R&D proposal for the Muon Veto System (MVS)

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1 Introduction

The Fermilab experiment CKM ("Charged kaons at the Main Injector", E905) is aimed to measure the branching ratio of the ultra-rare charged kaon decay $K^+ \to \pi^+\nu\bar{\nu}$ by observing a large sample of $K^+ \to \pi^+\nu\bar{\nu}$ decays with small background [1]. Our physics goal is to measure the magnitude of the Cabibbo, Kobayashi, Maskawa quark-mixing matrix element V_{td} with a statistical precision of about 5% based upon a $\sim$ 100 event sample with total backgrounds of less than 10 events. This decay mode is known to be theoretically clean [2]. The only significant theoretical uncertainty in the calculation of this branching ratio is due to the charm contribution. A 10% measurement of the branching ratio will yield a 10% total uncertainty on the magnitude of V_{td}.

The interest to $K^+ \to \pi^+\nu\bar{\nu}$ is greatly increased after the observation the first event of this ultra-rare mode ($\sim 10^{-10}$) in the BNL E787 experiment [3]. Now the main task for further works is not only to see such a decay or another very interesting process $K_L^0 \to \pi^0\nu\bar{\nu}$, but to measure corresponding rates with a reasonable precision.

The new data for $K^+ \to \pi^+\nu\bar{\nu}$, $K_L^0 \to \pi^0\nu\bar{\nu}$ and their comparison with future CP violation data for rare B-decays give a very clean and important test of Standard Model mechanism for CP violation or the observation of New Physics effects [4–6].

The experimental technique which was proposed for CKM experiment is decay in flight in a $\sim$ 22GeV/c RF separated K^+ beam with a kaon flux of 30 MHz and a purity of higher than 70% K^+ generated with about 5×10^{12} 120 GeV/c protons per spill from the Main Injector. The detector will have redundant measurements for both the K^+ and π^+ with conventional high rate magnetic spectrometers and velocity spectrometers based on phototube ring imaging Cherenkov counters for each particle. A hermetic photon veto system capable of rejecting π^0 decays with an inefficiency less than 2×10^{-7} and a muon range stack capable of rejecting μ^+ with an inefficiency less than 1×10^{-5} are also required. The expected signal acceptance of this apparatus after all cuts will be $\sim$ 1%. A data collection period of 2 years should yield a $\sim$ 100 event signal over a background of less than 10 events assuming a branching ratio of 1×10^{-10}.

It is planned that the main efforts of IHEP (Protvino, Russia) group which is participating in CKM experiment will be connected with development and construction of the forward structure consisting of Forward Photon Veto and Muon Veto systems which are crucial for the background suppression and for the success of the experiment. Members of IHEP group have significant experience with rare photonic and muon processes in many experiments at the IHEP accelerator, CERN and in the SELEX (E781) experiment at Fermilab.

The purpose of our studies, which would be an important part of generally approved R&D program of CKM experiment [7], is the design, construction and testing the prototype module of high efficiency muon veto system and technical design of the muon veto system for the CKM experiment.

2 The Muon Veto System

Muon rejection in CKM is critical for the background rejection and the separation of $K^+ \to \pi^+\nu\bar{\nu}$ decay. Studies of potential backgrounds from $K^+ \to \mu^+\nu$ and $K^+ \to \mu^+\nu\gamma$ have shown that muon rejection of 1×10^{-5} or better is needed for muons with momentum above 14 GeV. Our design goal for the muon veto system will exceed 1×10^{-5} by a conservative safety factor up to the level of $\leq 10^{-6} \div 10^{-7}$. The technique relies on the penetrating nature of muons versus pions. For example, a one meter thick iron absorber followed by a hodoscope can almost fulfill this task since most muons will penetrate and make signals in the hodoscope, while only a few pions will create such signals (via the punchthrough of cascade particles from the pion's hadronic interaction). Those pions producing such false muon signals introduce an inefficiency, not background. The limitation on this technique is that not all muons penetrate the iron absorber. Some decay inside the absorber and others catastrophically loose a large fraction of their energy — most often but not exclusively via bremsstrahlung — and then range out in the absorber. These occurrence will fake the pion signature. In our preliminary GEANT study it was shown, that such a technique with compact absorber gives the muon rejection power only on the level of $(2 \div 3) \times 10^{-5}$ which is inadequate by an order of magnitude.

By longitudinally segmenting the absorber and instrumenting the layers by hodoscope scintillators, it is possible to improve the muon rejection considerably. Muon decays produce electrons which will typically induce observable electromagnetic showers. Most catastrophic energy losses in the bremsstrahlung processes also produced electromagnetic showers. Only a small fraction of muon interactions induce hadronic showers similar to those associated with pion interactions. That is, by standard techniques for discriminating between hadronic and electromagnetic showers, it is possible to enhance the muon rejection by a large factor. The ultimate limitation on this technique comes from the cross section for high-inelastic muon scattering on nuclei which creates hadronic showers.

For the rejection of the electromagnetic showers linked with muon decays $\mu \to e\nu\bar{\nu}$ or with a high-inelastic muon bremsstrahlung the criteria connected with the relatively short length and small width of electromagnetic showers in the dense absorbers with small radiation length (lead, iron) were used.

We have performed a preliminary GEANT study with a model calorimeter shown in Fig.1. It consists of 13 elementary periods (4 cm Lead or Iron + 1 cm. Scintillator) with the total length of 130cm. The scintillator planes are devided into 4 cm strips (alternating X,Y), viewed by PM's. The signals from PM's are registered by simple latches, 1300 channels in total. "Standard" sandwich-like Pb-Scint electromagnetic calorimeter with a total length of

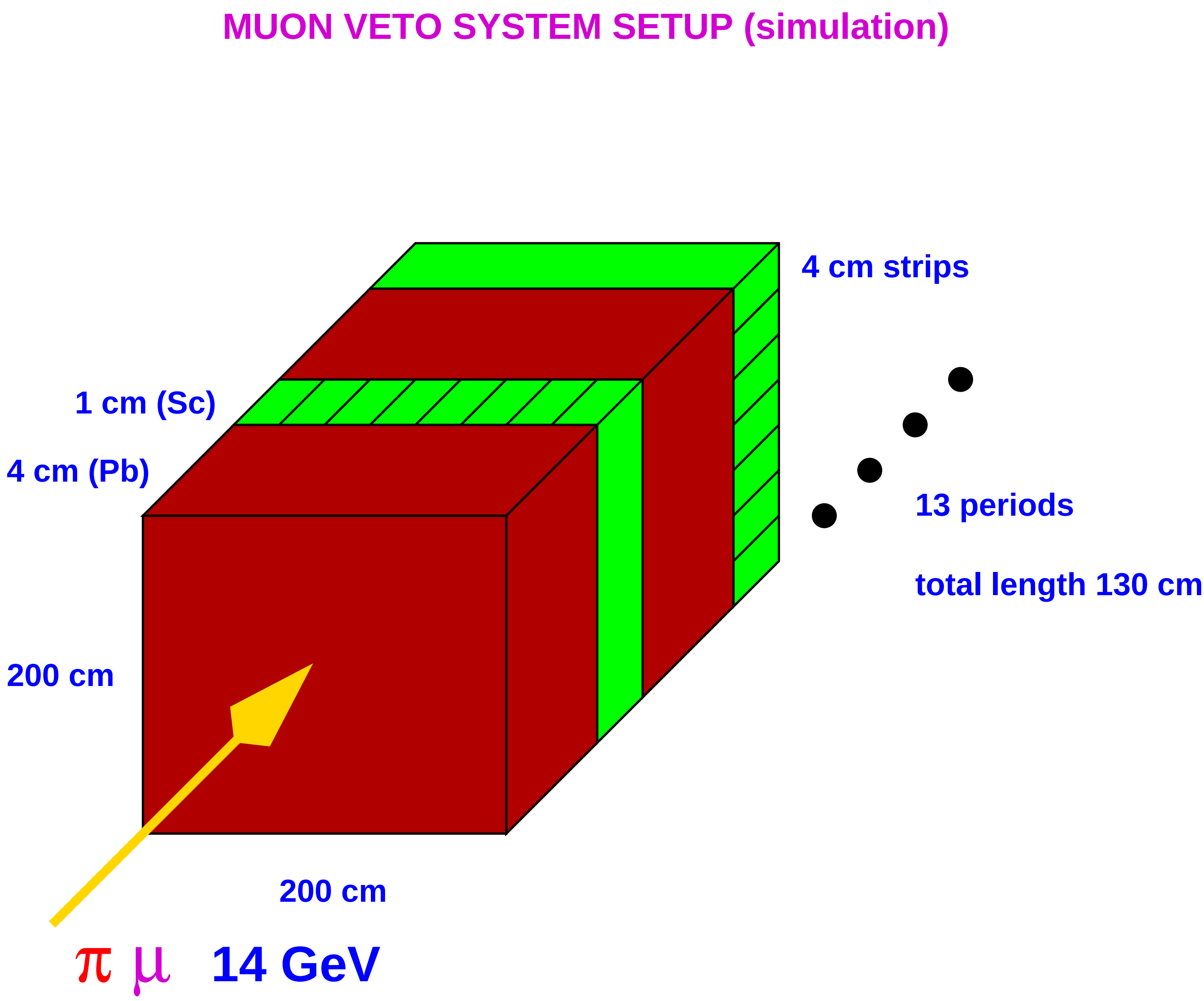

Figure 1: The Muon Veto model setup used in the GEANT simulation.

20 X_0 was placed in front of the setup. About 7.5×10^7 μ and 5000 π with momentum 14 GeV were passed throug the setup. Muons with momentum > 1 MeV were assumed to be detected by veto hodoscope surrounding the setup. For the events where there was no signal in the veto hodoscope, the number of planes with more than 2 strips fired with the threshold > 100 keV , as well as the total number of fired strips in such a planes was considered, the corresponding distributions for muons and pions is shown in Fig. 2.

Using a cut(for π identification) on number of planes $N_l > 1$ and on number of strips $N_h > 12$, the rejection of 1×10^{-7} (for lead) or 4×10^{-7} (for iron) was achieved. The efficiency of pion detection in these systems is $\varepsilon > 0.85 \div 0.90$. It seems that further increase of muon rejection power for the segmented muon veto system is possible, from longitudinal profile, for example.

3 Description of the R&D studies for the Muon Veto System

In the framework of CKM R&D program our group plans to carry out the following tasks:

(a) To perform a detailed GEANT MC simulation of Forward Photon Veto and Muon Veto to optimize the segmentation and parameters of the device and to achieve the rejection power for muon suppression on the level of $\leq 10^{-7}$.

(b) To build a prototype module of the muon veto and to test it in the muon beam of the IHEP accelerator (with energy of muons $E_\mu = 14 \div 20$GeV) to obtain experimental verification of the possibility to achieve the rejection power for muon suppression on the level of $\leq 10^{-6} \div 10^{-7}$.

(c) To complete a preliminary technical design of Muon Veto System for the CKM experiment.

(d) To test a full scale ($\sim$ 2m) counter.

(e) To test a multianode PM readout.

(f) To perform Monte Carlo calcullations for different background processes in the CKM experiment.

Proposed prototype module of muon veto system (see Fig .3)

consists of 26 hodoscope scintillator planes with transverse dimensions $48 \times 48 cm^2$ and with thickness of 1 cm. Each plane contains 12 x- or y- counters ($48 \times 4 \times 1 cm^3$). The planes are separated by lead or iron filters with thickness of 4 cm. Total number of scintillation counters in the module is $26 \times 12 = 312$. These parameters are preliminary and would be optimized by GEANT Monte Carlo simulation. The cost estimate for the prototype are presented in Table.1. As it is seen from the table, IHEP needs an extra support of $14600 from FNAL(iron, cables, mechanics) if scintillator + fibers will be provided by FNAL.

In this project we will use in a full scale the existing experimental equipment and infrastructure of our SPHINX and ISTRA-M setups at IHEP, the existing beams of IHEP accelerator, the support of our home institutes, the experience of IHEP engineering and

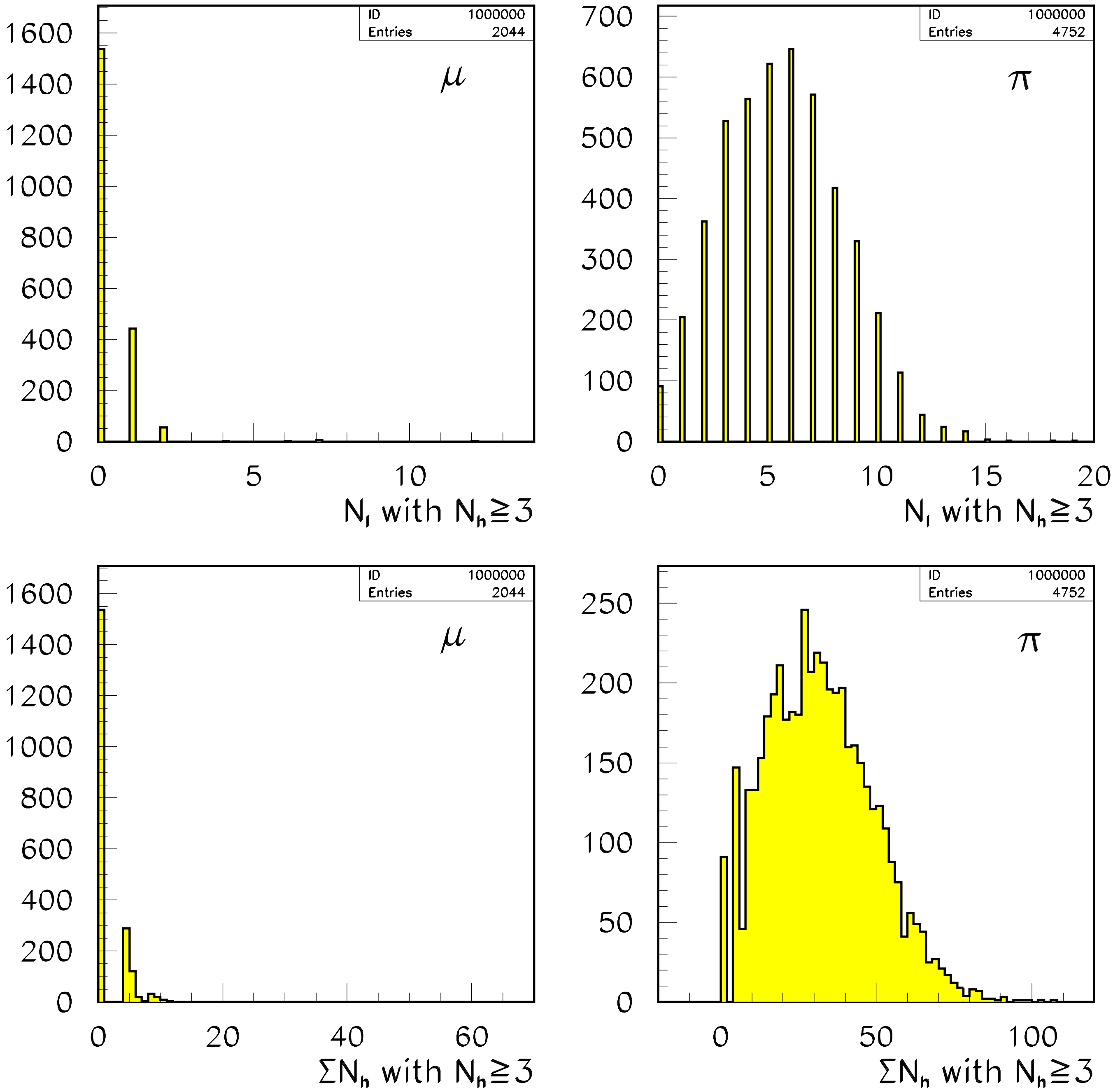

Figure 2: The distributions over number of "fired" planes and total number of "fired" strips in them for muons and pions absorbed in the calorimeter.

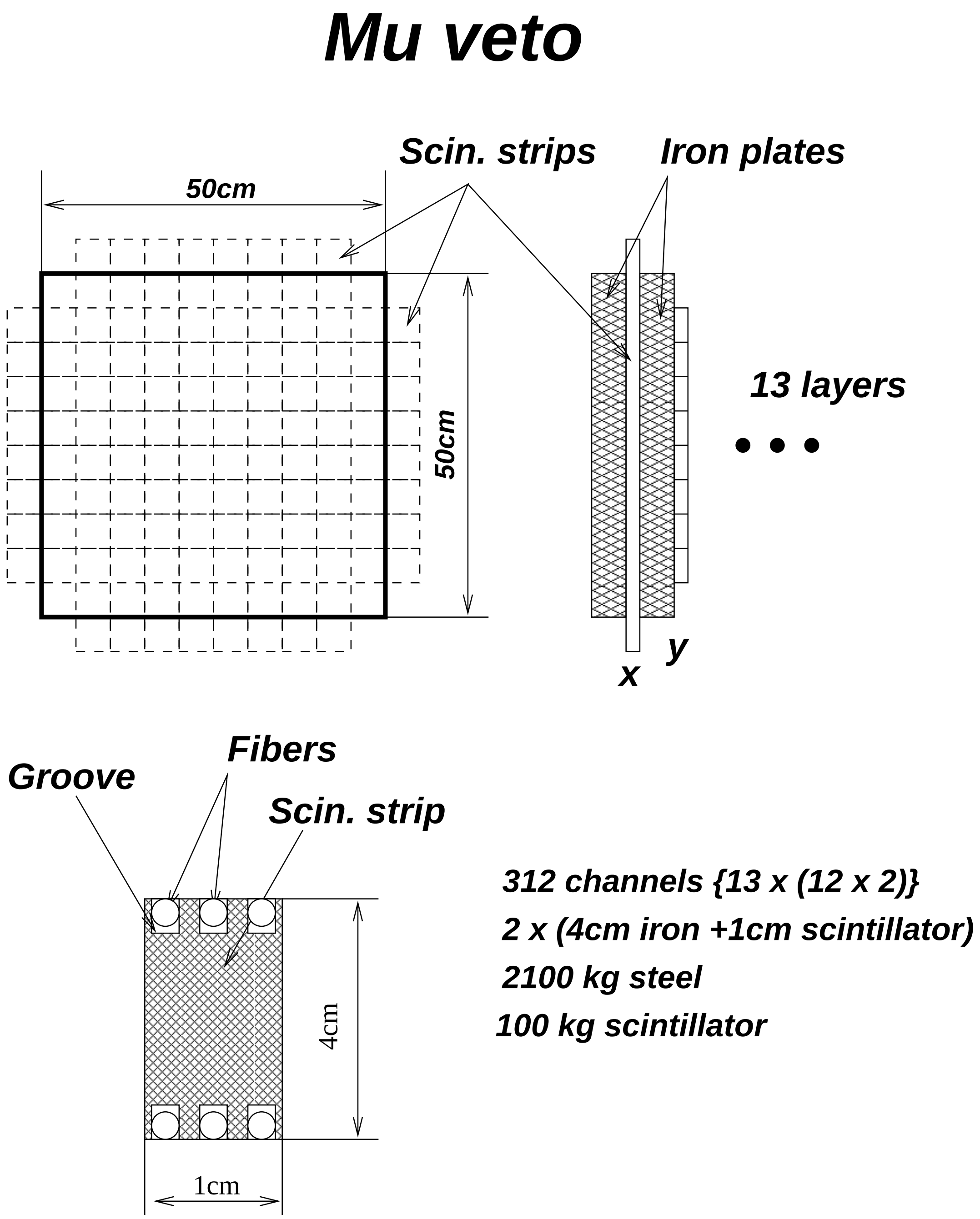

Figure 3: The structure of the prototype of the Muon Veto.

Table 1: The cost estimate for the MVS prototype construction

Item	Cost	Comment
Iron plates	$2600	
Scintillator raw mat.	$600	some scint. exists at FNAL
Scint. molding form	$5000	if scint. produced at IHEP
Cables, connectors	$8000	
WLS fibers, 6m/strip=2000m	$2000	exists ?
PMT's,	$21840	provided by IHEP
HV bases	$9360	provided by IHEP
support mech. structure	$4000	
Total	$14600	If scintillator+fibers provided by FNAL

technical personnel. We plan to perform the measurements in the November-December run of the IHEP accelerator. To insure that, the material and financial support from FNAL should come in the spring,2000.

References

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