Application of Micro Pattern Gas Detector @ JLAB

Kondo Gnanvo

University of Virginia, Charlottesville, VA

MPGD Snowmass 2021 - Bi-weekly Meeting - July 10, 2020

Outline

- GEM Trackers in High Rate Environment in Hall A JLab
- MPGDs for various Hall B Experimental Programs
- MPGD development for the Future Detector Upgrade @JLab

GEM Trackers in High Rate Environment in Hall A JLab

Super Bigbite Spectrometer (SBS) in Hall A @ JLab

Nucleon form factors

- Encode electric and magnetic structure of the nucleon
- Parametrize the properties of the quark and gluon
- Limited neutron measurements in terms the Q^2 range and the precision
- Better access to relatively small G_E
- No recoil polarimetery measurement above Q^2 of 1.5 GeV^2

Electromagnetic current density of nucleon:

$$\mathcal{J} = e\bar{N}(p')\left[\gamma^\mu F_1(Q^2) + \frac{i\sigma^{\mu\nu}q_\nu}{2M}F_2(Q^2)\right]N(p)$$

$$G_E = F_1 - \tau F_2$$
$$G_M = F_1 + F_2$$

In High Q^2 range:

→ G_E measurement will sensitive to up and down quark distributions in quark core

→ Insight to the complete set of form factors in the region with small pion cloud contributions

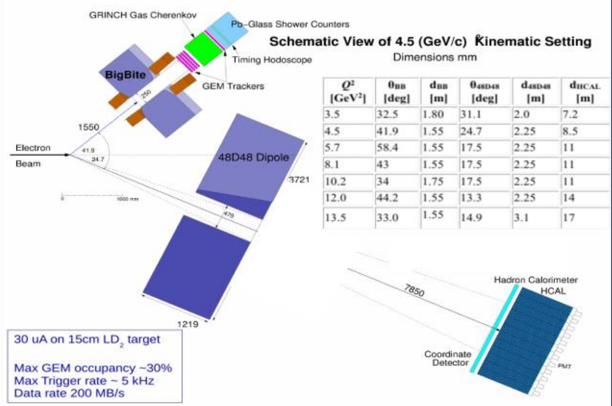
The Super-BigBite Spectrometer (SBS) in Jlab's Hall A will measure the G_E to high Q^2 (>10 GeV^2) using high luminosity + open geometry + GEM detectors

→ Allows for flavor decomposition to distance scales deep inside the nucleon

SBS GEM trackers:

- High counting rate (~ **500 kHz/cm²**) expected at highest luminosity of **10^{39}** electrons/s-nucleon/cm²
- Large acceptance & small field integral magnet ⇨ Spatial resolution **(70 µm)**
- Low cost for large tracking system when compared to silicon trackers and high rate compared to Drift chambers

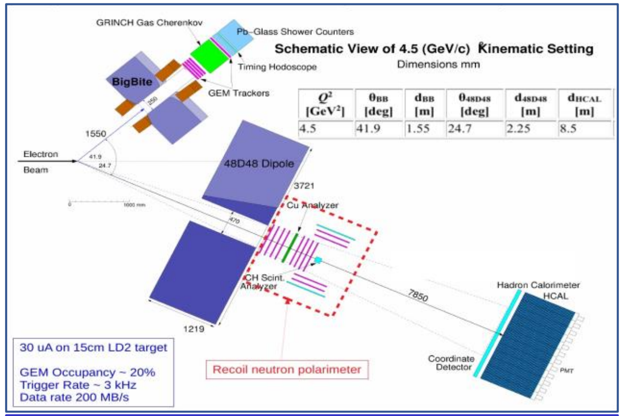
GEn & GMn: Neutron Form Factor @ high Q^2



Q^2 [GeV²]	θ_{BB} [deg]	d_{BB} [m]	θ_{48D48} [deg]	d_{48D48} [m]	d_{HCAL} [m]
3.5	32.5	1.80	31.1	2.0	7.2
4.5	41.9	1.55	24.7	2.25	8.5
5.7	58.4	1.55	17.5	2.25	11
8.1	43	1.55	17.5	2.25	11
10.2	34	1.75	17.5	2.25	11
12.0	44.2	1.55	13.3	2.25	14
13.5	33.0	1.55	14.9	3.1	17

E12-09-019: measurement of G^n_M/G^p_M up to Q^2=13.5 GeV^2 polarized deuterium target.
E12-09-016: measurement of G^n_E/G^n_M up to Q^2=10 GeV^2 using a polarized ^{3}He target.

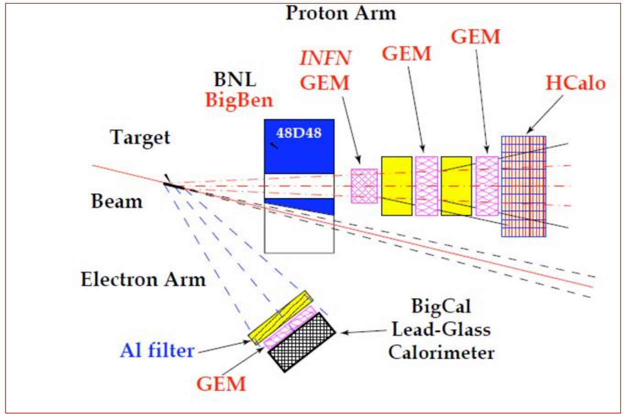
GEn-RP: Neutron Form Factor



Q^2 [GeV²]	θ_{BB} [deg]	d_{BB} [m]	θ_{48D48} [deg]	d_{48D48} [m]	d_{HCAL} [m]
4.5	41.9	1.55	24.7	2.25	8.5

E12-17-004: measurement of G^n_E/G^n_M up to Q^2=4.5 GeV^2 polarized deuterium target

GEp (5): Proton Form Factor @ high Q^2

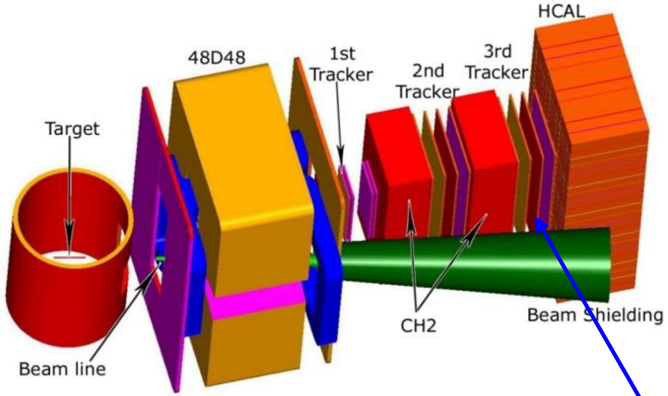


E12-07-109: measurement of G^p_E/G^p_M up to Q^2=12 GeV^2 using a target of liquid hydrogen

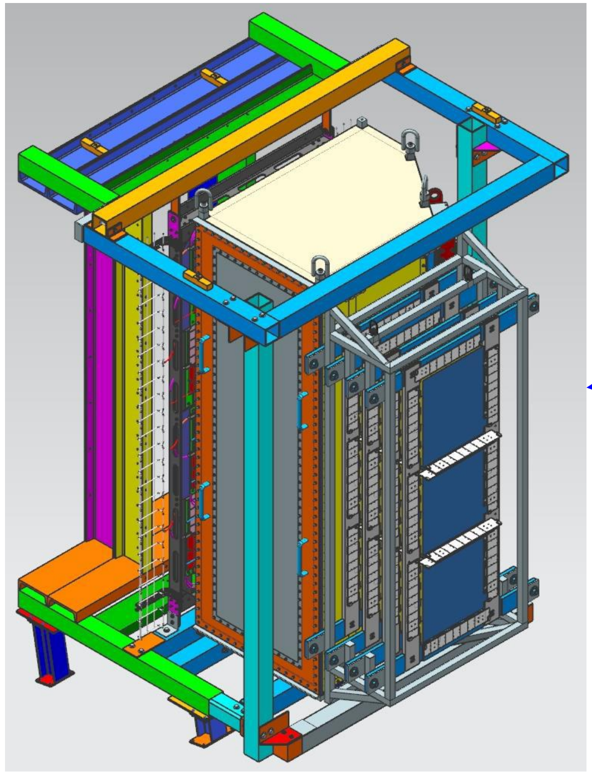
SBS GEM Trackers

- **INFN GEM layers: Main trackers in Bigbite and Super Bigbite Spectrometers**
  - ⇨ 6 GEM layers, active area of 150 × 40 cm^2
  - ⇨ **Completed production:** 18 modules (+3 spares)
- **UVa GEM layers: Polarimeter GEMs of the recoil protons**
  - ⇨ 11 layers, active area of 200 × 60 cm^2
  - ⇨ **Completed production:** 44 modules (+ 4 spares)

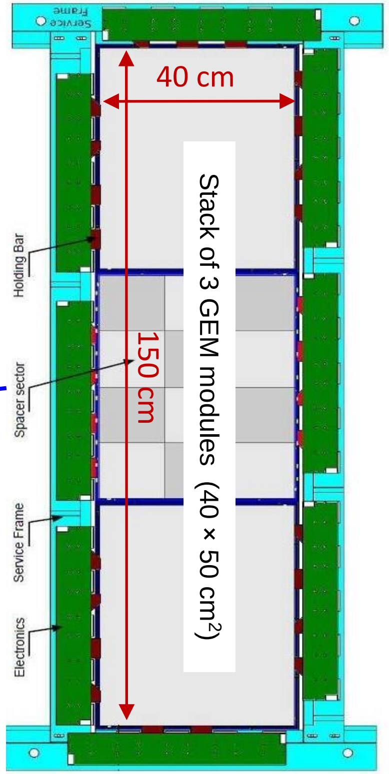
GEp(5): Super Bigbite Spectrometer – Hadron arm



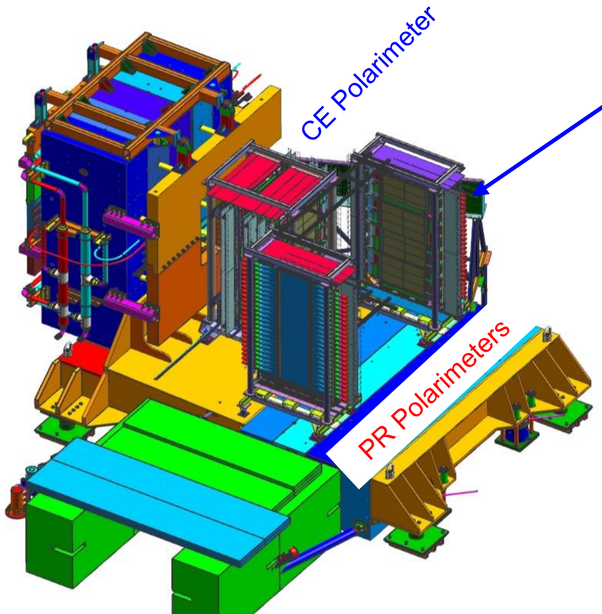
GMn: Bigbite Spectrometer – Electron arm



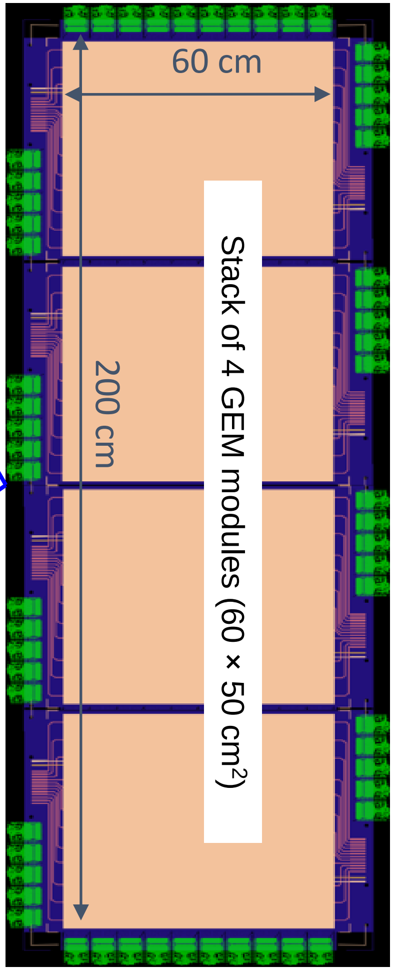
6 INFN GEM layers



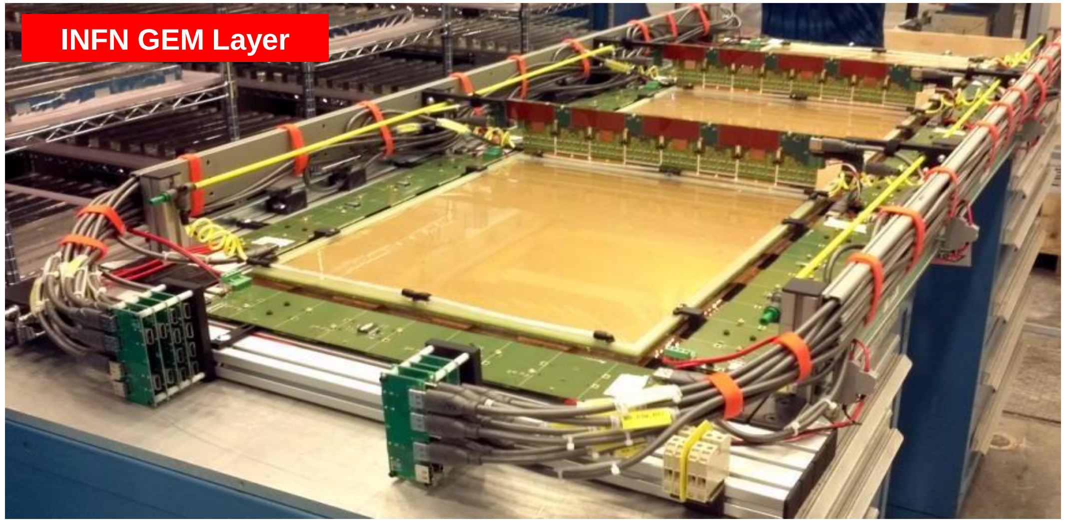
GEn-RP: Super Bigbite Spectrometer – Hadron arm

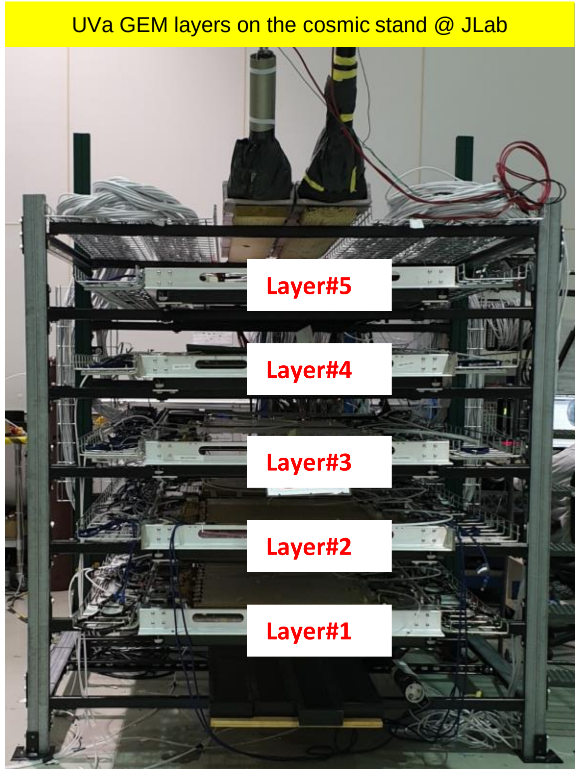


11 UVa GEM layers

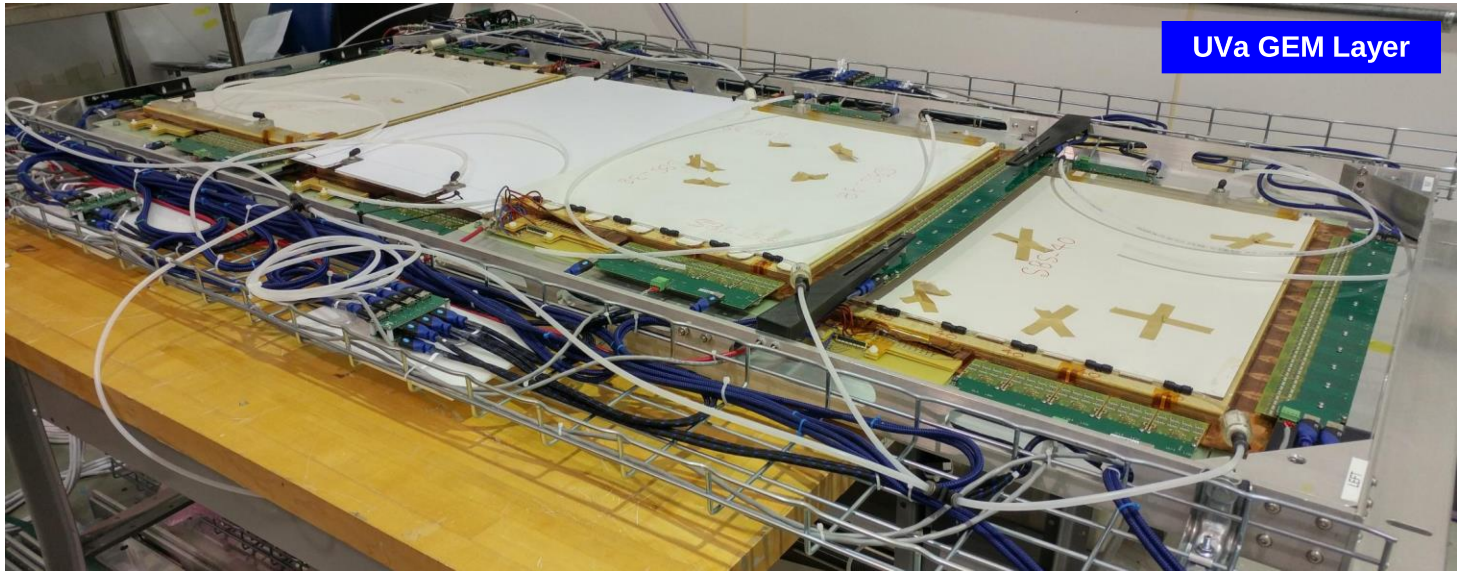


SBS GEM Trackers





- Production of All GEM modules (INFN and UVa) completed
- Assembly of 5 INFN layers & 6 UVa layers also completed
- 2 cosmic stand at JLab for the commissioning of the GEM layers
- Ongoing study of the detector performances ⇨ Efficiency > 95% for most modules
  - Modules with lower efficiency ⇨ Increase the HV
- First SBS experiment GMn scheduled to run Spring 2021



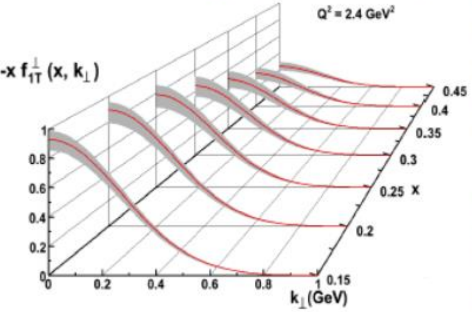
Solenoid Intensity Device (SoLID) in Hall A @ JLab

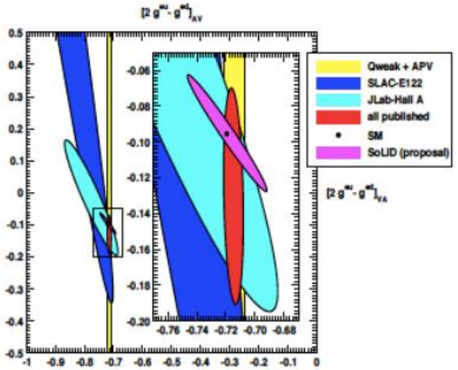
SoLID Physics Overview QCD at the intensity frontier

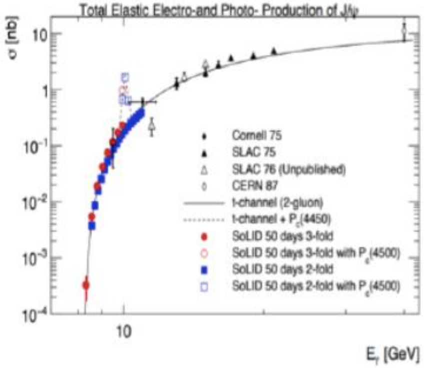
- **Full exploitation of JLab 12 GeV Upgrade to maximize scientific return**

A Large Acceptance Detector AND Can Handle High Luminosity (10^{37}-10^{39})

- SIDIS - reaching ultimate precision for tomography of the nucleon (E12-10-006, E12-11-007, E12-11-108)
- PVDIS in high-x region - providing sensitivity to new physics at 10-20 TeV (E12-10-007)
- Threshold J/ψ - probing strong color fields in the nucleon and the origin of its mass (trace anomaly) (E12-12-006)







- **2015 LRP recommendation IV**
  - We recommend increasing investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories – **SoLID – mid-scale project**

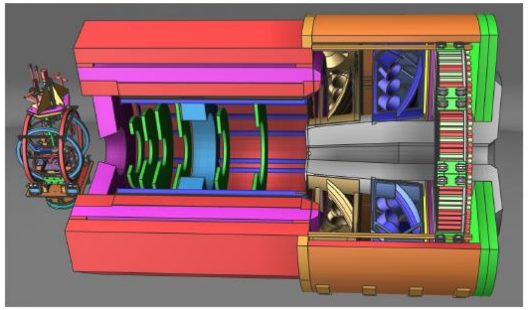
SoLID Jefferson Lab 3

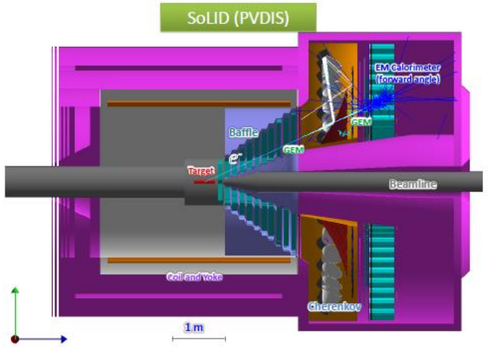
SoLID Apparatus

Requirements are Challenging

- High Luminosity (10^{37}-10^{39})
- High data rate
- High background
- Low systematics
- High Radiation
- Large scale (Like RHIC)
- New Technologies
  - GEM's
  - Shashlyk Ecal
  - Pipeline DAQ

Polarized ^{3}He (``neutron") @ SoLID





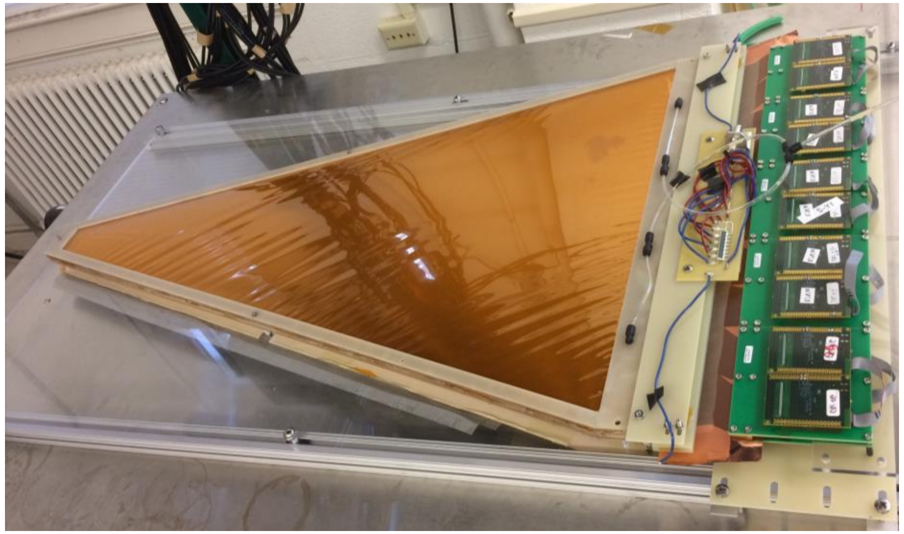
Courtsey Paul Souder – Jlab User Grooup Meeting 2020

SoLID GEM Trackers: Scope and Timeline of the project

University of Virginia

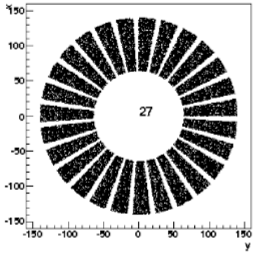
Jefferson Lab

GEM R&D: Synergy with EIC GEMs



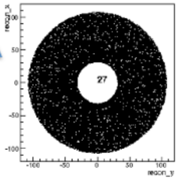
- Six locations instrumented with GEM:
- PVDIS GEM modules can be re-arranged to make all chamber layers for SIDIS. – move the PVDIS modules closer to the axis so that they are overlapping with each other

Plane	Z (cm)	R_I (cm)	R_O (cm)	Active area (m^2)	# of channels
1	-175	36	87	2.0	24 k
2	-150	21	98	2.9	30 k
3	-119	25	112	3.7	33 k
4	-68	32	135	5.4	28 k
5	5	42	100	2.6	20 k
6	92	55	123	3.8	26 k
total:				~20.4	~ 161 k



PVDIS

SIDIS



- More than enough electronic channels from PVDIS setup.
- The two configurations will work well with no need for new GEM or electronics fabrication.

Time Line for engineering design and prototyping

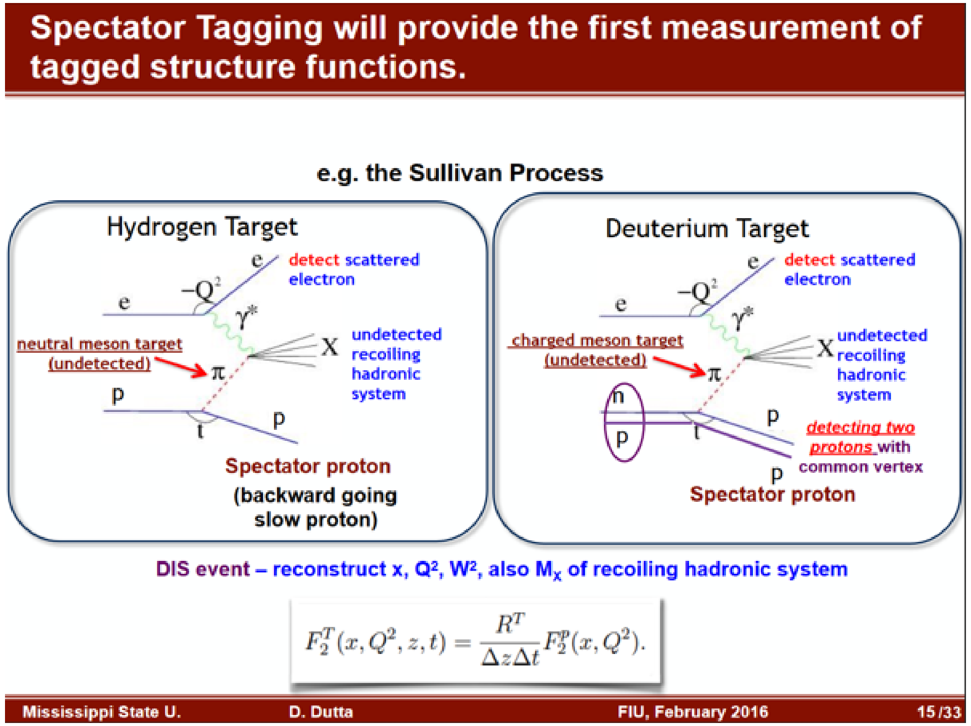
	Task	FY21				FY22			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1.1.4	**GEM Design and Prototyping**								
1.1.4.1	**GEM Module design**								
1.1.4.1.1	GEM Module component design and prototyping								
1.1.4.1.1.1	GEM Module component design for level 1 prototypes								
1.1.4.1.1.2	GEM Module component procument for level 1 prototypes								
1.1.4.1.1.3	GEM Module level 1 prototype fabrication and testing								
1.1.4.1.1.4	GEM Module component design for level 2 prototypes								
1.1.4.1.1.5	GEM Module component procument for level 2 prototypes								
1.1.4.1.1.6	GEM Module level 2 prototype fabrication and testing								
1.1.4.1.1.6	GEM Module final engineering design								
1.1.4.1.2	GEM fabrication tooling design and prototyping								
1.1.4.1.1.1	GEM fabrication tooling: level 1 design and fabrication								
1.1.4.1.1.2	GEM fabrication tooling: level 2 design and fabrication								
1.1.4.1.1.3	GEM fabrication tooling: final engineering design								
1.1.4.2	**GEM Readout design**								
1.1.4.2.1	VMM electronics level 1 prototype design, fabrirication								
1.1.4.2.2	VMM electronics level 1 prototype testing								
1.1.4.2.3	VMM electronics level 2 prototype design, fabrirication								
1.1.4.2.4	VMM electronics level 2 prototype testing								
1.1.4.2.5	VMM electronics final engineering design								
1.1.4.5	**GEM mechanical support design**								
1.1.4.5.1	GEM mechanical support wheels design								
1.1.4.5.2	GEM mechanical support cable support design								
1.1.4.5.3	GEM mechanical support: 1 sector prototype fabrication								
1.1.4.5.4	GEM mechanical support final engineering design								
1.1.4.6	Transport and travel								
1.1.4.8	Management								

Tagged Deep Inelastic Scattering (TDIS) in Hall A @ JLab

Probe mesonic content of the nucleon structure function via the Sullivan process N(e,e'N')X through Tagged Deep Inelastic Scattering (TDIS)

C12-15-006: Measurement of Pion Structure Function

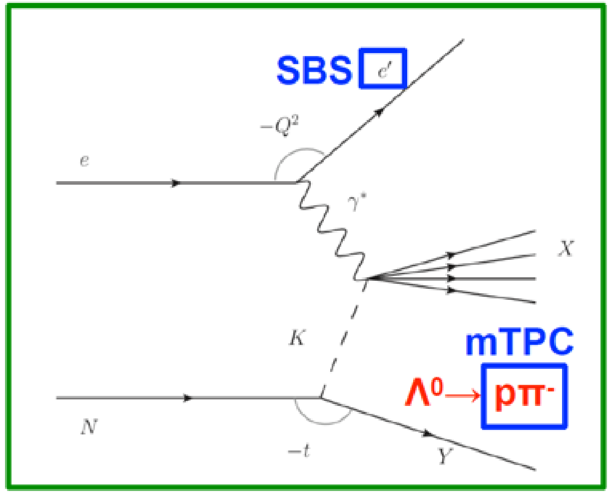
Spokespersons: *Cynthia Keppel, Bogdan Wojtsekhowski, Paul King, Dipangkar Dutta, John Annand, Jizie Zhang, Nilanga Liyanage*



High luminosity ($\mathcal{L} \sim 3 \times 10^{36}$ cm^{-2}/s) in Hall A at JLab

C12-15-006A: Kaon Structure Function

Spokespersons: *Tanja Horn(CUA), Rachel Montgomery(U. of Glasgow), Kijun Park(Jlab)*



- measurement of (DIS) cross section off meson cloud , while tagging low-momentum recoil spectator proton, to measure pion structure function.
- Tag proton and pion from lambda decay to to make the first ever measurement of Kaon structure function.
- Neutron DVCS with proton tagging.

TDIS Experimental Setup

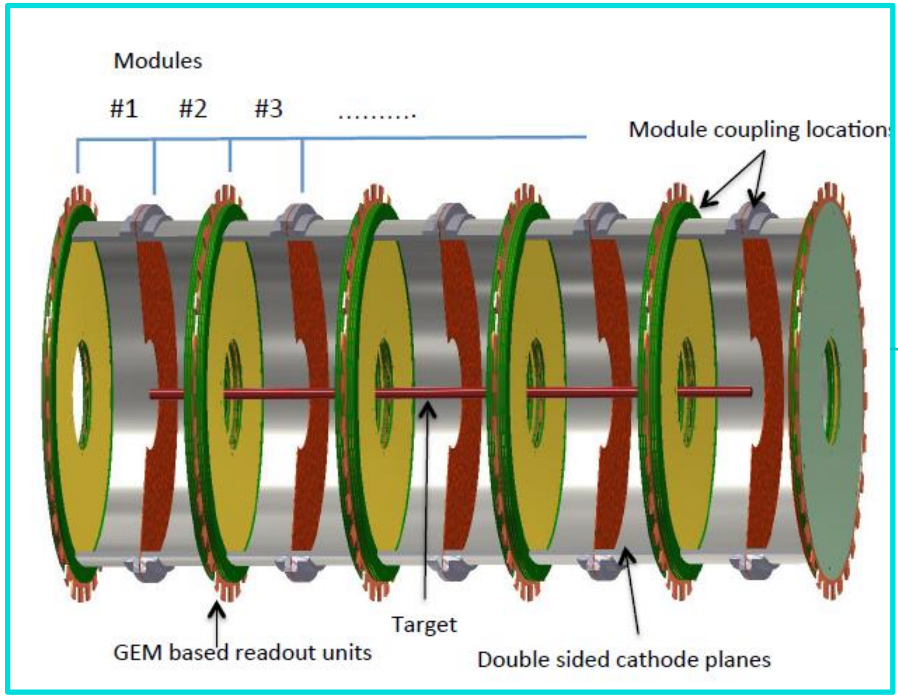
Recoil Proton Detector

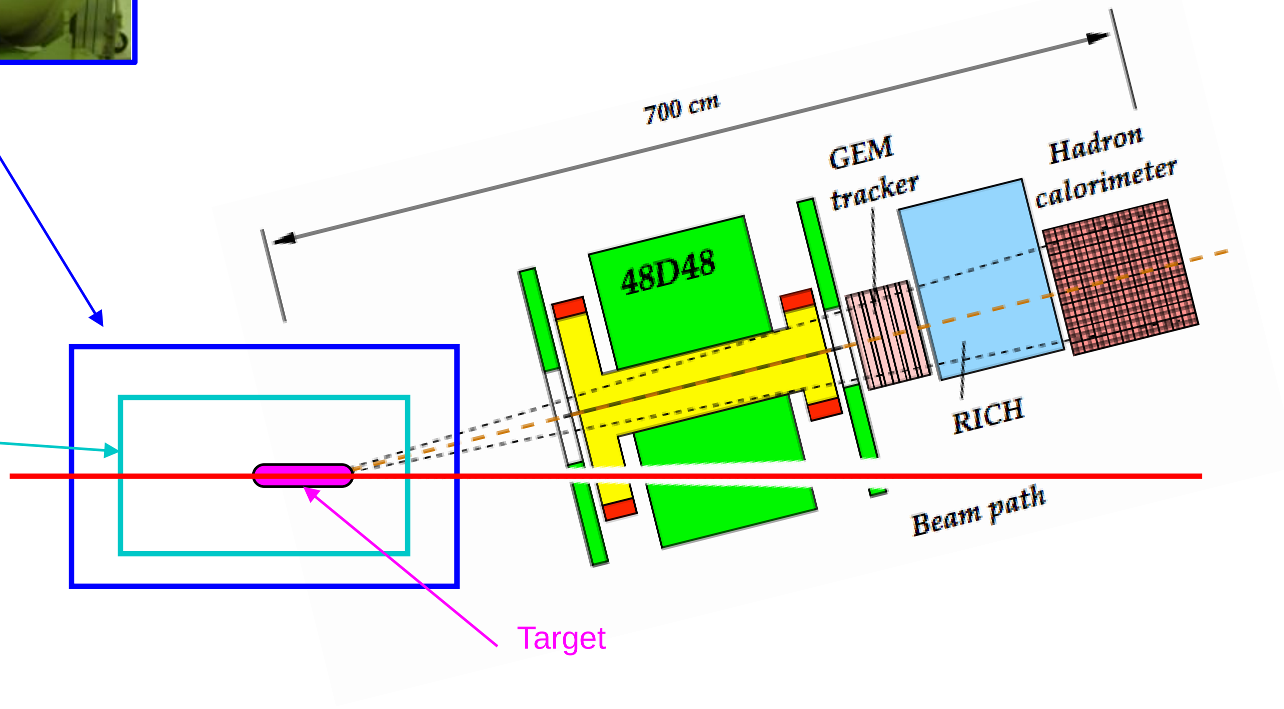
- **H2 or D2 Target:** Straw target (12 um Kapton cylinder with 10um Al end cap)
- **Proton Detector (mTPC) :** modular TPC consisting of stack of 10 sub modules
- **Solenoid:** 40 cm bore 5T super conductive solenoid magnet (UVa)

Electron Arm: SBS spectrometer

- **Tracker:** 5 SBS GEM planes
- **EM Calorimeter** (LAC from CLAS)
- **RICH** or threshold gas Cherenkov
- PID for trigger level 2: LAC + Cherenkov
- hadron calorimeter (HCAL) for quasi-elastic neutron calibration

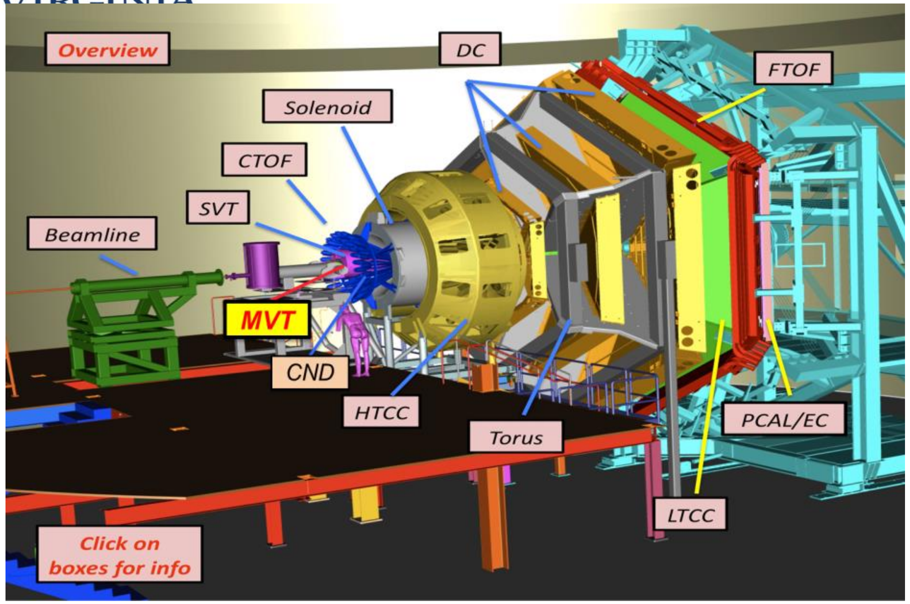
mTPC

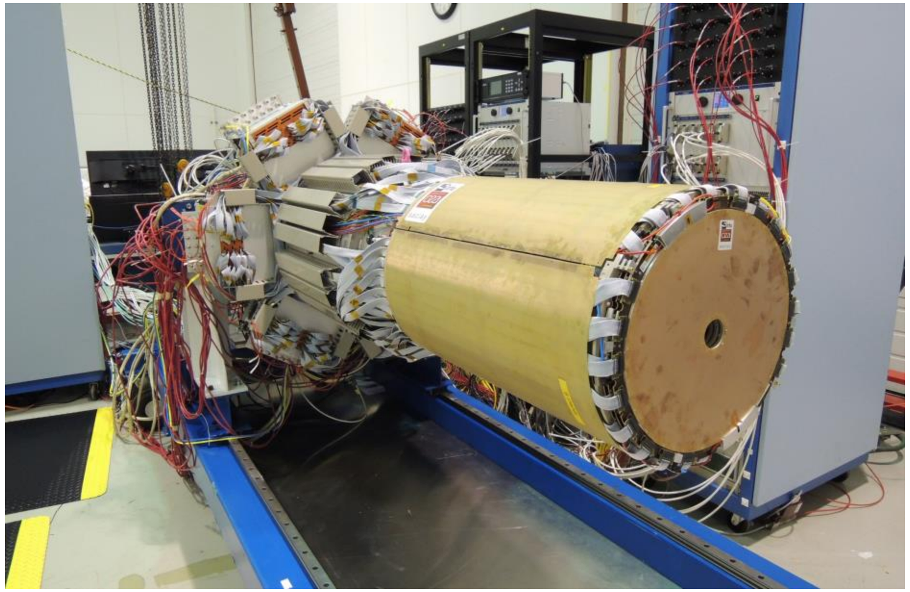




MPGDs for Hall B @ JLab

The CLAS12 Experiment in Hall B @ JLab





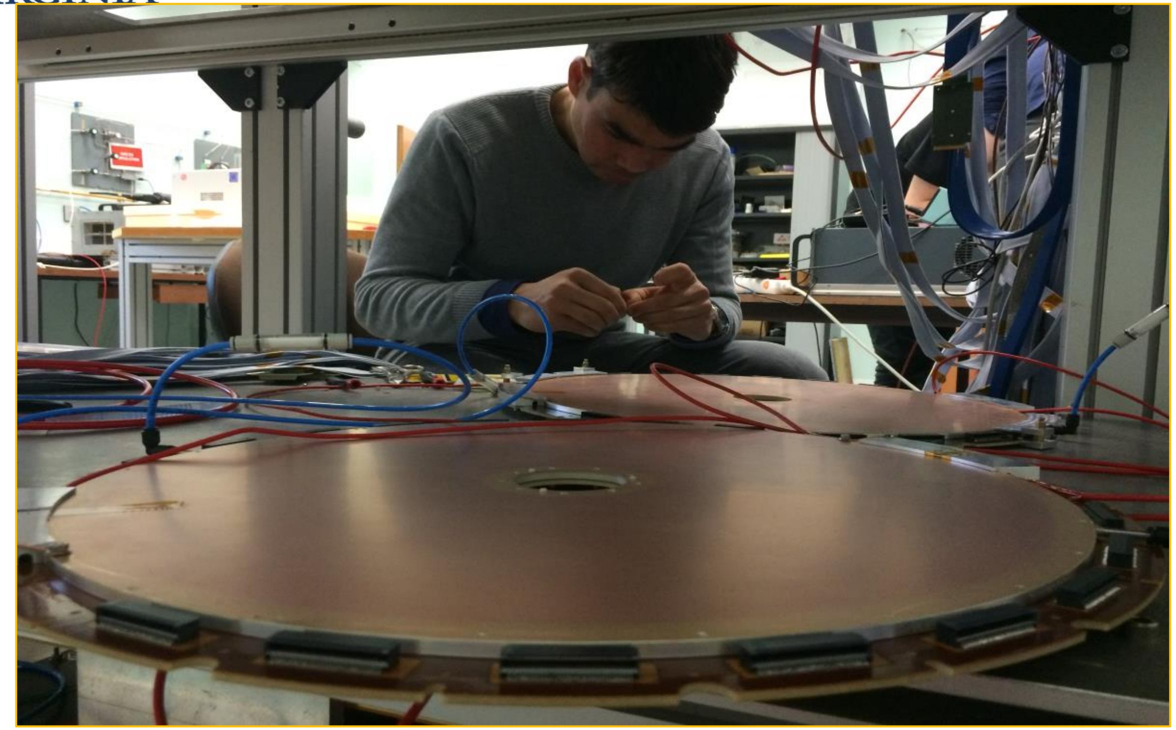
M. Vandenbroucke, MPGD2105, Trieste 2015

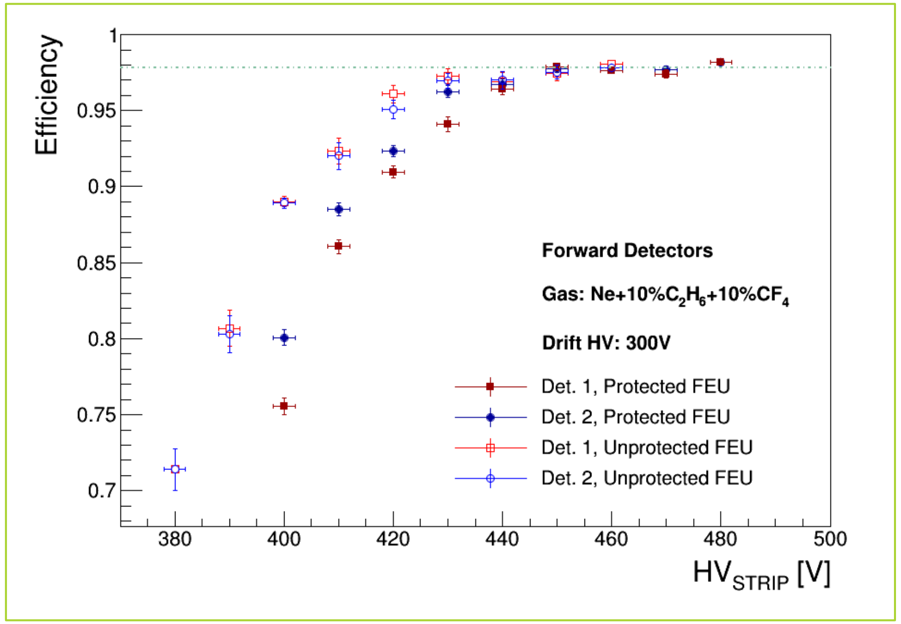
- Upgrade of the CLAS Experiment at Jefferson lab
- Study of the nucleon structure with ~11 GeV electron beam at high luminosity (1035 cm-2s-1)
- Targets : liquid hydrogen (protons), liquid deuterium (neutrons), other nuclei in the future

Micromegas Vertex Tracker (MVT) :

- 4 m² of Micromegas Improve the track reconstruction in the vicinity of the target
- Inserted in the 5T solenoid, in combination with the Silicon Vertex Tracker (SVT)
- Forward Detectors (Disks)
  - High particle rate (30MHz)
  - Resistive strips divided in 2 zones inner/outer
  - Dimensions: 6x 430 mm diameter disk with a 50 mm diameter hole at the center
- Cylindrical Barrel (Curved Tiles)
  - Low momentum particles => Light Detectors
  - Limited space of ~10 cm for 6 layers

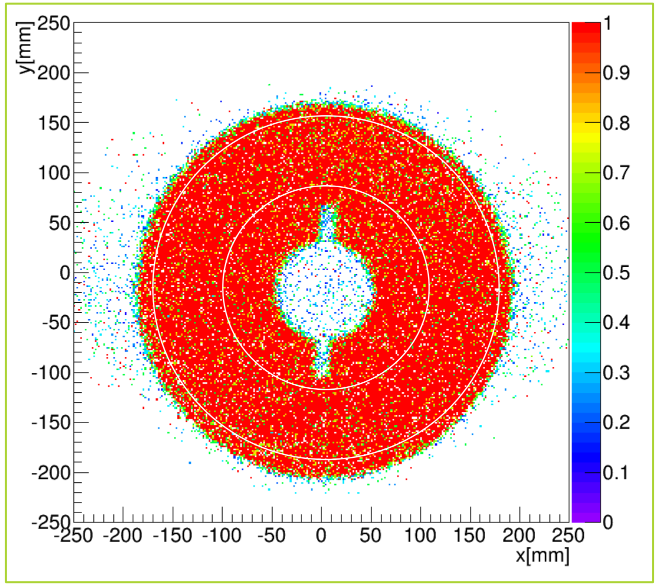
CLAS12 Micromegas Vertex Tracker (MVT)





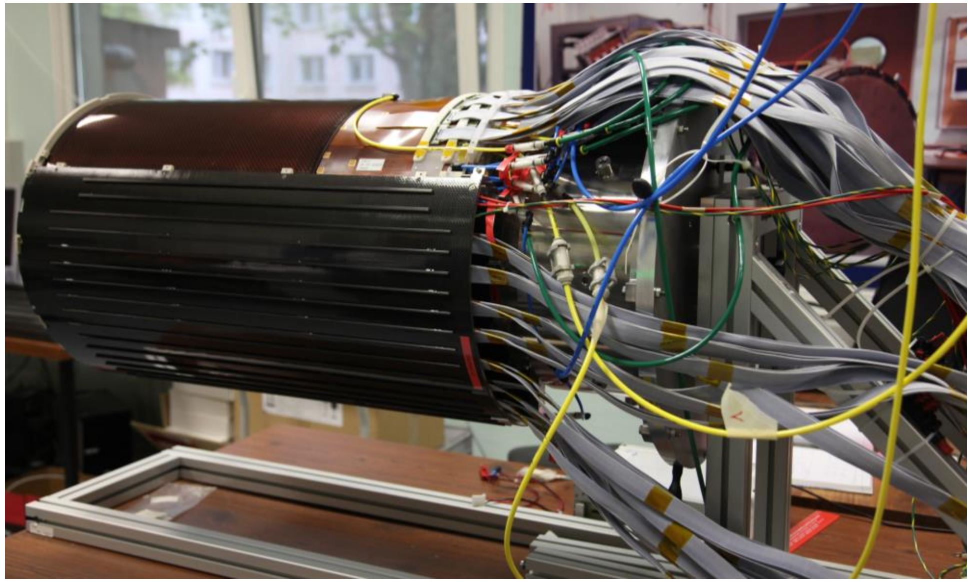
MVT Forward Tracker:

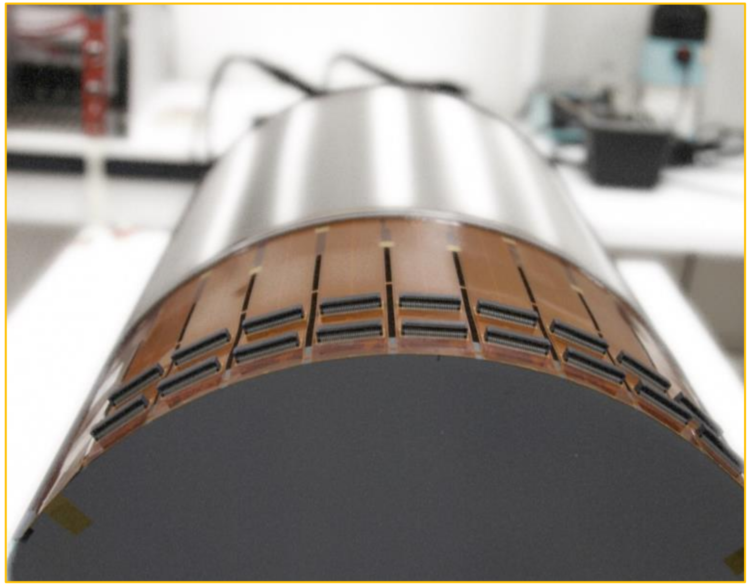
- 6 Detectors fully operational with no current on the resistive layer after many cleaning procedures
- 6 Detectors have been delivered to J-Lab in Sept. 2016
- Radiation length of 0.70% X/X0 => To be lowered for the next run
- Close to full efficiency (98%) in the active area
- Resolution better than 200 µm (limited by tracking of the test-bench)
- Time Resolution better than 20 ns (same)

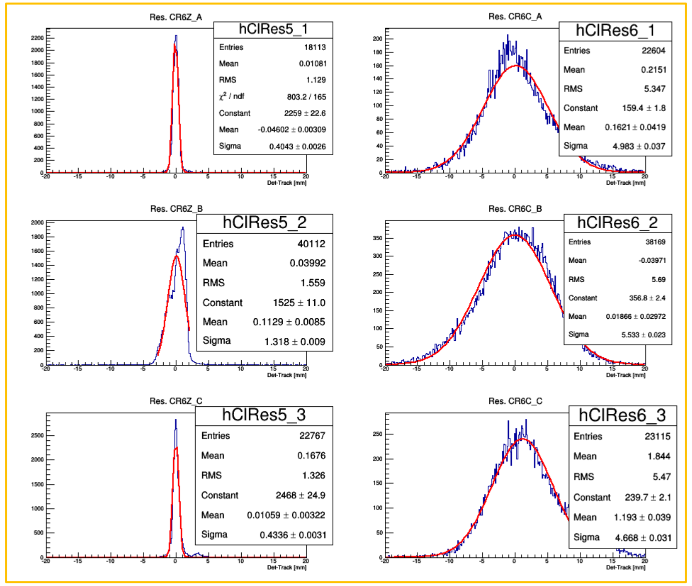


M. Vandenbroucke, MPGD2105, Trieste 2015

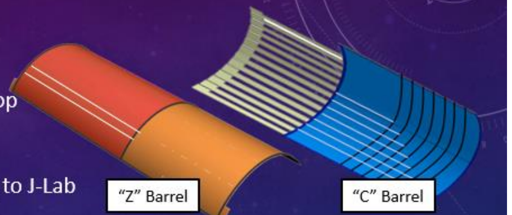
CLAS12 Micromegas Vertex Tracker (MVT)

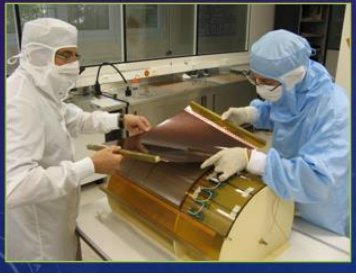






- Total of 6 layers segmented in phi (3 x 120° sectors) = 18 detectors total
- 6 Different detector's radii
- 2 different types (C and Z types)
- Material (PCB/Bulk + Drift) from the CERN Workshop
- Assembly to cylindrical shape at Saclay
- Test and Characterization at Saclay before shipping to J-Lab
- 8-9 days to assemble one detector + 1 week of test





Layer	Production	ch.	Radius	Length	Width
CR4-C	3 + 1spare	896	146mm	712mm	302mm
CR4-Z	3 + 1spare	640	161mm	712mm	333mm
CR5-Z	3 + 1spare	640	176mm	712mm	364mm
CR5-C	3 + 1spare	1024	191mm	712mm	396mm
CR6-Z	3 + 1spare	768	206mm	712mm	427mm
CR6-C	3 + 1spare	1152	221mm	712mm	459mm
CR6-C new	3 spare	1152	221mm	712mm	459mm

MVT Barrel Tracker:

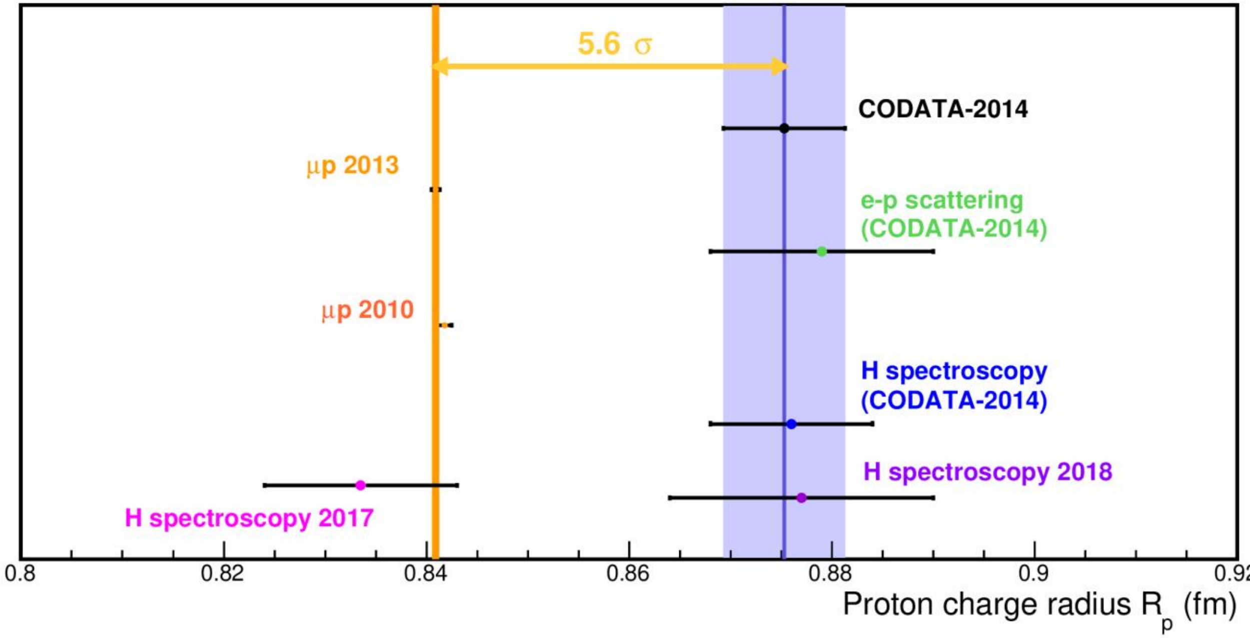
- 6 Layers of cylindrical detectors divided in 120° sectors = 18 Micromegas tiles
- Bulk + Resistive Micromegas
- Less than 0.5% of a radiation length per layer
- Cylindricity measured to be precise up to ~2mm in radius
- Resolution better than 200µm per layer with cosmic rays
- Time resolution of ~25ns with cosmic rays

M. Vandenbroucke, MPGD2105, Trieste 2015

Proton Radius Puzzle

Two techniques for proton charge radius measurement

- E-p elastic scattering
- Spectroscopy



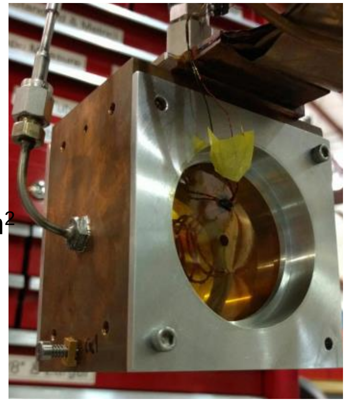
- Combined CODATA average: 0.8751 ± 0.00061 fm
- *ep* scattering average (CODATA): 0.879 ± 0.011 fm
- H-spectroscopy average (CODATA): 0.859 ± 0.0077 fm
- Muon spectroscopy: 0.8409 ± 0.0004 fm (CREMA 2010, 2013)
- H spectroscopy (2017): 0.8335 ± 0.0095 fm (A. Beyer et al. Science 358 6359 (2017))
- H spectroscopy (2018): 0.877 ± 0.013 fm (H. Fleurbaey et al. PRL 120 183001 (2018))

PRad Experimental in Hall B @ JLab

(June 2016)

Target specs:

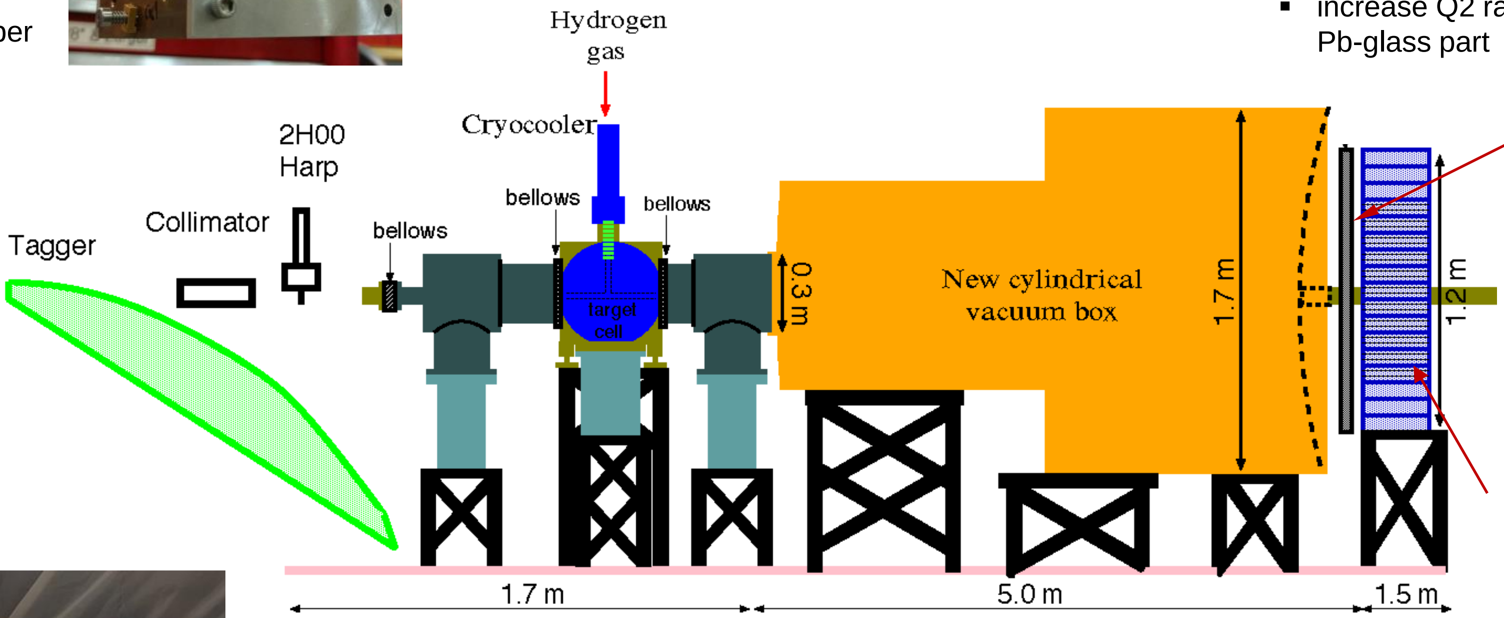
- cell length 4.0 cm
- cell diameter 8.0 mm
- cell material 30 μm Kapton
- input gas temp. 25 K
- target thickness 1×10^{18} H/cm^2
- average density 2.5×10^{17} H/cm^3
- Cell pressure 0.6 torr
- Vacuum in target chamber ~5×10^{-3} torr



PRad is a Electron Scattering Experiment that ran at JLab in Summer 2016 high precision measurement of the proton charge radius

GEMs:

- factor of >10 improvements in coordinate resolutions
- similar improvements in Q2 resolution (very important)
- unbiased coordinate reconstruction (including transition region)
- increase Q2 range by including Pb-glass part



HyCal specs:

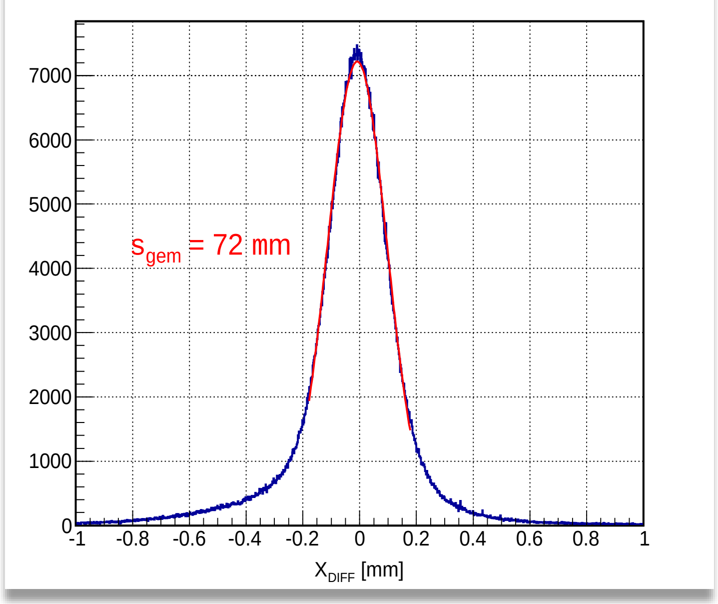
- *34 x 34 matrix of 2.05 x 2.05 x 18 cm^3 PbWO4 shower detectors*
- *576 Pb-glass shower detectors (3.82x3.82x45.0 cm^3)*
- *5.5 m from H_2 target (~0.5 sr acceptance)*
- *Resolutions for PbWO4 shower: $\sigma/E = 2.6\ \%/\sqrt{E}$, $\sigma_{xy} = 2.5\ mm/\sqrt{E}$*
- *Resolution for Pb-glass shower detectors factor of ~2.5 worse*

PRad GEM Trackers

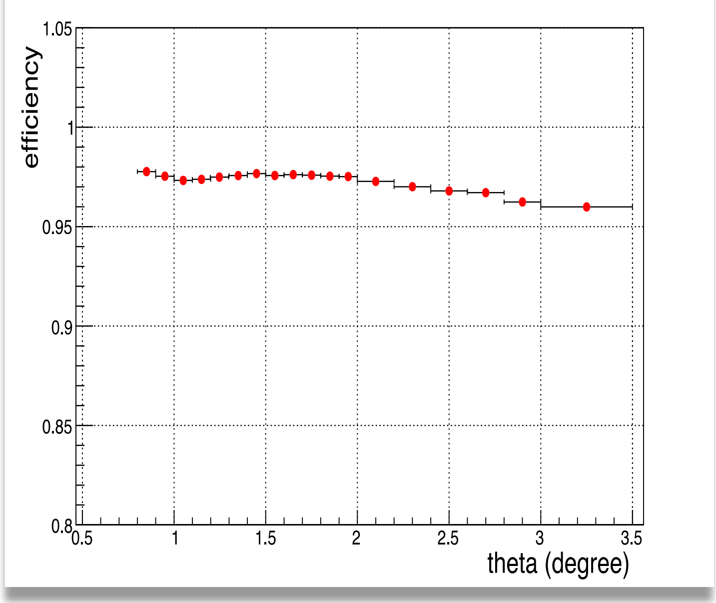
PRad GEMs in Hall B

- GEM detection efficiency measured in both photon beam calibration (pair production) and production runs (*ep* and *ee*)
- Using overlap region of GEMs to measure position resolution (72 μm)

Position Resolution

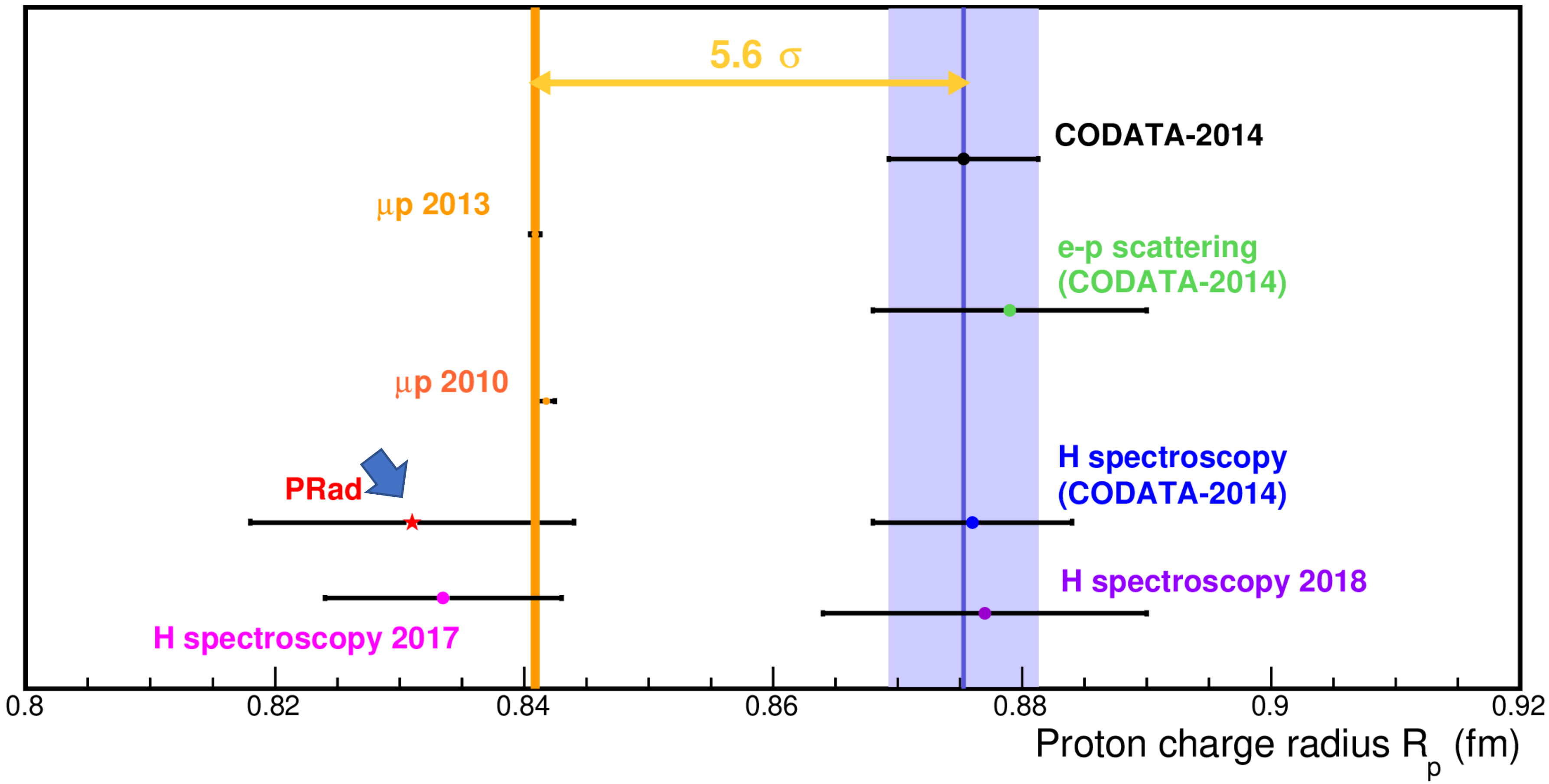


GEM Efficiency



PRad GEMs was in 2016 the largest GEM to successfully run in an HEP/NP experiment

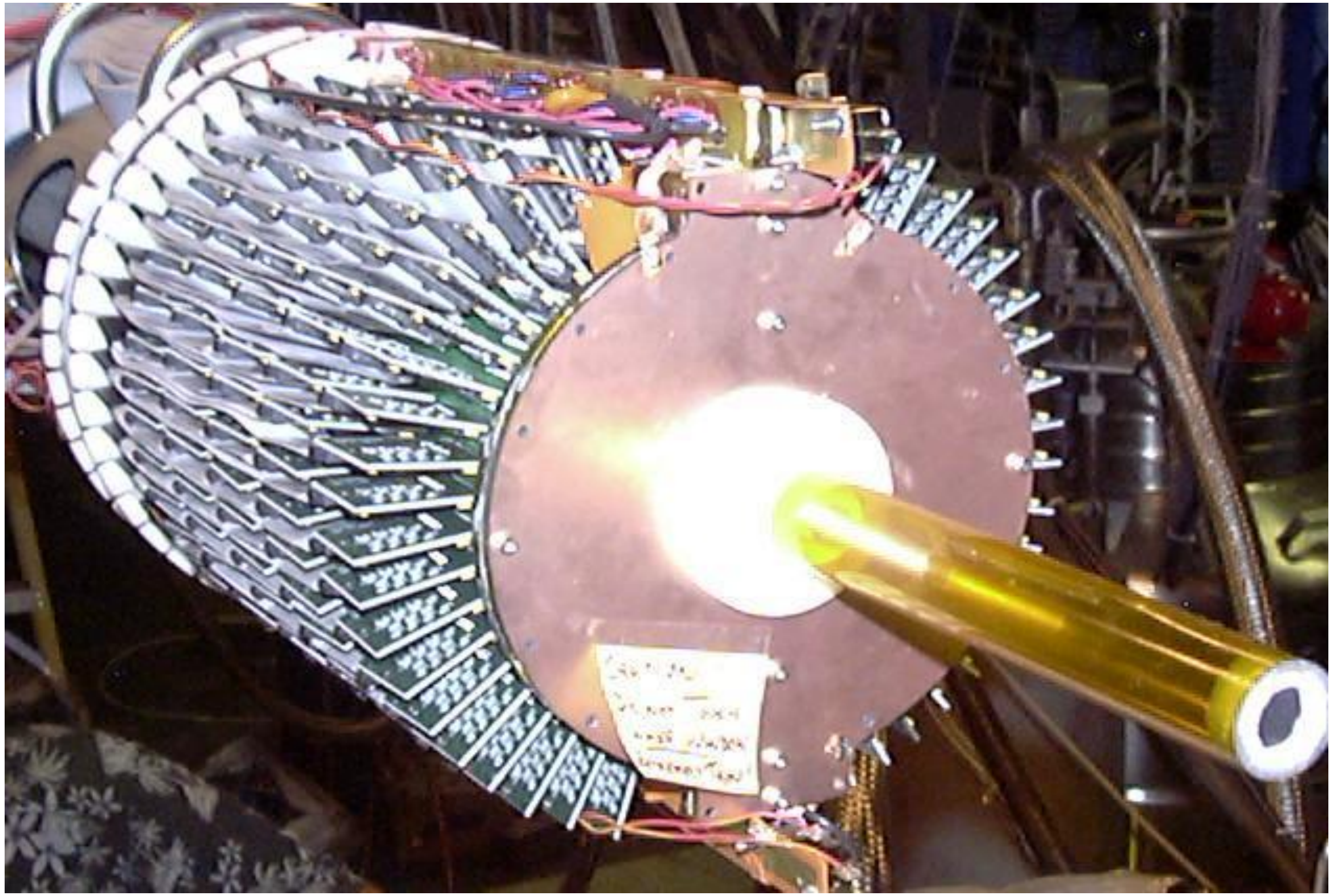
Proton radius from PRad



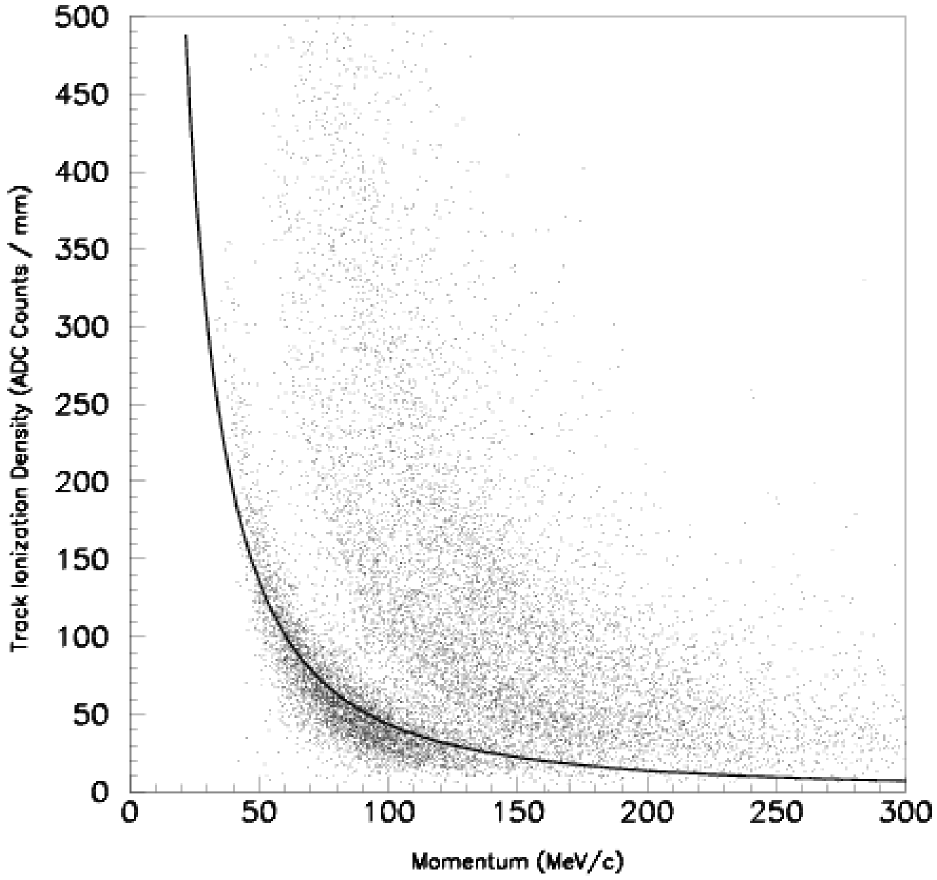
$$R_p = 0.831 \pm 0.007\ (stat.) \pm 0.012\ (syst.)\ fm$$

W. Xiong et al., Nature, 575, 147 (2019)

BoNuS: GEM based Radial TPC (rTPC) in Hall B @ JLab



dE/dx from charge track

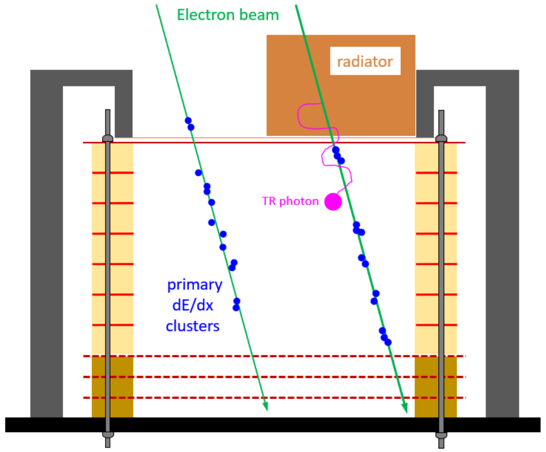


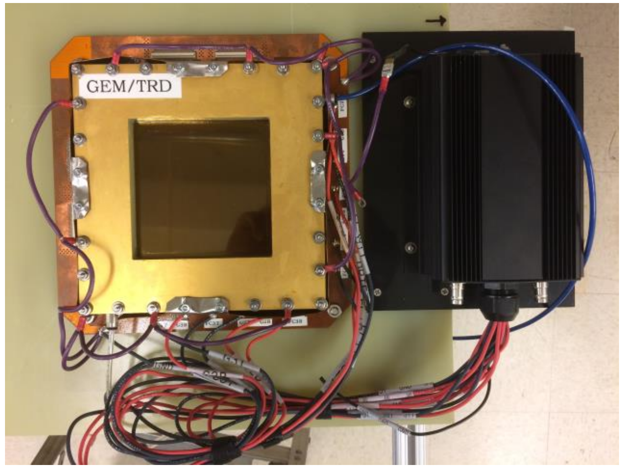
E. Christy. Tagged SF, JLAB 2014

MPGDs for Future Applications @ JLab

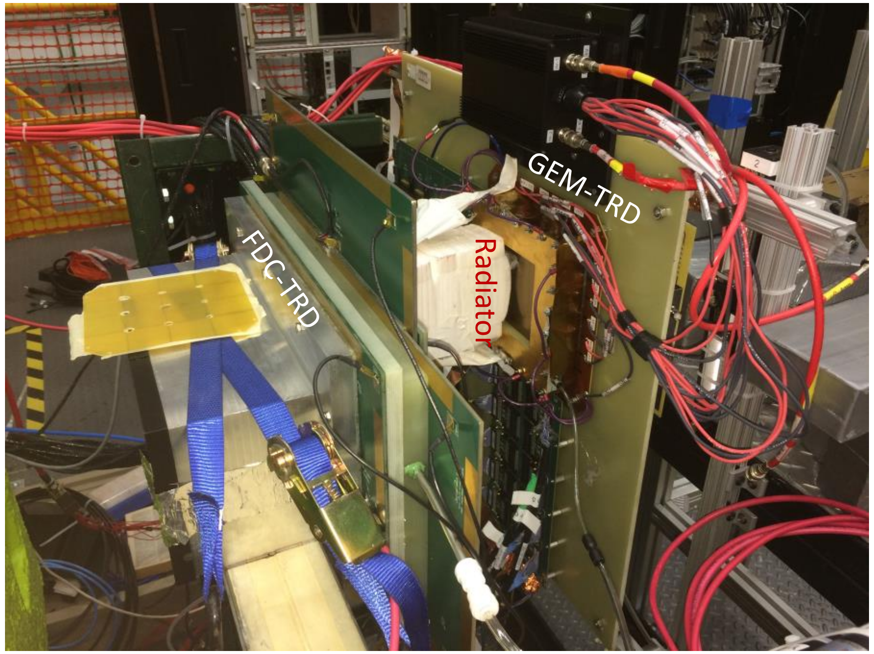
R&D on GEM-/Transition Radiation Detector: Possible Application in Hall D @JLab

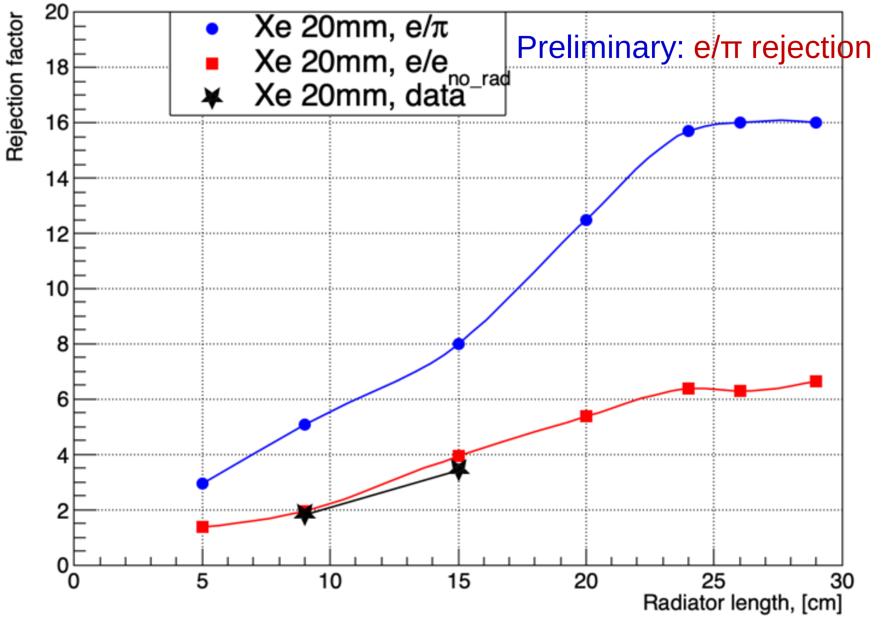
- Test beam campaign during JLab spring, fall run 2018 and spring Run 2019
- Tests carried out with GEM-TRD and FDC-TRD (Forward Drift Chambers)
- 3 to 6 GeV electrons are produced in the converter of a pair spectrometer
- No pion beam for direct comparison of the TR effect for JLab beam tests
- The radiators and covers about half of the sensitive area of the GEM-TRD
- Analysis is done by comparing the energy deposited in the drift volume covered with and without radiator





GEM-TRD setup @ JLab Hall D





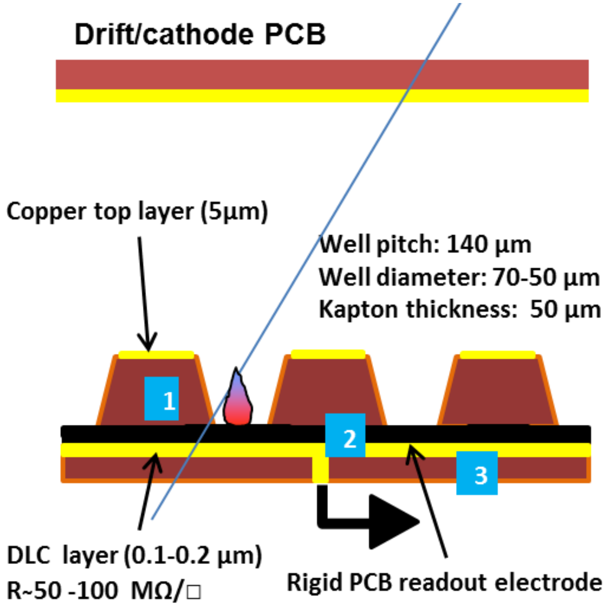
Recent MPGD: The Resistive Micro Well detector (μRWell)

The μRWELL is realized by coupling:

1. a "suitable WELL patterned Kapton foil as "amplification stage"
2. a "resistive stage" for discharge suppression & current evacuation:
3. a standard readout PCB

Combines the advantages of both GEMs & Micromegas

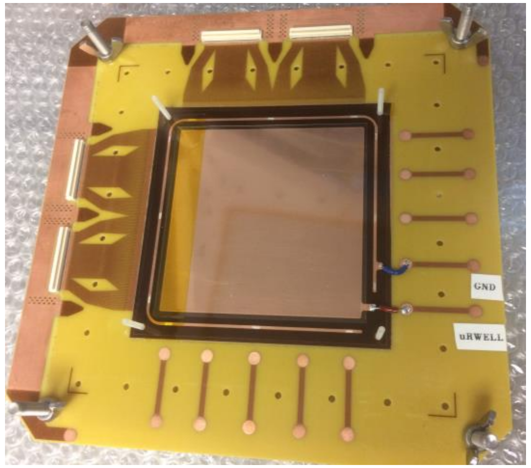
- Single amplification stage, thin structure, low material
- Like GEM ⇨ Simple amplification stage ⇨ **it is similar to a GEM foil**
- no stretching, no spacers ⇨ **almost full efficiency**
- Low material ⇨ **minimize multiple scattering**
- Low cost MPGD detector & Large area capability



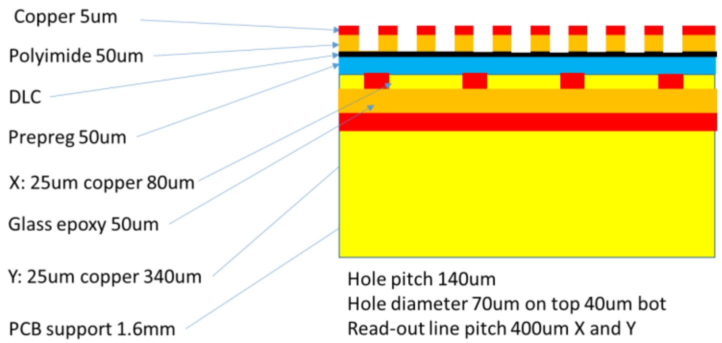
μ-RWELL PCB

G. Bencivenni et al., 2015_JINST_10_P02008

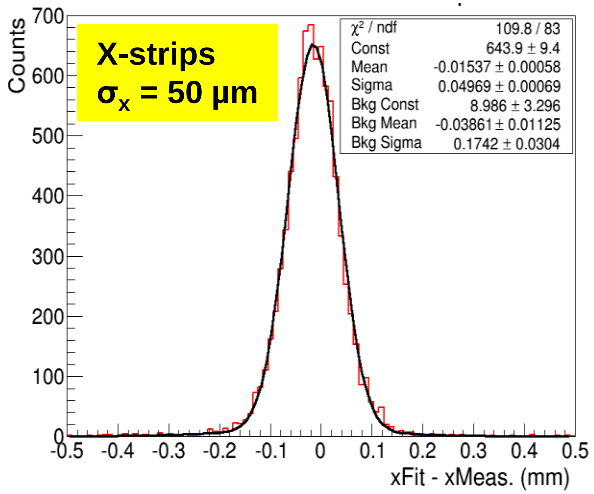
μRWELL with X-Y readout

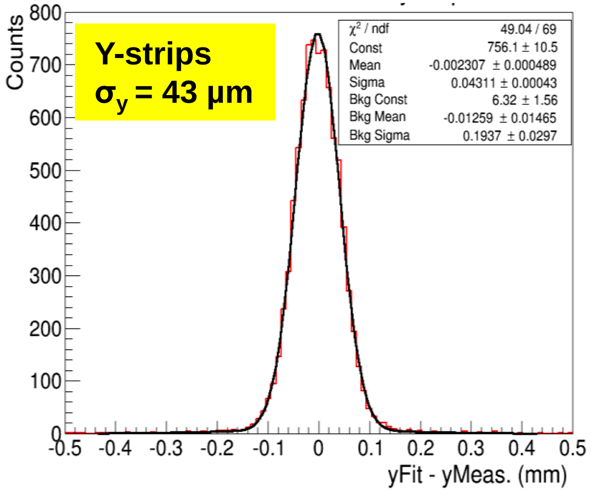


Cross section of μRWELL with X-Y readout



uRWELL position residuals from track fit with GEMs @FNAL



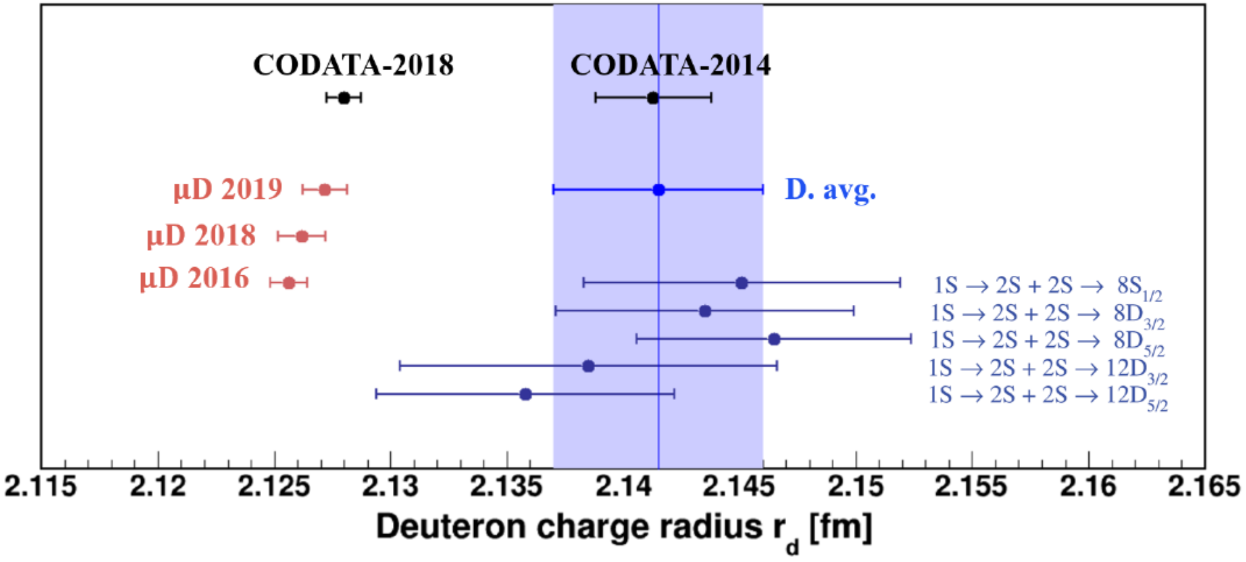


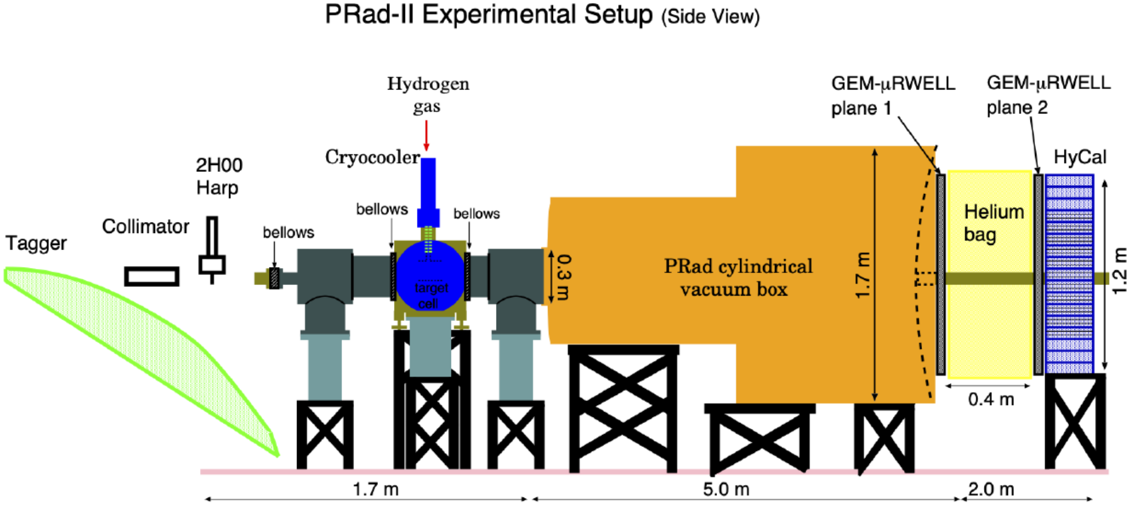
Large Area µRWELL: Replacing GEM for PRad-II & DRAD in Hall B

Two new proposals PRad-II & DRAD in Hall B @JLab

❖ **PRad-II** ➪ Push the precision measurement one order of magnitude better than the original PRad

❖ **DRad:** Deuteron radius puzzle similar effect with uH spectroscopy measurement





Why the choice of µRWELL instead of GEM

❖ Two large uRWELL layers (1m x 1.2 m)

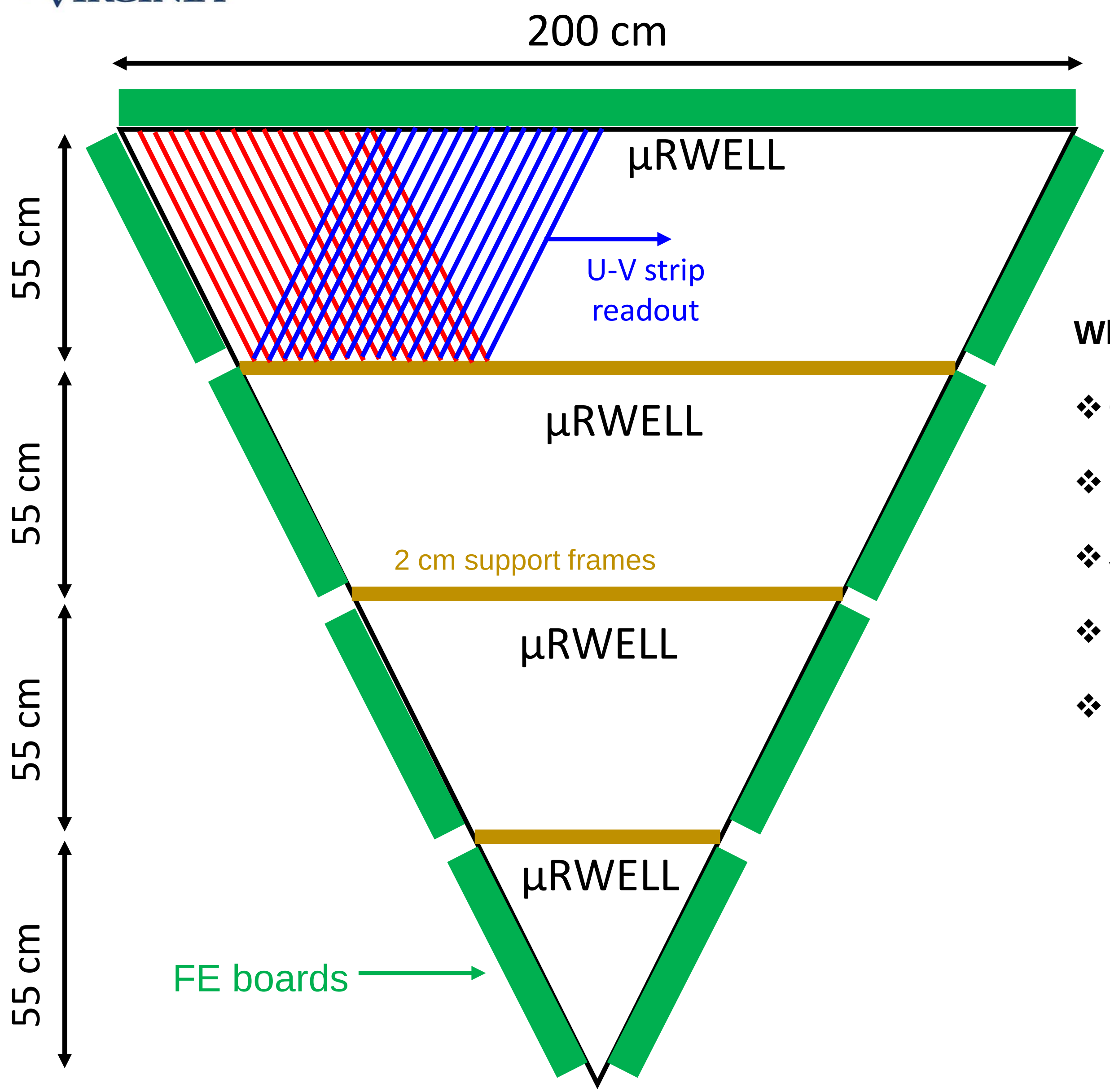
❖ Low cost detector technology

❖ Simple uRWELL configuration

❖ Same experimental setup for PRad-II and DRad

❖ **No spacer in the active area**

Large µRWELL: Forward Detector Upgrade for High-Lumi CLAS12



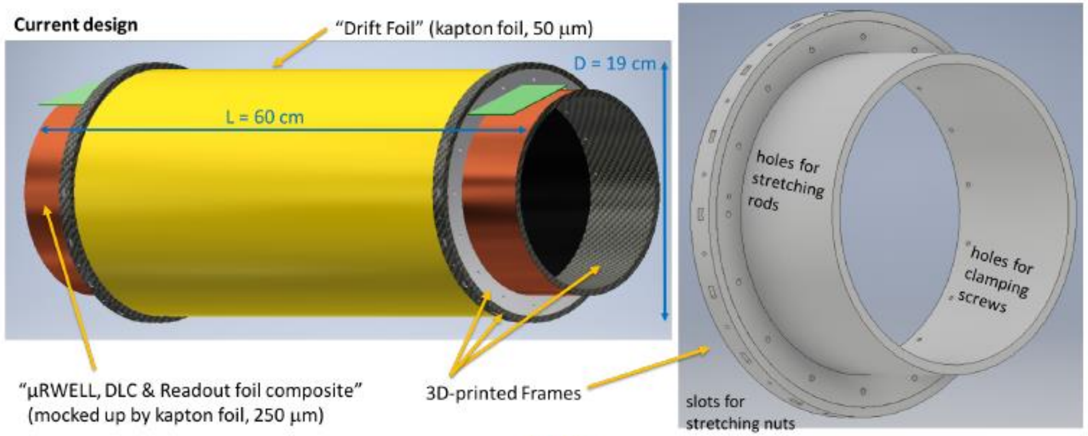
Why the choice of µRWELL over existing Drift Chamber

- ❖ Can handle the high rate of the CLAS12 upgrade
- ❖ Low cost detector technology
- ❖ **Simple uRWELL** configuration even for CLAS12 High Luminosity
- ❖ Detector construction simpler than GEM & Micromegas
- ❖ U-V strip readout to provide high resolution 2D space points
  - ❖ Ongoing R&D to reduce channel counts low while keeping same spatial resolution performances

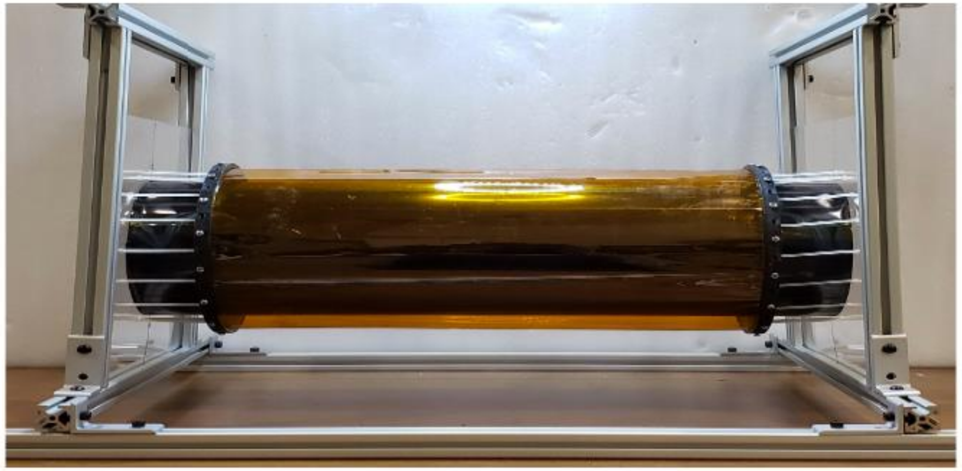
Cylindrical µRWELL: Upgrade of GLUeX Barrel Tracker in Hall D

µRWELL: possible candidate to replace / supplement GLUeX Central Drift Chamber (Straw tube)

- ❖ Cylindrical & large area (radius) tracking layers
- ❖ Low mass & low cost detector technology
- ❖ **Simple uRWELL** configuration even for CLAS12 High Luminosity
- ❖ Cylindrical **uRWELL** way simpler than GEM & Micromegas
- ❖ Ongoing R&D to reduce channel counts low while keeping same spatial resolution performances
- ❖ Synergy with ongoing R&D on EIC fast cylindrical tracker (Matt's talk)



FIT



FLORIDA TECH

Summary

MPGDs @ JLab is becoming more and more mainstream technologies for tracking system at JLab

- High luminosity experiment in Hall A require large area GEM detector (SBS, SoLID, MOLLER & TDIS)
- Lower luminosity in Hall B favorable for resistive Micromegas Cylindrical Vertex Trackers
- New MPGD technologies for detector upgrade for CEBAF high luminosity 12 GeV era
- Development of GEM based Transition Radiation Detector: Application for e ID in Hall D

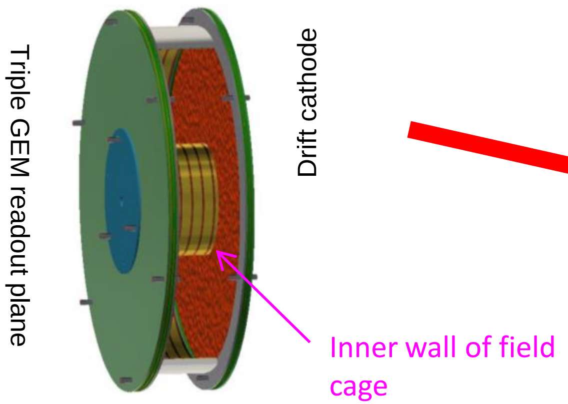
Backup

TDIS multi-TPC (mTPC)

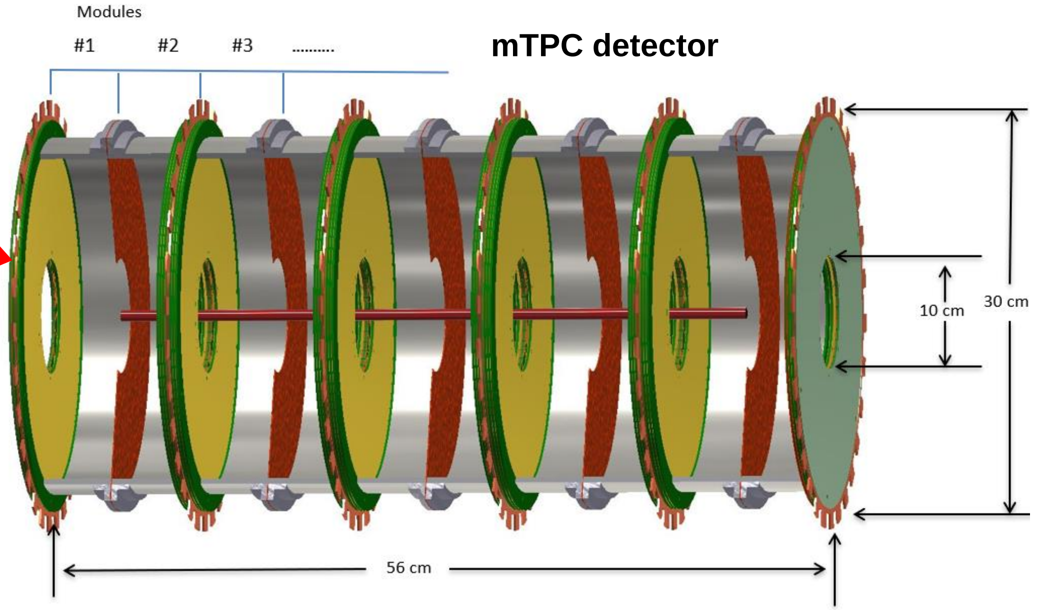
Proton Arm

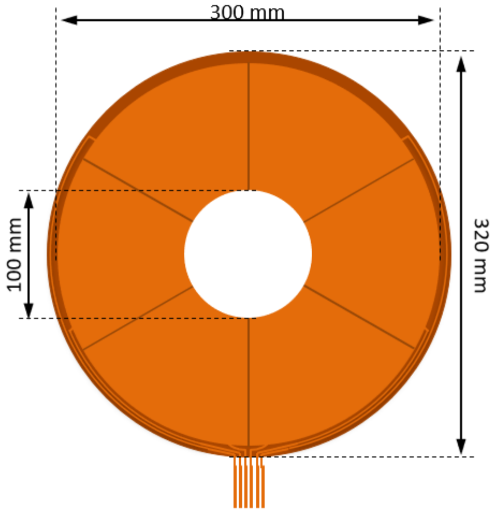
- **H2 or D2 Target:** Straw target (12 um Kapton cylinder with 10um Al end cap)
- **Proton Detector (mTPC) :** modular TPC consisting of stack of 10 sub modules
- **Solenoid:** 40 cm bore 5T super conductive solenoid magnet (UVa)

mTPC module



mTPC detector

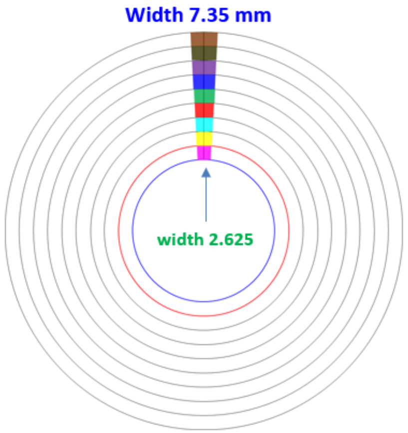




GEM foil design: divided into 6 to 12 HV sectors on bot top and bottom electrodes

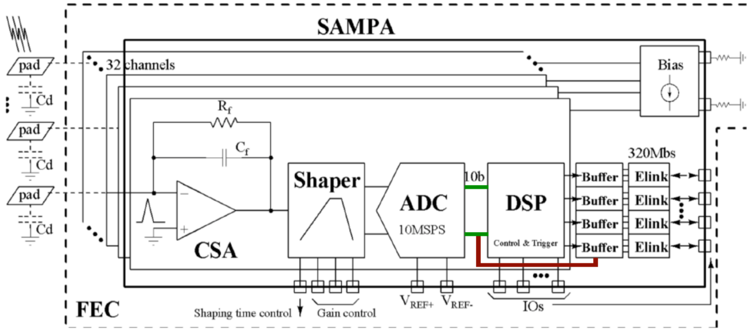
Pad readout foil design

- **20 concentric rings of 126 pads each**
- Trapezoidal-shape pads with height of 5cm
- width from 2.625 mm in inner ring to 7.325 mm in the outer ring
- higher occupancy in the inner region of the TPC



SAMPA Readout Electronics for TDIS mTPC

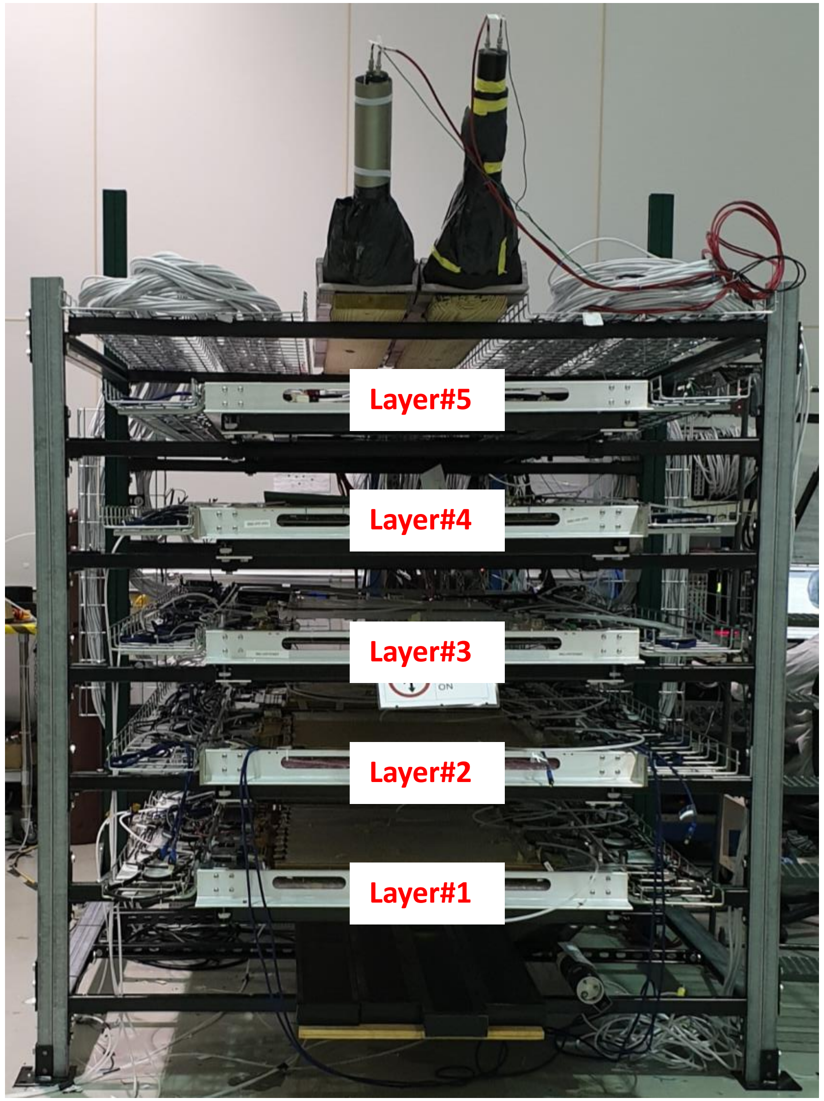
- Direct ADC serialization (DAS) mode ➝ bypass digital signal processor (DSP)
  - ALICE FEC design limits ADC rate to 5 MHz in DAS mode ➝ 10 e-links (max 3.2 Gb/s)
- DSP mode ➝ pedestal subtraction, baseline corrections, zero-suppression, compression
  - Sampling rates of 10 or 20 MHz ➝ 11 e-links (max 3.2 Gb/s or 6.4 Gb/s)



Slide Courtesy of E. Jastrzembski

SBS GEM Trackers

UVa GEM layers on the cosmic stand



- Production of All GEM modules (INFN and UVa) completed
- Assembly of 5 INFN layers & 6 UVa layers also completed
- 2 cosmic stand at JLab for the commissioning of the GEM layers
- Ongoing study of the detector performances ⇨ Efficiency > 95% for most modules
  - Modules with lower efficiency ⇨ Increase the HV
- First SBS experiment GMn scheduled to run Spring 2021

UVa GEM layers: Efficiency map for 4 layers