Fusion Research
at
Los Alamos National Laboratory

G. A. Wurden

Fusion Power Associates Annual Meeting and Symposium
Fusion Energy: Progress and Promise

Dec. 5-6, 2012

LA-UR-12-26728

LANL Fusion Energy Research

Los Alamos has a long history of participation in the US fusion energy (science) research program

- Our scientists and engineers provide critical skills and capabilities.
- About 16 FTE’s, involving 30 staff, are funded by Fusion Energy Sciences projects.
- All of our projects are fiercely competed, typically on a 3-year basis. We collaborate nationally and internationally.
- The downside, is that with budgets being extremely tight, we are turning into a collection of individual PI’s. The average project size doesn’t even support one FTE.

We won six proposals in the "HEDLP 11-583" call in 2012

Exploring the theoretical similarities between quark-gluon plasmas and warm dense matter

Ivan Vitev (T-2), Los Alamos National Laboratory ($255,000)

Large scale kinetic plasma simulation of laser-speckle interaction in nonlinear optical systems as a platform for study of self-organization phenomena

Lin Yin (XCP-6), Los Alamos National Laboratory ($260,000)

Magnetized shock physics for HEDP and astrophysics using a plasmoid accelerator

Tom Intrator (P-24), Los Alamos National Laboratory ($375,000)

Shock-driven hydrodynamic instability growth near phase boundaries and material property transitions

Eric Loomis (P-24), Los Alamos National Laboratory ($200,000)

Pedro Peralta, Arizona State University ($144,000)

Studies of dynamic, radiative macroscopic magnetized HED plasmas with closed B-field lines

James Degnan, Air Force Research Laboratory ($1,300,000)

Glen Wurden (P-24), Los Alamos National Laboratory ($860,000)

Michael Frese, NumerEx ($320,000)

Warm dense matter simulations beyond the Born-Oppenheimer approximation

Jerome Daligault (T-5), Los Alamos National Laboratory ($275,000)

More proposals in response to FES solicitations

- We submitted 7 proposals to the LAB 12-01 Basic Plasma Science call.

Mode conversion driven by plasma inhomogeneities: theory, simulations and experiments – Gian Luca Delzanno

Experimental and Computational Studies of Merging Supersonic Plasma Jets – Scott Hsu

High quality beam acceleration in compact plasma accelerator – Chengkun Huang

Scaling of 3D reconnection and dynamics using multiple flux ropes- Tom Intrator

Numerical Study of Energy Transfer in Spontaneous Current Sheets in Magnetized Collisionless Plasmas – Hui Li

Diffusion layer physics in magnetic reconnection with a large guide field – Andrei N. Simakov

Characterization of Free-floating Atmospheric Pressure Ball Plasmas – Glen Wurden

- We also participated in the SCIDAC call, with two submissions (Tang and Caro) in FY12.

Some recent FES solicitations (continued)

We submitted 6 proposals to the HEDLP-IFE call (LAB 12-02, Oct. 1, 2012).

4 Proposals with LANL as Lead:

Fast Ignition With Laser-Driven Ion Beams: Addressing Key Issue Towards Inertial Fusion Energy (Proposal # LANL20132147, PI: Juan Fernandez)

Plasma Physics Effects in ICF Target Performance (Proposal # LANL20138626, PI: Xianzhu Tang)

Stopping Powers in Inertial Confinement Fusion, Including the Role of Magnetic Fields: LEAD (Proposal # LANL20138625, PI: Anna Hayes-Sterbenz)

Combining high-contrast short-pulse laser and megagauss magnet capabilities for augmented flux, focusability and spectral control for the application of laser-ion sources (Proposal # LANL20138630, PI: Kirk Flippo)

2 Proposals with LANL as Collaborator

Energy and magnetic flux confinement in high energy density plasmas relevant to magneto-inertial fusion: COLLABORATION (Proposal # LANL20138627, LANL PI: Tom Intrator; Lead Lab: Sandia National Lab)

Macroscopic Magnetized HED Plasmas with Closed Magnetic Field Lines for Magneto-Inertial Fusion: COLLABORATION (Proposal # LANL20138629, LANL PI: Glen Wurden; Lead Lab (w/proposal submitted to the General Call) : Air Force Research Lab)

We await FES decisions and Congressional action on FY13 and FY14 budgets

We collaborate on the W7-X Stellarator experiment with PPPL, ORNL, and Germany

- The W7-X superconducting stellarator fusion experiment in Germany will operate for 30 minute long pulses.

- It will have ~ 20 high speed infrared and visible cameras to monitor conditions in the plasma and at the plasma/armor interfaces.

- High spatial resolution images, 14-bit, 1-4 Mpixel, at up to 400 Hz will be streaming over CamLink or 10GigE interfaces, back from the harsh radiation and magnetic environment to an auxillary data acquisition room. (2-3 Gigabytes per second of incoming image data)

- The images must be analyzed in real-time for hot spot development, melting of armor, and plasma position updates, in order to provide signals to the machine control system

W7-X stellarator construction is proceeding. Completion in late 2014

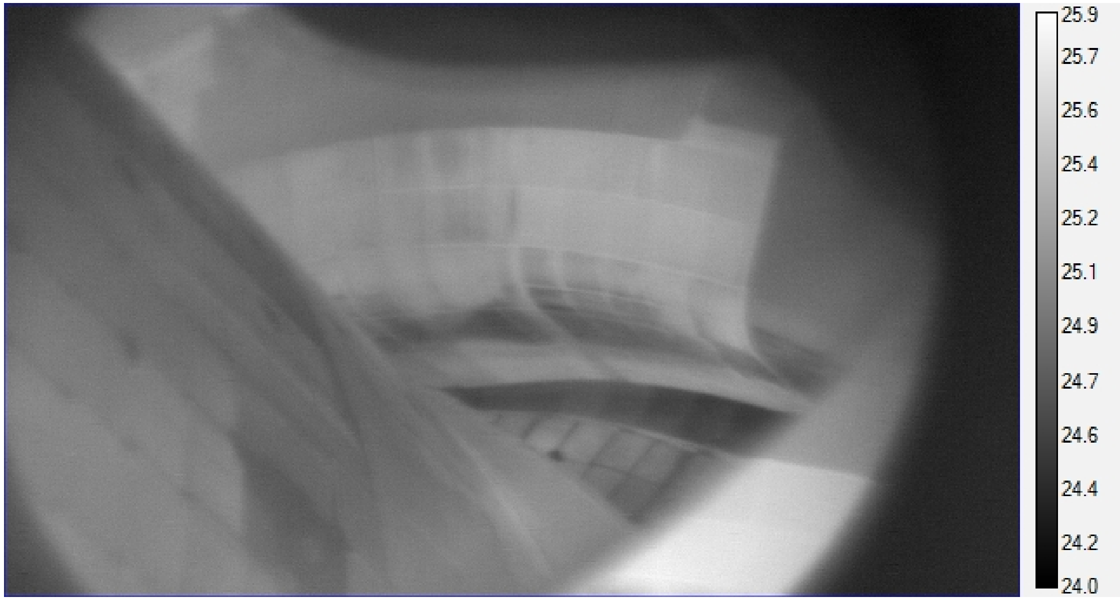
We tested a new high-resolution, high-speed, Infrared camera at Alcator C-Mod

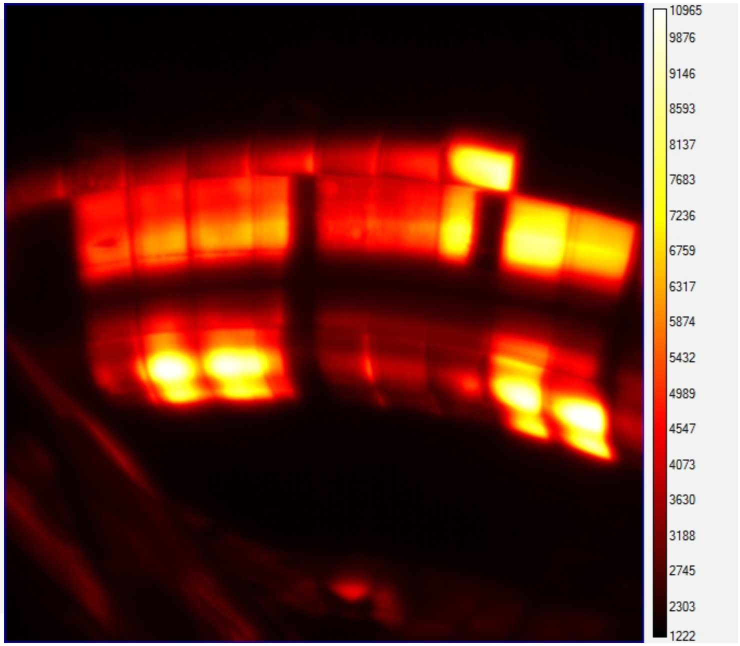
- FLIR SC8303HD camera, 3-5 micron wavelength, 1344x784 pixels, 124 frames/second at 265 Megabytes per second.

The achieved data rate uses a CameraLink (full) interface (Dalsa Xcelera-CL-PX8 frame-grabber) with EDT fiber optic transmitter/receivers. A separate GigE ethernet interface also works, but only up to 1 Gigabit/second (about ½ rate).

Observing the divertor in the mid-IR

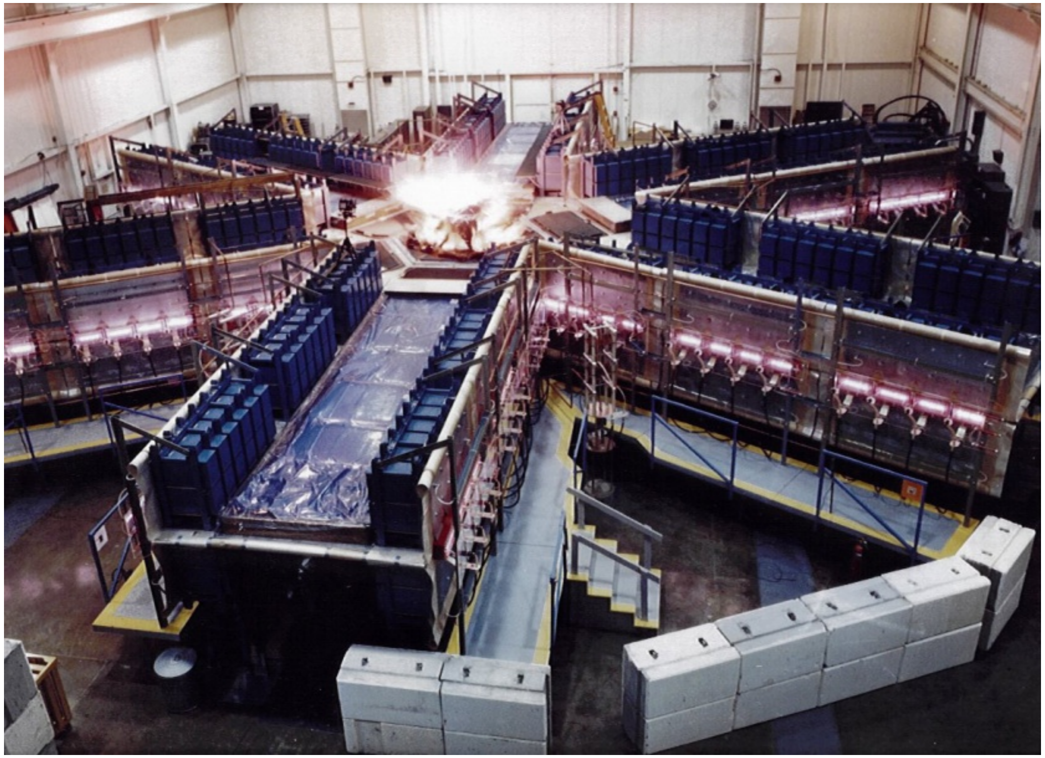
- A new 1344x784 pixel high speed infrared camera was procured this summer, and it and associated high speed fiber-optic communications hardware was tested successfully on the Alcator C-Mod tokamak (Sept 18-20, 2012). ~ 48 pixels across each tile.

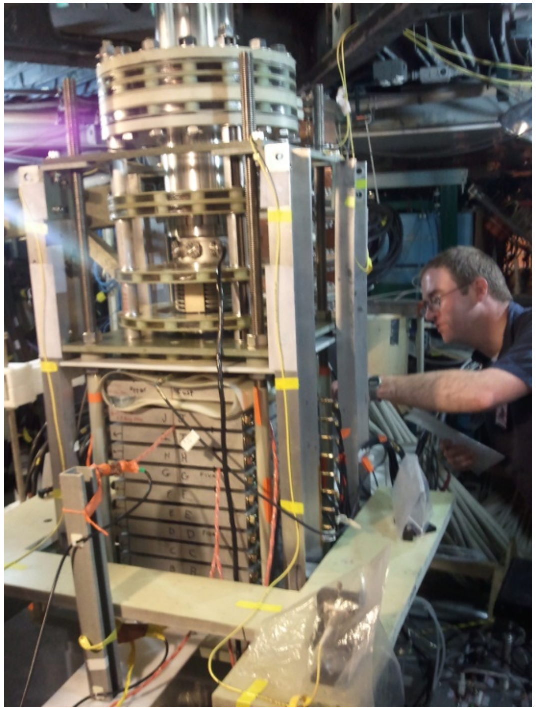




The Zinc Selenide IR periscope gives us a view from above, and looking slightly toroidally, to see the outboard nose and divertor plates.

We collaborate at the SHIVA STAR Air Force pulsed power facility on HEDP magnetized target fusion implosion experiments



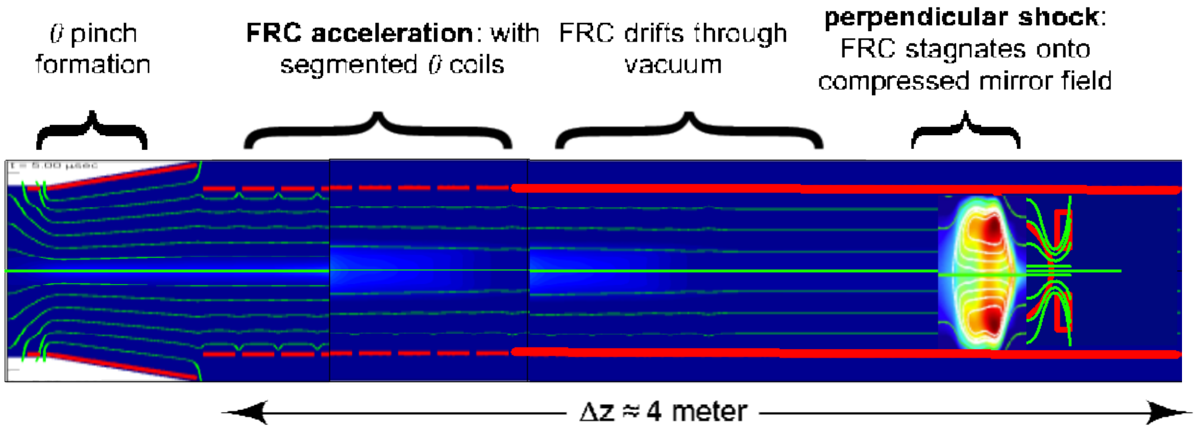


- We recently won an HEDLP funding competition, and received 1-year support (until June 2013). We are also competing in the recent HEDLP-IFE call, awaiting funding decisions from FES.

- Shiva Star can store 9 MJ of energy with 1.3 mF of capacitors, at up to 120kV. More typically, at 4.5 MJ, it delivers 12 MA of current to crush a 30-cm tall, 10 cm diameter, 1 mm thick, 300 gm Aluminum cylindrical liner load in FRCHX, which is located under the center of Shiva Star. We are adding a Russian plasma gun to stabilize the FRC, and improve the FRC lifetime.

Magnetized Shock Experiment (MSX)

OFES/NNSA funded experiment: T. Intrator, T. Weber



After formation and ejection, the FRC is accelerated to high velocities using peristaltically pulsed coils, then impacts against a target.

FRC Field Reversed Configuration: conical θ-pinch

FRC ejection → accelerate to high velocity

Stagnate against a mirror field and/or target plasma

__Advantages over previous experiments:__

Possible long length scales for shock propagation

Macroscopic targets (cm scale)

Plasma is magnetized

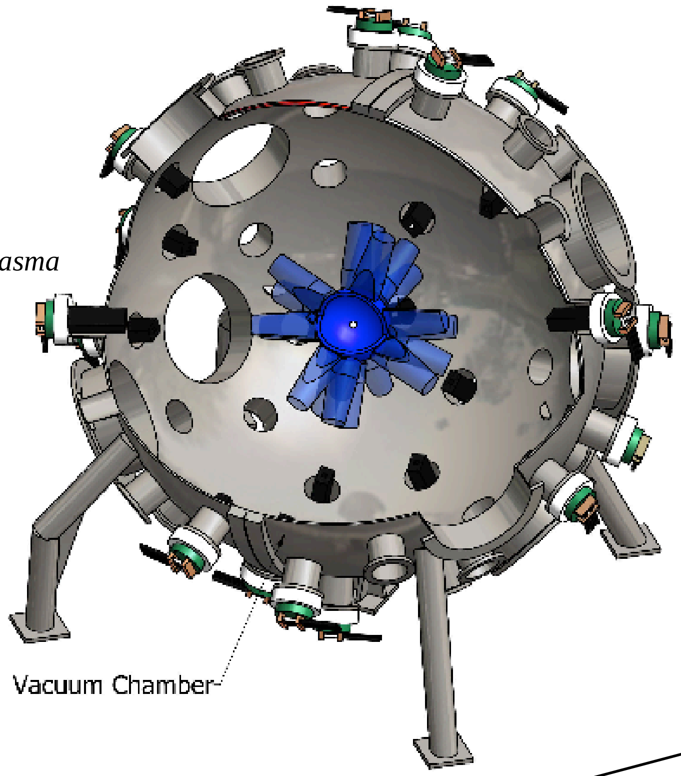
Diffusive Shock Acceleration (DSA) “box” size smaller than experiment

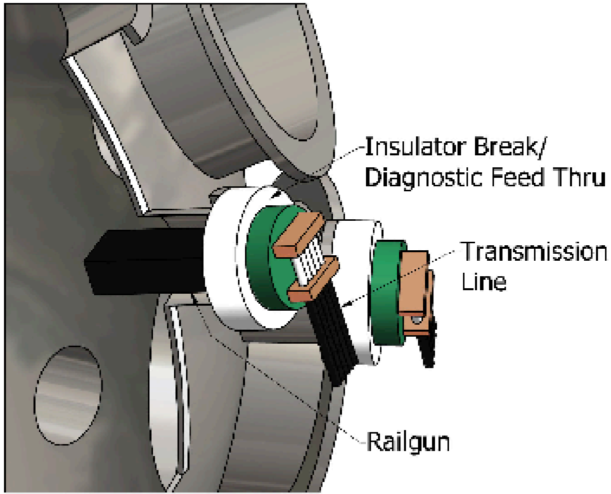
Can access parallel, perp, oblique shocks

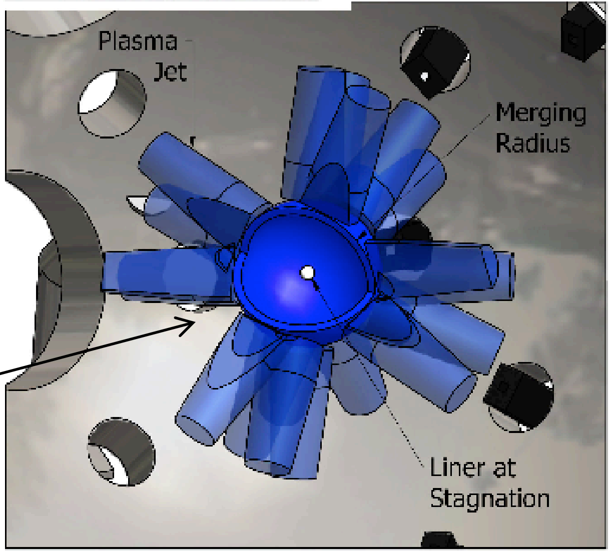
The Plasma Liner Experiment (PLX) was designed to generate imploding spherical plasma liners via thirty merging plasma jets

- **Generate cm-, µs-, Mbar-scale plasmas for HEDLP science**
- **Potential standoff driver for magneto-inertial fusion***
- **Facility now being used for collisionless shock studies (next 2 years)**

*S. C. Hsu *et al.*, "Spherically imploding Plasma Liners as a Standoff Driver for Magnetoinertial Fusion," *IEEE Trans. Plasma Sci.* **40**, 1287 (2012).







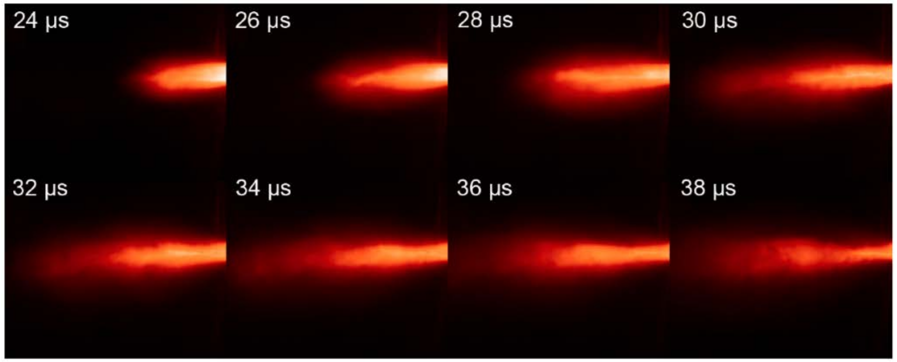
Project goal: achieve 0.1–1 Mbar peak pressures with ~1.5 MJ of initial stored energy.

Plasma liner formed by 30 merging plasma jets

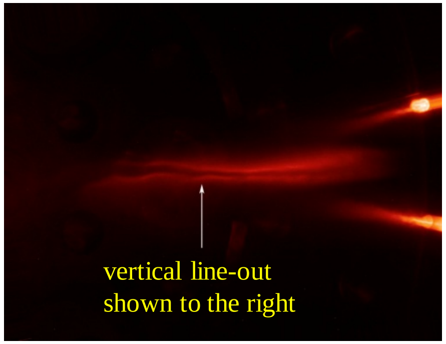
Drawings by David van Doren, HyperV

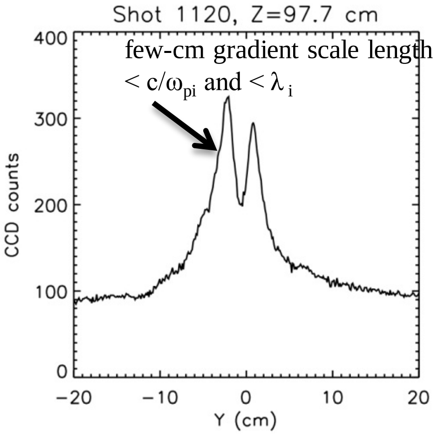
Characterization of the propagation and oblique merging of supersonic argon plasma jets in PLX was completed in 2012

- **Jet parameters, evolution, profiles determined via extensive diagnostic measurements:**
    - Jet parameters are in the range needed by PLX: $n \approx 10^{16}$ cm^{-3}, $V \approx 30$ km/s, M≈15
    - Density drops by ~10x over 40 cm of propagation,
    - Jet profiles have been characterized
    - Record-setting jet parameters demonstrated by project collaborator HyperV Technologies: $n \approx 10^{17}$ cm^{-3}, $v \approx 50$ km, mass=8 mg
- **Interesting jet merge physics obtained:**
    - Multi-layered structure (likely a shock) in plasma emission with thickness < c/ω_{pi} and $<\lambda_i$
    - Two-fluid and possibly kinetic effects important
- **Results are promising for use of merging supersonic jets to form imploding liners:**
    - No degradation in Mach number observed (which would be deleterious for liner performance)
    - Merged structure has inward radial velocity about 25% greater than initial jet velocities
    - Merged structure remains coherent and does not break up



S. C. Hsu *et al.*, “Experimental characterization of railgun-driven supersonic plasma jets motivated by high energy density physics applications,” submitted to *Phys. Plasmas* (2012).





2D electromagnetic PIC simulations demonstrate magnetization of dense plasmas via beat-wave current drive

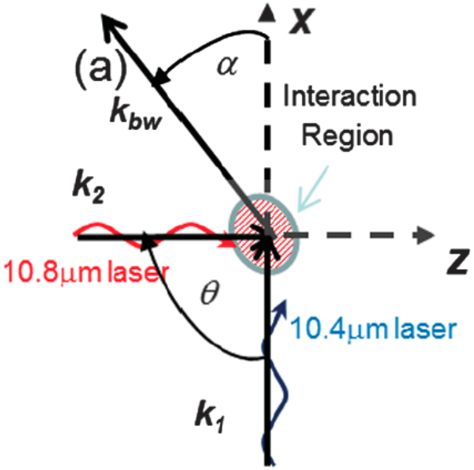
PRL **109,** 225002 (2012) PHYSICAL REVIEW LETTERS week ending 30 NOVEMBER 2012

Simulations of Magnetic Field Generation in Unmagnetized Plasmas via Beat-Wave Current Drive

D. R. Welch,[1] T. C. Genoni,[1] C. Thoma,[1] N. Bruner,[1] D. V. Rose,[1] and S. C. Hsu[2]
[1]*Voss Scientific, LLC, Albuquerque, New Mexico 87108, USA*
[2]*Physics Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*

(Received 14 May 2012; published 28 November 2012)

Setup using LSP code:



- **Key simulation findings:**
  - Beat-wave generation in agreement with theory
  - Electron acceleration, current-drive, and B-field generated demonstrated
  - Process depends on injection angle θ between injected waves, and ratio of beat-wave v_{ph} to $v_{th,e}$
- **Potential applications:**
  - Standoff magnetization for MIF and magnetized ICF experiments
  - Novel plasma physics experiments needing to avoid magnetic coils

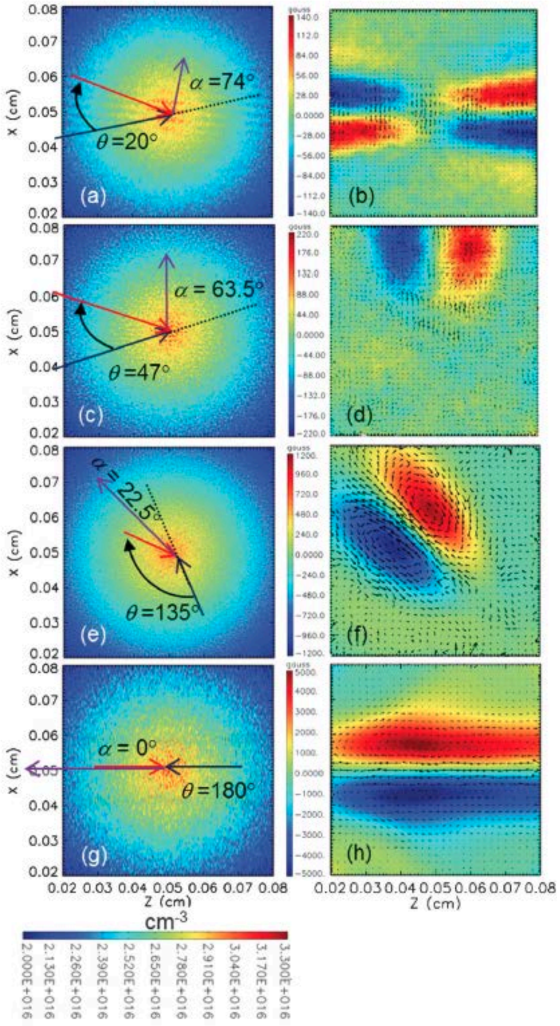
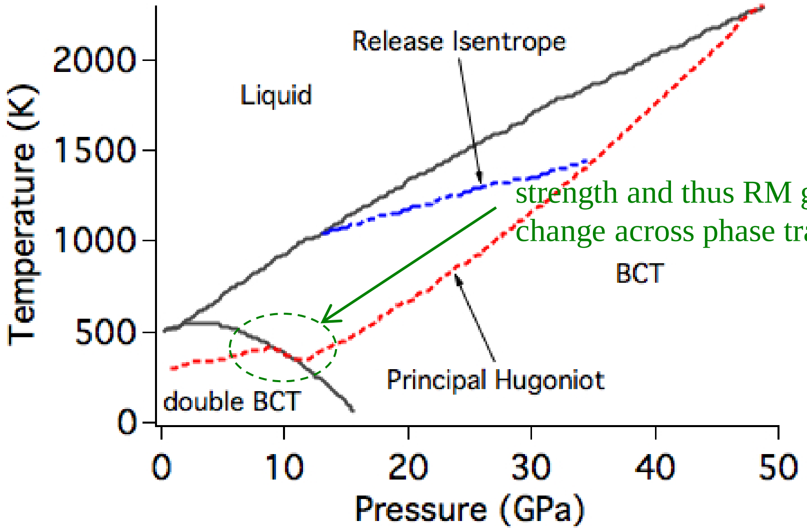


FIG. 2 (color). Beat-wave modulated electron density contours (left column) at $t = 20$ ps for (a) 20°, (c) 47°, (e) 135°, and (g) 180°; magnetic field contours and electron mean velocity vectors (right column) for (b) 20° at 50 ps, (d) 47° at 50 ps, (f) 135° at 100 ps, and (h) 180° at 100 ps. This is for laser intensities of 3×10^{12} W/cm² and 50-eV plasma.

New TRIDENT HEDLP shock experiments will study dynamic material strength across solid phase transitions

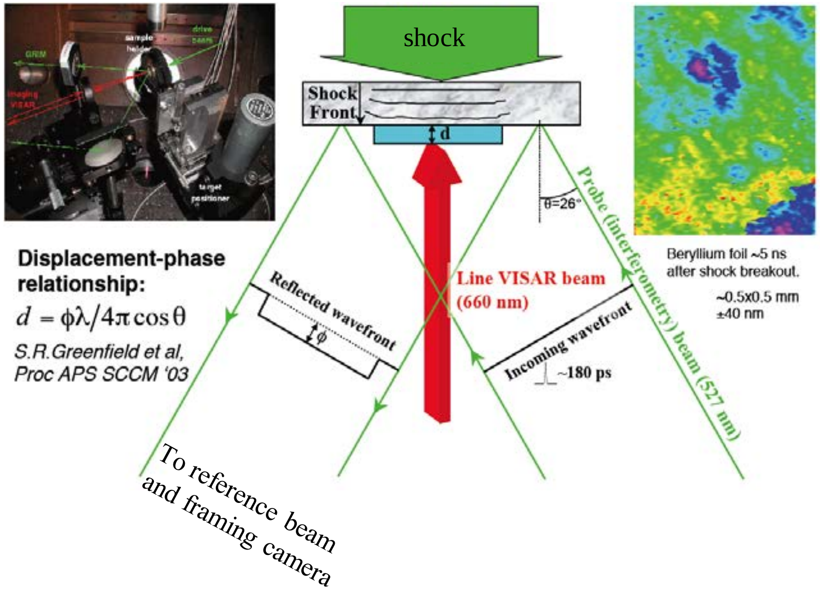
Motivation: Current hydrodynamics codes do not account for the abrupt changes in material strength across solid-solid phase boundaries that significantly affect the behavior of a wide range of dynamic phenomena. Our novel platform will provide the needed data and models using measurements of Richtmyer-Meshkov (RM) growth with optical interferometry. Once demonstrated this technique can then be applied to higher pressure phases and different materials.

Tin undergoes phase change at TRIDENT accessible pressures by plate impact



strength and thus RM growth will change across phase transition

The Transient Imaging Displacement Interferometer (TIDI) measures dynamic displacements in TRIDENT shock experiments



Displacement-phase relationship:

$d = \phi\lambda/4\pi\cos\theta$

S.R.Greenfield et al, Proc APS SCCM '03

Beryllium foil ~5 ns after shock breakout.

~0.5x0.5 mm

±40 nm

- "TIDI" measures relative out-of-plane displacements on a reflecting surface or interface
  - Lateral resolution (5-10 μm)
  - Displacement sensitivity (10's nm)
  - can take up to 16 images each separated by ~25 ns on each shot

LANL's theory/modeling of magnetic & inertial fusion

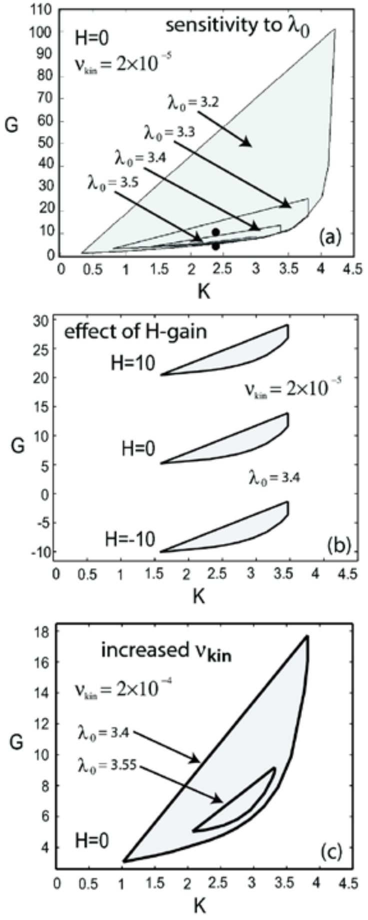
- **OFES supports a fusion theory program in the Theoretical Division: the T-5 Plasma Physics Team (team leader: Xianzhu Tang)**
  - Team has eight staff plasma physicists, six postdocs, four students
- **Magnetic fusion research**
  - Plasma-materials interaction in a tokamak environment: material focus is tungsten
    - Tritium retention: identifying a self-healing mechanism of radiation-induced defects (tritium trap site) via stress-induced grain boundary motion.
    - Helium recycling at W surface: molecular dynamics calculation of He reflection & implantation.
  - Sheath/Scrape-off layer of a tokamak with low-recycling and high-recycling walls :
    - develop a theory for parallel transport along a magnetic field including the parallel heat flux closure and the plasma profile variation, and the kinetic theory for ambipolar transport in a low collisionality edge plasma.
    - Develop sheath theory/simulation for both low recycling and high recycling regime; dust motion/survivability near a tokamak divertor/first wall.
  - Edge and pedestal transport and stability:
    - Develop a theory for turbulence driven bootstrap current
- **Inertial fusion research:** Plasma physics effect in ICF target performance:
  - Self-generated and externally imposed B on Rayleigh-Taylor mix and hot spot transport
  - Fuel ion separation by baro-, electro-, and thermo-diffusion
  - Tail ion depletion from the hot spot via collisionless loss into the cold fuel layer.

LANL Theory Collaborations

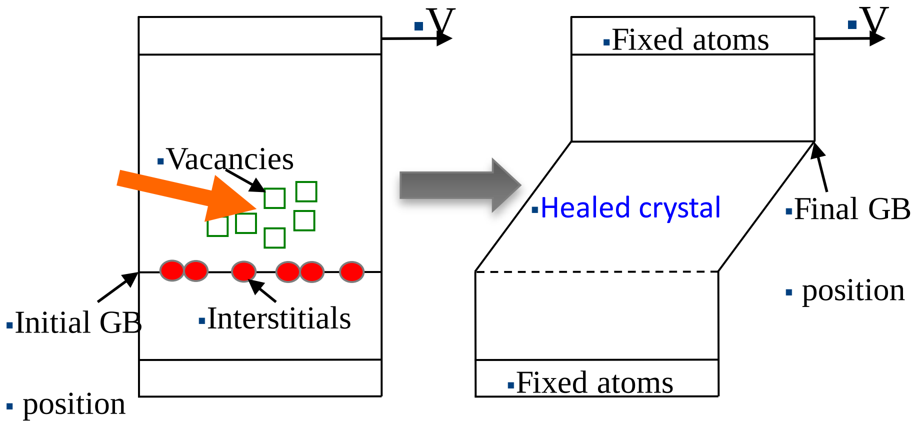
- PPPL collaboration (John Finn, C. L. Ellison – grad student; H. Qin; W. Tang) – variational integrator for guiding center equations with adaptive time step
- U. Wisconsin (John Finn, Z. Billey, grad student; E. Zweibel; W. Daughton, LANL; W. Gekelman, UCLA) – field line diagnostics for magnetic reconnection for use in MHD codes, PIC codes, and LAPD data.
- Columbia U, Wisconsin (John Finn, A. Cole, Columbia; C. Hegna, UWM, P. Terry, UWM) – momentum transport by overlapping resistive layers in RFPs and tokamaks
- U Tulsa (D. Brennan) – *m=1* mode (seen in DIII-D), localized inside radius of minimum of *q*, driven by energetic particles in reversed shear discharges (PEST, NIMROD)
- U Tulsa (D. Brennan, K. Sassenberg) – Resistive plasma, resistive wall external kink in toroidal geometry (PEST-III); preparation for control studies in toroidal geometry

Highlight: Plasma Control at RFX in Italy Finn, Brennan, et al.

- Resistive wall control in Reversed Field Pinches – 3 components of magnetic field
- To model RFX-mod: 2 resistive walls: stainless vacuum vessel & copper shell outside
- *(G,K)*: gain for radial and 1st tangential components; *H*=gain for second tangential component. l_0 in (a) is current parameter $j \cdot B/B^2$ at $r=0$
- Stable region shrinks as ideal plasma – ideal wall limit is approached – well above resistive plasma – ideal wall limit, *H* gain changes shape in *(G,K)*; viscosity stabilizing
- RFX-mod team (Piron, Piovesan, Martin, Marrelli) has plans to try this control scheme *(G<K)* soon

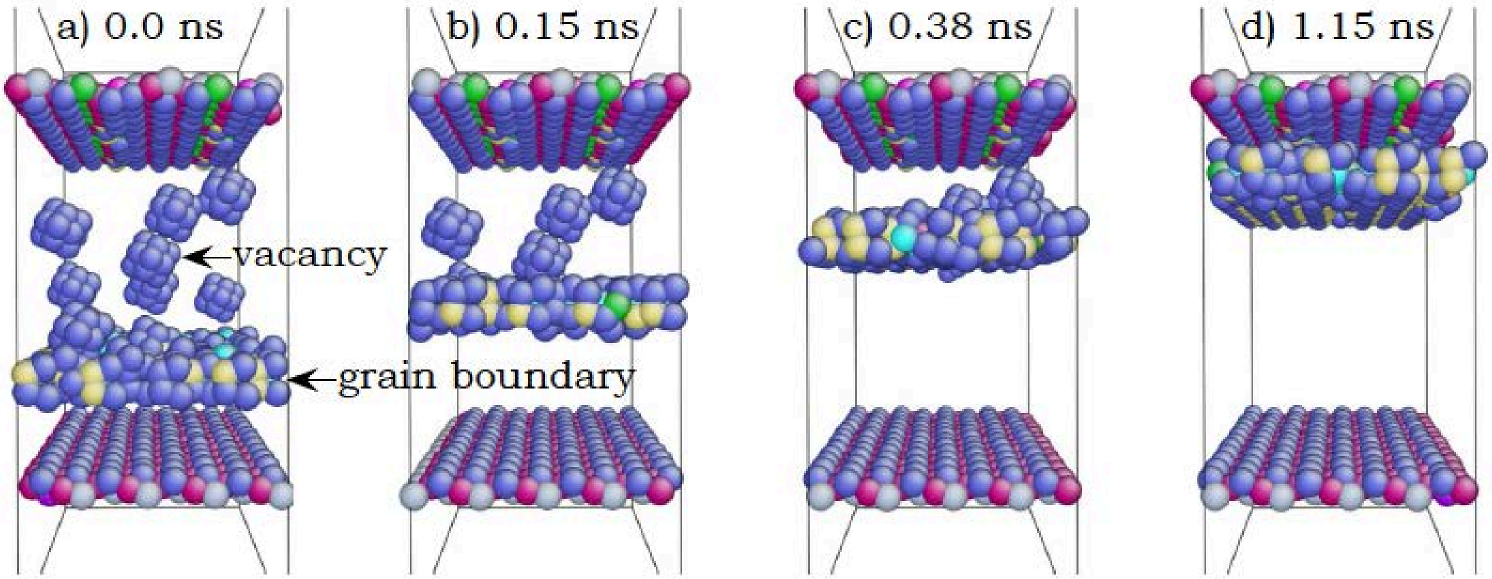


Theory Highlight: Tritium trapping, self-healing by grain boundary motion



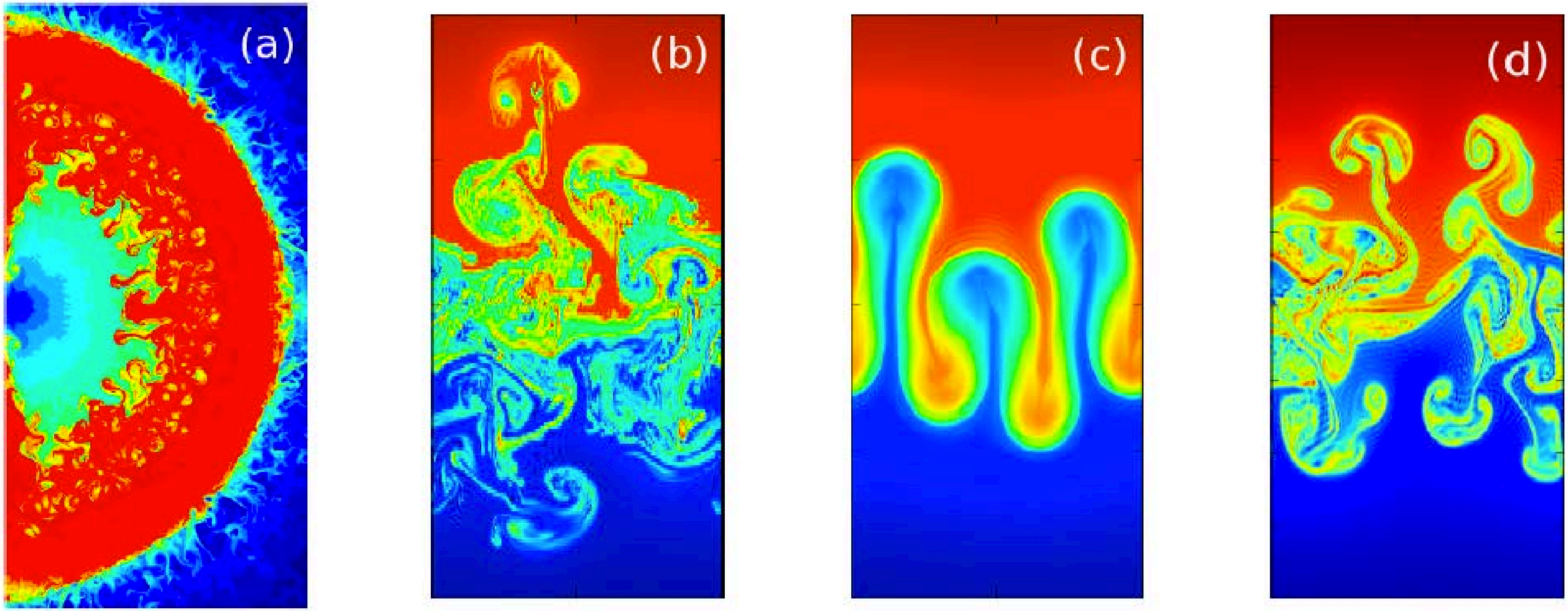
- V
- Vacancies
- Initial GB
- Interstitials
- position
- Fixed atoms
- V
- Healed crystal
- Final GB
- position
- Fixed atoms

A collision cascade produces vacancies and highly mobile interstitials; the diffusing interstitials find, and are trapped at, a nearby GB. The interstitial-loaded GB is now so easy to shear that internal stresses in the crystal may start it moving, and the coupled motion causes it to sweep past the cascade center, sweeping up the vacancies as it moves through.



Borovikov & Tang et al, J. Phys. Condensed Matter (2012)

B field & ion viscosity have a large impact on ICF mix & hot spot thermal loss



Our two-fluids plasma simulation show dramatic effect of externally imposed B field (c) and hot spot ion viscosity (d) on Rayleigh-Taylor mix compared with inviscid limit (b) in a planer geometry with plasma parameters typical of the ICF spherical implosion (a). The electron magnetization is found to reduce thermal conductivity from the hot spot by a factor of a few to 3 orders of magntiude.

Srinivasan, DiMonte, & Tang, PRL (2012); Srinivasan & Tang, PoP (2012); Invited Talk at APS/DPP’12.

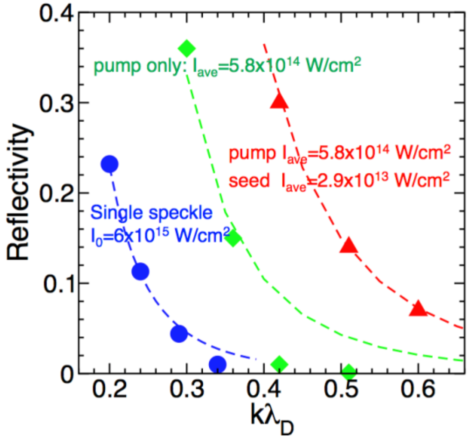
LANL Engineering Tritium programs for Fusion

- Z-Pinch Tritium Injector Fill Final Design, FAB/Procure
  - (Partnership with SNL) Craig Taylor
- LIFE Tritium Plant Conceptual Design
  - (Partnership with LLNL, SRNL and SRS) Craig Taylor
- Shell DT Target Fill Design
  - (to be implemented at LLNL) Art Nobile
- ITER Tritium Building Preliminary Safety Analysis (WFO)
  - Kirk Hollis
- ITER Tritium Plant Commissioning Plan (WFO)
  - Craig Taylor and John Tapia
- ITER Liquid Phase Catalytic Exchange Column Simulation (WFO)
  - Bill Kubic

*We would like to land US-ITER work packages, rather than just a string of ITER-IO sole source (350k Euro max) contracts.

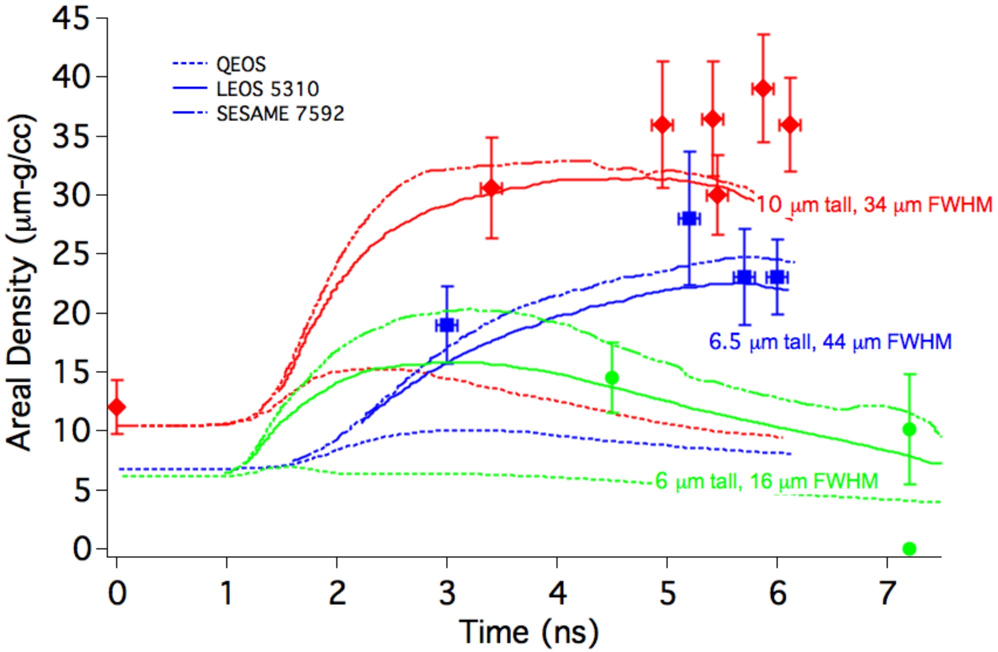
ICF @ LANL provides basics of theory, diagnostics, and experimental results for fusion

- Petascale PIC investigations show higher Te lowers SRS



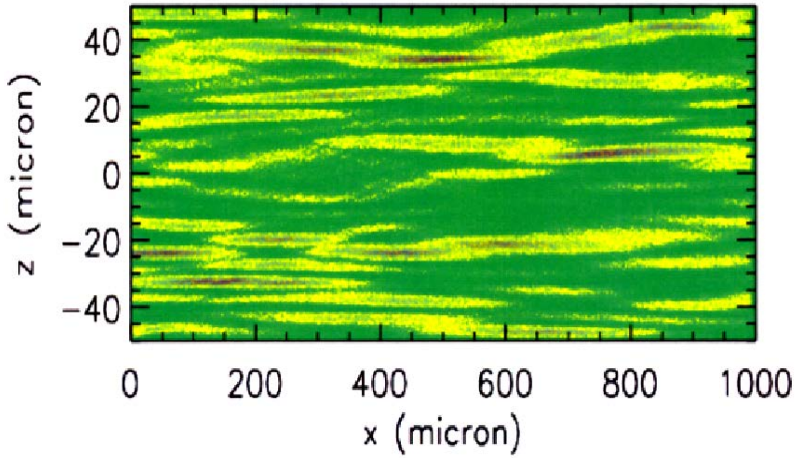
- Gamma diagnostic measures DT branching ratio
- On NIF, measures time of peak neutron burn. We have multiple personnel stationed at NIF.

- **Experiments at Omega validate ablative Richtmyer-Meshkov theory and simulations**



Stimulated Raman scattering in multi-speckled IFE laser beams has complex, nonlinear behavior

Multi-speckle laser field from VPIC simulation



DOE FES project: "Large scale kinetic plasma simulation of laser-speckle interaction in nonlinear optical systems as a platform for study of self-organization phenomena" – PI Lin Yin

- Self-organization arises when the interactions among elements in a system give rise to *ordered, collective* phenomena
- Stimulated Raman Scattering (SRS) exhibits self-organization[1] - the "systems" are laser beams comprising hundreds or thousands of individual laser speckles (for f/8 beam, λ = 351 nm, speckle size is 3x3x140 μm)
- Self-organization is a property of the *ensemble*, not the individual elements, and must be studied in the aggregate
- **One of LANL's IFE research thrusts is to use large-scale multi-speckle simulations with the VPIC code[2] to understand self-organization of laser speckles**

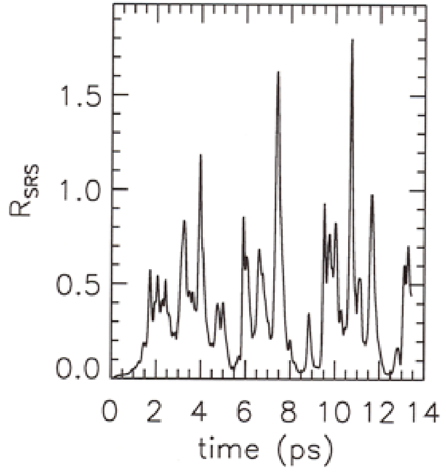
[1] Yin et al., *Phys. Rev. Lett.*, 108, 245004 (2012)

[2] Bowers et al., *Phys. Plasmas*, 15, 055703 (2008)

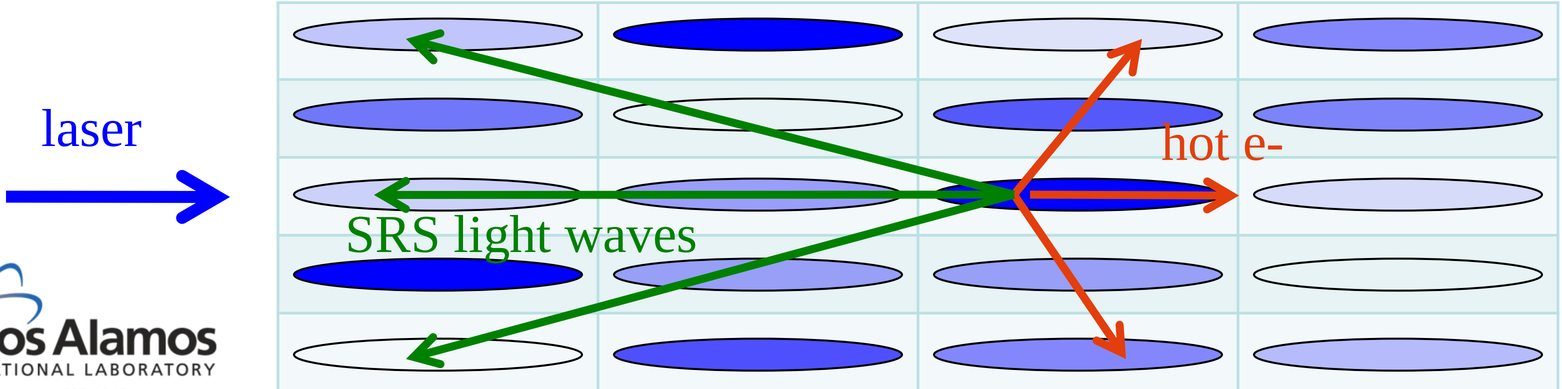
This multi-speckle coupling takes place through the exchange of electrons and light waves

- SRS generates hot electrons in a high-intensity laser speckle that propagate forward, lowering the Landau damping in the neighboring speckles and destabilize them for SRS
- SRS also generates backward-propagating scattered light that seeds large SRS in neighboring speckles
- **This nonlinear interaction of ensembles of speckles gives rise to bursty, avalanche behavior**

SRS reflectivity showing bursty behavior



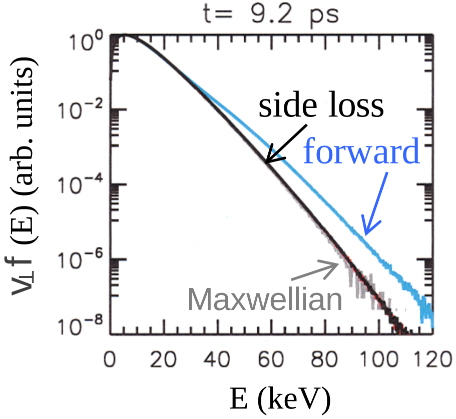
Laser beam: an array of speckles



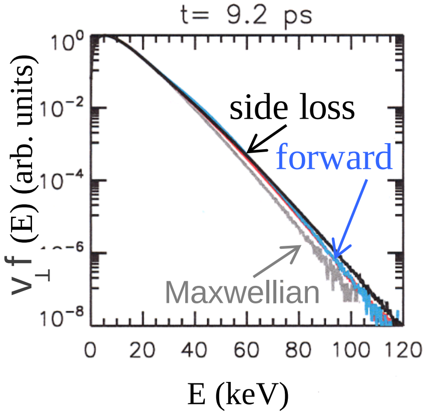
Multi-speckle simulations with a B field allow us to isolate effects of SRS light wave and hot e- exchange

- A strong B field allows us to control the cross-speckle hot e- coupling
- By changing speckle polarization and plasma conditions ($k\lambda_D$), we can adjust light wave coupling

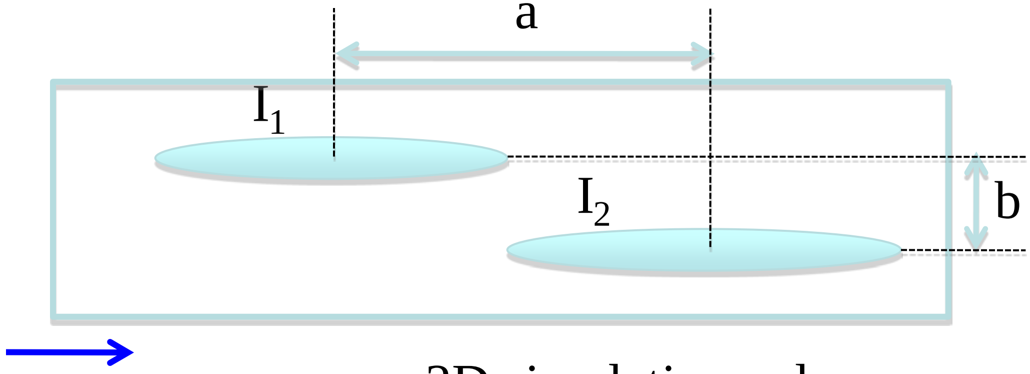
Hot e flux with B_x field
$\Omega_{ce}/\omega_{pe} = 0.01$



Hot e flux without B_x field



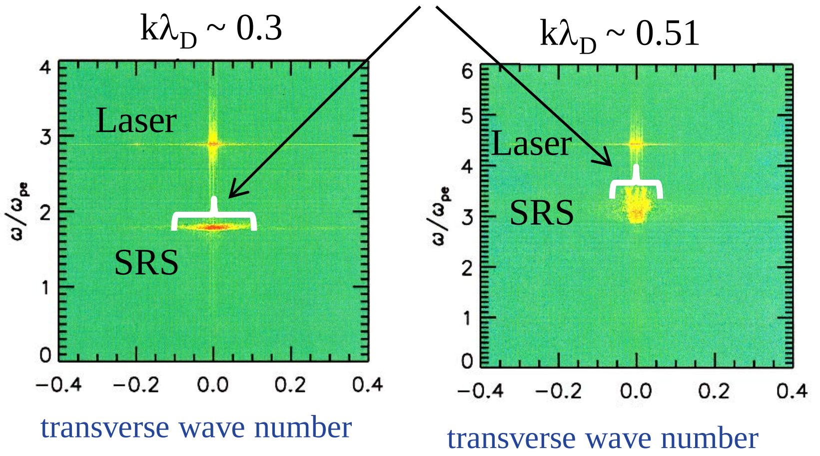
We also simulate SRS in small numbers of interacting laser speckles



Laser launched from left boundary

2D simulation volume

Scattered light-wave spectra – higher $k\lambda_D$: smaller cone of SRS backscatter

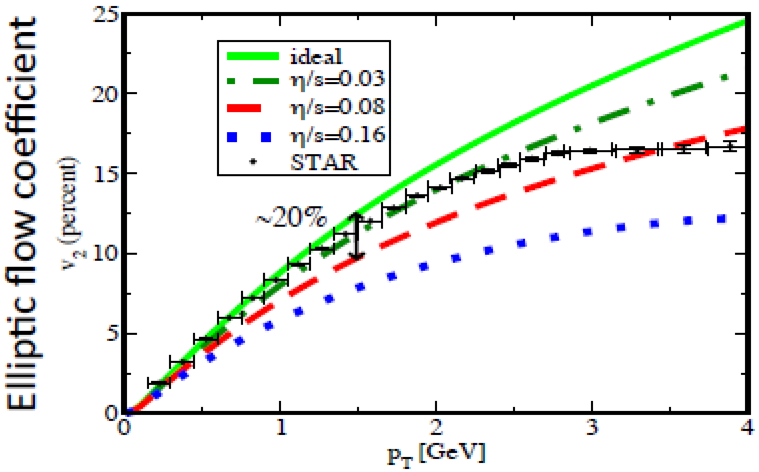


Exploring the Theoretical Similarities between Quark-Gluon Plasma and Warm Dense Matter

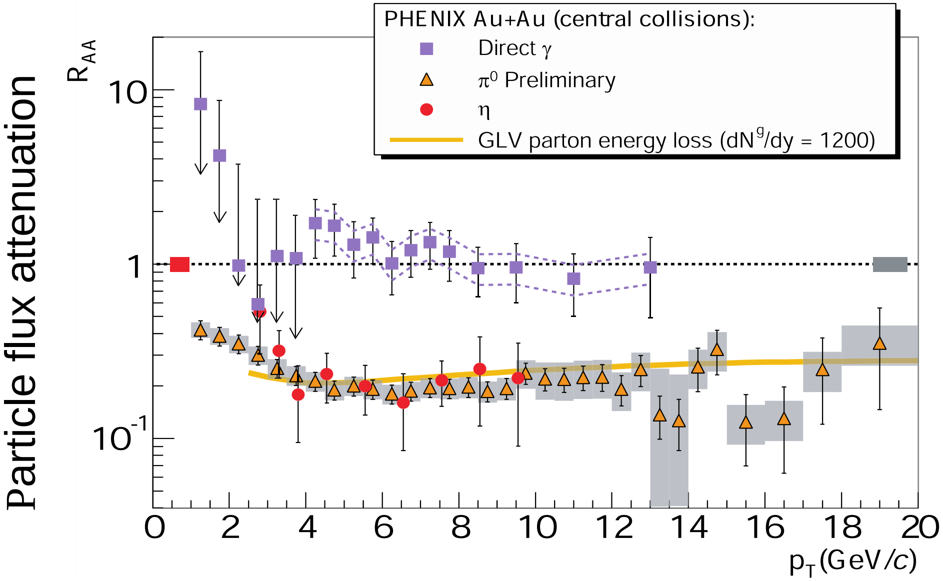
PI Ivan Vitev (APS Fellow and DOE-NP Early Career Award) , Co-PI Jerome Daligault,

Use the tremendous commonality in the intellectual approach to the theoretical and experimental tools for the characterization of quark-gluon plasmas (QGP) and warm dense matter

Collective QGP behavior

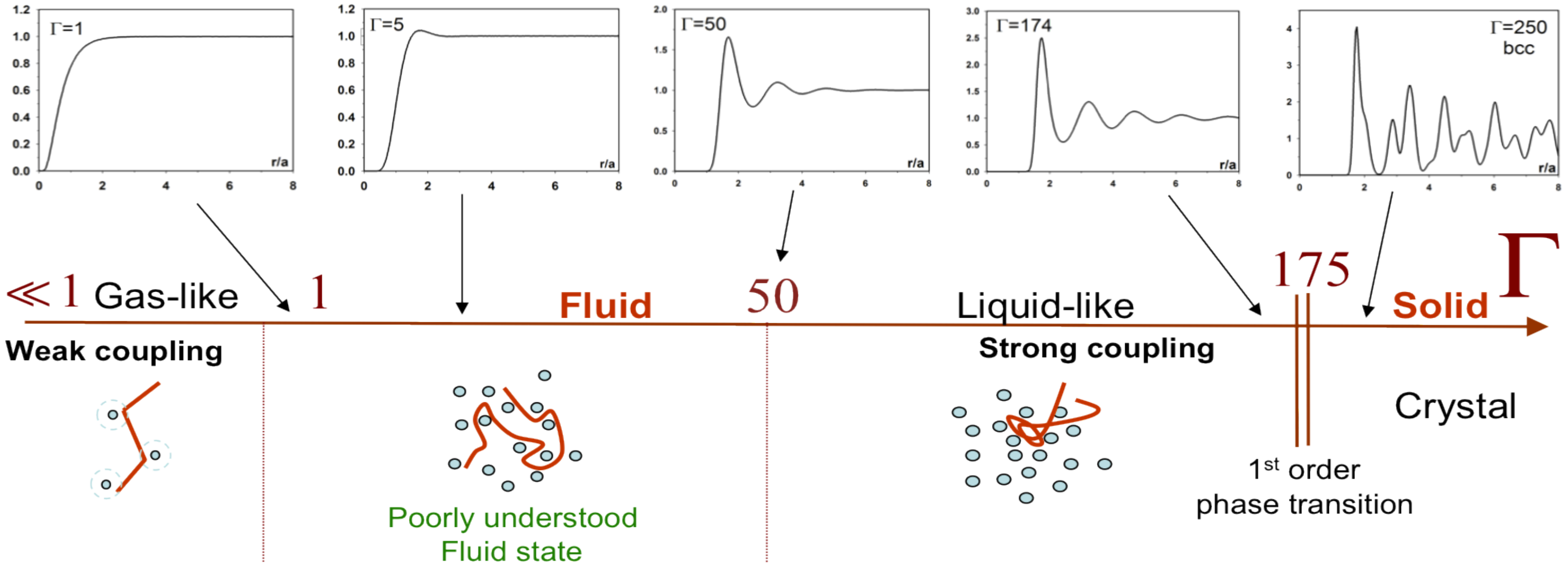


Large stopping power



The Strongly-Coupled Regime

QGPs behave like strongly-coupled liquids with very small ratio of shear viscosity to entropy density. (Nearly perfect liquid). Coupling $\Gamma = \frac{P.E.}{K.E.} \approx 2-4$



QGPs are the least understood fluid state of strongly-coupled electron-ion plasmas

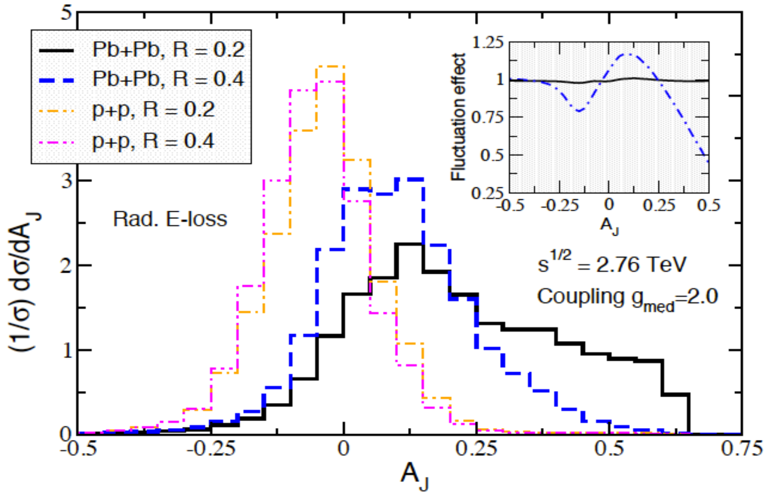
We focus on the stopping power of matter –dE/dx and formation of showers in such plasmas (quark-gluon showers and electron-ion showers). Compare the analytic calculations to molecular dynamics simulations for the SCCP.

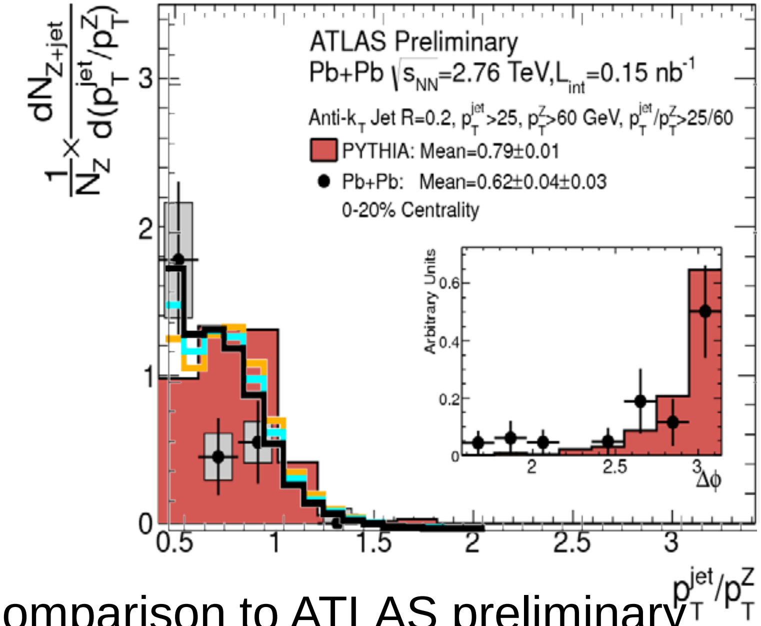
First Application of Our QGP Results: Z^0-Tagged Jets

Evaluating the Z^0-tagged jet asymmetry distribution modified by the strongly-coupled plasma at the LHC

$$A_J = \frac{p_{T\,Z} - p_{T\,Jet}}{p_{T\,Z} + p_{T\,Jet}}$$

R.B. Neufeld, I. Vitev. Phys.Rev.Lett. 108 (2012) 242001





Modified asymmetry distribution due to shower E-loos in the QGP

Comparison to ATLAS preliminary results for a related observable z_J

Selected as a highlight of the jet session of QM2012 – the biggest conference in the field

Use of Spallation Sources for Fusion Materials Testing

- The Spallation Neutron Source (SNS) and the proposed LANSCE Materials Test Station (MTS) utilize existing MW-class proton accelerator facilities that operate at 90% availability over 4000-5000 hours per year in support of non-fusion DOE missions in materials, nuclear science, and radioisotope production.
- Advantages: $B site credits, ability to produce relevant dpa rates & He/dpa ratios with the right target, ability to test bulk properties, & low operating costs (high neutron flux per Watt).
- Technical issues: High-energy neutron tail, temperature control, solid transmutation, & pulsed irradiation. SME peer-reviewed publications reveal conditions consistent with those of DEMO first wall, and transmutant in-growth should not be a concern. Proponents note that the broad range of He and H generation rates can be exploited to critically assess computational models of He & H effects.


SNS (Oak Ridge)

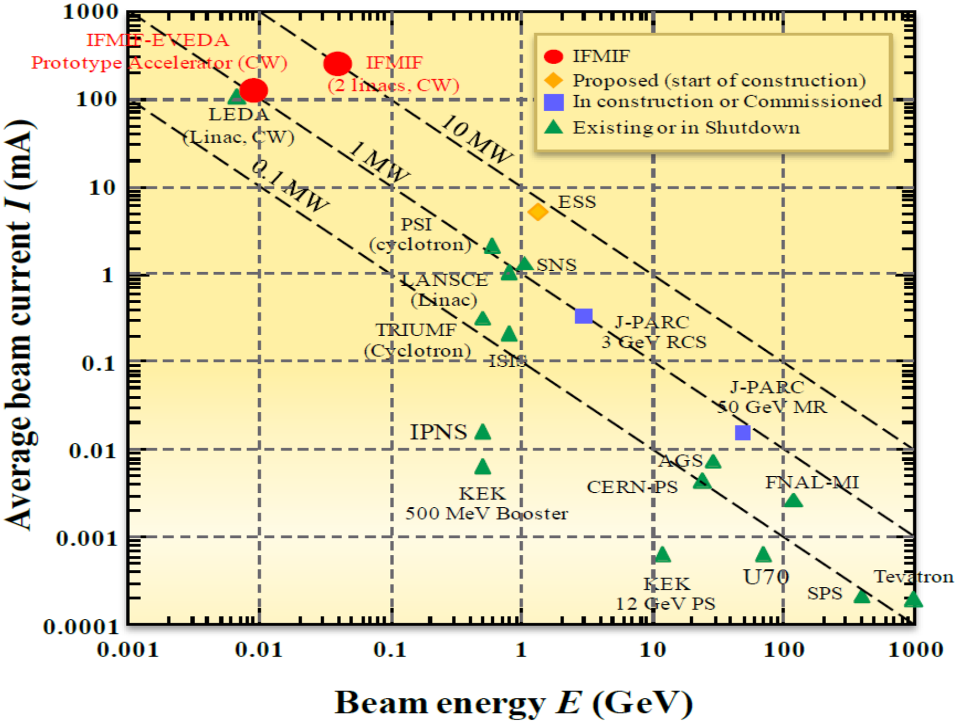

LANSCE (Los Alamos)


SINQ(Paul Scherrer Inst.)

J-PARC (JAEA & KEK)


ISIS (Rutherford Appleton Lab)

SNS & LANSCE are two of the five high-power proton linacs currently operating in the world.



Conceptual design studies at ORNL & LANL indicate viability of spallation sources for fusion materials development

- SNS (ORNL) w/ 1.4-MW beam power on existing spallation target
  - Irradiation volume: ~ 20 cm^3
  - Primary knock-on atom (PKA) spectra comparable to ITER
  - Displacement production: $\leq$ 5.5 dpa/yr in steel, $\leq$ 3.4 dpa/yr in SiC
  - He gas production: 13–75 appm He/dpa in steel, and 30–98 appm He/dpa in SiC
- LANSCE (LANL) w/ 1-MW beam power on the MTS target
  - Fusion-relevant irradiation volume: ~ 100 cm^3 (10% of total volume)
  - PKA spectra comparable to fusion reactor first wall
  - Displacement production: $\leq$ 15 dpa/yr in iron
  - He gas production: 5 – 35 appm He/dpa in iron
  - Transmutation residue yields of phosphorous and sulfur in steel alloys irradiated to high dose calculated to be less than typical as-fabricated concentrations
- LANL supports the ORNL Fusion Materials Irradiation Test Facility at SNS (FMITS) for proof-of-concept demonstrations

24th IAEA Fusion Energy Conference - IAEA CN-197

Contribution ID : 6

FTP/P1-27: Fusion Material Irradiation Test Facility at SNS

Tuesday 09 Oct 2012 at 08:30 (04h00')

THE SUITABILITY OF THE MATERIALS TEST STATION FOR FUSION MATERIALS IRRADIATIONS

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Received November 15, 2011
Accepted for Publication March 23, 2012

Los Alamos National Laboratory has completed the conceptual design of the Materials Test Station (MTS), an accelerator-driven neutron source for irradiating nuclear fuel and materials in a fast neutron spectrum. In many respects, the irradiation conditions in the MTS are quite similar to those experienced by the first wall of a fusion reactor. Calculated He-to-dpa (displacements per atom) ratios range from 35 down to 5 appm He/dpa, allowing for critical testing of helium effects on mechanical properties under fusion-relevant conditions. We present here a brief history on the assessment of spallation sources for fusion materials testing and discuss irradiation conditions in the MTS as they pertain to testing materials for fusion reactor applications. In particular, we examine the production of spallation residues in the MTS for the fusion reactor candidate alloy EUROFER97 and compare the concentrations of these transmutation elements to those predicted for a fusion reactor first wall. We show that predicted yields of phosphorous and sulfur in steel alloys irradiated to high dose in fusion-relevant regions of the MTS are below typical as-fabricated concentrations.

KEYWORDS: *spallation source, fusion materials testing, neutron irradiation*

Note: The figures in this paper are in color only in the electronic version.

I. INTRODUCTION

The Materials Test Station (MTS) is an irradiation facility under design at Los Alamos National Laboratory with the mission of providing a test bed for fuels and materials under development for the next generation of fast-spectrum fission reactors. As an irradiation facility for nuclear fuels and materials it is unique in that the source of neutrons is nuclear spallation rather than nuclear fission. The neutron source is driven by a 1-MW proton beam delivered by the Los Alamos Neutron Science Center (LANSCE) linear accelerator. Conceptual design of the facility is now complete. Preliminary and final design phases are estimated to take two years, followed by two years to construct the facility. The total project cost range to complete design, construction, and commissioning is \$75M to \$95M. The US Department of Energy's Office of Nuclear energy is the principal sponsor. The facility concept and essential features are described elsewhere.[1]

In the irradiation regions of the MTS, the neutron spectrum closely matches that of a fast reactor, with the addition of a high-energy tail (above 10 MeV) that is an unavoidable consequence of the spallation process used to produce the neutrons. The fraction of neutron flux in the irradiation region with energies exceeding 10 MeV ranges from 2.4% to 7.2%, depending on the irradiation position.[2] These neutrons can induce nuclear reactions, such as $(n, x\alpha)$, whose threshold energies exceed several MeV. For iron-based alloys, this leads to elevated concentrations of helium relative to that which occurs in fission reactors. In the peak flux positions, the He/dpa ratio matches very well that seen in a fusion reactor first wall, making the MTS potentially suitable for fusion materials testing.

II. HISTORY OF SPALLATION SOURCES FOR FUSION MATERIALS TESTING

The use of spallation sources for fusion materials testing was proposed as early as 1978 (Refs. 3 and 4). Several groups have investigated this concept, with perhaps the most significant effort in the 1980s being the EURAC facility, which used a 600-MeV, 6-mA (3.6-MW)

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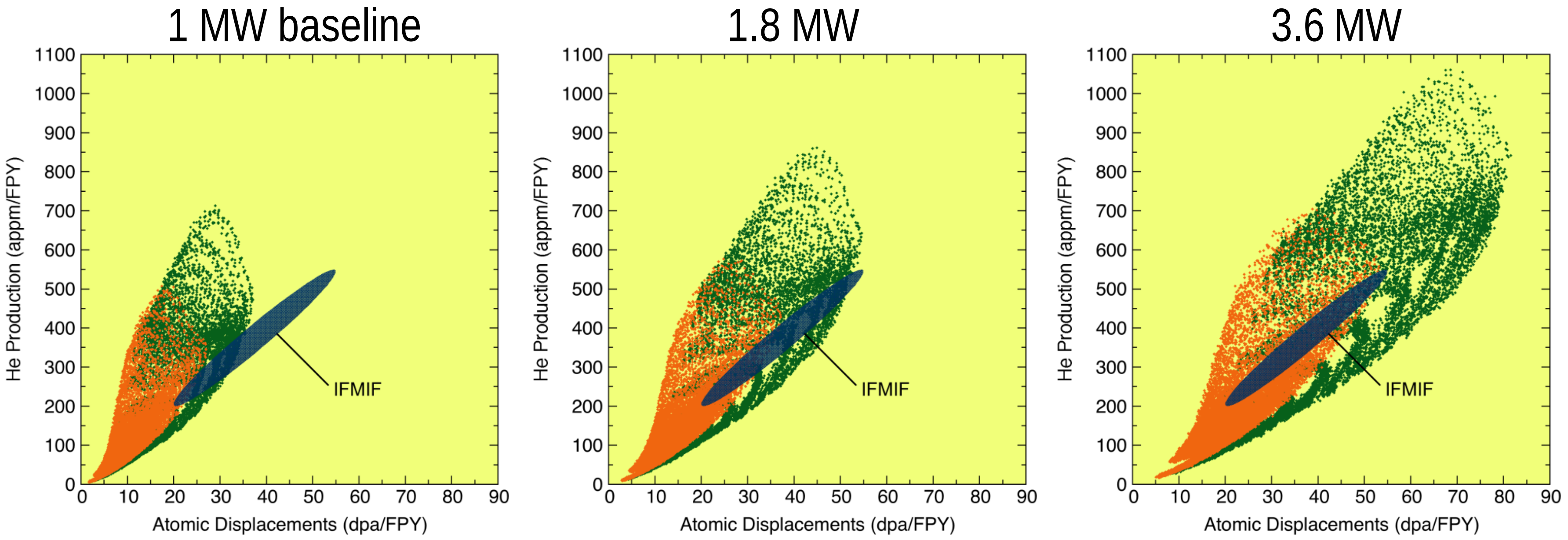
MTS would be a cost-effective international irradiation facility after successful demonstrations on FMITS

- Current MTS cost estiamte is \$75M to \$95M (1-MW baseline)
- LANSCE beam power upgrade options:



Displacement vs. helium production rates for 40-mm^3 volume elements in the central (green dots) and outer (orange dots) irradiation regions of MTS. The total irradiation volume is ~ 1000 cm^3.

Summary

- As a multi-mission NNSA laboratory, LANL brings many skills and talents to the FES Office of Science programs
- The LANL ICF program will continue to pursue ignition and HED physics with specialties in theory, simulation, experiment, and diagnostics.
- We support the goals of a balanced FES fusion research program in ITER, plasma simulation, plasma control, plasma materials science, HEDLP and basic plasma science.
- We are concerned about the impact of cuts to the domestic FES program, especially in light of growing ITER commitments, and the subsequent viability of the U.S. plasma physics and fusion research enterprise should there be additional cuts in future years. We are dangerously approaching the tipping point with the FY13 request.