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Advanced Photoinjector Development at the UCLA SAMURAI Laboratory

May 24 – 28, 2021

IPAC 21

Atsushi Fukasawa, Gerard Andonian, Obed Camacho, Claire Evangeline Hansel, Gerard Emile Lawler, Walter Lynn, Nathan Majernik, Joshua Isaac Mann, Pratik Manwani, Brian Naranjo, Yusuke Sakai, Oliver Williams, James Rosenzweig

University of California Los Angeles, California, USA

Zenghai Li, River Robles, Sami Tantawi

SLAC National Accelerator Laboratory, Menlo Park, California, USA

Monika Yadav

The University of Liverpool, Liverpool, UK

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Photoinjector Development at UCLA

- UCLA is proposing a compact light source, so called UC-XFEL, as a solution to satisfy the huge demand for XFEL facilities.
- UCLA built a radiation bunker and a clean laser room, SAMURAI Laboratory, for advanced accelerator researches.
- The bunker will be ready for use by this summer.

Future compact light source development.

Short term

SAMURAI
- 80 MeV Beamline
- S-band Hybrid Photoinjector
- Preliminary FEL study
- AI-assisted control system
- Design and basic tests on C-band cryogenic accelerator.

→

Mid term

SAMURAI
- 300 MeV upgrade
- IFEL microbunching and its instability
- EUV FEL
- C-band Cryogenic Photoinjector
- Ka-band RF source/cavity

→

Goal!

UC-XFEL*
- 1 GeV Beam
- 1.2 keV photon
- 40 m from start to end.

Other projects planned to be hosted at SAMURAI.
- Inverse Compton scattering for Au nano-particle therapy.
- Dielectric wakefield accelerator.

*J. B. Rosenzweig et al., New J. Phys. 22 (2020) 093067

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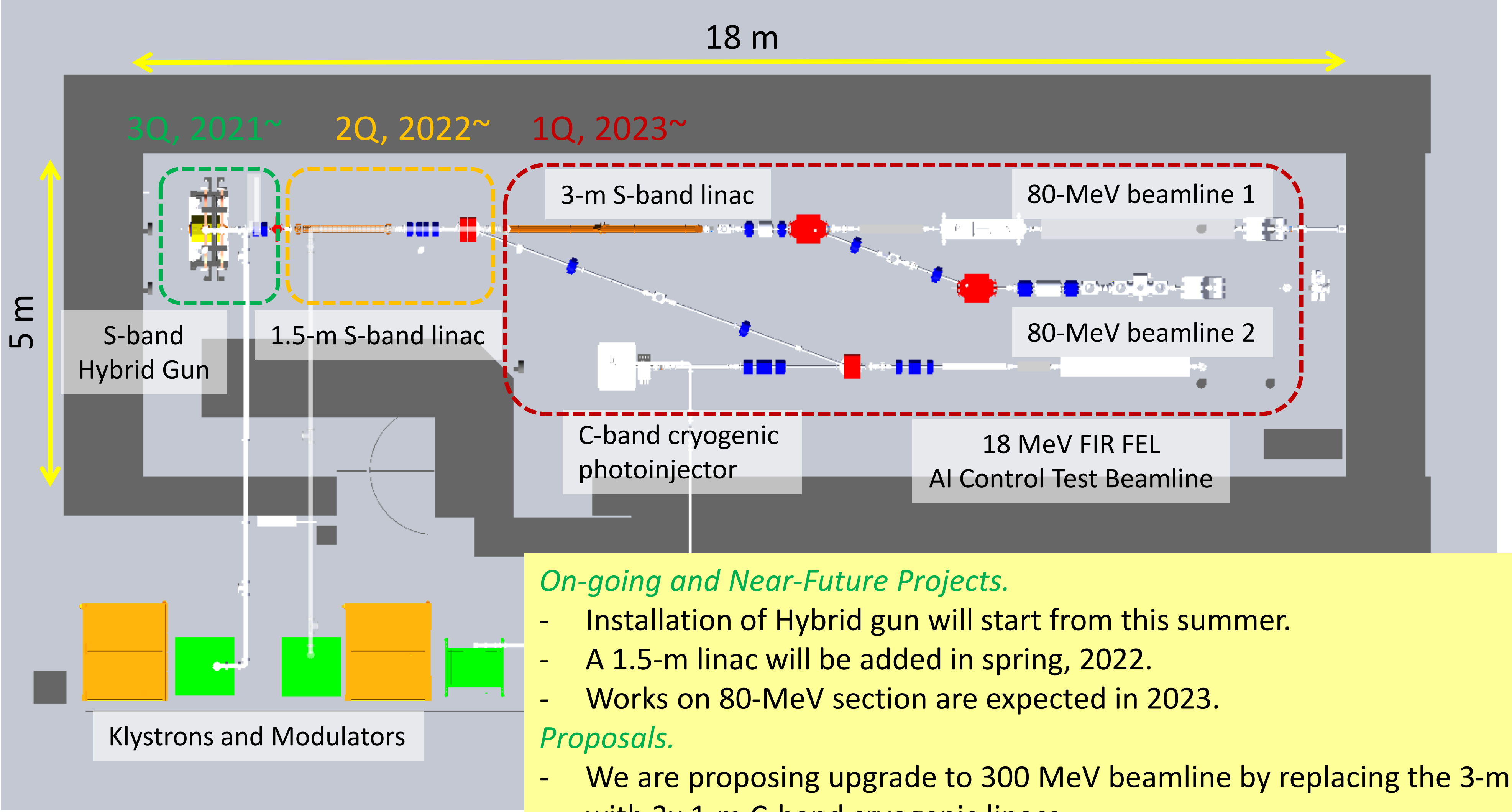
SAMURAI Bunker



On-going and Near-Future Projects.

- Installation of Hybrid gun will start from this summer.
- A 1.5-m linac will be added in spring, 2022.
- Works on 80-MeV section are expected in 2023.

Proposals.

- We are proposing upgrade to 300 MeV beamline by replacing the 3-m linac with 3x 1-m C-band cryogenic linacs.
- The area of C-band photoinjector is reserved for future development.

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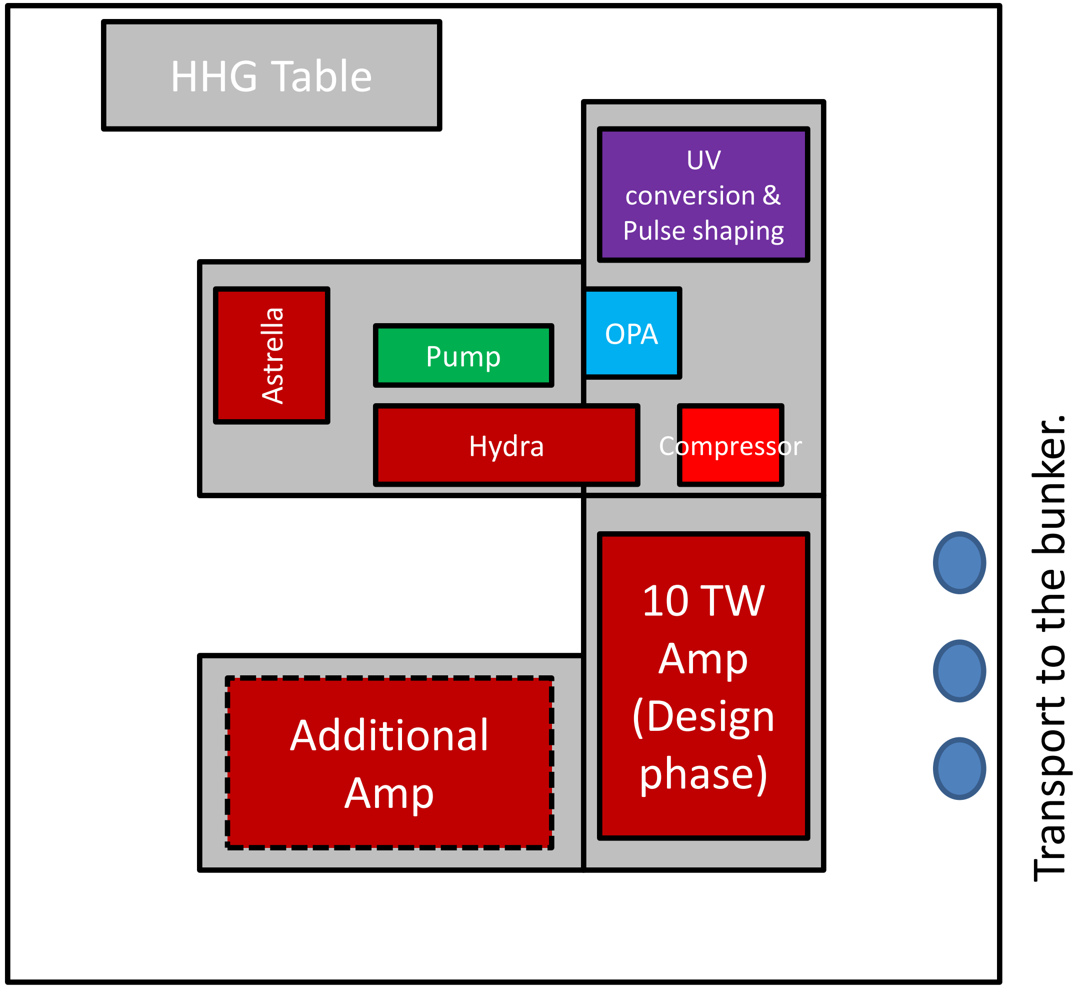
Laser Room Layout



Astrella* → 0.13 TW: 5 mJ, 40 fs, 500 Hz

- Photocathode.
- HHG.
- OPA, low power.

↓ seed

Hydra* → 2.5 TW: 100 mJ, 40 fs, 10 Hz

- Photocathode. High charge. Pulse shaping.
- OPA (HHG, Photocathode)

↓ seed

10 TW → 10 TW: 400 mJ, 40 fs, 10 Hz

- Inverse Compton scattering.
- Laser plasma.

↓

More Amp

- We have a Ti:Sapphire ultrafast high power laser system, which is more than enough to carry out the advanced photoinjector research.

* Coherent, http://www.coherent.com

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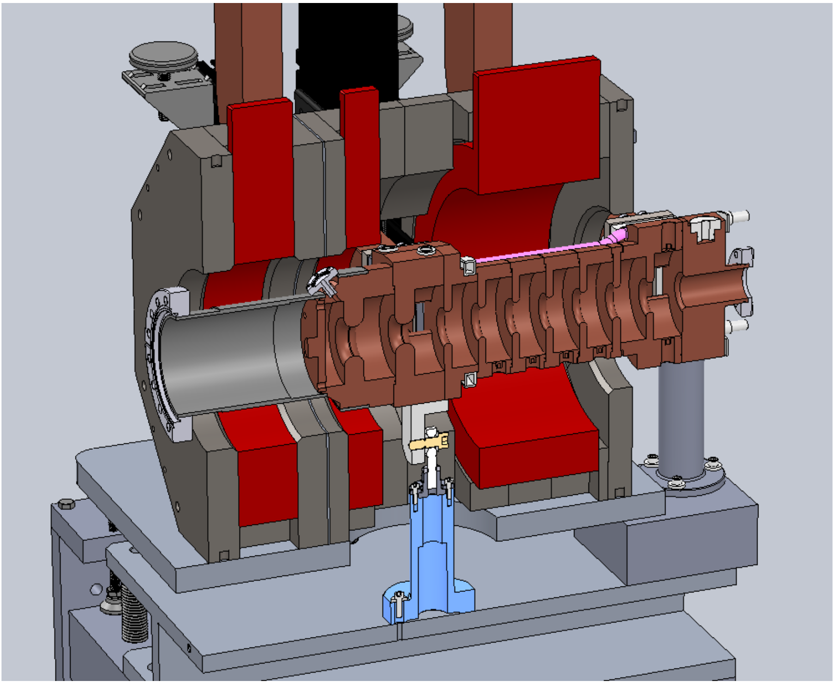
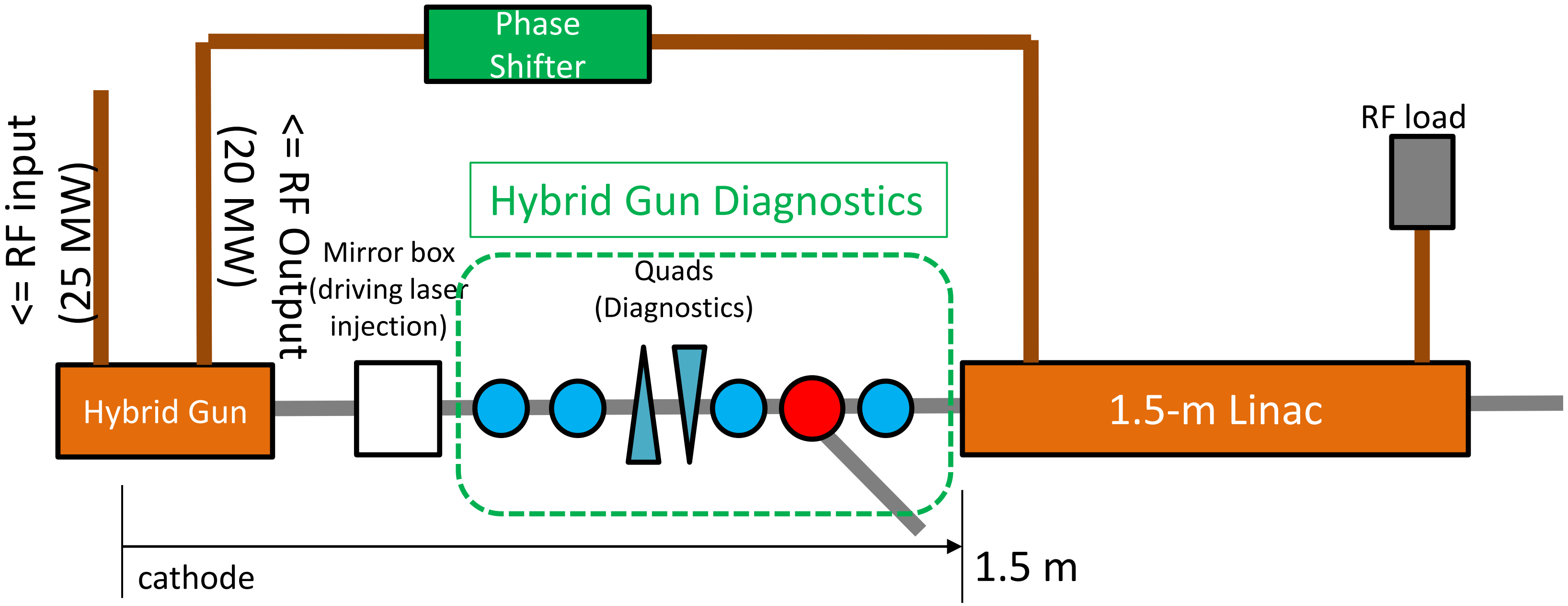
Hybrid Gun Section

Hybrid gun cavity and solenoid.



Hybrid gun beamline.



- Hybrid gun consists of a 1.5-cell RF gun and a traveling-wave velocity buncher.
- Hybrid gun and the 1.5-m linac are connected in series.
- The space for the diagnostics is very short. Because of it, we will diagnose the beam without 1.5-m linac, first. Then, we will optimize the layout of the diagnostics.

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30 MeV Beam Dynamics at S-band Hybrid Photoinjector (GPT*)

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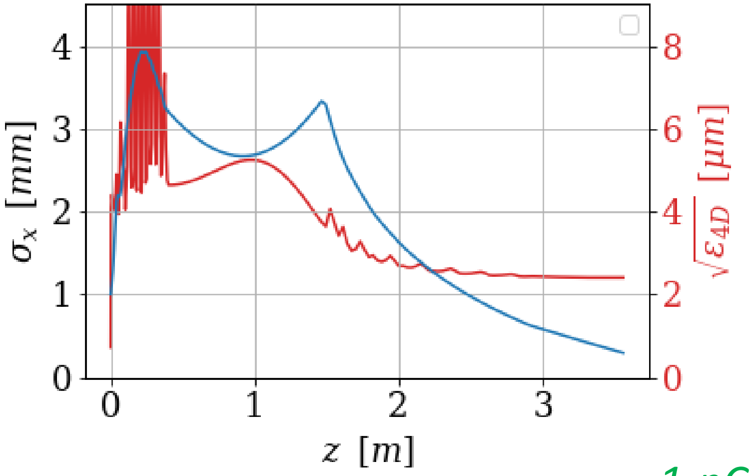
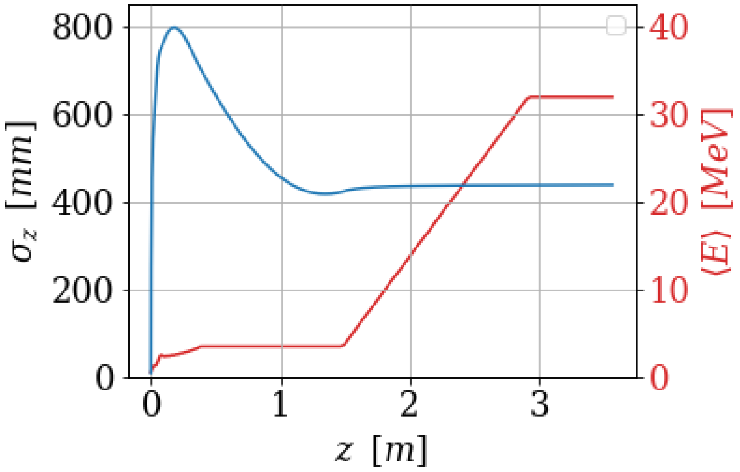
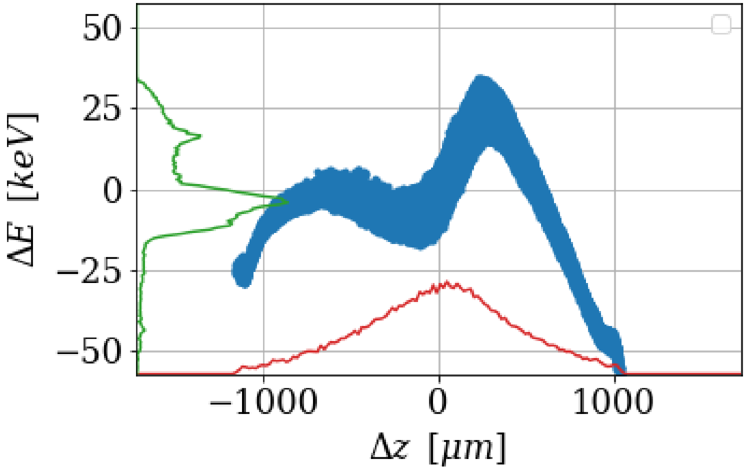
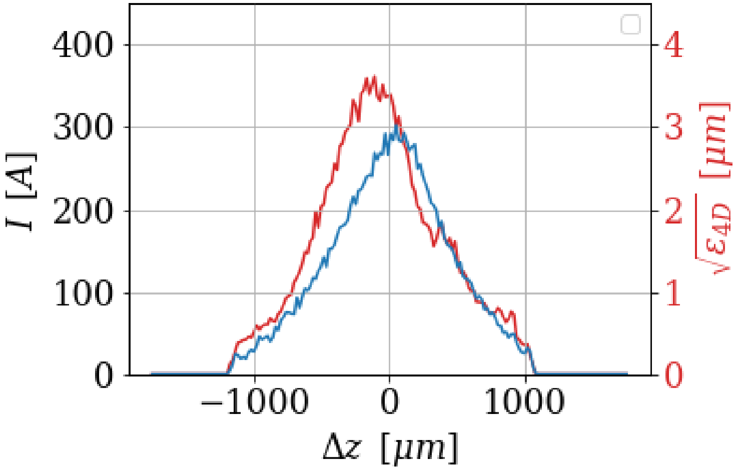




1-nC Beam





Parameter	Value
Beam Energy [MeV]	32 MeV
Charge	1 nC
R0, uniform	2.0 mm
T0, uniform	2.5 ps
Emittance, rms, normalized	2.4 um
Bunch length, rms	440 um (1.4 ps)
Energy spread, rms	14 keV
Slice energy spread, rms, max	6.6 keV (0.021%)

- The beam was launched with a relatively short length to avoid nonlinear effect at bunching.

*Pulsar Physics, http://www.pulsar.nl

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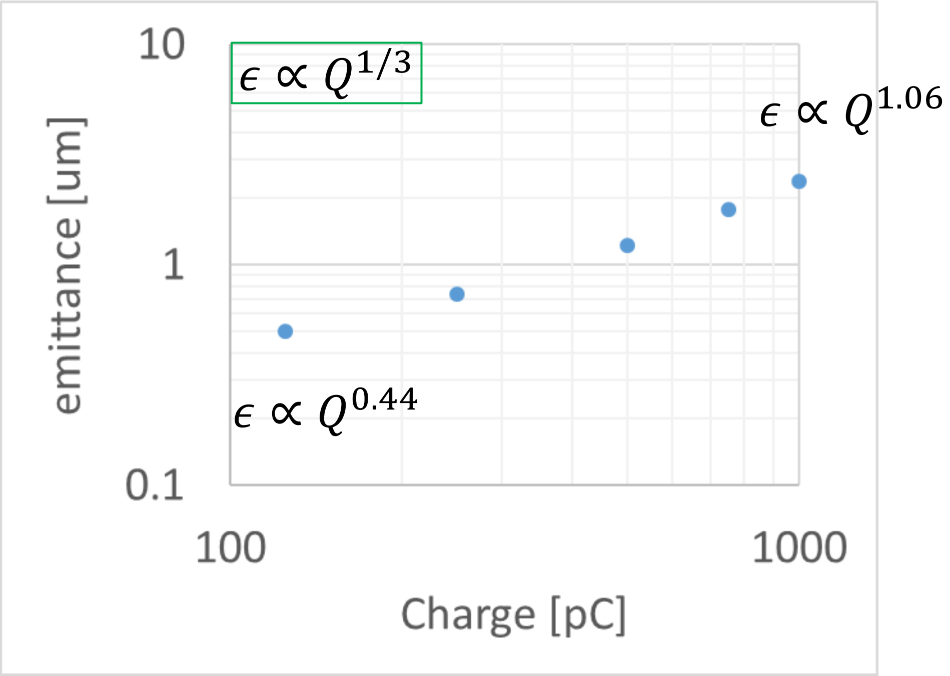
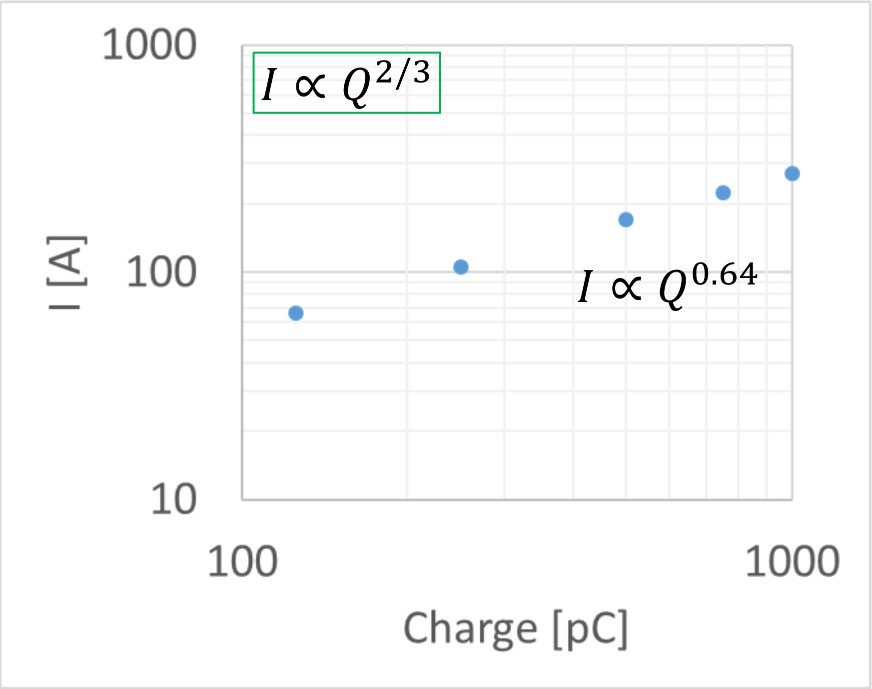
30 MeV beam, Charge Scaling





Linear scaling: $x, y, z \propto Q^{1/3}$

- The transverse motion deviate from the linear scaling. The dynamics involves strong nonlinear effects.
- The longitudinal motion agrees well with the scaling.

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30-MeV Test Beamline and 18-MeV FIR-FEL Experiment

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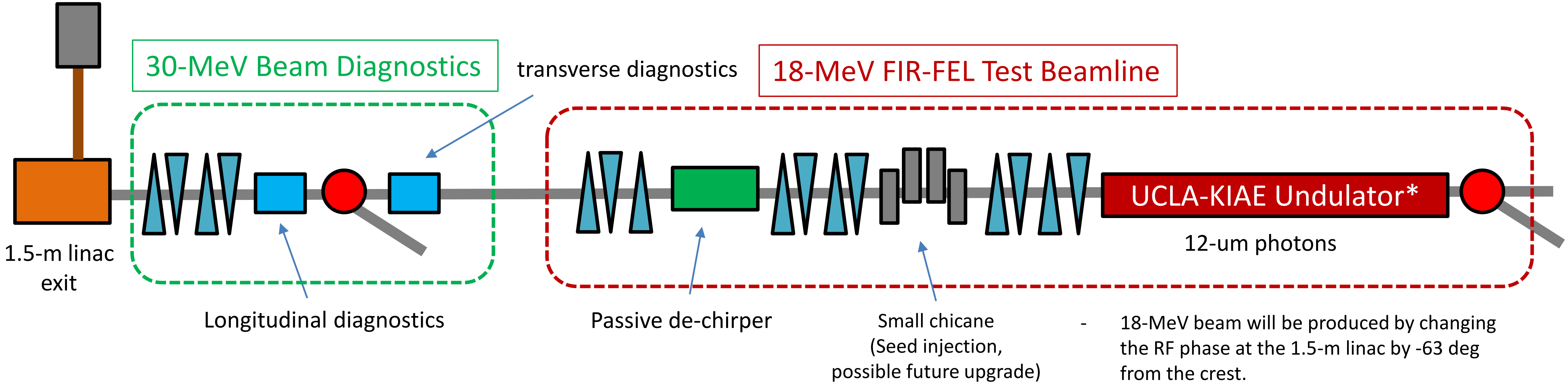

- 18-MeV beam will be produced by changing the RF phase at the 1.5-m linac by -63 deg from the crest.
- This beamline will be moved to dog-leg beamline to open the space for 3-m linac.

FIR-FEL Project

- Preliminary experimental study toward UC-XFEL.
- Development of AI-assisted control system for the future FEL facility.
- Student education on FEL physics.

*M. J. Hogan et al., PRL 81, 4867 (1998)

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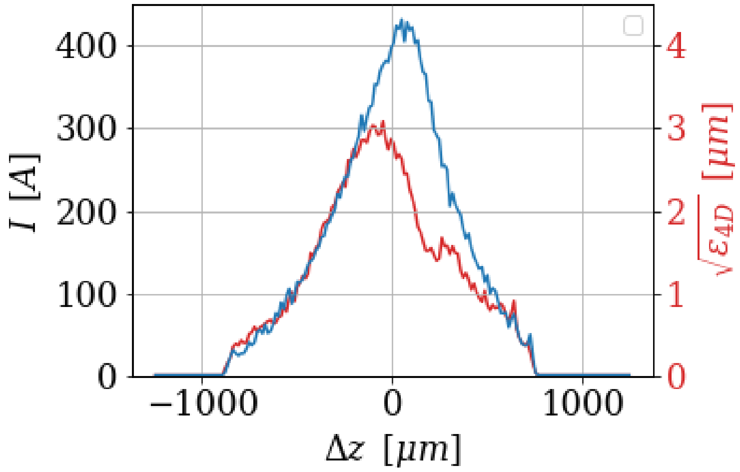
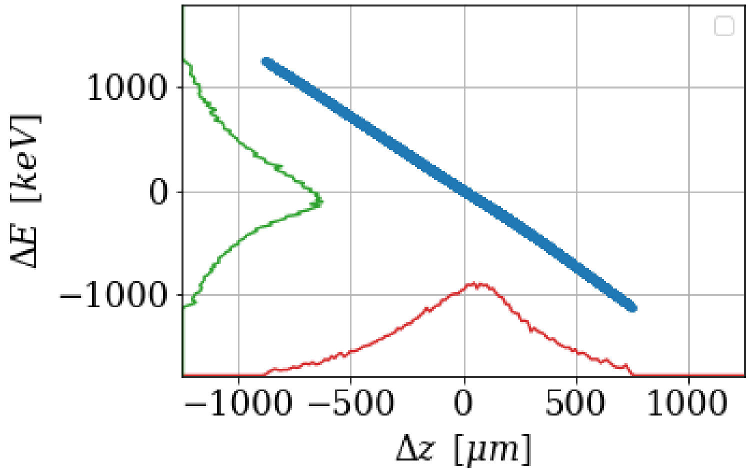
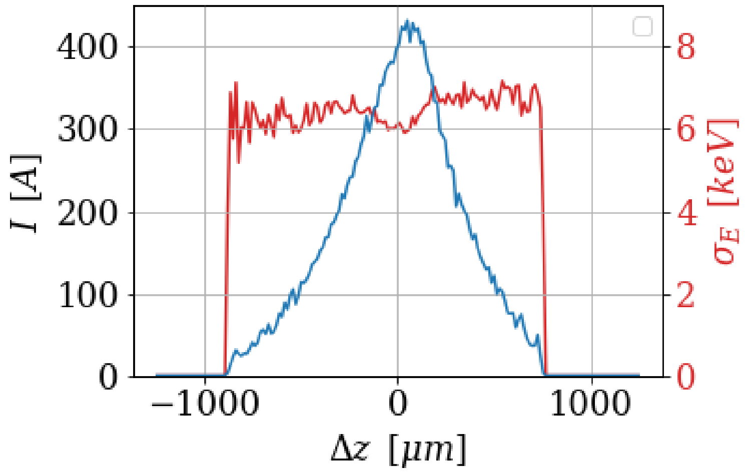
Beam Dynamics at 18-MeV Operation (GPT)





- Because the beam was accelerated at off-crest to reduce the energy gain, it got a relatively large energy spread.
- It can be compensated by using de-chirper.
- The other parameters looked good.



Parameter	Value
Beam Energy [MeV]	18 MeV
Charge	1 nC
Emittance, rms, normalized	2.2 um
Bunch length, rms	310 um
Energy spread, rms	450 keV
Slice energy spread, rms, max	7.2 keV (0.039%)

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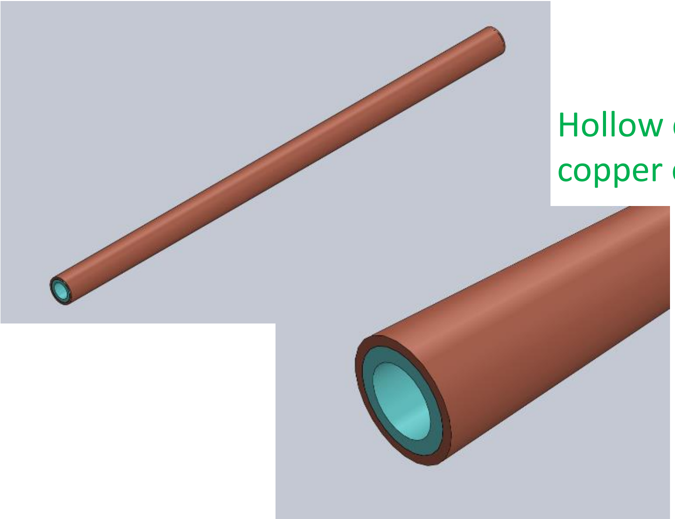
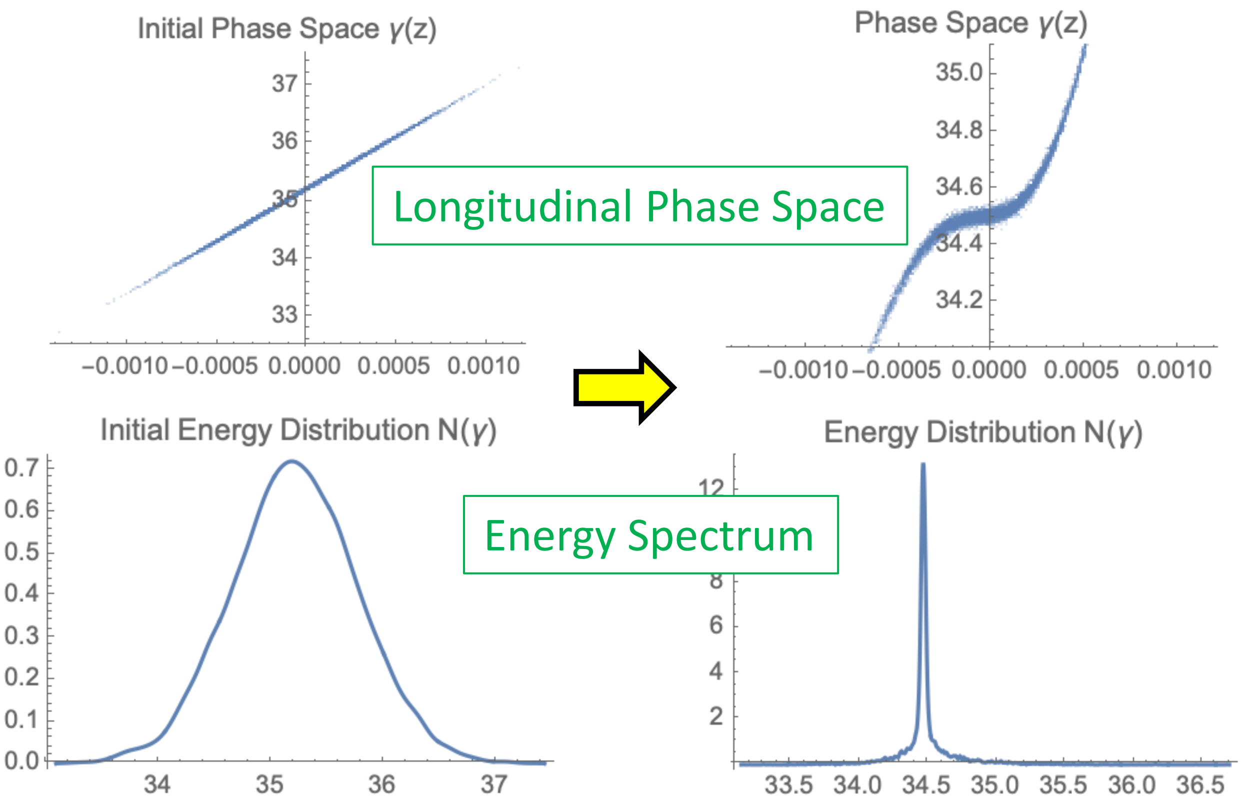
Dielectric Tube De-chirper



Hollow dielectric tube with copper cladding

Parameter	Value
Design frequency	60 GHz
Dielectric (ϵ_r)	Quartz (3.8)
Cladding	Copper
Inner Radius	1.5 mm
Outer Radius	2.1 mm
Length	100 mm



- A 60 GHz passive de-chirper made of a dielectric hollow tube with metal cladding could suppress the energy spread effectively.
- A dielectric tube is very compact, but it is not tunable.
- We are looking into slab geometry option for the tunability.
- We will consider the possibility of all-metal structure.

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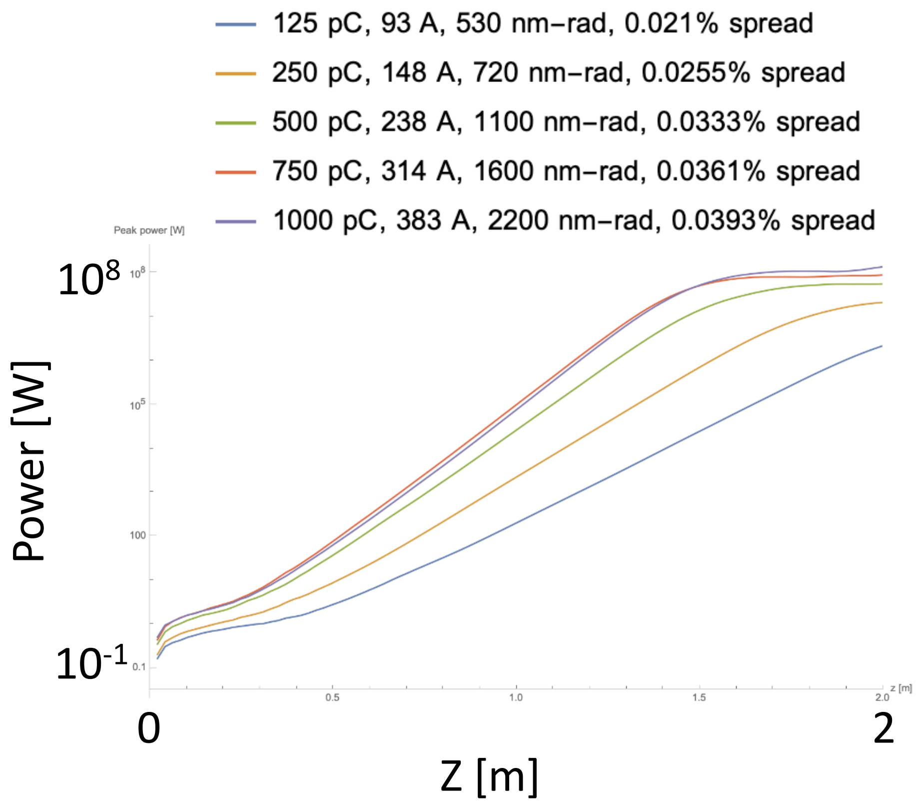
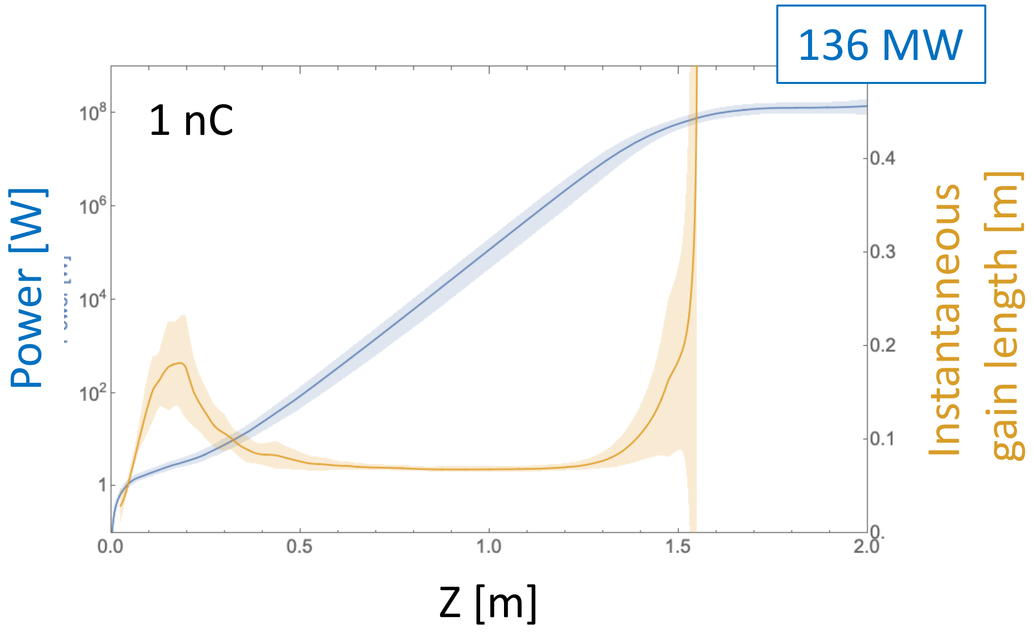
FIR-FEL, Preliminary Simulation (GENESIS*)





Parameter	Value
Undulator Period	2.05 cm
Number of Periods	98
Undulator Parameter	1.04
Radiation Wavelength	12 um

- Assuming a gaussian beam without energy chirp.
- Looking for the saturation by changing the beam charge.
- Saturation can be observed above 500 pC.
- For the next step, we will simulate with real bunch shapes.

*S. Reich, NIM A 429 (1999) 243

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Summary

- UCLA constructed a radiation bunker for 80-MeV beamline and a clean laser room for advanced accelerator researches, and they will be ready for use by this summer.
- The beam dynamics for 30-MeV photoinjector with S-band Hybrid gun was simulated by using GPT.
  - It demonstrated the generation of beams with the rms emittance 2.4 um and the rms bunch length 1.4-ps.
- As the first application, a preliminary simulation of FIR-FEL experiment was shown.
  - With GPT simulations, the condition was found to produce 18-MeV beam which matches to UCLA-KIAE undulator.
  - A passive de-chirper can be used to suppress the large energy spread of the beam from the photoinjector.
  - The preliminary GENESIS simulation was performed for the gaussian distribution. It showed we could observe the saturation with the peak power 135 MW, at best, by using 1-nC 18-MeV beam.