Proton Detector for TDIS

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University of Virginia

Hall A Winter Collaboration Meeting

Jefferson Lab, January 30-31. 2019

UNIVERSITY of VIRGINIA

Outline

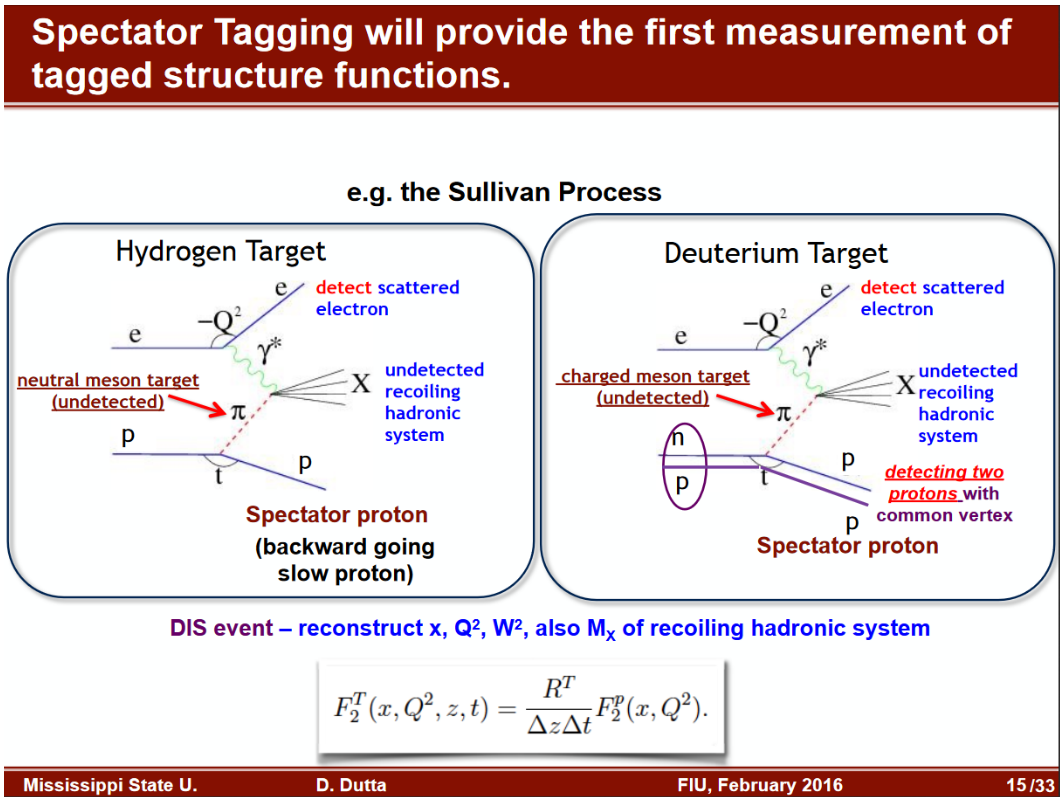
- Overview of the TDIS Experiment
- Overview TDIS proton detector
- Development of a new TPC detector concept (mTPC)
- SAMPA Electronics for the mTPC detector readout

TDIS Experiments

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

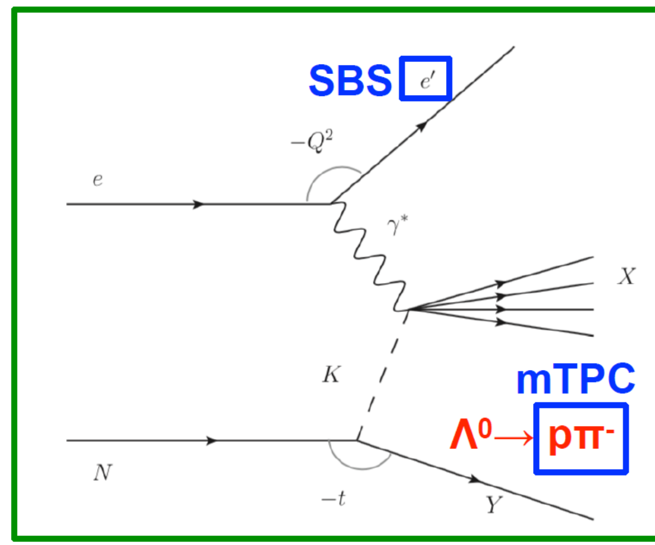
C12-15-006: Measurement of Pion Structure Function

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



C12-15-006A: Kaon Structure Function

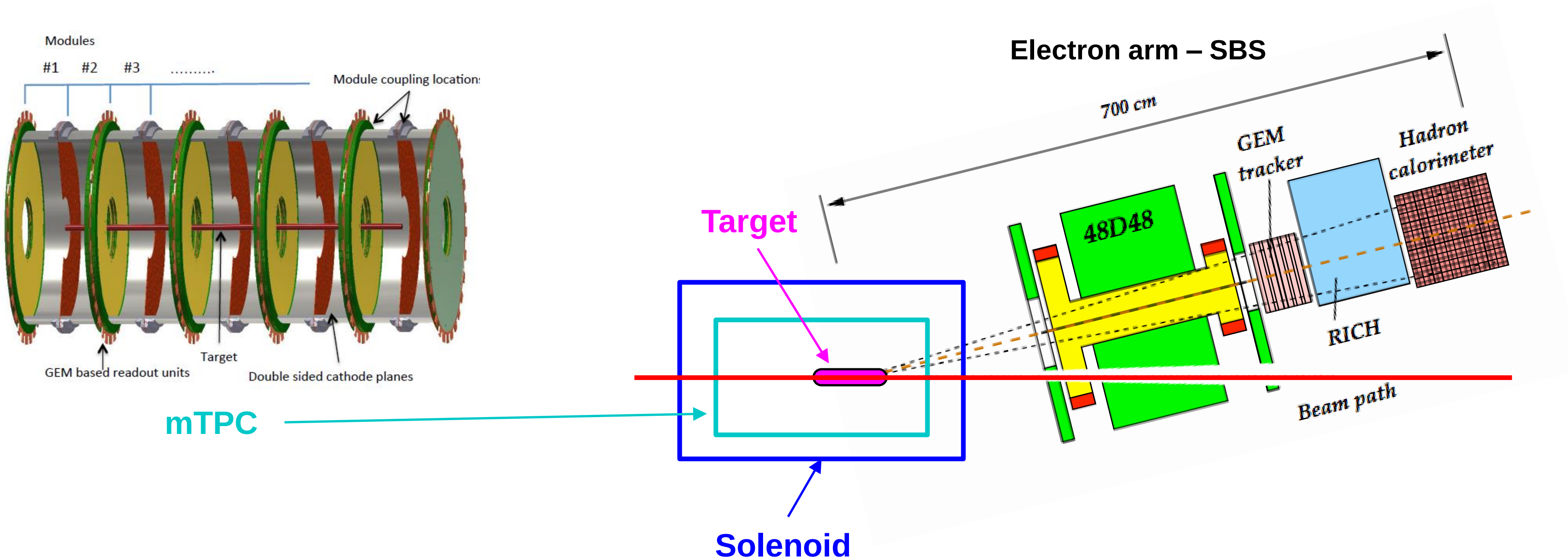
Spokespersons: *Tanja Horn(CUA), Rachel Montgomery(U. of Glasgow), Kijun Park(Jlab)*



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

TDIS Detector Setup

- **Electron arm:** Measure DIS cross section, detecting high W^2, Q^2 of scattered e- from H2 and D2 targets
- **Proton arm:** Coincidence tagging of low momentum recoil and spectator protons



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)

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

TDIS Target: Design (MSU)

(Dipangkar Dutta)

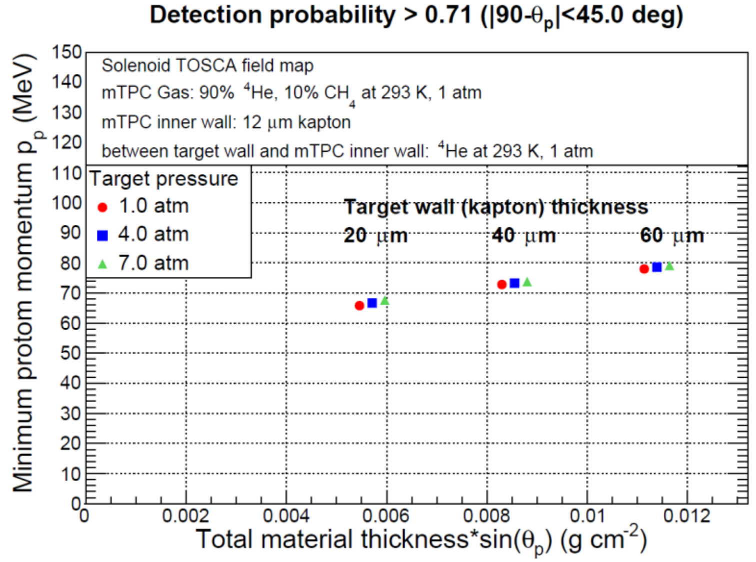
Straw cell:

- 10 mm diam. and 40 cm long, 20 μm (or less) Kapton wall
- Epoxied to metal tube with thin Al window (10 μm)
- Self supporting device
- use the end-caps of the mTPC detector for support

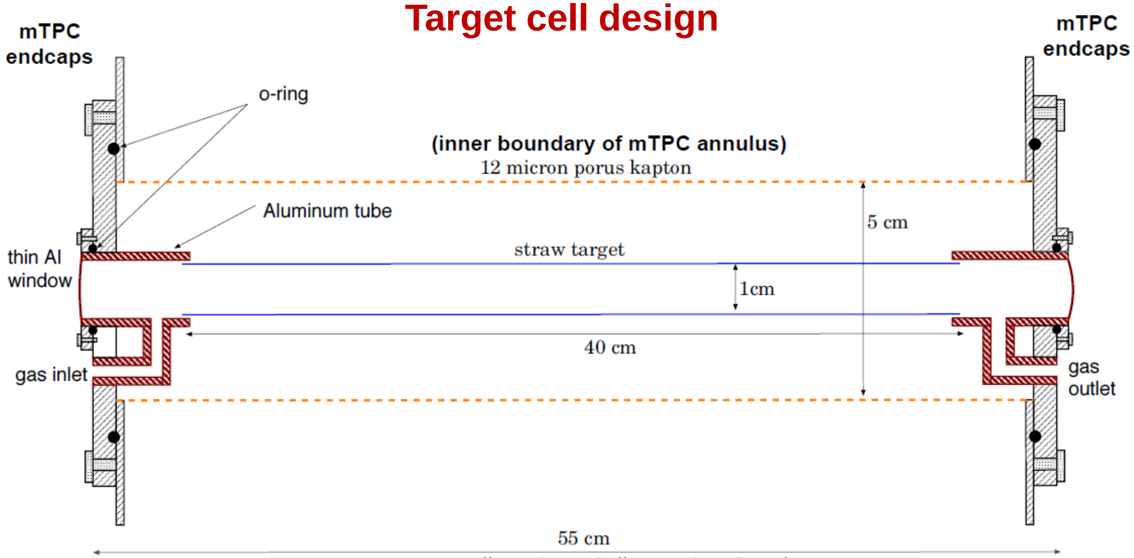
Gaz target: H2 and D2

- Room temperature @ ~ 4 atms

GEANT4 Simulation



Target cell design



Target: R&D & Prototype tests @ MSU

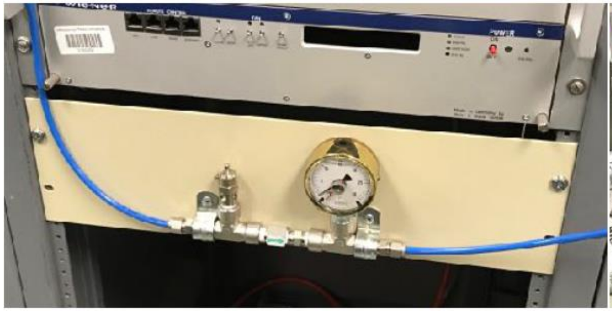
(Dipangkar Dutta)

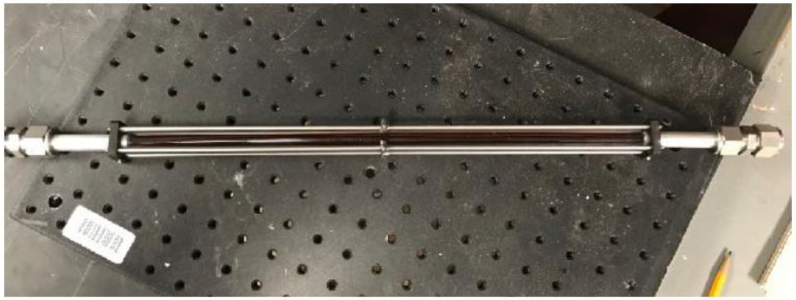
First prototype cell:

- 10 mm diam. Kapton tubes, 80 µm thick (40 µm of Kapton and 20 µm of thermoplastic on each side).
- The cell was attached the Kapton tubes to aluminum tubes and pressure tested up to 120 psi (~8 atms)

New vendor (Teknitape): thinner Kapton foil

- 12.5 µm thick Kapton sheets with a thin layer of adhesive applied to one side of the sheet.
- We will attempt to build custom tubes using this materials and pressure test them.
- Expect to complete these tests by the end of this year.





Aluminum tube epoxied to Kapton tube

Prototype cell
Kapton cell: 40 cm long, 1 cm diameter and 80 um wall thickness
(40 um Kapton with 20um thermoplastic coating on both sides)

Solenoid Magnet

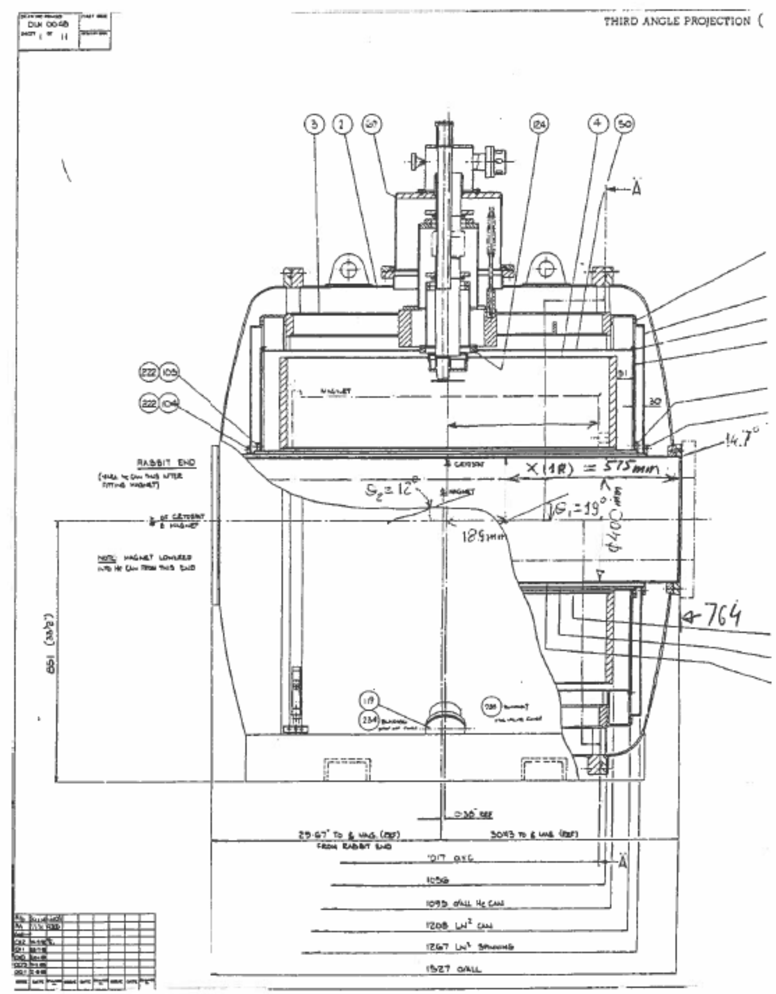


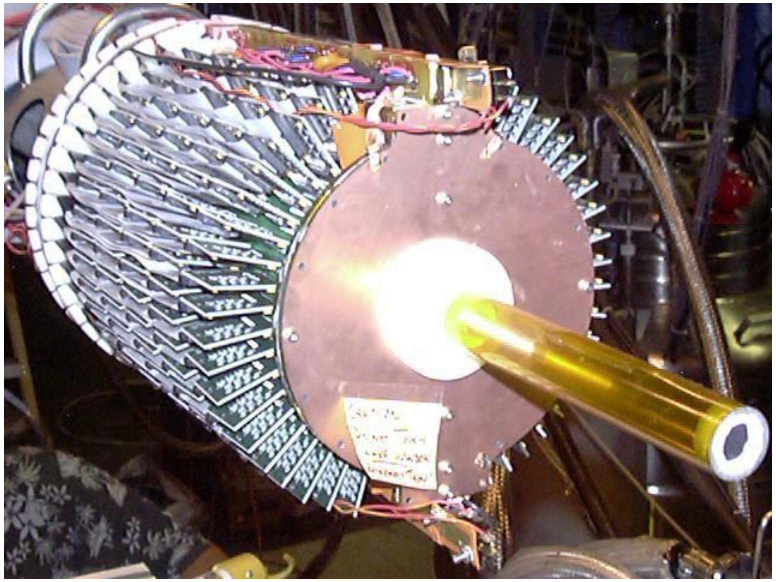
Figure 2: Technical drawing of the available solenoid.

- Large (40 cm bore) super conductive solenoid magnet (belongs to UVa Collaborators)
- Allow insertion of a larger TPC than for BoNUs
- Solenoidal magnetic feld 47G ⇨ confine most of the background δ-electrons created in the target into a narrow cylinder around the target so that they do not enter the TPC ionization region

Proton detector : Multiple TPCs (mTPC) approach

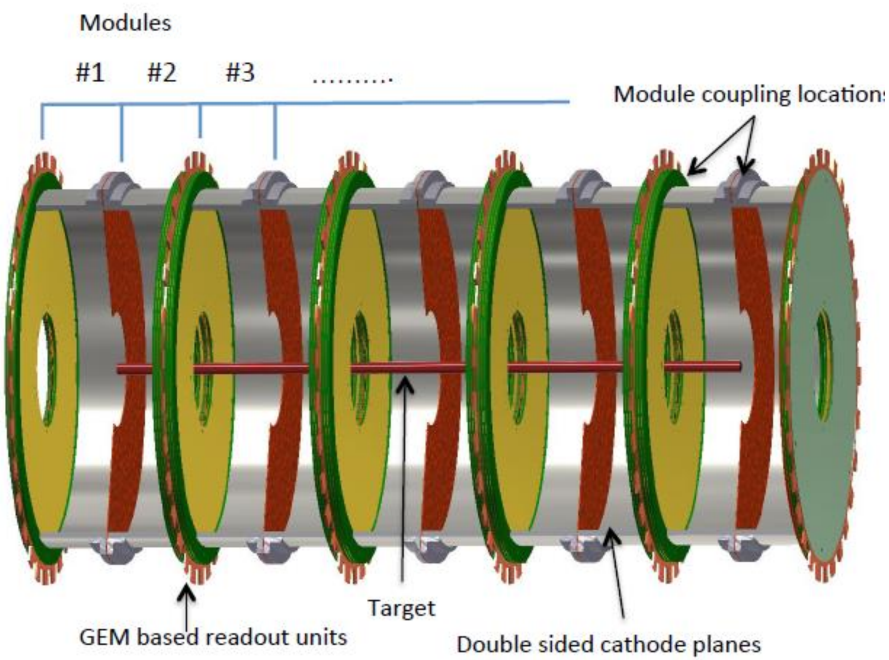
Original idea: Radial TPC a la BoNuS (rTPC)

- Fully cylindrical GEM chamber 5 / 15 cm inner / outer radius
- Radial (10 cm) drift field perpendicular B-field ⇨ very long track
- **Pros:** No material in active volume, 20K$ electronic channels
- **Cons:** very high particle rate (~980 Mhz in the volume), drift time too long ~ 20 μs for track, challenges with Cylindrical GEMs, momentum resolution etc …



Current design: multiple /modular TPCs (mTPC)

- 10 GEM readout / 5 drift cathodes each shared by 2 GEM readouts
- Each TPC block is a standard TPC ⇨ drift E-field (5 cm) parallel to B-field ⇨ shorter track and effective reduction of e- background
- **Pros:** Particle rate ~ 98 MHz / GEM layer, shorter track (1 μs), Detector construction less challenging, momentum resolution
- **Cons:** More material in the active TPC volume, need to minimize GEM material, 25K$ electronic channels



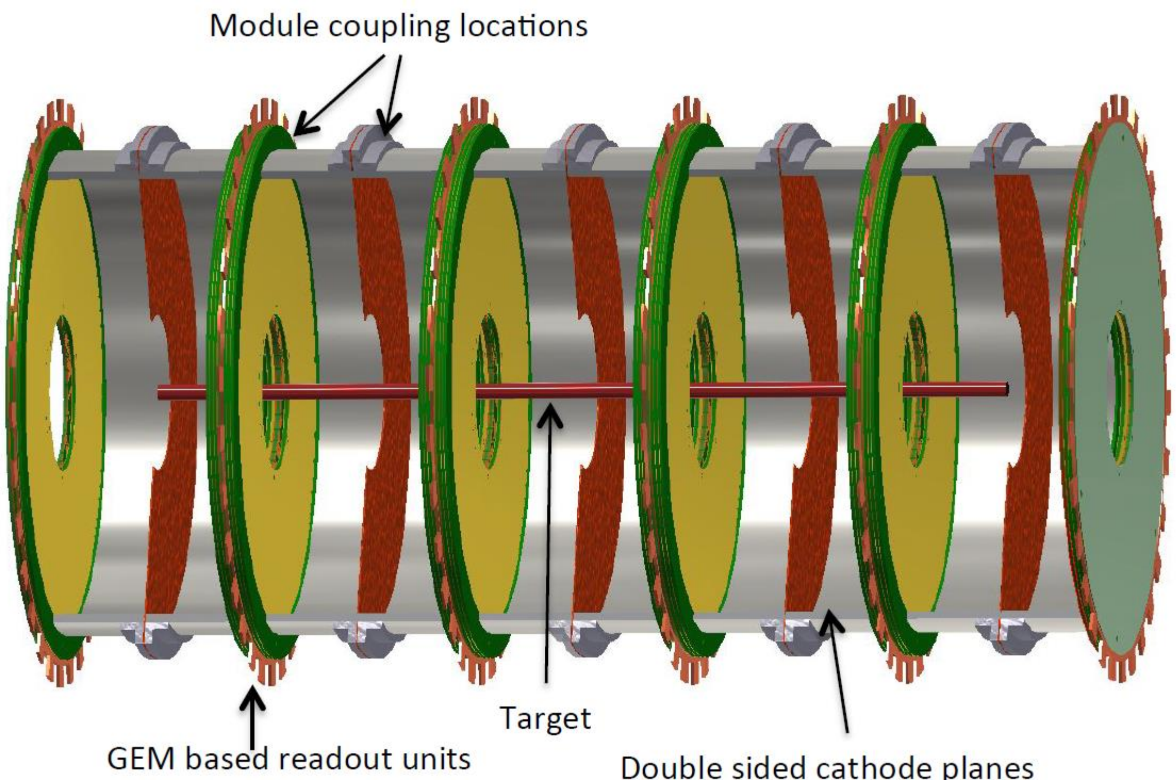
mTPC Design

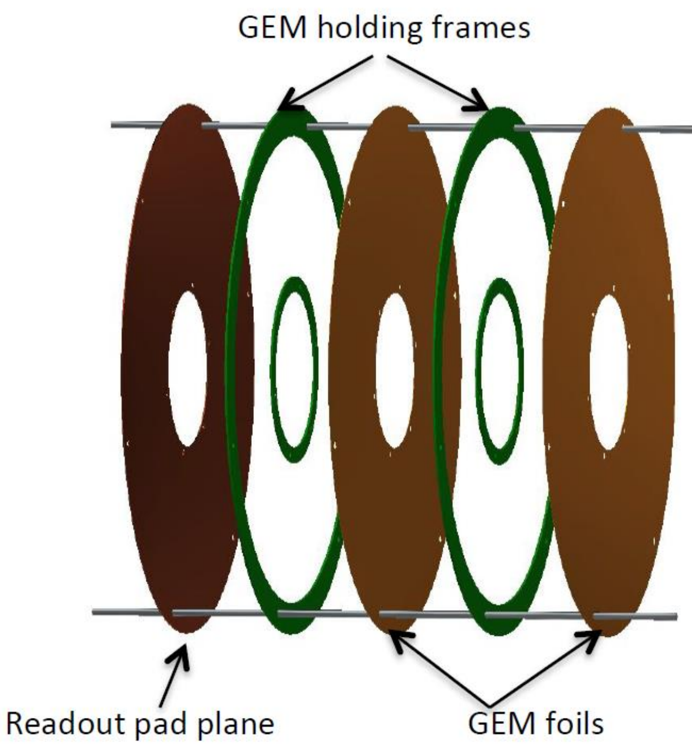
mTPC:

- Stack of 10 individual sub modules. Each sub module is a standalone TPC
- Gas mixture: He CH4 (90/10) at room temperature and atmospheric pressure

Sub module

- 5cm drift volume, a 2 stack of GEM foils for the amplification and pad readout for the signal collection
- Drift Cathode foil is shared by two sub modules



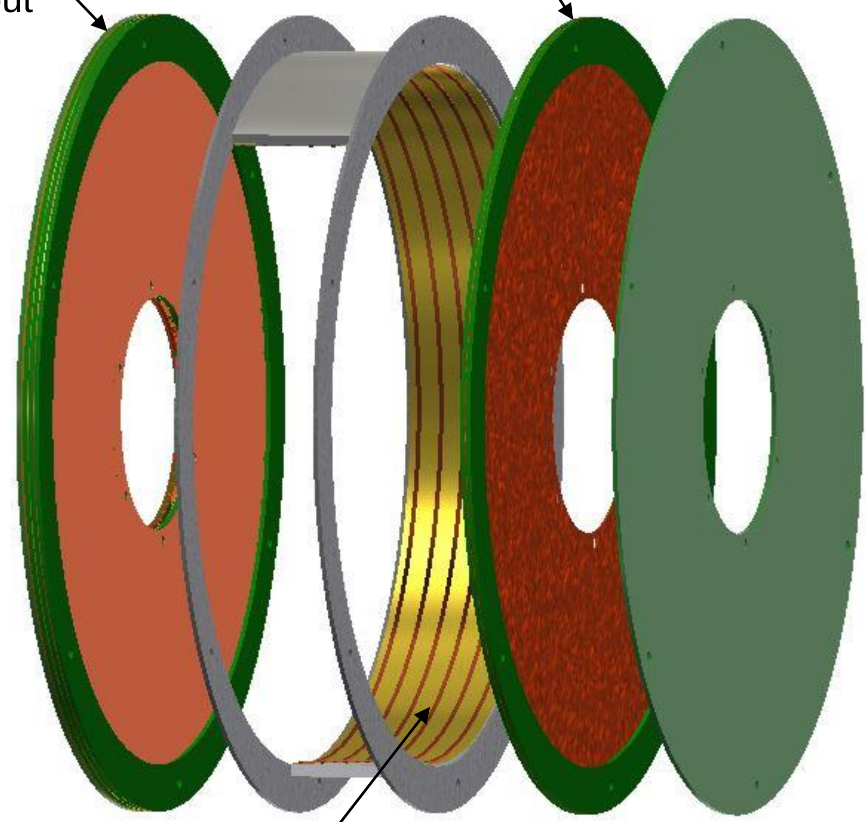


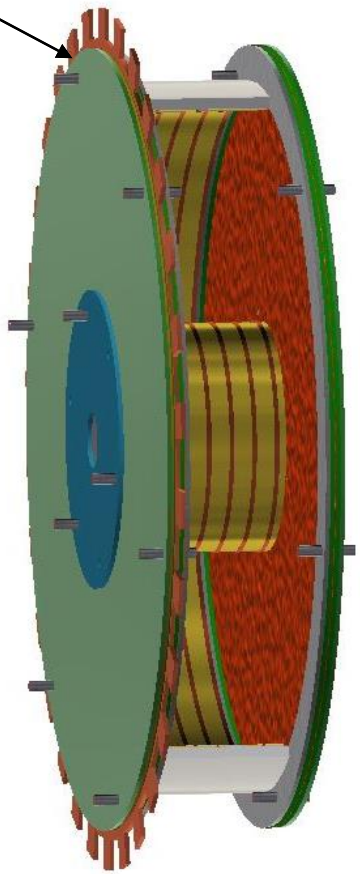
mTPC Design: TPC sub module

Sub module: 5cm drift volume, a 2 stack of GEM foils for the amplification and pad readout for the signal collection

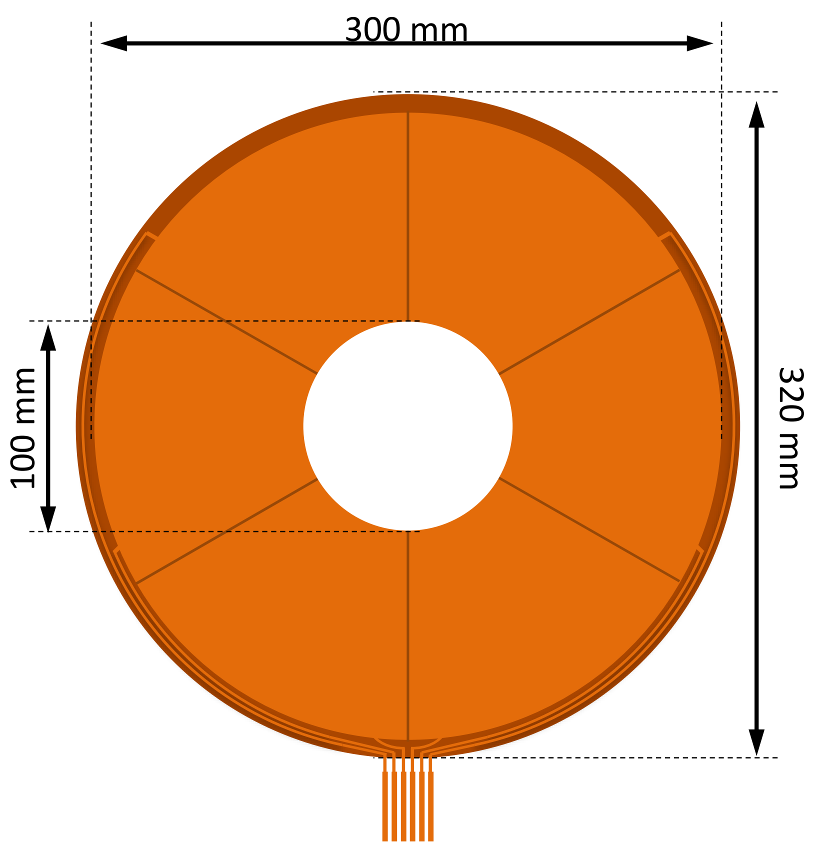
- Drift Cathode foil is shared by two sub modules

Field cage: Inner and outer Kapton with thin Cu-grid for the field cage



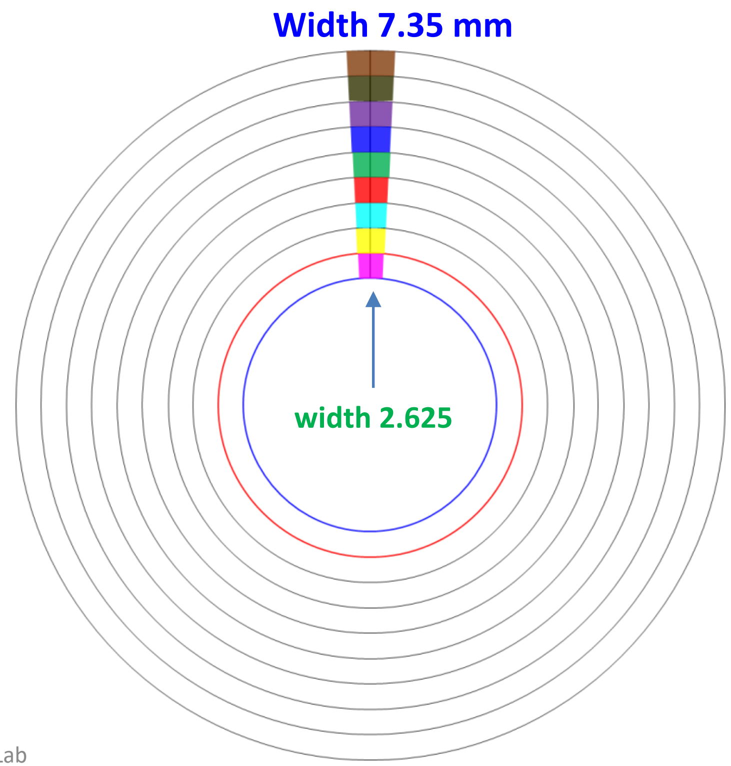


mTPC Design: Preliminary design



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



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

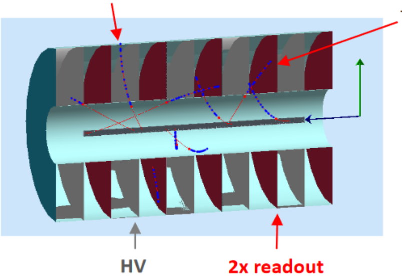
GEANT4 Simulation: Rate Estimation

(Marco Carmignotto, Rachel Mongomery, Eric Fuchey)

Particles track in mTPC

- Some tracks go through the entire active gas volume

- Some tracks hit readout discs though



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

(2 sets per disc, chambers are back to back)

- Particles may stop or scatter going through readout

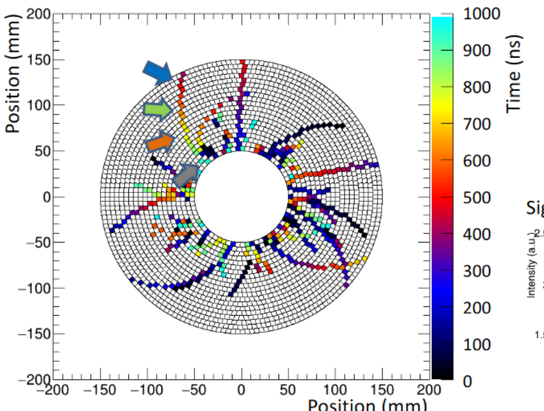
Study of effects on momentum reconstruction

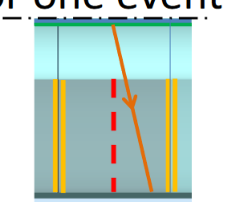
Thoughts on characterization

Paul King

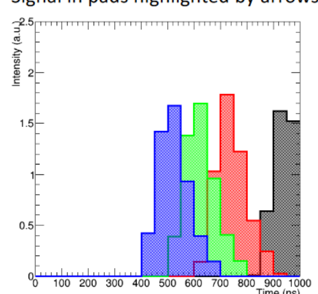
- The maximum drift time is 1 us for 5 cm
- A track with θ=45° would have a longitudinal extent of 5mm as it traverses one 5mm pad width; the drift time would vary by 100 ns across this pad. Drift time width for 30° is ~170 ns.
- There will also be some shaping time; the SAMPA chip shaping time is 160 ns (reduction to 80 ns possible with added development effort)
- Together, this maybe gives a 200 ns double-pulse resolving time

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

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Rate estimation from simulation data

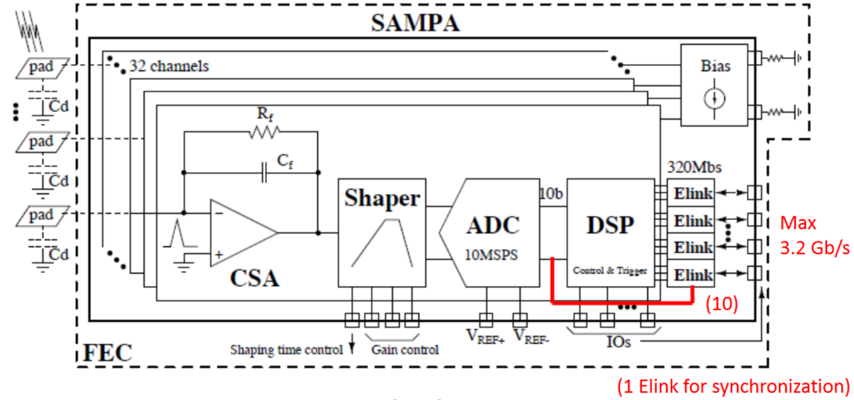
- 98 MHz in each TPC module (chamber)
- With 20 hits / track ⇨ 20 × 98 = ~2000 MHz
- Each chamber has ~2500 pads ⇨ 0.8MHz / pad
- In 1 μs window ⇨ 55% occupancy, 1.45 hits / struck pad
- 36% pads with 1 hit and 19% with more than 1 hits
- **In inner ring, 63% occupancy, 1.58 hits / struck pad and 28% pile up with (5 cm ×5 cm pad)**
- **Situation better with the new pad readout design**
  - Inner region ⇨ high rate ⇨ but smaller pad size
  - Outer region ⇨ lower rate ⇨ larger pad size

mTPC Readout Electronics: SAMPA chip

(Ed Jastrzembski)

- New ASIC for the ALICE TPC and Muon Chamber (MCH) upgrades
- Combines functions of the PASA (analog) and ALTRO (digital) chips currently being used
- Design effort led by University of São Paulo, Brazil (SAMPA)
- Chosen for TPC readout by sPHENIX and STAR upgrade at RHIC
- ALICE alone > 50,000 chips (1.5 M channels)
- All plan to use continuous readout mode for their TPC

SAMPA Block Diagram



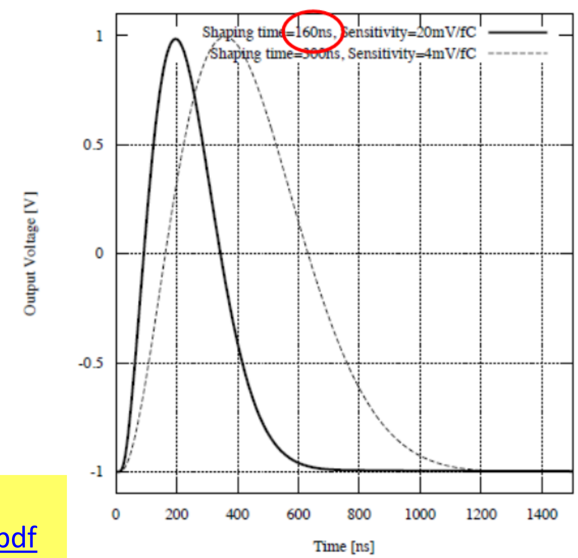
Direct Mode – bypass DSP

(Raw data rate (10MHz) = 3.2Gb/s)

Functional Blocks

- <u>Charge Sensitive Amplifier (CSA)</u>
  - Integrates and amplifies short current pulse
  - Output is a Voltage signal with amplitude proportional to the total charge Q
  - Tail of Voltage pulse is long (T = Rf*Cf)
  - Vulnerable to pile-up unless followed by a shaping filter
- <u>Shaper</u>
  - Creates a 4^{th} order semi-Gaussian pulse shape
  - Available shaping times (TS): ~~80~~, 160, 300 ns
  - Permits sampling by ADC at reasonable rates (10, 20 MHz)
  - 80 ns option eliminated in order to reduce noise in CSA

Pulse from Shaper



Ed Jastrzembski: TDIS Collaboration meeting, 2/22/18
https://www.jlab.org/indico/event/255/session/2/contribution/7/material/slides/0.pdf

mTPC Readout Electronics: SAMPA chip

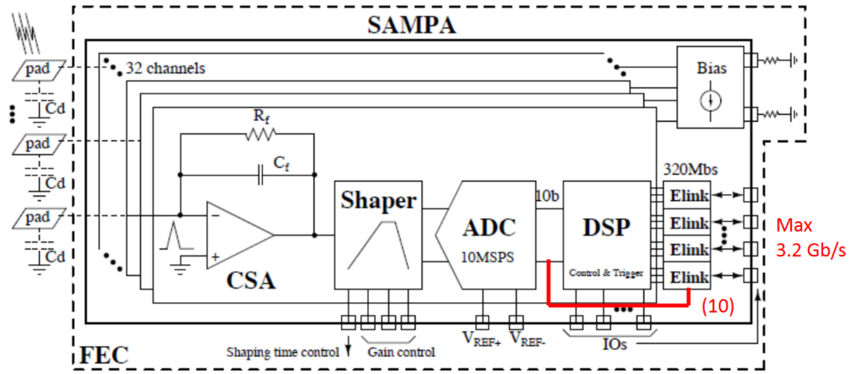
(Ed Jastrzembski)

SAMPA Specifications

Specification	TPC	MCH
Voltage supply	1.25 V	1.25 V
Polarity	Negative	Positive
Detector capacitance (Cd)	18.5 pF	40 pF - 80 pF
Peaking time (ts)	160 ns	300 ns
Shaping order	4th	4th
Equivalent Noise Charge (ENC)	< 600e@ts=160 ns*	< 950e @ Cd=40 pF* < 1600e @ Cd=80 pF*
Linear Range	100 fC or 67 fC	500 fC
Sensitivity	20 mV/fC or 30 mV/fC	4 mV/fC
Non-Linearity (CSA + Shaper)	< 1%	< 1%
Crosstalk	< 0.3%@ts=160 ns	< 0.2%@ts=300 ns
ADC effective input range	2 Vpp	2 Vpp
ADC resolution	10-bit	10-bit
Sampling Frequency	10 (20) Msamples/s	10 Msamples/s
INL (ADC)	<0.65 LSB	<0.65 LSB
DNL (ADC)	<0.6 LSB	<0.6 LSB
ENOB (ADC)**	> 9.2-bit	> 9.2-bit
Power consumption (per channel) CSA + Shaper + ADC	< 15 mW	< 15 mW
Channels per chip	32	32

*R_{esd} = 70Ω

SAMPA Block Diagram



(1 Elink for synchronization)

Direct Mode – bypass DSP

(Raw data rate (10MHz) = 3.2Gb/s)

Functional Blocks

- ADC
  - 10 bit precision
  - 10 MSPS or 20 MSPS
  - SAR architecture for low power (Successive Approximation Register)
  - ADC data rate = 10 MSPS * 10 bits * 32 channels = 3.2Gb/s (6.4 Gb/s)
- DSP
  - Baseline Correction 1 (BC1) – removes low frequency perturbations and systematic effects
  - Digital Shaper (DS) – tail cancellation or peaking time correction (IIR filter)
  - Baseline Correction 2 (BC2) – moving average filter
  - Baseline Correction 3 (BC3) – slope based filter (alternative to BC2)
  - Zero suppression – fixed threshold
  - Formatting; encoding for compression – Huffman
  - Buffering (16K x 10 bit)

Functional Blocks

- e-link
  - Electrical interface for transmission of serial data over PCB traces or electrical cables, for distances of several meters
  - Up to 320 Mb/s
  - Developed by CERN for the connection between Front-end ASICs and their GigaBit Transceiver (**GBTx**) chip
  - Based on SLVS standard (Scalable Low-Voltage Signaling) – supply voltage as low as 0.8 V
  - Radiation-hard IP blocks for integration into ASICs
  - SAMPA: 11 e-links → 3.52 Gb/s max data output
  - Number and speed of SAMPA e-links used is programmable

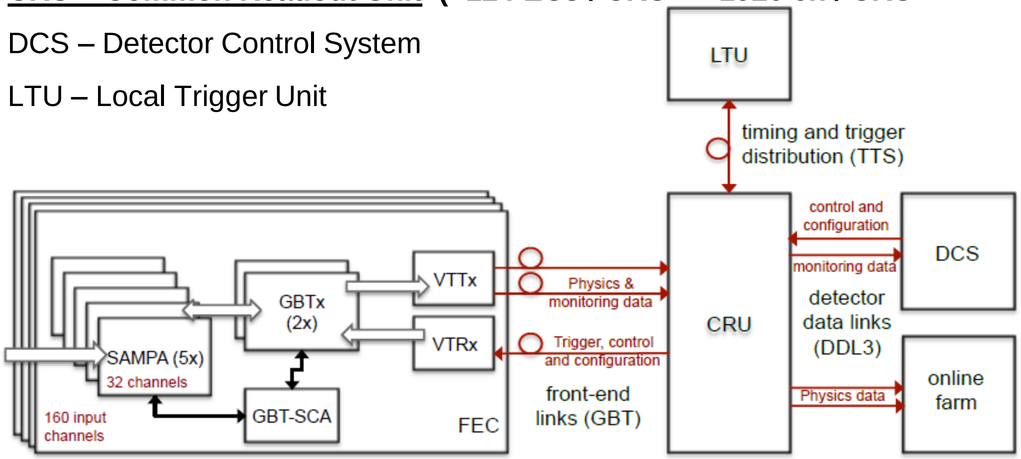
https://www.jlab.org/indico/event/255/session/2/contribution/7/material/slides/0.pdf

Development of Streaming Readout System

(Ed Jastrzembski)

based on ALICE Components

- **FEC – Front End Card** (160 ch / FEC)
- **CRU – Common Readout Unit** (~12 FECs / CRU = ~1920 ch / CRU
- DCS – Detector Control System
- LTU – Local Trigger Unit



ALICE Common Readout Unit (CRU)

- ALICE development firmware for the PCIe40 available
- Firmware implements the custom protocol of the GBTx chips using the FPGA gigabit transceivers
- PCIe Gen 3 x16 interface included (100 Gb/s)
- Remaining FPGA resources for data processing and formatting
- Software to configure and monitor SAMPA available

ALICE Common Readout Receiver Card (C-RORC)

- ALICE C-RORC / ATLAS RobinNP – identical except for firmware
- ALICE Run 2 has ended we have arranged to borrow one of their spare C-RORCs and install the GBT protocol firmware on it
- We're back to 'plug and play' since all the SAMPA TPC test stand software developed by others will directly run on our system

C-RORC

Data rate with SAMPA electronics

(Paul King)

Some data rate cases

- Assuming an average hit requires 12 50-ns time bins to be recorded (300 ns) and using the 0.8 MHz hit rate per pad, the "time-bin occupancy" will be 24%.
- Each chamber has 2500 pads sampling at 20 MHz, so there are 50e9 samples per second per chamber; 12e9 are filled.
  - Using SAMPA as a baseline, 1 chip handles 32 channels, with 10b sampling and 1.28 Gb/s output.
    - Keeping only filled bins & w/o timestamps would give 1.536 Gb/s, so to output 20 MHz sampling would require <26 pads per chip
- The trigger rate from electrons in the SBS should be ~6 kHz.
  - In each trigger, we expect an average of 0.8 hits/pad, so there would be 0.15e9 filled samples/chamber/trigger →0.6 GB/s/chamber at 4 bytes per filled sample (amplitude and timestamp)

2/22/2018 8

Summary

- TDIS is an SBS experiment to measure mesonic content of the nucleon structure function
  - via Sullivan process N(e,e'N')X
- Detect recoil and spectator low energy proton in coincidence with the scattered DIS electron
  - SBS spectrometer will detect the electron
- Development of the recoil proton detector
  - Extensive Monte Carlo simulation to estimate expected rate and background …
  - R&D on low mass target cell for the H2 and D2 TDIS targets
  - Development of a new TPC concept: the mTPC for the recoil proton detection
- Development of a new electronics based on the SAMPA chip for the readout of the mTPC
  - Will be based on the streaming readout scheme currently being developed at Jlab
- Submission of an MRI for the development of the mTPC
  - Collaborating institutes (UVa, Hampton Univ. and VUU)