DPSSL Driver: Smoothing, Zooming and Chamber Interface

Mercury

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We are investigating options, issues, and trades for DPSSL driver and direct-drive targets

- Motivation: We are working towards an updated laser design as basis for systems model and future integrated power plant study

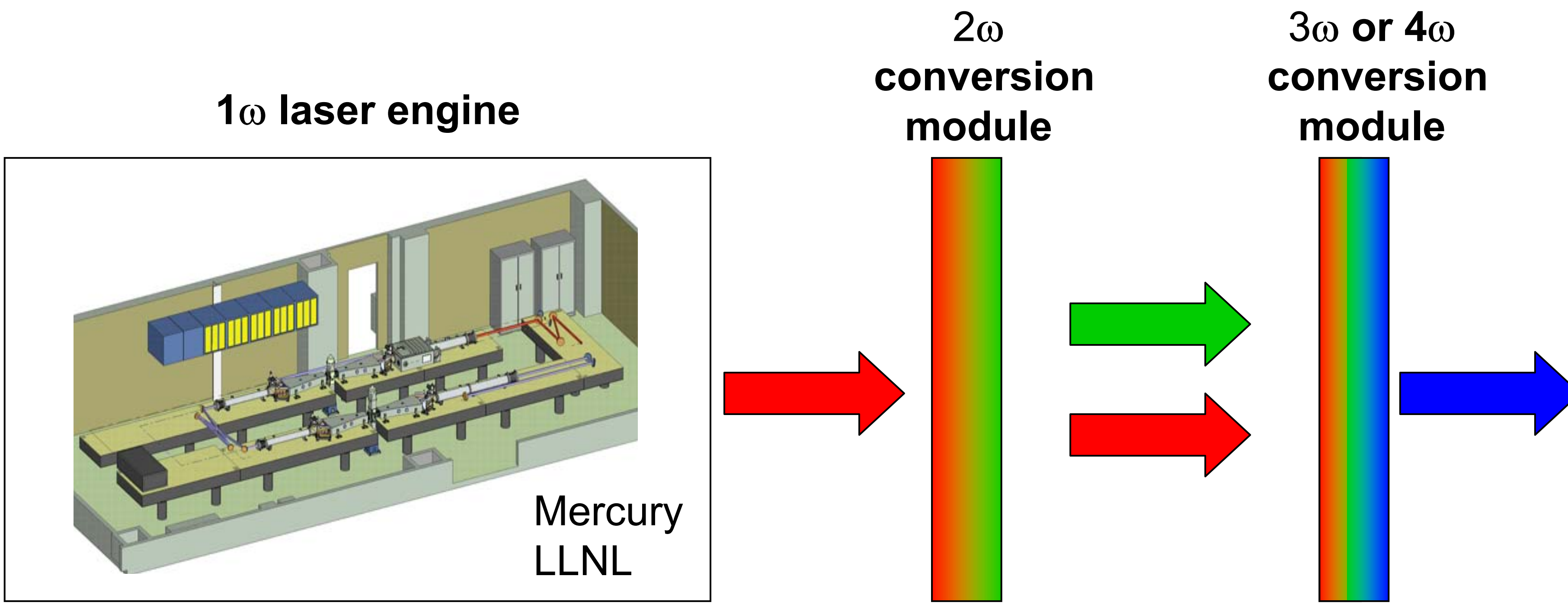
- We are considering trades (e.g., target performance and driver efficiency for 1ω, 2ω, 3ω and 4ω options

- We are developing design concepts for beam delivery:
  - final optics, phase plate, turning/focusing mirrors
  - beam segmentation, number of beams

  that meet target requirements:
  - energy, pulse shape, illumination uniformity,
  - beam smoothing and zooming

- Next step will be to update laser architecture, and cost scaling

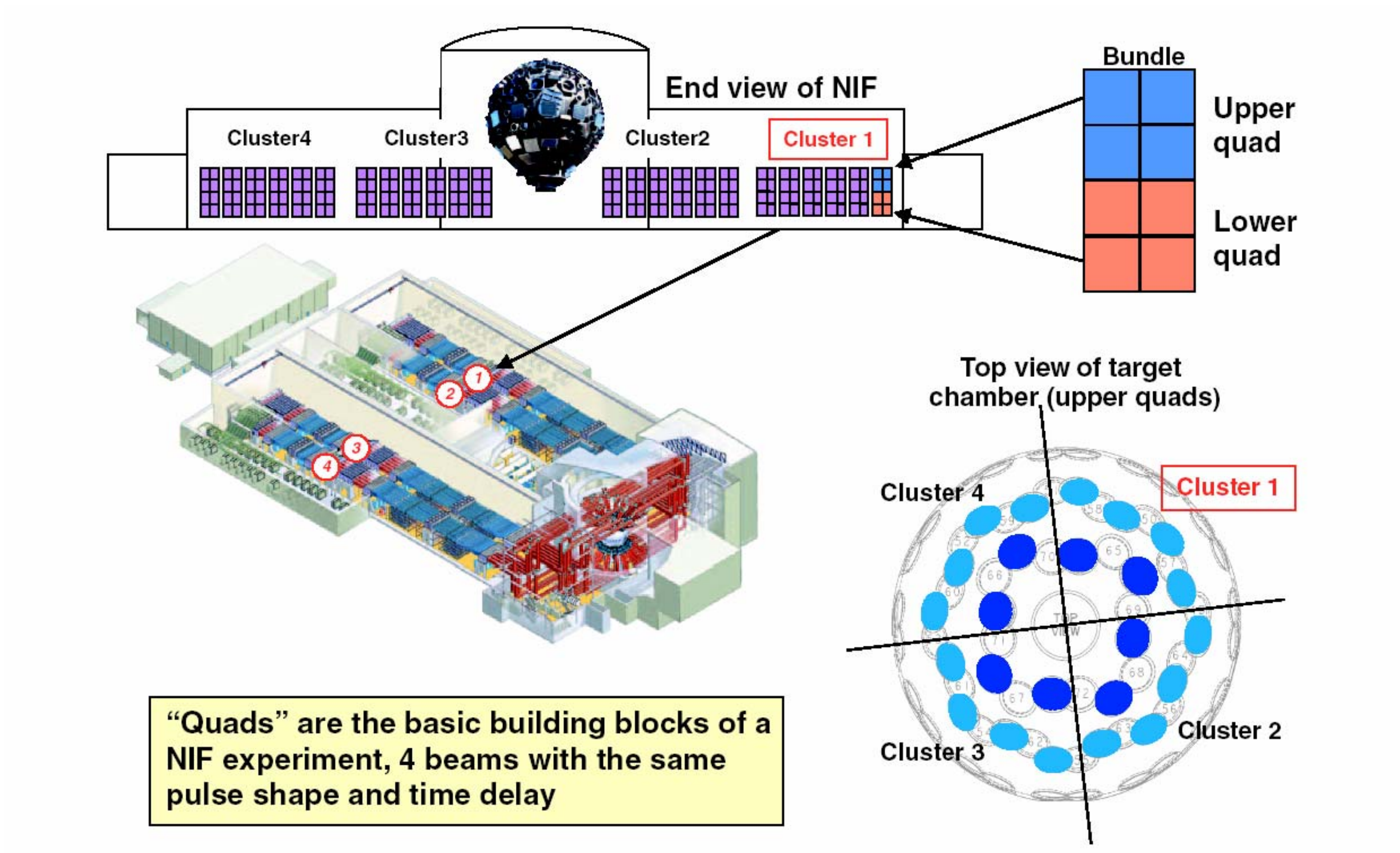
Mercury is a demonstration of a 1ω laser engine that could drive 2ω, 3ω or 4ω beam lines



Mercury is a sub aperture demonstration (100 $J_{1\omega}$) of a DPSSL beam line architecture that scales in pulse energy to the multi-kJ level

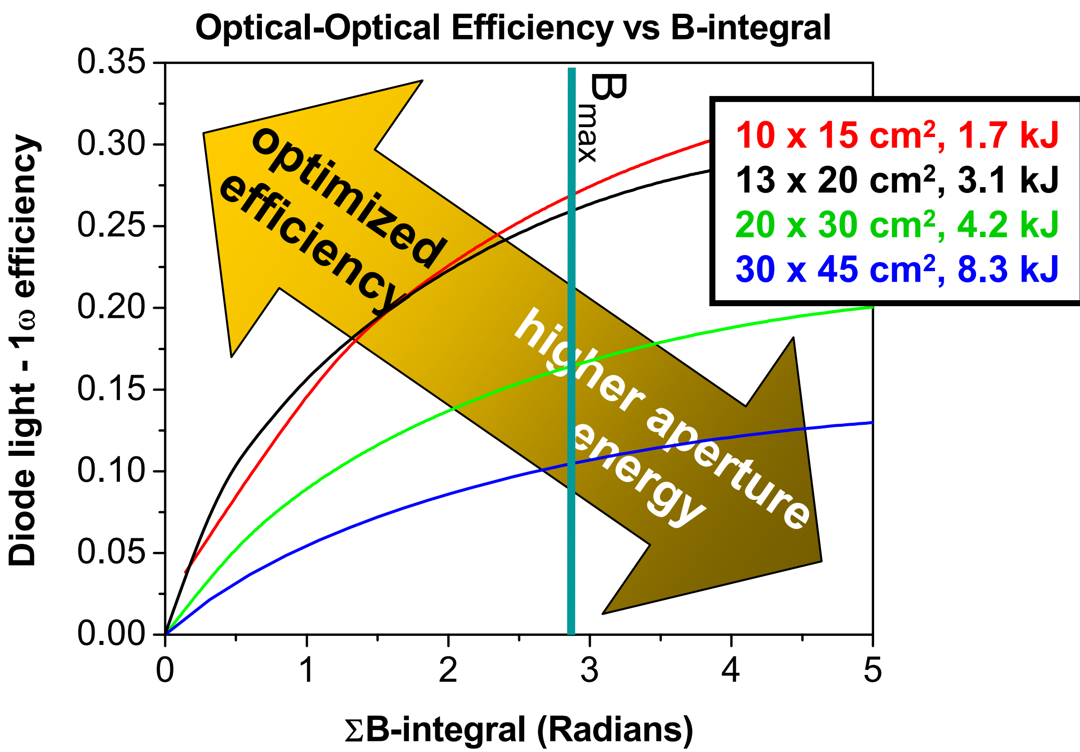
Envisioned IFE laser driver design builds on NIF architecture

- NIF consists of 192 beams that will generate 1.8 $MJ_{3\omega}$
- Beam line integration architecture is defined by "bays," "clusters", "bundles", and "quads"



IFE baseline DPSSL aperture size is a compromise between high efficiency laser and high pulse energy aperture

- Optimized aperture is 13 cm x 20 cm yielding an output energy of ~3.1 $kJ_{1\omega}$
- 96 chamber ports for laser entry
- ~4.5 $MJ_{1\omega}$ total 4π pulse energy or ~47 kJ per chamber port
- 4.5 $MJ_{1\omega}$ is built up with 1,536 total beam lines (or 8 x NIF)

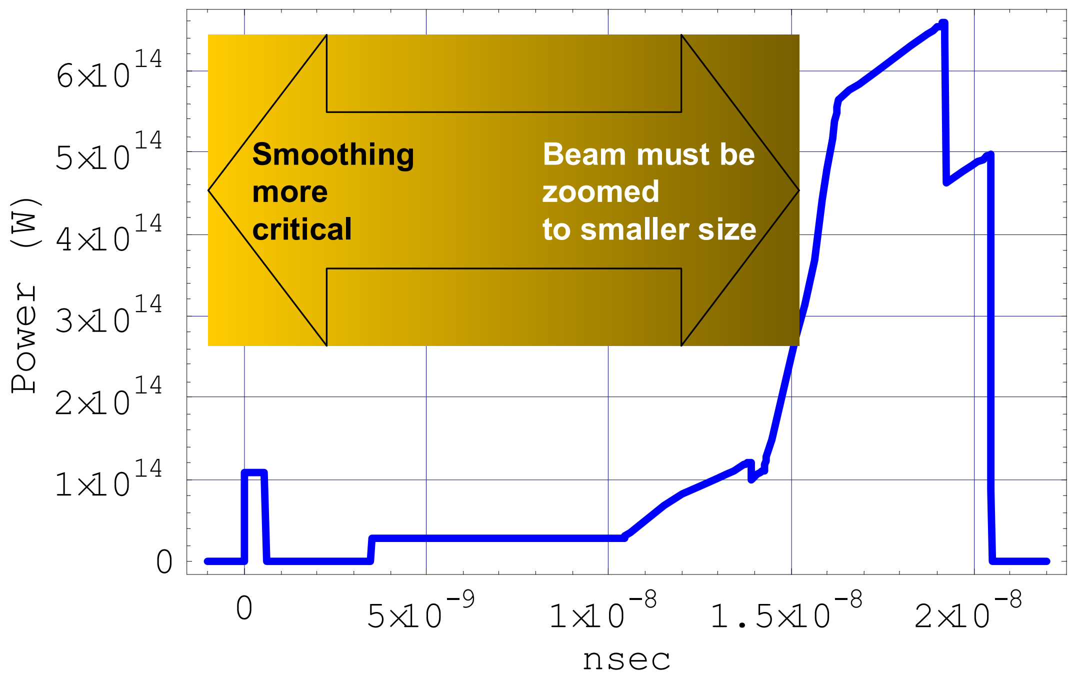


IFE DPSSL will have 16 individual beams per port (4 x NIF) – the 16 beams ("*IFE port bundle*") are the building blocks of a DPSSL driver

RJB/VG

We are investigating the construction of a drive pulse using "*IFE port bundles*" consistent with target and chamber requirements

3.6 MJ target drive pulse



Proposed 2ω drive pulse

- **Target considerations:**
  - **Beam smoothing through speckle averaging is required to eliminate laser imprint**
  - **Dynamic zooming of laser spot is required for efficient utilization of laser energy**

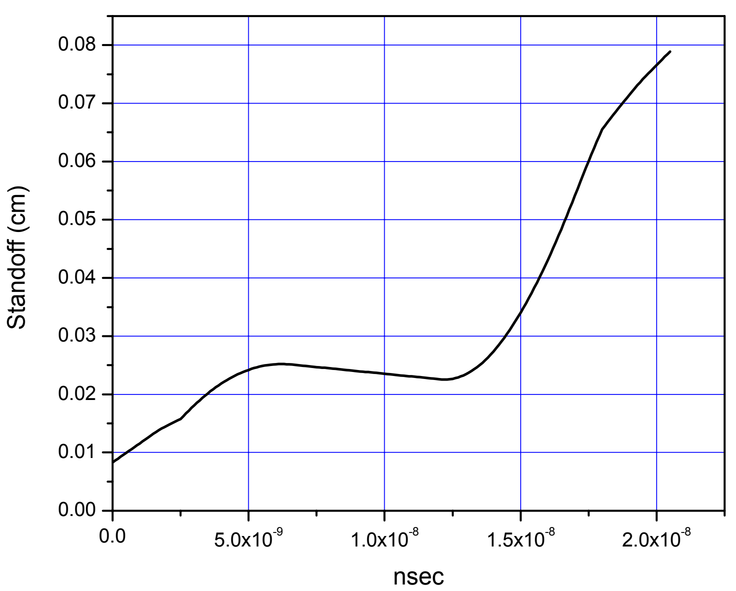
- **Chamber considerations:**
  - **Minimization of solid angle dedicated to laser ports is desired to minimize neutron leakage and achieve adequate tritium breeding**

Smoothing requirements impose a limit on product of target illumination solid angle and laser bandwidth

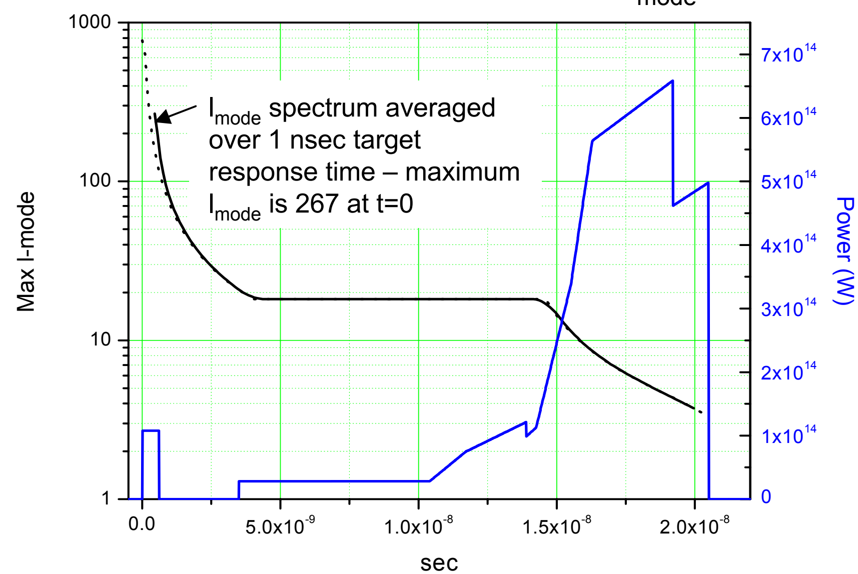
"… low spatial frequency speckle relevant to direct drive is fundamentally determined by the product of the optical bandwidth and the illumination solid angle," – Josh Rothenberg

$$\sigma_{tot}^2 = \frac{1}{(\Delta\nu\cdot\tau)\Delta\Omega_{tot}\left(d_{targ}/\lambda\ell_{\substack{\text{mode}\\ \text{max}}}\right)^2(\pi/2)}$$

Standoff for 0.48 cm dia. target implosion



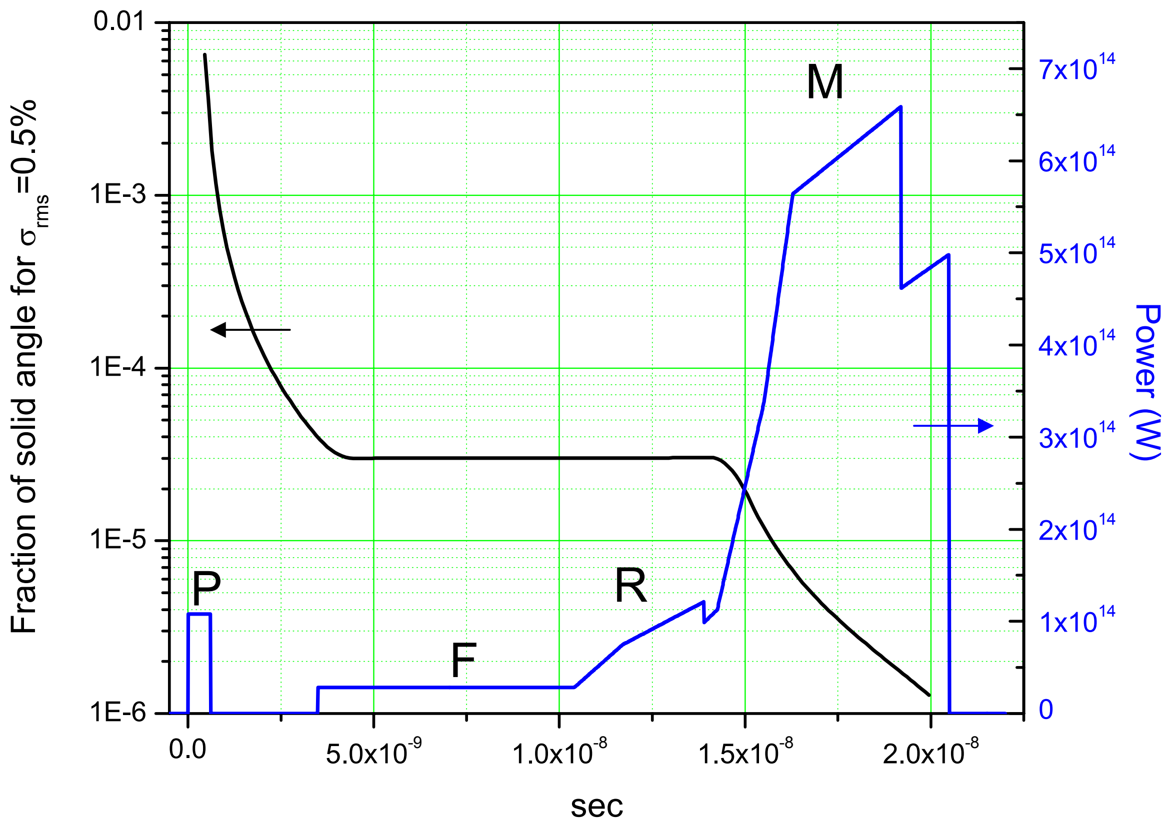
Time resolved maximum l_{mode}



$k_{imprint}\cdot d_{standoff} > 2$ or $l_{mode} > 2r_{critical}/d_{standoff}$ – condition for coronal thermal smoothing of laser imprint where $d_{standoff}$ is distance between ablation front and critical radius

Fraction of solid angle needed for a 300 $GHz_{2\omega}$ pulse to achieve 0.5% σ_{rms} on target between l=0 and the maximum l-mode that impacts target stability

$$\Delta\Omega_{tot} = \frac{1}{(\Delta\nu \cdot \tau)\left(\sigma^2_{\substack{tot \\ \ell=0-\ell_{max}}}\right)\left(d_{targ} / \lambda \ell_{\substack{mode \\ max}}\right)^2 (\pi/2)}$$

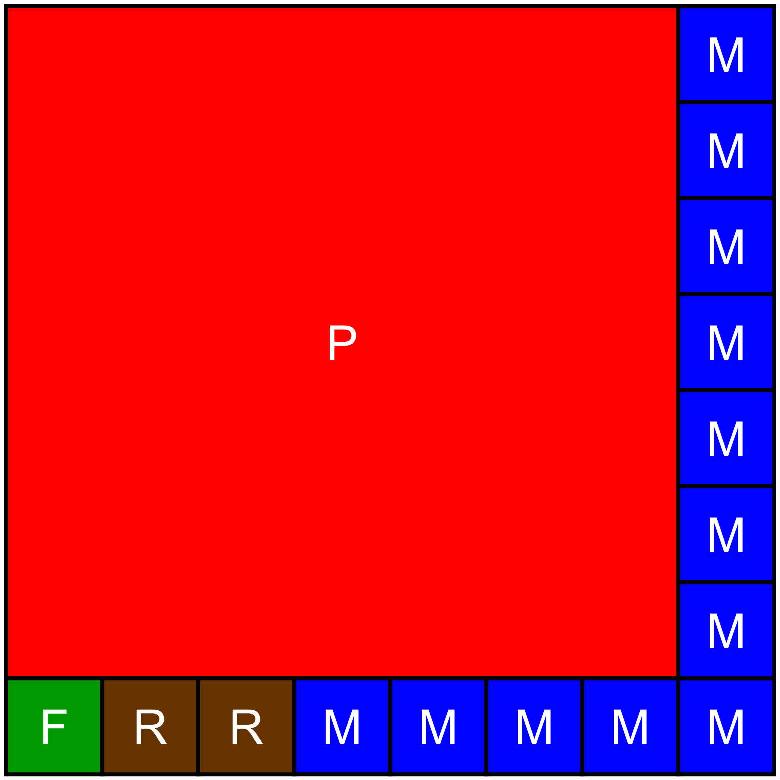


- Target integration time, τ, is 1 nsec
- d_{targ} ~ 4.8 mm
- λ = 523.5 nm
- $\Delta\nu_{2\omega}$ = 300 GHz
- σ_{tot} = 0.5%

The earliest portion of the pulse, the picket, requires the largest solid angle to achieve smoothing (~1% of 4π)

Because the target is most susceptible to laser imprint and subsequent instabilities early in the pulse, the picket requires the largest area in each port bundle for smoothing

Single aperture at 20 m from target



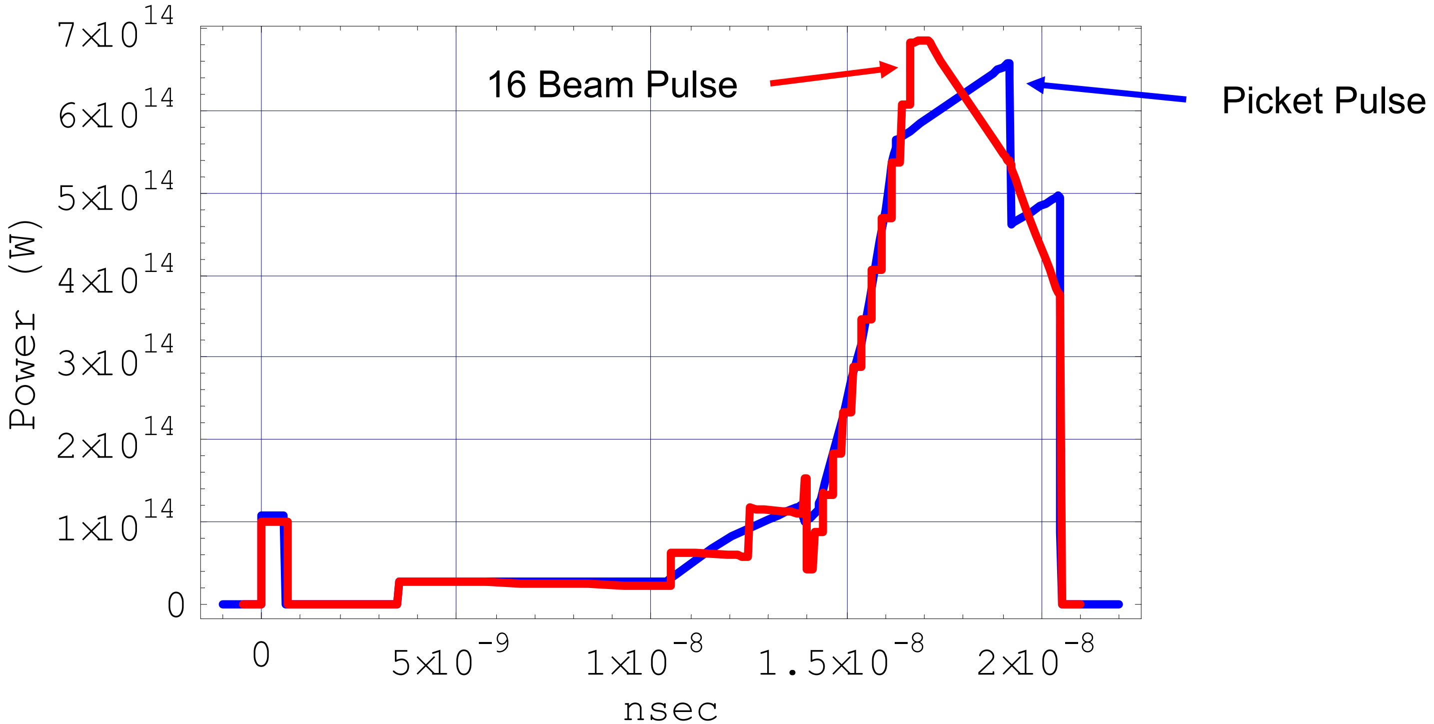
- **Each of the 16 aperture sources ~2.6 $kJ_{2\omega}$**
- **Picket aperture is 72 cm x 72 cm**
  $\Delta\Omega/4\pi$ = 0.99%
- **All other apertures are 10.3 cm x 10.3 cm**
  $\Delta\Omega/4\pi$ = 0.3%
- **Total solid angle dedicated to ports is 1.3%:**

$$\frac{\Delta\Omega_{total}}{4\pi} = \frac{N_{ports}\, A_{port}}{4\pi r^2} = \frac{96(72cm + 10.3cm)^2}{4\pi(2000cm)^2} = 0.013\ (1.3\%)$$

- 10.3 cm beam aperture is consistent with 20 m standoff of final optic, 5 TDL beam, and ~4.8 mm target size
- Spot size at target with 5 TDL beam: $d_{target} = \frac{F\lambda}{d_{beam}} TDL = \frac{20x10^3 mm \cdot 0.5235 \mu m}{10.3x10^4\ \mu m} 5 = 0.51 mm$

Pulse construction from port bundle using only rectangular in time pulses

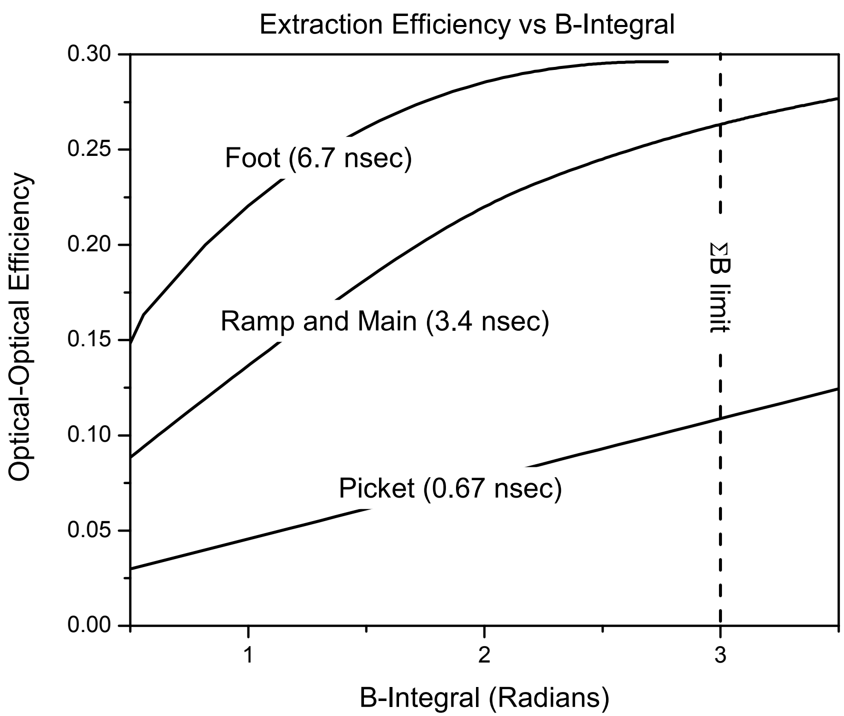
- Picket pulse overlaid with pulse constructed from 16 independently zoomed and overlapped beams (1 Picket,1 Foot, 2 Ramp, and 12 Main)



- **All 12 beams in Main are 4.3 nsec or longer in duration with optical-optical conversion efficiency ~ 0.28 (diode pump light to 1ω)**

- **Harmonic generation issues are mitigated with rectangular in time pulses**

Beam line point design assumes a 13 cm x 20 cm Yb:S-FAP crystal aperture and B-integral limited extraction



Component	Duration	Diode light to 1ω efficiency
Picket	0.67 nsec	0.11
Foot	6.7 nsec	0.29
Ramp	3.4 nsec	0.26
Main	3.4 nsec	0.26

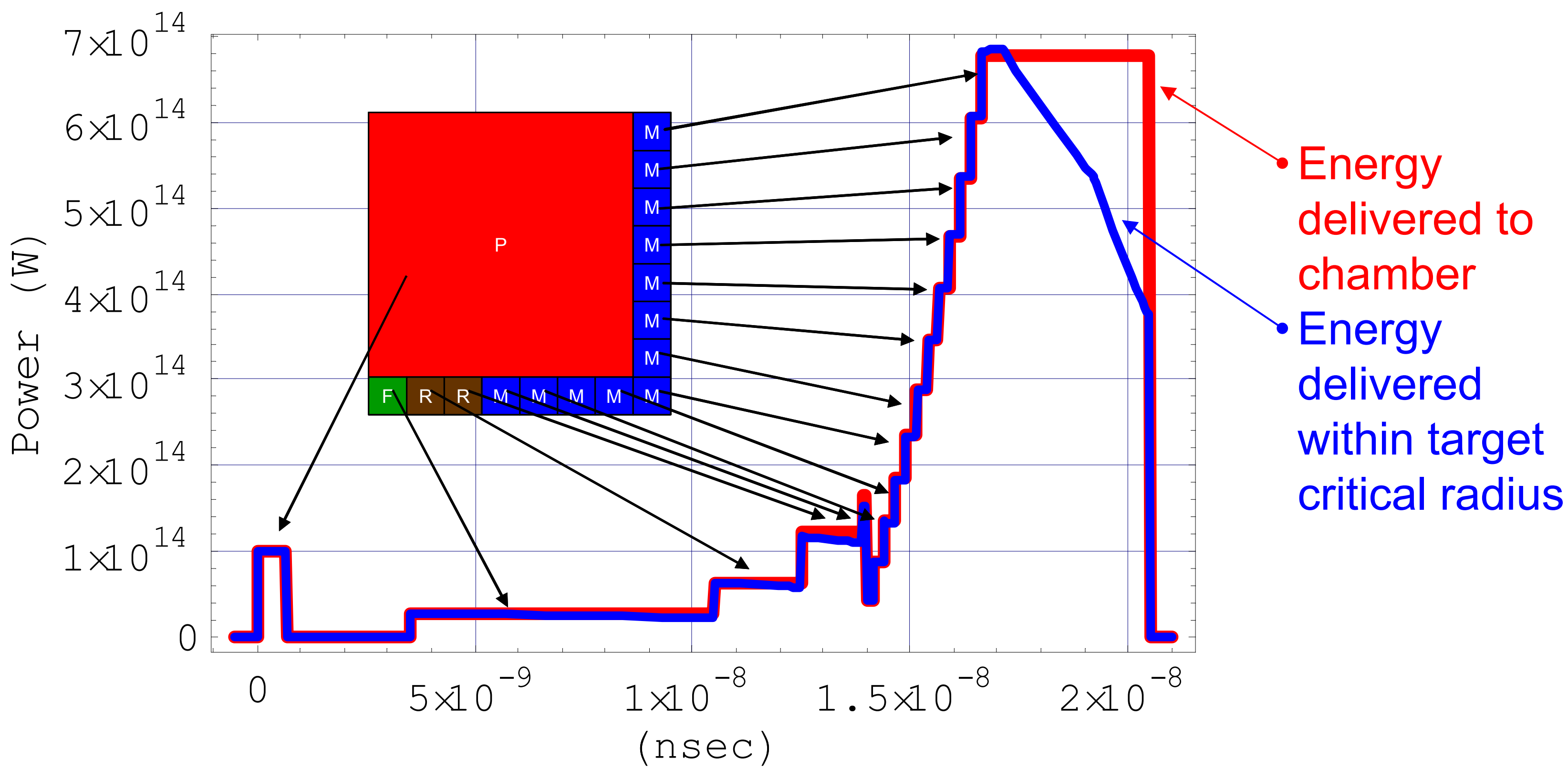
- **Due to B-integral limited extraction, shorter duration components are necessarily generated at lower efficiency**
- **Pulse-averaged optical-optical efficiency (1ω) = 0.25**
- **Each beam is assumed to have 150 GHz of bandwidth @ 1 ω**

Harmonic conversion efficiency

- 1ω irradiance is 3.3 GW/cm^2
- 2ω irradiance is 1.7 GW/cm^2
- 3ω irradiance is 1.1 GW/cm^2
- 4ω irradiance is 0.8 GW/cm^2

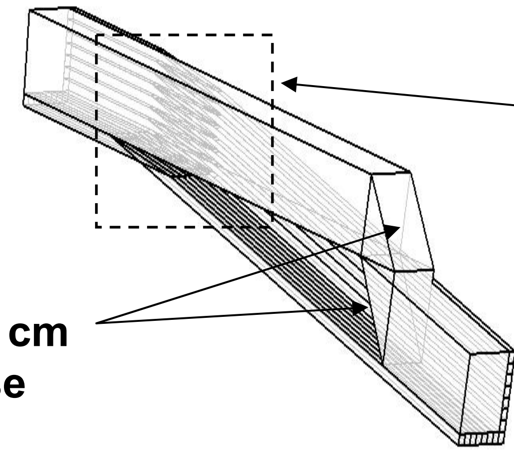
Process	1 ω Bandwidth	Efficiency	diode$\Rightarrow\omega_{final}$ Efficiency
$1\omega \Rightarrow 2\omega$	150 GHz	0.9	0.23
$1\omega \Rightarrow 3\omega$	100 GHz	0.8	0.20
$1\omega \Rightarrow 4\omega$	75 GHz	0.8	0.20

Independent zooming enables 88% of total pulse energy delivered to chamber to intercept target within critical radius

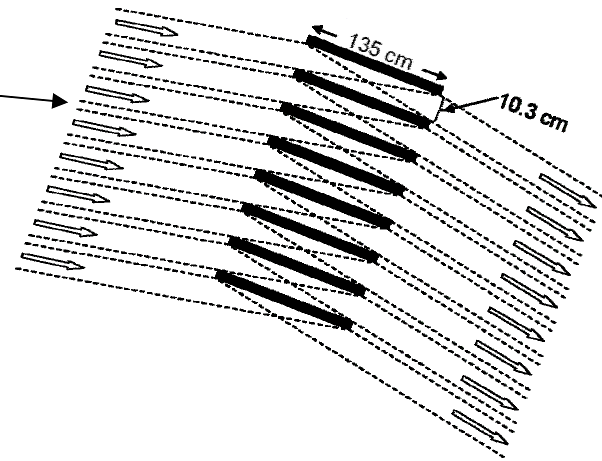


- **Total Pulse Energy = 4.02 MJ**
- **With zooming as shown, 3.55 MJ falls within time resolved critical radius**
  - **88% of pulse energy**
- **Without zooming, only 2.52 MJ falls within time resolved critical radius**
  - **63% of pulse energy**

Final optics scheme for port bundle – louvered GIM design

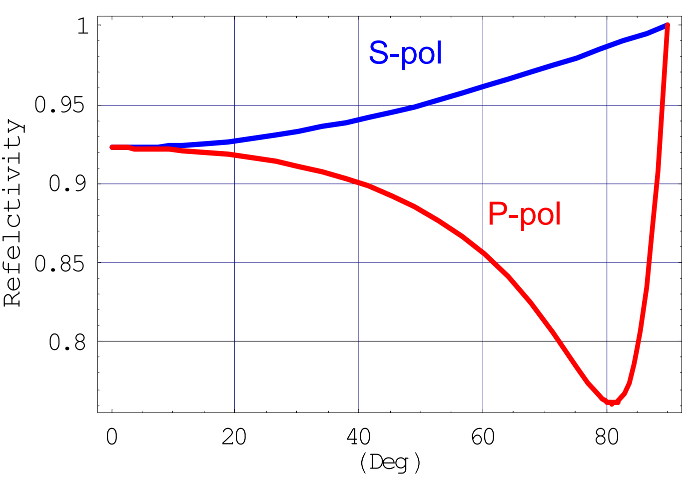


Mirrors for 72 cm x 72 cm picket pulse



GIMs for 15 pulse components that are after the picket

Al Reflectivity



- **Small GIMs for 10.3 cm x 10.3 cm beams need to be 135 cm in length (θ_{inc}=85.6°) to limit absorbed fluence to 10 mJ/cm²**
  - for S-polarized green light

- **Single GIM for the large area picket portion of the pulse (72 cm x 72 cm) would require a *9.45 m* long optic**

- **Two mirrors as small as *1.02 m* long can be used to replace the single large picket GIM (as shown above)**

Summary

- **Based on a "NIF-like" architecture, we are proposing "*chamber bundles*" as the basic building block of an IFE DPSSL driver**
- **Chamber bundles permit both zooming and smoothing to meet target and chamber requirements**
- **Concept is applicable to 1ω laser engine with 2ω, 3ω or 4ω harmonic conversion option**
- **We have developed a final optics concept that uses meter size GIMs**
- **The next step will be to update laser architecture, and cost scaling models**