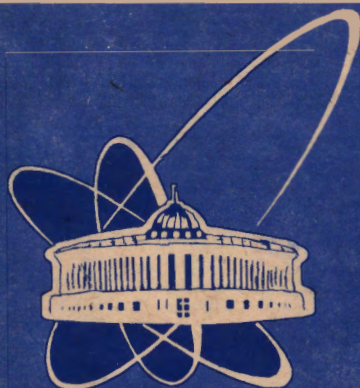


97-182



СООБЩЕНИЯ  
ОБЪЕДИНЕННОГО  
ИНСТИТУТА  
ЯДЕРНЫХ  
ИССЛЕДОВАНИЙ

Дубна

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PROGRAM BETA FOR SIMULATION  
OF PARTICLE DECAYS AND REACTIONS

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**Program description.** Program BETA is designed for simulation of particle decays and reactions. The program also produces integration over the phase space and decay rate or the reaction cross section are calculated as a result of such integration.

At the simulation process the program uses the adaptive random number generator SMART (See [1]). The generator was found to be useful for some calculations. It was shown that application of the generator permits to improve convergence essentially in many cases.

In the program BETA is assumed, that the phase space formula is as it given by Particle Data Group:

$$dF = \delta^4(P - \sum_i p_i) \prod_i \frac{d^3 p_i}{2E_i (2\pi)^3}$$

Here  $P$  is 4-momentum of decaying particle in case of decay or beam and target total 4-momentum in case of reaction,  $p_i$  is 4-momentum of each decay's or reaction's product and  $E_i$  is energy of the product.

Respectively, formula for calculation decay rate has the form:

$$d\Gamma = \frac{(2\pi)^4}{2M} |T|^2 dF,$$

where  $T$  is a matrix element and  $M$  is the mass of the decaying particle.

In case of reaction the differential cross section is given by

$$d\sigma = \frac{(2\pi)^4 |T|^2}{4p_{1cm} \sqrt{s}} dF,$$

where  $p_{1cm}$  and  $\sqrt{s}$  are the beam particle momentum and the total energy in the center-of-mass frame.

**Call statement:** CALL BETA(TFUN,USFUN).

TFUN is user function name, where matrix element squared should be calculated. Inside BETA the function is called by statement TF = TFUN(PL,PLAB),

where array PL(3) is momentum components of the decaying particle and PLAB(4,MPROD) contains 3 momentum components and energy for each decay or reaction product.

USFUN is user's subroutine name.

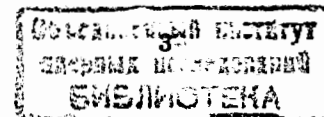
**Data file structure.** In order to explain data file structure let's consider as an example calculation of the decay rate for the neutron decay into proton, electron and neutrino. The call statement is CALL BETA(FTEST,LARK) (respectively FTEST and LARK should be declared in EXTERNAL statement). Input data file for the case is given below.

```
Test      0 100      1      1 20      0 0.05
DECAY
n -> p e- nu      0.940      3.      3.
1.                0.                0.
0.938             0.00051           0.
EXIT
```

#### Explanation.

The first line consists of 10 hollerith symbols, 6 integer and 1 real numbers. Reading format: (2A4,A2,6I5,F10.0). The first 8 holleriths are arbitrary. If the last 2 symbols are \*\*, then one more user subroutine US will be called before the simulation process is started. The six integer numbers are the following.

1. Ifsm : If Ifsm = 1, then adaptive random number generator SMART is used in the process of simulation.
2. Nsets : Number of sets (Default Nsets=100).
3. Nsups : Number of supersets (Default Nsups=1). One set consists of 1000 events, so the maximum number of simulated events is 1000 Nsets Nsups.
4. Lus : Lus=1 means that the user subroutine (LARK) will be called after each simulated event. Inside BETA the user subroutine is called by statement CALL LARK(IPOINT,PL,PLAB,FP,TF,X), where IPOINT is event number, PL(3) are momentum components of the decaying particle, PLAB(4,MPROD) are 3 components of momentum and energy for each decay product, FP is phase space weight, TF is matrix element squared and X is total weight of the event, including SMART weight (in case Ifsm=1).
5. Lprnt : Some additional statistical information about weights will be printed after each Lprnt sets. No such information is printed, if Lprnt=0.



6. Nbfuns : If Nbfuns > 0, then user has possibility to get final result (decay rate) for several matrix elements simultaneously. The additional Nbfuns matrix elements squared should be calculated by user and placed into COMMON/BETFUN/BFUN(Nbfuns). In the current version up to 20 additional matrix elements are permitted.

The last real number on this card is relative accuracy level, which user wants to achieve. The simulation process will be stopped, when estimated accuracy is below this level, or when ordered number of events is simulated.

Respectively, in the given example adaptive random number generator will be used, maximum number simulated events will be 100,000, user subroutine LARK will be called during the simulation procedure, an additional statistics will be printed after each 20,000 events and the simulation process will be stopped, if estimated accuracy 5% is achieved.

In general case the second line can be the word DECAY (for decay simulation) or REACTION or MODEL (for reaction). When it is MODEL then user is supposed to define (simulate) inside MODEL the components of momenta of the beam particle (PPA(3)) and target particle (PPB(3)). In this case the subroutine MODEL(PPA,PPB) will be called for each event.

In case of DECAY the next line is read in the format (5A4,4F10.0) and contains the following.

1. Twenty hollerith symbols are arbitrary.
2. RM — Mass of the decaying particle.
3. AMPROD — number of the secondary particles (products).
4. RNADD — a number of additional values, which user wants to read from the following line(s). This values will be put into array /ZBETA/AB(20) and can be used for user's needs.
5. PA — momentum of the decaying particle.

The next line(s) should contain the values, ordered by user (if RNADD > 0). The line(s) with this information will be read in the format (8F10.0). In our example three values are ordered. The first one can be used by the function FTEST for definition of the decay mode.

The following line(s) should contain secondary particles masses, and the reading format is also (8F10.0).

After reading of these data the simulation process is started and the instruction EXIT is a signal for return from BETA.

If we are going to calculate decay rates for two decays the following data file can be used.

```
Test          0 100      1      1  20      0 0.05
DECAY
n → p e- nu      0.940      3.      3.
1.              0.              0.
```

```
0.938          0.00051      0.
DECAY
pi → pi0 e- nu    0.140      3.      3.
2.              0.              0.
0.135          0.00051      0.
EXIT
```

Any number of decays can be calculated this way.

Program BETA also provides the possibility to obtain distributions of various kinematic variables for both decays and reactions. As an example one-dimensional distributions of proton and electron kinetic energy for the first decay are shown on Fig.1 and Fig.2. Two-dimensional distribution of both these variables is presented on Fig.3.

If one needs to perform the calculation for the second decay at different conditions (e.g. better accuracy), the command NEW should be used. For example:

```
Test          0 100      1      1  20      0 0.05
DECAY
n → p e- nu      0.940      3.      3.
1.              0.              0.
0.938          0.00051      0.
NEW
Test          0 100      1      1  20      0 0.01
DECAY
pi → pi0 e- nu    0.140      3.      3.
2.              0.              0.
0.135          0.00051      0.
EXIT
```

In case of REACTION the third line is read in the format (5A4,6F10.0) and contains the following.

1. Twenty hollerith symbols are arbitrary with one exception. If the last four symbols are .CMS (blank field before C), the program assumes, that a reaction in the center-of-mass frame will be simulated.
2. RM — Total energy of reaction in CMS (Sqrt(s)).
3. AMPROD — number of the secondary particles (products).
4. RNADD — a number of additional values, which user wants to read from the following line(s). This values will be put into array /ZBETA/AB(20) and can be used for various purposes.
5. PA — momentum of the beam particle.
6. RMA — mass of the beam particle.
7. RMB — mass of the target particle.

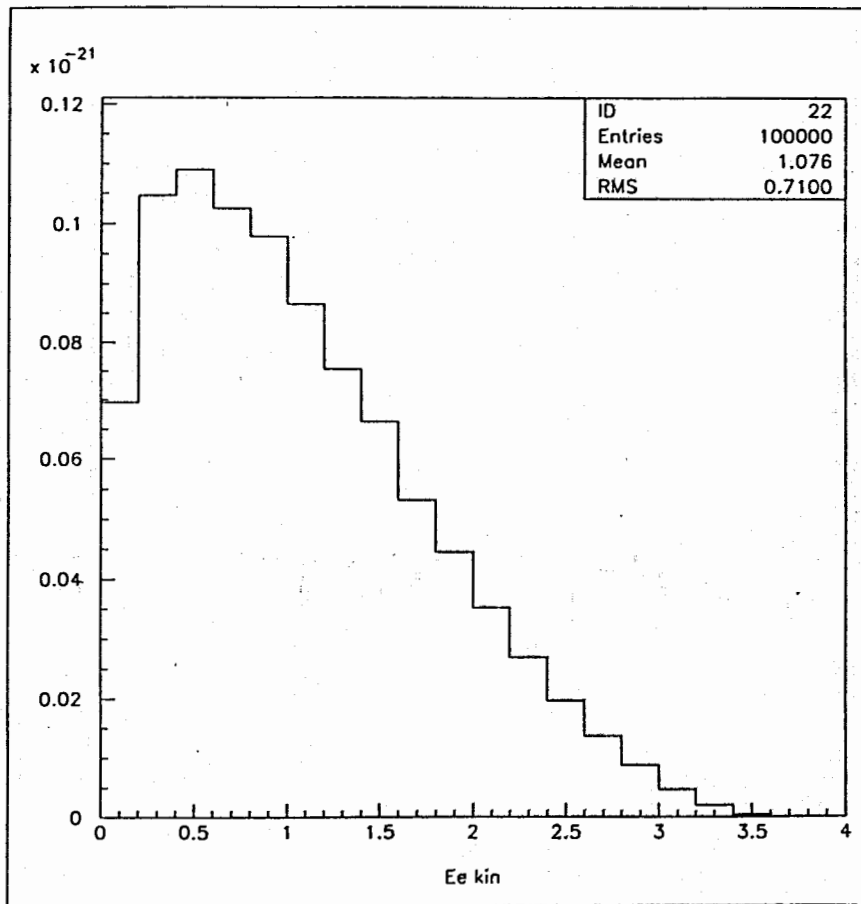


Fig.1

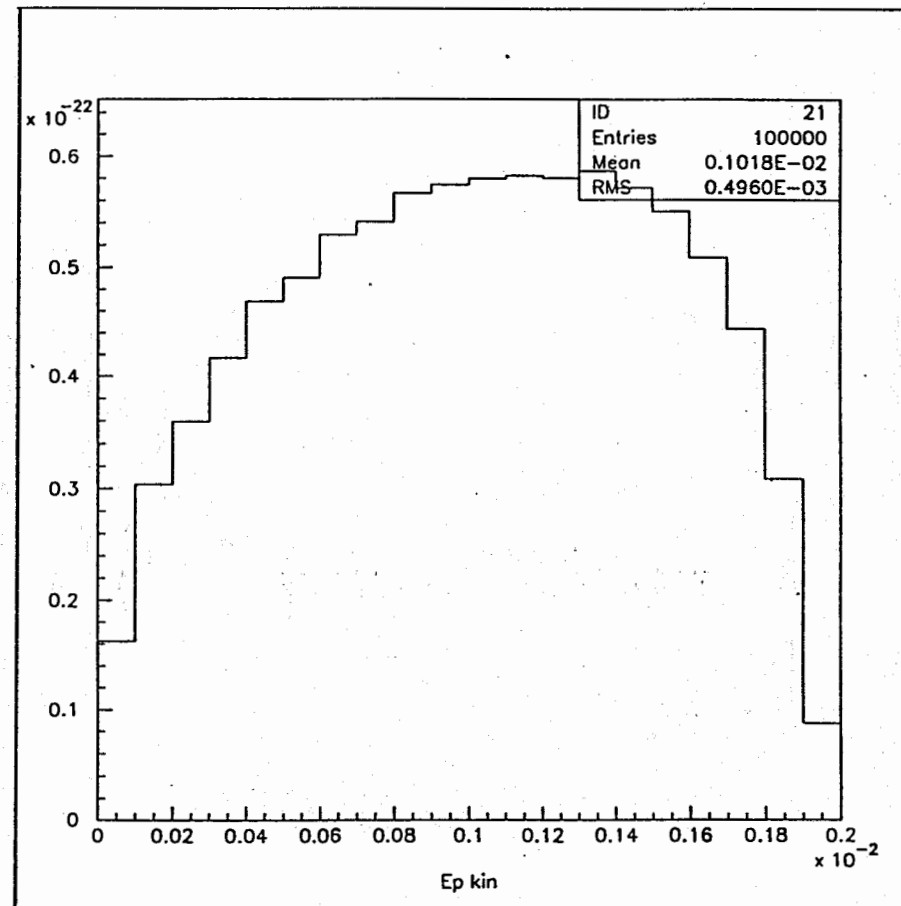


Fig.2

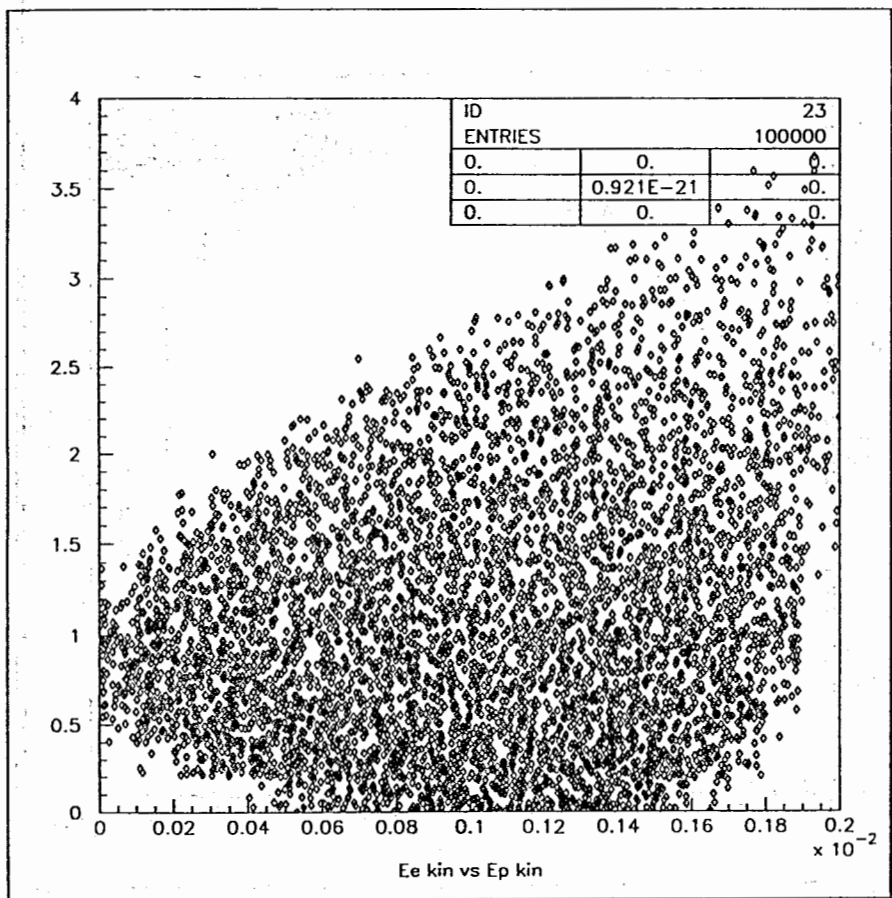


Fig.3

Energy of the reaction can be defined either via Sqrt(s) (RM), or via PA. If both these values are found to be greater, than zero, PA will be used for calculations.

Let's consider as an example calculation of the cross section for the reaction where colliding electron and positron produce Higgs boson, neutrino and antineutrino.

```

Higgs          1 100      1 . 1 20      0 0.01
REACTION
MEMO
ee -> nu nu H0 CMS 1000.    3.    3.    0.    0.00051  0.00051
3.             0.             0.
0.             0.0            600.
EXIT
  
```

Package BETA provides the possibility to store results of the calculation which can be used to continue the calculation later. The command MEMO should be used for the data storing (see the example above). In this case file *beta.out.dat* will be created. In order to use it for the continuation of calculation user should rename this file into *beta.in.dat* and use the command CONTINUE. Commands MEMO and CONTINUE can be used simultaneously.

Usage of SMART is essential for this reaction because the matrix element is rather difficult for integration. Particularly, the accuracy of 1% was achieved by simulation of about 130,000 events using this generator, whereas in order to achieve this accuracy with regular generator one needs to simulate almost 3,000,000 events.

In case of MODEL the card, which is on the fourth place in the last example, is read in format (5A4,4F10.0) and contains the same information except of RM and PA. For example, if we are going to simulate proton-proton interaction with three particles - proton, neutron and pion - as a result of the reaction, then the data file can be the following.

```

Test          0 10      1      1 20      0 0.05
MODEL
p + p -> p n pi    3.      3.      0.938  0.938
4.             0.             0.
0.938          0.940            0.140
EXIT
  
```

Program BETA was tested for number of decays, where decay rates were known. In all such cases we found the results of our calculations coincided with the expected answer.

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## References

- [1] T.A.Merkulova, G.G.Takhtamyshev. Communication of JINR E11-95-255 (1995).

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Тахтамышев Г.Г., Меркулова Т.А.

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Программа BETA для моделирования распадов и реакций частиц

Программа BETA предназначена для моделирования распадов и реакций элементарных частиц. Кроме того, программа выполняет интегрирование по фазовому пространству и в результате интегрирования вычисляется скорость распада или поперечное сечение реакции.

В процессе моделирования может быть использован адаптивный генератор случайных чисел SMART. Как показывает опыт, в некоторых трудных случаях это оказывается полезным.

Работа выполнена в Лаборатории вычислительной техники и автоматизации ОИЯИ.

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Program BETA for Simulation of Particle Decays and Reactions

Program BETA is designed for simulation of particle decays and reactions. The program also produces integration over the phase space and decay rate or the reaction cross section are calculated as a result of such integration.

At the simulation process the adaptive random number generator SMART may be used, what is found to be useful for some difficult cases.

The investigation has been performed at the Laboratory of Computing Techniques and Automation, JINR.

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