Low Energy RHIC electron Cooling (LEReC)

High-power Fiber Laser System for LEReC

Zhi Zhao

DOE Review
November 14-15, 2017

70 YEARS OF DISCOVERY
A CENTURY OF SERVICE

U.S. DEPARTMENT OF ENERGY
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Outline

- Laser parameter review
- Laser & control for beam operation
- Conclusion

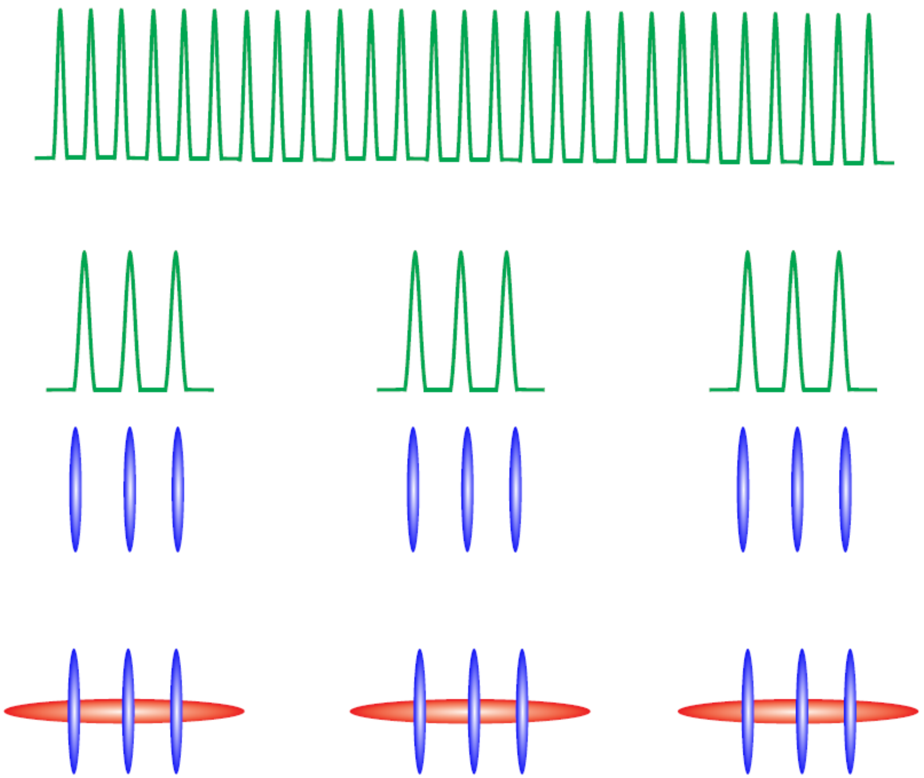
Laser Parameter Review

Laser Pulse Pattern for LEReC

Laser pulses
704 MHz

Laser bunch
Electron
9.1 MHz

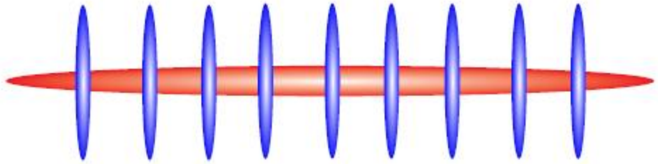
Electron/Ion
9.1 MHz



Pulsed mode: 704 MHz, 9.1 MHz bunch rate, 10-30/bunch

CW mode: 704 MHz

Laser Energy & Power for LEReC

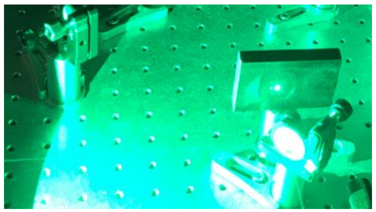


• Electron bunch charge:	130 pC	300 pC	120 pC
• Laser energy (QE=1%):	31 nJ	72 nJ	28 nJ
• Repetition rate (MHz):	9.1 x30 = 273	9.1x18 = 164	704
• Green power on cathode:	8.5 W	12 W	20 W
• Green power from laser:	8.5x3 =25.5 W	12x3=36 W	20*3 =60 W

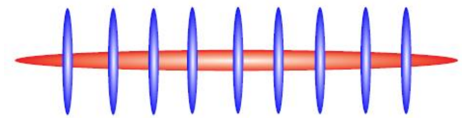
A higher laser power capability, a factor of 2-3, would be needed to achieve stable and reliable operation for beam experiment!

Laser Design Specifications

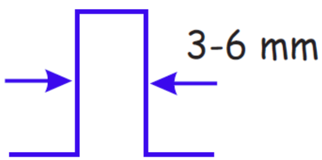
- Green average power: 60 W



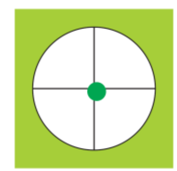
- Timing jitter: 1 ps rms



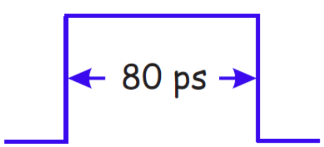
- Spatial profile: M^2<1.2



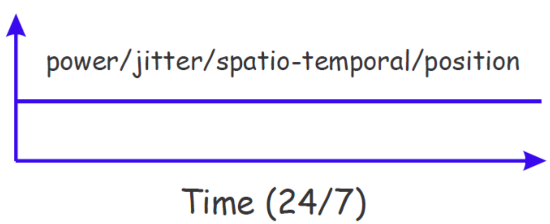
- Point instability: 40 μm rms



- "Flat-top" temporal profile

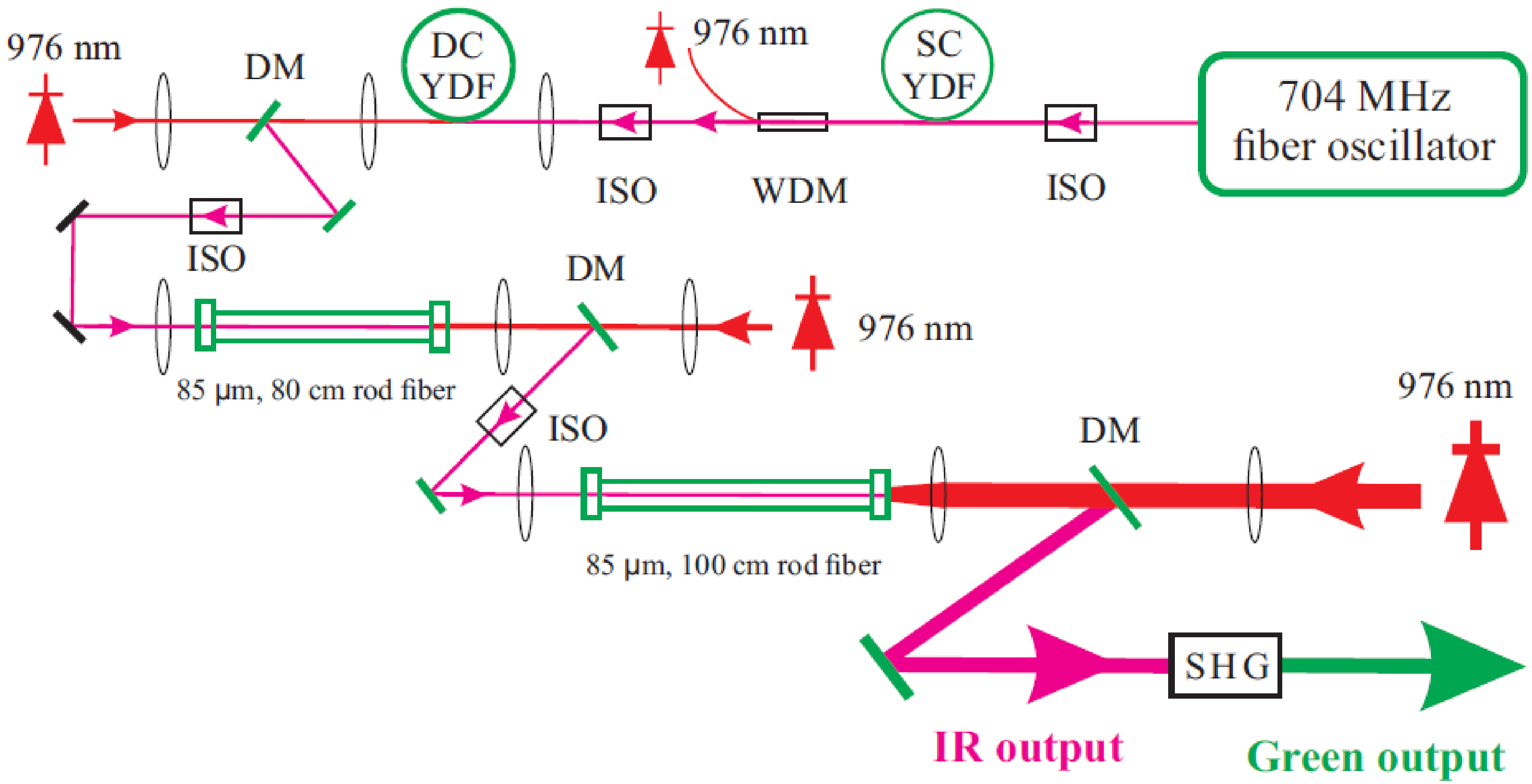


- Stability & reliability



Laser & Control for Beam Operation

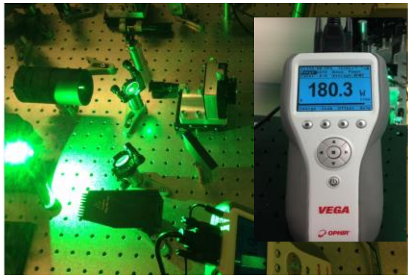
Yb-doped Fiber Laser System



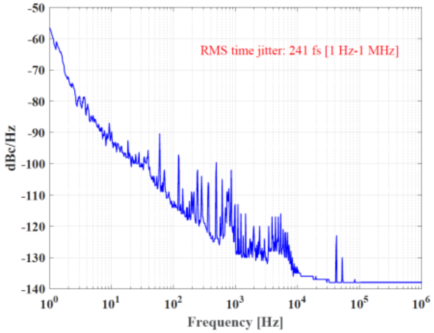
Key challenges: physical limitations & system engineering

Laser Specifications: Demonstrated

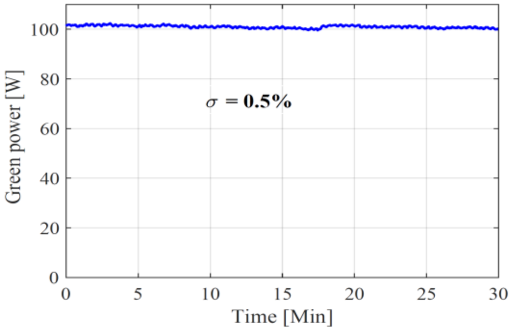
- Green average power: 180 W



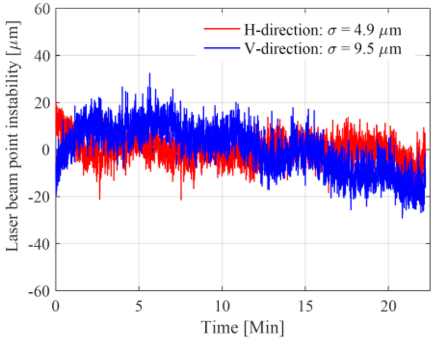
- Timing jitter: 240 fs rms



- Power stability at 100 W

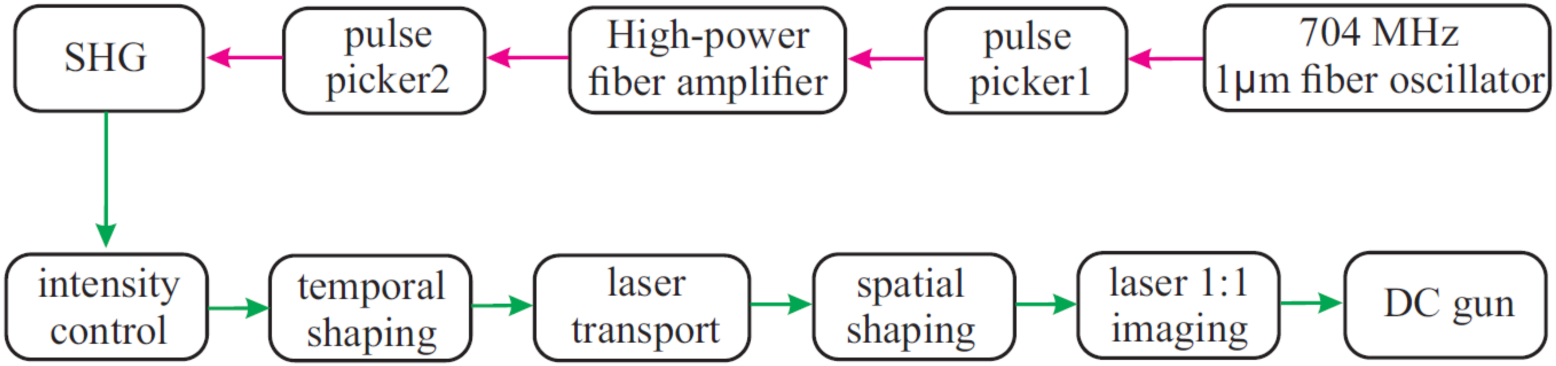


- Point stability at 60 W



- Spatial mode: M^2 < 1.1 at 100W

Layout of Laser Control for Beam Operation



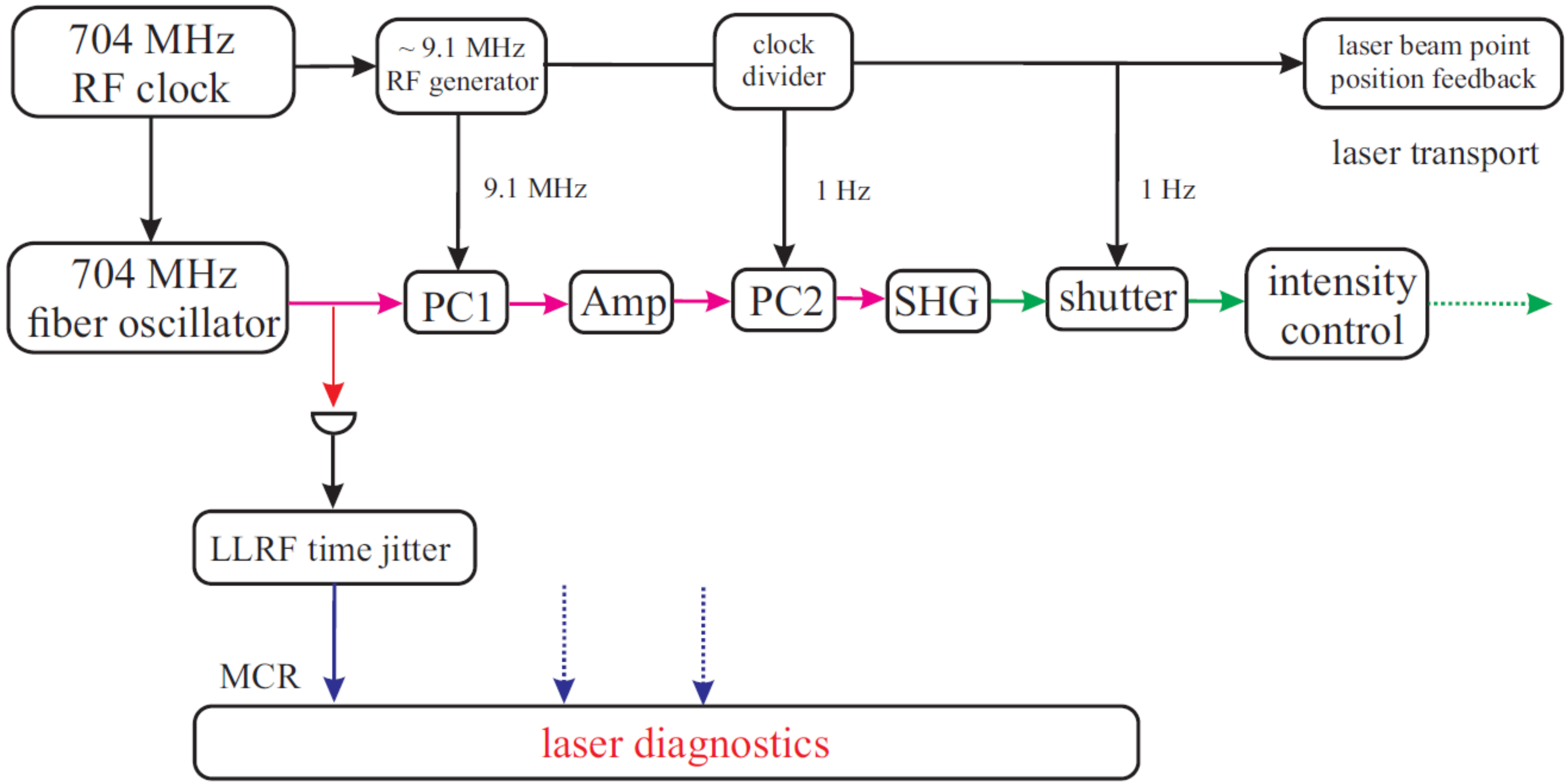
Key control

- Pulse pickers
- Intensity control
- Spatiotemporal shaping

Key diagnostics

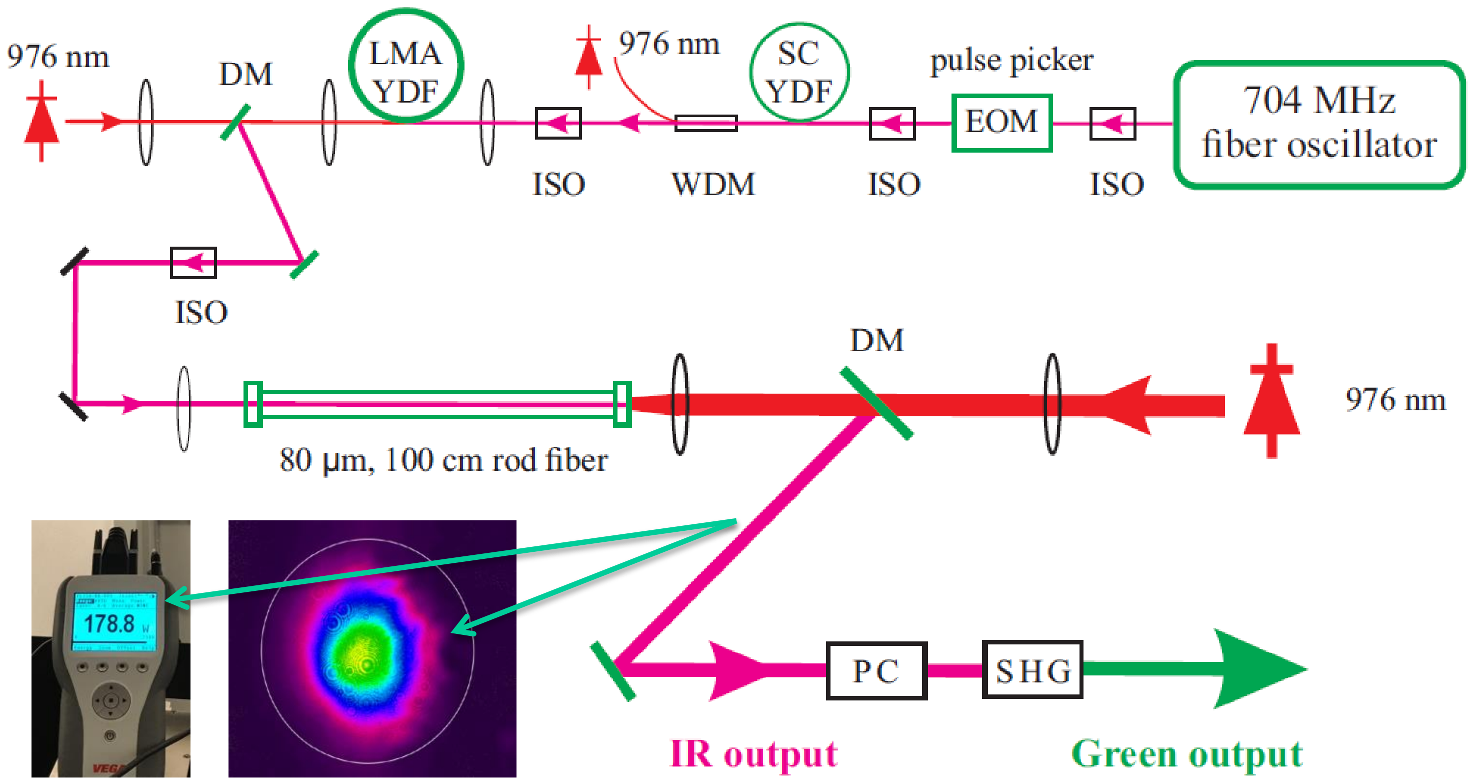
- Laser power and QE
- Laser spatial profile
- Point stability on cathode

Laser vs RF Phase Locking



- Both laser and RF cavities are locked to the same low-phase-noise RF signal generator.
- A feedback on RF phase is built to correct the phase slip between laser and RF cavities.

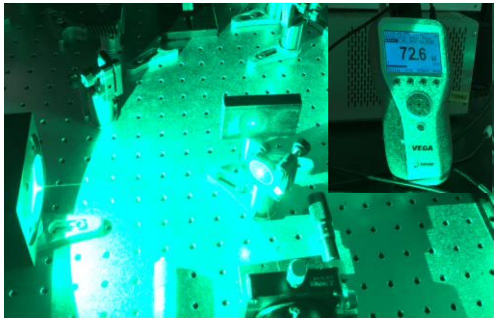
Final Laser System for Beam Operation



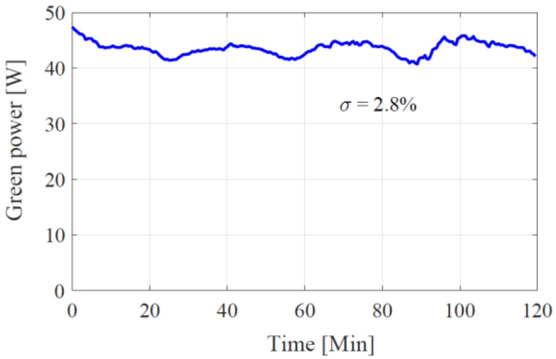
Final design: pulse pickers, control, diagnostics, & protection

Laser Specifications for Beam Operation

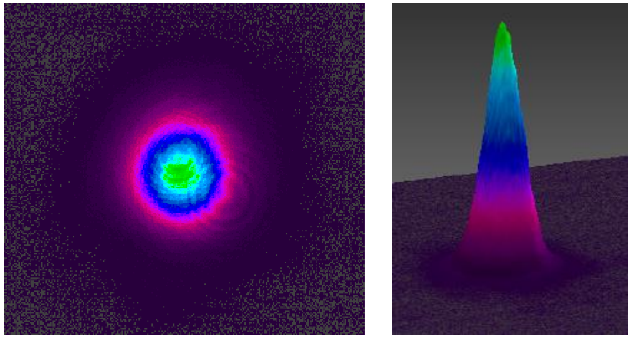
- Green average power: 72 W



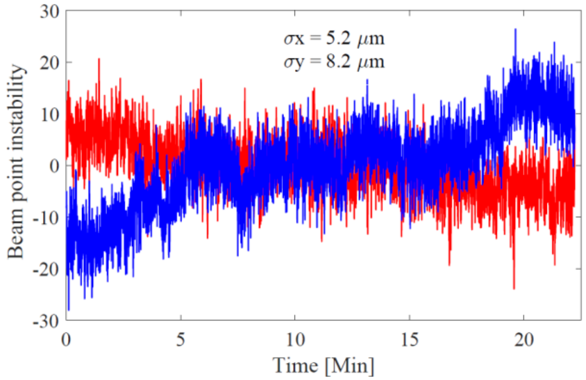
- Power stability at 45 W



- Spatial mode: $M^2 \sim 1$ at 30 W

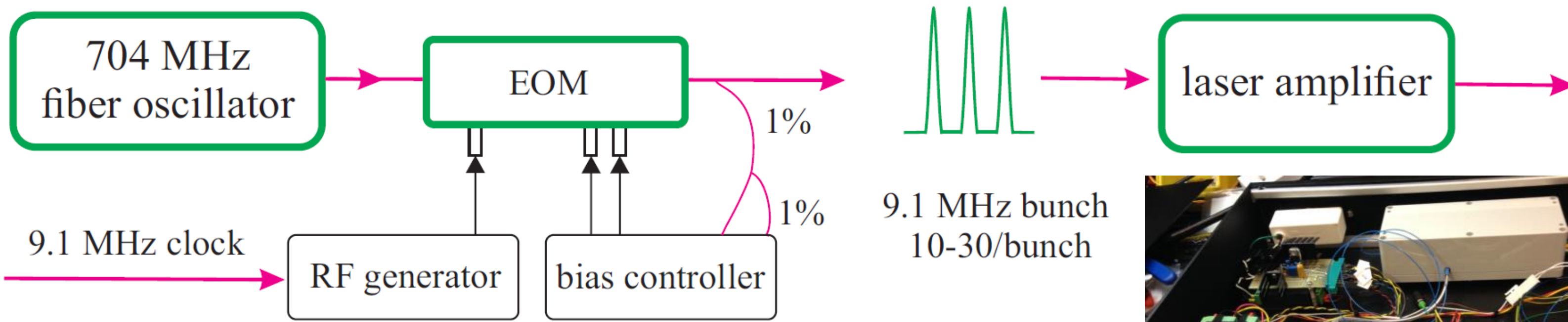


- Point stability at 30 W



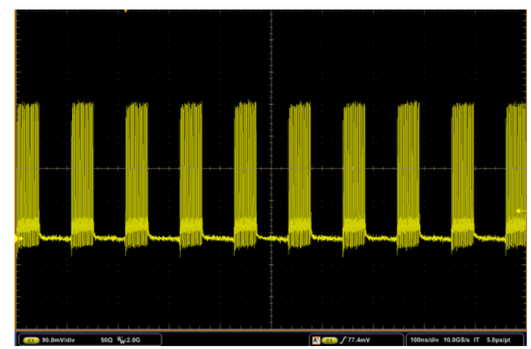
Ultrafast Pulse Picker

- Macro-bunch generator



Bias control box

- Mach—Zehnder intensity modulator
- Bias control for null locking with high extinction ratio: 42 dB
- RF on/off for activating pulse picker



9 MHz bunch rate

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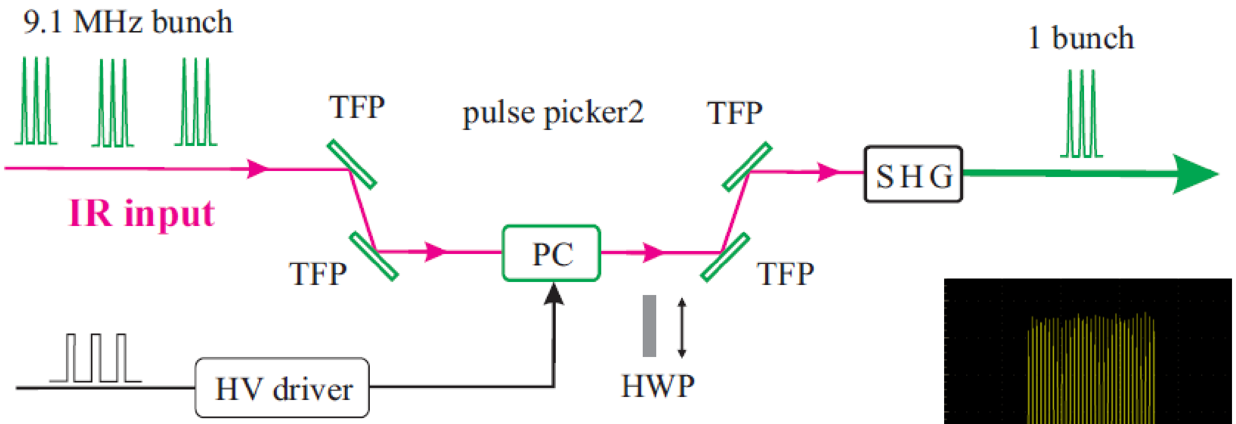
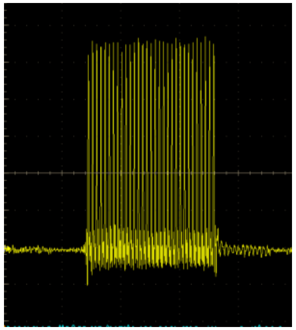
High-power Pockels Cell for Bunch Pickup

- Bunch pickup for beam diagnostic

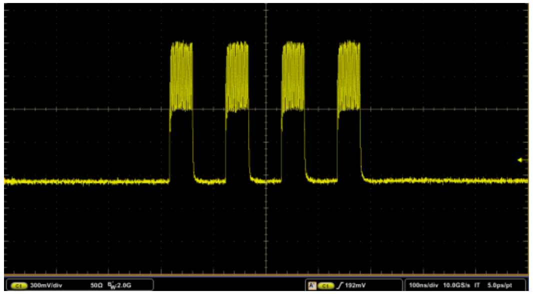




30 pulses/bunch

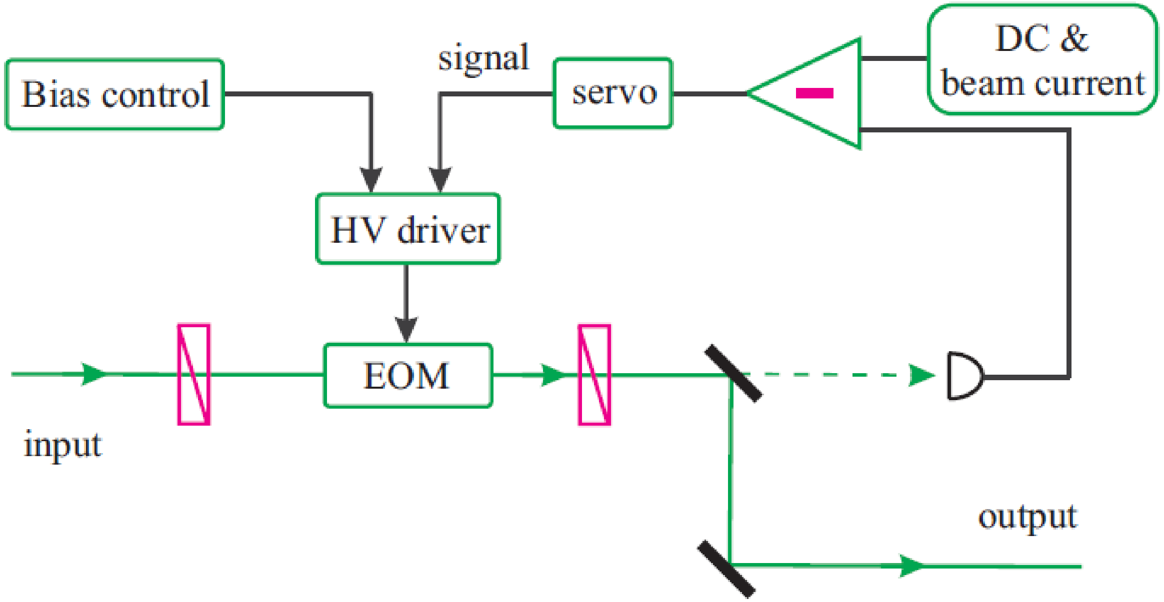
- Major specifications:

1. High extinction ratio: 3*10^5 @green
2. Fast switch time: ~ 5 ns
3. High average power: 100W IR
4. Switch between pulsed & cw mode
5. MPS in the pulsed mode



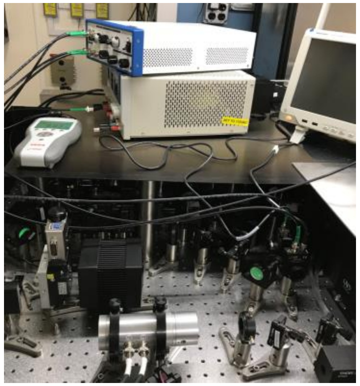
4 bunches

EOM for Intensity Control



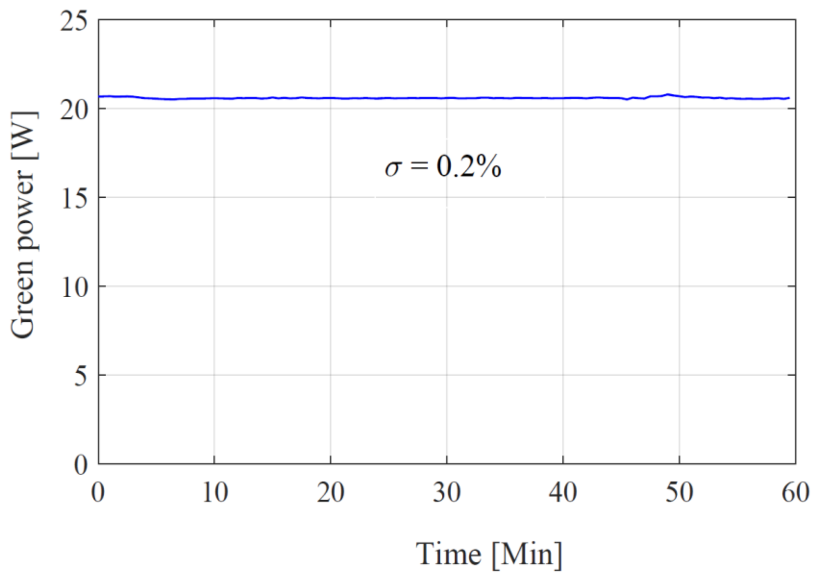
Three major functions:

- ***Stabilizing green light intensity***
- ***Stabilizing beam current***
- ***1.7 μs rise time for fast MPS***

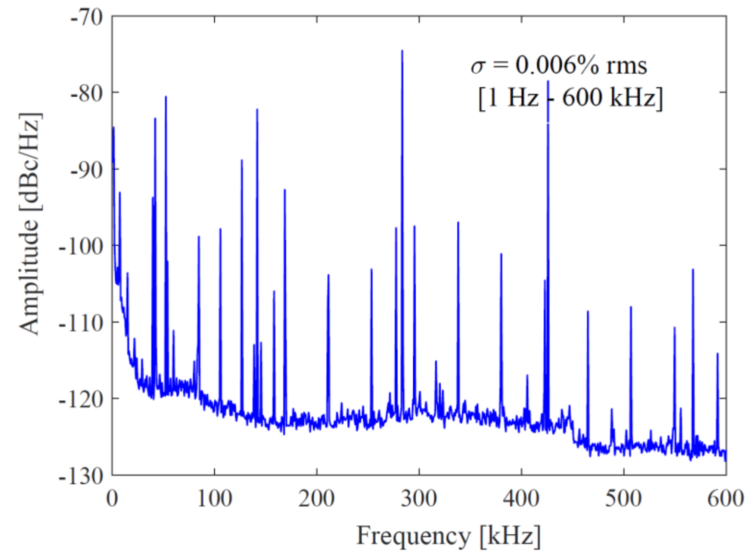


Green Power Stability with Feedback

- Power in the time domain



- Power in the frequency domain

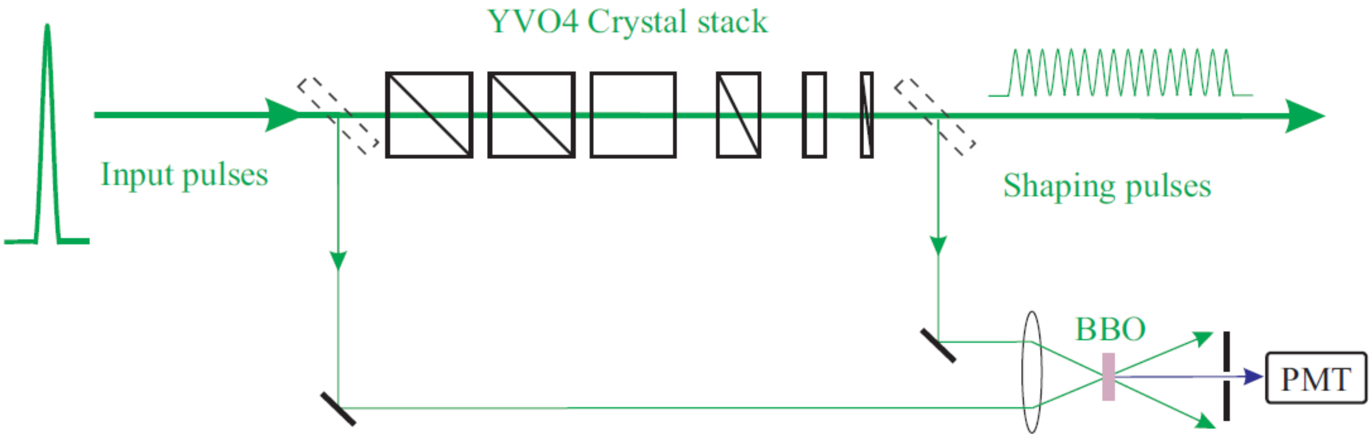


Relative intensity noise (RIN):

noise power/carrier power, $< P_n^2 > / P_0^2$

- Long-term test will be done in the future.

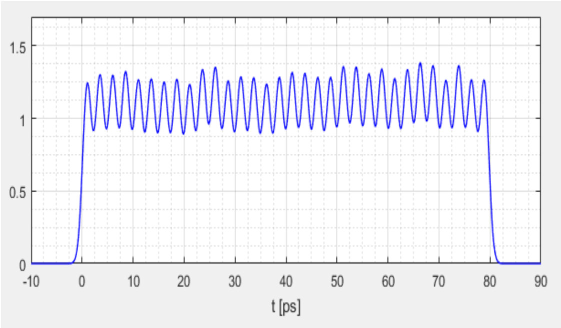
Crystal Stack for Longitudinal Beam Shaping



Specifications:

- Duration: 80 ps
- Rise & fall time: 2 ps
- Ripple modulation: 40%

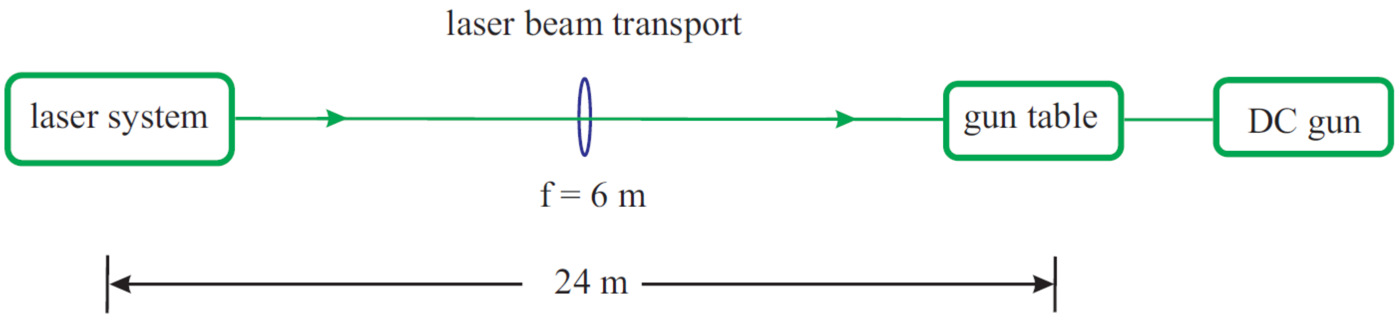
Simulation



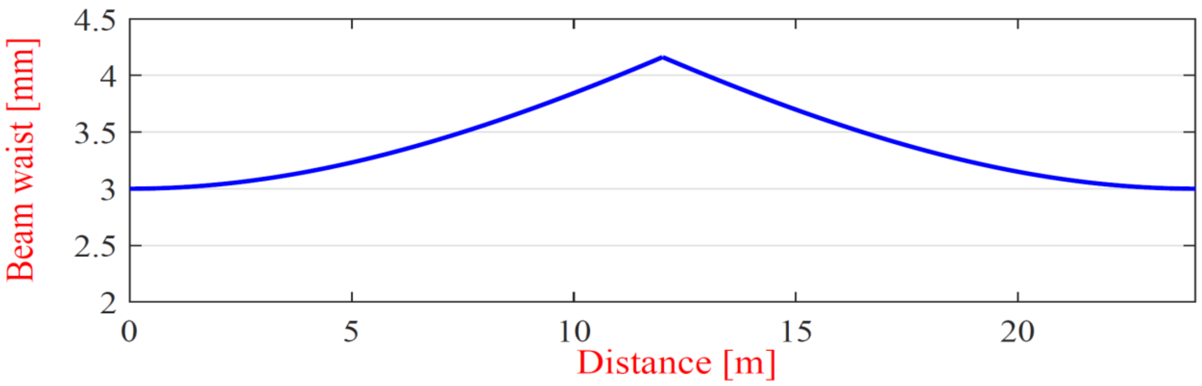
- Work is underway to conduct the measurement.

Free-space Laser Transport: Beam Optics

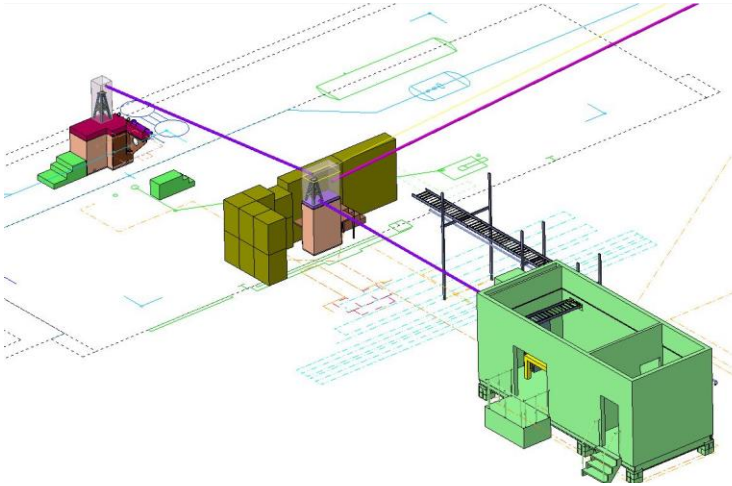
- Laser beam transport



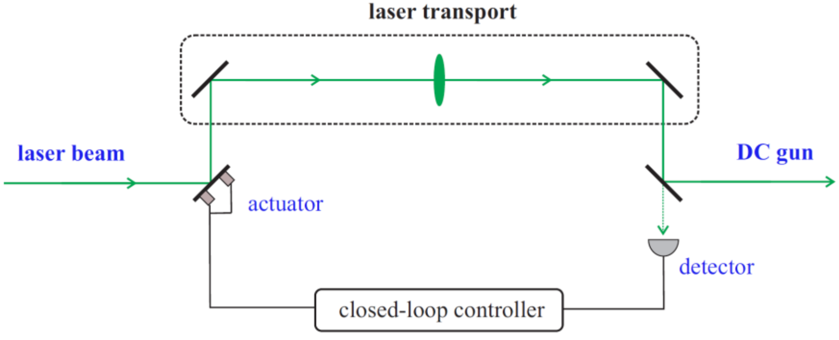
- Laser beam optics: simulation (M^2 =1.1)



Laser Transport: Design & Engineering



Active beam stabilization



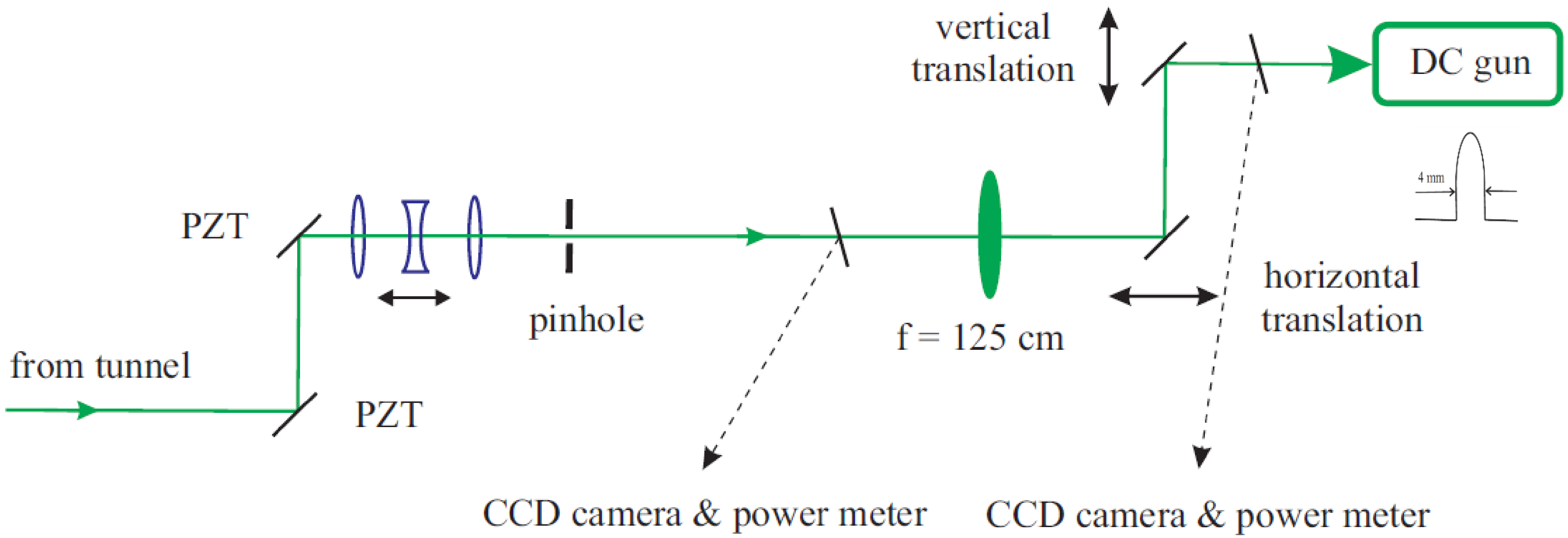
Highest engineering standards:

- Vibration reduction in the laser room & tables;
- Vacuum pipes for the laser transport;
- Preventing any air flows by sealing laser boxes;
- Laser decoupling from vacuum pipes
- Rigid mechanical mount and stands;
- Mirrors (R>99.97%), lens and view window (R<0.25%).

Target:

1. Correcting range: <2 mm
2. Vibration freq.: <100 Hz
3. Operation mode: cw & pulsed
4. Point instability: <40 μm

Laser Spatial Shaping & Diagnostics



Laser control & diagnostics:

- *Spatial mode shaping and 1:1 imaging*
- *Motion control for beam optimizing & QE*
- *Laser power & spatial mode monitoring*

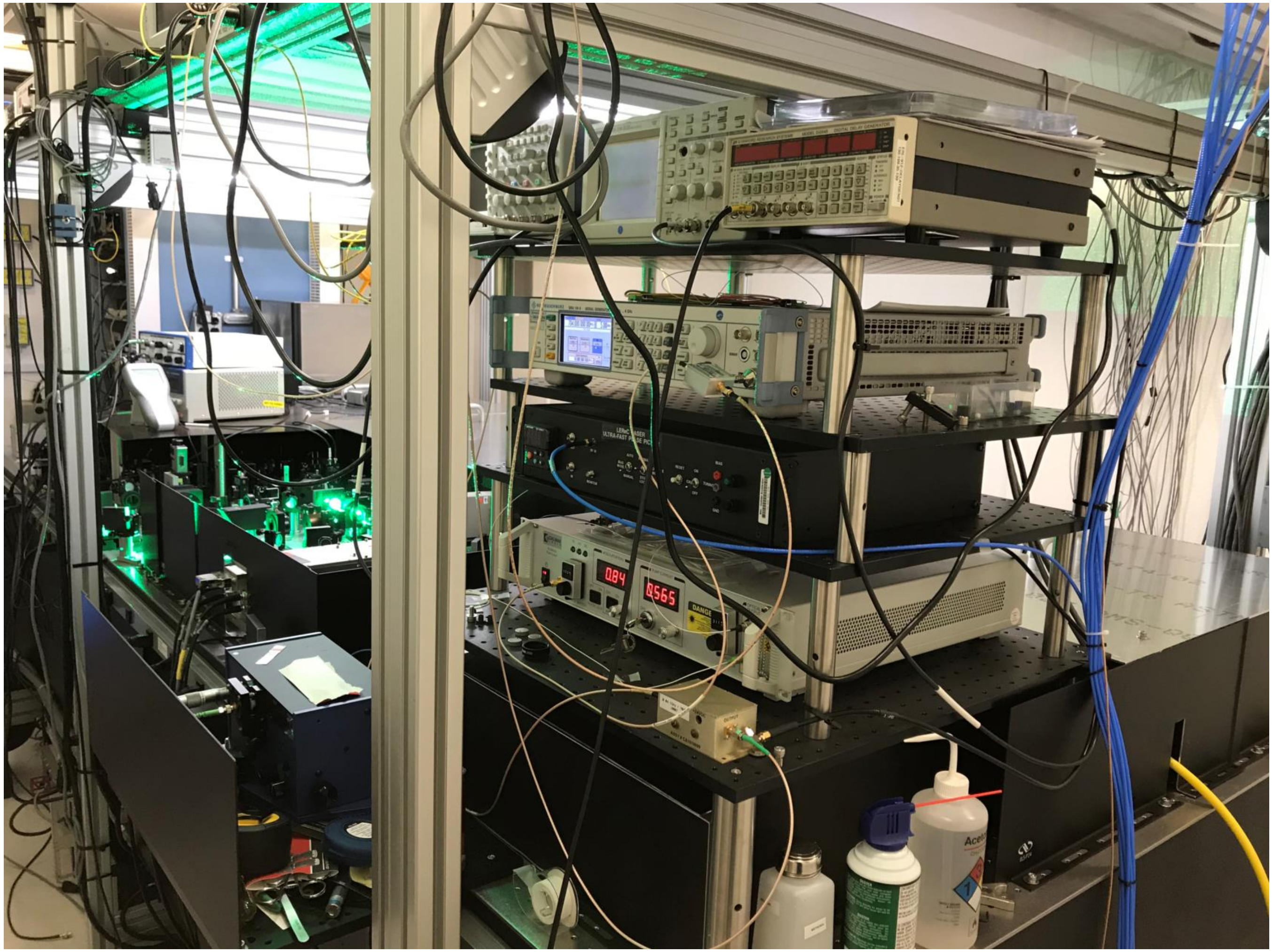
Conclusion

- High-power fiber laser design specifications: demonstrated

  Laser power (72W green), power stability (σ=0.006%), RMS time jitter (241 fs), excellent spatial mode (M^2<1.1), and laser point stability (σ<10 μm)
- Laser control & transport: Pulse pickers, intensity feedback, spatiotemporal shaping, laser transport, & diagnostics
- Remaining laser topics:

  Efficiency in the crystal shaping, cross-correlation measurement, & beam position feedback, long-term stability and reliability
- Laser operation: 12h shift in pulsed & CW mode during run 17
- Laser ready for 24/7 beam operation in run 18

Laser System in the Lab



Low Energy RHIC electron Cooling (LEReC)

LEReC Laser Transport Status

Patrick Inacker

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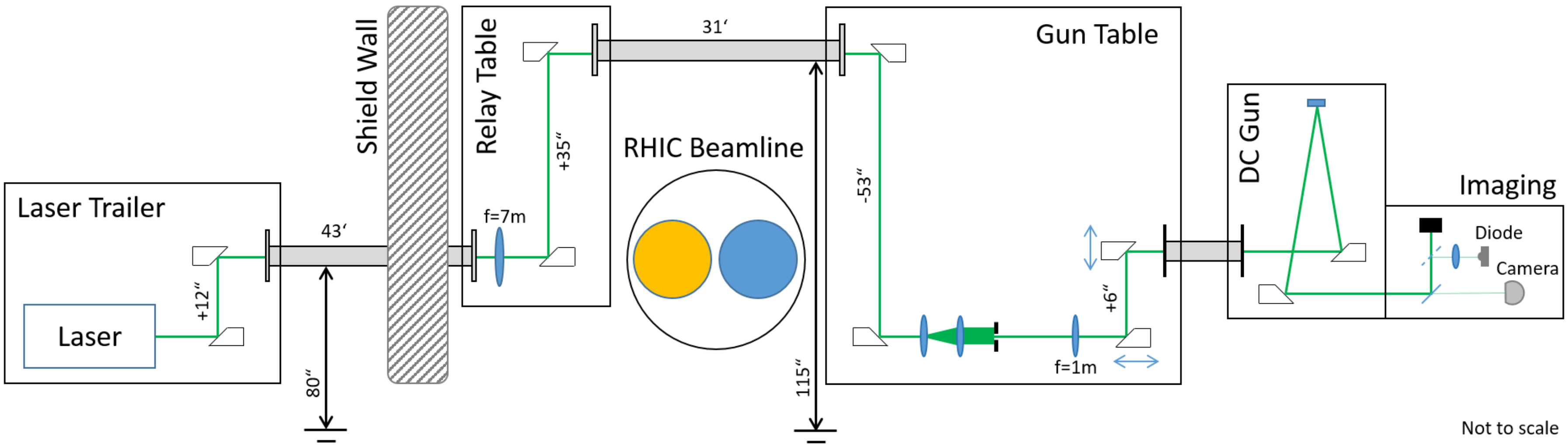
Laser Transport Overview



<u>Laser Transport Highlights:</u>
2 Vacuum Tubes
3 Laser Tables

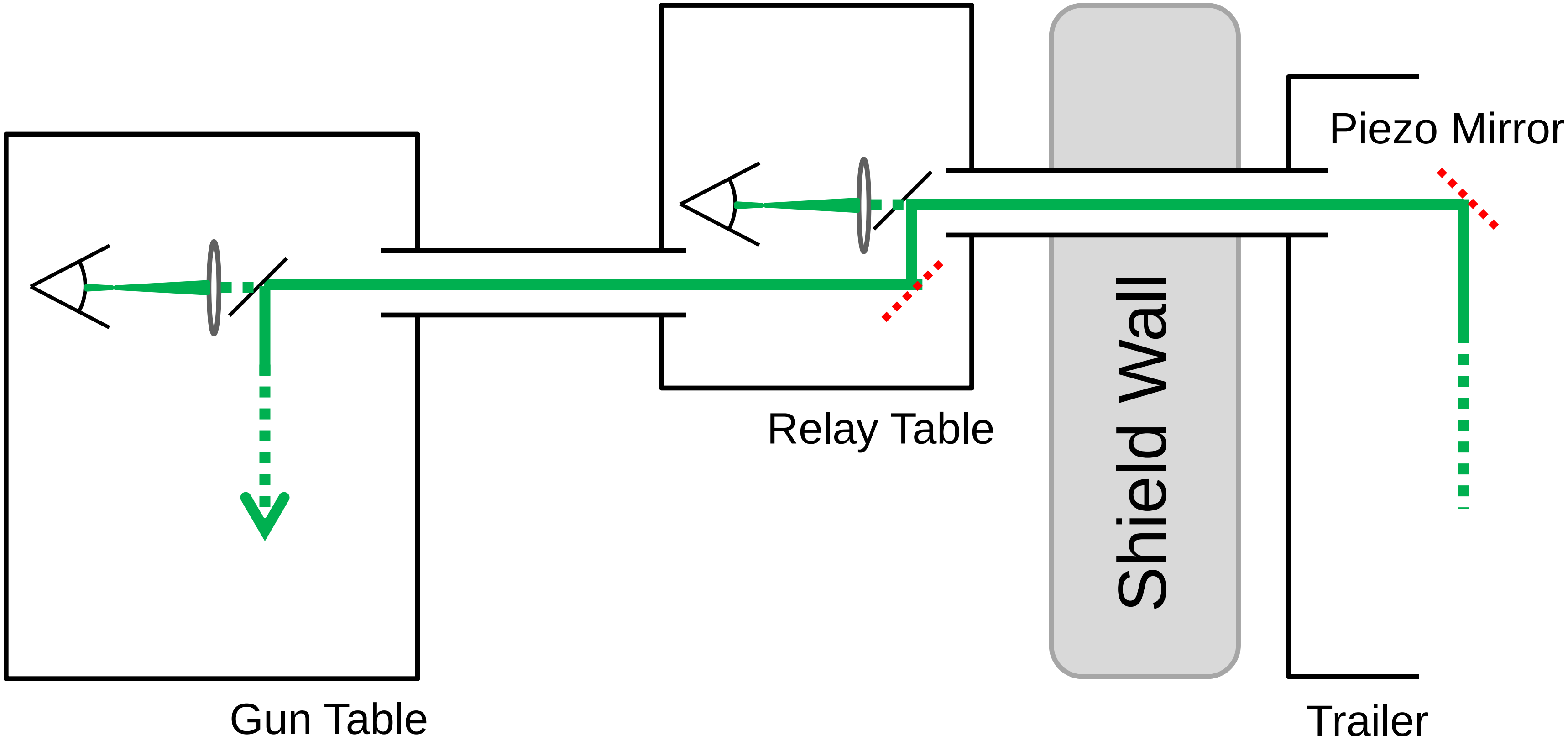
Transport Length (Trailer-Cathode) ~35m
Target Pointing Stability ~40µm RMS

Installed and successfully commisioned during run17

Comissioning Experience during run17

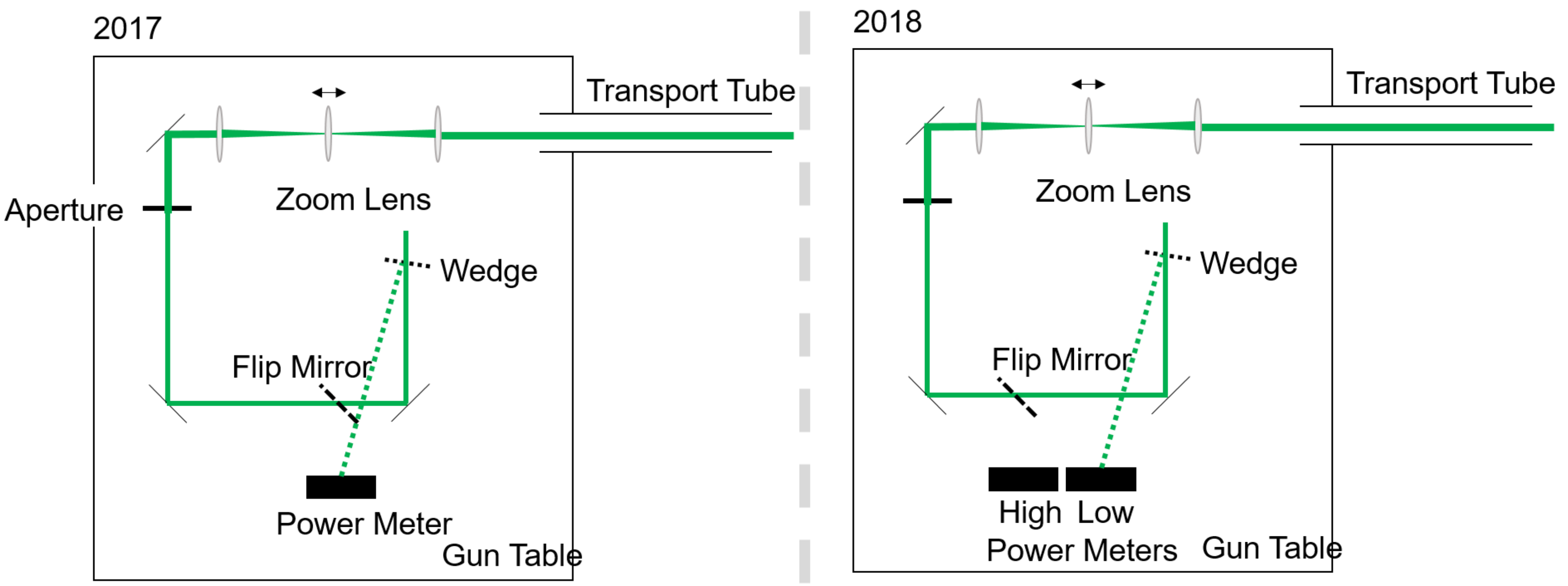
- Remote Alignment
- Live Power Measurements
- Laser Beam Pointing Stability 2017
- Temporal Shaping challanges for cw operation
- High Power cw transport
- Remote Control and Diagnostics

Remote Alignment Upgrade



Slow ground motion makes adjustments during operation neccessary
- Solution: Remote controlled Piezo Mirrors (Trailer Mirror successfully used in run17)

Live Power Measurement

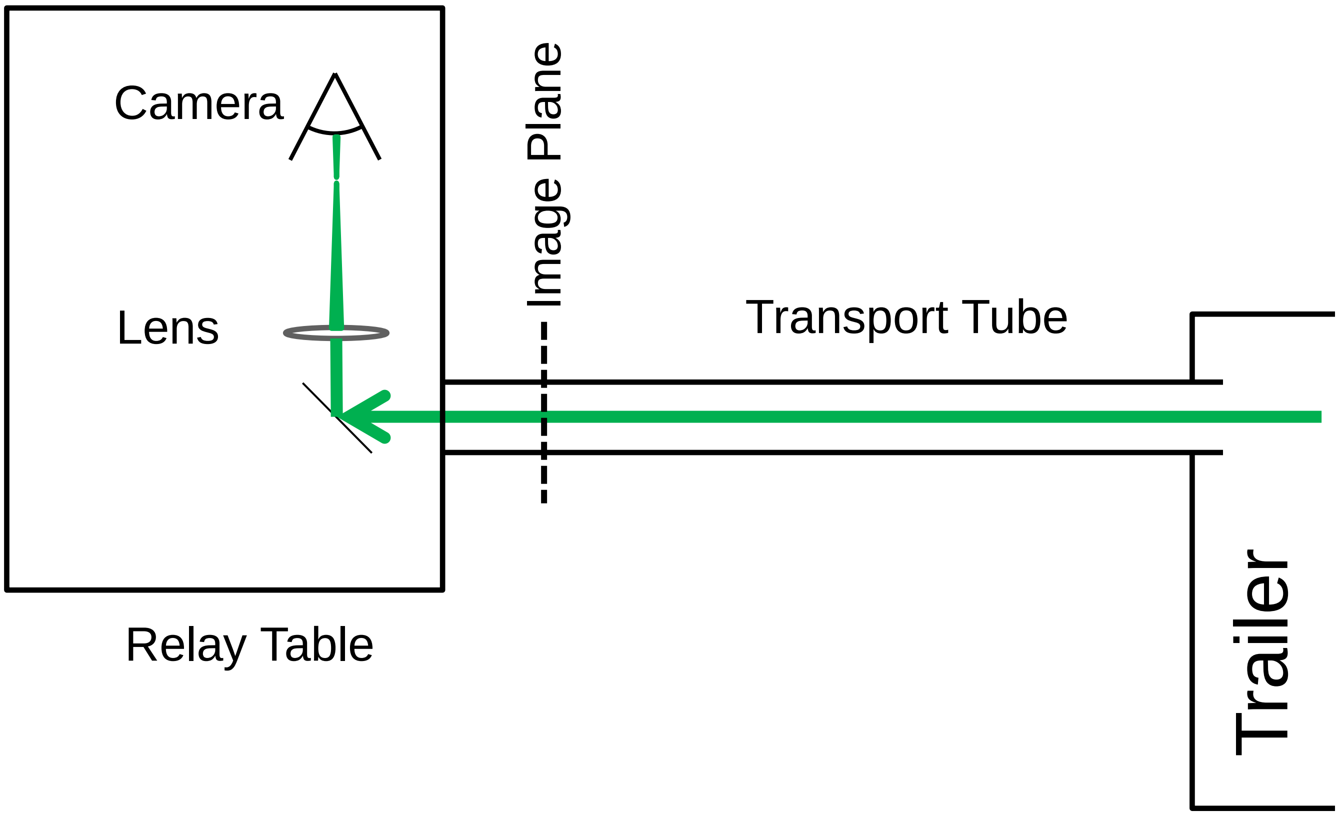


Additional Low Power meter for more accurate power measurements during low power cw operation

Laser Transport Stability

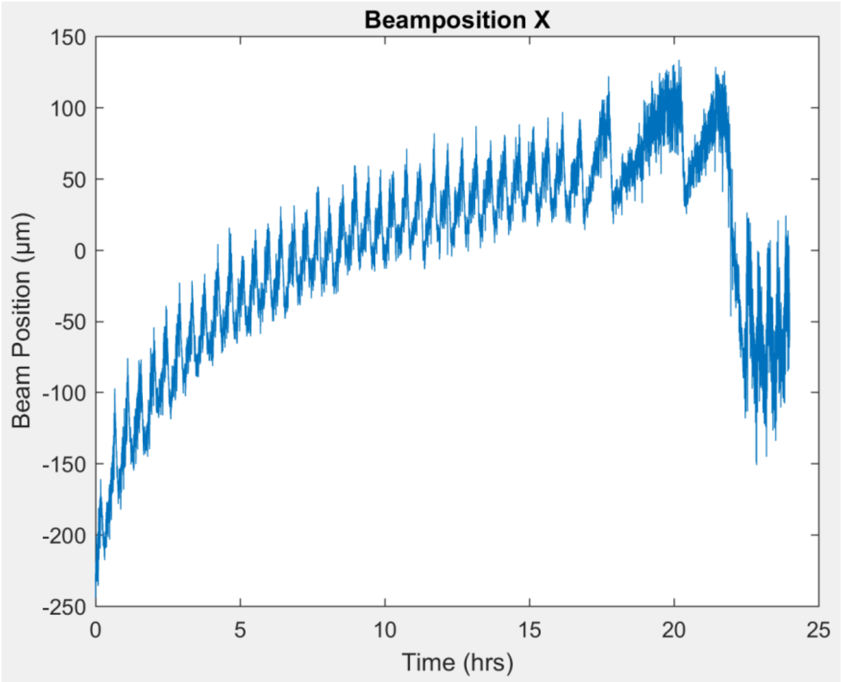
24hr- Measurements

Trailer – Relay Table

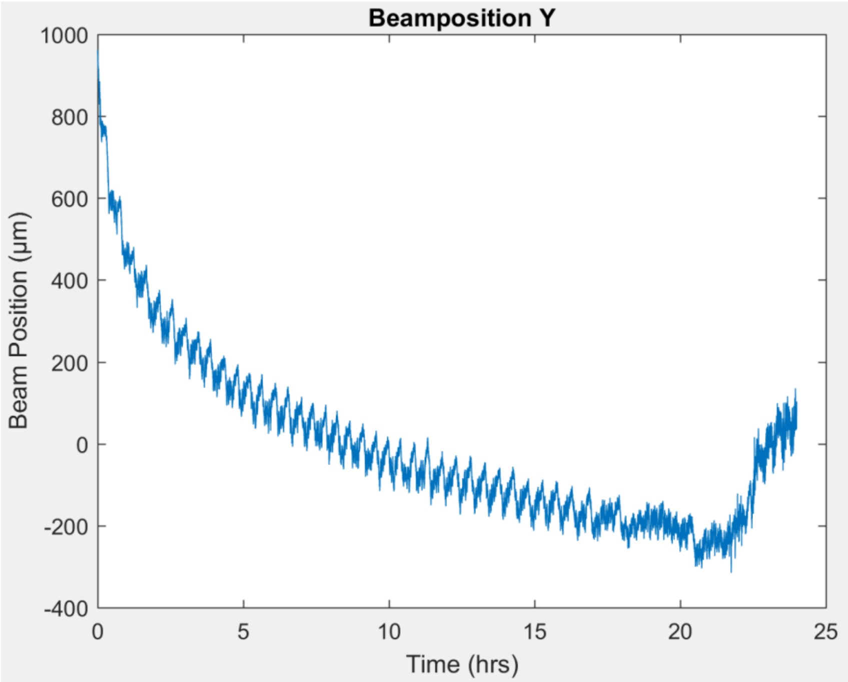


24hr Stability (1)
Trailer – Relay Table

$\sigma_{2\text{-}24} = 53\mu m$

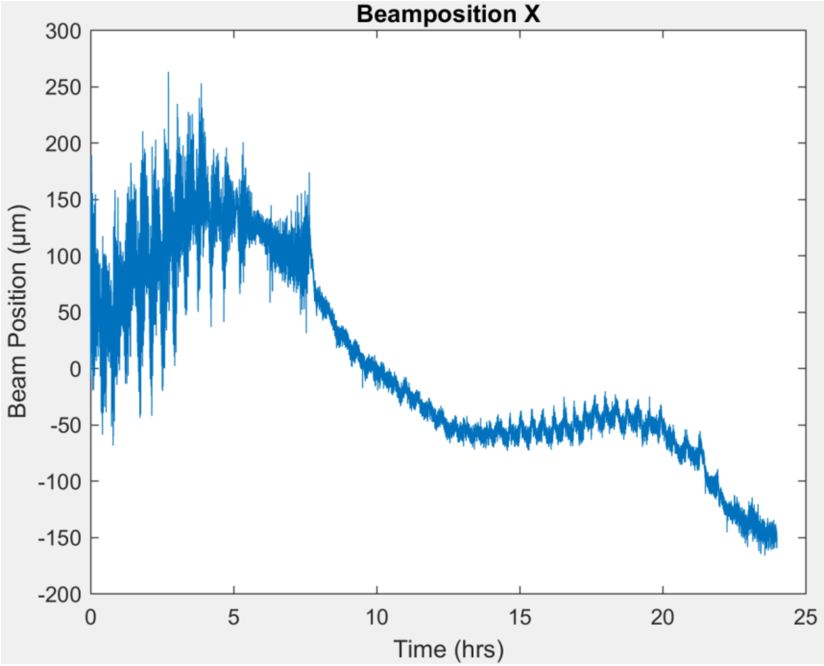


$\sigma_{2\text{-}24} = 147\mu m$

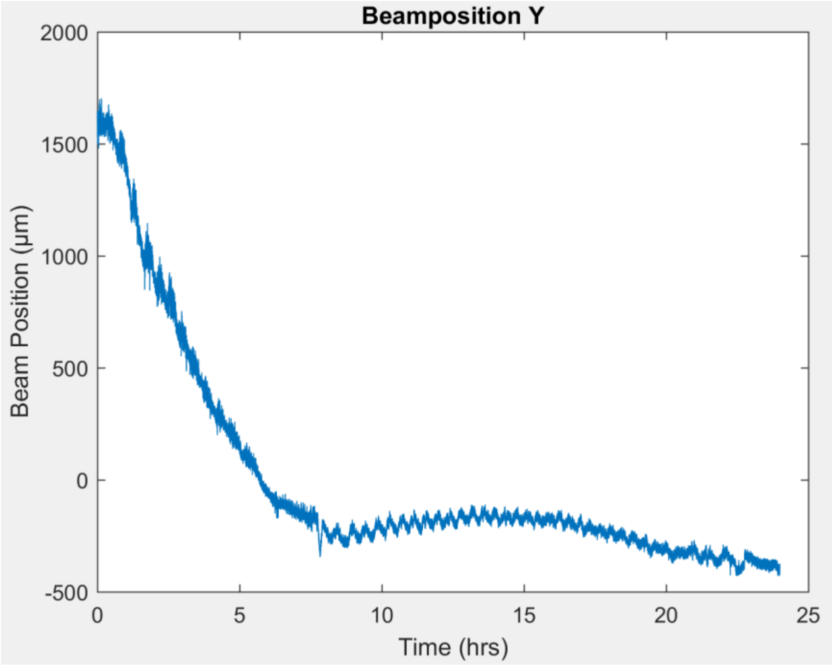


24hr Stability (2)
Trailer – Relay Table

$\sigma_{2\text{-}24}$ = 85µm



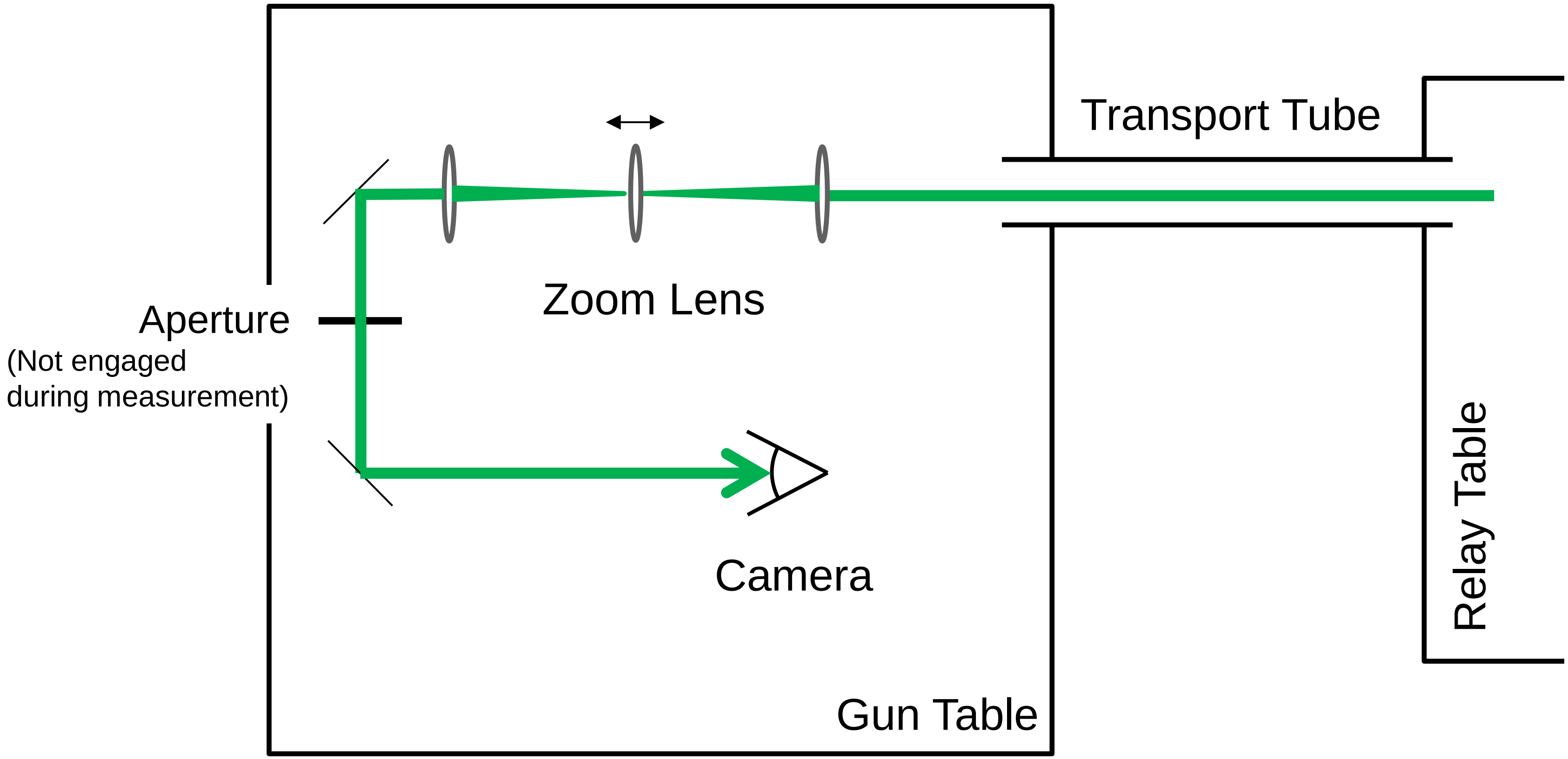
$\sigma_{2\text{-}24}$ = 279µm



Laser Transport Stability

24hr- Measurements

Trailer – Gun Table

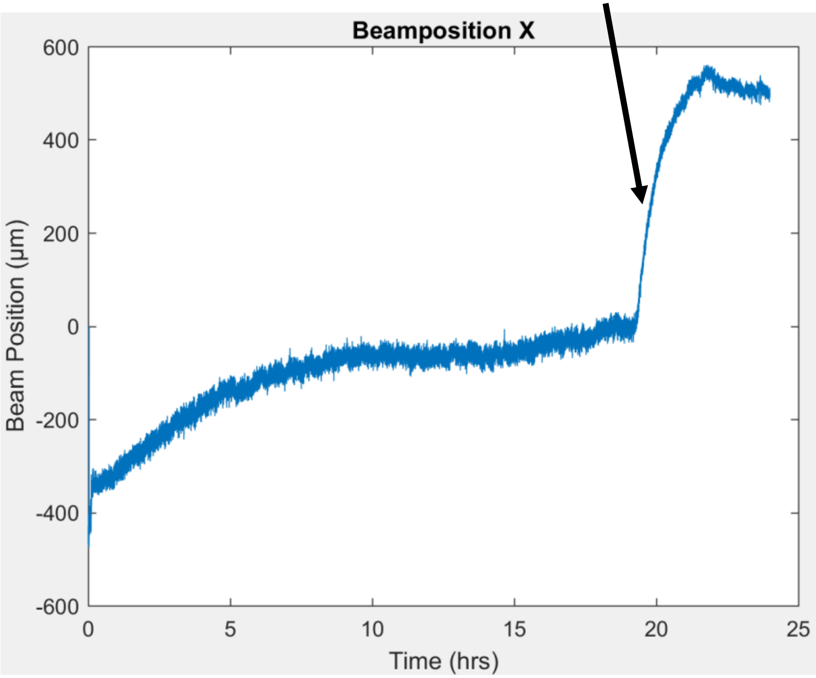


24hr Stability (1)
Trailer – Gun Table

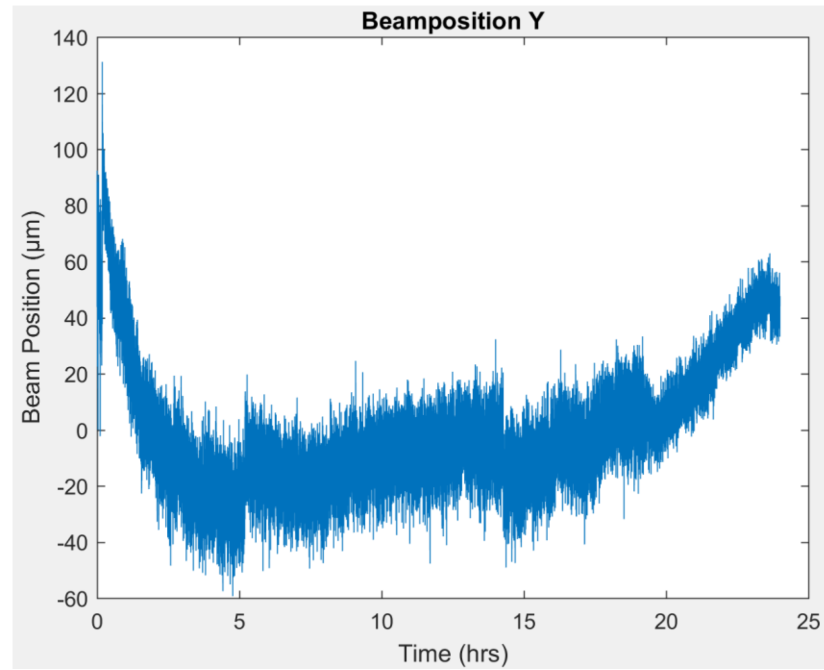
NOTE: Horizontal plane and Vertical plane swap from Relay to Gun table due to Beam guidence

$\sigma_{2\text{-}20} = 82\mu m$

Vertical Ground Motion
@ Relay Table



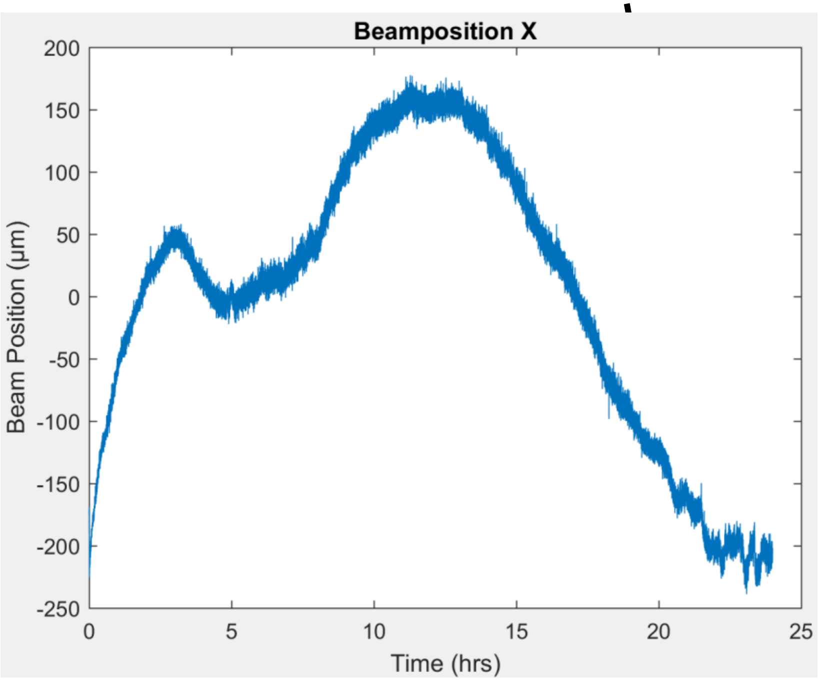
$\sigma_{2\text{-}20} = 12\mu m$



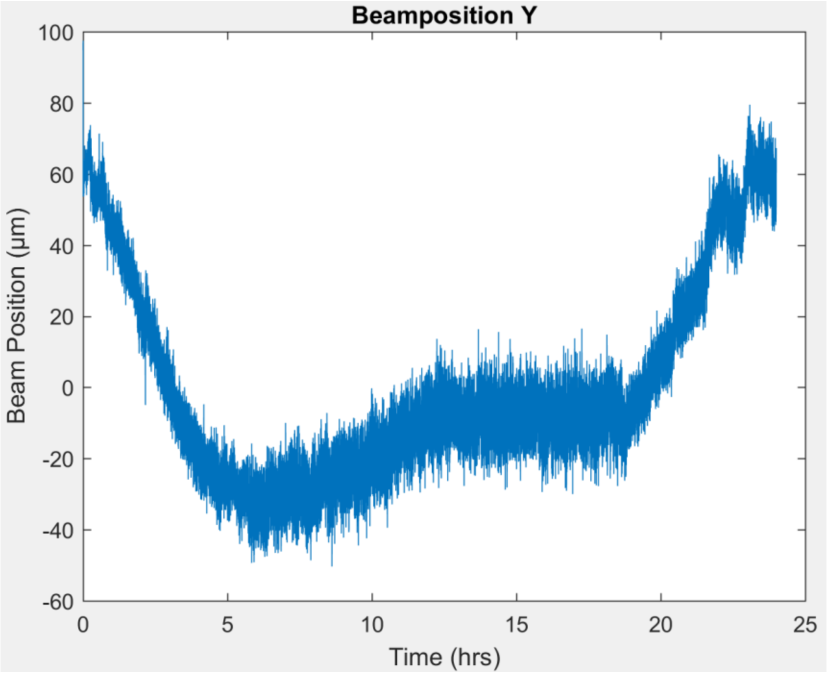
24hr Stability (2)
Trailer – Gun Table

NOTE: Horizontal plane and Vertical plane swap from Relay to Gun table due to Beam guidence

$\sigma_{2\text{-}24}$ = 114µm

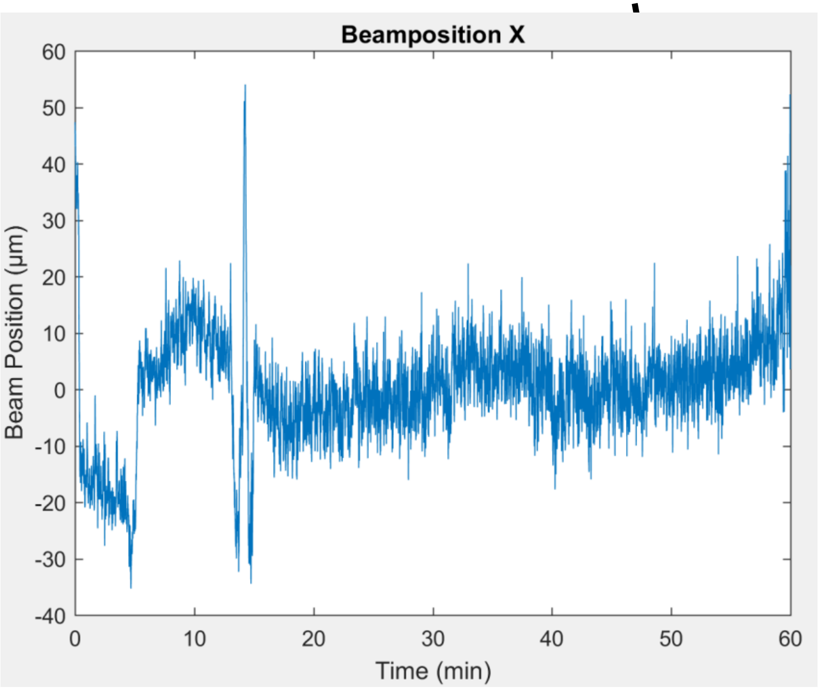


$\sigma_{2\text{-}24}$ = 25µm

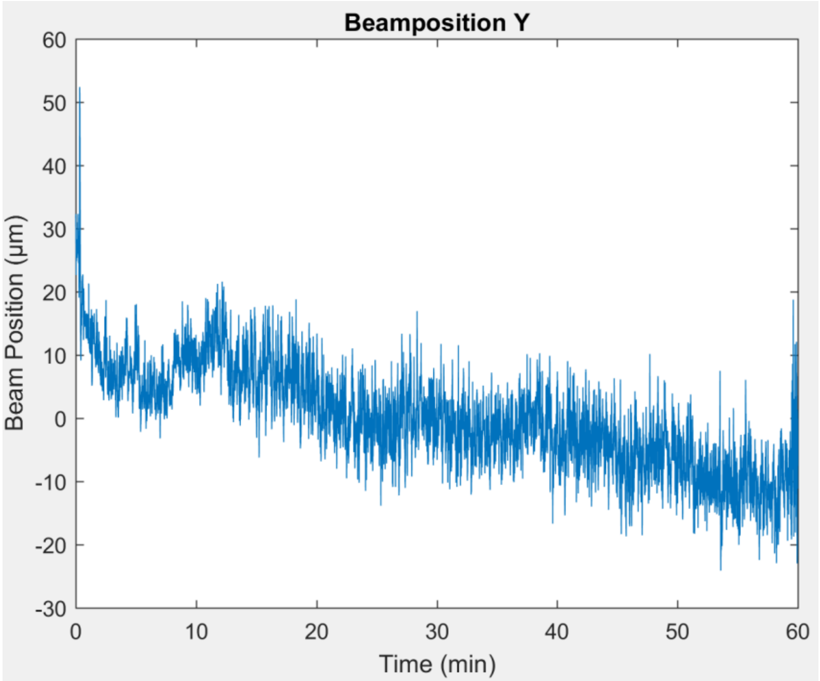


1hr Stability @ 4Hz (3)
Trailer – Gun Table

$\sigma_{10\text{-}60} = 7.6\mu m$

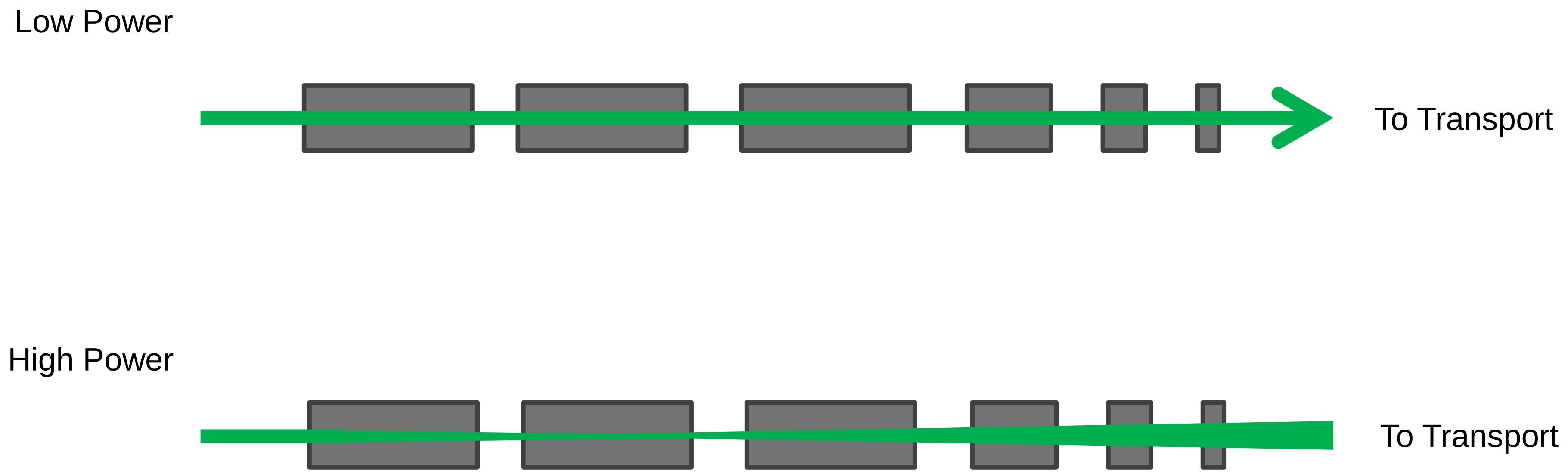


$\sigma_{10\text{-}60} = 7.2\mu m$



Conclusion: Slow Feedback neccessary

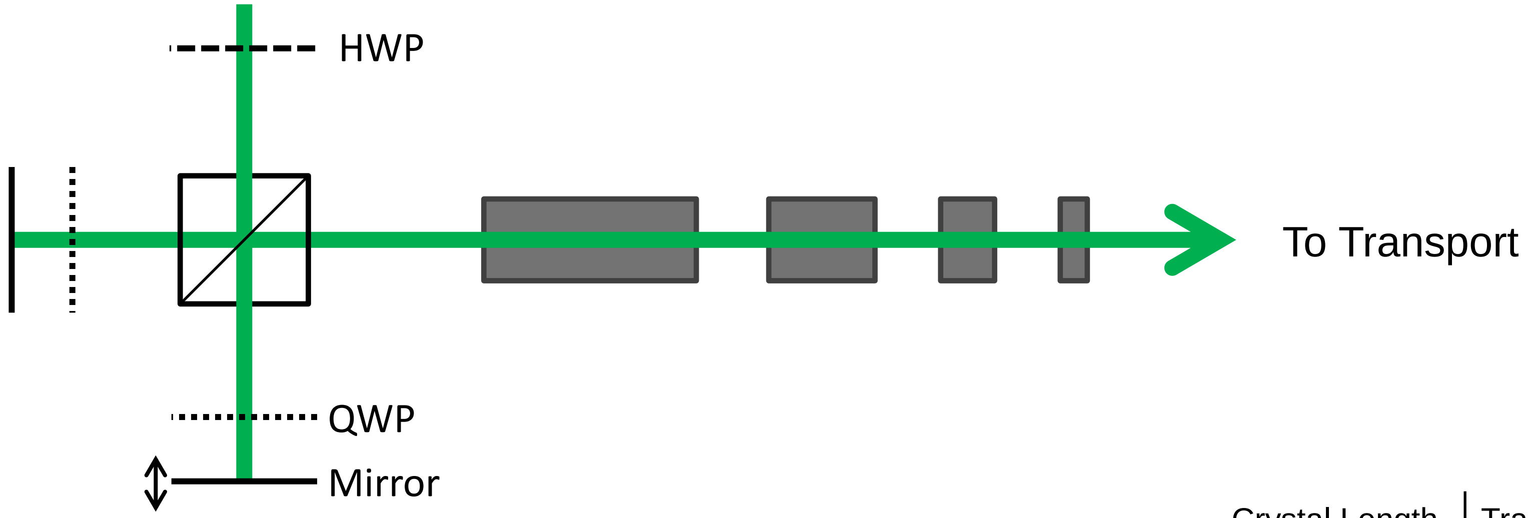
Temporal Shaping challanges for cw operation



Thermal Lensing prevents high average powers to be transported the same way as low powers

- 2 Types of Solutions are being investigated
    1. Replacing the thickest crystals with interferometers
    2. Increasing the Beam Size inside the Crystals

Temporal Shaping
Thermal Lensing investigation with Interferometer Setup

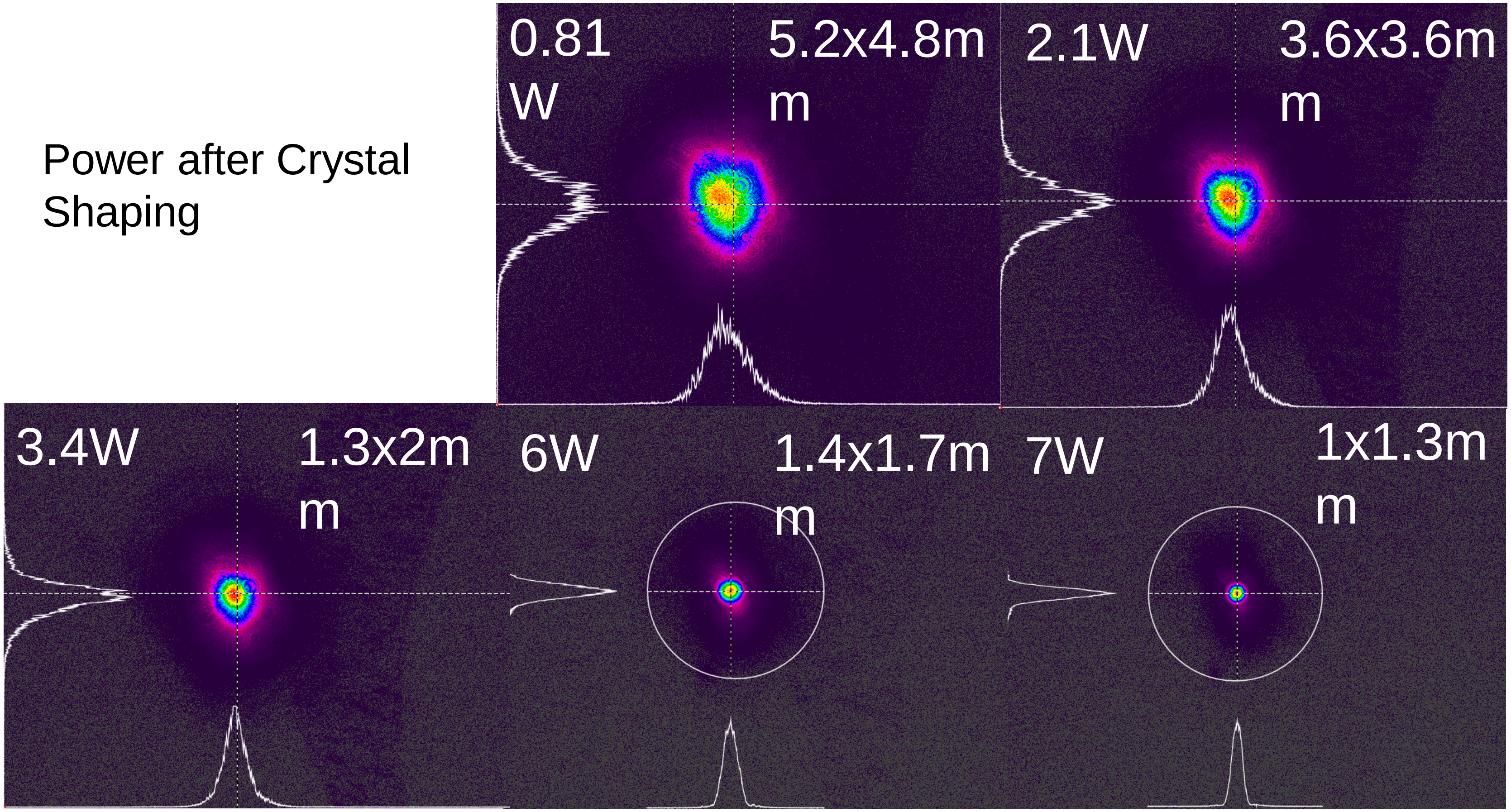


- Cut total Crystal length in half
  - Transmission increase from 50% to 70%
- Removed the strongest thermal lenses

Crystal Length	Transparency
Interferometer	88%
19.68mm	88%
9.84mm	96%
4.92mm	98%
2.46mm	-
Total	72%

Temporal Shaping
Thermal Lensing with Interferometer Setup

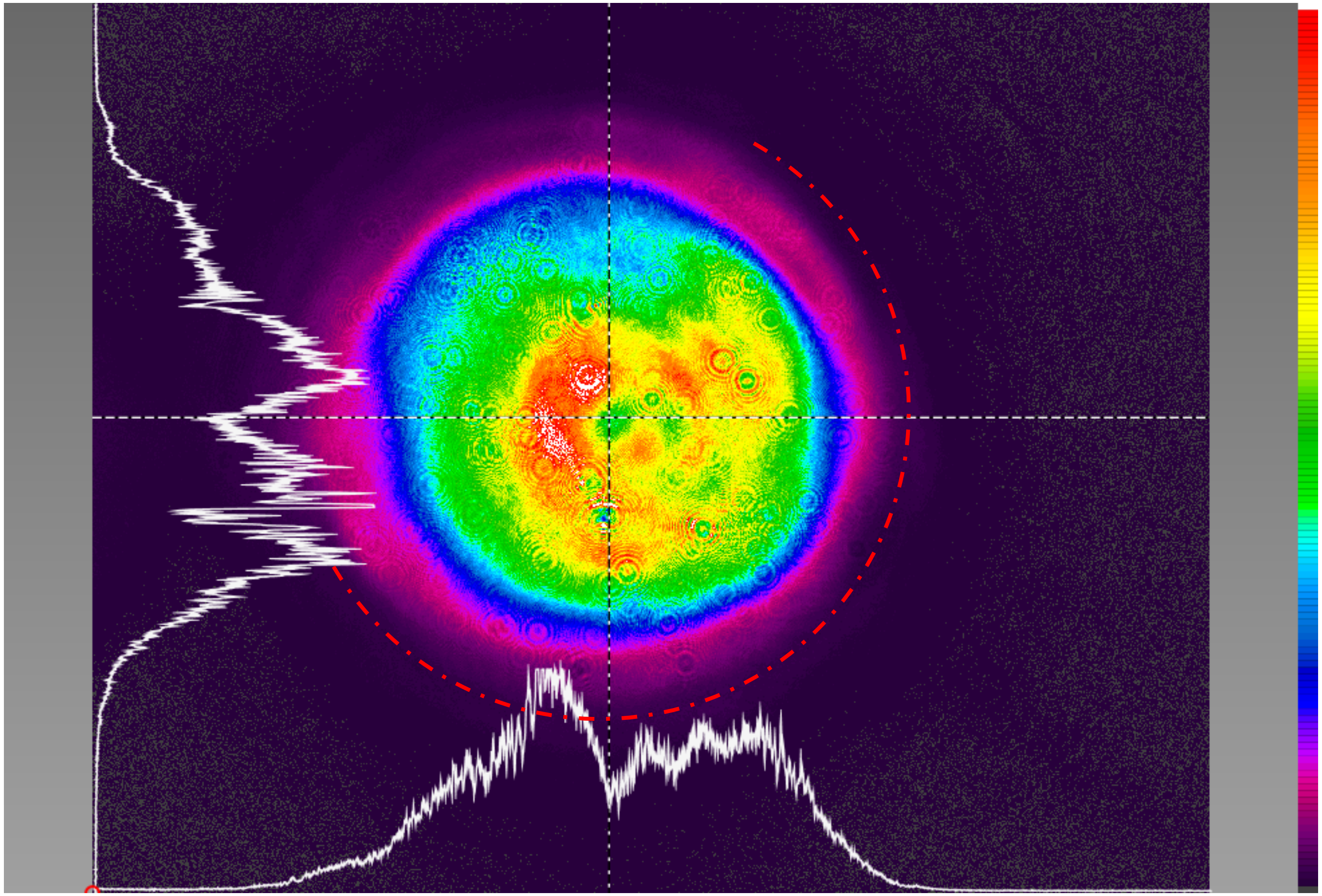
Power after Crystal Shaping



Temporal Shaping

Thermal Lensing with Interferometer Setup

Beam at the Gun Table @ 8.4W cw



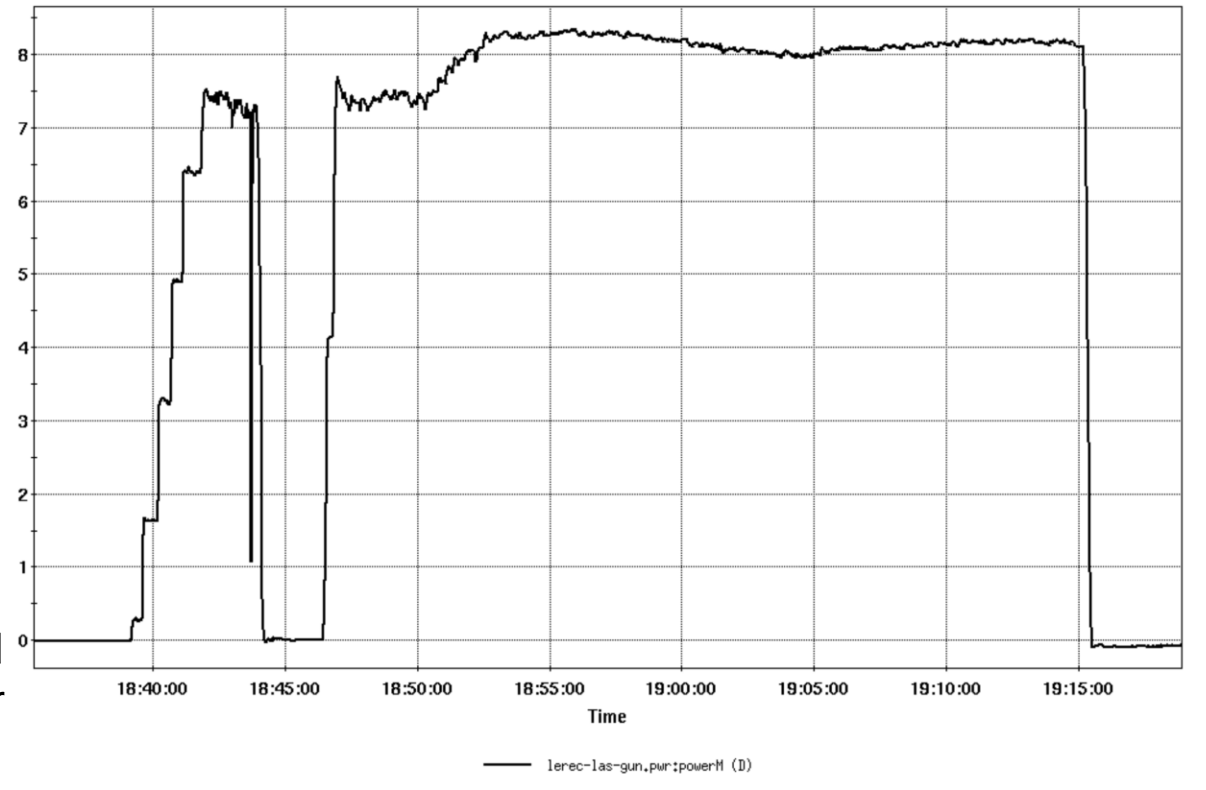
High Power cw Transport
with Interferometer Setup

- 18W from Laser
- 15.5W after EOM
- 10.1W after Crystal shaping
- 8.4W Transported

Beam too large for transport
- < 90% transport efficiency

Thermal Lens still too strong.

Conclusion:
Additional Interferometers could reduce the thermal lense further to allow more power and a better beam profile.



Remote Control and Diagnostics

Pockels Cell

- Analog Control through VME, Error Readback

Intensity Control

- RS232 Control over the rotation of a HWP

Steering

- Piezo Mirror in Trailer and on Relay Table
- Zoom Lens to adjust beam size on Gun Table
- 2 Axis motion for steering on Cathode on Gun Table

Current   Planned for This Year

Sensors and Cameras

Temp: Main Amplifier Coolant
Power Amplifier Coolant
Main Amplifier Surface

Flow: Main Amplifier
Power Amplifier
Dump Loop

Power: LP on Gun Table (Live)
(3W Thermal Sensor)
LP on Gun Table (Flipper)
(50W Thermal Sensor)

Diodes: IR 9.1MHz Macrobunch Signal
SHG Train Signal

Cameras: Relay Table
Gun Table
(Profile monitor, Virtual Cathode, Beam Stabilization)
Exit Table

Conclusion

- Laser Transport
  - Momentary Stability well below spec (10µm < 40µm)
  - Experience from run17 motivates the need for slow feedback on the beam position for 24/7 Operation
    - Bandwidth << 1Hz

- Temporal Shaping
  - Solution for High Power cw operation has to be found
    - 15-20W average power transport without beam degradation

      (8W achieved with 1 Interferometer)

- Overall
  - More Diagnostics need to be installed