CryoEDM - Cryogenics

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on behalf of the CryoEDM collaboration

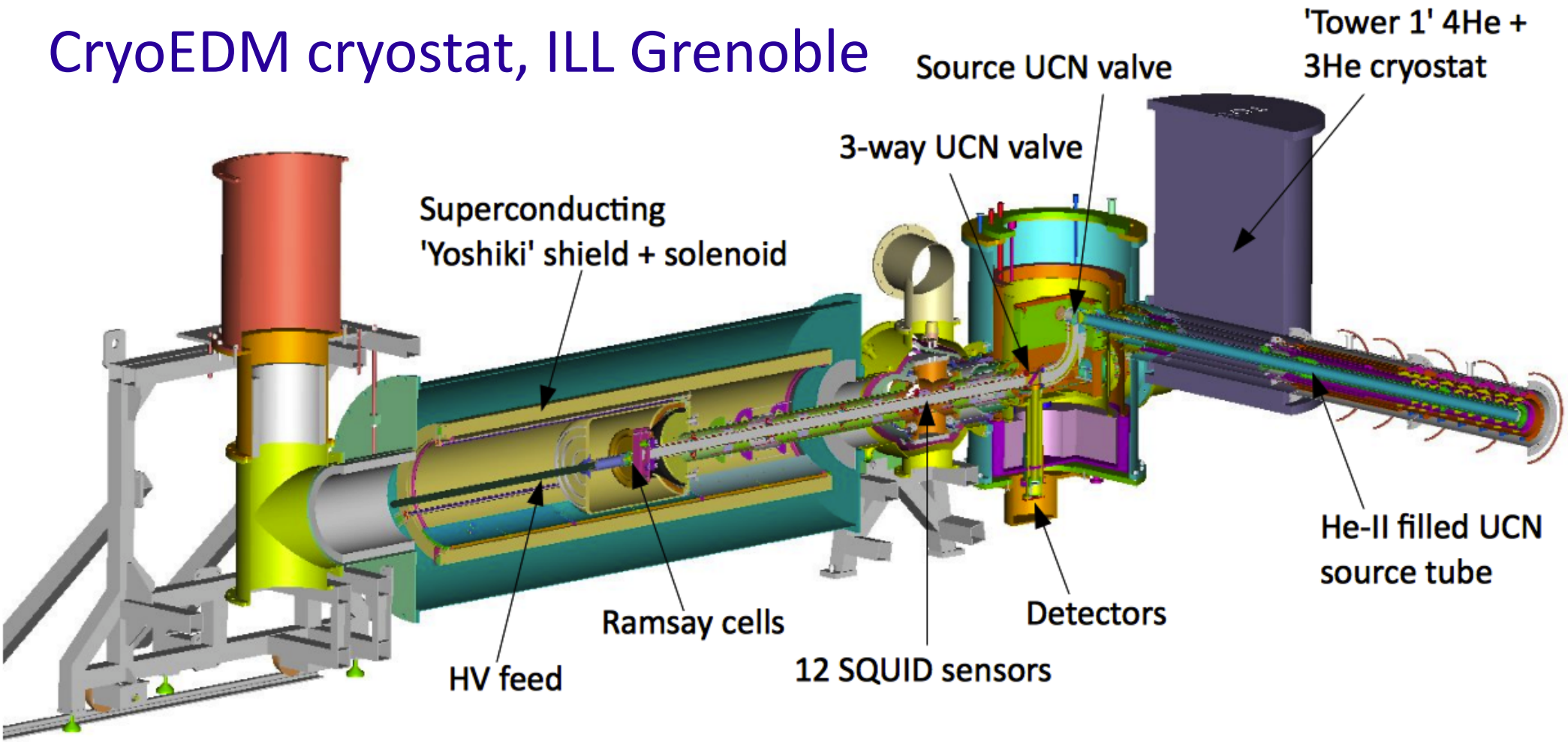
University of Sussex

CryoEDM - Cryogenics

- Overview of EDM cryostat
- Cryostat performance
  - Cooling power
  - UCN storage
- Superconducting magnetic shielding
  - B-field homogeneity
  - B-field stability
- SQUID magnetometry
  - Sensitivity
  - Stability

Cryogenics overview

CryoEDM cryostat, ILL Grenoble

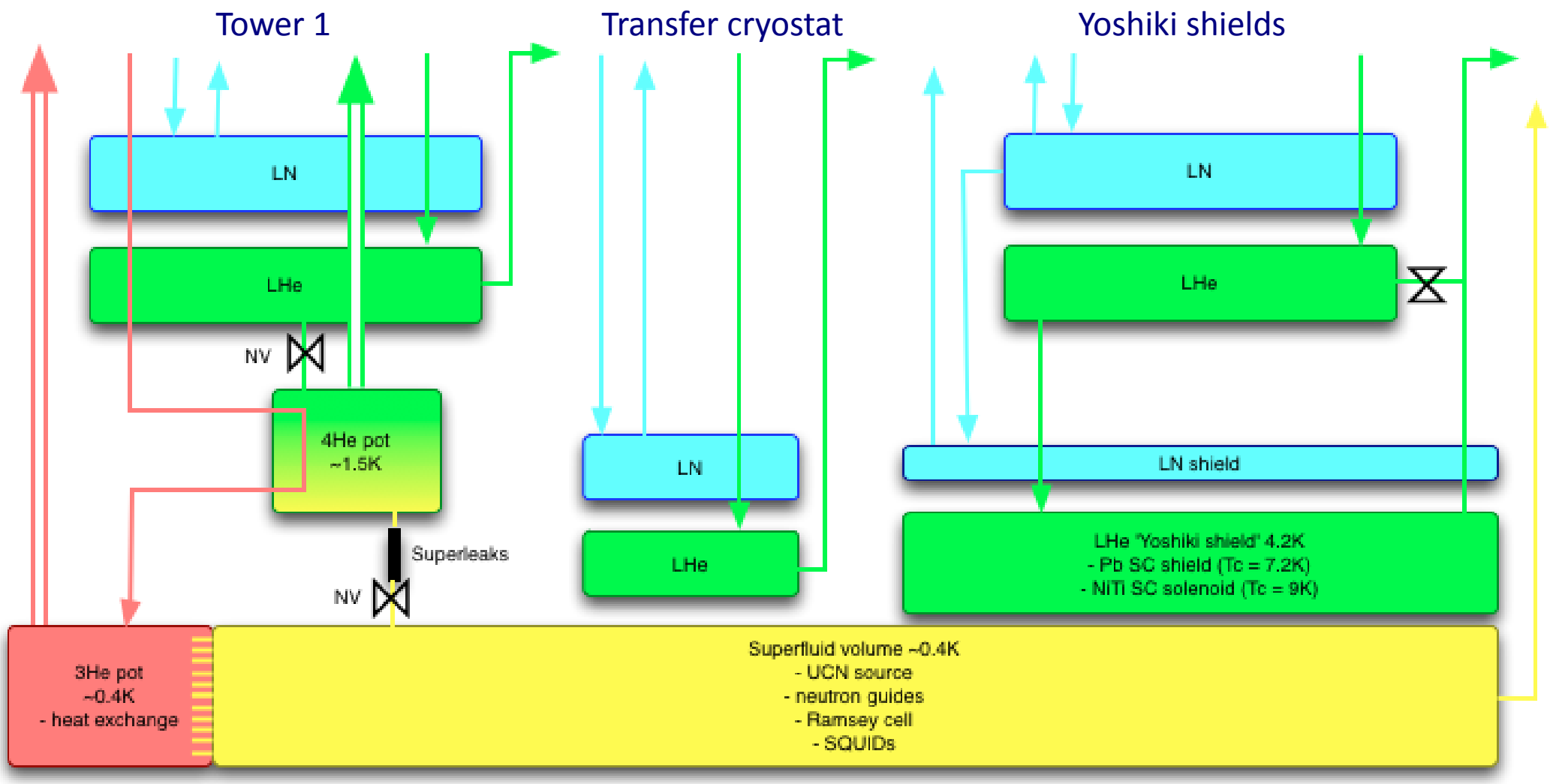


Cryogenics overview

- 'Tower 1'
  - UCN source
  - ^{4}He pot for SCV filling
  - ^{3}He pot for SCV cooling
- 'Yoshiki shields'
  - Magnetic shielding: mu-metal & SC Pb
  - Holding field: SC NbTi solenoid
- 'Transfer cryostat'
  - UCN guide turn and drop
  - Valve actuators
  - UCN detectors
- SQUIDs
- HV feed

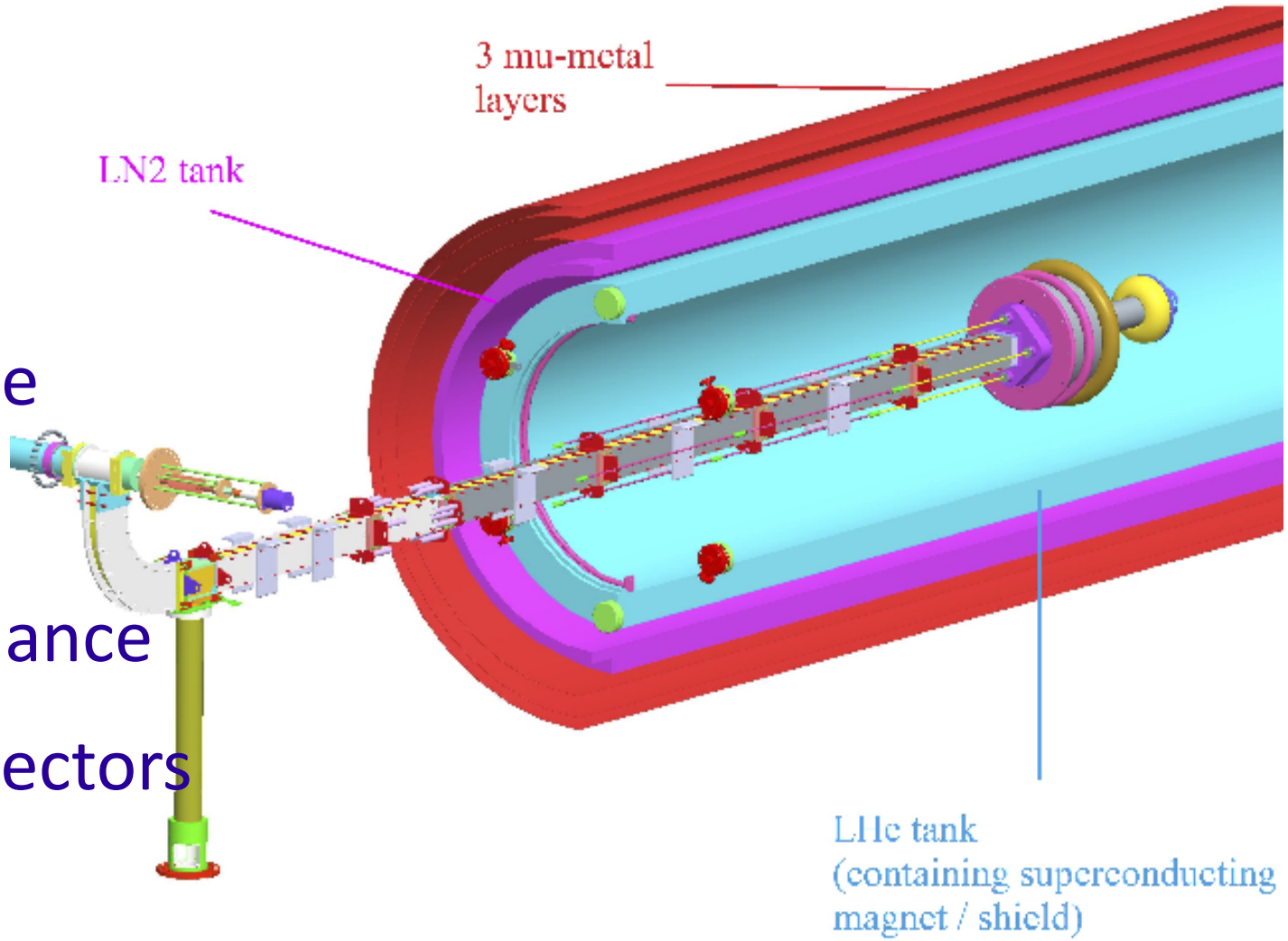
Cryogenics overview

Cryogenic system schematic



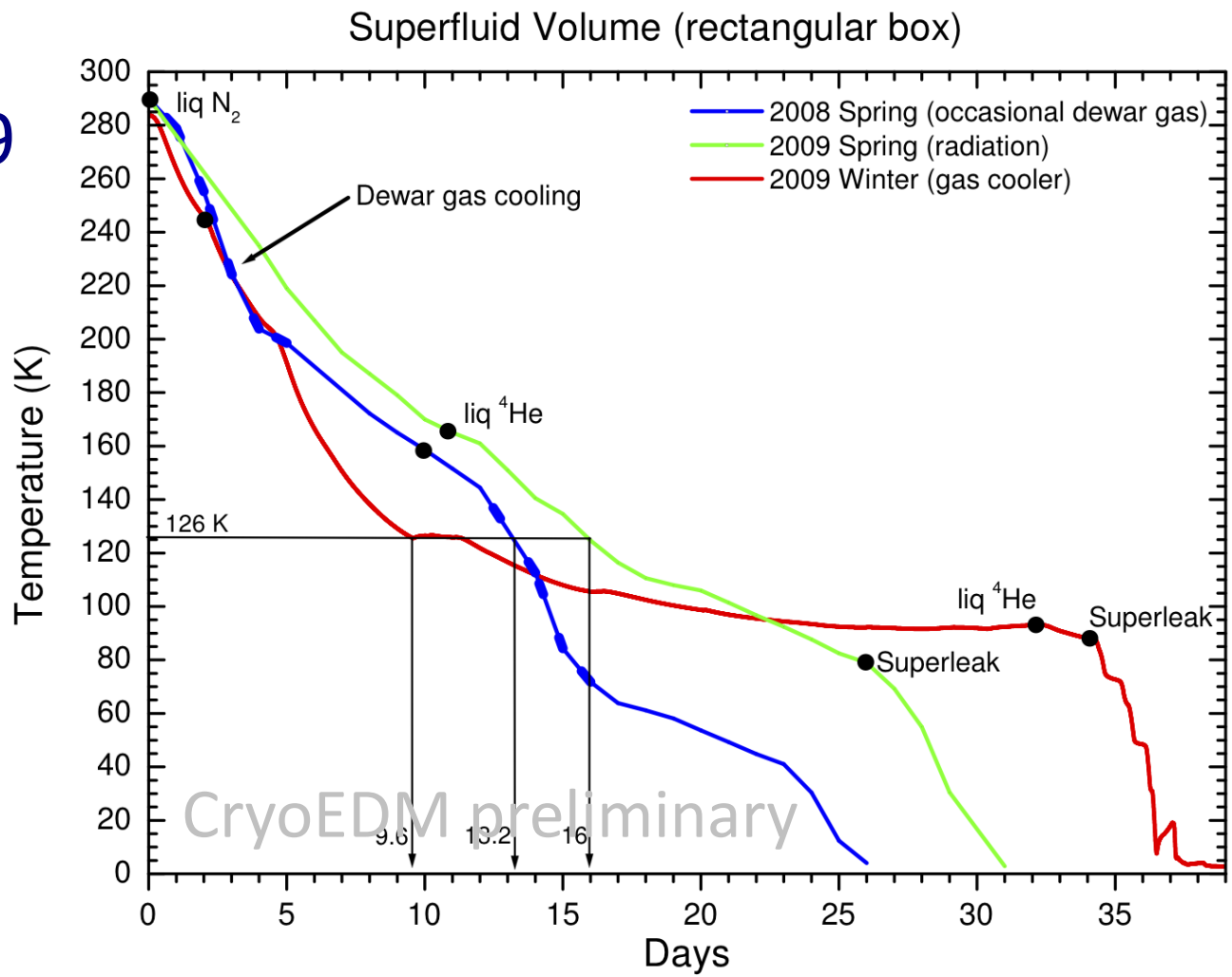
Cryogenics overview

1. UCN fill in source
2. Neutrons to RC
3. Storage & resonance
4. Neutrons to detectors



Cryostat performance

- SCV cooling curves 2008-2009
  - Dewar gas circulation
    - ^{3}He in SCV
  - 'Radiation'
    - Exchange gas
  - Closed cycle He gas flow

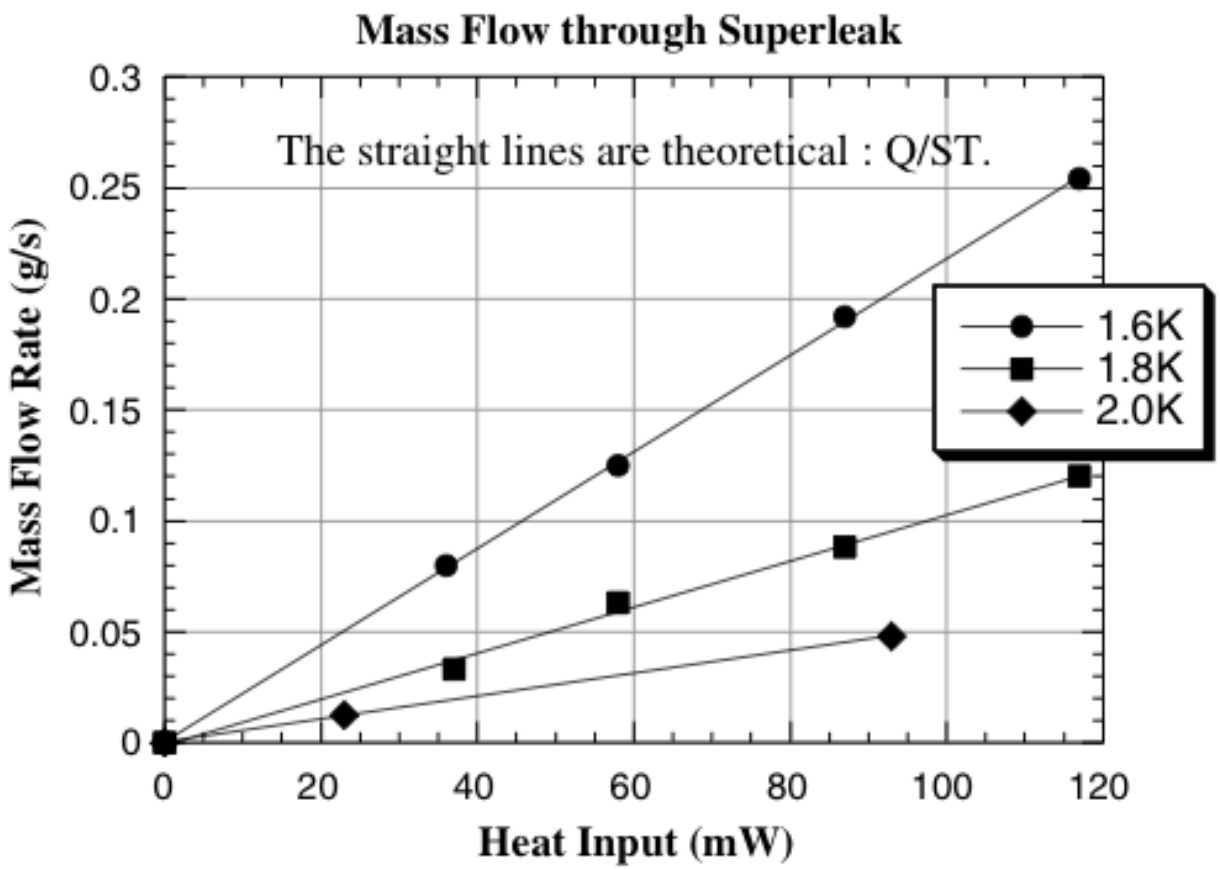


Cryostat performance

- SCV cooldown procedure 2010-2012
  - Shields LN cooling (SCV → ~160 K)
  - Shields LHe cooling (SCV → ~100 K)
  - Start ^{4}He evaporation
  - Cool SCV via superleak flow
  - Start ^{3}He evaporation (SCV → 0.4 K)

Cryostat performance

- Filling SCV
  - Pre-cool from ~100 K
  - 250 l volume
- Measured SF flow (H. Yoshiki et al. Cryogenics 45 (2005))
  - 12 days cool & fill
  - ^{3}He concentration $< 3 \times 10^{-9}$



Cryostat performance

- 2010-2012 cycle time
  - LN transfer: 10 days to 77 K
  - 2 days to purge LN
  - LHe transfer: 12 days to liquid fill
  - ^{4}He evaporation & superleak flow: 7 days to cool SCV to 2K
  - ^{3}He evaporation: 5 days to cool below 0.7K

Cryostat performance

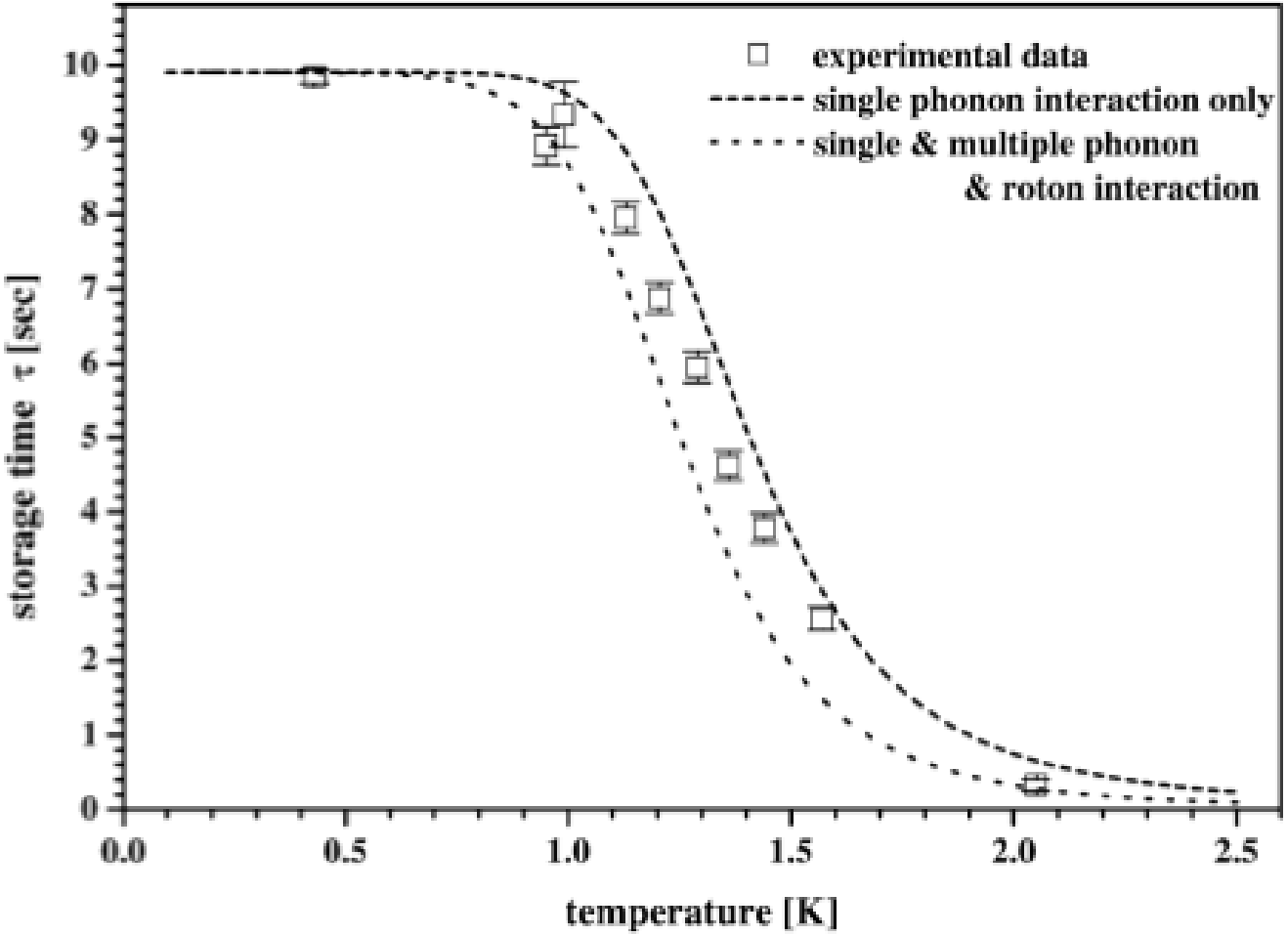
- 2010-2012 cycle time
  - LN transfer: 10 days to 77 K
  - 2 days to purge LN
  - LHe transfer: 12 days to liquid fill
  - ^{4}He evaporation & superleak flow: 7 days to cool SCV to 2K
  - ^{3}He evaporation: 5 days to cool below 0.7K
  - Total cooling: 36 days
- SFV kept free of ^{3}He

Cryostat performance

- Temperature dependence of storage time

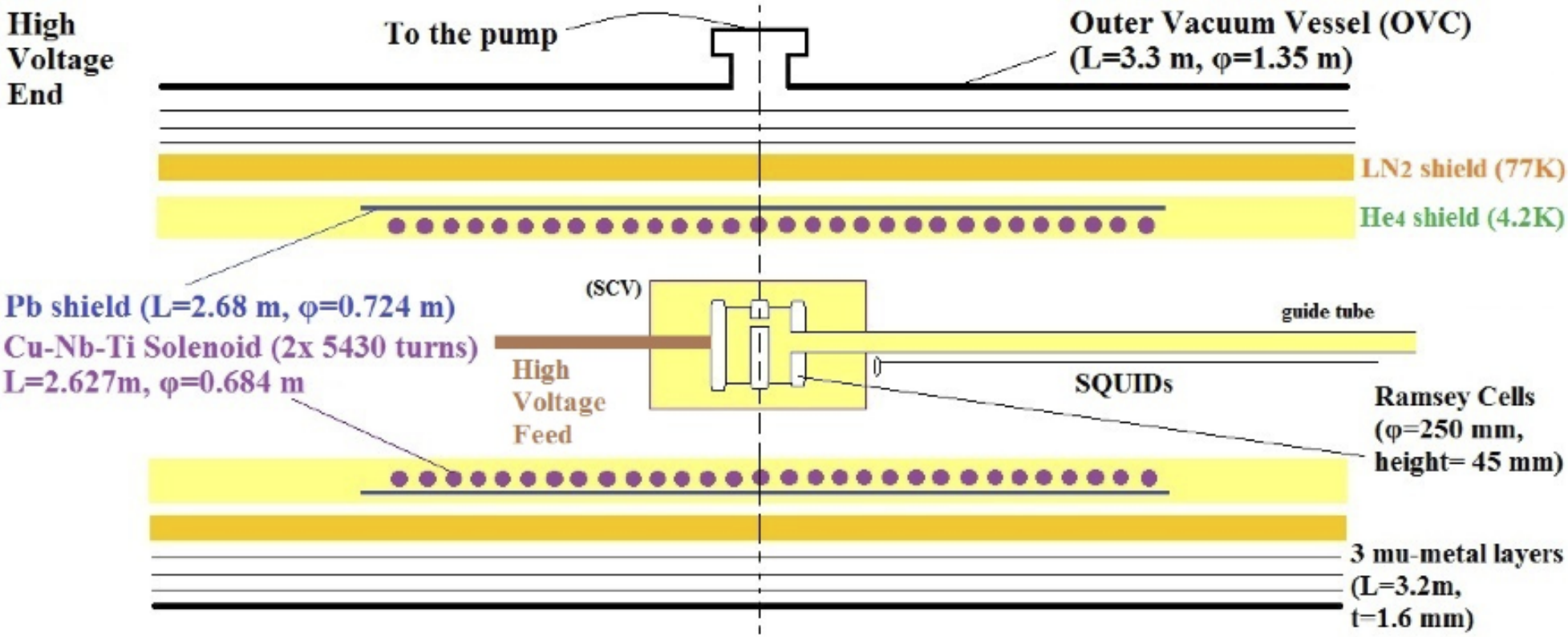
  - Neutron loss due to upscattering (C. A. Baker et al Phys Lett A 308 (2003))
  -Suppressed < 1K

- 0.4 ± 0.1 K below problem region



Cryogenics overview

- Horizontal 'Yoshiki' shields



Cryostat performance

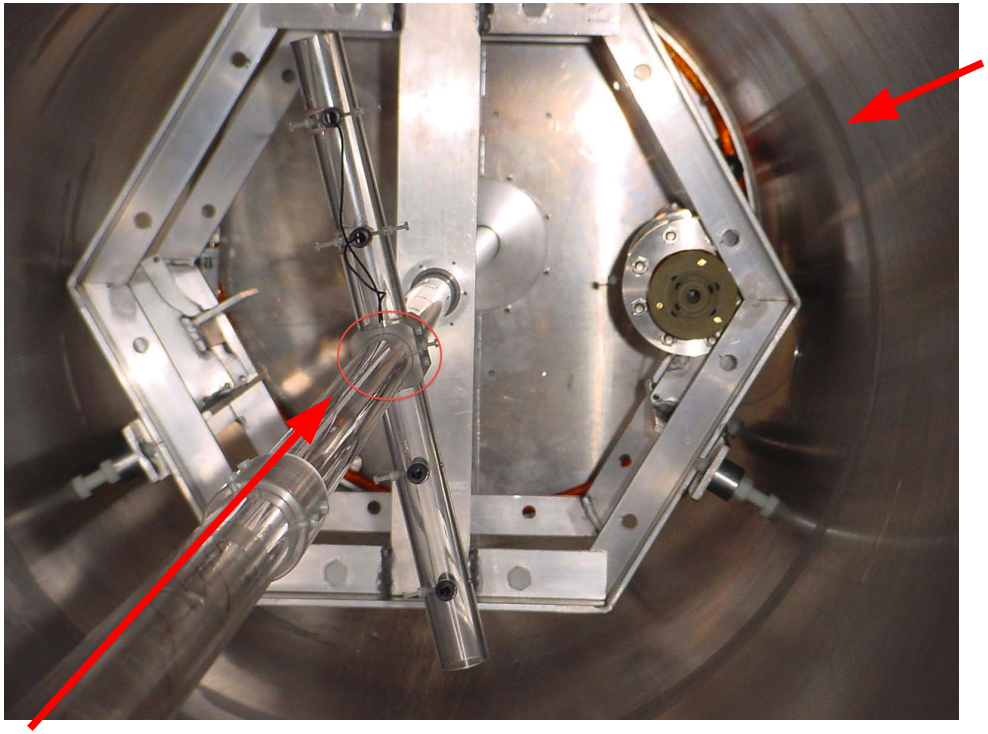
- Cooling of YS
  - LHe fill
  - Solenoid current supplied ~20 K
  - 9.2 K NbTi solenoid persistent
  - 7.2 K Pb shield SC
    - B-field locked in
  - Assess cryogenic performance via magnetic stability

B-field spatial homogeneity

- Performance of YS
- Requirements for nEDM
  - Maintain n polarisation
  - Avoid geometric phase effect
    - < 1 nT / m for $B_0 = 5$ μT

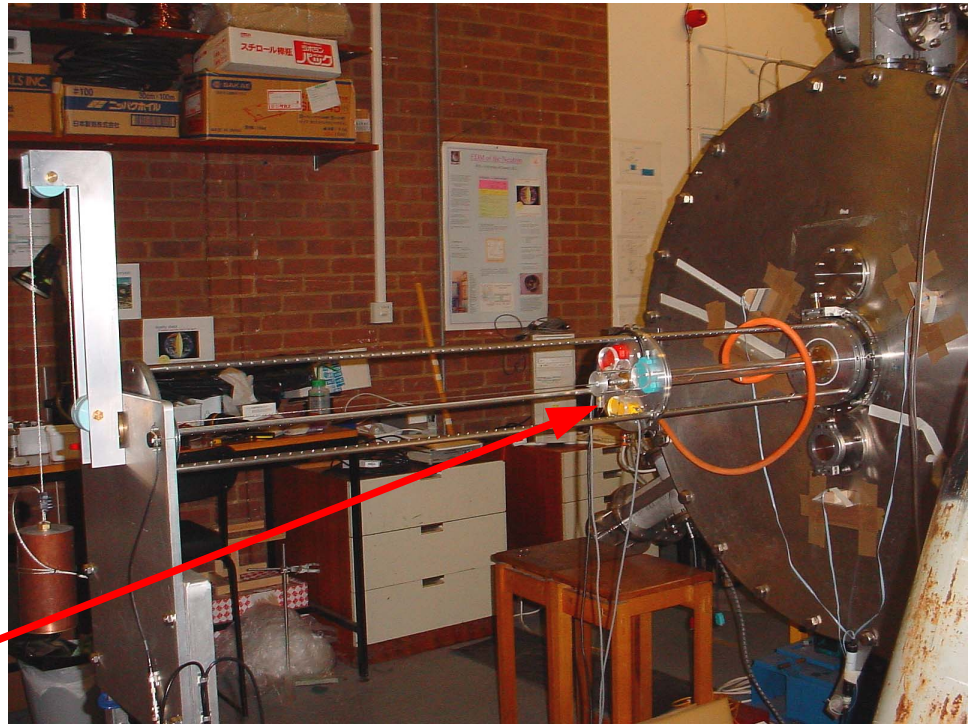
B-field spatial homogeneity

- 2004 magnetometry tests



Inside LHe shield/solenoid tank

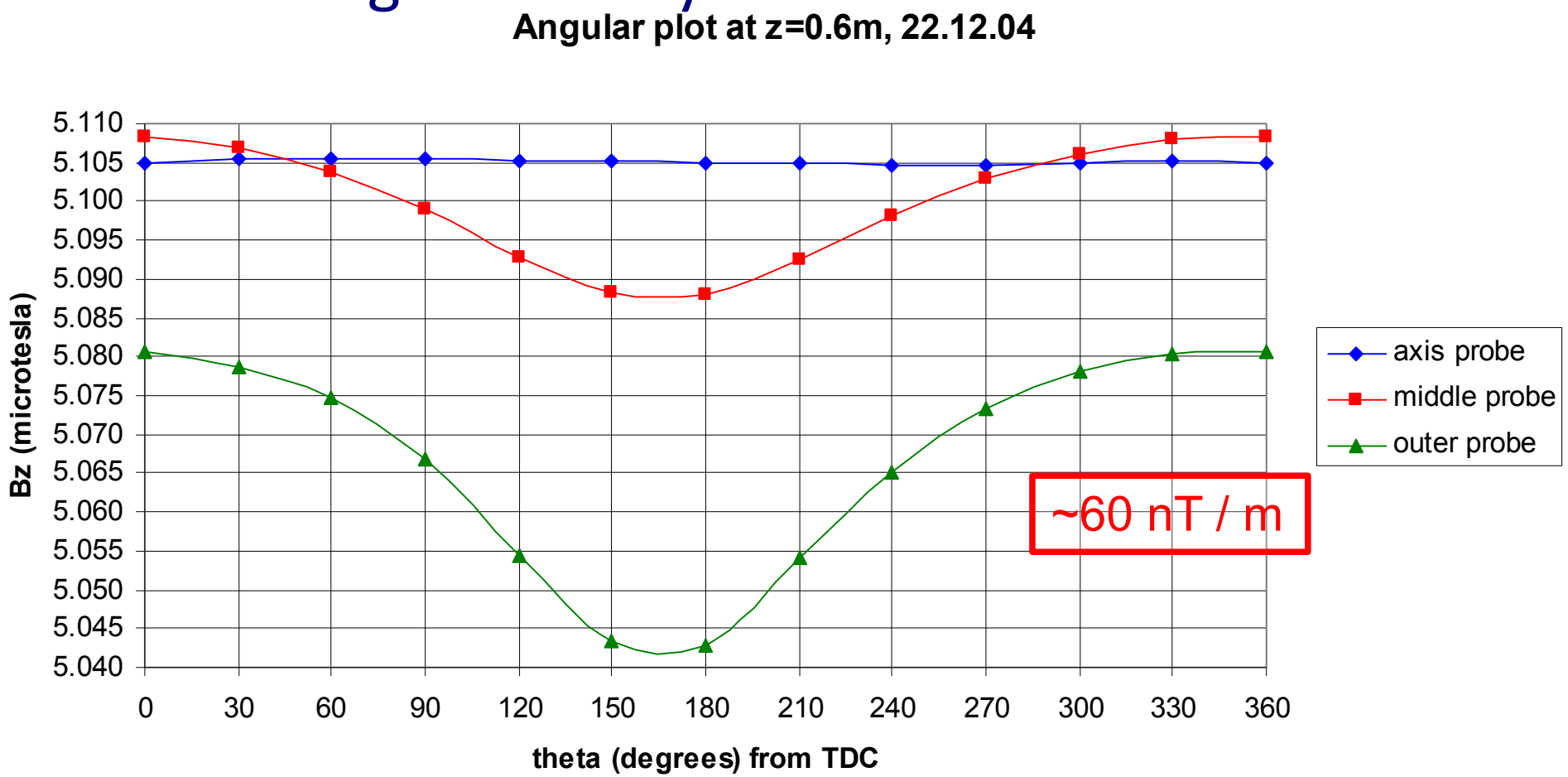
Rotating magnetometer probe



Probe location assembly

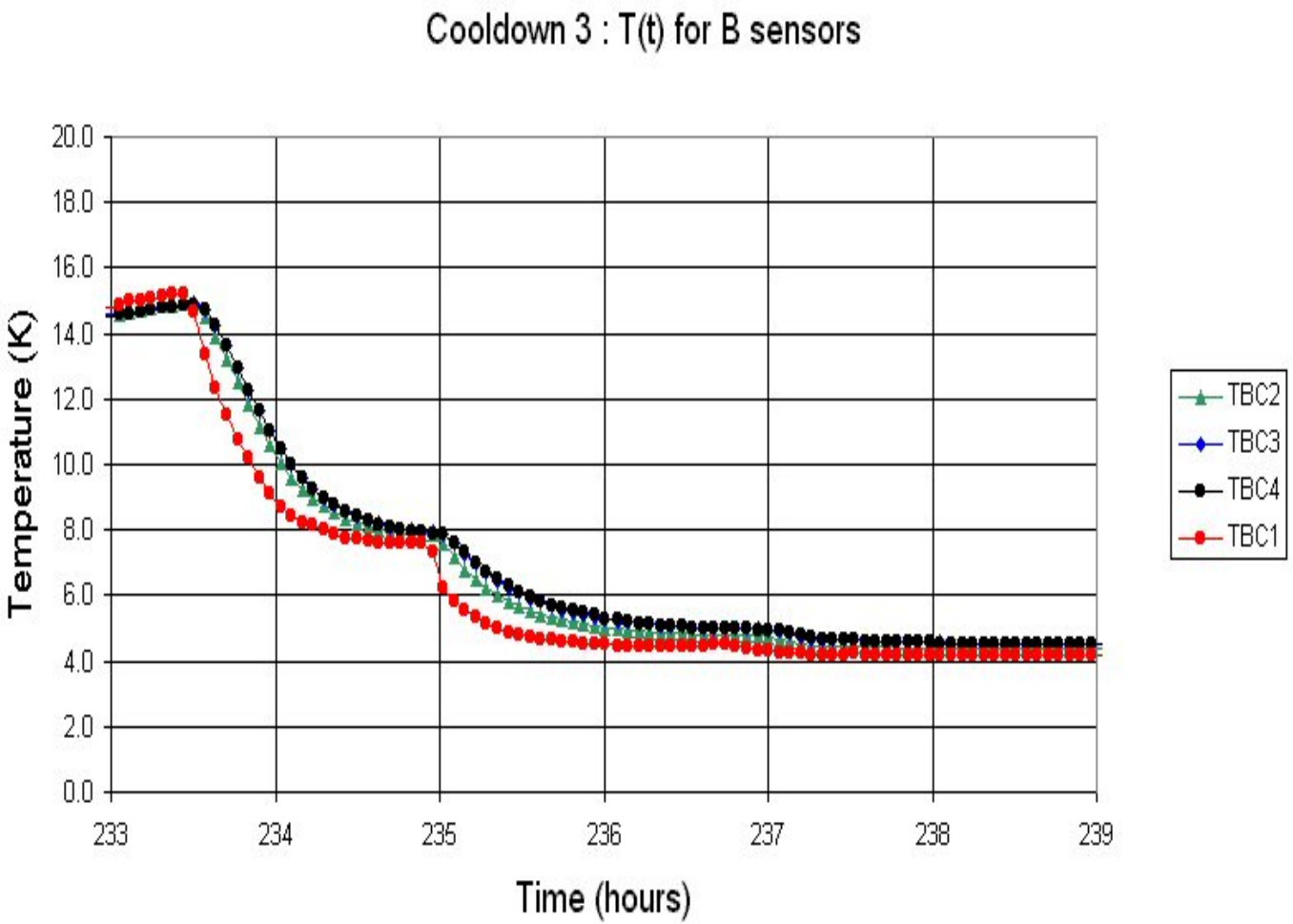
B-field spatial homogeneity

- 2004 magnetometry tests



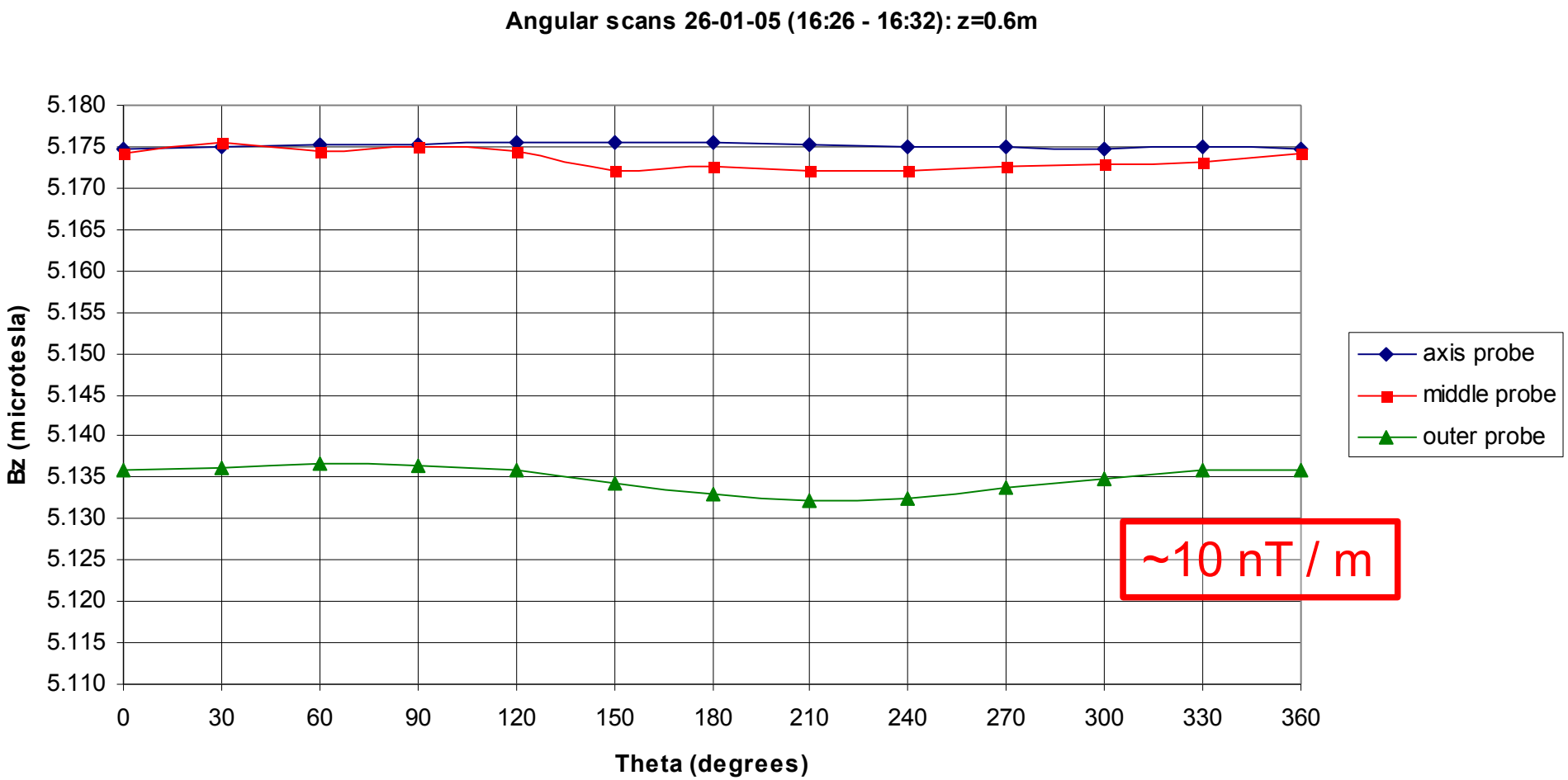
B-field spatial homogeneity

- Anomaly due to rapid cooling of shield & solenoid?
  - NbTi 9.2 K
  - Pb 7.2 K
- Rerun with pause at 8 K



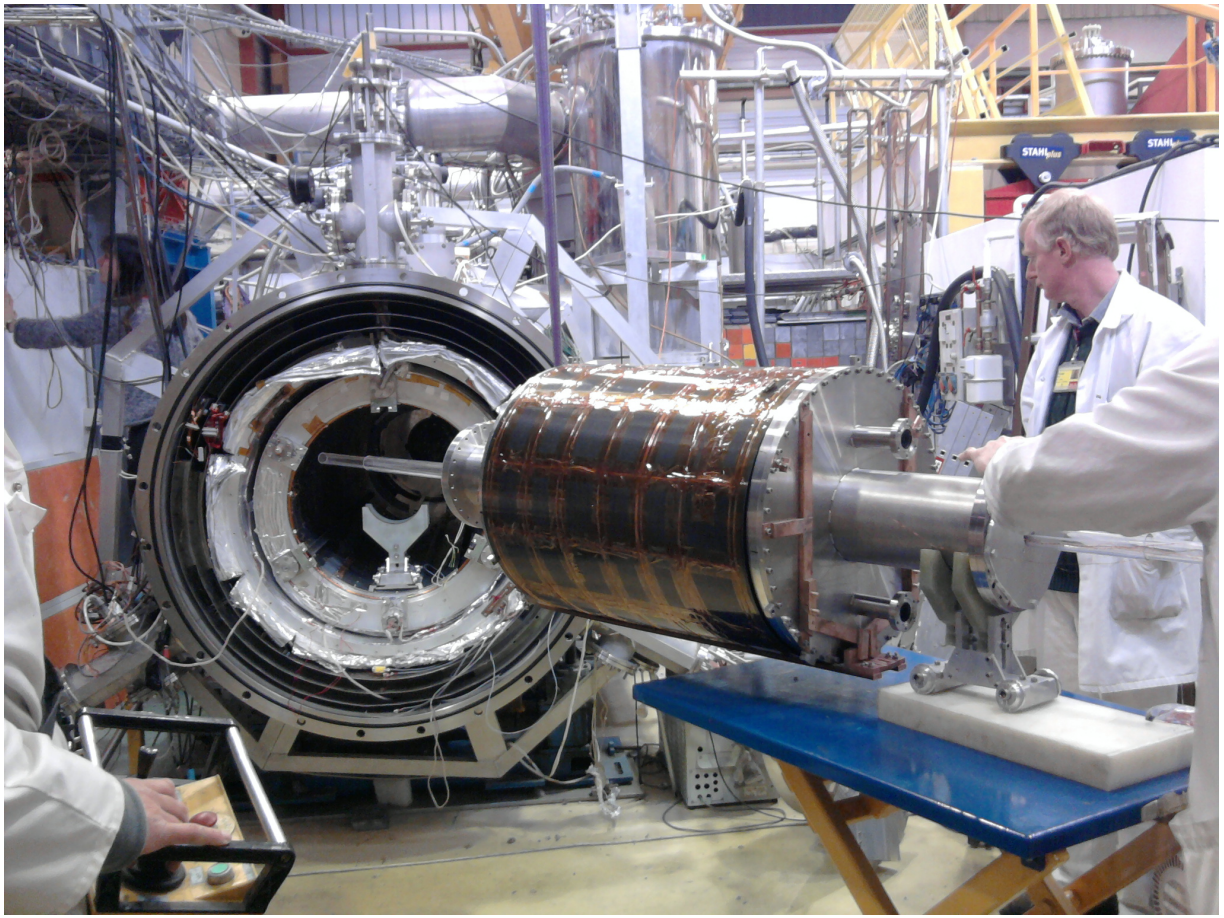
B-field spatial homogeneity

- 2004 improved homogeneity



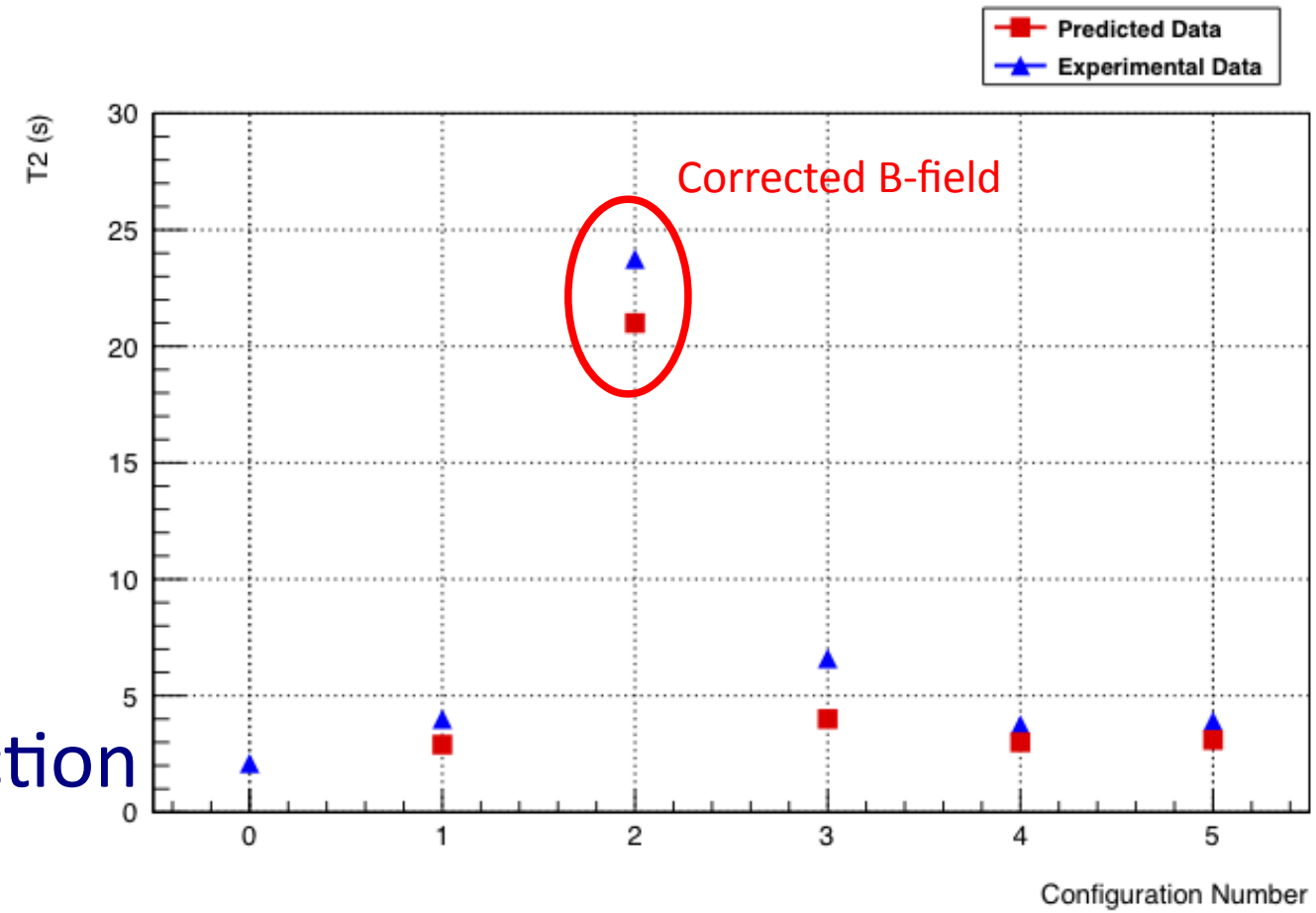
B-field spatial homogeneity

- Improve homogeneity further
  - Array 12 coils
  - Optimise coil currents
- Response map
  - Extensive effort 2010
    - 12 coils
    - 1440 points
  - Software optimisation



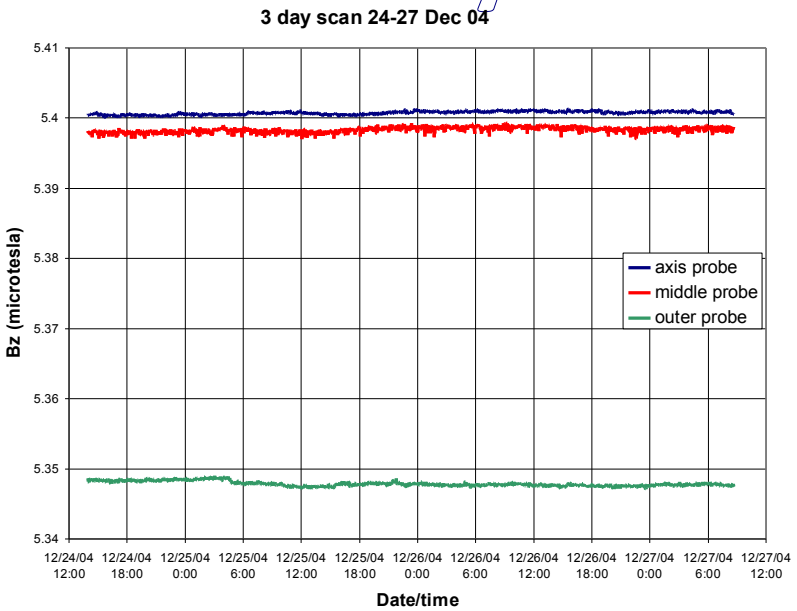
B-field spatial homogeneity

- Assess improvement
  - Neutron MC to calculate T_2
  - B-field map input
    - Predicted
    - Measured
- Factor ~ 10 to be gained from correction coils



B-field temporal stability

- B_0 stability
- Solenoid persistent current running 2004



B-field temporal stability

- B_0 stability
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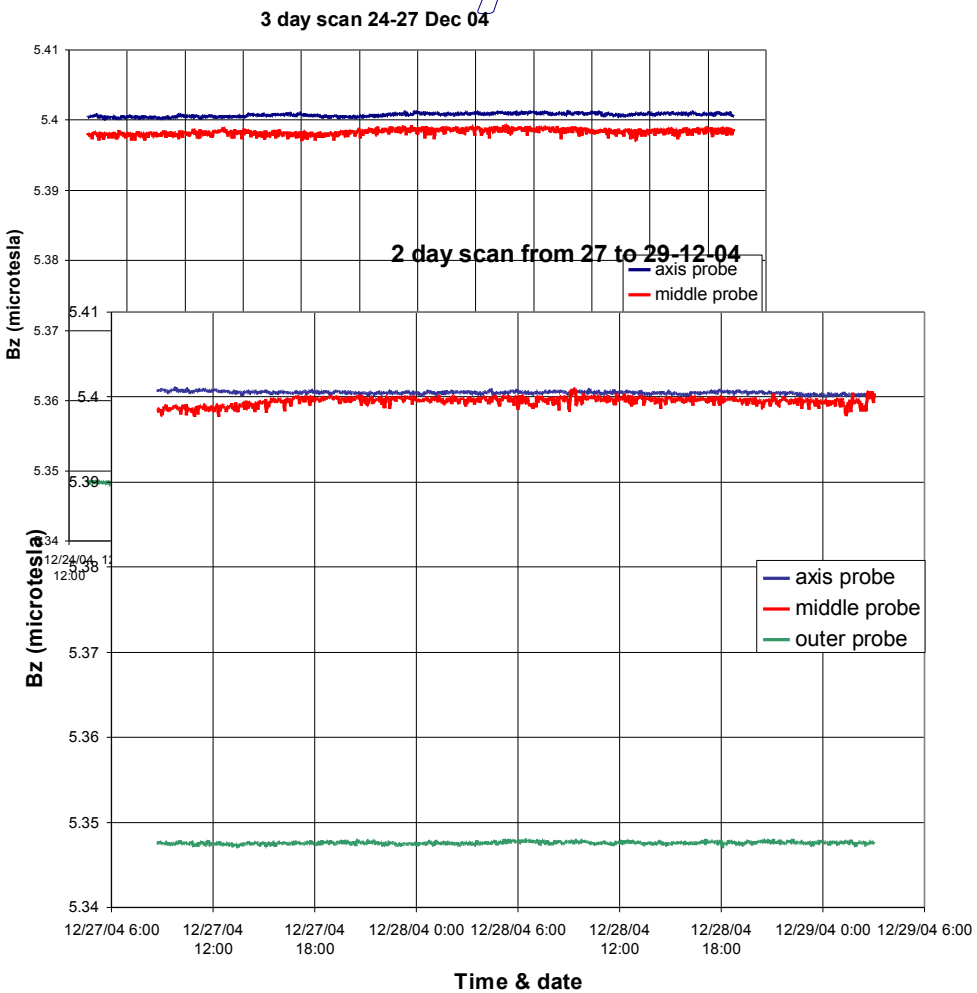
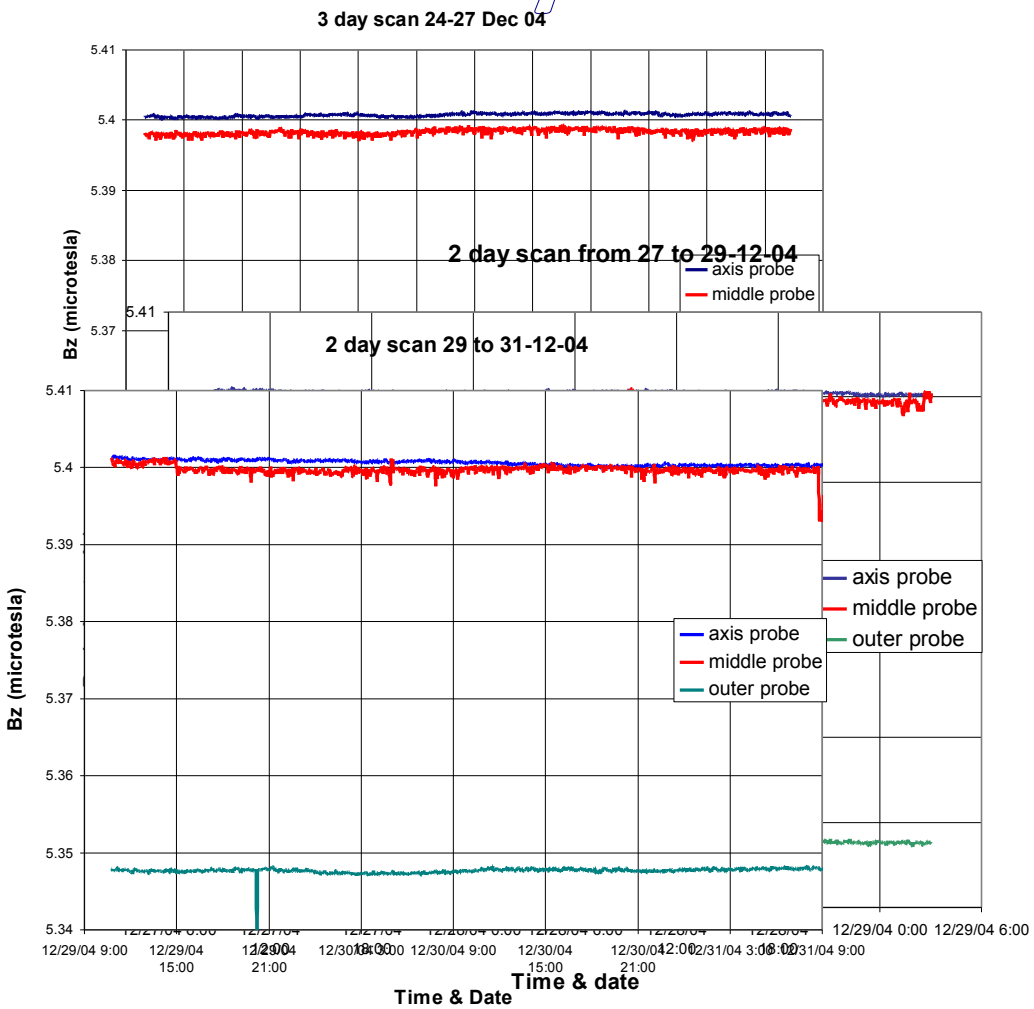


B-field temporal stability

- B_0 stability
- Solenoid persistent current running 2004
  - 288 hours
  - ΔB max 1.7 nT peak-peak
  - Upper limit on solenoid run-down < 3 pT / hr
    - Well within analysis tolerance

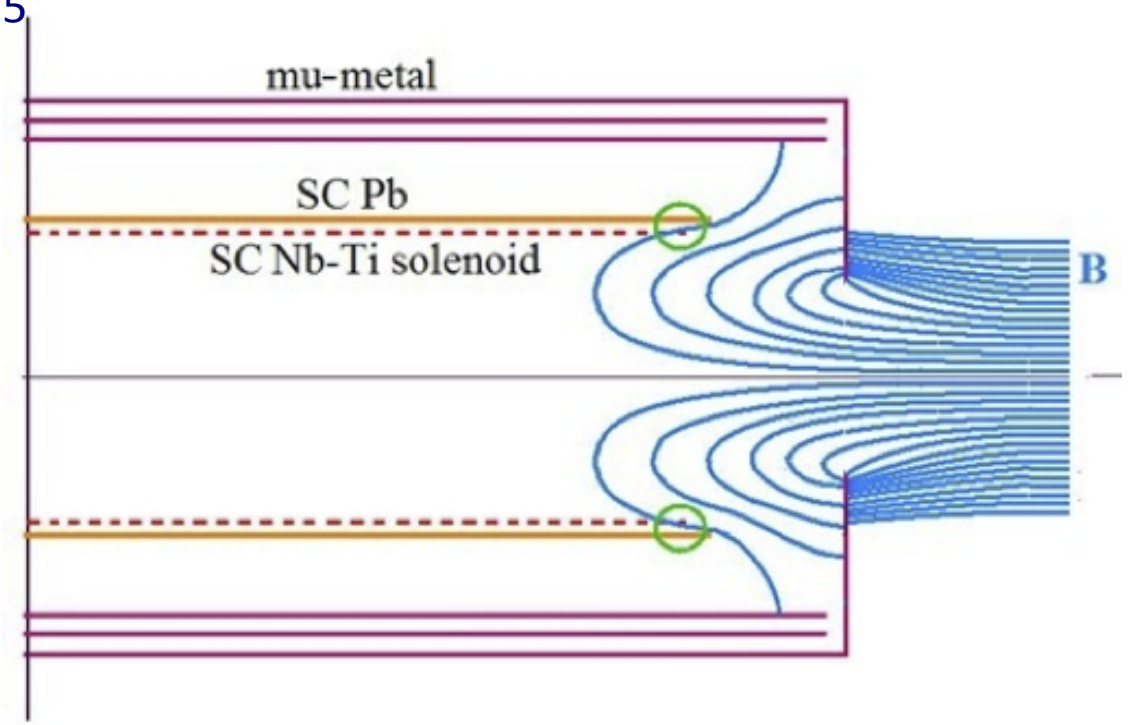


B-field temporal stability

- Noise reduction for nEDM
  - B-field freq shift < E-field freq shift
- < 3 fT over cycle
- Noise at site ~0.2 μT
  - ~100 reduction via statistics
- Required DSF 10^6
    - Mu-metal DSF 12 – extension needed?
    - Need Pb shield + solenoid → 10^5

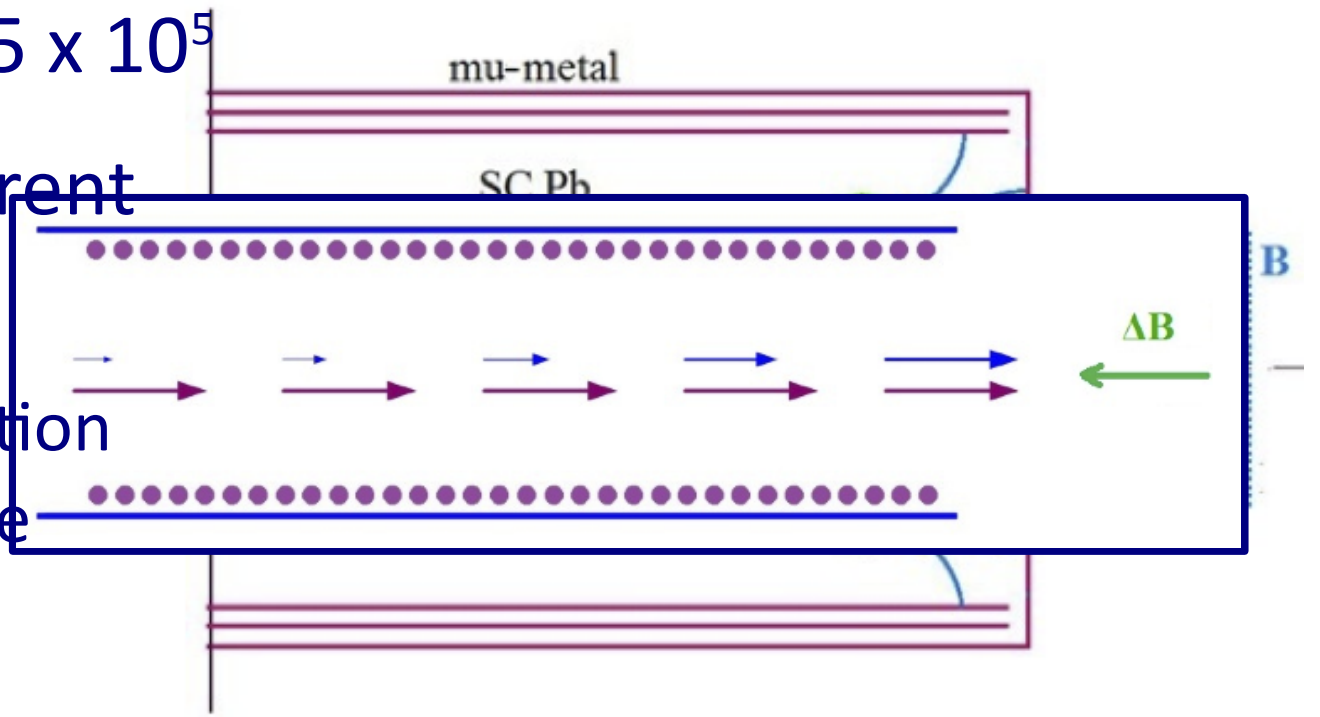
B-field temporal stability

- Penetration of transient fields
- Pb DSF should be 5 x 10^5
- Solenoid supercurrent uniform
  - External perturbation produces response
  - Inside Pb shield



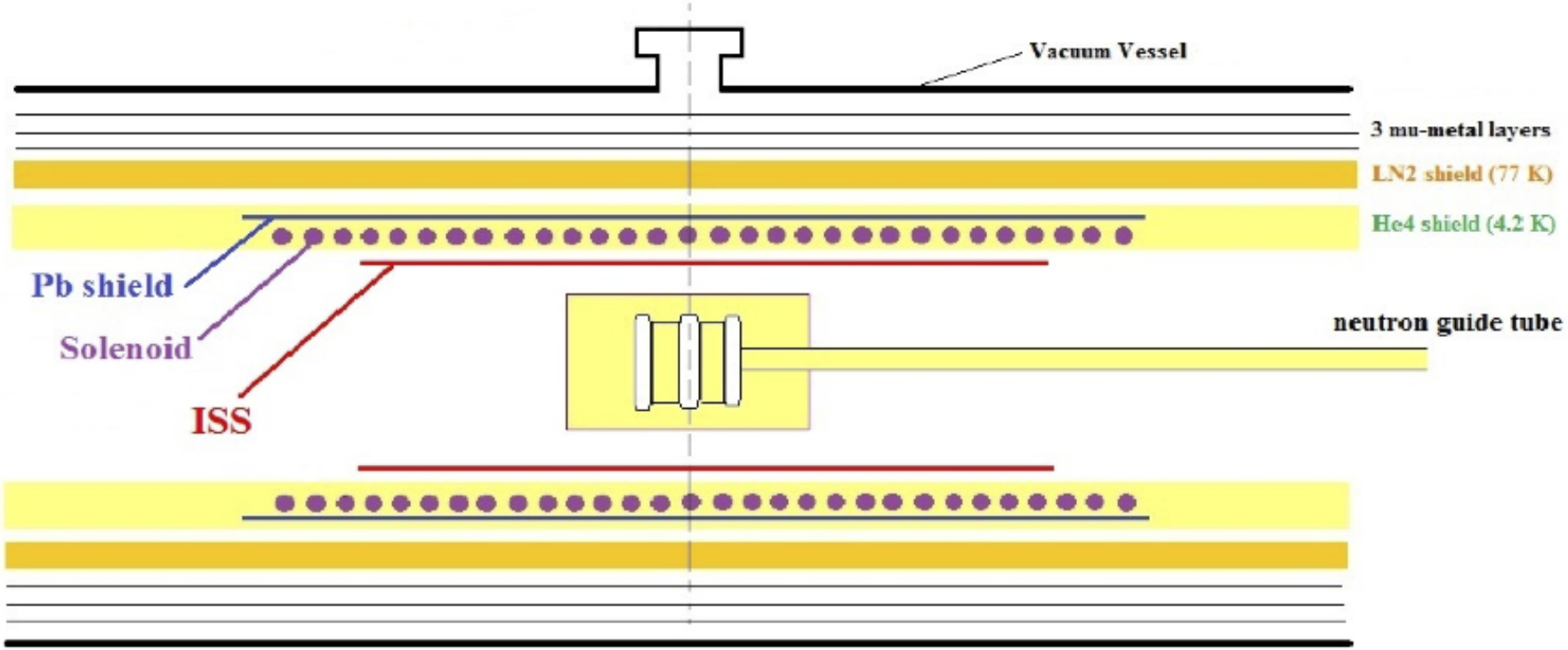
B-field temporal stability

- Penetration of transient fields
- Pb DSF should be 5 x 10^5
- Solenoid supercurrent uniform
  - External perturbation produces response
  - Inside Pb shield
- DSF estimated -175



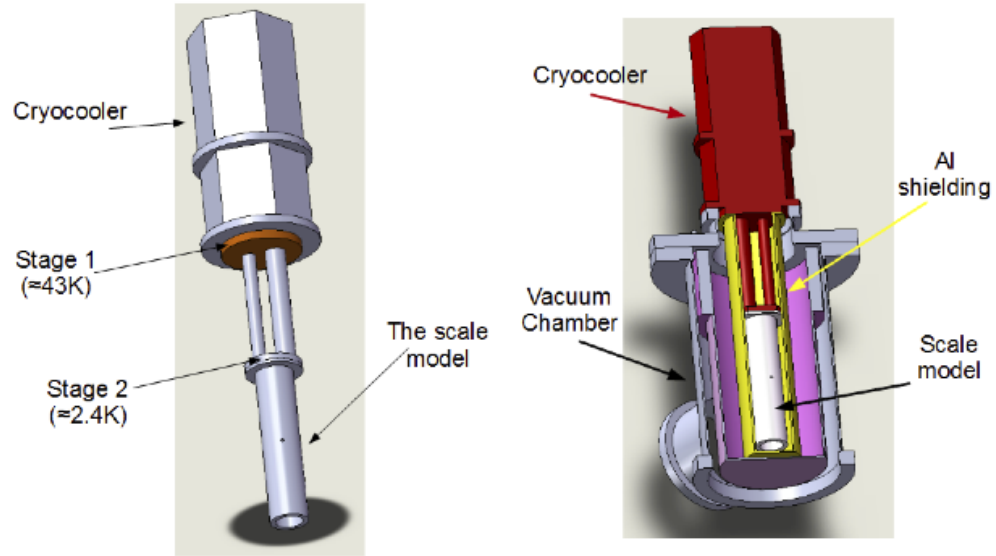
B-field temporal stability

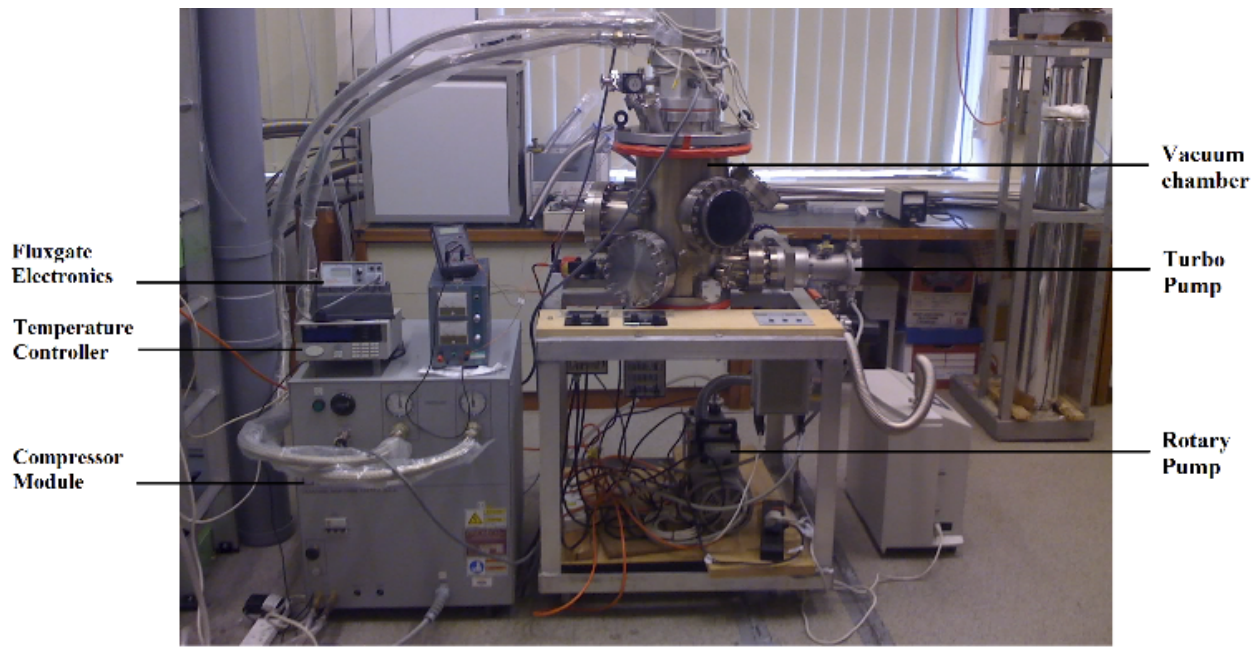
- Insert additional inner SC shield
  - Can 10^6 DSF be recovered?



B-field temporal stability

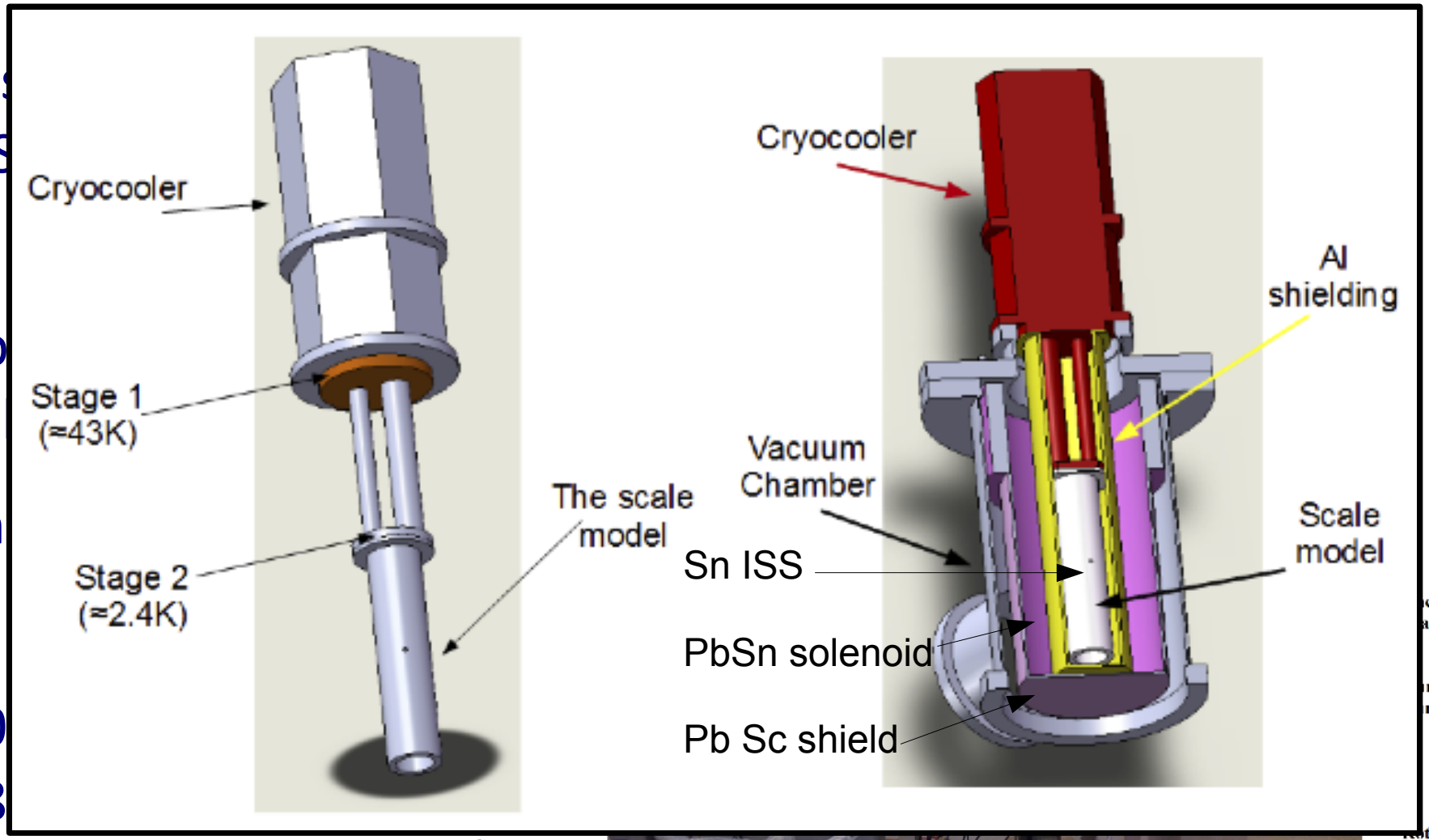
- Test 1:12.5 scale model ISS
  - A. Katsika PhD, Sussex
- Pb shield (7.2K) & PbSn solenoid (6.9K)
- Sn shield (3.7K)
  - Cooled to 2.1K
- 60 A external coil → 180 μT
- 0.1 nT resolution fluxgate





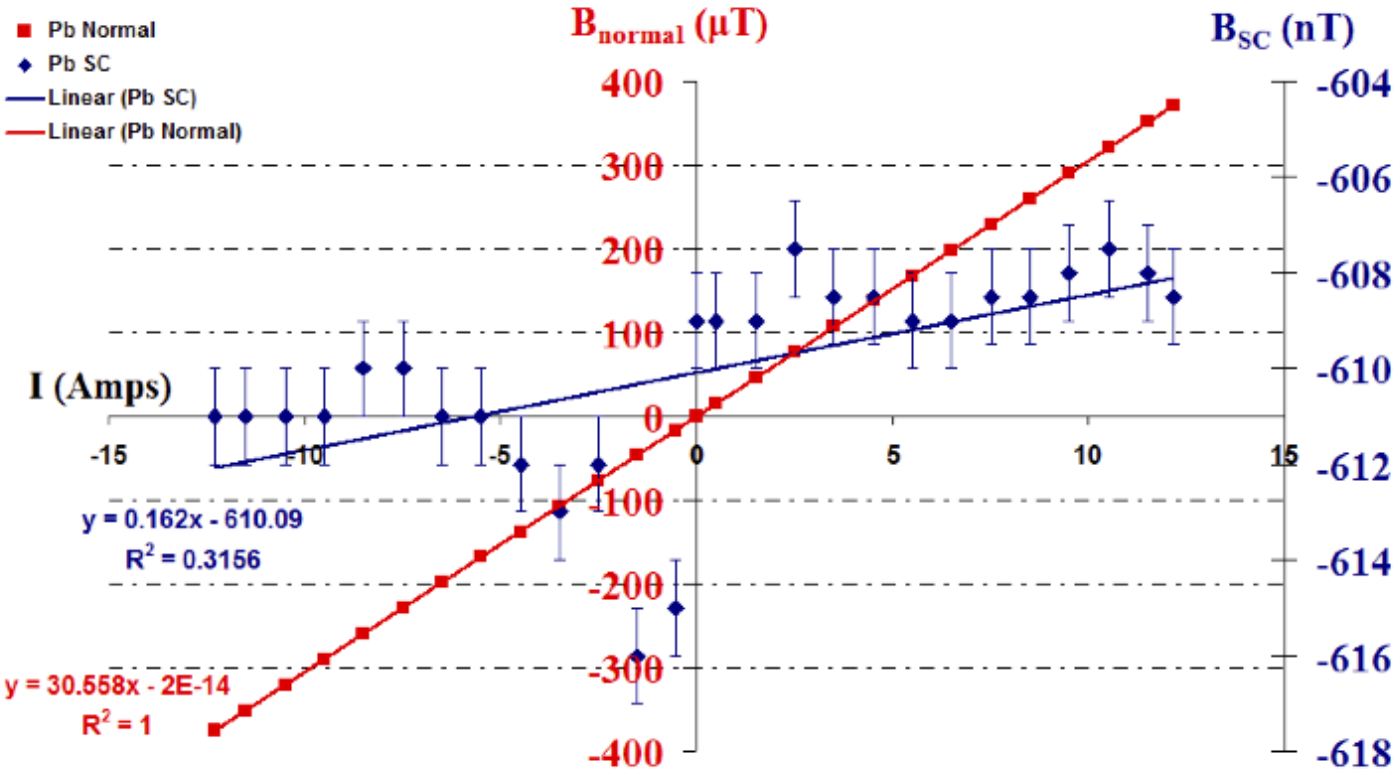
B-field temporal stability

- Tes
  ISS
  -
- Pb
  so
- Sn
  -
- 60
  18
- 0.1 nT resolution fluxgate



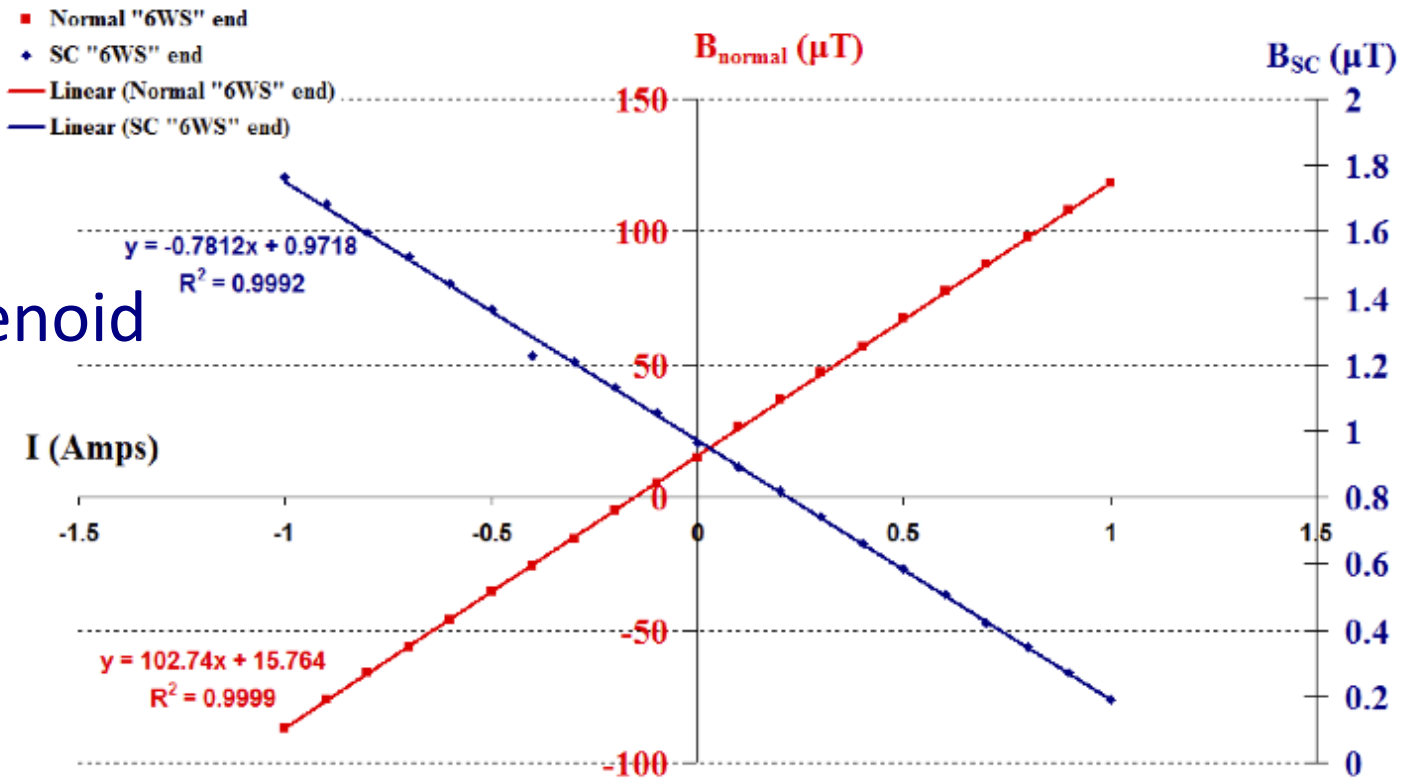
B-field temporal stability

- ISS model data
  - Pb shield
  - DSF 1.88 x 10^5



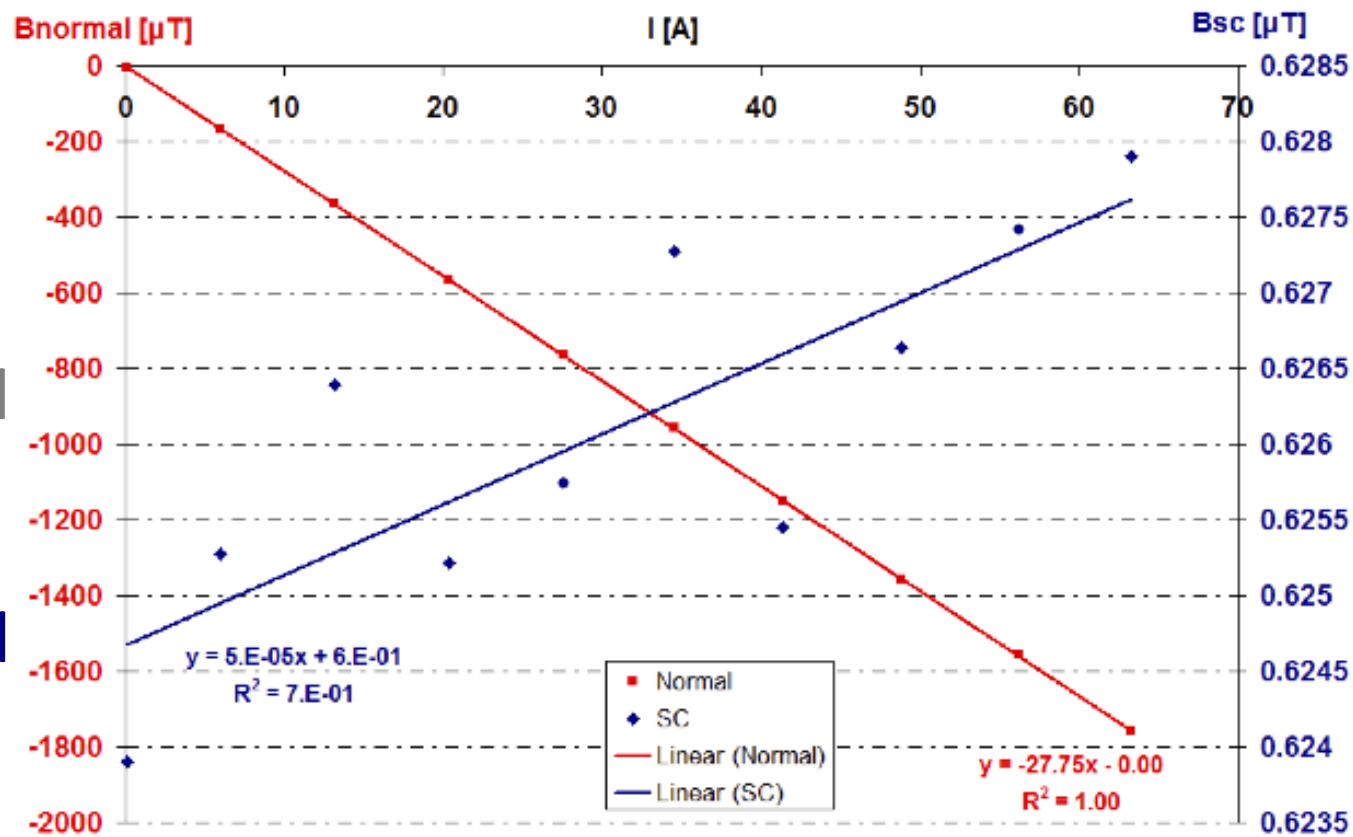
B-field temporal stability

- ISS model data
  - Pb shield
  - DSF 1.88 x 10^5
  - Pb shield + solenoid
  - DSF -234



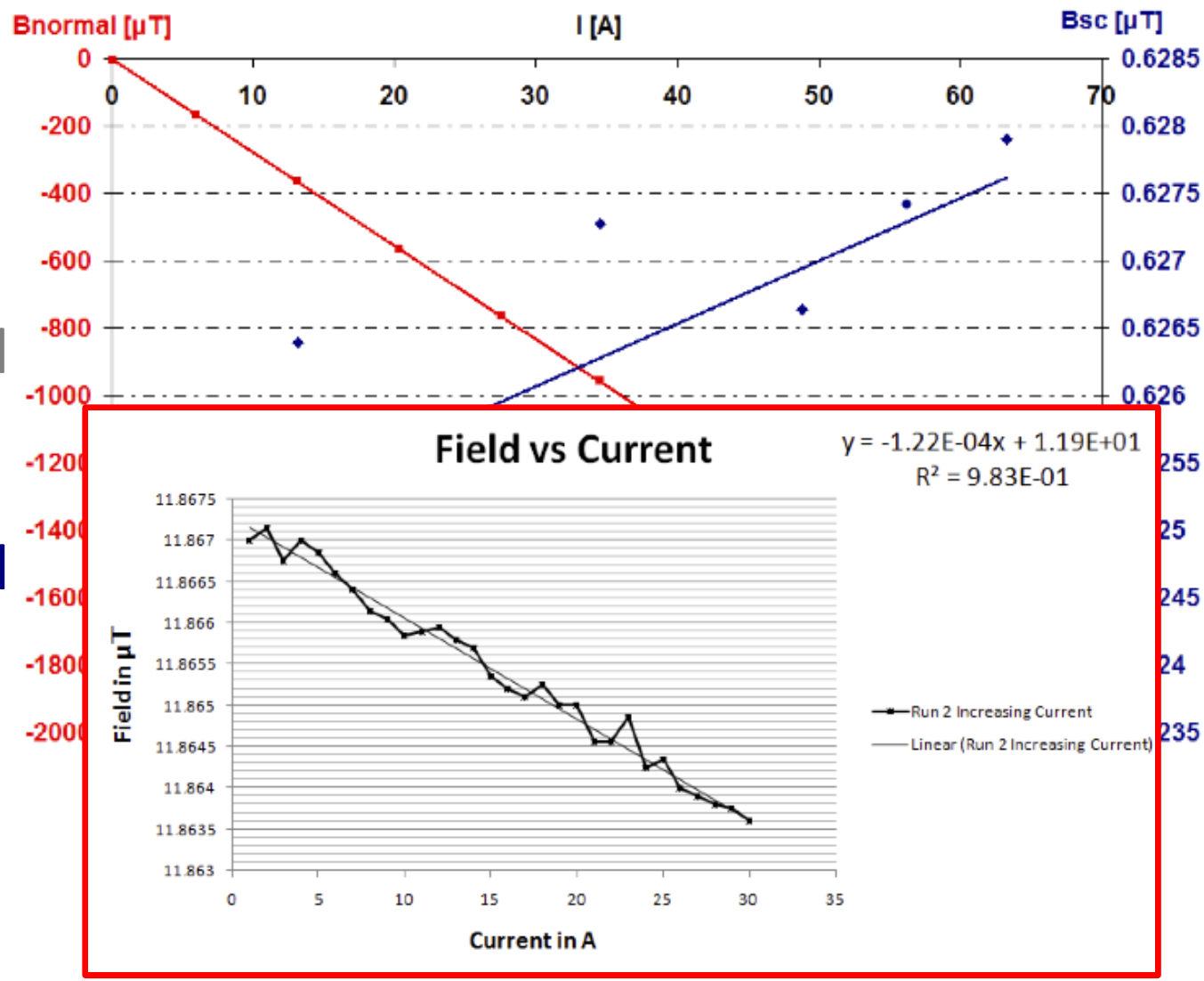
B-field temporal stability

- ISS model data
  - SC shield
  - DSF 1.88 x 10^5
  - Shield + solenoid
  - DSF -234
  - Shield + solenoid + ISS
  - DSF ~5 x 10^5



B-field temporal stability

- ISS model data
  - SC shield
  - DSF 1.88 x 10^5
  - Shield + solenoid
  - DSF -234
  - Shield + solenoid + ISS
  - 2012 data
  - DSF -2.8 x 10^5

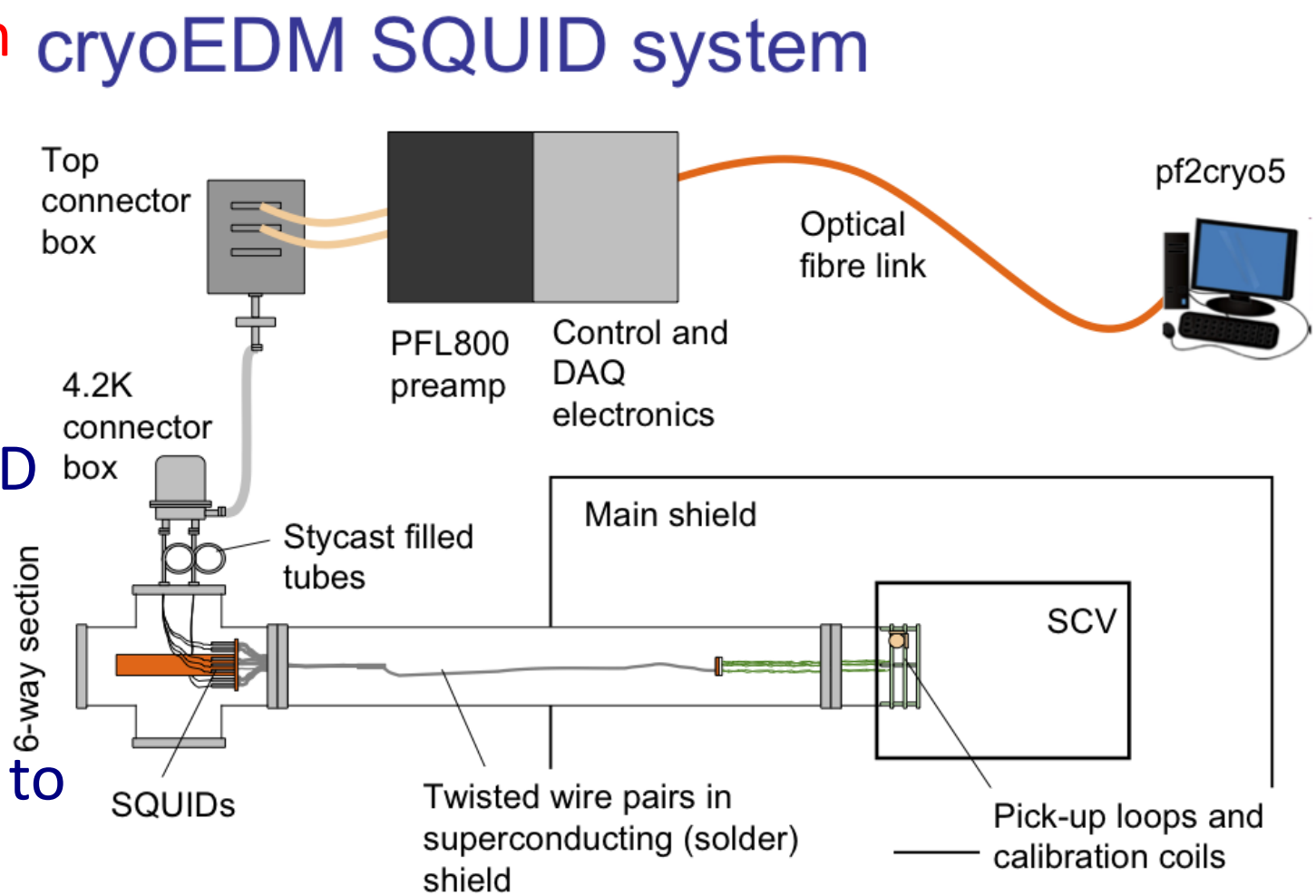


Magnetometry – SQUIDs

- Requirements for nEDM
  - Monitor 0.1 pT fields over 300 s storage time
  - Minimise heatload
  - Measure close to RC
    - HV compatible

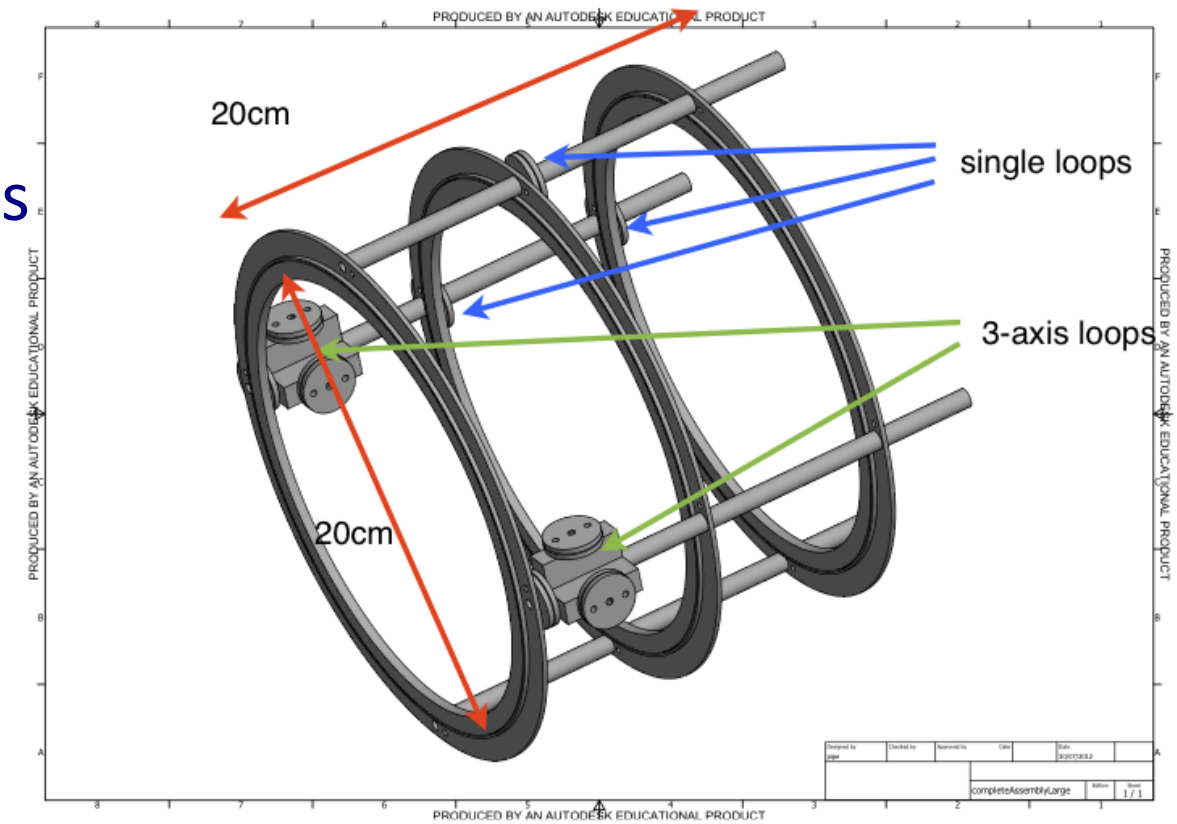
Magnetometry - SQUIDs

- 2006 installation
- Optical data transfer
- Heatload
  - 3 mW / SQUID
- Cryostat forms faraday cage
  - Still sensitive to EMF pickup



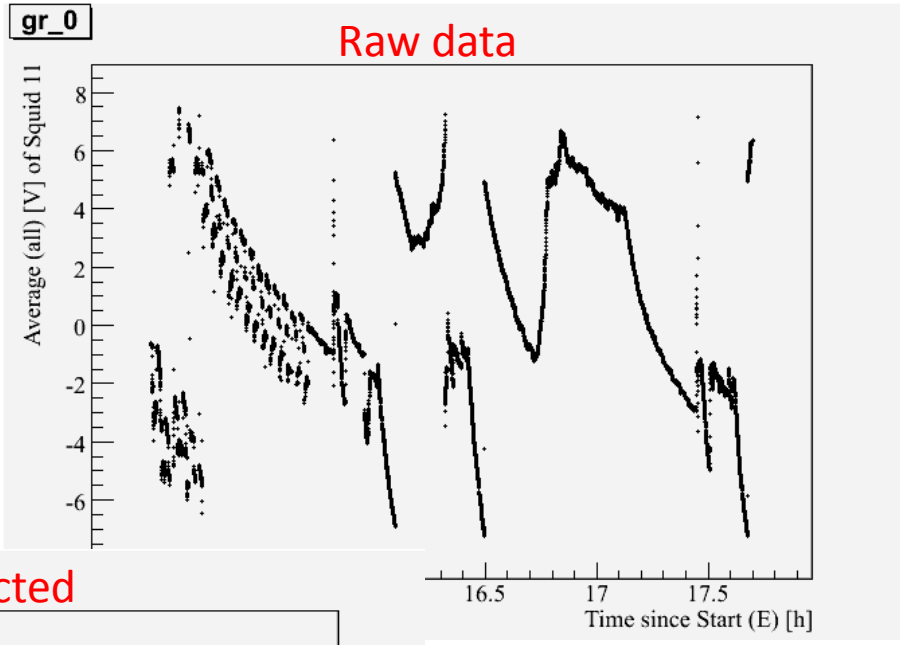
Magnetometry - SQUIDs

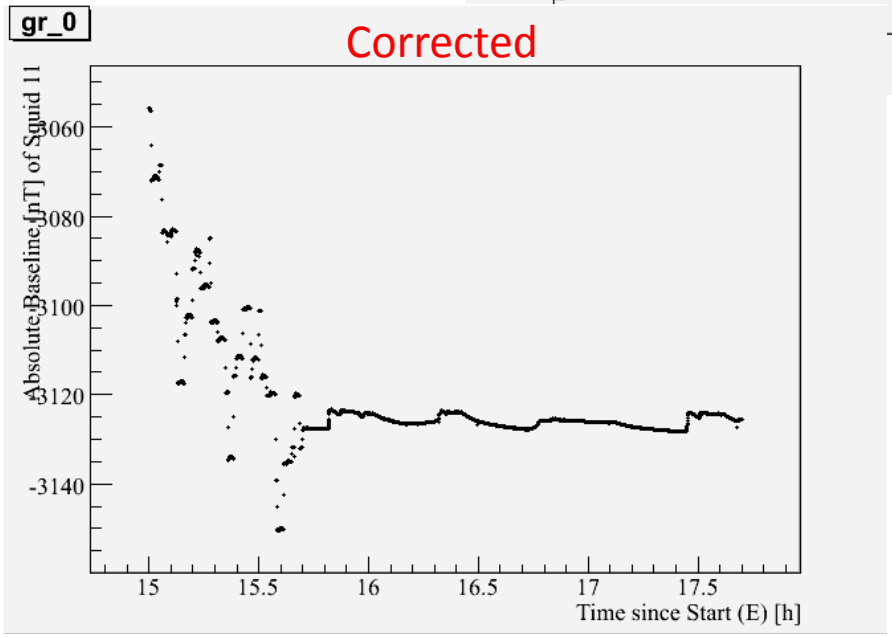
- SQUID pickup loops
  - 3x z-axis double loops
  - 3x off-axis z-loops
  - 2x 3-axis loops
  - 3x calibration coils
- Measure field in RC
  - 12 cm from coils



Magnetometry - SQUIDs

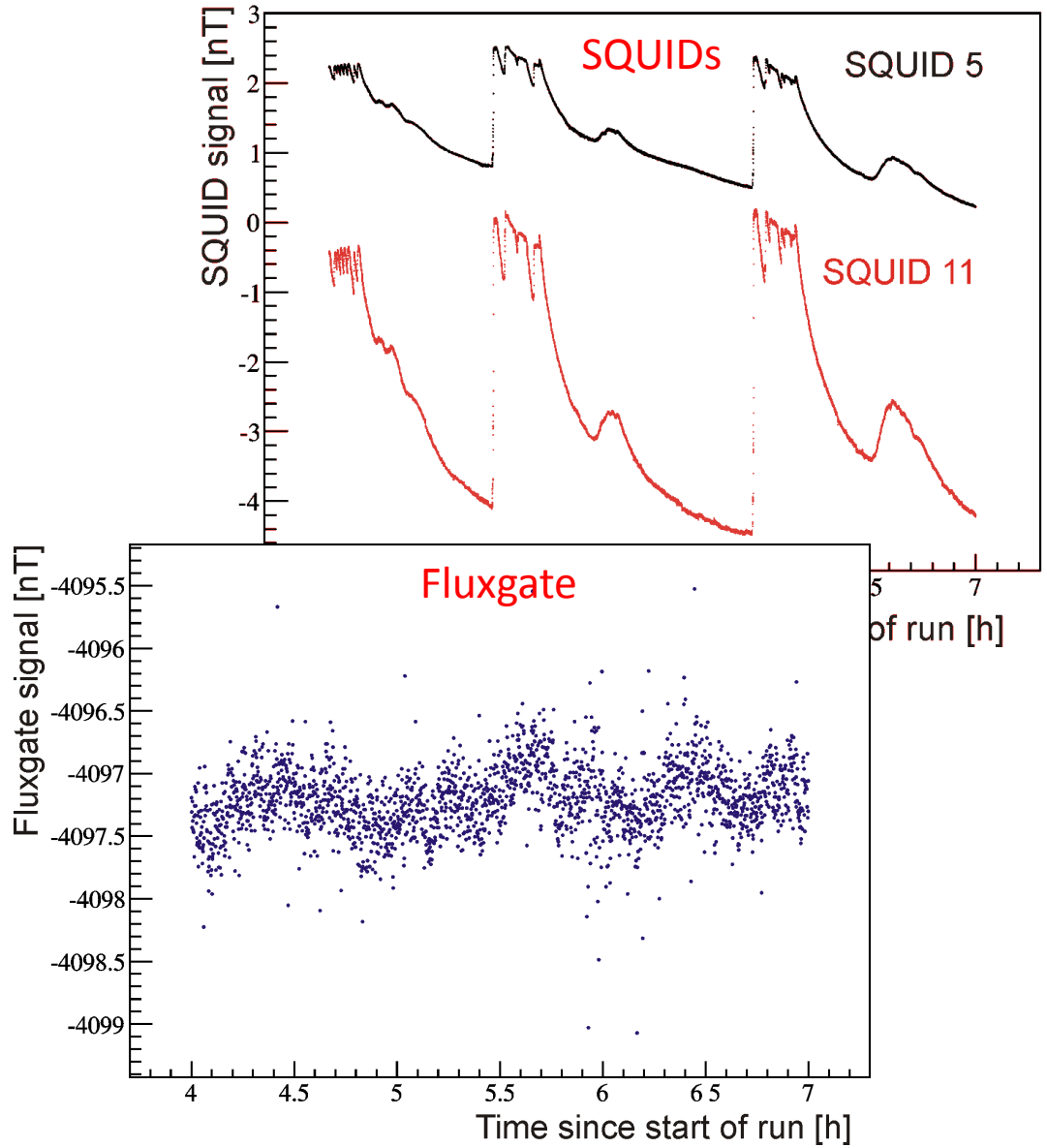
- SQUID resets
  - Flux locked loop
  - Periodic V / flux over one flux quantum
  - ~10 nT flux quantum
  - Corrected in software





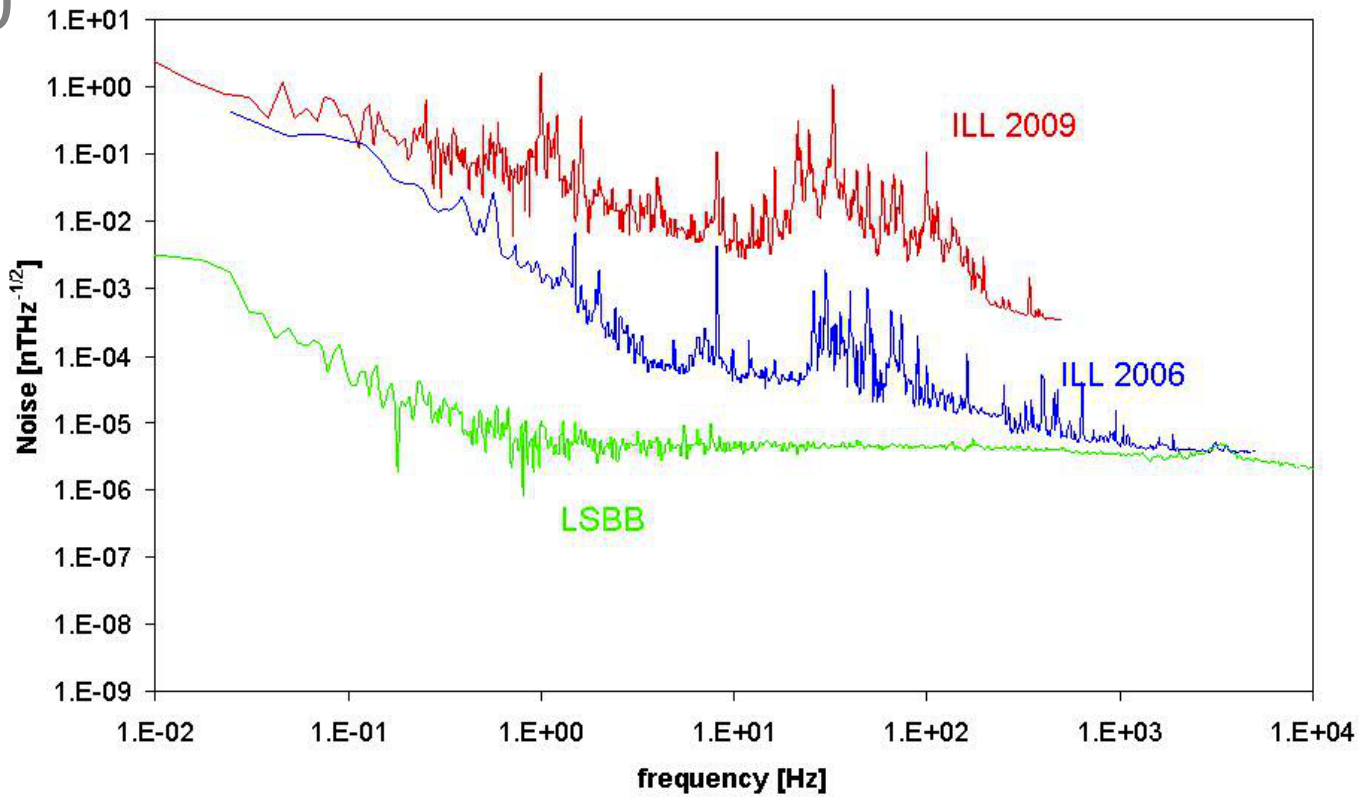
Magnetometry - SQUIDs

- SQUID system tests ILL 2009/10
- Good resolution
- EMI pickup



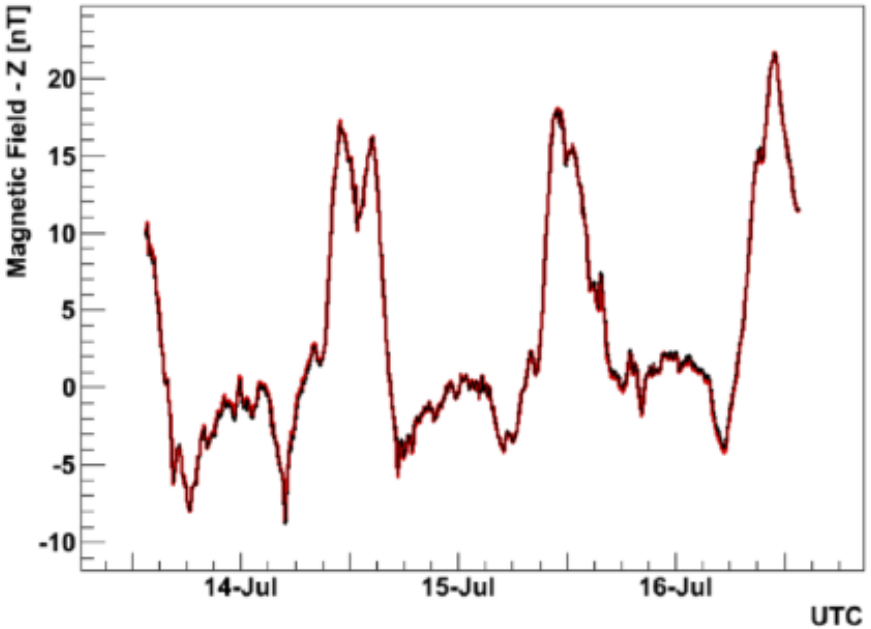
Magnetometry - SQUIDs

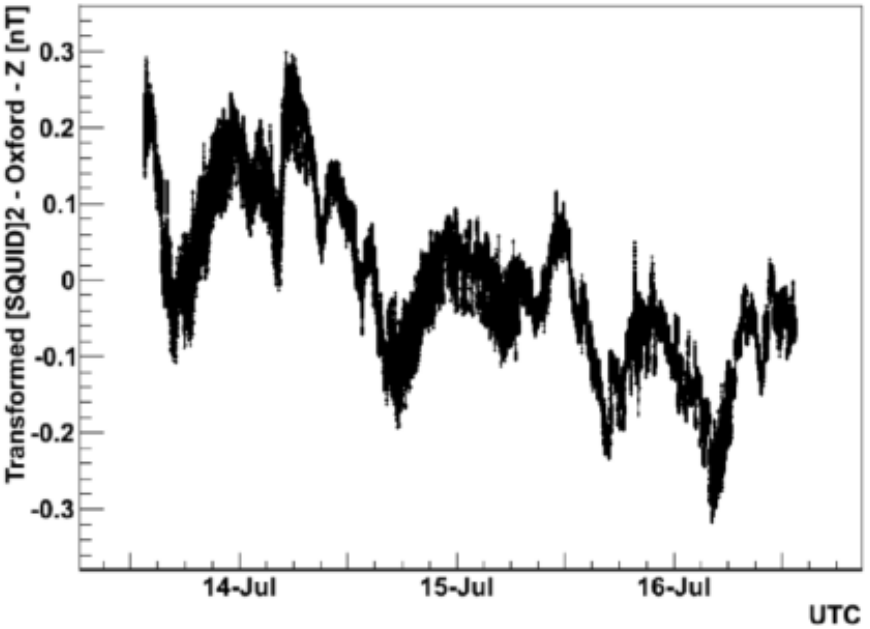
- SQUID system tests ILL 2009/10
- Good resolution
- EMI pickup
- Characterise system in low-noise LSBB
  - $< 10^{-1}$ pT/Hz$^{1/2}$



Magnetometry – SQUIDs

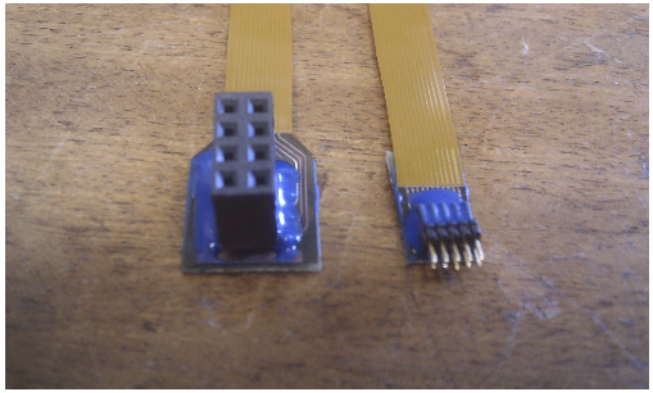
- Tests at LSBB 2012
  - Geomagnetic effects measured using 2 SQUID systems
  - 72 hours stable operation
  - Resolution to < 0.1 pT/Hz$^{1/2}$
  - RMS discrepancy < 56 pT

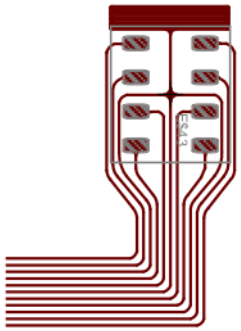


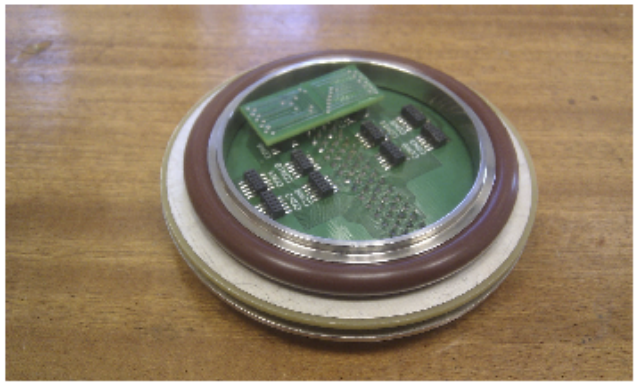


Magnetometry – SQUIDs

- SQUID upgrade plans
  - Low-heatload readout cabling
    - 30 μW / SQUID
  - Compact hardware
  - Magnetic modelling
    - OPERA
    - QuickField







Summary

- Cryostat performance established
  - Base temperature 0.4K reached
  - Temperature stability acceptable
  - Long cooling times

Summary

- Cryostat performance established
- B-field homogeneity
  - Pb shields delivering ~10 nT/m
  - Correction coils can give factor ~10 improvement in T_2

Summary

- Cryostat performance established
- B-field homogeneity
- B-field stability
  - Pb shield DSF ok ~10^5
  - Transmission in solenoid
    - Testing ISS
    - Regain DSF >10^5

Summary

- Cryostat performance established
- B-field homogeneity
- B-field stability
- SQUID performance
  - 0.1 pT/Hz$^{1/2}$ achieved in quiet environment
  - SQUID upgrade planned

Summary

- Cryogenics upgrade plans
  - New & replacement cryocoolers to reduce LHe shield boil-off
  - Thermally isolating UCN guide supports to allow in-situ bake-out
  - Large-bore SF valve for SCV pumping line to allow pressurisation