Muon System R&D Overview

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0.1 Introduction

The primary aim of the muon system R&D is to validate both possible detector choices and to develop cost-effective read-out designs. The RPC R&D effort is focused on adapting the KPIX ADC to digitize RPC signals[1]. Other studies will measure the aging characteristics of IHEP RPCs and search for gas mixtures or cathode materials with better aging properties[2]. The groups involved with the scintillating strip option will evaluate SiPM devices from different manufacturers and develop mounting, temperature control, and calibration designs[3]. Both the KPIX and SiPM effortswill be applicable to the HCAL RPC and scintillator detector options. Further details of the Muon System R&D plans can be found in the individual R&D proposals [1, 2, 3].

0.1.1 RPC R&D

Close integration of the RPCs and front-end and digitization electronics is necessary to minimize cabling and costs. It is imperative that low cost, reliable readout schemes for the RPCs be developed since the expected channel counts for the SiD detector are so high (nearly one million for the muon system). One possible low cost solution is to adapt the KPiX chip, presently being developed for use in the SiD electromagnetic calorimeter, for use with RPCs. An RPC/KPiX interface board was designed and built to provide ribbon cable connections to a 64 channel KPiX chip (v7). The RPC strip signal is AC coupled to the KPiX input through a 5 nF blocking capacitor and a 2 stage diode protection network. Each strip is also tied to signal ground via a resistor external to the interface board. Signals induced on the RPC strip have a very fast rise time ($<$ 10 nsec) and a fall time determined by the RC time constant of the strip capacitance (300 pF) and R, if R is less than the effective resistance of the Bakelite cathode/anodes. Previous experiments such a BaBar and BELLE used small values of R (50-100 ohm) to make short fast signals ($<$ 100 nsec) suitable for fast timing applications. However, the present KPiX chip samples the signal after $>$ 400 nsec, requiring longer signal widths. Understanding the response of the KPiX device to different values of R and the blocking capacitor is of fundamental importance in adapting the KPiX chip to gas detectors. It is likely that optimizing the performance of the RPC/KPiX will require modification of the KPiX shaping and integration times. Future KPiX versions are planned to have more timing options.

A BaBar test RPC was connected to the interface board by a .5 m cable.The chamber was operated at 9300 V in avalanche mode using a premix gas with composition of 75.5% Freon 134a, 19.4% argon, 4.5% isobutane, and 0.%5 SF6. The chamber efficiency had been previously measured to be >90% using BaBar electronics. The sum of the 13 RPC strips on the HV ground side (positive signal) is shown in Figure 1.The sharp spike near zero is due to cosmic ray tracks that either missed the test RPC or to RPC inefficiency. The width of this spike was 29 fC about three times larger than expected based on the noise performance of KPiX, indicating that there may be electronic pickup. The data peak is centered at 3.8 pC with a width of 2.2 pC. The data signal is consistent with, but larger than, avalanche RPC signals measured by other groups (-1 pC) which used avalanche gases with no argon component. The BaBar avalanche gas contains 20% argon and should have a higher gas gain. The size and distribution of charge in the RPC pickup strips was studied. The charge of the strip with the maximum charge for each trigger has less than half of the total charge in the event. A strip multiplicity was calculated as a function of the discrimination threshold. With a threshold of 300 fC, about 92% of the cosmic triggers have 1 or more strips hit and the average strip multiplicity is 3.1, more than twice that observed in BaBar. High strip multiplicities are undesirable since they degrade the position resolution and the ability to separate two tracks near each other. Further characterization and optimization of the interface board between the RPC and KPiX chip is needed to understand the larger than expected noise and strip multiplicities that were observed.

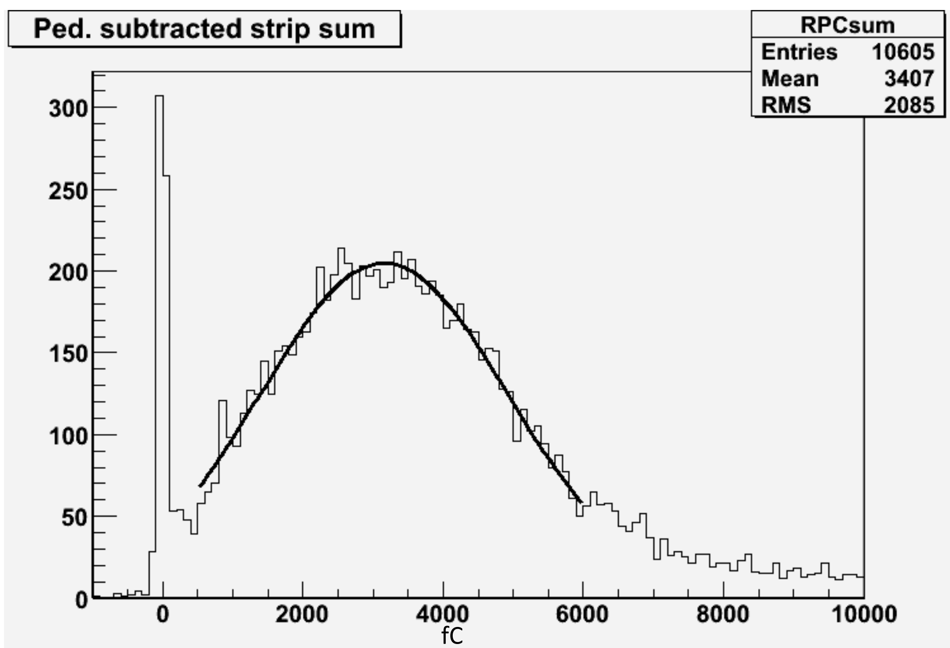

Figure 1: Sum of the pulse heights in 13 RPC strips readout by KPIX. The peak position of ∼3 pC and efficiency of >90% are consistent with previous studies of avalanche mode RPCs.

Many large RPC systems have been built within the last 10 years and understanding their performance will provide strong guidance for an SiD design. Several types of RPC construction have been used in high energy experiments. RPCs with Bakelite cathodes and anodes were pioneered by Santonico et al[4] and used in BaBar, CMS, ATLAS and a variety of cosmic ray and neutrino experiments. The early failure of many BaBar RPCs stimulated detailed study of RPC aging and lead to many significant improvements in construction practices and operation. The linseed oil used to coat the inner HV surfaces has often been a source of concern. The IHEP group and Chinese industry have developed a Bakelite /melamine cathode for use in the BES III and Daya Bay detectors that does not require linseed oil treatment to achieve acceptable noise rates. These RPCs are operated in streamer mode in their present applications. SiD proposes to operate its RPCs in avalanche mode. Tests of IHEP RPCs in avalanche mode will be used to determine the efficiency, current and noise rate as a function of HV and gas composition and to establish their suitability for use in SiD. Longer term tests will also be needed to investigate the aging properties of the IHEP RPCs. All of the working RPC systems utilize Freon as a major gas constituent. Several researchers have found significant levels of HF acid in the exhaust gas indicating the breakdown of the Freon or SF6 during the gas avalanche or streamer. BELLE found that in the presence of water vapor that the HF would etch the glass surface, generating sizable noise currents and lowering efficiency. The effect on Bakelite RPCs is less understood, but there is clear evidence that pollutants generated by high rate in the gas can affect both the noise rate and dark current. Groups from the University of Wisconsin and Roma have measured the fluorine levels of the exhaust gas in both streamer and avalanche RPCs at BaBar and correlated these levels with the chamber current, noise rate, and efficiencyl[5]. Further studies of BaBar RPCs may shed light on the long term effects of HF on the Bakelite surfaces. Longer term goals are to develop RPC gas mixes which either eliminate or substantially reduce the Freon component. A group at Princeton University is also studying the effect of HF on Bakelite surfaces and will extend these studies to the new RPCs developed by IHEP.

0.1.2 Extruded Scintillator and Photodetector R&D

In 2000 it was noted that the ILC muon system requirements could be met with a MINOS type scintillator detector design[6] that would give both muon identification and be used to measure the tails of late developing or highly energetic hadron showers. This seems rather appropriate since the depth of the ILC calorimeters is limited because they are inside the superconducting (SC) solenoid. As an example, neutral hadrons that represent ∼11% of the final-state energy in Higgs and W-W production, primarily neutrons and K_L's, prove to be difficult to identify and measure[7]. The physics case for tail catching of showers is based on improvement of jet energy resolution when the energy downstream of the SC solenoid is included in the definition of jet energy[8],[9].

The MINOS experiment has already proved that a strip-scintillator detector works well for identifying muons and for measuring hadronic energy in neutrino interactions. The ILC R&D muon scintillator detector effort is directed at understanding how to deploy such detectors in the ILC environment and to understand possible improvements that could lead to reduced complexity and /or cost, with photon detection based on SiPMS.

A possible layout of quadrant strips for the forward muon scintillator system could have alternate planes of detectors rotated by 90^o relative to each other. Each quadrant would contain $\sim$ 158 strips 4.1 cm wide and of variable length. The mean strip length is 5.05 m. Muon scintillator-strip detectors located in the Fe barrel octant gaps could be arranged in planes where the u-v strips are oriented at $\pm\, 45^o$ to a plane's edges or, alternatively, parallel to the edges in x-y fashion.

Earlier strip-scintillator R&D[10] using 4.1cm wide by 1cm thick extruded MINOS style scintillator that was readout with multi-anode photomultiplier tubes (MAPMTs) demonstrated that > 9 photo-electrons were achieved with 1.8m long strips in which the wavelength shifted scintillation light was carried to MAPMTs through a thermally fused clear optical fiber to the MAPMT a few meters away[11]. The measured light transmission was required to be $> 80\%$ for each splice.

We have recently procured Silicon based photon detectors (SiPMS) for tests with our scintillator. Sixty multi-pixel photon counters (MPPCs) have been purchased from Hamamatsu: 20 each of 100, 400 and 1600 pixels in a 1 mm square array. In addition INFN Udine-based collaborators have obtained 100 IRST SiPMS that have approximately 688 pixels inside a 1.2mm dia. circular matrix for muon/tailcatcher R&D.

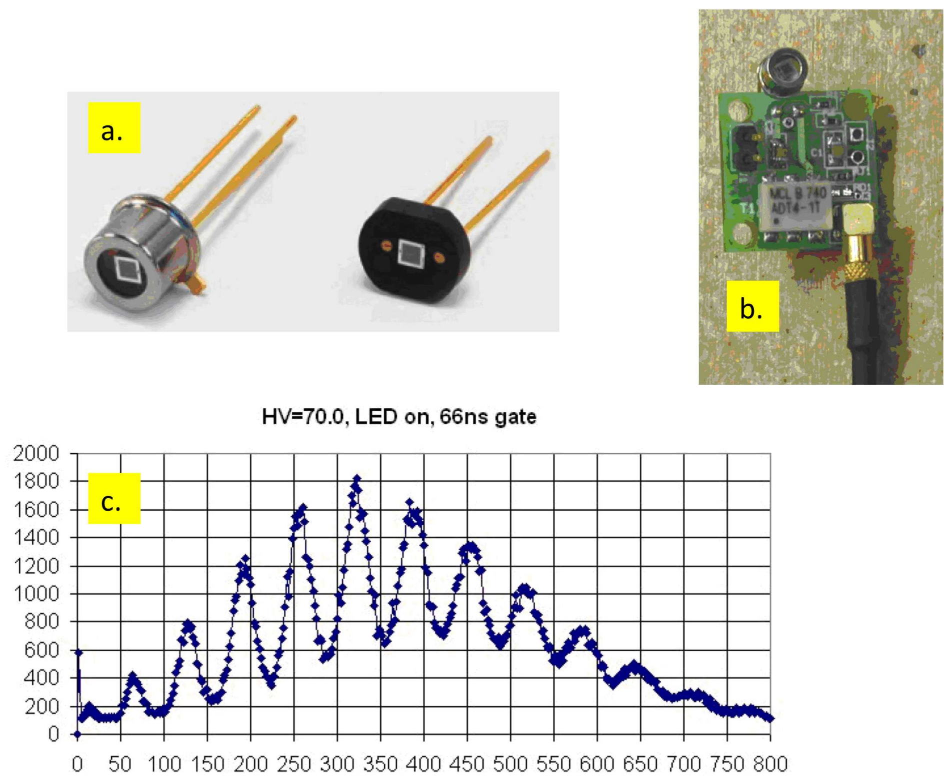

Figure 2: SIPM Hamamatsu MPPC and 2cm scale front-end electronics test setup. The output is generated with a pulsed LED providing the input light.

Recently strips with MPPCs and IRST devices have been assembled and tests with beam have begun. A real advantage of the SiPMS is the ability to see the summed output from the full assembly of pixels and observe in a pulse height spectrum that shows a number of photo-electron peaks. A modest calorimetric disadvantage is that the SiPMs put out spontaneous pulses with no defined input (noise). This disadvantage can be parlayed into an advantage in terms of calibration. With a good oscilloscope one observes bands of 1, 2 and sometimes 3 photo-electrons from which a reasonable calibration is possible. This calibration aspect needs study and engineering, which is part of our proposed R&D program. It should be mentioned that during our test beam studies we accumulated well over a million triggers using a 1.8m long strip and observed 100% efficiency when triggers were formed with independent trigger counters. Figure 2 shows an MPPC output spectrum from a test circuit and constant amplitude input LED pulses.

The SiD Muon Studies group consists of physicists from: Fermilab, Indiana U, INFN Udine, Livermore, NIU, U Notre Dame, Rochester, Wayne State and Wisconsin. These groups are testing RPCs, scintillator, SiPMS, prototype planes, frontend electronics and we are using beam test results to understand issues and costs associated with the application of RPCs and strip-scintillator technology to an LC muon system. The tests are an exploration of construction issues, device characteristics such as pulse shaping, readout, amplitude, gain and cross-talk, digitization, packaging, cables, signal collection from many strips and their transport from the detector to signal storage. A list of R&D items with the priorities and personnel is shown in Table 1.

0.1.3 Milestones

- RPC/KPIX proof of principle -2008-9
- Optimize interface board & protection circuitry design 2009-10
- Cosmic ray tests
- Beam tests – RPC/KPIX
- SiPM proof of principle -2008-9

Table 1: Muon/Tail Catcher R&D Summary

Rank	**R&D Item**	**Institutions**	**Personnel**	**K$**
1	Studies of KPIX/RPC readout with IHEP RPCs Continue tests of KPIX readout for RPCs in avalanche mode. Optimize interface board, test performance & reliability Begin aging tests of IHEP RPCs.	Wisconsin	H. Band & student	45 WIS
1	SiPMs from HPK and IRST - Bench Tests Current vs Bias Voltage to establish operating voltage, gain, noise rate vs. temp., threshold, etc. Test 150 devices from IRST (It.) & HPK (Jp.) LED pulser development.	Fermilab Indiana INFN Udine NIU Notre Dame Wayne State	Si Detector Facility: Para Van Kooten et al Pauletta et al. Hedin, Chakraborty, Dychkant, Zutshi. Wayne, Baumbaugh, McKenna Karchin, Gutierrez, et al.	30 F 21 IU 20 WSU
1	Strip & Fiber Mechanical R&D. Geometry of strip ends + SiPM FE miniature circuit. Prep. of ~30 strips w/WLS fiber. QC checks. Light pulser tests.	Notre Dame Fermilab INFN Udine	McKenna, Wayne Rubinov, Fisk. Pauletta	23 UND 50 F
1	MTest studies of strips and instrumentation. Calibration from photoelectron peaks. Signal/noise vs. trans. & long. position. CAMAC/Minerva electronics.	INFN Udine Fermilab Notre Dame Wayne State	Pauletta et al Rubinov, Fisk Baumbaugh Gutierrez, students	20 F
2	FE electronics devel. AC vs. DC coupling; Temp. compensated gain; Strip signal transport, collection & digitization. Multiplexing scheme.	Fermilab Indiana Wayne State INFN Udine	Rubinov, Fitzpatrick Van Kooten Karchin Pauletta	30 F
2	Tail catcher R&D with CALICE; Gain issues, E Res. vs. # of pixels.	NIU	Chakaraborty, Zutshi	30 NIU
3	Fast timing studies	NIU	Hedin	
3	Simulations. Testbeam software. Analysis software.	Rochester INFN Udine All	Manly Pauletta, et al	
4	Co-extrusion of scintillator and WLS fiber	Fermilab Notre Dame	Fisk Ruchti, Wayne,	

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