Overview of OFES LLNL Fusion Program

Fusion Power Associates
30th Anniversary Meeting and Symposium
Fusion Energy: Status and Prospects
December 2-3, 2009

Physical and Life SCIENCES

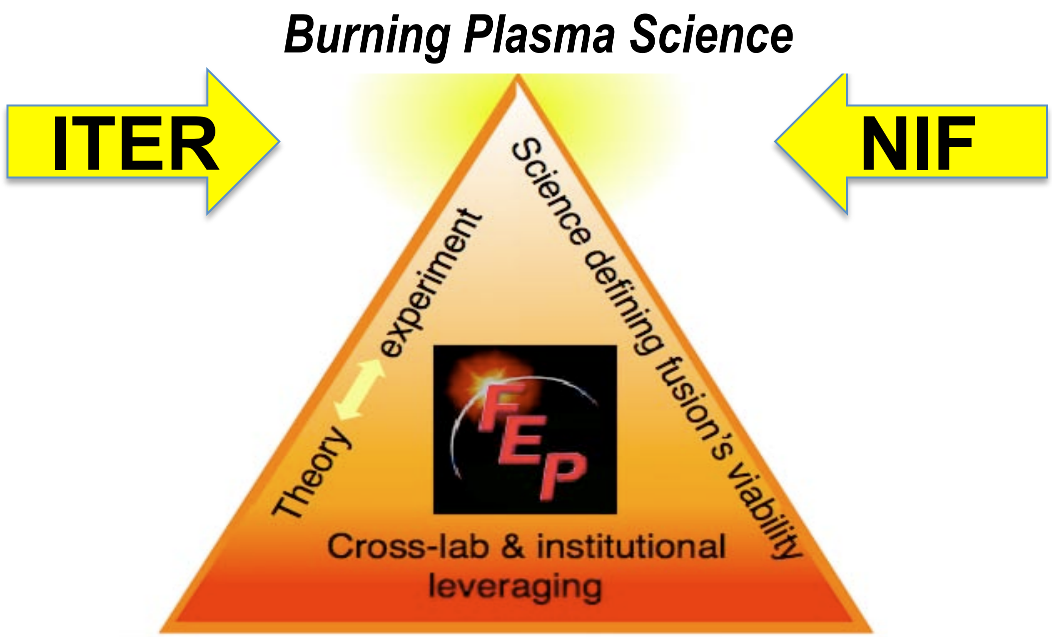
Don Correll

Fusion Energy Program Leader (acting)

Fusion Energy Program

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Security, LLC, Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344
LLNL-PRES-420586

LLNL's Fusion Energy Program is dedicated to advancing the science required for fusion's viability – MFE and HEDLP/IFE



FEP engages the OFES fusion community through multiple collaborations:

- DIIID
- NSTX
- Edge Simulation Laboratory
- Fusion Simulation Project
- SciDAC FACETS (Core-Edge Transport)
- SciDAC Center for the Study of Plasma Microturbulence
- Heavy Ion Fusion Sciences VNL
- FSC for Extreme States of Matter
- FI Advanced Concepts Exploration
- Virtual Lab for Technology

FEP reflects our OFES major deliverables, commitments to collaborative partnerships, and LLNL's fusion energy vision

FEP FY10 Funding

~ 12.5M$ OFES
~ 0.8M$ DIIID ARRA
~ 0.6M$ NDCXII ARRA
~ 0.3M$ U.S ITER Project
~ 0.2M$ NSTX Spectrometer ARRA

Don Correll
FEP Leader
(acting)

Wayne Meier
FEP DPL

Dave Hill
DIIID
Deputy Director

John Barnard
HIFS-VNL
Deputy Director

Harry McLean
ACE FI
LLNL Leader

DIIID and NSTX
Steve Allen

HEDLP/HIFS-VNL
Alex Friedman

HEDLP/Fast Ignition
Prav Patel

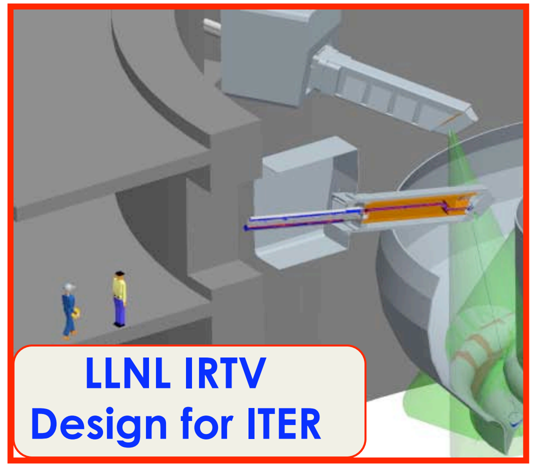
Theory/Modeling
Bruce Cohen

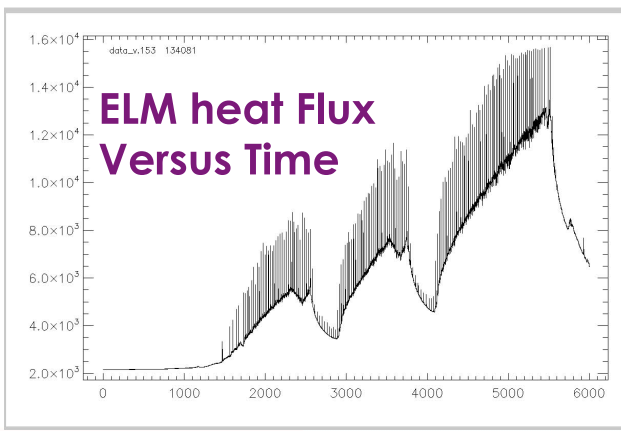
Technology/Materials
Wayne Meier

LLNL FEP – GA DIIID collaboration has been an effective science partnership since 1986; recent accomplishments . . .

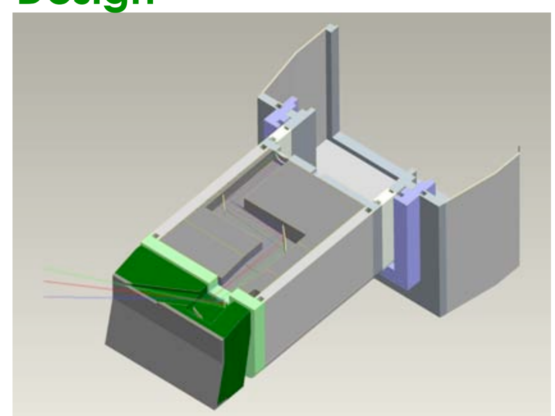
DIII-D and NSTX
Steve Allen

- **$800K ARRA funding for IR & Visible periscopes for DIIID**
  - ITER prototype
  - Previous U.S. ITER contracts
  - 3 fast IRTV systems
- **Motional Stark Effect**
  - 64 channel, fast DIIID system
  - ITER optical design
- **Comparison of Edge Plasma and Divertor models with new data**
  - Edge flow (with Australia University)
  - Heat flux





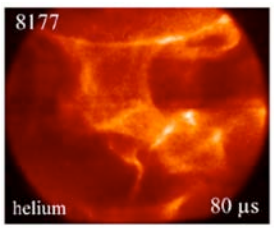
LLNL ITER MSE Optical Design

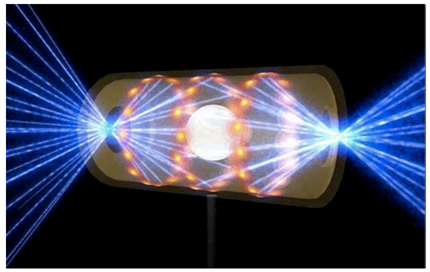


FEP theory and modeling continues to advance plasma understanding in MFE and HEDLP/IFE (>100 pubs 2006 - 2009)

Theory/Modeling
Bruce Cohen

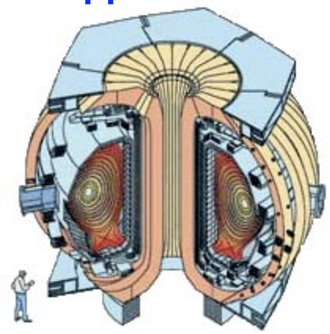
SSPX spheromak fast photo of kink



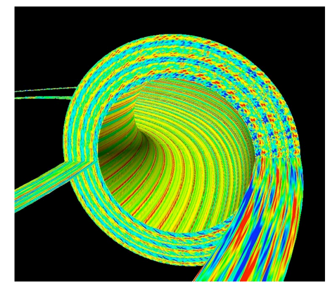


Theory and simulation of LPI for NIF and FI

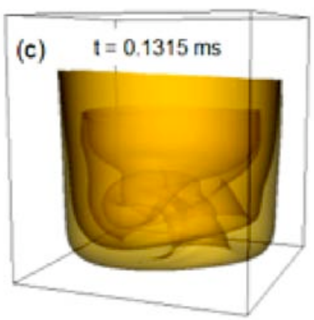
Support for DIII-D



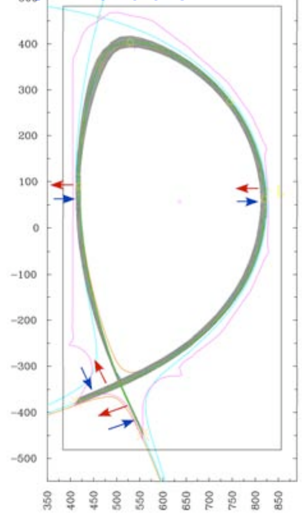
Simulation of tokamak core microturbulence



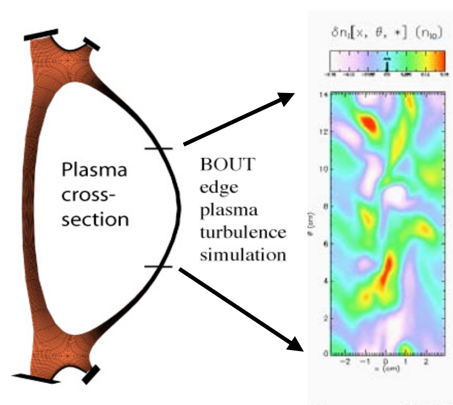
NIMROD MHD spheromak simulation



ITER Controller Simulation



Tokamak edge simulation and theory

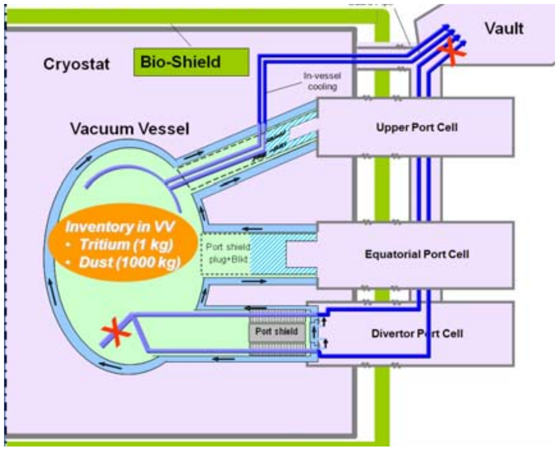


FEP personnel are contributing to important fusion technology R&D needs

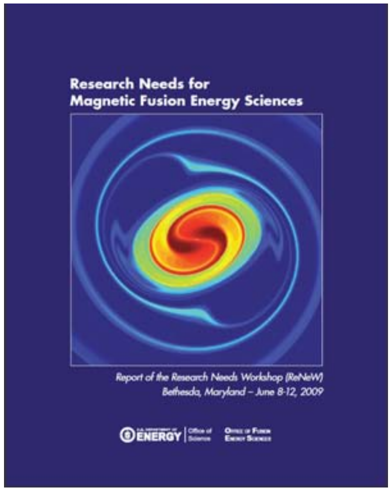
Technology/Materials
Wayne Meier

- Superconducting magnets including ITER central solenoid
- Multi-scale modeling of radiation damage to fusion materials
- Safety analyses in support of future fusion power plants and experimental facilities including ITER
- Chamber design and systems modeling & analyses for laser IFE

Central Solenoid Model Coil (ITER prototype)



Modeling divertor vacuum pipe break in ITER

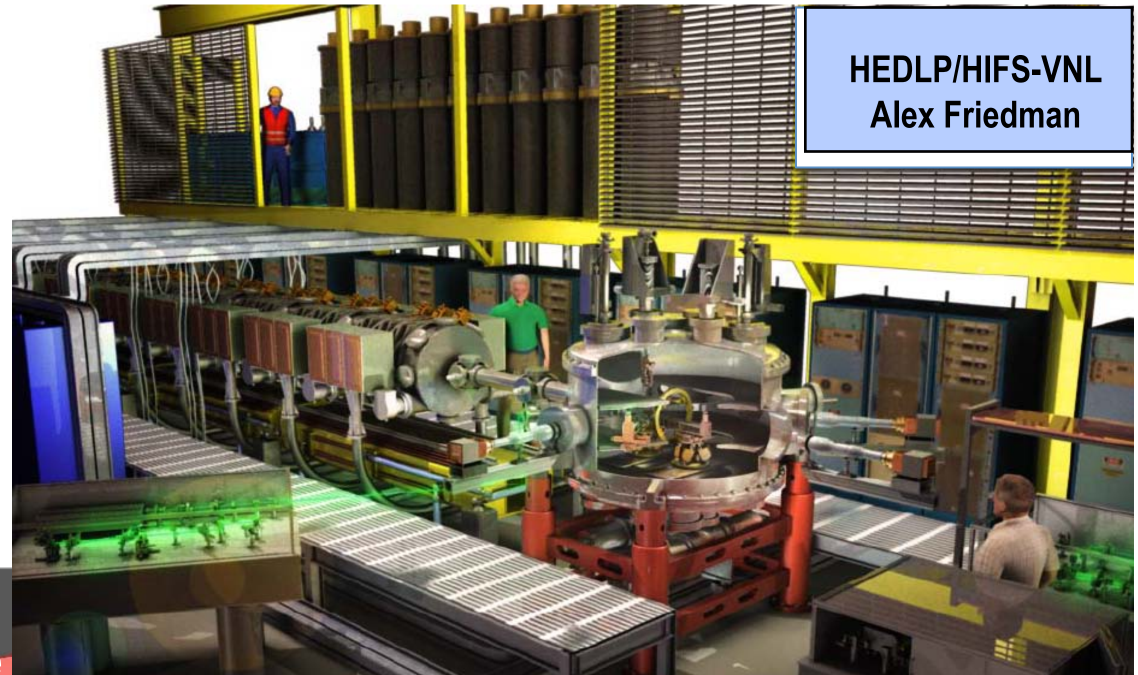


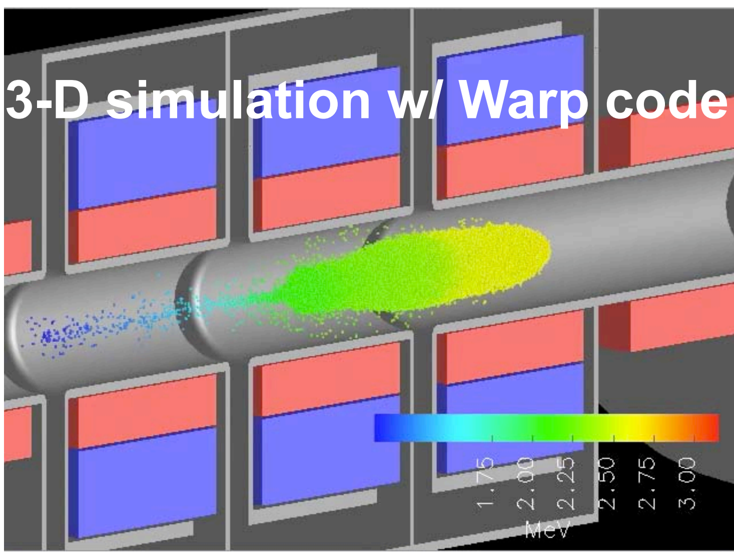
Harnessing Fusion Power Theme for MFE ReNeW

FEP has a key role in the HIFS-VNL's NDCXII project

HEDLP/HIFS-VNL
Alex Friedman

- FEP staff members lead
  - WDM theory and simulations effort
  - Machine physics design effort
- Innovative design using LLNL's ATA induction cells led to large costs savings

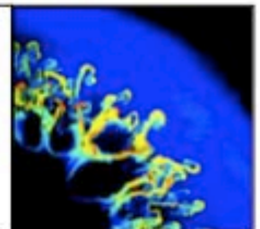
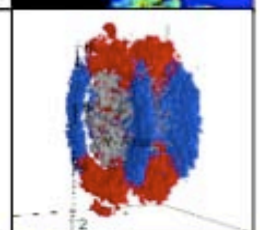
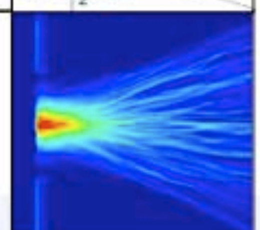




	NDCXI	NDCXII (projected)
Ion species	K^+ (A=39)	Li^+ (A=7)
Ion energy	300-400 keV	1.5 MeV & more
Focal radius	1.5 - 3 mm	0.5 mm
Pulse duration	2 - 4 ns	0.5 - 1 ns
Peak current	~ 2 A	~ 10 A & more

FEP HEDLP/Fast Ignition is developing experimentally validated 'state of the art' 3D computational tools

HEDLP/Fast Ignition
Prav Patel

State-of-the-art codes	
3D Rad-Hydro code—HYDRA Hydrodynamics, radiation transport, EOS, ionisation	
3D PIC code—PSC Relativistic laser absorption, electron generation, electromagnetic fields	
3D Hybrid-PIC—LSP Self-consistent electron transport, field generation, large-scale plasmas	

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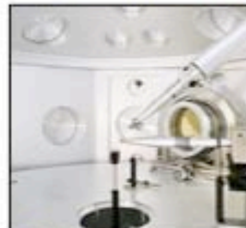
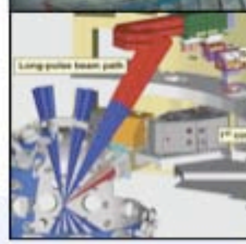
	Experimental benchmarking
	TITAN LLNL 200J, 0.5ps in 1 beam
	OMEGA EP LLE 5.2kJ, 10ps in 2 beams
	NIF ARC LLNL 10kJ, 10ps in 8 beams

Next Speaker:

Overview of Fast Ignition at LLNL

Prav Patel

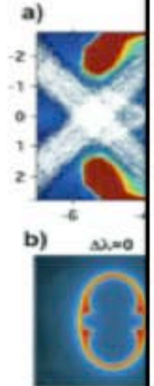
FEP Associate Program Leader for HEDLP/FI

FEP staff members are engaged in helping achieve ignition on NIF (e.g. 'tuning beam wavelength' result)

Recent NI… symmetry … ansfer

Two laser b… transfer en… … ember 2009 … ymmetry tuning … eam transfer

Earlier this y… energy trans… some of the …



PRL 102, 025004 (2009) PHYSICAL REVIEW LETTERS week ending 16 JANUARY 2009

Tuning the Implosion Symmetry of ICF Targets via Controlled Crossed-Beam Energy Transfer

P. Michel, L. Divol, E. A. Williams, S. Weber, C. A. Thomas, D. A. Callahan, S. W. Haan, J. D. Salmonson, S. Dixit, D. E. Hinkel, M. J. Edwards, B. J. MacGowan, J. D. Lindl, S. H. Glenzer, and L. J. Suter

Lawrence Livermore National Laboratory, Livermore, California 94551, USA

(Received 11 August 2008; published 14 January 2009)

Radiative hydrodynamics simulations of ignition experiments show that energy transfer between crossing laser beams allows tuning of the implosion symmetry. A new full-scale, three-dimensional quantitative model has been developed for crossed-beam energy transfer, allowing calculations of the propagation and coupling of multiple laser beams and their associated plasma waves in ignition hohlraums. This model has been implemented in a radiative-hydrodynamics code, demonstrating control of the implosion symmetry by a wavelength separation between cones of laser beams.

DOI: 10.1103/PhysRevLett.102.025004 PACS numbers: 52.57.Fg, 52.38.−r

Understanding and controlling the processes affecting capsule implosion symmetry remains a crucial task for the success of ignition experiments on facilities such as the National Ignition Facility (NIF, [1,2]) or the Laser Megajoule (LMJ, [3,4]). On these facilities, multiple laser beams arranged as cones enter both sides of a hohlraum and deposit their energy on the high-Z hohlraum walls, generating the x-ray radiation that eventually implodes the nuclear fuel capsule placed at the center of the hohlraum. A uniformity of the x-ray drive on the capsule of the one percent level is typically required to reach ignition; this is usually accomplished by appropriately setting the laser beam pointing and adjusting the power balance between the laser cones in order to control the distribution of energy deposition.

One of the processes that may particularly affect the implosion symmetry is the power transfer from one laser beam to another via *induced* Brillouin scattering. Kruer *et al.* [5] first showed that this process may occur at the laser entrance hole (LEH) of ignition hohlraums, where multiple beams cross in a flowing plasma; energy transfer between two crossing laser beams was then observed experimentally on the Nova laser facility by Kirkwood *et al.* [6], and significant theoretical or numerical [7–10] and experimental [11–14] work was then to follow.

In this Letter, we show that the transfer can be controlled and used to tune the implosion symmetry in ignition experiments. The first results of a new crossed-beam energy transfer model coupled to the radiative hydrodynamics code LASNEX [15] are presented. This model is the first to provide quantitative calculations for the propagation and energy transfer of multiple laser beams in three dimensions and full-scale volumes ($\approx 100\ mm^3$, 10^{11} cells). This is also the first crossed-beam transfer study that includes all laser beam smoothing techniques used in ignition experiments, such as phase plates [16], smoothing by spectral dispersion (SSD, [17]) and polarization smoothing (PS, [18]). Their effects on energy transfer are investigated for typical ignition conditions. A full-scale investigation of the most current NIF target design is then presented. We show that the transfer could alter the energy deposition for some of the beams, but that a wavelength separation between the laser beams allows one to control the transfer by Doppler shifting the coupling resonance. LASNEX simulations including our model show that such a wavelength separation allows tuning of the implosion symmetry in ignition ex-

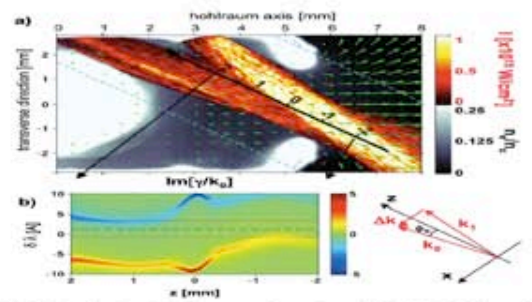
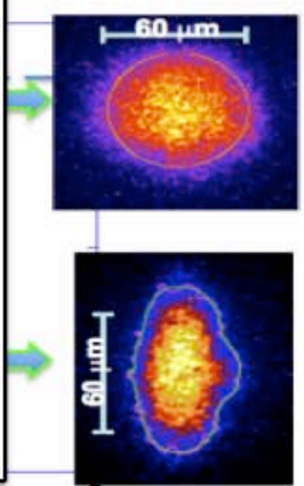


FIG. 1 (color). (a) Contour plot of a half NIF hohlraum's electron density (gray scale), and of the intensity of one pair of laser beams at 30° and 50° from the hohlraum axis; the green arrows represent the plasma flow, and the dashed blue lines the limits of the simulation box. (b) Normalized coupling coefficient $Im[\gamma]/k_0$ [cf. Eq. (3)] along the central bisector line as a function of z (distance along that line) and $\delta\lambda$ (wavelength shift between the two laser beams, in Å). A $\delta\lambda = 1.3$ Å shift (dashed black line) cancels the net transfer for that pair of beams; the red dotted lines represent the bandwidth induced by 2.2 Å of SSD on each beam.



3 4 5

λ (A)

Lasnex simulations with an … energy transfer model show … controlled crossed-beam tra…

** P. Michel et al., Phys. Rev. …*

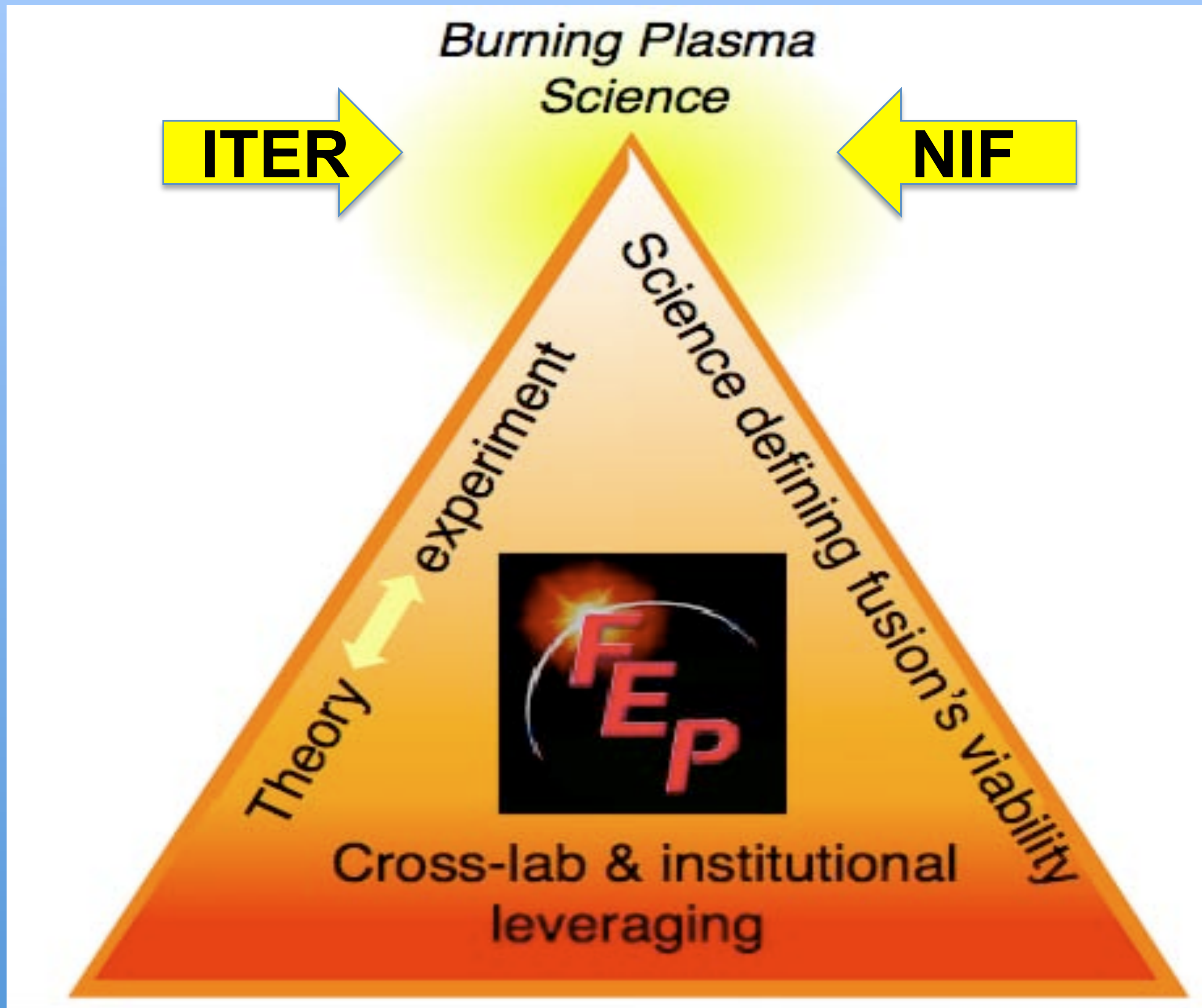
FEP's Pierre Michel, Laurent Divol et al.
Phys. Rev. Lett. 102, 025004 (Jan 2009)

A symmetric implosion was achieved without changing the laser energy, by simply tuning the wavelength shift by a few Angstroms between the inner and outer beams

Early Career PI's of interest to OFES reside not only in FEP but other LLNL fusion research areas

FEP helped LLNL submit six proposals to OFES in response to the DOE SC Early Career solicitation

Bayramian, Andy	NIF	World's First High Average Power Petawatt Laser for Fusion Neutron Generation, Particle Acceleration, and X-ray source for Fusion Materials Science
Kemp, Andreas	FEP	Integrated multi-scale simulation tool for intense laser-matter interaction - modeling plasma physics from near vacuum to 1000 times solid density
Marian, Jaime	Condensed Matter and Materials	Computational Modeling and Design of Nano-structured Materials for enhanced Radiation Resistance in Fusion Environments
Shverdin, Miro	NIF	Precision monoenergetic gamma-ray (MEGa-ray) source for time-resolved phase-space measurement of plasmas
Soukhanovdkii, Vlad	FEP	High Flux Expansion Divertor Program on the National Spherical Torus Experiment
Tang, Vincent	Engineering	Experimental and Numerical Study of Wave-Plasma Interactions at ITER Relevant Parameters


Burning Plasma
Science
ITER
NIF
Theory
experiment
Science defining fusion's viability
FEP
Cross-lab & institutional
leveraging