U.S. NAVAL RESEARCH LABORATORY

ICF physics research at NRL

Fusion Power Associates Meeting

Washington DC

13-14 December 2016

Stephen Obenschain
Laser Plasma Branch
Plasma Physics Division

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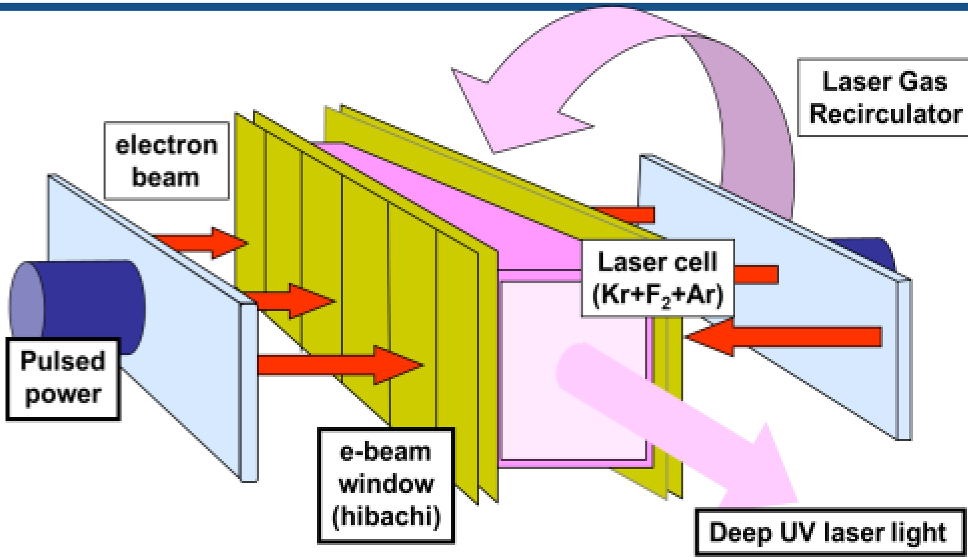
Current Research Efforts

NRL PPD

- NRL is working closely with LLE to develop the physics understanding and potential of direct-drive laser fusion (experiments, diagnostics and simulation codes)
- Hybrid x-ray/direct drive approach using high-Z layers to mitigate laser imprinting has been migrated to OMEGA-EP.
- Use of laser bandwidth produced by Stimulated Rotational Raman Scattering (SRRS) in air is being explored as a means to reduce CBET observed on OMEGA implosions.
- The Nike KrF facility remains our on-site workhorse for a variety laser-matter interaction experiments.
- Potential of still deeper UV ArF laser as an IC driver is being explored.

NRL uses and is advancing the excimer laser for ICF

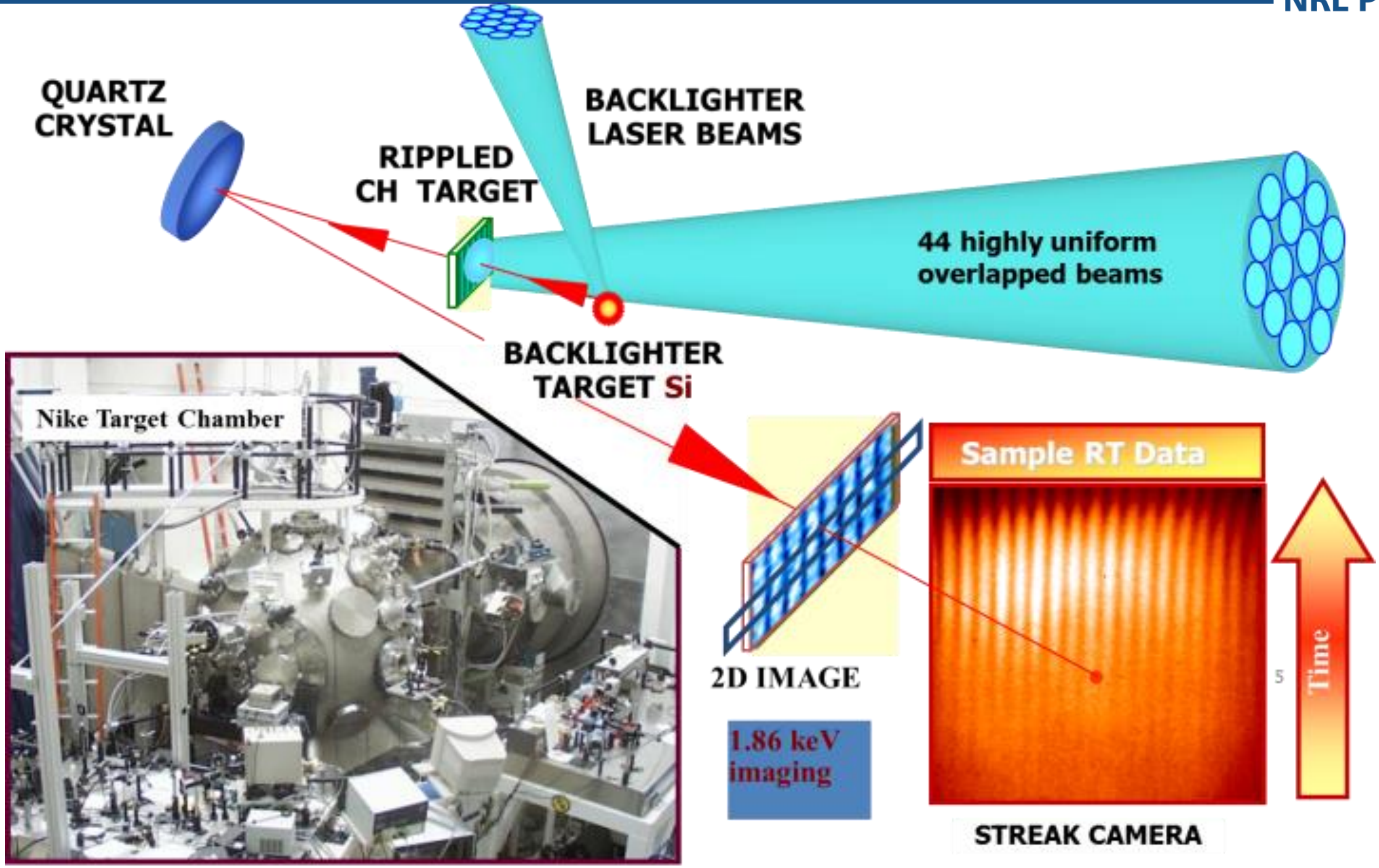


Nike 60-cm aperture KrF amplifier

- Gas laser versus glass used in NIF (easier to cool enabling faster shot rate)
- Electron beam pumped laser media versus flashlamp light with NIF.
- KrF's deep UV wavelength (248 nm), superior beam smoothing, and capability to zoom down the focal diameter provide enhanced capability to achieve high-performance direct-drive laser fusion.

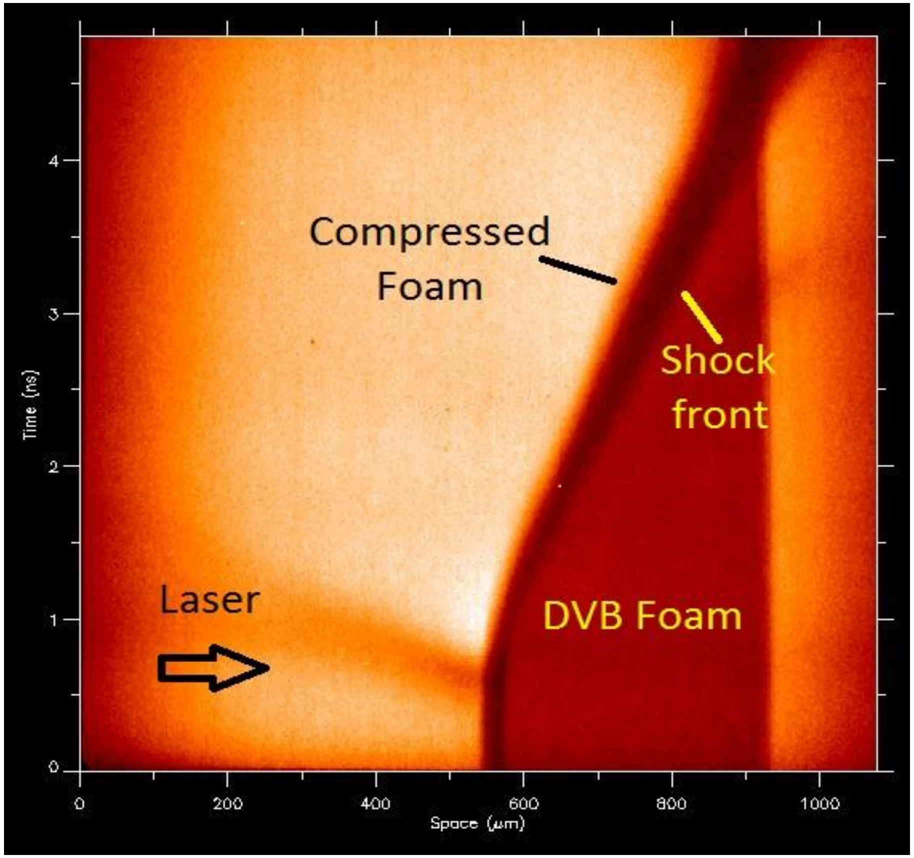
News: We have begun the basic exploring the potential and feasibility of the still deeper UV (193 nm) ArF laser

Nike KrF laser system is employed for basic laser-matter interaction experiments in planar geometry

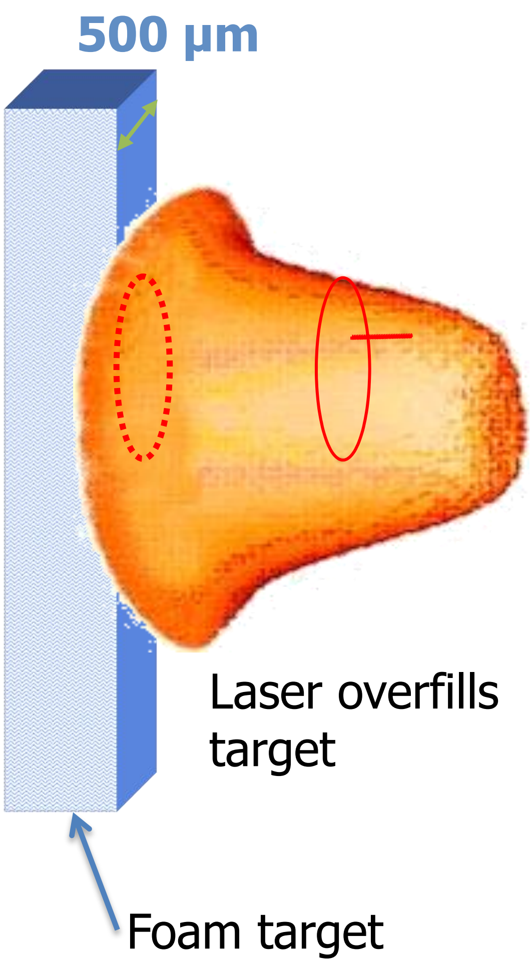


Advancing the basic physics of multi-megabar shock propagation in low density foam targets on Nike

Foams are complex materials that will no behave exactly as uniformly distributed matter

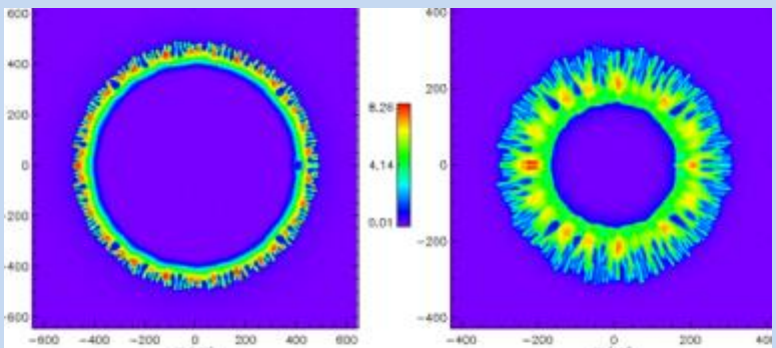


Near monochrome x-ray side-lighting @ 1.8 KeV

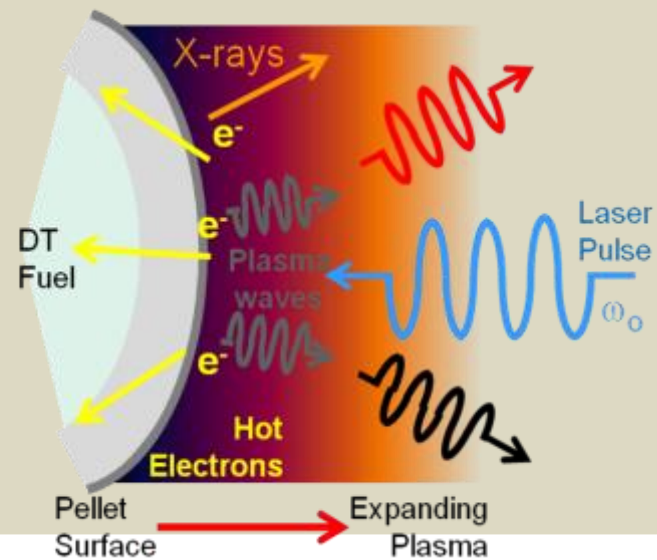


Two primary challenges for Direct Laser Drive

Even with smoothed laser beams there can be early time laser imprint that seeds hydro-instability.



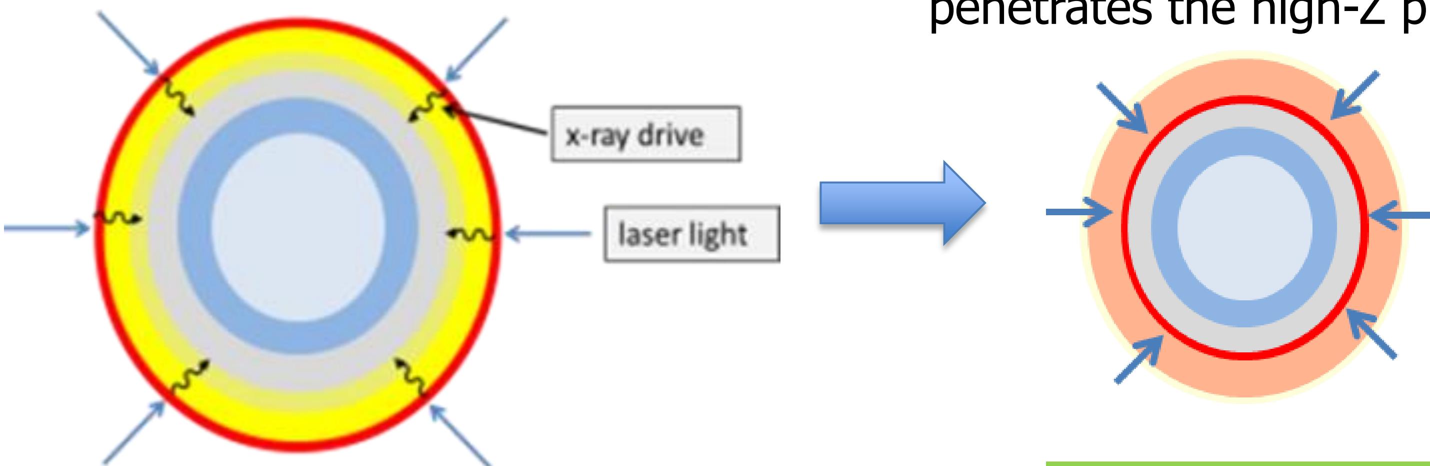
Laser plasma instability limits maximum laser intensity for direct and indirect laser drive.



Hybrid concept: thin high-Z layer on direct drive pellet produces early time x-ray drive that mitigates laser imprint

Initial X-ray drive

Later time direct drive when laser penetrates the high-Z plasma.

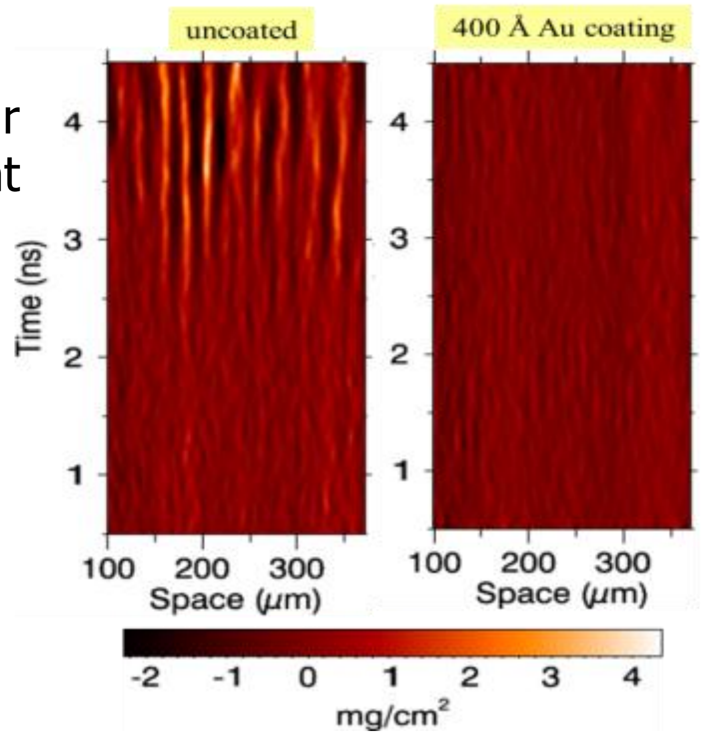


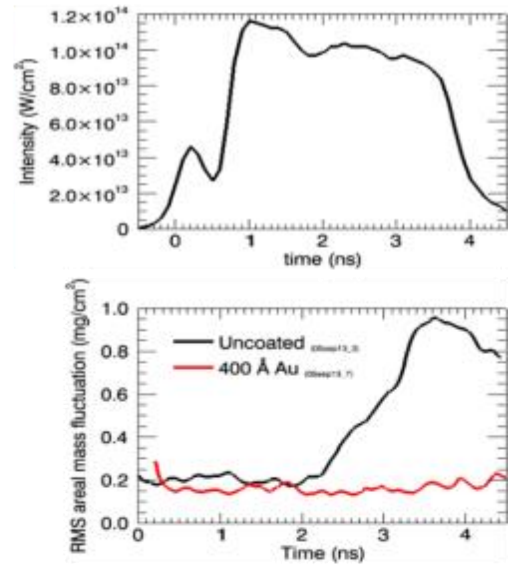
Efficiency of direct drive retained!

Spatial separation between laser absorption in the high-Z (Au or Pd) plasma and the x-ray driven pellet smooths imprint from laser nonuniformities.

Nike experiments confirm laser imprint reduction and suppression of hydro instability with high –Z layers.

Nike planar Experiment

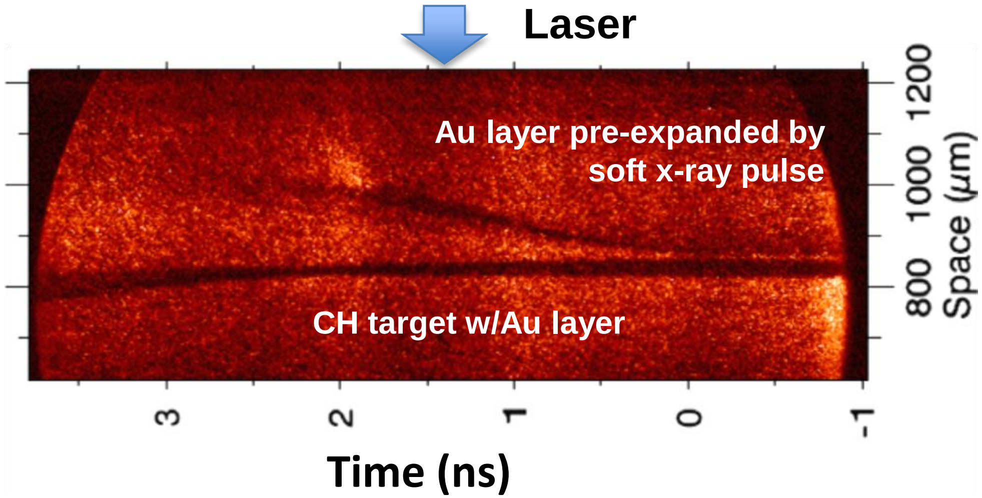




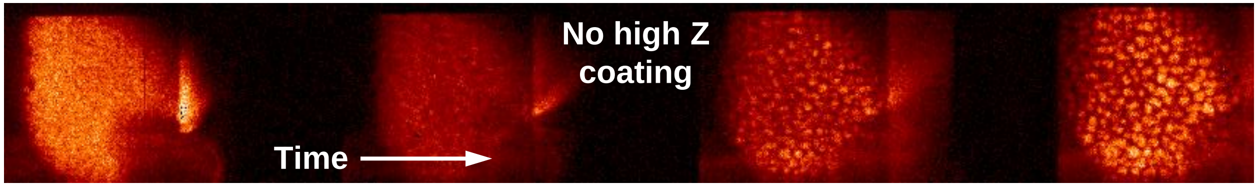
Max Karasik, J. L. Weaver, Y. Aglitskiy, J. Oh, and S. P. Obenschain Phys. Rev. Lett. 114, 085001 – Published 26 February 2015

But will this approach also work with frequency tripled Nd:glass lasers used on OMEGA and NIF?

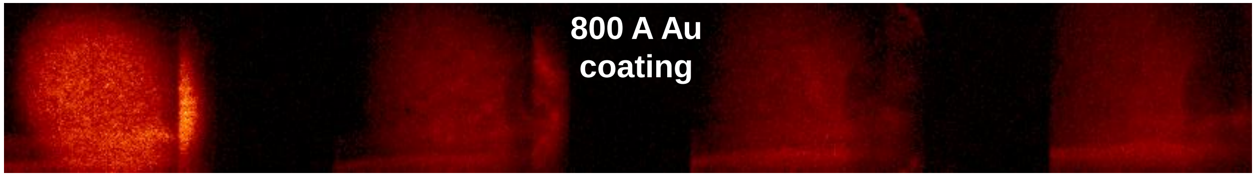
OMEGA-EP experiment showed that a high-Z layer pre-expanded by soft-x rays greatly reduced laser imprint



Face-on radiography (Omega EP) shows RT amplified imprint w/o Au layer



Radiographs with a pre-expanded Au layer show no measureable imprint



Is there a similar “magic bullet” for mitigating laser plasma instability to the high-Z layer?

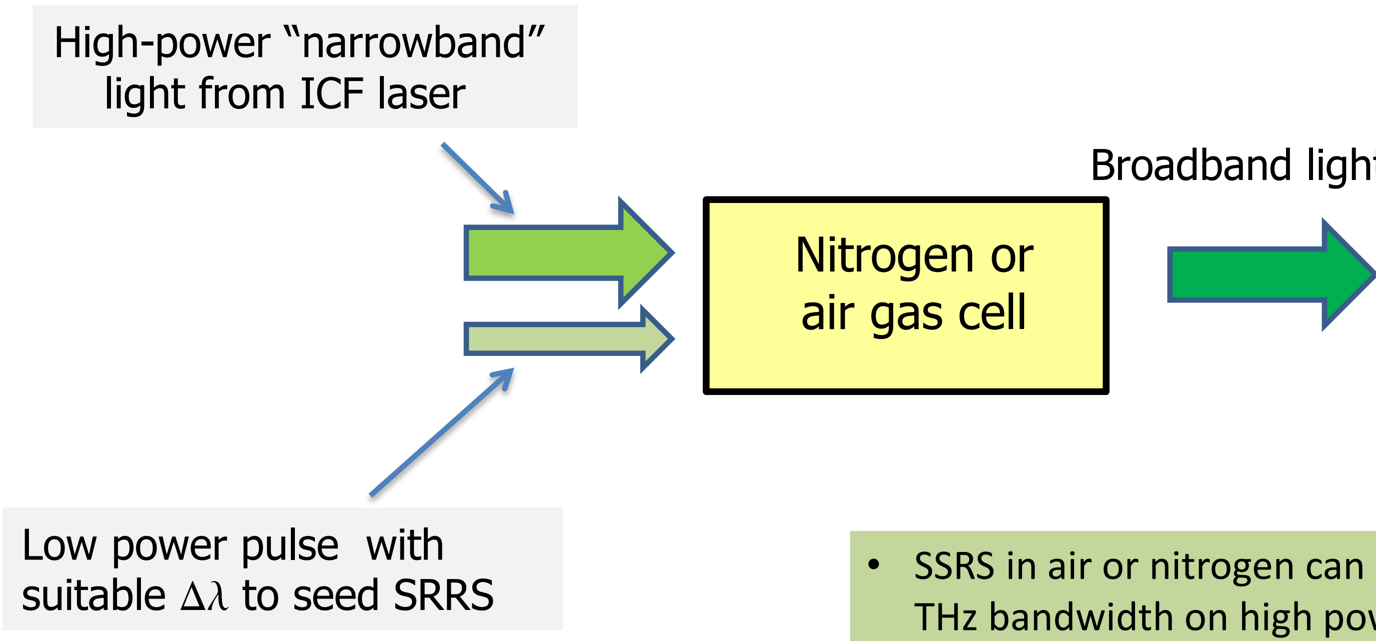
NRL PPD

Laser plasma instability (LPI) and the related Cross Beam Energy Transfer (CBET) complicate the laser-target interaction and limit the performance.*

- Very broad laser bandwidth has been predicted theoretically to reduce growth of laser plasma instability. (mid 1970’s – present)
- This effect has been observed in microwave-plasma interaction experiments. (mid 1970’s UCLA, UCD)
- But current ICF lasers cannot natively provide such bandwidths.
- Stimulated Rotational Raman Scattering (SRRS) in diatomic gases was proposed as a means to obtain such wide bandwidths (1980’s and 90’s)
- NRL has begun a substantial effort – now joined by LLE – to investigate if SRRS can provide the needed bandwidth to suppress CBET and other LPI.

Stimulated Rotational Raman Scattering (SRRS) in air may provide the bandwidth needed to suppress LPI/CBET with existing ICF lasers

NRL PPD

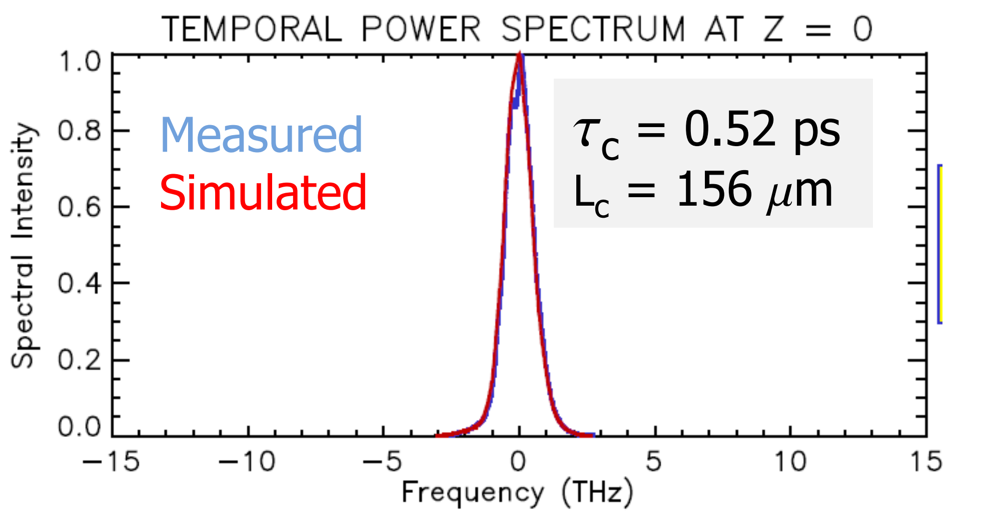


- SSRS in air or nitrogen can impose 5-10 THz bandwidth on high power beam.
- Initial SRRS experiments are underway on NRL Nike system.

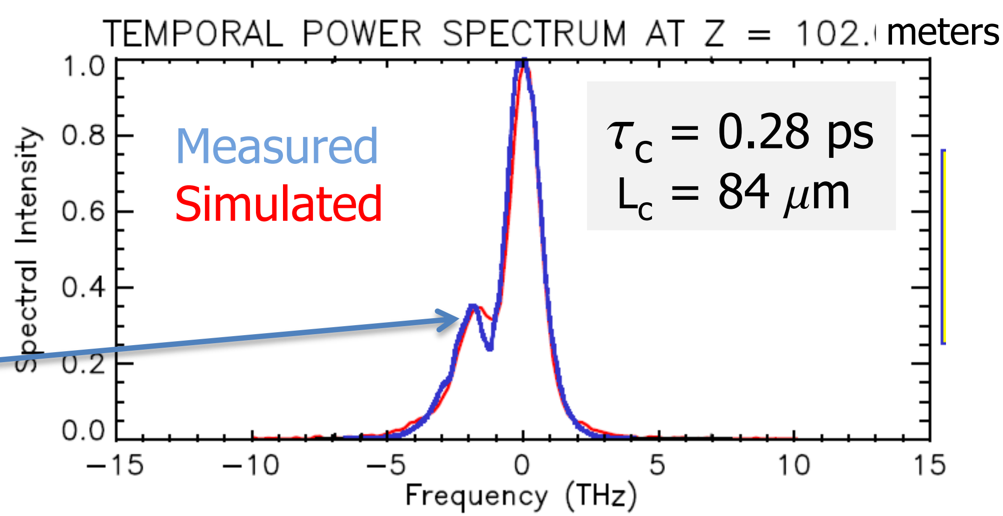
SRRS experiments on Nike is used to test code predictions

NRL PPD

Native KrF beam bandwidth (~1 THz FWHM) and after traversing 102 meters in air



coherence time = τ_c
coherence length =L_c
$L_c = c \times \tau_c$



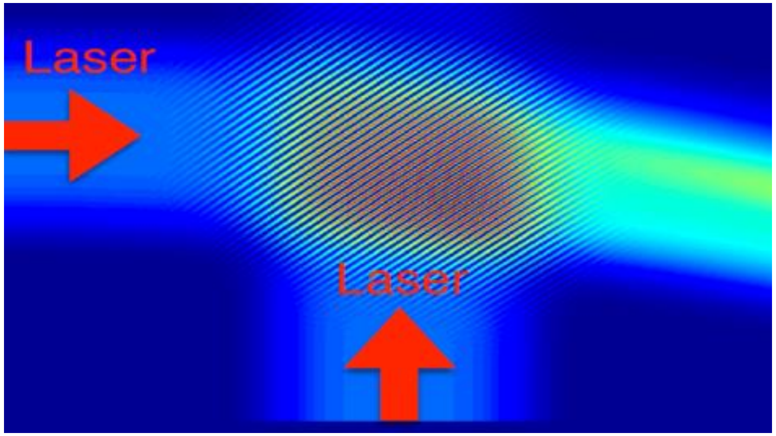
KrF bandwidth is sufficient to "self seed" SRRS

CBET mitigation strategies discussed at LLE-NRL workshop 7 June 2016

SRRS) in laser air paths is one option being explored.

- Determine bandwidth and spectra that would be effective via LLE's LPSE code.
- Develop SRRS physics and options for implementing on OMEGA

NRL LPSE simulation (max CBET)



Why consider the ArF laser?

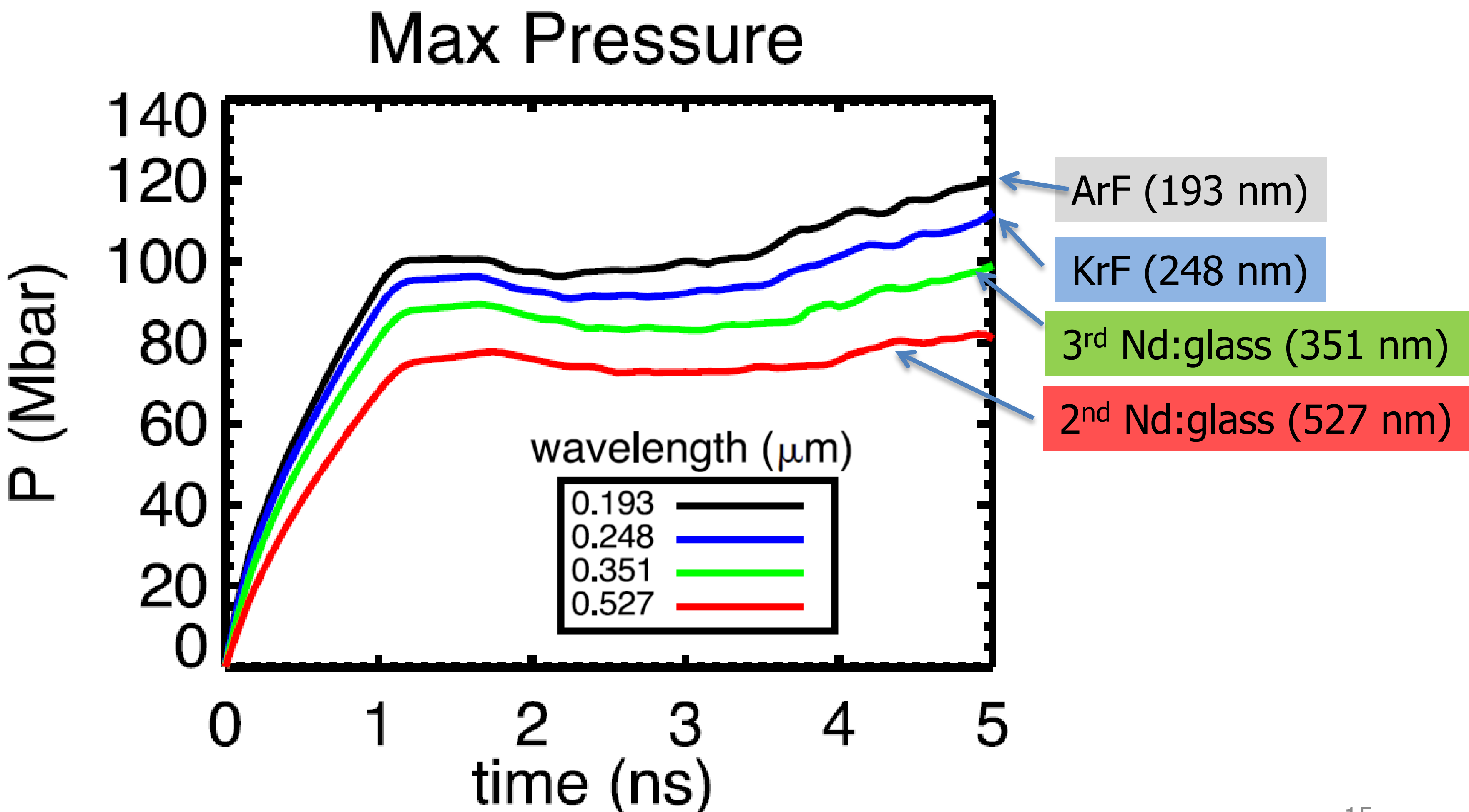
NRL PPD

- It's the deepest known UV laser that could scale to very high energy and power.
- It has very broad native bandwidth (KrF),that would enable extremely high powers in sub-picosecond pulses.
- It is compatible with the NRL-invented Induced Spatial Incoherence (ISI) beam smoothing scheme that allows ultra-uniform illumination of targets at high intensity.
- It would be superior to any other laser technology for inertial fusion.
- When pumped by electron beams it may have higher intrinsic efficiency than any other excimer laser.
- The high efficiency would help enable a new energy source using laser fusion.

FASTRAD3D shows the expected increased ablation pressure with shorter laser wavelength

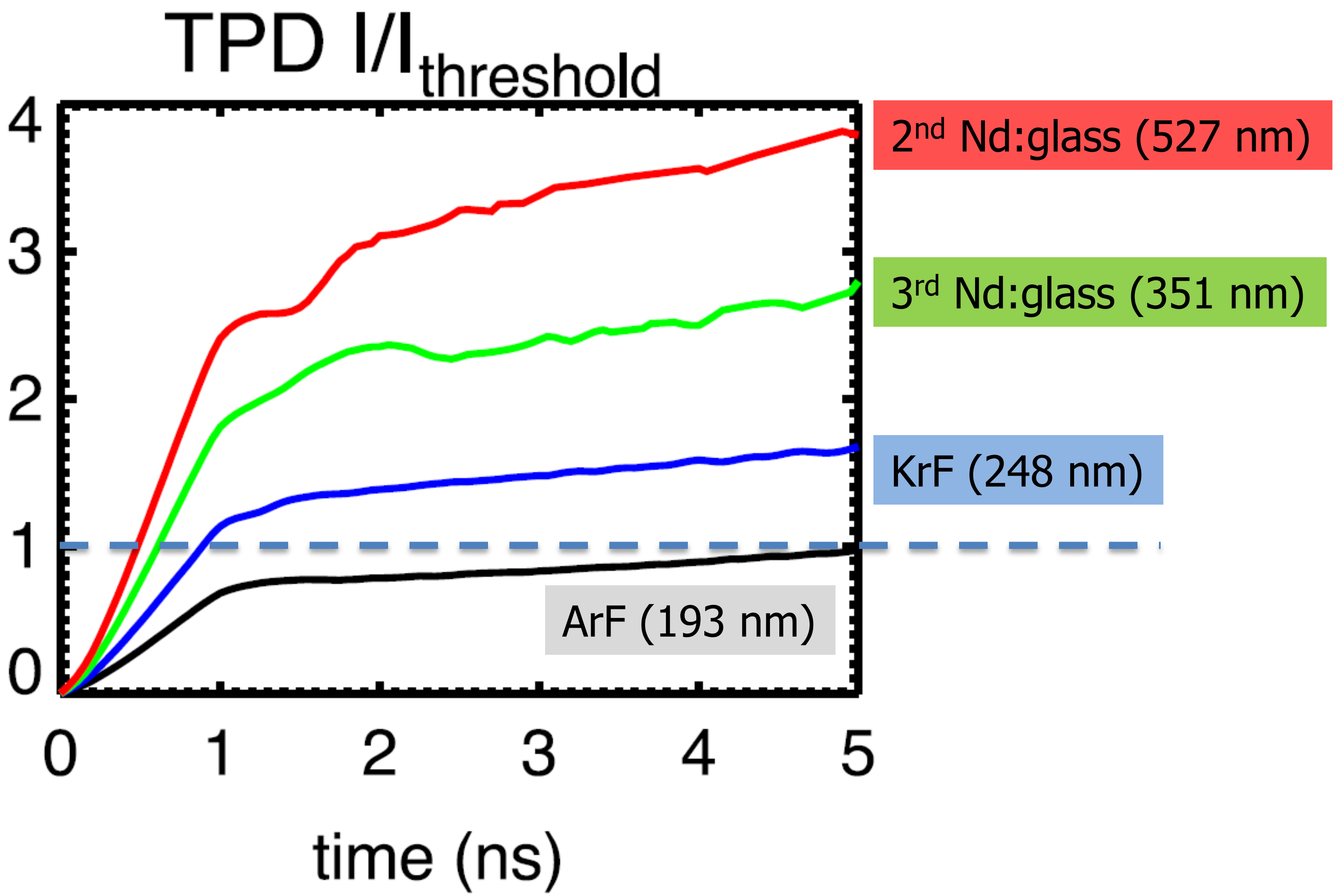
NRL PPD

5 ns square wave laser pulse incident on 2.6 mm diameter plastic sphere @ 10^{15} W/cm^2 (vacuum intensity)



ArF's short wavelength also increases the intensity threshold for LPI .

NRL PPD

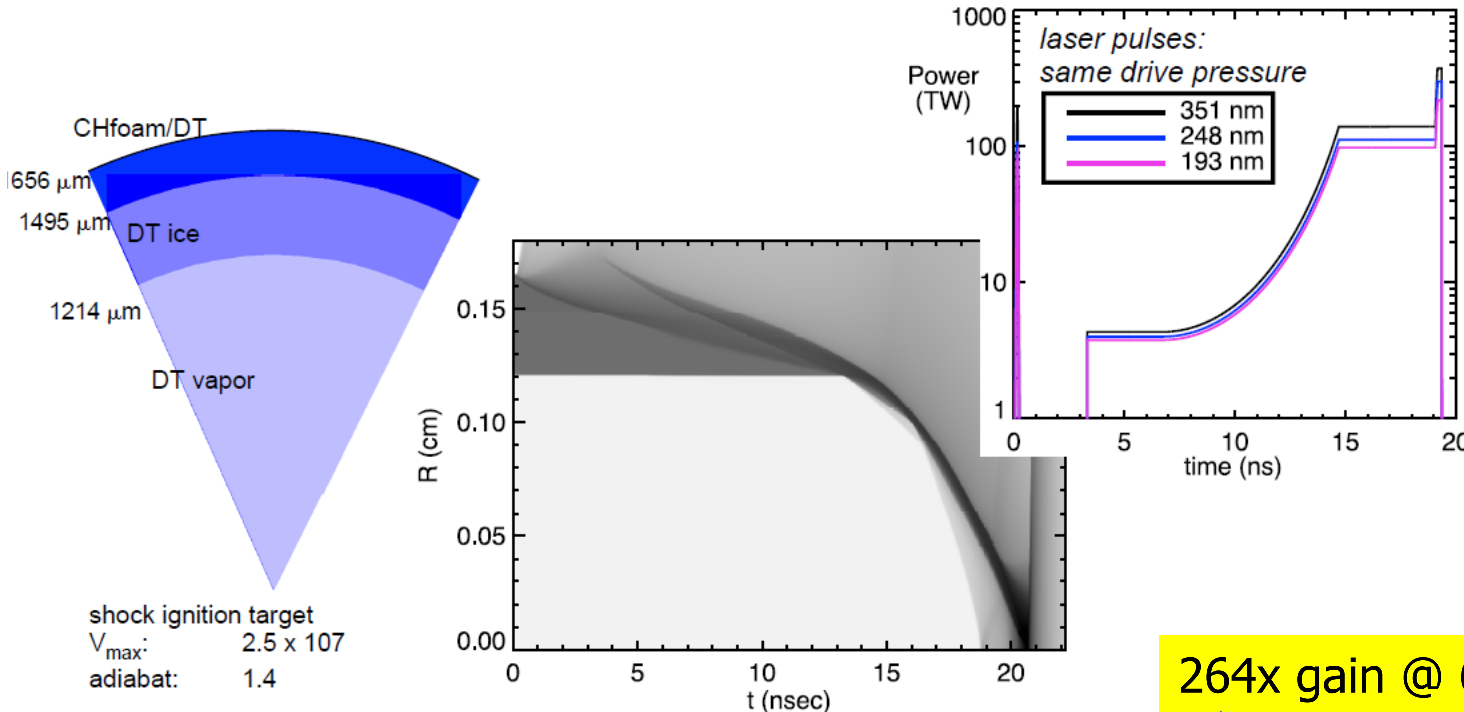


I_threshold [10^{15} W/cm^2] = 8.06 * Te[keV] * 1/(laser_wavelength[um]) * 1/Ln [um]
(Simon et al., Phys. Fluids 26, 3107 (1983).)

193 nm laser light gives the higher gain with smaller laser energies

NRL PPD

1-D simulations of shock ignited targets with focal zooming



264x gain @ 638 kJ !

Wavelength:	351 nm	248 nm	193 nm
Gain:	197	233	264
laser energy:	872	737	638
absorption:	89%	94%	96%
hydro efficiency:	7.47%	8.39%	9.23%

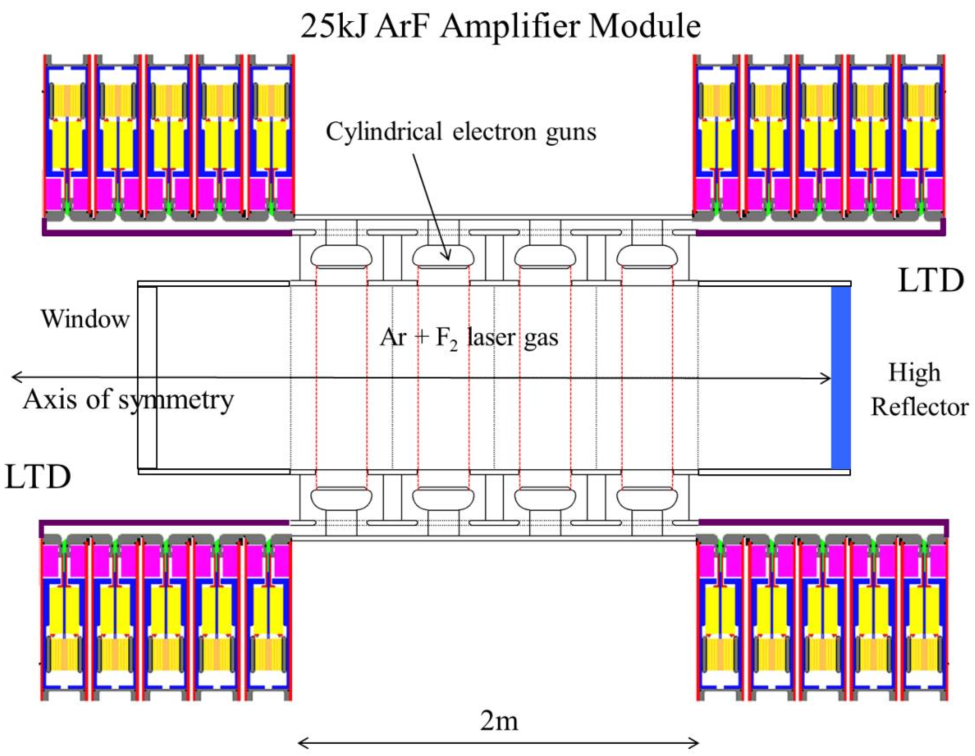
NRL laser fusion program

Advancing the physics and developing new approaches is critical to success of a grand challenge like ICF

For example:

Concept for compact ArF amplifier using LTD pulse power.

25 kJ in 100ns



DR. MALCOLM MCGEOCH
PLEX LLC,