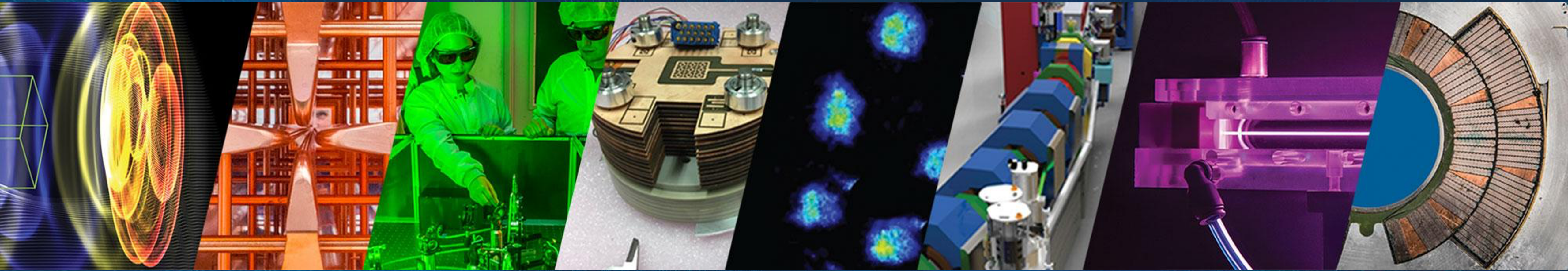
Update on Activities and Capabilities at LBNL

Steve Gourlay
Accelerator Technology & Applied Physics Division



INFUSE Workshop, Dec. 16, 2021

BERKELEY LAB
ACCELERATOR TECHNOLOGY & APPLIED PHYSICS DIVISION ATAP
U.S. DEPARTMENT OF ENERGY | Office of Science

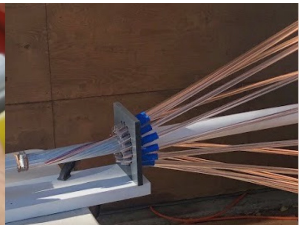
LBNL Offers Core Capabilities to Advance the FES Plan

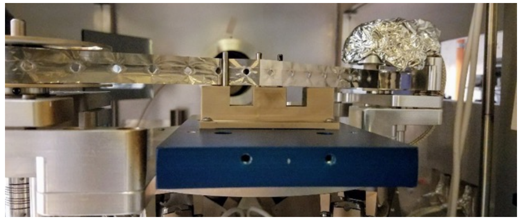
ATAP Programs

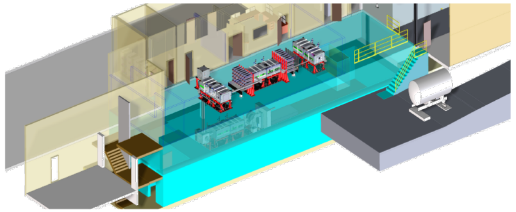
- Berkeley Center for Magnet Technology
- US Magnet Development Program
- Fusion Sci. & Ion Beam Technology Program
- Berkeley Lab Laser Accelerator (BELLA) Center
- Advanced Light Source Accelerator Physics
- Accelerator Modeling Program
- Berkeley Accelerator Controls & Instrumentation Program

- Capabilities in priority areas addressing the FES Long Range Plan
  - Magnet and fusion R&D
  - LaserNetUS user and collaborative science
  - High Energy Density Physics
  - Quantum Information Science

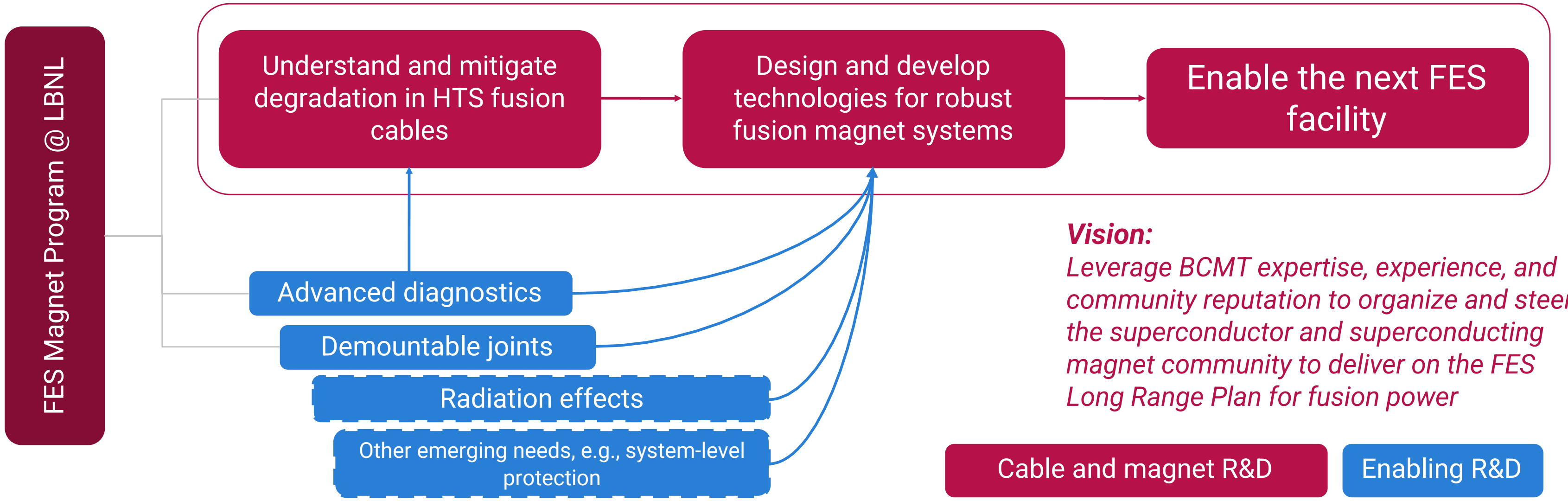
- Leveraging context of excellence in Computing, Lasers, Magnets, Engineering, and Quantum at LBNL and UC Berkeley







The challenge for a future compact Tokamak facility: A robust magnet system leveraging REBCO conductors

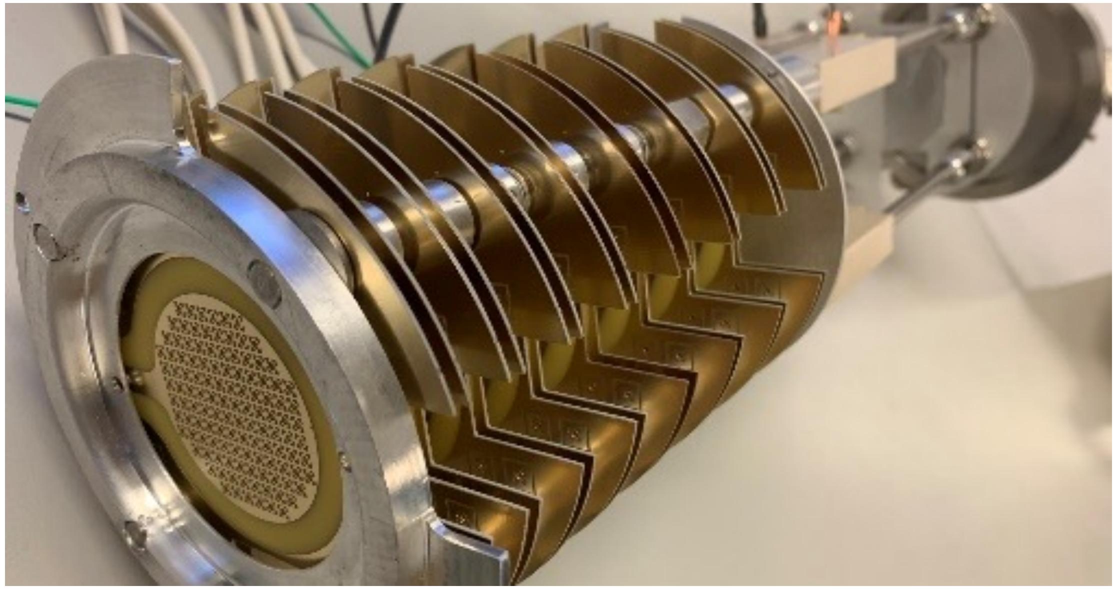


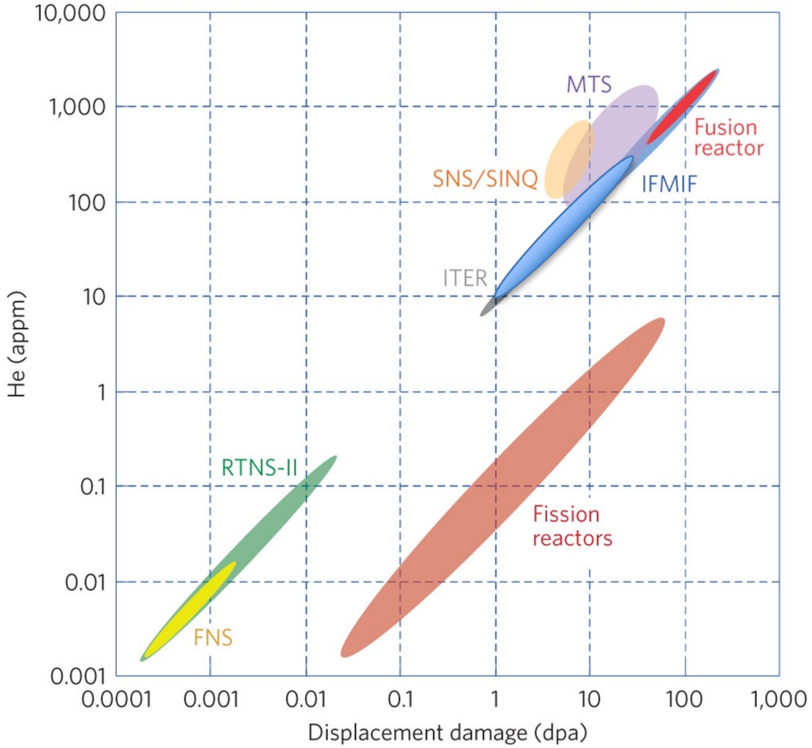
Vision:
Leverage BCMT expertise, experience, and community reputation to organize and steer the superconductor and superconducting magnet community to deliver on the FES Long Range Plan for fusion power

Point of contact: Soren Prestemon
- Superconducting materials
- Advanced design and analysis
- Magnet R&D & testing
- Magnet diagnostics, advanced electronics

Funded INFUSE projects:
- **ACT, SuperPower** – “Development of a Modeling Toolbox for CORC® Cable Performance Evaluation“
- **GA** - “Performance Testing of Low-Resistance Demountable HTS Joints for Large Segmented Magnets”

Multi-beam linacs can be scaled to high beam power at low cost for fusion materials testing and plasma heating



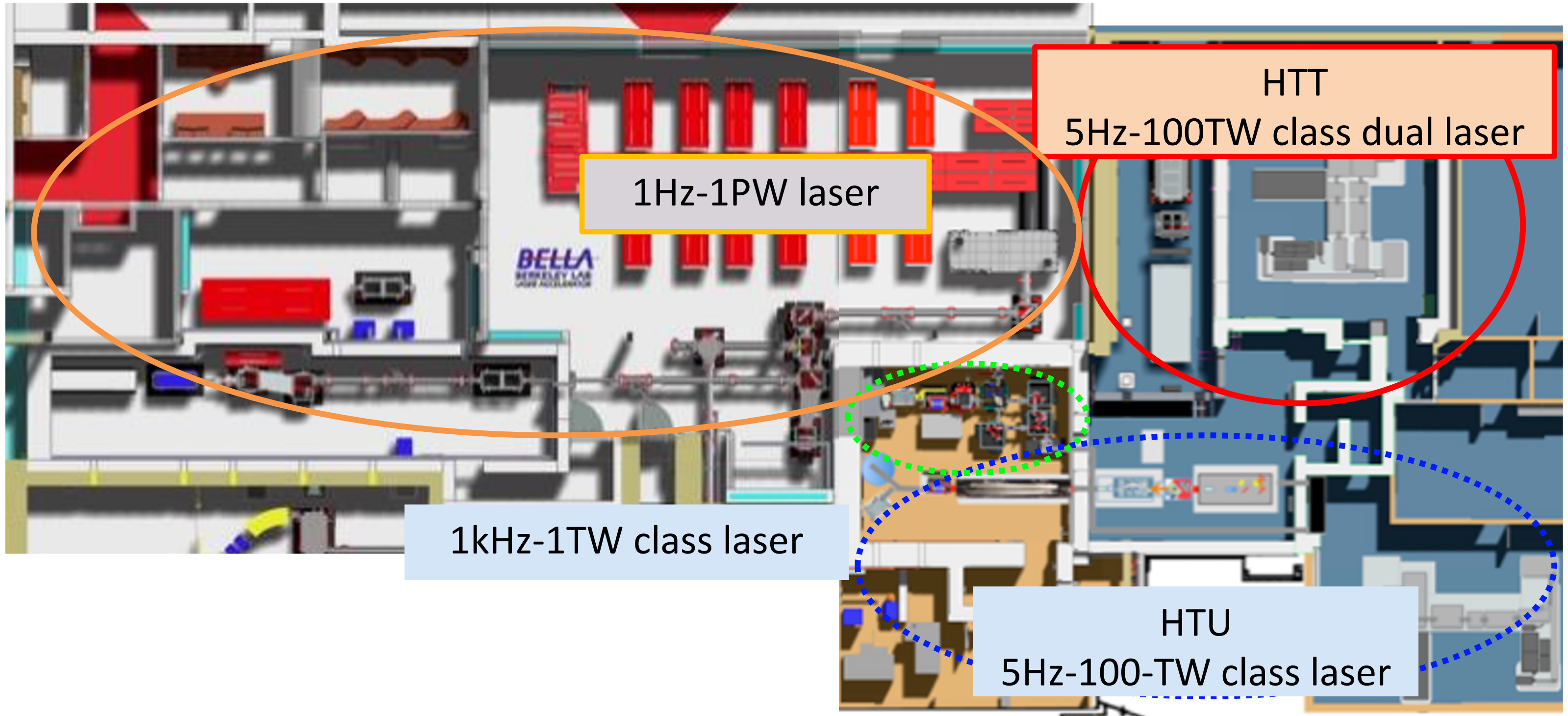


- We have now accelerated ions to over 50 keV in a stack of 16 wafers with 120 beams, cost per wafer: $15
- Next step is scaling to ≥1 MeV, ≥100 mA per module
  - → Ion beam driven neutron source for materials irradiations
  - → Applications also to Energy and Climate challenges
  - → Towards plasma heating

Point of contact: Thomas Schenkel
- **Path to 10^{15} n/s with ten modules**
- **Could be run with d-T or d-Li, ...**

- *P. A. Seidl, et al., Rev. Sci. Instr. 89, 053302 (2018); V. Kumar, et al., J. Appl. Phys. 125, 194901 (2019); Q. Ji, et al., in preparation (2021)*

BELLA Center provides unique capabilities as part of LaserNetUS



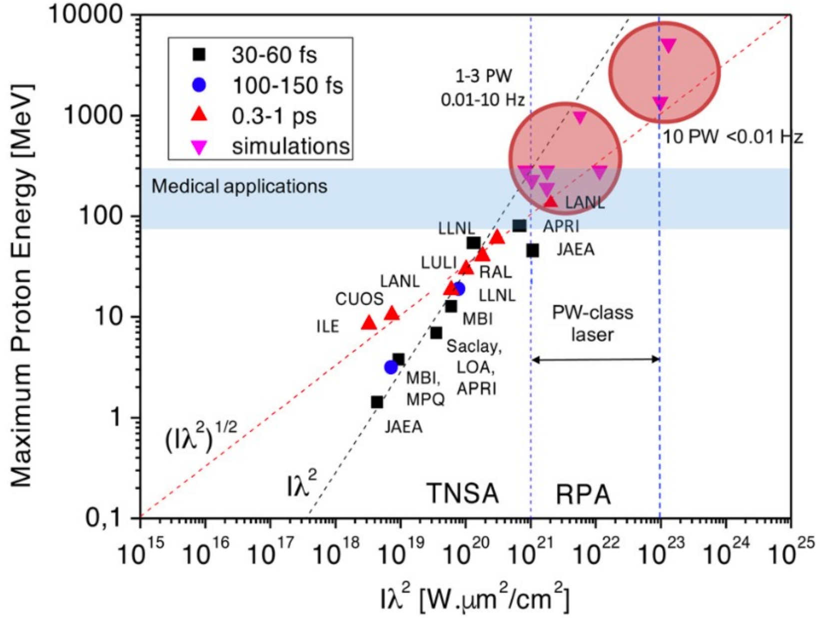
Peta-Watt long-focal
- $2 \cdot 10^{19}$ W/cm^2, long interaction length.
- High power diagnostics (laser diagnostic with full-power on-target)
- ~10 MeV proton beam platform with beam transport.
- HEP funded Multi-beam platform (2BL)

HTT 100 Terra-Watt
- Two synchronized and independently controlled few J lasers.
- Large chamber, flexible focusing and targets
- Multi-beam (2 lasers, electrons, x-ray) platform for HEDP
- Ion beams (this year)

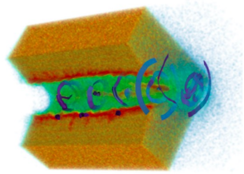
Peta-Watt short-focal (iP2) – installation in progress
- **FES funded high intensity (>10^{21} W/cm^2) platform**

Point of contact: Eric Esarey
- Accessible to users and collaboration
- High Energy Density Plasma, Inertial Fusion Energy diagnostics

Strong capability in High Energy Density Plasmas and ion acceleration experiments developed through FES & LDRD

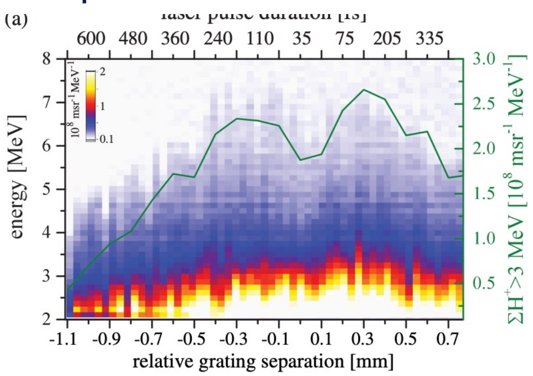


Scaling of maximum proton energy versus laser intensity showing scaling for various laser pulse lengths at different laser facilities.

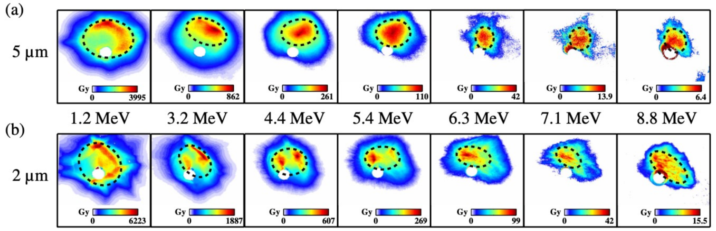


Bulanov, POP, 23, 056703 (2016)
Park, POP, 26, 103108 (2019)

A platform for ion acceleration experiments at high repetition rate has been developed



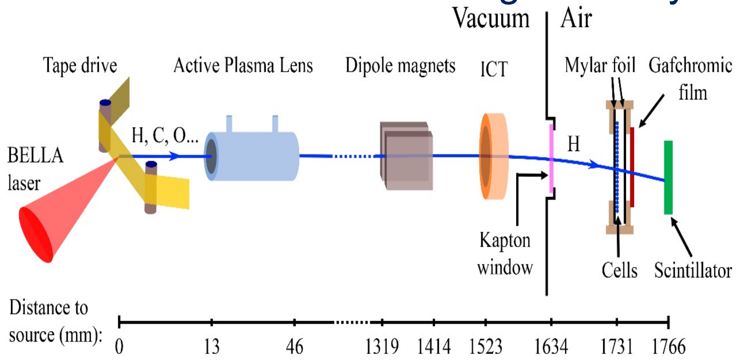
First PW experiments at high repetition rate has produced high-charge, low-divergence ion beams

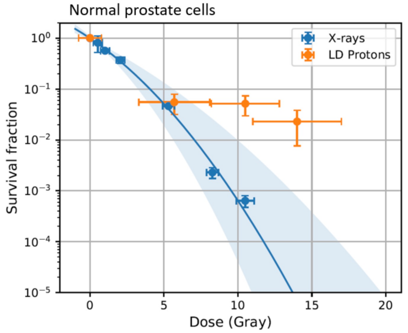


S. Steinke, PRAB, 23, 021302 (2020)

LaserNetUS: Thank you for early experimental support!

A program has been established to use ultra-high dose rate protons for in vitro radiobiological study and FLASH effects



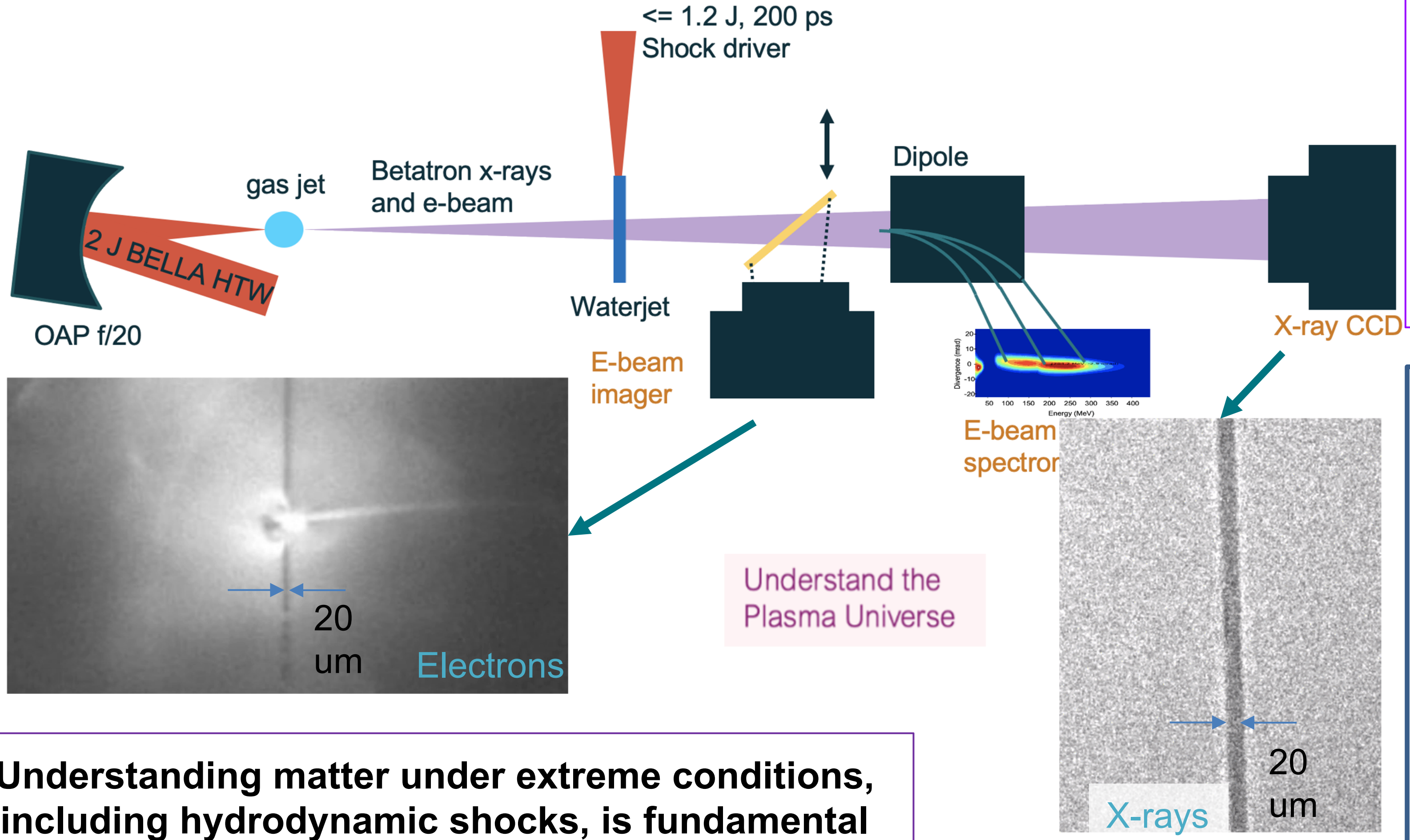


J. Bin & L. Obst-Huebl, submitted (2021)

Current LDRD: LASER-ACCELERATED ION BEAMS: EVALUATING RADIOBIOLOGICAL EFFECTS

LaserNetUS at BELLA HTT: platform developed for precision HEDP and IFE related research

LaserNetUS Experiment by Mario Balcazar, Yong Ma, Félicie Albert, Paul King, Alec Thomas, Carolyn Kuranz et al.



Laser shock-water jet-betatron x-ray imaging

Requires resolving: sub-micron turbulence structures and time evolution

High-resolution (μm, fs) imaging developed:

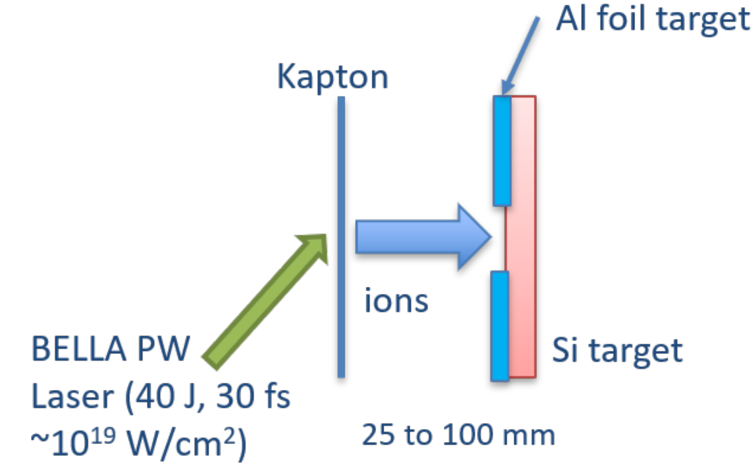
Density- keV X-rays,

Fields- 100 MeV-class electrons.

Understanding matter under extreme conditions, including hydrodynamic shocks, is fundamental for plasma science and inertial fusion energy.

Qubit synthesis far from equilibrium!

Point of contact: Thomas Schenkel



Accelerator Modeling Program offers leadership needed for FES Long Range Plan goals

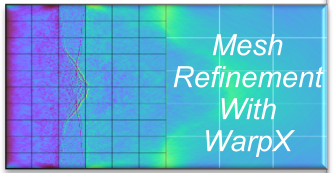
BLAST
BERKELEY LAB ACCELERATOR SIMULATION TOOLKIT

Cutting-edge, open-source, high-performance codes [1,3]

Warp/WarpX , FBPIC, HiPACE++, IMPACT

Applicability across FES portfolio

- Laser-plasma interactions
- Plasma acceleration
- Plasma mirrors
- High-field physics (with QED)
- Plasma instabilities
- Collisionless shocks
- Pulsars
- Magnetic reconnection
- Particle sources & accelerators
- Beams, plasmas for fusion
- …



Unique features (**mesh refinement**, boosted frame, …) + **coupling with AI/ML tools** (for design optimization & development of fast surrogate models).
Started exploration of **QIS algorithms**.

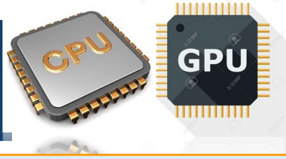
Leaders in Exascale[2] with WarpX

ECP EXASCALE COMPUTING PROJECT

https://github.com/ECP-WarpX

Leading multi-institution international development team of physicists + applied mathematicians + computer scientists

Portable: from single-user computer up to largest CPU/GPU-based supercomputers



Point of contact: Jean-Luc Vay

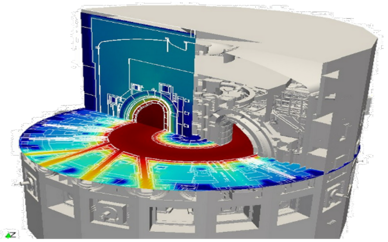
Input scripts and output data standardization ➔ integrated ecosystem

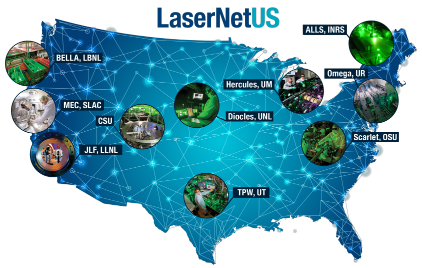
PICMI Standard | openPMD | CAMPA HEP funded | Consortium for Advanced Modeling of Particle Accelerators

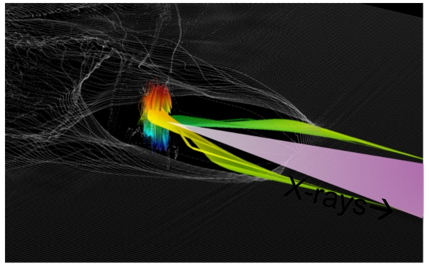
BERKELEY LAB | SLAC | UCLA | Fermilab

+ informal collaboration with LLNL, U. Cornell, Radiasoft, Tech-X, CEA-Saclay, DESY.

Vision: Enable fusion energy and transformative plasma science and technology, Leveraging multi-program capabilities in magnets, lasers, beams and simulations







- Lead high field strength superconducting magnet development for smaller, more effective fusion devices driving the US roadmap
  - Innovation in fusion materials and inertial fusion energy (IFE) approaches
- Pioneer precision ultra-intense laser, ion pulse and plasma control to create new states of matter as well as brilliant particle and X-ray technologies
  - Support LaserNetUS with existing lasers, iP2 project and new capabilities
  - Create unique materials and processes for quantum information science
  - Enable transformative high energy density physics (HEDP), plasma technologies
- Simulate at exascale to understand and control fusion and plasma science

We welcome collaboration!

Contact Cameron Geddes, ATAP Division Director