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CP Violation in K_S^0 Decay - Experiment 621

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Experiment 621 was the first experiment in the Proton Center beamline to run using 800-GeV/c protons. In preparation for the higher energies, a new focusing enclosure was built just south of the Proton Lab Pagoda (called the PC2 Enclosure), and extensive modifications were made to the whole Proton Center beam. We have now completed our approved experimental program. We wish to thank the Laboratory very much for all the enthusiastic help we received in the design, setup, and running of the experiment.

CP symmetry nonconservation in the weak interaction has been found only in four K_L^0 decays, to $\pi^+\pi^-$, $\pi^0\pi^0$, $\pi e\nu$, and $\pi\mu\nu$. Our experiment is looking for CP violation in the next easiest place to find it: in the decay $K_S^0 \rightarrow \pi^+\pi^-\pi^0$. We are measuring η_{+-0}, defined to be,

$$\eta_{+-0} = \frac{\mathrm{Amp}(K_S^0 \rightarrow \pi^+\pi^-\pi^0)}{\mathrm{Amp}(K_L^0 \rightarrow \pi^+\pi^-\pi^0)}$$

It is easy to make a beam of K_L mesons to study their CP violating decays, just go far from the production target so that the K_S are all gone. For our case, that trick doesn't work, and we therefore look for CP violation close to the target, in K_L-K_S interference. To see CP violation we must see a deviation from pure exponential behavior in the time evolution of $\pi^+\pi^-\pi^0$ decays.

If we study the time dependence of $\pi^+\pi^-\pi^0$ decays by collecting data and dividing by the acceptance of the detector, as calculated by a Monte Carlo simulation, we would be limited to an accuracy in $|\eta_{+-0}|$ of about .005. We instead decided to measure our acceptance by using two targets to produce the kaons. One target was located at the entrance to the P-Center Hyperon Magnet, which is 7.2 m long, with a field of 35 kG. A collimator with a straight hole in the magnet made a beam of neutral particles: gamma rays, neutrons, Λ^0 and Ξ^0 hyperons, and kaons. The second target was located 25 m upstream of the magnet, and produced a beam aimed at a second hole in the Hyperon Magnet collimator. From the downstream target we measure the K_L-K_S interference; from the upstream target, we detect almost pure K_L decays because of the falling time exponential factor in the interference term, and measure our acceptance. To minimize systematic errors due to rate differences, we split the P-Center beam into two proton beams (using an electrostatic septum and two Lambertson magnets) and struck both targets simultaneously. The beam design is described in Fermilab Technical Memo TM-1144 (unpublished).

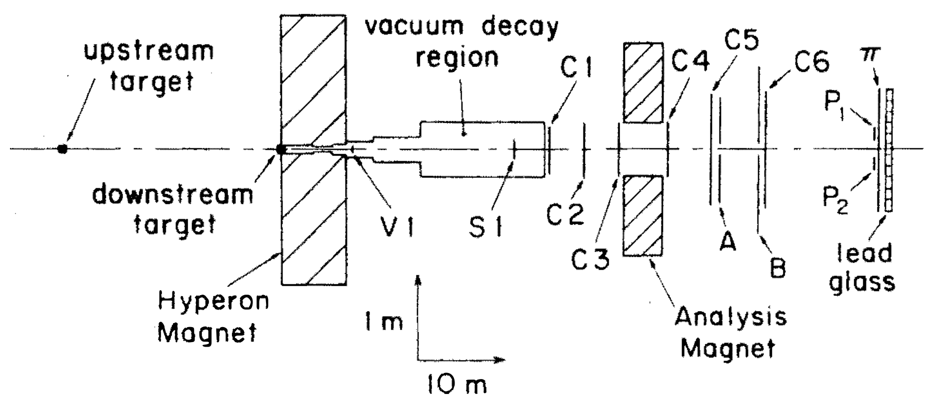

Figure 1. Targets, Hyperon Magnet, and detector for E-621.

Figure 1 shows the targets, Hyperon Magnet, and our vee spectrometer. It consisted of a vacuum decay region defined by scintillation counters (run in the vacuum) at both ends; six multi-wire proportional chambers (MWPC); a spectrometer magnet; three hodoscopes of scintillation counters; and an array of 86 lead-glass blocks. We triggered on a neutral particle decaying in the decay pipe; required two hits in each of the A and B hodoscopes, one on the left and one on the right; and demanded that each of three trigger processors gave a "yes" vote on the event.

The first trigger processor used commercial CAMAC memory look-up units, into which were fed signals from the A and B hodoscopes. Here we picked out decays where the π^+ and π^- positions were symmetric about the beam. $\pi^+\pi^-\pi^0$ decays are symmetric in this way, while one of our background decays, $\Lambda^0 \to p\pi^-$, is asymmetric. The second trigger processor also aimed at the same criterion, but used fast outputs of our MWPC's. We built a circuit, using ECL computer chips, that chose MWPC hits using a priority scheme, calculated the slopes of tracks behind the analysis magnet, and chose symmetric patterns. The third trigger processor used advanced TTL logic IC's, and counted clusters of hits in our lead-glass array. The pi-hodoscope just in front of the lead glass consisted of scintillation counters the size of rows of the lead-glass counters. By comparing hits in the pi-hodoscope with hits in the lead-glass array, it chose events with two or more neutral particles showering in the lead glass.

In April 1984, when the TEVATRON first delivered 800-GeV/c protons, our experiment was the first to take them. We tuned up our spectrometer and collected data for the rest of the run, amassing 200,000 $\pi^+\pi^-\pi^0$ events. From what we learned from this running, we made improvements to our beamline, spectrometer shielding, and trigger, and took data in the whole 1985 run, collecting 3,200,000 $\pi^+\pi^-\pi^0$ events. The 1985 run did not go as smoothly for us as we would have liked: part of the cable run from the experiment to our electronics trailer, going over the Proton-West berm, was struck by lightning, frying some of our electronics; and a terrorist woodchuck who lived in the Proton-West berm attacked some of these same cables. He was trapped and released in the middle of the ring.

As this article is being written, analysis of the two data sets is going on in parallel. To use a musical analogy, the analysis of the 1984 data is entering its coda, while the 1985 data is still in the first movement. For the 1984 data, our expectations of negligible background, and ability to measure the acceptance of the spectrometer are being borne out very well. Up to this point we have put 101,000 events into the proper time histogram, and have not found the bumps and wiggles that would signal CP violation. We can put an upper limit on $|\eta_{+-0}|$ of about 0.03. We feel that our final results will be a factor of 2 more accurate. The world's previous data consists of two experiments with about 400 events each, plus several experiments of considerably smaller statistics. The Particle Data Group summarized their results as $|\eta_{+-0}| < 0.35$.

The trigger used in the data collection in 1985 was biased more toward high-momentum events, which are more sensitive to CP violation. This and the factor of 32 more events leads us to expect an order of magnitude greater sensitivity when this analysis is complete.

Theoretical predictions of $|\eta_{+-0}|$ vary from .002 to .004, and if we have an uncertainty of .003 we might be close, but will have won no cigar. Our thought is that in this case we will go for more statistics. In E-621 we targeted the proton beams at a few tenths of a milliradian, and if we rotate the Hyperon Magnet to hit the targets at 3 mrad, the main backgrounds of gamma rays and neutrons will be reduced greatly. We would also build a new, larger spectrometer to maximize our acceptance. So it is quite possible that we will propose a "son of E-621" soon.