An OO Kalman Tracker

- Introduction
- Class Architecture
- Implementation
- Maximum Likelihood Fit
- Conclusions

Kalman Filter Tracking

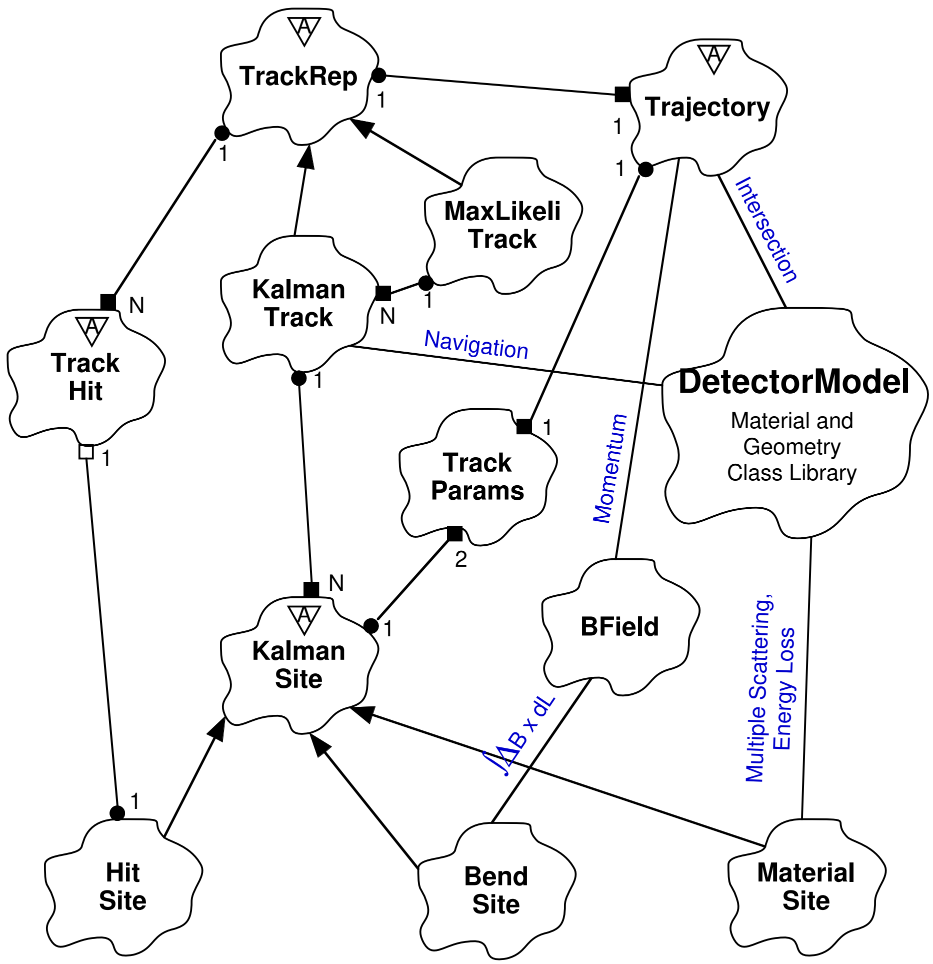
- The Kalman filter is well suited for tracking
  - BLUE algorithm for sequential processes

Best **L**inear **U**nbiased **E**stimate = Least Squares

BLUE(A,B,C) = BLUE(BLUE(A,B),C)

  - Models complex detectors as simple pieces
  - Involves low-dimensioned matrices, simple operations
  - Been implemented many times
- The algorithm is well suited for OO
  - Well-defined objects (Tracks, Hits, Material, Bfield)
  - Objects perform simple functions
  - Details can be hidden by polymorphism
  - Been implemented before
- Can be used in a Maximum Likelihood fit
  - Allows for non-Gaussian hit resolution and scattering
  - Exploits objectification for an efficient solution
  - Previous publication by Fruewirth

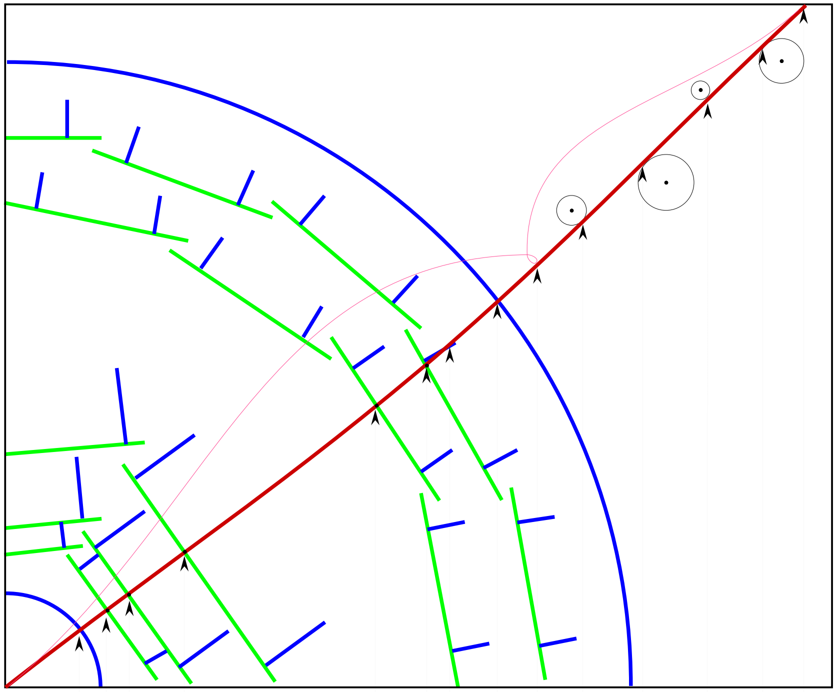
Simplified Class Diagram



Class Descriptions

- KalmanSite
  - Describes where 'something occurs' on the track
  - Referenced by flight length along a trajectory
  - Sub-classed to Hit, Material, and Bend sites
    - Hit sites describe measurements
    - Material sites describe scattering and energy loss
    - Bend sites describe non-uniform magnetic field effects
  - Holds local track linearization
    - Hit → residual and parameter derivatives
    - Material → scattering matrix and energy loss vector
  - *Process* method applies the occurance's effect
  - Holds results for *inward* and *outward* processing
- KalmanTrack
  - Holds an ordered list of KalmanSites
  - Builds the list from an initial trajectory and hit list
  - performs the fit
    - Chains through the KalmanSites *process* methods, in and out
    - Iteratively update (correct kinematics and relinearize) and refit
  - Builds the final Piecewise Helix Trajectory ('smoothing')
- Trajectory
  - Spatial representation of a track (position, direction, ...)
- DetectorModel
  - Position and composition of all material (DetElements)
- BField

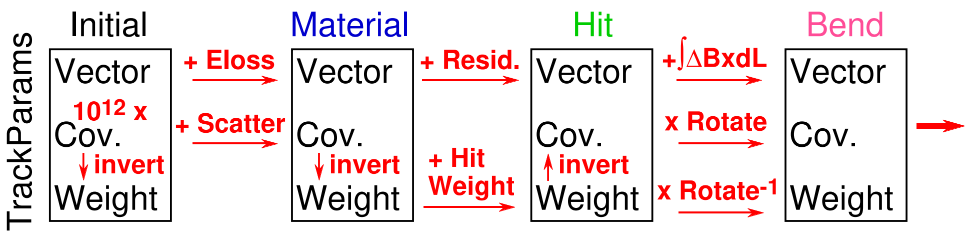
Implementation



Site Types

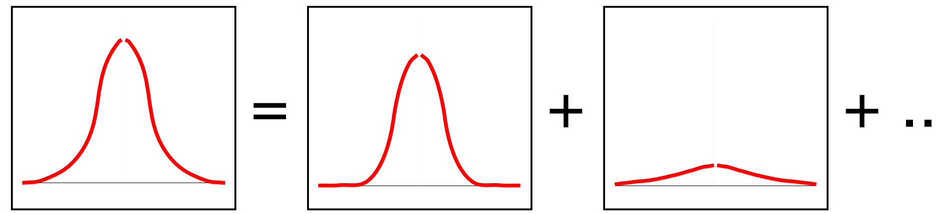
Material M M M M M M M M M
Hit H H H H H H H H H H
Bend B

Site Processing (one direction)



Maximum Likelihood Fit

- Model Parent Distributions for hit resolution and scattering as a sum of Gaussians

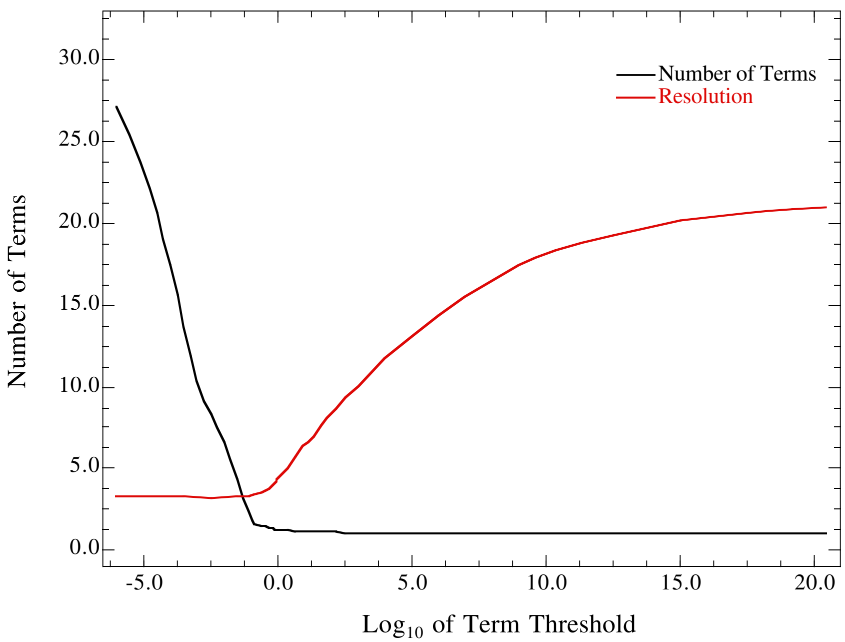


- Each Site has a state (-1=rms, 0=core, 1=tail,...)
- The full Maximum Likelihood equation is the sum of terms representing all possible fits using all possible site state combinations.
  - Number of terms = $(N_{states})^{N_{sites}} \cong 10^{19}$
- The terms can be ordered a-priori according to the Parent weights, and only significant terms (above threshold) need be evaluated.
- The minimization equation is transcendental, but it can be solved approximately.

Simple 1-D Model

- 1-D model to study Max Likelihood sum
- Parent modeled as 90% σ=1, 10% σ=4
- Study resolution of solving the Max Likelihood equation as a function of the term threshold (5 sites = max. 32 terms)

1-D Perturbative Maximum Likelihood Method

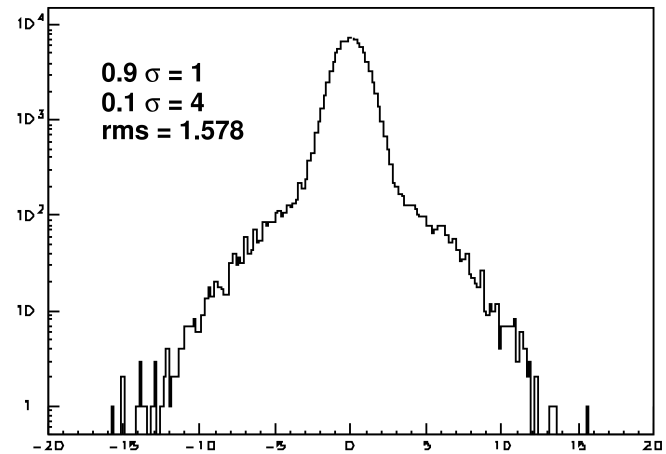


- Only a very few terms are needed!

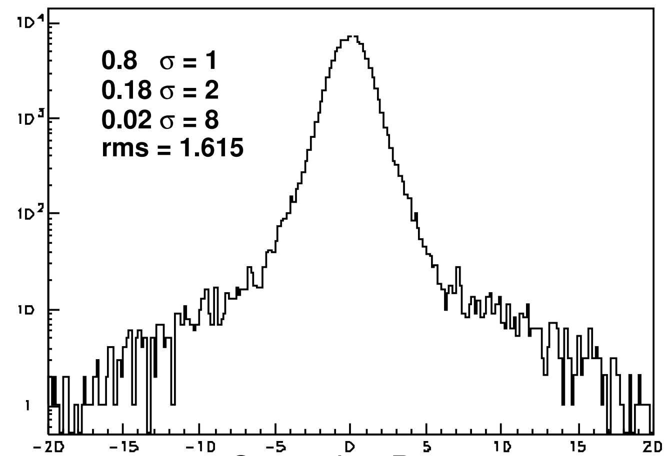
Parent Distributions

Modeled on ALEPH SVT measurements

Normalized Parent Distributions



Hit Parent

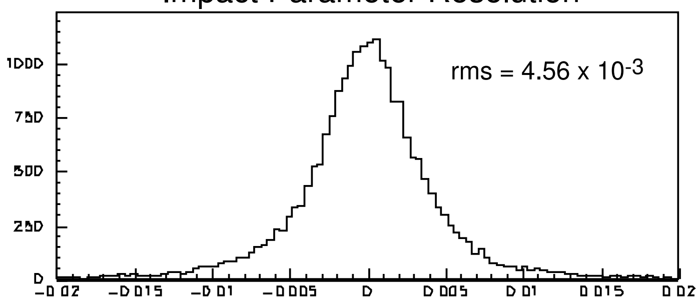


Scattering Parent

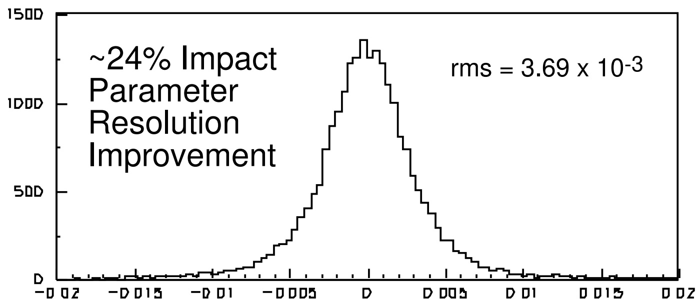
Results With Tracks

Compare resolutions for tracks with 0.4 < P < 4.0 GeV

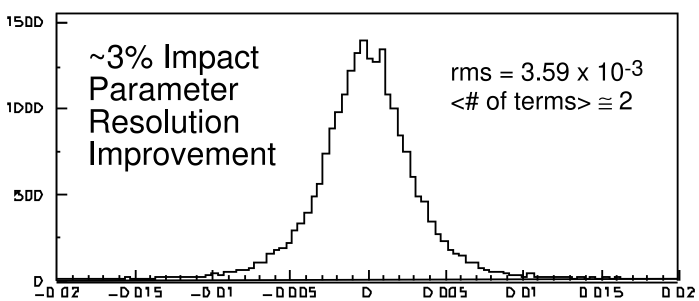
Impact Parameter Resolution



Least-squares fit (no scattering)



Kalman fit

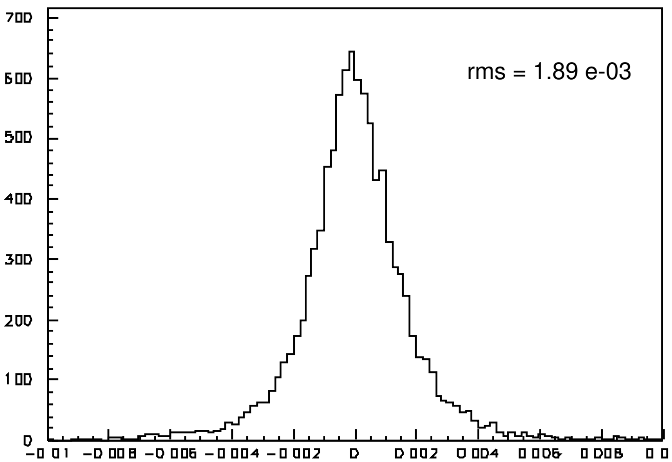


Maximum Likelihood fit

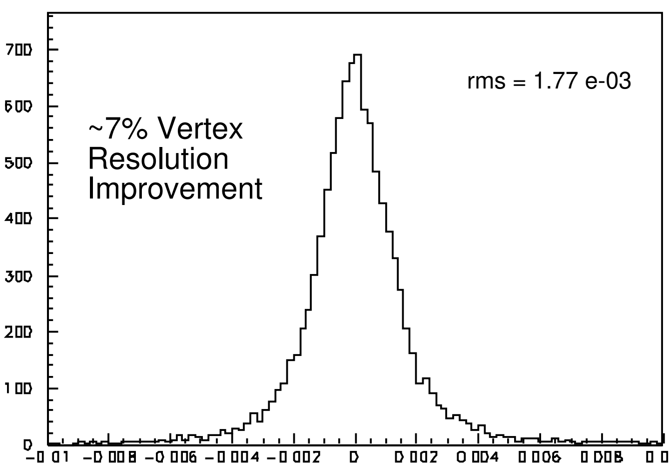
Results With Vertexing

Form a Primary Vertex from E_{cm}=10GeV hadronic events (no b quarks) using tracks fit with the different algorithms.

Vertex Position Resolution



Kalman Track Fit



Maximum Likelihood Track Fit

Conclusions

- An object-oriented formulation of the Kalman filter algorithm for tracking has been developed.
  - Identification of physical processes with C++ objects
  - Separation of parametric, geometric, and kinematic aspects of track fitting into different objects
  - A flexible and extensible design
- A Maximum Likelihood track fit has been implemented using this Kalman filter fit.
  - Models non-Gaussian hit resolution and scattering
  - ~7% vertex resolution improvement under realistic conditions
- The Kalman fit and the Maximum Likelihood fit will be used for tracking with the BaBar detector at the SLAC PEPII B-factory.