Nuclear Instruments and Methods in Physics Research A 389 (1997) 169–172

ELSEVIER

NUCLEAR
INSTRUMENTS
& METHODS
IN PHYSICS
RESEARCH
Section A

Cellular automaton and elastic net for event reconstruction in the NEMO-2 experiment

V. Kovalenko*, NEMO Collaboration

Joint Institute for Nuclear Research, Dubna, Moscow reg., 141980 Russia

Abstract

A cellular automaton for track searching and an elastic net for charged particle trajectory fitting are presented. The advantages of the methods are: simplicity of the algorithms, fast and stable convergence to real tracks, and a reconstruction efficiency close to 100%. Demonstration programs are available at http://nuweb.jinr.dubna.su/LNP/NEMO using a Java enabled browser.

PACS: 07.05.Mh, 84.35. + i, 23.40.-s, 29.40.Gx, 14.60.Pq, 29.90. + c
Keywords: Data analysis; Neural networks; Tracking

1. Introduction

The goal of the NEMO collaboration [1] is to study ββ decays of ^{100}Mo and other nuclei to probe the effective Majorana neutrino mass down to 0.1 eV. A prototype detector NEMO-2 designed for ββ studies has already provided some measurements and is presently running in the Fréjus Underground Laboratory. The detector is a 1 m^3 volume made of tracking chambers composed of drift cells operating in the Geiger mode and two plastic scintillators arrays for energy and time-of-flight measurements. In the following the Geiger drift cells will be called drift tubes to avoid confusion with the cellular automaton cells.

A typical event in this experiment has a few number of tracks usually well separated in space. But this situation is complicated by essential effect of multiple scattering and even hard scattering on wires. Reconstruction of such events in the presence of the left–right ambiguity of drift tubes becomes a task lying out of typical problems of event reconstruction in high energy physics. Therefore cellular automaton and elastic net methods were choosen as they are flexible ones and are suited to work in non-standard situations [2].

Another reason for using algorithms different from the traditional least-squares method in high energy physics has statistical ground. Usually the least-squares method is used to fit a particle trajectory to position measurements in such detectors as bubble chambers where errors of measurements are independent and Gaussian distributed. But this is no longer valid for electronic experiments with discrete detectors like multiwire proportional chambers and other devices, which are essentially digital in character. Here errors of measurements are in fact correlated and their distribution is not Gaussian. In such cases it is better to use methods having statistical basis corresponding to an experimental setup [3].

The tracking procedure based on a cellular automaton and an elastic neural net was developed for the NEMO experiment during the last year. It was applied to real data of the NEMO-2 experiment and compared with the previous tracking procedure based on the Kalman filter. This comparison promoted strong confidence in the new tracking methods.

2. Searching for tracks

Specific features of the experiment make preferable the segment model of cellular automaton [4] where an elementary unit (cell) is the segment connecting two fired wires in neighboring layers.

To construct a cellular automaton for track searching in NEMO-2 data, one follows the logic of cellular automata defining cell, neighbors, rules of evolution and time flow.

---

* Corresponding author. Tel.: + 7 9621 63791; fax: + 7 9621 66666; e-mail: koval@nu.jinr.dubna.su.

PII S0168-9002(97)00080-6

2.1. Cell

The cellular automaton is three dimensional. A cell is identified with a straight-line segment connecting two fired wires in neighboring layers, making the cellular automaton essentially local. To take into account inefficiencies of the experimental device one must also include segments connecting wires over one layer. This initial status is depicted in the top half of Fig. 1. During evolution each cell is characterized by its position on track.

2.2. Neighbors

In establishing the criterion for assigning segments to a track it is obvious that only segments with a common extremity can be considered as neighbors. Then owing to the coordinate detectors having a discrete structure and to multiple scattering in the material of the experimental apparatus, the angles between track segments in the real experiment are not zero, but an upper limit $\phi_{\max}$ can be imposed.

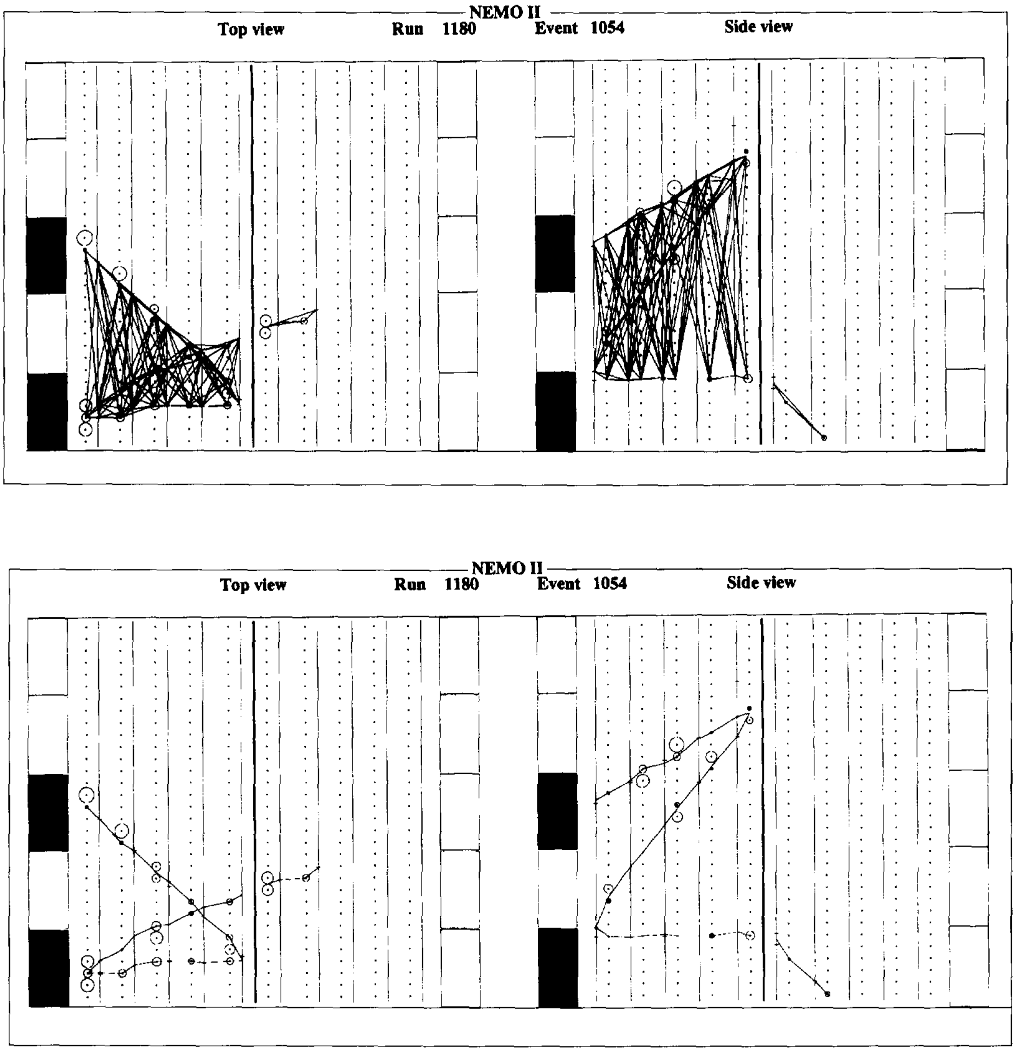

Fig. 1. Initial and final configurations of the cellular automaton for a complicated NEMO-2 event. For the drift tubes perpendicular to the figure plane, the drift distance is represented by the radius of a circle. For the drift tubes parallel to the figure plane, the small segments indicate the trajectory position along the drift tube.

2.3. *Rules*

All free cells are initialized with position value 1 and at each step of evolution they look on neighbors and increase the position value if there is a neighbor at the left (suppose) side with the same position value. This is similar to the rule SAFE-PASS [5].

2.4. *Time*

Time evolves discretly. All cells change their states simultaneously.

Knowing positions on track for all segments it is easy to collect all track candidates. Upon completion of the work of the cellular automaton additional testing of the quality of tracks is carried out. This permits rejecting "phantom" tracks, which could be constructed from hits belonging to different tracks.

In lower half of Fig. 1 the final configuration of the cellular automaton is shown for a complicated NEMO-2 event. Two tracks which originate in the central source foil are shown. One is back-scattered on the front face of a scintillator and leaves the detector after crossing the central foil.

3. Fitting of tracks

Actual fitting of charged particle trajectories with multiple scattering and hard scattering on wires is made by the elastic net method [6].

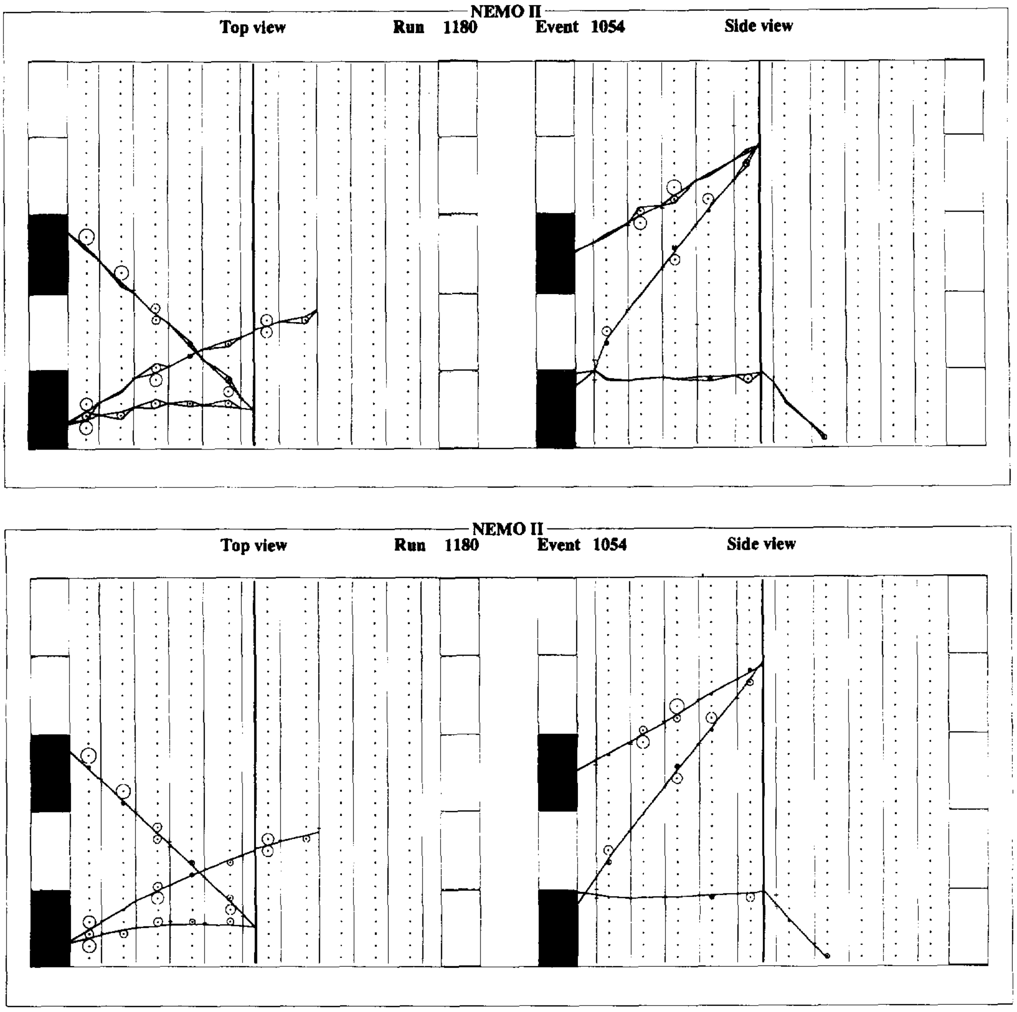

Fig. 2. Initial and final configurations of the elastic net for the NEMO-2 event already shown.

Let us

Define a track with multiple scattering as the "smoothest" line joining experimental points defined by hit drift tubes.

Then try to construct the elastic net as a line that is deformed under the influence of *two types of forces*:

(i) the first pulls it to the edges of drift cell circles for which the radius is directly proportional to the proximity of particle path with respect to the anode wire (depicted in Fig. 1).

(ii) the second smooths out the line defining the particle track.

To avoid the problem of local minima because of left–right ambiguity of drift tubes, we propose to start from two tracks which place bounds on the geometrical area where there is the real track. Effectively one of them touches the drift circles on the "upper side" while the other one on the "lower side". Next a *third type of force* is introduced:

(iii) an attraction between these tracks squeezes the geometrical area to get the real track.

This method allows one to find an optimal trajectory which corresponds to the track.

The elastic net can be simply modified to be able to reconstruct hard scattering tracks. Here one has only to switch off track smoothing at hard scattering points which are found during the preliminary analysis. Fig. 2 presents initial and final configurations of the elastic net for the same NEMO-2 event shown in Fig. 1.

4. Results of an application

The complete data set (6588 h of running time) was previously processed using a tracking procedure based on the Kalman filter [7]. The new tracking method presented here was applied to re-process the data.

An electron is identified by a track linking the source foil and one scintillator. The maximum scattering angle along the track is required to be less than 20° to reject hard scattering. A photon is recognized as one or two adjacent fired scintillators without any associated particle track. For photons and electrons an energy deposit greater than 200 keV is required for obtaining a sufficiently good time resolution. In the analysis of two-electron events a cut on the angle between the two electron tracks is applied ($\cos\alpha < 0.6$). In the case of two-electron events, the difference between the vertices of the two tracks is required to be less than 5 cm. This condition is imposed because of multiple scattering which leads to a rms of 1 cm for a 200 keV electron.

After applying the cuts to extract the $\beta\beta2\nu$ candidates with the new tracking method, 232 two-electron events were selected in the enriched foil, and 61 in the natural one including 14.8 calculated $\beta\beta2\nu$ events. The Monte-Carlo simulation data of the $\beta\beta2\nu$ decay in the NEMO-2 detector was also analyzed using the new tracking program. An overall efficiency of 1.88% for extracting two-electron events is obtained. The number of events entering the half-life calculations is 185.8. A half-life of $T_{1/2} = [3.75 \pm 0.35(\text{stat}) \pm 0.21(\text{syst})] \times 10^{19}\ y$ has been derived for both tracking programs. This supports strong confidence in the new tracking methods.

5. Conclusion

In summary the main features of the tracking program based on the cellular automaton and elastic net methods are given below:

- increase in the tracking efficiency of 9% (in the $\beta\beta2\nu$ analysis);
- increase by a factor 35 in the processing speed;
- working in 3D space to separate close tracks in a projection;
- good reconstruction of tracks with hard scattering on wires;
- reconstruction of short tracks (2 planes involved);
- simple to modify by introducing additional criteria in the analysis.

The results of the application to real NEMO-2 events demonstrate reliable operation of the cellular automaton and elastic net methods in the case of multiple scattering in a gas and hard interactions on wires in the tracking detector.

In the next stage of this investigation a detector with a magnetic field will be taken into account to develop algorithms for the NEMO-3 experiment.

References

[1] R. Arnold et al. (NEMO Collaboration), Nucl. Instr. and Meth. A 35A (1995) 338.

[2] I. Kisel, V. Neskoromnyi and G. Ososkov, Phys. Part. Nucl. 24 (November–December 1993) 657.

[3] N. Chernov, A. Glazov, I. Kisel, E. Konotopskaya, S. Korenchenko and G. Ososkov, Comp. Phys. Commun. 74 (1993) 217.

[4] M.P. Bussa, L. Fava, L. Ferrero, A. Grasso, V. Ivanov, I. Kisel, E. Konotopskaya and G. Pontecorvo, Nuovo Cimento A 109 (1996) 327.

[5] T. Toffoli and N. Margolus, Cellular Automata Machines: A New Environment for Modelling (MIT Press, Cambridge, MA, 1987).

[6] I. Kisel, E. Konotopskaya and V. Kovalenko, this proceedings.

[7] R. Arnold et al. (NEMO Collaboration), Z. Phys. C 72 (1996) 239.