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LUMINOSITY MONITOR SYSTEM FOR THE
ELECTRON-POSITRON COLLIDING BEAM
MACHINE, VEPP-3

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I. Introduction

In a colliding beam machine, the occurrence rate of a certain physical process which has a cross section σ can be represented as

$$\dot{n} = L \sigma \quad (1).$$

The coefficient, L , which is called luminosity, does not depend on types of physical processes. It depends only on the properties of circulating beams. VEPP-3, which is now closing to the end of its construction in the Institute of Nuclear Physics, Novosibirsk, has one electron bunch and one positron bunch which are circulating on the same orbit and in the opposite direction with respect to each other. In such a case, the luminosity is given as

$$L = \frac{I_+ I_-}{e^2 f S_{eff}} \quad (2),$$

where I_- and I_+ represent the current of electrons and positrons respectively, f is the revolution frequency of beams and S_{eff} is the effective area of the cross section of both beams. The direct measurement of the luminosity by the use of eq.(2) is not accurate, because it is difficult to measure the spatial distribution of the beam density.

The possible way to measure the luminosity is the use of known processes according to the eq.(1). Among them, electromagnetic processes in the forward direction are suitable. The reason is that, in electromagnetic processes in forward direction where the four momentum transfer is small, the validity of the Quantum-electrodynamics has been established theoretically and also has been proved in some experiments /1,2/. Furthermore, these processes have rather large cross section, so that these are convenient for a fast measurements of the luminosity. There are many electromagnetic processes in an electron-positron colliding beam: elastic scatter-

ing, single bremsstrahlung, double bremsstrahlung, double bremsstrahlung, two γ -ray annihilation etc. Some of these processes has been used to measure the luminosity in many colliding beam machines /1,2,3,4/. In our conditions the measurement of elastic scattering in forward direction seems to be more adequate for the luminosity monitor, which has been adopted by the ADONE group /4/. Therefore, we have decided to use this method as the main monitor system.

Chapter II describes the monitor system using elastic scattering of electrons and positrons. We analyze the effect of possible beam deviations on the absolute value of the luminosity and propose a method which eliminates these effects. Then we give correction factors for counting errors caused by angular spreads of beams and by radiative scatterings. In the last part, properties of counter and electronics are written. In chapter III, we suggest briefly another possible monitor system using γ -rays detections, which may be used for VEPP-3.

II. Monitor system using e^-e^+ elastic scattering

II-1. General description of the apparatus.

The apparatus consists of four counter telescopes and each telescope consists of a small defining counter P_i and a large sandwich counter S_i , as illustrated in Fig.1. The scintillators of small defining counters are 5 mm thick and $30 \times 30 \text{ mm}^2$ wide. The average angle of scattered particles hitting small counters is about 3° .

The aperture of sandwich counter is 120 mm in the vertical direction and 100 mm in the radial direction. The role of sandwich counter is to reduce the contribution from soft particles to counting rates. Their large sizes permit to compensate the effects of finite length of beams in the azimuthal direction as well as errors caused by beam deviations. Characteristics of all

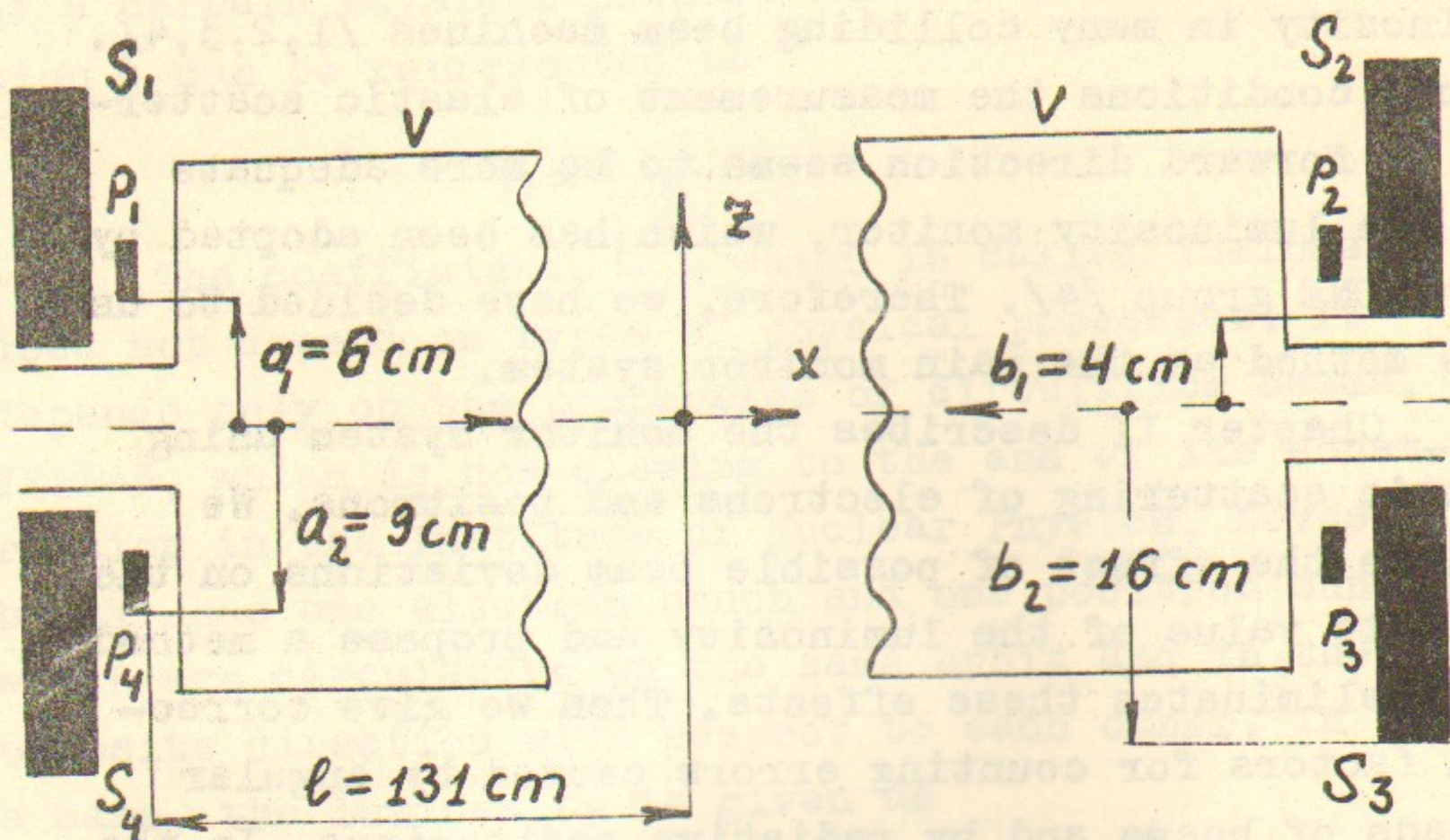


Fig.1. Geometrical configuration of counter telescopes;
 P_i - defining counter, S_i - sandwich counter,
 and V - vacuum chamber.

counters are given in later.

Two sets of telescopes make a pair and are set on a rigid platform and are placed in the vertical plane symmetrically with respect to the beam axis. The platform is fixed to the Q-magnet, however, the pair of small defining counters is adjustable their position without changing their relative distance. Another pair of telescopes is set in the same way at the opposite side of the intersecting region. With such a configuration three types of coincidences can be made:

a) four-fold coincidence: $F_{13} = S_1 P_1 S_3 P_3$, $F_{24} = S_2 P_2 S_4 P_4$

b) three-fold coincidence: $T_1 = S_1 P_1 S_3$, $T_2 = S_2 P_2 S_4$,
 $T_3 = S_3 P_3 S_1$, $T_4 = S_4 P_4 S_2$

c) OR - coincidence: $O_{13} = T_1 + T_3 - F_{13}$, $O_{24} = T_2 + T_4 - F_{24}$

Because of the symmetrical geometry of counter

telescopes the sum of three-fold coincidences has the best compensation for counting errors caused by possible deviations of the source. Therefore, we want to use the sum for the determination of the absolute luminosity. By the use of differences of counting rates between three-fold coincidences we can evaluate the value of beam deviations as described in section II-4.

The ratios between counting rates of three types of coincidences make us to determine the source length, which will be written in section II-8. Three types of coincidences are not independent, so we can check them internally by comparing them.

II-2. Calculation of counting rates.

The cross-section of the e^-e^+ elastic scattering at the small angle, θ , is represented as:

$$\frac{d\sigma}{d\Omega} = \left(\frac{2r_0}{\gamma}\right)^2 \frac{1}{\theta^4} \quad (3)$$

The accuracy of this formula is better than 0.1 % for our case. For simplicity, at first, we assume that the source is point like. Integrating the eq.(3) over the counters which are illustrated in Fig.1, we have the counting rate of each three fold coincidence as

$$\dot{n}_0 = L \frac{2r_0^2}{3\gamma^2} \rho \ell^2 \left\{ 4 \left(\frac{1}{a_1^3} - \frac{1}{a_2^3} \right) - 1.6 \rho^2 \left(\frac{1}{a_1^5} - \frac{1}{a_2^5} \right) \right\} \quad (4),$$

where $r_0 = e^2/mc^2$; $\gamma = E_0/m$; 2ρ is the size of the small counter in the radial direction; ℓ , a_1 , and a_2 can be understood from Fig.1.

The formula (4) is somewhat complicated to use, so that, in later, we will use following approximations

$$\dot{n}_{01} = L \frac{8r_0^2}{3\gamma^2} \rho \ell^2 \left(\frac{1}{a_1^3} - \frac{1}{a_2^3} \right) \quad (5),$$

$$\dot{n}_{02} = L \left(\frac{2r_0}{\gamma} \right)^2 \frac{\rho \ell^2}{d} \left(\frac{1}{a_1^2} - \frac{1}{a_2^2} \right) \quad (6),$$

$$\dot{n}_{03} = L \left(\frac{2r_0}{\gamma} \right)^2 \frac{S\ell^2}{d^4} \quad (7),$$

where S means the area of small counters and d means the distance of the center of small counters from the beam axis. Accuracies of approximations are as follows:

$$\dot{n}_{01} = 1.03 \dot{n}_0, \quad \dot{n}_{02} = 0.98 \dot{n}_0, \quad \dot{n}_{03} = 0.90 \dot{n}_0$$

Now let us consider the case where beam bunches have finite lengths in the azimuthal direction. Experiences in the VEPP-2 told us that, in such a colliding beam machine, the density distribution of particles along the azimuthal direction is well approximated by a gaussian distribution. Therefore, we are expecting in the VEPP-3 that the azimuthal distribution of the luminosity will be also a gaussian distribution as

$$P(x) = \frac{1}{\sqrt{2\pi} \sigma_L} e^{-\frac{x^2}{2\sigma_L^2}} \quad (8),$$

where $\sigma_L^2 = \frac{\sigma_+^2 \sigma_-^2}{\sigma_+^2 + \sigma_-^2}$, σ_+ and σ_- are the characteristic length of positron beams and that of electron beams respectively. By the use of the approximation of eq.(6) and the distribution function of eq.(8), one can calculate the counting rate of each four-fold coincidence as:

$$\dot{n}_4(\sigma_L) = L \left(\frac{2r_0}{\gamma} \right)^2 \frac{2\rho}{\sqrt{2\pi} \sigma_L d} \int_0^{x_0} e^{-\frac{x^2}{2\sigma_L^2}} \left\{ \left(\frac{\ell-x}{a_1} \right)^2 - \left(\frac{\ell+x}{a_2} \right)^2 \right\} dx \quad (9)$$

where $x_0 = \frac{a_2 - a_1}{a_2 + a_1} \ell$. In the similar way, the counting rate of each three-fold coincidence is given as

$$\dot{n}_3(\sigma_L) = L \left(\frac{2r_0}{\gamma} \right)^2 \frac{\rho}{\sqrt{2\pi} \sigma_L d} \left\{ \int_{x_1}^{x_2} e^{-\frac{x^2}{2\sigma_L^2}} \left\{ \left(\frac{\ell+x}{a_1} \right)^2 - \left(\frac{\ell-x}{b_2} \right)^2 \right\} dx + \int_{x_2}^{x_3} e^{-\frac{x^2}{2\sigma_L^2}} \left(\frac{1}{a_1^2} - \frac{1}{a_2^2} \right) (\ell+x)^2 dx + \int_{x_3}^{x_4} e^{-\frac{x^2}{2\sigma_L^2}} \left\{ \left(\frac{\ell-x}{b_1} \right)^2 - \left(\frac{\ell+x}{a_2} \right)^2 \right\} dx \right\} \quad (10)$$

$$\text{where } x_1 = \frac{a_1 - b_2}{a_1 + b_2} \ell, \quad x_2 = \frac{a_2 - b_2}{a_2 + b_2} \ell, \quad x_3 = \frac{a_1 - b_1}{a_1 + b_1} \ell,$$

$$x_4 = \frac{a_2 - b_1}{a_2 + b_1} \ell.$$

The counting rate of each OR-coincidence can be calculated according to their definitions. The counting rate of each three types of coincidence are plotted versus σ_L in Fig.2. From the figure, one can see that the counting rate of the three-fold coincidence depends very little on the source length if σ_L is less than 15 cm, while the four-fold coincidence and OR-coincidence are rather sensitive to the source length.

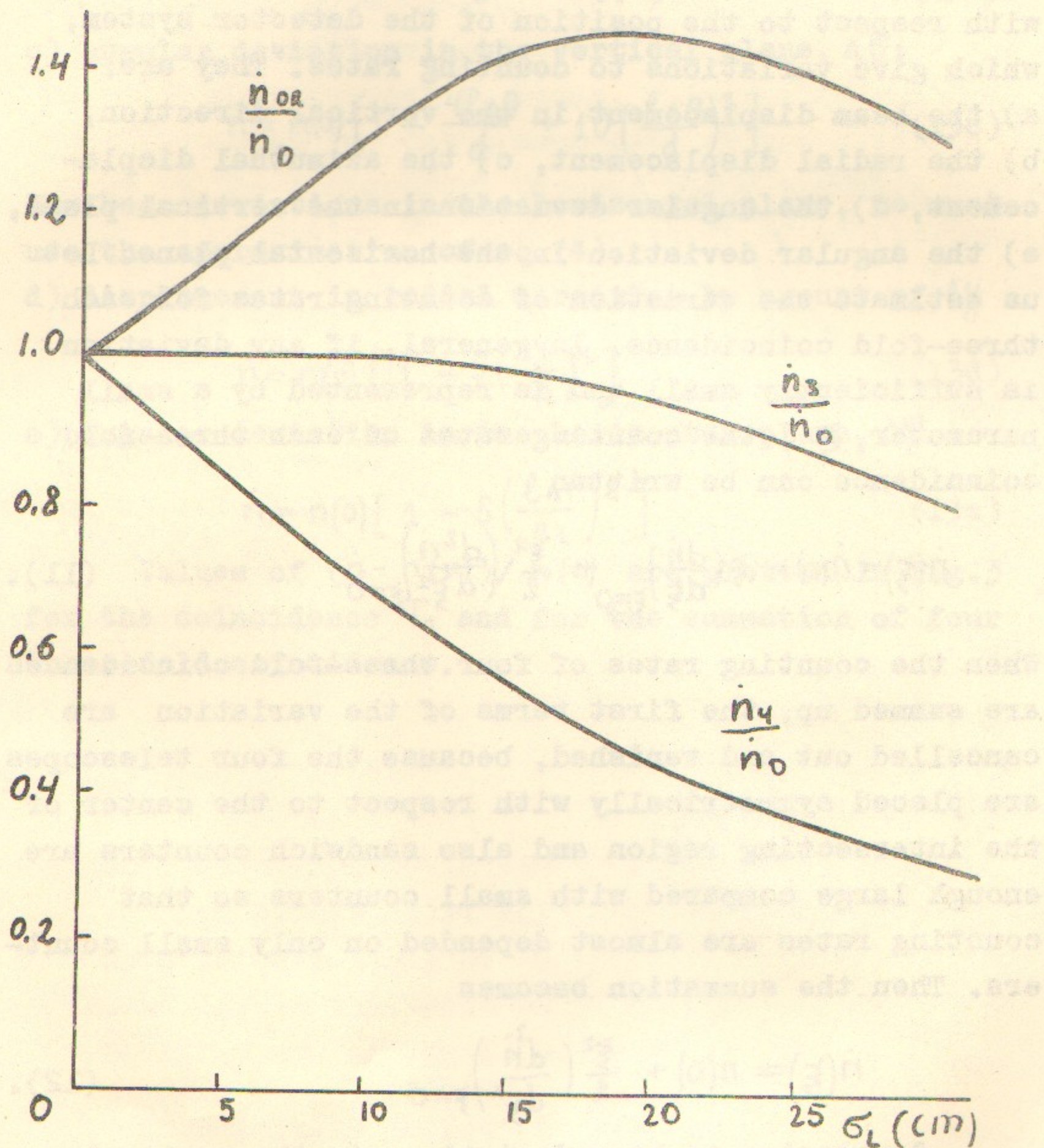


Fig.2. Dependence of counting rates on the source length. \dot{n}_3 , \dot{n}_4 , and \dot{n}_{OR} means three-fold, four-fold and OR-coincidence, respectively.

In the typical case, when the beam energy is 2 Gev and the luminosity is $5 \times 10^{33} \text{ cm}^{-2} \text{ h}^{-1}$, the counting rate of 3-fold coincidence is 4 per second. It is enough large to measure the luminosity in a short period.

II -3. Variation of counting rates caused by deviations of the source.

There are five possible deviations of the source with respect to the position of the detector system, which give variations to counting rates. They are: a) the beam displacement in the vertical direction, b) the radial displacement, c) the azimuthal displacement, d) the angular deviation in the vertical plane, e) the angular deviation in the horizontal plane. Let us estimate the variation of counting rates for each three-fold coincidence. In general, if any deviation is sufficiently small and is represented by a small parameter, ξ , the counting rates of each three-fold coincidence can be written

$$\dot{n}(\xi) = \dot{n}(0) + \xi \left(\frac{d\dot{n}}{d\xi} \right)_{\xi=0} + \frac{\xi^2}{2} \left(\frac{d^2\dot{n}}{d\xi^2} \right)_{\xi=0} \quad (11).$$

When the counting rates of four three-fold coincidences are summed up, the first terms of the variation are cancelled out and vanished, because the four telescopes are placed symmetrically with respect to the center of the intersecting region and also sandwich counters are enough large compared with small counters so that counting rates are almost depended on only small counters. Then the summation becomes

$$\dot{n}(\xi) = \dot{n}(0) + \frac{\xi^2}{2} \left(\frac{d^2\dot{n}}{d\xi^2} \right)_{\xi=0} \quad (12).$$

Concerning to beam deviations in the vertical plane, counting deviations of the three-fold coincid-

ence, $T_1 = S_1 P_1 S_3$, are easily calculated under the approximation described in Eq.(7). They are:

a) displacement in the vertical direction, by amount of Δz :

$$\dot{n} = \dot{n}(0) \left[1 + \frac{4\Delta z}{d} + 10 \left(\frac{\Delta z}{d} \right)^2 \right] \quad (13a)$$

b) displacement along the azimuthal direction, by amount of Δx :

$$\dot{n} = \dot{n}(0) \left[1 + \frac{2\Delta x}{\ell} + \left(\frac{\Delta x}{\ell} \right)^2 \right] \quad (13b)$$

c) angular deviation in the vertical plane, $\Delta\theta$:

$$\dot{n} = \dot{n}(0) \left[1 - \frac{4\ell\Delta\theta}{d} + 10 \left(\frac{\ell\Delta\theta}{d} \right)^2 \right] \quad (13c)$$

For beam deviations in the horizontal plane, we must use the approximation of eq.(4):

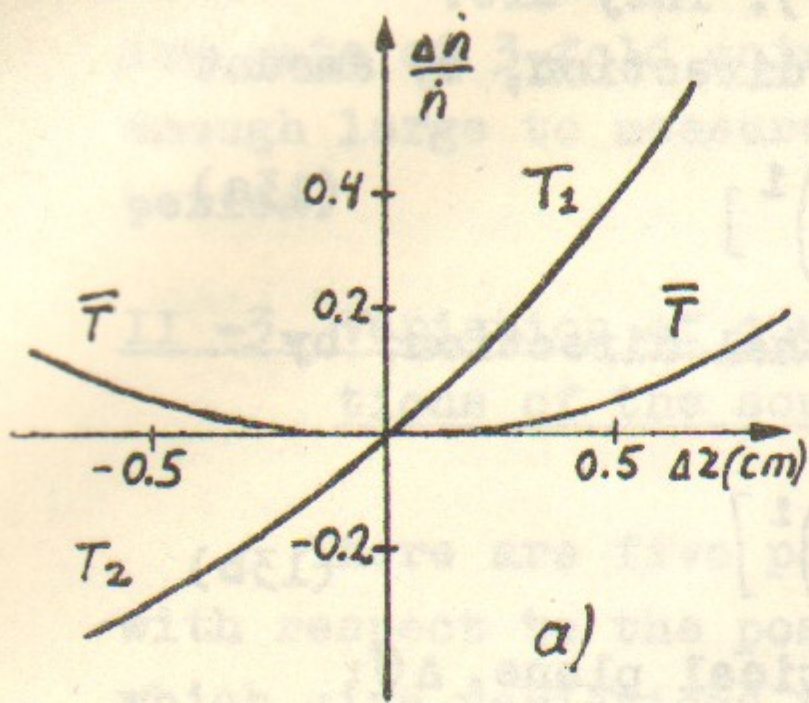
d) displacement in radial direction by amount of Δy :

$$\dot{n} = \dot{n}(0) \left[1 - 5 \left(\frac{\Delta y}{a_1} \right)^2 \right] \quad (13d)$$

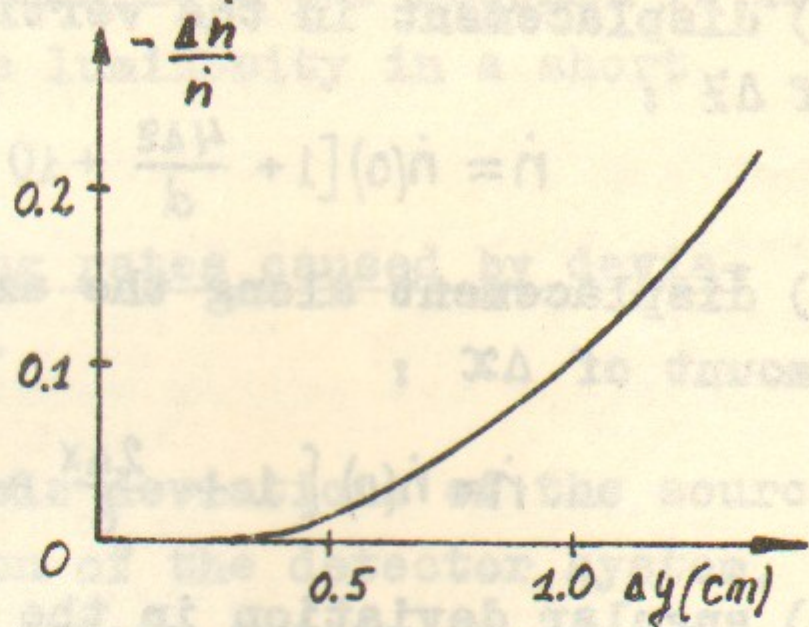
e) angular deviation in the horizontal plane, $\Delta\varphi$:

$$\dot{n} = \dot{n}(0) \left[1 - 5 \left(\frac{\ell\Delta\varphi}{a_1} \right)^2 \right] \quad (13e)$$

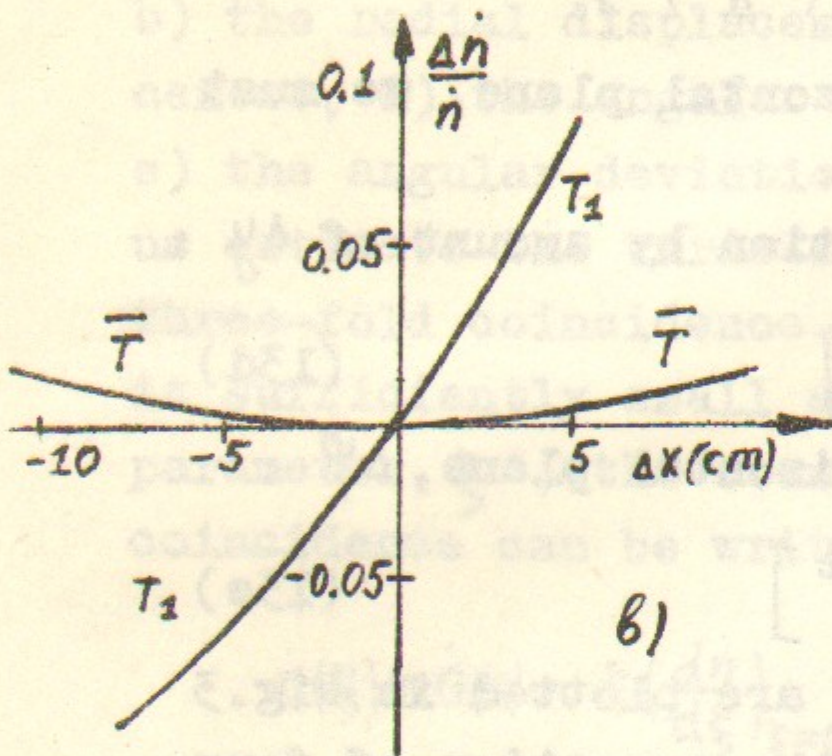
Values of $(\dot{n} - \dot{n}(0)) / \dot{n}(0)$ are plotted in Fig.3 for the coincidence T_1 and for the summation of four three-fold coincidence.



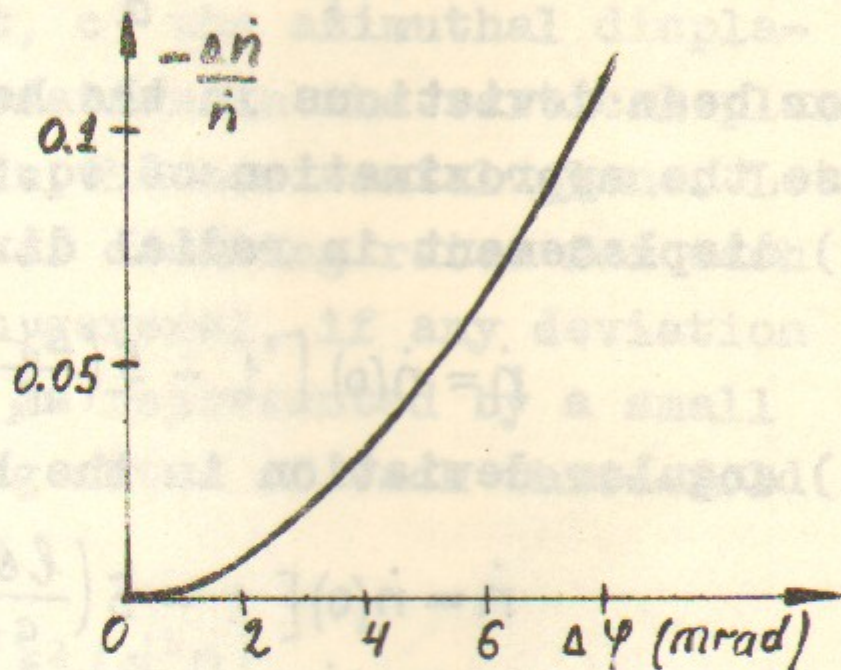
a)



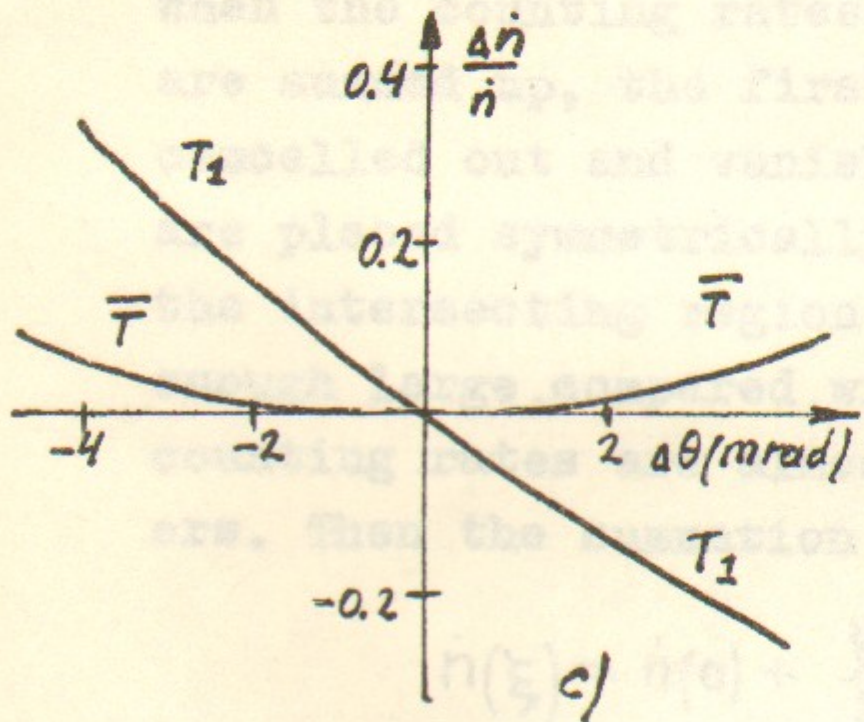
d)



b)



e)



c)

Fig.3. Deviations of counting rates caused by

- a) vertical displacement
- b) azimuthal displacement
- c) angle in the vertical plane
- d) radial displacement
- e) angle in the radial plane

II-4. Evaluation of beam deviations and the realignment of the detector system.

As described in the previous section, there are three types of beam deviations which give rather large variations to counting rates of each three-fold coincidence. They are beam deviations in the vertical plane. In our system, we have four data T_1 , T_2 , T_3 and T_4 . We want to know relative deviations between beams and the detector system using these four data. After evaluating the relative deviations, we can realign the detector with respect to beams. This realignment is very important for the measurement of the absolute value of the luminosity, because there are many corrections to determine the absolute value of the luminosity, which can be only estimate by calculations for the case where there are no beam deviations.

By the use of the approximation of eq.(7), counting rates of each three-fold coincidence in the case where there are beam deviations in the vertical plane can be calculated as

$$T_1 = \dot{n}(0) [1 + C_1 \Delta z + C_2 \Delta x + C_3 \Delta \theta + C_4 \Delta z \Delta x + C_5 \Delta z \Delta \theta + C_6 \Delta x \Delta \theta + C_7 \Delta z^2 + C_8 \Delta x^2 + C_9 \Delta \theta^2] \quad (14a),$$

$$T_2 = \dot{n}(0) \left[\begin{array}{cccccccc} + & - & - & - & - & + & + & + \\ & & & & & & & \end{array} \right] \quad (14b),$$

$$T_3 = \dot{n}(0) \left[\begin{array}{cccccccc} - & - & + & + & - & - & + & + \\ & & & & & & & \end{array} \right] \quad (14c),$$

$$T_4 = \dot{n}(0) \left[\begin{array}{cccccccc} - & + & - & - & + & - & + & + \\ & & & & & & & \end{array} \right] \quad (14d),$$

where $C_1 = 4/d$, $C_2 = 2/l$, $C_3 = 4l/d$, $C_4 = 8/dl$, $C_5 = 20l/d^2$

$C_6 = 8/d$, $C_7 = 10/d^2$, $C_8 = 1/l^2$, $C_9 = 10l^2/d^2$

We define four combinations of T_1 , T_2 , T_3 and T_4 as

$$T = T_1 + T_2 + T_3 + T_4 = 4\dot{n}(0) [1 + C_7 \Delta z^2 + C_8 \Delta x^2 + C_9 \Delta \theta^2] \quad (15a),$$

$$U = T_1 - T_2 - T_3 + T_4 = 4\dot{n}(0) [C_2 \Delta x + C_5 \Delta z \Delta \theta] \quad (15b),$$

$$V = T_1 + T_2 + T_3 - T_4 = 4\dot{n}(0) [C_1 \Delta z + C_6 \Delta x \Delta \theta] \quad (15c),$$

$$W = T_1 - T_2 + T_3 - T_4 = 4\dot{n}(0) [C_3 \Delta \theta + C_4 \Delta z \Delta x] \quad (15d).$$

We use a successive approximation to solve these equations and have

$$\Delta z' = \frac{1}{c_1} \left[\frac{V}{R} - \frac{c_6}{c_2 c_3} \frac{UW}{T^2} \right] \quad (16a),$$

$$\Delta X' = \frac{1}{c_2} \left[\frac{U}{R} - \frac{c_5}{c_1 c_3} \frac{VW}{T^2} \right] \quad (16b),$$

$$\Delta \theta' = \frac{1}{c_3} \left[\frac{W}{R} - \frac{c_4}{c_1 c_2} \frac{UV}{T^2} \right] \quad (16c),$$

$$\dot{n}(0) = \frac{T}{4} \left[1 + c_7 \Delta z'^2 + c_8 \Delta X'^2 + c_9 \Delta \theta'^2 \right]^{-1} \quad (16d),$$

where

$$R = T \left[1 + c_7 \left(\frac{V}{c_1 T} \right)^2 + c_8 \left(\frac{U}{c_2 T} \right)^2 + c_9 \left(\frac{W}{c_3 T} \right)^2 \right]^{-1} \quad (17).$$

Using the estimated values of deviations, one must realign the detector system with respect to beams. After doing the realignment, we shall have small deviations of beams and small differences between each counting rate. Then, again we apply this method successively. At last we can set the detector system in the right position and we will have an accurate absolute value of the luminosity.

To show the availability of this method, we have done a simulation and some of their results are listed up in Table 1. One can see from the Table 1, that for the large values of beam deviation it is necessary to use the method successively, while for the small values of beam deviations we obtain accurate results after the first realignment.

Table 1. Evaluation of beam deviation.

Δz is the vertical displacement in mm, ΔX is the azimuthal displacement in cm, and $\Delta \theta$ is the angular deviation in mrad. T_i are counting rates of three-fold coincidences. The luminosity, $T/4$, is the summation of T_i , while $\dot{n}(0)$ is the corrected values

with the use of the evaluated values of beam deviations. "I" means initial values and "C" means values after realigned.

| | | I | C | I | C | I | C |
|----------------|-----------------|-------|-------|-------|-------|-------|-------|
| Beam deviation | ΔZ | 3 | 0.08 | 5 | 0.03 | 10 | -1.17 |
| | ΔX | 5 | 0.33 | 10 | 0.31 | 10 | -9.13 |
| | $\Delta \theta$ | 3 | -0.18 | 5 | -0.42 | 10 | -1.65 |
| Counting rate | T_1 | 1.588 | 0.997 | 2.262 | 0.977 | 5.052 | 0.727 |
| | T_2 | 0.868 | 1.013 | 0.767 | 1.029 | 0.692 | 1.217 |
| | T_3 | 0.987 | 0.978 | 0.951 | 0.963 | 1.064 | 1.077 |
| | T_4 | 0.747 | 1.014 | 0.639 | 1.035 | 0.381 | 1.047 |
| Luminosity | $T/4$ | 1.048 | 1.000 | 1.155 | 1.001 | 1.797 | 1.017 |
| | $\dot{n}(0)$ | 1.000 | 1.000 | 1.014 | 1.000 | 1.084 | 1.001 |

This method can be applied to the case when σ_L is larger than 15 cm, because the coefficients C_i are slowly varying function of σ_L and the successive re-alignment is possible.

II-5. Effect of the angular spread of beams on counting rates.

To get a high luminosity, we make values of β - functions of the orbit near the intersecting region as smaller as possible by setting quadrupole magnets at the both sides of the intersecting region. In such a case, both electron and positron beams have large angular spreads which are approximately proportional to the inverse square root of the β -function. It is difficult to estimate the density distribution of beams in the phase space of betatron oscillations, because of the beam-beam interactions. Machine people

are expecting that the phase volume may be 2×10^{-3} cm rad for the vertical betatron oscillation. Then, it may be permitted to assume that the distribution of the projection angle of beams to the vertical plane including the beam axis is a gaussian distribution with a standard deviation of θ_η for electron beams and θ_ζ for positron beams respectively and the order of θ_η and θ_ζ is

$$\theta_\eta, \theta_\zeta \approx \sqrt{\frac{2 \cdot 10^{-3}}{\pi \beta}} \quad (18)$$

where the unit of β is cm. This means that for the extreme case, say, $\beta = 5$ cm, θ_η and θ_ζ become about 10 mrad and give an increment to the counting rate.

By the use of the approximation of eq.(5), let us calculate the increment. At first, we consider about the following case; an electron with energy of E goes into the intersecting with an angle of η and collides with a positron which has the same energy and has an angle of ζ . Then, the electron is elastically scattered into the direction of θ and is detected by a small counter. The positron is scattered into a certain angle not collinear with respect to the electron, however, the deviation of the angle from linear with respect to the electron is so small that the positron is always detected in coincidence with the electron by a large sandwich counter. We calculate the transformation matrix which connects the laboratory system to the particular center of mass system in which the electron and the positron move on the X -axis. Neglecting the higher terms than quadratic terms of η and ζ , we have a following equation

$$\begin{pmatrix} P_x \\ P_y \\ E \end{pmatrix}_{CM} = \Gamma \begin{pmatrix} P_x \\ P_y \\ E \end{pmatrix}_{LAB}$$

and

$$\Gamma = \begin{pmatrix} 1 - \frac{(\eta + \xi)^2}{8} & \frac{\eta + \xi}{2} & 0 \\ -\frac{\eta + \xi}{2} & 1 - \frac{\eta \xi}{2} & -\frac{\eta - \xi}{2} \\ \frac{\eta^2 - \xi^2}{4} & -\frac{\eta - \xi}{2} & 1 + \frac{(\eta - \xi)^2}{8} \end{pmatrix} \quad (19)$$

where p_x and p_y means the momentum of the electron in the azimuthal direction and that in vertical direction respectively. The energy of the electron and the positron in the center of mass system is calculated to be

$$E' = E \left\{ 1 - \frac{\eta^2 - \xi^2}{8} \right\} \quad (20).$$

By the use of eq.(19), we can calculate the differential cross section in the laboratory system and the result is

$$\left. \frac{d\sigma}{d\Omega} \right|_{L, \eta, \xi} = \left. \frac{d\sigma}{d\Omega} \right|_{E, \theta} \left\{ 1 + \frac{\eta \xi}{2} + 3 \frac{\eta}{\theta} + 6 \frac{\eta^2}{\theta^2} \right\} \quad (21),$$

where $\left. \frac{d\sigma}{d\Omega} \right|_{E, \theta}$ means the cross-section in the case of the head on collision. Assuming that the electron beam and the positron beam have gaussian distribution, we integrate eq.(21) over the whole angle of η and ξ , we have the effective cross-section as

$$\frac{d\sigma}{d\Omega} = \left. \frac{d\sigma}{d\Omega} \right|_{E, \theta} \left\{ 1 + \frac{3\theta^2}{\theta^2} \right\} \quad (22).$$

In similar way we calculate for the case where a positron is detected with a small counter. Summing up both cross-section and integrate it over small counters, we have the sum of counting rates for four three-fold coincidences. The result is approximately

represented as:

$$\dot{n} \approx \dot{n}(0) \left[1 + \frac{g}{10} \frac{\theta_2^2 + \theta_5^2}{\theta_1^2} \right] \quad (23)$$

where $\theta_1 = \frac{a_1}{\ell}$. Combining eq.(23) and eq.(18) the increment of the sum counting rate is calculated as a function of the β -function and is plotted in Fig.4. In the extreme case where β is nearly 5 cm, the increment becomes 11 %.

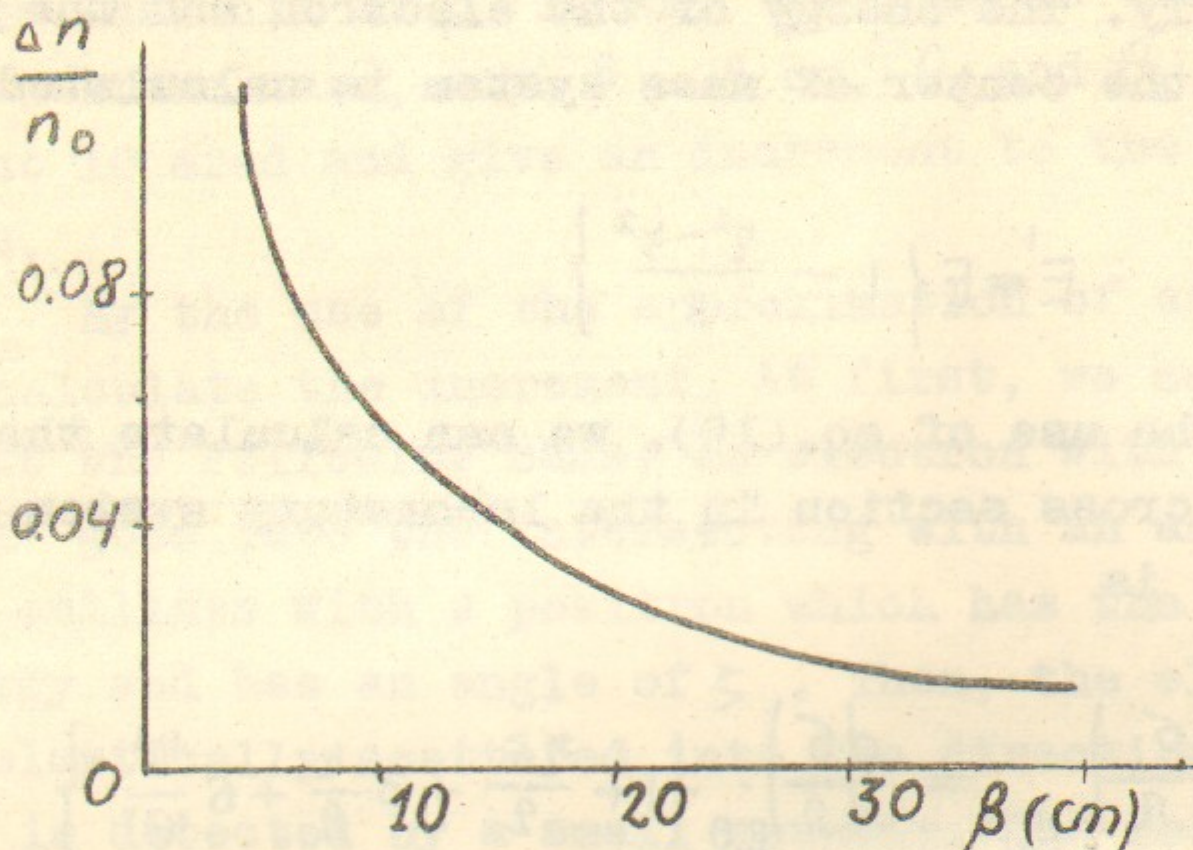


Fig.4. Increment of counting rate versus the betatron function.

II-6. Counting errors caused by geometrical errors of the detector.

As previously described, the idea of the compensation with the use of four symmetric counter telescopes and the realignment method of the detector system reduce the counting errors caused by relative geometrical errors between beams and the detector as a whole. Still, remain counting errors caused by the internal configuration of counters and by the counter sizes and by the edge effects of small counters. We estimate these counting errors individually by the use of the approximation presented in eq.(7) and give necessary accuracies for the machinings and the settings.

a) Distance between small counters in a pair of telescopes. Let Δd be the setting error between two small counters which have a distance of $2d$ with respect to each other. Then, counting error is estimated to be

$$\frac{\Delta \dot{n}}{\dot{n}} = - \frac{2\Delta d}{d} \quad (24)$$

Setting accuracy of $\Delta d = 0.4$ mm is enough to reduce the counting error less than 1 %.

b) Distance between two counter telescopes which do not make a pair.

Let Δl be the setting error. The distance between two counter telescopes which do not make a pair is $2l$. Then, the counting error is

$$\frac{\Delta \dot{n}}{\dot{n}} = \frac{\Delta l}{l} \quad (25)$$

and one percent of counting error corresponds to the setting error of 1.3 cm.

c) Area of small counter

$$\frac{\Delta \dot{n}}{\dot{n}} = \frac{\Delta S}{S} \quad (26)$$

In our case, the machining accuracy to make small counters is ± 0.05 mm, and this gives to the counting error of 0.3 %.

d) Edge effect of small counter.

As illustrated in Fig.5, for a particle which starts from the source, small counters can be seen as if the area is increased near the lower edge and is decreased at the upper and side edges. The counting efficiency of the scintillator in these parts, however, is less than unity, say, $\xi(\theta)$. Then the additional contribution of counting rate from the lower edge part is estimated to be

$$\left(\frac{\Delta \dot{n}}{\dot{n}}\right)_{\text{low}} = \frac{\int_{\theta_1 - \Delta\theta}^{\theta_1} \xi(\theta) d\theta / \theta^4}{\int_{\theta_1}^{\theta_2} d\theta / \theta^4} \quad (27)$$

where θ_1 , θ_2 and $\Delta\theta$ can be understood from Fig.5.

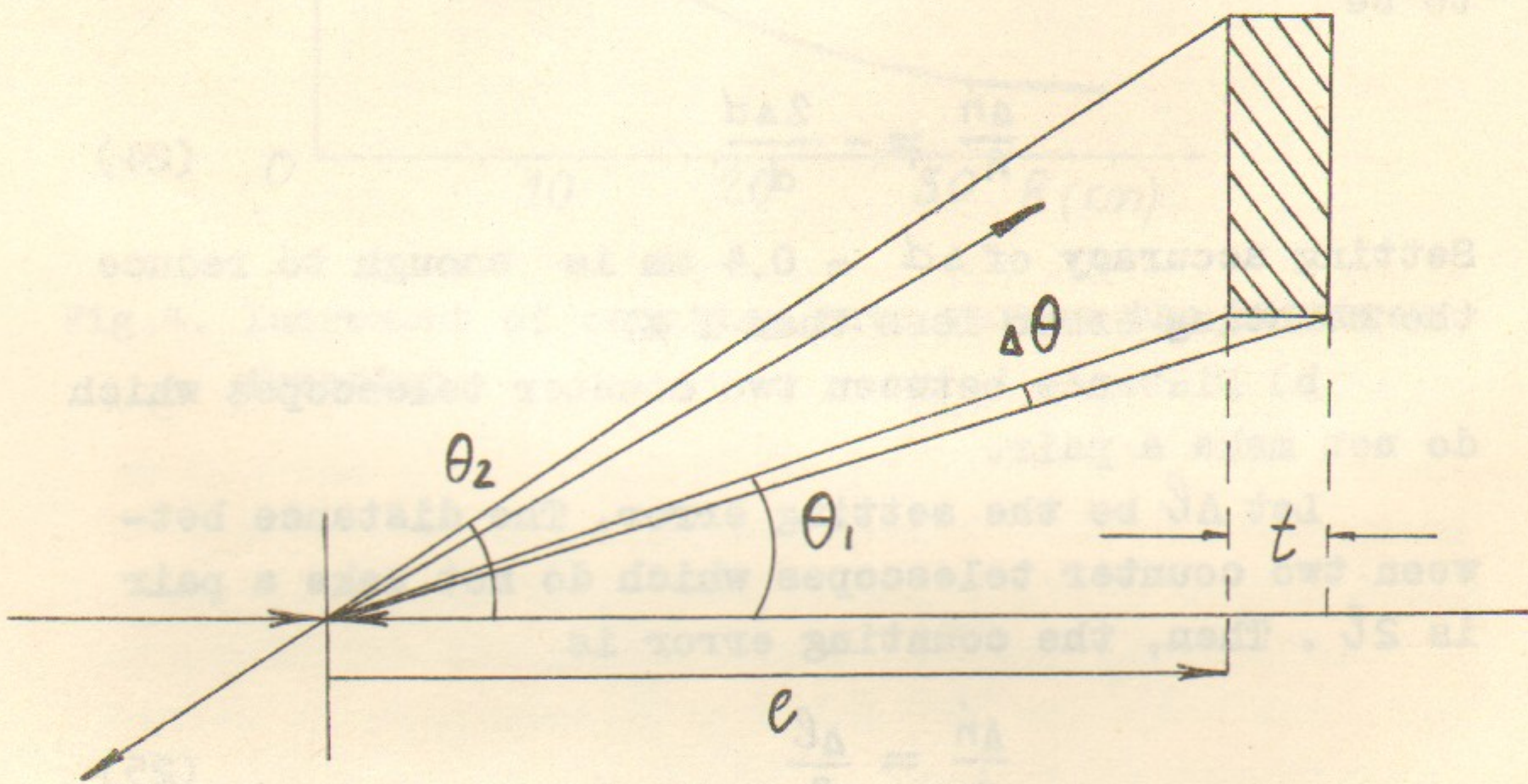


Fig.5. Edge effect of small counter.

In the narrow range of $\Delta\theta$, $\varepsilon(\theta)$ may be substituted by its average value, that is 0.5. Then we have

$$\left(\frac{\Delta\dot{n}}{\dot{n}}\right)_{\text{low}} = \frac{2t}{l} \quad (28),$$

where t means the thickness of small counters. In the similar way, we can estimate the decrement of the counting rate. The results are

$$\left(\frac{\Delta\dot{n}}{\dot{n}}\right)_{\text{up}} = -\frac{0.6t}{l} \quad (29),$$

and

$$\left(\frac{\Delta\dot{n}}{\dot{n}}\right)_{\text{side}} = -\frac{0.5t}{l} \quad (30),$$

for the upper edge and the side edge respectively. Therefore, the total increment of the small counter is

$$\left(\frac{\Delta\dot{n}}{\dot{n}}\right)_{\text{edge}} = \frac{0.9t}{l} \quad (31),$$

and the numerical value is 0.4 %.

II-7. Radiative corrections.

Radiative electron-positron scatterings give additional contributions to the counting rate of elastic electron-positron scatterings. Such a radiative correction was calculated in reference /5/. Here we summarize their result. Let p_1 and p_2 be the momentum of the scattered electron and that of positron respectively, and define the angle θ as the average angle of p_1 and $-p_2$ with respect to incident electron beams. Then, as illustrated in Fig.6, the angles of p_1 and p_2 can be written as $\theta_1 + \frac{\Delta\theta}{2}$ and $\theta_1 - \frac{\Delta\theta}{2}$ respectively in the case when the electron emits γ -ray and the signs of $\Delta\theta$ are inversely when the positron emits γ -ray. Fixing the angle θ , they integrate the cross-section of such a reaction within the ellipsis which is made by the polar angle $\Delta\theta$ and the angle $\Delta\varphi$ under the condition

$$\frac{1}{\gamma} \ll \Delta\theta \ll \theta$$

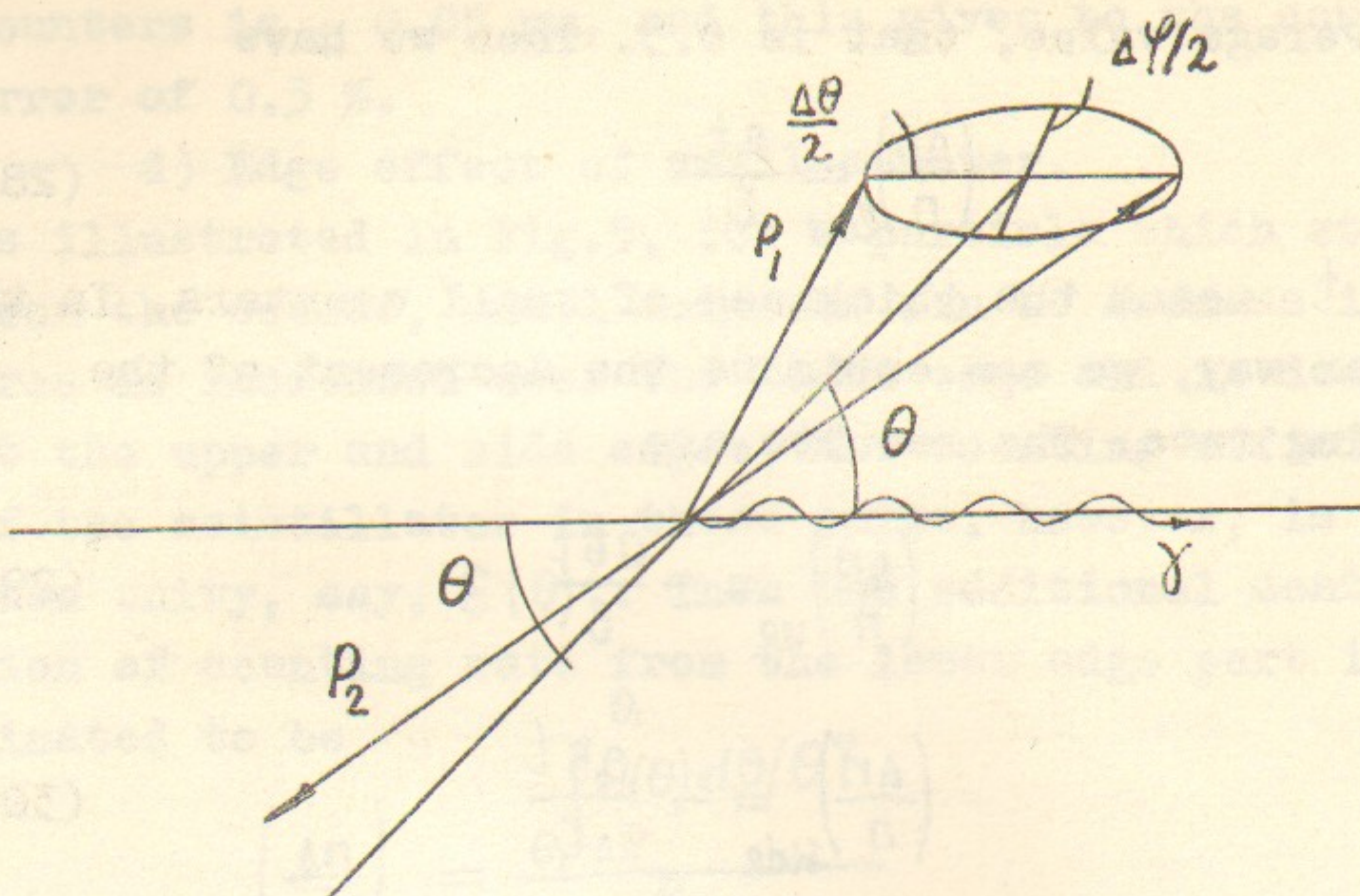


Fig.6. Radiative scatterings.

The cross-section which includes vacuum polarizations and also contributions from hard photon emissions is written as

$$d\sigma = d\sigma_0 (1 + \delta) \quad (32)$$

and

$$\delta(\theta, \Delta\theta) = \frac{2\alpha}{\pi} \left\{ \ln \gamma \left[\frac{11}{3} - 2\varepsilon + \frac{\varepsilon^2}{2} + 2 \ln \varepsilon \right] + \ln^2 \left(\varepsilon \frac{\Delta\theta}{\theta} \right) + \right. \\ \left. + \ln \frac{\Delta\theta}{\theta} \left[2 \ln \gamma - 1 - 2\varepsilon + \frac{\varepsilon^2}{2} - 2 \ln \frac{\Delta\theta + \Delta\psi}{2\theta^2} \right] \right\} \quad (33)$$

where $\varepsilon = 1 - E_{\min} / E$ and E_{\min} mean the threshold energy of particles which can be detected. To apply eq.(6) to the three fold coincidence of our system, we divide radiative scattering into three cases.

The first case is when an electron emits a γ -ray and is detected by the small counter and the positron is detected by the sandwich counter in the region between b_1 and a_1 as illustrated in Fig.7a. Such a coincidence does not occur in elastic scatterings when the source is point like. The region of θ is between a_1/l

and b_1/l and the relation between θ and $\Delta\theta$ is limited by following three inequalities

$$\begin{aligned}\Delta\theta/2 &< \theta - b_1/l \\ \Delta\theta/2 &< a_2/l - \theta \\ \Delta\theta/2 &> a_1/l - \theta\end{aligned}\tag{34}$$

The region which is limited with these inequalities is indicated as "A" in Fig.8. Then, the radiative correction contributed from this case is described as

$$\delta_1 = \frac{\int_{\theta_0}^{a_1/l} \left\{ \delta\left(\frac{\Delta\theta}{2} = \theta - \frac{b_1}{l}\right) - \delta\left(\frac{\Delta\theta}{2} = \frac{a_1}{l} - \theta\right) \right\} \sigma_0 \theta d\theta}{2 \int_{a_1/l}^{a_2/l} \sigma_0 \theta d\theta}\tag{35}$$

and $\theta_0 = \frac{1}{2} \left(\frac{a_1}{l} + \frac{a_2}{l} \right)$. The factor 2 means that there are no contribution coming from the case where positrons emit γ -rays.

The second case is that an electron emits a γ -ray and the region of θ is between a_1/l and a_2/l as illustrated in Fig.7b. Similar to the first case, the inequalities are

$$\Delta\theta/2 < a_2/l - \theta, \quad \Delta\theta/2 < \theta - b_1/l\tag{36}$$

and the region is the sum of "B" and "C" which is illustrated in Fig.8. The radiative correction is

$$\delta_2 = \frac{\int_{a_1/l}^{\theta'} \delta\left(\frac{\Delta\theta}{2} = \theta - \frac{b_1}{l}\right) \sigma_0 \theta d\theta + \int_{\theta'}^{a_2/l} \delta\left(\frac{\Delta\theta}{2} = \frac{a_2}{l} - \theta\right) \sigma_0 \theta d\theta}{2 \int_{a_1/l}^{a_2/l} \sigma_0 \theta d\theta}\tag{37}$$

The third case is that a positron emits a γ -ray and the region of θ is between a_1/l and a_2/l as shown in Fig.7c. The inequalities are

$$\Delta\theta/2 < \theta - \frac{a_1}{l}, \quad \Delta\theta/2 < \frac{b_2}{l} - \theta\tag{38}$$

and the region is "C" + "D" in Fig.8. The radiative

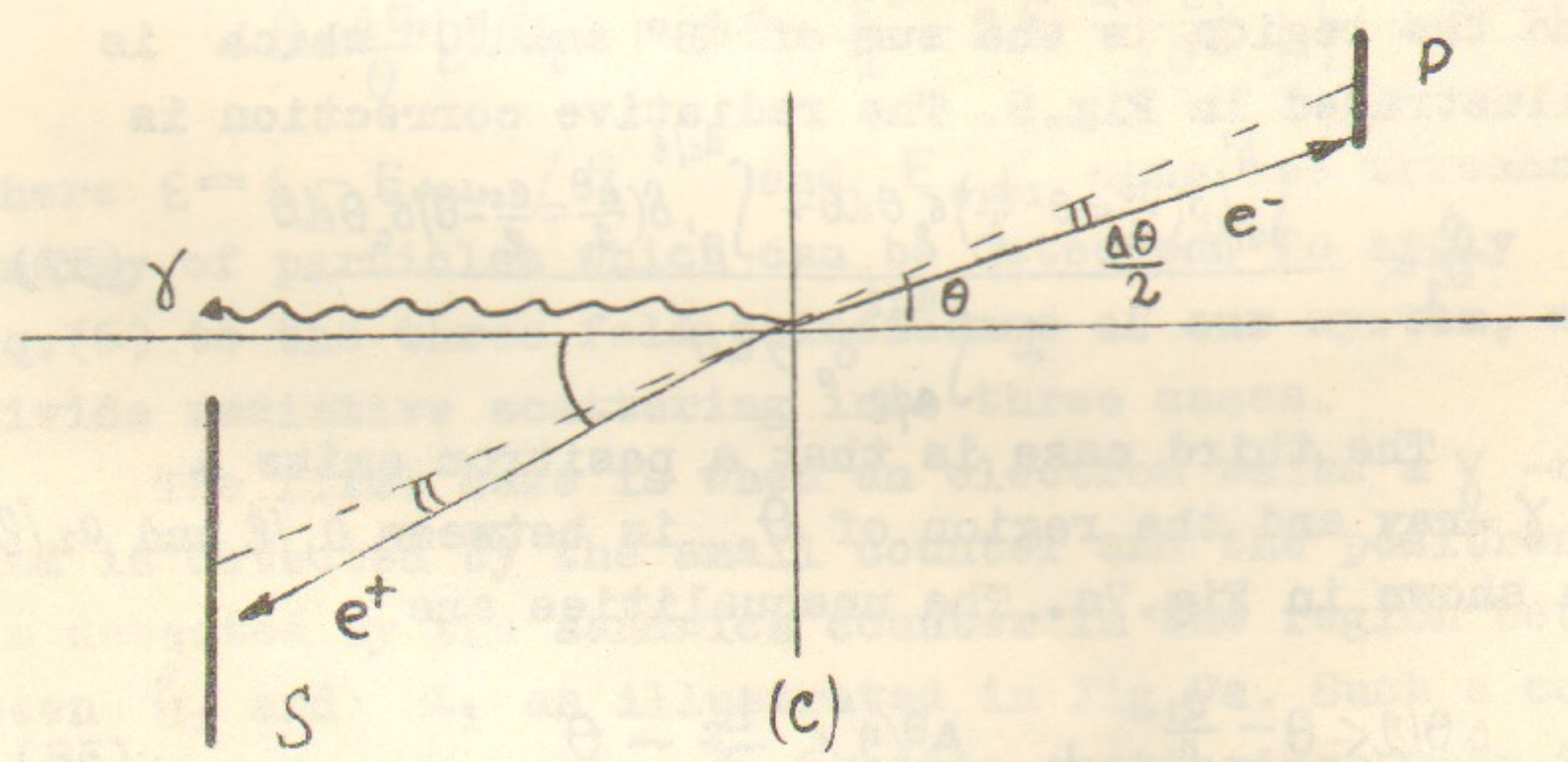
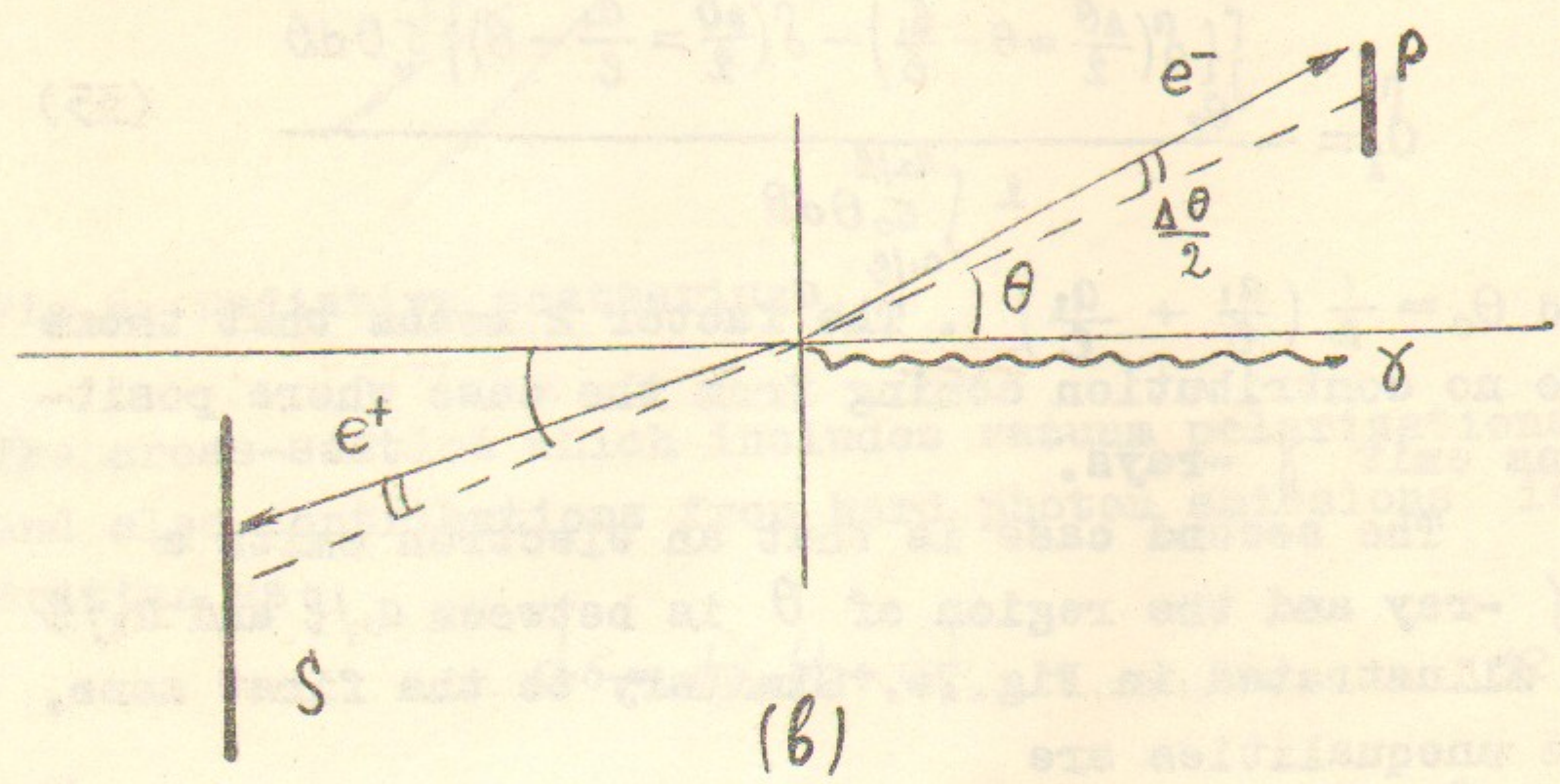
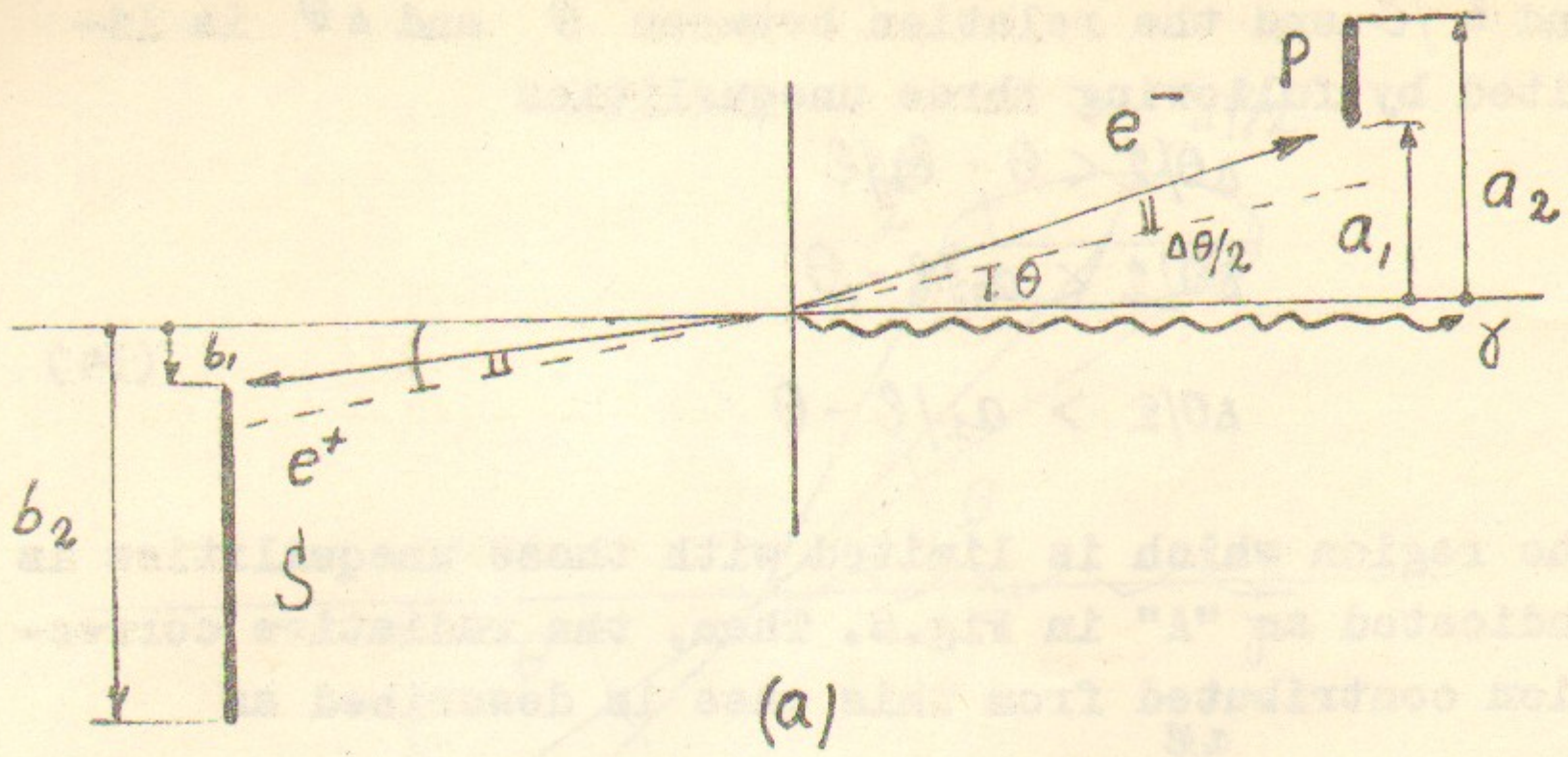


Fig.7. Illustration of three cases of radiative scatterings. P: small defining counter. S: sandwich counter.

correction is

$$\delta_3 = \frac{\int_{\frac{a_1}{l}}^{\frac{a_2}{l}} \delta\left(\frac{\Delta\theta}{2} = \theta - \frac{a_1}{l}\right) \sigma_0 \theta d\theta}{2 \int_{\frac{a_1}{l}}^{\frac{a_2}{l}} \sigma_0 \theta d\theta} \quad (39)$$

The numerical calculations shows that the energy dependence of the radiative correction is rather small. In our system $\mathcal{E} = 1$ is always satisfied. Then, for the energy of 1 GeV the radiative corrections of each cases are $\delta_1 = 1.1\%$, $\delta_2 = 2.3\%$, $\delta_3 = 1.6\%$ and the total is $\delta = 5.0\%$ respectively, while for the energy of 3.5 GeV the total is 5.2%.

One question will arise, because the requirement that $\Delta\theta$ is enough smaller than θ is not always satisfied in our case. The dependence of $\delta(\theta, \Delta\theta)$ on $\Delta\theta$ in the region of θ which we use here, however, is rather slowly. Therefore, the large value of $\Delta\theta$ does not give a large error to the radiative correction.

II-8. Measurement of the azimuthal distribution of the luminosity.

The azimuthal distribution of the luminosity can be measured after an experiment was done by choosing events which occurred in a certain interaction but in different positions of the source. We wish, however, to measure the luminosity distribution during the experiment. If we will be possible to add sets of wire spark chamber in front of each counter telescope already described, we can measure the luminosity distribution with a good accuracy. This method is desirable, however, troublesome to make and to operate.

In the case of VEPP-2 the azimuthal density distribution of both electron and positron bunches had been measured independently by the use of synchrotron radiation /6/. The apparatus has the resolving time of

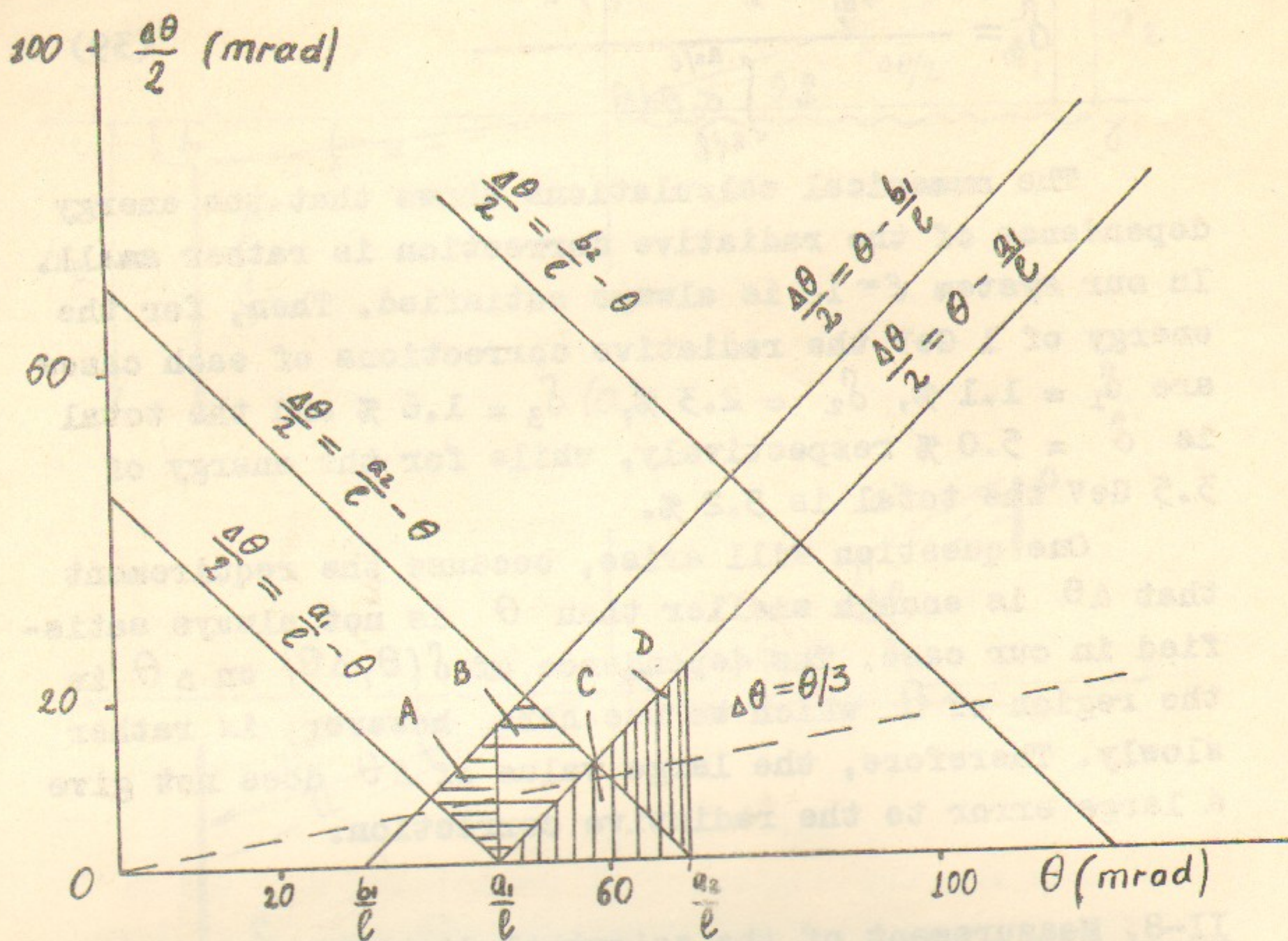


Fig.8. The relation between θ and $\Delta\theta$ in the three cases of radiative scatterings. Regions A, B+C and C+D give contributions to the first, the second and the third case, respectively.

0.05 nsec which corresponds to the spatial resolution of 1.5 cm. The experience of VEPP-2 told us that the azimuthal distribution of bunches were very closely to a gaussian distribution. Then, they could calculate the azimuthal distribution of the luminosity. Of course, we will apply such a method to the VEPP-3. In addition to this we will try to use the following method to check the value of the characteristic half length of the luminosity, σ_L , during an experiment.

In our monitor system, we have two independent data. One is the sum of the counting rates of the three-fold coincidence, \dot{n}_T . Another is the sum of the four-fold coincidences, \dot{n}_F . One can see from Fig.2, that \dot{n}_T is not sensitive to the value of σ_L , however, \dot{n}_F is largely varied with σ_L . Then, the ratio

$$F = \dot{n}_F / \dot{n}_T$$

has large dependence on the value of σ_L and is independent from the absolute value of the luminosity. The accuracy of the determination of σ_L with the use of the values F is presented as

$$\frac{\Delta\sigma_L}{\sigma_L} = \frac{F}{\sigma_L} \cdot \frac{dF/d\sigma_L}{F} \cdot \frac{\Delta F}{F} \quad (40)$$

In Fig.9 the coefficients of $F/\sigma_L \cdot dF/d\sigma_L$ are plotted. One can see that in the region of the expecting value of σ_L , that is from 10 cm to 25 cm, the values of the coefficient are in the range between 1.5 and 2.5.

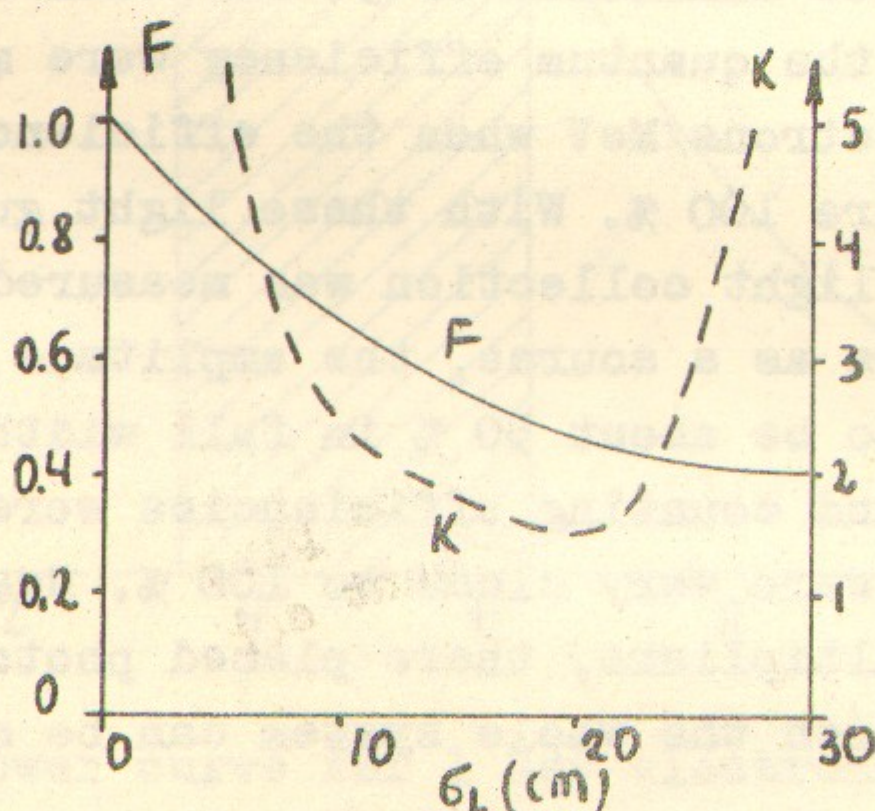


Fig.9. The ratio, F , between the counting rate of the three-fold coincidence and that of the four-fold coincidence versus the source length. K means the error coefficient of the measured source length.

One must be careful to measure the ratio F , because \dot{n}_T is not sensitive to the beam deviations as was already mentioned, however, the counting rate \dot{n}_F is rather sensitive to beam deviations. Fortunately, we have the alignment system of counter telescopes as a whole with respect to the possible beam deviations as described in section II-4. Then the systematic errors of measured values of σ_L is expected to be within several percents. Therefore, we can determine the value of σ_L within an accuracy of several percents.

II-9. Counters and electronics.

Small defining counters are made by plastic scintillator NE-102. Their sizes are 5 mm thick and 30x30 mm² wide. The lights generated are guided by air light guides to photomultipliers. The air light guides are 12 cm long and inside apertures are 20x50 mm². They are made by steel 0.2 mm thick and inside walls are covered with aluminium foils. Photomultipliers are FEU-30 which have diameters of 50 mm. With the use of a cobalt source, the quantum efficiency were measured to be 500 photoelectrons/MeV when the efficiency of light collections were 100%. With these light guides, the efficiency of light collection was measured to be 8%. With cosmic rays as a source, the amplitude resolutions were measured to be about 50% in full width of the half maximum, and counting efficiencies were also measured and they were very close to 100%. Near the side tops of photomultipliers, there placed photoemission diodes, with which the whole system can be checked in any times.

Sandwich counters consist of four layers, each of which consists of a plastic scintillator of 5 mm thick and a lead plate of 5 mm. In front of layers, a lead plate of 20 mm thick is placed, which prevents to count soft energy particles and makes to develop

cascade showers. The shower curve shown in Fig.10 shows the average number of charged particles in the lead block when an electron with the initial energy of 1 Gev goes through. Scintillators of sandwich counters are placed in the shaded region of Fig.10. This region does not give a maximum amplitude to scintillators, however, give well a distinction between high energy electrons and soft particles. The lights generated in scintillators are gathered and guided by the two plexiglasses to one photomultiplier FEU-30.

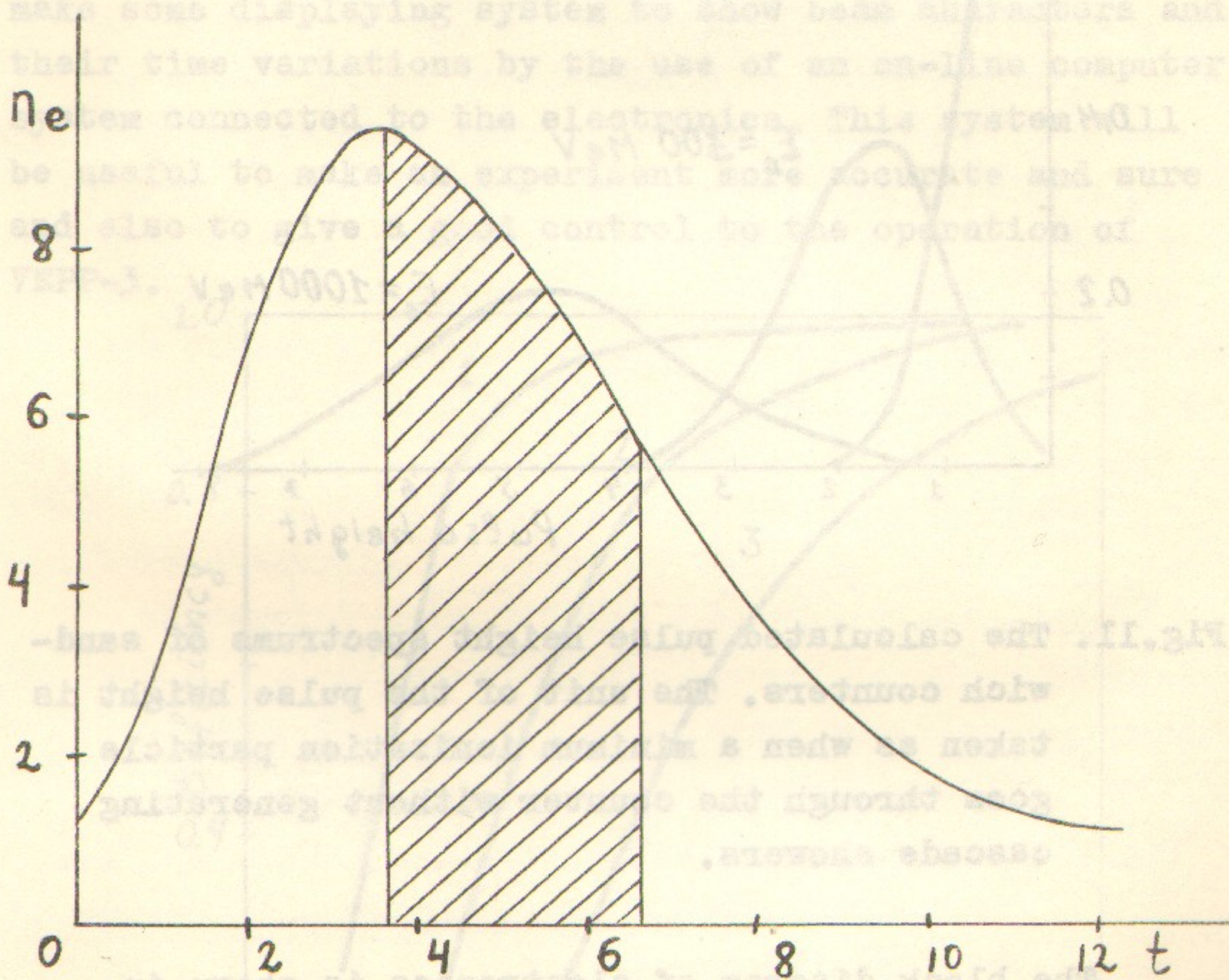


Fig.10. Shower curve for 1 Gev electrons in lead.

n_e means the number of charged particles produced. Abscess is the pass length in unit of the radiation length. Scintillators are distributed in the shaded region.

The amplitude spectrums of sandwich counters for electrons up to 1 Gev were calculated by the use of Monte Carlo method and results are plotted in Fig.11. The counting efficiencies were also calculated and are illustrated in Fig.12. The energy resolutions and the counting efficiencies of real sandwich counters will be measured with beams of the VEPP-3.

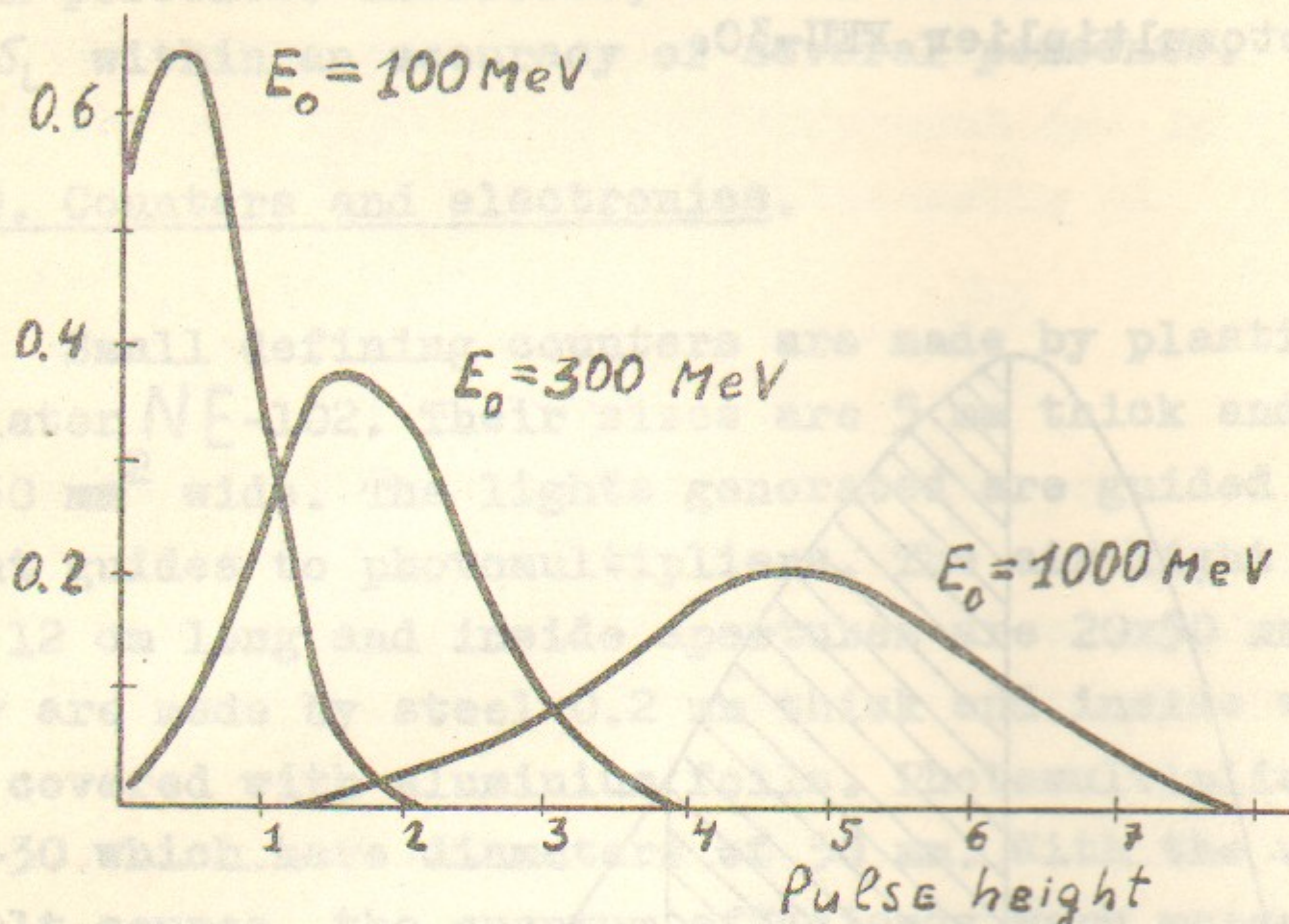


Fig.11. The calculated pulse height spectrums of sandwich counters. The unit of the pulse height is taken as when a minimum ionization particle goes through the counter without generating cascade showers.

The block diagram of electronics is shown in Fig.13. There are four channel of three-fold coincidences (T_1, T_2, T_3 and T_4), two of four-fold coincidences (F_{13}, F_{24}) and three of OR coincidences (O_{13}, O_{24}, O_{1234}). The resolving time of coincidence circuits are 40 nsec. These output are registered with scales which have cycle times of 6 MHz and are enough fast to compare the revolution frequency of beams, 4 MHz. There are two types of

the data handling. The first one is simply to integrate counts during each run of the operation of VEPP-3. This gives the integrated absolute values of the luminosity. The second is that; after each period of 1000 seconds, each data registered in scalers are readed out and are recorded on a trap and on a magnetic tape of the computer system. These differential data are used to know the time variations of the absolute value of the luminosity and also variations about beam deviations. The later informations give the correction factor to the absolute value of the luminosity. In future we will intend to make some displaying system to show beam characters and their time variations by the use of an on-line computer system connected to the electronics. This system will be useful to make an experiment more accurate and sure and also to give a good control to the operation of VEPP-3.

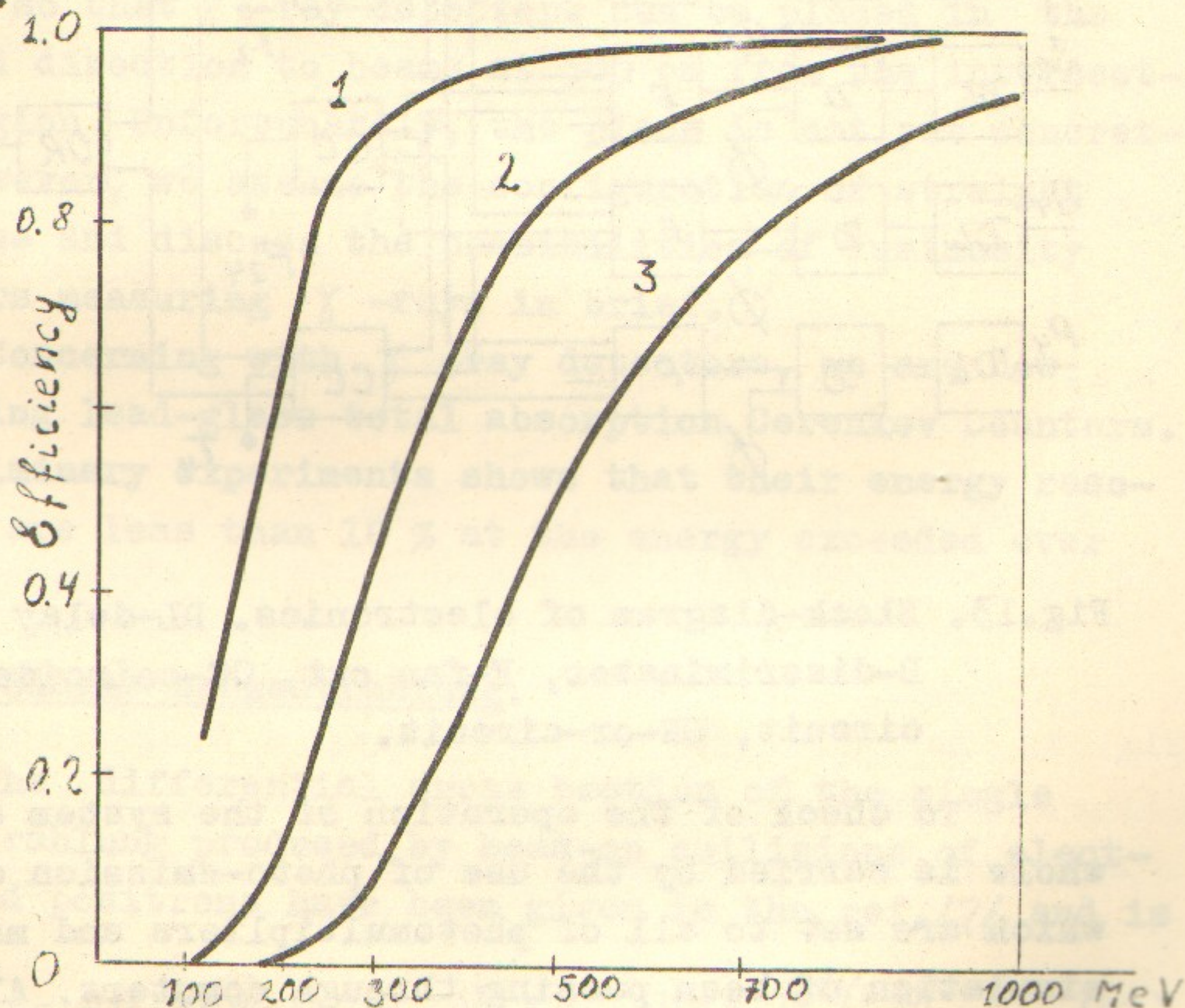


Fig.12. Counting efficiency of sandwich counters as a function of the particle energy. Numerals written on curves mean the threshold energy of the detector in units of the pulse height given by a minimum ionization particles.

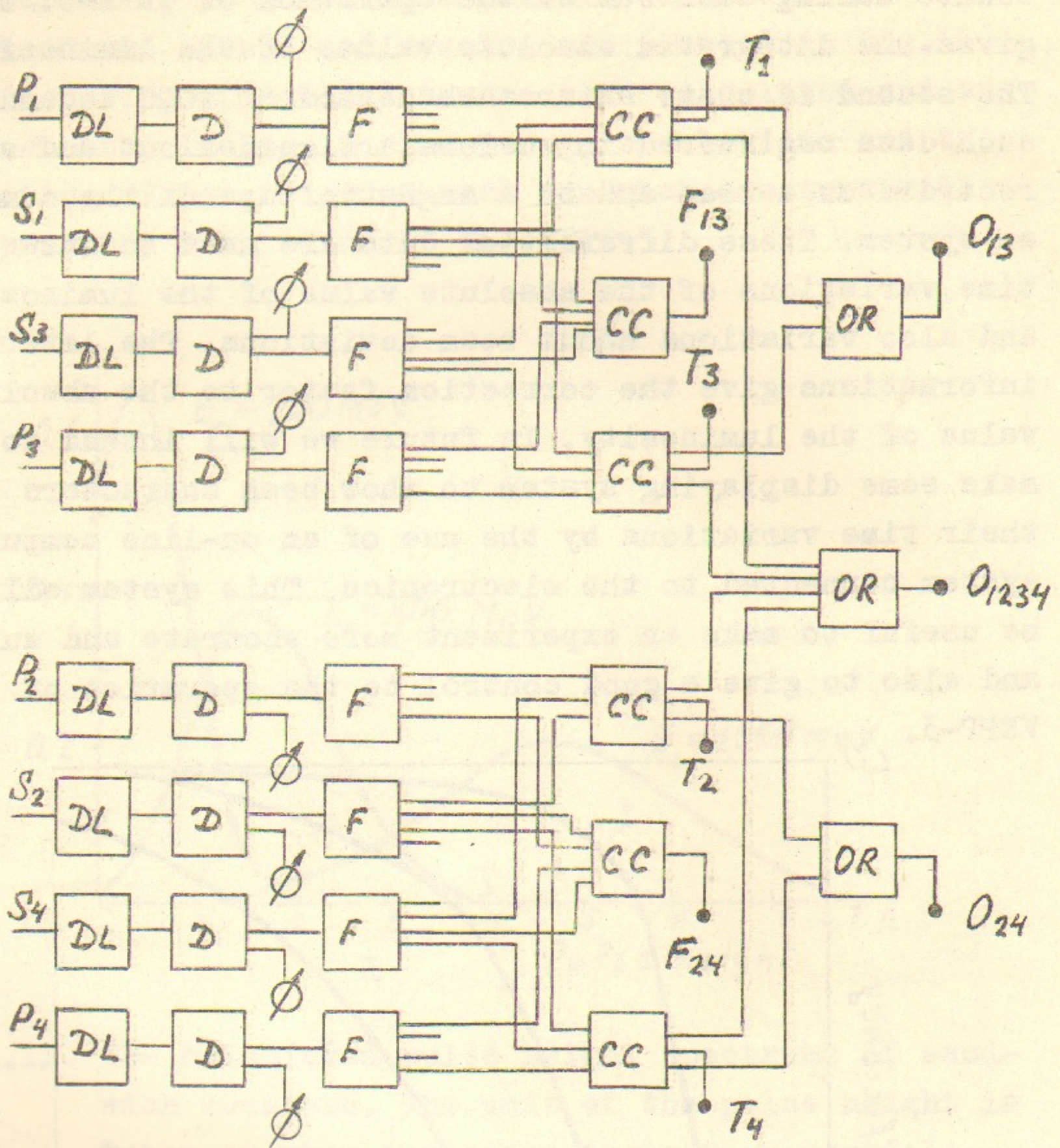


Fig.13. Block-diagram of electronics. DL-delay line, D-discriminator, F-fan out, CC-coincidence circuit, OR-or-circuit.

To check of the operation of the system as a whole is carried by the use of photo-emission diods which are set to all of photomultipliers and make a simulation of beam passing through counters. All of electronic circuits are placed in the counting room and are connected to counter telescopes with cabels of 80 m long, which have impedance of 50 ohms.

III. Possibility of luminosity monitors measuring γ -rays.

We have mentioned in previous sections that the luminosity monitor using small angle $e^- - e^+$ elastic scattering is available and suitable for VEPP-3. Still we want to have another type of monitors, because we want to make the system to be a trustfull one, especially in the unstudied energy region of colliding beam machines. In the case of VEPP-2 they had used phenomena of double bremsstrahlung as luminosity monitors.

VEPP-3 has two long straight sections of 12 m, in the middle of which beams are colliding. Such a long straight section is inconvenient to detect forward γ -rays. Nowadays, there are many plans how to deal with long straight sections. One of them is that, just behind focusing quadrupole magnets, bending magnets are placed so that γ -ray detectors can be placed in the forward direction to beams at 500 cm from the intersecting region. Unfortunately, the plane is not yet concreted, however, we assume the configuration of straight sections and discuss the possibilities of luminosity monitors measuring γ -rays in brief.

Concerning with γ -ray detectors, we are now preparing lead-glass total absorption Cerenkov Counters. A preliminary experiments shows that their energy resolution are less than 10 % at the energy exceeded over 1 GeV.

III-1. Single bremsstrahlung.

The differential cross section of the single bremsstrahlung produced by head-on collisions of electrons and positrons have been given in the ref./7/ and is

$$d\sigma_{\gamma} = 4\alpha r_0^2 \frac{d\omega}{\omega} \left[1 + (1-\omega)^2 - \frac{2}{3}(1-\omega) \right] \left[2 \ln \frac{4E^2(1-\omega)}{\omega} - 1 \right] \quad (41)$$

where ω means the γ -ray energy in unit of the beam energy. The integrated cross section over a certain value of E_1 to maximum energy is plotted in Fig.14. In the typical condition, where $E = 2 \text{ GeV}$, $L = 5 \times 10^{33} \text{ cm}^{-2} \text{ h}^{-1}$ and the threshold energy of γ -detector is assumed to be 200 MeV, the counting rate is 3×10^5 per second.

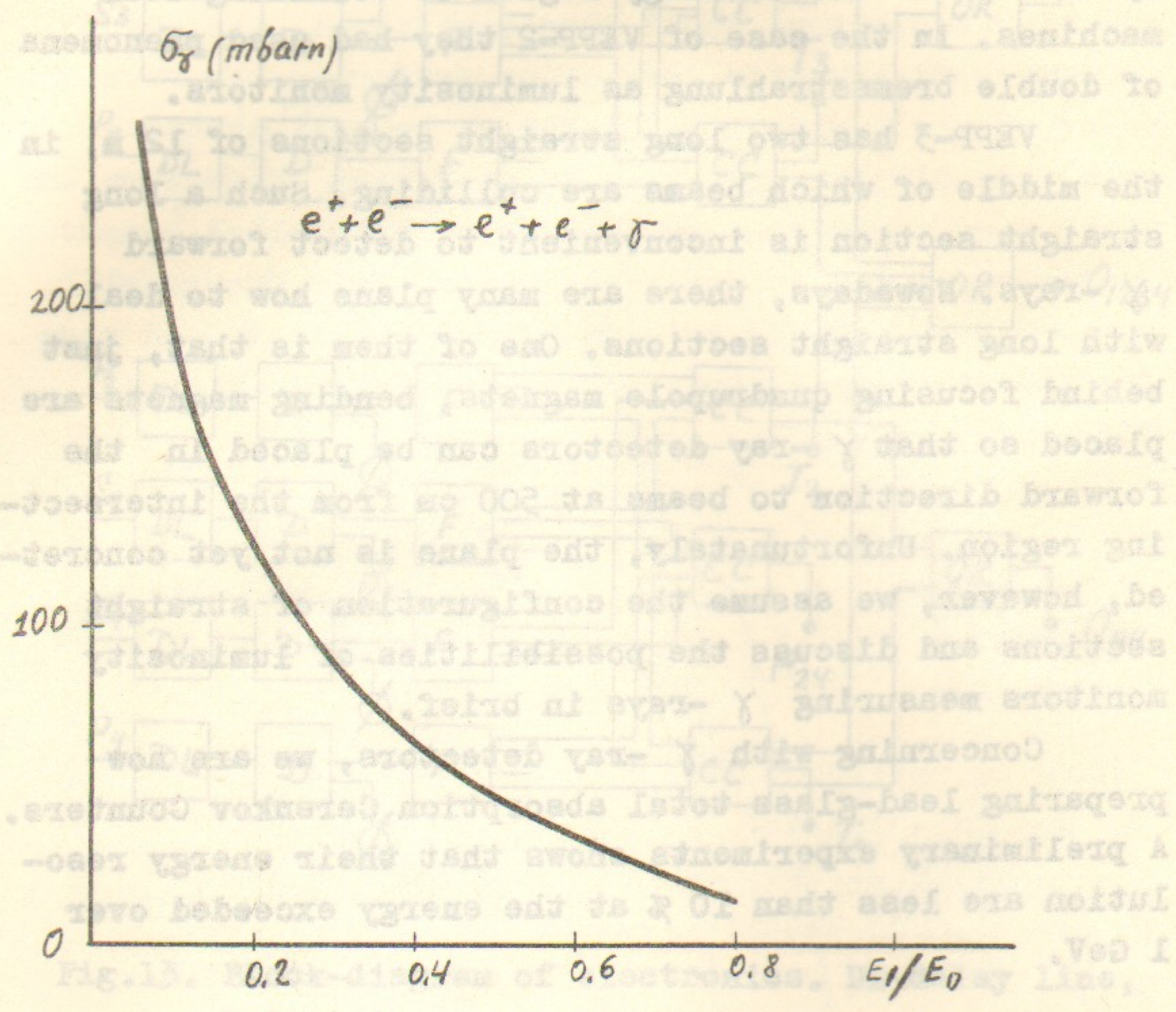


Fig.14. The integrated cross section of single bremsstrahlung, $\int_{E_1/E}^1 \frac{d\sigma}{d\omega} d\omega$ versus threshold energy, E_1 .

One must be careful when the counting rate becomes comparable to the revolution frequency of beams, because one collision time is about 3 nsec during which γ -ray detectors do not resolve successive γ -rays. This means that the detection of single bremsstrahlung can be a candidate of the luminosity monitor if the luminosity is less than $5 \times 10^{33} \text{ cm}^{-2} \text{ h}^{-1}$. When the luminosity exceeds this value, there occurs pile up phenomena of γ -rays and the counting rate begins to saturate and the detected energy spectrum of γ -rays will be varied. In principle, if we measure the counting rate and the energy spectrum of γ -rays simultaneously, it may be possible to determine the luminosity, however, this method is tedious to calculate.

The measurement of single bremsstrahlung has another difficulty caused by the mixing of γ -rays which are generated by collisions between beams and residual gases. Unfortunately, the energy spectrum and the angular distribution of both γ -rays are very similar and do not distinct with each other. The ratio between the counting rate of beam-beam collisions and that of beam-gas collisions is

$$R_{\gamma} = 0.635 \cdot 10^{-39} \frac{\sigma_{\gamma}}{\sigma_{g}} \cdot \frac{L}{I \rho \ell'} \quad (42)$$

where I is the beam current in ampere, ρ is the vacuum pressure in Torr, ℓ' is the length of straight pass seen in cm and L is the luminosity in $\text{cm}^2 \text{ h}^{-1}$. Under the typical experimental condition, where $I = 100 \text{ ma}$, $\rho = 10^{-9} \text{ torr}$, $\ell' = 600 \text{ cm}$ and $L = 5 \times 10^{33} \text{ cm}^2/\text{h}$, the ratio R_{γ} becomes 5. To subtract the contribution from residual gases, another bunch of electrons is injected in an empty bucket. This bunch of electrons does not collide with the positron bunch at the intersecting region, so that if we measure counting rates of both cases separated by time discriminating

circuits we have

$$\begin{aligned} \dot{n}_1 &= \dot{n}_\gamma + \kappa I_- \\ \dot{n}_2 &= \kappa I'_- \end{aligned} \quad (43)$$

where \dot{n}_γ is the counting rate of electron-positron collisions, I_- is the current of the electron bunch which collide with the positron bunch at the intersecting region and I'_- is that of the auxiliary electron bunch. Furthermore, we measure the current ratio $H = I'_- / I_-$ by some methods and, then, we have

$$\dot{n}_\gamma = \dot{n}_1 - \frac{\dot{n}_2}{H} \quad (44)$$

The systematic errors of \dot{n}_γ caused by the measurement of H is

$$\frac{\Delta \dot{n}_\gamma}{\dot{n}_\gamma} = \frac{1}{R_\gamma} \frac{\Delta H}{H} \quad (45)$$

There are many methods to measure the current ratio. Among them, the usage of synchrotron radiations seems to be the best. This method gives several percent errors to H . Then, the absolute value of the luminosity can be measured with an error of 1 %.

III-2. Double bremsstrahlung.

Detections of double bremsstrahlung as a luminosity monitor had been used in VEP-1 /1/, VEPP-2 /8/ and ACO /2/, nevertheless, will not be used in VEPP-3. The reason is accidental coincidences caused by single bremsstrahlungs. The $S-N$ ratio, that is, the ratio between the coincidence counting rate of double bremsstrahlung and that of accidental coincidences is easily calculated under the assumption that the number of events during one collision of bunches is much less than unity. It is

$$R_{2\gamma} = \frac{f}{L} \frac{\sigma_{2\gamma}}{\sigma_\gamma^2} \quad (46)$$

where $\sigma_{2\gamma}$ and σ_{γ} are the cross sections of double and single bremsstrahlungs, respectively, which are integrated over the whole angle and also are integrated over a certain energy range of γ -rays. The cross section, $\sigma_{2\gamma}$, was given by Baier et al./9/. When the threshold energy of γ -ray detectors is chosen at one-third of the beam energy, the $S-N$ ratio becomes $10^{32}/L$, where L is in unit of cm^2h^{-1} . This means that double bremsstrahlung can be a possible luminosity monitor if the luminosity is much less than $10^{32}\text{cm}^2\text{h}^{-1}$.

III-3. Single bremsstrahlung γ -rays in coincidence with recoiled electron or positron.

We consider the following process; an electron collides with a positron and emits a γ -ray in the forward direction which is detected by a γ -ray detector. The recoiled positron loses its energy little and is detected in coincidence with γ -ray by counter telescopes which are prepared for the monitor system using the detection of electron-positron elastic scatterings. The cross section of this process can be easily deduced from the formula for the differential cross section of single bremsstrahlungs, which was given in the reference /5/. For example, when we assume that the beam energy is 2 GeV and the threshold energy of γ -detectors is 0,2 GeV and we integrate the cross section over the range of the γ -ray energy and over the solute angle of four sandwich counters, we have the total cross section of $1.2 \times 10^{-29}\text{cm}^{-2}$ which is enough large for the system to be a luminosity monitor.

The signal to noise ratio of coincidence countings is represented as

$$\frac{S}{N} = \frac{f}{L} \frac{\sigma_{sc}}{\sigma_{\gamma} \sigma_{el}} \quad (47)$$

where σ_{sc} is the differential cross section of this process and σ_{el} is that of $e^{-} + e^{+}$ elastic scatterings.

The ratio is almost independent on the beam energy and the threshold energy of γ -detectors. In our case, it is about $4 \times 10^{33}/L$ which means this method is useful if the luminosity is less than $10^{33} \text{ cm}^2 \text{ h}^{-1}$. The most important fact is that this method gives a connection between electron detectors and γ -detectors so that it plays a good check to both systems.

III-4. Two γ -rays annihilation.

The cross section of the electron-positron annihilation into two γ -rays is proportional to the inverse square of the beam energy, while the energy dependence of the cross section of single bremsstrahlungs and that of double bremsstrahlungs are rather slowly varied. Therefore, in the high energy region, it was considered that the coincidence measurement of two γ -rays annihilation must be masked by accidental coincidences caused by single bremsstrahlungs and coincidences from double bremsstrahlungs. One possible way to measure annihilation γ -rays is to use a γ -ray detector which has a good energy resolution. Unfortunately, the total absorption Cerenkov counter made by lead glass has an energy resolution of about 10 %, and it is not enough to distinguish annihilation events from other processes. One fact may give us a possibility to eliminate contributions coming from single and double bremsstrahlungs. That is, single and double bremsstrahlungs have sharp angular distributions in the forward direction, while the two γ -rays annihilation has a rather wider angular distribution as illustrated in Fig.15. For example, when the energy of beams is 2 GeV, 99 % of γ -rays caused by single bremsstrahlung are concentrated within 2.5 m rad, and 80 % of double bremsstrahlungs are also in this cone.

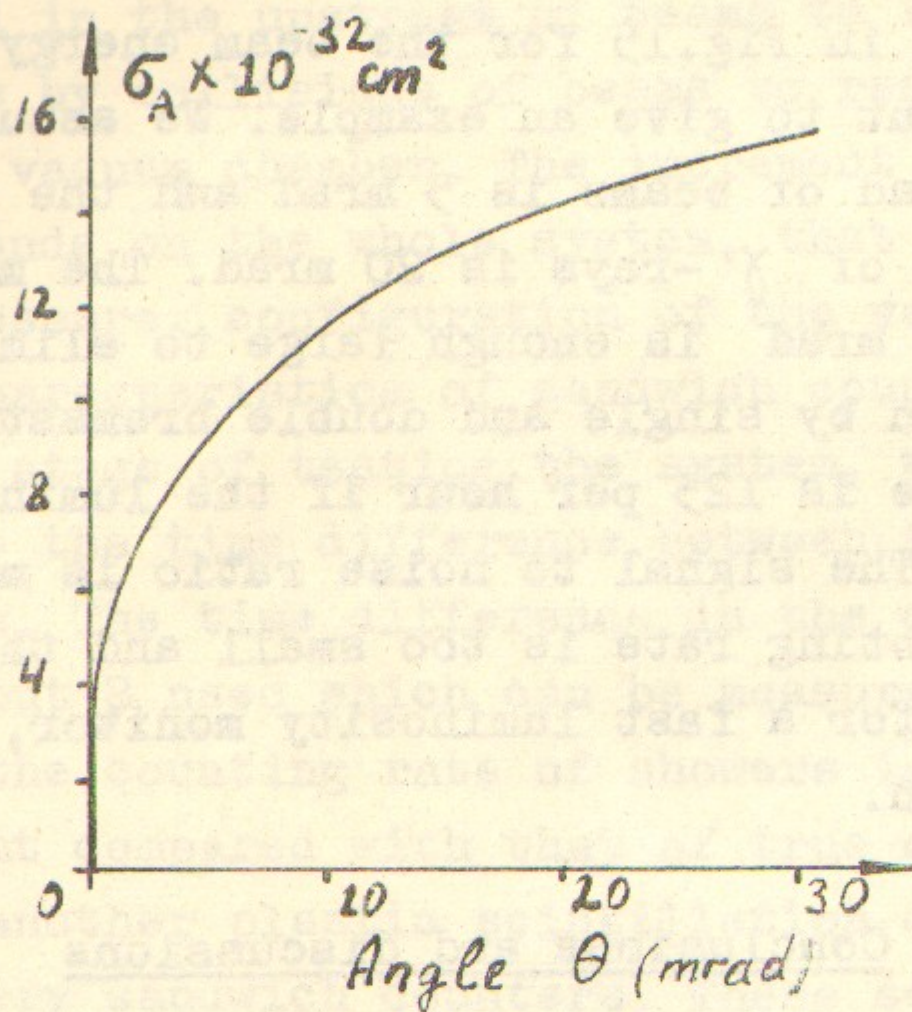


Fig.15. The cross-section of two γ -rays annihilations integrated over an angle, θ . The beam energy is 2 GeV.

Then, if we provide a scintillation counter and a lead plate converter in the front of the Cerenkov counter and make a slit in the scintillator with a certain width in the radial direction and take coincidences between the scintillation counter and the Cerenkov counter, we can measure two γ -ray annihilations with a good signal-noise ratio. One must be notified that the slit is necessary instead of a hole, because

γ -rays which are produced by the beam-residual gas collisions during beams pass through the bending magnet and change their direction hit the scintillator to give accidental coincidences. Concerning with the width of the slit, one must take into account the angular spread of beams except to the angular spread of γ -rays.

The cross-section of two γ -rays annihilation integrated over a certain angle, θ , is given as

$$\sigma(\theta) = \frac{d^2\pi}{2E^2} \ln \left[1 + \left(\frac{E\theta}{mc^2} \right)^2 \right] \quad (48)$$

which is plotted in Fig.15 for the beam energy of 2 Gev. Now we want to give an example. We assume that the angular spread of beams is 5 mrad and the maximum detectable angle of γ -rays is 20 mrad. The maximum slit angle of 10 mrad is enough large to eliminate the contamination by single and double bremsstrahlungs. The counting rate is 125 per hour if the luminosity is $5 \times 10^{33} \text{ m}^{-2} \text{ h}^{-1}$. The signal to noise ratio is more than hundred. The counting rate is too small and this method is not suitable for a fast luminosity monitor, however, the data is clean.

IV. Conclusions and discussions

Now it is clear that the luminosity monitor system using electron-positron elastic scatterings is available in the energy region of several Gev. The estimated systematic error was within several percents. The symmetric configuration of counter telescopes gives an automatic cancellation to counting errors caused by first order deviations of beams. The realignment system of counter telescopes as a whole gives second order corrections to any beam deviations in the vertical plane, however, it does not give corrections to deviations in the radial plane. So it is desirable to add another set of counter telescope which is just the same to the first one, but is placed in the medium plane of the storage ring. These two sets of counter telescopes give the complete information about beam deviations, and the correction factors to the luminosity. Furthermore, the comparison between counting rate of two sets of telescopes

will give some idea to the systematic error of the system.

Another possible counting errors except beam deviations may be caused by cascade showers which are originated in the upstream of beams to the counter telescopes by collisions of beams to residual gases or to the vacuum chamber. The increment of coincidences depends on the whole system, that is, on the vacuum pressure, configuration of the vacuum chamber and the characteristics of sandwich counters etc. In the first stage of testing the system, we will try to measure the time difference between two counter telescopes. The time difference in the case of showers is about 8 nsec which can be measured easily. Then, if the counting rate of showers is larger than one percent compared with that of true events, we will add another plastic scintillation counters just before every sandwich counters. These scintillation counters have their apertures a little smaller than sandwich counters and have much faster rise times of pulses than that of sandwich counters. Then, the time different between two counter telescopes are measured between the small counter of one telescope and the large counter of the other telescope. Another convenience to add these large scintillation counters is as follows: Sandwich counters have large thickness and have edge effects which give some errors to the counting rate specially in the case where the source is long. The large scintillation counters can help to define the effective area of sandwich counters by taking coincidences between large counters and sandwich counters. Therefore, these coincidences reduce the ambiguity caused by edge effects.

Making some combinations between counting rates of each counter telescope and connecting them to an on-line computer system, we can calculate the variation of the luminosity and deviations of beams and

can display them with some method during experiments. Such a display system will be useful for the operation and the control of VEPP-3 itself and also give a trust on experimental results. We will intend to make the system in future.

We have estimated the increment of counting rates caused by beam divergences and have found that it was rather large when betatron functions became small. Unfortunately, we have no way to measure the density distribution of beams in the phase space of betatron oscillations. The correction factor for this phenomena may have large error. When we want to recommend that, in future when one wants to get a larger luminosity, one must set Charpak chambers in front of every counter telescopes, which also help to measure the azimuthal density distribution of beams.

One can see in the chapter III that γ -ray detections are also available for monitor systems. To have a trustful beam monitor is the most important things, specially, for the study in the unknown region of the particle physics. If we have two monitor systems and check each other, then, the system becomes more trustful. Therefore, we want to have a monitor system using γ -ray detectors. Unfortunately, it is necessary for the γ -ray detectors to have bending magnets near the intersecting region which is troublesome to make and may delay the first experiment. The decision in which the second monitor system will be made or not depends on the whole project of VEPP-3. Nevertheless, we want to emphasize the necessity of the second monitor.

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