UNIVERSITY OF CAMBRIDGE

B|S|G

Portable, desktop high-field magnet systems using bulk high-temperature superconductors

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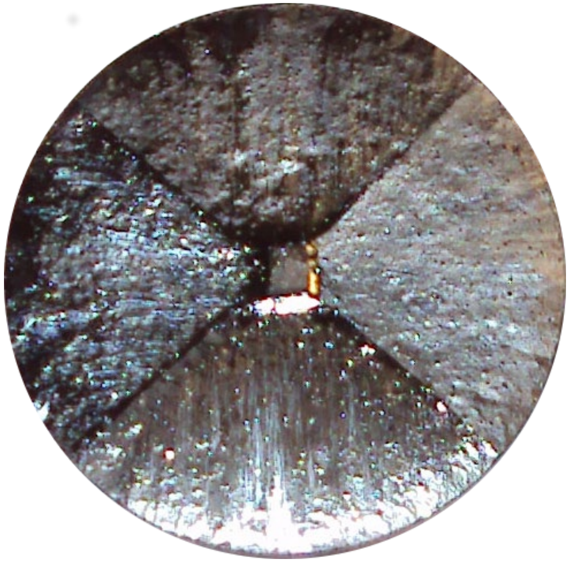
Bulk Superconductivity Group, Department of Engineering

Bulk Superconductors

- Bulk superconducting materials can 'trap' large magnetic fields
- Achieved by pinning penetrated magnetic field (quantised flux lines) → macroscopic electrical currents
- Magnetisation increases with sample volume



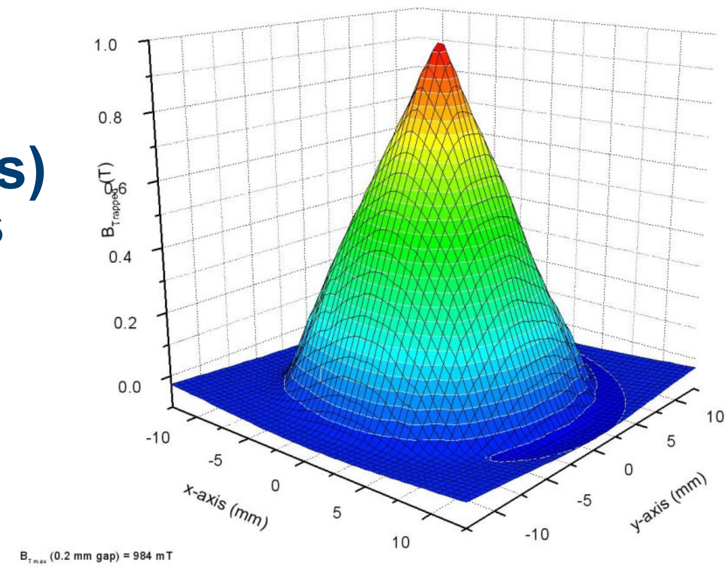
A large, single grain bulk superconductor

Bulk Superconductors

- **Bulk superconducting materials can ‘trap’ large magnetic fields**
- **Achieved by pinning penetrated magnetic field (quantised flux lines) → macroscopic electrical currents**
- **Magnetisation <u>increases</u> with sample volume**
- **Trapped field given by**

$$B_{trap} = k\,\mu_0\,J_c\,R$$

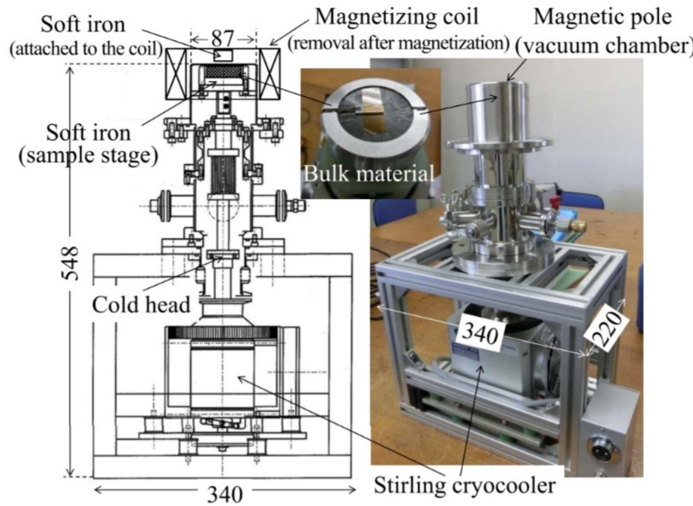
where $$k = \frac{t_B}{2R} \cdot \ln\left(\frac{R + \sqrt{R^2 + {t_B}^2}}{t_B}\right)$$



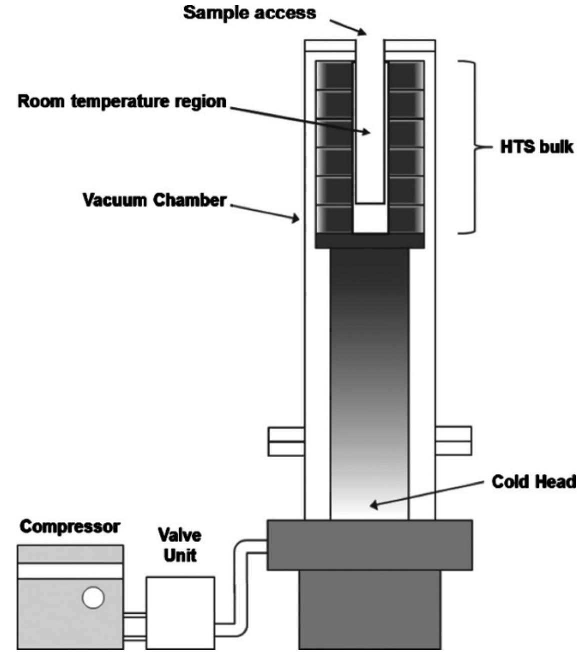
Typical trapped magnetic field profile of a bulk superconductor

Portable High-Field Magnet Systems

Cambridge's portable bulk magnet system (1^{st} generation)



Portable bulk magnet system, Yokoyama *et al*. (Ashikaga Inst. of Tech., Japan)

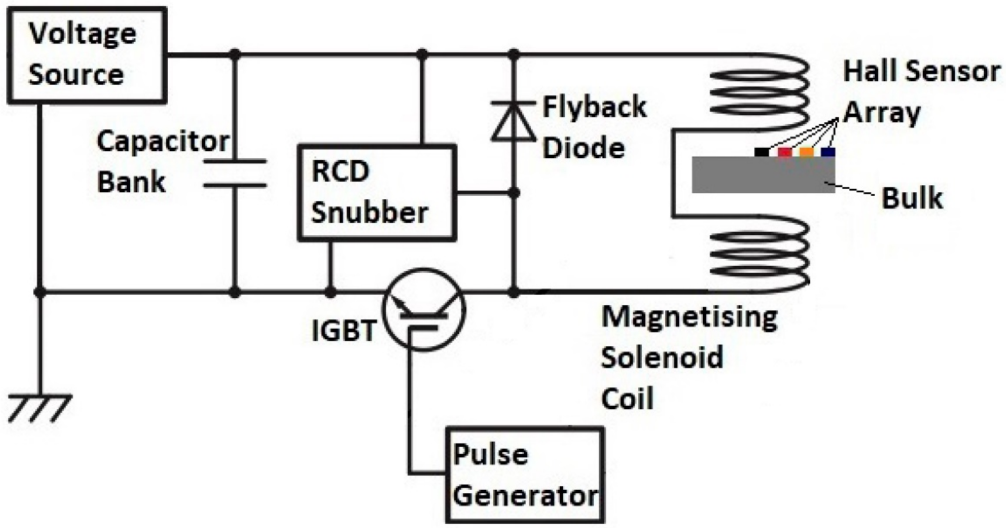


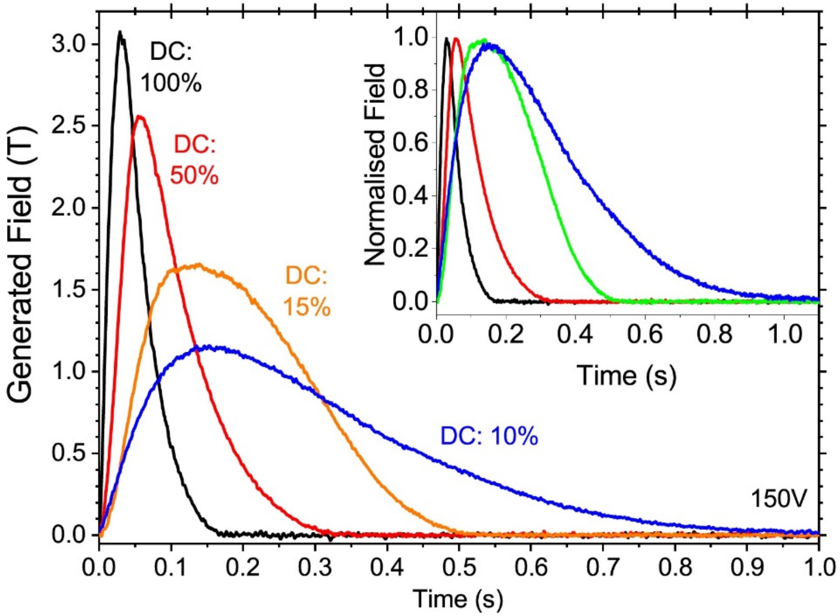
Bulk NMR/MRI magnet system (RIKEN, Japan)

Magnetic separation
Medical: NMR/MRI, magnetic drug delivery
Lorentz force velocimetry
Electromagnetic acoustic transducer (EMAT)

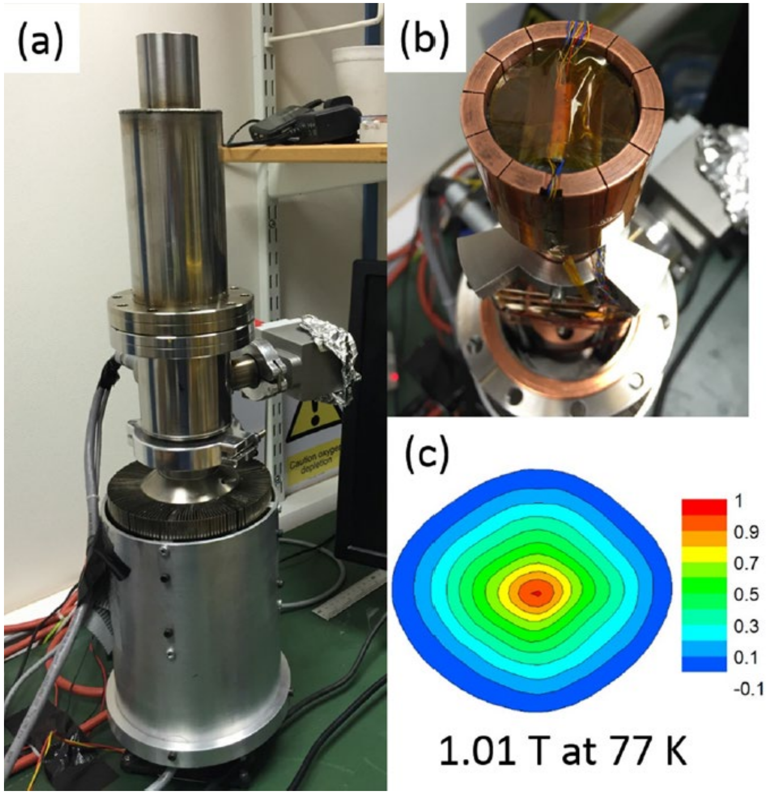
Pulsed Field Magnetisation (PFM)

- **PFM technique: fast, compact, mobile, relatively inexpensive**
  - Stored energy in capacitor bank discharged through copper magnetising coil + pulse waveform control with IGBT switching

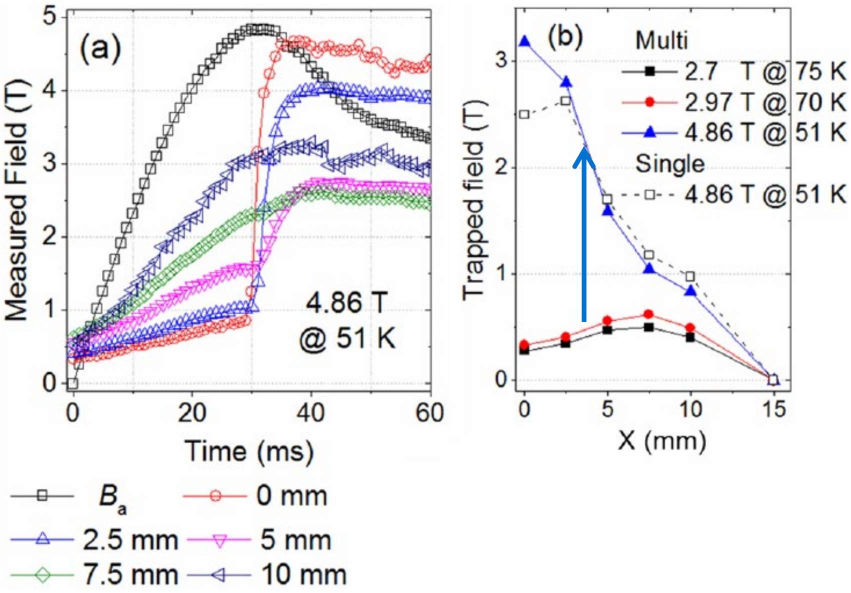




1st Generation Portable Bulk Magnet System (>3 T)



D. Zhou et al. 2017 Appl. Phys. Lett. **110** 062601

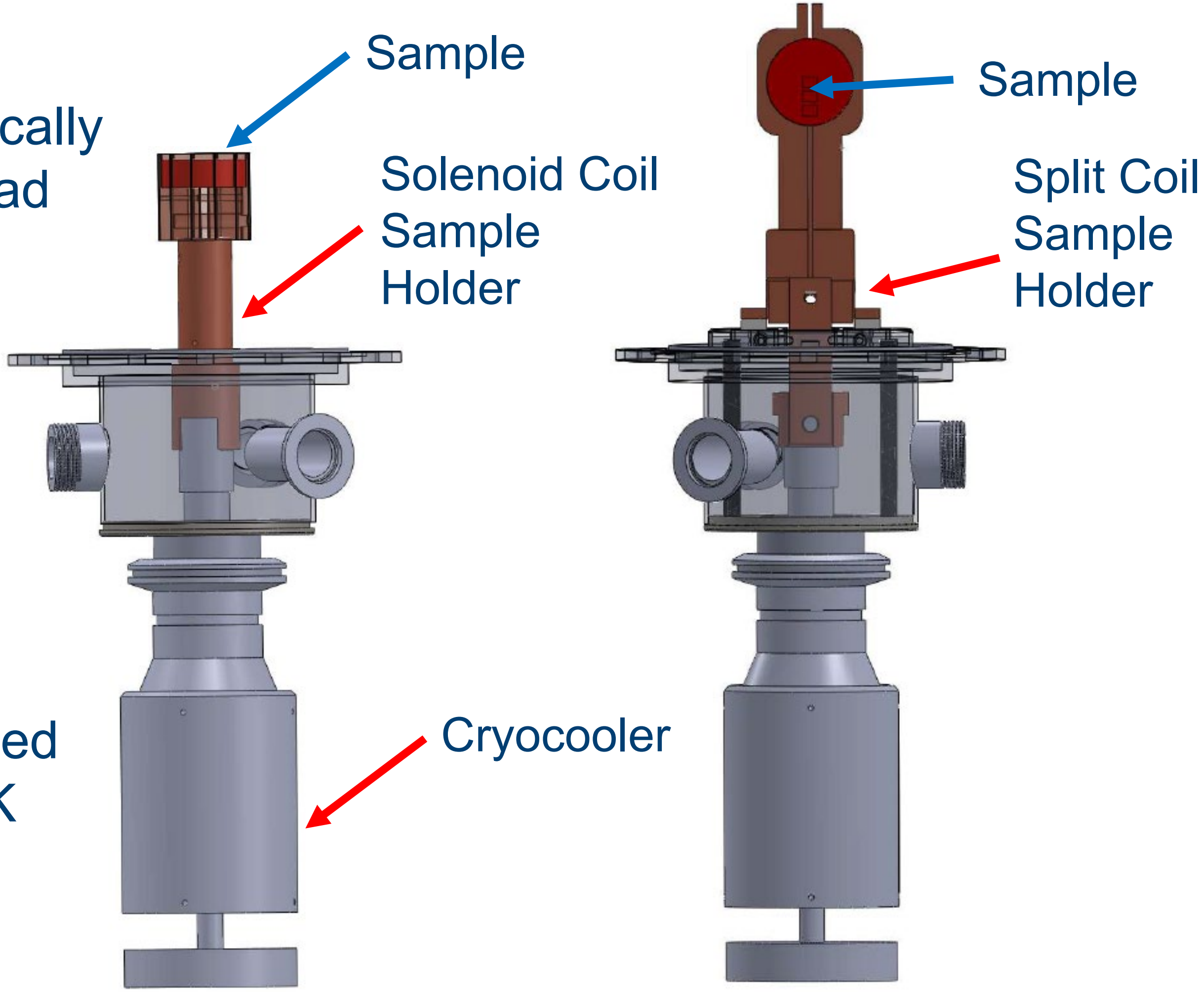


1st generation portable bulk magnet system

- **Flux jumps exploited to trap > 3 T @ 50 K (30 mm diameter Gd-Ba-Cu-O)**
- **Multi-pulse, stepwise-cooling (MPSC) PFM technique**

2nd Generation Portable Bulk Magnet System

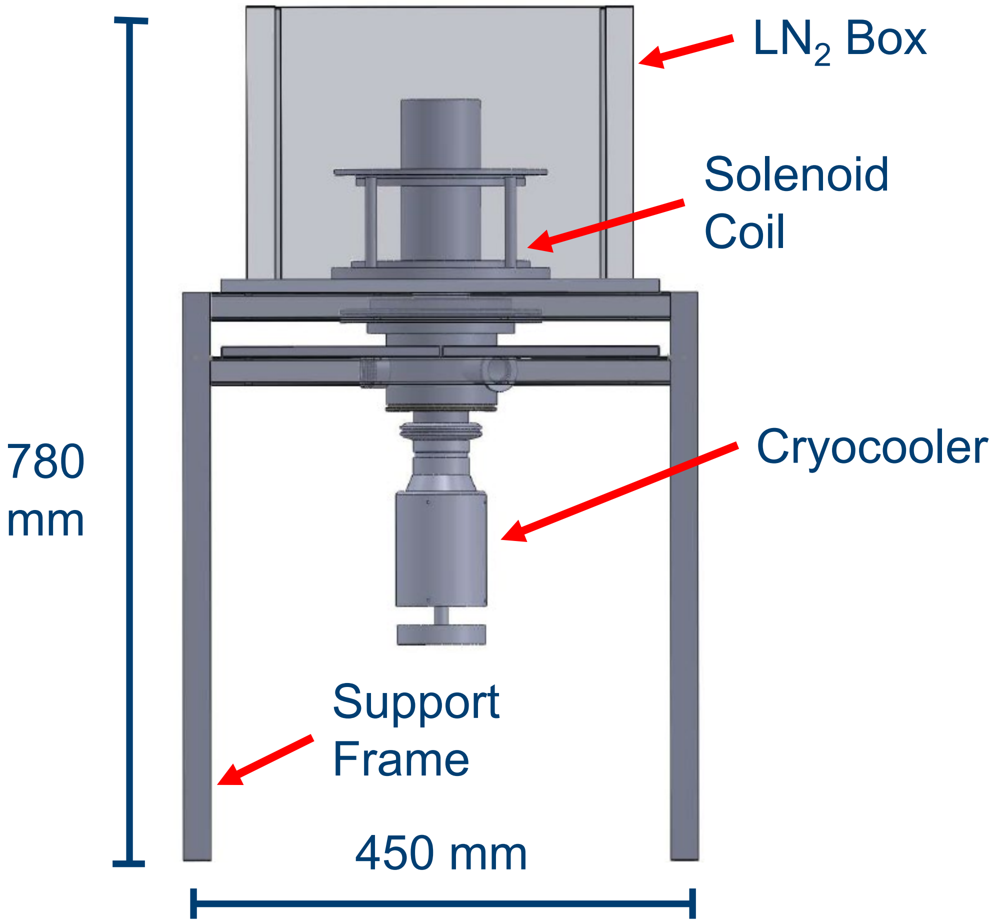
- Sample holder mechanically decoupled from cold head



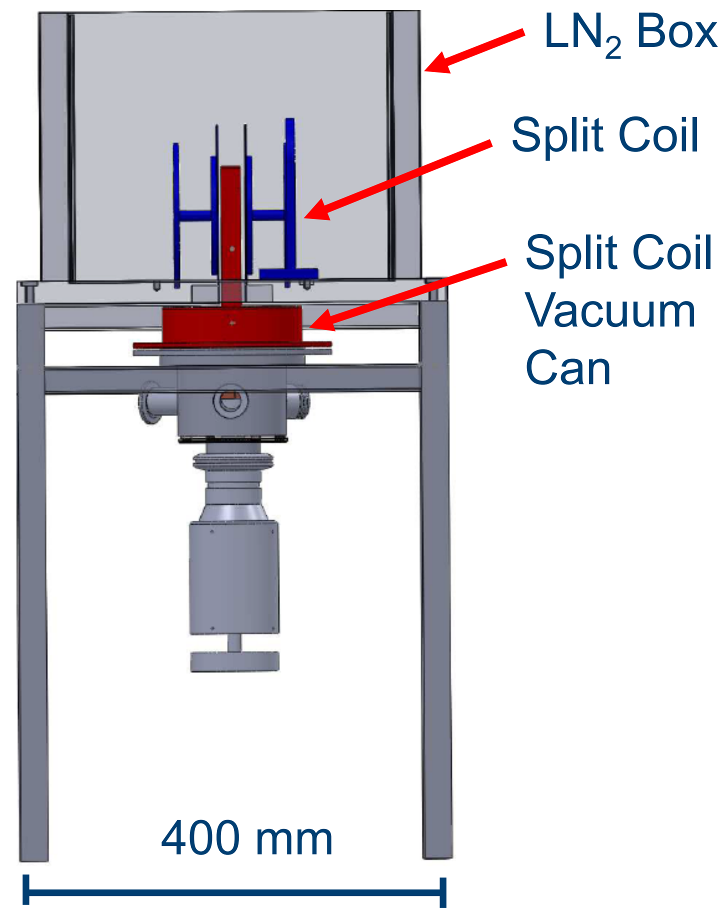
- Sunpower CryoTel GT
- No compressor, air-cooled
- Base temperature ~40 K
- ~1 hour to < 50 K
- > 3 W cooling @ 45 K

Solenoid or Split Coil Magnetisation

Solenoid Coil System



Split Coil System



Sample Information

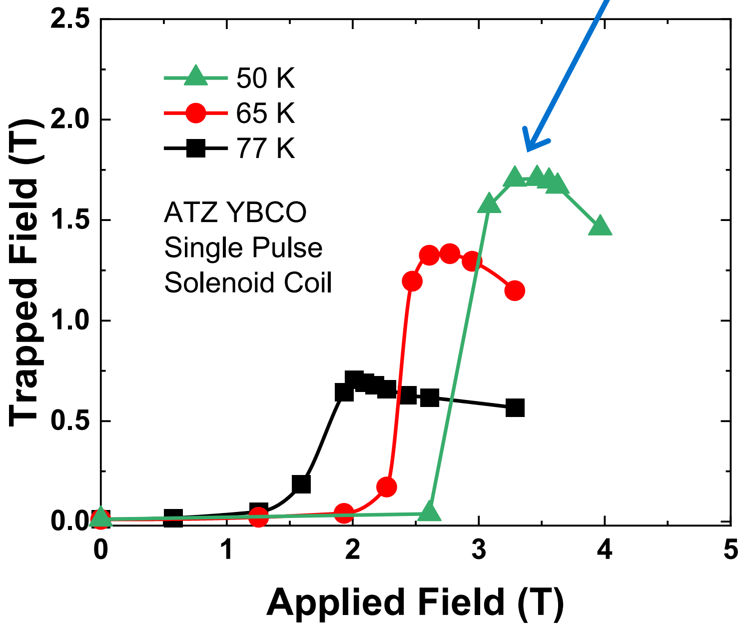
Composition	Type	Manufacturer	Diameter, *D* [mm]	Thickness, *H* [mm]	FCM Data, 77 K [T]
YBCO	Disc	ATZ*	41.1	14	1.07
	Disc	CAN	41.3	13	1.09
GdBCO	Disc	BSG	38.6	11.3	1.02
	Disc	BSG	36.3	12.1	1.17
EuBCO	Disc	CAN	41.1	13	1.26
GdBCO	Ring	BSG	31.6 [ID = 13]	9.4	0.64

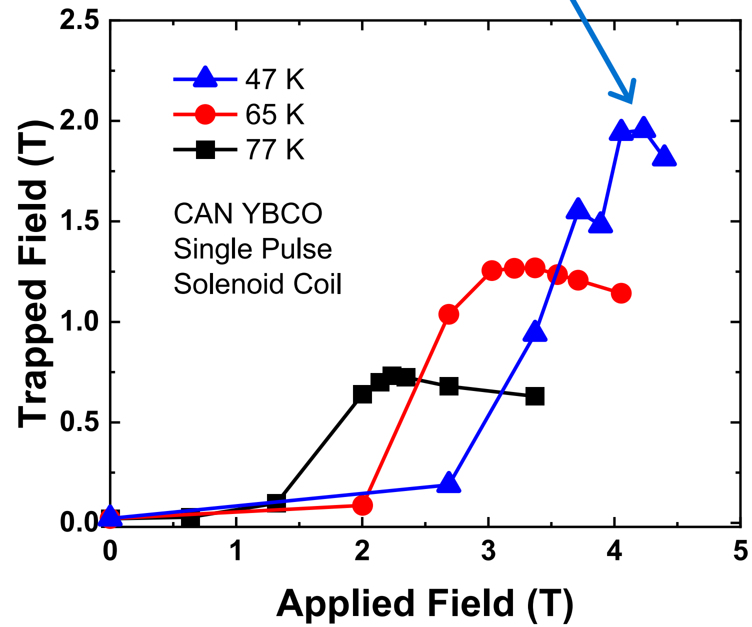
*courtesy of Dr Frank Werfel, ATZ

Solenoid – YBCO Discs – Single Pulse

1.7 T
B_{app} = 3.5 T @ 50 K

2.0 T
B_{app} = 4.25 T @ 47 K





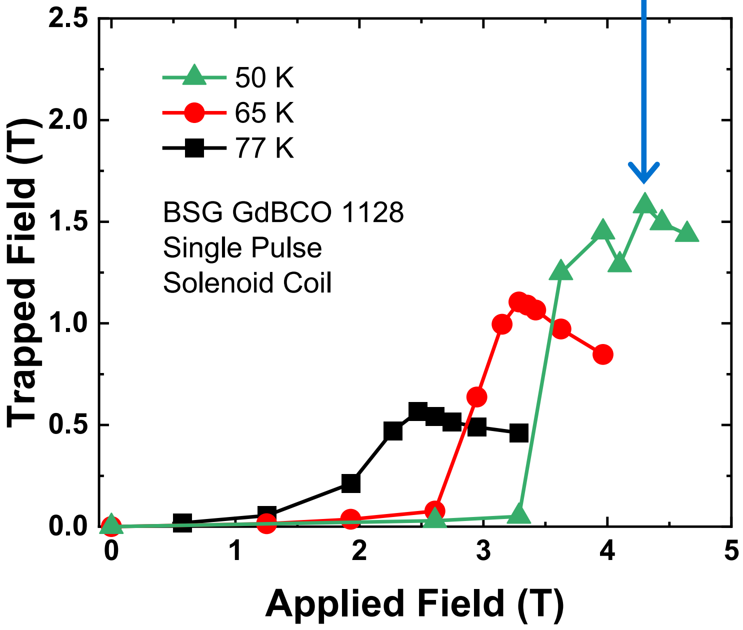
ATZ YBCO
***D* = 41.1 mm, *H* = 14 mm**

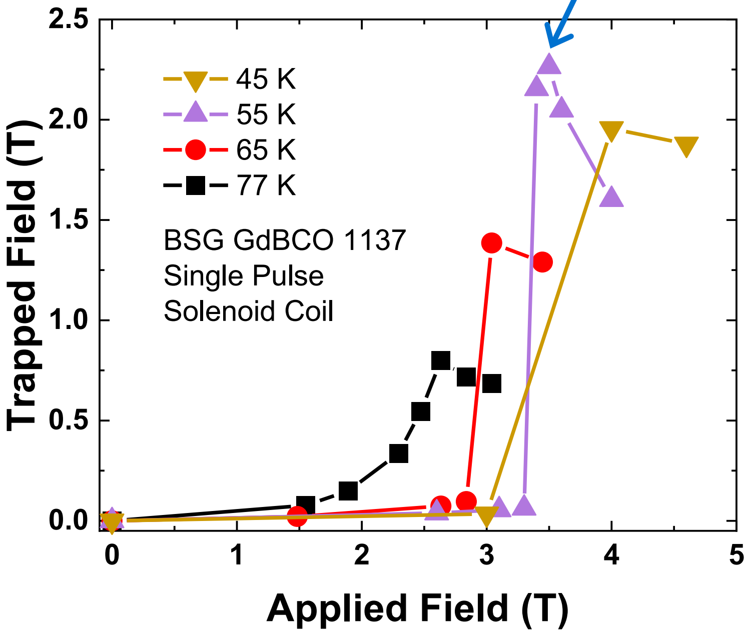
CAN YBCO
***D* = 41.3 mm, *H* = 13 mm**

Solenoid – GdBCO Discs – Single Pulse

1.6 T
B_{app} = 4.4 T @ 50 K

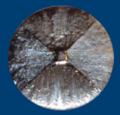
2.25 T
B_{app} = 3.5 T @ 55 K





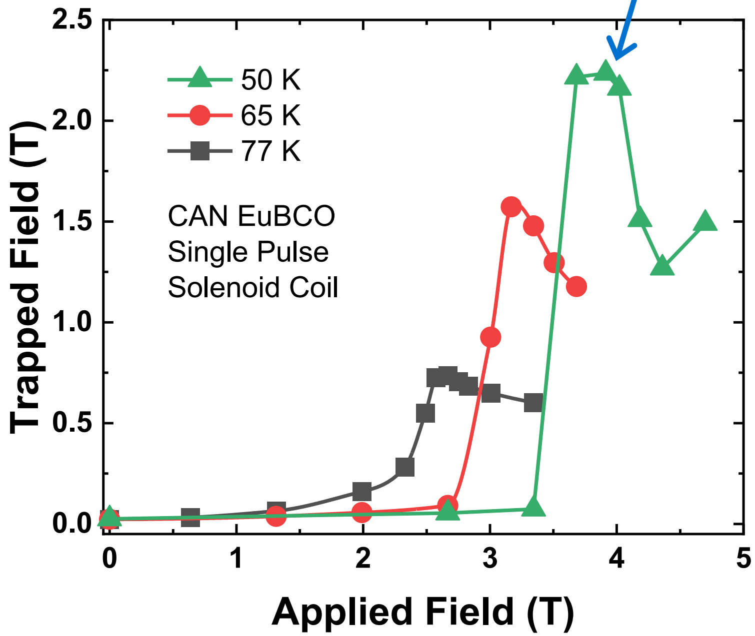
BSG GdBCO #1
***D* = 38.6 mm, *H* = 11.3 mm**

BSG GdBCO #2
***D* = 36.3 mm, *H* = 12.1 mm**



Solenoid – EuBCO Disc – Single Pulse

2.25 T
B_{app} = 3.9 T @ 50 K



CAN EuBCO
***D* = 41.1 mm, *H* = 13 mm**

<u>Summary:</u>

Trapped fields increased as operating temperature decreased (greater instability ~50 K); higher applied fields needed:

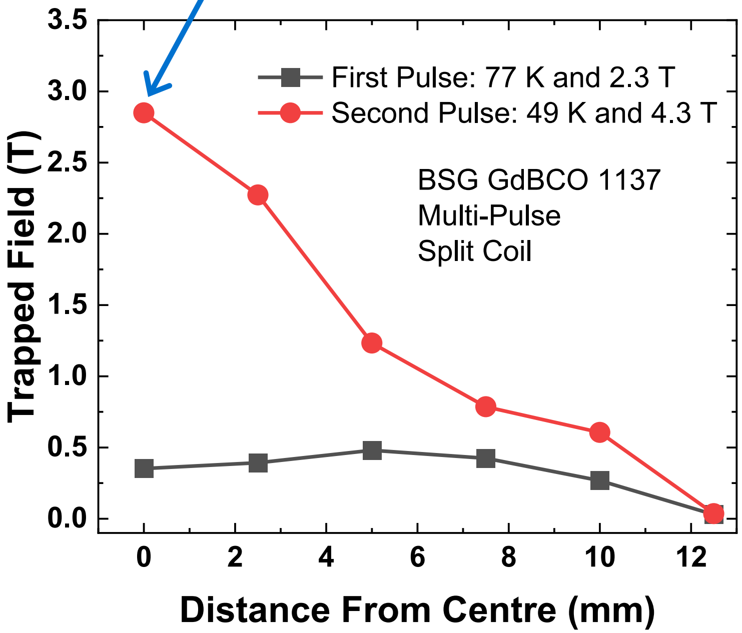
77 K → 2 - 2.5 T to fully magnetise
65 K → 2.75 - 3.25 T to fully magnetise
50 K → ~3.5 T to fully magnetise

Highest trapped fields of
2.25 T (B_{app} = 3.9 T @ 50 K), EuBCO
2.25 T (B_{app} = 3.5 T @ 55 K), GdBCO #2

Solenoid – Discs – Two-Step MPSC PFM

2.9 T

B_{app} = 4.3 T @ 49 K

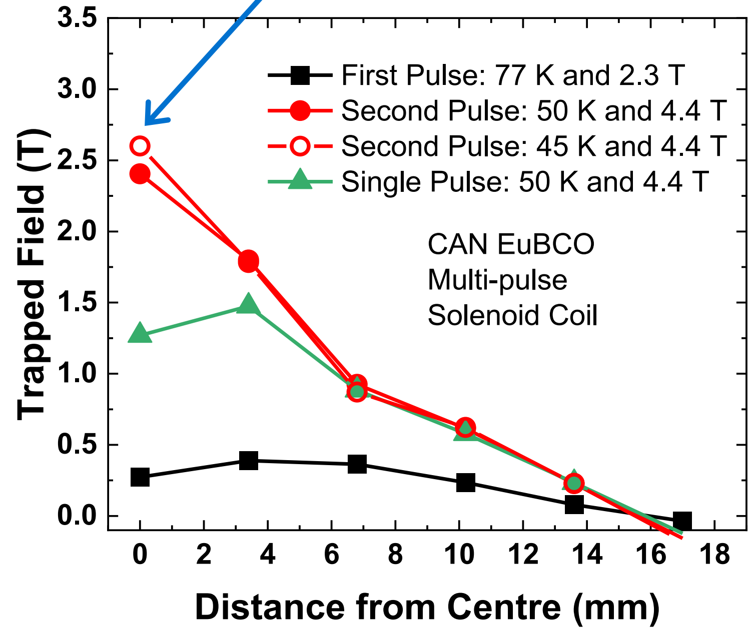


BSG GdBCO #2

***D* = 36.3 mm, *H* = 12.1 mm**

2.6 T

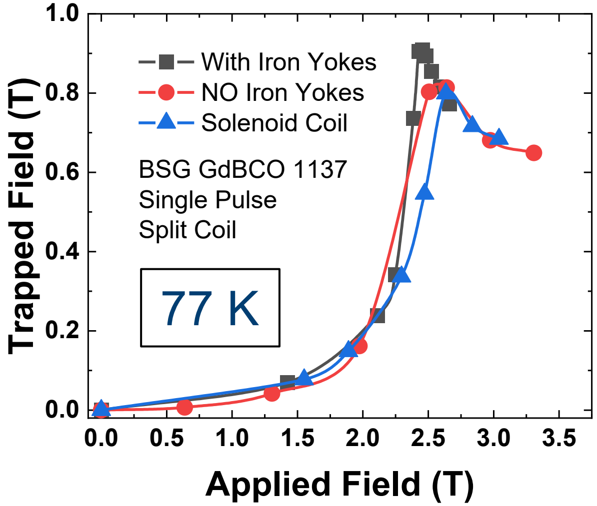
B_{app} = 4.4 T @ 45 K

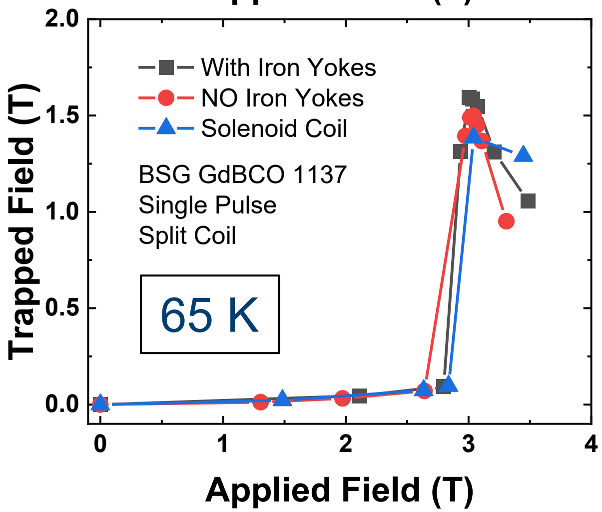


CAN EuBCO

***D* = 41.1 mm, *H* = 13 mm**

Split – Discs – Single Pulse



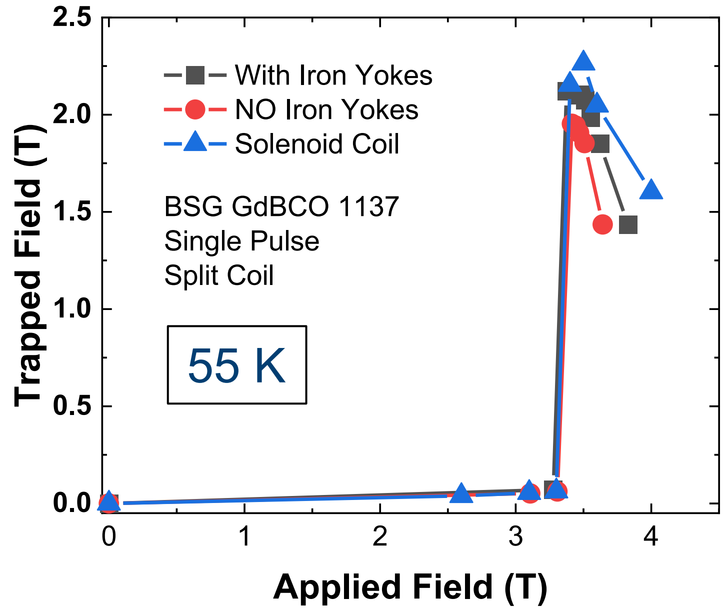


Summary:

Similar behaviour to solenoid coil

Split coil trapped field slightly higher at higher temperatures (77, 65 K) slightly worse at 55 K

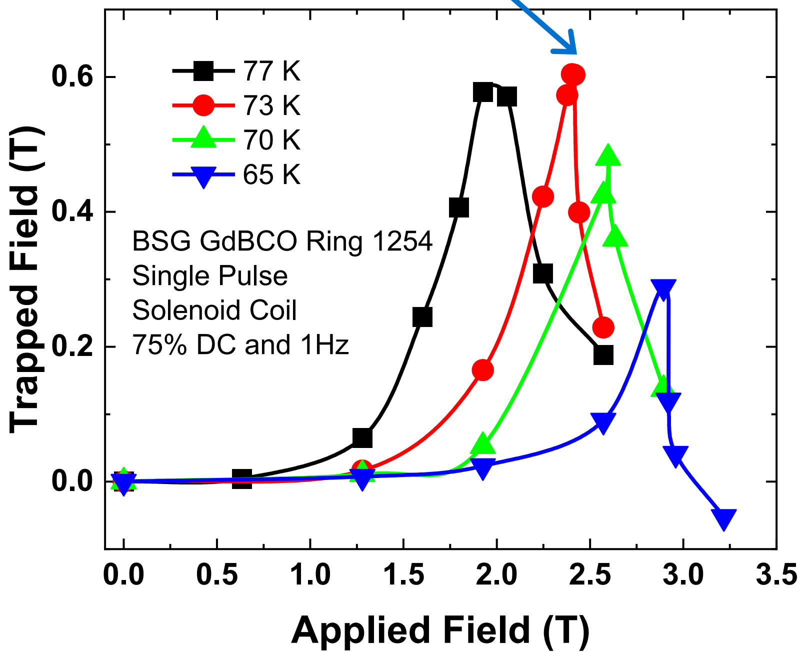
Insertion of iron yoke slightly better vs no yoke

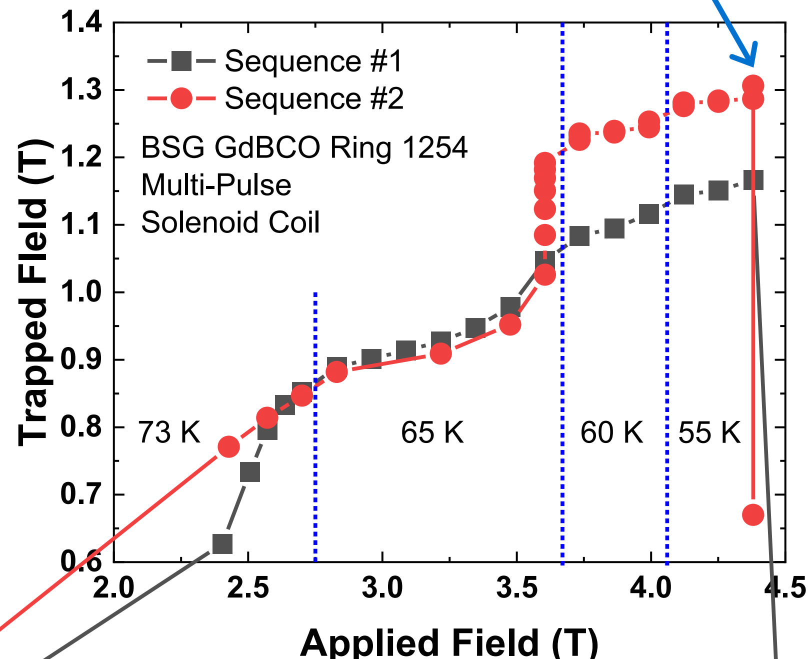


Solenoid – GdbCO Ring – Single + Multi-Pulse

0.6 T
B_{app} = 2.4 T @ 73 K

1.3 T
B_{app} = 4.4 T @ 55 K





BSG GdBCO Ring
***OD* = 31.6 mm, *ID* = 13 mm, *H* = 9.4 mm**

Summary

- **Bulk superconductors can be used in portable high-field magnet systems capable of generating magnetic fields of several tesla**
- **Extensive tests have been carried on our next generation magnet system, focussed on:**
  - Flexibility (sample interchange; split or solenoid coil magnetisation)
  - Portability (compact design; no compressor or water-cooling)
  - Advanced PFM techniques (split coil with iron yoke; multi-pulse, multi-temperature; waveform control; flux jump-assistance)
- **2.9 T trapped in a 36.3 mm diameter GdBCO disc at 49 K using a two-step, multi-pulse stepwise-cooling (MPSC) PFM technique**
- **1.3 T trapped in a 31.6 mm diameter [ID = 13 mm] GdBCO ring at 55 K using an MPSC PFM technique**