Simulation updates: Rates estimate and Digitization

Marco Carmignotto

TDIS Collaboration Meeting

Jefferson Lab – February 22, 2018

Topics

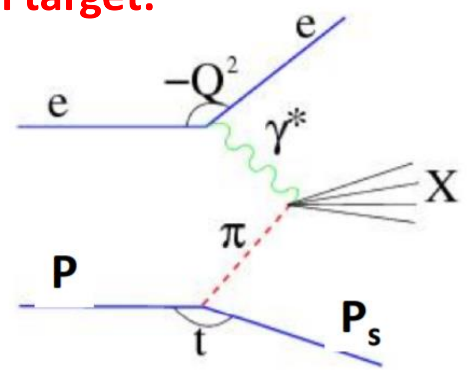
- Brief overview of the mTPC
- GEMC simulation:
  - First rates estimate – Upper limits
  - Rates estimate based on Geant4 cross sections
  - Momentum resolution
  - Occupancy of readouts
- Ongoing digitization studies

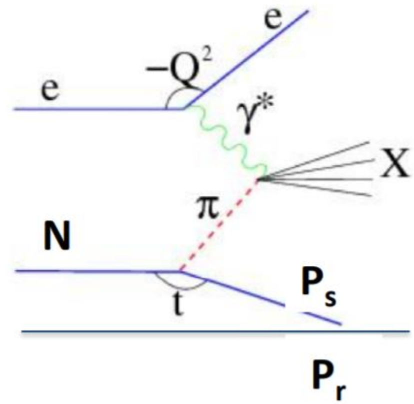
TDIS experiments

C12-15-006 - Measurement of Tagged Deep Inelastic Scattering

Spokespersons: Cynthia Keppel, Bogdan Wojtsekhowski, Paul King, Dipangkar Dutta, John Annand, Jixie Zhang

Meson target:





TDIS at JLab:

High luminosity

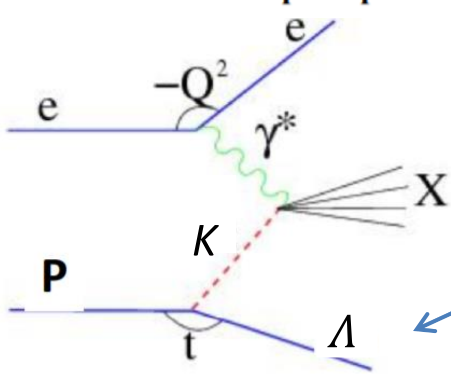
($\mathcal{L} \sim 3 \times 10^{36}$ cm^{-2}/s)

$$H(e, e'p_{spectator})X \quad D(e, e'p_{spectator}p_{recoil})X$$

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

Spokespersons: Kijun Park (Contact), Tanja Horn, Rachel Montgomery

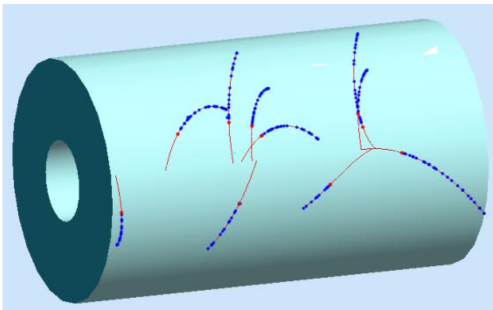
"First to explore kaon structure function"



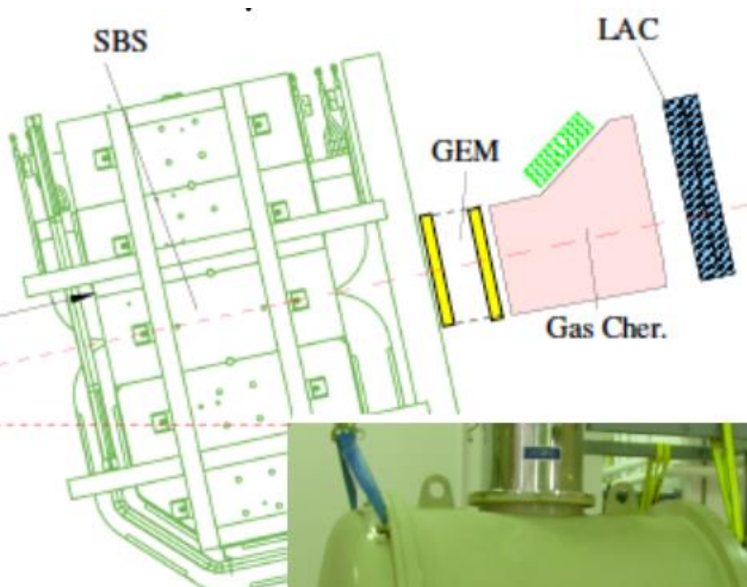
Reconstructed by measuring decay products (p + π)

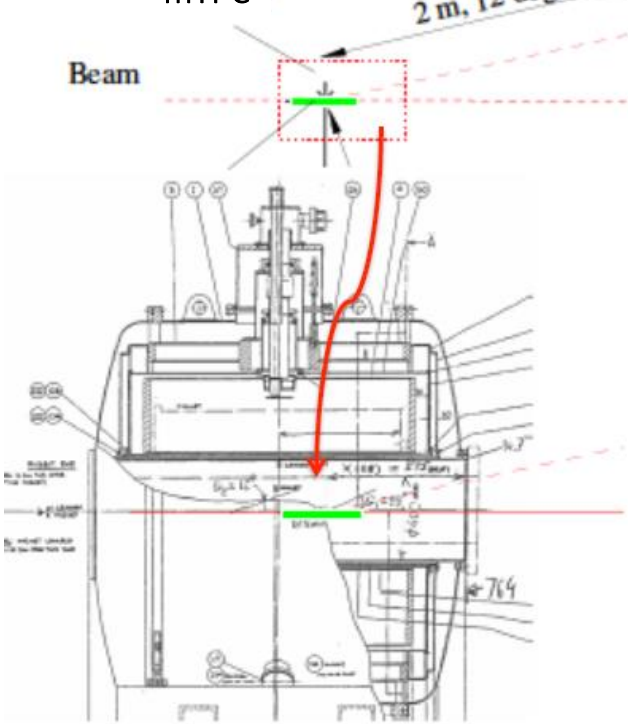
Detector setup – SBS + mTPC

Multiple Time Projection Chamber (mTPC):
50 cm long chamber to measure protons (+pion)



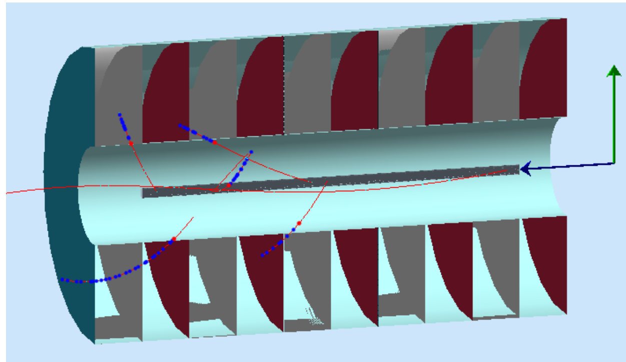
mTPC





[by Nilanga Liyanage]

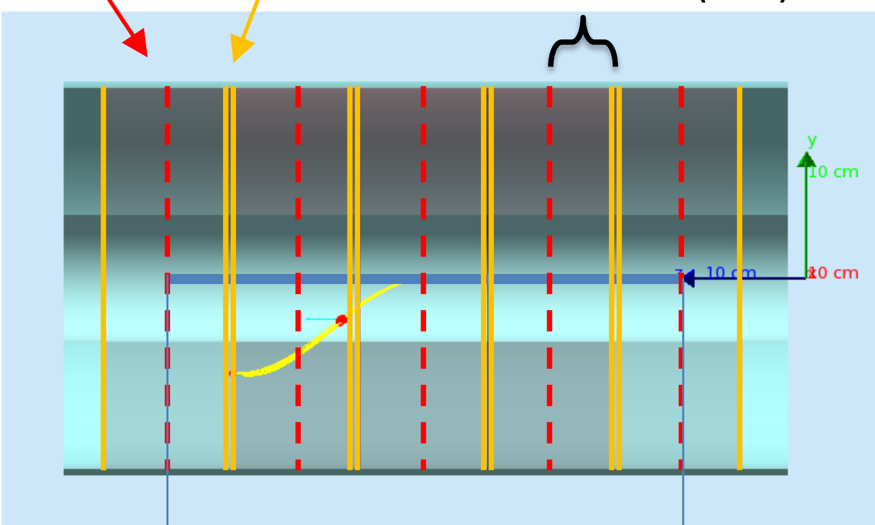
mTPC geometry



4.5 Tesla field

5x HV 10x Readout

chamber (x10)

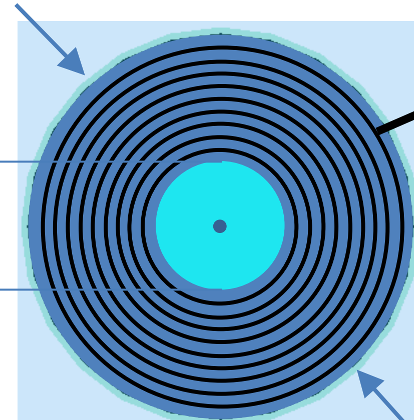


40 cm D_2 target @ 77K 1atm
d = 0.64 mg/cm^3

Readout disc:

ϕ30 cm

ϕ10 cm

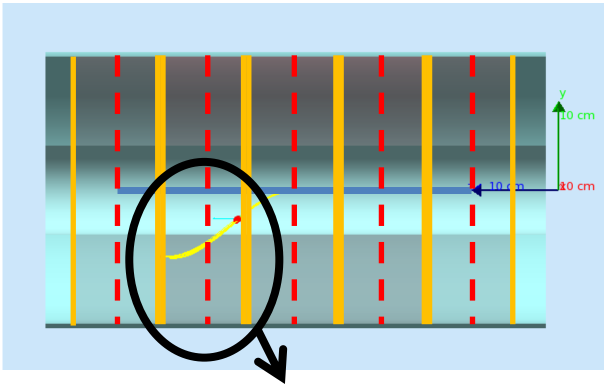


Readout element:

5mm x 5mm

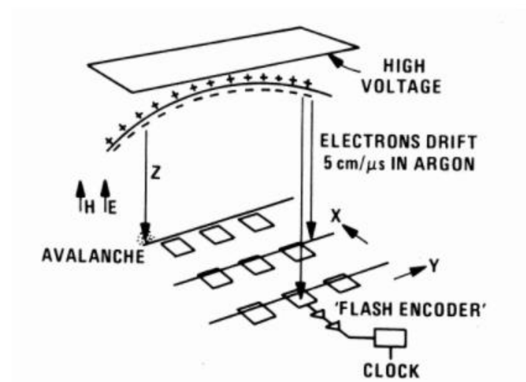
Readout disc segmented in 20 “rings”, which are segmented in readout elements of 5mm

mTPC geometry - materials

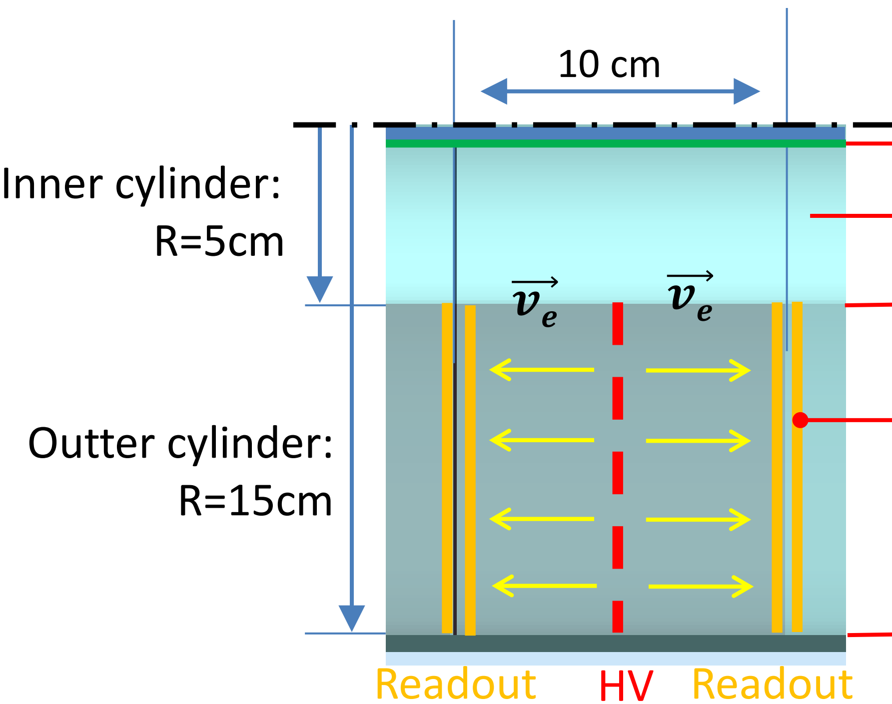


Time window required to collect electrons:

1 μs



(Nathan Baillie)



Target cell: Al straw with 10μm wall

All volumes: He (for now)

Inner electrode: 2μm kapton + 0.1 μm Au

Each readout disc:

- 1 readout: 130μm kapton
- 2 GEM: 5μm Cu + 50μm kapton + 5μm Cu

Outer electrode: 0.1 μm Au + 2μm kapton

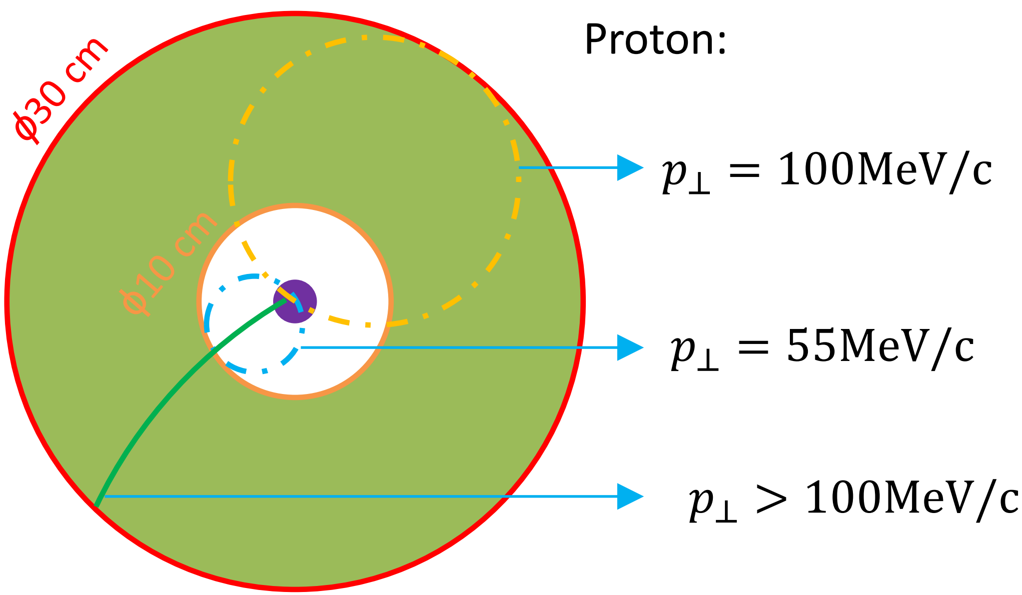
Rates estimate

mTPC momentum acceptance

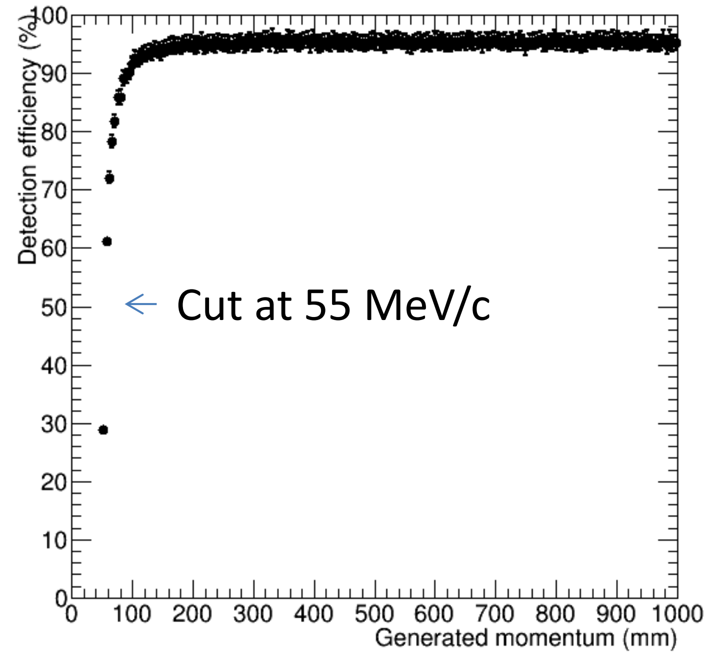
<u>mTCP</u>: GEMC/Geant4 simulation:

- Target straw of 400mm (10 um thick Aluminum)
- Target D_2 with 638 g/m^3 (density at 77K / 1atm)
- Active gas
- 2 um kapton foil defining inner cylinder of the chambers

4.5 T field:



Proton Momentum:



Rates estimate for mTPC

Protons

Rate per chamber (we have 10 chambers) for 60 µA beam in D2:

First estimate: Upper limits

Use the "scaled" EPC code, by Lightdoby and O'Connell 1988

Produced protons parametrized in function of angle and Kinetic Energy:

$$\frac{d^2\sigma(e,N)}{dT_N\, d\Omega_N} = \int_0^{\pi} \sin\theta\, d\theta \int_0^{2\pi} d\phi\, \frac{d^3\sigma}{d\Omega_N\, dT_N\, d\Omega} .$$

$$\text{Rate} = t_{D2} \cdot I_e \cdot \int d\Omega \cdot dT \cdot \frac{d\sigma}{dT\, d\Omega} \cdot A(p)$$

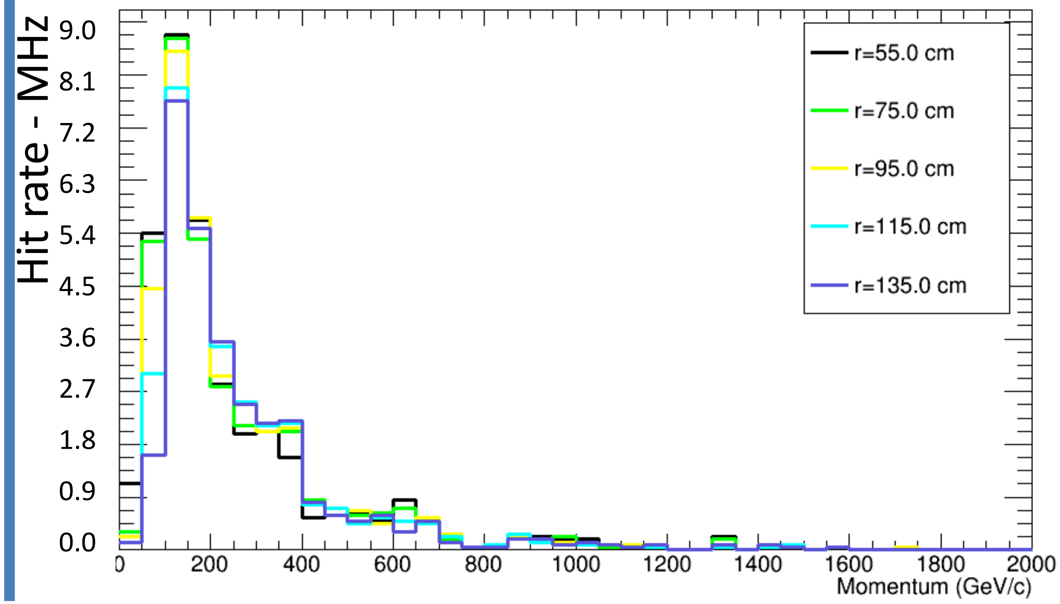
Rate (upper limit) =

= 690 MHz / 10 chambers

= 69 MHz / chamber

GEMC/Geant4 based estimate

- Approx. 10^9 incident electrons simulated (relying on GEMC/Geant4 cross sections)
- Considering protons created at the target AND at the components of the mTPC



Proton rate: 34 MHz/chamber

Rates estimate for mTPC

Deuteron

Rate per chamber (we have 10 chambers) for 60 μA beam in D2:

First estimate: Upper limits

- Need transverse momentum of at least 84 MeV/c to reach active gas

Mott cross section:

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4\,(E_e)^2 sin^4\left(^{\theta_e}/_2\right)} cos^2\left(^{\theta_e}/_2\right)$$

$$\text{Rate} \approx t_{D2} \cdot \text{I}_e \cdot \int_{\theta_{min}}^{\theta_{max}} 2\pi\, sin\theta\, d\theta \cdot \frac{d\sigma}{d\Omega}$$

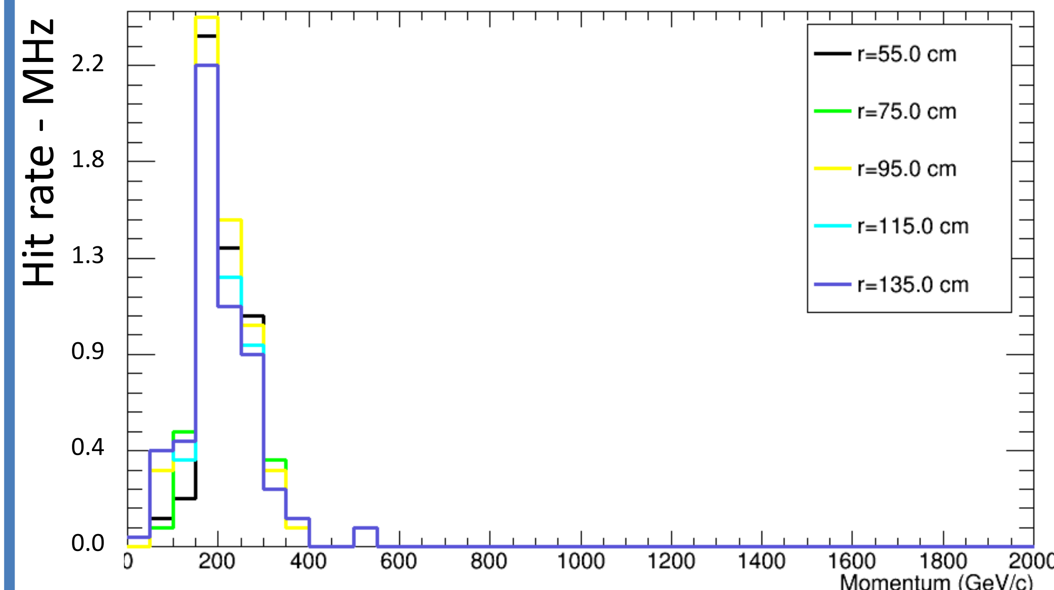
0.43° to produce deuterons with 84 MeV/c

$$\text{Rate} \approx 2.9\ 10^{36} \left[\frac{1}{cm^2.s}\right] \cdot 0.36\ 10^{-28} [cm^2]$$

Rate (upper limit)
= 105 MHz / 10 chambers
= 10 MHz / chamber

GEMC/Geant4 based estimate

- Approx. 10^9 incident electrons simulated (relying on GEMC/Geant4 cross sections)
- Considering protons created at the target AND at the components of the mTPC



Deuteron rate: 6 MHz/chamber

Rates estimate for mTPC

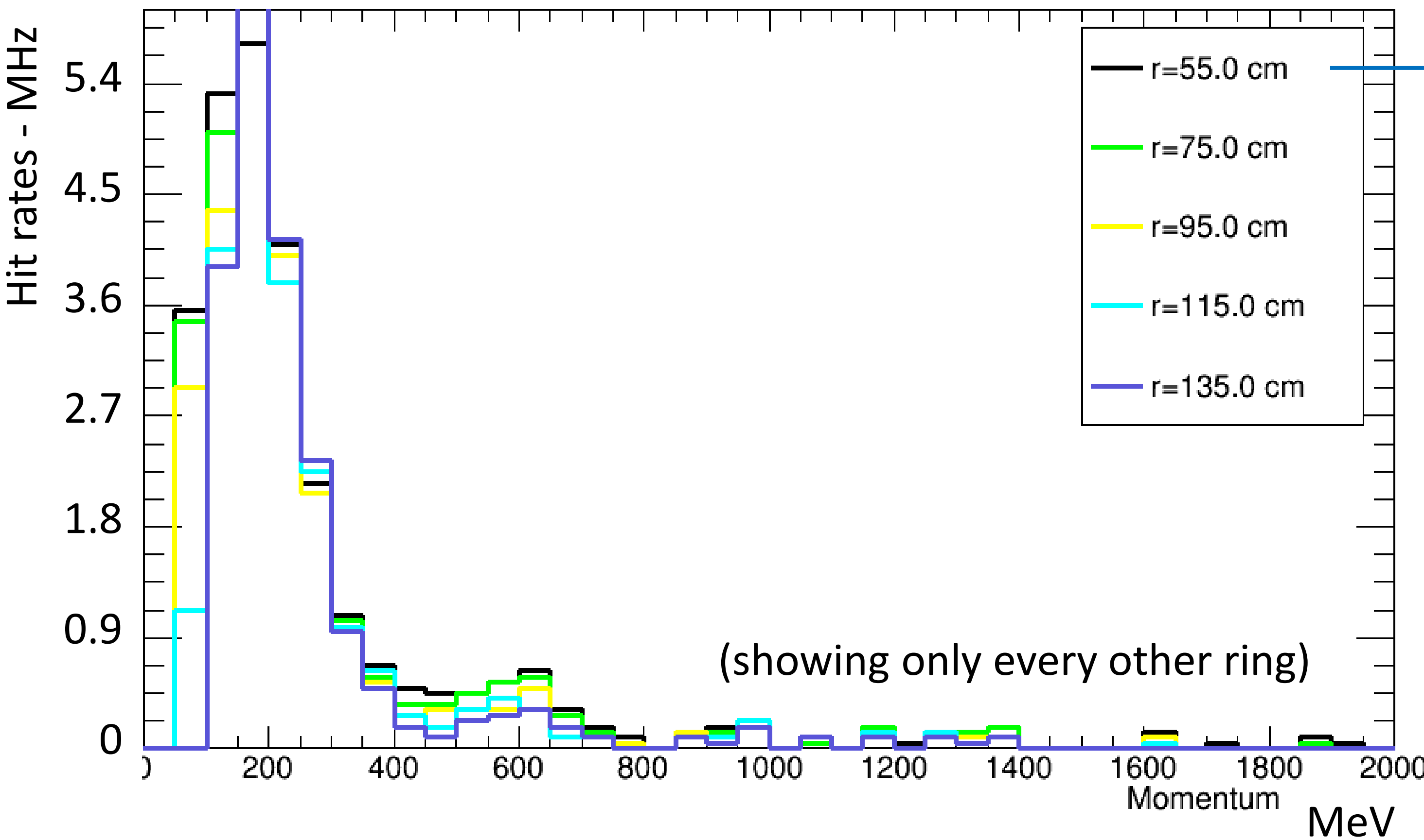
π^+ and π^-

Rate per chamber (we have 10 chambers) for 60 μA beam in D2:

GEMC/Geant4 based estimate

Integrated rates (per chamber):

27.1 MHz



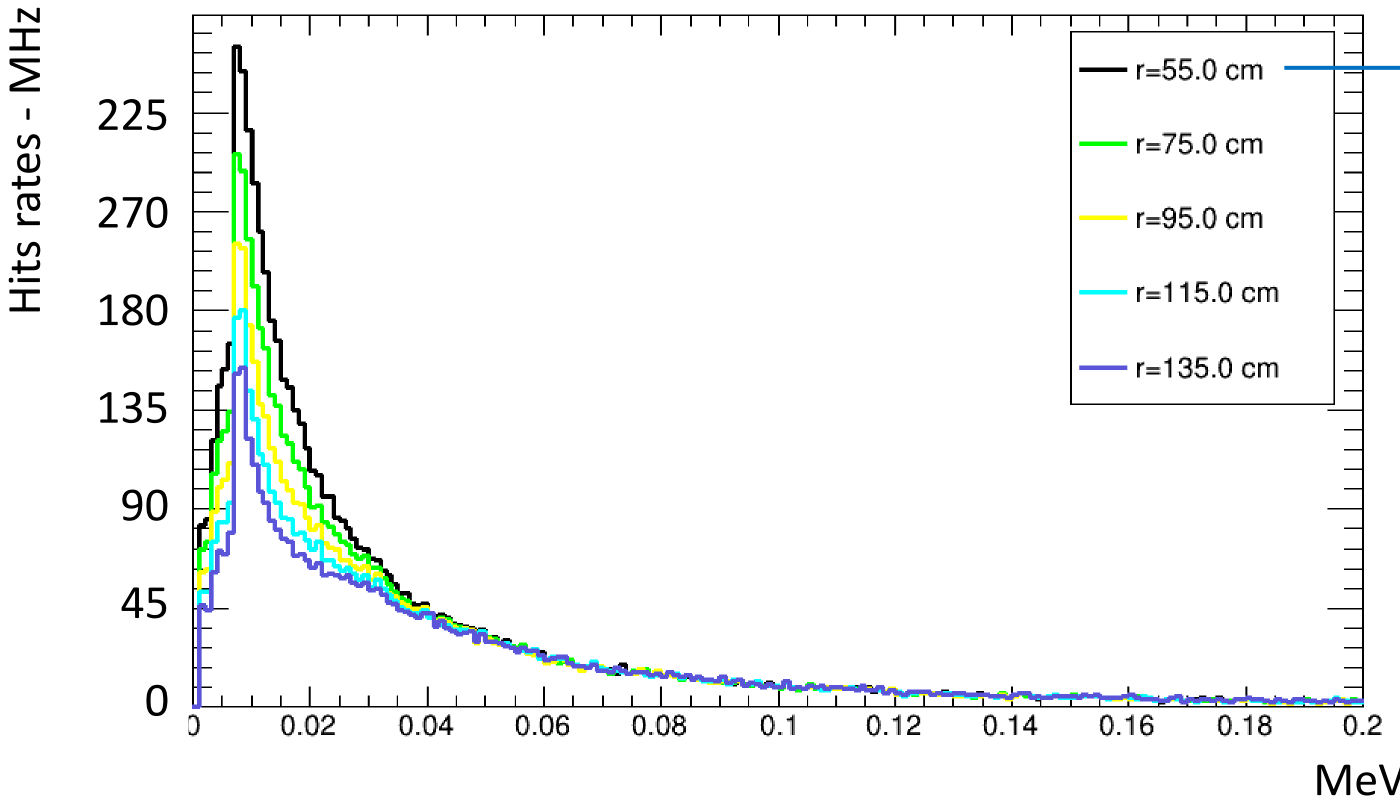
Rates estimate for mTPC

Photons

Rate per chamber (we have 10 chambers) for 60 µA beam in D2:

(x-rays can ionize gas, creating tracks – already accounted in simulation)

GEMC/Geant4 based estimate

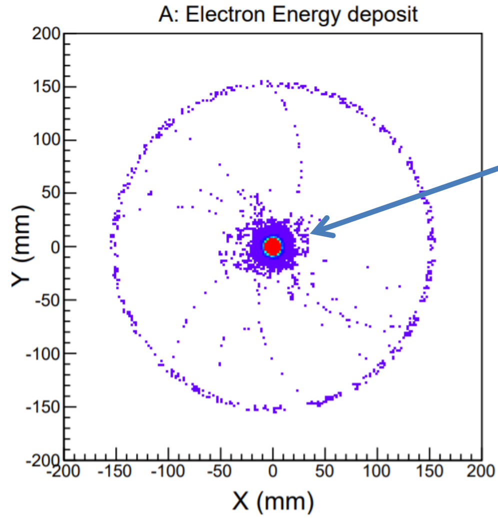


Integrated rates (per chamber):

6 GHz

Rates estimate for mtpc

Electrons:



Most electrons are confined within the inner cylinder of the mTPC by magnetic field

High momentum electrons still contribute:

Rate = 41 MHz / 10 chambers
= 4.1 MHz / chamber

TOTAL RATES:

- Protons: 34 MHz / chamber
- Deuterons: 6 MHz / chamber
- Pions: 27 MHz / chamber
- Electrons: 4 MHz / chamber

71 MHz / chamber

(time window per event)

71 MHz x 1 us = 71 tracks per event

Timing resolution of pads readout
+
Vertex position from SBS

We can deal with track identification out of background!

- Additional consideration: level 2 DAQ trigger: Read chambers near vertex only(?)

Readout occupancy with these rates

Total Rate = 70 MHz / chamber

Chamber multiplicity

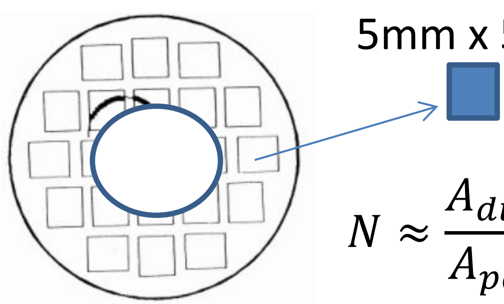
Rate of particles in a chamber within time

$$\mathcal{M}_c = \tau_m \cdot f_{hit}$$

$$\mathcal{M}_c = 1\ \mu s \cdot 70\ \text{MHz}$$

70 tracks in a chamber within a time window

- Readout plane – number of channels:



$$N \approx \frac{A_{disk}}{A_{pad}} = \frac{\pi(150^2 - 50^2)}{5 \cdot 5}$$

Total: 2500 channels

PAD occupancy

Rate of hits in a specific readout channel

- "Mean" path length: 10 cm
- Pad time resolution: 250 ns
- Pad spacing: 5 mm

- Number of triggered channels per track:

$$N_{ch} \approx \frac{10}{0.5} = 20$$

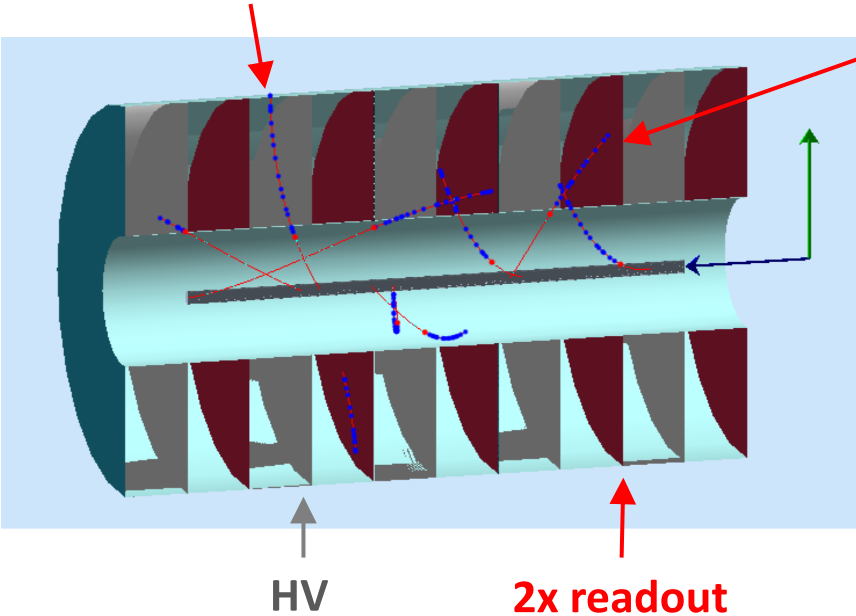
- Readout occupancy:

$$\mathcal{M}_c = 70 \cdot \frac{20}{2500} \cdot \frac{250\ ns}{1 \mu s} = 0.14$$

Momentum resolution

Particles track in mTPC

- Some tracks go through the entire active gas volume



- Some tracks hit readout discs though

<u>Materials of readout discs</u>:
- 1 readout: 130μm kapton
- 2 GEM: 5μm Cu + 50μm kapton + 5μm Cu

(<u>2 sets per disc</u>, chambers are back to back)

- Particles may stop or scatter going through readout

Study of effects on momentum reconstruction

Momentum resolution

$$\frac{dp_\perp}{p_\perp} \sim \frac{dR}{R} \cong \frac{1}{\sqrt{N}} \cdot \frac{4\,\sigma\,R}{(L/2)^2}$$

Perpendicular momentum:

$$p_\perp = 0.3 \cdot B \cdot R$$

Size of pad:

$$D_{pad} = 5mm$$

Spatial resolution:

$$\sigma \sim \frac{D_{pad}}{\sqrt{12}} mm$$

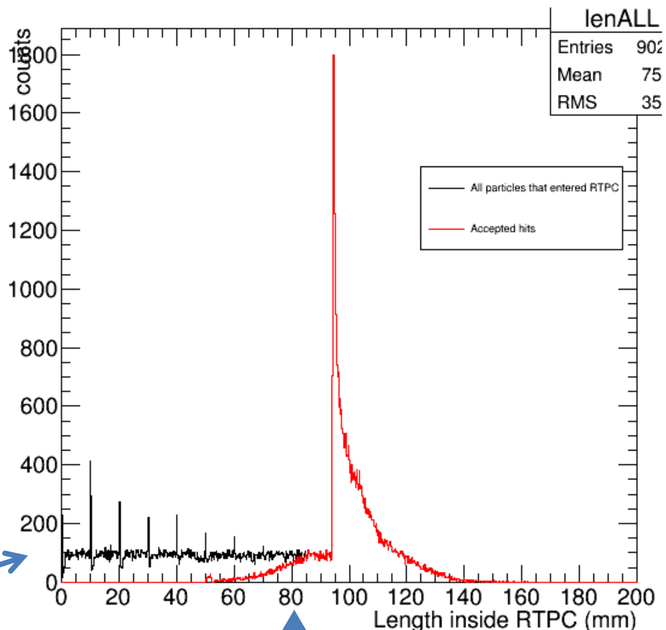
L = path length inside gas

Number of triggered pads:

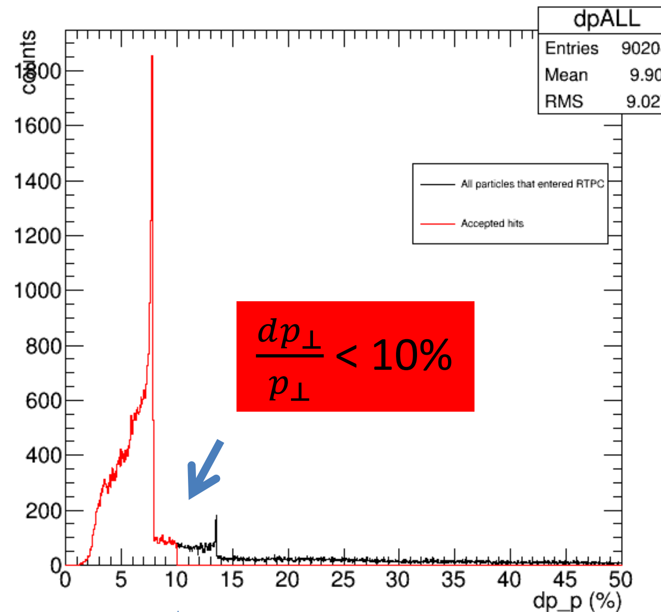
$N = L/D_{pad}$.n

Example: 250 MeV/c protons

Length of particles track in chamber



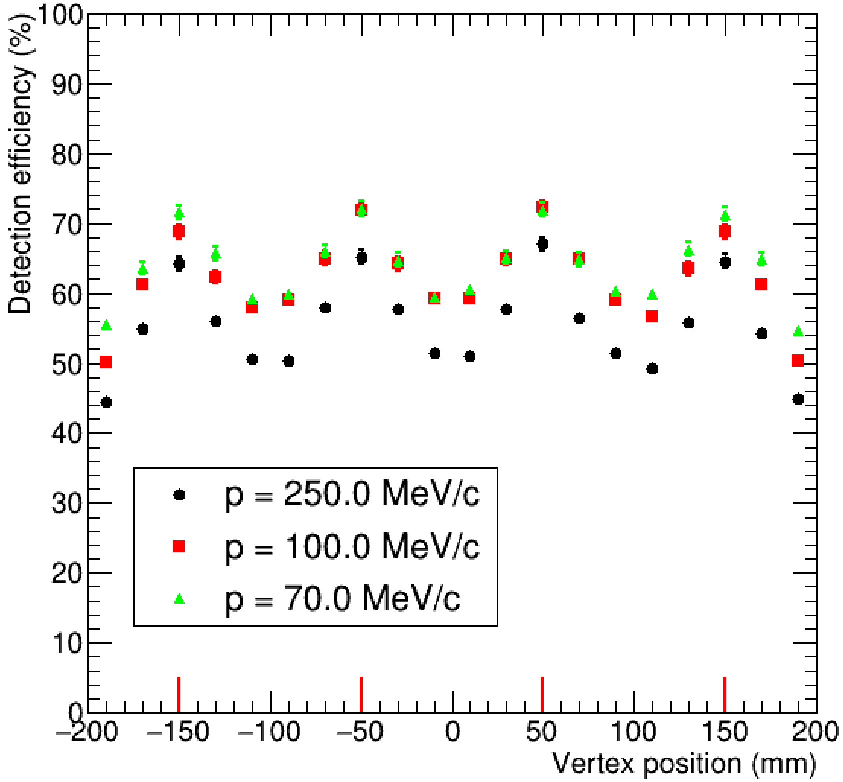
Momentum resolution

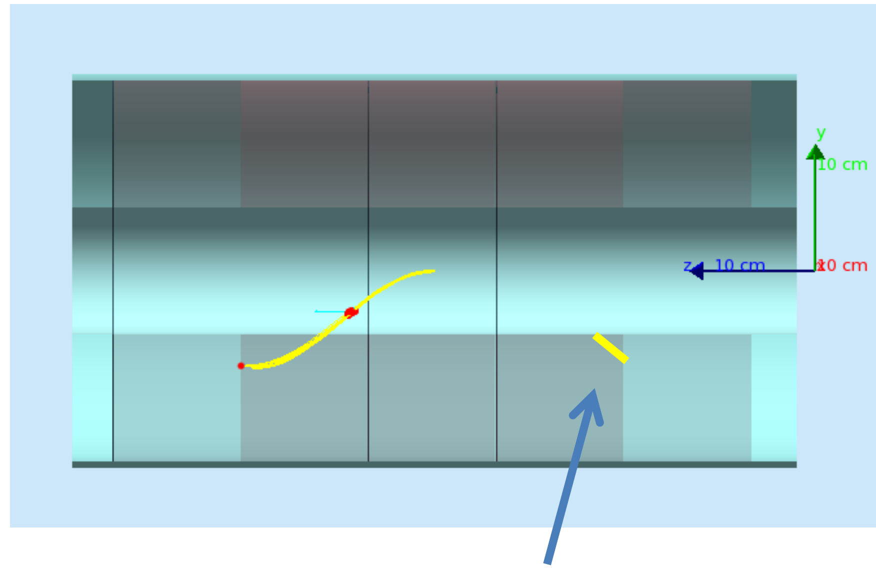


Momentum reconstructed better than 10%

(required for Physics)

Efficiency for momentum reconstruction





Short track
(particle entered too close to readout)

Relatively short length of chamber (5 cm) reduces the detection efficiency
This length is required though to accommodate high particles rate

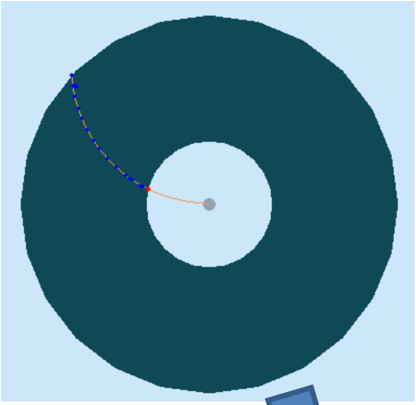
<u>Still need to consider effects of tracks overlaps in efficiency</u> – to come with digitization

Digitization - mTPC readout

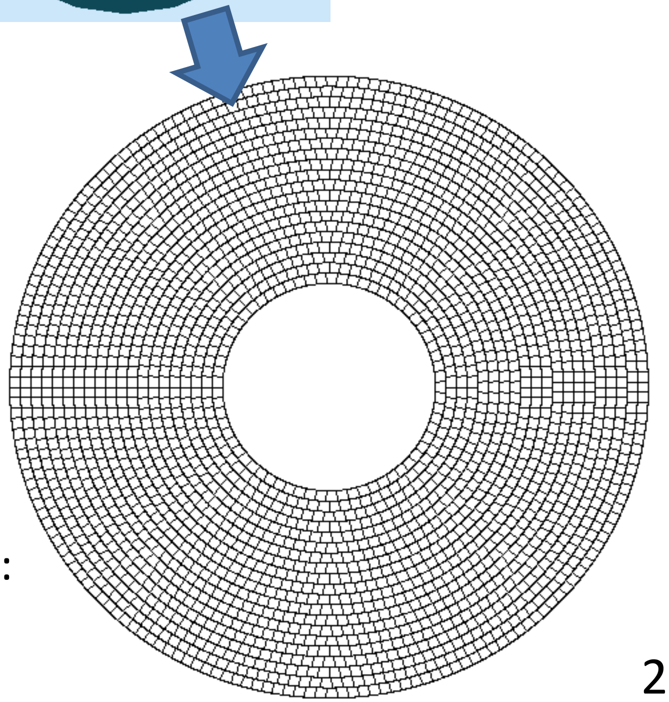
Digitization of signal

- What we have from GEMC now is the path of the particles in the gas with their momenta and energy loss

Particle momentum at every blue dot (~1mm apart)



- Digitization: simulate the signal to be read by the mTPC to further study:
  - Detector efficiency
  - Momentum reconstruction
  - Overlap of tracks
  - Readout capability
  - etc



Readout disc considering 5x5 mm^2 elements: (approximately 2500 elements per disc)

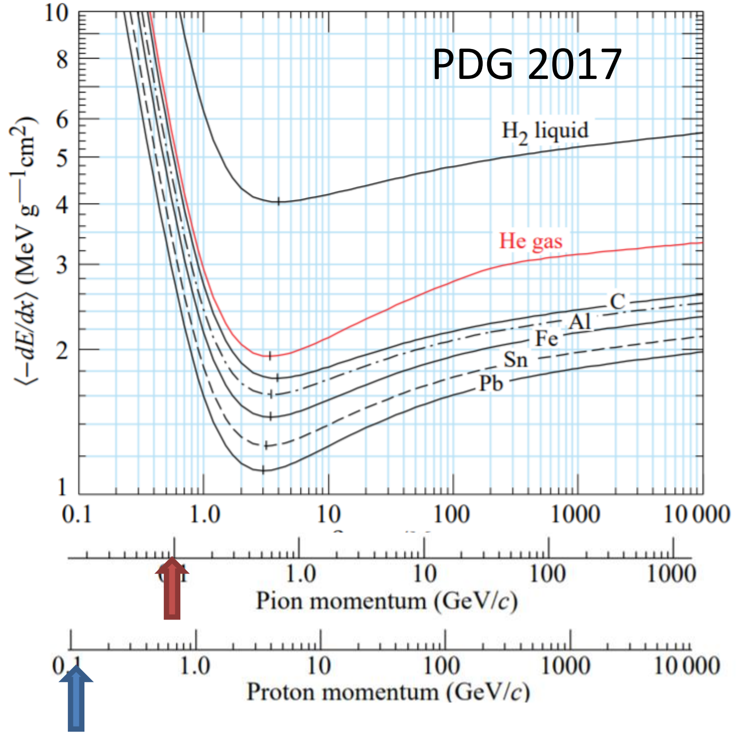
Digitization of signal

Amplitude: estimating strength of signal in each readout element:

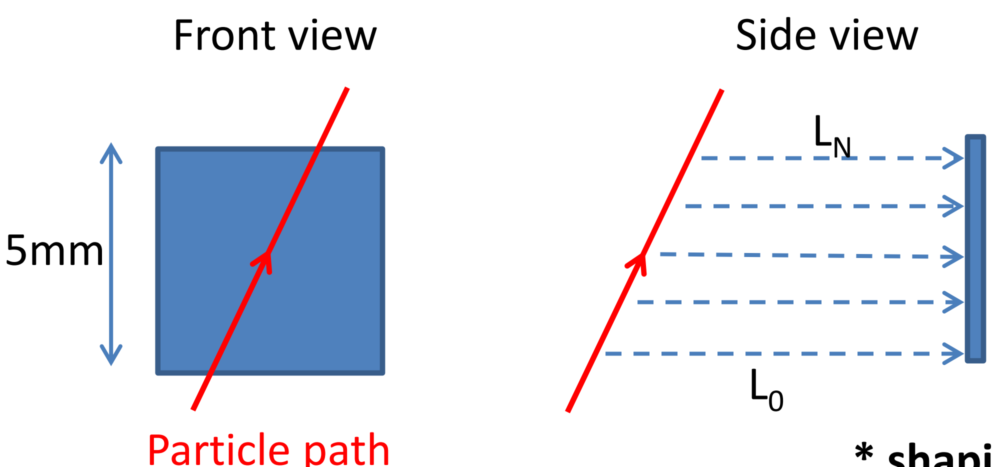
$N_e \propto$ ionization $\propto dE/dx$

- For our momentum range, protons have higher dE/dx than pions

(Concern for K^+ TDIS?)



Width: estimating duration (time) of signal in each readout element:



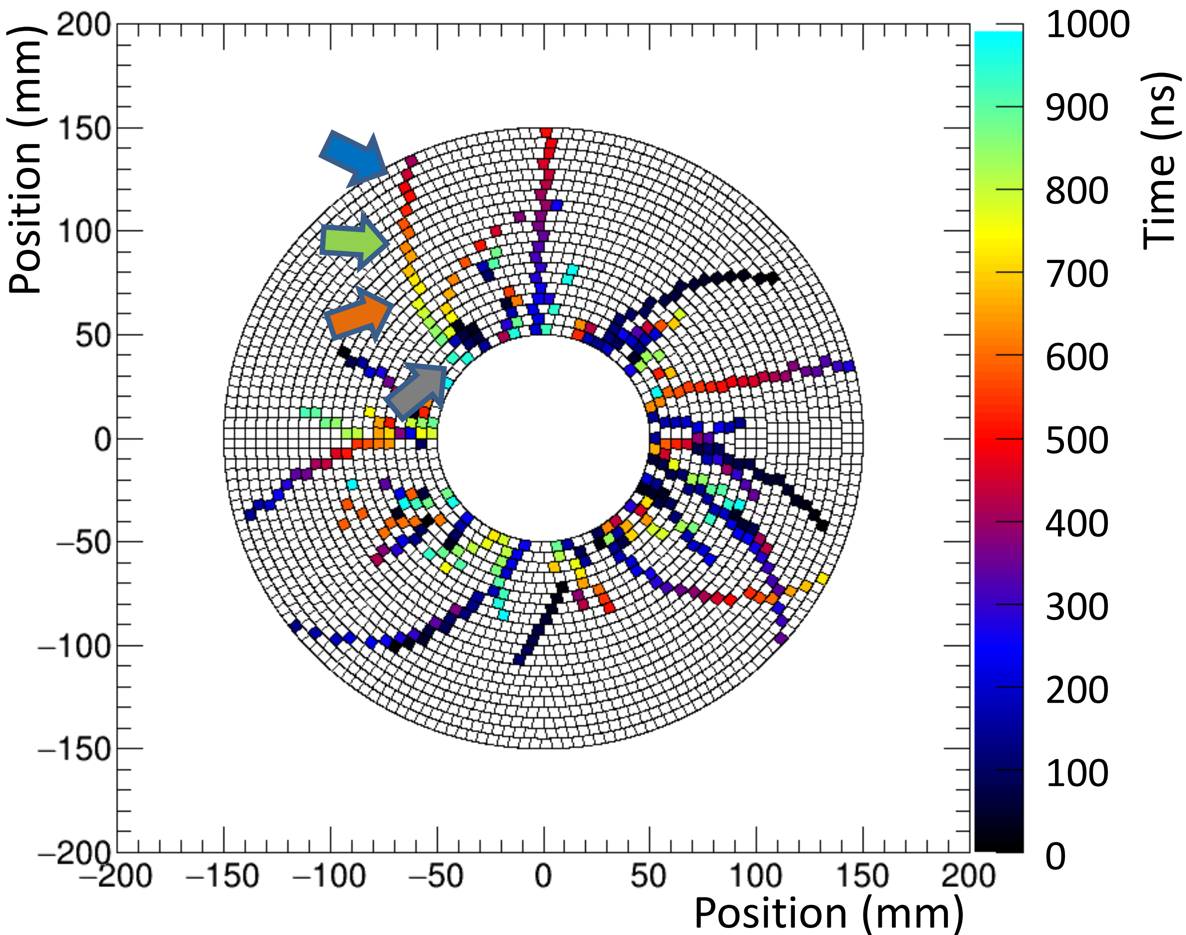
Drift velocity:

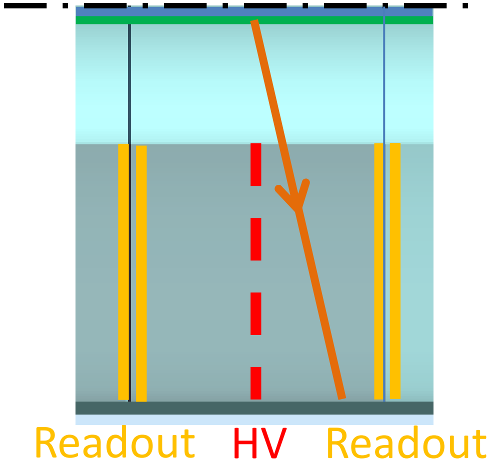
v = 5 cm/us = 50 um/ns

Signal width = $(L_N - L_0) / v$

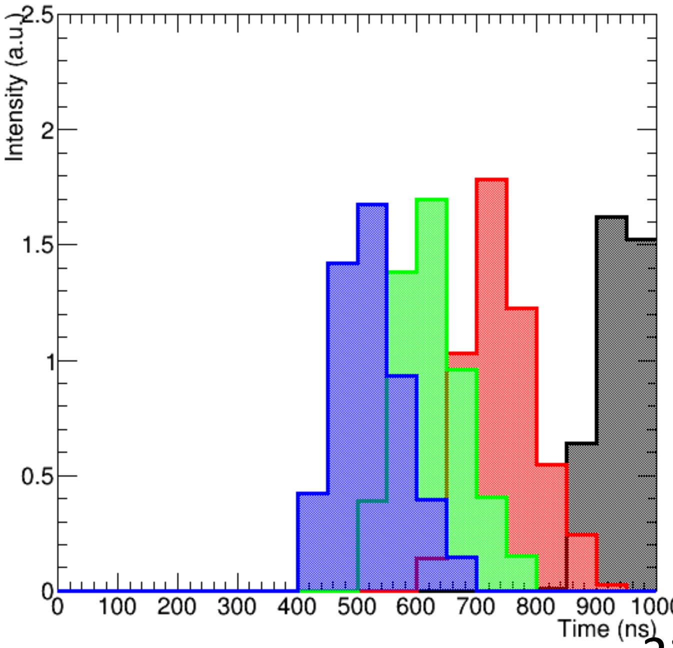
*** shaping time of SAMPA chip (160 ns)**

Example of one readout for one event





Signal in pads highlighted by arrows:



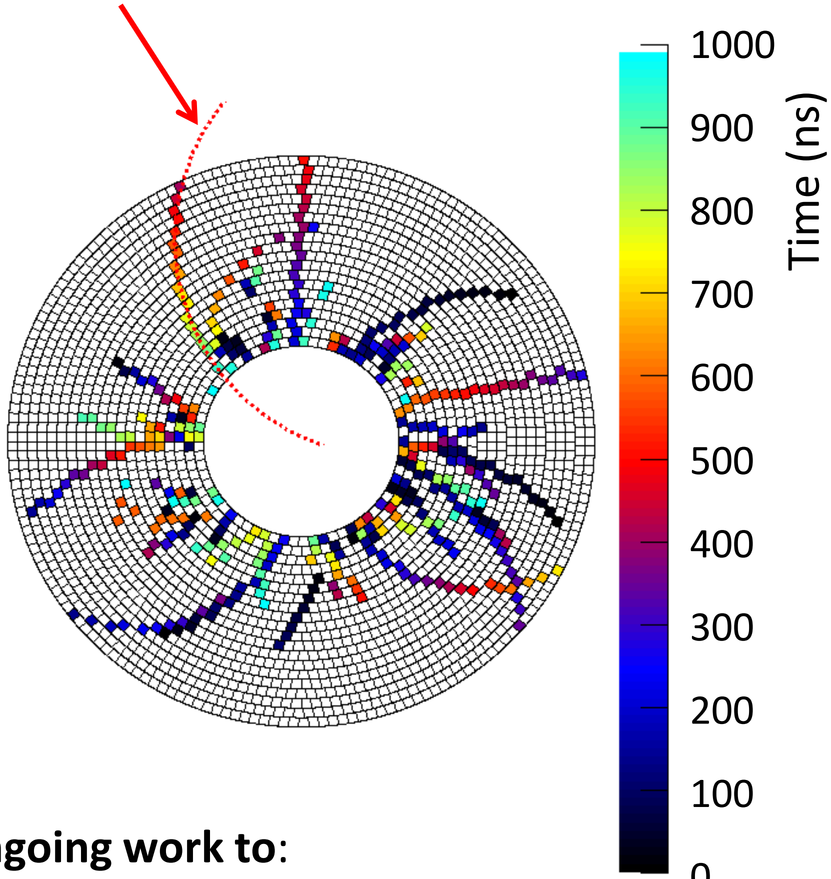
Considering:

- Total rate = 70 MHz / chamber
- Time window = 1000 ns
- SAMPA shaping time = 160 ns
- SAMPA sampling rate = 20 MHz

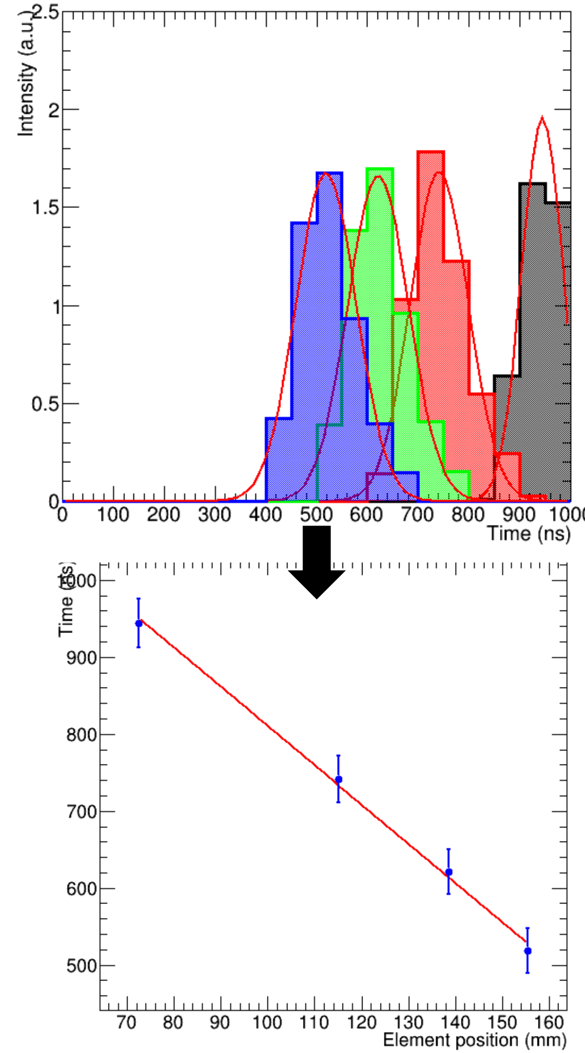
Reconstructing particles' momentum

In this example : $p_{\perp}$ from simulation: 164.3 MeV/c
$p_{//}$ from simulation: 42.6 MeV/c

$\boldsymbol{p_{\perp}}$ **reconstructed from fit**: 2.5% off the actual value



$\boldsymbol{p_{//}}$ **reconstructed from fit**:



Ongoing work to:

- Identify tracks
- Resolve overlaps
- Study momentum resolution and efficiencies

Summary and Next steps

- Two TDIS experiments using SBS and mTPC to explore the meson content of the nucleon and the pion/kaon structure function (+ opportunity for nDVCS and others!)
- Ongoing development of simulations for mTPC design optimization
- Rates estimated on the order of 70 MHz/chamber (we have 10 chambers)
- 15% of readout occupancy was estimated
- Ongoing efforts on digitization to better quantify acceptance and momentum resolution of the detector

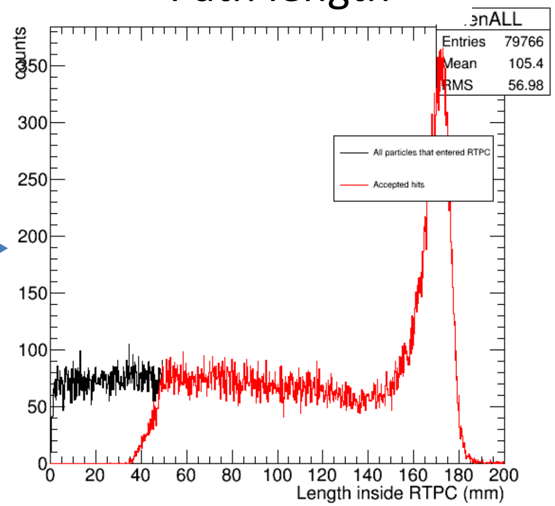
BACKUP

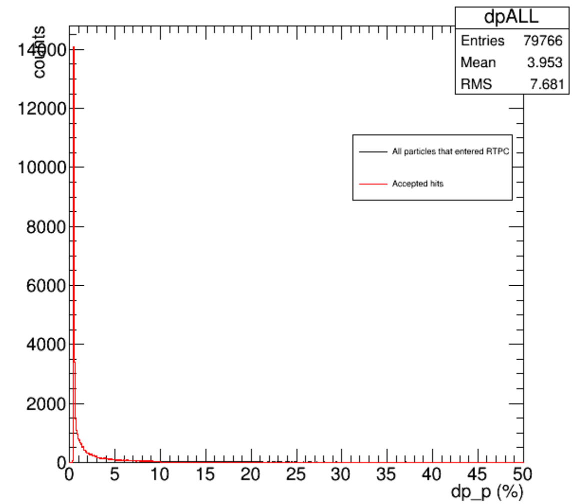
Path length inside mTPC and momentum reconstruction

Path length

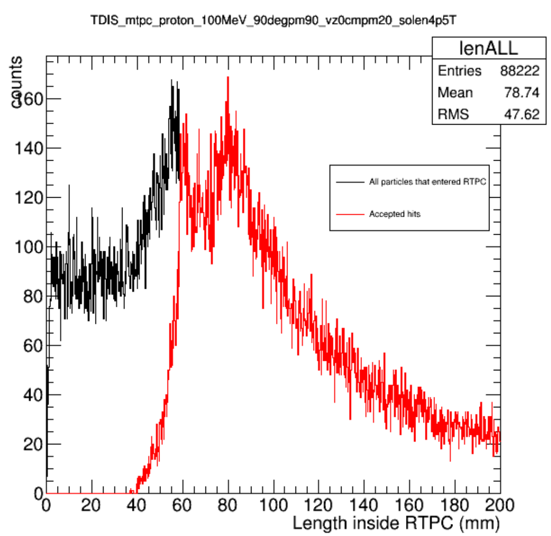
Momentum resolution

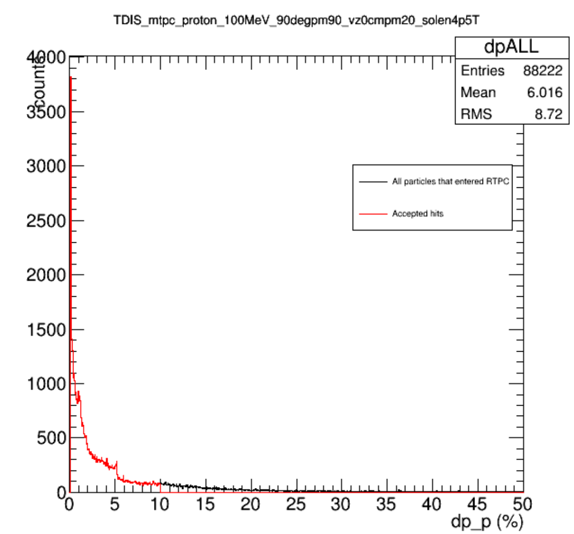
70 MeV/c





100 MeV/c





Luminosity

$$\mathcal{L} = t_{D2} \cdot \mathrm{I}_e = \frac{6.02*10^{23}}{2.014} * \left(180\,\frac{g}{m^3} @0\; oC\right) * \frac{273}{77} * 400mm * \left(\frac{60*10^{-6}}{1.6*10^{-19}}\right) \sim 2.9 \cdot 10^{36}\ \text{cm}^{-2}/\text{s}$$

PAC43 report

Recommendation: Conditionally approved (C1) for 27 days

Measurement and Feasibility:
The actual measurement is the ratio of tagged (e N —> e p X) over untagged (e N —> e X) DIS events, which gives the nucleon tagged structure functions F_2^T. Sensitivity, particularly to the low momentum protons in the deuteron measurement, requires very low amounts of material in front of the RTPC as well as high luminosity. This drives the aggressive design of the target/RTPC system which are proposed to run at cryogenic temperatures in order to maximize the target density while eliminating thermal insulation between the target and detector volume. Likewise, the need for sufficient luminosity to explore the rare TDIS process results in high detector occupancy which drives the large channel count and data rates expected.

- Reduce target cell thickness and amount of other materials in detector to reach sensitivity to low momentum protons

Issues:
While the committee is excited about the physics possibilities of this experiment and impressed by the boldness of the proposal, the PAC is concerned about the technical risk inherent in running the RTPC at cryogenic temperatures and the costs of the high channel count necessary to overcome the high occupancies necessary to achieve the luminosity goals.

- Target at 77 K to have higher density (not at 4K!)
- Could use high pressure instead of low temperature (investigating material for very thin target cell)

- Rates are indeed a concern
- Optimization of original RTPC idea
- New consideration: mTPC