U.S. NAVAL RESEARCH LABORATORY

# Need for and development path to a next generation laser driver for ICF /IFE

Fusion Power Associates Meeting
Grand Hyatt Hotel, Washington D.C.
STRATEGIES AND EXPECTATIONS THROUGH THE 202Os

**Presented by Stephen Obenschain**
**Laser Plasma Branch**
**Plasma Physics Division**

December 4, 2018

Work supported by DOE-NNSA

PLASMA PHYSICS DIVISION
NAVAL RESEARCH LABORATORY

# Improvements needed to advance laser fusion towards robust high performance (high yield, high gain, repeatable)

NRL PPD

Higher precision in the S&T underpinnings for ICF

- Physics understanding and simulation codes
- Diagnostics on the lasers and targets
- Target fabrication ...

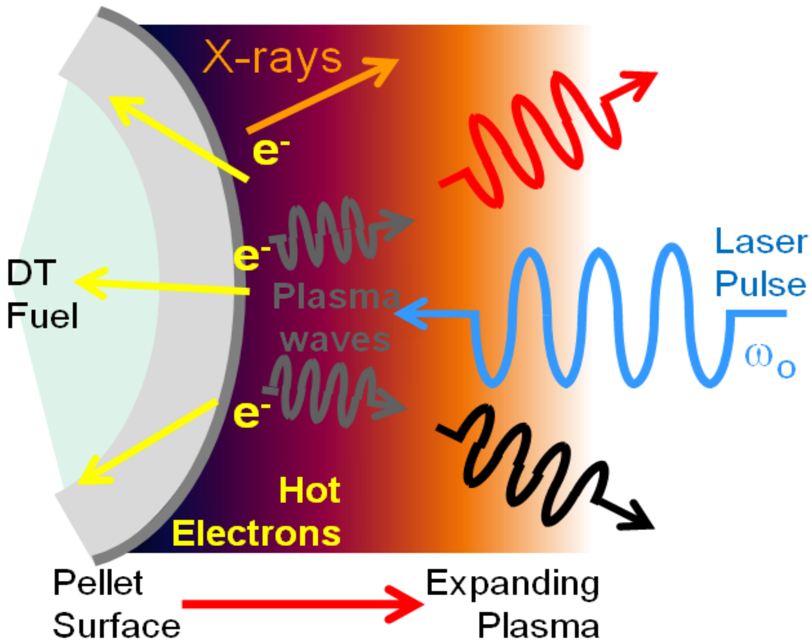
Next generation laser driver

- Resistant to laser plasma instability (broader bandwidth and deeper UV)
- Higher repetition rate (many shots per day)
- Capable of high performance direct laser drive (high-gain and fusion yield)

# Laser plasma instabilities (LPI) cause problems for ICF and HED experiments

NRL PPD

- LPI produced high energy electrons can preheat target impeding its compression.
- LPI induced scattering reduces laser drive and can spoil symmetry.
- LPI limits the maximum usable laser intensity and ablation pressure

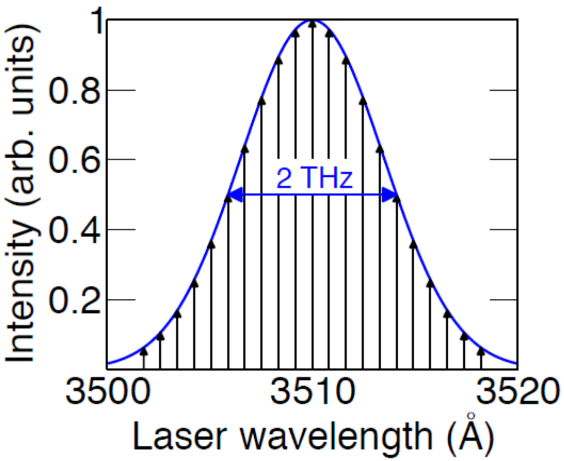


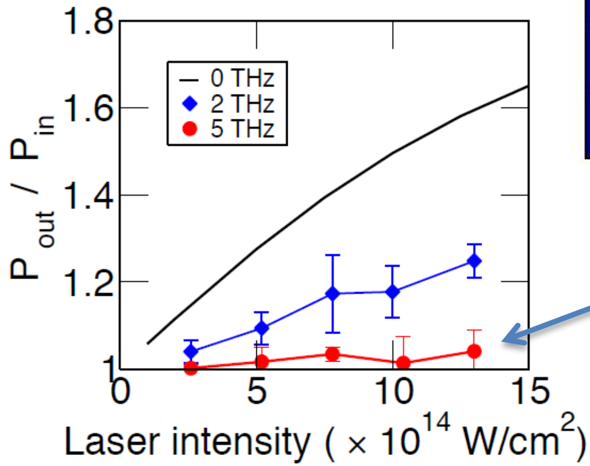

- ➢ Short laser wavelength increases the instability intensity thresholds
- ➢ Broad laser bandwidth can disrupt the coherent wave-wave interactions that produce LPI

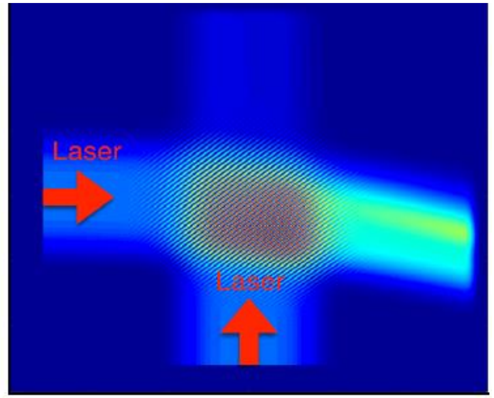
# Simulations utilizing LLE's LPSE code indicate cross beam energy transport (CBET) can be suppressed with broad laser bandwidth

NRL PPD

Simulations show that 2 THz bandwidth produced by discrete randomly phased lines begins to mitigate CBET, while 5 THz has a large effect



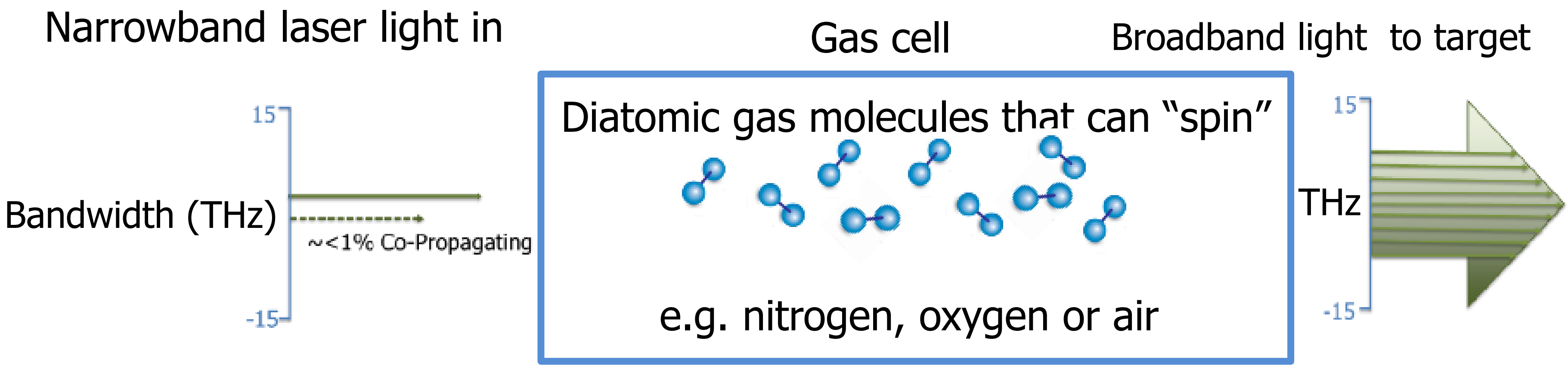




CBET almost eliminated with 5 THz bandwidth

Mitigation of cross-beam energy transfer in inertial-confinement-fusion plasmas with enhanced laser bandwidth, J. W. Bates, J. F. Myatt, J. G. Shaw, R. K. Follett, J. L. Weaver, R. H. Lehmberg, and S. P. Obenschain, Phys. Rev. E 97, 061202(R) – Published 18 June 2018. https://journals.aps.org/pre/abstract/10.1103/PhysRevE.97.061202

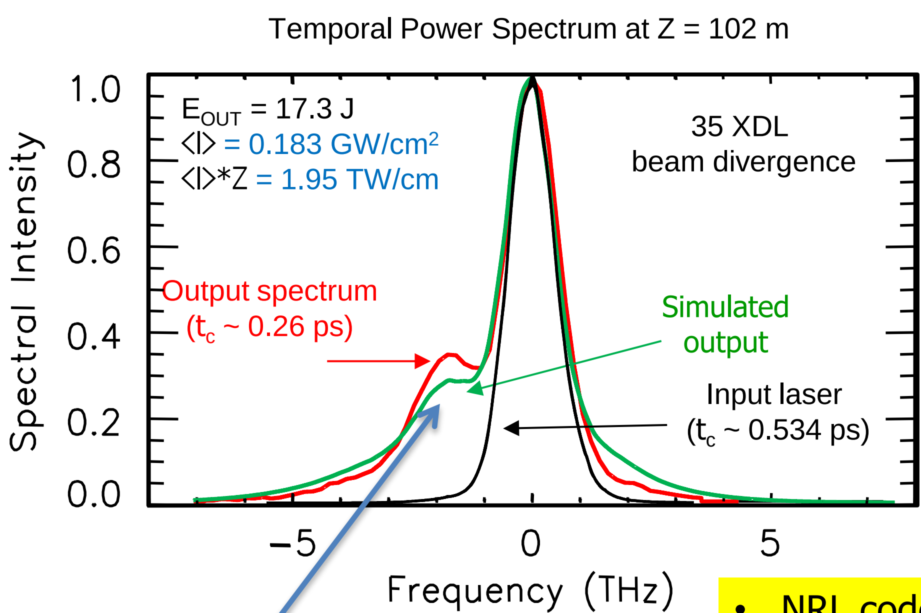
# Seeded Stimulated Rotational Raman Scattering (SRRS) could provide the bandwidth needed to suppress LPI/CBET with existing ICF lasers

NRL PPD

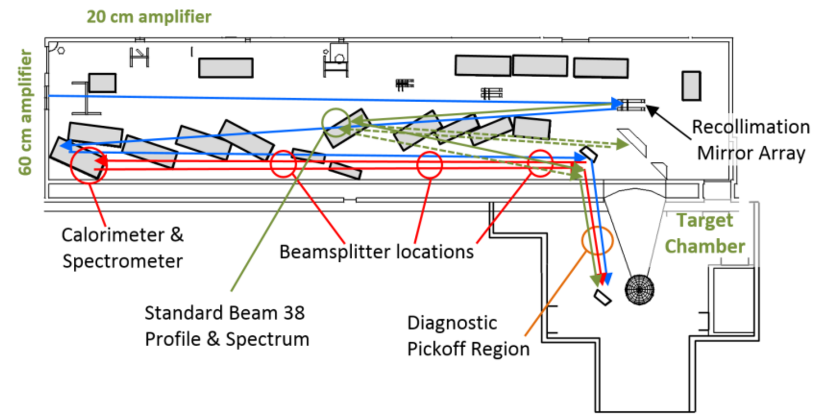



*Advancing the S&T of SRRS enhanced laser bandwidth is underway at NRL*

# We have agreement between SRRS generated on a Nike beam and an NRL developed SRRS simulation code




Data taken using one of Nike's beams with its path extended in air




- NRL code is 1st to deal with SRRS with partially coherent laser light

SRRS is self seeded by tail of the Nike beam's spectral distribution

Spectral and far-field broadening due to stimulated rotational Raman scattering driven by the Nike krypton fluoride laser, J. Weaver, R. Lehmberg, et al. *Applied Optics* 2017
https://www.osapublishing.org/ao/abstract.cfm?uri=ao-56-31-8618

# New NRL facility will advance the S&T of seeded SRRS using the Nd:glass laser technology employed on NIF and OMEGA

NRL PPD

Beam combiner

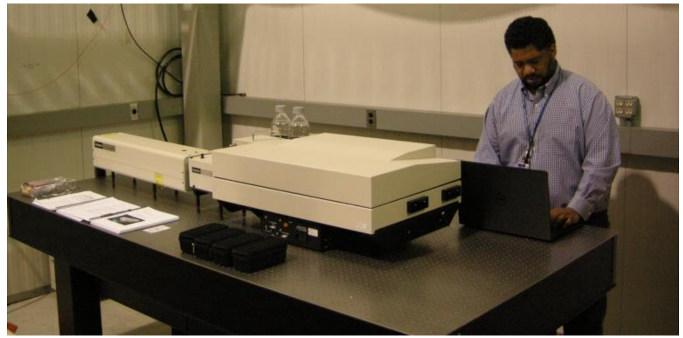
527 nm Nd:glass laser
10 J in 1-3 ns

Expect delivery in December

10's of meters air, nitrogen or deuterium optical paths

- Time resolved spectra
- Laser focal distribution
- Laser pulse shape

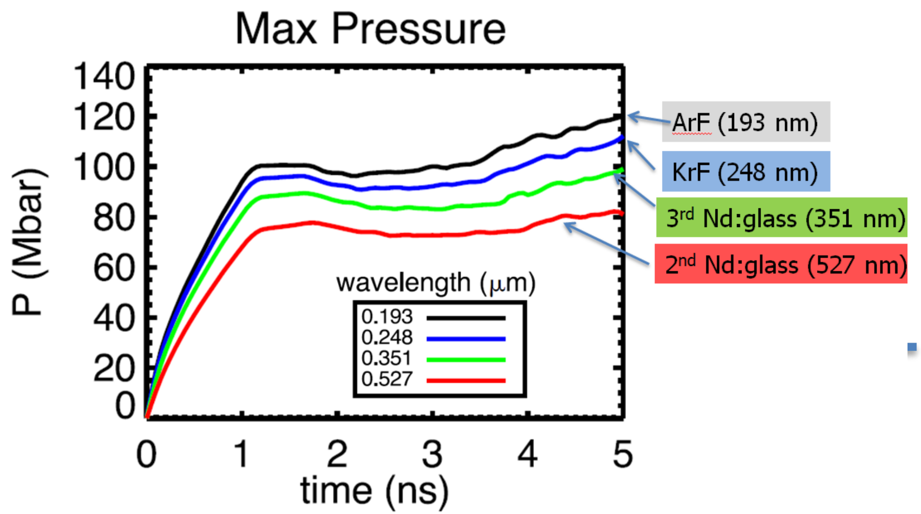
Tunable low energy laser (red shifted)



# Deeper UV light improves hydro efficiency and increases LPI thresholds

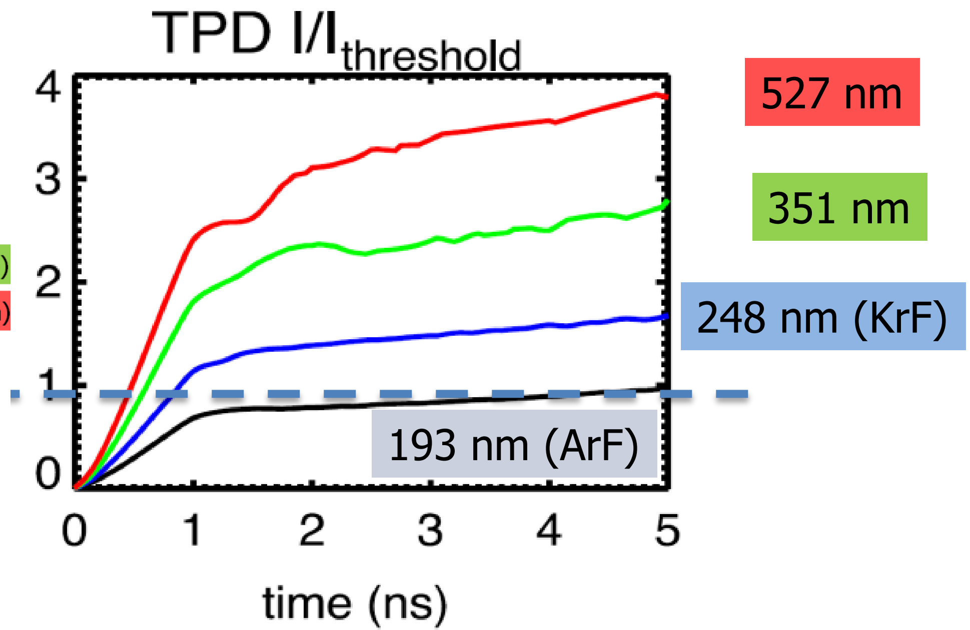
NRL PPD

**Ablation pressure vs laser λ from hydrocode**
$10^{15}$ W/cm$^2$ 2.6 mm solid CH sphere



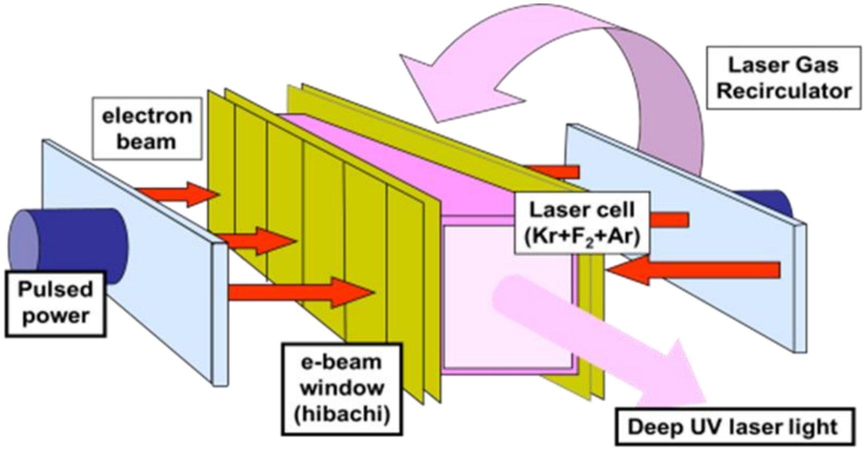

Direct drive ablation pressure increase's with shorter laser wavelength

**TPD thresholds vs laser λ from hydrocode**
$10^{15}$ W/cm$^2$ 2.6 mm solid CH sphere




In this simulation one remains below the TBD threshold with 193 nm light

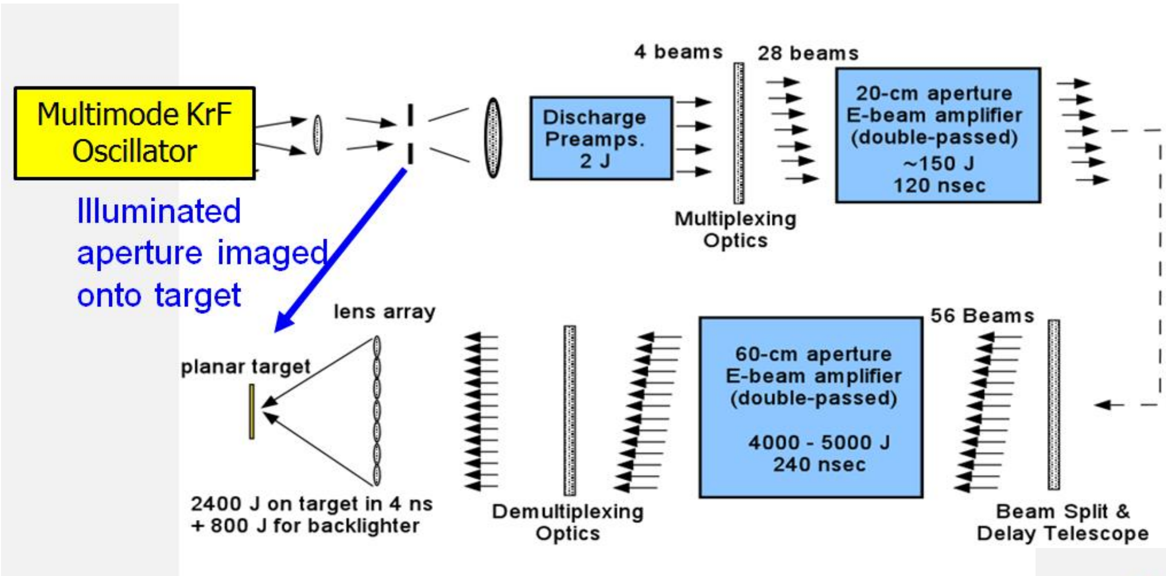
# KrF and ArF excimer laser drivers are attractive driver candidates for ICF – deep UV and broad native bandwidth



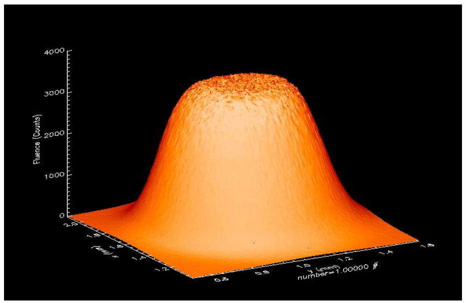

Nike 60-cm aperture KrF amplifier

- Gas laser (easier to cool enabling faster shot rate)
- Electron beam pumping for large amplifiers
- The NRL Nike 3-kJ KrF system (248 nm with up to 3 THz bandwidth) has operated for 23 years
- Electra KrF system demonstrated 5 pulses per second operation for hours
- The deeper UV (193 nm) and broader native bandwidth ArF laser would provide still better light for ICF

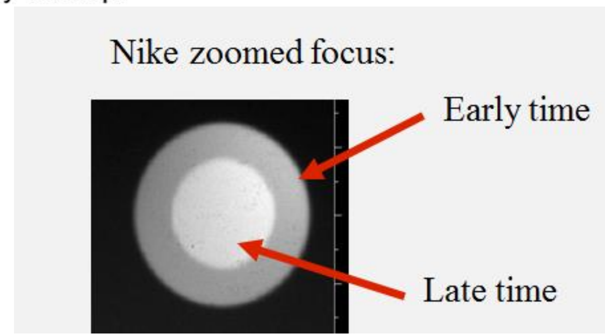
# Excimer angularly multiplexed laser optical systems provide high target illumination uniformity and easy implementation of focal zooming




Nike KrF optical system with ISI smoothing
An ArF system would be similar



Time averaged laser spatial profile in target chamber



# Why ArF for ICF?

NRL PPD

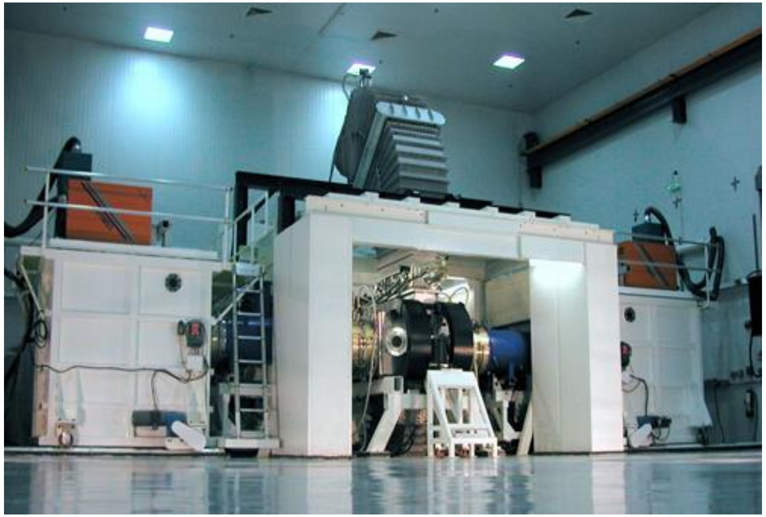
- Deepest UV laser (193 nm) with capability to reach energies needed for ICF
- Expect 5 THz+ native bandwidth capability onto target
- Compatible with ISI beam smoothing and focal zooming implemented on Nike
- Should have substantially higher intrinsic efficiency than KrF's ~12% -- would lower cost of e-beam driver and good for IFE.

NRL has started a small program to advance basic election-beam pumped ArF S&T and evaluate the ICF application.

# NRL 6.1 funded effort will advance the basic physics of E-beam pumped ArF laser using the Electra facility

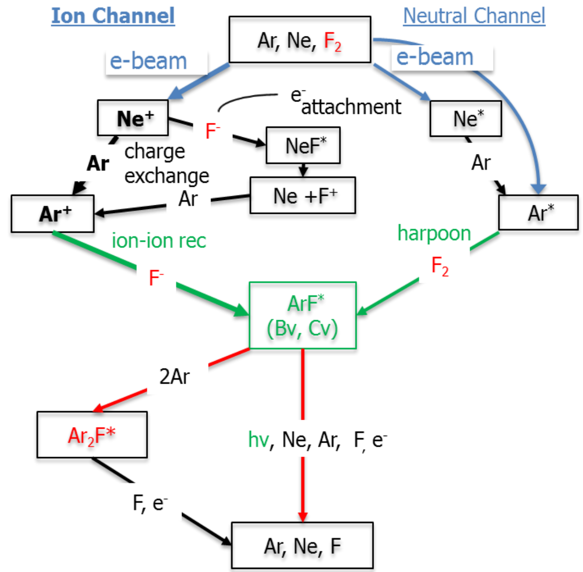
NRL PPD

## Parametric experimental studies on Electra



## ArF theory and simulations

**Modify & validate NRL Orestes laser kinetics model for ArF**



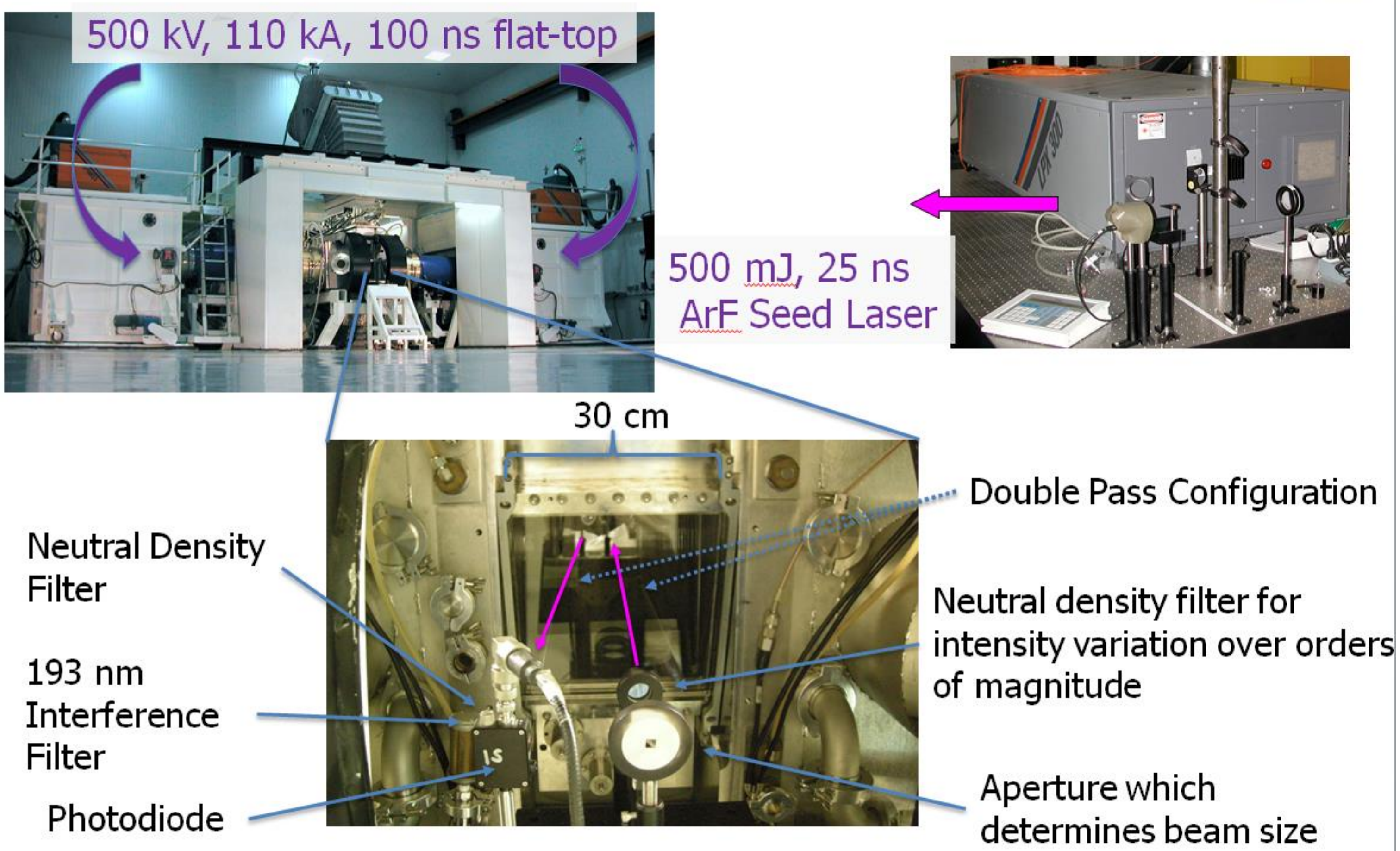

**Notes**

- ArF can utilize electron-beam pumping developed for KrF
- But details are different – lower gain and higher saturation flux
- ArF lithographic industry has developed durable 193 nm optics – need to be scaled up in size for ICF

# ArF Small Signal Gain Measurements Experimental Hardware

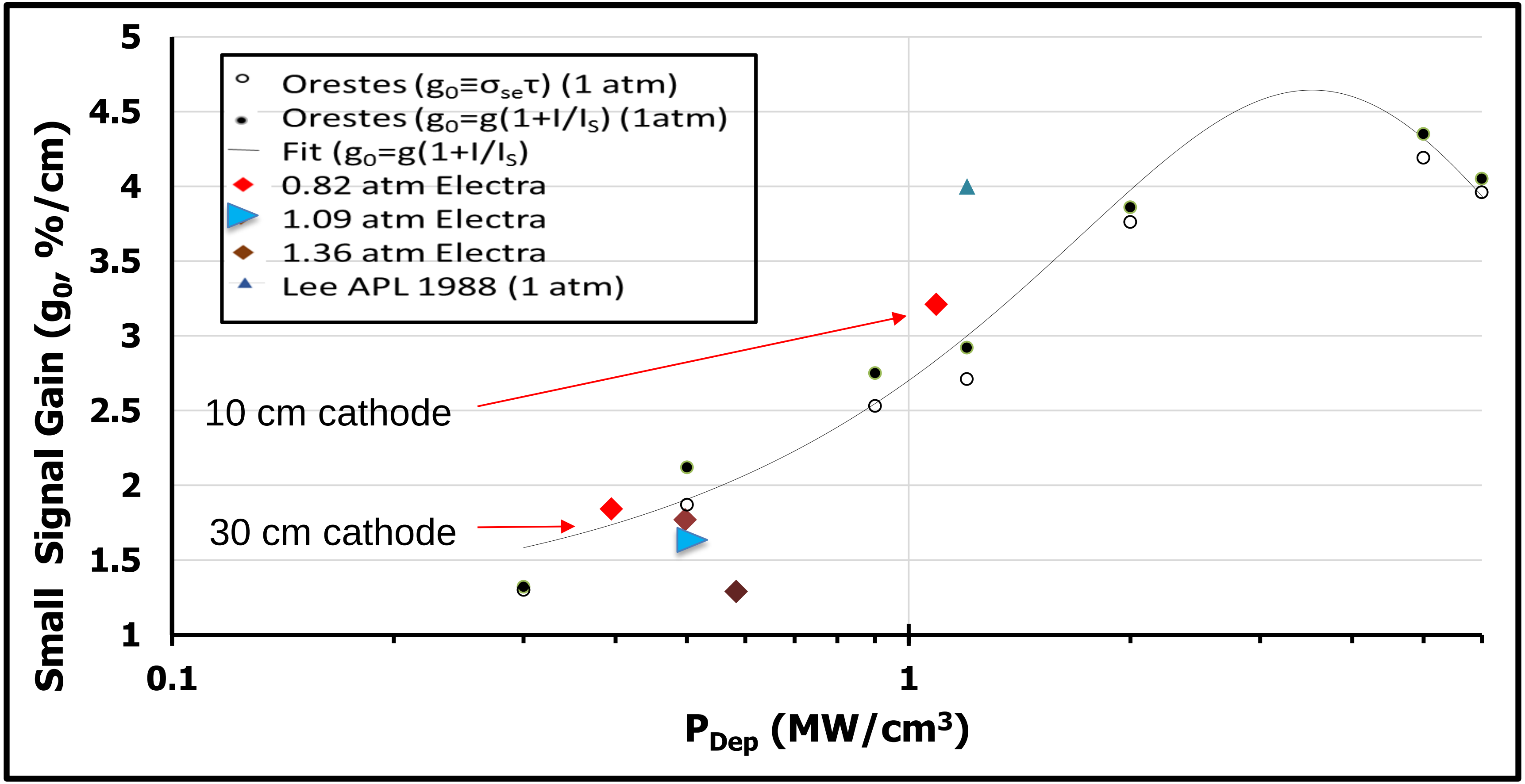
## Uses Electra amp with cathode height reduced 3x to increase current density



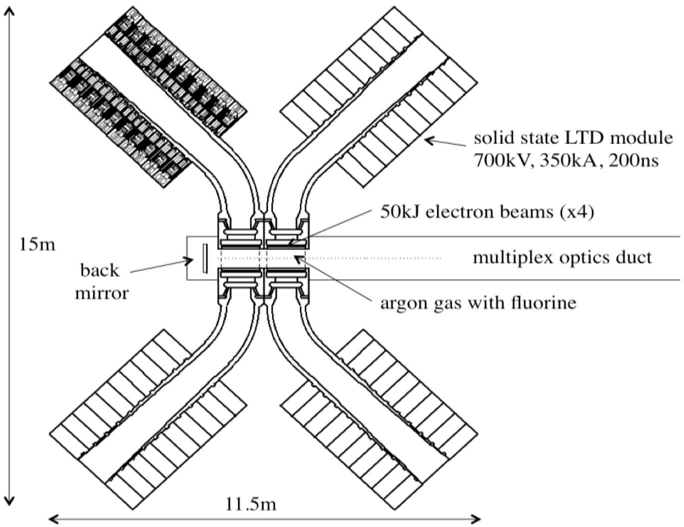


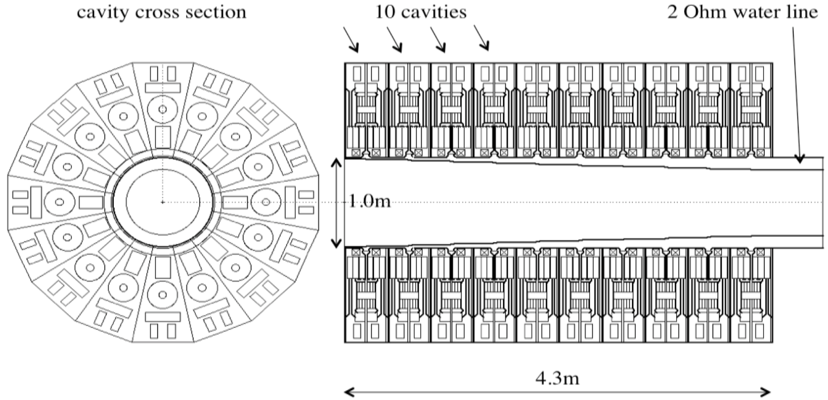
# Kinetic simulations agree well with Electra ArF gain measurements and literature.

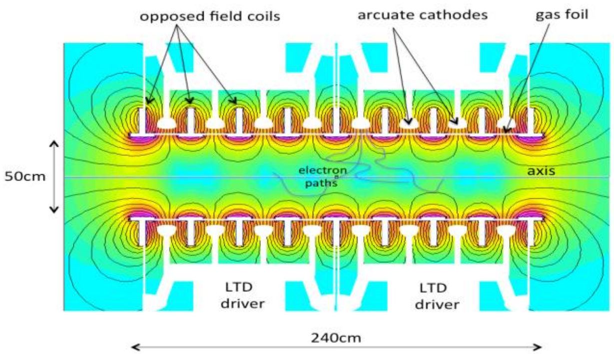
NRL PPD

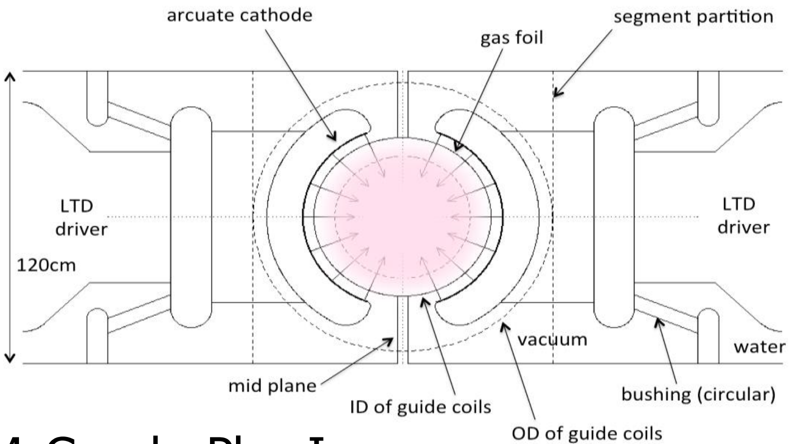


# Concept for a high-energy e-beam pumped ArF laser amplifier using axial pumping and LTD pulsed power to reduce the footprint




M.W. McGeoch, Plex Inc

# Phased program that could lead to a high-gain high-fusion yield implosion facility using an ArF laser driver

NRL PPD

### Phase I

Advance basic E-beam pumped ArF laser S&T

Develop/evaluate high energy ArF architecture designs

Evaluate potential for robust high fusion yield/high-gain ArF direct drive implosions

3 years

A-OK →

### Phase II

Design and build high energy (~20 kJ) ArF beamline

LPI/hydro experiments with above to check ArF laser-matter interactions

Develop basic design for a 2 MJ class implosion facility & estimate cost

6 years

A-OK →

### Phase III

Design and build ~2MJ implosion facility

High rep rate (many shots per day) for experiments

Optimized for direct drive with goal of high yield and gain (>200 MJ and >100x)

Also applicable to indirect drive

ICF/SSP and IFE missions

↓

**Evaluate and develop energy application:**
~10 Hz operation, tritium breeding, chamber longevity, safety, economics…