The Global-χ^2 Track Fitter in ATLAS

Thijs Cornelissen (CERN)

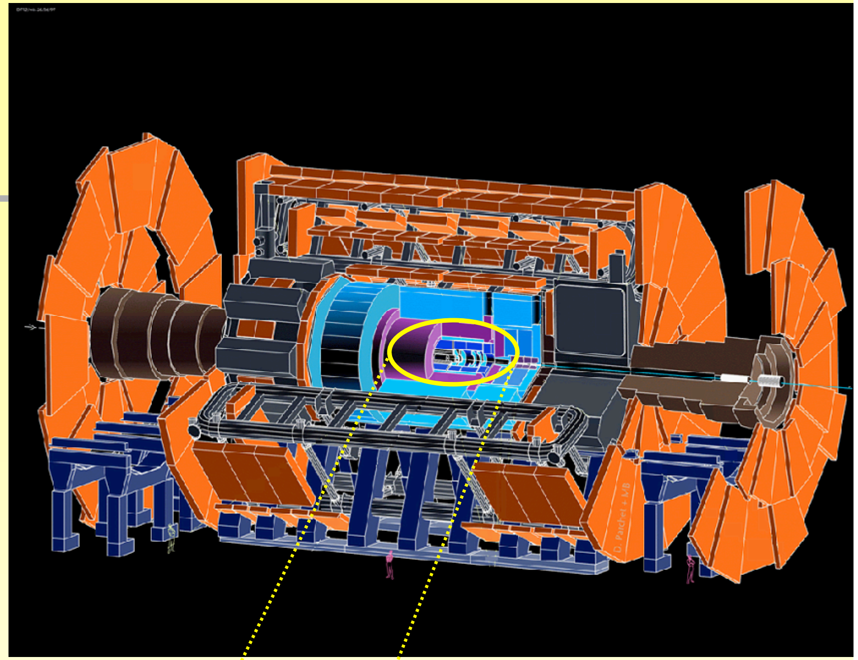
On behalf of the ATLAS collaboration

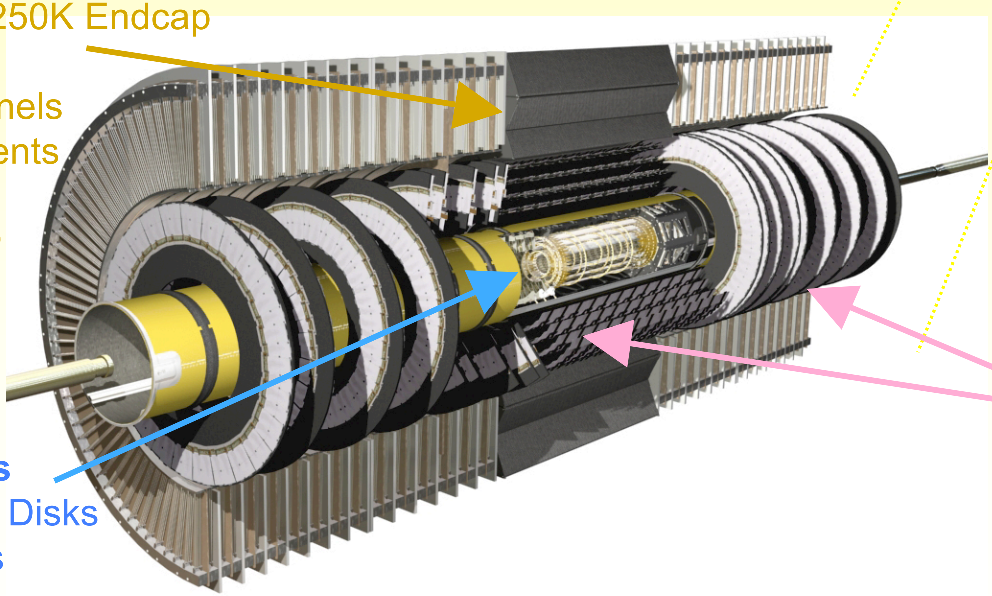
Talk presented by M. Elsing (CERN)

CHEP07 conference
5 September 2007, T. Cornelissen

The Inner Tracker

- Cylindrical cavity, length:6.8m, diameter:2.2m
- Axial field of max strength 2T, superconducting solenoid in front of the ECAL, length:5.3m
- Precision tracking, 2ndary vertex detection
- Passive material in supports, cooling pipes, …

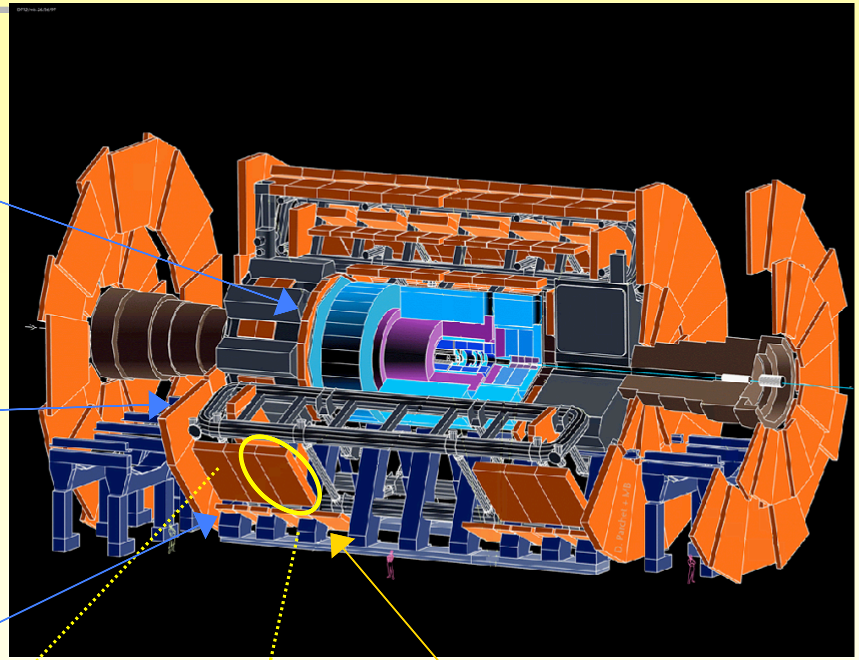




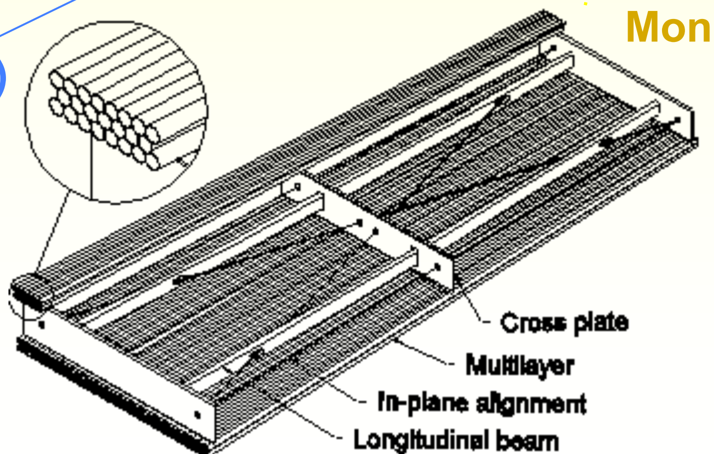
The Muon Spectrometer

Cathode strip chambers (CSC)
~70,000 channels
Hit resolution 60 μm
4 precision hits per track
$2 < |\eta| < 2.7$

Thin gap chambers (TGC)
~440,000 channels
Hit resolution ~1 cm
$1 < |\eta| < 2.4$
Triggering



Resistive Plate Chambers (RPC)
~355,000 channels
Hit resolution ~1 cm
$|\eta| < 1$
Triggering



Monitored drift tubes (MDT)
~320,000 tubes
Hit resolution 80 μm
~20 hits per track
$|\eta| < 2.7$

ATLAS Common Tracking Project

- The common tracking framework provides a basis for track reconstruction in the Inner Detector and the Muon Spectrometer
- It emphasizes:
  - Modularity: For each step in the reconstruction, abstract interfaces are defined such that the user can choose at runtime between several modules
  - Abstraction: The Common Tracking tools and classes are designed to be applicable in both the ID and the MS
  - Consistency: The Event Data Model (e.g. Trk::Track, Trk::MeasurementBase, …) imposes strict conventions on the output of the tracking modules, ensuring that they communicate properly.
- The combination of these features leads to an open and flexible framework, making it easy for new developers to contribute
- The common tracking framework is being used as well as a testbed for new tracking techniques (e.g. STEP, advanced brem fitting, …)

Use Cases for Global-χ^2 Track Fit

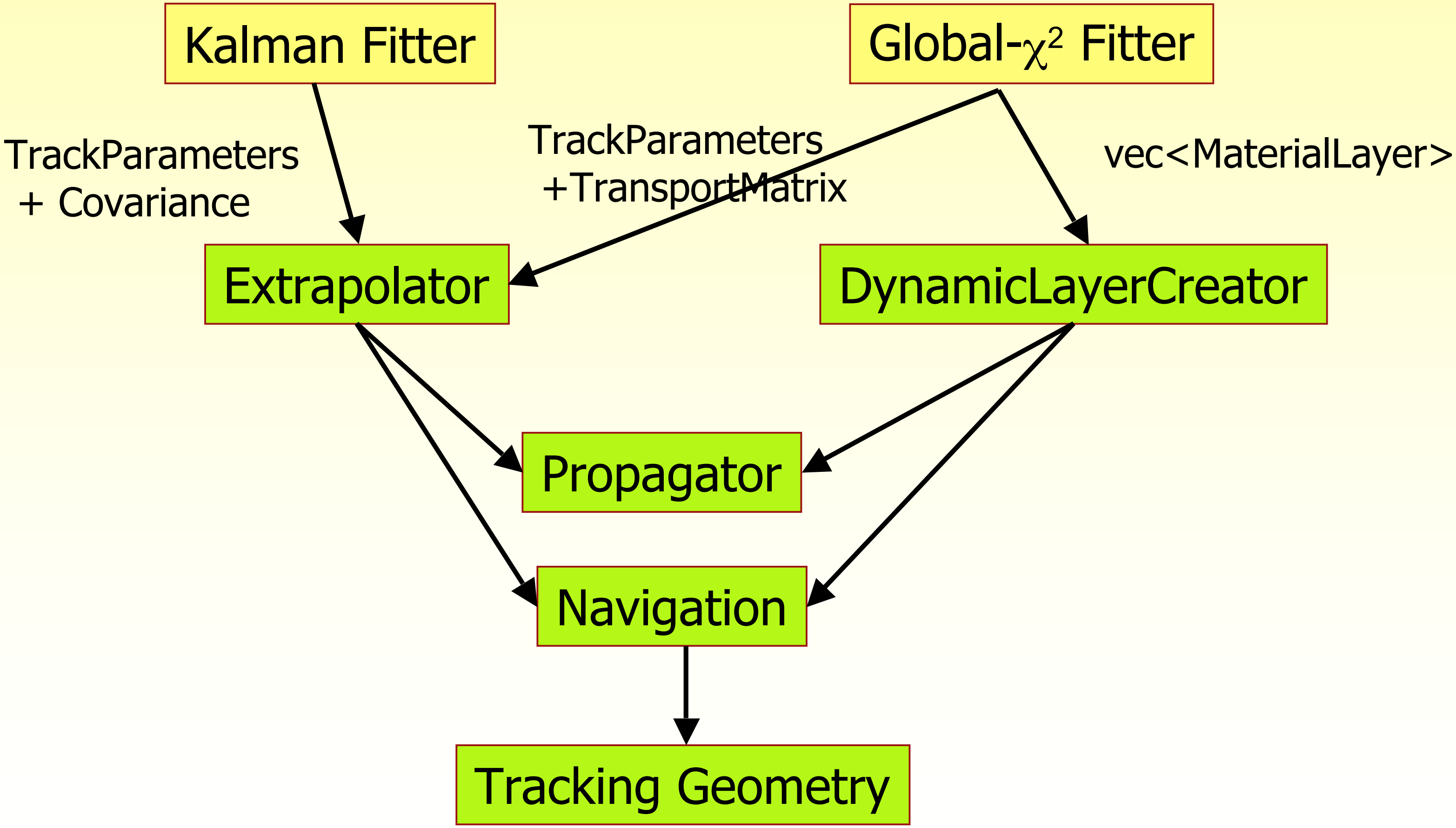
- The Global-χ^2Fitter package is used in the following places:
  - One option for Inner Detector tracking (default is Kalman Filter)
  - Default track fitter for Inner Detector cosmics and testbeam reconstruction
  - Default track fitter in one of the muon reconstruction packages
- By design, any track fitter in the common tracking framework can refit a track on ESD/AOD from any other package, e.g. an ID track, a muon track, or a combined ID+muon track
- An important feature of the global track fit is that it provides the scattering angles. The interfaces in the ATLAS Tracking model allow to expose this information to other algorithms, such as:
  - The global χ^2 alignment algorithm (see talk by S. Gonzalez Sevilla et al., abstract #129)
  - The HitDisplay event display package (it shows the scattering angles in the track)
- Another feature is that it can solve the left/right signs in the TRT by itself.

Approaches to Track Fitting

- Different approaches to track fitting are available in ATLAS:
  - Kalman Fitter: progressive linear estimator, a “local” approach, updates the track parameters by adding one measurement at a time
  - Global-χ^2 Fitter: is “global”, in the sense that it uses all the measurements at once during an iteration
  - Specialized track fitters: Gaussian Sum Filter, Dynamic Noise Adjustment KF for brem-fitting, Deterministic Annealing Filter
- All approaches use an Extrapolator tool for parameter transport between measurements
- The extrapolator has “knowledge” of the tracking volumes and material layers, by using the Navigator tool
- The actual propagation through the magnetic field is performed using the Propagator tool (e.g. Runge-Kutta)

Integration in Tracking Framework

- Both the Kalman Fitter and the Global-χ^2 Fitter use a common material source, the Tracking Geometry (see talk by A. Salzburger, abstract #192)



Newton-Raphson Minimization

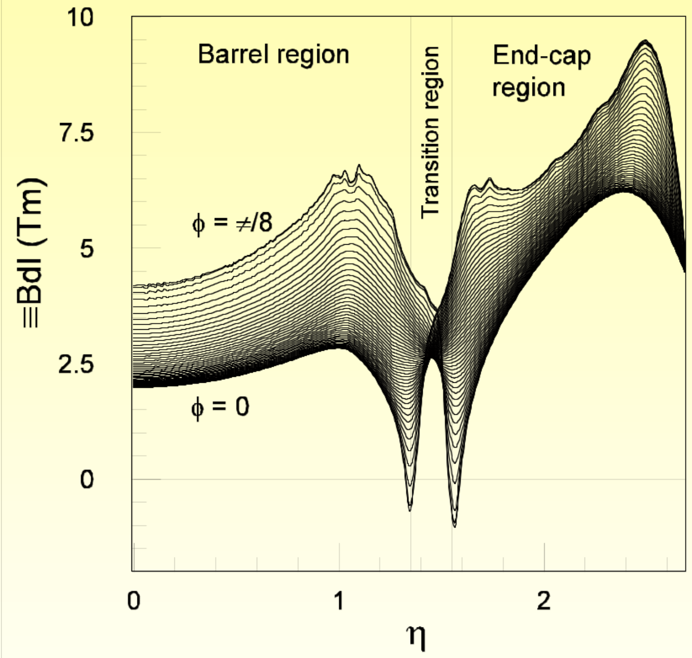
- Reminder: given *N* uncorrelated residuals *r* and their derivatives d*r*/dα, the update formula for the track parameters α is:

$$A \cdot \Delta\alpha = b, \quad A_{kl} = \sum_{i=1}^{N} \frac{1}{\sigma_i^2} \cdot \frac{\partial r_i}{\partial \alpha_k} \cdot \frac{\partial r_i}{\partial \alpha_l}, \quad b_k = \sum_{i=1}^{N} \frac{1}{\sigma_i^2} \cdot r_i \cdot \frac{\partial r_i}{\partial \alpha_k}$$

- By multiplying the inverse of the matrix *A* with *b*, the difference between the old and the new track parameters is obtained. This process continues until the fit converges.
- The residuals *r* are obtained by propagating to each hit using the propagator.
- The derivatives are obtained using the Runge-Kutta propagator:
  - It provides the transport matrix for each propagation
  - Simple matrix multiplication then provides the derivatives required by the global fit

Propagation of Track Parameters

- The highly inhomogeneous magnetic field in the muon system makes numerical stability in the track fit a delicate issue.
- The Runge-Kutta propagator in ATLAS uses the Bugge-Myrheim method for calculating the transport matrix. Fully (semi-)analytic, i.e. precise, fast and robust.
- A new propagator, the STEP propagator (E. Lund et al.), applies a continuous material correction at each Runge-Kutta step. This will improve the tracking precision in the presence of dense volumes, like the toroids and feet in ATLAS.

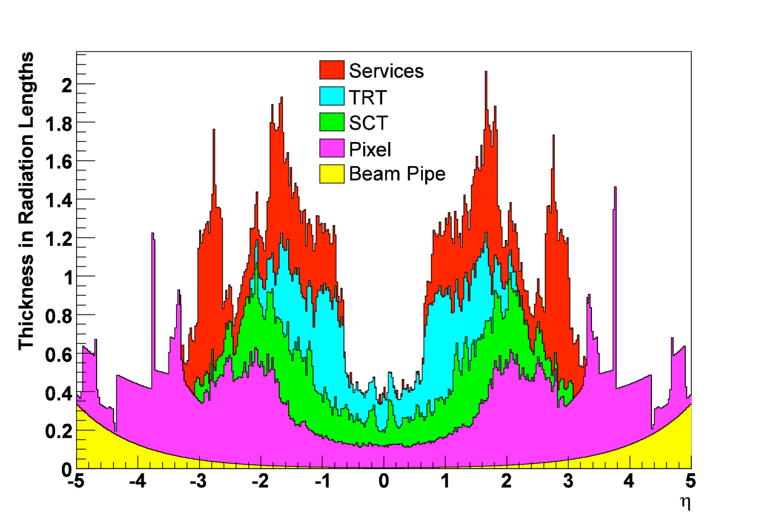


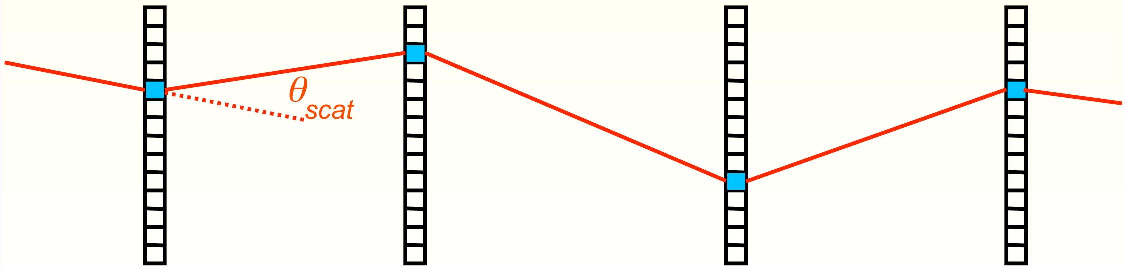
Scattering Angle Formulation

- The scattering angles and the energy losses become additional fit parameters, along with the track parameters at the vertex (i.e. impact parameter, direction and momentum).
- The χ^2 function to be minimized w.r.t. the fit parameters is:

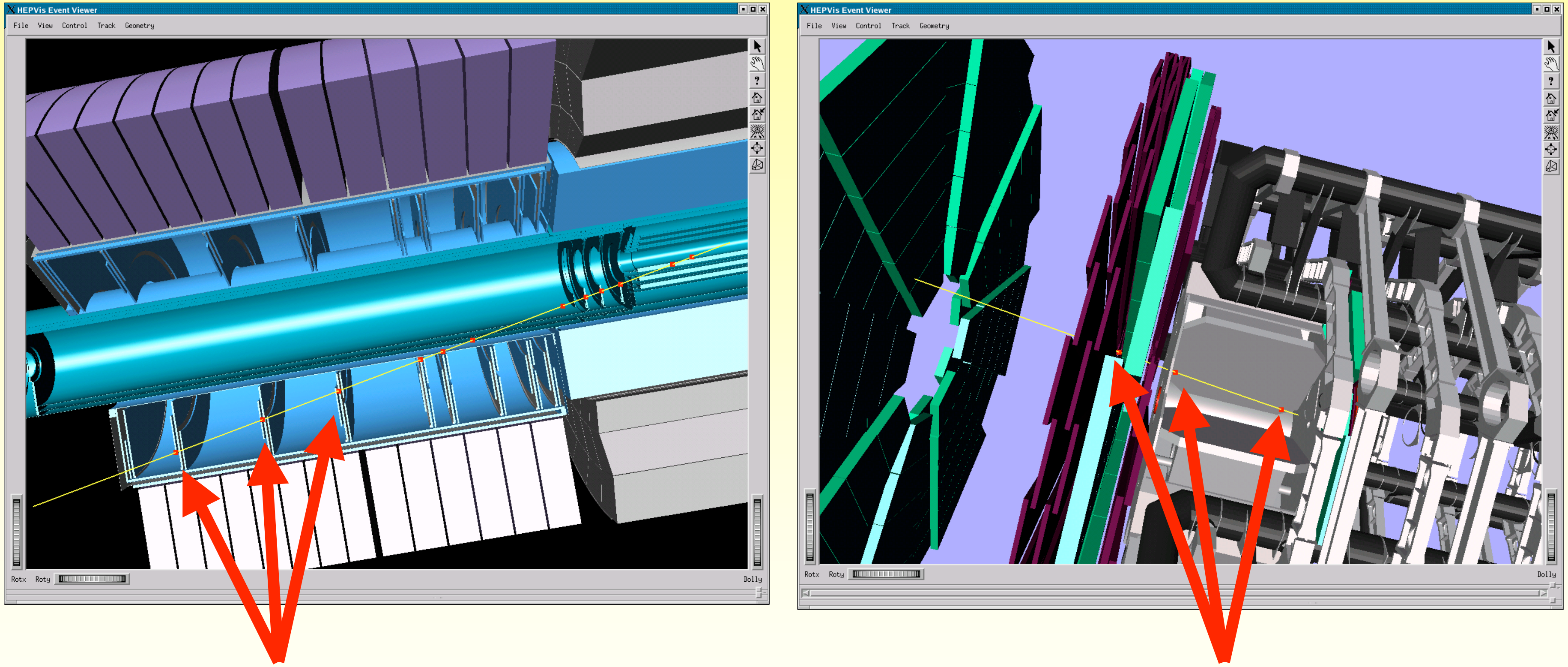
$$\chi^2 = \sum_{hits} \frac{\Delta y^2}{\sigma_{hit}^2} + \sum_{scatters} \frac{\theta_{scat}^2}{\sigma_{scat}^2} + \sum_{Eloss} \frac{(\Delta E - \overline{\Delta E})^2}{\sigma_{Eloss}^2}$$

where Δy are the residuals, and σ_{scat} and $\overline{\Delta E}$ can be estimated from the material properties (done by the MultipleScatteringUpdator and EnergyLossUpdator tools)





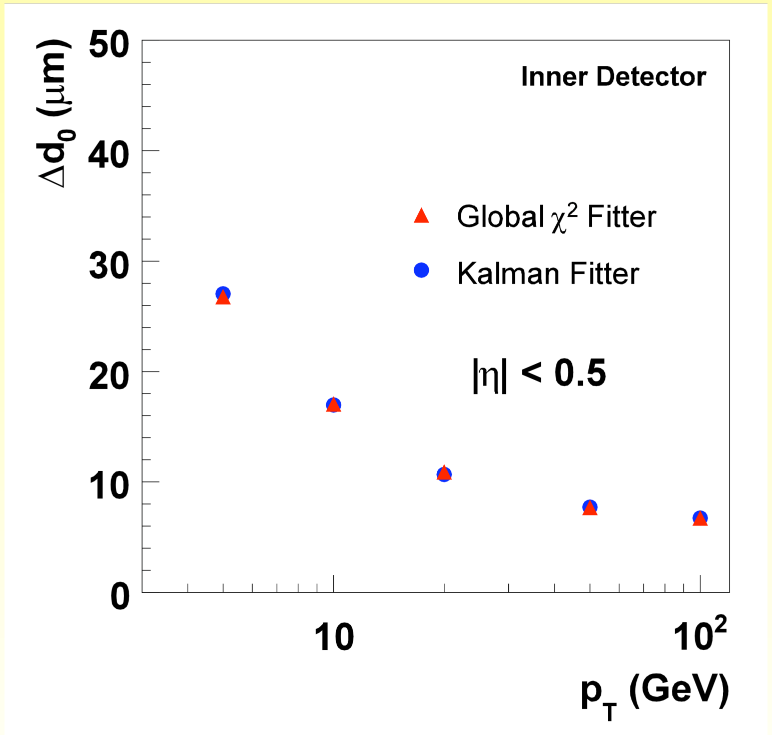
Single Muon Tracks (simulated)

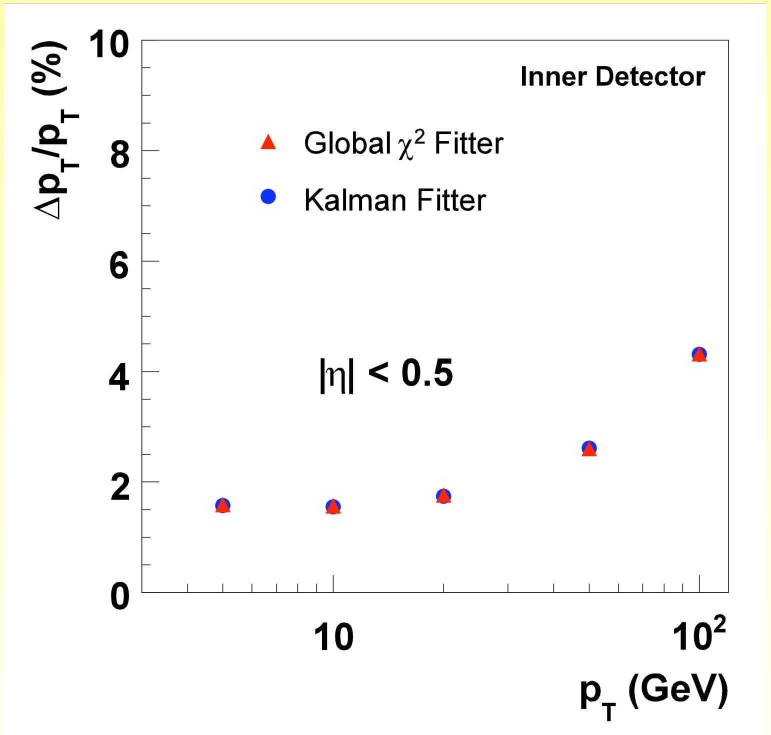


- Example of a fitted track in the Inner Detector (left) and the Muon Spectrometer (right). The scattering centers are drawn as red dots.

P 12

Track Parameter Resolutions (G4)

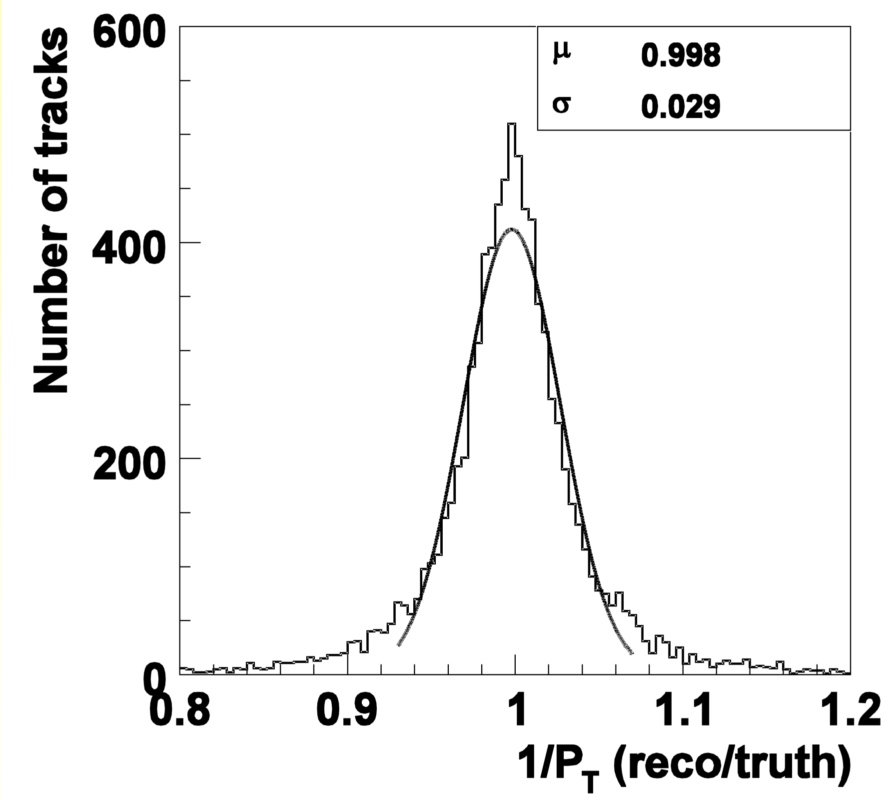




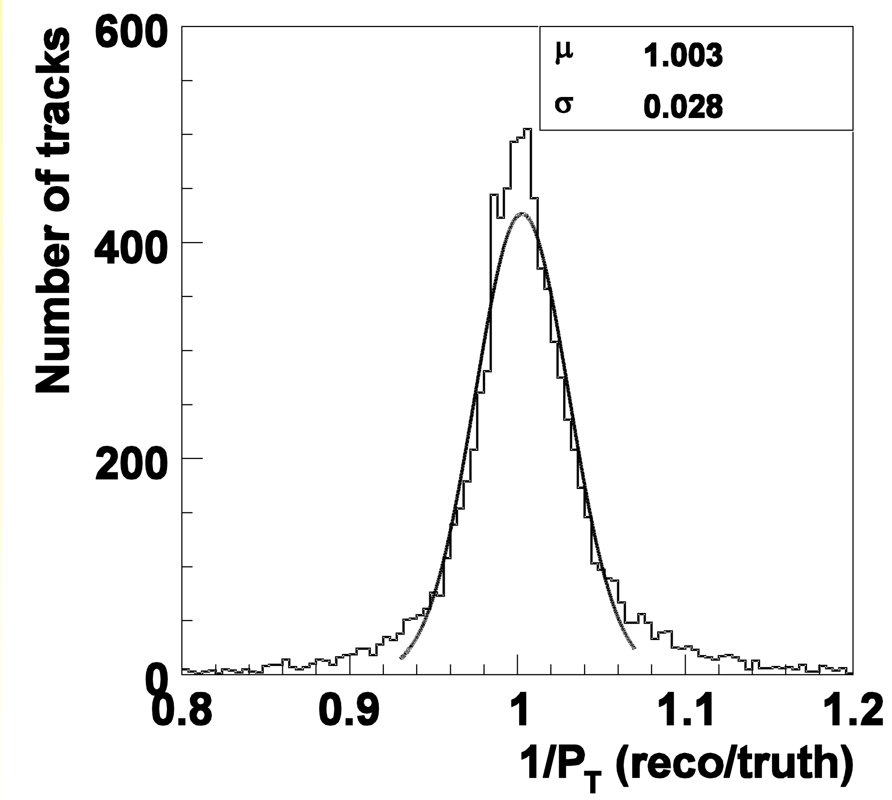
- As expected, the track parameter resolutions of the Kalman Fitter and the Global-χ^2 Fitter are identical
- The timing of the Global-χ^2 Fitter can still be improved, currently twice as slow as the Kalman Fitter in the ID

Momentum Resolution (p_T=10 GeV)

Muon reconstruction



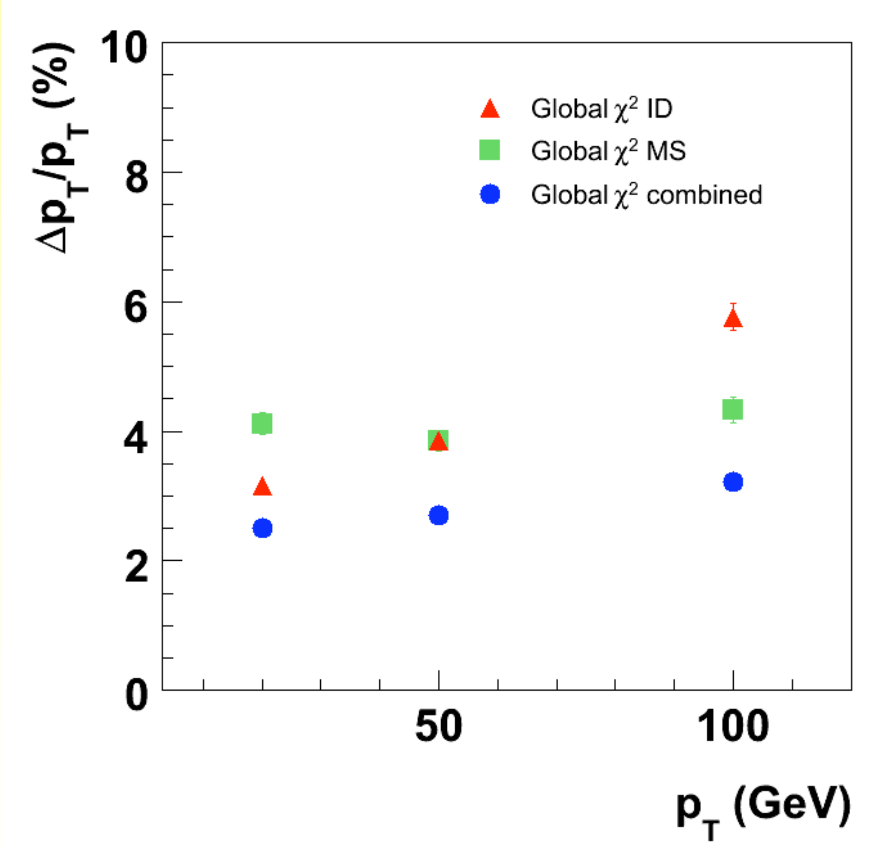
Refit with Global-χ^2 Fitter



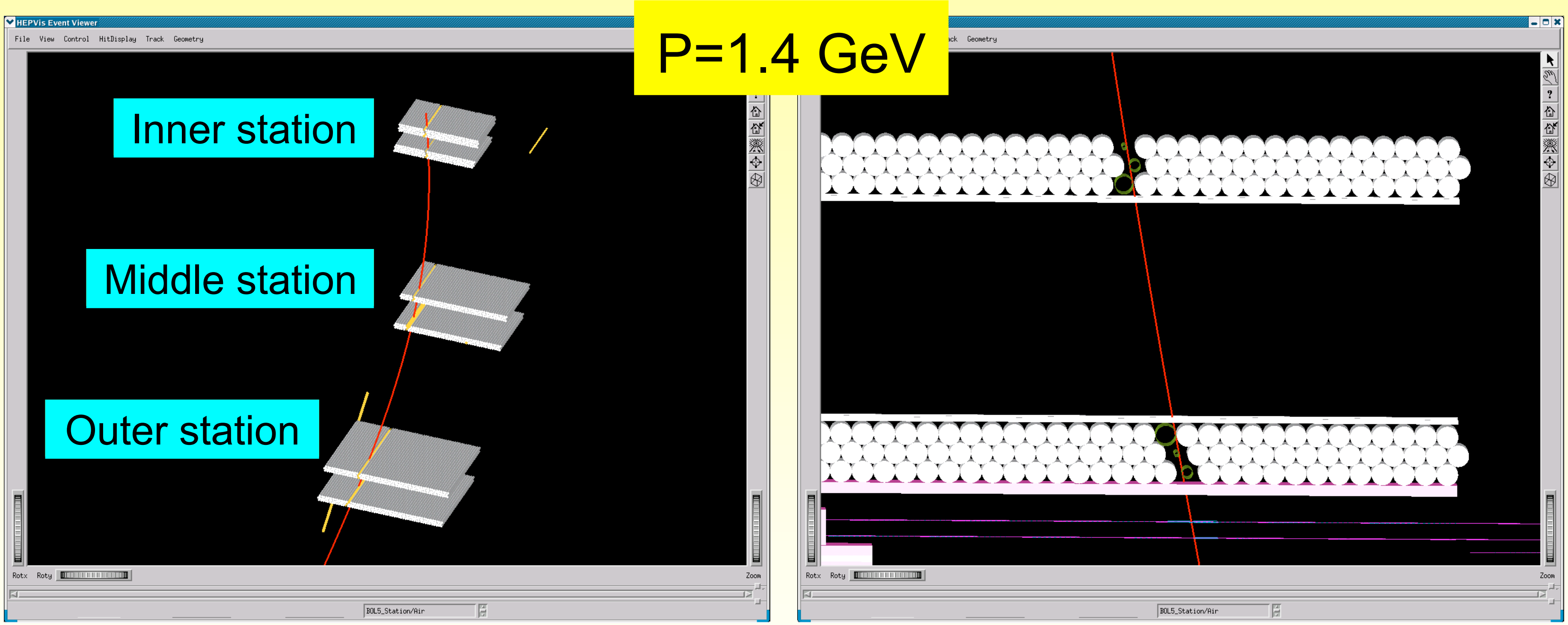
- As expected, the momentum resolution of the Global-χ^2 Fitter is at least as good as in the standard muon reconstruction.

Combined Muon Tracking in ALTAS

- Incorporates Inner Detector and Muon Spectrometer measurements into a single track fit with O(100) degrees of freedom. Has several advantages over ID and MS standalone fits:
  - Gives best possible momentum resolution
  - Allows to perform global ID-muon alignment
  - Reduces fakes from e.g. pion decay
- Energy loss in the calorimeter can not be ignored
  - becomes additional parameter in fit
  - fit can use either a parametrized or a measured energy loss
  - calorimeter measurement is preferred if a strong brem is detected, and if the track is isolated.

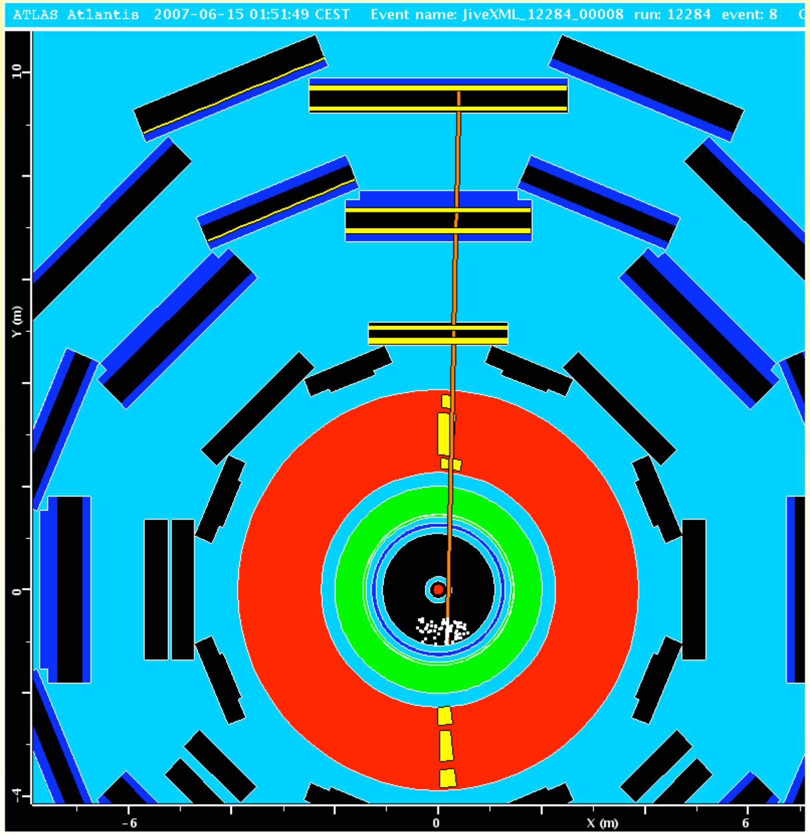


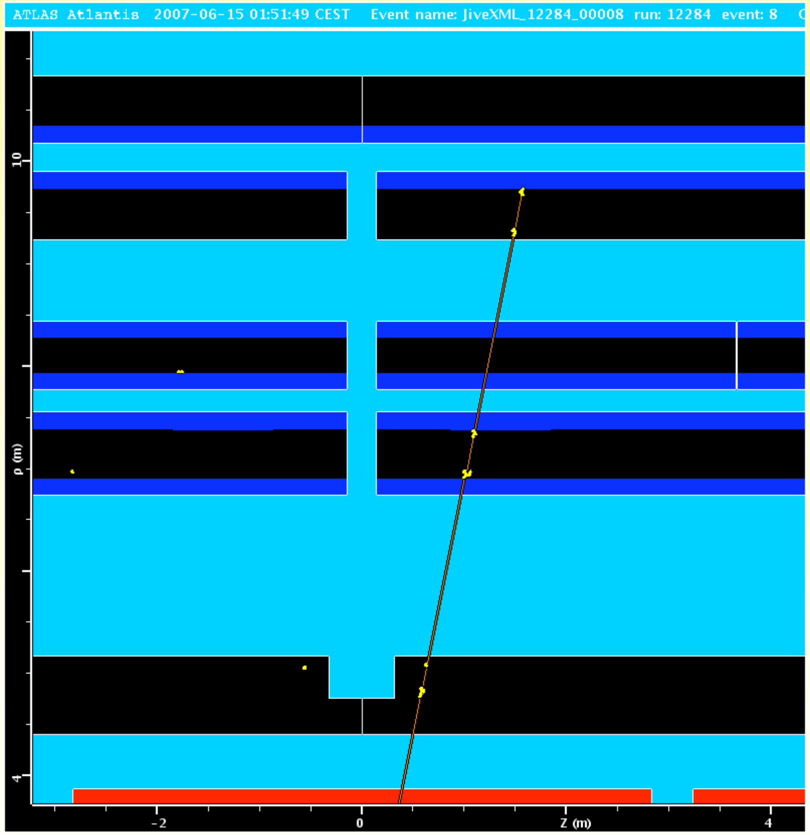
Cosmics with Toroid field ON



- November 2006: cosmics data taken in the muon spectrometer with the toroidal field enabled
- Plots show fitted cosmic track with field using the Global-χ^2 Fitter

First Combined Muon in Cosmics





- Straight line fit to the TRT and MDT hits (56 hits in total)
- Fit quality: χ^2/ndf = 94/52 (assuming 3 mm for the MDT resolution)
- Integration of material corrections not straightforward with straight tracks!

Conclusions

- The Global-χ^2 track fitting algorithm has been implemented in the ATLAS common tracking framework
- Robust track fitter used for reconstruction cosmics and test beam data
- It offers some unique features, such as the scattering angles on the track
- It is integrated with a powerful alignment algorithm
- The track parameter resolutions are equivalent to those obtained with the Kalman Fitter (common material and field model)