



# How to use High Magnetic Field measurements to improve critical current performance

**Boris Maiorov**

National High Magnetic Field Laboratory (NHMFL) –  
Los Alamos National Laboratory (LANL)



Collaborators:

**Christopher A. Mizzi**, Fedor F. Balakirev, Doan Nguyen, Scott Crooker (NHMFL LANL), M. Miura (Seikei Univ.)

Previous Collaborators: Maxime Leroux, I. Nekrashevich, & Leonardo Civale

LA-UR-25-22524

Email: [maiorov@lanl.gov](mailto:maiorov@lanl.gov)

Funded by:  
National Science Foundation, National High Magnetic Field Laboratory,  
Basic Energy Science, BES, DOE,  
Los Alamos National Laboratory LDRD Program



Managed by Triad National Security, LLC, for the U.S. Department of Energy's NNSA.

# CCA2025

International Workshop on Coated Conductors for Applications

CERN | March 11-13, 2025

# Thanks to the organizers, Feeling at home

- Studied at Bariloche (Patagonia), Argentina
- Called the “*South-American Switzerland*”

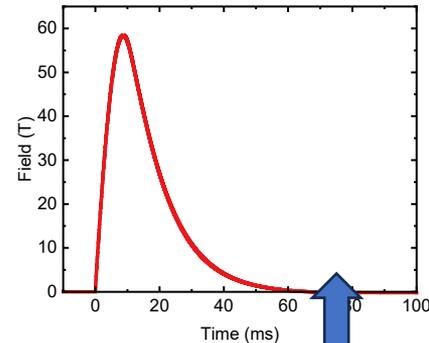


# High Magnetic Fields → Pulsed Fields

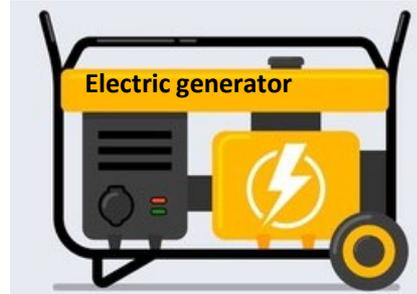
NHMFL PFF offers different flavors of magnets:

65T (4 cells), 60T mid-pulse, 73T duplex, 85T duplex, 100T, 60 T Long pulse  
 50ms      400ms      50+7ms      deploying/ Generator back soon

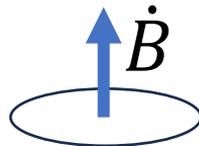
“Standard” 65T magnet



Capacitor- or Generator-driven pulsed magnets



1.4 GW



$V \propto A dB/dt$



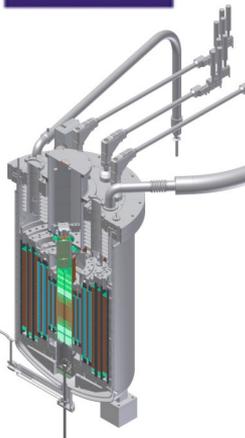
**Unique challenges:**

- Time scale
- Large  $dH/dt$
- Large field range → want “smart” current to not burn out your sample!



L, R fixed  
 Inductance, Resistance

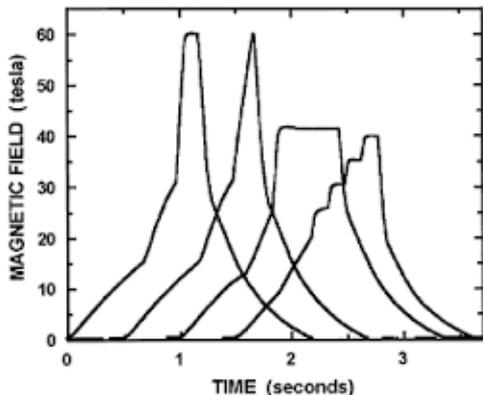
# Plenty to learn at high fields



Magneto-quantum oscillations reveal the Fermi surface of materials



The 1.4GW generator produces 90% of NM power (for 2 seconds) **Made in Switzerland**



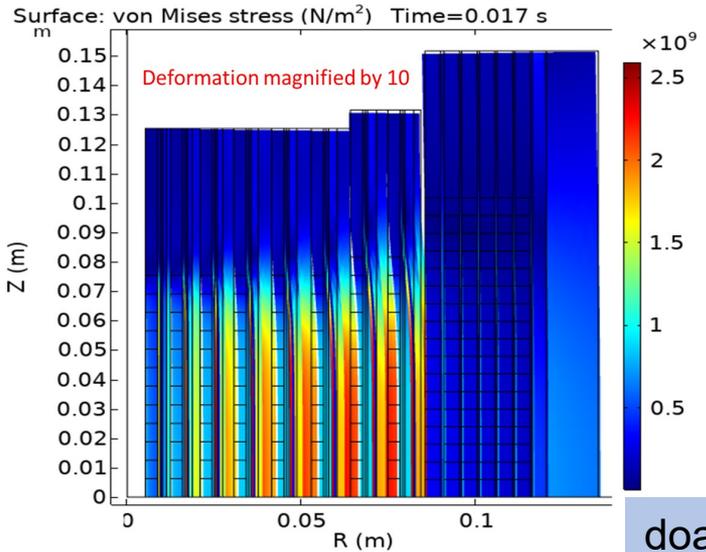
# Magnet design and high current capabilities flexible

*Magnet design ad-doc of application*

- Comprehensive 2D transient coupled Multiphysics (Electromagnetic-Mechanical-Thermal- Circuit) FEA simulations
- Based on Java + COMSOL for automation of simulation generation and optimization
- Temperature dependences of electrical conductivity and mechanical properties of material are considered for better accuracy

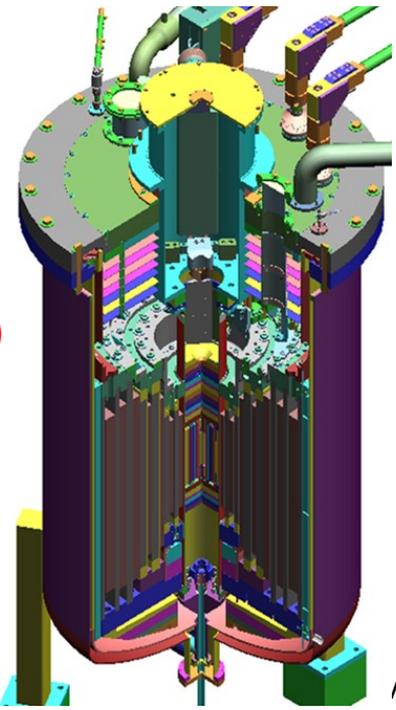
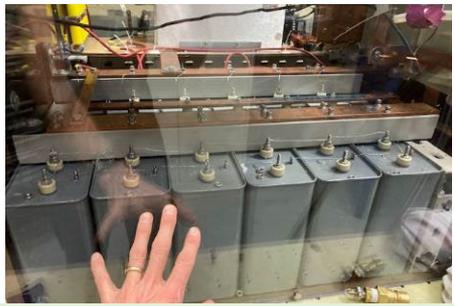
## 100 kA pulsed current capability:

16 kV – 4MJ capacitor can provide 100 kA-10ms pulsed current to perform impulse testing for cables



144 turns of  
Cu-Ag wire,  
15 mm bore  
20T, 4ms  
THz optics  
(Now 31T)

Custom 20 kJ cap bank (4.4mF, 3kV)



doan@lanl.gov

Post et al, PRB **103**, 134515 (2021)

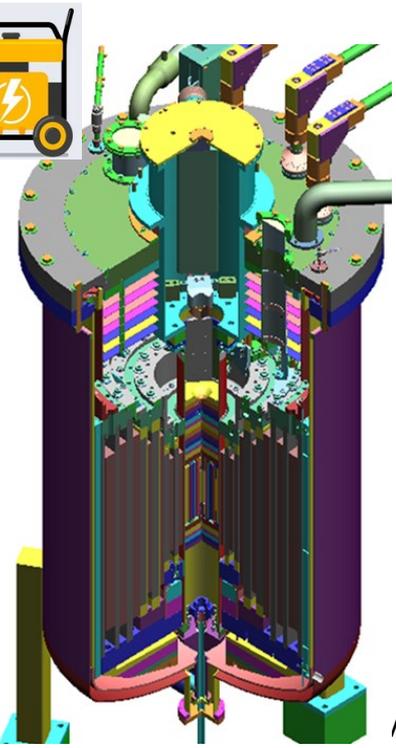
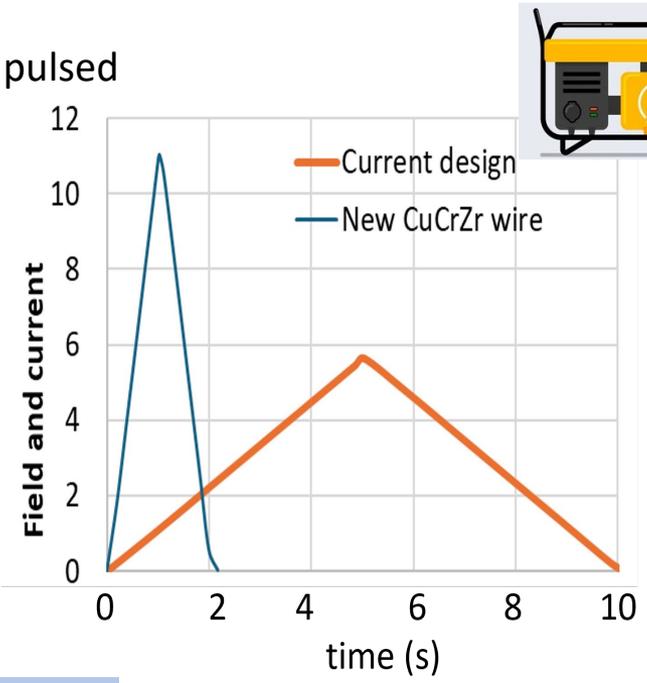
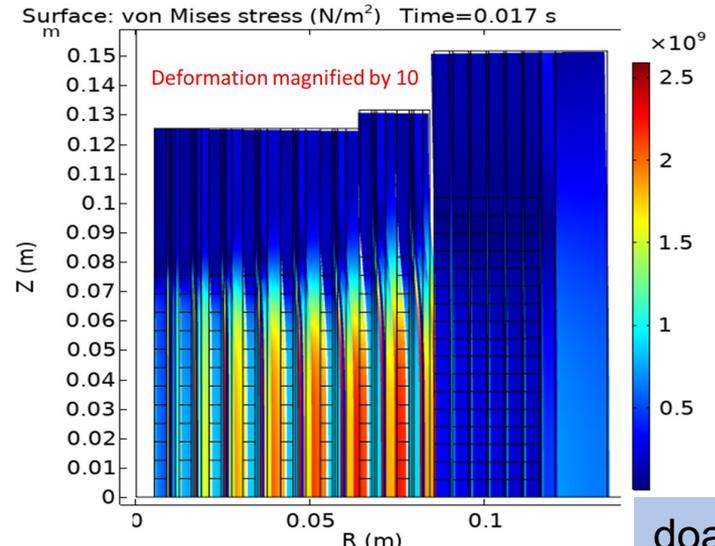
# Magnet design and high current capabilities flexible

*Magnet design ad-doc of application*

- Comprehensive 2D transient coupled Multiphysics (Electromagnetic-Mechanical-Thermal- Circuit) FEA simulations
- Based on Java + COMSOL for automation of simulation generation and optimization
- Temperature dependences of electrical conductivity and mechanical properties of material are considered for better accuracy

## 100 kA pulsed current capability:

16 kV – 4MJ capacitor can provide 100 kA-10ms pulsed current to perform impulse testing for cables

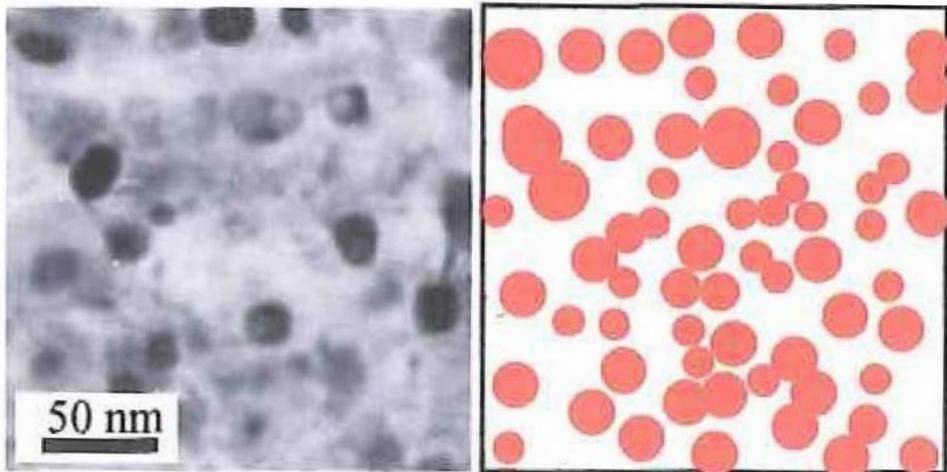


doan@lanl.gov

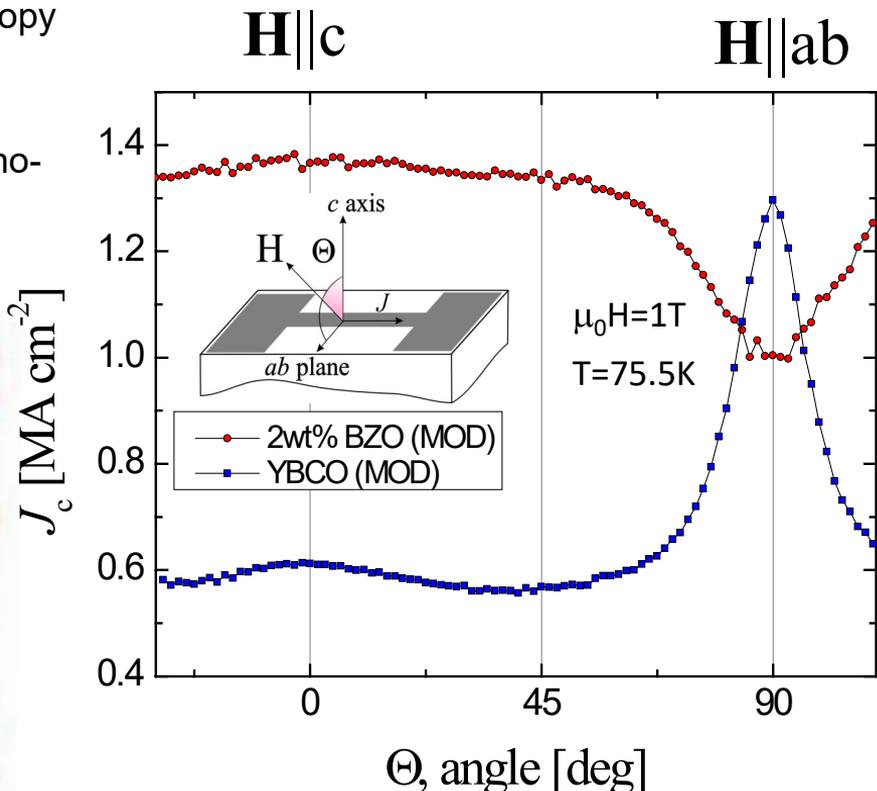
D. Nguyen *et al*,(priv. comm)

# Pinning landscapes dominated by nanoparticles in entire angular range in YBCO+BZO by Metal Organic Decomposition method

- Nanoparticle dominated samples show opposite anisotropy pinning
- Coated conductors YBCO/IBAD-MgO and (Y,Gd)BCO+BZO/IBAD-MgO (MOD, ISTEK) (random nanoparticles)
- $J_c(sf) \sim 4 \text{ MA cm}^{-2}$



average particle diameter  $\sim 25\text{nm}$

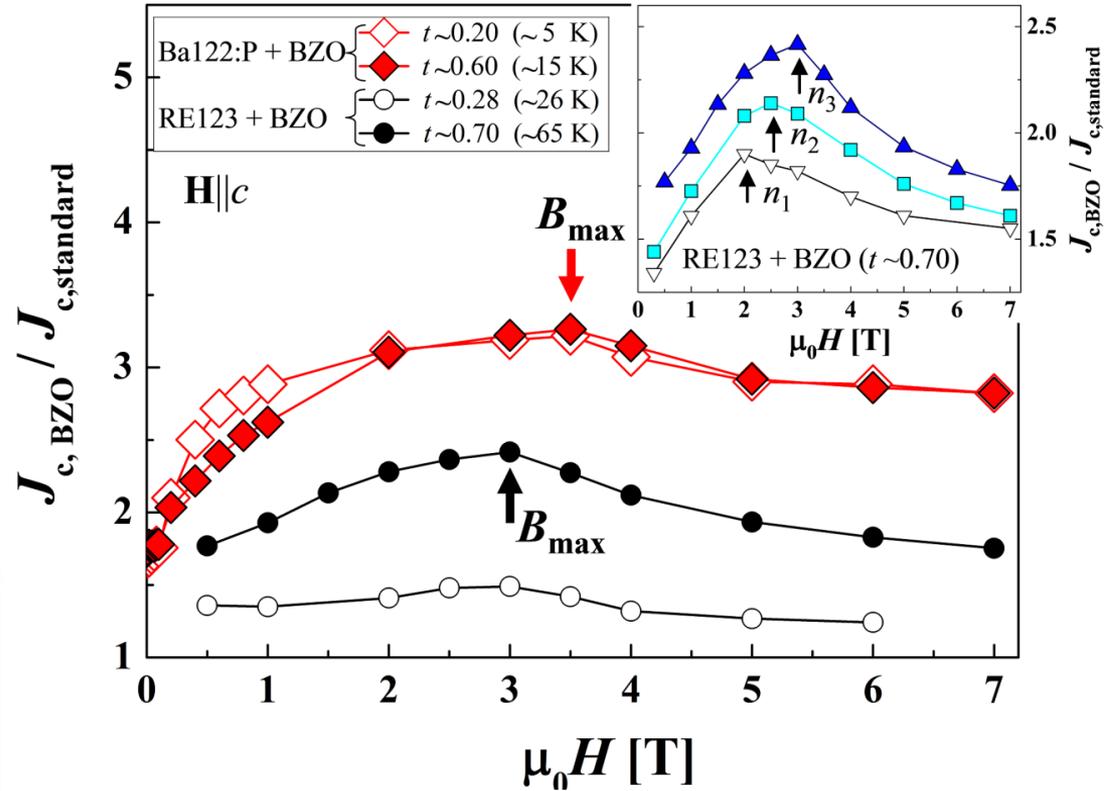
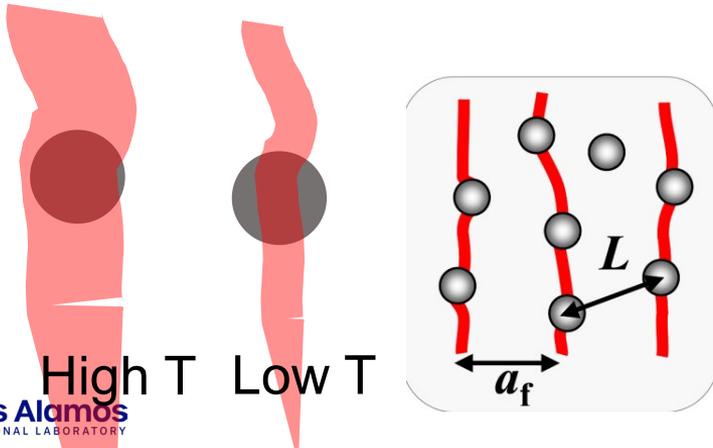


Cu-based (M. Miura et al Phys. Rev. B, npg Asia Mat.)  
Fe-based (M. Miura et al Nat. Comm. )

maiorov@lanl.gov

# Pinning by nanoparticles continuous to be effective at very large fields

- Nanoparticles inclusion improvement in YBCO and Iron based superconductors
- Ba122:P improvements are maintained at all  $T$
- Nanoparticles in YBCO *too big at low T*
- Relative maximum improvement occurs when 'matching field'  $a_f \sim L$

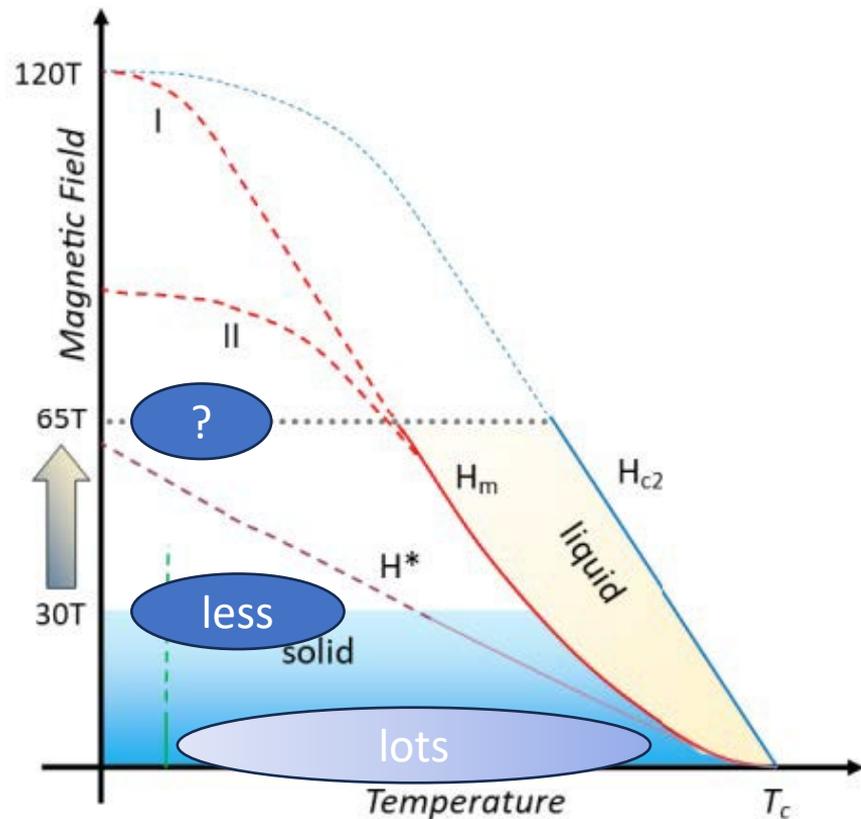
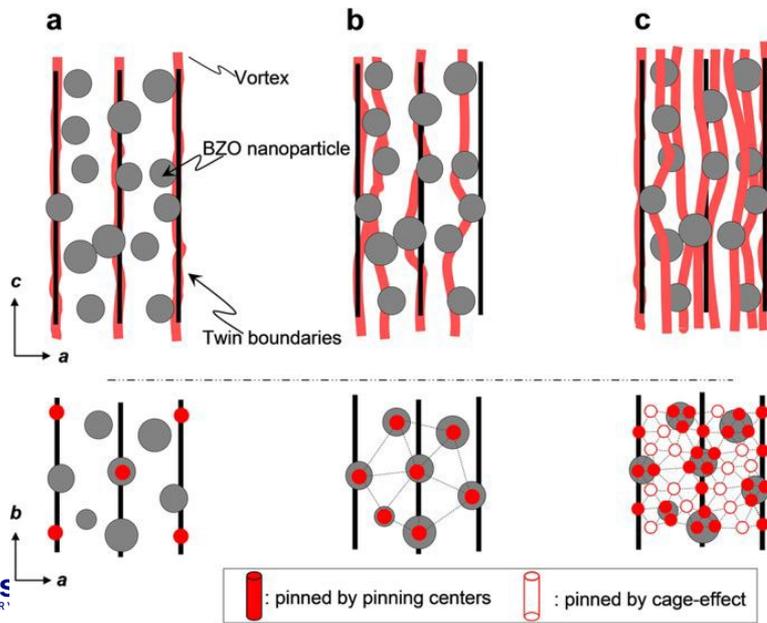


M. Miura *et al* Nature Comm. 4, 2499 (2013)

maiorov@iani.gov

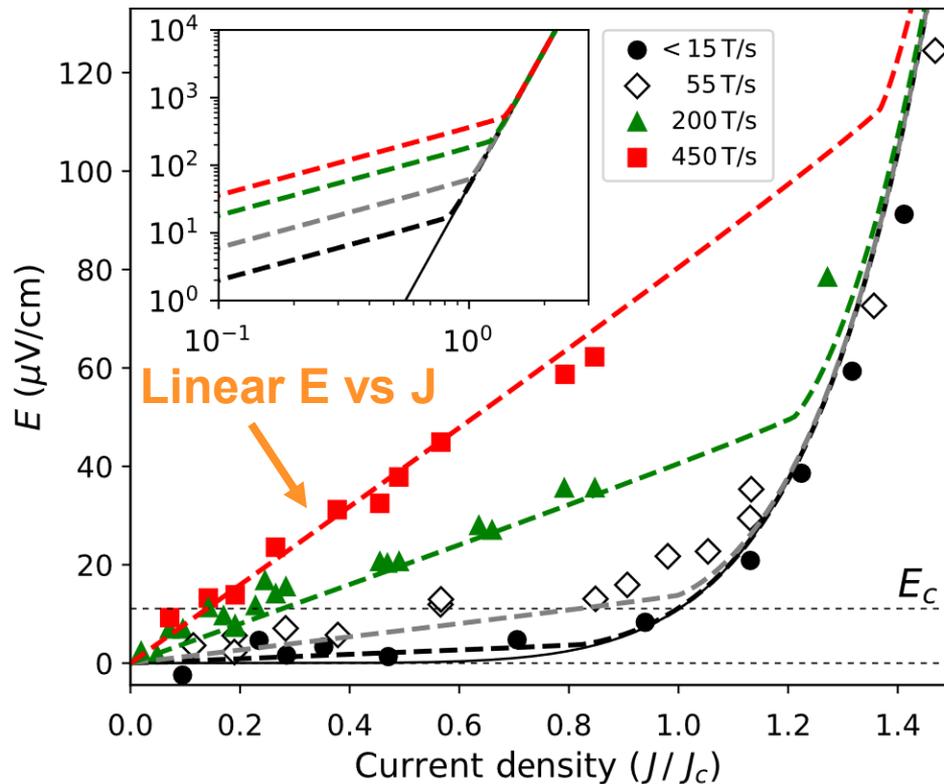
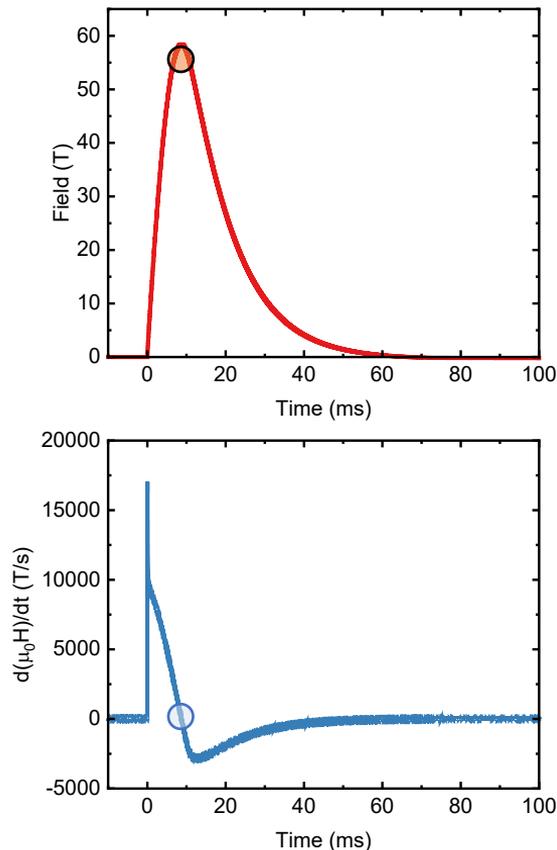
# $H_{irr}$ and $J_c$ are sensitive to nature and density of defects

- Nanoparticles inclusion improve critical current and affect  $H_{irr}$
- Morphology, distribution, and relative defect to vortex densities determine response



# I-V curves possible using Field Programmable Gate Array

Large  $dH/dt$  'away' from peak field    Deviations from power law behavior if  $\frac{1}{2} \mu_0 \dot{H} W \gg E$



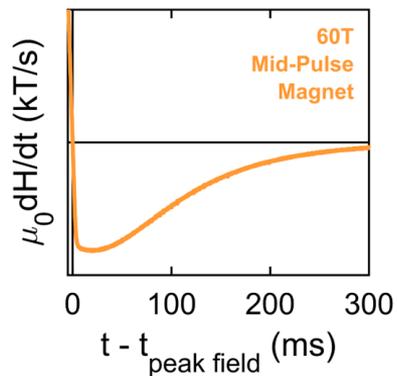
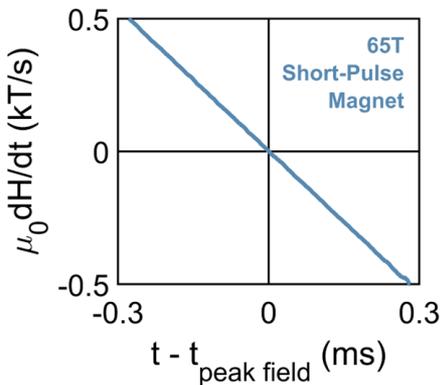
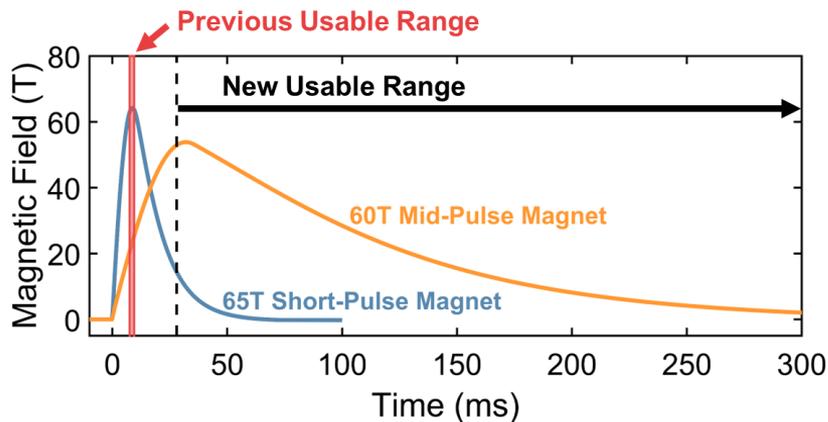
Red Pitaya



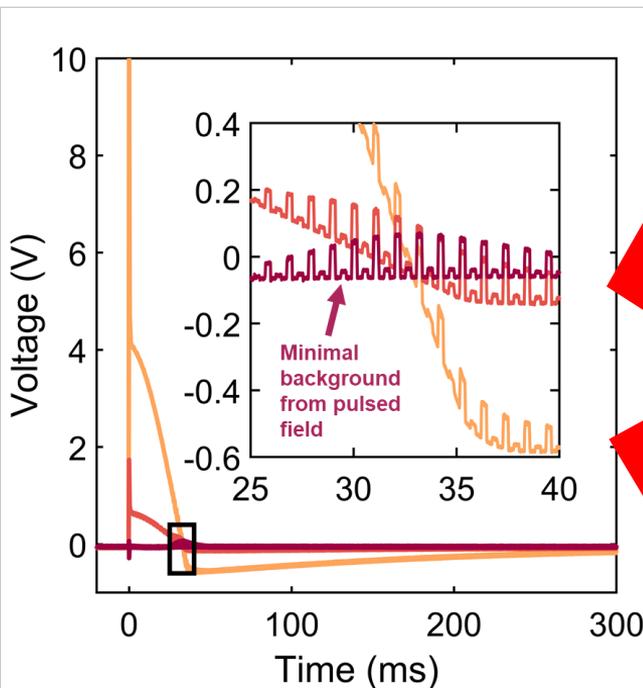


# Combining mid-pulse with other improvements yields $J_c$ extraction over large field range in a single pulse

a Improvements in pulsed-field magnets

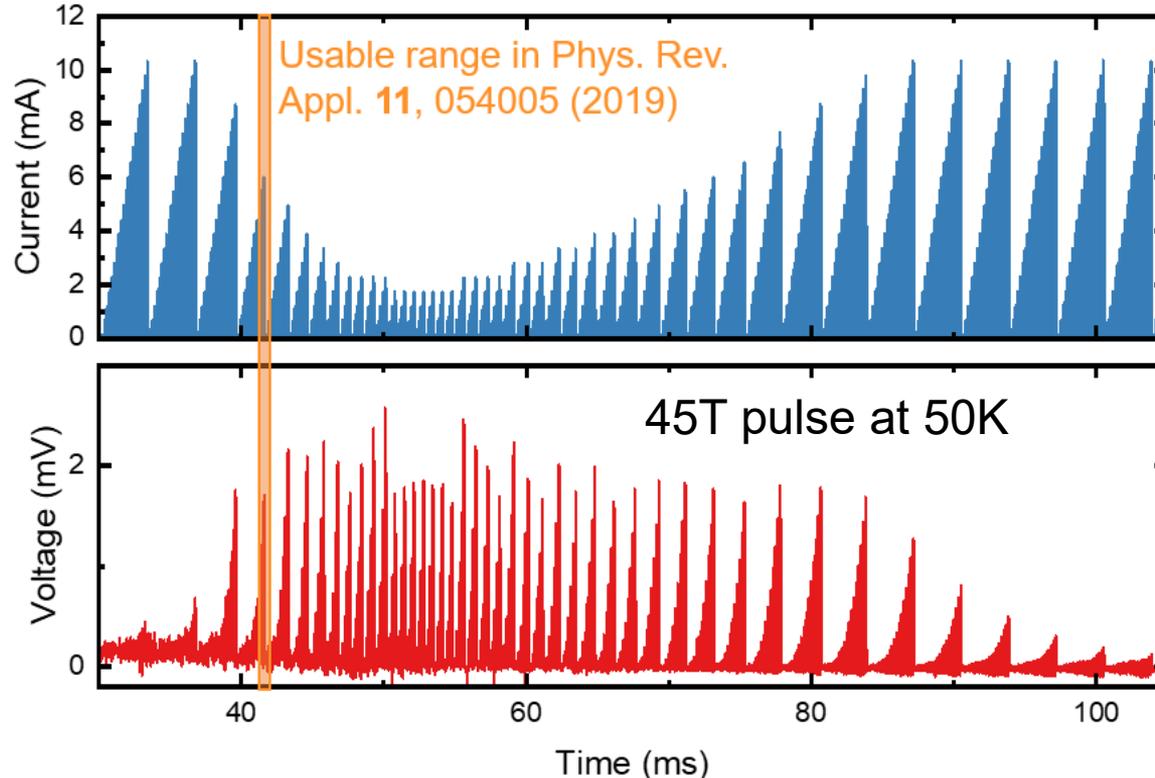


b Improvements in *in situ* compensation

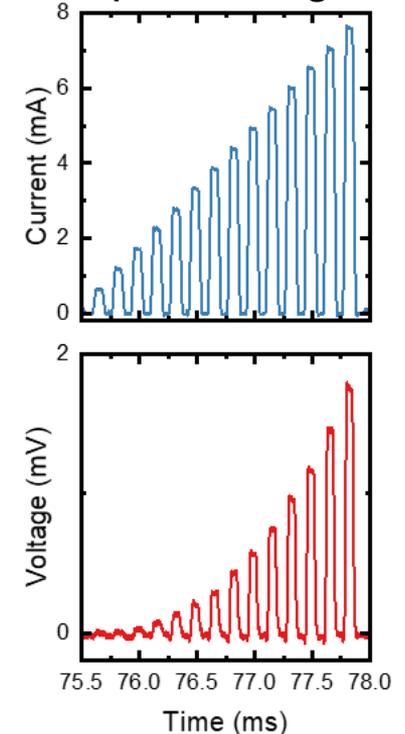


# Continuous IVs in single pulse in mid-pulse magnet

- Any bridge can be measured (needs to fit in bore and have contacts).
- Magnetization also possible.

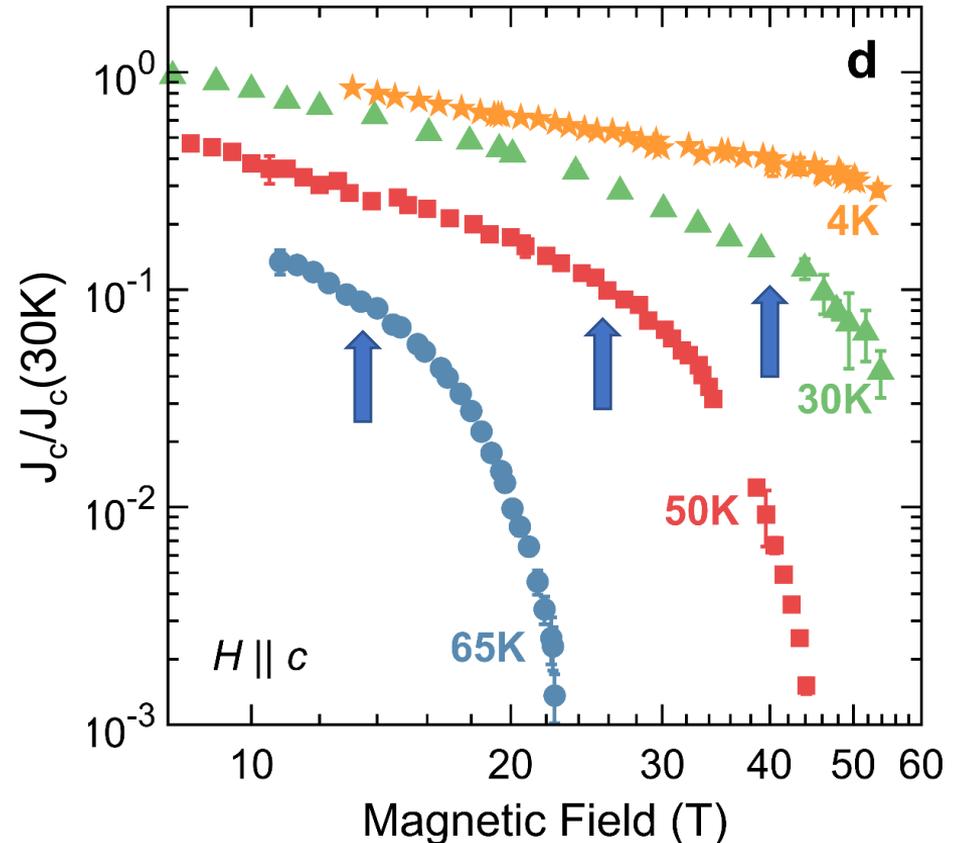


## Example of single IV



# Combining mid-pulse with other improvements yields $J_c$ extraction over large field range in a single pulse

- Now we can measure with a single field shot what would have taken a day!
- Significantly higher field resolution
- Focused on research samples



# What about something intrinsic?

- We find and theory predict

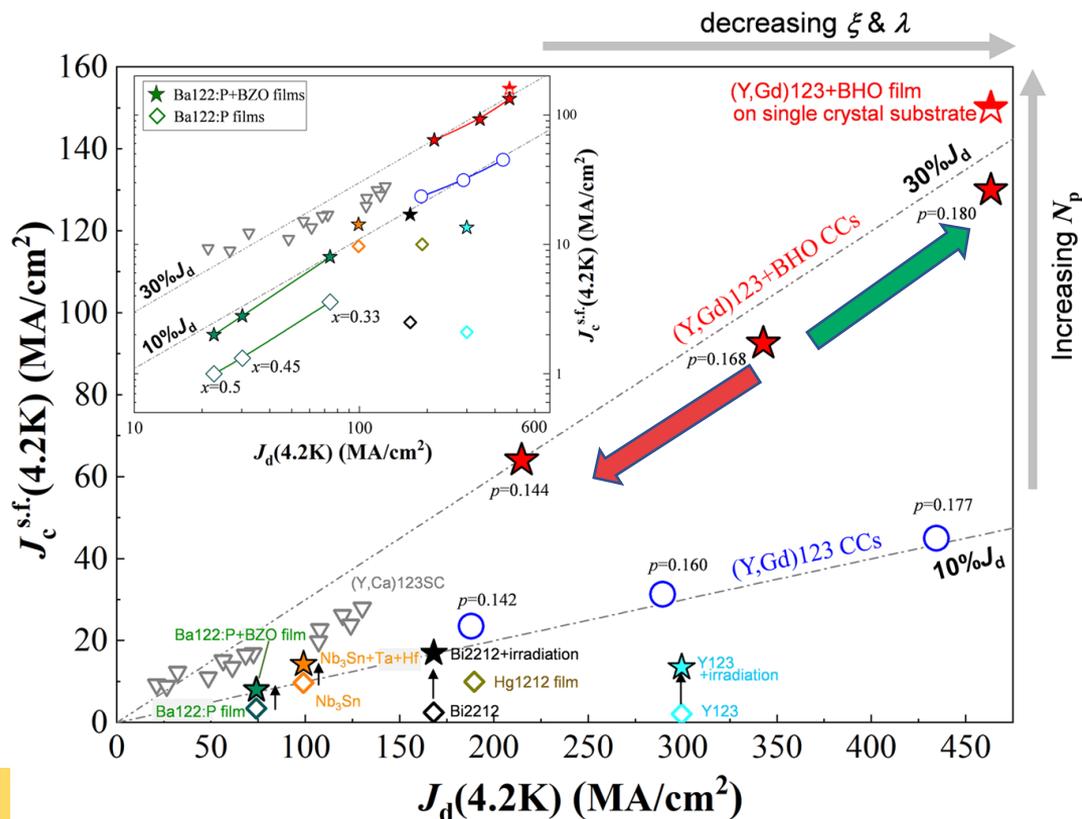
$$J_c = \mathbf{A} J_d$$

$J_d$  = Depairing current =  $1/(\lambda^2 \zeta)$

$\mathbf{A}$  = Effectiveness of pinning

- We improved  $J_d$ , and  $\mathbf{A}$
- Shown in YBCO, Ba-122, Sm1111\*

**The road to increase pinning**

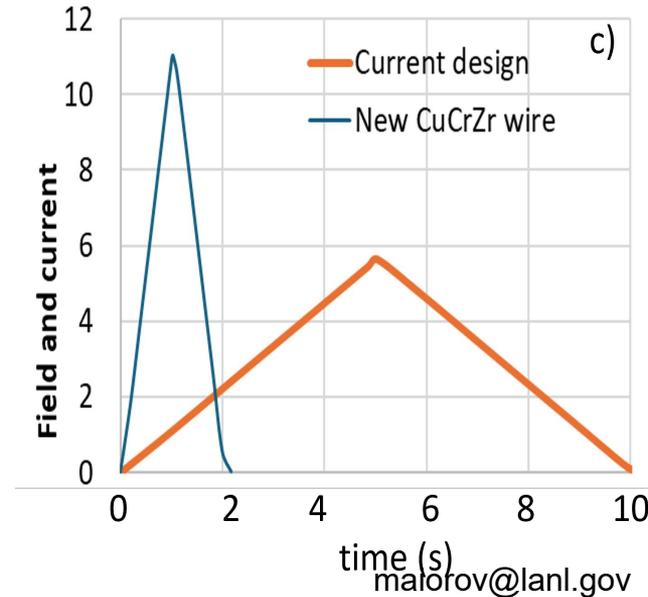
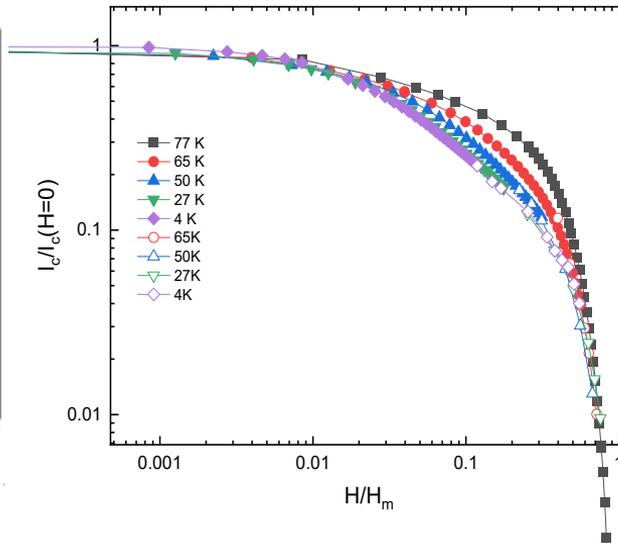
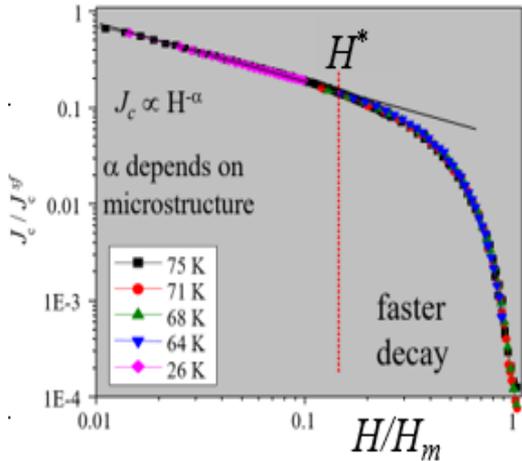


Miura *et al*, *npg Materials* (2022)

\* Miura *et al*, *Nat. Materials* (2024)

# Summary and conclusions

- Design of magnets for experiments of high currents and energies
- We can measure superconducting properties in different magnets with unique and specially designed experiments
- Measuring up to highest fields is key to understand vortex pinning and improve superconductors



# How do I measure there?

- Proposal for all NHMFL sites (Gainesville, Tallahassee, LANL) good for 3 years
  - Peer reviewed, if there are proprietary information we can discuss the details
  - We can work other arrangements with companies
- Propose experiments time, 1 system 1 place. You can propose multiple experiments per cycle (e.g. one in Tallahassee and LANL). 3 calls per year
- Multiple techniques and experts
- Sample preparation is usually up to the user, you are encouraged to discuss and come

## Funding Opportunities

- **Dependent Care Travel Grant Program:** Early-career scientists. Up to \$800 per calendar year
- **First-Time User Support:** First-time principal investigators with approved and scheduled magnet time. \$1,000 for international users; \$500 for domestic principal investigators
- **Visiting scientists:** \$500 - \$5,000; more under special circumstances
- **User Collaboration Grants Program:** Magnet Lab personnel