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1) - STATEMENT OF THE PROBLEM -

Neutral non strange bosons can be singly produced in e^+e^- collisions; in particular they will be produced at rest in e^+e^- storage rings. The production cross section is peaked around the boson mass and reproduces, as a function of the total center of mass energy of the primaries, the line shape characteristic of a free unstable particle⁽¹⁾. Thus, a plot of the counting rate versus total c.m. energy of the colliding e^+e^- should exhibit a line structure over a flat non resonant background: a storage ring can be used in this sense as a boson mass spectrometer.

Actually, quantum numbers conservation imposes some limitations on the intensity of the boson lines. Production to the lowest electromagnetic order (one photon channel) is allowed only when the final boson has $J^{PC} = 1^{--}$. When $J = 0, 2$ and $C = +$ the line intensity will be depressed by a factor $e^4 \approx 10^{-4}$; other cases will be even more severely contrasted by helicity arguments⁽¹⁾.

2) - THE ρ^0 CASE. -

A typical feature of single boson production in e^+e^- storage rings is the absence of strongly interacting partners to the produced particle.

The ρ^0 case is particularly interesting in that ρ^0 's life time is so short that when it is strongly produced it also usually decays in presence of strong fields.

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2.

High energy forward photoproduction of ρ^0 on nuclei⁽²⁾ shows some perplexing features suggesting a possible difference in the line shape of a free ρ^0 from that usually observed. This remark suggests that an accurate investigation of the ρ^0 production in Adone be made.

3) - ADONE AS A BOSON MASS SPECTROMETER. -

The mass range of Adone as a mass spectrometer goes up to 3 BeV, twice the maximum energy of each primary electron.

The lower mass limit at which the ring can be safely operated is not well known: it presumably extends down to 600 MeV without any trouble and a non negligible luminosity⁽³⁾.

The mass resolution is given by the energy spread of the primaries. The total c. m. energy definition should be given to within a few hundred keV according to the design characteristics of the machine⁽³⁾. In view of the present knowledge on the line width of strongly decaying bosons this figure for the energy spread should be largely adequate. A line narrower than, say, 500 keV will have its width masked and its peak intensity reduced by averaging over the energy spread of the beam particles.

4) - THE EXPERIMENTAL SETUP. -

The non resonant background of e^+e^- reactions will span the same variety as the boson decay products. However a large fraction of non resonant events will be due to electron-positron scattering whereas electron-positron boson decay should be rare. It could be convenient to consider the possibility of reducing e^+e^- counting rates but this seems at present not so easy to achieve all over the wide energy range to be scanned.

A simple detection system accepting both charged products and γ rays is shown in fig. 1. No attempt has been made to distinguish among charged particles in this system; however pulse height analysis could be of help in some cases.

The accepted solid angle of the counter system in fig. 1 is 70% of the total.

Fig. 1 shows 4 scintillation counter sandwiches, numbered from 1 to 4; counters in each sandwich are labeled A, B, C moving from the interaction region of the primary beams (at the center of the array).

Lead converters are inserted in between counters A, B and B; C.

A charged particle reaching sandwich n^o 1, say, will at least

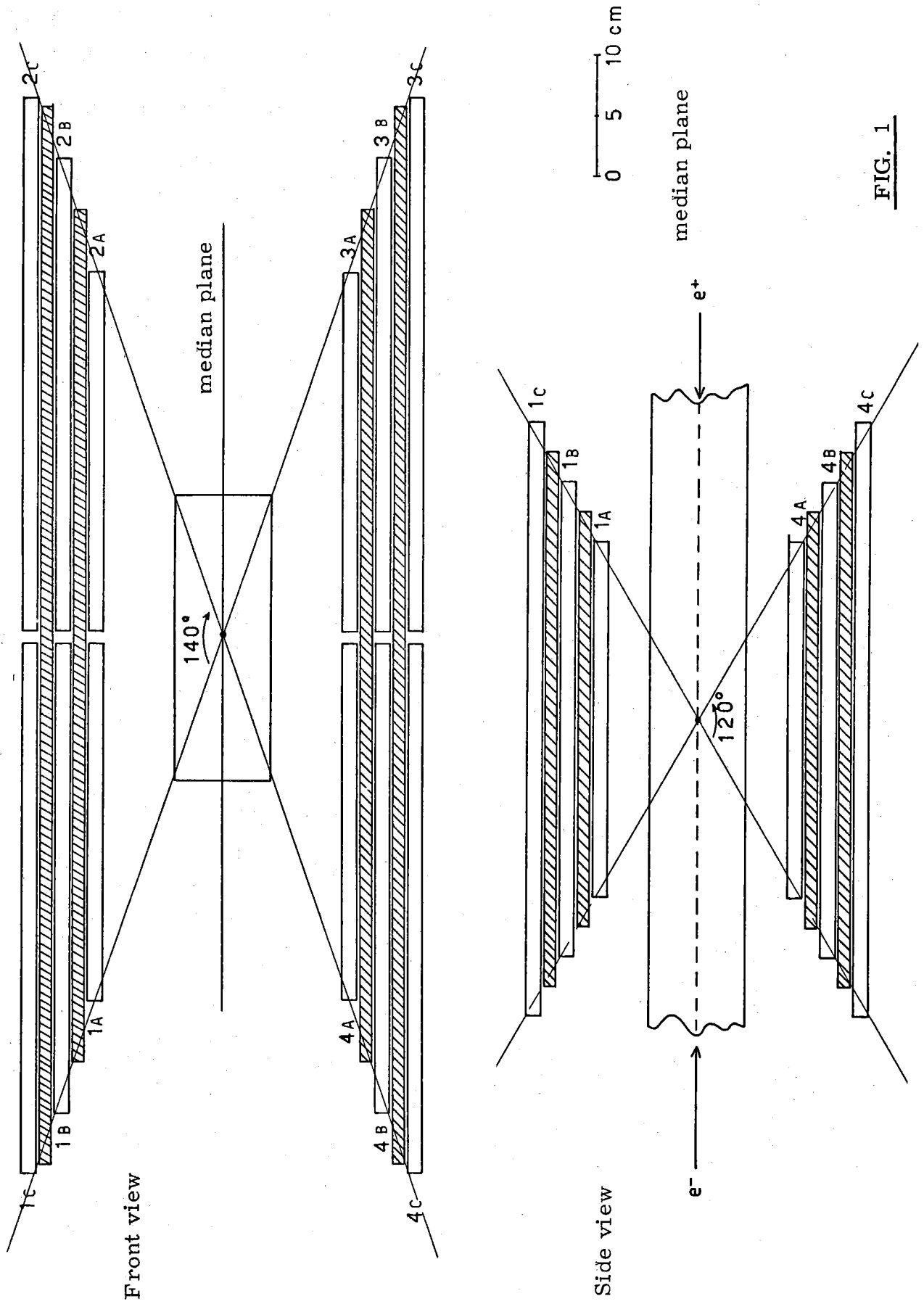


FIG. 1

4.

give a pulse in A; this event will be classified as 1_C and corresponds to A or A + B or A + B + C. A + C will possibly be electronically excluded.

A γ ray will usually not give a pulse in A (less than 10%, depending on the angle, will convert into the 1 mm steel walls of the donut; in this case the γ ray will be classified as a charged particle). Shower production in the lead converters can be detected by pulses in B or C or both (B + C) in anticoincidence with A. The conversion efficiency can be made high enough by choosing each lead converter 1.5 radiation lengths thick: this corresponds to about 95% conversion efficiency.

Events like $\bar{A} + B$ or $\bar{A} + C$ or $\bar{A} + B + C$ will be classified as neutrals; thus 1_N means a neutral triggering sandwich $n^0 1$.

In the following, by the symbol 1 we will mean either an event 1_N or 1_C and a similar notation will be used for the other channels. We will further classify events as follows:

- a) two or more body decay events correspond to such coincidences as 1 + 3 or 2 + 4.
- b) three or more body decay events correspond to coincidences 1 + 2, 2 + 3, 3 + 4, 4 + 1, 1 + 2 + 3, 1 + 2 + 4, 1 + 3 + 4, 2 + 3 + 4,
- c) four or more body decay events correspond to coincidences 1 + 2 + 3 + 4.

It must be noted that the possible outcomes are ordered according to increasing smallest number of decay products in each group (a, b, c). The groups actually overlap.

A short account of a possible electronic presentation of data according to this classification will be given in appendix.

5) - A FAST METHOD TO EXPLORE THE WHOLE MASS RANGE. -

The main idea is that of exploring the whole mass range by continuously varying the energy of the ring from the minimum to the maximum. A slow triangular modulation of the machine field appears easily feasible provided the period is longer than one minute⁽⁴⁾.

The main virtue of this method is that intense single boson lines will be simultaneously evident after a short running time wherever they are in the scanned mass range. Smaller bumps will gain statistical significance as the time goes on: there one has to decide when to stop according to the fluctuations of the non resonant background.

A crude sketch of the expected plot (counting rate versus energy) is given in fig. 2 including only the known vector bosons ρ^0 , ω^0 , ϕ^0 .

Once a bump is observed the energy modulation can be restricted to the neighborhood of the relevant energy to obtain better statistics

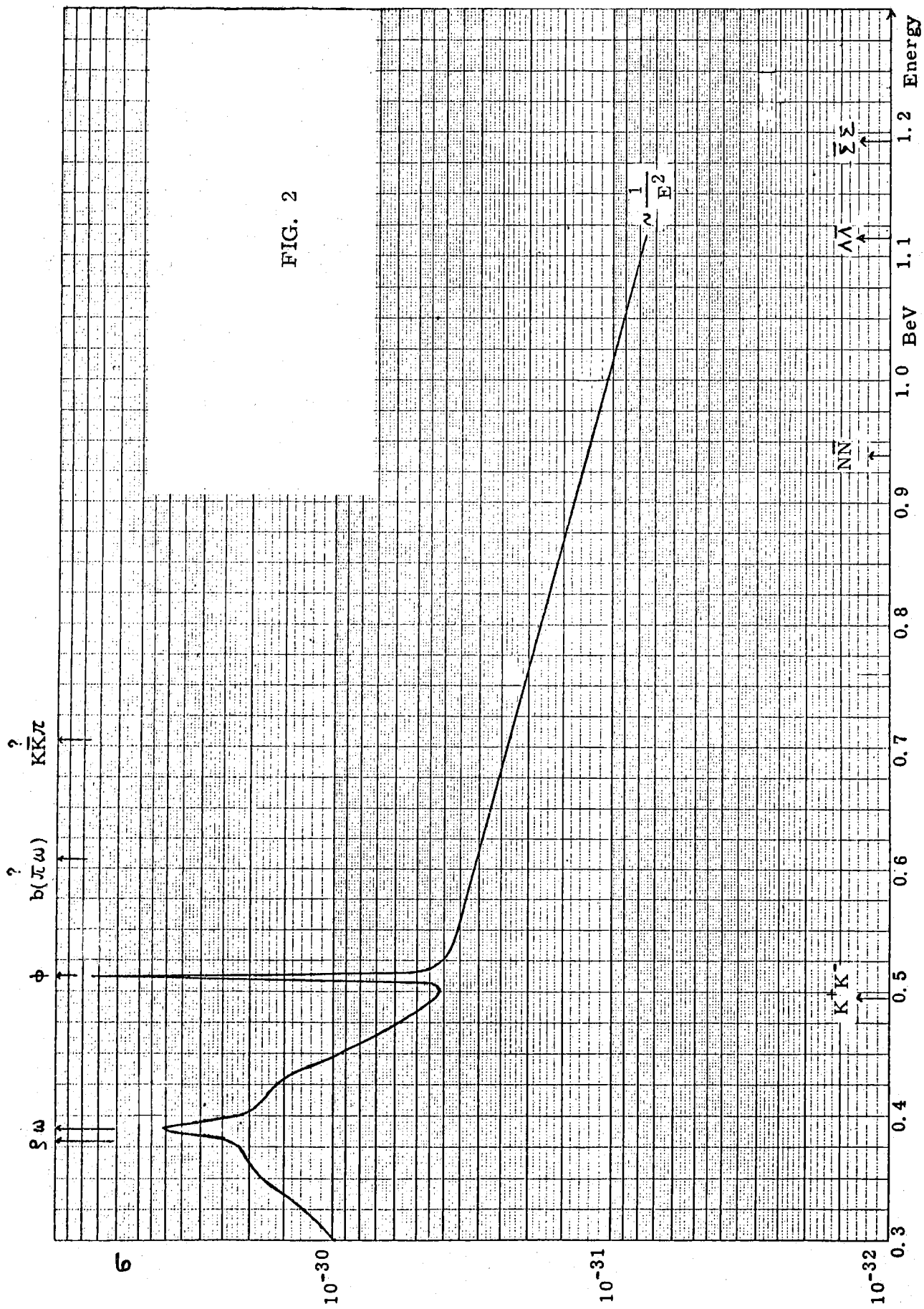


FIG. 2

6.

in a short time.

6) - COUNTING RATE ESTIMATES. -

Let us call ΔE the amplitude of the energy modulation; ΔE will be divided in \mathcal{N} channels, $\delta E = \Delta E/\mathcal{N}$ wide each.

The channel width can be at minimum of the order of the energy spread of the primary electrons: we will fix $\delta E = 1$ MeV as a typical figure. \mathcal{N}^{-1} measures the fraction of the total time spent on each channel, since triangular modulation of the energy provides a simple linear time-energy correspondence.

Assuming modulation over the full energy range, that is $\Delta E \simeq \simeq 1000$ MeV, we will have a typical duty-cycle of 10^{-3} per MeV.

The number of counts per channel after a total running time t is given by

$$n_c = \frac{1}{\mathcal{N}} L \sigma t$$

where L is the luminosity and σ is the cross section of any detectable event. σ can be divided in three parts:

σ_r = cross section for resonant processes

σ_{nr} = cross section for non resonant processes from the interaction region.

σ_b = equivalent cross section for machine background (coincidence events from the gas or the walls, equivalent cross section for accidentals).

By taking

$$\mathcal{N} = 10^3$$

$$t = 100 \text{ hrs}$$

$$L = 5 \times 10^{32} \text{ cm}^{-2} \text{ hr}^{-1}$$

it follows that

$$n_c = 5 \times 10^{31} \sigma \text{ (in cm}^2\text{) events/channel}$$

7) - FIRST COMMENT ON BACKGROUND. -

Both σ_{nr} and σ_b are supposed to be flat over several 10 MeV. However σ_{nr} can exhibit some curvature when the energy passes through the threshold of a pair production process; σ_b can simulate a peaking behaviour because of systematic machine failure at some energy. In the first case (σ_{nr}) we just say that pair thresholds are known, otherwise

they are interesting in themselves. In the second case (σ_b) a dummy counter system not illuminated by the good source can monitor the unwanted background alone (it must be noted in this occasion that the strict time-position correspondence for machine background events makes every point near the interaction region equivalent).

To the number of counts n_c one must add a uniform contribution n' from cosmic rays.

Non resonant events are unavoidable (a part from a possible reduction of the contribution of e^+e^- scattering); machine background and cosmic rays can be minimized and we shall present later the expected situation.

8) - CRITERION FOR THE EVIDENCE OF A PEAK. -

The counts per channel can be divided in two parts:

$$n_c = n_r + n_o$$

Here n_r is supposed to be due to single boson production, n_o to other events including cosmic rays.

Let us assume that n_r is bell-shaped as a function of the electron energy E and given by

$$n_r = n_p \frac{w^2}{(2E-M)^2 + w^2}$$

Here we call n_p the peak number of counts, M the boson mass, w the half width, usually given as $\Gamma/2$.

We next assume that n_o is independent of energy; this limits the following analysis to $w \ll$ than any possible energy structure parameter in n_o unless n_p is anomalously big (compare the ρ^0 case as an example of this last situation).

We thus expect that when the number n_r of counts in an energy interval $2w$ is reasonably larger than the fluctuation in the corresponding background a boson line will appear. Roughly the condition on the number of counts per channel is

$$(1) \quad n_p \gg \left(\frac{\delta E}{2w} n_o \right)^{1/2}$$

Montecarlo calculations are in progress simulating various possible boson production processes. Actually the problem of statistical e-

vidence is not so difficult as compared to that of evidence against the energy dependence of the background; we have no precise feeling about at present.

Coming back to the rough criterion (1) and using the formulas

$$n_p = \frac{\delta E}{\Delta E} L \sigma_p t$$

$$n_o = \frac{\delta E}{\Delta E} L \sigma_o t$$

we get

$$(2) \quad \sigma_p \gg \left(\frac{\sigma_o}{L t}\right)^{1/2} \left(\frac{\Delta E}{w}\right)^{1/2} = \Sigma$$

a result independent of the channel width. This qualitative formula is very important since it indicates some simple features of the proposed method.

Assume first that the evidence criterion is $\sigma_p = 3 \Sigma$ (at least). This criterion defines the shortest useful running time t_c from (2). L depends on the energy, but we will take $L = 5 \times 10^{32} \text{ cm}^{-2} \text{ hr}^{-1}$ for the sake of simplicity. σ_o should be of the order 10^{-30} cm^2 (assuming minimization of machine background and cosmic ray counts). Eventually we take $\Delta E = 1000 \text{ MeV}$.

Thus

$$3 \Sigma \simeq 5 \times 10^{-30} \frac{1}{\sqrt{t_c w}} \text{ cm}^2$$

with t in hrs and w in MeV. It follows that

$$\sigma_p \sqrt{w} \gtrsim \frac{5 \times 10^{-30}}{\sqrt{t_c}} \text{ cm}^2 \text{ MeV}^{1/2}$$

It must be noted however that the criterion applies only when n_p (the number of counts per channel) is a substantially large number; thus we will further require

$$n_p \gtrsim 5 \text{ counts per MeV}$$

and define a minimum running time in consequence as follows

$$(3) \quad t_{\min} = 5 \Delta E \text{ MeV} \frac{1}{L \sigma_p}$$

Comparison of t_{\min} and t_c according to the definitions shows that $t_c > t_{\min}$ only when

$$\sigma_p \leq \frac{2\sigma_0}{w(\text{MeV})}$$

That is, a peak-like structure will appear after a sizable (5 per MeV) number of events is accumulated in a channel in the case of weak resonances. We will classify resonances as "strong" and "weak" according to the inequalities

$$\begin{aligned} \sigma_p w(\text{MeV}) < 2\sigma_0 & \quad \text{"weak"} \\ \sigma_p w(\text{MeV}) > 2\sigma_0 & \quad \text{"strong"} \end{aligned}$$

9) - EXAMPLES OF KNOWN RESONANCES. -

As an example we give here the data relative to the known vector mesons (according to Gatto⁽¹⁾)

$$\rho^0) \quad \sigma_p = 1.6 \times 10^{-30} \text{ cm}^2$$

$$w = 53 \text{ MeV}$$

the evidence criterion would be satisfied after 10 minutes; however, setting $\delta E = 1 \text{ MeV}$, $t_{\min} \approx 6 \text{ hrs}$ (a "strong" resonance)

$$\omega^0) \quad \sigma_p = 1.7 \times 10^{-30} \text{ cm}^2$$

$$w = 5 \text{ MeV}$$

Here again $t_{\min} \approx 6 \text{ hrs}$ against 2 hrs to satisfy the evidence criterion ("strong" resonance)

$$\phi^0) \quad \sigma_p = 5 \times 10^{-30}$$

$$w = 1.5 \text{ MeV}$$

Here $t_{\min} \approx 2 \text{ hrs}$ against 1 hr to satisfy the evidence criterion ("strong" resonance).

A reasonable lower limit for the running time seems to be 10 hrs; this figure is however deliberately based on the extreme assumption $\Delta E = 1000 \text{ MeV}$, $\delta E = 1 \text{ MeV}$.

A graphic presentation of the criteria is shown in fig. 3.

Assuming however $\Delta E = 100 \text{ MeV}$ centered on the boson mass peak, both t_c and t_{\min} would be scaled down by a factor of ten. The most convenient ΔE will be chosen after a first look has been given to the general landscape of detected events.

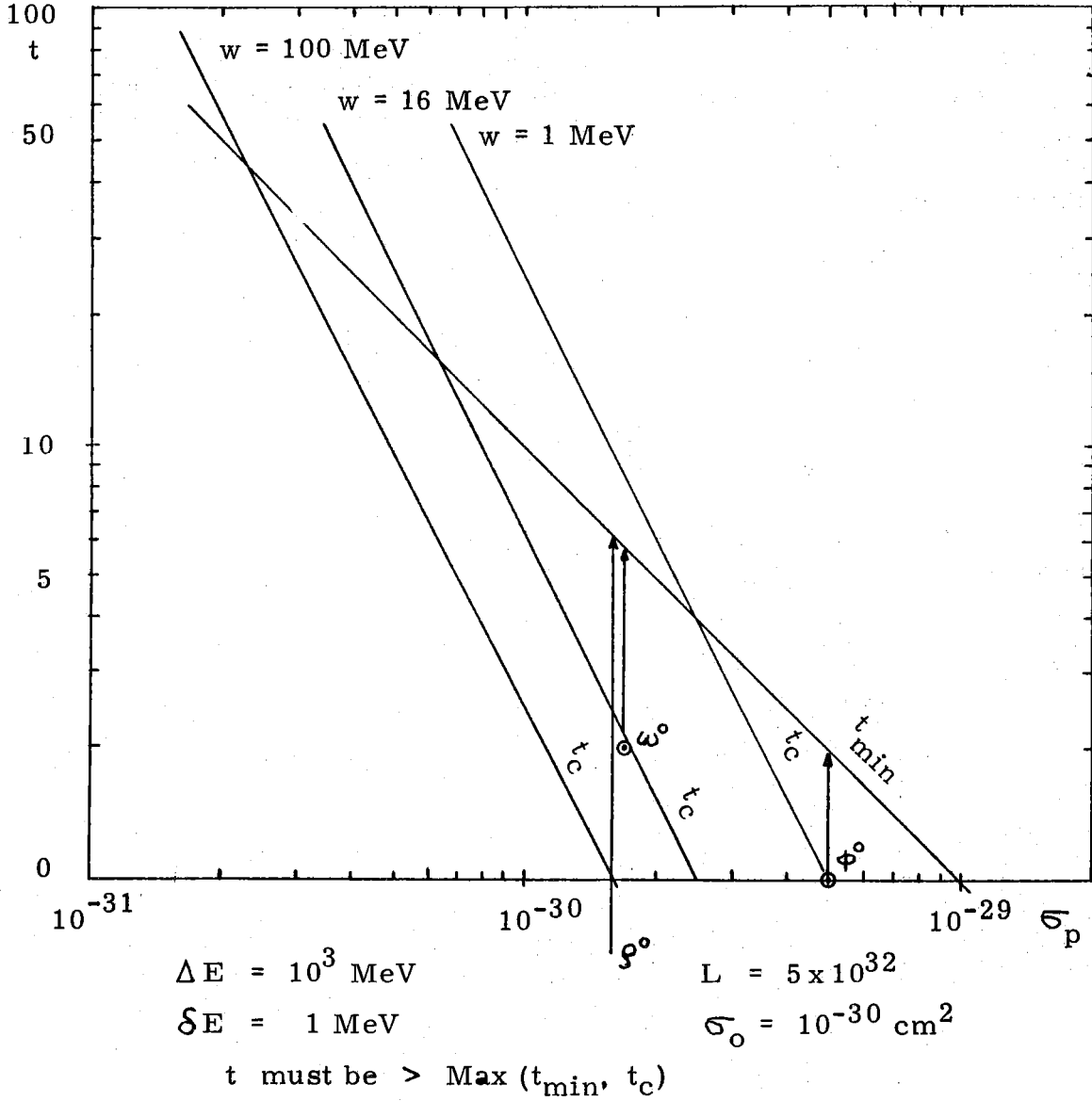


FIG. 3 - t_c and t_{\min} according to formula (2) and (3) respectively in § 8 as a function of σ_p for various widths of the resonance.

10) - BACKGROUNDS. -

a) We shall consider first non resonant background. As we already remarked in par. 4, the main beam-beam contribution from the interaction region is due to e^+e^- scattering. Thus

$$\sigma_{nr} \approx \xi_e \sigma_{scatt.}$$

where ξ_e is a rejection factor for electrons and σ_{scatt} is the e^+e^- scattering cross section integrated over the detected solid angle.

We do not know yet whether electrons can be rejected with a good efficiency or not; for the moment being ξ_e will be left unspecified.

To evaluate σ_{scatt} we use the formula

$$\frac{d\sigma}{d\Omega} = \frac{5 \times 10^{-26}}{\gamma^2} \frac{(1 + \frac{1}{3} \cos^2 \theta)^2}{(1 - \cos \theta)^2} \text{ cm}^2$$

where γ is the electron energy in mass units and θ the scattering angle.

Integration over the apparatus gives with a very good approximation

$$\sigma_{scatt} = \frac{5 \times 10^{-26}}{\gamma^2} \frac{\Delta \Omega}{\sin^2 \theta_{min}}$$

where $\Delta \Omega$ is the total detected solid angle; θ_{min} is the minimum θ value of the scattered electrons. With $\Delta \Omega = 0.7 \times 4\pi$ and $\theta_{min} = 30^\circ$ as in fig. 1 we get

$$\sigma_{scatt} \approx \frac{1.8 \times 10^{-24}}{\gamma^2} \text{ cm}^2$$

Thus σ_{scatt} goes from $5 \times 10^{-30} \text{ cm}^2$ at $E = 300 \text{ MeV}$ to $2 \times 10^{-31} \text{ cm}^2$ at $E = 1.5 \text{ BeV}$. Note that going from $\theta_{min} = 30^\circ$ to $\theta_{min} = 45^\circ$ σ_{scatt} will be reduced by a factor 2.4; at the same time $\Delta \Omega$ is only reduced by a factor 0.8. Smaller counters than in fig. 1 could prove convenient if a rejection factor ξ_e appreciably less than 1 could not be obtained.

b) Machine background constitutes the central headache. Of the 4×10^{11} particles circulating at full intensity (sum of the two beams), nearly 2×10^7 are lost per second (precise values depend slowly on the energy). Assuming an uniform loss all around the ring and taking into account the geometry of the machine a figure of 10^{-2} is expected for the fraction of the total source length seen by the counters in fig. 1.

Thus a flux of 2×10^5 particles per second constitutes the ma-

chine background.

Showers generated in the donut will invest the counters laterally and must be quite efficiently shielded. Expected rates are as follows

accidentals: $10^4 \mathcal{E}^2$ per second
 true coincidences: $10^5 \mathcal{E}^2 p_2$ per second

Here \mathcal{E} is a shielding factor; p_2 is the probability that 2 or more particles generated by the same lost beam particle are detected in coincidence.

Clearly \mathcal{E} must be less than 1/300 in order that the equivalent cross section σ_b be substantially less than 10^{-30} cm² (see par. 6). This could be not so easy to achieve: to study this crucial point in advance an experiment simulating beam losses on a tube will be performed in the next few months using the extracted electron beam at Frascati.

c) Cosmic rays would give a uniform in time counting rate of 10^5 particles per hr if not properly shielded. A substantial reduction can be achieved however by requiring a time coincidence of the events with the passage of a bunch in the interaction region. This coincidence (already used in the more difficult case of AdA⁽⁵⁾) will provide a duty cycle factor of 5×10^{-2} thus reducing the cosmic ray events to 5×10^3 /hr.

An anticoincidence roof will further reject cosmic rays and we hope that this anticoincidence will be able to reduce the cosmic rays rate to 50/hr.

APPENDIX -

Blok scheme of the electronics.

A possible scheme of the electronics will be sketched in this appendix. As shown in the text (par. 4) each of the four counter sandwiches can give a pulse in two channels corresponding to charged or neutral events respectively. We need every type of coincidences between the four sandwiches retaining the information on the neutral or charged character of the triggering particles.

There will be $6 \times 4 = 24$ double coincidences marked by the relevant charge state. By using sum coincidences it is possible to reduce the number to 6 if the information on the charge state is given by suitable circuitry in the form of pulse height. Then one can identify the original charge state by pulse height analysis.

The 6 output signals from the coincidences will be registered through a digital codifier on a magnetic tape recorder together with the simultaneous digital information on the energy of the event and the RF phase.

The energy will be measured by counting the oscillations of a blocked oscillator triggered by a peaking strip in the machine field. The RF phase will be provided by the pulses on a photomultiplier exposed to the synchrotron light of the beam particles.

A bloch scheme of the electronics fulfilling the requirements above is given in fig. 4.

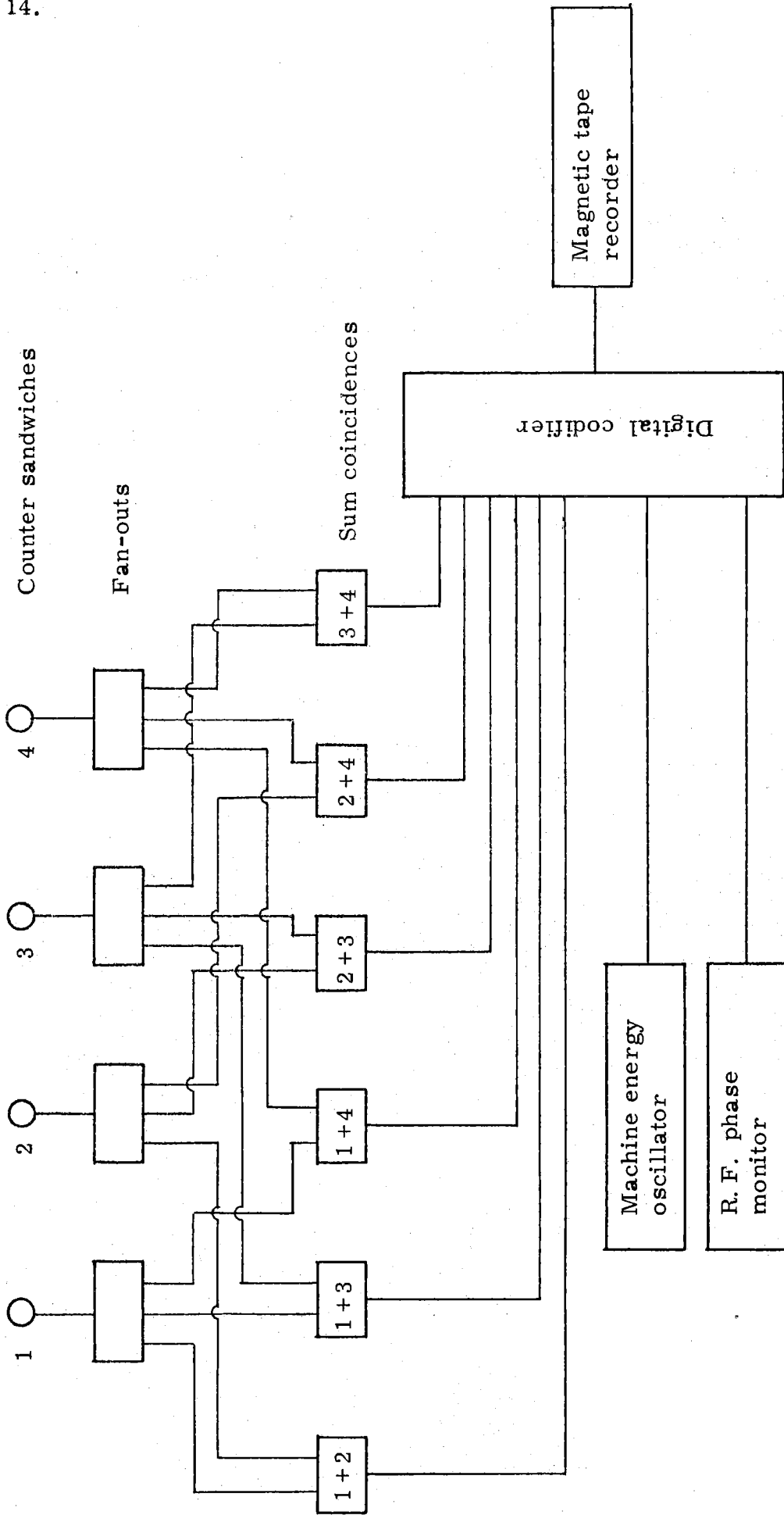


FIG. 4

NOTE -

- (1) - R. Gatto; Theoretical aspects of colliding beam experiments; in *Ergebnisse der exacten Naturwissenschaften* vol. 39, 106 (1965).
- (2) - B.B. Blumenthal et al.: *Phys. Rev. Letters* 15, 210 (1965);
We owe the remark in this par. to the review presented by G. Salvini at the 1965 Accelerator Conference at Frascati.
- (3) - F. Amman; Dimensioni dei fasci, vite medie, luminosità e caratteristiche della zona di interazione in Adone; LNF 66/6, Frascati 1966 (Internal report)
- (4) - F. Amman, private communication.
- (5) - C. Bernardini et al.; *Nuovo Cimento* 34, 1473 (1964).