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SUGGESTIONS FOR THE LUMINOSITY MEASUREMENT OF THE ISR

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A report on the luminosity measurement was made by C. Rubbia at the ISR Users' Meeting in June 1968 [1].

It is convenient to write the luminosity L in the form

$$L = \frac{J_1 J_2}{e^2 c} \circ \frac{1}{tg\, \alpha/2} \cdot \frac{1}{h} ,$$

where J is the current, e the charge of the electron, α the intersecting angle, and h the effective dimension of the colliding beams in the vertical direction

$$\frac{1}{h} = \frac{\int \rho_1(Z)\ \rho_2(Z)\ dZ}{\int \rho_1(Z)\ dZ \cdot \int \rho_2(Z)\ dZ} .$$

$\rho_1(Z)$ and $\rho_2(Z)$ are functions of the density distribution of the beams in the vertical direction.

The measurement of the luminosity may be done by means of two systems. One system, consisting of rather simple counters, detects some particles from the beam-beam interactions; for example, the neutrons, as suggested by Rubbia.

With the other system we have to make only one measurement of the size of the beams. Simultaneously, we must measure the currents and the repetition rate of the counters. These data make it possible to determine the absolute cross-section of the reactions which are detected by the counters. Such measurements can be made for the different energies, and we then use only these counters for the measurement of the integral of the luminosity.

The most difficult question is that of the measurement of h. Darriulat and Rubbia[2] put forward the interesting proposal to measure h by means of a wire crossing the beams. This method makes it possible to be very precise, but the construction of such a system seems to me to be a difficult technical problem. Rubbia's other idea about the measurement of the beam shape by means of the electrons, created by the beam as a result of the ionization of the residual gas, has not yet been discussed in detail.

After the ISR Users' Meeting, Van der Meer[3] and Steinberger[4] made some suggestions. In Van der Meers' idea there is a principal difficulty, connected with the limited dimensions of the aperture. It means that we cannot measure the tails of the distribution of the beams. Besides, it is possible that the size of the beam changes without control when we displace it.

Steinberger suggested measuring the beam shape by means of the particles from the interactions of the beams with the residual gas. This idea is very interesting because the system is outside the vacuum chamber and the beams are not displaced.

In this note we will examine some suggestions for the use of particles from beam-gas and particles from beam-beam interactions.

1. The first question is that of background. It is clear that in the detector system, besides the useful particles, other particles will cross which are created as a result of interactions with the chamber walls of particles leaving the beam because of its finite lifetime.

To avoid this difficulty, one can make a poor vacuum in the interaction region during the measurement of the beam dimensions. If the mean vacuum in the ring is 10^{-9} Torr and the vacuum in the intersection region is 10^{-11} Torr, we can change the vacuum in the intersection region for a length of about 1 metre up to 10^{-8} Torr. The repetition rate will increase, although the lifetime changes very little. The rates, which were obtained with a good vacuum, can be subtracted as background. If one were to follow this suggestion, it would mean changing the vacuum conditions and having the homogeneity of a vacuum of about 1% in the vertical direction for a length of about 1 cm. E. Fischer believes that this is not a very difficult problem.

2. To check the correctness of the beam density measurements for $\rho_1(Z)$ and $\rho_2(Z)$, we can measure the density distribution of the beam-beam interactions $\rho_{bb}(Z)$ simultaneously by means of this detector system. If the measurements are correct, it must be

$$\rho_{bb}(Z) \sim \rho_1(Z) \cdot \rho_2(Z) .$$

Estimates show that the accidental coincidences for $\rho_{bb}(Z)$ at the vacuum of 10^{-8} Torr are unsubstantial.

I should like to say that if one believes that the forms of the beams are identical and that the axes of the beams are in one plane, it is enough to measure only the density of the beam-beam interactions

$$\rho_{bb}(Z) .$$

3. The demand for space resolution of the detector system can be fulfilled by the following method. We shall designate the r.m.s. dimensions of the beams in the Z-direction as S_1 and S_2, and the r.m.s. error of the determination of the point of the created particle as σ_{db}. The error of the determination of the beam dimension is

$$\sigma_s = \sigma_{db}/\sqrt{2} .$$

The effective height of the colliding beams depends on the distribution forms $\rho_1(Z)$ and $\rho_2(Z)$. In the case of the Gaussian, $h = 2\sqrt{\pi}\ \sqrt{S_1^2 + S_2^2}$. If $S_1 = S_2 = S$, the relative r.m.s. error of h is

$$\delta_h = \frac{\sigma_h}{h} = \frac{1}{2}\frac{\sigma_{db}}{S} .$$

The real shape of the beams is known only roughly. The measurements of the beam dimension in the PS[5)] showed that the distribution is approximately Gaussian and $S \approx 3$ mm. If one can maintain the beam dimensions in the channel between the PS and the ISR, the beam dimensions will be the same as in the PS after the injection, and then the multiple scattering will slowly increase the dimensions [by approximately a factor of $\sqrt{2}$ for 12 hours[6)]].

To be on the safe side, we shall assume S = 3 mm. In this case, for δ_h = 2% one needs σ_{db} = 0.12 mm. Still, it should be noted that we can obtain the function of the distribution of σ_{bd}. Taking into account this function and also that the real dimensions of the beams will apparently be bigger than S = 3 mm, we can hope to bring the error down to δ_h = 1% with this space resolution.

The accuracy of the measurement of 0.1 mm can be obtained with wire spark chambers[7)]. To increase the precision, we can put in a few such chambers; the multiple scattering conditions make this possible.

4. We shall now consider the multiple scattering in the walls of the vacuum chamber. The error of the determination of the point of the particle creation depends on the design of the vacuum chamber and on the momentum of the detected particles.

In the case of the cylindrical chamber, the r.m.s. error of the determination of the Z-coordinate of the point of the particle creation is

$$\sigma_{ms} = \frac{d}{2} \frac{1}{\Theta^{3/2}} \frac{15}{(pc)_{MeV}} \sqrt{\frac{\Delta t}{X_0}} ,$$

where d is the chamber diameter, $\Delta t/X_0$ is the chamber thickness in radiation lengths, Θ is the angle between the chamber axis and the momentum of the particle.

For d = 5 cm, Δt = 0.1 mm of steel, Θ = 120 mrad, p = 10 GeV/c:

$$\sigma_{ms} = 0.07 \text{ mm} .$$

For an experiment on the measurement of beam dimensions, one can design a special vacuum chamber with the walls perpendicular to the direction of the particles which are detected.

5. The repetition rate depends substantially on the detector system. We shall examine roughly the two possible variants of detector systems. The first variant is when we use the standard vacuum chamber in the tube form of diameter d = 5 cm and Δt = 0.1 mm. For the second variant, the vacuum chamber is specially designed with the walls perpendicular to the momentum of the particles which are detected.

a) The first variant is shown in Fig. 1: CH are wire spark chambers for the measurement of the Z-coordinate, SI are scintillation counters, M are magnets.

The scintillation counters SII are used to measure the distribution $\rho_{bb}(Z)$. These counters surround the beam with $\Theta \approx 100$ mrad. The left (right) telescope of these counters SII is connected in coincidence with the right (left) telescope SI.

Magnets M are used to detect the particles p > 10 GeV/c. For this purpose, one needs the magnet with a gap of about 5 cm and horizontal aperture of about 25 cm. For a field of 15 kG, the length of the magnet is about 3 m.

In principle, the left part of the detector system does not need to be between the beams; it can be put at the right side of the outgoing beam.

The estimate of the repetition rate can be calculated roughly, based on the calculations of the thermodynamical model; these were used by Anderson and Daum[8]) for the background estimates.

The demand of the space resolution of σ_{db} = 0.12 mm leads to the region of the angle $\Delta\varphi \approx \pm \sigma_{db}/d$.

For the conditions of $p > 10$ GeV/c, Θ = 100–140 mrad, $2\Delta\varphi = 1/250$, and a vacuum of 10^{-8} Torr, the repetition rate is of the order

$$R_{bg} \approx 10 \text{ sec}^{-1} .$$

The repetition rate for the measurements of $\rho_{bb}(Z)$, also based on the thermodynamical model[8]), is of the order

$$R_{bb} \approx 0.2 \text{ sec}^{-1} .$$

b) Figure 2 shows the second variant of the experiment, where we use a special vacuum chamber with the walls perpendicular to the momentum of the detected particles.

The range of the angles is Θ = 15–25 mrad, $2\Delta\varphi = 1/250$. The vacuum chamber flange has dimensions of about 5 × 5 cm and can be covered with very thin foil (for example, 0.05 mm Ti), so that we can detect the particles with $p > 3$ GeV/c.

The aperture of the magnet is about 5 × 15 cm; for H = 15 kG, the length of the magnet is about 1.5 m.

The repetition rate for the vacuum of 10^{-8} Torr is of the order

$$R_{bg} \approx 10^{2} \text{ sec}^{-1} .$$

For the measurement of $\rho_{bb}(Z)$, in this case it is very interesting to use the elastic scattering of the protons. On the basis of Di Lella's report[9]), the repetition rate of this detector system will be

$$R_{bb} = 5 \text{ sec}^{-1} .$$

It should be noted that the measurement of the coordinates of both protons makes it possible first, to increase the precision of the measurement of the scattering point of the protons by $\sqrt{2}$ times and, secondly, to measure the function of the errors σ_{db} of the detector system as the protons go out from one point. Thus it seems that both variants make it possible to obtain the measurement precision of the effective dimension of h to about 1%. The second variant is more interesting, as the repetition rate is higher and the measurement precision is better.

It should be noted that evidently it is sensible to enlarge the system so as to measure the interaction region in both the azimuthal and the radial directions. For this we must detect the reactions with two non-collinear particles and measure both coordinates. Still, the demands for the precise measurement of these coordinates are substantially lower than for the vertical coordinate.

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Figure captions

Fig. 1 : Experimental arrangement for the vacuum chamber of diameter 5 cm and wall thickness 0.1 mm: CH are the wire spark chambers, SI and SII are scintillation counters, M are the magnets.

Fig. 2 : Experimental arrangement for the special vacuum chamber: CH are the wire spark chambers, S are the scintillation counters, M are the magnets.

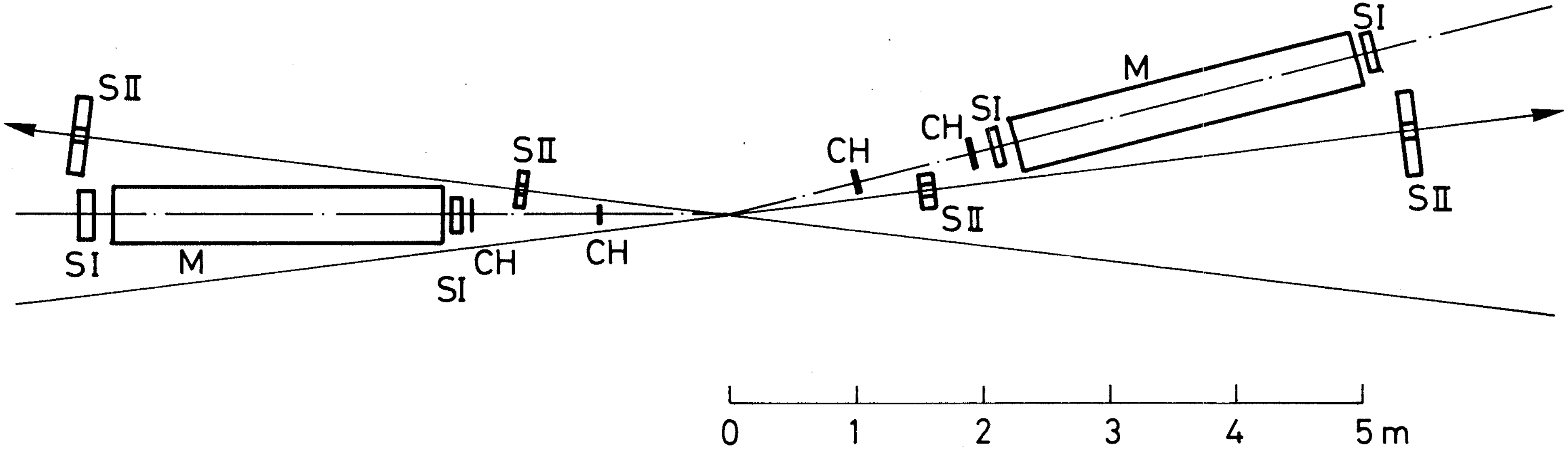

FIG. 1

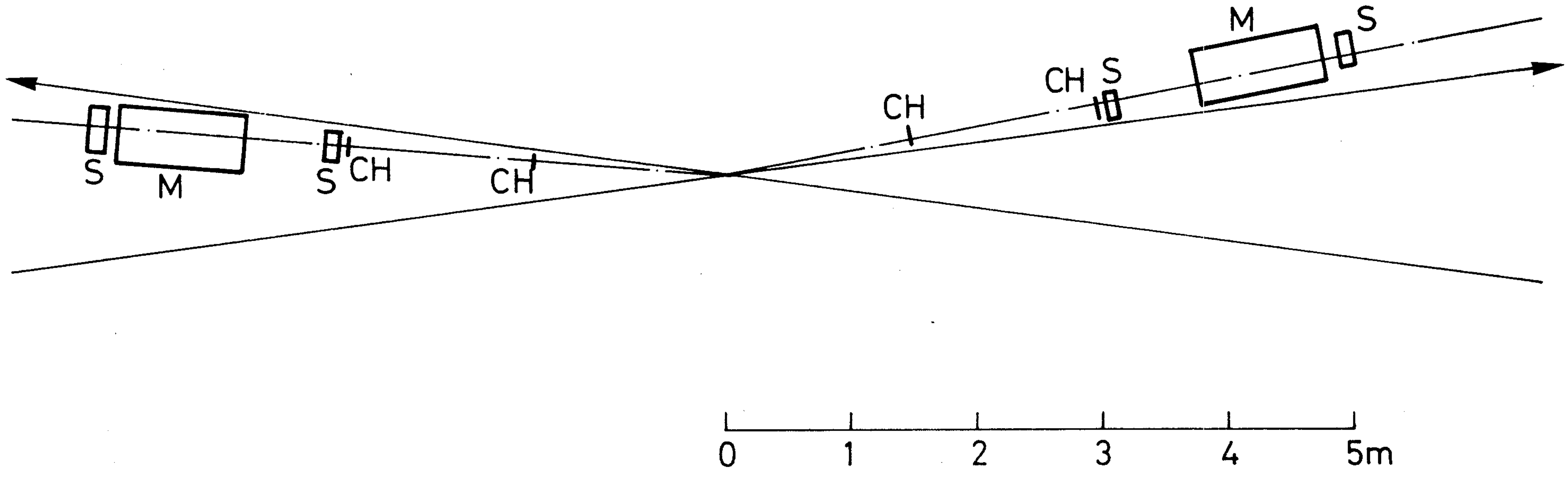

FIG. 2