Beam, magnets, and modeling to advance the quest for fusion energy science at Berkeley Lab

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LBNL POC for INFUSE

Slides provided by Qing Ji

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LBNL Contacts

- Compact multi-beam ion accelerators for plasma heating
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- High Temperature Superconductor Technology for Fusion Reactors
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- Collisional interaction modules in WarpX for Fusion Research
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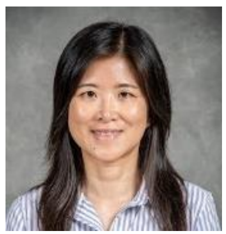
Compact multi-beam ion accelerators for plasma heating

LBNL


T. Schenkel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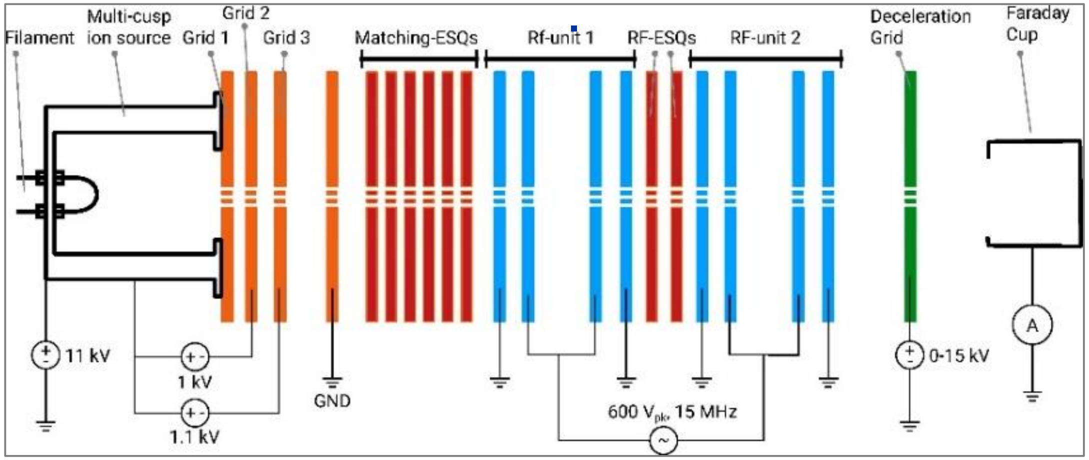
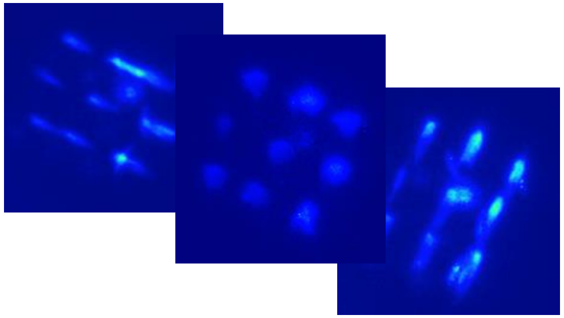
Compact, low cost multi-beam ion accelerators that can be scaled to high power

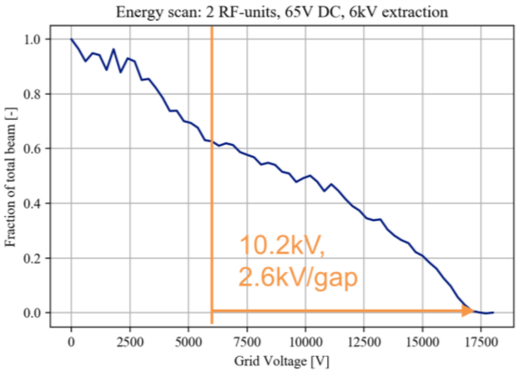
Ion beams are widely used in many applications, and they are attractive for fusion plasma heating.



Schematic with focusing and acceleration wafers.



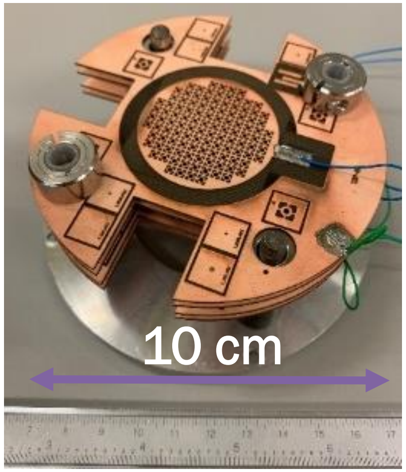
Images of ion beamlets for a series of electrostatic quadrupole (ESQ) settings demonstrating focusing.



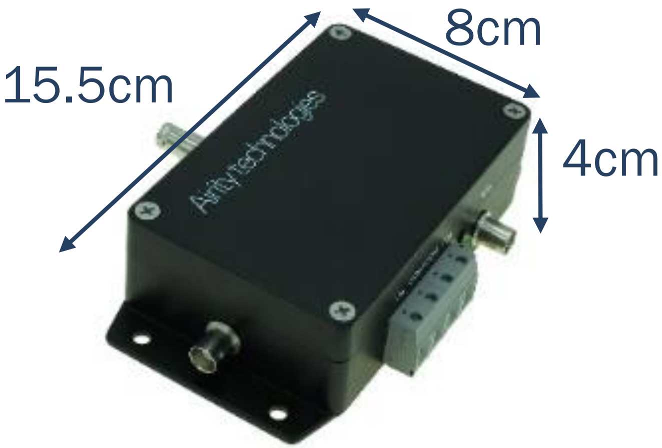
Multi-beamlet Ar^+ ion current vs. retarding grid bias showing ion acceleration with 2.6 kV/gap.

Demonstrated concept using stacks of low cost wafers

The next step is scaling to high beam power.



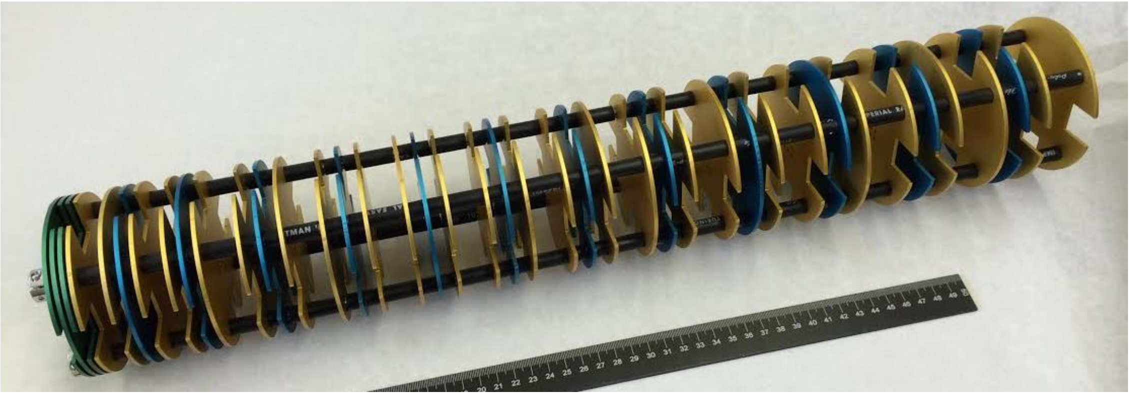
Multi-beamlet RF accelerator unit with 112 beamlet array (1 mm apertures, 3 mm spacing).



Compact RF power supply from Airity Tech, LLC, designed for 10 kV/gap at 13.56MHz

High power, multi-beam RF accelerators can advance plasma heating in MFE (neutral beam injectors), MTF (liner formation and compression and IFE/HIF)

Next Steps to demonstrate scalability



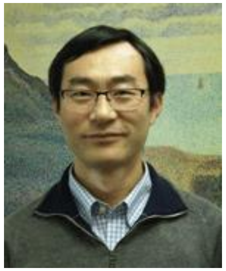
Scalability to high ion current (>1 Ampere) and high kinetic energy (>1 MeV) in a modular approach. Left: model of a 300 keV module.

- 10x higher system current density than single beam accelerators
- Mid term goal is 1 MeV in 1 m, higher gradients in progress
- Safe – no need to stand-off high voltages due to sequential acceleration, no x-ray hazard

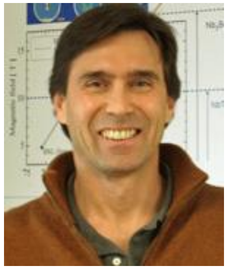
- *US Patent 2019/0159331 A1, May 23, 2019.*
- *A. Persaud, et al. Rev. Sci. Instrum. 88, 063304 (2017)*
- *P. A. Seidl et al., Rev. Sci. Instrum. 89, 053302 (2018).*

High Temperature Superconductor Technology for Fusion Reactors

S. Prestemon



X. Wang



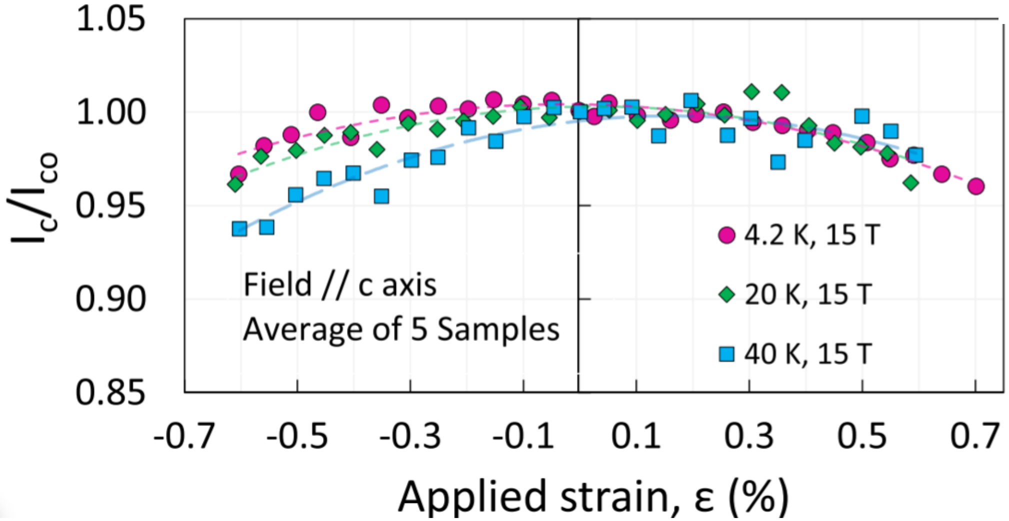
G. L. Sabbi

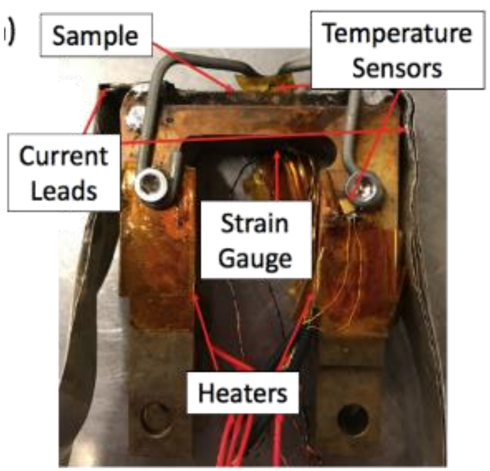
M. Martchevskii

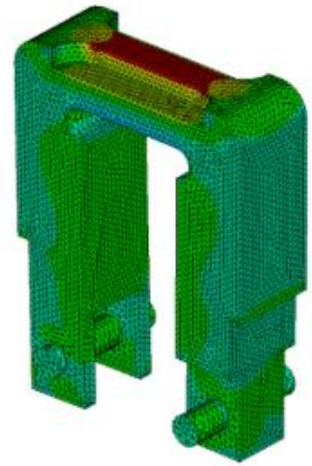
F. Pierro

Exploration, Development and Applications of HTS for Fusion

- **Conductor characterization and initial feedback to cabling**
- **Novel diagnostics for quench detection/protection**





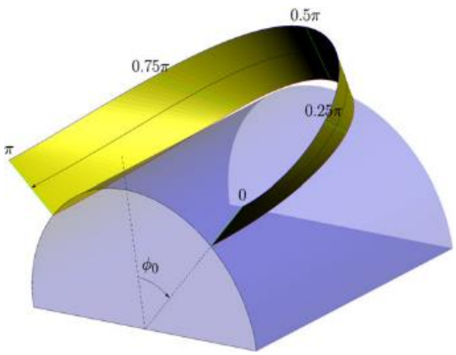


Ref. F. Pierro et al, "Measurements of the Strain Dependence of Critical Current of Commercial REBCO Tapes at 15 T between 4.2 and 40 K for High Field Magnets", IEEE Trans. Appl. Supercond. Vol. 29, No. 5, 8401305(2019)

Modeling Benchmarked by Experiments

Development of optimal cable and magnet geometry to manage strain in REBCO cables and magnets

A helical winding used in CORC® cable



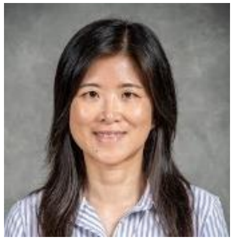
A bending mode relevant for stacked cable

High-field REBCO magnet technology relevant for HTS fusion

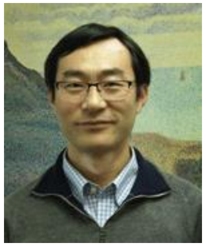
Development complemented by world-class cabling capabilities

Ref: X. Wang et al, "Strain Distribution in REBCO Coated Conductors Bent with the Constant-Perimeter Geometry", IEEE Trans. Appl. Supercond., 6604010, 2017. https://doi.org/10.1109/TASC.2017.2766132

Enhancing HTS Quench Detection



Q. Ji



X. Wang

Z. Yang

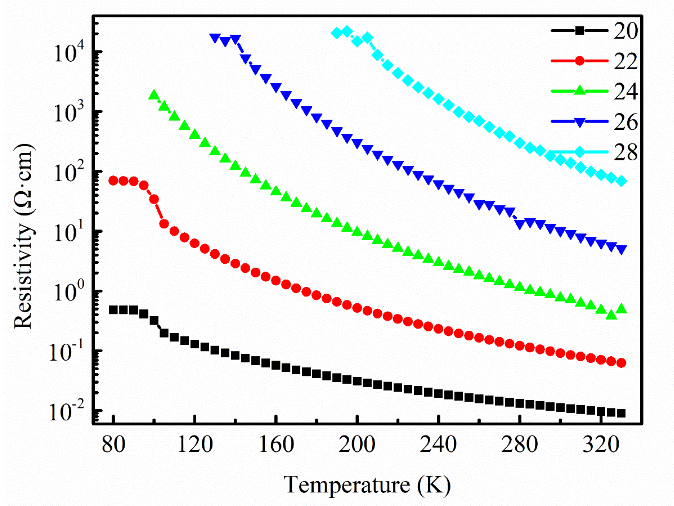
A. A. Martinez

A. Anders

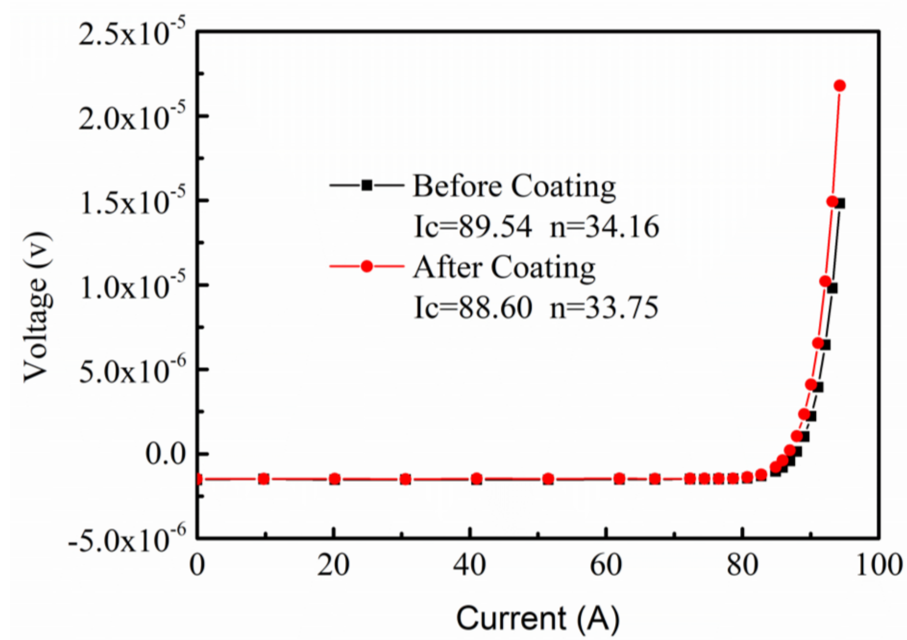
Demonstration of Dynamic Resistivity Control

We demonstrated VO_x coating on short REBCO tapes using cathodic arc plasma deposition as a first step to enhance protection capability for REBCO cables and magnets

$\rho(T)$ with various O_2 flow rate



Hall effect measurements indicated that the resistivity of the VO_x films at room temperature was at least 3 orders of magnitude lower than at 77 K.

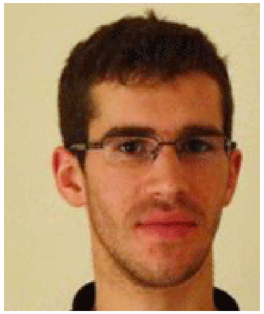


Change of the critical current of the REBCO tape before and after coating is negligible.

Ref: Z. Yang et al, “Cathodic arc deposition of VOx films and their application in quench protection of high-temperature superconducting magnets”, in preparation.

Collisional interaction modules in WarpX for Fusion Research

J. L. Vay



R. Lehe

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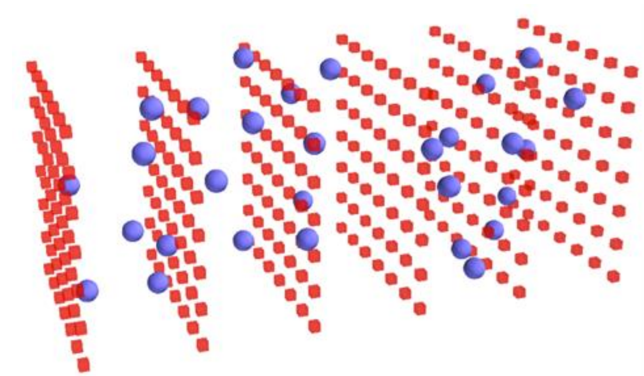
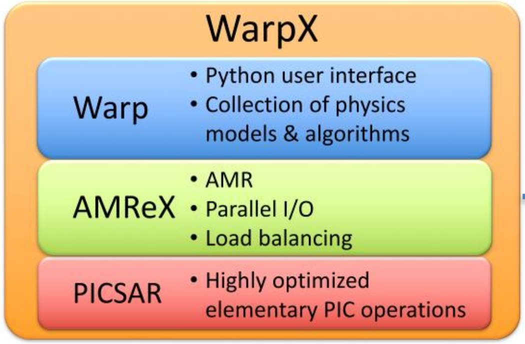
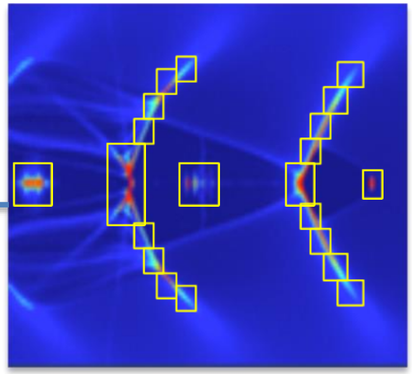
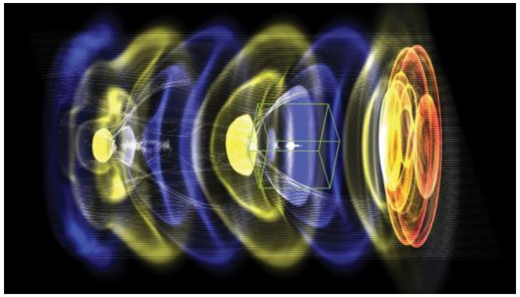
Broad Expertise in Plasma and Electromagnetic Field Interactions

- WarpX is a Particle-In-Cell code: *ab initio* simulations of interaction between plasma particles and electromagnetic fields









ECP EXASCALE COMPUTING PROJECT

NNSA National Nuclear Security Administration — U.S. DEPARTMENT OF ENERGY | Office of Science

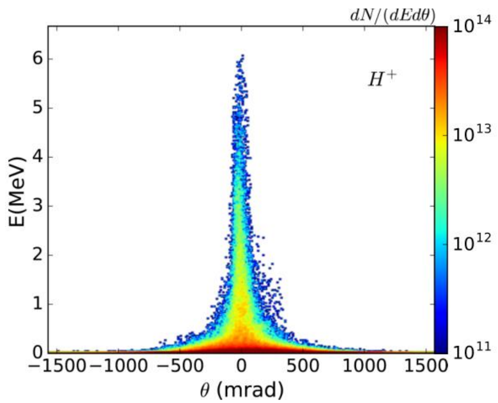
Highly Developed Modeling Code

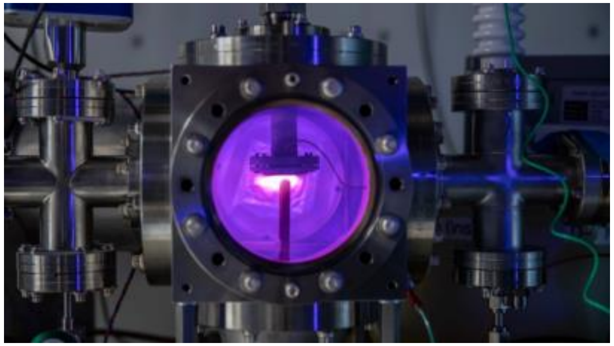
- WarpX is massively parallel, optimized on DOE supercomputers; supported by the DoE Exascale project
- Examples of fusion relevant applications:
  - Interaction between intense lasers, intense beams and dense targets for inertial fusion, fast ignition
  - Interpenetration of high-energy plasmas, Weibel instability, …
  - Kinetic effects in heating processes inside plasmas, heating by RF fields or neutral beams in tokamaks, laser heating, …
  - Some applications may require developing new modules in WarpX, esp. collisional interactions

J.-L. Vay, et al, Nucl. Inst. Meth. A 909, 486-479 (2018)

Fundamental studies of fusion processes with high impact potential

Fusion rates are determined by tunneling through the Coulomb barrier. Can we discover new ways to enhance tunneling rates? Electron screening in dense plasmas is a known-unknown, let's hack it !

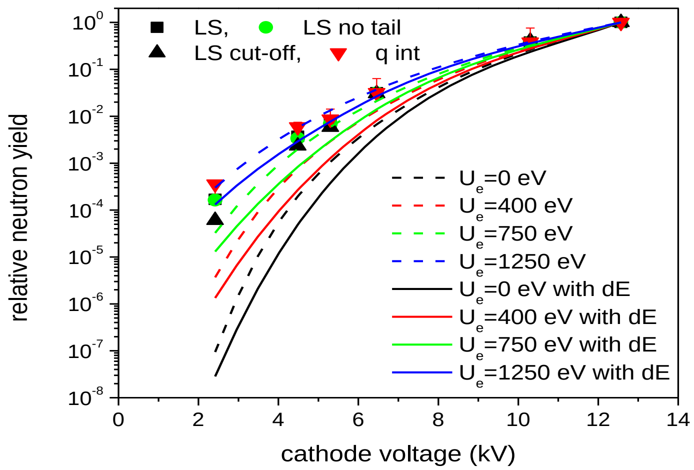




Exploratory; opportunities to advance basic understanding and master new control vectors to enhance fusion rates. Theory, simulations and fusion experiments with ion pulses, lasers, plasmas, …

- J. H. Bin, et al., Rev. Sci. Instrum. 90, 053301 (2019)
- T. Schenkel, et al., https://arxiv.org/abs/1905.03400
- C. P. Berlinguette, et al., Nature 570, 45 (2019)

- **funded in part by GOOGLE LLC through a Crada with LBNL**



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