DPSSL Systems
The Next Generation

High Average Power Laser
Program Workshop

Naval Research Laboratory

March 3-4, 2005

Presented
by
Ray Beach

Future IFE solid state laser

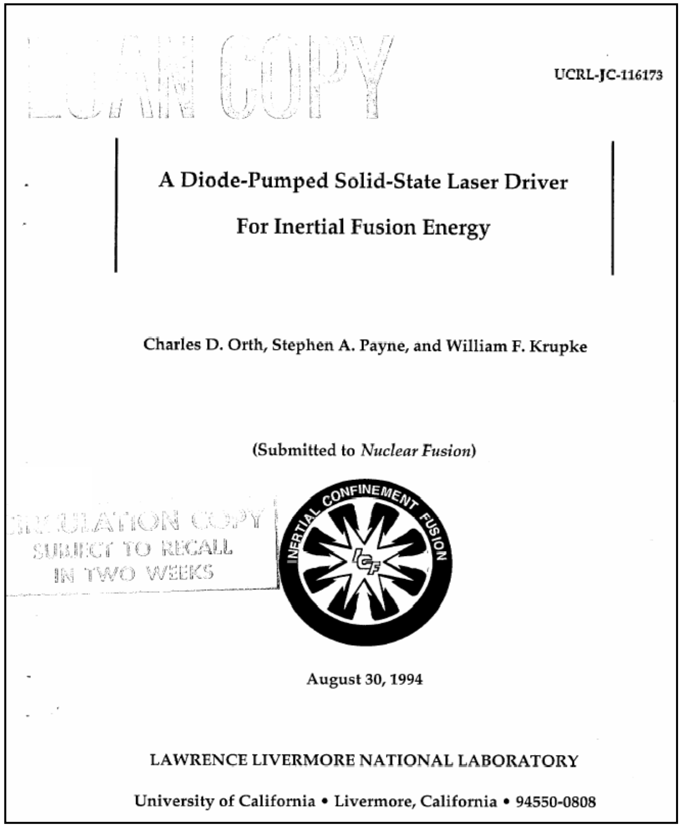
- **Technical laser requirements**
  - Energy/power to drive target
  - Beam conditioning
  - Efficiency $\Longrightarrow$ optical-optical efficiency > 0.2
  - ASE $\Longrightarrow$ $\alpha \cdot \ell < 4.5$
  - Beam filamentation $\Longrightarrow$ $\delta B < 1.8$

- **IFE specific constraints**
  - Cost
  - Rep rate
  - RAM

safe, efficient & reliable

Challenge – What is the gain medium?

How did we come to use Yb:S-FAP?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UCRL-JC-116173

A Diode-Pumped Solid-State Laser Driver

For Inertial Fusion Energy

Charles D. Orth, Stephen A. Payne, and William F. Krupke

(Submitted to *Nuclear Fusion*)

ULATION COPY
SUBJECT TO RECALL
IN TWO WEEKS

INERTIAL CONFINEMENT FUSION

ICF

August 30, 1994

LAWRENCE LIVERMORE NATIONAL LABORATORY

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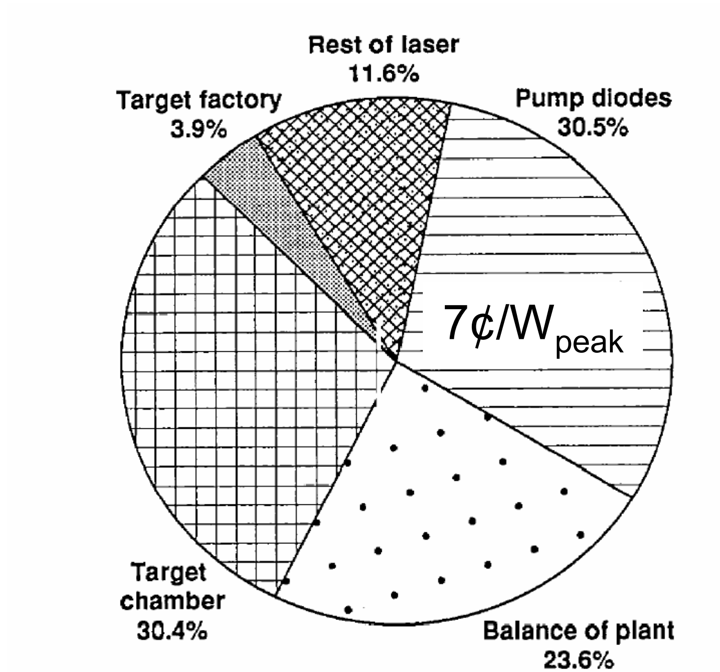
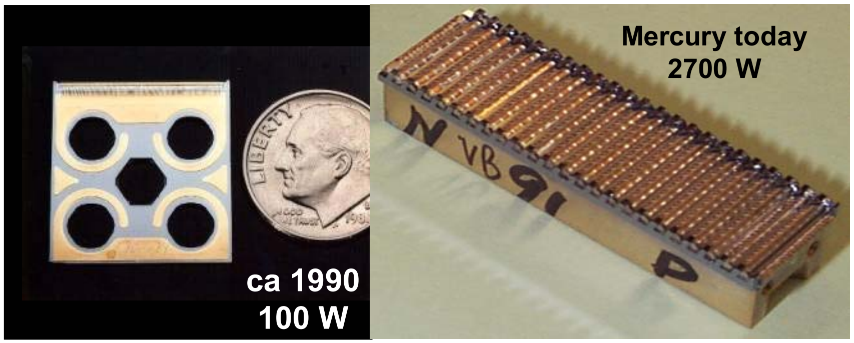


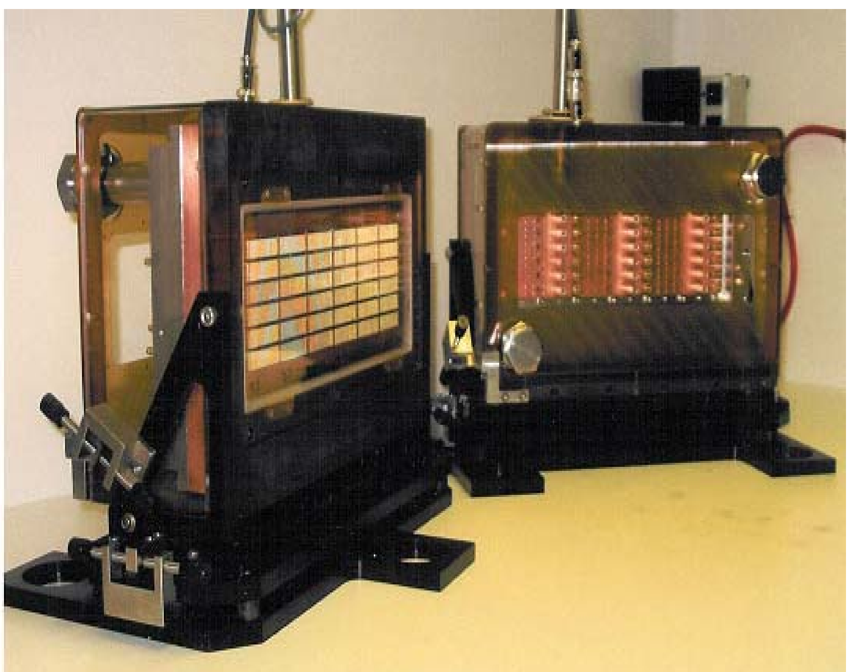
FIG. 13. Relative contributions to the total (direct plus indirect) capital cost (TCC) for the 1-GW_e baseline DPSSL-driven IFE plant.

- **In early 90's minimizing the number of diode arrays was the primary concern**
- **New materials doped with Yb^{3+} were actively pursued to take advantage of its long 1 msec storage lifetime**

Mercury and others have rapidly advanced diode technology



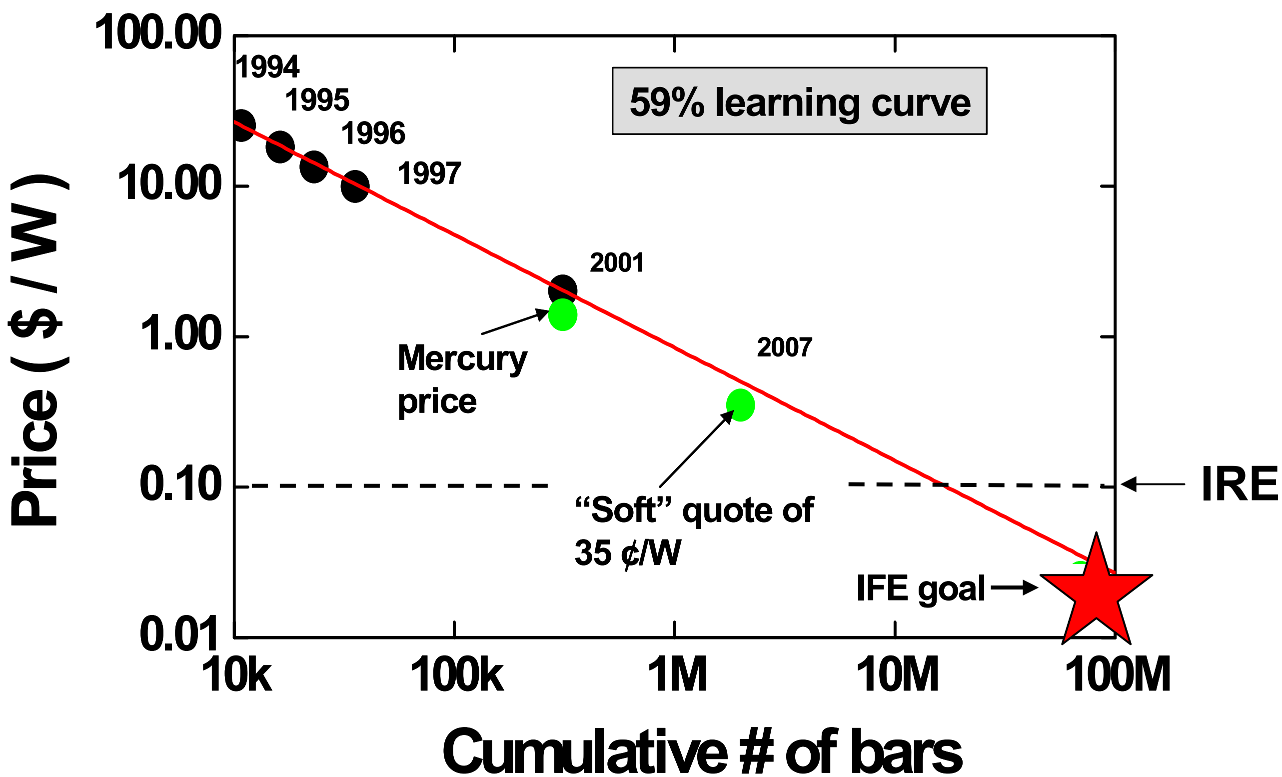
- Monolithic package has driven down cost
- Mercury diode bar cost - $1.30/W_{peak}$



- Diode cost will continue to drop
  - Advanced manufacturing technologies
  - Performance improvements
  - Expanding market: DoD, laser machining,…
- 80 kW_{peak} Mercury arrays can scale to 10’s of MW

Diode bar prices are dropping with growing market

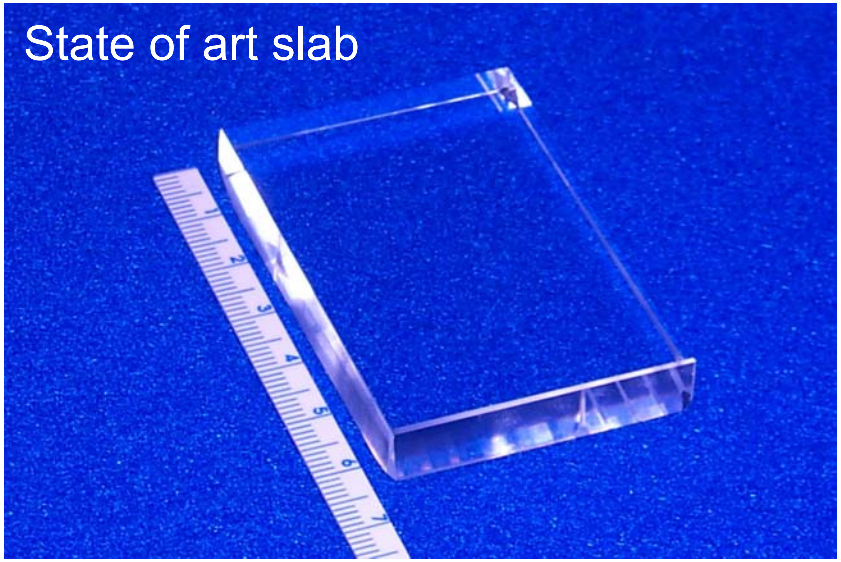
- Cost data follows a classic learning curve
- Every doubling of quantity cuts the cost 41%

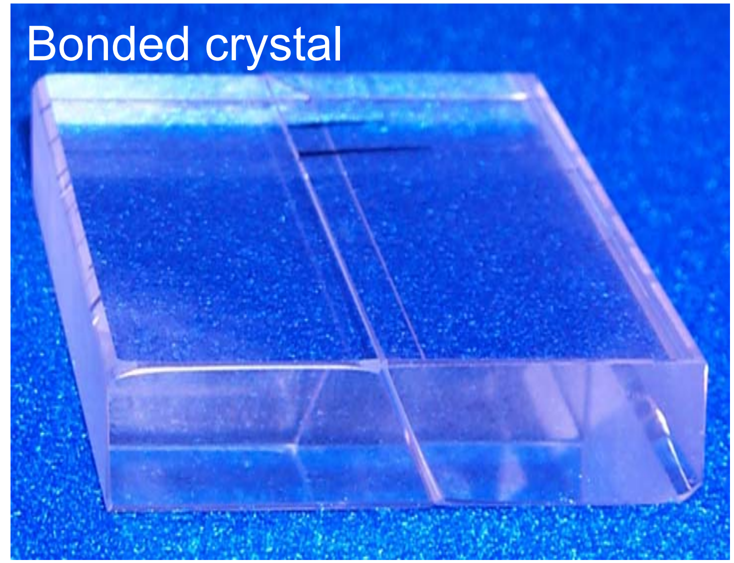


Challenge – What is the gain medium?

- Yb^{3+}:S-FAP
- Nd^{3+}:Glass
- Optical (transparent) ceramics

Yb^{3+}:S-FAP

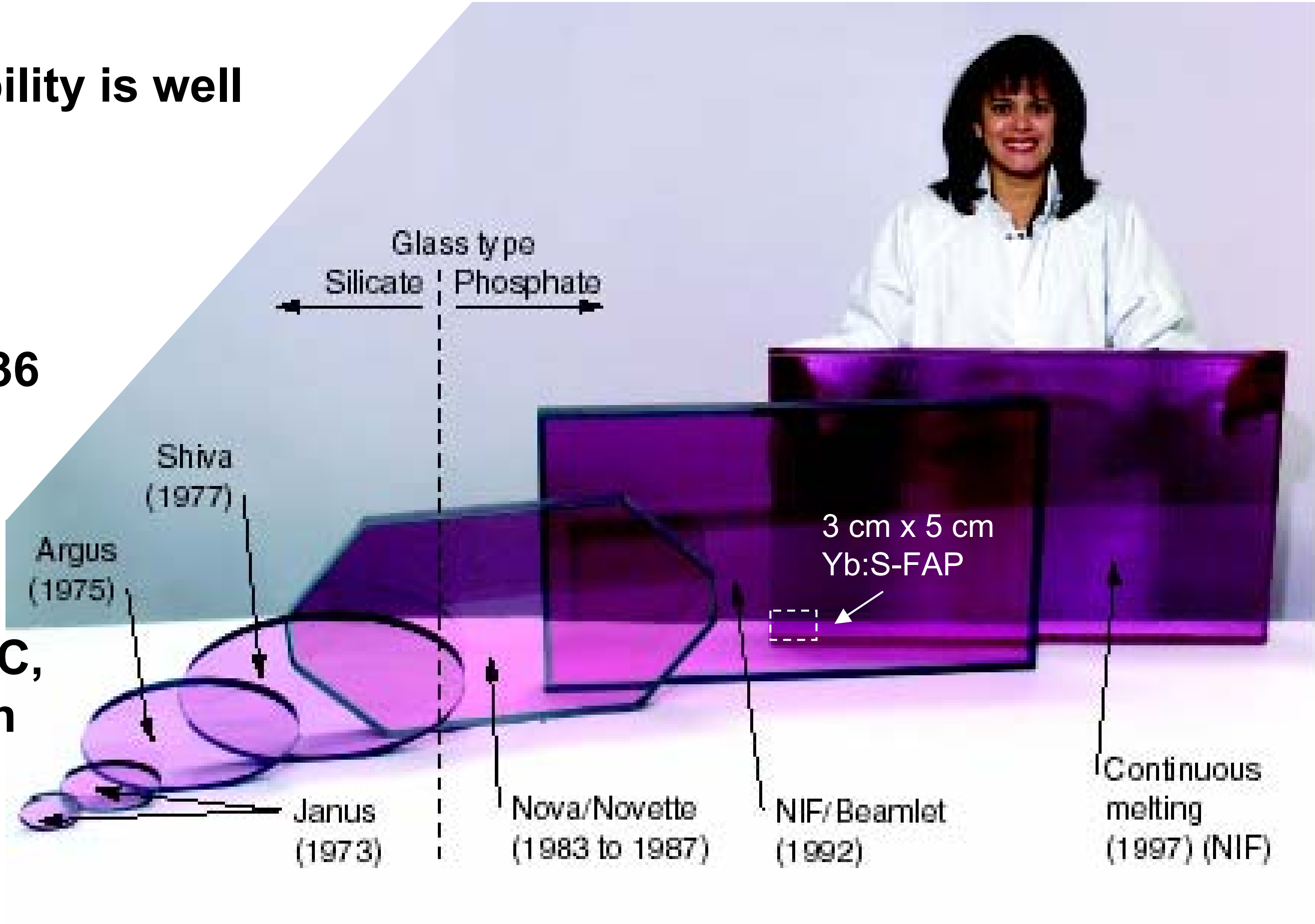




- **Strength**
  - **Yb^{3+} ion has a long storage lifetime (~1 msec) minimizing diode array count**
- **Weakness**
  - **Development is being driven by only one program – Mercury**
  - **Limited aperture sizes (Mercury is 3 cm x 5 cm), but this may be mitigated through crystal bonding (stitching)**
  - **Quasi-three level laser**

Nd^{3+}:Glass

- Strengths
  - Large apertures (NIF slabs are 40 cm x 70 cm)
  - Production capability is well established
  - Four level laser
- Weaknesses
  - Nd^{3+} lifetime is 0.36 msec (3x more diodes than Yb^{3+})
  - Low thermal conductivity (~0.0058 W_{th}/cm-°C, about 4x less than Yb:S-FAP)

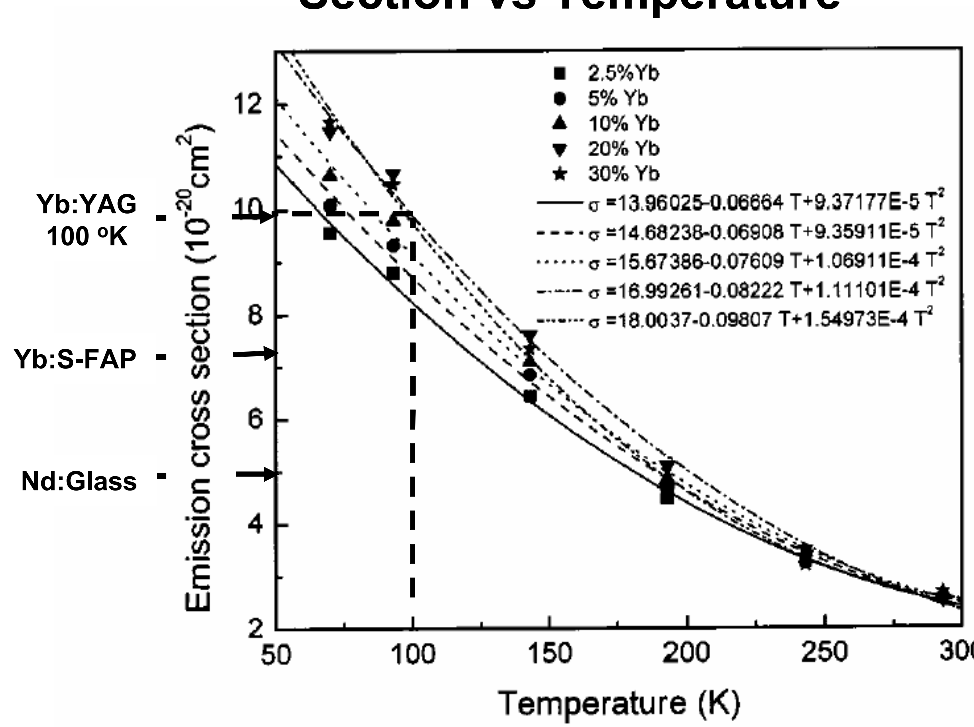


Optical ceramics have arrived!

- Optical quality comparable to NIF glass

- 10 cm x 10 cm x 2 cm slabs of Nd:YAG
- Ceramic media scales like glass

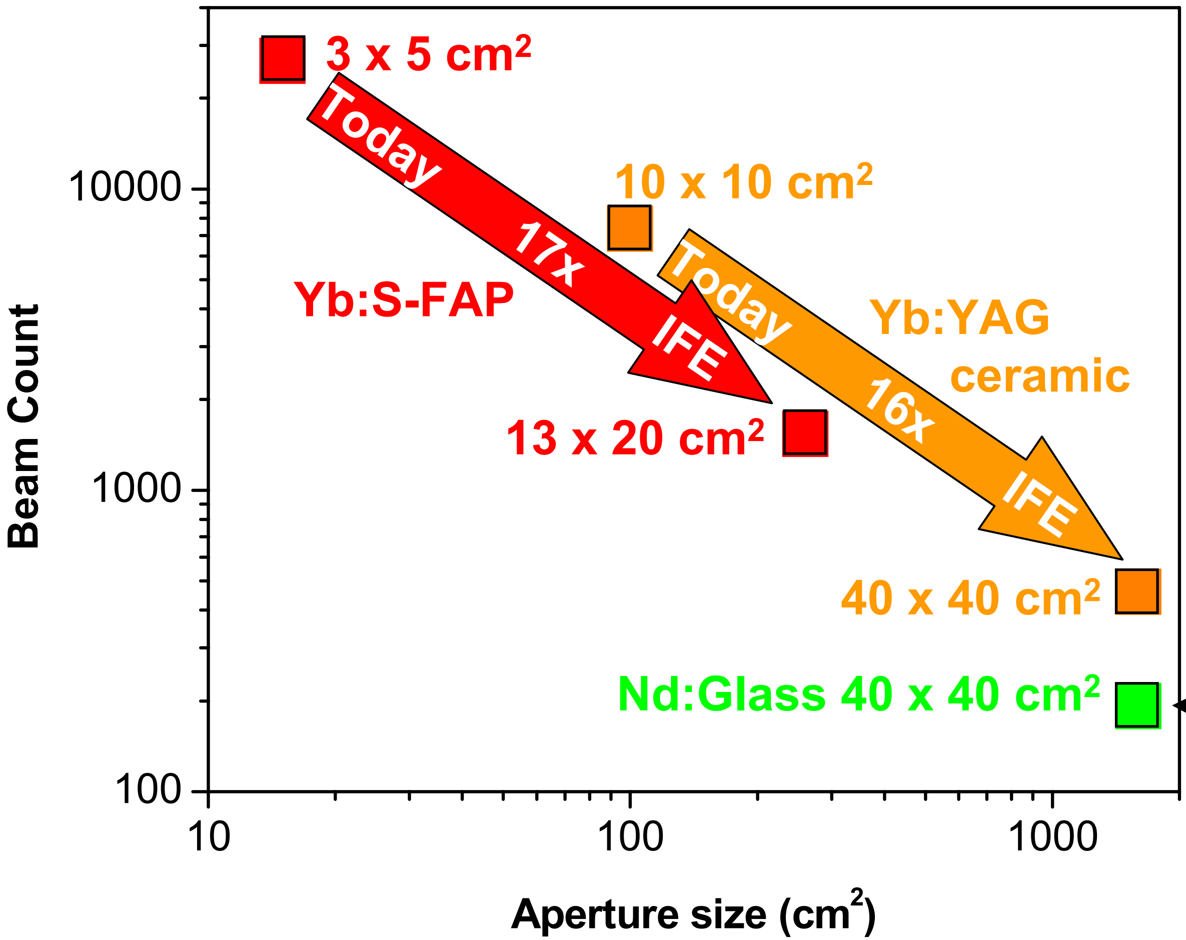
Yb:YAG Emission Cross Section vs Temperature*



100°K Yb^{3+}:YAG is a potential large aperture crystal for a four-level IFE DPSSL driver

* J Dong, M Bass, Y Mao, P Deng, and F Gan, "Dependence of the Yb^{3+} emission cross section and lifetime on temperature and concentration in yttrium aluminum garnet," JOSA B 20, p 1975, 2003

Aperture sizes today and those needed for IFE



Only Nd:Glass is at the required IFE aperture size

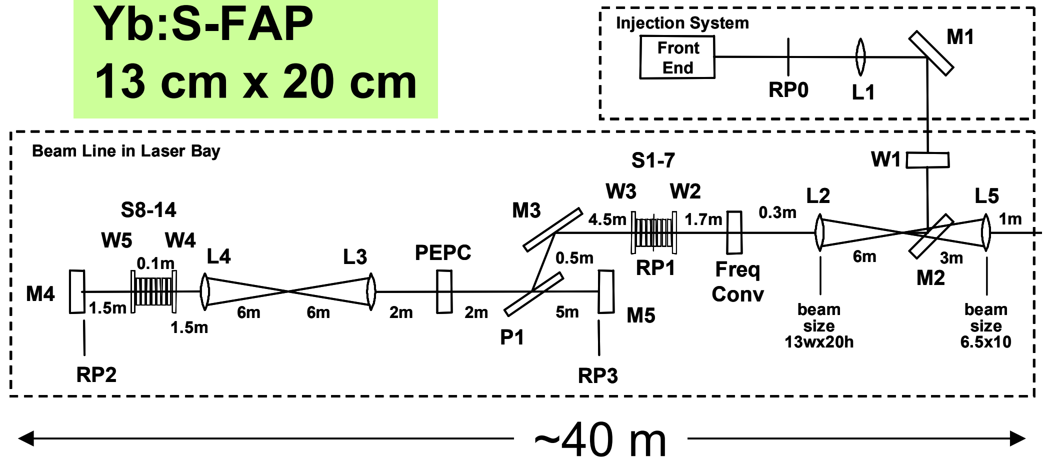
We are embarking on a cost analysis of candidate DPSSL systems for IFE

Comparison of Yb:S-FAP, Nd:Glass, and Yb:YAG (ceramic) based IFE drive lasers:

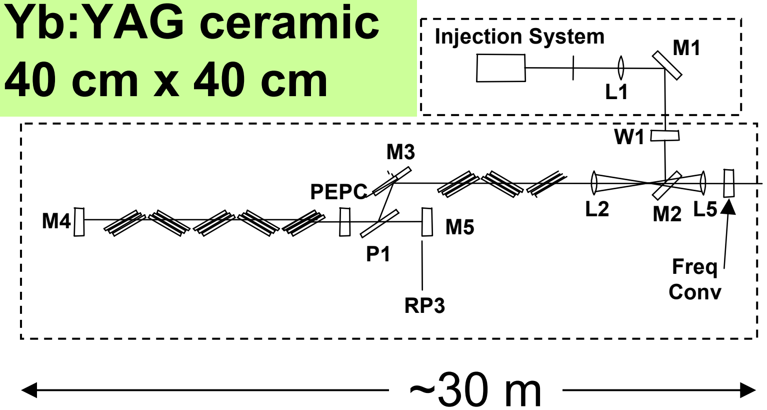
- Nd:Glass based system
  - Traceable to NIF beam line
  - Leverages technology base developed for NIF: large optic finishing, beam line bundling, switchyard, and LRUs
- Yb-S-FAP based system
  - Traceable to Mercury architecture, but using a NIF-like configuration
  - Leverages design of Mercury amplifiers
- Yb doped optical ceramics
  - Scales like glass but has long storage time
  - Replace NIF glass slabs with Yb:YAG ceramic
  - Requires large scale cryo-cooling

Beam line comparison

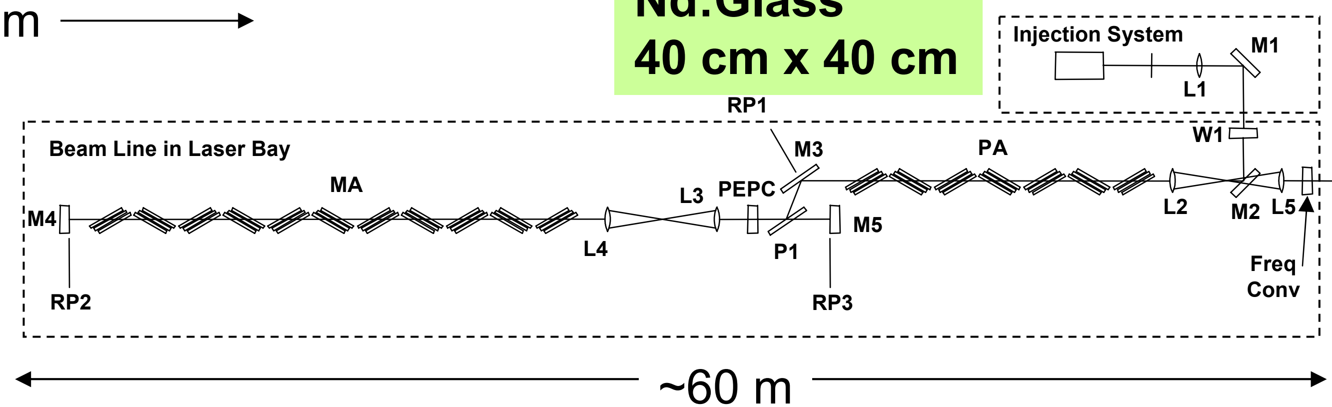
Yb:S-FAP
13 cm x 20 cm



Yb:YAG ceramic
40 cm x 40 cm

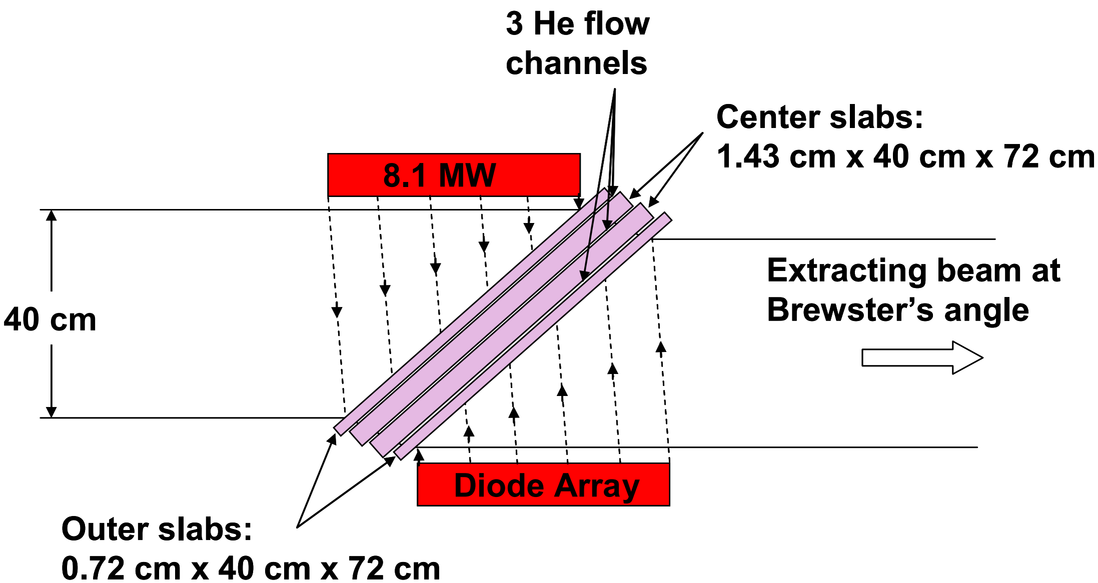


Nd:Glass
40 cm x 40 cm

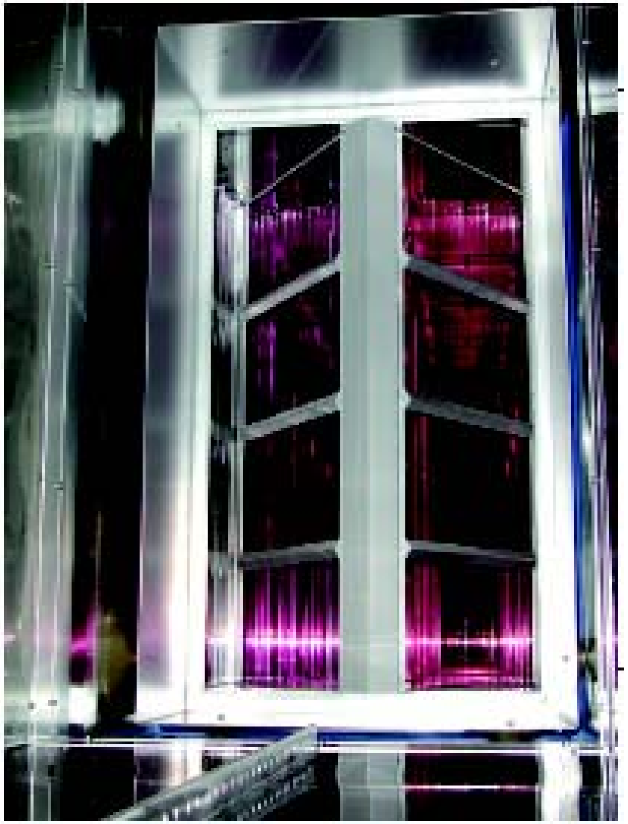


RJB/VG

Diode pumped Nd:Glass head with He cooling

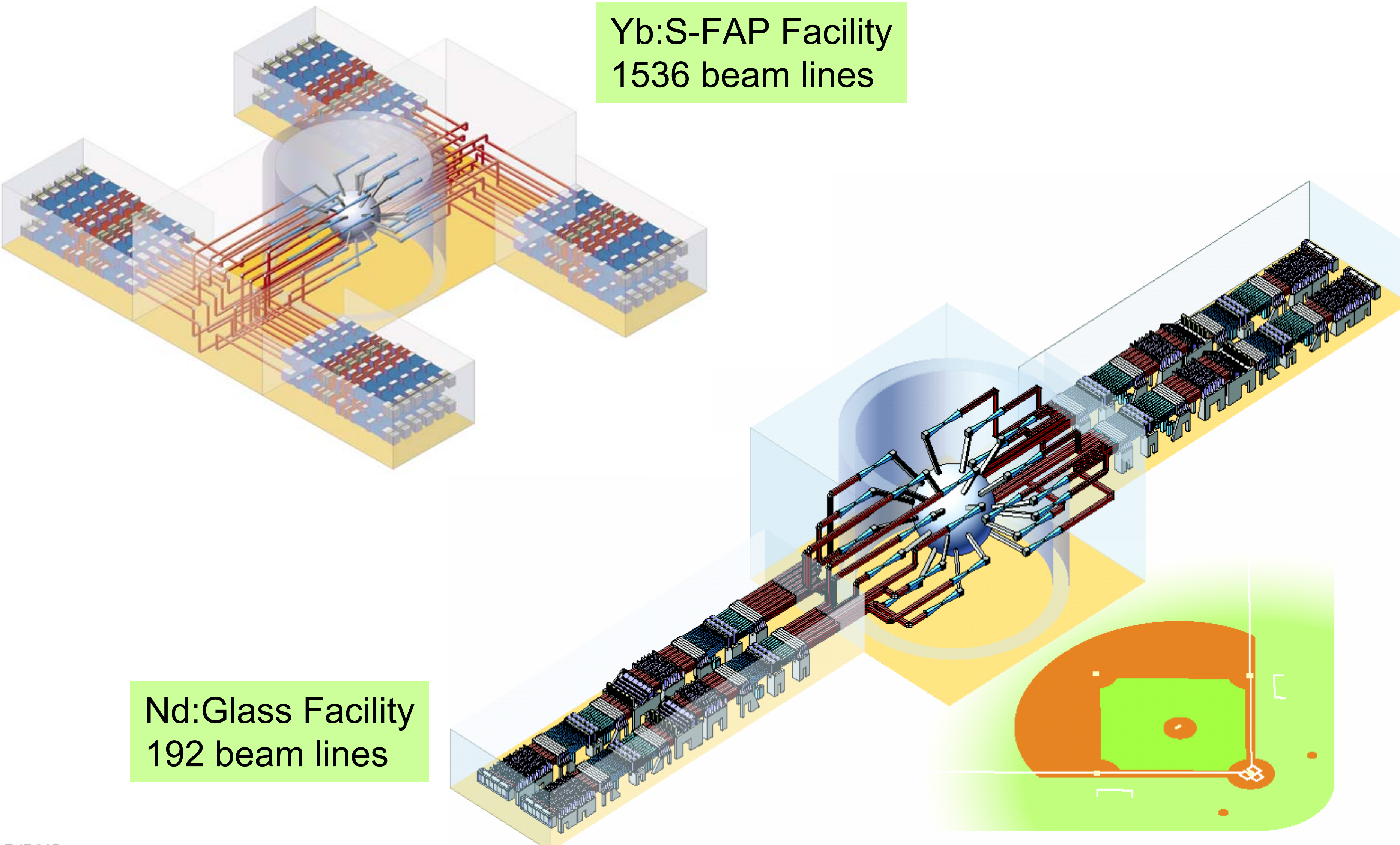


NIF

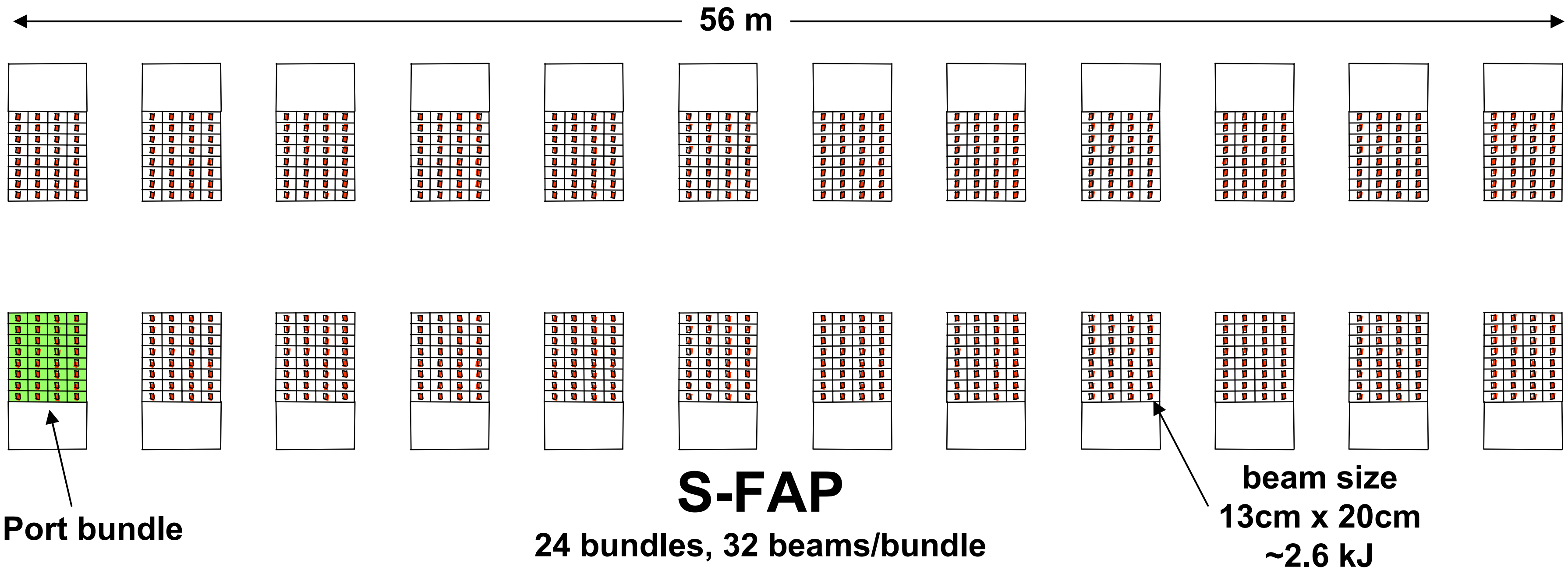


- Multiple thin slabs required for thermal management
  - Central slabs are 1.43 cm thick
  - Outer slabs are 0.72 cm thick
- Heat intensity at all interior slab surfaces is 0.92 W/cm^2

Facility comparison

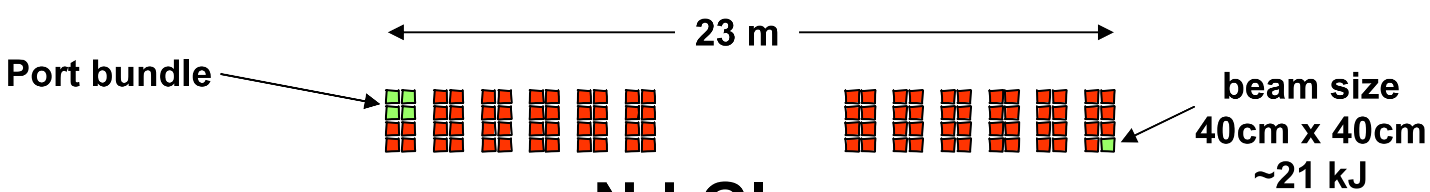


Aperture area comparison, end on (half of the beam lines)



S-FAP

24 bundles, 32 beams/bundle
768 beam lines

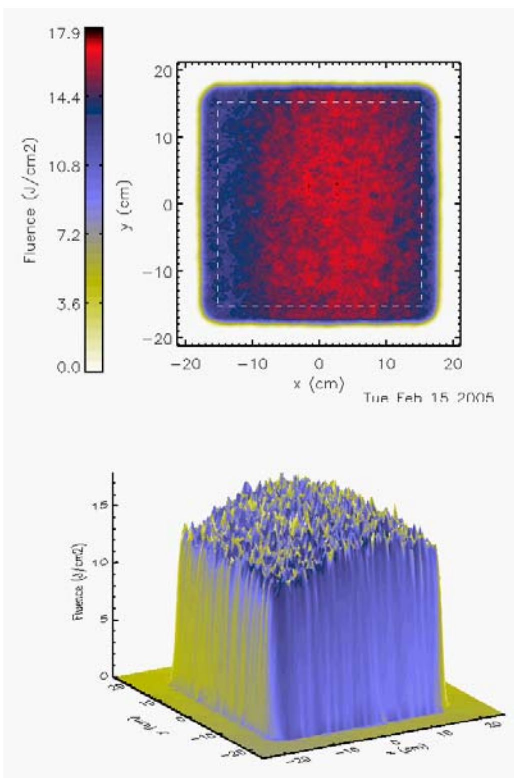


Nd:Glass

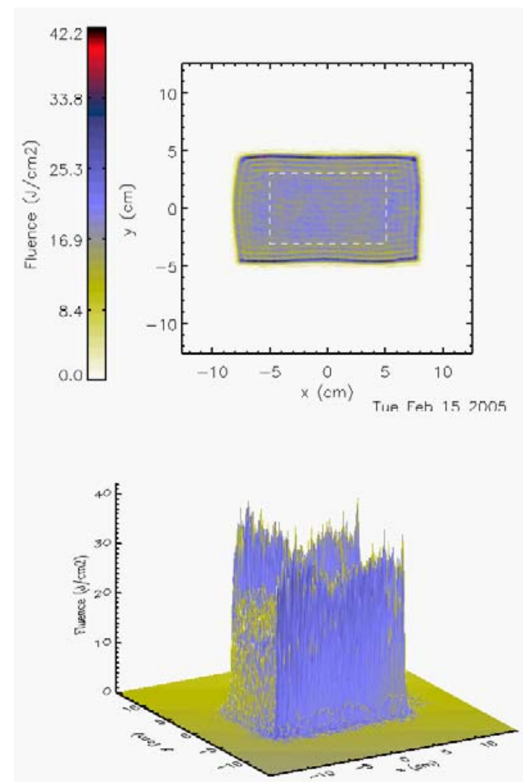
24 bundles, 4 beams/bundle
96 beam lines

Virtual beam line simulations can be carried out for proposed systems

- Nd:Glass
  - ~18.5 kJ aperture
  - NIF has demonstrated 26 kJ/aperture

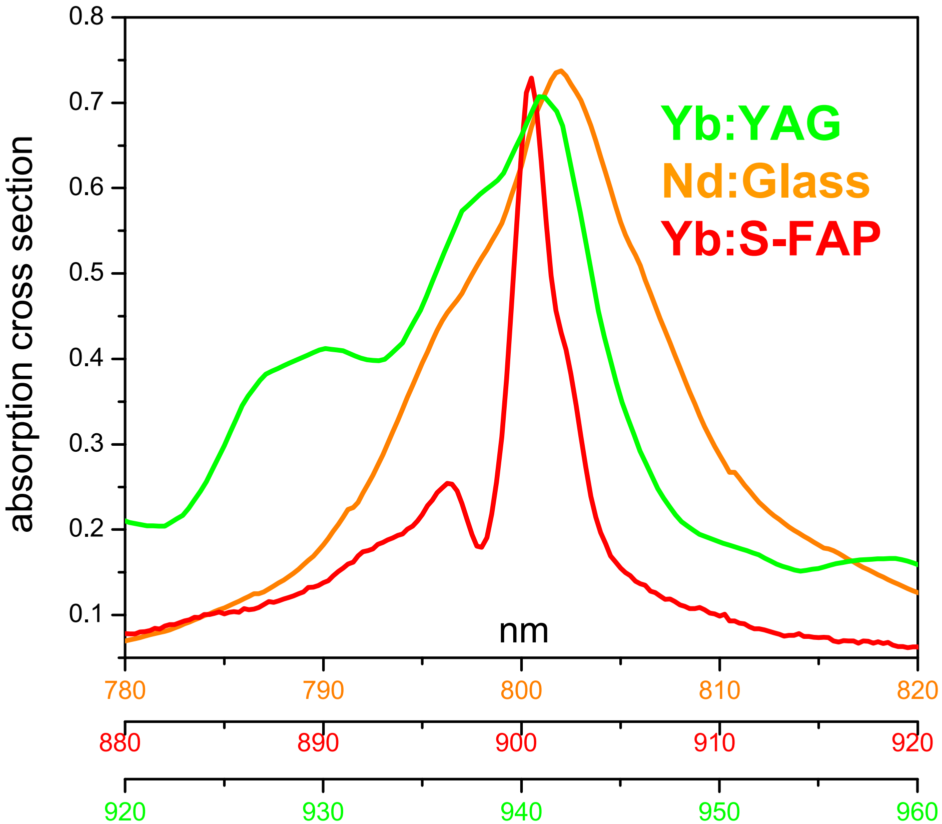


- Yb:S-FAP
  - ~ 2.8kJ aperture
  - 7-8 beams can deliver the same energy as one glass aperture



Comparison of diode-pump absorption feature

Spectrally Resolved Absorption Cross Section (normalized)



	Absorption FWHM
Yb:YAG	15 nm
Nd:Glass	12.5 nm
Yb:S-FAP	3.4 nm

Lower cost diodes

Convert a NIF beam line to 10 Hz operation

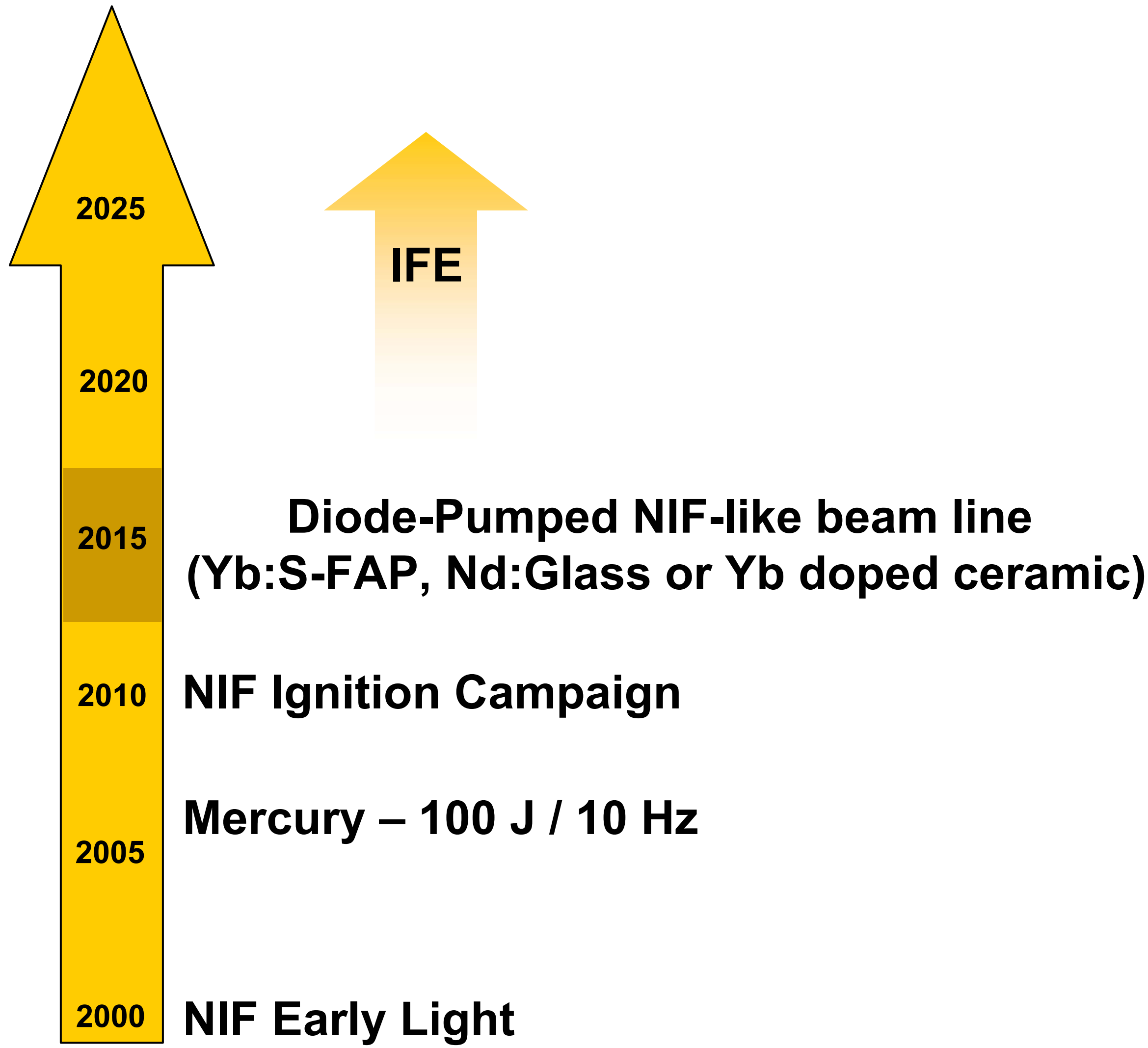
NIF technology	Beam line upgrade to enable 10 Hz operation
Flashlamps	Diode arrays
4.3 cm thick Nd:Glass slabs	• Thinner Nd:Glass slabs • Yb:YAG ceramic slabs • Mercury-like Yb:S-FAP amplifier heads
KDP PEPC	KD*P PEPC
Air slab cooling	He cooling
KDP harmonic generation	KD*P harmonic generation

Three solid state laser systems for IFE

	Yb:S-FAP	Nd:Glass	Yb:YAG (100°K)
Laser type	Quasi-three level	Four level	Four level
Storage time	1 ms	0.36 ms	1 ms
Peak diode pump power	20 GW	56 GW	20 GW
Absorption FWHM	3.4 nm	12.5 nm	15 nm
Operating temperature	Room Temperature	Room Temperature	100 K
Aperture size	13 cm x 20 cm (near normal incidence	40 cm x 40 cm (Brewster)	40 cm x 40 cm (Brewster)
Number of beam lines	1536	192	460
Total aperture area	40 m^2	31 m^2	74 m^2

Baselined systems are 4 $MJ_{1\omega}$ with $\geq$ 20% optical-optical efficiency

Leveraging NIF and Mercury technology provides a near term pathway to the demonstration of a DPSSL based IFE beam line



RJB/VG