The Continuing Role of High Energy Density Science in National Security

Presented to:

The Omega Laser User's Group Workshop
LLE University of Rochester

Presented by:

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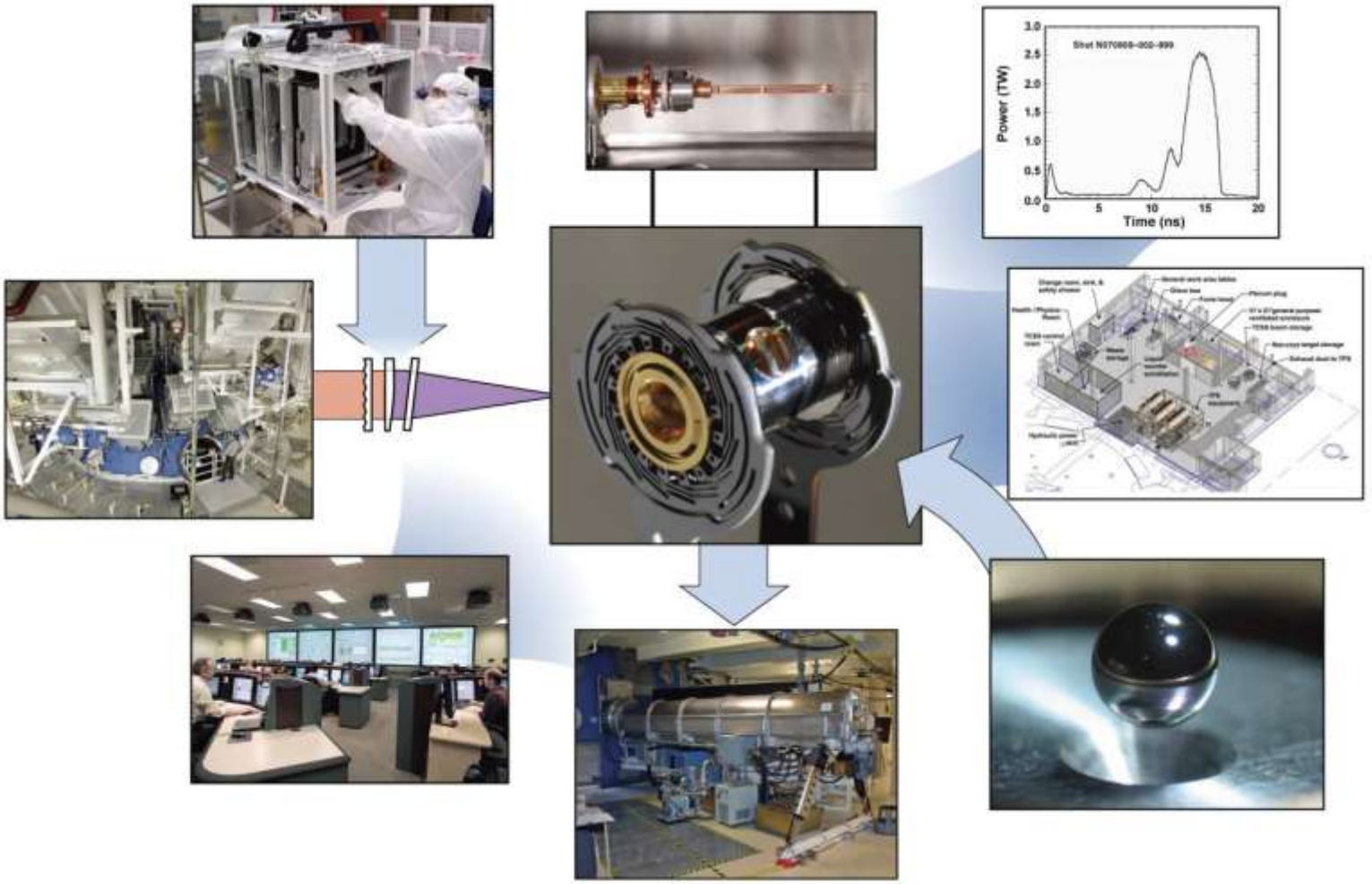
Outline

- First ignition experiments this year – a key milestone for basic plasma / HED science as well as weapons science.
- NNSA as a sponsor and steward of High Energy Density Physics
- Upcoming NAS study of Inertial Fusion Energy – NNSA participation.
- How does stewardship of plasma science benefit NNSA?
- Conclusion

The achievement of igniting conditions will open new frontiers in plasma research

- Plasma temperatures > 20 keV ; compressed densities > 1000 gm / cm^2 ; pressures ~ 1 Tbar
- The high perfomance implosions needed for ignition can also be employed in a variety of non-ignition basic science investigations.
  - Planetary and astro- physics
  - Materials under extreme conditions
- Performing detailed measurements under igniting conditions will present a considerable diagnostic challenge.

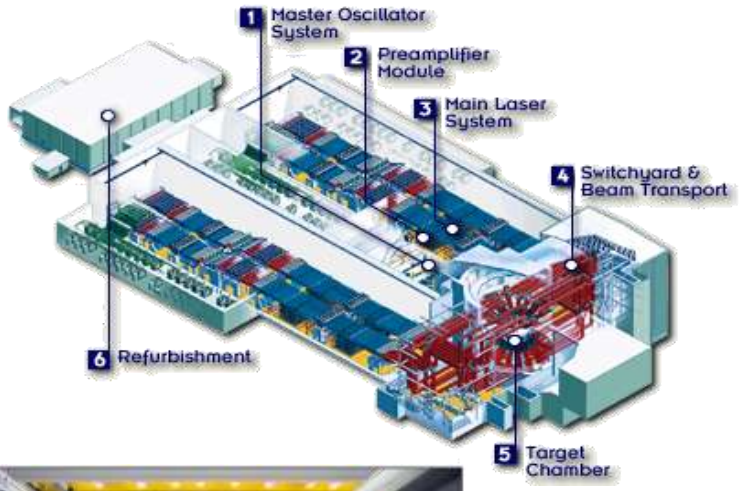
Ignition will be the start of a new scientific era for NNSA and the Nation



Ignition on NIF will be a defining moment for inertial confinement fusion energy

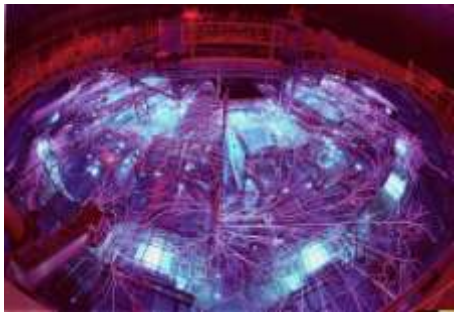
Extraordinary new HED capabilities are now in place

- **National Ignition Facility (NIF)**
  - Only access to burning plasma conditions
  - Important mission experiments have already been performed



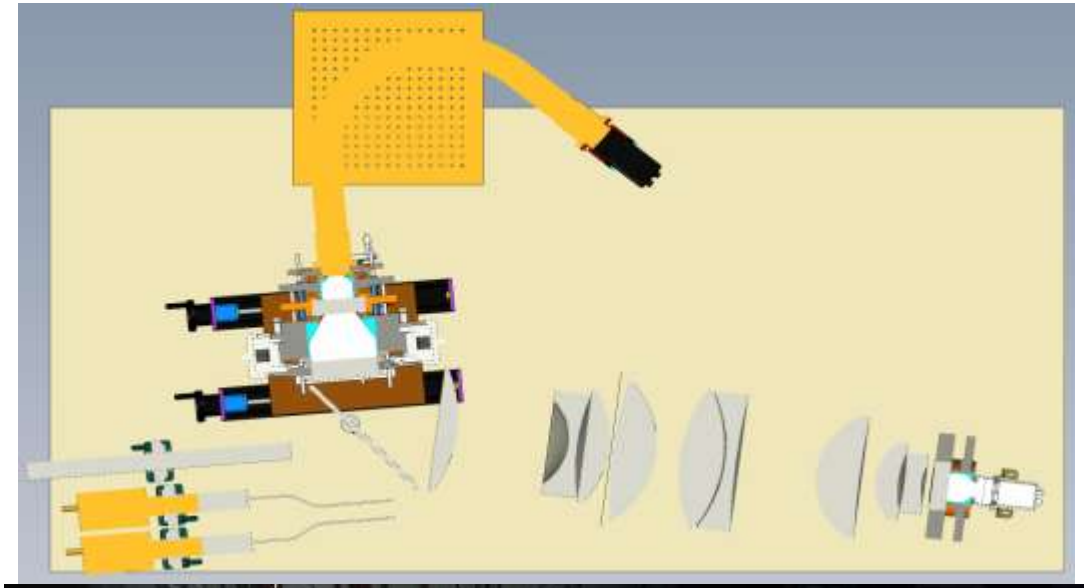
- **Omega EP**
  - Sophisticated high irradiance capabilities
  - Important venue for advanced fusion research

- **Z Machine**
  - Key venue for materials science measurements
  - Outstanding new results at 4 Mbar.



- **Enormous increase in computational power**

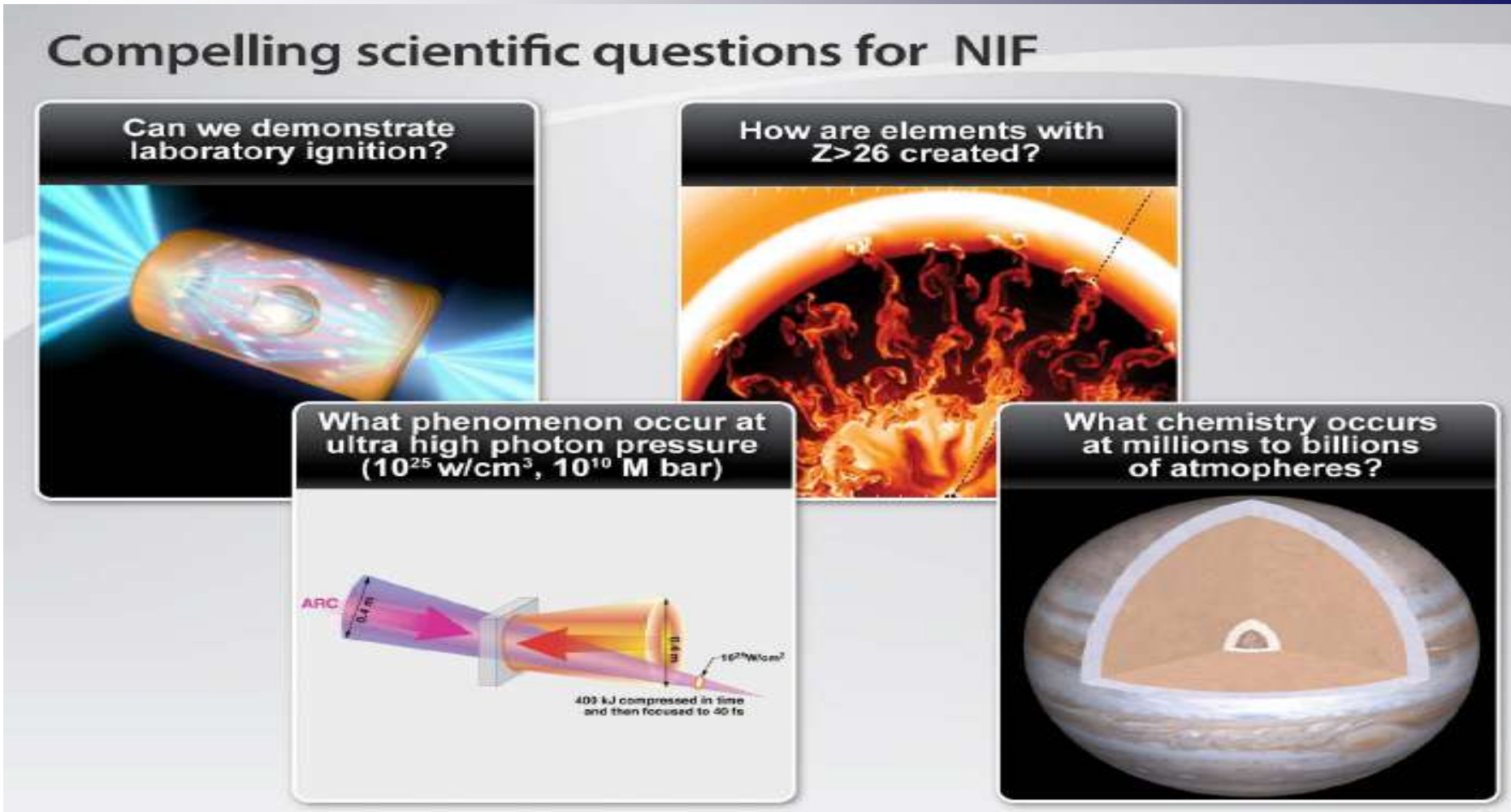
Los Alamos NIF Neutron imager is tested and calibrated on Omega



2 axis / 2 image system will allow simultaneous primary(14-MeV) and downscattered (10-12 MeV) imaging.

Future testing of NI will likely involve polar direct drive capsules thus advancing both basic science and diagnostic development

Compelling scientific questions for NIF



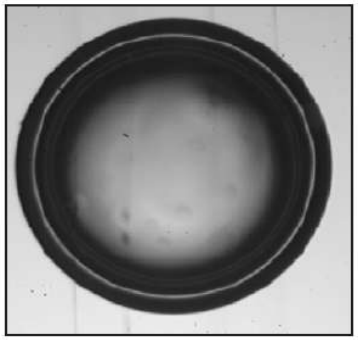
Omega will play a key role in preparing for all of this work

The Omega EP Laser is a very versatile tool for HED / ICF research

- Omega is the only facility worldwide that can currently perform cryogenic target implosions
  - ***cryogenic implosions are essential for the success of ignition experiments at NIF***
- Cryogenic target physics research:
  - Allows the development of high areal density diagnostics
  - Validates the understanding of cryogenic implosion physics
- 300 mg/cm^2 areal densities have been demonstrated on Omega – the minimum value required for ignition

Ignition requires smooth DT ice layers

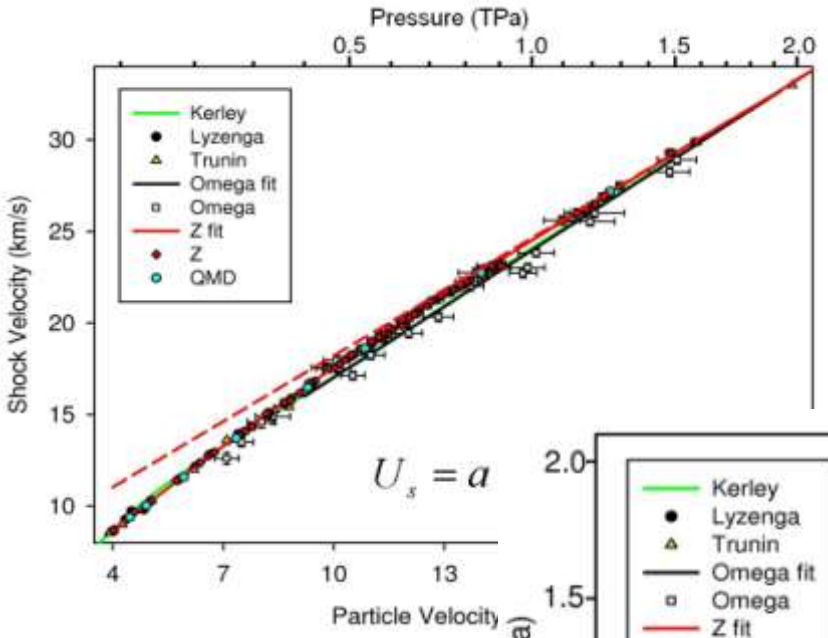
Shadowgraph image
of a cryogenic DT target
(~100-μm-thick layer)

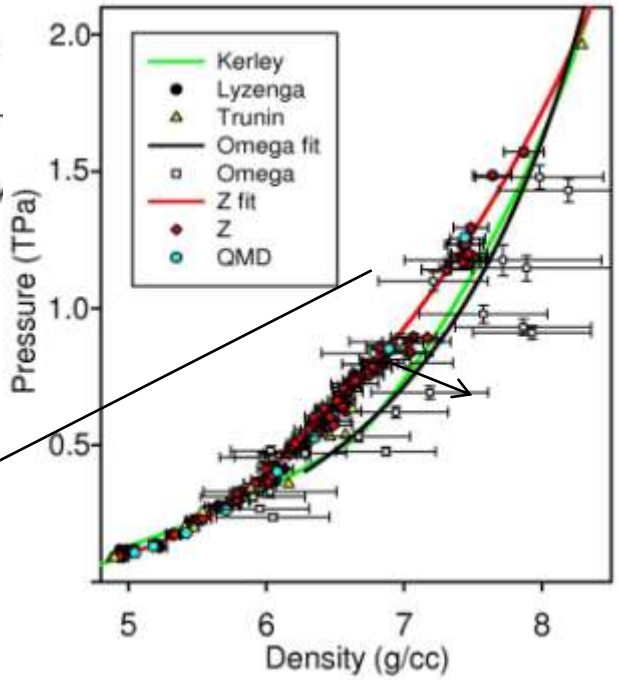


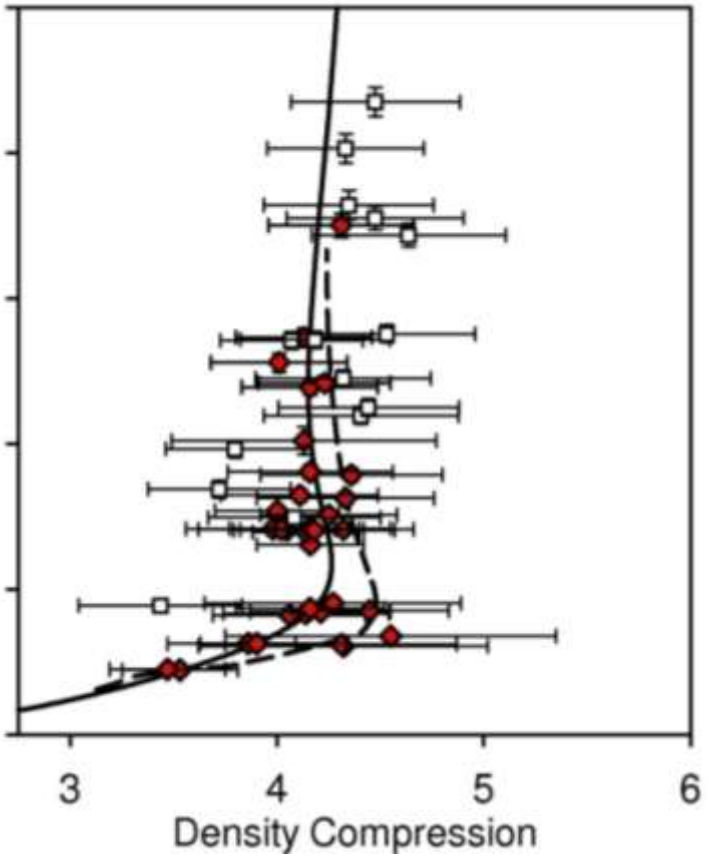
Ice-surface roughness:
0.47-μm rms in a single view

The fuel areal density measured by "internal" neutron backlighting

The effect of a more accurate α-Quartz on Omega deuterium hugoniot is profound







Data with larger error bars measured only transit time. More recent data measured transit time and shock velocity directly

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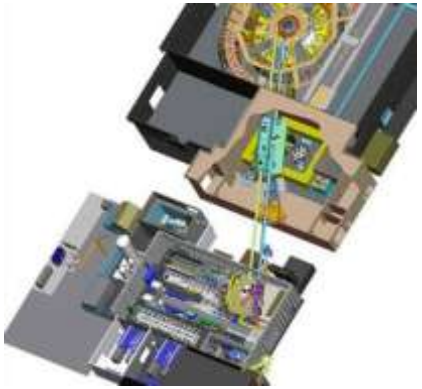
NNSA relies on intermediate scale plasma science facilities for basic science support

Examples of intermediate size plasma facilities:

- **Jupiter at LLNL (lasers): support of NIC and NIF; mission; users**
- **Trident at LANL (laser): support of NIF and NIC; mission; users**
- **Texas Petawatt at UTX (laser): discovery-driven research; users**
- **Z-Beamlet / Z Petawatt at SNL (laser): diagnostic for ZR; users**
- **Nevada Terawatt at UNR: pulsed power**



Intermediate-size plasma facilities provide both direct and indirect mission support, and we are encouraging user access at our intermediate facilities

The expansion of HED Laboratory Plasma Science continues

- **There has been active work in Laboratory astrophysical experiments**
  - One experiment contributed to Hubble planning
  - A center for Lab Astrophysics has been established as part of the Joint HEDLP Program.

- **Discovery driven, high energy density plasma science**
  This is specifically supported by NNSA through: the HEDLP joint program, User Facilities (including NLUF), LDRD, University programs, workshops and individual contracts.

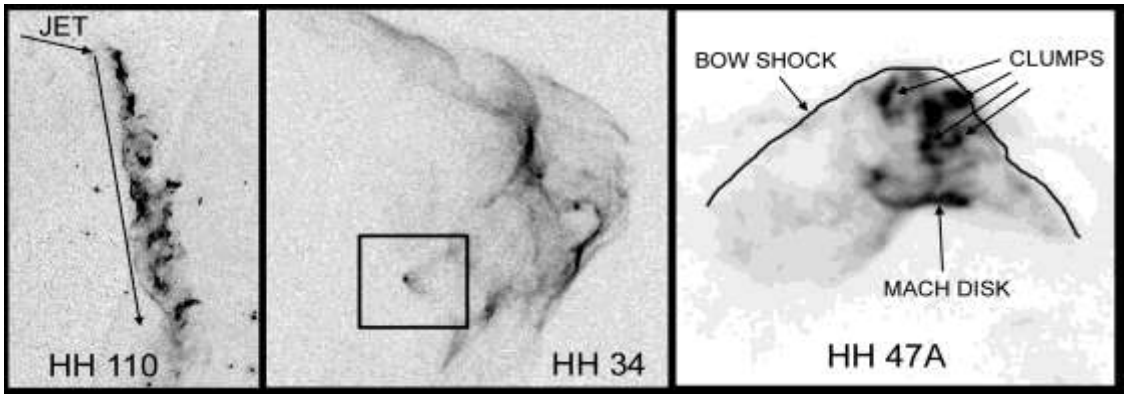
- **Intermediate –scale plasma science**
  NNSA continues to develop its intermediate scale User Facilities, where peer-reviewed academic use for discovery-driven science is growing

- **Cross-cutting research**
  NNSA is growing its collaborative partnerships with other agencies, institutions, and individuals through WFO, LDRD, User Facilities, and University programs. This is an effective method to optimize cross-cutting research

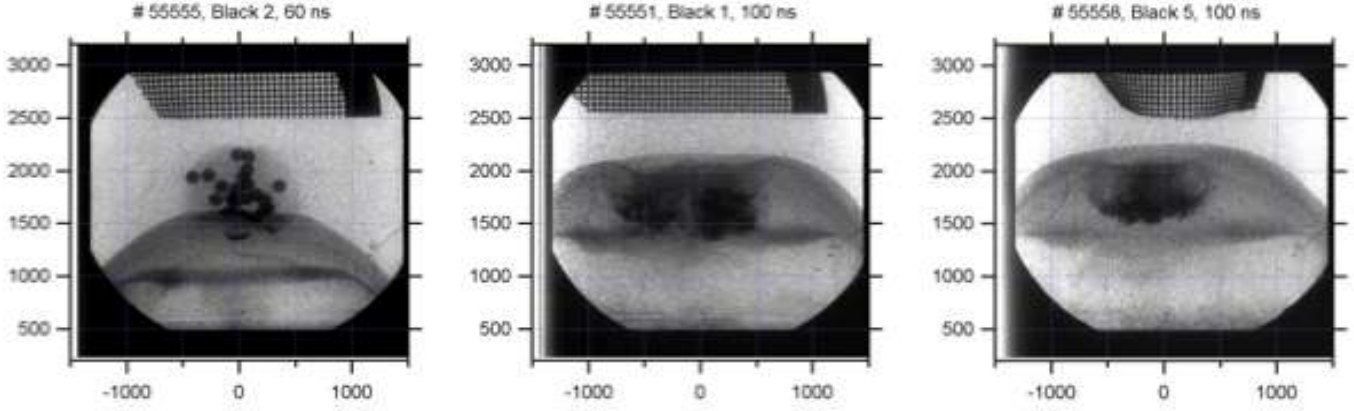
Data from an NLUF experiment on OMEGA was used to obtain observational time on the Hubble Space Telescope (HST)

- P. Hartigan (Rice) and collaborators study the interaction of astrophysical jets with clumps in the interstellar medium with the HST and the same physics on OMEGA

Examples of shocked clumps from jets in young stars (HST images)



OMEGA data showing a shock overrunning a region of clumps

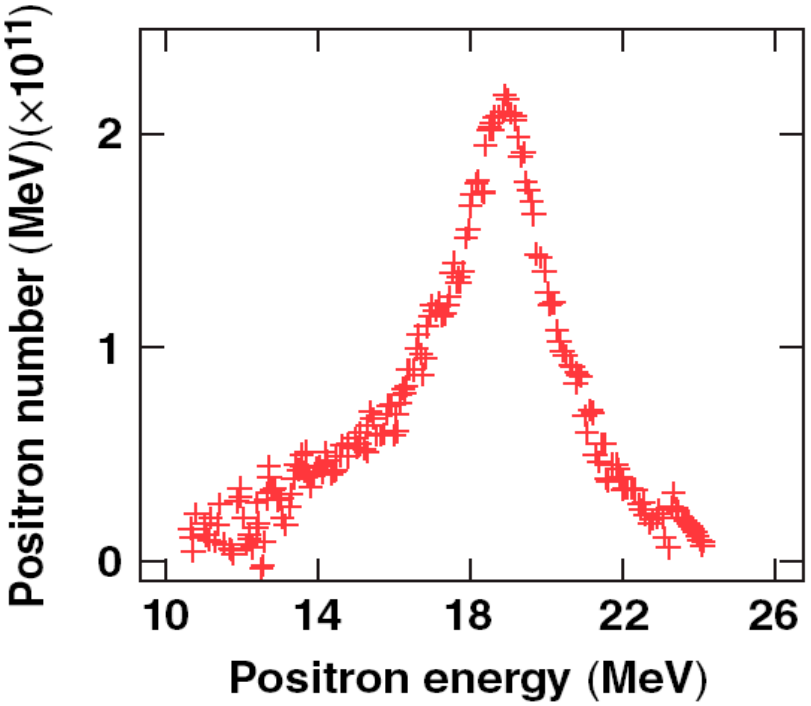


Builds on Hartigan et al., Astrophysical Journal, 705, (2009) 1073-1094

An OMEGA EP experiment resulted in the highest positron production rate achieved in the laboratory

- A jet of relativistic positrons is emitted from the rear surface of the mm-thick Au target – beam temperature ~1 MeV
- LLNL-LLE collaboration, H. Chen, PI

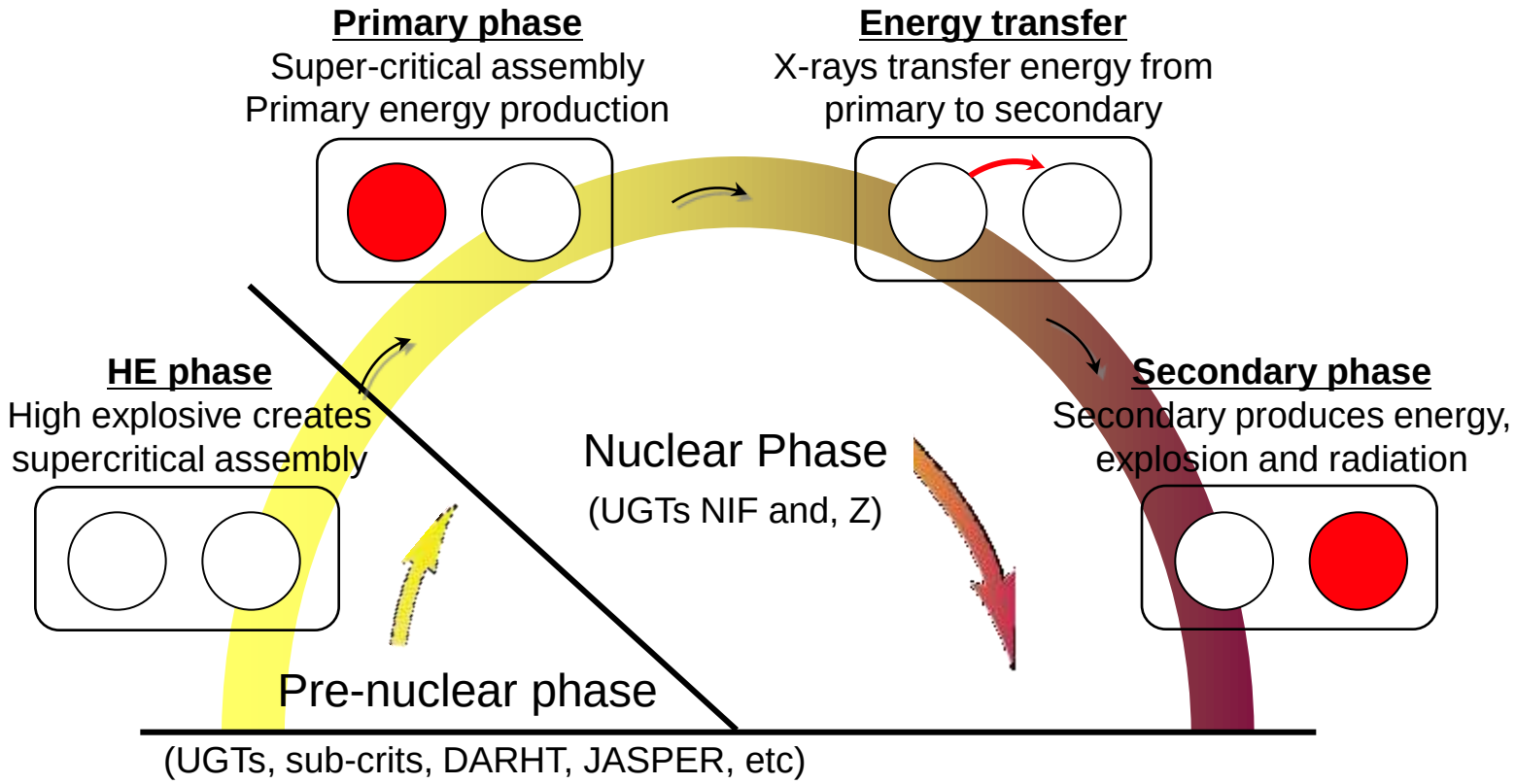
- **1 kJ, 10 ps OMEGA EP laser pulse**
- **~ 10^{12} positrons produced**
- **~ 0.3% conversion efficiency from laser to positrons**
- **No magnetic field in the initial experiments**



*H. Chen *et al.*, Phys. Rev. Lett. 102, 105001 (2009).

The challenge is to confine them into an electron-positron plasma

After the explosive phase, weapons rapidly evolve into the HED and plasma regimes



Weapons operation proceeds through the conditions of planetary interiors, to stellar interiors – the Recent Nuclear Posture Review Re-asserts the national commitment to National Security

ICF / HED Post-NIC Strategy

Work Agenda	% of Program	Planning Methods
Application of HED / ICF methods and facilities to **specific weapons requirements**	65% **Examples:** • C4 Radiation transport • C2 very high pressure materials measurements • C1,C10…. advancing the limits of ignition / "robust" ignition for specific applications	National Requirements (Primary and Secondary Assessment, DSW, PCF)
Application of HED / ICF Methods and facilities to **Basic Science**	15%	National Peer Review Process
• Weapons basic science • Advanced/long-term "platform development" • Advanced fusion for the Weapons Program • IFE	20%	National Internal Program Review

User Facilities and Shared National Resources – an important component of the future of NNSA facilities

- **Strengthening the HED science base** is an essential part of the NNSA mission and a responsibility to the nation.
- **15% of facility time** devoted to basic science is a goal.
- **Mission oriented work** will still dominate the agenda for the foreseeable future.
- **Uniform policies and procedures** will give a clear picture to the international science community and to our sponsors
- A broader constituency for our facilities is attractive to substantial segments of **congress**.

Carefully addressing the needs of the mission-oriented agendas while promoting a level of peer review that will grow to be consistent with Office of Science standards

Conclusions

NNSA invests in plasma science in the broadest national interest, including discovery-driven science

- **Discovery driven, high energy density plasma science**
  This is specifically supported by NNSA through: the HEDLP joint program, User Facilities (including NLUF), LDRD, University programs, workshops and individual contracts. Core program has led and will continue to generate discoveries

- **Intermediate –scale plasma science**
  NNSA continues to develop its intermediate scale User Facilities, where peer-reviewed academic use for discovery-driven science is growing

- **Cross-cutting research**
  NNSA is growing its collaborative partnerships with other agencies, institutions and individuals through WFO, LDRD, User Facilities, and University programs. This is an effective method to optimize cross-cutting research

- **NNSA welcomes the IFE study and will contribute its ICF expertise**

BACKUPS

The pursuit of ignition will dominate the agenda at NIF through 2012

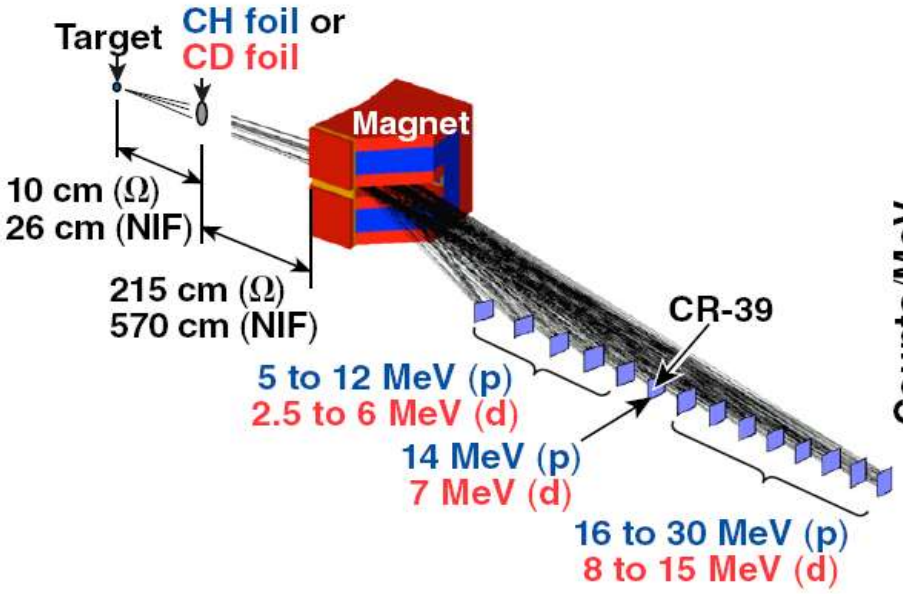
- **3 major series of ignition experiments are planned for 2010-2012.**
  - The plan is to transition to development of an "ignition weapons physics platform"
  - **This "platform" development shares many common goals with energy research**
    - **Robust operation, moderate to high gain**

- **The diagnostic suite will be rapidly evolving during this period.**
  - Neutron imaging will installed in 2011
  - Several beam lines of the ARC backlighting system will be available in late 11.
  - **Diagnostics that may be unique to the energy mission should be under consideration now.**

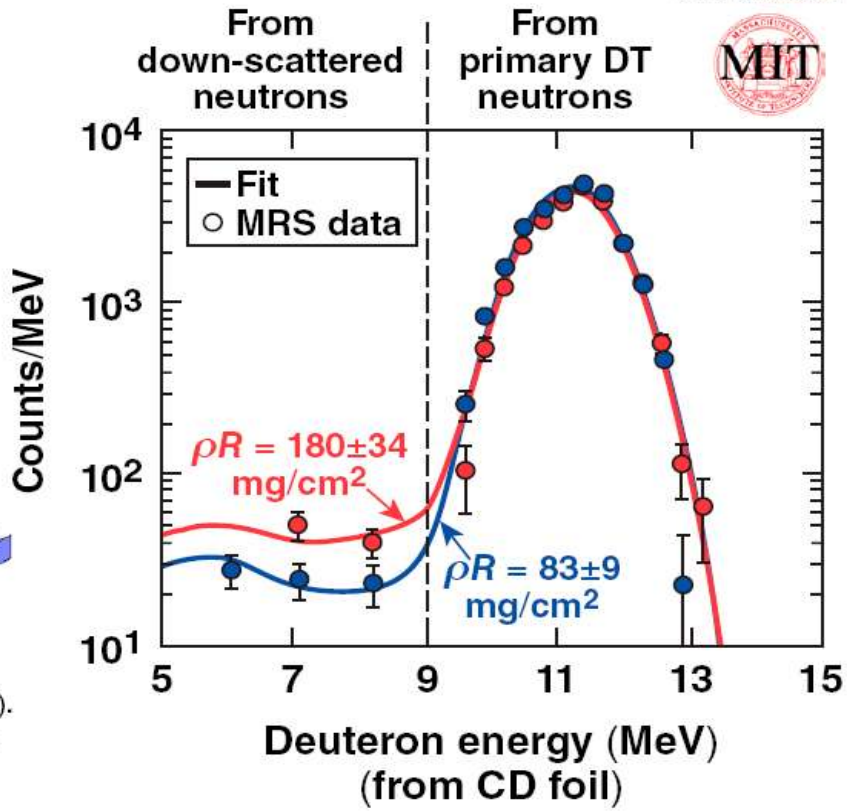
- **Detailed diagnostics that operate during an ignition shot remain a major challenge.**

- **A successful ignition shot will mandate a 1-2 week suspension of experimental operations at NIF.**

A magnetic recoil spectrometer (MRS) is used to infer the areal density in OMEGA cryogenic-DT implosions



J. A. Frenje *et al.*, NIF MRS System Design Review (April 2006).
J. A. Frenje *et al.*, to be published in Rev. Sci. Instrum. (2008).



The MRS has been used on ~17 cryogenic DT implosions and measured areal densities from <100 mg/cm² to ~300 mg/cm².

NNSA supports HED facilities of varying scale

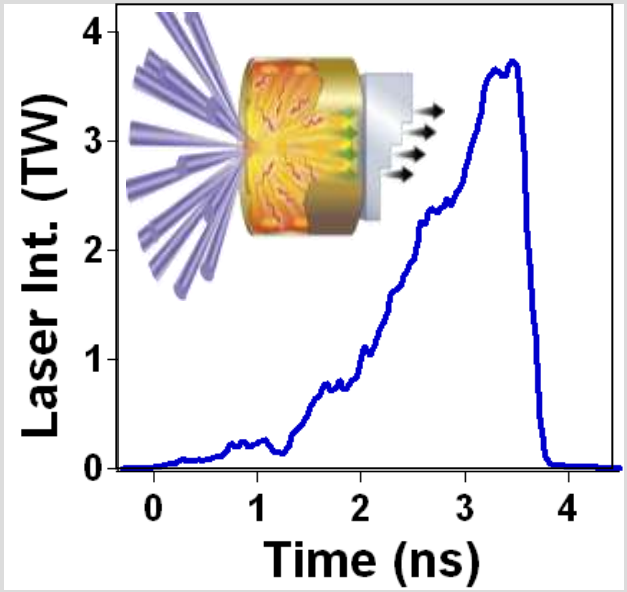
- Large facilities – NIF, OMEGA, Z
  - Most extreme conditions, complex experimental setups, large operations crews, few hands-on opportunities
- Intermediate Scale – Trident, Jupiter, Zebra, …
  - Modest operations crew, hands-on opportunities
- University Scale – Texas Petawatt, OSU high rep. rate, …
  - Small operations crew, serve as a basic training ground for new students, many hands-on opportunities

In many cases, experiments will progress from small to intermediate to large scale facilities

Smaller scale work will also continue to play a role in IFE

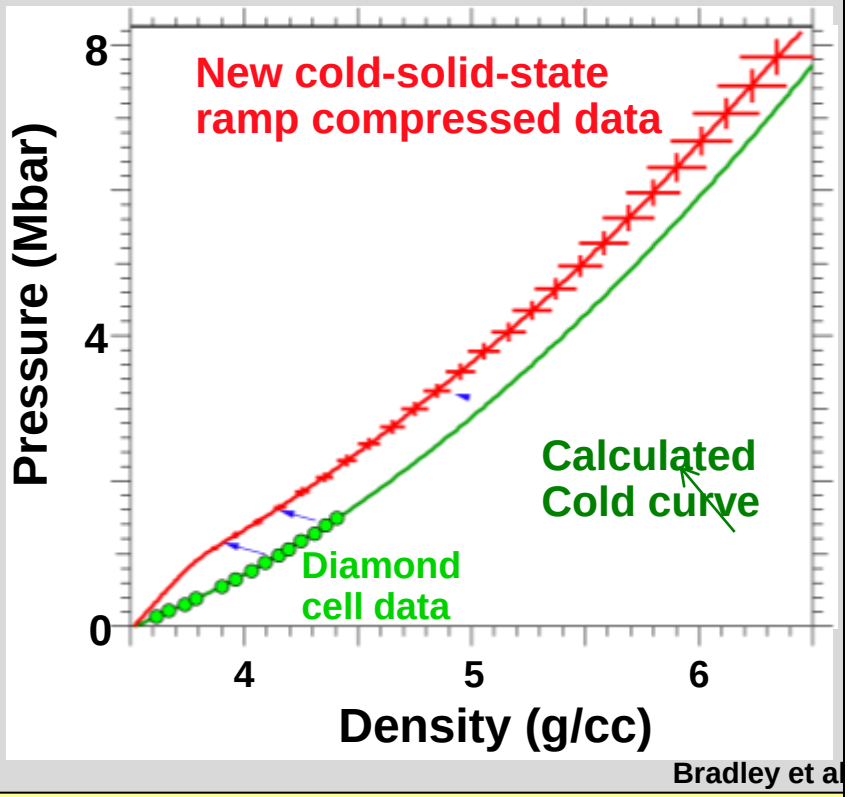
High energy lasers have been used to extend solid state physics to the 10 Mbar regime

Ramp laser intensity to produce shockless compression



- Edwards, et al. (PRL 04)
- Smith, et al. (PRL 06)
- Bradley, et al. (PRL 08)
- Eggert et al. (SCCM 07)

Ramp compression shows diamond is stable and strong to 8Mbar



Bradley et al

NIF designs use the same technique to study solids to many >30 Mbar

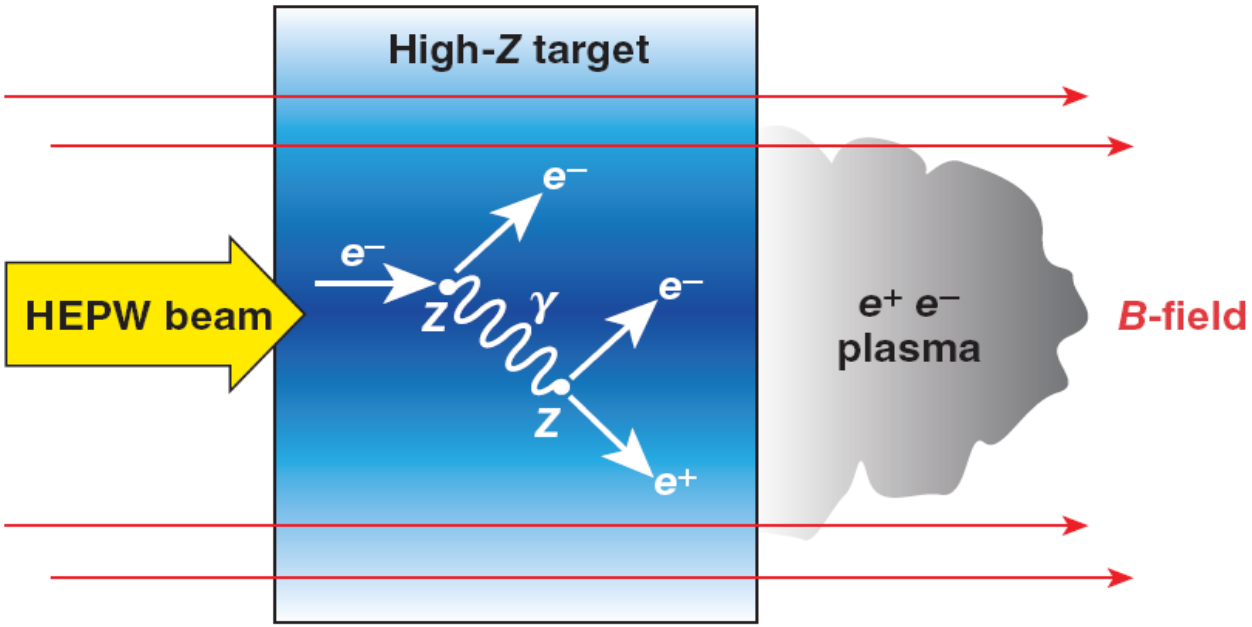
Plasma Science Issues and Path Forward

- **While broadest-interest plasma science, involving users, is undertaken by NNSA, it is under pressure:**
  - **Intermediate scale NNSA facilities must often be funded through institutional channels**
  - **While a large response to calls for HEDLP proposals illustrates a healthy interest, only a few will likely be funded**
  - **The importance of science to the NNSA-DP mission is not fully appreciated**

- **Path Forward:**
  - **The NNSA HED Program recognizes the value of discovery science, especially the role of intermediate facilities**
  - **We commit to stable funding with (hopefully) growth**
  - **Joint Program will be main vehicle, institutional channel**
  - **We must widely disseminate information about our facilities**

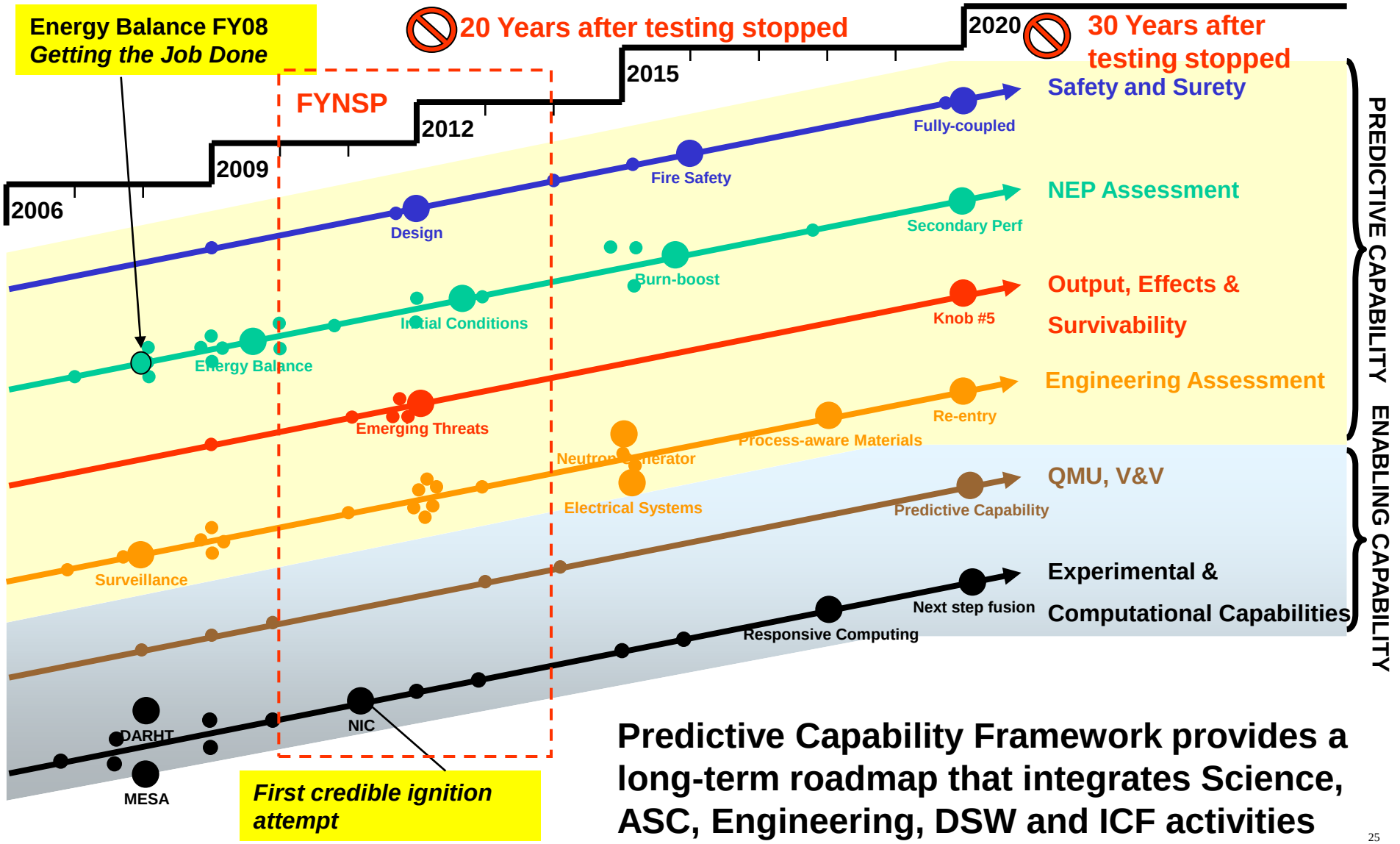
It may be possible to create an electron-positron plasma with high irradiance lasers

- With sufficient HEPW energy an electron-positron plasma may be created
  - conversion of HEPW energy to hot electrons in a high-*Z* target
  - bremmsstrahlung produces high-energy gamma rays
  - gamma rays decay into electron–positron pairs
  - charge-neutral plasma escapes the target — magnetic-field confinement



Electron-positron plasmas are thought to be part of gamma-ray bursters and other astrophysical objects

The Predictive Capability Framework (PCF) is our principal tool for planning the weapons Science and Technology agenda



Predictive Capability Framework provides a long-term roadmap that integrates Science, ASC, Engineering, DSW and ICF activities

User Facilities and Shared National Resources – an important component of the future of NNSA facilities

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There is active work in coupling the PCF with HED planning

Fundamental Source Documents – set weapons requirements

- Primary and secondary certification plans
- SNM Plans

PCF – produces an integrated picture of the linkage and schedule of tasks required for certification and assessment on a continuing basis

Major emphasis areas (e.g. HED) – utilize the PCF linkages And schedules to analyze **resource requirements**

This same methodology can be used to outline the key Directions for IFE research