Fermilab

Directorate

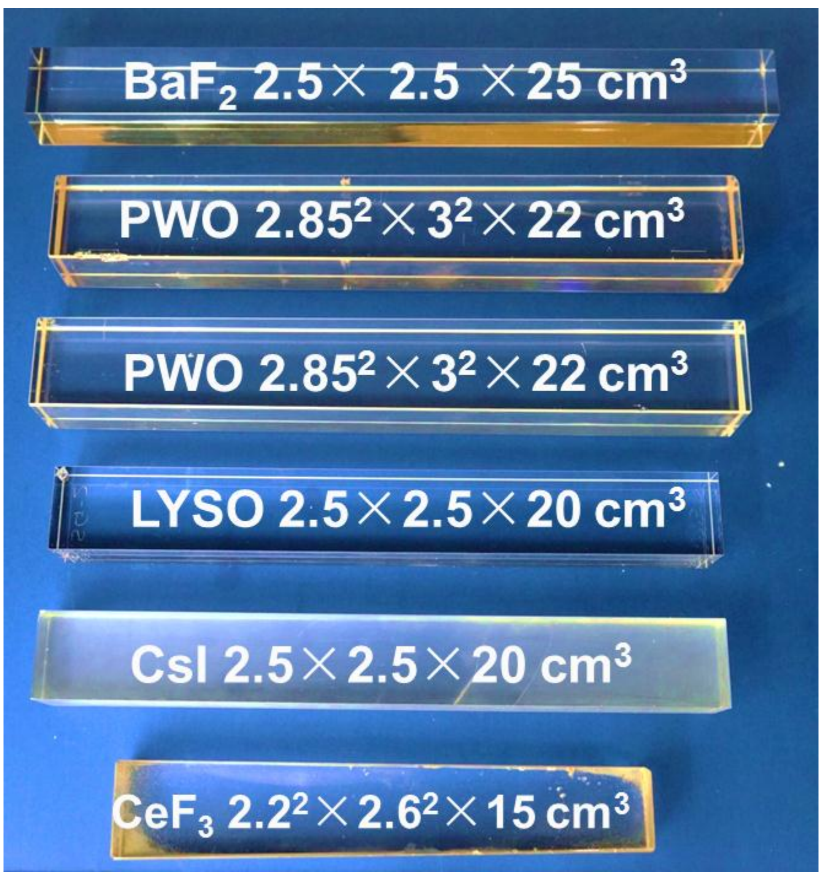
TECHNICAL SCOPE OF WORK

FOR THE 2014 FERMILAB TEST BEAM FACILITY PROGRAM

T-1055

Proton Induced Radiation Damage in Crystal Scintillators

March 11, 2014



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INTRODUCTION

This is a technical scope of work (TSW) between the Fermi National Accelerator Laboratory (Fermilab) and the experimenters of California Institute of Technology who have committed to participate in beam tests to be carried out during the 2014 Fermilab Test Beam Facility program.

The TSW is intended primarily for the purpose of recording expectations for budget estimates and work allocations 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 modify this scope of work to reflect such required adjustments. Actual contractual obligations will be set forth in separate documents.

This TSW fulfills Article 1 (facilities and scope of work) of the User Agreements signed (or still to be signed) by an authorized representative of each institution collaborating on this experiment.

Description of Detector and Tests:

Because of their superb energy resolution and detection efficiency crystal scintillators are widely used in HEP experiments. Lead tungstate ($PbWO_4$ or PWO) crystal calorimeter, for example, has played an important role for the discovery of the Higgs boson by the CMS experiment. One crucial issue, however, is crystal's radiation hardness against γ-rays, neutrons and charged hadrons. After two years of operation up to 70% loss of light output was observed in CMS PWO crystals at large rapidity *in situ* at LHC as shown in Figure 1 while the LHC was running at a luminosity of 5×10^{33} $cm^{-2}s^{-1}$ and about a half of its designed energy.

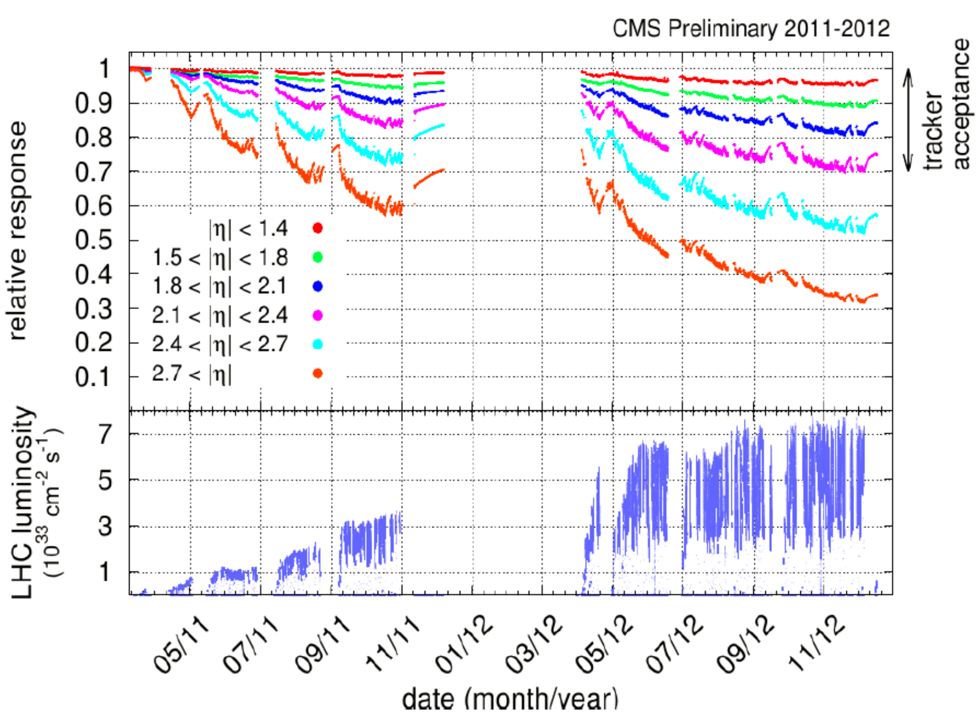

Figure 1. Light monitoring response observed in CMS PWO crystals

With 10^{35} $cm^{-2}s^{-1}$ luminosity and 3,000 fb^{-1} integrated luminosity the HL-LHC presents the most severe radiation environment, where up to 100 Mrad dose from the electromagnetic energy deposition and 10^{14} hadrons/cm^2 are expected. To face these challenges bright, fast and radiation hard cerium doped lutetium yttrium oxyorthosilicate ($Lu_{2(1-x)}Y_{2x}SiO_5$:Ce, LYSO) crystals have been proposed to construct a sampling Shashlik calorimeter for the CMS upgrade for the HL-LHC. LYSO crystals were also proposed to construct a total absorption calorimeter by the Mu2e experiment at Fermilab.

The high cost of LYSO crystals caused by high Lu_2O_3 price, however, may limit their use in future HEP experiments. Other cost-effective fast crystals, such as barium fluoride (BaF_2), cerium fluoride (CeF_3) and CsI, may also be considered as alternative crystals. BaF_2, for example, is now baselined for the Mu2e experiment. Table 1 below compares their optical and scintillation properties with LYSO and PWO.

Table 1. Properties of Fast Crystal Scintillators for Future HEP Experiments

Crystals	LSO/LYSO	CsI	BaF_2	CeF_3	PWO
Density (g/cm^3)	7.40	4.51	4.89	6.16	8.29
Melting point (℃)	2050	621	1280	1460	1123
Radiation Length (cm)	1.14	1.86	2.03	1.70	0.89
Molière Radius (cm)	2.07	3.57	3.10	2.41	2.00
Interaction Length (cm)	20.9	39.3	30.7	23.2	20.7
Effective Z value	64.8	54.0	51.6	50.8	74.5
dE/dX (MeV/cm)	9.55	5.56	6.52	8.42	10.1
Emission Peak (nm)	420	420 310	300 220	340 300	425 420
Refractive Index	1.82	1.95	1.50	1.62	2.20
Relative Light Yield	100	4.2 1.3	42 4.8	8.6	0.30 0.077
Decay Time (ns)	40	30 6	650 0.9	30	30 10

The goal of this investigation is to understand the proton induced radiation damage in candidate fast crystal scintillators for future HEP experiments. Degradations of the optical and scintillation properties, including emission and transmittance spectra, light output, decay time and light response uniformity, will be measured at Caltech Crystal Lab before and after each step of proton irradiation at Fermilab with a defined fluence. The irradiation will start with a fluence of 10^{10}/cm^2 and going up in four steps to 10^{13}/cm^2. Proton induced radiation damage in these crystals is expected to be understood through this investigation, which will provide crucial input for future HEP experiments at both the energy and intensity frontiers.

I. PERSONNEL AND INSTITUTIONS:

Spokesperson: Ren-Yuan Zhu, Caltech

Lead Experimenter in charge of beam tests: Erik Ramberg

Fermilab Liaison Officer: Aria Soha

The group members at present are:

	Institution	Country	Collaborator	Rank/Position	Other Commitments
1.1	California Institute of Technology	USA	Ren-Yuan Zhu	Senior Scientist	ADR, CMS, Mu2e
			Liyuan Zhang	Scientist	ADR, CMS, LIGO
			Fan Yang	Postdoc	ADR
1.2	Fermilab	USA	Erik Ramberg	Scientist	
			Todd Nebel	Op Specialist	FTBF

II. EXPERIMENTAL AREA, BEAMS AND SCHEDULE CONSIDERATIONS:

2.1 LOCATION

The beam tests will take place in the High Rate Tracking Area (MT3 Alcove).

2.1.1 BEAM TYPES AND INTENSITIES

Energy of beam: 120 GeV
Particles: protons
Intensity: 10k – 100k particles/ 4 sec spill
Beam spot size: > 1 cm^2 up to cover a part or the entire front surface of the crystal sample.

2.1.2 BEAM SHARING

The irradiation can be carried out when the beam is not used by other experiments. Since irradiation of the crystals may take only a few minutes, the time impact of this experiment will be dominated by the actual installation and retrieval of the crystals.

Radiation lengths are given in Table 2 in section 2.3.1.

2.1.3 RUNNING TIME

No access is needed when a crystal sample is on the beam. The irradiations will be carried out to reach a defined fluence, from $10^{10}/cm^2$ to $10^{13}/cm^2$ in four steps, and can be carried out at any hours of the day, including night. See section 2.3.3 and 2.4 for the total run time required.

2.2 EXPERIMENTAL CONDITIONS

2.2.1 AREA INFRASTRUCTURE

The experiment would like to install in the High Rate Tracking Area, utilizing the remote controlled, movable table. Table 2 (below) lists the crystal samples to be irradiated, where crystal dimension, total radiation length, total nuclear interaction length and weight are listed.

A remotely controlled motion table is needed to hold the crystals longitudinally aligned with the beam and then move it into the beam at an appropriate time.

Table 2. List of the Crystal Samples

Crystal	ID	Dimension (cm^3)	Radiation Length (X_0)	Interaction Length (λ_I)	Weight (g)
BaF_2	SIC2012	2.5×2.5×25	12.3	0.81	764
CeF_3	SIC	$2.2^2 \times 2.6^2 \times 15$	8.83	0.64	533
CsI	SIC CsI	2.5×2.5×20	10.8	0.51	564
LYSO	SG-L2	2.5×2.5×20	17.5	0.96	925
PWO	SIC	$2.85^2 \times 3^2 \times 22$	24.7	1.1	1,561
PWO	BTCP	$2.85^2 \times 3^2 \times 22$	24.7	1.1	1,561

2.2.2 Electronics Needs

There are no electronics in this experiment.

No PREP electronics are required. No devices will be connected to the network.

2.2.3 Description of Tests

The crystals samples are wrapped with alumina foil, and are placed on a table with its longitudinal axis aligned with the proton beam as shown in Figure 2.

Figure 2. The relative position of proton beam and crystals

A comparison between the expected proton fluence for the CMS ECAL Endcap at the HL-LHC and the FTBF beam is listed in Table 3. The goal is to reach 1×10^{13} /cm^2 for each crystal, which is more than the fluence expected by the crystals located at the highest rapidity for one year at the HL-LHC.

Table 3. Comparison of the Proton Fluence in CMS ECAL Endcap and Fermilab

Environment/Source	Flux on Crystal ($n\ s^{-1}\ cm^{-2}$)	Fluence on Crystal (cm^{-2})
CMS FCAL (η=1.4) at HL-LHC	5.6×10^3	2.8×10^{10} / year
CMS FCAL (η=3.0) at HL-LHC	1.2×10^5	6.1×10^{12} / year
FTBF Beam	2.5×10^9	1×10^{13}

The irradiations will be carried out to reach a defined fluence, from $10^{10}/cm^2$ to $10^{13}/cm^2$ in four steps, for all samples. After each step crystal samples are shipped back to Caltech for characterization.

2.3 Schedule

Table 4 lists the irradiation time needed for each sample in each step taking into account the cumulated fluence from previous steps.

Table 4. Irradiation Time Required for Each Sample at FTBF in Four Steps

Total Integral Fluence on Crystal (cm^{-2})	1×10^{10}	1×10^{11}	1×10^{12}	1×10^{13}
Irradiation time (minutes)	0.1	0.6	6	60

The total irradiation time is 66.7 minutes for each sample, leading to a total of 400 minutes for six crystal samples. The total beam time needed is about four days with less than one day for each step. Since samples need to be shipped back to Caltech for characterization after each irradiation step, so the entire experiment, including characterization at Caltech and shipping back force, is expected to last for more than twelve weeks. Note, crystals are expected to be radioactive after proton irradiation so will have to be handled with care. Some waiting time may be needed after irradiation steps of large fluence for crystals to cool down before the crystals can be shipped back to Caltech.

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III. Responsibilities by Institution – Non Fermilab

3.1 California institute of technology:

- Provide all crystals in the experiment
- Characterization of crystal samples after each step of irradiations
- Ship all crystals to Fermilab
- Final Report

[$20,000]

IV. RESPONSIBILITIES BY INSTITUTION – FERMILAB

4.1 FERMILAB ACCELERATOR DIVISION:

4.1.1 Use of MTest beamline as outlined in Section II.
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 Scalers and beam counter readouts will be made available via ACNET in the MTest control room.
4.1.4 Reasonable access to the equipment in the MTest beamline.
4.1.5 Connection to beams console and remote logging (ACNET) should be made available.
4.1.6 The test beam energy and beam line elements will be under the control of the AD Operations Department Main Control Room (MCR). [0.5 FTE/week]
4.1.7 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.
4.1.8 The integrated effect of running this and other SY120 beams will not reduce the neutrino flux by more than an amount set by the office of Program Planning, with the details of scheduling to be worked out between the experimenters and the Office of Program Planning.

4.2 FERMILAB PARTICLE PHYSICS DIVISION:

4.2.1 The test-beam efforts in this TSW will make use of the Fermilab Test Beam Facility. Requirements for the beam and user facilities are given in Section II. 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 FTBF computers. [6.5 FTE/week]
4.2.2 Place crystals on a supporting table for irradiation, remove crystals after irradiation and ship them to Caltech: [1.0 FTE] [$2k]
4.2.3 Conduct a NEPA review of the experiment.
4.2.4 Provide day-to-day ESH&Q support/oversight/review of work and documents as necessary.
4.2.5 Provide safety training as necessary, with assistance from the ESH&Q Section.
4.2.6 Update/create ITNA's for users on the experiment.
4.2.7 Initiate the ESH&Q Operational Readiness Clearance Review and any other required safety reviews.

4.3 FERMILAB SCIENTIFIC COMPUTING DIVISION

4.3.1 None

4.4 FERMILAB ESH&Q SECTION

4.4.1 Assistance with safety reviews.
4.4.2 Provide safety training, with assistance from PPD, as necessary for experimenters. [0.2 FTE]

V. SUMMARY OF COSTS

Source of Funds [$K]	**Materials & Services**	**Labor** (person-weeks)
Accelerator Division	0	0.5
Particle Physics Division	$ 2.0 k	7.5
Scientific Computing Division	0	0
ESH&Q Section	0	0.2
Totals Fermilab	$2.0K	8.2
Totals Non-Fermilab	[$25k]	[12]

VI. General Considerations

6.1 The responsibilities of the Spokesperson and the procedures to be followed by experimenters are found in the Fermilab publication "Procedures for Researchers": (http://www.fnal.gov/directorate/PFX/PFX.pdf). The Spokesperson agrees to those responsibilities and to ensure that the experimenters all follow the described procedures.

6.2 To carry out the experiment a number of Environmental, Safety and Health (ESH&Q) reviews are necessary. This includes creating an Operational Readiness Clearance document in conjunction with the standing Particle Physics Division committee. The 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 Spokesperson will ensure at least one person is present at the Fermilab 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 ESH&Q section.

6.5 All items in the Fermilab Policy on Computing will be followed by the experimenters. (http://computing.fnal.gov/cd/policy/cpolicy.pdf).

6.6 The Spokesperson will undertake to ensure that no PREP or computing equipment be transferred from the experiment to another use except with the approval of and through the mechanism provided by the Scientific Computing Division management. The Spokesperson also undertakes to ensure no modifications of PREP equipment take place without the knowledge and written consent of the Computing Sector management.

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

At the completion of the experiment:

6.8 The 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 Spokesperson will be required to furnish, in writing, an explanation for any non-return.

6.9 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 ESH&Q requirements, including those related to transportation. All the expenses and personnel for the removal will be borne by the experimenters unless removal requires facilities and personnel not able to be supplied by them, such a rigging, crane operation, etc.

6.10 The experimenters will assist Fermilab with the disposition of any articles left in the offices they occupied.

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

SIGNATURES:

The spokesperson is the official contact and is responsible for forwarding all pertinent information to the rest of the group, arranging for their training, and requesting ORC or any other necessary approvals for the experiment to run.
The spokesperson should also make sure the appropriate people (which might be everyone on the experiment) sign up for the test_beam emailing list.

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Ren-Yuan Zhu, Experiment Spokesperson

APPENDIX I: - HAZARD IDENTIFICATION CHECKLIST

There is no anticipated need for items on this checklist.

Flammable Gases or Liquids		Other Gas Emissions		Hazardous Chemicals		Other Hazardous /Toxic Materials
Type:		Type:			Cyanide plating materials	List hazardous/toxic materials planned for use in a beam line or an experimental enclosure:
Flow rate:		Flow rate:			Hydrofluoric Acid	
Capacity:		Capacity:			Methane	
Radioactive Sources		**Target Materials**			photographic developers	
	Permanent Installation		Beryllium (Be)		PolyChlorinatedBiphenyls	
	Temporary Use		Lithium (Li)		Scintillation Oil	
Type:			Mercury (Hg)		TEA	
Strength:			Lead (Pb)		TMAE	
Lasers			Tungsten (W)		Other: Activated Water?	
	Permanent installation		Uranium (U)			
	Temporary installation		Other:	**Nuclear Materials**		
	Calibration	**Electrical Equipment**		Name:		
	Alignment		Cryo/Electrical devices	Weight:		
Type:			Capacitor Banks	**Mechanical Structures**		
Wattage:			High Voltage (50V)		Lifting Devices	
MFR Class:			Exposed Equipment over 50 V		Motion Controllers	
			Non-commercial/Non-PREP		Scaffolding/ Elevated Platforms	
			Modified Commercial/PREP		Other:	
Vacuum Vessels		**Pressure Vessels**		**Cryogenics**		
Inside Diameter:		Inside Diameter:			Beam line magnets	
Operating Pressure:		Operating Pressure:			Analysis magnets	
Window Material:		Window Material:			Target	
Window Thickness:		Window Thickness:			Bubble chamber	

The following people have read this TSW:

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Michael Lindgren, Particle Physics Division, Fermilab

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Sergei Nagaitsev, Accelerator Division, Fermilab

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Robert Roser, Scientific Computing Division, Fermilab

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Greg Bock, Associate Director for Research, Fermilab

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Stuart Henderson, Associate Director for Accelerators, Fermilab