Front end design for the full Mercury laser system

Front End laboratory
showing installation of fiber components

A. Bayramian, R. Beach,
C. Bibeau, C. Ebbers,
J. Dawson, S. Payne

HAPL Review
University of Wisconsin, Madison
September 24, 2003

The Mercury front end laser requirements

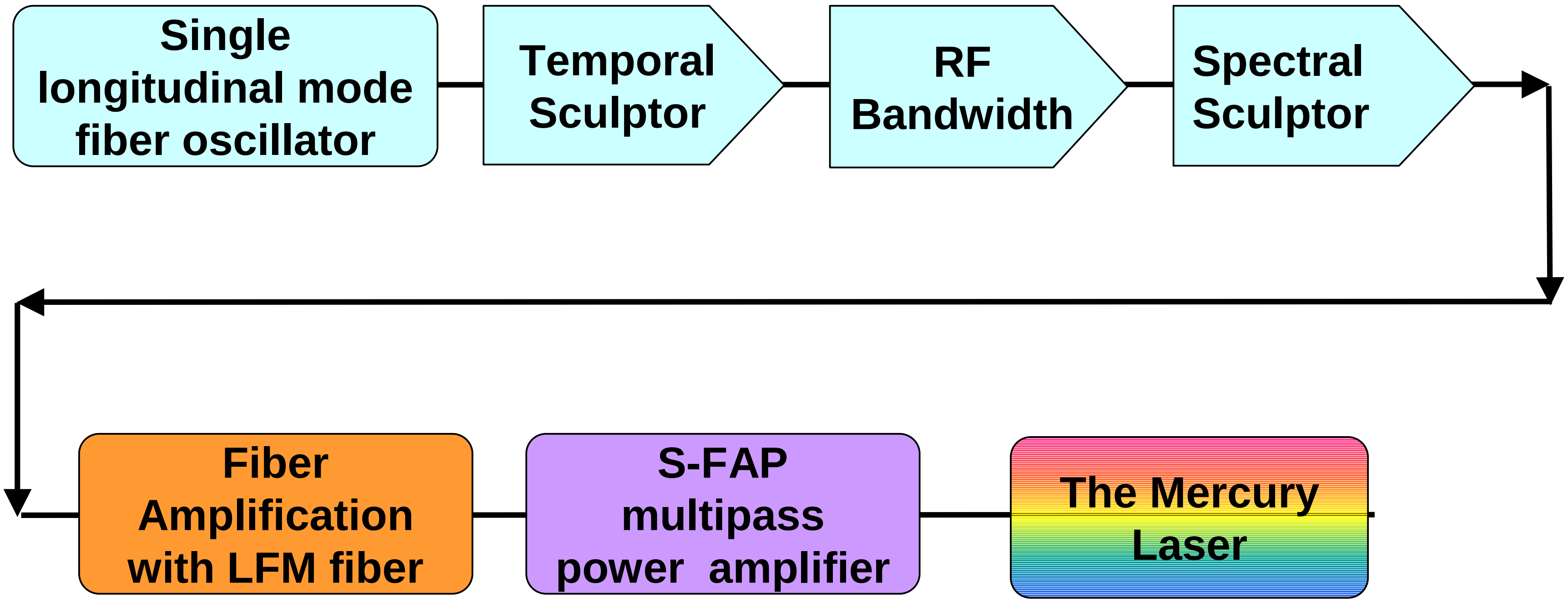
Primary mission requirements:

1. **Spectral bandwidth - beam smoothing by spectral dispersion (dithering of speckle pattern on target surface decreases imprinting and Rayleigh Taylor instabilities)**
2. **Temporal pulse shaping – necessary to avoid preheating target, compressing along proper adiabat, and optimizing fusion gain**

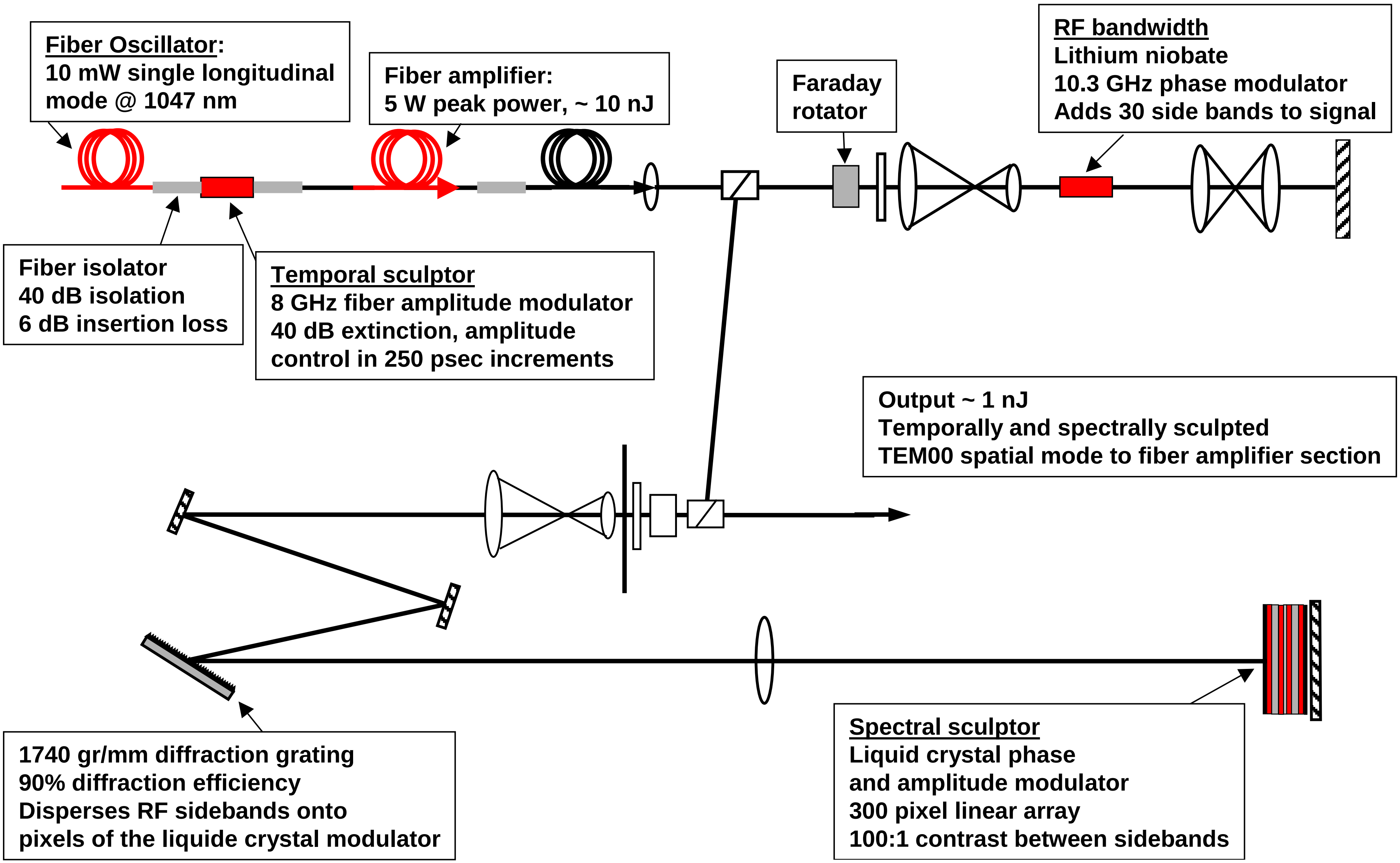
Laser specification

- **10 Hz pulse repetition frequency**
- **500 mJ output energy**
- **< 5% temporal amplitude fluctuations**
- **< 250 ps temporal jitter**
- **Beam quality: $M^2 < 1.1$**
- **10,000:1 contrast ratio between main 1047 nm signal and noise**
- **20:1 temporal contrast to limit square pulse distortion**
- **100:1 spectral contrast**

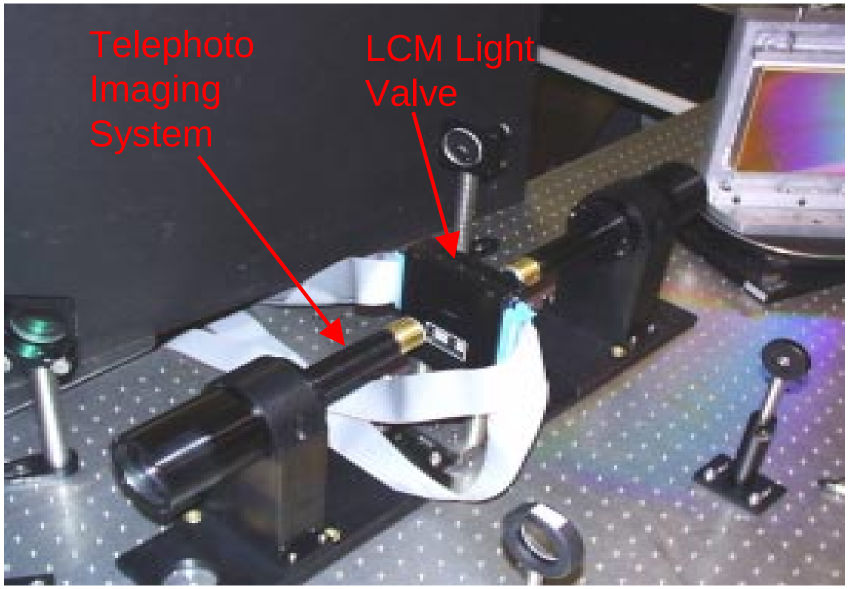
The Mercury front end is designed to provide broad bandwidth and temporal sculpting of DPSSL pulses necessary for target physics



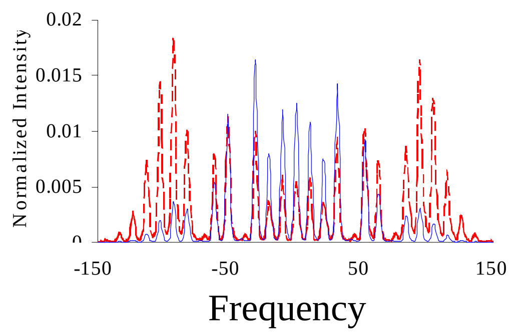
The oscillator, temporal, and spectral shaper for the Mercury front end relies heavily on fiber technology for stability

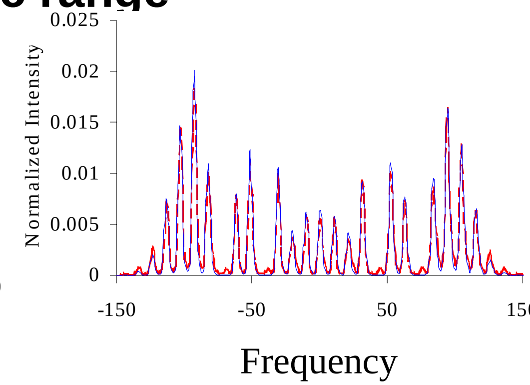


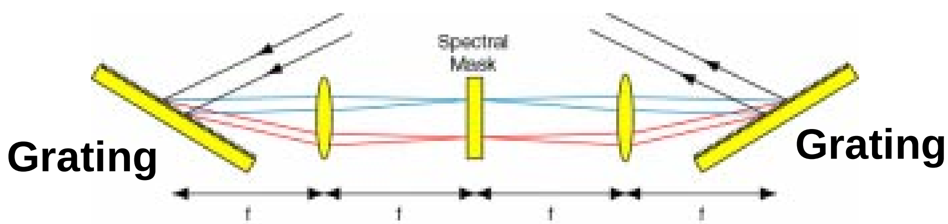
A compact spectral sculptor using a liquid-crystal modulator light valve has been demonstrated



- **Sculptor was achieved with ~ 100:1 dynamic range**







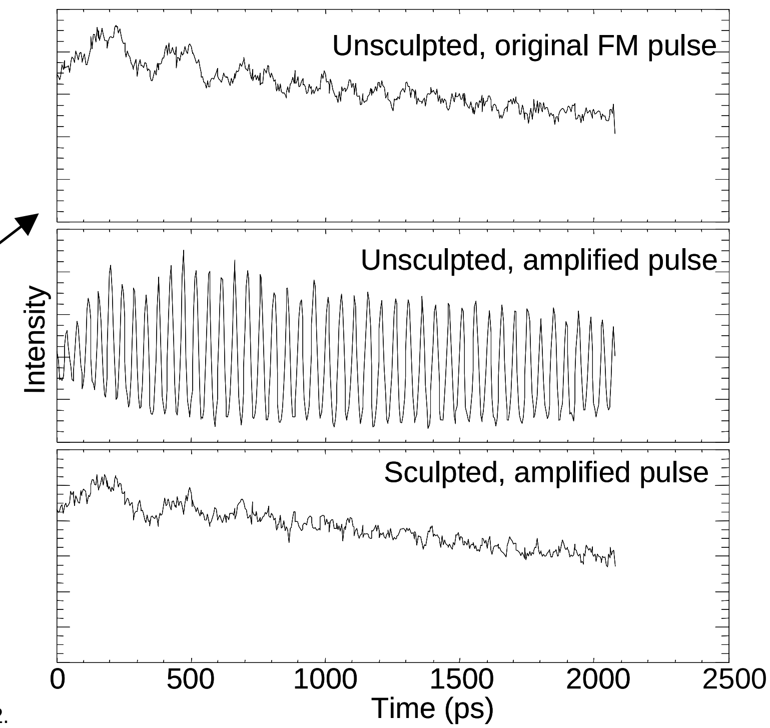
Experimental Setup

Gain media: Nd:YLF

Total gain: 9200

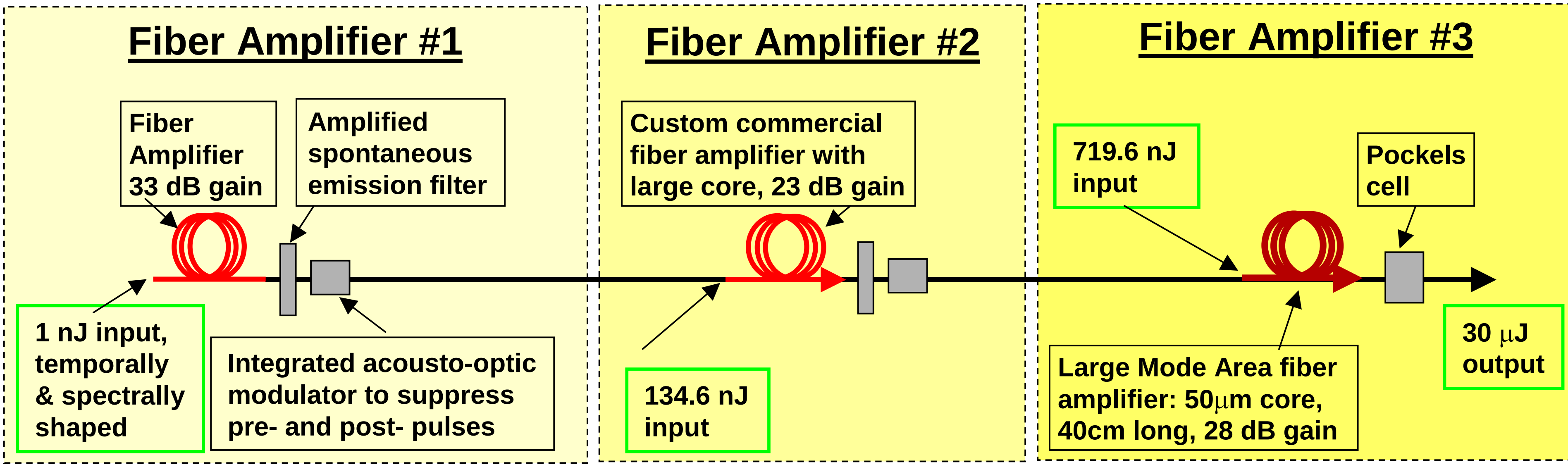
YLF bandwidth: 13 A

RF bandwidth: 8.3 A



* L.J. Waxer, J.H. Kelly, J. Rothenberg, A. Babushkin, C. Bibeau, A. Bayramian, and S. Payne, "Precision spectral sculpting for narrow-band amplification of broadband frequency modulated pulses, *Opt. Lett.*, **27**(16), 1427-1429, 2002.

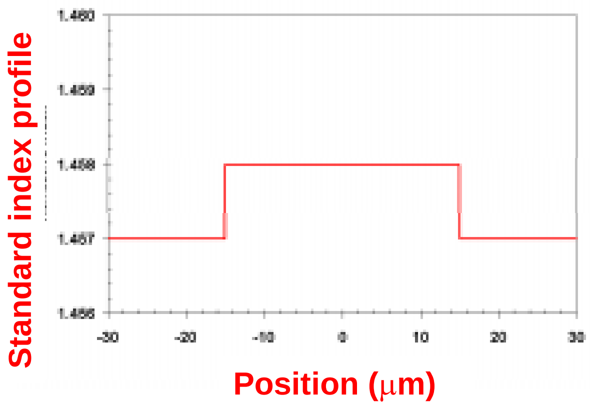
Block diagram of fiber amplifier section for Mercury laser

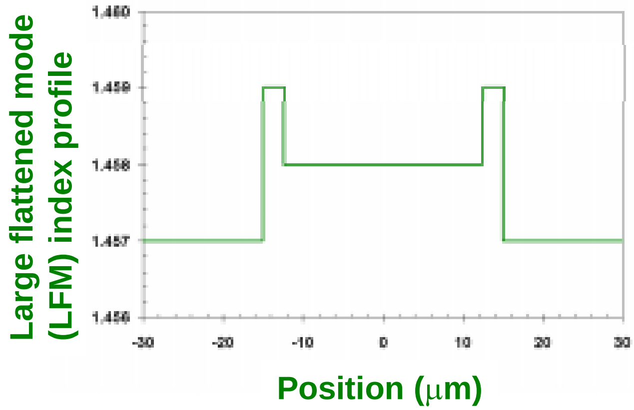


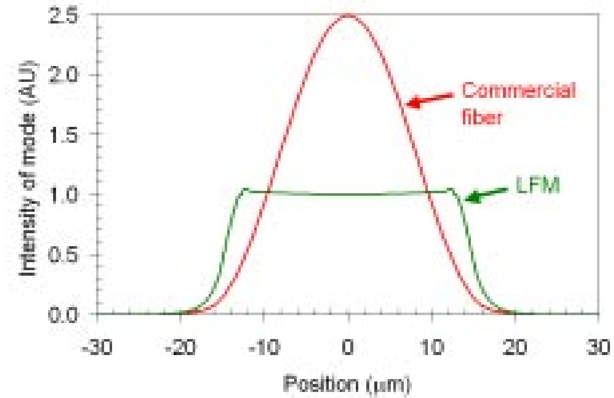
<u>Linear and nonlinear losses are managed with proper design</u>

- At full output, the B-integral is 0.3 => Self phase modulation of the spectrally sculpted pulse is negligible for all amplifiers.
- Operation point is less than the Stimulated Brillouin and Stimulated Raman scattering threshold for all amplifiers

The final stage of the fiber amplifier employs a LLNL custom designed large flattened mode (LFM) fiber which is capable of amplifying pulses to higher peak powers than standard fiber

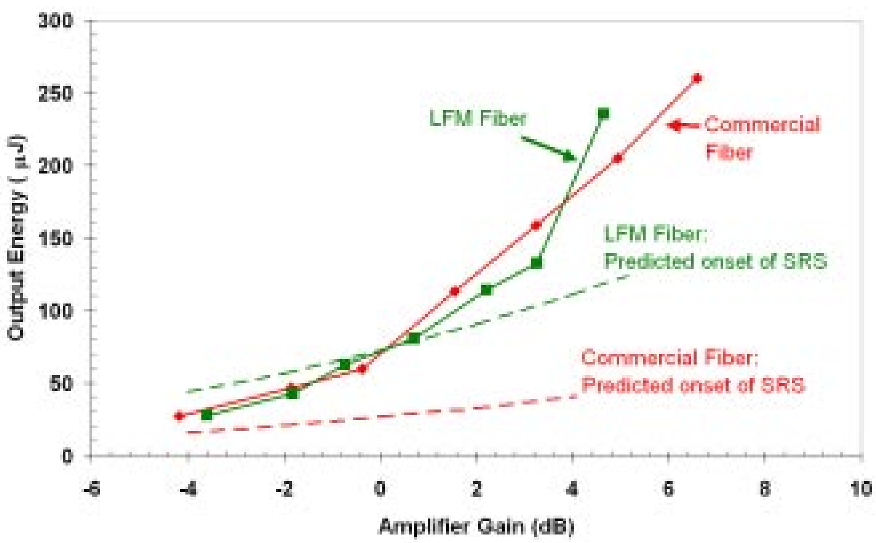


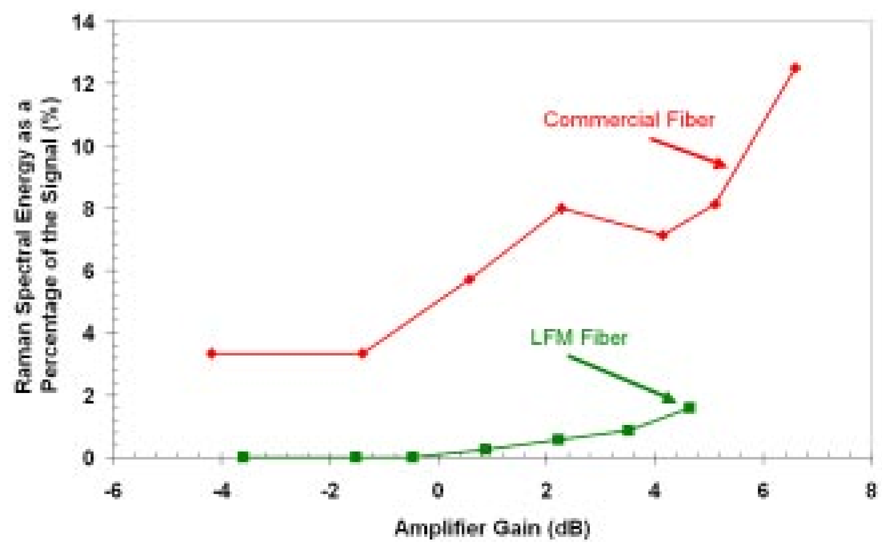




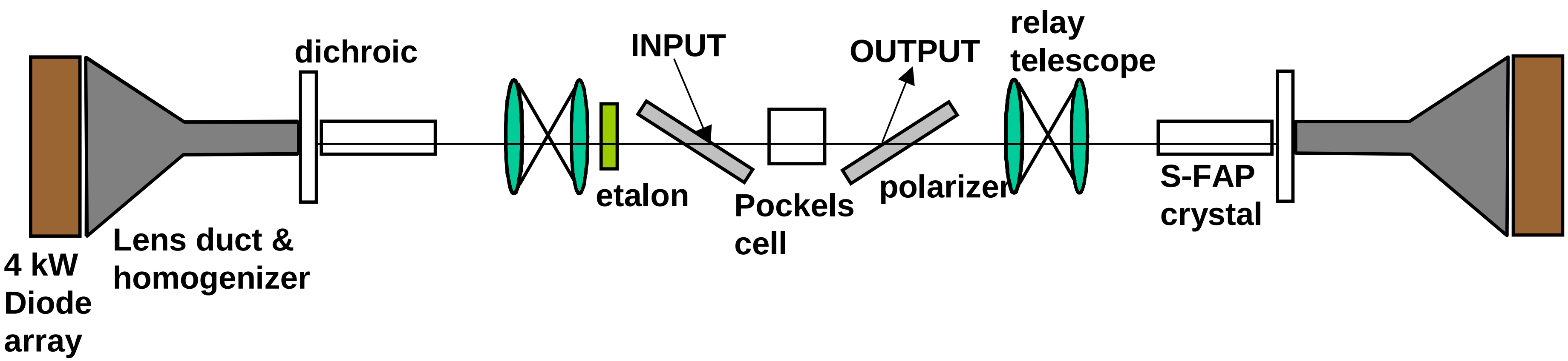
The LFM profile yields a larger lower intensity supergaussian mode

The LFM outperforms standard fiber due to the much higher Stimulated Raman Scattering (SRS) threshold





Yb:S-FAP multipass power amplifier layout



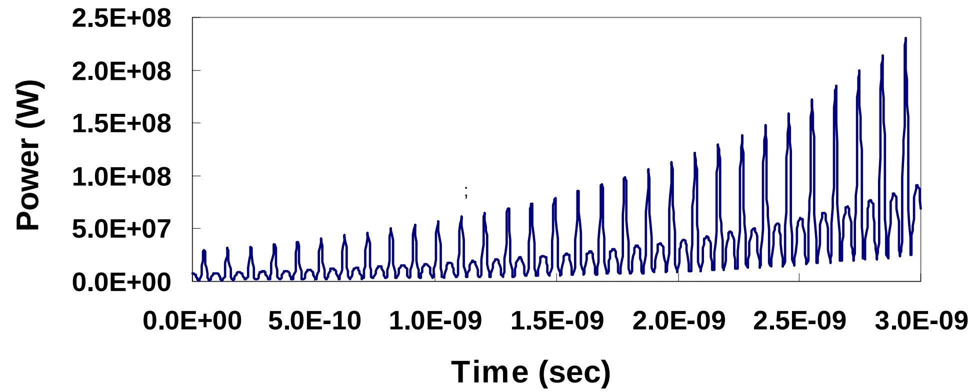
<u>**Features**</u>**:**

- **Use of Mercury diodes and S-FAP gain media**
- **Rectangular amplifier rod geometry matches the aspect ratio of the Mercury extraction beam**
- **Simple relay-imaged multipass amplifier eliminates mode-matching and stability problems associated with a regenerative amplifier**

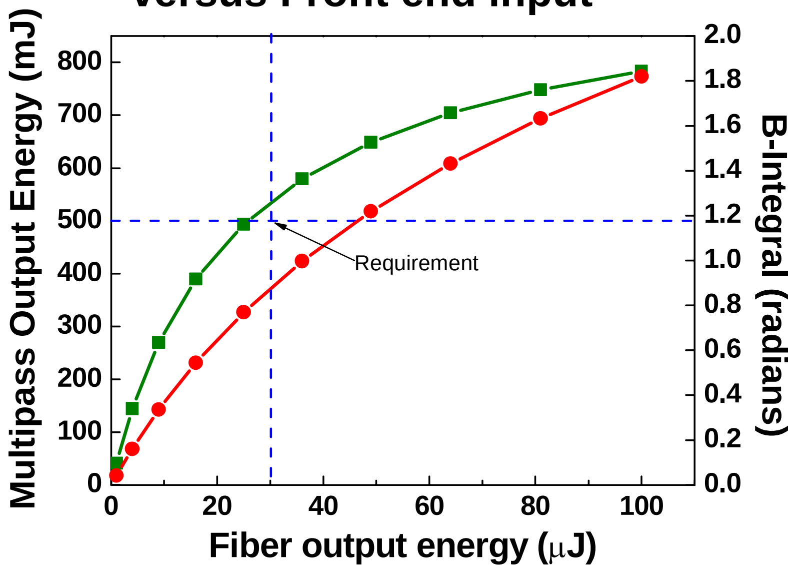
Modeling indicates the S-FAP multipass power amplifier will meet requirements, and utilizes the knowledge base from existing system

Energetics Parameters:
- 2 S-FAP crystals
- 7x4.2x20 mm
- 1.46 J extractable stored energy
- 2% of thermal fracture
- Gain = 33 (round trip)
- Number of roundtrips = 4
- Average Fluence ~ 3 J/cm^2 (= F_{sat})
- Input: 30 μJ, Output: > 500 mJ

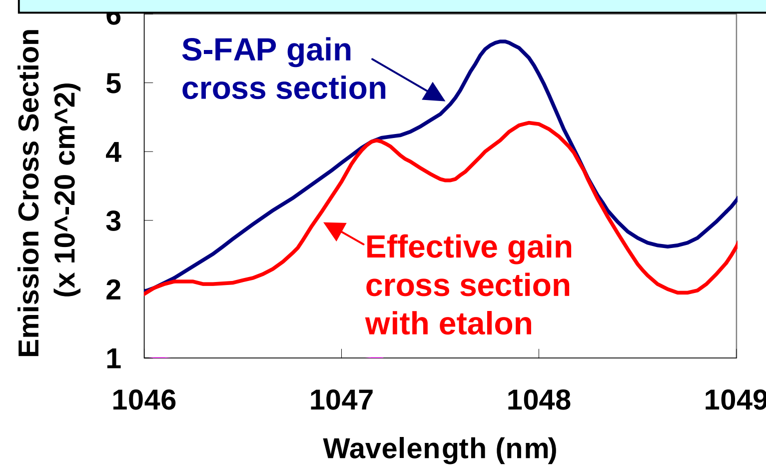
Required input pulse for the Mercury laser (spikes due to sculpting of RF bandwidth)



Output energy & B-integral versus Front end input



Intracavity etalon used for gain flattening
- Fused silica design: 345 μm thick, coated for 8% reflectivity on each surface
- Undoped YAG design: 276 μm thick, surfaces uncoated



Summary and schedule for CY2003-CY2004

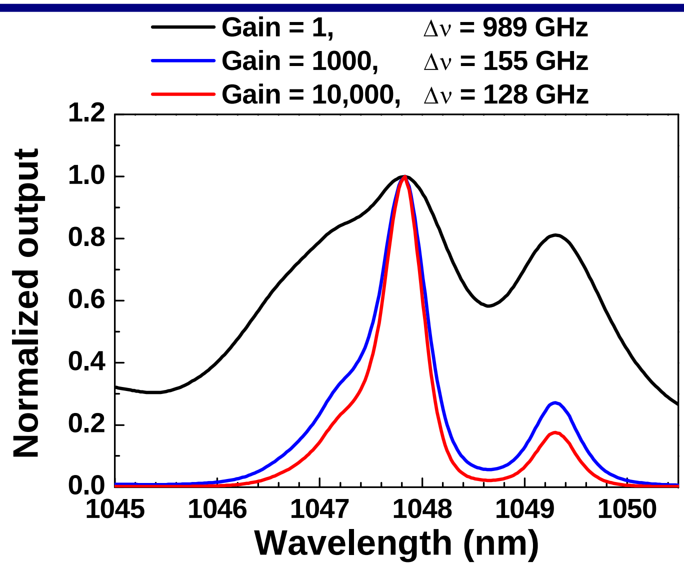
- A front end has been designed capable of meeting Mercury requirements which makes use of the stability inherent in fiber based laser systems as well as the use of S-FAP gain media and diodes already being fabricated for the Mercury laser

- The fiber based sculpting section is currently being assembled and tested

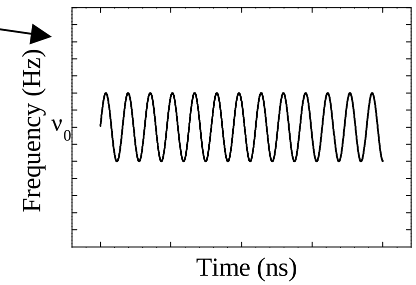
- Fiber amplifier components will be purchased and assembled during CY2004

- S-FAP multipass amplifier engineering and construction will begin in CY2003

If the RF spectrum is not sculpted spectrally, gain narrowing will lead to temporal amplitude modulation in the output pulse

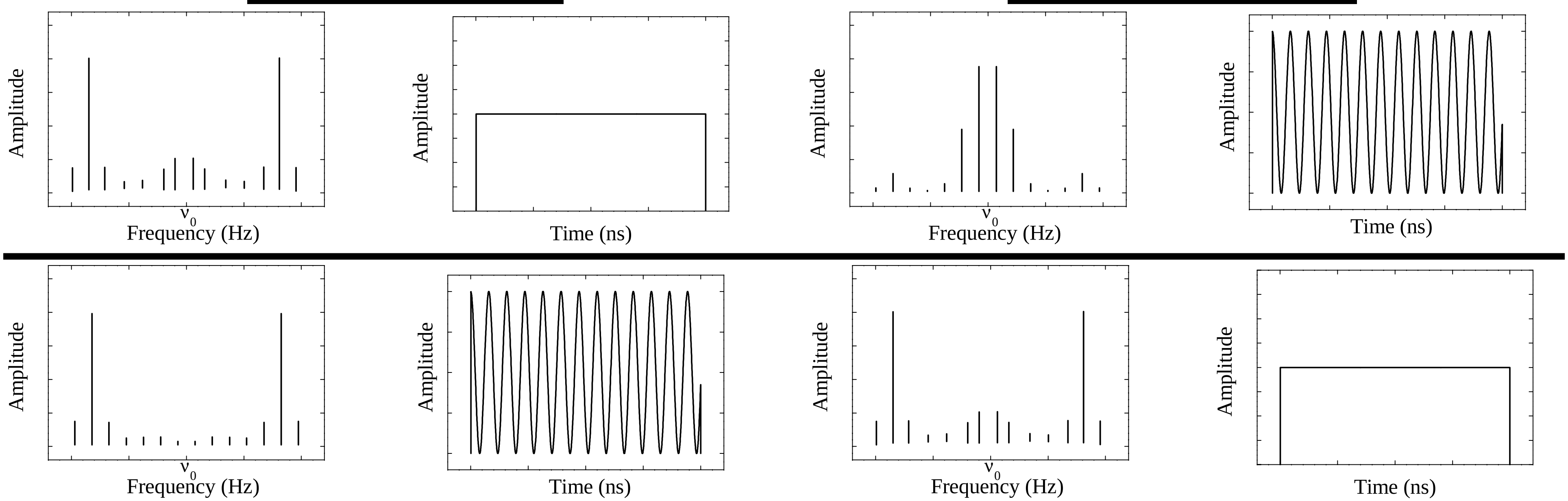


The single frequency input to the phase modulator is converted to a sinusoidally varying frequency with time



Input to amplifier

Output of amplifier



We have designed a front-end laser that offers the attributes needed for full Mercury

- Present system is a commercial unit, borrowed for temporary use
- New system is designed to spectrally, temporally, and spatially tailor the pulses to meet our IFE goals

<u>Basic layout</u> (see poster for details)

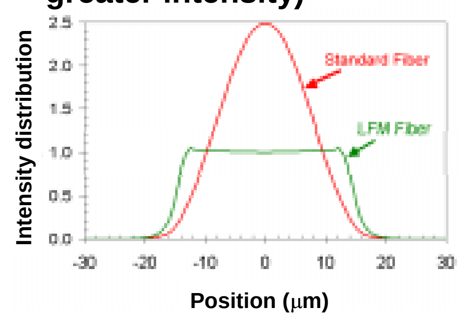
Fiber oscillator → **Pulse shaping** → **Bandwidth** → **Fiber amplifiers** → **Yb:S-FAP multipass amplifier**

Shapes pulses temporally to prevent square pulse distortion

Spectral sculpting prevents amplitude modulation at the Mercury output

*** Demonstrated at University of Rochester**

Large-Flattened Mode Fiber (LFM, capable of 2.5X greater intensity)



*** In negotiation with a company for commercialization**

Gain flattening demonstrated by Japanese with intracavity etalon