University Linear Collider Detector R&D
FY2009

RPC/KPiX Studies for Use in Linear Collider Detectors

Personnel and Institution(s) requesting funding

Henry Band
University of Wisconsin

Collaborators

KPiX, M. Breidenbach, D. Freytag, G. Haller, and R. Herbst of the SLAC National Accelerator Center.
Test IHEP RPCs, Yifang Wang and Qingmin Zhang of IHEP China.
RPC aging studies, Changguo Lu, Princeton University.

Project Leader

H. R. Band
hrb@slac.stanford.edu
510-926-2655

Project Overview

Resistive Plate Chambers (RPCs) are the present SiD baseline detector choices for both the muon system and hadron calorimeter. Front-end and digitization electronics will have to be closely integrated with the RPCs 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, ~.6 10^6 for the muon system and ~10 10^6 for the hadron calorimeter. We propose to adapt the KPiX chip, presently being developed for use in the SiD electromagnetic calorimeter, for use with RPCs. This study will extend the work started by LCDRD grant #7.8 (FY07) in which a prototype KPiX chip(version 7) was used to observe cosmic ray signals in a small test RPC. 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.

Several types of RPC construction have been used in high energy experiments. RPCs with Bakelite cathodes and anodes were pioneered by Santonico et al 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. Since RPC aging effects are believed to be proportional to the total integrated charge produced by the detector, 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. Longer term tests will be needed to investigate the aging properties of the IHEP RPCs.

For the RPC and KPiX tests we will build and maintain a cosmic ray test-stand utilizing spare BaBar RPCs and electronics with test RPCs provided by our IHEP China collaborators. In the first project year we will fully characterize the IHEP RPCs and continue tests with the KPiX chip. We hope to understand the KPiX response as a function of the interface board components and operating modes. With control of the electronic noise it should be possible to readout multiple RPCs by using all 64 channels of the present KPiX chip (v. 7). From this data we could then reconstruct cosmic rays tracks through our apparatus and study the position resolution and efficiency of the IHEP RPCs. Reconstructed tracks will also allow us to study RPC geometries of interest to the hadron calorimeter (arrays of 1 cm square pads). Study of the KPiX chip and the IHEP RPCs over several years will also demonstrate the robustness and stability of the IHEP RPC and KPiX readout option, validating them as the preferred SiD detector and DAQ choice.

Broader Impact

The cosmic ray test-stand developed and maintained for this proposal should prove useful in tests of other SiD detector elements readout by the KPiX chip and provide valuable experience in the operation of the KPiX device. We hope to extend our tests to the glass RPCs and GEM detectors proposed for use in the SiD hadron calorimeter. The test-stand is also an ideal detector to give graduate students experience in detector hardware and analysis.

Results of Prior Research

The proposed work continues and extends studies of the KPiX chip and IHEP RPCs started under the FY07 LCDRD grant 7.8 “RPC and Muon System Studies”(20k$). The RPC aging studies build upon studies of the BaBar RPCs which were supported by the Wisconsin base grant. Although the nominal LCRD grant time period was from Sep. 2007 to Aug. 2008, funds were only available in Wisconsin after early 2008. The time period has been extended by a year. The milestones for this grant were:

FY2007/8 Milestones:

1. Rebuild Cosmic ray test-stand
2. Interface KPiX chips to test-stand DAQ
3. Test KPiX chips with a Bakelite RPC operating in avalanche mode
4. Procure and test BESIII RPCs

The cosmic ray test stand shown in Fig. 1 was constructed from BaBar spare RPCs and spare front end electronics. The trigger chambers were ~ 1.1 by 1.3-1.6 m in size and were supplied with the standard BaBar streamer gas mix of 34.9% Freon 134a, 60.6% argon and 4.5% isobutane. Initially 4 IHEP RPCs (0.5m by 0.5m) and 2 Italian Bakelite RPCs (0.5m by 0.5m) were available for tests. A three-fold coincidence of signals from Test 1, Test3, and IHEP2 were used to generate cosmic ray triggers at a rate of ~10Hz, enabling crude efficiency measurements of RPCs mounted beneath IHEP2.

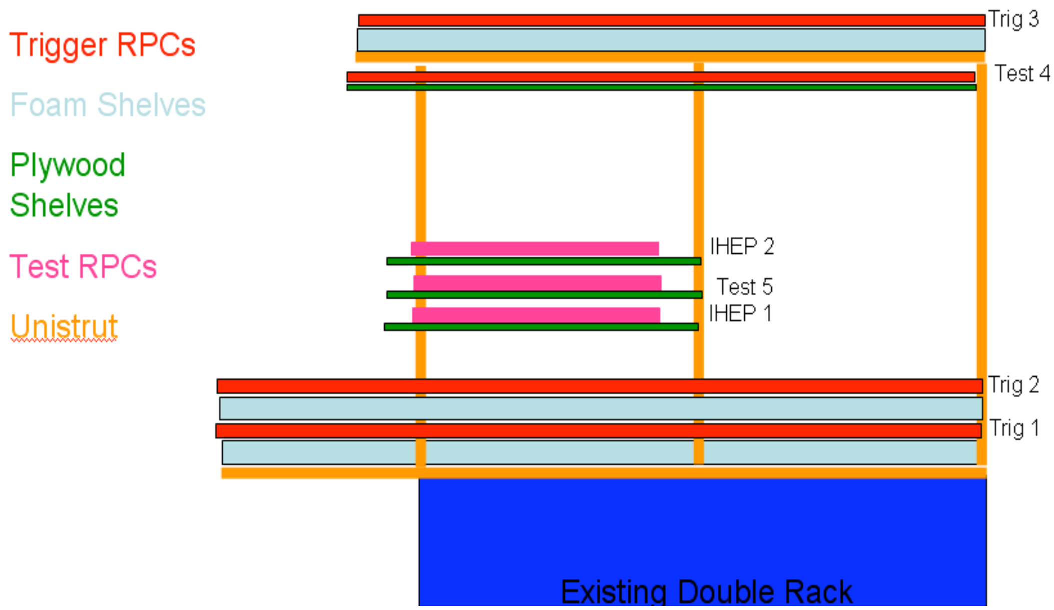

Figure 1. Cosmic ray test stand constructed from spare BaBar RPCs and electronics.

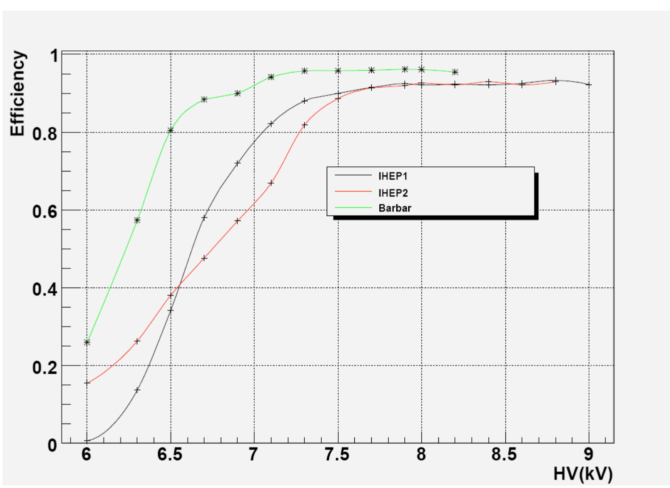

Figure 2. Efficiency vs. voltage for 3 test RPCs, approximately 0.5m by 0.5 m in size, operating with a streamer gas mix.

The original 4 IHEP RPCs were damaged during shipping and required re-gluing of 1 or more edges. Subsequent studies showed that several of the internal spacers were also broken. These IHEP RPCs required external weights to keep the gas gap near the nominal 2mm. With these weights the chambers behaved normally. The efficiency versus voltage responses of 2 of the IHEP chambers and an Italian Bakelite test RPC (labeled BaBar) are shown in Fig.2. The efficiency measurements have a systematic error of about 5% due to errors in the relative alignment of the trigger RPCs and the test RPC. The IHEP RPC efficiency curves are shifted to higher voltages, indicating that the gap size is larger than the BaBar RPC. Seven more IHEP RPCs were received undamaged in the fall of 2008 and are currently being studied.

An RPC/KPiX interface board, shown in Fig. 3, 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(~ 10^8 Ω). Previous experiments such a BaBar and BELLE used small values of R (50-100Ω) 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 prime importance to adapting the KPiX chip to gas detectors. It is not unlikely that optimizing the performance of the RPC/KPiX will require modification of the KPiX shaping and integration times. The next KPiX version (v.8) is planned to have more timing options.

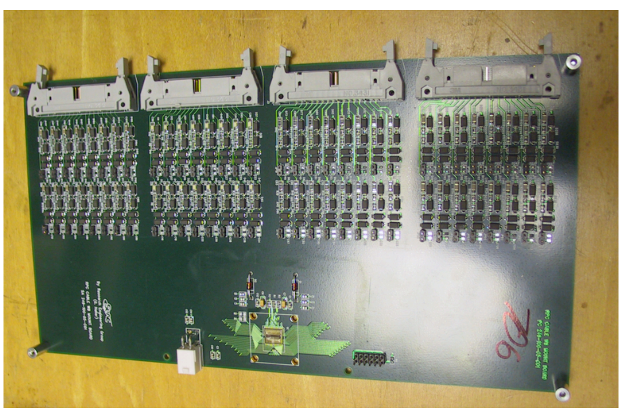

Figure 3. RPC/KPiX interface card developed for connecting the 64 channel KPiX chip to the RPC strips. The diode protection network is visible between the ribbon cable connectors and the KPiX chip located inside the square at the bottom of the card.

The BaBar test RPC was connected to the interface board by a .5 m twist&flat 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% SF_6. The chamber efficiency had been previously measured to be > 90% using BaBar electronics.

The KPiX chip was controlled and readout with UNIX based software developed by SLAC's R. Herbst and 2 intermediate timing and control cards. Since the chip is designed for a pulsed power mode appropriate to the ILC beam time structure it cannot be run continuously. The KPiX modules were powered on at ~60 Hz for ~ 1.1 msec. If an external cosmic ray trigger was received within that msec window, the KPiX data was recorded in coincidence with the cosmic ray (synchronous mode). Triggers could also arbitrarily asserted during this window independent of activity in the RPC to measure pedestal (asynchronous mode). The effective live time of the RPC + KPiX was thus about 7%, resulting in a useable event rate of ~1 Hz.

Data were taken overnight in this configuration, recorded to disk, and analyzed in ROOT. The sum of the 13 RPC strips on the HV ground side (positive signal) is shown in Fig. 4. 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, compared with the expected noise performance of the KPiX chip of 10 fC, 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.

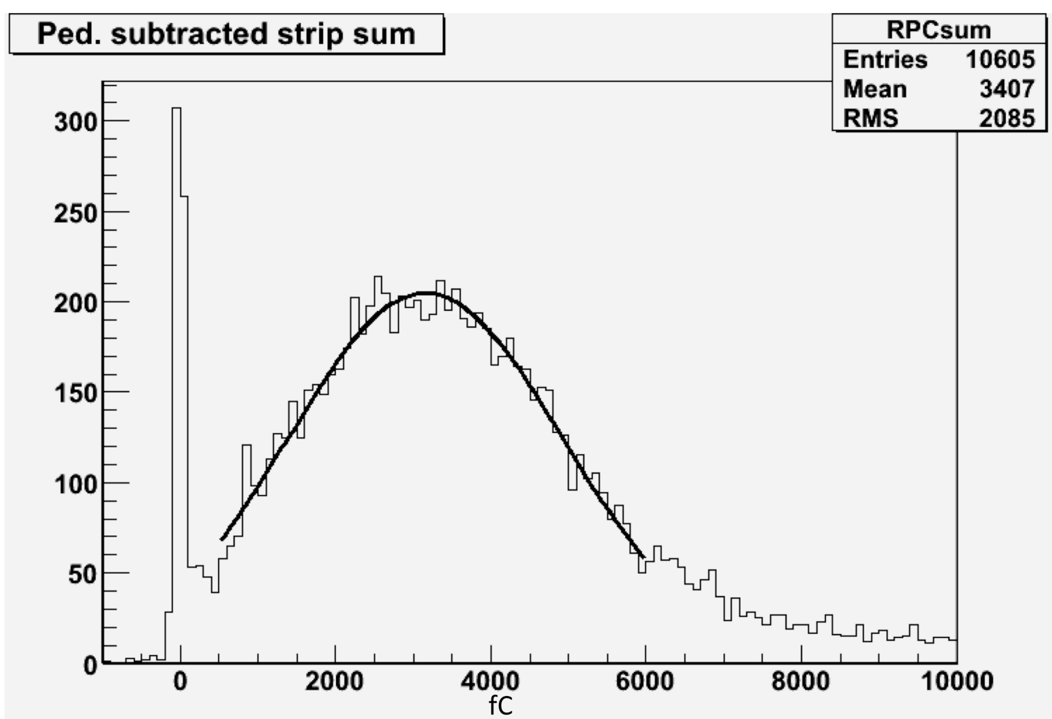

Figure 4. Pedestal subtracted charge sum of the 13 RPC strips digitized by KPiX. The pedestal peak on the left has a width of ~29 fC. Over 92% of the cosmic ray triggers have a total pulse height above 300 fC.

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 is plotted in Fig 5. Less than half of the total charge in the event is contained by the central strip. 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. The multiplicity is plotted for this cut in Fig. 6. The average strip multiplicity of 3.1 is 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. The cause of the higher multiplicity is not yet understood.

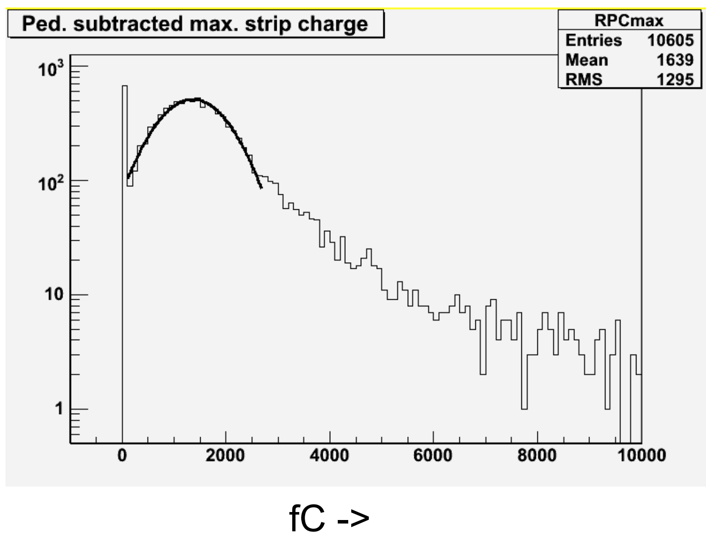

Figure 5. Pedestal subtracted charge of the RPC strip with the largest signal. Less than half of the total RPC signal is contained in the central strip.

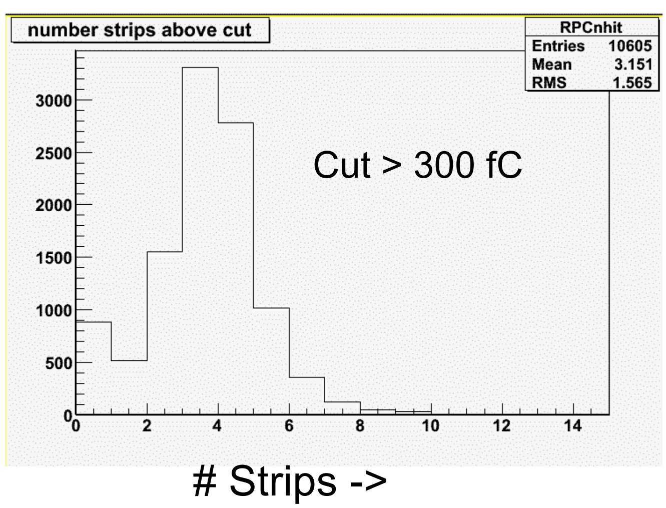

Figure 6. Number of RPC strips with > 300 fC. Approximately 9% of cosmic ray triggers have no strip above threshold. The average strip multiplicity is above 3.

When more than one plane of RPC strips were connected to the interface board a significant fraction of the events had large negative signals. Similar behavior had been observed when trying to take data in the DC reset mode of the KPiX chip. It is believed that the negative signals occur shortly after the KPiX chip is powered up. These problems will need further study to disentangle the RPC and KPiX effects.

Some or all of the recent data described above have been presented at SiD collaboration meetings in 2008 and at LCWS08 (H. Band "RPC/KPiX Studies") and IEEE08 (D. Freytag "KPiX, An Array of Self-Triggered Charge Sensitive Cells Generating Digital Time and Amplitude Information", SLAC-Pub-13462).

Facilities_ Equipment and Other Resources

The test-stand is presently located in the BaBar lab area at SLAC and utilizes spare BaBar RPCs, computers, and electronics as well as the BABAR IFR gas delivery system. Since BaBar is being dismantled and de-commissioned, the test-stand has to move. Agreements are being negotiated for use of the present BaBar gas shack. Wisconsin and our SLAC collaborators will take over responsibility for the gas shack and gas mixing system maintenance and operation. We hope to operate the mixing system for at least one more year to provide streamer gas for the trigger chambers. The smaller test chambers are supplied by bottles of pre-mixed avalanche gas. Retention of these areas is crucial to minimizing safety concerns about the use of flammable gases such as isobutane in the gas mix. The close proximity of the SLAC KPiX experts has already proven beneficial in debugging the KPiX DAQ stream.

FY2009 Project Activities and Deliverables

During 2009 studies of the IHEP RPCs and KPiX readout will continue after the test-stand has been relocated. Panels of pickup strips, HV, and gas connections will be added to the IHEP chambers. The efficiency and noise rates of the new IHEP chambers will be measured with both avalanche and streamer gas mixtures. The IHEP chambers will then be connected to KPiX (existing version 7) for further tests of the entire readout chain.

Our present understanding of the overall system noise and stability must be improved. We plan to study the pedestal and signal size as a function of the trigger time to help discriminate between KPiX timing effects and RPC noise. The different KPiX reset options will be studied as we vary the size of the blocking capacitor and strip termination resistor. We intend to reproduce the results of last summer with the IHEP RPCs and then slowly increase the number of channels and RPCs read by KPiX as we study the noise. We will test the negative input mode of KPiX by connecting strips from the HV side of the RPC. Data will be then be taken with several different avalanche gas mixes. If a new KPiX version becomes available, some of these studies will be repeated.

Preliminary measurements of HCAL glass RPC prototypes may be made using the interface board developed for the GEM chambers. When all the optimization studies are completed and we can read all the KPiX devices supported by the present hardware (3), we should be able to digitize x-y strips from 3 or 4 RPCs and reconstruct cosmic ray tracks through our test-stand.

FY2009 Milestones:

1. Relocate test-stand
2. Make current, rate, and efficiency measurements of IHEP test RPCs operating in avalanche mode.
3. Readout multiple RPCs with 1 KPiX(v. 7) chip
4. Readout negative RPC signals with KPiX(v. 7)
5. Test KPiX (v. 7 & v. 8) trigger and reset operating modes.
6. Optimize RPC/KPiX interface board design to maximize efficiency and minimize strip multiplicity.

Project Activities and Deliverables Beyond FY2009

In the following years we intend to complete optimization of the RPC/KPiX interface board and make full use of the two-dimensional position information from the trigger and test chambers to reconstruct cosmic ray tracks event by event. This will allow detailed studies of the RPC efficiency versus position and of the position resolution. Better knowledge of the cosmic position will enable more sensitive tests of HCAL prototypes. Once the present AC coupled KPiX readout is established, studies of other detector architectures (for example reading pads forming the ground plane) can be studied. Production and absorption of HF by the IHEP RPCs operating in avalanche mode will also be studied.

FY2010 & FY2011 Milestones:

1. Readout multiple KPiX chips
2. Use position and charge information from multiple RPC/KPiX devices to make fitted cosmic ray tracks
3. Study position resolution of RPC/KPiX tracks,
4. Test HCAL prototypes in teststand
5. Study response on IHEP RPCs to HF.
6. Begin IHEP RPC aging studies

Total Project Budget

Item	FY2009
Scientists	1,015
Graduate Students	14,991
Undergraduate Students	0
Total Salaries and Wages	16,006
Fringe Benefits	3,624
Total Salaries, Wages and Fringe Benefits	19,630
Equipment	5,000
Travel (4.5K Domestic/2.5K Foreign)	7,000
Materials and Supplies	5,400
Other direct costs	0
Total direct costs	37,030
Indirect costs MTDC @ 26% Off Campus	8,328
Total direct and indirect costs	45,358

Budget justification:

Progress to date on the cosmic rays tests has been manpower limited. This budget supports the summer salaries of two graduate students to modify and operate the test stand and analyze data. To oversee the efforts we request fraction of 1% of the PI salary be charged to this grant. The fringe rate for academic personnel is 39.5% and for graduate students it is 21.5%.

Included in the travel budget are trips from Madison to SLAC for the summer students and trips to SiD collaboration meetings and LC workshops to discuss and present results. A small amount of supplies are needed to assemble fully functional RPCs from the bare HV modules provided by our IHEP collaborators. The remaining supply budget is for bottles of premixed RPC gas. Equipment upgrades will be used to combine the KPiX DAQ and information from the BaBar trigger chambers into a common data stream.

Indirect cost rates for all Federal grants and contracts are computed on the basis of actual costs incurred and regulations from the U.S. Office of Management and Budget that define the cost categories that are eligible for reimbursement. Indirect cost reimbursement rates are periodically negotiated with our cognizant Federal audit agency, the Department of Health and Human Services (DHHS). The most current signed agreement, dated March 31, 2008, allows for a 26.0% off-campus research F&A rate.

The Indirect Costs rate(s) and base(s) have been approved by a Federal agency and are applicable to the time period covered by the proposed award.