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New proposal to measure O(100) events of $K^+ \to \pi^+ \nu \bar{\nu}$ at the CERN SPS

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A new proposal (P326) [1] has been submitted to the CERN SPSC to measure the rare decay $K^+ \to \pi^+ \nu \bar{\nu}$. The interest in this decay (and of $K_L \to \pi^0 \nu \bar{\nu}$) is the opportunity for testing the Standard Model and improve the knowledge of the CKM matrix in a complementary way wrt the B sector. In particular, the charged mode determines the right hand side of the unitarity triangle with different systematics from the measurements of $B_0 - \overline{B_0}$ oscillations. Moreover the decays in the kaon sector are second order weak interaction processes which probe the short distance behaviour of the SM and could be sensitive to new physics.

A new intense charged K^+ beam, with an energy of 75 GeV and 1% spread in momentum, could produce $4 \cdot 10^{12} K^+$ decays in a typical SPS year. With new detectors and the NA48 LKr calorimeter, it will be possible to reduce the background from $K^+ \to \pi^+ \pi^0$ and $K^+ \to \mu^+ \nu$ by at least 10^{12}, aiming at a signal to background ratio of 10/1. With the proposed detector the acceptance for the decay $K^+ \to \pi^+ \nu \bar{\nu}$ is around 10%. For a branching ratio of 10^{-10}, the experiment will collect about 80 events in two years of data taking, bringing the error on the vertex of the unitarity triangle close to the one obtained in the B sector.

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1. Physics motivations

The rare decays $K^+ \to \pi^+ \nu\bar{\nu}$ offer unique opportunities to test the standard Model and to improve the knowledge of the CKM matrix, being complementary to B decays. Together with $K_L \to \pi^0 \nu\bar{\nu}$, it is a very clean mode: it is dominated by short distance dynamics and the amplitude is governed by one single semileptonic operator whose matrix element can be determined experimentally with the decay $K^+ \to \pi^0 e^+ \nu$, eliminating the main hadronic uncertainties[2][3]. The rate of $K^+ \to \pi^+ \nu\bar{\nu}$ determines one of the sides of the unitarity triangle and its measurement is a valid alternative to the one using $B_0 - \bar{B_0}$, with different and possibly smaller uncertainties. Moreover the decay is very sensitive to new physics beyond the Standard Model. As the theoretical prediction is clear, one is led to very accurate constraints on new physics models. In addition an accurate measurement not compatible with the Standard Model could show direct evidence of new physics[4].

2. The actual state and the prospects of the measurement

The latest results for the branching ratio comes from E949 at BNL[5], using a stopped kaon technique. With an acceptance of 0.1%, 3 events have been found, corresponding to a branching ratio of $1.47^{+1.30}_{-0.89} \cdot 10^{-10}$, compatible within the errors with the Standard Model. It is worth to note that a future experiment collecting 100 events will have on the branching ratio an error which could rule out the SM if the mean value is the one reported by E949.

For the decay at rest technique, there is a window of opportunity for E949 to get more beam time before 2010. A letter of intent for an experiment with the same technique has been submitted at JPARC and it will likely not be operational before 2010. Decays in flight could profit from larger aceeptances and higher photon rejection. Two experiments have been proposed in the past years at Fermilab: CKM with a separated beam of 22 GeV/c kaons and KPLUS with an unseparated beam at 120 GeV/c. Both have been cancelled.

The goal of the P326 proposal is to collect about 80 events in two years of data taking, using decays in flight of 75 GeV/c K^+. The acceptance will be $\approx$ 10% and the expected intensity $4 \cdot 10^{12} K^+$ decays/year. The use of an unseparated beam allow to have higher momentum kaons, which implies a larger yield of K^+ and a better photon veto performance. The acceptance is also higher than for decays at rest. A disadvantage of this technique is the high π/K ratio in the beam and the high rate ($\approx$ 1 GHz) in the beamtracker needed to identify momentum and time of the decaying particle.

3. Background reduction

The main background source comes from the decays $K^+ \to \pi^+ \pi^0$ (21.2%) and $K^+ \to \mu^+ \nu$ (63.5%). To effectively reduce the background it is planned to use kinematics cuts on the missing mass and hermetic photon and muon detectors.

With the measurement of the pion and of the kaon momenta, one can define a squared missing mass m^2_{miss} under the assumption that the final charged particle is a pion.

$$m^2_{miss} \simeq m^2_K \left(1 - \frac{|P_\pi|}{|P_K|}\right) + m^2_\pi \left(1 - \frac{|P_K|}{|P_\pi|}\right) - |P_K||P_\pi|\theta^2_{\pi K}$$

Without resolution effects, the m^2_{miss} distribution for $K^+ \to \pi^+\pi^0$ is a line at $m^2_{miss} = m^2_{\pi^0}$. The distribution for $K^+ \to \pi^+ \nu\bar{\nu}$ overlaps this line and can be divided into two regions

$$\text{(I) } 0 < m^2_{miss} < m^2_{\pi^0} - (\Delta m)^2$$
$$\text{(II) } m^2_{\pi^0} + (\Delta m)^2 < min(m^2_{miss}(\pi^+\pi^+\pi^-)) - (\Delta m)^2$$

where Δm term depends on the resolution.

Assuming veto inefficiencies of 10^{-8} for photons and of $5 \cdot 10^{-6}$ for muons, it has been shown that for S/B $\geq$ 10 with an acceptance > 10%, $(\Delta m)^2$ should be around $8 \cdot 10^{-3} GeV^2/c^4$. This will translate in a requirement for the resolutions of 0.3% on kaon momentum, of better than 1% on pion momentum and of 50-60 μrad on kaon-pion angle. These requirements define the performances of the upstream and downstream spectrometers, the Gigatracker and the Double Spectrometer. A critical aspect is that the rate in the Gigatracker is around 1 GHz and a wrong association of a kaon upstream with a pion downstream degrades the rejection factor. To avoid that a very good time resolution (better than 150 psec) of the Gigatracker is needed.

Photons from $K^+ \to \pi^+\pi^0$ have a wide range of energies and angles. To efficiently veto them a quasi hermetic system of photon vetoes will be used. The system is made up of a forward Small Angle Calorimeter, two Intermediate Ring Calorimeters, the NA48 LKr Calorimeter and 13 Large Angle Vetoes and have an hermetic coverage up to 50 mrad. Above this angle, some photons will not be detected, but their fraction is below 1% with a very little contribution to the average π^0 detection inefficiency (as the other photon will hit one of the vetoes). A π^0 rejection of better than 10^8 is expected.

The background from muons is handled with a Magnetized Muon Detector at the downstream end of the experiment, composed of magnetized iron (with a P_t kick of 1.5 GeV/c) and extruded scintillator.

4. The beam and the detector

The choice of a K^+ beam of 75 GeV/c is the compromise among several conditions which vary with momentum and also it appears to be the maximum momentum for which a beam with the requested characteristics could be built with conventional beam elements in the existing available length. The beam design is derived from the NA48/2 simultaneous K^+ and K^- beams [6]. The main feature is an achromat system made with four dipole magnets and a momentum-selecting slit to allow the selection of a narrow ($\approx 1\% \Delta p/p$) momentum. It is followed by focusing, muon sweeping and additional focusing to bring the beam parallel. At this point a CEDAR differential counter [7] is installed to tag only the K^+ in the beam. After the CEDAR there is another achromat where the silicon detectors of the Gigatracker are installed.

With a nominal intensity on target of $3 \cdot 10^{12}$ protons/pulse, the number of kaon decays in the fiducial region is about $1.6 \cdot 10^7$/pulse, giving in a typical SPS year $4 \cdot 10^{12}$ decays. The rate in the Gigatracker is about 1 GHz.

5. The detectors

A schematic of the layout of the experiment is shown in fig.1. Besides the already mentioned detectors, there are shown:

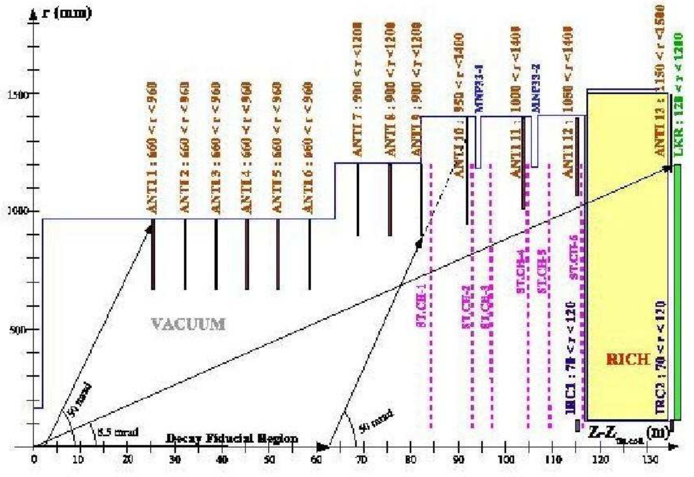

Figure 1: A schematic of the proposed detector

- the double spectrometer, composed of 2 magnets and 6 straw chambers (4 planes each) for redundant momentum measurement
- a RICH counter, designed to separate pions from muons and to give an additional and redundant identification of muons
- a charged hodoscope made with glass RPC to have a precise timing of the charged track to be used in the trigger

6. Time schedule

The Collaboration has submitted the proposal during 2005 to the CERN SPSC, following a statement of support by the Villars report, where the case for the esperiment was presented as a Letter of Intent. In parallel to the preparation of the proposal, R&D activity has started in several areas. It is expected to have the approval in 2006. The construction of the detectors will be done in 2007-2008. The final goal is to have the first run in 2009 and to complete the measurement in 2010.

References

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