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Track reconstruction for the CDF silicon tracking system

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Abstract. The Collider Detector at Fermilab (CDF) Collaboration will install a new silicon micro-strip tracking system for Run 2 at Fermilab starting in 1999. The new detector will require powerful new pattern recognition algorithms to exploit its full capabilities. This talk discusses the design, implementation and performance of some of these algorithms.

INTRODUCTION

In 1991, the Collider Detector at Fermilab (CDF) began operating a silicon microstrip detector in order to increase sensitivity to Standard Model top decays and other processes that create b-flavored or long-lived particles in $\sqrt{s} = 1.8$ TeV $p\bar{p}$ collisions at the Fermilab Tevatron. Spurred by the success of this detector and the prospect of significantly higher luminosities during the upcoming "Run 2" at Fermilab, CDF embarked on a significant upgrade of the entire detector, and the tracking systems in particular [1]. A new silicon system will offer both greatly increased acceptance, and full three-dimensional information with sufficient redundancy to allow stand-alone pattern recognition. Exploiting the capabilities of this new silicon system will require powerful new pattern recognition algorithms. To address this need, CDF is developing an object-oriented pattern recognition program implemented in C++. In this talk, we will discuss a few of the important features of the new silicon detectors, some pertinent aspects of the Run 2 tracking envi-

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ronment, the basic design of the pattern recognition framework, and finally some details and preliminary results from the algorithms currently under development.

THE SILICON TRACKING SYSTEM

The silicon tracking system consists of two independent detectors, the Silicon Vertex detector II (SVXII) and the Intermediate Silicon Layers (ISL). The SVXII consists of five layers of sensors with double-sided readout arranged around the beam axis. One side of each sensor has "R-ϕ" readout strips oriented parallel to the beam axis. The layout of the strips on the other side depends upon the layer. Three of the five have strips oriented at 90° to the beam axis; the remaining two layers have small-angle-stereo strips oriented at 1.2° to the beam axis. Longitudinally, the sensors are segmented into six independent readout units, each about 14 cm long. The 90°-stereo strips are ganged into two, three or four groups within each readout unit, depending upon the layer.

The ISL surrounds the SVXII with an additional layer of sensors in the central region, and two in the forward and backward regions. All sensors have R-ϕ strips on one side and small-angle-stereo strips on the other.

Outside the silicon detectors lies an axial-wire drift chamber with 96 measurement layers. This detector provides stand-alone pattern recognition for high-momentum tracks in the central region.

Figure 1 shows the angular coverage of each element in the tracking system. Tracks with measurements in both the drift chamber and the inner layer of silicon

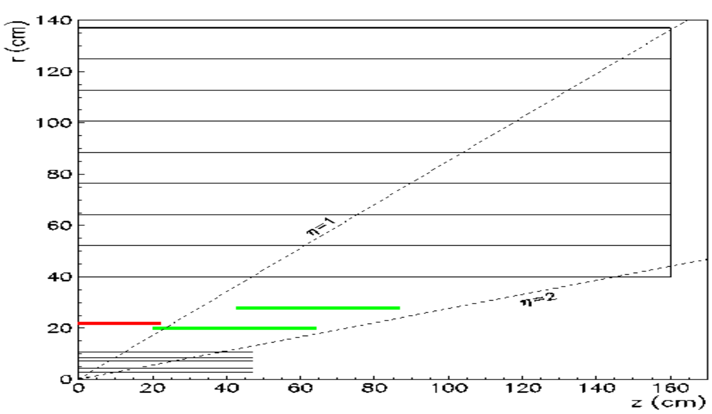

FIGURE 1. Angular coverage of the SVXII (lower left), ISL (red, green) and drift chamber.

will have an impact parameter resolution given by $\sigma = \sqrt{A^2 + B^2/P_T^2 \sin\theta}$, where A = 10 μm to 15 μm, and B = 35 to 70 μm/GeV-c for tracks at normal incidence.

CDF RUN 2 TRACKING ENVIRONMENT

Several features of the tracking environment represent important considerations in the design of the pattern recognition. The instantaneous luminosity in Run 2 produces an average of three $p\bar{p}$ collisions per beam crossing, introducing an average of about 50 particles in each event in addition to those from the hard scattering. The interactions are normally distributed along the beam axis with a standard deviation of about 24 cm. Secondary interactions within the material of the detector introduce another factor of two in the total particle multiplicity. In addition, multiple Coulomb scattering must be taken into account at the pattern recognition stage for particles at low momentum. Finally, the multiplexing of 90°-stereo strips introduces ghost hits on three layers.

DESIGN OF THE PATTERN RECOGNITION

The complexity of events in the silicon detectors coupled by the large angular acceptance suggests that several different algorithms may be required to find all tracks in the detectors. A reasonable approach to optimize the overall performance is to apply several algorithms sequentially, allowing each to find only those tracks it is best suited to find, removing hits on those tracks from further consideration.

The basic design pattern of the pattern recognition is that of a “Strategy.” [2] Algorithms, each encapsulated within a distinct Strategy class, respond to an “execute” method. The tracker class collects and sequentially executes a set of Strategies, passing each the allowed input and output classes.

To deal with the problem of fitting tracks across multiple devices, we have developed a set of fitting classes that separates the fitting engine from knowledge of the type of fit being performed, delegating this task instead to the inputs to the fit. The principal base classes (see Fig. 2) are the FitAction and the Fitter. Sub-classes of the FitAction perform calculations to incorporate specific information within the fit, such as the measurement type, the effects of multiple scattering, energy loss, constraints and magnetic field inhomogeneities. The Fitter class operates by collecting and sequentially applying a set of FitActions specified by the client. This design is a generalization of a design from the BaBar experiment.

The entire structure is templated on the “measurable” being fit, a helix in the case of a track fit, and a space-point for a vertex fit. The result of a fit is itself a measurable and can therefore be used as an input to another fit.

PATTERN RECOGNITION ALGORITHM

The silicon track reconstruction algorithms fall into two categories: stand-alone, and "outside-in." In the latter, tracks from the drift chamber are extrapolated into the silicon detector. We will discuss only the former.

Silicon stand-alone pattern recognition

The stand-alone pattern recognition algorithm is based primarily upon the "triplet strategy." This algorithm exploits the three-dimensional information in the detector at a very early stage in order to reduce the combinatoric complexity.

The algorithm proceeds by first pairing small-angle-stereo and R$-\phi$ strips on all small-angle-stereo sensors to form three-dimensional hits. A set of three such "seed-hits" are used to define a track candidate. Since a triplet over-constrains the trajectory, the algorithm can eliminate spurious hit combinations by imposing a χ^2 requirement. A triplet also provides sufficient information to isolate a particular kinematic or angular region, or associate it with a particular primary vertex. Such

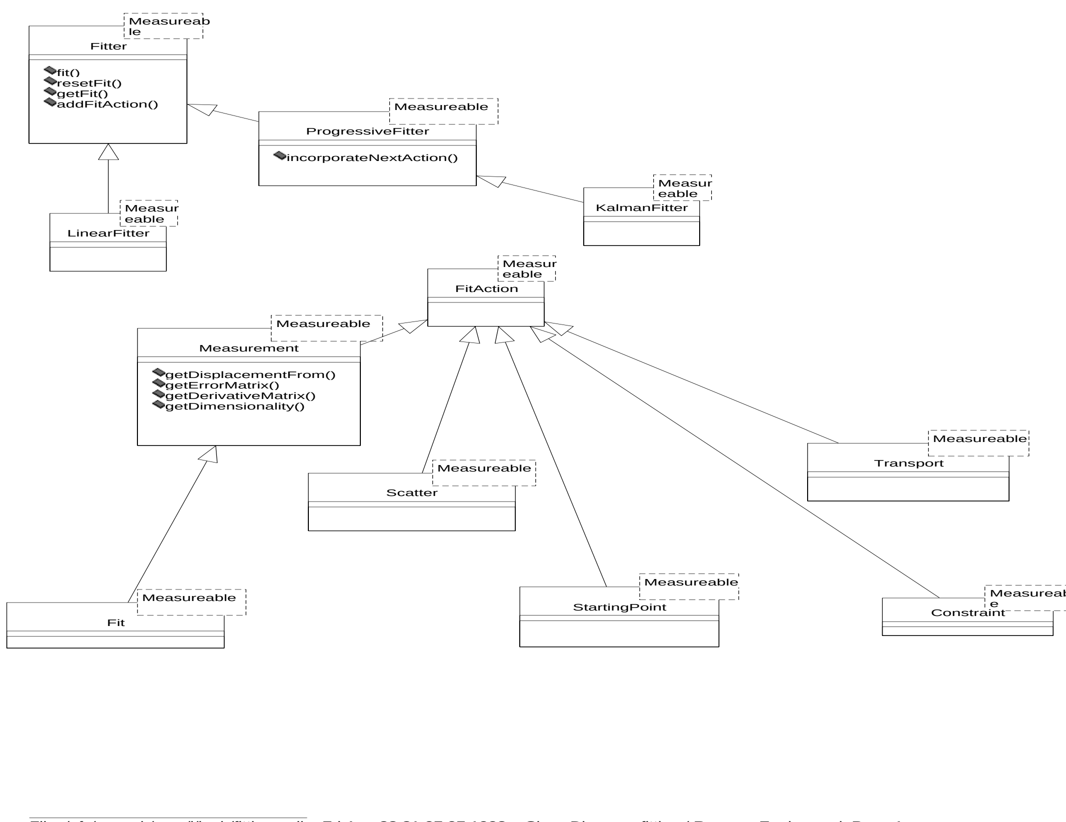

FIGURE 2. Class diagram for the fitting classes.

tuning at the candidate selection phase makes the triplet strategy an ideal choice to run when the hit density is the highest.

The triplet strategy next searches within a road for additional hits. Multiple hits within the road are pursued independently on cloned candidates. After the pursuit is completed, all clones but one are pruned, choosing the best based upon the χ^2 and the number of hits found.

The final phase selects or rejects track candidates using more stringent requirements on the χ^2 and the number of hits found. Conflicts between tracks sharing seed hits are resolved by minimizing a linear objective function [3] that includes the χ^2, and a penalty for missing hits or shared hits with insufficient charge to be consistent with more than one track.

Figure 3 shows the tracks reconstructed in a typical simulated $\bar{\mathrm{p}}\mathrm{p} \rightarrow \mathrm{t}\bar{\mathrm{t}} \rightarrow W+$ jets event. A displaced vertex is clearly visible in the lower jet.

Performance

The track-finding efficiency has been measured in simulated samples of top and single muon events (Fig. 4). In top events, the average efficiency is about 95% over most of the P_T range, with a purity around 93%. The loss of efficiency relative to single muons is predominantly due to hit contention. Multiple scattering accounts for part of the loss for $P_T < 0.2$ GeV/c in both the top and single muon samples.

Missed hits appear mostly in the 90° stereo layers. A new global approach in the longitudinal plane promises significantly improved efficiency in these layers.

Detector geometry limits the ultimate efficiency of the triplet strategy to about 98%, so other algorithms will be required even if the triplet strategy performs

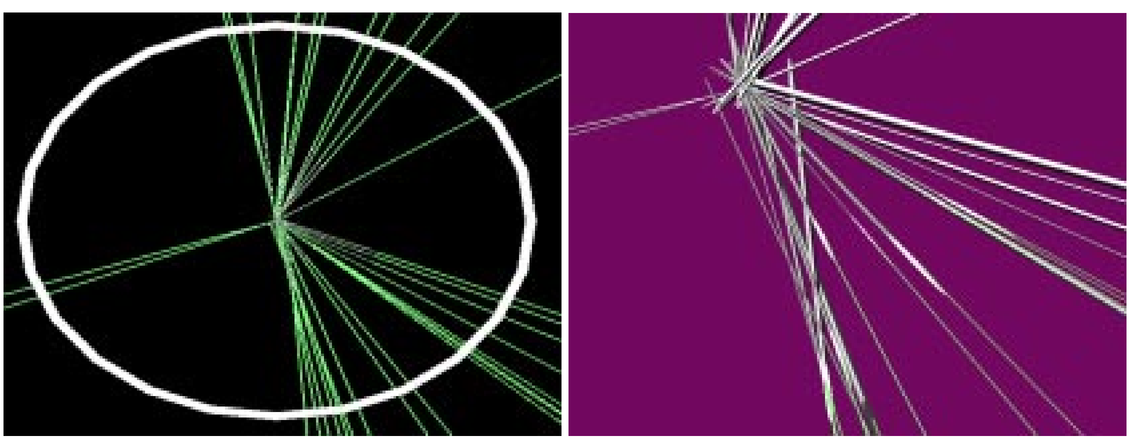

FIGURE 3. Tracks found in a typical simulated $\mathrm{t}\bar{\mathrm{t}}$ event. The picture on the left shows the region within the beam pipe (circle), while that on the right shows the region around the primary vertex. The error ellipses for the tracks are also shown.

perfectly. An outside-in strategy is currently under development for this purpose.

SUMMARY

CDF has designed and implemented an object-oriented stand-alone pattern recognition for the Run 2 silicon detectors. The design includes an innovative and flexible design for the fitting classes that provides a unified interface for dealing with a wide variety of measurements, constraints, and other types of effects in the fit. The triplet strategy exploits the three-dimensional potential of the system at an early stage in the pattern recognition and is therefore ideally suited for use in the dense Run 2 tracking environment. The performance to date looks promising, although much work remains to optimize the efficiency and CPU performance.

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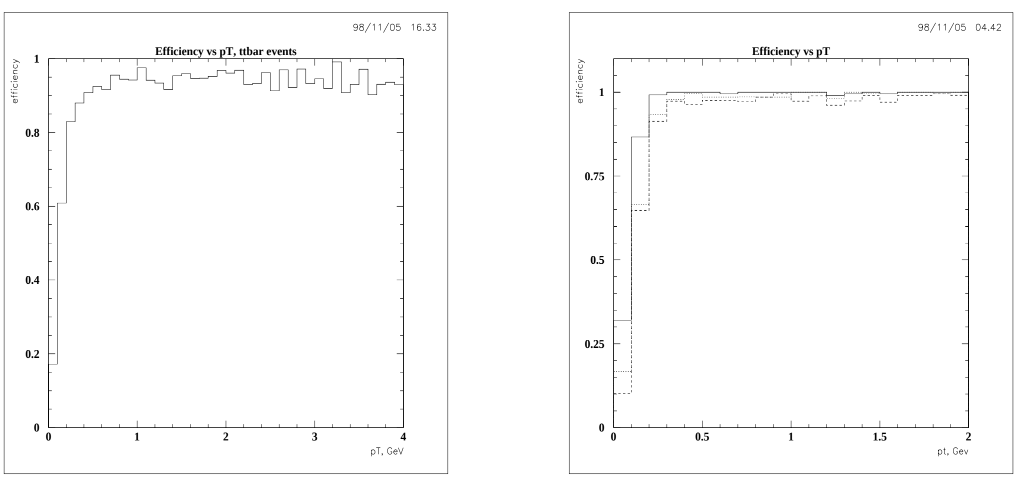

FIGURE 4. Track finding efficiency vs. $P_T$in $t\bar{t}$ (left) and single muon events (right). The upper curve in plot on the right is with no multiple scattering; the lower curves are different multiple scattering models in the simulation.