Pattern Recognition Algorithms for B Meson Reconstruction in Hadronic Collisions

Rainer Mankel [a,1],

[a] *Humboldt Universität zu Berlin, Institut für Physik, Invalidenstr 110, 10115 Berlin*

Dedicated B physics experiments as HERA-B [1] and LHC-B [2] are confronted with huge track densities in the tracking system. These next generation B physics experiments require pattern recognition methods which yield high efficiencies in spite of large occupancies in complex detector geometries. This paper discusses methods based on track following, histogramming and neural networks and their performance in the HERA-B detector geometry.

Key words: Pattern Recognition; Tracking; Histogramming; Hough transform; Denby-Peterson; Neural networks; HERA-B; LHC-B; B physics; CP Violation; Drift chamber;

1 Introduction

B physics at hadron machines offers a new depth of research in this field during the next decades because the large b cross section in high energy pp or pN collisions gives access to large samples of B hadrons, which are needed to study eg. CP violation. However, the large number of particles produced in hadronic interactions, multiplied by event pileup, presents new challenges for the pattern recognition of charged tracks in spectrometers. In the HERA-B outer tracker for example, the mean occupancy per cell in typical events with 5 superimposed interactions will range up to 20%. Hence, the performance of the pattern recognition algorithm determines directly the experimental reach in precision measurements in the B sector. In the following, very different approaches for pattern recognition are applied to the event topology of HERA-B. The particular problem considered here is the finding of straight track segments in the HERA-B *pattern tracker*, which is a system of four superlayers of inner and outer tracker modules in the field-free area behind the magnet (for details of the geometry, see [1]).

2 Track Following Methods

Very detailed studies have been performed with an algorithm based on a *track following* philosophy [2]. The track finding process starts with an initialization generated from three nearby hits within the same superlayer, called a *triplet*. Triplets with similar track parameters are merged to form a *cluster*. This cluster is then used as a *seed* for propagation through an iterative procedure, where the Kalman filter technique [4] is used to update the track parameters at the position of the next hit candidate. The Kalman filter operates in each step by making a *prediction* for the track parameters in the next layer from the current estimate and updating the track parameters by including the measured coordinate from the next hit, which is called *filtering*. The prediction and filtering processes are also illustrated in fig. 1, where the propagation proceeds from right to left.

The main problem for using a track following method in a high occupancy environment is the fact that frequently several continuations appear possible for a track candidate. A useful track following

---

[1] Email: `mankel@ifh.de`

[2] At HERA-B, this method is known as the *ranger* algorithm

algorithm must be able to optimize between several available paths. In the method described here, this problem is solved using a 'concurrent candidate evolution' approach, which propagates an arbitrary number of candidates in parallel (fig. 1). Since there is no room here for a detailed description of this concept, the reader is referred to [3]. In the implementation shown here, the track following procedure is applied in projections, dealing with only two track parameters at the same time, before constructing the three-dimensional track candidate.

The performance of this algorithm has been tested on events composed of one $pN \rightarrow B^0 + X, B^0 \rightarrow J/\Psi K_S^0$ interaction superimposed with on average four inelastic pN interactions, which were generated with a combination of PYTHIA and FRITIOF and passed through a full detector simulation. A particle was considered as *found* if a track candidate existed to which it contributed at least 70% of the hits. The results are summarized in table 1. The mean efficiency for leptons and pions from the golden B decay is better than 96%. The ghost rate around 8%, a reasonable value regarding the fact that ghosts are likely to be eliminated in the subsequent reconstruction step which propagates the track candidate through the magnet.

3 Histogramming Methods

A potential weakness of local methods is their dependence on a suitable *seed* for a track candidate. The seeding strategy must contain redundancy to compensate effects from detector inefficiency or track overlap which may destroy a seed. To overcome the seeding bias, *global methods* attempt to treat all detector hits in the same way. Histogramming can be regarded as an implementation of the Hough transform. Two measured coordinates in the same projection from nearby hits in different detector layers give a straight track segment which represents a point in the *feature space*. Histogramming all segment entries in the feature space may reveal track candidates as local maxima.

This type of methods has been investigated for a typical HERA-B geometry in [5]. Due to the large occupancy in the HERA-B outer tracker, careful tuning of threshold and bin size (separately for inner and outer tracker) and suitable selection of segment size are prerequisite for reasonable results. Figure 2 shows the pattern recognition efficiency as a function of peak occupancy. Parameter matching has been used to define the efficiency, which is remarkably constant at a high value of 90%, while the ghost rate increases to 33% at HERA-B-typical occupancy. These results do however not yet include the additional complication of left-right ambiguity in the drift chambers, and the generalization for three dimensions is not trivial.

4 Neural Network Methods

Neural network algorithms based on *Hopfield nets* and *elastic arms* in their application for HERA-B have been studied in [6]. The Hopfield model in the implementation by Denby and Peterson [7] assigns a neuron to each segment consisting of two hits in nearby layers. Two segments having one hit in common can interact, and the interaction is such that segments with a small relative angle are favoured (the third combination in fig.3). The interactions of all neurons are iterated until the system converges to a stable state, which is the solution to the pattern recognition problem. No track model enters explicitly, but more or less straight tracks are clearly preferred.

This method was successfully tested using a model detector similar to the one in the previous section, ie. only the two-dimensional problem was considered. The studies showed that better results were obtained with a modification of the original Denby-Peterson potential, which superimposes linearly the *cost functions* of angle and segment length [6]. Figure 4 shows efficiency and ghost rate as a function of occupancy. Though the efficiency drops below 90% at occupancies above 10%, a closer investigation shows that many of the ghosts consist of improperly merged track fragments, part of which might be recovered by subsequent processing. The computing effort per event is however considerably higher than with the track following approach.

5 Summary

Pattern recognition methods of very different character have been investigated with regard to their applicability under HERA-B conditions. A track following approach based on 'concurrent candidate evolution' has been tested on a very detailed level of detector geometry, including drift distance simulation and different inner/outer tracker resolutions and gives very good efficiency and ghost suppression. Two global methods have been tested in a simplified, two-dimensional detector setup: Histogramming gives reasonable efficiencies, but an additional step is needed to filter the correct hits after a cluster in feature space has been found. This method may be useful as initialization of a track following method. The neural network algorithm using the Denby-Peterson approach appears to suffer from lack of an explicit track model at high occupancy. Additional processing would be needed to sort out wrongly matched track fragments. Both the histogramming and Denby-Peterson methods may not be easily generalized for a three-dimensional detector geometry.

References

[1] T. Lohse et al. (HERA-B Collaboration), DESY-PRC 94/02 (1994).
E. Hartouni et al. (HERA-B Collaboration), DESY-PRC 95/01.

[2] K. Kirsebom et al. (LHC-B Collaboration), CERN/LHCC 95-5 (1995).

[3] R. Mankel, document in preparation.

[4] *see eg.* R. Frühwirth, Nuclear Instr. and Meth. A262 (1987) 444.

[5] T. Schober, 'Investigation of the Hough Transform as a Global Method of Pattern Recognition in the HERA-B Main Tracking System', Diploma thesis (in German), Berlin 1996 (unpublished).

[6] C. Borgmeier, 'Global Pattern Recognition in the HERA-B Tracking Chambers', Diploma thesis (in German), Berlin 1996 (unpublished).

[7] B. Denby, Comput. Phys. Comm. 49 (1988) 429.
C. Peterson, Nucl. Instr. and Meth. A279 (1989) 537.
G. Stimpfl-Abele, L. Garrido, Comput. Phys. Comm. 64 (1991) 46.

Figure Captions

Fig.1 Illustration of the concurrent candidate evolution strategy in a closeup from the HERA-B outer tracker. The hexagons represent the honeycomb cells with wires in the middle, the circles show the measured drift distances in those cells hit by tracks.

Fig.2 Efficiency and ghost rate for pattern recognition using the 2D histogramming technique

Fig.3 Three typical cases for adjacent track segments in the Denby-Peterson algorithm. The first two combinations correspond to incompatible segments, in the third case, both segments are likely to come from the same track.

Fig.4 Efficiency and ghost rate for pattern recognition using the 2D Denby-Peterson algorithm

Tables

Particle	ϵ_{PR}
$e^{\pm}_{J/\Psi}$	$(95.3 \pm 1.3)\%$
$\mu^{\pm}_{J/\Psi}$	$(96.4 \pm 1.2)\%$
$\pi^{\pm}_{K^0_S}$	$(97.3 \pm 0.8)\%$
Ghosts	$(7.7 \pm 0.2)\%$

Table 1
Pattern recognition efficiencies for the main tracker, using the track following method described in the text

Figures

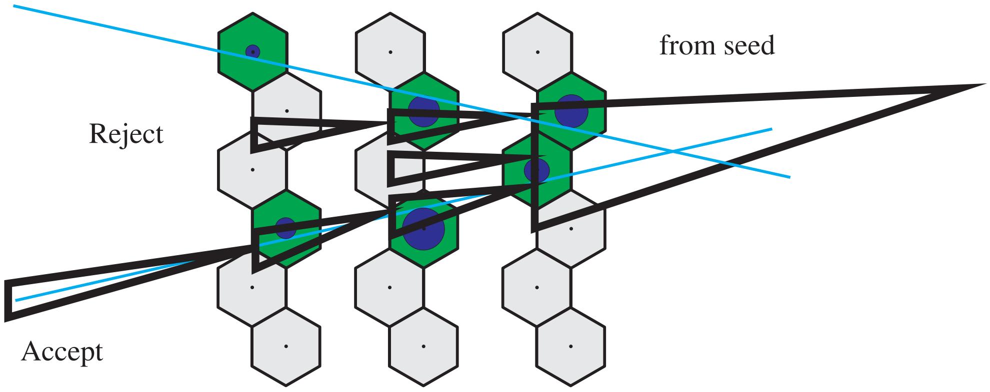

Fig. 1. Illustration of the concurrent candidate evolution strategy in a closeup from the HERA-B outer tracker. The hexagons represent the honeycomb cells with wires in the middle, the circles show the measured drift distances in those cells hit by tracks.

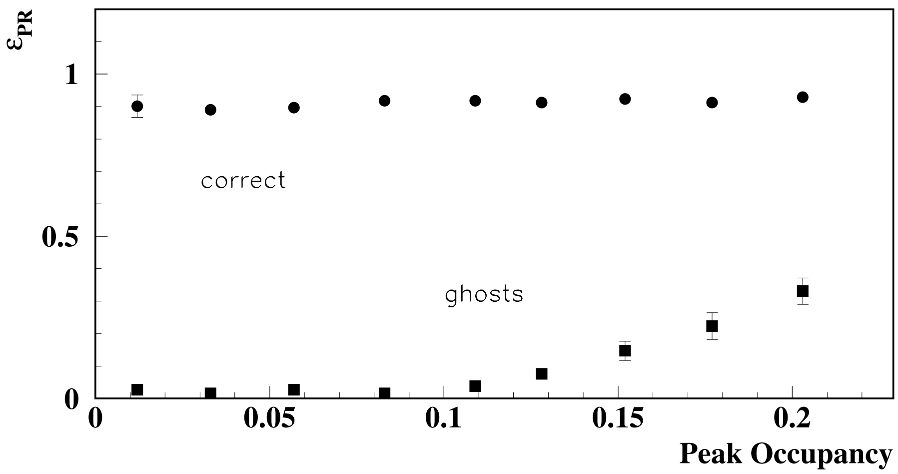

Fig. 2. Efficiency and ghost rate for pattern recognition using the 2D histogramming technique.

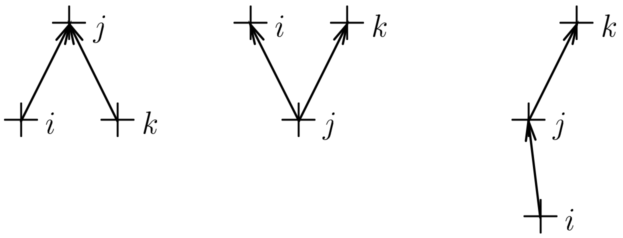

Fig. 3. Three typical cases for adjacent track segments in the Denby-Peterson algorithm. The first two combinations correspond to incompatible segments, in the third case, both segments are likely to come from the same track.

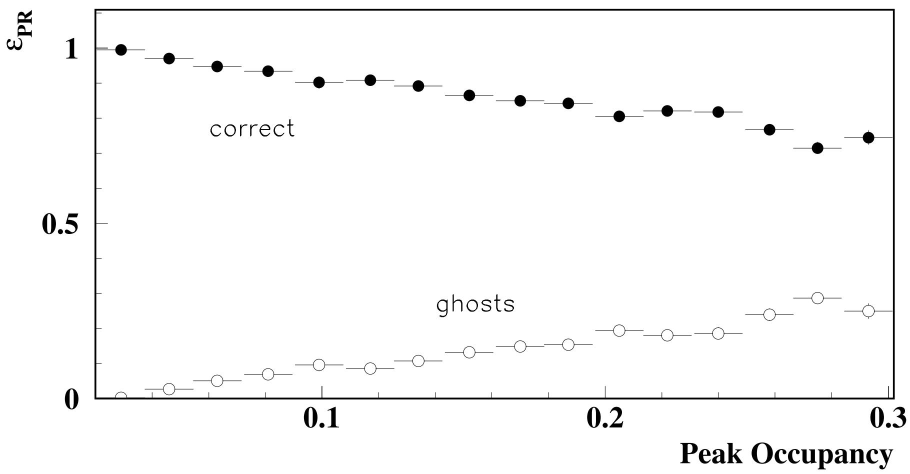

Fig. 4. Efficiency and ghost rate for pattern recognition using the 2D Denby-Peterson algorithm