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1 Facility overview

The Advanced Superconducting Test Accelerator (ASTA) is housed in the New Muon Lab (NML) building at Fermilab. It will be capable of testing 3 or more ILC-type SRF cryomodules under full ILC beam intensity and bunch structure. In addition, test beamlines and downstream beamlines will provide a venue for advanced accelerator R&D (AARD). The original NML building had been previously used for a high energy physics experiment, but has recently been repurposed to house ASTA. The original footprint has been extended to accommodate high energy beamlines, a high energy beam dump, and an experimental area for AARD. Figure 1.1 shows the plan view of the upstream half of the facility, and Figure 1.2 shows the plan view of the downstream half.

The electron beam is produced by a 1.3 GHz RF photoinjector and then accelerated to ~50 MeV by two 1.3 GHz SRF cryomodules each containing a 9-cell cavity. There is space allotted for a future SRF 3.9 GHz cavity intended to be used for bunch linearization. The 50 MeV injector beamline contains a 4-dipole chicane for bunch rotation, a low energy beam dump and spectrometer magnet, a dogleg to transport beam to a parallel 50 MeV test beamline, and adequate quadrupoles, correctors, and instrumentation to inject beam into the cryomodule string under a large variety of beam conditions.

Initial beam commissioning of the cryomodule string will take place with a single Tesla type III cryomodule [1]. The next stage of beam commissioning will take place with two Tesla type III cryomodules and one ILC type IV cryomodule. The entire string is driven by a 5 MW klystron, with its associated HV power supply, modulator, and waveguide distribution system. The 5 MW klystron will eventually be replaced by a 10 MW multi-beam klystron.

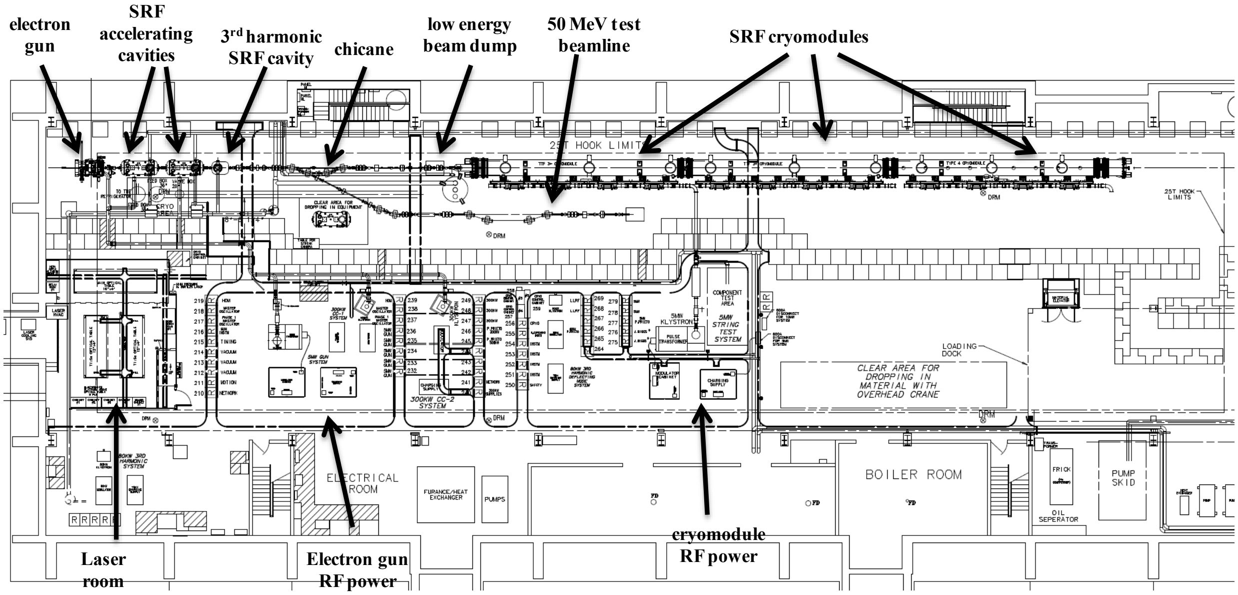

Figure 1.1: Upstream floor plan of the ASTA photoinjector and 3 SRF cryomodules in the original building footprint. The beamline is 1.2 m above the floor, the floor is 6.1 m below grade, and the building length is 74 m.

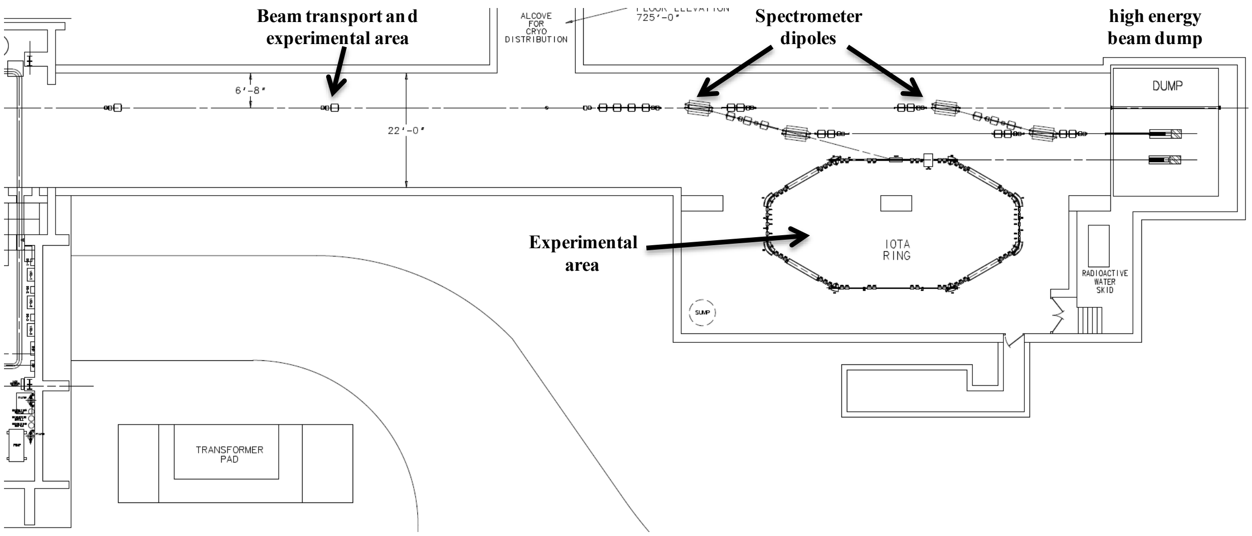

Figure 1.2: Downstream plan view of the ASTA high energy beamlines and experimental areas in the new underground tunnel. The tunnel extension is 70 m long. A service building is located above the experimental area.

The 37 m beamline directly downstream of the cryomodule string consists of a matching section, followed by a FODO transport lattice, followed by another matching section into the first spectrometer dipole. This region could eventually be used for additional cryomodules, a 2nd bunch compressor, a single bunch pickoff beamline, or other AARD experiments. There are 2 additional ~9 m beamline sections reserved for AARD experiments, one in the straight through beamline and one in the dogleg beamline. For initial commissioning, all beam will be directed to the central dump core shown in Figure 1.2. The upper dump core in the Figure is simply a hollow pipe, to allow the exit of FEL light for possible future experiments, and the lower dump core is reserved for future beamlines. Beam can be extracted from the 1st dipole in the dogleg line to be directed to the experimental area indicated in the Figure. The first planned experiment in this area is the Integrable Optics Test Accelerator (IOTA) [2].

The cryogenic plant currently consists of 2 Tevatron-style satellite refrigerators capable of delivering a total of 110 W of 2 °K helium and does not have the capacity to cool all 3 cryomodules at full beam intensity and at full pulse repetition rate. The Cryomodule Test Facility (CMTF) [3] is currently being built adjacent to NML and will provide the additional capacity to deliver 600 W of 2 °K helium to NML and cryomodule test stands in CMTF.

The beam parameters for ASTA will have a wide range, depending on the particular application. Table 1.1 lists selected beam parameters for ILC-like conditions and the possible range for each parameter. As with all photoinjectors, many beam parameters are coupled, especially to the bunch intensity, because of space charge effects in the electron gun and low energy bunch compressor.

Table 1.1: Beam parameters for ASTA. The ILC-like parameter values are listed and also the range of each parameter.

parameter	ILC RF unit test	range	comments
bunch charge	3.2 nC	10's of pC to >20 nC	minimum determined by diagnostics thresholds; maximum determined by cathode QE and laser power
bunch spacing	333 nsec	<10 nsec to 10 sec	lower laser power at minimum bunch spacing
bunch train length	1 msec	1 bunch to 1 msec	maximum limited by modulator and klystron power
bunch train repetition rate	5 Hz	0.1 Hz to 5 Hz	minimum may be determined by gun temperature regulation and other stability considerations
norm. transverse emittance	~25 mm-mrad	<1 mm-mrad to >100 mm-mrad	maximum limited by aperture and beam losses; without bunch compression emittance is ~5 mm-mrad @ 3.2 nC
RMS bunch length	1 ps	~10's of fs to ~10's of ps	minimum obtained with Ti:Sa laser; maximum obtained with laser pulse stacking
peak bunch current	4 kA	> 10 kA (?)	4 kA based on Impact-Z simulations with low energy bunch compressor
injection energy	50 MeV	5 MeV – 50 MeV	may be difficult to transport 5 MeV to the dump; maximum is determined by booster cavity gradients
high energy	820 MeV	50 MeV – 1500 MeV	radiation shielding issues limit the maximum; 1500 MeV with 6 cryomodules

2 Subsystems

2.1 Electron gun, laser, and cathode preparation systems

The RF electron gun is identical to the guns recently developed at DESY Zeuthen (PITZ) for the FLASH facility [4]. It is a normal-conducting 1½ cell 1.3 GHz gun operated in $TM_{010,\pi}$ mode and driven by a 5 MW klystron. The power is coupled into the gun via a coaxial RF coupler at the downstream end of the gun. The gun is capable of total DC power dissipation of ~20 KW, and a temperature feedback system will regulate cooling water temperature to better than ±0.05 °C for good phase stability. The gun will be routinely operated at peak gradients of 40-45 MV/m, and output beam kinetic energy of ~5 MeV. (For comparison, PITZ has successfully operated an identical gun at 60 MV/m for 700 μsec pulse lengths.) The photocathode is Cs_2Te with 5 mm diameter sensitive area. These photocathodes are coated at a separate facility on the Fermilab site and transferred to the gun under vacuum. The photocathode preparation facility was developed by D. Sertore at INFN Milano [5]. The gun is surrounded by 2 solenoid magnets for emittance compensation, and ASTRA [6] simulations indicate that transverse normalized emittances of 5 μm can be attained at a bunch charge of 3.2 nC.

The photocathode laser system is housed in an enclosed structure adjacent to the beam enclosure. A diagram of the laser system driving the photocathode is show in Figure 2.1. The seed laser is a YB-fiber laser acquired from Calmar, Inc. The 1.3 GHz output is reduced to 3 MHz by two pulse pickers, amplifed by a multipass and a 2-pass amplifier and frequency quadrupled by two BBO crystals. The UV pulse is transported to the gun through a vacuum pipe and directed to the photocathode via a 45° off-axis mirror downstream of the gun RF coupler. The UV amplitude is sufficient to produce 10's of nC of bunch charge from the cathode, and the rms (gaussian) pulse length is 3 ps. In addition there will be a Ti:Sa laser for short pulse experiments (~150 fs) and laser lab space for other R&D efforts.

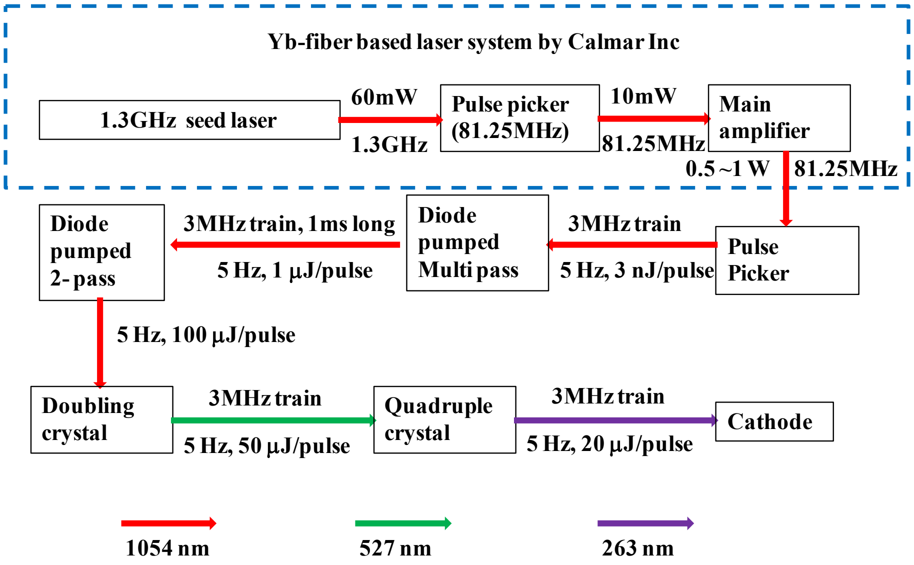

Figure 2.1: Schematic diagram of the photocathode laser system

2.2 Low energy beamline

After a short instrumentation section, the electron gun is followed by two SRF cryomodules to accelerate beam to ~50 MeV. Each cryomodule contains a 9-cell L-band cavity operating at 1.3 GHz, each driven by a 300 KW klystron, and capable of peak accelerating gradients of >22 MV/m. These cavities will also be used to "chirp" the beam, ie., generate a time-momentum correlation, in preparation for bunch compression in the chicane.

The SRF cavities are followed by a quadrupole doublet to control the beam size for the emittance measurement, 3 skew quads to generate flat beam, a matching section into the chicane, a 4-dipole chicane for bunch compression, a matching section into the vertically downward-bending dipole to the low energy dump, and finally a matching section into the first 8-cavity cryomodule.

2.3 SRF cryomodules

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2.4 High energy beamlines and magnets

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2.5 Beam dumps

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2.6 Instrumentation

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2.7 Program and schedule

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3 Lattice calculations and simulations

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4 References

[1] E. Harms, *et al.*, "RF Test Results from Cryomodule 1 at the Fermilab SRF Beam Test Facility", MOPO013 in 15th International Conf. on RF Superconductivity (SRF2011), Chicago, IL, July 2011

[2] A. Valishev, *et al.*, "Ring for Test of Nonlinear Integrable Optics", WEP070 in NA-PAC'11, New York, NY, March 2011; (http://www.JACoW.org.)

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[4] M. Otevrel, *et al.*, "Conditioning of a New Gun at PITZ Equipped with an Upgraded RF Measurement System", WEPB05 in The Proceedings of FEL2010, Malmo, Sweden, Aug. 2010; (http://www.JACoW.org.)

[5] D. Sertore, *et al.*, "Review of the Production Process of TTF and PITZ Photocathodes" MOPB009 in PAC05, Knoxville, TN, May 2005; (http://www.JACoW.org.)

[6] K. Floettman, "ASTRA – A Space Charge Tracking Algorithm", http://www.desy.de/~mpyflo/

5 Appendices

5.1 xxx