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НОВЫЙ МЕТОД ОПТИМИЗАЦИИ ПОРОГОВ ОБРЕЗАНИЙ В ЭКСПЕРИМЕНТЕ E391: КОНЦЕПЦИЯ И ТЕКУЩИЙ СТАТУС РЕАЛИЗАЦИИ

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NEW METHOD FOR THE CUTS THRESHOLD OPTIMIZATION IN THE E391 EXPERIMENT: CONCEPTION AND CURRENT IMPLEMENTATION

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Представлена новая техника оптимизации катов с использованием генетических алгоритмов. Главным преимуществом данного метода является полностью автоматический поиск точек обрезания. Это позволяет находить точки экспериментальных ограничений установок без вмешательства человека. Более того, автоматический поиск этих точек является более точным по сравнению с ручным методом. В работе представлены предварительные результаты для кат-оптимизации вето системы эксперимента E391. Данная методика может быть использована в других экспериментах.

Ключевые слова: *редкий распад, K_L – мезон, генные алгоритмы, каты.*

New cut optimization technique with using gene Algorithms is proposed. The main advantage of this method is completely automatic search for cut points. This allows finding cut points without of human intervention. Moreover, precision of cut points obtained by automatic searching is much higher than for those obtained «by hand». Preliminary results of the veto system cut optimization in the E391 [1] experiment is presented. The developed technique is applicable to other experiments.

Keywords: *rare decay, K_L – meson, gene algorithms, cuts*

Introduction

The rare $K_L^0 \to \pi^0 + \nu + \bar{\nu}$ decay process is one of the clearest and «cheapest» critical Standard Model (SM) probes. In several papers (for example [2], [3]) it was shown that this decay is sensitive to the «new physics» effects as well as to the SM parameters. For a long time, this decay measurement was impossible and just with the start of the E391 experiment studies of this decay on special setups began. Sensitivity of the E391 experiment is too low to observe this decay because the planned precision of the experiment is $\sim 10^{-9}$ while the SM-based predictions show $Br(K_L^0 \to \pi^0 + \nu + \bar{\nu}) \sim 10^{-11}$. The most important task of this experiment was developing methods for the $K_L^0 \to \pi^0 + \nu + \bar{\nu}$ decay registration to be applied to more sensitive experiments in the future.

During the experimental data analysis it was found out that one of the most important tasks of the E391 experiment is to optimize cuts of observable quantities. In the E391 setup 1200 ADC channels are used, and 20 kinematic values are reconstructed. All work on choosing signal phase space was done by hand. To do this, methods for sensitivity and background estimation were developed. Cut values were tuned to obtain the best ratios between signal and background with keeping the latter value reasonable. It is a natural approach used without significant changes since the first high energy physics experiments till nowadays. The experience gained during the analysis phase of the E391 experiment showed that the case of the classical cut optimization method is accompanied by a lot of restrictions:

1. With the hand approach, it is very difficult to take into account the correlation between visible kinematic variables because there are a lot of them. They are assumed to be orthogonal to each other and are optimized in the zero approximation.
2. There is no way to check convergence of solutions.
3. The optimization process yields range of cut point of kinematic variables, ADC and TDC values. It is much more convenient to use one function of lot of variables (visible and reconstructed).

4. Cut points founding is a labor-consuming process. The main goal of the present paper was to create a new method of the computer cut optimization for the E391 experiment. To achieve that goal we used gene algorithms [4].

1 Gene Algorithms

Gene algorithms are heuristic search algorithms used for solving tasks of optimization and simulation by random exhaustion, combination, and variation of searching parameters, as in biological evolution [4].

During the evolution process of a system, it is modified to meet external requirements. For this rules of evolution transformation and fitness function are defined. The evolution process continues until the requirements are met or the number of generations exceeds the predetermined value.

As in biological evolution, the following evolution mechanisms can be selected in gene algorithms: reproduction, mutation, termination, elitism.

Reproduction is a process of combination of two individuals for obtaining two descendants. The latter will possess exceptional characteristics of both parents. Mutation is a change in the single individual in accordance with the predetermined algorithm.

Termination is exclusion of the individual from further evolution of the system.

Elitism is the transition of the individual to the next phase of evolution without change.

Application of gene algorithms for finding the values of the cuts in the experiments of particle physics is a new and promising trend. In the last three years several papers on data processing using the developed approach have been published ([5], [6], and a few others).

2 Cut optimization in the E391 experiment

To find the corrected values of the cuts, we have created a special program that works on the principles of genetic algorithms. We used the lil-gp framework developed at Michigan State University [7] as a part of the GARAGE (Genetic Algorithms Research and Applications Group) project. We divided optimization process into several phases.

At the first stage we optimized the cut thresholds for one detector (Main Barrel) of the E391 setup. This stage was necessary to make sure that the proposed approach allows automatic cut search. At the next stage we optimized thresholds for the whole veto system, and after that we optimized all cuts. The next step in the development of the effective approaches to signal/noise separation will be search for the single function from all visible variables, with their correlation taking into account.

At the present investigation stage each individual in the population was represented by 43 numbers. The value of each of them is proportional to the cut threshold used in the E391 experiment data analysis. Kinematic observable quantities correspond to 23 numbers, and the energy release in the veto detectors – 20 numbers. The total number of such individuals in the population was 200.

During evolution, each individual could be subjected to the above mechanisms (reproduction, mutation, deletion, elitism).

The value of each threshold was limited to the top and the bottom. These boundary conditions are needed to exclude the possibility of obtaining non-physical results in the machine search. For a more complete coverage of the set of real numbers in this range, as well as for avoiding large jumps in the process of mutation, the value of each number in a set of cutoffs was represented as a tree of functions. During reproduction, individuals can share the branches of the trees. The maximum degree of nesting of the functions was limited to 10.

The criterion for the effectiveness of circumcision, which corresponds to a particular individual, is a fitness function. We have defined it as

$$f(S) = \frac{Acc(S)}{Bg(S)},\ Bg(S) < 0{,}55;$$

$$f(S) = \frac{1/2\ Acc(S)}{Bg(S)},\ 0{,}55 < Bg(S) < 0{,}65;$$

$$f(S) = \frac{1/4\ Acc(S)}{Bg(S)},\ Bg(S) > 0{,}65,$$

where $Bg(S)$ is the background level, which resulted from the reconstruction of events $K_L^0 \to \pi^0 + \nu + \bar{\nu}$ with applying S selection cuts, $Acc(S)$ is the sensitivity of the method to $K_L^0 \to \pi^0 + \nu + \bar{\nu}$ events after applying S selection cuts. Differences in the coefficients for different ranges of values of backgrounds are needed to maintain an acceptable background contribution to the recent results of computer search.

In the process of computer calculations for each individual the function f was evaluated. Then, based on the obtained fitness function value, individual either jumped to the next generation in the process of reproduction, mutation, or elitism, or was terminated. The relative probability of the first three operators was 0, 1, 0, 1 and 0,8, respectively. The relative probability of the termination of the individual was f^{-1}. Three hundred generations of individuals, were calculated.

Acceptance calculation. We used the procedure of background and acceptance estimation as well as experimental and Monte-Carlo statistics developed for the E391 experiment RunII analysis [8]. This allowed to comparing the effectiveness of imposing the cuts found and used in the standard analysis without any whatever amendments to the differences in the methods. Acceptance was calculated by reconstruction of events with applying of all cuts. For taking into account accidental losses and applying timing cuts, we calculated additional coefficients of acceptance loss, as shown in [8].

Background calculation. Among all sources of background, we have identified those whose contribution cannot be considered negligible [8]. By the method presented in this work, we analyzed the following sources of background: decays $K_L^0 \to 2\pi^0$, $\eta \to 2\gamma$ and sources associated with the neutron beam.

3 Results

After the calculations we obtained new cut values that were more effective than those found by hand. The results of the calculation of backgrounds are represented in Table 1.

Table 1 – Background estimation

Background	Contribution in the case of manual selection of cuts	Contribution in the case of machine cut search
Core neutron background	0,20	0,17
Halo neutron background	0,08	0,13
$K_L^0 \to 2\pi^0$ events	0,12	0,12
$\eta \to 2\gamma$ events	0,06	0,08
Total	0,46	0,50

As seen from Table 1, the contribution of backgrounds increased by 8%. However, the increase of sensitivity was 10%. Signal plots for the classical set of cuts of the E391 experiment and the results obtained in the present work are shown in Figure 1 and 2, respectively.

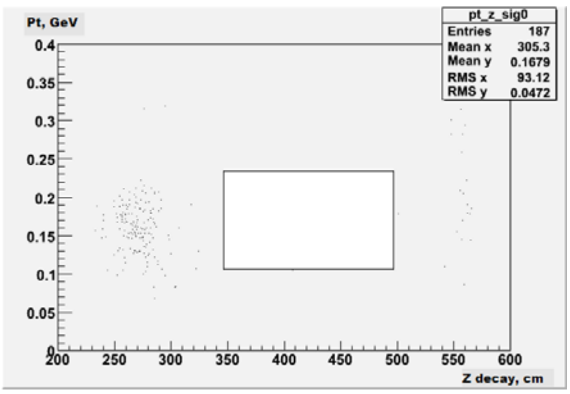

Figure 1 – Signal plot for Run II of the E391 experiment, after applying standard cuts. Events in the signal region are absent

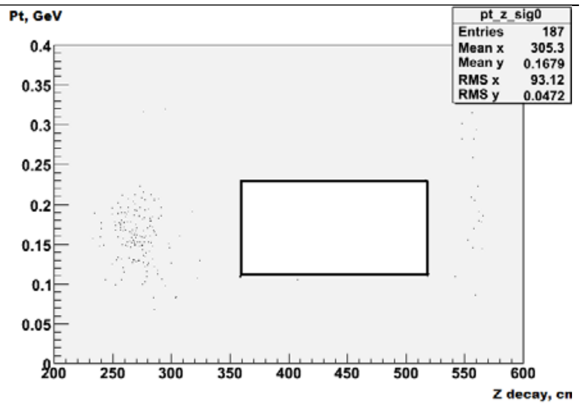

Figure 2 – Signal plot for Run II of the E391 experiment, after applying the cuts found by using gene algorithms. Events in the signal region are absent

Conclusion

As a result of this work, we have found new cut thresholds, which are more effective than those found by the usual selection. Acceptance to events increased by 10%. This work will continued to find a single threshold function of all observed variables to take into account correlations between them.

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