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STORAGE RING LUMINOSITY MEASUREMENT BY SMALL ANGLE e^+e^- SCATTERING.

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STORAGE RING LUMINOSITY MEASUREMENTS BY SMALL ANGLE e^+e^- SCATTERING. -

We present a counter system designed to measure the luminosity of Adone, the Frascati e^+e^- storage ring, by detecting electron-positron pairs scattered at small forward angles. Characteristics and performances of the apparatus are discussed on the basis of the results collected during several months of measurements at energies of 600 to 1500 MeV per beam. The results are found to be in agreement, within the quoted systematic errors, with those obtained by a single bremsstrahlung luminosity monitor.

1. - APPARATUS. -

The luminosity monitor here described is a slightly improved version of a previous one, already presented(1, 2). It is designed to measure the absolute luminosity of Adone with an accuracy of 5% by means of the Bhabha scattering.

$$e^+e^- \longrightarrow e^+e^- \qquad (1)$$

in a small forward solid angle: $3.3^\circ \leq \theta \leq 6.0^\circ$. The space-like(1) momentum transfers, $q^2 = -4E^2 \sin^2\theta/2 \simeq -E^2\theta^2$, where E is the beam energy, involved in this process are limited to small values so that

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the measurement of the cross section

$$\frac{d\sigma}{d\Omega} = 4\, r_o^2 \left(\frac{mc^2}{E}\right)^2 \frac{1}{\theta^4}$$

would be unaffected by a possible breackdown of quantum electrodynamics. The counting rate for the average luminosity of Adone is about 10^3 events per hour.

The apparatus is made up of four symmetrical counter telescopes named 1 to 4 in Fig. 1. Each telescope consists of three scintillation counters:

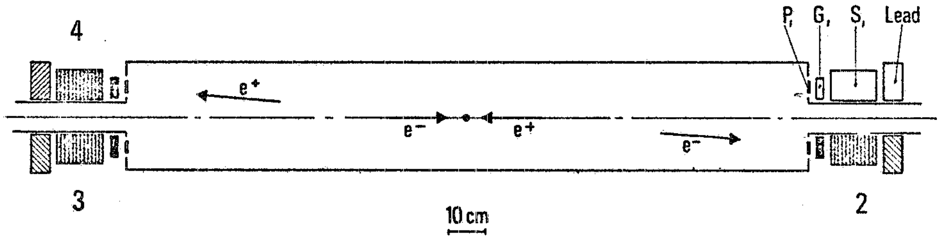

FIG. 1 - Cross sectional view of the monitoring system. Counters P_i, G_i are plastic scintillators. Counters S_i are "sandwiches" (0.5 cm Pb plates alternated with 0.3 cm plates of plastic scintillator for a total of 13 radiation lenghts) which discriminate against low energy background electrons.

i) a small counter, P, which defines the solid angle;
ii) a counter, G, placed behind counter P;
iii) a shower counter, S, which discriminates against low energy electrons (positrons).

Counters P have transverse dimension of 3×9 cm^2 and thickness 0.1 cm; they are viewed by a single photomultiplier through an air light pipe in order to correctly define the accepted solid angle. Their distance from the median plane of the machine is known within an uncertainty of 0.05 mm by means of an optical system. In order to reduce the effects due to the interaction of electrons (positrons) in the vacuum chamber walls, counters P are placed behind a small steel window 0.1 mm thick.

Counters G have transverse dimensions of 5.6×11.6 cm^2 and thickness 2 cm; they are viewed each by a single photomultiplier through a plexiglass light pipe. Each pipe is connected to the end of the scintillator away from the beam line in order to equalize the lengths of the light paths.

Counters S are "sandwiches" made up of 0.5 cm thick lead plates alternated with 0.3 cm scintillators. The total lead thickness is about 13 radiation lengths insuring the absorption of 90% of the energy released by 1 GeV electrons. Counters S were calibrated with 100 to 700 MeV electrons at the Frascati electrosynchrotron; the pulse height distributions obtained during these calibration runs are shown in Fig. 2. During the actual measurements the pulses of the counters S were attenuated in order to have full detection efficiency for electrons with the beam energy, E, and a high rejection factor for electrons of energy lower than E/3. Fig. 3 shows the pulse height distribution of counter S_1 gated by the threefold coincidence $P_1 G_1 S_1$.

A 5 cm lead absorber is placed behind counters S in order to screen the telescopes from electrons (positrons) which come out of the beam and would cross the counters in the wrong direction.

2. - DETECTION SYSTEM. -

The events originated from process (1) are characterized by the following properties:

i) the scattered particles are collinear;
ii) the scattered particles carry out the energy of the beam, E.

On the basis of these simple criteria, elastic scattering events are detected by four fivefold coincidences which involve counters of opposite telescopes:

$$Q_i = T_i D_{\underline{i+2}} \qquad i = 1, 2, 3, 4$$

where $T_i = P_i G_i S_i$ and $D_j = G_j S_j$. The counting rate of the coincidences Q_i depends on the dimensions of the electron-positron interaction region, hereafter called "source", and on its position relative to the center of the straight section of Adone where the apparatus is installed.

In the following we call "bunch length", l_b the standard deviation of the longitudinal distribution of the particles in the bunches which is assumed to be gaussian(3). The source length, $l_s = l_b / \sqrt{2}$, originated from the crossing of two bunches, depends mainly on the energy, E, and the radiofrequency voltage, V_{rf}, in the approximate form: $l_s = 1.67\, E^{3/2}\, V_{rf}^{-1/2}$ where E is expressed in GeV, V_{rf} in kV and l_s in m. The actual values of l_s, which are typically of 10 to 30 cm, are known from the parameters of Adone to within an uncertainty of $\pm 5\%$.

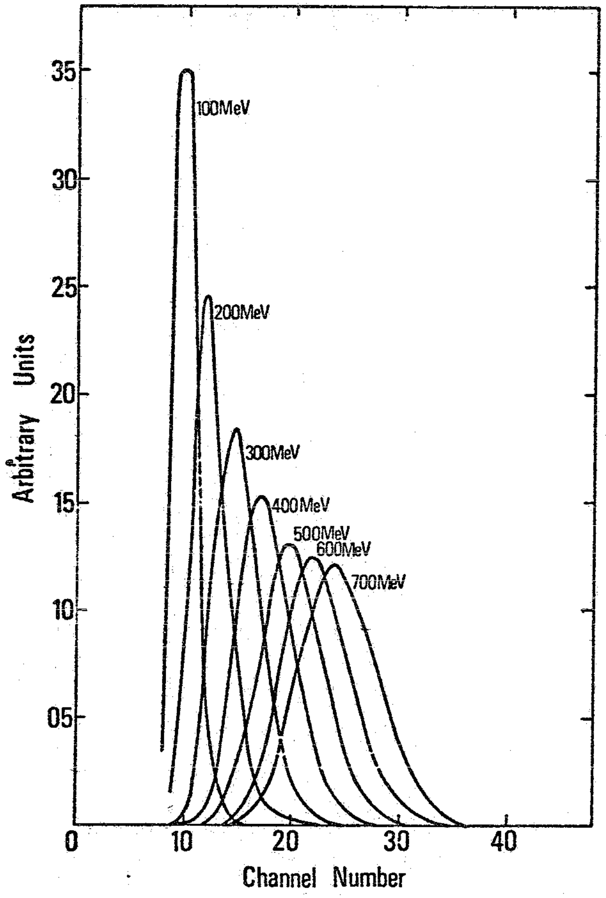

FIG. 2 - Pulse height distributions, normalized to the same area, of one of the shower detectors, S_i, for electrons of the indicated energies. Zero pulse height corresponds to channel no. 8.

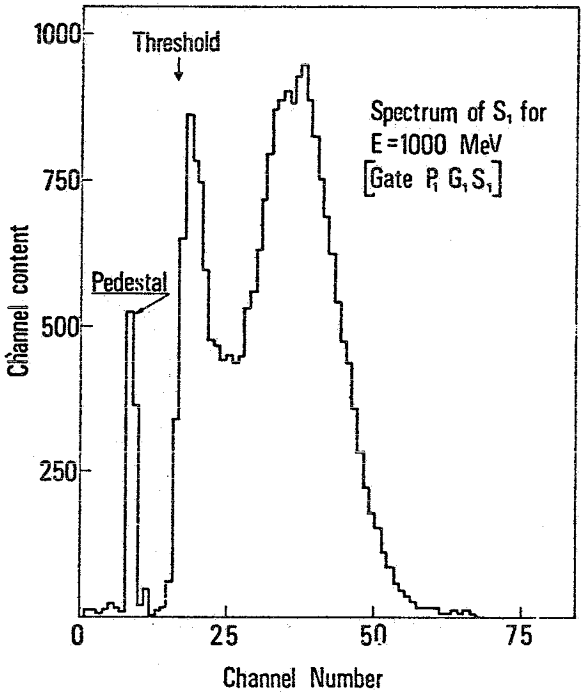

FIG. 3 - Pulse height distribution of counter S_1 gated by the threefold coincidence $P_1G_1S_1$ obtained with 1 GeV electrons.

This result has been obtained with an independent measurements of l_s based on the distribution of the emission points of e^+e^- scattering events detected in a wide angle telescope$^{(4)}$.

Due to the θ^{-4} dependence of the differential cross section of process (1), the counting rate of the coincidences Q_i is critically dependent on even small displacement of the source both in the longitudinal and vertical directions. The effect of the displacements of the source on the counting rate of the coincidences Q_i have been evaluated$^{(5)}$ and it has been found that such a critical dependence can be reduced using the averaged "or" of the four coincidences Q_i, defined as

$$OR = \frac{1}{2}(OR_{1,3} + OR_{2,4})$$

where $OR_{i,i+2}$ is the "or" of the two coincidences Q_i and Q_{i+2}. The counting rate, $\dot{n}_{OR}$, of the averaged "or" is more stable against small displacement of the source since, becacuse of the symmetry of the detection system, the first order terms in $\Delta \dot{n}_{OR}$ vanish. For displacements of the source which, as usual, do not exceed 5 cm in the longitudinal direction and 0.5 cm in the vertical direction, the instability in the counting rate is: $\Delta \dot{n}_{OR}/\dot{n}_{OR} = (-4 \div +1)\%$.

We thus realize two independent measurements of the luminosity, L, which are obtained from the counting rates of the two coincidences $OR_{i,i+2}$, $\dot{n}_{OR}$, through the relation:

$$L = K_{OR}\, \dot{n}_{OR}(h^{-1})\, E^2(GeV^2)\, 10^{29} \qquad cm^{-2}\, h^{-1}$$

where the function K_{OR}, plotted in Fig. 4, depends on the source length only. From Fig. 4 one sees that, due to the uncertainty of $\pm$ 5% in the value of l_s, the absolute luminosity is affected by an error of about $\pm$ 3%$^{(x)}$. It should be noted that the displacements of the

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(x) - It should be noted, that a similar error affects the counting rate, $\dot{n}_x$, of the events produced through the reaction $e^+e^- \rightarrow x$, so that the two errors compensate each other in some way in the expression of the total cross section $\sigma_x = \dot{n}_x/L$. As an example the cross section for muon pair production, $e^+e^- \rightarrow \mu^+\mu^-$, as measured by an apparatus with solid angle $45^\circ \leq \theta \leq 135^\circ$, similar to those used in the first generation experiments at Adone$^{(6)}$, would be affected by an error of less than 1% due to the quoted uncertainty on l_s.

source can be controlled by means of the ratios between the counting rates of the coincidences Q_i, since these coincidences are not symmetrical with respect to the center of the straight section, and therefore corrections can be applied to the counting rate of the coincidences $OR_{i,\,i+2}$. Since this method is not very sensitive to small and rapid fluctuations of the source position, these corrections are in general not taken in account unless they are larger than the quoted systematic error for this effect:

$$\Delta L/L = (-4 \div +1)/ .$$

3.- BACKGROUND AND CORRECTIONS.-

Background event which are detected by the coincidences Q_i and can simulate events from process (1) originate mainly in the following processes:

a) electromagnetic showers due to electrons or positrons lost from the beam, which cross several counters of the apparatus;

b) simultaneous scatterings of electrons and positrons on the residual gas inside the vacuum chamber which cause random coincidences;

c) electron-positron pairs produced via two photons annihilation$^{(7)}$

$$e^+e^- \longrightarrow e^+e^-\gamma\gamma \longrightarrow e^+e^-e^+e^- \tag{2}$$

The events of type a) are rejected by means of the time of flight between counters G of opposite telescopes, $\Delta t_{1.3}$ and $\Delta t_{2.4}$, recorded on a multichannel analyzer. A distribution of $\Delta t_{1.3}$, gated by the coincidence $OR_{1.3}$, is shown in Fig. 5 where the central peak originates from e^+e^- pairs crossing simultaneously the two telescopes and the two lateral peaks are due to showers produced by the electron and positron beams respectively.

The time interval between the pulses of the counters G due to events of type a) is 6.2 ns and the resolution of the time of flight system is 0.9 ns (full width at half maximum measured during cosmic rays calibration). The central peak width is essentially due to the length of the source. The background subtraction from the counting rate of the coincidence $OR_{i,\,i+2}$ is of the order of 5%.

The events of type b) are rejected by means of the delayed fivefold coincidences, $Q_i(d) = T_i D^{(d)}_{i+2}$, in which the twofold coincidence D_j is delayed for a complete period of the machine, 350 ns. The contribution to the counting rate of the coincidences $OR_{i,\,i+2}$ is 1% to 2%.

These background subtraction technique have been checked

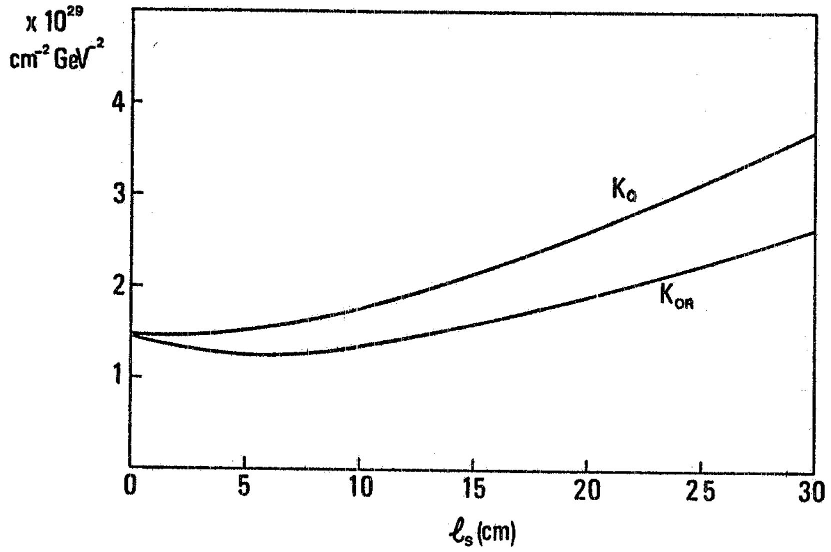

FIG. 4 - Coefficients K_q and K_{or} as a function of the source length, l_s. The luminosity is obtained from the counting rate, $\mathring{n}$, through the relation: $L = K \mathring{n} E^2$ in units cm^{-2}h^{-1} if $\mathring{n}$ is expressed in h^{-1} and E in GeV.

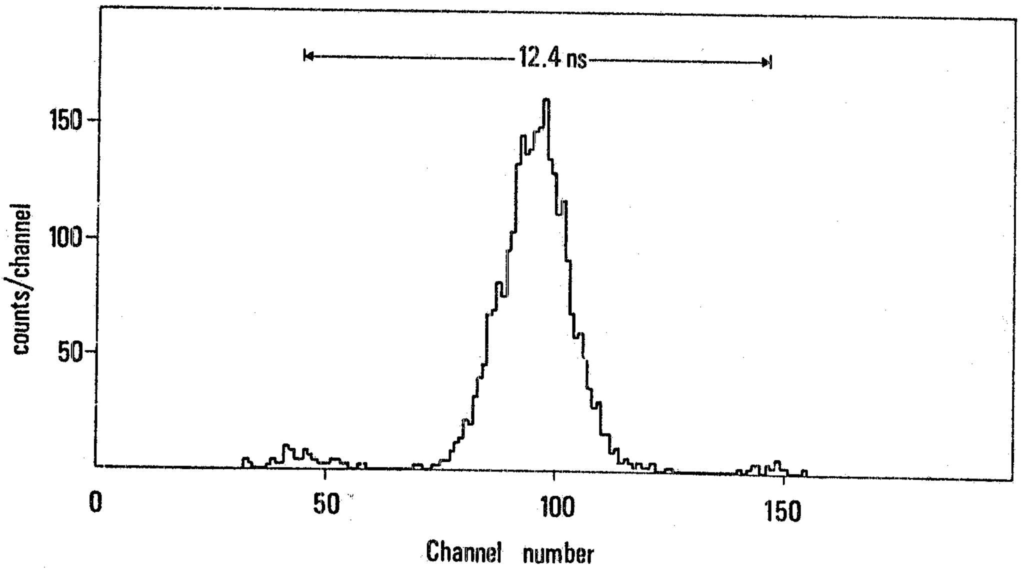

FIG. 5 - Time of flight distribution of the pulses from counters G_1 and G_3. The central peak originates from simultaneous e^+e^- scattering events. The two lateral peaks are due to showers originating from the electron and positron beams respectively. The conversion factor is about 0.12 ns/channel.

during background runs in which two non intersecting beams were circulated in Adone. In these conditions the beam intensity was monitored by the counting rate of the threefold coincidences T_i which is roughly proportional to the product, $p \times i$, of the residual gas pressure and the circulating current.

To evaluate the contribution due the events of type c) the apparatus has been operated in coincidence with a counter system, installed in the same straight section, designed to detect the forward emitted electrons (positrons) exploiting the bending magnets of Adone as momentum analyzers(8). This tagging counter system accepts forward going electrons (positrons) of energy $0.2E \div 0.85E$ with geometrical efficiency of about 50%(9). The counting rate recorded at $E = 1.4$ GeV, where the background due to the events of type c) is expected to be higher(x), is 0.6% of coincidences $OR_{i,i+2}$ and the time of flight distribution shows that these coincidences are mainly caused by showers.

Taking into account the angular and energy resolution of the tagging counters we can put an upper limit of 1% on the contamination from events of type c) at $E = 1.4$ GeV whereas at energies below 1 GeV it is expected to be negligible.

The radiative corrections to process (1) have been evaluated with the statistical method of B. Touschek(10) and have found to be of the order of 2%(11). Using the peaking approximation(12), which is believed to be valid since the angular resolution of the apparatus ($\Delta\varphi \simeq 30^{\circ}$; $\Delta\theta/\theta \simeq 1/3$) and the energy resolution of counters S_i($\Delta E/E \simeq 2/3$) are both very poor, one obtains corrections of less than 1%. Since both methods are approximate and the evaluated corrections are small, these have not been applied to the measured values of the luminosity.

The overall effect of the radiative corrections and of the contribution from e^+e^- pairs originating in $\gamma\gamma$ collisions in thus to enlarge the systematic error to the value $\Delta L/L = (-5 \div +2)\%$.

4. - RESULTS. -

The apparatus described, hereafter called a small angle Bhabha scattering (SABS) monitor, has been used as a 5% luminosity monitor during three years of operation of Adone (1970-72). Another apparatus, installed in the same straight section by the "Adone group"(13)

(x) - We recall that the energy dependences of the cross section of process (2) and of process (1) are $(\ln E)^3$ and E^{-2} respectively.

has been used to measure the absolute luminosity by means of the single (SB) and double bremsstrahlung (DS), during special runs in which two electron bunches and three positron bunches where circulating in Adone(x), in order to subtract the relevant background due to the beam-gas bremsstrahlung.

The data collected during such special runs at energies E=800, 900, 1000, 1100 MeV are shown in Fig. 6 where the points represent the ratios L_{SABS}/L_{SB} obtained during each run (the runs lasted about 4 hours) and the crosses are the average values over all points at the same energy. The results of Fig. 6 do not show any appreciable energy dependence and the energy-averaged ratio is: $L_{SABS}/L_{SB} = 1.045 \pm 0.005$, where only statistical errors are included. The quoted systematic errors are:

$$(\Delta L/L)_{SABS} = (-5 \div +2)\% \qquad (\Delta L/L)_{SB} = (-1 \div +3.7)\%$$

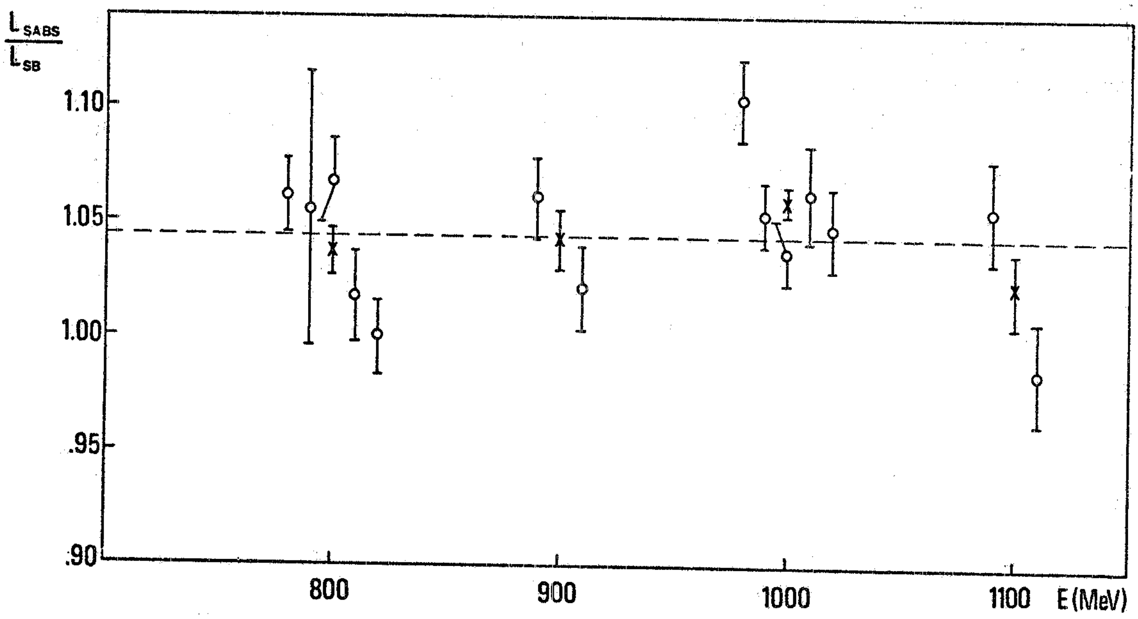

FIG. 6 - Measured values of the ratio L_{SBS}/L_{SB} during each run. The crosses show the average values over all runs at the same energy. The dashed line shows the energy-averaged ratio $L_{SABS}/L_{SB} = 1.045 \pm 0.005$ (only statistical error included).

(x) - The normal condition of operation of Adone were with three electron and three positron bunches, each carrying a current of about 20 mA at E = 1 GeV. Typical values of the residual gas pressure were $1 \div 5\ 10^{-9}$ tor and of the mean life of the bunches were $5 \div 10$ hours.

It should be noted that the SB luminosity monitor is quite insensitive to the machine conditions such as the position of the source, the closed orbit angle at the crossing point and the length of the bunches, which on the contrary originate the main source of errors in the SABS luminosity measurements. Thus in comparing these two measurements one should include a ± 3% systematic error due to the quoted uncertainty on the actual value of the source length.

Since the sources of the uncertainties in the two apparata are not related each other, we can conclude that the SB and the SABS luminosity measurements are in fair agreement within the quoted systematic errors.

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