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Development of a Parallel Plate Proportional Counter TRD with Suppressed Sensitivity to Ionization

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Abstract

The development of a Parallel Plate Proportional Counter which has a highly suppressed sensitivity to ionization but retains a good X-ray signal to noise ratio is presented. Details of the laboratory development and actual beam tests showing the e/π rejection are described. Because of its insensitivity to ionization this type of detector can be useful in an environment where the number of minimum ionizing particles are high, but uninteresting; however, the detector is very sensitive to the highly localized electron cloud from converted X-rays making it ideal as a transition radiation X-ray detector. Thus, this detector only gives a signal for charged particles above TR threshold; all other particles below this threshold produce no TR X-rays giving only a pedestal-like signal. The system's potential performance for π/p separation in the intended neutral Hyperon experiment is evaluated.

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Introduction

There exists the potential to explore a large number of topics in hyperon physics in the KTeV experiment being built for the next fixed target run at Fermilab. Neutral Lambda and Cascade decays are the only hyperons with lifetimes long enough to be copiously studied in this experiment. The study of Lambda beta decays, $\Lambda^0 \rightarrow p e^- \bar{\nu}_e$, to check an anomalous neutrino asymmetry reported in 1977 [1] is the main emphasis of the hyperon group of the KTeV experiment. If this neutrino asymmetry anomaly is confirmed then the form factor g_2 , weak magnetism [2], would be non-zero and would indicate physics beyond the standard model. This would be a positive indication of additional currents, commonly referred to as second class currents, not already part of the Standard Model giving rise to the non-vanishing g_2 form factor. Other prospective rare hyperon decay physics can be explored by looking for forbidden $\Delta S=2$ decays of the neutral Cascade, $\Xi^0 \rightarrow p e^- \bar{\nu}_e$ or $\Xi^0 \rightarrow p \pi^-$. These forbidden decays may proceed through either an additional current in weak decays, or are actually allowed in the standard model by second order processes. Full details of the KTeV hyperon program can be found elsewhere [3].

The KTeV facility will have a large acceptance CsI calorimeter with better than 1% energy resolution above 10 GeV [4]. A large TRD system is being built to provide further e/π rejection [5]. Although the Hyperon group of KTeV will make full use of both of these planned detectors it was necessary to design a special particle identification system for the beam region that could distinguish pions from protons in the momentum range of 150 to 350 GeV/c. Although the beam region of KTeV has 90 % geometrical acceptance for protons from Lambda beta decays, an equal number of Ke3 decays of neutral long lived Kaons, $K^0 \rightarrow \pi e^- \bar{\nu}_e$, are a substantial background that would make the neutrino asymmetry measurement impossible if not substantially degraded. Other constraints also exist on the beam line particle identification detector system of KTeV. The detector must be able to survive in a 25 MHz beam of neutrons. Although the high momentum, $>150\text{GeV}/c$, charged particle rate is only 30 to 50 kHz, a ten times higher rate of much lower energy charged particles below transition radiation threshold will also be present.

This paper reports on the development of a beam TRD system, to distinguish protons from pions above 150 GeV/c. It is remarkable insensitive to the ionization from dE/dx and only responds to X-rays. The particle identification system based on this development is currently under construction and its performance will be further evaluated after the KTeV experiment finishes its first physics run.

Detector Description

Traditionally, a gaseous Transition Radiation Detector (TRD) has consisted of a radiator with a multi-wire proportional chamber (MWPC) to detect the TR X-rays and distinguish electrons from pions [6]. Other experiments have used a TRD system to

distinguish pions from protons using a MWPC, but these experiments were performed at lower rates and in a cleaner environment [7] than expected at KTeV. The hyperon physics program of KTeV needs a beam TRD system in each of the two neutral beam lines to distinguish pions from protons at a level of 20:1 rejection so that the K_S^0 level will be less than 5 %. The beam TRD design was adapted from a parallel plate proportional chamber (PPPC) because it performs better at high rates and is less sensitive to space charge problems than MWPCs. Because of the high rate of uninteresting charged particles a detector designed to be insensitive to ionization would be a distinct advantage. PPC or Multi-Step Avalanche Chambers (MSAC), the combination of several PPC operated in high gain mode forming avalanches, have been used recently in a limited capacity to detect minimum ionizing particles [8]. In the CERN group of Georges Charpak from 1986 to 1988 these type of detectors were extensively studied. To their disappointment, it never performed adequately for charged particle ionization detection before sparking limitations set in [9], even though their response to X-rays was excellent. In the work reported here we have inverted the problem by making the detector more insensitive to ionization while retaining the fine X-ray signal. Hence with a detector that is insensitive to ionization but still responds to X-rays it is well suited as the readout plane of a TRD in a high background of non X-ray generating minimum ionizing particles.

The PPC, shown in figure 1(a), consists of three electrical planes. A 6 mm gap is formed between the Aluminum coated mylar entrance window which is 12.5 μm thick coated with 80 nm of Aluminum and a wire mesh plane. The voltage difference between these two electrodes is low for fast charge collection and is called a conversion gap. Any charge deposited in this region is swept by the electric field into an amplification gap formed by the two mesh planes at high voltage difference, 4300 V with the final gas mixture. The amplification gap is maintained with a high electric field gradient such that the electrons entering this gap are accelerated to an energy sufficient to further ionize the gas, avalanching into a signal. Furthermore, our PPC has the ability to suppress the dE/dx signal while maintaining the X-ray signal. Minimum ionizing particles deposit charge equally along a track throughout the conversion gap. If the readout electronics has a small time constant such that an electron along the perpendicular track is amplified, the resulting charge is quickly drained before further ionization from the track reaches the end of the amplification gap. Then the dE/dx signal is suppressed. The X-ray is still observable because the converted electron generates ionization in the gas of only 50 to 100 μm in length depending upon the initial energy of the X-ray. This electron cloud is equivalent to about 5 ns of drift time. Here the amplification gap's response and electronics is slower than the X-ray signal and should still be clearly visible. Because of the fast fields in the conversion and amplification gap the PPC can sweep away the positive ions a 100 times faster than a MWPC; thus the PPC prevents the build up of space charge. Additionally, the PPC is not as susceptible to radiation damage as a MWPC since electrons do not avalanche onto individual wires.

These detectors operate with a low concentration of quencher gas, a typical gas is 97 % Argon and 3 % Ethane or Methane. It was necessary however to study other gas

mixtures more appropriate for the beam TRD project. First, the gas mixture must have the ability to convert TR X-rays as efficiently as possible. Xenon rich mixtures are best for this. Second, the gas must have a fast drift velocity so that it may have high rate applications. Third, the best mixture should have a high gain at low voltage. Finally, the mixture should have good X-ray energy resolution since this improves the rejection. Mixtures of pure Xenon with 3 % Ethane had extremely high operating voltages and worse energy resolution than the standard gas mixture of Argon and 3 % Ethane. Xenon rich mixtures were still desirable because of the higher X-ray cross section. It was found that diluting the Xenon with Neon or Helium reduced the operating voltage and improved the energy resolution. The final gas mixture selected was 50 % Xenon 47 % Neon and 3 % Ethane and the detector performance will be reported below.

A charge sensitive pre-amp that suited our needs was designed, see figure 1(b). The CLC425 is currently the best amplifier having both the best signal-to-noise ratio and the highest gain. The CLC425 is a high speed, ultra-low noise amplifier with a 1.9 GHz bandwidth and a gain range up to 1000V/V. Figure 2 shows the average detector response for dE/dx minimum ionization signal and a 5.9 keV X-ray signal using this amplifier. It should be noticed from this figure that the X-ray signal is prominent while the ionization signal is small even though the deposited charge for the X-ray signal is only half that of the ionization. This demonstrates the type of ionization suppression that the detector and electronics were designed to perform. The observed shape of the X-ray signal is due completely to amplifier shaping and does not reflect the timing structure of the initial deposited charge.

Detector Performance in Laboratory Tests

Using a variety of X-ray sources ranging in energy from 5.9 to 22.1 keV, the detector was studied in self trigger mode to measure its linearity and energy resolution as a function of X-ray energy. Figure 3 demonstrates the detector's excellent linearity and energy resolution as a function of X-ray energy. The PPC was linear to within 1 %, and had a typical average energy resolution across this region of 22 % FWHM.

In an effort to save money and reduce the number of electronics channels in the planned experiment, each PPC plane in the beam TRD system will have no position information. Since each TRD signal will be used in the trigger, the detector should have a uniform signal response better than 10 %. Figure 4 shows the gain uniformity in the planned active region of $15 \times 15 \text{ cm}^2$, while the actual detector's inside area is $19 \times 19 \text{ cm}^2$. A prototype was built, uniform in gain to 6.0 %: well within the acceptable limit.

The beam TRD will be in a region of high flux of TR X-ray producing particles, so these detectors need to work with a constant performance at high X-ray rates. Rate effects were studied with the final TRD gas mixture and a 97 % Argon 3 % Ethane mixture using a ^{55}Fe source. The rate was controlled by changing the collimation of the X-ray beam, and was varied between 5 and 200 kHz. Figure 5(a) shows that the gain does not vary up to 200 kHz and figure 5(b) illustrates that the resolution of the detector is affected only slightly at levels above 100 kHz. Slightly worse results were

obtained with the final TRD gas mixture, also shown in the figure.

TRD performance in a 20 GeV/c electron beam

The beam TRD prototype was brought to a 20 GeV/c test beam of CERN in May and August of 1994. The radiator consisted of a polypropylene foil stack of either 100 or 200 foils, using 17 μm thick polypropylene with an air gap spacing between foils of 120 μm . Between the radiator and the gaseous detector entrance window was a 6.5 mm air gap and the PPC was operated with our standard gas mixture of 50 % Xenon, 47 % Neon and 3 % Ethane.

Both beam tests of this prototype were actually tested with a 20 GeV/c electron beam that was 98.4% pure as determined by two threshold Cherenkov detectors and in the August test a Csl calorimeter. The TRD data can be divided into three types. First, data was taken with the radiator placed in front of the PPC, allowing events with TR X-rays and their ionization to be detected; here different types of radiators were used with 100 or 200 foils which will be discussed later to simulate π/p rejection. Second, data was taken with the radiator replaced by a plate of equivalent material to that of the radiator. Only ionization was present simulating a pion-like sample for the e/π rejection. Finally, the chamber was calibrated without beam using a 8 keV ^{65}Zn source and a 5.9 keV ^{55}Fe source in self trigger mode to determine the TR X-ray scale.

The best results came from the second beam test in August, because transition radiation in the real environment can only be obtained with a high energy beam and much was learned for improvement in the first test of May 1994. Figure 6(a) shows the ADC pulse height spectrum with a 200 foil stack radiator with 20 GeV/c electrons that were selected by cuts on the Cherenkov counters and the Csl calorimeter in the beamline [4]. A TR X-ray peak is clearly visible, separated from the ionization signal. Figure 6(b) shows the ionization for the pion-like data sample as a solid line and the dashed line is the pedestal signal. Most of the ionization signals are consistent with a pedestal signal. The data in this plot were taken at the highest gain attempted, here the ionization signal started to just separate from the pedestal. Lower gain runs where the pedestal and ionization are more overlapped also show a TR X-ray peak separated from the ionization-pedestal peak. During the test beam run was other physicist testing the Csl calorimeter where looking at the TRD X-ray signal on a storage oscilloscope with the radiator mounted. While on a beam access the radiator was removed and replaced with a plate to accumulate pion-like data. After the access ended and data acquisition resumed, the TRD group went on a short coffee break. When they returned the Csl physicists were trying to find the TRD signal and since they could not they were certain that the TRD detector was not working. However, after being reminded that without a radiator there are no TR X-rays and since the chamber is effectively blind to ionization there should be no signal as they saw earlier, shown previously in figure 2, hence ending the confusion. The test beam run had only a 100 Hz rate so further testing of the detectors performance at actual rates will be done in

the experiment.

After all cuts were made on the data, the e/π rejection was obtained from the data using a maximum likelihood method. A twelve chamber stack was simulated by using 12 separate electron or pion-like events summed together. The e/π rejection is defined as $R=E_e/E_\pi$ where E_e is the electron event efficiency to pass the cut and E_π is the pion-like efficiency. The rejection grows rapidly as E_e decreases, as shown in table 1. The PPC with a radiator stack of 100 foils provided 20:1 rejection for a simulated twelve chamber system at 90% electron acceptance. The 200 foil stack radiator had an e/π rejection of 49:1 at 90 % electron acceptance for the same simulated twelve chamber system was achieved, shown in figure 7. The e/π rejection at different electron acceptance is presented in table 1, it is seen that the rejection becomes extremely large at lower acceptance which will be useful for any rare decay searches.

Since we were unable to get a sample of high energy pions and protons at 250 GeV/c, a rough π/p rejection is inferred from the the 20 GeV/c electron data. Using the fact that 200 GeV/c pions yield half the number of TR X-rays as 20 GeV/c electrons, see figure 8, the π/p rejection for a 200 GeV/c pion beam through a 200 foil stack radiator should be similar to a 20 GeV/c electron beam with a 100 foil stack radiator. Therefore, the PPC with a 200 foil stack radiator should be able to provide a π/p rejection of 20:1 at 90% pion acceptance for the twelve chamber system planned. At a momentum of 350 GeV/c, which is the maximum range expected in the planned KTeV experiment in the beam region, this rejection is expected to yield TR X-rays for 85 % of the events. This is estimated to be a π/p rejection of 40:1 at 90 % efficiency.

Conclusion

After spending two years developing and testing a beam TRD in both laboratory and two beam studies, the design for the beam TRD system in KTeV has been approved for construction. The beam TRD system is expected to provide an average rejection of at least 30:1 for π/p in the region of 150 to 350 GeV/c. An important feature of this detector is that it is effectively blind to ionization while still being sensitive to X-rays, such as those from transition radiation, this feature will permit this experiment to be conducted in the harsh environment of KTeV's beam line. This detector system will be further tested in the KTeV experiment where its good performance will permit a high statistics analysis of polarized Lambda beta decays. For rare Hyperon decays where more data can be discarded to get better rejection this detector system will permit a search for forbidden or second order weak decays.

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Figure and Table Captions

Figure 1: a) Sketch of the PPC with dashed lines representing meshes and solid lines the Al coated mylar, and b) Circuit diagram of charge sensitive pre-amp.

Figure 2: a) Average oscilloscope traces of 5.9 keV calibration X-rays, and b) average ionization signal; both pictures represent the detectors performance with the TRD gas of 50 % Xenon 47 % Neon and 3 % Ethane.

Figure 3: a) Linearity and b) energy resolution versus the X-ray energy for two different gas mixtures.

Figure 4: The gain uniformity of 6 % over the active area of the prototype TRD X-ray detector plane.

Figure 5: The effect of X-ray rate on a) the gain and b) the energy resolution for two different gas mixtures.

Figure 6: Part a) shows the detector ADC spectrum for 20 GeV/c electrons using a 200 foil stack radiator; the clearly visible peak separated from the ionization signal is due to TR X-rays. Part b) shows the pion-like data with only ionization as the solid curve and the dashed curve is the pedestal spectrum which significantly overlap.

Figure 7: Maximum likelihood method of e/π rejection calculated from the two spectrum of electron data and pion-like data shown in figure 6.

Figure 8: Monte-Carlo simulation of transition radiation X-ray yield for a foil stack radiator with 200 foils for different particles as a function particle momentum, triangles are for leptons: electron and muon, stars are pions, squares Kaons and circles protons.

Table 1: Calculated e/π rejection at different electron acceptances. At lower acceptances the rejection of this detector becomes extremely large which will be very useful for rare hyperon decay searches.

<u>Acceptance:</u>	<u>e/π rejection measured:</u>	<u>π/p rejection estimated at 250 GeV/c:</u>
90 %	49:1	30:1
85 %	92:1	55:1
80 %	156:1	94:1
75 %	240:1	125:1
60 %	>1000:1	>500:1

Figure 1

a)

b)

Figure 2:

Figure 3:

Figure 4:

Figure 5:

Figure 6:

Figure 7:

Figure 8: