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Fermilab

Directorate

MEMORANDUM OF UNDERSTANDING FOR THE 2002-2003 MESON TEST BEAM PROGRAM

T932

The Diamond Detector Research Group

January 12, 2003

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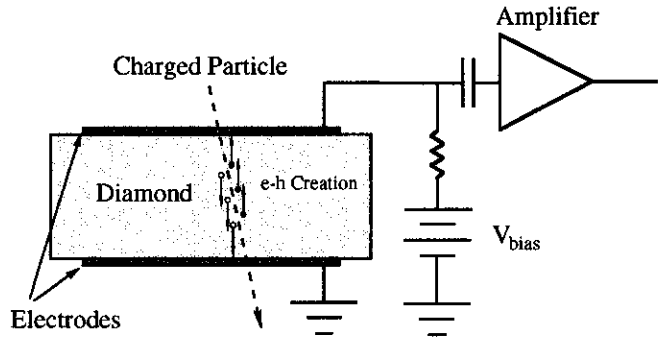
INTRODUCTION

This proposal requests beam time at Fermilab during the 2003 Meson Test Run to test Chemical Vapor Deposition (CVD) diamond pixel detectors. Our research in this area began nearly a decade ago when we realized that CVD diamond is a promising, radiation-hard alternative to silicon. Our work has been funded by DOE, TNRLC, and NSF; we are currently funded by an NSF MRI grant. Below we detail what we expect to accomplish in beam tests of diamond detectors as well as what resources are required.

In Appendix I, we summarize the properties of diamond and, for comparison, those of silicon. The most distinctive feature of diamond is its large band gap, 5.5 eV. This large band gap along with the associated large cohesive energy are responsible for much of the radiation hardness of diamond. The large band gap also makes diamond an excellent electrical insulator. As a result, a large electric field can be applied without producing significant leakage current. Thus, there is no need for a reverse biased *pn*-junction and the diamond detector functions much like a "solid-state" ionization chamber. Diamond has two additional properties that are favorable compared to silicon. Its smaller dielectric constant yields a smaller detector capacitance and, thereby, better noise performance of the associated front-end electronics. In addition, even though diamond is an electrical insulator, it is an excellent thermal conductor with a thermal conductivity exceeding that of copper by a factor of five. A common problem with large strip detector systems is the management of the thermal load generated by the large number of electronic channels used in the detector readout. The handling of this thermal load would be simplified if the detectors were constructed from diamond.

Diamond appears ideal in many respects but it does have a limitation: the large band gap which produces many of its outstanding properties limits the signal size to at most half that of silicon for a given detector thickness in radiation lengths. This may be partially compensated by lower front-end electronic noise due to diamond's nearly non-existent leakage current and, for strip detectors, diamond's lower capacitive load.

In the figure below, we show the basic principle behind the use of diamond as a charged particle detector. Several hundred volts (~1V/μm) is applied across a layer of diamond a few hundred microns thick.



When a charged particle traverses the diamond, atoms in the crystal lattice sites are ionized, promoting electrons into the conduction band and leaving holes in the valence band. On average, 3,600 electron-hole pairs are created per 100 μm of diamond traversed by a minimum

ionizing track. These charges drift across the diamond in response to the applied electric field producing a signal that can be measured.

An interesting feature of diamond sensors is the improvement in charge collection with exposure to ionizing radiation for exposures up to about 1 kRad. This ''pump-up'' effect is due to an increase of carrier lifetime caused by passivation of deep traps. Because diamond has such a large band gap there may exist traps more than 1 eV from the valence or conduction bands. Exposure to radiation fills these traps with electrons (holes) produced by the radiation. If the traps are far enough from the conduction (valence) bands, the rate of thermal ionization of these traps will be slow and they will remain passivated for long times. We have found that diamonds kept in the dark remained ''pumped'' for many months. Exposure to light of the energy of the traps rapidly ionizes the traps and ''depumps'' the diamond.

This is a memorandum of understanding between the Fermi National Accelerator Laboratory and Rutgers and Purdue University High Energy experimenters who have committed to participate in beam tests to be carried out during the 2002-2003 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 which will reflect such required adjustments.

I. PERSONNEL AND INSTITUTIONS:

Physicist in charge of beam tests: Steven Worm, Rutgers Univ.

Fermilab liaison: Erik Ramberg

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

1.1 Rutgers University: J. Doroshenko, T. Koeth, L. Parera, S. Schnetzer, R. Stone, S. Worm

Other commitments:
CDF: S. Worm
CMS: J. Doroshenko, L. Parera, S. Schnetzer, R. Stone, S. Worm
HiRes: L. Parera, S. Schnetzer

1.2 Purdue University: D. Bortoletto, I. Shipsey, G. Bolla, J. Lee, K. Arndt, A. Roy, S. Son.

Other commitments:
CDF and CMS: D. Bortoletto, G. Bolla, A. Roy
CLEO and CMS: I. Shipsey, J. Lee, K. Arndt

II. EXPERIMENTAL AREA, BEAMS AND SCHEDULE CONSIDERATIONS

2.1 LOCATION

2.1.1 The experiment is to take place in the MTEST beam line and located in the area designated MT6-A2. In addition, the alcove control room to the east of the MTEST line will be used to house electronics (up to two 19" racks of electronics)

2.1.2 Additional work space will be needed in this control room, equivalent to at most two 6'x3' tables. This space will be used for computing and general work space.

2.2 BEAM

2.2.2 The tests will use slow resonantly-extracted, Main Injector proton beam focused onto the MTest target. The tests require a beam of untagged, charged particles of energy approximately 80 GeV.

2.2.3 Intensity: Variable, in the range of 1-10 KHz in an area of 1 square cm. With the current beam line design this is expected to require up to 2×10^{10} primary protons per second.

2.2.4 We can make good use of the planned initial beam to MTEST. Currently this is envisioned to be a 1 sec spill per 60 sec supercycle. We are modifying our DAQ to take advantage of this scenario.

2.2.5 We anticipate some parasitic running during the test beams outlined in T927 (BTeV pixel test beam, located at MT6-A1). We would like to be informed of any accesses.

2.3 SETUP

2.3.2 At least one full day of access to the experimental area will be needed to set up the pixel test stand. This includes not only the silicon telescope planes and mechanical apparatus, but also the cable work.

2.3.3 At least one additional day will be needed to install and debug the DAQ and NIM logic associated with the trigger. This would require only sporadic access.

2.3.4 Cabling to the counting room is significant. We have allowed one day of setup time. An outline of our cable needs between counting house and MT6-A2 include:

- Strip sensors (3 cond. for power, 20 cond. ribbon, 6 RG58 BNC coax)
- Pixel sensors (3 cond. for power, 60 cond. ribbon, 16 RG58 BNC coax)
- Trigger scintillators (5 RG59 SHV for voltage, 38 RG58 BNC coax)
- Power, Ethernet, DAQ interconnection cables (in counting house)

2.4 SCHEDULE

2.4.2 We are requesting a few days of setup time followed by three weeks of regular data taking. Each run will consist of a few hours of measurements, and we will take data with about 12 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.

III. RESPONSIBILITIES BY INSTITUTION - NON FERMILAB

([] denotes replacement cost of existing hardware.)

3.1	Diamond samples under test ($1k each)	[$12k]
3.2	Mechanical translation stage, stepper motors, computer control	[$10k]
3.3	(All equipment and DAQ will be supplied by the Rutgers University group.)	
3.3.1	Repeater card box, repeater boards, (Vienna) ADC	[$5k]
3.3.2	VME Crate w/ 5, 2V supplies (if item 2 in Appendix I is unavailable)	[3]
3.3.3	Silicon telescope mechanical assembly	[2]
3.3.4	Silicon telescope detector planes and holders	[15]
3.3.5	Digital scope	[10]
3.3.6	Keithley 237 Voltage/Current Source	[8]
3.3.7	Pulse generator w/ adj rate knob	[2]
3.3.8	Comp. control attenuator	[1]
3.3.9	2 10V supplies 10A	[1]
3.3.10	2 PC's, monitors, Ethernet and hub	[3]
3.3.11	2 DLT drives and tapes	[2]
3.3.12	Soldering iron	[1]
3.3.13	Asst. lemo cables, voltmeters, tools, toolbox	[1]
3.3.14	60 150' BNC, SHV, lemo, and ribbon cables	[2]
3.3.15	Remote positioning system (manipulators, encoders)	[3]
3.3.16	CCD camera for monitoring	[1]
	Total existing items	[$82K]

IV. RESPONSIBILITIES BY INSTITUTION - FERMILAB

([] Denotes replacement cost of existing hardware.)

4.1 Fermilab Beams Division:

4.1.1 Use of MTest beam.

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

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

4.1.4 Reasonable access to our equipment in the test beam.

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

4.1.6 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.

4.1.7 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.

4.1.S Summary of Beam Division costs:

Type of Funds	Equipment	Operating	Personnel (person-weeks)
Total new items	$0.0K	$0K	0.0

4.2 Fermilab Particle Physics Division

4.2.1 Adequate lighting for the MT6-A2 area is requested, as there is currently only indirect lighting from upstream. The estimated cost and time are given below.

4.2.2 Cooling water (or a chiller) and dry nitrogen (for electronics) should be provided.

4.2.3 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.

4.2.S Summary of Particle Physics Division costs:

Type of Funds	Equipment	Operating	Personnel (person-weeks)
Total new items	$0.2K	$0K	0.2

4.3 Fermilab Computing Division

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

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

4.3.3 See Appendix II for summary of PREP equipment pool needs.

4.4 Fermilab ES&H Section

4.4.1 Assistance with safety reviews.

4.4.2 Loan of radioactive source (preferably Sr^{90}, 5mCi) for the duration of the test beam.

V. SUMMARY OF COSTS

Source of Funds [$K]	**Equipment**	**Operating**	**Personnel** (person-weeks)
Particle Physics Division	$0.2K	$0K	0.2
Beams Division	0	0	0
Computing Division	0	0	0
Totals Fermilab	$0.2K	0	0.2
Totals Non-Fermilab	[$82K]		

VI. SPECIAL CONSIDERATIONS

6.1 The responsibilities of the Diamond 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 Diamond 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 Diamond Detector Test Beam 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.

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.

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

6.6 The Diamond 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 Diamond 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 Diamond 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 and magnetic tapes.

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

SIGNATURES:

9/03/2003
Steven Worm, Rutgers University

2/25/2003
John Cooper, Particle Physics Division

8/4/2003
Roger Dixon, Beams Division

/ /2003
Victoria White, Computing Division

2/10/2003
William Griffing, ES&H Section

8/14/2003
Hugh Montgomery, Associate Director, Fermilab

8/25/2003
Steven Holmes, Associate Director, Fermilab

8/25/2003
Michael Witherell, Director, Fermilab

APPENDIX I – DIAMOND DETECTOR BEAM TEST – DIAMOND PROPERTIES

Property	Diamond	Silicon
Band Gap [eV]	5.5	1.12
Breakdown field [V/cm]	10^7	$3x10^5$
Resistivity [Ω cm]	$>10^{11}$	$2.3x10^5$
Intrinsic Carrier Density [cm^{-3}]	$<10^3$	$1.5x10^{10}$
Electron Mobility [$cm^2V^{-1}s^{-1}$]	1800	1350
Hole Mobility [$cm^2V^{-1}s^{-1}$]	1200	480
Saturation Velocity [km/s]	220	82
Mass Density [g cm^{-3}]	3.5	2.33
Atomic Charge	6	14
Dielectric Constant	5.7	11.9
Thermal Expansion Coefficient [K^{-1}]	$0.8x10^{-6}$	$2.6x10^{-6}$
Thermal Conductivity [W m^{-1} K^{-1}]	1000-2000	150
Cohesive Energy [eV/atom]	7.37	4.63
Energy to create e-h pair [eV]	13	3.6
Radiation Length [cm]	12.0	9.4
Spec. Ionization Loss [MeV/cm]	4.69	3.21
Ave. Signal Created/100 μm [e]	3600	8900
Ave. Signal Created/0.1% X_0 [e]	4500	8400

Table 1: The physical properties of diamond and silicon at 293K {Zhao91}.

APPENDIX II – DIAMOND DETECTOR BEAM TEST – EQUIPMENT POOL NEEDS

Equipment Pool items needed for Fermilab test beam, needed on the first day of setup:

Quantity	Description
4	Nim crates, with cooling fans
1	VME crate and power supply with CERN modified JAUX: -5,-2 Volt
1	NIM 4CH 3/8KV 3/1mA HV POWer CAEN N470 or equivalent
5	NIM Octal descriminators Lecroy 623
4	NIM logic fan in/out Lecroy 429a
2	Quad Scaler and Preset Counter CAEN N145 or equivalent
6	NIM Dual Timing unit CAEN N93B/2255B
4	NIM Tri- coincidence logic Lecroy 465
3	NIM quad-coin. logic Lecroy 622
1	TTL ←→ Nim level adapter Lecroy 688AL
2	Caen N570 dual +HV supplies or equivalent
1	pulse gen. fast risetime (<5ns) +- 20v
1	analogue or digital oscilliscope
2	adjustable (~7Volt @ >= 2 amp) DC low noise supplies for Si strips
2	adjustable (~8Volt @ >= 2 amp) DC low noise supplies (Vienna pixel)

APPENDIX III - 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
	Analysis magnets		capacitor banks		planned for use in a beam line or experimental enclosure:
	Target	X	high voltage		
	Bubble chamber	X	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	X	temporary use		Beryllium (Be)
	operating pressure	Type:	**Sr90**		Lithium (Li)
	window material	*Strength:*	**5 mCi**		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	X	Motion controllers
Wattage:			photographic developers		*scaffolding/elevated platforms*
class:			Other: Activated Water?		Others