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ORION: AN ADVANCED ACCELERATOR FACILTY AT SLAC*

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Abstract

Extending the center-of-mass energy frontier for high-energy physics depends on the research and development that is conducted now in the area of advanced accelerator physics and technology. In this article, we present the design and beam dynamics simulations for the emittance-compensated, RF photoinjector of the ORION Facility.

1 INTRODUCTION

Table 1: Nominal Parameters for the ORION Facility

Beam Energies	7, 67, 350 MeV
Bunch Charge	0.25 nC
Transverse Emittance	≤ 2 mm-mrad
Bunch Length	1.8 psec, rms
Charge Stability	< 5 %, rms
Timing Jitter	500 fsec, rms
Repetition Rate	10 Hz
Electron Source	1.6 cell S-Band RF Gun
Drive Laser System	Commercial Ti:Sapphire
Injector Linac	Two X-Band 0.9 m NLC

The ORION Facility will be constructed in the environs of SLAC End Station B (ESB) at the existing NLCTA. The nominal design parameters for the ORION Facility are presented in Table 1. The key modifications to the NLCTA are the ORION photoinjector with its S-band RF system, UV drive laser, and laser room, a 1600 sq. ft., low-energy experimental hall, an 800 sq. ft. user laser room, a 1000 sq. ft. high-energy experimental hall and a 3500 sq. ft. staging area. Laser rooms and experimental halls will be interlocked. Adequate water and power utilities already exist at ESB for ORION and only new distribution from electrical breakers and water mains is required. In the following sections, we will present an overview of the various technical components of the ORION Photoinjector and preliminary beam dynamics simulation.

2 ELECTRON SOURCE

2.1 RF GUN

In order to eliminate as much photoinjector research and development from the ORION construction project as possible, a design based on the Next Generation Photoinjector (NGP) [1] was chosen. The NGP, which was developed originally as an ultra-low emittance injector for advanced light sources, is comprised of a modified version of the BNL/SLAC/UCLA 1.6 cell rf gun along with its single emittance compensation solenoid magnet.

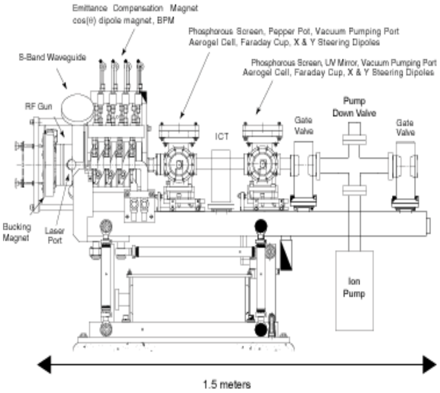

Figure 1: Layout of the ORION facility S-Band RF gun.

The NGP photoinjector is a π-mode standing wave structure and is manufactured from OFE grade II copper. A cut-and-measure technique will be used to enforce balanced fields for the π-mode at 2856 MHz. The RF gun geometry places the cathode surface in a high-field region (140 MV/m). A polycrystalline copper cathode was chosen for the baseline design because it is mechanically robust, simple to prepare, and in spite of its low quantum efficiency, bunch populations of 0.25 to 1 nC are achievable using commercially available 1 mJ UV lasers.

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SUPERFISH, POSSION, and MAFIA computer codes were used to determine the electromagnetic properties of the NGP. To produce an on-axis accelerating field of 140 MV/m the RF gun will require approximately 15 MW of S-Band power. The NGP temperature will be stabilized to within ±0.1^{o}C using a closed loop water chiller. To remove the field asymmetry induced by the RF coupling port, a vacuum port is placed on the opposite side. Two full cell tuners are placed orthogonal to the waveguide/vacuum ports plane. Both near normal and grazing incidents laser ports have been incorporated into NGP design.

A schematic drawing of the RF gun, solenoid and diagnostics section is shown in Figure 1. The electron beam charge is expected to vary from 2 pC to 4 nC, and the bunch length from 300 fsec to 10 psec. The beamline distance of 150 cm from the cathode plate to the middle of the input coupler of the first of two X-band accelerating sections was determined by beam dynamics simulations [2]. In this limited space the RF gun, emittance compensation magnet, and low-energy photoinjector diagnostics must be placed. This suite of diagnostics will measure on a single-pulse basis the electron beam's charge, energy, spot size, bunch length, position, and emittance. Also beam steering and vacuum pumping must be accomplished in the diagnostics region.

2.2 Drive Laser System

A commercial Titanium-Sapphire (Ti:Sapphire) laser system adequate to produce 1 mJ in the UV is described in reference [3], and its parameters are given in Table 2. A diode-pumped, green laser pumps a Ti:Sapphire oscillator delivering 2 psec pulses at 79 1/3 MHz with a wavelength selectable from 720 to 850 nm (IR). An Nd:YAG pumped Ti:Sapphire regenerative amplifier produces ten individual pulses per second over a wavelength range of 750 to 840 nm and up to a micro pulse energy of 10 mJ. After any spatial and Fourier masking for pulse shaping, these pulses are frequency-tripled to a nominal wavelength of 266 nm (UV). The laser system will be designed to allow a straightforward upgrade of the IR energy, if necessary.

Table 2: UV drive laser system requirements including performance enhancements.

Repetition Rate	10 Hz
Laser Energy [1]	> 1 mJ
Laser Energy Jitter	< 5 %, rms
UV Timing Jitter [2]	< 500 fsec, rms
Pulse Length	6.3 psec
Temporal Amplitude Profile	Uniform [3]
Radial Amplitude Profile	Approx. Uniform [4]

Spatial and Fourier masking will be used for transverse and longitudinal pulse shaping for emittance optimization. Laser pulse length will be adjustable over a range of 300 fsec to 10 psec to accommodate different experimental requirements. The laser system will be mode-locked to the RF system to meet a timing jitter requirement of < 500 fsec, rms. The laser amplitude in the UV must be stable to < 5%, rms to insure the desired charge stability.

2.3 Radio Frequency (RF) System

The NGP photoinjector requires a single, high-power S-band klystron and modulator system to power its accelerator cells. To operate at the accelerating gradient of 140 MV/m, the photoinjector requires 15 MW of peak RF power. A SLAC 5045 klystron is available on site and is the baseline choice. Its 65 MW output capability is more than adequate. A new solid-state modulator [4], consisting of twenty insulated-gate bipolar transistor (IGBT) drivers arranged in a pulse-forming network, has been designed at SLAC for the Next Linear Collider project. The modulator will be limited to a 10 Hz rate.

The RF power from the klystron will be split with 15 MW going to the photoinjector and the excess power available for an RF test station. The RF power will be transferred to the photoinjector through an evacuated waveguide and pass through a circulator (for klystron protection from reversed power flow) prior to entering the NLCTA enclosure. Sulfur-hexafloride (SF-6) gas at 24 psi is used in a circulator to reduce electrical breakdown problems.

3 BEAM DYNAMICS SIMULATIONS

The initial optics design for the ORION injector reference case has been optimized by HOMDYN simulation. The relevant parameters describing the conditions found by this optimization process are given in Table 3. The electromagnetic fields were mapped into HOMDYN from SUPERFISH and POISSON simulations. The simulation results are summarized in Figures 2 and 3.

Table 3: HOMDYN simulation parameters for the ORION injector reference design.

Bunch Charge	0.25 nC
Bunch Length	6.3 psec
Cathode Spot Size	0.63 mm
Gun Gradient	140 MV/m
NGP Solenoid Field	3.09 kG
Launch Phase	33^o
X-Band Gradient	33.6 MV/m
X-Band Solenoid Field	0.7 kG

In Figure 2, the transverse rms beam size and normalized emittance are given as a function of distance along the beam line starting from the cathode. The simulated emittance compensation performance in the 0.25 nC reference case is impressive, with a final value after acceleration of $\varepsilon_{x,n}$ = 0.1 mm-mrad. To take into account uncertainties in the simulation codes, a conservative design of ≤ 2 mm-mrad, for the normalized rms emittance, at 0.25 nC was been adopted.

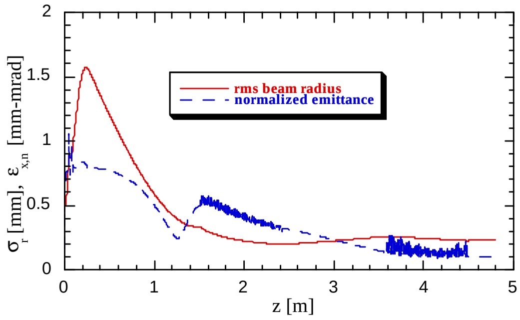

Figure 2: Evolution of the transverse rms beam size and normalized emittance of a 0.25 nC bunch as a function of distance along the injector axis for the ORION reference design case, from HOMDYN simulation. The first X-band section begins at 1.5 m and the second at 3.6 m.

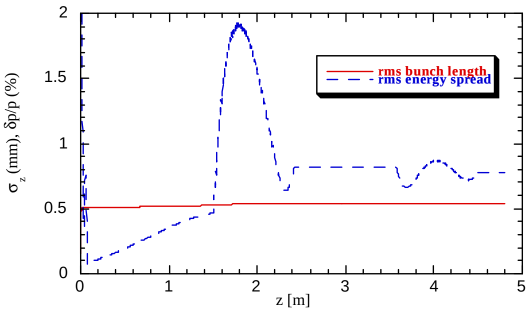

Figure 3: Evolution of the rms bunch length and relative energy spread of a 0.25 nC bunch as a function of distance along the injector axis for the ORION reference design case, from HOMDYN simulation.

In this design, the beam pulse length, illustrated in Figure 3, is well preserved from injection at 0.55 mm, rms or 1.8 psec. Thus the total momentum spread for the reference design is not small, being limited to at least 0.8%. For cases where smaller energy spread is required, shorter laser pulses (with concommitant lower charges) will be injected. Bunch length on the other hand is adjustable using the magnetic chicane, as described in the next section.

3.1 Magnetic Chicane

Plasma and laser acceleration experiments at ORION will require a large range of bunch lengths and even tailored longitudinal bunch profiles. Bunch length compression using magnetic chicanes is now a standard technique in many RF photoinjector labs around the world with achieved pulse lengths measured well below the picosecond level. Correlated momentum variation in a bunch implies corresponding path length differences in a magnetic transport line, resulting in correlated arrival times, and hence bunch length, downstream. The ORION Facility will take advantage of the existing NLCTA chicane and further develop this technique to create pulses which are not only short, but have optimized profiles, and ultra-short trailing pulses.

Recent work at UCLA has shown that if instead of using a chicane-like transformation to remove the momentum-chirp imparted by running the linac off the wave crest, one uses a negative R_{56} transport line, then a ramped pulse can be obtained. In this case, because $R_{56} < 0$, the beam is behind the rf wave crest, and effects such as wake-fields and longitudinal space-charge aid the compression process, making it even more powerful. The phase space associated with this process, displayed in Figure 4, creates a projected current distribution with a ramped rise and a very sharp fall, that is nearly ideal for driving wake-fields with a high transformer ratio. The chicane in the NLCTA beamline is nominally tuned for $R_{56}= 0$, and thus both negative and positive values of R_{56} may be utilized, as experiments require. This type of pulse shaping is unique to the ORION program because the existing chicane and (naturally negative R_{56} transport to the experimental halls) allows fine tuning of this type of compression.

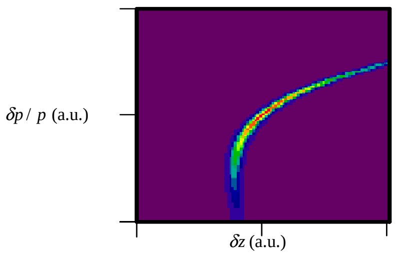

Figure 4: False-color plot of the simulated longitudinal phase space after compression using a negative R_{56} magnetic chicane system at ORION.

4 CONCLUDING REMARKS

The ORION Facility is the next major advanced accelerator research user facility coming online. The ORION Photoinjector design is based on operating S-Band units, and this source is expected to perform reliably over its parameter range. For more details on the ORION Facility and it capabilities please download the ORION Technical Design Study at http://www-project.slac.stanford.edu/orion/

5 REFERENCES

[1] D.T. Palmer, “The Next Generation Photoinjector”, Stanford Univ. Thesis, 1998.

[2] M. Ferrario et al, “HOMDYN Study for the LCLS Photoinjector”, presented at the 2nd ICFA Advanced Accelerator Workshop on the Physics of High Brightness Beams, Nov. 9-12, 1999, Univ. of California, Los Angeles.

[3] SLAC DOCUMENT NUMBER: PS-290-328-00

[4] A. Donaldson and R. Cassel, SLAC, private communication.