TDIS mTPC update

M. Eric Christy

Jefferson Lab

Hall A Collaboration Meeting, January 16, 2024

The Tagged Deep Inelastic Scattering (TDIS) Experiment C12-15-005

Spokespersons: D. Dutta, N. Liyanage, C. Keppel, P. King, R, Montgomery, B. Wojtsekhowski

Goal:

Provide 1st direct measurement of the mesonic content of the nucleon and a unique extraction of the pion's F_2 structure functions by scattering from a virtual pion target, accessed via spectator tagging.

Pions and kaons are the simplest bound states of QCD and its Nambu-Goldstone bosons- knowledge of meson structure is critical to a complete understanding of the emergence of hadron mass.
But, very little data due to the lack of "meson targets".

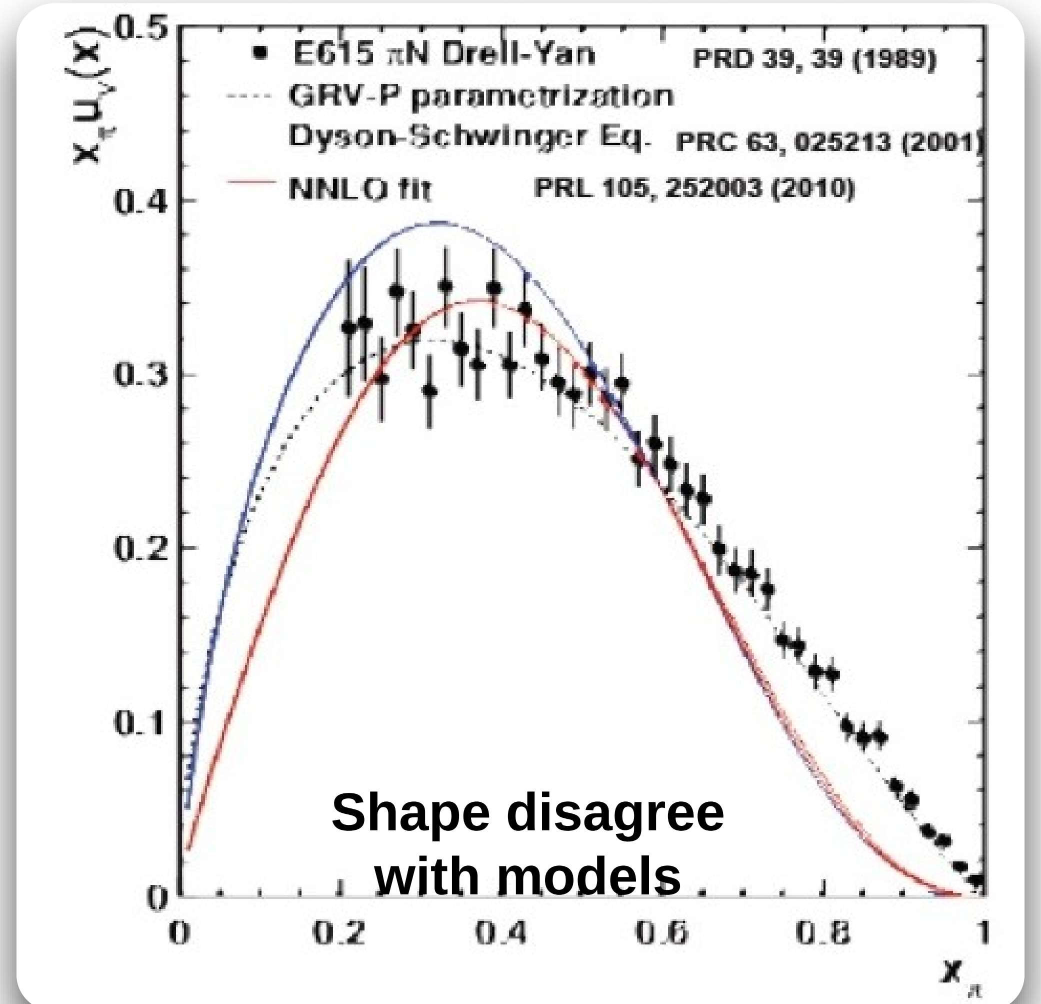
Motivations:

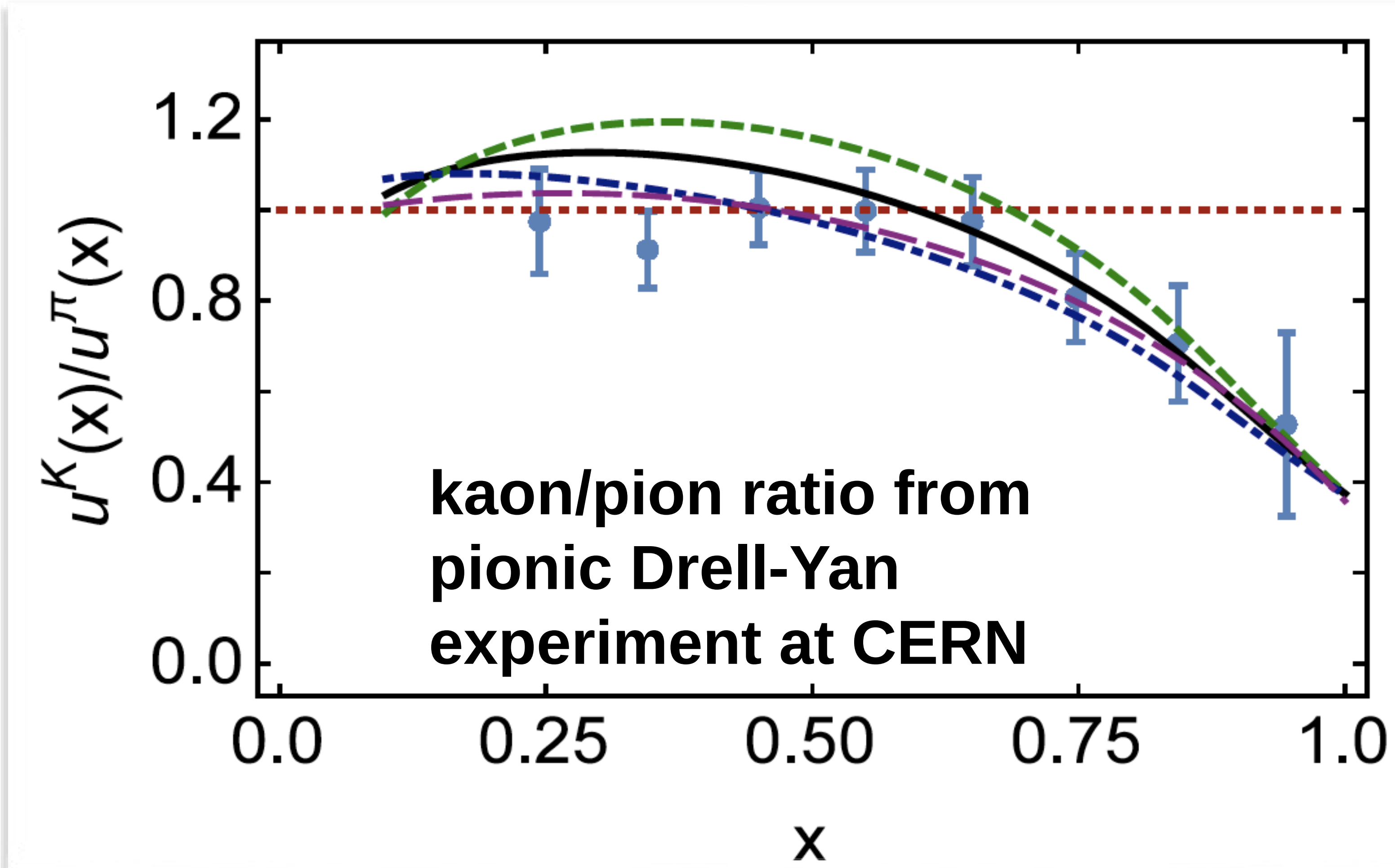
TDIS will use spectator tagging - well established technique (eg. BONuS) - to tag the "meson cloud" of the nucleon.

TDIS is a pioneering experiment but the proposed technique to extract meson structure function is an essential first step for future experiments at the EIC & 22 GeV JLab.

Although no direct measurement of magnitude of mesonic content of nucleons...

Data from Drell-Yan experiments in valence region





Calculations with the gluonic contributions can explain data

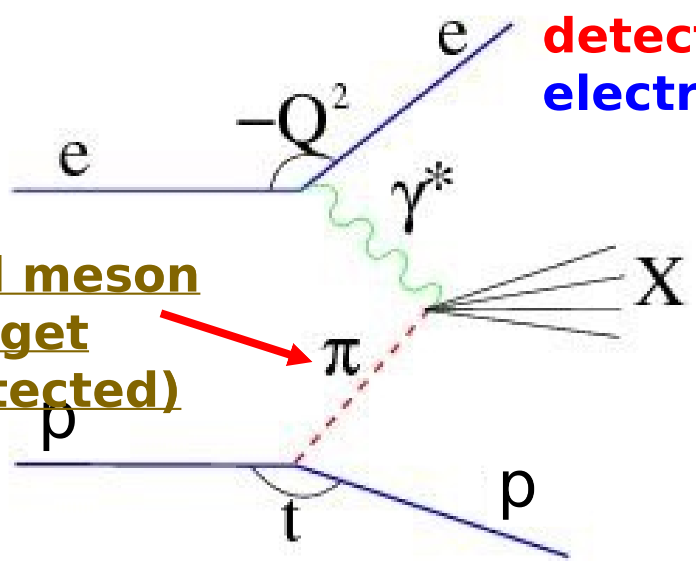
… but more precise data needed

L. Chang, C. Mezrag, H. Moutarde, C. D. Roberts, J. Rodriguez-Quintero, P. C. Tandy, Phys. Lett. B420, 267 (2014)

C. Chen, L. Chang, C. D. Roberts, S. Wan and H.-S. Zong, Phys. Rev. D 93, 074021 (2016)

Spectator Tagging can be used to tag the "meson cloud" target.

Hydrogen Target



detect scattered electron

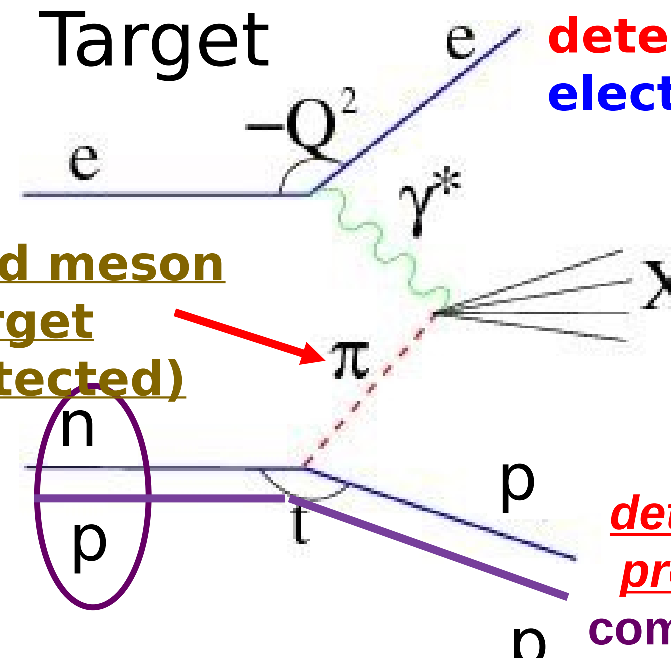
undetected recoiling hadronic system

neutral meson target (undetected)

Spectator proton

(backward going slow proton)

Deuterium Target



detect scattered electron

undetected recoiling hadronic system

charged meson target (undetected)

detecting two protons with common vertex

Spectator proton

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

$$R^T = \frac{d^4\sigma(ep \to e'Xp')}{dx dQ^2 dz dt} \Big/ \frac{d^2\sigma(ep \to e'X)}{dx dQ^2} \Delta z \Delta t \sim \frac{F_2^T(x, Q^2, z, t)}{F_2^p(x, Q^2)} \Delta z \Delta t.$$

Tagged structure function
a direct measure of the mesonic content of nucleons

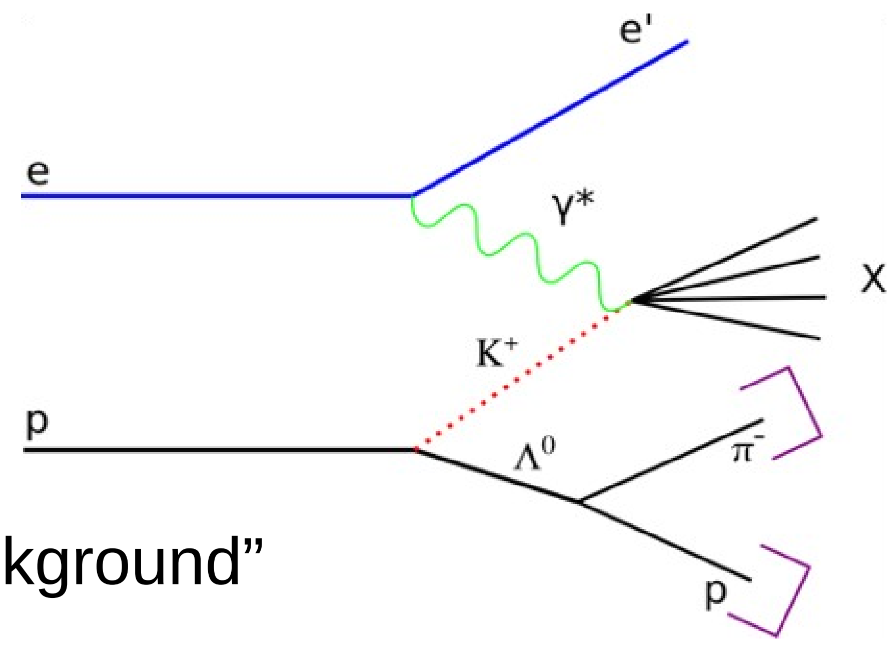
$$F_2^T(x, Q^2, z, t) = \frac{R^T}{\Delta z \Delta t} F_2^p(x, Q^2).$$

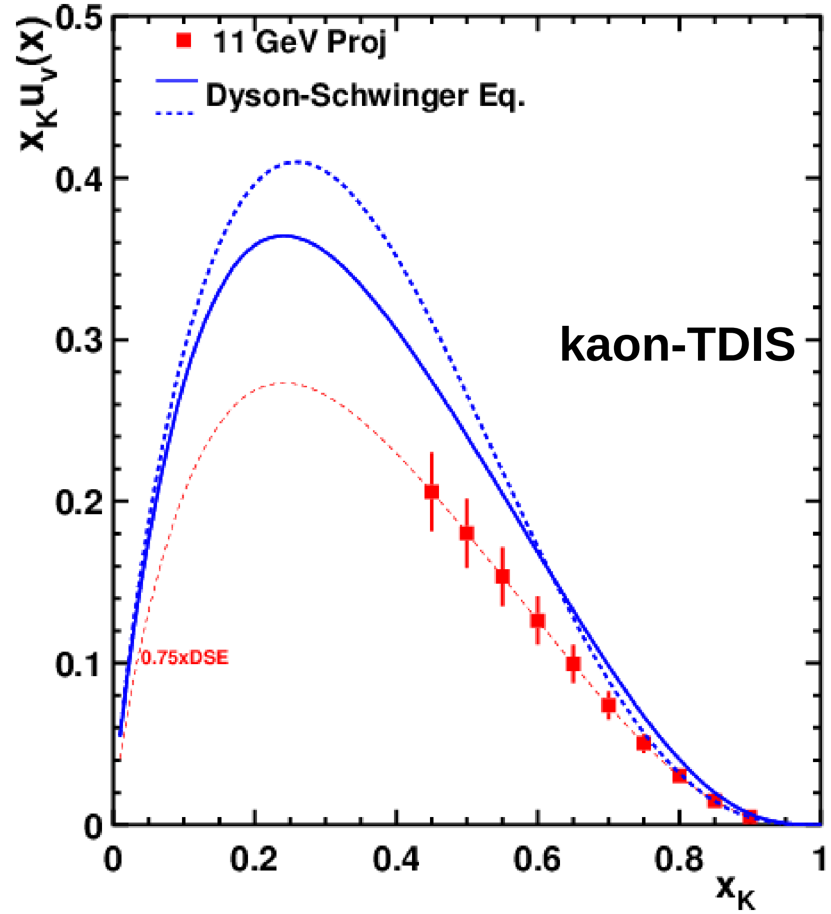
D. Dutta

Two run group experiments endorsed (kaon TDIS & nTDIS)

C12-15-006A
Measurement of Kaon Structure Function through Tagged Deep Inelastic Scattering(TDIS)

Spokespersons:
T. Horn, R. Montgomery & K. Park

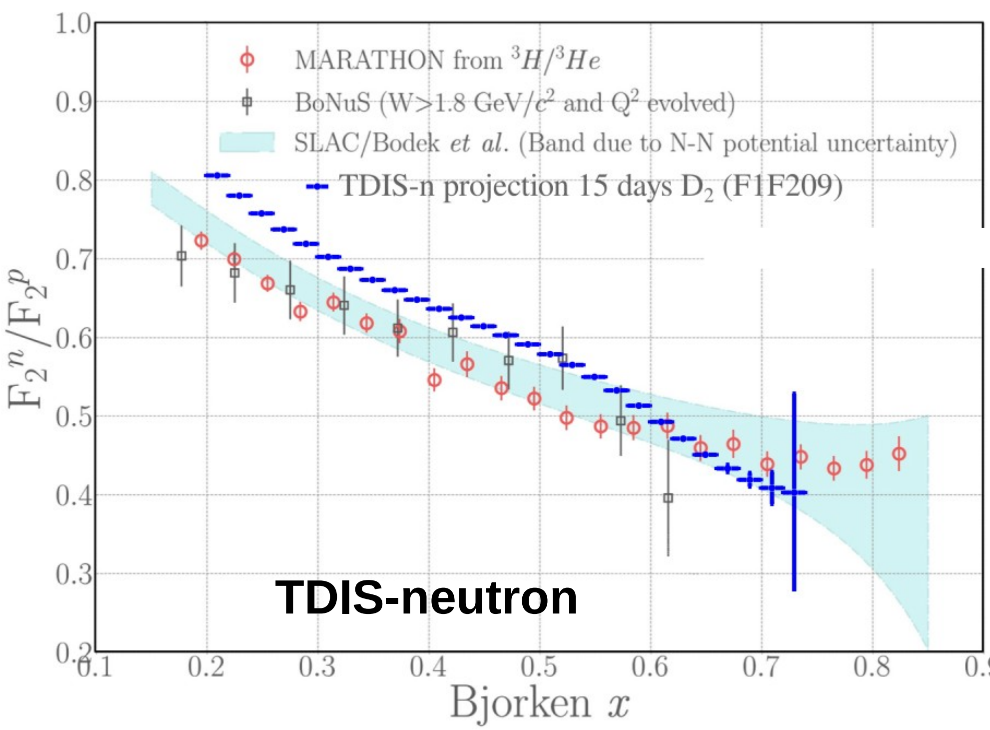




Kaon TDIS events are "background" for pion TDIS

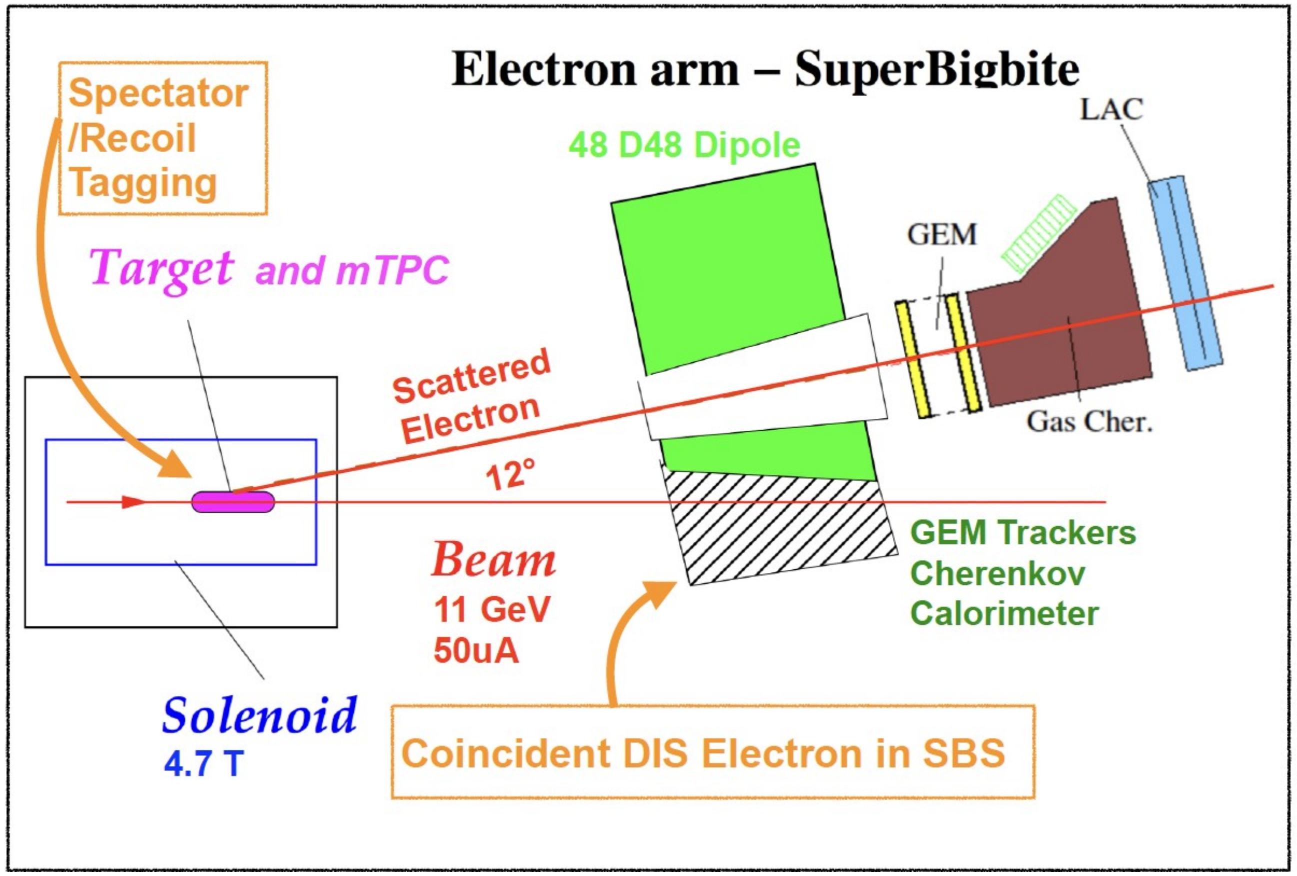
C12-15-006B
TDIS-n:Tagged DIS measurement of the Neutron Structure Function (ala BONuS)

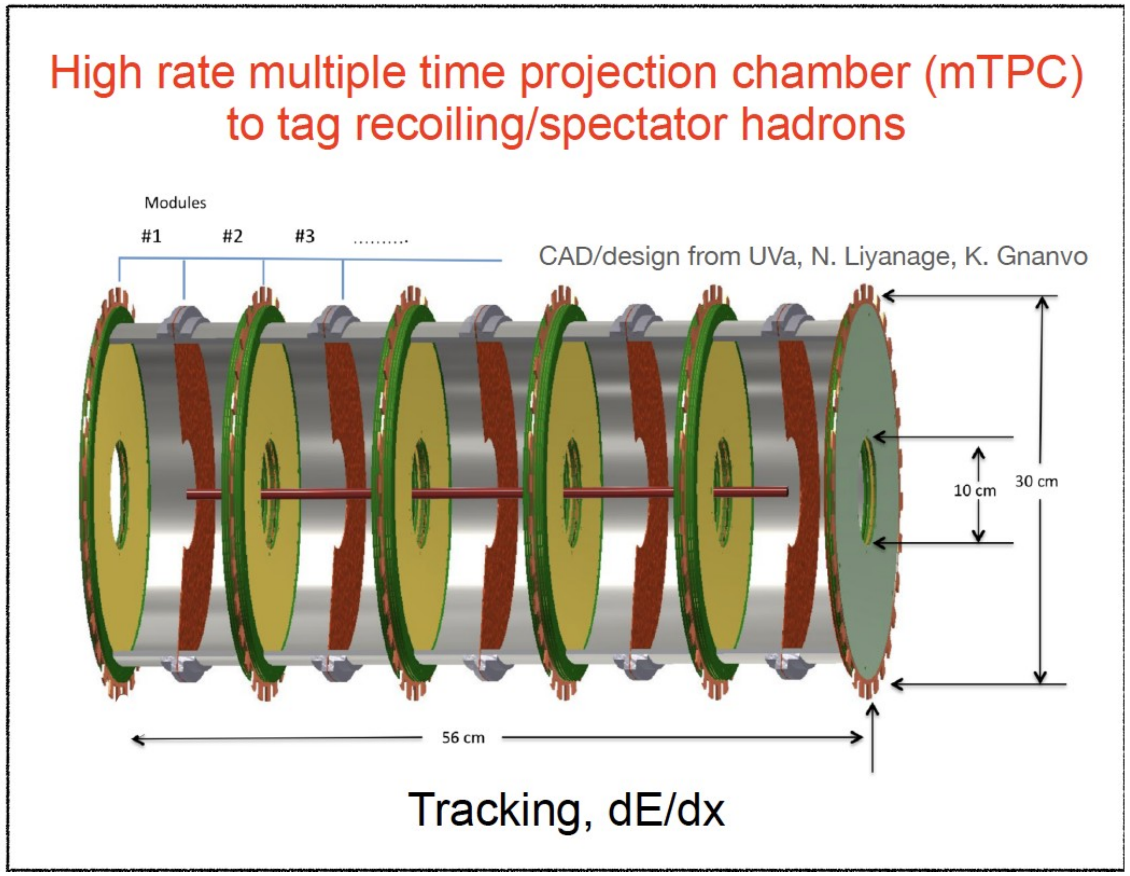
Spokespersons:
J. Arrington, M.E. Christy, C. Ayerbe Gayoso, E. Fuchey, C. Keppel, S. Li, R. Montgomery, A. Tadepalli

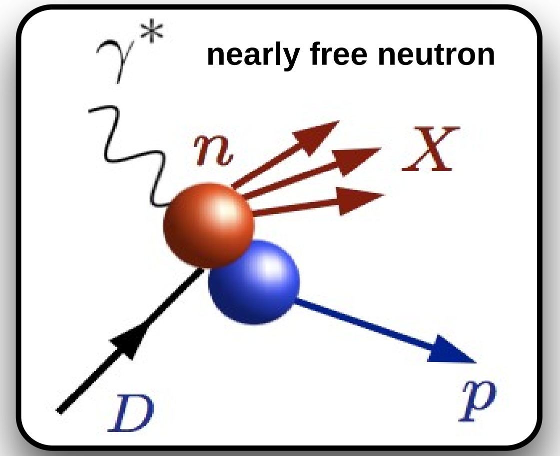


D. Dutta

Experimental Setup







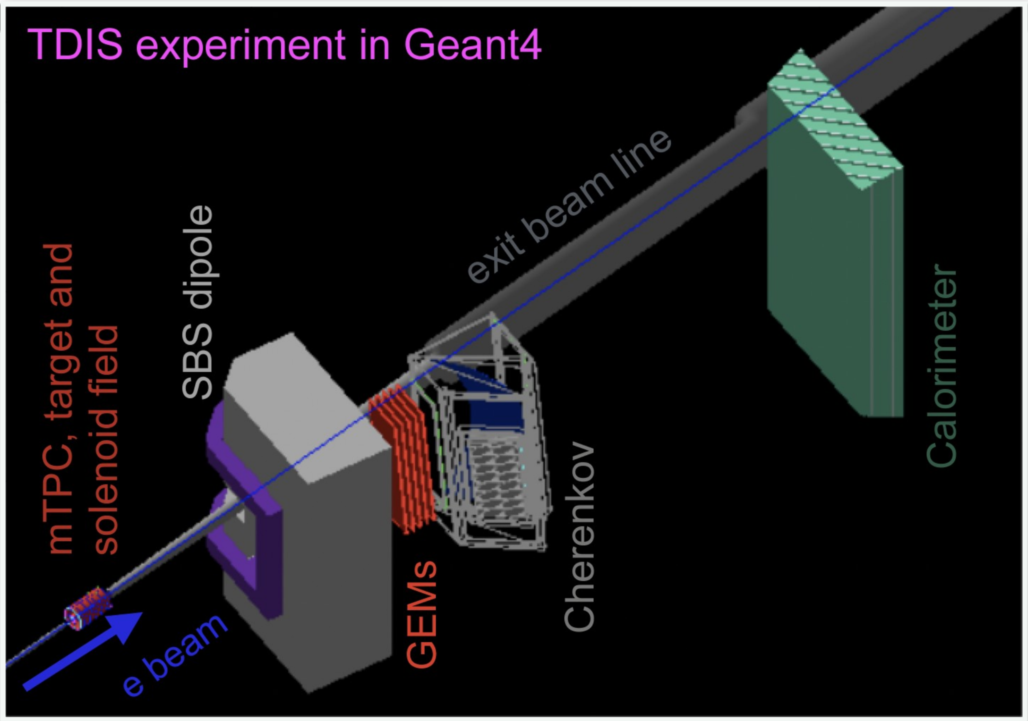
Deuteron **Spectator proton (backward going slow proton)**

TDIS will be a pioneering experiment that will be the first direct measure of the mesonic content of nucleons.

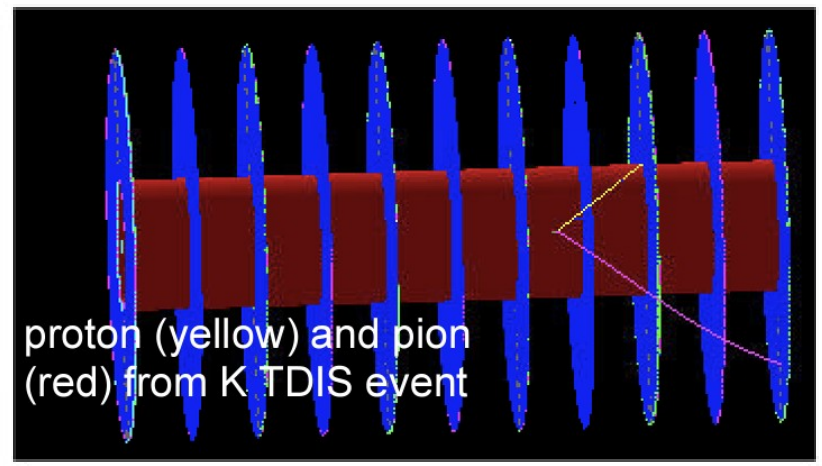
The techniques used to extract meson structure function will be a necessary first step for future experiments

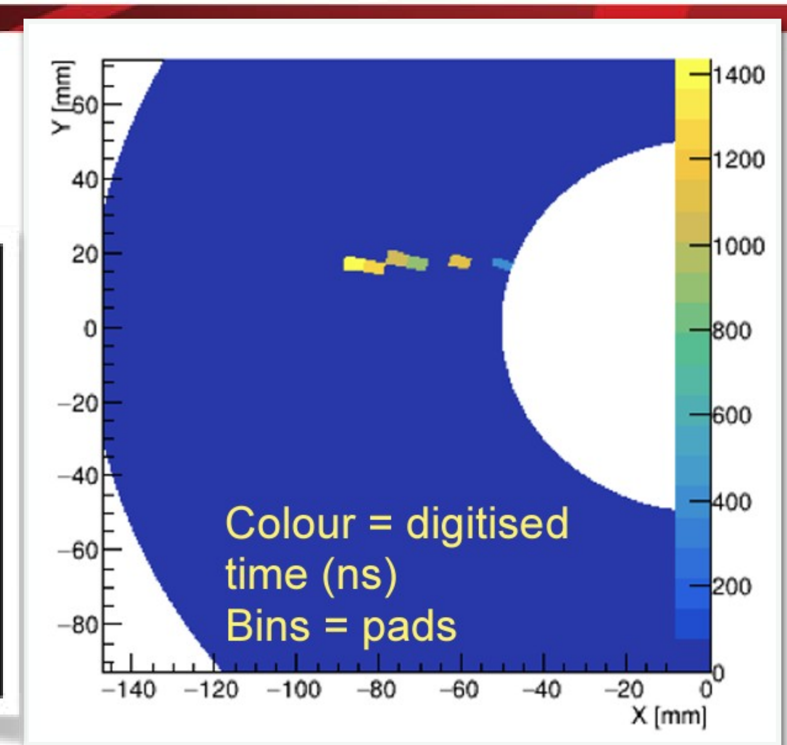
Recent Work

A comprehensive Geant4 based simulation with digitization has been developed and validated with BoNUS12 data.

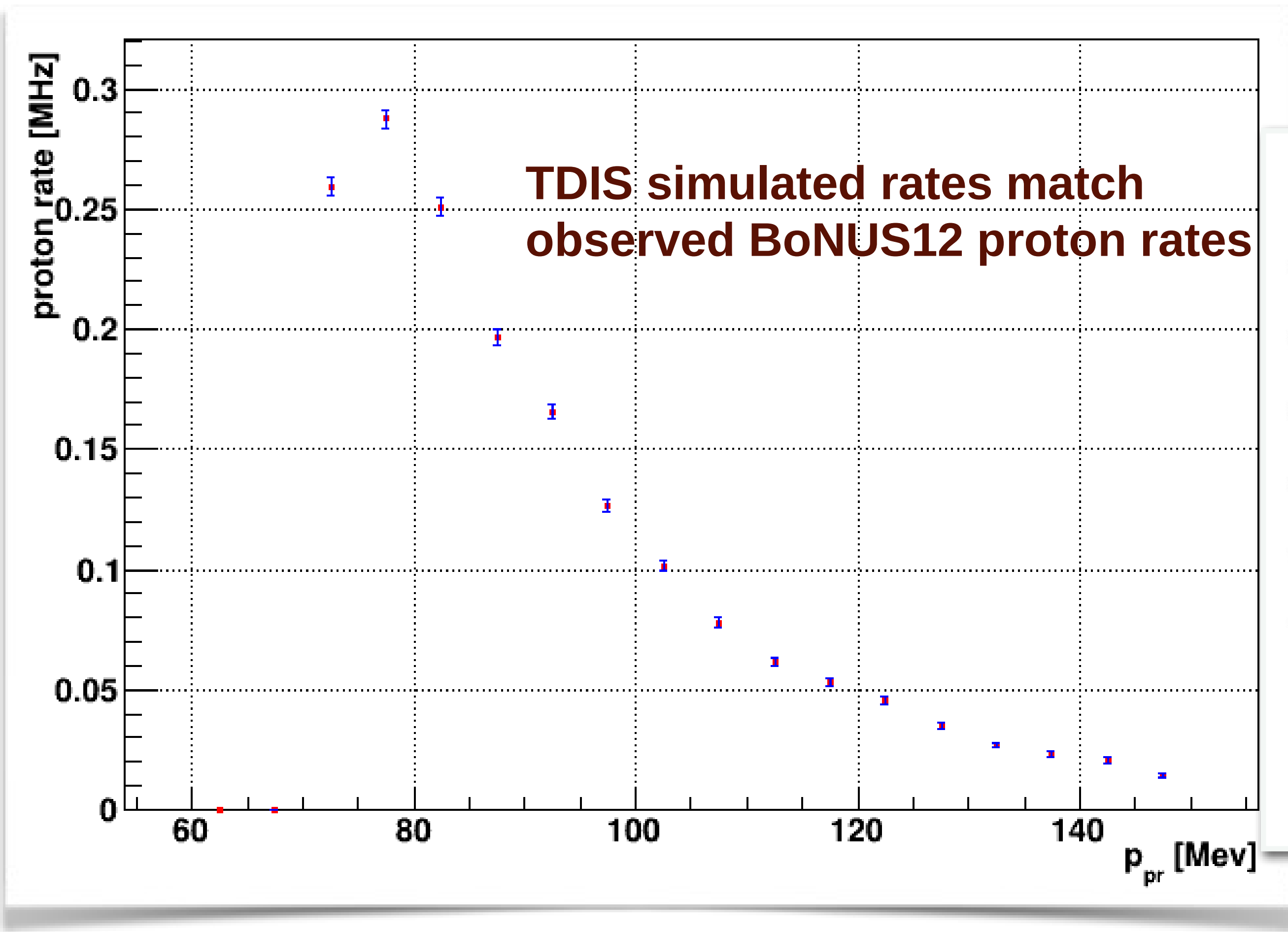


mTPC simulated with Magboltz/Garfield

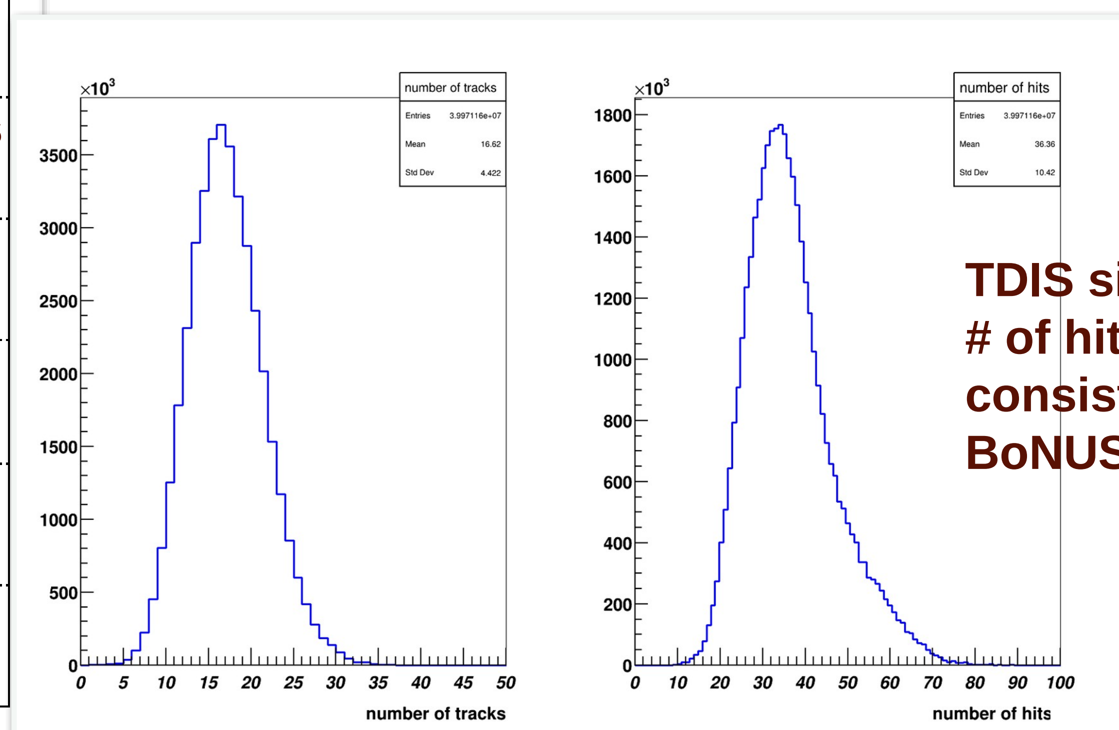




images credit: R. Montgomery



TDIS simulated rates match observed BoNUS12 proton rates



TDIS simulated # of hits & tracks consistent with BoNUS12

plots credit: A. Nadeeshani

A new hadron blind gas Cherenkov detector is being designed by new collaborators from U. of Tennessee

Penny Duran (UofA), Burcu Duran (UT), Nadia Fomin (UT)

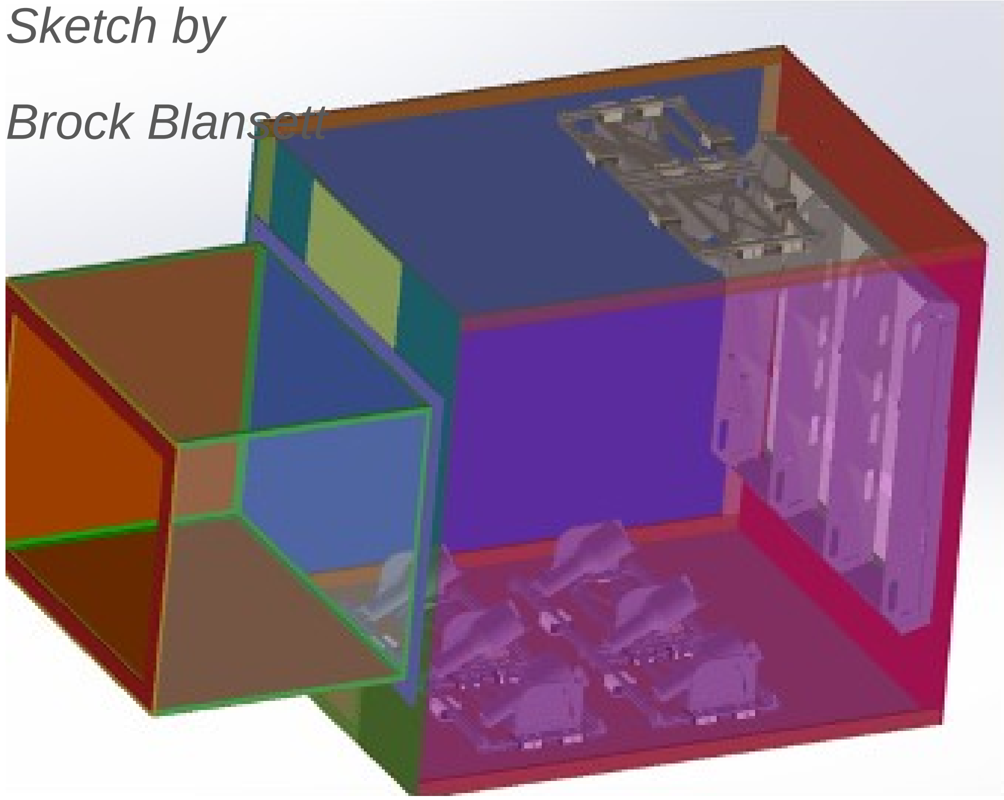
- Requirements: discrimination between electrons and pions in the 2 GeV – 11 GeV range
- UT proposes a threshold Cherenkov detector based on SHMS NGC

4 meters long

Neon or Argon/Neon at 1atm

9 PE at 11 GeV/c

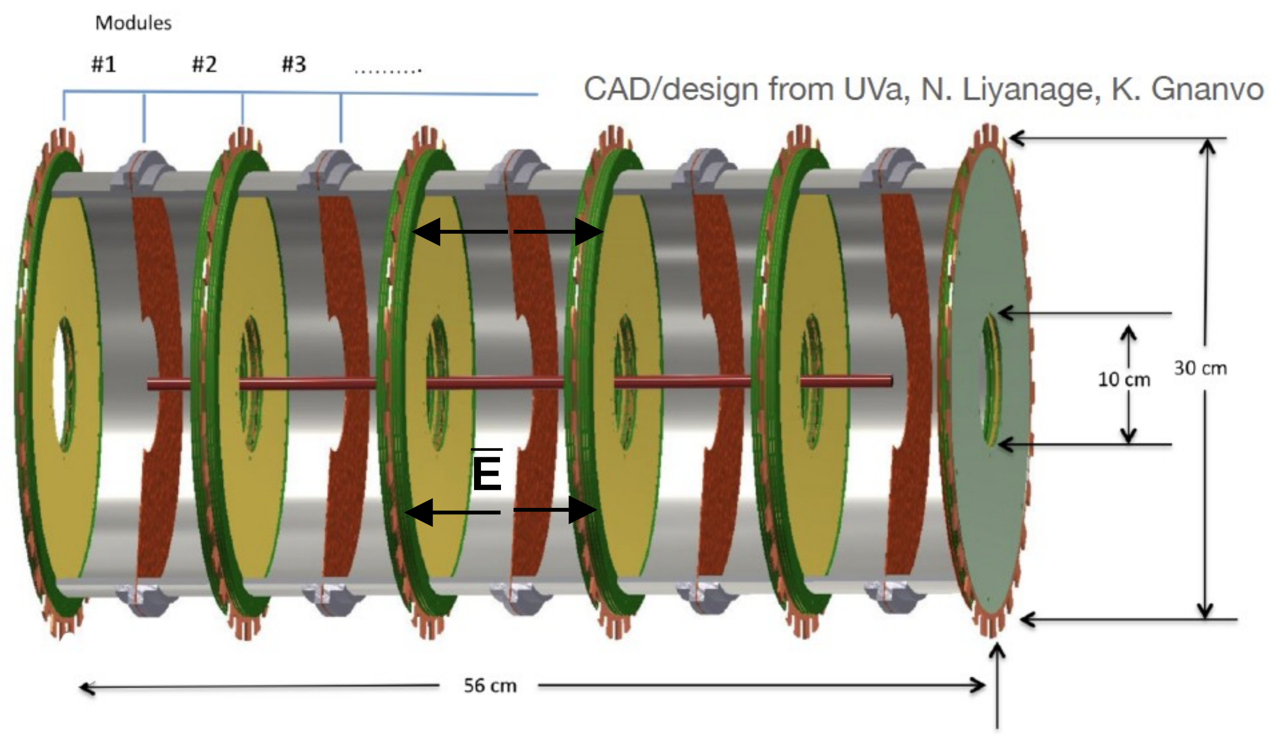
Sketch by Brock Blansett



The LAC has been refurbished and is being tested and a FPGA based electron trigger will be developed

mTPC conceptual design

High rate multiple time projection chamber (mTPC)
to tag recoiling/spectator hadrons

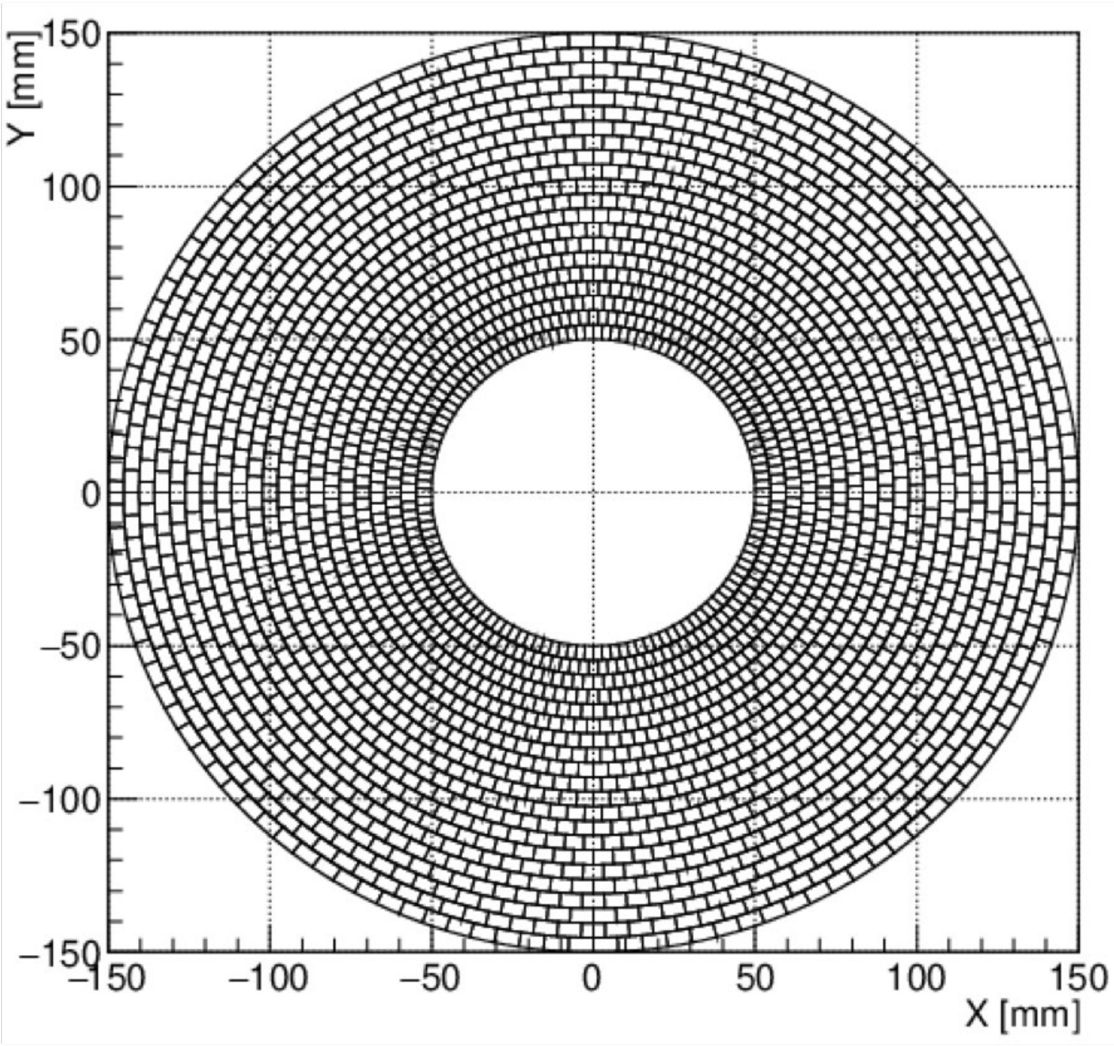


Tracking, dE/dx

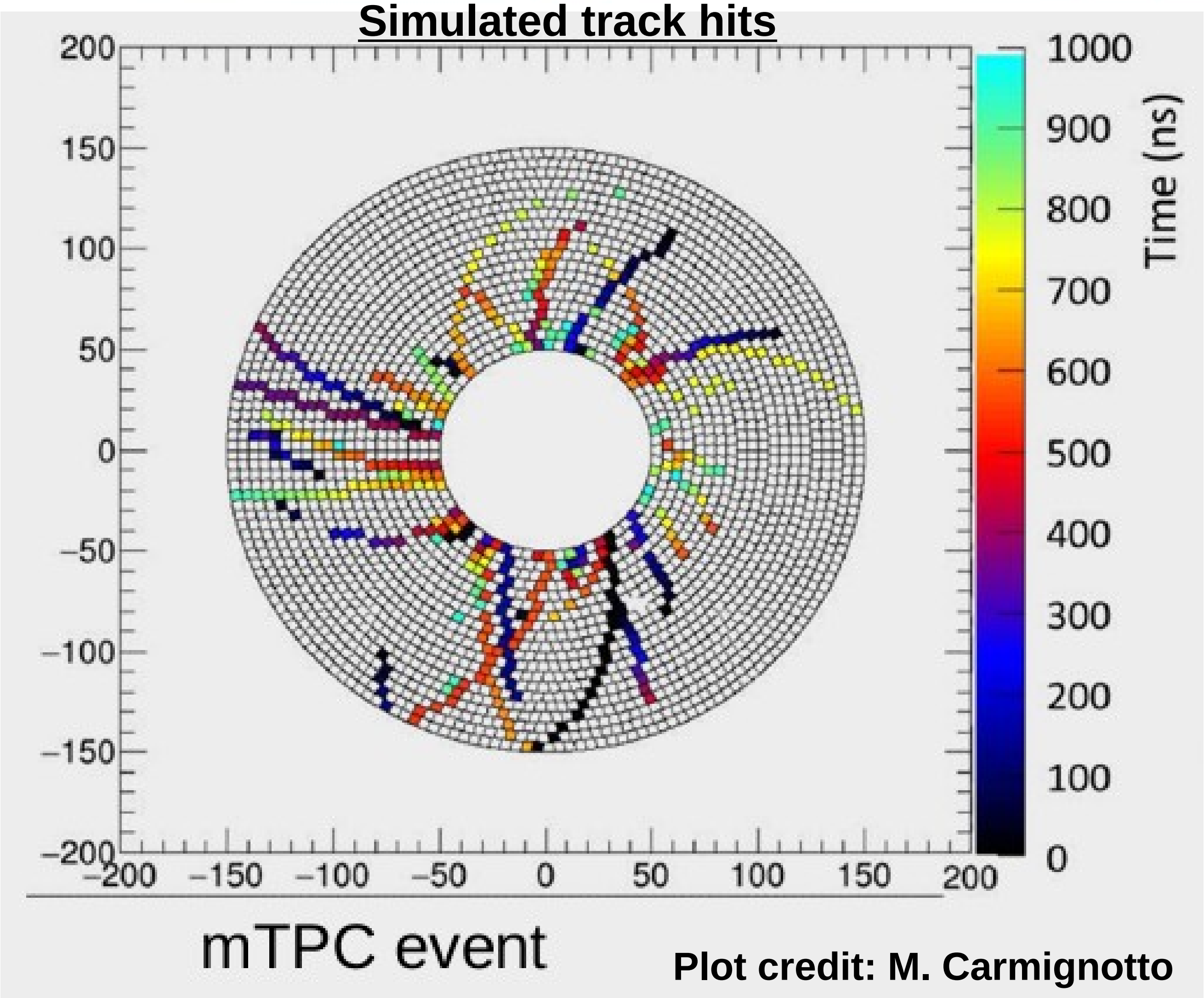
- Each TPC module of the composite mTPC will be exposed to a fraction of the total background rate.
- The drift field is parallel to the magnetic field, leading to reduced drift times and significantly simplified track reconstruction.
- Each cathode will be shared by 2 TPCs with separate drift regions, GEM layers, and readout boards.

Target: 25 um wall thickness Kapton straw at room temperature and 3 atm. pressure.

Readout Board

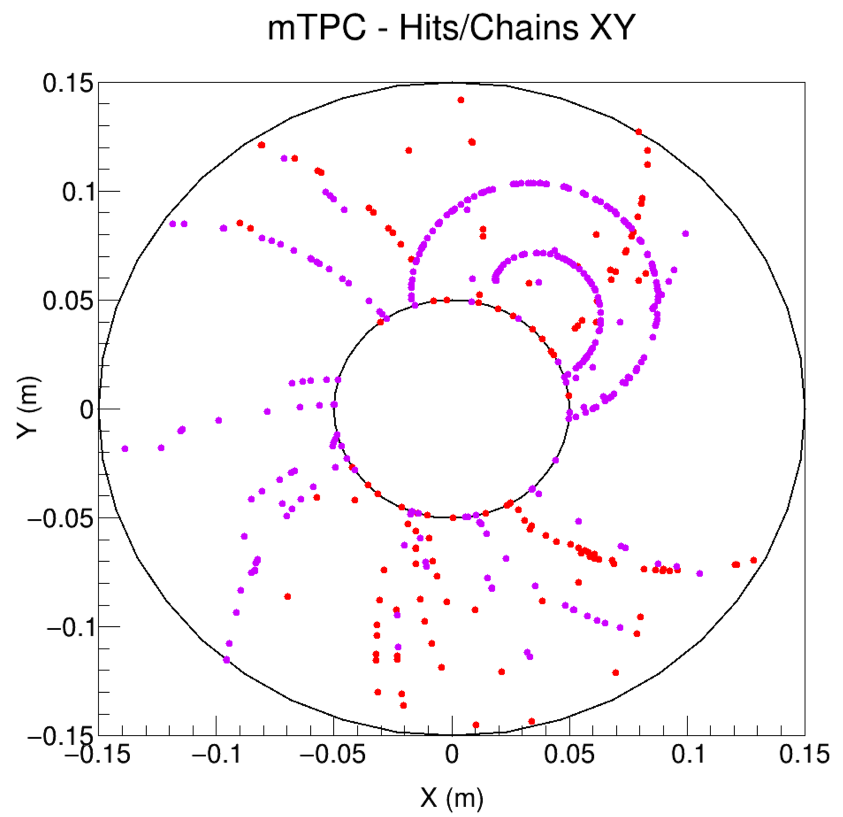


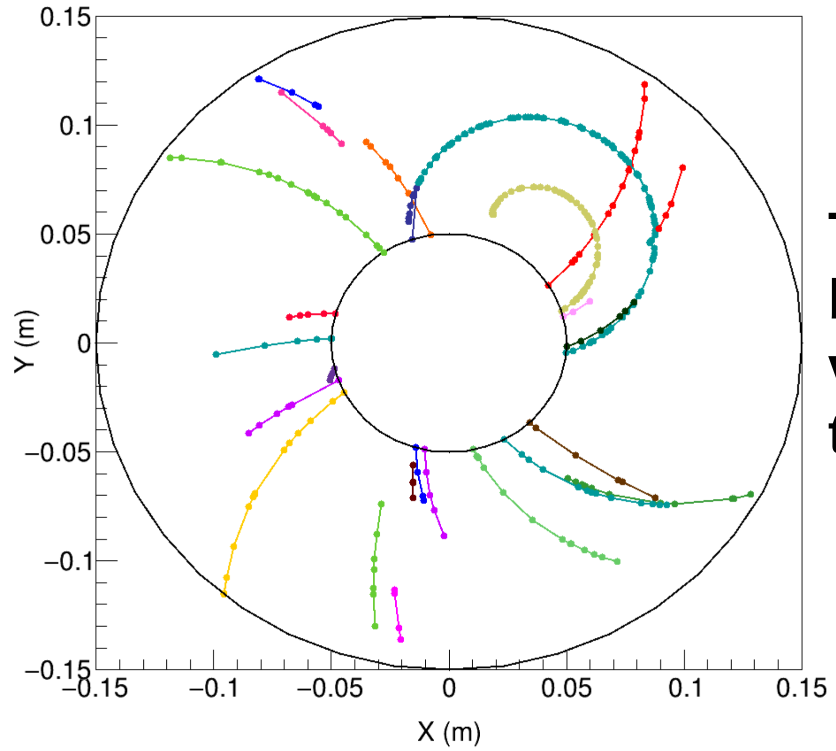
CAD design: K. Gnanvo



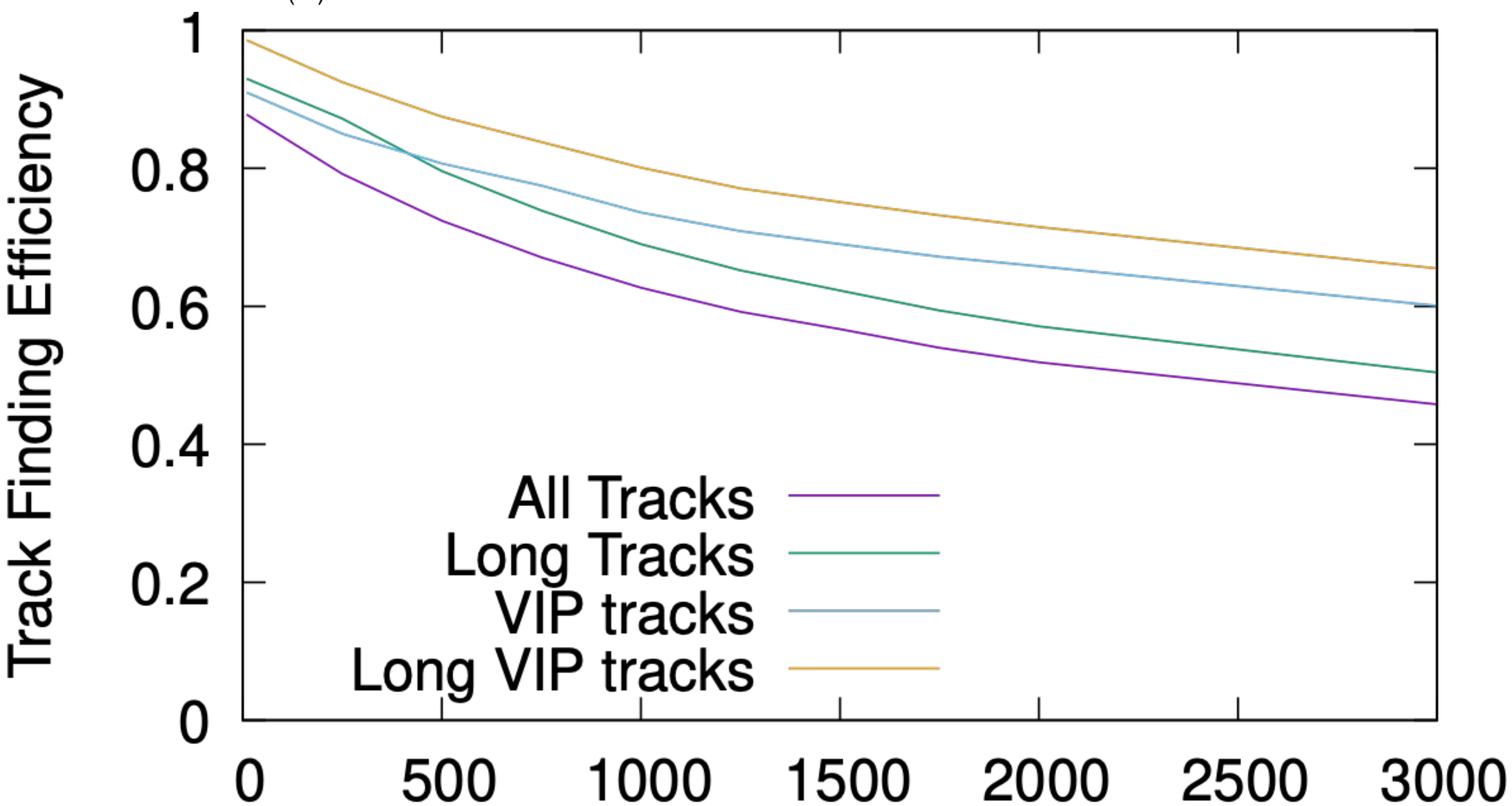
- **Decreasing pad sizes at small radii for better**
- **separation of tracks and ϕ resolution.**

High rate and high occupancy tracking algorithms have been developed and are being optimized





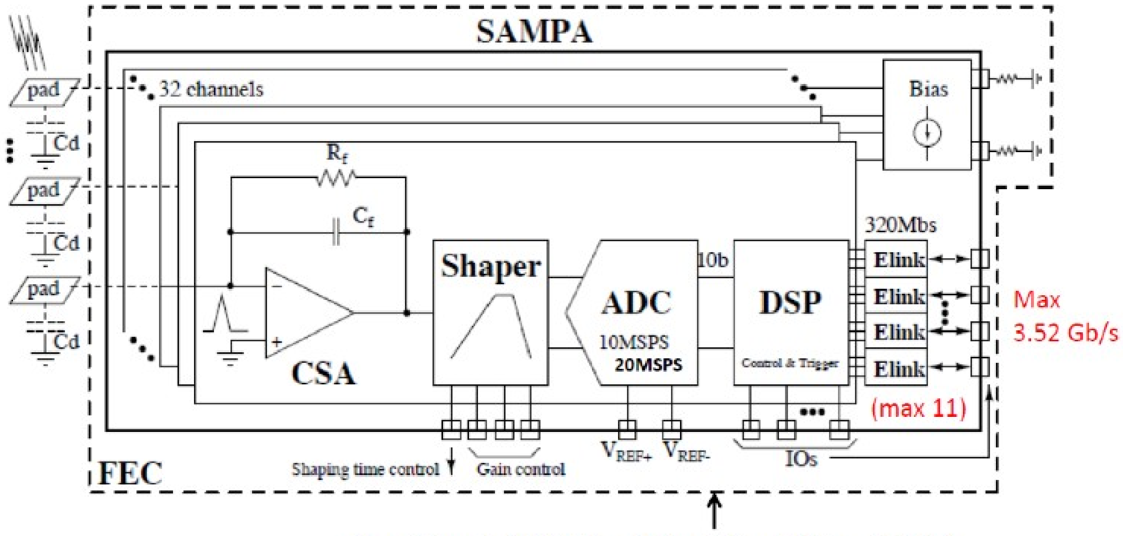
Two tracking algorithms have been developed, a new hybrid version is being developed using the best features of each.



At multiplicity of 2000 tracks per event (i.e. rate of 1 GHz in the mTPC) shows an efficiency of 68% for clean tracks

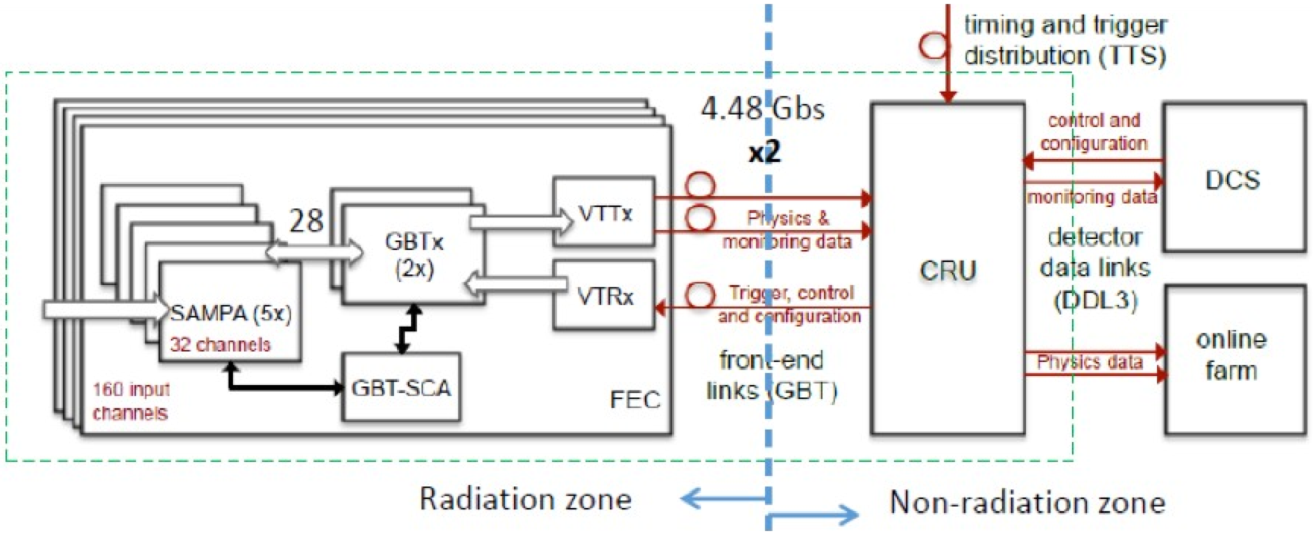
Readout for mTPC has been developed using the SAMPA chip

Effort led by E. Jastrzembski Jlab FE

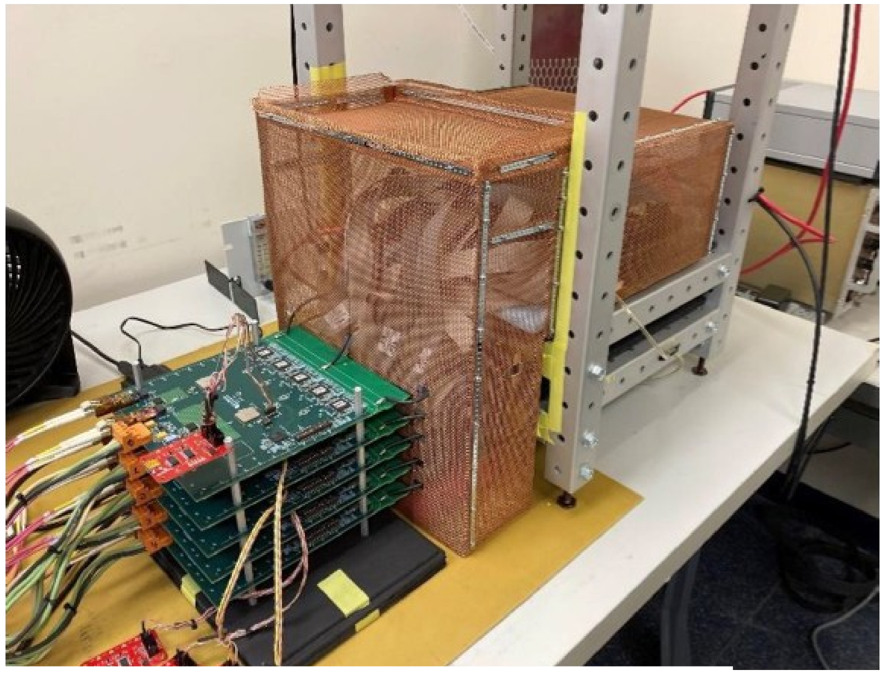


Raw data rate (10MHz) = 32ch x 10b x 10M/s = 3.2Gb/s
(20MHz) = 6.4Gb/s

DSP mode (zero suppression)



FEC – Front End Card (160 ch / FEC)
CRU – Common Readout Unit (~12 FECs / CRU = ~1920 ch / CRU)
GBTx – Giga Bit Transceivers
GBT-SCA – GBT Slow Controls Adapter
VTTX, VTRx – Fiber optic tranceivers



JLab Cosmics Test Stand
FEC, coupled to GEM detector

SAMPA V5 - 80 ns shaping time

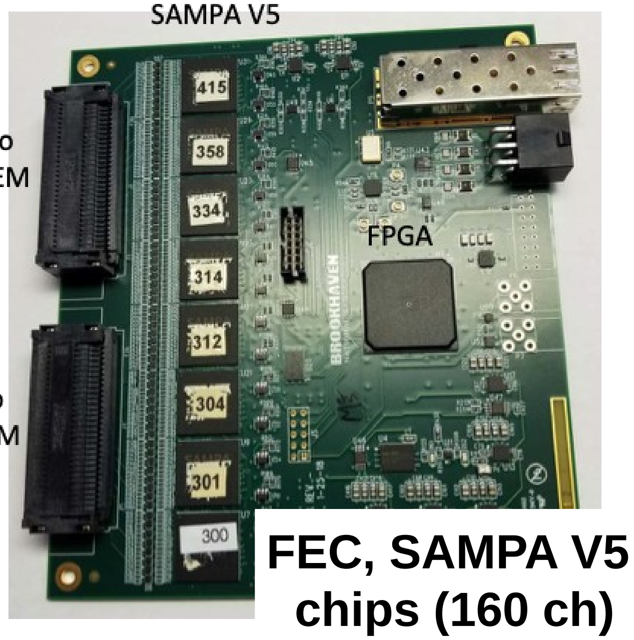
SAMPA can be used in streaming mode or triggered mode

mTPC prototype will be testing using the sPHENIX TPC Front-end card (FEC)

SAMPA V5

to
GEM

to
GEM

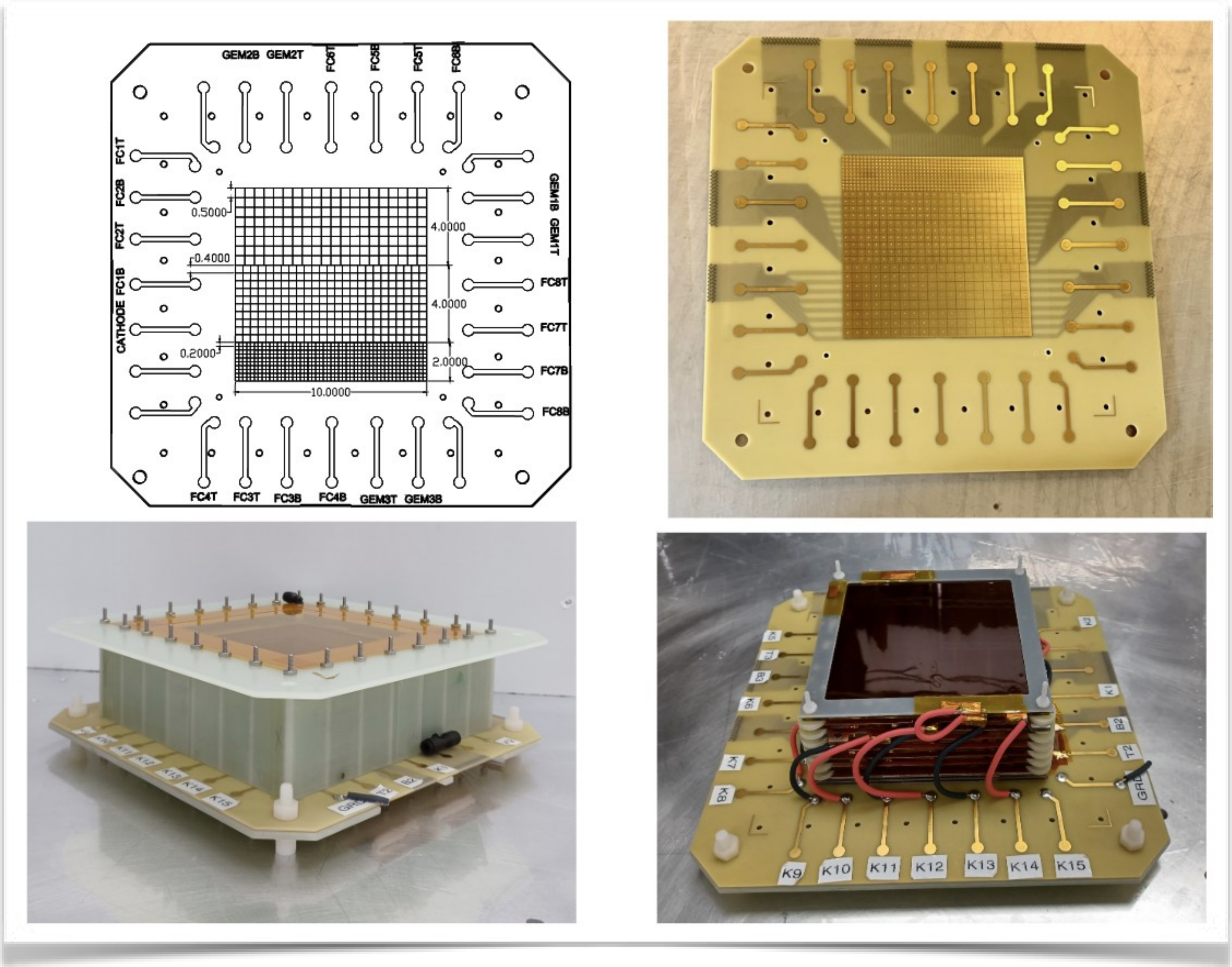


FEC, SAMPA V5 chips (160 ch)

MTPC High Voltage

- 5 independently powered, double-sided TPC Modules
- Each TPC module has
  - → 2 drift regions, GEM amplification layers, readout boards
  - → shared Cathode
- Single HV to GEMs with voltage divider chain
  - → 3 HV channels for each double-sided TPC
  - → 15 channels total required.
- Want capacity for over 1.5 kV /cm to shorten drift time window for reduced backgrounds – over 10 kV required.
- CAEN R1570ET to power each MTPC segment. (4-channels, 15 kV max)
- HV supply in hand – cables being made by Fast Electronics - expected around the end of this month.

Rectangular prototype designed and constructed at Uva.



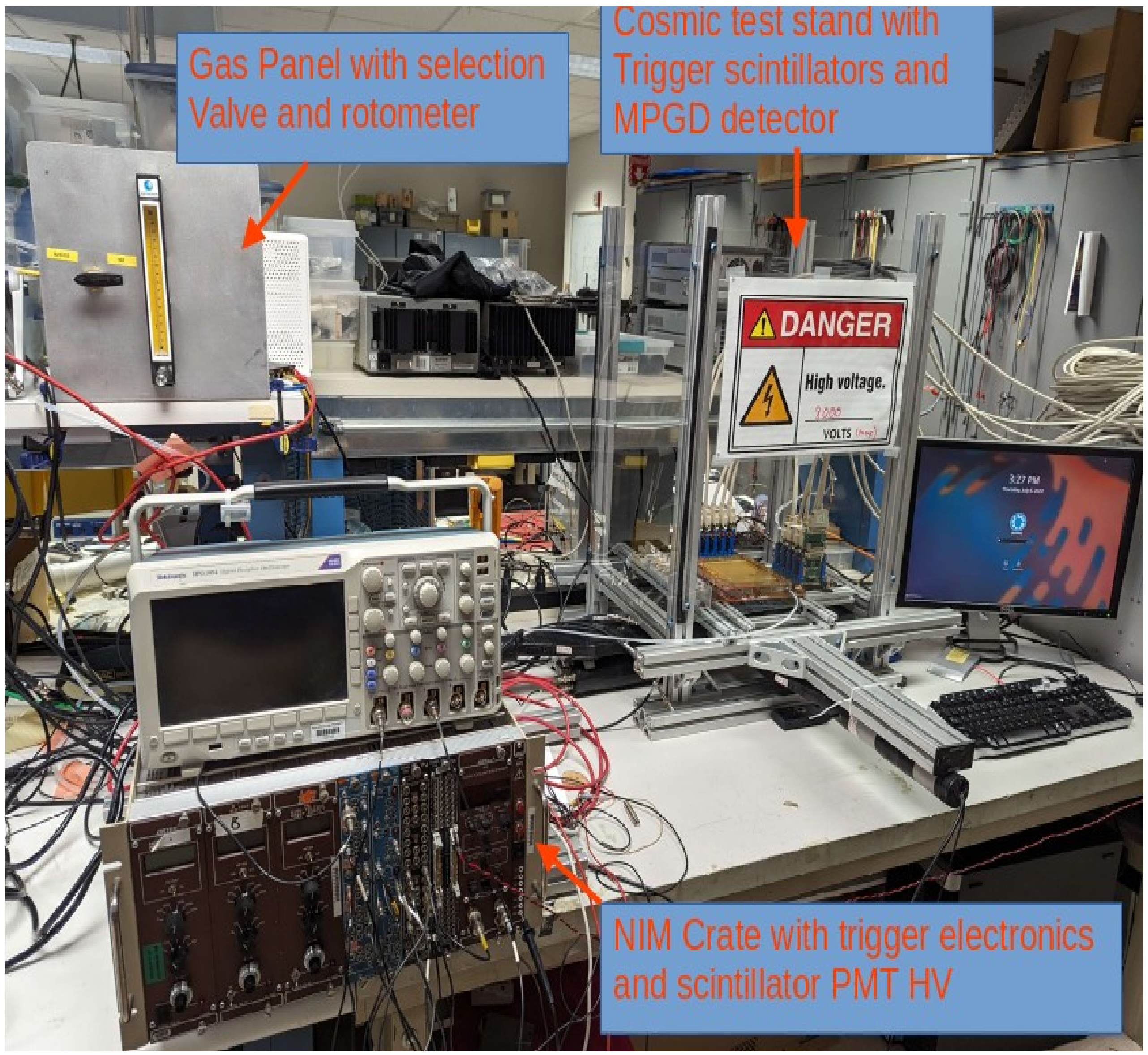
→ **5 cm drift**
→ **3 stage GEMs**
→ **3 different sizes of readout pads**

Testing is currently underway at JLab

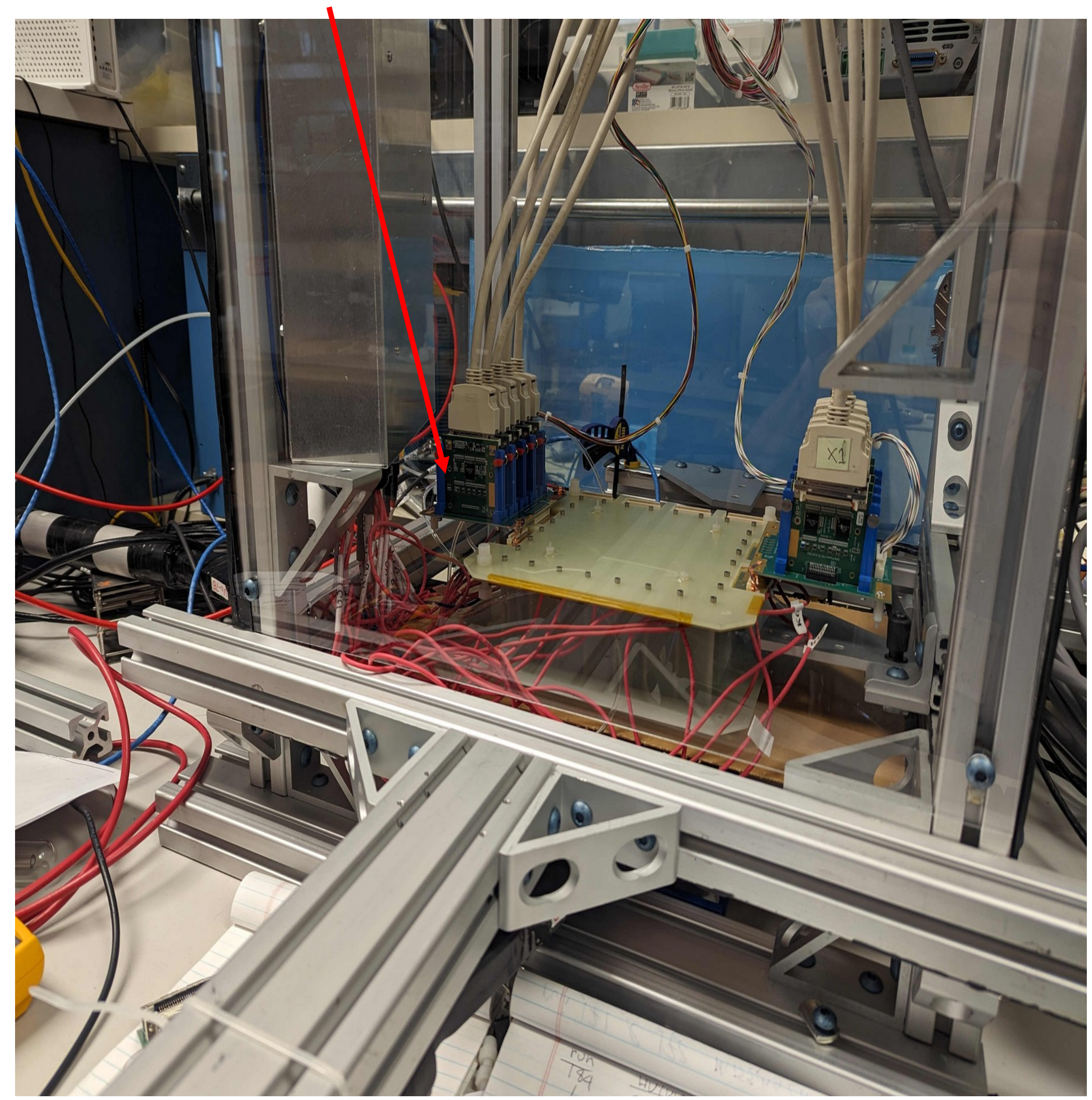
→ **validate field cage, readout**
→ **test tracking algorithms**
→ **study track resolution for different pad sizes.**
→ **study different drift gases.**

TDIS prototype TPC tested with JLab FA125 VME system

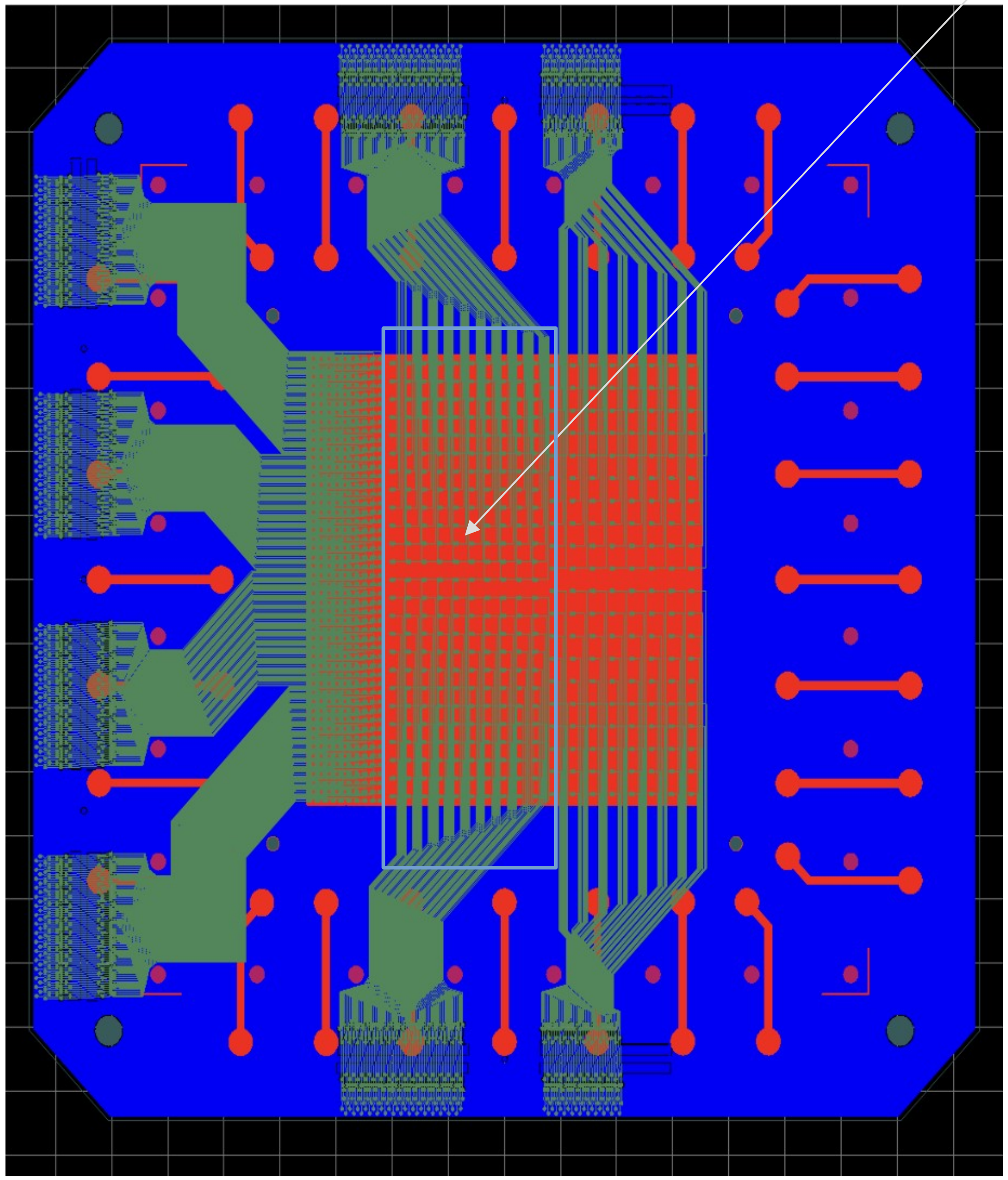
→ **Allows for testing same DAQ and frontend electronics we plan to use for pCT system**

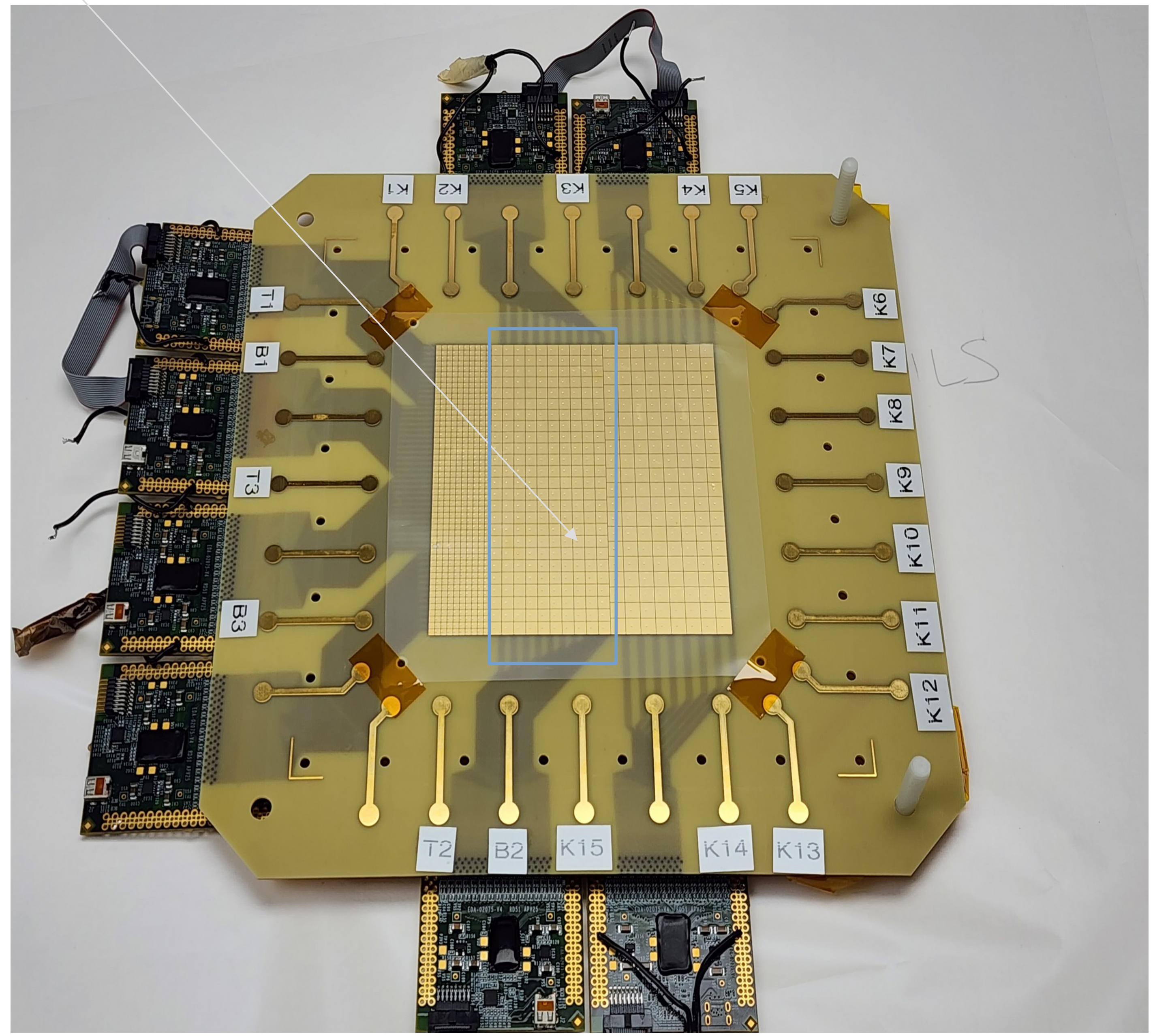


Preamp cards with shaper
24 channels per card / 5 cards per baseboard



Currently Instrumented pads





FA125 waveforms for cosmic events

- GEM HV @ ~3100 V

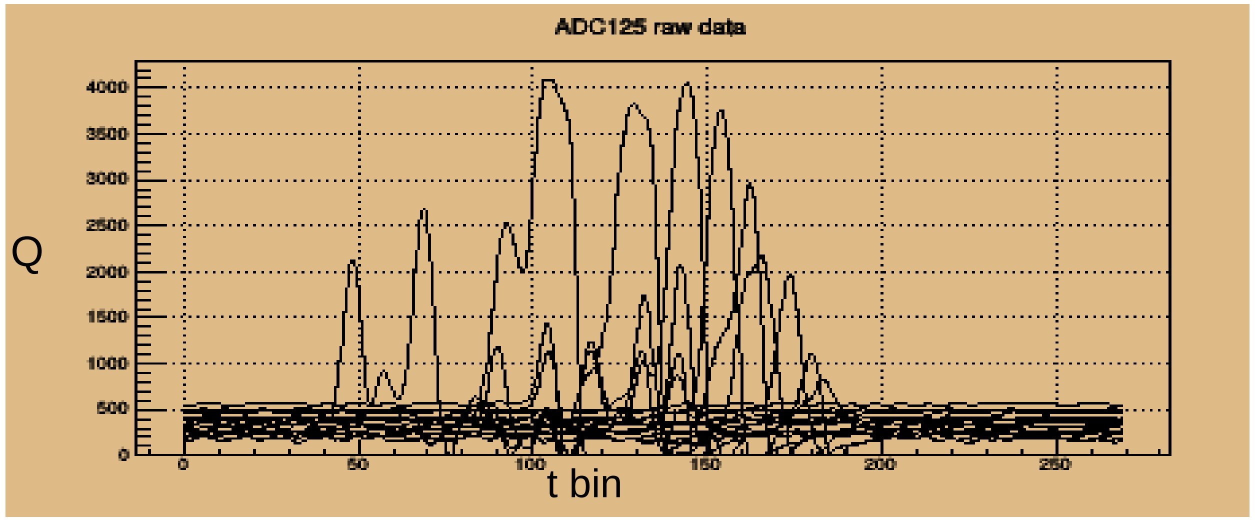
- Waveforms (Q vs time bin) for events

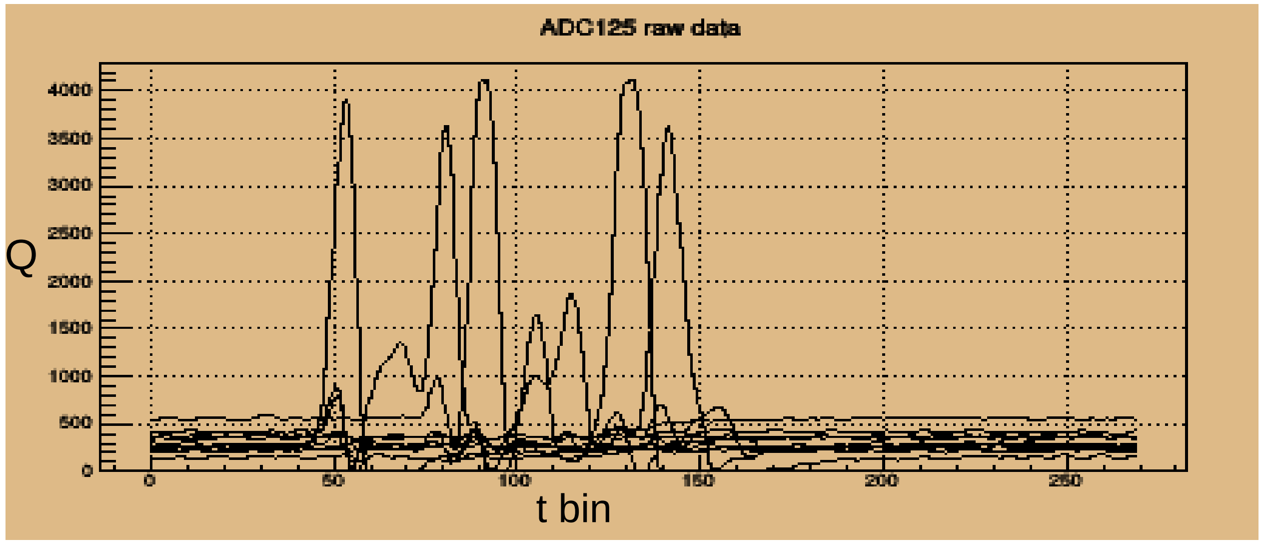
- 8 ns / time bin – allows separating hits from pileup protons.

- multiple channels (pads) contributing

- 12 bit ADC - 4096 max bin in Q

→ Some channels saturating
=> lowered HV to reduce gain





Drift velocity measurements

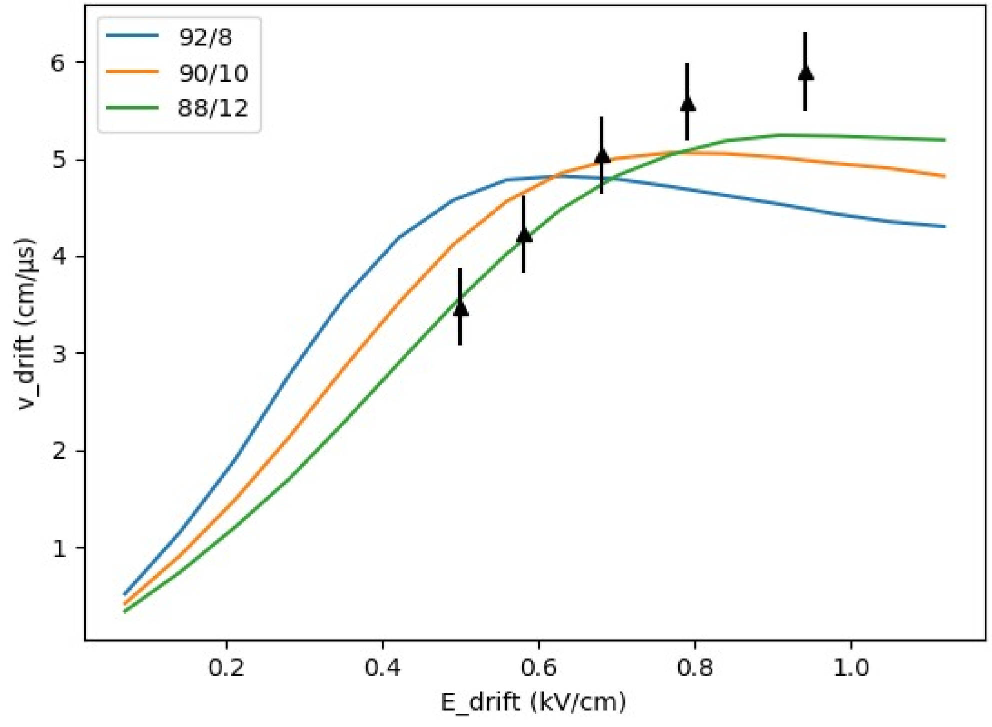
(Rachael Hall, Duquesne U. SULI student)

Expect hits along tracks to be uniformly populated in position and, therefore, in drift time.

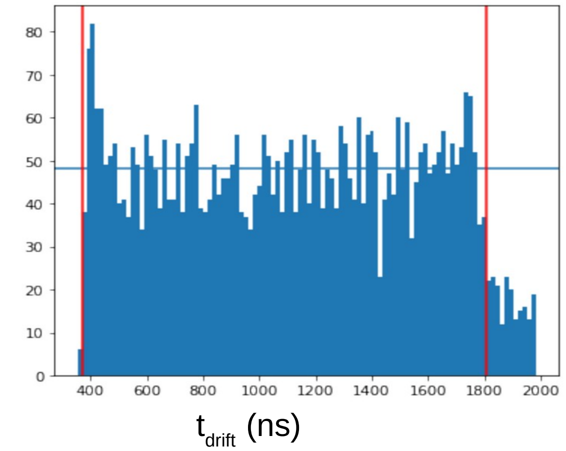
=> Range of drift time distribution dt = t_{max} -t_{min} corresponds to time for full 5 cm drift and removes amplification and signal propagation time.

$$\mathbf{v_{drift} = 5\ cm / dt}$$

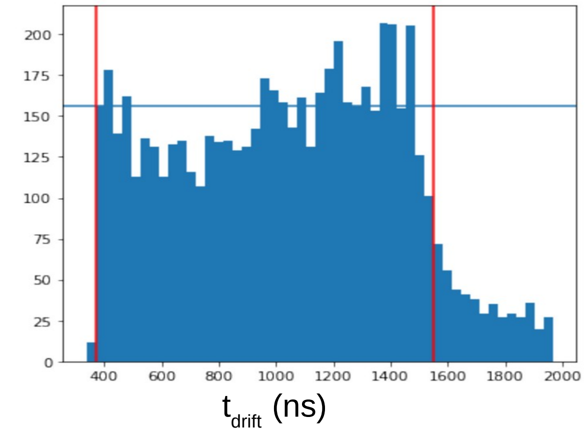
Note: the gas percentage uncertainty is +/- 2%.



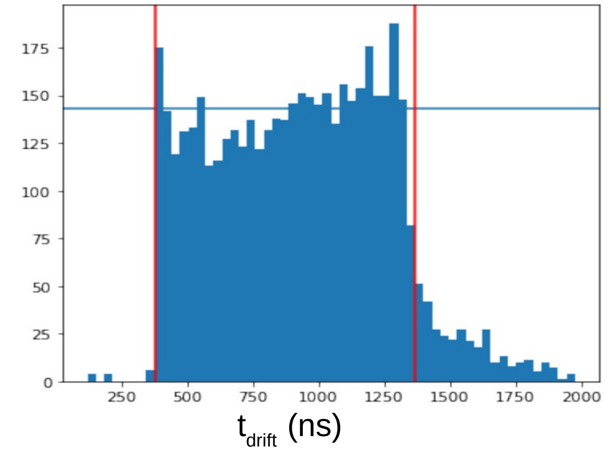
Runs with range of E_{drift} for Ar/CO2 90/10



Run: 254
E_{drift} : 0.50 V/cm
t_{max} - t_{min}: 1440 ns
v_{drift} = 3.47 cm/ms



Run: 257
E_{drift} : 0.58 V/cm
t_{max} - t_{min}: 1184 ns
v_{drift} = 4.22 cm/ms

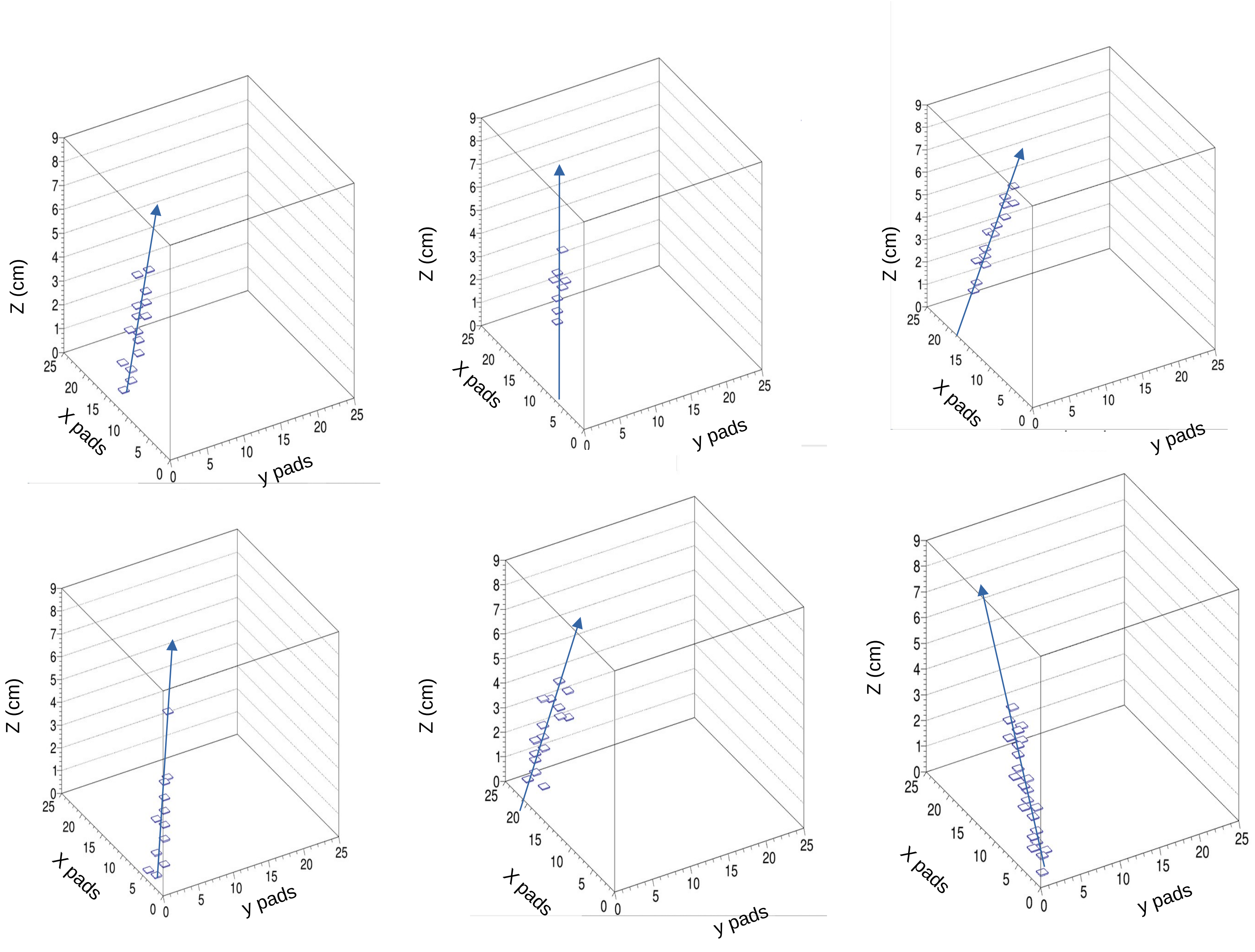


Run: 259
E_{drift} : 0.69 V/cm
t_{max} - t_{min}: 992 ns
v_{drift} = 5.04 cm/ms

Examples of reconstructed 3-D track hits

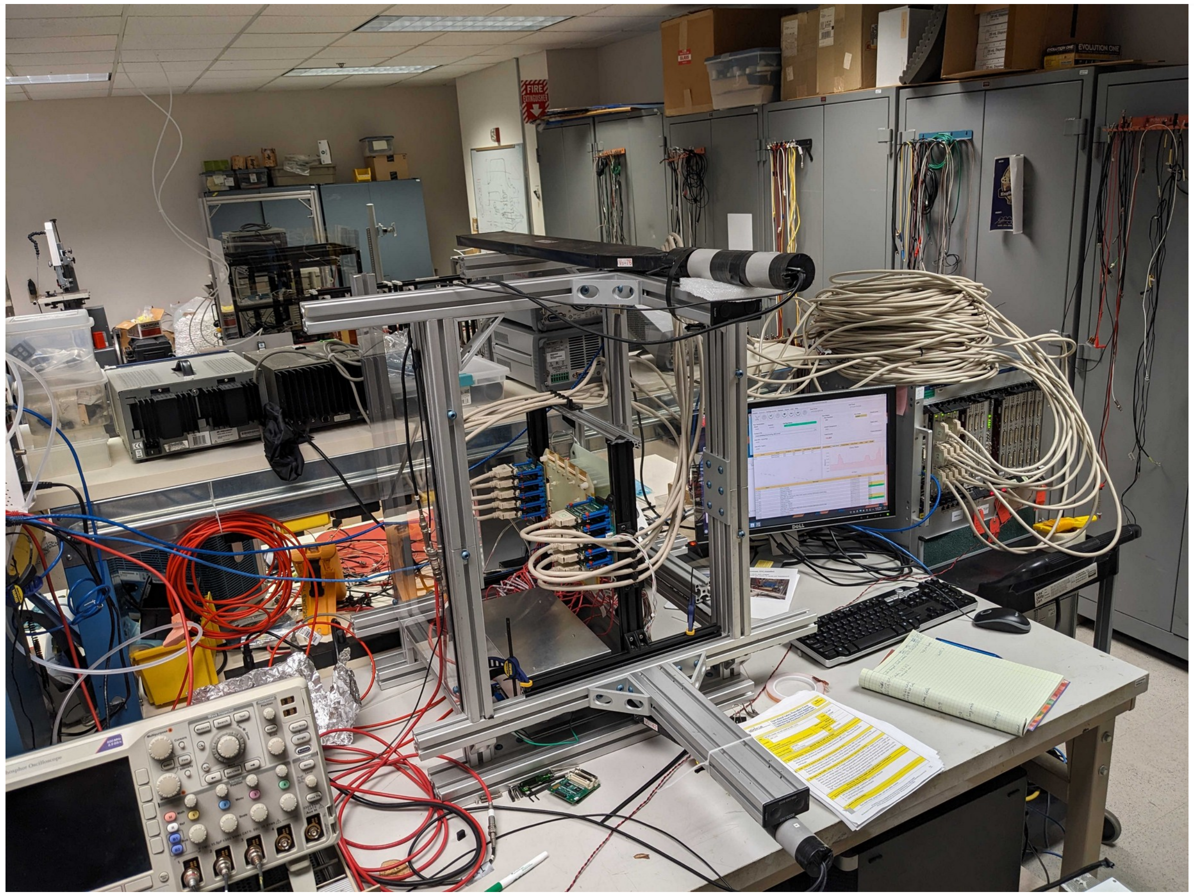
(Sudipta Saha, JLab)

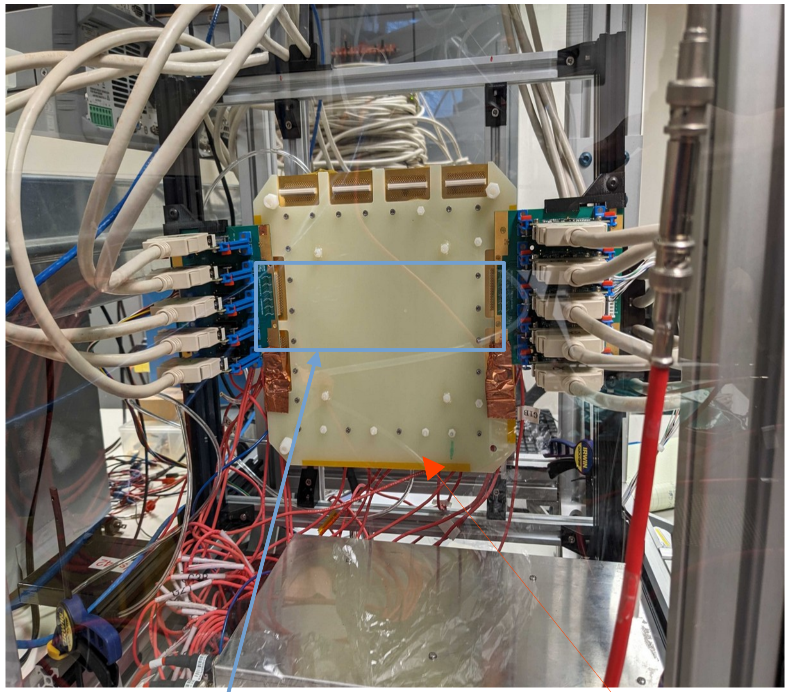
Tracks not fitted. Lines just to guide the eye

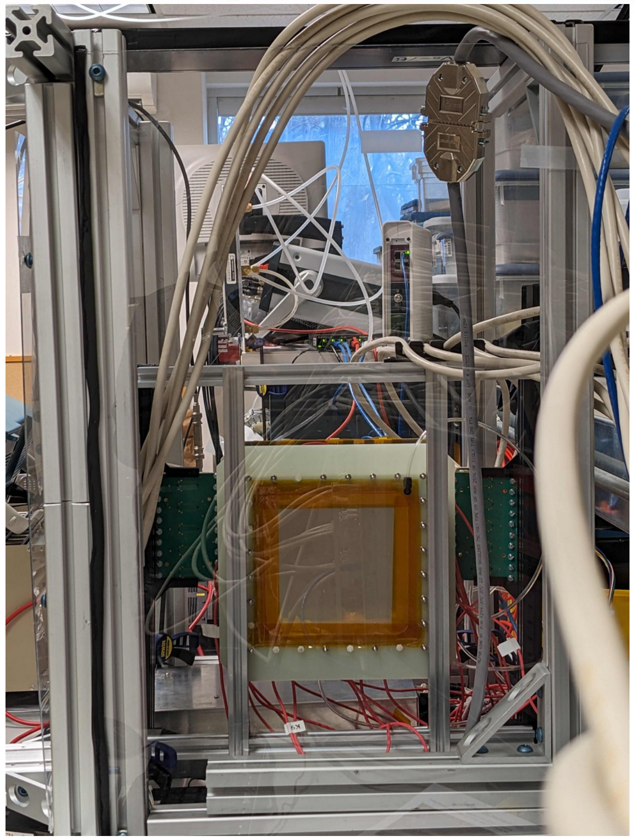


- → **Many reasonable looking tracks**
- → **Allow checks of channel map**
- → **Allow basic tests of tracking**
- → **Study track resolution.**

Ongoing tests – vertical orientation







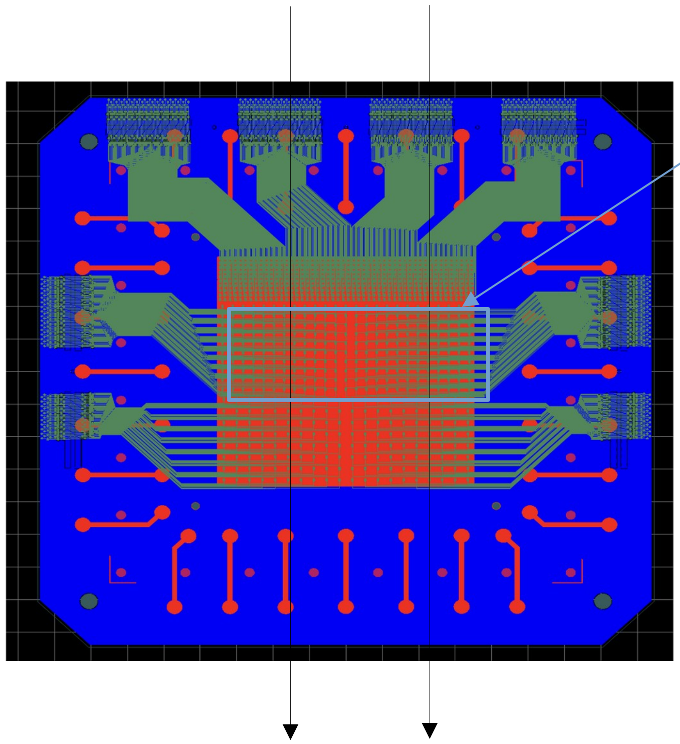
Instrumented pads

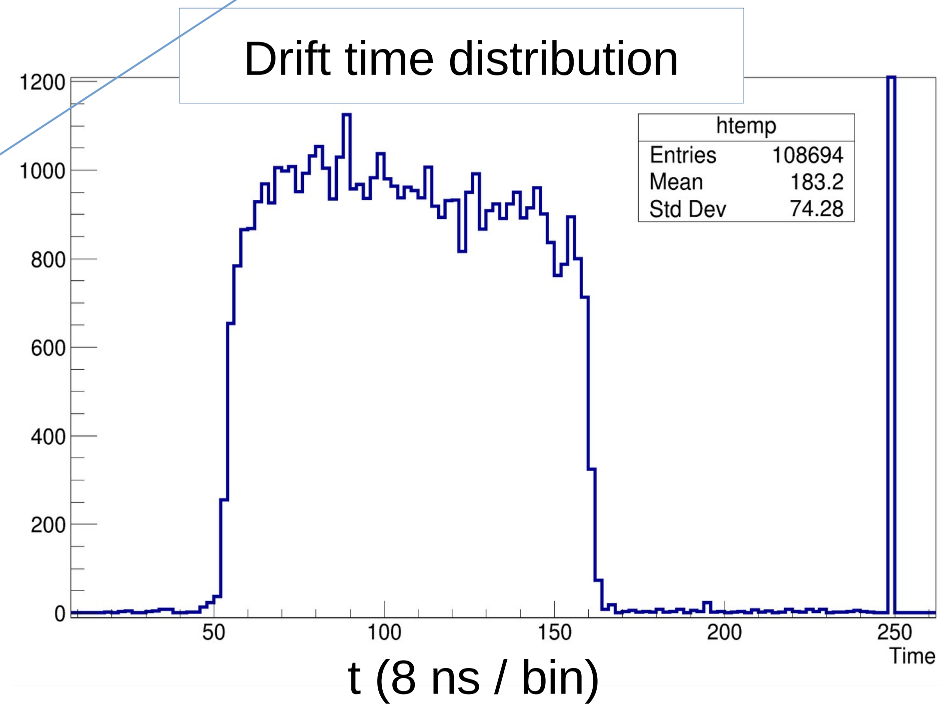
cosmics

y

x

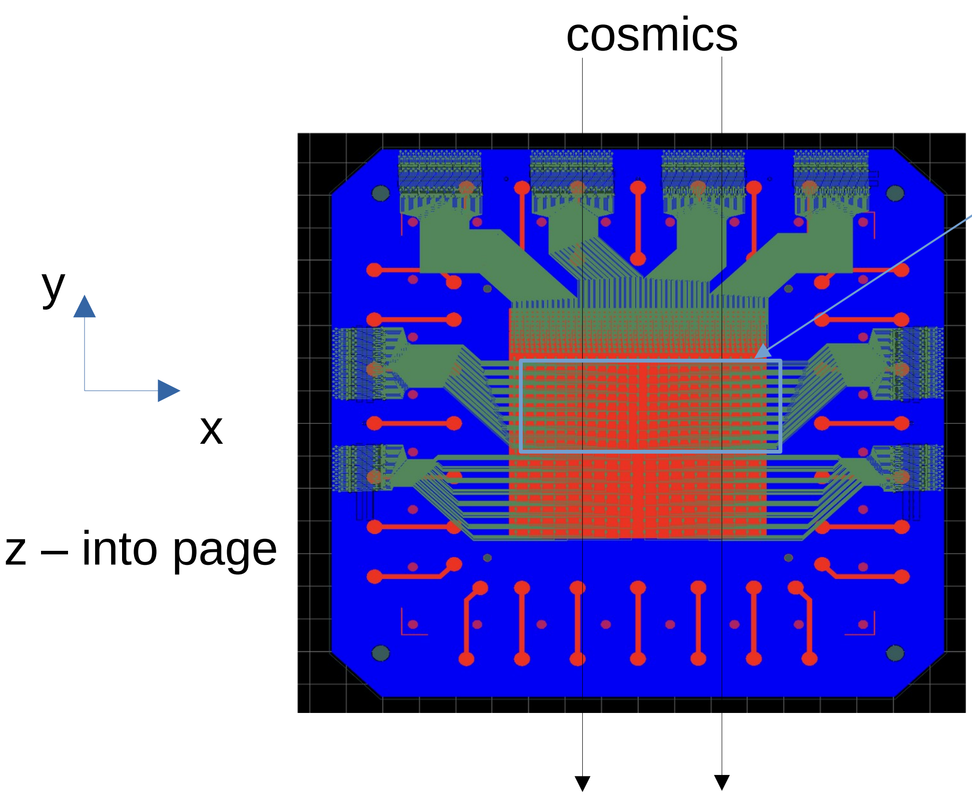
z – into page





- Replace some metallic bolts with nylon to address discharges seen at cathode V > 6 kV.
- Cosmic triggers uniformly illuminate drift region.
- ~ Uniform drift distribution with width as expected for 840 V/cm.

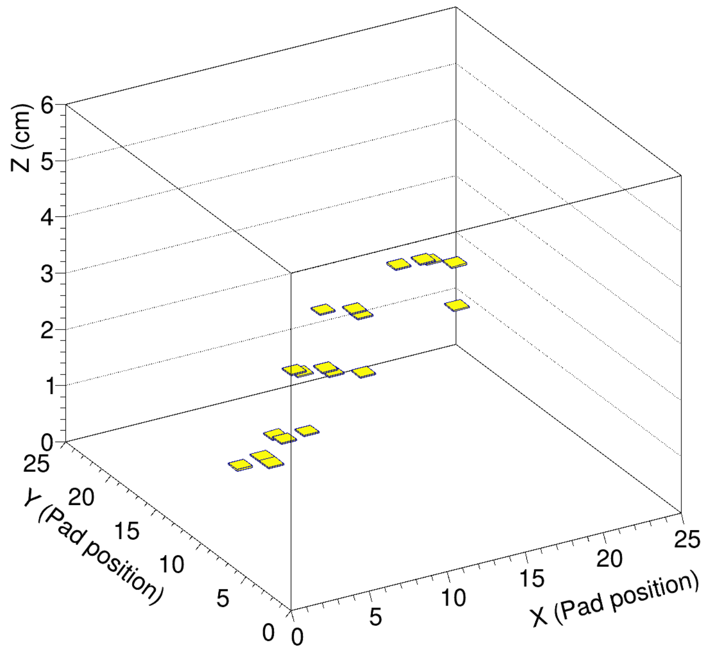
Reconstructed 3-D track hits (vertical orientation)

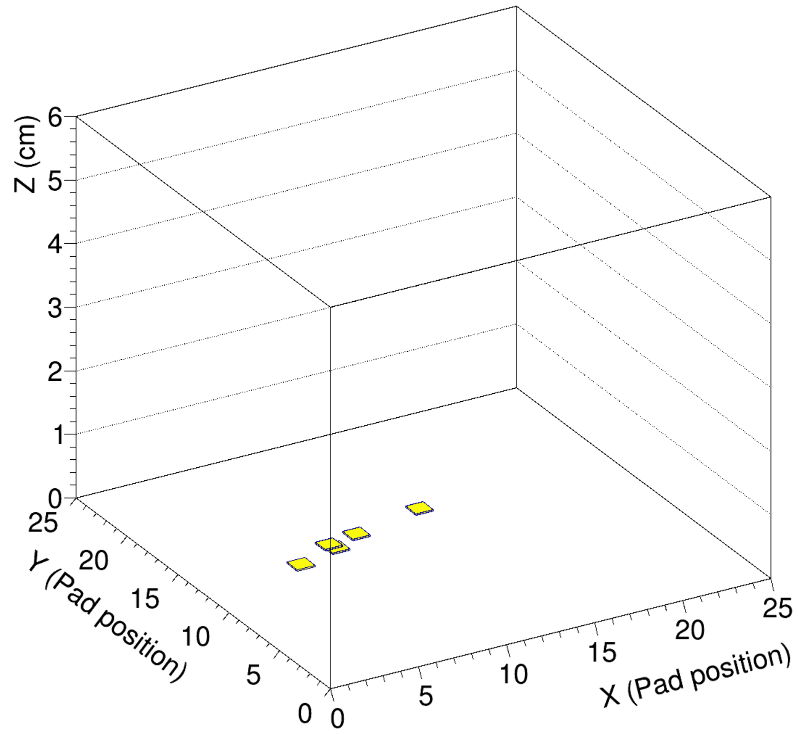


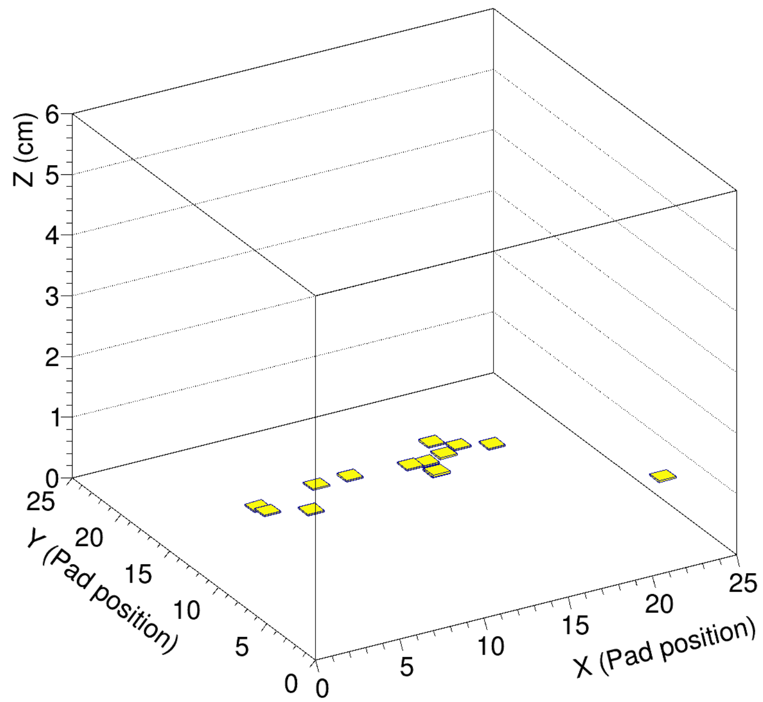
- Need to further check channel map
- Take additional data for testing tracking:

→ Take data with different mixtures of pad sizes instrumented.

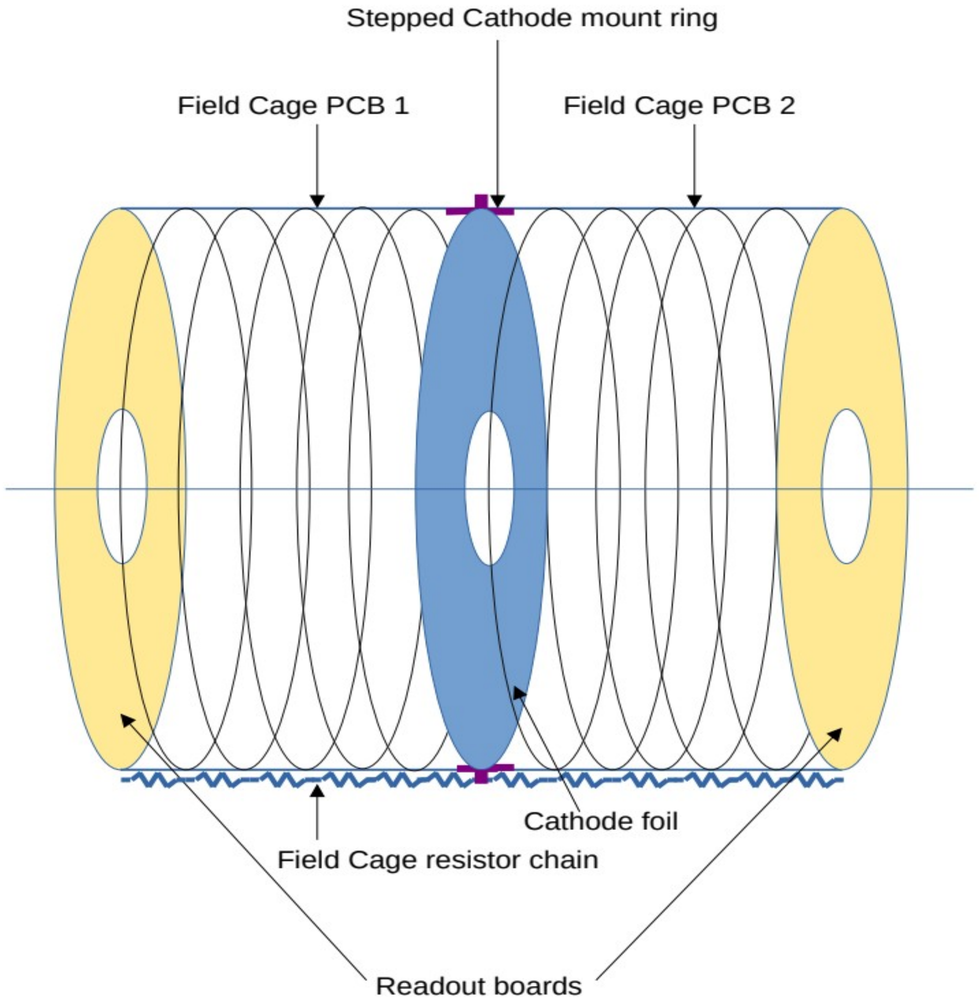
→ Allow basic tests of tracking

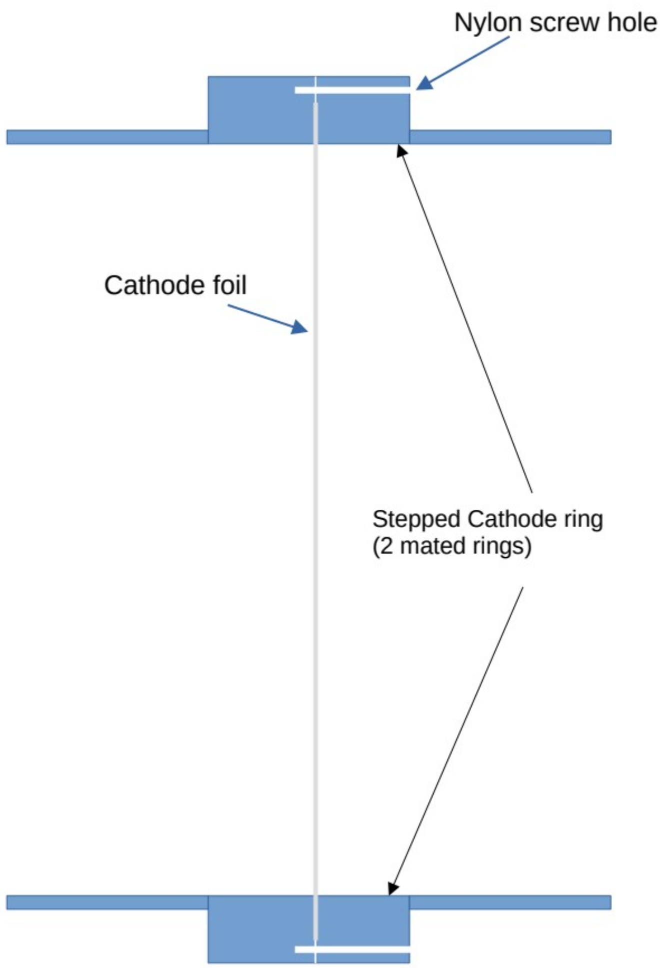






MTPC Detailed Design and Construction plan getting underway





Anticipated CY2024 Work

- ***January***
  - *Continue cosmic testing of rectangular TPC prototype*
    - ***=> provide data tracking group for basic algorithm testing***
  - **Begin MTPC prototype module design work.**

- **February**
  - **Complete test stand in EEL126, continue cosmic tests (varying drift gases)**
  - **Validate HV cables to > 12 kV**

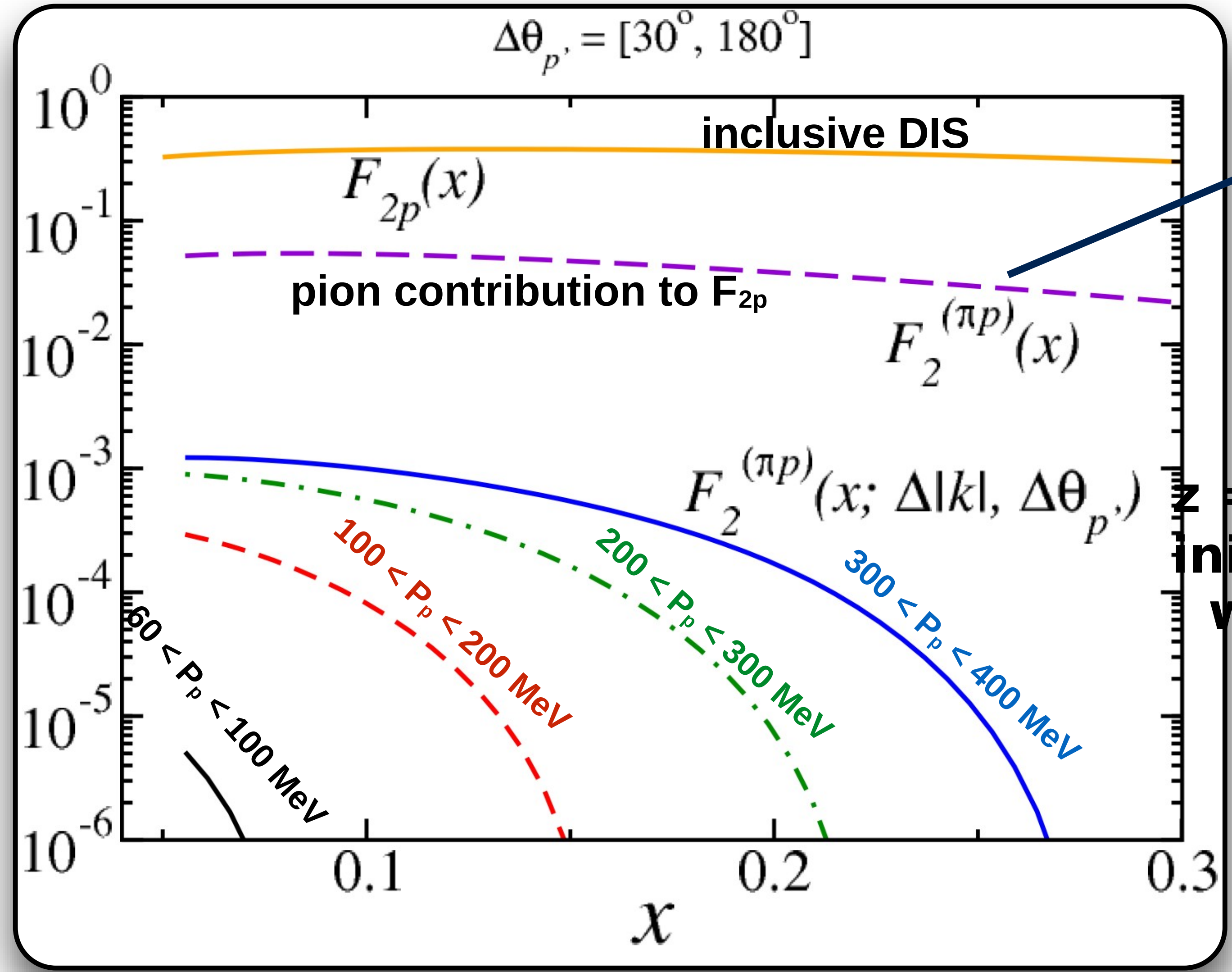
- ***Spring***
  - **Begin test of rectangular TPC readout with SAMPA FE.**

- **Summer**
  - **Test jigs and construction techniques for mTPC**
- **Fall**
  - **Begin construction of mTPC prototype module**

Much more to come this year!

Thanks!

Backup Slides



$$F_2^{(\pi N)}(x) = \int_x^1 dz\, f_{\pi N}(z)\, F_{2\pi}\left(\frac{x}{z}\right),$$

light-cone momentum distribution of pions in the nucleon

$z = k^+/p^+$ - light cone momentum fraction of t initial nucleon carried by the virtual pion, where k is p 3-momentum = -p'

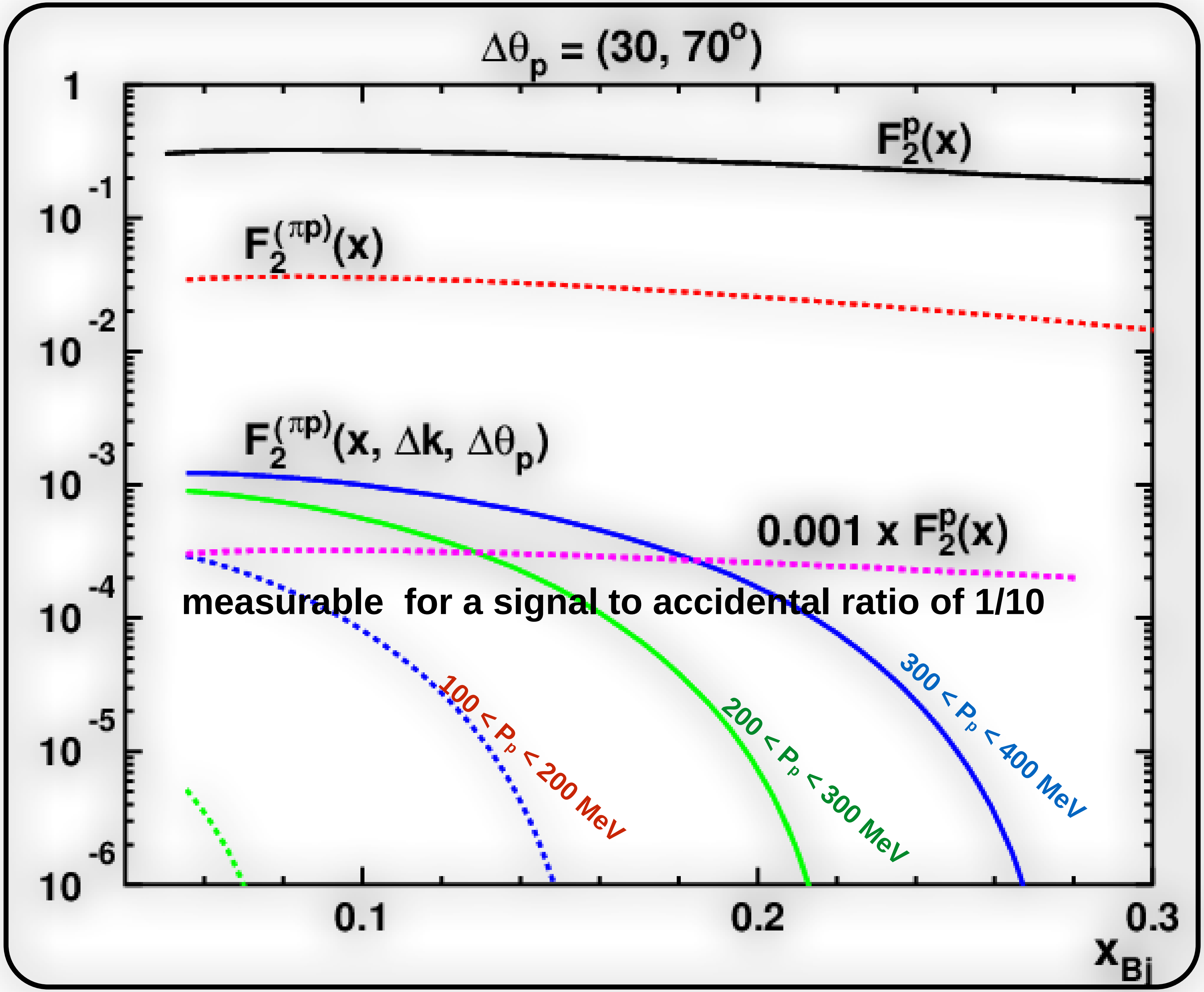
When tagging pion by detecting recoil proton

$$F_2^{(\pi N)}(x, z, k_\perp) = f_{\pi N}(z, k_\perp)\, F_{2\pi}\left(\frac{x}{z}\right)$$

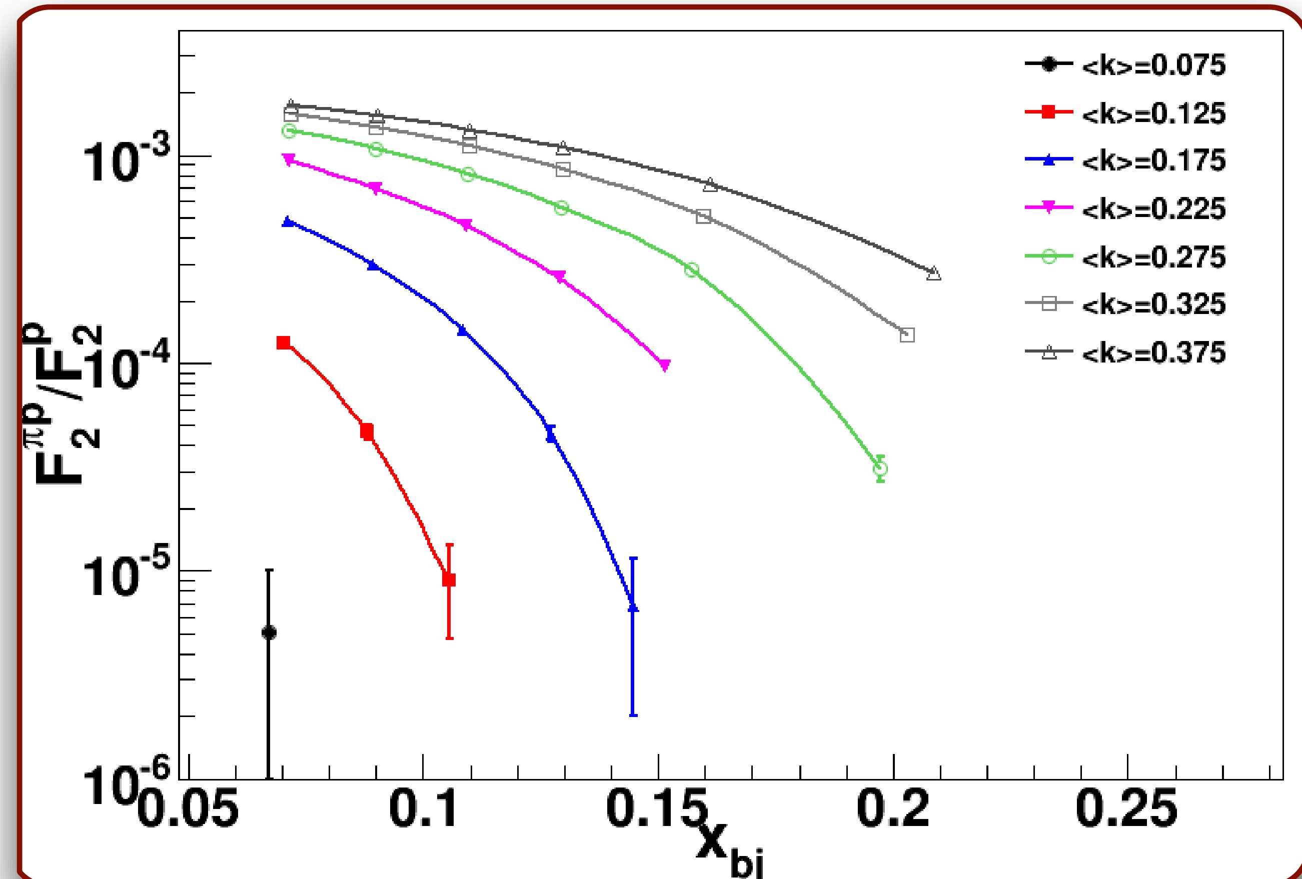
Tagged SF **pion "flux"** **Pion SF**

Pion contribution dominates at JLab kinematic (with ~ 1% for P_p < 400 MeV/c)

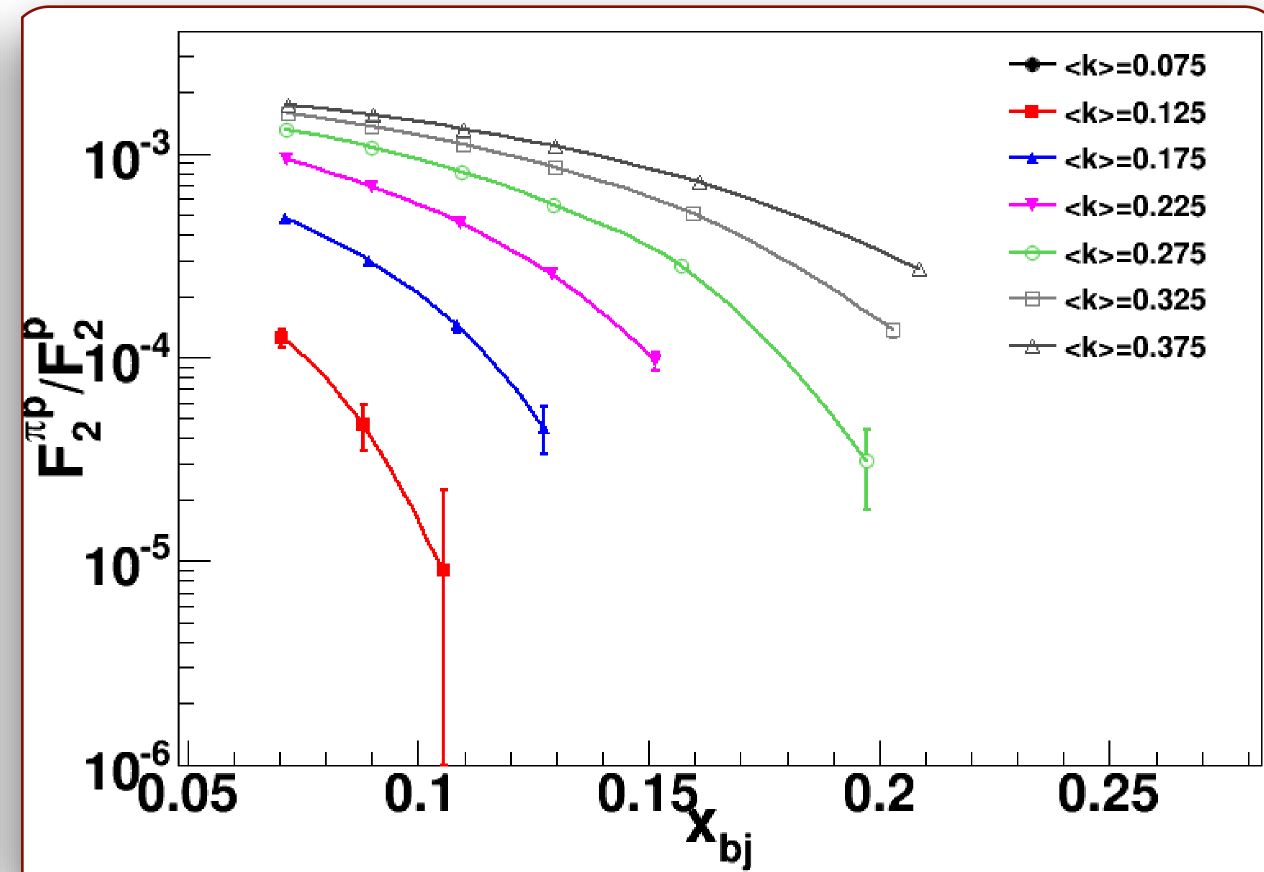
T. J. Hobbs, Few-Body Cyst. 56, 363–368 (2015);
H. Holtmann, A. Szczurek and J. Speth, Nucl. Phys. A 596, 631 (1996);
W. Melnitchouk and A. W. Thomas, Z. Phys. A 353, 311 (1995)


$\Delta\theta_p$ = (30, 70°)
$F_2^p(x)$
$F_2^{(\pi p)}(x)$
$F_2^{(\pi p)}(x, \Delta k, \Delta\theta_p)$
0.001 x $F_2^p(x)$
measurable for a signal to accidental ratio of 1/10
100 < P_p < 200 MeV
200 < P_p < 300 MeV
300 < P_p < 400 MeV
x_{Bj}

proton target



neutron target

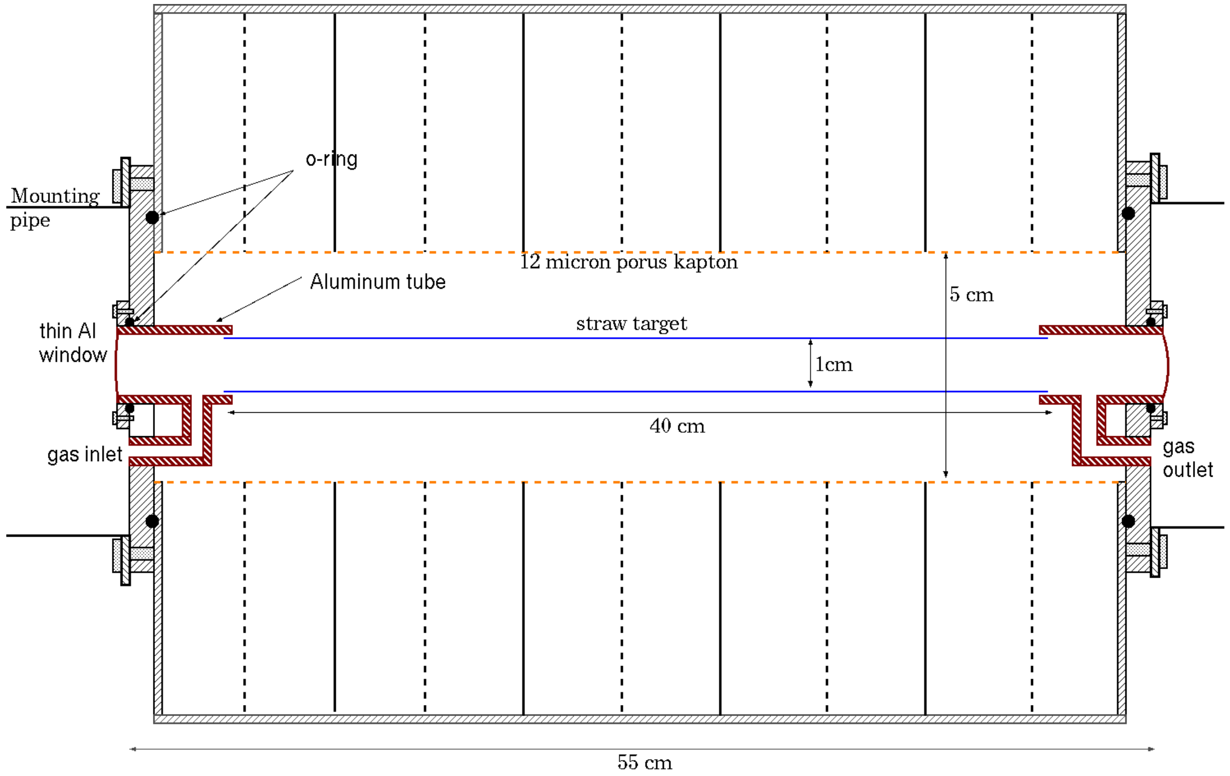


Full momentum range (collected simultaneously) - all momentum bins in MeV/c
Error bars largest at highest x points - at fixed x, these are the lowest t values

some kinematic limits:

- **$150 < k < 400$ MeV/c corresponds to $z < \sim 0.2$**
- **Also, $x < z$**
- **Low x, high W at 11 GeV means $Q^2 \sim 2$ GeV^2**

spiral wound 25 um kapton straw Target



UVa 4T Solenoid

Pressure tested to 60 psi