FORWARD TRACKING REPORT

CLAS COLLABORATION MEETING

DANIEL S. CARMAN

APRIL 28, 2020

Forward Tracking Task Force

Hall-B Task Forces 2020

https://clasweb.jlab.org/wiki/index.php/Hall-B_Task_Forces_2020

Overview | Analysis Framework | Central Tracking | Data Preservation | Forward Tracking | Novel Tracking | Polarized Targets | Particle ID | Software | Streaming GEMC | BG Merging & Efficiency

Goal

To identify issues in current CLAS12 forward tracking and propose a path forward to obtain the maximum efficiency, resolution, and speed.

Members

- Daniel Carman (PI)
- Veronique Ziegler (core)
- Mac Mestayer (core)
- Maurizio Ungaro (external)
- Dave Heddle (external)
- Maxime Defurne (external)
- Maxence Vandenbroucke (external)

Charge

- Assess the current CLAS12 forward tracking efficiency, resolution, and execution speed
- Assess limitations in hardware, reconstruction software, calibrations, tracking algorithms, ...
- Quantify the expected improvement in efficiency, resolution, and execution time provided by the proposed solutions
- Define a work plan to more forward provide a time chart and milestones for:
  1. Assessment
  2. Definition of alternative solutions
  3. Validation (data and Monte Carlo)
  4. Implementation in the current reconstruction framework
- Estimate resources needed in the different phases of the project
- Evaluate synergies with other projects at the lab providing a list of shared resources and common goals

Documentation

- Kick-off meeting outline [5]
- HADES drift chamber poster [6] (time-over-threshold technique)
- COMPASS Micromegas detector [7]

Meetings

February 17, 2020

- Agenda: Kick-off meeting of core task force members
- Minutes: [8]

March 9, 2020

- Agenda: Review near term, medium term, long term tasks from the last meeting and discuss next steps
- Minutes: [9]

April 2, 2020

- Agenda: Review status of report preparation and preparations for initial presentation
- Minutes: [10]
- Group Presentation Slides: [11]

April 23, 2020

- Agenda: Review status of report, manpower estimates, high priority tasks, next steps
- Minutes: [12]

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Forward Tracking Task Force Report

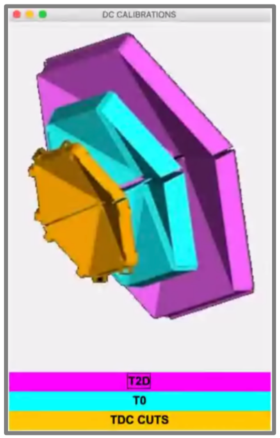
1. Improve track resolution
2. Improve track efficiency
3. Improve matching of data and simulation
4. Improve speed of reconstruction
5. Validate tracking software and implement correction procedures

Assign as: HIGH, MEDIUM, LOW priority

1. Improve Track Resolution

Drift Chamber Time-to-Distance Calibration:

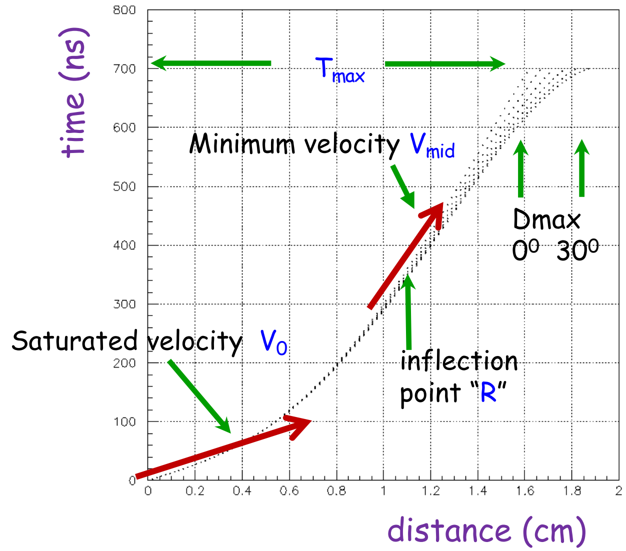
- Finish updating and validating the DC calibration suite
- Finalize the drift chamber calibration procedure

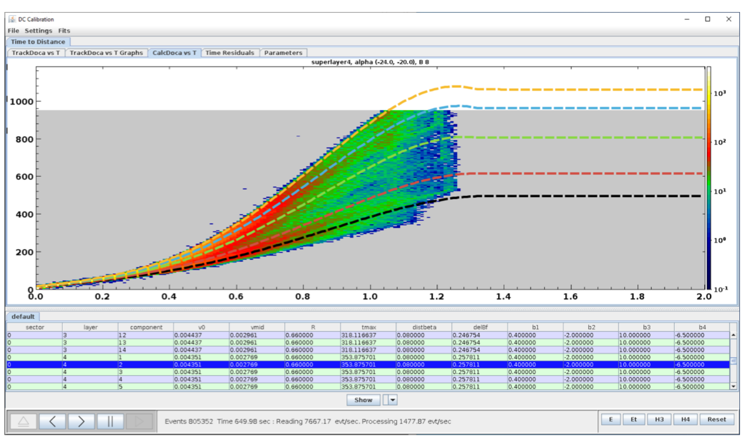


DC calibration suite:

used for RG-A/B/K calib

Veronique Ziegler





Time-to-distance functional:

$$T(x) = a\,x + b\,x^2 + c\,x^3 + d\,x^4$$

- Simple calculus: $(a,b,c,d) \rightarrow (V_0, V_{mid}, R, T_{max})$
- Physically meaningful parameters
- Published data for V_0, V_{mid}

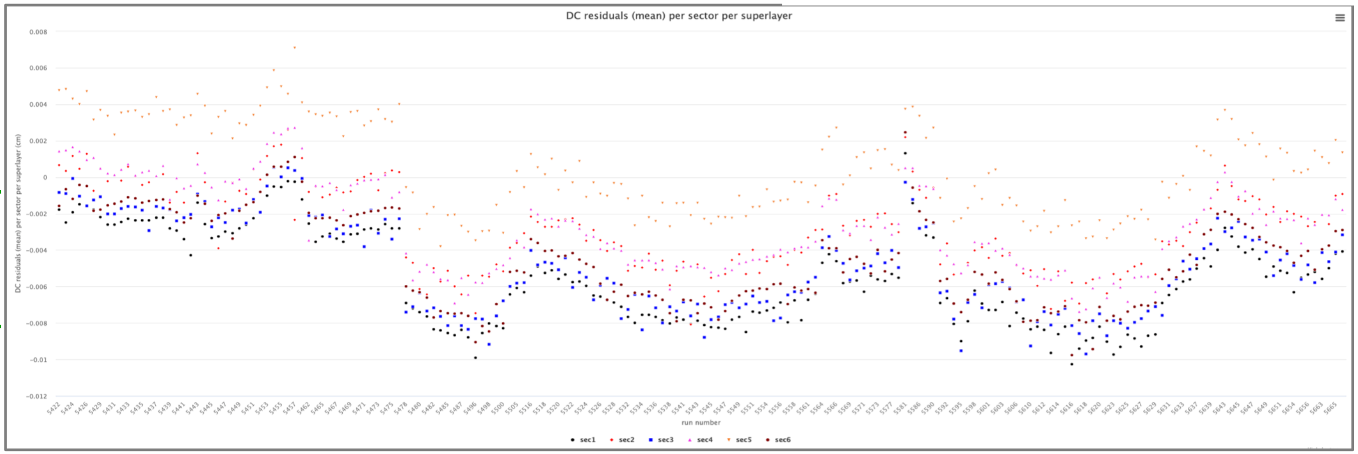
Drift Chamber Time-to-Distance Calibration:

- Study calibration stability and correlations with atmospheric pressure

DC residuals (mean) per sector per SL

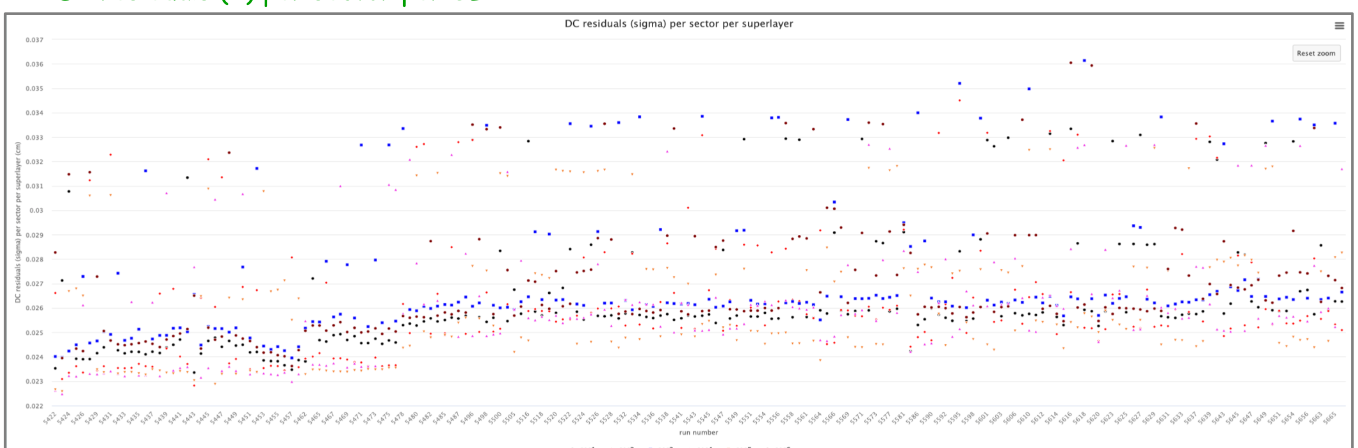
RG-A fall 2018 outbending timelines

100 μm



DC residuals (σ) per sector per SL

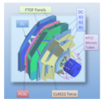
30 μm



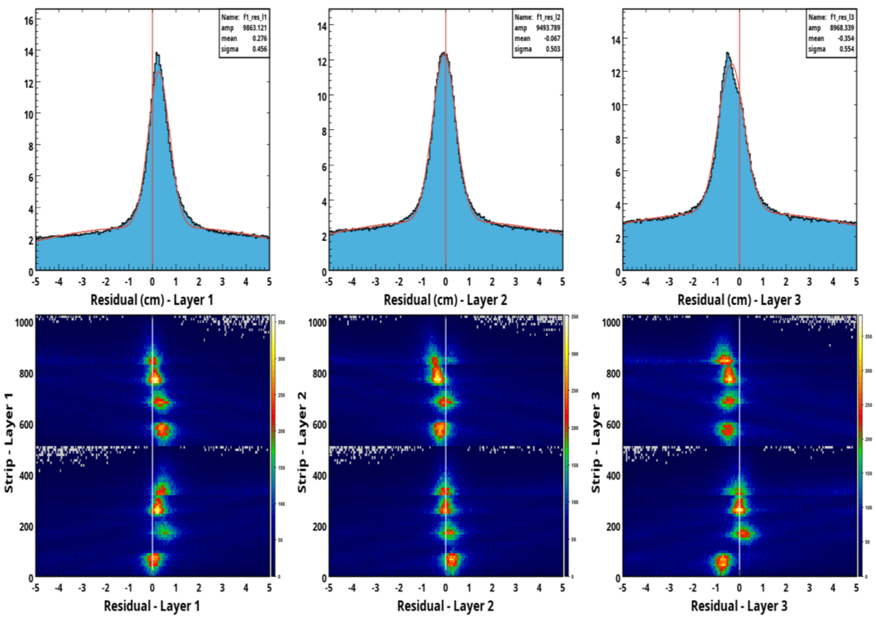
1. Improve Track Resolution

Forward Tracker Alignment:

- Devise procedure to align FMT relative to DCs
- Study effects of misalignment on momentum and angle resolution



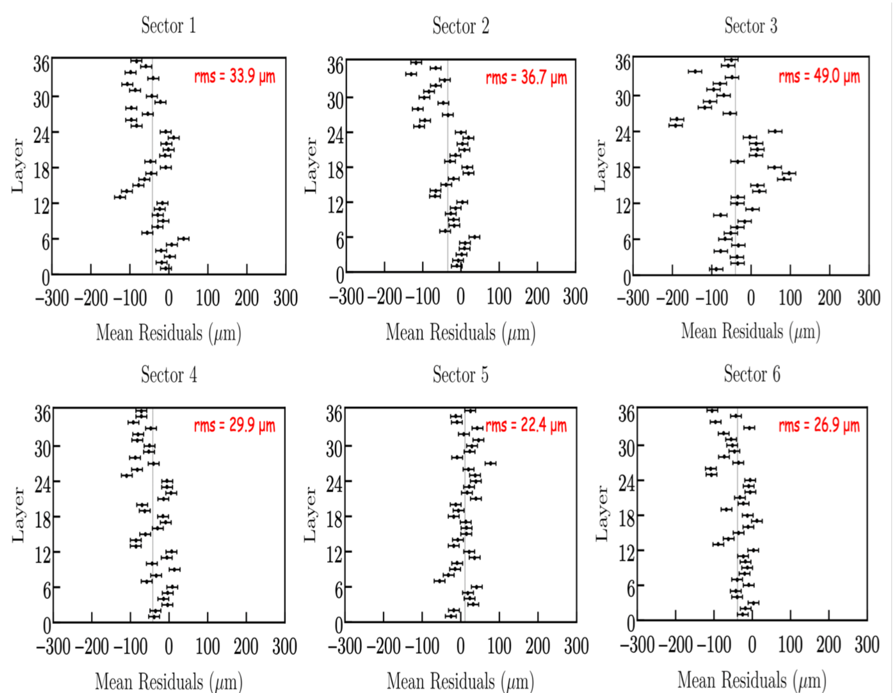
FMT alignment



Work getting underway

Bruno Benkel (Chile), Maxime Defurne (Saclay)

DC alignment



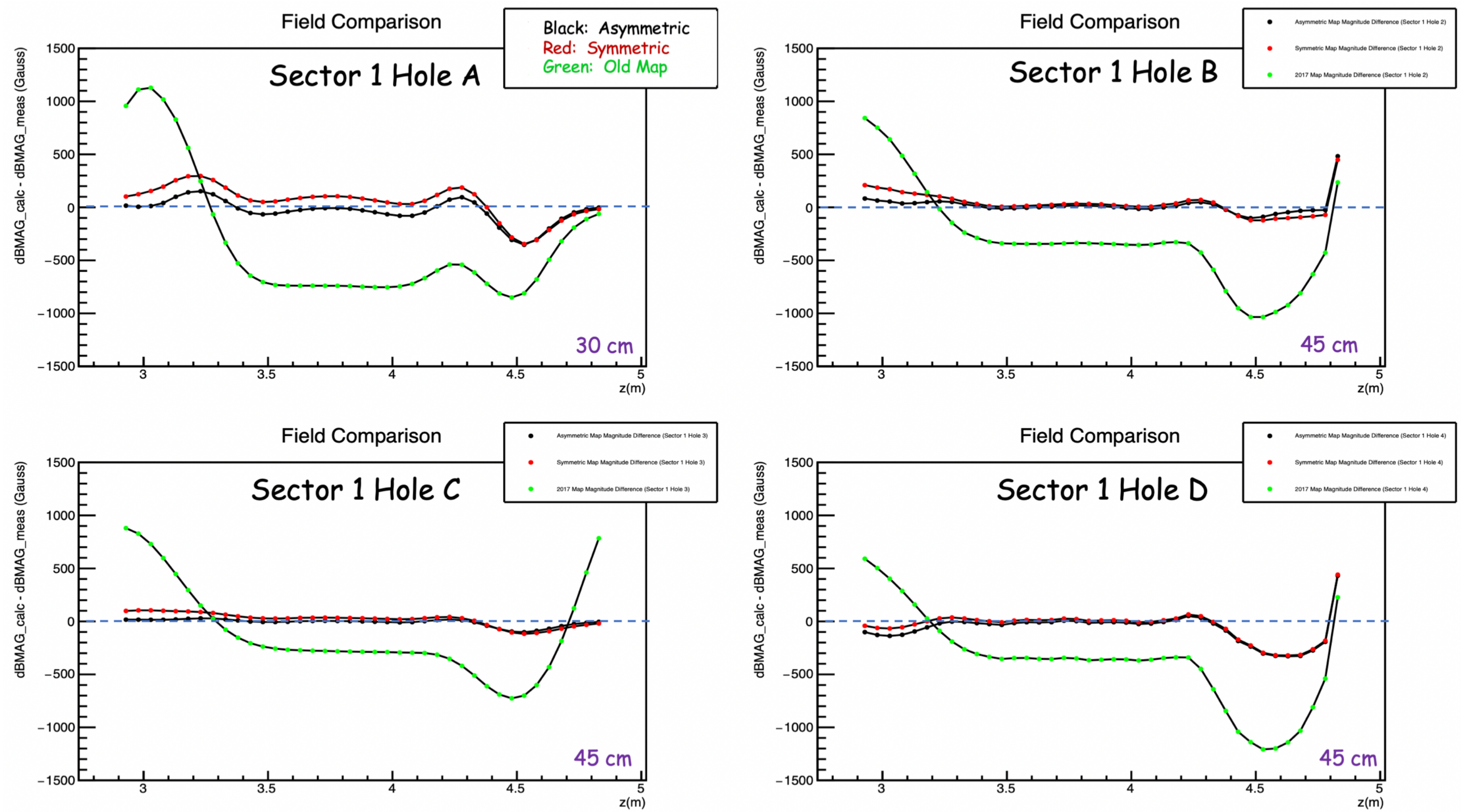
Offsets from CLAS12 zero-field data

Timothy Hayward (W&M)

1. Improve Track Resolution

Torus Field:

- Decide on “best” torus map and if additional map development is needed



Field map used for RG-A cooking: 0.2-0.7% too high

Joseph Newton (ODU)

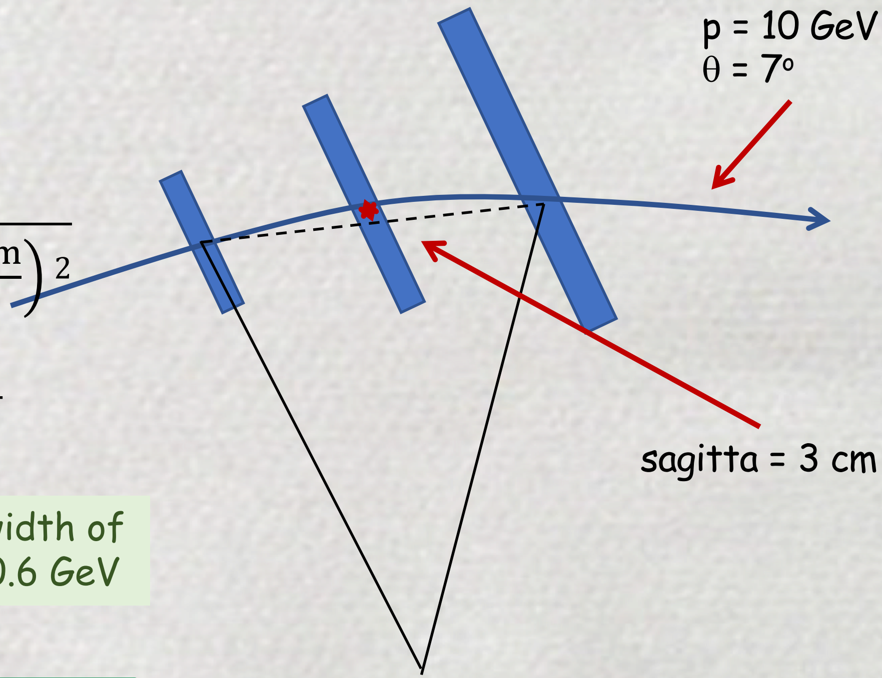
DC Momentum Resolution

- B-field: model agrees with measurement to ~0.5%
- Alignment: known to ~ $\sqrt{3} \times 100\ \mu\text{m}$
- DOCA resolution on sagitta: ~ 200 μm

$$dp/p = \sqrt{\left(\frac{db}{b}\right)^2 + \left(\frac{dAlign}{3\text{ cm}}\right)^2 + \left(\frac{dDoca}{3\text{ cm}}\right)^2}$$

$$dp/p = \sqrt{(0.005)^2 + \left(\frac{.017\text{ cm}}{3\text{ cm}}\right)^2 + \left(\frac{.020\text{ cm}}{3\text{ cm}}\right)^2}$$

$$dp/p = \sqrt{(0.005)^2 + (0.006)^2 + (.007)^2}$$



$dp/p \cong 0.9\%$

Consistent with width of elastic peak at 10.6 GeV

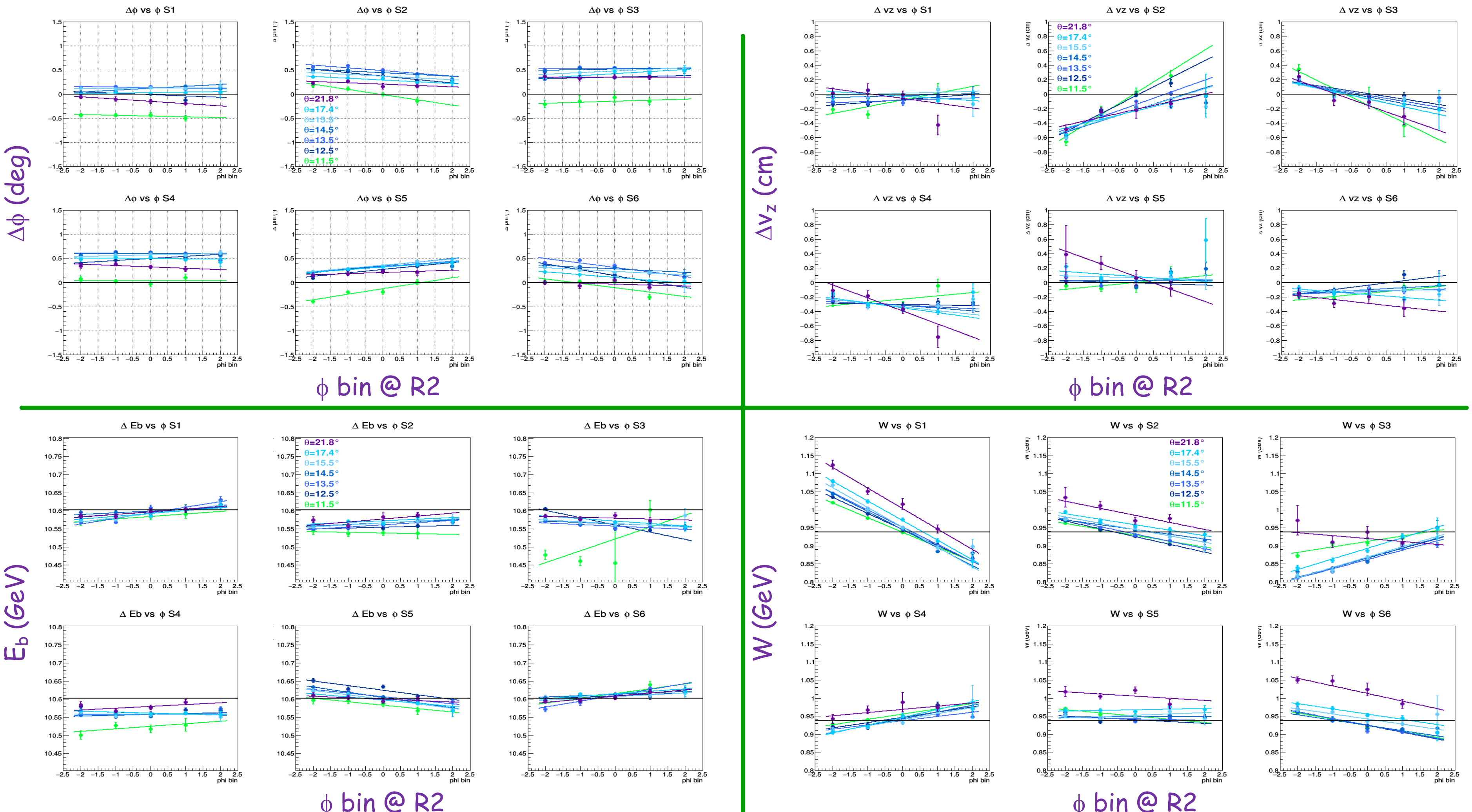
Note: proposals based on 0.3% $\Delta p_e/p_e$

RG-A Elastic Event Reconstruction

RG-A fall 2018 pass-1 reconstruction 10.6 GeV (inbending polarity)

both e & p in Forward Detector

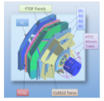
Francois-Xavier Girod



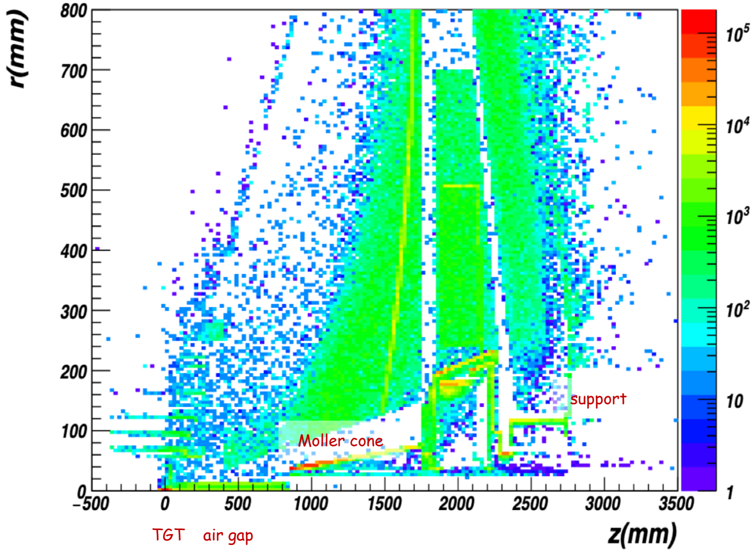
1. Improve Track Resolution

Beamline and shielding improvements:

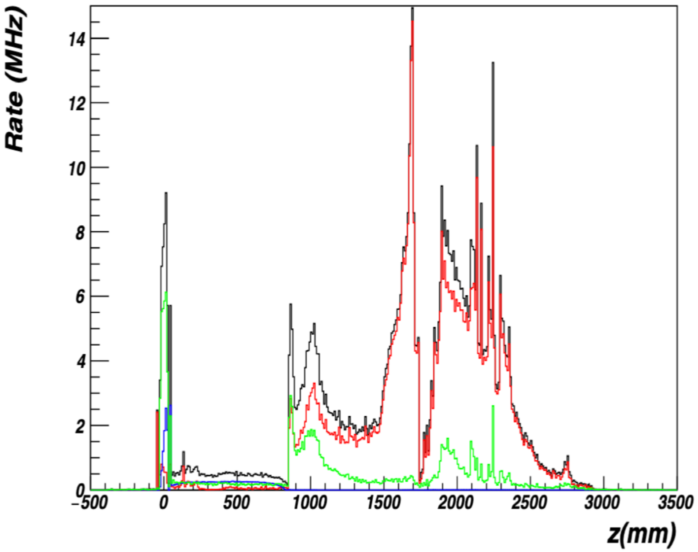
- Re-do Monte Carlo studies with different shielding geometries (incl. removing air gap)*



CLAS12-Note 2016-006



Maurizio Ungaro, Raffaella De Vita



Origin of background particles hitting DC R1

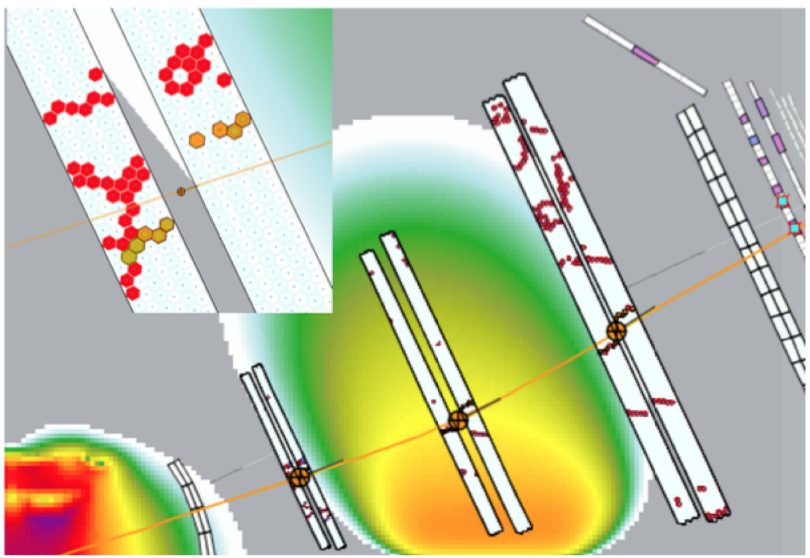
Note also that an additional 35% R.L. (~20% of luminosity contribution) comes from the 60 cm air gap downstream of the scattering chamber

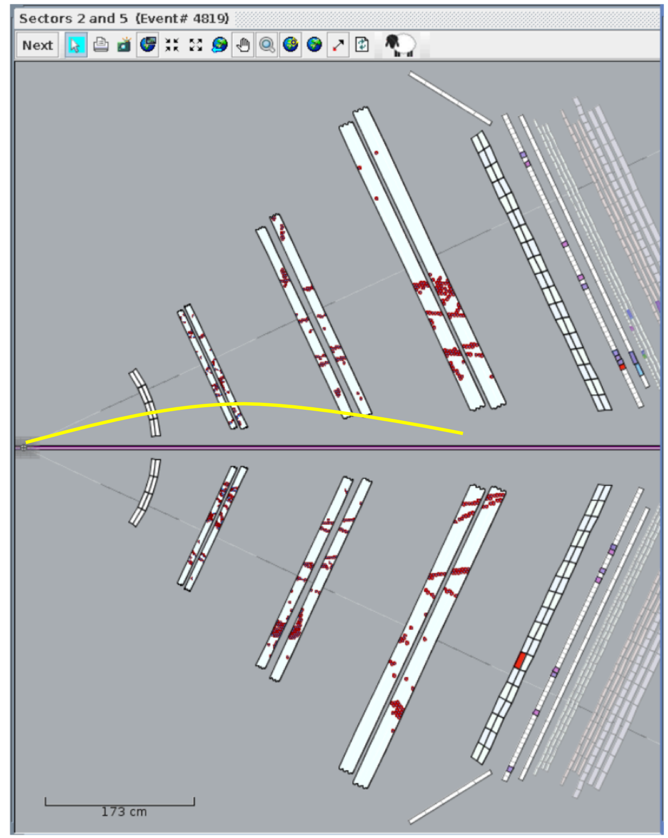
*Also part of High Luminosity Task Force

2. Improve Track Efficiency

Track-Finding Algorithms:

- Study DC segment finding pathologies and "ghost" tracks
- Develop new background rejection algorithms (for DC and FMT)
- Develop DC "4 superlayer" tracking (to improve eff and low momentum acc)

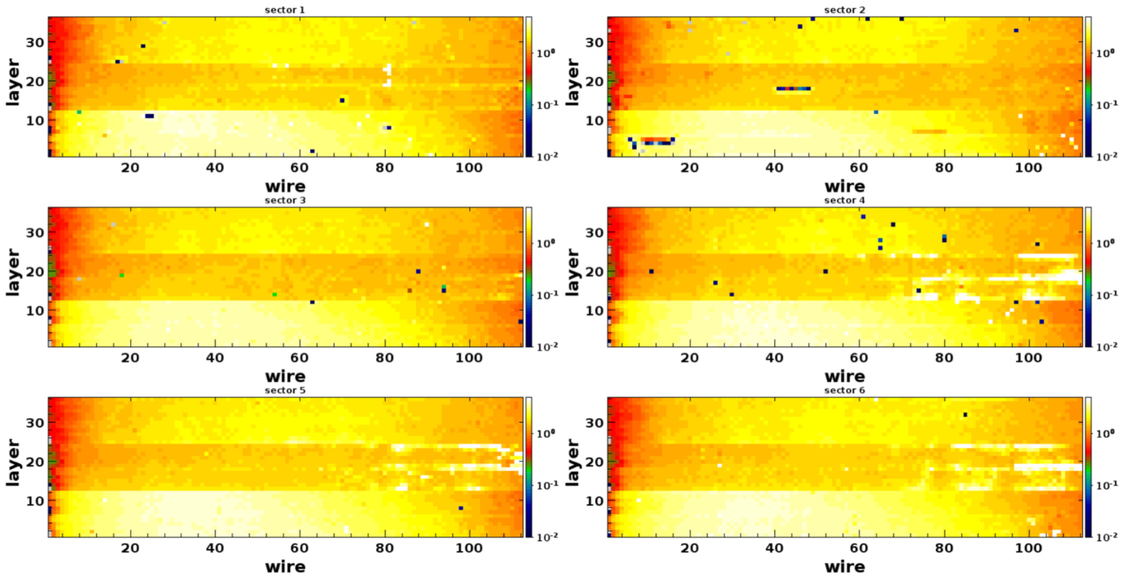




2. Improve Track Efficiency

Hardware (or Firmware) Improvements:

- Reduce coherent noise in drift chambers



- Study modifications to DC HV system to allow operations at higher voltages and currents*

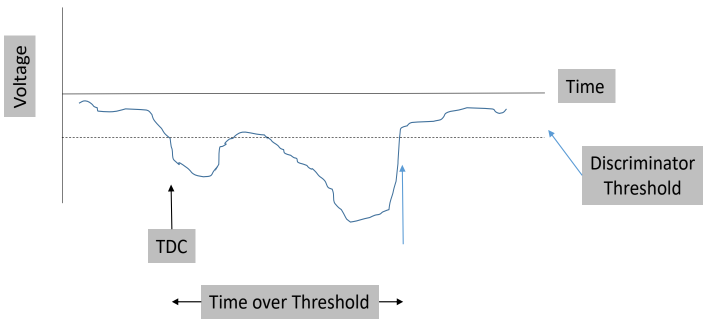
A "precision" plateau curve is needed to optimize the HV settings to maximize cell efficiencies in R1, R2, R3 – cannot presently run at higher voltages due to current limitations ⇒ finer segmentation, more HVPS

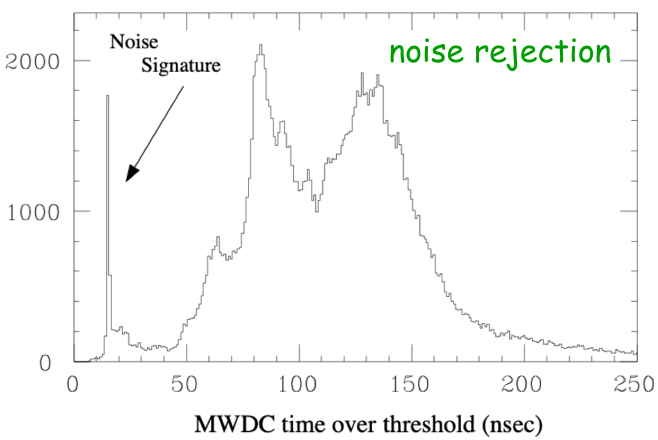
*Also part of High Luminosity Task Force

2. Improve Track Efficiency

Hardware (or Firmware) Improvements:

- Study implementation of "time-over-threshold" in DCRBs*

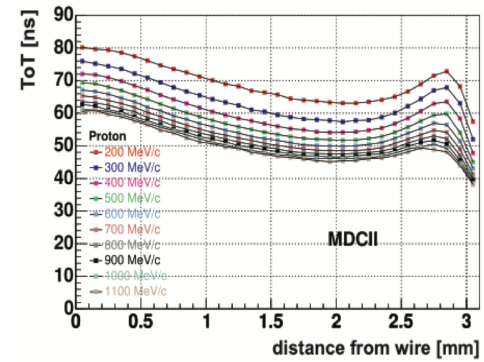


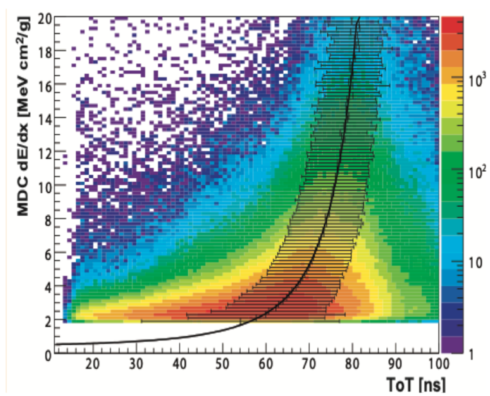


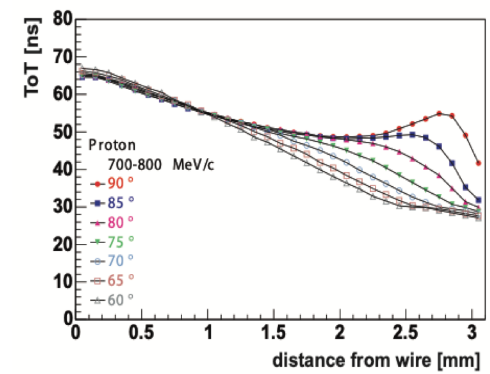
Mac Mestayer, Ben Raydo

ToT depends on:

- Track topology
  - local angle, dist from wire
- Gas mixture
- Reduced electric field (E/p)
- dE/dX of particle







Plots from HADES @ GSI

*Also part of High Luminosity Task Force

2. Improve Track Efficiency

Hardware (or Firmware) Improvements:

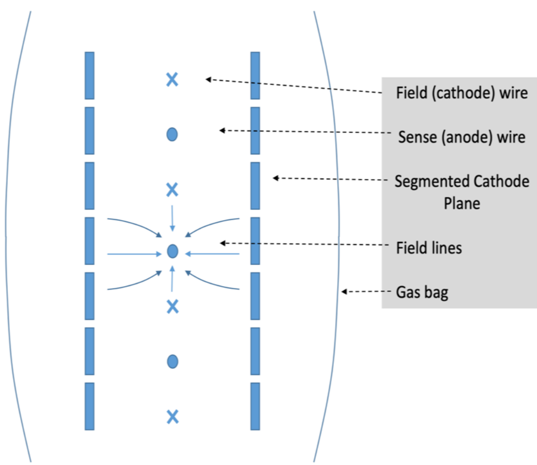
- Design “add-on” detector to augment DCs and reduce out-of-time backgrounds*
- Investigate new detectors to replace drift chambers*
- Study design, technology, and readout to allow FMT operations at higher luminosities*

Explore:

- Thin detector with small “pixel” size to reduce background – before R1

Cathode Strip Chamber

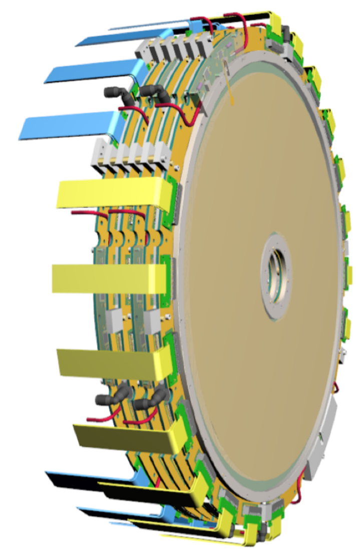
- One plane of wires (axial)
- Segmented cathode plane (oriented at +/- 6°)
  - Perforated to equalize gas pressure
- Read out
  - Sense wires → time
  - Cathode strips → position



Mac Mestayer

Explore:

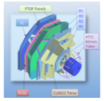
- How to operate at higher currents & rates
- Update readout electronics
- Pixel technology?

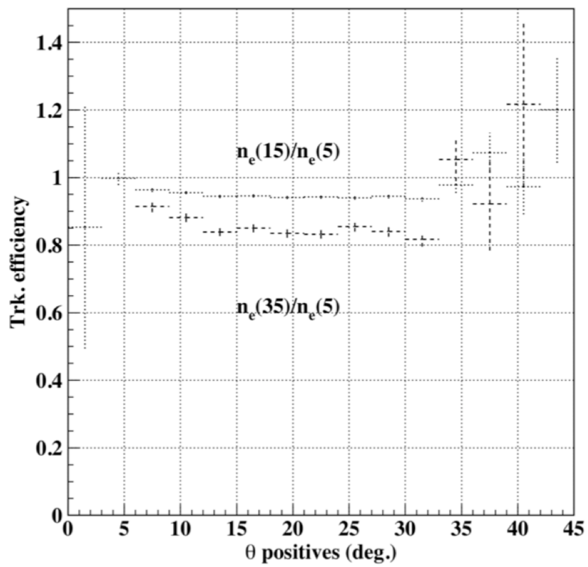


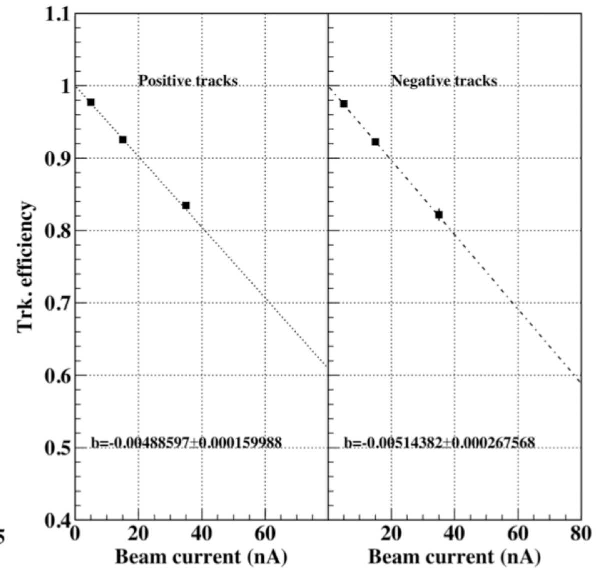
*Also part of High Luminosity Task Force

3. Improve Matching of Data and Simulation

- Study momentum and vertex resolution of data and Monte Carlo (DC+FMT)
- Adjust equipment status tables to match simulation and data "occupancies"
- Tune GEMC digitization to match data hit resolution and efficiency (DC+FMT)
- Study luminosity-dependence of tracking efficiency*







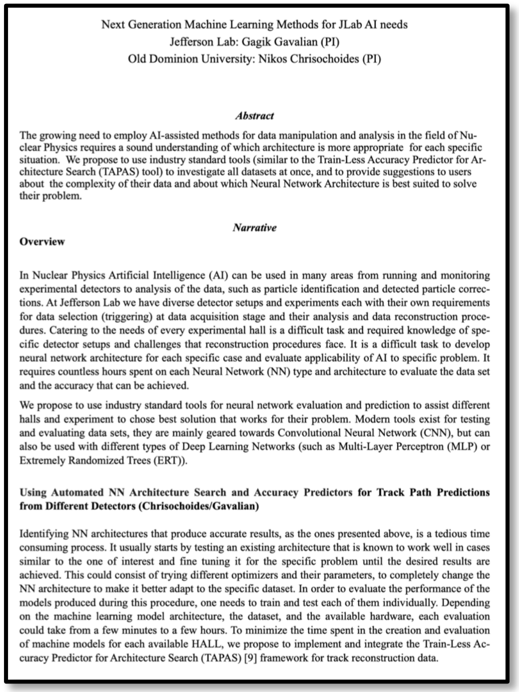
Stepan Stepanyan log entry 3654152 – 2/16/19

*Also part of Background Merging Task Force

4. Improve Speed of Reconstruction

- Develop artificial intelligence methods for tracking*
- Study feasibility and performance of streaming readout*

LDRD - Tracking



Next Generation Machine Learning Methods for JLab AI needs
Jefferson Lab: Gagik Gavalian (PI)
Old Dominion University: Nikos Chrisochoides (PI)

Abstract

The growing need to employ AI-assisted methods for data manipulation and analysis in the field of Nuclear Physics requires a sound understanding of which architecture is more appropriate for each specific situation. We propose to use industry standard tools (similar to the Train-Less Accuracy Predictor for Architecture Search (TAPAS) tool) to investigate all datasets at once, and to provide suggestions to users about the complexity of their data and about which Neural Network Architecture is best suited to solve their problem.

Narrative

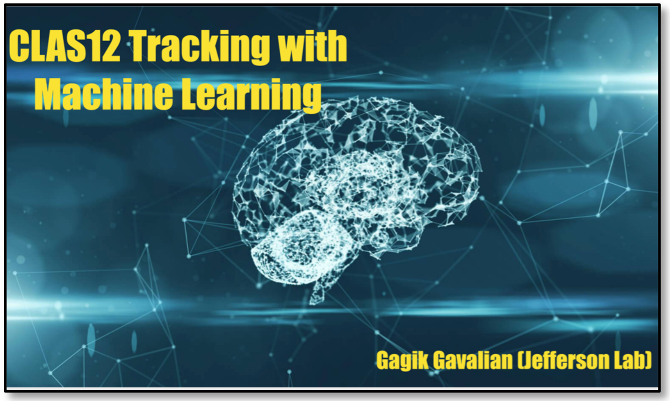
Overview

In Nuclear Physics Artificial Intelligence (AI) can be used in many areas from running and monitoring experimental detectors to analysis of the data, such as particle identification and detected particle corrections. At Jefferson Lab we have diverse detector setups and experiments each with their own requirements for data selection (triggering) at data acquisition stage and their analysis and data reconstruction procedures. Catering to the needs of every experimental hall is a difficult task and required knowledge of specific detector setups and challenges that reconstruction procedures face. It is a difficult task to develop neural network architecture for each specific case and evaluate applicability of AI to specific problem. It requires countless hours spent on each Neural Network (NN) type and architecture to evaluate the data set and the accuracy that can be achieved.

We propose to use industry standard tools for neural network evaluation and prediction to assist different halls and experiment to chose best solution that works for their problem. Modern tools exist for testing and evaluating data sets, they are mainly geared towards Convolutional Neural Network (CNN), but can also be used with different types of Deep Learning Networks (such as Multi-Layer Perceptron (MLP) or Extremely Randomized Trees (ERT)).

Using Automated NN Architecture Search and Accuracy Predictors for Track Path Predictions from Different Detectors (Chrisochoides/Gavalian)

Identifying NN architectures that produce accurate results, as the ones presented above, is a tedious time consuming process. It usually starts by testing an existing architecture that is known to work well in cases similar to the one of interest and fine tuning it for the specific problem until the desired results are achieved. This could consist of trying different optimizers and their parameters, to completely change the NN architecture to make it better adapt to the specific dataset. In order to evaluate the performance of the models produced during this procedure, one needs to train and test each of them individually. Depending on the machine learning model architecture, the dataset, and the available hardware, each evaluation could take from a few minutes to a few hours. To minimize the time spent in the creation and evaluation of machine models for each available HALL, we propose to implement and integrate the Train-Less Accuracy Predictor for Architecture Search (TAPAS) [9] framework for track reconstruction data.

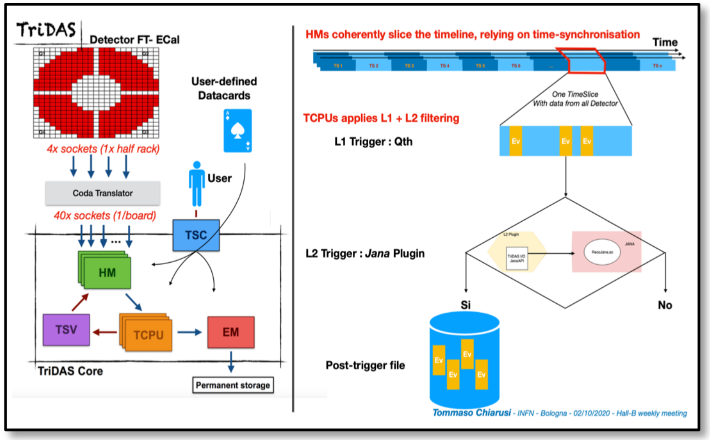


Advanced AI/machine learning techniques under development

Gagik Gavalian

Trigger-less DAQ development in progress – tested during radiation test using FT for readout

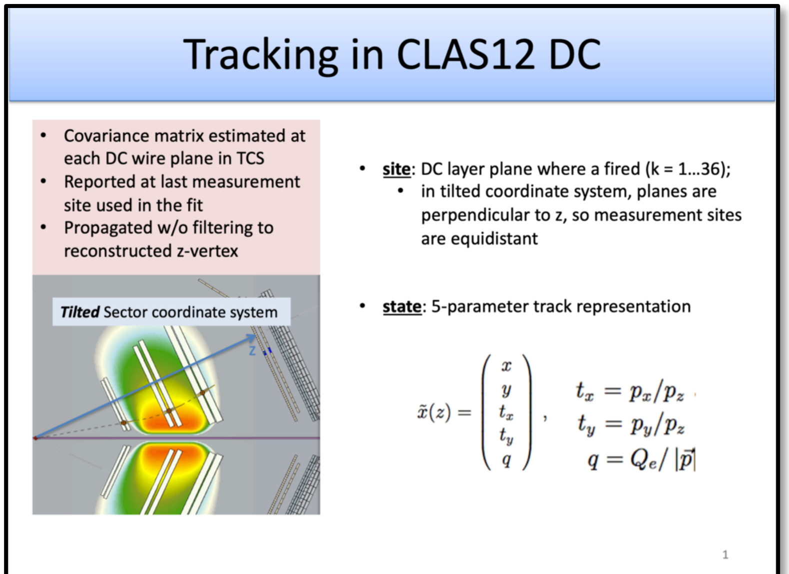
Tommaso Chiarusi (INFN)



*Also part of AI and Streaming Readout Task Forces

5. Validate Tracking Software and Implement Correction Procedures

- Implement kinematic fitting for forward tracking*
- Develop a common package for momentum corrections*
- Implement/study energy loss in tracking*
- Review current tracking algorithms and assumptions



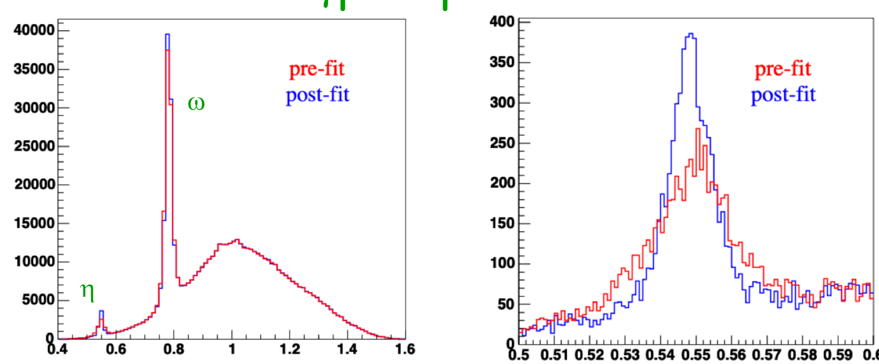
Development by Veronique Ziegler, Luca Marsicano (Genova), Mylene Caudron (Orsay)

*Also part of Software and Momentum Correction Task Forces

Work on covariance matrix

$$C_\eta = \begin{pmatrix} \sigma^2_{E_\gamma} & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & C_1^{pp} & C_1^{p\lambda} & C_1^{p\phi} & \cdots & 0 & 0 & 0 \\ 0 & C_1^{p\lambda} & C_1^{\lambda\lambda} & C_1^{\lambda\phi} & \cdots & 0 & 0 & 0 \\ 0 & C_1^{p\phi} & C_1^{\lambda\phi} & C_1^{\phi\phi} & \cdots & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \cdots & C_k^{pp} & C_k^{p\lambda} & C_k^{p\phi} \\ 0 & 0 & 0 & 0 & \cdots & C_k^{p\lambda} & C_k^{\lambda\lambda} & C_k^{\lambda\phi} \\ 0 & 0 & 0 & 0 & \cdots & C_k^{p\phi} & C_k^{\lambda\phi} & C_k^{\phi\phi} \end{pmatrix}$$

$\gamma p \rightarrow p' \pi^+ \pi^- \pi^0$



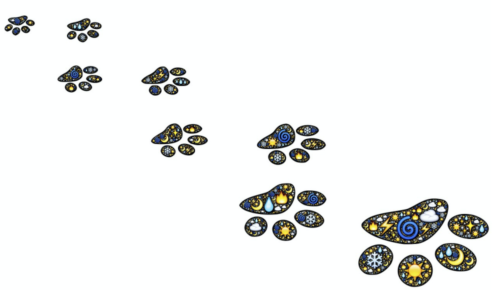
MM(p)

Mike Williams, CLAS-Note 2003-017

Summary and Conclusions

- The CLAS12 Forward Tracking Task Force was formed to make recommendations to improve forward tracking with regard to resolution, efficiency, and speed:
  - The Task Force has been working to identify the most promising areas to realize improvements in these areas for the past 2 months
  - A deliverable report to Marco Battaglieri has been drafted and is being finalized to provide reasonable estimates of manpower resources and timelines
  - The tasks are denoted as HIGH priority (CY2020), MEDIUM priority (1-2 yrs), and LOW priority (3-5 yrs)
  - We have flagged tasks that could be taken as service work tasks by Collaborators

- Items that have synergies/overlaps with other Task Forces are being noted:
  - High Luminosity Task Force
  - Artificial Intelligence Task Force
  - Software Task Force
  - Streaming Readout Task Force
  - Momentum Corrections Task Force



Backup Slides

Forward Tracking Task Force

Approach:

- In each area under our charge (*resolution, efficiency, speed*), we have considered work tasks for the forward tracking system (DC + FMT) in three different time scales:
  - Near term work (CY2020)
  - Medium term work (1-2 years)
  - Long term work (3-5 years)

  and for three different priorities:
  - HIGH priority
  - MEDIUM priority
  - LOW priority

- We are still working to:
  - Estimate resources: manpower and timelines
  - Identify synergies/overlaps with other groups
  - Ensure completeness of task list

Forward Tracking Task Force Report

Tracking Improvement Task Force Report

April 15, 2020

Members: Daniel Carman (lead); Mac Mestayer, Veronique Ziegler (core); Dave Heddle, Maxime Defurne, Maxence Vandenbroucke, Maurizio Ungaro (external)

Abstract

This document identifies areas in which the CLAS12 forward tracking can be improved in terms of tracking efficiency, momentum resolution, and execution speed, and provides estimates of the time-scale and manpower requirements of the various tasks.

Tracking Improvement Goals

We have identified five work areas to improve CLAS12 forward tracking:
- Improve track resolution (momentum and angle)
- Improve efficiency of tracking; especially at high luminosity
- Improve the matching of data and simulation with respect to efficiency and resolution
- Improve the speed of reconstruction
- Validate tracking software and procedures

We identify 29 specific studies to accomplish our six goals. We characterize each task by time priority: HIGH (CY2020), MEDIUM (1-2 yrs), LOW (3-5 yrs). *(Note: Tasks flagged with a "*" can be assigned as Service Work items for the collaboration.)*

- **Improve Track Resolution (Momentum and Angle)**

Drift Chamber Time-to-Distance Calibration

1. **Finish updating and validating the DC calibration suite**
   HIGH priority, 2 months, 0.5 FTE
2. **Finalize drift chamber calibration procedures***
   HIGH priority, 4 months, 0.2 FTE
3. **Determine metrics for necessity of partial or full recalibration***
   HIGH priority, 2 months, 0.2 FTE
4. **Study calibration stability and correlations with atmospheric pressure***
   MEDIUM priority, 4 months, 0.2 FTE

Forward Tracker Alignment and Torus Field

5. **Devise procedure to align FMT relative to DCs**
   HIGH priority, 6 months, 0.3 FTE
6. **Study effects of misalignment on momentum and angle resolution***
   MEDIUM priority, 4 months, 0.2 FTE

1

ifferent torus field maps on resolution
y, 4 months, 0.2 FTE
' torus map and if additional map development is needed
y, 4 months, 0.2 FTE

Beamline and Shielding Improvements

rlo studies with different shielding geometries (incl. removing air gap)
y, 4 months, 0.2 FTE *(incl. in High Lumi task force)*

cy of Tracking; Especially at High Luminosity

Track-Finding Algorithms

nt-finding pathologies and "ghost" tracks
y, 4 months, 0.2 FTE
ckground rejection algorithms (for DC and FMT)
y, 4 months, 0.2 FTE
uperlayer" tracking (to improve eff and low momentum acceptance)
months, 0.1 FTE

Hardware (or Firmware) Improvements

t noise in drift chambers
y, 2 months, 0.2 FTE
ons to DC HV system to allow operations at higher voltages/currents
y, 6 months, 0.2 FTE
ce of track resolution and efficiency on HV
y, 4 months, 0.2 FTE
tation of "time-over-threshold" in DCRBs
y, 4 months, 0.2 FTE *(incl. in High Lumi task force)*
detector to augment DCs and reduce out-of-time backgrounds
months, 0.2 FTE *(incl. in High Lumi task force)*
detectors to replace drift chambers
months, 0.2 FTE *(incl. in High Lumi task force)*
chnology, and readout to allow FMT operations at higher-luminosities
months, 0.2 FTE

ng of Data and Simulation for Efficiency & Resolution

m and vertex resolution of data and Monte Carlo (DC+FMT)*
y, 2 months, 0.2 FTE
nt status tables to match simulation and data "occupancies"*
y, 4 months, 0.2 FTE
ization to match data hit resolution and efficiency (DC+FMT)*
y, 4 months, 0.2 FTE

2

ity-dependence of tracking efficiency
rity, 4 months, 0.2 FTE

peed of Reconstruction

cial intelligence methods for tracking
rity, 12 months, 0.4 FTE *(incl. in AI task force)*
ty and performance of streaming readout
rity, 24 months, 0.1 FTE *(incl. in Streaming task force)*

mprove Tracking Software and Procedures

nematic fitting for forward tracking
rity, 6 months, 0.2 FTE *(incl. in Software task force)*
nmon package for momentum corrections
rity, 8 months, 0.2 FTE
udy energy loss in tracking
rity, 4 months, 0.1 FTE
t tracking algorithm and assumptions
rity, 3 months, 0.5 FTE

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DC Alignment

Minimization criterion:

$$\chi^2 = \sum_{\theta=1}^{4} \sum_{\ell=1}^{36} \frac{\mu(\Delta_{xi}, \Delta_{yi}, \Delta_{zi}, \Delta_{cyi})^2}{w_{\theta\ell}^2} + \sum_{\theta=1}^{4} \frac{\left[v_{x0}(\Delta_{xi}, \Delta_{yi}, \Delta_{zi}, \Delta_{cyi}) - v_{x0\,survey}\right]^2}{w_{\theta}^2}$$

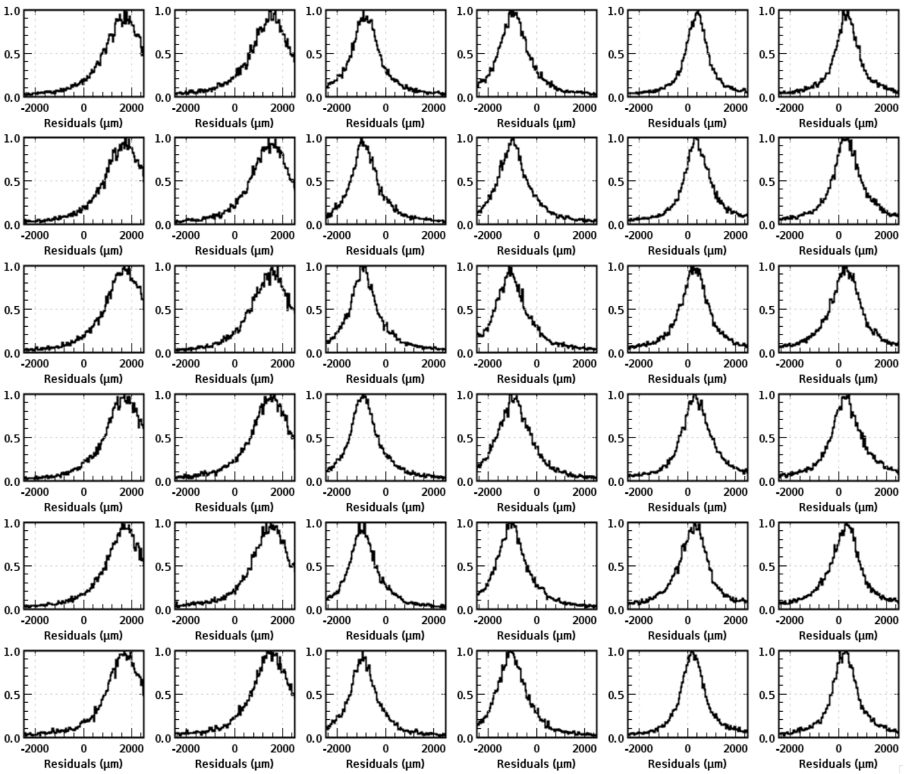
- $\mu(\Delta_{xi}, \Delta_{yi}, \Delta_{zi}, \Delta_{cyi})$ = mean of the fit residual distribution reconstructed with shifts in x, y, z and rotations around y
- $w_{\theta\ell}$ = weights of each region
- $v_{x0}(\Delta_{xi}, \Delta_{yi}, \Delta_{zi}, \Delta_{cyi})$ = z-position of downstream target wall reconstructed with shifts in x, y, z and rotations around y
- $v_{x0\,survey}$ = z position of downstream target wall as given by survey

Alignment procedure uses zero-field runs with the target window location as a constraint

DC Alignment

Before Alignment

SL 1 SL 2 SL 3 SL 4 SL 5 SL 6



After Alignment

SL 1 SL 2 SL 3 SL 4 SL 5 SL 6