TERAHERTZ AND OPTICAL MEASUREMENT APPARATUS FOR THE FERMILAB ASTA INJECTOR*

R. Thurman-Keup#, A.H. Lumpkin, J. Thangaraj, FNAL, Batavia, IL 60510, USA

Abstract

ASTA is a facility at Fermilab that, once completed, will consist of a photoinjector with two superconducting capture cavities, at least one superconducting ILC-style cryomodule, and a small ring for studying non-linear, integrable beam optics. This paper discusses the layout for the optical transport system that will provide THz radiation to a Martin-Puplett interferometer for bunch length measurements as well as optical radiation to an externally located streak camera, also for bunch length measurements. It will be able to accept radiation from two synchrotron radiation ports in the bunch compressor, a diffraction/transition radiation screen downstream of the compressor, and a transition radiation screen after the spectrometer magnet for measurements of energy-time correlations.

INTRODUCTION

The Advanced Superconducting Test Accelerator (ASTA) is a facility that has been constructed at Fermilab for advanced accelerator research [1-3]. It consists of a photoinjector followed by an ILC-type cryomodule and a small ring called IOTA (Integrable Optics Test Accelerator) for studying non-linear optics. Recently, the initial photoinjector beamline was completed and rf tests of the cryomodule reached the ILC design goal in 7 of the 8 cavities, with one cavity just short of it. The plan for the photoinjector is to run it at 20-25 MeV while the beamline from the cryomodule to IOTA, and the corresponding accelerator enclosure are completed. At some point in time, the photoinjector will receive a second capture cavity (currently being repaired) which will increase the energy to around 50 MeV The photoinjector will support a number of small user experiments, some of which are already planned. When the full beamline to IOTA has been completed, the photoinjector will provide beam to IOTA to map out the optics of the ring. In support of photoinjector operations and experiments, there will be an optical / THz transport system with a number of instruments including a Martin-Puplett interferometer, and a Hamamatsu streak camera. This paper will describe the plan for this system.

ASTA

The ASTA injector (Fig. 1) starts with a 1.3 GHz normal-conducting rf photocathode gun with a Cs_2Te coated cathode. The photoelectrons are generated by a YLF laser at 263 nm that can provide several μJ per pulse [4]. Following the gun are two superconducting 1.3 GHz capture cavities that accelerate the beam to its design energy of around 50 MeV. Initially only the second capture cavity will be in place giving an energy of 20-25 MeV. After acceleration there is a section for doing round to flat beam transforms, followed by a magnetic

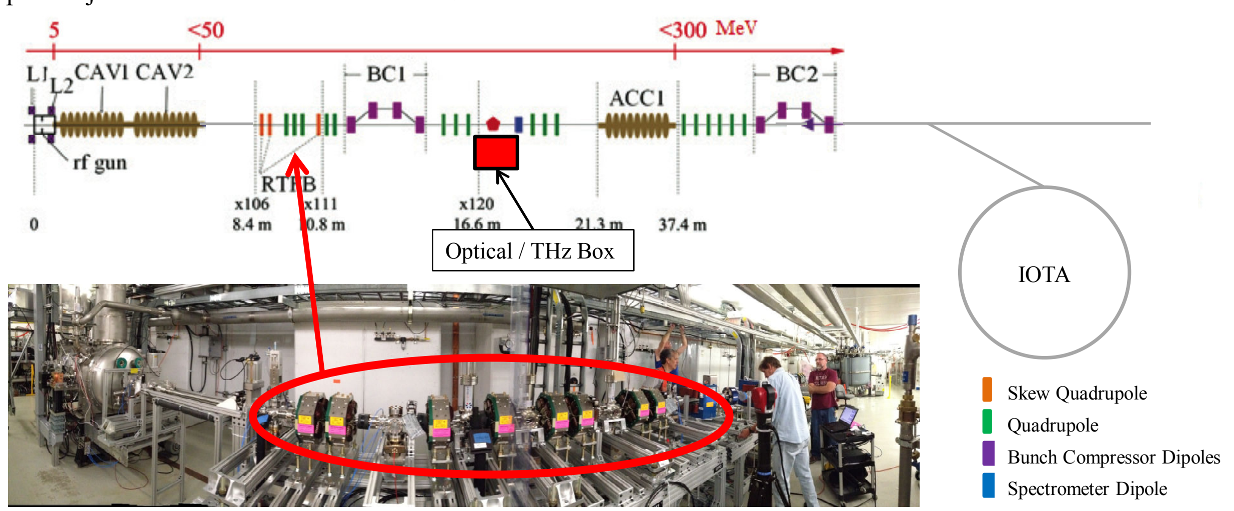

Figure 1: ASTA beamline layout. L1 and L2 are the gun solenoids. CAV1 and CAV2 are the capture cavities. Presently only CAV2 is installed. The section titled RTFB is the round-to-flat beam transform section which is followed by the magnetic bunch compressor BC1. The next section contains space for user experiments and is the location of the optical / THz system. ACC1 is the ILC-type cryomodule.

*Operated by Fermi Research Alliance, LLC under Contract No. De-AC02-07CH11359 with the United States Department of Energy.
#keup@fnal.gov

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bunch compressor and a short section that can accommodate small beam experiments. At the end of the experimental section is a spectrometer dipole which can direct the beam to the low energy dump. If the beam is not sent to the dump, it enters the ILC-type cryomodule where it gets up to 250 MeV of additional energy. It can then be sent to a high energy dump, or to the IOTA ring. Table 1 lists the typical expected beam parameters for ASTA.

Table 1: Expected Beam Parameters for ASTA

Parameter	Value
Energy	50 – 300 MeV
Bunch Charge	0.02 – 5 nC
Bunch Frequency	3 MHz
Macropulse Duration	≤ 1 ms
Macropulse Frequency	0.5, 1, 5 Hz
Transverse Emittance	0.1 – 100 μm
Longitudinal Emittance	5 – 500 μm
Peak Current	3 – 10 kA

OPTICAL AND TERAHERTZ INSTRUMENTATION SYSTEM

The optical / THz instrumentation system (OTIS) is located near the low energy dump. The transport system is constructed of stainless steel pipes and flanges purchased from GVC.net and normally used in the food industries (breweries, dairy, etc…). Figure 2 shows a 3-D model of the layout. There will be four source points for the radiation. One each from dipoles 3 and 4 in the bunch compressor, one from a cross (X121) in the user experiment section, and one from the cross (X124) in the low energy dump beamline that normally measures the energy spread.

The source points in the bunch compressor will provide coherent synchrotron edge radiation (CER) from the entrance of the corresponding dipole magnets (Fig. 3). The CER is generally in the high GHz / low THz region [6]. For 50 MeV beam it will also be possible to observe optical synchrotron radiation (OSR) from these points with an intensified or cooled camera. At 20 MeV the optical intensity is too low to observe.

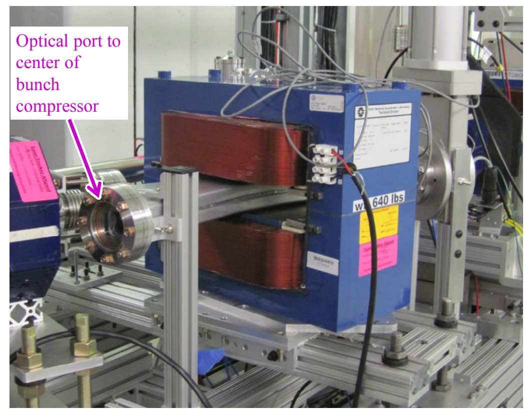

Figure 3: Second dipole in bunch compressor showing the optical entrance port to the center leg of the chicane. The beamline through the dipole is X shaped.

The source point at X121 consists of an aluminized, silicon wafer on a rotatable and translatable actuator (Fig. 4). The wafer can be inserted all the way into the beam to generate both coherent transition radiation (CTR) and optical transition radiation (OTR). The screen can also be extracted partly, with its edge a few mm above the beam, to generate coherent diffraction radiation (CDR).

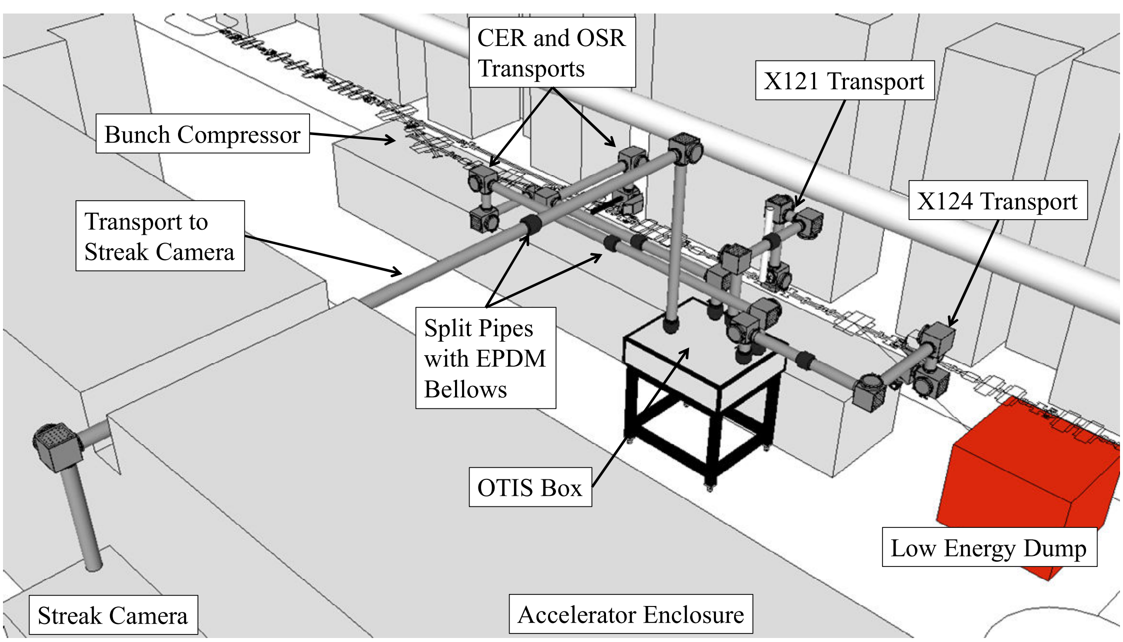

Figure 2: OTIS transport pipes just after the bunch compressor.

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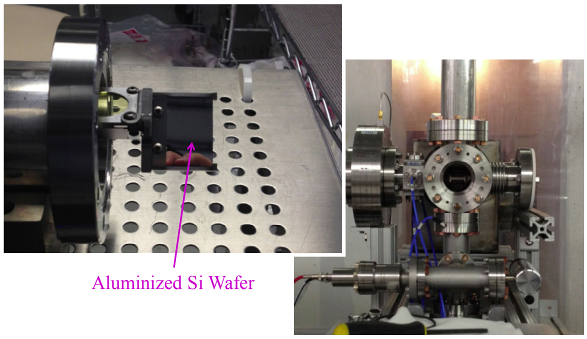

Figure 4: Left) X121 actuator retracted; OTR wafer is visible. Right) X121 cross with actuator installed.

The source point at X124 is also an aluminized, silicon wafer that will provide OTR (Fig. 5). This location is normally used to obtain the energy spread since it lies after the spectrometer dipole.

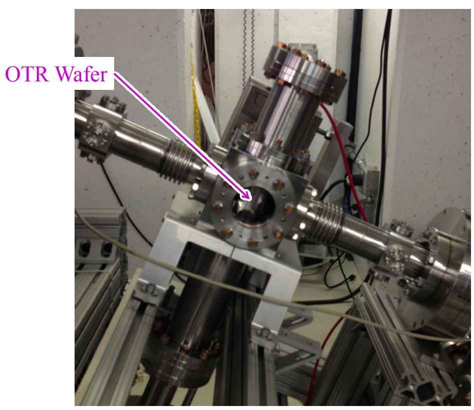

Figure 5: X124 cross in downward beamline to dump. There will be an optics system attached to this side of the cross.

All the sources converge to the OTIS box containing translatable mirrors to switch between the various inputs (Fig. 6). There are effectively three outputs from the box: Hamamatsu streak camera, Martin-Puplett interferometer (Fig. 6) which is housed inside the OTIS box, and a user experiment location which is also inside the box. All four inputs (plus one spare) are able to be switched to any of the outputs. Additionally, radiation sent to the interferometer or streak camera is split via a dielectric mirror such that the optical light is sent to the streak camera while the THz radiation continues to the interferometer.

The transport lines will consist of stainless steel, 4” diameter pipes with quick disconnect flanges (Tri-clamp). In the bunch compressor, light is extracted through a single crystal quartz viewport. Since space is limited at these ports, a small box with one or two flat mirrors is attached to the port to redirect the radiation to a more readily accessible location (Fig. 7). The radiation is then collimated by a pair of 3” diameter, 90° off-axis, parabolic, aluminium coated, UV-enhanced mirrors located in stainless steel boxes (Fig. 8). A pair is needed

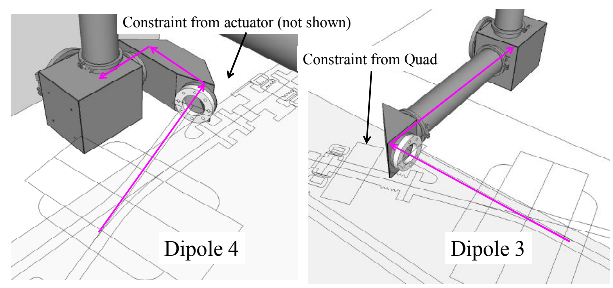

Figure 7: The two compressor source port boxes.

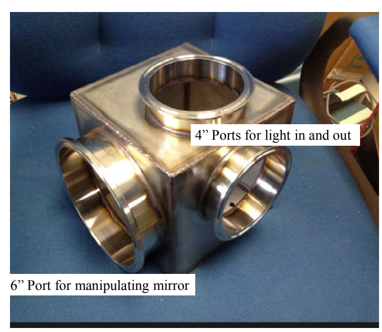

Figure 8: Stainless steel mirror box.

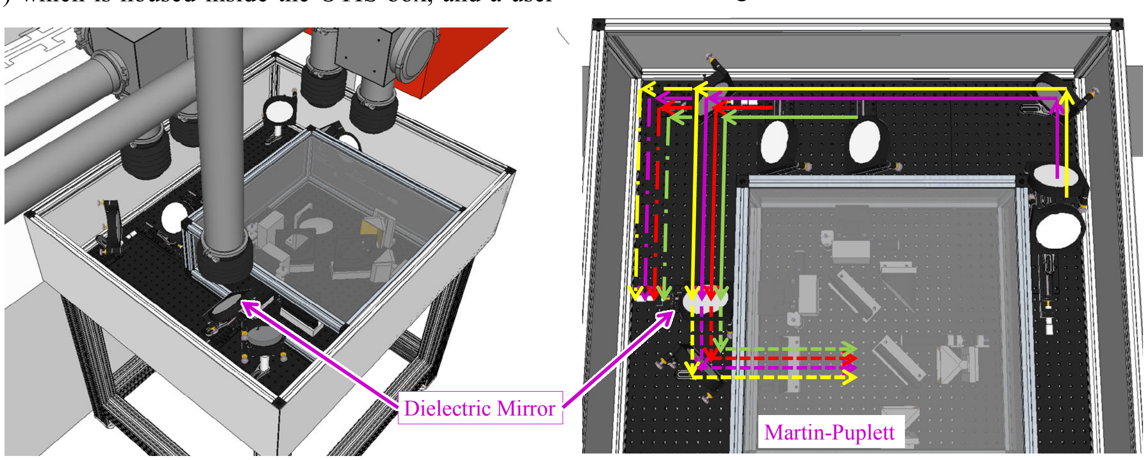

Figure 6: Left) 3-D model of OTIS box. Right) The colors indicate source, Yellow – X124, Purple and Red – Compressor, Green – X121. Solid lines go to the streak camera. Dashed lines go to the interferometer, Dot-Dash lines go to the user area in the box.

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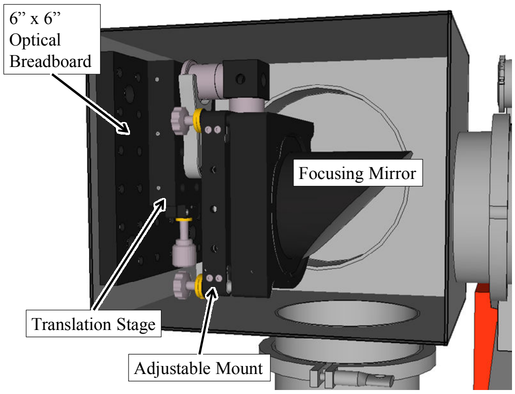

Figure 9: Off-axis parabolic optics in stainless steel box.

since the focal length of the mirrors is much smaller than the closest distance to the dipole source point. The mirrors are mounted in an adjustable mirror mount which sits on a translatable stage to enable both direction and focusing adjustments (Fig. 9).For X121, the light is also extracted through a single-crystal-quartz viewport (Fig. 10). Here it is not necessary to have two focusing mirrors, since the mirror can be positioned at its focal point.

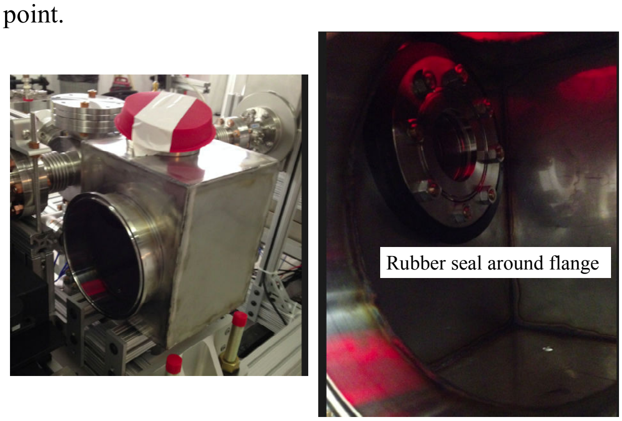

Figure 10: Stainless steel box mounted over flange on X121. Box is sealed around flange with a Uniseal gasket.

At X124, the only accessible extraction point is through the optics arm for the normal camera imaging system (Fig. 11). A beam-splitting pellicle will split the OTR light between the normal camera and OTIS.

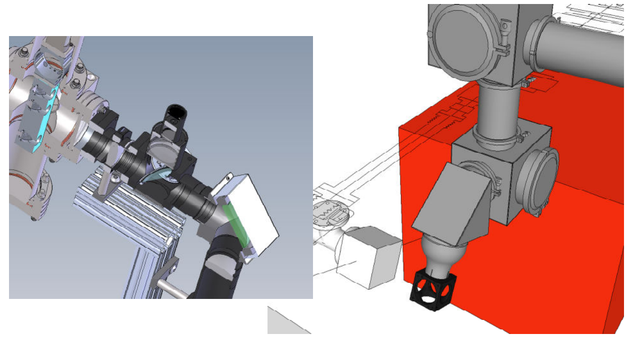

Figure 11: OTIS extraction from X124. Left) Normal camera optics cross section. Right) Attachment point of OTIS transport line.

Ninety degree bends in the transport are handled by 4"-diameter, flat, aluminium-coated, UV-enhanced mirrors mounted in an adjustable mount. To enable the system to be disassembled when access to the beamline is needed, the longer pipes are cut in two and have an EPDM bellows between them.

The streak camera will be located outside the accelerator enclosure. The pipe running to the streak camera goes through one of the penetrations to the outside where the streak camera is housed in a small enclosure (Fig. 12).

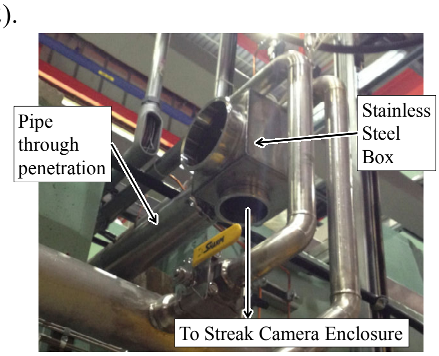

Figure 12: Penetration pipe and mirror box before the streak camera.

ALIGNMENT

The OTIS setup has many mirrors which forces one to consider how to align everything such that light gets from one end to the other (Fig. 13). For the bunch compressor

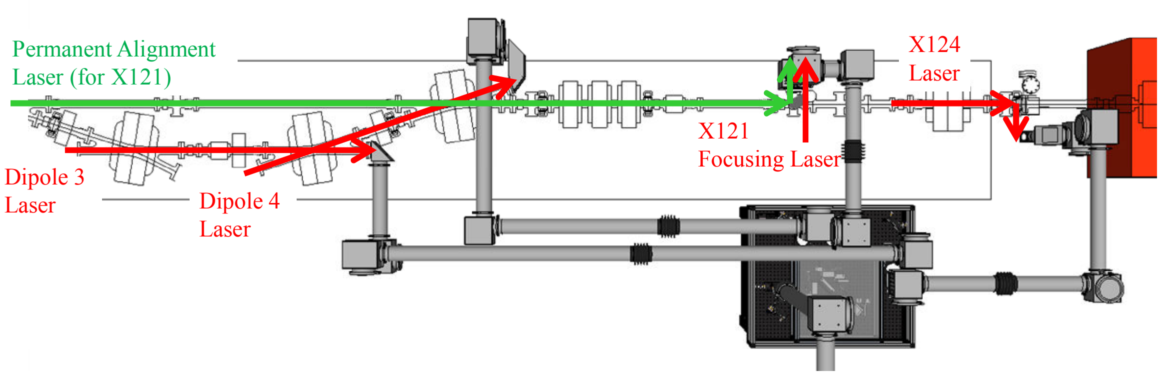

Figure 13: Laser paths for alignment purposes. Dipole 3 and 4 and X124 lasers will do both focusing and alignment.

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and X124 ports, a laser will be directed down the beamline with its waist at the location of the radiation source point. The mirrors will then be adjusted first for directionality and then for focus with the process iterated as necessary. At X121, a permanent alignment laser upstream will be used to set the directionality, while a local laser will be used to adjust the focusing.

INSTRUMENTATION

There are several end points of the optical and THz radiation including a Hamamatsu streak camera and a Martin-Puplett interferometer, both of which are used for bunch length measurements. In addition there is a space for a user instrument which initially will be used for testing a THz spectrometer based on a CsI crystal.

Streak Camera

The streak camera [5] is a Hamamatsu C5680 mainframe with S20 PC streak tube that can accommodate a vertical sweep plugin unit and a horizontal sweep unit or blanking unit. The device is fitted with all-mirror input optics enabling the assessment of the UV OTR component as well as the visible light OTR. The mirror optics also mitigate the streak image blurring due to the inherent chromatic temporal dispersive effects of the lens-based input optics for broadband sources such as OTR. The unit is also equipped with the M5675 synchroscan unit with its resonant circuit tuned at 81.25 MHz so the streak image would have jitter of less than 1 ps from the system itself.

Interferometer

The Martin-Puplett interferometer is a polarizing-type interferometer with wire grids as the polarizer and beam splitters (Fig. 14). The wire grids are 10 μm diameter Tungsten wires with a 45-μm wire spacing. The device uses THz frequencies to determine the bunch length. The relative capabilities of the streak camera and interferometer are listed in Table 2.

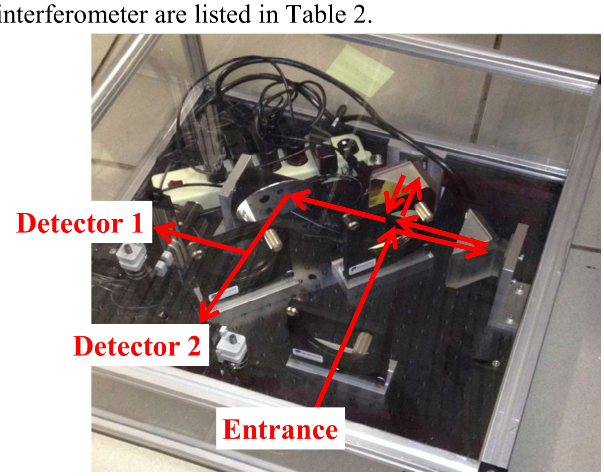

Figure 14: Interferometer light path. The THz is split and recombined from different path lengths. The interference determines the frequency content which in turn determines the bunch length.

Table 2: Bunch Length Capabilites

Device	Range (σ)	Charge Needed
Streak Camera	≥ 0.5 ps	8-10 nC
Martin-Puplett	0.1 – 1 ps	10 – 50 nC

SUMMARY

A system for distributing THz and optical light from four separate source points to three measurement points has been designed and is in the process of being constructed at Fermilab's ASTA facility. This system will enable both bunch length measurements for operational purposes and a variety of other experiments relating to both THz and optical radiation.

ACKNOWLEDGMENT

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