Application of Ultraintense Lasers to validate materials for laser fusion: production of ions and other relevant species

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CONTENT

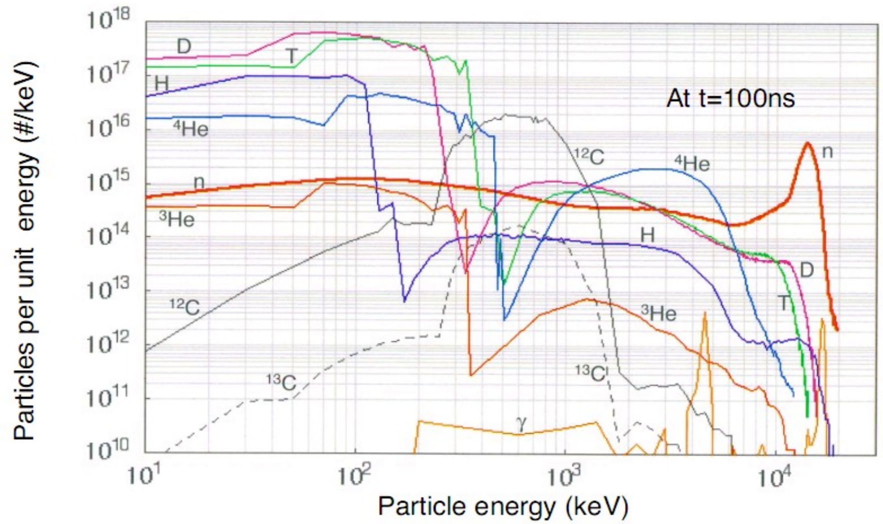
The Instituto de Fusión Nuclear is responsible for Chamber Design and materials research within the HiPER project.

- Justification of the need and demand of experimental facilities to test and validate materials for first wall in laser fusion reactors
  - Characteristics of the laser fusion products
  - Current "possible" facilities for tests

- Ultraintense Lasers as "complete" solution facility
  - Generation of ion pulses
  - Generation of X-ray pulses
  - Generation of other relevant particles (electrons, neutrons..)

PRODUCTS OF LASER FUSION

X-ray and Ion products of a 48MJ Target			
Particle	Energy (keV)	Av. E (keV)	Particles
X-ray	655	8,8	1,5e14
H	270	143	1.2e19
D	3200	191,4	1e20
T	3550	235	9.4e19
4He	3630	1334	1.7e19
12C	1680	760	1.4e19



For a 5 m radius chamber

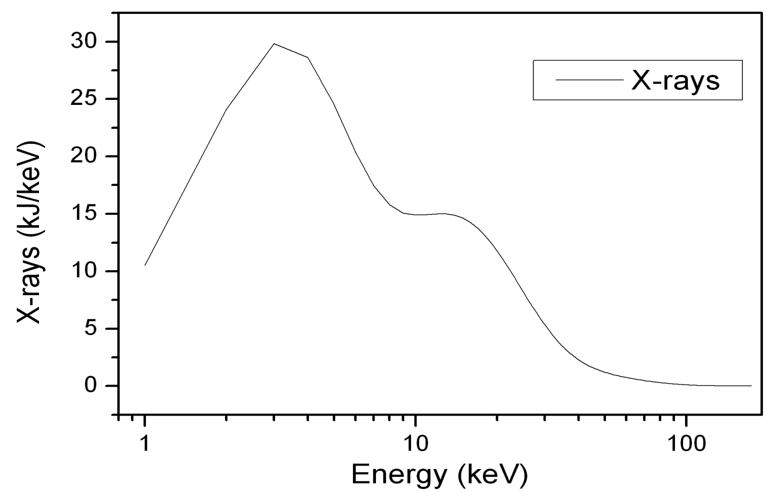
Energy Fluences: 40kJ/m^2

Pulse Duration: 2.5 µs

Peak. Intensity: 1TW/m^2 X-rays

Av. Intensity: 16GW/m^2

Ion flux: 1e24p/m^2/s



CHARACTERISTICS OF PRODUCTS

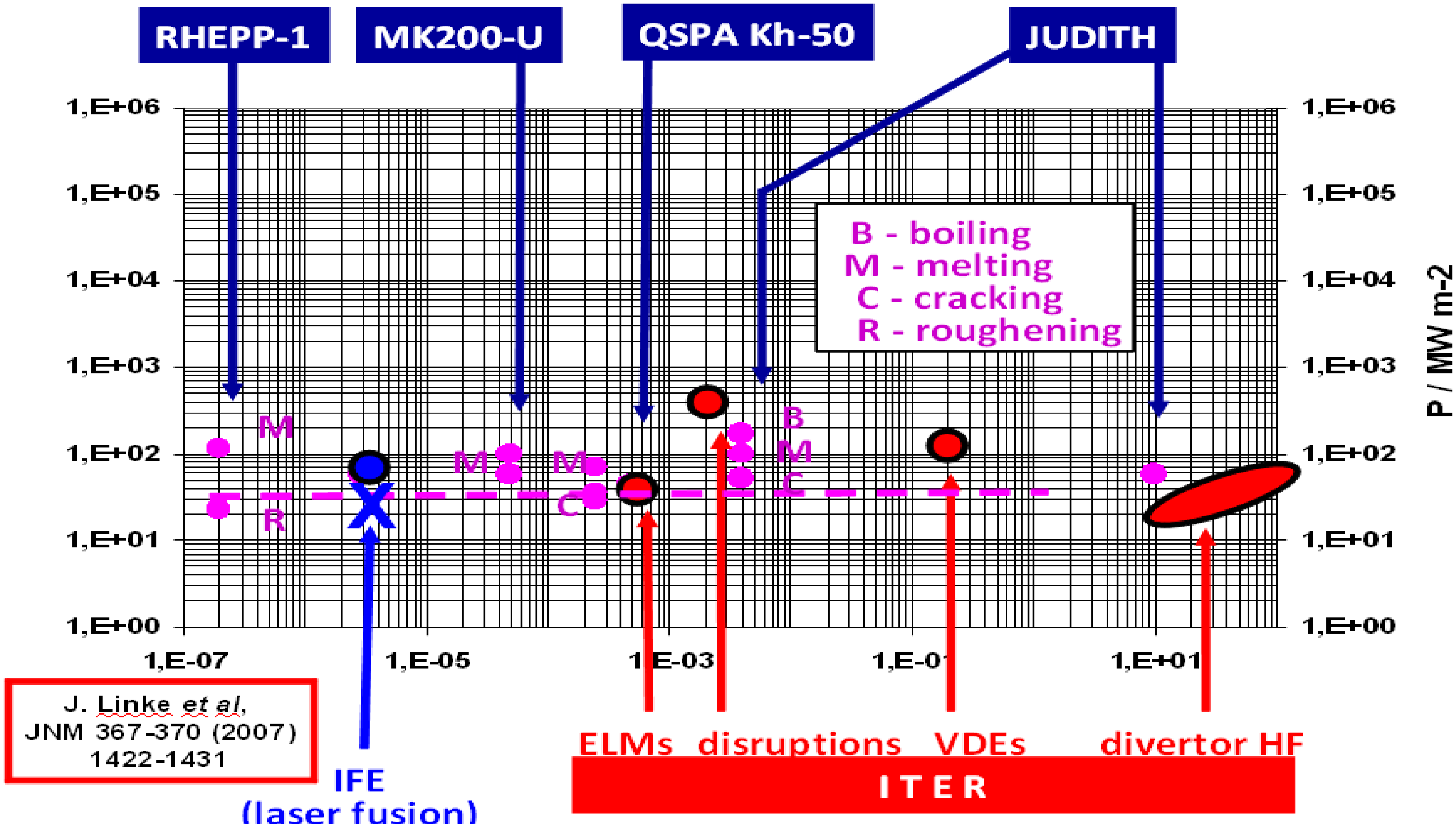
HIGH FLUXES OF ENERGETIC PARTICLES

SHORT PULSES
BROAD ENERGY SPECTRA

CAUSING THERMO-MECHANICAL AND ATOMISTIC DAMAGE

THOUSAND/ MILLIONS OF SHOTS

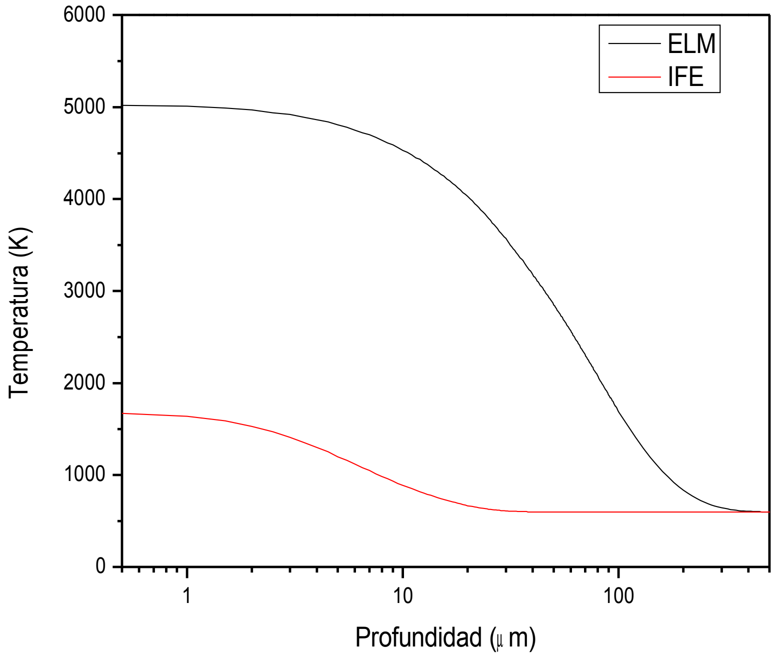
THERMAL SIMULATIONS



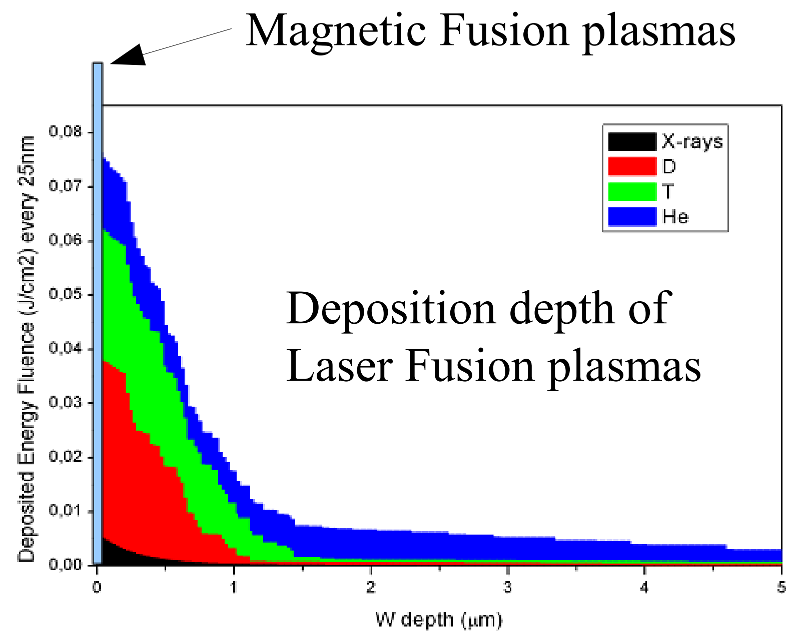
Magnetic fusion facilities "seem" to be valid for laser fusion from a thermal point of view. However penetration depth and atomistic damage are not reproducible.

MECHANICAL AND ATOMISTIC CHANGES

Similar heat flux parameter and temperatures in magnetic and laser fusion implies very different total delivered energy-> different thermo-mechanical effects.



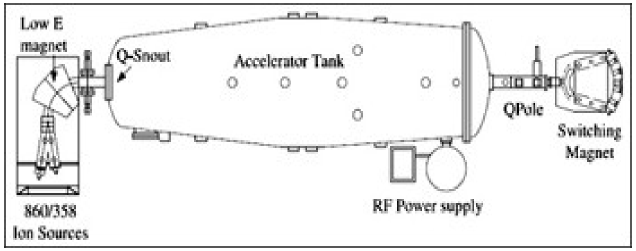
Atomistic Damage

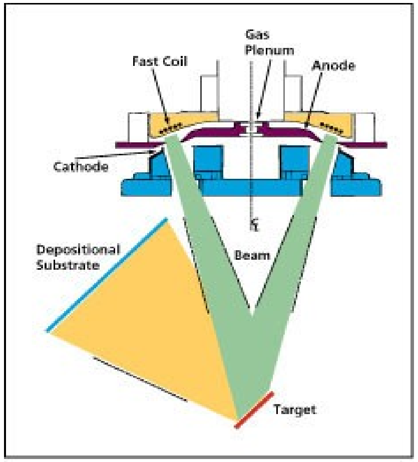


Shot	p/cm^2	Sput p/cm^2	Dpas
D	3,3*10^{13}	4,3*10^{10}	0,002
T	3,0*10^{13}	3,9*10^{10}	0,0003
He	5,4*10^{12}	1,5*10^{10}	0,0007
C	4,4*10^{12}	8,8*10^{10}	0,022

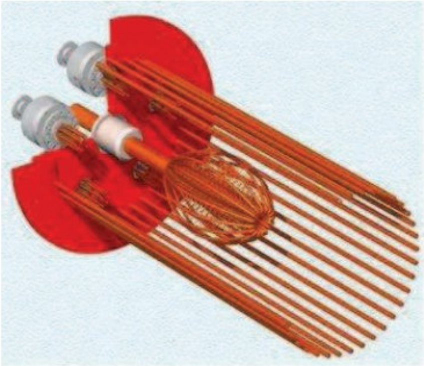
CURRENT FACILITIES FOR ION BEAMS

Linear Accelerators
High energies achieved but low fluxes ($1e14\ p/m^2/s$) and long pulses.





Plasma Guns
Relatively short pulses < 0,5 ms
Peak Intensity < 100 GW/cm^2
Energy Fluence < 40 MJ/m^2
Similar Fluxes
But... low ion energies



<u>Rhepp-1</u>
Pulses of 100-500ns
He energies of 800 keV
High Intensities 16GW/m2
Good fluxes
...but being deccommisioned!

Spalation sources
Pulses of 1.5ms (maybe less)
High energy protons (50MeV)
Intensities > 4GW/m2

CURRENT FACILITIES FOR X-RAY BEAMS

XAPPER (LLNL)
Plasma pinch - X-ray (100 eV)
X-ray fluence ~1 J/cm2
Pulse duration ~10 ns
Samples can be irradiated with up to 10^6 pulses

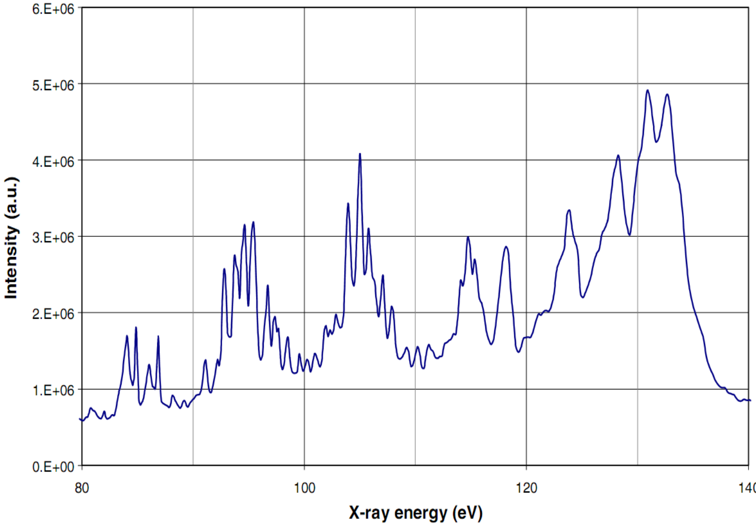
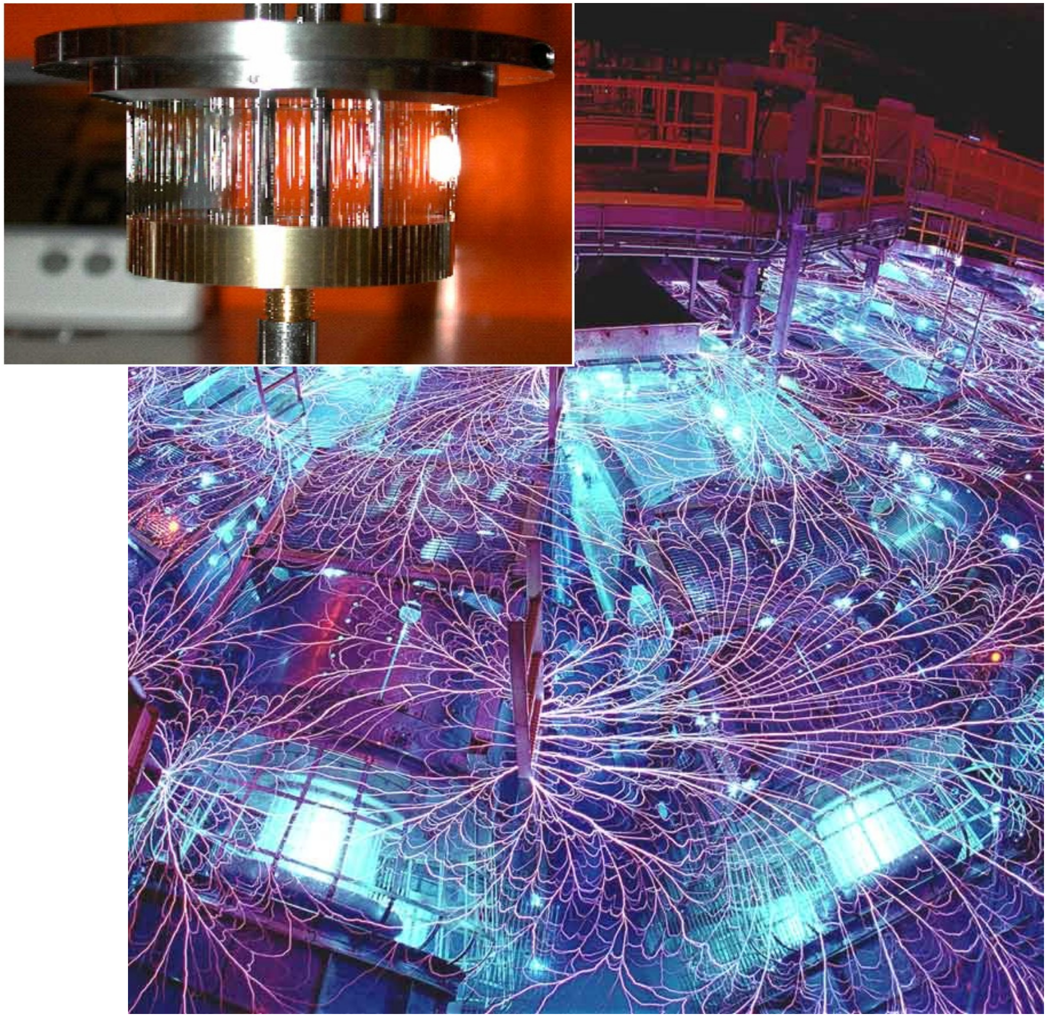


Fig. 1. The XAPPER X-ray spectrum ranges from ~80 to 140 eV.

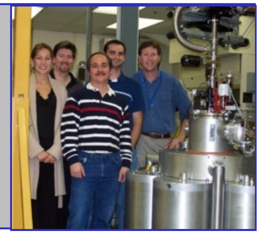


Z-pinch (SANDIA)
Black body at 300eV with 10% at 600eV
Pulse duration ~10 ns

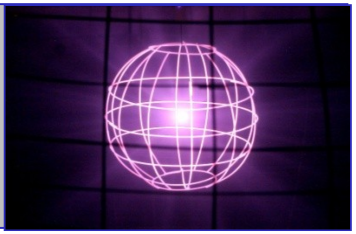
Thermal load, Secondary e^- and E-M pulses

LASER FUSION FACILITIES

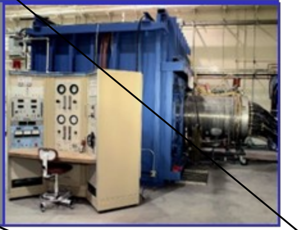
X-rays:
XAPPER – LLNL



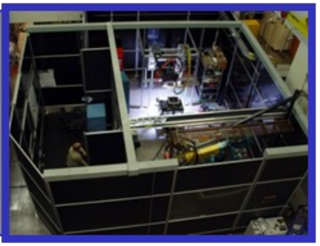
Helium:
IEC – Wisconsin
He beam – UNC



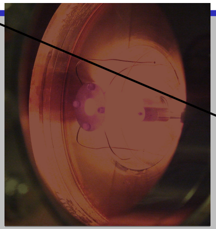
Ions:
RHEPP – SNLA



Cyclic heating:
IR lamp, e-beam: ORNL

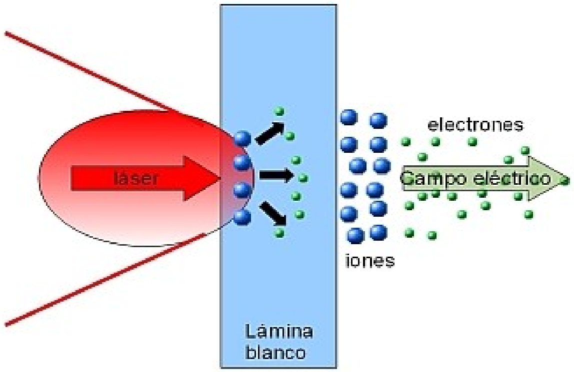


Cyclic heating:
Lasers – UCSD



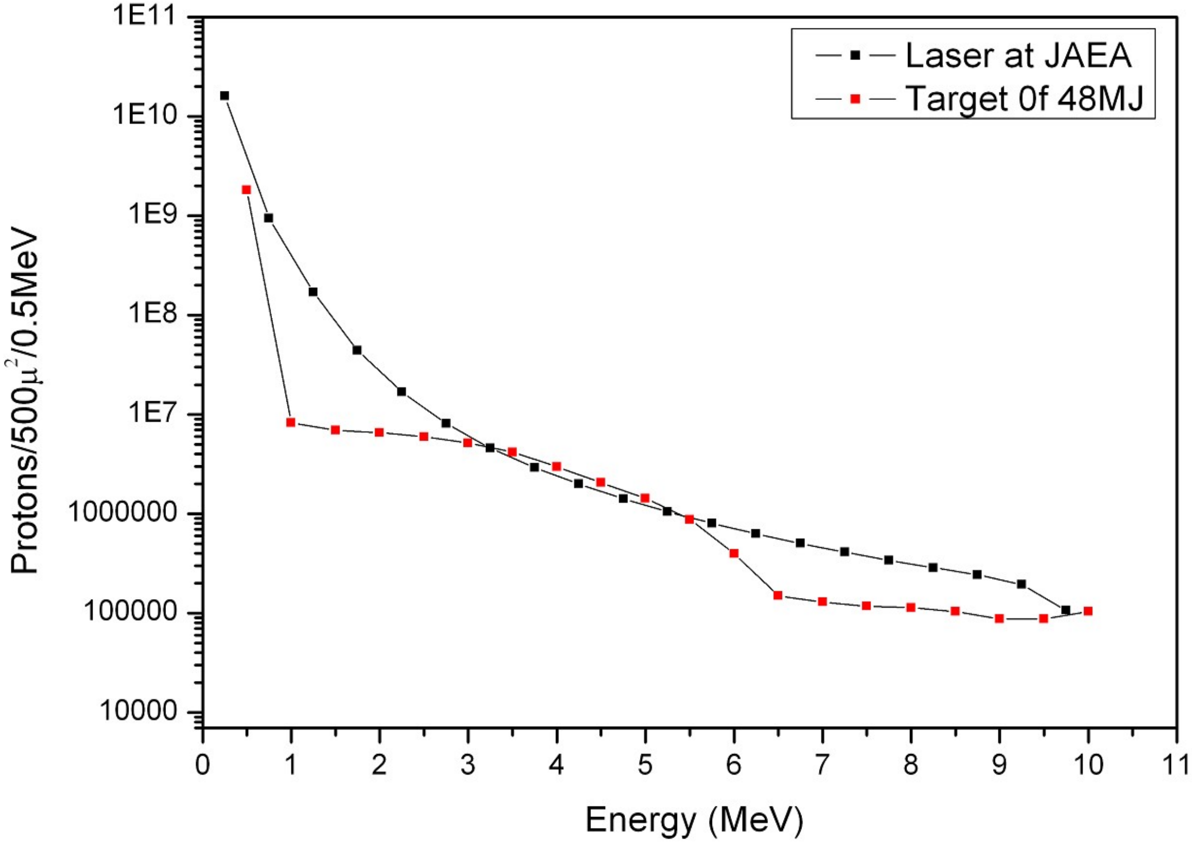
Ultraintense Laser (>100 TW)

LASER DRIVEN ION PULSES



Target Normal Sheath Acceleration

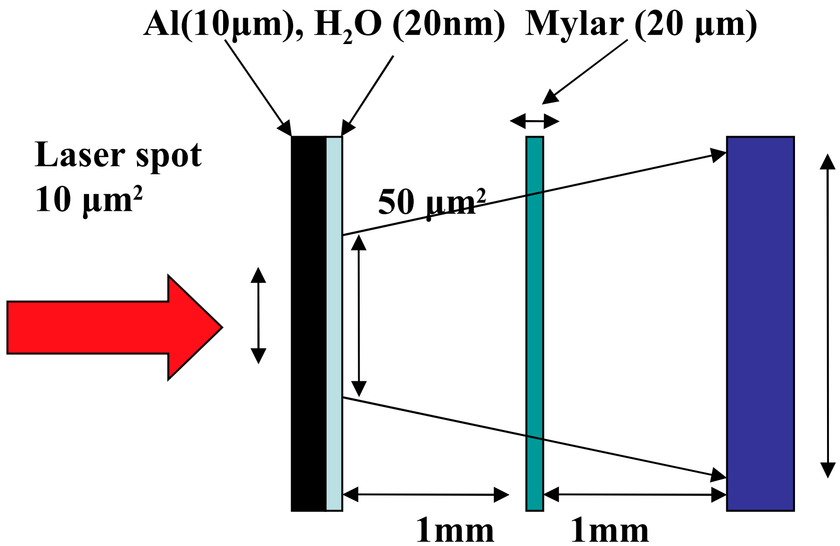
·Short pulse duration (ps-ns)
·High Fluxes $10^{29}/m^2/s$
·High energies > MeV
·Broad Energy spectrum
·Different ions

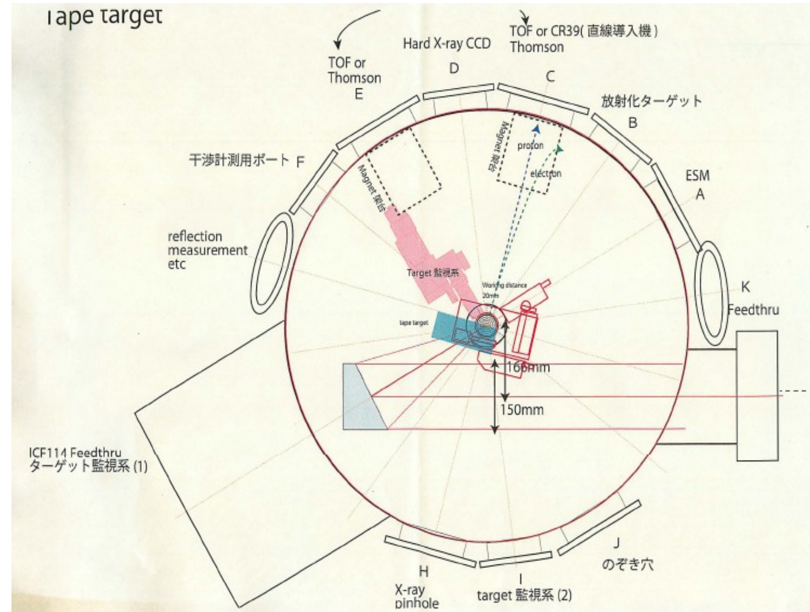


M. Borghesi et al. Fus. Sci. Tech. 49 (2006) 412
J. Fuchs et al. Nature Physics 2, (2006) 48

PROTON SPECTRUM

LASER DRIVEN PROTON PULSES





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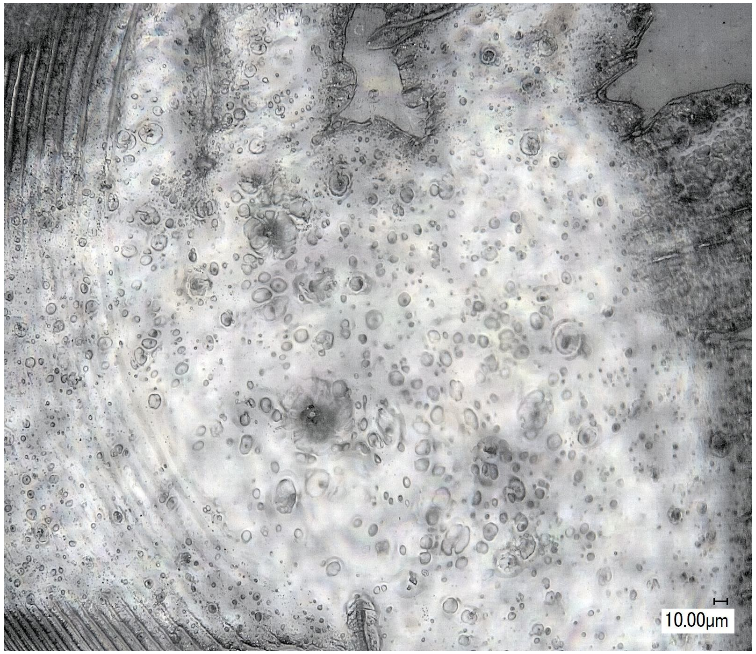
LASER DRIVEN PROTON PULSES

Several protron spectra were generated

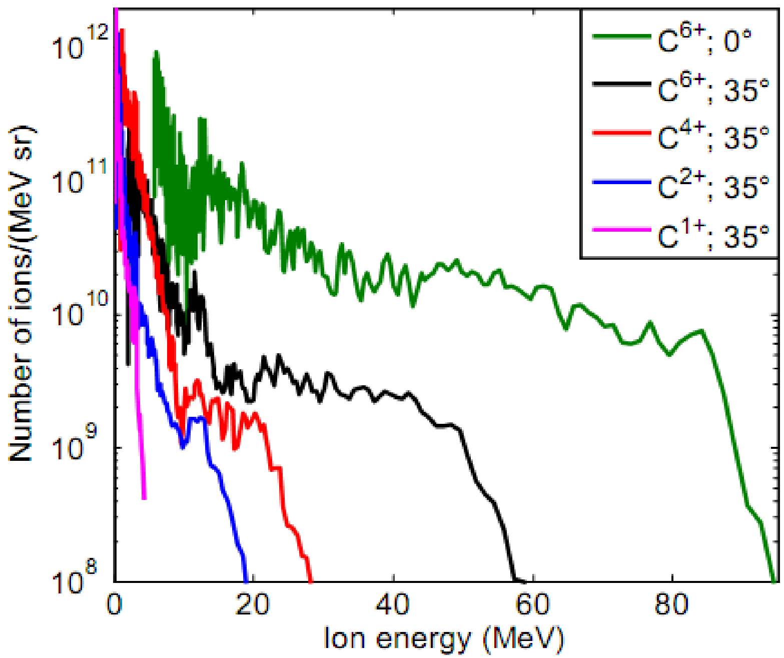
·From 2J laser pulse energy and intensity of $7x10^{19}$ W/cm^2 for which proton flux conversion efficiency was estimated to be around 0.4%

·To 20J laser pulses and intensities of $7x10^{20}$ W/cm^2 on target for which proton flux conversion efficiency was estimated to be around 4%.



LASER DRIVEN ION PULSES

H isotopes, Carbon and High Z ions



Rear side of 100 nm-thick Al targets for laser incident angles of 0◦ and 35◦. Laser pulses with energy 5 J (on the target), duration 50 fs and intensity $6–7\times10^{20}$ W/cm^2
From P. McKenna et al. New J. Phys. 12 (2010) 045020

Even He pulses

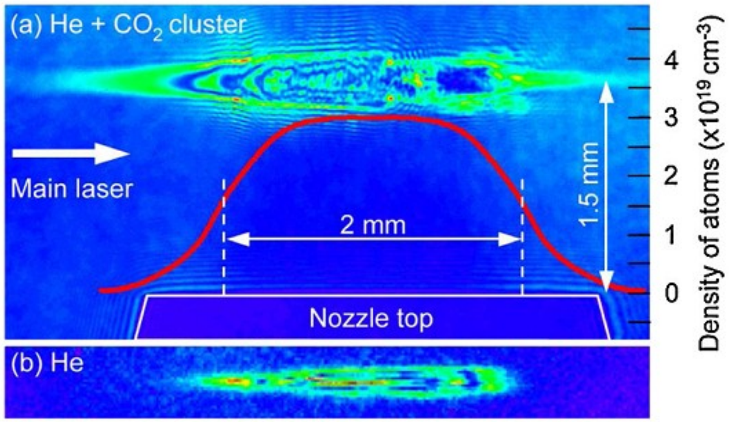
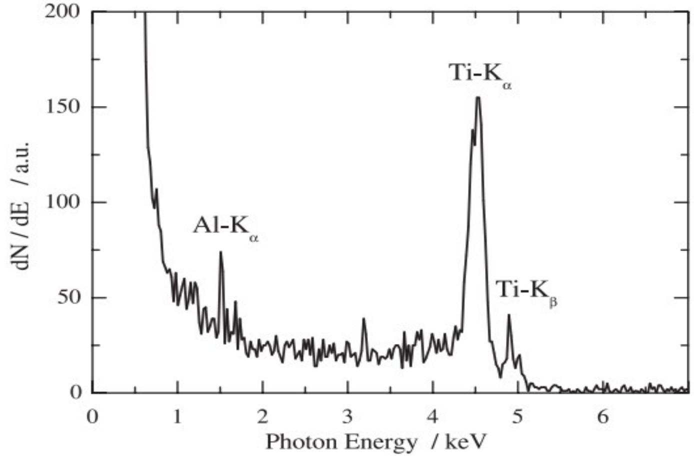


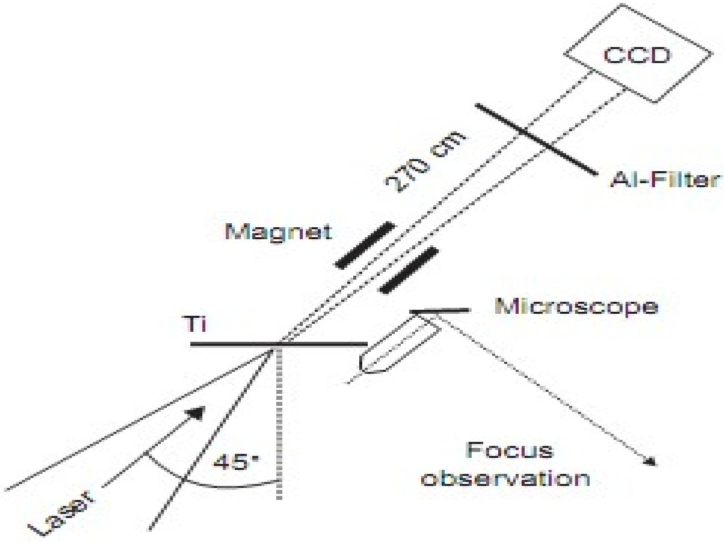
FIG. 2 (color online). (a) The shadowgraph image for a mixture of He gas and CO_2 clusters. The red (or gray) line shows the initial atom density profile. (b) The shadowgraph image for a pure He gas target. (From Fukada, PRL 165002 (2009)

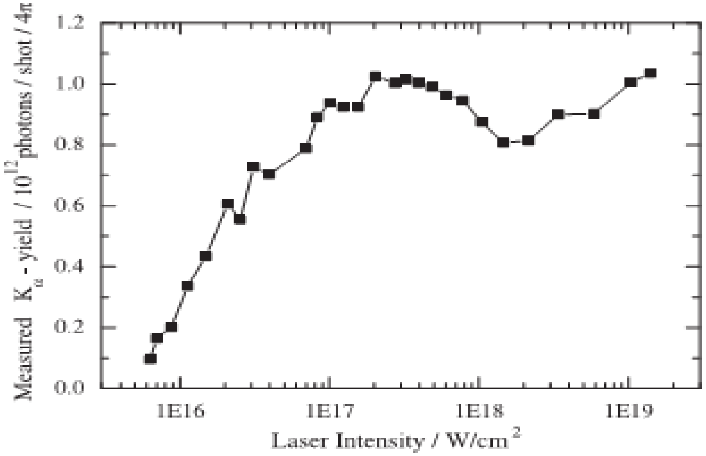
L.Willingale et al. PRL 96, 245002 (2006)
L. Willingale et al. IEEE Transactions on plasma science, 36 (2008)

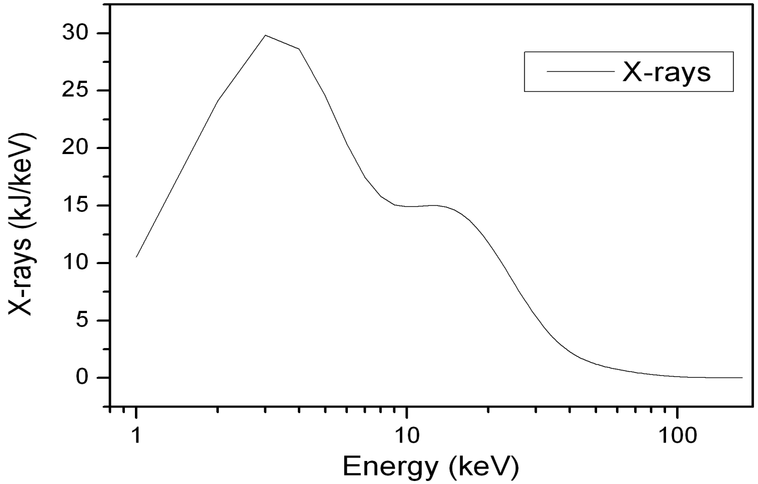
LASER DRIVEN X-RAY PULSES

Atomic Lines and Bremsstrahlung









F. Ewald et al. Europhys. Lett., 60 (5), 710 (2002)

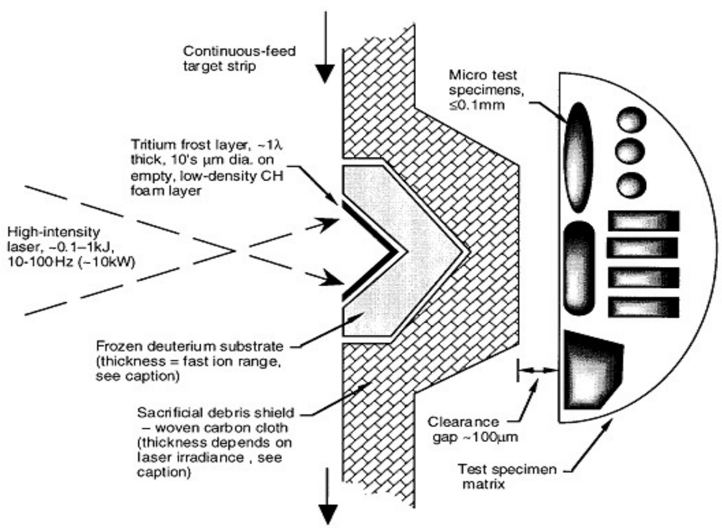
LASER AS A NEUTRON SOURCE

J. Perkins et al. Nuc. Fus. 40, 1 (2000)
Laser energies 100J-rep.rate100 Hz
neutron flux: 10^{14}-10^{15}/cm^2/s
Pros:
- D-T reactions-> 14.1 MeV n.
- cost effective small source
- Available over extended times

Table 2. Overview of currently achievable neutron strengths for different commercially available neutron sources. Recent experimental results for laser-generated neutrons are added for comparison. Average neutron source strengths were calculated assuming one laser shot every 30 min. Peak neutron source strengths were estimated assuming 1 ns neutron pulse length.

Stationary Neutron Sources s^{-1}		Flux [neutrons·cm^{-2}]	
Traditional Reactor		from 10^7 to 10^{13}	
High Flux Research Reactor		up to 10^{15}	
Accelerator Driven Spallation		up to 10^{14}	
Compact and Portable Neutron Sources		Typical Source Strength [neutrons · s^{-1}]	
Radioactive Neutron Sources		10^5 to 10^7	
Spontaneous Fission Sources		around 10^{10}	
Portable Neutron Generators		10^8 to 10^{10}	
Lasers on Solid Targets	Reaction(s) Used	Measured Source Strength [neutrons/shot]	Laser Energy [J/shot]
Lancaster [30]	$^7Li(p,n)^7Be$	$2 \cdot 10^8 sr^{-1}$	69
Yang [29]	natZn(p,xn)Ga	$\approx 10^{10}$	230
Yang [29]	$^7Li(p,n)^7Be$	$5 \cdot 10^{10}$	230
Zagar [28]	natPb(p,xn)Bi	$2 \cdot 10^9$	400

Eur. Phys. J. Special Topics 175, 147–152 (2009)

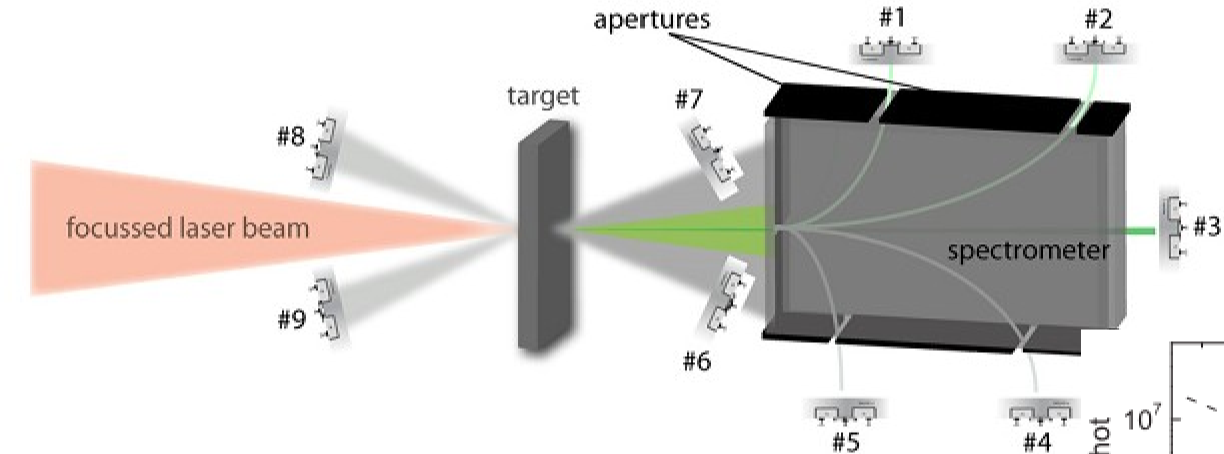


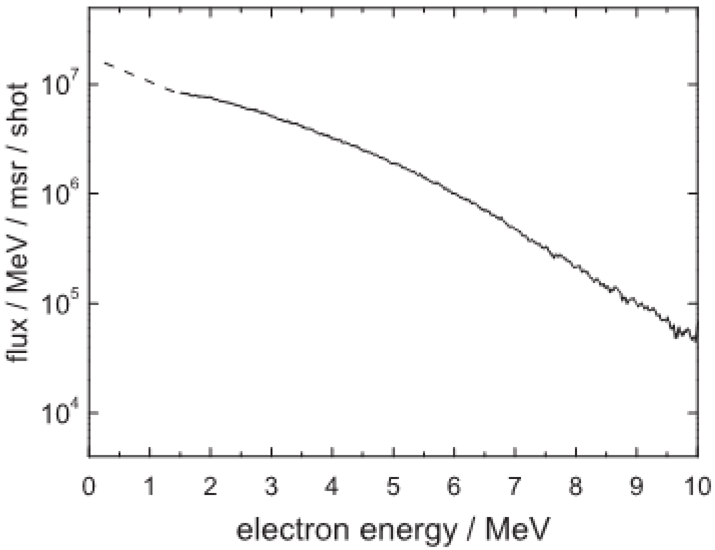
K W D Ledingham and W Galster. New J. Phys. 12 045005 (2010) presents a nice discussion on this topic.

LASER AS A ELECTRON SOURCE

B. Hidding et al. Nuclear Instruments and Methods in Physics Research A 636 (2011) 31–40

For testing electronics/diagnostics





Also positrons and gamma rays

CONCLUSIONS

The Laser Fusion Community needs Ultraintense laser systems

ANYONE INTERESTED IN COLLABORATING WITH US?

THANKS FOR YOUR ATTENTION