Advancing HED Science with ELI: An LLNL perspective on opportunities for U.S.-ELI collaboration

U.S.-ELI Joint Workshop

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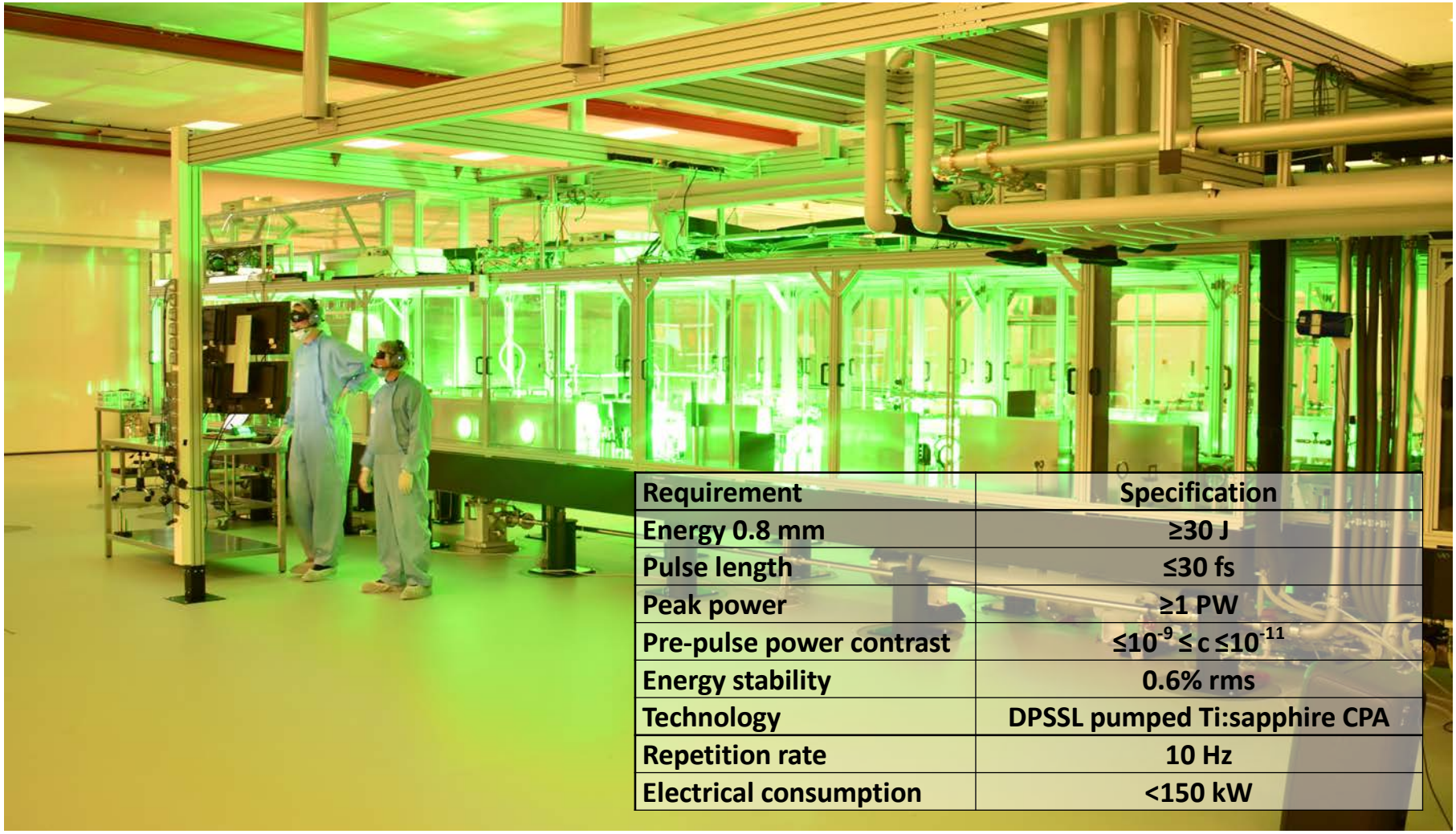
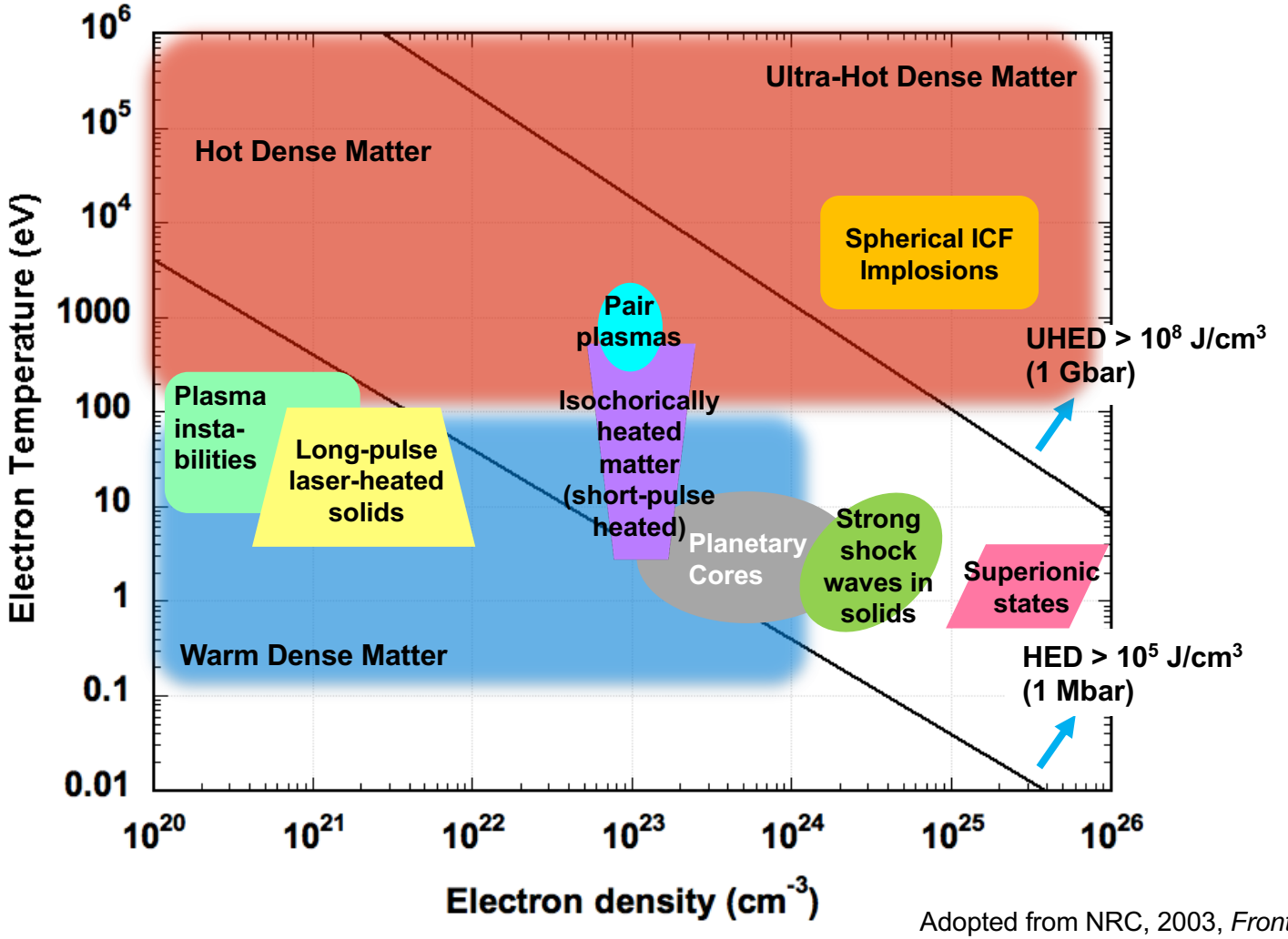
LLNL and ELI started a fruitful collaboration in 2013 developing the world's most capable Petawatt laser under the ACT agreement



Requirement	Specification
Energy 0.8 mm	≥30 J
Pulse length	≤30 fs
Peak power	≥1 PW
Pre-pulse power contrast	$\leq 10^{-9} \leq c \leq 10^{-11}$
Energy stability	0.6% rms
Technology	DPSSL pumped Ti:sapphire CPA
Repetition rate	10 Hz
Electrical consumption	<150 kW

LLNL research interests span the T-ρ space of HED, and touch on many of the areas outlined in the ELI whitebook



Adopted from NRC, 2003, *Frontiers in High Energy Density Physics: The X-Games of Contemporary Science.*

Experiments at high-rep-rate are transformative for HED physics, and is a major element of LLNL's strategic roadmap

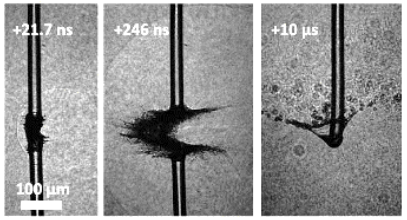
High repetition rate

- Enhanced precision through decreased error bars
- Qualitative & precision science
- More experiments and more PIs foster a higher rate in discoveries & learning
- More phase space
- High repetition rate lasers provide reliability, repeatability and high availability

LLNL is applying its broad expertise to access the advantages of experiments with significant rep rates

High Rep-Rate Targets

- Gas/liquid sprays
- Spool/tape targets
- Liquid jets

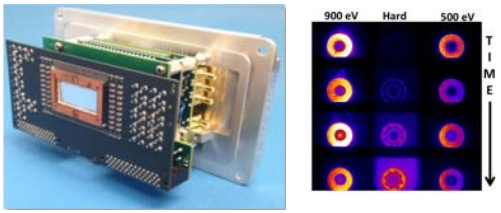


*Feister et al. RSI **85,** 11D602 (2014)*

Target Diagnostics

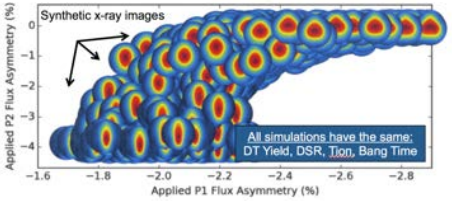
- Digitization, rapid storage, electronic readout, hardening, duty cycled analysis, feedback
- Maintain high spatial & temporal resolution

Single Line Of Sight CMOS on NIF



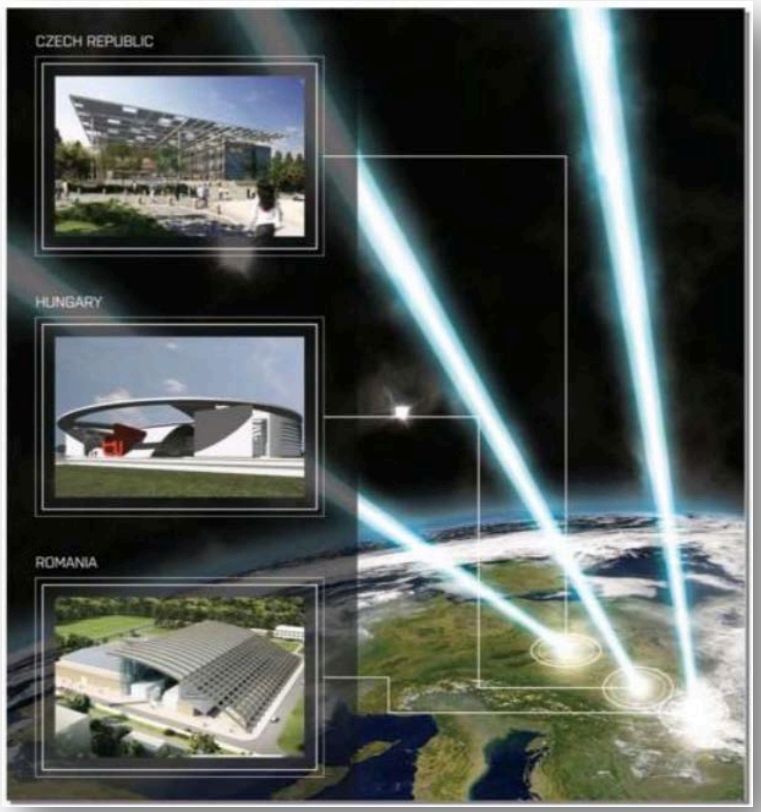
Machine Learning & HPC

- New techniques in big data, machine learning, ensembles of simulations



Development of the HAPLS Laser for ELI Beamlines was driven by LLNL's interest in jointly enabling a paradigm change in HED experiments consistent with LLNL's strategic roadmap

The emerging Extreme Light Infrastructure provides one of the world's most capable high intensity laser matter interaction experimental facility



- The unique combination of experimental capabilities is unmatched elsewhere
- LLNL's main interests are twofold:
  - HED physics, e.g.
    - Matter under extreme conditions
    - Physics of HED plasmas
    - Generation of high brightness secondary sources with lasers
  - Experimental methods
    - Development of precision high rep rate laser drivers
    - High rep rate targets
    - Computational tools

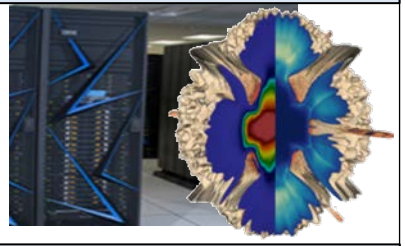
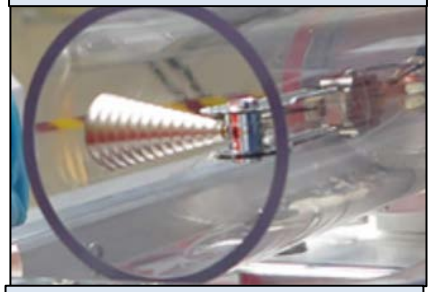
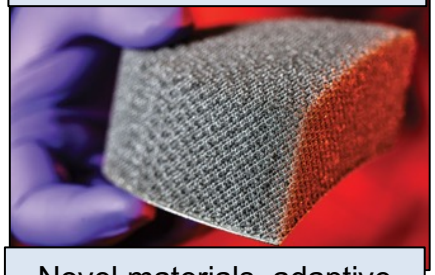
LLNL seeks to foster and participate in a vibrant US collaboration with ELI

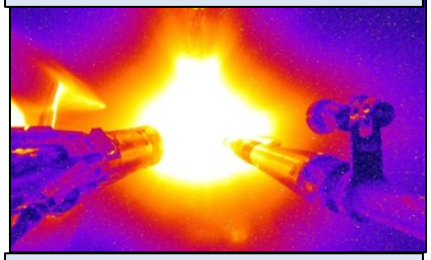
What mechanisms could be envisioned to support a mutually beneficial U.S.-ELI collaborative partnership?

Method of partnering	Comment	Benefit
Direct (U.S.-PI) grants for specific experiments at ELI that include travel, prep time, support for pre- and post-studies	Consider a joint team approach (user/mentor) to increase probability for successful outcome	Classical way of doing things, no specific agreements needed
Support to conduct scaled pre-experiments at U.S. LaserNet facilities with ELI participation	Test concepts before going on big machines. May include experimenters from ELI to learn together	**Lead-up/risk-reduction** experiments while **expanding and enhancing U.S. capability**
In-kind contributions from the U.S. to ELI	Funding of technology development in the U.S. then deployment on ELI facilities. Needs umbrella agreement	Provides ELI access to the vast **expertise and capabilities** in U.S. National Labs and universities Allows U.S. researches continued **training, innovation and advancement** of key technologies

The expertise that U.S. users will develop in performing experiments at ELI will inform and support the development of the next high intensity capability in the US

LLNL combines a unique and strong infrastructure of capabilities to expand our knowledge of plasma physics

Optical Technology	HPC & HED Codes	Target Fabrication	Additive Manufacture
			
Large optics	Advanced modeling, codes, machine learning	Exquisite & complex	Novel materials, adaptive preparation

User Facilities	User communities	Diagnostics	Modern Lasers
			
JLF & NIF	Discovery Science & User Group Meetings	Transformative experimental capability	kW-MW Petawatt Lasers

We are interested in leveraging our capabilities to complement and enhance ELI experiments.

LLNL seeks to foster and participate in a vibrant U.S. cooperative framework with ELI

- There is significant interest from LLNL to build on our mutual interests and expand an already strong partnership
- The U.S. possesses a strong and unique infrastructure of capabilities that can support and complement ELI as we work together
- LLNL's main interest is in jointly exploring high rep rate science
- Our Advanced Photon Technologies (APT) program has been pushing many of the technologies relevant to ELI, and continues to be committed to its strategic goals pushing Petawatt lasers to MegaWatt class average power. We and our U.S. laser developers are interested in jointly with ELI pushing the capability envelope for ELI to stay competitive.
- LLNL and its user communities are interested in participating in developing a joint vision for future improvements and upgrades
- We are prepared to support a number of partnership models that can be used as a vehicle to work together

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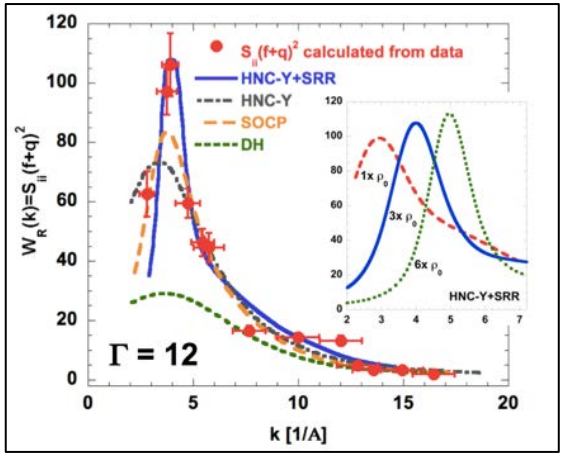
Repetition rate enables unique and precise knowledge acquisition for rapid scientific progress

Compressed aluminum ion-ion structure factor measurements

OMEGA data taken over 2 years

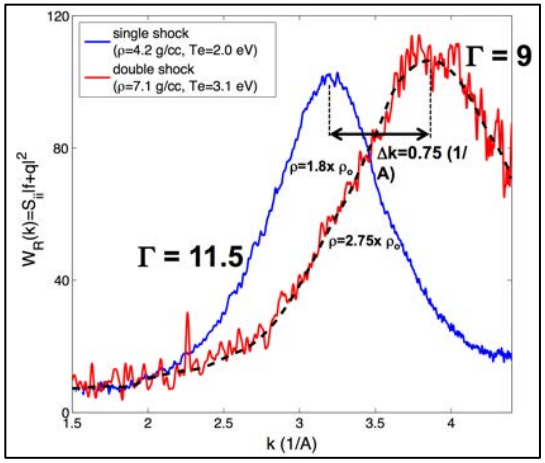


PRL 110, 065001 (2013) PHYSICAL REVIEW LETTERS week ending 8 FEBRUARY 2013

X-Ray Scattering Measurements of Strong Ion-Ion Correlations in Shock-Compressed Aluminum

T. Ma,[1] T. Döppner,[1] R. W. Falcone,[2] L. Fletcher,[2] C. Fortmann,[1,3] D. O. Gericke,[4] O. L. Landen,[1] H. J. Lee,[5] A. Pak,[1] J. Vorberger,[4] K. Wünsch,[4] and S. H. Glenzer[1]

MEC/LCLS data taken in 1 night



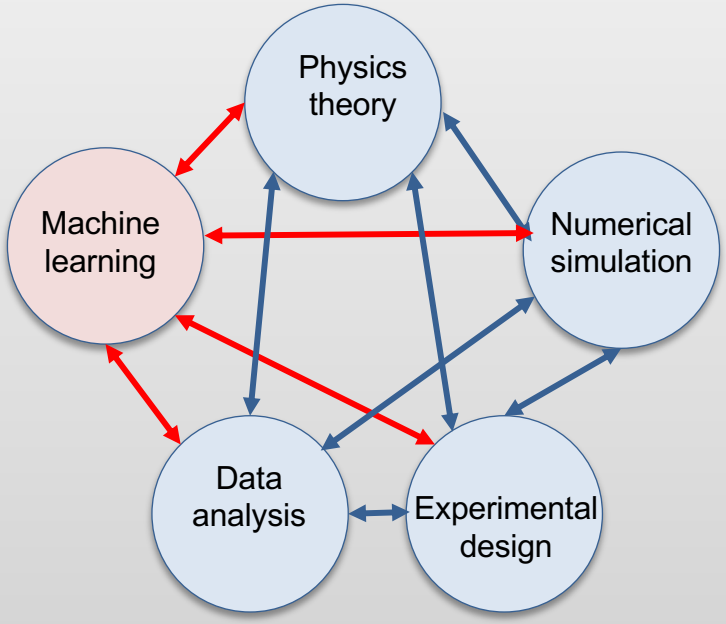
nature photonics ARTICLES
PUBLISHED ONLINE: 23 MARCH 2015 | DOI: 10.1038/NPHOTON.2015.41

Ultrabright X-ray laser scattering for dynamic warm dense matter physics

L. B. Fletcher[1,2*], H. J. Lee[1], T. Döppner[3], E. Galtier[1], B. Nagler[1], P. Heimann[1], C. Fortmann[4], S. LePape[3], T. Ma[3], M. Millot[2,3], A. Pak[3], D. Turnbull[3], D. A. Chapman[5,6], D. O. Gericke[6], J. Vorberger[7], T. White[8], G. Gregori[8], M. Wei[9], B. Barbrel[2], R. W. Falcone[2], C.-C. Kao[1], H. Nuhn[1], J. Welch[1], U. Zastrau[1,10], P. Neumayer[11], J. B. Hastings[1] and S. H. Glenzer[1*]

Today's high energy lasers are single-shot: our scientific progress is data and capability limited. A rep-rated facility accelerates the advancement of HED

We are interested in pushing the forefront of a growing alliance for cognitive simulation + data-augmented science



Simulation-based surrogate models → maps for exploring design space
Transfer learning → models that can improve with additional experiments
Uncertainties in pre-shot predictions → Bayesian experimental design

High rep rate technologies produce vast amount of data

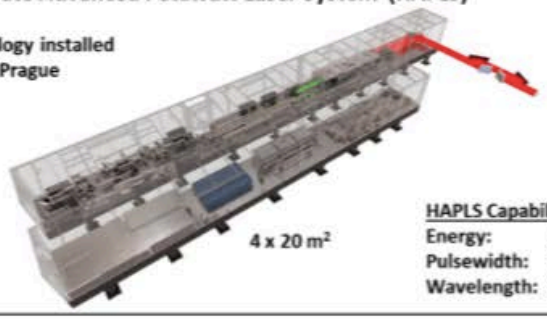
Physics inscribes patterns in the data that will allow us finding relationships in parameters previously not understood

LLNL has a 25-people working group exploring the application of ML in HED

LLNL's continued investment in developing energetic high rep rate lasers towards MegaWatt power is reflective of our strategic plan to realize competitive secondary source applications

HAPLS

High-repetition-rate Advanced Petawatt Laser System (HAPLS)
1 PW @ 10 HZ
Operational technology installed
at ELI-Beamlines in Prague

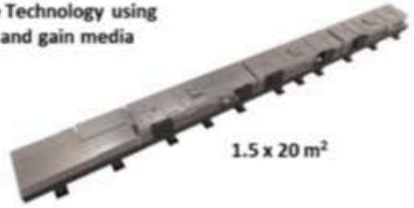


HAPLS Capabilities
Energy: 30 J
Pulsewidth: 28 fs
Wavelength: 820 nm

Scalable High-power Advanced Radiographic Capability (SHARC)
1 PW @ 10 HZ
Direct implementation
of HAPLS pump laser technology

SHARC Capabilities
Energy: 150 J
Pulsewidth: 150 fs
Wavelength: 1.053 µm

Big Aperture Thulium (BAT) System
0.3 PW @ 10 kHZ
High TRL HAPLS-like Technology using
Commercial Diodes and gain media



BAT Capabilities
Energy: 30 J
Pulsewidth: 100 fs
Wavelength: 1.95 µm

300 W
Indirect CPA
Max E-O Efficiency 1.5%

1,500 W
Direct CPA
Max E-O Efficiency 7.6%

300,000 W
Direct CPA
Multi-pulse Extraction
Max E-O Efficiency 21%

Continuing our partnership on frontier laser technology will ensure staying competitive in capability and technology