Fast Ignition Driver Issues

by

E. Michael Campbell

Collaborators too numerous to mention

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Snowmass 2002 Fusion Energy Sciences Summer Study

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July 8-19, 2002

GENERAL ATOM

PW ignition pulse issues

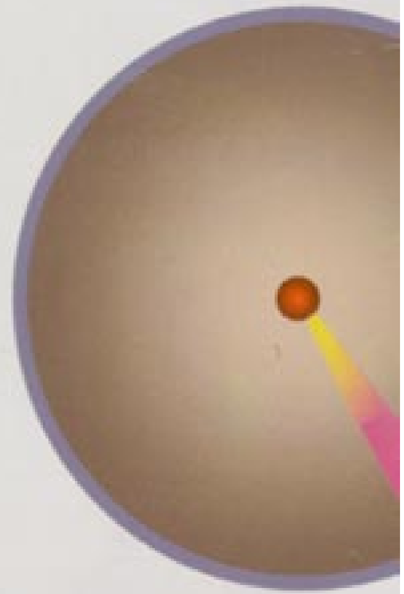
Damage on gratings and optics
- Puts a lower limit on optics size

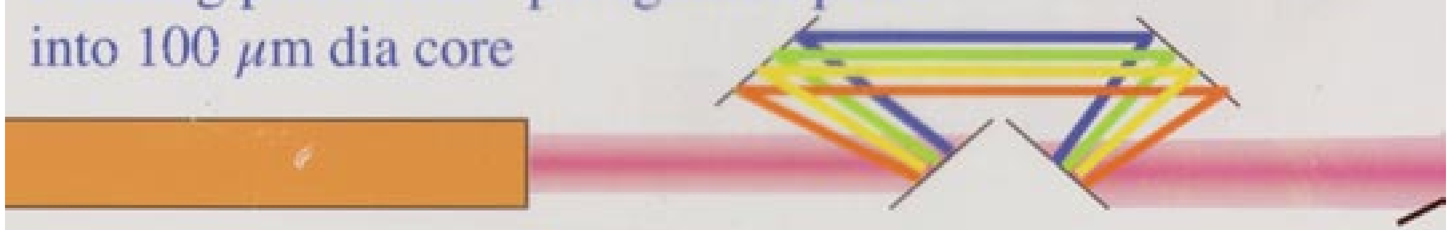
Pulse propagation reactor chamber atmosphere
- Self-ionization creates increasing plasma density

Brightness - require focus to ~30 μm dia

Timing - ignition window ~100 ps

Pointing placement - put ignition pulse into 100 μm dia core



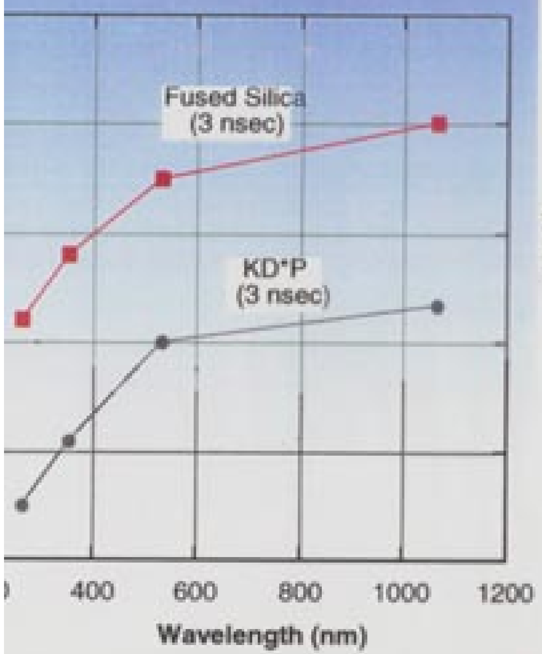


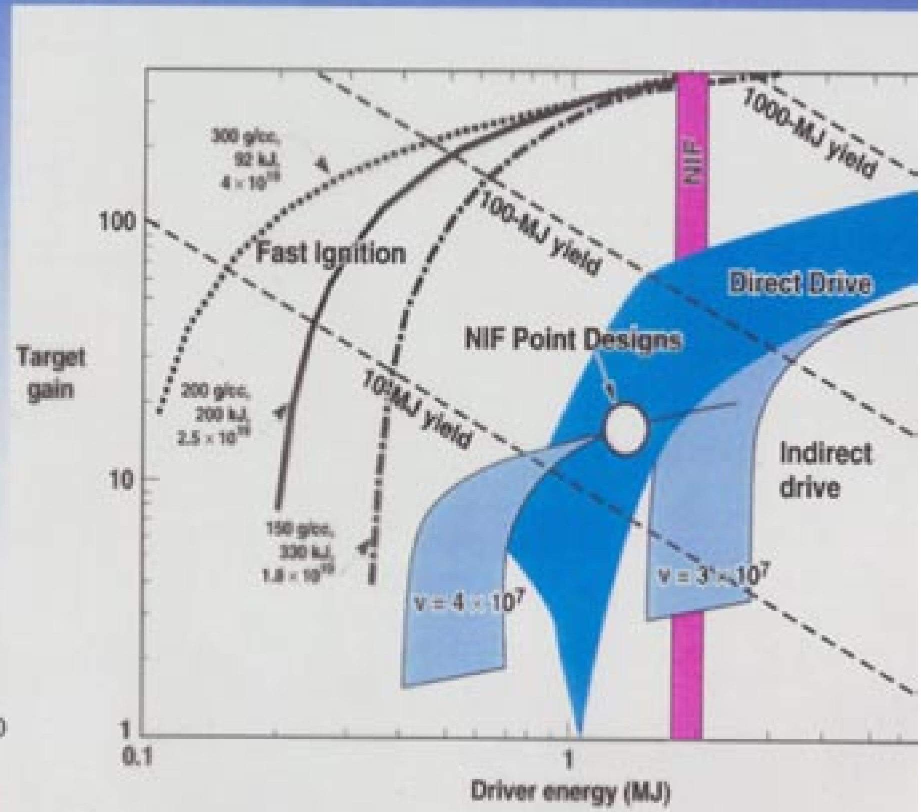
A wide range of Laser Drivers may contribute to FI Research

- Compression Drivers
  - Motivation for short wave length (laser-plasma coupling, hydro efficiency) not readily applicable to FI
    - Lower intensity possible with thin, hydro unstable shells)

  $\Rightarrow$ • 0.53μm and perhaps 1.05μm
- Ignitor Drivers
  - Short pulse (~10's of psec) $C0_2$ lasers for ignitor pulse coupling and energy transport

ast Ignition may enable high gain with a 2ω ompression beam thereby eliminating many of the oncerns associated with 3ω damage





imination of the need to form a hot spot and reduced symmetry require

Should allow compression with 2ω (maybe 1ω ?) drive

Fast Ignition requires two drive systems

Compression Driver to compress the fuel to 100-300 g/cm^3

- ~1 MJ, 10 ns pulse
- Could be any of the previously described drivers
- Compression requirements are more relaxed - lower brightness, less demanding uniformity
- Must allow access for ignitor laser

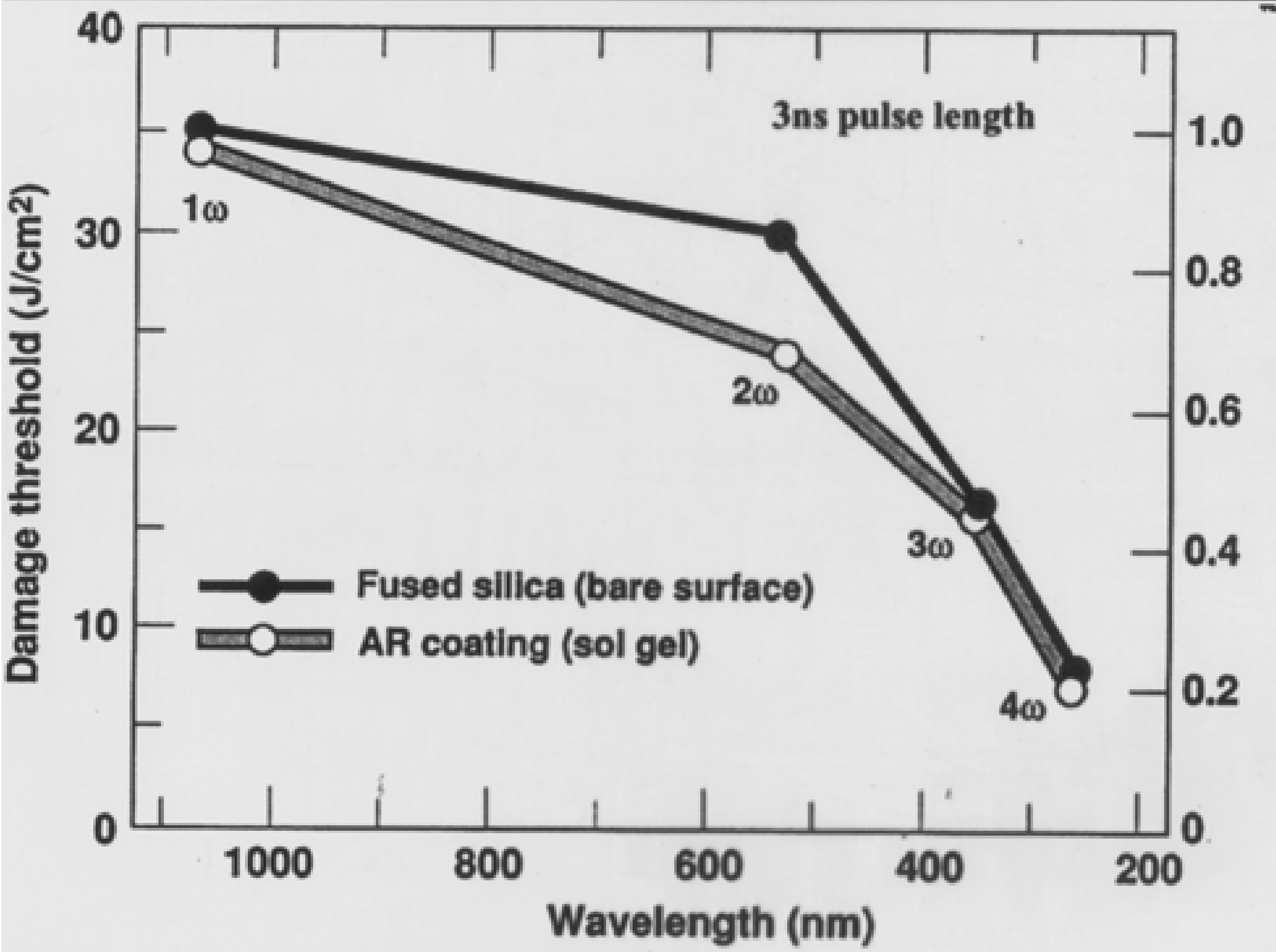
)river requirements somewhat relaxed for FI targets

Short pulse Ignitor Beam

- ~100 kJ, 20 ps pulse
- Only sufficiently bright candidate is high avg power laser with pulse compression optics
- Long wavelength preferable - improves Iλ^2

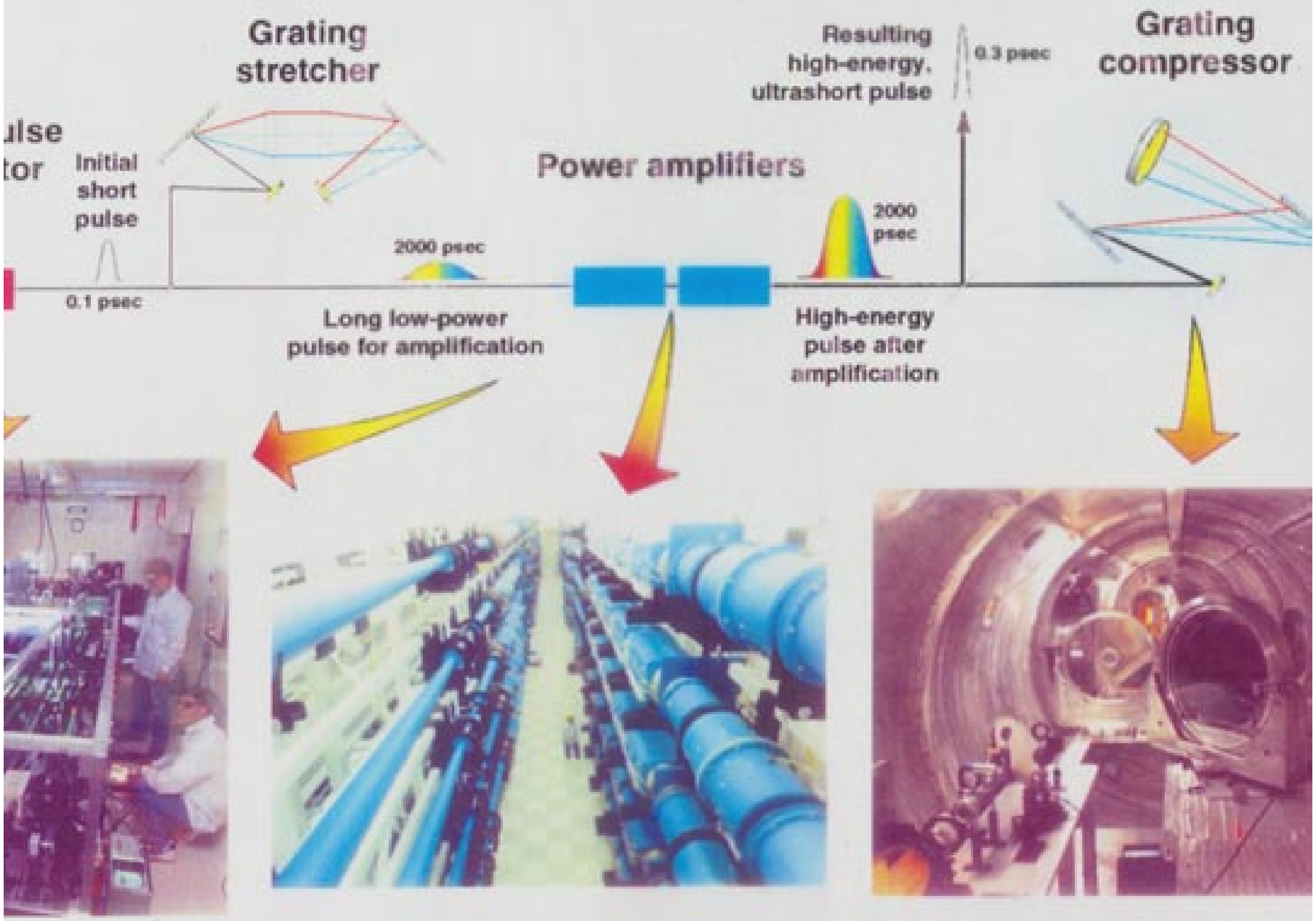
;nitor Beam pointing, timing, propagation into target
ıamber are chalienges

Probability for damage increases dramatically at shorter wavelengths



ımpbell and F. Rainer, SPIE 1761 (1992) 246-255

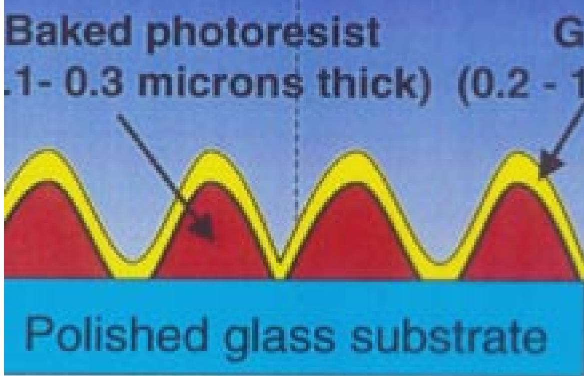
eration I Petawatt Lasers were the first to be demonstrated and being constructed throughout the world (UK, Germany, Japan

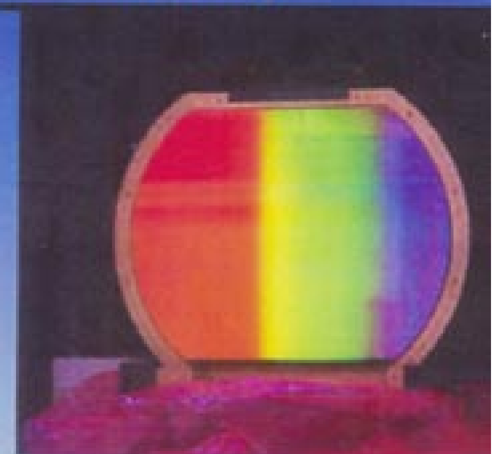


LLNL Petawatt Laser: M.D. Perry, et al, CLEO (1997), Opt. Lett.,24, 160 (1999)

1899B

en I Petawatt Lasers are limited to < 800 J due to e damage threshold of gold gratings (0.42 J/cm²)





94 cm Gold grating - LLNL

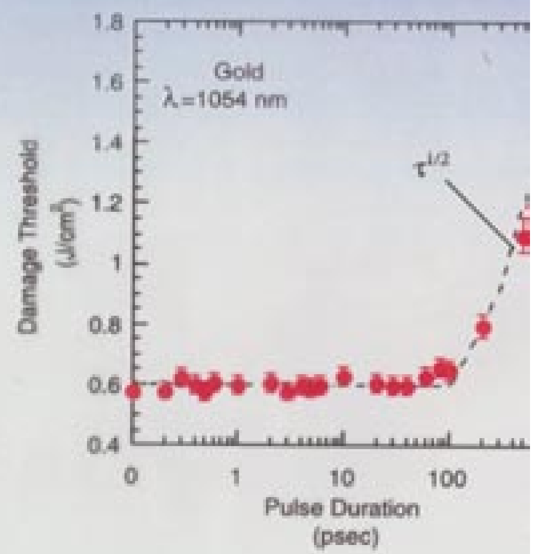
Advantages:

) Fabrication requires no etching step

I) Mature technology (up to 94cm)

Disadvantages:

) Damage threshold



M.D. Perry, P. Banks, M.D. Feit, H. Nguyen anc
LIA Materials Processing Handbook (19

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ast ignition separates fuel compression and ignition.
ıbak et al. concept uses electrons to ignite the fuel

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cone for
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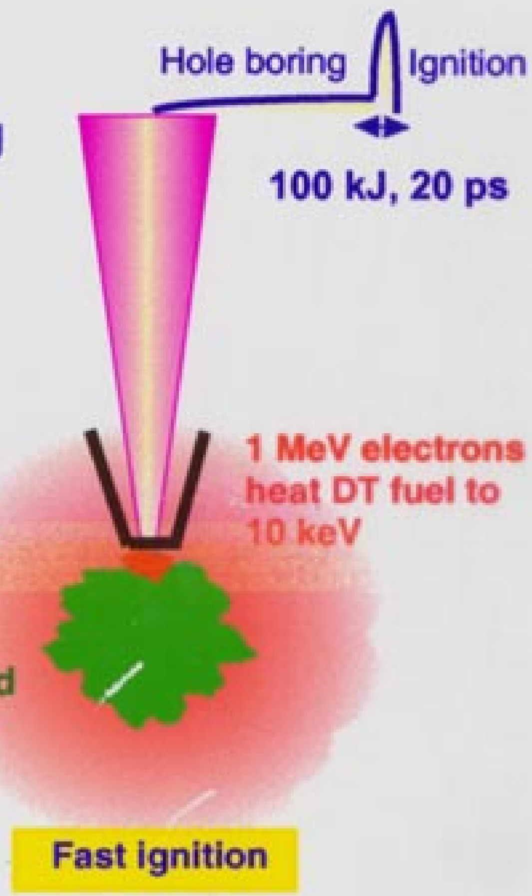
ıetrate
se to
ıse fuel



Ignition spot energy

$$E = 140\ (100/\rho)^{1.8}\ \text{kJ}$$

e.g. ρ=300 g cm^{-3}, E=17 k
in <20 ps
to r=19 μm hot spot
at 7x10^{19} Wcm^{-2}

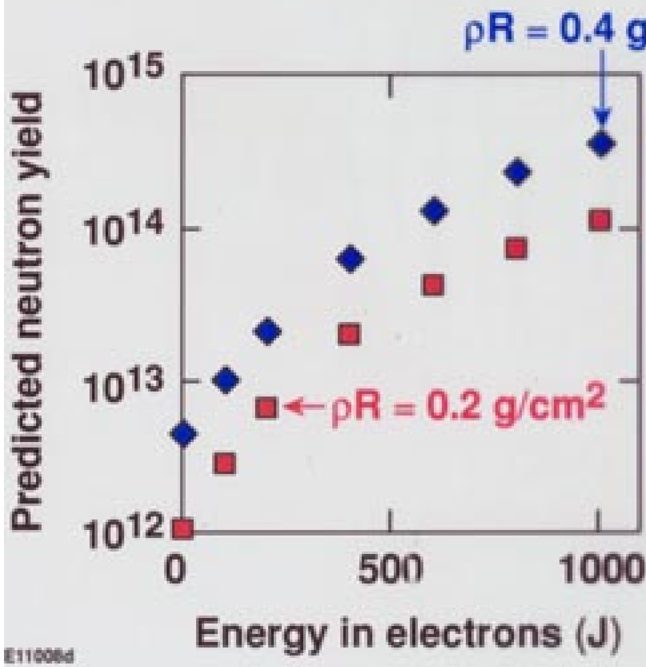
laser energy increases w
transfer efficiency as ε

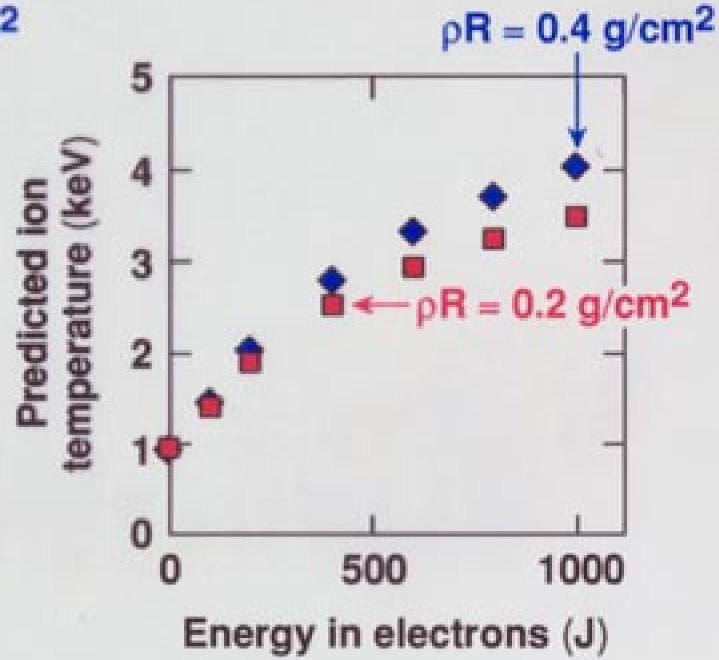
E_L<100kJ for ε>20%

Jasc

Combining OMEGA's cryogenic target capabilities with OMEGA EP's short-pulse beams provides a unique fast-ignition test bed

- Fast ignition is a route to higher gains on the NIF for improved margin experiments.
- Low-adiabat implosions will allow DT areal densities of 0.2 to 0.4 g/cm^2 to be produced on OMEGA (this allows detailed spark plug physics experiments).

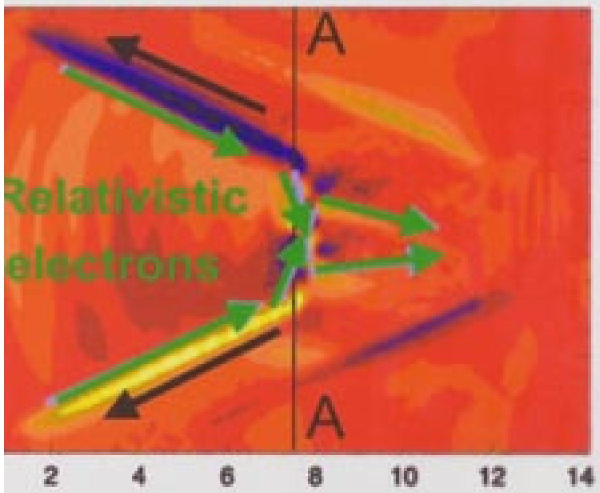




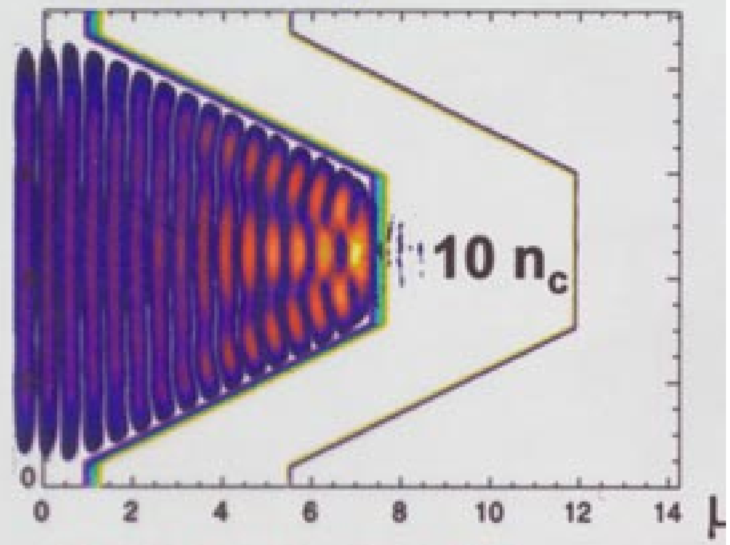
E11006d

ewest Japanese PIC modeling suggests cone may also oncentrate both optical and electron energy

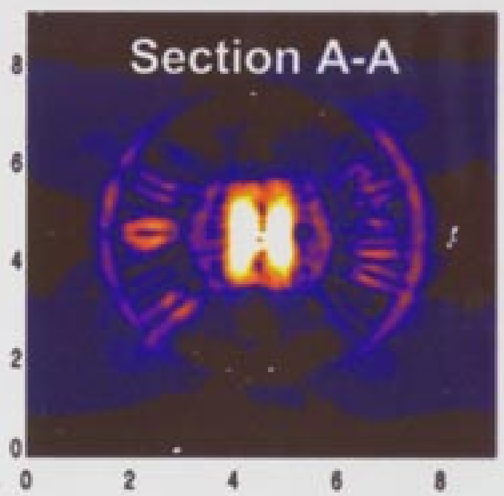
3 field due to electron flow



Laser intensity



Intensity enhanced 20x



Electron current concentrated at tip of cone

K Mima et al
US Japan FI Workshop 2

eration III Petawatt Lasers will open new regimes of stud
er-matter interactions with direct NNSA benefit

Long-pole in the tent is grating damage threshold
However -> New results on MLD gratings appear encouraging

Fabrication of these dielectric gratings at 1 m scale still needs to be done

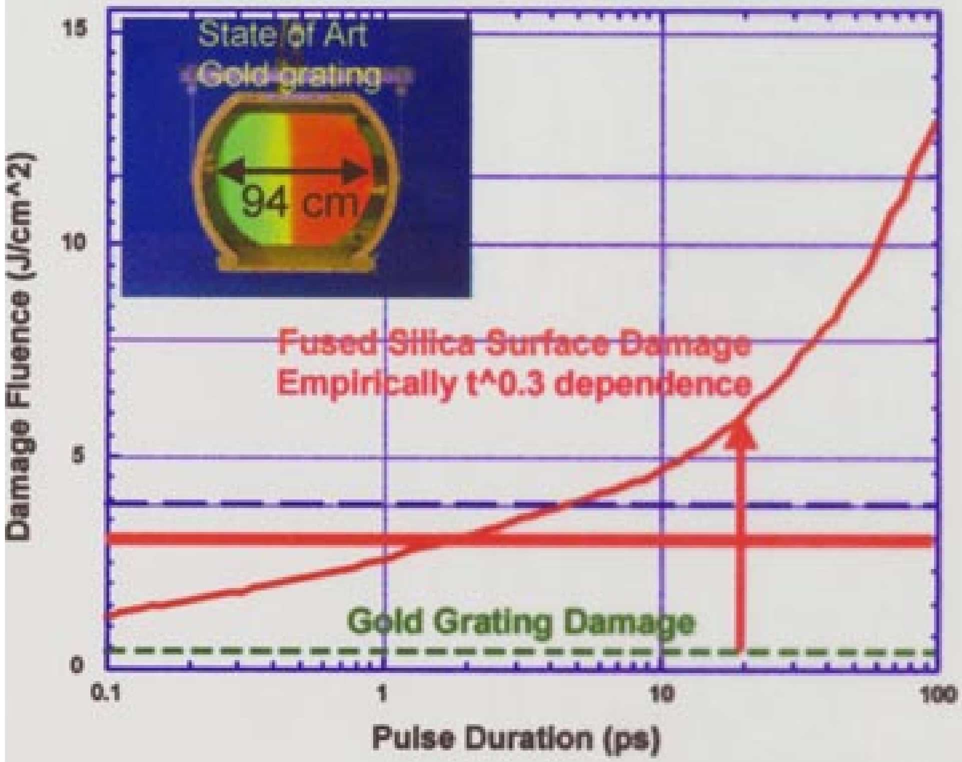
Lots of laser engineering and work on beam combining needs to be done

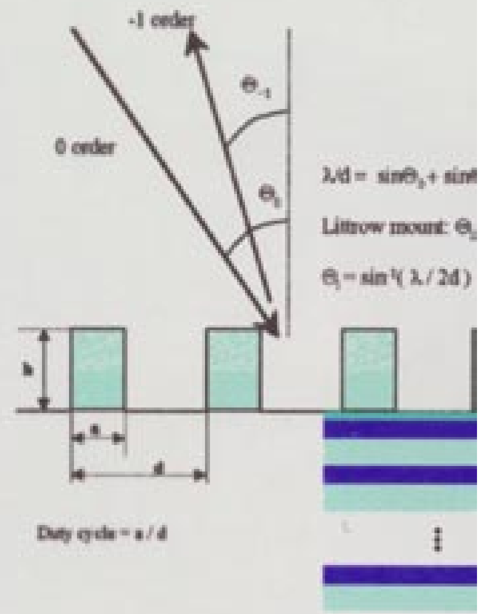
Fast Ignition offers the potential for BOTH
-> Promise of higher gain for less laser energy
and
-> Compression at 2ω (maybe even 1ω)

DOE provides no funds to industry for the development of Petawatt laser technology
->Very different philosophy from DOD in technology development

lectric Final Optics for ps HEPW pulses

The National Ig





Increased damage resistance of fused silica suggests moving away from traditional gold coated gratings to multilayer dielectric (MLD) gratings

For fixed aperture, higher energy is obtained at increased pulse duration

Exact MLD performance will depend on electric field strength within the grating structure. Present designs should provide ~3 J/cm^2 at 20 ps

rating size and damage thresholds required for eneration III and IV Petawatt Lasers

	Beam size (cm)			Grating size (cm)		
amage Threshold (J/cm²)	0.42	1.0	2.0	0.42	1.0	2.[illegible]
rgest dimension @ 0.5kJ	40	25	18	70	48	37
rgest dimension @ 2kJ	78	50	36	127	85	64
rgest dimension @ 4kJ	110	72	50	175	118	85

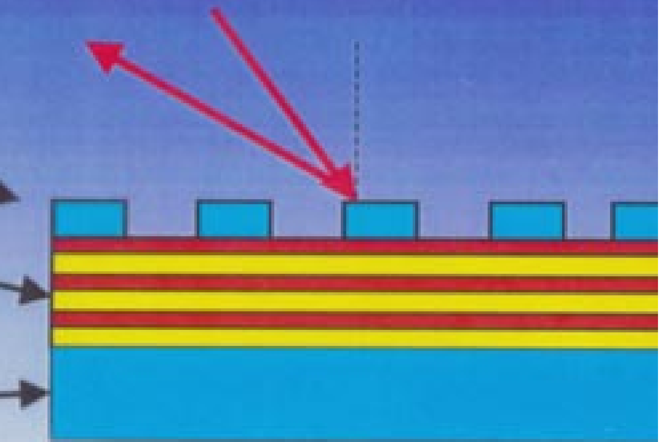
Assuming circular beams and ~50° grating incident angle

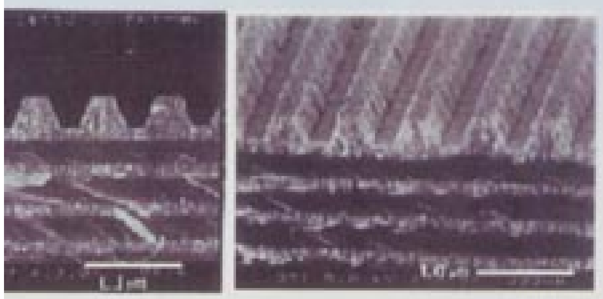
ultilayer dielectric gratings offer higher amage threshold and increased efficiency

Transparent dielectric (~1 micron thick)

Reflective dielectric multilayer stack (>10 layers)

olished glass substrate





dielectric grating –
rry, et al, US Patent No 5,907,436
etters., **20**, 940 (1995)

Dielectrics have inherently higher damage thresholds than metals

The interaction of the surface pha custom multilayer provides much freedom in the grating design

-> Higher performance gratings

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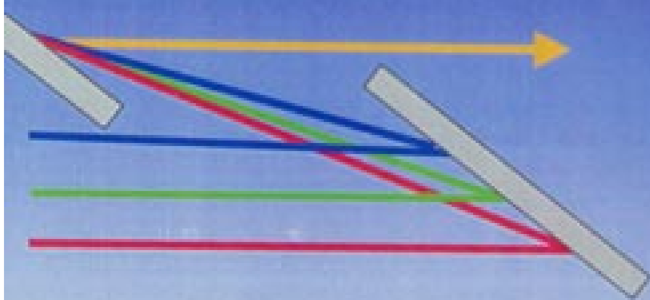
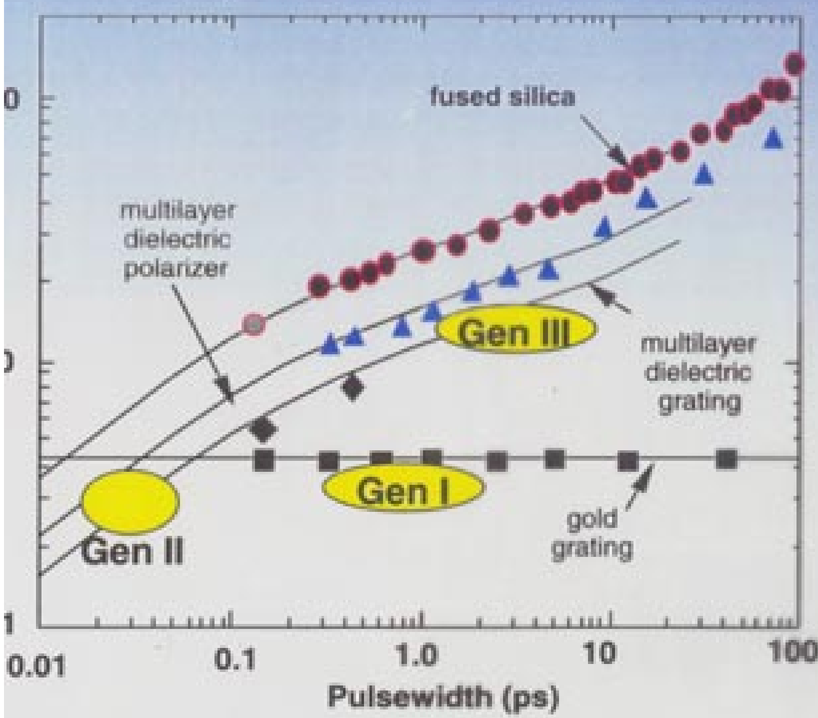
only way to achieve multi-kilojoule Petawatt laser pulses
utilizing dielectric gratings (multilayer reflection or silica transm



The energy of the compressed pulse m
distributed over an area that is large en
avoid damage



Dielectric & fused silica grating damage thresholds

- **higher than gold**
- **increase with pulsewidth**

The enabling technology for petawatt systems are grating can handle higher fluen

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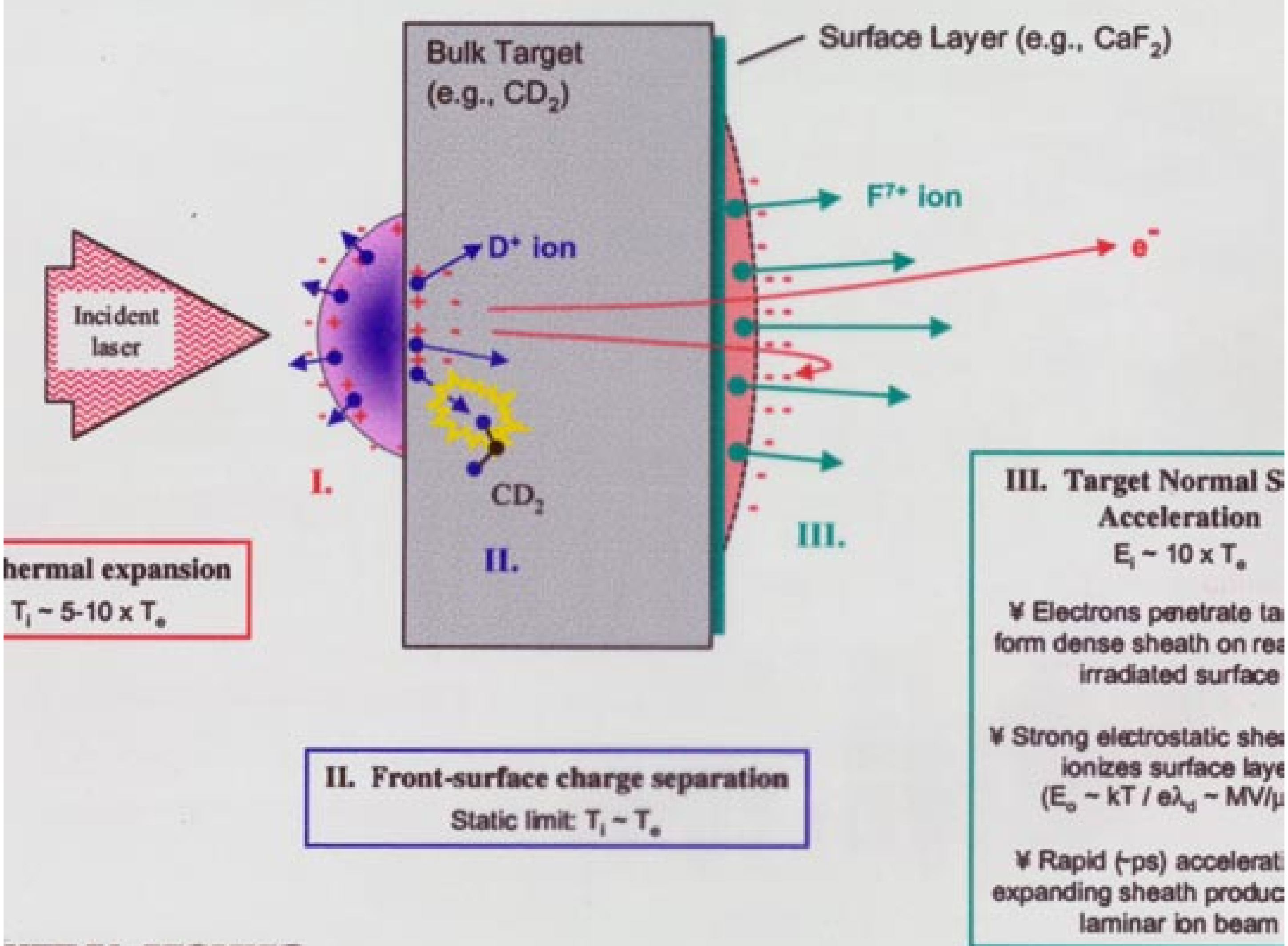
Reference
M.D. Perry, et al, "Development of Pe
Conference on Lasers and Electro-Op

Protons and ions are accelerated in relativistic laser-soli[d] interactions by three principal mechanisms



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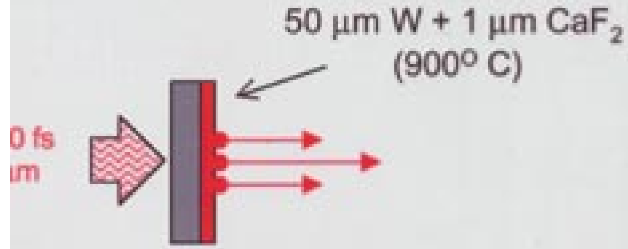
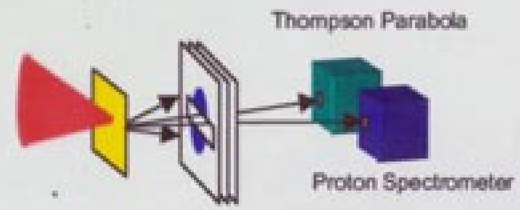
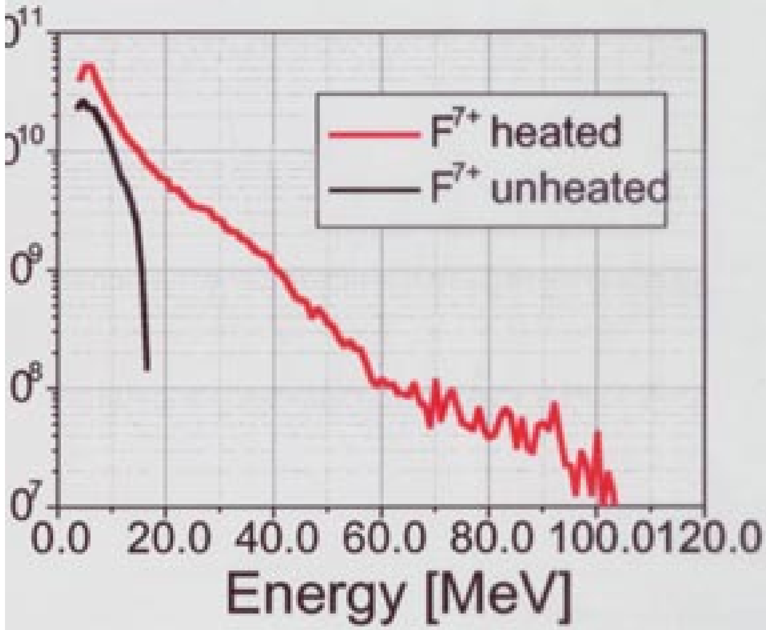
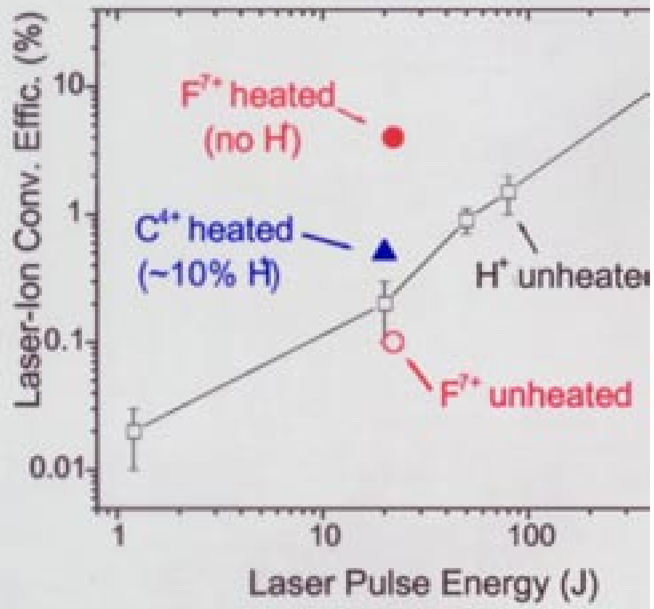
gh efficiency conversion of laser to ion energy is achiev by removing hydrogen contaminants from target









4% conversion of laser energy to F^{7+} ion beam observed !!

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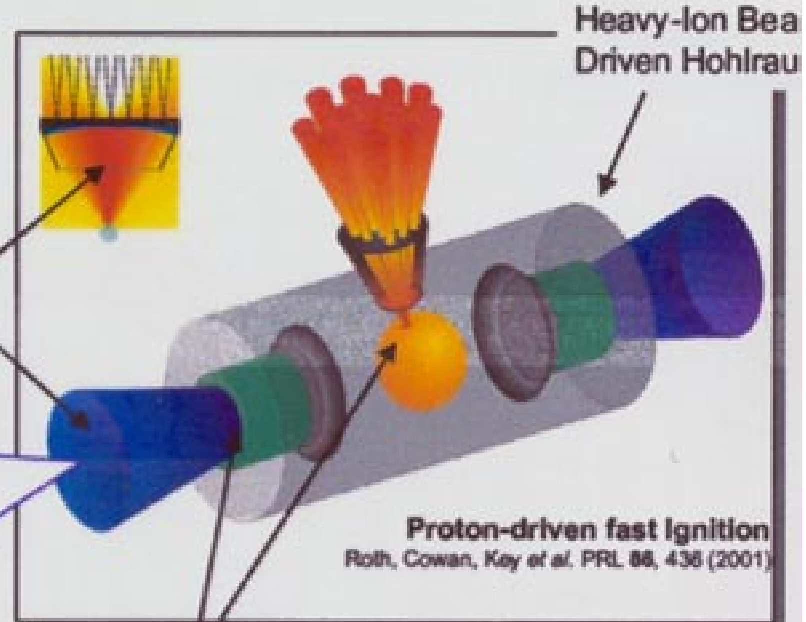
ser-Ion acceleration should be explored in conjunction n Heavy Ion Fusion program

ligh particle-current density eutral beam transport physics & elf-heating at focus (FI & HIF)

vel Ion Sources for ction Accelerators?



High energy density beam-target interaction physics (FI & HIF)

- beam-plasma transport
- collective stopping, ion energy deposition

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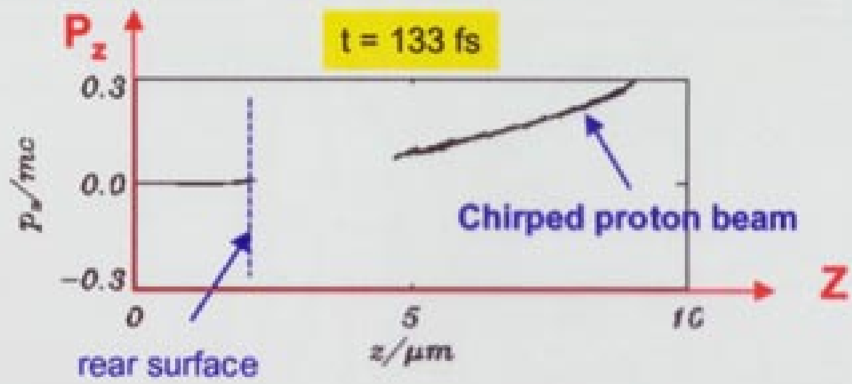
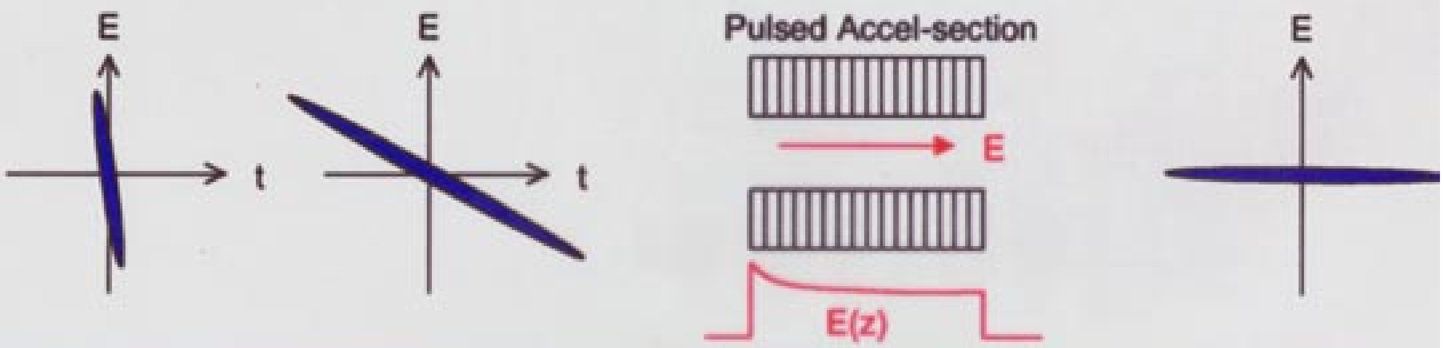
Short pulse duration produces small longitudinal emittance



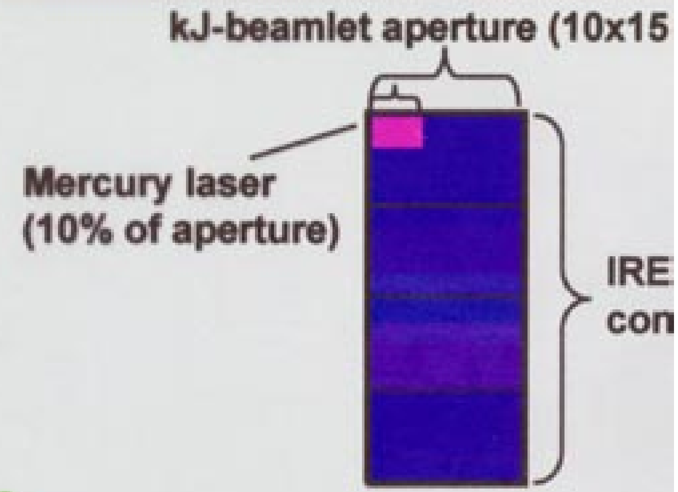
- Rapid acceleration produces strong ΔE-Δt correlation
- Longitudinal phase space comparable to RF linacs

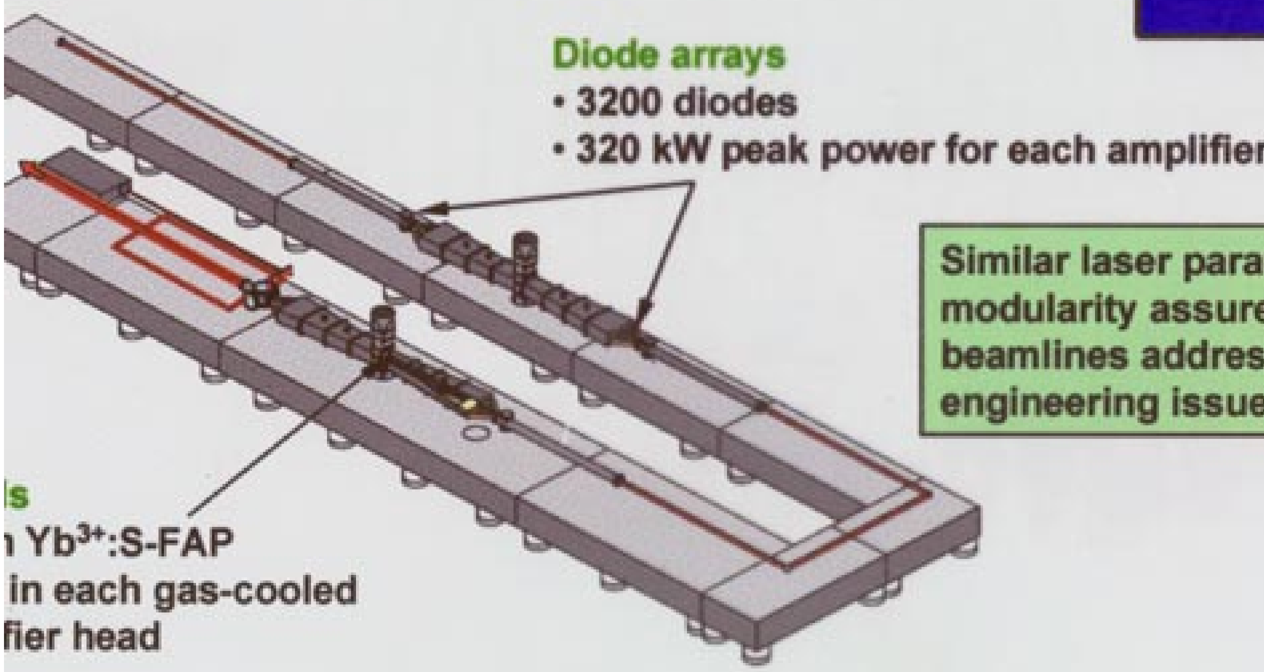
  ΔE Δt < MeV-ps ~ keV-ns
- Energy- or time-bunching possible with post-acceleration



Mercury is a 1/10 aperture diode-pumped gas-cooled crystalline laser for IFE

gy:	100 J
bility:	> 10^8 shots
e length:	2-10 ns
ency:	10 %
ate:	10 Hz
n quality:	< 5x diff. limit
bility:	Scales to > kJ aperture





Similar laser parameters an
modularity assure that sub-
beamlines address physics
engineering issues of IRE

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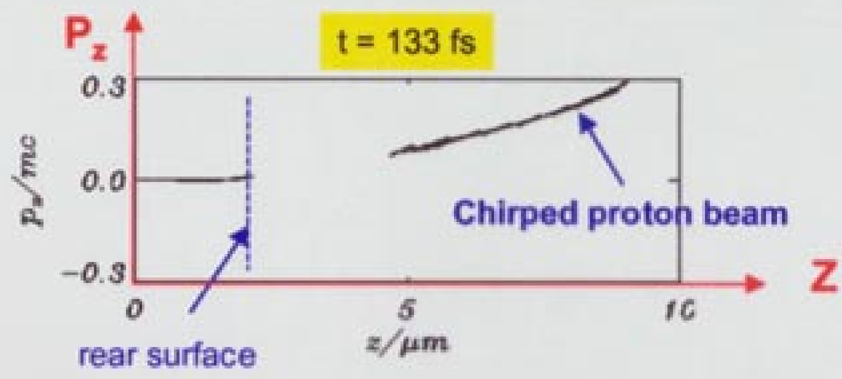

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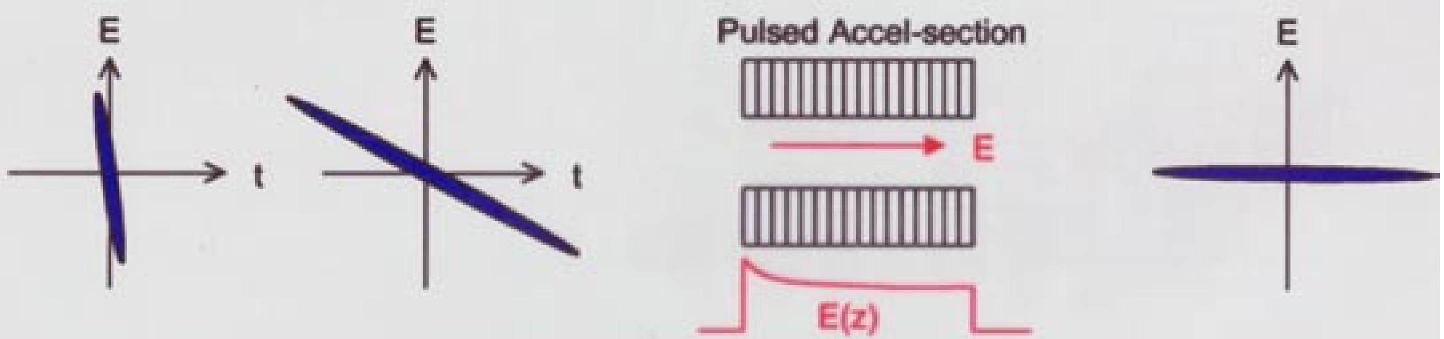

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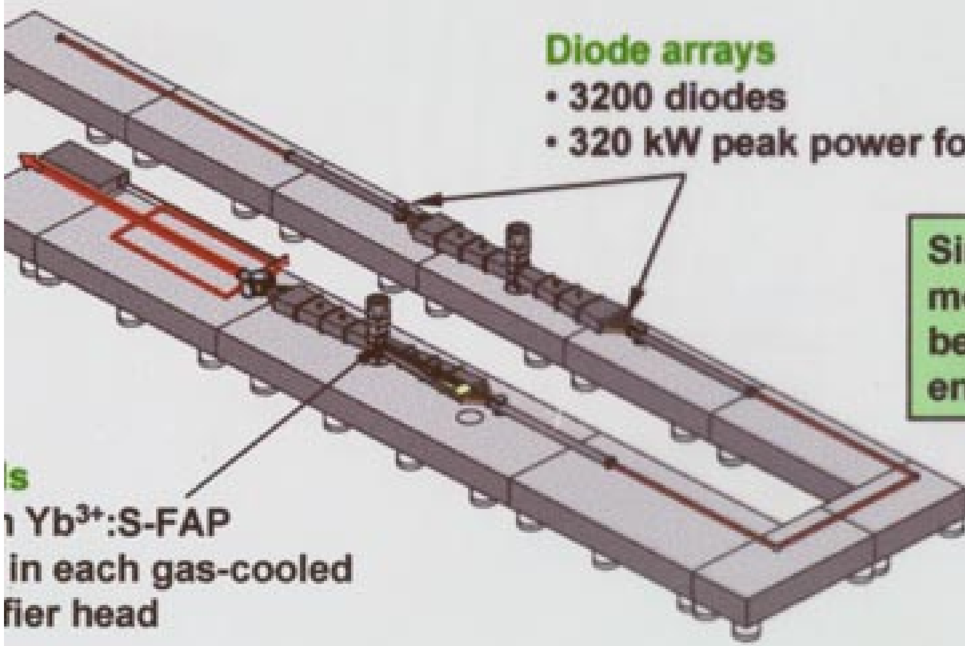
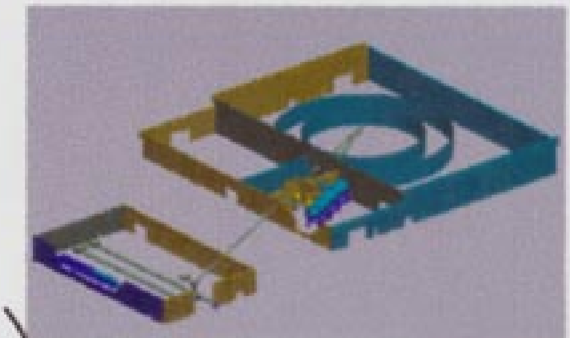
kJ-beamlet aperture (10x15 c

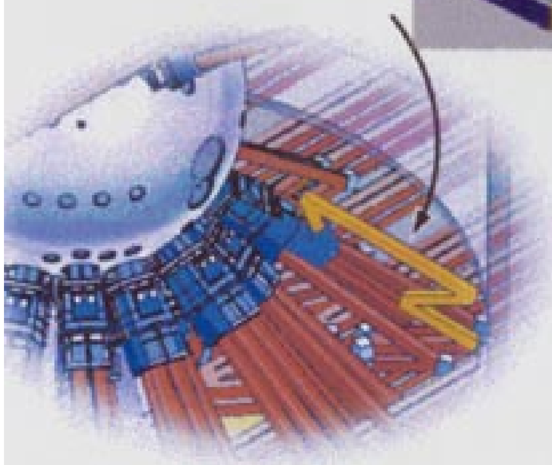


Similar laser parameters and modularity assure that sub-s beamlines address physics a engineering issues of IRE

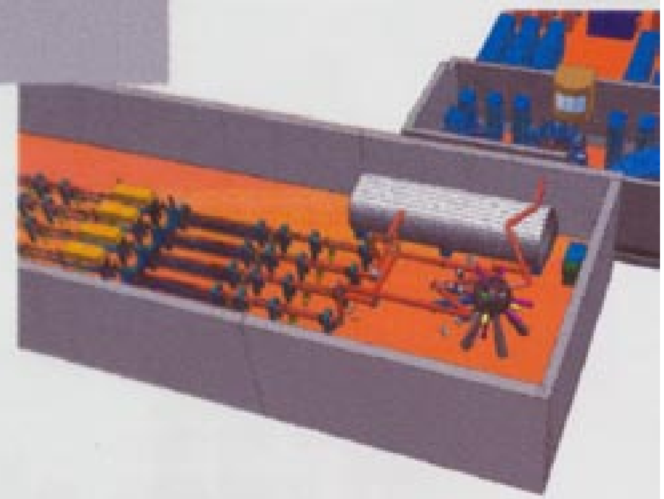
New NNSA facilities will be available as phase A concludes and will support Phase B

SNL Z Beamlet / Z





HEPW at NIF



Omega EP