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Presentation given at Coated Conductors for Applications Workshop, Houston, TX, USA, April 2023.

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Latest advances for determining critical currents in pulsed fields

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Los Alamos National Laboratory LDRD Program
Basic Energy Science, BES, DOE

Critical Currents, materials, physics and applications

Most Type II SC applications involve mixed phase region

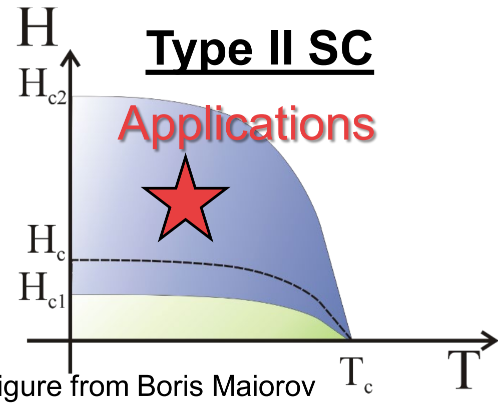
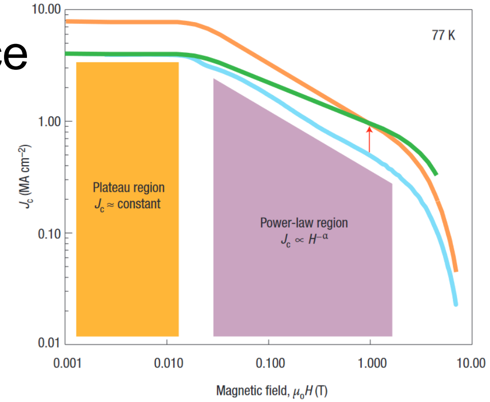
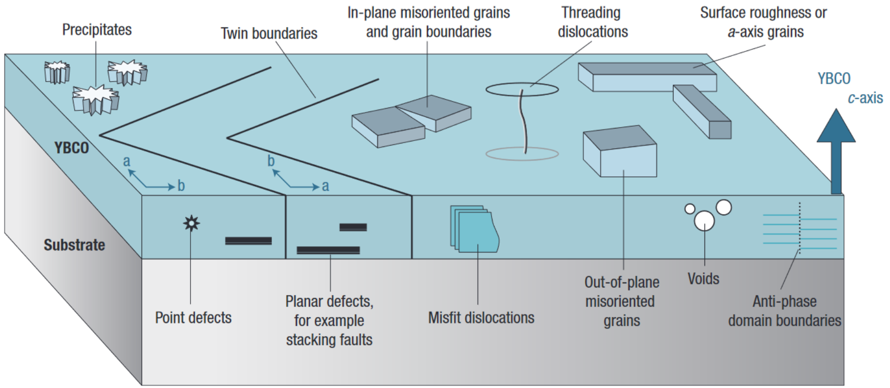


Figure from Boris Maiorov

J_c field dependence important for understanding effectiveness of different pinning centers



Defect engineering offers rich opportunities to tune SC properties



Blatter *et al.*, Rev. Mod. Phys. **66**, 4, (1994).

Foltyn *et al.*, Nat. Mat **6**, 631-642 (2007).

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Applications and new physics require J_c data at high fields

Significant progress in J_c engineering

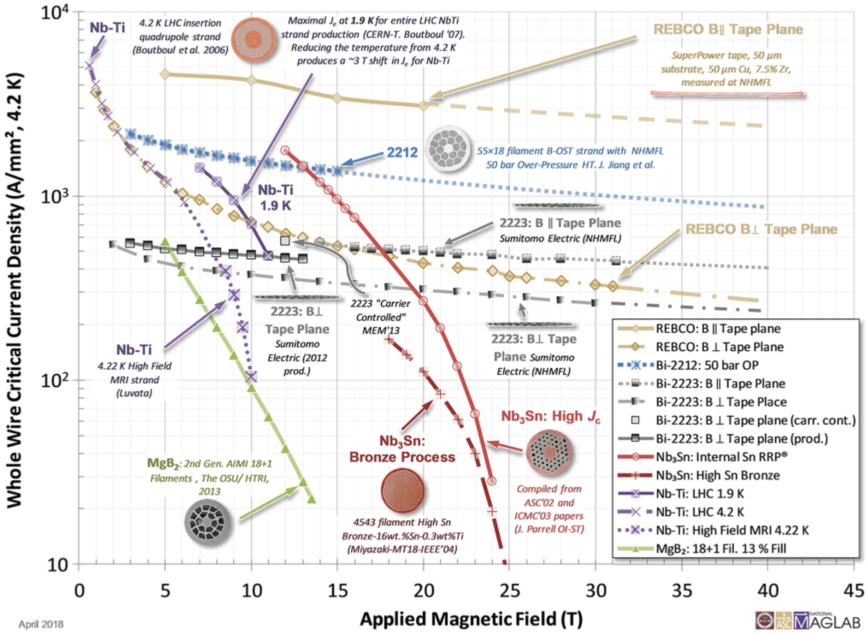
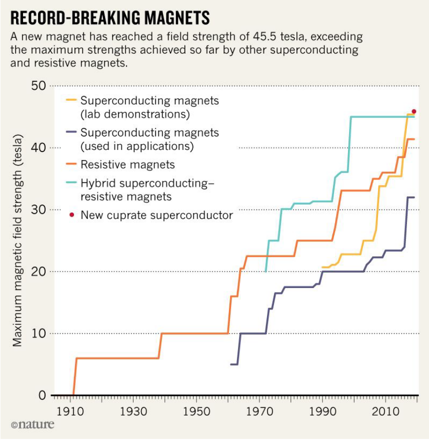
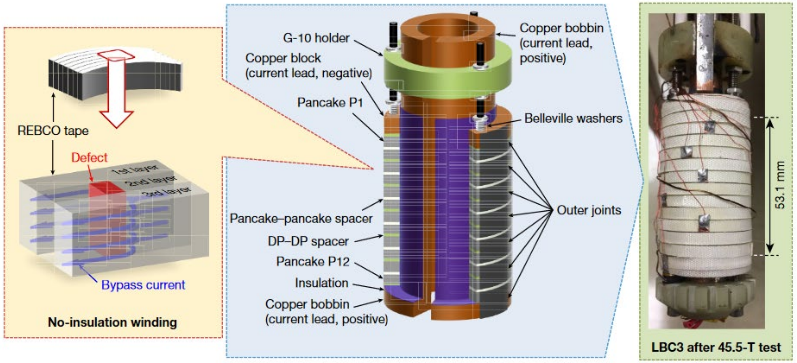


Figure from Peter Lee, ASC NHMFL



45.5T with SC insert

Many all SC magnets!



Hahn *et al.*, Nature **570**, 27 (2019).

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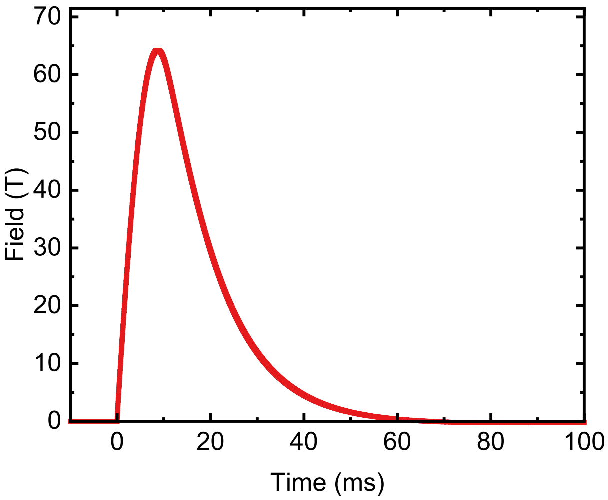
High Magnetic Fields → Pulsed Fields

NHMFL PFF offers different flavors of magnets:

65T (4 cells), 60T mid-pulse, 73T duplex, 85T duplex, 100T, 60 T Long pulse
ready to deploy/ Generator repair

"Standard" 65T magnet



Capacitor-bank driven pulsed magnets

Unique challenges:

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

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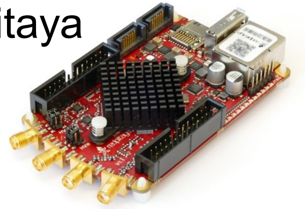
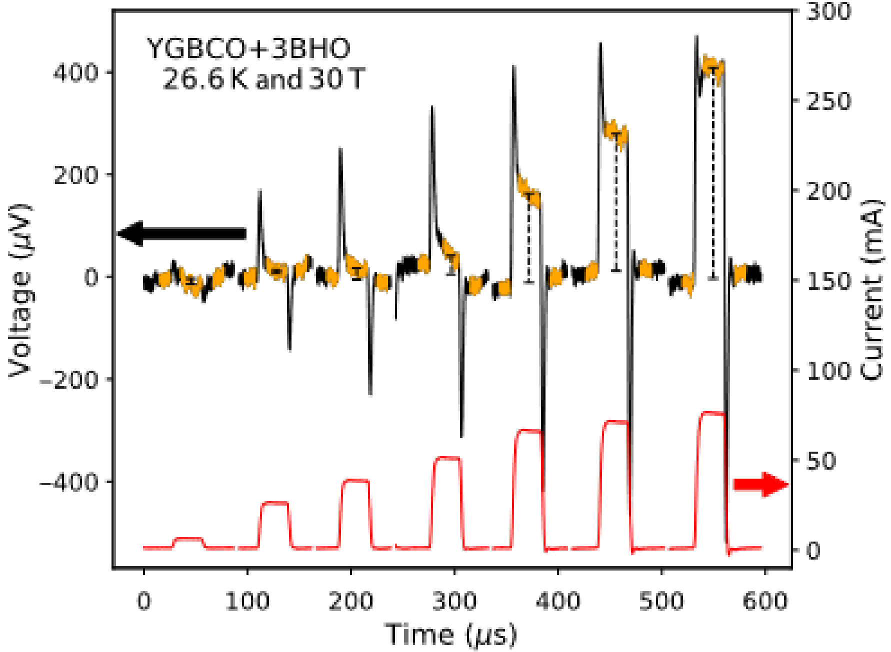
FPGA-enabled critical current measurements

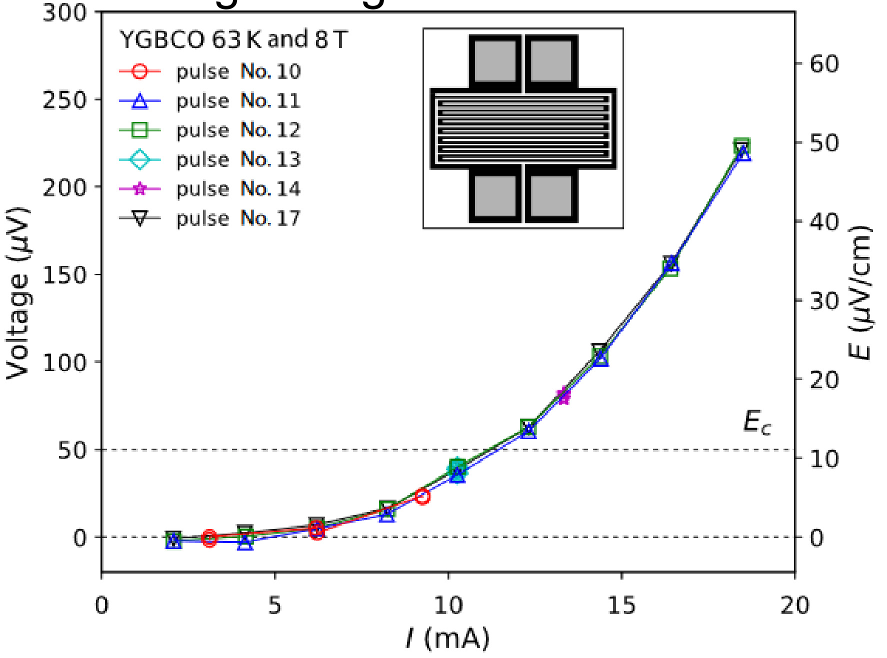
Red Pitaya



FPGA generates current pulses and measures voltage



Voltage in current pulses are averaged to get I-V



Leroux *et al.*, Phys. Rev. Appl. **11**, 054005 (2019)

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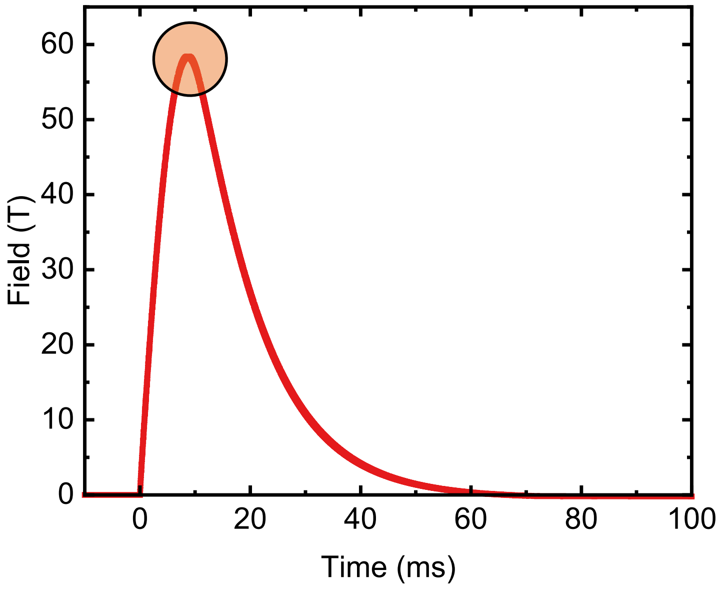
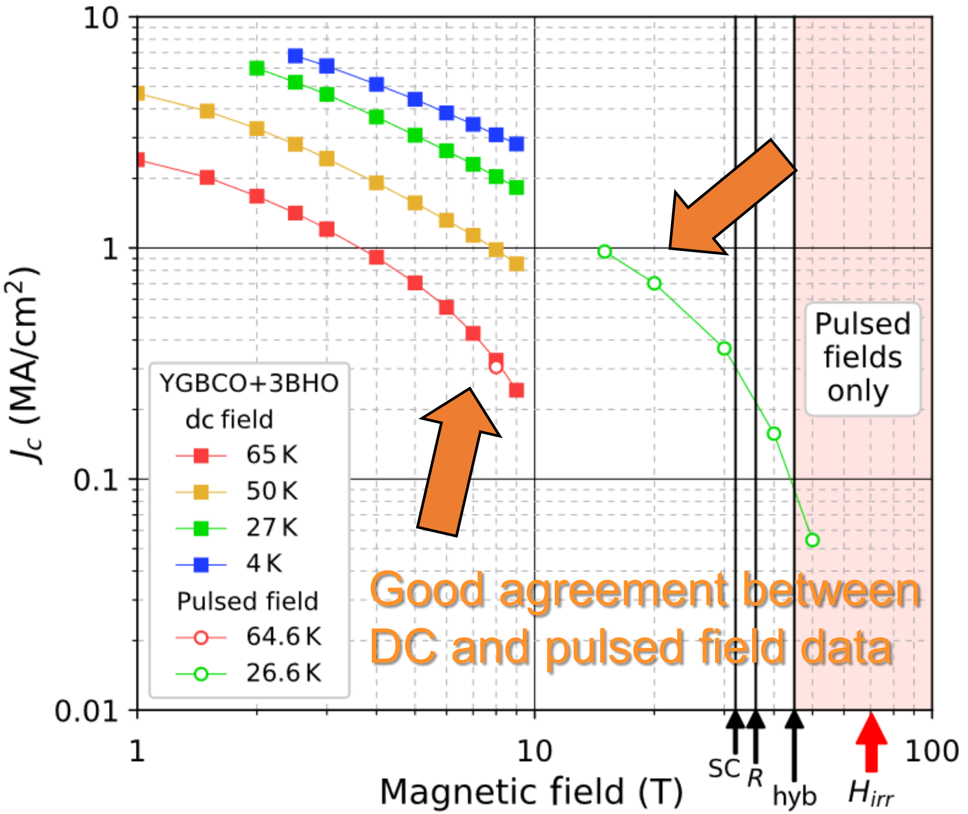
Quantitative agreement with DC field J_c near peak field

Works great close to peak field





Leroux *et al.*, Phys. Rev. Appl. **11**, 054005 (2019)

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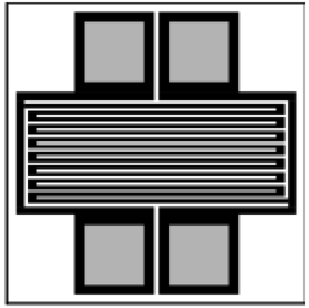
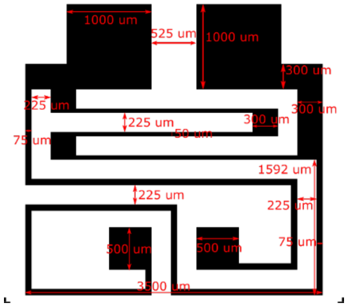
New meander, improved compensation, and reduced impedance effects

Old design

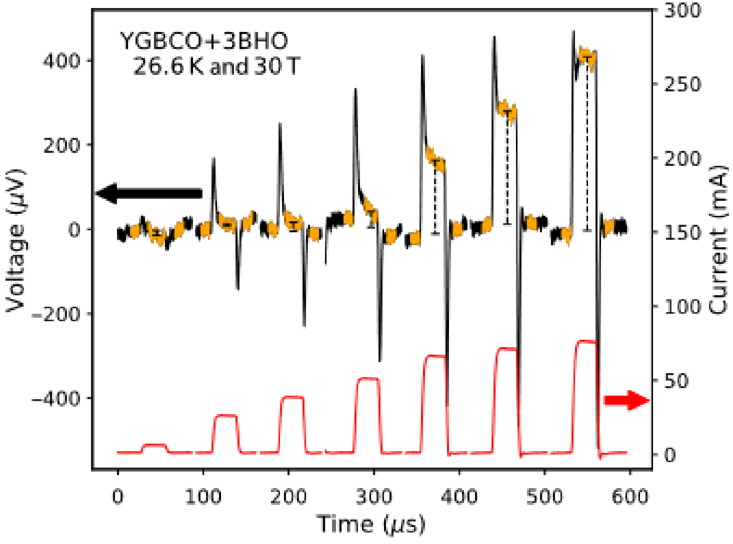


New design



Better open loop compensation, lower impidance
→ improved signal to noise ratio

Old measurements



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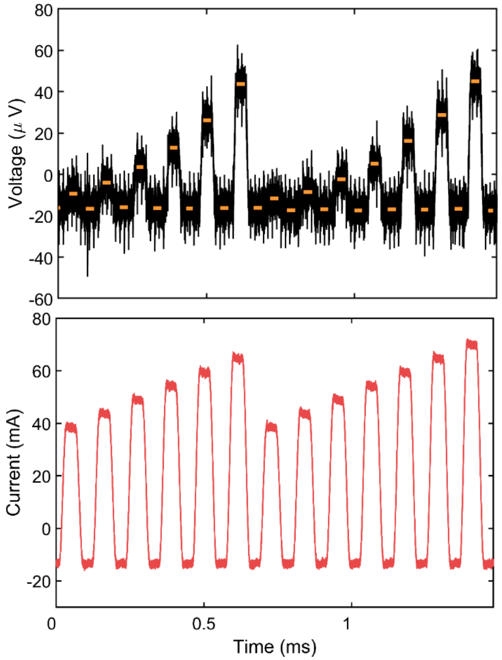
New measurements



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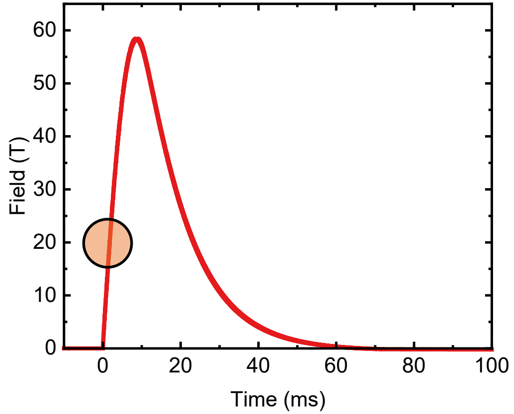
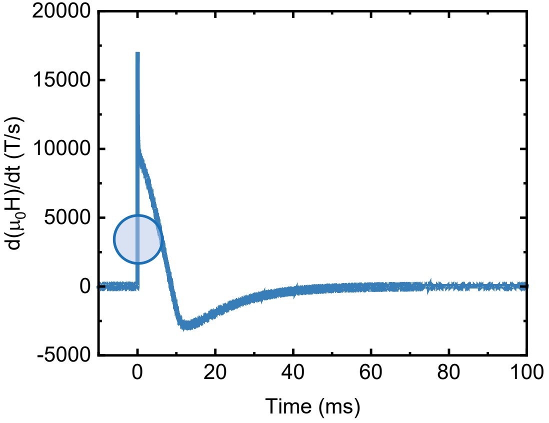
dH/dt provides additional electric field affecting vortex motion

Large dH/dt away from peak field





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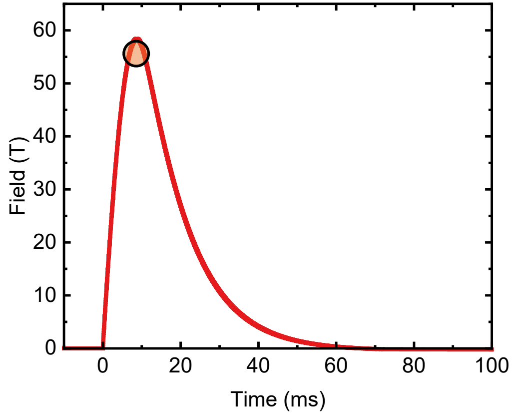
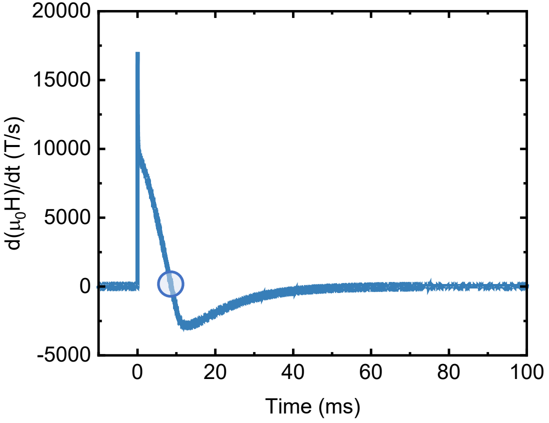
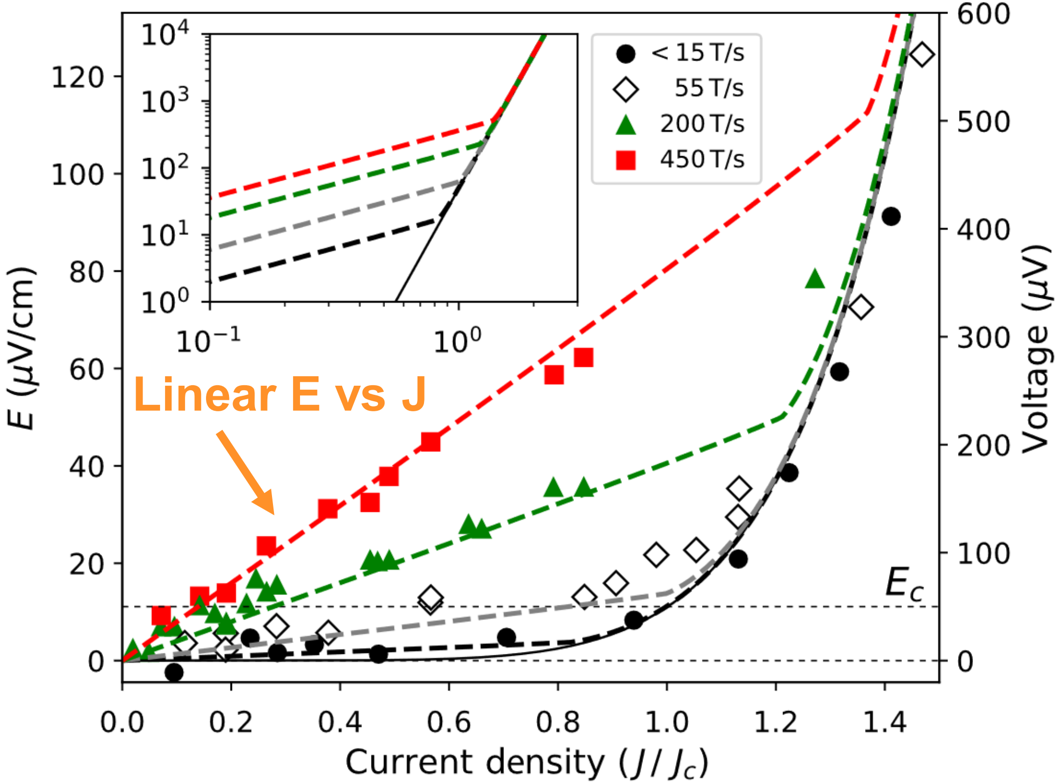
dH/dt provides additional electric field affecting vortex motion

Large dH/dt ‘away’ from peak field





Deviations from power law behavior if $\frac{1}{2}\mu_0\,\dot{H}\,W \gg E$



Leroux *et al.*, Phys. Rev. Appl. **11**, 054005 (2019)

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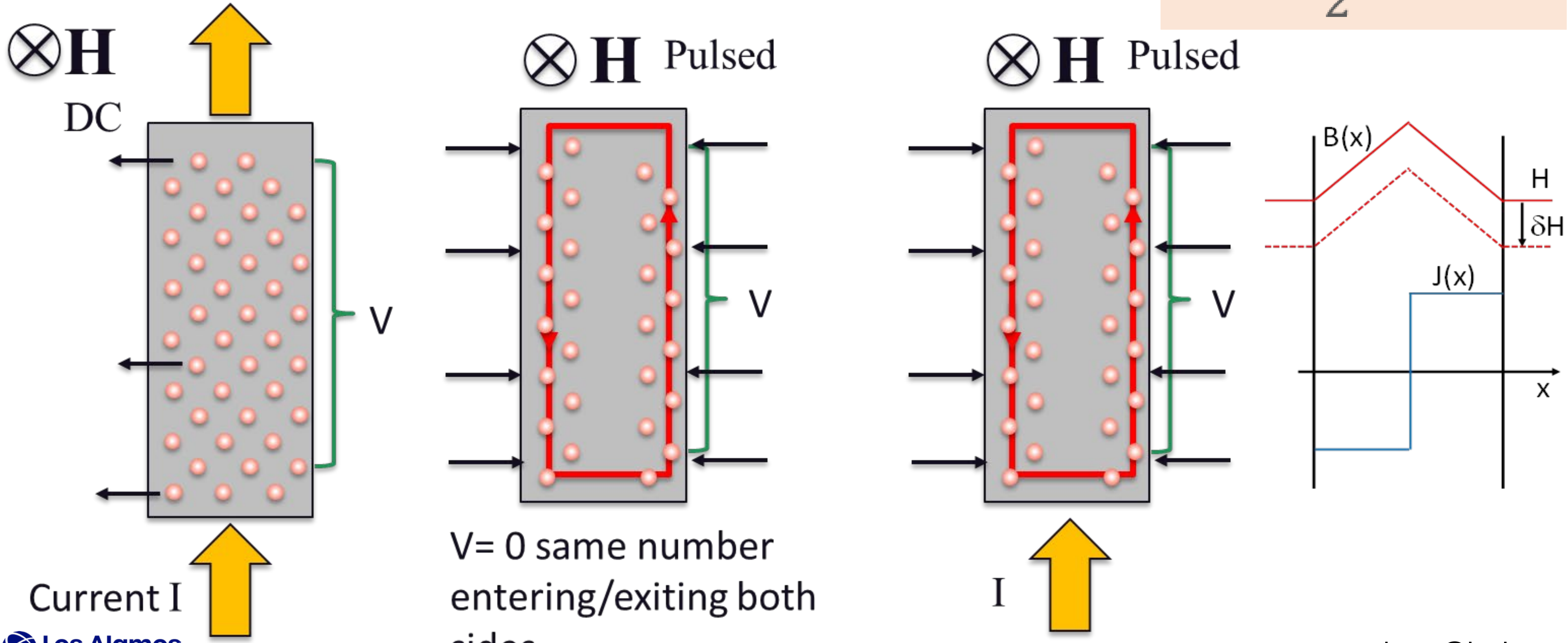
Voltage-Current curve shape changes with higher *dH/dt:*
Two different regimes (semi-static aproach)

$$\epsilon = \frac{1}{2} W \mu_0 \dot{H}$$



V= 0 same number entering/exiting both sides

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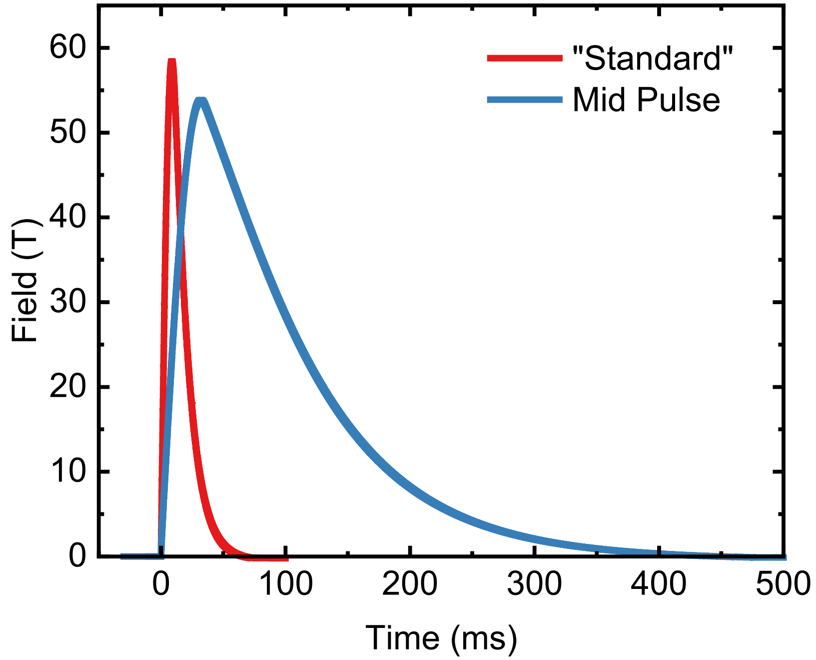
Mid-pulse magnets have lower dH/dt→ Larger "usable" range

Mid-pulse magnet has 6x longer pulse duration



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Mid-pulse magnets have lower dH/dt→ Longer usable range

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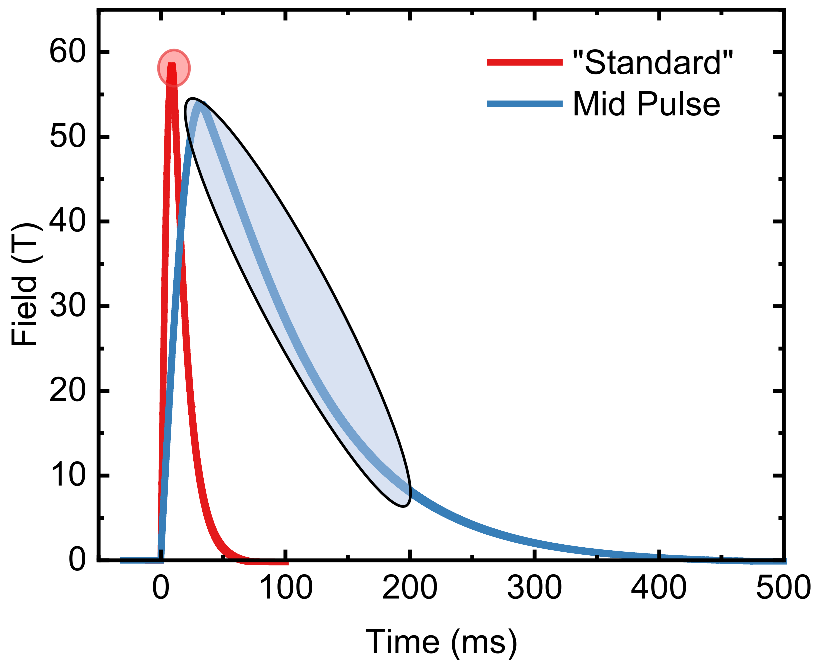
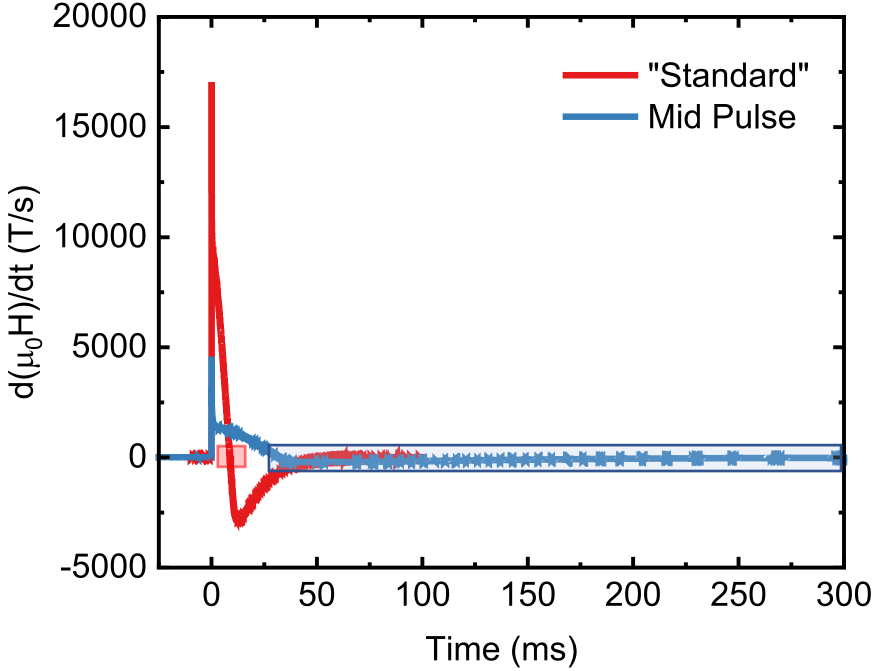


Significant reduction in dH/dt values



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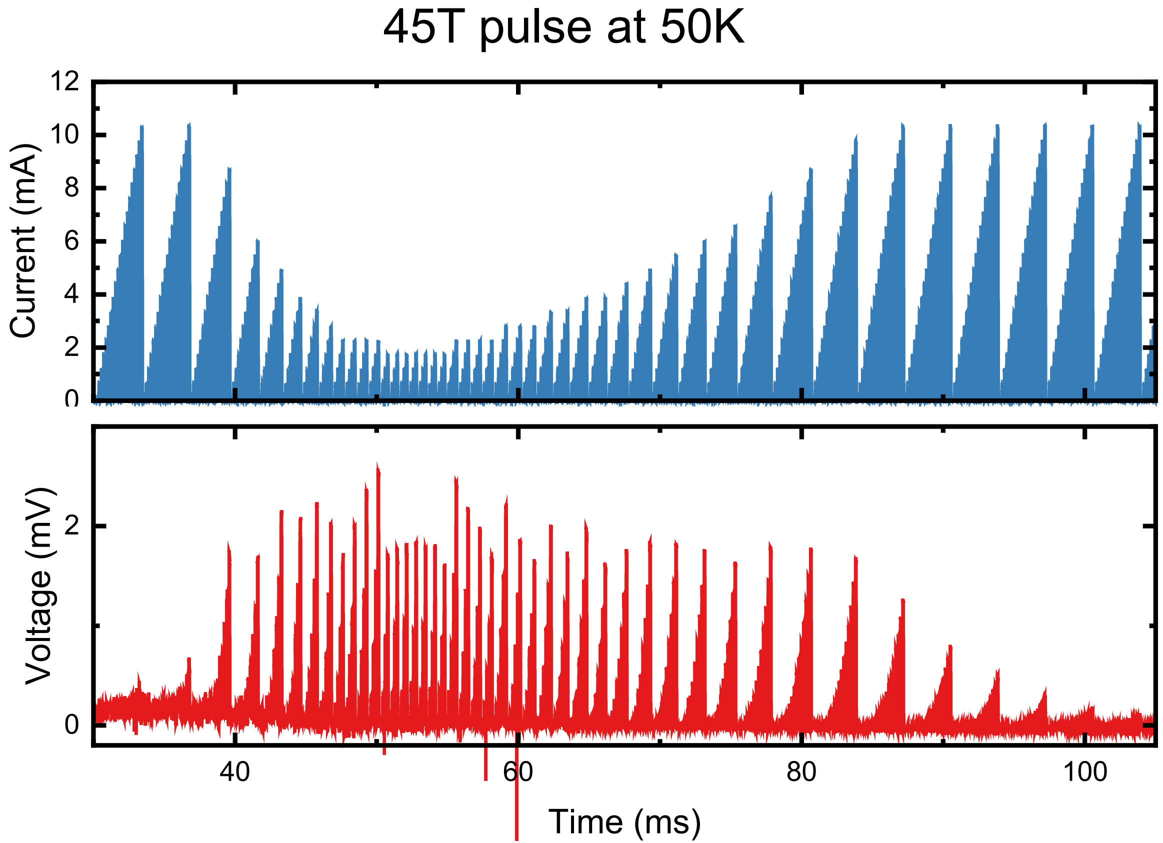
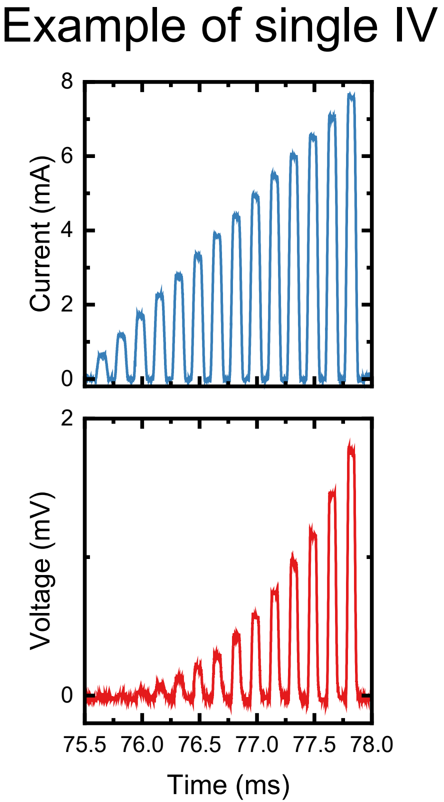
Example IVs from single pulse in mid-pulse magnet





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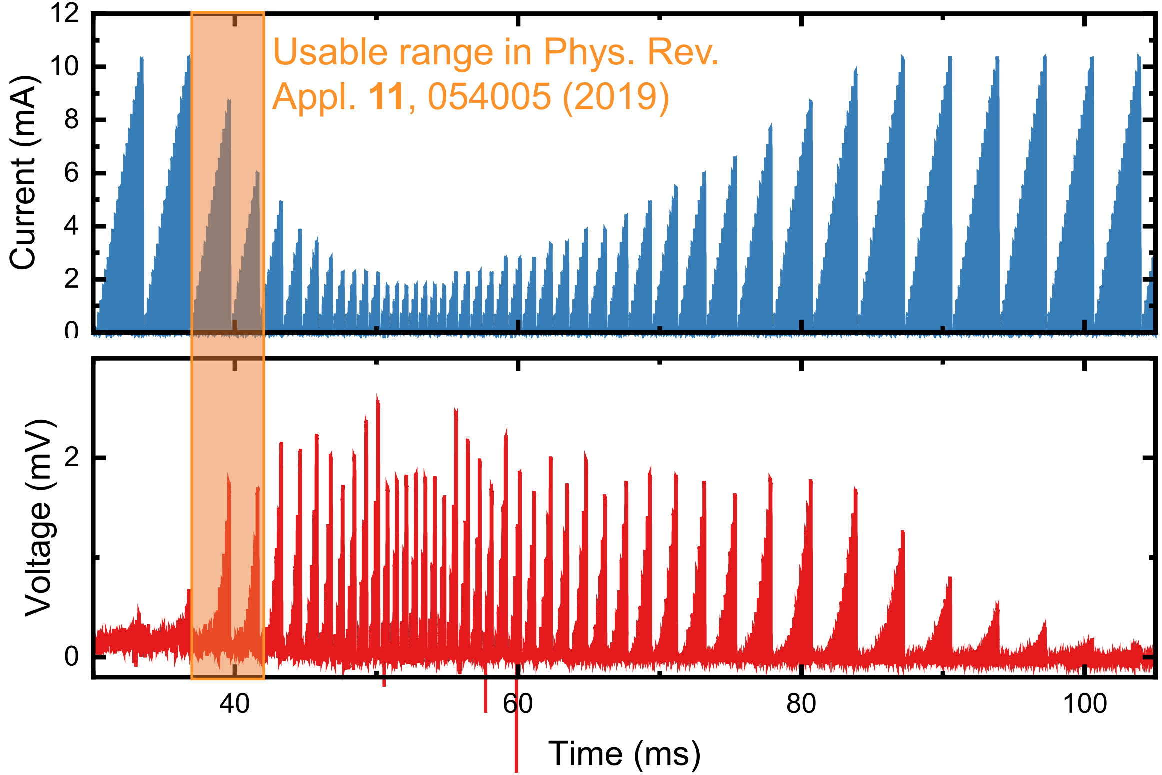
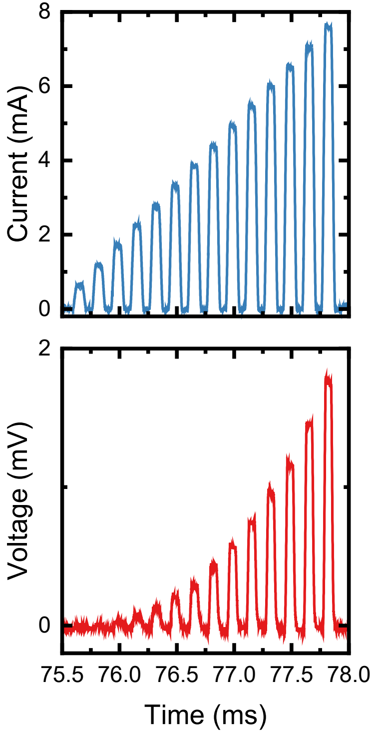
Example IVs from single pulse in mid-pulse magnet

45T pulse at 50K



Example of single IV



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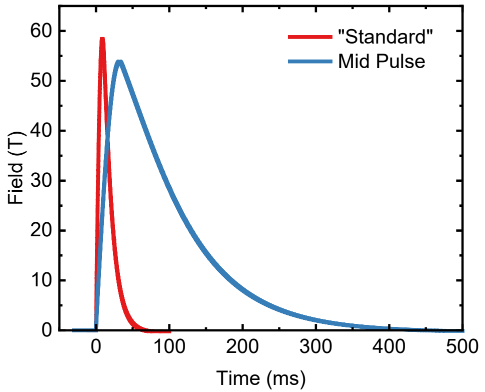
Combining mid-pulse with other improvements yields J_c extraction <u>over large field range in a single pulse</u>



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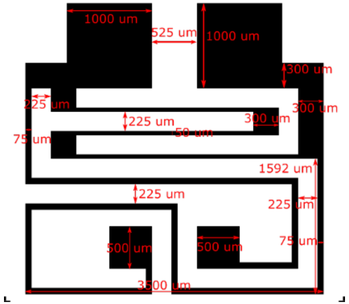

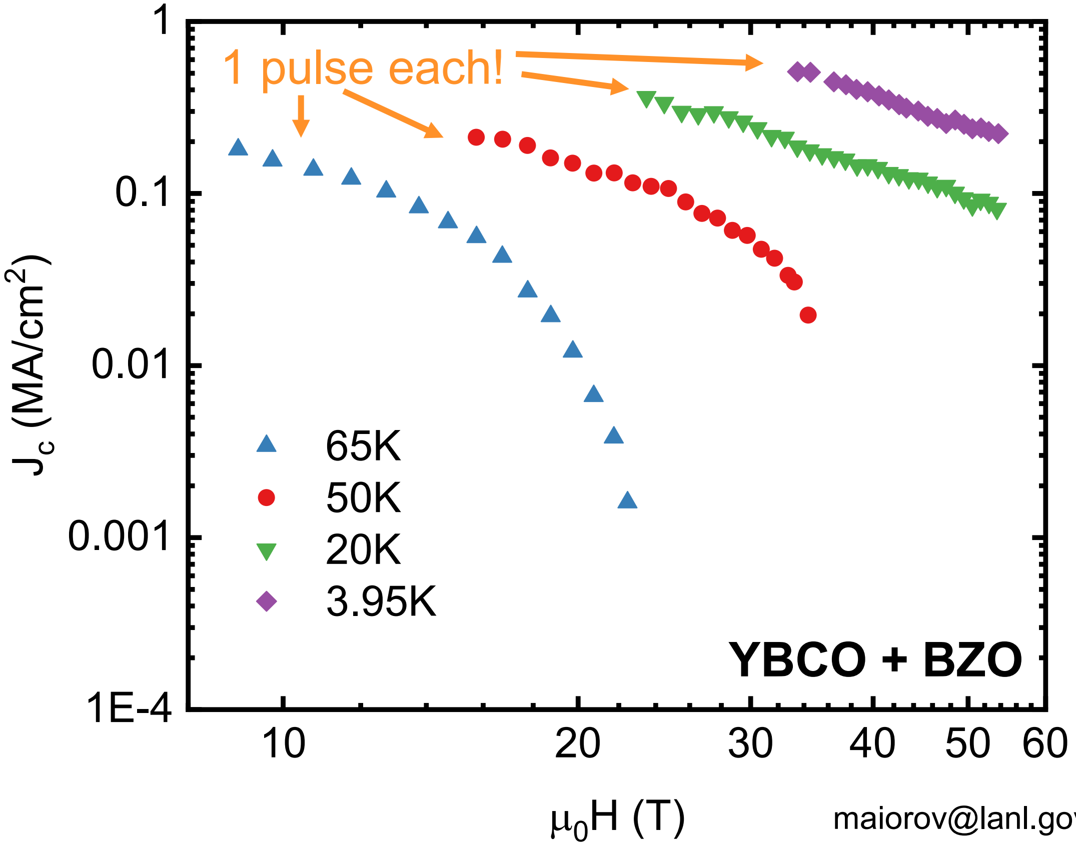

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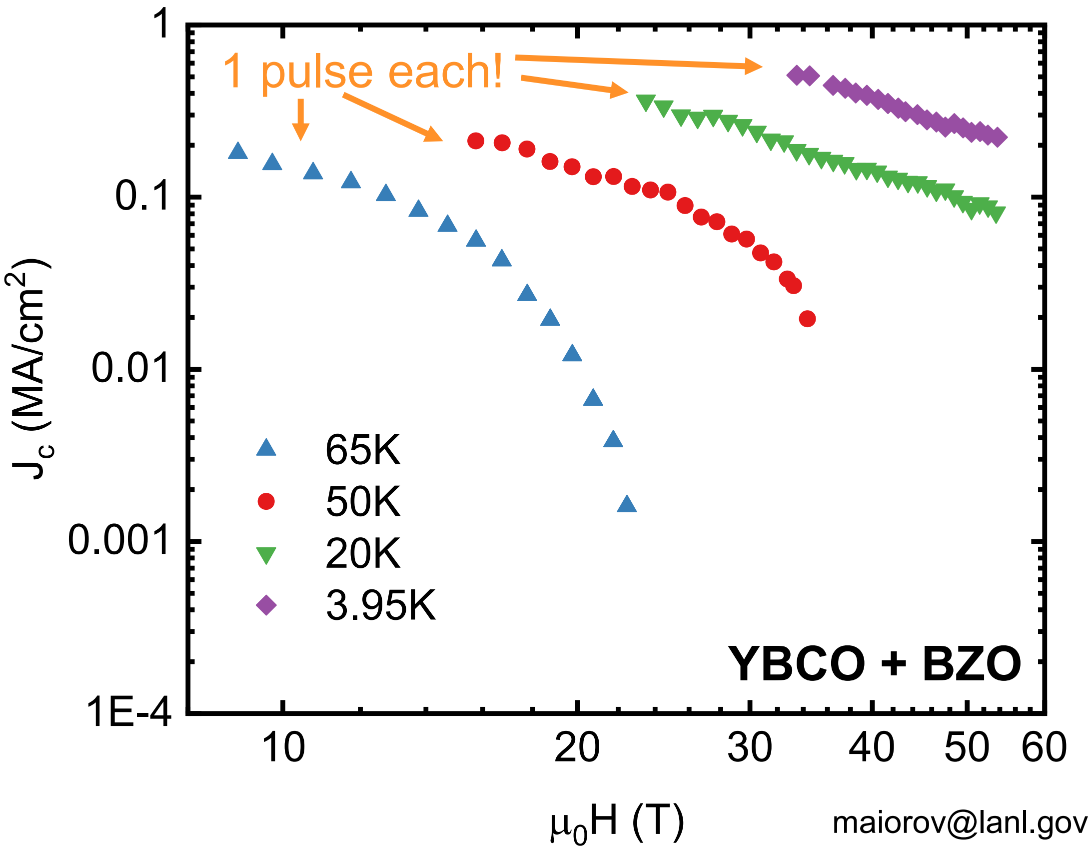
Combining mid-pulse with other improvements yields J_c extraction over large field range in a single pulse

- Now we can measure with a single field shot what would have taken a good part of a day!
- Significantly higher field resolution
- Limited by current we can source



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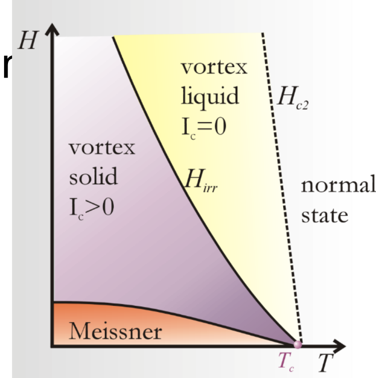
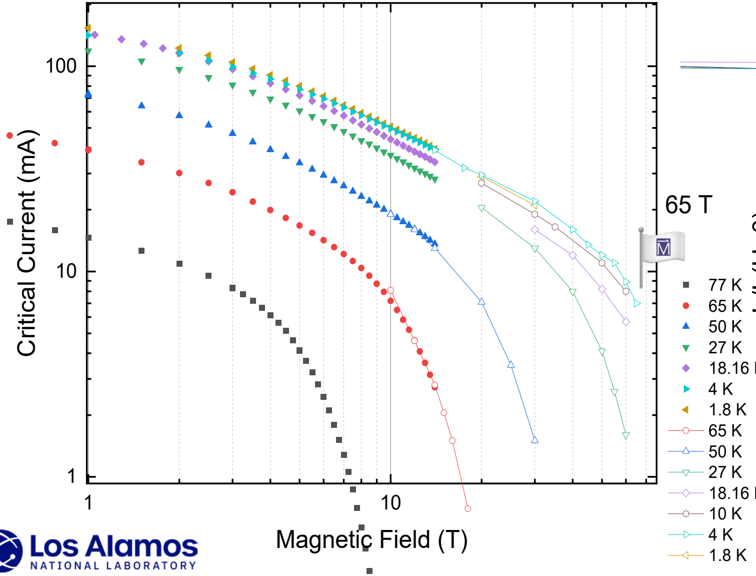
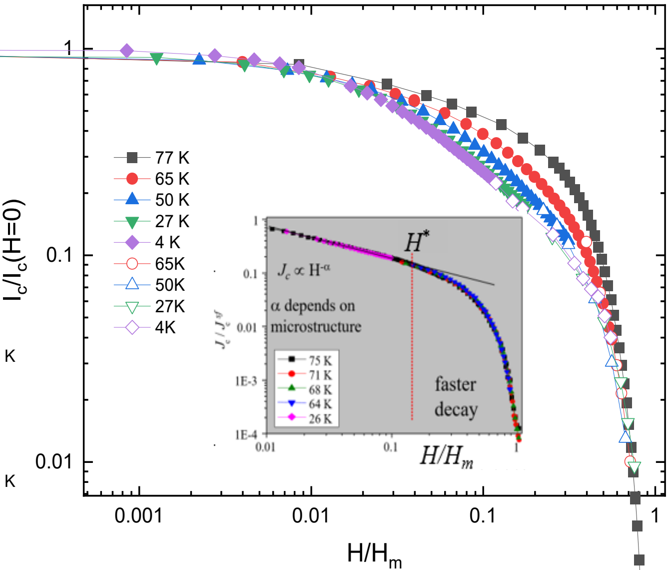
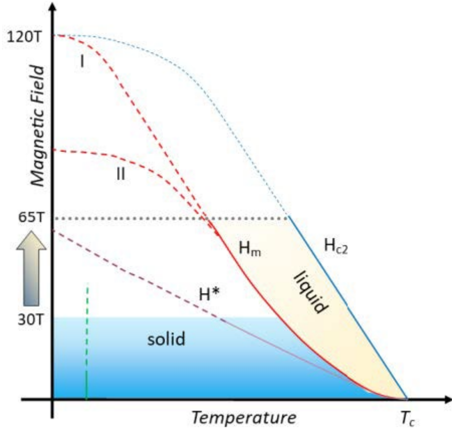
Experiments up to 65T determine the onset of fluctuations on J_c at low temperatures

- Power law regime in $J_c(H)$ followed by faster decrease dominated by fluctuations
- Sample with self-assembled columnar defects (YBCO+BZO by PLD)
- Collapse of curves with extrapolated melting line
- Field dependences showcase different pinning characteristics









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How do I measure there?

NATIONAL HIGH MAGNETIC FIELD LABORATORY

- Proposal for all NHMFL sites (Tallahassee, LANL) good for 2 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). Calls are quarterly
- Maximum current 0.5 Amps. We will increase depending on user's needs
- Sample preparation is up to the user, we can help on wiring/design
  - With the new magnet we can simplify geometries/compensation

Funding Opportunities (Depending on funding)

- **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

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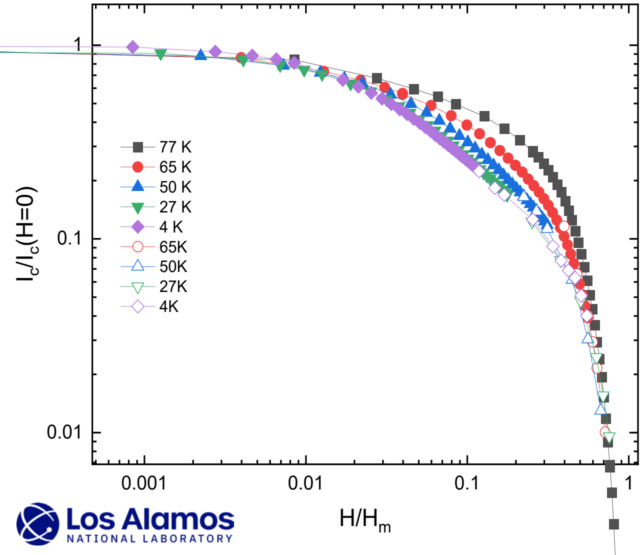
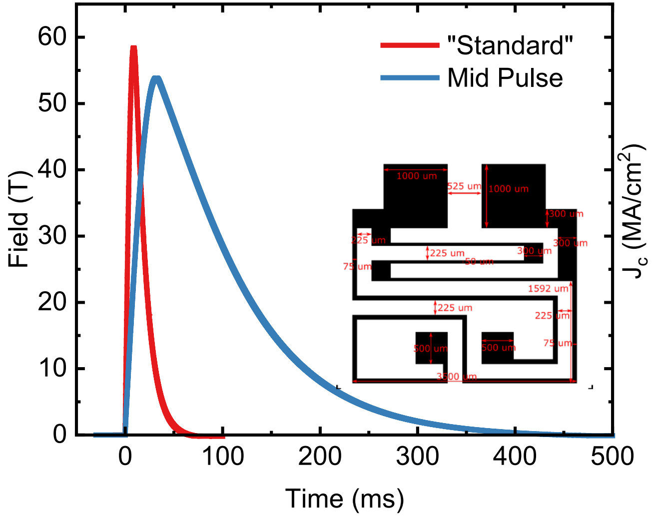
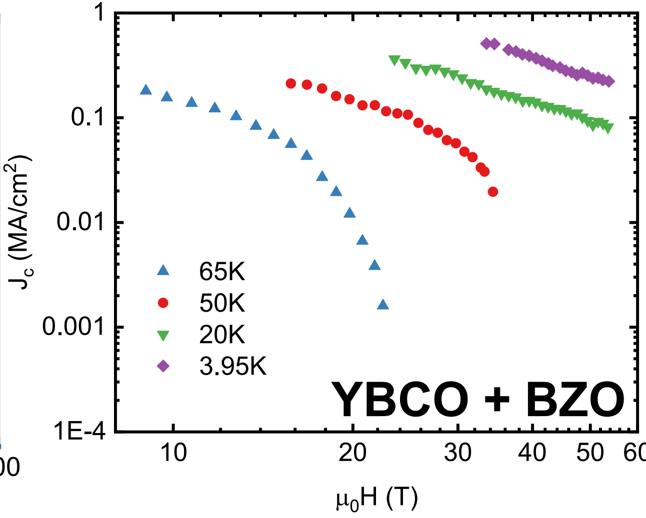
Summary

- Pulsed I-V allows to determine pinning regimes up to 65T
- Fluctuation regime continues down to 4K
- Improvements in pulsed IV technique allow for determining $J_c(H)$ from a ***single pulse*** to efficiently study SC properties at high fields relevant for applications







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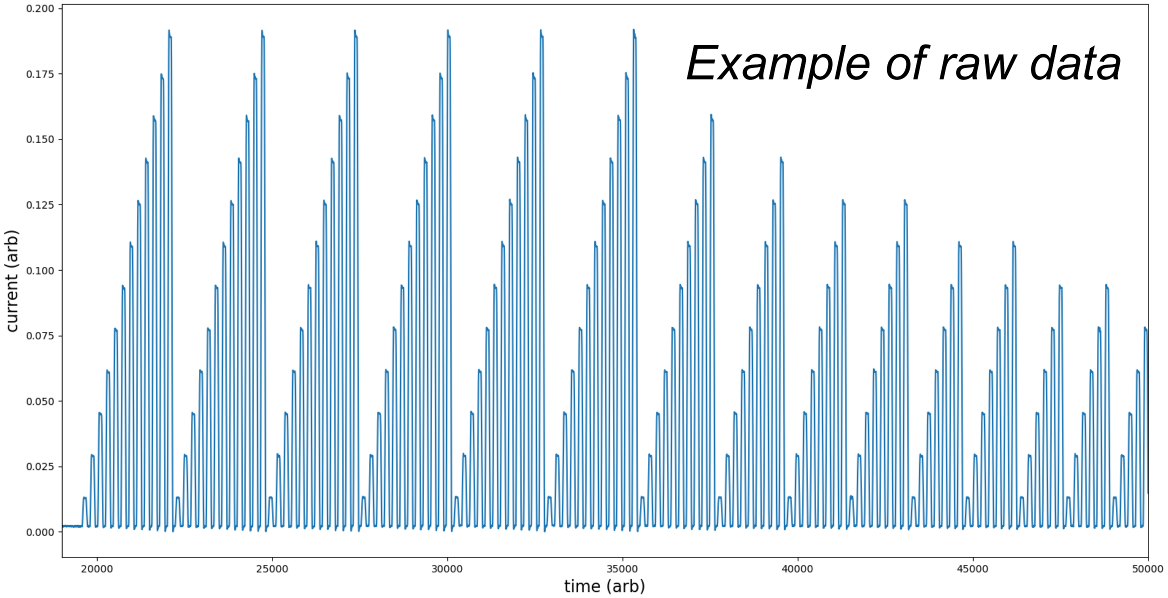
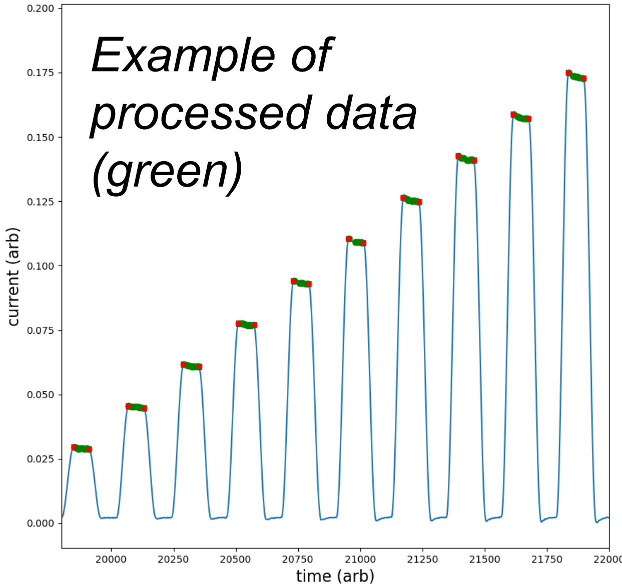
"Big" data → Automated analysis code

- Can now have ~300 IVs, each with 10 different currents
- Want automated code to determine IVs





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