High-power Fiber Laser System for LEReC

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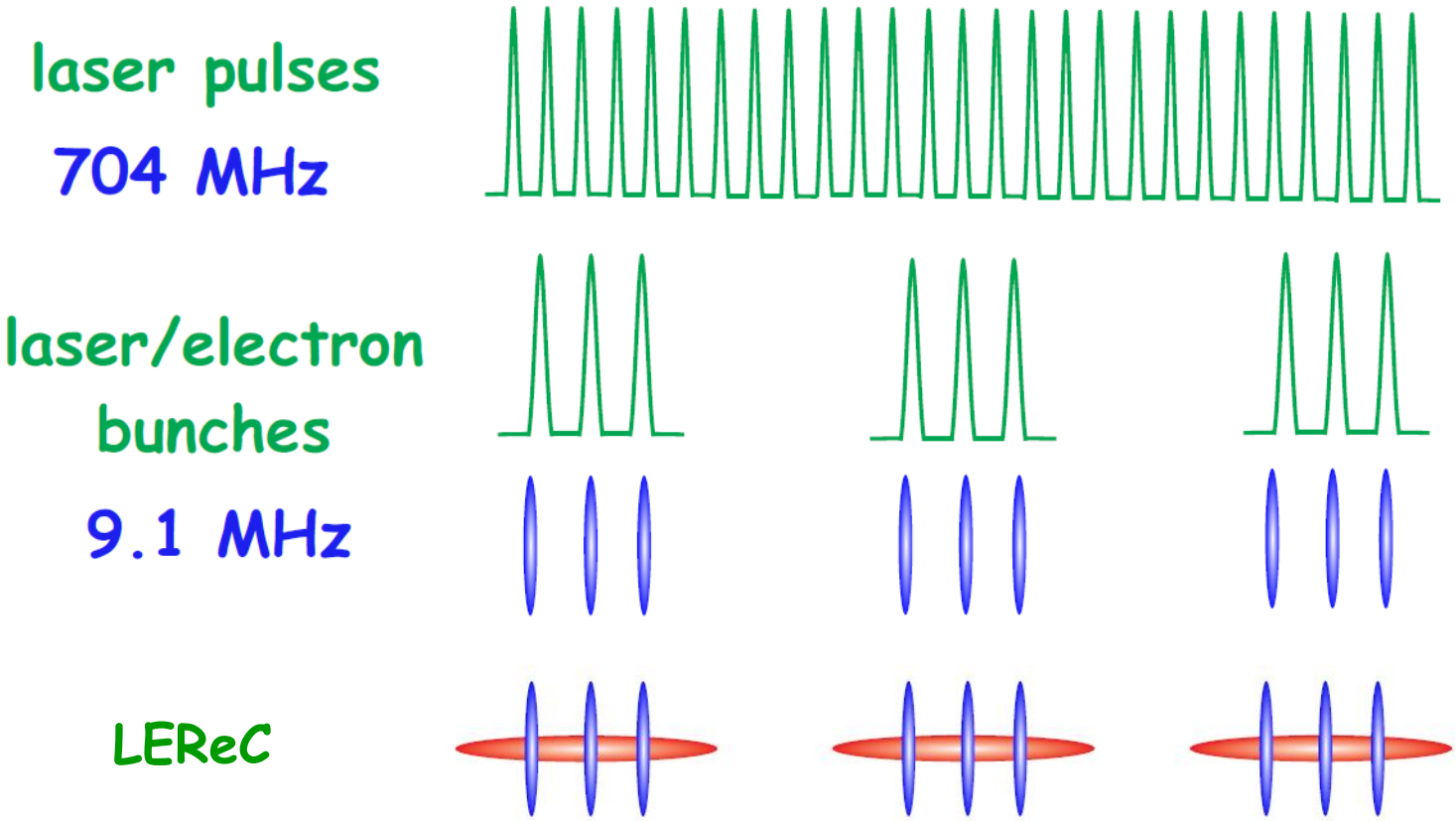
Dec. 16, 2015

Outline

- Laser parameter review
- Laser design & progress report
- Laser control for beam experiment
- Budget update & request

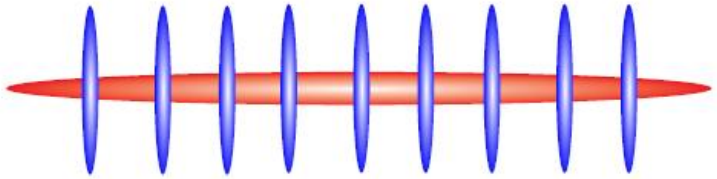
Laser Parameter Review

Laser Pulse Pattern for LEReC



Laser pattern: 704MHz, 9.1MHz bunch rate, 10-30/bunch

Laser Energy & Power for LEReC



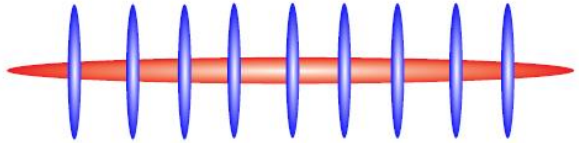
• **Electron bunch charge:**	100 pC	300 pC
• **Laser energy (QE=1%):**	24 nJ	72 nJ
• **Repetition rate (MHz):**	9.1 x30 = 273	9.1x18 = 164
• **Green power on cathode:**	6.6 W	12 W
• **Green power from laser:**	6.6x3 =20 W	12x3=36 W

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

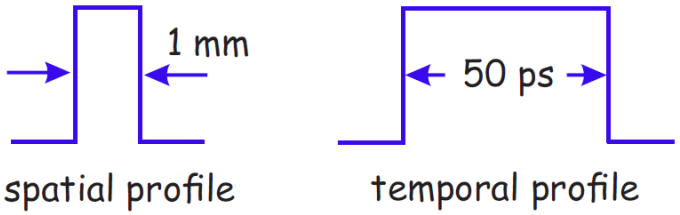
Laser Parameters: Wish List

- High average power

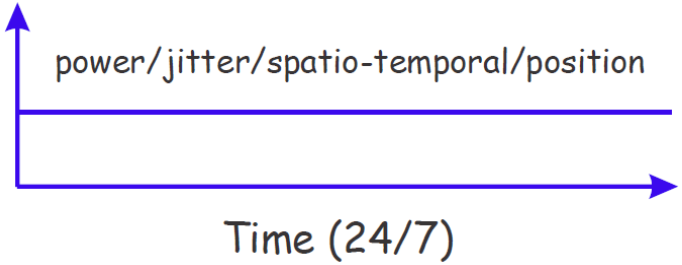
- Timing: Laser/RF/Ion



- "Flat-top" profile



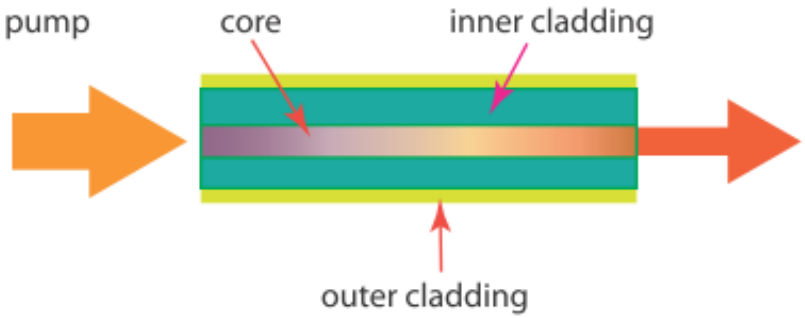
- Stability & reliability



Laser Design & Progress Report

High-power Fiber Laser

Double cladding fiber



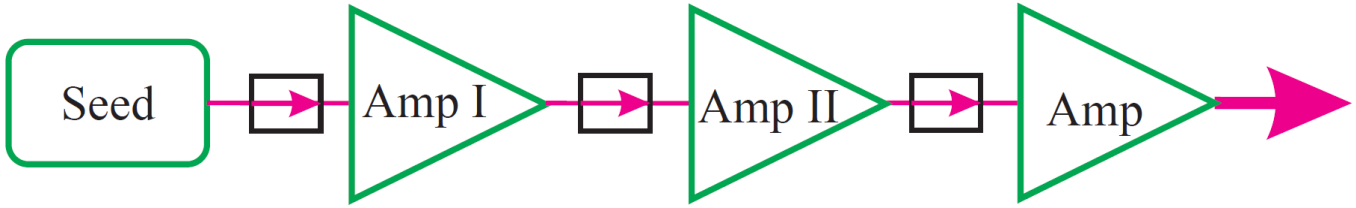
Advantages for fiber lasers

- High slope efficiency & average power
- Excellent thermal management
- Excellent spatial mode & point stability
- Maintenance-free operation

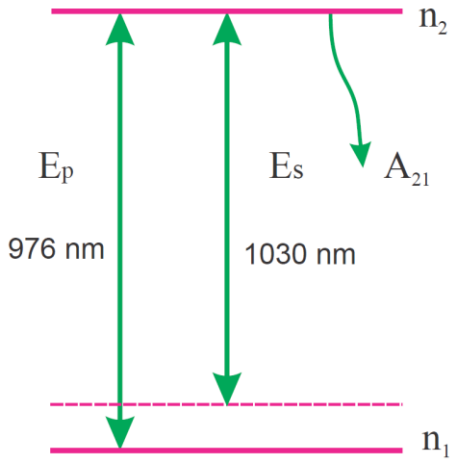
Fit best to acceleration applications !

Yb-doped Fiber Amplifier

Master oscillator power amplifier



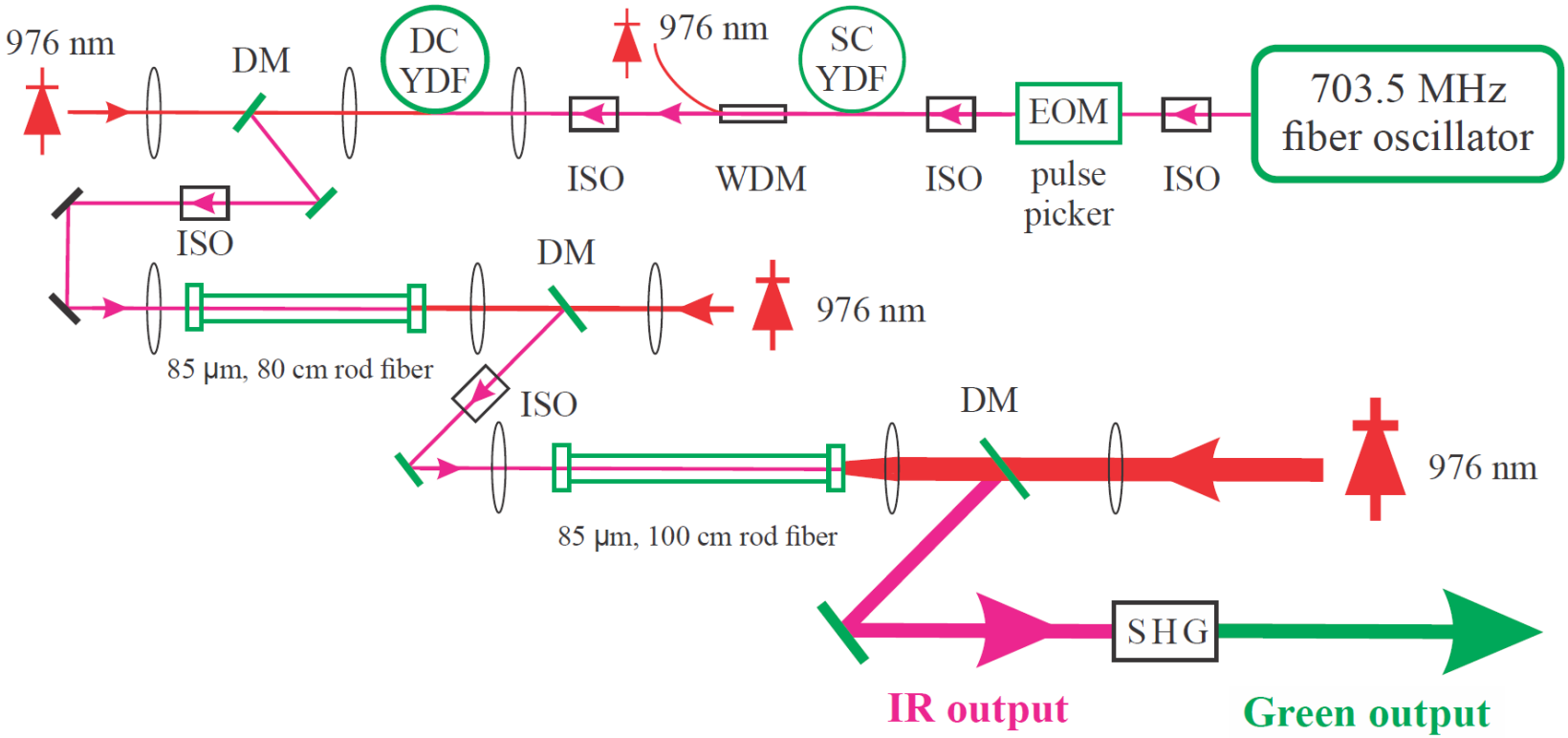
Energy structure



Major limiting factors:

- Peak power damage
- Nonlinear phase shift
- Mode instability
- Noise: ASE, SRS

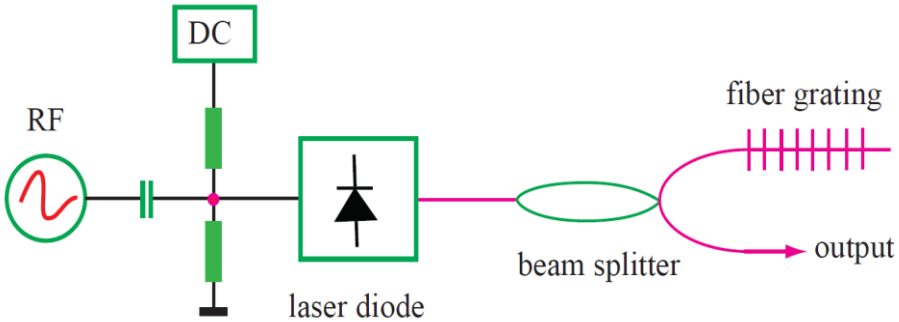
Fiber Laser System

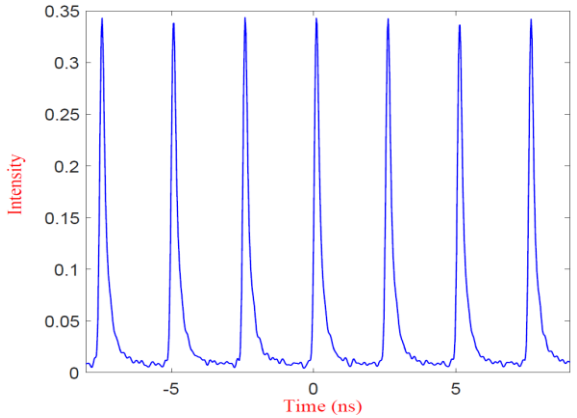


- Physical & technical limitations
- System engineering issues

Fiber Oscillator

Gain-switched diode laser towards 20 ps

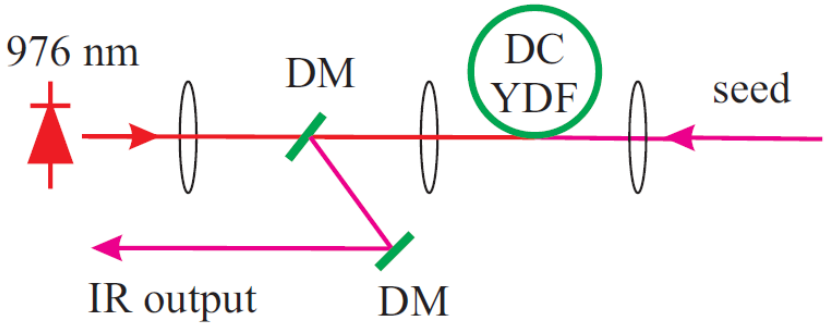




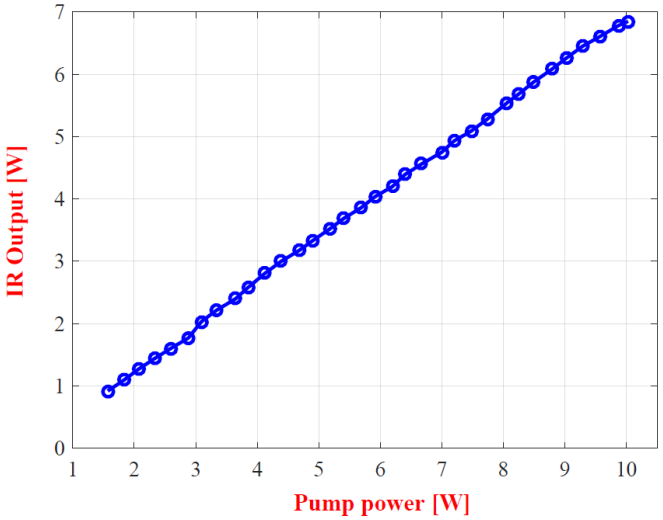
High-harmonic fiber oscillator

- Syn. to RF: 704 ± 0.13 MHz
- Time jitter: < 200 fs
- Pulse duration: 1.5-2.5 ps
- Time-bandwidth-product: 0.45
- Sideband: < 65 dB

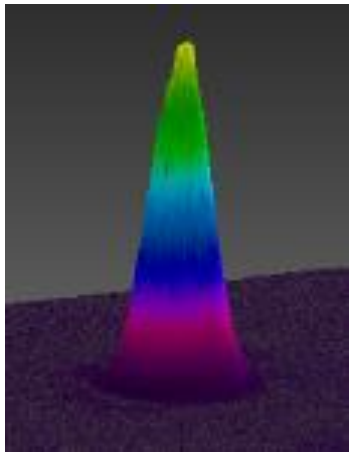
PCF Preamp II



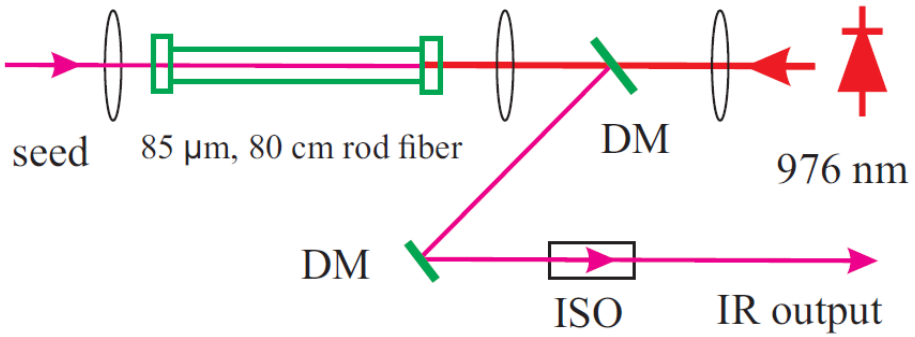
IR output from PCF preamp



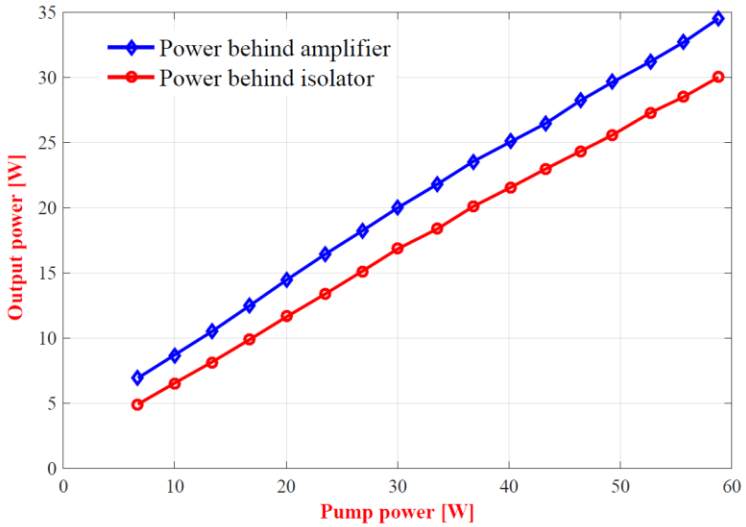
Spatial mode



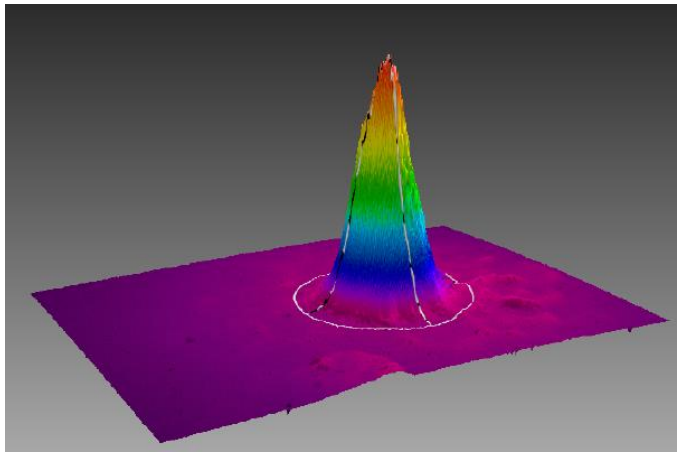
Rod Fiber Preamp III



IR Output from rod preamp



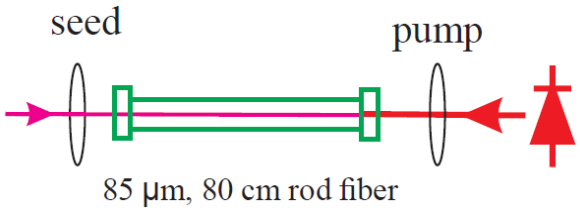
Highly symmetric beam mode



D4σX=1.845 mm; D4σY=1.842mm;

DkeX16/84=1.820mm; DkeY16/84 =1.809 mm

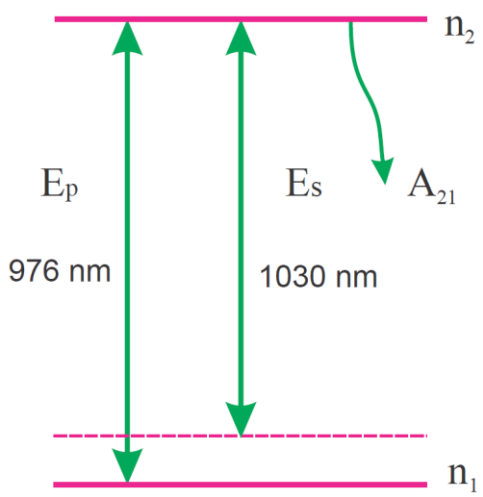
Modeling of Rod Fiber Amplifier



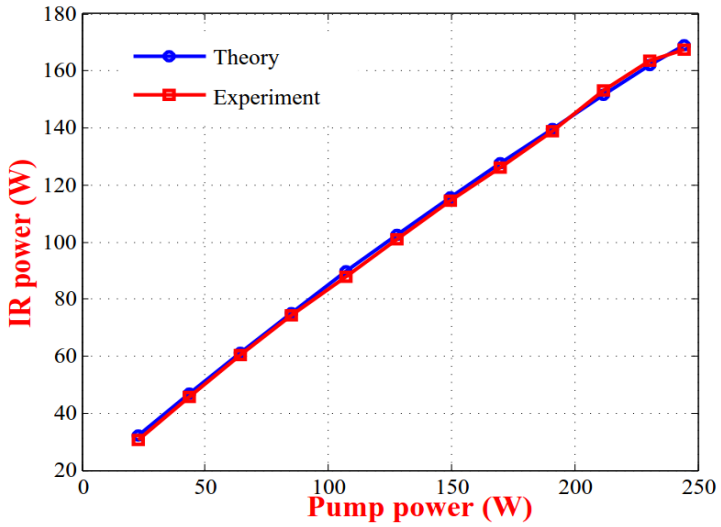
Propagation & rate equ. (n1, n2)

$$\frac{dP}{dz} = \eta_p(\sigma_{21p}n_2 - \sigma_{12p}n_1)N_{tot}P$$

$$\frac{dS}{dz} = -\eta_s(\sigma_{21s}n_2 - \sigma_{12s}n_1)N_{tot}S$$

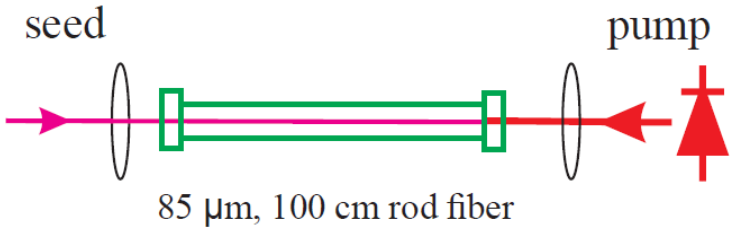


IR vs pump at 250 W pump

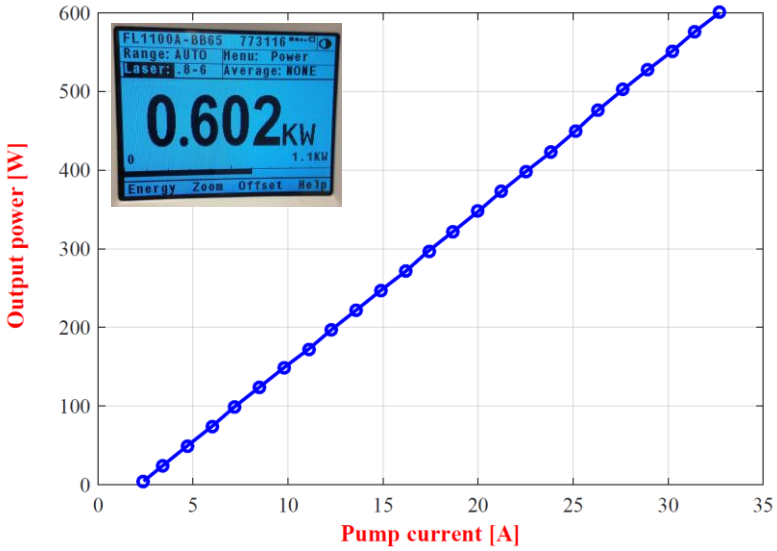


Zhao, et al, Opt. Express 22, 25065 (2014).

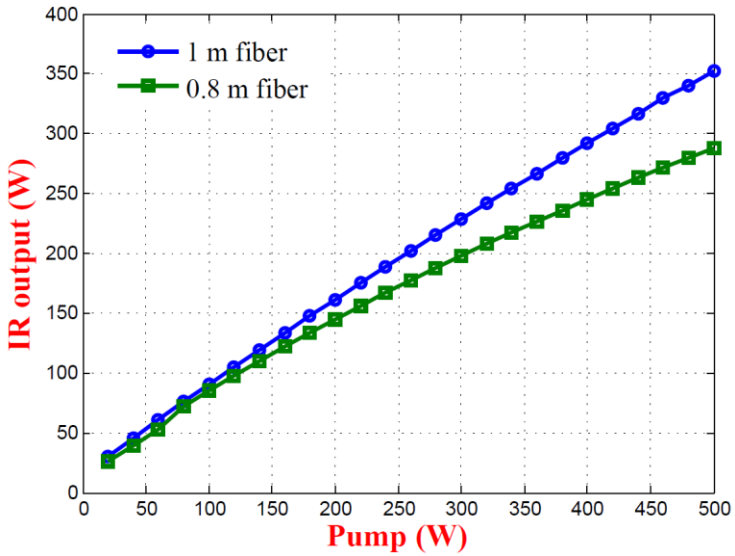
Main Rod Fiber Amplifier



600 W Pump laser diode

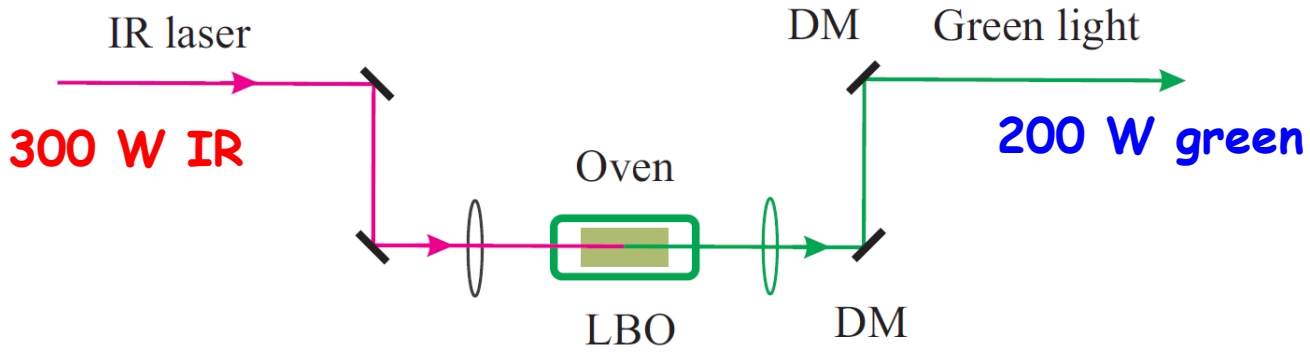


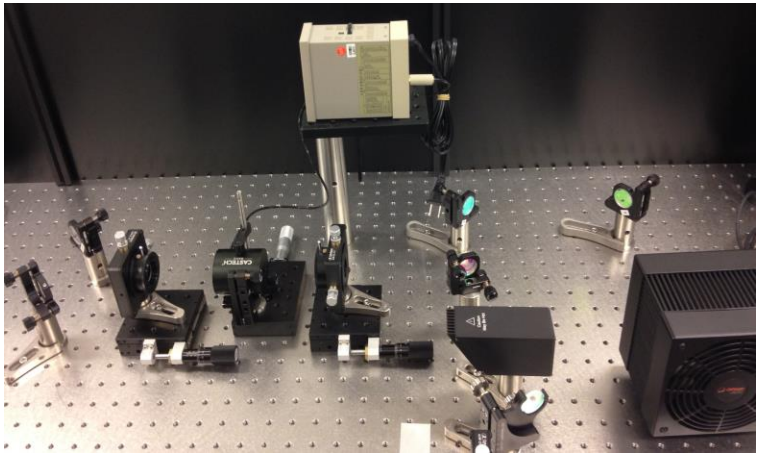
Rod amplifier: simulation



Green Light Generation by SHG

Frequency doubling: noncritical phase matching

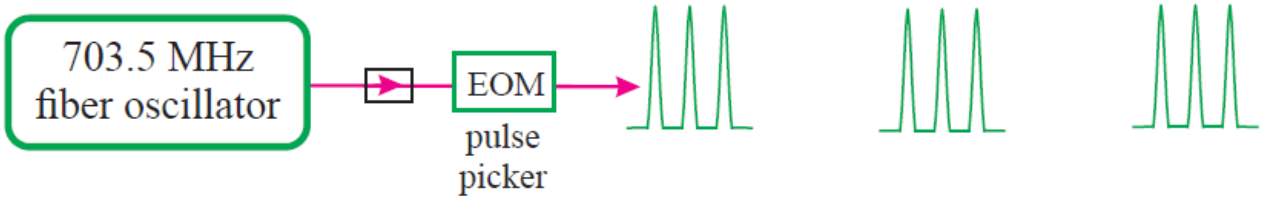




Old Cornell picture

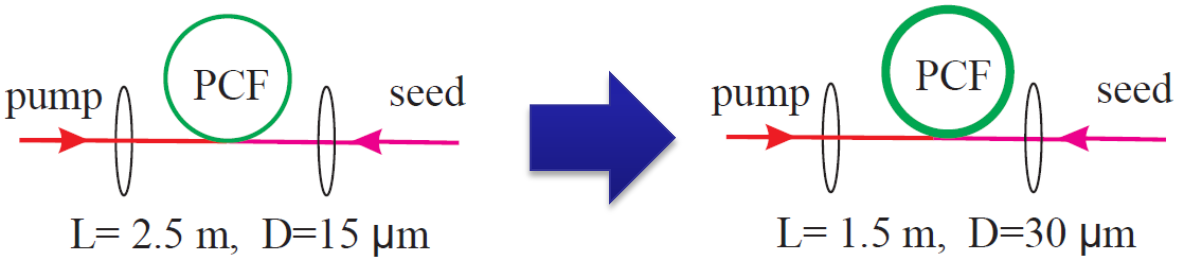
Repetition Rate Considerations

- Macro-bunch pulse picker



Actual average rep. rates: 160-270 MHz

- Nonlinear phase reduction in preamp



$\phi = 2.5\ \pi$

$\phi = 0.4\ \pi$

Physical & Technical Limitations

Laser maxima

- Green power from laser: 12x3 = 36 W
- Green pulse energy: 72x3 = 216 nJ
- IR pulse energy: 324 nJ
- IR peak power: 216 kW

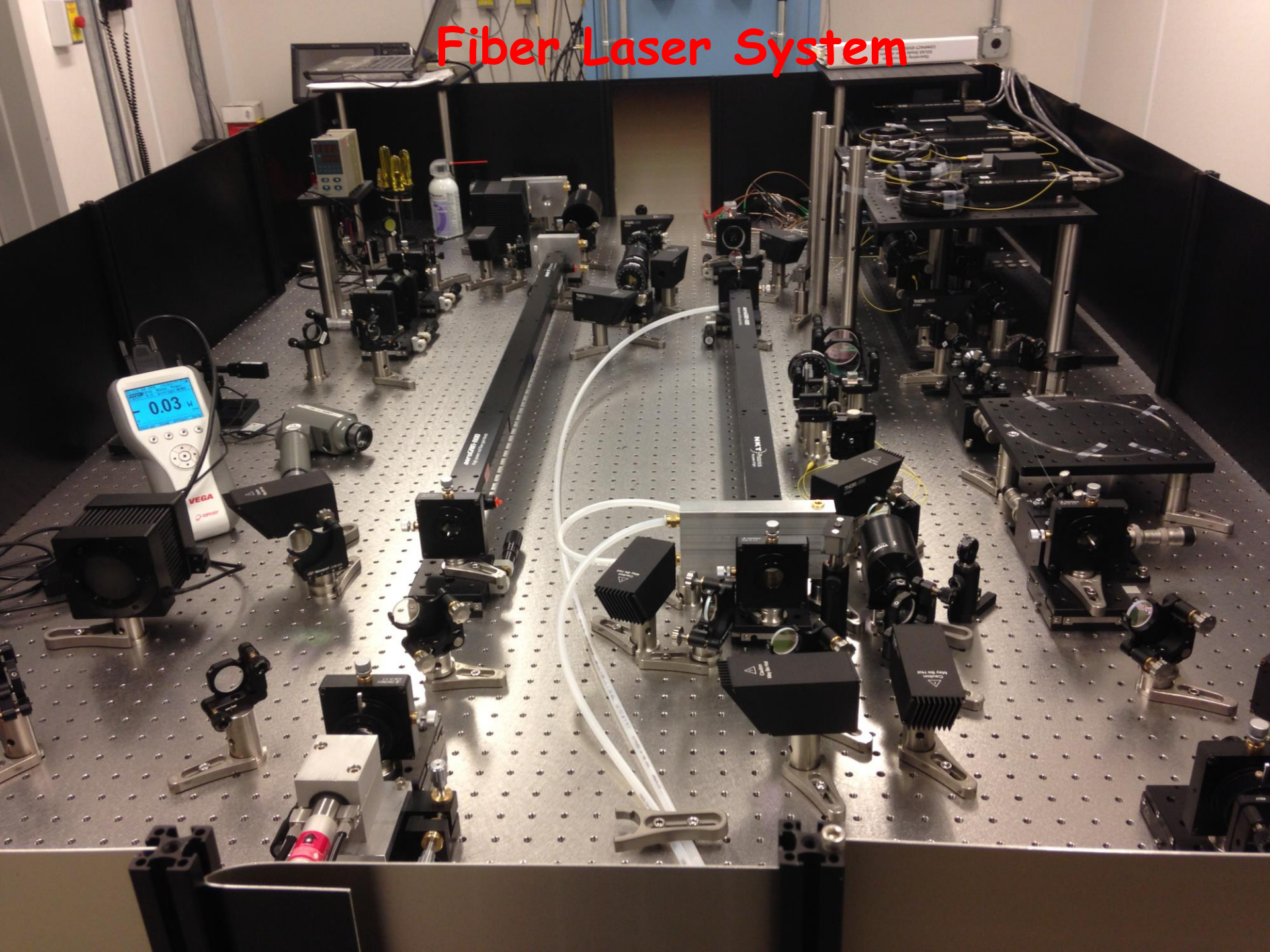
Physical limits

- Peak power damage: 4 MW
- Raman scattering threshold: 1.8 MW
- Nonlinear peak power: 330 kW
- Mode instability: 300 W average power

More options for higher energy or peak power:

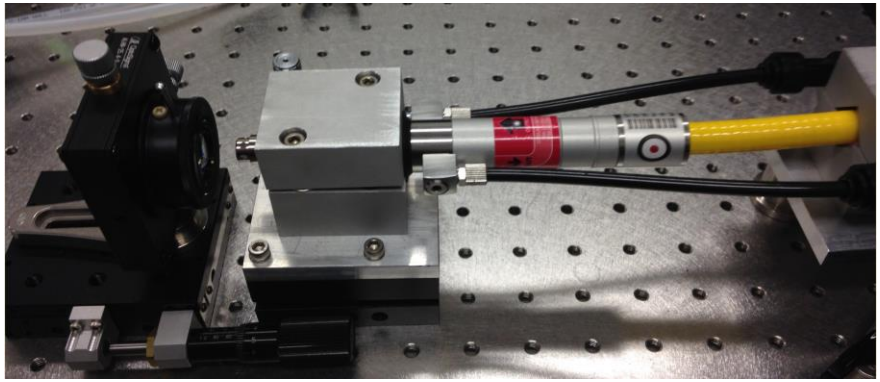
Larger MDF fiber & modest chirped CPA

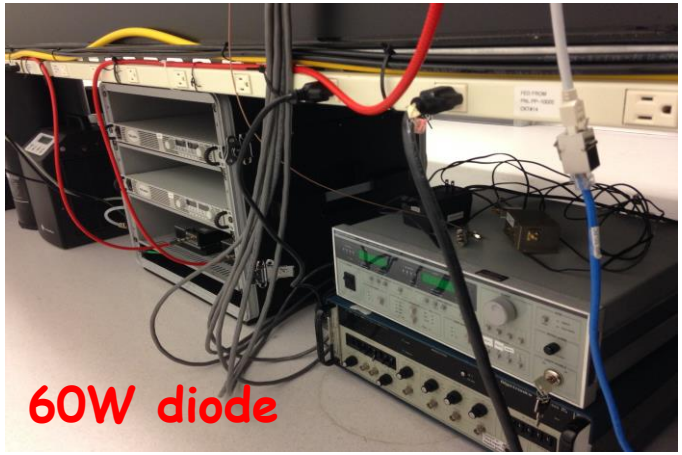
Fiber Laser System

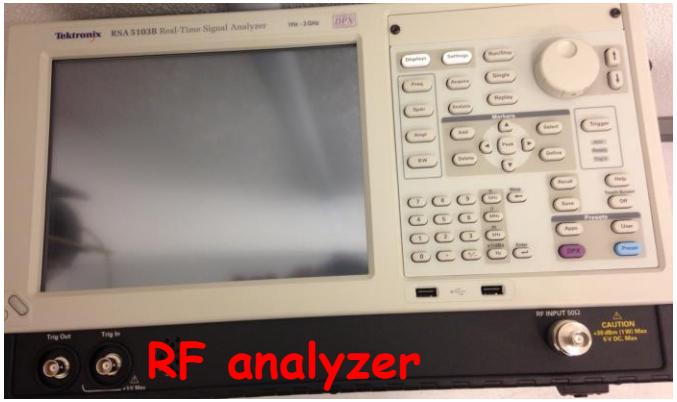


Major Equipment

600 W diode

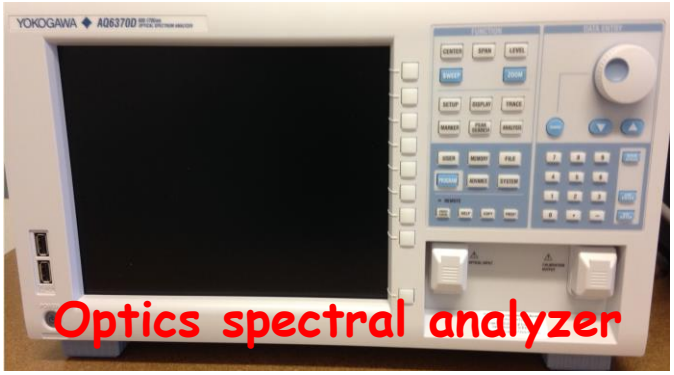



60W diode



RF analyzer


chiller



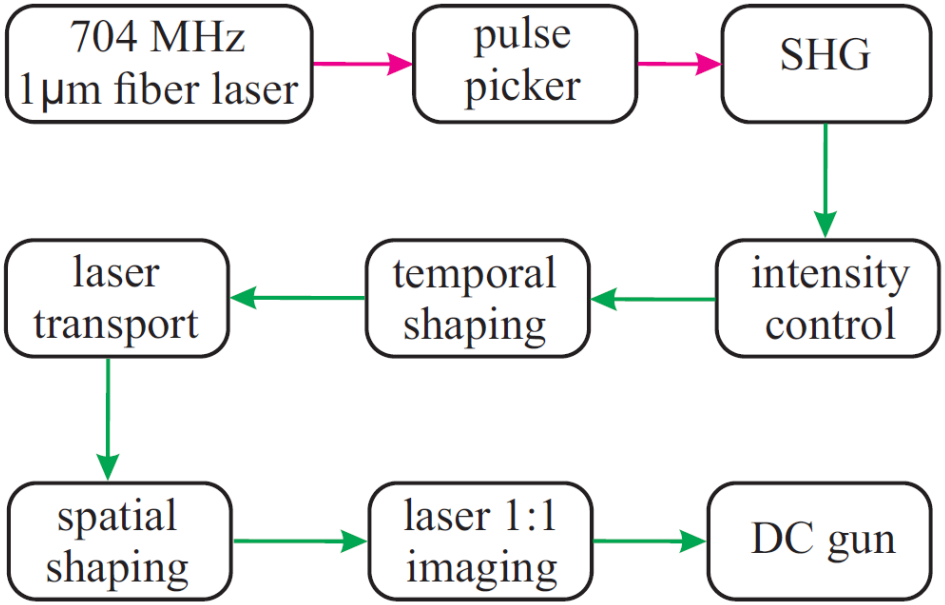
Optics spectral analyzer

Waiting list

- Fiber oscillator
- Chiller
- …

Laser Control for Beam Experiment

Layout of Laser System for LEReC



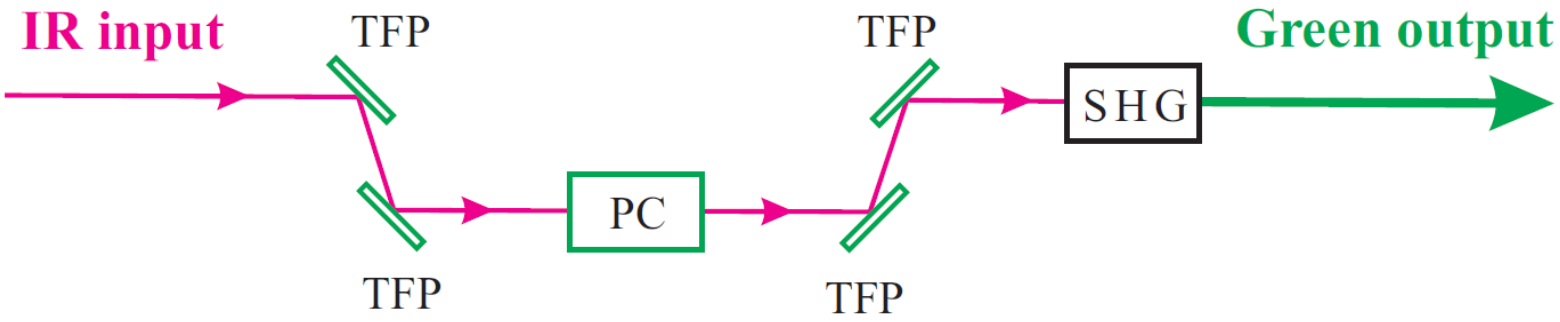
Key control

- Pulse picker
- Intensity control
- Spatiotemporal shaping

Key diagnostics

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

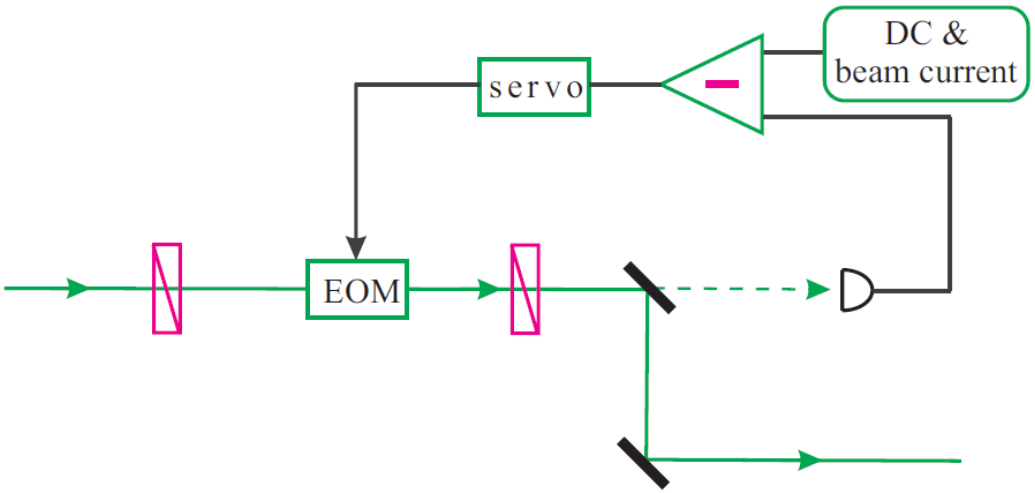
Pulse Pickup



Three major requirements

- High extinction ratio: 1000:1@IR and 10^6:1@ green
- Fast switch time: ~ 5 ns
- High average power: >100W

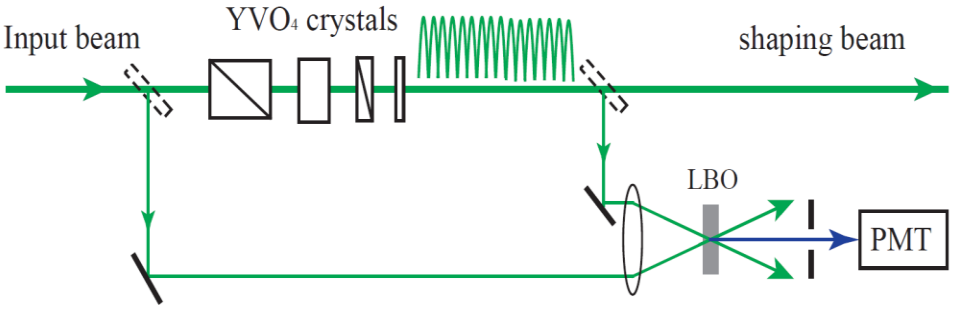
Intensity Control

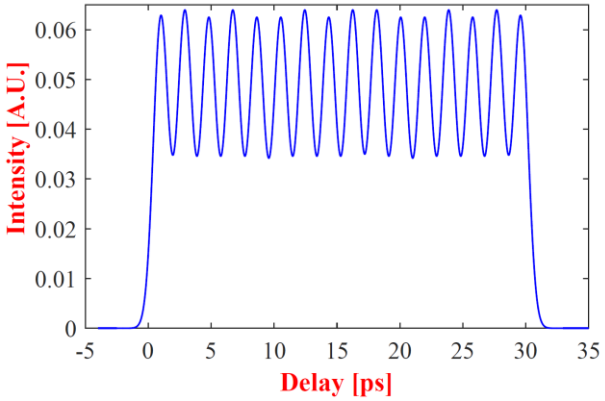


Three major functions

- Stabilizing green light intensity
- Stabilizing beam current
- Machine protection & fast shutdown

Crystal Stack for Laser Beam Shaping

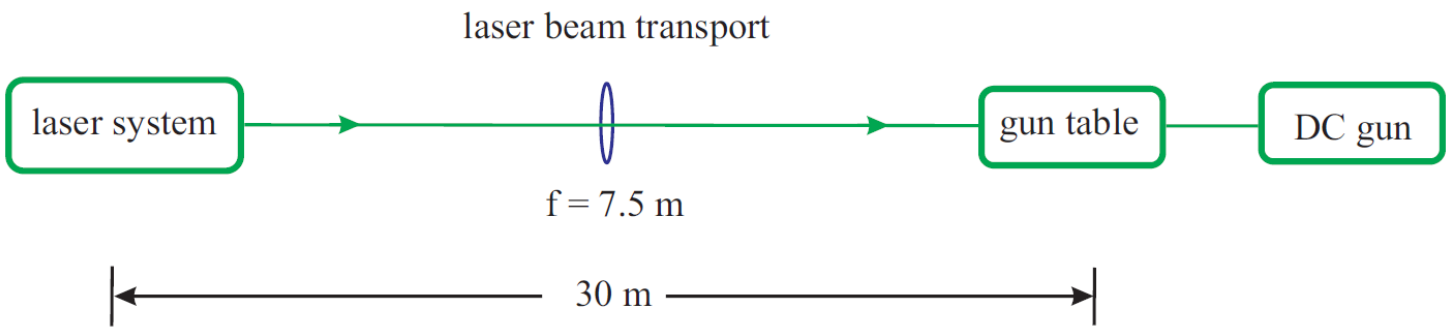




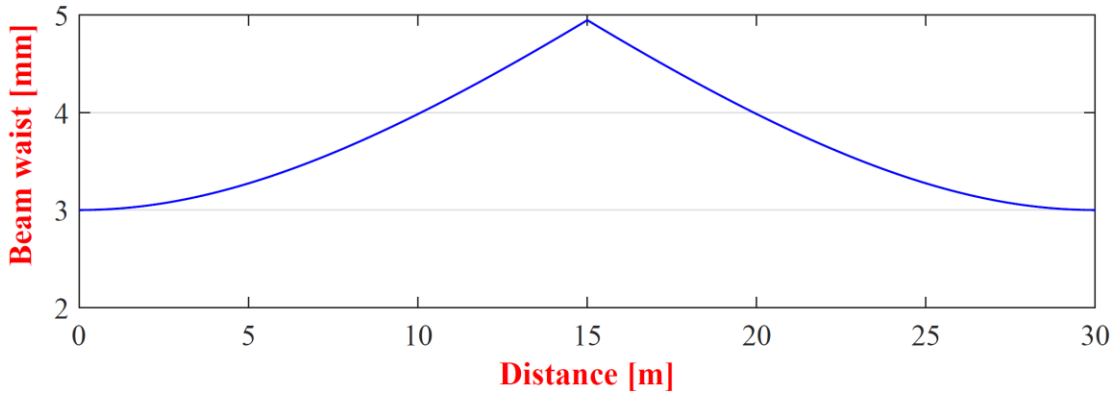
- Duration: thickness of shaping crystals
- Rise & fall time: duration of input pulses
- Ripple & stability: duration of input pulses

Laser Transport & Beam Optics

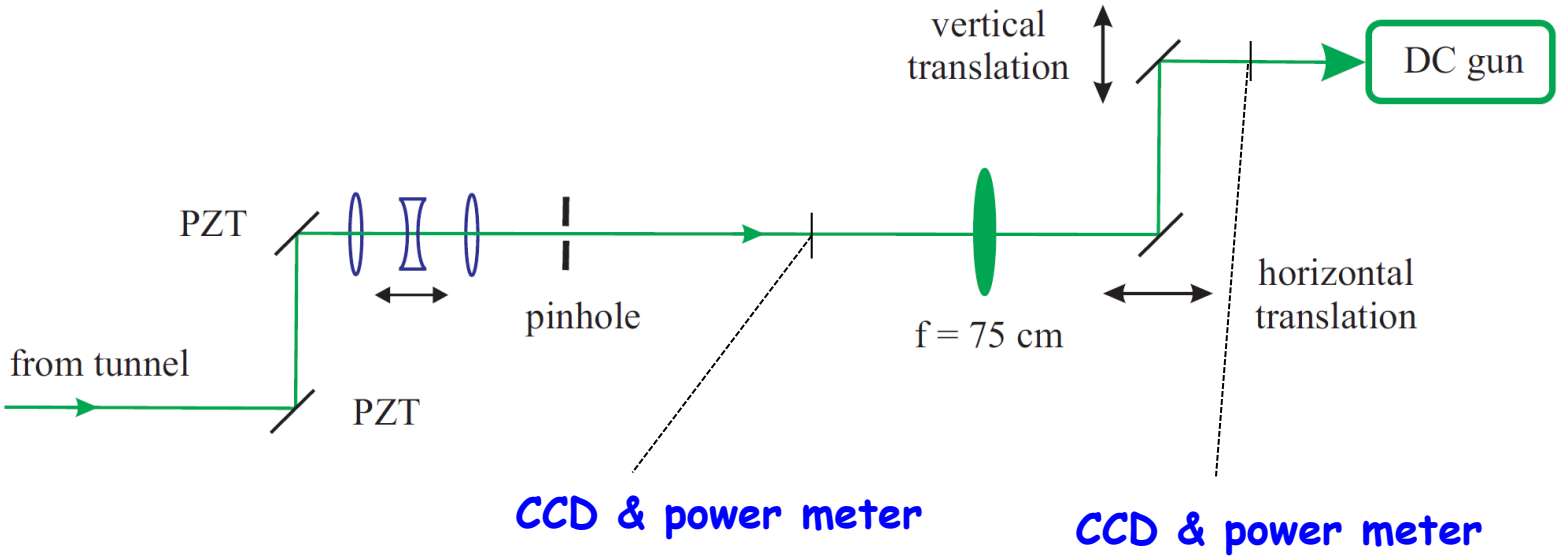
- Laser beam transport



- Laser beam optics (M^2 =1.2)



Laser Spatial Shaping & Diagnostics



Laser control & diagnostics

- Laser power and QE
- spatial mode & position on cathode
- Beam point stability

Budget Update & Request

Procurement

Total budget: 414k (regular) + 86k (AD) = 500k

Procurement: 376k + 86k

- Gain fibers and pump diodes
- Diagnostic tools: oscilloscope, RF spectral and optical analyzers
- Diode controller, isolator, dichroic mirrors, HP mirrors & polarizers, waveplates, frequency doubling crystals, & optomechanics
- High-harmonic mode-locking fiber oscillator
- Optical table

Planned: 18k

Remaining: 20k

Need I: Key Backup for Fiber Laser

- Fiber oscillator: 60k
- Gain fibers: 54 k

  PCF fibers: 6K x 3 = 18k

  Rod fiber: 12k x 3 = 36k
- Pump diodes: 96k

  25 W pump diode: 2 x 13k = 26k

  600 W pump diode: 61k

  Chiller: 9 k
- Total: 210k

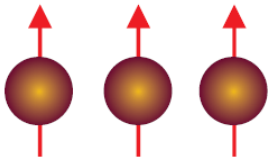
Need II: Parts for Laser Control for Beam

- IR Pockels cell (10Kx2=20k) and driver (20kx2=40k): (60k)
- Green Pockels cell, driver, and feedback electronics: (15x2k=30)
- Shaping crystals and rotation stages (25k+10k) = (35k)
- Lenses (5k), manual stages (6k), mounts (4k), & motors (20k) = (35k)
- Three power meters and four sensors: (15k)
- Three CCD camera: (15k)
- Cross-correlator (galvonometer, driver, crystal, PMT, & amplifier): (40k)
- HP mirrors, polarizers, samplers, and beam dump: (12k)
- Optical tables: (8k)
- Total: 250k

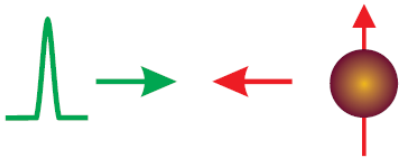
Need III: eRHIC Laser R&D

- Laser R&D for eRHIC

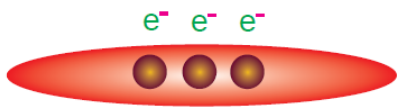
50 mA pol. beam



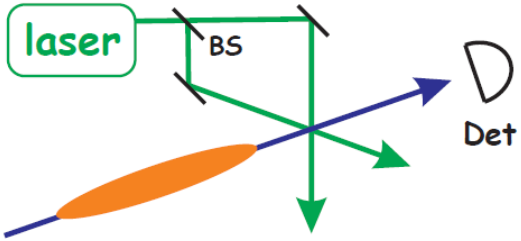
electron polarimetry



370 mA beam



laser wire



- High-power fiber oscillator & amplifier techniques
- Laser shaping techniques, i.e., parabolic pulses
- Laser R&D budget: ?

LEReC Laser: Summary

- Fiber laser design: meeting all the requirements
- New budget request: 460k

key backup (210k) + laser control (250k) + laser R&D (?)

	start	finish
Amplifier Construction	current	1/31/2016
receive Harmonically mode-locked (HML) oscillator	current	1/15/2016
integrate HML oscillator	1/15/2016	2/15/2016
frequency doubling	current	**3/1/2016**
order parts for laser control		1/1/2016
Pockels cells & controllers	3 months	
birefringent crystals	3 months	
cross correlator parts	3 months	
receive parts for laser control		3/31/2016
complete laser control for beam expt	4/1/2016	**8/1/2016**

Need to act quickly on laser control funding to protect schedule