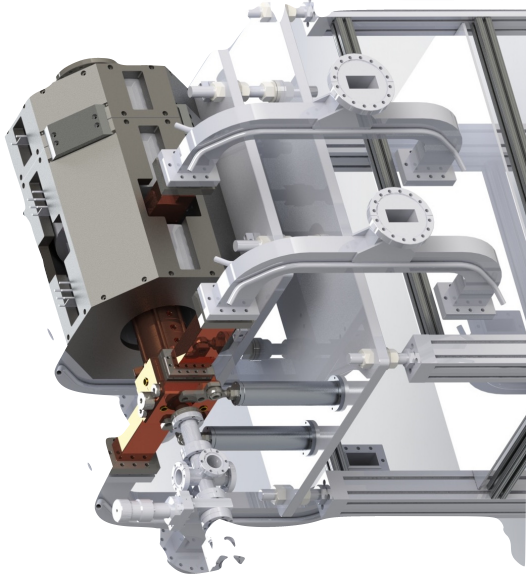
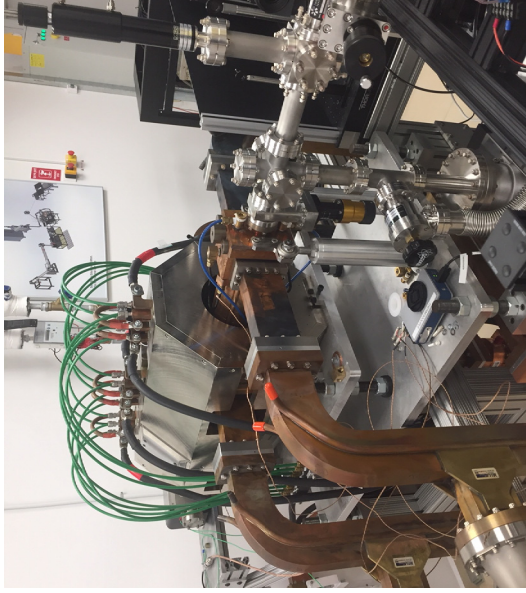


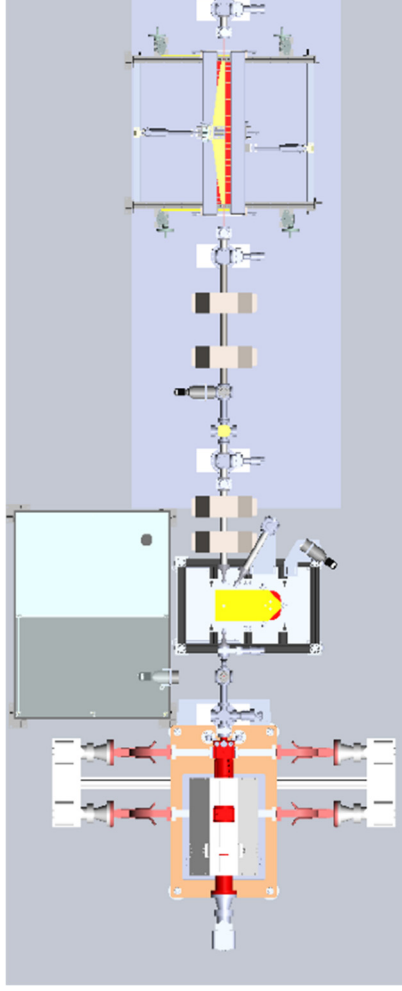
# First Operation of a Hybrid E-Gun at the “Schlesinger Center For Compact Accelerators” in Ariel University



A. Nause, A. Friedman, J. Rosenzweig, A. Fukasawa,  
R. Roussel, B. Spataro

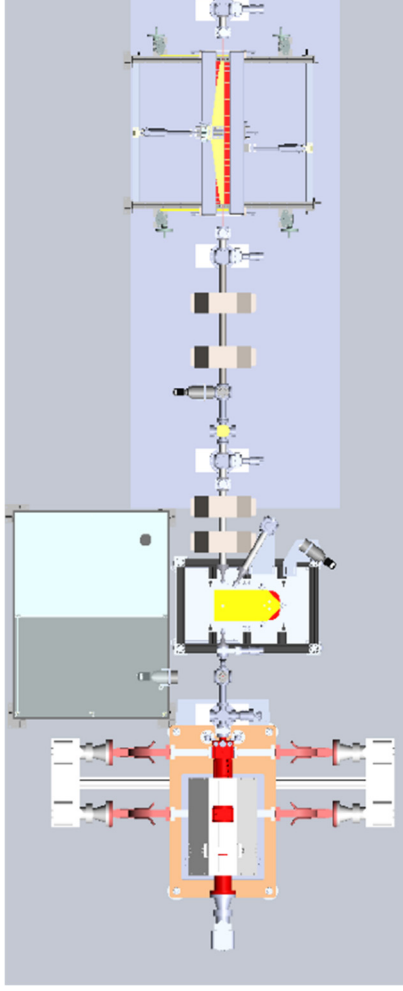
# Advanced Hybrid Photo-injector

- Commissioned at Ariel University in Israel as an on-going collaboration between the two universities.



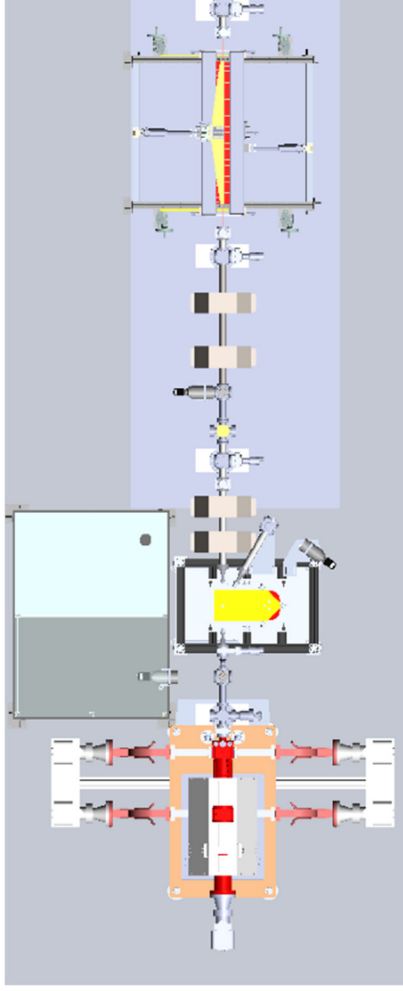
# Advanced Hybrid Photo-injector

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- Designed at UCLA's Particle Beam Physics Laboratory (PBPL).



# Advanced Hybrid Photo-injector

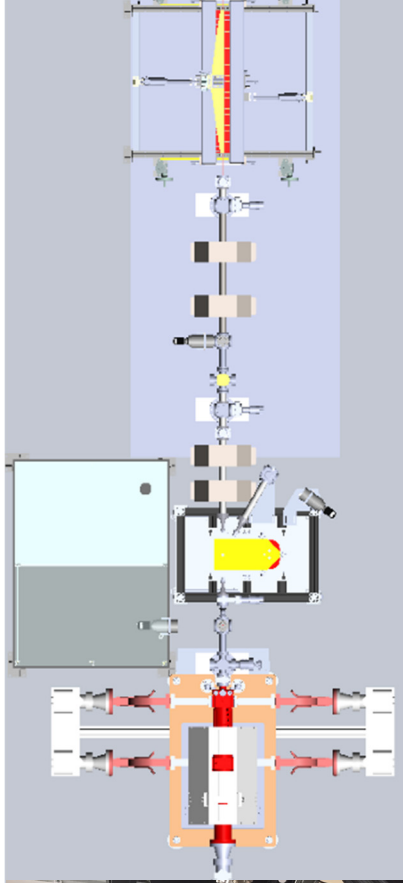
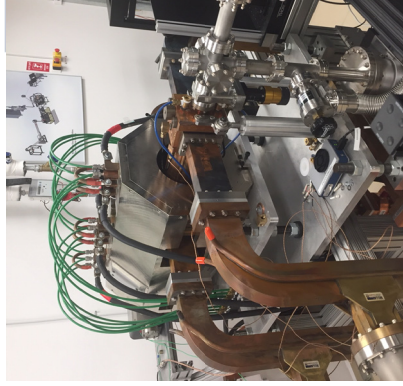
- Commissioned at Ariel University in Israel as an on-going collaboration between the two universities.
- Designed at UCLA's Particle Beam Physics Laboratory (PBPL).
- Second generation to a novel **hybrid** photo injector.





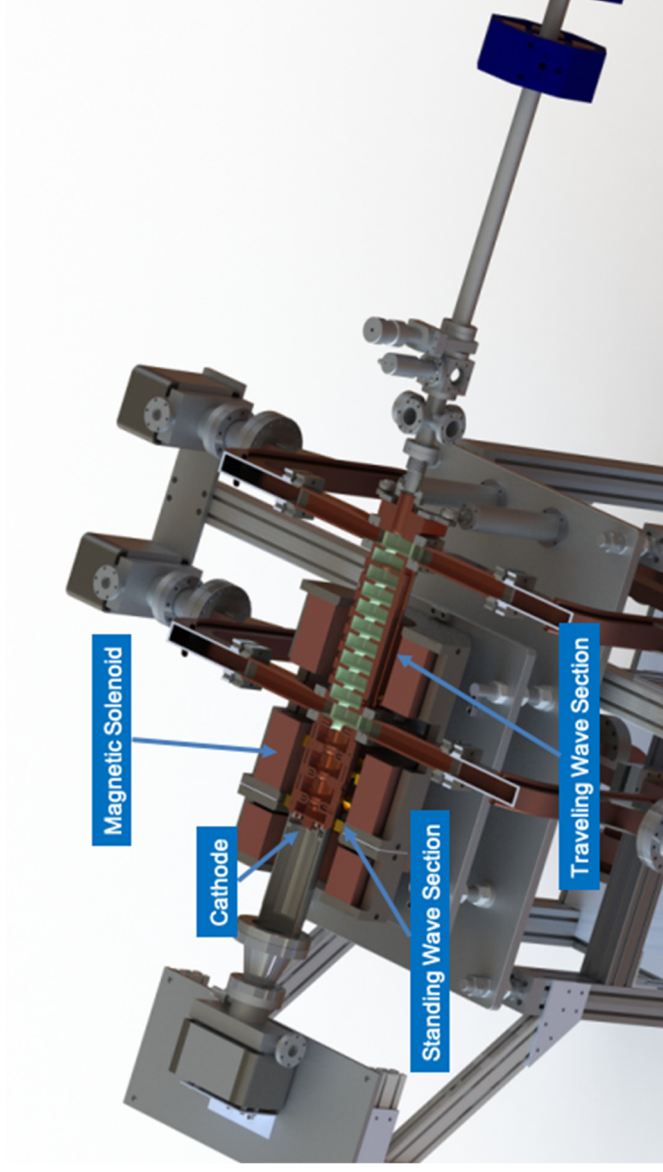
# Advanced Hybrid Photo-injector

- Commissioned at Ariel University in Israel as an on-going collaboration between the two universities.
- Designed at UCLA's Particle Beam Physics Laboratory (PBPL).
- Second generation to a novel **hybrid** photo injector.
- Will be used as a source for THz FEL operating at the super-radiance regime.



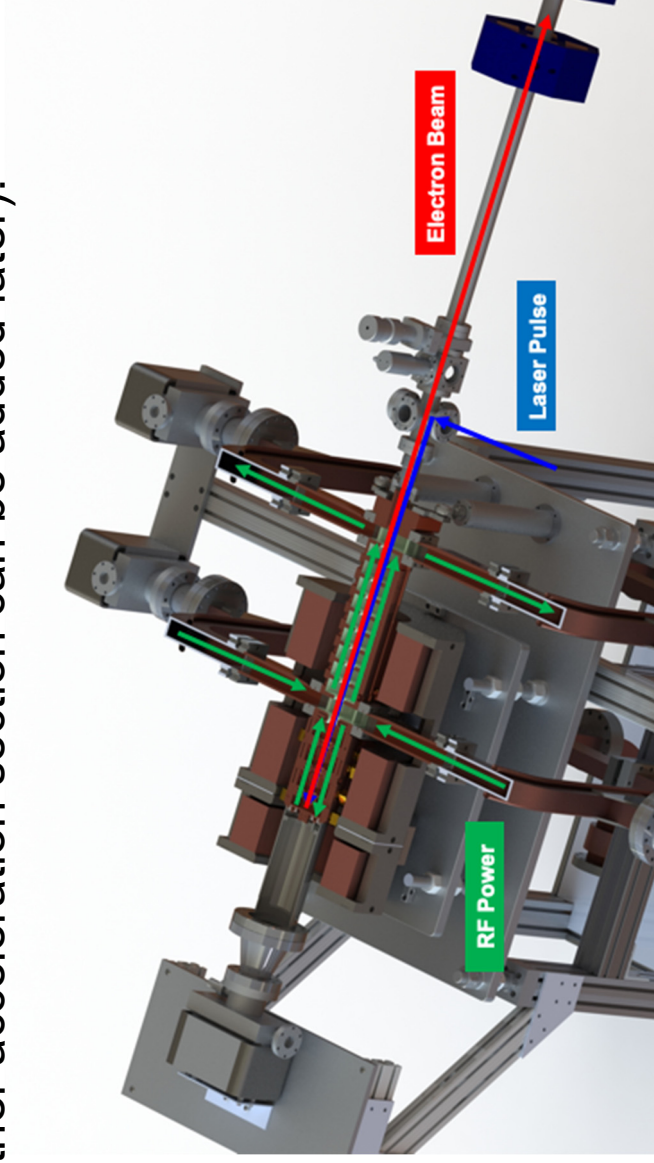
# Advanced Hybrid Photo-injector

- S-band gun (2.856 GHz), beam energy of 6 MeV, emittance of  $< 3 \mu\text{m}$ , and a 150-200 fs pulse duration at up to 1 nC per pulse.
- Low rep rate of up to 5 Hz due to capacitor-based modulator limitations.

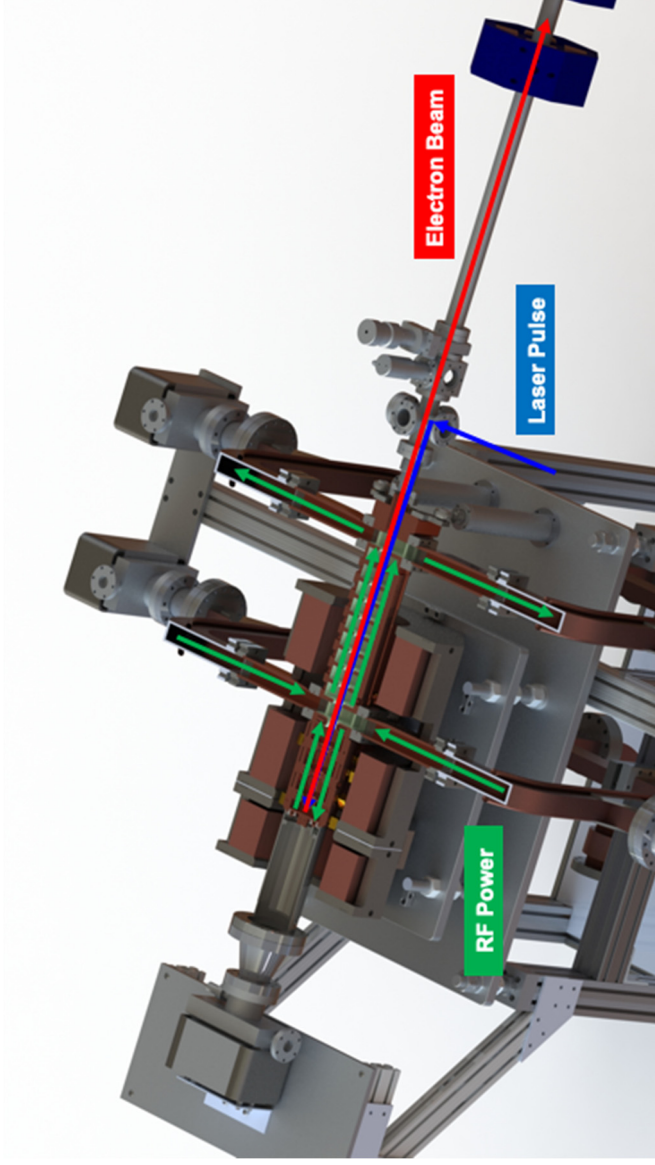


# Hybrid RF Design

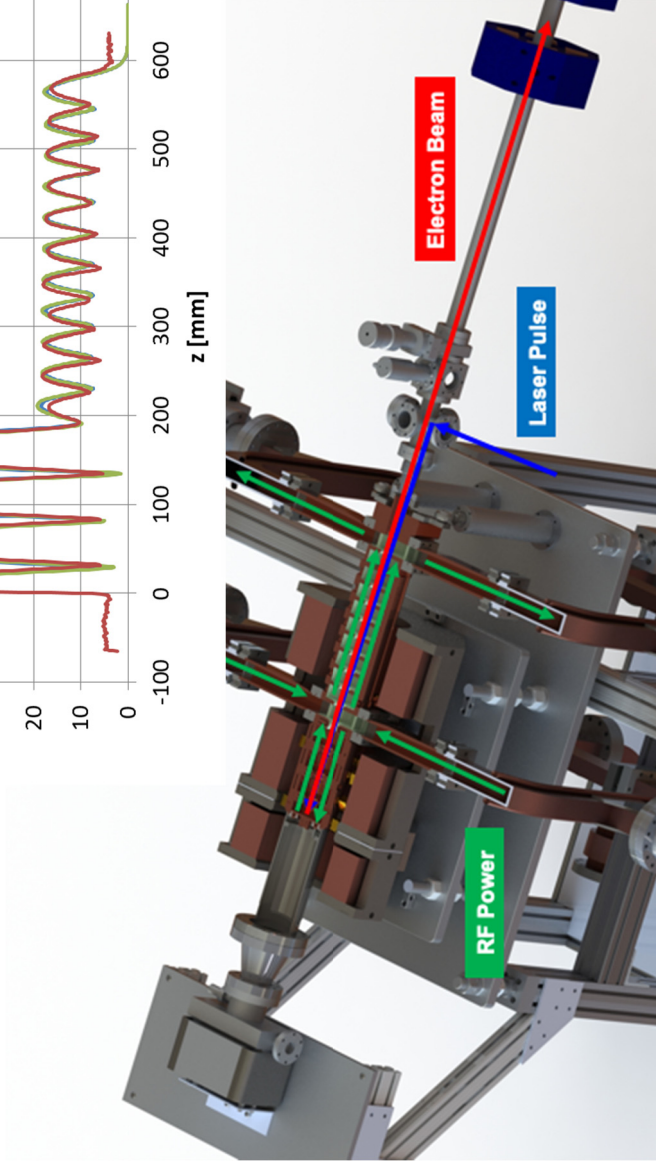
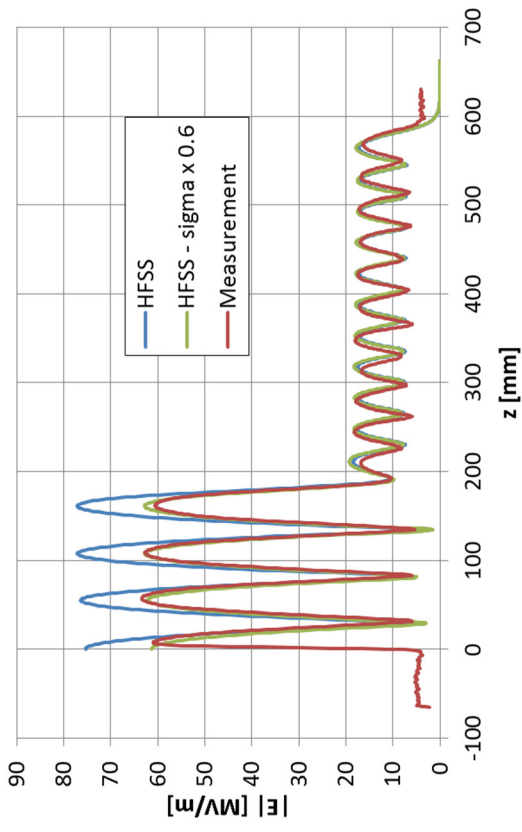
- Integrated structure consisting of standing wave (SW) gun cells (3.5) connected at the input coupler to a long traveling wave (TW) section (9 cells)
- Most of the RF power passing through the device and being directed to a load (another acceleration section can be added later).



# Hybrid RF Design



# Hybrid RF Design



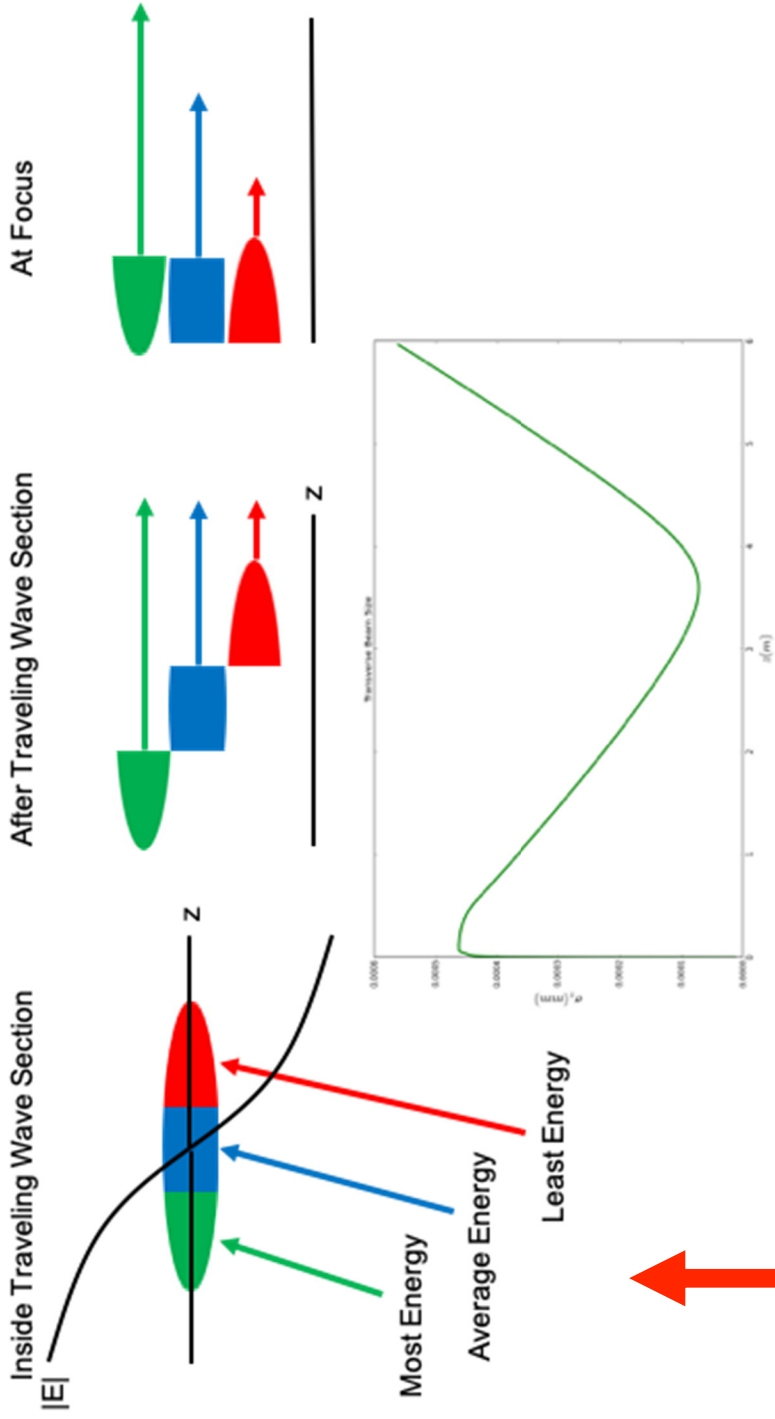
# Hybrid RF Design

Benefits of Hybrid design:

- Nearly mitigates impedance mismatches, and therefore reflected RF power;
- The device requires a much simpler high power RF system than a split photo-injector: there is only one klystron and waveguide section; attenuators and phase shifters are avoided;
- Hybrid structure is much more compact than a split system;
- The acceleration dynamics is robust, this indicates flexibility in operating energy by simply changing RF power and laser injection parameters;
- It avoids the bunch lengthening observed during the drift in a split photo-injector and in fact strongly longitudinally focuses, through velocity bunching due to  $90^\circ$  phase shift between SW cell and input coupler. As a consequence ten's of femtosecond rms bunch length beams are obtainable at  $\sim 6$  MeV;



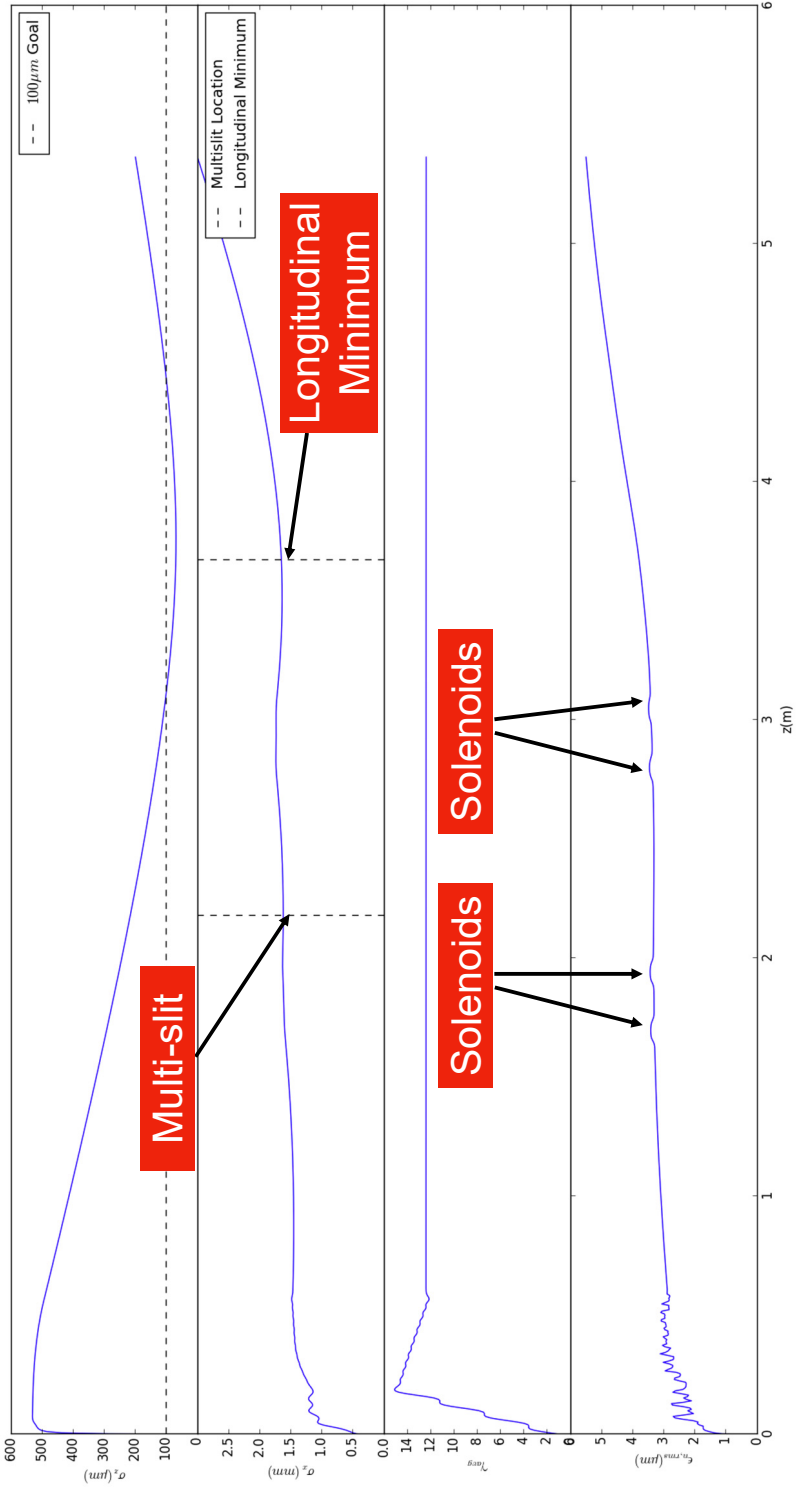
# Velocity Bunching



App 1 MeV of energy chirp per bunch

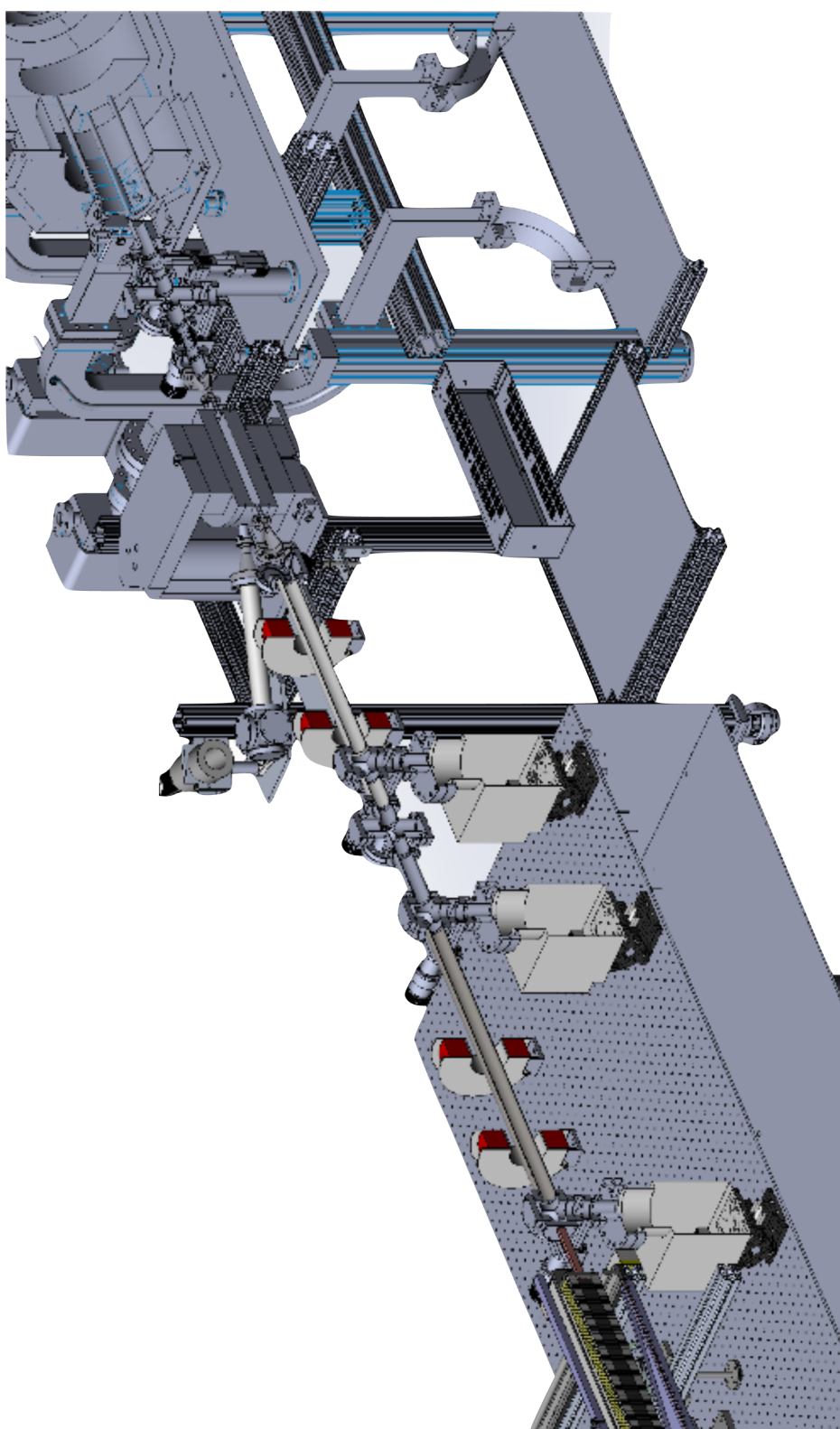
# Beam Dynamics

## Start-to-end GPT simulations

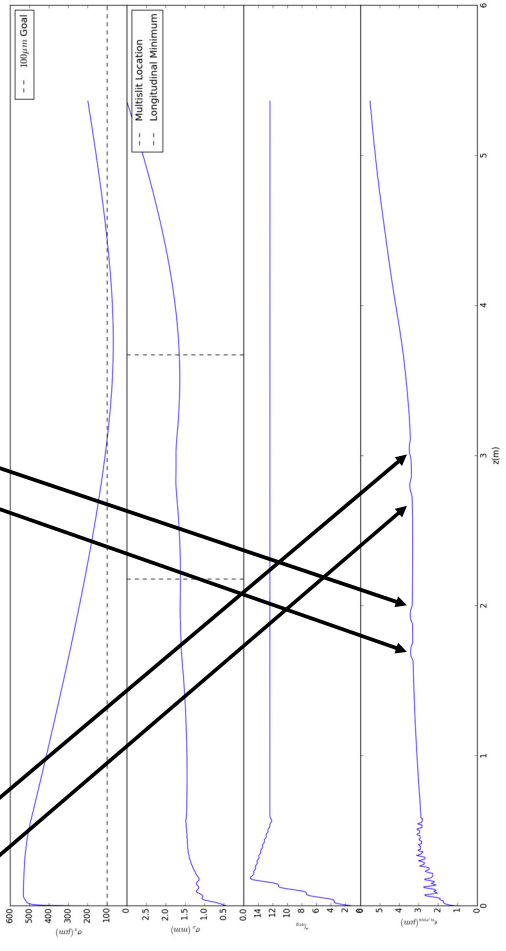
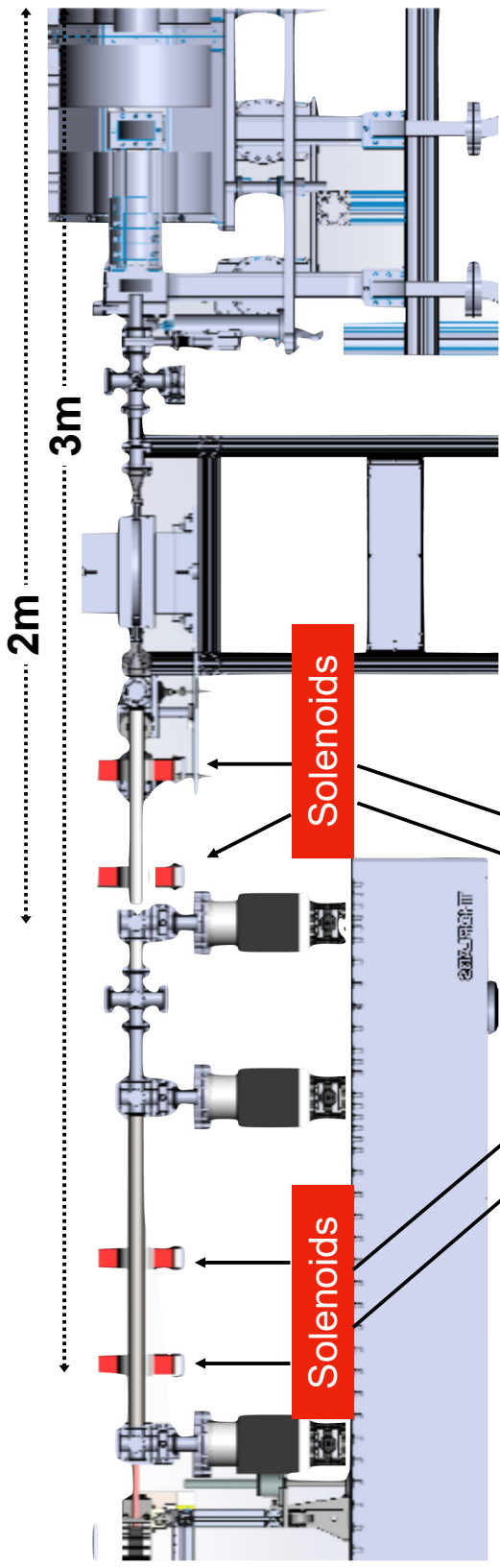




# FEL Layout

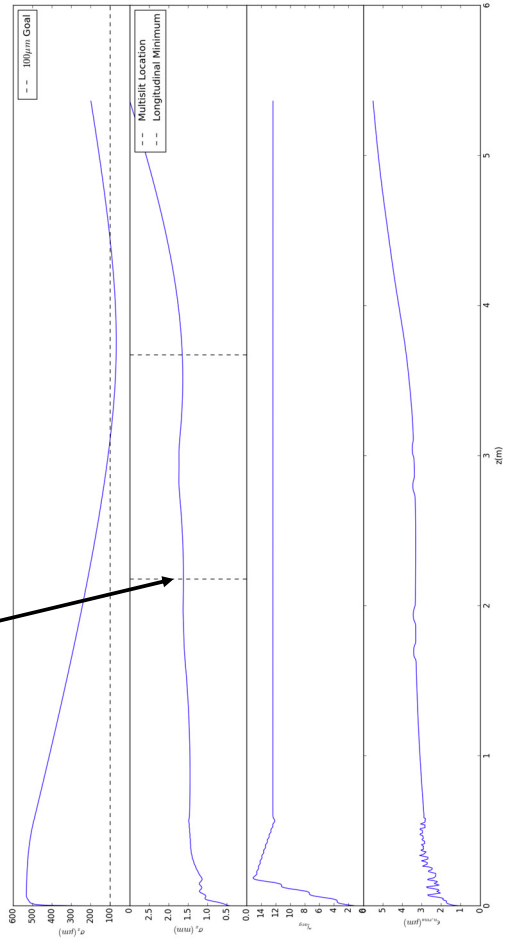
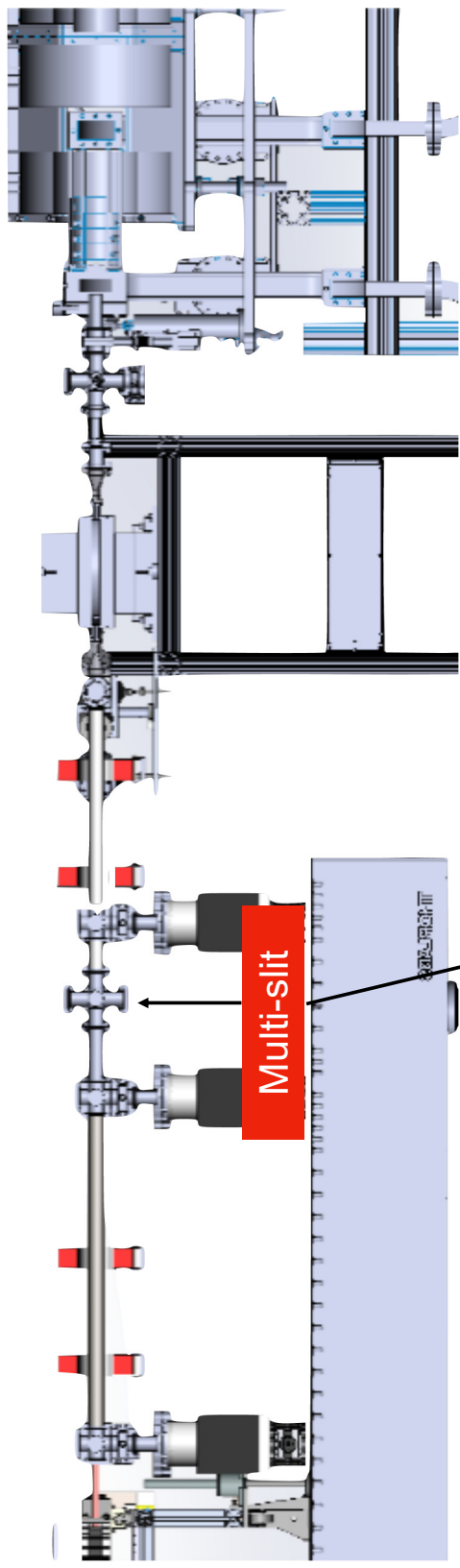


# FEL Layout



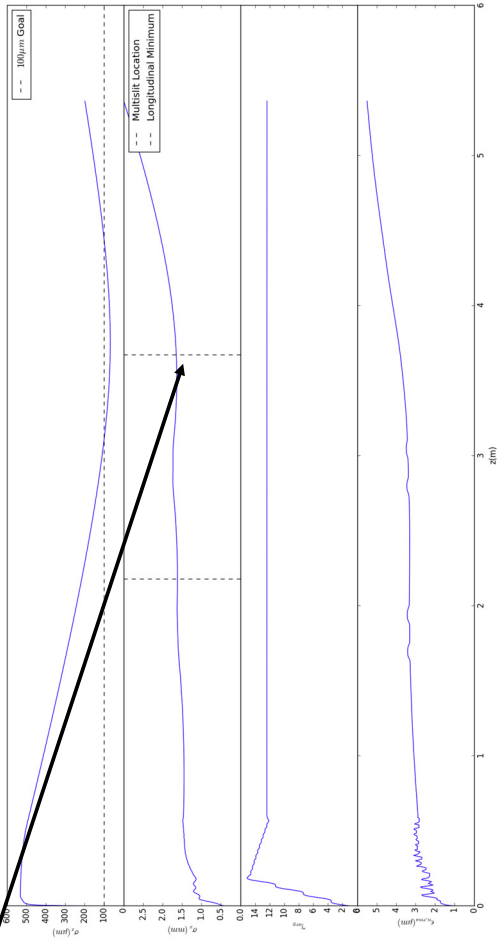
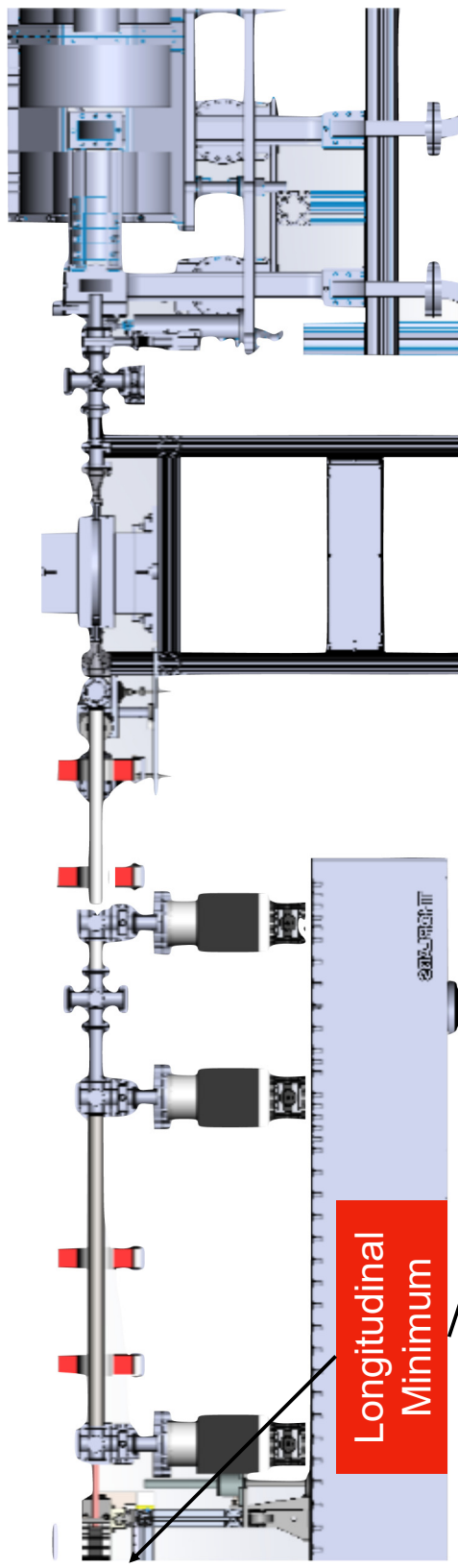
# FEL Layout

←..... 2m .....→



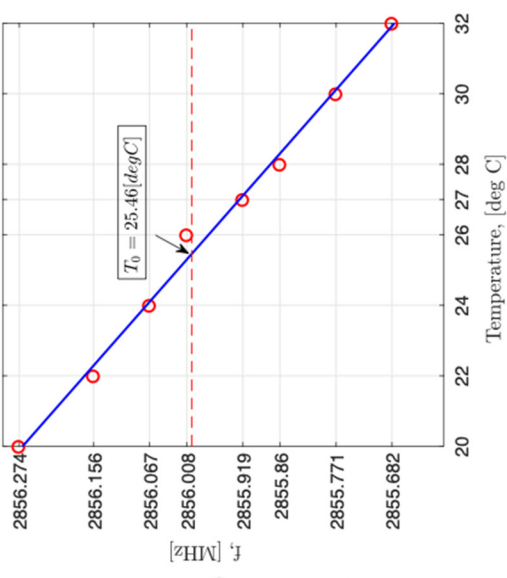
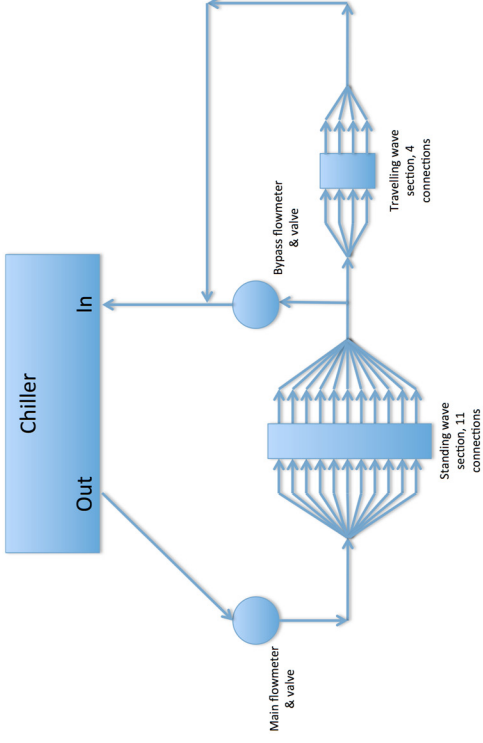
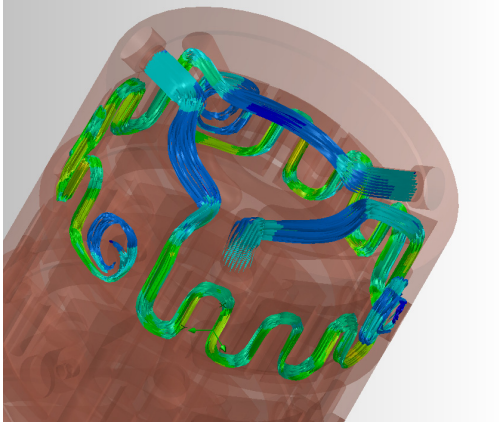
# FEL Layout

3.5m



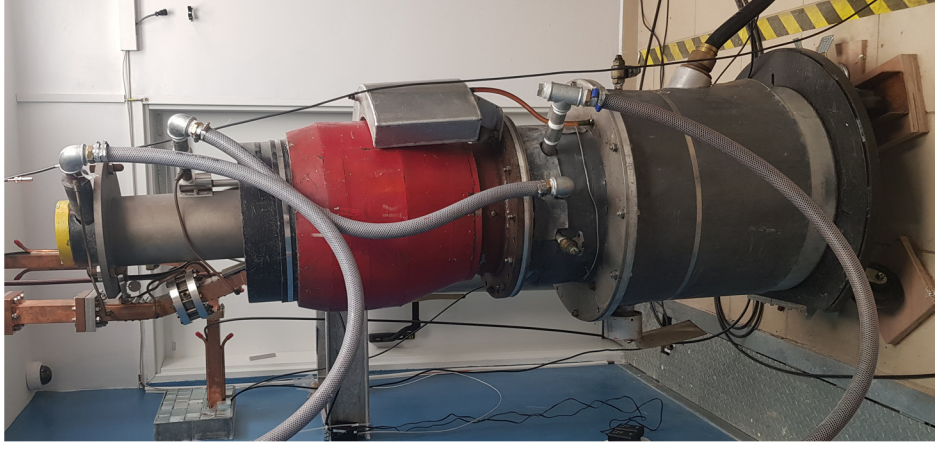
# Cooling/Heating Circuit

- Tightly controlled temperature (0.1 deg C).
- The TW has no sensitivity over a wide range of temperatures ( $\pm 10$  deg C).
- Relative phase between sections is tunable.

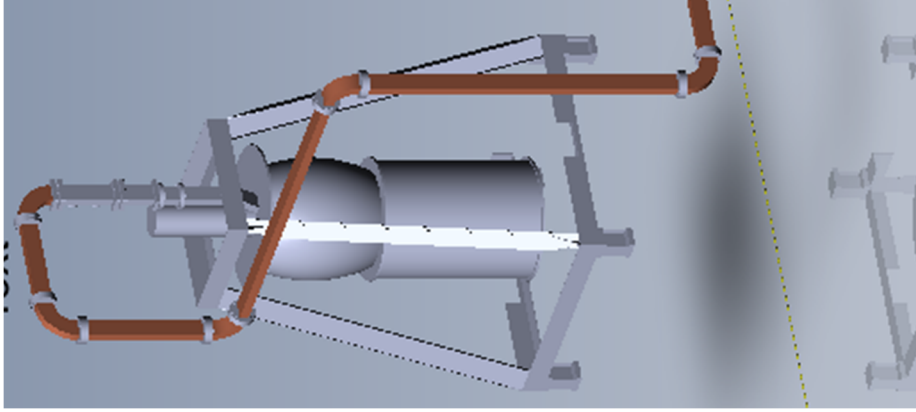


# High Power RF System

## Klystron



- The RF power for the gun is supplied by a 25 MW Klystron which has been manufactured at SLAC (XK-25).
- The Klystron requires an electrical pulse of 250 kV @250 A. A pulse transformer with a ratio of 1:12 is located in the bottom of the Klystron, which determines the requirements for the driving Modulator
- RF waveguides are filled with SF6.





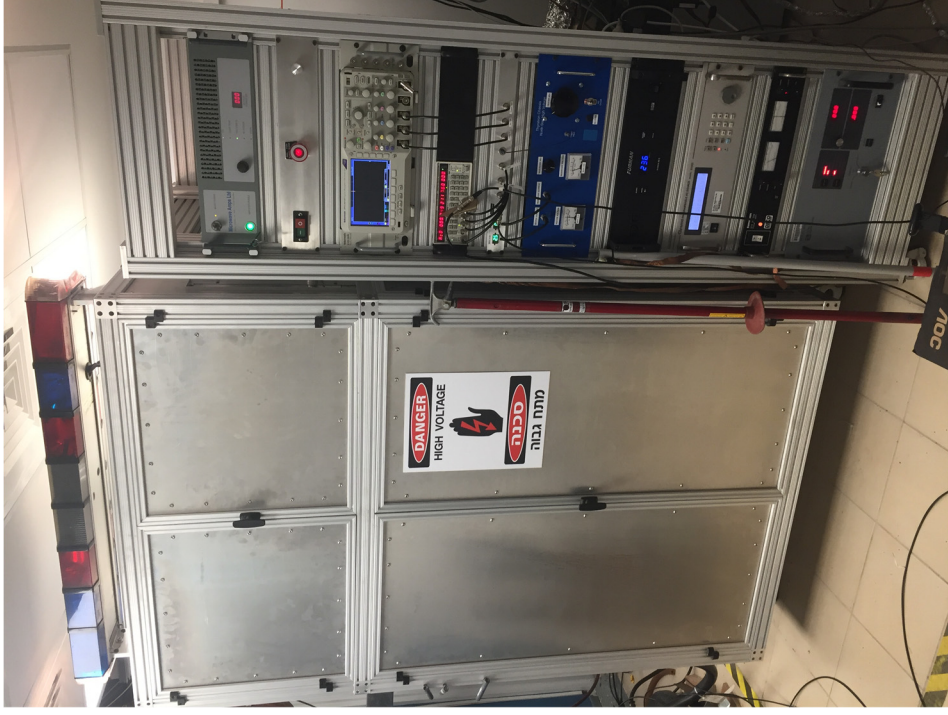
# High Power RF System

## Modulator

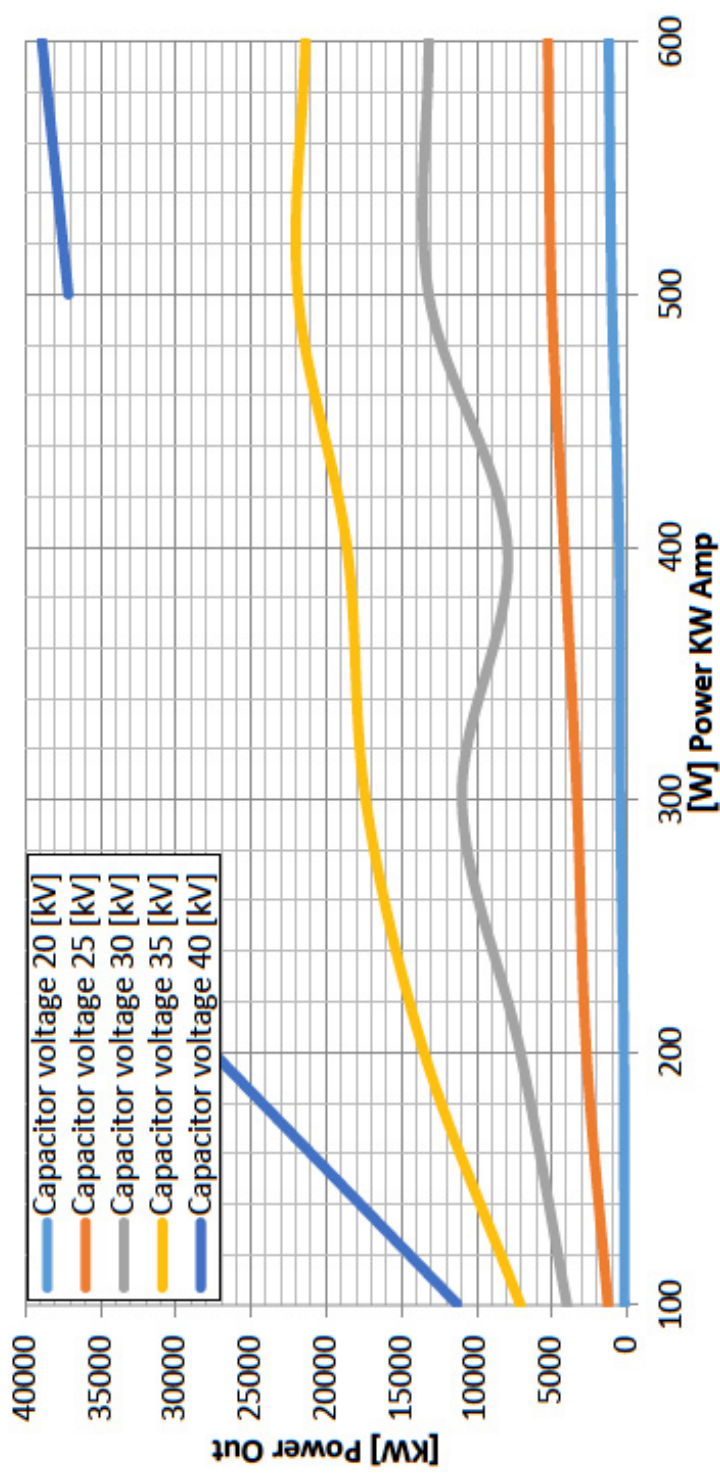
The modulator was built in UCLA, and is based on charging and discharging of oil capacitors via a Pulse Forming Network. It is limited to 5 Hz operation, and will typically work at 1 Hz.

Table 1: Modulator parameters

Output pulse voltage (max)	25 kV
Output pulse current (max)	3 kA
Pulse duration	3 $\mu$ s
Pulse repetition rate	1-5 Hz
Ripple	$\pm 0.5\%$

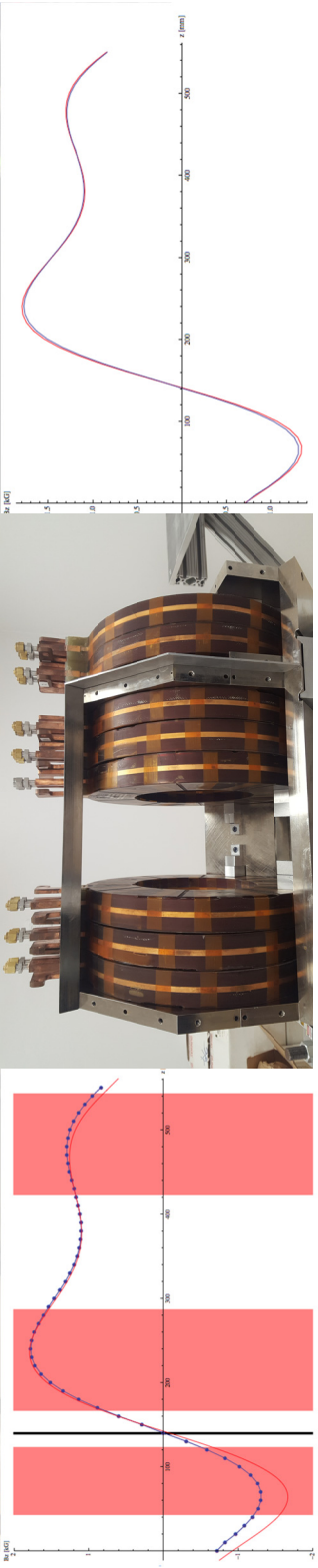
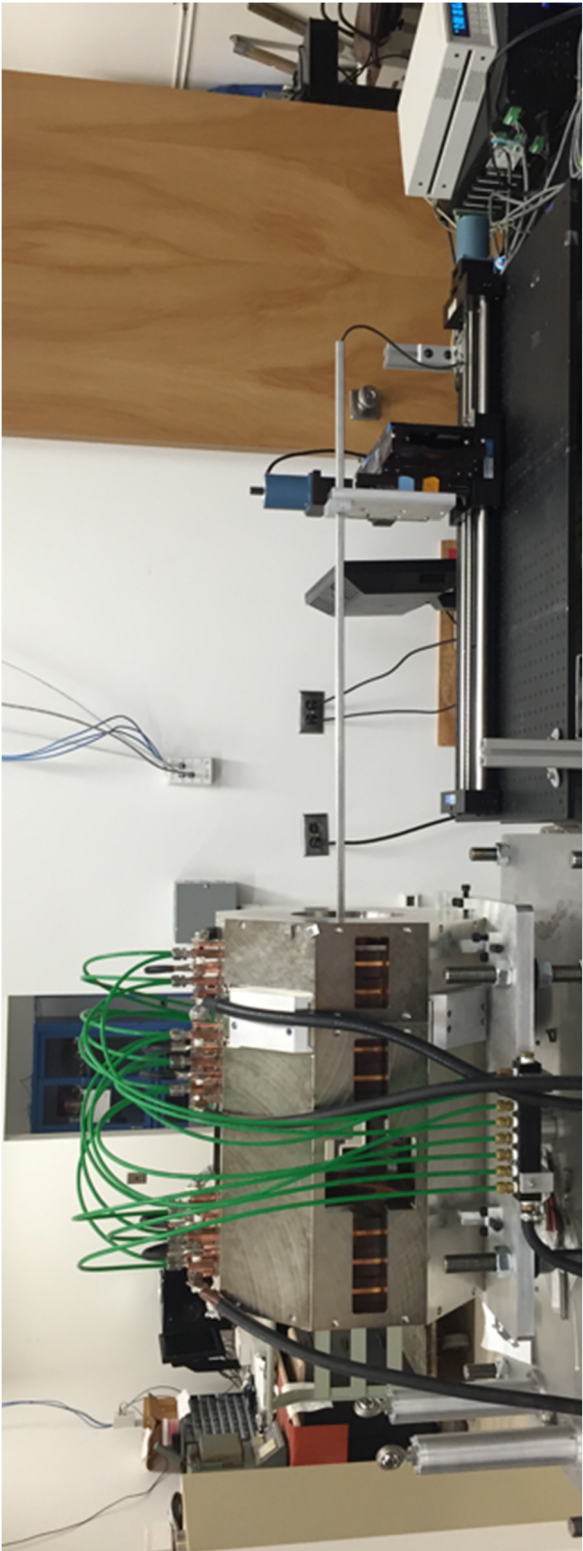


# Klystron Power Measurements





# Solenoid



# High Power RF Testing

- Operation of the gun requires launching RF signal of over 20 MW into the gun structure.
- High power RF field entering a cavity can cause effects such as field emission of electrons from protrusions on the surface.
- These effects can cause arcing or sparks which can destroy the RF gun or the RF window. For this reason, a careful and rigorous conditioning process was necessary to prevent such damage.

# High Power RF Testing

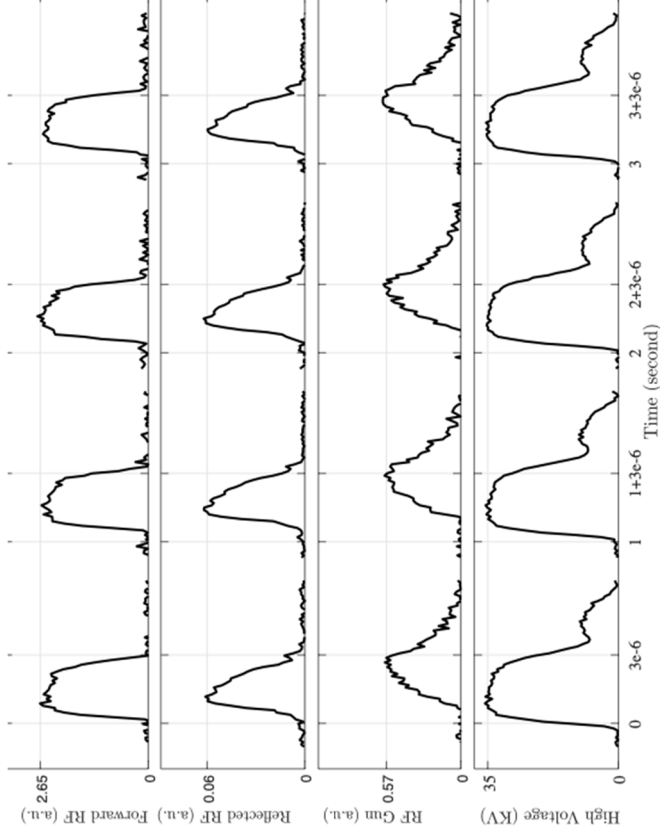
- Conditioning process took about a month.
- A control software with a dedicated algorithm was used to automatize the process.
- We monitored pressure, temperature, and RF amplitude at different locations.

# High Power RF Testing

- Using a fast-switch we varied the pulse duration from 500 ns to 3 us, while slowly ramping the field amplitude.
- When peak-power reached, pulse duration was increased.
- **Final RF field peak-power was 22 MW at 3 us.**

# High Power RF Testing

Typical data collected during four RF pulses:



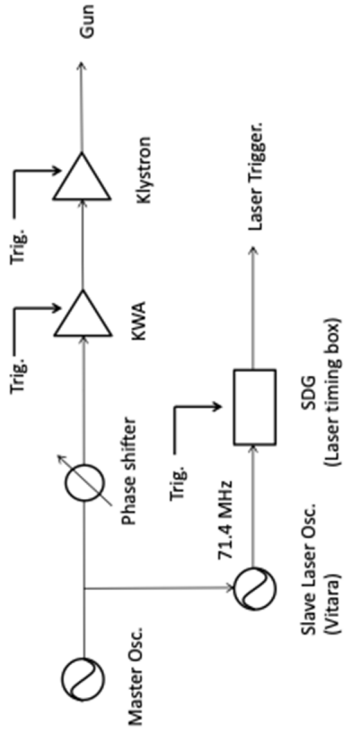
RF power is measured both in the forward and backward directions and inside the first cell of the SW section of the gun.

# Laser System

## Amplifier

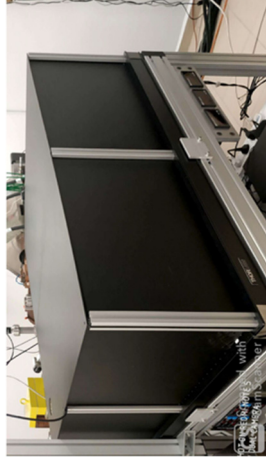
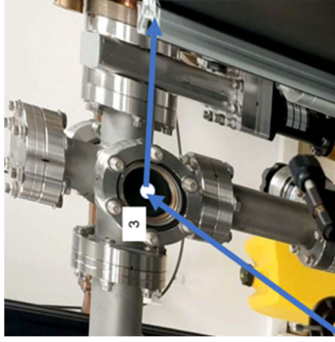
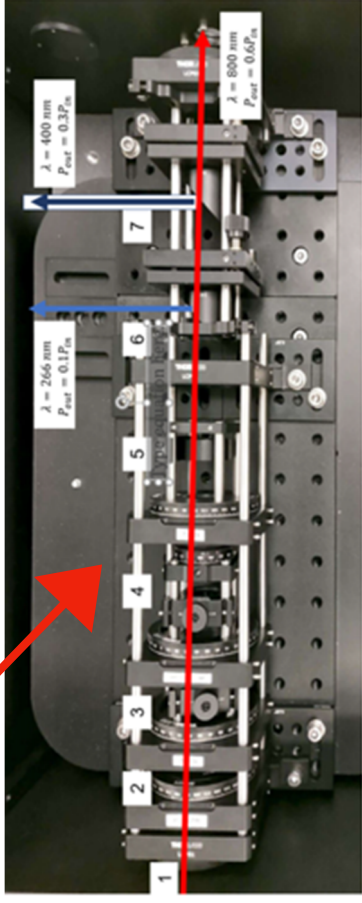
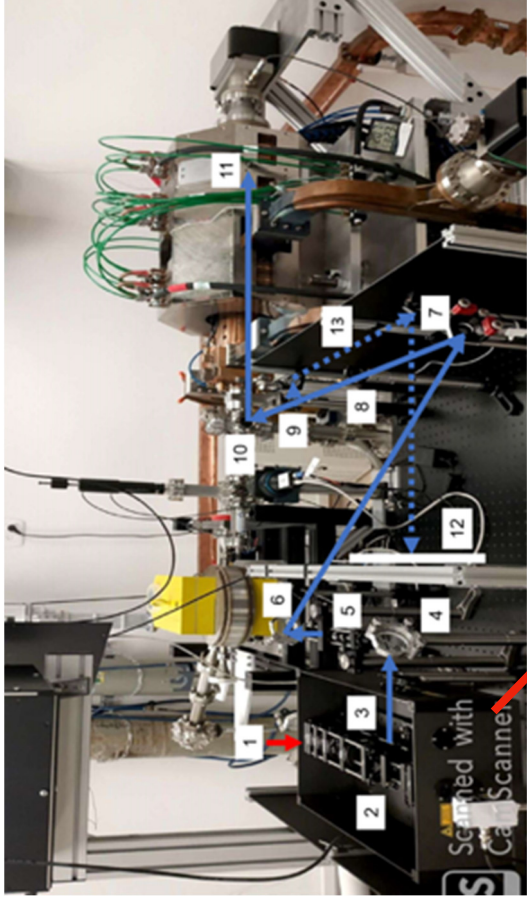
"Astrella" laser amplifier by Coherent, with 35 fs pulse and 3 mJ per pulse @500 Hz.

An analog locking system, based on mixing of the master oscillator with the 40th harmonic of a 71.4MHz signal from a diode installed inside the seed oscillator, was built in-house, in order to lock the laser to the master oscillator.



# Laser System

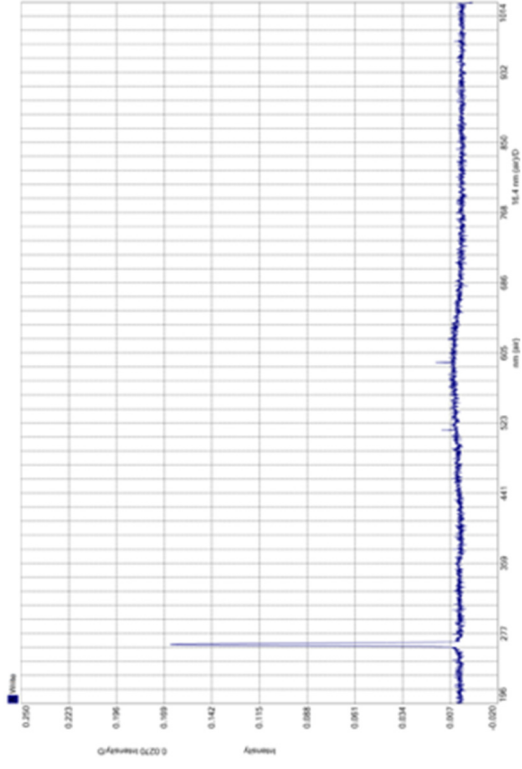
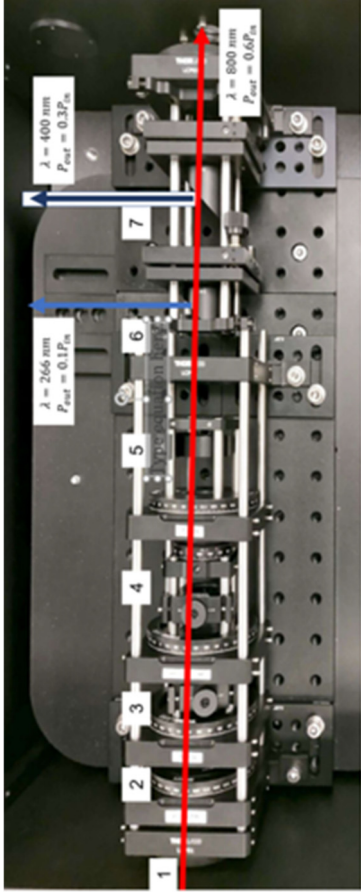
- 4f optical System
- A third-harmonic system provides the needed UV pulse to extract electrons off the Copper cathode.
- Conversion efficiency of 9%.
- The fs UV pulse is stretched by a fused silica crystal to 1 ps.





# Laser System

IR to UV



1. Zero order waveplate.
2. Type 1 2nd harmonic generation (SHG) BBO crystal.
3. Calcite plate for group velocity delay compensation.
4. Zero order dual waveplate  $\lambda/2@800+\lambda@400 \text{ nm}$ .
5. Type 1 3rd harmonic generation (THG) BBO crystal.
6. Harmonic Separator HR @ 266 nm and HT @ 800+400 nm at AOI=45.
7. Harmonic Separator HR @ 400 nm and HT @ 800 nm at AOI=45 deg.

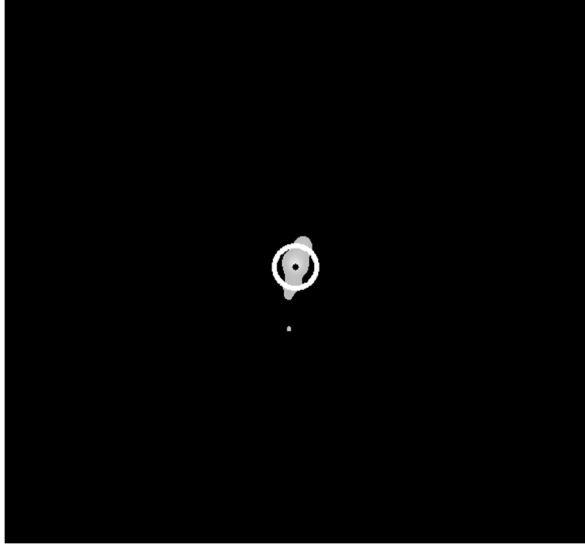


# First Operation

- A combined operation of all sections - performed March 2019.
- Synchronisation of RF system and diagnostics were first. Dark current due to the high-fields in the RF structure witnessed.
- Laser locking tested and worked well.
- Laser system turned on, hitting the Cathode and releasing a pulse of electrons into the standing wave section.

# First Operation

- Beam capturing using a scintillator screen and a 100 mm Macro lens on Basler sCA mono-chromatic camera.
- Screen was tilted at 45 deg - this is the reason for the elongated shape of the image.
- Ring and center dot in the image are an algorithm designed to find beam center and spot dimensions using real-time image processing.



## Beam was captured!