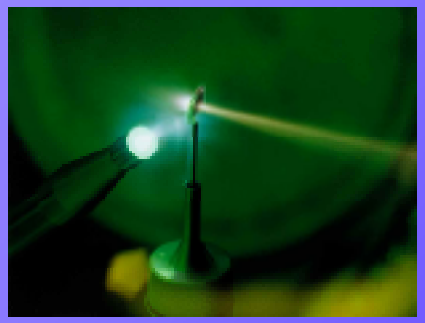
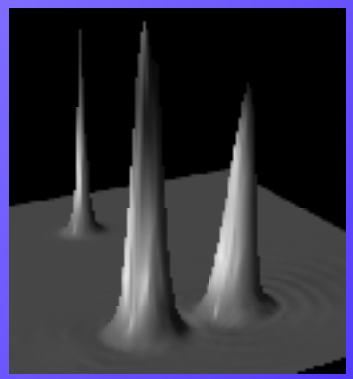
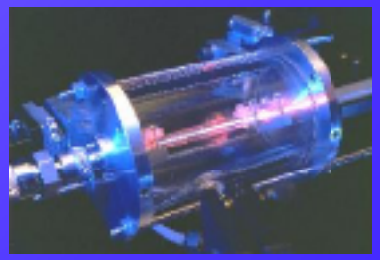
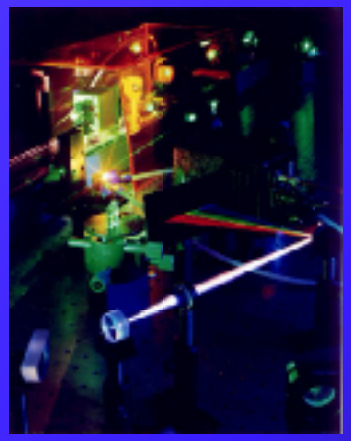
High Energy Density Physics with Ultrafast, Ultraintense Lasers

Summary of the Ultrafast, Ultraintense Laser Working group

Presentation made at the Workshop on High Energy Density Physics
May 24, 2004

The Ultrafast, Ultraintense Laser working group

UUL Working group members:

Todd Ditmire (U. Texas), Chair
Lou DiMauro (BNL)
Roger Falcone (UC Berkeley)
Wendell Hill (U. Maryland)
Warren Mori (UCLA)
Margaret Murnane (U. Col and JILA)

Also contributing to this presentation were:
Mike Key (LLNL), Mike Campbell (GA), Prav Patel (LLNL), Don Umstatder (U. Mich.), Gerard Mourou (U. Mich), Victor Yanovsky (U. Mich), John Porter (Sandia), John Caird (LLNL), Wim Leemans (LBNL), Howard Milchberg (U. Maryland), Richard Klein (LLNL), Tom Cowan (UN Reno), Dick Lee (LLNL) and many others...

Outline of the UUL talks

Presented by Todd Ditmire

I. Introduction to the technology of UULs

II. Overview of the nature of science opportunities in this field
- **Discussion of facility needs in this community**

III. Outline of the compelling questions facing the field

IV. The principal thrusts isolated by the UUL working group

4. Compact high energy electron and proton acceleration
5. Inertial fusion energy fast ignition
1. Intense laser excitation of many particle systems at the relativistc extreme

Presented by Lou DiMauro

IV. Continued...

2. Control of intrinsic and strong-field dynamics on attosecond time-scales
3. Ultrafast, high peak power x-ray generation

V. Discussion of a proposed method for organizing this field and HED science in the US.

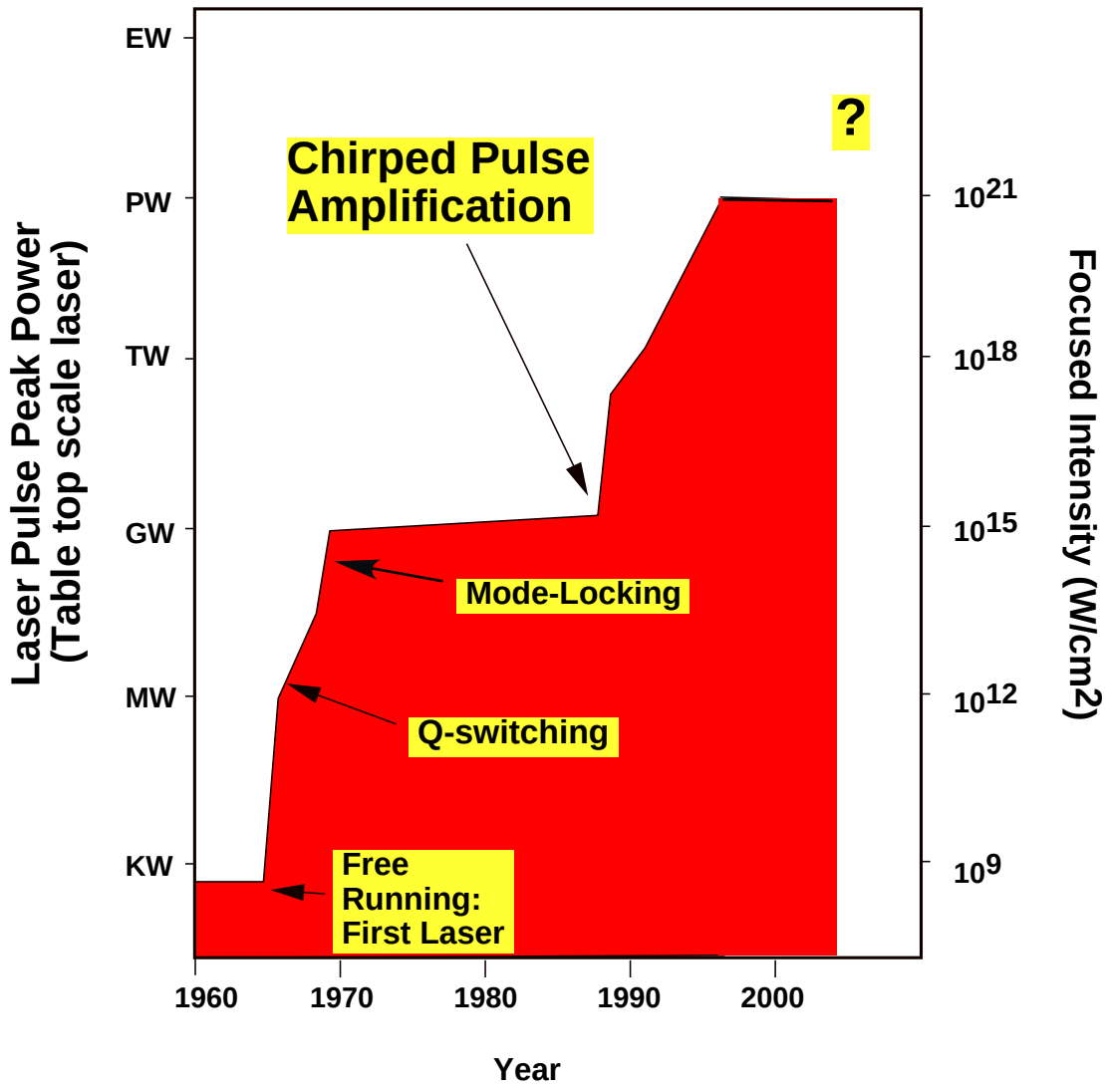
An important advance in laser peak power was made possible by the invention of chirped pulse amplification

The scope of this community includes all aspects of science enabled by breakthroughs in high intensity short pulse laser technology since the invention of chirped pulse amplification

Enabling technology includes:

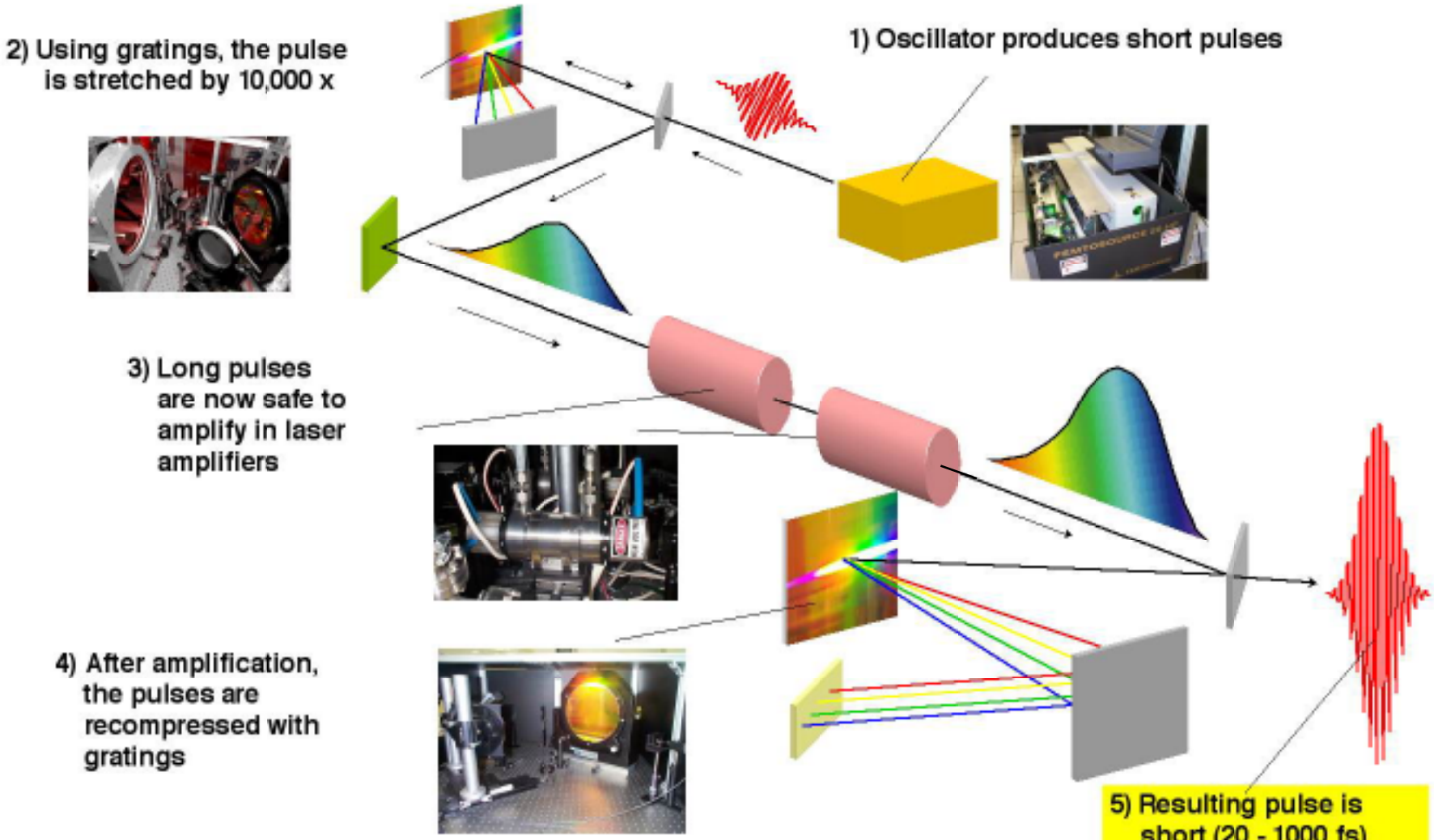
- Table top terawatt lasers
- Petawatt class lasers
- High average power CPA lasers

Some of these technologies are beyond single user capabilities



Principal focus is on science and applications, though the common thread is similar technology and techniques

The enabling technology for this research field is chirped pulse amplification (CPA)



• Strickland and Mourou *Opt. Comm.* 56, 219 (1985)

The current state-of-the-art ultrafast, ultraintense lasers (UULs) tends to fall into two categories

Table top terawatt lasers:

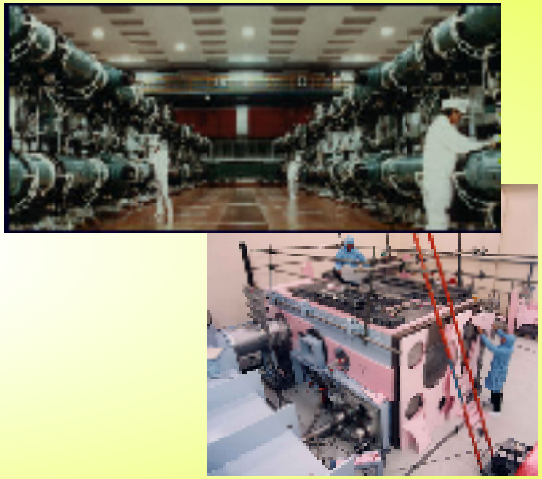
Pulse energy ~ .001 - 1 J,
Pulse duration <100 fs,
Peak Power < 100 TW
Repetition Rate ~ 1 kHz - 10 Hz

Usually Ti:sapphire based

Large scale multi- terawatt to petawatt

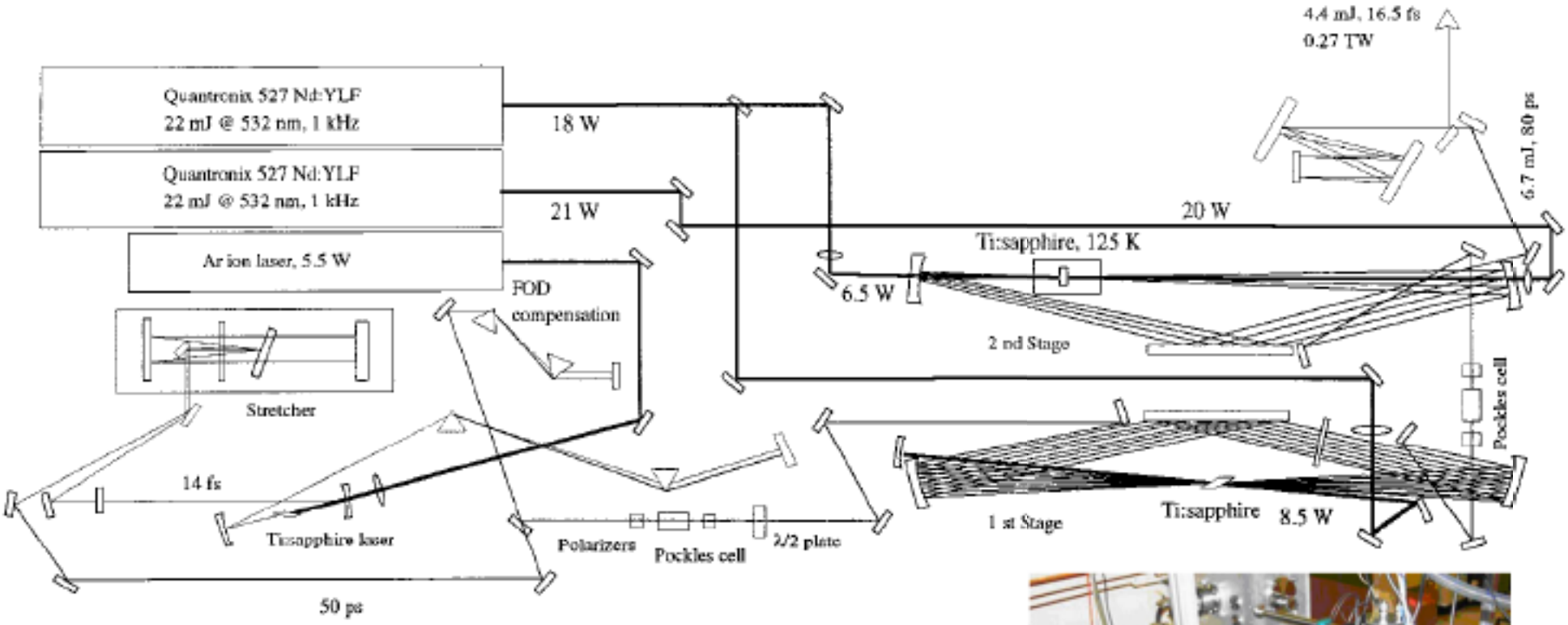
Pulse energy 10 - 1000 J
Pulse duration > 500 fs
Peak power 10 - 1000 TW
Repetition rate ~ 1 shot/hour

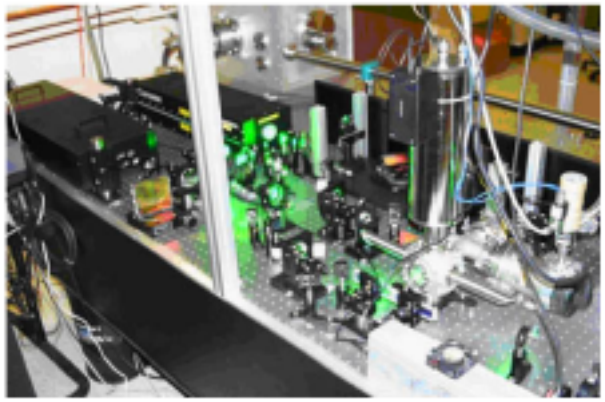
Usually Nd:glass based



Terawatt-class kHz lasers are now possible using high average power pump lasers and Ti:sapphire amplifiers

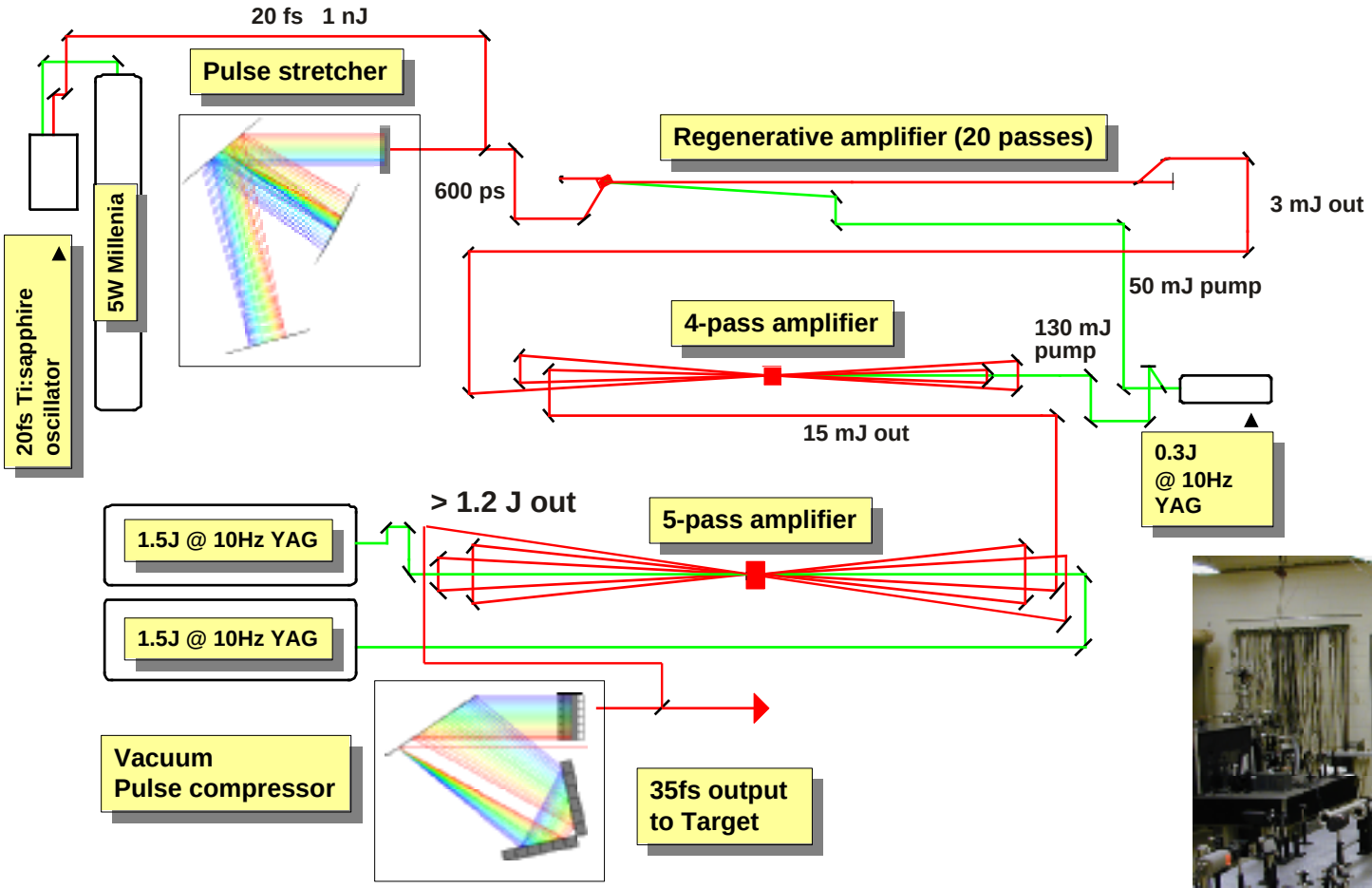
0.3 TW high rep. rate kHz laser developed by Backus, Murnane and Kapteyn

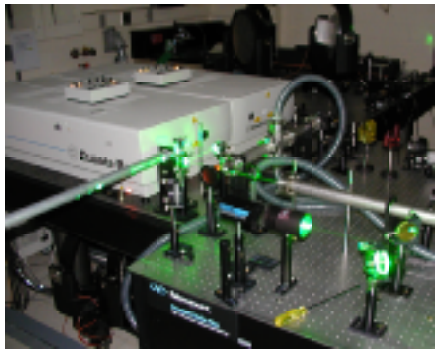


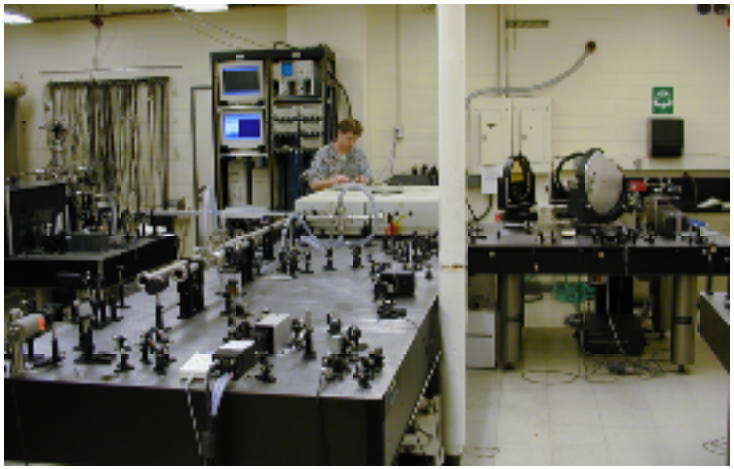


Taken from S. Backus et al. "High power ultrafast lasers" Rev. Sci. Inst. 69, 1207 (1998)

The "Texas High intensity Optical Research laser" (THOR) currently delivers 20 TW/10 Hz

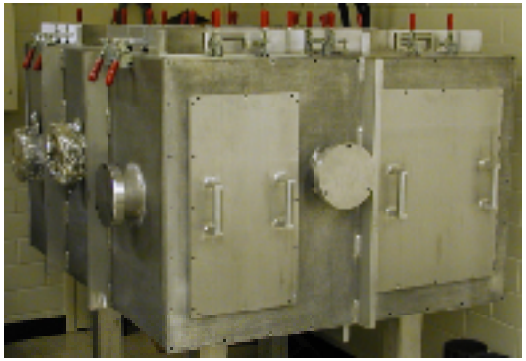




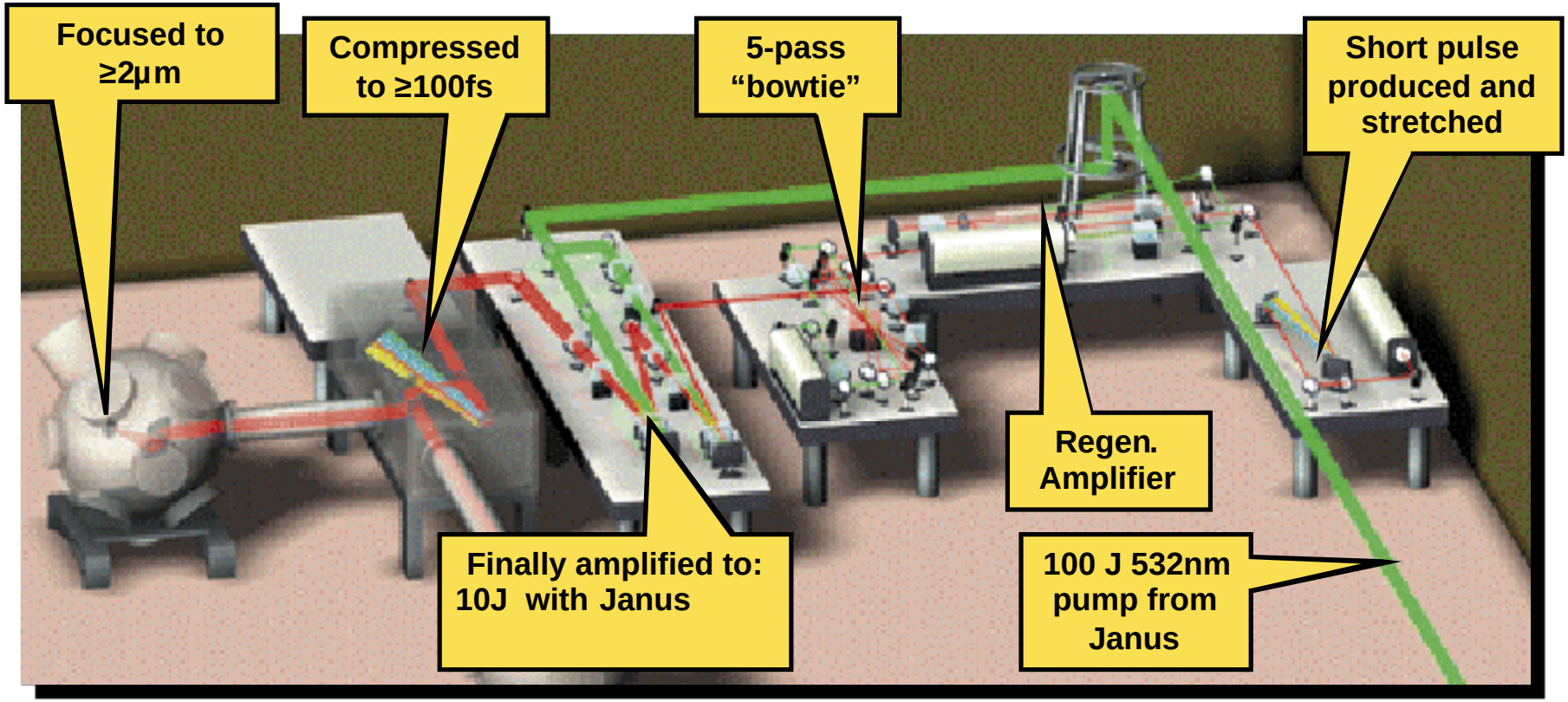


Present performance specs:

~ 35 fs pulsewidth
0.75 J energy @ 10 Hz
→ ~ 20 TW peak power

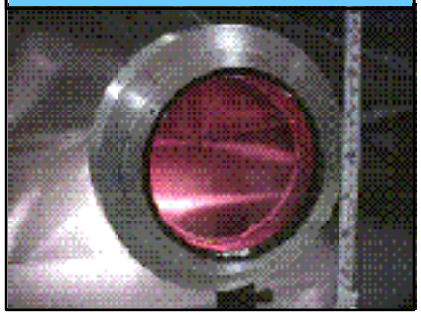


The LLNL JanUSP laser delivers 10 J, 100 TW pulses



- Intensities can exceed 10^{20} W/cm^2 at 100fs/pulse

10cm diameter Ti:Sapphire crystal



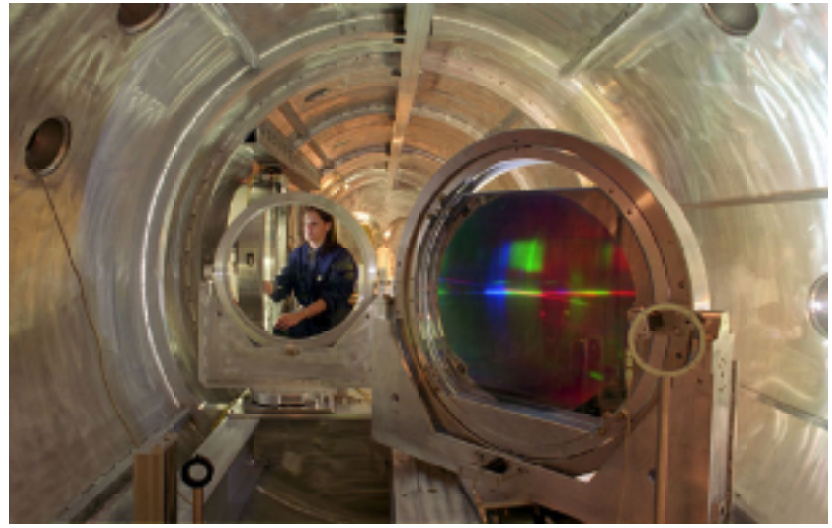
40cm diffraction gratings

120J, 6ns, 532nm pump laser

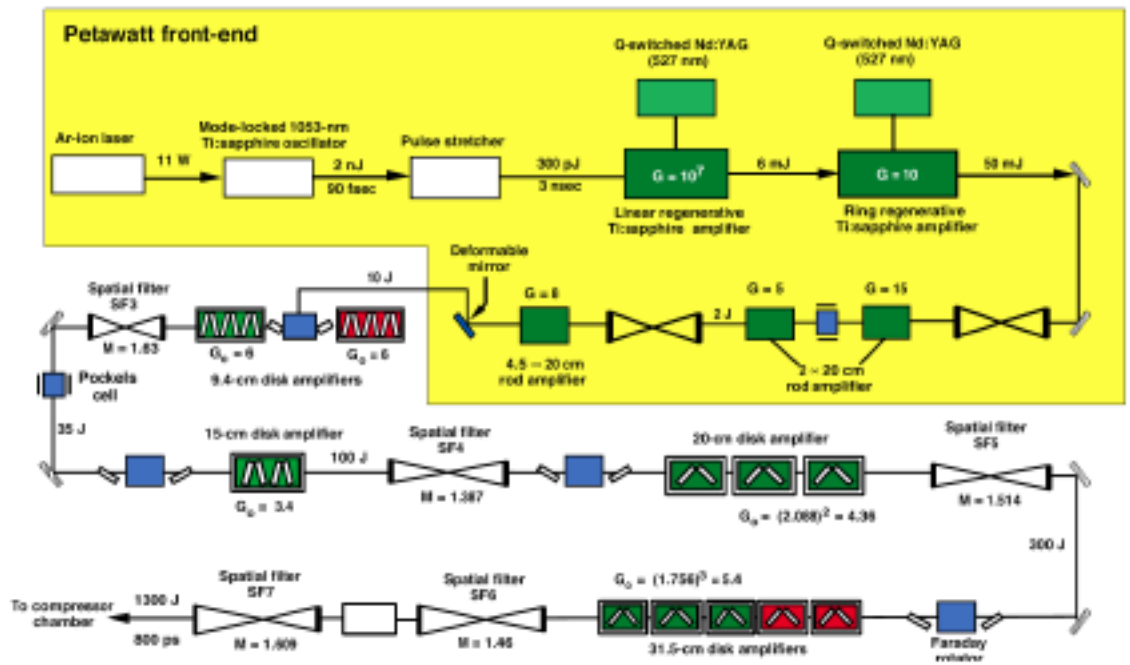
The first Petawatt laser was demonstrated at Lawrence Livermore by implementing CPA on the NOVA laser

The Petawatt at LLNL

Nova laser



90 cm gratings to compress Nova pulses



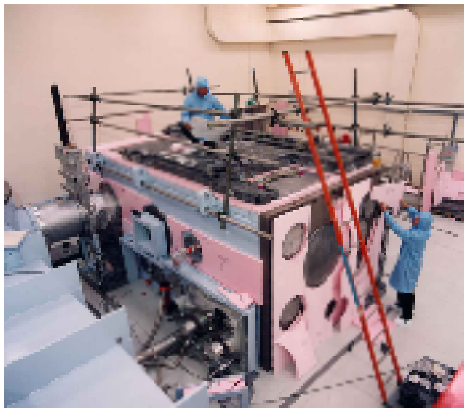
Petawatt specs:
500 J energy
500 fs pulse duration
Peak intensity > 10^{20} W/cm^2

Information derived from M. D. Perry et al "Petawatt Laser Report" LLNL Internal report UCRL-ID-124933.

High intensity laser development is very active world wide

Representative list of short pulse laser facilities above 10 TW world wide

Facility	Peak Power	Type	Pulse duration	Pulse Energy
LLNL, USA	1 PW	Nd:glass	500 fs	500 J - Decommissioned
RAL, UK	1 PW	Nd:glass/OPCPA	600 fs	600 J
JAERI, Japan	850 TW	Ti:sapphire	20 fs	17 J
ILE, Japan	700 TW	Nd:glass/OPCPA	700 fs	350 J
MBI, Germany	100 TW	Ti:sapphire	50 fs	5 J
LLNL, USA	100 TW	Ti:sapphire	100 fs	10 J
LULI, France	100 TW	Nd:glass	300 fs	30 J
LOA, France	100 TW	Ti:sapphire	25 fs	2.5 J
ILE, Japan	60 TW	Nd:glass	500 fs	30 J
Lund, Sweden	35 TW	Ti:sapphire	35 fs	1.2 J
FOCUS, USA	30 TW (→500 TW)	Ti:sapphire	32 fs	1 J
Texas, USA	21 TW	Ti:sapphire	35 fs	0.75 J
LBNL, USA	18 TW (→100 TW)	Ti:sapphire	40 fs	0.7 J
Jena, Germany	17 TW	Ti:sapphire	60 fs	1 J
Ibaraki, Japan	12 TW	Ti:sapphire	50 fs	0.6 J
CREOL, USA	13 TW	Cr:LiSAF	75 fs	1 J
CUOS, USA	10 TW	Nd:glass	400 fs	4 J
NRL, USA	10 TW	Nd:glass	500 fs	5 J
ILE, Japan	10 TW	Ti:sapphire	100 fs	1 J
RAL, UK	10 TW	Ti:sapphire	50 fs	0.5 J
Soreq, Israel	10 TW	Ti:sapphire	45 fs	0.45 J
Garching, Germ.	10 TW	Ti:sapphire	100 fs	1 J



PW lasers under construction:

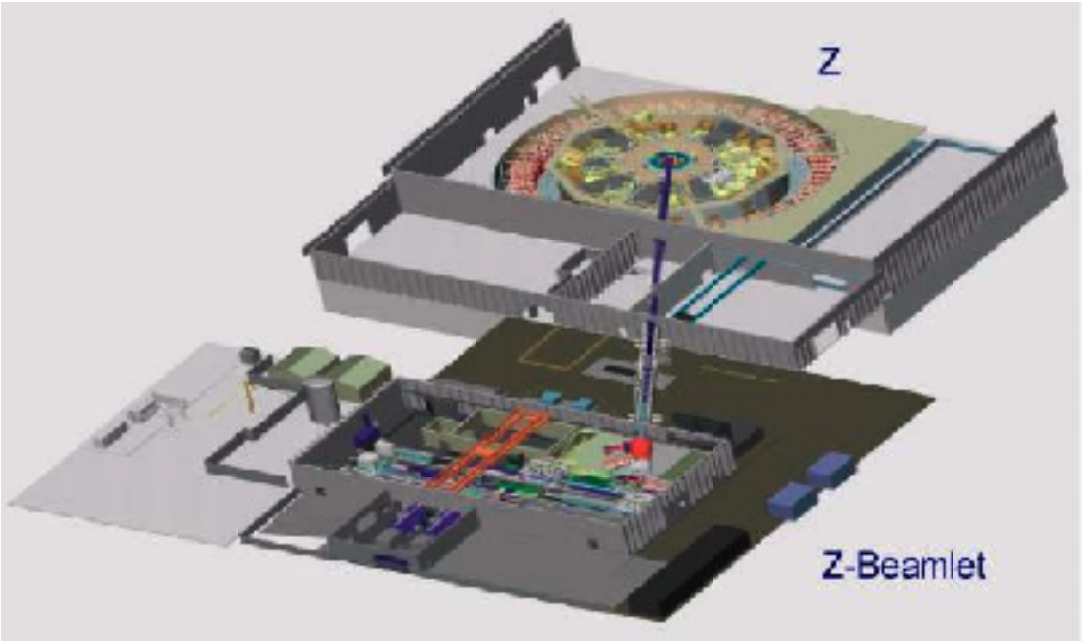
JAERI, Japan
LULI, France
CELIA+CESTA, Fr.
Jena, Germany
GSI, Germany

Sandia Nat. Lab
LLNL
U. of Texas
LLE Rochester
U. of Michigan

An upgrade of the Sandia Z-Beamlet laser to the 1 PW level is underway

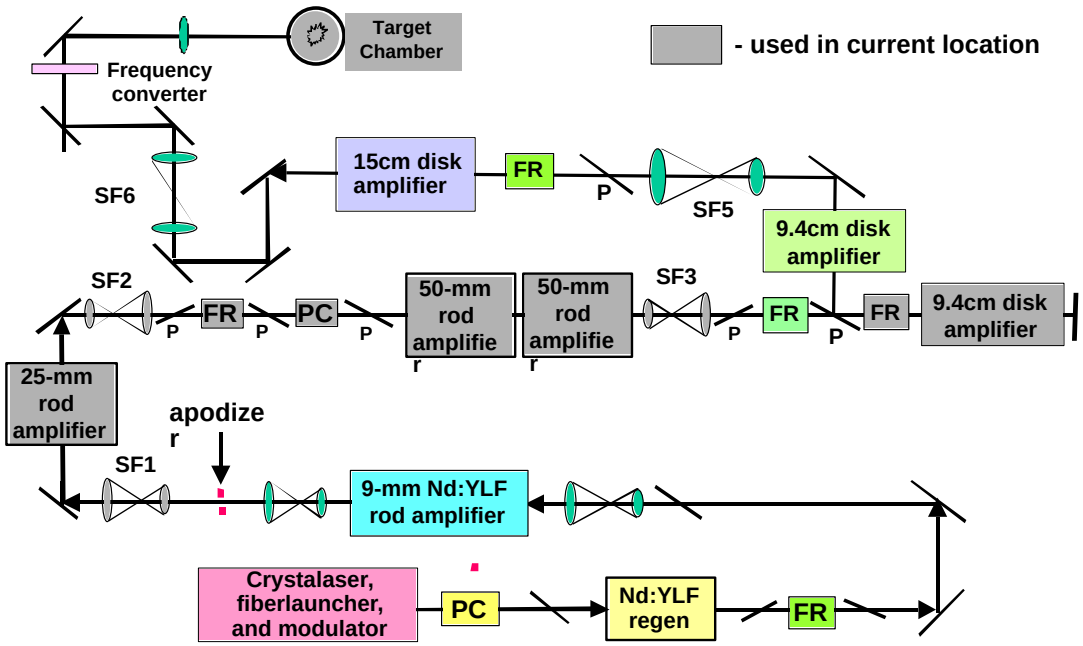
Sandia National Laboratories

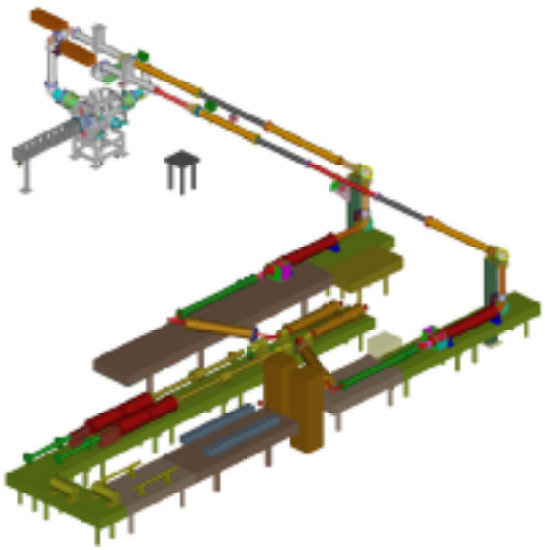
- Modification of the Z-Beamlet Laser (ZBL) facility will enable near-term HEPW capability for high-energy radiography and fast-ignition experiments on Z.
  - Existing laser technology (available FY04)
    - 500 J in 0.5 ps
    - enhanced radiography
  - Near-term technology
    - 1.5 to 3 kJ in 5 ps
    - advanced radiography, FI studies, UHI



The Janus laser at LLNL will be upgraded to 1 PW in the near future

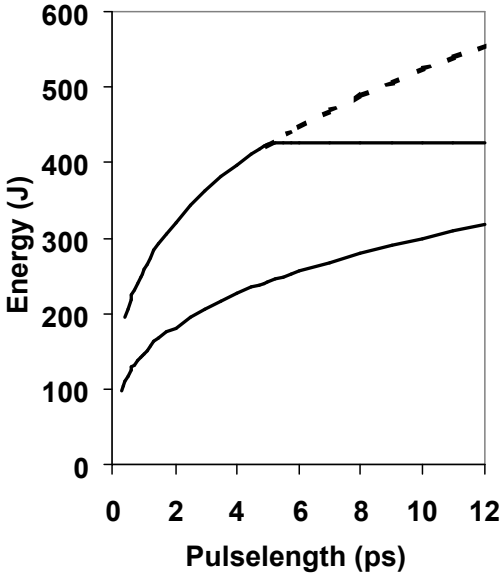
Schematic diagram for the upgrade design



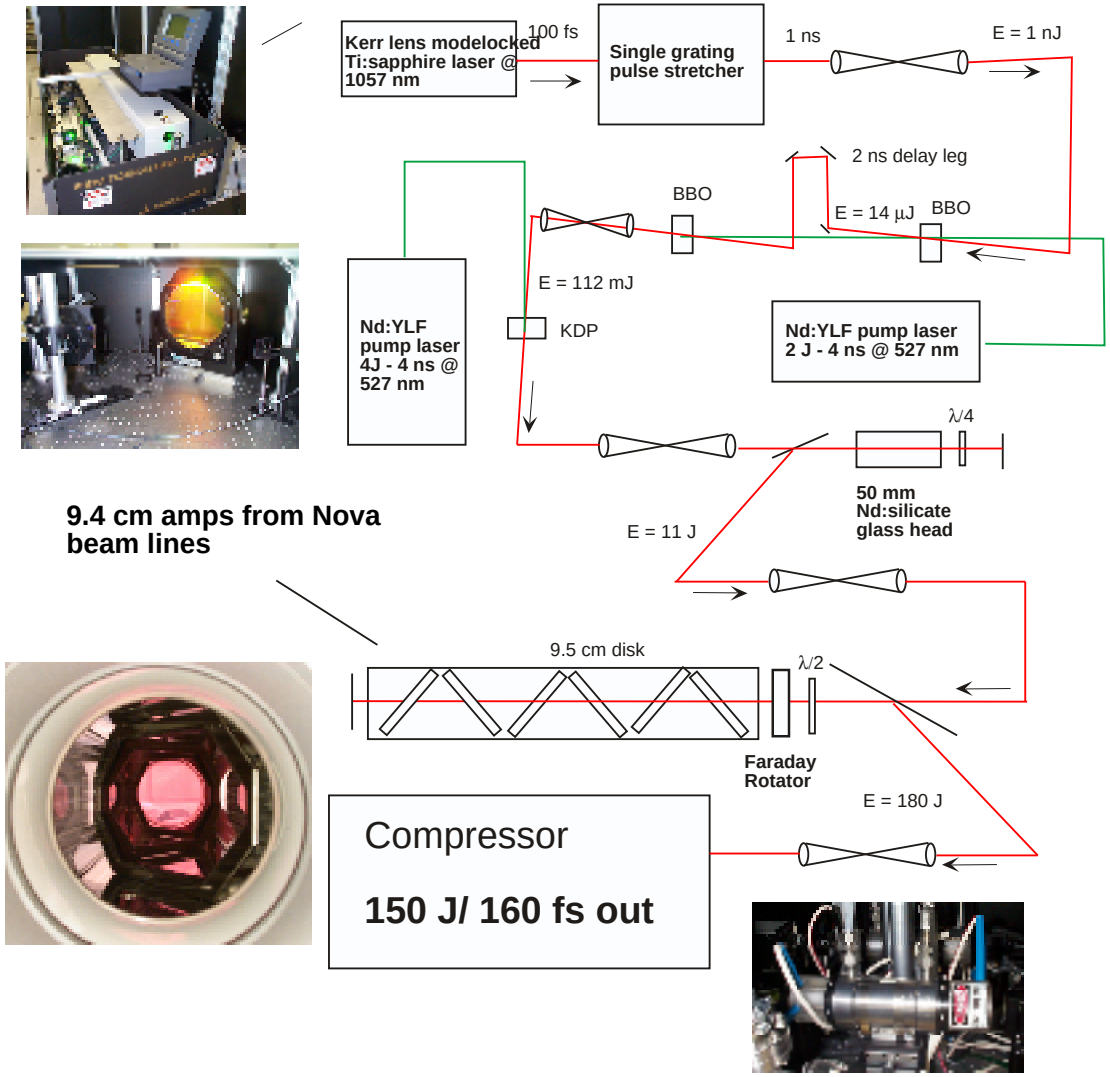


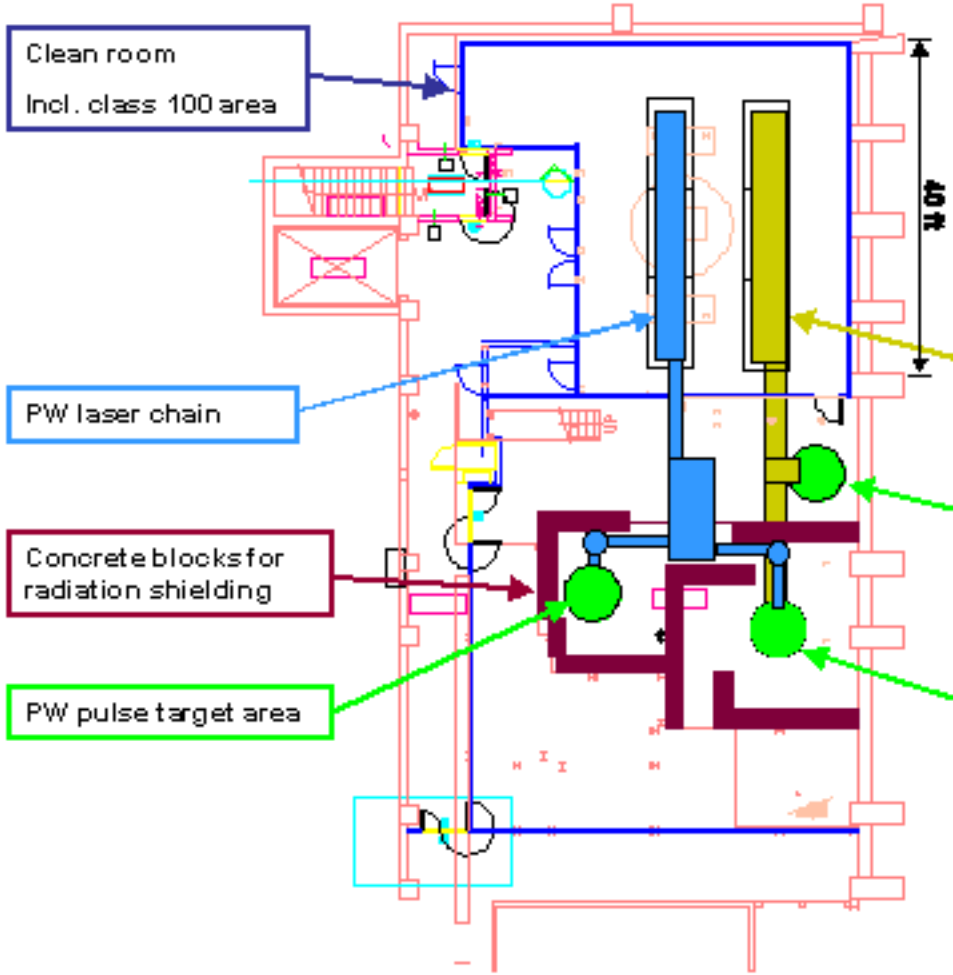
August 27, 1999

Janus Upgrade performance capability for short laser pulse generation has been analyzed



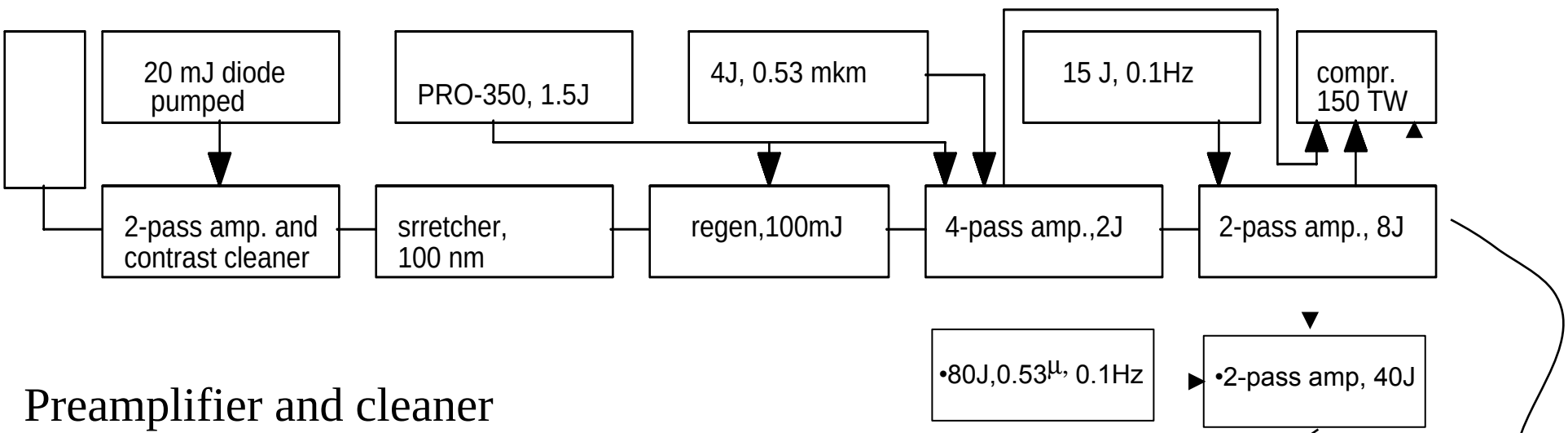
We have initiated the construction of the Texas Petawatt Laser



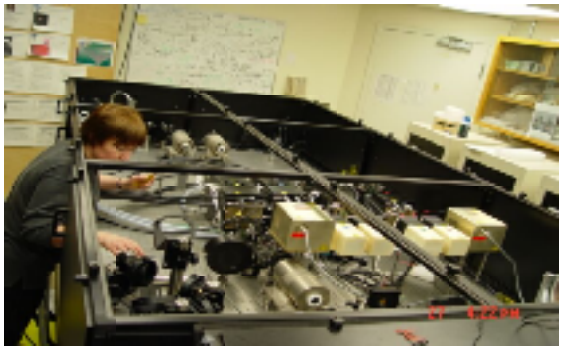


A Petawatt class Ti:sapphire laser is under construction at the University of Michigan

PW-class Hercules laser

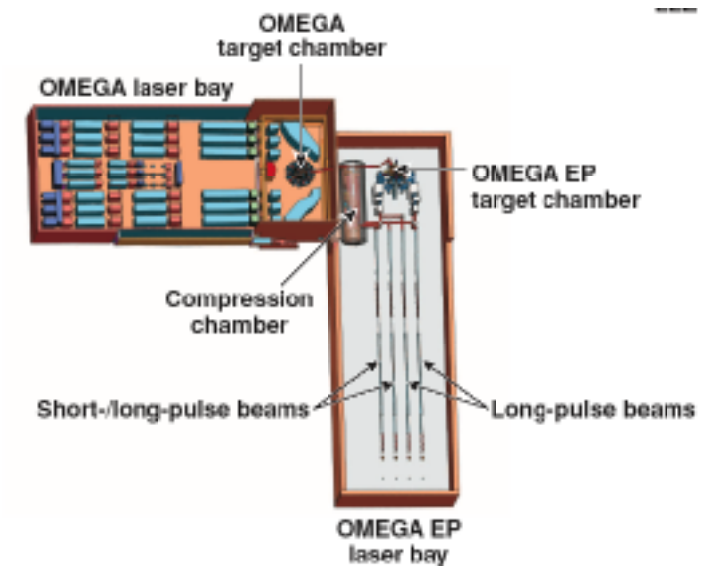


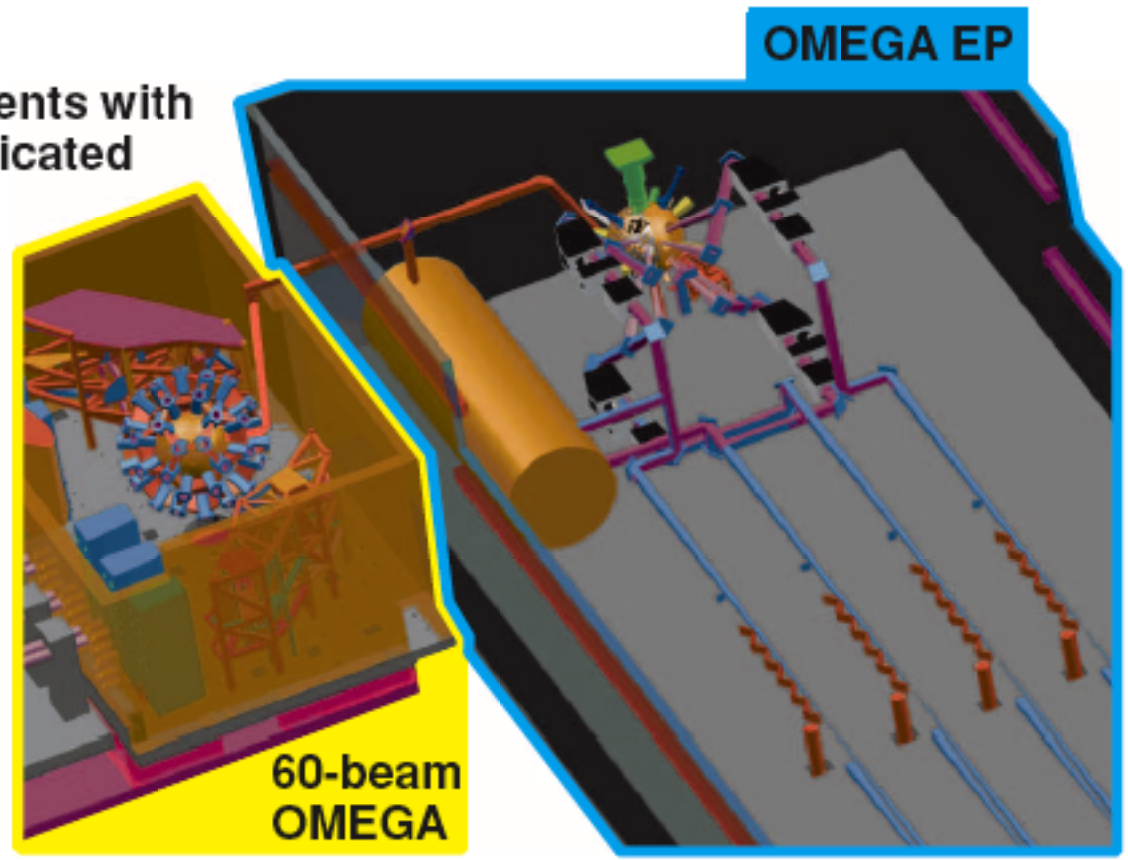
- Preamplifier and cleaner
- Large aperture high energy (~50mJ) regenerative amplifier
- Cryogenically cooled 4-pass amplifier
- 15J, 80J green pump lasers.



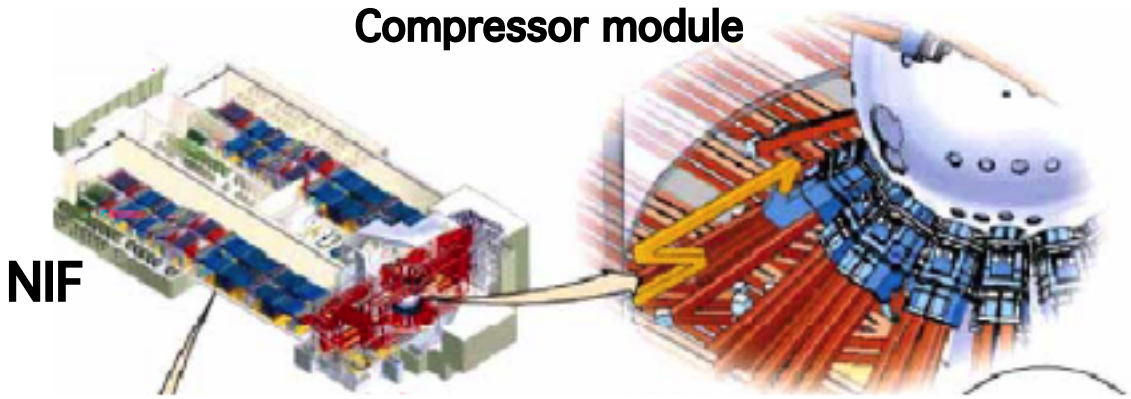
A new high-energy petawatt capability at OMEGA next to the existing 60-beam facility will allow integrated FI experiments

- Two short-pulse, 2 ~ 3-PW, 2.6-kJ beams
- Up to four long-pulse (10-ns) UV beams with ~6.5 kJ each
- NIF-like staging
- Integrated experiments with OMEGA or in a dedicated target chamber
- < 2-h shot cycle

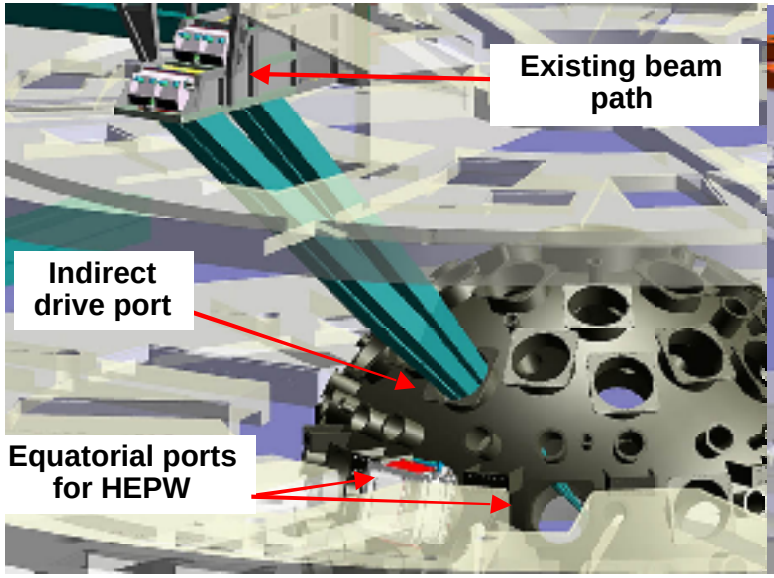




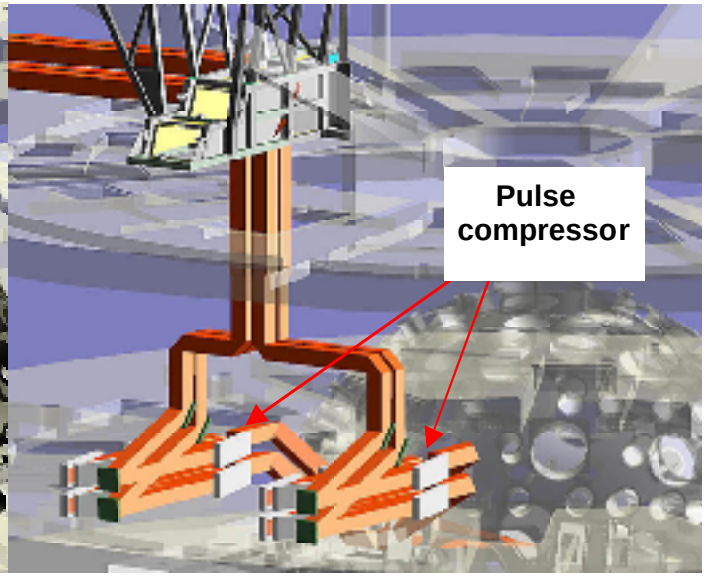
NIF can be modified to provide quads of HEPW beams (2 to 5 kJ, 0.5 - 50 ps) for the HEDS and SSP mission



Indirect drive configuration



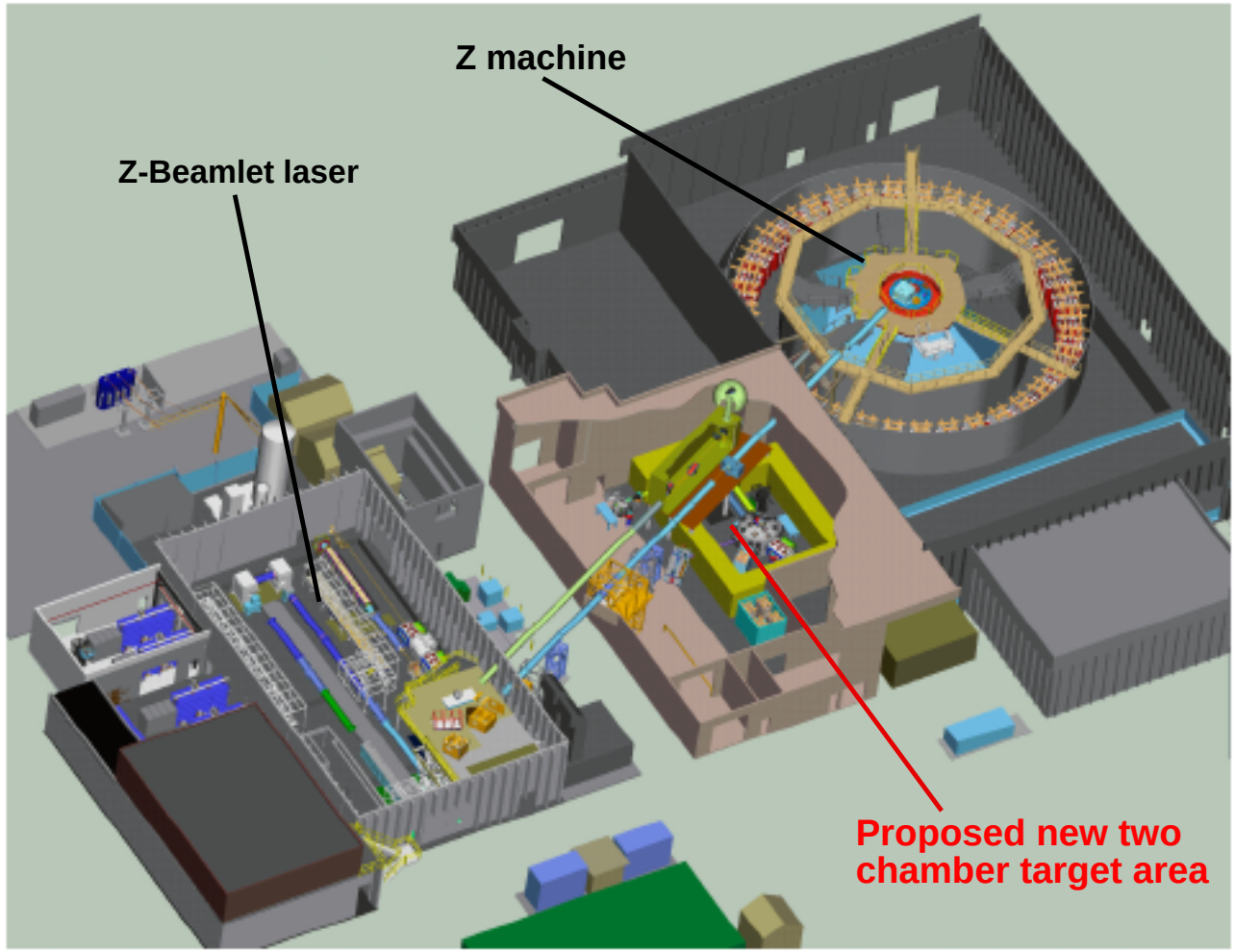
HEPW Configuration



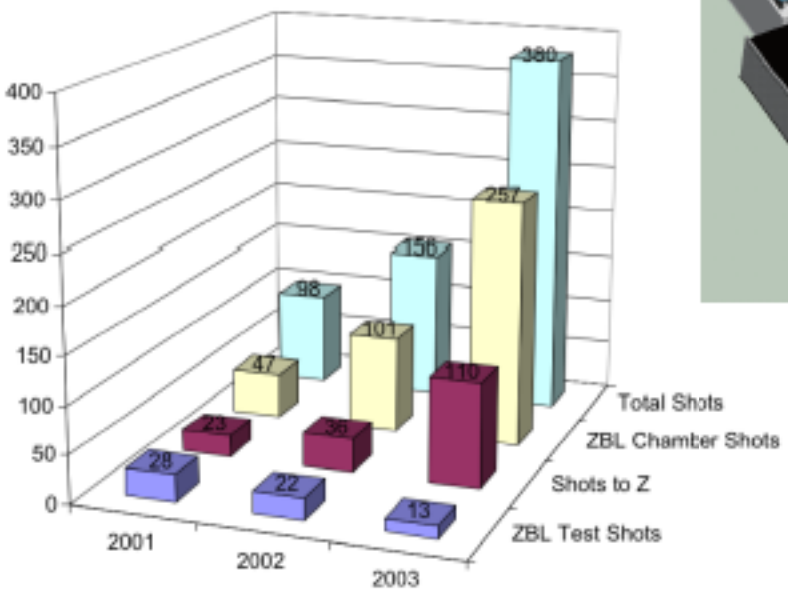
4 HEPW beams could be redirected to two, dual-beam, compact compressors and sent to one equatorial port

The Sandia Z-BL/PW facility represents an example of a mid-scale NNSA facility potentially ideal for outside use

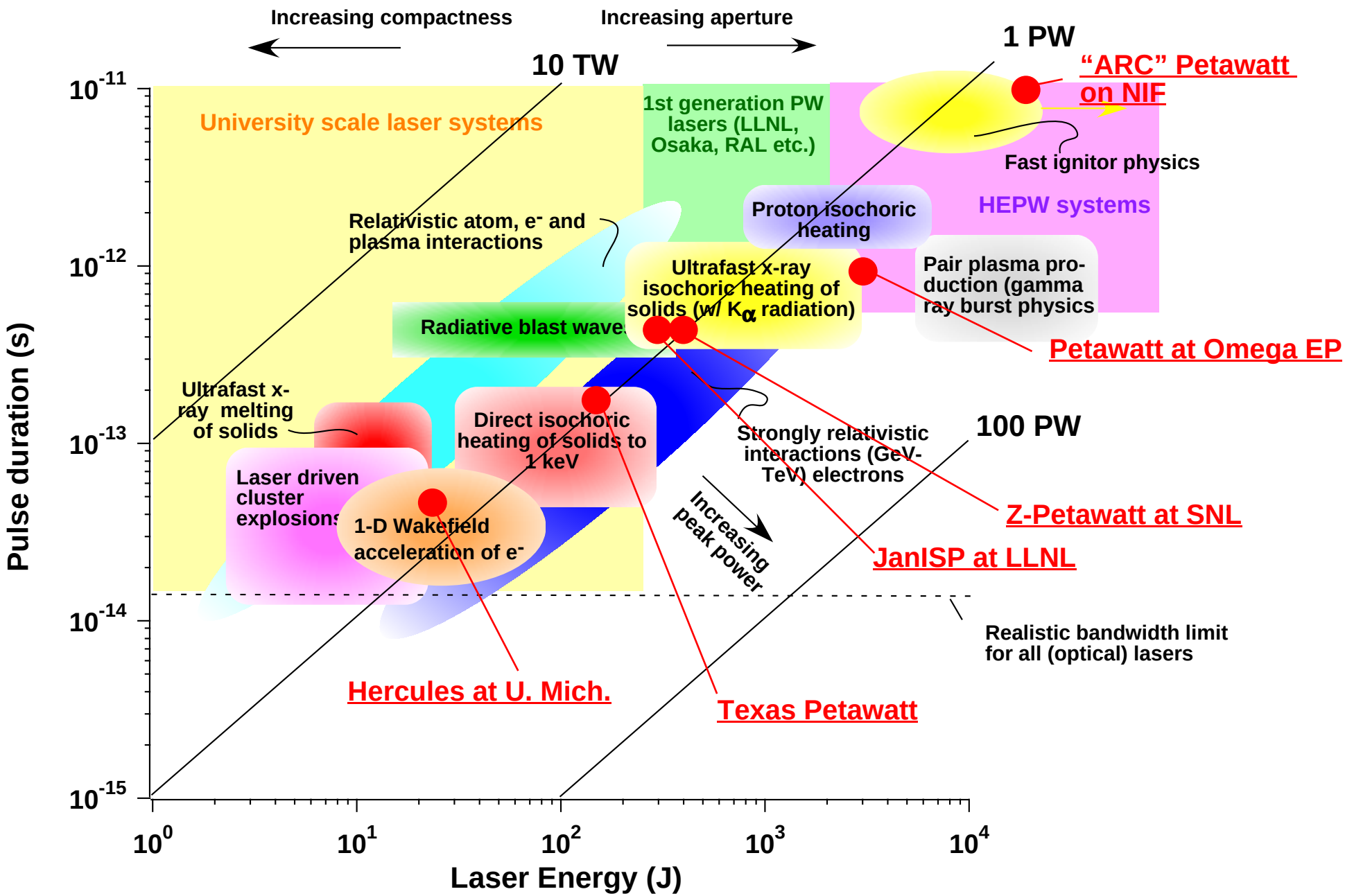
Proposed location of the Sandia Two-Beam Target Area



Summary of Z-Beamlet shots 2001 - 2003



Different Petawatt lasers are needed to access most potential science areas



Applications in UUL science impact the research interests of all the agencies

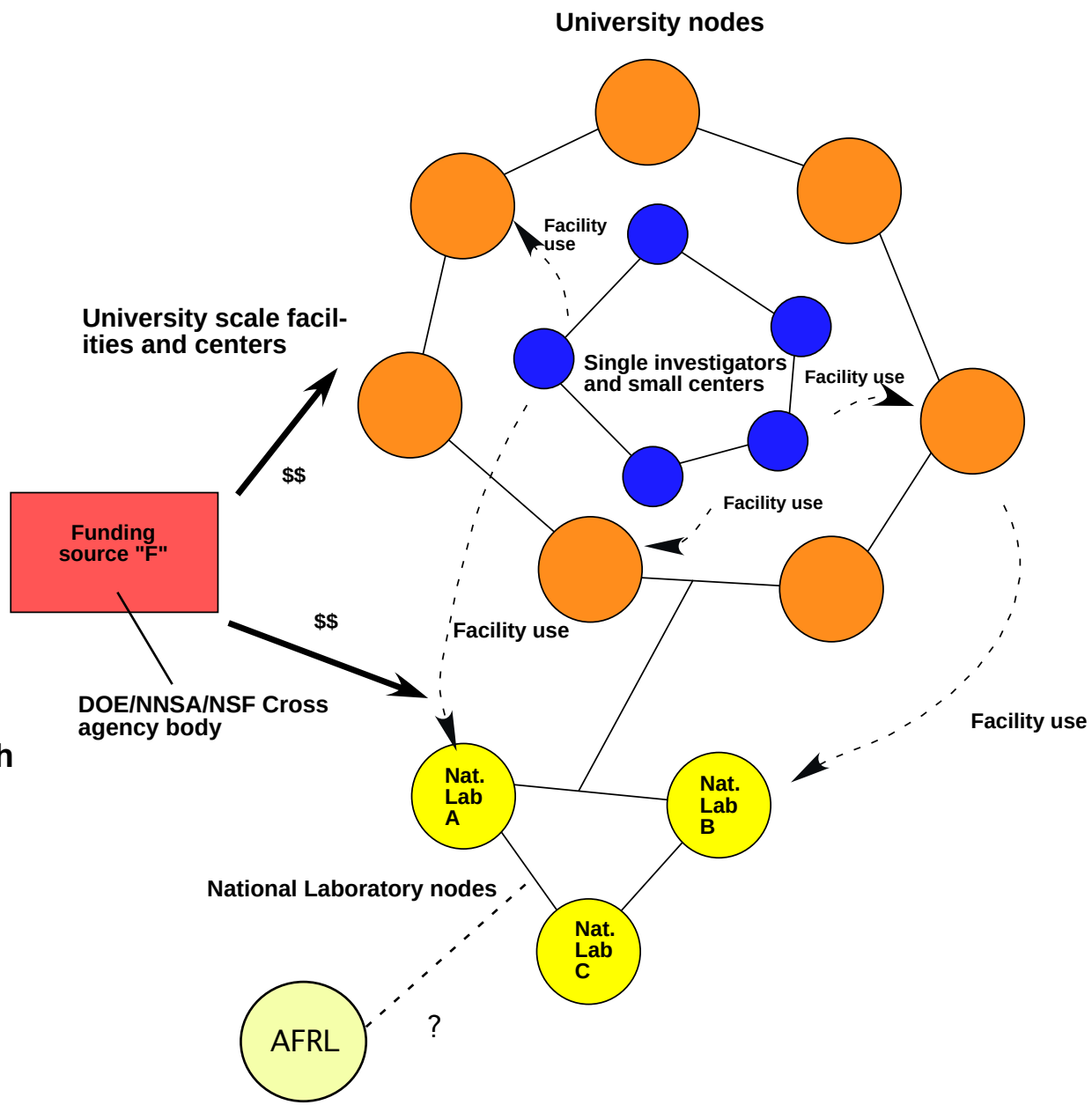
NNSA	Warm and hot dense matter eq. of state
DOE OFES	Fusion energy/ Fast ignition
DOE BES	Ultrafast x-ray generation and use in chemcal systems; attosecond science
DOE HEP	Advanced plasma acceleration
NSF	Fundamental high field AMO physics; astrophysics; high energy physics
Air Force/AFRL	TBD; short pulse laser machining; nondestructive evaluation with laser sources; directed energy

The US requires a plan for the complete portfolio of laser facilities needed to exploit the science opportunities of interest to all the agencies

One effective way to organize the national effort would be to form a national network in UUL science

Action plan for establishment of a UUL network:

1) Formation of a funded cross agency body (CAB)
2) The CAB would hold nation-wide competition for the formation of network nodes.
3) The network would include three kinds of nodes:
   (a) Facilities at National Labs and existing large scale laboratories.
   (b) Centers at universities.
   (c) Single investigator efforts
4) Single Investigators are a key component. Will have access to the facilities at the network nodes
5) Network will be a dynamic entity with a recurring competition for new and existing nodes. Can also sunset nodes.



Chirped pulse amplification lasers access extremes in field strength and energy density

Multi-TW laser focused to <10 μm

↓

Focused light intensity of

> 10^{18} - 10^{20} W/cm^2

High Field Science

High electric fields

E ~ 10^{10} - 10^{11} V/cm

Field strength is 10 to 100 times that of the electric field felt by an electron in a hydrogen atom

High electron quiver energy

U_{osc} = 60 keV - 3 MeV

Electron motion can become relativistic ($U_{osc} > m_e c^2$ = 512 keV)

High Energy Density Science

Concentrated energy

Energy density in a femtosecond pulse is 10^9 J/cm^3

Corresponds to ~ 10 keV per atom at solid density

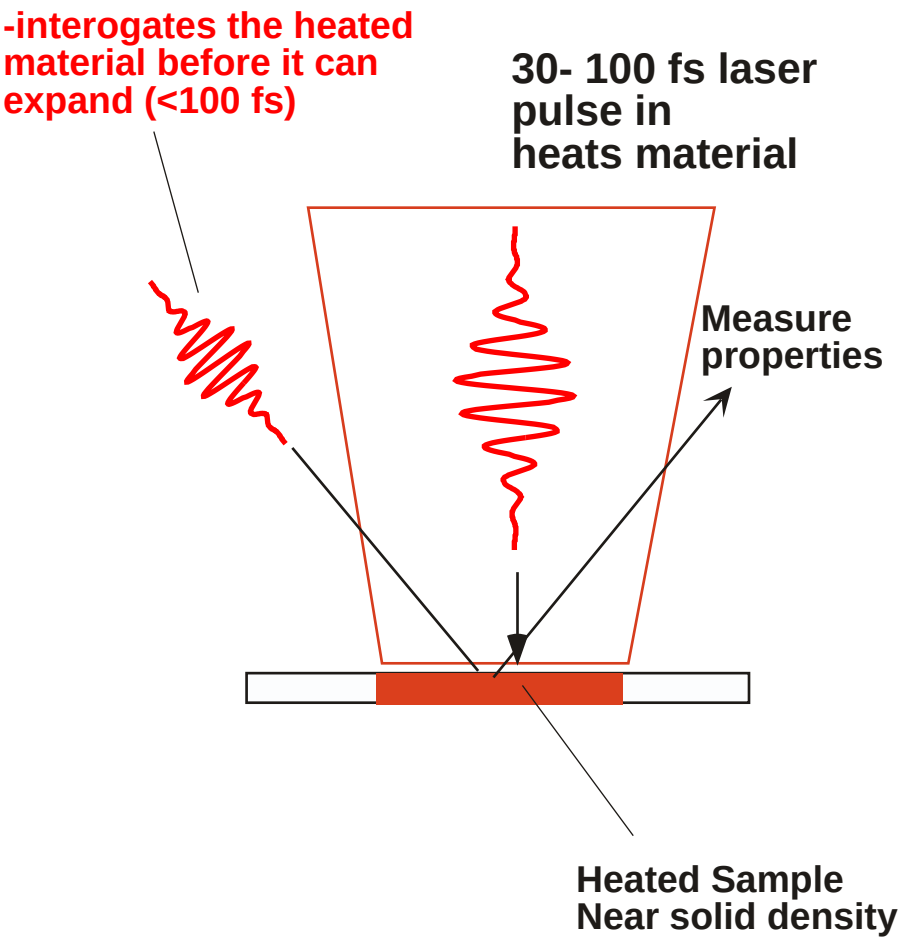
High brightness and pressure

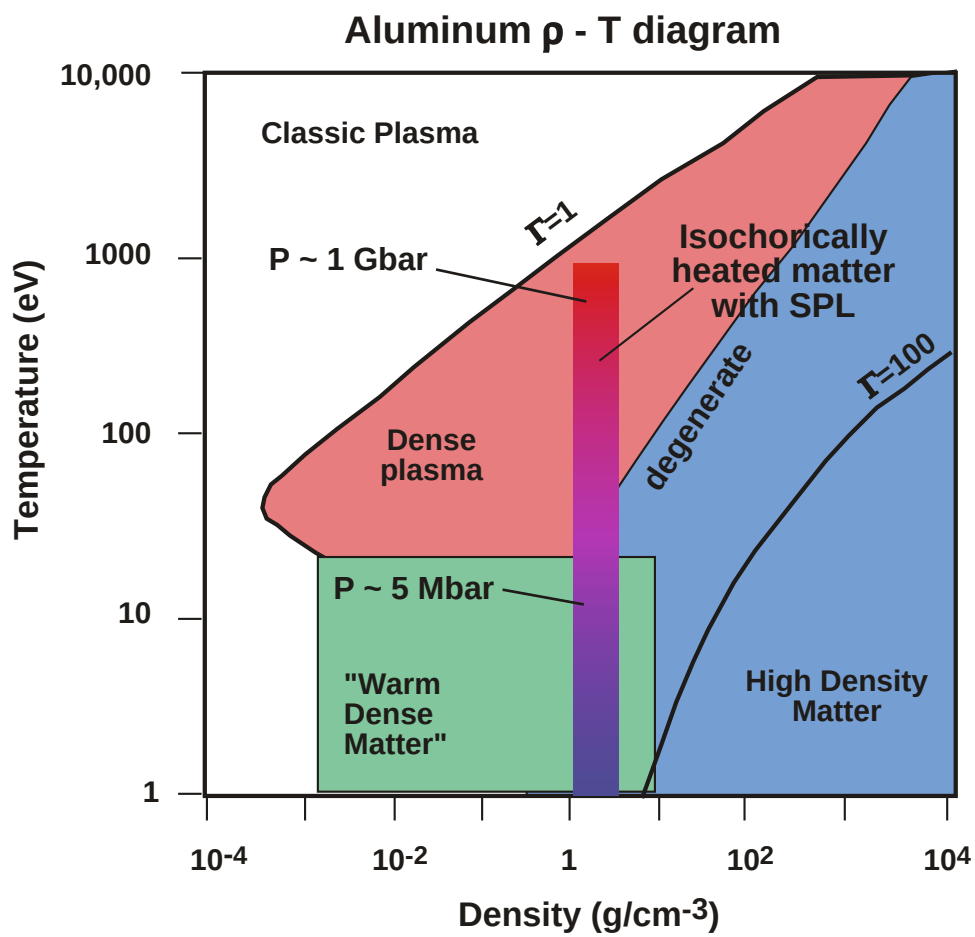
Radiance exceeds that of a 10 keV black body

Light pressure P = I/c = 0.3 - 30 Gbar

An intense ultrafast laser can produce very extreme states of matter by isochoric heating

An intense femtosecond laser interacts with hot matter faster then that matter can expand



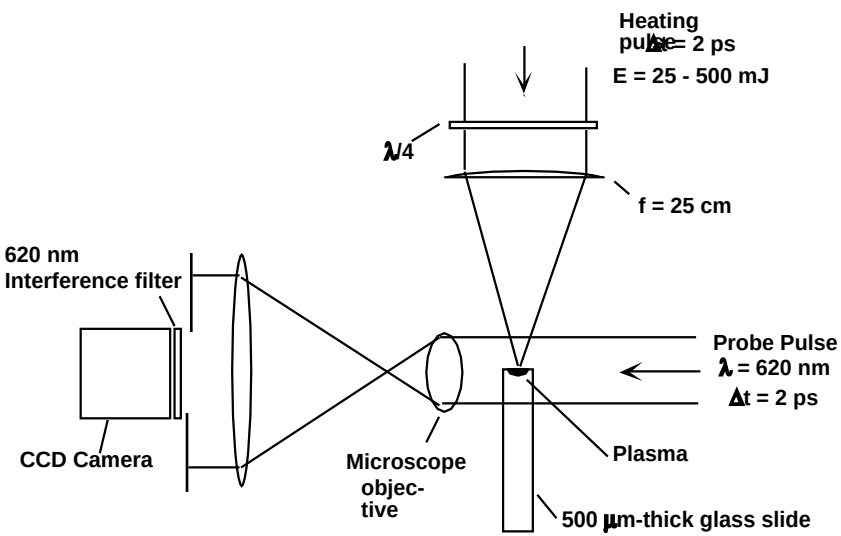


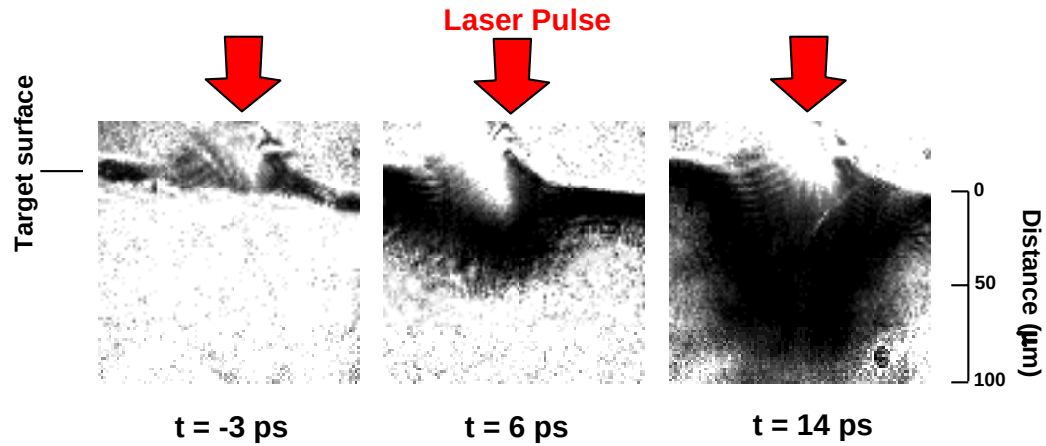
Target expands

- ~ d/c_s
- ~ 10 nm/ 5 x 10^6 cm/s (for 100 eV Al)
- ~ 200 fs

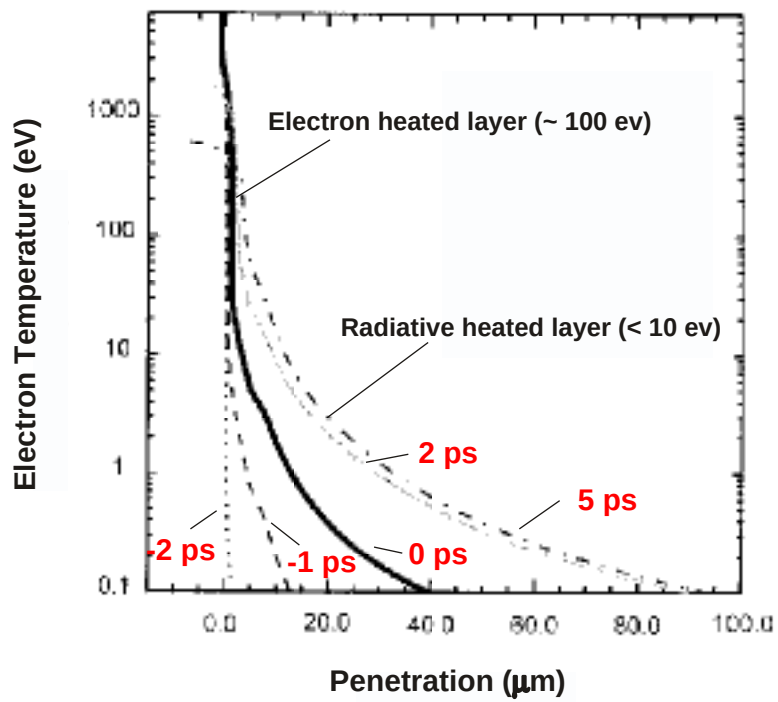
Ultrafast electron and radiative heat conduction distribute laser energy in the underlying material

Picosecond optical probing of heat transport driven ionization wave in fused silica from laser irradiated solid at 2 x 10^{17} W/cm^2





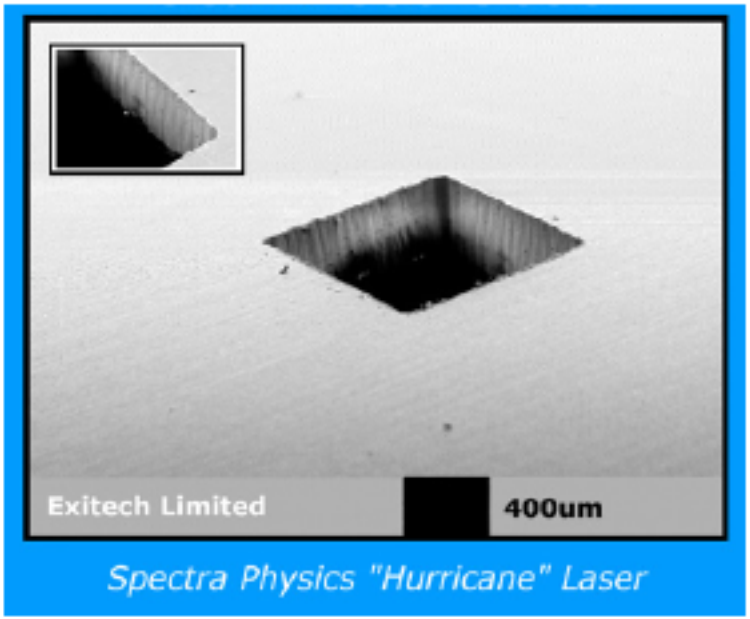
MEDUSA Hydro- simulation of Imperial College experiment on Fused Silica with a 2 ps laser focused to 10^{17} W/cm^2



Data and simulation from Imperial College,
Phys. Rev. Lett. 77, 498 (1996)

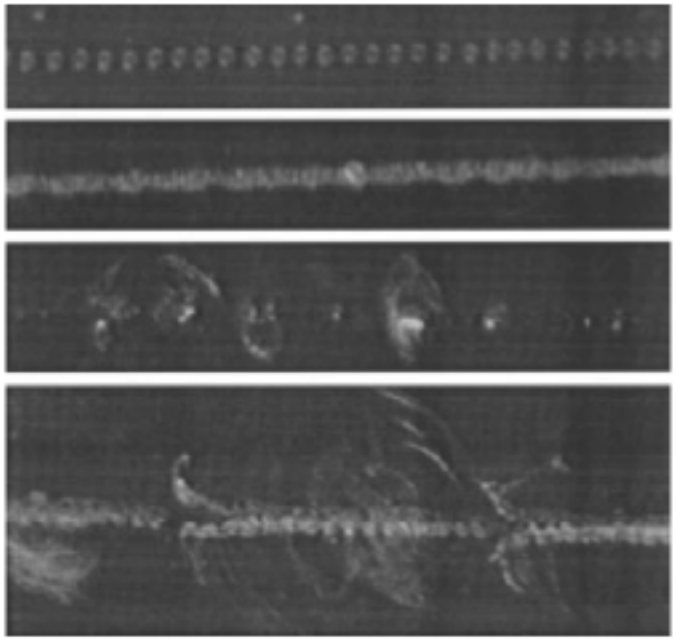
Intense femtosecond lasers show great promise for micromachining

- Femtosecond based Micromachining
- Metals machining with no recast or heat-affect zone
- No post processing required



Laser Machining of Stainless Steel with Femtosecond Laser (As Machined – No Post Processing Required

Intense laser irradiation of plastic at two pulse durations



80 fs pulses

80 fs pulses

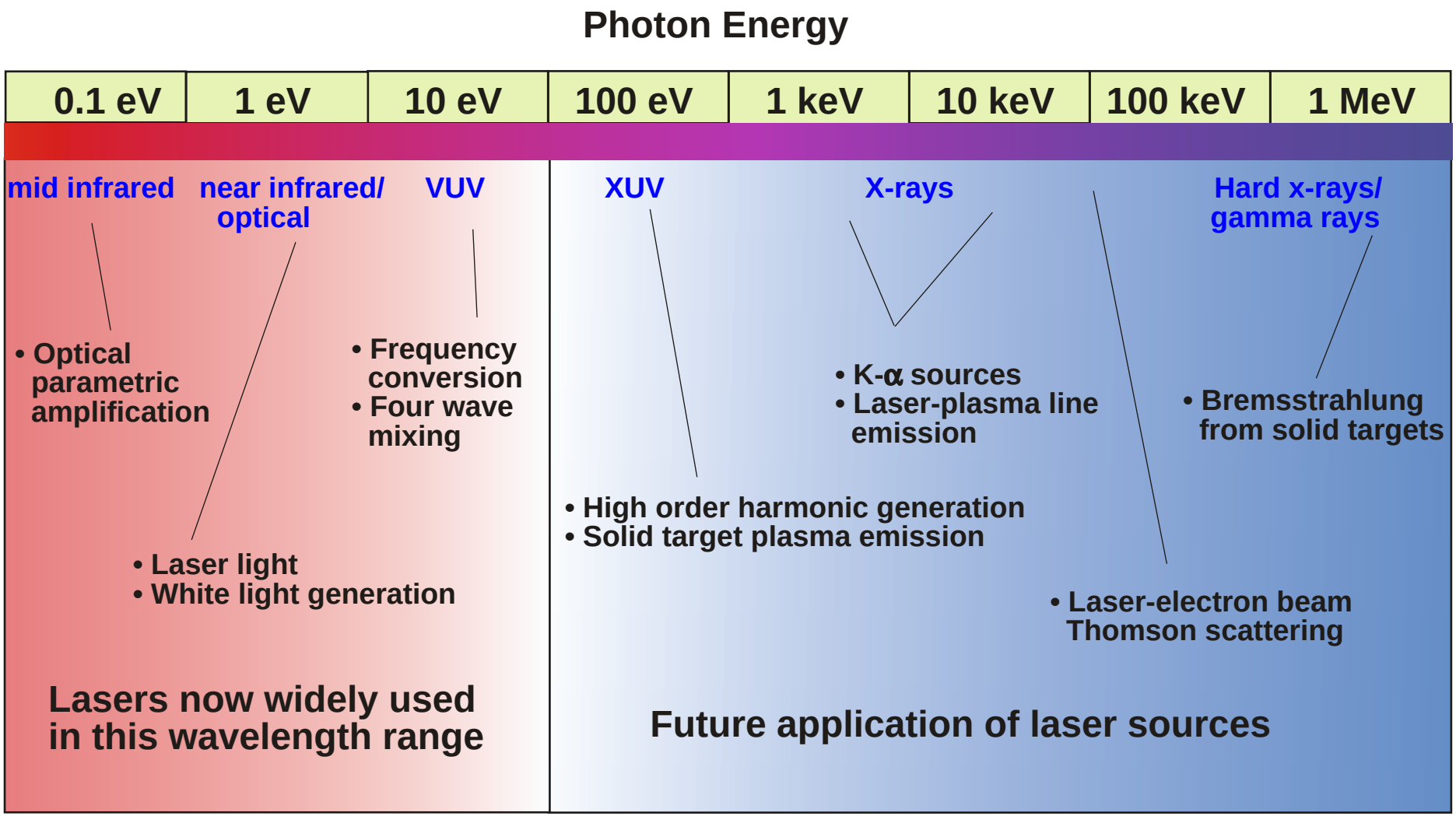
200 ps pulses

200 ps pulses

Courtesy Mound Laser & Photonic Center

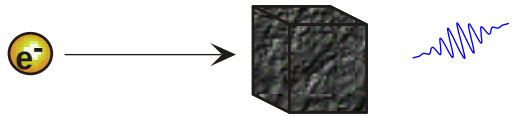
From X Liu et al. IEEE JQE 33, 1706 (1997)

High intensity ultrafast lasers can produce photons with energy ranging from 0.1 eV to >1 MeV

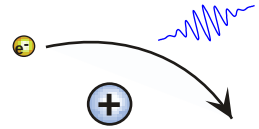


An intense laser focused onto a solid can produce ultrafast x-ray pulses

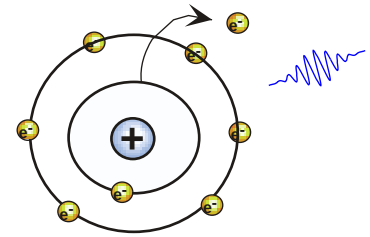
When electrons strike material with enough energy...



... they produce x-rays by:

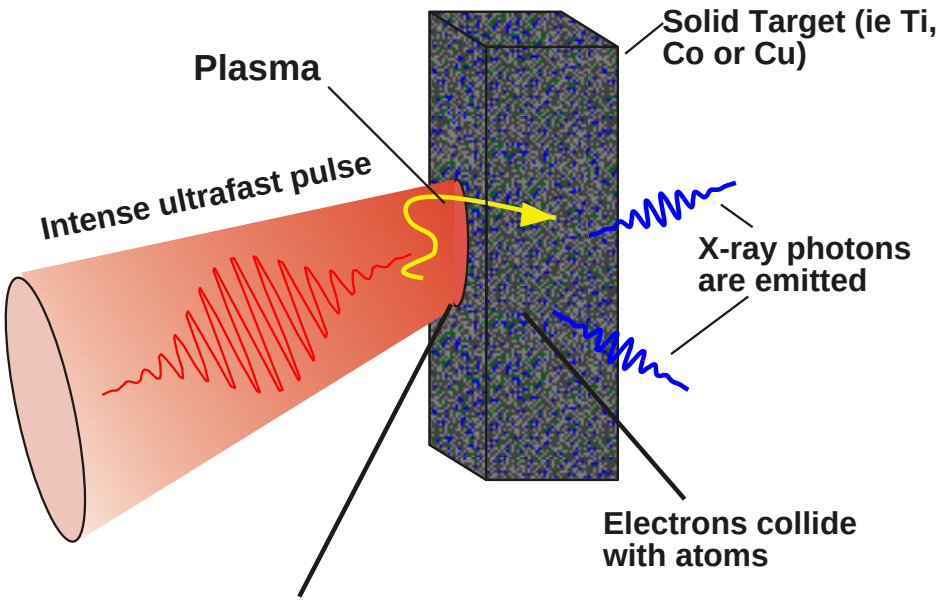


Bremsstrahlung



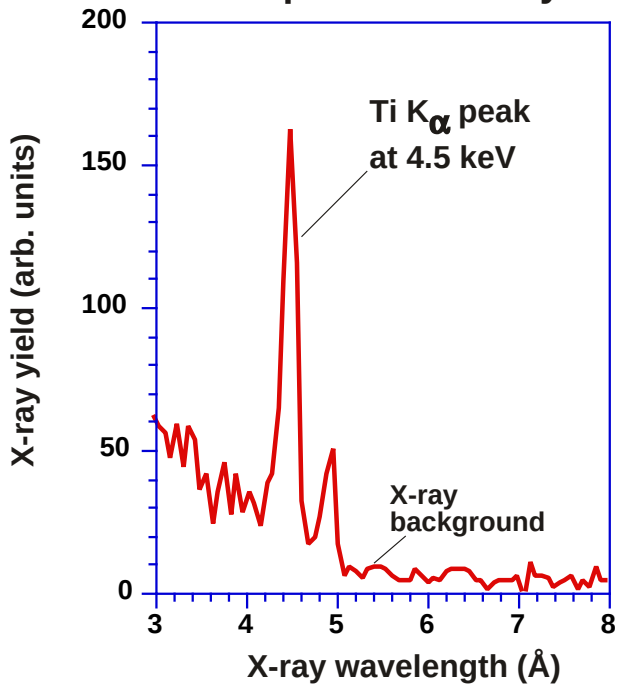
Atomic emission

Intense lasers can also produce x-rays



Strong laser electric field accelerates electrons → T_{hot} ~ 10 - 100 keV

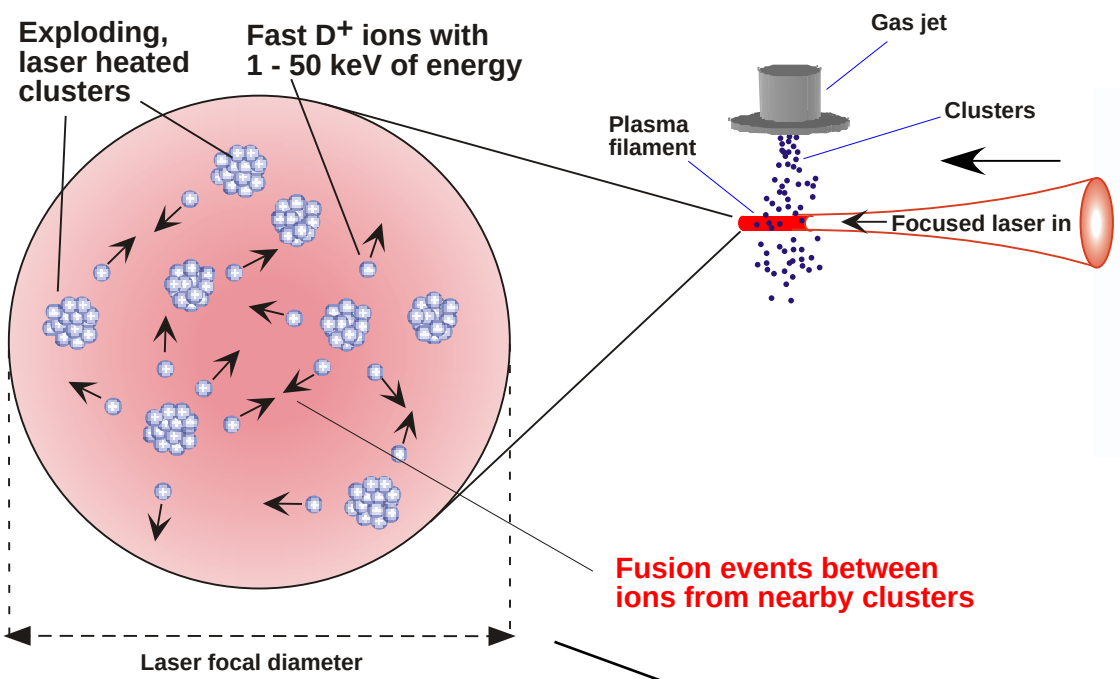
Laser produced x-rays

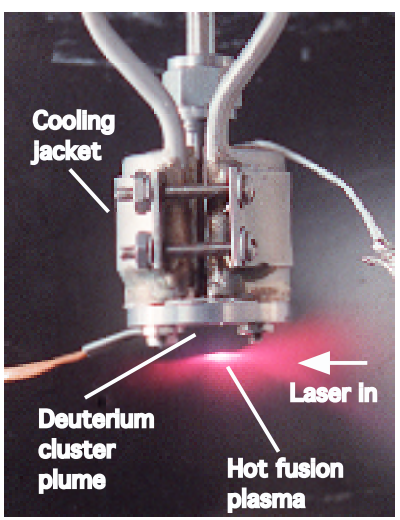


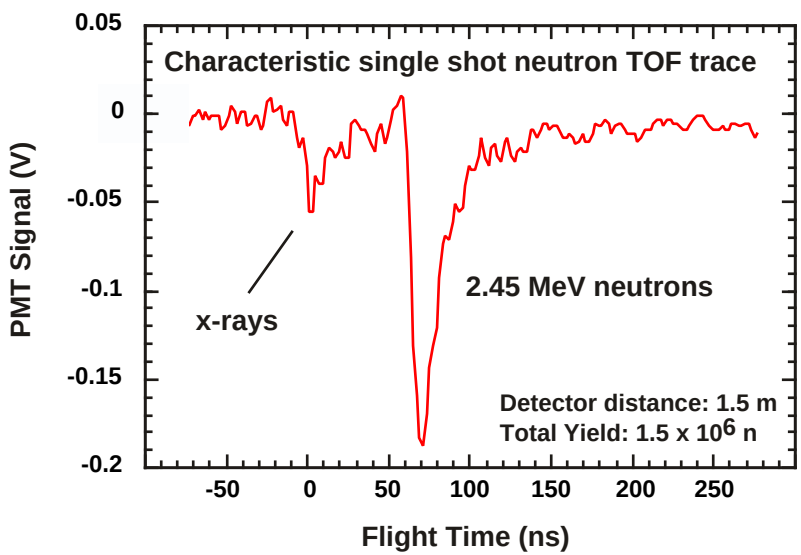
Furthermore, these x-rays are, like the laser pulse, ultrafast

Intense lasers can generate bright bursts of neutrons from small spots with short time duration

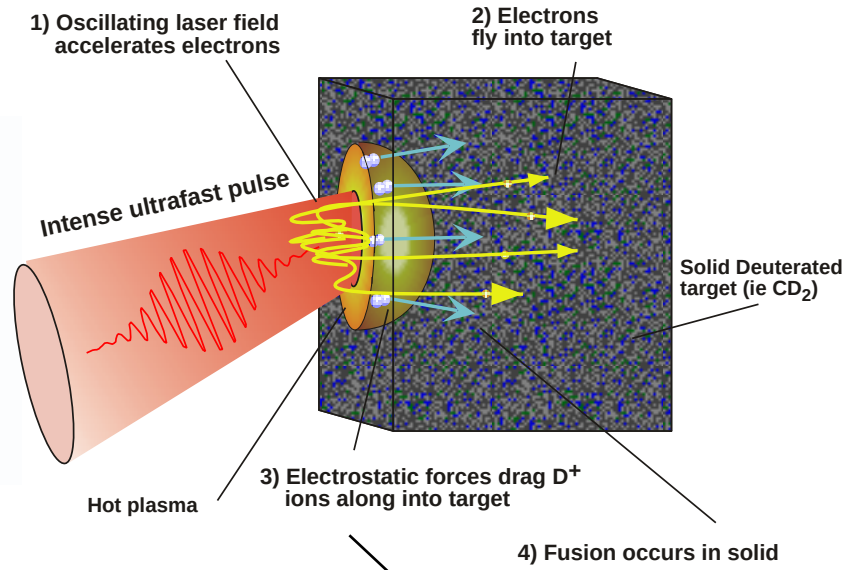
Fusion Neutrons from exploding Clusters

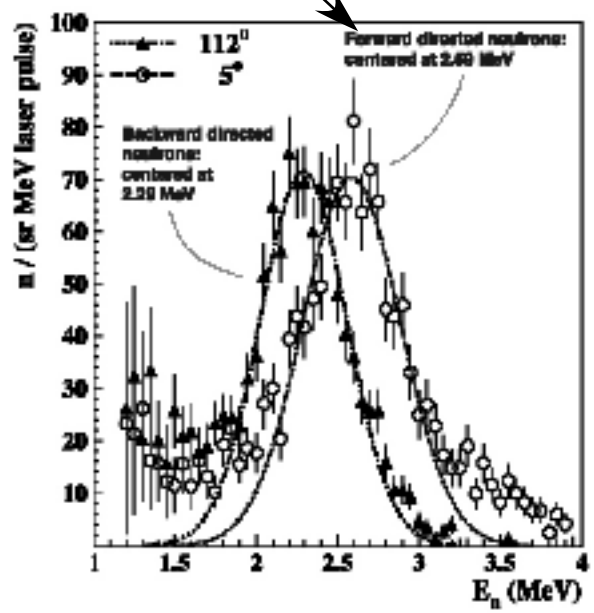






Neutrons from beam target fusion in a solid target





D. Hilscher, et al., Phys. Rev. E 64, 016414 (2001).

We have formulated six compelling intellectual questions facing the field of ultrafast ultraintense laser science

- How do many-body systems evolve in a light field under extreme relativistic conditions where an electron is accelerated to relativistic energies and particle production becomes possible in one optical cycle?

- Can physical and chemical processes be controlled with man-made light pulses that possess both the intrinsic time- (attoseconds, 1 as = 10^{-18} s) and length- (x-rays, 1 Å) scales of all matter?

- Can intense, ultra-fast x-rays become a routine tool for imaging the structure and motion of "single" complex bio-molecules that are the constituents of all living things?

- Can nonlinear optics be applied as a powerful, routine probe of matter in the XUV/x-ray regime?

- Can ultra-intense ultra-short pulse lasers be used to drive table-top GeV class electron and or proton/ion accelerators?

- Is it possible to make controlled nuclear fusion useful and efficient by heating plasmas with an intense, short pulse laser ?

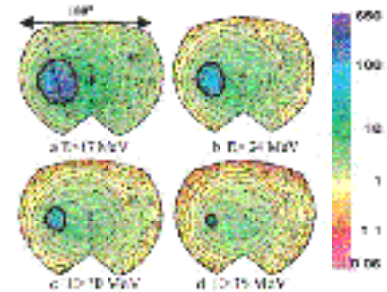
UUL Frontier 4: Compact acceleration of particles with lasers

Principal frontiers:

Production of pulsed high-energy protons and heavy ions

Multi-MeV proton and ion beams can be accelerated over a few microns

→ This could lead to compact medical accelerators or to compact front ends for conventional ion accelerators



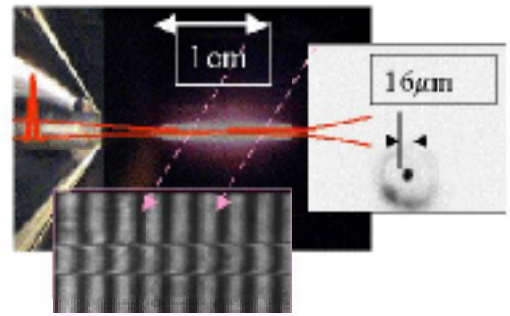
Directed beams of 50 MeV protons from the Petawatt laser

Low emittance relativistic electron acceleration

Intense laser driven waves in plasmas make possible very high gradient electron accelerators

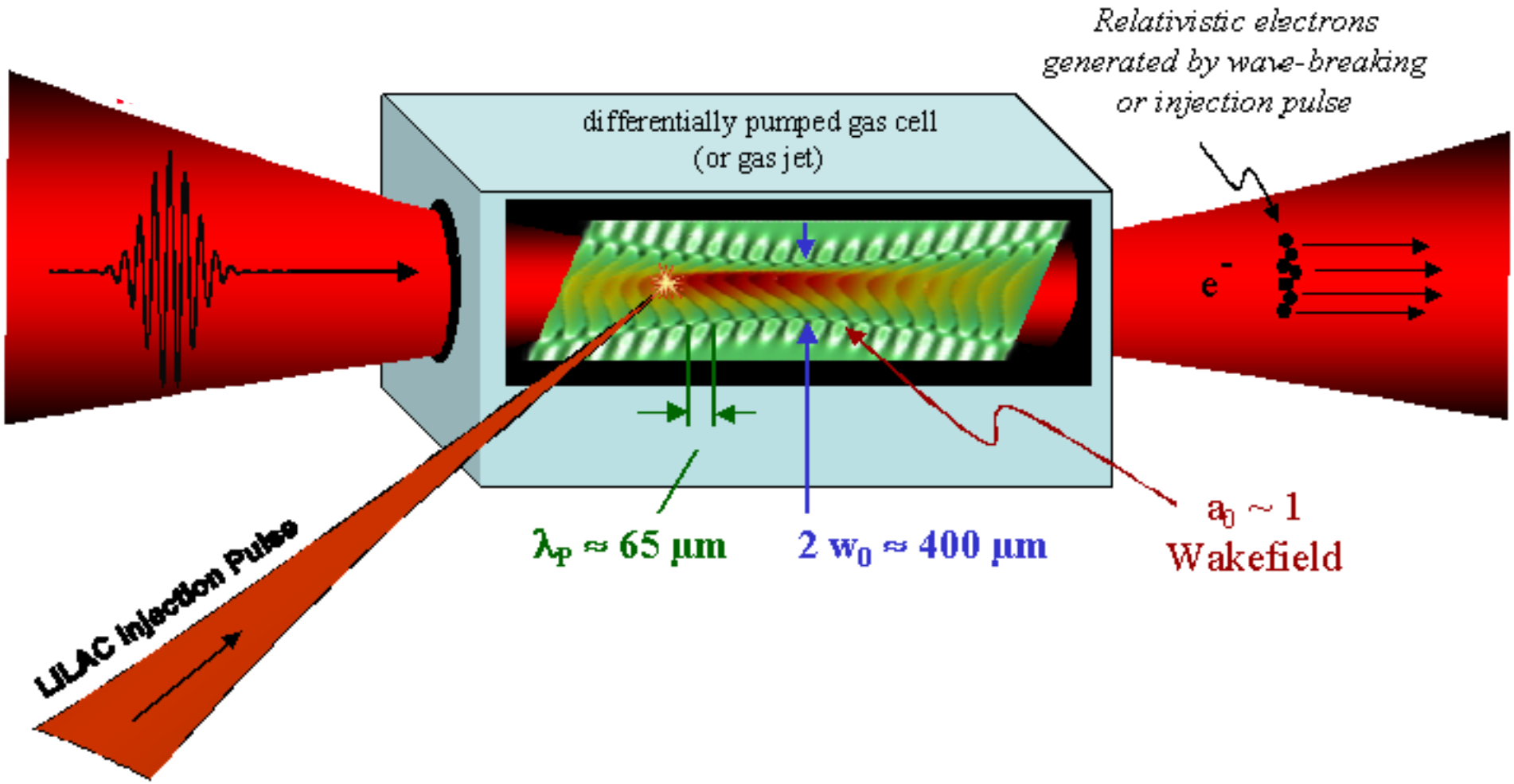
Radio isotope production

Compact accelerators might make possible radioactive isotope generators in medical facilities



A “plasma waveguide” used to accelerate electrons with wakefields

An intense laser can accelerate electrons by driving a plasma wave in a gas

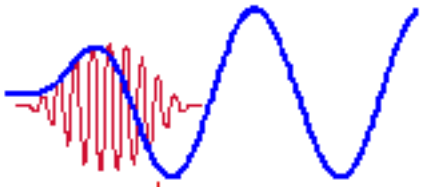


Umstadter, PRL ('96)

Various schemes for laser driven wakefield generation have been explored

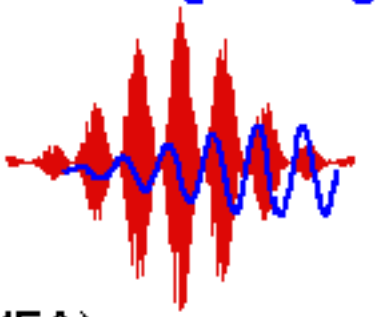
- Laser Wake Field Accelerator(LWFA)

  A single short-pulse of photons



- Plasma Beat Wave Accelerator(PBWA)

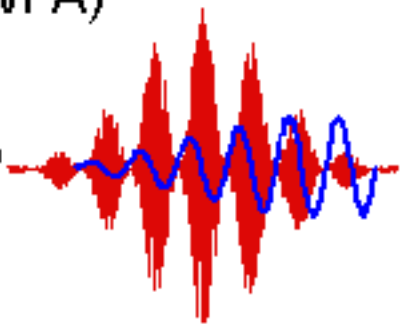
  Two-frequencies, i.e., a train of pulses



- Self Modulated Laser Wake Field Accelerator(SMLWFA)

  Raman forward scattering instability

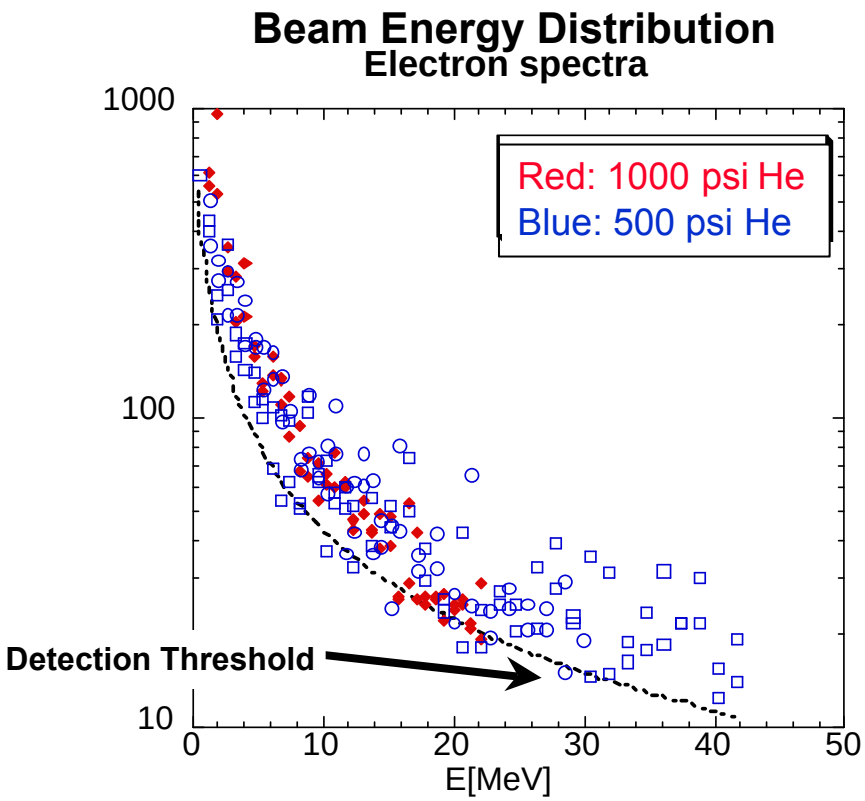
evolves to

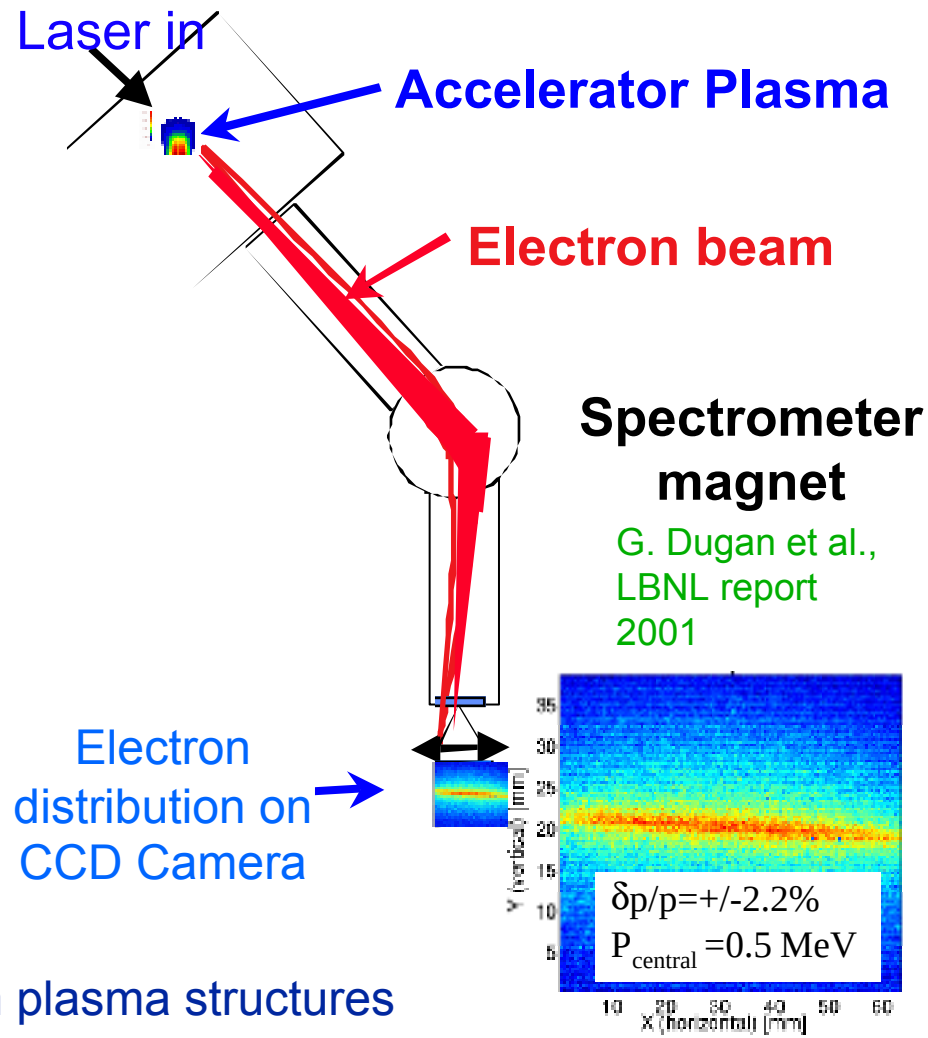


- **The radiation pressure, 100 Gbar, expels plasma electrons which are then attracted back by the more massive ions. This creates a high gradient wake, eE~[n_o (cm-3)]$^{1/2}$ V/cm. This can easily exceed 100 GeV/m (SLAC is 20 MeV/m).**

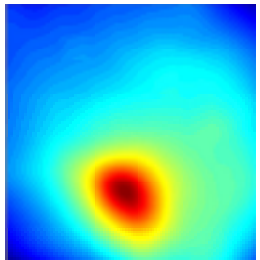
- **Energy density of plasma wave, ~106J/cm3.**

50-MeV Energy Achieved in 1.5- to 2.0-Millimeter Plasma Structures: ~25 to 50 GeV/Meter Gradient





- 25 to 50 GeV/Meter in 1.5- to 2.0-mm plasma structures
- Produced radio-isotopes (^{61}Cu, ^{62}Cu, ^{18}F, ^{11}C)

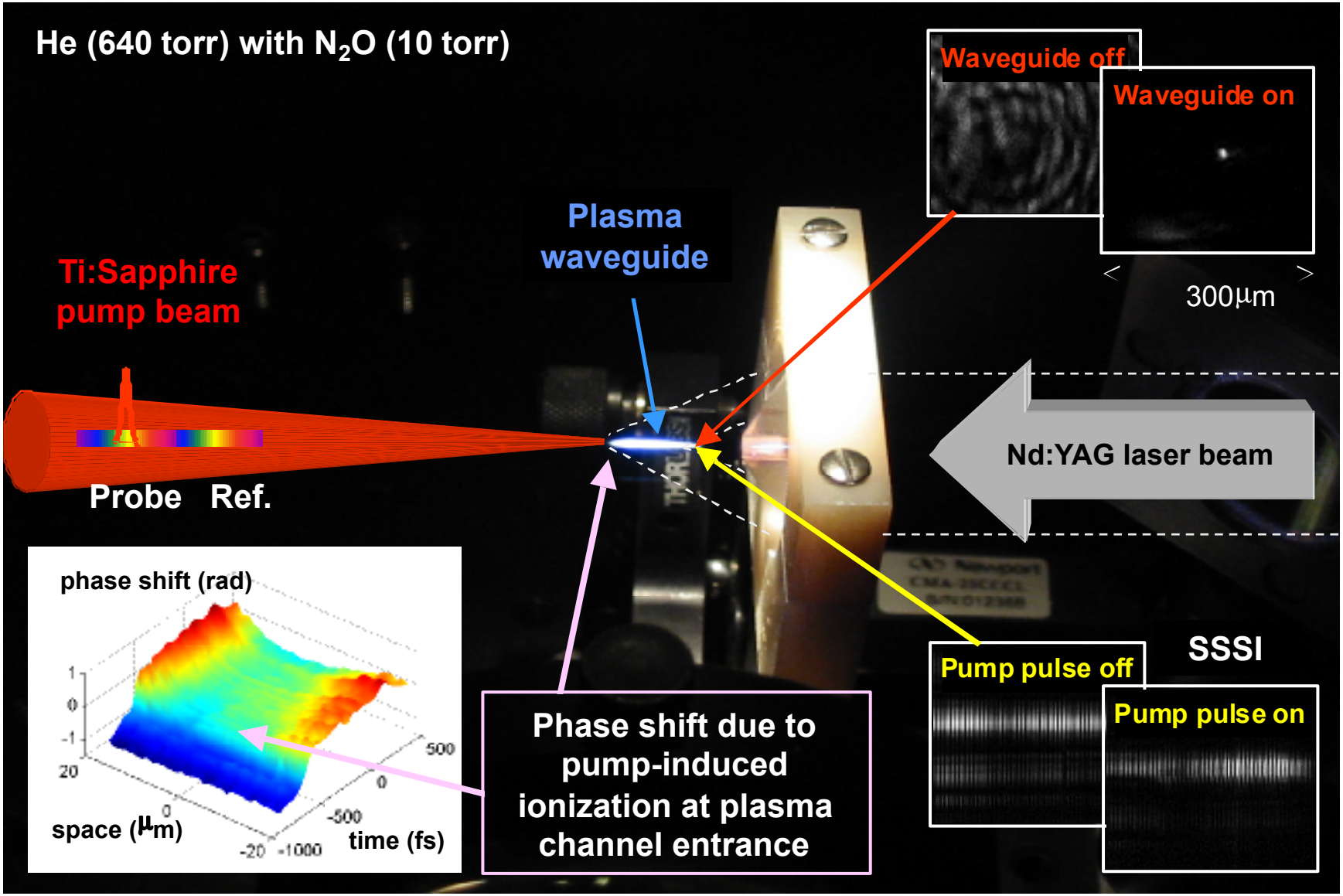


> 1-5 nC/bunch
10's of fs pulse
at up to 10 Hz
@ 10-100 GeV/m

Data from W. P. Leemans et al. Phys. Plas. 8, 2510 (2001)

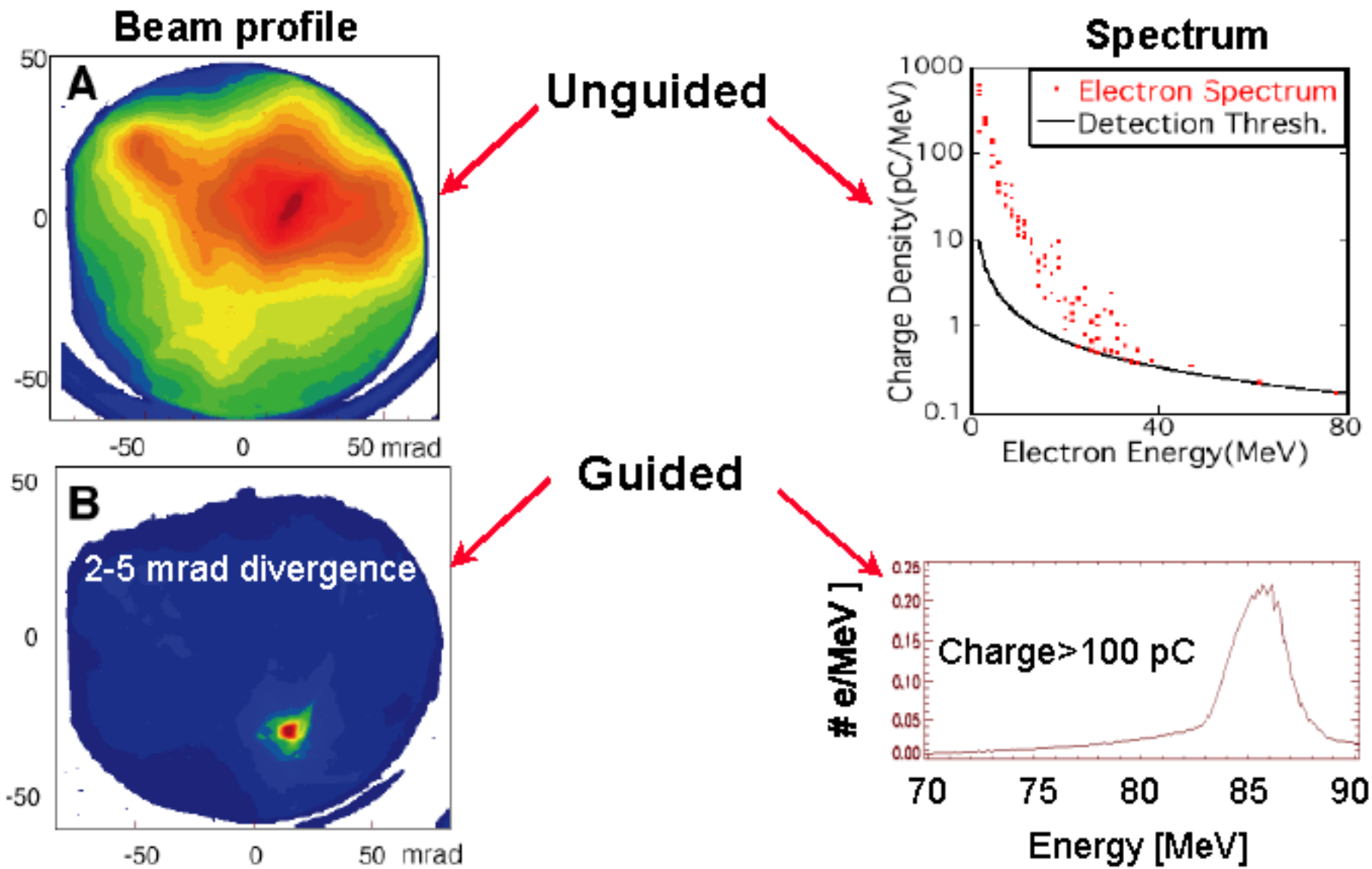
Example of channeled pulse propagation from U. of Maryland

Application of SSSI : Injection of a terawatt laser pulse into a plasma channel



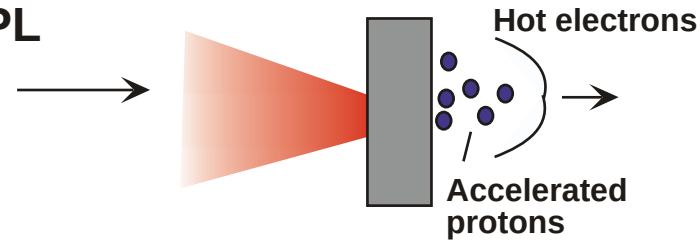
Example of nearly monoenergetic electrons from a wakefield

Breakthrough result: 85 MeV e-beam with % - level energy spread from laser accelerator



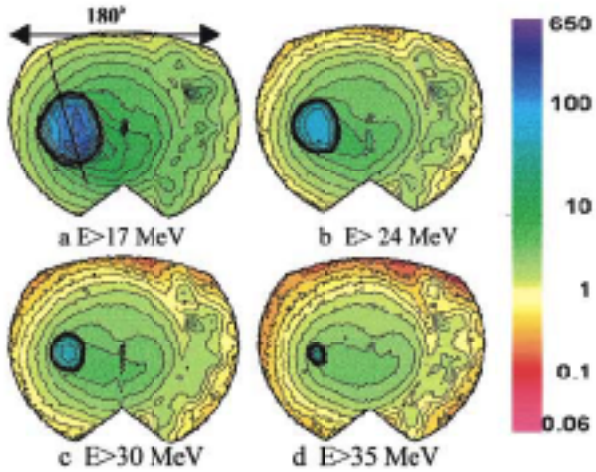
Fast electrons created by the intense laser can drive proton acceleration with an ambipolar potential

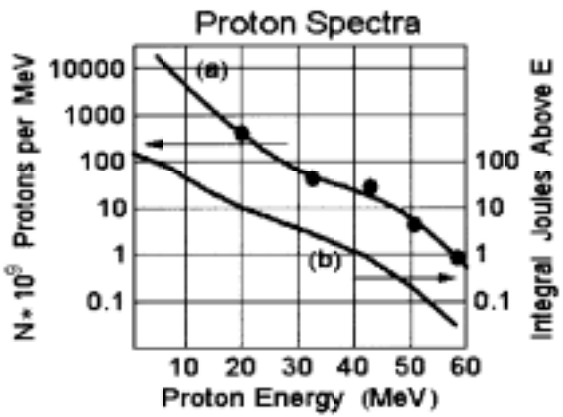
Relativistic electrons produced by a SPL can accelerate protons from a solid



At 3 x 10^{20} W/cm^2 on LLNL PW laser:

Up to 48J of protons (12% of laser energy) were observed in protons with energy >10 MeV





From Snavely et al. PRL 85, 2945 (2000)

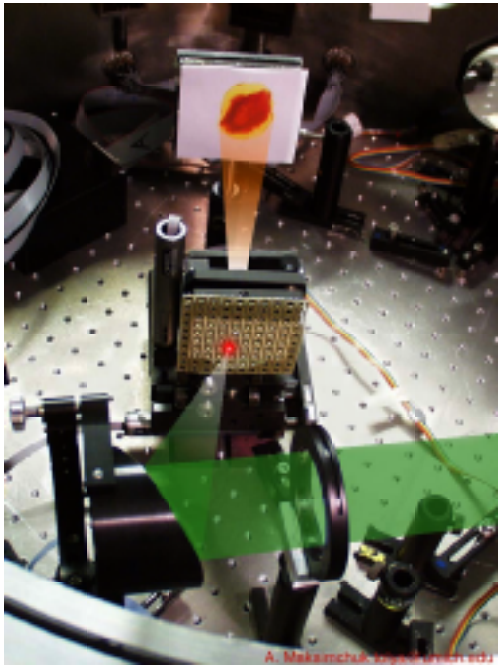
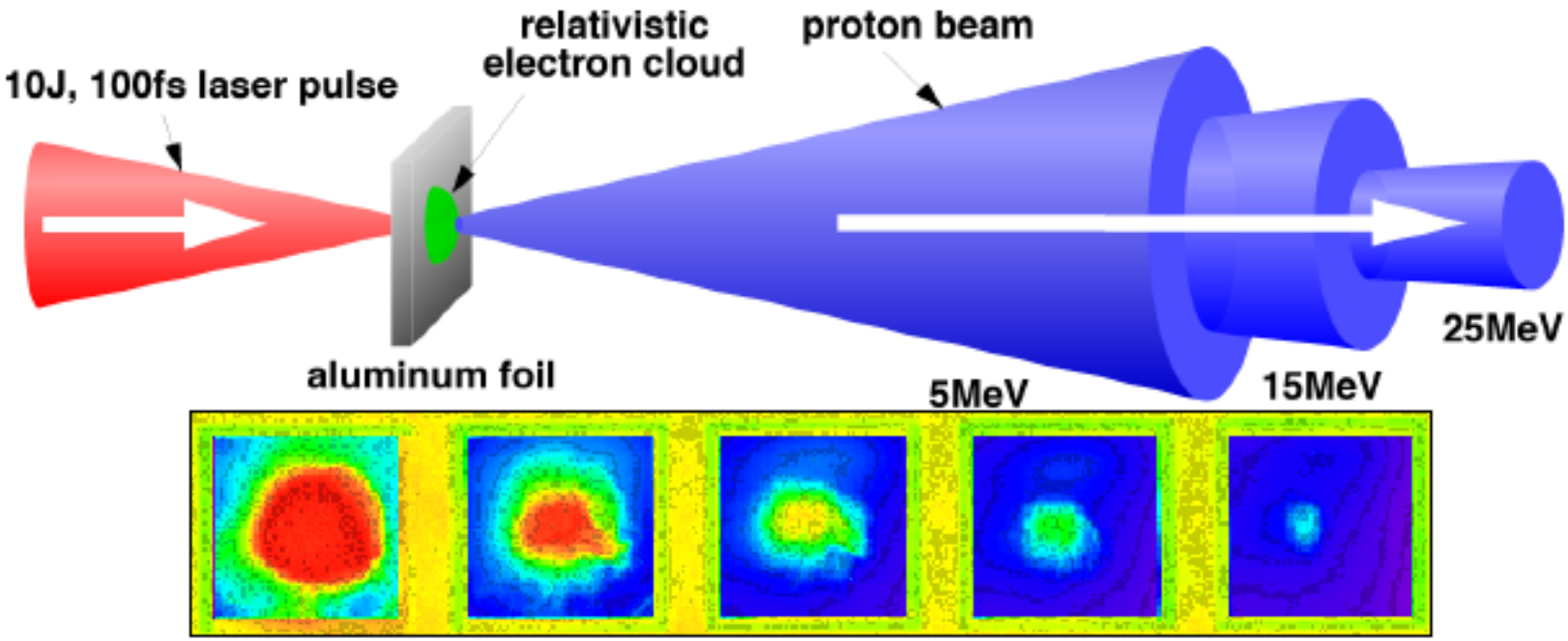


Photo of 1 MeV protons on a phosphor screen on the U. Michigan T^3 laserat intensity > 10^{19} W/cm^2 (from Umstader et al.)

Proton acceleration data from LLNL

Ultra-high intensity laser pulses can efficiently generate intense, energetic beams of protons



Laser-Ion diode Characteristics

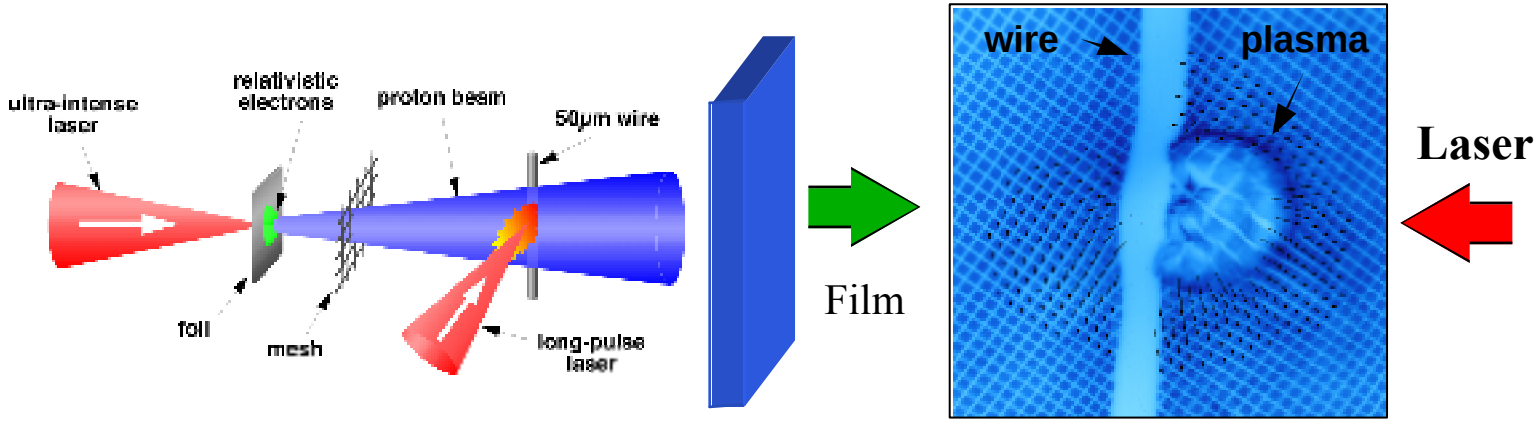
- Transverse emittance: < 0.006 π mm-mrad
- Longitudinal emittance: < keV-ns (velocity correlated)
- Energy spread: 100%
- Bunch charge: $10^{11} - 10^{13}$ protons/ions
- Source diameter: ~50 μm (fwhm)
- Charge state purity: >80% He-like
- Particle current: >100 kA (at source)
- Laser-ion efficiency: >> 1% (4-20% observed)

P K Patel *et al*

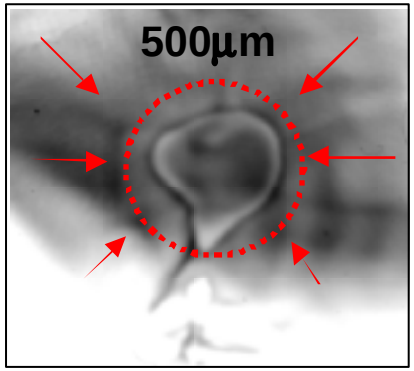
Proton radiography is providing a completely a new probing capability for HEPW applications

The National Ignition Facility

• Proton deflectometry- measurements of transient electromagnetic fields

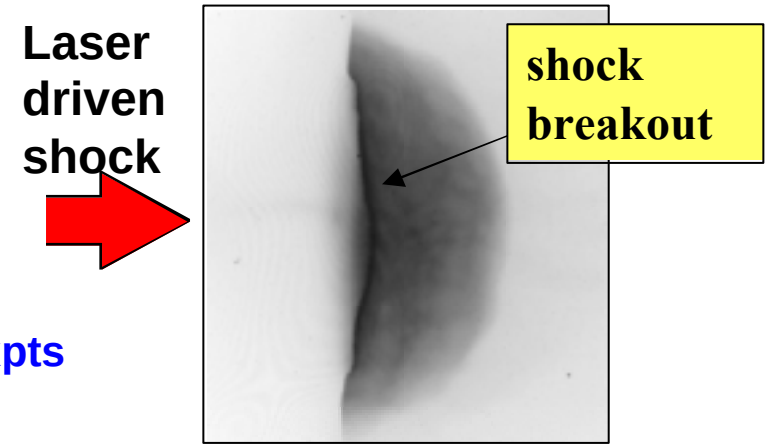


• Proton image of imploding cores



Asymmetric drive

• Proton image of shock break-out



A MacKinnon (LLNL) and collaborators at expts in France and UK

Viewgraph supplied by M. Key, LLNL

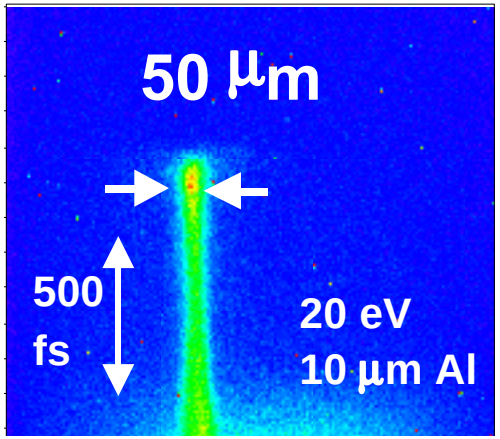
LLNL has recently pioneered the ballistic focusing of proton beams - it is being developed for EOS and FI at NIF

- Focused beam gives 8x more temp rise than unfocused

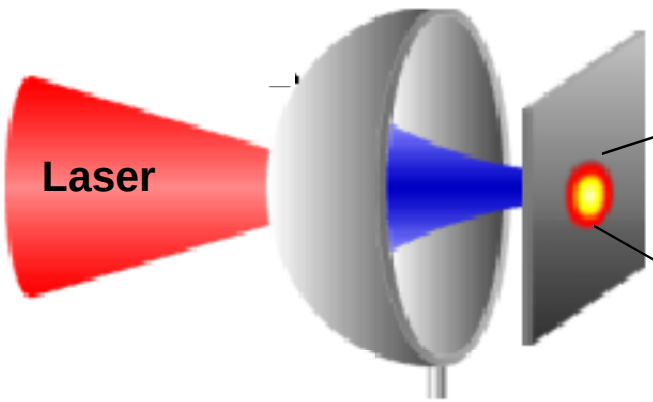
- Focused protons give 2 to 3 x temperature obtained with electron heating

P Patel et al.
In press in
Phys Rev Letts

Streak visible image JanUSP

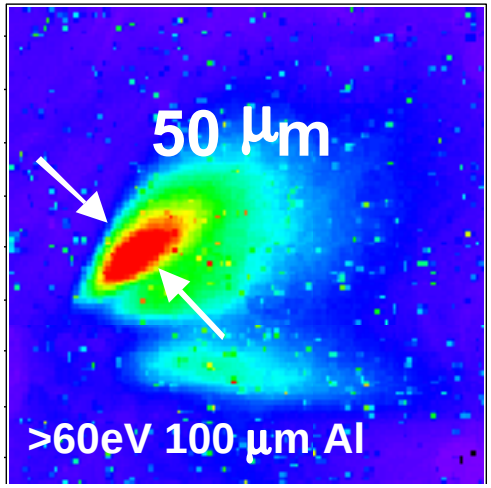


XUV image at Gekko PW in Japan



Al hemisphere shell
320 μm diameter

LLNL,UC Davis,
GA, Osaka Univ.
Collaboration



Viewgraph supplied by M. Key, LLNL

Laser driven acceleration has made large progress in over the previous 15 years

- Ultra-high gradients have been observed: 100 GeV/m over mm distances.
- Energies between 200-300 MeV have been observed with 100% energy spread.
- Very recent experiments (LBNL, IC/RAL) are producing ~50-100 MeV mono-energetic beams over mm distances.
- Solid target experiments are producing ~50 MeV proton beams.
- GeV stages can be modeled in full 3D using full PIC simulations on massively parallel supercomputers.

How do we scale accelerators to the GeV level?

→ Laser power from 10 TW to 100 TW to PW
→ Extend the channel lengths from 1cm to 10 cm
→ Increase the efficiency of converting laser energy into the wake
→ Develop staging: What is the acceptance from one stage to the next for these e^- bunches

UUL Frontier 5: Heat a compressed plasma to fusion temperature - "Fast Ignition" approach to fusion energy

Principal frontiers:

Control of high intensity laser heating of compressed fusion fuel

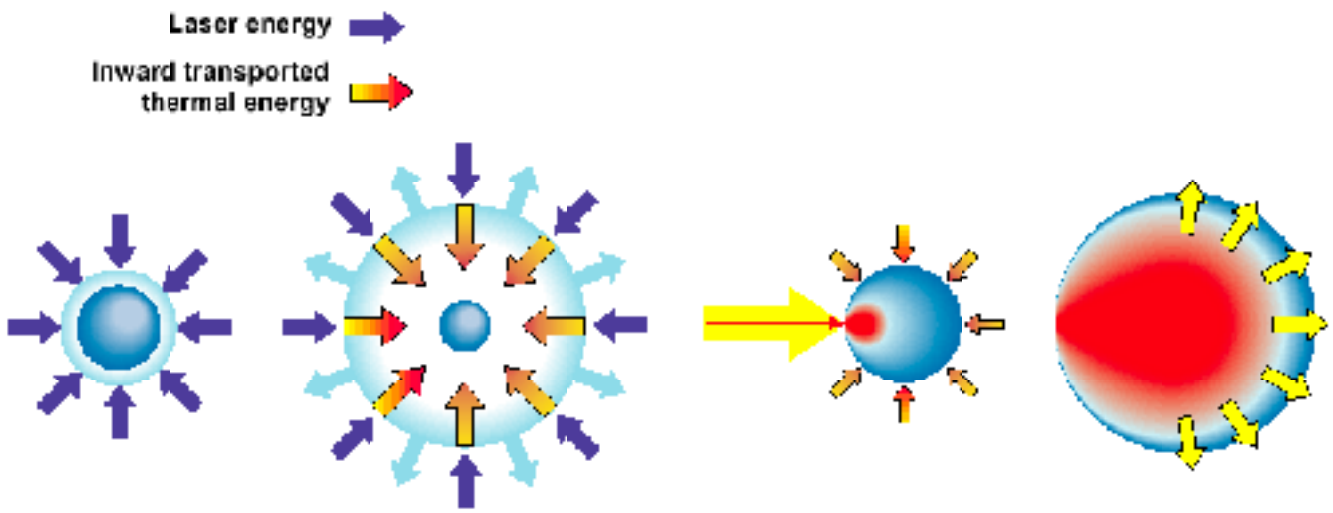
Short pulse laser ignition of a fusion target holds the promise of much higher energy gain. This could make inertial fusion energy more economically viable

Laser plasma coupling physics

How a laser deposits energy at such extreme intensities is not well understood

Advanced computational techniques

Integrated fusion experiments require sophisticated computer models



Atmosphere Formation

Laser or particle beams rapidly heat the surface of the fusion target forming a surrounding plasma envelope

Compression

Fuel is compressed by rocket-like blowoff of the surface material

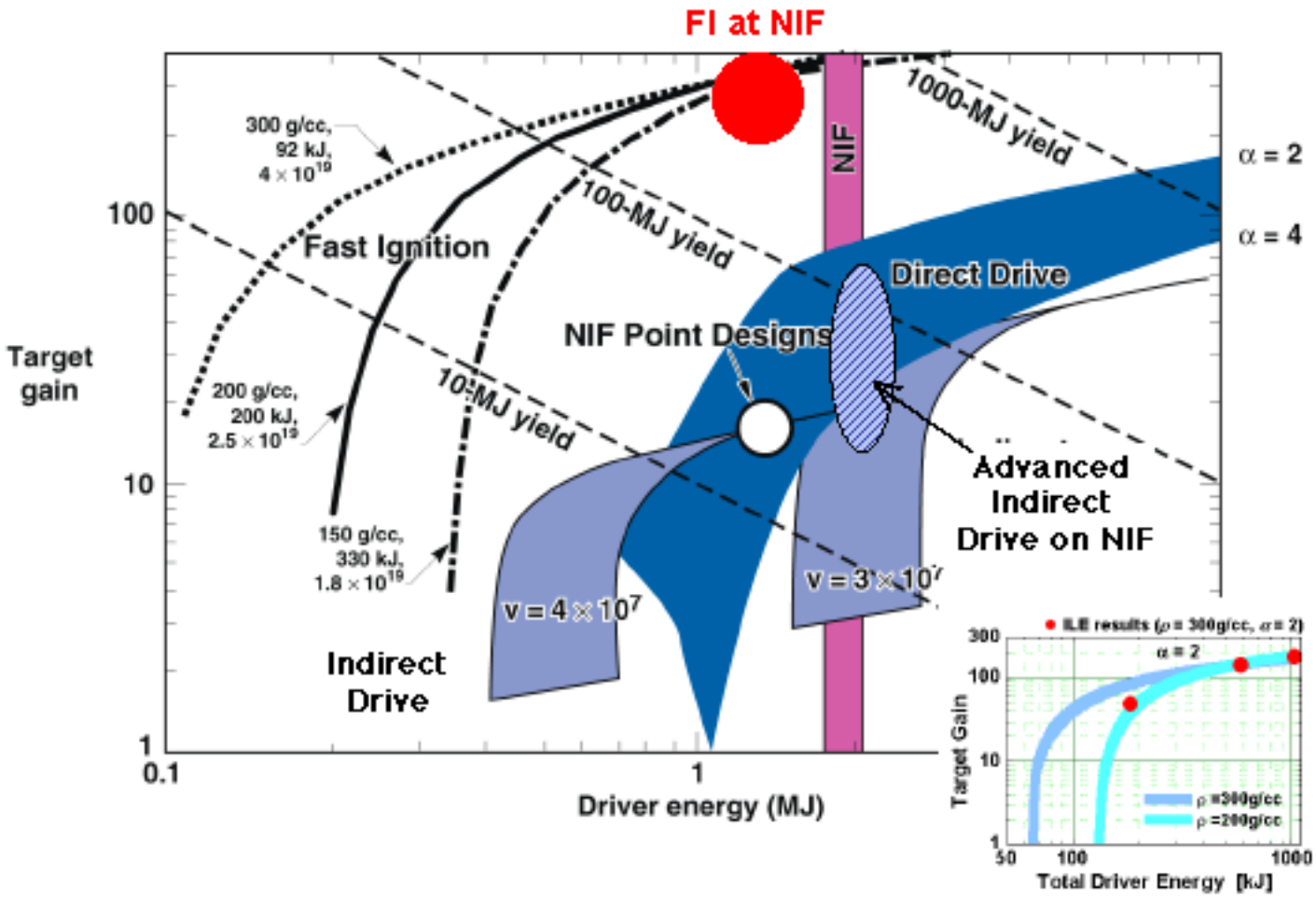
Ignition

At the moment of maximum compression a short (1–10 psec) high intensity (10^{19} W/cm^2) pulse ignites the capsule

Burn

Thermonuclear burn spreads rapidly through the compressed fuel, yielding many times the driver input energy

Fast ignition may lead the way to high gain (>100) in ICF and enable application to fusion energy

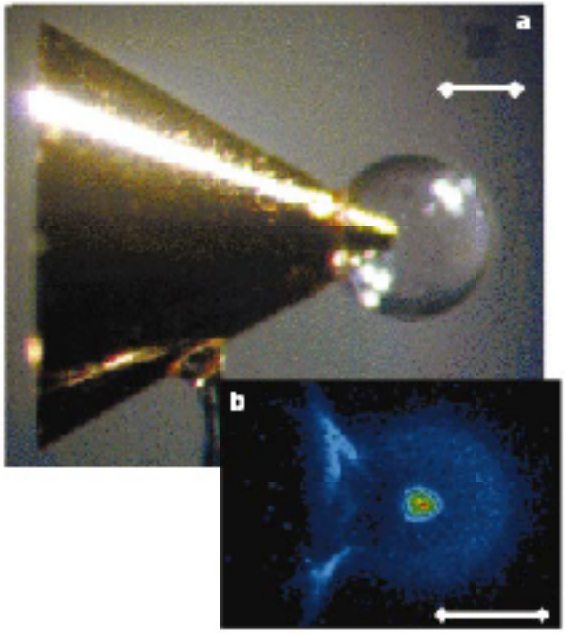


— Fast ignition potentially gives more gain and lower threshold energy than "Hot Spot" ICF but the science and technology are far less developed

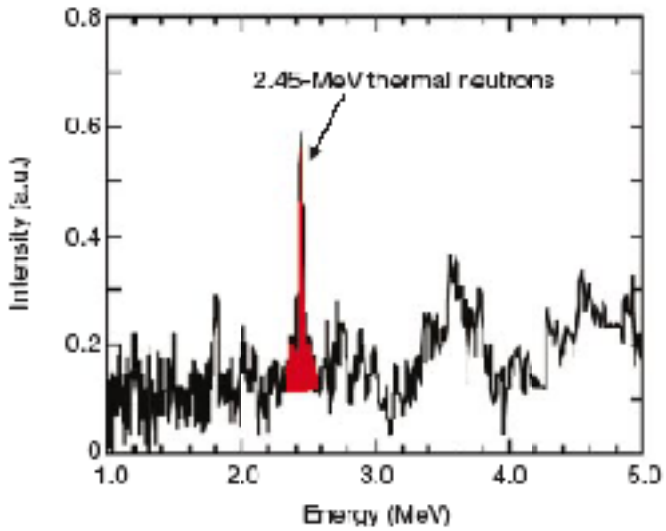
Enhanced fusion yield in ICF implosions using a fast ignition beam has been observed on the Gekko laser

The Gekko XII laser at the University of Osaka

"Fast heating of ultrahigh-density plasma as a step towards laser fusion ignition" Kodama R, et al.
NATURE **412** pp. 798-802 AUG 23 2001



Cone target used in the Japanese fast Ignition experiments



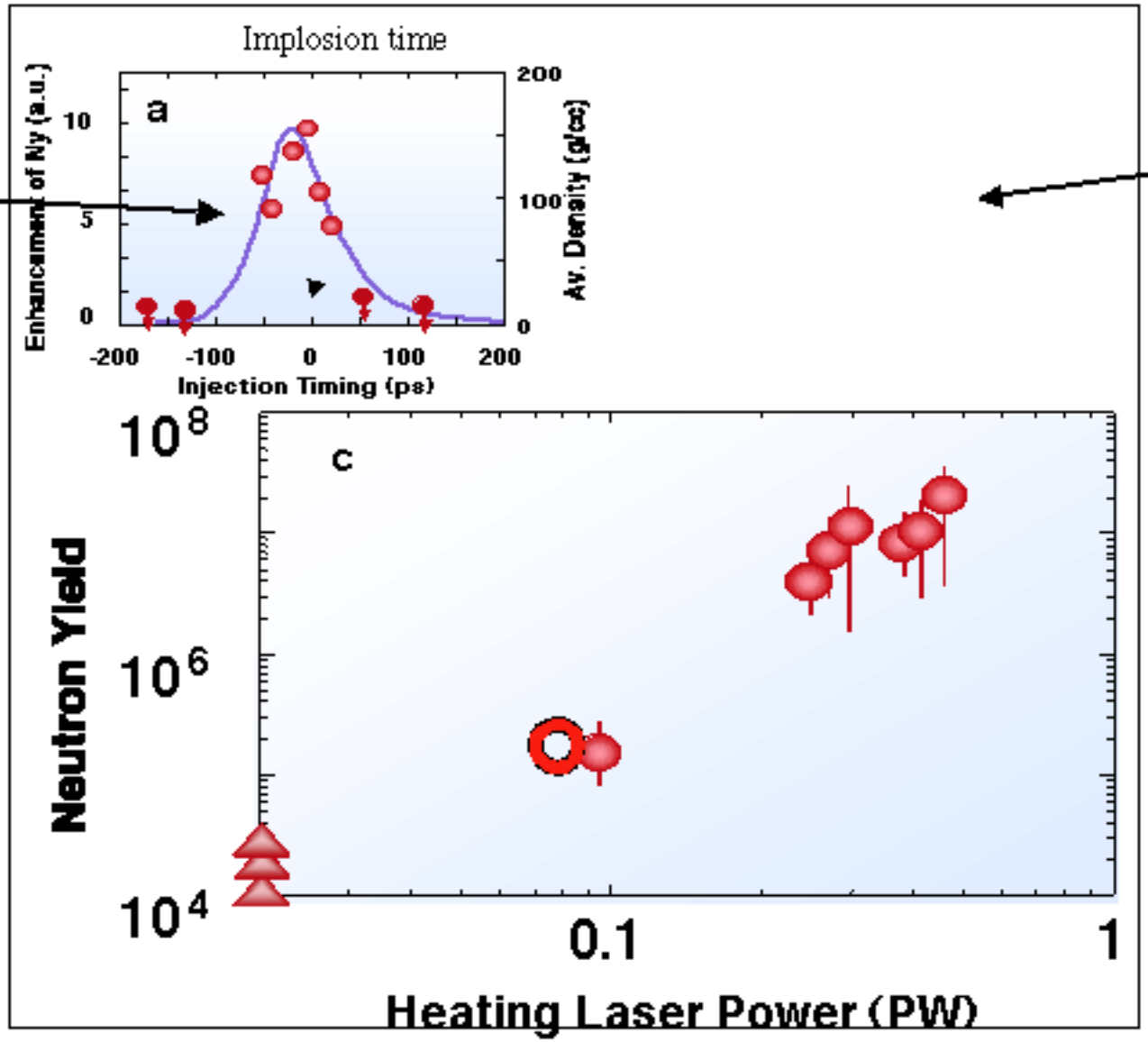
An order of magnitude enhancement in fusion yield was observed when an intense short pulse laser was injected

Fusion yield data from ILE fast ignition experiments

Petawatt laser heating experimental results of cone guide

ILE OSAK

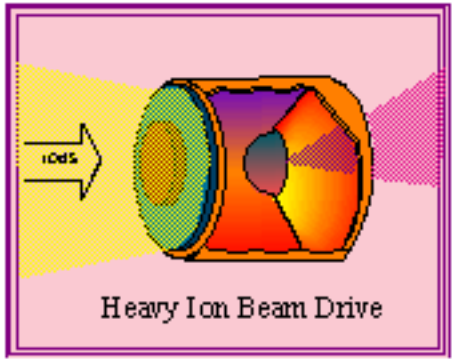
Required timing is 50ps

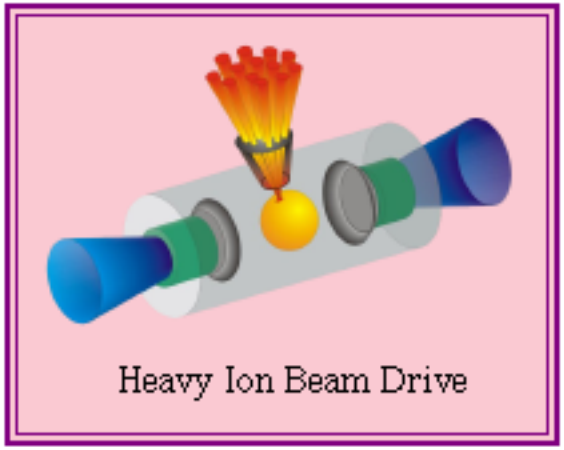


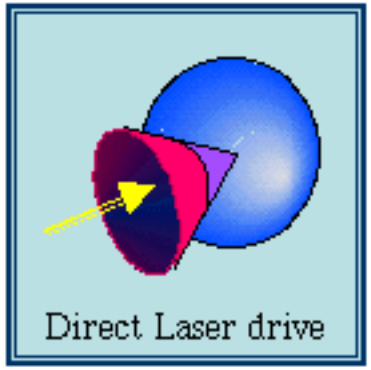
800keV

IF/OV1
T.Yamanaka

Fast ignition is compatible with all compression drivers



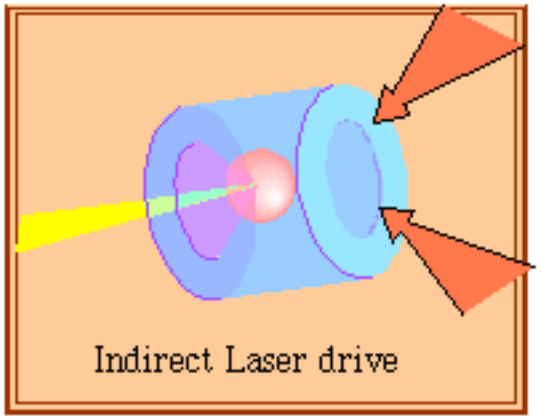


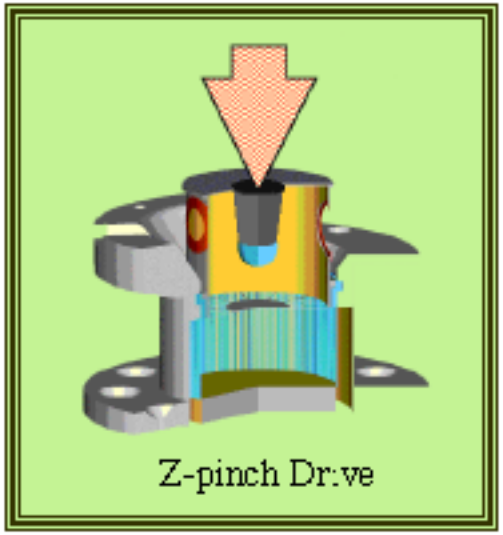


Innovative target designs are possible

BUT

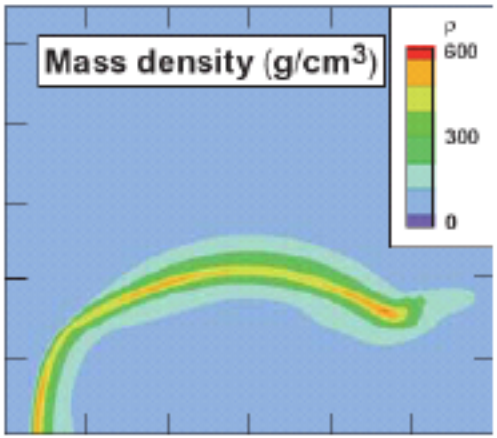
Ignitor laser energy must be determined!

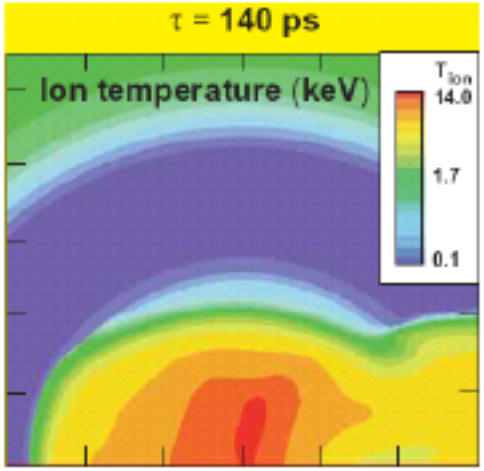


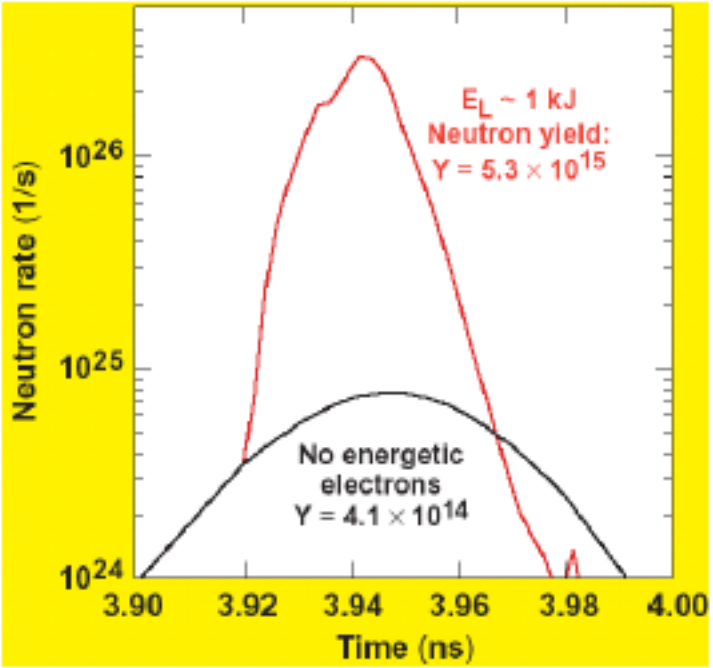


Proof of Principle Experiments are possible on US and Japanese facilities in the 2006- 2010 time frame

2-D simulation of Omega-EP using 25kJ compression, 1 kilojoitor e-beam







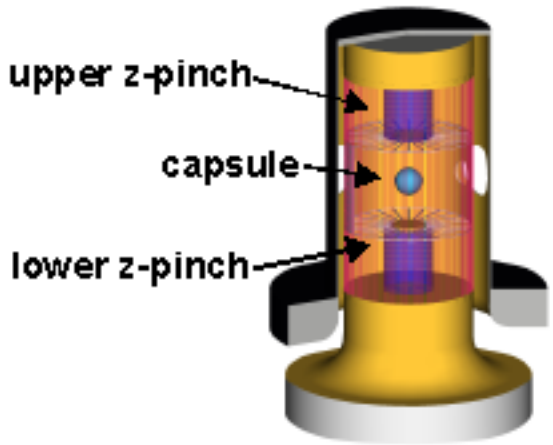
Simulation shows Q≤0.5:

ρ~300 g/cc, T_{ion} up to 14 keV, n~5x10^5

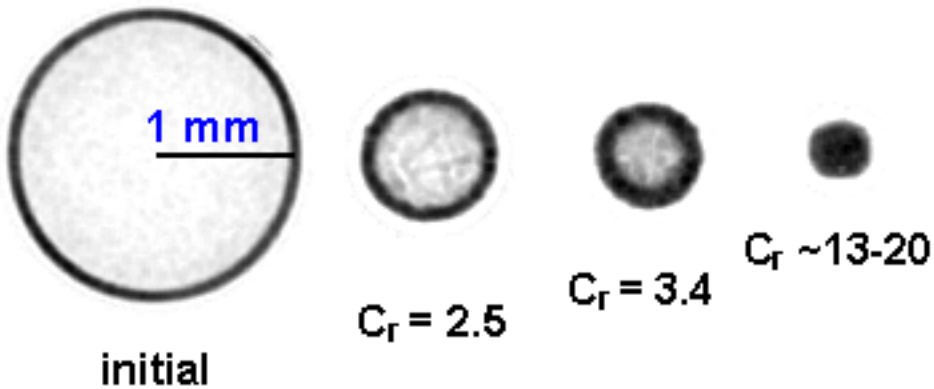
A multikilojoule PW laser will be used to study the fast ignitor ICF target concept on Z

Sandia National Laboratories

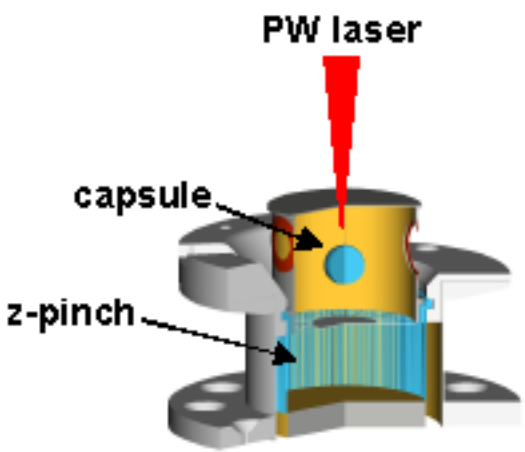
Conventional ICF target driven by a double ended z-pinch



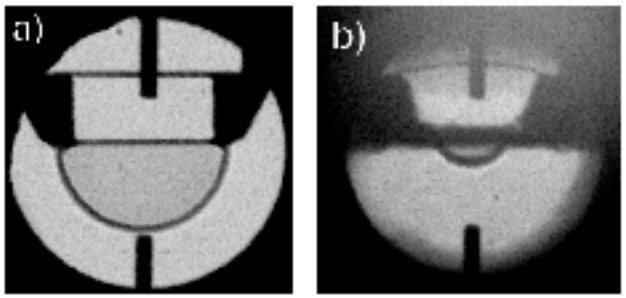
Experimental 6.7 keV backlit capsule images on Z



Fast Ignitor ICF target driven by a single sided z-pinch

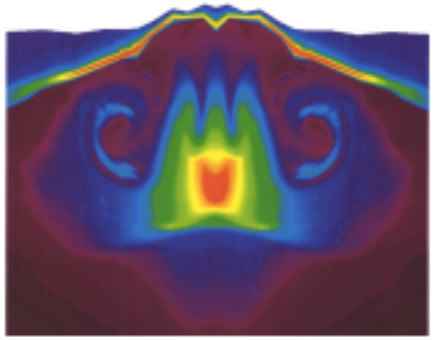


Experimental 6.7 keV backlit capsule images on Z



initial C_r = 3

2D Rad-Hydro simulation of capsule compression on Z

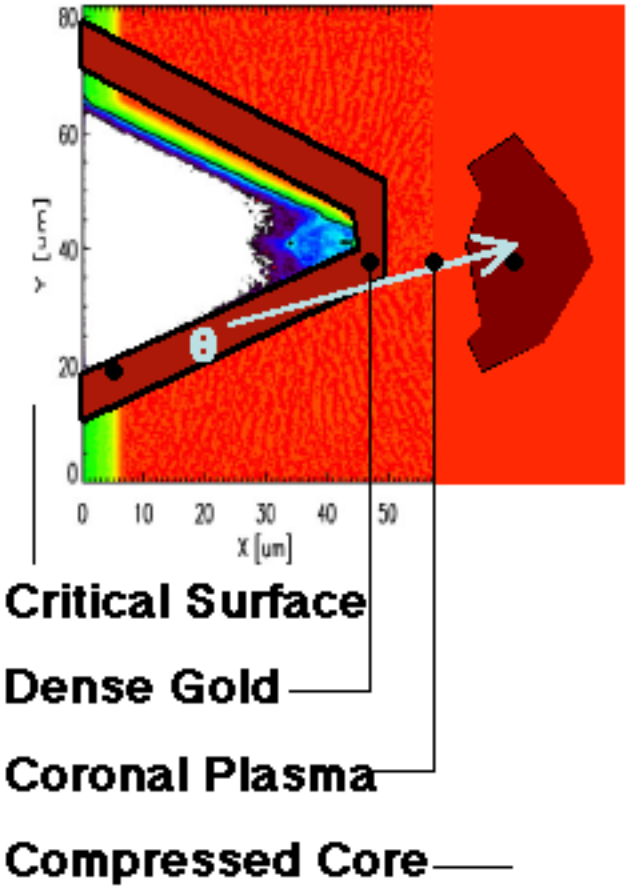


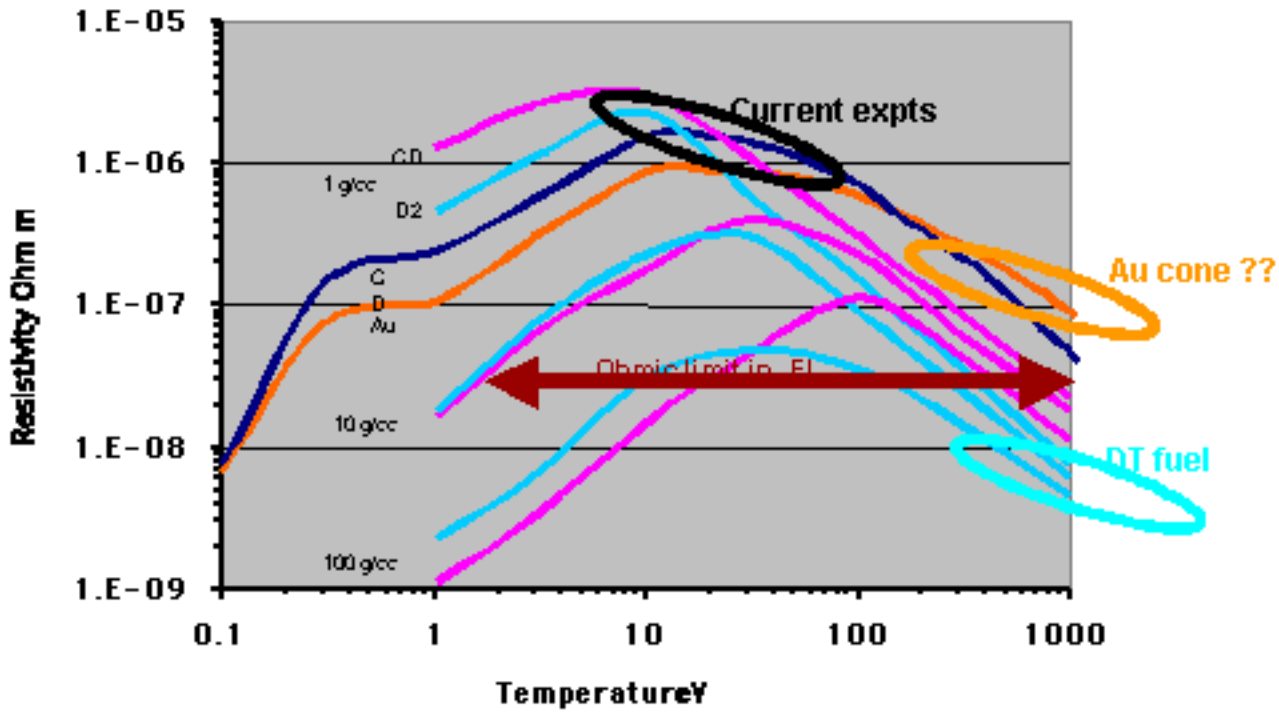
max density = 135 g/cm^3
max ρz = 1.1 g/cm^2

Electron transport at high density and temperature is one of the principal physics issues facing fast ignition

Plasma resistivity is important

- **R(T, Z,ρ) changes dramatically in transit**
- **Reactive fields couple REB with cold electrons**





Experiments are evolving toward high temperature regime

Five year FI road map

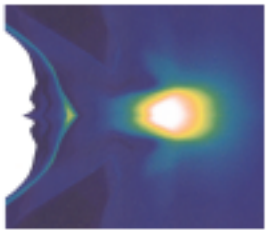
Expand the Science to match the expanding experimental capability

FY05 FY06 FY07 FY08 FY09 FY10

Concept Exploration	Proof of Principle	Performance Extns'n
E_{comp}~10kJ, E_{heat}~1 kJ	E_{comp}~10 kJ E_{heat}~10 kJ G= 0.1-0.5	E_{comp}~100 kJ E_{heat}~100 kJ G ~1

Transport	Hi Ω	Hot lo-Z	Dense lo-Z	Core heating
Fuel assy	Cone geometry	Integrated	pure DT	
Target	Wetted foam	Layered ice		
Diagnostic	E,B-fields	Core x-ray	Localized n	
Modeling	Benchmark	Laser-cone	Integrated	

Ignited Plasma



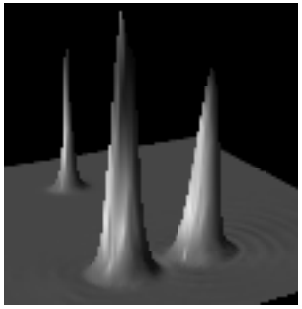
Japan	Gekko	Firex I	FirexII
US	Omega, Z	Omega EP, Z-R	NIF

UUL Frontier 1: Matter driven by relativistic light intensity: many body relativistic physics

Principal frontiers:

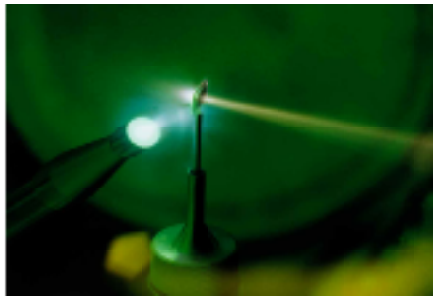
- **Study of light-atom interaction with fields at relativistic energies.**

Light intensities are high enough to accelerate particles to relativistic intensity in one optical cycle:
exotic atomic physics
novel ways of producing bursts of ultrafast x-rays



- **Relativistic plasmas**

Nonlinearities in the electron motion give rise to new plasma proerties at relativistic intensity
Pair production can become important

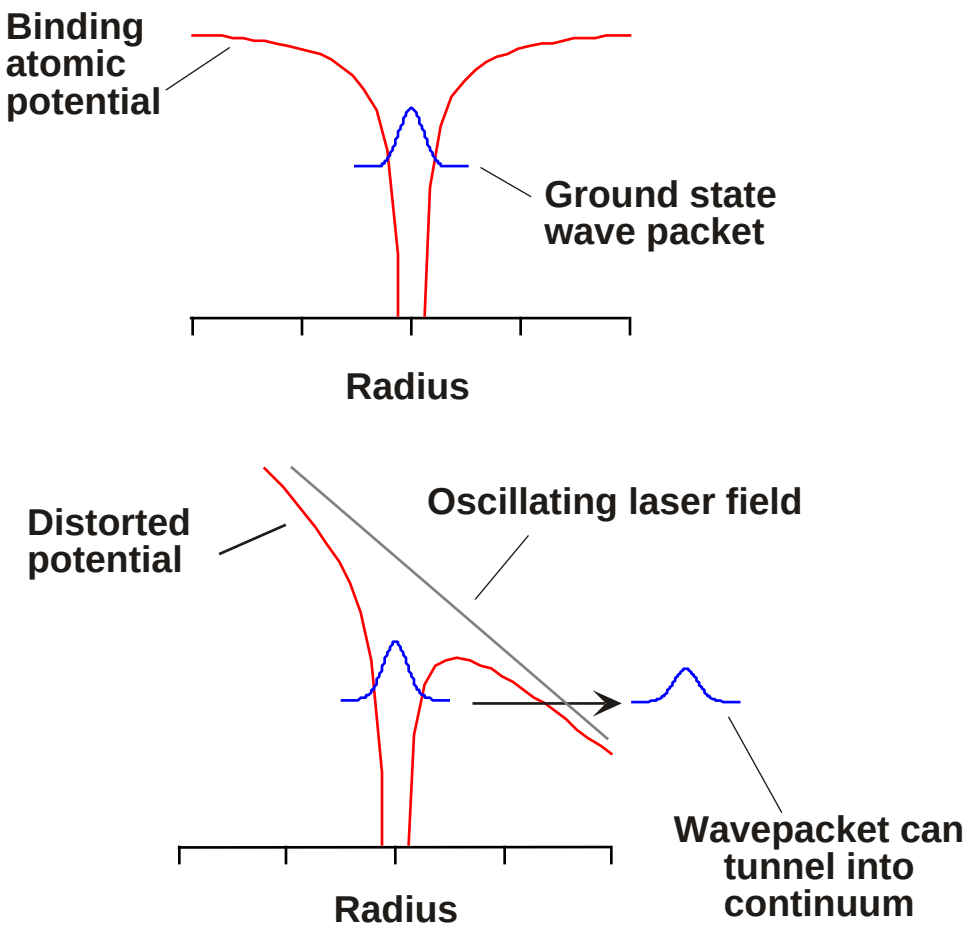


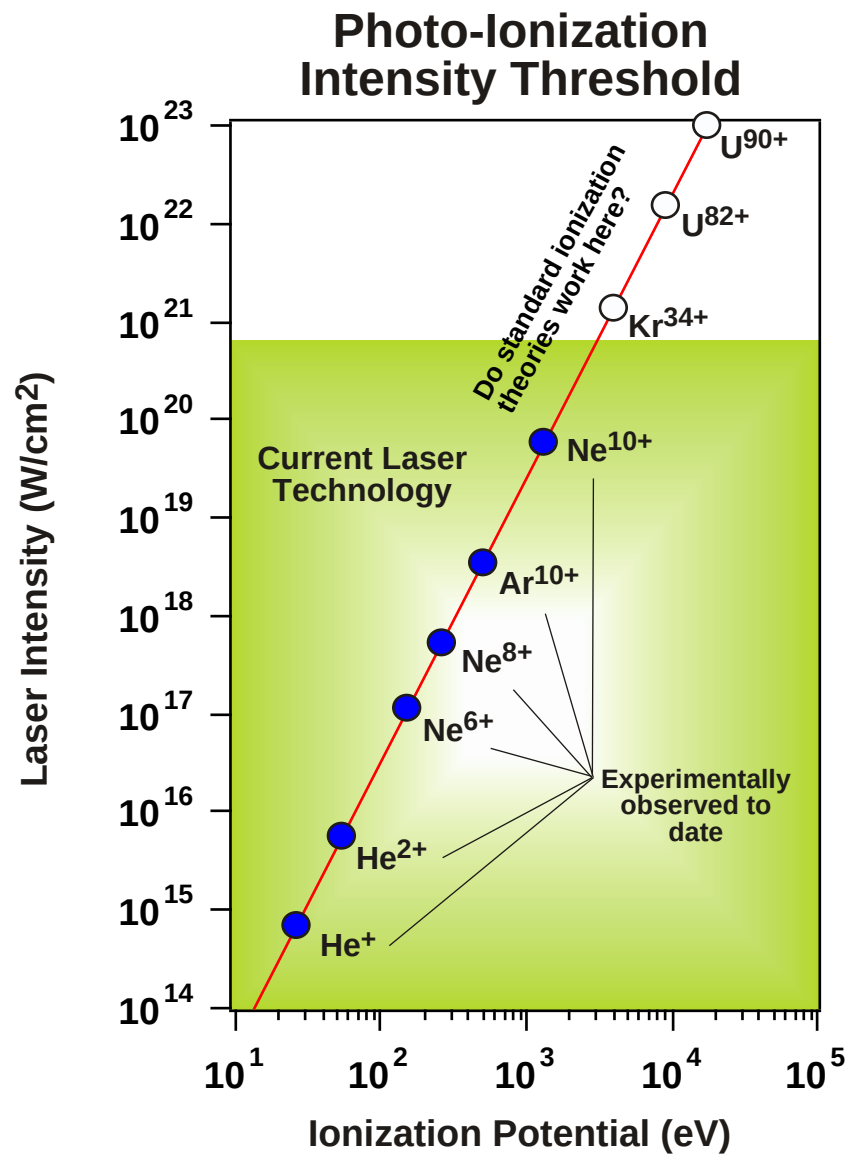
Positron burst from a Petawatt laser target

Electron oscillation energy approaches mc^2 at intensity ~ 10^{19} W/cm^2

Strong laser fields can ionize atoms and highly charged ions by tunnel ionization

A strong laser field can ionize an atom by tunneling



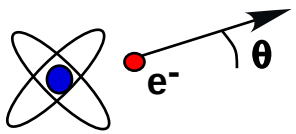


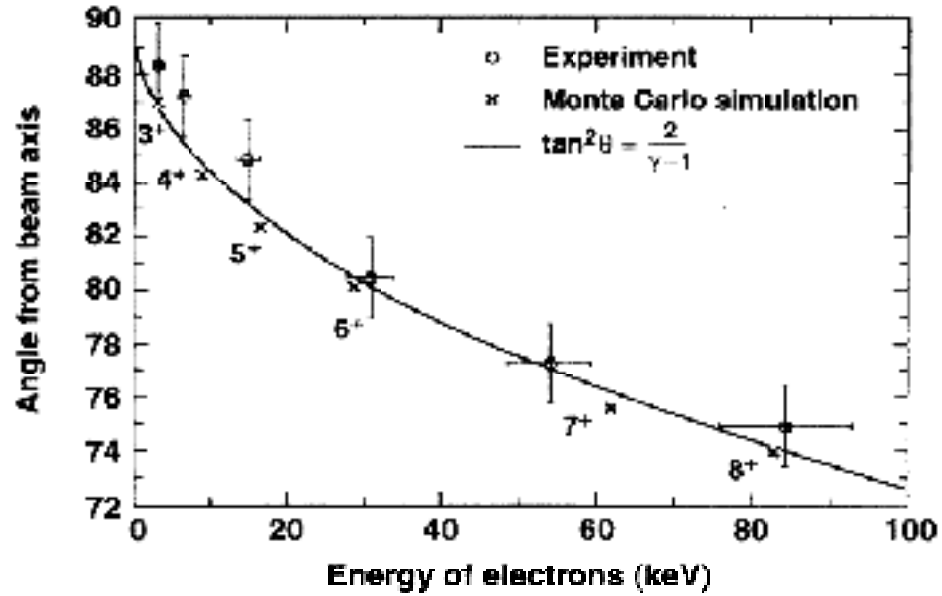
Strong field above threshold ionization is affected at relativistic intensity

Moore, Knauer, Meyerhofer, PRL 74(13), 2439 (1995)

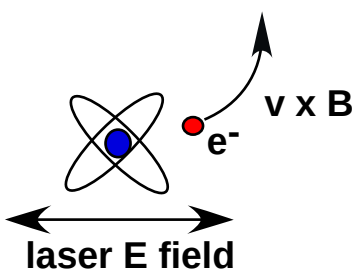
Laser parameters: 1.053μm, 1 ps, waist size - 5 μm, peak intensity - 10^{18} W/cm^2

In weakly relativistic laser fields (~10^{18} W/cm^2) electrons ejected by ionization are slightly folded in the forward direction

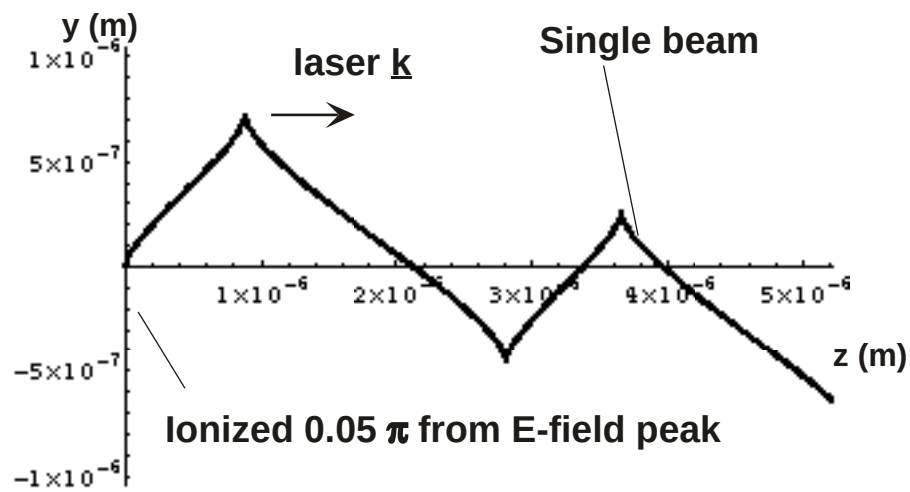




In strongly relativistic laser fields (>10^{19} - 10^{20} W/cm^2) electrons ejected by ionization are rapidly accelerated in the laser propagation direction



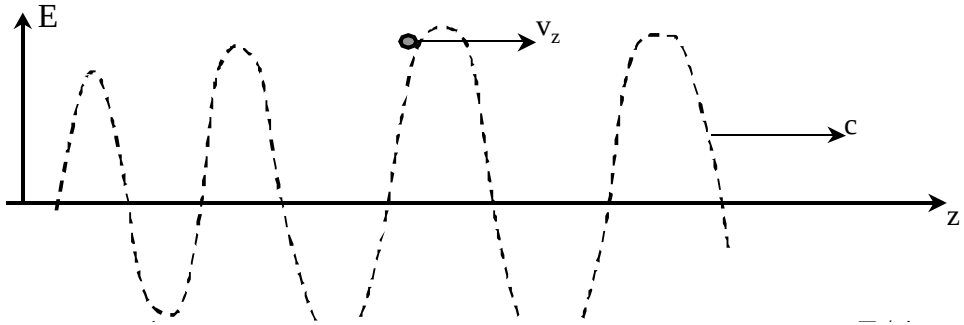
I = 3 x 10^{19} W/cm^2



Ionization in a strongly relativistic beam will be accompanied by strong, free-wave acceleration of the ejected electrons

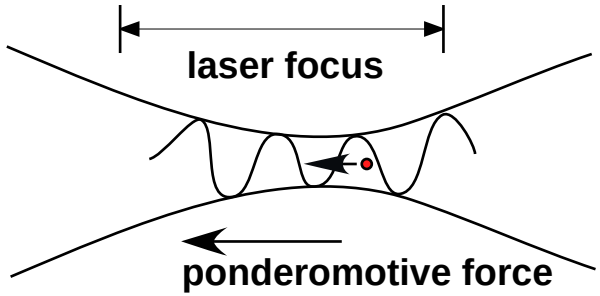
- Ionization "injects" electrons right at the peak of the field
- This yields much greater energies than if the laser interacts with free electrons

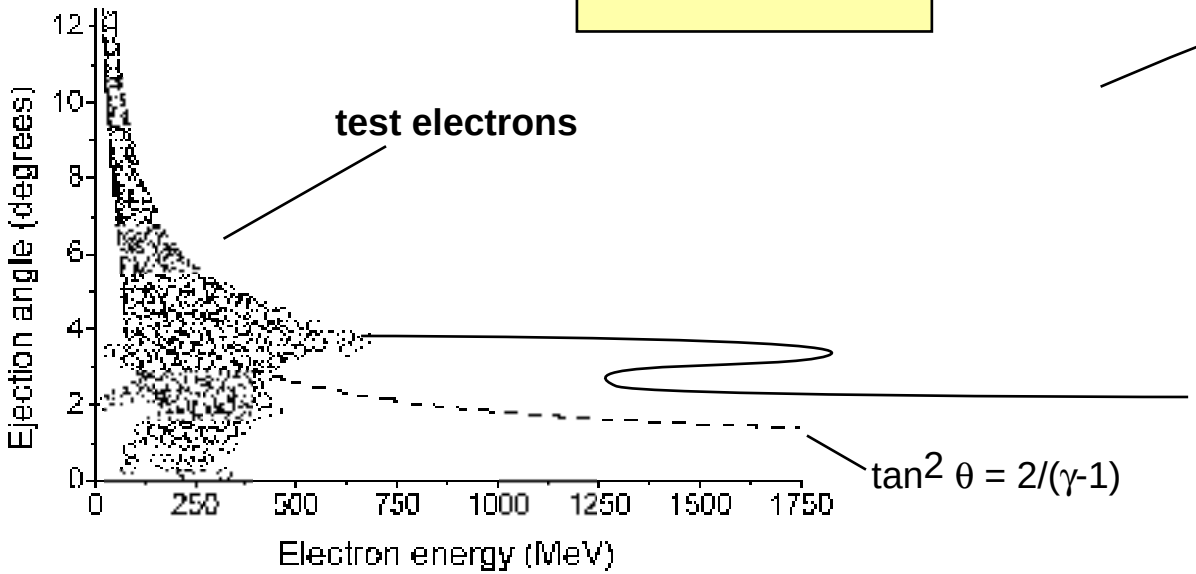
Electrons with large longitudinal momentum can"ride" the laser wave



Monte Carlo simulation using a focused PW beam

Ar^{17+} ionization
$I = 5 \times 10^{21}$ W/cm^2



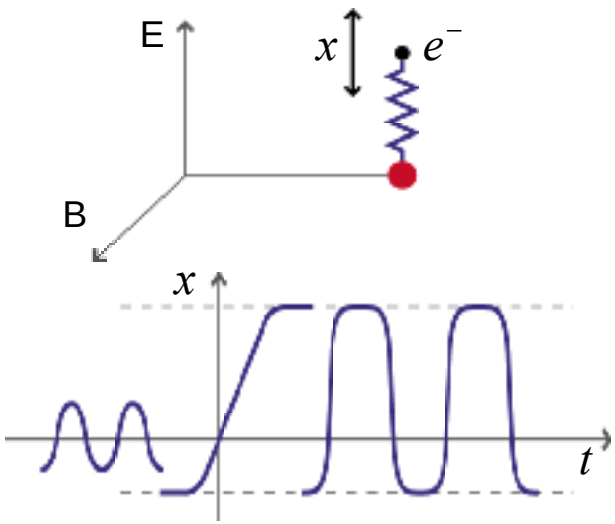


Near GeV electrons ejected within 4° of the laser axis

Ultraintense pulses can now access a new regime of "relativistic nonlinear optics"

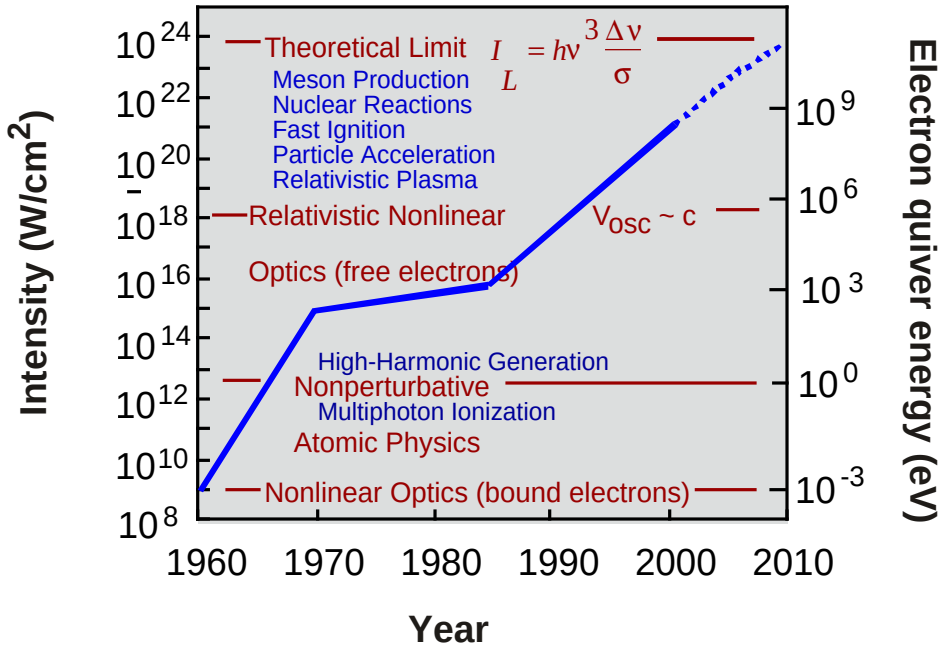
Classical nonlinear optics:

Bound

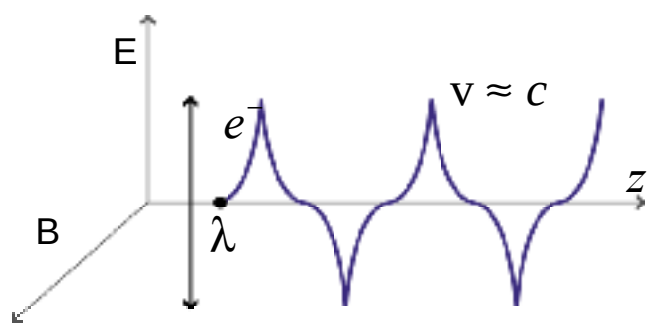


$x \not\propto F$

- **Harmonics**
- **Optical Rectification**
- **Self-focusing**



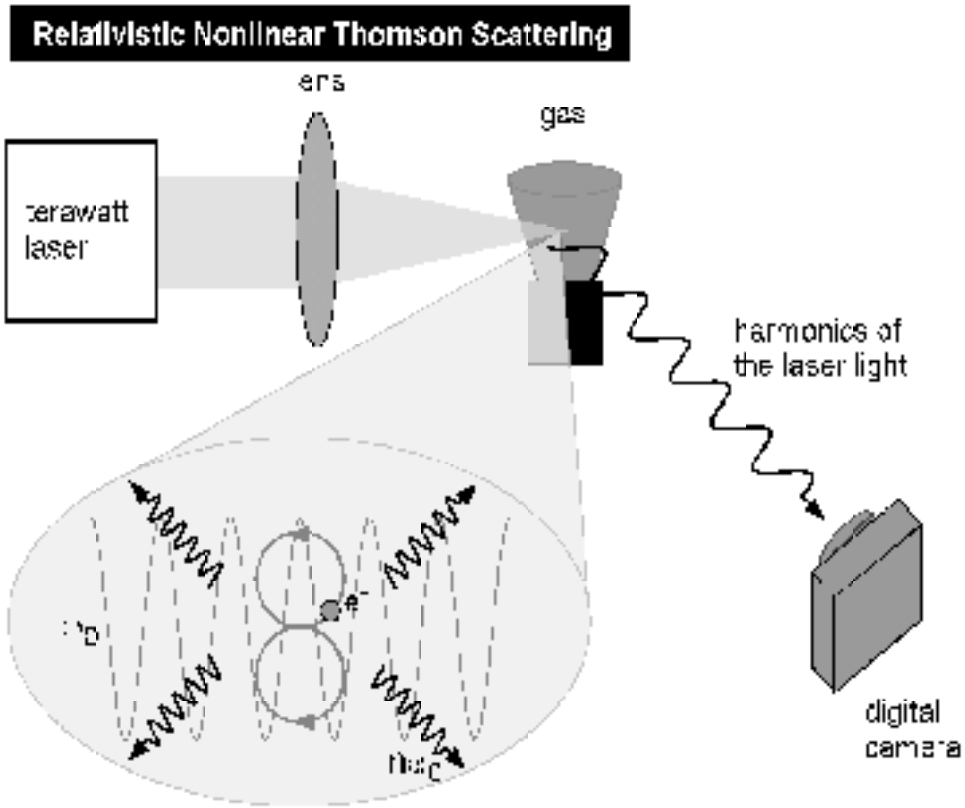
Relativistic (free electron)

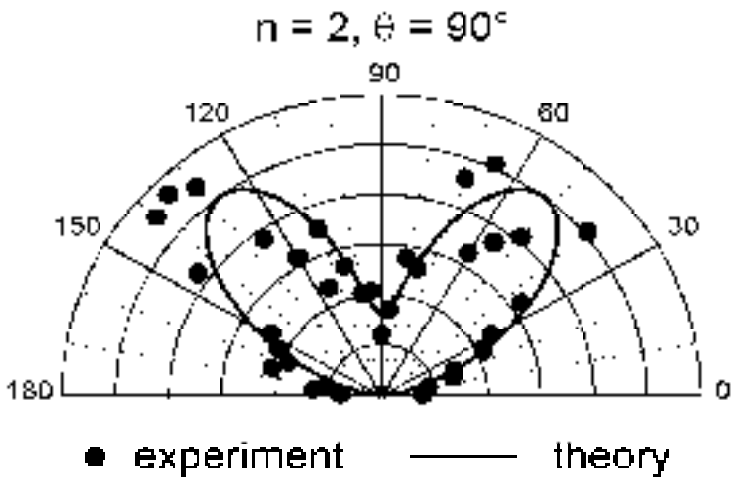


$x \not\propto F$

- **Harmonics**
- **Optical Rectification (wake field production)**
- **Self-focusing**

Relativistic nonlinear Thomson scattering has been observed



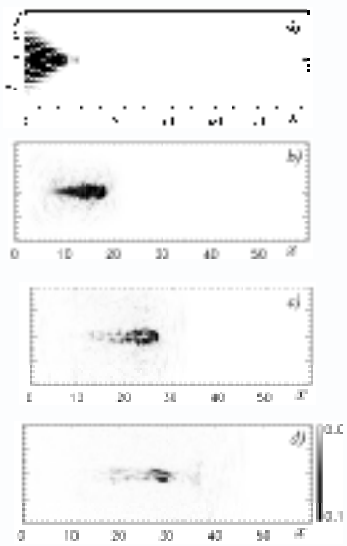


S.Y. Chen, A. Maksimchuk & D. Umstadter, "Experimental Observation of Relativistic Nonlinear Thomson Scattering," *Nature*, **396**, 653 - 655 (1998).

An ultrafast pulse interacting with plasma at relativistic intensity leads to a range of nonlinear phenomena

Examples of nonlinear phenomena attributed to the mass increase of the electron at relativistic intensity:

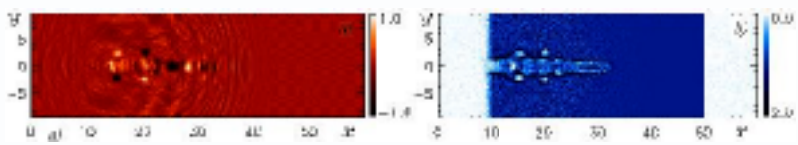
Relativistic self focusing



PIC simulation of relativistic self focusing at 5 x 10^{19} W/cm^2 (by Bulonov et al.)

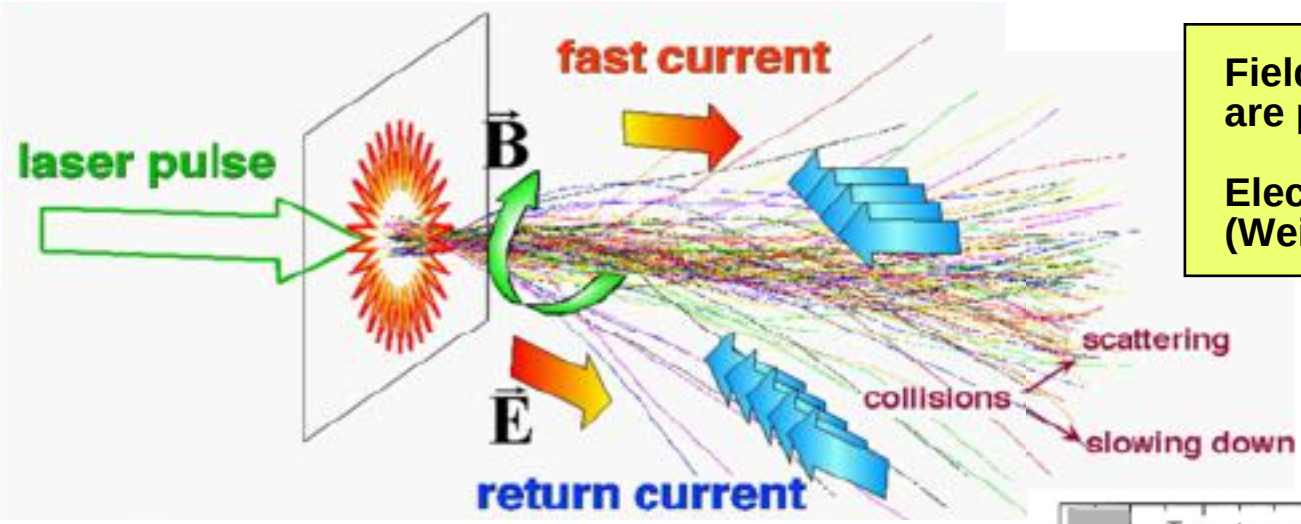
Relativistic transparency

Relativistic soliton propagation



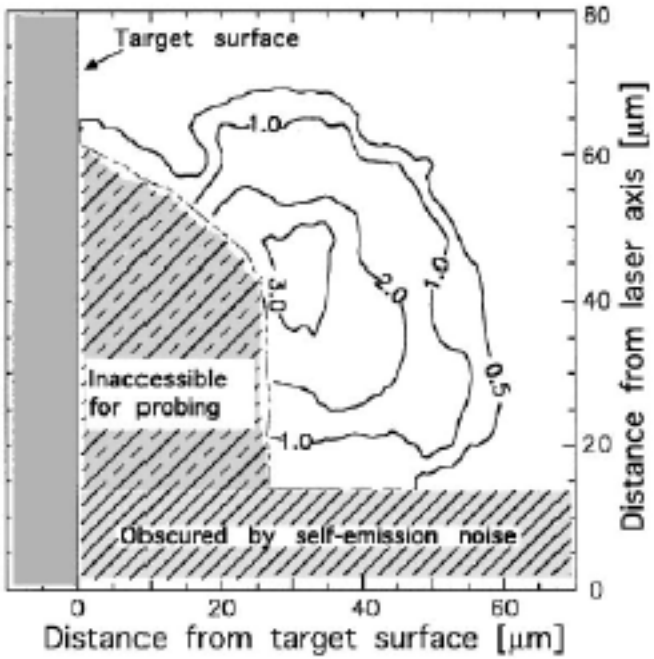
Soliton simulated by Giulietti et al.

Very strong magnetic fields are produced from the production of high currents of relativistic electrons



Fields as high as hundreds of MegaGauss are predicted in the target

Electron transport leads to instabilites (Weibel instability)

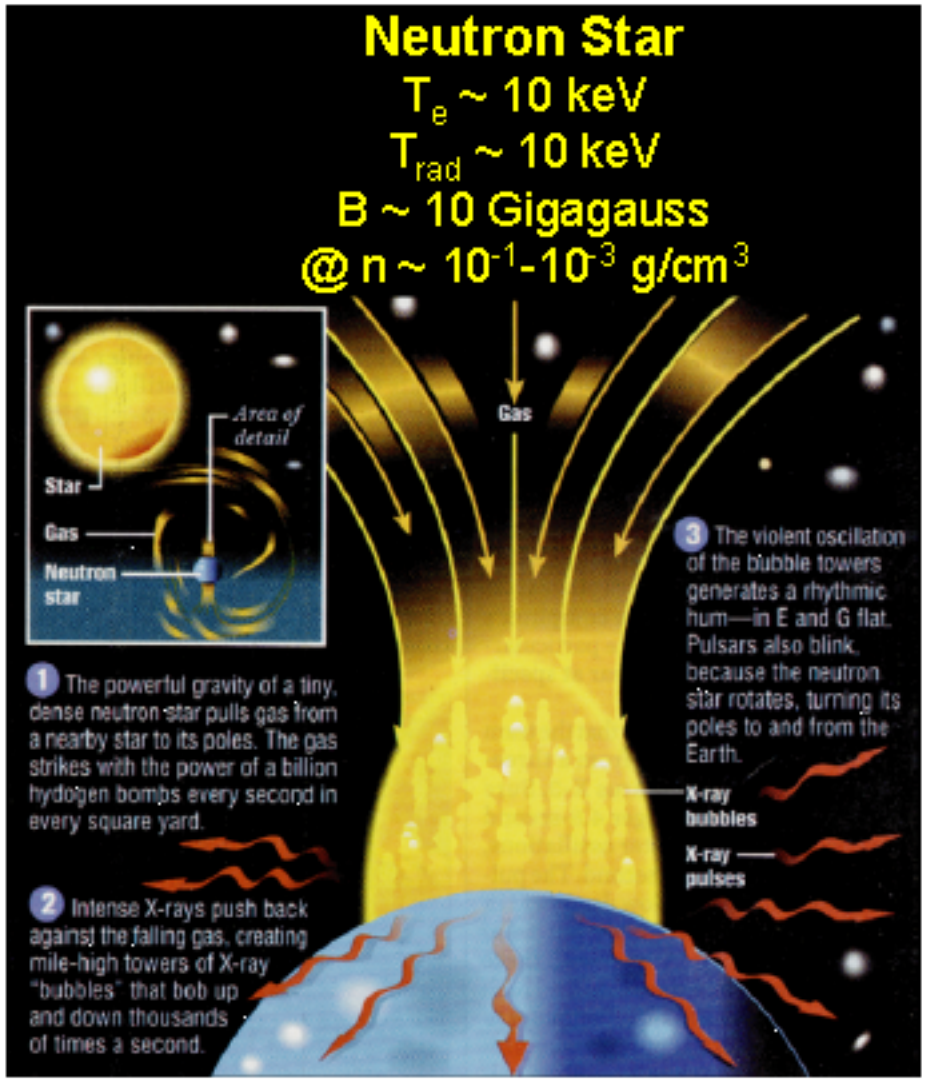


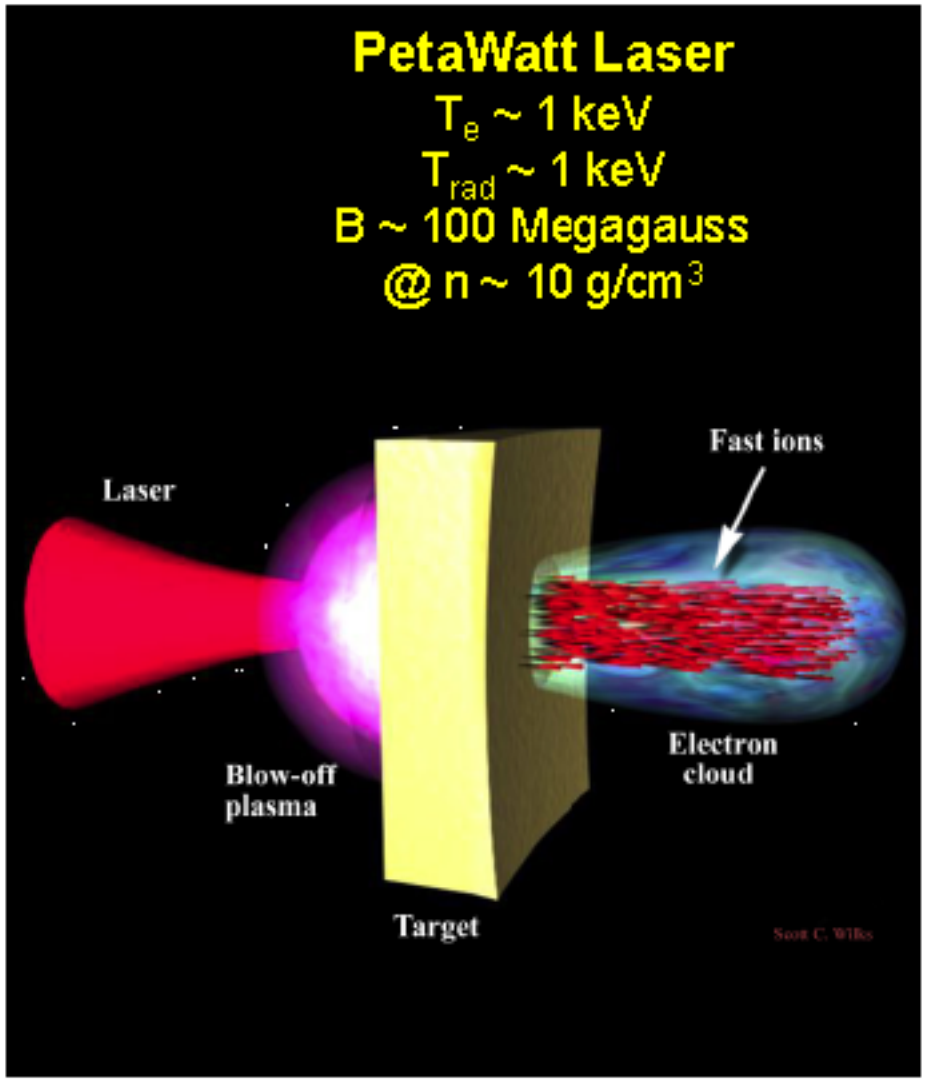
Measured B-field in MegaGauss on the Vulcan laser at intensity ~10^{19} W/cm^2

M. Borghesi et al. PRL 81, 112 (1998)

Matter in these super strong B fields is exotic: at ~ 500 MegaGauss, the electron gyroradius in an H atom approaches its wavepacket size (a Bohr radius)

Neutron Star atmospheric conditions possible in a lab?





The minimal requirements for photon-bubble instability could potentially be met with a properly configured 10 pSec PetaWatt laser experiment.

Courtesy of Richard Klein, LLNL

Positron production was observed recently in high field laser target interactions on the LLNL Petawatt Laser

The Petawatt laser and compressor

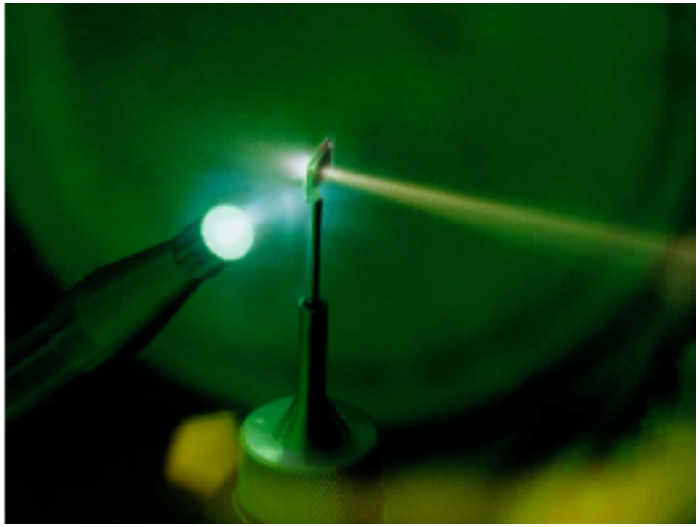
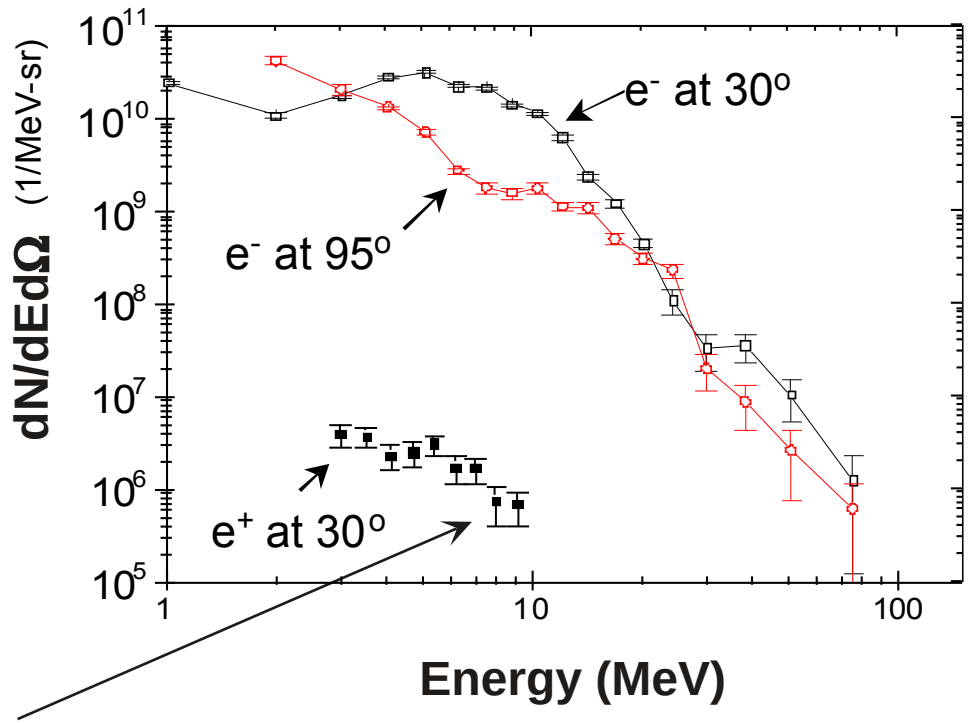


Photo of Petawatt shot on Au slab target

Hot electron and positron spectrum measured from the LLNL PW laser

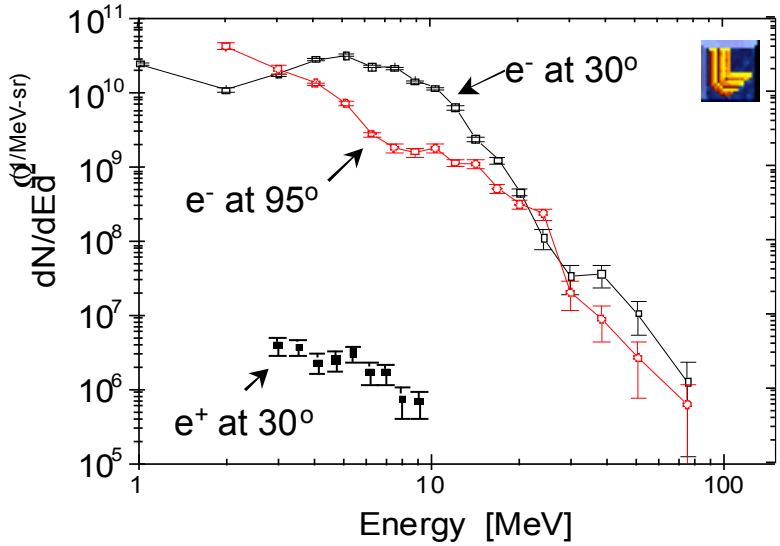


Positron spectrum

from T. E. Cowan et al. Las. Part. Beams 17, 773 (1999).

At sufficiently high intensity, in the right geometry, pair plasma production may be possible

from T. E. Cowan et al. Las. Part. Beams 17, 773 (1999).



Experiment proposed by Liang et al. PRL 81, 4887 (1998)

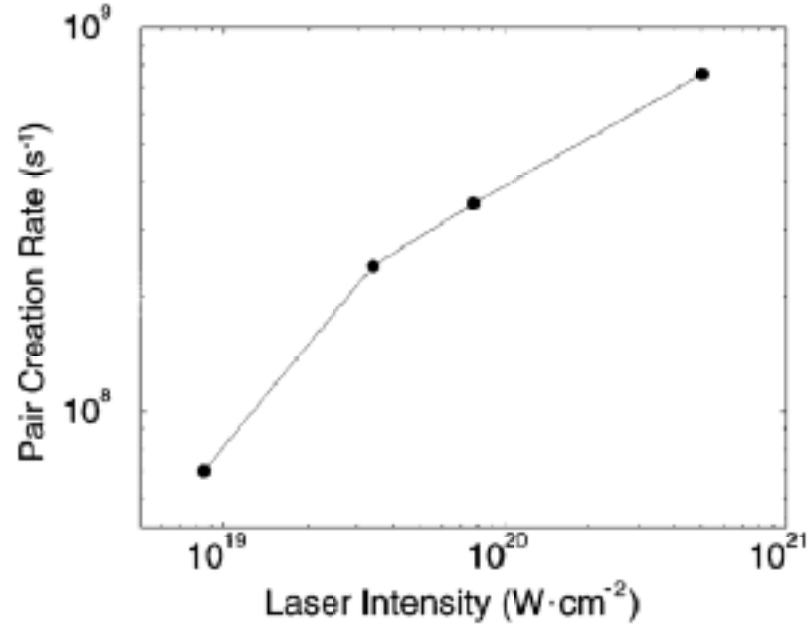
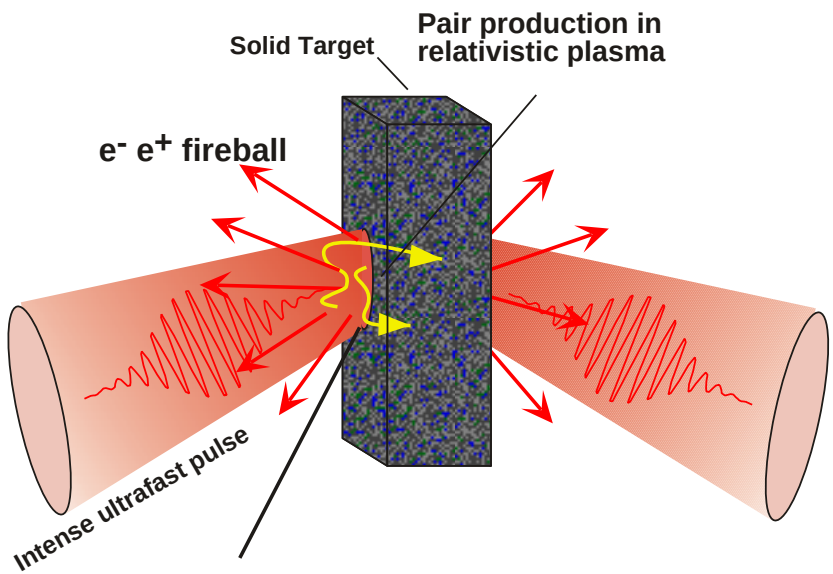


FIG. 2. Pair production rate Γ plotted as a function of laser intensity I. Dashed curve is just to guide the eye. At $I \gg 10^{20}$ W/cm^2 we expect the curve to level off due to the log dependence of pair production cross section on Lorentz factor γ. [Refer to Eq. (4).]



Strong ponderomotive forces drive electrons → T_{hot} ~ 1 MeV

Production of a pair plasma results and the explosion of this plasma results in an e^-e^+ fireball → with potential relevance to gamma ray bursts