national accelerator laboratory

FN-176
0106

MEASUREMENTS OF LUMINOSITY

Richard Wilson - Harvard University

December 1968

One of the important features of any experiment is the absolute normalization of the cross section. In this memo we discuss ways of doing this. We start by discussing the normalization procedures used at electron-positron storage rings, although they are mostly not available for proton-proton rings.

Four methods have been tried of which the first three have been used:

(i) small-angle electron-positron or electron-electron scattering

(ii) large-angle electron-positron scattering

(iii) double bremsstrahlung from e^+e^- or e^-e^- collisions

(iv) single bremsstrahlung.

Method (i) has been used at Novosibirsk on both WEP I and WEP II. A coincidence-counter arrangement can easily be placed to pick up the small angle particles. The only problem is the $1/\theta^4$ dependence of the cross section, which means that counters have to be precisely located.

For protons this method also works <u>in principle</u>. But the angles involved must be less than the Coulomb interference minimum and, at the energies that concern us, these are

smaller than the angular divergence of the beam. In a high-β straight section, this method might possibly be used, especially if the beam angular divergence is reduced.

Method (ii). At both Novosibirsk and Orsay, large-angle Bhaba scattering has been used as a monitor. This assumes QED; for protons, large-angle scattering is entirely nuclear in origin.

Method (iii). Double bremsstrahlung is used at Stanford and Orsay. The calculations (Altarelli et al) are straightforward but tedious. PP bremsstrahlung, in contrast, has a different source. Electrons and positrons radiate because they are accelerated by the known electrodynamic forces. Protons radiate because they are accelerated by the nuclear forces. In fact PP bremsstrahlung is proportional to PP elastic scattering.

Method (iv). Single bremsstrahlung can be separated from bremsstrahlung in the residual gas at storage rings with low β (and high luminosity). It is planned to use this at CEA by counting the photons at low luminosity and by integrating them (and putting the results on a "luminosity meter") at high luminosity.

None of these methods works for protons. I discuss here the possibilities of evaluating the luminosity directly from the formula for beams intersecting at an angle (say it is vertical)

$$L \propto N_1 N_2 \frac{\sin \alpha}{h} .$$

Here α is the angle of intersection of the beams and h their

average height.

We discuss first why this has not been used for electrons. For electrons there is a strong damping due to synchrotron radiation giving a characteristic damping time of 1/10 sec to 1 nsec. A measurement of h often takes some time; it may not be relevant to measurement of beam interactions due to this damping. Moreover, N_1 and N_2 have decayed quite fast.

Also, the electron storage rings operate at the beam-beam interaction limit and h and w change due to the interactions. We don't expect this with the proton-proton ring.

With protons, there is no such damping and we can reasonably expect a measurement of h to stay constant. We can also measure h in a different interaction region and assume we know the β function very well. However, there is one problem. Since we have no rf there is likely to be no definite structure in time of the current. The ordinary total current and position monitor at acceleration depend upon a repeated zero of the signal to work; this enables ac circuitry to be used.

Total current monitors for measuring dc currents <u>are</u> possible. They are, in fact, now used instead of shunts for measuring or stabilizing dc currents. Currents of 100 mA are now regularly measured. I suggest a balancing procedure here; a toroidal core concentrates the dc magnetic flux from the current; a wire puts a dc current to cancel it; and a null measuring device is used in a gap in the toroid. See Figure 1.

This then leaves the measurement of the effective height

of the beam h. If indeed there is no rf structure left, we must again make a dc measurement.

Darriulat and Rubbia have suggested shooting a thin wire through the interaction region and measuring the counts therefrom, both of particles scattered from each beam and coincidence counts. They find

$$h \propto \frac{N_1 \quad N_2}{N_{coincidence}} ,$$

independent of whether or not rf structure exists. It seems that this idea, which has mechanical complications, will be tested at CERN. However, in this note, I will list some other possible procedures in case this does not work or is too tedious.

As noted above, we expect h to either stay constant or increase; there is no damping mechanism. Therefore, we can, unlike the case with electron beams, measure over a period of time and expect the answer to be useful.

We will measure the vertical distribution for each beam. Then the average heights h_1 and h_2 can be determined and the effective interaction height computed by integration.

The distribution can be measured by (i) scattering from residual gas or a molecular beam. The scattered particles can be detected in many ways. At CERN, it has been proposed to collect the ions on a set of secondary emitting electrodes. This should give a measure in a few seconds. We could measure scattered particles in a spark-chamber telescope. The information would come more slowly, but it might be useful to have

an integration over the measurement time. (ii) we can envisage complicated pick-up and position monitors. For ac purposes, all accelerators now use these. The technology would have to be extended for our use. Firstly a quadrupole coil to measure beam sizes has not yet been successfully used. Secondly, the dc measurements necessary would restrict the range of the measurements. If spurious electrical pick-up is not present (an unlikely hope) it should be possible to use dc integrators, to set them to zero before each run (with no current in the ring) and have them read the total current N, and the various positional moments $\langle x \rangle$ $\langle x^2 \rangle$ etc. They could be checked at some later points in the run. A rough calculation suggests that this might be possible down to 5 amps current in the rings.

The formula for luminosity fails if there remains any bunching of the beam. AC current monitors can easily pick up this bunching and provide accurate information to correct the other signals.

I believe that the set of monitors discussed here will be useful for beam-diagnostic purposes and should be developed quite apart from their importance for experiments. However, I see no major problem in getting the precision required.

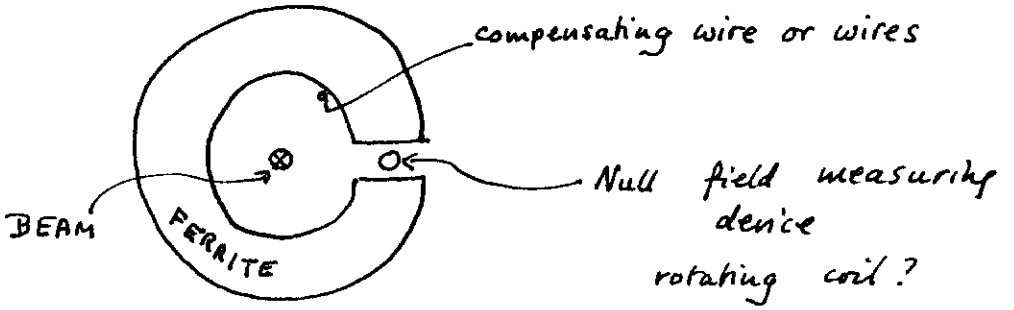
I envisage that a set of measurements at different energies could be made to calibrate a secondary monitor. (1 BeV π at 90°, for example).

I personally believe that one of the most important features of a storage ring is to explore Asymptopia; how do

cross sections go as $E \to \infty$? In any case, it represents a severe demand on luminsoity monitoring and probably the most severe demand. We can check our monitoring procedure at a center-of-mass energy given by $E = \sqrt{2 \times M \times 200 \text{ BeV}} = 20$ BeV. (If the rings can work this low.) Then all the procedures can be verified. We want to know, to an accuracy of 1%, how our measurements go as a function of energy.

The electromagnetic measurements discussed above should be independent of energy. Errors will arise from amplifier calibrations, positional errors, and other matters independent of energy. One possibility is that of the residual bunching varying with energy, which should be unimportant if it is small.

Thus, even if we fail to verify the procedures absolutely to 1%, the relative measurements may still be adequate for all our experiments.



Method of Measuring total Current.

FIGURE 1.