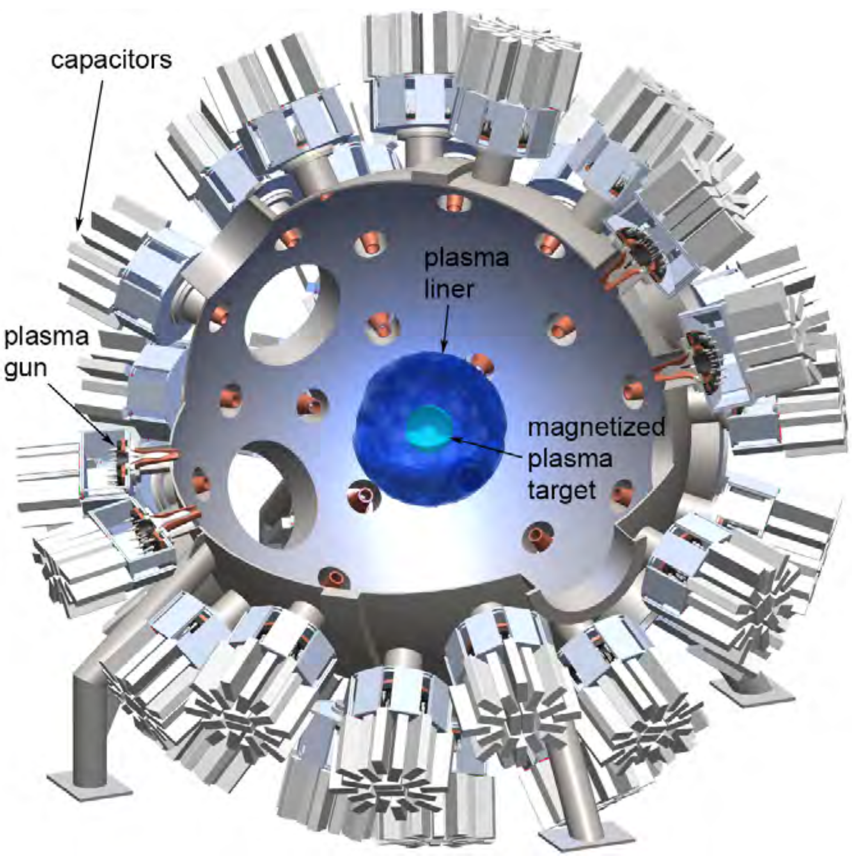
Spherically Imploding Plasma Liners: A Potentially Transformative Fusion Driver



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CHANGING WHAT'S POSSIBLE

Scott C. Hsu, LANL

for the PLX-α Project Team

ALPHA Annual Meeting

Seattle, WA

August 10, 2016

Plasma Liner Experiment–ALPHA (PLX-α) project institutions and team members

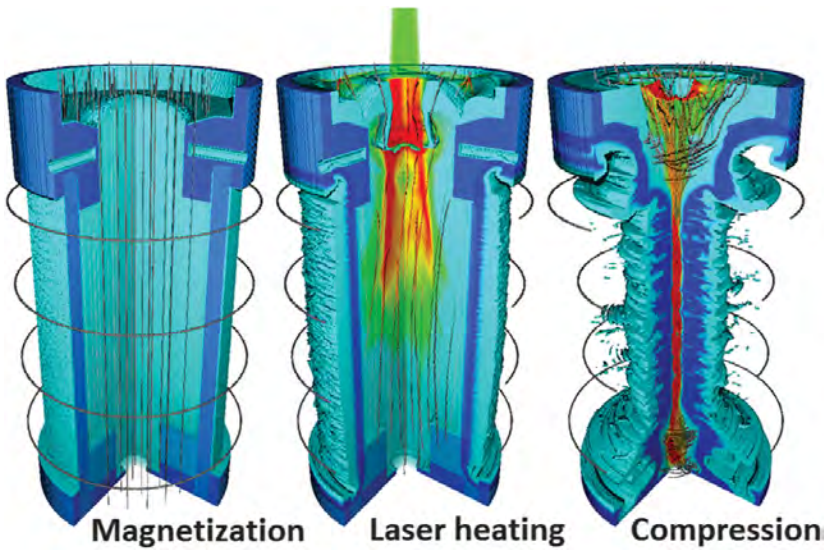
Institution	PI	Personnel	Primary role
Los Alamos National Laboratory	Scott Hsu	Samuel Langendorf§ John Dunn Ricardo Martinez Jackie Vaughan*	Overall lead; plasma-liner experiments
HyperV Technologies Corp.	F. Douglas Witherspoon	Sam Brockington Andrew Case Ed Cruz Marco Luna	Coaxial-plasma-gun development & fabrication
University of Alabama in Huntsville	Jason Cassibry	Kevin Schillo*	Simulations (3D SPH) in support of PLX-α experiments
University of New Mexico	Mark Gilmore	Kevin Yates§	Diagnostics
Brookhaven National Laboratory	Roman Samulyak	Wen Shih*	Simulations (3D FronTier) in support of PLX-α experiments
Tech-X Corporation	Peter Stoltz	Kris Beckwith Madhusudhan Kundrapu	Simulations (1D/2D radiation-MHD) of fusion-relevant PJMIF configurations

§Postdoc
*Student

Outline

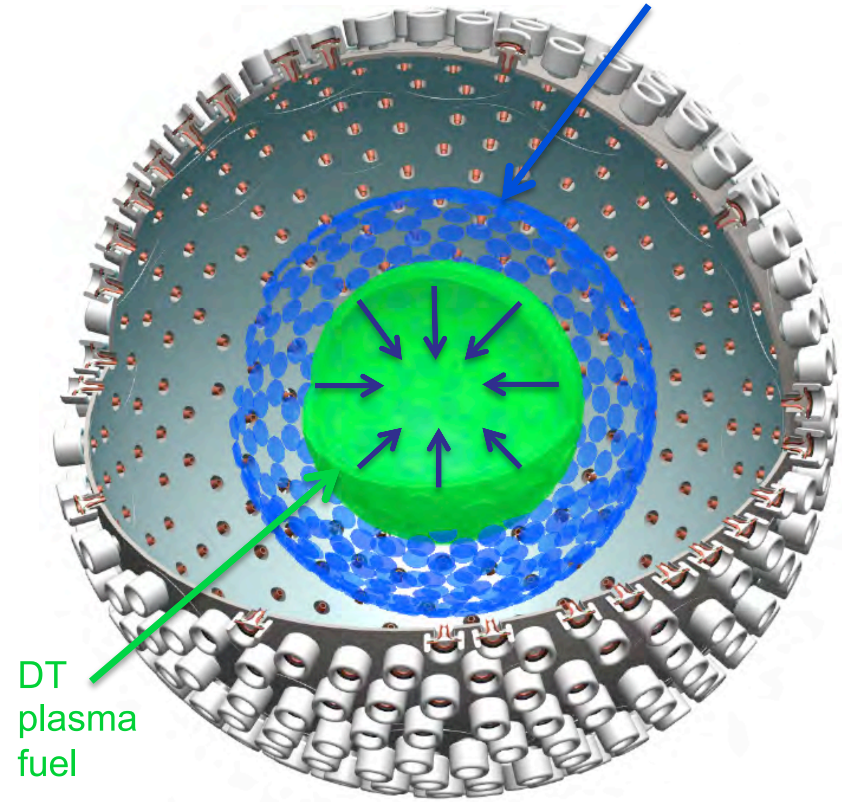
- **Overview of the PLX-α project**
- **Major accomplishments of Year 1**
  - Design, fabrication, qualification of the new PLX-α coaxial plasma gun (HyperV)
  - Numerical modeling of PLX-α experiments and fusion-relevant configurations (UAH, BNL, Tech-X, LANL)
  - Upgrade of the PLX facility and diagnostics for 6- and 7-gun experiments starting Fall 2016 (LANL, UNM, HyperV)
  - TT&O activities
- **Project challenges (and potential shared solutions) & plans**

From MIF proof-of-concept toward a viable fusion-reactor technology



Sandia's MagLIF experiments demonstrated:
- *BR* (magnetic field x fuel radius) values relevant for breakeven-scale MIF
- fusion-relevant temperatures
- confinement of charged fusion products

Gomez et al., *PRL* **113**, 155003 (2014).
Schmit et al., *PRL* **113**, 155004 (2014).

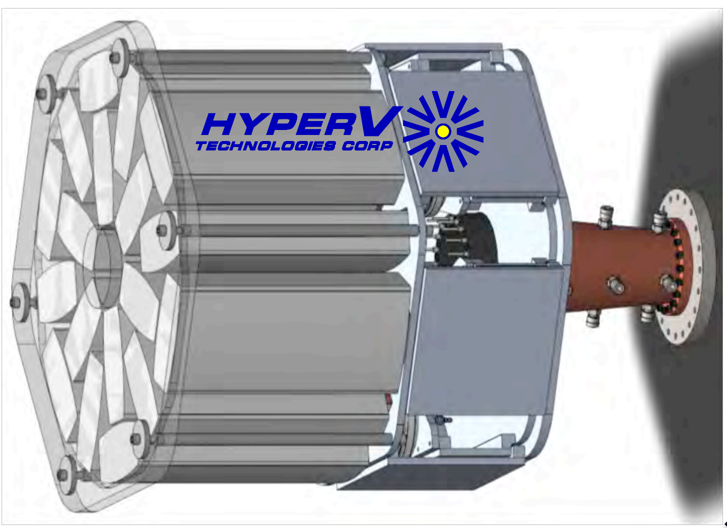


Plasma-jet-driven MIF: Can we recreate similar conditions with a high-repetition-rate technology allowing for attractive reactor engineering and economics?

Thio et al., in *Current Trends in International Fusion Research–Proc. Second Symposium*, p. 113 (1999).
Hsu et al., *IEEE Trans. Plasma Sci*. **40**, 1287 (2012).

PLX-α goal: Form plasma liner via merging plasma jets, and demonstrate its viability as an MIF driver

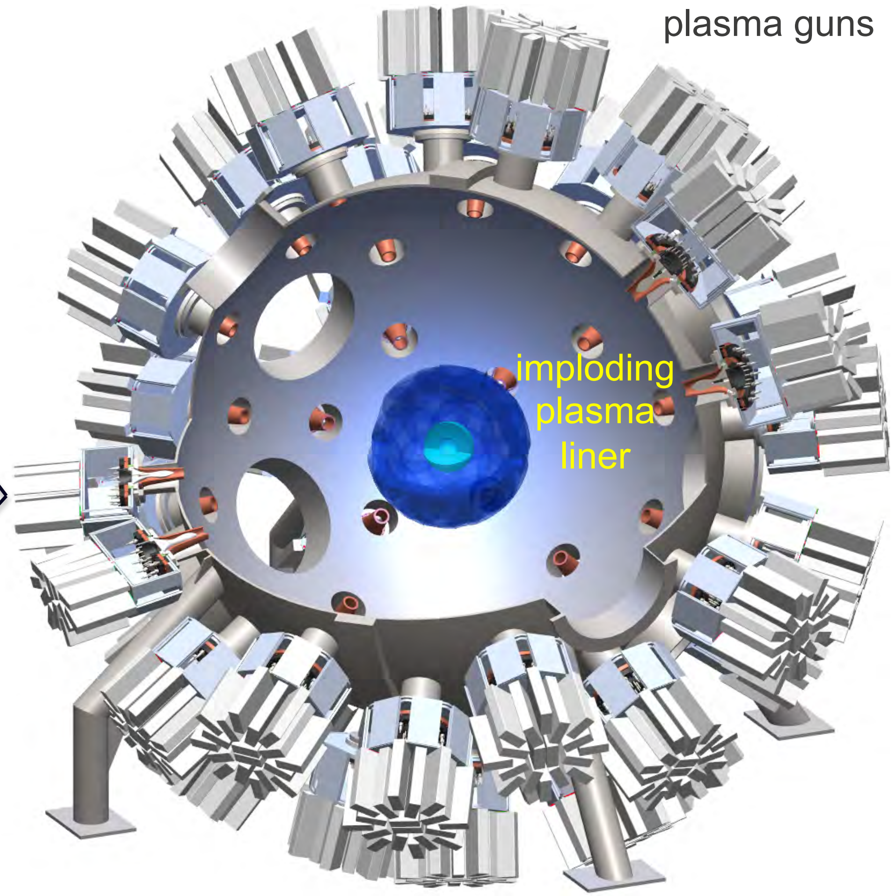
New PLX-α coaxial plasma gun with integrated pulsed-power module



1 m

7.5-kJ capacitor stored energy
1.5-kJ jet kinetic energy

Planned PLX-α experiments with 60 plasma guns

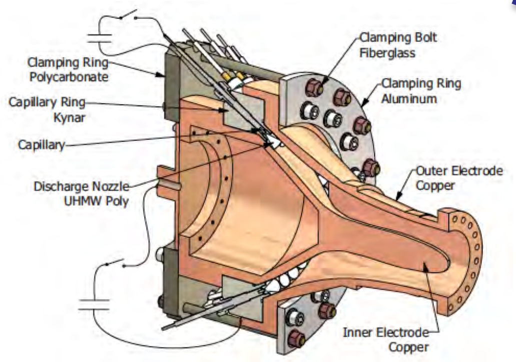


2.7 m

0.1-MJ plasma-liner kinetic energy
(need tens of MJ in a reactor)

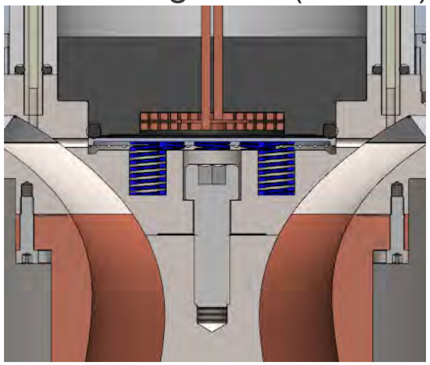
Design, fabrication, and testing of the new PLX-α coaxial plasma gun was a key Year-1 accomplishment

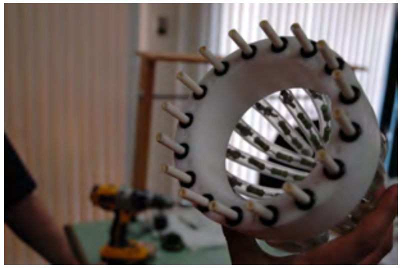
Starting from previous gun with ablative injectors

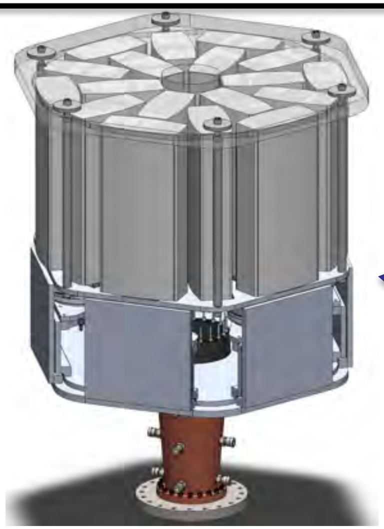


Use MACH2 to design new gun and set requirements for achieving ~50× higher jet density and mass

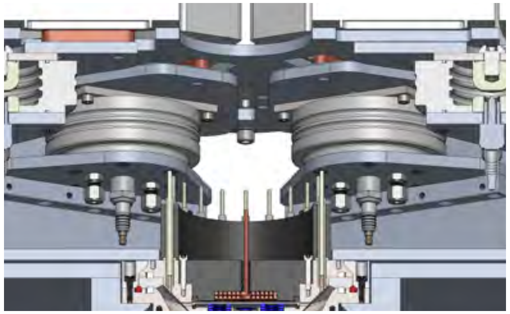
New gas-valve (top) and pre-ionization ignitors (bottom)





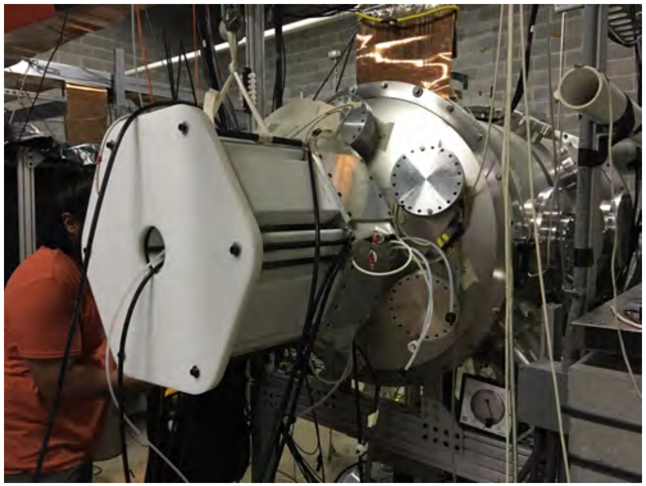


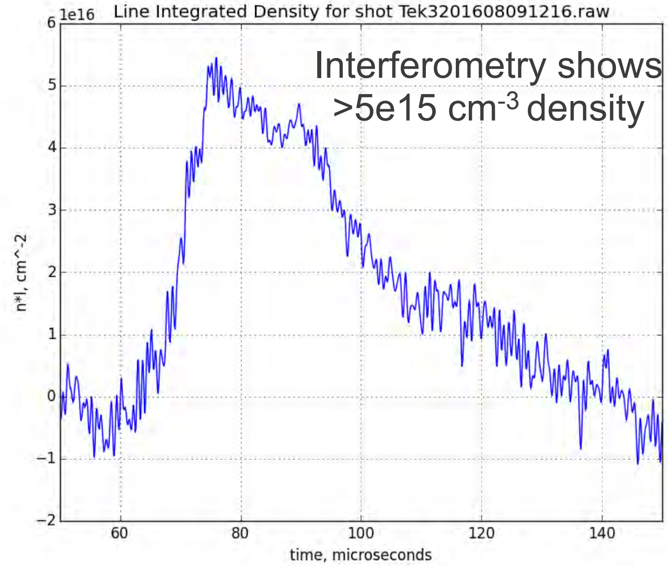
Final assembly

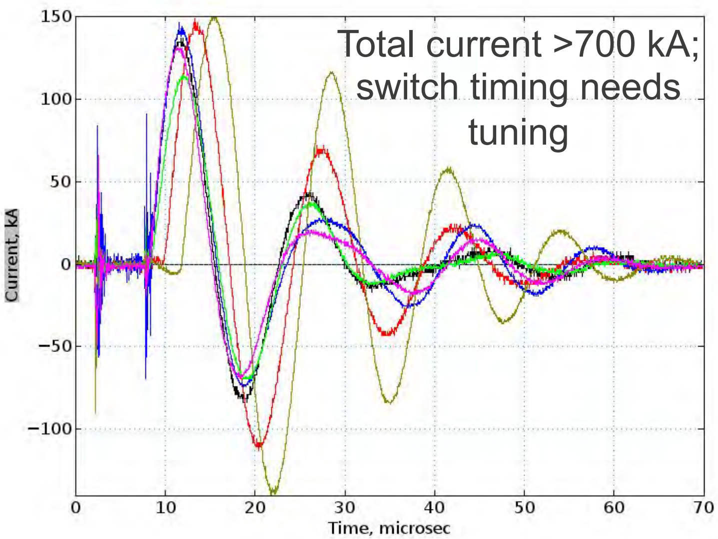


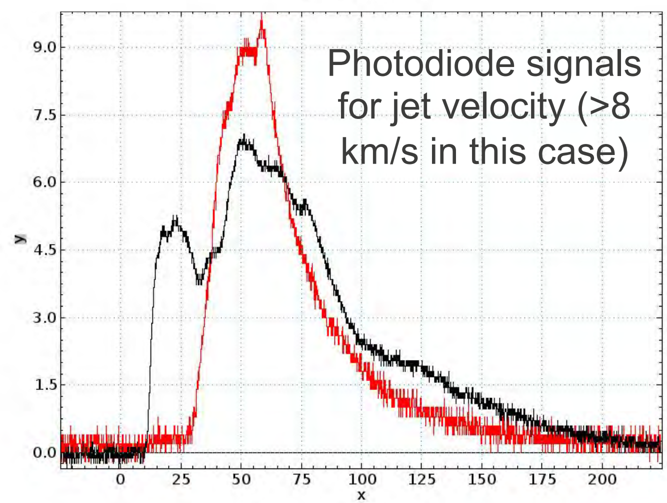
Integrated capacitors and switches to minimize inductance and required stored energy

We are presently validating PLX-α gun performance, and fabricating the next 6 guns

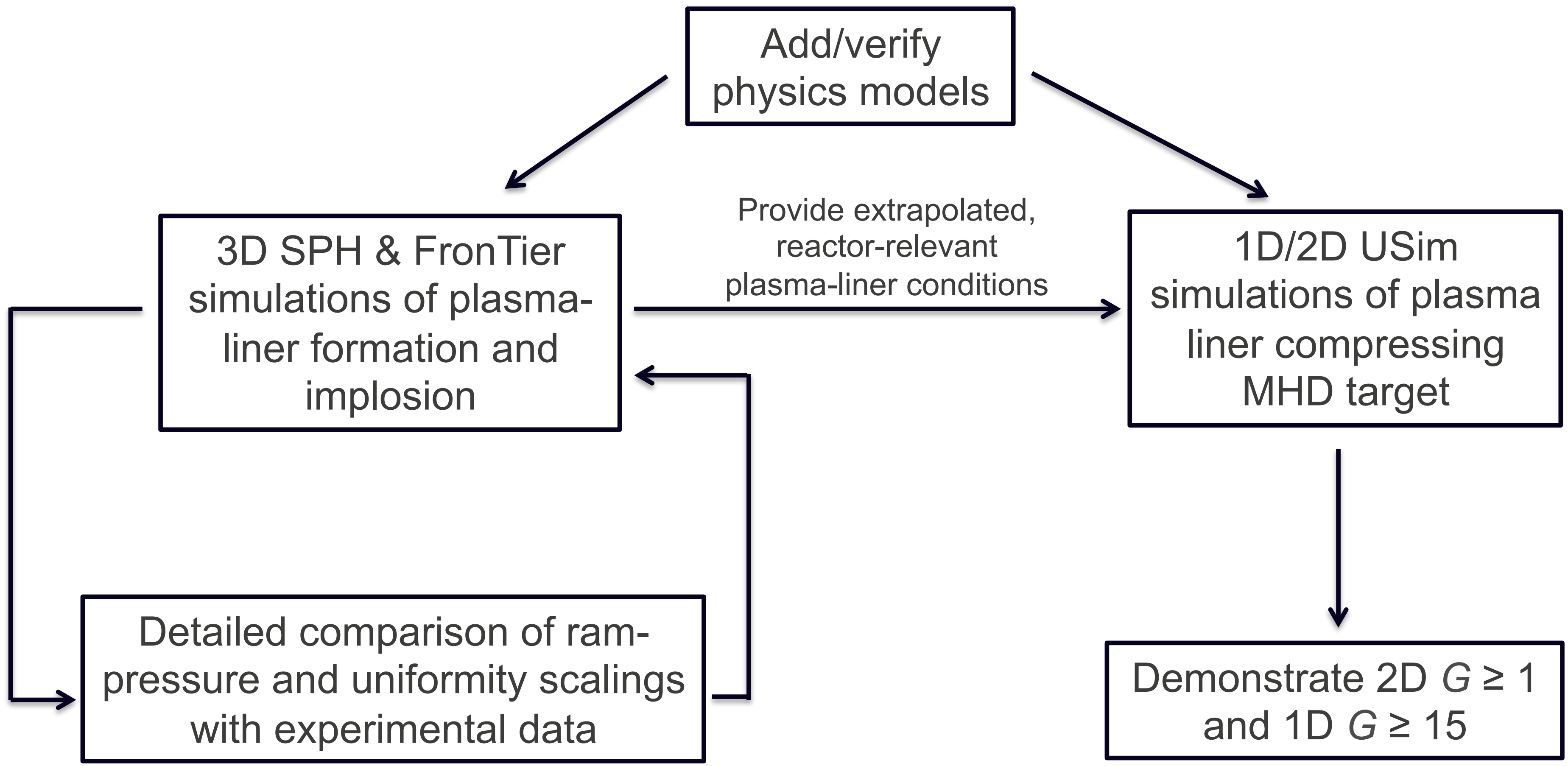




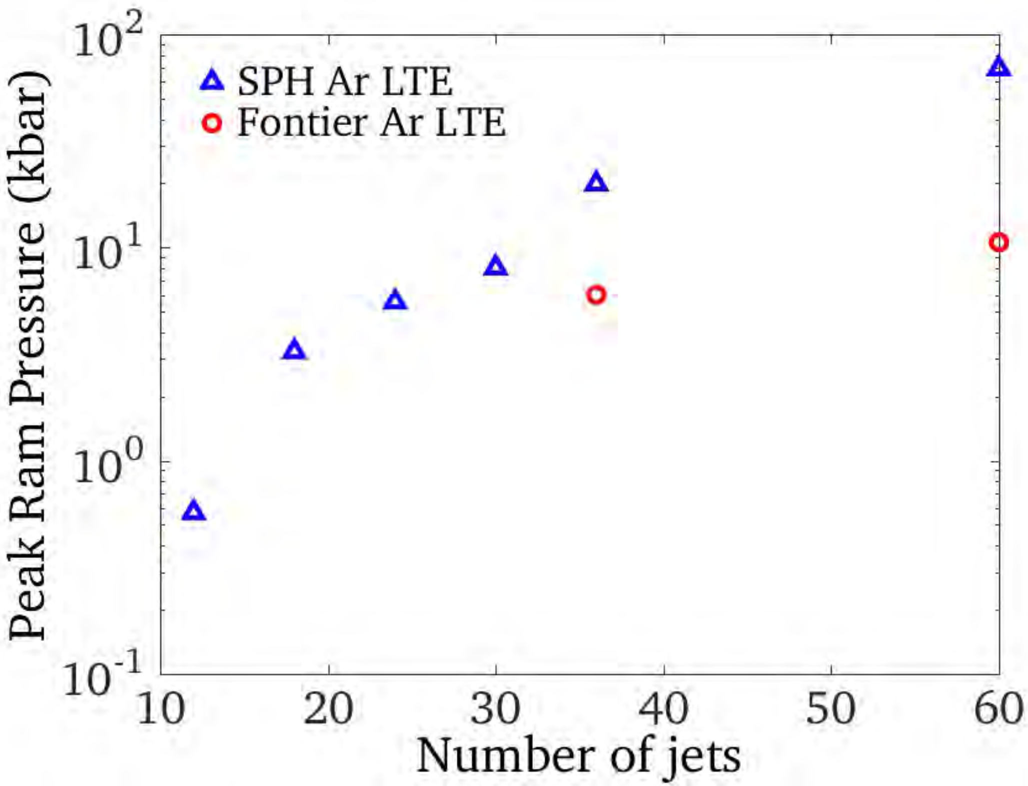


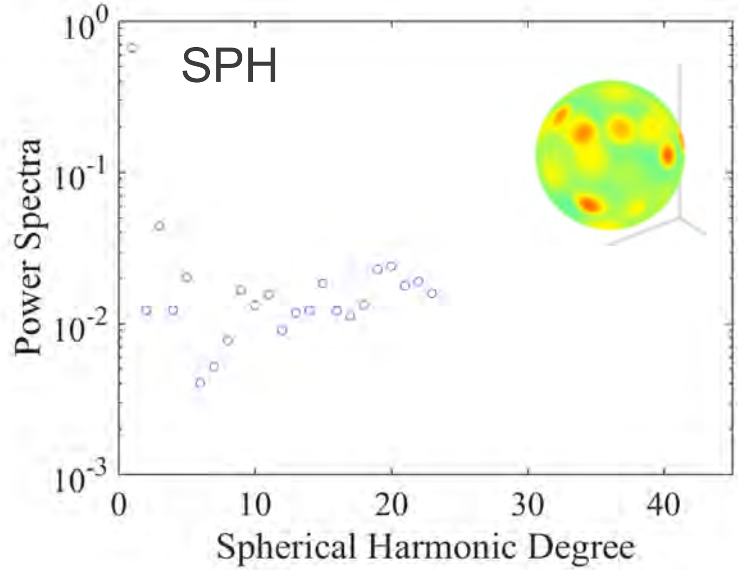


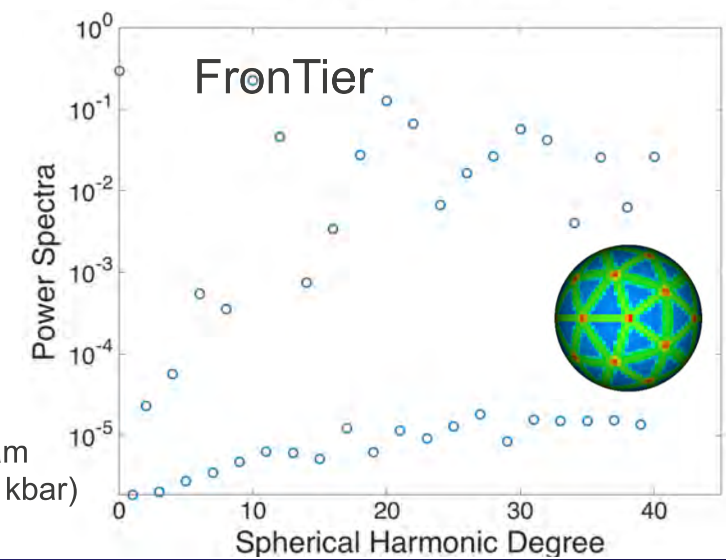
PLX-α modeling efforts are addressing plasma-liner ram-pressure/uniformity and scalability to fusion-energy gain



3D hydrodynamic simulations with advanced EOS are assessing plasma-liner ram-pressure and uniformity



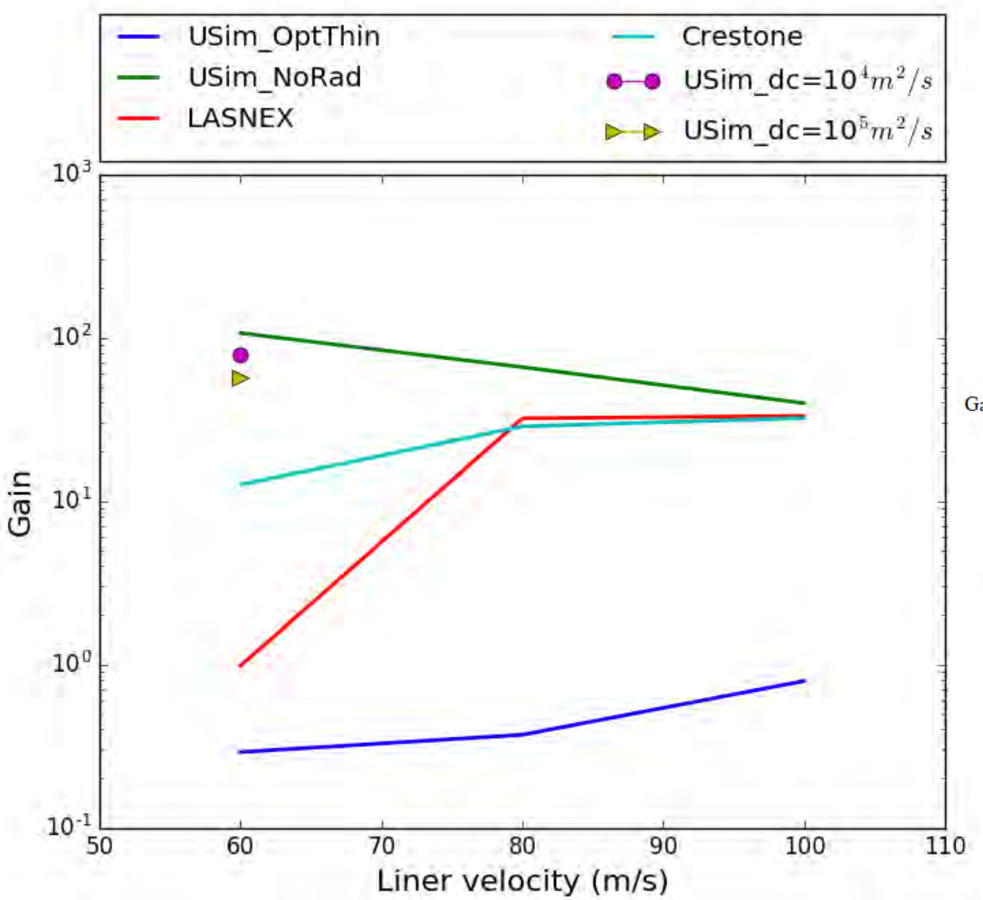




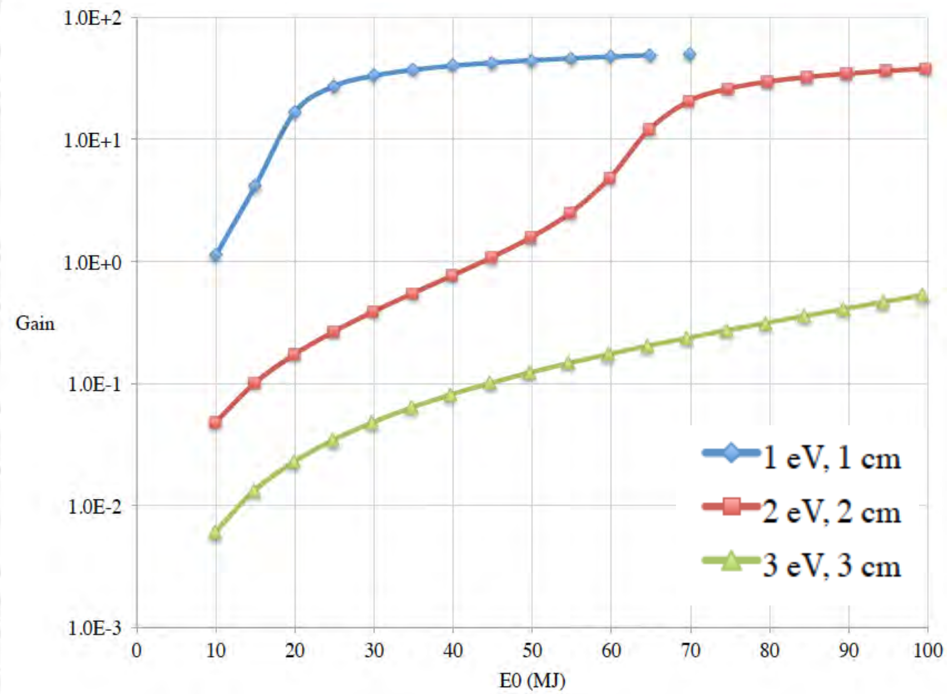
Initial conditions:
Density = 3.19e16 cm^{-3}
Temperature = 2.5 eV
Jet length = 10 cm
Jet diameter = 8.5 cm
Velocity = 50 km/s

Liner peak ram pressure (~1 kbar) at 10 cm

Benchmarking & optimization of 1D USim simulations is a precursor to 2D rad-MHD simulations showing path to fusion-energy gain



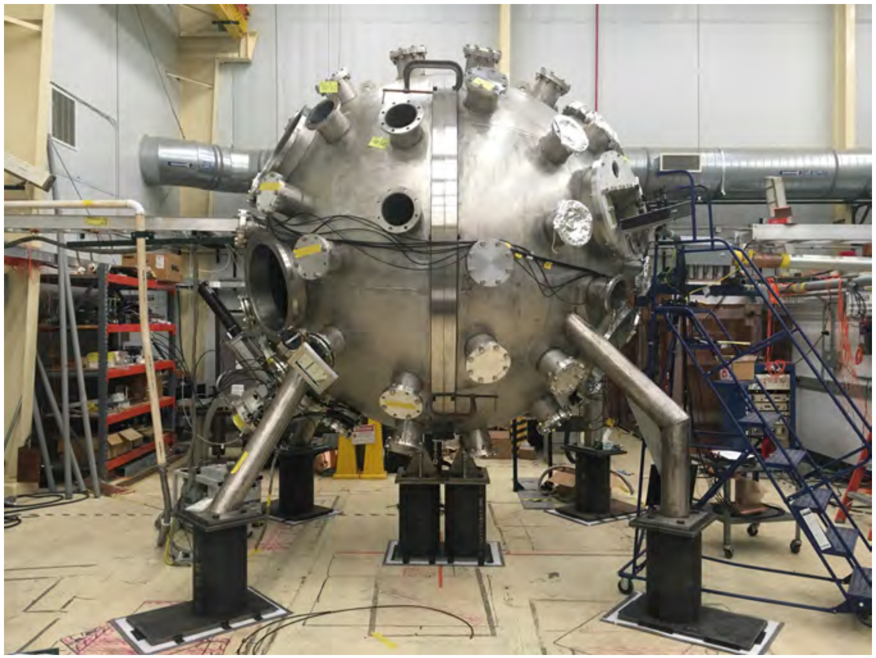
USim benchmarks against published 1D Crestone and LASNEX results of Knapp & Kirkpatrick, Phys. Plasmas **21**, 070701 (2014).



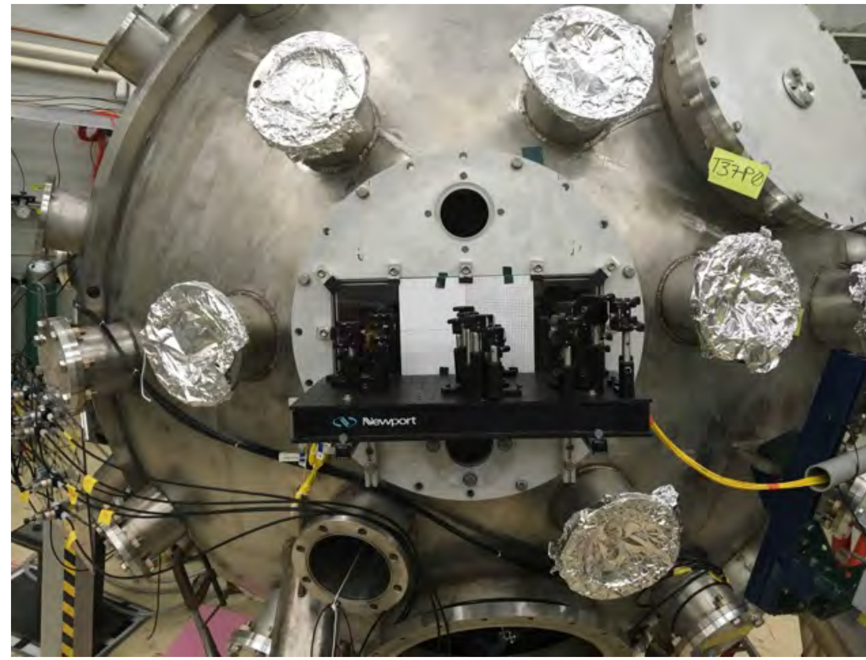
Legend is liner temperature and thickness at moment of engagement with target at *r* = 3.5 cm.

From semi-analytic model of PJMIF (by S. Langendorf) including treatments of thermal conduction, Nernst effect, radiation losses, alpha deposition.

We have upgraded the PLX facility and diagnostics to conduct 6- and 7-gun experiments starting Fall 2016

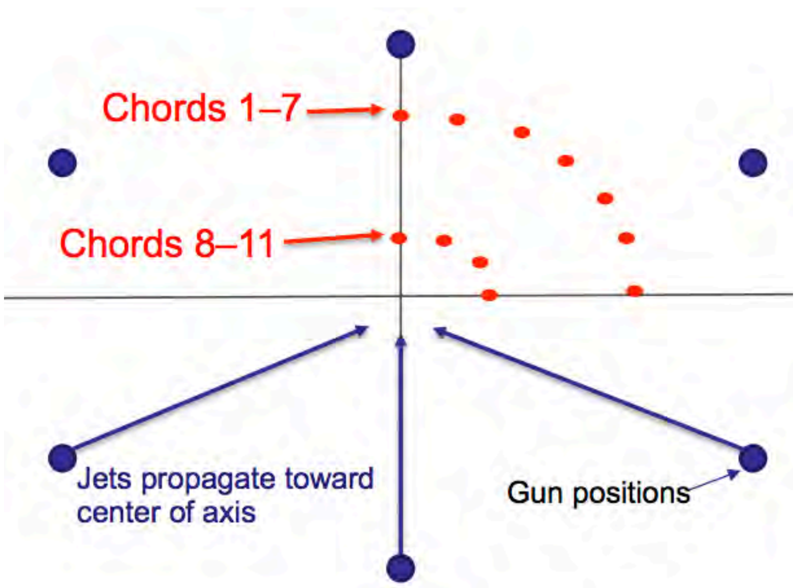


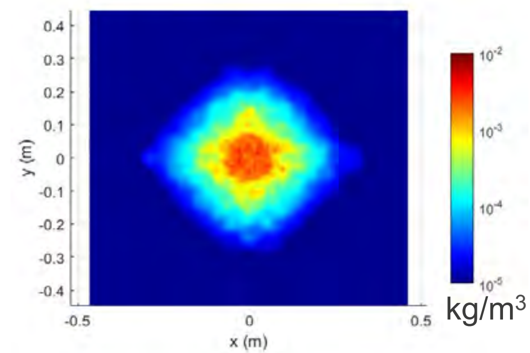
PLX vacuum chamber
mounted on 2'-tall pedestals

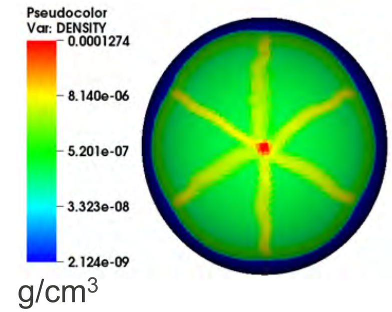


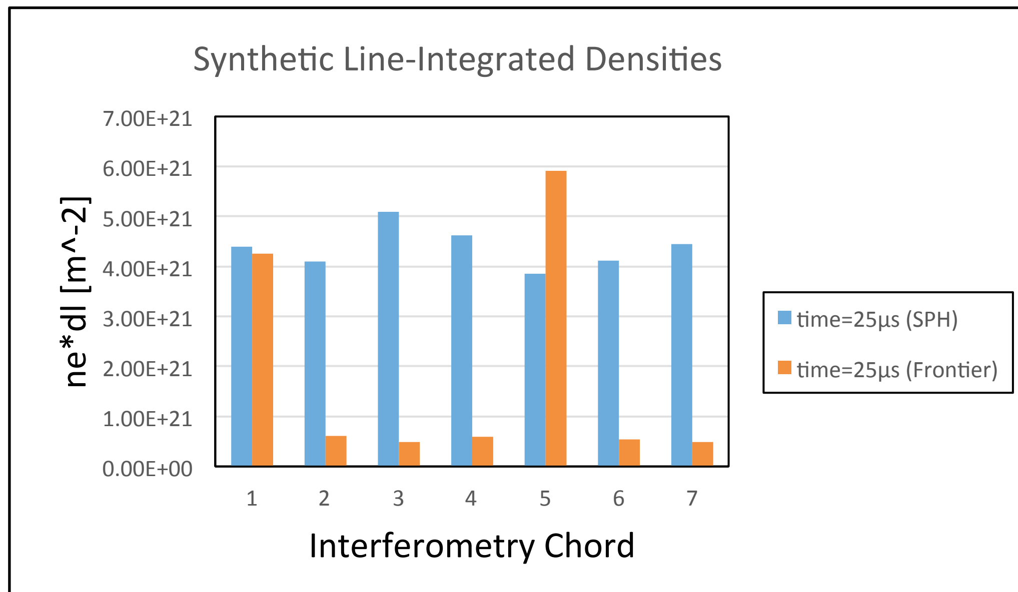
Interferometer launch optics
(surrounded by 6 gun ports)

First PLX-α experiments: 12-chord interferometry will diagnose uniformity in conical section of plasma liner formed by 6 guns









Our TT&O efforts have focused on publicizing the need for a healthy, sustainable public-private partnership to develop fusion energy, enabled by lower-cost and faster development pathways

Doug Witherspoon at ASP Hill Briefing on Fusion Energy (12/15/15)

PLX-α featured in LANL's 1663 S&T magazine (7/16):

Tied for "best pitch" at LANL DisrupTECH Forum (7/14/16):

Feature article in Scientia (publication dedicated to science diffusion):

Scientific/technical challenges and potential shared solutions

- **More space- and time-resolved measurements of liner uniformity and peak ram pressure**
  - Traveling diagnostics?
- **Modeling of radiation losses (especially in transitional regime between optically thin and thick), alpha-deposition in magnetized plasma, and effects of physical viscosity**
  - Would like to compare notes on others' implementations, especially reduced models
- **3D radiation-MHD simulations of PJMIF with adequate treatments of advanced EOS, radiation, physical viscosity, and alpha deposition**
  - This is beyond our capabilities/resources; need help!

PLX-α plans for Years 2 & 3

Year 2:

- Conical experiments
- Go/no-go milestone addressing “quality” of conical liner and path to fusion-energy gain
- Build up for 4π plasma-liner experiments
- Continued liner and PJMIF modeling

Year 3:

- Finish building up for 4π plasma-liner experiments
- Continued liner and PJMIF modeling
- 4π plasma-liner experiments with up to 60 guns

Our goal at the end of the ALPHA Program is to have demonstrated the viability of plasma liners as an MIF driver, and to be well-positioned to undertake plasma-liner compression of a target to 1 keV.