Advanced Micro Pattern Gaseous Detectors (MPGDs) for the EIC

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Hall A TDIS Collaboration

ClAS12 High Luminosity Upgrade Collaboration

EIC Early Career Workshop

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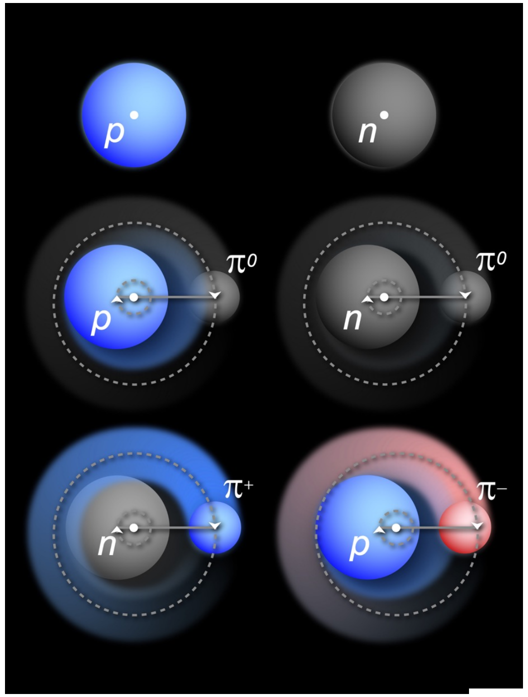
UNIVERSITY of VIRGINIA

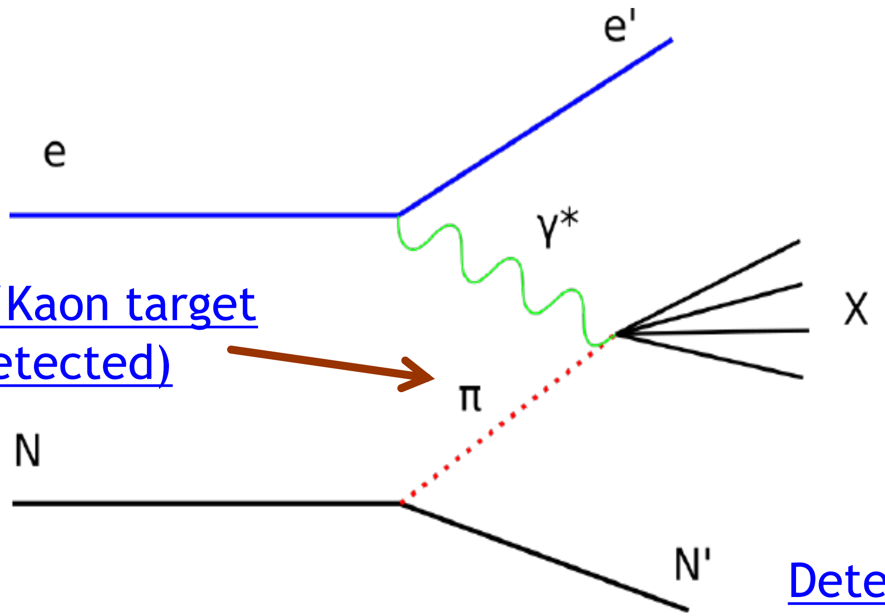
Jefferson Lab

Motivation: Physics Objects for Pion/Kaon Structure Studies

Sullivan process – scattering from nucleon-meson fluctuations



Detect scattered electron



Pion/Kaon target (undetected)

DIS event – reconstruct x, Q^2, W^2, also M_X (W_π) of undetected recoiling hadronic system

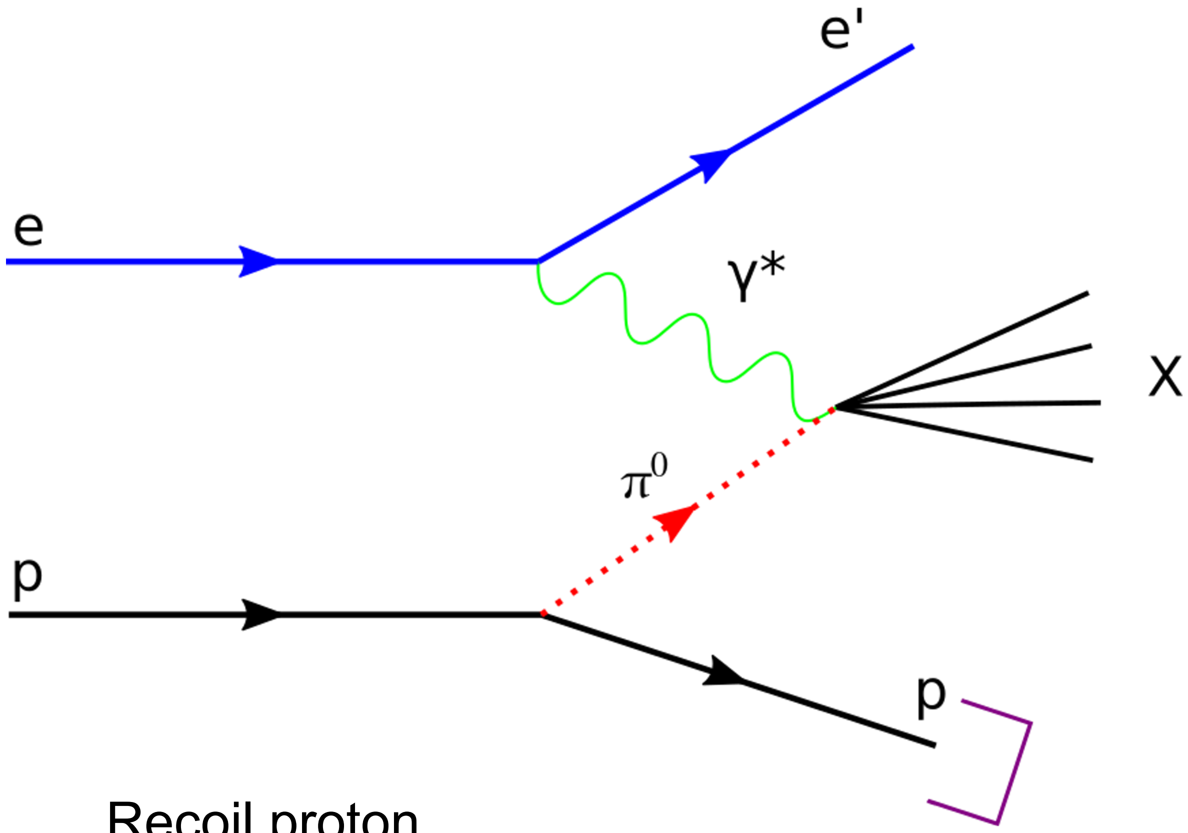
Detect "tagged" proton/neutron/lambda

$$F_2^{LP(3)} = \sum_i \left[\int_{t_0}^{t_{min}} f_i(z,t)\,dt \right] F_2^i(x_i, Q^2)$$

$i = \pi, \rho, \ldots$

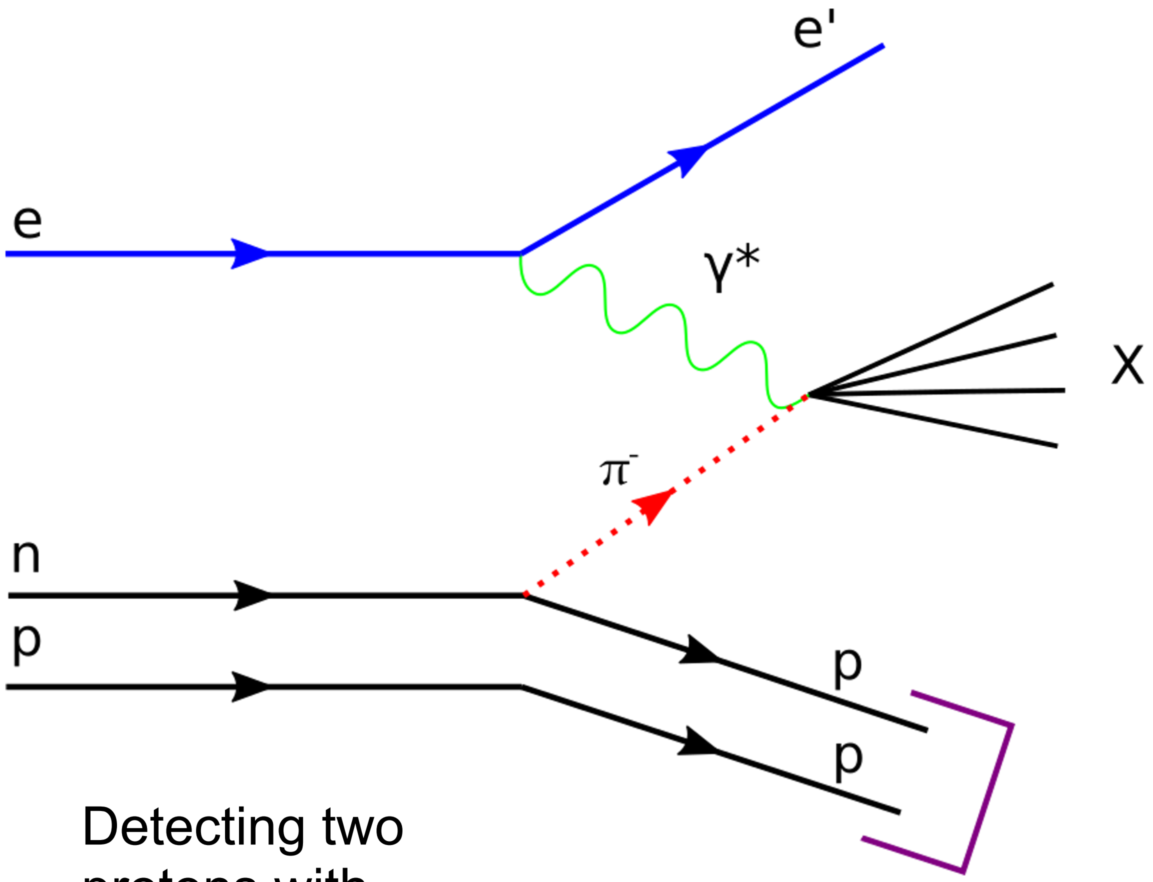
"Flux factor"

Pion structure from Sullivan process:
Tagged Deep Inelastic Scattering (TDIS)



Recoil proton
(backward going
slow proton) **TAG**

- Effective π^0 target

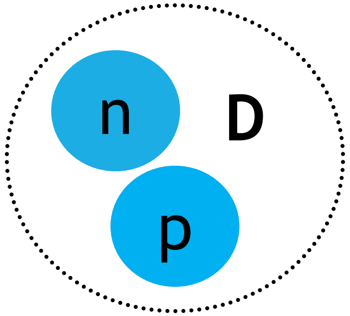


Detecting two
protons with
common vertex
Spectator proton

- Effective π^- target

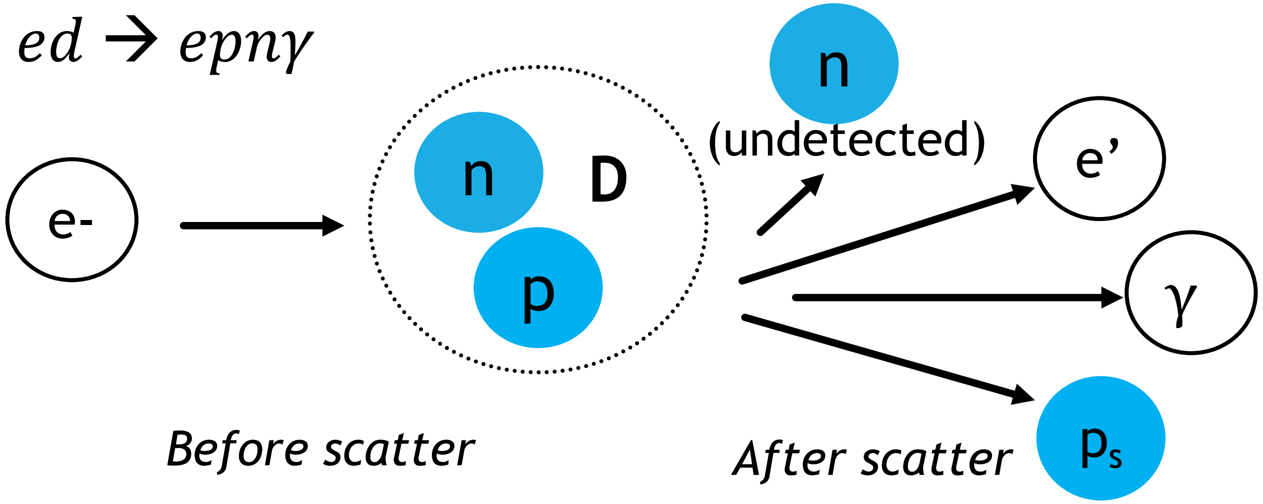
What about the neutron? → tagged-neutron DVCS

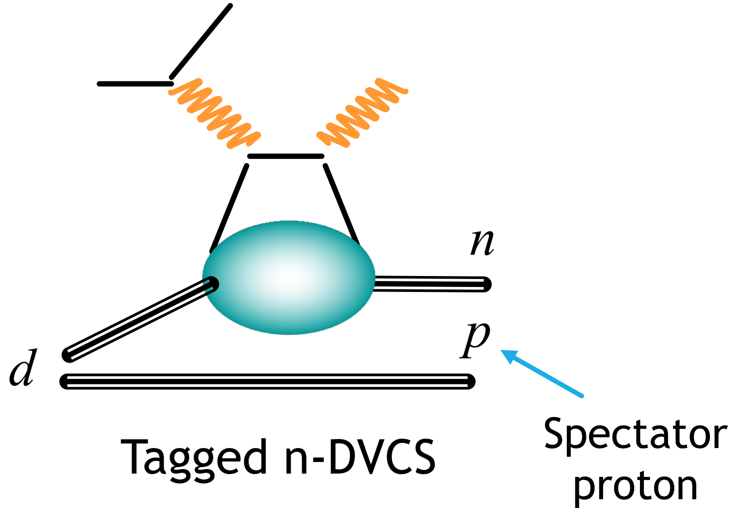
- We can study neutron structure, but need "free" neutron target → use deuterium target



- In tagged neutron DVCS, we detect "spectator" proton, p_s , coincident with scattered electron e' and photon

$ed \rightarrow epn\gamma$

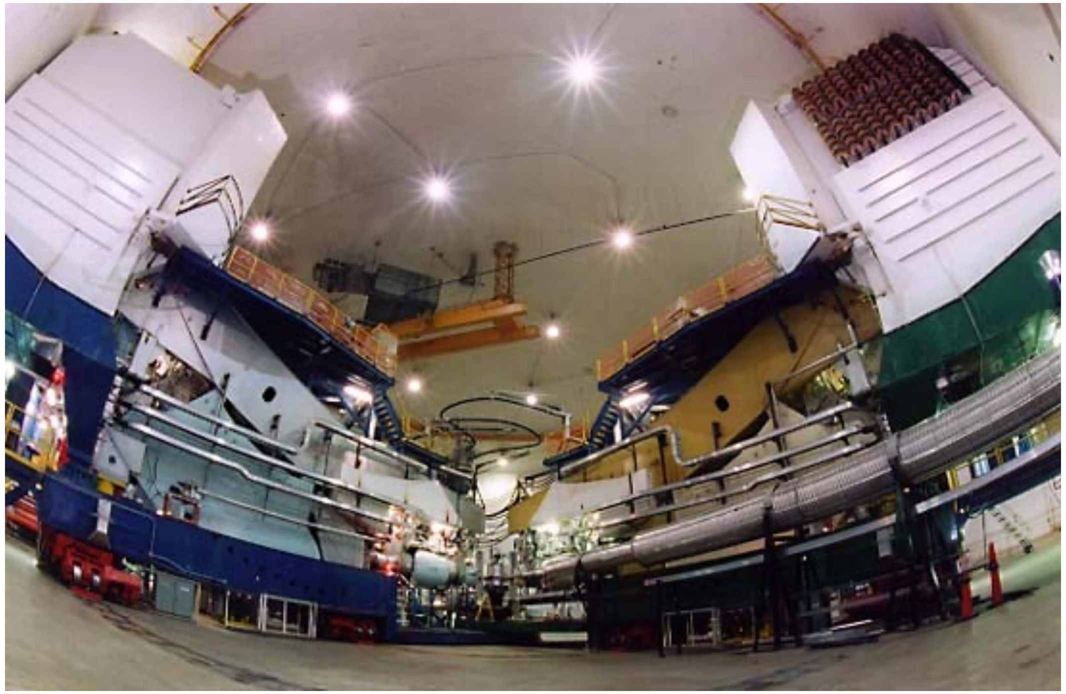


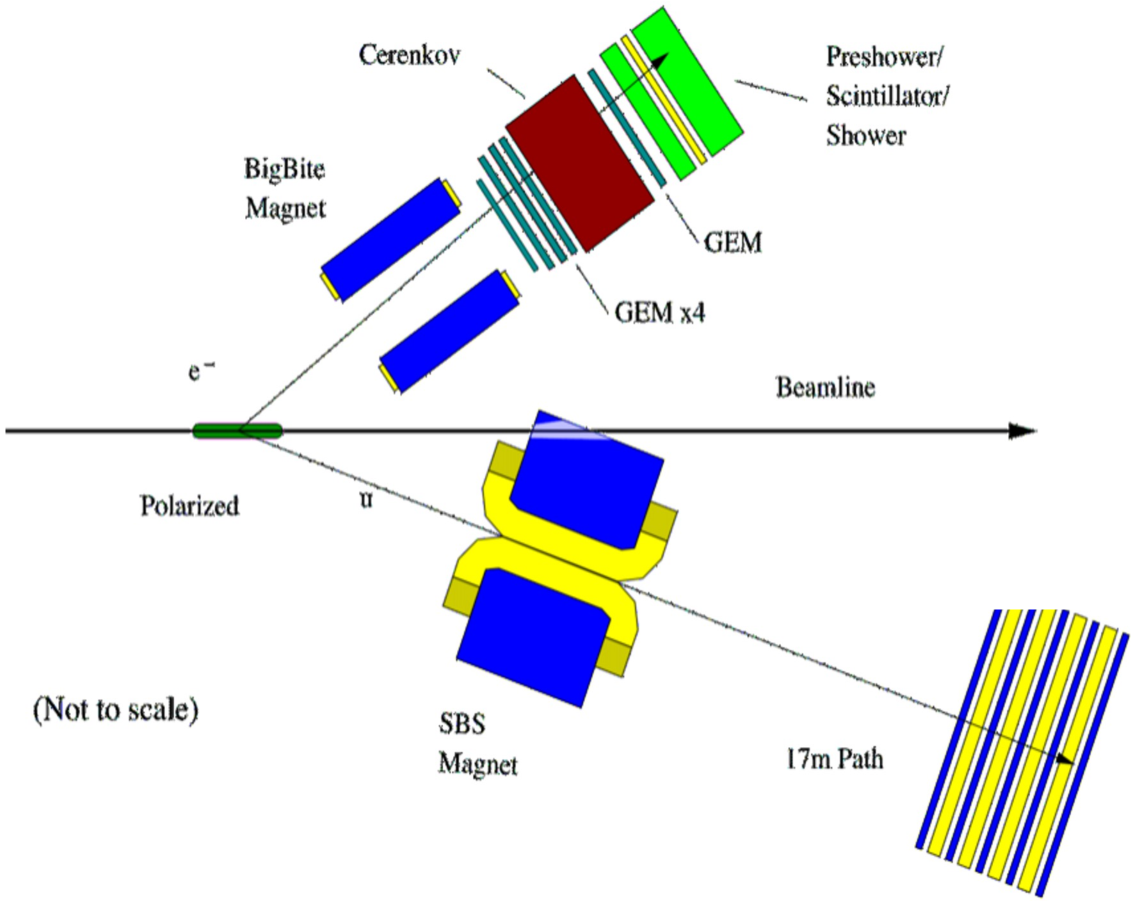


- The highly energetic electron knocks out the neutron inside the deuteron nucleus and the spectator proton is able to be identified.
- 12 GeV era experiment → **Tagged n-DVCS** is possible with an addition of an EM calorimeter to detect the photon

Hall A, Jefferson Lab in 2021-present

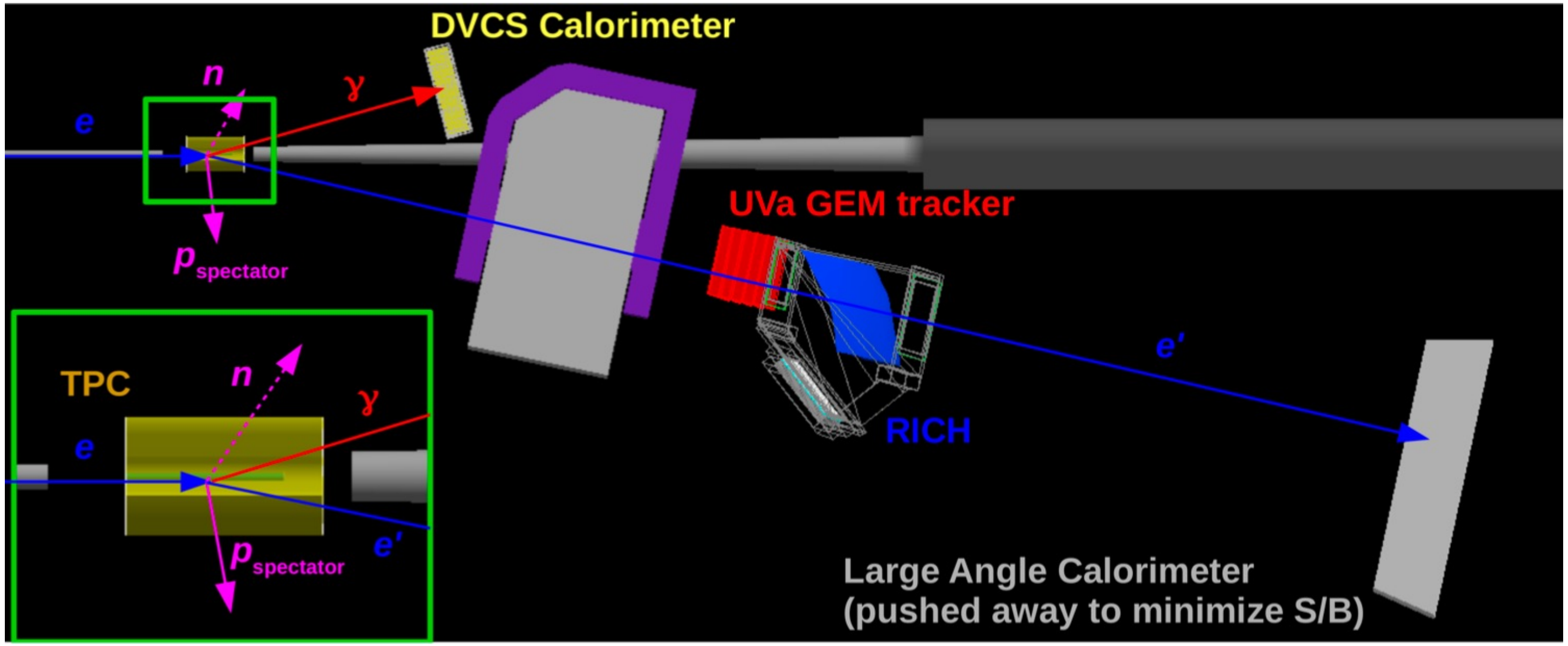
- Specialized in studying inclusive and exclusive reactions via electron scattering (DIS, DVCS, and SIDIS), Form factors (GMn, Gen-Rp)
- High Resolution Spectrometers retired: upgraded recently (2021) for Super Bigbite Spectrometer (SBS) program





Tagged n-DVCS with TDIS setup + ECAL

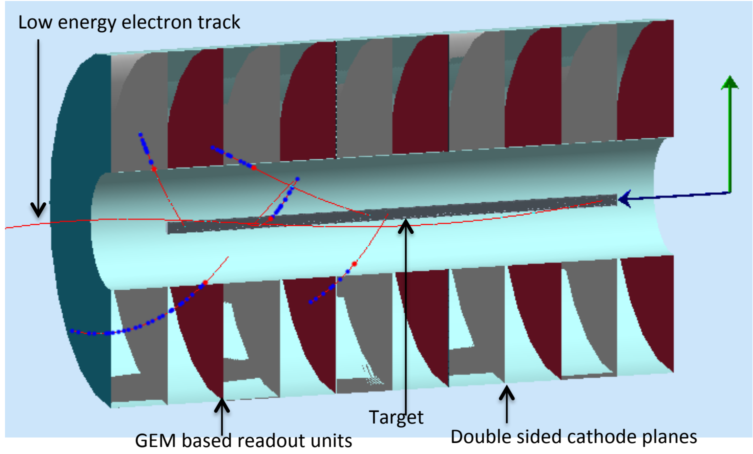
- Measure exclusive photon and neutral pion electroproduction on deuterium, with identification of the spectator proton $D(e, e' \gamma p_{spec})n$ and $D(e, e' \pi^0 p_{spec})n$, in the valence region ($x > 0.1$) and deep inelastic regime: $Q^2 > 1$ GeV^2, $W^2 > 2$ GeV^2
  - Addition of electromagnetic calorimeter (ECAL) to TDIS experimental setup (photon detection)
  - mTPC will TAG "spectator" proton → allow PID of nDVCS events
  - SBS will detect e'
  - Run group Letter of Intent submitted to PAC 46 (LOI12-18-002)



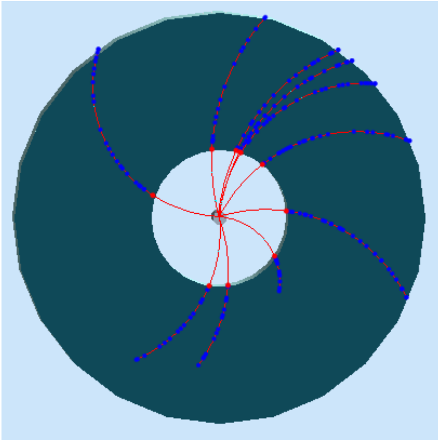
A new detector → mTPC: multi-Time Projection Chamber to measure low-momentum protons (p_{spec})
- Uses *Gas Electron Multiplier (GEM)*-based readout → has multiple stages for amplification

multi-Time Projection Chamber (mTPC) in TDIS and nDVCS

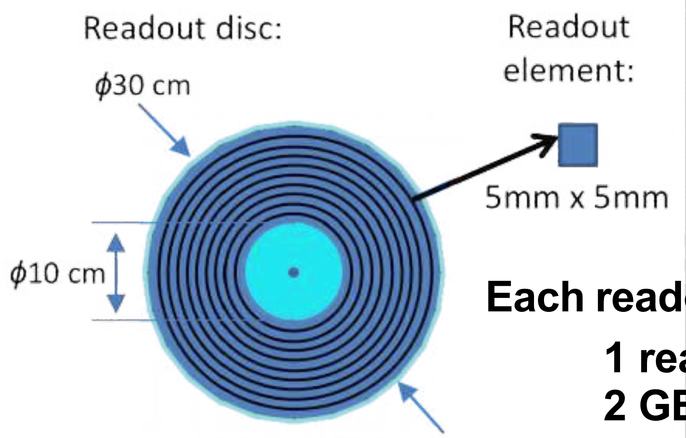
- Will be placed in the bore of the UVa superconducting solenoid magnet (L=152.7 cm, $\vec{B}$= 4.7 T) to fit the requirement of strong magnetic field parallel to $\vec{\boldsymbol{E}}$
- Consist of 10 TPC modules to form one composite mTPC → takes care of high rates compared to single/radial TPC



Ptcl tracks

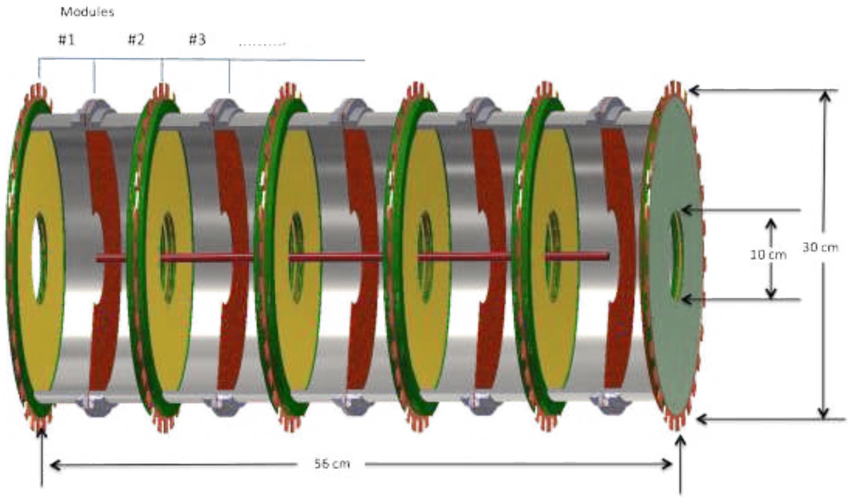


Dimensions : 55 cm long, Inner (outer) radii = 5 cm (15 cm)



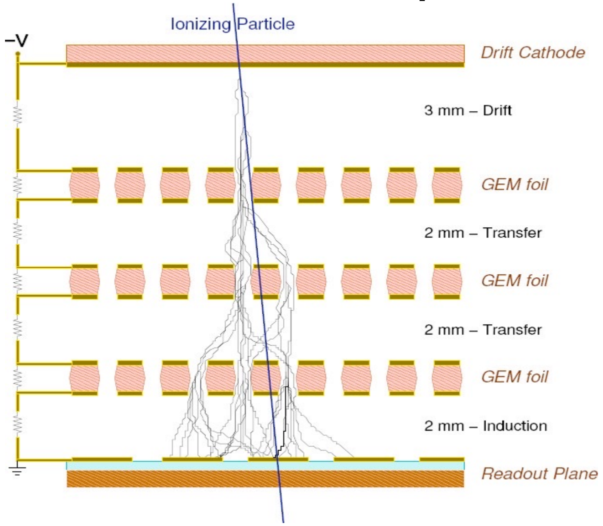
Each readout disc:

1 readout
2 GEM



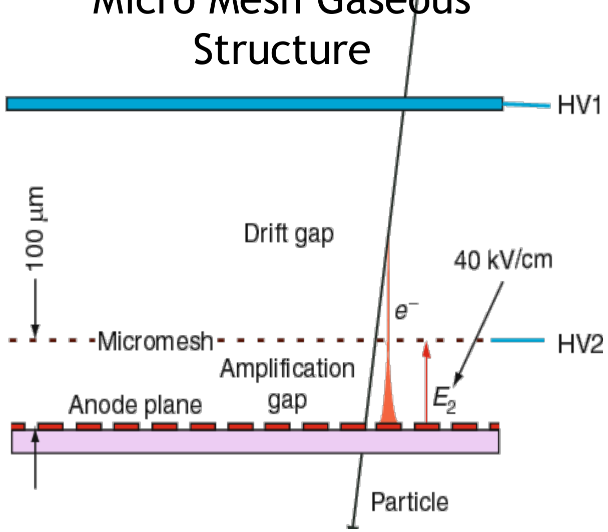
Micro Pattern Gas Detector (MPGD) Technologies

GEM:
Gas Electron Multipliers



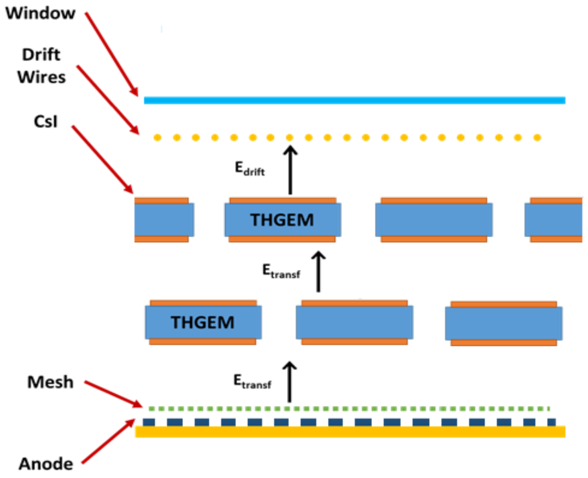
F. Sauli, Nucl. Instr. and Meth. A386 (1997) 531

Micromegas:
Micro Mesh Gaseous Structure



Giomataris, Nucl. Instr. and Meth. A419 (1998) 239

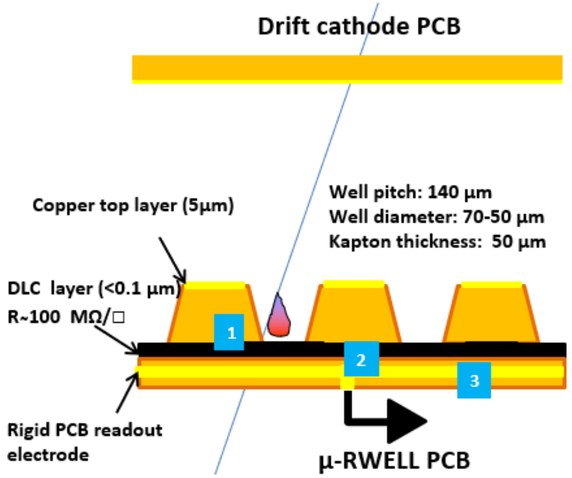
THGEM:
Thick GEM



R. Chechik, A. Breskin, C. Shalem

µRWELL:
Resistive micro-WELL Detector

G. Bencivenni et al., 2015_JINST_10_P02008



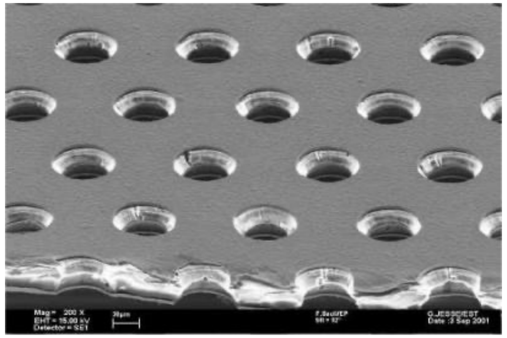
G. Bencivenni et al.; 2015_JINST_10_P02008

- Mature MPGD technologies such as triple-GEM, Micromegas, Thick GEM, and uRWELL are favored for tracking and triggering capabilities in high rate physics experiments
- MPGDs provide good position resolution (~50 um) and cost effective coverage over large areas
- So far, large area triple-GEM detectors have been built and successfully run in experiments (e.g., COMPASS, SBS, PRad, CMS, etc.)
- For low-material-budget-seeking detectors to serve as front trackers in CLAS12 and end-cap trackers in the EIC, more advanced micro-Resistive WELL technology in detectors is suitable

In this talk: triple-GEM and micro Resistive WELL detectors

Gas Electron Multiplier (GEM)

- Thin, metal-clad polymer foil chemically perforated by a high density of holes, typically 100/mm2
- Voltage of ~350 V across the Cu electrode creates a strong electric field in the hole ("avalanche") leading to amplification
- The ionization pattern is preserved by design with the electric field focusing the charges inside the holes



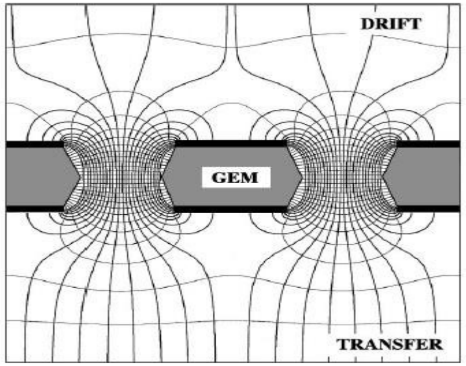
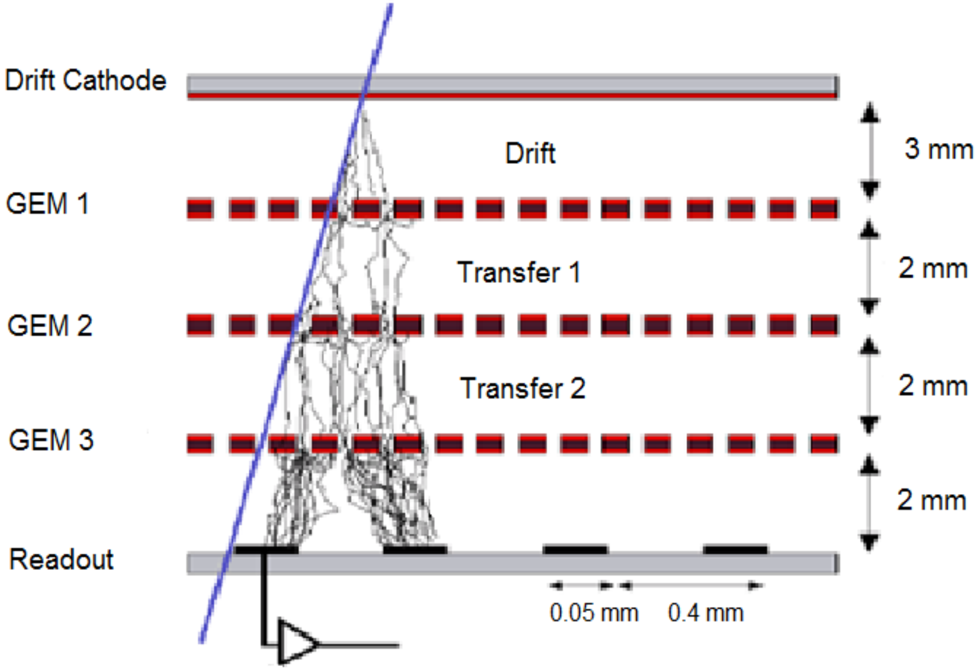


Figure 34 Electric field and equipotentials lines in the gas electron multiplier.

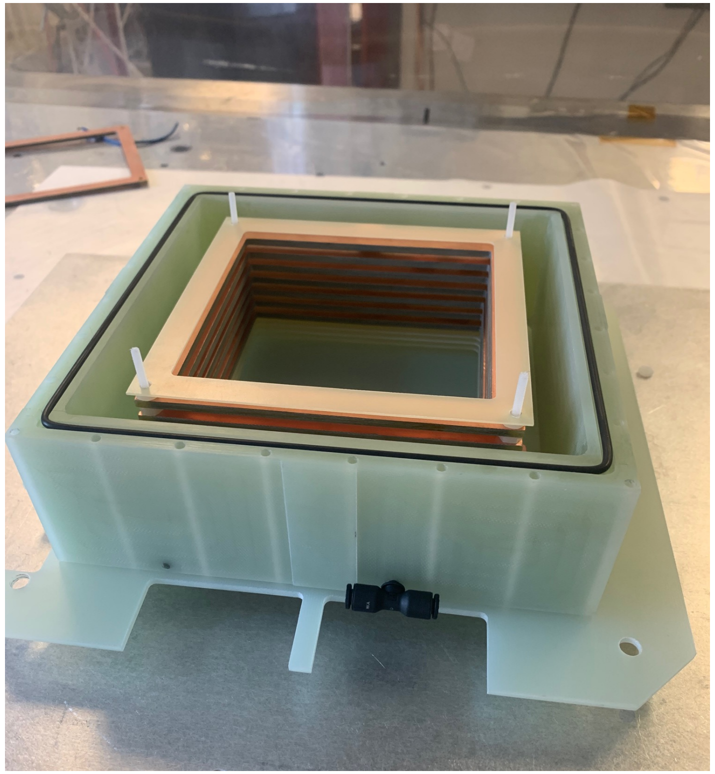
- High voltage is applied across GEM foils so high electric field makes an avalanche of electrons through the holes.
- Gas mixture of Argon and CO_2 in the volume proportion to 70:30.
  - Spatial resolution ~70 μm.

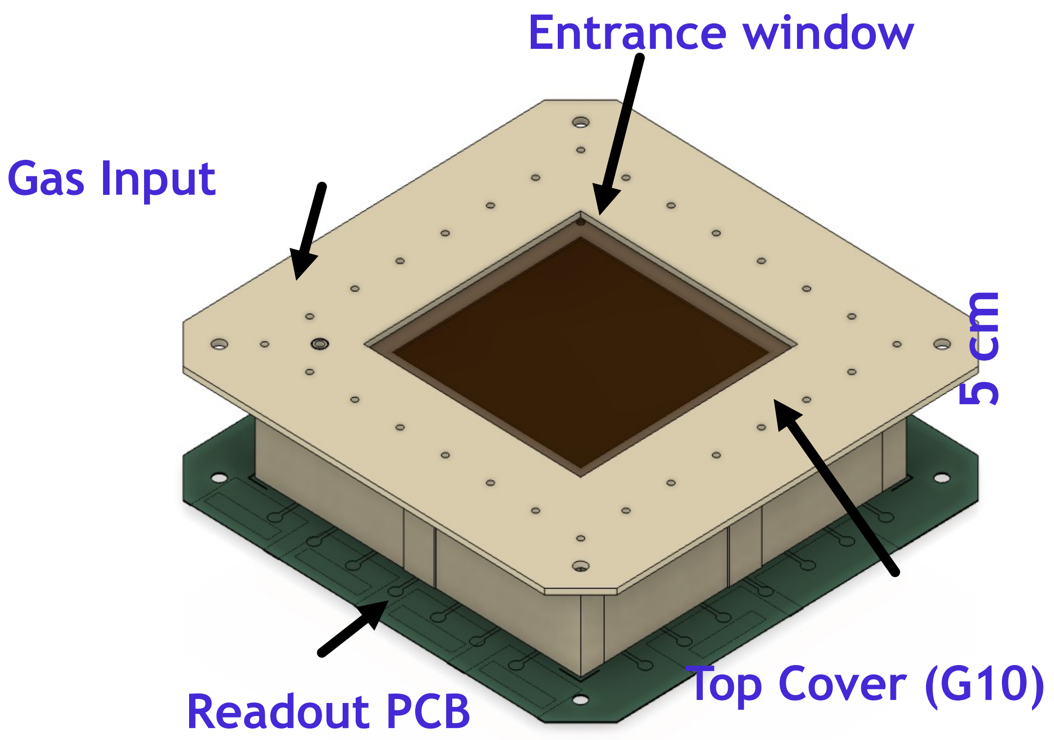


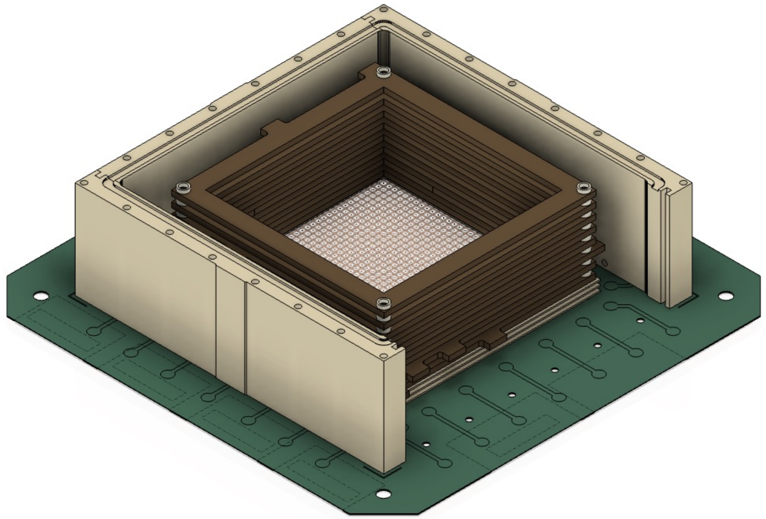
Triple-GEM concept

mTPC prototype for TDIS/nDVCS

- This prototype detector is a micro-TPC, a GEM detector with a few cm TPC stage.
- This one GEM detector gives both position and angle for a track.
- **This R&D will be very useful for future EIC endcap detectors.**

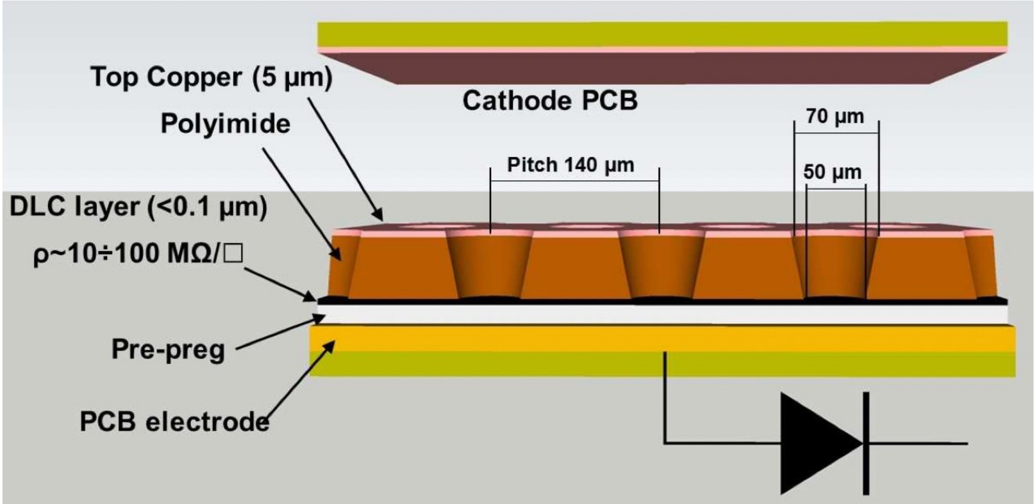






Alternative to triple-GEM detectors: Micro resistive-WELL ($\mu RWELL$) Concept

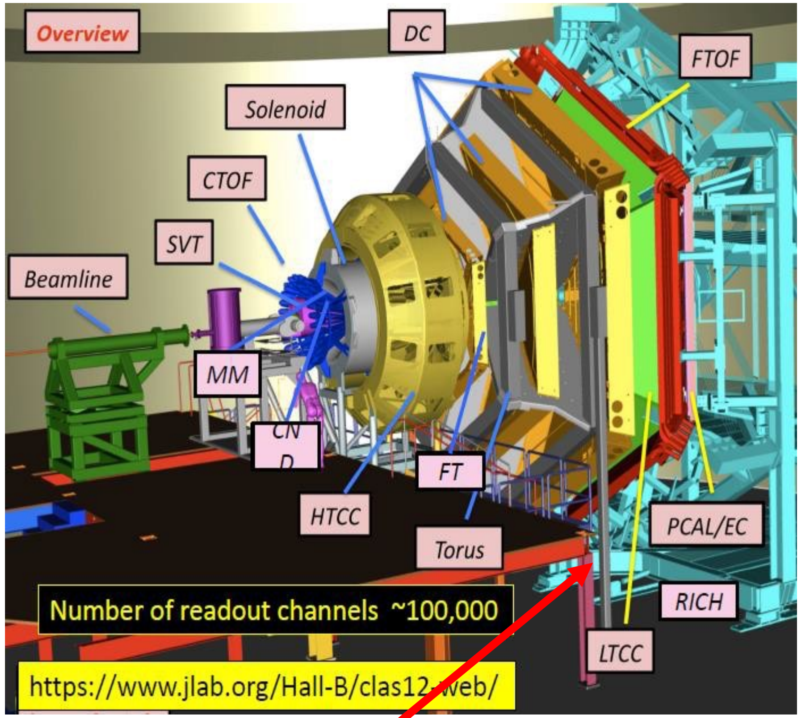
- A μRWELL detector has two main components: **the cathode** and the **μRWELL printed circuit board (PCB)**
  - The **μRWELL PCB** is realized by coupling:
    - Suitable WELL patterned Kapton foil as "amplification stage"
    - "Resistive stage" for discharge suppression & current evacuation
    - A standard readout PCB with pad/strip readout
  - Position resolution ~50 μm
- Since μRWELL detectors have one active foil only, easier than GEM to build cylindrical detectors:
    - **a very good choice for EIC barrel detectors**



G. Bencivenni et al.; 2015_JINST_10_P02008

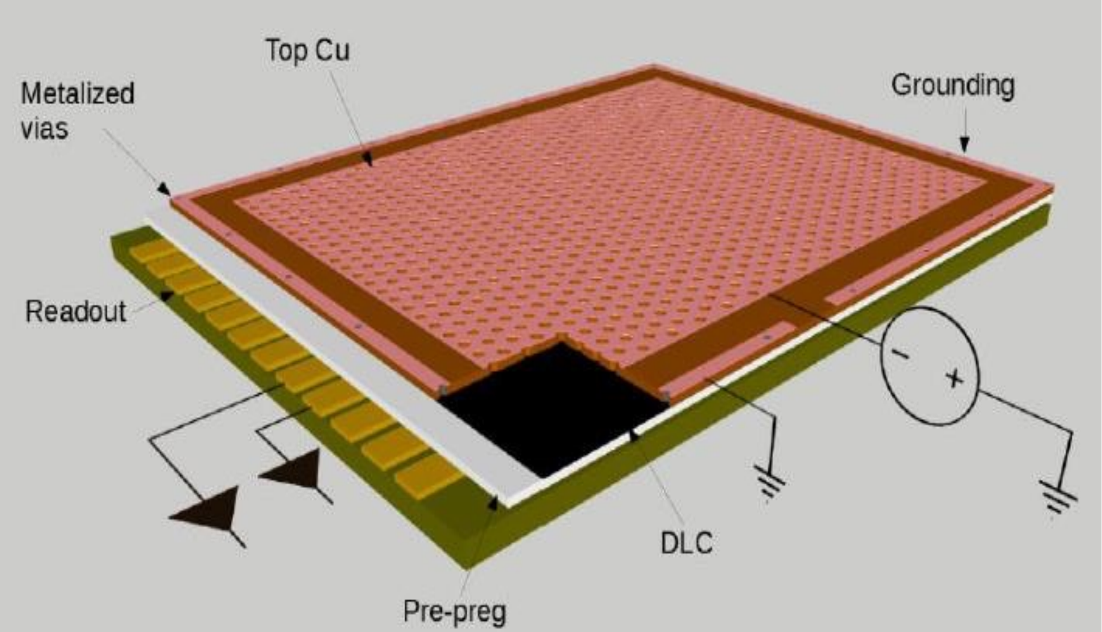
Great opportunity for large area uRwell R&D for EIC

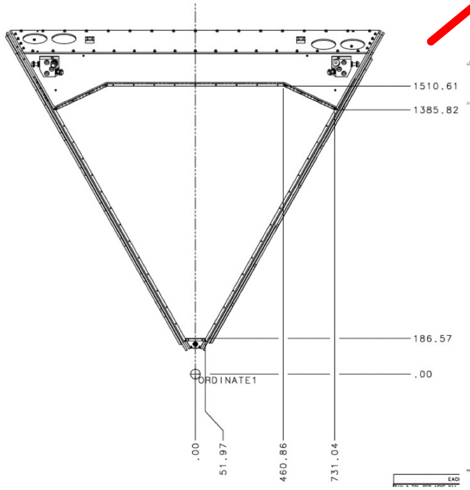
Hall B: Upgrade of CLAS12 Forward Tracker with μRWELL detectors

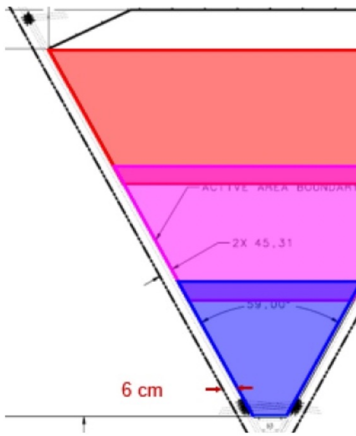


- Goal for upgrade: achieve higher luminosity
  $2\ x\ 10^{35}\ cm^{-2}\ s^{-1}$ than current running conditions
  $0.7x\ 10^{34}\ cm^{-2}\ s^{-1}$ per nucleon [physics tgts only]
- Limiting factor is forward tracker (FT)
- Introduce uRWELL technology in FT detectors
  - Low-material budget detector; "low mass"

μRWELL technology



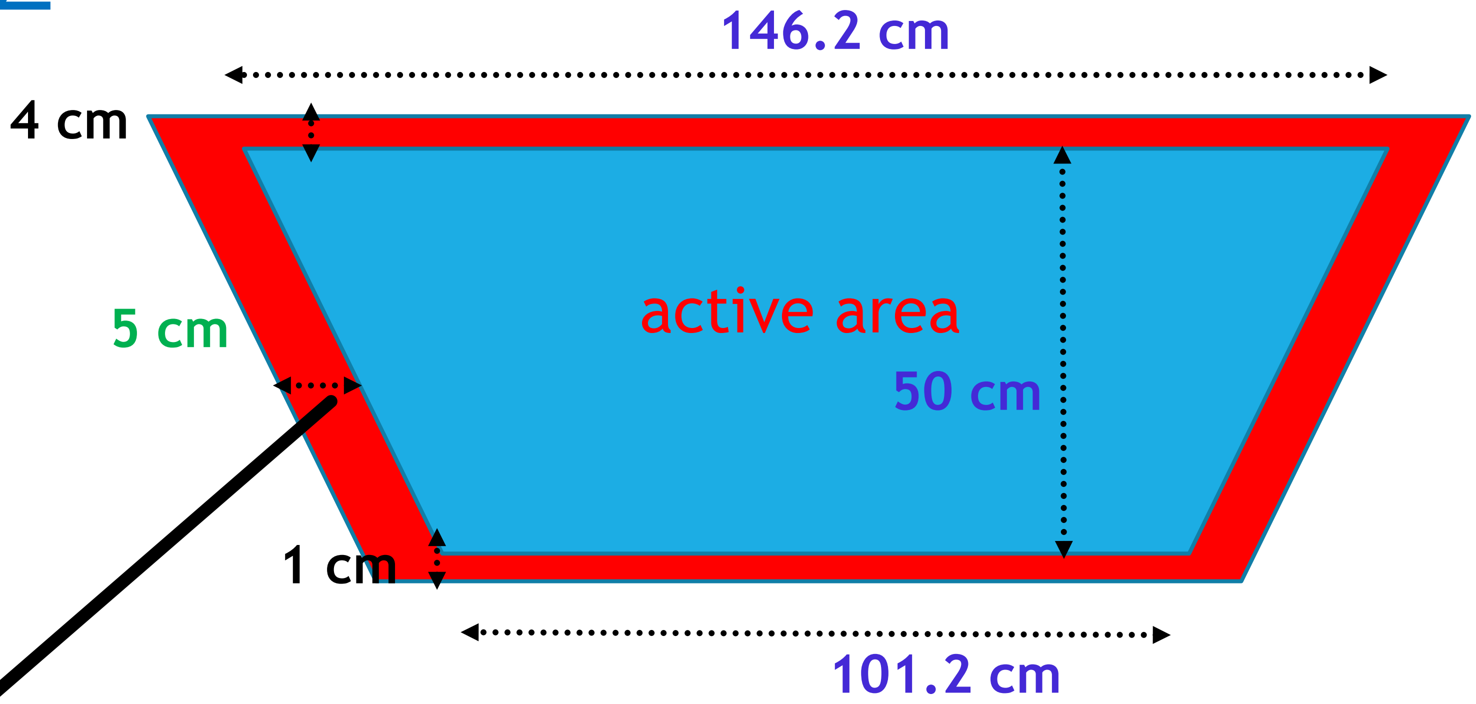


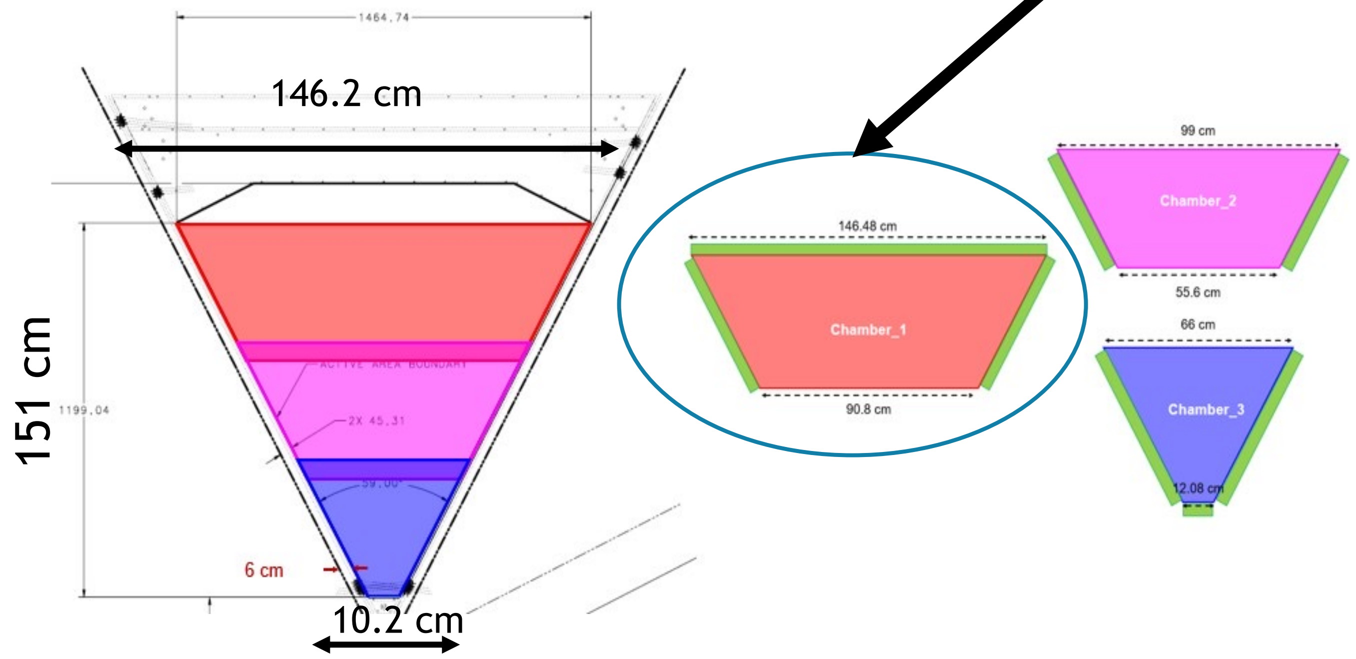


Design Large-area urWELL 146.2 cm x 101.2 cm Chamber 1 prototype at UVa/JLab

CLAS12 uRWELL Prototype design

- Mechanical design for CLAS12 prototype

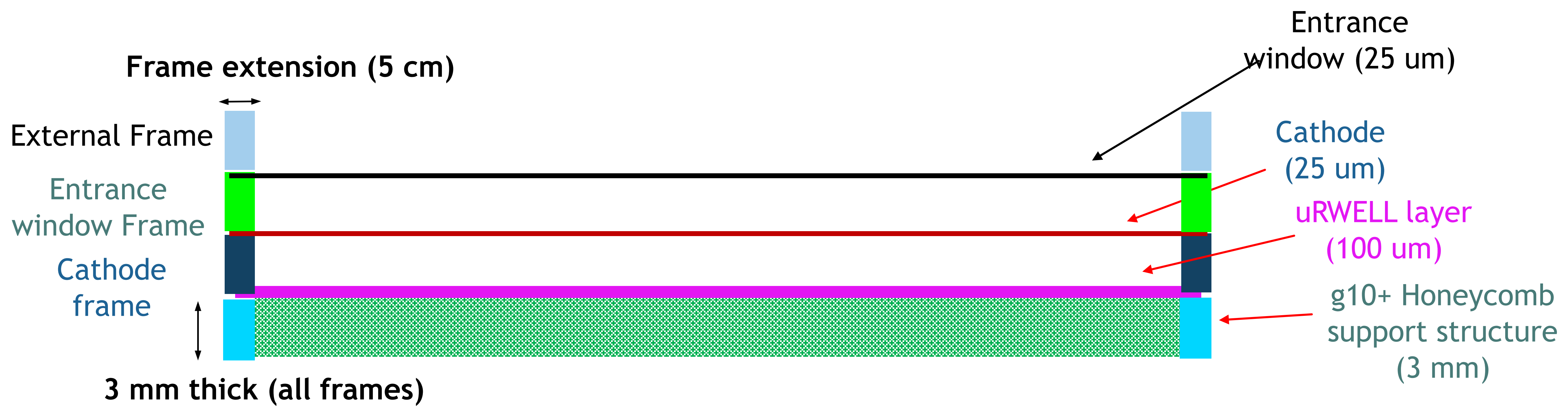




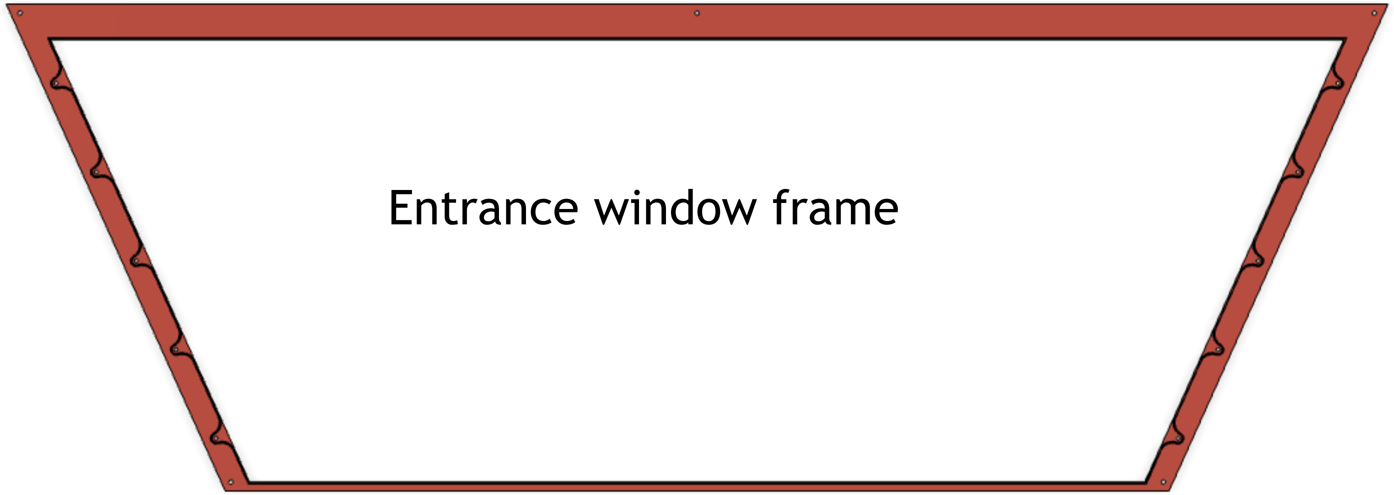
Active area = urWELL foil

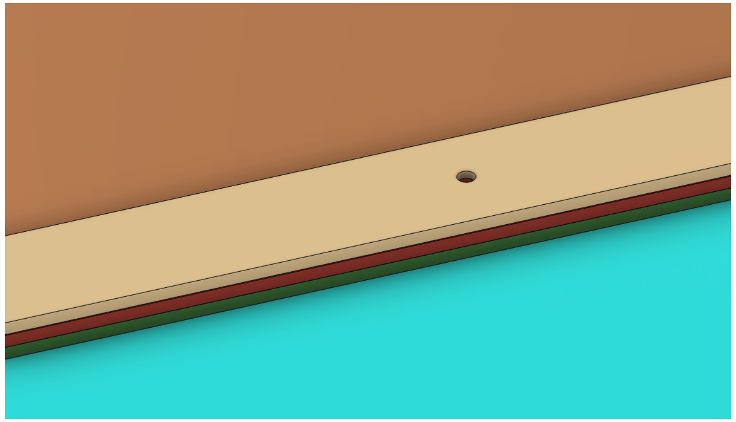
CLAS12/EIC uRWELL mechanical design layout

- Side-view

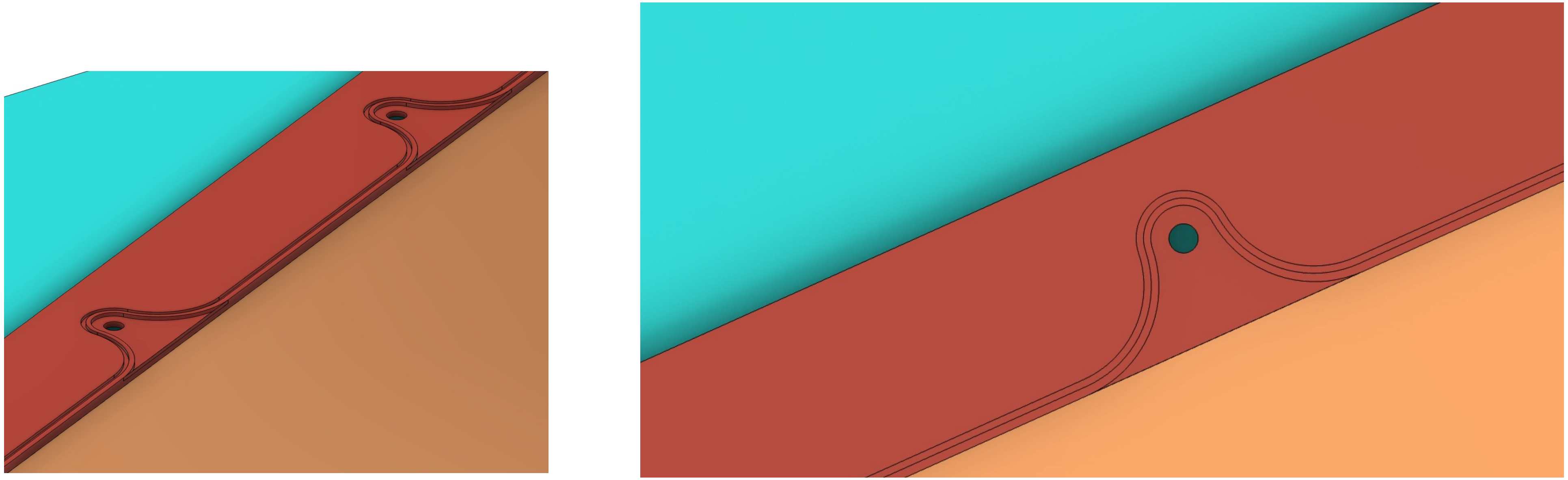


CLAS12/EIC uRWELL mechanical design



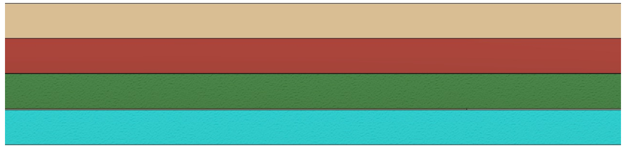


Top view of detector



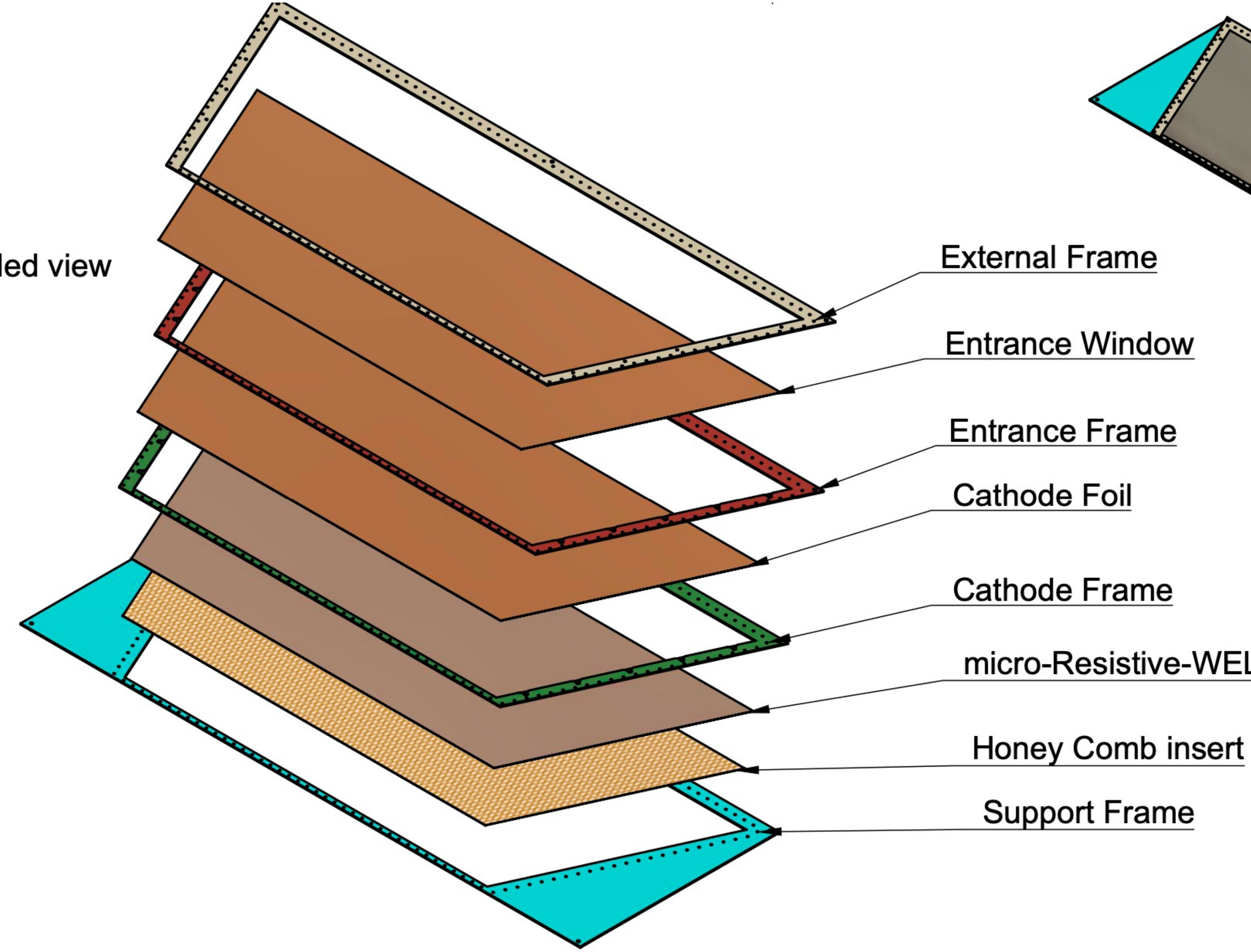
Close-up of gas hole design on one frame

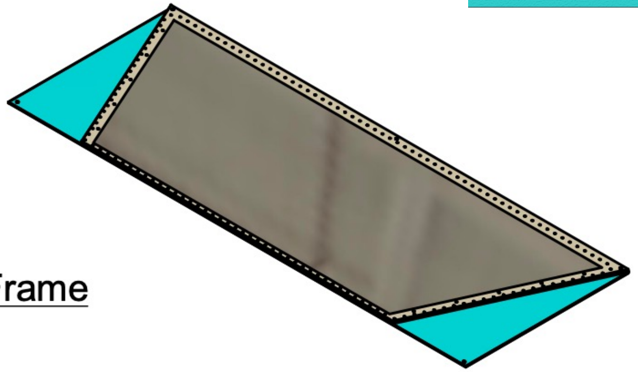
CLAS12/EIC uRWELL Prototype Explosive View



Side view

Exploded view





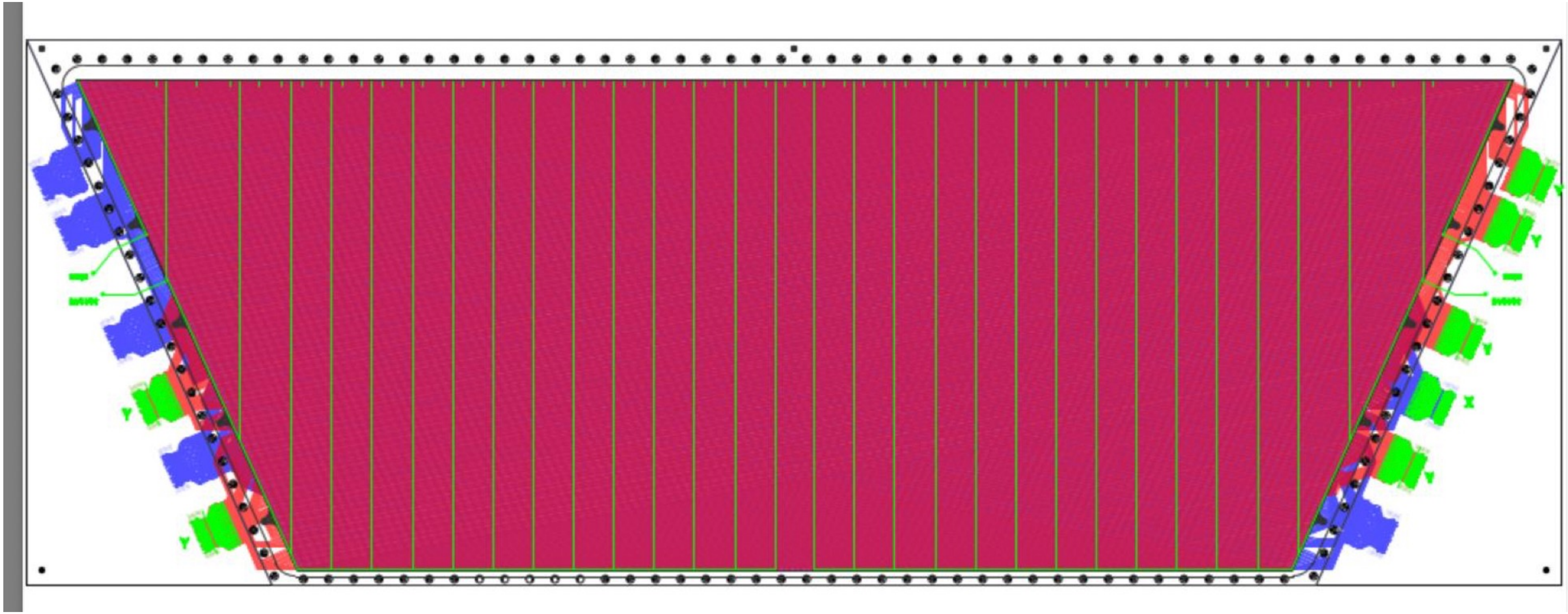
Isometric view

***Same design used for large-area** EIC uRWELL detector – designed by Uva..in the works now*

- *Low-mass, low-readout channel count uRWELL detector suitable for end-cap detection systems in the EIC*

University of Virginia

uRWELL Foil (Gerber view)



Summary and Outlook

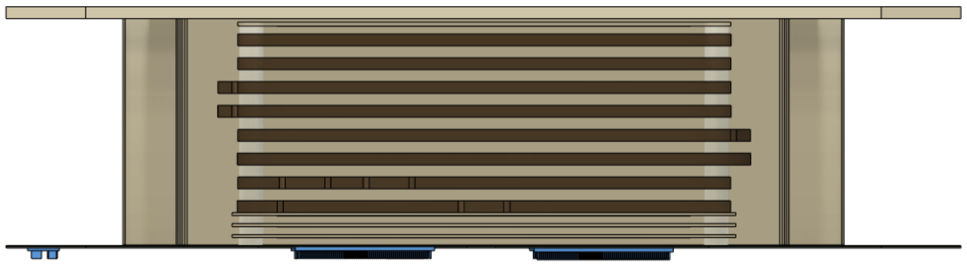
- Opportunities for spectator tagged physics (TDIS and tagged neutron DVCS) in Hall A of JLab
- New detector, multiple-Time Projection Chamber (mTPC) will detect low momenta recoil protons in the TDIS experiment in Hall A
- Micro-Pattern Gas Detectors (MPGDs) [GEMs, Micromegas] prominent in high and medium energy physics experiments..excellent tracking and triggering capabilities!
  - Designed a triple GEM based “micro TPC” prototype (a few cm TPC stage) to test important features of the mTPC for the TDIS experiment
    - **Useful R&D for future EIC endcap detectors**
  - CLAS12 uRWELL detector for High luminosity upgrade:
    - The front tracker for region I design will adopt uRWELL technology. Prototype design is finalized, waiting for frames to arrive
    - Same mechanical design will be adopted for EIC uRWELL end-cap detector design (EIC fellowship work)

Back up

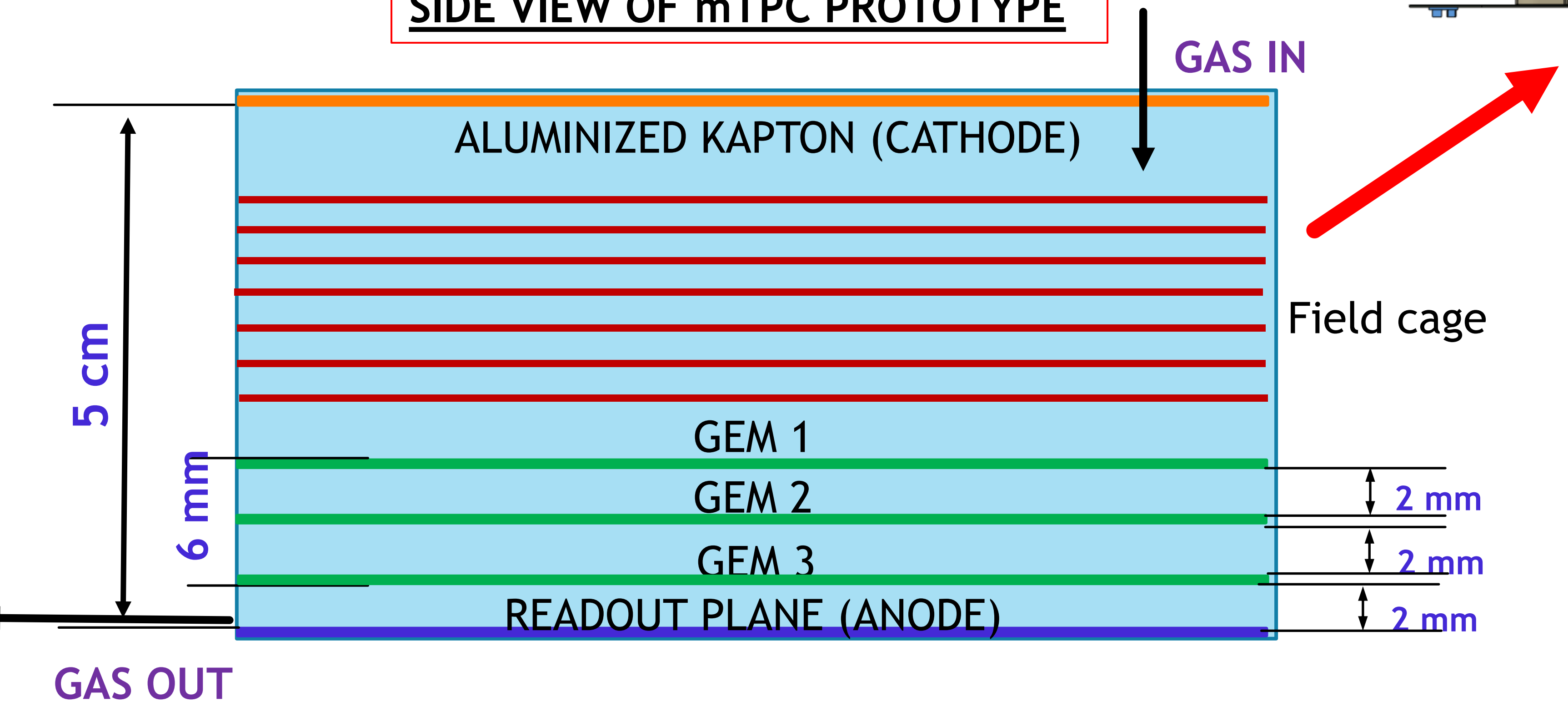
mTPC prototype

- mTPC square prototype at UVa → 10 x 10 cm^2 GEM active area:
  - Three GEMs stacked with 2 mm spacing (provided by spacers)
  - Eight 3-mm-thick field cage frames each separated by
  - 3 mm
  - ~5 cm space between top GEM foil and bottom of cathode

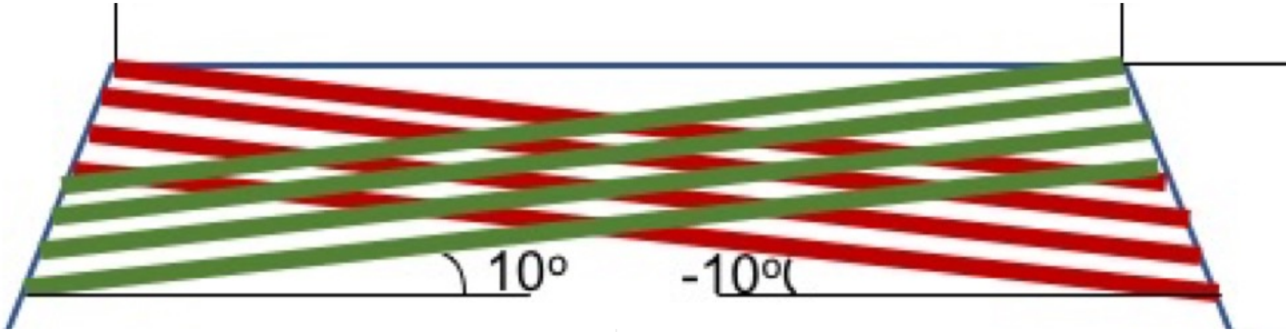
3D CAD view of stacked layers



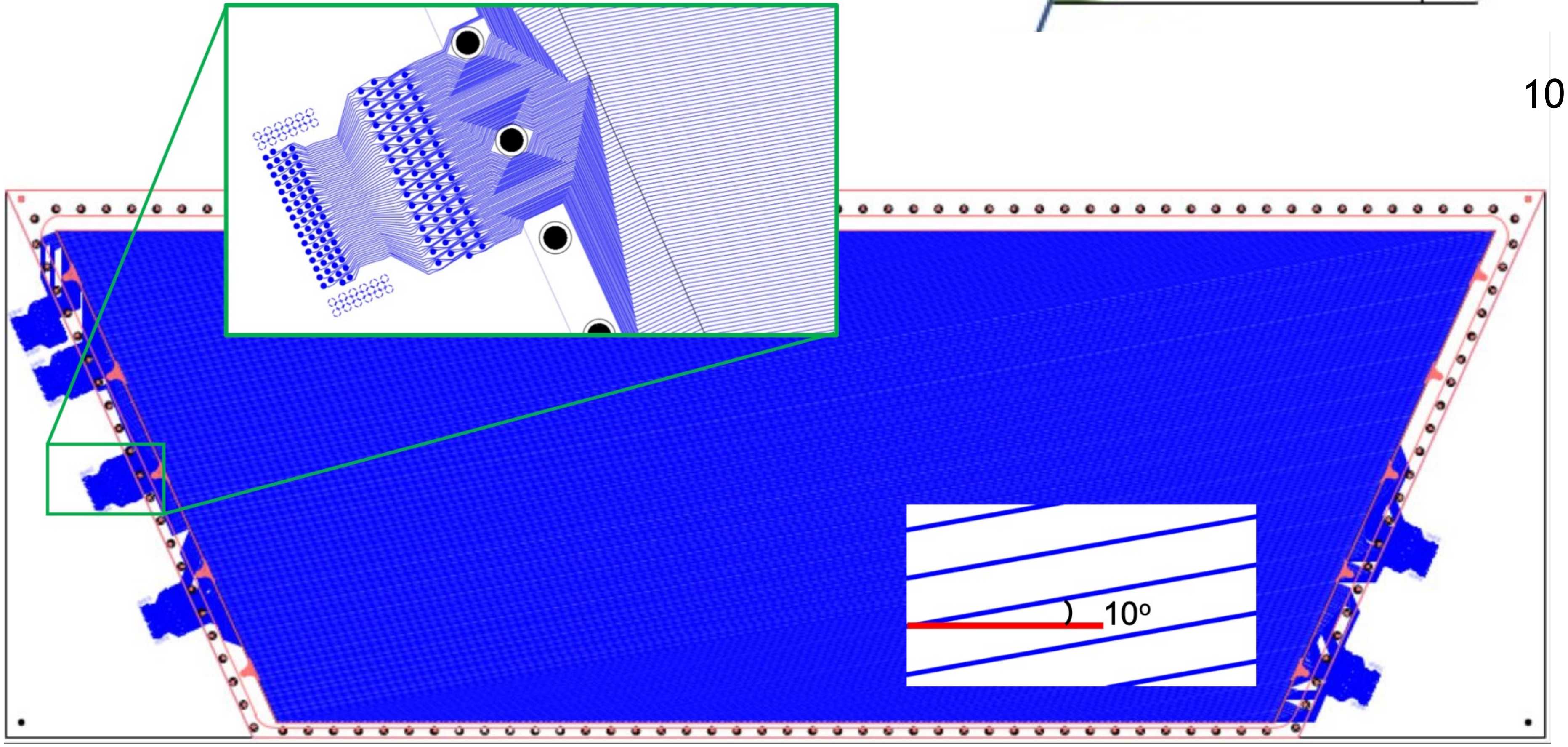
SIDE VIEW OF mTPC PROTOTYPE



“UV” layout



10 degree stereo angle



Tagged Deep Inelastic Scattering (TDIS) in Hall A

DIS experiment:
11 GeV electron beam

+

We need to detect low momentum protons:

60 – 400 MeV/c

eH $\rightarrow$ 1 proton

eD $\rightarrow$ 2 protons with common vertex

Under these kinematics:

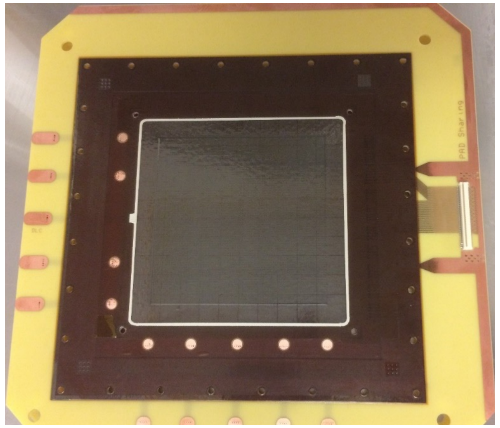
$8 < W^2 < 18\ GeV^2$
$1 < Q^2 < 3\ (GeV/c)^2$
$0.05 < x < 0.2$

High luminosity is required $\sim 10^{36}$ Hz/cm

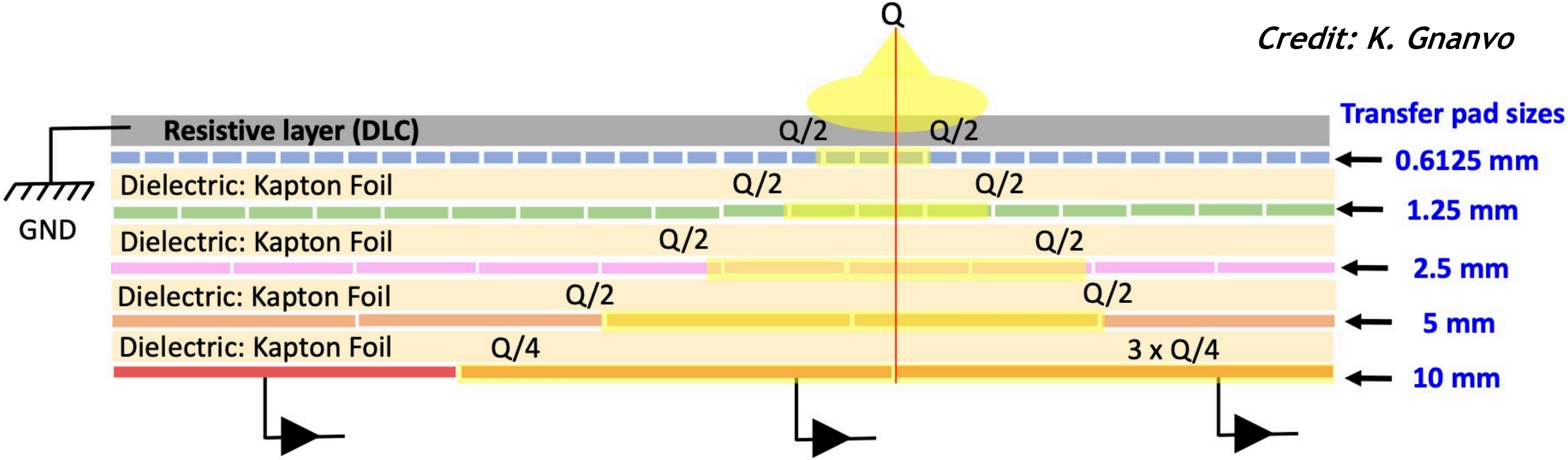
Low-channel count approach: Capacitive sharing readout

- Principle of **capacitive-sharing large-pad Readout**
- Vertical stack of pads layers ⇨ Transfer of initial charge from MPGD by **capacitive coupling**
- Space arrangement of the pads and doubling pad size from one layer to the one below allow:
  - the preservation of the spatial resolution performance (expected better than 100 µm for 1 cm^2 pad readout)
  - significant reduction of number of electronic channels to be read out
- Low cost and highly flexible readout technology
  - Suitable to a variety of applications related to EIC detector R&D programs

large-pad readout prototype @ UVa

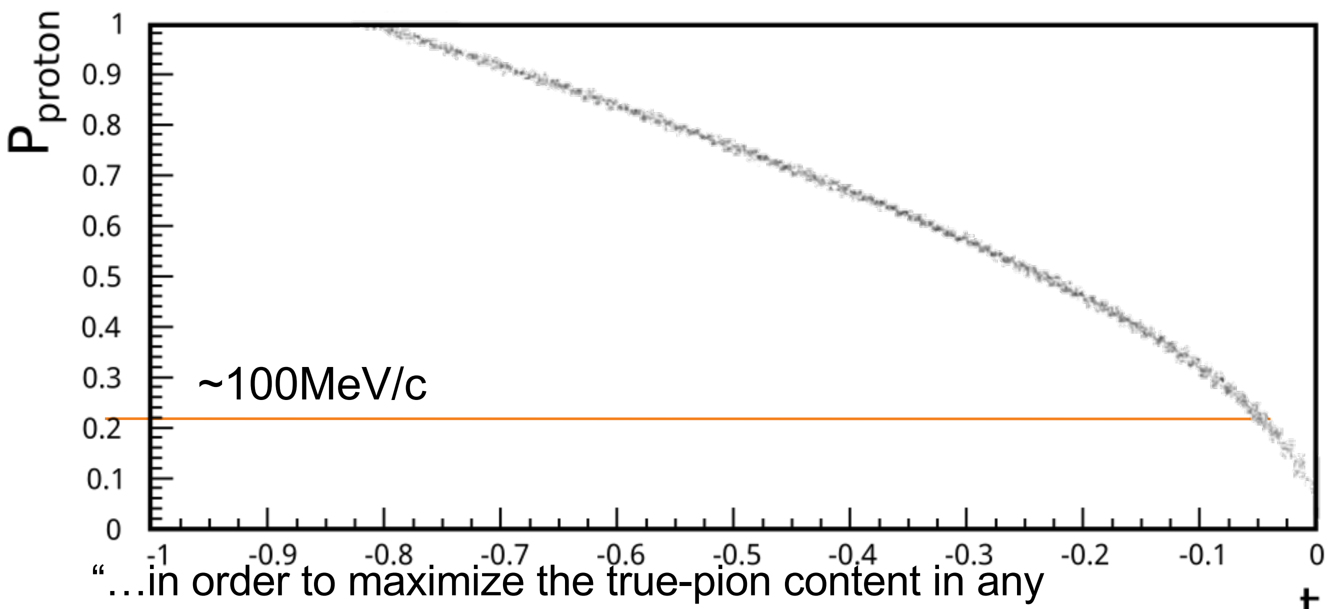


Credit: K. Gnanvo



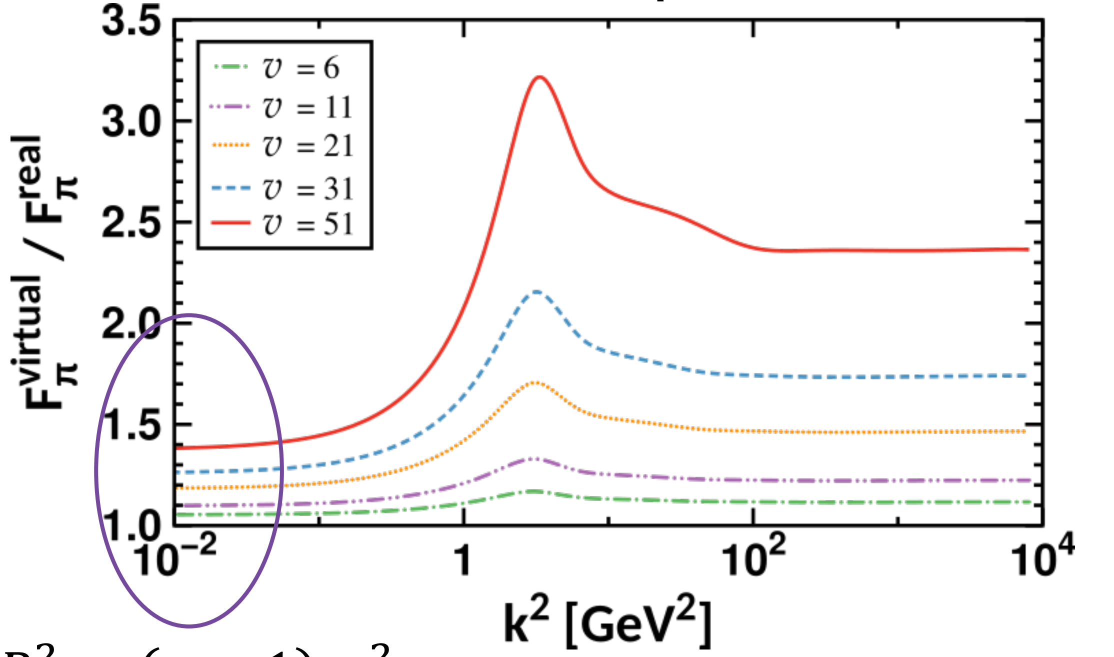
How to access the physical pion?

(GeV/c) **Sullivan process kinematics**



"…in order to maximize the true-pion content in any measurement, kinematic configurations are chosen in order to minimize | -*t* | "

Ratio of off-shell to on-shell pion EM form factors



$$P^2 = (v-1)m_\pi^2$$

Proton momentum

$v \geq 0$: pion virtuality

P: pion momentum (k-k')

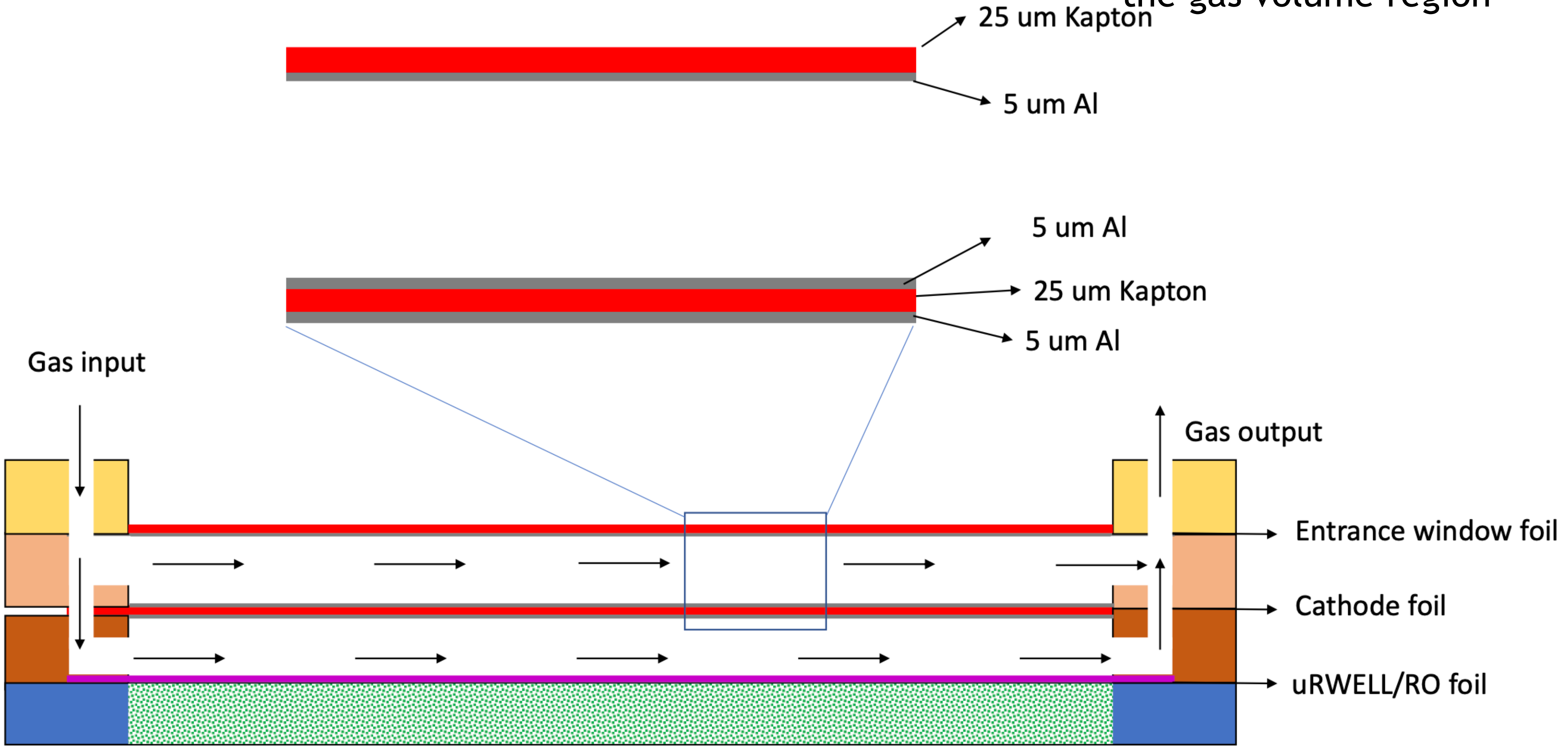
virtuality-independent form factor implies virtuality-independent pion structure function

Detection of very low momentum recoil protons

Si-Xue Qin, Chen Chen, Cédric Mezrag, and Craig D. Roberts
Phys. Rev. C 97, 015203 (2018)

CLAS12 FT uRWELL prototype (Chamber 1)

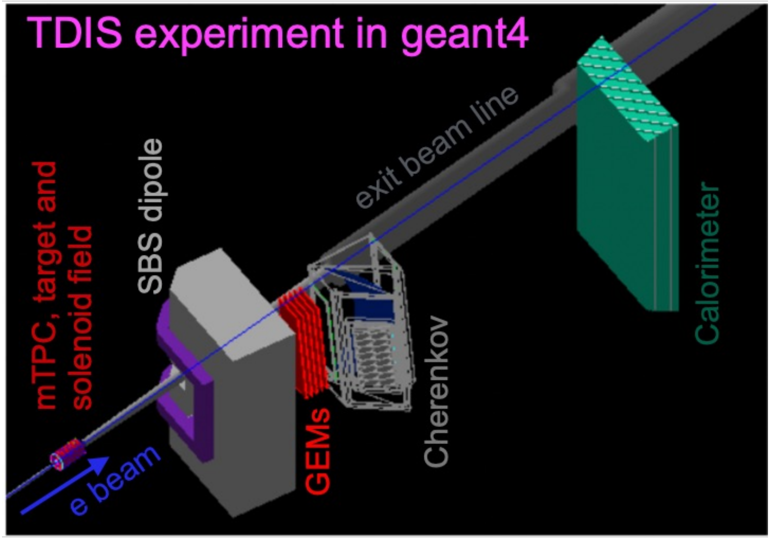
- Gas will flow horizontally in the gas volume above and below the cathode foil. It will remain flat by pressure-equalizing and maintain the uniform gap in the gas volume region

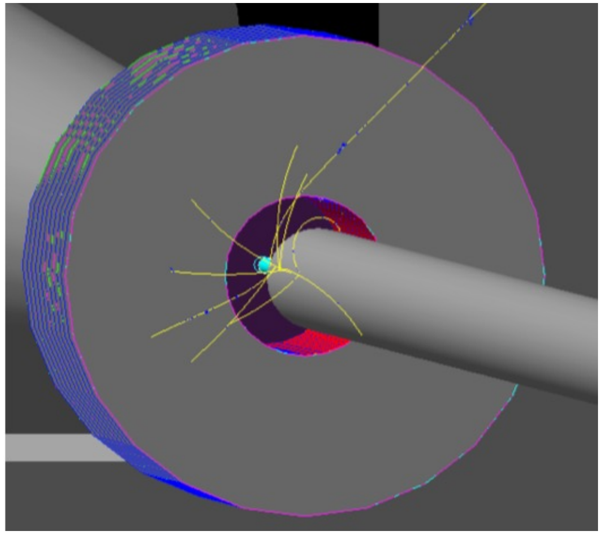


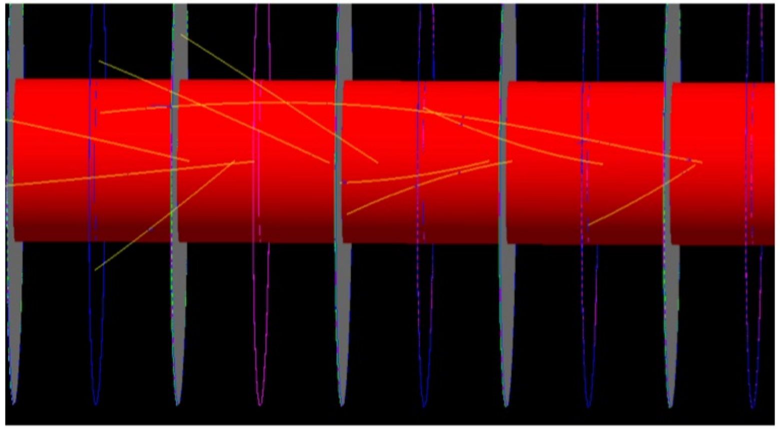
Credit: *K. Gnanvo (JLab)*

mTPC Simulation Status: digitization

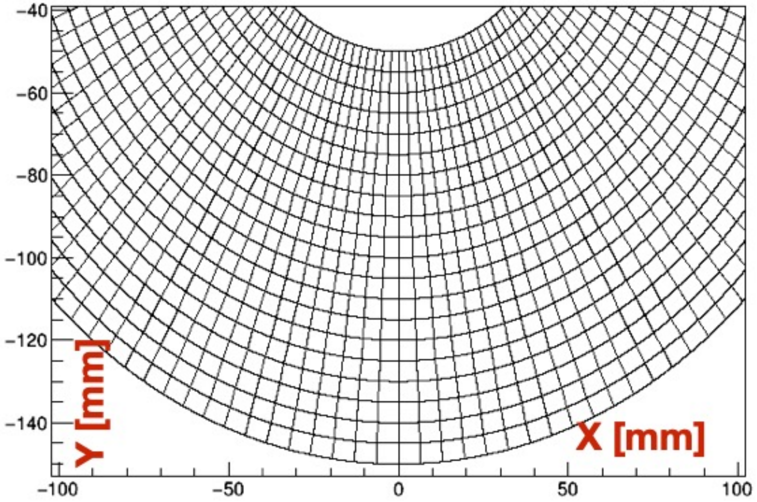
Credit: R. Montgomery (University of Glasgow)



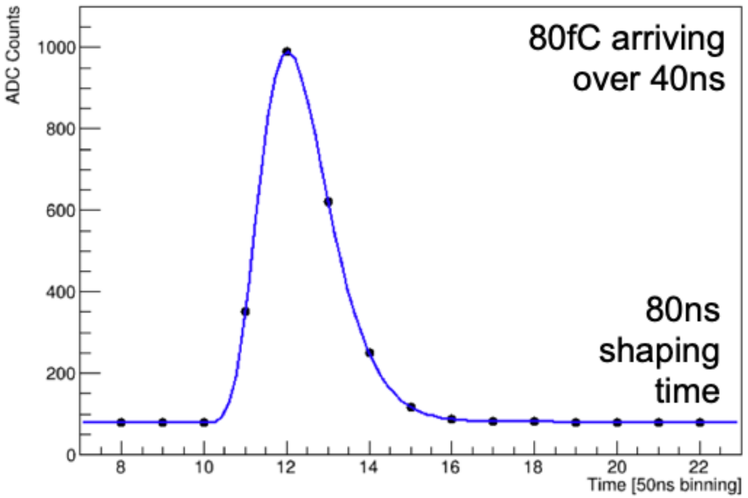




SBS geant4 framework g4sbs is used for simulation studies



- Example readout pad layout
- 22 rings in radial direction
- 122 pads/ring (area increases with radius)



- Markers are sampled points
- Curve is convoluted output pulse shape from SAMPA impulse responses to charge over time window

- Digitisation of signals extracted from mTPC plus SAMPA readout
- Entire chain of signal considered from energy deposition, to charge diffusion, to SAMPA shaping
- Tracking studies using digitised output is underway
- Updated background rate studies are underway

mTPC Simulation Status: Background rate studies

Credit: C. Gayoso (MSU)

- Background rates from Quasi-elastic (Deuterium)
  - 480 MHz (protons)

J. W. Lightbody Jr. and J. S. O'Connell , Computers in Physics 2, 57-64 (1988)
https://doi.org/10.1063/1.168298.

- Background rates from DIS
  - Proton target:
    - π^{+}: 730 kHz
    - π^{-}: 590 kHz
  - Neutron target:
    - π^{+}: 430 kHz
    - π^{-}: 690 kHz

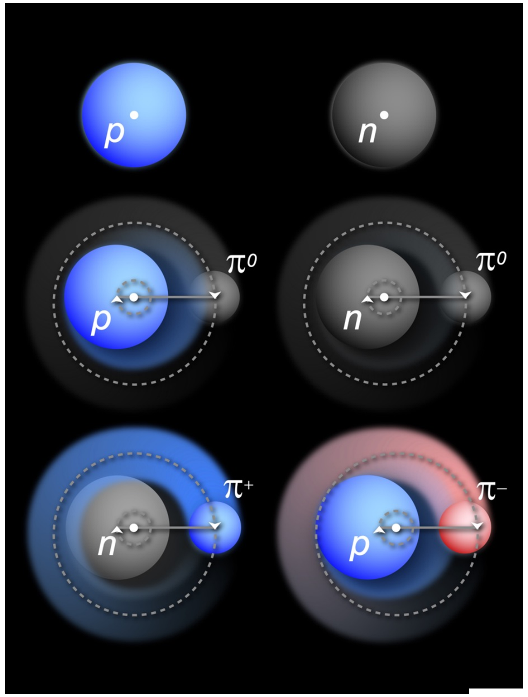
Hydrogen DIS rate: ~1.3 MHz

Deuterium DIS rate (naïvely p+n): ~2.4 MHz

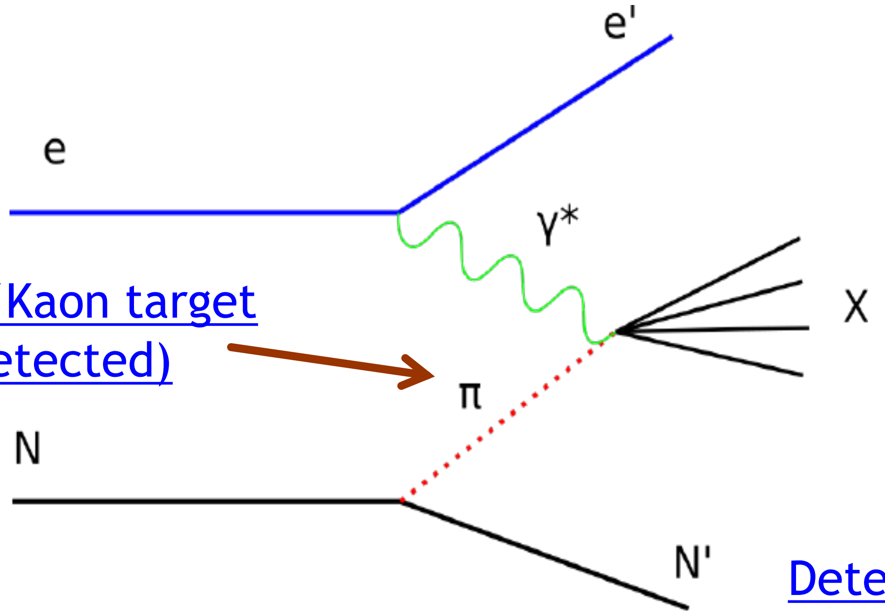
Different quasi-elastic generators will be tested to compare rates, as **bggen** → Hall D photoproduction code, adapted by R. Beminiwattha to allow electroproduction generation.

TDIS: Physics Objects for Pion/Kaon Structure Studies

Sullivan process – scattering from nucleon-meson fluctuations



Detect scattered electron



Pion/Kaon target (undetected)

DIS event – reconstruct x, Q^2, W^2, also M_X (W_π) of undetected recoiling hadronic system

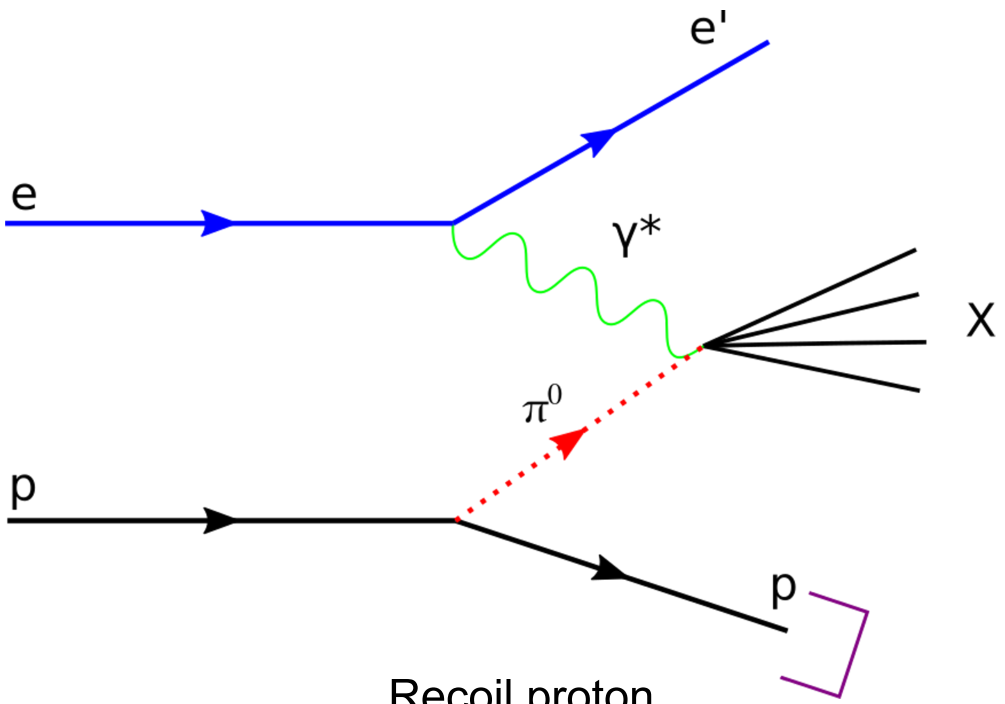
Detect "tagged" proton/neutron/lambda

$$F_2^{LP(3)} = \sum_i \left[\int_{t_0}^{t_{min}} f_i(z,t)dt \right] F_2^i(x_i, Q^2)$$

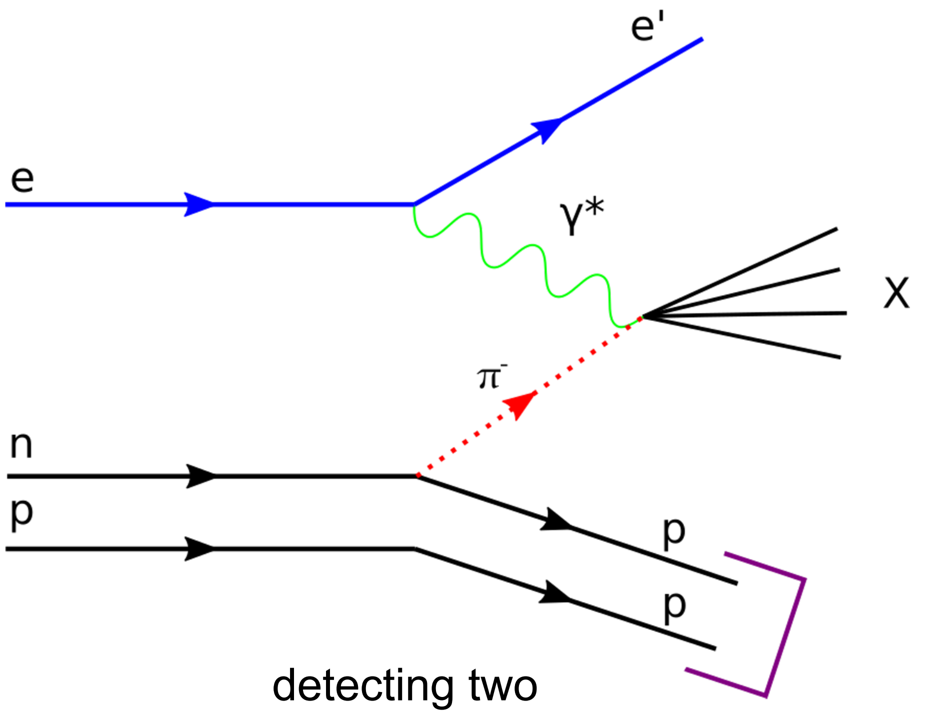
$i = \pi, \rho, \ldots$

"Flux factor"

Pion structure from Sullivan process: Tagged Deep Inelastic Scattering (TDIS)



Recoil proton
(backward going
slow proton) **TAG**



detecting two
protons with
common vertex
Spectator proton

- Effective π^0 target

- Effective π^- target

Tagged Deep Inelastic Scattering (TDIS) in Hall A

DIS experiment:
11 GeV electron beam

+

We need to detect low momentum protons:

60 – 400 MeV/c

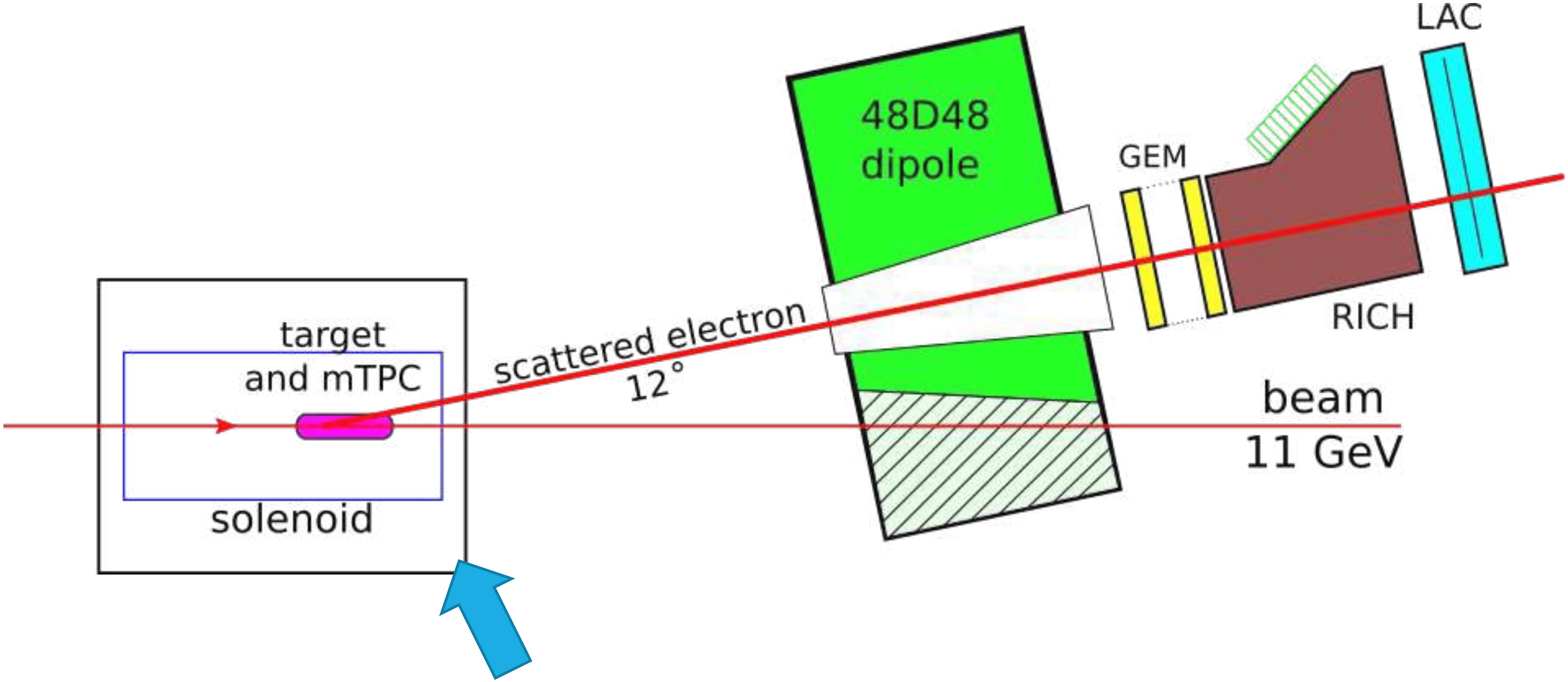
- eH → 1 proton
- eD → 2 protons with common vertex

Under these kinematics:

$8 < W^2 < 18\ GeV^2$
$1 < Q^2 < 3\ (GeV/c)^2$
$0.05 < x < 0.2$

High luminosity is required $\sim 10^{36}$ Hz/cm

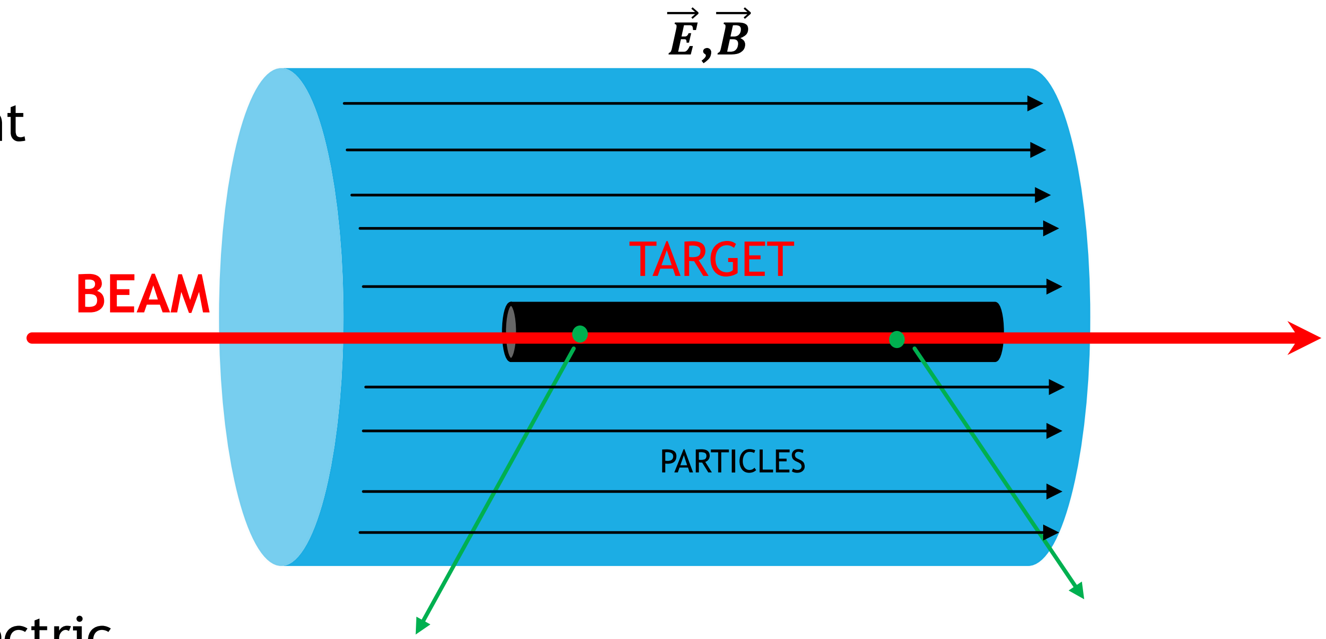
TDIS in Hall A: Experimental layout



A new detector → mTPC: multi-Time Projection Chamber to measure low-momentum recoil protons

Time Projection Chamber (TPC) concept

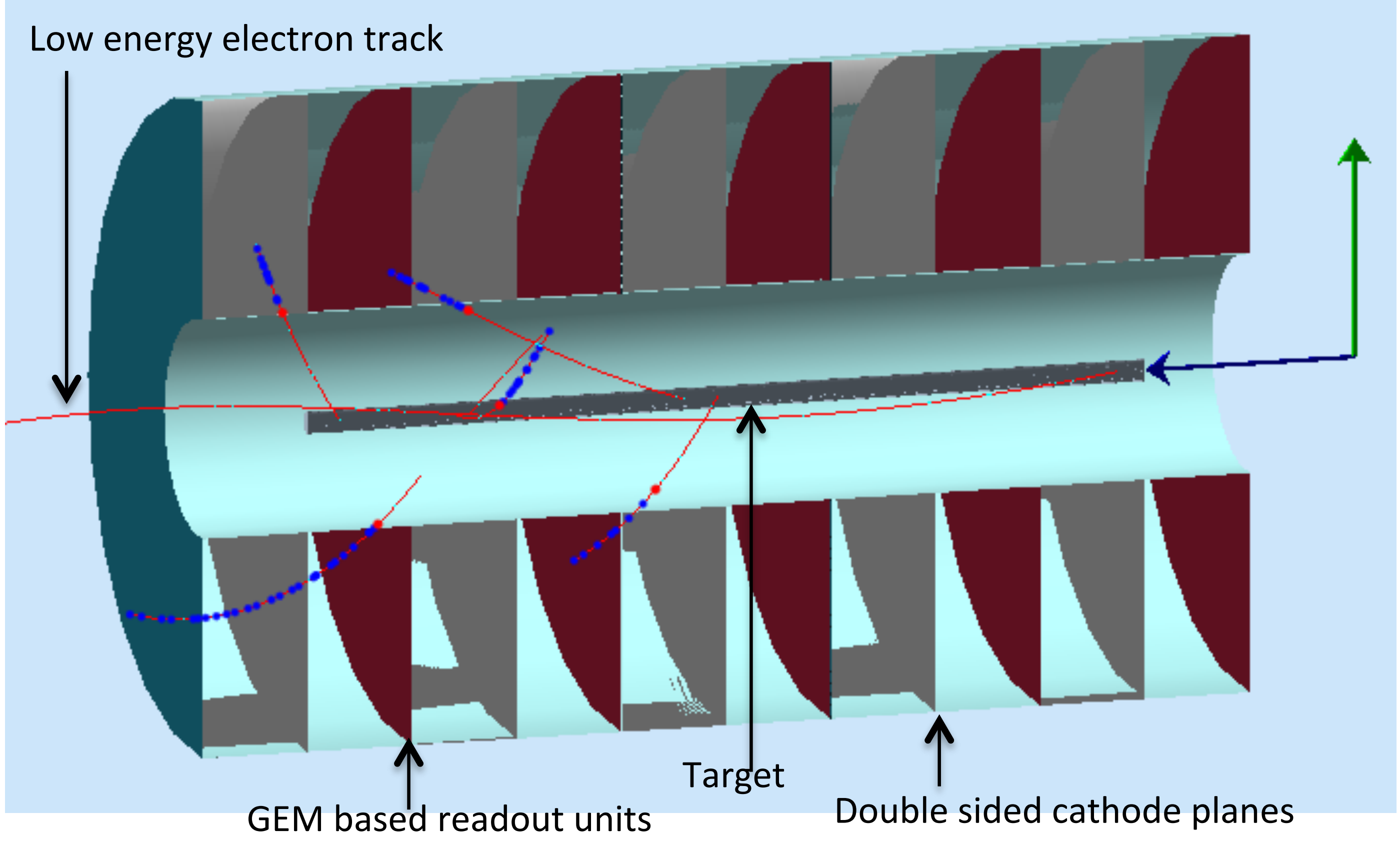
- TPC tracking is different than typical 2D GEM tracking→ TPCs provide FULL 3D picture of the ionization deposited in the gas
  - Useful for tracking → can map position and angle of particle!
  - This "field cage" allows direct measurement of the position of particle **BUT $\vec{E}$ must be uniform (good t→ x conversion)**
    - Uniformity achieved by concentric electrode strips placed on the inside of the TPC
- How to measure the momentum of particle?
  - Need strong magnetic field parallel to electric field

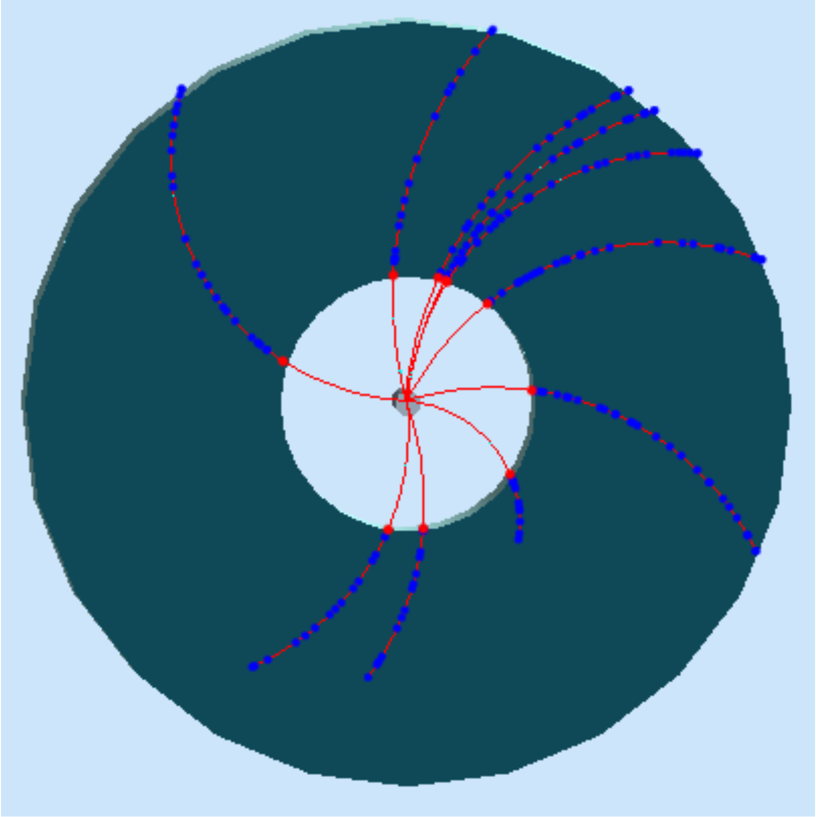


Downside of a single radial TPC → high rates
SOLUTION: multiple TPC!

GEM-based mTPC for the TDIS experiment

- Will be placed in the bore of the UVa superconducting solenoid magnet (L=152.7 cm, $\vec{B}$= 4.7 T) to fit the requirement of strong magnetic field parallel to $\vec{\boldsymbol{E}}$
- Consist of 10 TPC modules to form one composite mTPC → takes care of high rates compared to single/radial TPC

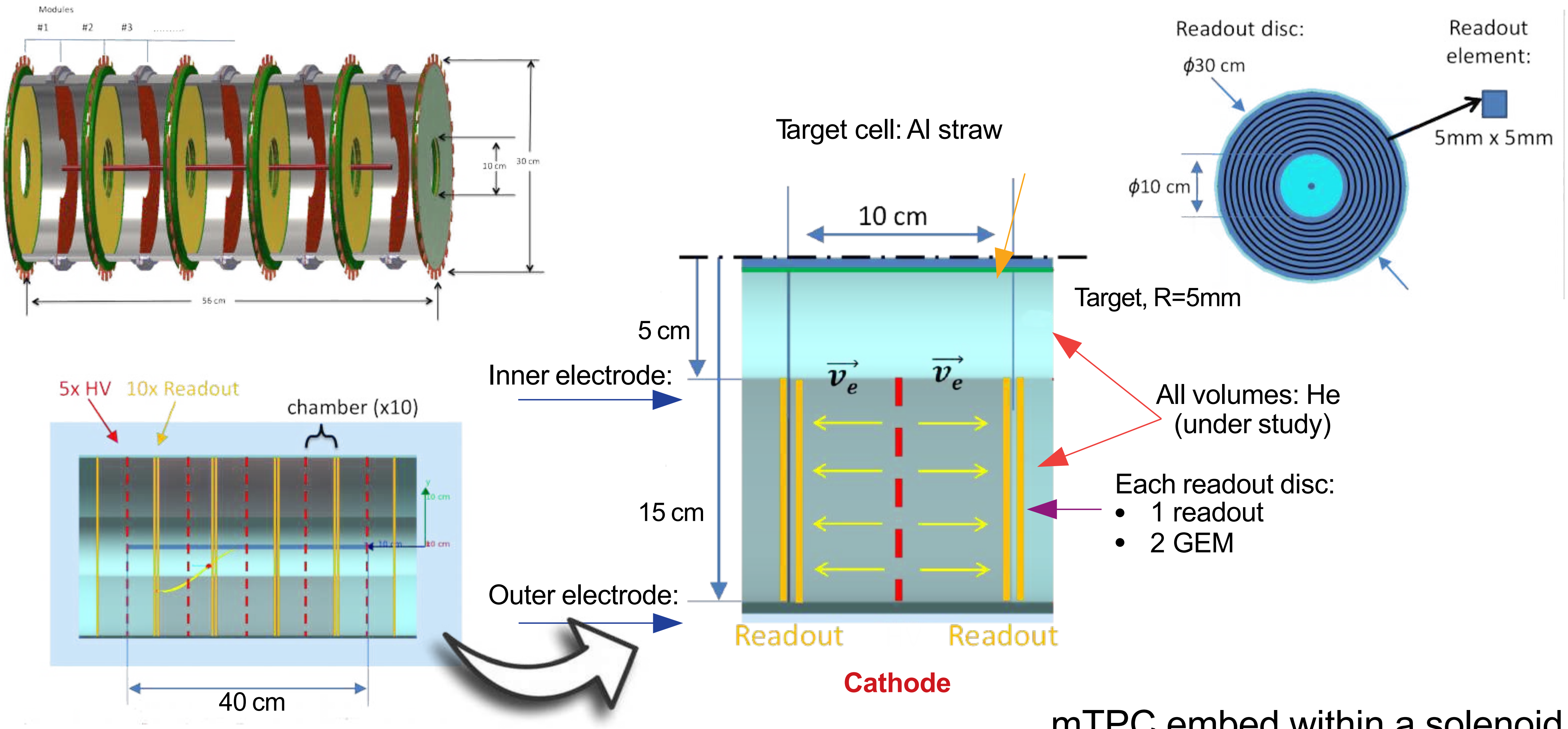




Ptcl tracks

Dimensions : 55 cm long, Inner (outer) radii = 5 cm (15 cm)

The multiple-Time Projection Chamber (mTPC)

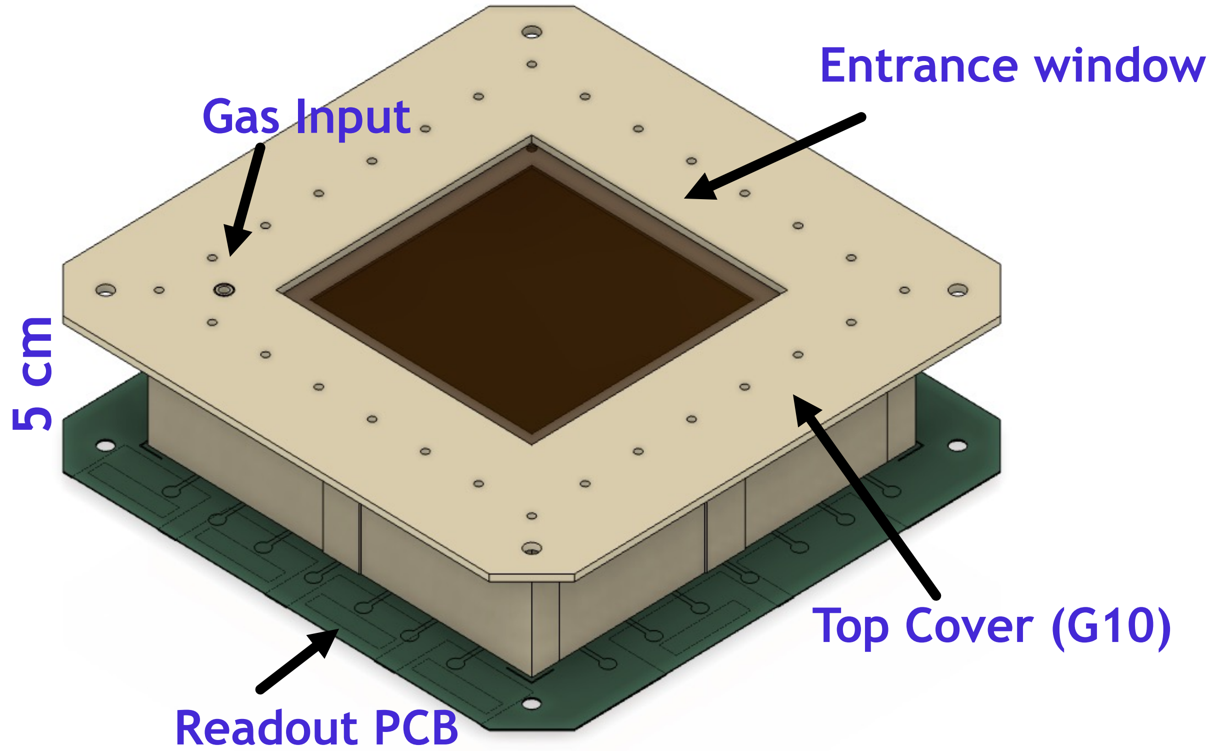


mTPC embed within a solenoid

mTPC prototyping and development

- This prototype detector is a micro-TPC, a GEM detector with a few cm TPC stage.
- This one GEM detector gives both position and angle for a track.
- **This R&D will be very useful for future EIC endcap detectors**

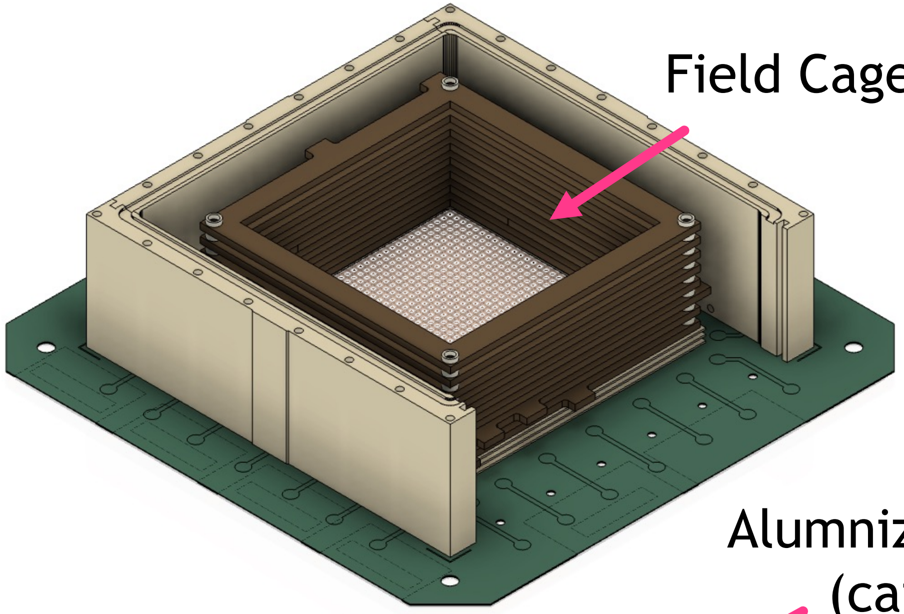
- Prototype layout:
  - Anode (Readout PCB)
  - Triple-GEM layout (10 x 10 cm^2 GEM active area): three GEMs stacked with 2 mm spacing provided by spacers
  - *Field cage:* 5 cm space between anode and cathode endplates
  - Aluminized Kapton to act as cathode
  - Entrance window



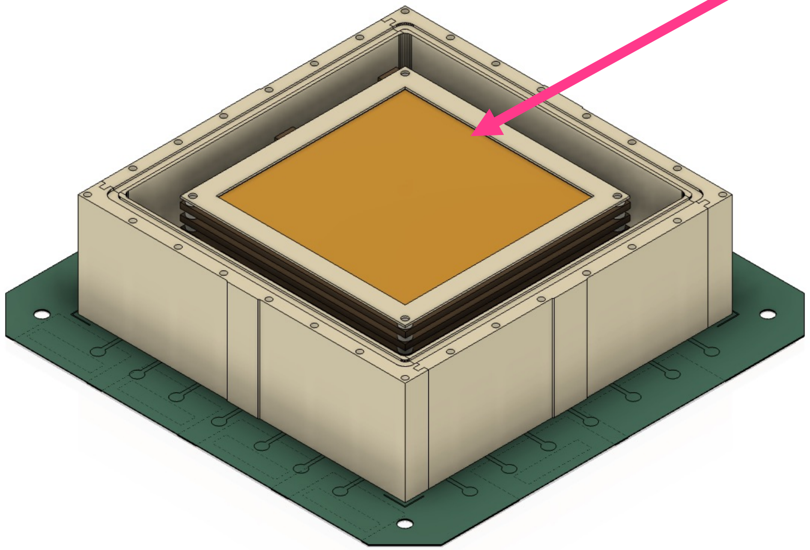
mTPC prototyping and development

View of square prototype without top cover

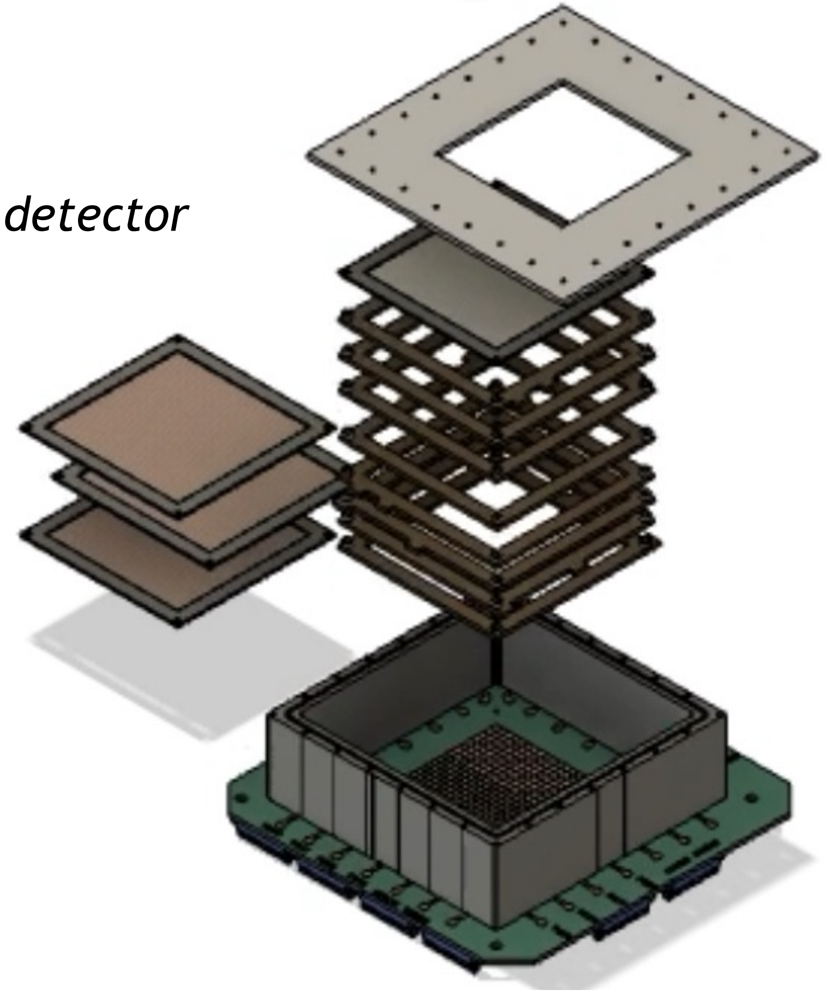
Field Cage



Alumnized Kapton
(cathode)



Explosive view of detector

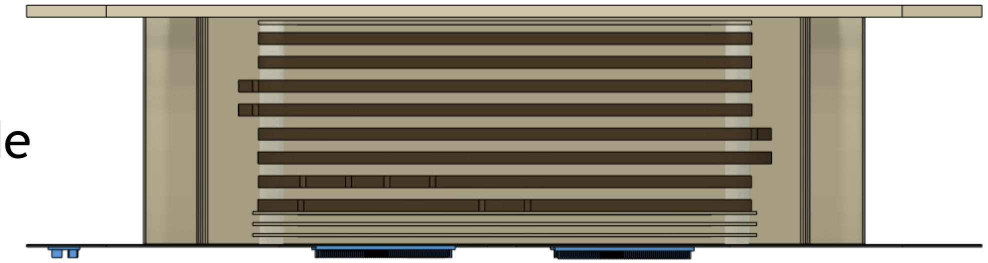


mTPC prototyping and development

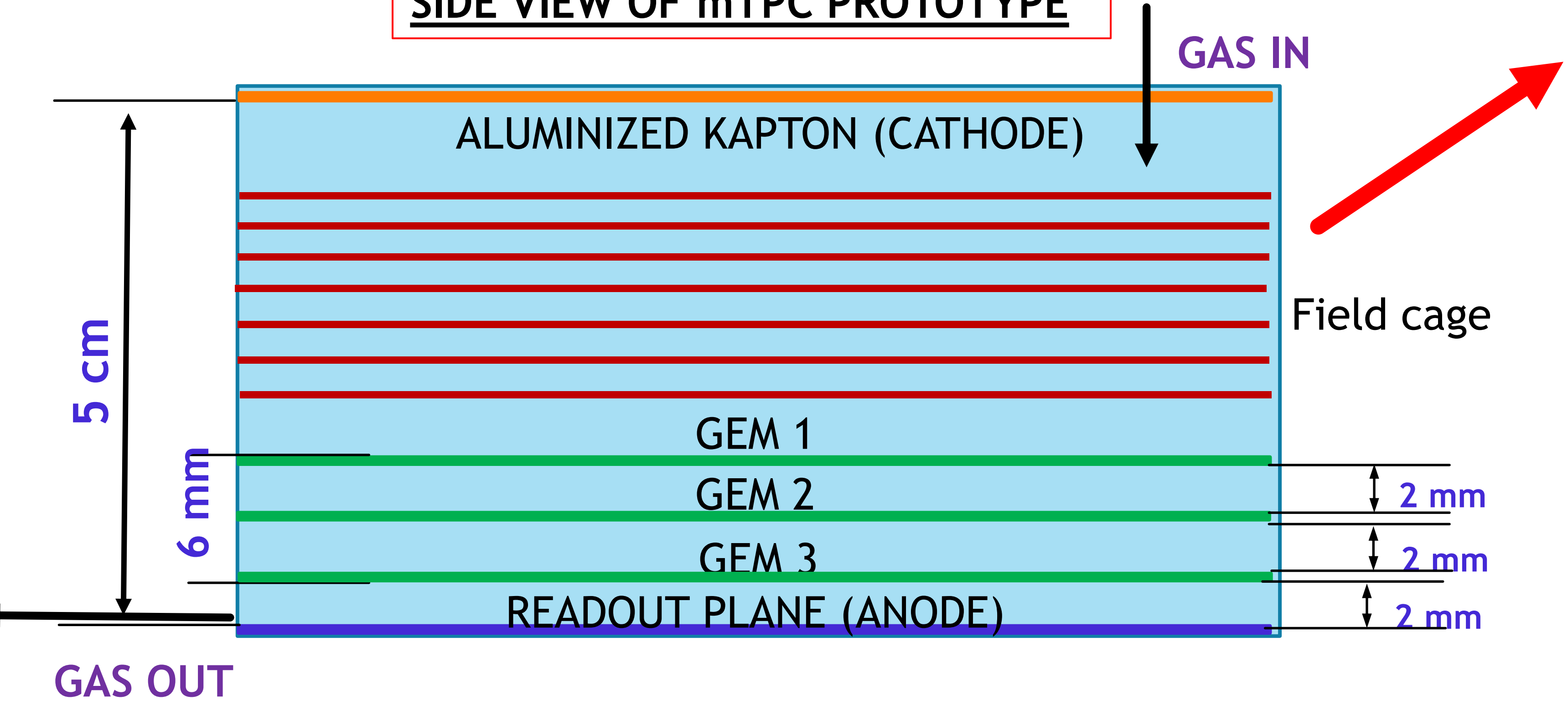
University of Virginia

- mTPC square prototype at UVa → 10 x 10 cm^2 GEM active area:
  - Three GEMs stacked with 2 mm spacing (provided by spacers)
  - Eight 3-mm-thick field cage frames each separated by
  - 3 mm
  - 4.7 cm space between top GEM foil and bottom of cathode

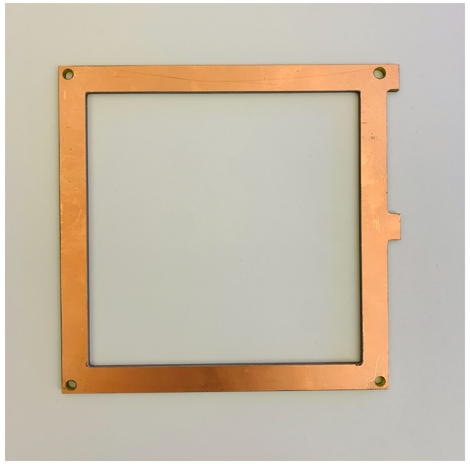
3D CAD view of stacked layers



SIDE VIEW OF mTPC PROTOTYPE

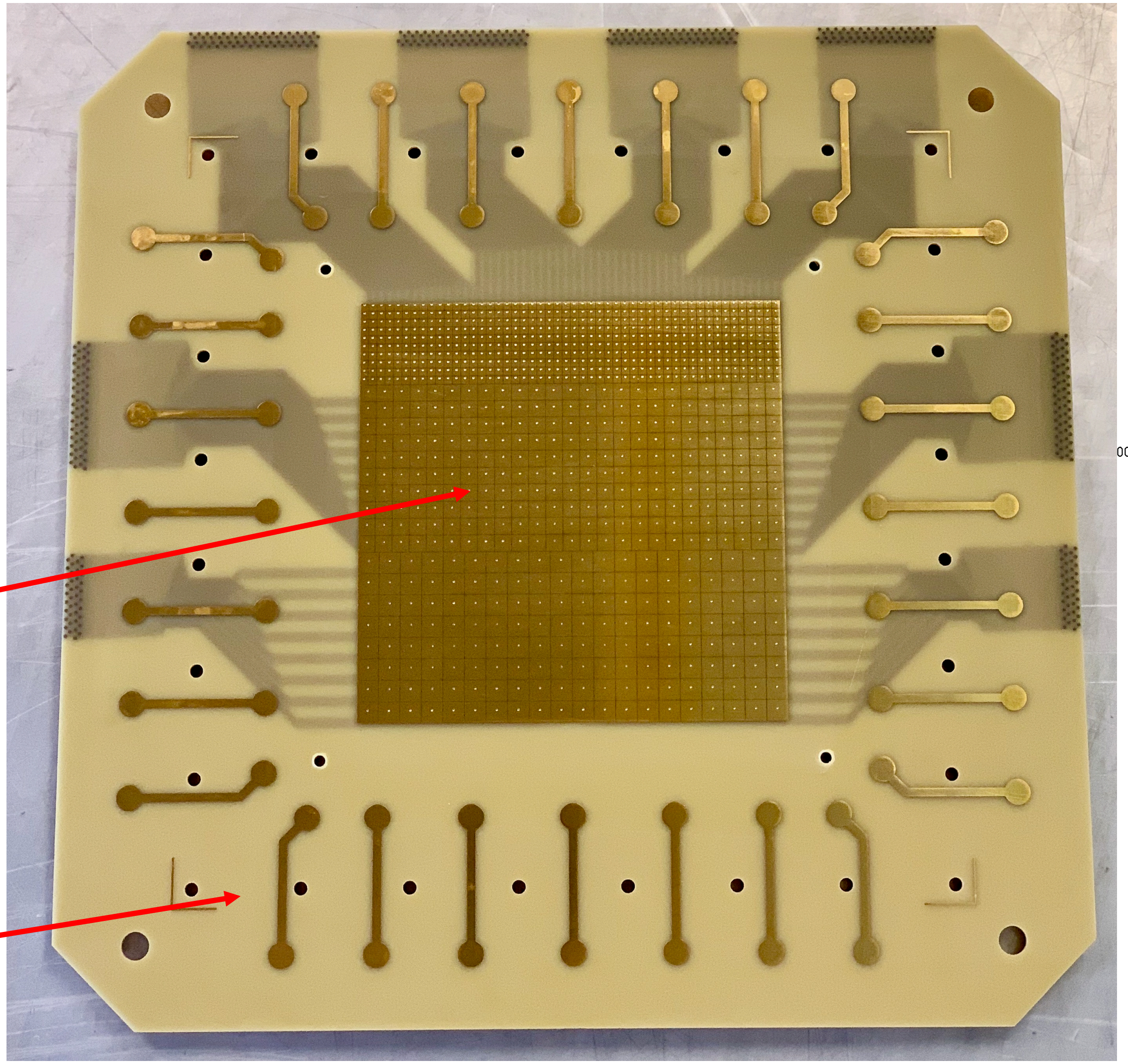


Top view of field cage frame



mTPC square prototype: Readout PCB

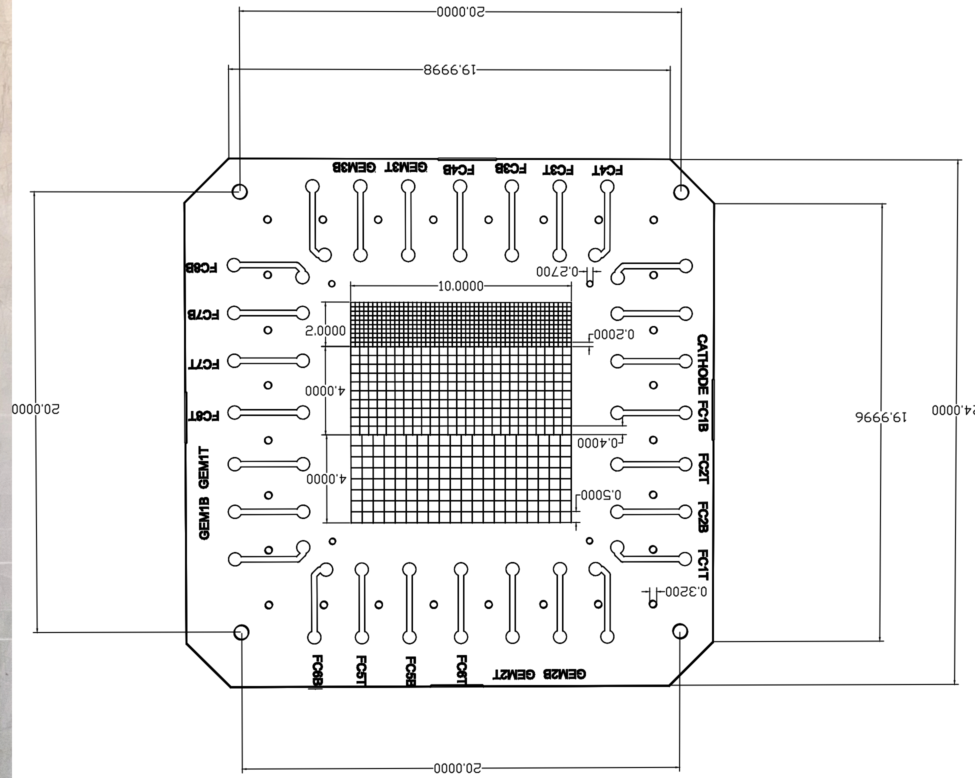
Front of Readout



Pads
2 x 2 mm^2
4 x 4 mm^2
5 x 5 mm^2

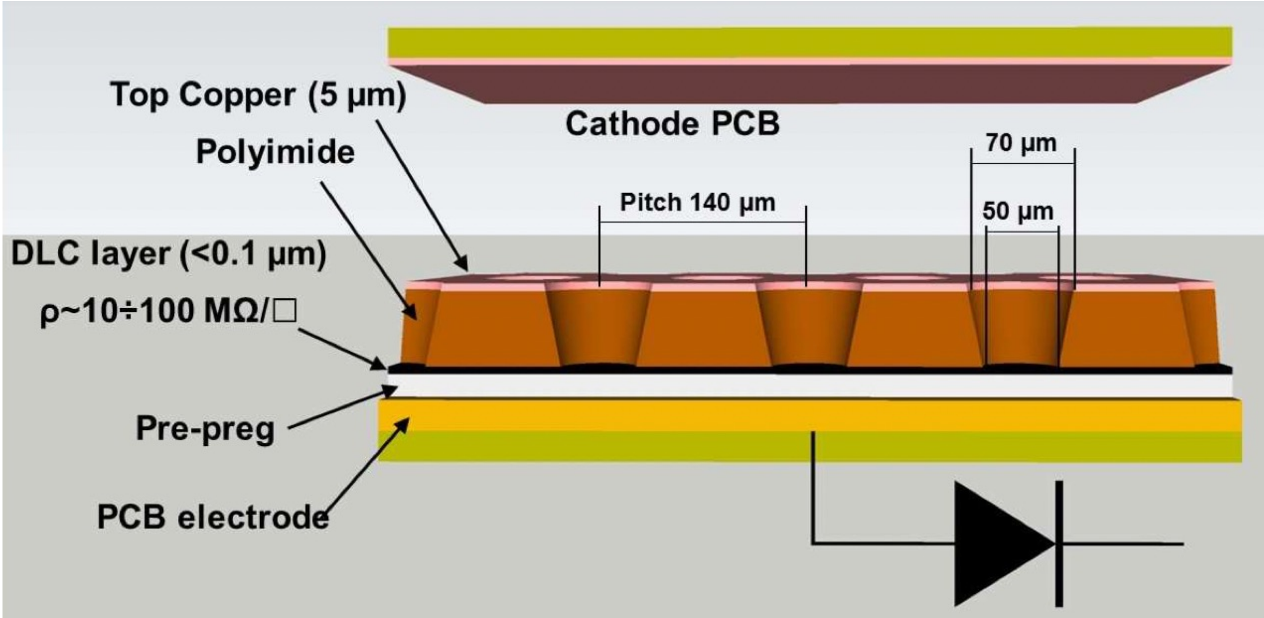
HV strips

Dimensions on CAD



EIC R&D: 30 cm x 30 cm uRWELL Prototype

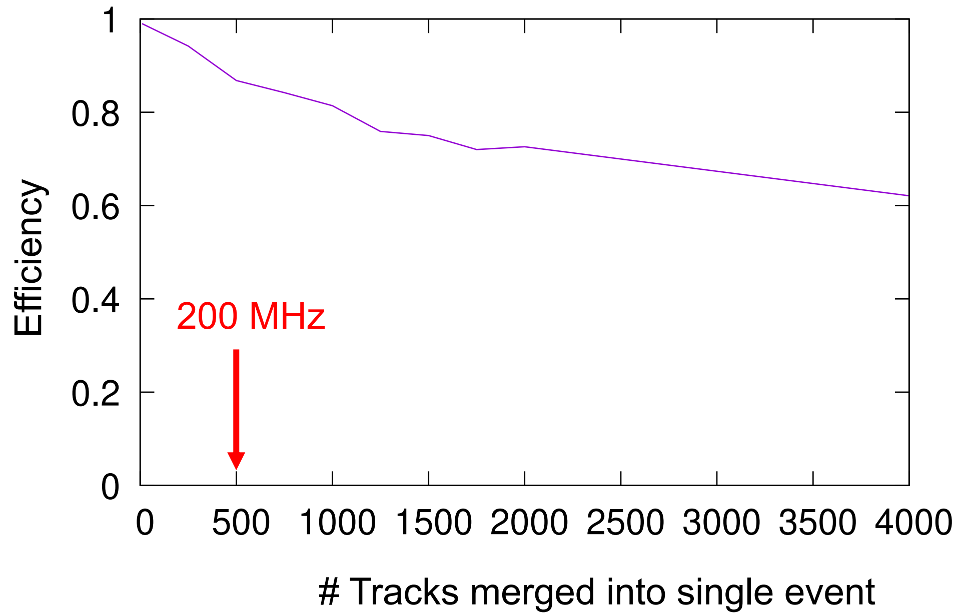
- We plan to build a 30 x 30 uRwell prototype, parts paid for by EIC R&D
- uRwell foil shipped from CERN, arriving at UVa next week
- Expect to complete the detector and test with high rate x-rays at UVa, and with beam at JLab



mTPC Simulation Status: track-finding efficiency

Credit: S. Wood (JLab)

- For given electron trigger, mTPC will be filled with many random proton tracks.
- Generate events for p(e,p) according to EPC singles code. Momentum and θ chosen to follow EPIC distribution.
- For each event choose random ϕ and z (target position).
- Choose random start time (T_0) between -1300 to 1300 ns for each event.
- Run each event through mTPC G4 simulation, providing list of hits for each event. Max drift time = 1000 ns.
- Hit = Pad ID# + TDC value.
- Merge hits from multiple tracks (up to 4000) into single hit list/event.
- Use simple chain/track finding algorithm to identify as many tracks as possible. Use TDC times to choose best hits on adjacent pads.



Fraction found of kinematically interesting protons tracks with 4 or more hits

Interesting proton =

$70 < p < 400$ MeV/c

$30° < \theta < 80°$

-225 ns $< T_0 < 225$ ns