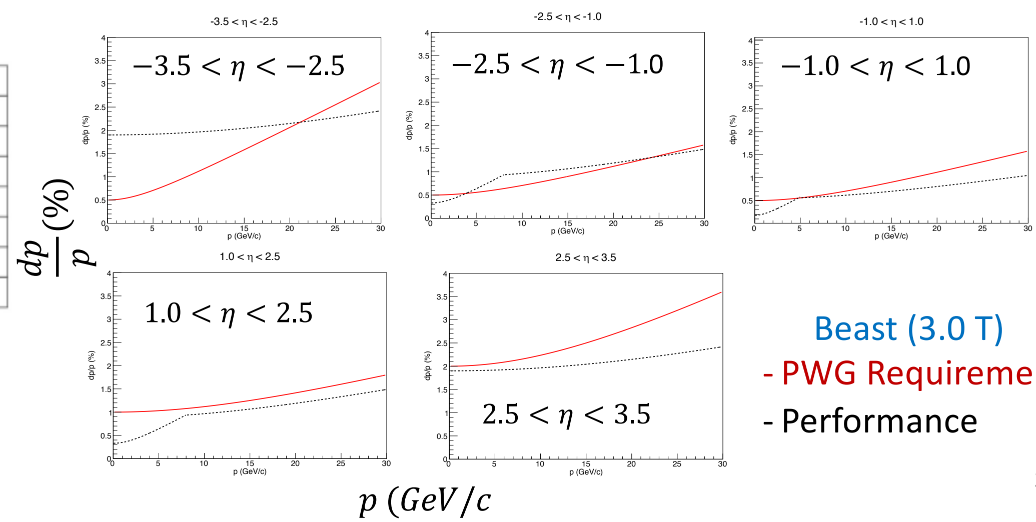
Disk	z position	Inner radius	Outer radius
Disk 1	220 mm	36.4 mm	71.3 mm
Disk 2	430 mm	36.4 mm	139.4 mm
Disk 3	586 mm	36.4 mm	190.0 mm
Disk 4	742 mm	49.9 mm	190.0 mm
Disk 5	898 mm	66.7 mm	190.0 mm
Disk 6	1054 mm	83.5 mm	190.0 mm
Disk 7	1210 mm	99.3 mm	190.0 mm

(b) Disk region

Layer	Length	Radial position
Layer 1	420 mm	36.4 mm
Layer 2	420 mm	44.5 mm
Layer 3	420 mm	52.6 mm
Layer 4	840 mm	133.8 mm
Layer 5	840 mm	180.0 mm
TPC start	2110 mm	200.0 mm
TPC end	2110 mm	780.0 mm

(a) Barrel region

Hybrid (Si+TPC) @ 3T

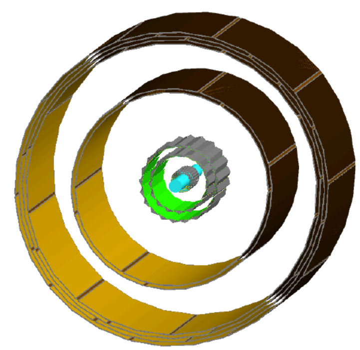


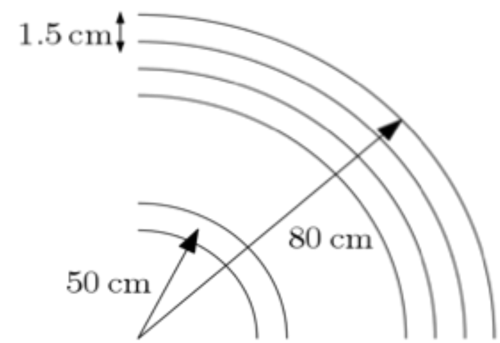
Beast (3.0 T)
- PWG Requirements
- Performance

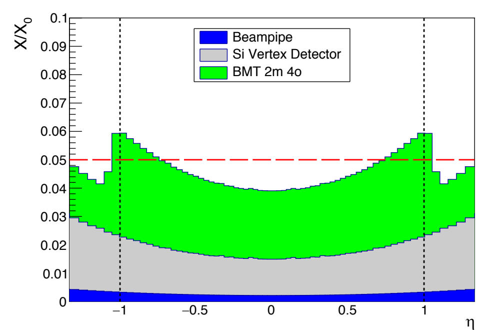
Yellow Report Studies

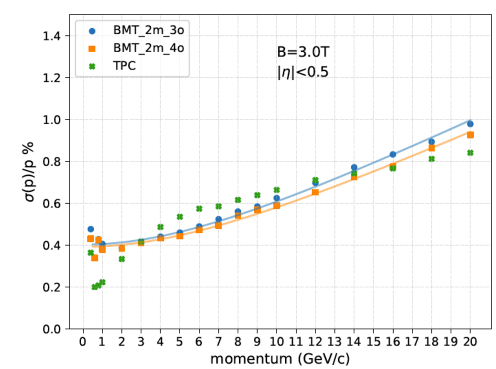
Hybrid detector: silicon vertex detector + gaseous barrel tracker

- Micromegas tiles arranged in concentric cylindrical layers
- Each tile is about 50cm wide
- Technology based on CLAS12 Micromegas, with 2D readout
- Assumed resolutions: 150 µm both in rϕ and z directions
- Six layers tracker well within material budget requirements
- Several layer geometries tested
- **Comparable to TPC momentum performance**





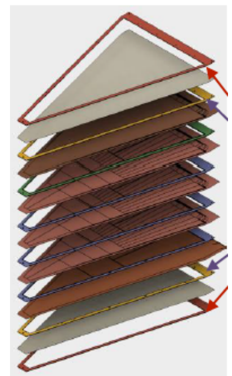


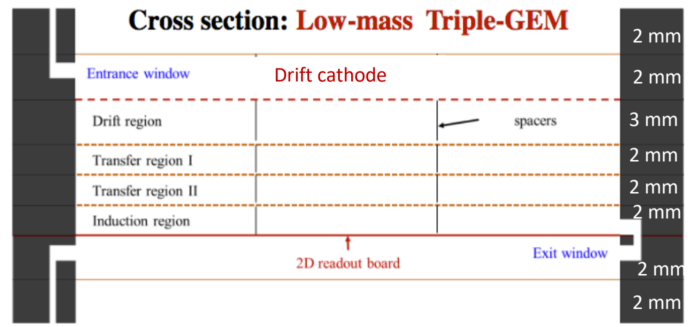


MPGD End Cap Trackers

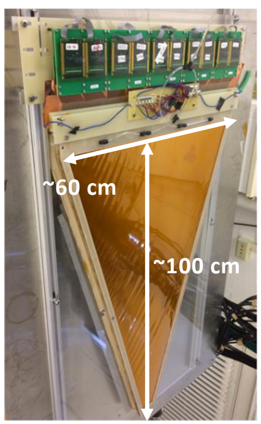
- Combine concepts of various systems
- Help with 3.5 < |eta| < 1.5
- Located at both electron and hadron end caps
- GEM tracker placed in front of EM cal in electron direction to serve as hit locator
- GEM technology very mature used in many NP and HEP exp.
- Low mass ~0.4% X/X0 in active area
- Large area coverage: ~100 cm (can be larger) x 60 cm
- Good special resolution: $50\ \mu m\ (r\phi) \times 250\ \mu m\ (r)$

UVa prototype cross section

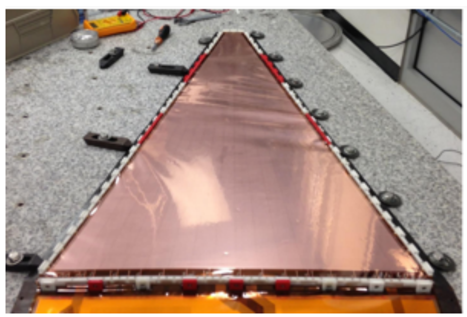


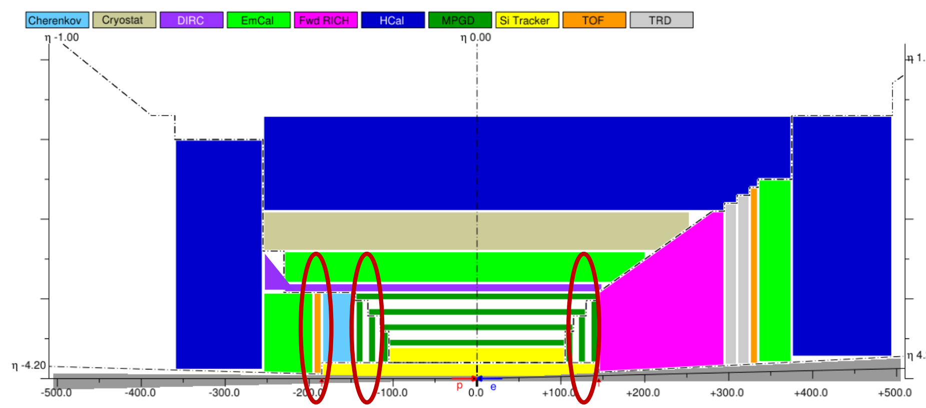


UVa Prototype



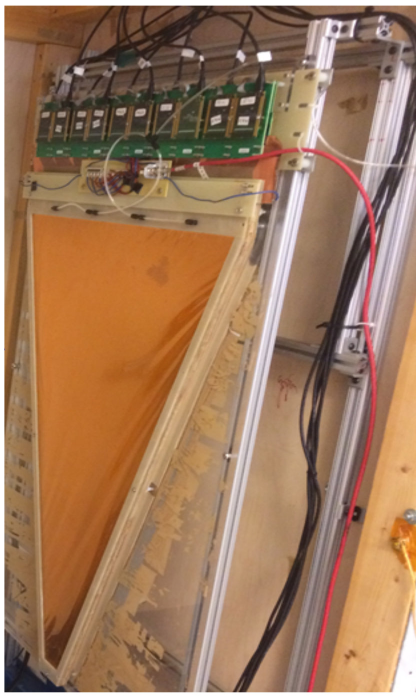
FIT Prototype

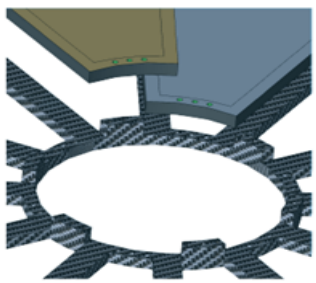




GEM End Cap Trackers

- Light weight CF support material
- All serveries outside EIC acceptance
- Need to implement CF support wheel and serveries is ongoing
- Can we reduce material budget more? …

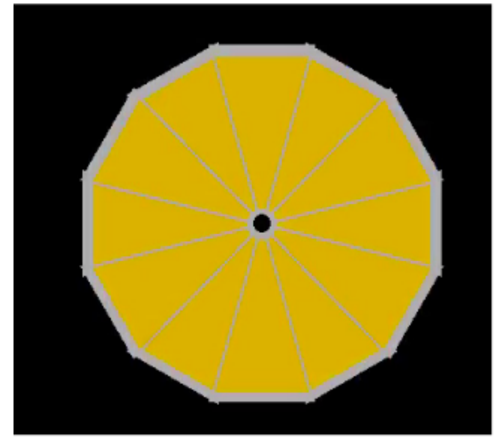


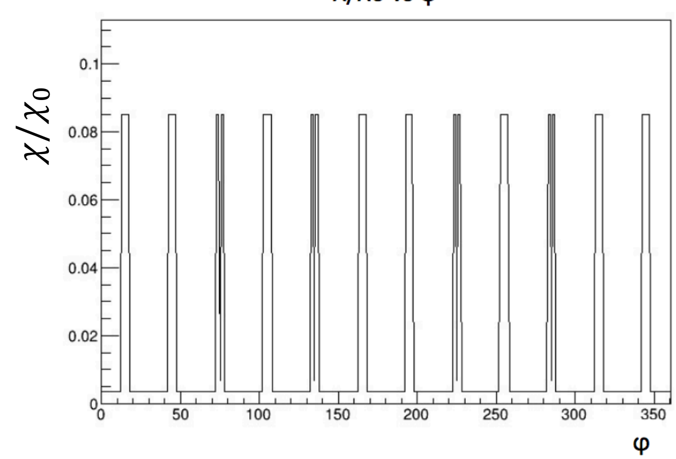


Detector installation

Wheel support frame

Carbon Fiber Support Structure

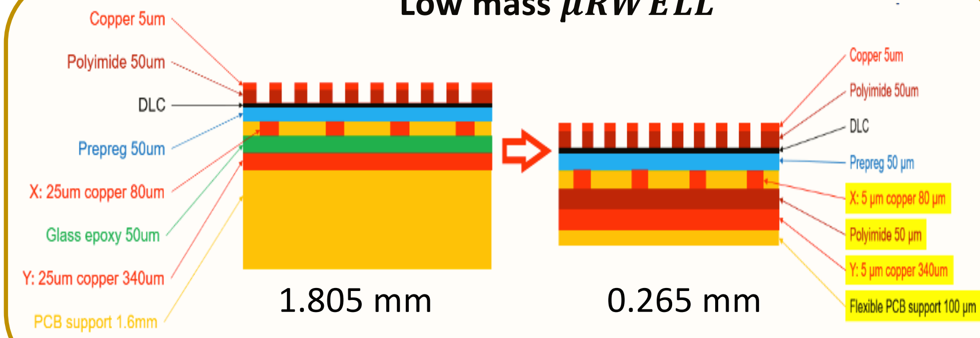


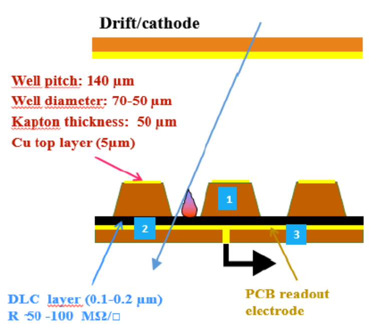


μRWell End Cap Trackers

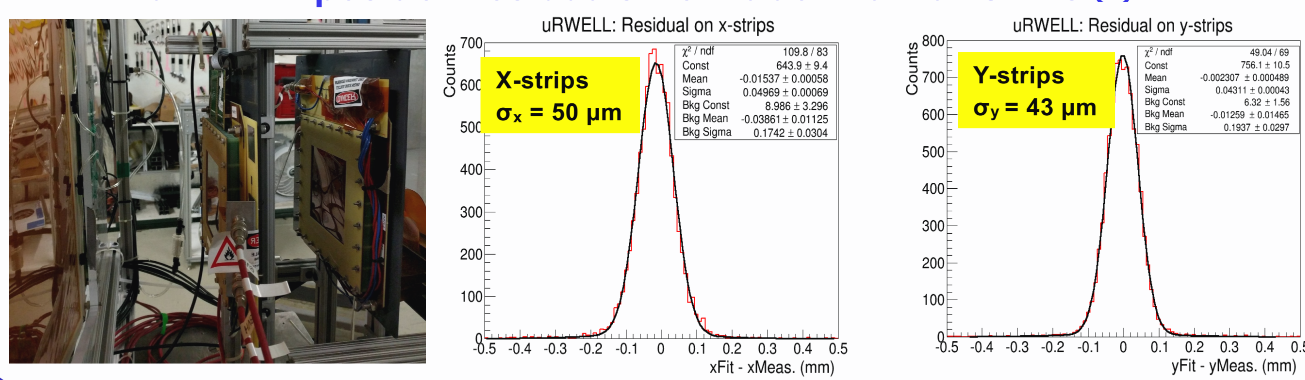
- Technology not as mature as GEM
- Lots of R&D has been done and demonstrated promising substitute for GEM
- Better construction
  - Less technical assembly complications
  - Cuts assembly time/module by days -> save in cost
- Low mass in active area
- Large area coverage: ~100 cm (can be larger) x 60 cm
- Good special resolution: Similar to GEM
- Active R&D on large-area $\mu RWELL$ from JLab
- Fall back option: GEM

Low mass $\mu RWELL$





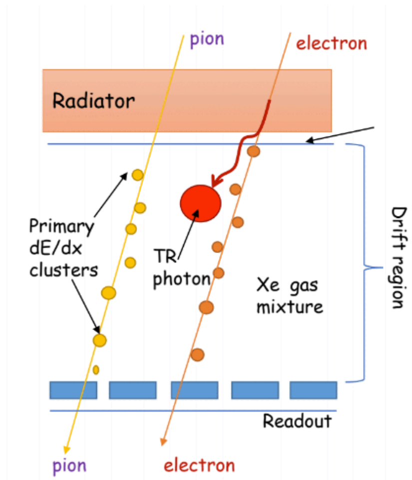
uRWELL position residuals from track fit with GEMs @FNAL



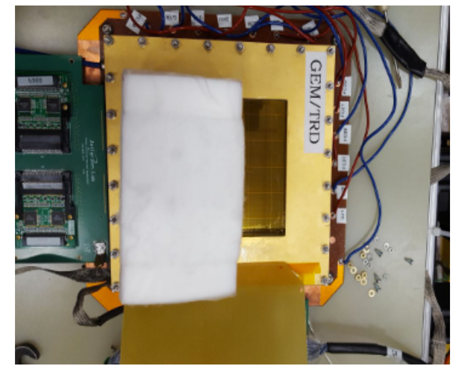
(UVa)

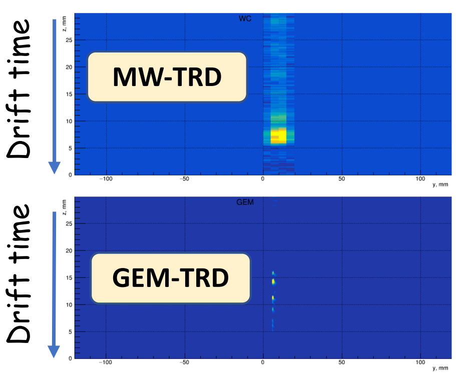
GEM TRD

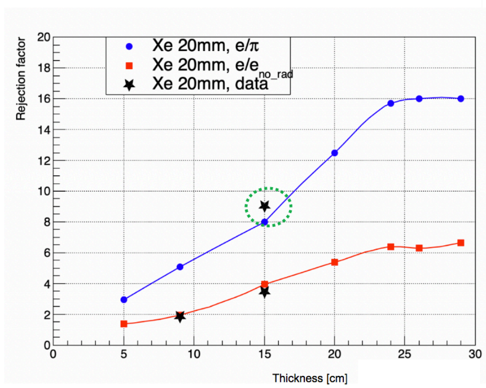
- GEM based TRD PID capabilities to GEM tracking precision
- Located behind RICH in hadron going direction
- Low mass (for TRD)
  - ~0.4% GEM + ~0.1% Xe gas + ~1.5% radiator (X/X0)
- Large area coverage: ~100 cm (can be larger) x 60 cm
- Good special resolution and e/π discrimination
- Fall back option: GEM, but loose PID

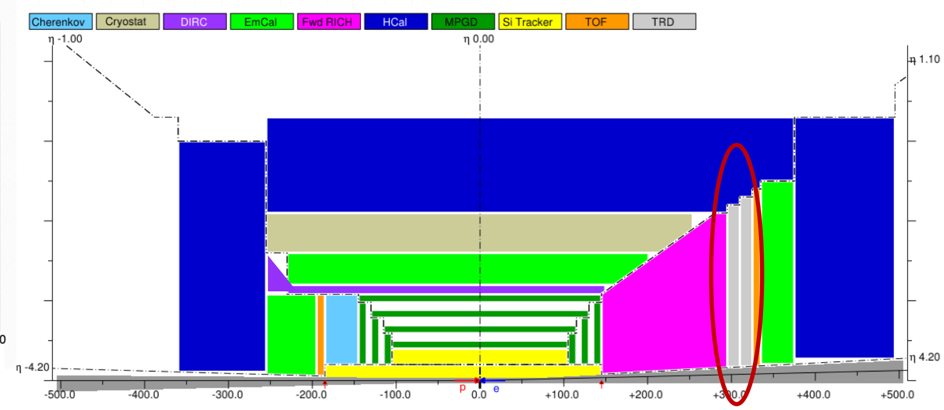


(eRD22)





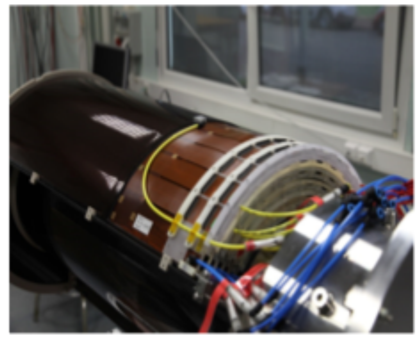


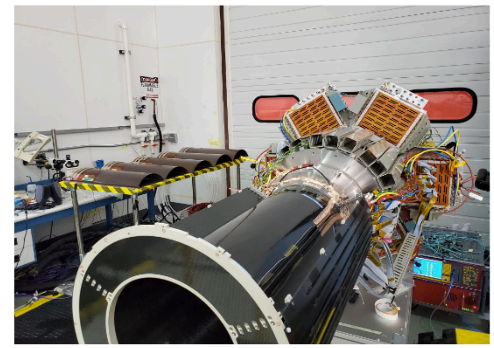


Micromegas Barrel Tracker

- Micromegas barrel layers in barrel region
- Technology very mature used in many NP and HEP exp.
- Cylindrical Micromegas used in JLab CLASS 12 exp.
- Low mass
- Large area coverage:
- Good special resolution: $\sim 150\mu m$ (z) and $150\mu m$ $(r\phi)$

CLAS12 BMT





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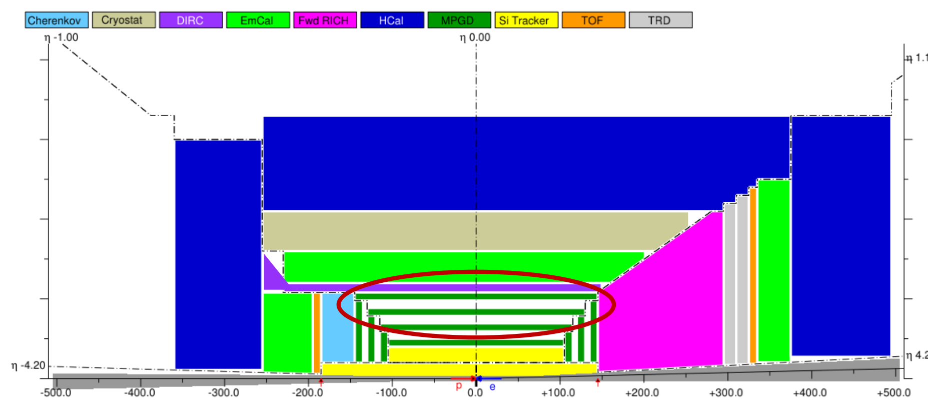
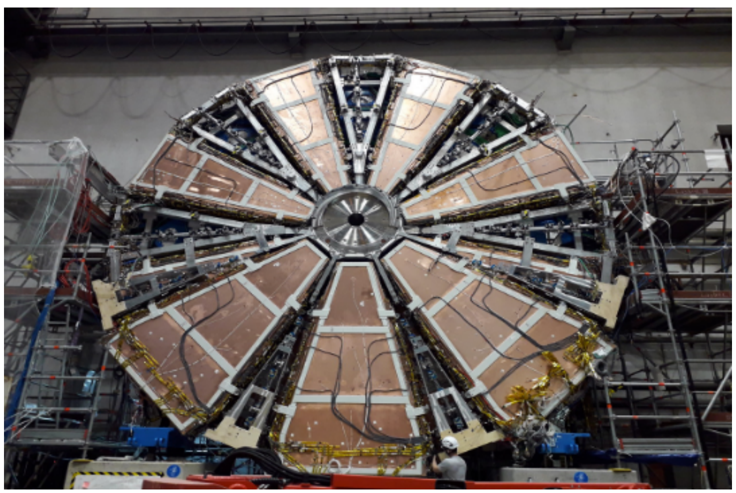
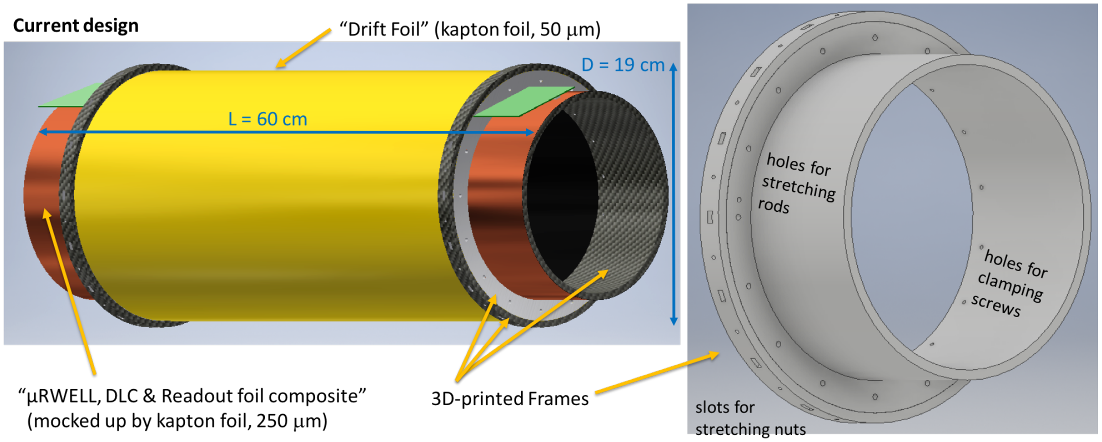


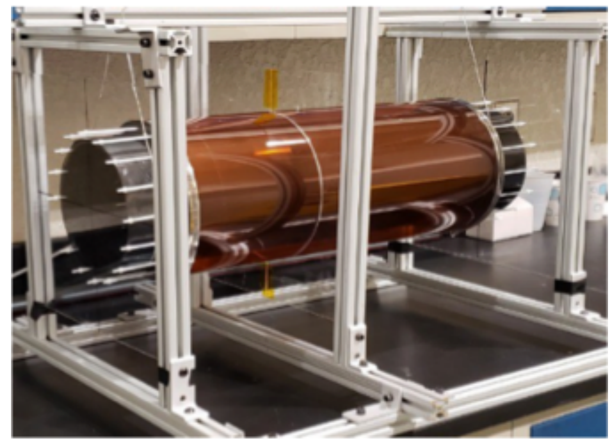


ATLAS

μRWell Barrel Tracker

- $\mu RWell$ barrel layers in barrel region
- Technology still needs R&D, has not been used in NP or HEP exp.
- Low mass
- Large area coverage: Like GEM limited in raw material width of 60 cm
- Good special resolution: $\sim 150\mu m$ (z) and $150\mu m$ $(r\phi)$





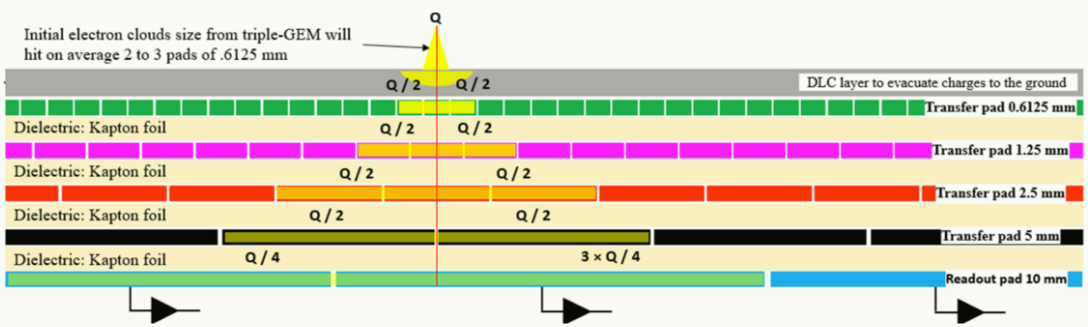
Cylindrical $\mu RWELL$ mock-up (FIT)

MPGD Readout

- MPGD detectors cover large area → lots of readout channels needed for good spatial resolution.
- Dedicated R&D efforts:
  - Readout patterns
  - Capacitive-sharing large-pad readout

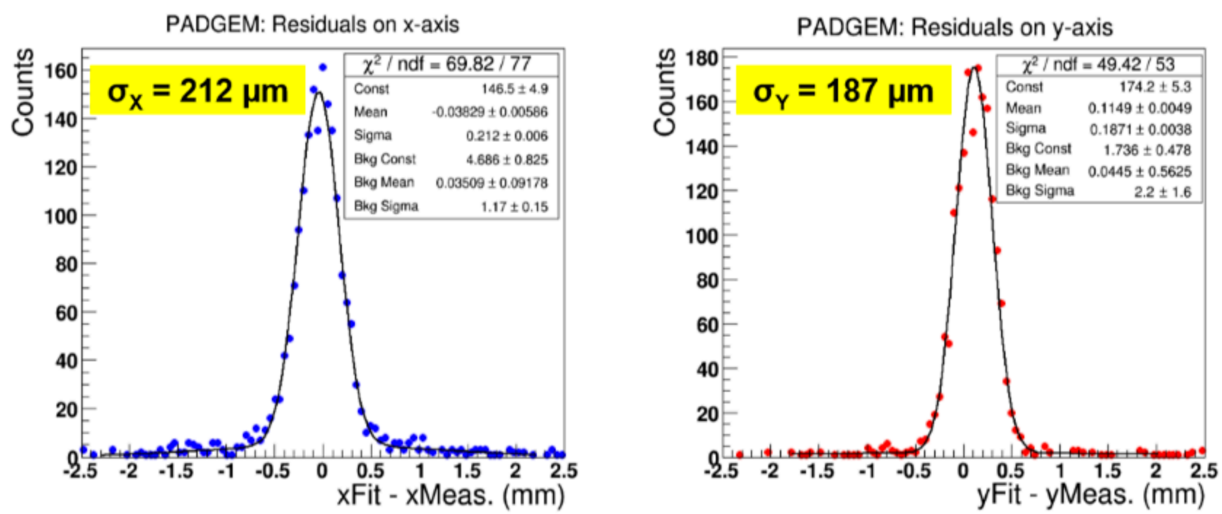
Principle of capacitive-sharing large-pad readout

- Vertical stack of pad layers: charge transfers from layer to layer via capacitive coupling
- Pad geometry and arrangement allows for excellent resolution with large readout pads
- Low cost, large area capability and applicable to many technologies: MPGDs, GEM-RICH, LAPPD…
- Concept can be expended to strip readout



MPGD Readout

- 1 cm^2 pad prototype: Resolution better than 190 μm
- Next studies will optimize pitch vs. resolution, and carry concept over to strip readouts



UVa's beam test results for large pad readout

R&D Time Line

More details: https://wiki.bnl.gov/conferences/index.php/March_2021

GEM End Cap Trackers

TASK	**R&D on Large & low-mass GEMs for EIC End Cap Trackers** 1 - UVa prototype with U-V strips readout 2 - FIT prototype with carbon Fiber frames & zigzag strip readout
YEAR	detailed tasks - **(date are expected milestone)**
2021	**UVa prototype**
	Jun 2021: Test performance in beam test at FNAL
	Dec 2021: Finalize FNAL test beam data analysis
	FIT prototype
	Jun 2021: Complete the refurbishment & test performance at FNAL
	Dec 2021: Finalize FNAL test beam data analysis
2022	**UVa GEM prototype & FIT GEM prototype**
	Jul 2022: Publication of beam test results in peer-reviewed journal
	Completion of the generic large, low-mass GEM R&D program

$\mu RWELL$ End Cap Trackers

TASK	**R&D on Large & low-mass µRWELL for End cap Trackers** 1-) Large & low-mass µRWELL detectors 2-) Development of high performance capacitive-sharing anode readout
YEAR	detailed tasks - **(date are expected milestone)**
2021	**Large µRWELL**
	Dec 2021: Design of large prototype (synergy with prototyping at Jlab)
	Capacitive-sharing readout
	Jun 2021: Study various small prototypes in beam test FNAL
	Dec 2021: Analyse beam test results
	Dec 2021: Optimization & design of large U-V strip capacitive-sharing readout
2022	Jun 2022: construction of large trapezoidal µRWELL with U-V strip readout
	Jul 2022: Test performances of large µRWELL in beam test @ FNAL
	Dec 2022: Analyse beam test results
2023	July 2023: Publication of test beam results on large µRWELL in peer-review paper
	Dec 2023: Complete the R&D on large µRWELL for EIC End Cap Tracker

Currently at beam test

R&D Time Line

More details: https://wiki.bnl.gov/conferences/index.php/March_2021

Micromegas Barrel

Year	Barrel Micromegas Tracker
2021	**Ultra light:** - Goal: from 0.5% X0 (Clas12) to 0.05% X0 with this R&D - Full simulation of ultra light MM design - Design and construction of stretch bulked Kapton demonstrator (no FR4) **2D readout design studies:** - Procurement of large pads readout PCBs - Finalize 2D zigzag readout pattern studies
2022	**Ultra light:** - Aluminium based strips - Thin aluminium mesh manufacturing with laser ablation **Readout studies** - Bulking and test of large pads readout **Cylindrical MM:** - Design of MM tracker support structure within EIC detector
2023	**Ultra light:** - Prototype construction **Cylindrical MM:** - Final prototype with 2D zigzag readout

$\mu RWELL$ Barrel

TASK	Development of Cylindrical uRWELL
YEAR	detailed tasks
2021	Completion of mechanical mockup
	Procure components and begin building small-radius functional cylindrical uRWELL
2022	Complete construction of small cylindrical prototype
	Commission small cylindrical prototype
	Perform beam test of small cylindrical prototype
	Analyse beam test results
	Design and procure materials for full-size mechanical mock-up
2023	Finish analyzing beam test results
	Build full-size mechanical mock-up and evaluate
	Design and build large-radius cylindrical uRWELL prototype
2024	Complete large cylindrical uRWELL prototype
	Perform beam test of large cylindrical uRWELL prototype
2025	Complete analysis from large cylindrical uRWLL prototype test beam
	Begin design of production detectors

R&D Time Line

More details: https://wiki.bnl.gov/conferences/index.php/March_2021

GEM TRD

Generic R&D:

- Test of **different readout architecture** (strips, pad,zig-zag) to minimize the noise level, number of readout channels, and spatial resolution. This would require use to build several small(10x10 cm2) prototypes with different readouts options and test them at JLAB and Fermilab.
- Tests of a new **streaming readout** architecture hardware (SRO125) and ML-FPGA –based data reduction concepts.
- Test of different **TR-radiators**

Targeted R&D:

- Build and test **large-size modules** in order be able to workout possible issues: like noise, gain-uniformity, drift-time issues, HV stability, etc. A field/gas-cage needs to be developed and optimized for TRD applications.
- **Test beams** at Fermilab with electron and pion beams (once per year)
- Design and development of a **recirculation gas** system to purify, distribute, circulate, and recover the gas (in collaboration with other labs/universities).
- Development of final design specifications for the **streaming readout architecture** as input to a coordinated ASIC design program