PEP-143

PRECISE MEASUREMENT OF THE TOTAL CROSS SECTION

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This note will analyze the problems involved in making a precise measurement of the total cross section for e^+e^- annihilation into hadrons. Based on this analysis, we will suggest that a relatively simple non-magnetic device employing calorimetry over a 4π solid angle is the optimum apparatus for such a measurement. We will describe one such device in some detail.

I. Why Bother?

We are interested in a measurement of the total cross section to the level of 1 to 2%. The determination of the total cross section as a function of energy is one of the most fundamental measurements of elementary particle physics. It is certainly as fundamental as the measurement of total hadron-hadron cross sections, for which experiments have sought even higher accuracy. In the PEP energy region, the cross section will undoubtedly have some simple energy dependence. The determination of that dependence and the search for deviations from it will be extremely interesting.

II. What are the Problems?

The SPEAR magnetic detector was designed to be a general purpose detector, which, as one of its main objectives, would measure the total cross section. Experience has shown that it is incapable of making this measurement to an accuracy of better than about 15%. There are two reasons for this. First, the SPEAR magnetic detector has a biased trigger. It requires two charged particles with momenta greater than about 200 MeV/c to be produced in a region which is 65% of the solid angle. In order to calculate the efficiency of such a trigger, one must model the final state. This modeling introduces a possible systematic error of the order of 10%. To avoid this problem, one must have an apparatus which covers the entire solid angle and is sensitive to <u>every</u> hadronic event.

In this regard, it is important not to ignore completely neutral final states. At low energies, these states have been ignored because the prime candidate

$$e^+e^- \to n\pi^0 + m\eta \qquad (1)$$

is forbidden by C conservation. There are, however, completely neutral states which are allowed. For example,

$$e^+e^- \to n\bar{n} + n\pi^0 \qquad (2)$$

$$e^+e^- \to K_L^0\, \underset{\hookrightarrow 2\pi^0}{K_S^0} + n\pi^0 \qquad (3)$$

$$e^+e^- \to \underset{\hookrightarrow \pi^0\gamma}{\omega} + n\pi^0 \qquad (4)$$

$$e^+e^- \to \gamma + n\pi^0 \qquad (5)$$

At $\sqrt{s} = 4.8$ GeV, reactions (2) and (3) alone are estimated to contribute 1%. At PEP energies these reactions could contribute from 2 to 5% of the total cross section and must be included if we are to achieve the desired precision.

The second problem encountered by the SPEAR magnetic detector is the separation of signal from background. Although for most events the separation is clear, there is confusion as to whether an event is an e^+e^- annihilation into hadrons on about the 10% level.

Table I gives a list of backgrounds and the characteristics by which they may be separated. A careful consideration of this table reveals that the most important charcteristic of a device which discriminates against backgrounds is that it measures the total energy of each event. The only backgrounds not eliminated by the total energy criterion are the leptonic processes $e^+e^- \to e^+e^-$ and $e^+e^- \to \gamma\gamma$. These processes must be eliminated by their unique signature.

TABLE I

Background	Can it be separated by Total energy	Timing	Background runs	Vertex position	Special topology	Electro-magnetic shower	Lack of e-m or hadronic shower
Cosmic rays	yes	yes	yes	yes[1]	yes[2]	no	yes[2]
Beam-gas	yes	no	yes[3]	yes[1]	no	no	no
$e^+e^- \rightarrow e^+e^- + X$	yes[4]	no	no	no	no	no	no
$e^+e^- \rightarrow \mu^+\mu^-$	yes[5]	no	no	no	yes	no	yes
$e^+e^- \rightarrow \gamma\gamma$	no	no	no	no	yes	yes	no
$e^+e^- \rightarrow e^+e^-$	no	no	no	no	yes	yes	no

Footnotes:

1. Vertex position is not useful when backgrounds simulate all neutral events.
2. In general cosmic rays appear as a single muon, but the flux is high and occasional showers are bothersome.
3. Background runs for beam-gas contamination are not entirely satisfactory. Non-colliding beams are inherently different than colliding beams due to beam-beam effects on beam size. Normalization of background runs is also a difficult problem.
4. A small fraction of these events will double-tag, leaving all of their energy in the detector. These events, however, have a special topology which resembles Bhabha scattering.
5. Muons will escape from a calorimeter of reasonable dimensions.

A device which has 100% trigger efficiency, measures the total energy, and does not relinquish any of the other methods of background separation would seem to be the optimum device to measure the total cross section.

III. Calorimetry will work

A non-magnetic 4π hadron calorimeter with tracking before and interspersed among the absorbers will meet the requirements of the previous section. In contrast to electromagnetic calorimetry, hadron calorimetry is not easy. There are losses due to escaping muons and neutrinos, stopping muons, saturating heavy fragments, and nuclear break-up. However, the energy resolution needed by this device is not great and the measurements and calculations of Engler et al.[1] indicate that a calorimeter will work in the PEP energy range. The design we describe below should give rms resolutions of 16% at 10 GeV and 10% at 30 GeV. Since we are interested in differentiating between the full energy and about half the energy (i.e., the maximum energy a beam-gas event could deposit), we have about 3 standard deviations at 10 GeV and about 5 standard deviations at 30 GeV.

The measurements and calculations of Engler et al. are for a single incident high energy hadron. A natural question is whether these results also apply to this case in which there are many incident lower energy hadrons. We have concluded that they do, and that, if anything, the resolution should be better in this case. When a high energy hadron enters a calorimeter it interacts creating several low energy charged particles, several π^0's, and one or two high energy particles which interact further downstream. Most of the energy deposition is from ionization loss of the low energy particles and from electromagnetic showers initiated by π^0 decay. The resolution is limited by fluctuations in the hadronic cascade. The situation is identical in e^+e^- annihilation except that the first interaction occurs in a well defined place. This allows us to remove the fluctuations associated with this interaction and, in so doing, possibly increase the resolution. We can measure the charged multiplicity and the fraction of energy going into π^o's, and make corrections based on this information.

IV. Other Physics

In addition to measuring the total cross section precisely, this device will provide precise measurements of the charged multiplicity, the topological cross sections, and the division of energy into electromagnetic and hadronic particles (i.e. π^o's, η's vs. charged π's and K's). It will also measure some of the gross structure of the final states. It can, for example, look for jet structure. It will measure neutral multiplicities with somewhat less precision. It might also be used to search for states which lose energy through neutrino production such as heavy leptons.

V . Design

In this section we outline the design of a simple non-magnetic iron-liquid-scintillator calorimeter. In practice, one might wish to construct a more sophisticated device which is capable of more detailed measurements, but such a device would be considerably more complex and unless one is careful, might even compromise the measurement of the total cross section. In any case, our aim here is only to describe the simplest device which will serve the purpose.

The detector consists of a series of drift chambers around the beam-pipe, surrounded by a total energy calorimeter capable of measuring the energy deposited by charged and neutral particles. The calorimeter is a group of twelve iron-scintillator sandwich total-absorption counters, viewed by 5" photomultiplier tubes. In order to measure the correlation between energy deposition and particle direction, a series of large drift chambers is inserted in the total-absorption detector. The detector is schematically indicated in Fig. 1.

We have considered the use of Fe-liquid Argon ionization chambers as the calorimeter, but have rejected them because of the problem of achieving 4π geometry while inserting tracking chambers, caused by the necessity of having a large dewar around each counter.

The overall size of the detector is fixed by the requirement that it contain hadronic showers initiated by 10-15 GeV incident particles. The configuration chosen presents at least 1 meter of iron in all directions, which is sufficient to contain all but a few percent of the energy in such showers. In order to minimize sampling fluctuations for low energy showers we have used 1.5 cm thick iron plates coated with teflon and separated by 1 cm of liquid scintillator. Each of the twelve calorimeter sections consists, therefore, of 67 iron plates, and has a total thickness of 1.67 m. Measurements and Monte Carlo calculations of Engler, et al.[1] indicate that the fluctuations in the hadronic cascade in such a configuration should dominate the energy resolution, producing an rms resolution of ~ 10% for a 30 GeV shower. The statistics of the scintillation light and light collection process contribute only a few percent to the energy resolution of the calorimeter. Light collection is accomplished through lucite light pipes coupled to 5" photomultiplier tubes, a scintillator area of ~ 240 cm^2 being coupled to the 95 cm^2 sensitive area of the 5" photocathode. A total of 464 phototubes are required. The longest section has a light collection path of 3 meters. This distance will be comparable to the attenuation length so that it will be necessary to correct for attenuation by either using the drift chamber information, the time distributions of the photomultiplier pulses, or by a hardware correction. One way to achieve the last possibility is to segment the liquid scintillator tanks with transparent spacers and use scintillators whose light output varies according to the distance to the photomultiplier.

The calorimeter is divided into slabs of 2, 3, 10, 20 and 20 radiation lengths, with each slab followed by a single drift chamber. The initial fine division allows the separation of hadronic and electromagnetic showers. The drift chambers are of a type recently developed by Breskin, et al.[2] which permits two dimensional readout in one plane, with spatial resolution of .1 - .2 mm perpendicular to the sense wires (which are spaced 5 cm apart), and 2 - 3 mm along the sense wires, by means of a delay line. A total of 60 such planes are required, with a total area of 212 m^2. Since the time resolution required of this system is rather modest, drift chambers appear to be the least expensive approach to shower localization in such a system, especially since two coordinates can be read out in a single plane. The spatial resolution required is much poorer than the ultimate resolution of which these devices are capable; very inexpensive digital electronics can therefore be employed. In fact, a slow digitizing speed is an advantage in this application, in that it will provide the centroid of the electromagnetic or hadron shower directly.

The central region of the detector consists of four concentric drift chambers with two dimensional readout and eight planes of planar drift chambers as end caps, four at each end. Each of these chambers is rotated at 45^o, so that three determinations of the coordinates of each track are obtained, despite the presence of the beam pipe. The total area of the central region detector is 13.5 m^2.

The holes in the end caps are tapered such that the minimum angle subtended is 150 mrad to the beam direction, in order that the Bhabha scattering rate be less than 5/sec. This represents a loss in solid angle of 1%. The identification of Bhabha events is crucial to the measurement, both because it constitutes a dangerous potential background and because it allows the calorimeter to serve as its own luminosity monitor.

The trigger for the total hadronic cross section measurement is a total energy deposition in the calorimeter of a few GeV. Cosmic rays will deposit a maximum of $\sim$ 4 GeV.

We estimate the cost of this device to be 655 k 1974 dollars, as is shown in Table 2.

TABLE 2

Cost estimate	k 1974 $
Iron @ $400/metric ton	140
Liquid scintillator @ $1/l	35
Tanks and support structures	50
Photomultipliers (including light pipes and bases) @ $300 each	140
Drift chambers (including electronics)[3] @ $1000/$m^2$	240
Fabrication	50
	655

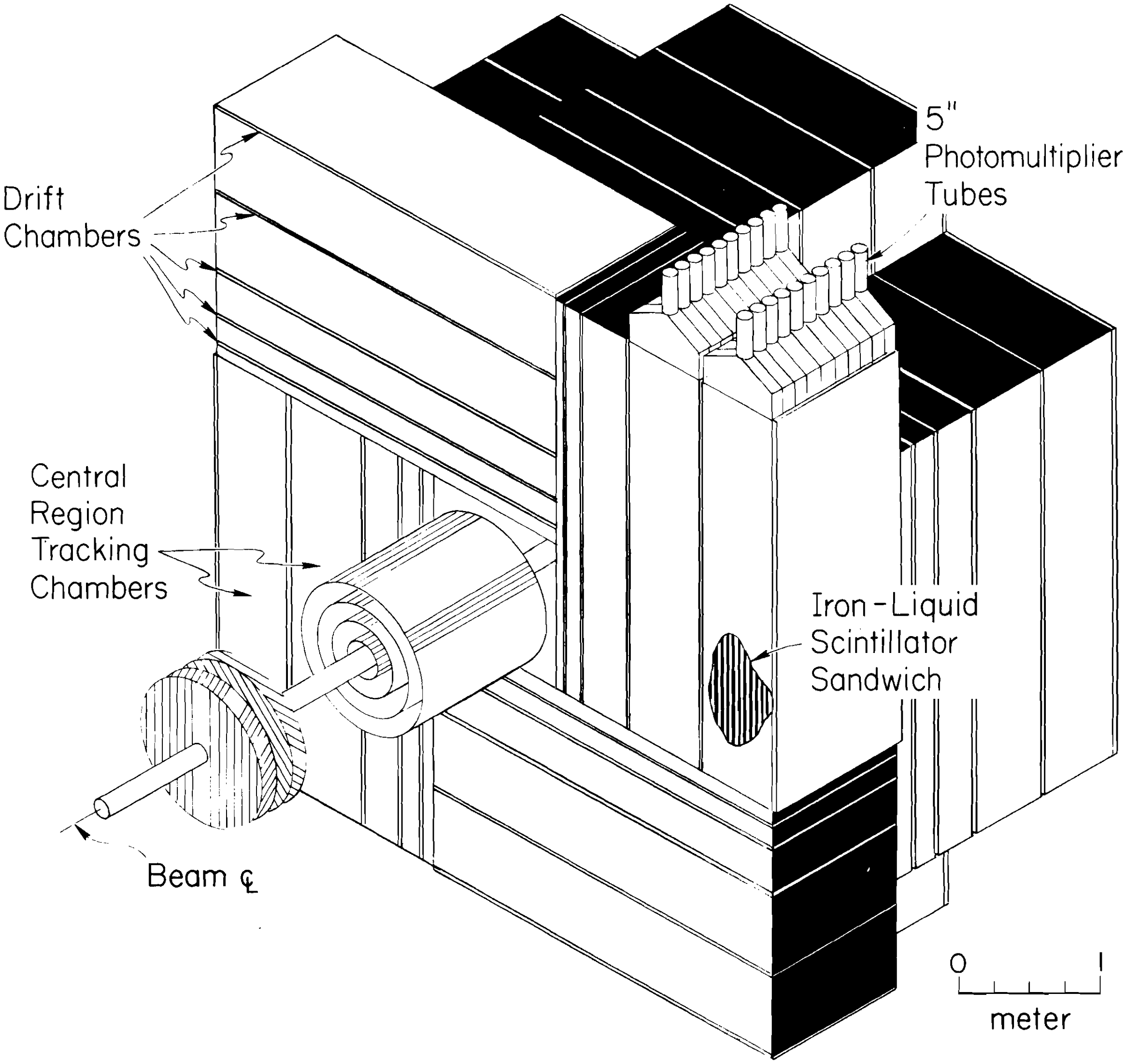
Counter electronics and power supplies to be supplied by Electronics Pool

VI . Conclusion

We have discussed the attributes that a detector capable of measuring the total hadronic cross section to 1 to 2% must have. We have described one such design which is technically well within the state of the art and reasonably inexpensive on the scale of proposed PEP detectors.

REFERENCES

1. Engler, et al., Nucl. Inst. Meth. 106, 189 (1973).
2. Breskin, et al., Nucl. Inst. Meth. 119, 1 (1974).
3. L. Sulak (private communication).



NOTES:

1. The Four-End Cap Modules Have Been Removed From Near Side For Clarity And Are Not Shown.
2. ■ Shaded Areas Are Viewed By 5" Photomultiplier Tubes (Not Shown).
3. The Central End Cap Modules Are Pierced By Tapered Holes Such That θ_{min} Is 150 mrad.

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Fig. 1