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# ADVANCED PHOTOINJECTOR DEVELOPMENT AT THE UCLA SAMURAI LABORATORY

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*Abstract*

UCLA has recently constructed SAMURAI, a new radiation bunker and laser infrastructure for advanced accelerator research. In its first phase, we will build a 30 MeV photoinjector with an S-band hybrid gun. The beam dynamics simulation for this beamline showed the generation of the beam with the emittance 2.4 µm and the peak current 270 A. FIR-FEL experiments are planned in this beamline. The saturation peak power was expected at 170 MW.

## INTRODUCTION

There is a huge demand for XFEL facilities all over the world. However, due to the nature of its large-scale facility, it is very hard to build so many light sources to satisfy the demand. To solve the problem, UCLA is proposing a compact light source, so-called UC-XFEL [1]. The size is reasonably small to be operated by a university-class institute. For the first step to realize these ambitious goals, UCLA has constructed a radiation bunker and a clean laser room for the compact light source research as well as other advanced accelerator research. The new facility is called SAMURAI laboratory, and it will host in the coming years advanced C-band cryogenic research.

In the first phase, however, we will develop a 80-MeV beamline based on the photoinjector with the S-band hybrid gun [2, 3] as sourcce. The layout is displayed in Fig. 1. An FIR-FEL experiment with UCLA-KIAE undulator [4, 5] is planned as a preliminary test for UC-XFEL. We also consider this beamline as a test bench to develop an AI-assisted control system, which is one of the key technologies needed to operate the UC-XFEL successfully. For the next phase, we are proposing a 300 MeV upgrade by introducing c-band cryogenic linacs. We will perform IFEL and EUV-FEL studies which include 3D CSR effects and microbunching instability. In parallel, we plan to develop a c-band cryogenic photoinjector to generate beams with the emittance as low as 50 nm [6]. In this paper, we discuss the design of the 30-MeV S-band photoinjector and its application to FIR-FEL.

### *Laser System*

The laboratory is equipped with an ultra-fast Ti:Sapphire laser system from Coherent Inc., models Astrella and Hydra. Their nominal outputs are 5 mJ 40 fs 500 Hz and 100 mJ 40 fs 10 Hz, respectively. We plan to build an additional multipass amplifier to produce 10-TW pulses.

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## GENERATION OF 30-MeV BEAMS

The 80-MeV hybrid photoinjector beamline consists of three sections: S-band hybrid gun, a 1.5-m S-band linac, and a 3-m S-band linac. The first two devices are explained here.

### *Hybrid Photoinjector*

UCLA has developed a hybrid gun, which has an RF gun and a velocity buncher in one structure. Unlike a normal standing-wave RF gun, the hybrid gun does not show RF reflection, as the most of the power goes into the traveling-wave section in the cavity. It is also capable of producing a high peak current beam with a low emittance, eliminating the need for magnetic chicane for the bunch compression.

Hybrid gun was designed to be powered by 25 MW S-band RF pulse, using only a small fraction of this input, and passign the remainder to the downstream 1.5-m Research Instruments linac section. It is connected in series to the gun and a phase shifter is placed to control the phase of the linac. The linac is located 1.5-m from the cathode which is determined by the beam dynamics simulation. The diagnostic section is currently under design.

### *Beam Dynamics*

The beam dynamics are simulated by using GPT. The beam is launched with the radius 2.0 mm and the length 2.5 ps uniform distributions. The initial pulse length has been chosen so that the beam does not suffer nonlinear effects duee to velocity bunching, seen in Figs. 2 and 3. The emittance compensation process is shown in Fig. 4. It is similar to a standard RF gun, but the emittance reaches only 2.4 µm due to the strongly compressed beam. The longitudinal motion was frozen right after entering into the linac for the on-crest acceleration (Fig. 5), and the rms peak current was 280 A for 1-nC operation. Some beam parameters are summarized in Table 1.

Figure 6 shows the emittance as a function of bunch charge. The lower charge has much better emittance considering the linear charge scaling. For certain applications, the lower charge is a more optimized choice.

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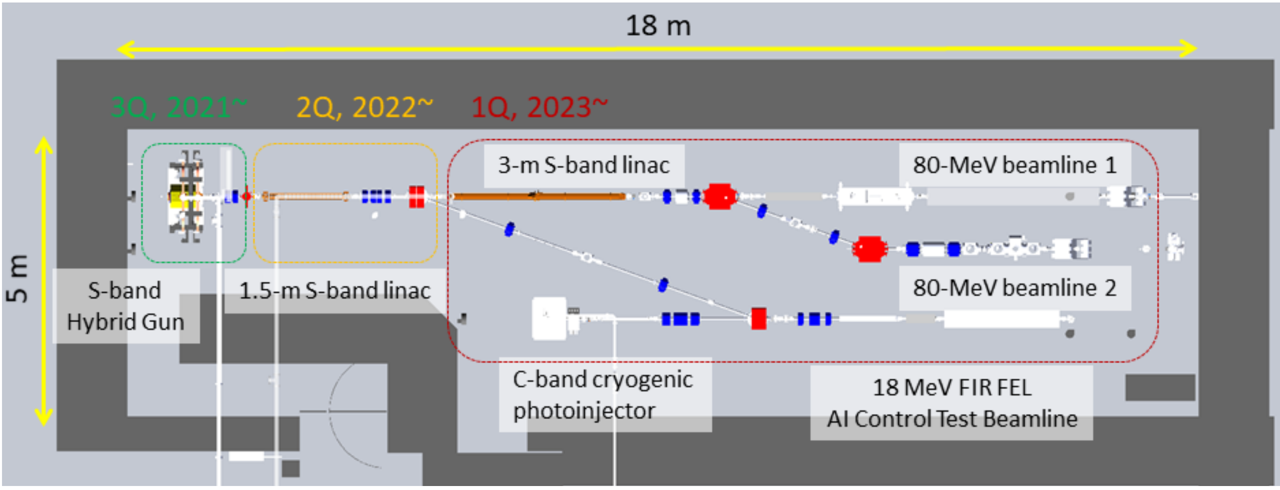


Figure 1: Layout of SAMURAI bunker.

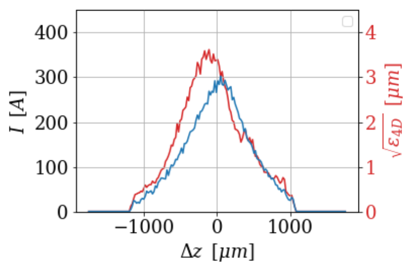


Figure 2: Current profile and slice emittance in 1-nC case.

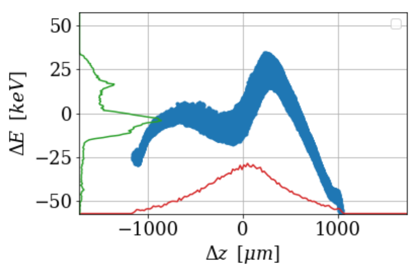


Figure 3: Longitudinal phase space in 1-nC case.

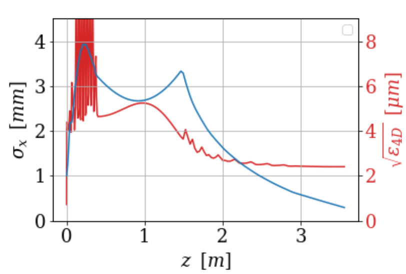


Figure 4: Beam size and emittance along Z in 1-nC case.

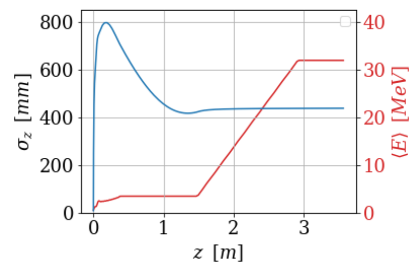


Figure 5: Bunch length and energy along Z in 1-nC case.

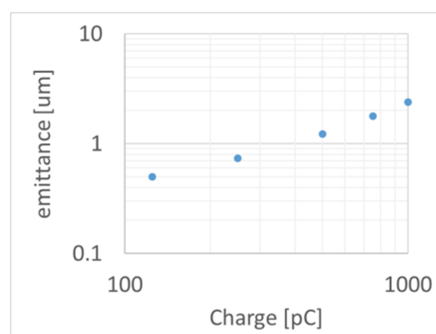


Figure 6: Emittance vs bunch charge.

Table 1: Beam Parameters

| Parameter | 30 MeV | FIR-FEL |
|---|---|---|
| Energy | 32 MeV | 18 MeV |
| Charge | 1 nC | 1 nC |
| Emittance | 2.4 μm | 2.2 μm |
| Current | 280 A | 380 A |
| Energy Spread | 14 keV | 450 keV |
| Energy Spread, Slice | 6.6 keV | 7.2 keV |

## FIR FEL

Two decades ago, UCLA and KIAE developed a 2-m undulator which has embedded quadrupole focusing mag-

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nets [4, 5]. The undulator was designed to be operated with 18-MeV beams. To produce 18-MeV beams at the hybrid photoinjector, the RF phase in the 1.5-m linac was chosen to be off-crest by -63 degrees. This produces a large energy charp after the linac. To cancel it, we are considering using a passive dechirper [7].

### *Beam Dynamics*

The beam parameters are listed in Table 1. The beam emittance is similar to the 30-MeV case. The beam obtains additional bunching due to the off-crest acceleration. The longitudinal phase space is shown in Fig. 7. There is a large energy chirp, as expected.

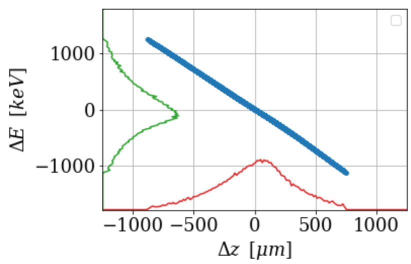


Figure 7: Longitudinal phase space in the case of 18-MeV FIR-FEL.

### *De-chirper*

To check the possibility of the passive de-chirper in our application, we estimated the effect by using our home-made code. We designed a 60 GHz hollow dielectric tube with copper cladding structure (Table 2). Because this geometry is simple and easy to calculate the effect. The other form factors, such as an all-metal corrugated structure and a slab geometry, will be considered in the future. As shown in Fig. 8, the de-chirper removed the energy chirp from the beam's core successfully.

Table 2: Design Parameters of the Hollow Dielectric De-chirper

| | |
|---|---|
| Frequency | 60 GHz |
| Dielectric ($\epsilon_r$) | Quartz (3.8) |
| Inner, Outer Radius | 1.5 mm, 2.1 mm |
| Length | 100 mm |

### *FEL Simulation*

The preliminary FEL simulation was performed by using GENESIS [8]. Here, we used a gaussian distribution to get quick results. We could observe the saturation with 1-nC beams as shown in Fig. 9. The results are summarized in Table 3.

## SUMMARY

UCLA has constructed SAMURAI laboratory for advanced accelerator and light source research. The beam dynamics simulation for the initial phase 30-MeV hybrid photoinjector has been discussed. It showed the generation of the beam with the emittance 2.4 μm and the peak current 270 A. For application of this beam, the FIR-FEL simulation was performed. We could observe the saturation power of 170 MW.

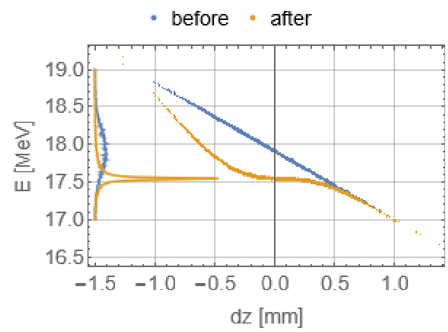


Figure 8: Longitudinal phase space before and after the De-chirper.

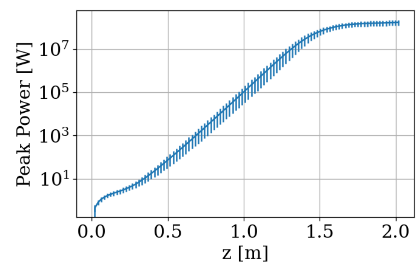


Figure 9: Evolution of the radiation peak power in the undulator.

Table 3: FIR FEL Parameters

| **Undulator** | |
|---|---|
| Period length | 20.6 mm |
| Number of periods | 98 |
| Peak field strength | 0.54 T |
| Embedded quad strength | 1.5 T/m |
| **Radiation** | |
| Wavelength | 12.8 μm |
| Peak power | 170 MW |
| Pulse Energy | 88 μJ |
| Efficiency | 0.50 % |

## ACKNOWLEDGMENTS

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