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A monitoring system to measure the absolute luminosity of a machine operating with $e^{\pm}$, e^{-} colliding beams

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SEZIONE II

(Fisica, chimica, geologia, paleontologia e mineralogia)

Fisica. — *A monitoring system to measure the absolute luminosity of a machine operating with $e^{\pm}$, e^{-} colliding beams.* Nota di GUIDO BARBIELLINI, BRUNO BORGIA, MARCELLO CONVERSI e RINALDO SANTONICO, presentata (*) dal Corrisp. M. CONVERSI.

RIASSUNTO. — Si descrive un dispositivo sperimentale, da installare presso una macchina acceleratrice a fasci collidenti di elettroni ($e^{\pm}, e^{-}$), per misurarne la «luminosità» assoluta utilizzando come «monitor» il processo $e^{\pm} e^{-} \rightarrow e^{\pm} e^{-}$ («scattering» di Bhabha o di Møller). Sulla base di misure eseguite sulle varie parti di cui il dispositivo è composto, si conclude che questo può consentire di determinare con una precisione del 2% circa, la luminosità assoluta (mediata su ~ 1 hr di misura) di una macchina del tipo dell'anello di accumulazione «Adone» in costruzione nei Laboratori Nazionali del CNEN a Frascati (Roma).

1. – For any process produced by two colliding beams, the rate, $\dot{n}$, of the events detected with efficiency η by a given apparatus, can be expressed as [1]

$$\dot{n} = \mathrm{L}\eta\sigma \tag{1}$$

where σ is the cross-section of the process integrated over the solid angle of the detector and L is a parameter, the *luminosity*, which is characteristic of the machine only. For some experiments, such as those requiring the determination of the cross section σ of an unknown process, detected with a known efficiency η, a knowledge of the effective value of L over the duration of the experiment is essential. Such knowledge can be achieved through Eq. (1), by measuring with known efficiency the rate $\dot{n}$ of events due to a "monitoring process" for which the cross section is known without ambiguity.

We describe in this note a monitoring system based on Bhabha or Møller scattering ($e^{\pm} e^{-} \rightarrow e^{\pm} e^{-}$). It has been developed in view of an experimental investigation to be carried out with the Frascati storage ring "Adone" [2], on the reaction $e^{+} e^{-} \rightarrow \mu^{+} \mu^{-}$. Since it is planned [3] to measure the cross section for this reaction, in the GeV region, with an accuracy of ~ 5 %, the monitoring system must have an accuracy in the neighbourhood of 2 % or better. Thus the system (details of which have been reported elsewhere [4] [5]) is of a rather general interest, being accurate and applicable to any machine operating with $e^{\pm}$, e^{-} colliding beams.

(*) Nella seduta del 10 febbraio 1968.

2. – A cross sectional view of the monitoring system is given in fig. 1, which refers to the installation planned for Adone. The source S of the scattering events is a small region [6], near the center O of the special straight section (fig. 1). O is the point where the e^+, e^- beams should ideally meet. The scattered particles (e^+ or e^-) are recorded if they produce any of the four electronic coincidences ($P_1C_1S_1C_3S_3$), ($P_2C_2S_2C_4S_4$), ($P_3C_3S_3C_1S_1$), ($P_4C_4S_4C_2S_2$) among the counters P_i, C_i, S_i, ($i = 1, 2, 3, 4$) described below.

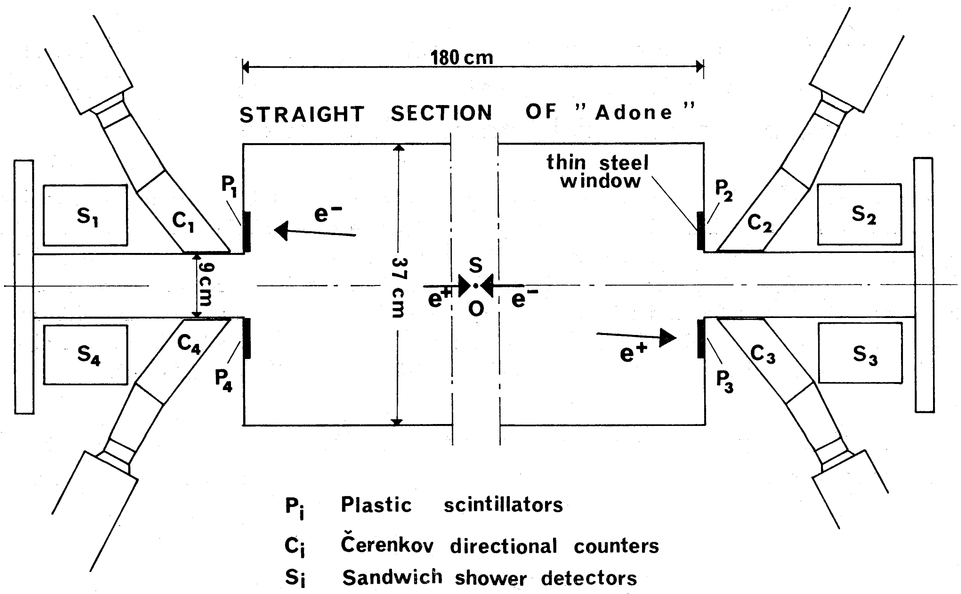

Fig. 1. – Vertical cross-sectional view of the monitoring system, as it will be installed on a special straight section of "Adone", provided with 1 mm steel exit windows, perpendicular to the donough axis. The monitoring events are produced by $e+$, $e-$ scattered at small angle (3,5° to 6,1°) in the interaction regions, S, around the ideal beam intersecting point O.

P_i are plastic scintillators .1 cm thick (3 cm and 9 cm are their other dimensions) used to define the solid angle of acceptance of the scattered particles. The scattering angle has then to be from 3.5° to 6.1°; small enough to insure that the scattering cross section can be described by standard electrodynamics, using unit form factors and unmodified propagators. If the center of the beam intersecting region undergoes a little displacement Δ from the ideal point O, this causes an increase of the flux of scattered particles through a given counter, say P_1, and correspondingly a decrease of the flux through the opposite counter, P_3. Thus, the sum of the counting rates for any pair of coincidences ($P_iC_iS_iC_{i\pm2}S_{i\pm2}$) corresponding to counters on opposite sides of O, turns out to be [4] independent of first order terms in Δ, provided that the solid angle from O to P_i is always covered (as it is apparent from fig. 1) by the counters C , S_i.

3. – The counters C_i and S_i are included in the monitoring system for the purpose of reducing the background counting rate, by rejecting particles coming with wrong directions and/or wrong energy. Counters C_i are directional Čerenkov counters operating as sketched in fig. 2. Their performance

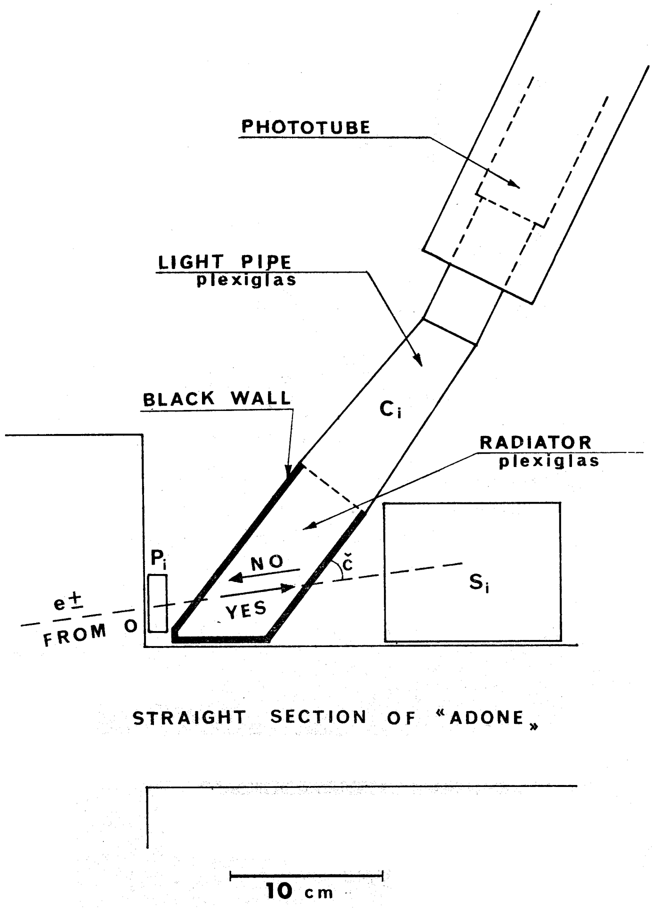

Fig. 2. – Detail of fig. 1 showing the operation of the directional Čerenkov counters C_i. Electrons ($e^{\pm}$) from O, crossing counter P_i produce in the radiator of C_i light (at an angle $\check{c}$) which reaches the phototube (case labeled " YES "). Electrons going in the opposite direction ("NO ") produce Čerenkov light which is absorbed by the black wall of the radiator.

has been tested using a 1 cm × 1 cm " pencil " beam of electrons from the pair spectrometer of the Frascati 1 GeV electron-synchrotron. Curves giving their response to electrons coming from different directions have thus been obtained [5]. One finds in particular, from these curves, that by a suitable choice of the photo-tube voltage, the counters can be made to operate so that both the loss of " good events " ($e^{\pm}$ coming from O) and the recording of " unwanted events " ($e^{\pm}$ travelling in the opposite direction) are less than .5 % (see fig. 3).

Counters S_i (fig. 4) are " sandwiches " made up of .5 cm thick Pb plates, alternated with .3 cm thick scintillator plates. The light from the latter is seen by a single photomultiplier operating at a certain voltage V_s. High energy $e^{\pm}$ from the monitor process produce electromagnetic showers as they

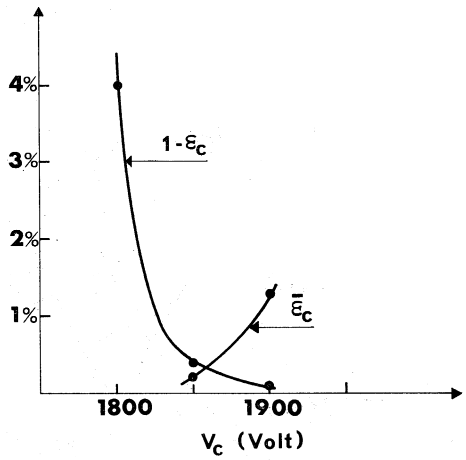

Fig. 3. – Curve " $1 - \varepsilon_c$ " gives, as a function of the phototube voltage, V_c, the percentage loss of electrons coming from O (labeled " YES " in fig. 2) for a given counter C_i. Curve " $\bar{\varepsilon}_c$ " gives similarly the detection efficiency for electrons travelling in the opposite direction (" NO " in fig. 2).

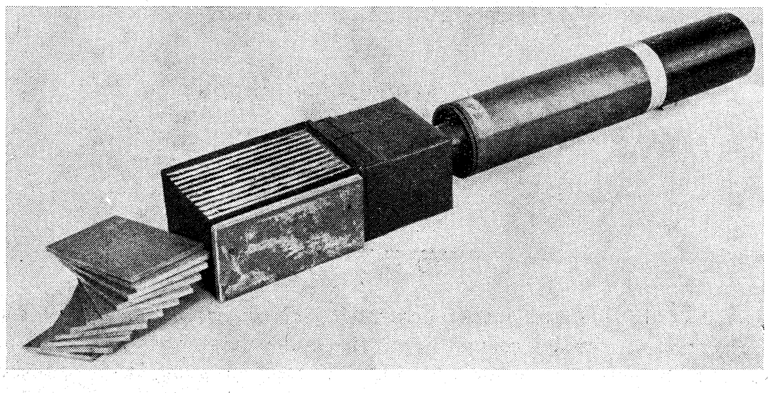

Fig. 4. – Picture of one " sandwich " shower detector, S_i with its phototube. The 11 internal .5 cm thick Pb plates are seen here outside the counter. The first (external) plate—in place in this picture—is 1 cm thick. Thus, a total thickness of nearly 13 radiation lengths is available for shower development from electrons, the energy of which is thereby measured.

penetrate into counters S_i. For a suitable choice of V_s, the phototube yields a pulse whose average amplitude is proportional to the energy of the primary electron. This is seen from the differential amplitude spectra of fig. 5 obtained, with the help of a multichannel pulse-height-analyser, exposing one counter S_i to electrons of the indicated energies. Curves giving the counter efficiency,

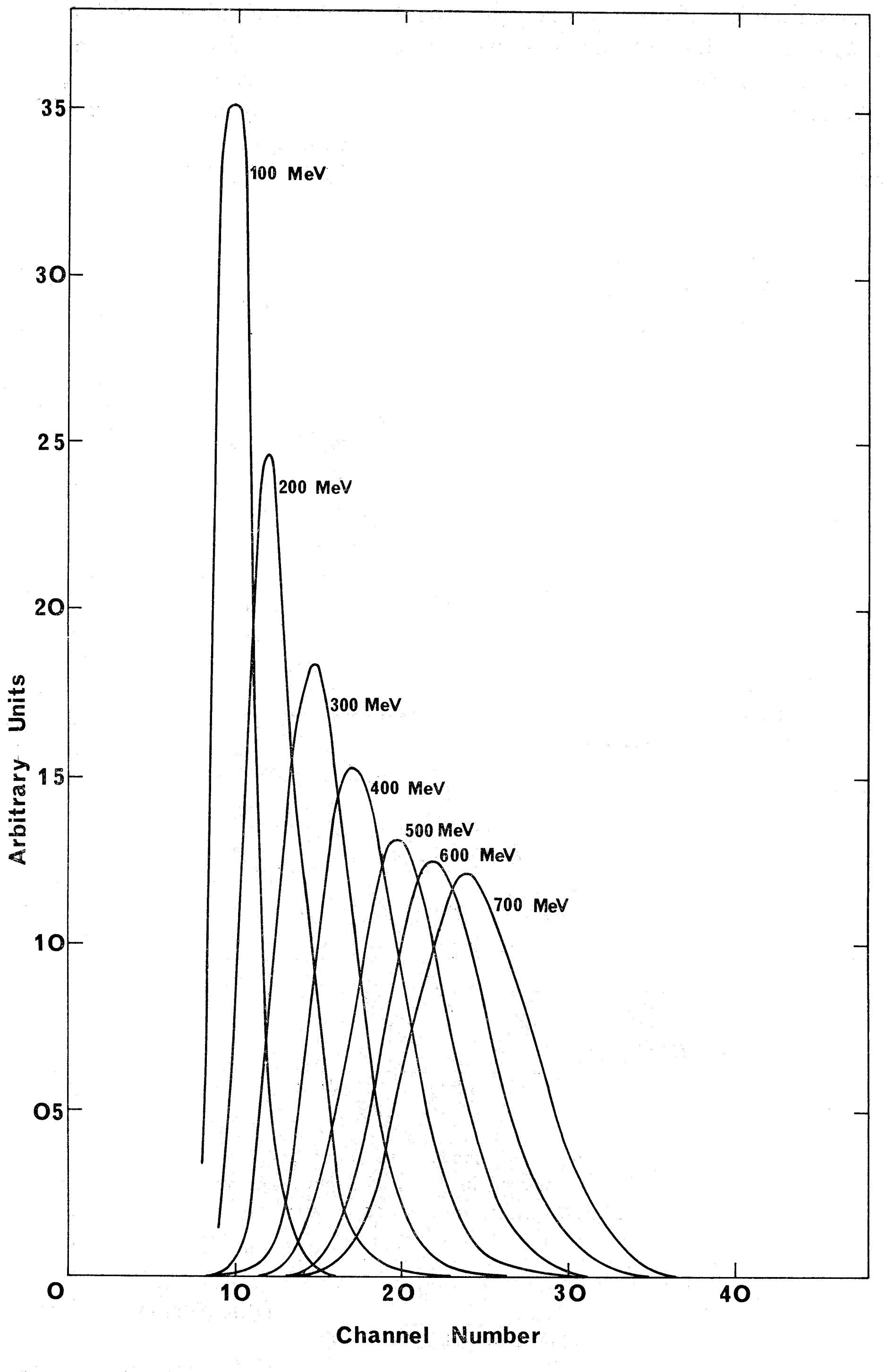

Fig. 5. – Pulse height distributions—normalized to the same area—of one of the shower detectors S_i, for electrons of the indicated energies. The origin of pulse heights (" O–amplitude " pulses) is at channel n. 8 (energy resolution $\sim \pm 25\%$ for 500 MeV electrons).

ε_s, as a function of electron energy, E, have also been obtained, for two values of V_c and for different values of the attenuation imposed on the pulse height, as shown in fig. 6. These curves show, for example, that operating with $V_s = 2050$ Volts and a 4 db attenuation, counter S_i detects 500 MeV $e^{\pm}$ with nearly 100 % efficiency, whereas it rejects 80 % of the 200 MeV $e^{\pm}$ and practically all $e^{\pm}$ of energy smaller than 100 MeV.

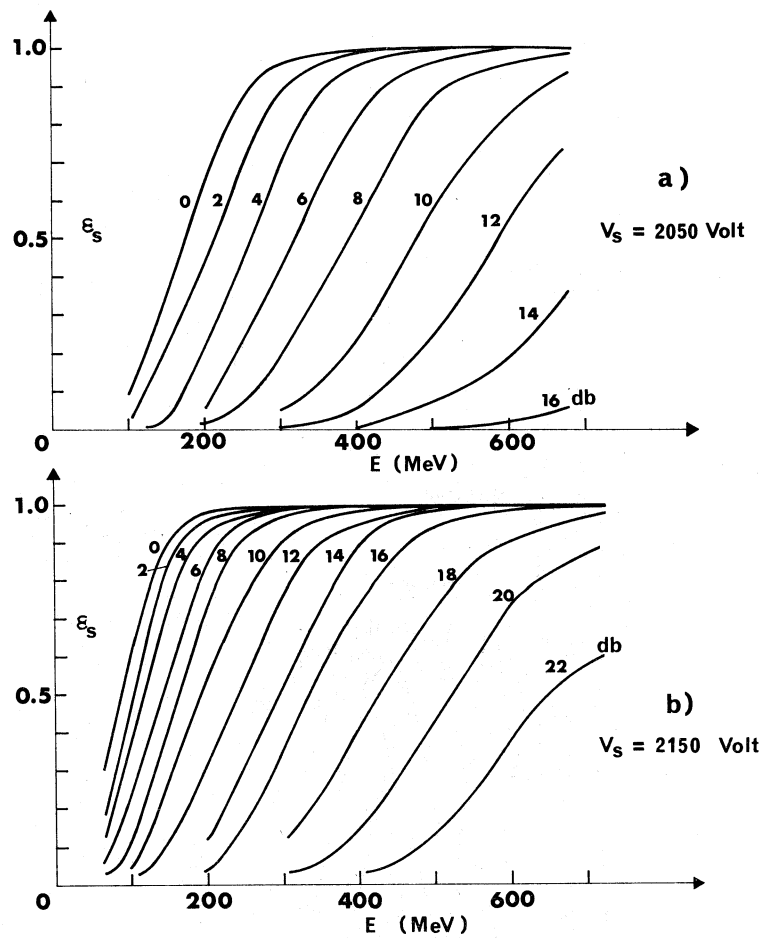

Fig. 6. – Efficiency, ε_s, of one the shower detectors S_i, *vs.* electron energy, for different attenuations (expressed in db) of the pulse height, given by the phototube when operating with: *a*) $V_s = 2050$ Volt; *b*) $V_s = 2150$ Volt.

4. – Combining the results of a rough estimate of the electron background near Adone [7] with those on the rejection power of counters C_i and S_i for electrons coming from wrong directions with a wrong energy, one finds that these should give a negligible contribution (less than 1 %) [5] to the monitor counting rate, $\dot{n}$ [$\dot{n} \sim 3 \cdot 10^{-33}$ L events/sec, from (1), if $\eta \cong 1$ as in our case].

In order to determine edge effects on the 1 mm thick plastic scintillators P_i, one of these counters was cut parallel to its side 3 cm long in two equal halves. These were subsequently joined, without glue, and the pencil beam was sent once through the center of one half and a second time through the center of the two joined halves, i.e. through the cut. From the efficiency in electron detection measured under these two conditions, one can derive the equivalent thickness of " blind material ", which turns out be $< .002$ cm along the scintillator edge [5]. To reduce also geometrical border effects, the edge of each counter P_i is cut according to the pyramid having vertex at O and P_i as a base.

A special support, with high precision mechanical movements, allows one to set counters P_i at the right position on the straight section of Adone, within ± 0.005 cm. This figure corresponds to an error of less than .5 % in the measured luminosity. It represents also the limit of the changes in position which are allowed to occur during the measurements of the luminosity itself.

Since systematic errors are seen to be not in excess of ~ 1 % and since the maximum luminosity of Adone is expected to be [6] $L_a = \sim 10^{33}\ \mathrm{cm}^{-2}\ \mathrm{hr}^{-1}$, we conclude that the instrument described in this note should be capable of measuring L_a with ~ 2 % accuracy in runs lasting ~ 1 hr. This conclusion does not take into account uncertainties due to radiative corrections (1) since these can be evaluated with a great accuracy ($< .1$ %) and presumably are not in excess of 2 %.

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[3] G. BARBIELLINI *et al.*, *Internal report n. 89 of Istituto di Fisica*, University of Rome (1966); G. BORGIA *et al.*, *Proceedings of the International Conference on High Energy Electrons and Photons*, VIIa-4-1 (presented by M. Conversi) (1966).

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[7] C. DEHENE and S. TAZZARI, private communication of unpublished results.

(1) One of us (M.C.) wishes to thank professor R. Gatto for a clarifying discussion on this subject.