First production release of a kink finding module in ATLAS track reconstruction.

F. M. Brochu
Cavendish Laboratory
Madingley Road
CB3 0HE CAMBRIDGE

May 2, 2006

Abstract

This note describes the general layout and performance of the kink finding module developed during the year 2005.

1 Introduction.

The need for a dedicated kink finding algorithm arose from a desire to improve the track reconstruction degraded by a fair amount of detector interactions (about 10 % of the tracks undergo material interaction in the Inner Detector, according to [1]). The main client for such algorithm is electron reconstruction, to recover from hard bremstrahlung emission in the Inner Detector. Other clients are searches for exotic, metastable, charged particles [2].
In this paper, we will describe the layout of the Kink finding module as implemented in ATLAS offline release 11.2.0, as well as its interactions with other components of the offline software. In a second part, we will focus on the performance of the module, evaluated on simulated data reproducing a potential signal (for efficiency evaluation) and a typical ATLAS event (in terms of track multiplicity) for timing and "background" evaluation. We will eventually describe the performance of the module against real data from the 2004 Combined Test Beam run, before concluding.

2 General Layout.

2.1 Description of the module.

The kink finding module as implemented in ATLAS offline release 11.2.0 is made of 4 packages, 2 in the Tracking realm (prefix Trk) and 2 in the Inner Detector realm (prefix InDet):

- **InDetKinkFinder**: package containing the steering Algorithm and track selection method.
- **InDetCBNTKink**: class implementing a dedicated CBNT (combined ntuple) module to write out useful kink data.
- **TrkKinkMethods**: package collecting all methods used to find break points, split and refit track segments before building a kink object.
- **TrkKinkObject**: package implementing the description of the kink object and taking care of the persistification of the data in StoreGate (ATLAS transient Data Store).

2.2 Interactions with other modules.

The steering Algorithm **InDetKinkFinder** retrieves a Collection of pre-processed TrkTracks from StoreGate to use as input. Because of this pre-processing, it is actually called at the end of the track processing chain (as shown in Figure 1).

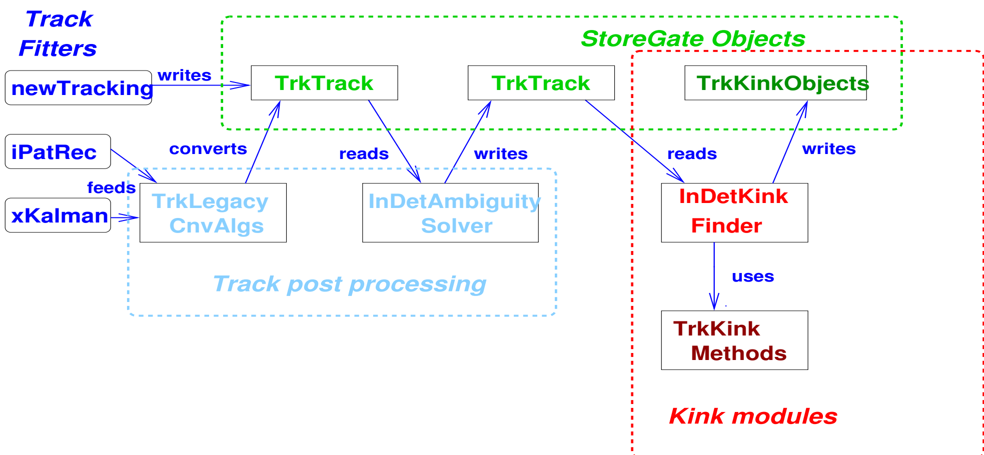

Figure 1: Tracks reconstruction chain and the location of the Kink finding modules.

Looping through the input TrkTrack collection, it performs two kind of selections mutually exclusive:

- *"Broken tracks"*. This selector aims to select kink configurations where both segments have been resolved separately at the first pass of the track fitting and would intersect. Another loop on input track is made to make a track pair, and we look for a common intersection point away from the Interaction point (IP). This selector is seldom used and not optimised yet.

- *"Bad Tracks"*. This selector looks for kinks with unresolved segments reconstructed as a single track with bad quality fit or a cluster of outliers hits. Selection is based on the ratio of the track fit chi squared and the number of degrees of freedom, tunable by job options. The main selection setting is a cut on the initial track fit quality: we select tracks with $\frac{\chi^2}{n.d.o.f} >= 1.5$, corresponding to a fit probability $\mathcal{P} \sim 5$ % with the average number of degrees of freedom (n.d.o.f) in a track around 40.
  This cut is refined to reject low p_t tracks ($p_t < 5$ GeV) with Pixel and

SCT hits in good agreement with the fit hypothesis ($\frac{\chi^2}{n.d.o.f}_{(SCT+Pixel)} < 1.5$).
This cut is set to reduce drastically the background track selection in top pair events, dominated by low p_t pion tracks with multiple scattering in the TRT degrading the track fit quality.

After this selection stage, all subsequent work on the input track(s) is performed by the various methods of **TrkKinkMethods**. **KinkCandidates** formed in **TrkKinkMethods** are collected in **InDetKinkFinder** and stored in StoreGate for future use.
The package **TrkKinkObject** gathers all representations of kink data objects and classes used for persistification in POOL. The main data representation is the **KinkCandidate**, a struct made of a **TrkRecVertex** for the kink vertex and **ElementLinks** to three **TrkTrack** objects: one for the refitted mother segment, one for the refitted daughter segment, and one link to the initial track. Another used data instance is **KinkCollection**, a vector of KinkCandidates for interactions with StoreGate.
The package **TrkKinkMethods** is made of four classes:

- **TrkKinkFinder** is the public interface to InDetKinkFinder. It contains data conversion methods (a segment merger), methods to create **KinkCandidates** from refitted components on top of the main public method `makeKinks()` called by InDetKinkFinder.

- **BreakpointAnalysis** analyses the initial track and look for breakpoint to be used as seeds for the track refit. There are distinct methods for tracks with outliers (search for outlier clusters) and without (direct search of breakpoint, based on maximum deviation from fit).

- **TrackSplitter** performs track splitting and segment refitting, based on a single input track (track pairs from *"Broken Tracks"* selector are merged into one using the segment merger of **TrkKinkFinder**) and a vector of potential breakpoints, used as seeds. It outputs pairs of tracks to intersect. ATLAS Track Fitters like **KalmanFitter** are used by TrackSplitter, track quality cut for refit can be set at will as a job option.

- **TrackIntersection** extends a pair of tracks in a discretized, cylindric volume, using the **TrackExtrapolation** tools. Returns the location of intersection point if it has converged. Convergence cut (3D tolerance) is a job option parameter.

Finally, the package **InDetCBNTKink** implements a separate Algorithm which queries the **KinkCollection** generated by **InDetKinkFinder**, and fills up a CBNT block with the kink data. This part of the software was not used for the following performance evaluation though.

3 Performances.

3.1 Monte-Carlo evaluation.

Two sets of simulated data were used for performance evaluation: one set of single Σ^+ baryons generated with the *SingleParticle* event generator and forced to decay thanks to the package *EvtGen*, and another set of events containing top pair decays.
The first one was used to evaluate the reconstruction efficiency and the second one for evaluation of CPU and memory usage, as this kind of event provides a track multiplicity close to the expected average on normal running conditions.
Both samples have been simulated with the "Rome-Initial" ATLAS geometry layout reproducing expected detector layout when the data taking will start in 2007.
The results of this initial evaluation are provided in table 1:

Monte Carlo sample	$t\bar{t}$	Σ^+ ($p_t = 20$ GeV)
Statistics (events)	2000	10000
average CPU/event (s)	0.39 ± 0.17	0.056 ± 0.022
max CPU/event (s)	8.5	19
Total tracks in input	94368	11720
Selected tracks	23541 (23.7 %)	8754 (74.7%)
Reconstructed kinks	5592 (5.9 %)	(14.2 %)
"Refitted Primary tracks"	5130 [91.7 %]	1247 [74.9%]
"Refitted Secondary tracks"	2 [–]	1 [–]
"Fully Resolved kinks"	560 [8.3 %]	417 [25.1%]

Table 1: Statistical data from Monte Carlo samples: CPU consumption, total number of tracks in input, after selection, and reconstructed by the kink finder module. Reconstruction breakdown is shown in the three last rows, with percentage numbers referring to the "Reconstructed Tracks" rows (=100%).

In this table, CPU consumption is given by event, both average and longest event processed over the whole sample. The CPU consumption is not

normalised, but both samples were processed on the same machine, so the two values can compare with each other. The processing time is proportional to the number of selected tracks per event.
Selected tracks are kink candidates.
The reconstruction patterns in the breakdown part are the following:

- "Refitted Primary tracks" are partly resolved kinks where the daughter segment could not be refitted (usually because it has not enough hits). They are most of the time good tracks with few TRT outliers that were discarded during the refit, but can be late decays in the TRT as well.

- "Refitted Secondary tracks" are the same as above, except that the missing part is near the IP.

- "Fully Resolved kinks" are kinks with two refitted track segments.

In both samples, the dominant topology ($>$ 99.9 % of selected tracks) is "Bad track". This is due to the fact that the track reconstruction proceeds from SCT and pixel hits to form prototracks and extend to TRT afterwards. The number of degree of freedom to make these proto-tracks is limited, disfavouring track splitting which would lead to the "Broken tracks" topology". This topology is further disfavoured by the fact that TRT-only tracks are not available yet.
The dominance of the "Refitted Primary tracks" over the reconstructed patterns is due to the difficulty to fit TRT-only tracks with the traditional Kalman filter used in the Kink finding module. This difficulty could be overcome with the use of a dedicated track fitter for drift circle, the Deterministic Annealing Filter [3], under evaluation.
Single Σ^+ were simulated to be fired within the Inner Detector acceptance ($|\eta| < 2.5$), but no generation cut was applied to the decay length. As a consequence, most Sigma baryons decayed before reaching the first detector layer ($\rho = 12$ cm) and the daughter track was reconstructed as a good track, evading selection.
Computing performances are pretty good: not a single crash observed during any simulated sample processing, CPU time consumption is of the order of the **NewSCT_Clusterization** module in both cases. A minor memory leak of the order of 0.4 MB per $t\bar{t}$ event was found, and will be cured in the coming releases.

3.2 Evaluation on real data: combined test beam data from 2004 run.

Again, two data sets were used for performance evaluation. One with a muon beam to use as control sample (given the suppressed interaction rate of muons) and one with electron beam (as bremsstrahlung interactions will provide a fair amount of kinked tracks). We selected runs with all Inner detector components (Pixel, SCT and TRT) on and a non-zero magnetic field in the inner detector (MBPSID magnetic field).
The selected muon run number was 2102423 (150 GeV muons, MBPSID magnet current = 100 A, $\eta = 0.449$) and 2102195 for the electrons (180 GeV beam, MBPSID magnet current = -850 A, $\eta = 0.55$). The results of this evaluation are provided in table 2:

run number	2102195 (electrons)	2102423 (muons)
Statistics (events)	535	1387
average CPU/event (s)	0.049 ± 0.054	0.042 ± 0.044
max CPU/event (s)	2.1	1.9
Total tracks in input	508	1391
Selected tracks	500 (98.4 %)	1308 (94.0%)
Reconstructed kinks	75 (14.8 %)	63 (4.8 %)
"Refitted Primary tracks"	0	0
"Refitted Secondary tracks"	0	0
"Fully Resolved kinks"	75 [100 %]	63 [100%]

Table 2: Statistical data from Combined Test Beam analysis: total number of tracks in input, after selection, and reconstructed by the kink finder module. Reconstruction breakdown is the same as Table 1.

Limited statistics are due to very frequent crashes from an unprotected matrix inversion in the Kalman Filter module. This bug was especially virulent in the electron sample, but was not found at all in the simulated data with ATLAS geometry.
It is quite hard to compare Combined Test Beam (CTB) data and Monte-Carlo, as the geometry and detector layout are completely different: the CTB setup is a wedge, a slice of the ATLAS detector, reproducing the expected detector layout but in a different scale [4]. Furthermore, the CTB magnetic field does not extend to the TRT, hence the large number of kinks which happen to be located around the same place, at the entrance of the TRT volume.
High levels of selection are achieved due to misalignment issues, not found

in the ideal Monte-Carlo setup.
No software crash was caused by the Kink module directly (the only crashes reported were due to the Kalman Filter module), and CPU consumption was found to be in agreement with single Sigma sample's numbers.
More investigations will be needed for the kinks found in the combined test beam data, mostly to state if the reconstructed kink is due to the magnetic field transition , misalignment between the TRT in one hand and the rest of the Inner Detector on the other hand, or material interactions (as the kink reconstruction rate was found to be three times higher for electrons than for muons). This work will be detailed in a future note.

4 Conclusion.

The scope of this report was to assess the computing performances of the kink finder module and provide a first glimpse of the reconstruction abilities of this module and the underlying physics. More analysis work is needed for Combined Test Beam data and will be detailed in a future note.

References

[1] ATLAS Collaboration, *"ATLAS: Detector and Physics Performance Technical Design Report"*, CERN/LHCC/99-15 (1999).

[2] see for instance:
A.J. Barr *et al.*, JHEP 0303 (2003) 045.
B.C. Allanach, A. Dedes, H.K. Dreiner, Phys.Rev. D69 (2004) 115002.
M. Sher, Phys. Rev **D 52** (1995) 3136.

[3] see `http://agenda.cern.ch/askArchive.php?base=agenda&categ=a057207&id=a057207s14t4/transparencies` for a recent update on this track fitter.

[4] ATLAS Collaboration, *"ATLAS Barrel Combined Run in 2004 Test Beam Setup and its evolutions"*, ATC-TT-IN-0001 (2005).