Tagged Deep Inelastic Scattering (TDIS) in Hall A

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Hall A TDIS Collaboration

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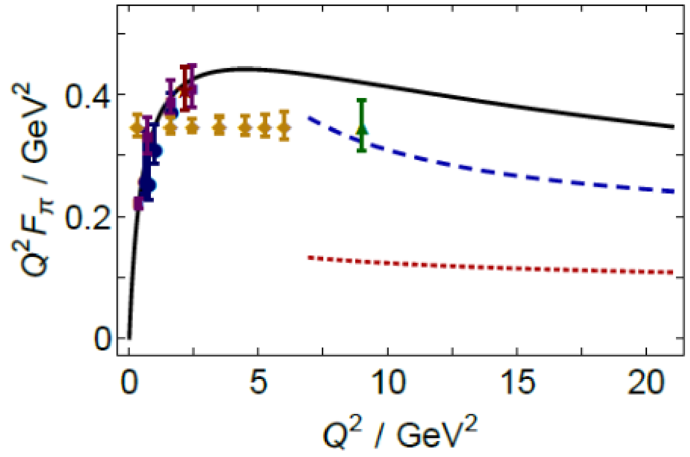
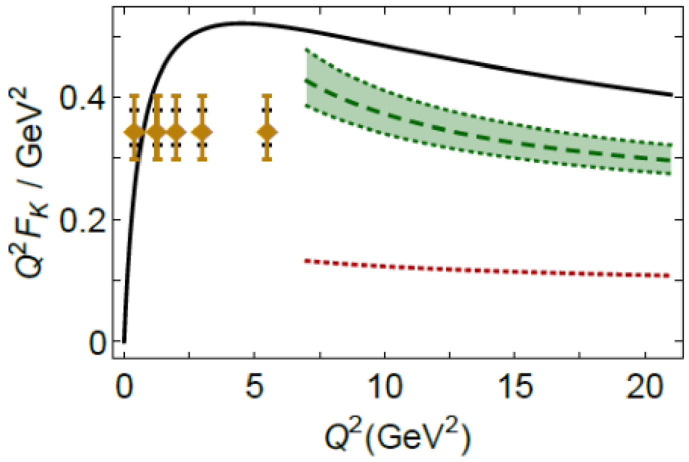
Hall A Winter Collaboration Meeting 2022

Pion and Kaon Structure at 12 GeV

- Jefferson Lab will provide the beam energy of 11 GeV → take data for the pion (kaon) form factor up to Q^2 ~ 10 GeV^2, and measurements of the pion (kaon) structure functions at large-x (> 0.5) through the Sullivan process.

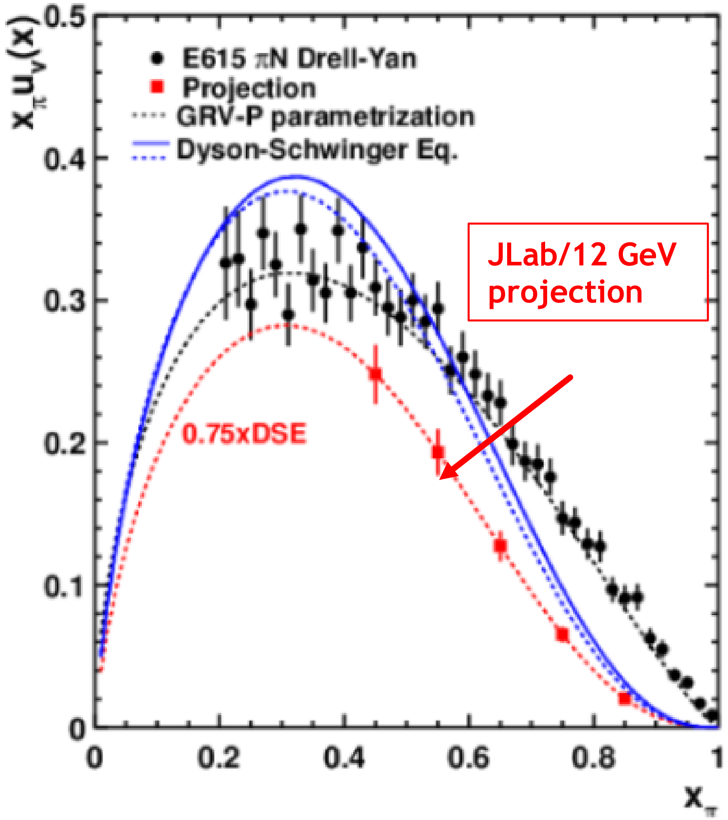




Pion FF – first quantitative access to hard scattering scaling regime?

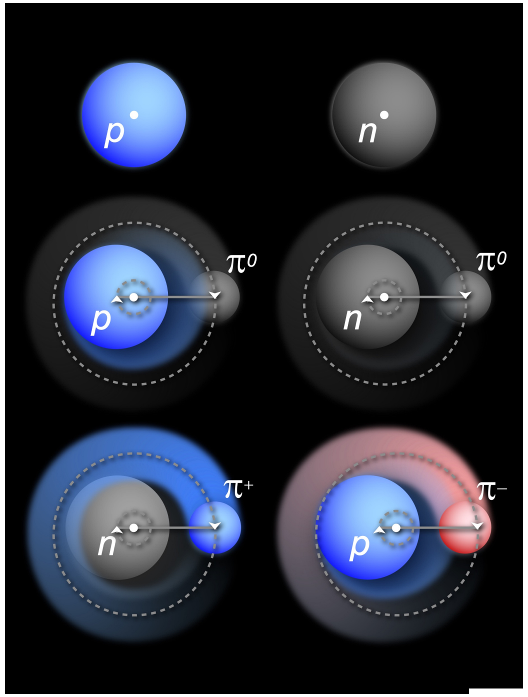
Pion SF – $(1-x)^1$ or $(1-x)^2$
A dependence at large x?

PR12-15-006 TDIS in Hall A

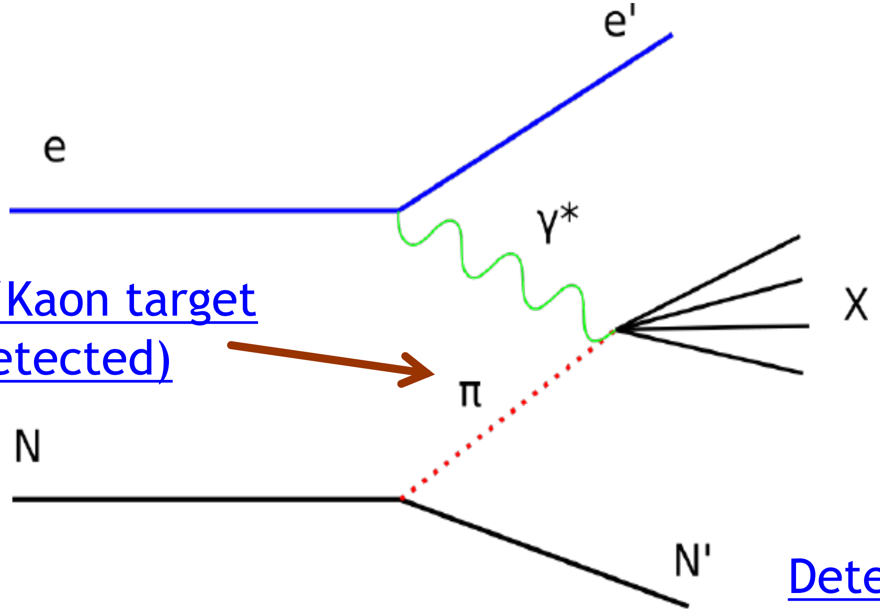


Physics Objects for Pion/Kaon Structure Studies

Sullivan process – scattering from nucleon-meson fluctuations



Detect scattered electron



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

Pion/Kaon target (undetected)

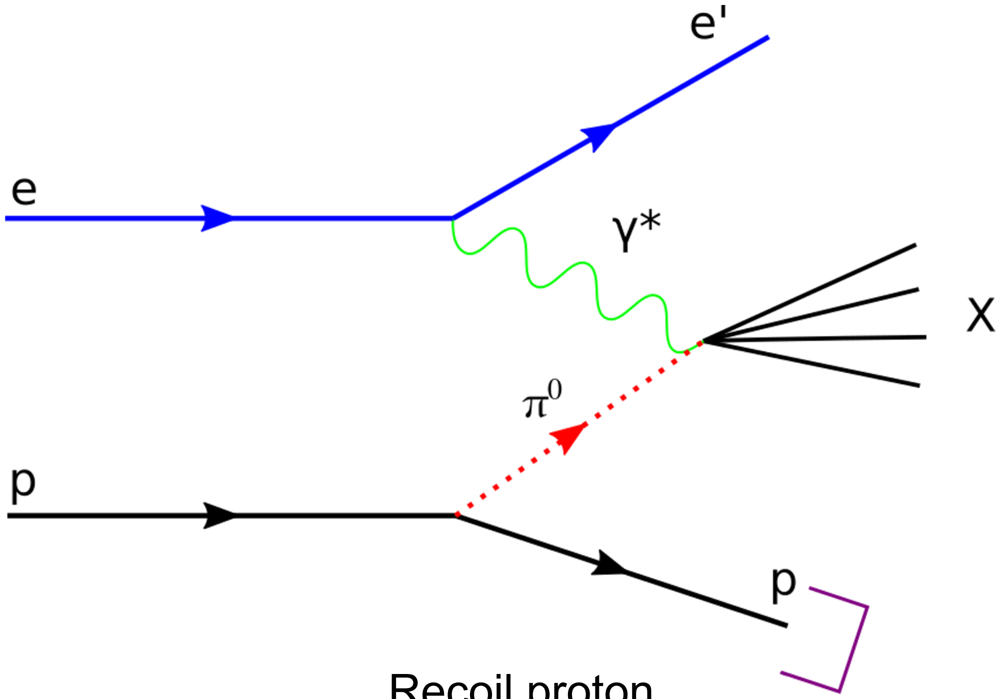
Detect "tagged" proton/neutron/lambda

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

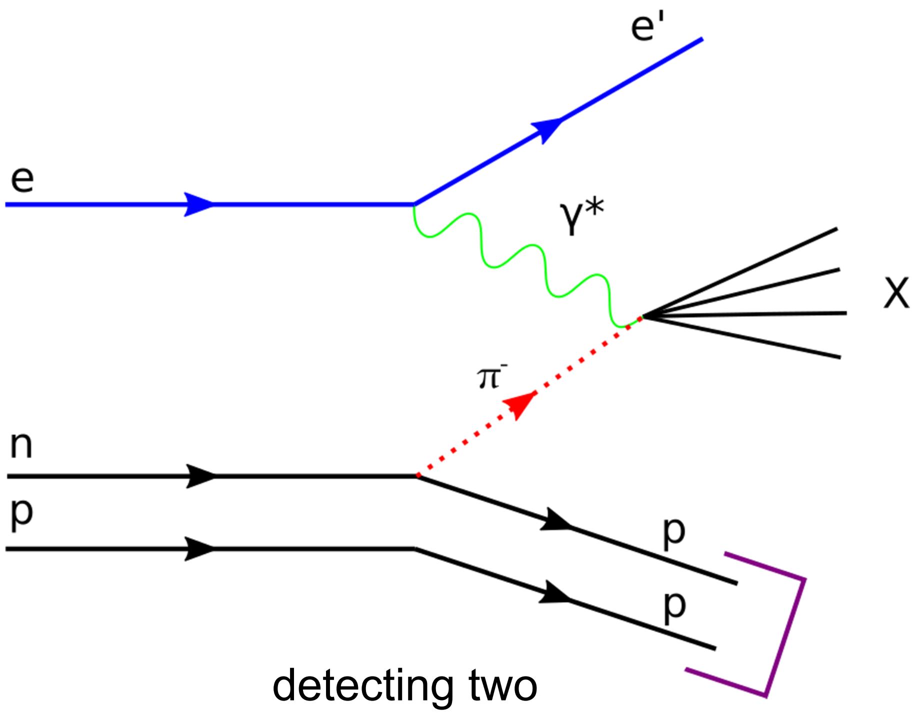
i = π, ρ, …

"Flux factor"

Pion structure from Sullivan process: 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:

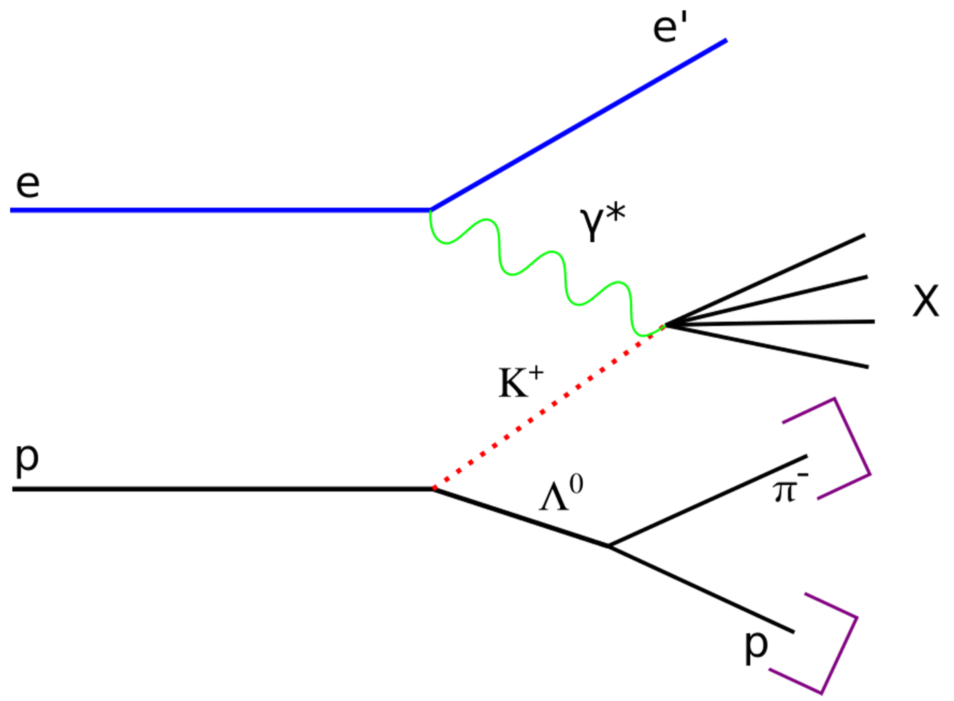
$8 < W^2 < 18\ GeV^2$
$1 < Q^2 < 3\ (GeV/c)^2$
$0.05 < x < 0.2$

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

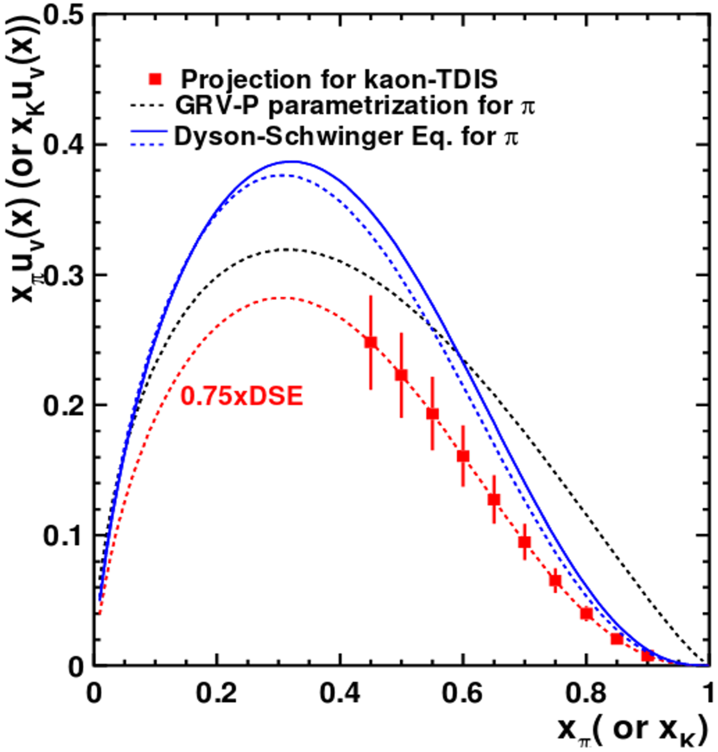
Run Group Addition: Kaon TDIS (C12-15-006A)

Kaon Tagged Deep Inelastic Scattering (TDIS)

C12-15-006A

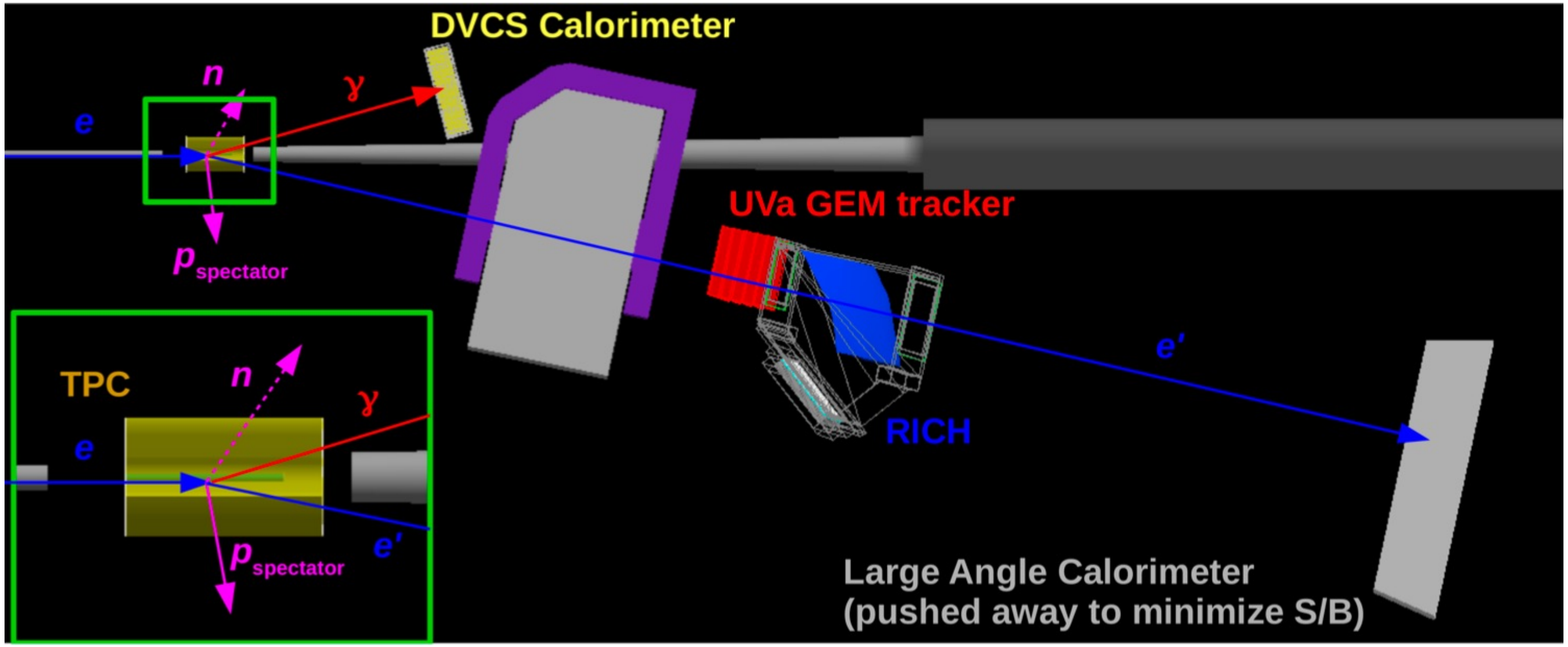


- TDIS run group proposal accepted PAC45 July 2017 Conditionally approved, as pion TDIS (same set-up/27-day beam time)
- **Mesonic content/flux factors unknown, both pion and kaon TDIS measurements will be extremely useful experimental tests**
- Kaon TDIS gives background measurement for pion TDIS



More spectator tagged physics: nDVCS using TDIS setup

- 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 to TDIS experimental setup (photon detection)
  - mTPC will detect spectator proton → allow PID of nDVCS events
  - SBS will detect e'

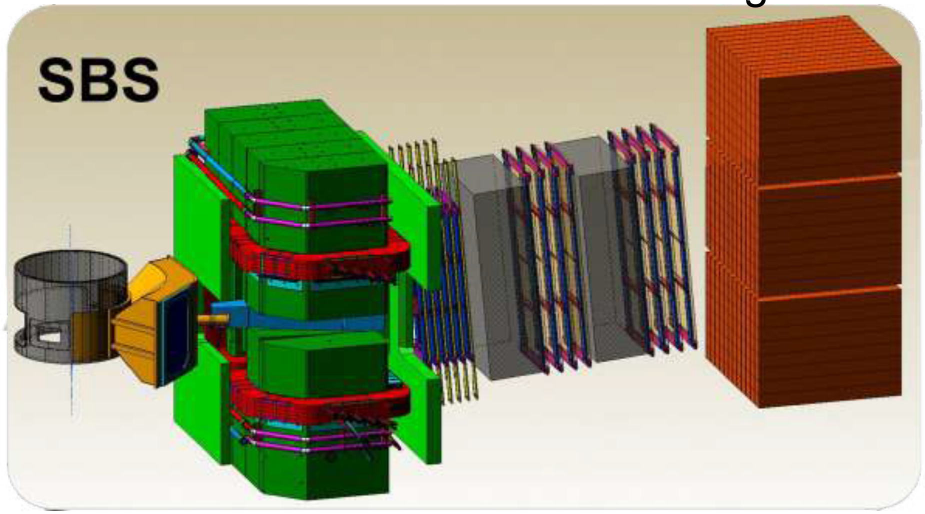


e’ detection: Super BigBite Spectrometer (SBS)

- $\Delta\Omega$: 76 *msr* @ 15°, 5 *msr* @ 3.5° (forward/small angle hadrons detected)
- Δp: 2-10 *GeV/c*
- σ_p/p: ~1×10^{-4}

Angular resolution 0.5 *mrad*

Hadron detection configuration

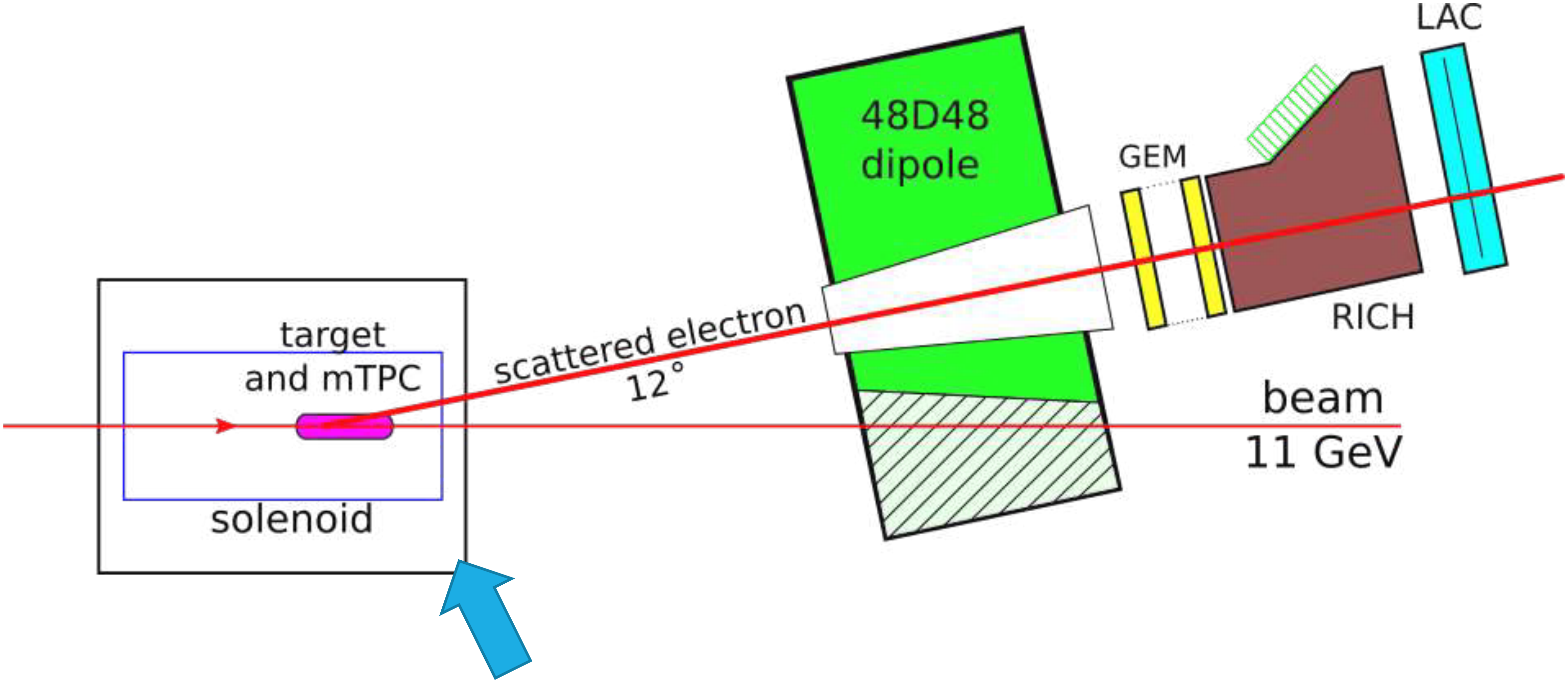


courtesy D. Dutta

courtesy A. Puckett

SBS configured for e^- detection; 12° scattering angle (large acceptance, ~50msr)
- 5 GEM tracker planes (70μm resolution)
- Threshold CO_2 Cherenkov detector (modified HERMES RICH)
- Large angle calorimeter (from Hall B CLAS)
- e^- PID and e^- trigger (L2) = Cherenkov + calorimeter (combined π rejection factor ~10^4)

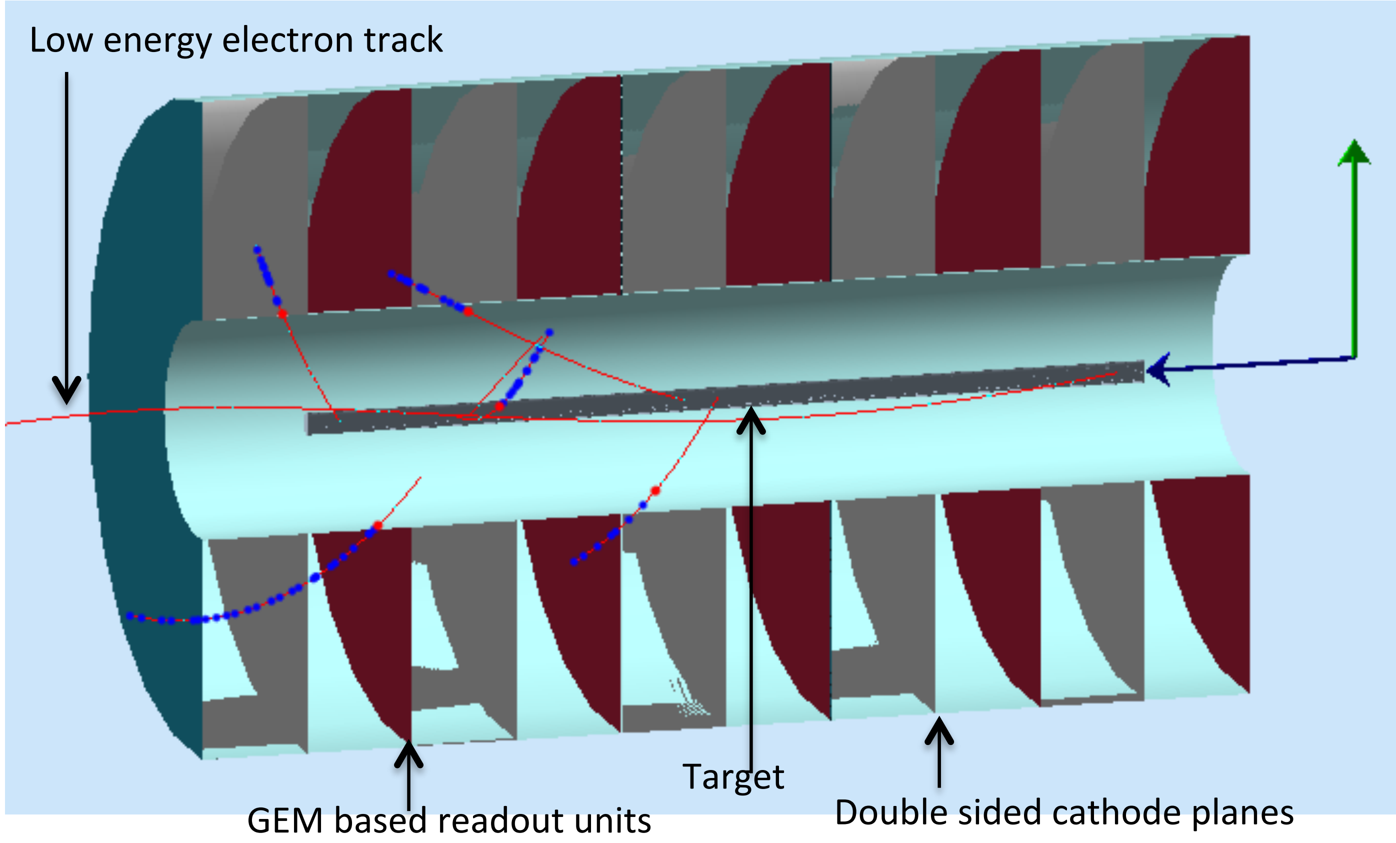
TDIS in Hall A: Experimental layout

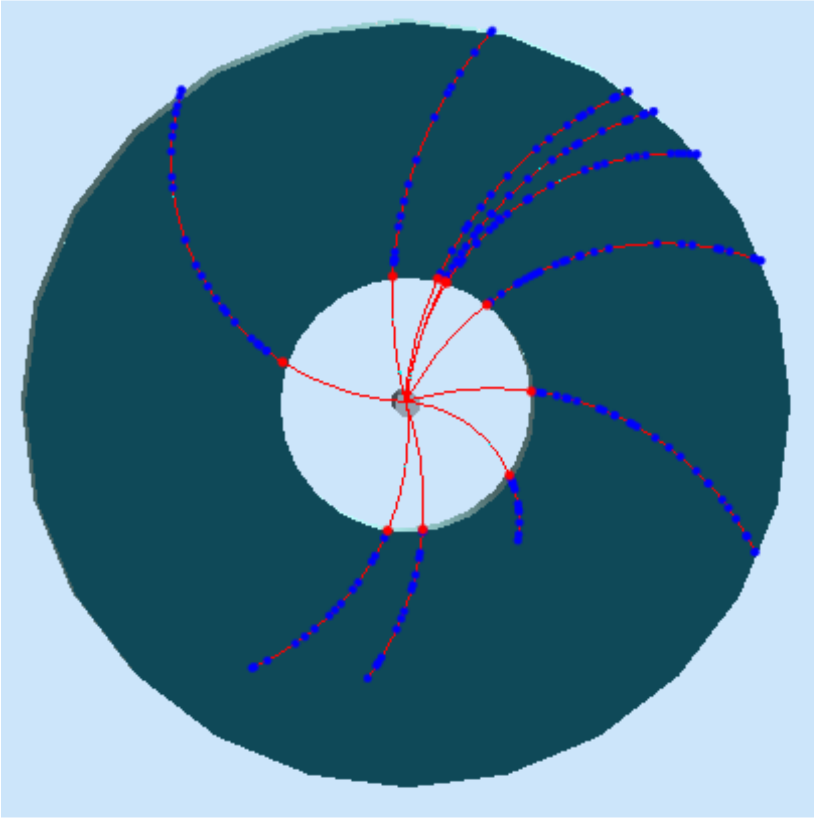


A new detector → mTPC: multi-Time Projection Chamber to measure low-momentum recoil protons

The multiple-Time Projection Chamber (mTPC) in TDIS

- 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 $\vec{E}$
- Consist of 10 TPC modules to form one composite mTPC → takes care of high rates compared to single/radial TPC

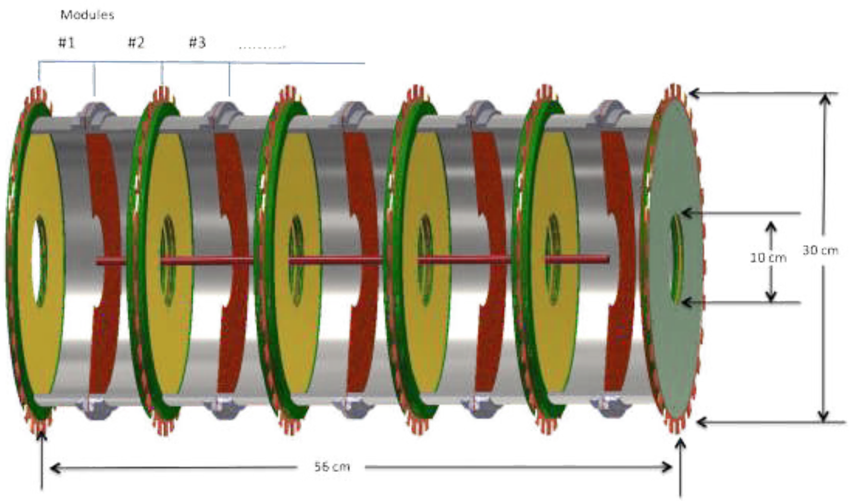


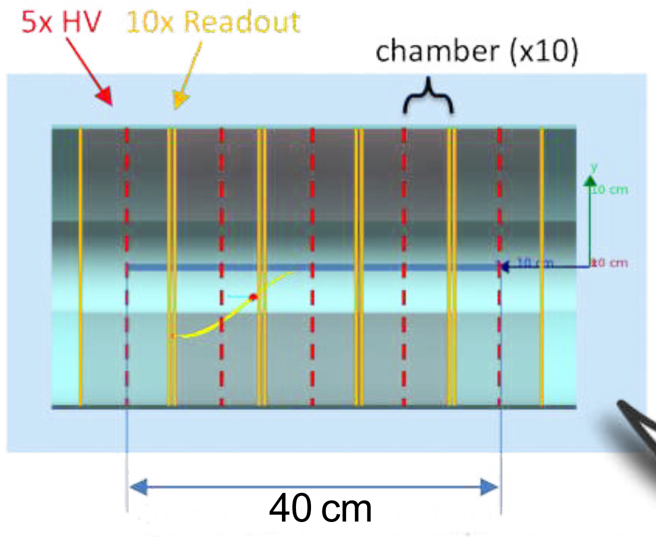


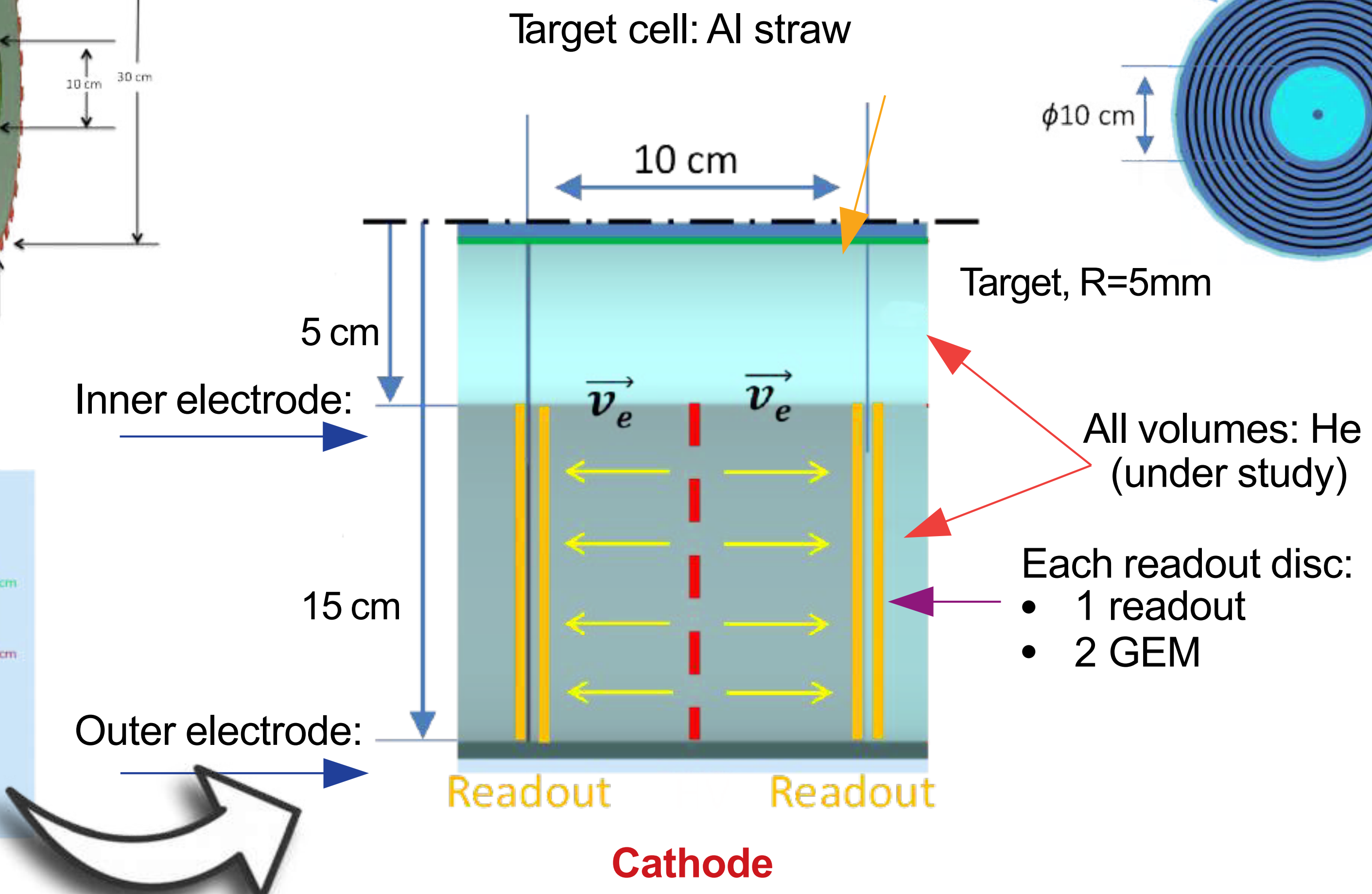
Ptcl tracks

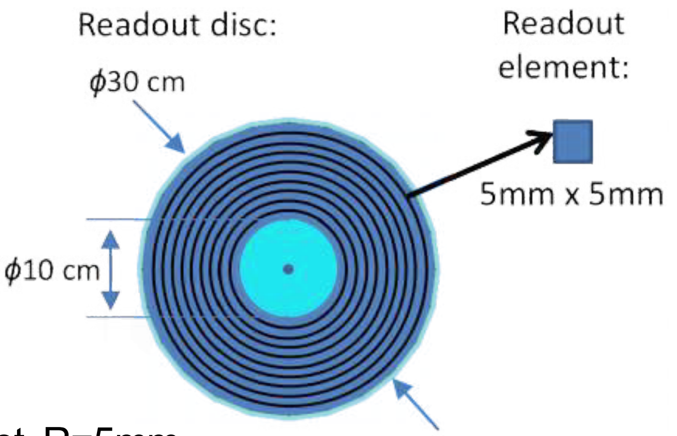
Dimensions : 55 cm long, Inner (outer) radii = 5 cm (15 cm)

A new detector: mTPC





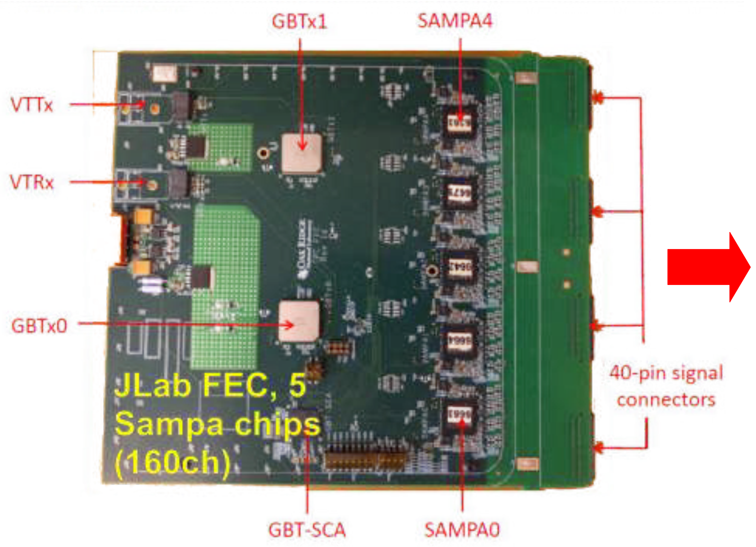


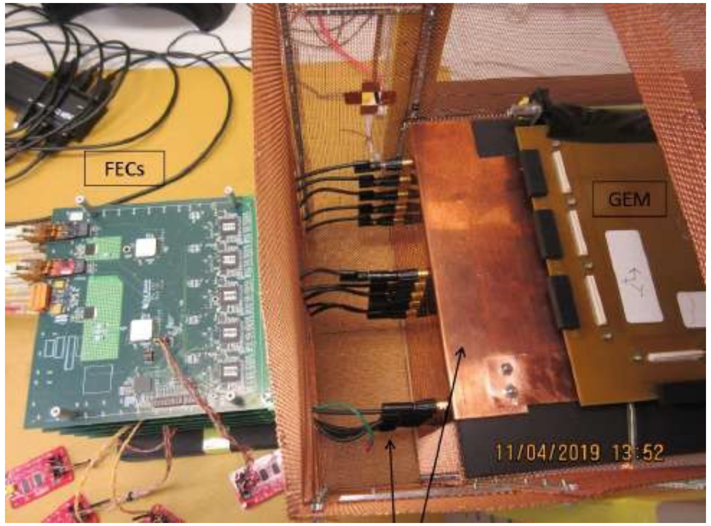


mTPC embed within a solenoid

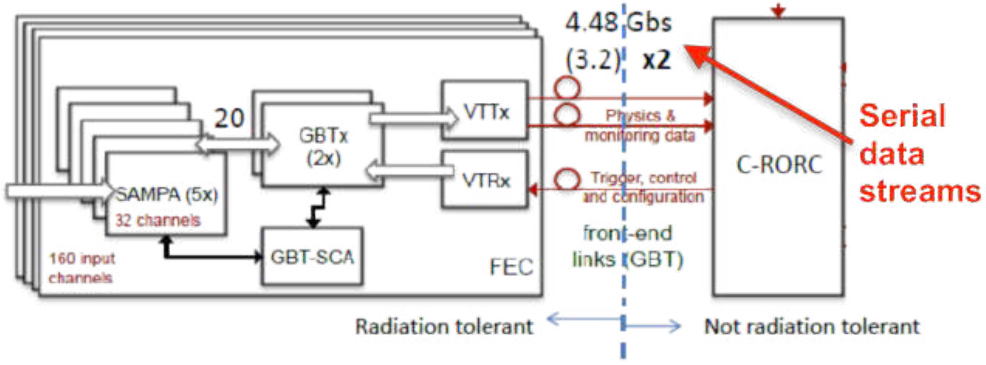
Streaming Data Acquisition

- Design/prototyping/testing
  - E. Jastrzembski, E. Pooser, G. Heyes (JLab)
- SAMPA chip
  - M. Bregant (U. Sao Paulo) and streaming readout developed for ALICE TPC upgrade





SAMPA - charge-sensitive pre-amp, ADC, DSP (zero-suppresion e.g.)



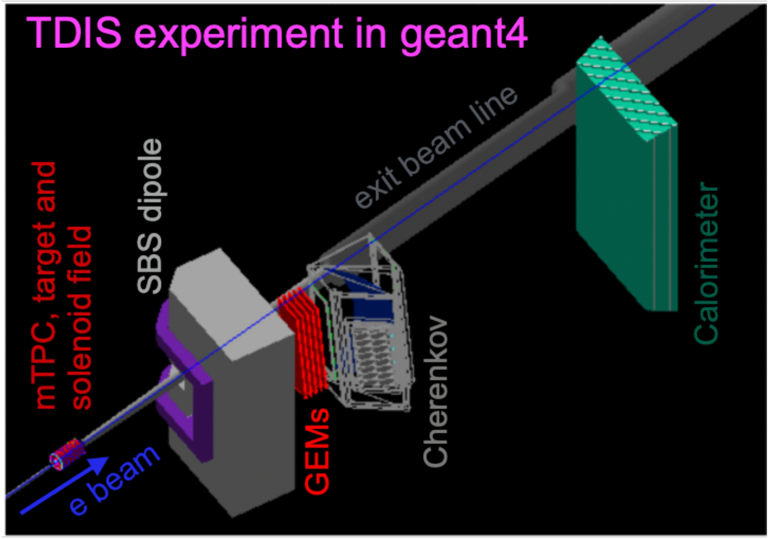
FEC – Front End Card (160 ch / FEC) (5 FEC = 800 ch)
C-RORC – Common Read Out Receiver Card (PCIe)
GBTx – Giga Bit Transceivers
GBT-SCA – GBTx Slow Controls Adapter
VTTx, VTRx – Fiber optic transceivers

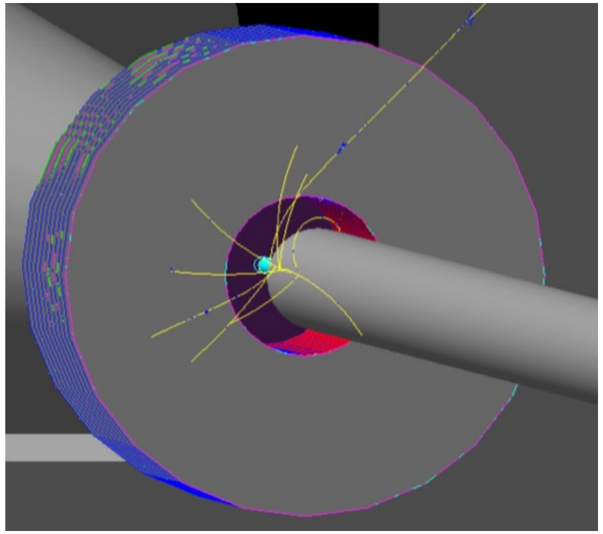
Readout Electronics Updates:

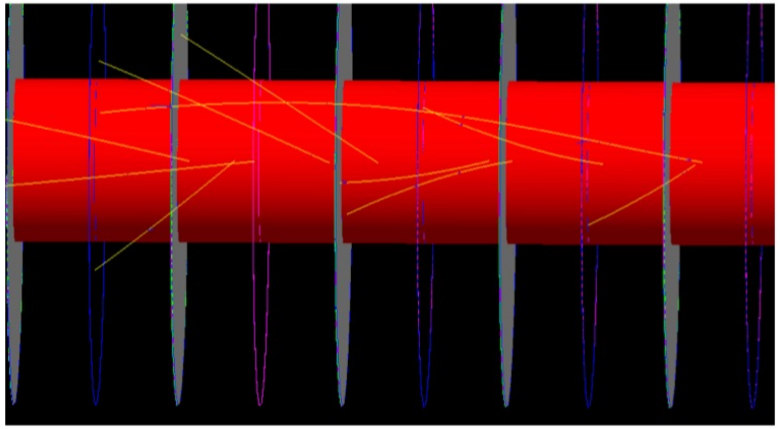
- Obtain radiation hard components from CERN
- 2nd generation data transmission and power conversion components
  - lpGBT, VTRX+ (for High Luminosity LHC)
  - bPOL12V, bPOL2V5, linPOL12V (for HL LHC)

mTPC Simulation Status: digitization

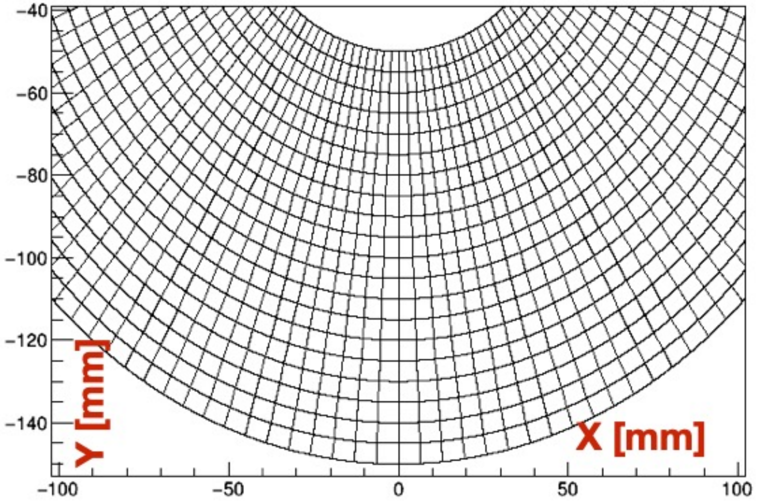
Credit: R. Montgomery (University of Glasgow)



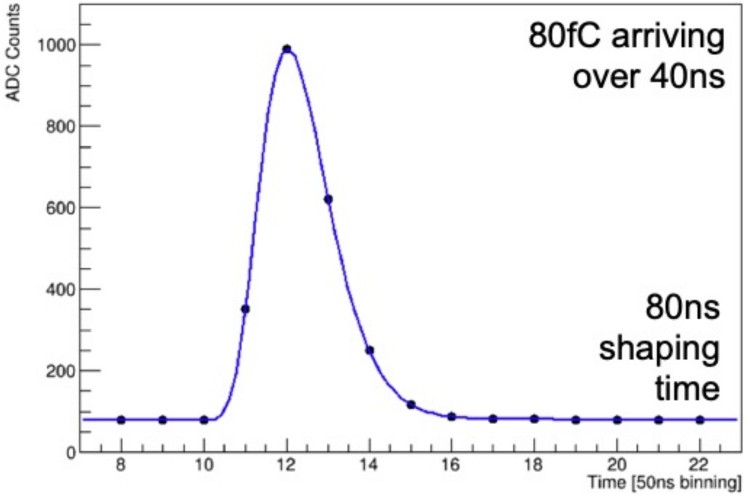




SBS geant4 framework g4sbs is used for simulation studies



- 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

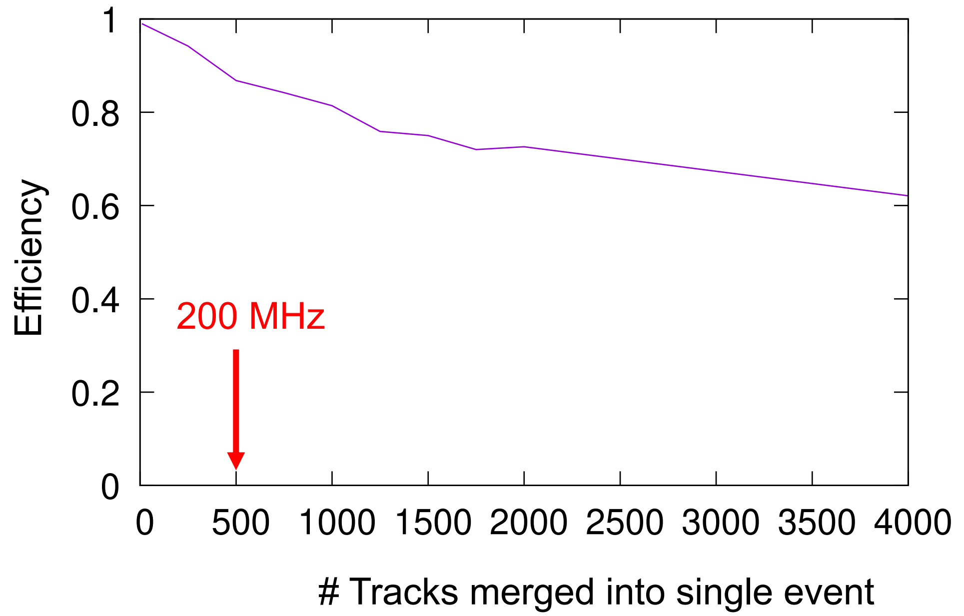
Deuterium DIS rate (naïvely p+n): ~2.4 MHz

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

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 =

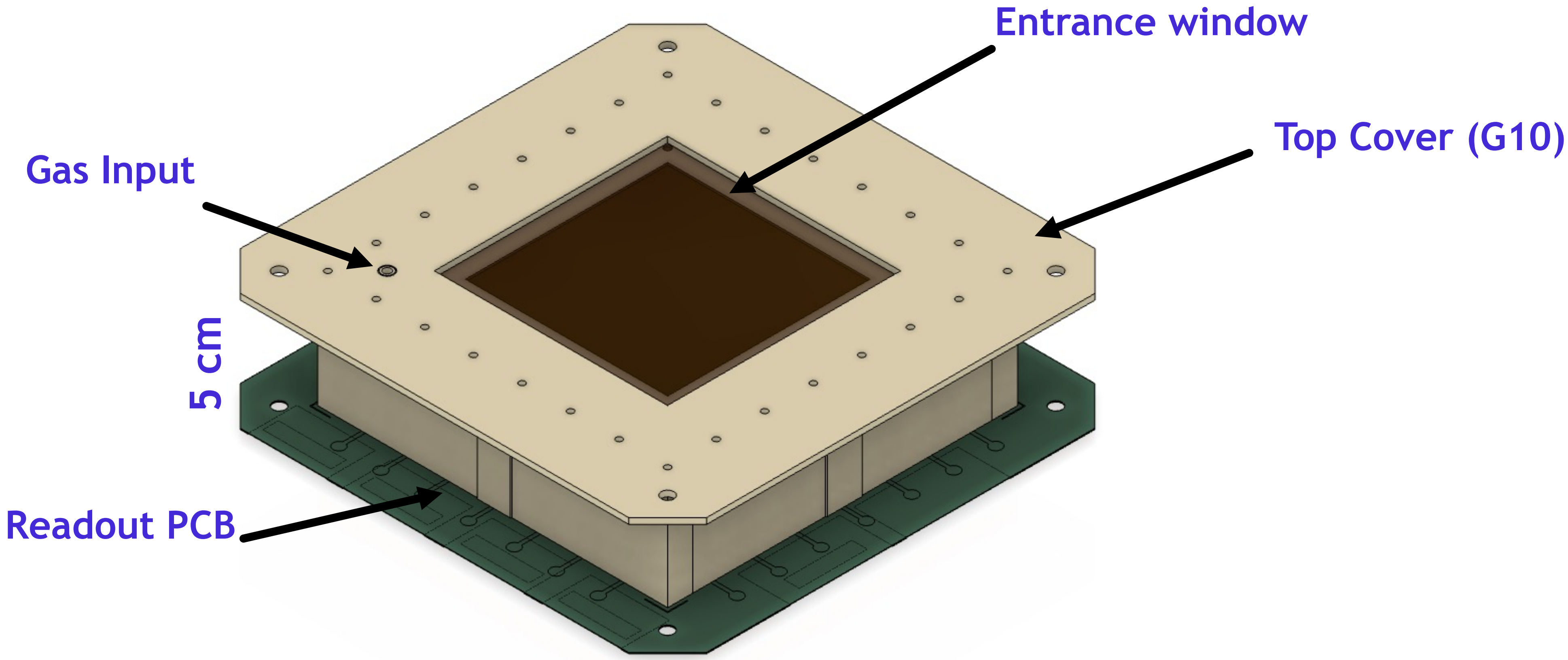
$70 < p < 400$ MeV/c

$30° < \theta < 80°$

-225 ns $< T_0 <$ 225 ns

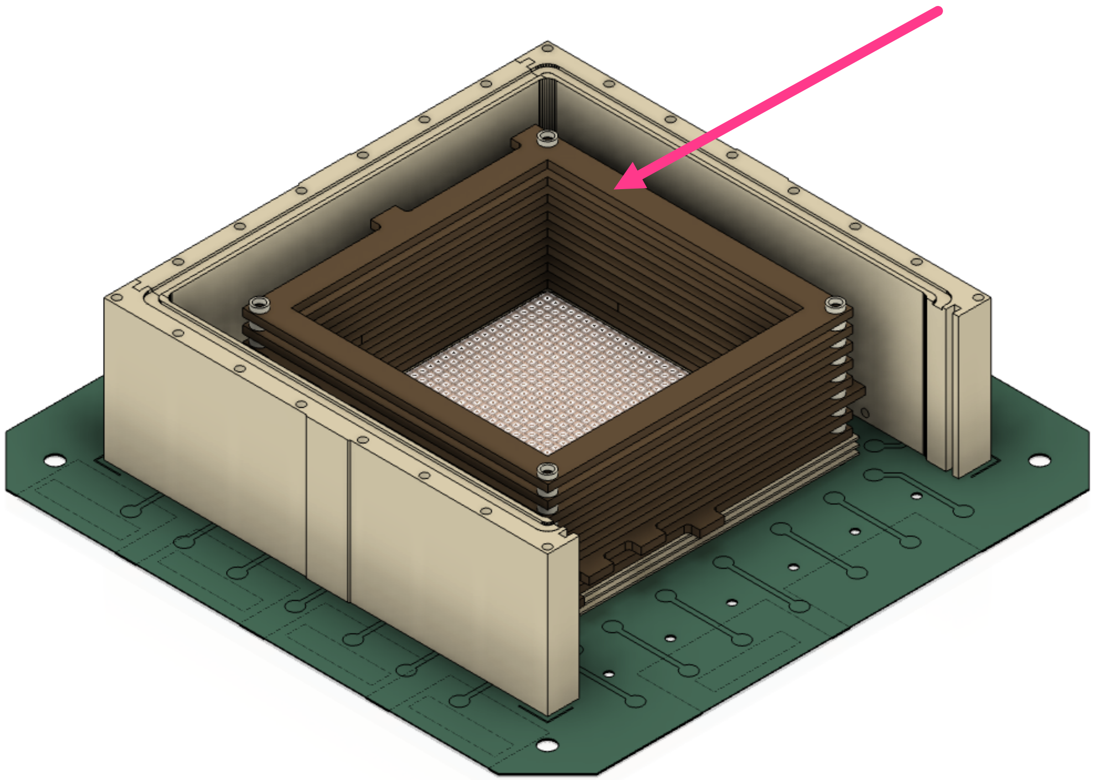
mTPC prototyping and development

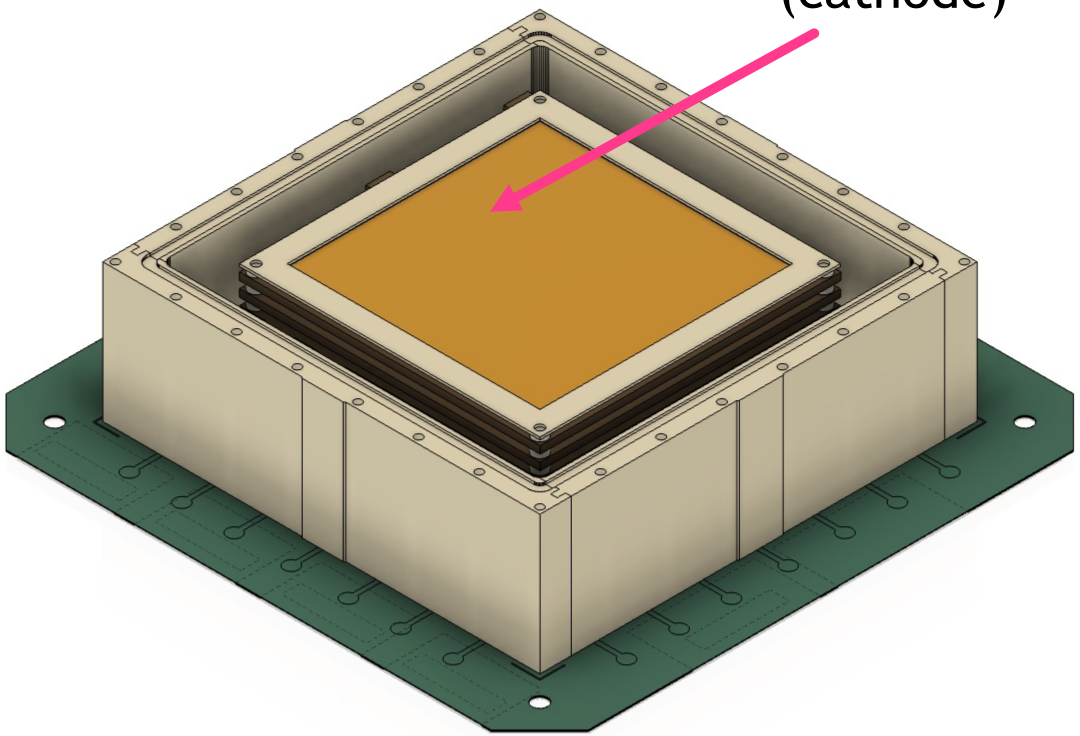
- Design small prototype with 10 x 10 cm^2 GEM active area → test important features of mTPC
  - Anode (R/O plane),
  - Three GEMs stacked with 2 mm spacing (provided by spacers)
  - Aluminized Kapton to act as cathode
    - 5 cm space between anode and cathode endplates → *field cage*



mTPC prototyping and development

View of square prototype without top cover

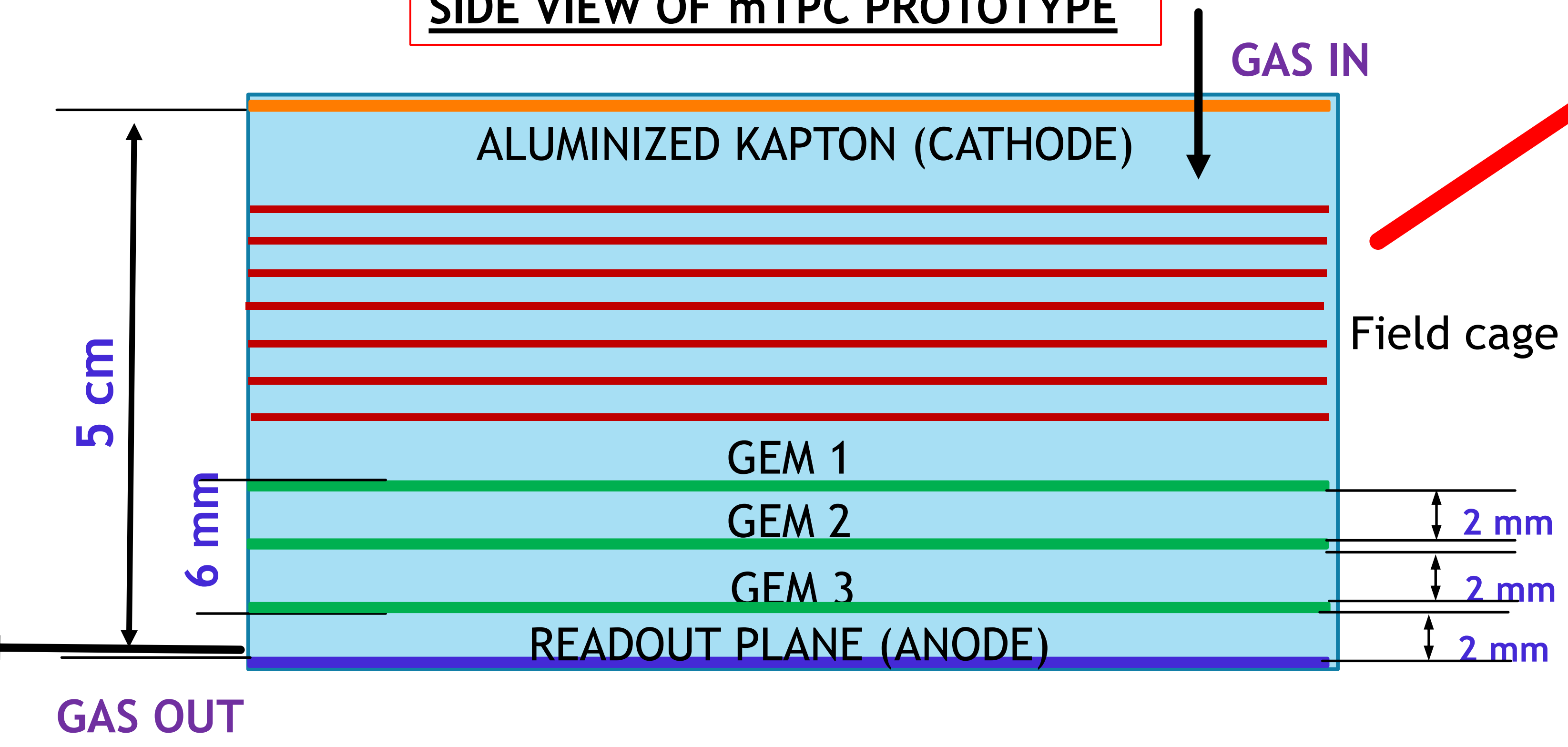




mTPC prototyping and development

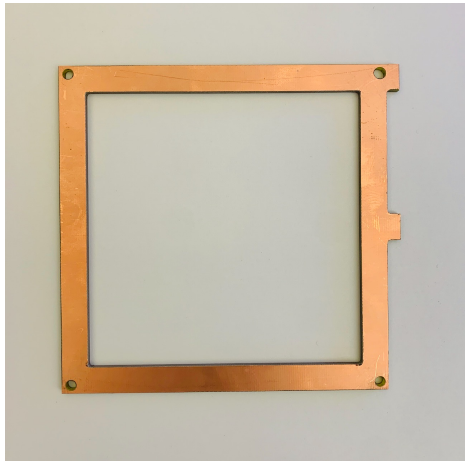
- mTPC square prototype at UVa → 10 x 10 cm^2 GEM active area:
  - Three GEMs stacked with 2 mm spacing (provided by spacers)
  - Eight 3-mm-thick field cage frames each separated by 3 mm
  - 4.7 cm space between top GEM foil and bottom of cathode

SIDE VIEW OF mTPC PROTOTYPE



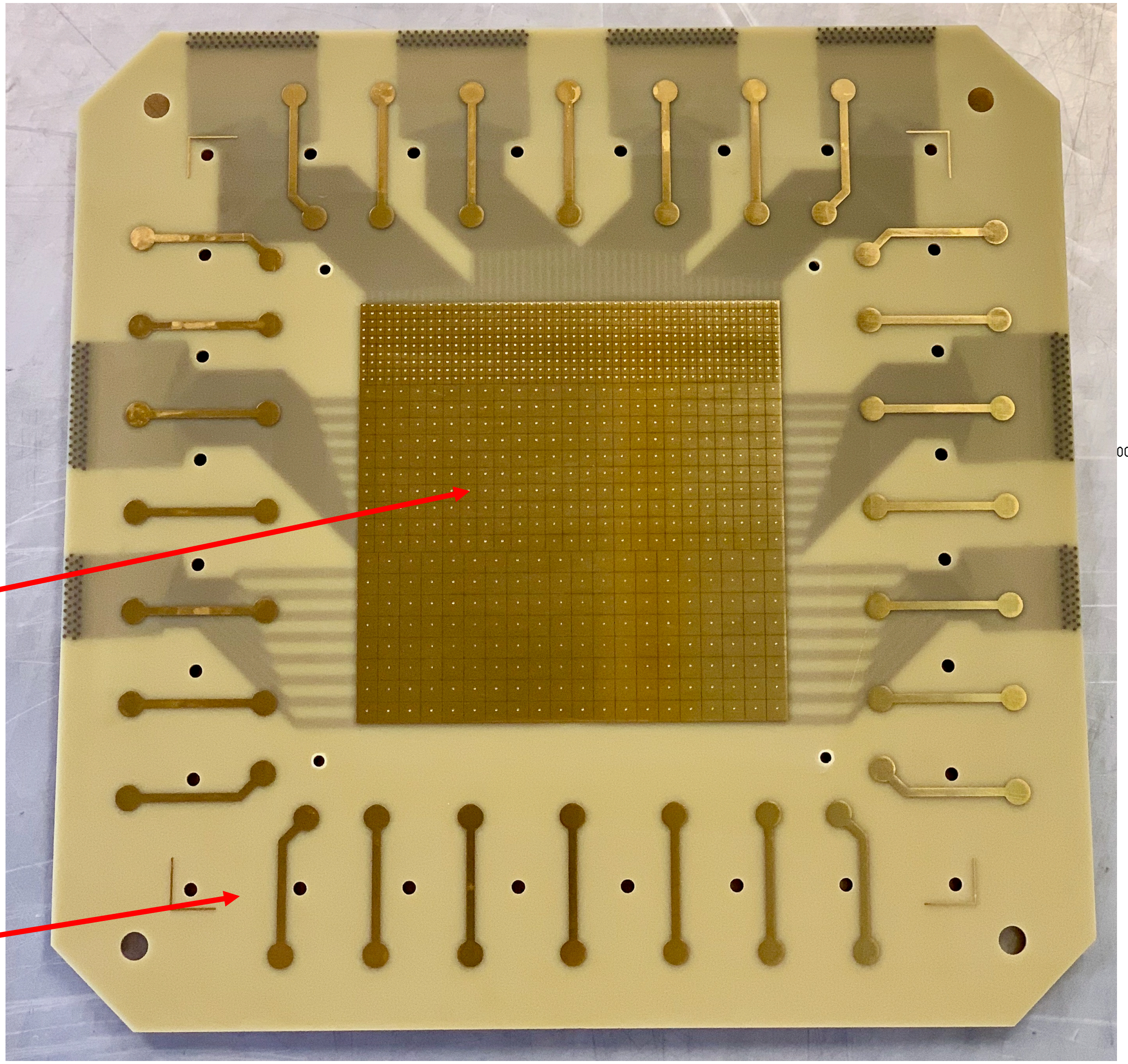
3D CAD view of stacked layers

Top view of field cage frame

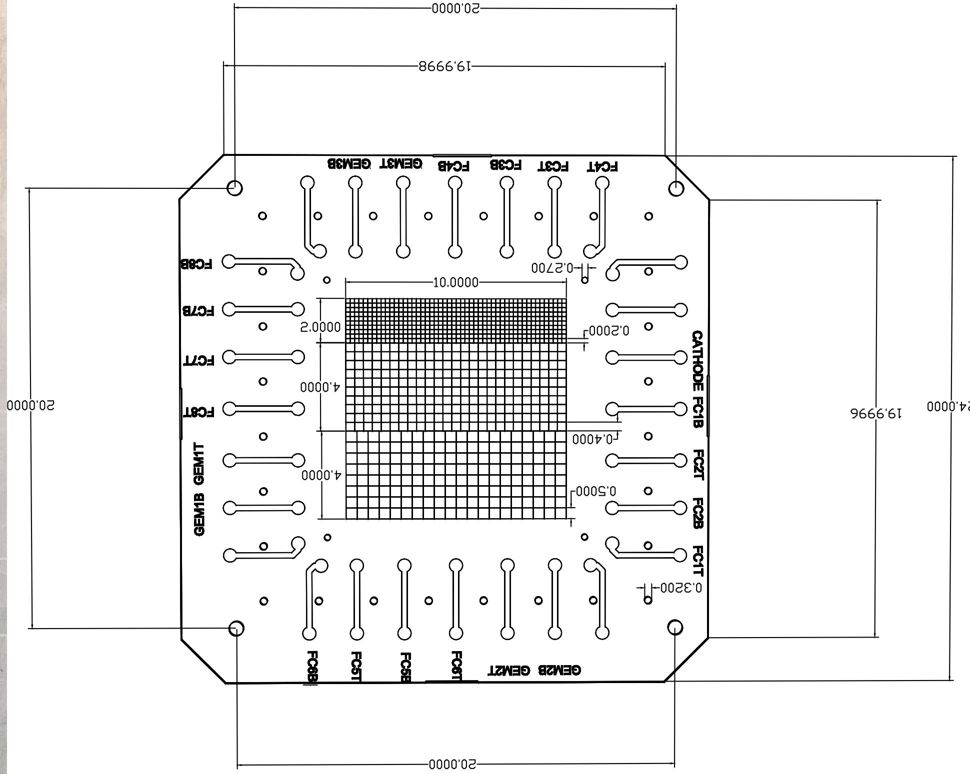


mTPC square prototype: Readout PCB

Front of Readout



Dimensions on CAD

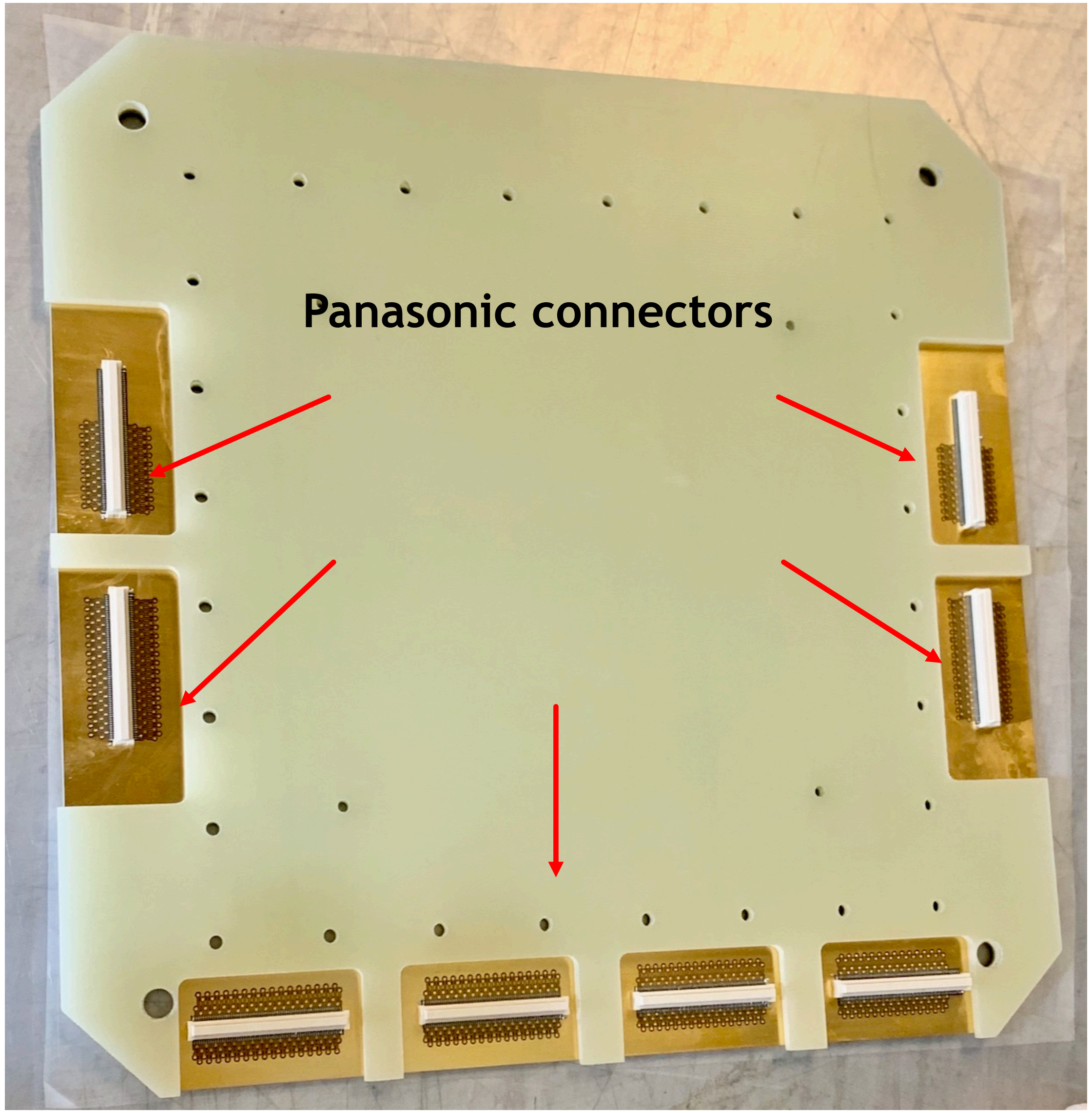


Pads
2 x 2 mm^2
4 x 4 mm^2
5 x 5 mm^2

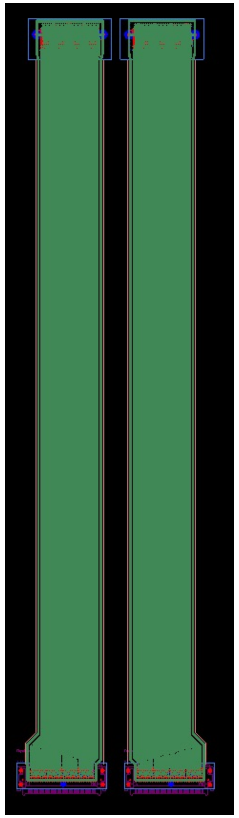
HV strips

mTPC prototyping and development: Readout PCB

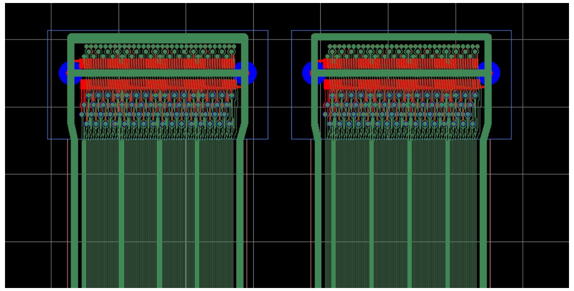
Back of Readout PCB



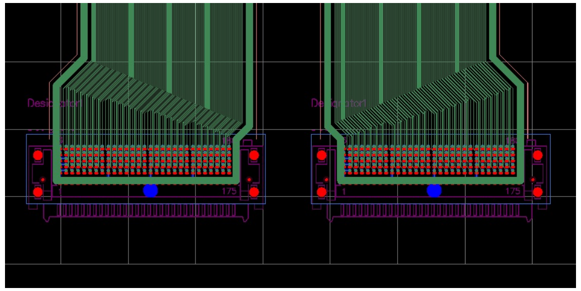
- Panasonic connectors (130 pins each) connected to signals from readout pads (910 channels).
  - APV25 chip will be used to readout signals in initial testing
  - APV25 to SAMPA flex circuit: Signals will be mapped via 40 cm long flex circuit adapter



40 cm long flex adapter (GBR)



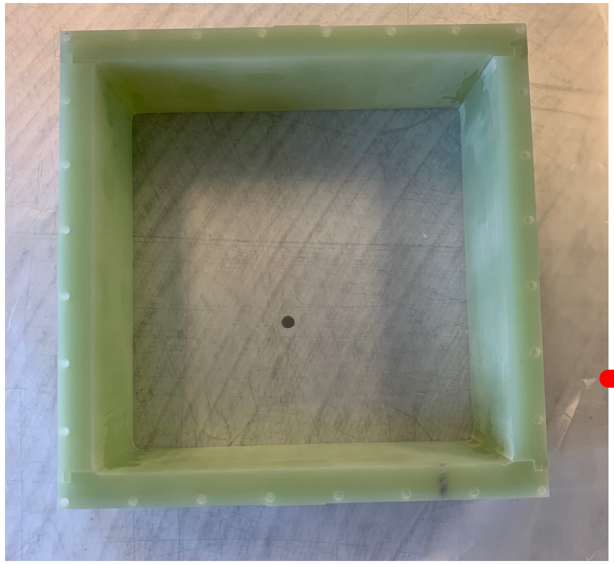
Panasonic/APV25 mapping on flex (GBR)



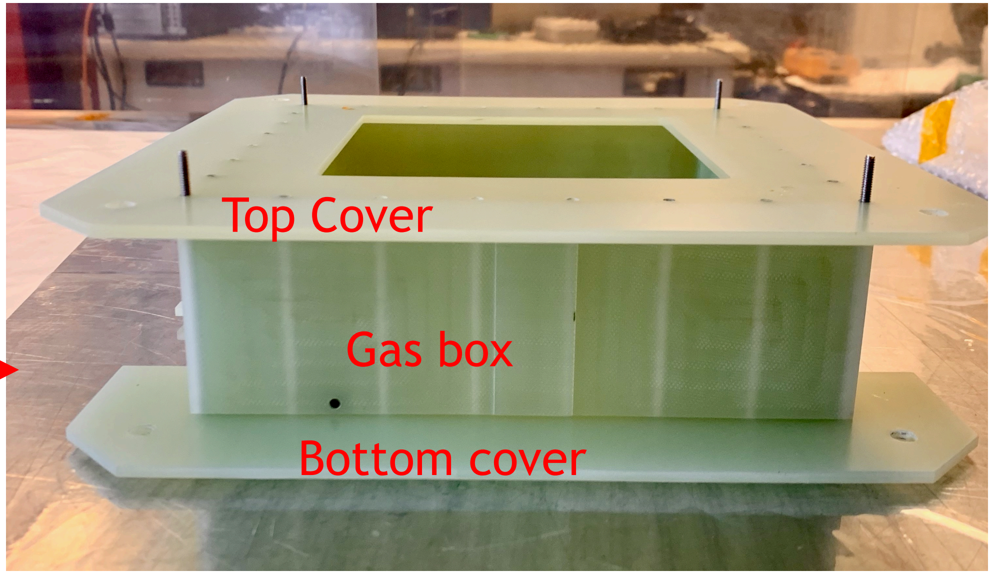
SAMTEC/SAMPA mapping on flex (GBR)

mTPC prototype assembly update

- Currently in assembly phase. Gas box is assembled, next step is to assemble detector.



Top view of assembled gas box



Side profile of aligned G10 parts of prototype (top cover, gas box, bottom cover)

Near-future plan:
- After the assembly, preliminary testing will be done at UVa with APV25.
- High rate tests of prototype will utilize flex circuit adapter (APV25 to SAMPA) and will be done parasitically in Hall A in the next few months

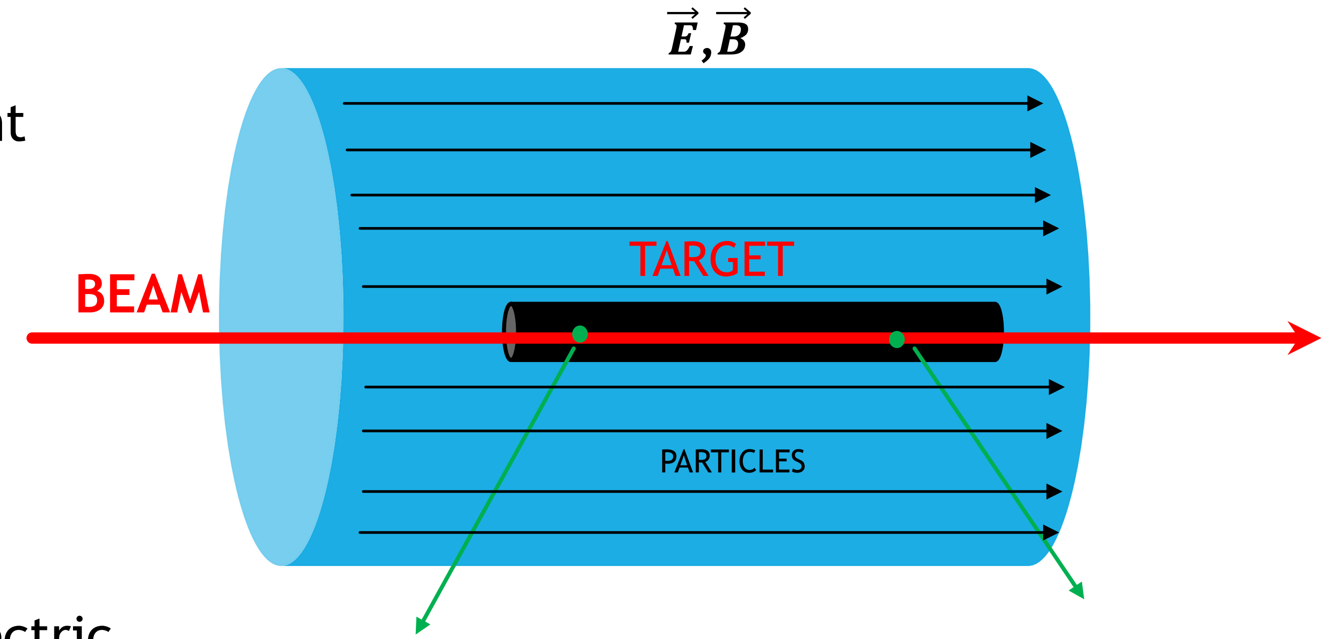
Summary and Outlook

- The TDIS experiment at JLab Hall A (C12-15-006) will make use of the Sullivan process to measure the pion/kaon SF at low xBj through the spectator-tagging technique
  - Modification of the SBS detector package: addition of the mTPC
  - Run addition group - Kaon TDIS: measure Kaon SF for the first time
  - Other possibilities: addition of calorimeter to TDIS setup to do nDVCS with TDIS to map GPDs
- mTPC is a new type of detector to detect the low momenta recoil protons
  - Obtaining radiation hard components from CERN for readout electronics for mTPC (will use the SAMPA chip)
  - Simulation studies are underway: digitization of data, background studies of DIS and quasi-elastic, and track reconstruction efficiency studies
  - Design a square prototype to test important features of the mTPC
    - Fabrication of all prototype parts is complete. Currently in assembly phase.
    - Parasitic tests in high rate environment using the flex adapter will be done at JLab.

Back up

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

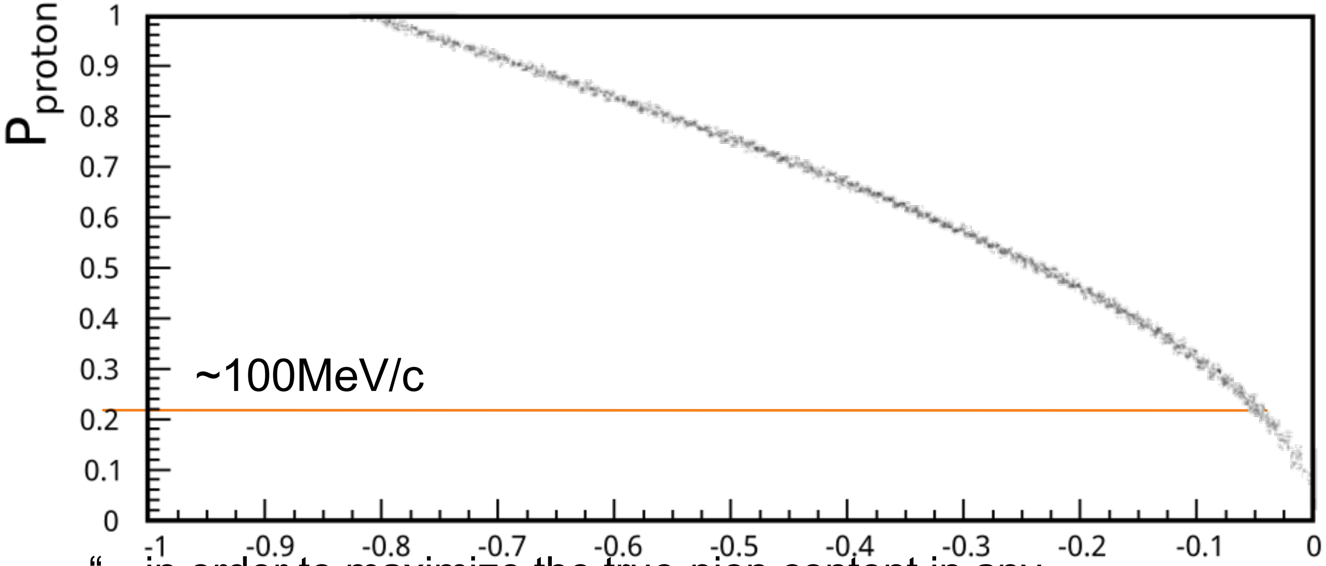


Downside of a single radial TPC → high rates
SOLUTION: multiple TPC!

How to access the physical pion?

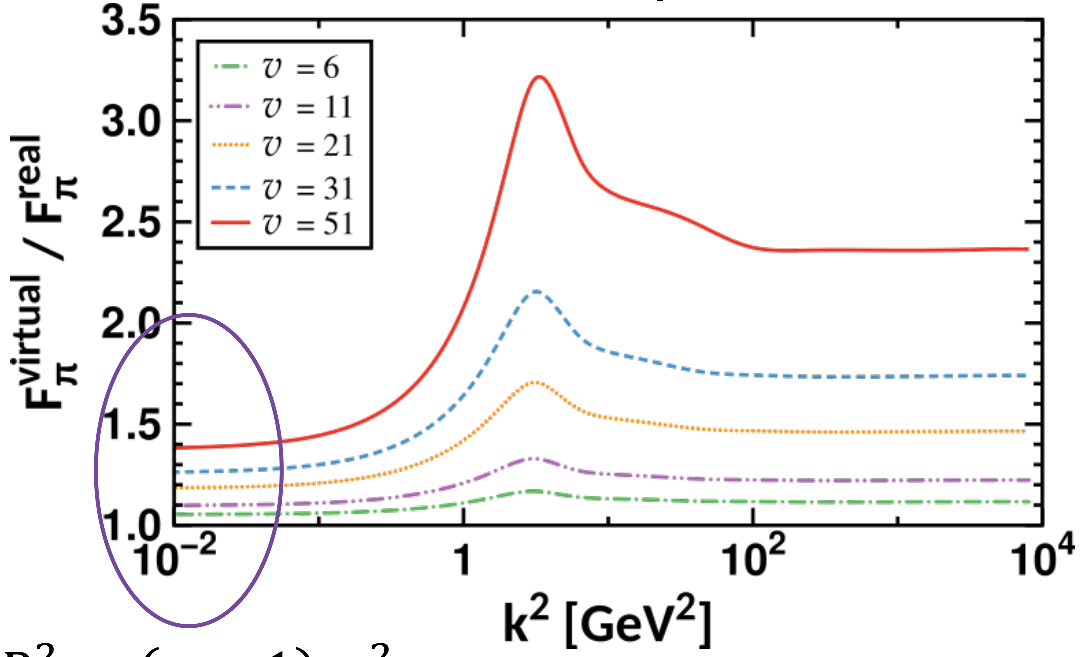
(GeV/c)

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)

mTPC Explosive view of gems and cathode