Parameterization-based tracking for the P2 experiment

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P2 setup

Integrating Cherenkov Detector

Tracking Planes

Target

Sheild

Magnet

$e^-$

$\gamma$ (Bremsstrahlung)
Why is tracking necessary?

“Measure” actual $Q^2$ distribution

\[ A_{PV} = \frac{N \downarrow - N \uparrow}{N \downarrow + N \uparrow} = \frac{\sigma \downarrow - \sigma \uparrow}{\sigma \downarrow + \sigma \uparrow} = \frac{G_F Q^2}{4 \sqrt{2} \pi \alpha} (Q_W - F(Q^2)) \]
Why is tracking necessary?

Validate the acceptance, alignment, and magnetic filed map

The magnetic field is anyways necessary, even without tracking
Why is tracking necessary?

Monitor the beam and the target conditions (e.g. boiling)

Continuously, at full rate, but with small duty cycle.

On-line analysis
GEANT4 simulation
(only relevant components displayed)
Reconstruction frame (45ns) at 1% beam rate without the background from the beam
Reconstruction frame (45ns) at 1% beam rate without the background from the beam

12 hits
Reconstruction frame (45ns) at the full beam rate with the background from the beam.

- 1600 hits
- 10 cm
Conventional track following

y-z view

- e\(^{-}\) beam
- target
- 2 cm
- 54 cm
Conventional track following
Conventional track following
Conventional track following

- e⁻ beam
- target
Conventional track following
Conventional track following
Parameterization-based track finding

$\text{Parameterization-based track finding}$

$f( x_2, y_2, x_3, y_3 )$

$3^{rd}$ order polynomial
Extrapolation
Extrapolation
Extrapolation with constraints
Using reference tracks instead of extrapolation
Reference tracks:

- from MC
- brute-force reconstruction at low rate; select by $\chi^2$. 
How to construct the parameterizations?
Search window for plane 2

\[ f(x_3, y_3) \]

\[ x_3, y_3 \]
Search window for plane 2

$\text{R}_3$

$\text{f}(\text{R}_3)$
Take reference tracks with the given $R_3$ (with some tolerance)
Take large number of reference tracks
Group tracks in $R_3$ bins
Search window for every $R_3$ bin:
Extract window position and size:

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### Fit

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$x_{\text{POS}} = \text{pol3}(R_3)$
## Fit

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$x_{POS} = \text{pol3}(R_3)$

$y_{POS} = \text{pol3}(R_3)$

$x_{SIZE} = \text{pol3}(R_3)$

$y_{SIZE} = \text{pol3}(R_3)$

$\phi_{ROT} = \text{pol3}(R_3)$

Fake plot. For illustration only.
Search window for plane 2

\[ x_{\text{POS}} = \text{pol}3(R_3) \]
\[ y_{\text{POS}} = \text{pol}3(R_3) \]
\[ x_{\text{SIZE}} = \text{pol}3(R_3) \]
\[ y_{\text{SIZE}} = \text{pol}3(R_3) \]
\[ \phi_{\text{ROT}} = \text{pol}3(R_3) \]
Search window for plane 1

\[ f(\Delta x'_{23}, \Delta y'_{23}, R_3) \]

\[ \Delta x'_{23}, \Delta y'_{23} \]

\[ R_3 \]
bin by \{R_3, \Delta x'_{23}, \Delta y'_{23}\}

determine the search windows

\begin{align*}
    x_{\text{SIZE}} &= \text{pol3}( R_3, \Delta x'_{23}, \Delta y'_{23} ) \\
    y_{\text{SIZE}} &= \text{pol3}( R_3, \Delta x'_{23}, \Delta y'_{23} ) \\
    x_{\text{POS}} &= \text{pol3}( R_3, \Delta x'_{23}, \Delta y'_{23} ) \\
    y_{\text{POS}} &= \text{pol3}( R_3, \Delta x'_{23}, \Delta y'_{23} ) \\
    \phi_{\text{ROT}} &= \text{pol3}( R_3, \Delta x'_{23}, \Delta y'_{23} )
\end{align*}
Search window for plane 0

\[ f(\Delta x'_{13}, \Delta y'_{13}, R_3) \]

\[ \Delta x'_{13}, \Delta y'_{13} \]
Relative distance from the center of the search window
Relative distance from the center of the search window
Relative distance from the center of the search window

Overall about 90% efficiency (depending on settings).
Performance

Number of candidates per signal track

\[ \frac{N \text{ candidates}}{N \text{ signal}} \]

Parameterized search windows

Relative beam intensity

Ideal
Performance

Number of candidates per signal track

\[
\frac{N \text{ candidates}}{N \text{ signal}} = 10^{2}\times 10^{3} \frac{1}{10}
\]

- Fixed-size search windows (same efficiency)
- Parameterized search windows

Relative beam intensity

Number of candidates per signal track
Parameterization instead of fitting

Rigorous fit

Fit replaced by parameterization:
\[ \text{momentum} = \text{pol3}(R_3, \Delta R_{31}, \Delta \varphi_{31}) \]

Using GBL fit within the GENFIT framework

GBL: Kleinwort C. General Broken Lines as advanced track fitting method
http://dx.doi.org/10.1016/j.nima.2012.01.024

GENFIT: Rauch J., Schlüter T. GENFIT — a Generic Track-Fitting Toolkit
https://doi.org/10.1088/1742-6596/608/1/012042
Summary

Parameterization-based tracking:
- replaces rigorous model calculations by simple analytical parametric functions
- parameters can be tuned based on real data or model (MC or deterministic with covariance)
- enables accurate, efficient, and very fast track finding
- can be used to estimate the kinematic parameters
- works well in P2 due to narrow momentum range