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U.S. DEPARTMENT OF ENERGY

Laser

Temporal & Intensity Jitter, Position Stability

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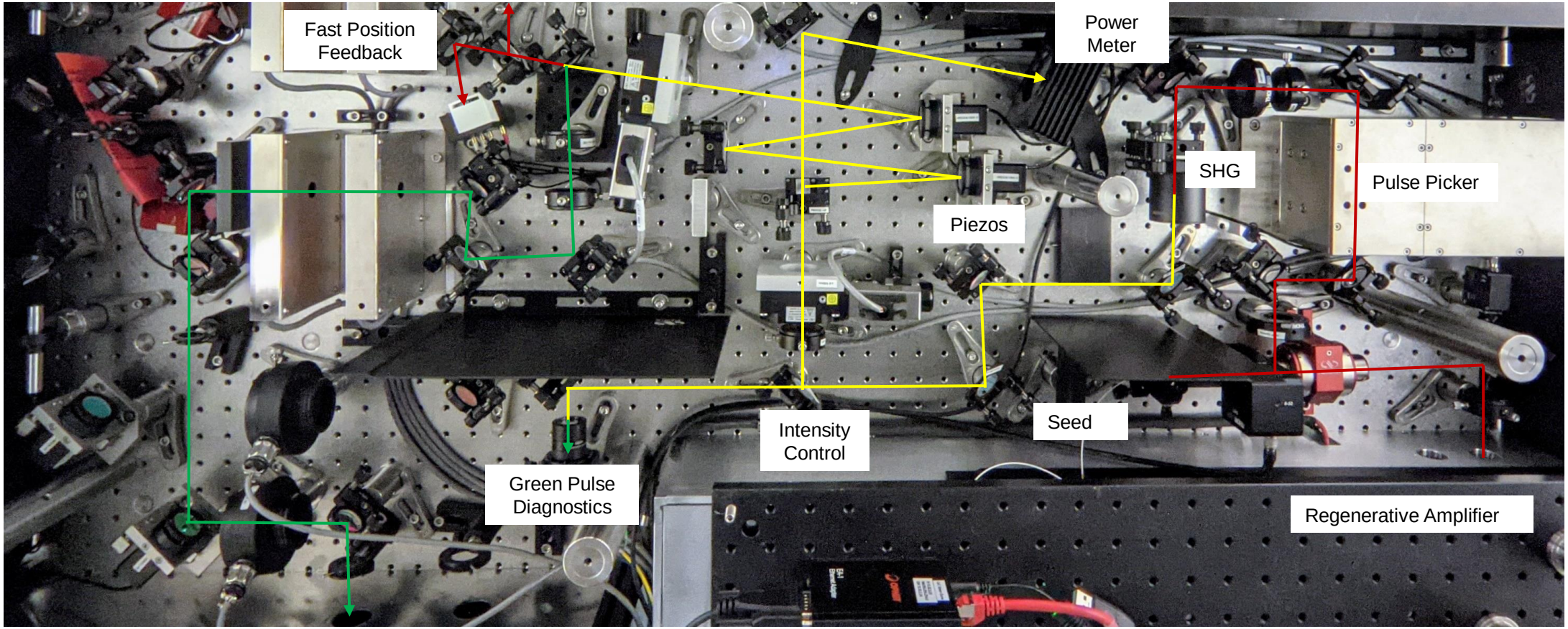
Agenda

- Laser Layout run21
- Performance Overview
- Temporal Jitter performance
- Intensity Noise
- Slow Position Stabilization System
- Position Jitter
- Updated Layout for run22
- Summary
- Option: Modelocked Seed Laser

Laser Layout run21

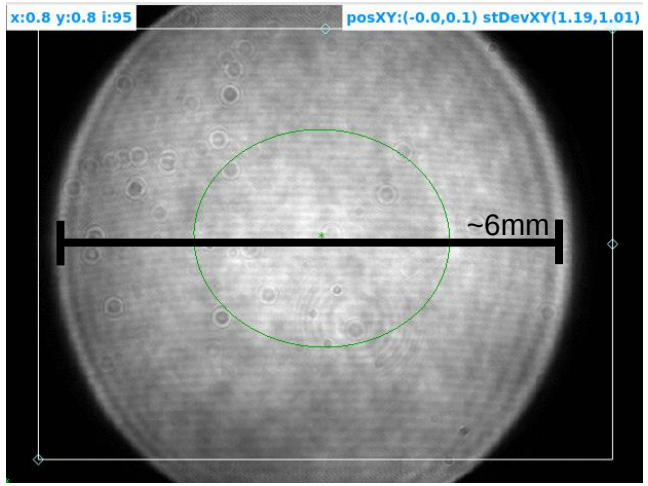


Pulse Picking in IR increases achievable ON/OFF contrast to 10^5 level
Co-propagation of Green and residual IR enables high bandwidth position feedback in pulsed mode

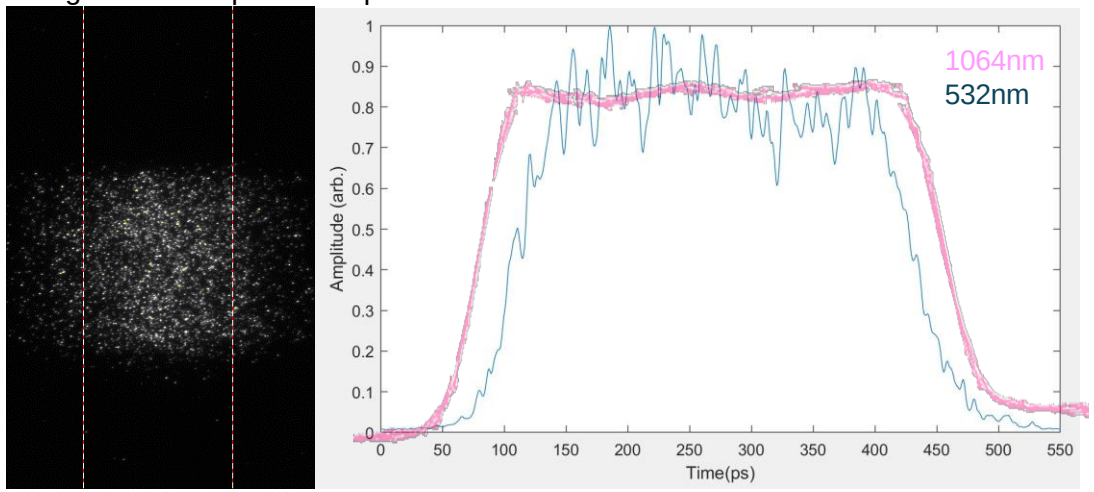
Performance Overview

Rep. Rate	78kHz
Pulse Energy 1064nm 532nm	 125µJ 85µJ
Pulse duration	125-1000ps
M^2	<1.05
Output stability 1064nm 532nm	rms 1% 2%
CoM stability Downstream of Aperture	<10µm rms

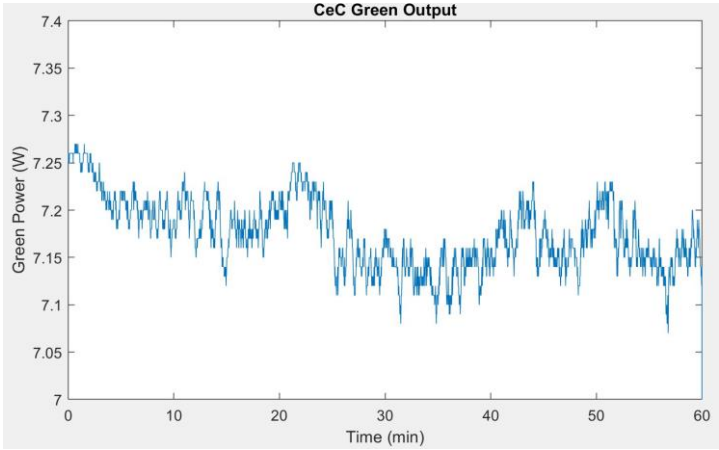
Transverse Profile imaged to the Cathode



Longitudinal 375ps Flat-Top

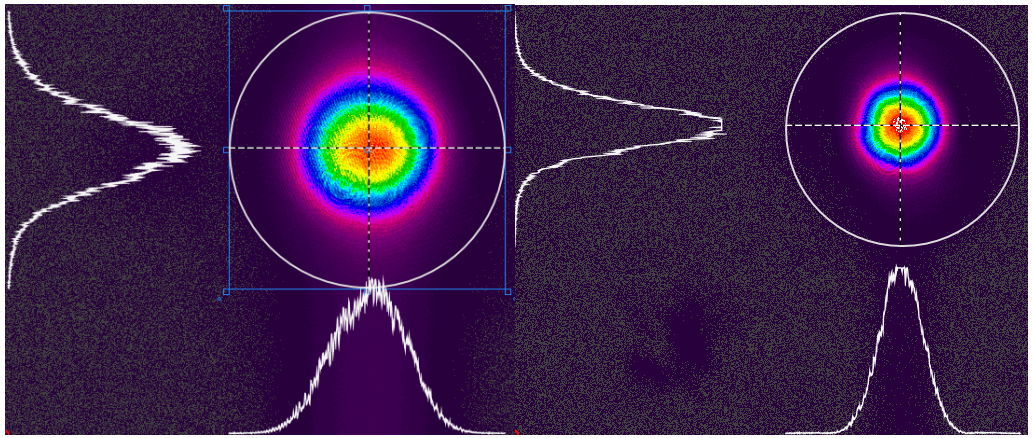


532nm Output Power



Transverse Profile 1064nm

Transverse Profile 532nm



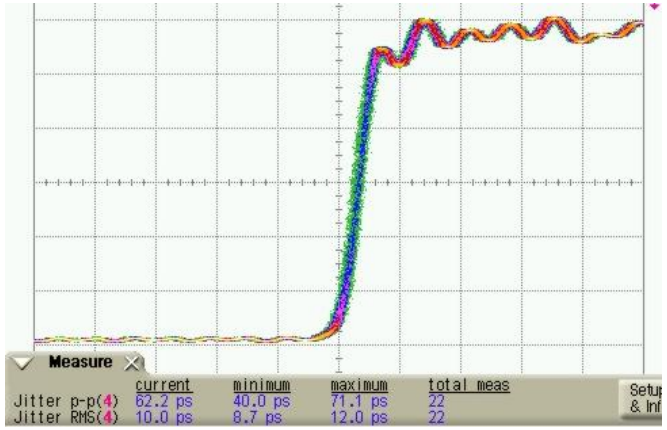
Temporal Jitter Performance

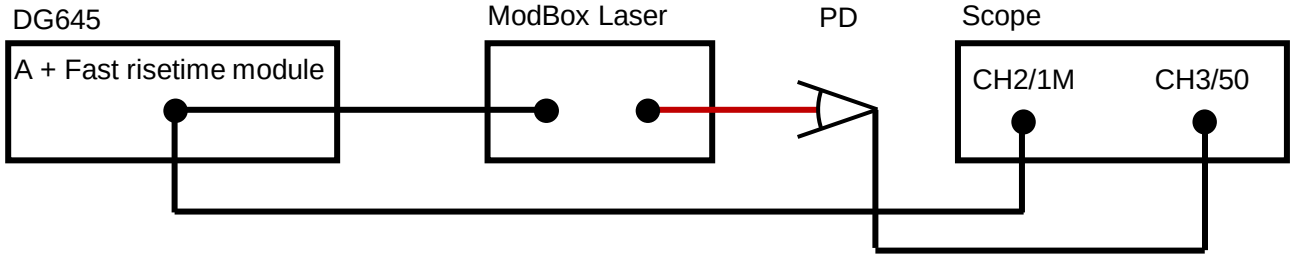
In-House Measurement

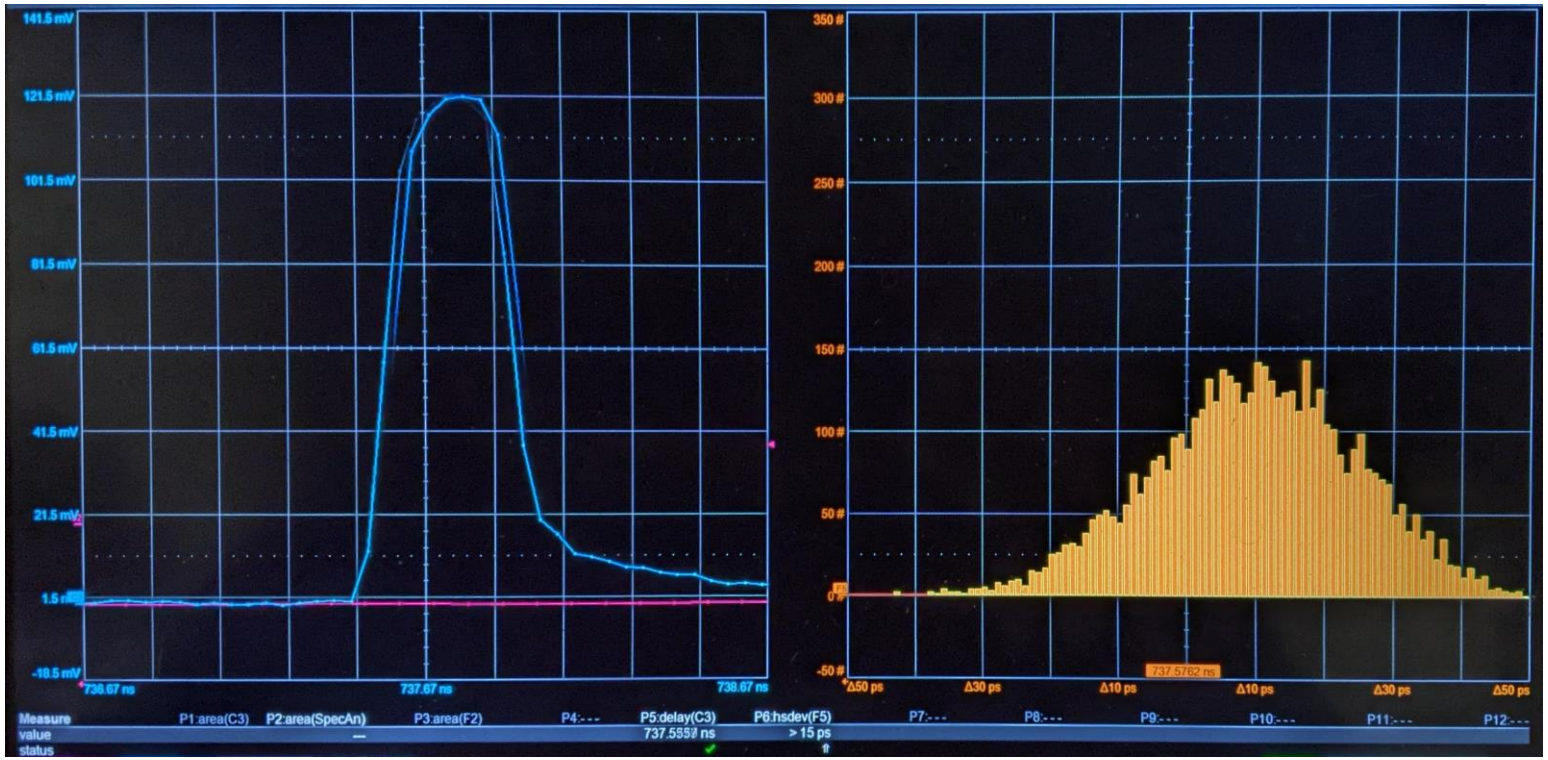
Jitter Measurement performed using a local delay generator and Oscilloscope
- Result: 14-15ps rms

Measurement is very sensitive to trigger edge slope; Result likely upper limit

Manufacturer measurement:
- Result: 8.7-12ps rms:







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- Measurements in IR and Green agree
- RMS values double as expected for conversion to green
- No noise peak detected at ~4kHz (ICT Sawtooth structure)
- Most noise is sub 1kHz

Intensity Noise

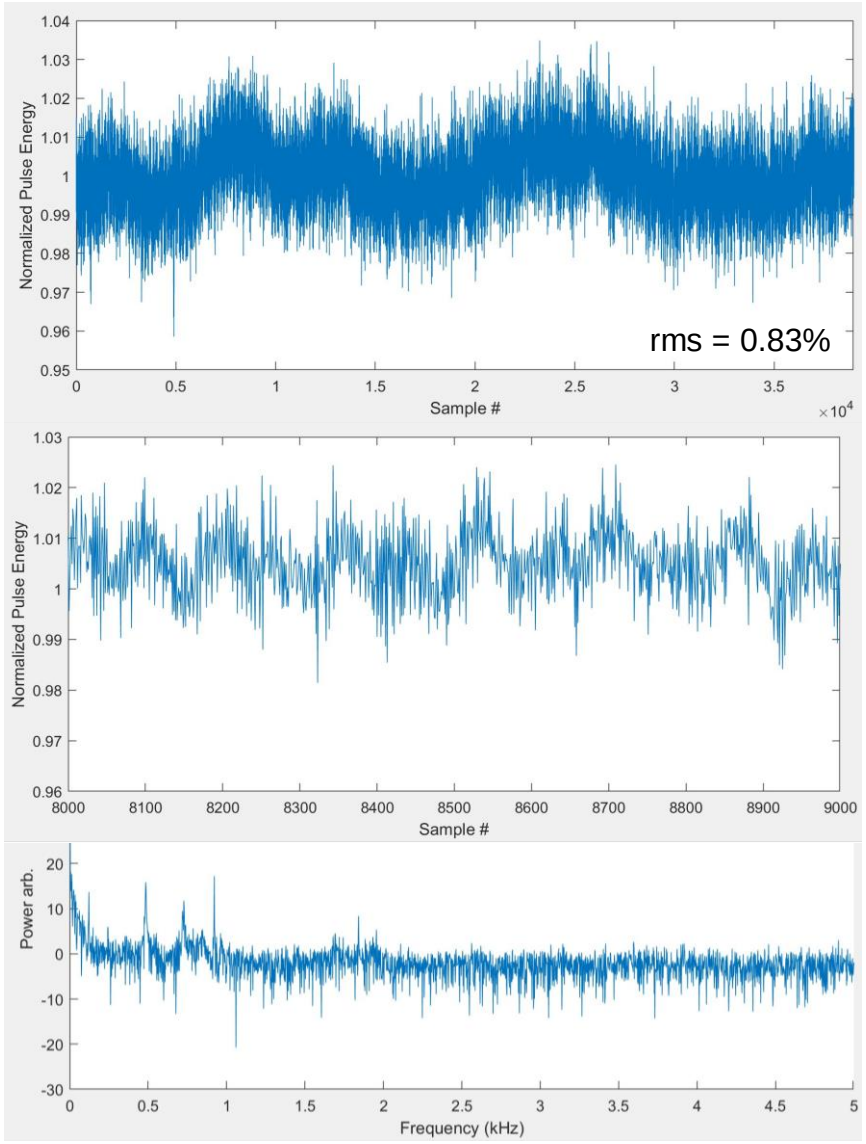
IR

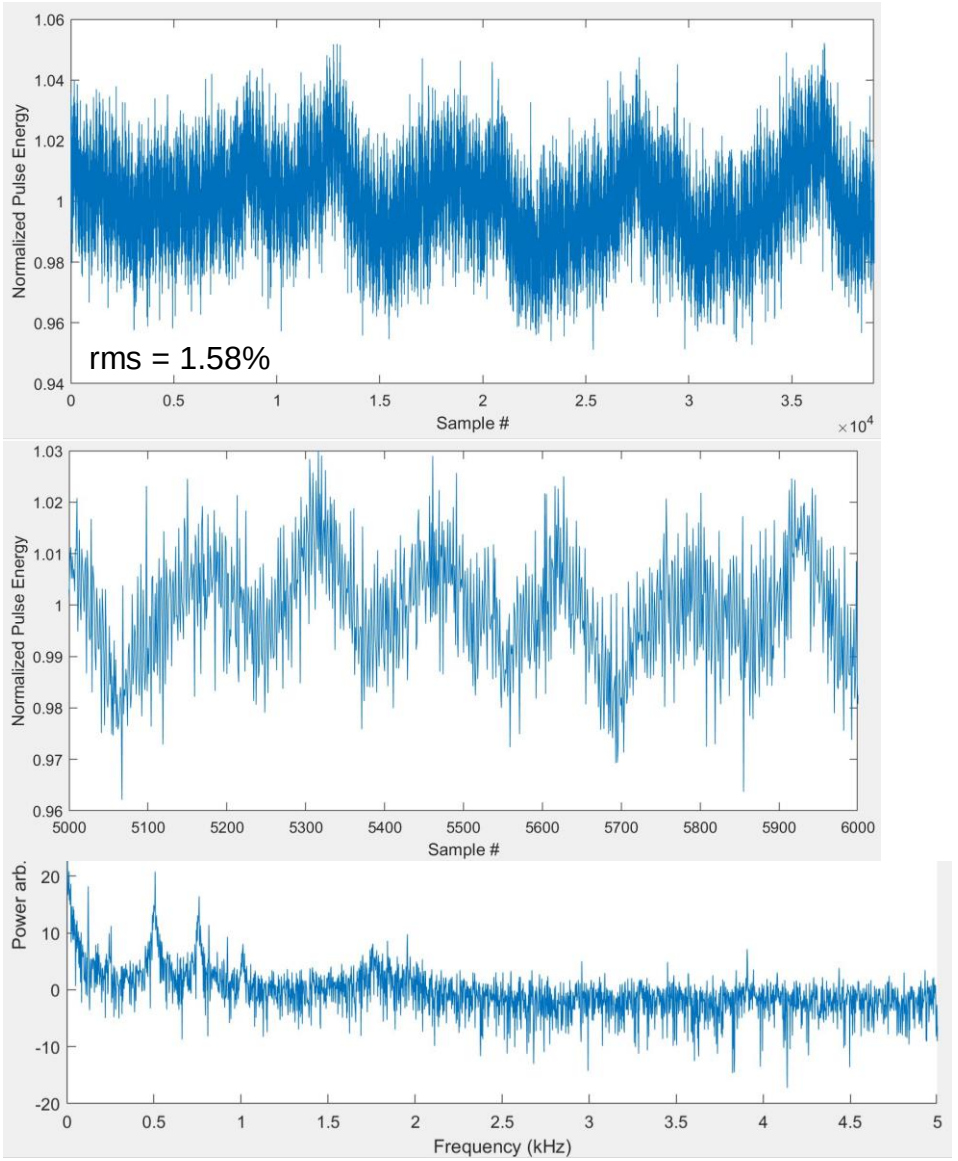
Green

Single-Shot integration at 78kHz

Zoomed in

Noise Spectrum





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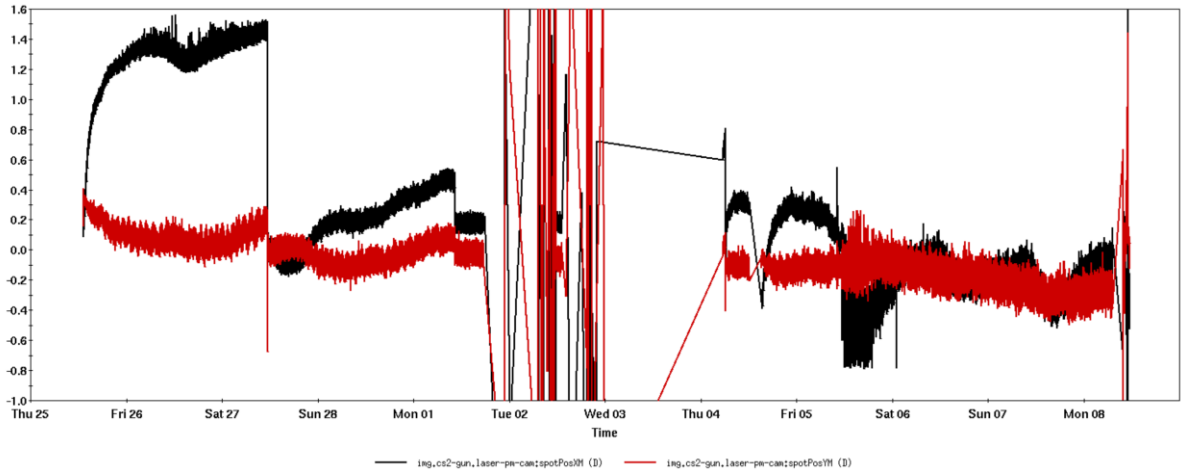
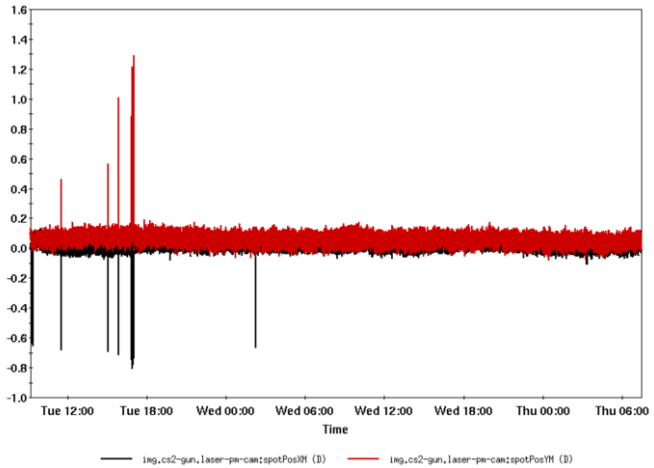
Slow Position Stabilization System
(Drift compensation)

System OFF

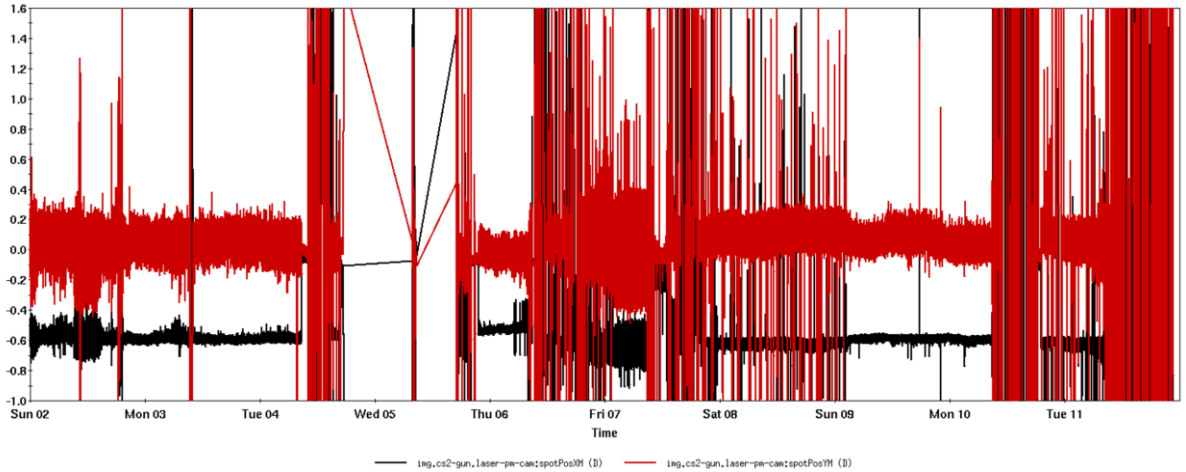
Iris open;
Drift of the transport system with environmental changes
(Temperature, Precipitation…)



System ON



45-Hour Controlled Test
(10 bunches, 1% Intensity level, Iris open)



10-Day Field Results (Iris ~4mm)
Position measurement noisy due to low power level on operations camera

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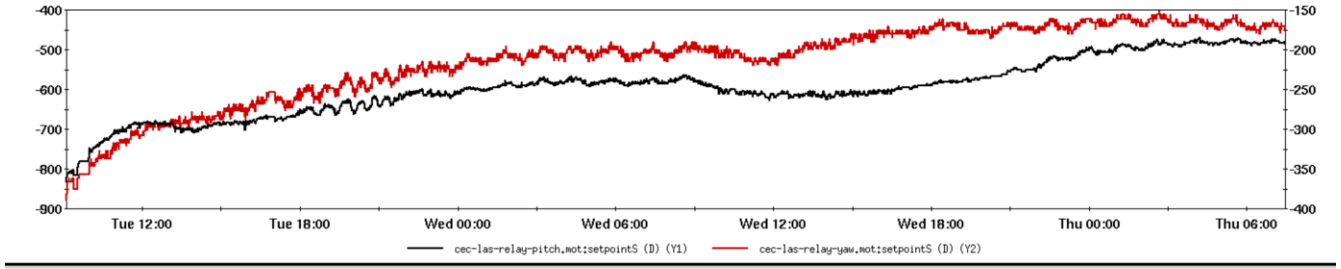
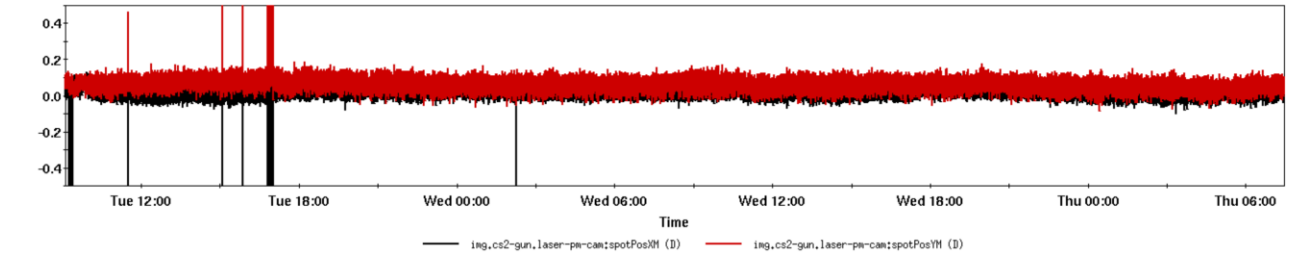
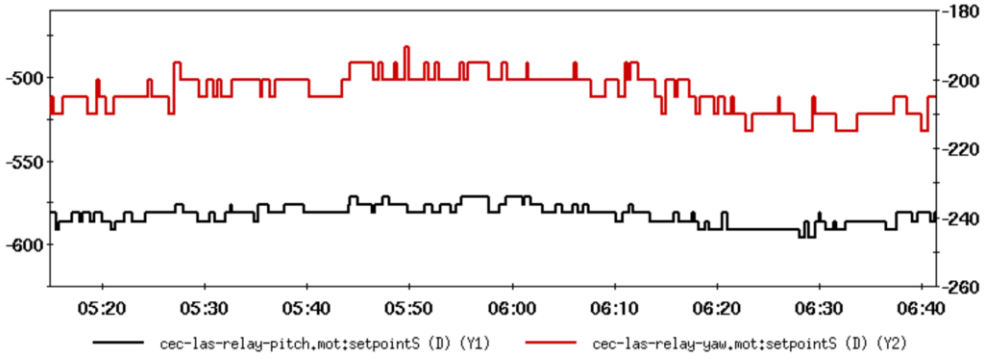
Slow Position Stabilization System (Drift compensation)

- Slow Position Feedback is operating in the background using dedicated cameras with increased dynamic range
- Ops. Camera dynamic range has trouble with position measurement at very low power settings
- System holds the alignment within 0.1mm

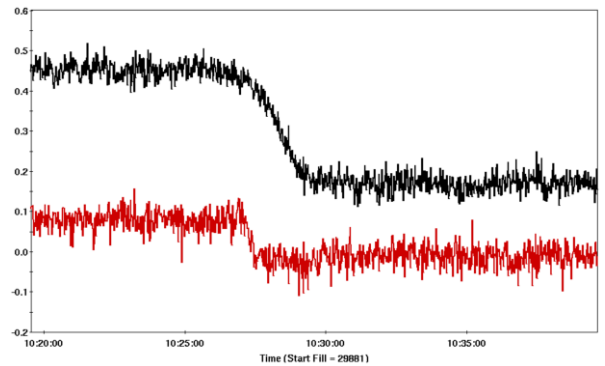
Piezo behavior







Hard-coded 0.167Hz response
(3-second iterations, 2 trips to provoke response

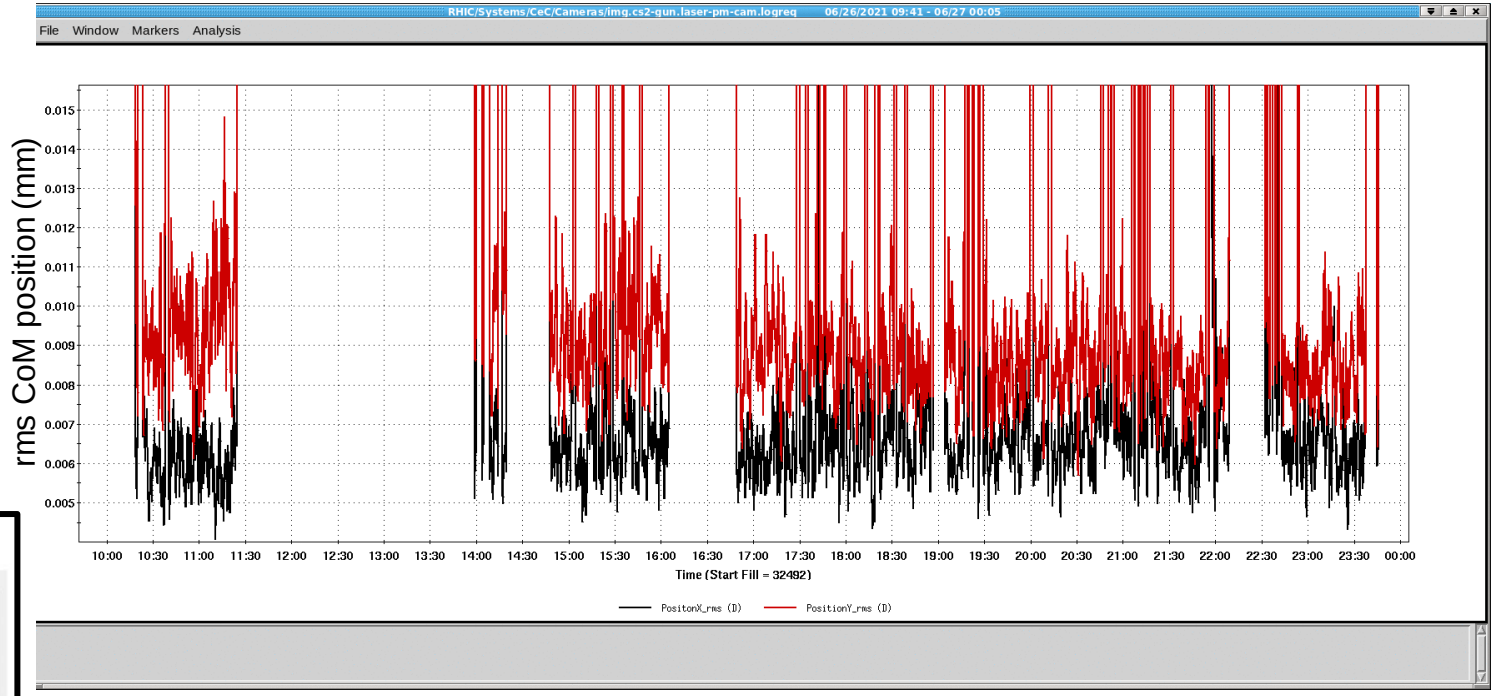


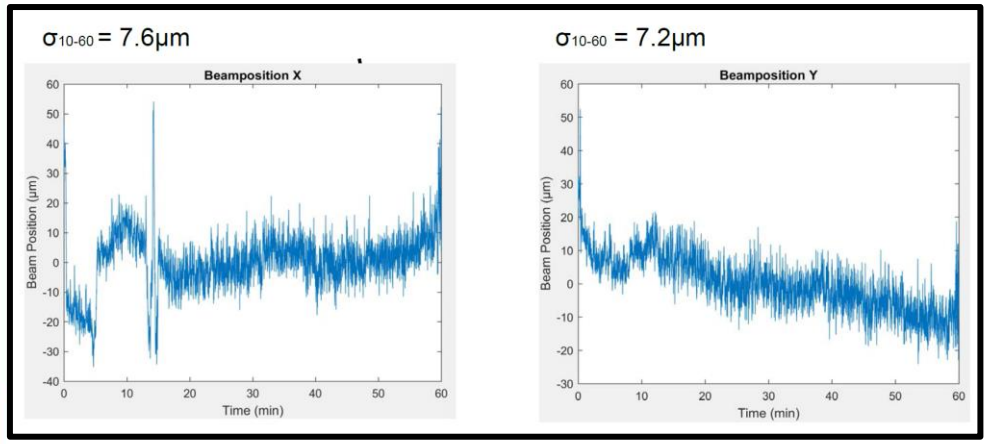
Maximum alignment speed (0.12mm/min)

Position Jitter

Center of Mass motion downstream of the Gun Table Aperture

- RMS Position Measurement using Gun Table Profile Monitor Camera
- In range of measurements using fixed alignment beam in 2017
- Fast Position Feedback is removing vibrations present upstream of the 40m free-space laser transport





2017 Measurement through free-space laser transport using fixed alignment beam

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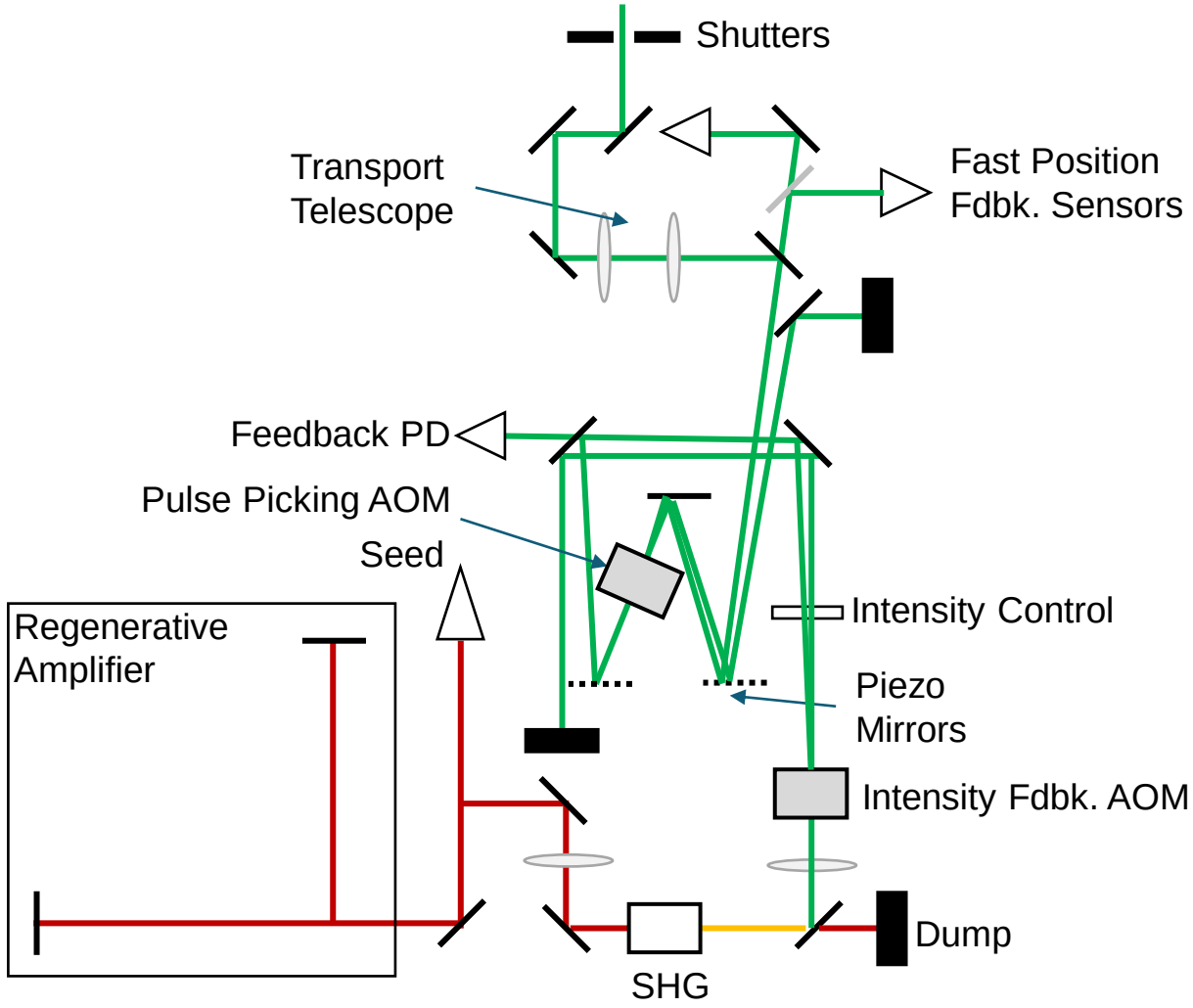
Updated Layout for run22

- Exchange of IR Pockels Cell Pulse Picker with AOM to enable 0-100% duty cycle operation for high repetition rate operation (1-5MHz)

- Maintaining CW beam throughout the entire system to enable high bandwidth position and intensity feedbacks and limit thermal effects from repetition rate changes

- Addition of second AOM for fast intensity feedback
  - Still need to work out efficient noise detection method to reach 2kHz Fdbk. Bandwidth for operation at variable repetition rates (78kHz-5MHz)

- Space is VERY limited



Summary

Run21 takeaways:

- An update to the Jitter spec. for CeC makes a new seed laser necessary
  - Replacement of current seed with another function generator underway (Jitter 5.6ps rms)
  - Option to use a Modelocked laser instead in Proposal stage (Jitter <250fs rms)
- The Shot-Noise of the free-running laser was deemed to large, making a fast intensity feedback necessary
- Slow Position feedback provides enough dynamic range to hold the transport alignment at all operational power levels within 0.1mm
- Position stability on the Gun table aperture is close to achievable limit without direct stabilization on the gun table which would require CW beams (CoM rms < 0.25% of Aperture size)

Added challenges for run22:

- All operational capabilities need to support low repetition rate (1Hz;78kHz) pulsed up to MHz cw
  - Pockels Cell Pulse Picker needs to be replaced with AOM due to duty cycle concerns at high rep. rates
  - Pulse Picking shifts from IR to green to allow high bandwidth position and intensity feedbacks

Option: Modelocked Seed Laser

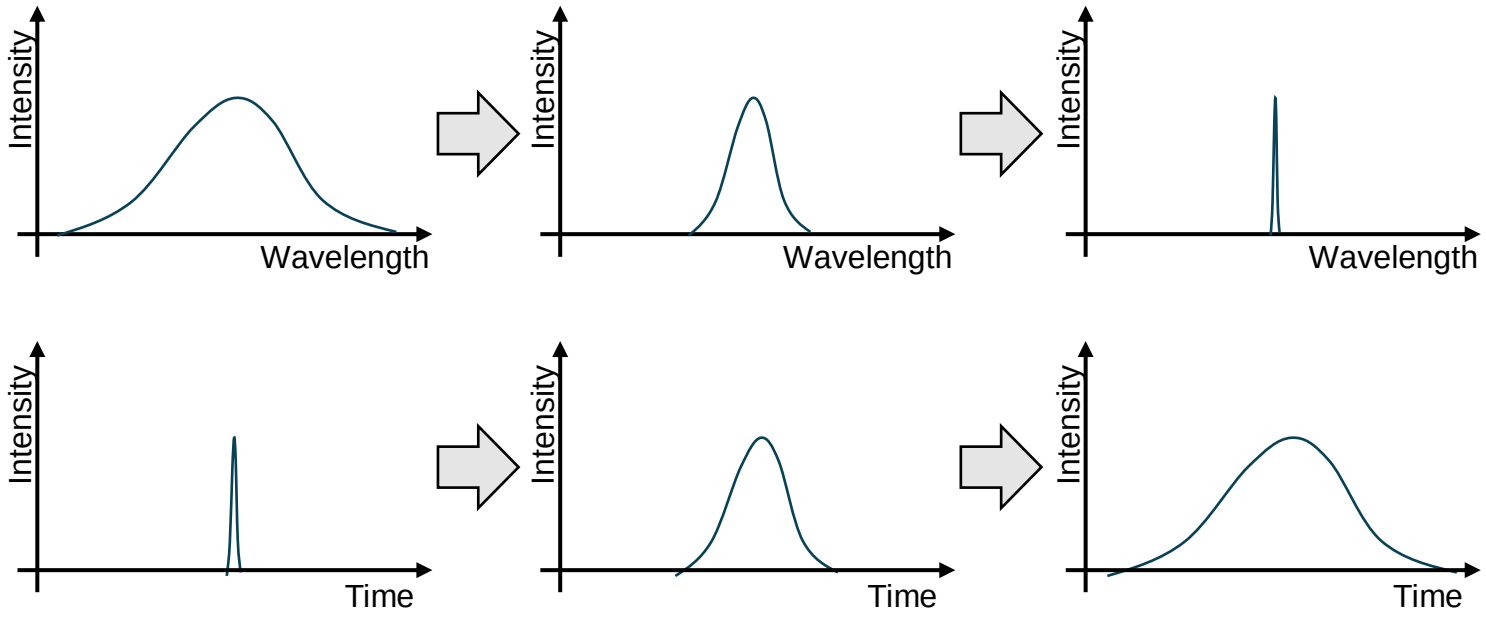
- Modelocked Oscilator Jitter: ~200fs rms
- 2-4ps pulse duration, 5-10nm Bandwidth
- Chirped gaussian output

Time-Bandwith Product for transform limited Gaussian pulse:
Bandwidth(Hz)*Pulse duration (FWHM) > 0.44

Bragg Grating inside of Regenerative amplifier narrows spectral bandwidth and increases pulse duration with each roundtrip:

Target duration: 350ps FWHM => 1.25GHz Bandwidth (4.7pm)

Spectral filtering to reduce bandwidth of seed pulse



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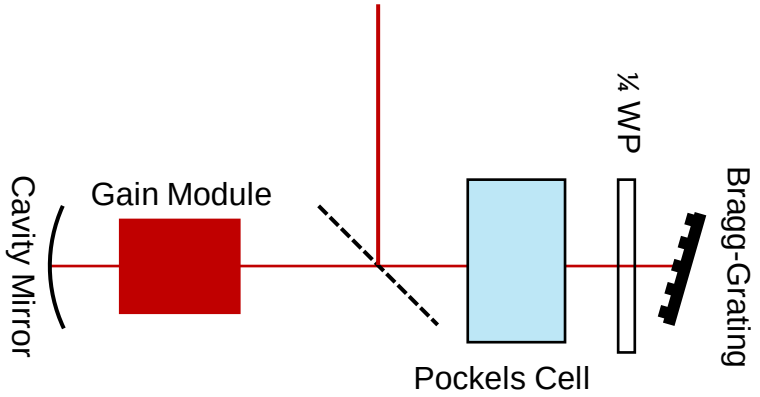
Option: Modelocked Seed Laser

Spectral filter: Narrow bandpass filter, Gaussian filter response

Filter FWHM: 60pm => FWHM = σ * 2.35

Filter effect after N roundtrips:

$$e^{-\left(\frac{2*N*x^2}{2\sigma^2}\right)} = e^{-\left(\frac{x^2}{2\left(\frac{\sigma}{\sqrt{2N}}\right)^2}\right)}$$



Regenerative Amplifier
2 Grating bounces per roundtrip

$\frac{\sigma}{\sqrt{2N}} = \sigma_{new}$ Spectral width narrows with sqrt(2N) => 37 Roundtrips using 60pm filter = 4.64pm output bandwidth

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Pulse shape is always gaussian and symmetric