Advanced Magnet Lab

# EXPERIMENTAL INVESTIGATION OF $MgB_2$ SWITCHING WITH MAGNETIC PULSES

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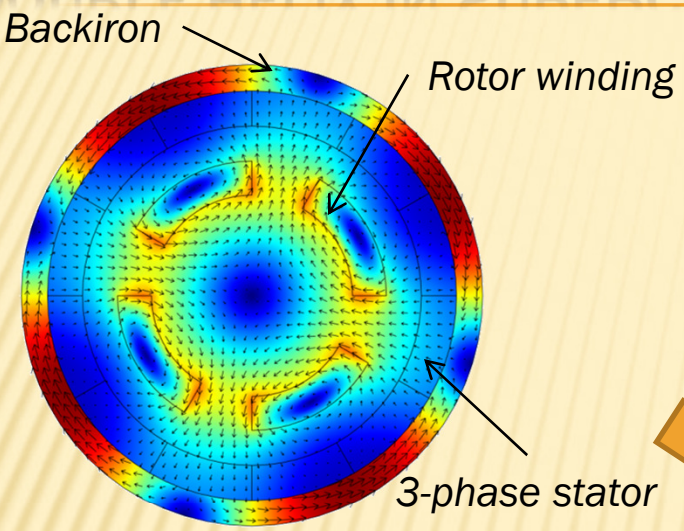
# INTRODUCTION

- Large superconducting machines represent a very promising application
  - Large wind generators
  - High efficiency industrial motors
  - Synchronous condensers
- MgB2 present interesting advantages
  - Cost
  - Multi-filamentary wires
  - Ultra low resistivity splicing
- Magnetic switching of MgB2 needs to be investigated

# DOUBLE-HELIX IN SUPERCONDUCTING ROTATING MACHINERY



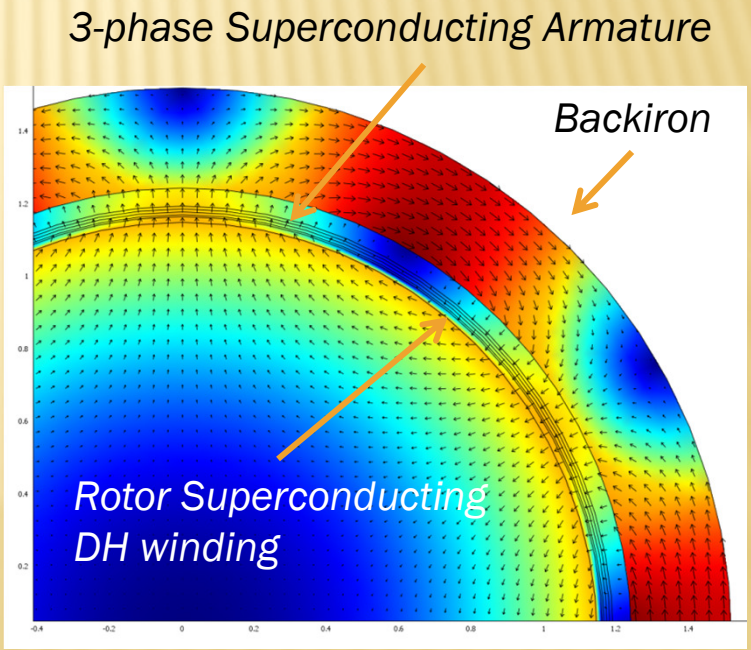

***Partially Superconducting*** *Generator*

## High Specific Torque/Power

- High air gap flux density
- No iron core in the rotor
- Outstanding mechanical torque transfer
- High RPM possible due to DH's intrinsic distributed containment
- Number of poles not limited by radius
- Superior dynamic capabilities

## High Reliability/Robustness

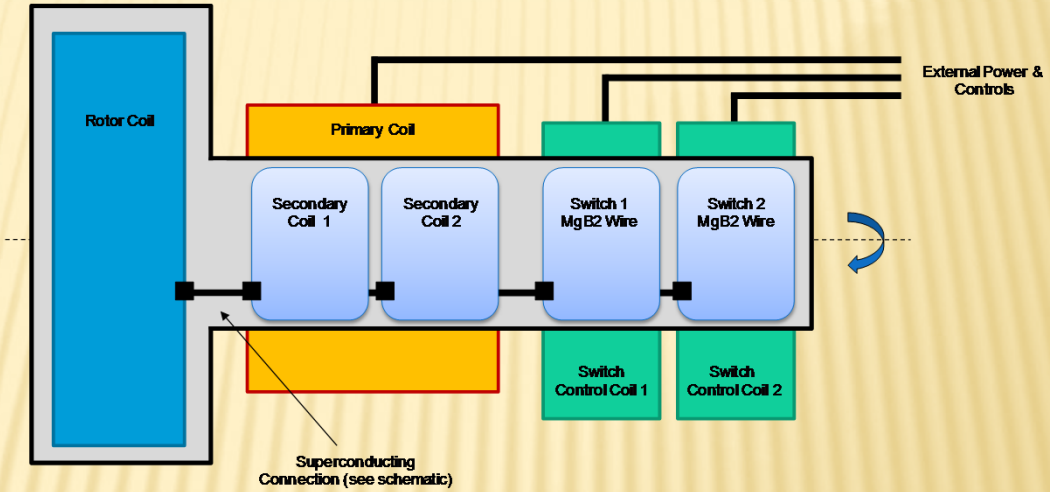
- Pure field: no vibrations
- Outstanding conductor stabilization
- Distributed structural containment
- Improved quench propagation (winding spreads in different direction)
- Winding is self protected against quench when using $MgB_2$
- Excitation using AML's flux pump technology
- Splice free multi-pole rotor




*Double-Helix* ***Fully Superconducting Generator***

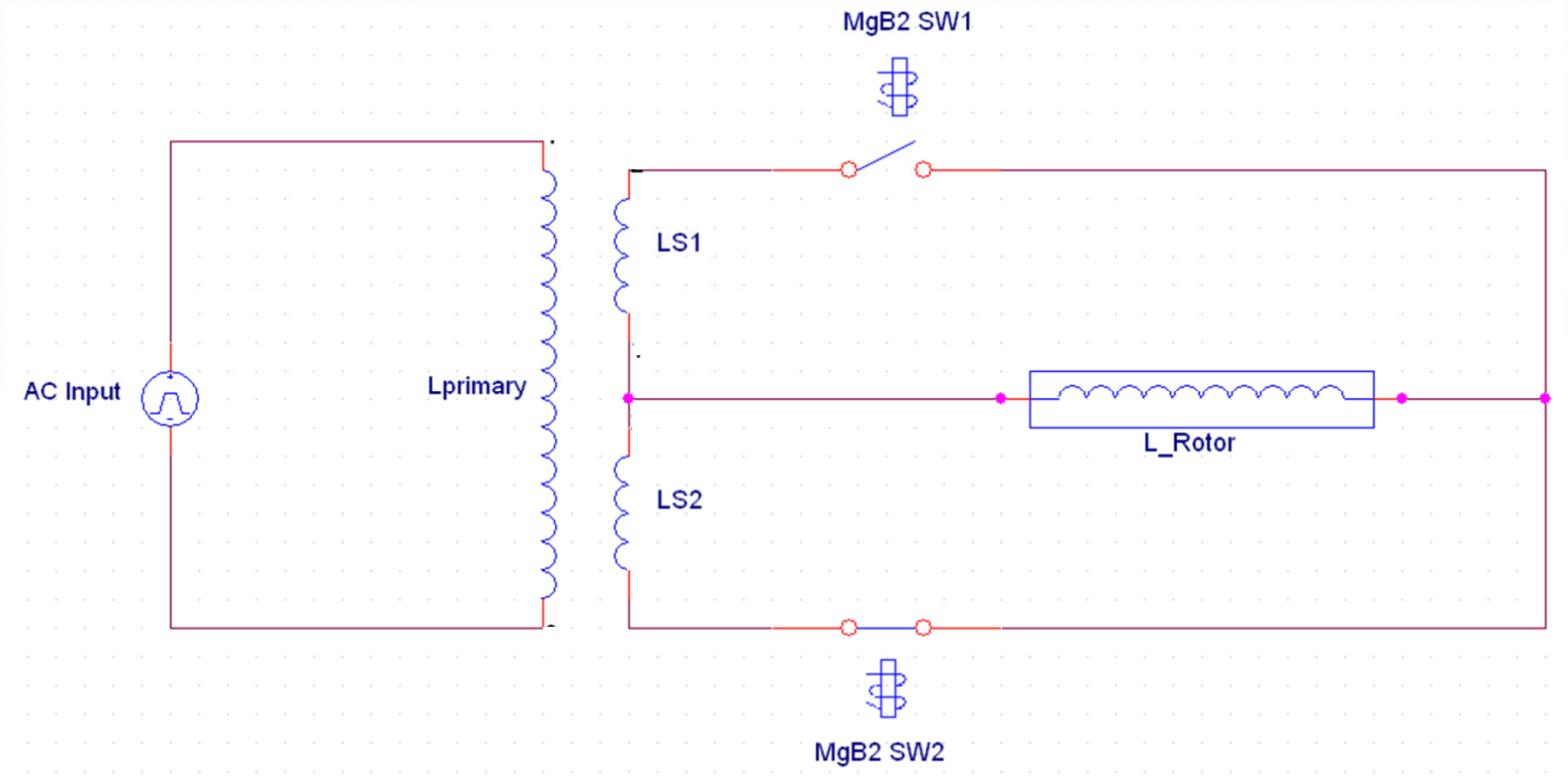
# EXCITER OPTIONS

- Current needs to be fed to the superconducting rotor coils, possible options:
  - "Conventional" brushless exciter (rotating transformer with rectifier bridge) > Applicable to "low" current to limit switching losses
  - Flux pump (AML design) > High excitation current




- $MgB_2$ allows for semi-persistent operation of the rotor coils
- AML's proprietary flux pump provides high excitation current
  - Very **low switching losses**
  - Magnetic flux can be "pumped" in or out for **control of the excitation current**
  - Operation at **very high current** is possible
  - Switching **frequency is controllable** independently from rotation speed
  - Current **control dynamic is adequate** to low speed generators

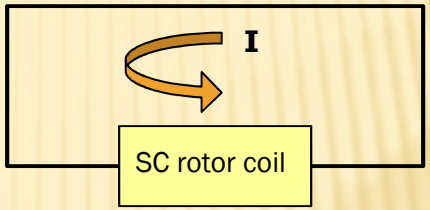
# FLUX PUMP CONCEPT

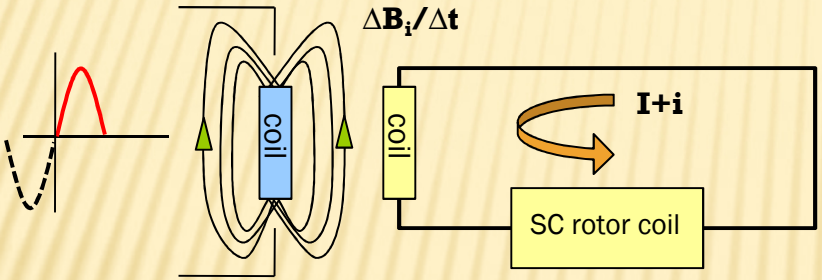



- Eliminate Current Leads Using Full Wave Rectifier Type Flux Pump
- Low loss switching
- Semi-persistent Mode Operation:
- Flux Pump Rotor, $MgB_2$ Switches, Splice Joints

# FLUX PUMP … HOW DOES IT WORK?

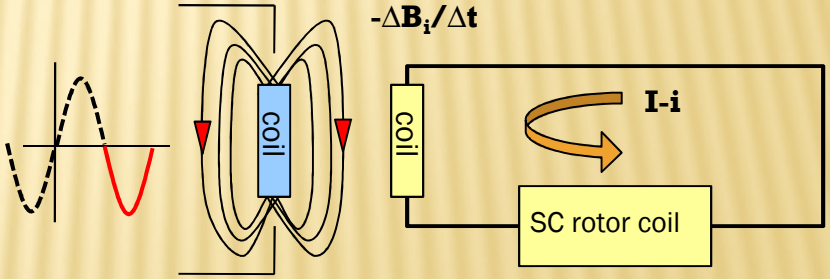
A closed circuit that is **fully superconducting** will sustain an existing current "forever"
This is called *Persistent Mode*




The current in this circuit can be increased by induction of a coil in the circuit (one half of the "pumping" cycle)

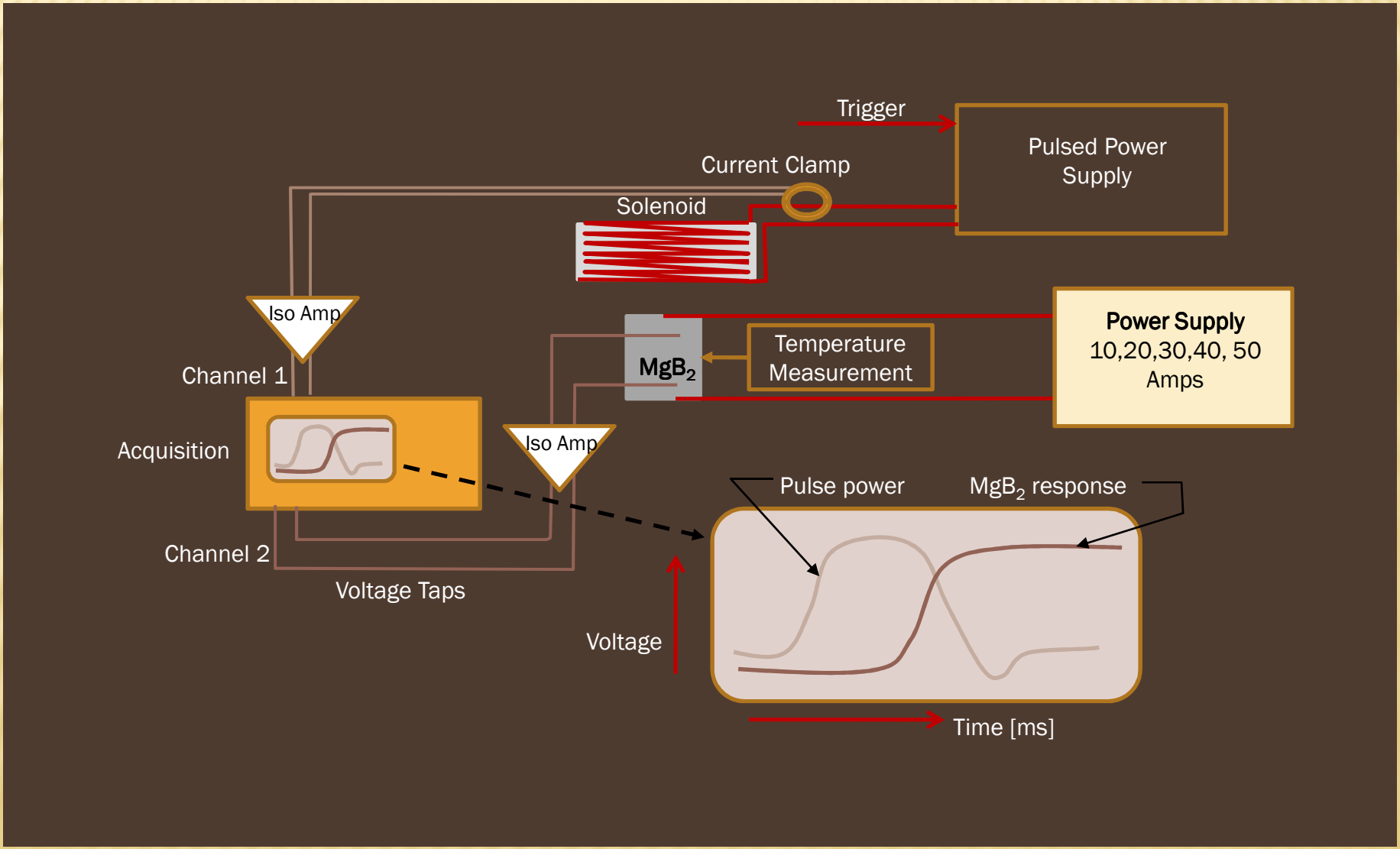
However, at the second half of the pumping cycle, we induce a current in the opposite direction.
***Not good …***



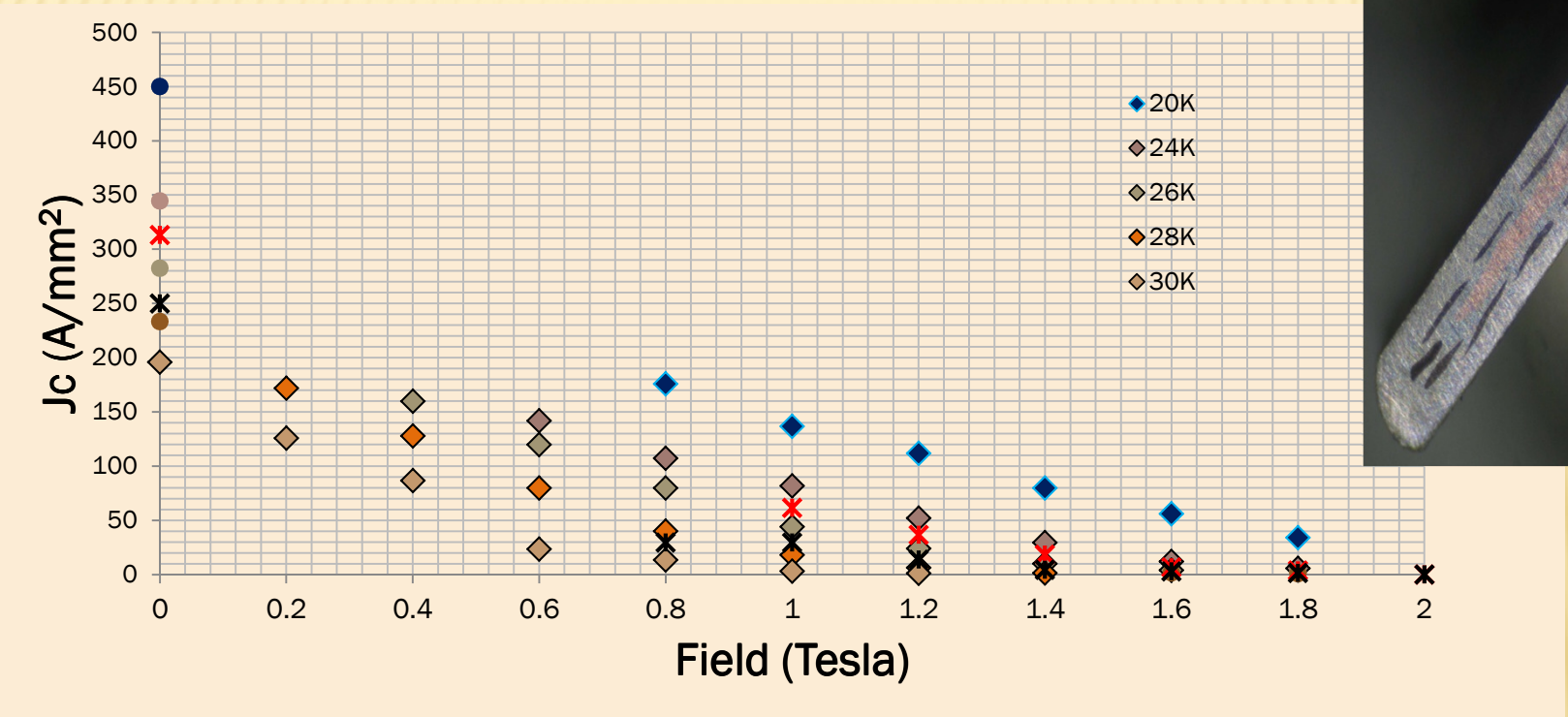

Solution: Use a superconducting rectifier circuit to always pump current in the same direction and thereby continuously increasing the current…

$$I_{excitation} = i + i + i + i \ldots..$$

# EXPERIMENTAL SET-UP



# $MGB_2$ CONDUCTOR TESTED

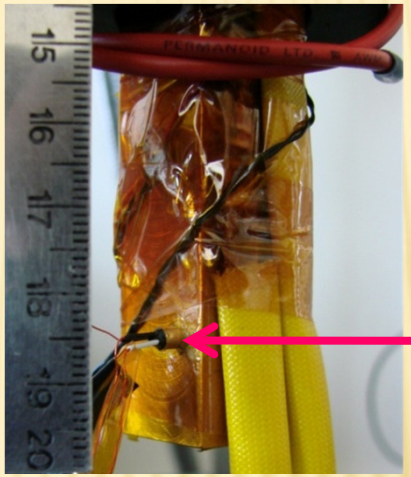


- Tape provided by Conlumbus Superconductor
- 12 $MgB_2$ filaments, S.C. Area: 0.2 $mm^2$
- Thickness: 3.6 mm Width: 0.65mm
- Ic (20K, 1 T) = 383 A

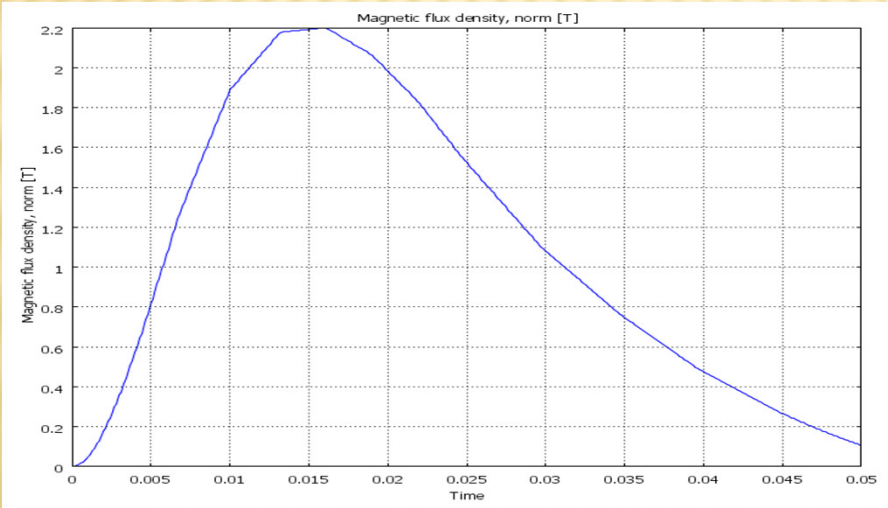
# PULSE GENERATION & SAMPLE HOLDER

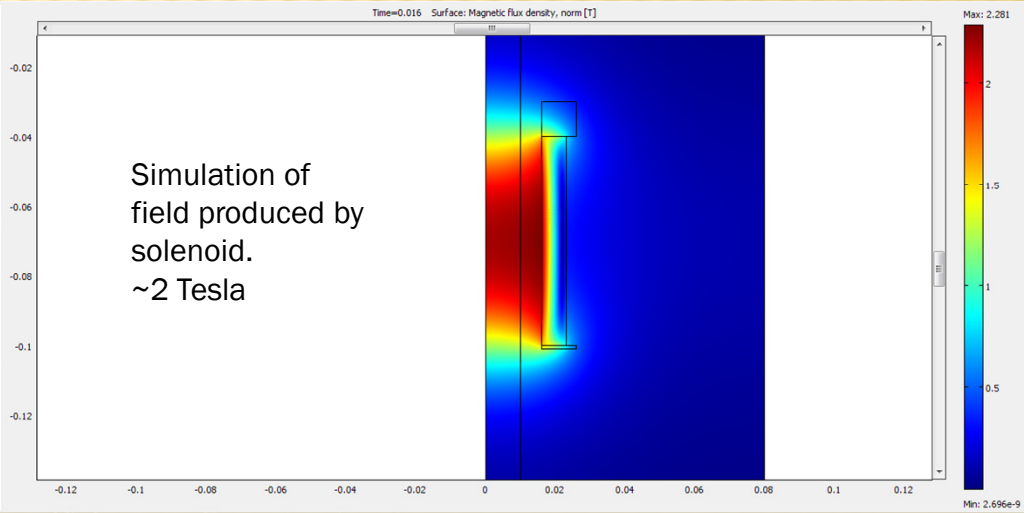
Brass sample holder.
Provides large thermal mass.

Solenoid:
Insulated Copper wire.
1mm diameter
~ 60 turns
10 layers



Cernox temperature sensor embedded in sample holder




Simulation of field produced by solenoid.
~2 Tesla

# COMPONENTS OF EXPERIMENT

Connection to Cryo-head

Brass piece makes direct contact to Cryo-cooler head

Copper coil to apply external field

Brass piece onto which MgB2 sample is mounted.

Temperature controller

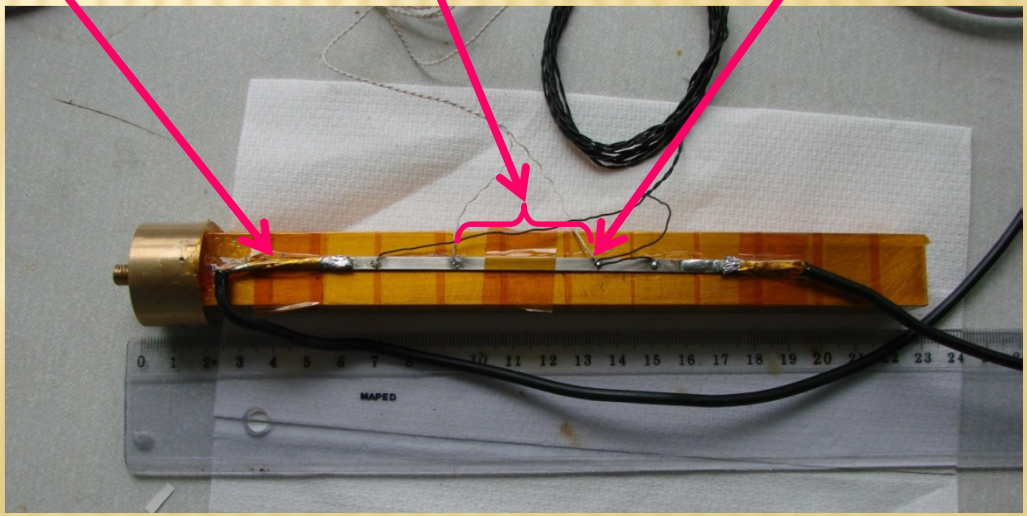
Cryo-cooler & Compressor

Power Supply

Brass Piece Insulated with Kapton, Thermal grease use for good thermal contact between sample and holder.

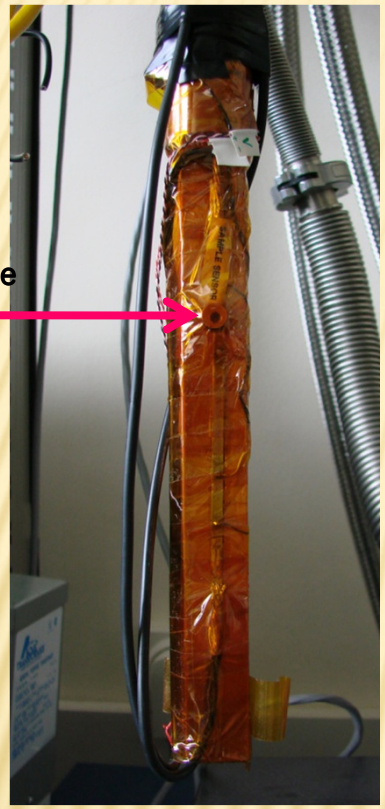
~ 4 cm between voltage taps.

Voltage tap point

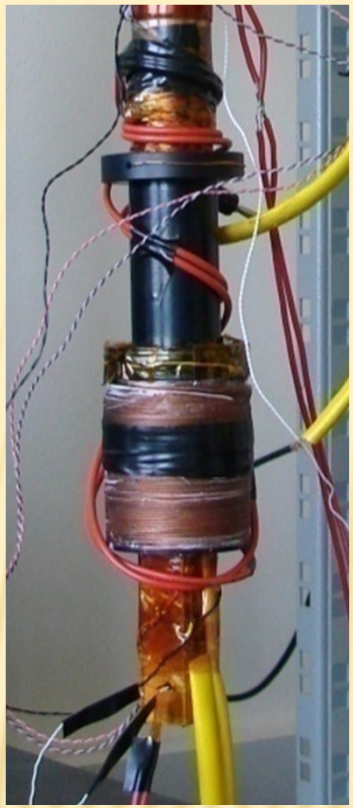


# CIRCUITRY & COMPONENTS OF EXPERIMENT

Temperature sensor



Above: Sample holder with $MgB_2$ mounted to cryo-cooler head



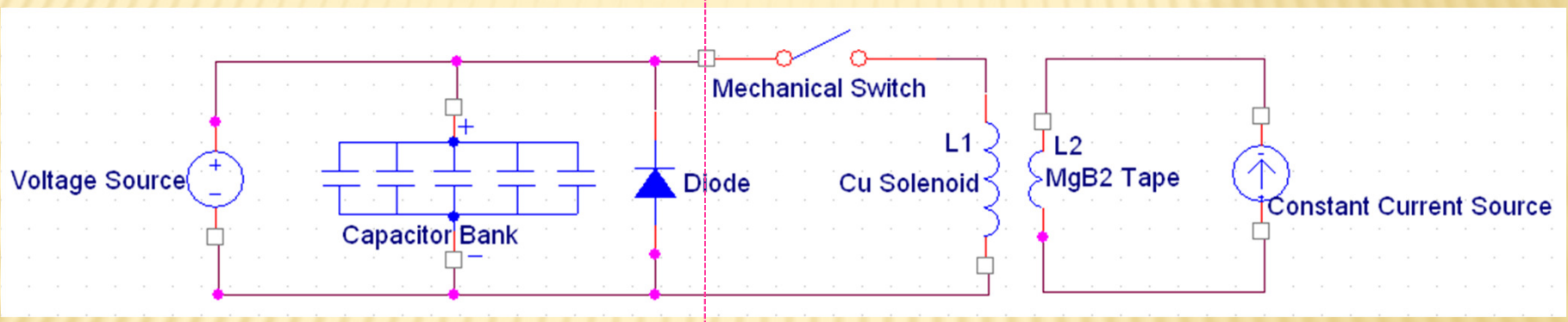
Above: Solenoid positioned around $MgB_2$ sample holder and mounted to cryo-cooler head

Above: Capacitor bank used in discharge circuit to solenoid

Right: Switch, Current sensor

# EQUIVALENT CIRCUIT

Charge / Discharge Circuit




Capacitor Bank = 14430 µFarad

Capacitors charged to ~ 300V

Current to Solenoid ~ 300 Amps

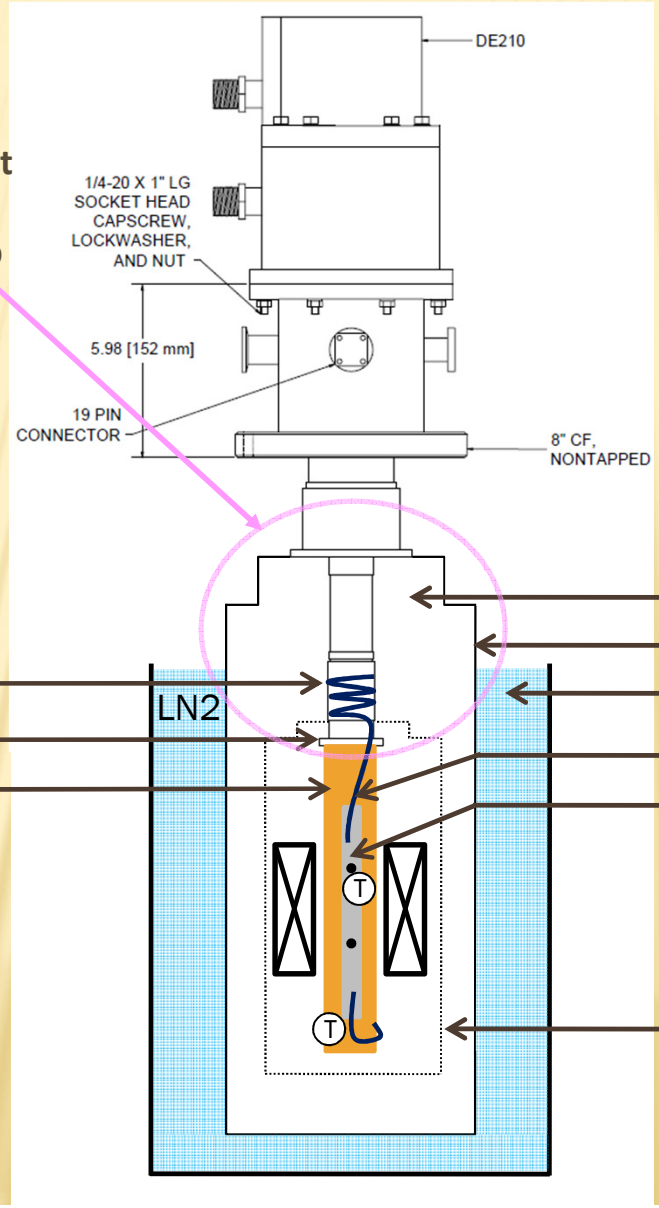
L1 = 87 mHenry
L2 = ~ 0 H

Resulting field calculated to be ~2 Tesla

# COOLING

**Heat loads present:**

1. **Conduction losses – due to current leads to $MgB_2$ & Cu solenoid**
2. **Some radiation losses close to top portion of experiment**




Current leads thermally anchored

Cryocooler head

Insulated brass sample holder

Vacuum

Cryostat

Liquid Nitrogen (LN2)

Current Lead

$MgB_2$

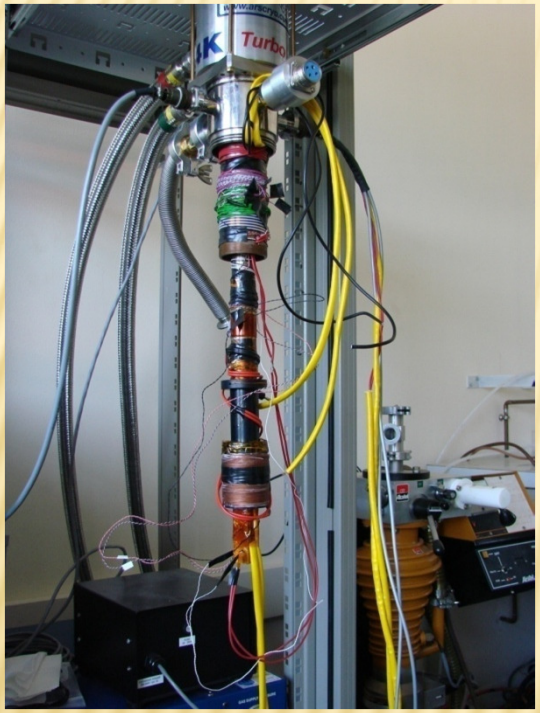
• Voltage Taps

Ⓣ Cernox Temperature Sensors

ML Insulation

Cu solenoid

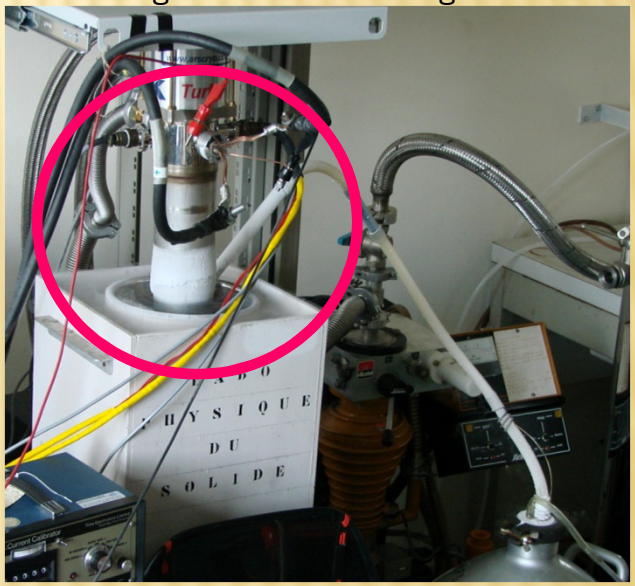
# PREPARATION AND COOLING



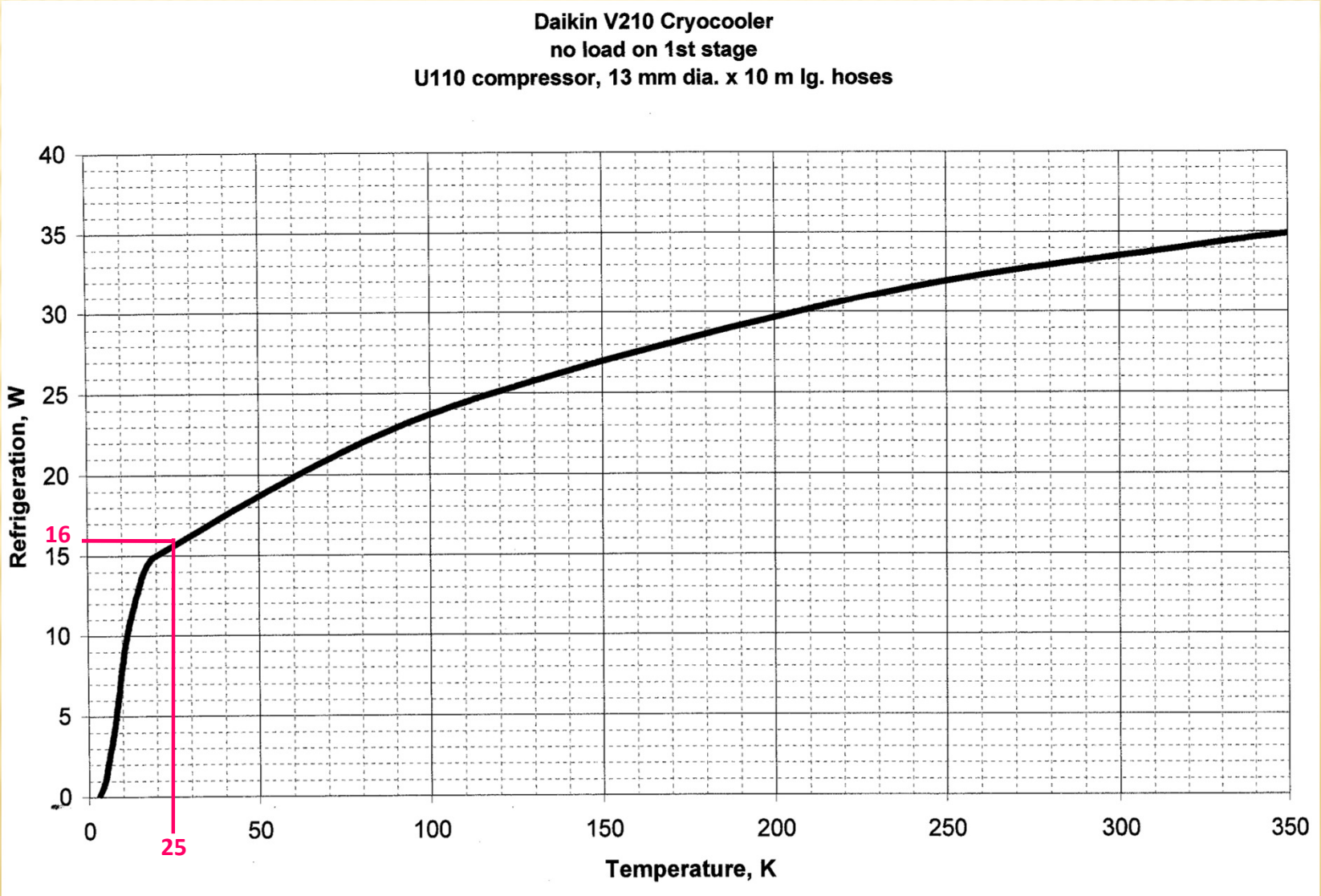
Above: Experiment mounted to cryo-cooler

Above: Multi layer insulation

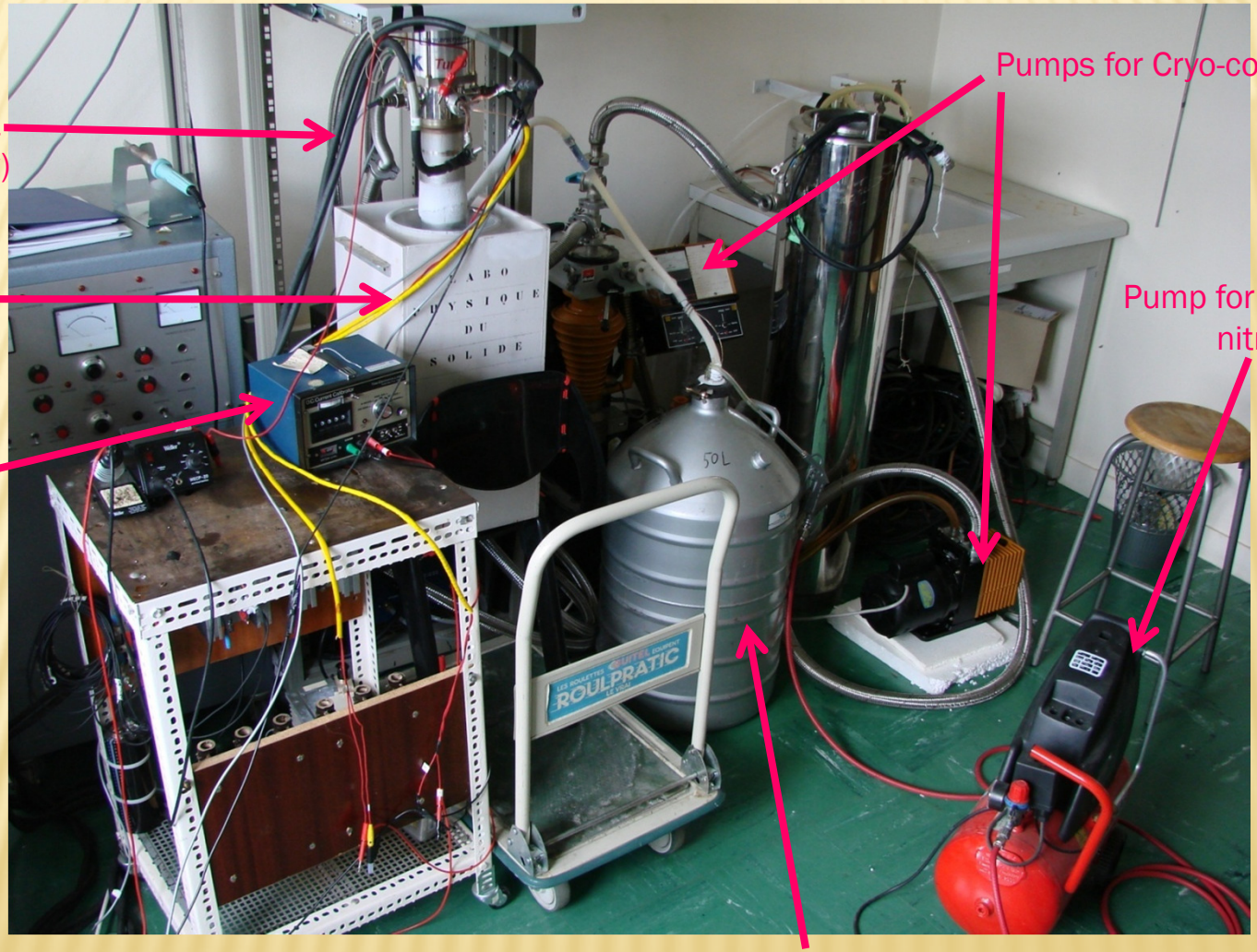
Circled region shows area of high heat load



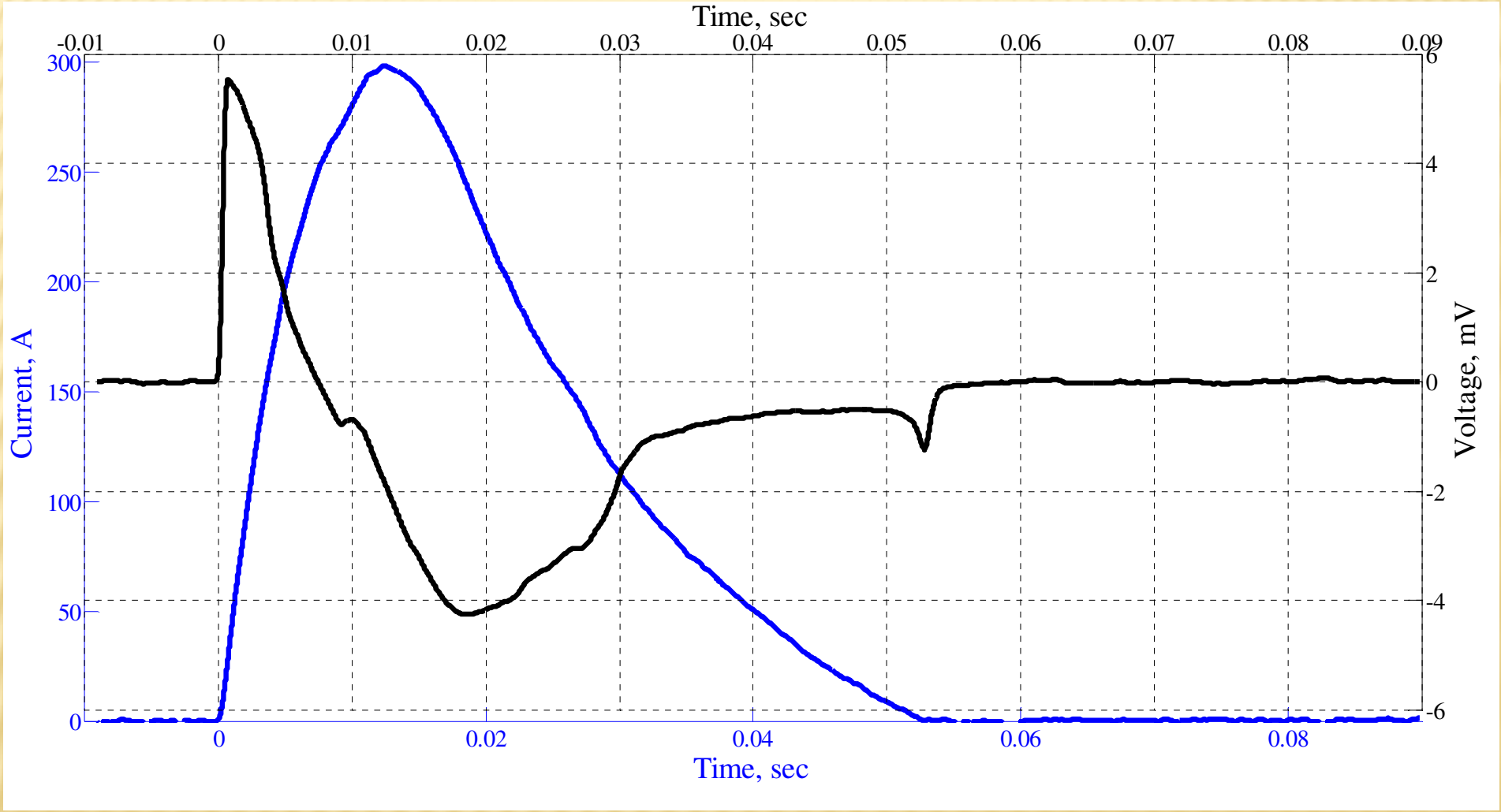
# CRYOCOOLER – POWER CURVE



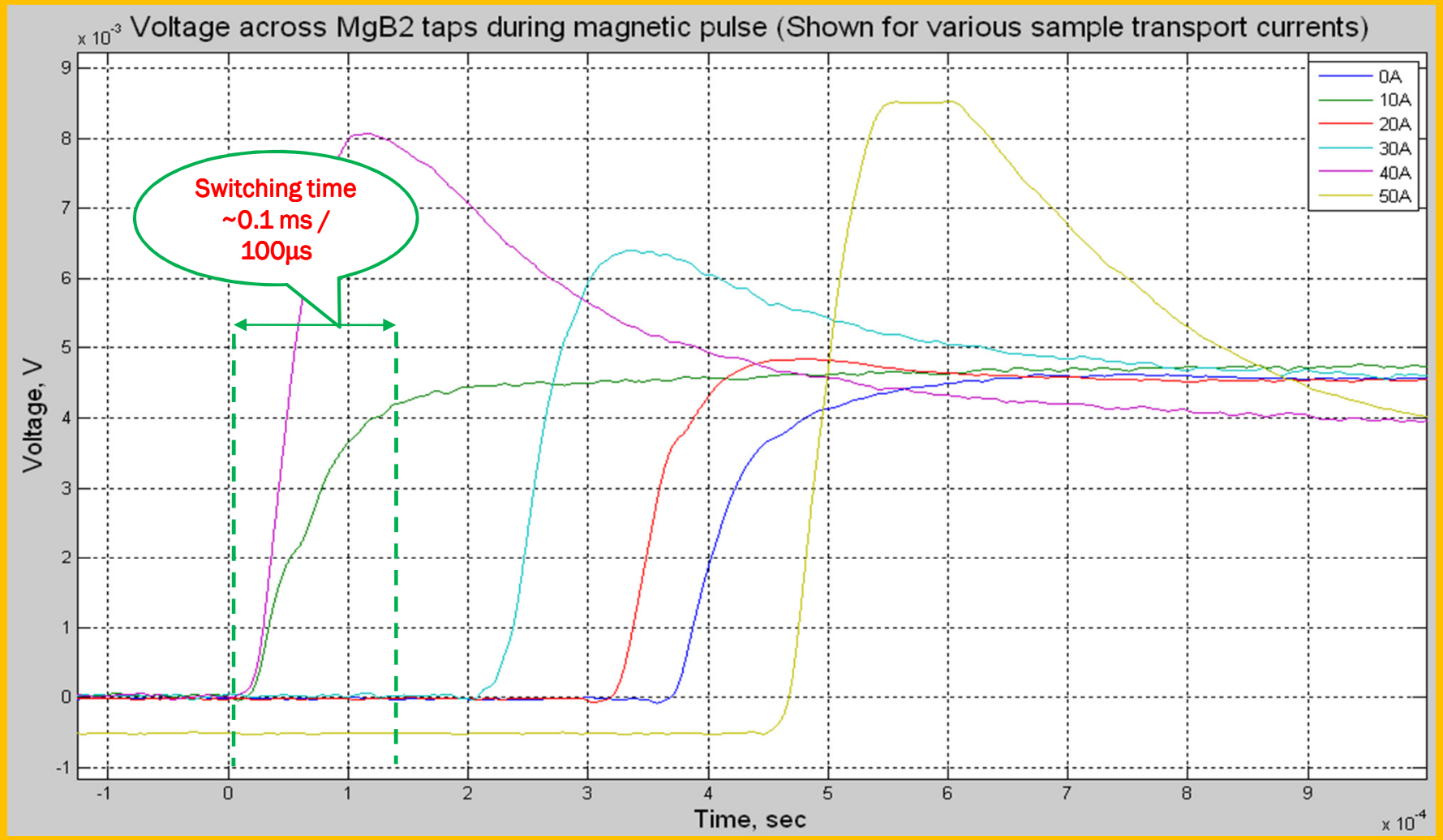
# EXPERIMENTAL SET UP



# MAGNETIC PULSE AND VOLTAGE RESPONSE

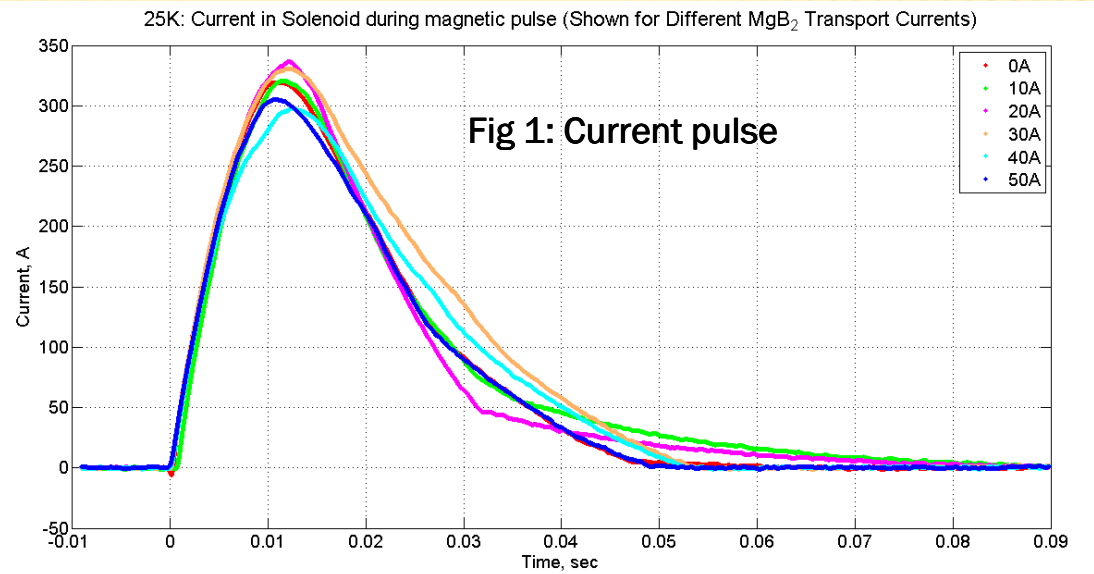


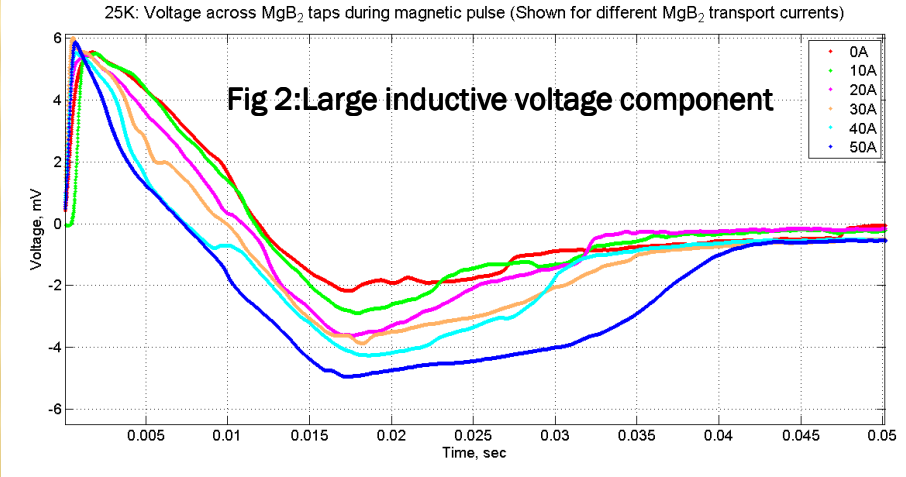
# TRANSITION TO RESISTIVE STATE

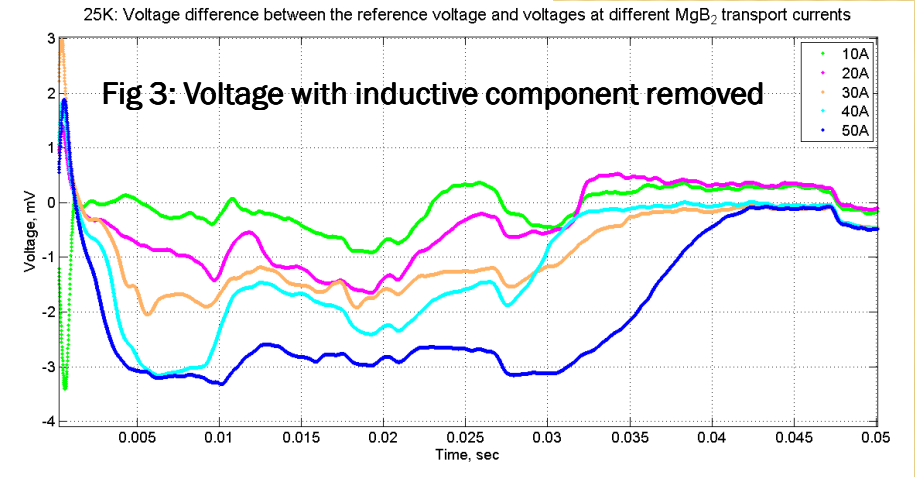


# EXPERIMENTAL DATA @ DIFFERENT TRANSPORT CURRENTS

Temperature = 25K

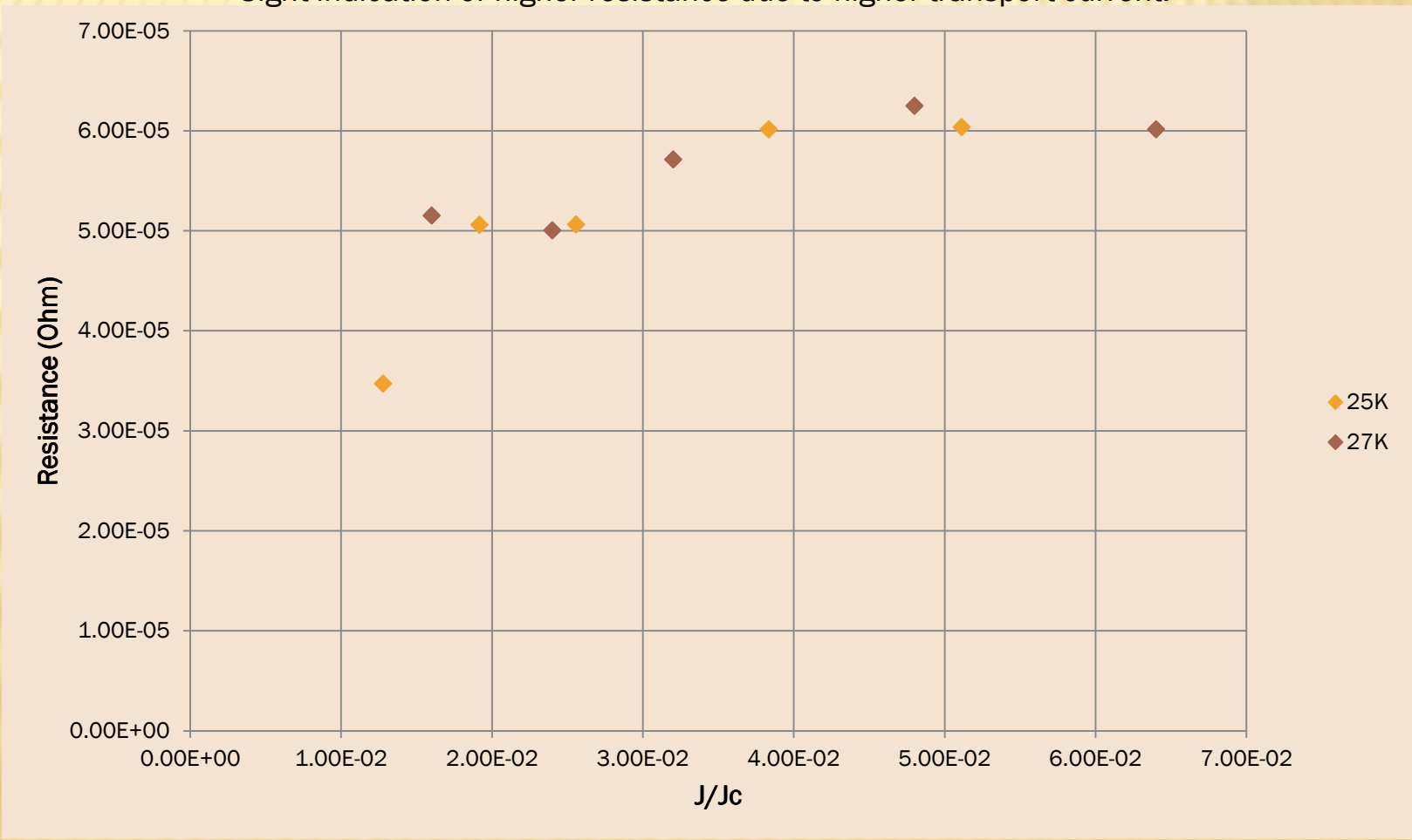


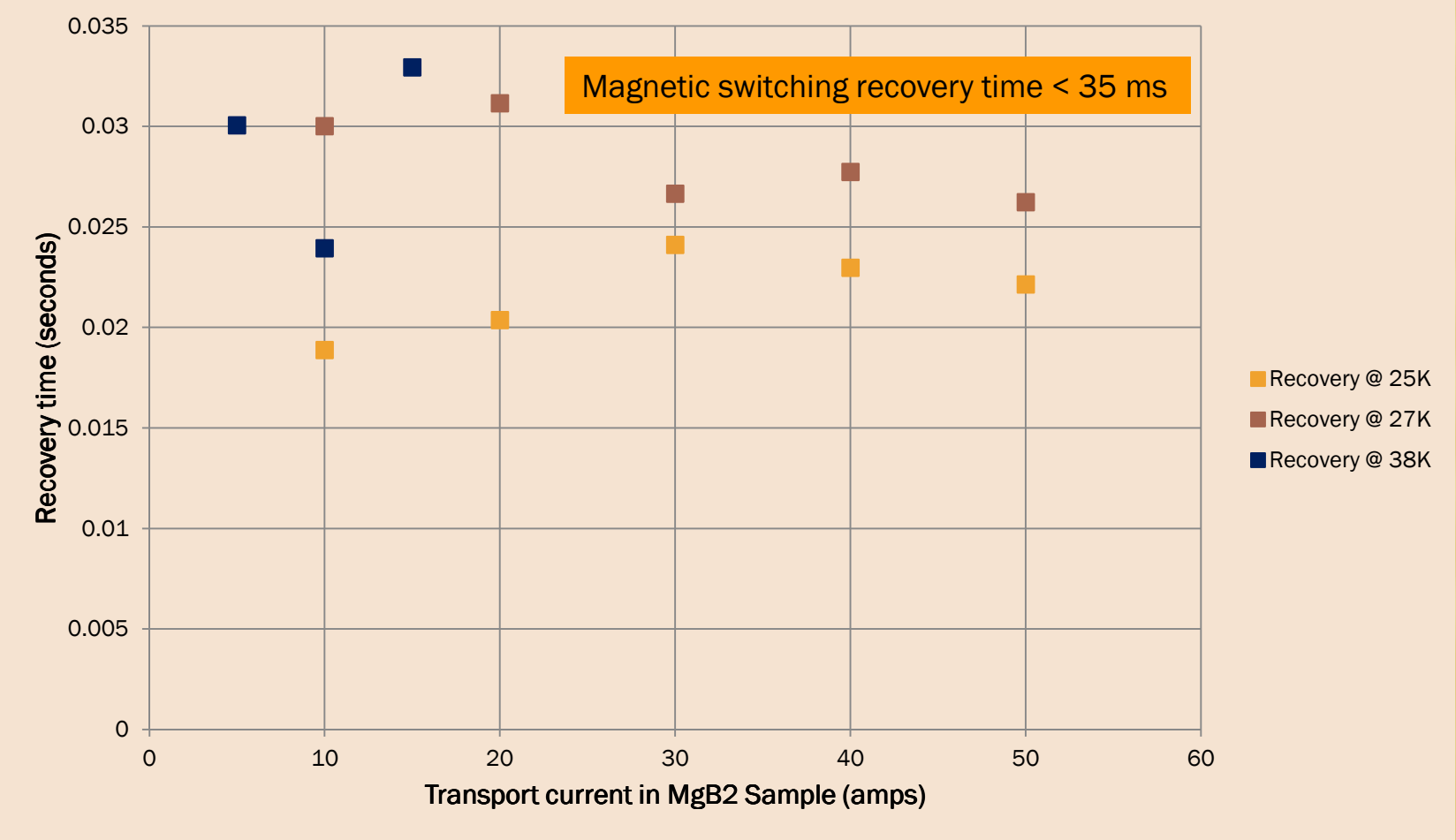
# EFFECTIVE RESISTANCE OF SWITCH

No clear indication of the dependence of switch resistance on temperature.
Sight indication of higher resistance due to higher transport current.



# RECOVERY TO SC STATE

Data indicates that the recovery time has no dependence on temperature or transport current



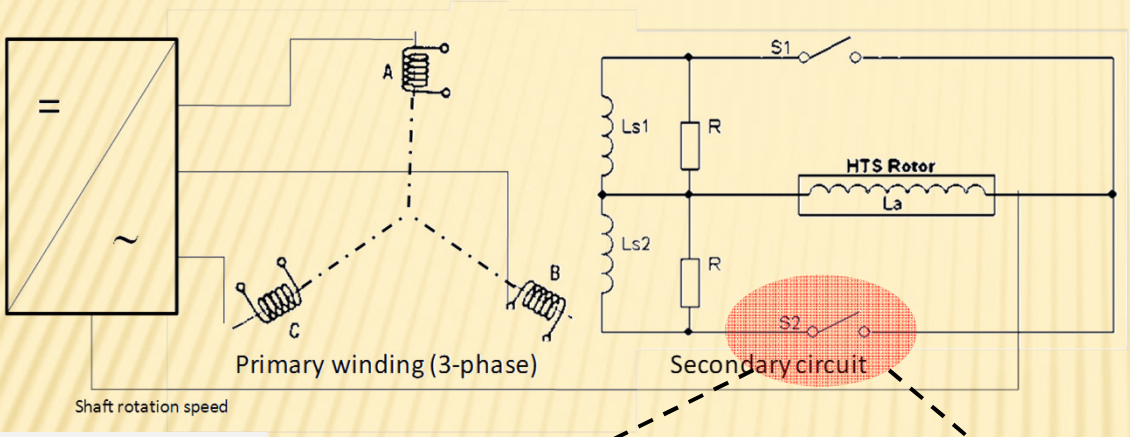
# $MgB_2$ MAGNETIC SWITCHING CHARACTERISTICS

## Key Experimental Conclusions:

- Initial data analysis supports use of magnetically pulsed $MgB_2$ as a switch
  - No occurrences of quench during magnetic pulsing
  - No significant temperature rise observed
  - Resistance of switch depends on the transport current; no clear observation of large temperature dependence
  - Recovery time from superconducting (SC)to resistive state shows no dependence on operational temperature

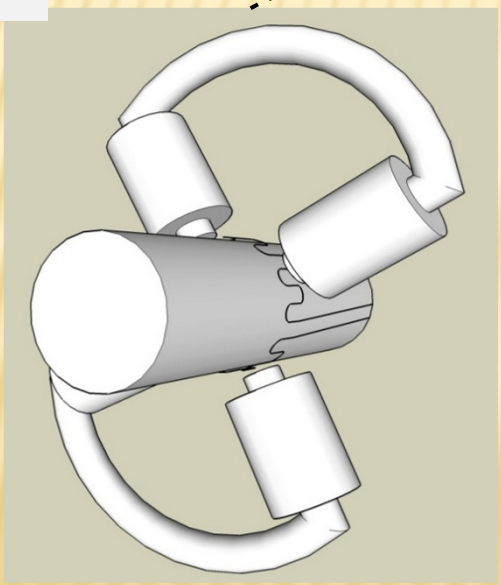
- Switching times:
  - Time to switch off (from SC to resistive): < 35ms
  - Time to switch on (from resistive to SC): ~ 0.2ms

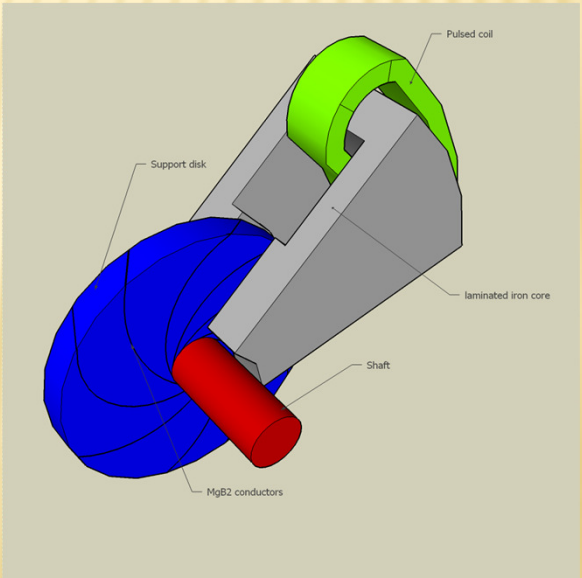
# EXAMPLES OF EMBODIMENT – MAGNETIC SWITCHING




- Switching accomplished by pulsed field or AC losses
- Switching frequency decoupled from machine RPM

Possible Switch Embodiments :






- Further measurements and simulations are underway

# AKNOWLEDGEMENTS

Special thanks to Columbus Superconductor for supplying $MgB_2$ and allowing to use their facility for measuring $MgB_2$ samples.

Presented:

Cryogenic Engineering Conference & International Cryogenic Materials Conference

2009

# END