TOTAL CROSS SECTIONS AND ELASTIC SCATTERING AT THE SSC

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An important special purpose detector is needed for the measurement of elastic scattering at the SSC. Indeed it is the antithesis of the generic 4π detector, covering a very small solid angle, as close to 0° as is practical! However, total cross sections and elastic scattering cross sections are very basic quantities that should be measured at every new energy regime -- for example, a measurement of the real part of the scattering amplitude provides a "Crystal-Ball" to even higher energies via the forward dispersion relations. Since the appropriate intersection region is very different from the standard I feel that it requires careful attention as the machine design proceeds.

Elastic Scattering

The measurement of elastic scattering was considered in great detail at the Snowmass Workshop in 1984, and I will draw very heavily on information reported[1-3] in the proceedings.

The basic problem is alluded to above -- the need to measure at very small scattering angles. Consider the very low values of four-momentum transfer, $(-t)^{1/2}$, required to measure Coulomb-nuclear interference in order to deduce the value of the real amplitude; the nuclear and Coulomb cross sections are equal at about $|t| = .0004\ \mathrm{GeV}^2$ which corresponds to ≈ 1 μrad at 20 TeV; since

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the standard intersection has a beam divergence of ≈ 7 μrad it is clear that special conditions are required: very high β^* at the IR, followed by a focussing system to transform scattering angle into spatial displacement. A very simple (though not practical) scheme is shown in Fig. 1. Here scattering in the IR region shows up as spatial deviations in the focal plane of size ≈ $f\theta$. In general the displacement from the beam in an accelerator can be calculated from the "effective distance", L_{eff}, between the interaction point and the detector, by the relations:

$$\text{displacement} = L_{eff} \times \text{scattering angle} \tag{1}$$

$$L_{eff} = (\beta^* \beta_{det})^{1/2} \sin\psi \tag{2}$$

where ψ is the betatron phase advance. Clearly one should maximize $|\sin\psi|$. The system in Fig. 1 has $\sin\psi = 1$ and small β_{det}. Note that since the beam size at the detector is proportional to $(\beta_{det})^{1/2}$, the displacement in standard deviations is independent of β_{det}. Two possible scenarios each with $\beta_{det} = \beta^* \approx 4$ Km were presented by R. Siemann[3] at Snowmass. With these parameters the angular spread at the IR is ~ 0.1 μrad and particles scattered by 1 μrad are separated from the beam at the detectors by about 4 mm or about ten standard deviations. Each had a total length of about 4Km. While these designs are by no means optimized, it is clear that this IR will be markedly non-standard.

Another possible solution was suggested at Snowmass by L. Jones (reported in Ref. 2) who noted that phase advance around the entire ring gives $\sin\psi \approx -1$, so one can conceive of placing the detectors alongside the IR, using each ring as a 90Km focussing spectrometer with the small angle detectors at 90° to the IR!! This interesting suggestion also raises a very serious question about the ultimate limit to measurements of small angle scattering; if the scattered particle remains in the dynamic aperture of the main ring it will, of course, make multiple turns unless a thick absorber is introduced in its path. If the phase advance around the entire ring is $2\pi \times 97.76$ radians,[2] then on successive turns we have $\sin\psi = -0.96, 0.52, 0.68, -0.89$, etc. effectively mapping out most of the detector! One should note that this background is different from normal "halo" in that there are coincident particles in the two beams which completely mimic elastic scattering. These effects could cause trouble even if they occur at a rate of a few Hz, a real challenge for the designers of beam scrapers. I suggest that this problem be considered as part of the SSC design.

With the parameters described above, i.e. $\beta^* = \beta_{det} \approx 4$Km, beam spot at the detectors is ~ 0.4 mm, so a detector resolution of 100 to 200 μm will suffice. Many detectors meet this specification, so the choice will depend on practical questions, such as "is the detector inside the machine vacuum or in 'Roman Pots' at atmospheric pressure"; obviously because of their proximity to the beam, radiation hard devices should be chosen.

Assuming an elastic scattering cross section of 40 mb, an exponential slope of 20 GeV^{-2} and a coverage of $\Delta\phi/\phi \approx 10\%$, the useable cross section for $|t| <$ .04 GeV^2 is ≈ 1 mb. For a good measure of the real amplitude one would like ≈ 1% statistical errors in each of 20 bins for $|t| < .04\ \mathrm{GeV}^2$, or a total of ~ 2×10^5 events. At a luminosity of $10^{28}\ \mathrm{cm}^{-2}\mathrm{sec}^{-1}$ this would take about one day, clearly an adequate rate. In fact, should beam halo cause high rates in the detectors the beam intensity could be reduced even further without ruining the experiment. However, the luminosity must be well-determined.

Based on experience at the CERN $\bar{p}p$ collider[4-5] it is possible to estimate the trigger rate and the requirements of the data acquisition system. With a coincidence of two roughly co-linear particles the UA1 experiment[4] found that ~ 20% of the triggers had the correct topology and most of those were elastic scatterings; with a similar trigger the UA4 experiment[5] found that ~ 40% were of the correct topology. If the beams are halo-free one can perhaps expect trigger rates of a few hundred Hz at the SSC. Since the detectors are very simple point-measuring devices, even when one allows for redundancy in the measurement, an event size of a few hundred bytes is reasonable. This gives 10^4-10^5 bytes/second. Since one needs a good absolute measurement, one must minimize accidental coincidences by reducing the beam intensity until clean event selection is possible.

In summary, the detector trigger and data collection needs of this experiment can be satisfied easily with today's technology. Similarly the computing needs are small (< 1 VAX 780). On the other hand the demands on the machine are such that this experiment must be considered with every iteration of the machine design or perhaps it will not be possible!

With regard to larger $|t|$ it was suggested by Orear[2] that the t-range be varied for fixed detectors by manipulating the values of β^* and β_{det} -- see Equations 1 and 2. He showed that in this way one can cover out to $|t| \approx 16$ GeV^2 with $\beta^* = \beta_{det} \approx 100$ m.

Total Cross Sections

Two techniques have been used at hadron storage rings to measure total cross sections.[4-6] The direct method is to measure the interaction rate in an IR of known luminosity. This is a very tricky measurement whose difficulty increases with increasing energy since it is more difficult to detect events where the produced particles stay in the beam pipe. Since a very comprehensive 4π detector is needed, I do not believe that one can justify a dedicated setup; rather, one might consider the approach of the UA4 experiment[6] at the CERN $\bar{p}p$ collider that used large parts of the UA2 detector, adding special detectors at small angles to reduce the correction in extrapolating to full 4π coverage. These experiments basically measure the inelastic cross section and measurements of elastic scattering are needed to obtain a total cross section. The trigger requirements are simple, record every interaction. The data collection problems are related to those for the generic 4π detector, but scaled down by at least a factor of 10^5, since these measurements are best made at low luminosity.

A second method is to use the optical theorem which relate the total cross section to the imaginary part of the elastic scattering amplitude.[4-5] Here one has to assume spin independence of the forward scattering amplitude and must measure or calculate the real part of the forward scattering amplitude. The experiment, however, is simpler.

In principle one needs to know the luminosity very well, but a combination of the two above measurements in the same apparatus at the same time can be used to eliminate the need for absolute luminosity measurements although one must still assume spin independence. This technique has been used recently at the CERN $\bar{p}p$ collider.[6]

References

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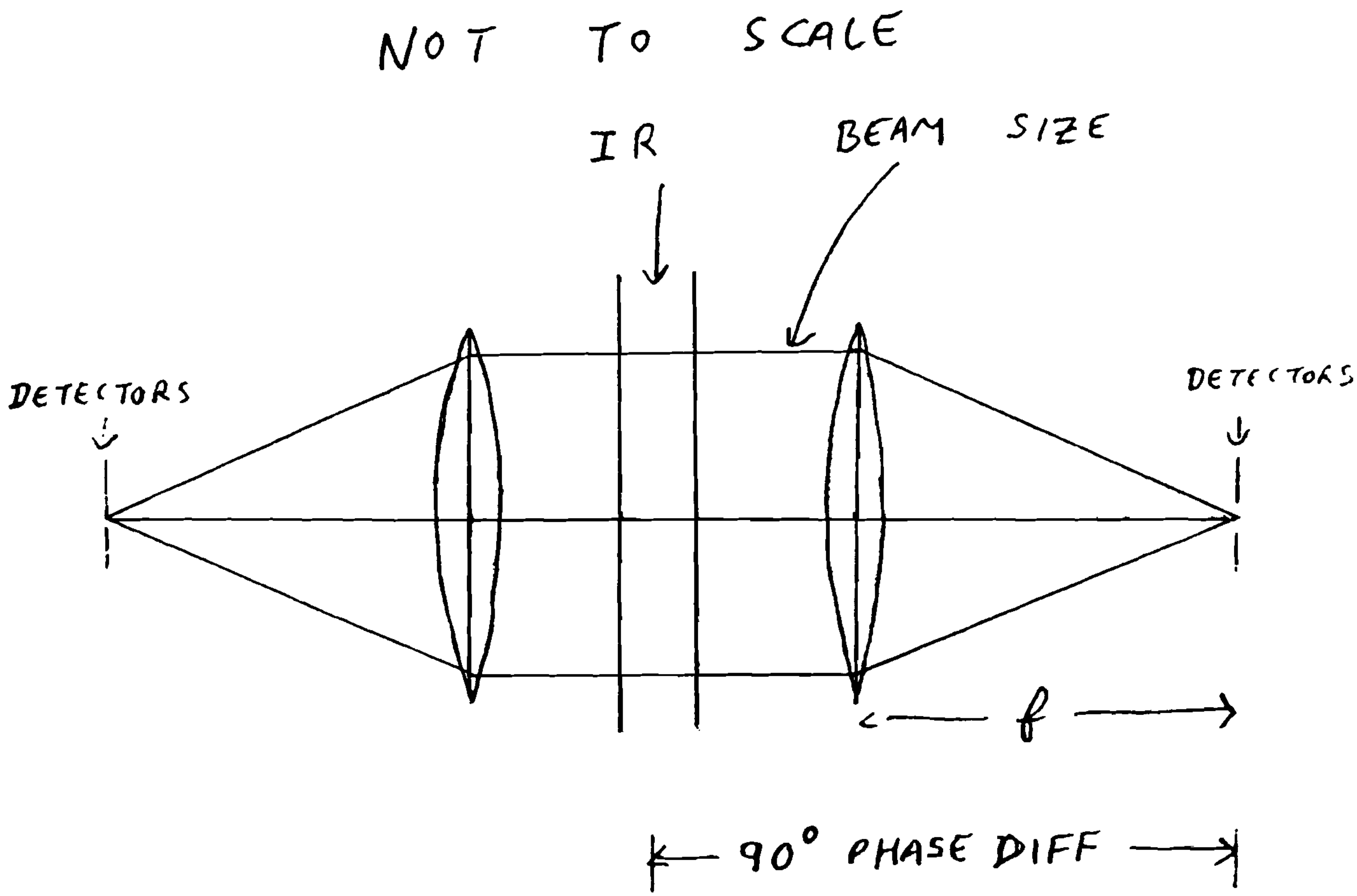

Figure 1
A Simplistic Illustration of the Principle