Self-Shielded Magnets for Neutron Scattering

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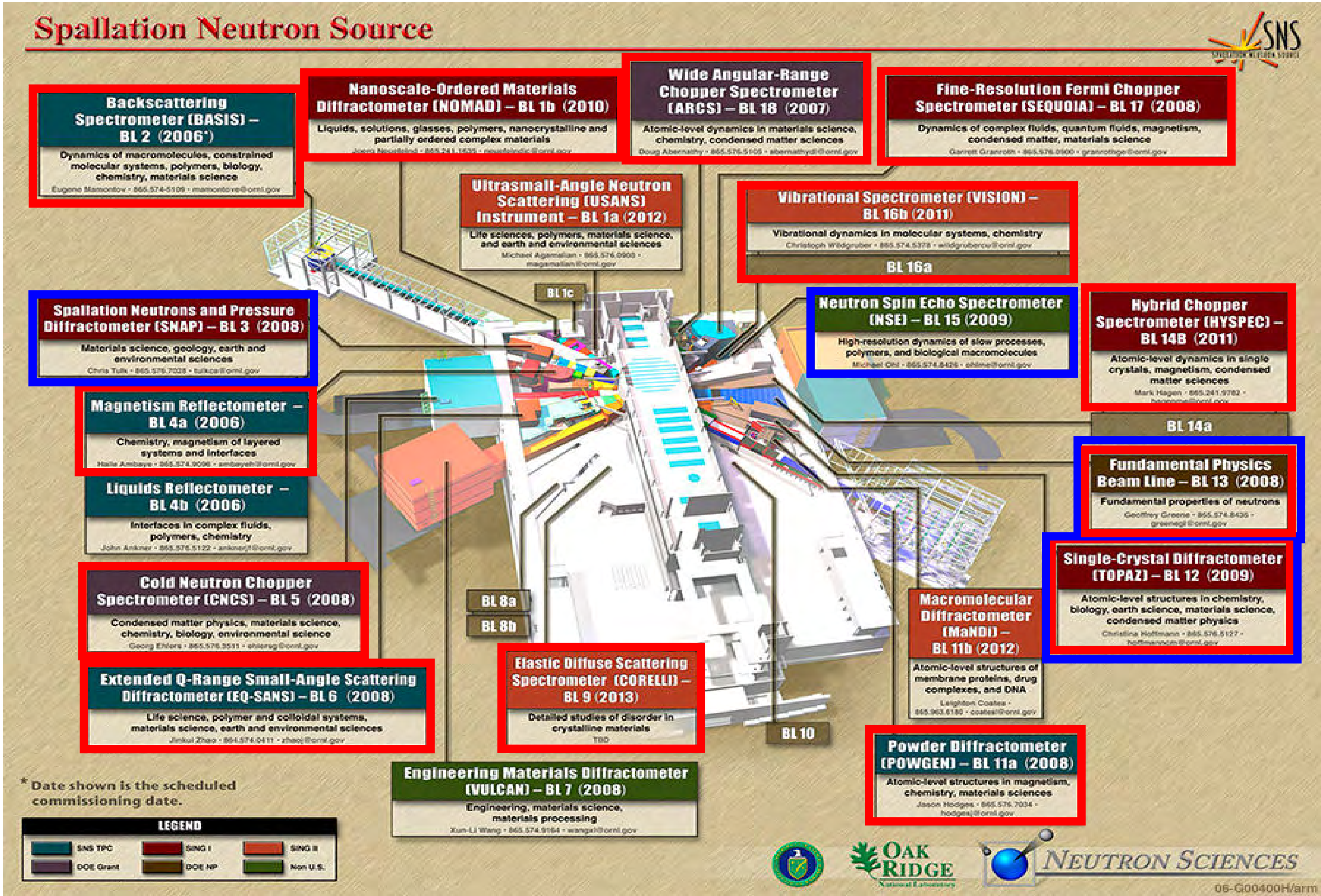
Outline of Presentation

- SNS layout and requirements
- Magnetic Interference issues
- Study of compensated magnet
- 5-Tesla SLIM SAM (shielded asymmetric magnet)
- What is next for SNS?

High field and field-sensitive instruments



RED: Use high field **BLUE: Field-sensitive**

Requirement set up for SNS

- SNS adopted stray field policy in 2004
  - On magnet systems
  - 5 Gauss @ 0.5 meter, 0.05 Gauss @ 5 meters
  - But we have put in provision for exceptions

A survey of magnetic interference issues

- In 2003, we carried out a survey on the magnetic interference issues encountered at neutron scattering facilities. Out of this came the issues below:

(1) Instruments: Fringe fields from sample magnets were disabling field-sensitive instruments and devices. Examples are spin-echo spectrometer, fundamental physics setup, and detectors that use photomultipliers.

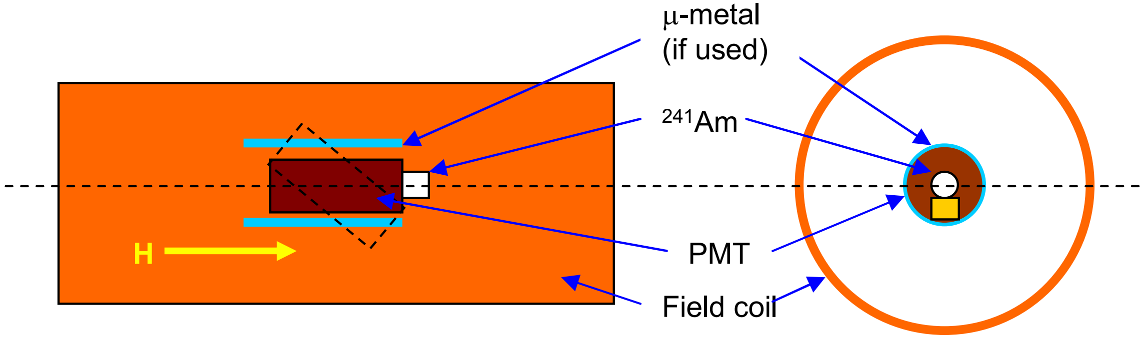
(2) Superconductor sample magnets: Are too close to the steel instrument components that they quenched. Some were even damaged. The large fringe field also attracted magnetic components in the vicinity!

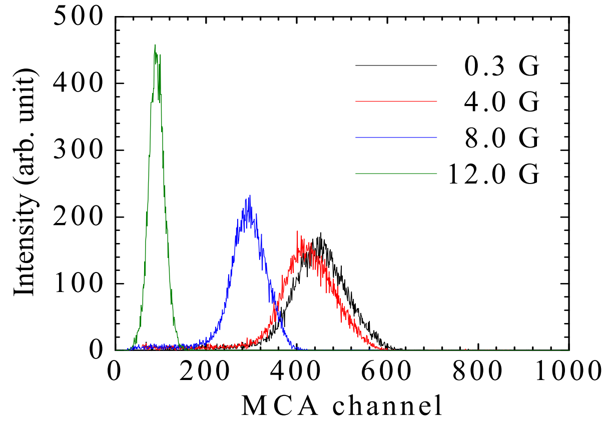
(3) Instrument components: On instruments that use a strong sample magnet, the drive mechanism of goniometers, samples stages, and other moving parts ceased to function due to the strong magnetic forces in their gears and motors.

A survey of magnetic interference issues

- **We found the following steps had been taken in dealing with the interference:**
  (1)Scheduling**: Interference between instruments were mostly dealt with by restricting the use of magnets and scheduling measurements that were not affected by magnetic interference to coincide with the use of magnets in other instruments.**
  (2)Shielding sensitive instrument from the fringe field**: This is commonly used in fundamental physics setup which is sensitive to small field disturbance. The SNS Neutron Spin Echo spectrometer is shielded by μ-metal panels covering its instrument hub. Unshielded fringe field from a high-field magnet, however, will disturb the measurements. Also not all instruments can use this option.**
  (3)Compensating fringe field near the magnet**: Compensating current loops mounted on instrument hubs or structural frames had shown to be rather effective, also cost-effective in reducing the fringe fields at far distances. They however had little impact in the vicinity of the magnet.**

Devices that are susceptible to stray field: Photomultiplier

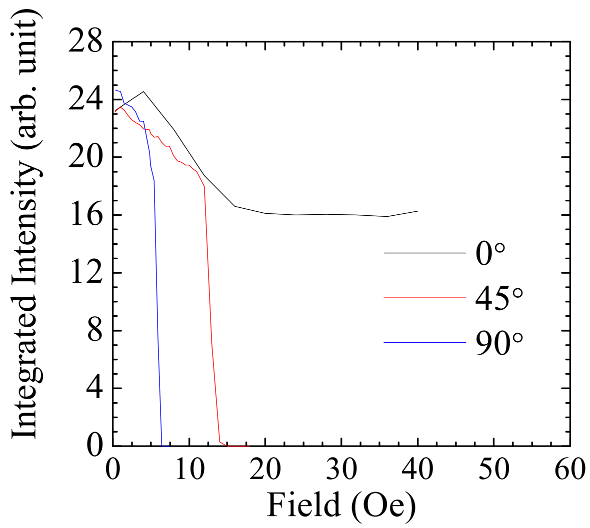




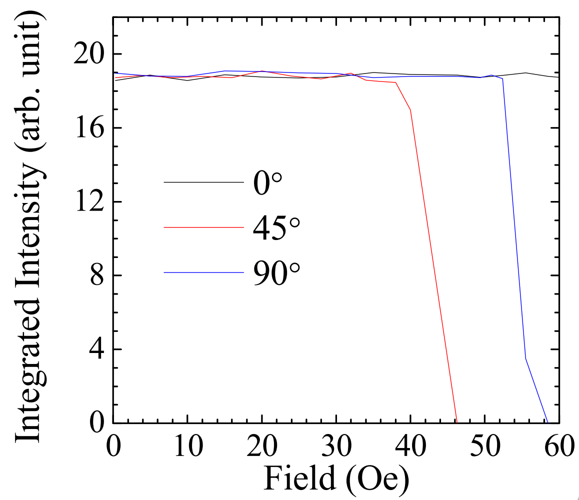
Measurements using a unshielded PMT in a magnetic field showed a field strength of 0.5 gauss began to disturb the intensity reading. A few gauss can disable the PMT.

A PMT shielded with μ-metal can sustain up to 30-40 gauss field environment. However, in many detector settings, there is little space for μ-metal shield.

No μ-metal shielding

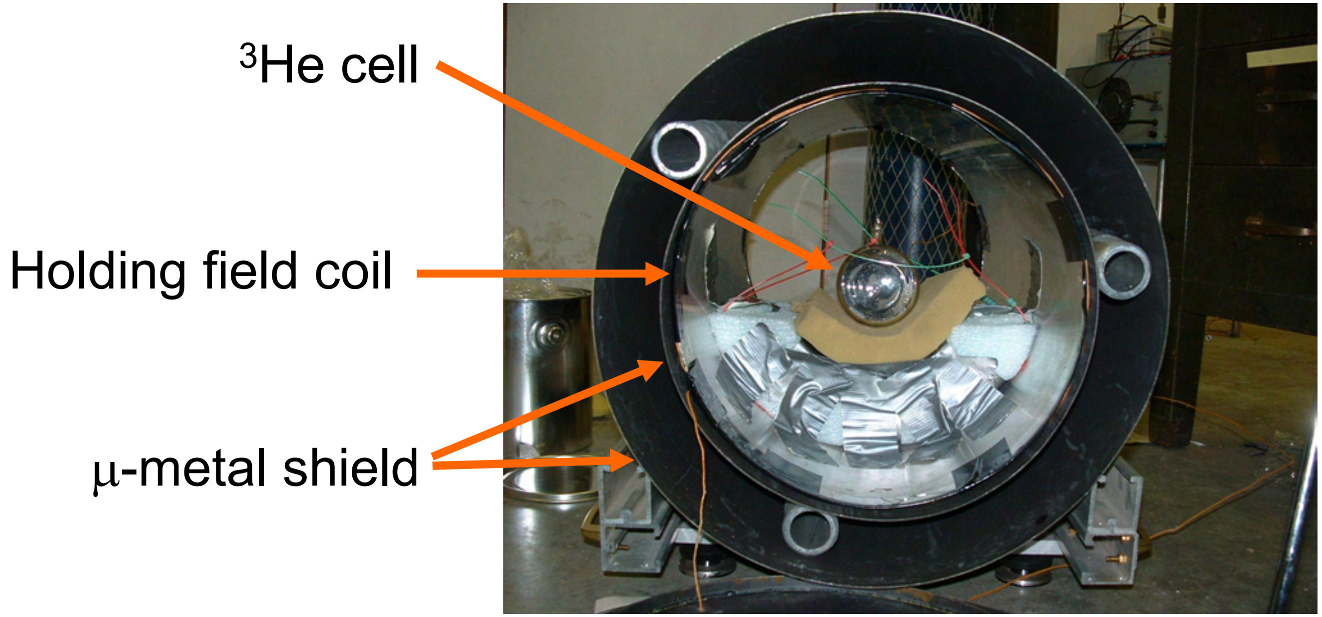


With μ-metal shielding



Measured by W.T. Hal Lee and Patrick De Lurgio

Devices that are susceptible to stray field: Polarized ^{3}He



(Photo courtesy Xin Tong)

Relaxation time T_1

$$\frac{1}{T_1} = \frac{2kT}{mB_z^2}\left(\frac{\partial B_y}{\partial y}\right)^2 \frac{\tau_c}{1+\omega_0^2\tau_c^2}$$

T=temperature
m=3He mass
B_z=holding field
B_y=transverse field

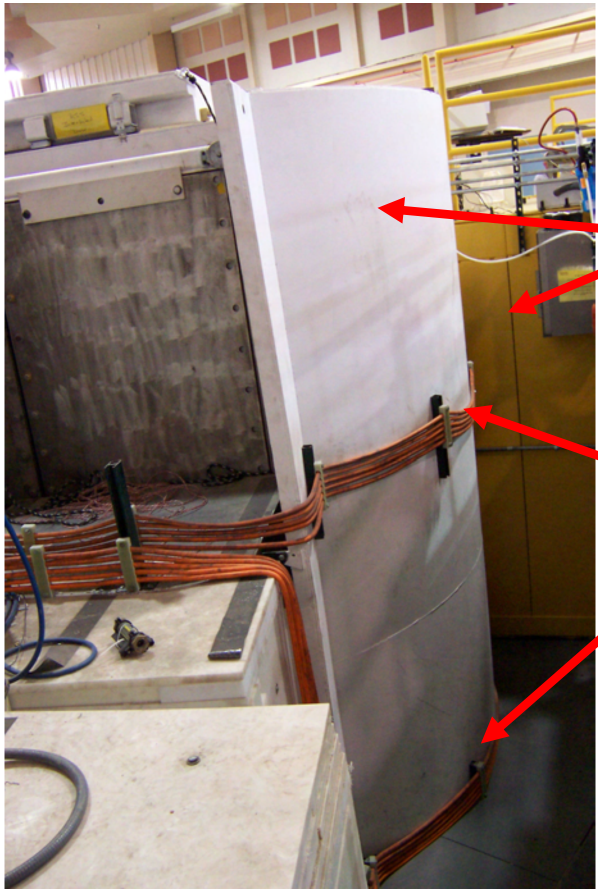
τ_c (sec) =mean collision time
=2.2 x 10-7 / P (mm-Hg)
ω_0 =Larmor precession freq.
= γB_z

$$(\partial B_y / \partial y) / B_z < 10^{-4} / cm$$

Polarized ^{3}He devices are susceptible to magnetic field gradient. In an unshielded 10 gauss holding field, a field gradient less than 1 mG/cm is recommended for operations that last 2-3 days. At a shortened ^{3}He polarization lifetime, up to 10 mG/cm is acceptable for a day-long use. Using a μ-metal shielded holding field, the device can sustain external fringe field up to 5-10 gauss.

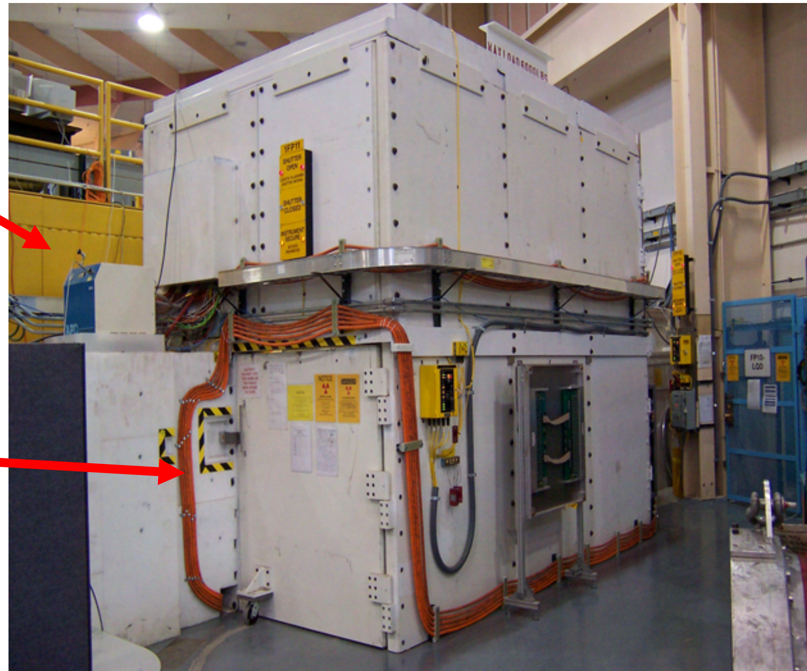
Dealing with fringe field: Passive shielding and active shielding in near-field situation – partial success

- Steel shielding (Asterix, Fundamental Physics Hub)
- Active field compensation with “bucking coils”
- This allows the fringe field to be reduced along the most susceptible part of the Fund. Phys. Beam line beam path
- The setup allows the use of the 12 T magnet on Asterix



Steel shielding

“Bucking” coil



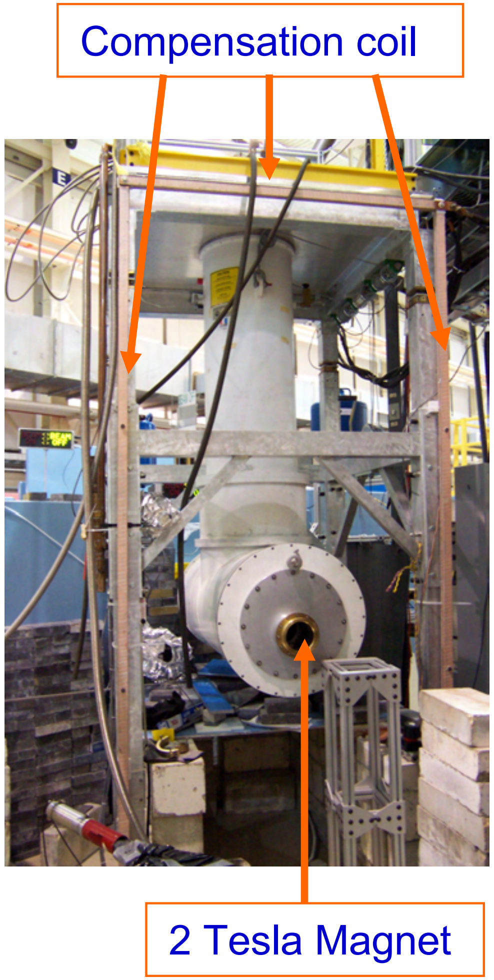
Dealing with fringe field: Active shielding in far-field situation

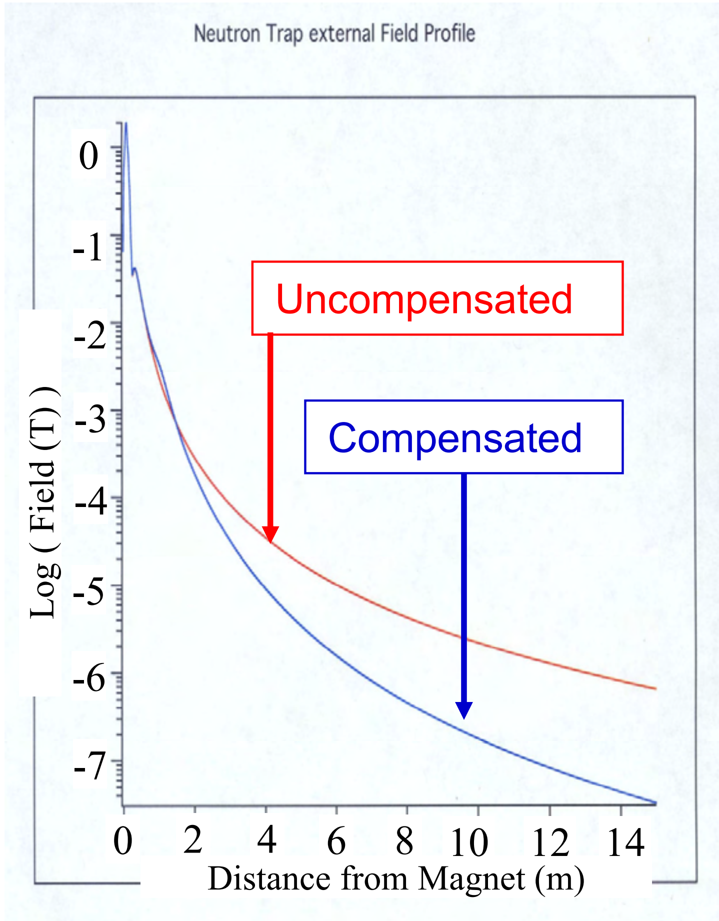
Using a compensation coil mounted on the structural frame of a 2-Tesla magnet, a fundamental physics setup at NIST managed to reduced the fringe field by more than an order of magnitude at 4m and beyond. In fact it actually eliminated the disturbance to the spin-echo spectrometer at 10m away.

Due to the location and a geometry that is not symmetric and co-axial to the magnet, the fringe field at less than 2m was not significantly reduced.

This setup demonstrated that it is more effective and more cost-effective to compensate the fringe field near the source.

Field compensation at the fundamental physics beam line at NIST.





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Study of Compensated Magnet, the outcome

- Our survey has shown that the most effective and, at the facility-wide scale, most cost-effective method is to compensate the fringe field at the source.
- As a consequence of the survey, we began to work with magnet designers to develop self-shielded split-pair sample magnets.
- Subsequently, we carried out a study with American Magnetics Inc. to evaluate the merit of 10 T self-shielded magnet with asymmetric coil geometry.

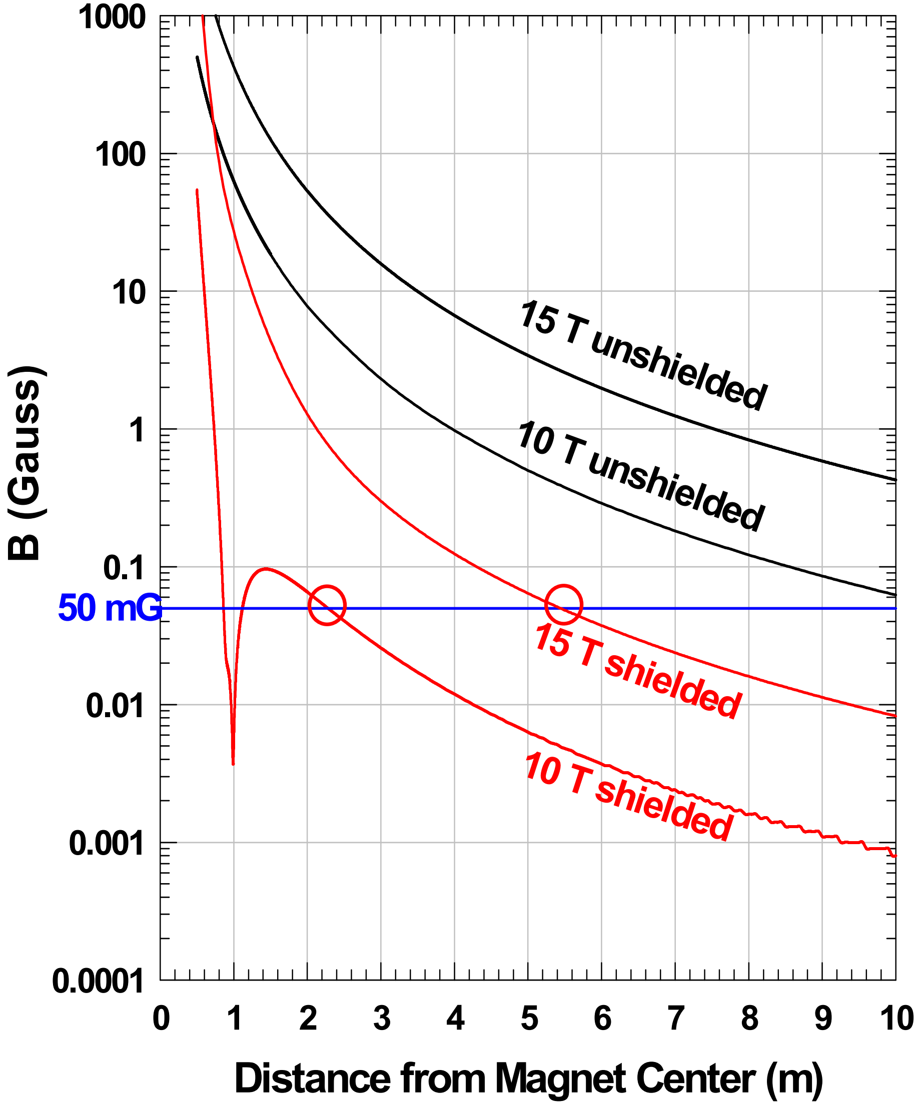
Study of 10 Tesla Compensated Asymmetric Split-pair Superconducting Magnet

- Sample field Uniformity
  - +/-1% over 20 mm diameter x 10 mm & 20 mm height
- Fringe field limit
  - Near field: <5 G at 1 m.
  - Far field: <50 mG at 5 m
- Neutron beam access
  - Horizontal angle: >320º
  - Vertical angle: +/-5º to +/-10º, +30º/-2º
- Spin-transport (Asymmetric mode)
  - From 100 G to 10 T $\frac{1}{|B|}\frac{\partial \theta_B}{\partial z}$ from 0.2 rad/G-m up to 0.082 rad/G-m

    Neutron polarization loss < 0.5% for 0.5 Å neutrons
- Magnet structure
  - Within the SNS standardized sample environment device limits – 78 cm/31" diameter in order to use it on most instruments.
  - Least amount of structural support materials in the neutron flight path

Self-Shielded Magnet

- 10 T Self-shielded magnet study (SNS-American Magnetics Inc.)
- 15 T Self-shielded magnet proposal (SNS-PSI-Bruker)



Self-shielded magnet is effective in reducing fringe magnetic field.

A shielding factor of 30-50 can be achieved with little impact on the field strength, field uniformity, spin-transport (asymmetric mode), and the force on the structure.

- **Fundamental physics (BL 13) to:**
  - **-SCD (BL12) = 4 m**
  - **-NSE (BL15) = 8 m**
- **NSE (BL 15) to:**
  - **-SCD (BL12) = 12 m**
  - **-SEQUOA (BL17) = 8 m**
  - **-ARCS (BL18) =10 m**

The first SLIM SAM – 5-Tesla compensated asymmetric magnet

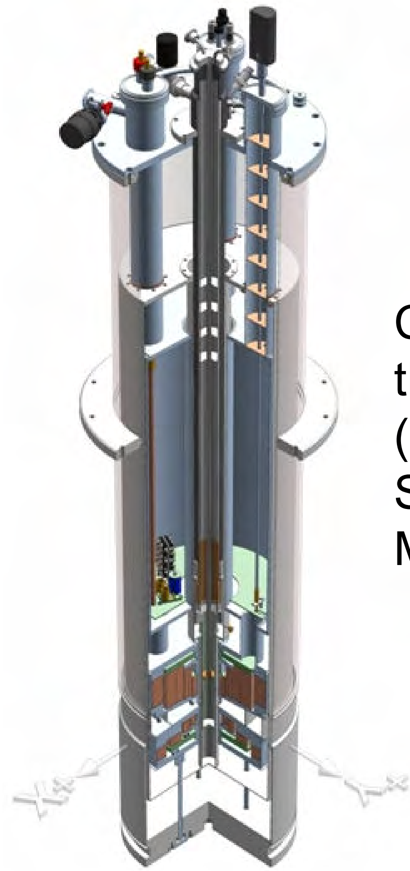
- After the study, it was decided that we really wanted a 'work horse' of a magnet system that would be for general purpose, a useable, simple to run cryostat.
- We also decided that it was a good idea to start of 'easy' with our first magnet.
- A 5-Tesla compensated asymmetric sample magnet contract was awarded to Scientific Magnetics who are based at Culham in the UK.
- This contract was to design and construct the magnet for late summer 2007.
- The magnet was delivered to the SNS in early March 2008.

The first SLIM SAM – 5-Tesla compensated asymmetric magnet specs

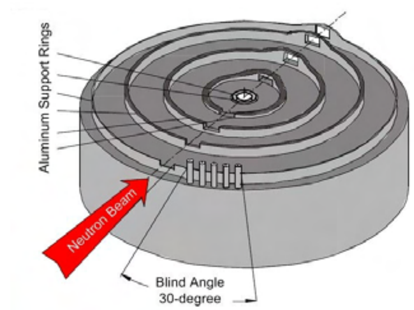
- Sample field Uniformity
  - ±1% over ø10 mm x 20 mm tall
- Fringe field limit
  - Horizontal near field <5 G at 0.5 m
  - Horizontal far field: <50 mG at 5 m
  - Vertical near field: <15 G at -0.5 m
- Neutron beam access
  - Horizontal angle: >320º
  - Vertical angle: ±5º
- Neutron spin-transport

$$\frac{1}{|B|}\frac{\partial \theta_B}{\partial r} < 0.046 rad/(G.m)$$

  - Zero-field node is outside the beam path
- Magnet structure
  - Within the SNS standardized sample environment device limits – ø 40 cm/15.5”.
  - Least amount of structural support materials in the neutron flight path



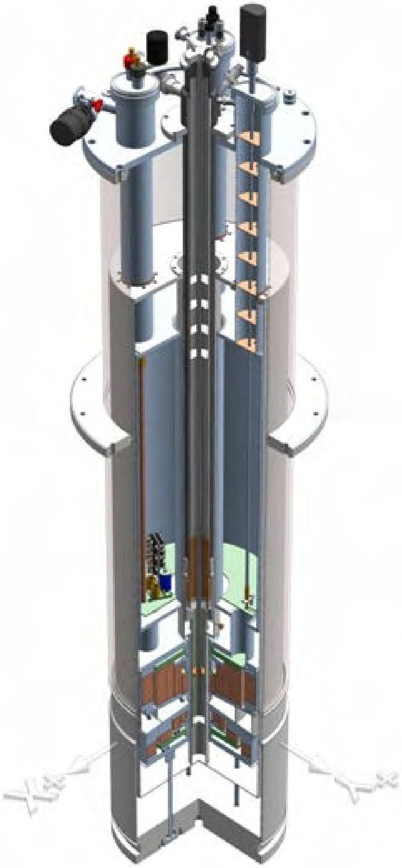
Cut-out view of the magnet (Courtesy Scientific Magnetics)



The first SLIM SAM – 5-Tesla compensated asymmetric magnet specs

- Additional requirements
  - Complete system tilt able to ± 5 degrees from vertical
  - 34mm sample space size
  - Vapour shielded helium cryostat
  - >72hr hold time with magnet persistent at 5T and VTI running at 2K
  - To have body and tail flange loading

One of the 5T coils being wound.



Cut-out view of the magnet (Courtesy Scientific Magnetics)

Arrival day in Tennessee

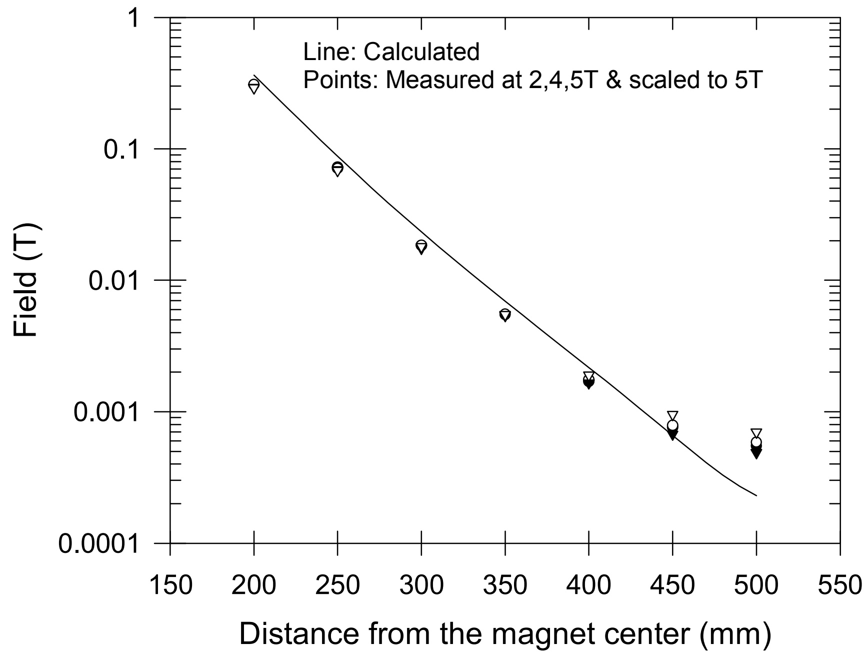
- The month of March saw the magnet system delivered to sunny Tennessee, uncrated, the transport packaging removed and it placed in the sample environment 'cage' for testing

Commissioning Time

- The system was so reliable that we were able to assemble, pump out the OVC, pre-cool overnight, fill with helium, run magnet to 5T in both directions and run the VTI at 1.6k for an extended time all in four days.
- The magnet only quenched once, it actually made 5T on its first run then went, and has been quench free since then.

The first SLIM SAM – 5-Tesla compensated asymmetric magnet

- Tests have shown that the magnet actually reached 5 Tesla.
- Fringe field measurement showed the fringe field is slightly less than the calculated values.



This is me positioning the field probe while measuring the fringe field

Slim SAM and Friends.

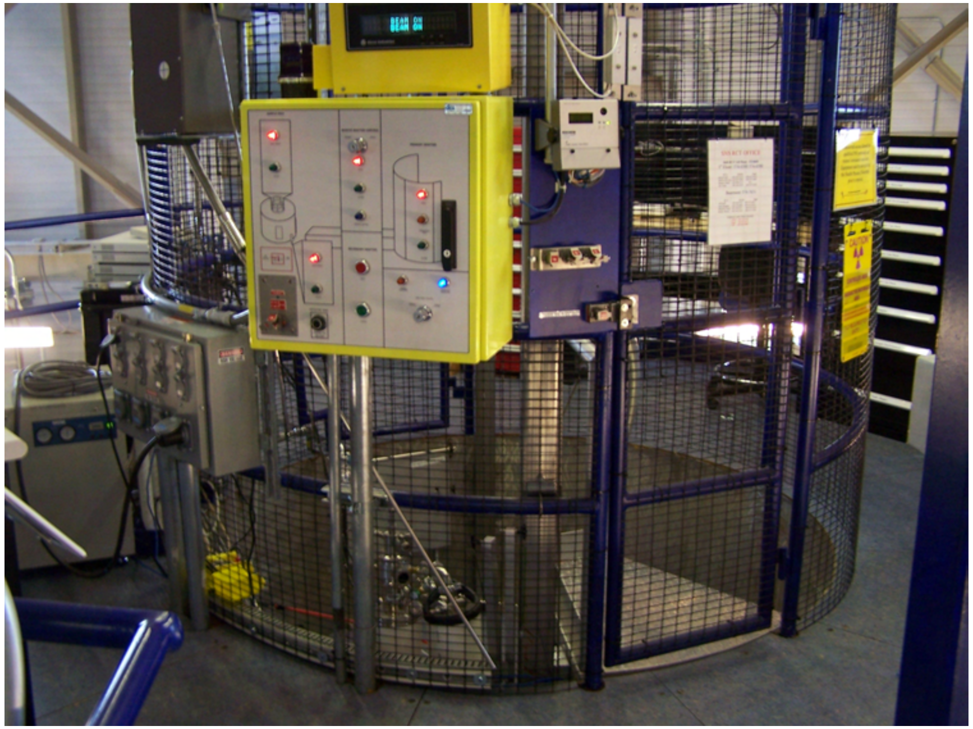
- So here it is, ready for action
- A fully commissioned 5T self-shielded asymmetric magnet system and VTI ready for the onslaught of scientists and users alike!!

First Experiment

- May 27th through 31st is the date for the first experiment of Slim Sam which will be on the backscattering spectrometer BASIS
- The fringe field compensation is instrumental in allowing the magnet to be used on BASIS.

First Experiment

- The BASIS cage, which will house sample environment equipment



Sample tank, limited space!

Getting to the beam line

- Due to the construction of further beam lines, SAM had to be transported by an outside route. Looks like a nice day again!!

Getting to the beam line

- **Nearly there, one last uphill push. SAM being pre-cooled at the base of the BASIS beam line.**

The Experiment itself

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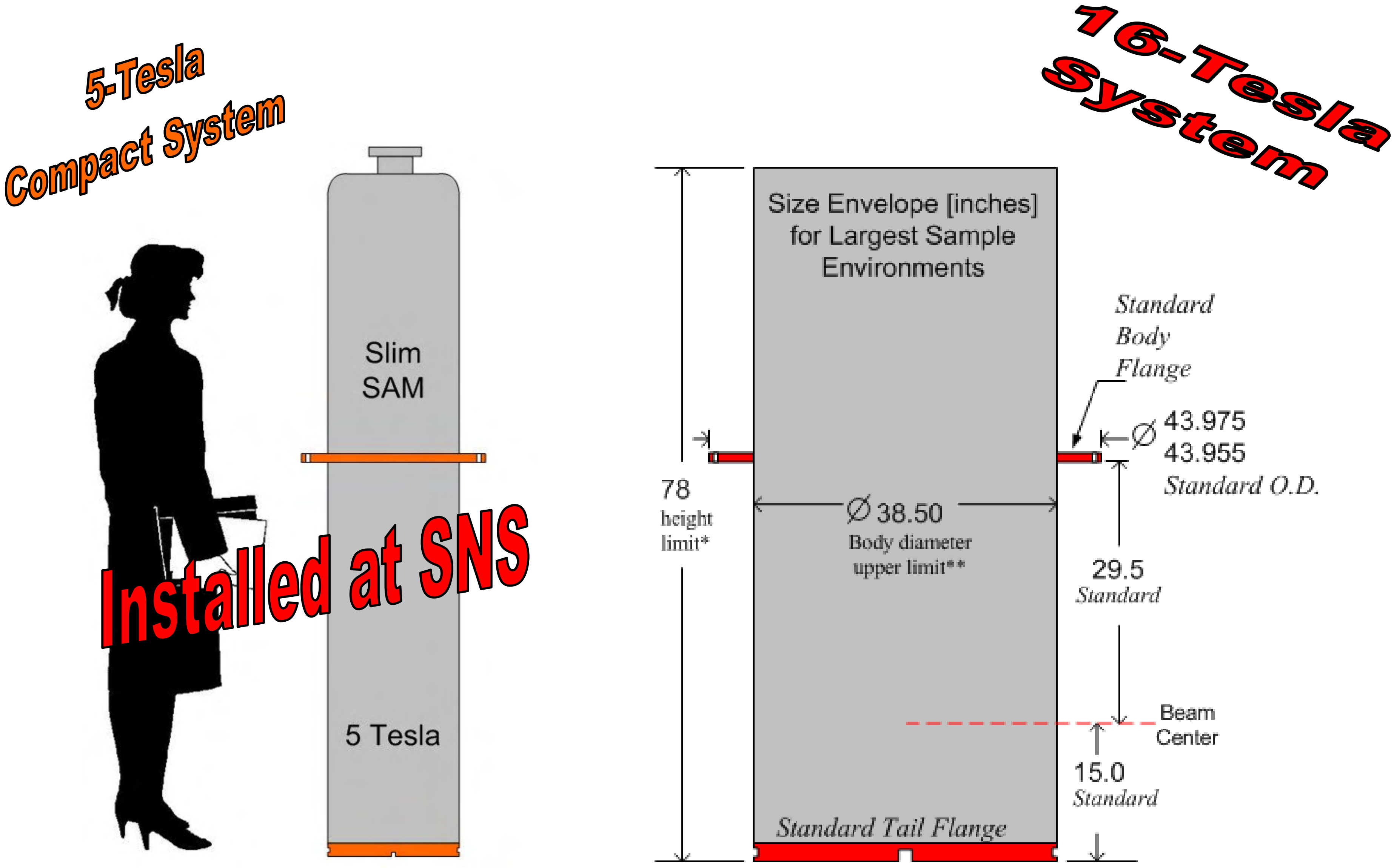
What's next for SNS?



What's next for SNS?

- A 16T SNS-PSI-Bruker collaboration with symmetric coil geometry has recently just completed its design stage.
- About to go into fabrication
- 2009 delivery date to SNS
- 10T self shielded planned in 08-09 budget
- Ready to go out to tender any day!

Acknowledgments

- Myself
- Lou Santodonato
- Wai Tung Hal Lee
- Andre A. Parizzi
- Patrick De Lurgio
- Xin Tong
- Scientific Magnetics
- NIST
- American Magnetics Inc
- PSI
- Bruker
- Los Alamos
- Anyone else who I have missed!

The last slide!

- **Thank you for listening and enjoy the rest of the workshop.**

My running partner, 58min 10k