Update on Laser Fusion Energy and Activities at the University of Alberta

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Presented at CNS Annual Congress,

Virtual Meeting, June 5, 2022

UNIVERSITY OF ALBERTA

Outline

- Laser Fusion
- World progress in Laser Fusion
- New International Initiatives
- UofA Facilities and Programs
- Future opportunities – Spinoff Technologies
- Next Steps

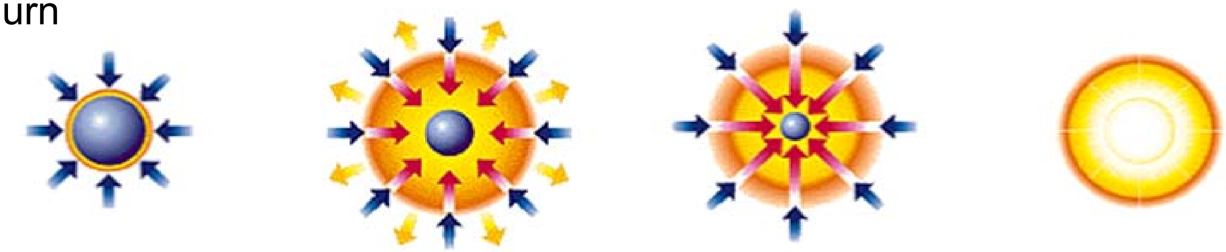
Laser Fusion

Approaches to Inertial Fusion

Two compression pathways – direct & indirect drive

Direct Drive – laser compresses and heats fuel pellet directly

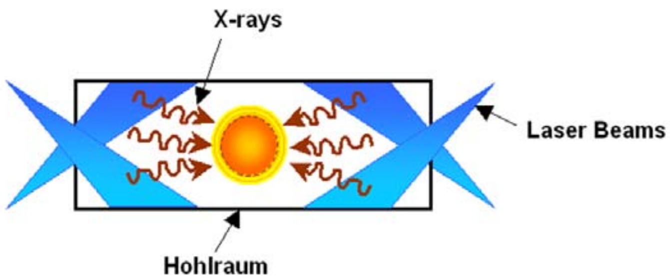
Laser irradiation Ablation/compression Ignition
Burn



Neutrons and Helium deposit heat energy

Generate Electricity

Indirect Drive – laser irradiated hohlraum
– laser energy converted to x-rays
which then compress & heat target

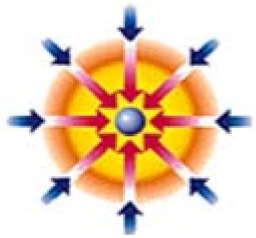


Instabilities limit energy delivery and compression

Approaches to Ignition

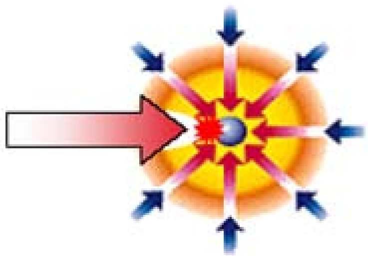
Three ignition pathways – central hot spot, Fast Ignition (FI) and Shock Ignition (SI)

Central Hot Spot– laser compression directly causes central point ignition (similar to a diesel engine)



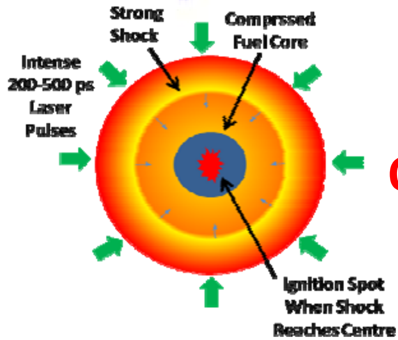
Predicted
Q ~ 50-100

Fast Ignition – 40ps 20kJ burst of electrons or protons generated by an ultraintense laser pulse ignites the target (similar to a spark plug)



Predicted
Q ~ 100-200

Shock Ignition – Intense laser spike at end of laser pulse launches a very strong shock inwards to ignite



Predicted
Q ~ 100-200

World Progress

National Ignition Facility (NIF)
at Lawrence Livermore National Laboratory, USA

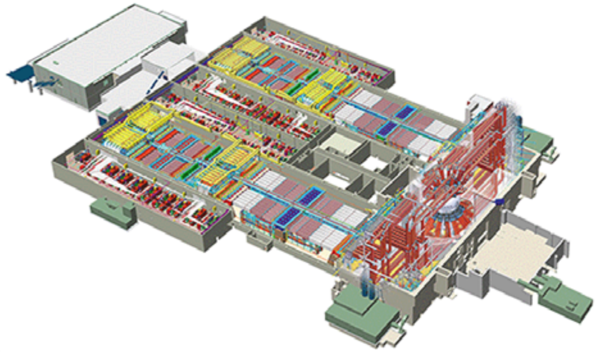
Indirect Drive (192 beamlines)

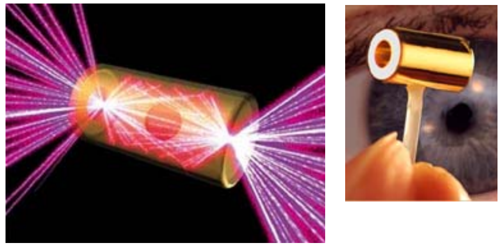
Best Result to date Q = 0.68 - 1.3 MJ output for 1.9 MJ laser heater pulse!

Aug. 17, 2021

On Aug. 8, 2021, an experiment at the National Ignition Facility put researchers at the threshold of fusion ignition, achieving a yield of more than 1.3 megajoules — an 8X improvement over experiments conducted in spring 2021 and a 25X increase over NIF's 2018 record yield. Credit: John Jett, LLNL.

https://lasers.llnl.gov/about/what-is-nif





Indirect Drive Converting Laser Light into X-ray Radiation First

Omega Laser Facility

University of Rochester, USA

Direct Drive (60 beamlines, 40 kJ)

Best Result to date would scale to Q = 0.26 - 500 kJ output for 1.9 MJ laser pulse)

31 JANUARY 2019 | VOL 565 | NATURE | 581

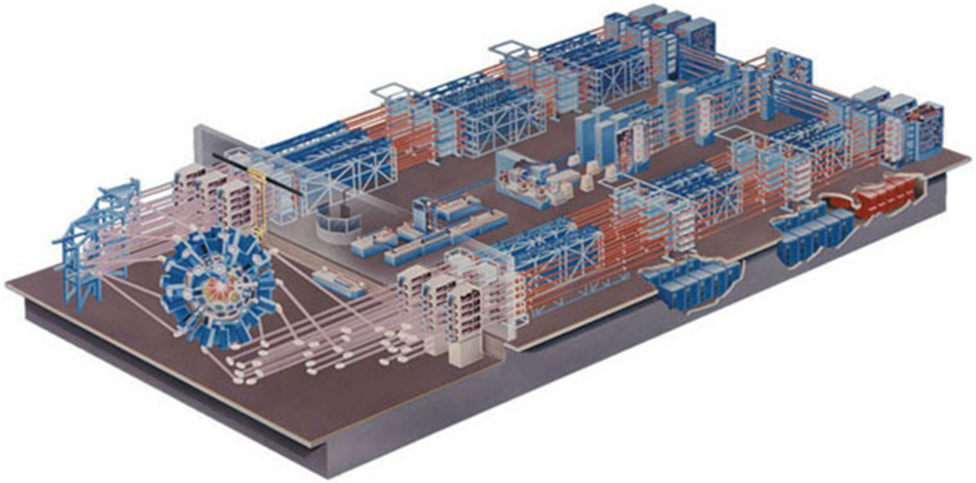
Tripled yield in direct -drive laser fusion through statistical modelling

V. Gopalaswamy[1,2*], R. Betti[1,2,3], J. P. Knauer[1], N. Luciani[1,2,4], D. Patel[1,2], K. M. Woo[1,3], A. Bose[1,5], I. V. Igumenshchev[1], E. M. Campbell[1], K. S. Anderson[1], K. A. Bauer[1], M. J. Bonino[1], D. Cao[1], A. R. Christopherson[1,2], G. W. Collins[1], T. J. B. Collins[1],

When scaled to the laser energies of the National Ignition Facility (1.9 megajoules), these targets are predicted to produce a fusion energy output of about 500 kilojoules.

Currently limited by Laser Plasma instabilities which can be mitigated with less coherent larger bandwidth lasers

http://www.lle.rochester.edu/omega_facility/omega/index.php



Institute of Laser Engineering (ILE)

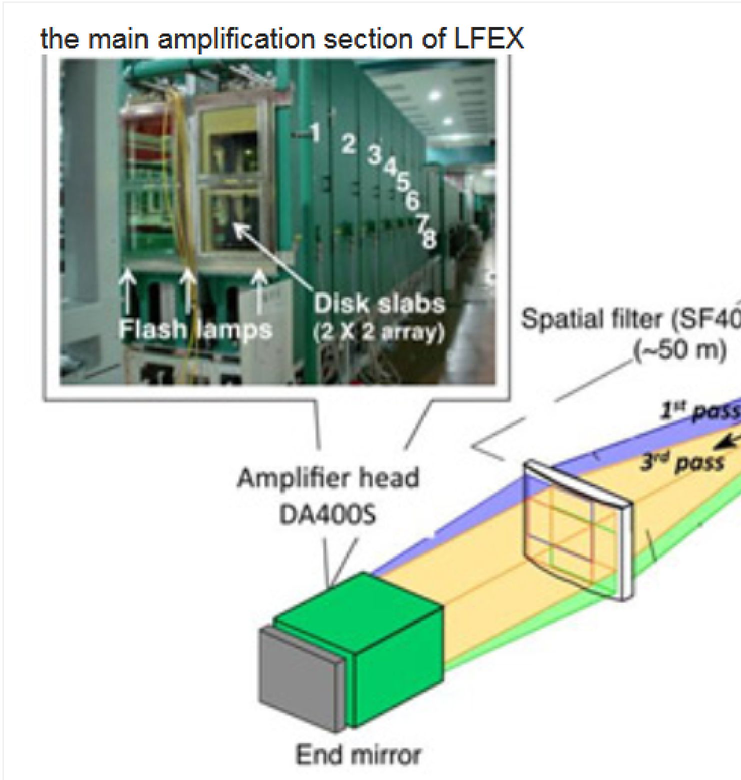
University of Osaka, Japan

GEKKO-12 (12 beam, 12 kJ) and PW (10kJ in 1-10ps) LFEX

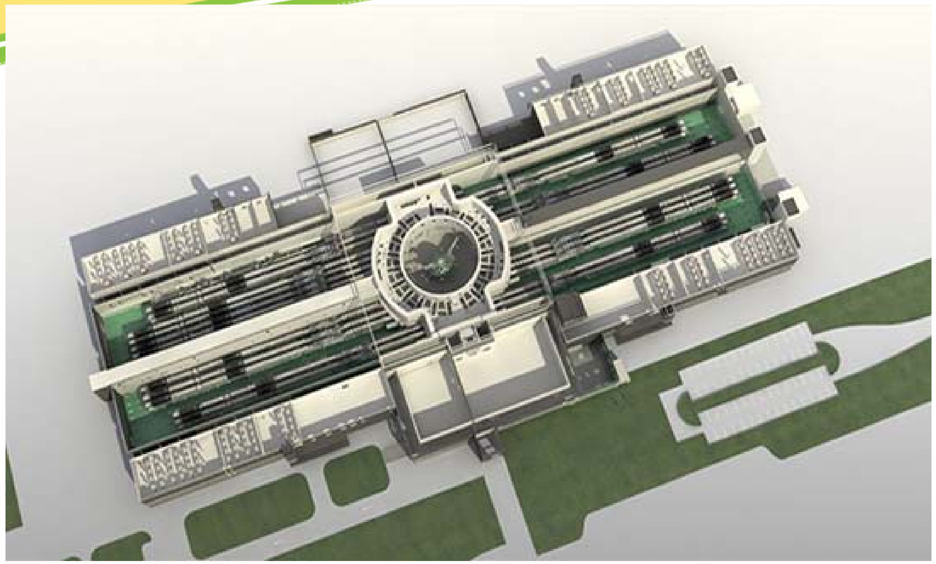
Demonstration of Fast Ignition heating of core to 2 keV

GEKKO-12 Laser (1983)

LFEX PW laser



LMJ France



172 Beamlines 1.8MJ
about 20% operational

http://www-lmj.cea.fr/en/lmj/index.htm

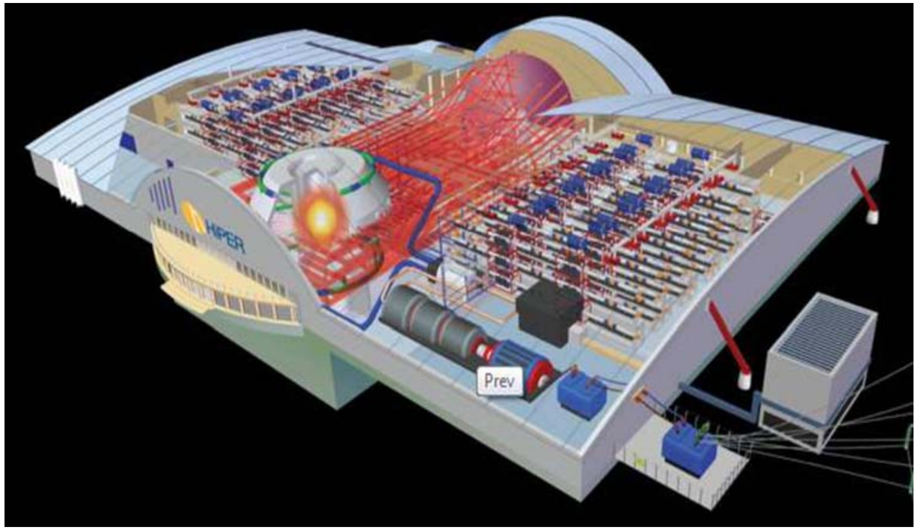
HIPER- II

European Union Revived Proposal for Laser Fusion Program

Direct Drive Shock Ignition

Simulation predictions of Q = 100-200 for 1-2 MJ laser pulses

Previous Hiper Direct Drive Laser Fusion Proposal



New Proposal Starting in EU

BREAKTHROUGH AT THE NIF PAVES THE WAY TO INERTIAL FUSION ENERGY

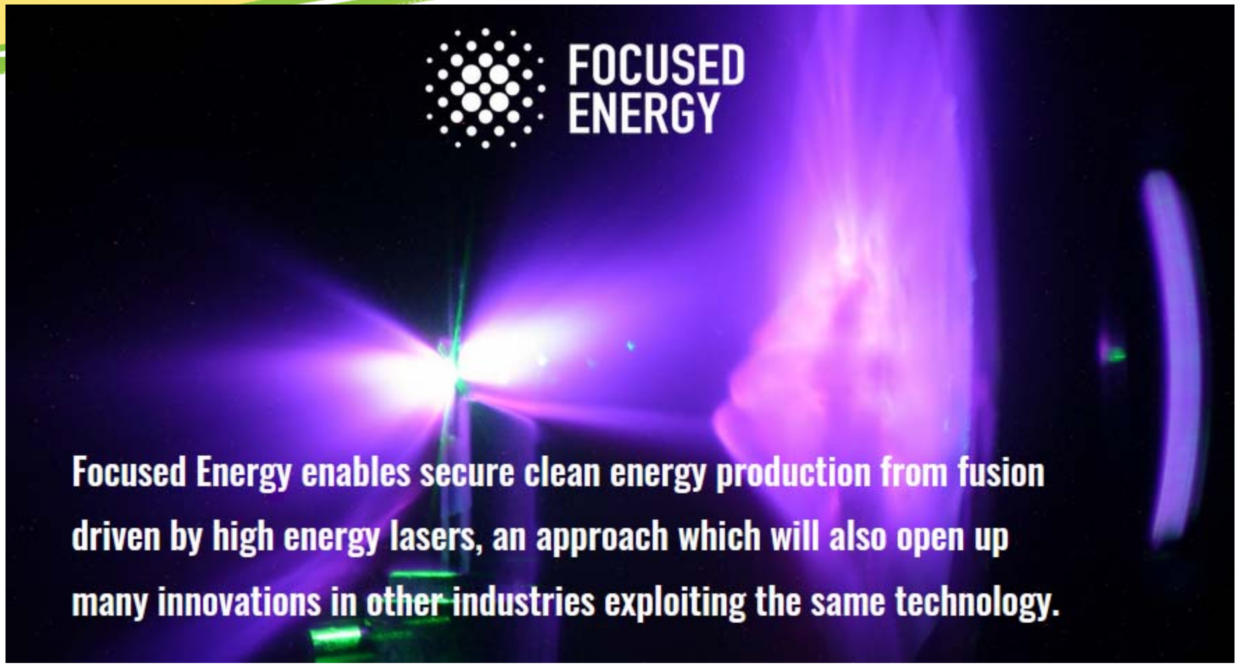
S. Atzeni[1], D. Batani[2], C. N. Danson[3,4], L. A. Gizzi[5], S. Le Pape[6], J-L. Miquel[7], M. Perlado[8], R.H.H. Scott[9], M. Tatarakis[10,11], V. Tikhonchuk[2,12], and L. Volpe[13,14] – DOI: https://doi.org/10.1051/epn/2022106

A similar facility but based on the latest laser technology, possibly with a higher repetition rate, is needed by the scientific community to establish a science and technology IFE programme in Europe. High energy density science and direct-drive laser fusion could be studied

Europhysics News 53/1, 2022, p. 18-23

New Private Start Up Companies

Focused Energy Texas & Germany



Pursuing Direct Drive Proton Fast Ignition Approach to Laser Fusion

OUR FOCUS

Develop Fusion Power

A power plant based on cutting edge breakthroughs in laser and target technology

GW Range Power Plants

Build and operate commercially viable fusion power plants at scale

Laser Driven Radiation Sources

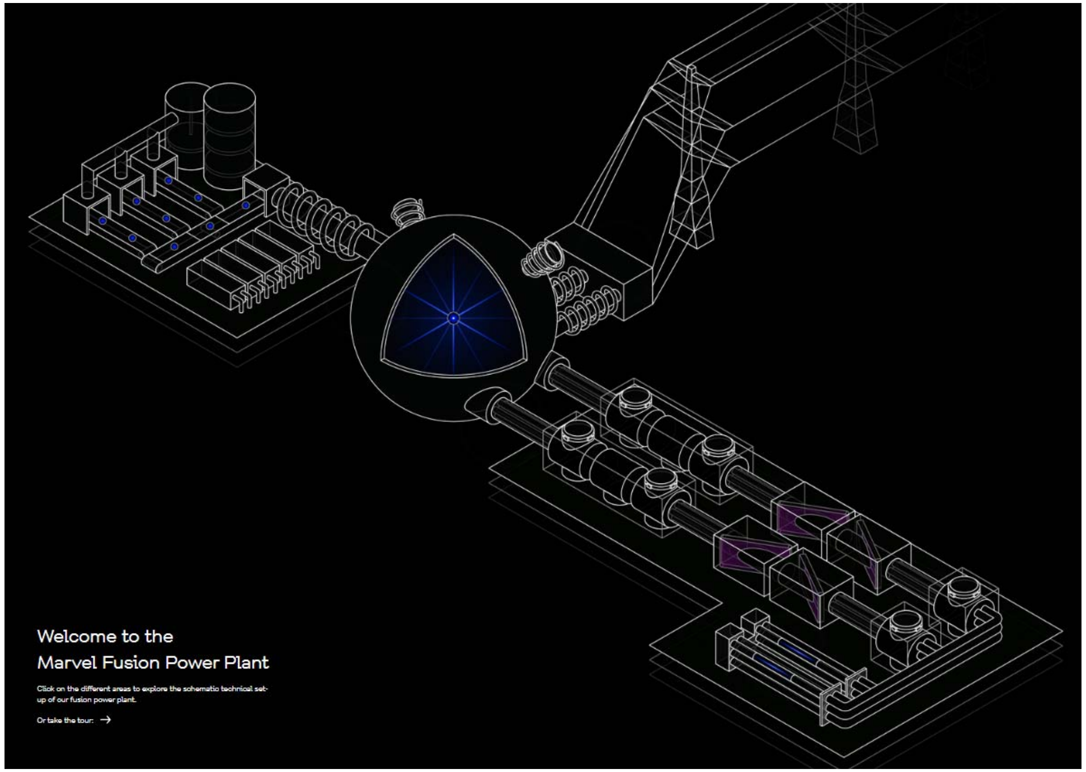
Develop and commercialize a new level of non-destructive high resolution testing of large and complex objects

https://focused-energy.world/

Marvel Fusion Munich

Munich-based Marvel Fusion gets €35 million to accelerate roll-out of ‘Made In Europe’ clean energy

By **Patricia Allen** - February 3, 2022 EU-Startups



Pursuing Quantum Enhanced Proton Fast Ignition Approach to Laser Fusion

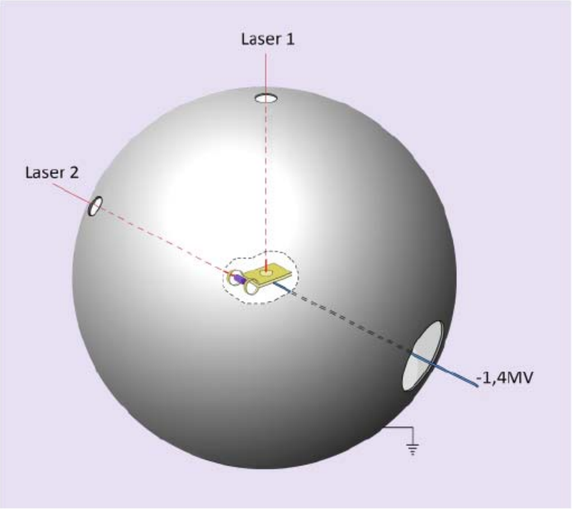
https://marvelfusion.com/

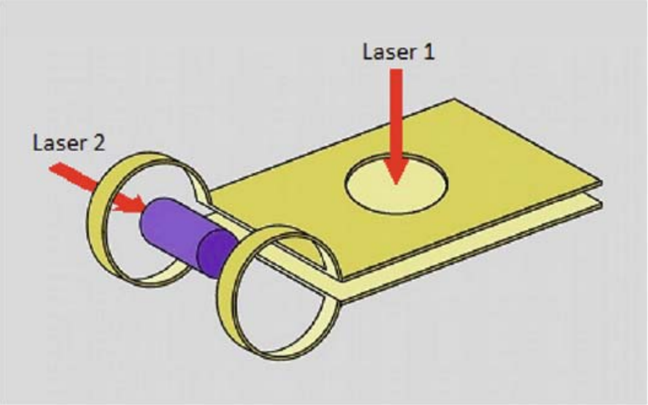
HB11 Energy Australia

https://www.hb11.energy/

Proton Boron-11 Fusion – 3 alpha particles and no neutrons

Laser 1 creates a 10 kG magnetic field for enhanced confinement, Laser 2 creates an ultra-intense shock heating the fuel, Energy is extracted directly by decelerating the Multi-MeV alpha particles





Research at the University of Alberta

Electrical and Computer Engineering Research Facility

Fusion Related Researchers at UofA

Y. Y. Tsui, J. Myatt, A. Hussein, M. Gupta and R. Fedosejevs

Department of Electrical and Computer Engineering

W. Rozmus, R. Sydora and R. Marchand

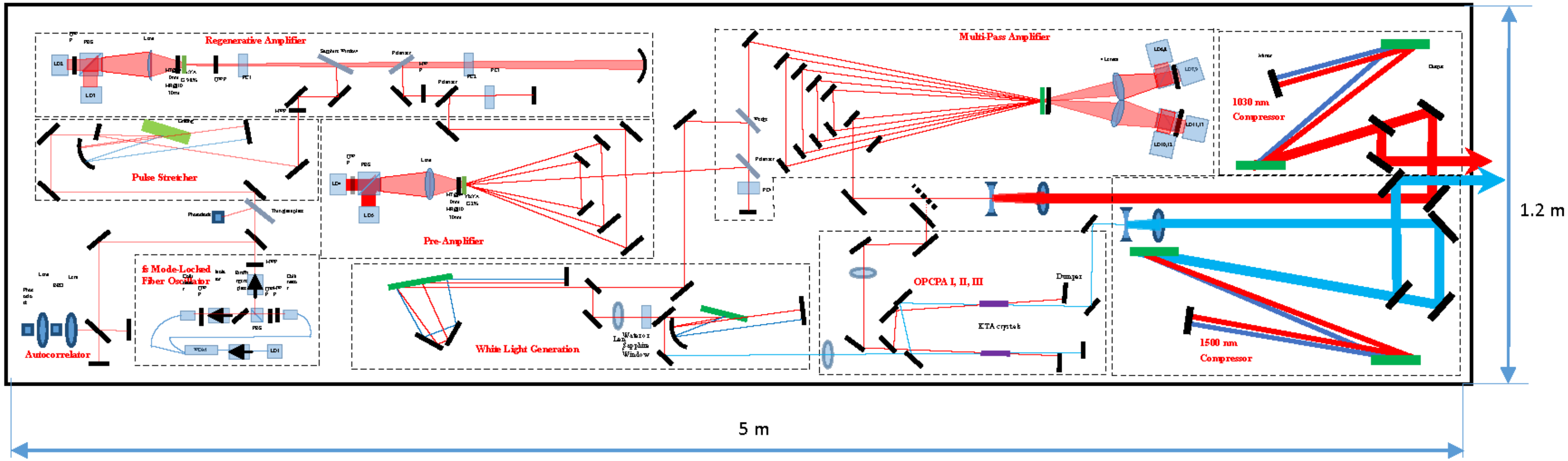
Department of Physics

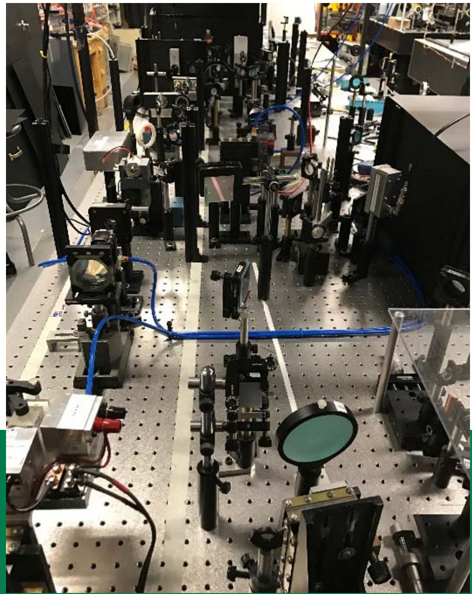
J. Bowman

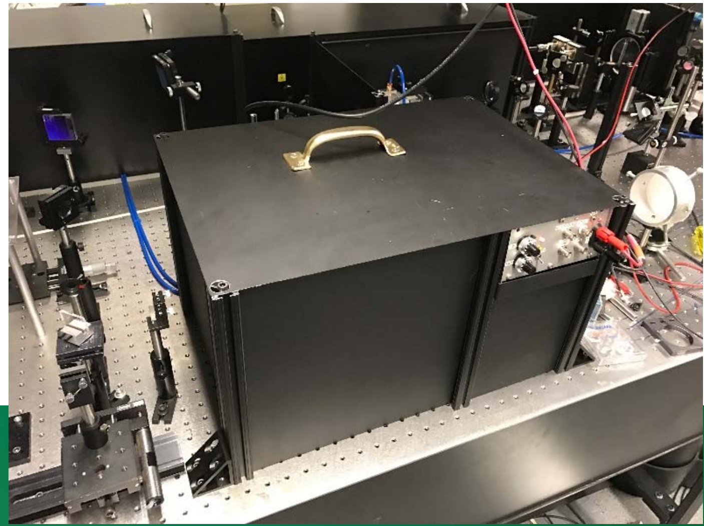
Department of Mathematics

University of Alberta Terawatt Laser System – UATLS-1

1TW (1J, 1ps) Efficient diode-pumped Yb:YAG system







University of Alberta 15 Terawatt Laser System – UATLS-15

15 TW (0.6J, 40 fs) Ti:Sapphire laser system

Electric and Thermal Conductivity of WDM Solids

Electrical Conductivity in WDM gold

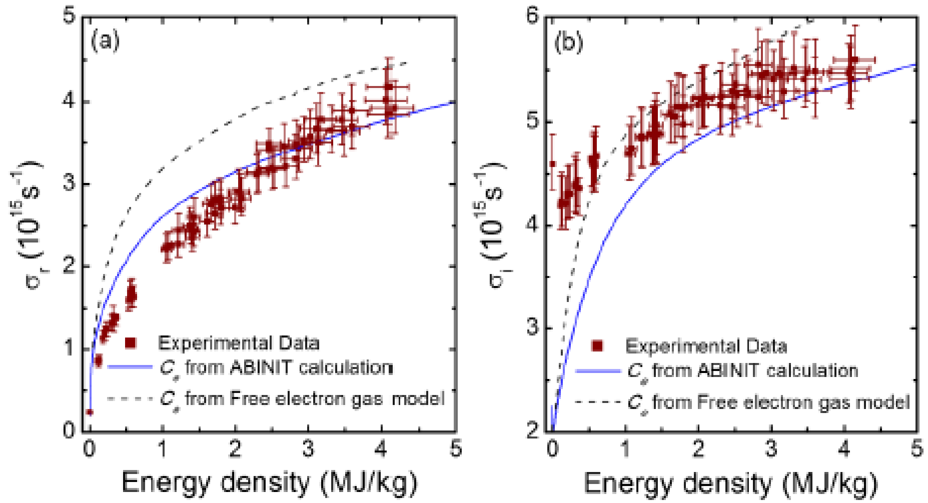


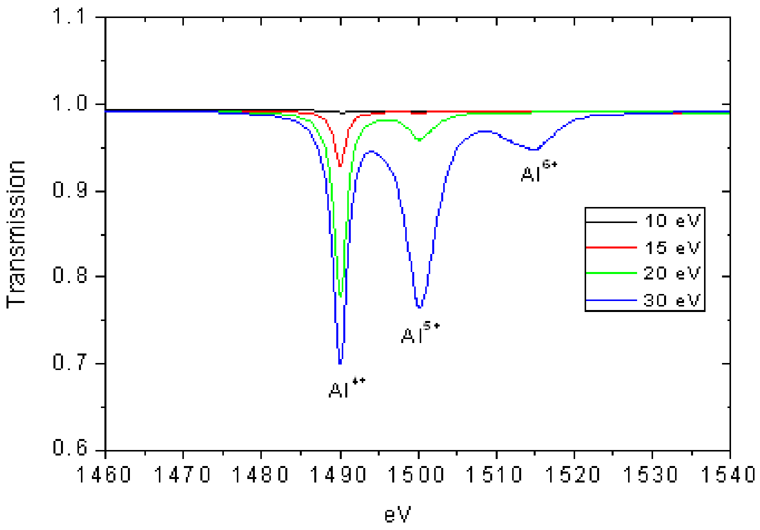
FIG. 4 (color online). (a) Real and (b) imaginary parts of initial ac conductivity as a function of excitation energy density.

Z. Chen et al., "Evolution of ac Conductivity in Nonequilibrium Warm Dense Gold", Physical Review Letters 110, 135001 (2013)

Measurement of Ionization State of High Density plasmas (Warm Dense Matter)

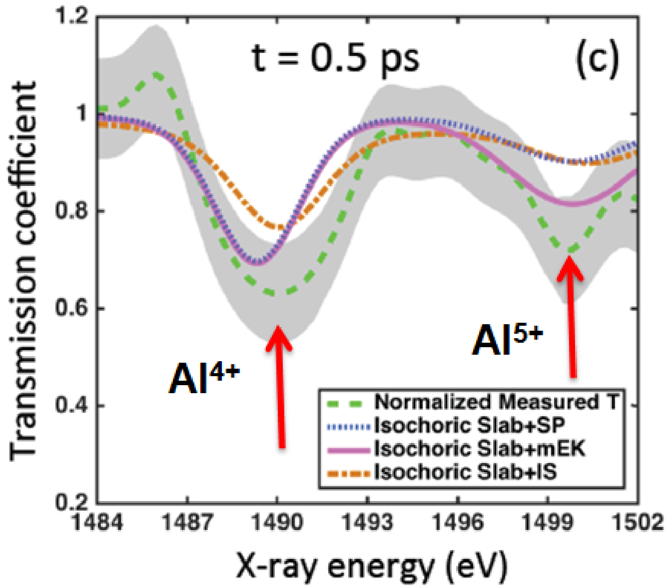
Femtosecond time resolution soft x-ray absorption measurements

Theory



Simulated K-shell absorption lines versus different temperatures for 50-nm-thick Aluminum at solid density. (Calculated using PrismSpect Software)

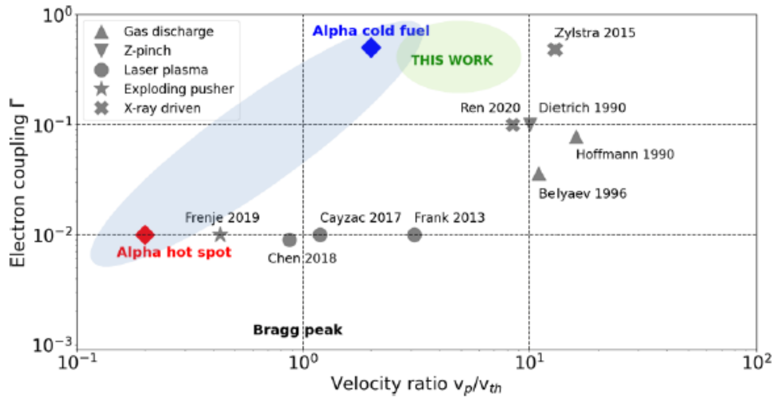
First Experiment



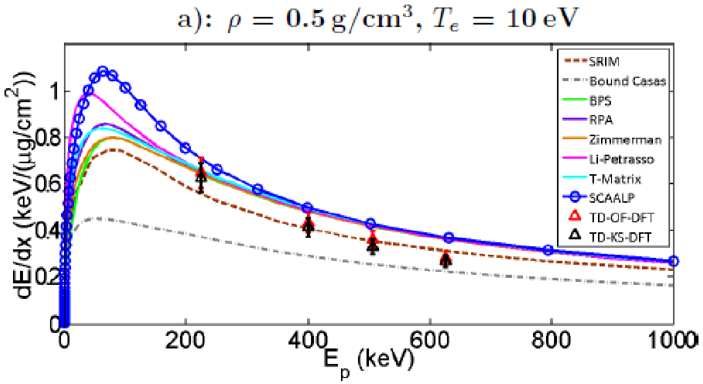
M. Mo et al., "Measurements of ionization states in warm dense aluminum with betatron radiation", Physical Review E 95, 053208 (2017)

Stopping Range of MeV Particles in WDM (similar to laser generated fusion core)

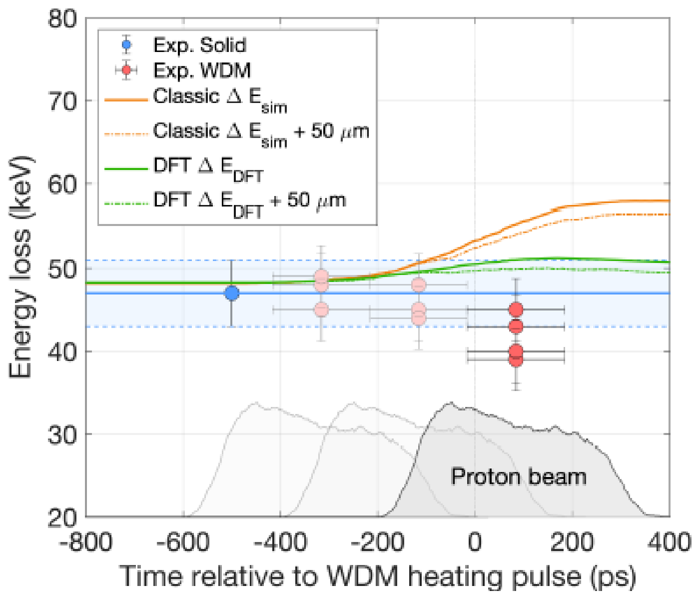
Relevant to alpha heating of fusion core



Various theories predict different stopping power



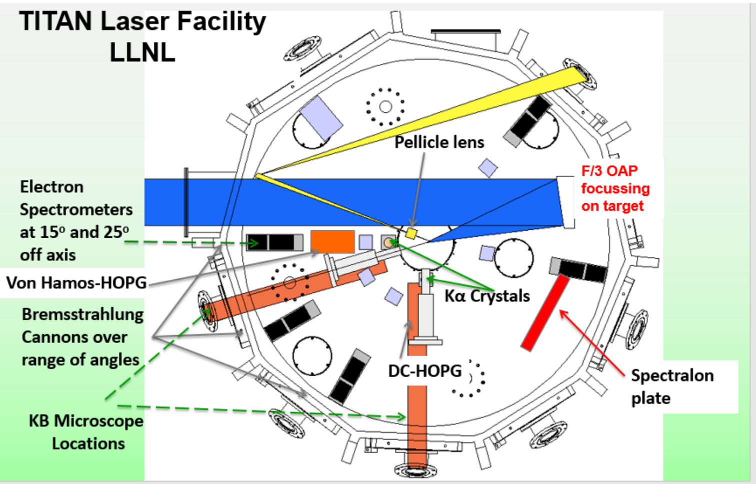
Experiment Agrees best with latest Quantum calculations (DFT) of stopping power



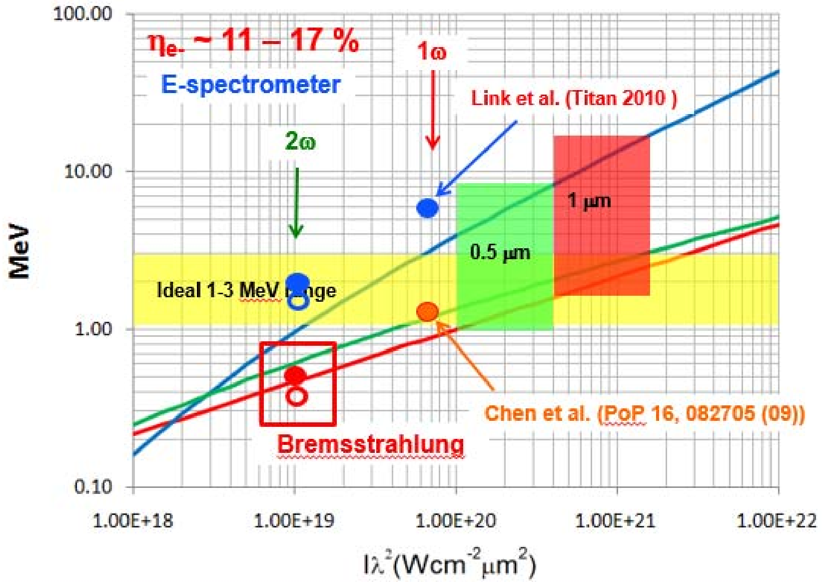
S. Malko et al., "Proton stopping measurements at low velocity in warm dense carbon", Nature Communications 13, 2893 (2022)

MeV Electron Generation for Fast Ignition Using Second Harmonic Laser Pulses

Some of first experiments demonstrating high efficiency MeV electron generation for Fast Ignition using clean second harmonic laser pulses



Almost ideal scaling of electron energy and generation efficiency for Fast Ignition using second harmonic pulses



Remaining issue is large divergence of electrons – need magnetic guide fields which are under development

R. Fedosejevs et al., Characterization of MeV Electron Generation Using 527 nm Laser Pulses for Fast Ignition, 39th International Conference on Plasma Science, Edinburgh, July 8-12, 2012.

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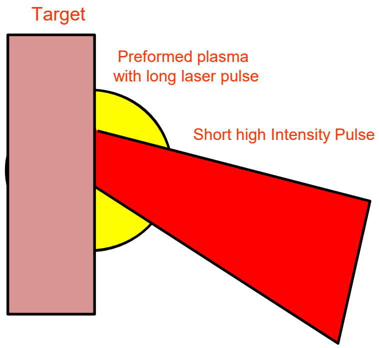
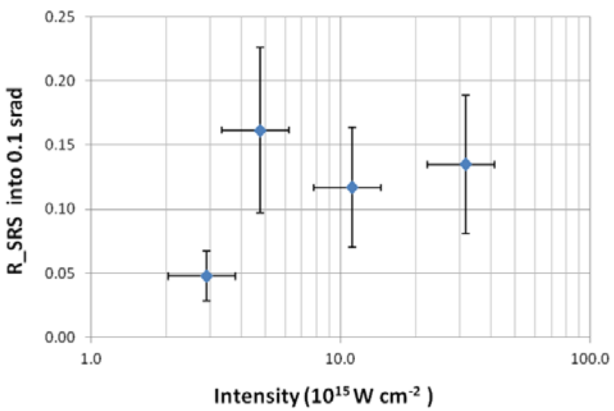
Laser Plasma Interactions in Long Scale Length Plasmas for Shock Ignition

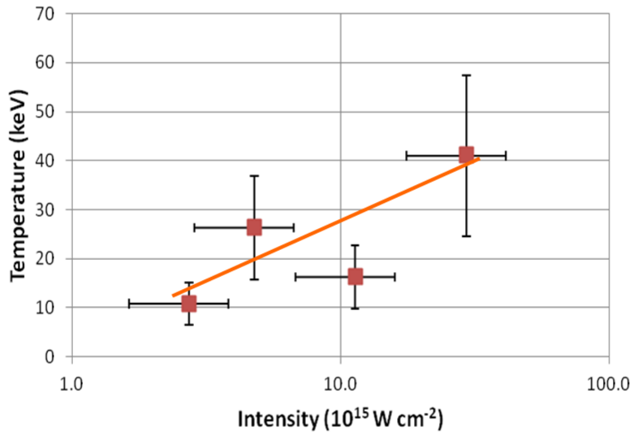
Study the Raman backscatter of light and hot electron generation from 1.06 um laser pulses in hot preformed plasmas (conditions for Shock Ignition)



Experiments at the Titan Laser facility at LLNL

Up to 15% backscatter and up to 40 keV hot electrons



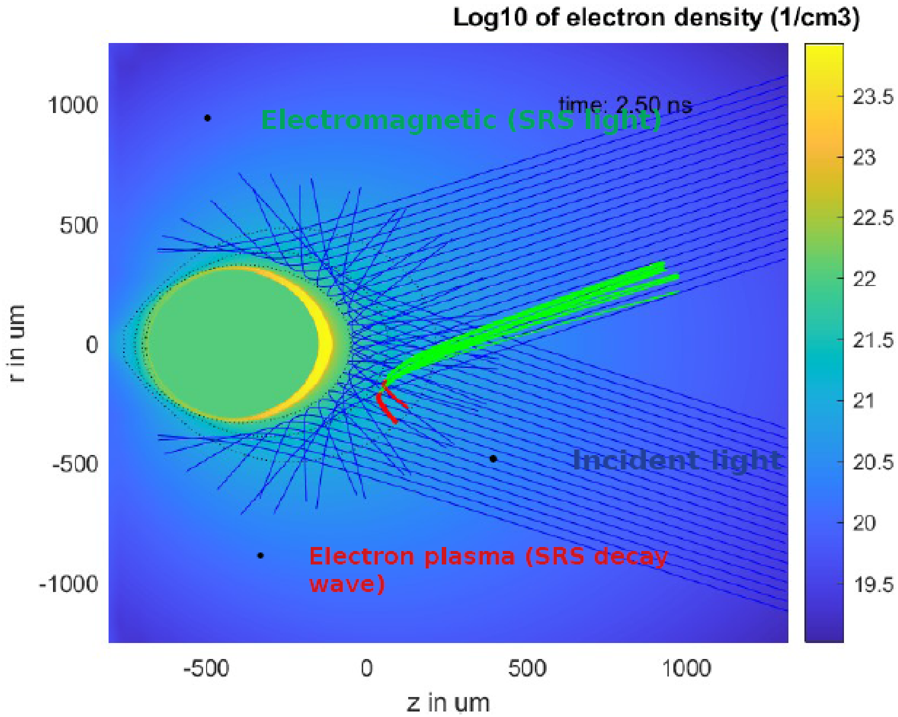


R. Fedosejevs et al., Backscatter Instabilities and Electron Heating in Long Scale Length Shock Ignition Plasma Conditions, the 8th International Conference on Inertial Science and Applications, Nara, September 8-13, 2013

Laser Plasma Interactions Studies

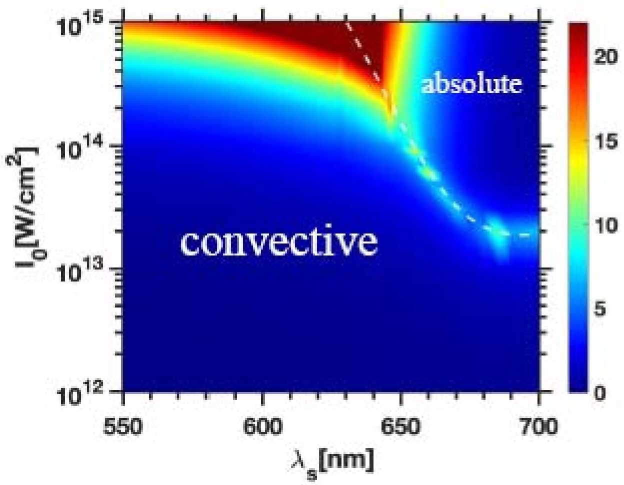
Study the Raman backscatter and sidescatter of light in fusion scale plasmas

Jason Myatt's group



. S. Hironaka et. al., First identification of stimulated Raman side scattering on OMEGA EP, Canadian Association of Physicists Annual congress, June 8, 2021, virtual. 2021

Log_n(gain) for Raman sidescatter at different scattered wavelengths for 353 nm input light

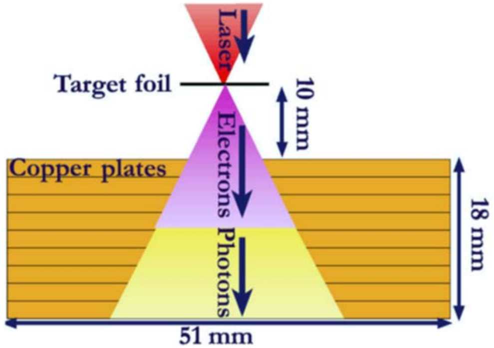


Q. Wang et al., 2D PIC Simulations of the competition between forward and backward stimulated Raman side-scattering in direct-drive ignition-scale plasmas, 62nd Annual Meeting of the American Physical Society Division of Plasma Physics Pittsburgh, Pennsylvania, November 8-12, 2021

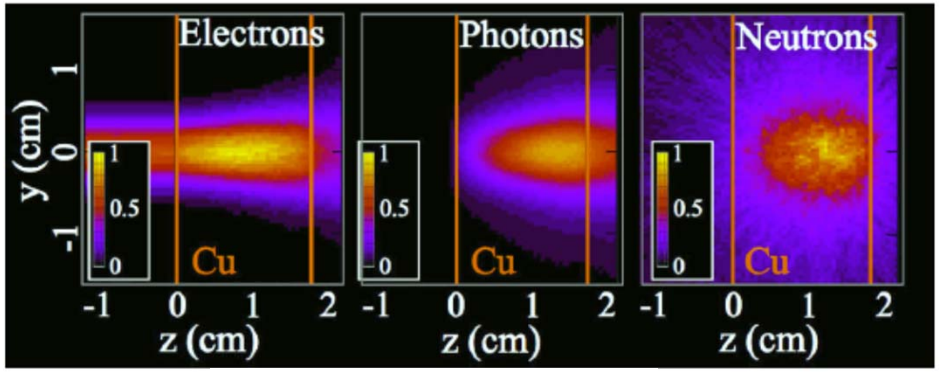
Applications of Neutrons and Particle Beams

MeV Neutron Generation

I. Pomerantz et al., “Ultrashort Pulsed Neutron Source”, Phys. Rev. Lett. 113, 184801 (2014)

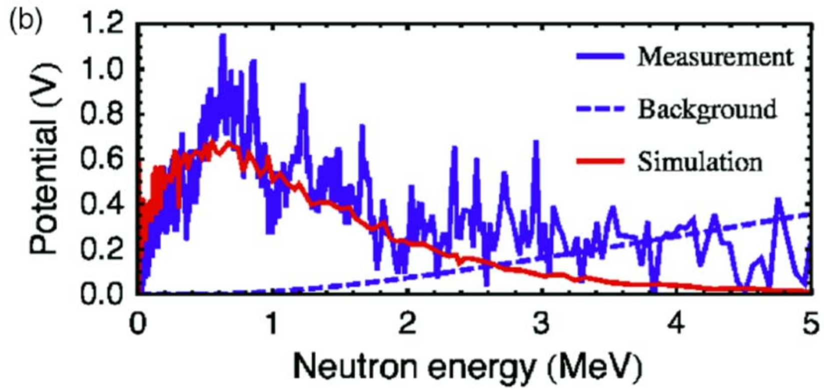


Texas Petawatt laser: 90J in 150fs
10 μm spot: ~ 5 x 10^{20} W cm^{-2}



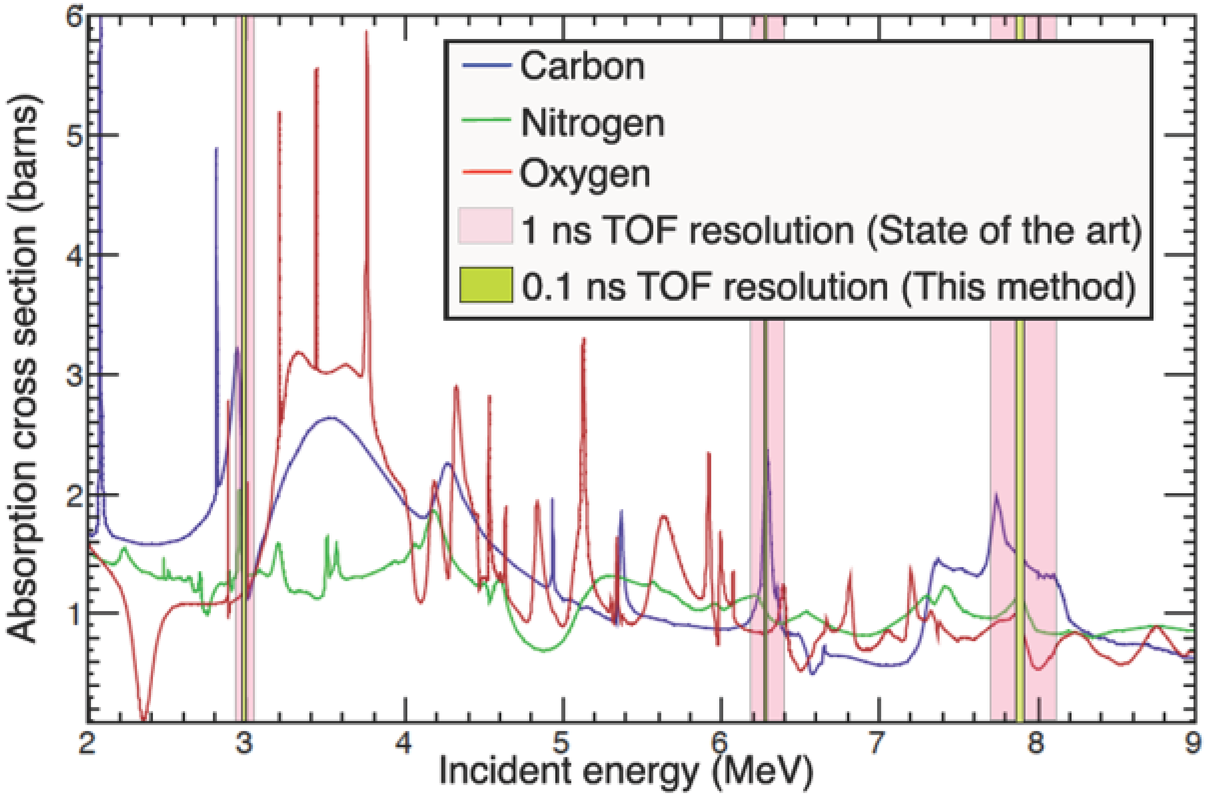
simulations

2 x 10^9 neutrons per shot in 50ps
^{65}C(γ,n)^{64}Cu and ^{63}Cu(γ,n)^{62}Cu reactions



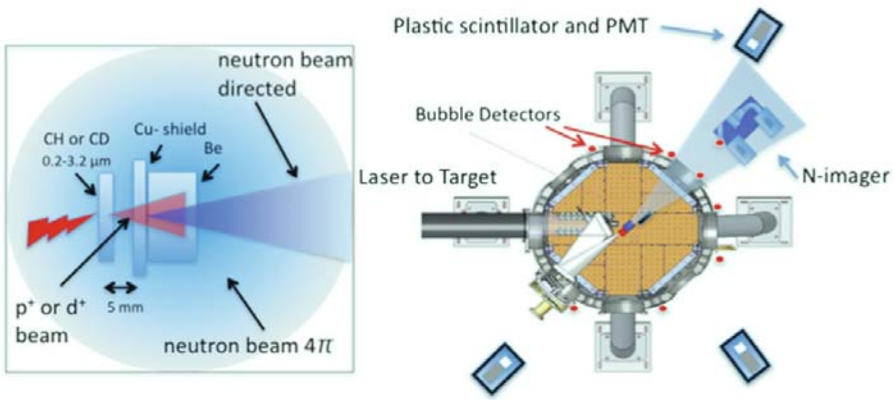
Neutrons

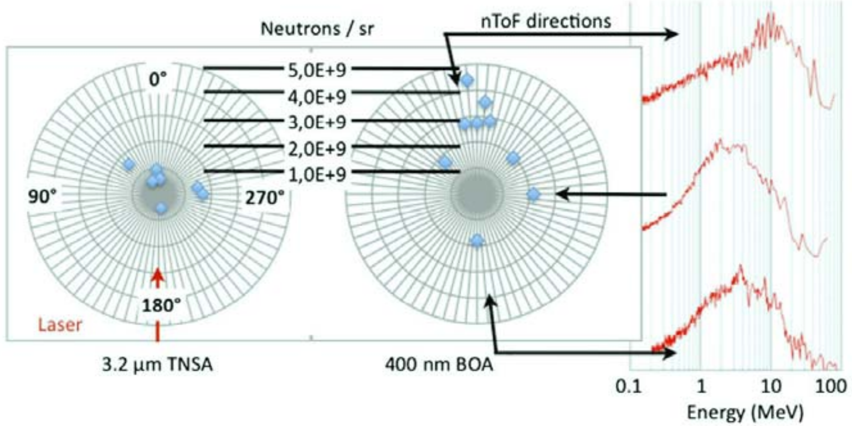
Prospects:
Fast Neutron Radiography
(from I. Pomerantz, PRL 113, 184801 (2014))



MeV Neutron Generation and Inspection Applications

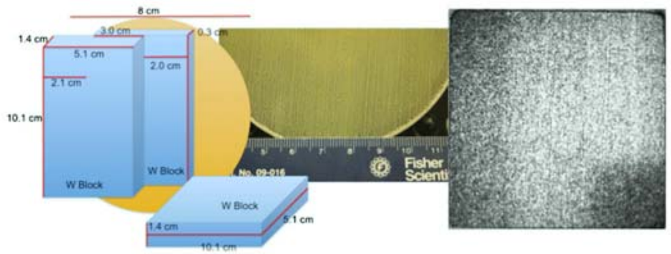
M. Roth et al., “Bright Laser-Driven Neutron Source …”, Phys. Rev. Lett. 110, 044802 (2013)





LANL Trident laser: 80J in 600fs
10^{20} - 10^{21} W cm^{-2}

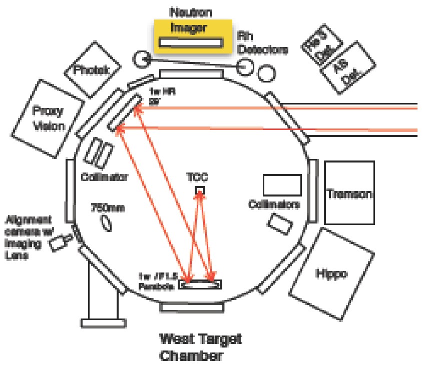
5 x 10^9 neutrons per shot in few hundred ps
via the nuclear reactions ^{9}Be(p,n), ^{9}Be(d,n) and deuteron breakup

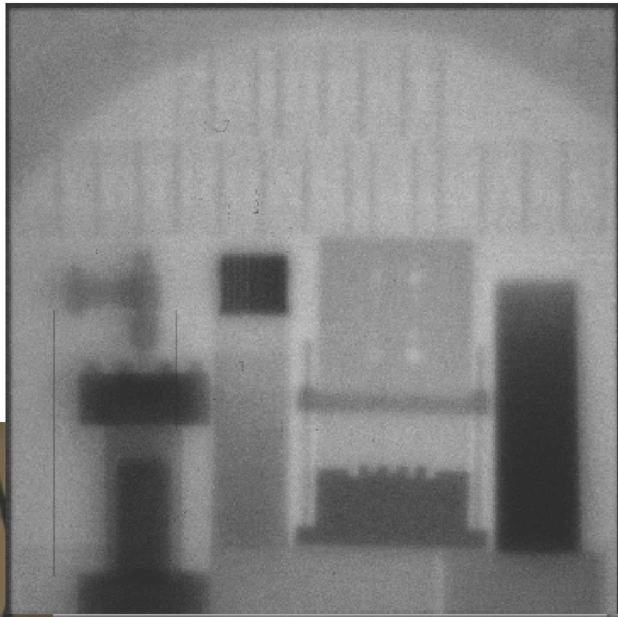


Application to neutron radiography of tungsten blocks

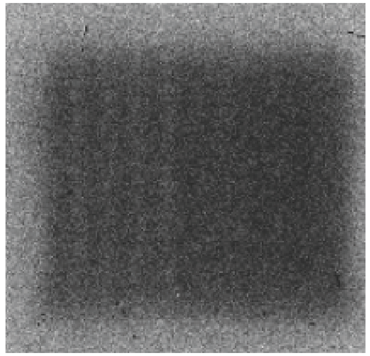
Fast neutron imaging

Technical University of Darmstadt Imaging Examples

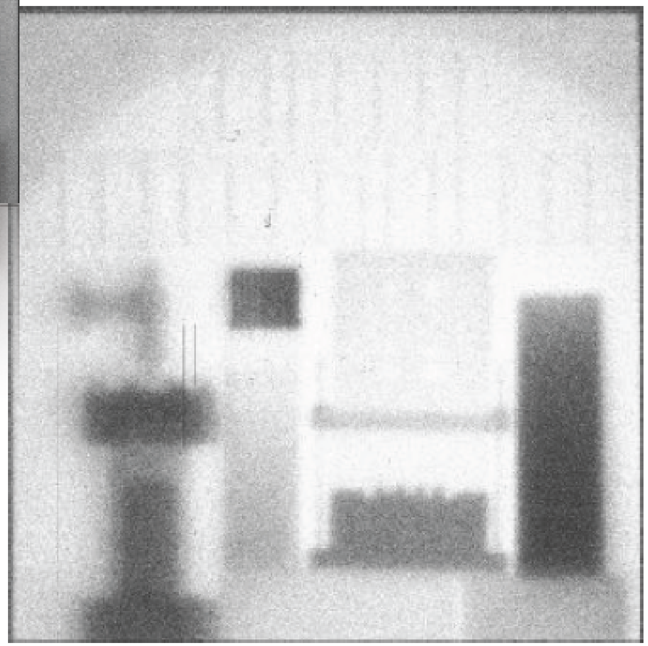




0.25cm W and Poly also 1mm visible



1 cm Poly
Cu doped Zn Selenide 30x30 cm @ 1.5 m from converter



Reactor Size Engineering Demo Project Proposals

LLNL LIFE Power Plant Design
Addresses Engineering Requirements for a Real Reactor)

Plant Primary Criteria (partial list)
Cost of electricity
Rate and cost of build
Licensing simplicity
Reliability, Availability, Maintainability, Inspectability (RAMI)
High capacity credit & capacity load factor
Predictable shutdown and quick restart
Protection of capital investment
Meet urban environmental and safety standards (minimize grid impact)
Public acceptability
Timely delivery

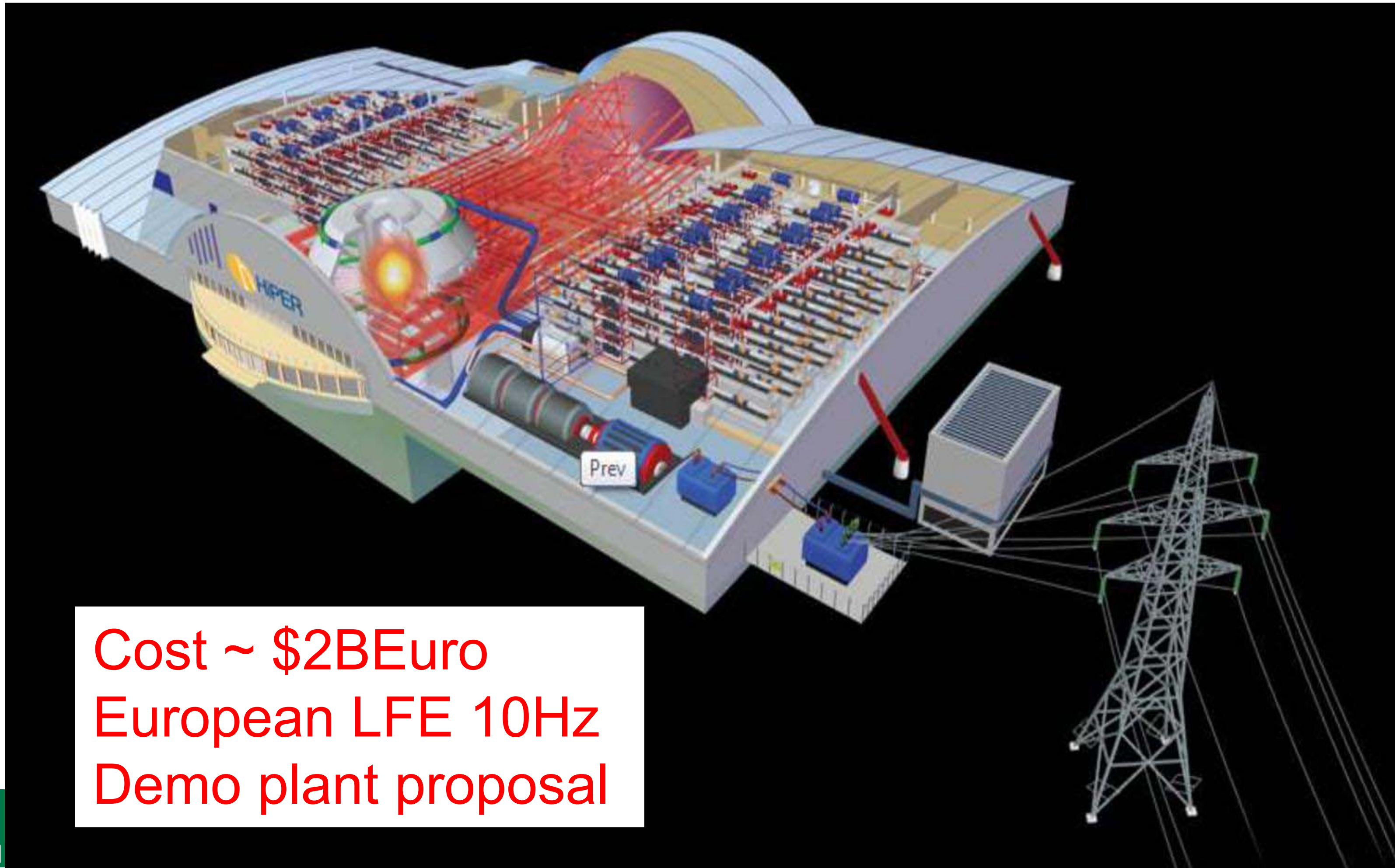
Use of commercially available materials and technologies

Focus on pure fusion, utility-scale, power-producing facility

LLNL : Initial engineering and planning already carried out

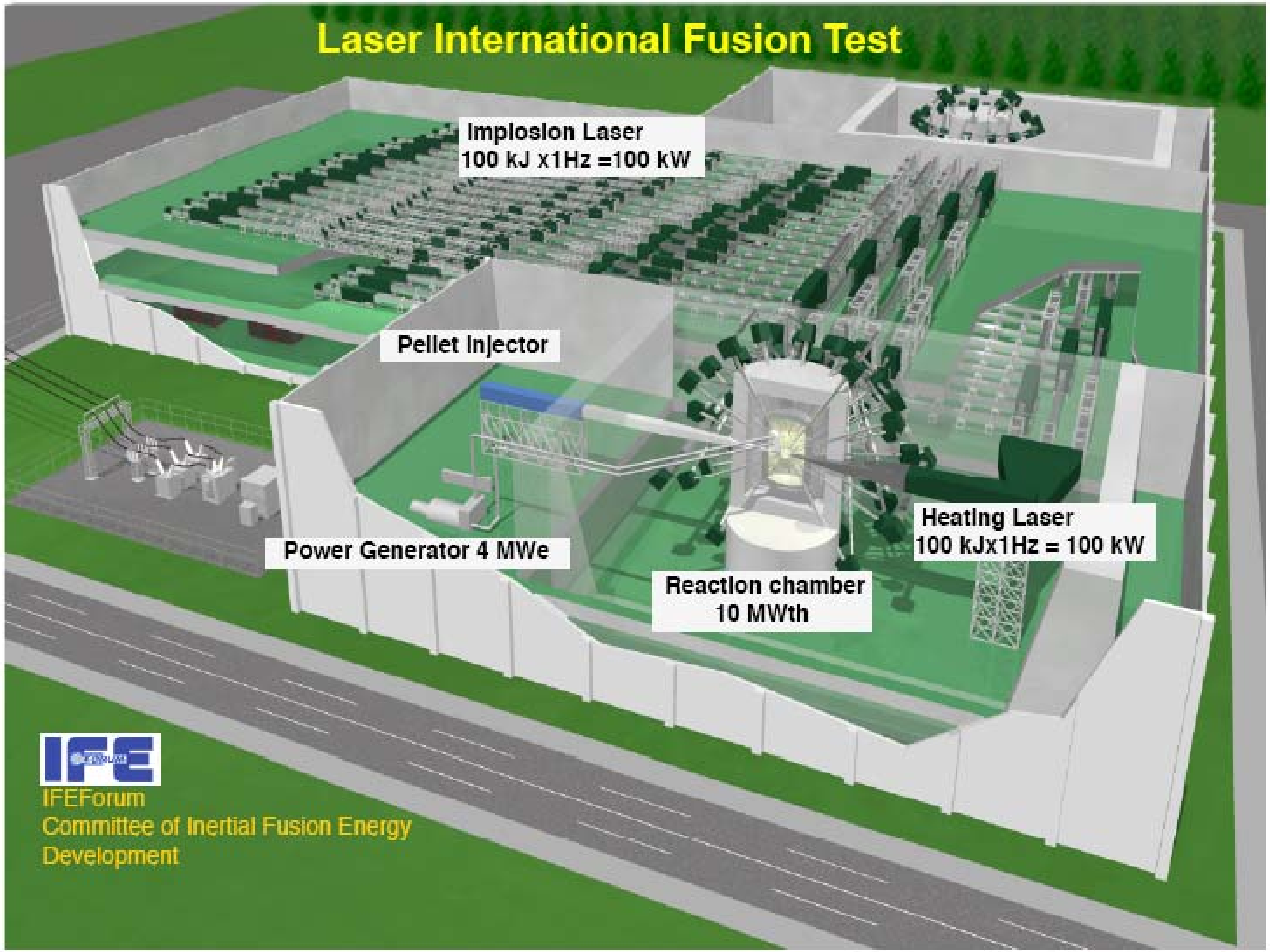
Revival of HiPER Proposal in European Union

HiPER



Cost ~ $2BEuro
European LFE 10Hz
Demo plant proposal

LIFT Demo Reactor Proposal - Japan



Conclusions

- Laser Fusion is close to break even – hopefully in the next year or two
- World activity is growing
- New International and Private Initiatives coming online
- UofA is a player in many aspects of Laser Fusion
- Currently most of our graduate students end up working in the programs In USA (3 at LLNL and 3 at SLAC at present)
- We need a strong Canadian Fusion program to be significant player in the future fusion energy sector

Thank You

The End