Laser Drivers for Inertial Fusion Energy

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The two options for an IFE laser Driver are:
1) Krypton Fluoride (KrF) Laser
2) Diode Pumped Solid State Laser (DPPSL)

Laser Technologies are very different:

- **KrF: electron beam pumped gas laser ($\lambda = 1/4\ \mu m$)**
- **DPSSL: Semi conductor diode pumped glass laser ($\lambda = 1/3\ \mu m$)**

Development of an IFE laser is relatively inexpensive

- **Reactor uses many parallel beam lines**
- **laser science & technologies can be developed on a single beam line**

At present:

- **KrF has the better beam for current high gain targets**
  - **(smoother beam, higher bandwidth, shorter wavelength)**
- **DPPSL has the greater durability**

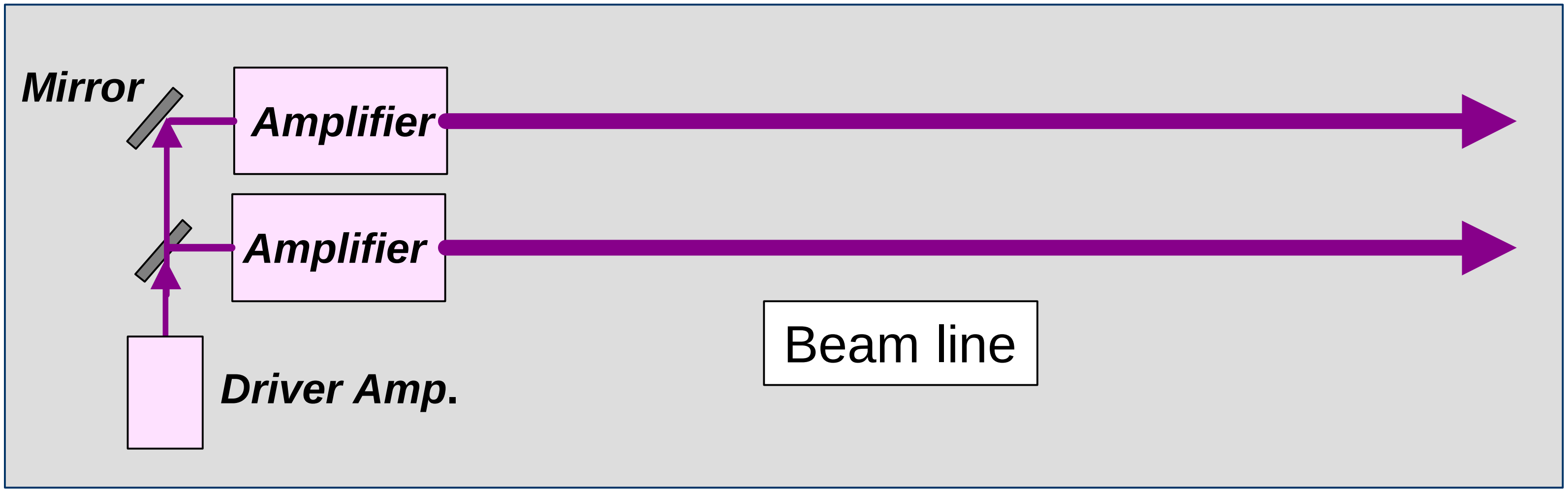
Both lasers have the potential to meet the IFE requirements for:

Beam uniformity	**Rep rate**	**Efficiency**
Durability	**Cost**	

Both lasers have well defined programs and goals to meet these requirements

The laser technology can be developed without building the entire system

An IFE laser would consist of a number of identical parallel beam lines--



One <u>possible</u> IFE laser architecture:

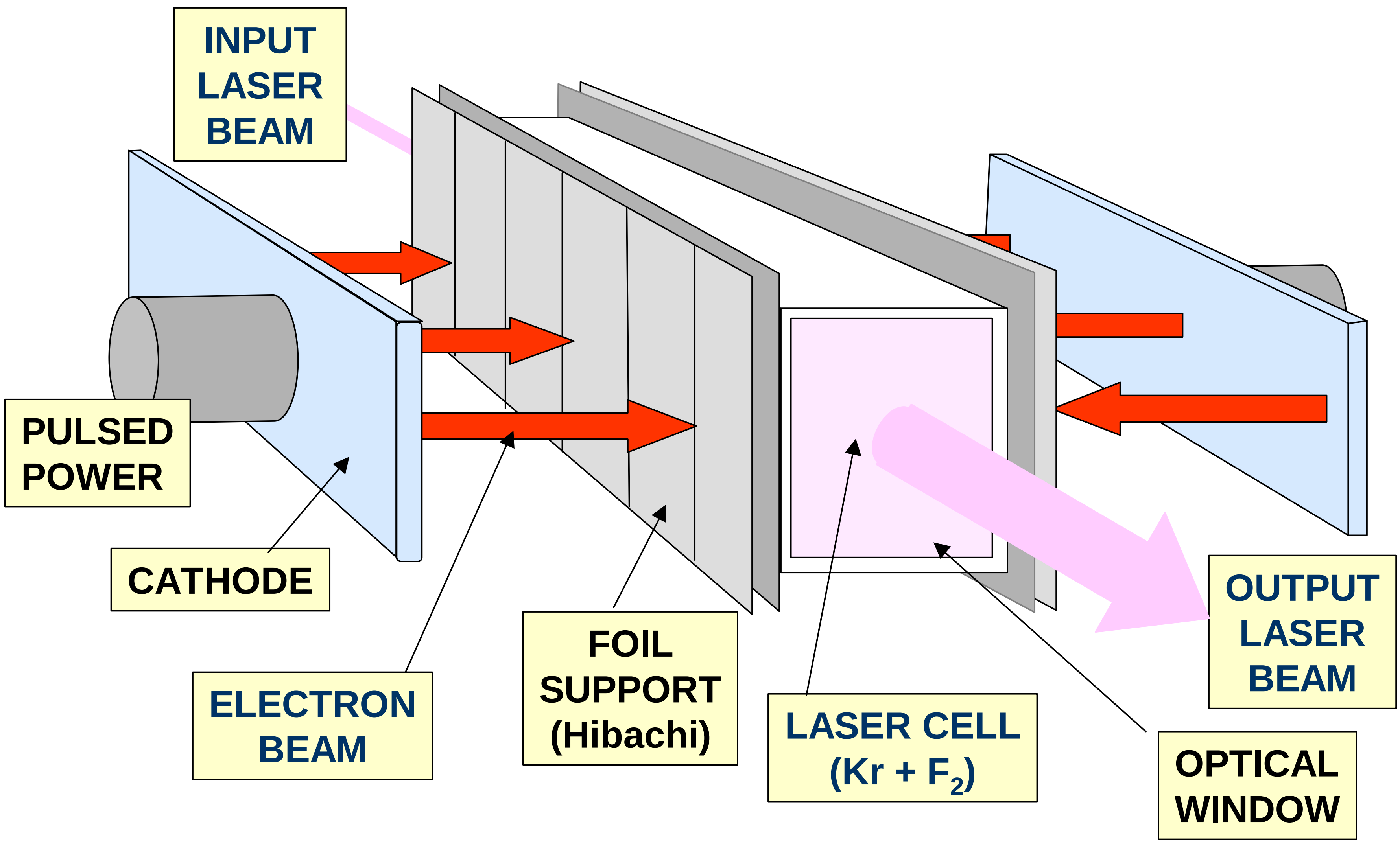
20 parallel beam lines, each of output 120 kJ (2.4 MJ total)

Each 120 kJ beam line would consist of two identical 60 kJ amplifiers

To develop and evaluate KrF lasers requires we build one 60 kJ amplifier i.e. *<u>one part</u>* of *<u>one line</u>*

This modular nature leads to relatively low development costs.

The Key Components of a KrF Laser

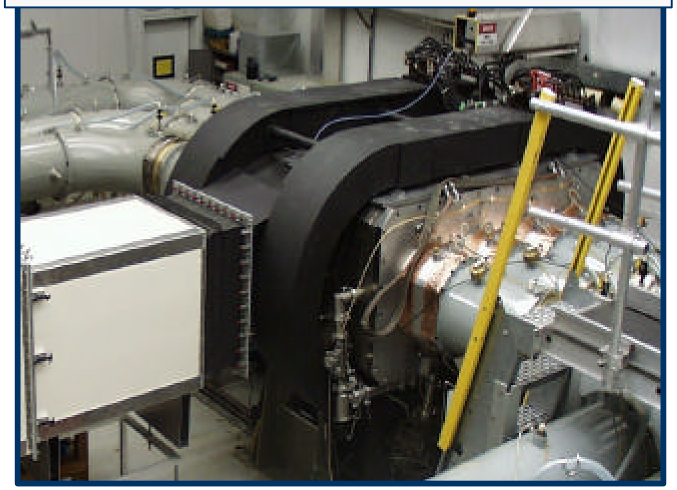


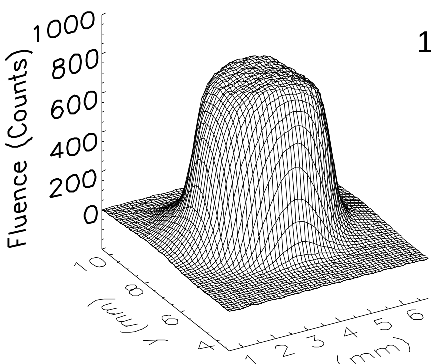
ENERGY + ($Kr + F_2$) Þ $(KrF)^*$ + F Þ ($Kr + F_2$) + hn

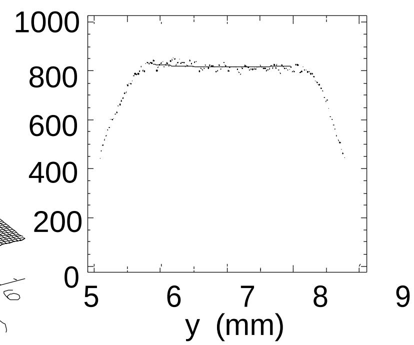
Nike Krypton Fluoride Laser demonstrated outstanding beam uniformity, and an architecture that can be scaled to an IFE-sized system

Beam uniformity

NRL NIKE Laser Main amplifier



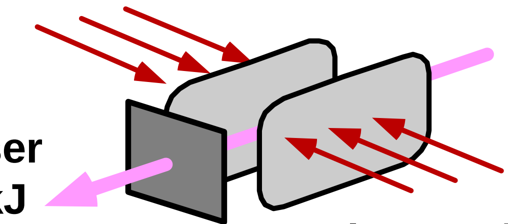




1.2% spatial non-uniformity per beam
0.3% non-uniformity, overlapped beams

Scalable to IFE-size systems

Nike 60cm Amplifier

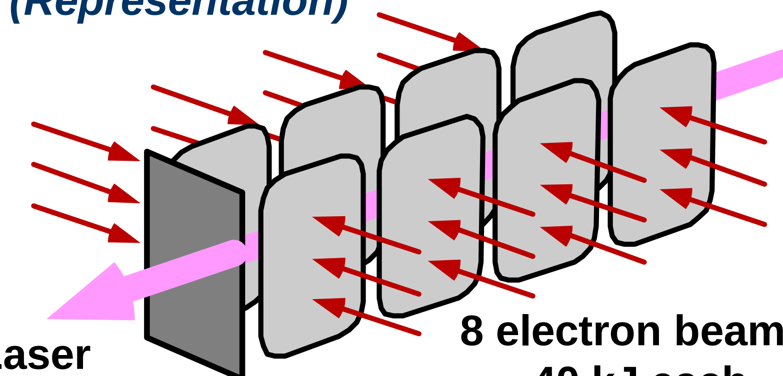


Laser
5 kJ

2 electron beams
40 kJ each

Optical Aperture
60 x 60 cm^2

IFE-sized Amplifier
(Representation)



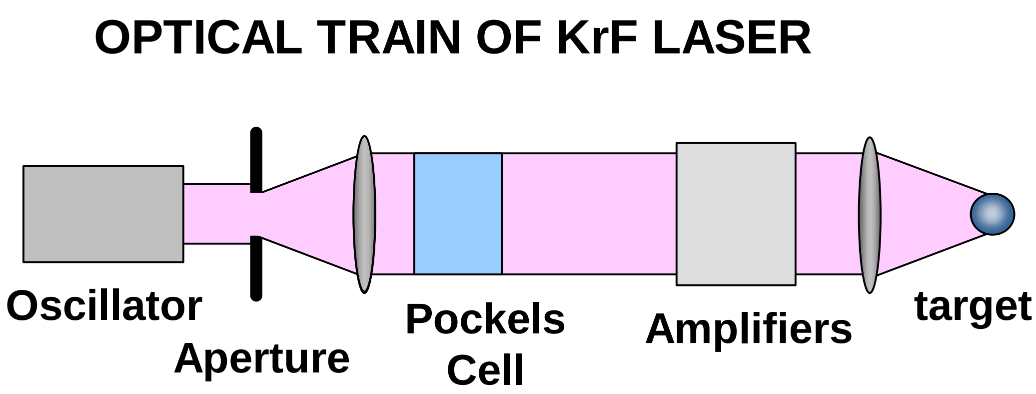
Laser
60 kJ

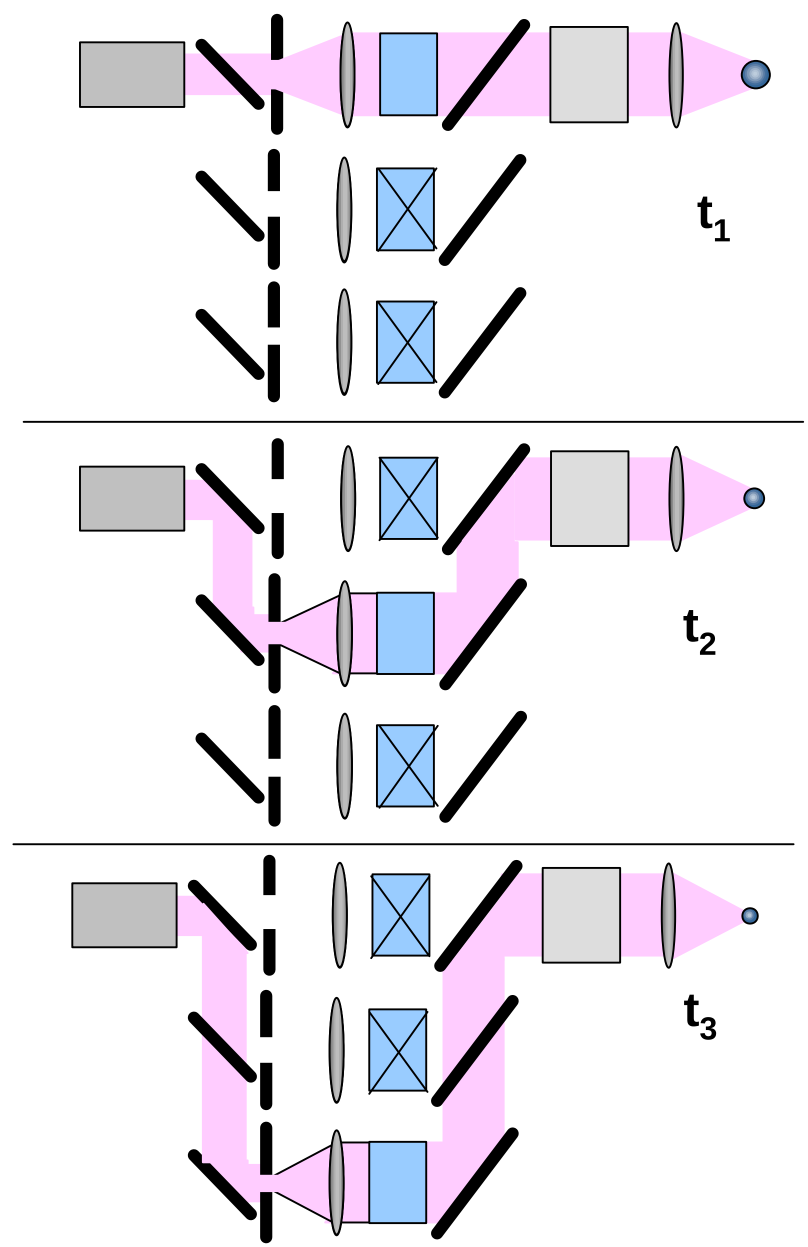
8 electron beams,
40 kJ each

Optical Aperture
~100 x 200 cm^2

The challenge is to achieve the required cost, rep-rate, durability, & efficiency

How to Zoom with KrF





Why NRL likes KrF lasers

1. Electron beam pumped architecture scalable to large systems

2. Low cost (pulsed power is cheap!)

3. Pulse shaping & zooming can be carried out at low energy in front end “seed” amplifier

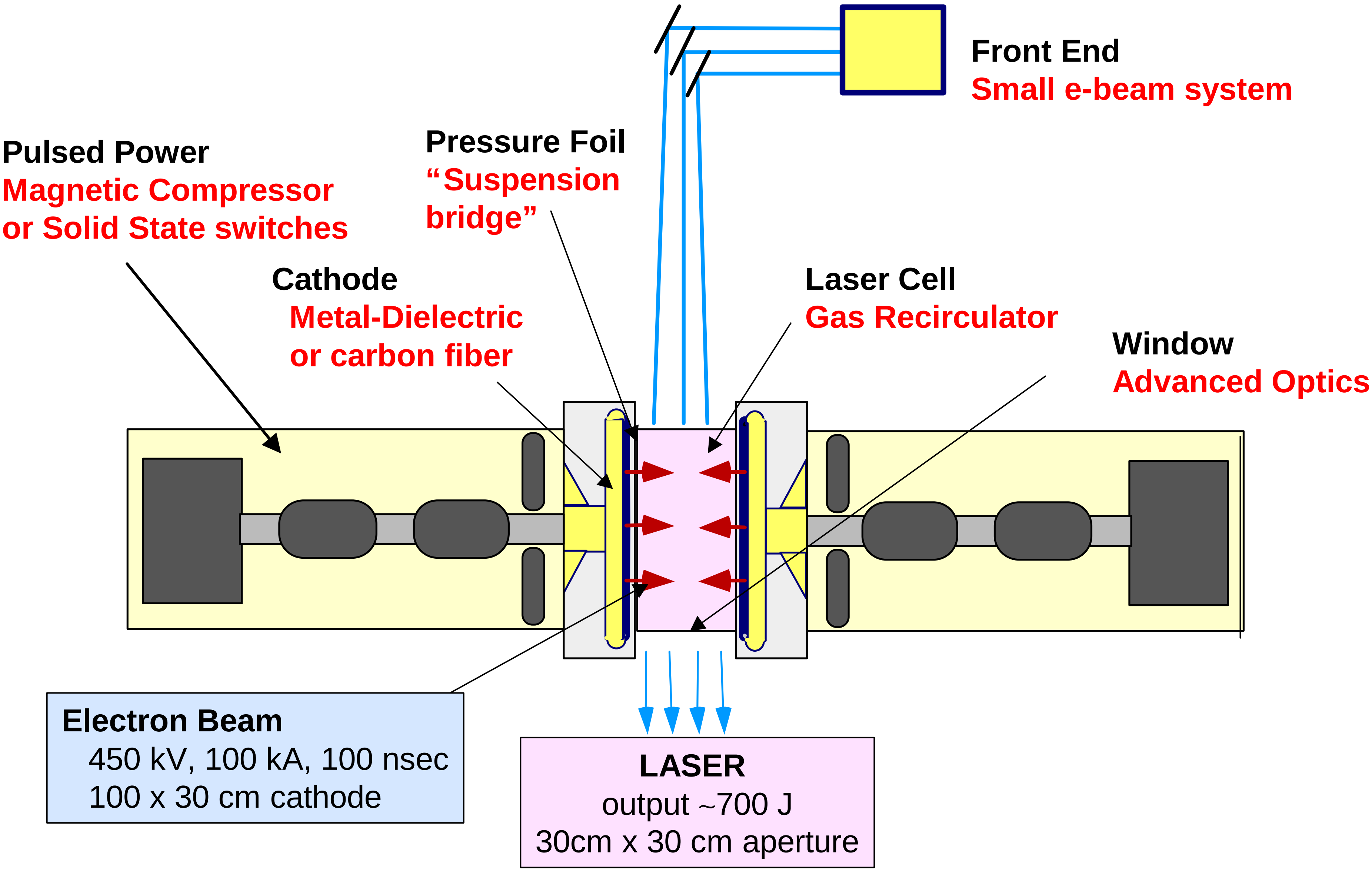
4. KrF laser beam better suited to present high gain target designs:

   a. Shortest wavelength (1/4 mm) maximizes absorption efficiency and rocket efficiency, minimizes risk of laser-plasma instability.

   b. ISI optical smoothing minimizes laser non-uniformities at all mode numbers

   c. Broadest bandwidth (2-3 THz) maximizes statistical smoothing of residual laser perturbations

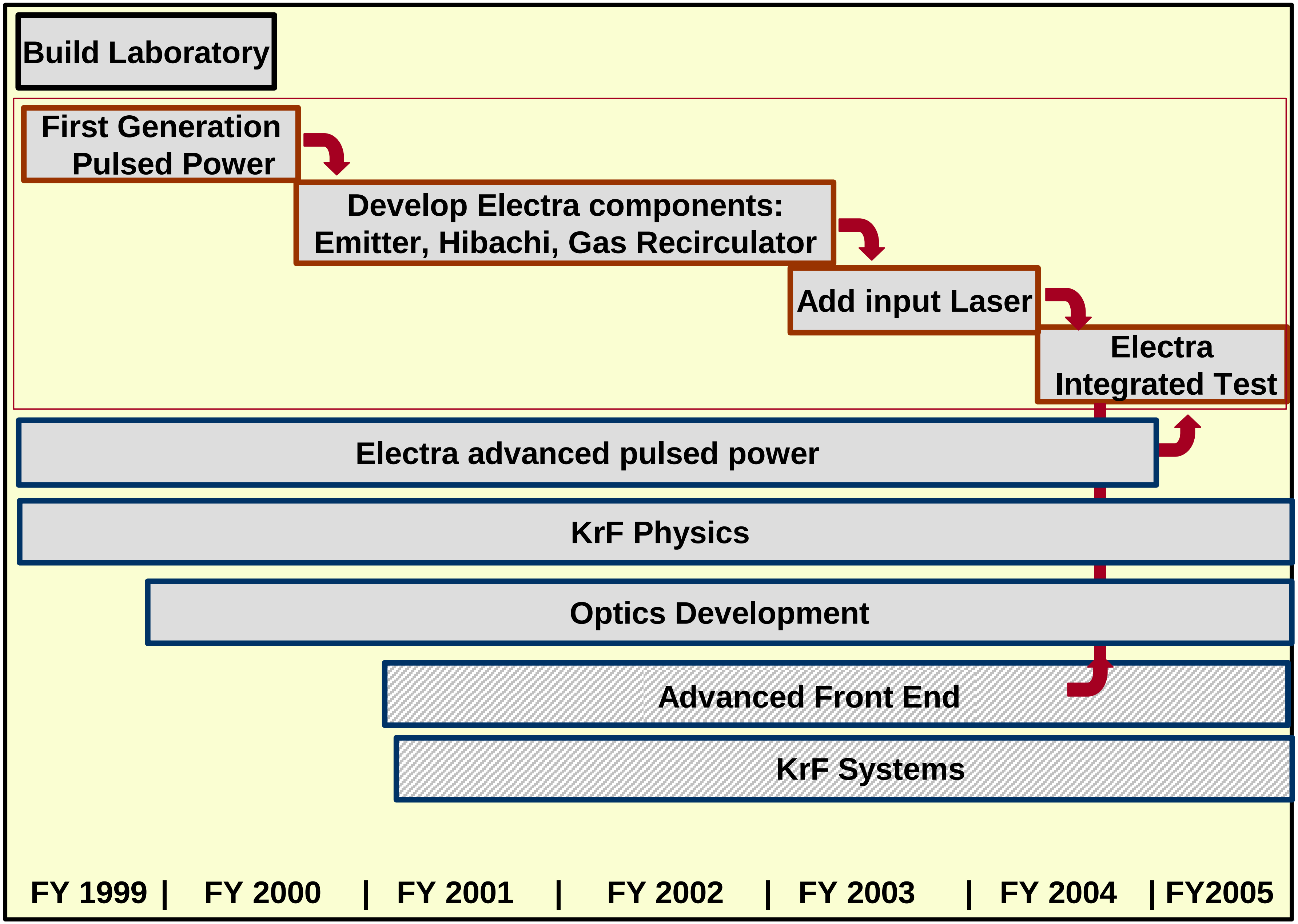
We can develop most of the required technologies with a single, 700 J, 5 Hz laser, called Electra



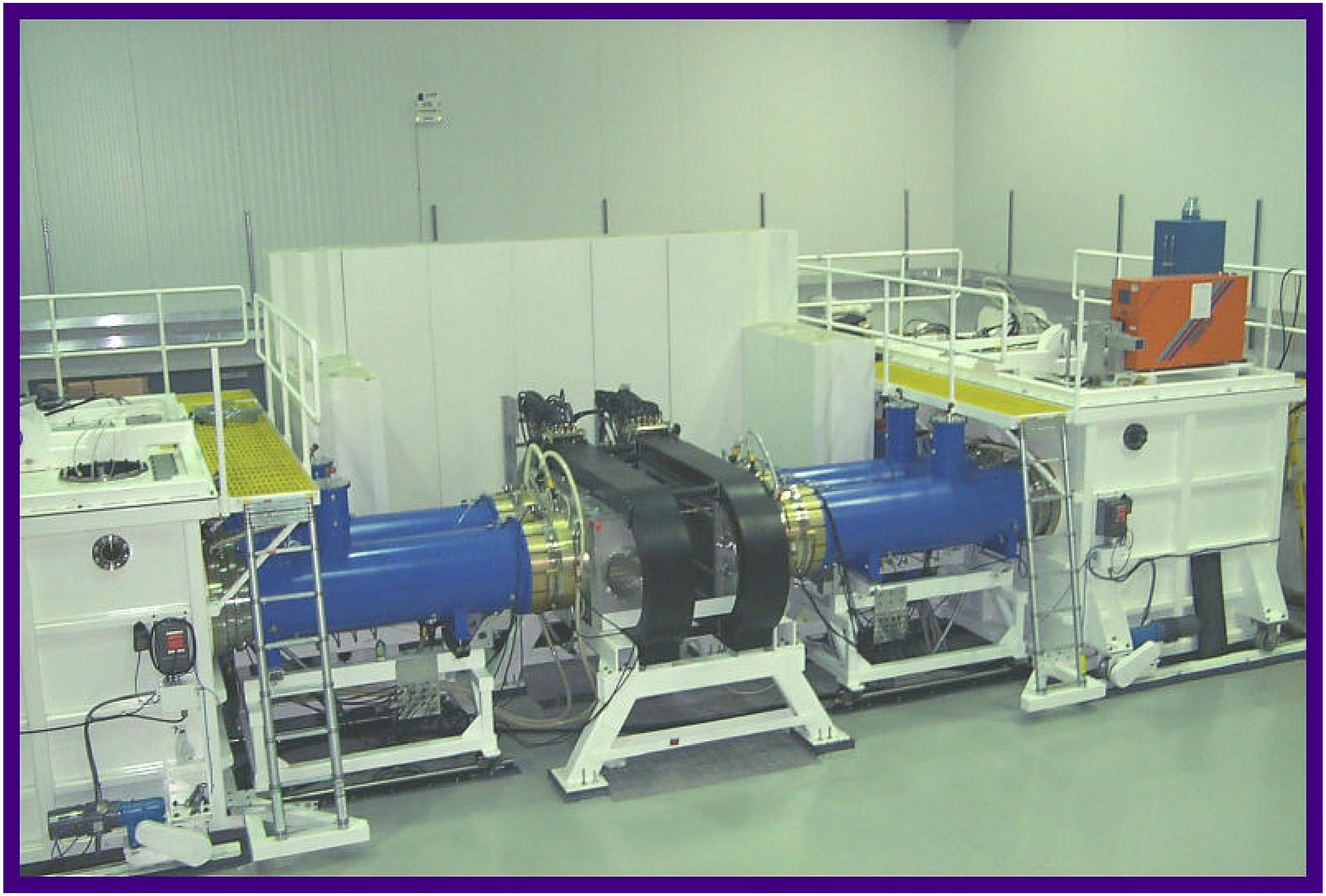
ELECTRA
A six part program to develop the KrF laser technologies

Electra Laser…………………………….. (30 cm aperture, 5Hz, 400-700 J)	**Develop technology for e-beam rep-rate, durability, efficiency, cost. Repetitively amplify ISI laser beam**
Advanced Pulsed Power……………..	**Long life/efficient Pulsed Power**
KrF Physics……………………………..	**Study relevant physical processes Optimize laser efficiency**
Advanced Optics……………………..	**Develop durable amplifier windows and steering focussing optics**
Advanced Front End………………..	**Pulse shaping, profiles, zooming**
KrF Systems Studies ……………..	**Design architecture 1-2.5 MJ system**

The Electra Program Plan



The Electra Laser



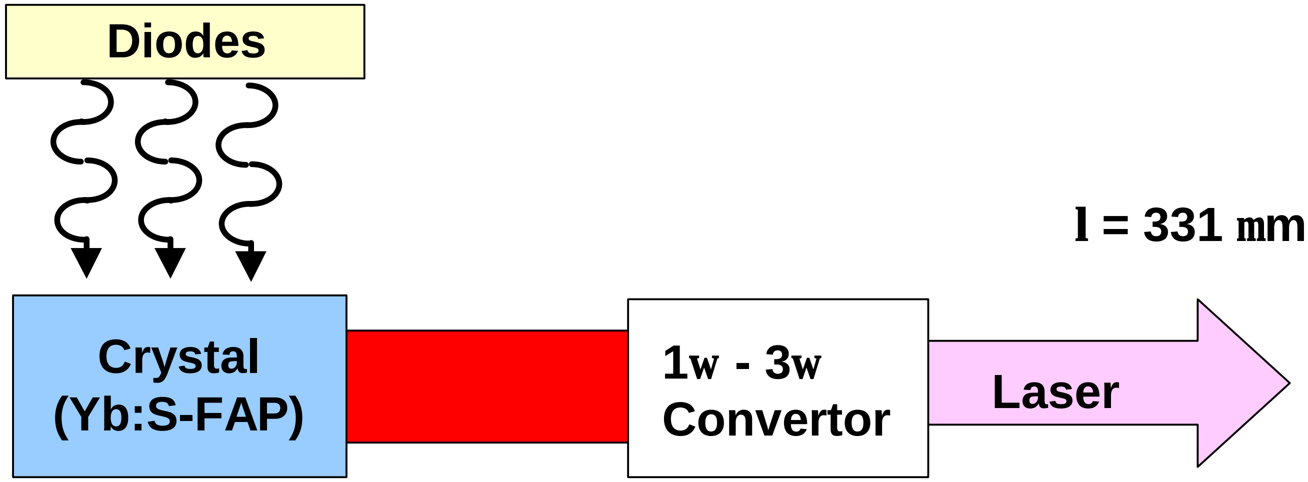
GOALS OF THE ELECTRA LASER PROGRAM

Parameter	Now	Electra	IFE Req	DD
EFFICIENCY	**1.5%**	**6-7%**	**6-7 %**	
Pulsed power efficiency	63% (RHEPP)	80% (1)		+
Hibachi Efficiency	50% (Nike)	80%		-
Ancillaries efficiency	N/A	95% (1)		0
Intrinsic Efficiency	7% (Nike)	12% (2)		-
Transport (laser-target)	75% (Nike)	90%		+
DURABILITY (shots)	**N/A**	**10^5**	**3 x 10^8**	
Pulsed Power	3 x10^7 (RHEPP)	10^{10} (1)		+
Cathode	10^8 (RHEPP)	> 10^5		0
Hibachi	100	> 10^5		-
Amplifier window	1000	> 10^5		-
COST	**N/A**	**study (1)**	**$225/$J_{laser}$**	
Pulsed Power Cost	N/A	$5-10/$J_{e\text{-}beam}$ (1)		+
OPTICS DAMAGE	**3 J/cm^2**	**5-8 J/cm^2**	**5-8 J/cm^2**	+
REP RATE	**.0005 Hz**	**5 Hz**	**5-10 Hz**	**+**
LASER UNIFORMITY				
Bandwidth	3.0 THz (Nike)	2.0 THz	2.0 THz	++
Beam quality-high mode	0.2% (Nike)	0.2%	0.2 %	++
Beam Power Balance	N/A		2%	0

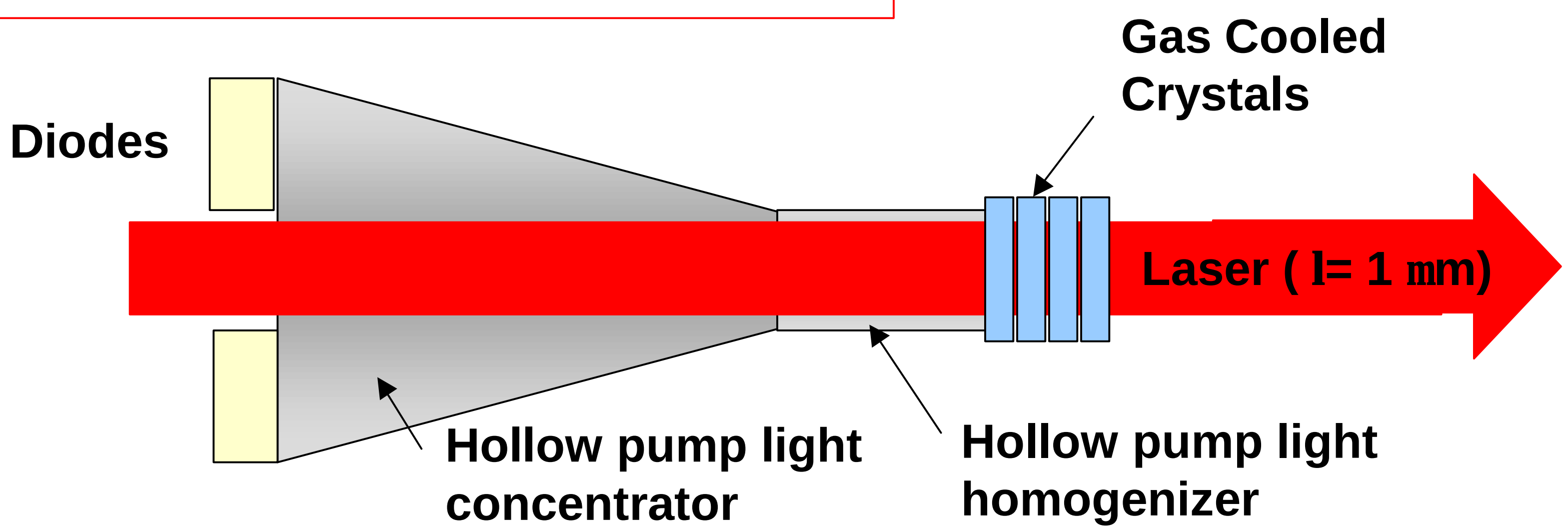
1. Electra will be too small to scale efficiency, needs Nike experiments for validation
2. Electra will validate technology. Both efficiency and cost will be established with modeling from Electra results

Diode Pumped Solid State Lasers

CONCEPT

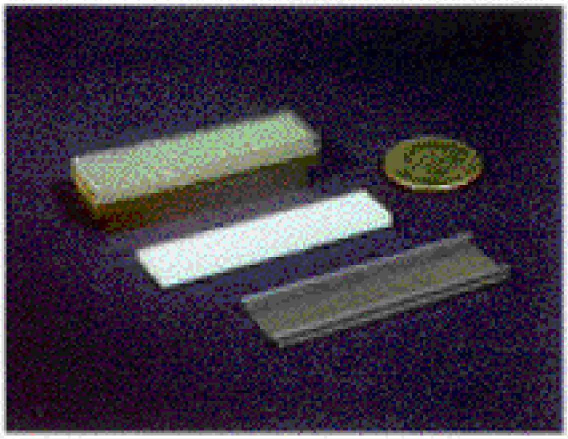


MERCURY LASER ARCHITECTURE

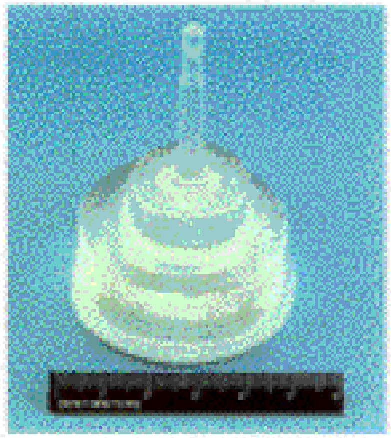


We are building Mercury (100 J/10 Hz/10% efficiency) as a first step toward megajoule/megawatt class lasers for rep-rated fusion ignition

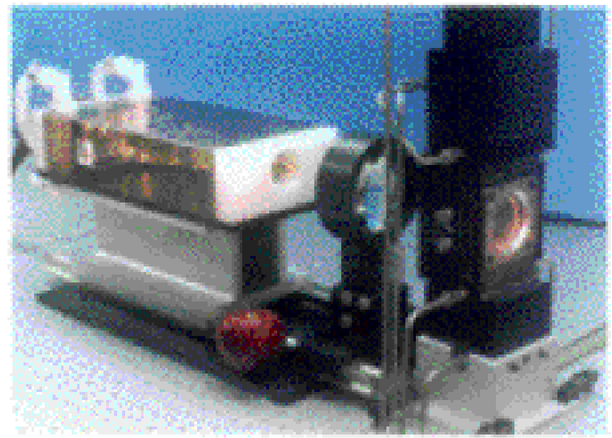
Diodes



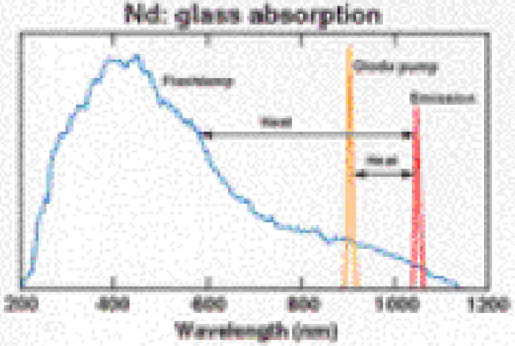
Crystals

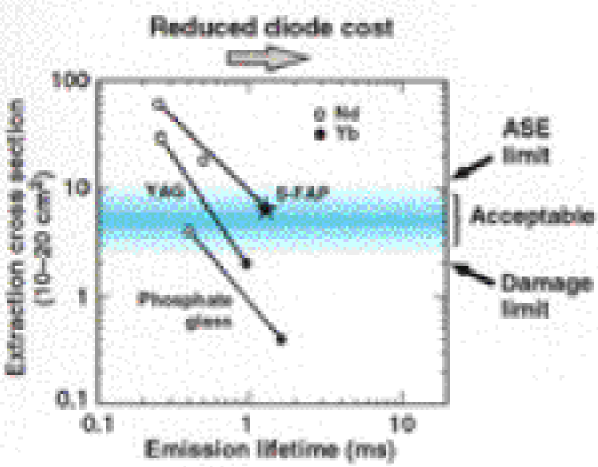


Gas cooling

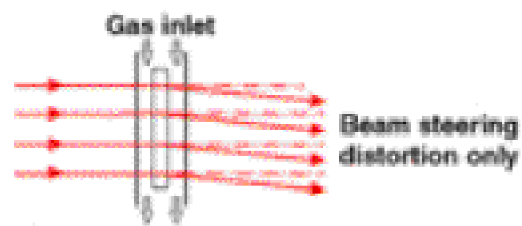


Flashlamp emission and Nd: glass absorption





Issue: Heat removed in a scalable manner
Solution: Passive cooling ⟹ forced cooling



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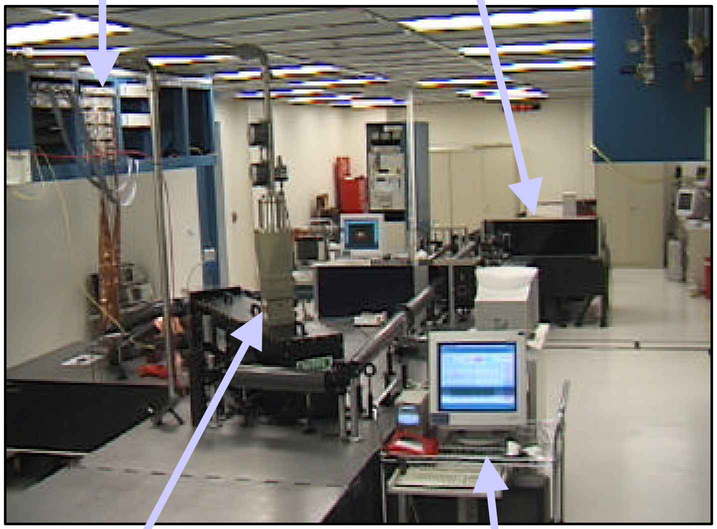
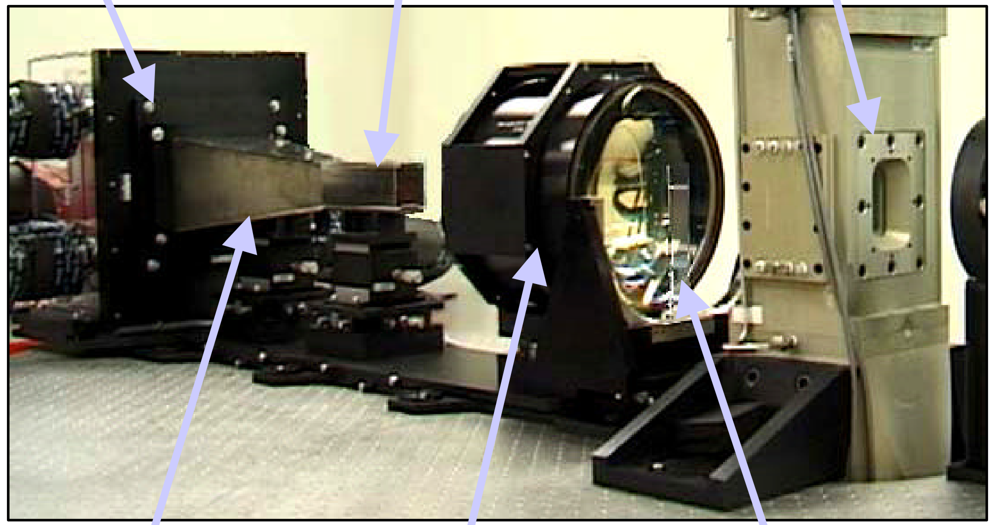
We are presently building the Mercury Laser, a 100J / 10 Hz / 10% efficient laser serving as the template for future systems

Pulsers
Diagnostic Laser
Diode Array
Homogenizer
Gas-Cooled Amplifier





Gas-Cooled Amplifier
Control System
Lens Duct
Condenser Lens
Dichroic

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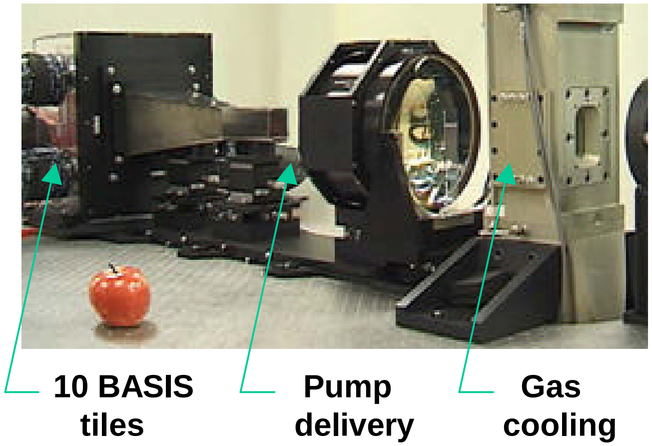
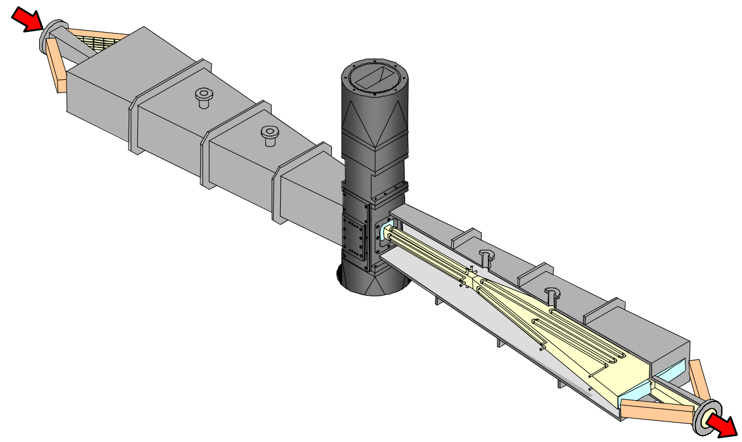
Mercury Laser is progressing toward our goal of 100J/10Hz/10%

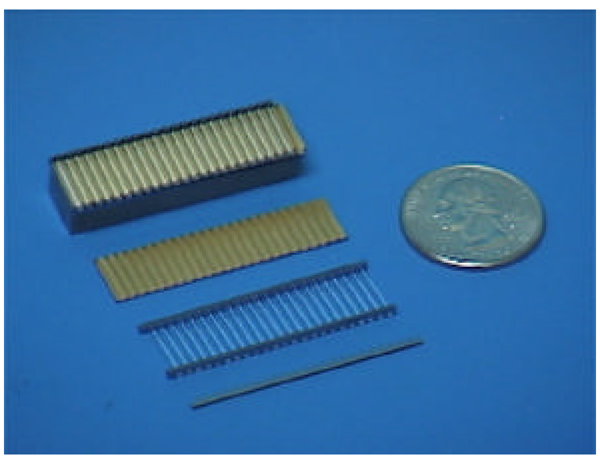
- **Gas-cooled head vibration-free; gain and wavefront (surrogate Nd:Glass slabs) consistent with modeling**



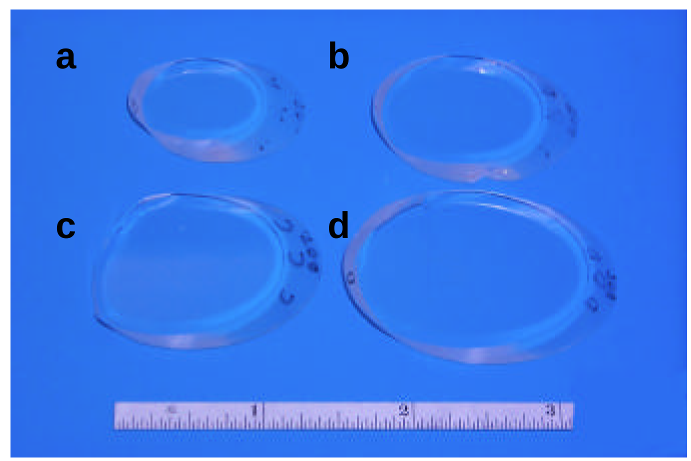
- **Improved, robust architecture uses no pump lenses, integrated pump and spatial filter cavities; procurements in process**



- **Diode package is reliable and simple; 13 tiles built since 5/00 operating at 115W/bar**



- **Yb:S-FAP crystal growth issues are nearly resolved; no bubble core, grain,or smoke; 25% larger boules needed**



Laser driver requirements for inertial fusion energy are challenging but achievable with DPSSLs

Specification	Requirement	Challenge for DPSSLs
Energy / rep rate	> 2 MJ / > 5 Hz	Modular scaling / gas cooling
Efficiency	> 5%	10 to 20% achievable
Driver cost	< $1.5 B (for GW_e)	Reduce diode costs to 5¢/W peak
Wavelength	< 0.4 mm	Frequency – convert with average power
Beam smoothness	< 1% rms	Maximize bandwidth and multi-beam overlap
Reliability	> 10^9 shots	Improve optical damage thresholds and diode lifetime

Why LLNL Likes DPPSLs

1. Durability (all solid state)

2. Potential for higher efficiency (10%- 20%)

3. Final reactor optic may be easier

4. Pulse width flexibility (nsec-psec/femtosecond)

4. Beam quality may be sufficient
   - 1/3 μm reduceslaser imprinting more than 1/4 μm
   - 1 THz bandwidth sufficient
   - SSD (smoothing technique) smooth enough when optimized
   - May have target designs that don't require best beam quality

5. A lot of other, non IFE, applications (very compact, very modular)

Note: Comments by JDS , taken from LLNL documents

Summary

There are two complementary lasers for an IFE driver

Both have active development programs with well defined goals

	KrF	DPPSL
Beam Quality	easy	hard
Rep-rate	easy	easy
Durability	OK	easy
Efficiency	hard	OK
Cost	OK	hard

Of course, the ultimate test is how well these lasers meet <u>all</u> the reactor requirements….
And the only way to know that is to develop IFE as an integrated system.