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CompHEP - COMPUTER SYSTEM FOR CALCULATIONS OF PARTICLE COLLISION CHARACTERISTICS AT HIGH ENERGIES

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CompHEP - COMPUTER SYSTEM FOR CALCULATIONS OF PARTICLE COLLISION CHARACTERISTICS AT HIGH ENERGIES

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CompHEP system is thought as a universal program environment for working out theoretical foundation of physical programs for the new generation accelerators. Tedious calculations for elementary particles scattering and decay processes at TeV energies can be fulfilled rapidly and without mistakes for a wide class of gauge models. The opportunity of different model parameters choice exists. The user does not need any understanding of computer techniques and programming. The dialogue with the system is simple and the well known notations are used. The interactive mode is available.

I. INTRODUCTION

At present time the accelerators of the new generation are under elaboration or construction in different countries. These accelerators will be able to reach TeV particle energies. According to the State Scientific Program "High Energy Physics" the storage and accelerator complex is under construction in the USSR to start operation in 1994-1996. Three colliders are planned for the UNK and VLEPP complex: pp at $\sqrt{s}$=6TeV, e^+e^- at $\sqrt{s}$=1TeV and ep at $\sqrt{s}$=3TeV. Two colliders started operation: in Europe e^+e^- at $\sqrt{s}$=0.1TeV (LEP1, CERN) and in the USA $p\bar{p}$ at $\sqrt{s}$=2TeV (FNAL). Several colliders are under construction to start operation: ep at $\sqrt{s}$=0.3Tev (HERA, DESY, 1991), e^+e^- at $\sqrt{s}$=0.2TeV (LEP2, CERN, 1992), pp at $\sqrt{s}$=18TeV (LHC, CERN, 1996), pp at $\sqrt{s}$=40TeV (SSC, 1998).

It is expected that all these unique and very expensive experimental installations will make possible the discovery of the new physical phenomena. On the basis of modern theoretical notions one can hope that at 0.5-1 TeV energies the effects of supersymmetry, quark and lepton substructure, GUT etc. can be discovered. Everybody is waiting for the confirmation of the existence of predicted particles (t-quark, higgs boson). The experiments in the TeV energy range will lead to the fundamental changes of our understanding of the structure of matter.

Foundation of physical investigations program at the accelerator of the new generation is the very important part of the whole accelerator project. From the technical point of view the problem is the detailed computation of all possible collision processes and decays of the final state necessary for reliable identification of the desired interaction processes and separation from the background. The detailed preliminary computations allows trustworthy planning of experiments, fast data handling and finally leads to sufficient decrease of expenses. As an illustration let us mention the W discovery at SppS in 1983. The W bosons were seen as single leptons with large missing p_t events at the beginning of the collider operation. This experiment and also other points of the experimental physical program of CERN Collider were based on the preliminary theoretical computations.

The tedious part of the accelerator physical program foundation is the theoretical calculation of cross-sections and decay rates. From the physical point of view not only the final result but also the preliminary results (Feynman diagrams, symbolic expressions for the amplitudes, cross-sections, decay rates, different forms of final result graphical representations) are interesting. Briefly speaking, the input is the Lagrangian and the output is formulas and plots. In all cases special groups of physicists, including theoreticians, experimenters and computer specialists are formed for the theoretical foundation of the accelerator physical program. Such groups were formed in all particle centers (CERN, FNAL, DESY, KEK ...) and also in the universities (see reports [1]). In the USSR such group is organized in IHEP (Serpukhov) [2]. Our purpose is the creation of a system to perform such kind of computations.

II. The problem features

Let us emphasize four groups of features essential for the problem under consideration.

1. There is a large number of theoretical models describing particle interactions at TeV energies (Standard Model of Glashow-Salam-Weinberg, nonstandard electroweak models, compositeness models, SUSY, GUTs, etc.). Therefore the system should contain some standard models and give user a chance to change these models or to create a new one.

2. A large number of Feynman diagrams appears for every physically interesting process. For instance, in the Standard Model the number of vertices is 74 and the number of diagrams for the $2 \longrightarrow 2$ processes is close to 100 (in the case when there are two final arbitrary particles, two jets) and for the $2 \longrightarrow 3$ processes can be close to 1000. Furthermore there are several background processes for every one under consideration. Therefore the task consist of the large number of simple similar calculations and the system must be

very fast if we want to work in interactive mode.

3. Only the lowest order of perturbation theory is necessary in the task. One can also use the limited number of exclusive processes (subprocesses) types: $2 \longrightarrow 2$, $2 \longrightarrow 3$ (probably $2 \longrightarrow 4$), and $1 \longrightarrow 2$, $1 \longrightarrow 3$, $1 \longrightarrow 4$. A limited number of final characteristics is needed in the task (cross-sections, asymmetries and decay rates in formulas and plots). All this give the opportunity to specialize the system if it will be necessary for speed and/or service.

Note. One-loop corrections are desirable in some cases. We suppose to give such opportunity by means of creation a new vertex (with corresponding logarithmic terms) and/or corresponding modifications of propagators.

4. The user interface should be simple with the implications of well known high energy physics notations. The knowledge of computational techniques and programming should be not necessary for the user.

III. COMPUTER APPLICATION OPPORTUNITIES

Theoretical calculations for a wide class of processes are impossible without computers and developed software. At present time developed software is available for some components of high energy physics calculations. Let us mention symbolic computation systems like REDUCE, SCHOONSCHIP, MACSYMA, MAPLE, MATEMATICA, SCRATCHPAD II, a large number of packages for numerical calculations and also Monte-Carlo simulation programs (IZAJET, PYTHIA, COJET, EUROJET, FILDAJET for pp, Ali MC, Webber MC, LUND MC for e^+e^-). Unfortunately such programs are not connected with each other and have poor service abilities. Only highly qualificated user is able to use them in full scope. For this reason a large number of skilled programmers is present in the collider physical programs groups.

Finally we conclude that the universal program environment for calculation of high energy particle interaction processes is absent at present time. A system capable to create such environment would be in fact a new stage of planning collider experiments. Creation of such a system would allow us to solve a great number of calculation and model dependent problems without the involvement of computer specialists.

IV. CompHEP system

CompHEP system for computer calculation of particle collision processes characteristics at high energies (TeV range) is under creation at the Institute for Nuclear Physics of Moscow State University from the beginning of 1989 in the framework of the State Program "High Energy Physics".

The realization of the CompHEP system takes into account all the specific features mentioned in II. The interface language is based on the graphic menu. The system is realized on personal computers for continuous availability by the user.

The general structure of the CompHEP project is thought as five closely connected units:

- *Management Module*
- *Computational Package*
- *Data Bases*
- *Module for Results Treatment and Analysis (knowledge basis for intermediate and final results $\longleftrightarrow$ expert systems)*
- *Switch Block for standard programs (REDUCE, MC programs).*

At present time our main efforts are directed on elaboration of *Computational Package*. The package realization includes six modules:

- for manipulations with Lagrangians
- diagrams generator
- for graphical diagrams representation
- for symbolic computations
- for numerical calculations
- graphical module for plots.

In the version of CompHEP created for wide distribution the following possibilities for the user will be presented in the *Computational Package:*

1) choice of the model Lagrangian and/or its

modification;

2) selection of the process - the definition of the particles in the initial and final states, if necessary the definition of the polarizations;

3) subprocesses generation contributing to the selected process;

4) generation of Feynman diagrams corresponding to subprocesses types;

5) generation of squared diagrams;

6) construction of symbolic expressions corresponding to the squared diagrams according to Feynman rules;

7) symbolic calculation of the squared matrix element (tensor algebra, trace calculations, average and sum over colors, average and/or sum over polarizations, the contribution of ghosts);

8) choice of the set of kinematic variables of the process or subprocess, choice of the reference frame (lab, center of mass, beam,...) in the case of the noninvariant variables, computation of the matrix element squared in chosen variables;

9) search in the data bases in standard cases or computation in nonstandard cases of the process or subprocess phase space;

10) construction of the process or subprocess differential cross section or decay rate and numeric integration over all or over some chosen independent kinematical variables, if necessary the integration with kinematical cuts in carried out;

11) numeric calculation (in the QCD case) of the convolution of subprocess cross section with corresponding structure and(or) fragmentation (recombination) functions with QCD-evolution;

12) sum of the convolutions for different subprocesses to the full process cross-section;

13) graphical representation of the results (plots and/or tables) for different sets of the parameters (masses, mixings, ...).

There will be a possibility of screen and/or printer output and editing of the intermediate results.

At present time the CompHEP project is realized on IBM PC/AT type of hardware (640 Kbytes RAM is needed). Realization language is PASCAL. Symbolic computations are performing by REDUCE.

Characteristic calculation time (10 MHz PC frequency) needed for 2→3 QED process $e^+e^- \to e^+e^-\gamma$ is now 15 seconds for one squared diagram.

V. Example of CompHEP user interface.

In the following we give a cut example to illustrate the style of work in CompHEP.

After CompHEP start the general information about the system appears on the screen. Pressing any key leads to menu with available standard field theory models list. At present time the menu contains

QED	Quantum ElectroDynamics,
QCD	Quantum ChromoDynamics,
SM	Standard Model (QCD unified with Glashow-Salam-Weinberg model),
SUSY SM	simplest supersymmetric extension of the SM.

After user's choice of one of the standard models the fundamental particles list appears on the screen. In the lower part of the screen the command line appears

Enter process:

The example will be shown if one presses the F1 key

Example: U,u ⟶ d,2*X

In this example u-quark interacts with U-antiquark and d-quark with two arbitrary particles are created.

The maximum allowed number of particles involved is equal to 6. The existence of the final particles is checked by the program which points to the mistake if necessary. Initial particles not present in the model list can be considered as composite objects. For instance, after the input process

Enter process: e,proton ⟶ 3*X

one can see the message

Is 'proton' a composite particle (Y/N)?

After "Y" it will be necessary to define the partonic contents of the proton

'proton' consists of:

If the user answers "N" it will be considered as a mistake.

After the input mistake the system gives a corresponding message, shows the position of the mistake by the cursor and proposes to repeat the input.

In the case of particle collisions (no decay) the system offers to input center of mass energy

Enter Sqrt(s) in GeV

and then allows to restrict the number of virtual particles of different types

Restrict virtual particles:

An example is shown if one presses the F1 key

Example: $W^+ < 2$

In this case not more then one intermediate W^+ is possible. This restriction allows the user to exclude the processes which can be neglected from the very beginning due to the large mass of the intermediate particle or small coupling constant.

After the input of virtual particles restrictions the system begins to generate Feynman diagrams for the chosen process, compatible with the energy conservation and virtual particles restrictions.

The information about the number of generated diagrams appears continuously in the lowest screen line.

The number of generated diagrams in the case of the inclusive process or the process with arbitrary final particles can be too large, especially if there are no restrictions on the intermediate particles. For this reason after generating of 500 diagrams the further generation is stopped and the system asks for the confirmation continue or not. Approximately 5 seconds is necessary for generation of 500 diagrams.

When the diagram generation is completed, the following menu appears:

squaring, display diagrams,
enter new process,
select new model,
exit.

User can look at the diagrams by "display diagrams" selection. The diagrams of the process under consideration are shown in groups corresponding to various subprocesses. The corresponding menu appears in the lower part of the screen (the classification of the processes over particle types) where the number of the diagrams corresponding to the every subprocess type is shown. There is a possibility to edit each of the subprocesses. In order to do that it is necessary to point the subprocess type by the cursor and press "Enter". The graphical images for diagrams of chosen subprocess are displayed now. The search for the diagram can be carried out by arrow keys, PgDn, PgUp, Home, End keys, or the number of the diagram in the whole set can be typed. The chosen diagram appears in the bright frame. Also the number of the generated diagrams, input process and other information appears on the screen. The user can exclude the diagrams which seems to him unimportant. The diagrams graphical lines are dashed for spin 0 particles, continuous for spin 1/2 particles dotted for spin 1 particles and dash-dotted for spin 3/2 particles. Superpartners are marked by additional (~). Charged particle propagator lines have arrows. After pressing "Esc" the user goes back to the subprocess menu and he can edit another subprocess. "Esc" in the phase of subprocess menu leads to the end of editing.

The "enter new process" or "select new model" selection leads to the one of positions from previous menu.

The "squaring" selection leads to the generation of squared Feynman diagrams. As a result the squared subprocesses menu appears and editing is possible analogous to the procedure described above.

The symbolic computation of chosen squared diagrams are performed by pressing "Ctrl+Enter". The corresponding REDUCE program is created automatically by CompHEP. Symbolic computation is made by REDUCE system. The result is shown on the screen with the usual notations. It can be printed and/or can be directed for further calculations in CompHEP system. Let us notice that created REDUCE program can be used for investigations independent from CompHEP.

VI. CompHEP POSSIBILITIES AND COMPUTER TECHNICAL DATA

At present time the CompHEP system is realized on IBM PC/AT computers (10 MHZ, 640 Kbytes RAM). As we have mentioned in IV the characteristic time needed for typical case in the Standard Model is of order 10 seconds for one squared diagram. We have created specialized symbolic package for diagram computations in the frame mentioned in II. Computation time with this package is three-ten times smaller for a number of $2 \longrightarrow 3$ squared diagrams.

This speed gives hours for typical process in Standard Model. So interactive mode is impossible in this case. Note that installation of CompHEP system at work stations (APOLLO, SUN IV, VAX type etc.) can give times two orders smaller. Therefore the convenient interactive mode will be achieved in this case (seconds for one typical process in Standard Model).

VII CONCLUSION

CompHEP system is thought as a universal program environment for working out theoretical foundation of physical programs for the new generation accelerators. At present time there are no analogous systems. Tedious calculations for elementary particles scattering and decay processes at TeV energies can be fulfilled rapidly and without mistakes for a wide class of gauge models. The opportunity of different model parameters choice exists. The user does not need any understanding of computer techniques and programming. The dialogue with the system is simple and the well known notations are used. The interactive mode is available.

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СИСТЕМА CompHEP -

КОМПЬЮТЕРИЗАЦИЯ РАСЧЕТОВ ХАРАКТЕРИСТИК СЕЧЕНИЙ И РАСПАДОВ ПРИ ВЫСОКИХ ЭНЕРГИЯХ (ОТ ЛАГРАНЖИАНА ДО ГРАФИКОВ СЕЧЕНИЙ)

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