GenFit2 for SpinQuest Tracking

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(For SpinQuest Collaboration)

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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

$$\Delta\Sigma_q \approx 25\%$$

$$L_u \approx -L_d$$

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

$$2 J_g \approx 25\%$$

- **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 target
- Beam commissioning: **Spring 2021**
- Expected to run for two years of beam time

SpinQuest: Spectrometers

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)

Preliminary Look (No detector resolution and efficiencies)

Residuals at st.1

	DAF	KF	KFREF	DAFREF
$X, \mu\text{m}$	2.56	0.17	0.17	0.38
$Y, \mu\text{m}$	14.58	4.98	5.04	6.65
$t_x, 10^{-5}$	5.11	4.18	4.25	4.18
$t_y, 10^{-5}$	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

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 and 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 Contrc Viewer 1

Go to event: 0 Redraw Event Hide Viewer 1 Actions

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
- Error scale: 1

TrackRep options

- ☒ Draw cardinal rep
- Else draw rep with id: 0
- ☒ Draw all tracks
- Else draw track nr.: 0

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

KFREF

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

KFREF

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

KFREF

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

KFREF

Truth momentum: St.1 and St.3

Projecting X- and Y- values at same Z

X and Y Residual (KFREF)

(RecoX-truthX) at st1

(RecoY-truthY) at st1

8/13/20

Projected at same Z

(RecoX-truthX) at st1

(RecoY-truthY) at st1

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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

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

St. 2

St. 3