

High-Energy Density Physics research is funded by several agencies

- **Funding Agencies: NNSA, OFES, OHEP, ONP, OBES**
- **HEDP includes:**
 - (a) High energy density approaches to fusion: IFE, Fast Ignition, MTF**
 - (b) High energy density astrophysical systems**
 - (c) Beam-induced HEDP**
 - (d) HEDP for stockpile stewardship (ICF, EoS, Hydro)**
 - (e) Ultra-fast, ultra-intense laser science**

WORKING GROUP FOCUSED ON OFES-FUNDED HEDP

- **The WG briefly addressed the general issues pertaining to high-energy density implosions**
- **The WG focused on the OFES-funded HEDP:** a relatively modest effort funded at a level of a few million \$.

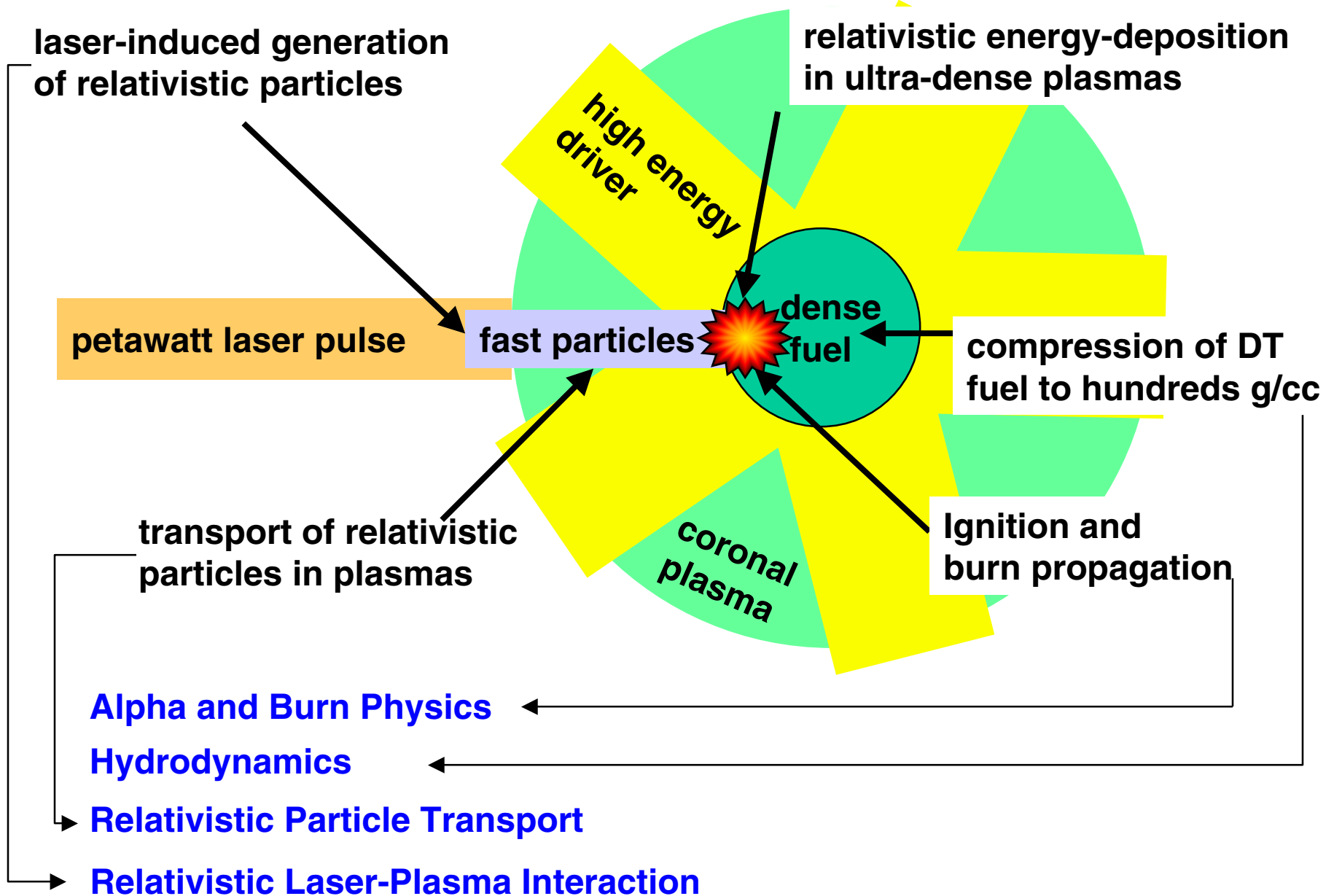
• COMPONENTS OF THE OFES-HEDP ACITIVITY

(1) Fast Ignition Research

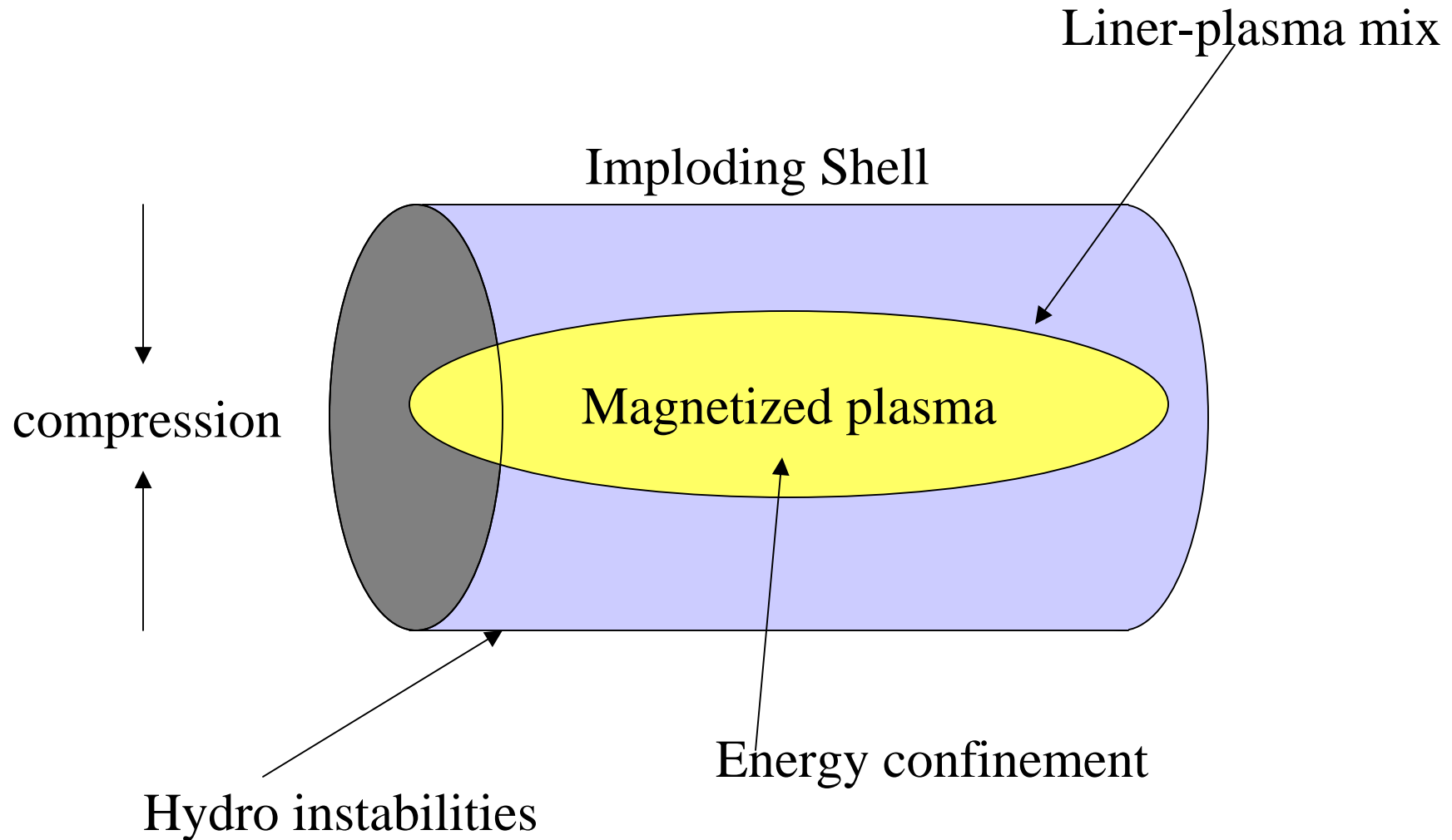
(2) Magneto-Inertial Fusion [mostly MTF (Magnetized Target Fusion),
with small exploration initiatives in Jet compression and magnetized ICF)]

(3) ICF Target Physics/Design

Fast Ignition



Magnetized Target Fusion



HEDP WORKING GROUP

M. Tabak (Chair)	LLNL	T. Ditmire	UT
R. Betti (V. Chair)	UR	M. Campbell	GA
J. Hammer	LLNL	W. Mori	UCLA
M. Key	LLNL	G. Wurden	LANL
T. Cowan	UNR	N. Fisch	PPPL
S. Slutz	SNL	R. Siemon	UNR
C. Sangster	UR		

- **Work carried out by e-mail and conference calls (3)**
- **To lowest order: working group ~ community**

HEDP TOPICAL QUESTIONS

T7 “How can high energy density fusion plasmas be assembled and ignited in the laboratory?”

T8 “How do hydrodynamic instabilities affect implosions to high energy density?”

T7 “How can high energy density fusion plasmas be assembled and ignited in the laboratory?”

- **NNSA-funded: general ICF implosion research thrusts**
 - (1) Control of driver low-mode asymmetries (beam imbalance, hohlraum)
 - (3) Pulse Shaping (entropy control and shock timing)
 - (5) Equation of State at high energy densities
 - (6) Cryogenic target manufacturing and handling
 - (7) Code validation

- **OFES-funded: Fast Ignition and target physics thrust areas**

- (a) Develop the physics understanding of fast particle transport and relativistic laser-plasma interaction in HED plasmas**
- (b) Develop targets and implosions for the optimal hydro-assembly of HED plasmas at densities of hundreds g/cc**

- **OFES-funded: Magneto-Inertial Fusion**

- (c) Investigation of the energy confinement and macroscopic stability of magnetically insulated plasmas compressed to high energy density**

T8 “How do hydrodynamic instabilities affect implosions to high energy density?”

- **NNSA-funded: Hydro instabilities in ICF thrust areas**
 - (1) Understand hydrodynamic instabilities (R-T, R-M, B-P)
 - (2) Simulate hydro-instabilities in 3-D
 - (3) Control R-T growth rates (using laser-induced adiabat shaping and/or differential doping)
 - (4) Control of R-T seeds induced by driver illumination non-uniformities (using laser prepulses and/or high-Z layers)

Supporting documentation (do not show)

SPECIFIC THRUSTS IN FAST IGNITION

- (1) Understanding Fast Electron Transport*
- (2A) Realizing a Suitable Fuel Assembly*
- (2B) Understanding Laser-Plasma Interaction*
- (3) Design Integrated Experiments*
- (4) Exploring Fast Ion Generation*

Goal: Carrying out Integrated Experiments to verify the Feasibility of Fast Ignition

Supporting documentation (do not show)

(1) Fast Electron Transport

#1 priority) Fast electron transport is key to the success of FI. The electron beam must remain focused while propagating through the coronal plasma. The electrons must also deposit their energy within a relatively small region of the compressed fuel. These two conditions are essential for a proof-of-principle demonstration of FI.

Required Capabilities. Well diagnosed implosion facilities (Omega, GEKKO, Z, and NIF with $>\sim$ kJ, \sim 5-10 psec PW. Explicit PIC codes. Implicit PIC codes with subscale models including anomalous stopping and resistivity along with material property models. Vlasov and Fokker-Planck codes also have roles. These codes are being developed at various institutions. A variety of targets will be necessary to diagnose electron transport and to optimize electron energy concentration.

Supporting documentation (do not show)

(2A) Hydrodynamic Assembly

#2A priority) An adequate fuel assembly with $\rho \cdot R > 0.5-1 \text{ g/cm}^2$ is necessary for demonstrating fast electron stopping in the compressed fuel. The experimental capabilities for integrated experiments will soon be available at LLE, but no target design has yet been developed to reliably achieve the required areal densities on OMEGA. An appropriate fuel assembly is essential for a proof-of-principle demonstration of FI. An efficient fuel assembly can also dramatically improve the prospects for higher energy gains and power generation.

Required Capabilities. Experimental/modeling campaign. 2D and 3D codes continue to be developed in the NNSA funded ICF program and will be available to guide experiments. Flexible target fabrication capability will be essential. Testing new designs require drivers capable of a variety of illumination geometries. The Z-machine and the Omega laser at Rochester will be essential for this study. Diagnostics for the experimental conditions are also essential.

Supporting documentation (do not show)

(2B) Laser-Plasma Interaction

#2B priority) Understanding and predicting the characteristics of electron generation by intense lasers is key to determining the electron transport properties and their interaction with the coronal plasma and compressed core.

Required Capabilities. Lasers capable of producing $>10^{19}$ watts/cm² in 5-10 psec pulse and a plasma forming facility that can produce “underdense” FI relevant plasmas (both laser and xray generated) additional features for looking at guiding the ignitor beam via channeling will require a pulse shaping capability with the short pulse or additional laser beam capable of >100 psec and $>10^{16}$ watts/cm².

Supporting documentation (do not show)

(3) Integrated Experiments

#3 priority) Integrated experiments will assess the feasibility of FI. In this experiments, the fuel is assembled by a high-energy driver and heated by a high-power (Petawatt) laser.

Required Capabilities. High power lasers capable of $>10^{19}\text{W}/\text{cm}^2$ in $\sim 1\text{-}10$ psec and high energy lasers capable of delivering $\geq 30\text{kJ}$.
Integrated facilities: Z-Beamlet, Omega- Omega EP and NIF

Supporting documentation (do not show)

(4) FI with Fast Ions

#4 priority) This is a relatively new idea that should be actively explored. Using Fast Ions has the potential to eliminate many complications associated with fast electron transport.

- Required Capabilities. Lasers capable of $>10^{19}$ W/cm² in ~1-10 psec
Expected Results and Impacts. Evaluation of Proton FI

Supporting documentation (do not show)

Thrusts in MTF

- (1) Verifying the physics of magnetic compression and energy loss from a plasma that is being compressed rapidly and dynamically, in a density and magnetic field regime of plasma physics that up to now has very little experimental and theoretical data;
- (2) Developing the science for compressing a magnetized plasma in an attractive and practical manner. Develop an understanding of liner limitations such as speed, maximum pulsed magnetic field, and hydrodynamic stability.
- 3) Developing the feasibility of fusion based on this approach. System gains must be sufficiently large compared to source efficiencies that net electricity can be produced. Can a dense fuel layer be ignited in and MTF target? Can the liner/magnet system be powered remotely?

Supporting documentation (do not show)

The primary objective of the research being undertaken today is to experimentally determine the energy loss rate between a magnetized plasma in a Field Reversed Configuration (FRC) being imploded by a metallic shell. An FRC is a plasma cylindrical in shape, in which self-sustained electrical currents flow in circular manner about the cylindrical axis, producing the magnetic field embedded in the plasma.

Analyze and compare the various MTF driver and plasma target possibilities to quantify the physical properties important to practical fusion such as energy efficiency, fusion gain, etc, through a predictive science/numerical simulation theory effort, with validation through experiments. Detailed comparison with experiments is required.

Analyze and compare the various MTF driver and plasma target possibilities to quantify the physical properties important to practical fusion such as energy efficiency, fusion gain, etc, through a predictive science/numerical simulation theory effort, with validation through experiments. Detailed comparison with experiments is required.

Supporting documentation (do not show)

Required Capabilities. The FRC must have certain plasma characteristics such as a density of at least 10^{17} ions per cc and a temperature of three million degrees Celsius, and of a certain size. The field-reversed configuration under development at Los Alamos is the primary MTF candidate, and the hard-core stabilized diffuse z pinch will be studied in a new experiment at the University of Nevada, Reno. Spheromaks are an interesting possibility not yet being explored. NNSA computer codes with MHD capabilities like Allegro or TRACK, including realistic material properties in 3D. Surrounding the magnetized plasma with a dense fuel layer and triggering a burn wave in this fuel would dramatically increase the energy gain. Exploring this possibility has the potential to improve the economic attractiveness of MTF.

Supporting documentation (do not show)

Expected Results and Impacts. The development in imploding a solid liner contributes to meeting the scientific challenge for MTF, namely, developing the science underpinning the techniques of imploding the magnetized plasma. Demonstrating the physics of such implosions is one of the near-term (5 year) goals. On the longer (10-year) timescale, experiments to explore DD or even DT fusion gain ($Q>1$) may be possible with MTF. There are other techniques with better driver-standoff that have been proposed for imploding magnetized plasmas for magneto-inertial fusion, such as high velocity plasma jets, and for creating magnetized plasmas other than Field Reversed Configurations but little work has been done to assess their credibility.