Calculating high energy particle production according to
statistical theories on an electronic computer

R. Hagodorn
CERN, Geneva

ABSTRACT

This is a manual for users of the programme which evaluates
results of Monte Carlo phase space calculations.

* * * * *

TABLE OF CONTENTS

Introduction ......................................................... 1
A. Preparation of data tapes ..................................... 2
   1) the m-tape ................................................. 3
   2) the b-tape ................................................. 7
B. Behaviour of the machine under the programme ........ 8
C. Restart procedure ............................................ 9
D. List of hand switches ....................................... 10
E. Logical structure (flow diagram) ......................... 11
F. Storage lay-out ............................................. 16
G. Lay-out of results .......................................... 18
H. Auxiliary programmes ....................................... 20
   1) the converting programme ............................... 20
   2) reaction probabilities in per cent .................. 21
I. Final remarks ............................................... 24
Calculating high energy particle production according to statistical theories on an electronic computer

Introduction.

The programme in question has been described in general in the yellow CERN publication CERN 59-25 (title as above), which must be read first, and which we shall refer to as I.

Here we give details for the use of the programme, but only those which are necessary. Further details (as well as the programme tape) may be obtained from CERN on request. The evaluated results are those from a Monte Carlo calculation of phase space integrals. The corresponding programme has been described in:

"A programme for calculating multiple phase space integrals by a Monte Carlo method on the Ferranti-Mercury computer"

by the author. We shall refer to it as II.
A. Preparation of data tapes.

We use three types of data tapes apart from the Monte Carlo (MC)-results, namely \[\text{see } I, \text{ p.14}\] :

- m-tape
- b-tape
- f-tape.

1) The m-tape.

This tape contains the three versions of the interaction volumes and the total isospin (doubled, in order to have it as an integer). This tape must be of the following form:

\[
\begin{align*}
\Omega_1, & \quad 1\text{st version} \\
\Omega_2, & \\
\Omega_3, & \\
\Omega_1', & \quad 2\text{nd version} \\
\Omega_2', & \\
\Omega_3', & \\
\Omega_1'', & \quad 3\text{rd version} \\
\Omega_2'', & \\
\Omega_3'', & \\
\end{align*}
\]

three sets of three interaction volumes, punched as floating point numbers. Example: "Natural"

Interaction volume for pions, nucleons:

\[
\Omega_N = \frac{4}{3} \lambda_N^3 \cdot \frac{2M_{\text{nucl.}}}{E_{\text{CM}}} = 1.365
\]

\[M_N = c = \frac{h}{4\pi} = 1, E_{\text{kin lab}} = 25 \text{ GeV.}\]

\[\Omega_j = 0 \quad \text{is admissible.}\]

2T twice the total isospin punched as integer.

\[
\begin{bmatrix}
P \\ P' \\ P''
\end{bmatrix}
\]

these numbers shall be on the tape only when needed and in that case handswitch 7 must be in 1-position during reading-in of m-tape. They add to the sums of weight factors accumulated during the calculation.
2) The b-tape.

The b-tapes contain the necessary information for reading-in the MC-results. Since in the preparation of these tapes errors are easily made, some precautions must be taken, namely:

(i) floating point numbers should always be punched as such (i.e. with decimal point). If then somewhere a number has been forgotten or written once too much, the machine will very soon encounter a floating point number where it expects an integer. Then it comes to an error print (Q18) and stops.

(ii) all sector numbers $s_1$ must be divisible by 3, if anyone is not, the machine hoots 3 times and stops. This helps to avoid mixing up spectra of different particles.

In the following list of data we indicate by a star (*) all those data which should be punched as floating point numbers (with decimal point, e.g. 1.0) and explain below the details.
<table>
<thead>
<tr>
<th>(b) (*)</th>
<th>number of the MC-case</th>
</tr>
</thead>
<tbody>
<tr>
<td>either</td>
<td>or</td>
</tr>
<tr>
<td>(\alpha) (=) -1</td>
<td>(\alpha =) number of isospin 1/2 particles</td>
</tr>
<tr>
<td>(\beta) (=) (W_{\alpha\beta})</td>
<td>(\beta =) number of isospin 2/2 particles</td>
</tr>
<tr>
<td>(\gamma) (=) (\delta) (=) ((3/2) particles)</td>
<td>(\delta =) number of isospin 3/2 particles</td>
</tr>
</tbody>
</table>

must all be set

\[
\sigma (1/2) \\
\sigma (2/2) \\
\sigma (3/2) \\
\sigma (4/2) \\
\sigma (5/2)
\]

numbers of particles of ordinary spin \(1/2 \ldots 5/2\) must all be set. (If there is no such particle: set zero).

\[
N_1 \\
N_2 \\
\vdots \\
0
\]

numbers of equal particles. Set only if \(N > 2\), otherwise leave out. All members of an isospin-multiplet are considered as equal. The 0 must appear at the end. It tells the machine that this type of information ends here. The 0 must always be set, even if there are no \(N > 2\).

\[
n_1 \\
n_2 \\
n_3
\]

powers of \(\Omega_1\) respectively \(\Omega_1^0\) gives \(n_1 = 0\) gives \(\Omega_1^0 = 1\) also for \(\Omega = 0\).

\[
p_1 \\
s_1 \\
Z_1 (*)
\]

The contents of page \(p_1\) are multiplied by \(P, Z_1, P^i Z_1, P^i Z_2\) and added to sectors \(s_1, s_1^j, s_1^{j+1}, s_1^{j+2}\). One may write up to 21 such operations (21 being the largest allowed subscript) terminating them with 0 to tell the machine that this information ends. \(s_j\) must be divisible by 3 and \(300 \leq s_j \leq 474\). The spectra in the computing store are not changed by these operations.

\[
p_2 \\
s_2 \\
Z_2 (*)
\]

Additional weight factor for sum of probabilities: \(Z\) is the number of implicit interpretations of a spectrum (i.e., occurring on one single b-tape). If that is \(\neq 1\) one uses this facility. The spectrum is added with weight \(\sum P, \sum P', \sum P''\) is added to \(\sum P, \sum P', \sum P''\). \(Z\) should be punched only if necessary. In that case B58 must be in 1-position.

\[
\mathbf{v} \quad \mathbf{[0]} \\
\mu \quad (even!)
\]

number of original spectra

number of decay spectra

---

1) Only \( \alpha =0,1,\ldots,4, \beta =0,1,\ldots,10, \gamma =0,1,\ldots,4, \ 2T=0,1,2,3\) are admitted. If \( \alpha, \beta, \gamma, T \) lie outside this range, \( W_{\alpha\beta\gamma} (T) \) must be found from elsewhere. Then one gives - followed by the numerical value of \( W_{\alpha\beta\gamma} (T) \).

2) If \( \psi \) is put \(=0\), then no new spectra are read in. The data of the b-tape are applied to the spectra already present in the machine.
Some explanations may be useful:

(i) The facility of giving \( W_{\sigma_j} (T) \) numerically (rather than taking it from the table in the drum store) can be used as a trick to introduce any desired additional weight factor. This factor will then multiply the spectra and the probabilities \( P, P', P'' \) of the considered reaction. It enters therefore into the total sum of probabilities.

On the other hand, the \( z_{j} (z_{j}; p_{j}; s_{j} \rightarrow s_{j}) \) multiply only the spectra which from MC are normalized to unity. The \( z_{j} \) therefore are meant mainly as particle numbers (e.g. \( N+N \rightarrow N+N+5 \pi \); then the \( z_{j} \) for the \( \pi \)-spectrum is to be 2; that for the pions \( z_{j}^{\pi} \)). Also here one can use the \( z_{j} \) for introducing any desired further weight factor, but it only multiplies the spectrum and not the probabilities \( P, P', P'' \). It therefore does not enter into the total sum of probabilities.

(ii) In order to use nevertheless the \( z_{j} \) as weight factors more generally, \( Z \) is introduced, which multiplies \( P, P', P'' \) immediately before adding them to the sum of weight factors. Example: consider \( N+N \rightarrow 3N+N^* \).

One of the final particles has to be an antinucleon. Hence:

\[
\text{either } \begin{cases} 2N+1N+N^* \\ 3N+N^* \end{cases} \quad \text{both follow from the same MC-results.}
\]

One may interpret both channels on one single \( b \)-tape and assume \( N=3 \) (3 equal particles; \( \frac{1}{3!} \)). The first reaction has only two equal particles and this will be corrected by multiplying the \( z_{j} \) by three. The total weights to be added to \( \sum P, \sum P', \sum P'' \) are therefore \((3+1)P\) etc.

Hence in this case \( Z=4 \). In more complicated cases \( Z \) may be non-integral. Whereas \( 2P, 2P', 2P'' \) is added to the sum of weight factors, only \( P, P', P'' \) is printed as weight for the reaction. These weight factors are meant to apply "per channel". They must be corrected by hand after the printout. In general this must be done for each channel separately. Of course no such correction is necessary if the \( Z \)-facility has not been used.
(iii) Interpreting one set of MC-results several times on a single b-tape may become very complicated, in particular when many data of interpretation change. In that case one interprets the same MC-results once more by means of another b-tape without reading in the MC-results again. It suffices to begin a new b-tape (same number b on the head !) with the new interpretation and to put \( V = 0 \) at its end. One may proceed so as often as desired **).

For the next MC case the b-tape (next b on the head) has then \( V \neq 0 \). The numbers \( b \) on the head of the b-tapes and those on the MC spectra are checked against each other. 3 hoots and stop if they are different. If HS1 is in 1-position, this check is omitted. That is permissible only if the MC-results do not bear a "b". This happened, however, only in MC-calculations made in an earlier stage of development of the MC-programme. The b-check (HS1=0) is the normal thing.

The numbers \( s_j \) must designate the first of a set of three sectors on the drum - the following two will be filled automatically by the second and third version. Therefore the \( s_j \) must be divisible by 3. The machine checks this. The original spectra go to pages 22, 23, ..., 3'. The decay spectra to 21, 20, 19, ..., 14, exactly as they were before output in the MC-calculation [See II, p.23]. The \( p_j \) refer to these page numbers, e.g. \( p_j = 22 \) means the spectrum of the heaviest particle of the case under consideration.

*) In particular, one may have more than 21 operations \( p_i s_i \rightarrow s_i \).

**) For each b-tape the weight is calculated, printed, and added to \( \Sigma P, \Sigma P', \Sigma P'' \). If one does not want this last feature, one can always restore the "right" \( P \ldots \) by subtracting a suitable number, by m-tape, before starting the evaluation proper. (See p.2).
3) The f-tape.

It guides the final calculation: decay spectra are calculated \( \text{see II, p. } 3 \) including zero-mass decay products \( (\pi^0 \rightarrow 2\gamma) \). Sectors (spectra) are superposed.

Structure:

<table>
<thead>
<tr>
<th>( \Delta )</th>
<th>Tells the computer that this is not a b-tape.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( m^* )</td>
<td>Mass of decaying particle.</td>
</tr>
<tr>
<td>( M )</td>
<td>Heavier decay product ( (M=\mu=0 \text{ is allowed}) )</td>
</tr>
<tr>
<td>( \mu^* )</td>
<td>Lighter decay product ( (M=\mu=0 \text{ is allowed}) )</td>
</tr>
<tr>
<td>( s^* )</td>
<td>Sector which shall decay.</td>
</tr>
<tr>
<td>( s_M )</td>
<td>Sector where to place ( M )-spectrum. ( s ) must be divisible by 3.</td>
</tr>
<tr>
<td>( s_{\mu} )</td>
<td>Sector where to place ( \mu )-spectrum. ( s ) may be repeated as often as desired. Decay products may decay themselves afterwards.</td>
</tr>
<tr>
<td>( \cdots )</td>
<td>End of decay. Must be set also if no decay took place.</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
 s_1 \{ \\
  z_1 \{ \\
  s_2 \{ \\
  z_2 \{ \\
  s_3 \{ \\
 \cdots \\
\end{align*}
\]

Operation: \( z_1 \cdot s_1 + z_2 \cdot s_2 \rightarrow s_3 \)

Previous contents of \( s \) are lost; \( s_1 \) and \( s_2 \) are preserved. \( z_3 \) may be any number, including negative and zero. All \( s \) must be divisible by 3.

may be repeated as often as desired.

<table>
<thead>
<tr>
<th>( \theta_0 )</th>
<th>( \theta_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>first ( { ) sector to be punched and plotted out.</td>
<td></td>
</tr>
<tr>
<td>last ( { )</td>
<td></td>
</tr>
<tr>
<td>( s_0 ) must be divisible by 3,</td>
<td></td>
</tr>
<tr>
<td>( s_1 ) must be of the form ( 3n+2 ).</td>
<td></td>
</tr>
</tbody>
</table>
B. Behaviour of the machine under the programme.

a) Together with the programme the table of $W_{\alpha,\beta} (T)$ (contained in
the programme tape) is read in and stored. Stop.

b) Place m-tape under reader. Propulse.
If $\Sigma P, \Sigma P', \Sigma P''$ is on m-tape, HS7 must be in 1-position. Title
and interaction volumes ($\Sigma P, \Sigma P', \Sigma P''$) are punched. Stop.

c) Place MC data with b-tapes under the reader in the order

\[ \text{spectra} \quad \text{b-tape} \quad \text{spectra} \quad \text{b-tape} \quad \text{spectra} \quad -- -- -- \]

If HS0 is in 1-position, stop after each spectrum (propulse),
otherwise go on reading. HS0 serves to avoid running out at the
end of tape *). Case numbers and weight factors are punched.

d) When all is read, place f-tape under reader.

$b = 0$ and $-1,000,000$ is punched (for later use in another programme
only). $\Sigma P, \Sigma P', \Sigma P''$ is punched. 3 hoots, stop.

e) Propulse. Decay is calculated; superposition is carried out; spectra
are normalized and interpolated. Punching begins ($s_0 \leq s \leq s_1$).
Only mean particle numbers $\langle n \rangle$ and mean energies $\langle \epsilon \rangle$ if HS5=1.
Only first version spectra (but all $\langle n \rangle$ and $\langle \epsilon \rangle$) if HS4=1.
Everything is punched otherwise.

f) 5 hoots and 100 FS indicate end of punch for teleprinter. Punching of
plottable results follows immediately. If that is not wanted, stop the
machine here by "single". Only first of three versions if HS4=1,
otherwise everything is punched.

100 hoots and stop indicate end of calculation.

*) Instead of HS0=1 one also may use the $\rightarrow$ facility: if a $\rightarrow$
is punched at the end of the tape, the machine will stop and can be
propulsed if wanted.
C. Restart procedures.

Restart may become necessary in case of faults (tape or machine) or in order to apply several f-tapes to the final state of the drums. In case of faults one restarts and begins the case in which the fault occurred anew.

Restart:

- **HS=1,** press initial transfer, tap out 128.
- **While the title is punched:** set **HS2=1.**
- (Otherwise the programme expects now the \( W_{Pb}(T) \)-table to be read in).
- **Stop.** Before prepulsing set **HS3:**

![Diagram](attachment:image.png)

- **Prepulse.** b-tape for next case (or the case to be repeated) is read in.
- \( \Sigma P, \Sigma P', \Sigma P'' \) is conserved; the machine is in the state it was after the preceding case had just finished, drums are not cleared.

**HS3**

- **0**
  - Place m-tape under the reader.
  - Prepulse. z-tape is read, drum sectors 300-476 are cleared to \( 0 \times 10^{-77} \). This restart is used only for beginning a new evaluation run.
D. List of handswitches.

0 1 stop before reading next b-tape.
0 1 go ahead reading next b-tape

0 1 do not control case number b=b_{mC} /Only admissible if MC-results do not contain b_{mC}.
1 1 This is the exception!/

0 0 control case number b=b_{mC} /This is the normal case!/

0 1 restart such that next case or new m-tape may be read. To be set to this position during the title is punched. /Normal !/.

0 2 restart with reading W_{\rho \phi} (T)-table again.
1 0 /Exception !/.

0 1 restart with new m-tape. Drums are cleared. To be used if new evaluation begins.

0 1 restart at next b-tape (or repeating last case after fault). Drums are preserved, also \Sigma P, \Sigma P', \Sigma P''.

0 1 only the spectra of the first version (\Omega \Omega \Omega \Omega) are punched out, but the mean particle numbers \langle n \rangle \langle n' \rangle \langle n'' \rangle \langle n''' \rangle and energies \langle E \rangle \langle E' \rangle \langle E'' \rangle \langle E''' \rangle are punched in all versions.

0 0 everything is punched in three versions.

0 1 only \langle n \rangle \langle n' \rangle \langle n'' \rangle \langle n''' \rangle \langle E \rangle \langle E' \rangle \langle E'' \rangle \langle E''' \rangle are punched, no spectra.
0 0 everything is punched in three versions.

0 1 Fourier-least-square-fit of 5th order only. To be used if apparently bad statistics. /Exception !/.

0 1 Fourier-fit of variable order if good statistics. /Normal !/.

0 1 read in \Sigma P, \Sigma P', \Sigma P'' with m-tape /Exception !/.
0 0 do not read \Sigma P, \Sigma P', \Sigma P'' with m-tape /Normal !/.

0 0 The \Sigma P's should not be on the m-tape !.

0 1 read Z /must be on b-tape/ for Z-fold interpretation with one single b-tape.

0 0 do not read Z /Z must not be on the tape !/.

7580
E. Logical structure.

In the following we give an oversimplified flow-diagram showing the logical structure and omitting everything which is not necessary to understand the working of the programme. In particular all those routines have been omitted here, which merely carry out frequently used operations as acoustical warning, printing, division, etc.

The boxes stay for one or several routines, the numbers in circles refer to the routine numbers as used in the actual programme:

\[ 99 \]

means routine R99

\[ 5/99 \]

means address labelled by (5 in R99)

The reader should be able to understand the general working of the programme by using the description I, and the following flow-diagram.

The present writer is aware of the fact that many details are missing. He feels, however, that writing them down would make this report too complicated and perhaps unreadable. The user of the programme should spend rather two or three times a 10-minutes' run on the machine to become familiar with the programme.
Chapter 3

Print $0$ and $-1.000$
print $S_P, S_{P'}, S_P^*$
last 3 times

Chapter 4

Read $z_1, z_2, z_3, ..., \text{from tape}$
until 0 is read. Hoops 3 times
and stops if any 3 not divisible
by 3. Points
$x_1 + x_2 + x_3 \Rightarrow x_3 \ldots$
All operations three times
(Three versions)

Chapter 3

Read $\mu$, read $\mu^2, \mu_0$,
repeat until $-1$ is read
Calculate decay spectra

If $\mu^2 < 10^{-6} (\mu_0^2 - \mu^2)$
Then $M = 0$
$\mu = 0$

All operations are carried out three times (Three versions)

Chapter 4

Read $z_0$ and $z_1$ from tape.
Normalize all vector
$x_0 \leq \ldots \leq x_1$
Calculate mean energy

Print number
of every third
spectrum. Print
mean particle
number $\langle n \rangle$, $\langle n' \rangle$

Chapter 4

Print first of 3
spectra only
Print spectra only
Print all spectra

Prepare some numerical
constants for interpolation
in C7

Punch tape for
graph plotter:
Spectra and least
square Fourier fit.

END
Chapter 7

Find "end" of spectrum: n
1st
HS 6
17. variable (7th) order

Find position $x_0$ of
maximum
Calculate $\lambda = (1 - \frac{2x_0}{\lambda})^2$

Multiply spectrum by $x^\lambda$. Interpolate resulting histogram by least square Fourier sum of order $\frac{n}{2}$ (or 5 according to HS 6, see 87) ($n =$ number of contributions to histogram)
Divide resulting smooth curve by $x^\lambda$. Go to plot
F. Storage lay-out.

We shall not go into details here. As already mentioned, the spectra occupy in the fast store exactly the same pages as they did before MC-output.

The table \( W_{\alpha \gamma} (T) \) is stored in the drum, sector 256 to 299. The numerical value of \( W_{\alpha \gamma} (T) \) is stored at

\[
\text{sector number} = 256 + 22.T + \beta \\
\text{register number} = 10\alpha + 2\gamma
\]

On s255 we store p1 of the fast store. In case of fault and restart s255 \( \rightarrow p1 \) such that the faulty case can be redone. This goes automatically.

The sectors s300 to s476 contain weighted sums of spectra. When a restart with HS3=1 is done and also after reading the programme, these sectors are filled by 0x10^-73.

The structure of s300 to s476 is:

```
| 300 | 301 | 302 |
| 303 | 304 | 305 |
| 474 | 475 | 476 |
```

Each sector contains the spectrum of one kind of particle and a mean energy - together 32 fl. pt. numbers. In the b- and f-tapes only the first of the three consecutive sectors is given explicitly. The operations are carried out three times automatically and thus all three sectors s, s+1, s+2 will be filled with the three versions respectively.
It is strongly recommended to divide up the available drum space into three sections: in the first set of sectors $s_{300}$ to $s_{387}$ (388, 389) one accumulates the sums of weighted spectra. The third set of sectors $s_{432}$ to $s_{474}$ (475, 476) is used as working space for carrying out decay and superposition of spectra in such a way that the data in the first set are preserved. One arranges then the data for punching in consecutive sectors of the second set *) $s_{390}$ to $s_{429}$ (430, 431). The printing of results is then caused by giving $s_o$ and $s_i$ (in our example $s_o = 390, s_i = 431$) and only those sectors are normalized, whereas those in the first set are not touched. This has the advantage that one may now restart (as if it were for a new b-tape, i.e. BS3=0) and read in another f-tape for a different final interpretation. To do this successfully, the accumulated spectra must of course remain unnormalized. This is achieved by separating the available drum store in the above mentioned three sets of sectors **).

Any variation of this scheme may be used to the convenience of the programmer. The three sets of sectors may interlace. The only important thing is, that spectra which have to be interpreted several times (i.e. by several f-tapes) must never be punched out, since they will then be normalized and no longer can represent total particle numbers.

*) To transfer a spectrum (e.g. $s_{300}$) to another sector (e.g. $s_{402}$) one writes on the f-tape:

300
1.0
399 (or any other sector)
0.0
402

**) If the evaluation took a long time (more than one hour, say) it is useful to punch out in binary form the first set of sectors containing the accumulated spectra. If one has then a machine fault or an error in the f-tape, or if one wishes later on another f-interpretation, then one simply reads in the binary tape without going through the whole evaluation process again.
### G. Lay-out of results.

**EVALUATION OF MC RESULTS**

\[
\begin{align*}
\Omega_1 & \quad \Omega_1' & \quad \Omega_1'' \\
\Omega_2 & \quad \Omega_2' & \quad \Omega_2'' \\
\Omega_3 & \quad \Omega_3' & \quad \Omega_3'' \\
\end{align*}
\]

\( \{ \) three versions of interaction volumes

\( 2T \)

\[
\begin{bmatrix}
\sum_P & \sum_{P'} & \sum_{P''} \\
\end{bmatrix}
\]

\( \text{only if read in} \)

\[
\begin{align*}
b_1 & \quad P_{b_1} & \quad P_{b_1}' & \quad P_{b_1}'' \\
b_2 & \quad P_{b_2} & \quad P_{b_2}' & \quad P_{b_2}'' \\
\vdots & \quad \vdots & \quad \vdots & \quad \vdots \\
b_n & \quad P_{b_n} & \quad P_{b_n}' & \quad P_{b_n}'' \\
\end{align*}
\]

\{ case numbers b (to identify reaction) and unnormalized reaction probabilities P \}

\( \text{serves as instruction for another programme} \)

\[
\sum_{b} P_{b} \quad \sum_{b} P_{b}' \quad \sum_{b} P_{b}''
\]

total sums of weights

\( s_0 \)

\[
\begin{align*}
\langle n \rangle & \quad \langle n' \rangle & \quad \langle n'' \rangle \\
\vdots & \quad \vdots & \quad \vdots \\
\langle \varepsilon \rangle & \quad \langle \varepsilon' \rangle & \quad \langle \varepsilon'' \rangle \\
\end{align*}
\]

\{ sector numbers s \\
(to identify kind of particle), mean absolute particle number per collision, spectra (only first version if HS4=1; no spectra at all if HS5=1), mean kinetic energies expressed in the adopted energy unit (e.g. \( M_{\text{nuc1}=1} \)) \}

All three versions of \( \langle n \rangle \langle n' \rangle \langle n'' \rangle \) and of \( \langle \varepsilon \rangle \langle \varepsilon' \rangle \langle \varepsilon'' \rangle \) are printed without regard to HS4 and HS5. These hand-switches influence only the punching of spectra.
After the teleprinter results, the data for the graph plotter follow. Only the first version is punched, if HS4=1. If no plotter results are wanted, one stops the machine after teleprinter output (announced by 5 hoots). The Fourier-smoothing out interpolation is done only on the plotter results.

The plotter results can be printed also on the teleprinter where they look as follows:

\[
\begin{array}{c|c}
\text{x coordinate, } \xi & \text{y coordinate, } \varphi(\xi) \\
0050 & 0172 \\
0150 & 0193 \\
0250 & 0215 \\
0350 & 0200 \\
\vdots & \vdots \\
3050 & 0000 \\
\end{array}
\]

That is, the x-coordinate is always in the middle of the energy interval (there are just 31 such cells numbered from 0 to 30, hence \(x = 0.5, 1.5 \ldots 30.5\)). No mean energies and particle numbers occur here. The interpolated version has again 31 number-pairs but in general the distance of the x-coordinates is smaller, since only the non-vanishing part of the spectrum is interpolated and then reproduced by 31 numbers again to facilitate drawing. Plotted it looks like this:

![Graph Plot](image)
By proper use of the scaling and parallax facilities of the automatic graph plotter one can plot a spectrum which has been calculated in:

"particles/ΔE" for e.g. ΔE = 0.5 nucleon masses in any other scale, e.g. "particles per 1 MeV".

If HS4=0 all spectra are punched for the plotter, first the three original versions for one kind of particle. They are followed by the same three versions in the Fourier-smoothed out form, then the next kind of particle (3 original, 3 smoothed) follows, etc.

If HS4=1, only the first version is punched for the plotter, immediately followed by its smoothed form.

H. Auxiliary programmes.

There are two auxiliary programmes:

1) the converting programme \[^{Footnote in II, p.47}\]

2) reaction probabilities in per cent.

1) The converting programme.

The first one converts the MC-results into a form which is accepted by the machine. These cannot be read in their original form, since it was necessary to leave out some spaces in order to be able to print MC-results for up to 10 different particles \[^{II, p.39, 46 and 47}\].

One proceeds as follows: according to II, p.47 the main results of the MC-calculation are contained between two pieces of about 24 cm blank tape each:

\[
\begin{array}{c|c|c}
24 \text{ cm} & b & 24 \text{ cm blank} \\
\hline
\end{array}
\]

\(\Phi^*\) spectra, decay spectra
(The case number b is not mentioned in II, p.47. This has been built into the programme after that manual was written).

One cuts the MC-tape in the blank sections and fits to it by means of scotch tape (red !) the b-tape interpreting that case.

The same for the next case and so on. The whole is then put together into one long tape:

\[ \begin{array}{c|c|c|c|c|c} b\text{-tape} & MC\text{-results} & b\text{-tape} & MC\text{-results} & \ldots & b\text{-tape} & MC \end{array} \]

If a MC-case is interpreted by several b-tapes see p.6, (iii) this looks as follows:

\[ \text{first b-tape, } \psi \neq 0 \quad \text{MC-results} \quad 2\text{nd b-tape, } \psi = 0 \quad 3\text{rd b-tape, } \psi = 0 \quad \ldots \]

\[ \text{last b-tape, } \psi = 0 \quad \text{first b-tape for next case } \psi \neq 0 \quad \text{MC-results} \quad \ldots \]

One reads the "converting programme", puts the ready prepared tape under the reader; propulse. It is read and immediately punched out in a converted form ready for input in the evaluation programme. One must avoid that the tape to convert runs out of the reader - this would cause a faulty punch on the converted tape. Copies of this converting programme are available at CERN.

2) Reaction probabilities in per cent.

The weight factors $P_b, P_b', P_b''$ are not normalized when they come to the teleprinter. If one really needs them (that will be the case in lower energy reactions only) it may be more useful to have them either normalized to unity (absolute probabilities) or to hundred (probabilities in per cent). For this one uses a special programme and a teleprinter output of the evaluation results.
To this end one punches a little tape containing below each other
\[
\sum_P \quad \sum_{P'} \quad \sum_{P''}
\]  
for prob. normalized to unity

or
\[
\frac{1}{100} \sum_P \quad \frac{1}{100} \sum_{P'} \quad \frac{1}{100} \sum_{P''}
\]  
for prob. in per cents.

These data are taken from the print-out of the evaluation programme, where they appear at the end of the list of P's just before the spectra come out. \(\text{see p.127.}\)

The line
\[0 \quad -1.000, +0\]
on the evaluation print-out is for this programme. It tells the computer that the list of probabilities ends now. The list of P's from evaluation may contain ERROR-prints - that does not cause difficulties for the present auxiliary programme.

The programme will not be described in detail, we only give here a prescription for the use:
REACTION PROBABILITIES IN PER CENT

1) Read programme. Stop.

2) Read tape with \( \bar{\Sigma}_P, \bar{\Sigma}_P', \bar{\Sigma}_P'' \) (or \( \frac{1}{100} \) of them). Stop.

3) Place evaluation results under reader. Propulse. P-data are read, divided by the sums and punched out again. Lay-out as in the evaluation programme \( \overline{E} - \overline{I} - \overline{P} \).

4) When \(-1.000, +0\) on evaluation output is encountered (end of reaction probabilities): hoot, jump to 2) above, stop. Ready for a new run if wanted.

5) When ERROR-print or floating point number is encountered where a b (integer) is expected: machine hoots and makes ERROR-print.

If now

END of prob. list is not reached:

- a) Restart : H3=1, press initial transfer, tap 128. Stop. Read again \( \bar{\Sigma}_P, \bar{\Sigma}_P', \bar{\Sigma}_P'' \) with H3O=1. Stop.

- b) Place evaluation results under reader such that next b comes as the first number to be read. Propulse.

END of prob. list is reached:

Finished. If further lists of P shall be transformed : Restart. Begin at 2) above (H3O=0).
I. Final remarks.

The present description should suffice to use the programme. It is not detailed enough to allow improvements of the programme. If that is wanted, the print-out of the programme tape must be consulted and further details are available from the author.

Copies of the programmes described here are available at CERN.

I thank Dr. F. Cerulus (CERN) for suggestions based on his experiences in using the programme, which led to some improvements of the programme, as well as of this description.