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Observation of Final State Coulomb Interactions in Proton-Proton Collisions at 27.5 GeV/c

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2.2.4 Cherenkov Counter

Particles of momenta above the range where TOF can be used may be identified by a highly segmented threshold Cherenkov counter that detects photons radiated by charged particles traveling through a volume of unpressurized Freon gas above the speed of light in the Freon.

The E766 Cherenkov counter is located immediately downstream of the sixth drift chamber (see Fig. 2-1). The side view in Fig. 2-9 shows the arrangement of the optics. Particles enter the Freon after passing through a thin aluminum/vinyl window having the same size as the aperture of chamber 6. Specially shaped toroidal mirrors reflect the Cherenkov light on to photomultiplier tubes. Since the same number of photons are radiated per unit frequency (over the region the index of refraction is independent of frequency), and since the quantum efficiency of the photocathodes are greatest at an optical wavelength of ~4200 Å, more Cherenkov light can be detected by coating the phototube faces with P-terphenyl that converts ultra-violet light to 4600 Å. (The freon is opaque to photons below 2200 angstroms, and the photocathode quantum efficiency falls rapidly above 5000 Å.) The Cherenkov counter contains 96 mirrors each matched to an individual phototube. Smaller mirrors cover the central part of the counter where the particle densities are higher. To increase the amount of light collected, especially from curving particles, and secondary particles not created in the target (V^0's and $V^{\pm}$'s), a reflective cone surrounds each phototube. The alignment of mirrors, phototubes, and cones is such as to maximize light collection for an infinite momentum (straight line) particle that projects upstream to the target. Various parameters of the Cherenkov counter are listed in Table 2-4.

The Cherenkov counter is used to distinguish pions, kaons, protons, and in some cases, electrons. The momentum threshold for pions to radiate is 2.55 GeV/c which corresponds to a β of 0.9985, (γ of 18.25), an index of refraction for Freon of 1.0015, and kaon/proton thresholds of 9.0 and 17.0 GeV/c. All final state electrons reaching the Cherenkov counter radiate, although below ~2 GeV/c, the light collection efficiency drops rapidly as the deviation of the trajectory from a straight line increases. Thus while virtually all particles below pion threshold that are associated with Cherenkov light are electrons, the converse is not true; ie not all electrons below pion threshold are associated with Cherenkov light.

The amount of Cherenkov light radiated and subsequently detected is measured indirectly as a digitized pulse area (ADC) of the analog signal from the phototube. The ADC values are converted to units of photoelectrons that were emitted when the wavelength shifted Cherenkov light (photons) struck the photocathode. This conversion to photoelectrons, P.E., is

$$\#\text{P.E.} = \frac{\text{(ADC-Pedestal)}}{\text{Gain}} (\#\text{P.E. for } \beta=1 \text{ particle}) \tag{2-2}$$

where "Gain" and "#P.E. for ß=1 particle" are constants determined using pions from K^o decays[24]. The method of calibration makes use of the expression[25] relating the number of photoelectrons observed to the number for a ß=1 particle:

$$\frac{\#\text{P.E.}}{\#\text{P.E. } (\beta=1)} = 1-(P_{Th}/P)^2 \tag{2-3}$$

where P_{Th} is the threshold momentum for a pion. The gain constants and photoelectrons for a ß=1 particle were determined by fitting ADC-Pedestal distributions to Poisson distributions for bands of $1-(P_{th}/P)^2$. The fit for each gave an estimate of the number of photoelectrons. These estimates could be extrapolated to estimate the number of photoelectrons for a ß=1 particle. The numbers obtained range from 10 to 25 photoelectrons and depend on a variety of factors including the average length of the radiator traversed, the efficiency of the optics, and variations between groups[26] of phototubes and associated electronics.

Two figures demonstrate the ability of the Cherenkov counter to separate electrons, pions, kaons, and protons as a function of momentum. The three scatter plots of pulse area (ADC) normalized in units of photoelectrons vs. particle momenta (Fig. 2-10) use three different samples of data. Fig. 2-10a for fully reconstructed $pp2,3(\pi^+\pi^-)$ final states shows clear pion and proton distributions. An addition kaon component is also present in Fig. 2-10b where the final state selected was $ppK^+K^-1,2(\pi^+\pi^-)$. Fig. 2-11 shows the same set of plots normalized to the number of photoelectrons expected for a $\beta=1$ particle. Superimposed are the curves $1-(P_{th}/P)^2$ using pion, kaon, and proton thresholds. Although their spread is relatively large, the π,K,p distributions follow these curves reasonably well. Several factors contribute to the range the number of photoelectrons measured for a given momentum interval. Much of the spread is due to Poisson statistics. Also, these plots combine all 96 cells which have a variety of mirror sizes and correspond to different radiator lengths. Finally, the calibration could be improved somewhat.

For particles from small opening angle +/- pairs the distributions look very different than those corresponding to fully reconstructed events. (See Figs. 2-10c,11c). Most of these radiating particles have momenta below pion threshold and are electrons(positrons) from photon conversion in material. (A clear "turn on" of pions above 2.55 GeV/c can also be distinguished.) The apparent low momentum cutoff for electrons is due partially to the fact that most particles below 500 MeV/c are swept outside the spectrometer aperture and never reach the Cherenkov counter, and is due partially to the Cherenkov counter optics that are designed to collect light from stiff tracks that point back to the target. The latter contributes to the relatively wide spread in the amount of measured light from electrons.

In this analysis, the Cherenkov counter is used as a threshold device. Particles of momentum below pion threshold and associated with more than one photoelectron were called electrons. Above pion threshold, the measured number is compared with the predicted numbers assuming pion/kaon/proton. A particular hypothesis is called inconsistent if no light was measured and the prediction exceeded some number (typically 5) photoelectrons, or if at least one photoelectron was measured and none were predicted. In limited cases, identification of electrons was also possible. No attempt was made to identify muons since they are an extremely small fraction of the particles produced in pp interactions. (The use of particle ID, both TOF and Cherenkov, to identify fully reconstructed events will be discussed in the next chapter.)

We mention in passing that the Cherenkov counter actually provides more particle ID information than a simple threshold measurement. For example, as Fig. 2-11 shows, one can distinguish between radiating particles. (kaons and pions above kaon threshold, and similarly between radiating pions or kaons and protons above proton threshold) This sort of measurement could be used to form some sort of a particle ID "chi square" and could be made more accurate by improving the current calibration.

Finally, we note that the Cherenkov counter also provides useful timing information. Because the arrival time of light reaching the phototubes is not dispersed by a light guide, the timing resolution of the Cherenkov counter is better than that of the TOF scintillation counters. FWHM for a typical mirror/phototube is ~0.7 ns. These measurements are used in the calculation of the event T_0 to subsequently improve the overall resolution of the TOF system.

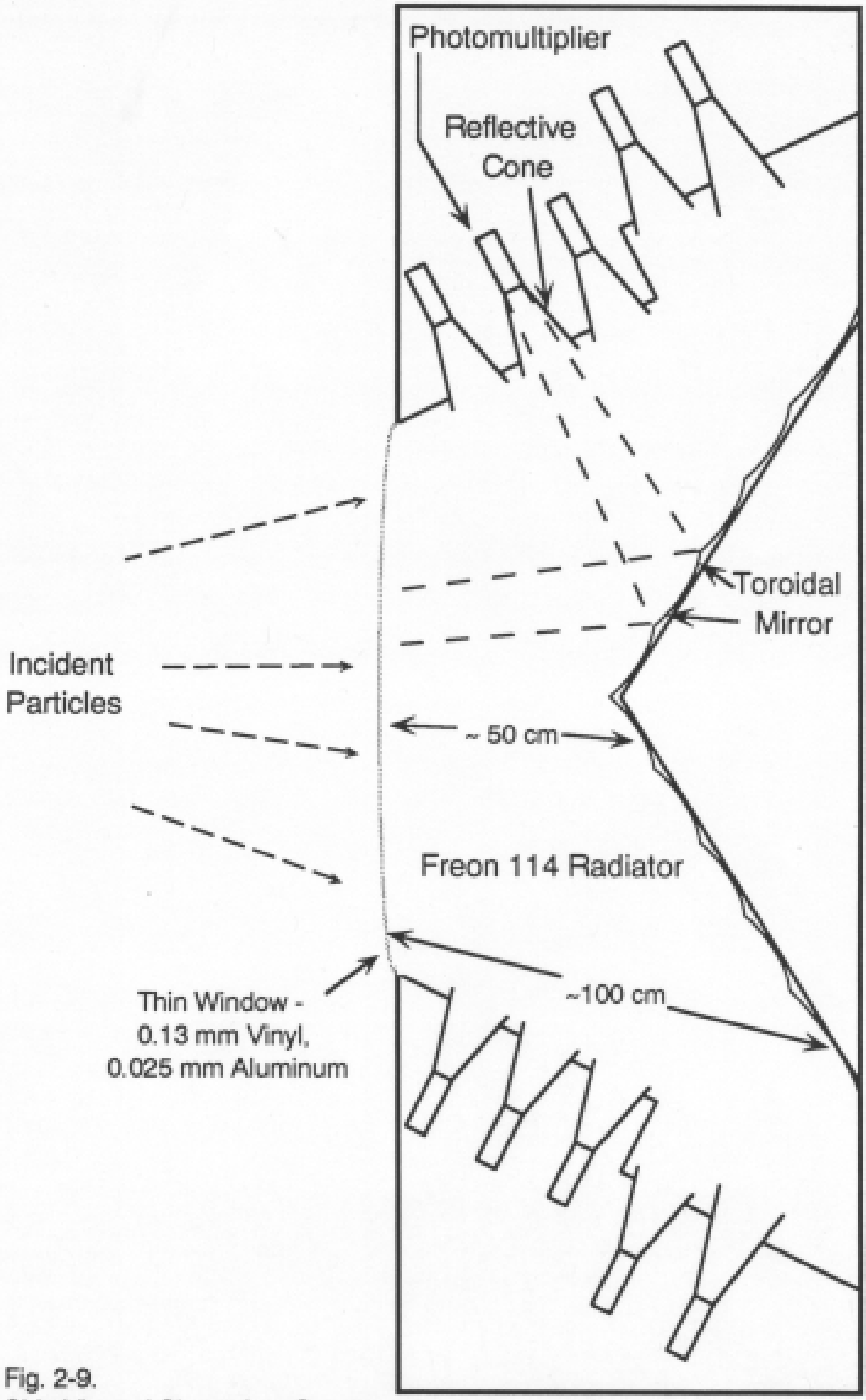

Fig. 2-9.
Side View of Cherenkov Counter

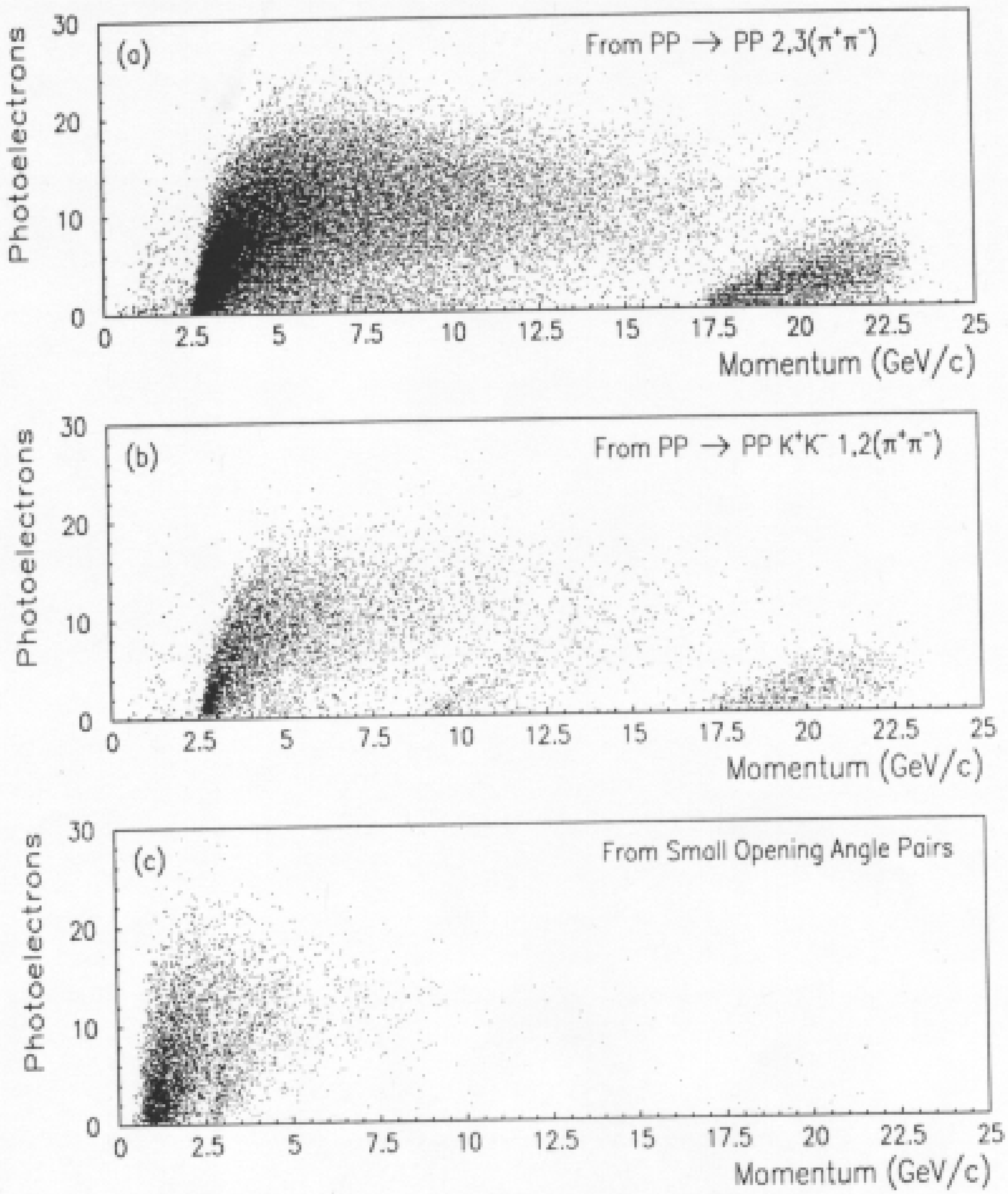

Fig. 2-10: Cherenkov counter measurements of pulse area normalized in photoelectrons vs. momentum. For fully reconstructed $ppK^+K^-1,2(\pi^+\pi^-)$ final states, a kaon component can be seen in (b) between the pion and proton measurements. For tracks from small opening angle pairs, most of which are e^+e^- pairs from photon conversions in material, the electron component is greatly enhanced and the hadron components suppressed.

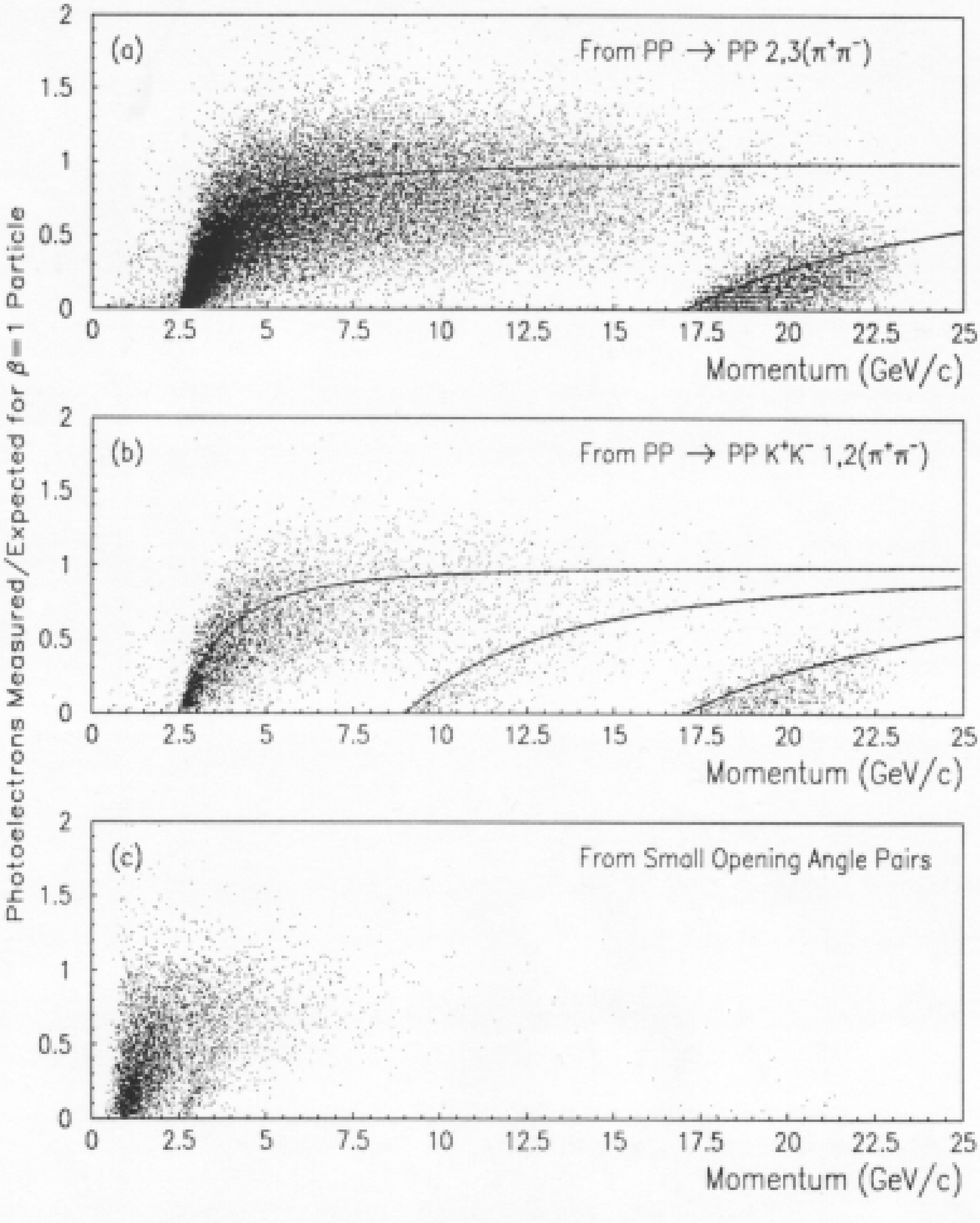

Fig. 2-11: Cherenkov counter measurements identical to those of Fig. 2-10 but with the number of photoelectrons normalized to the number expected for a ß=1 particle. Superimposed is the function $1-(P_{th}/P)^2$ for pion, kaon, and proton thresholds. In the absence of limited photoelectron statistics, this function is the theoretical prediction.