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Redesign of the CKM RICH Velocity Spectrometers for use in a 1/4 GHz Unseparated Beam

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Abstract

I report here a redesign of the CKM RICH velocity spectrometers for use in a 1/4 GHz unseparated beam adapted to the KTeV beam line and detector hall at Fermilab (P940). The redesigns reported here comprise modest modification to the original designs for CKM(E921) to accommodate the change in beam flux, momentum, and momentum bite of the primary beam. The ultimate performance of the velocity spectrometer systems, as quantified by the missing mass squared resolution for $K^+ \to \pi^+ x^0$, remains largely unchanged from the original design.

Key words:
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1 Introduction

CKM(Fermilab E921) is an approved experiment to measure $\mathrm{Br}[K^+ \to \pi^+ \nu\overline{\nu}\,]$ with 100 signal / $<$ 10 background events in a high flux separated beam at 22 GeV/c. The P5 sub-committee of HEPAP stopped CKM in October 2003 for lack of resources.

P5 judged CKM to be an elegant world class experiment which based on present budgetary models should not proceed.

Since that time the CKM collaboration has undertaken a redesign of the experiment in order to make this world class measurement at a cost the field can afford.

2 Redesign Requirements

An analysis of the costs associated with CKM identified the new superconducting RF separated beamline and all its associated new civil construction as the major cost driver. At the same time the NA48 collaboration at CERN demonstrated successful operation of a new ultra high rate

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tracking chamber (μMegas) [1]. This advancement in detector technology allows us to consider a redesigned experiment in an unseparated beam using the existing beamline and detector hall previously built for the KTeV experiment at Fermilab.

Re-optimizing the experiment for an unseparated beam leads to a $\Delta p/p \pm 15\%$ beam at twice the beam momentum. The 50 MHz beam rate becomes 230 MHz for which ultra high rate tracking technology is required. The photons which must be vetoed to control critical backgrounds become much more energetic substantially reducing difficulty, and the cost, of the photon veto systems required. The redesigned apparatus (P940) is shown in figure 1. The concept and design of the experiment remains unchanged save that the upstream kaon tracking system now need to handle a 230 MHz flux and the photon veto system is suitably descoped.

3 Redesign for P940

The redesigned P940 layout is shown in Figure 1. The coordinate system has its origin at the kaon production target and the detector elements are arranged to fit into the existing KTeV beam enclosure (NM2) and detector hall (NM3-4). We estimate, by subtraction of costs no longer required, that the redesign should require 1/4-1/3 of the 101M\$ cost estimate of the separated beam proposal.

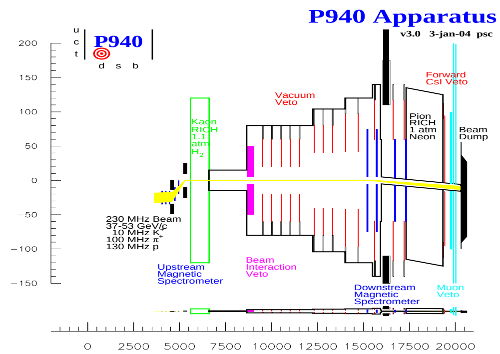

Fig. 1. overall plan view layout for the P940 design.

3.1 Beamline

With the choice of an unseparated $37 - 53\,\mathrm{GeV/c}$ positive beam with a $1\mu sr$ solid angle produced by $120\,\mathrm{GeV/c}$ protons on a 1 interaction length ($40cm$) Be target the fluxes of particles [2] entering a decay volume $86m$ downstream of the production target are shown in Figure 1.

The secondary beam is achromatic (no net bend) in the decay volume. This is a requirement of both the geometry of the NM2-4 enclosures and the need for a small parallel beam. The goal for the beam size is $1 \times 1cm^2$ in the decay volume with small $\sim$ 0.1 mrad angular divergence.

The upstream kaon decays in this beam amount to only 23% which greatly reduces the flux of muons in the detector relative to the separated beamline. Pion decays are at $1.4\times$ the rate of kaon decays. The majority of the muons from pion decays will remain inside a $5cm$ radius beam pipe for the $\sim$ $100m$ achromatic beam region.

This beam-line design is motivated by the existing NA48/2 charged beam whose characteristics are similar. It is under detailed design now to adapt it to the NM2-4 enclosures.

4 Kaon RICH

The Kaon RICH now needs to measure the vector velocity of beam kaons from 37 − 53 GeV/c. The working gas of choice is Hydrogen at $\sim 0.9\ atm$ with a 12 m long gas volume and a single 12 m focal length mirror with a 2 cm hole for the beam. The lowest momentum kaons have a 5 mrad Cherenkov angles so the light from the last $2m$ of gas goes in the mirror hole. The ring radius distribution across the phototubes is approximately uniform. We require about 300 PMTs for the kaons rings with an average rate of 300 kHz per tube.

Looking at the 100 MHz of beam pions is very difficult. All the pion light would hit one ring of $\sim$ 70 PMTs with 30 photons per pion for an average tube rate of $\sim$ 40 MHz. Protons are below Cherenkov threshold an therefore unobservable in this counter. The Kaon RICH provide a precision spectrometer for only the kaons allowing us to measure well the velocity and time of only the 4% kaon component of the beam.

4.1 Redesign

The windows on the kaon rich can be small in diameter and thin enough that the material seen by the beam is very small. Either Beryllium or Kevlar windows can be used. The multiple Coulomb scattering in the RICH is $\sim 100\,\mu$rad which is comparable to the beam divergence and the angular resolution. The angle change necessary to move background events into the signal region is 10× this scale. There will be $\sim 1MHz$ of beam interactions, half from protons, in the RICH. The material in the kaon RICH dominates the material seen by the beam. A critical issue is controlling the potential backgrounds from these interactions.

Table 1
RICH parameters

parameter	K		π
	CKM	P940	
Flux [MHz]	50	230	~ 2
K^+	30	10	-
X_L $[10^{-3}]$	78	3.8	63
I_L $[10^{-3}]$	17	3.7	19
PMT_{max} [kHz]	1400	500	30
Size [m]	2.4	1.2	2.4
Radiator [m]	10	12	20
Focal length [m]	20	17	20

The layout of the Kaon RICH in the NM2 enclosure is shown in figure 3. The optical path has been unfolded from the original design in order to fit the device into the enclosure. The small transverse beam size permits a hole in the primary mirror which

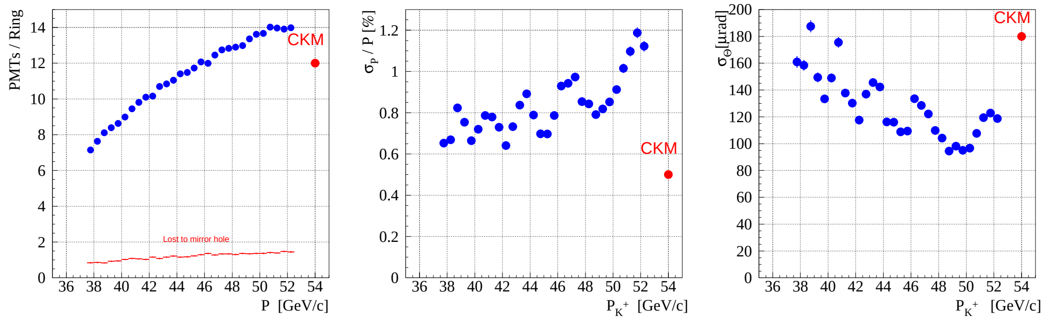

Fig. 2. Kaon RICH resolutions as a function of kaon momentum: (left) number of hits per ring, (middle) fractional momentum resolution, (right) angular resolution. Red points on each plot are the corresponding value for the CKM design at 22 GeV/c.

greatly simplifies the optics and removes the challenge of fabricating a thin flat mirror of acceptable optical quality.

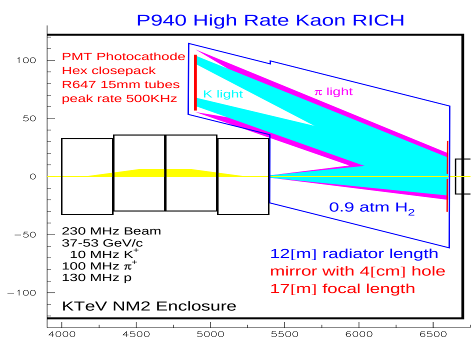

Fig. 3. Redesigned Kaon RICH in NM2 enclosure

4.2 Achieved resolutions

The number of Cherenkov photons per ring and resolutions from a full GEANT simulation are shown as a function of kaon momentum in figure 2. The equivalent resolutions for the 22 GeV/c separated beam design are shown as the red dots on this plots. The loss of Cherenkov photons to the hole in the mirror is small.

5 Pion RICH

The pion RICH design is largely the same as for CKM. It has useful velocity resolution ($\sigma p/p < 2\%$) in the momentum range $14 - 30 GeV/c$. There will now be a vacuum beam pipe running down the middle of the radiator volume to limit beam interactions. We need to split the mirror to minimize the Cherenkov photon losses from the beam pipe obstruction. Most accepted π^+'s are at larger angles than their Cherenkov angles in Neon. The loss of Cherenkov photons before they are reflected by the mirror is small.

5.1 Redesign

The layout of the pion RICH shown in figure 5. The optical paths for all Cherenkov light from accepted events and the light from an accepted π^+ near the beampipe are shown. The device is essentially the SELEX RICH [8] with twice the radiator and mirror focal lengths, implemented with a split photocathode. Its im-

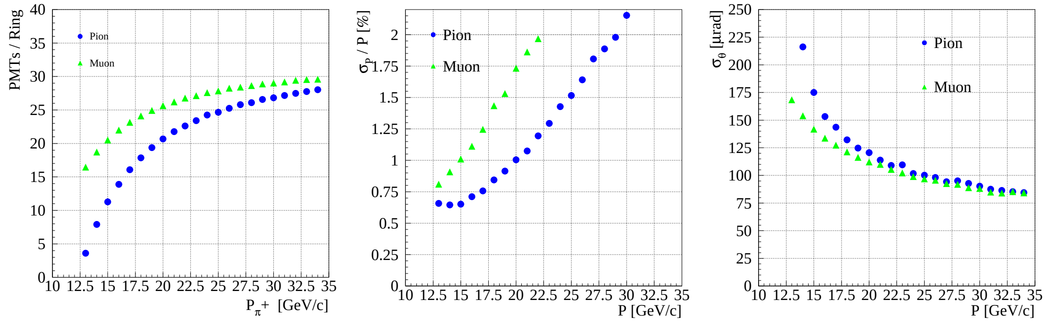

Fig. 4. Pion RICH resolutions as a function of pion momentum: (left) number of hits per ring, (middle) fractional momentum resolution, (right) angular resolution.

portant parameters are shown in Table 1.

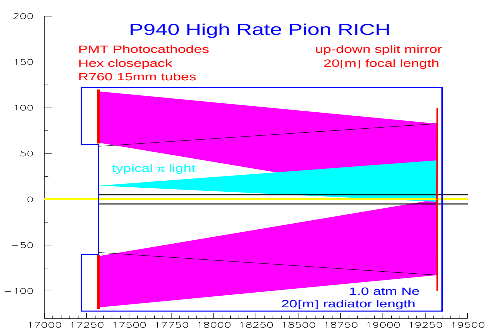

Fig. 5. Redesigned Pion RICH

5.2 Achieved resolutions

The number of Cherenkov photons per ring and resolutions from a full GEANT simulation are shown as a function of pion or muon momentum in figure 4. The loss of Cherenkov photons to the beampipe is small.

6 Summary

The final criterion for the requirements on the charged particle tracking systems in either CKM or P940 is the missing neutral mass squared resolution $M^2_{X^0}$ in $K^+ \to \pi^+ X^0$. The RICH velocity spectrometers and the tracking momentum spectrometers need to be approximately matched in this resolution in order to provide redundant rejection of backgrounds like $K^+ \to \pi^+ \pi^0$. In the P940 redesign the RICH resolution has degraded somewhat while the magnetic momentum resolution has improved somewhat. Either design has adequate resolution to control these backgrounds. Either CKM or P940 can achieve sufficient sensitivity to measure the decay amplitude (the square-root of the branching ratio) for $K^+ \to \pi^+ \nu \overline{\nu}$ with a statistical precision of $< 6\%$ while the theoretical uncertainty due to the charmed quark mass is $\sim 8\%$.

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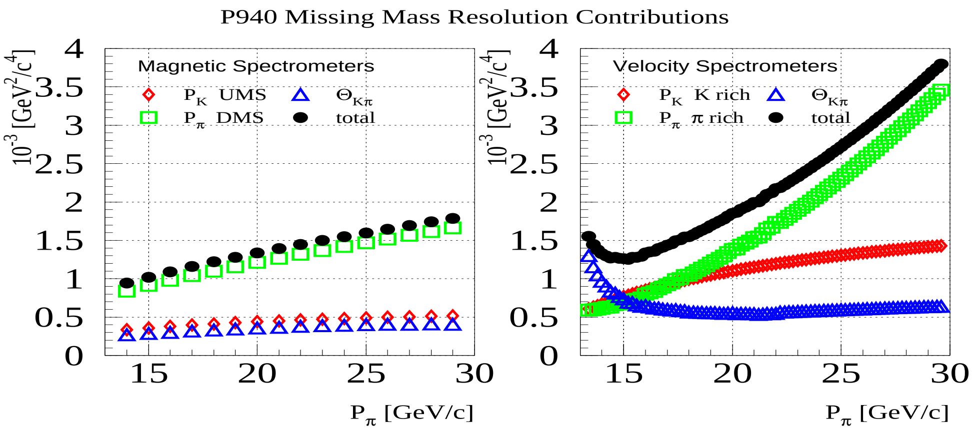

Fig. 6. Magnetic (left) and RICH velocity (right) spectrometer contributions to missing neutral mass squared resolution.

cept for phototube based RICHes as velocity spectrometers grows directly from the SELEX RICH which I first presented at the initial conference in this series in 1993 [3]. A complete list of references including the other related presentations in this workshop are included in the bibliography [4] - [14].

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