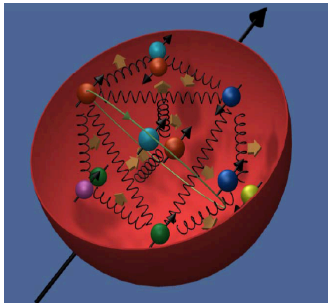
# GenFit2 for SpinQuest Tracking

**Abinash Pun**
(For SpinQuest Collaboration)
**New Mexico State University**

August 25, 2020

Fermilab New Perspectives 2.0, Batavia, IL

# Proton and its Spin

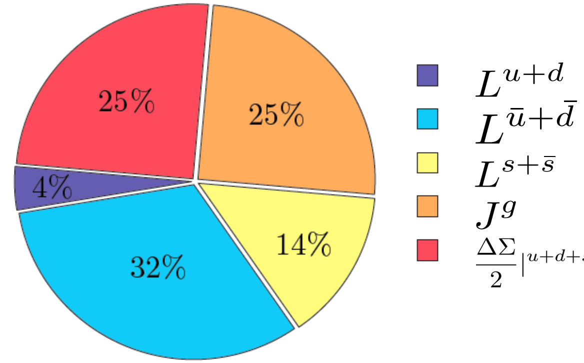


$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + J^g + L$

Contribution of spins of quarks and antiquarks

Gluon contribution

Angular Momentum of valence and sea quarks




Lattice QCD: K.-F. Liu *et al* arXiv:1203.6388

$\Delta\Sigma_q \approx 25\%$ $L_u \approx -L_d$

$2\ L_q \approx 46\%$ (0%(valence)+46%(sea))

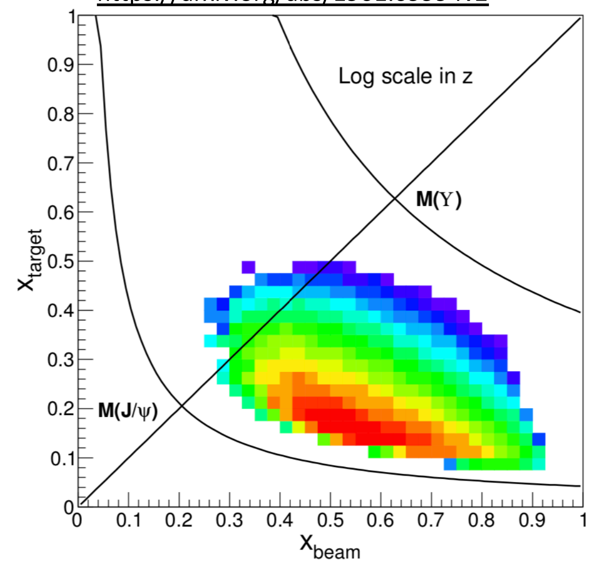
$2\ J_g \approx 25\%$

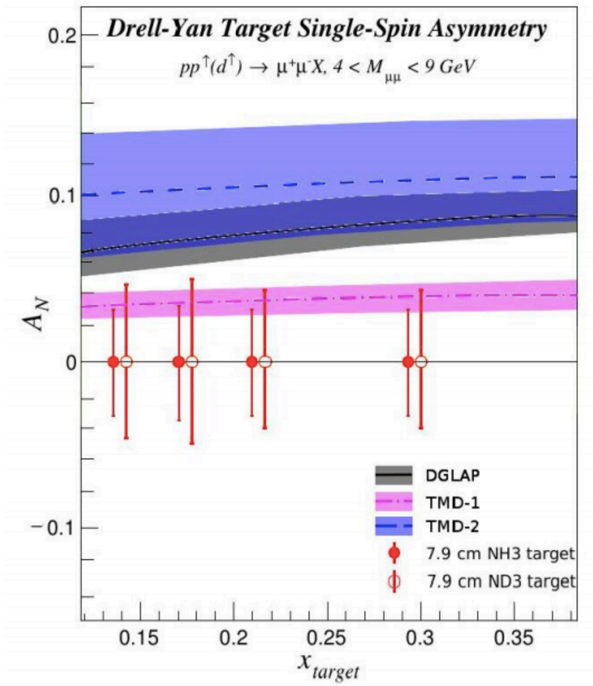
- **Spin puzzle**: constituent quarks' and antiquarks' spins don't add up to spin of proton (1/2)
- **Lattice calculation**: contribution of orbital angular momentum
  - ➢ Transverse motion study for the understanding of nucleon spin
- **Meson cloud model:** angular momentum of quarks and the flavor asymmetry in the sea quarks
  - ➢ sea quarks' contribution in proton spin
- **Sivers function**: correlation between nucleon spin and transverse momentum of parton
  - Nonzero Sivers asymmetry shows the non-zero orbital angular momentum

# SpinQuest at Fermilab

- E1039 experiment to measure azimuthal asymmetry in dimuons from Drell-Yan and extract the magnitude and sign of Sivers function of sea quarks ($\bar{u}$ and $\bar{d}$)
- Beam: Unpolarized 120 GeV proton beam from the Fermilab main Injector
- Target: Transversely polarized **$NH_3$** or **$ND_3$**
- Beam commissioning: **Spring 2021**
- Expected to run for two years of beam time

https://arxiv.org/abs/1901.09994v2



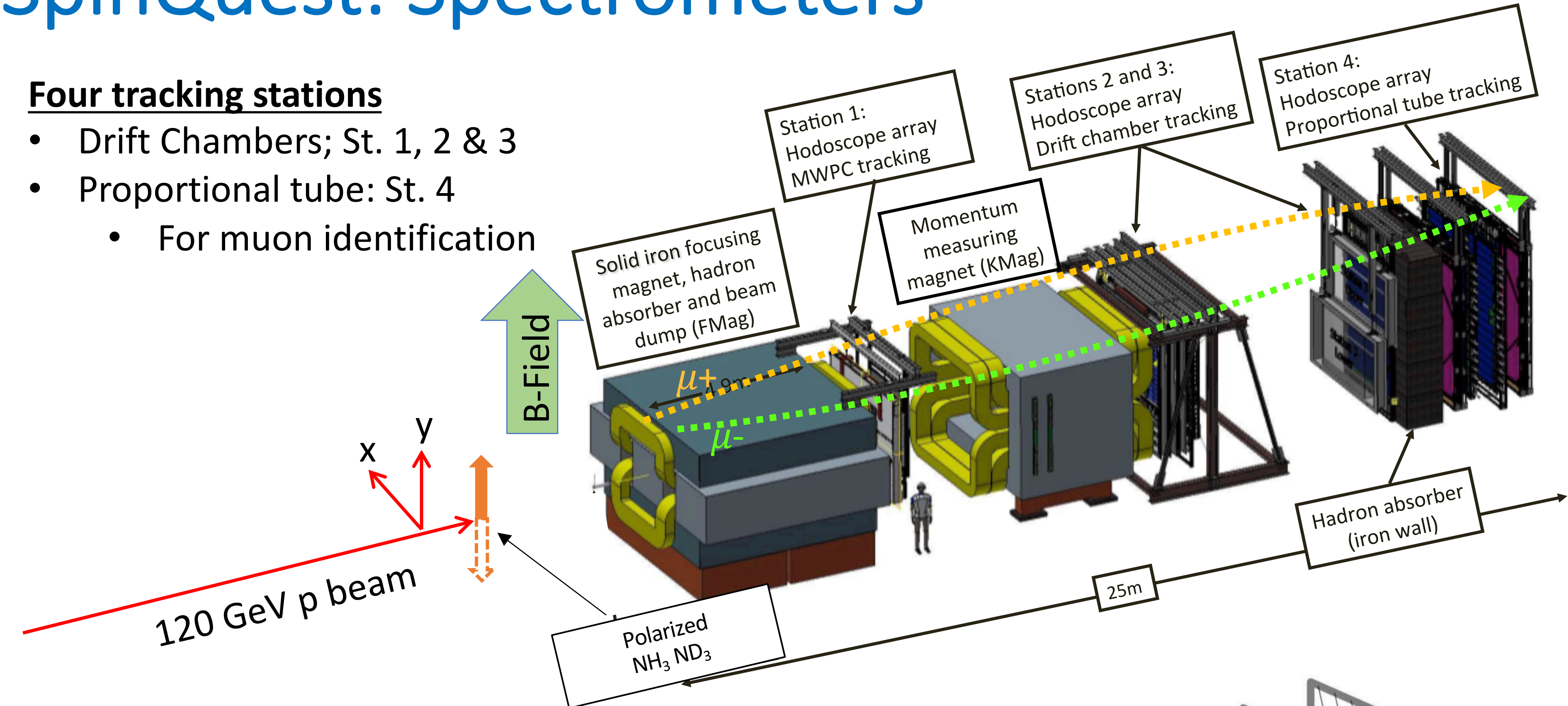

DGLAP: M. Anselmino et al arXiv:1612.06413
TMD-1: M. G. Echevarria et al arXiv:1401.5078
TMD-2: P. Sun and F. Yuan arXiv:1308.5003

# SpinQuest: Spectrometers

C.A. Aidala et al., Nu In, volume **930**, 49 (2019 )

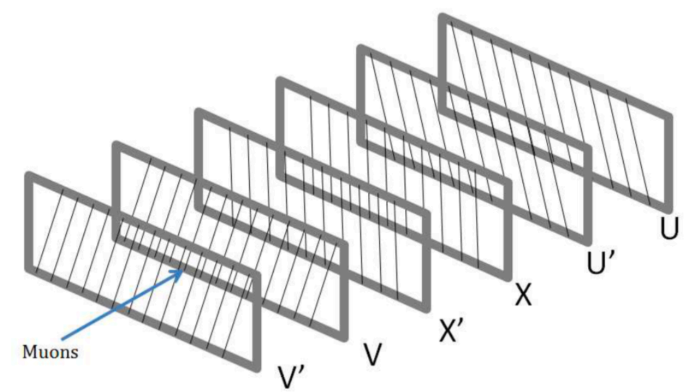
**Four tracking stations**

- Drift Chambers; St. 1, 2 & 3
- Proportional tube: St. 4
  - For muon identification




**Drift Chambers**

- x-, y- positions of muon track
- Principle: Ionization Chamber
- 6 planes of wires in each station




Rough structure of Drift Chamber

# Simulation/Data Flow

**Simulation**

- MC generators
- Geant4Simulation
  - Detector Geometry
  - Hit extraction
- Digitization
  - Efficiency and resolution

**Data**

- Tracking and Reconstruction
  - Track Building
  - **Track Fit** (from st.3 to st. 1): **Discussed in this talk**
  - Vertex Fit (from st.1 to interaction region)
- Analysis

# GenFit: Introduction

- Experiment-independent track fitting toolkit which uses ROOT data analysis framework
- Originally developed in the framework of PANDAROOT at TU München and major update “**GENFIT2**” based on Belle II study
- Reads ROOT geometry (TGeo) and magnetic field map
- Interface to Rave, **GFRave**, a general-purpose vertex fit package and  to alignment-code **MILLIPEDE II**
- Tested at several experiments (PANDA, Belle II, SHiP, AFIS, etc..)

# GenFit2: Modular Design

Combines **hit geometries**, **track representation** and **fitting algorithms** into a modular framework

**Measurements**

- measured coordinates (corresponding covariance) from a detector
- provide (virtual) detector plane for non-planer measurements (space-point, wires)

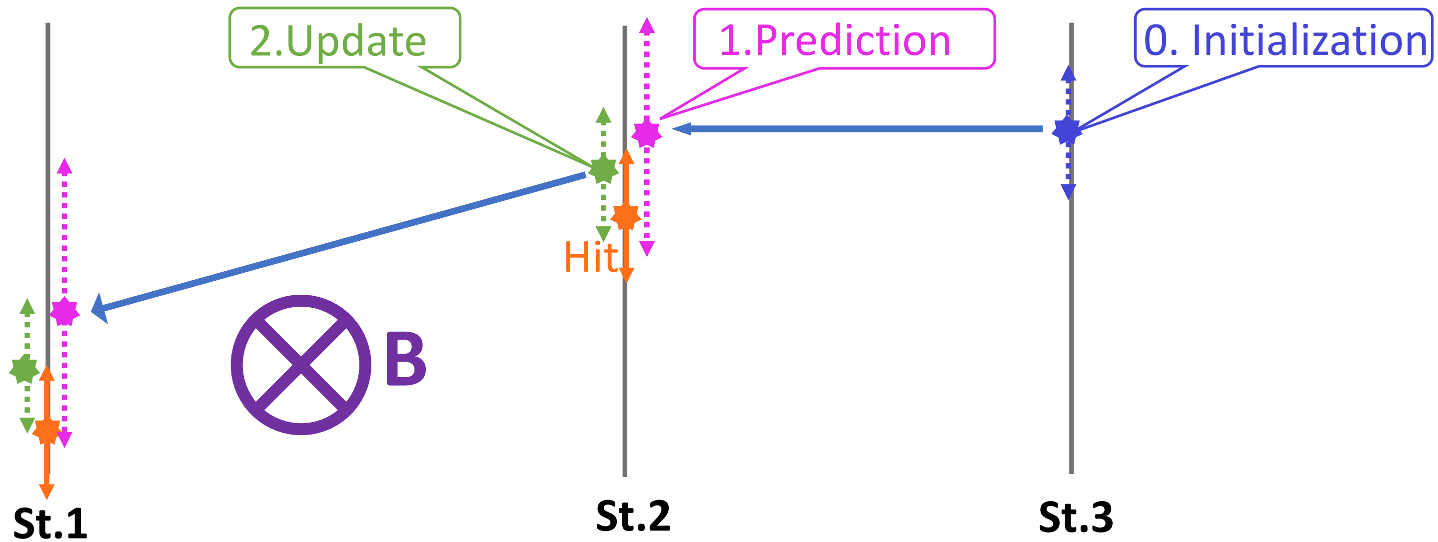
**Track representations ("TrackReps")**

- Track-parameterization and track-extrapolation
- Extrapolations (Runge-Kutta) of track parameters considering the effects of material and magnetic field
- Particle hypothesis

**Track fitting algorithms**

- Take reconstructed hits and uses the track representation to propagate between hits and fit the track

# Kalman Filter Algorithm




**0.Initial Estimation:**

- State Vector with 5 parameters ($q/p$, $t_x$,$t_y$, $x_0$,$y_0$) and corresponding covariance matrix

**1. Prediction Step:**

- extrapolate the state vector (error matrix) to next layer considering multiple scattering and energy loss

**2. Filter (Update) Step:**

- Combine the extrapolated state vector (error matrix) and the measured hit positions (uncertainty) by taking weighted mean

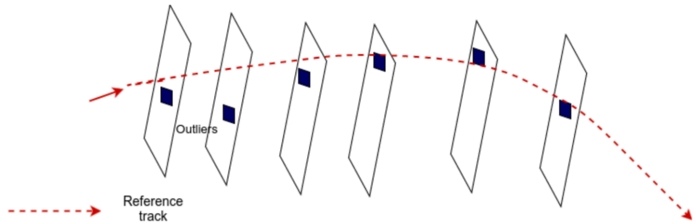
# GenFit: Track Fitting algorithms

## Kalman filters (KF)

- Linearization around the prediction state

## Kalman filter with reference track (KFREF)

- Linearize around reference track instead of state predictions.
- Reference track: estimated track parameters from pattern recognition or previous fit or calculated by extrapolating the start parameters




## Deterministic annealing filter (DAF)

- powerful tool for the rejection of outlying measurements
- weighting procedure between iterations based on the measurement residuals to determine the proper weights
- Can be useful to resolve left-right ambiguities of wire measurement

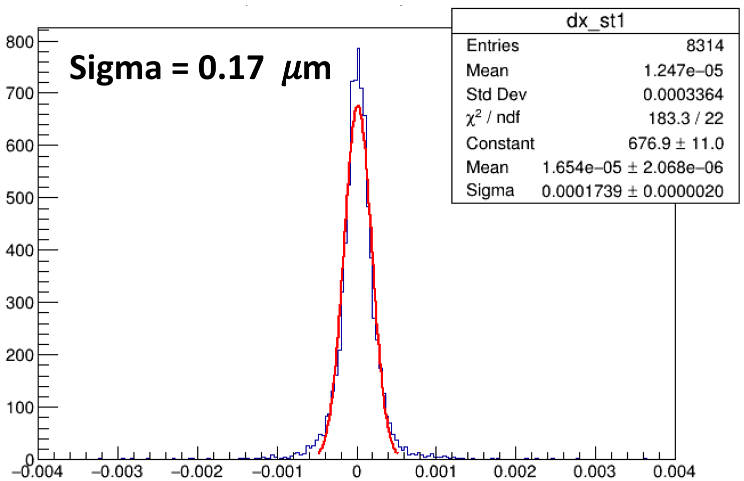
## DAF with reference track (DAFREF)

- DAF with reference track

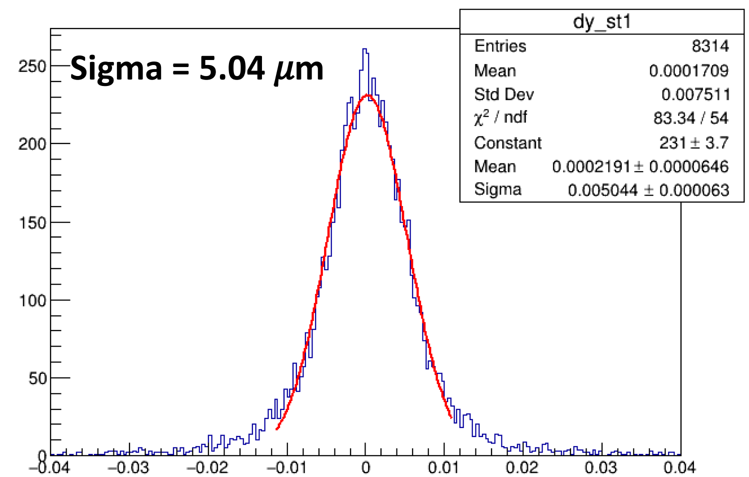
# Residual Examples (Track Parameters at station 1)

**KFREF with single muons**

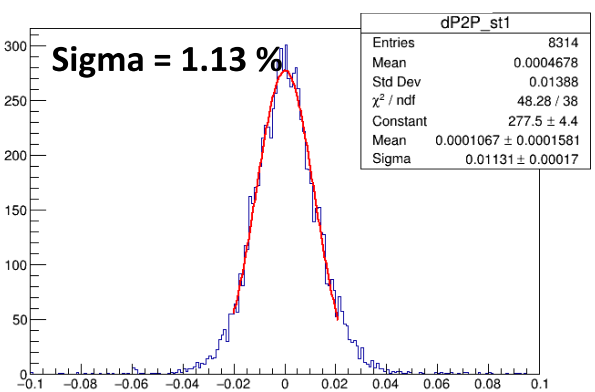
(No detector resolution and efficiency)



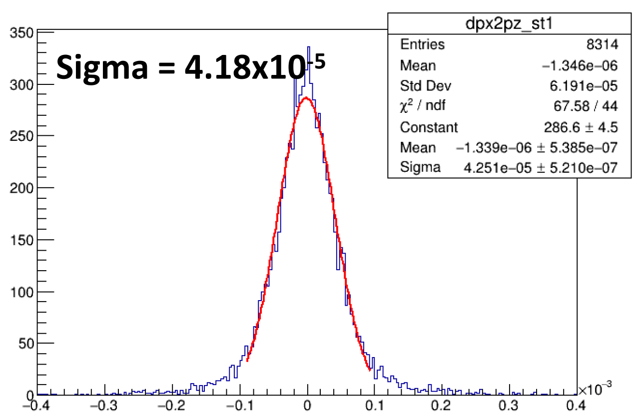

$X^{reco} - X^{truth}$ [cm]



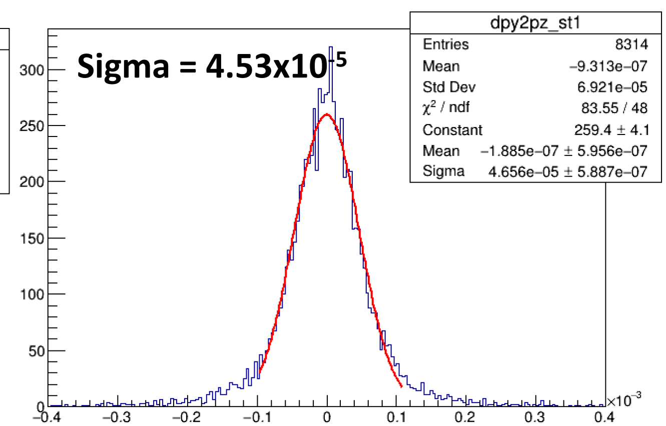

$Y^{reco} - Y^{truth}$ [cm]




$(p^{reco} - p^{truth})/p^{truth}$




Δ(slope in X-Z plane)




Δ(slope in Y-Z plane)

# Preliminary Look (No detector resolution and efficiencies)

## Residuals at st.1

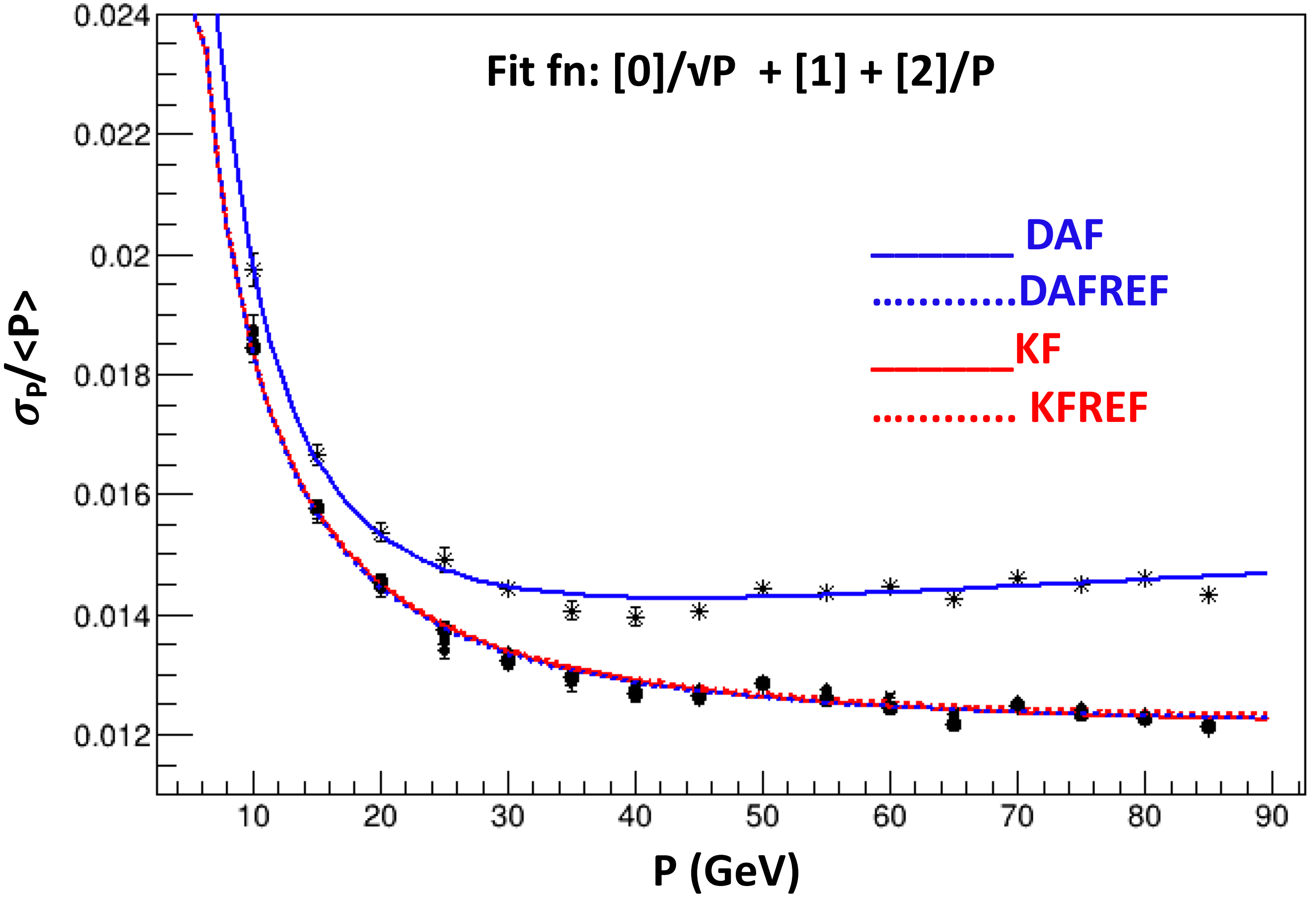
| | DAF | KF | KFREF | DAFREF |
|---|---|---|---|---|
| **X, $\mu$m** | 2.56 | 0.17 | 0.17 | 0.38 |
| **Y, $\mu$m** | 14.58 | 4.98 | 5.04 | 6.65 |
| **tx, $10^{-5}$** | 5.11 | 4.18 | 4.25 | 4.18 |
| **ty, $10^{-5}$** | 4.75 | 4.53 | 4.65 | 4.53 |
| **P, %** | 1.34 | 1.13 | 1.13 | 1.14 |

## Speed and Iterations

| | DAF | KF | KFREF | DAFREF |
|---|---|---|---|---|
| **Average iterations per track** | 7.074 | 2.058 | 2.022 | 6.990 |

# Preliminary Look (No Detector Resolution and efficiencies)

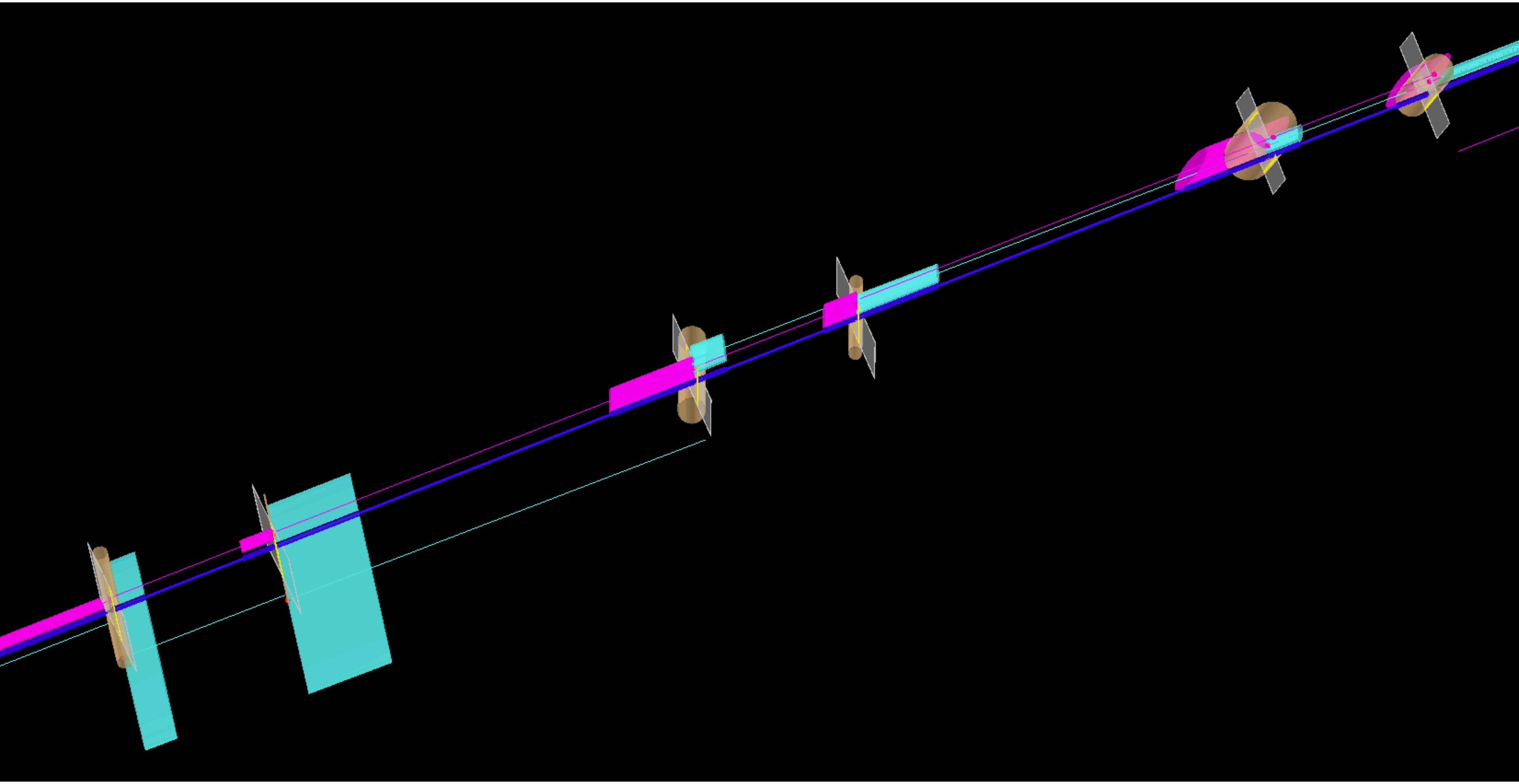
## Kinematic dependence (at st.1)



# Summary and Outlook

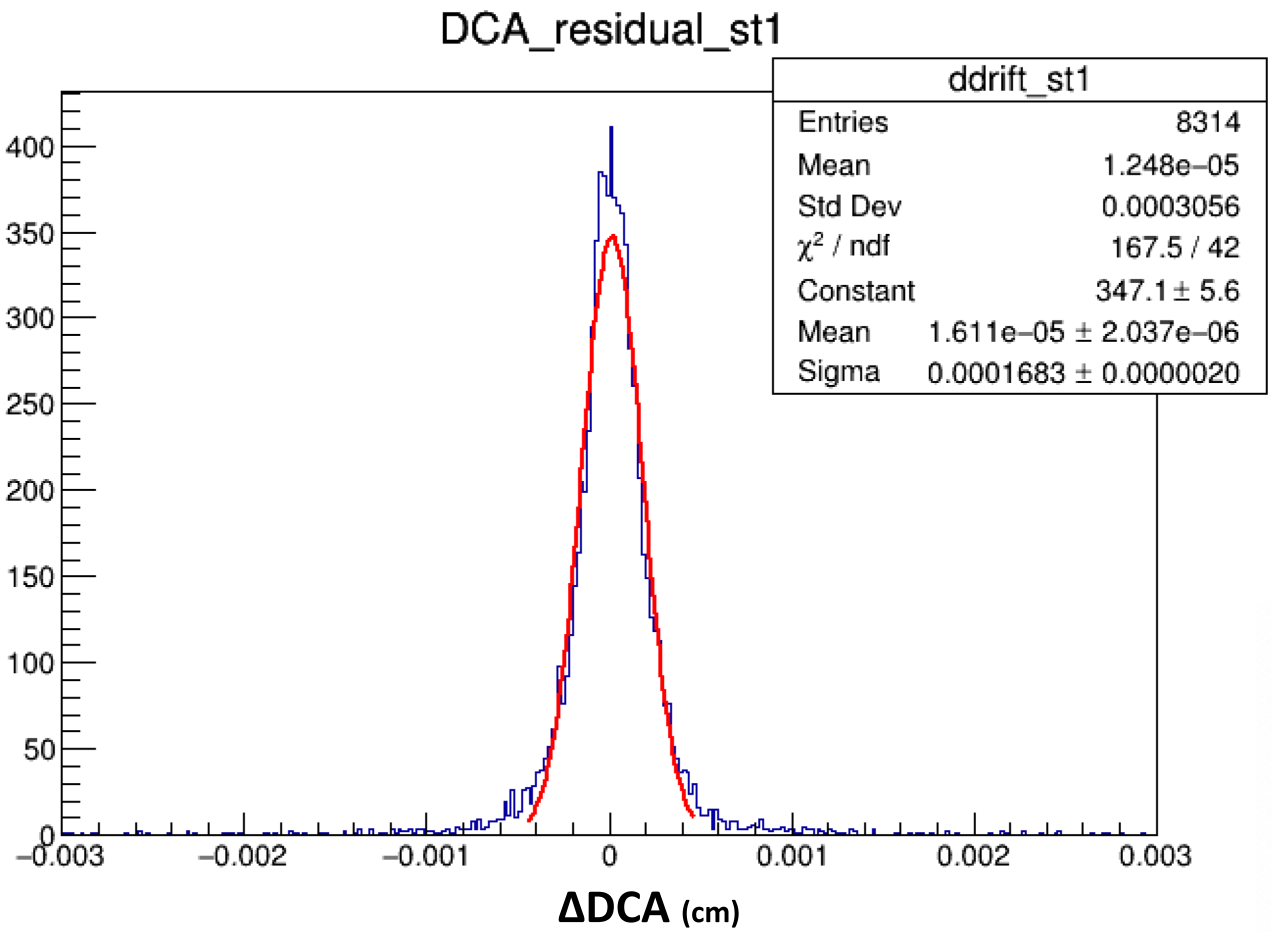
- Integrated GenFit in our software framework and tested four different fitter options
- In current scenario (no efficiency/resolution) KF, KFREF, DAFREF have almost similar performance in residuals and KFREF & KF show better performance in terms of no. of iterations
- **Work in progress**
  - Implement the finite resolutions, efficiency and background mixing
  - Analyze pull distribution
  - Integrate GFRave for vertex fitting
- Collaboration goal to reconstruct the 4 sec spill in our counting house

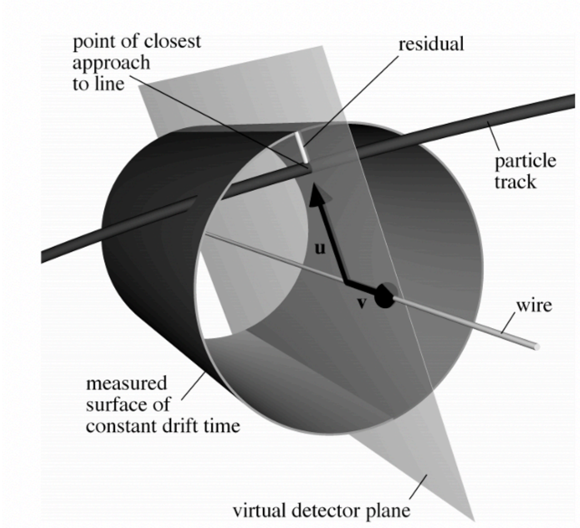
# THANK YOU

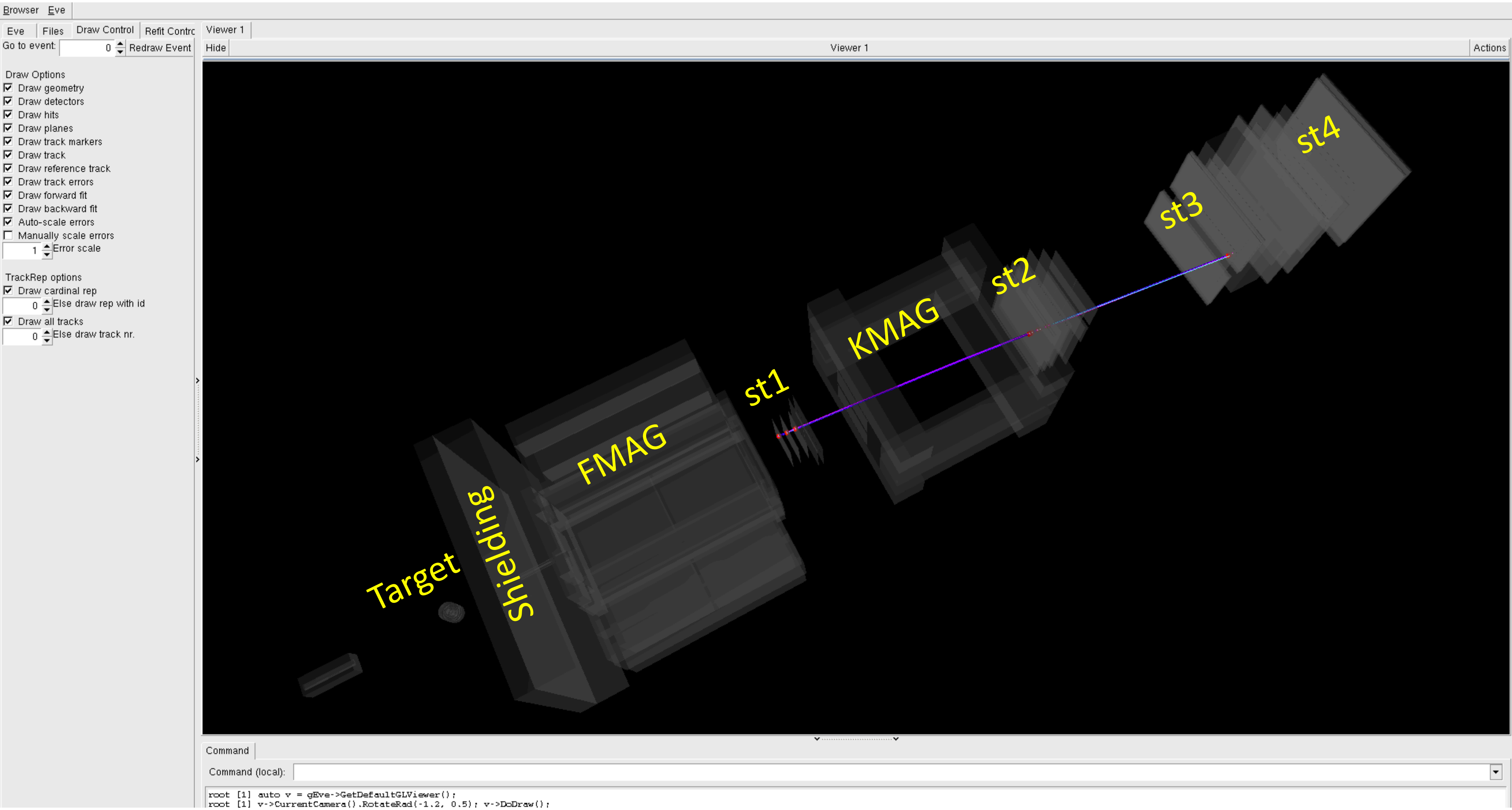


**St.2: Drift Surface, Detector Plane, Reference Track, Forward Fit, Backward Fit, Final Fit**

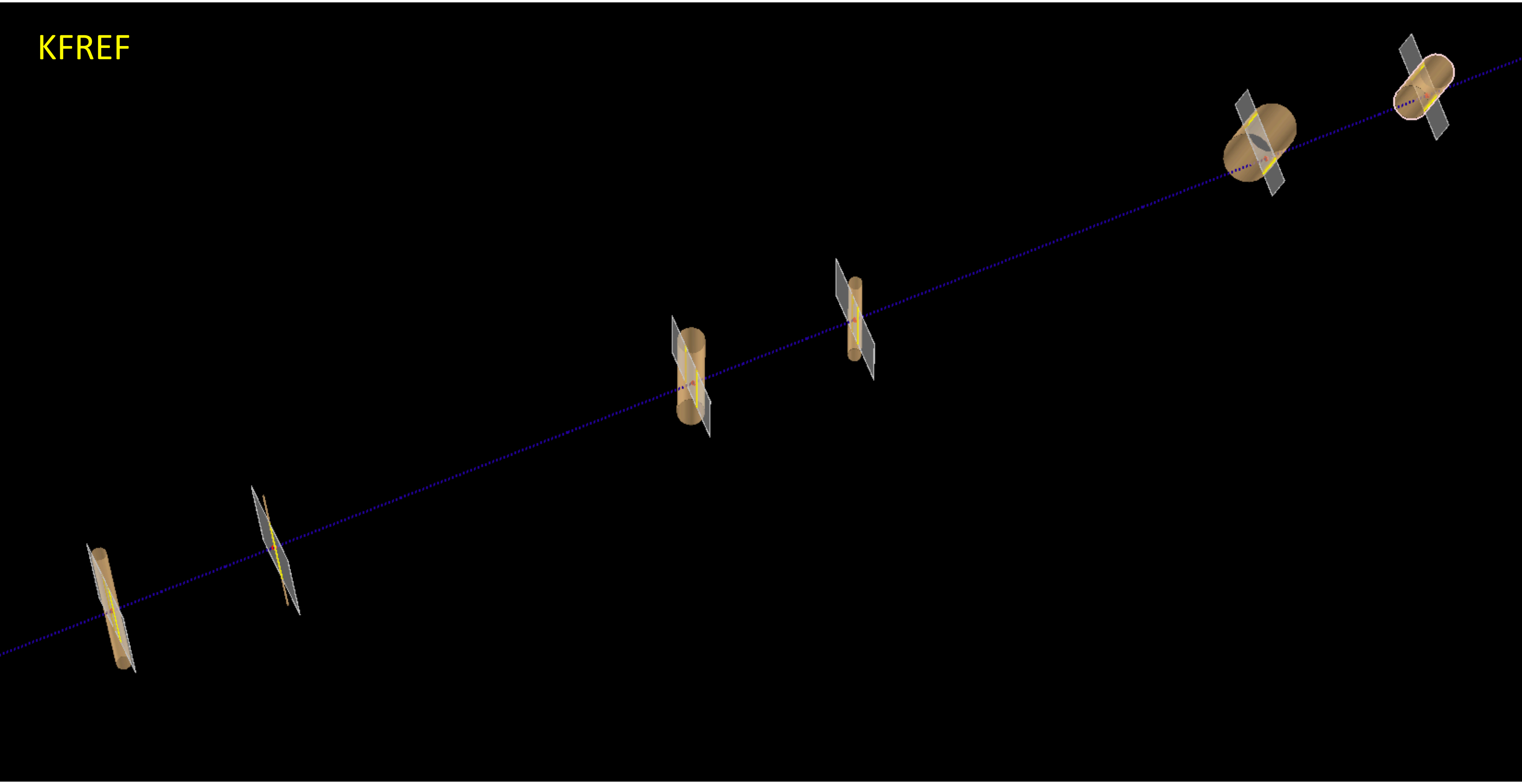
# DCA Residual (KFREF)



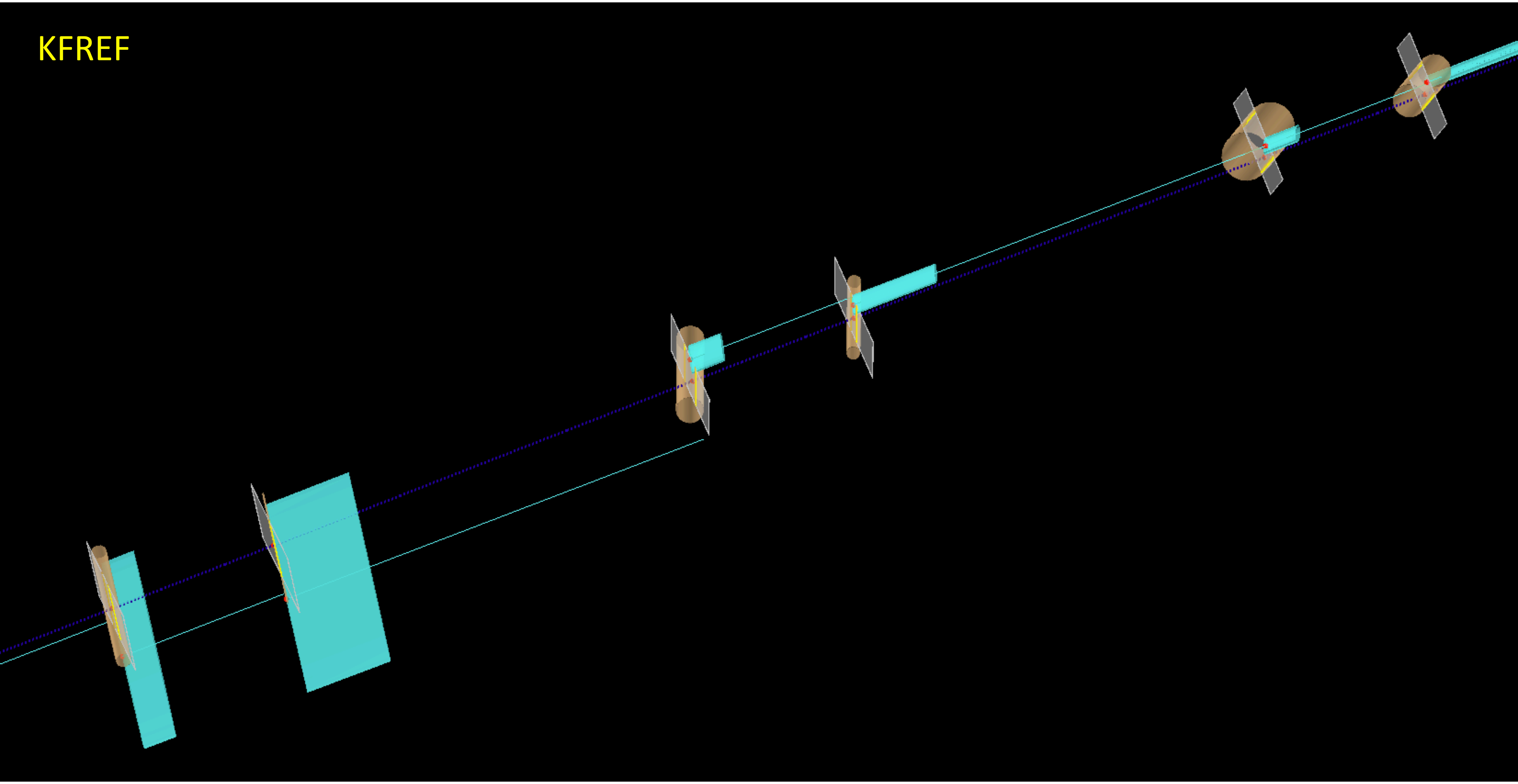




Browser Eve
Eve
Files
Draw Control
Refit Contro
Go to event: 0
Redraw Event
Draw Options
Draw geometry
Draw detectors
Draw hits
Draw planes
Draw track markers
Draw track
Draw reference track
Draw track errors
Draw forward fit
Draw backward fit
Auto-scale errors
Manually scale errors
1 Error scale
TrackRep options
Draw cardinal rep
0 Else draw rep with id
Draw all tracks
0 Else draw track nr.
Viewer 1
Hide
Viewer 1
Actions
Target
Shielding
FMAG
st1
KMAG
st2
st3
st4
Command
Command (local):
root [1] auto v = gEve->GetDefaultGLViewer();
root [1] v->CurrentCamera().RotateRad(-1.2, 0.5); v->DoDraw();

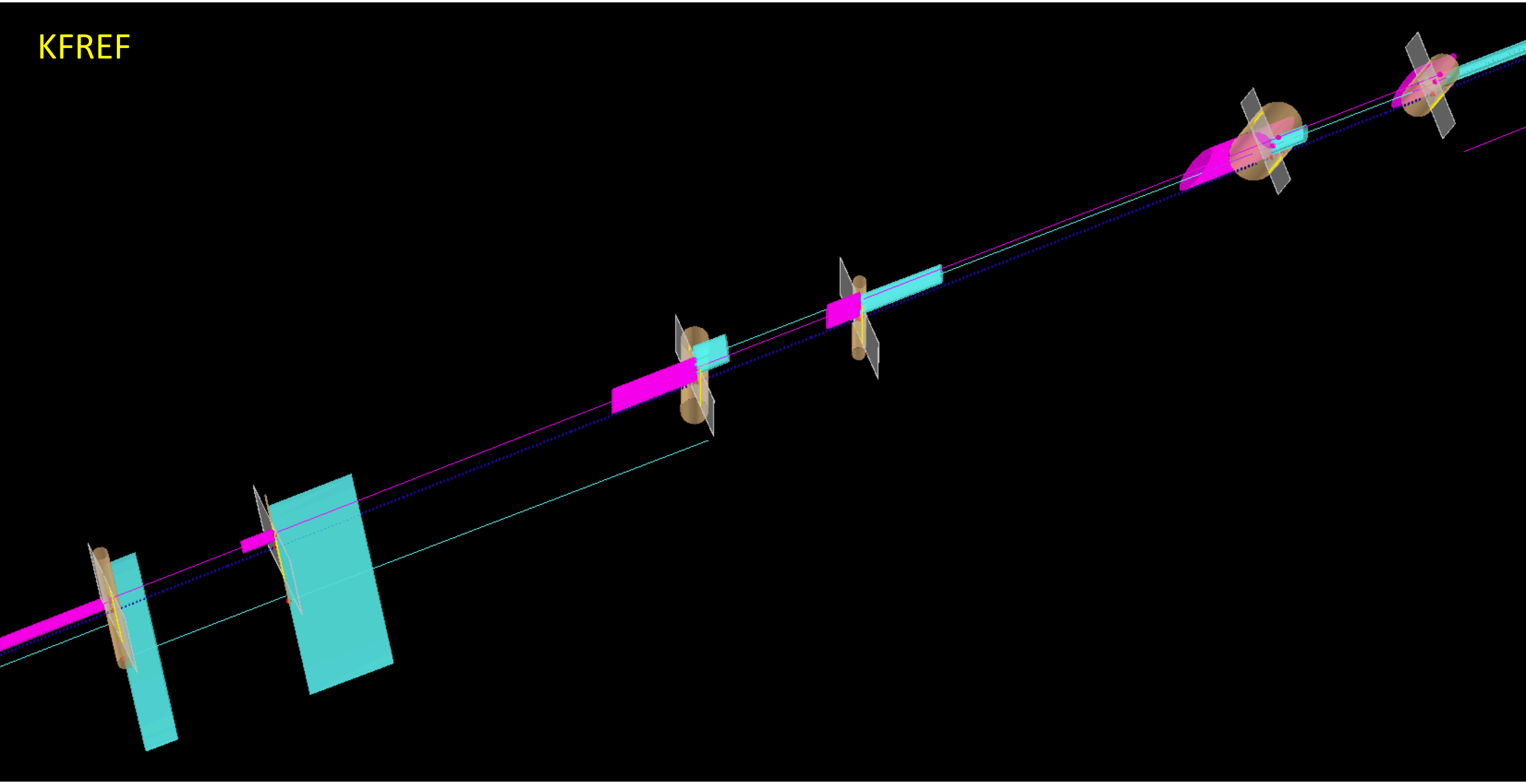
## St.2: Drift Surface, Detector Plane, Reference Track



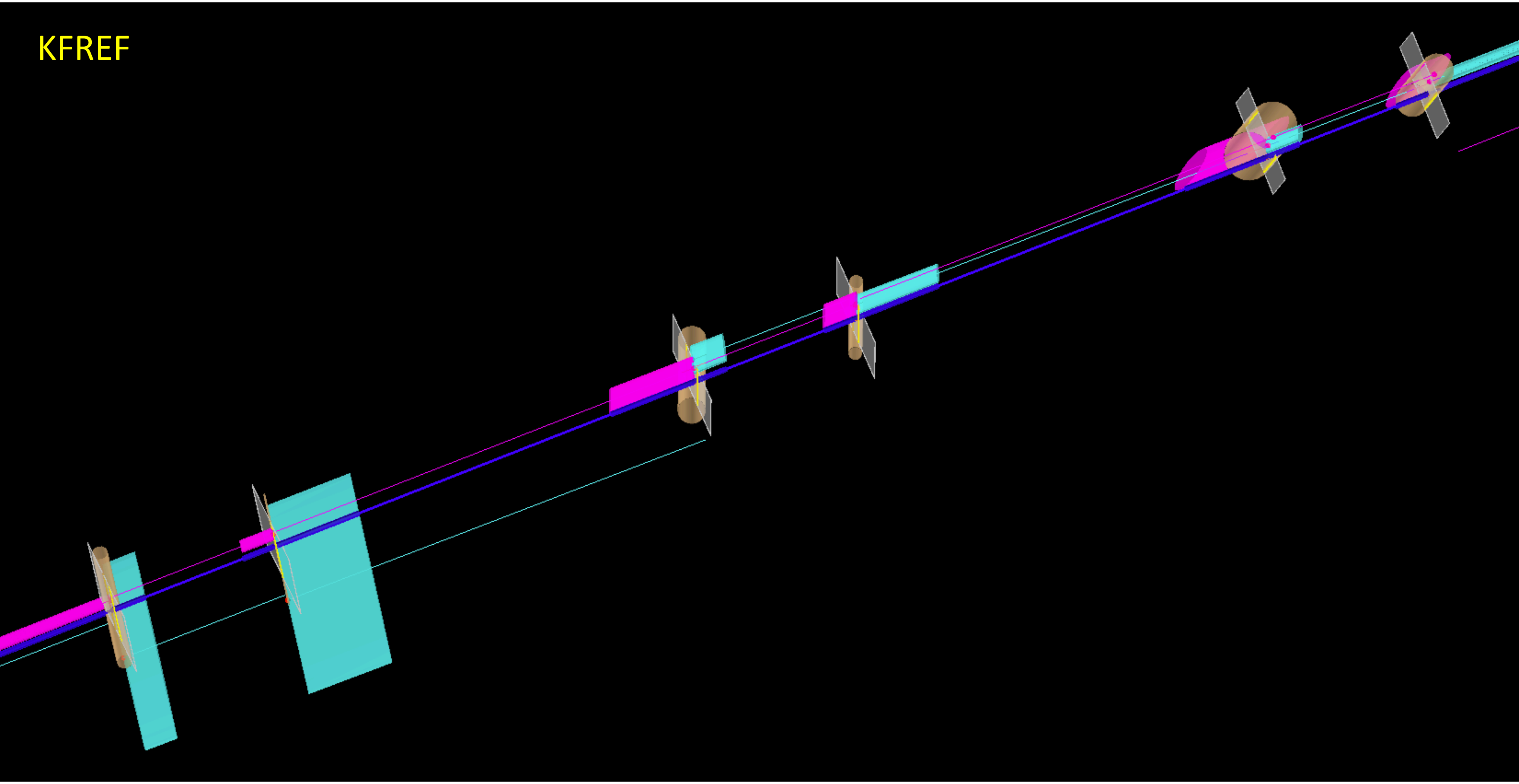
## St.2: Drift Surface, Detector Plane, Reference Track, Forward Fit



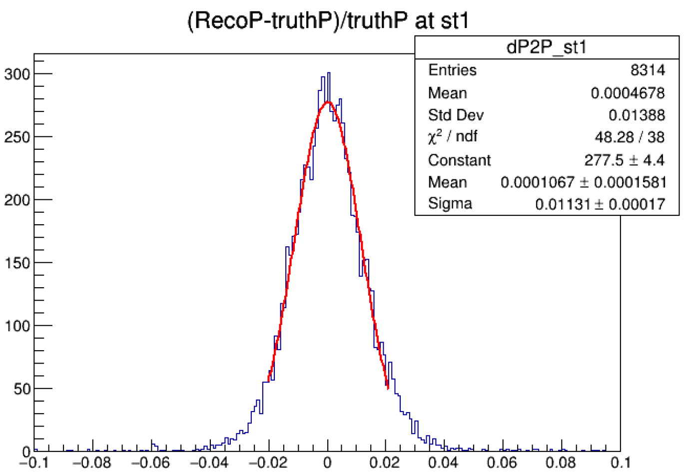
## St.2: Drift Surface, Detector Plane, Reference Track, Forward Fit, Backward Fit

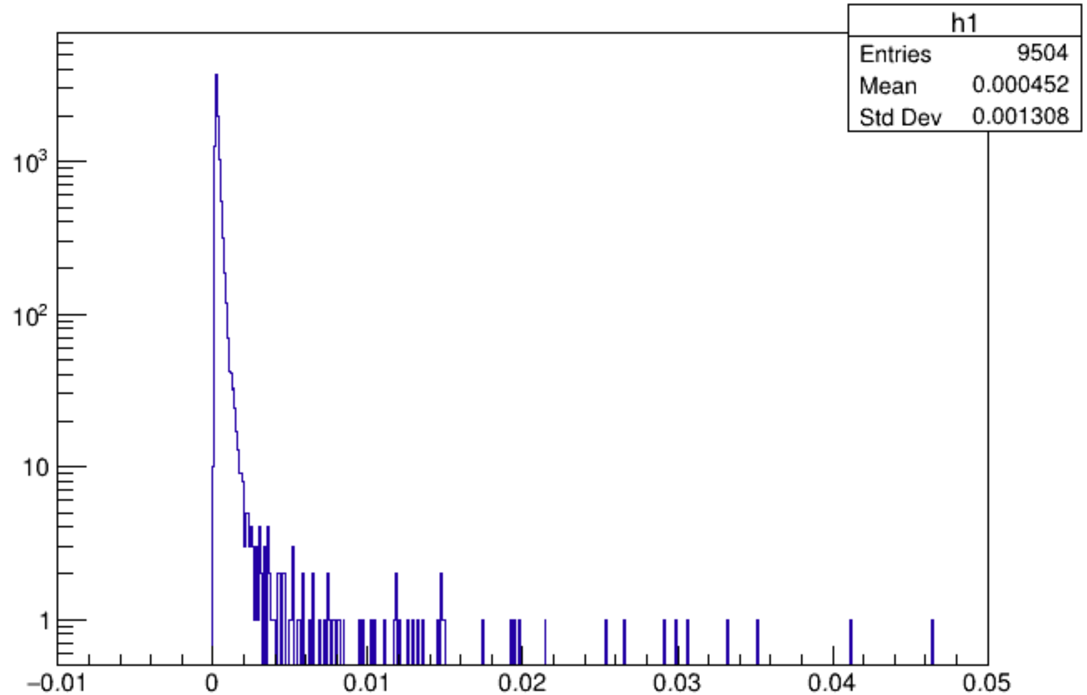


## St.2: Drift Surface, Detector Plane, Reference Track, Forward Fit, Backward Fit, Final Fit



# Truth momentum: St.1 and St.3



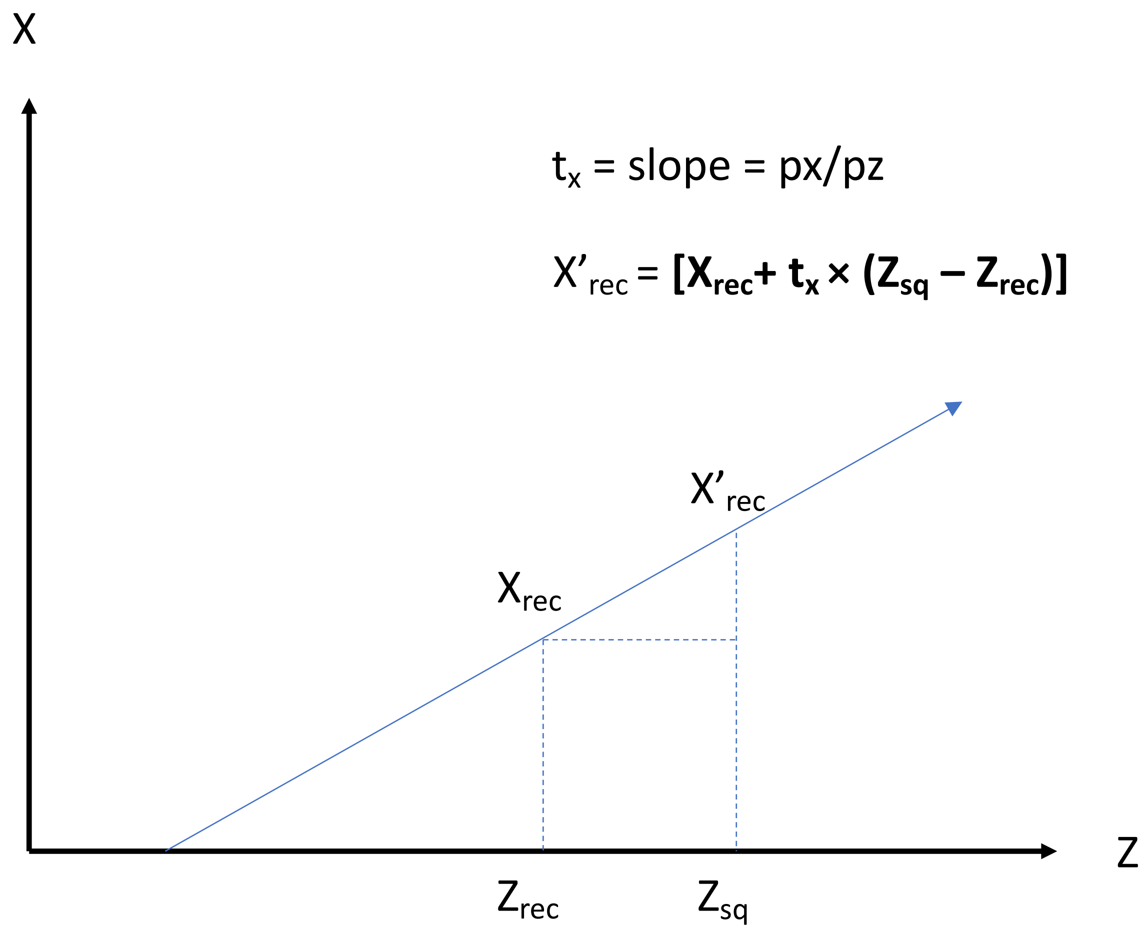




$(P_{st1}^{truth} - P_{st3}^{truth}) / P_{st1}^{truth}$

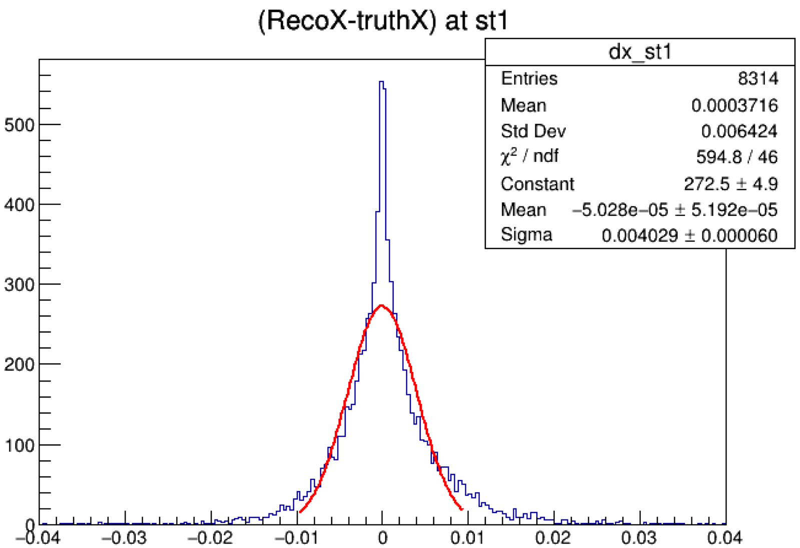
# Projecting X- and Y- values at same Z

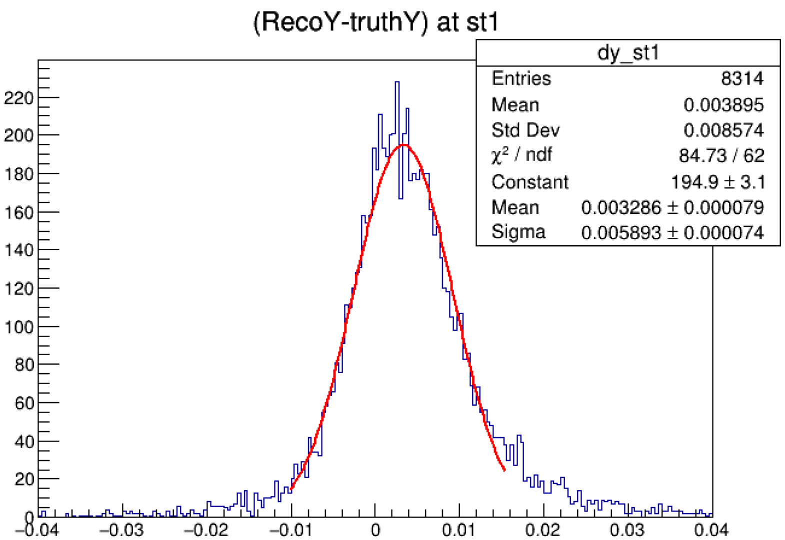
$t_x$ = slope = px/pz

$X'_{rec} = [X_{rec} + t_x \times (Z_{sq} - Z_{rec})]$

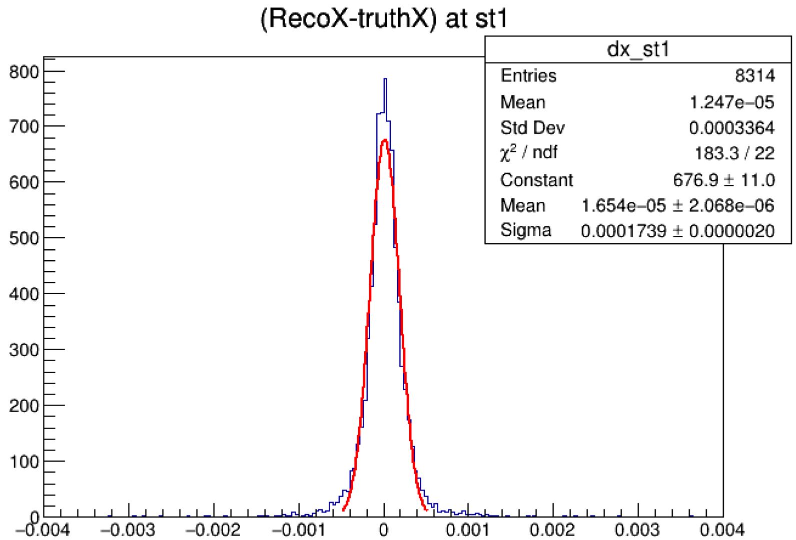


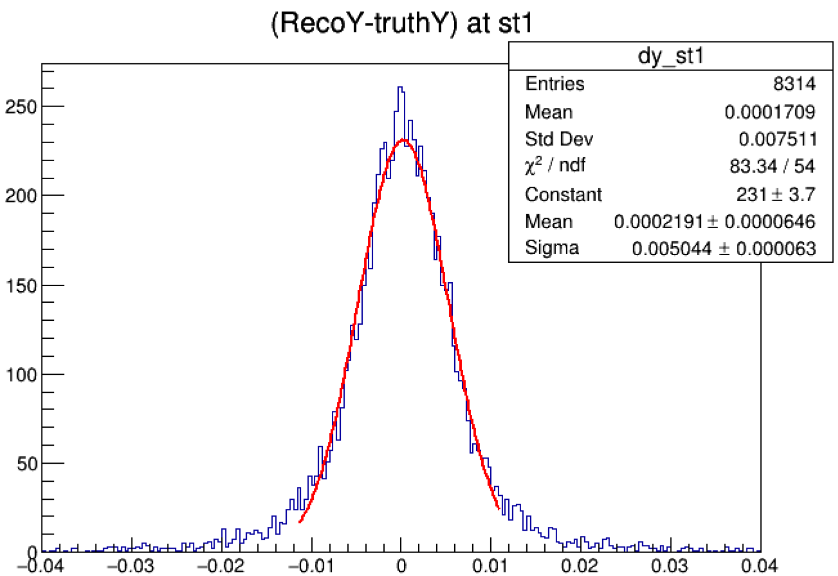
# X and Y Residual (KFREF)




## Projected at same Z



# St1., St.2, and St3. Drift chambers

| Detector | ID | Position |
|---|---|---|
| D0U | 1 | {-0.794,2.689,**594.541**} |
| D0Up | 2 | {-0.794,2.689,**595.177**} |
| D0Xp | 4 | {-0.552,2.743,**615.701**} |
| D0X | 3 | {-0.552,2.743,**616.337**} |
| D0V | 5 | {-0.423,2.791,**639.044**} |
| D0Vp | 6 | {-0.423,2.791,**639.679**} |
| D2V | 13 | {-2.45704,-0.733593,**1314.98**} |
| D2Vp | 14 | {-2.44096,-0.736408,**1321.96**} |
| D2Xp | 15 | {-0.821354,-0.0440208,**1340.36**} |
| D2X | 16 | {-0.816646,-0.0619792,**1347.34**} |
| D2U | 17 | {-0.465114,-0.800546,**1365.99**} |
| D2Up | 18 | {-0.481466,-0.789314,**1372.98**} |
| D3mVp | 25 | {-2.69882,-79.5892,**1886.71**} |
| D3mV | 26 | {-2.69402,-79.5889,**1888.71**} |
| D3mXp | 27 | {-2.6844,-79.5882,**1892.71**} |
| D3mX | 28 | {-2.6796,-79.5878,**1894.71**} |
| D3mUp | 29 | {-2.66998,-79.5871,**1898.71**} |
| D3mU | 30 | {-2.66518,-79.5868,**1900.71**} |
| D3pVp | 19 | {-1.009,78.6891,**1923.3**} |
| D3pV | 20 | {-1.01243,78.6905,**1925.3**} |
| D3pXp | 21 | {-1.01929,78.6933,**1929.3**} |
| D3pX | 22 | {-1.02271,78.6947,**1931.3**} |
| D3pUp | 23 | {-1.02957,78.6975,**1935.3**} |
| D3pU | 24 | {-1.033,78.6989,**1937.3**} |

**St. 1**

**St. 2**

Get the truth and reco information from the ones in red box for corresponding station f

**St. 3**