The large-angle photon veto detector for the P326 experiment at CERN

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The P326 experiment at CERN plans to measure BR($K^+ \to \pi^+ \nu\bar{\nu}$) with an uncertainty of $\approx$ 10%. The π^0 rejection factor should be at the level of 10^8 to achieve the required signal to noise ratio. For the construction of the large-angle photon veto system, a test program of different technological solutions has started. A module based on lead and scintillating fibers has been constructed and it has been tested together with a lead/ scintillator with WLS readout prototype originally developed by CKM at Fermilab and with some lead glass blocks formerly used in the OPAL calorimeter. Preliminary results on the inefficiency to electrons are presented.

Keywords: Detector; Photon veto;

1. Introduction

The P326 experiment [1] has been proposed to measure the branching ratio of the rare decay $K^+ \to \pi^+ \nu\bar{\nu}$. An accurate measurement of this BR allows a precise test of the Standard Model and a 10% accurate evaluation of $|V_{td}|$. Furthermore, given its sensitivity to physics beyond the Standard Model, one can also observe clean signals of new physics. Presently the only existing measurement is based on three signal events collected by the E787(E949) [2] experiment at BNL, giving $BR(K^+ \to \pi^+ \nu\bar{\nu}) = (1.47^{+1.30}_{-0.89}) \cdot 10^{-10}$.

2. Experimental requirements

The experiment is particularly demanding. The kaon beam should have a high intensity in order to collect significant statistics in a reasonable time. The proposed beam has a high momentum (75 GeV/c with $\sigma(p)/p \approx 1\%$) and it will be produced by 400-GeV protons from the CERN SPS. The main advantage of an high energy beam is the high energy of the photons from π^0 decays, which will improve the photon detection efficiency. The experimental layout is shown in Fig. 1.

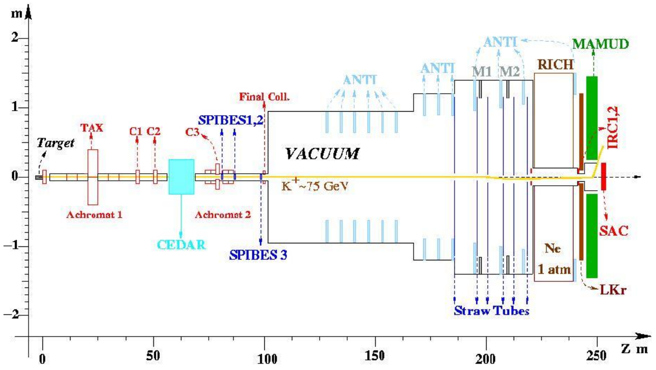

Fig. 1. The P326 experimental layout.

The rejection power for the most common background channels should be around 10^{12} to have the expected signal to noise ratio of about 10. This is most important in the two-body decays $K^+ \to \pi^+\pi^0$ and $K^+ \to \mu^+\nu$, where the combined use of missing mass cuts and particle identification should be used. In the case of $K^+ \to \pi^+\pi^0$ an hermetic system of calorimeters should be used, with a very low detection inefficiency ($\leq 10^{-4}$) over a large energy range.

The two photons from the π^0 decay exhibit energy correlation: one low energy photon, detected with somewhat poor inefficiency at a large angle, is paired with a high energy one, hitting the forward, very efficient, detector.

A simulation has been performed, taking into account the kinematics of the decay and it has shown that an inefficiency of 10^{-4} down to 200 MeV is well enough to reach the expected level of rejection.

3. Photon Vetoes

The Photon Veto system should be able to detect photons with high efficiency in order to reject the background decays, mainly from $K^+ \to \pi^+\pi^0$. The average inefficiency for the π^0 should be $\approx 10^{-8}$. Different detectors will be used for different angular regions: below 15 mrad, the LKr calorimeter and small calorimeters in the very forward direction and around the beam pipe will be used. For an hermetic coverage up to 50 mrad, a system of 12 ring calorimeters (Large Angle Vetoes) will be used.

4. Large Angle Vetoes

The veto system is composed of 12 modules of annular shape located along the decay vacuum tube; the total active surface is $\approx 27m^2$. The photon energy to be detected varies from $\approx$ 10 MeV to $\approx$ 25 GeV, depending on the angle of incidence and on the module hit. For comparison, in any of the three technologies described below, the detected energy of a minimum ionizing particle is below 100 MeV.

For the construction of these detectors, three options have been taken into consideration and prototypes have been built or provided to test for the response and inefficiency in an electron beam.

One design consists of a sandwich of lead sheets and scintillating tiles with WLS fiber readout. An assembly of 16 wedge-shaped modules forms the veto counter. An example of such a detector, using 80 layers of 1-mm thick lead sheets and 5-mm thick scintillating tiles, was designed for the (now canceled) CKM experiment at Fermilab. Tests at the Jefferson Lab showed that the inefficiency of the detector for 1.2 GeV electrons was at most $3 \cdot 10^{-6}$ [3].

Another solution is based on the design of the KLOE calorimeter [4], and consists of 1-mm diameter scintillating fibers sandwiched between 0.5-mm thick lead foils. The fibers are arranged orthogonal to the direction of particle incidence and are read out at both ends. Two U-shaped modules form a veto station.

The third option is to use the lead glass modules already used in the barrel of the OPAL calorimeter and which could be available in a more than sufficient quantity. Each block is a kind of truncated pyramid with an height of 37 cm and with trapezoidal bases of about 11*11 cm. A 4-cm long light guide couples the lead glass block to a Hamamatsu R2238 photomultiplier. A veto station could be composed of four or five layers of blocks radially arranged with the long axis perpendicular to the beam axis. The blocks will not touch each other and the different layers will be arranged such as to have the complete coverage of the solid angle as well as a minimum thickness in radiation lengths.

In order to determine the best choice in terms of detection inefficiency, we have asked for the loan of the CKM prototype, taken few of the OPAL lead glasses and built a lead-fiber prototype.

4.1. *The lead-fiber prototype*

One U-shaped module was built in Frascati in fall 2006. The inner radius (60 cm) and length (310 cm along the inner face) are identical to the specifications for one of the upstream veto stations. The prototype has a radial thickness of 12.5 cm, about a third of the final one, but sufficient for the transverse containment of low-energy electron showers incident along the center line of the module. Layers of the module were constructed by rolling 1-mm grooves into 0.5-mm lead foils and gluing scintillating fibers into the grooves. The longitudinal depth of the module is determined by the width (25 cm) of the lead foils. The desired radial thickness was obtained by stacking 99 layers. The ends of the module were milled and then fitted with light guides, with a segmentation in the plane transverse to the fibers of six cells along the depth and three along the radius. In the region covered by the last two cells in depth, scintillating fibers in alternating grooves were replaced by lead wires, in order to have the back part of the detector with less fiber density, without complicated modifications to the lead-foils grooving machine.

5. The tests

The three prototypes were tested at the Frascati Beam Test Facility. This is an electron transfer line leading off the DAΦNE linac. It can provide electrons or positrons, in 10-ns pulses with a repetition rate of 50 Hz, with $50MeV < E < 750MeV$ and mean multiplicities from < 1 to 10^4 per pulse.

A "tagging system" has been built to define without ambiguity the arrival of an electron on the device to be tested. It is composed of two beam profile measuring devices, two tagging counters to define the beam and two veto counters (scintillators with an hole inside), mounted on the same support and well aligned along the beam axis. The tagging efficiency of this system varies with the momentum; the global tagging efficiency for 1-electron events depends also from the Poissonian probability to have one electron in the beam. Fig. 2 shows the effect of the tagging: out of all events with different multiplicities, the loose selection (only with the two defining counters) is shown in red and the tight, final one, using also the vetoes, is plotted in black.

Table 1 gives the total statistics obtained in the June-July 2007 run.

The determination of the inefficiency was done looking for tagged events with an energy deposit less than 50 MeV, which were declared inefficient. Table 1 shows the numbers of inefficient events and the preliminary results for the inefficiency to electrons. Fig. 3 summarizes these results. All three

Table 1. Statistics accumulated in the June-July 2007 run

	Energy	P(1e-)	Eff. (tag*1e-)	Tagged Events	Ineff. Events	Inefficiency
Fiber prototype	200 MeV	23.6%	3.4%	69689	8	$11.5^{+4.8}_{-3.4} \cdot 10^{-5}$
	350 MeV	35.9%	9.0%	220702	5	$2.3^{+1.3}_{-0.8} \cdot 10^{-5}$
	500 MeV	36.3%	14.7%	414632	3	$7.2^{+5.6}_{-3.1} \cdot 10^{-6}$
CKM prototype	200 MeV	29.5%	3.7%	65165	2	$3.1^{+3.1}_{-1.5} \cdot 10^{-5}$
	350 MeV	31.8%	8.8%	221162	3	$1.4^{+1.0}_{-0.6} \cdot 10^{-5}$
	500 MeV	29.0%	17.6%	192412	1	$5.2^{+0.8}_{-3.2} \cdot 10^{-6}$
Lead Glass	200 MeV	30.2%	3.9%	25069	3	$12.0^{+9.2}_{-5.2} \cdot 10^{-5}$
	500 MeV	26.0%	17.1%	91511	1	$1.1^{+1.8}_{-0.7} \cdot 10^{-5}$

solutions give a value for the inefficiency below the requirements for the P326 Large Angle Veto system.

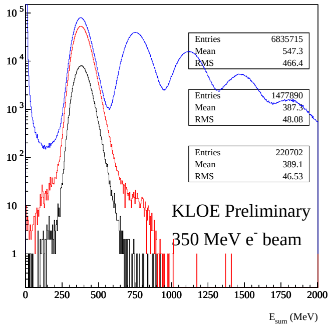

Fig. 2. Effect of the tagging system

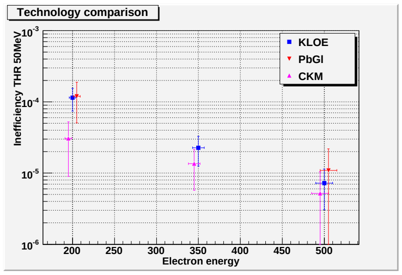

Fig. 3. Inefficiency vs energy for the 3 solutions

6. Conclusions

For the P326 experiment at CERN, three technologies for the construction of a large angle photon veto system with an inefficiency of 10^{-4} have been tested with prototypes at the Beam Test Facility in Frascati. The preliminary results for the inefficiency to electrons show that all three could satisfy the requirements of the experiment.

References

1. G. Anelli et al., *Proposal to measure the rare decay* $K^+ \to \pi + \nu\bar{\nu}$ *at the CERN SPS*, CERN-SPSC-2005-013 (2005)
2. V.V. Anisimovsky et al., Phys. Rev. Lett. **93** (2004) 031801
3. E. Ramberg et al., IEEE Trans. Nucl. Sci. **51** (2004) 2201
4. M. Adinolfi et al., Nucl. Instrum. Meth. **A482** (2002) 364
5. G. Mazzitelli et al., Nucl. Instrum. Meth. **A515** (2003) 524