LDC Tracking Package

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This note describes the software, performing tracking in the detector at the International e^+e^- Linear Collider (ILC). The code is designed specifically for the Large Detector Concept (LDC). It is implemented within the framework of Marlin and uses LCIO as the data format. Results of initial performance studies are presented for the tracking system of the LDC detector. The note is based on the talk given at the LCWS07 Conference [1].

1 Introduction

The ambitious physics program at the ILC sets stringent requirements on the detector. For the tracking system this means:

- excellent momentum resolution $\delta(1/p_T) \leq 5 \cdot 10^{-5}$ (GeV/c)$^{-1}$;
- very good flavour tagging capability, the vertex detector must measure impact parameter of tracks with the resolution $\delta(IP) \leq 5\mu\text{m} \oplus 10\mu\text{m}/p[\text{GeV/c}] \cdot \sin^{3/2}\theta$;
- efficient reconstruction of tracks in the dense jets, characterized by high local multiplicities of charge particles;
- full reconstruction of low p_T loopers, enabling precise extrapolation of tracks to the endcap calorimeters with subsequent linkage of tracks with calorimeter clusters.

Several detector concepts have emerged as a result of intensive R&D program for the ILC detector [2]. This note describes the tracking software designed within the framework of the Large Detector Concept (LDC). The LDC tracking system consists of the following components.

1. Microvertex pixel detector (VTX) surrounds the primary interaction point. The detector has 5 coaxial silicon layers. The innermost layer has radius 1.55 mm and the outermost - 6.0 mm.
2. Large volume Time Projection Chamber (TPC) ($r \sim 170$cm, $L \sim 2 \times 270$cm) represents the main component of the LDC tracking system.
3. Intermediate Si Tracker (SIT) has two cylindrical layers with radii 160 and 300 mm. Strip-wise readout is foreseen for this detector. SIT serves as a linker between VTX and TPC.
4. Forward Si tracking discs (FTD's) ensure good track reconstruction in the forward region. In the baseline LDC detector design, the forward tracking detector consists of 7 discs in both hemispheres placed at distance between 200 and 1300 mm from the interaction point. The three innermost discs on both sides will be instrumented with hybrid pixels, while for the remaining discs the strip readout is planned.

2 Structure of the Package

The LDC tracking code is implemented within the framework of MARLIN [3] and constitutes a part of the MARLINRECO package [4]. The code includes:

- MARLIN processors performing digitization of the signal in various tracking subdetectors;
- MARLIN processors implementing pattern recognition in TPC and silicon detectors;
- the track fitting code based on the Kalman filter approach;
- utility classes facilitating fast and efficient pattern recognition;
- class `MarlinTrackFit` providing an interface to the FORTRAN based DELPHI code;
- FORTRAN code from DELPHI, which performs pattern recognition in TPC, the interface of the FORTRAN code to the MARLINRECO package is realized in the form of C++ wrappers.

The software is compliant with the LCIO data format [5]. The track parameterization follows the ILC convention documented in Ref. [6]. The track parameters and corresponding covariance matrix are evaluated with the Kalman filter at the point of closest approach to the nominal e^+e^- interaction point.

2.1 Digitization Processors

The digitization of the simulated tracker hits (`SimTrackerHits`), produced during the detector simulation run, is performed in two different ways. The first approach is based on the Gaussian smearing of `SimTrackerHits` according to a-priori known and specified spatial point resolutions. This approach is implemented in the processors `VTXDigiProcessor`, `FTDDigiProcessor` and `TPCDigiProcessor`. The module `VTXDigiProcessor` performs digitization of `SimTrackerHits` in the vertex detector and SIT, `FTDDigiProcessor` - in the forward tracking discs and `TPCDigiProcessor` - in TPC. All processors require `SimTrackerHit` collection names as an input parameters. The `VTXDigiProcessor` treats VTX and SIT as cylindrical detectors. The two spatial point resolutions, one in the $r - \phi$ projection and another - along z, should be provided by user as a processor parameter. `FTDDigiProcessor` treats forward tracking discs as a rigid measurement planes at fixed positions in z. It is assumed that the hit position in the FTD's is measured "isotropically", thus a user has to provide only spatial point resolution in the r-ϕ projection. The TPC spatial resolution in r-ϕ is given by $\sigma^2(r - \phi) = \sigma_0^2 + D^2 \cdot L_{drift}$ where σ_0 is the constant term, D is the diffusion coefficient and L_{drift} is the drift length. Resolution along z axis is assumed to be independent of L_{drift}.

For the DEPFET-based microvertex detector, a detailed digitization procedure is implemented in the MARLIN processor `VTXDigitizer`. The procedure takes into account Lorentz effect, charge diffusion, electronic noise and energy loss fluctuations along the charged particle trajectory within the sensitive silicon layer.

All digitization processors produce as an output LCIO collections of the digitized tracker hits (`TrackerHit`)s. Each `TrackerHit` is attributed with the 3D position and covariance matrix of the position measurement. The covariant matrix of the hit position measurement is then used in the track fitting procedure.

2.2 Pattern Recognition in TPC

Pattern recognition in TPC is done using C++ wrappers of the LEP code. The main MARLIN module is `LEPTrackingProcessor`, which invokes FORTRAN routines, which perform inward search for spatially continuous sequences of hits, compatible with the helix hypothesis, and fits these sequences. The LEP code is capable of finding only semiloops of the tracks. As a consequence, the low p_T loopers are splitted into several segments, which are then identified and merged by the `FullLDCTracking` processor described below. `LEPTrackingProcessor` requires as an input LCIO collection of the TPC `TrackerHits` and produces LCIO collections of the TPC tracks and inter-relations between tracks and Monte Carlo particles.

2.3 Pattern Recognition in Silicon Detectors

Combined pattern recognition in all silicon tracking devices (VTX, FTD and SIT) is implemented in the processor `SiliconTracking`. The procedure starts with the search for hit triplets in the outermost layers of the combined VTX-SIT tracking system and in FTD. Once such triplets are found, an inward extrapolation of the track candidates is performed and additional hits in the inner layers of VTX and FTD are assigned to the track candidates. The `SiliconTracking` processor requires as an input collections of VTX, FTD and SIT `TrackerHits` and produces the collections of silicon tracks and track - particle relations.

2.4 Association of the Silicon and TPC track segments. Full LDC Tracking.

The final step of the track reconstruction in the LDC detector consists of the association of track segments found in TPC and silicon detectors, merging splitted loopers in TPC and assignment of the left-over hits to the found tracks. All this is done by the `FullLDCTracking` processor. It requires as an input collections of VTX, FTD, SIT and TPC `TrackerHits` and collections of silicon and TPC tracks. An output is produced in the form of the fully reconstructed LDC tracks and track $-$ MC particle relations.

2.5 TrackCheater Processor

The `TrackCheater` processor is designed to construct true Monte Carlo tracks from the hits attributable to the same Monte Carlo particles. Thus, this processor just emulates perfect pattern recognition. An user can optionally set track parameters, using generated values of the 4-momentum of charged particles or perform a fit of the cheated tracks. The `TrackCheater` processor requires as an input collections of `TrackerHits` in various subdetectors and produces collections of true Monte Carlo tracks and track $-$ MC Particle relations.

2.6 Detector Geometry and Material Description

The information on the detector geometry and material properties is needed both at the stage of the signal digitization and the track reconstruction. Description of the detector is provided via GEAR interface [7].

3 Performance Studies

Performance of the code has been evaluated on the samples produced with MOKKA program [8] simulating the LDC detector response. The detector model LDC01Sc was used. The following spatial point resolutions were assumed for various tracking subdetectors:

- VTX : $\sigma_{r-\phi} = \sigma_z = 4\mu\text{m}$,
- FTD : $\sigma_x = \sigma_y = 10\mu\text{m}$,
- SIT : $\sigma_{r-\phi} = \sigma_z = 10\mu\text{m}$,
- TPC : $\sigma_{r-\phi} = 55\mu m \oplus 3\mu\text{m}^{1/2}\sqrt{L_{drift}}$, $\sigma_z = 0.5\text{mm}$

Simple digitization procedure, performing Gaussian smearing of the simulated hit positions, is applied for each tracking subdetector.

The resolution on the track parameters has been investigated with the samples of single muons. Both momentum and polar angle of muons have been varied to study the dependence of resolution on the track momentum and polar angle. In the central part of the detector, the overall momentum resolution asymptotically reaches $\delta(1/p_T) = 3.5 \cdot 10^{-5}$ $(\text{GeV/c})^{-1}$ with increasing particle momentum. The multiple scattering degrades the resolution at lower momenta. For the charged particles with momentum around 1 GeV, the resolutions varies from $\delta(1/p_T) = 1.5 \cdot 10^{-3}$ to $3 \cdot 10^{-3}$ $(\text{GeV/c})^{-1}$ depending on the polar angle. The impact parameter resolution is found to be $\delta(IP) = 4\mu\text{m} \oplus 9\mu\text{m}/p[\text{GeV/c}] \cdot \sin^{3/2}\theta$. In the central region, the polar and azimuth angles are measured with precision better than 0.1 mrad for particle momenta $p > 50$ GeV. The resolution degrades to few mrad at $p < 1$ GeV.

The track finding efficiency has been studied on the sample of the pair produced top quarks at 500 GeV. Figure 1 shows the efficiency as a function of the particle momentum and polar angle. The overall efficiency is found to be 99(97.5)% for track momenta $p >$ 1(0.4) GeV/c.

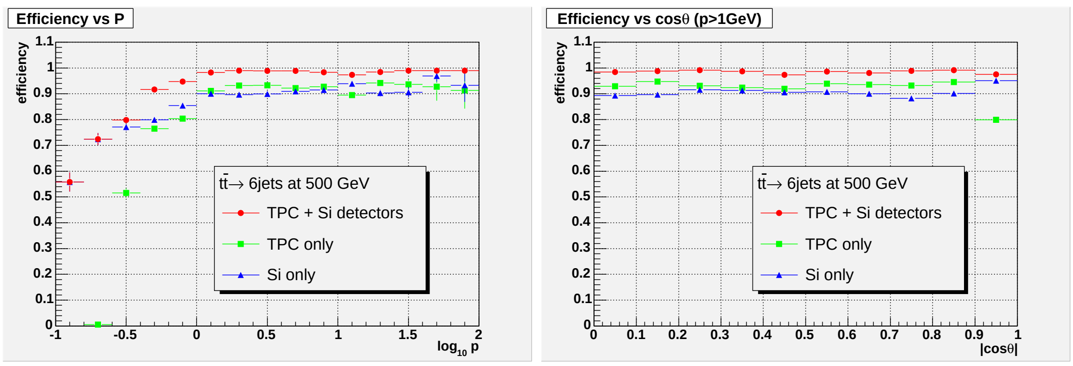

Figure 1: The track finding efficiency as a function of the track momentum (left plot) and polar angle (right plot) in the sample of the $e^+e^- \to t\bar{t}$ events at 500 GeV. The dependence of the track efficiency on the polar angle is presented only for tracks with momentum greater than 1 GeV.

The tracking code has been also tried in combination with the particle flow algorithms (PFA). The PFA-related performance has been evaluated in two ways. First, the tracking code has been combined with the ideal PFA, implementing perfect clustering in the calorimeters and fully efficient cluster-track association. In the second trial, the tracking code has been interfaced to the realistic algorithm Wolf-PFA [9]. The performance has been estimated in terms of the di-jet mass resolution in the sample of the Higgs boson production via the W-fusion mechanism, $e^+e^- \to W^+W^-\nu\bar{\nu} \to H\nu\bar{\nu}$. The center-of-mass energy is chosen to be 800 GeV, the Higgs boson mass is set to 120 GeV.

To eliminate the impact of missing neutrinos from b and c-hadrons decays on the di-jet mass resolution, the Higgs boson is forced to decay to $s\bar{s}$ pairs. Thus, only those effects, which are related to the event reconstruction efficiency and detector resolution, are studied.

Figure 2 shows the reconstructed Higgs boson mass for the runs with the perfect and Wolf particle flow algorithms. For each of the considered cases, the results are compared between the perfect tracking, performed by the `TrackCheater` processor, and realistic LDC tracking. Only slight deterioration of the di-jet mass resolution is observed for the realistic LDC tracking when compared to the runs with `TrackCheater`.

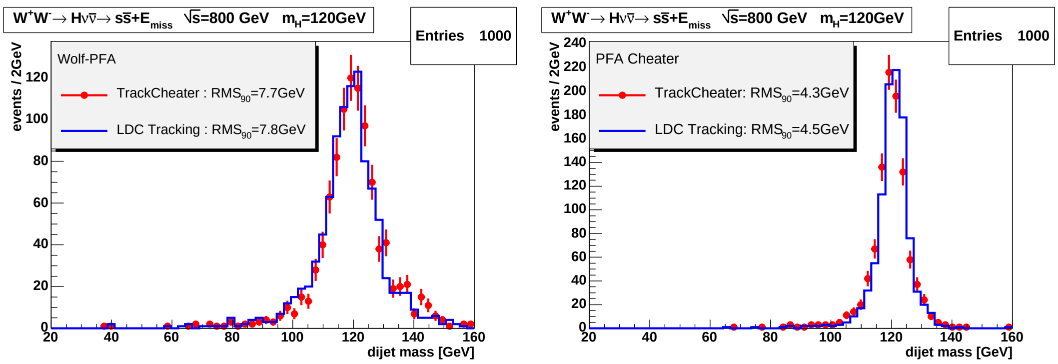

Figure 2: The di-jet mass distribution in the sample of the $e^+e^- \to W^+W^-\nu\bar{\nu} \to H\nu\bar{\nu}$ events. Left plot shows results obtained with the realistic Particle Flow Algorithm Wolf-PFA. Right plot - with the perfect PFA. Dots with error bars correspond to the runs with the perfect tracking, solid histograms - with the realistic LDC tracking.

4 Conclusion

The LDC tracking software has been developed as a part of the MarlinReco package. The code performs digitization of the signal in various tracking subdetectors, followed by track finding and fitting in the LDC detector. Initial studies showed that the LDC detector supported by the designed code meets the performance requirements imposed by the ILC physics program. The package can be used in future detector optimization and performance studies and in physics analyses relying upon the full detector simulation and event reconstruction.

References

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