Physics Use cases and Methods for a Kink–finding Algorithm in ATLAS.

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Abstract

This document is a review of the possible physics cases, existing methods and implementations of a kink–finding tool to be developed for the track reconstruction in the ATLAS experiment. This review is to be used to define and optimize the development strategy of such tool.

1 Introduction.

The need for a kink–finding algorithm running as part of the offline reconstruction arose around 2000, as a second–level tracking tool. Its main aim is to improve the reconstruction of tracks affected by the large number of decay lengths in the Inner detector (see [1]). It can also be used for several physics analysis, as we will see later in this note.
The organization of the document is the following: we will start by a review of the physics use cases for such tool, then we will review the existing (and documented) implementations and methods developped by a selected panel of HEP experiments. We will conclude by providing a first draft on the integration of this AlgTool in the ATLAS Reconstruction framework and some ideas about its content.

2 Physics cases.

There are two main physics cases for kink–finding.
The first one is to improve the track reconstruction efficiency, by recovering tracks who failed pattern recognition due to interactions with the detector material (about 10-20% of the tracks, according to [1]).
The second one is the reconstruction of long–lived, charged particles, either exotic ones (SUSY GMSB or RPV staus, AMSB charginos) or charged hyperons.
A potential third use case may arise from B physics, to improve the identification and rejection of low p_T pions and kaons decaying in flight into muons.

2.1 Track recovery.

Tracks undergoing single or multiple interactions usually fail to be fully reconstructed by the two pattern recognition algorithms in use in ATLAS (xKalman [2] and iPatRec [3]), leaving small track segments (or seeds) in the inner layers of the tracking system.
This is especially the case for very energetic tracks (multiple scattering) or particles likely to interact with the detector medium (electrons, pions).
Recovery of these very energetic tracks and electrons (in coordination with the Bremstrahlung recovery group) will increase the selection efficiency in many physics channels depending on this signature.

2.2 Long–lived, charged Supersymmetric particles.

Some supersymmetric models predict the existence of charged particles with very small (of the order of the eV) decay width. This kind of width can be achieved for AMSB charginos that are nearly mass–degenerate with the lightest neutralino. Their only decay processes are: $\tilde{\chi}_1^{\pm} \rightarrow (\pi^{\pm}, \mu^{\pm}, e^{\pm})\tilde{\chi}_1^0$, depending on the model (see for instance [4]).
eV range decay widths can also be achieved by R-Parity violating (RPV) staus, when this particle is the Lightest Supersymmetric Particle (LSP) (high tan β). In this case, only RPV modes are allowed (modes with no supersymmetric particle emitted), three, four or even five body decays can happen with a very small decay length, resulting on a long or intermediate lifetime of the stau, depending on the coupling involved and its relative strength [5].
A third class of extended supersymmetric models [6] requiring an extra set of lepton doublets and singlet to achieve gauge unification at intermediate scale ($10^{11} GeV$) may provide a charged lepton whose lifetime can be compatible with decay in the outer layers of the tracker.

As these new particles may decay anywhere in ATLAS, this particular use case will require to extend the search for kinks up to the Muon chambers, instead of restricting the reconstruction to the Inner Detector.
The kink finding tool must therefore be flexible enough to deal with tracks and hits from other detectors.
As this development will certainly not be available on the first release cycles of the tool, flexibility must be kept in mind to allow us to eventually achieve this goal of reconstruction across the different subdetectors.

2.3 Charged Hyperons.

These particles can be reconstructed very efficiently, with a reduced level of combinatoric background if we apply a kink finding method to discriminate against QCD background. As they are produced abundantly in p–p collisions, they can be used for detector scans, alignment checks, control sample for systematic checks and kink–finding algorithm training, as well as for baryon physics.

2.4 Improvement on rejection of low p_T secondary muons.

One of the main trigger for B physics in ATLAS are low p_T muons from semileptonic B decays. Unfortunately, this channel suffers from a large background coming from lighter mesons semileptonic decays, like $\pi^+ \to \mu^+\nu_\mu$ or $K^+ \to \mu^+\nu_\mu$.
Given the long lifetime of these two particles and their low momentum, these decays in flight are likely to happen before the particle reaches the muon chambers, producing a small kink at the production point of the secondary muon.
A powerful selection technique is already applied to get rid of most of these secondary muons, performing a chisquare matching between track segments in the Inner Detector and the Muon Chambers. Given the large lever arm between these two detectors, it is hardly conceivable that any measurable kink is left among the track passing the selection, so we think that there is very little room for improvement here.
However, it is always worth checking this assertion once we have a prototype set.

3 Existing Implementations.

The documentation about existing implementations of a kink–finding algorithm is scarce and very hard to find. We focused at first on CDF and D0, which are already running and present the closest data taking conditions in terms of tracker occupancy. Both experiments [7] have reconstructed the light, charged hyperons $\Omega^- \rightarrow K^-\Lambda$ and $\Xi^- \rightarrow \pi^-\Lambda$, but they were actually pairing one loose quality track to a V^0, and checked that there was a track segment in the Vertex detector matching the direction of the reconstructed hyperon.
CMS does not seem to have developed any kink–finding algorithm either. LHCB would be the best suited candidate, as we share the same computing framework (Gaudi) and have roughly the same physics environment. Unfortunately, we could not find anything on kink finding algorithm development, most probably because a significant fraction of the long–lived particles do not decay in their tracker (extrapolated from K_s^0 reconstruction numbers in [8]).
The next candidates are the LEP experiments. Lower charged multiplicities and occupancies may lead to an algorithm which might be unsuitable for LHC conditions in terms of processing speed and efficiency. Furthermore, we would have to port the code from FORTRAN to C++.
Most of the existing references on kink–finding implementations and methods are coming from fixed target, neutrino experiments (CHORUS, NOMAD). These experiments are very far away from LHC conditions in terms of track density and event rates, so we will just study their methods.

4 Methods.

The kink–finding methods found in the litterature apply to track refitting, small angle kink finding and the treatment of multiple scattering.
Multiple scattering treatement methods are discussed in [9] and [10].
In [9], the author propose a new, iterative, fitting method, avoiding the inversion of large covariance error matrices and thus saving CPU time which is clearly an issue given the large tracking multiplicity achieved in LHC p–p collisions.
In [10], different methods (global fit, break point analysis and progressive Track element merging) are compared and applied to the case of the LEP experiment DELPHI. ATLAS tracking layout is somewhat different, with a larger material budget, so the evaluation performed must be redone, including the method described in [9].
Fit estimators are compared in [11] in terms of performance and goodness–

of–fit. They show that correlations variables based on the distance between measurements could provide better results on finding small kinks on a track than the least chi square test. Furthermore, this new test is independant from the least chi square test, usually performed on initial Kalman filtering, and can be used on top of the output of this track fitting method.
Unfortunately, it seems that the net improvement of applying these correlations variable to a small number of measurements (up to 40 in ATLAS) is somewhat reduced. We will nevertheless redo the evaluation of this kink–finding method in ATLAS conditons.
A track breakpoint analysis applied to tracks reconstructed with a Kalman filter is performed in the framework of the NOMAD experiment in [12]
They use it to locate kinks from δ electrons emitted by muons and improve the event reconstruction. They claim that the processing time was negligible, and helped a lot in performing the track (error) matrix inversion.
This method looks promising, and will be studied in collaboration with the Bremstrahlung recovery people.

5 Discussion and suggested plans.

5.1 Fitting ATLAS Inner Detector Reconstruction Code layout.

The ATLAS Event reconstruction chain for the Inner Detector Tracking is described in Figure 1:

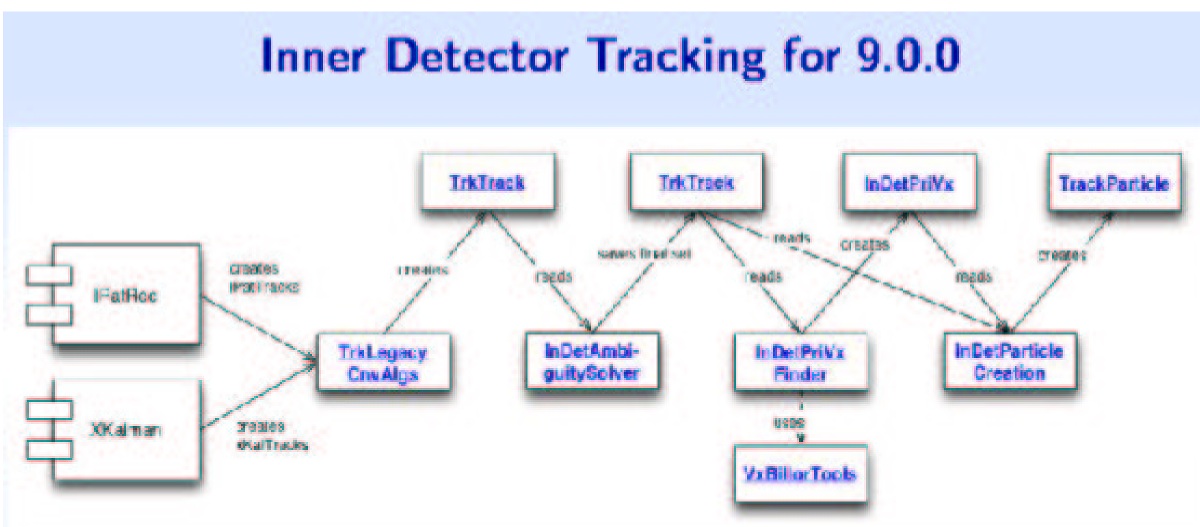

Figure 1: Event reconstruction chain for ATLAS 9.0.0. and greater.

According to this schema, we should aim for a package that would sit near the end of the chain, like the InDetPriVxFinder class in Figure 1.
It will take as input the Trk::Track collections of tracks found and fitted by one of the of the two track finding algorithm used in ATLAS, iPatRec and xKalman, sorted by increasing fit quality.
Unfortunately, both algorithms require a minimum number of hits in the SCT (6 for iPatRec and 8 for xKalman) which prevents the reconstruction of secondary tracks coming from the decay of long–lived particles ($\beta\gamma c\tau > 40$ cm). This effect has been seen in the reconstruction of K_s^0 in B physics analyses [13]. Furthermore, the same study show a strongly reduced K_s^0 reconstruction efficiency (< 50 % over the whole range of decay length considered).
A dedicated tool for an improved secondary track reconstruction is therefore needed.

The algorithm will be twofold, as we have to consider two different cases of kinks.
Small opening kinks will be found by refitting "bad quality" single tracks from the Trk::Track collection used as input.
Wide opening kinks will be seen as two different tracks, which will be extrapolated to their intersection point. Track extrapolation tools will be used and tailored to this particular need.
Track refitting will be applied first. The methods mentionned in the section 4 will be evaluated. The refitted tracks will be stored on a transient Trk::Track collection, and their matching hits removed.
Secondary track reconstruction will be performed next, using all unused hits from the first pass track reconstruction and refitting. Secondary tracks will be added to the input Trk::Track collection, sorted by increasing fit quality (χ^2).
Track extrapolation and intersection for wide–opening kink finding will be performed as a final operation.
Track refitting, track extrapolation and intersection AlgTools are coded as separate classes whose methods are called by the main kink-finding module. Since several methods (for track extrapolation and intersection) have already being developped for a different use in ATLAS, we will just need to tailor them to our use.
The secondary track finder will be developped together with the V0 reconstrcution people. The break point analysis developped in [12] will be investigated together with the Bremstrahlung recovery people.

The output of the kink-finding algorithms would be a collection of Kink objects, described below, as well as a collection of Trk::Tracks and Trk::Particles objects containing refitted tracks and secondary tracks from unused hits.

5.2 The Kink object.

The "Kink" object should be a composite object, made of:

- 2 "Track" objects, the mother and the daughter.
- 1 "Vertex" object for the location of the kink. Vertex fitting variables can be reused (to a certain extent) to accomodate most of the kink fitting useful data.
- 1 "block" of dedicated variables (private and public) for the kink fit. Unless it is already included on the Vertex object (most likely).
- 1 "neutral Particle" object for the neutral daughter. Most likely a 4 vector, may be improved if needed.
- dedicated methods to access/set some kinematics variables, like the mass of the particles involved (mother/daughter/neutral), locate the closest detector layer to the kink and returns the probability of a "conversion", and so on...

5.3 Matching the proposed milestones.

This document and the different discussions with other people sharing some interest in developping common methods will lead to some minor alterations of the milestones proposed on the Logbook, mostly second level ones, to take into account methods developped in collaboration with other computing groups (V0 finding, Bremstrahlung recovery) and further work needed (Secondary track finder, development of track extrapolation tools).
The general layout of the project will not be affected though, as it already takes into account most of the developments proposed in this note, and is optimized to provide quickly a working prototype, with minimal functionnality, based on existing developments in ATLAS.
New level–2 milestones describing the methods developped in collaboration with other subgroups (V0 finding, Bremstrahlung recovery) will be discussed within the WP2 group before being added to the Logbook.

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