Fermilab Directorate

MEMORANDUM OF UNDERSTANDING
FOR THE 2004 MESON TEST BEAM PROGRAM

T943

The Super B-Factory Monolithic Active Pixel Detector Prototype Group

29 August, 2004

I. INTRODUCTION:

This proposal requests beam time at Fermilab during the 2004 Meson Test Run to evaluate prototype Monolithic Active Pixel Sensors developed for use in a Super-B Factory upgrade. In recent years, both the BaBar and the Belle collaborations have taken advantage of the excellent performances of their respective colliders, PEPII and KEKB. At both sites, instantaneous luminosities on the order of $1.10^{34}.\mathrm{cm}^{-2}.\mathrm{s}^{-1}$ have been recorded.

With such high instantaneous luminosities, the innermost layers of the Silicon Vertex Detectors reach occupancies close to the 10% level. From the perspective of a Super-B Factory upgrade, backgrounds will increase by a factor of at least 20. Projected occupancies in the innermost layers of the tracking detectors will not be manageable unless a drastic technology change is pursued. Since conventional Silicon Strip detectors are unable to cope with the projected occupancy, we propose to use a detector of a finer granularity. Pixel detectors come naturally to mind, though hybrid pixel detectors are not well suited to the relatively low energy B Factory environment, as they introduce too much material near the interaction point. Monolithic Active Pixel Sensors (MAPS), on the other hand, are much better matched to our needs, as they provide fine granularity and can also be thinned.

The University of Hawaii has developed two prototypes denoted the Continuous Acquisition Pixel prototypes, CAP1 and CAP2. Both are based on the TSMC 0.35μm process that is a standard CMOS process (good reliability, high volumes for low cost, etc.). The basic concept of the CAP is quite simple. As a first exercise, and to gain experience with these devices, we took the standard 3-transistor cell, which is shown in Figure 1, and built an infrastructure around it to read out as fast as possible.

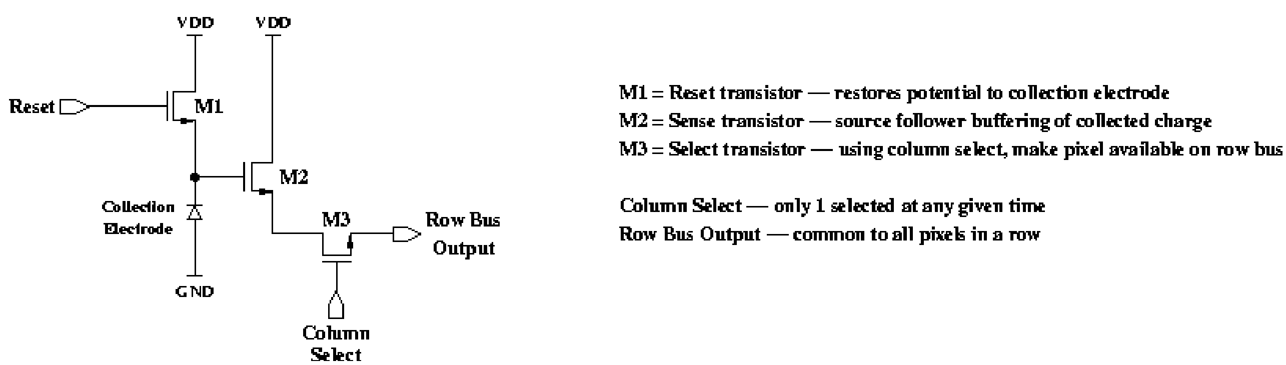

Figure 1: The basic 3-transistor pixel cell. M1 is the reset, M2 senses the gate voltage shift due to collected charge, and M3 is the output select.

An electrode is tied to the gate of transistor M2. When held at a positive potential with respect to the surrounding well and substrate, electrons from deposited ionization are collected on this electrode. As this eventually causes the collection potential to be lost due to negative charging, a periodic reset must be applied to transistor M1 to restore the collection potential. A further transistor, M3, provides the mechanism by which individual pixels may be selectively accessed for readout. In order to gain experience with this architecture, two variations of this basic theme were designed. CAP1 consists only of the above-mentioned 3-transistor circuit and an array of logic and analog multiplexors to pass the analog values out as promptly as possible. For the design of CAP2, 8 storage buffers were implemented in each pixel cell, as well as a mechanism to loop through the storage buffers and select the appropriate one (for read and write). Hence in CAP2, data can be recorded in each pixel for the trigger latency time, and does not need to be transferred out of the CAP for verification: therefore only the relevant data frames - corresponding to a trigger- need to be transferred. With its internal buffering, a CAP2-like structure fits the need of high live-time and short integration time.

CAP1 and CAP2 are both made of an array of 6336 pixels. Each pixel size is 22.5μm^2. A previous test beam has been performed in the summer 2004 and the operational capability of CAP1 has been demonstrated. During this test beam, an upper limit on the intrinsic resolution of 11μm was measured. GEANT simulations show the large separation between detectors and excess material in the detector supports limited the resolution that could be obtained. Subsequently, a new compact set-up with reduced material has been developed with guidance from simulation and we expect to be able to probe the intrinsic resolution of these devices. Also, operation of CAP2 was achieved in the lab and first testing of CAP2 looks very promising. We would like now to prove operation of this second CAP prototype in a beam test environment. Finally, MAPS radiation-hardness has still to be assessed. Initial testing looks very promising, as can be seen in Figure 2, which compares a measurement done by *Eid et al.* [IEEE Trans. Nucl. Sci., Vol. 48, No. 6, pp. 1796-1806] and our own experience with CAP1.

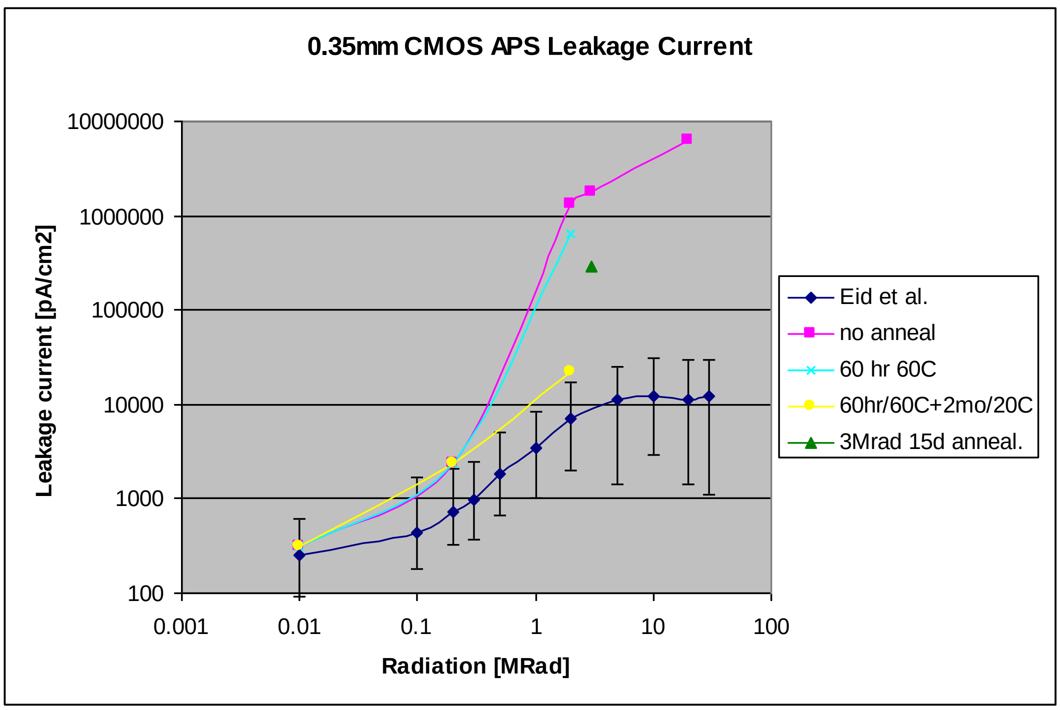

Figure 2: Leakage current in pA.cm^{-2} as a function of radiation in Mrad, and effect of annealing on the CAP1 detector.

As can be seen in this figure, the leakage current for a prototype irradiated to a 2 Mrad dose decreased by 2 orders of magnitude after proper annealing. Annealing of detectors irradiated at 3

Mrad and 20 Mrad is in progress. These results are encouraging but we must now demonstrate operation of these heavily irradiated detectors in a beam test context.

This is a memorandum of understanding between the Fermi National Accelerator Laboratory and the Hawaii, Tsukuba, KEK and INP Krakow high energy experimenters who have committed to participate in beam tests to be carried out during the 2004 MTBF program. The memorandum is intended solely for the purpose of providing a budget estimate and a work allocation for Fermilab, the funding agencies and the participating institutions. It reflects an arrangement that currently is satisfactory to the parties; however, it is recognized and anticipated that changing circumstances of the evolving research program will necessitate revisions. The parties agree to negotiate amendments to this memorandum that will reflect such required adjustments.

II. PERSONNEL AND INSTITUTIONS:

Physicist in charge of beam tests: Gary S. Varner, University of Hawaii

Fermilab liaison: Erik Ramberg

The group members at present and others interested in the testbeam are:

2.1 University of Hawaii: M. Barbero, T. Browder, F. Fang, S. Olsen, K. Trabelsi, G. Varner

Other commitments:
Belle: M. Barbero, T. Browder, F. Fang, S. Olsen, K. Trabelsi, G. Varner
ANITA: G. Varner

2.2 KEK: M. Hazumi, T. Tsuboyama

Other commitments:
Belle: M. Hazumi, T. Tsuboyama

2.3 INP Krakow: A. Bozek, H. Palka

Other commitments:
Belle: A. Bozek, H. Palka

2.4 Tsukuba University: S. Stanic.

Other commitments:
Belle: S. Stanic

III. EXPERIMENTAL AREA, BEAMS AND SCHEDULE CONSIDERATIONS

3.1 LOCATION

3.1.1 The experiment is to take place in the MTEST beam line. We are flexible in the precise location of our sensors and readout electronics, but it is likely that we will use the area designated as MT6-B2.

3.1.2 Additional work space will be needed at a location of convenience, equivalent to at most two 6’x3’ tables. This space will be used for computing and general work space.

3.2 BEAM

3.2.1 The tests will use slow resonantly-extracted, Main Injector proton beam focused onto the MTest target. We are flexible in the composition of the beam providing momentum is well above 1GeV/c.

3.2.2 Intensity: Variable, in the range of 1-10 KHz in an area of 1 square cm. Self triggering permits efficient operation at lower rates, if necessary.

3.2.3 We can make good use of any reasonable operating mode planned for MTEST.

3.3 SETUP

3.3.1 At most half a day of access to the experimental area will be needed to set up the pixel test stand, and includes not only survey of the pixel telescope planes and mechanical apparatus, but also the cable work.

3.3.2 At least one additional shift will be needed to install and debug the DAQ and logic associated with the trigger. This will require only sporadic access.

- Cabling to the counting room is minimal and consists primarily of the 8 Cat-5 ethernet cable connections between the front-end readout boards and out back-end compact-PCI readout crate. These cable provide both power and signal transfer.
- Cabling is simplified by obviating the need for separate High Voltage and DC power cabling

3.3.3 We will need a static, adjustable-height stage to locate the detector assembly in the beamline.

3.4 SCHEDULE

We are requesting a half day of setup time and a subsequent shift of DAQ commissioning (sufficient from previous experience) followed by the rest of a week of regular data taking. Each run will consist of a few hours of event logging, and we will take data in a couple of different configurations with normal and severely irradiated devices and possibly at several angles of incidence to the beam for each. Upon changing to a new device under test or a new angle of incidence, access to the experimental area will be needed.

IV. RESPONSIBILITIES BY INSTITUTION - NON FERMILAB

([] denotes replacement cost of existing hardware.)

4.1 All equipment and DAQ will be supplied by the U. Hawaii group. This includes:

4.1.1	MAPS samples under test($0.5k each)	[$16k]
4.1.2	layer mounts (1+1 spare), plus mini trigger scintillators/PMTs	[$4k]
4.1.3	cPCI Crate, with embedded CPU	[$4.5k]
4.1.4	2 laptop PC's, monitors, Ethernet and hub	[$5k]
4.1.5	CD drives for data archiving	[$0.5k]
4.1.6	Soldering iron	[$1k]
4.1.7	CAT-5 cables, voltmeters, tools, toolbox	[$1k]
	Total existing items	[$32K]

V. RESPONSIBILITIES BY INSTITUTION - FERMILAB

([] Denotes replacement cost of existing hardware.)

5.1 Fermilab Accelerator Division:

5.1.1 Use of MTest beam.

5.1.2 Maintenance of all existing standard beam line elements (SWICs, loss monitors, etc) instrumentation, controls, clock distribution, and power supplies.

5.1.3 A scaler or beam counter signal should be made available in the counting house.

5.1.4 Reasonable access to our equipment in the test beam.

5.1.5 The test beam energy and beam line elements will be under the control of the AD Operations Department Main Control Room (MCR).

5.1.6 Position and focus of the beam on the experimental devices under test will be under control of MCR. Control of secondary devices that provide these functions may be delegated to the experimenters as long as it does not violate the Shielding Assessment or provide potential for significant equipment damage.

5.1.7 The integrated effect of running this and other SY120 beams will not reduce the antiproton stacking rate by more than 5% globally, with the details of scheduling to be worked out between the experimenters and the Office of Program Planning.

5.2 Fermilab Particle Physics Division

5.2.1 The test-beam efforts in this MOU will make use of the Meson Test Beam Facility. Requirements for the beam and user facilities are given in Section 2. The Fermilab Particle Physics Division will be responsible for coordinating overall activities in the MTest beam-line, including use of the user beam-line controls, readout of the beam-line detectors, and MTest gateway computer.

5.3 Fermilab Computing Division

5.3.1 Ethernet and printers should be available in the counting house.

5.3.2 Connection to beams control console and remote logging (ACNET) should be made available in the counting house.

5.3.3 No PREP equipment will be needed for this experiment.

5.4 Fermilab ES&H Section

5.4.1 Assistance with safety reviews.

VI. SPECIAL CONSIDERATIONS

6.1 The responsibilities of the CAP Pixel Detector Research Group Spokesperson and procedures to be followed by experimenters are found in the Fermilab publication "Procedures for Experimenters" (PFX). The Physicist in charge agrees to those responsibilities and to follow the described procedures.

6.2 To carry out the experiment a number of Environmental, Safety and Health (ES&H) reviews are necessary. This includes creating a Partial Operational Readiness Clearance document in conjunction with the standing Particle Physics Division committee. The CAP Pixel Detector Research Group Spokesperson will follow those procedures in a timely manner, as well as any other requirements put forth by the division's safety officer.

6.3 The CAP Pixel Detector Research Spokesperson will ensure that at least one person is present at the Meson Test Beam Facility whenever beam is delivered and that this person is knowledgeable about the experiment's hazards and has the relevant radiation and controlled access training.

6.4 All regulations concerning radioactive sources will be followed. No radioactive sources will be carried onto the site or moved without the approval of the Fermilab ES&H section. The CAP Pixel Detector Research Group will ensure that any irradiated devices will be monitored for activation and that any experimenter handling irradiated materials will have the proper training.

6.5 All items in the Fermilab Policy on Computing will be followed by experimenters.

6.6 The CAP Pixel Detector Research Group Spokesperson will undertake to ensure that no PREP and computing equipment be transferred from the experiment to another use except with the approval of and through the mechanism provided by the Computing Division management. They also undertake to ensure that no modifications of PREP equipment take place without the knowledge and consent of the Computing Division management.

6.7 Each institution will be responsible for maintaining and repairing both the electronics and the computing hardware supplied by them for the experiment. Any items for which the experiment requests that Fermilab performs maintenance and repair should appear explicitly in this agreement.

6.8 If the experiment brings to Fermilab on-line data acquisition or data communications equipment to be integrated with Fermilab owned equipment, early consultation with the Computing Division is advised.

6.9 At the completion of the experiment:

6.9.1 The CAP Pixel Detector Research Group Spokesperson is responsible for the return of all PREP equipment, Computing equipment and non-PREP data acquisition electronics. If the return is not completed after a period of one year after the end of running the CAP Pixel Detector Research Group Spokesperson will be required to furnish, in writing, an explanation for any non-return.

6.9.2 The experimenters agree to remove their experimental equipment as the Laboratory requests them to. They agree to remove it expeditiously and in compliance with all ES&H requirements, including those related to transportation. All the expenses and personnel for the removal will be borne by the experimenters.

6.9.3 The experimenters will assist the Fermilab Divisions and Sections with the disposition of any articles left in the offices they occupied, including computer printout, tapes, etc.

6.9.4 An experimenter will be available to report on the test beam effort at a Fermilab All Experimenters Meeting.

SIGNATURES:

______________________________ / / 2004
Gary Varner, University of Hawaii

____________________________________ / / 2004
Jim Strait, Particle Physics Division

____________________________________ / / 2004
Roger Dixon, Accelerator Division

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Victoria White, Computing Division

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William Griffing, ES&H Section

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Hugh Montgomery, Associate Director, Fermilab

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Steven Holmes, Associate Director, Fermilab

APPENDIX I - Hazard Identification Checklist

Items for which there is anticipated need have been checked

	Cryogenics		**Electrical Equipment**		**Hazardous/Toxic Materials**
	Beam line magnets		Cryo/Electrical devices		List hazardous/toxic materials planned for use in a beam line or experimental enclosure:
	Analysis magnets		capacitor banks		
	Target		high voltage		
	Bubble chamber		exposed equipment over 50 V		
	Pressure Vessels		**Flammable Gases or Liquids**		
	inside diameter	Type:			
	operating pressure	Flow rate:			
	window material	Capacity:			
	window thickness		**Radioactive Sources**		
	Vacuum Vessels		permanent installation		**Target Materials**
	inside diameter		temporary use		Beryllium (Be)
	operating pressure	Type:			Lithium (Li)
	window material	Strength:			Mercury (Hg)
	window thickness		**Hazardous Chemicals**		Lead (Pb)
	Lasers		Cyanide plating materials		Tungsten (W)
	Permanent installation		Scintillation Oil		Uranium (U)
	Temporary installation		PCBs	**X**	Other : **Si, C (diamond)**
	Calibration		Methane		**Mechanical Structures**
	Alignment		TMAE		Lifting devices
type:			TEA		Motion controllers
Wattage:			photographic developers		scaffolding/elevated platforms
class:			Other: Activated Water?		Others