Overview of the NRL laser fusion program:

Progress in the Science and Technology of Direct Drive Laser fusion with the KrF laser

Fusion Power Associates Meeting
3 December 2009

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Plasma Physics Division
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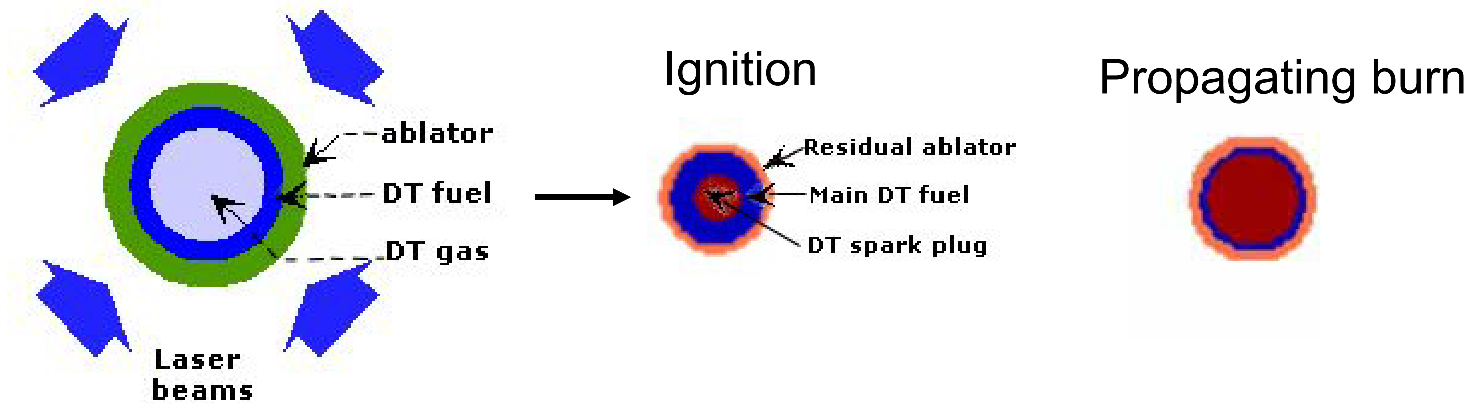
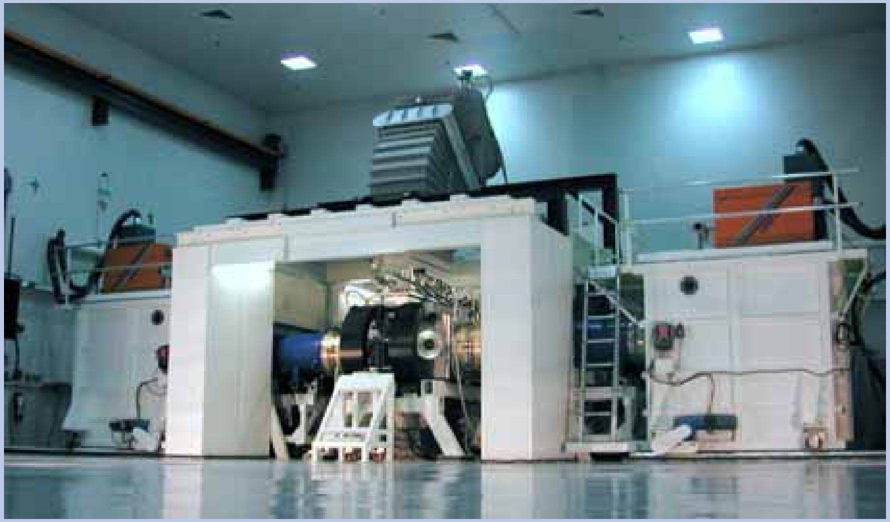
We are committed to Direct Laser Drive



- Simplest approach to inertial fusion.
- Easiest targets to fabricate.
- Challenges of obtaining uniform illumination & sufficient hydro-stability have been overcome with advances in laser technology & target design.
- Predicted gains are more than sufficient for the energy application.

Two laser options for Laser Fusion Energy :
Electron beam pumped Krypton Fluoride (KrF)
Diode pumped solid state (DPPSL)

Electra KrF Laser (NRL)
λ = 248 nm (fundamental)
Gas Laser



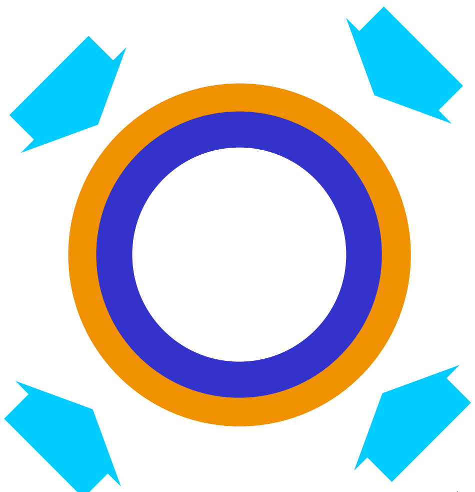
Mercury DPPSL Laser (LLNL)
λ = 351 nm (tripled)
Solid State Laser

KrF has inherent physics advantages for obtaining high gain with direct drive pellet fusion implosions

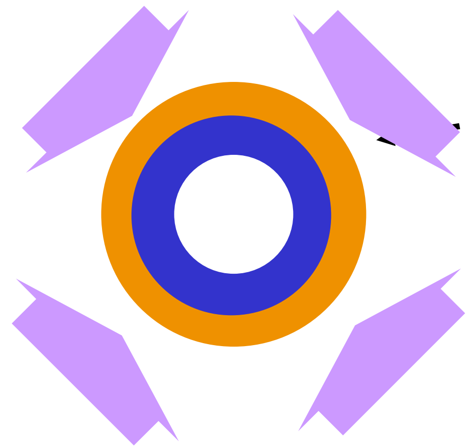
KrF Light helps the target physics (1)

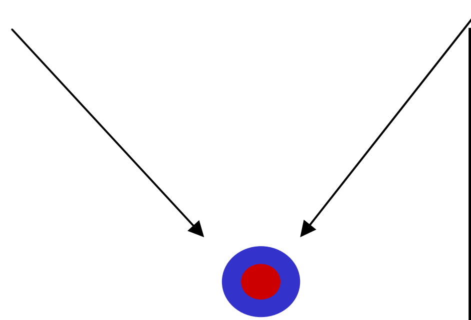
Deep UV (λ=248 nm) light provides higher ablation pressures that leads to higher target performance.

Frequency Tripled Solid state laser (e.g. NIF)
100 megabars



KrF
200 megabars



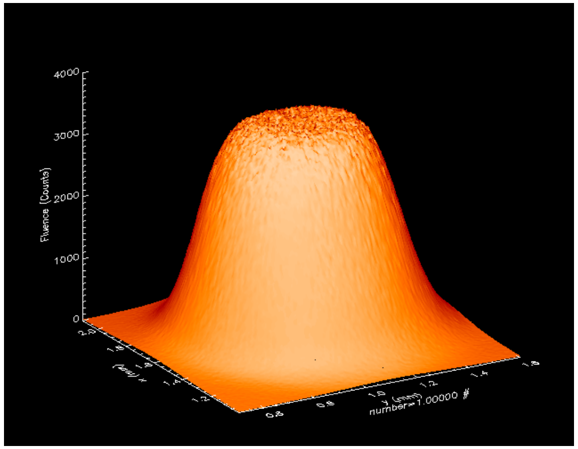


High ablation pressure allows:

- Use of lower aspect ratio targets
- Higher implosion velocities
- Higher energy gain
- Reduced laser size.

KrF Light helps the target physics (2)

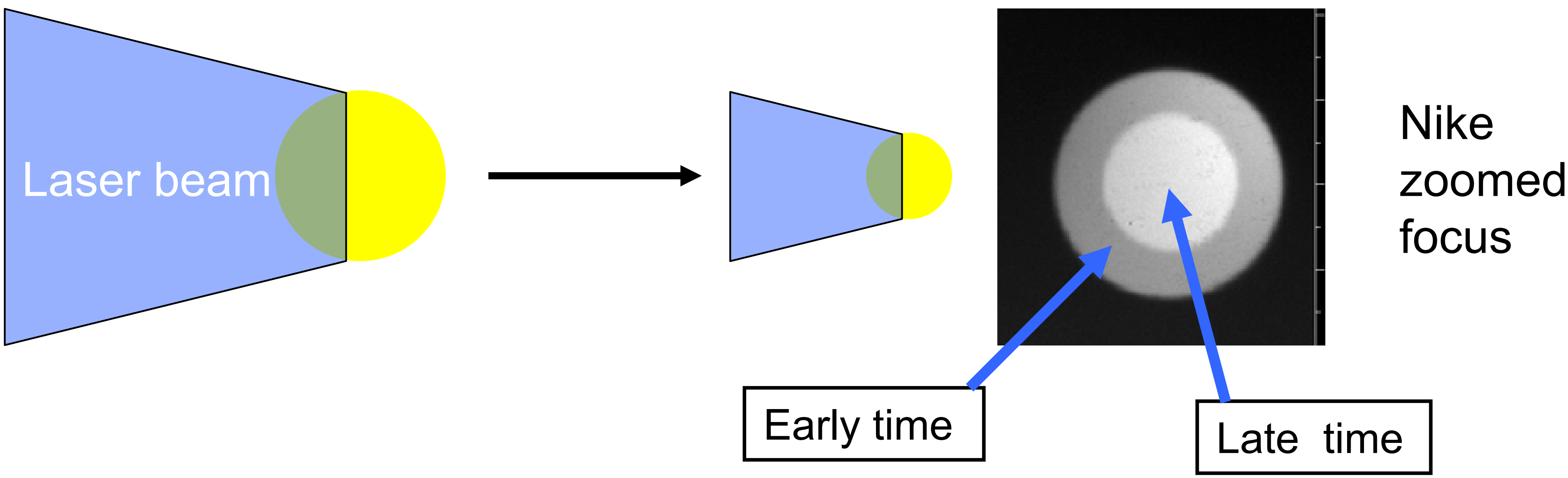
- KrF's ISI beam smoothing can provide the most uniform target illumination of all ICF UV lasers
  - Reduces seed for hydrodynamic instability
  - Bandwidth of up to 3 THz and spatial incoherence may help suppress laser plasma instabilities.



Nike KrF focal profile

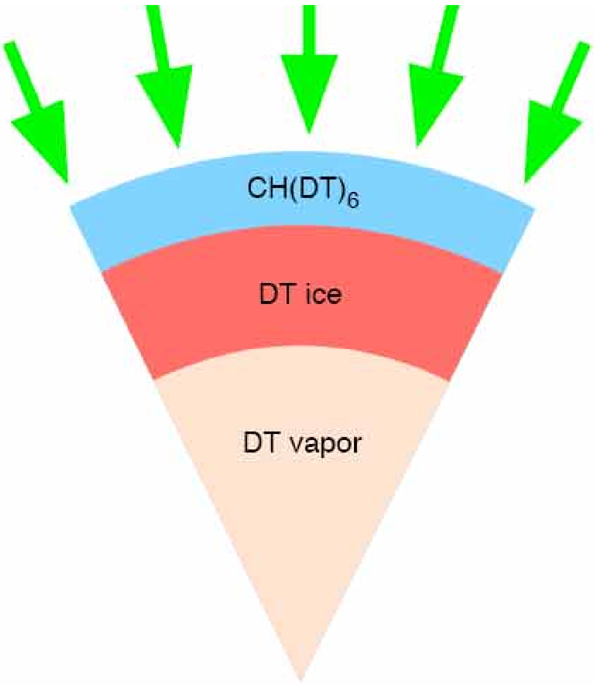
KrF Light helps the target physics (3)

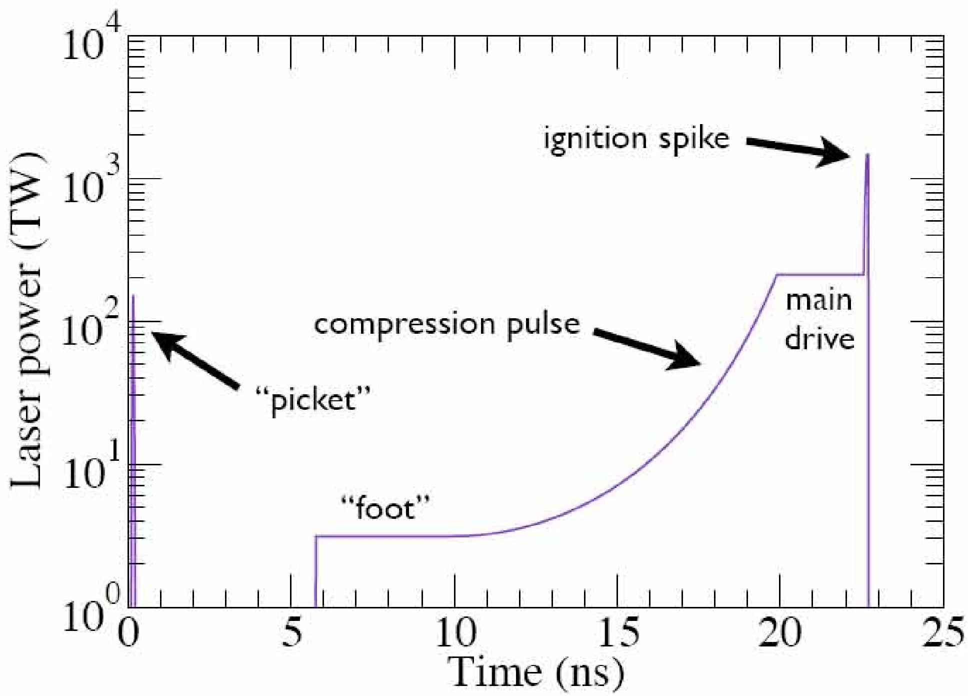
- KrF focal profile can zoom to "follow" an imploding pellet.
  - Simulations indicate more laser energy absorbed, which reduces required energy by up to 35%



Shock Ignited (SI) direct drive targets*

Pellet shell is accelerated to sub-ignition velocity (<300 km/sec), and ignited by a converging shock produced by high intensity spike in the laser pulse.





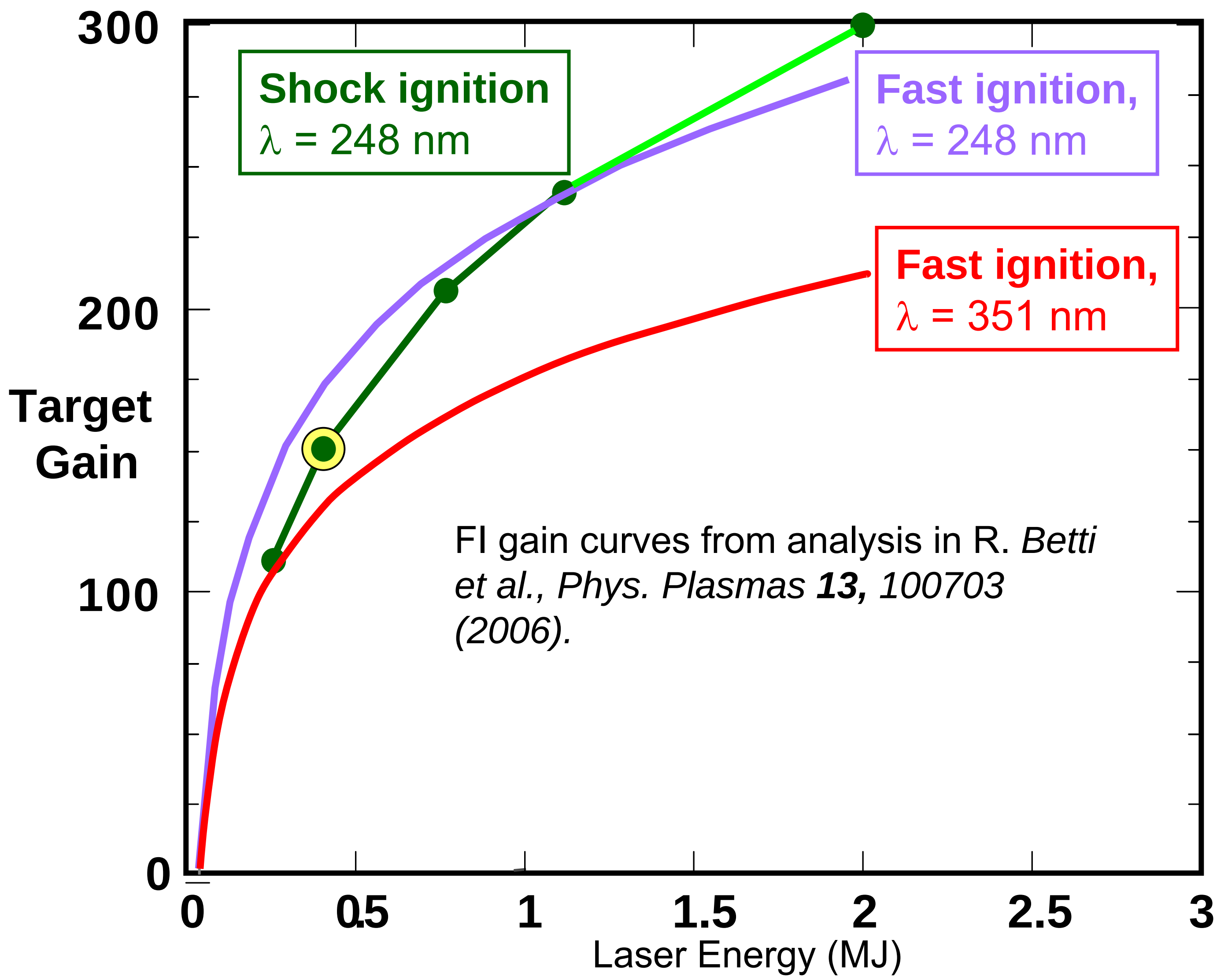
Low aspect ratio pellet helps mitigate hydro instability

Peak main drive is 1 to 2 × 10^{15} W/cm^2

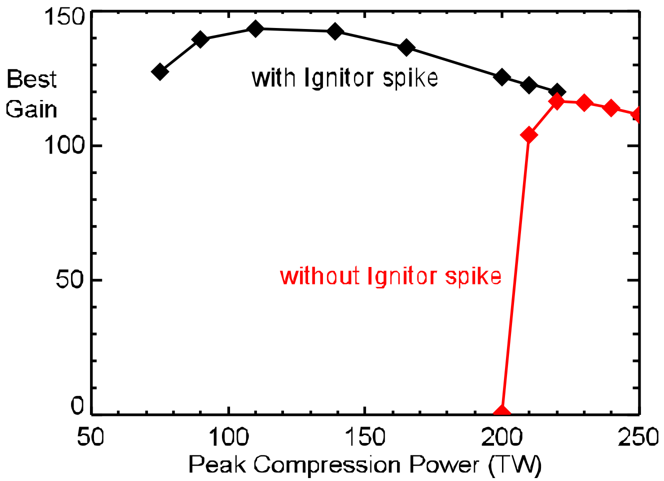
Igniter pulse is ~10^{16} W/cm^2

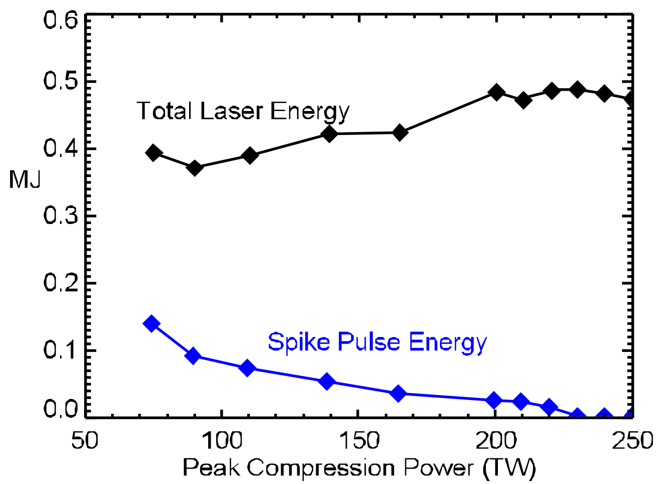
* *R. Betti et al., Phys.Rev.Lett.* ***98****, 155001 (2007)*

Shock Ignition simulations predict comparable gains as Fast Ignition…but with simpler driver, targets, & physics



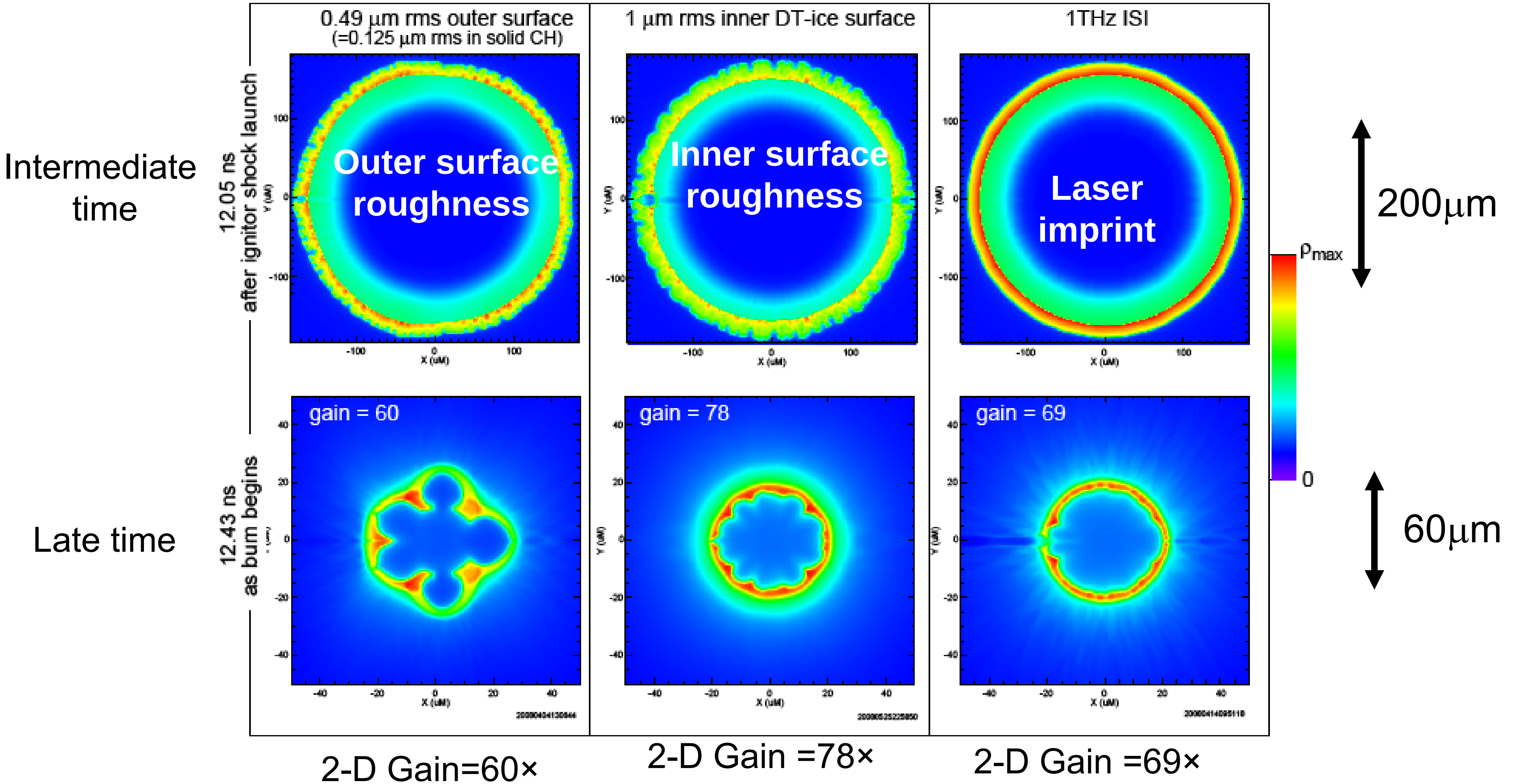
Shock Ignition connects continuously to conventional central ignition





- NRL “Scale 2” targets
- Shock ignition provides higher gain with less laser energy.
- Can reduce ignition spike energy & intensity by increasing initial main drive.

High resolution 2-D simulations show that the energy gains should be robust against hydro-instability growth.



250 kJ shock ignited target – NRL FASTRAD3D simulations

Simulations predict sufficient energy gains (G) for the energy application.

G>100 with a 500kJ KrF laser → Fusion Test Facility (FTF)

G >200 with a 1MJ KrF laser

G >300 with a 2 MJ KrF laser

→ **Fusion Power plants**

Desire $G \times \eta \geq 10$ for energy application

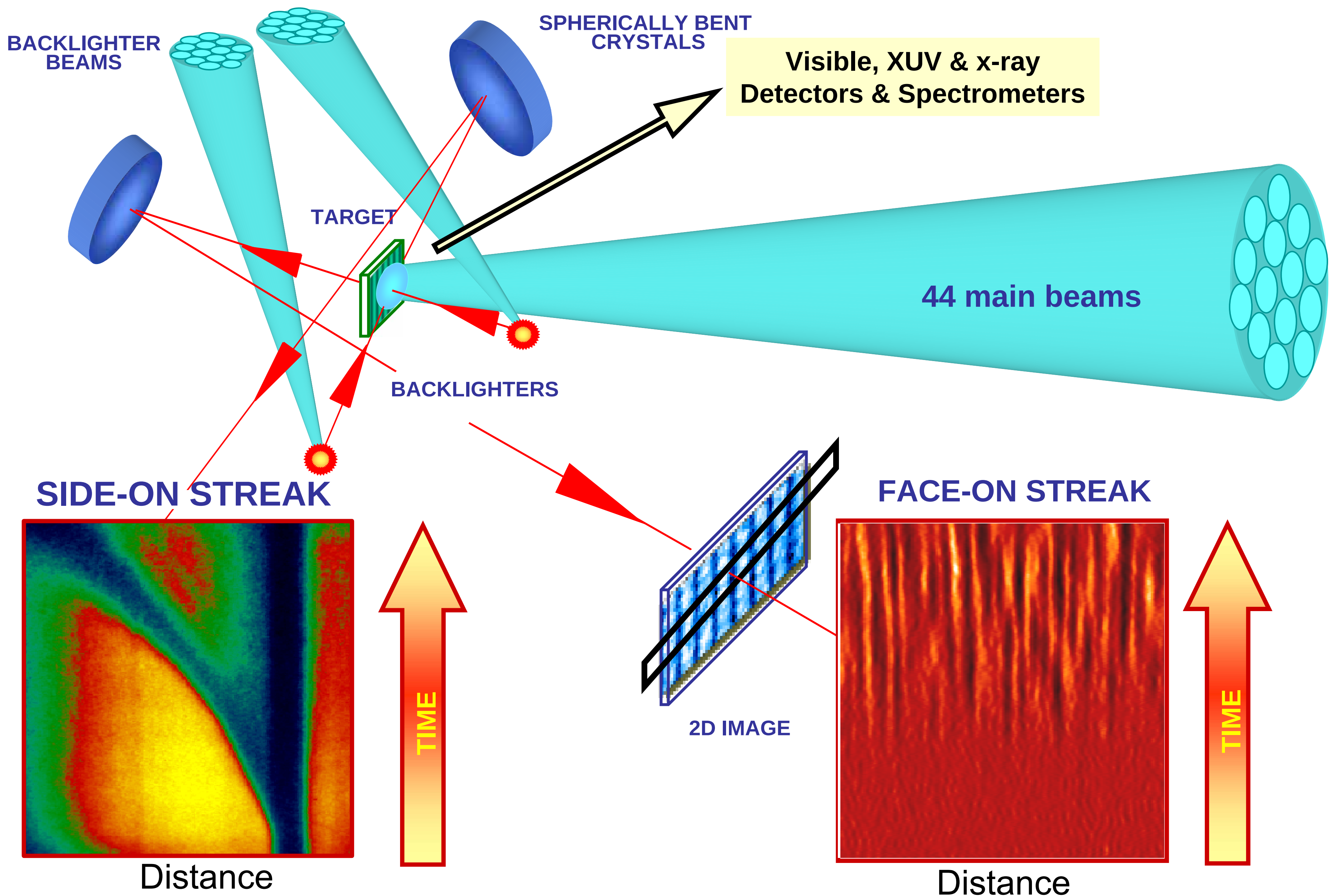
η = laser wall plug efficiency $\cong$ 7% for KrF

→ need $G \geq 140$

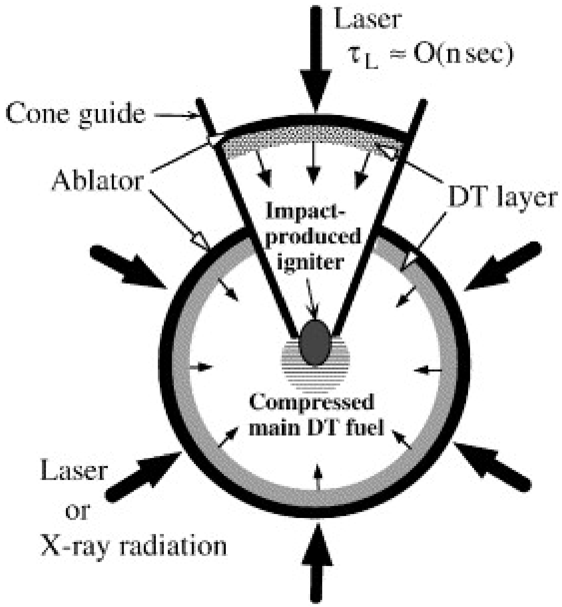
Nike Krypton-fluoride laser target facility

Nike Target chamber

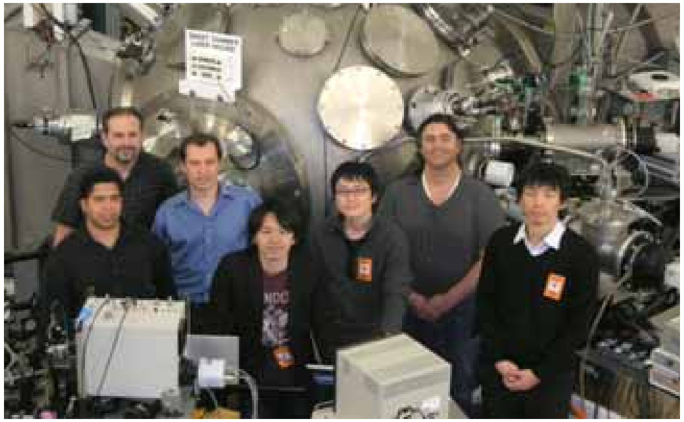
Nike is used to study physics of laser-accelerated planar targets



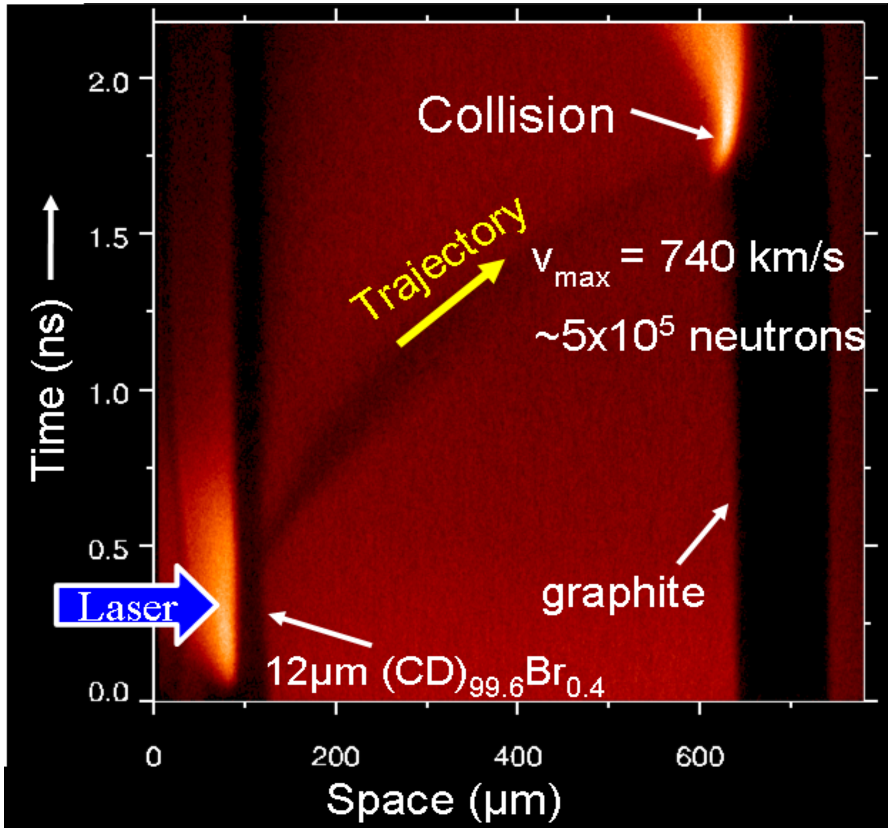
Nike experiments are also exploring feasibility of attaining the very high velocities required for impact Ignition



See Murakami M, Nagatomo H, Azechi H, et al. **NUCLEAR FUSION** Volume: **46** Issue: **1**



Joint experiment with U. Of Osaka, ILE

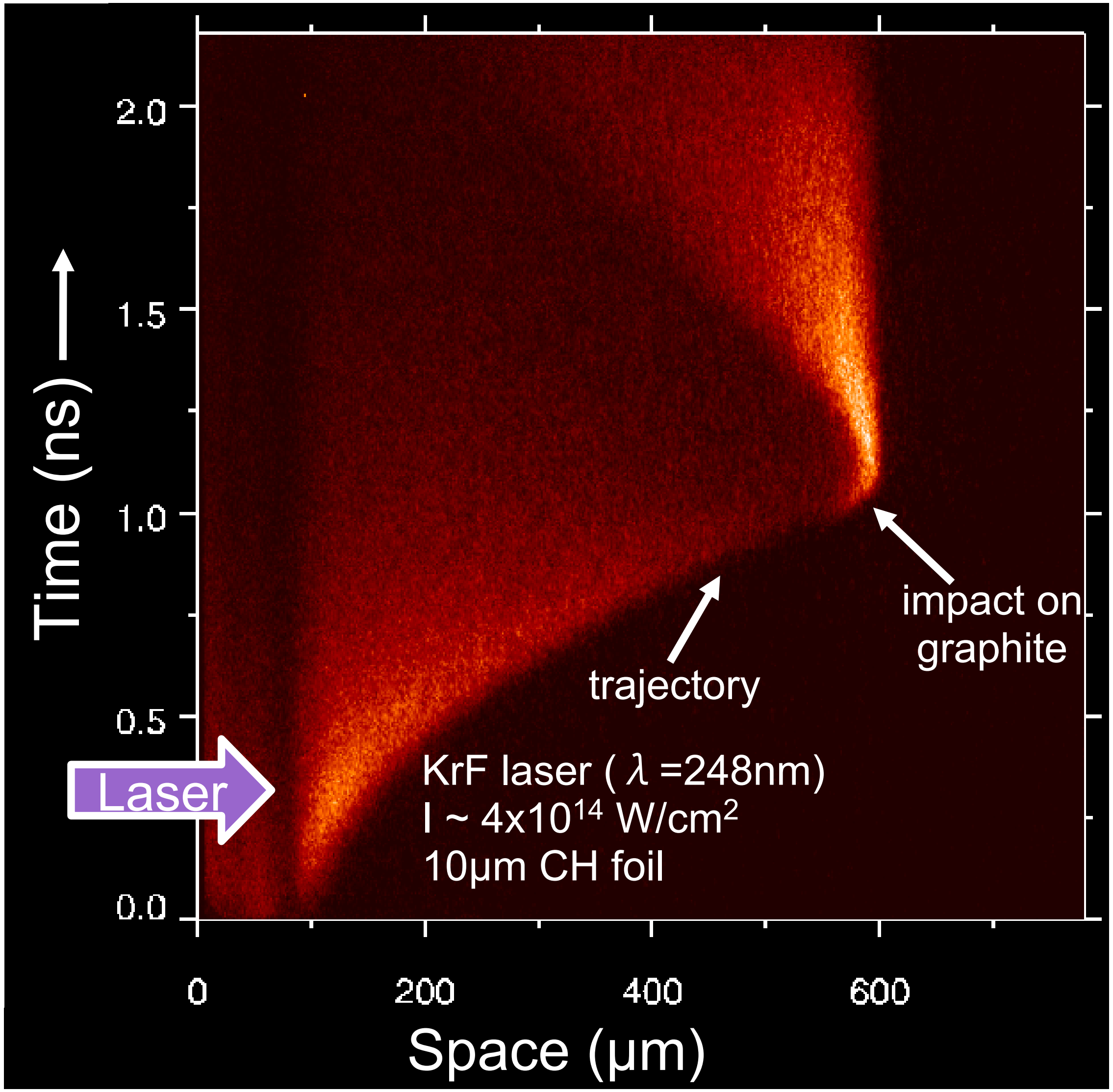


X-ray backlit steak camera image

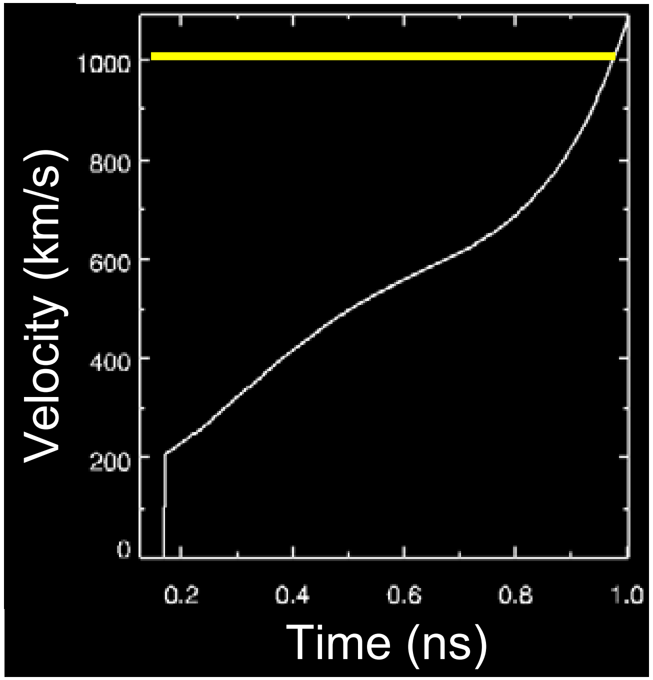
Nike target accelerated to greater than 1000 km/sec

(0 to 2.2 million miles per hour in 1 billionth of a second)

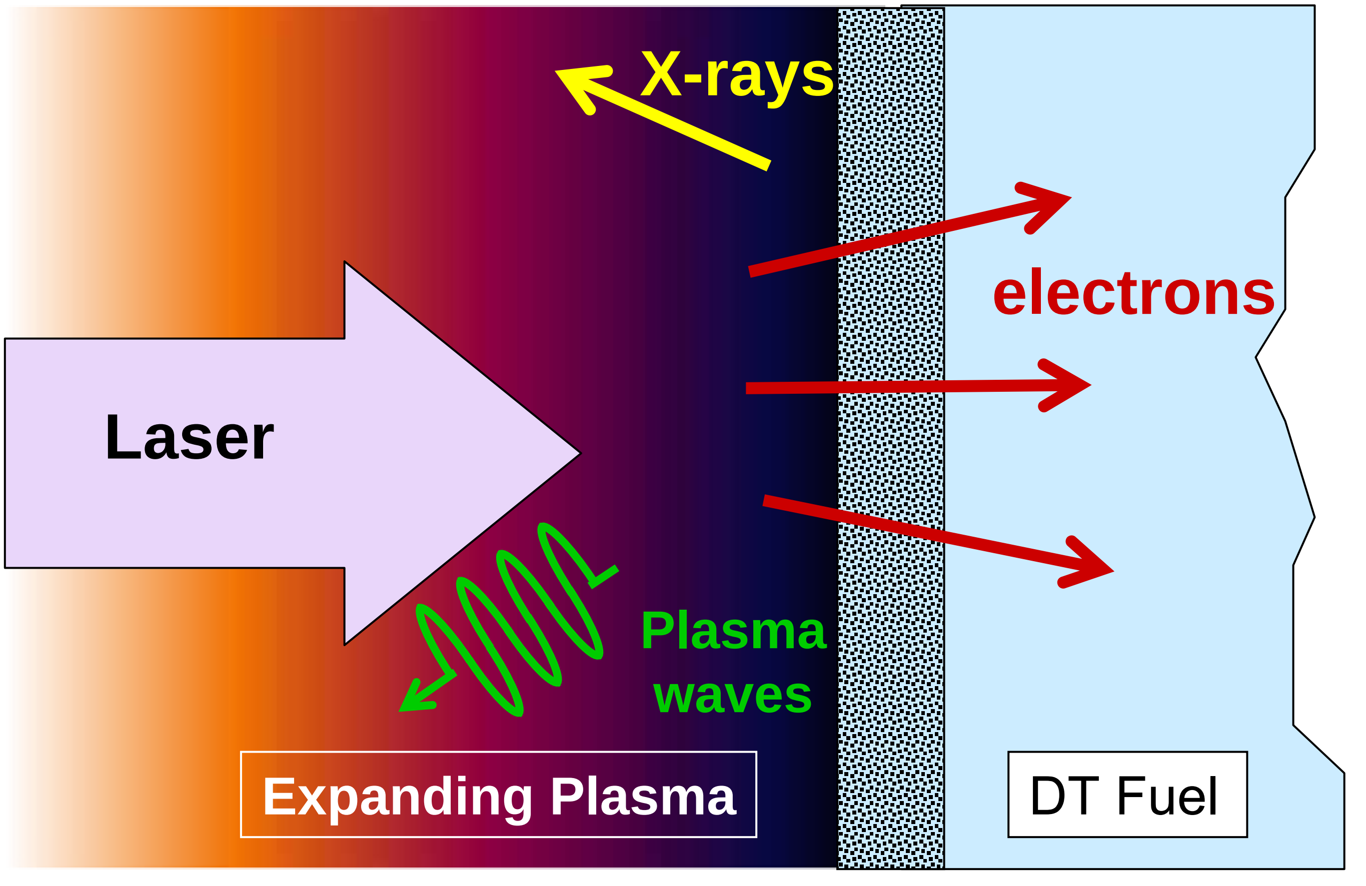
Streak camera of emitted1.86 keV x-rays



Target velocity verses time



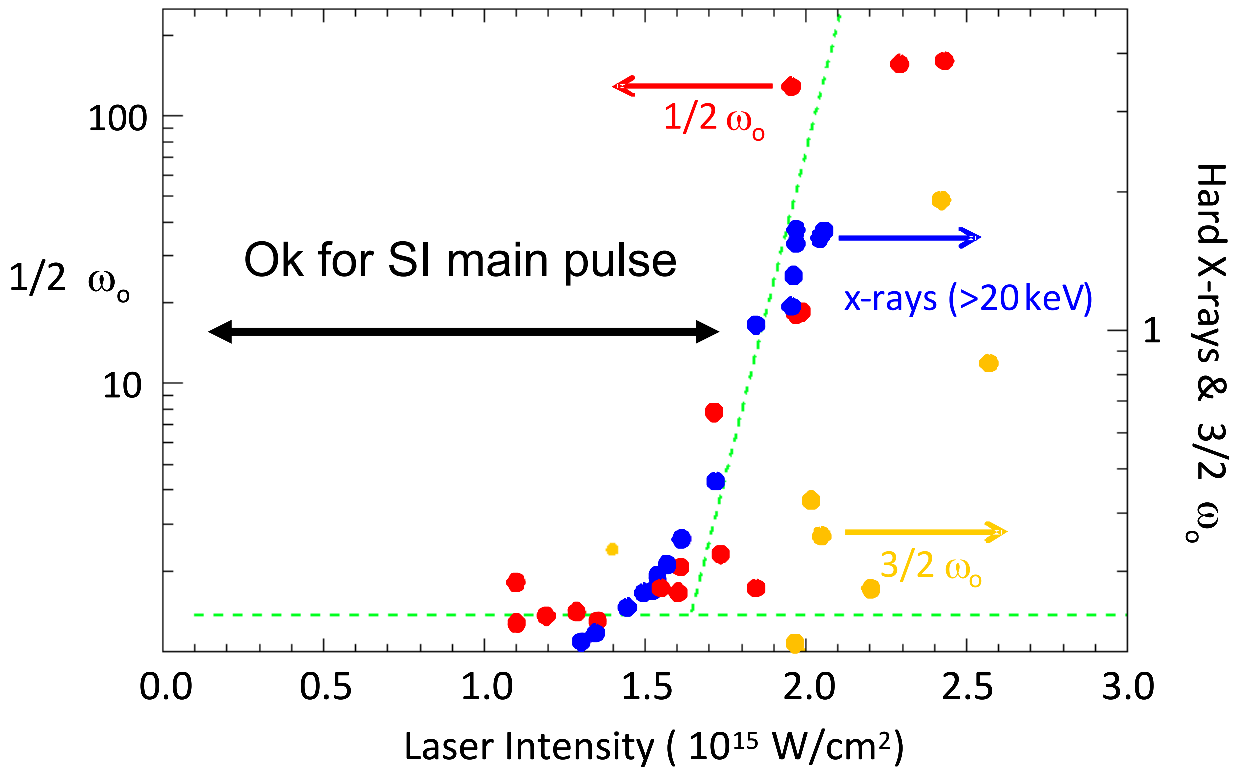
A challenge for *any* laser target design --- Predicting effects of Laser Plasma Instabilities (LPI)



LPI limits the maximum intensity
- Can produce high energy electrons that preheat DT fuel
- Can scatters laser beam, reducing drive efficiency

Nike experiments explore LPI thresholds with KrF

300 ps ≤1 kJ laser pulses in 40 overlapped beams



$\omega_0/2$ and x-ray signal give intensity thresholds ~1.7×10^{15} W/cm^2

LPI thresholds with KrF are ~2× those typically reported for λ=351 nm

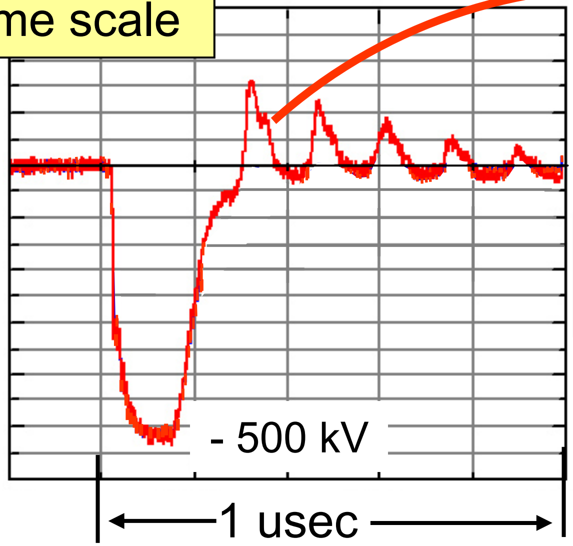
Ok, so the physics is great with KrF..
But can you make it large, efficient, reliable etc.

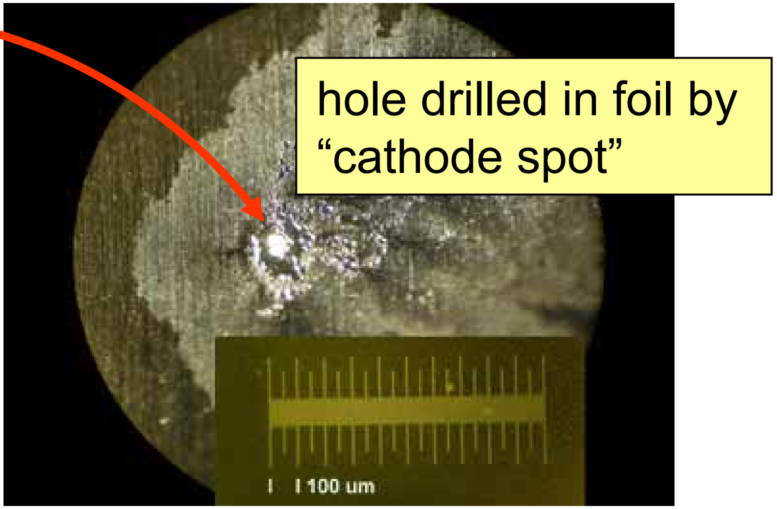
A key element to E-beam pumped KrF durability

One needs to minimize late time residual current in the electron beam diode.

100 nsec time scale

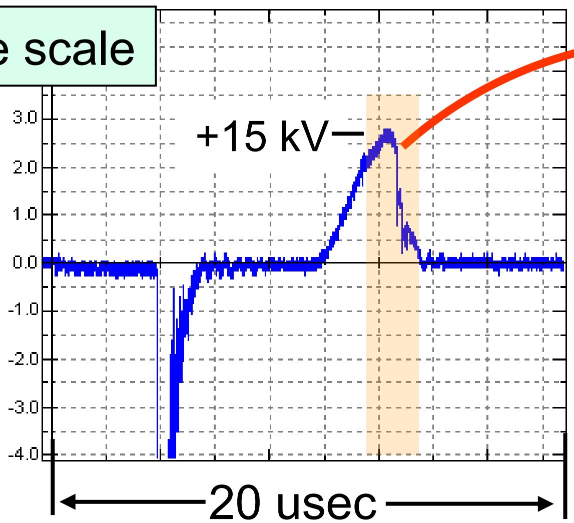
Diode Voltage

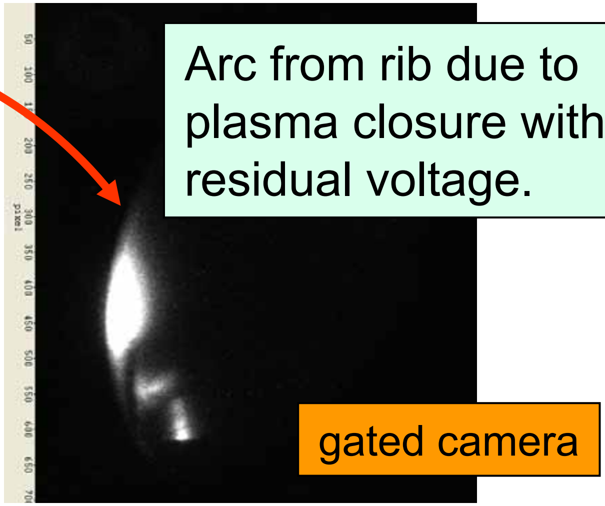




1 μsec time scale

Diode Voltage

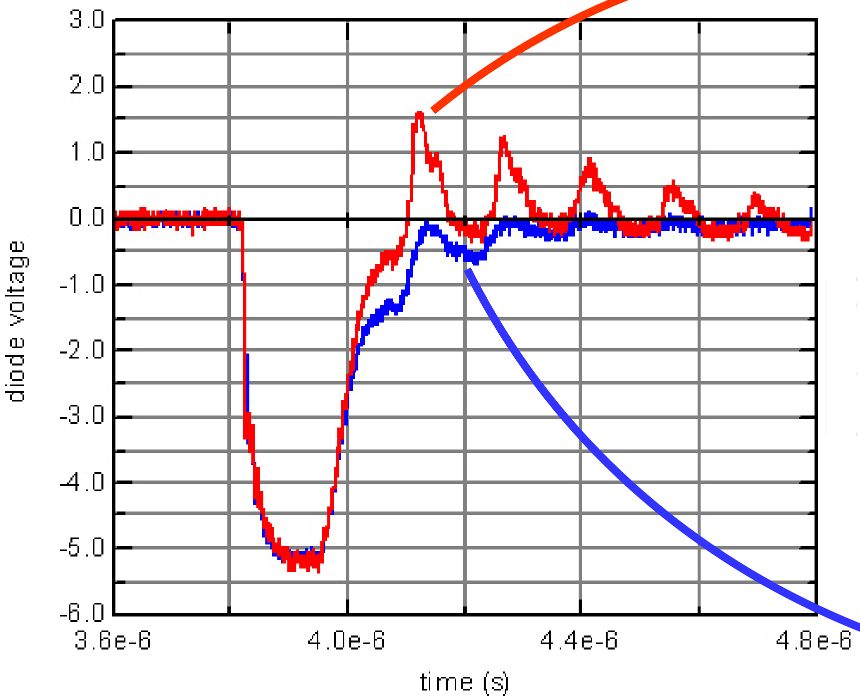




These correspond to < 1% of the energy in the system

Eliminating late time current can be accomplished by tuning pulse power, reducing plasma in diode, or both

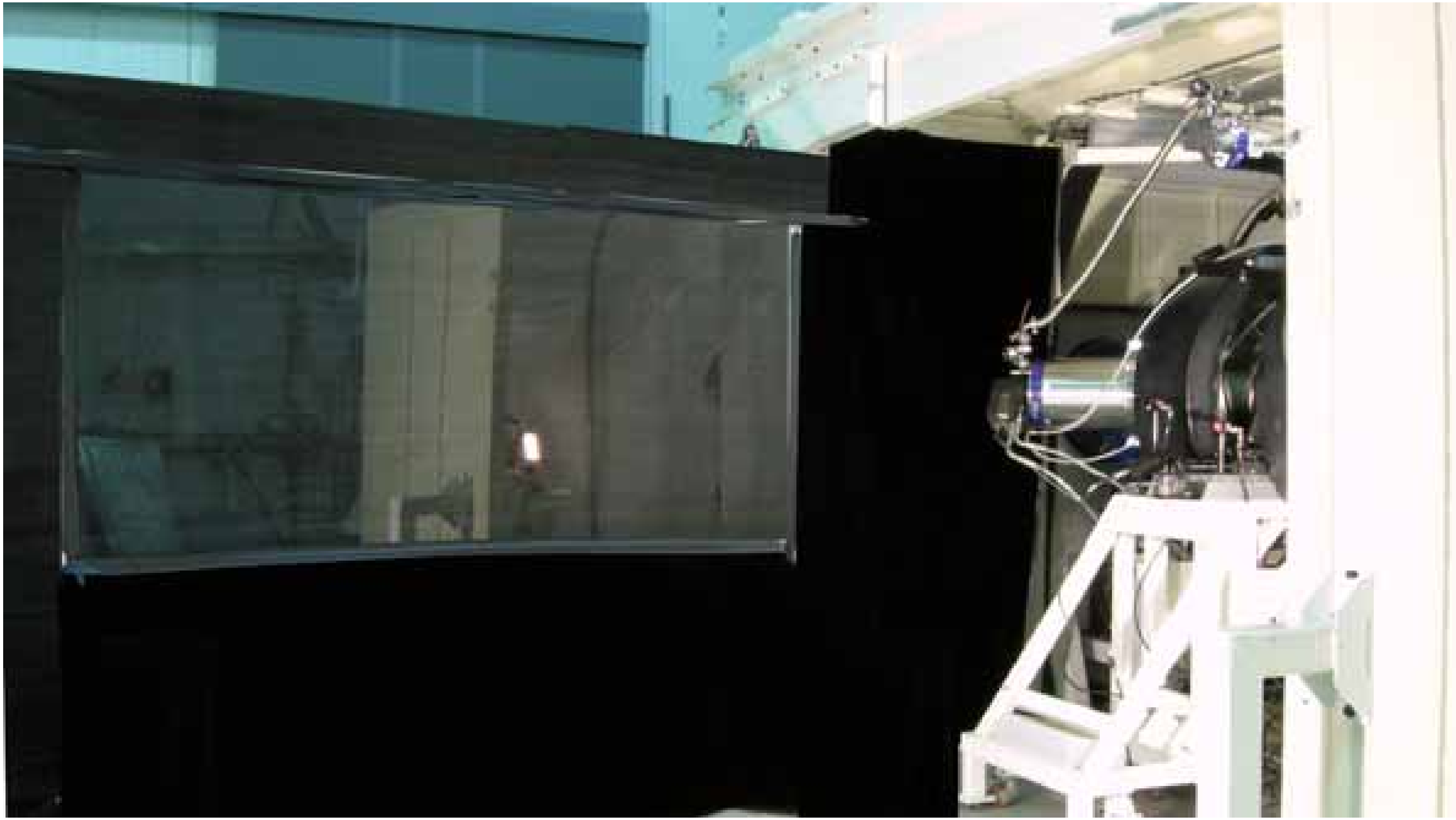
Example: eliminate short time scale voltage reversal by adjusting diode parameters



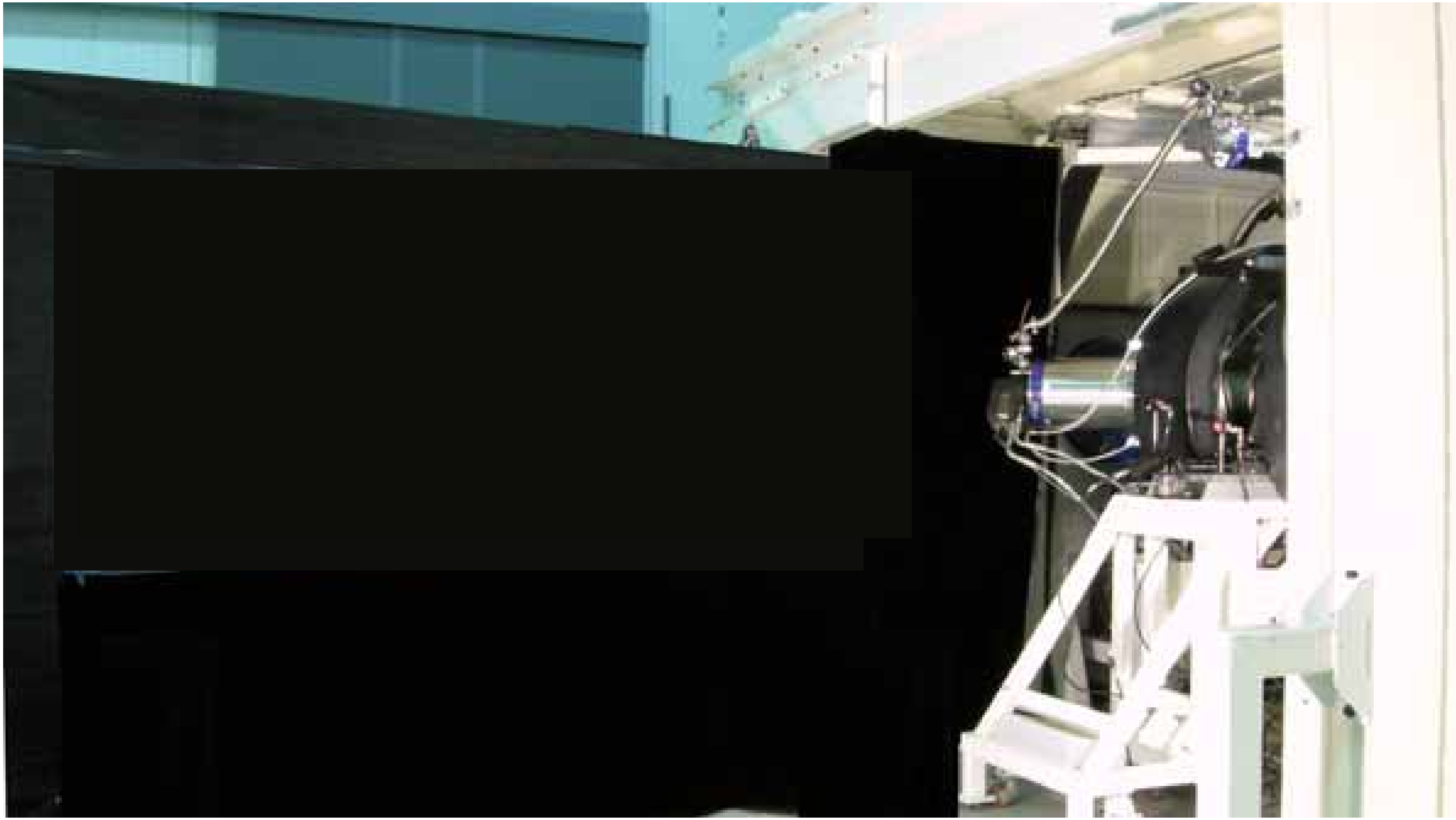
5000 - 10,000 shot continuous runs

90,000 shot (10 hr) continuous run
350,000 laser shots in 2009

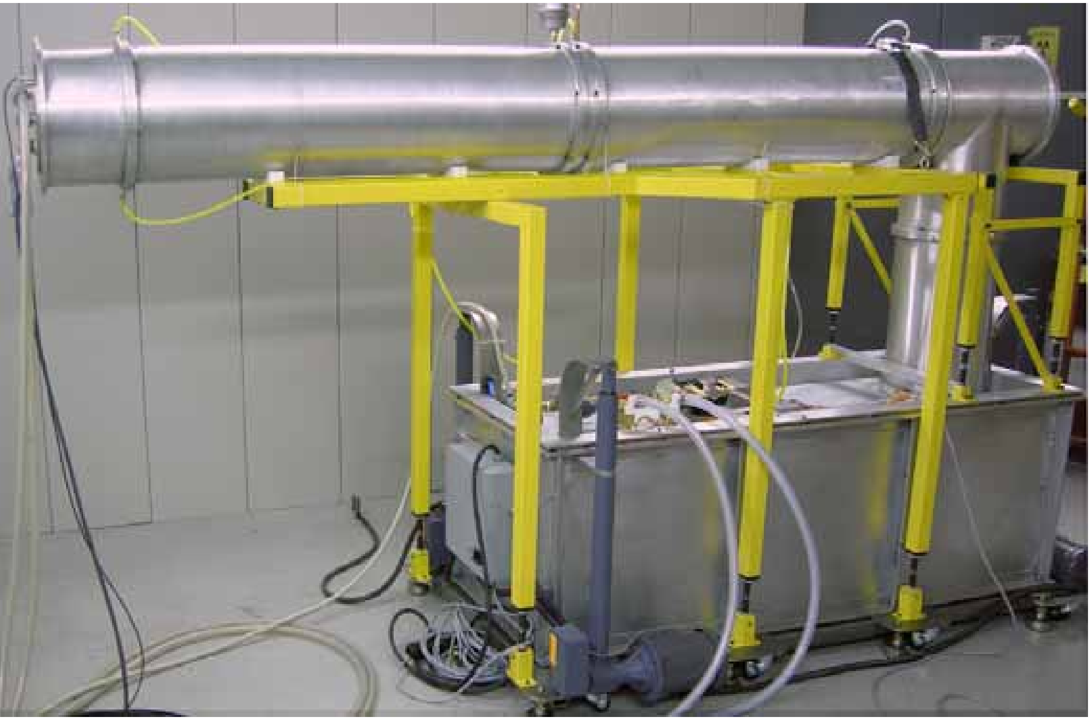
Electra Amplifier



Electra Amplifier @ 5hz



All solid state pulsed power system has run continuously for 11.5 Million shots at 10 Hz (319 hrs)



180 kV, 5 kA, 250 nsec

Components tested to 300M shots

PLEX, LLC

Summary

- Shock ignited direct drive continues to look very attractive for the energy application.
- Both simulations and experiments indicate KrF light significantly improves the laser-target interaction physics.
- Good progress in the S&T of E-beam pumped KrF towards the goal of obtaining the high system durability needed for IFE.

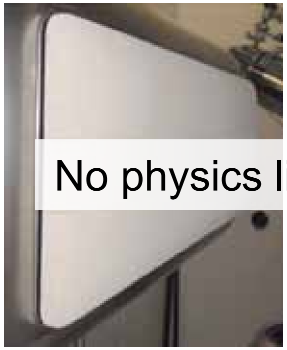
Extra slides

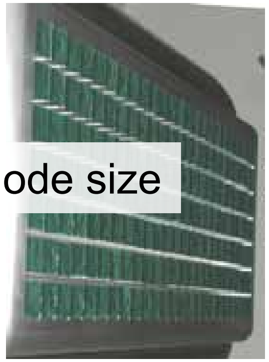
KrF science and technology updates

All solid state 10 Hz 200 kV Marx
$>10^7$ shots continuous (319 hours)

Components show > 300 M shots, no failures

Demonstrated two methods to suppress
E-beam instability on Nike Main amplifier



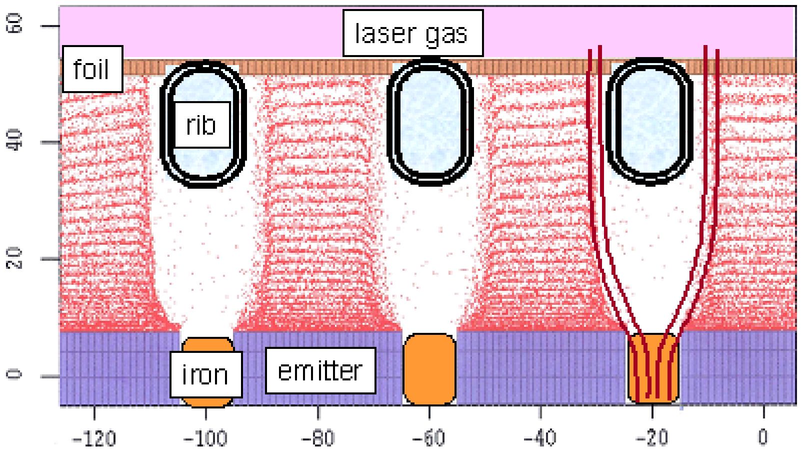


No physics limit on diode size

Ceramic Cathode

Patterned cathode

Modeling predicts e-beam and laser results



electron beam guided by tailored magnetic field

>7% wall-plug efficiency looks feasible.

Intrinsic (experiment)	12%
Pulsed power (experiment)	82%
Hibachi @ 800 kV (experiment)	80%
Optical train to target (est)	95%
Ancillaries (est)	95%
Global Efficiency	7.1%

How to shrink the time scale for Fusion Energy

- Develop science, technology, and engineering together
- Develop as an integrated system focusing on the goal of an attractive power plant
- Include inertial fusion and leverage off vast physics base in NNSA's initial confinement fusion program.
- Adopt a staged approach:

  Settle Highest science/technology risks in early (less costly) stages