Fusion Energy Sciences at LBNL – status and directions

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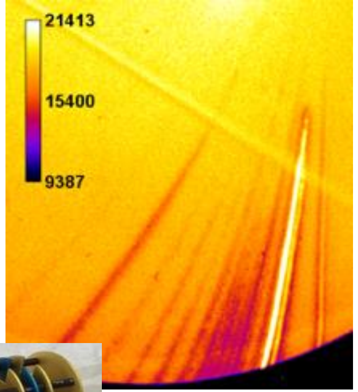
Fusion Power Associates, December 17, 2020

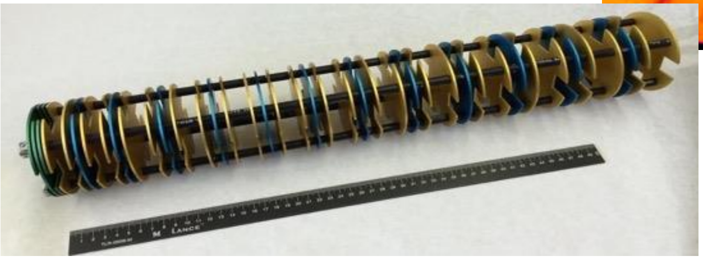
The work is supported by the U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-05CH11231 and by ARPA-E.

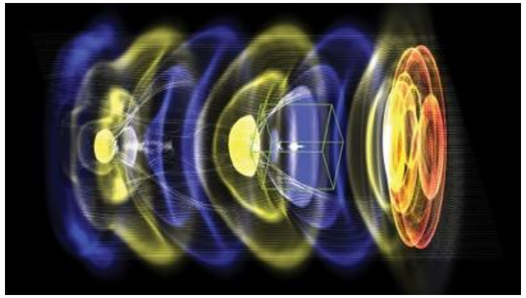
Our R&D portfolio to advance fusion energy sciences at Berkeley Lab

1. High Tc superconducting magnets for high-field tokamaks
2. High Energy Density Physics with lasers and particle beams
    1. LaserNetUS
    2. Materials and qubits
    3. New ideas for Inertial Fusion Energy research
3. MEMS-based accelerators for nuclear materials testing and plasma heating
4. Modeling and Simulations of beams and plasmas

- DOE FES, ARPA-E, Infuse, SBIR/STTR, industry, …







https://atap.lbl.gov/


A long-range plan to deliver fusion energy and to advance plasma science

Powering the Future
Fusion & Plasmas

DRAFT

A Report of the Fusion Energy Sciences Advisory Committee 2020

- **Do we love it**
- **Can we live with it**

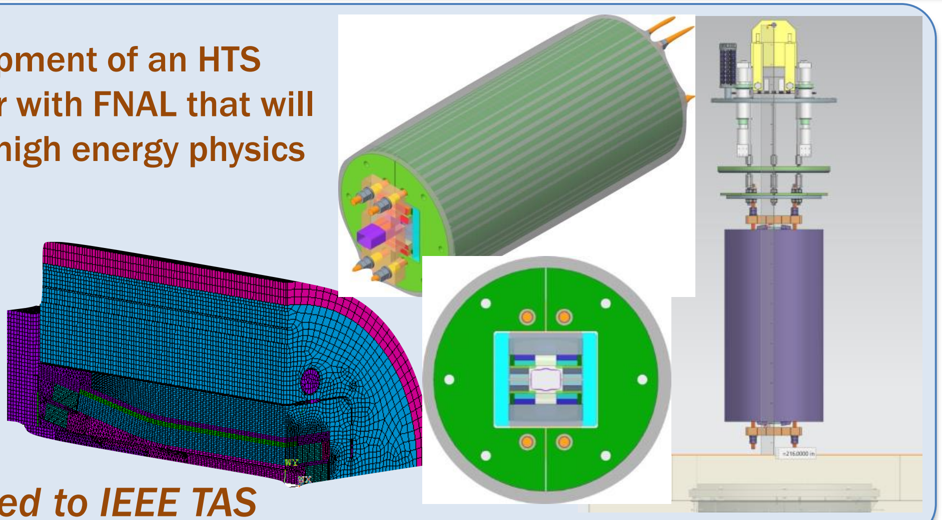
- **Let’s do it**

1. High Temperature Superconducting Magnets for Fusion

- HTS magnets are key to enabling future fusion systems that are higher field and more compact than currently possible
- We have leading expertise in low temperature (e. g. Nb_3Sn) and high temperature superconducting magnet technology (e. g. REBCO and Bi2112)
- Development of HTS magnets for fusion, in close collaboration with US Industry, synergies with High Energy Physics

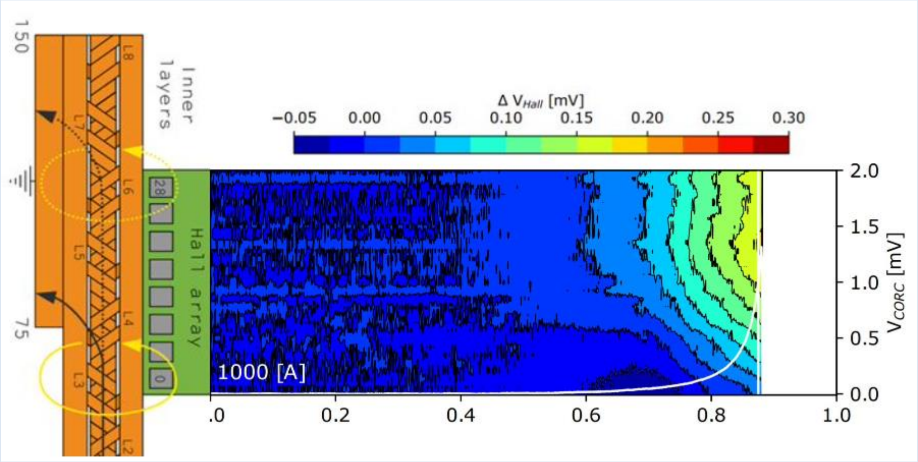
We are leading the development of an HTS Cable Test Facility together with FNAL that will serve both the fusion and high energy physics communities

- 15 Tesla on sample
- Variable temp.
- 100x150 mm bore



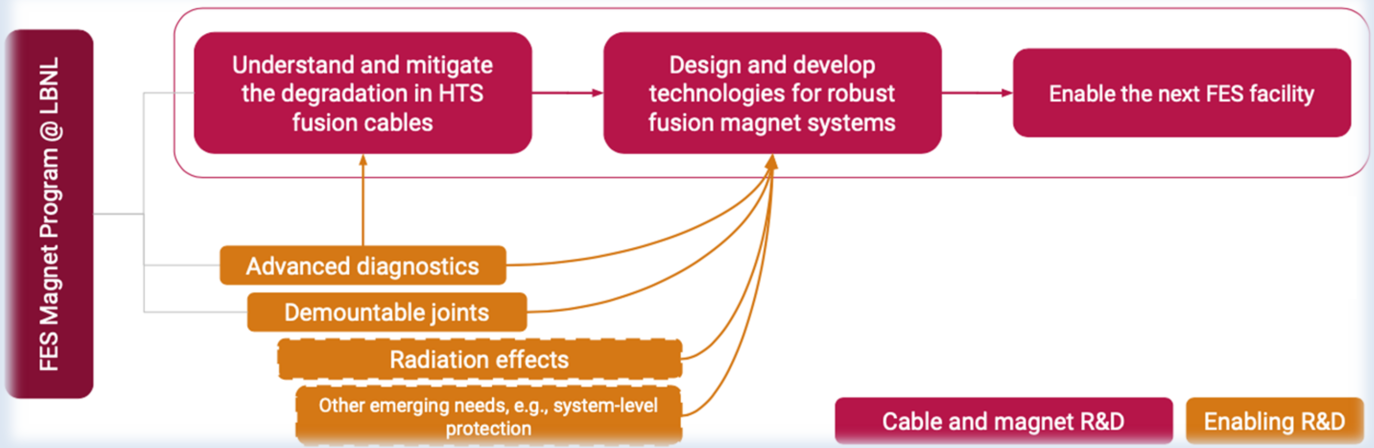
Vallone et al., submitted to IEEE TAS

Hall-sensor arrays located at cable terminals for passive, non-invasive detection of quench precursors



Teyber et al., SUST 33 (9) 095009, 2020

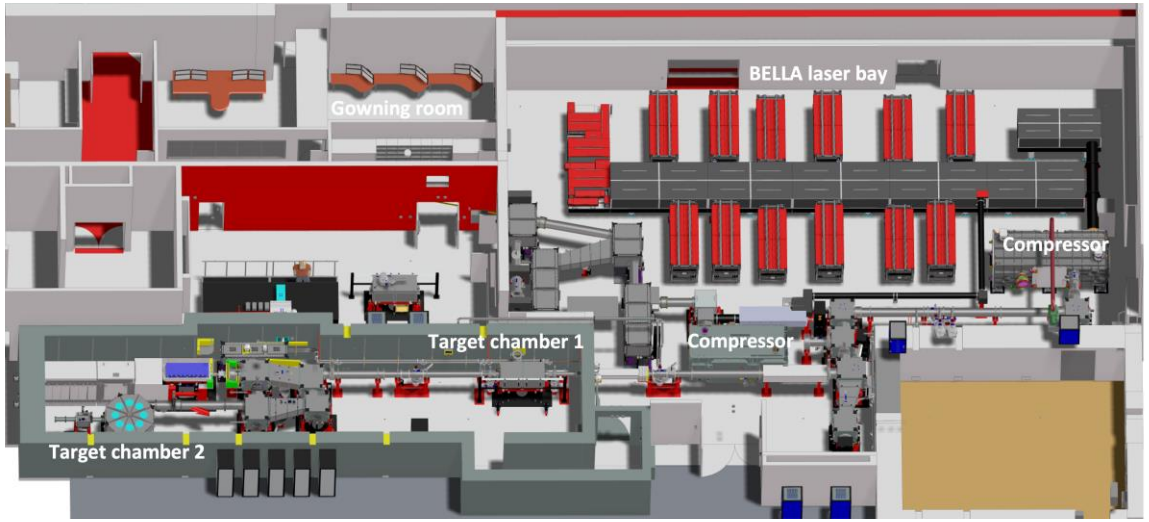
Our strategy to enable new fusion facilities



Contact: Soren Prestemon, soprestemon@lbl.gov

2. High Energy Density Science and applications of laser driven particles sources with users and collaborators in LaserNetUS

1. **BELLA PW, long focal length beamline**
   - $2 \cdot 10^{19}$ W/cm^2 available now
   - laser-plasma interactions, electron acceleration, ion acceleration, ion-neutrons, …



2. **BELLA PW, short focal length beamline**
   - $>10^{21}$ W/cm^2 available in 2021
   - unique HEDLP for users in LaserNetUS

3. **100 TW laser**
   - up to 5 Hz, 2.4 J
   - pump-probe experiments, available now
   - laser-plasma interactions, secondary beams (x-rays, gammas, ions, neutrons)

4. **kBELLA** – short pulser laser at high rep rate and high average power - proposed

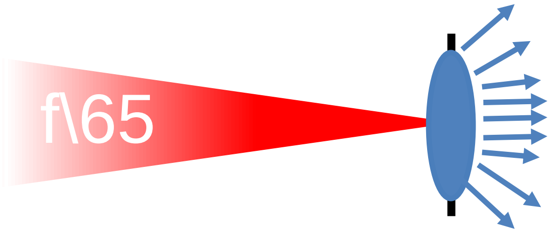
https://atap.lbl.gov/

LaserNetUS

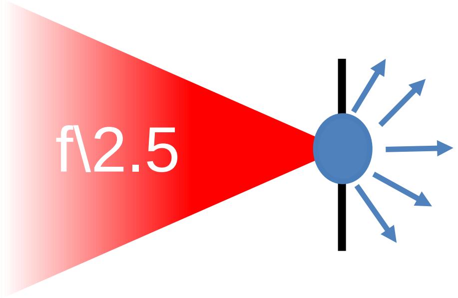
- 3rd round of beam time proposals now under review

https://www.lasernetus.org

We are operating with long focal length and are building a short focal length beamline with a dedicated target chamber for High Energy Density Physics and LaserNetUS

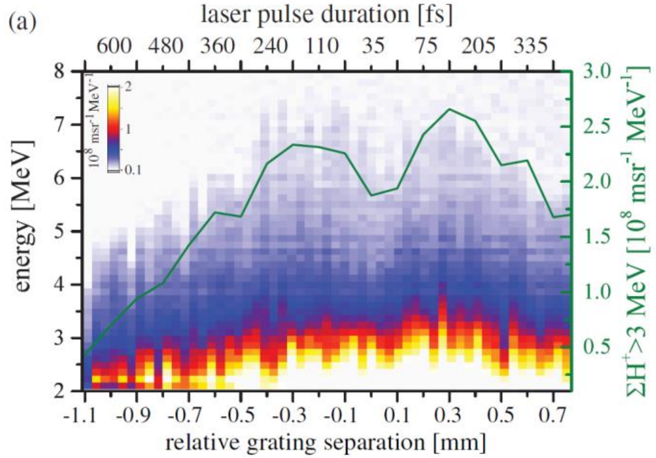


in operation now, 2x10^{19} W/cm^{2} , large laser spot, 100 μm, low divergence pulses with 10^{12} protons and heavy ions

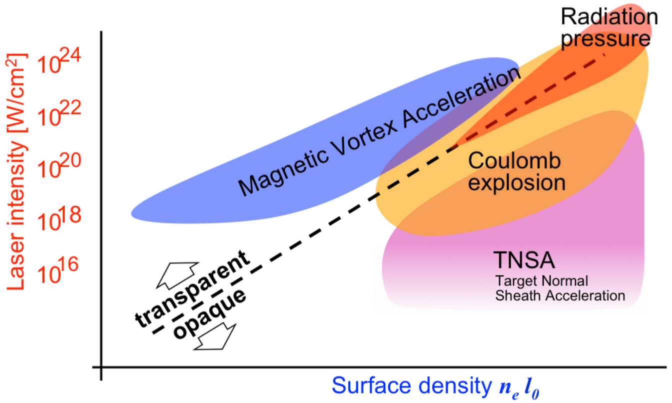


2021, >10^{21} W/cm^{2}, small laser spot, ~10 μm, relativistic plasma science at 1 Hz, ion acceleration to >100 MeV

Can we test new ideas for fast ignition and Inertial Fusion Energy in scaled experiments ?

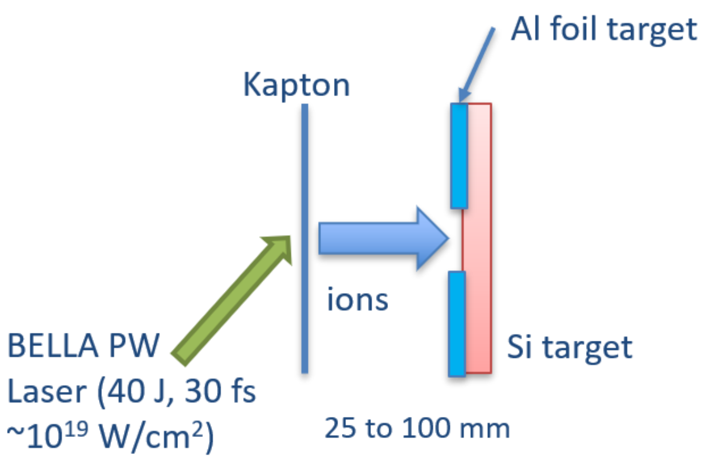


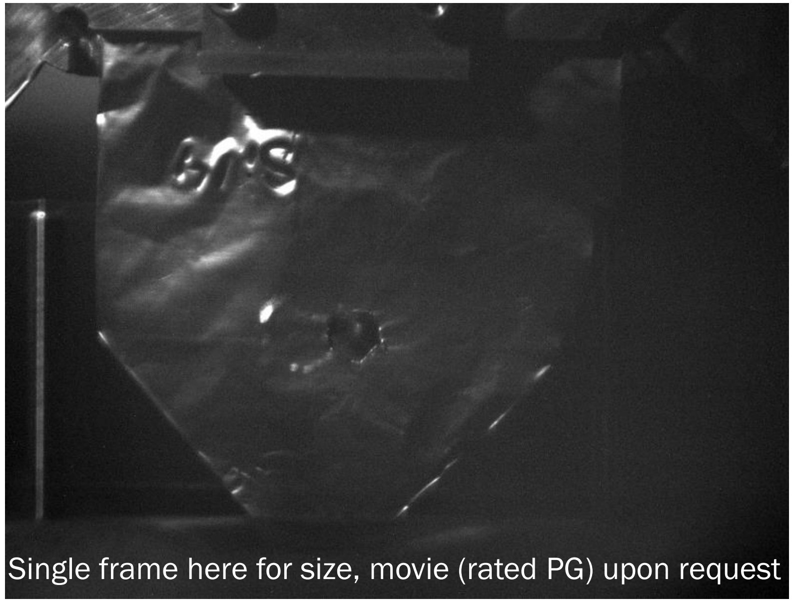
- S. Steinke, et al., Phys. Rev. Accel. Beams 23, 021302 (2020)
- J. Park, et al., Phys. Plasmas 27, 123104 (2020)



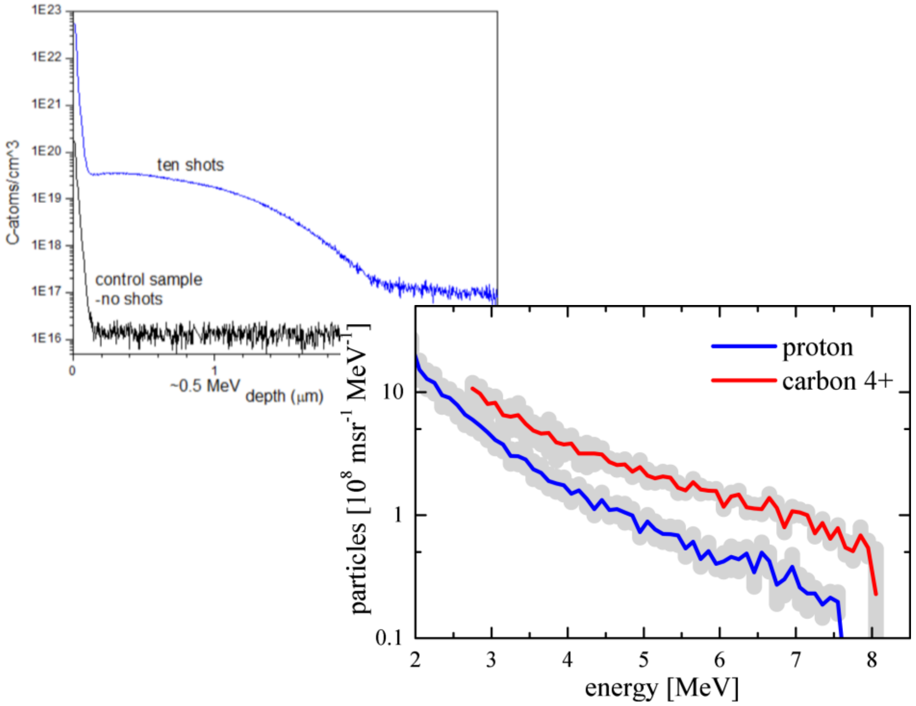
- e. g. J. Park, et al., Phys. Plasmas 26, 103108 (2019)

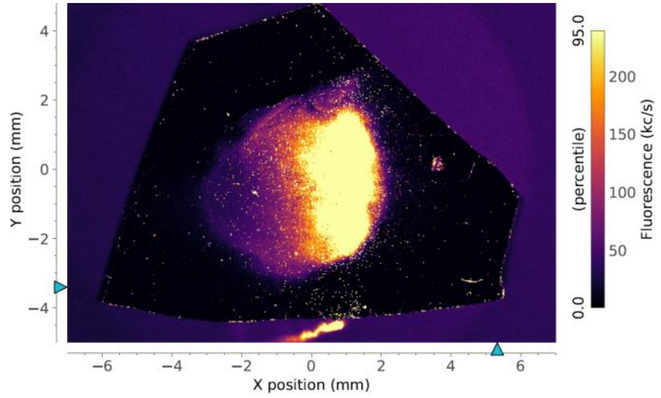
Target heating and materials experiments with ion pulses from laser-plasma acceleration

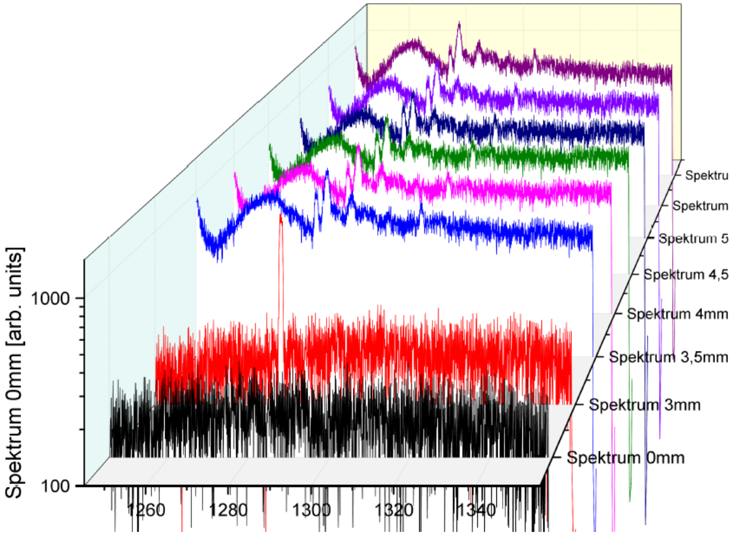




Single frame here for size, movie (rated PG) upon request

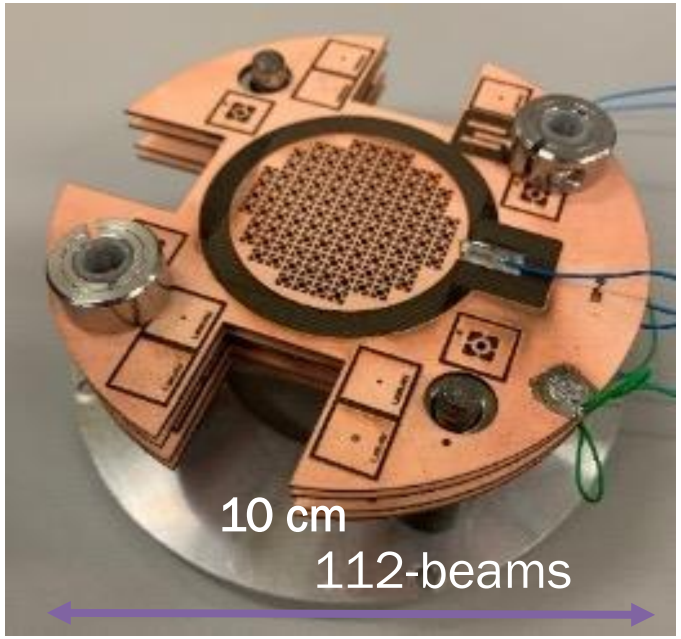


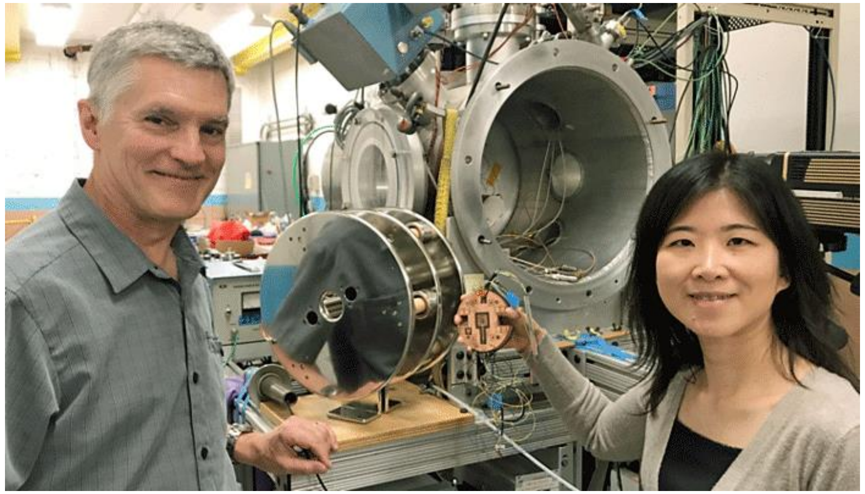


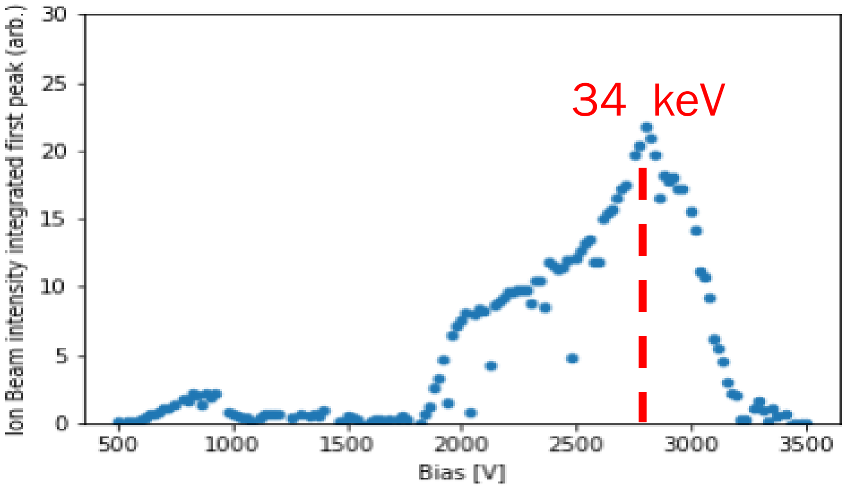


- Our rep rate was 0.2 Hz (can be up to 1 Hz)
- Protons, ions, 0 to 8 MeV, >1 J/cm^2 de-bunched to >10 ns
- Balance of defect formation and annealing, and formation of (novel) color center qubits
- NIR measurements by R. Wunderlich and J. Meijer, U Leipzig
- S. Steinke, et al., Phys. Rev. Accel. Beams 23, 021302 (2020) and in preparation
- Contact: T_Schenkel@LBL.gov

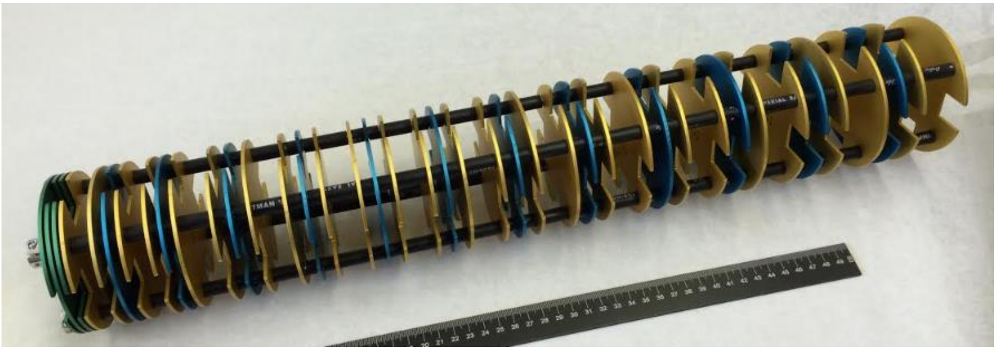
3. MEMS-based accelerators for (nuclear) materials and plasma heating. Can we scale accelerators to high beam power at much lower cost ?







- Multi-beam RF linac made from low cost wafers
- We have now scaled to acceleration by 7 kV/gap
- Gradient is equivalent to 1 MV/m
- Goal is to scale to ≥1 MeV, ≥10 mA per module for applications in manufacturing, beam driven neutron sources, …



- Model of a multi-beam linac scaled to 300 keV, >10 mA

arpa·e

Contact: Qing Ji, QJi@LBL.gov

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

4. Accelerator Modeling offers cutting-edge computational tools and expertise for fusion and plasma sciences

BLAST
BERKELEY LAB ACCELERATOR SIMULATION TOOLKIT

Broad toolset of plasma & accelerator codes

BeamBeam3D, IMPACT, FBPIC, HiPACE++, Warp/WarpX

Applicable to the modeling of

- Plasma acceleration.
- Laser-plasma interactions and plasma mirrors.
- High-field physics (with QED).
- Collisionless shocks.
- Pulsars.
- Magnetic reconnections.
- Intense particle beams.
- Accelerator designs.
- Light sources and particle sources.
- Beam – plasma interactions for IFE, …

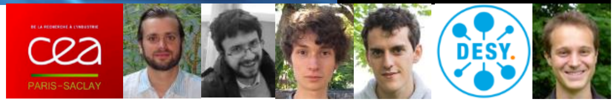
Contact: Jean-Luc Vay
https://atap.lbl.gov/accelerator-modeling-program/

New generation plasma code

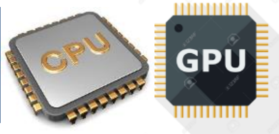
WarpX ECP EXASCALE COMPUTING PROJECT

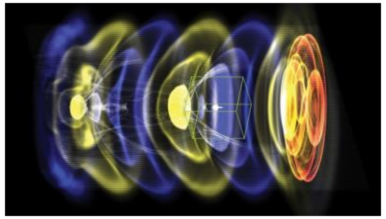
Open source, developed by tightly integrated team of physicists + applied mathematicians + computer scientists

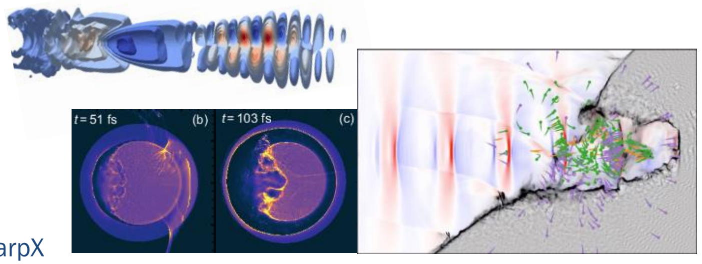
and international collaborations



Runs on single user desktops/laptops up to largest CPU or GPU-based supercomputers







https://github.com/ECP-WarpX/WarpX

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We thank the U.S. Department of Energy, Office of Science, Fusion Energy Sciences and ARPA-E for their support.

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