Laser Wires: Technical Challenges Outstanding

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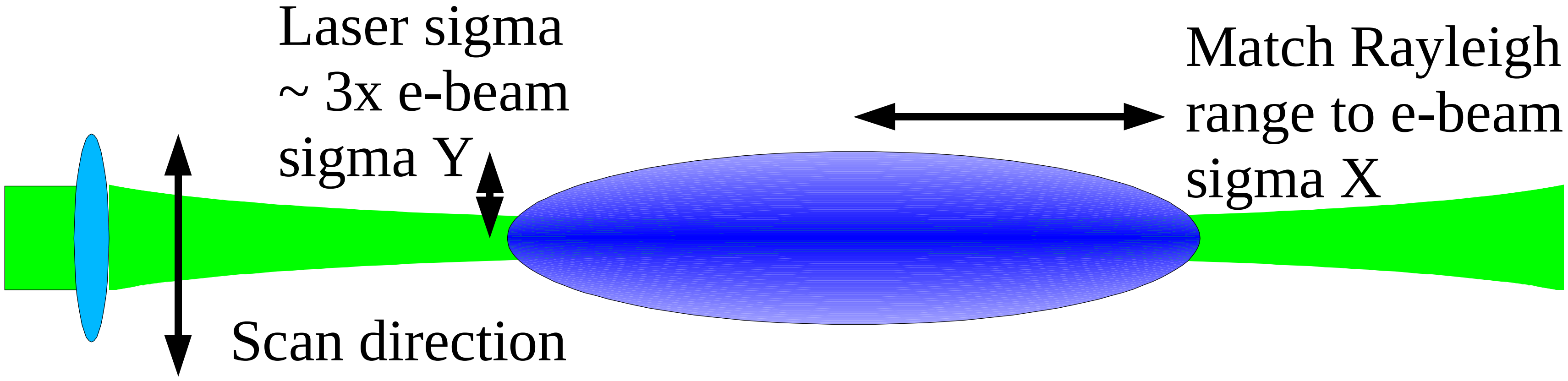
Challenges

- Measuring small beam sizes
  - Wavelength requirements
  - CW cavity laser wire challenges
  - Tricks to achieve better resolution (difficult)
- Low beam energies - backgrounds
- Temporal structure
- Optical damage

Wavelength Requirements

For Scan of Y spot size:
Small Y size -> small laser waist
Large X size -> large laser Rayleigh range



Laser sigma
~ 3x e-beam
sigma Y

Match Rayleigh
range to e-beam
sigma X

Scan direction

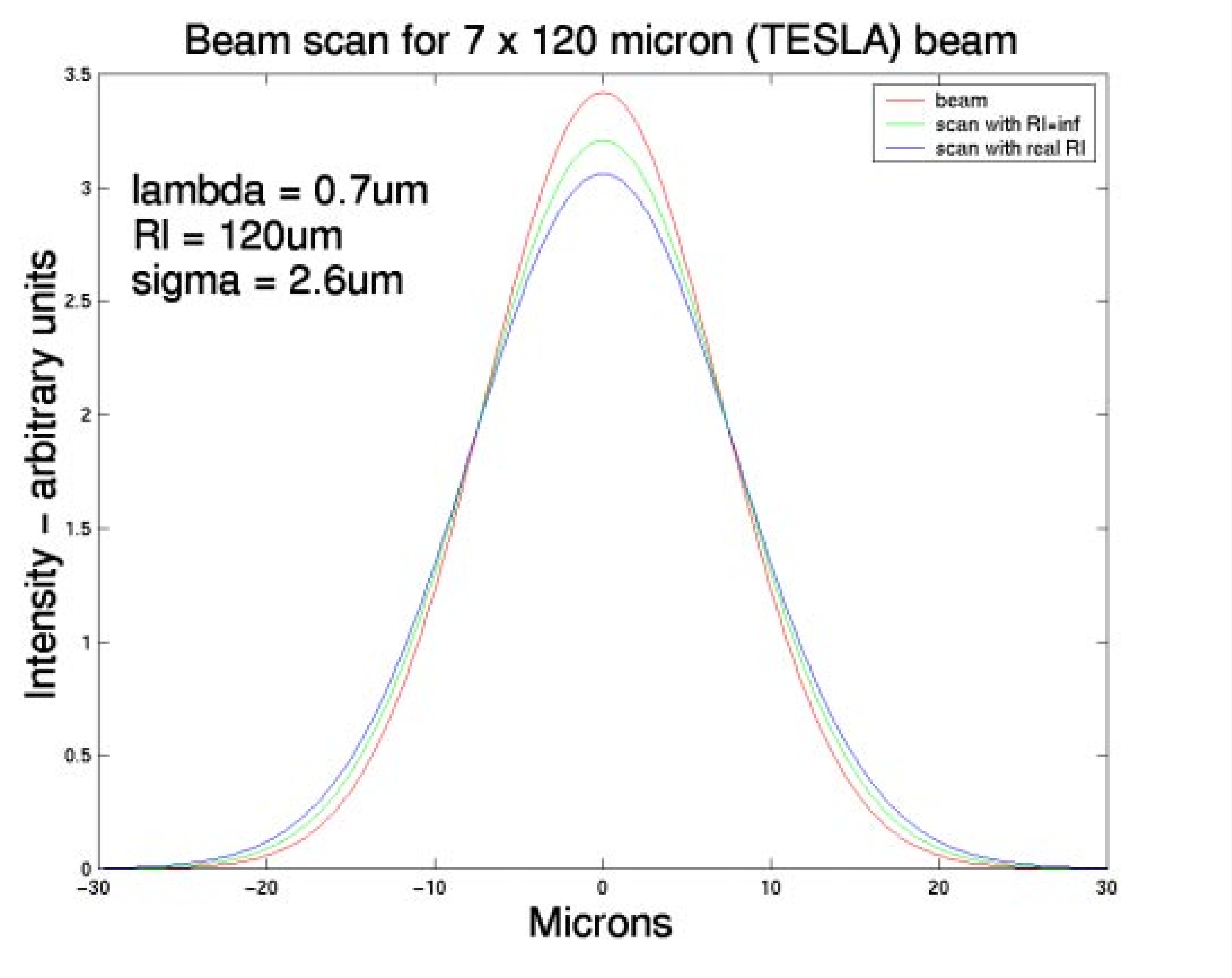
Required Wavelength

- For laser size to contribute <10% of spot size
- Use $R_L=\sigma_x$, and $\sigma_\gamma=0.3\sigma_y$ (Approximate)

$$\lambda = \frac{4}{9}\pi\frac{\sigma_y^2}{\sigma_x}$$

Example: NLC 1000 Linac end: 7.5x0.9 micron spot. Need 0.15 micron light!

Simulated Laser Scan



Wavelength vs. Laser Options

- 1 Micron: Nd:YAG.
  - Commercial systems to ~1J, 5 nanosecond
  - Nd:YLF, Nd:Glass, Yb:YAG, etc, etc for various application requirements.
- 0.5, 0.35, 0.25 micron: Frequency multiplied Nd:YAG (or similar)
  - ~100mJ at 250nm
- For short pulse: Ti:Sapphire, 800, 400, 260nm.
  - Commercial systems – expensive but high power (many GW, and short pulse: 50fs – few ps).

Shortest Wavelength Options

- 5 X YAG: 205nm.
  - Commercially available but cutting edge
- F_2 Excimer laser: 157nm
  - Commercial – for semiconductor processing
  - Energy, pulse length: few nanoseconds.
- ~125nm Hard limit for transparent optics
- TW laser pumped XUV lasers down to (40nm), but not practical for a measurement device.
- SASE FEL (just kidding).

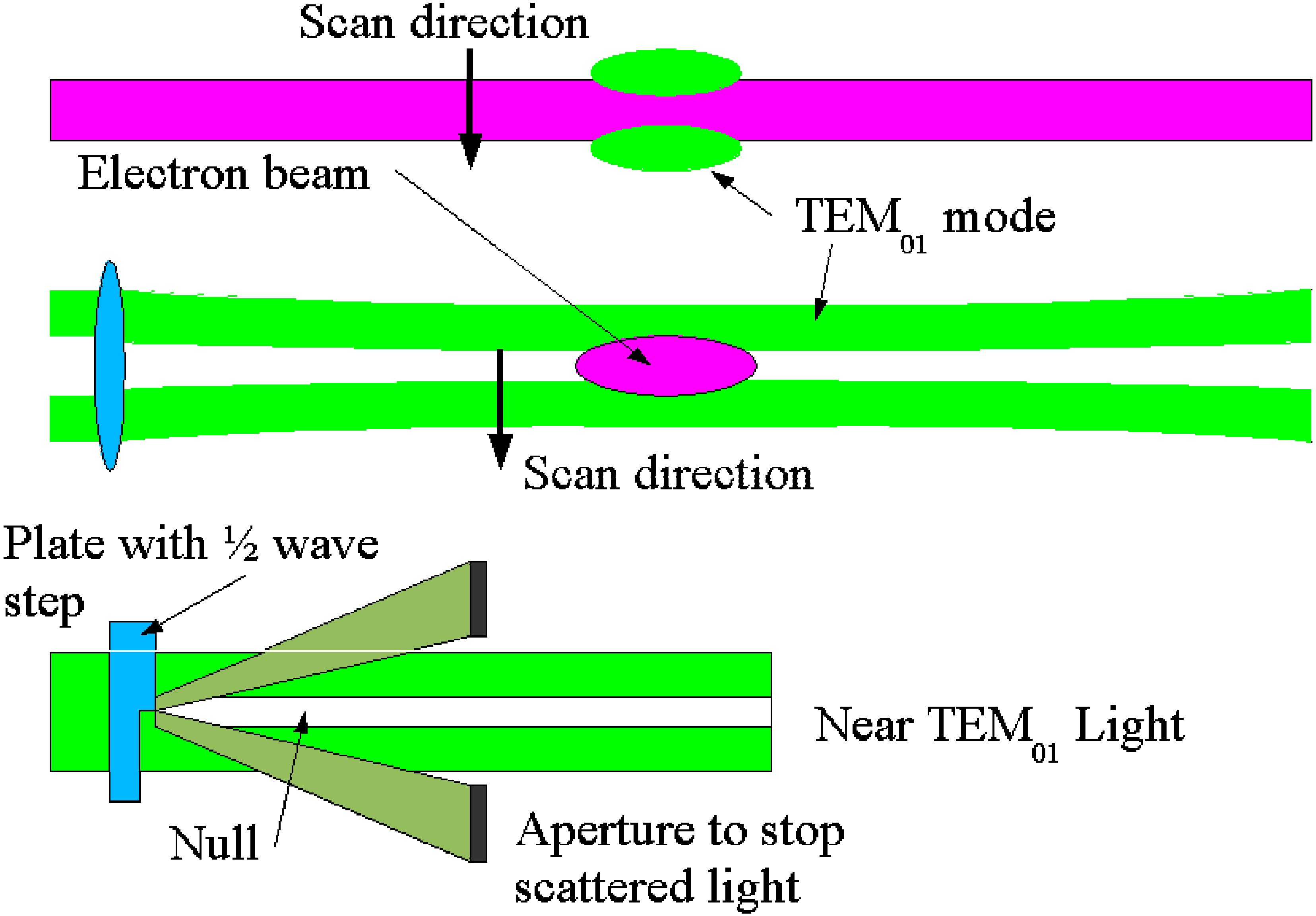
Interferometers to Beat the Wavelength Limit

- Get fringe spacing of λ/2
  - Scan and measure modulation depth
  - Modify fringe spacing (typically slow)
- For Gaussian beams, can measure very small spots (<70 nm demonstrated at .5 micron λ. in FFTB at SLAC)
- Limit depends on tails and vibrations.
- Even with 250nm light, need <~1% electron beam in tails to see a 5 micron spot.

TEM_{01} Mode Operation

- Generate mode with null on axis (easy)
- Effect is similar to an interferometer
- Resolution not as good as an interferometer
- Can do a scan rather than a power spectrum like measurement
- Can also be used for beam tail measurements
- Pushes resolution a factor of 2 or so relative to TEM_{00} for the same optics.

TEM$_{01}$ Beams



Scan direction

Electron beam

TEM$_{01}$ mode

Scan direction

Plate with ½ wave step

Near TEM$_{01}$ Light

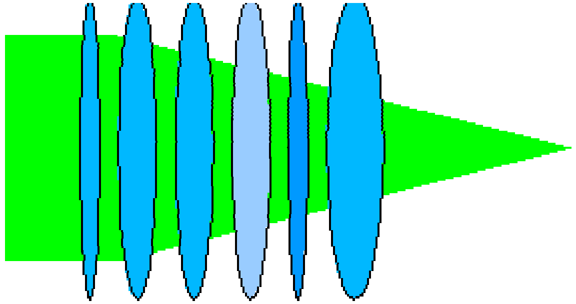
Null

Aperture to stop scattered light

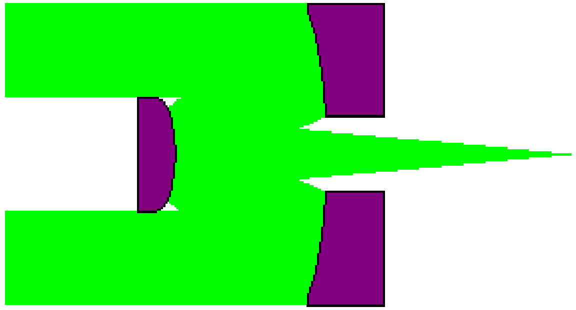
Final Focus Lens Issues

- Optical design becomes more complex as F/# decreases: F/10 easy, F/1 very difficult.
- Short wavelength lasers limit available materials.
- Commercial lenses very good optically
  - Diffraction limited down to almost F/1
  - Cannot be used in vacuum
  - Do not focus correctly through windows
    - Check with ray tracing code (ZEEMAX or similar).
- Re-Imaging good for checking optics

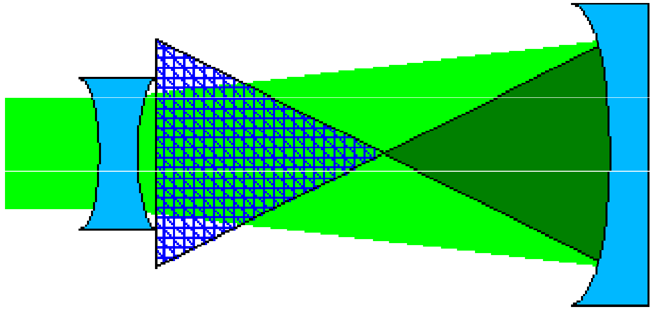
Lens Options



Multi-element lens: Standard Design



All reflective telescope:
Broadband, but worse F/# and
working distance for same size
Requires hole in beam.



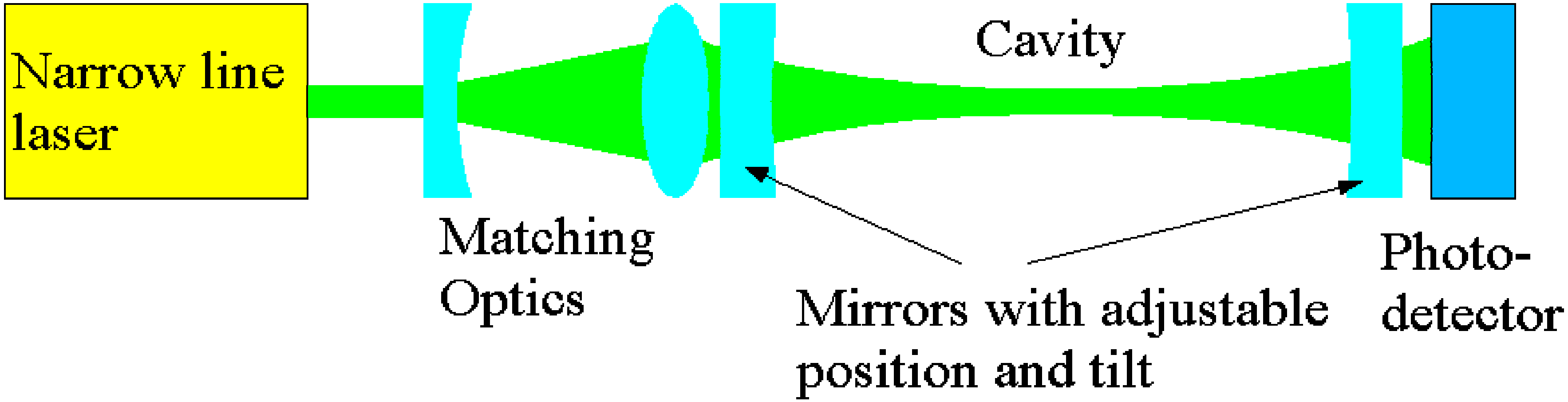
Lens / Mirror combination:
Short and good performance
Cannot re-image beam
Beam dumped in vacuum.

Low Energies

- Compton edge varies as γ^2.
  - At high energies, degraded electrons and GeV gammas provide a low background signal
  - A low energies need to see X-rays superimposed on a large background: need high laser power
- Low energy beams are physically large
  - Need high laser power.
  - In many cases carbon wires / TR monitors better
- In many cases, physical wires are a better choice for low energies.

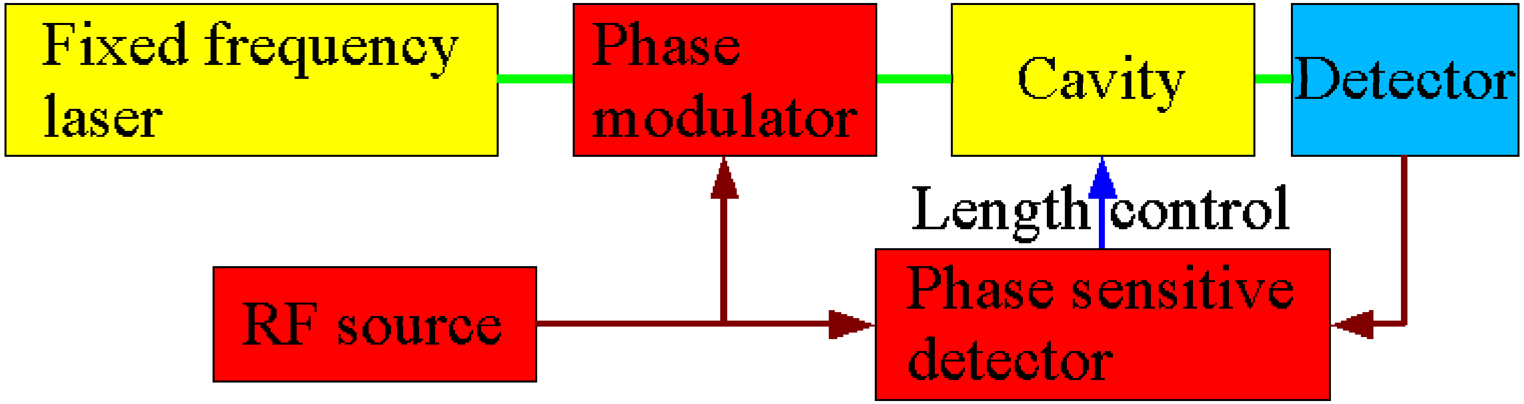
Resonant Cavity Laser Wires

- CW laser with optical cavity to enhance power.
  - Power enhancement of X 100 typical,
  - Power enhancement X 10^4 might be possible
    - Tight tolerances, Damage issues
- Useful for rings where duty factor is high.
- Tolerances are the primary technical problem

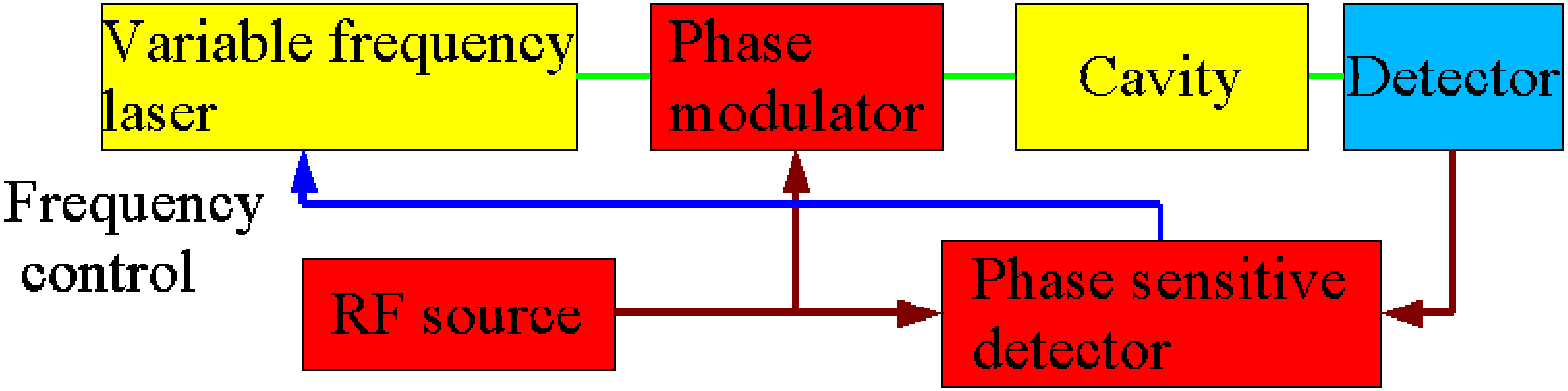


Cavity Feedback Options

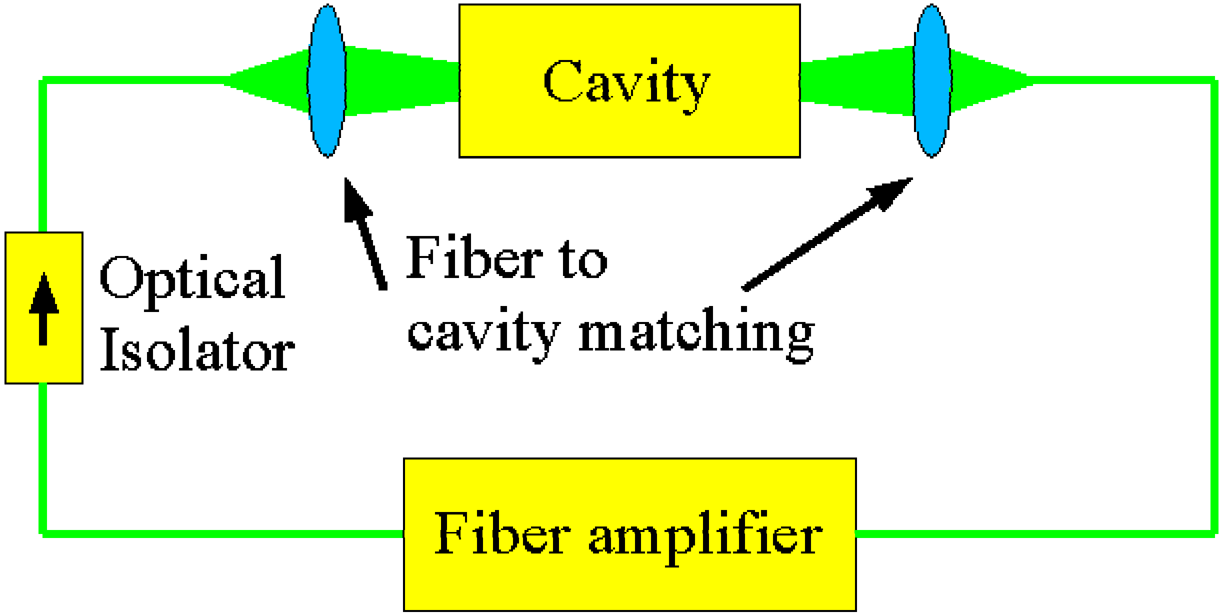
Cavity length feedback: Uses simple fixed frequency laser, but requires more complex in-vacuum cavity control



Laser frequency feedback: Cavity is simple, but requires frequency tunable laser



Self Locking Feedback Concept



- Use Erbium doped fiber laser (or similar).
  - Commercial devices to >100mW, single mode
- Self Q-switching, etc, may be a problem

Resonant Cavity Wires – Spot Size

- Cavity length must be an exact multiple of λ/2
  - Length control ~λ/Q, typically <1nm. (feedback easy)
- Additional length requirement for spot size

$$\left(1-\frac{L}{2R}\right)=\frac{R_L^2}{L^2}$$

- Example: 50x5 micron spot, 0.5μm wavelength, 2cm cavity
  - Length Accuracy 0.25 microns (absolute).
    - There may be no usable fringes!
  - Mirror radius accuracy $2.5\text{x}10^{-5}$.

Temporal Pulse Structure

- Q-switched lasers provide few nanosecond pulses.
- Mode-locked (and amplified) lasers provide picosecond (or shorter) pulses.
- Mode-locking makes more efficient use of laser power

BUT

- **You don't pay by the photon!!**

Mode locked vs. Q-switched lasers

Q-switched and Injection Seeded

- Pulse length: 5 – 20 nanoseconds
- Repetition rate 30 – 120 Hz
- Peak power up to ~100MW

Mode Locked and Amplified

- Pulse length: 50 fs to 100ps
- Repetition rate <10KHz. Up to MHz
- Peak power (~), But average power <~ 1Watt.

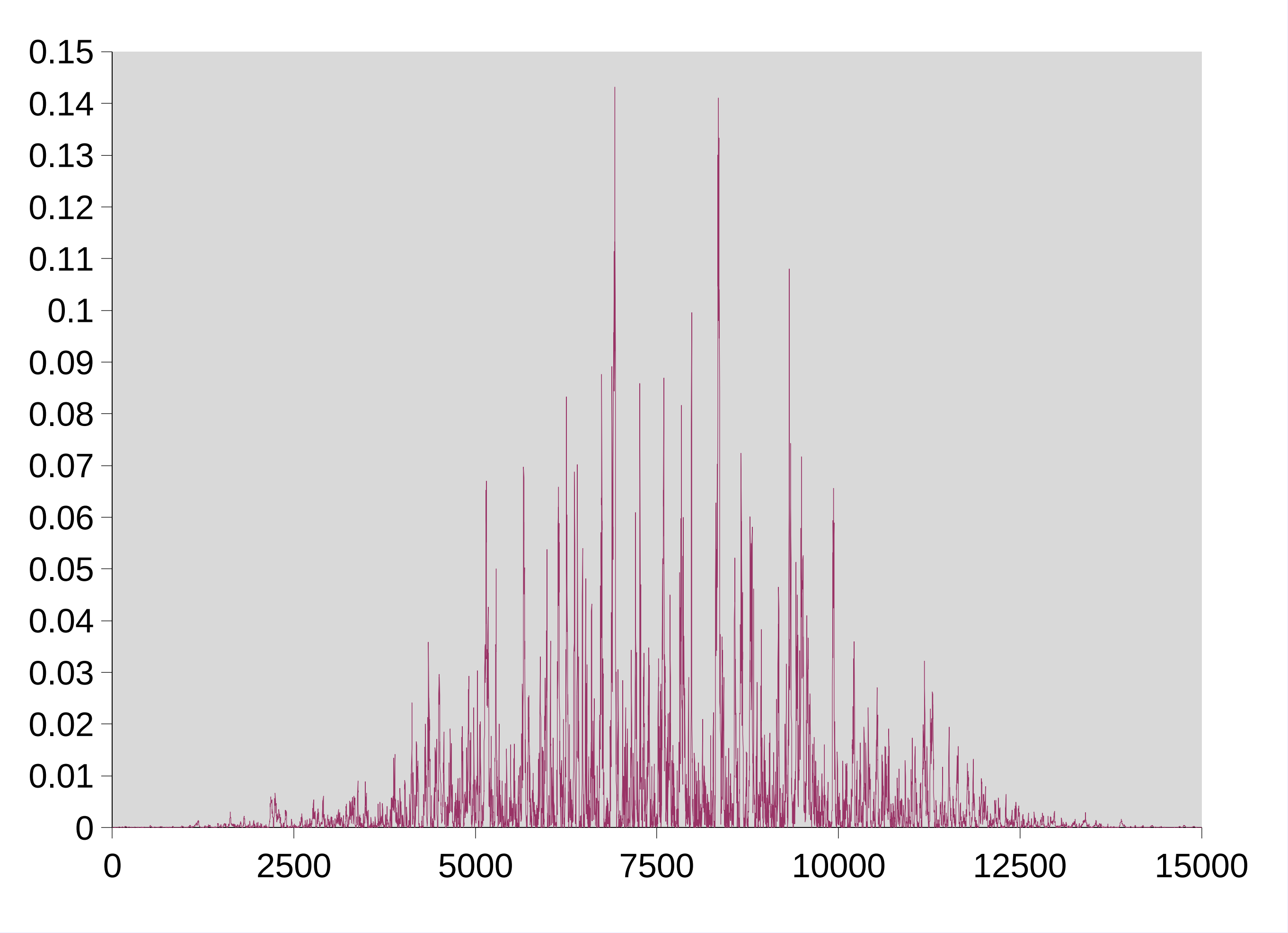
Mode Locked Laser Timing Issues

- Timing jitter for mode-locked lasers is typically a few picoseconds.
- Jitter can be as good as ~250 femtoseconds (with a LOT of work).
- Want timing jitter < ~1/10 laser pulse length to have low noise overlap.
- Short pulses can make it difficult to find the initial signal (need to scan Y and T).
  - This was tough in SLC even with 100ps pulses.

Q-Switched Laser Timing Issues

- Long (few nanosecond) pulse makes it easy to find the beam
- But: Output from standard Q-switched laser has strong longitudinal mode beating.
  - Light is 100% modulated at the bandwidth of the laser material (few X 100 GHz)
  - Too fast to see on most photodetectors, but the beam will see it.
  - Produces output with large fluctuations
- Can fix mode beating with an “injection seeded” laser.
  - Commercial technology, but expensive ($40K)

What a Q-switched laser pulse looks like to a fast detector (like a picosecond electron beam)



Optical damage

- Safe numbers are 5GW/cm^2, 1J/cm^2.
  - Billion shot damage threshold is lower than million shot threshold
- Can go higher but must be very careful
  - Clean optical surfaces
  - No transverse mode beating in laser (hot spots)
  - Accurate peak energy density measurement
  - Extreme care during alignment / focusing
- Typically no good reason to go to high densities.

Cumulative Nonlinear Damage

- Discovered for Excimer lasers at 308nm, for semiconductor processing.
- Long term change in index of refraction for Fused Silica.
  - Degrades focus
- Source is 2-photon damage:
  - Best to user materials which transmit ½ laser wavelength
    - (OK for green, but not for hard UV – 250nm)
  - Limit peak power density
- Reflective optics (mostly) immune.

Laser System Issues

Honesty Scale:

- 1. Used Car Dealers
- 2. Political Candidates
- 3. Laser Vendors

Biggest lies:

- 1. The car was only driven to church and back
- 2. Cutting taxes will increase revenue
- 3. The laser produces a TEM_{00} Beam

- Be very suspicious of performance claims.

Its a Diagnostic, Not an Experiment (apple pie and motherhood)

- Keep the laser wire system simple
  - Even if this is a performance trade-off
- Must work even for unexpected electron beam parameters
  - If the beam is good, you don't need to measure it.
- Use conservative parameters for good reliability.