# Stability and Quench Propagation of HTS Conductors

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# Introduction

- Many HTS applications under development:
  - Motors, generators, transmission cables, transformers, high field inserts …
- BSCCO conductors may operate as high as ~50 K
- YBCO CC potentially useful at ~77 K
- Specific heat increases greatly from 4.2 K to 50 K or higher; HTS magnets should be stable but can they be protected ??
- Minimum Quench Energy (MQE) and Quench Propagation Velocity (QPV) need (more) study
  - Influence BSCCO conductor design and YBCO development
  - Influence magnet design

# Outline

- Introduction
- Experimntal setup
- Bi-2223 measurements & conclusions
- YBCO CC measurements
  - V-T-time-location
  - Fixed $T_{start}$=80.6 K, Various $I/I_c$
  - MQE, QPV
  - Conclusions

# Experimental Details

- Samples studied:
  - BSCCO MF 2223 –

    used primarily to establish experimental methodology
  - AMSC YBCO coated conductor

    ~50 A @ 77 K

    (circa Fall 2001)
- Experimental procedures
  - Sample mounted and instrumented with multiple voltage taps, Cernox temperature sensors
  - Heat pulse supplied by NiCr wire driven by a power supply and pulse generator
  - Quasi-adiabatic with $N_2$ gas convection (~81 K)
  - Heat pulse amplitude or duration increased until quench occurs (vs. $I/I_c$)

# Experimental Setup

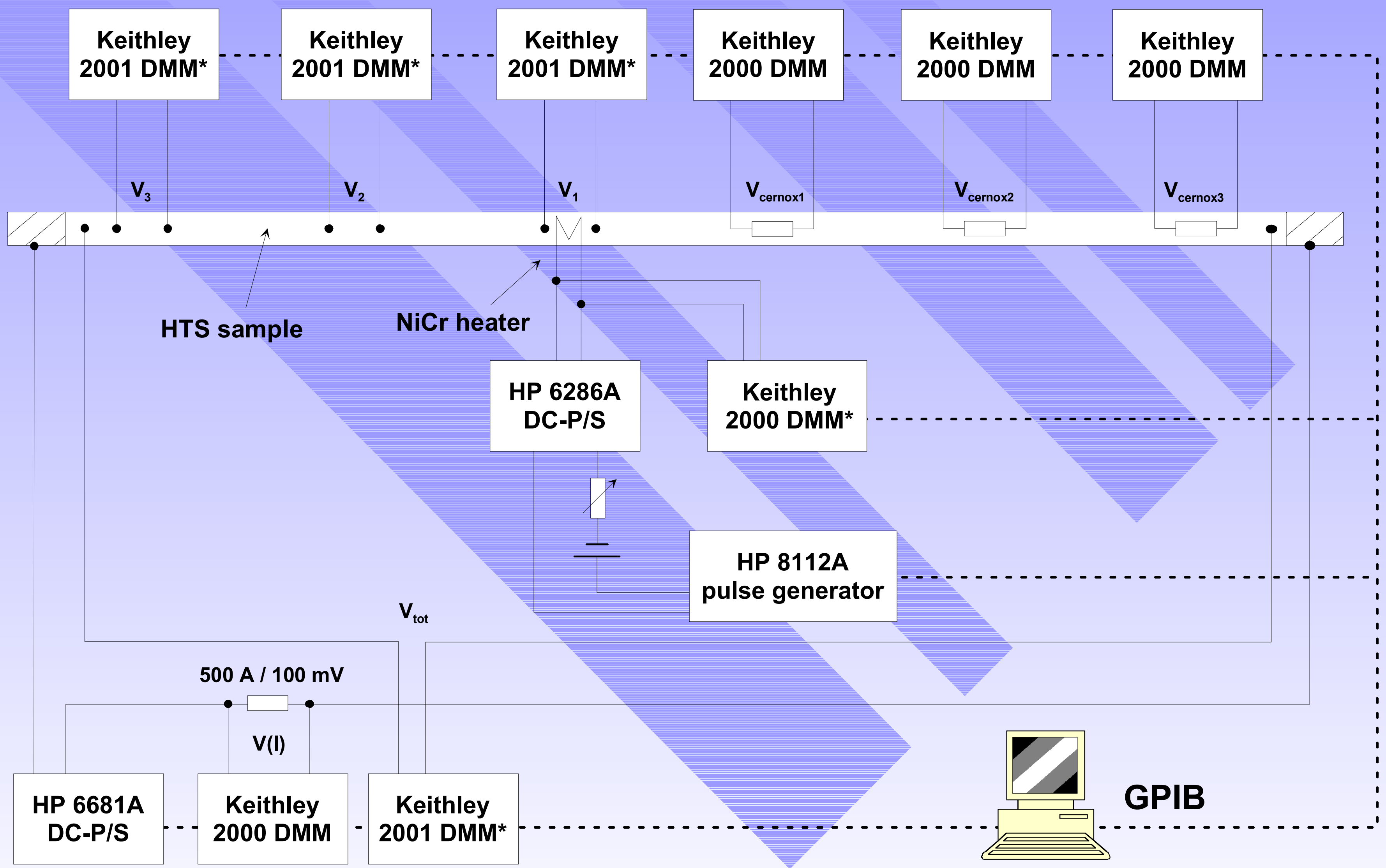
Cryostat with $LN_2$ jacket, experimental chamber filled with $N_2$ gas

Array of Keithley DMMs, pulse generator, PS for heater

DAQ computer and power supplies

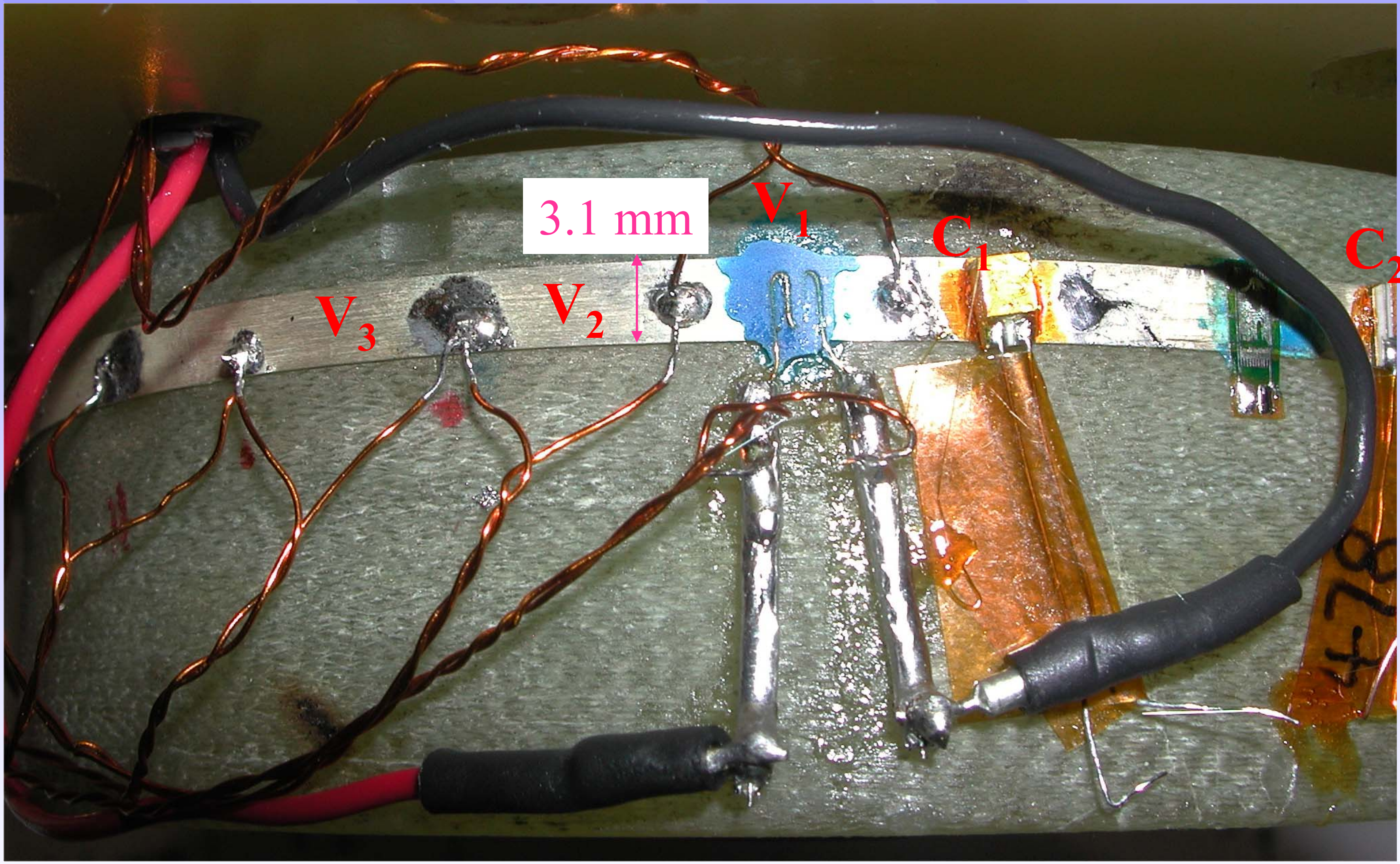
LabView controls all instruments

# Wiring Schematic Quench Experiments

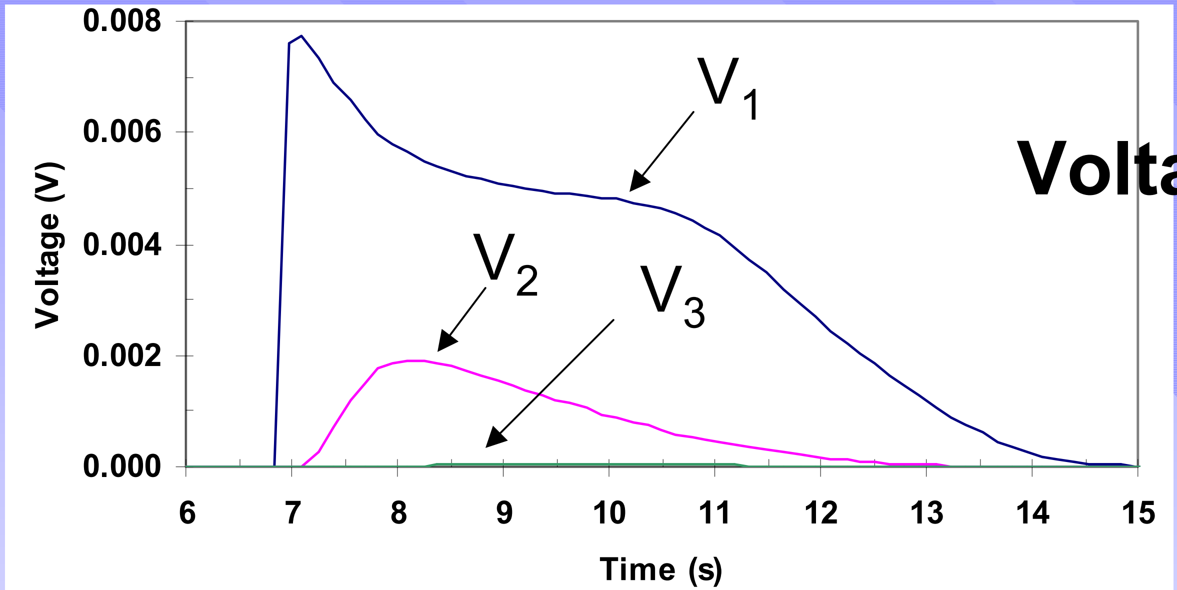



*set on buffer read for increased speed/resolution

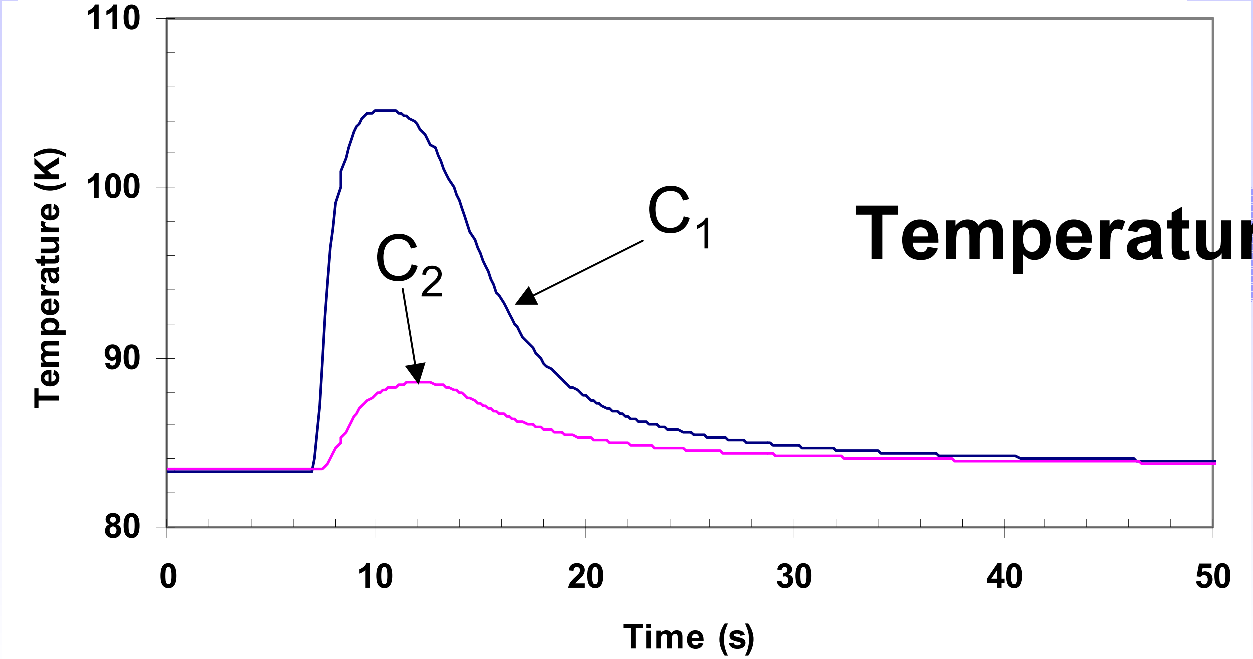
# Bi-2223 tape mounted on G-10 holder



# Bi2223 tape     Pulse E<MQE

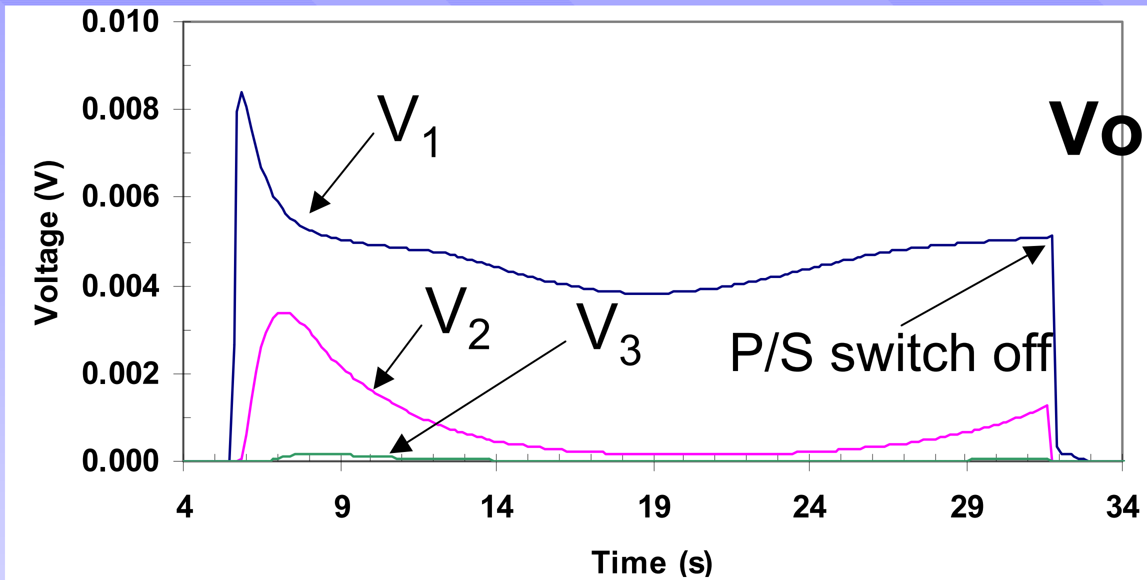



**Voltage-time-location**

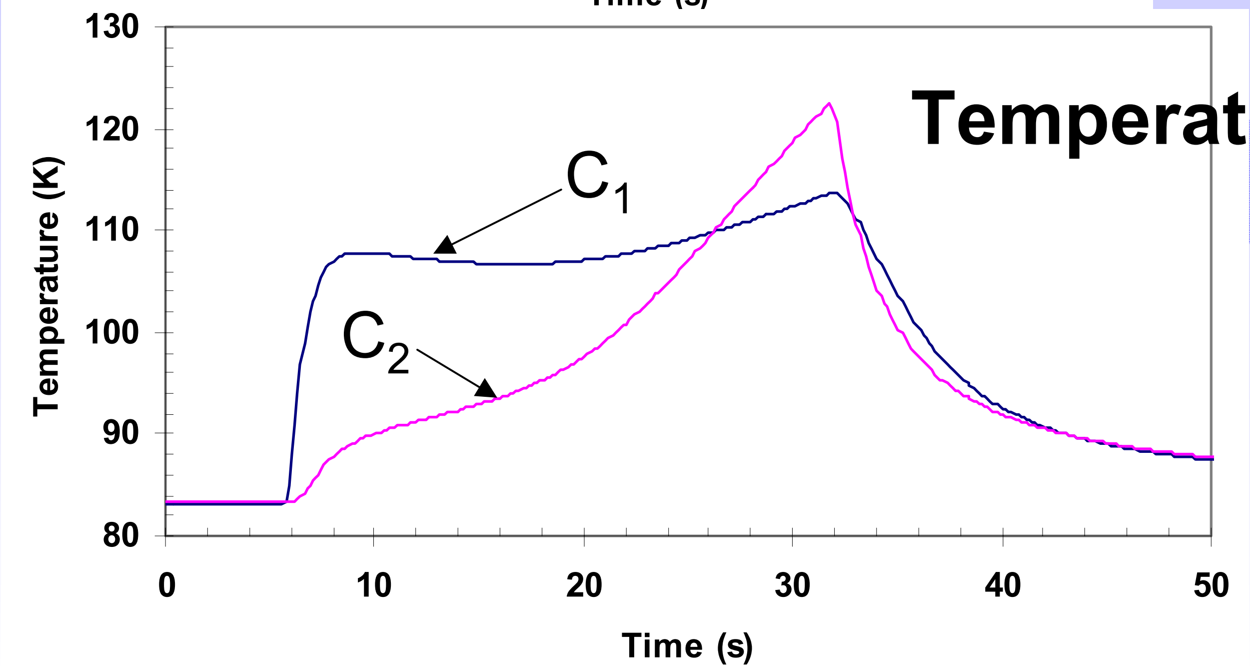



**Temperature-time-location**

# Bi2223 tape during quench ($I>I_c$)




**Voltage-time-location**



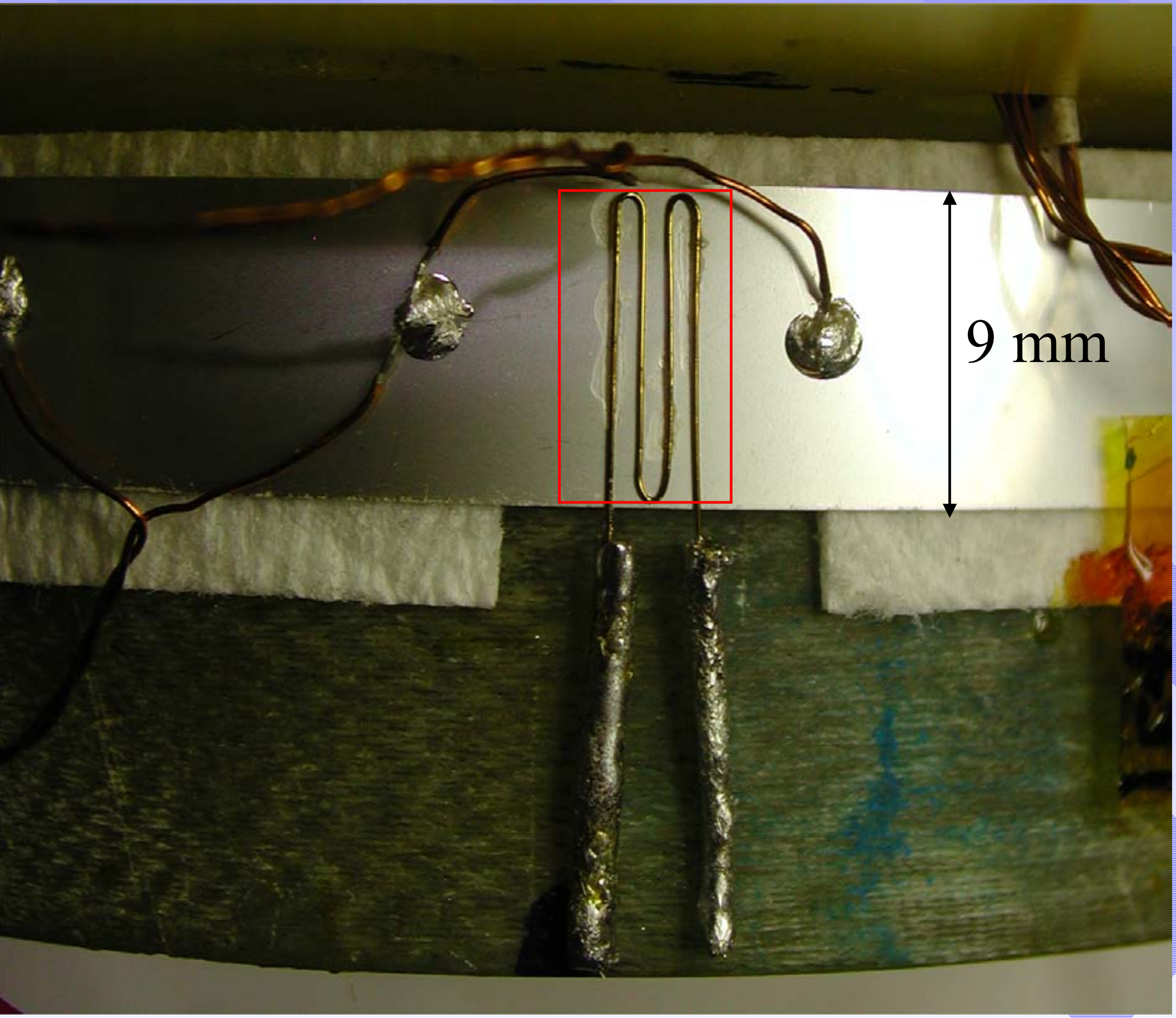

**Temperature-time-location**

$E_{pulse} = 128$ mJ

# BSCCO Conclusions

- Conductor under these conditions is very stable
  - Heat spreads very little if below MQE
  - Relatively low $J_c$, lots of Ag
  - Gas heat exchange is *not* dominant
    - » Contact with G10?
  - Results and conditions very reproducible
- Setup is fine electrically/DAQ
  - Needs improvements cryogenically
  - We prefer NiCr wire over strain gage

# NiCr heater loop on YBCO CC



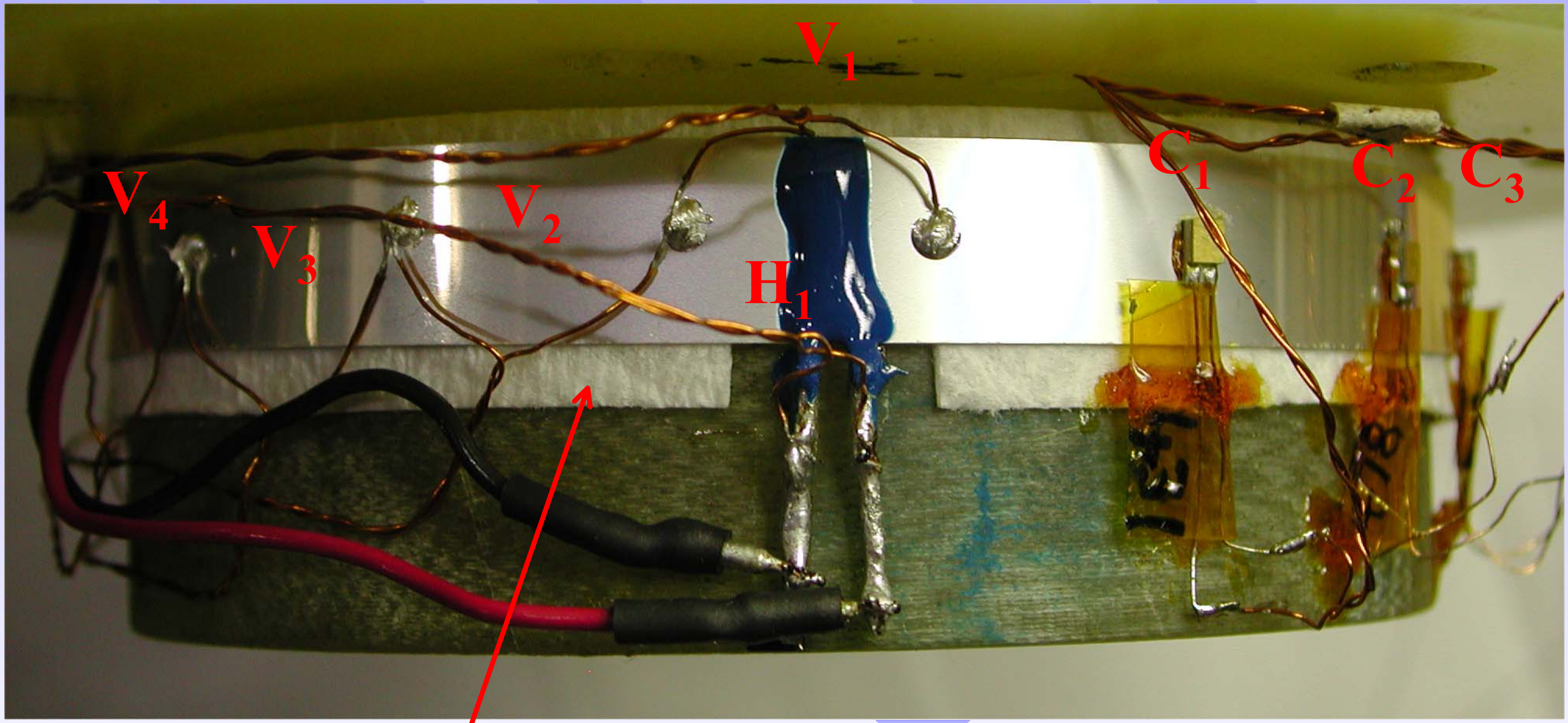

Area under heater:
~ 23 mm$^2$, 3.2 mm$^3$

"Hot zone" after pulse
~40 mm$^2$, 5.6 mm$^3$
(est. with QPV)

Every 0.8 mm CC = 1mm$^3$

# YBCO CC mounted

$V_1$ covers heated zone ($H_1$)
$C_1$ mirrors $V_2$
$C_2$ mirrors $V_3$ etc

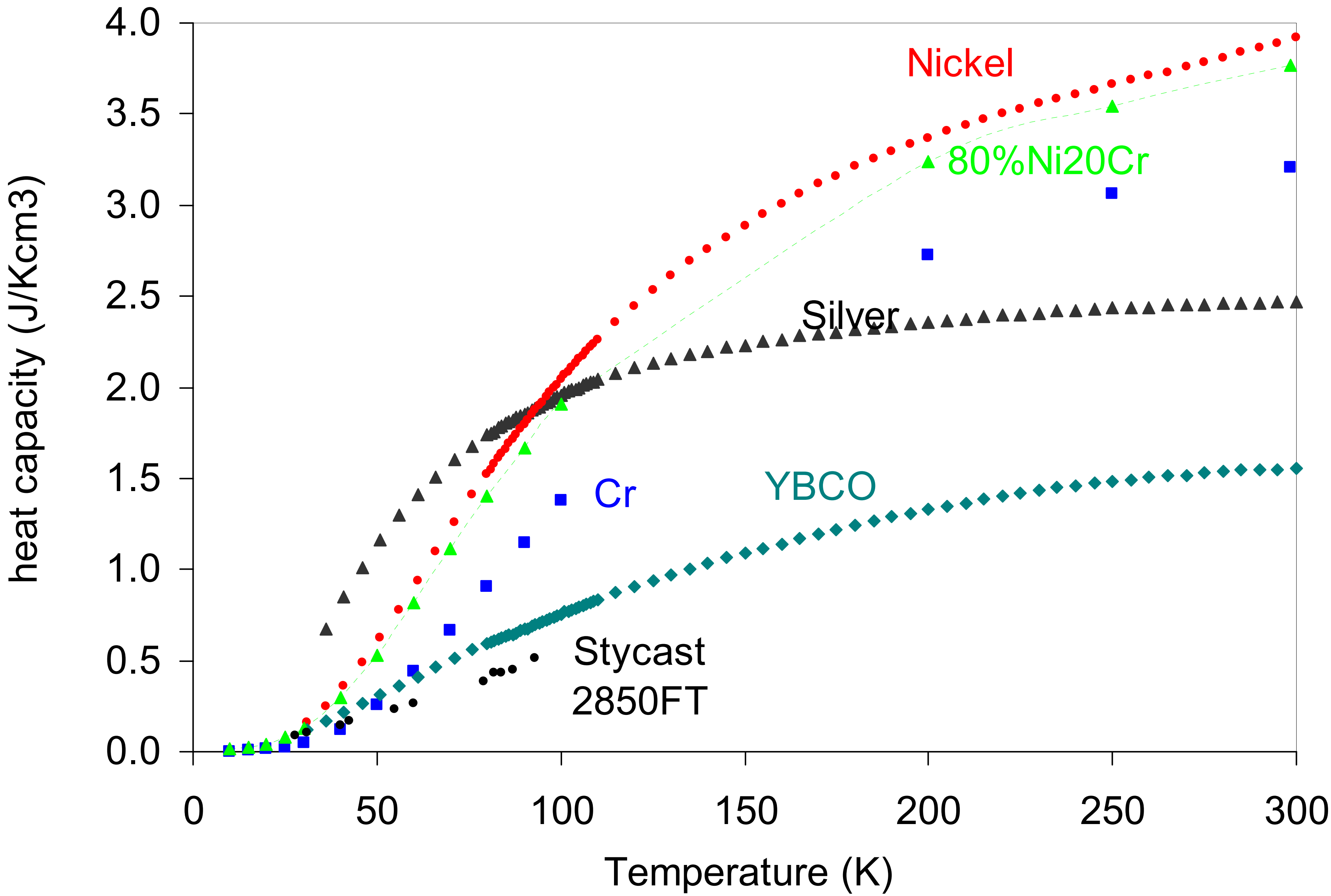



paper to accommodate thermal contraction
and reduce conduction to G10

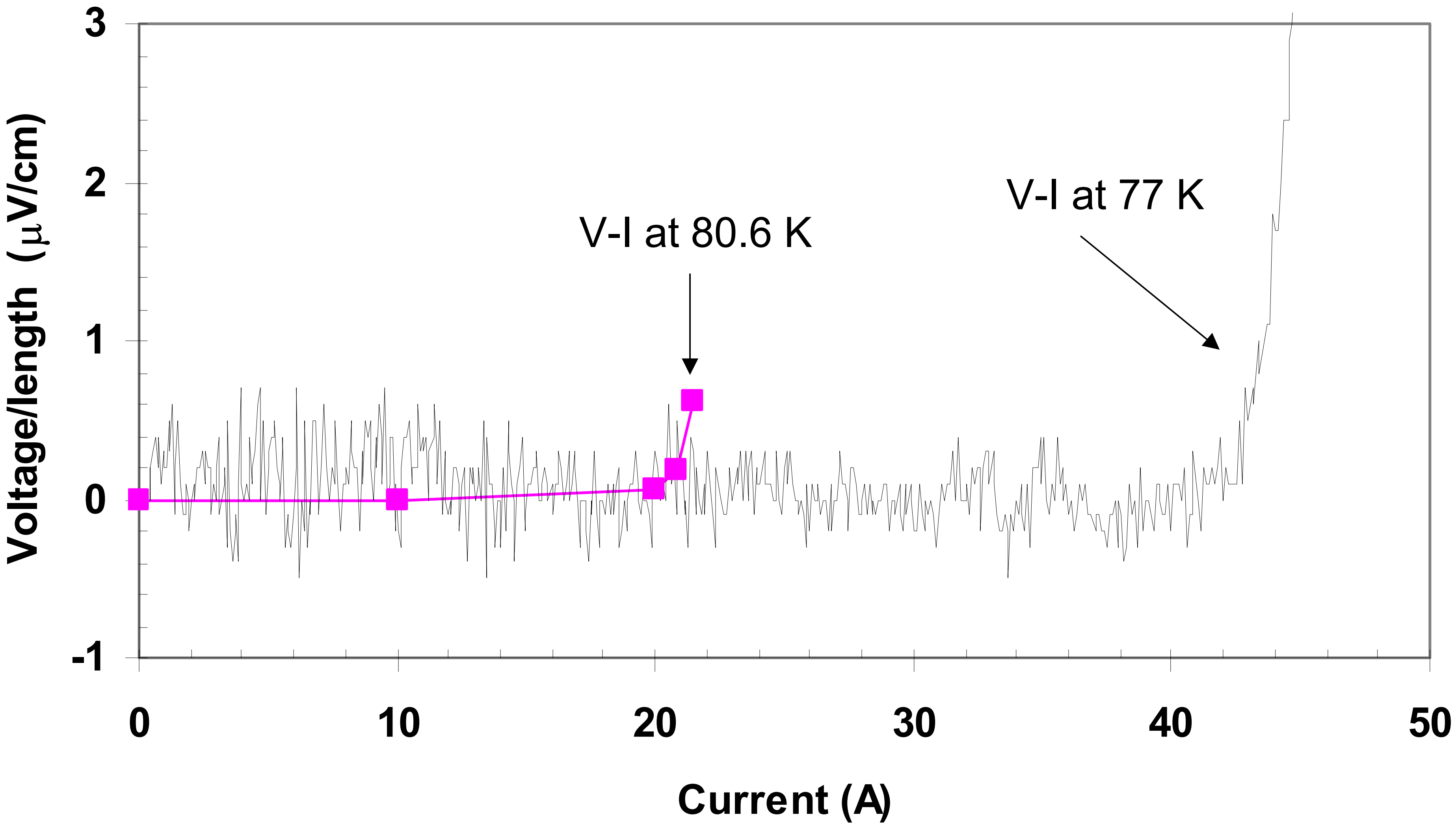
# NiCr Heater Characteristics

| "Stablohm650": 80% Ni, 20 % Cr, silicone insulated | |
|---|---|
| d | 0.14 mm |
| L | 43 mm |
| R | 2.1 Ω |
| typical heater range | 55 – 80 mJ |
| pulse height | 300 mV |
| typical pulse duration | 140 – 220 ms |
| failure of heater | 5- 10 J |

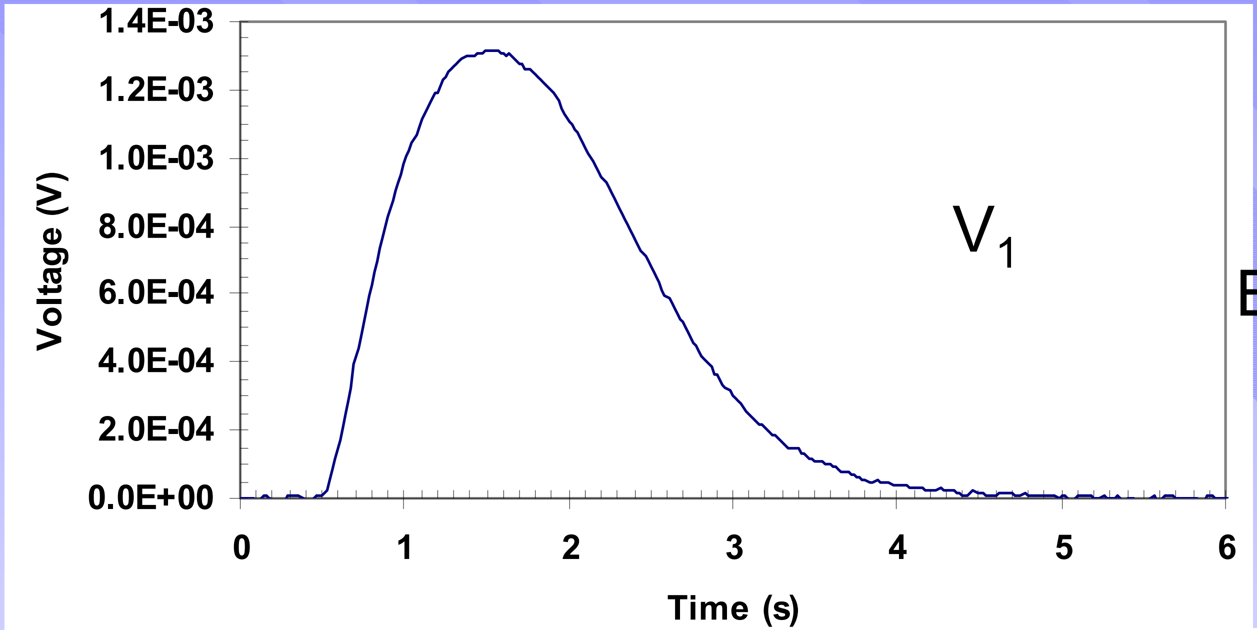
# Relevant Heat capacities



# YBCO I(V) at 77 K and 80.6 K

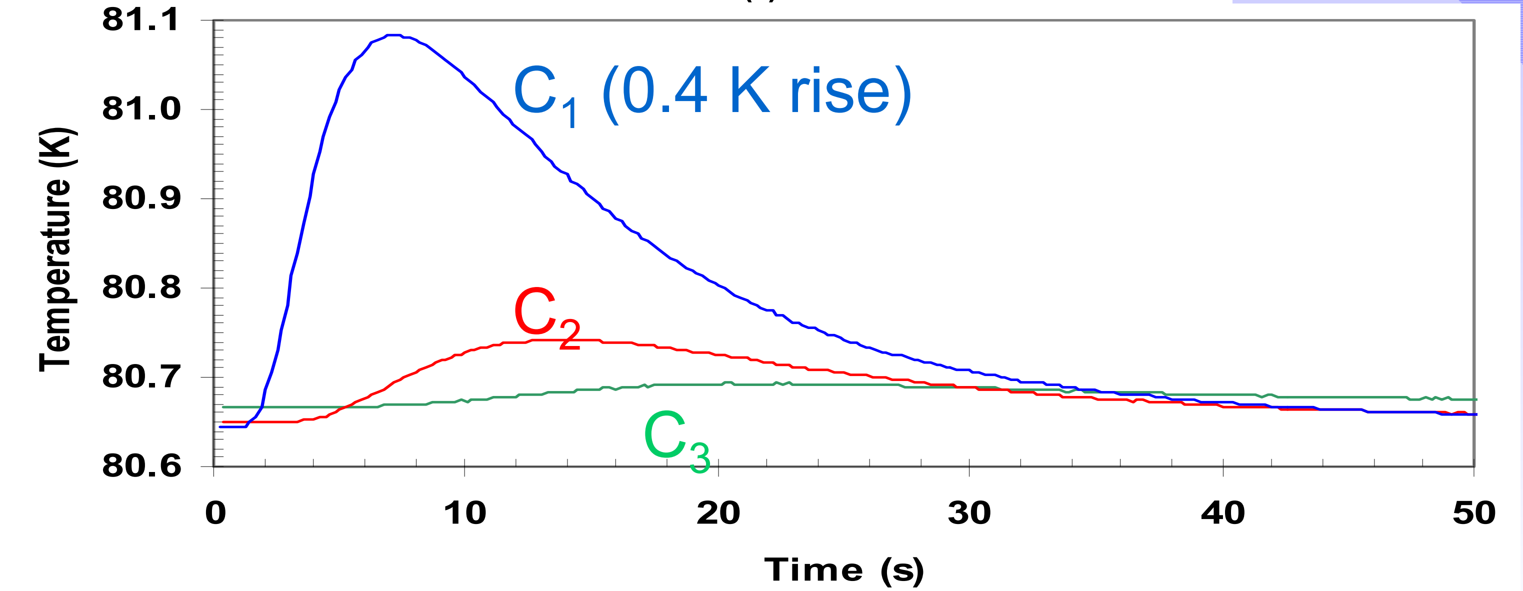


# Voltage-time I=19 A; $I_c$=22 A, $J_e$=18A/mm$^2$



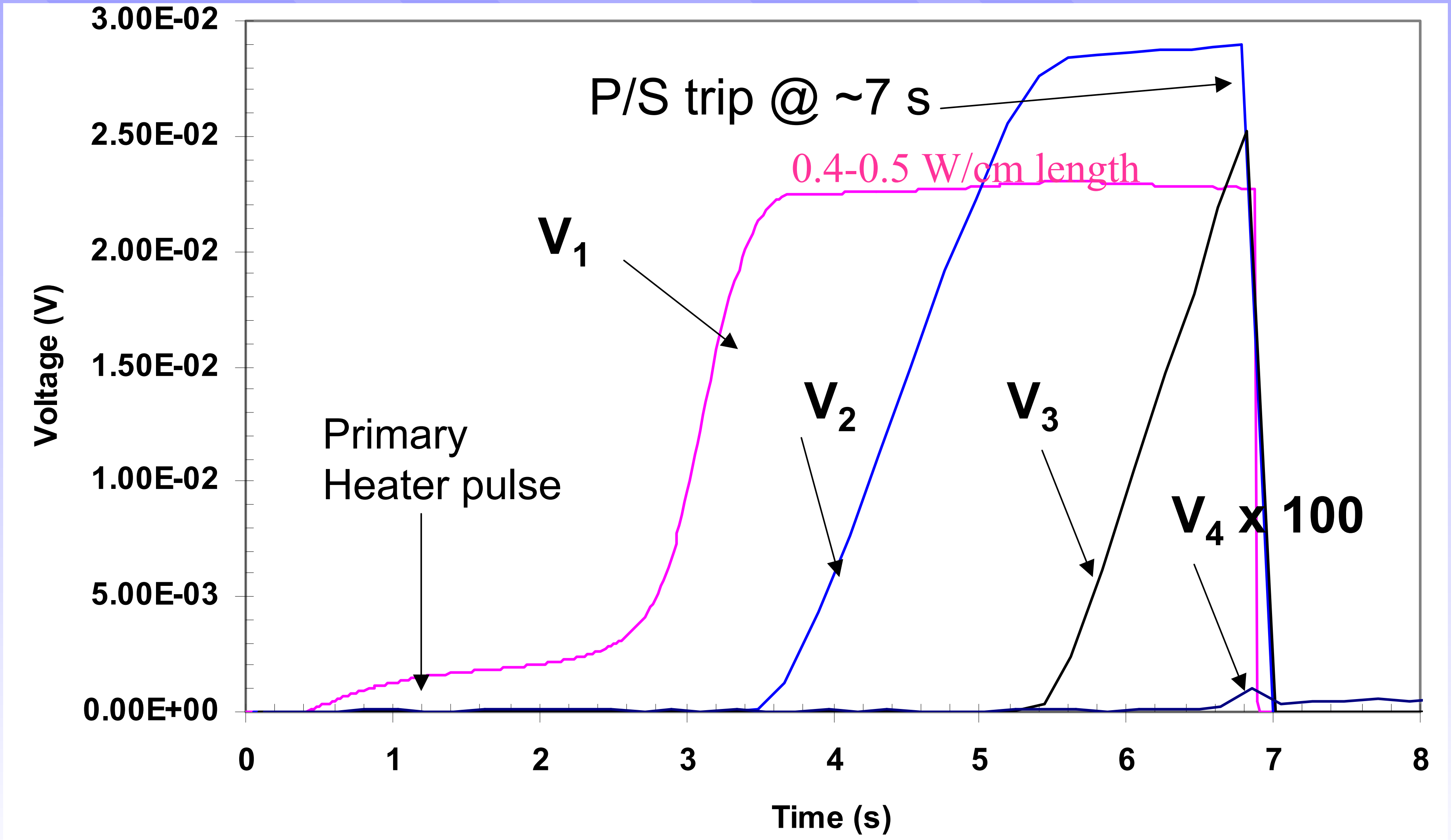

$E_{pulse}$ = 52.1mJ < MQE

T=80.6 K



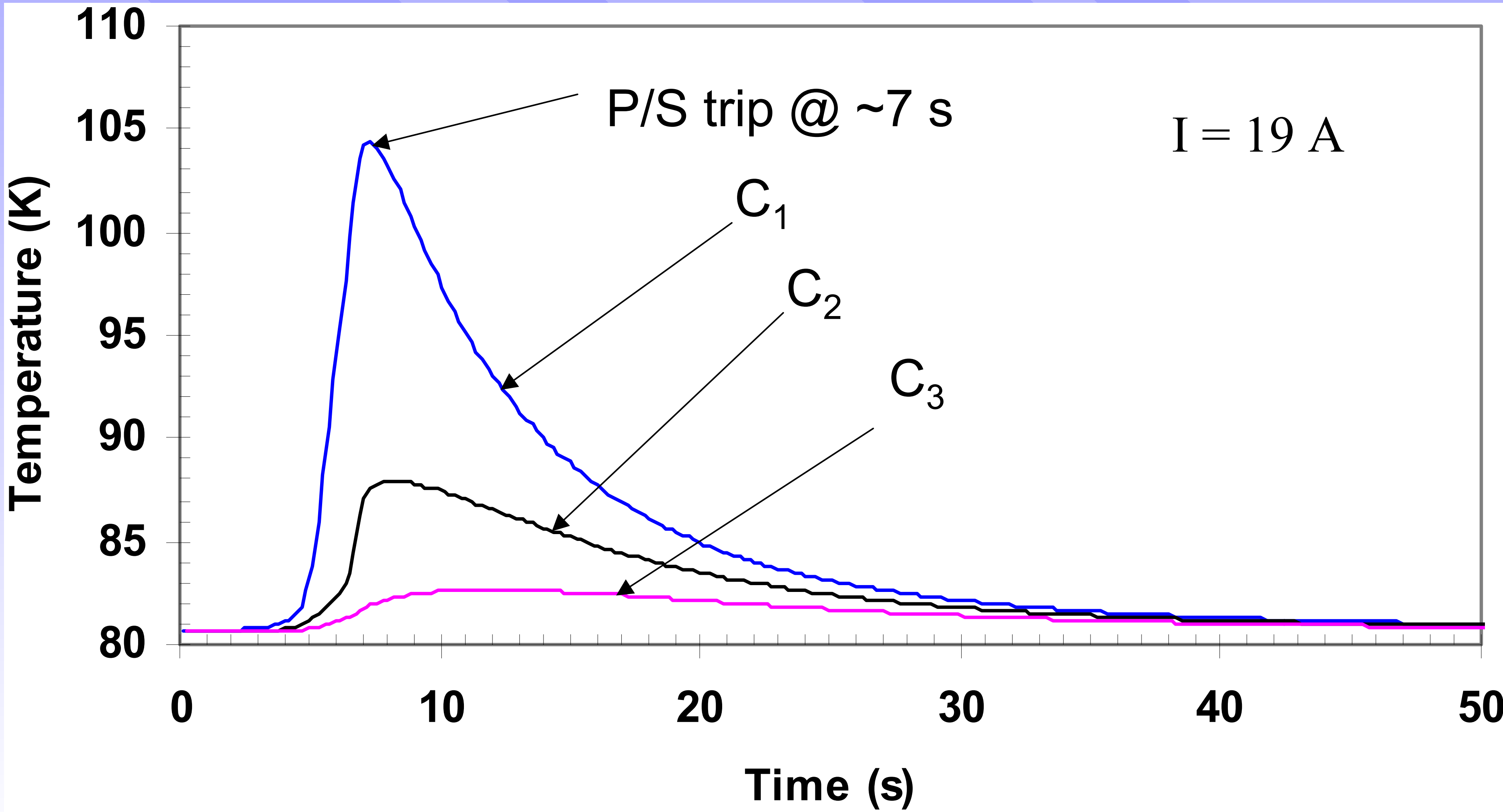
# Voltage-time-location during quench
# I = 19 A

$E_{pulse}$ >~ MQE
T=80.6 K



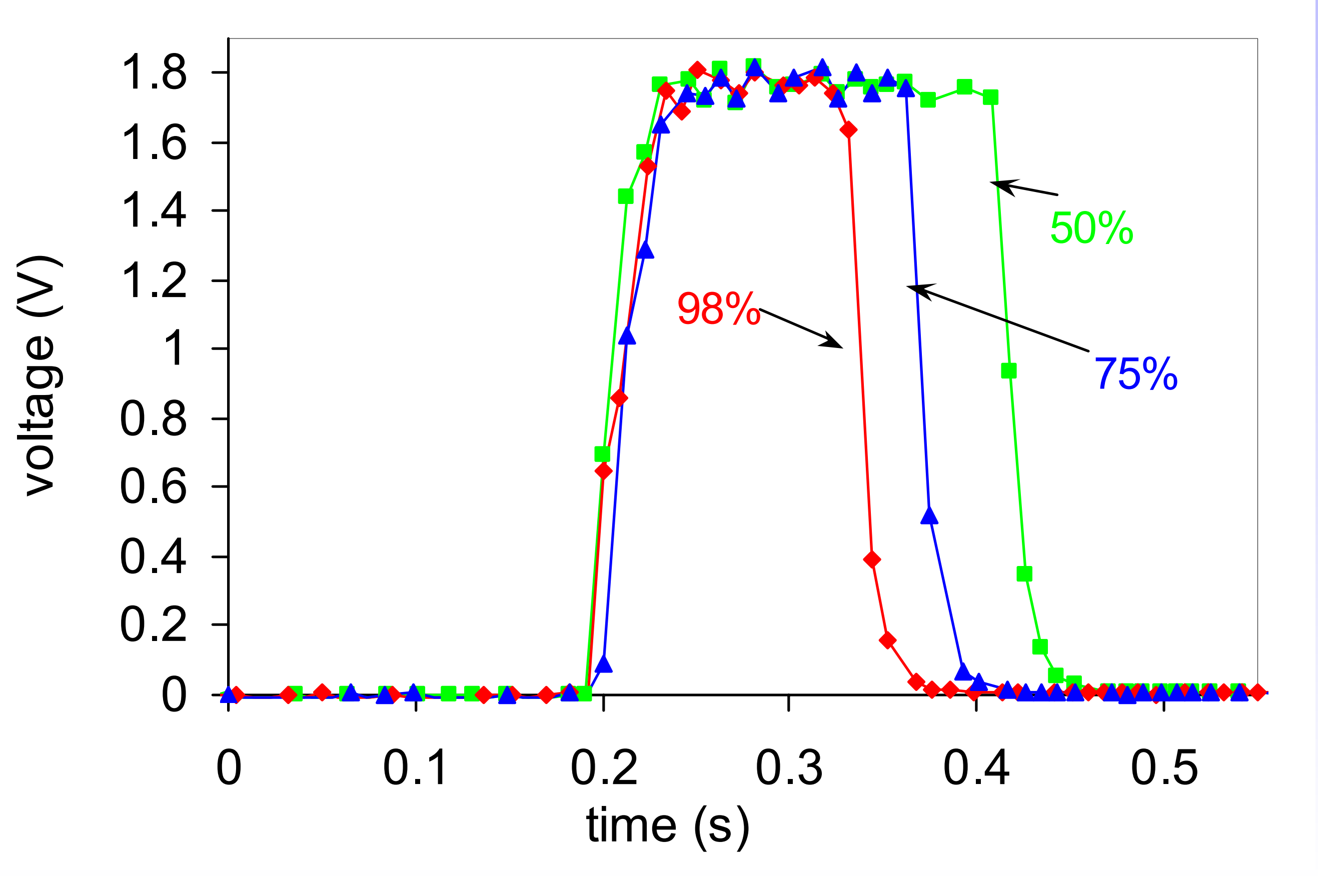
# Temperature-time-location during quench

$E_{pulse}$ >~ MQE
T=80.6 K



# Recorded data at "MQE", various $I<I_c$

- 50%, 75%, 98% of $I_c$
- Vary heater pulse *length*
- $T=80.6\ K$
- $I_c=19\ A$



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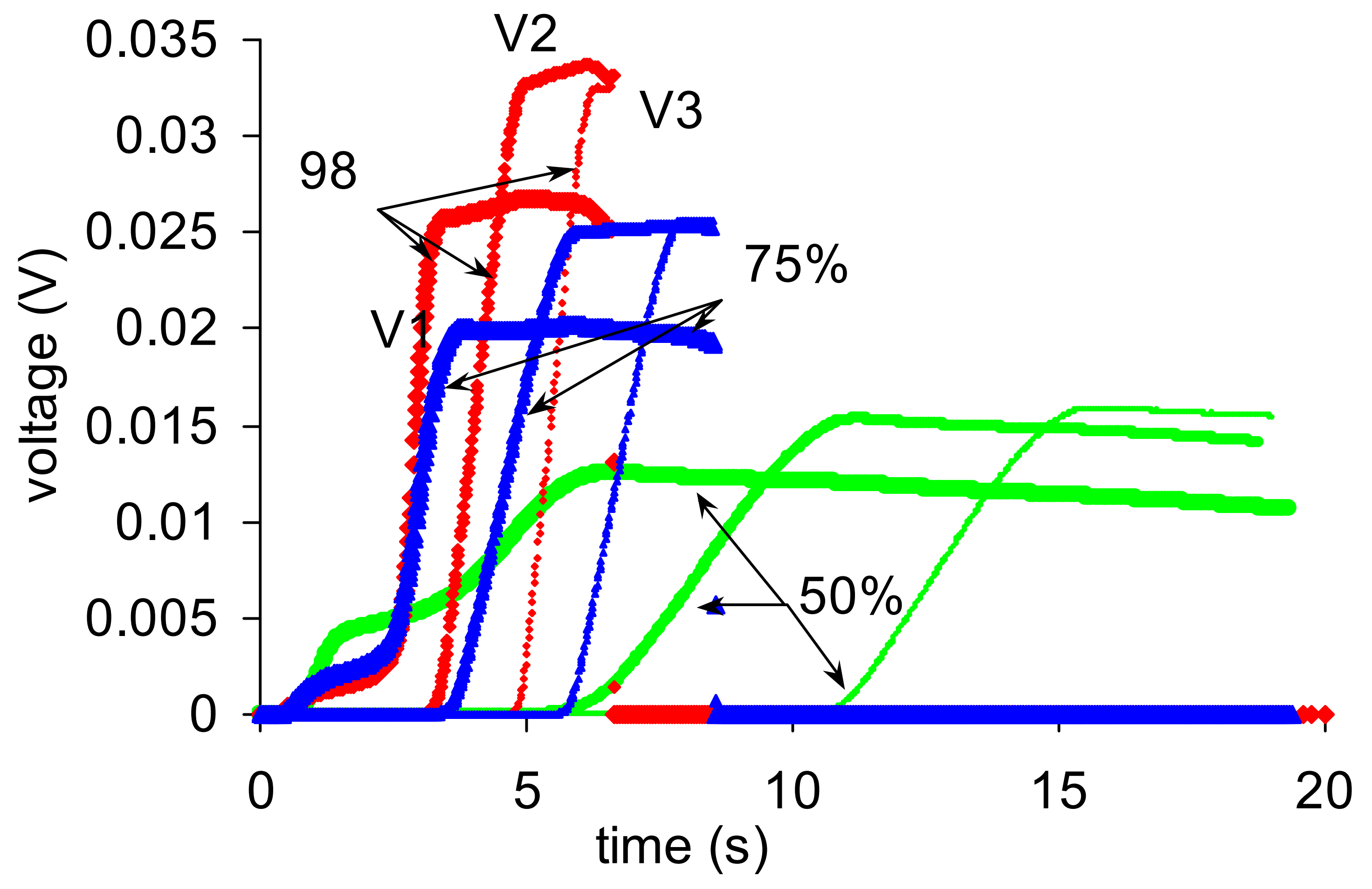

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- $T=80.6\ K$
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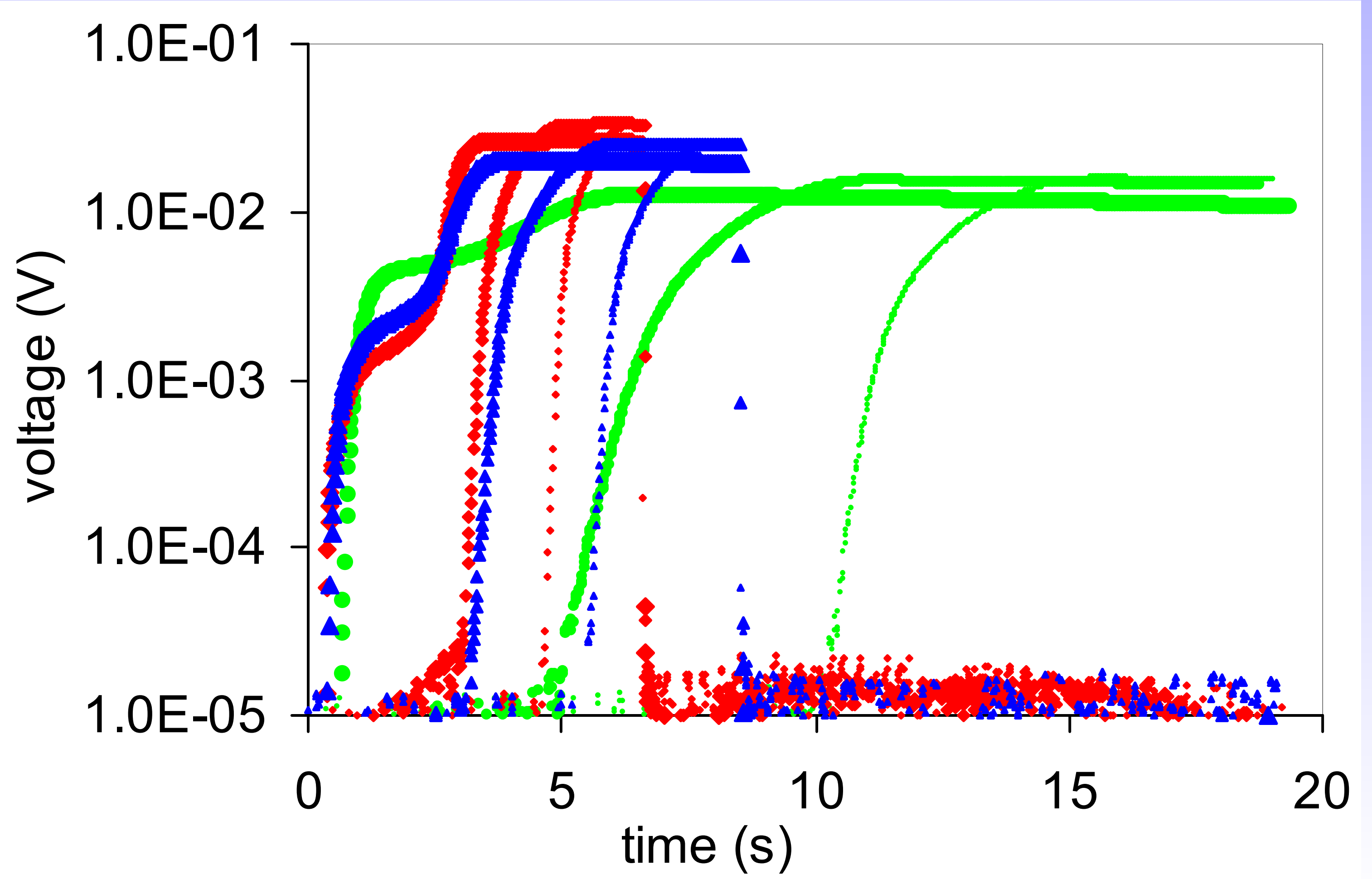
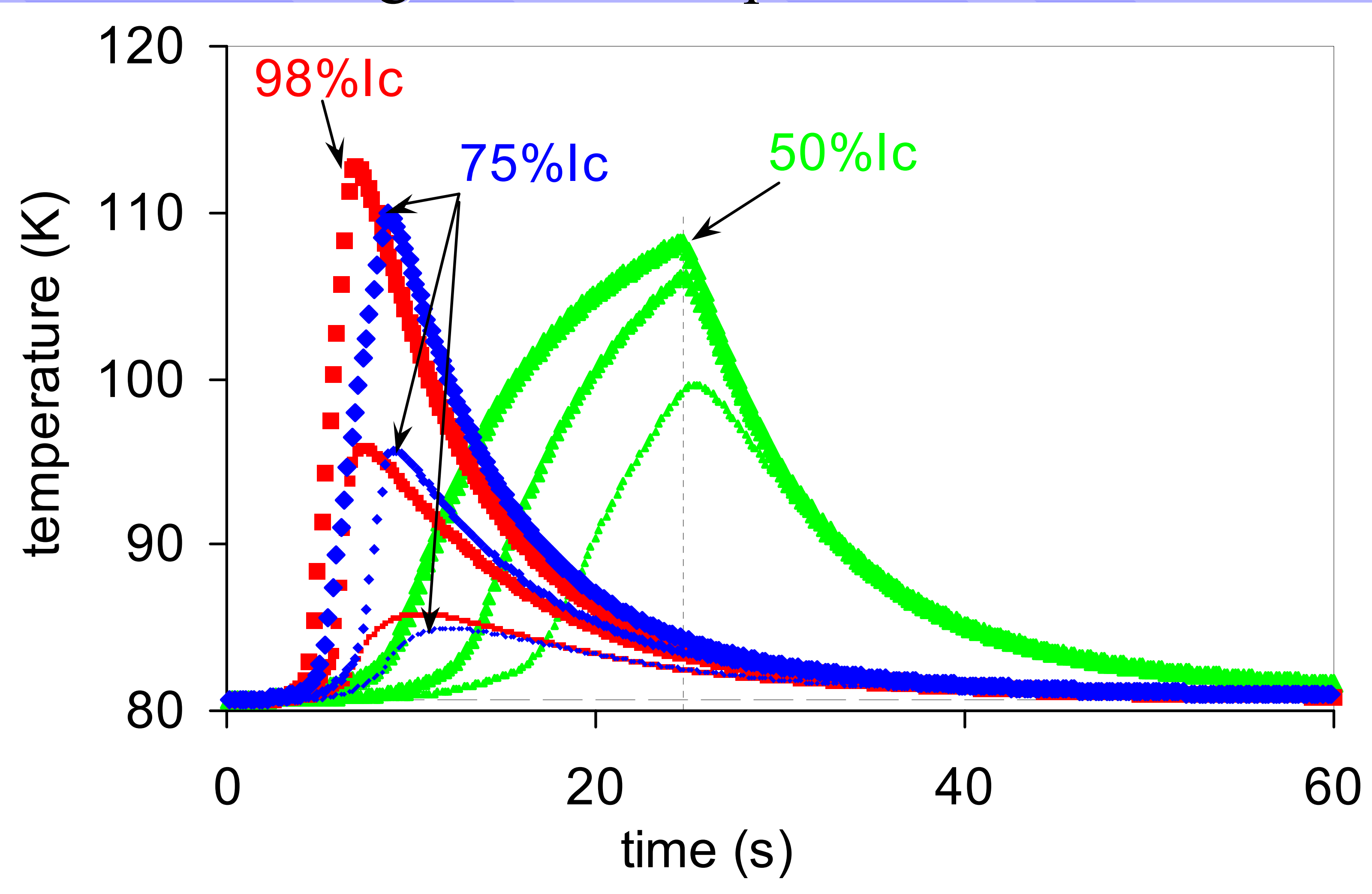


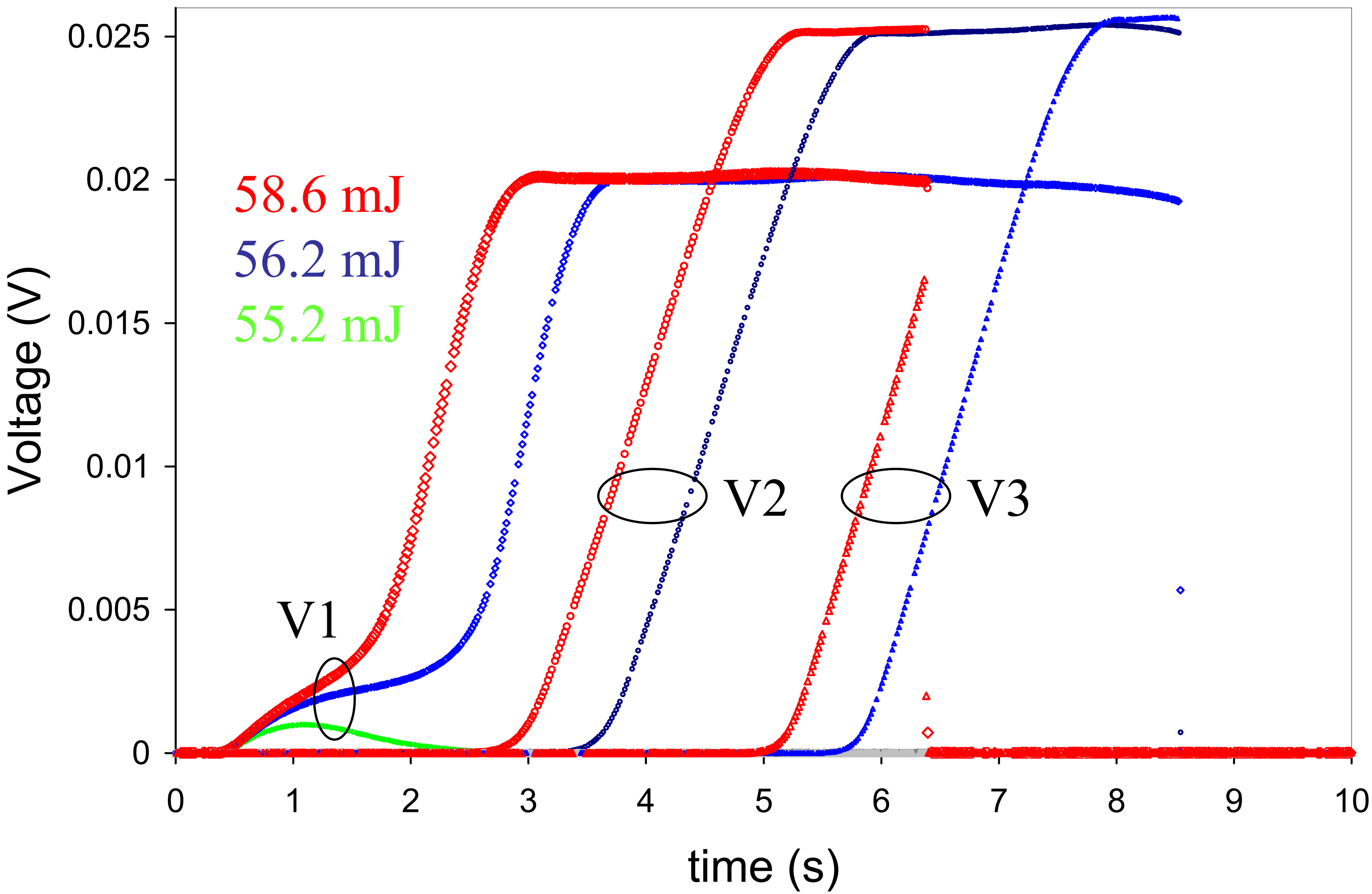
# Recorded temperatures at "MQE", various $I<I_c$

- Timescales are larger than anticipated

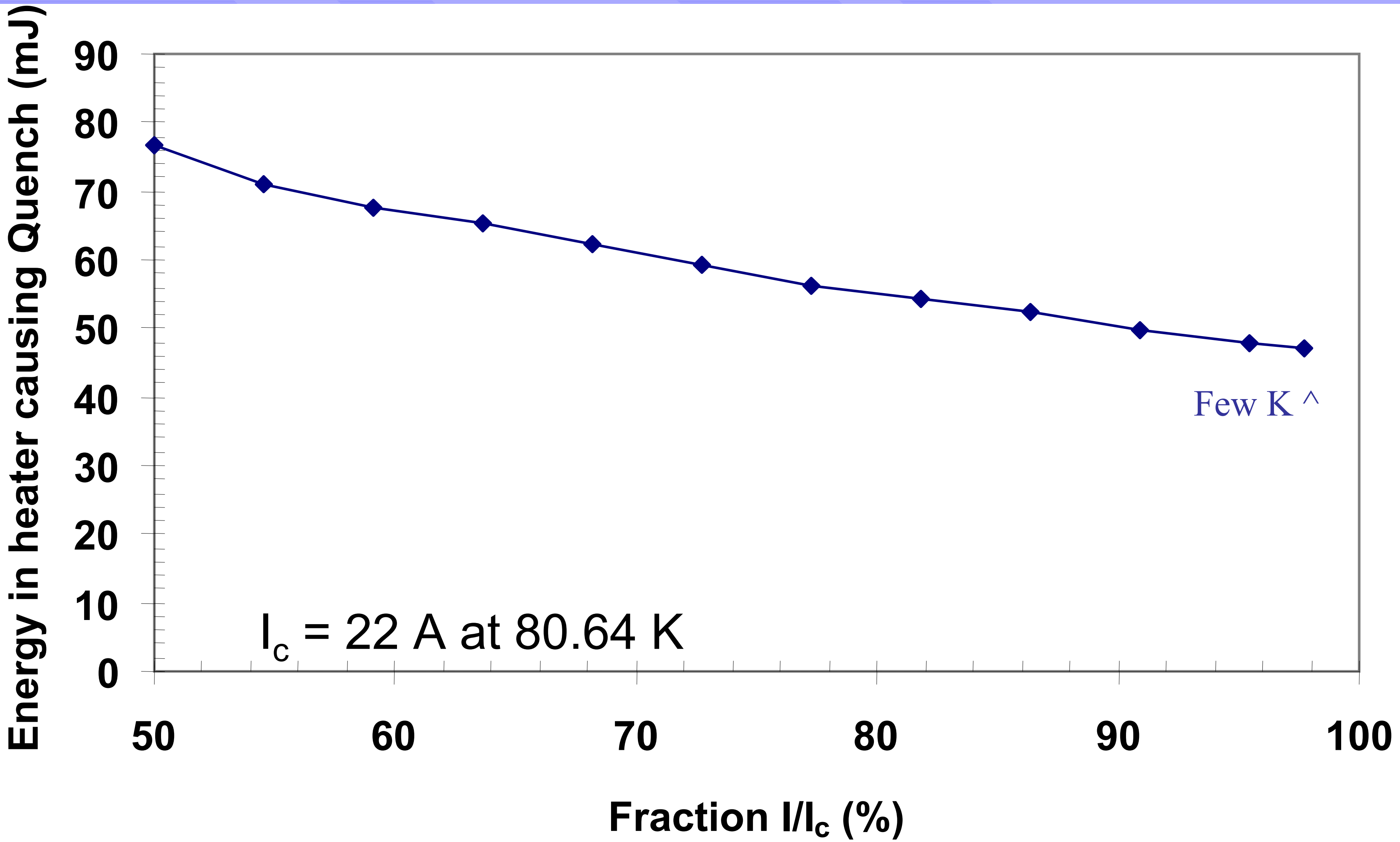


# Above and below "MQE", 75% $I_c$

- *Precise & repeatable*

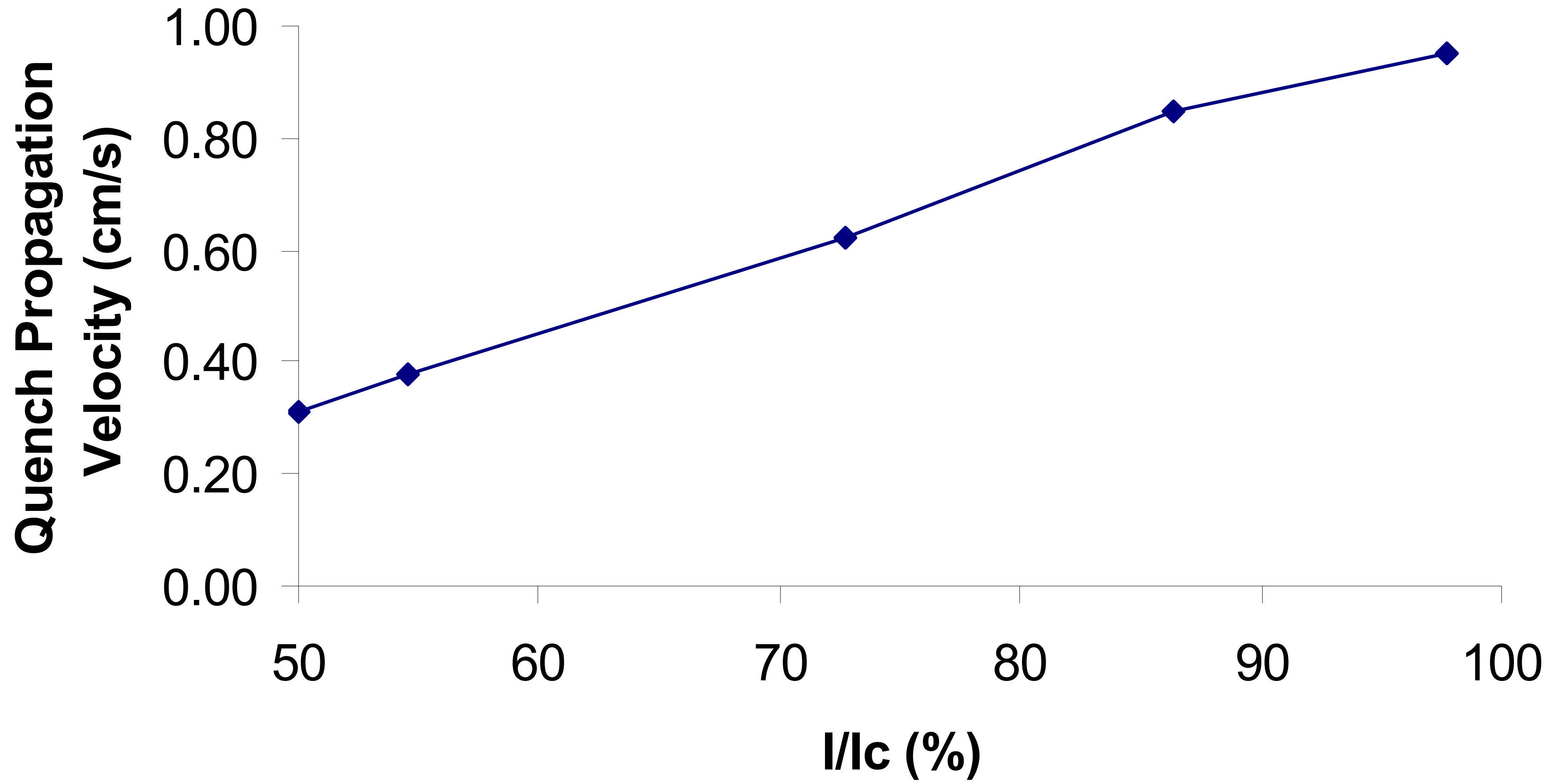


# "MQE" v. $I/I_c$ YBCO CC

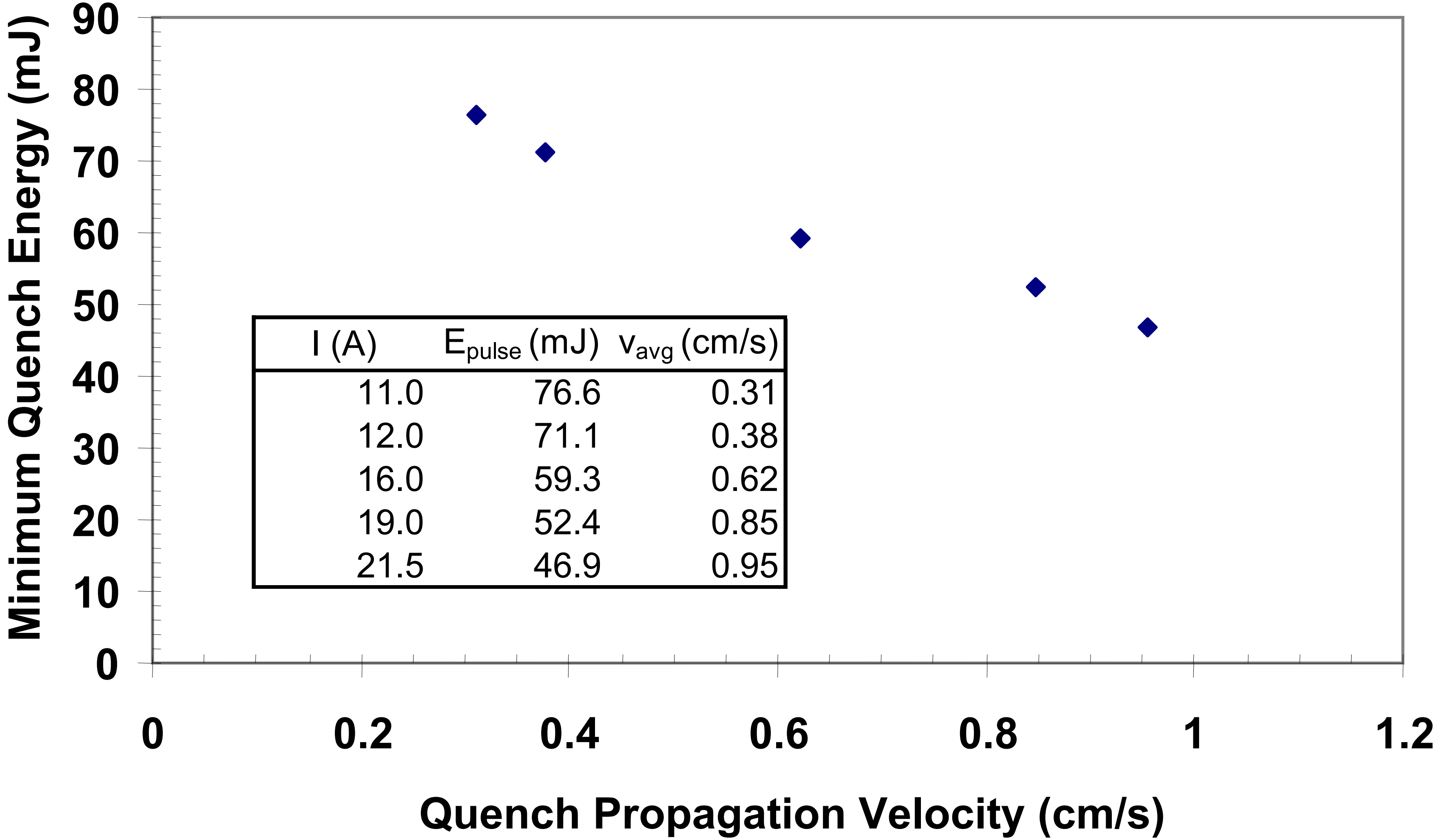



N.B. No sample damage

# Quench Propagation Velocity v. $I/I_c$ YBCO CC



# Quench propagation velocity v. “MQE” YBCO CC




| I (A) | $E_{pulse}$ (mJ) | $v_{avg}$ (cm/s) |
|---|---|---|
| 11.0 | 76.6 | 0.31 |
| 12.0 | 71.1 | 0.38 |
| 16.0 | 59.3 | 0.62 |
| 19.0 | 52.4 | 0.85 |
| 21.5 | 46.9 | 0.95 |

# Model

- Just beginning
  - Heat capacity of NiCr & Stycast
    - » Equivalent of few mm conductor
  - Radiation heat exchange appears minor
- Electrical connectivity YBCO/Ag-Ni
  - Variable
- Benchmark against “I=0 A” thermal diffusion
- Next:move to cryocooler/vacuum

# Conclusions

- Methodology for studying MQE and quench propagation velocity established for HTS conductors
  - NiCr heater provides easy, effective method of locally heating conductor
  - $N_2$ gas atmosphere, 80.65 K, cryostat $LN_2$ shield provides indirect cooling
- First data: Relatively friendly quenches in YBCO
  - No “burned samples” or degradation, ~$10^2$ Q
  - “stable normal zone, Q Prot available but unused
  - “linear” MQE, I/Ic, QPV relations
- QPV very slow at 80.6 K; expect (hope for) “faster” behavior at higher $J_c$&$J_e$
  - DAQ ready
  - High aspect ratio > radial propagation and insulator properties relatively more important in windings.
- Upcoming experiments
  - Broader range of tape quality (BSCCO and YBCO)
  - Lower temperatures & vacuum with cryocooler