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Development of Model Nb_3Sn Superconducting Helical Undulators (ANL Update)

S.H. Kim, Advanced Photon Source

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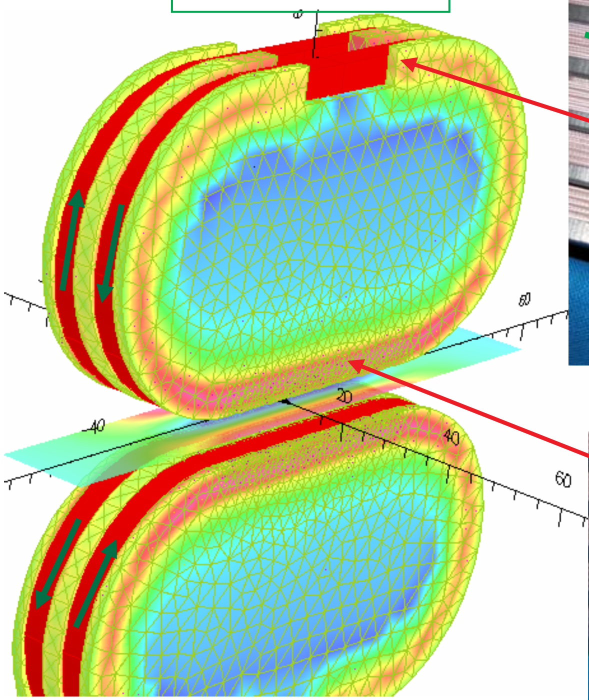
ILC Positron Source Collaboration Meeting at ANL

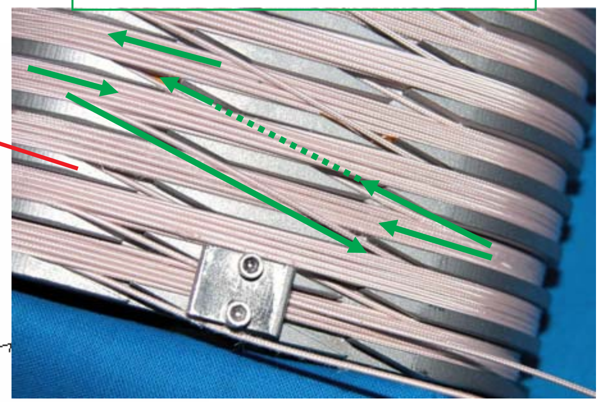
Introduction

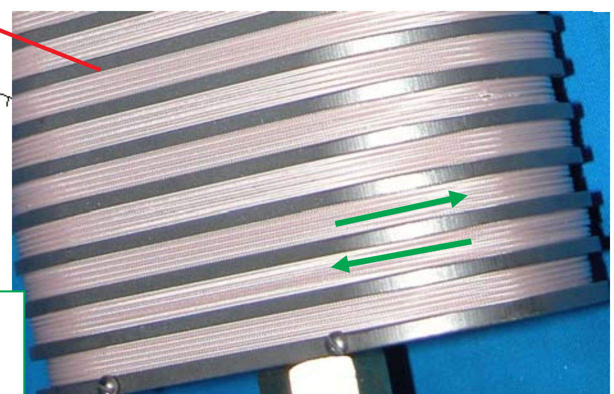
- Currently, 4.5-mm-period planar-type Nb_3Sn superconducting undulators (SCUs) and a horizontal field measurement system are under development for the Advanced Photon Source (APS)
  - Oven for low-carbon steel heat treatment & SC reaction
  - Full scale coil winding machine
- The skills and facilities at the APS could be easily adapted to developing helical SCUs and field mapping
- LDRD Project "Undulator for the ILC Positron Source" began in April, 2006:
  - To design test facilities for field mapping and SC stability
  - To develop model Nb_3Sn helical SCUs for the test facilities
- Brief update of planar and helical Nb_3Sn SCUs development at ANL

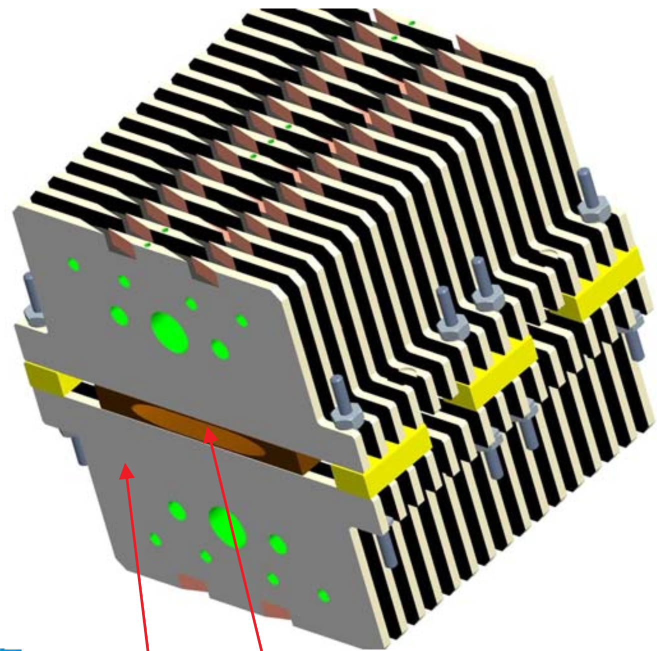
Planar Nb_3Sn SCU

Design, Fabrication & Assembly



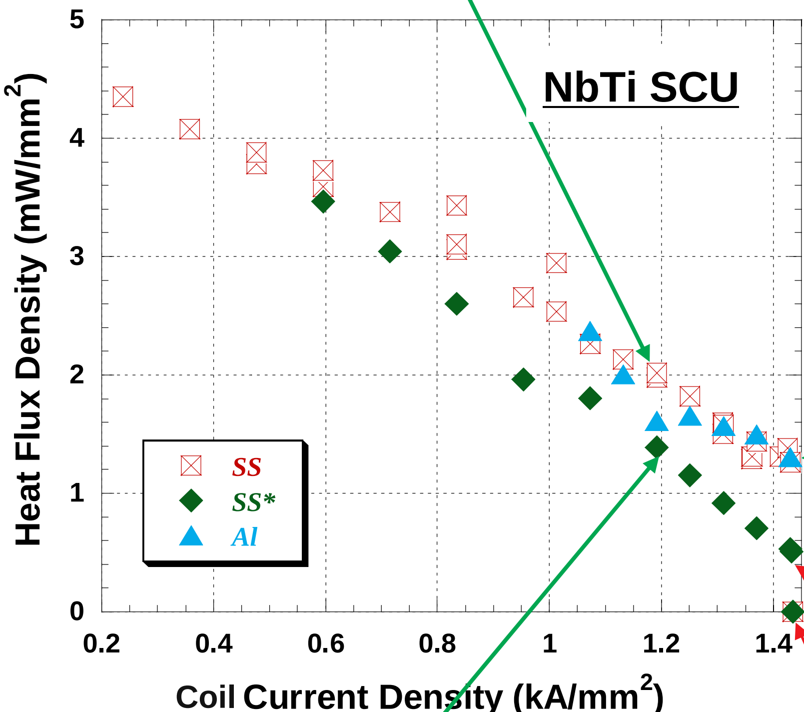






Heat Loads (steady state) Tests in Pool-Boiling LHe 4.2 K

Heat flux needed to quench the coil with LHe at the coil/chamber interface

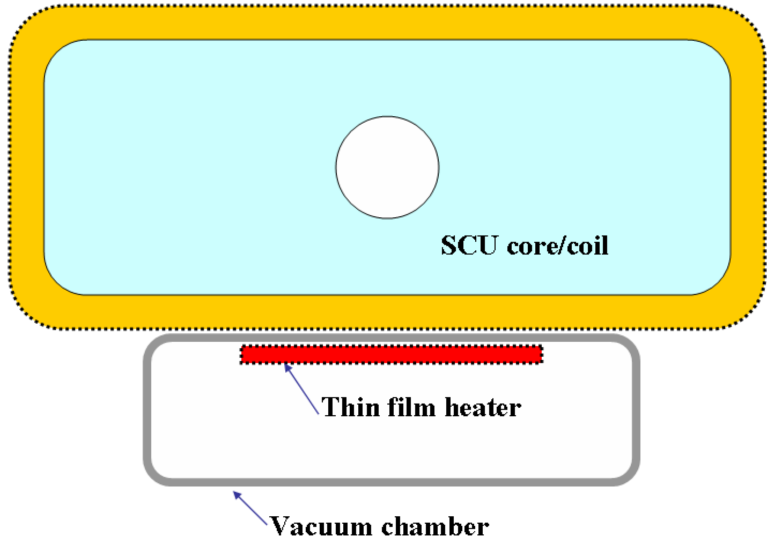


1.3 mW/mm² (26 W/m)

0.5 mW/mm² (10 W/m)

1202 A

1204 A

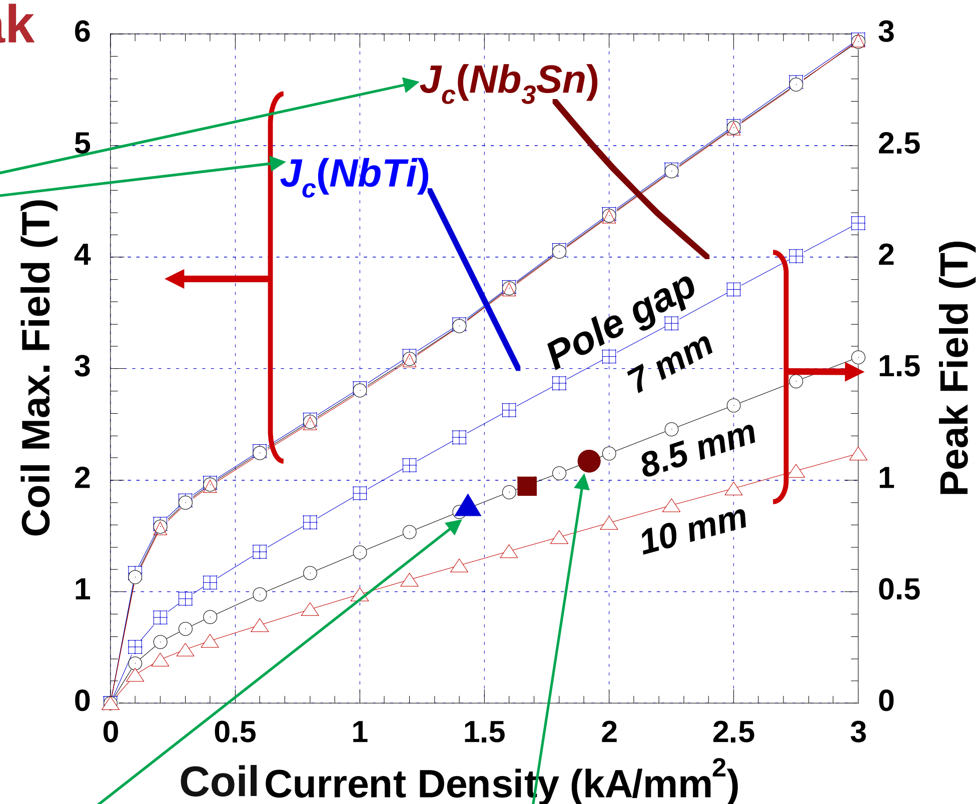


Heat flux needed to quench the coil without LHe at the interface

Planar NbTi & Nb_3Sn SCUs, λ = 14.5 mm

Achieved Current Densities &Peak Fields for Short Models at 4.2 K

J_c: Average critical current density in the coil pack ("engineering" J_c)



- J: Achieved current density in the coil pack
- B_{max}: Coil maximum field
- B_0: Peak field on the beam axis for a pole gap of 8.5 mm

Parameters	NbTi	Nb_3Sn
J_c at B_{max}	1.5 kA/mm², 3.48 T	2.12 kA/mm², 4.46 T
J at B_0	1.43 kA/mm², 0.86 T	1.92 kA/mm², 1.08 T
J/J_c ratio	> 95 %	~90 %

Helical Undulator: Magnetic Field Analysis

(Helical) Solenoid Smythe (1939) $B_{tr} = \frac{\mu_0 I}{\lambda}\{kr_0 K_0(kr_0) + K_1(kr_0)\}$

Helical Undulator Kincaid (1977) $B_0 = 2B_{tr}$: **On-axis transverse field**

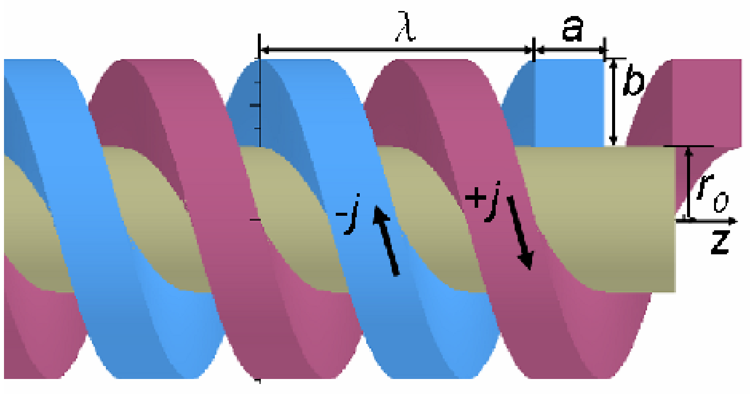
Current I in a filamentary wire on radius r_0

Helical Undulator with coil dimensions (a, b)

By expressing the current density in Fourier series,

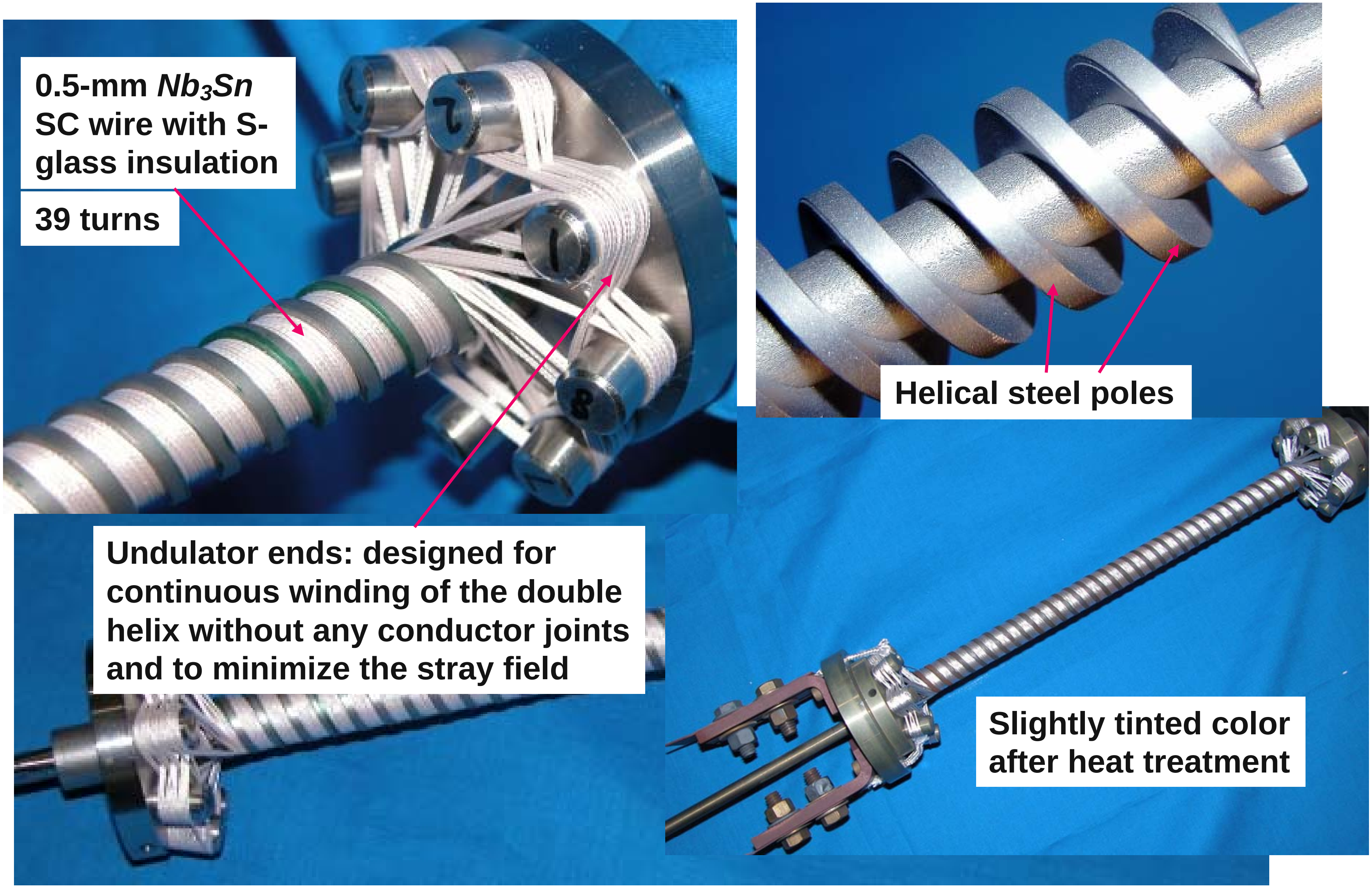
$$\mathbf{B}(kz-\phi) = B_0\left\{\hat{r}\cos(kz-\phi) + \hat{\phi}\sin(kz-\phi)\right\}$$

$$B_0 = \frac{2\mu_0 j\lambda}{\pi}\sin\left(k\frac{a}{2}\right)\int_{r_0}^{r_0+b}\{krK_0(kr) + K_1(kr)\}\frac{dr}{\lambda}$$



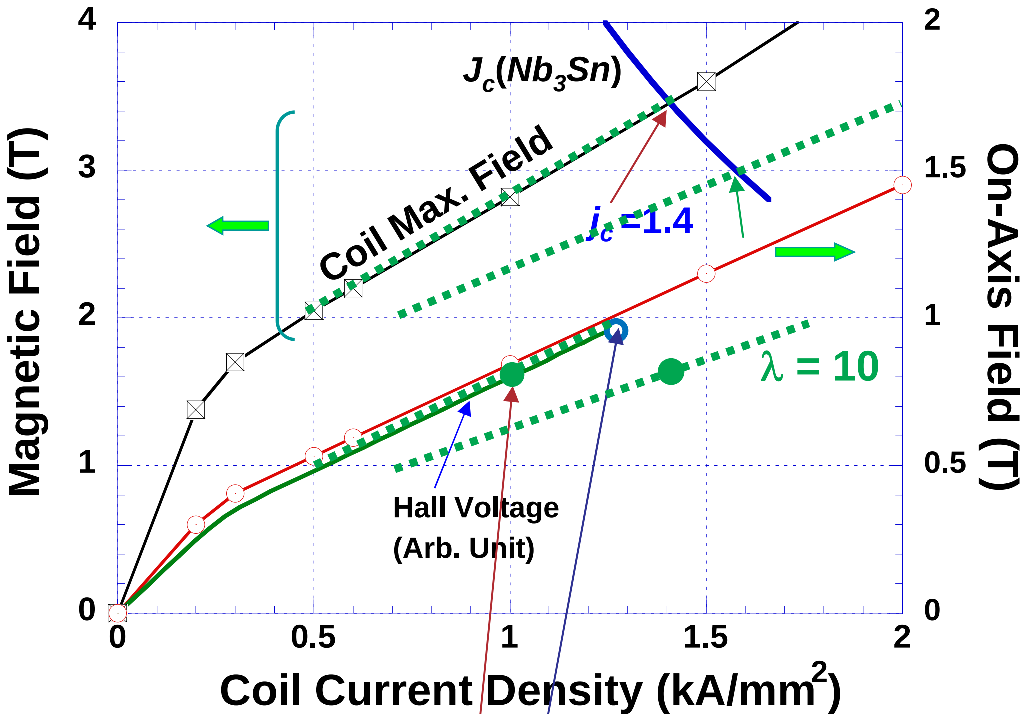
- ***B_0*** **has the first harmonic only regardless of the coil/pole width ratio**
  - **modified Bessel function *$I_n(n2\pi r/\lambda) \rightarrow 0$ as $r \rightarrow 0$, ($n > 1$)***
- **Off-axis field, however, contains higher harmonic fields**
- **Nonlinear steel poles: for a constant *$j\lambda$*, the magnetic flux density distribution, including *B_0*, remains unchanged provided that the undulator dimensions are scaled according to the period ratio**

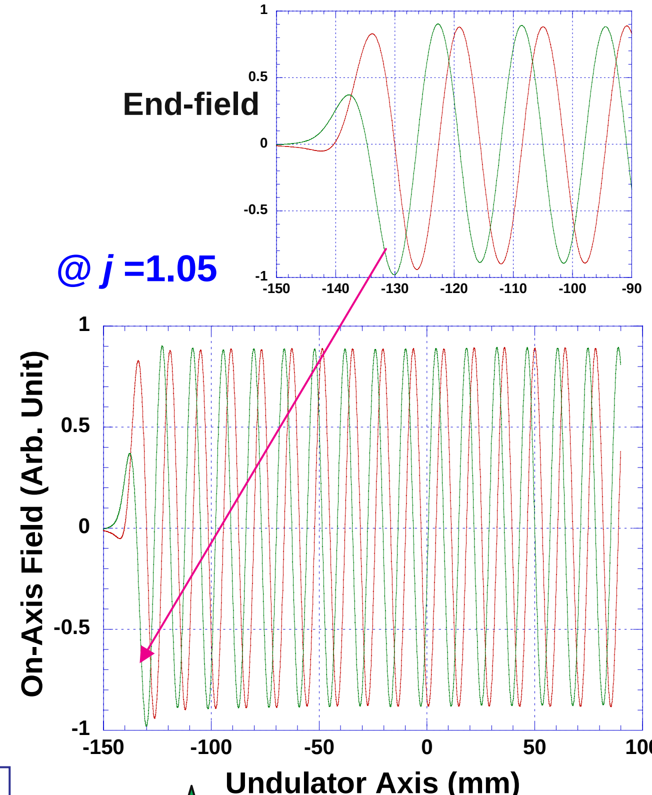
Helical Nb_3Sn SCU Fabrication, λ = 14 mm



Helical Nb_3Sn SCU, λ = 14 mm, r_0 = 3.97 mm

Calculation and Test Results at 4.2 K





Approx. B_0 =1 T, j =1.28 (820 A, 90% of j_c) after four quenches

$j\lambda$ Scaling Law

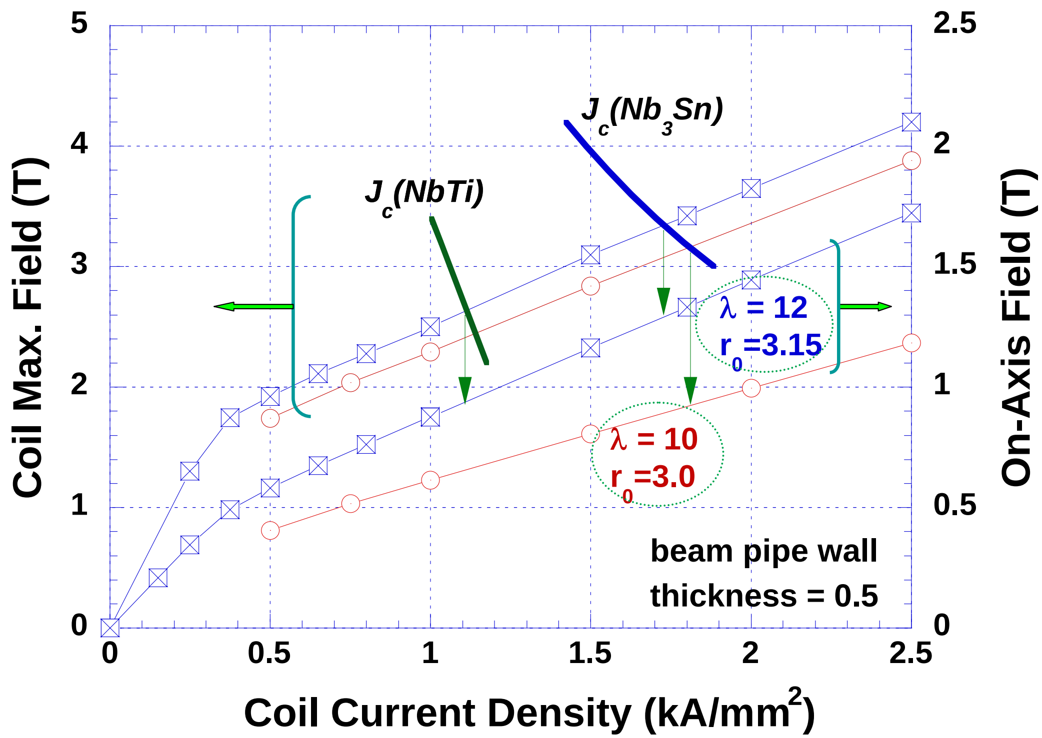
B_0 = 0.8, λ = 14, j = 1.0, r_0 = 3.97, a, b

B_0 = 0.8, λ = 10, j = 1.4, r_0 = 2.84

Peak field deviation < $7x10^{-3}$

Higher harmonics coeff < $5x10^{-3}$

Helical Nb_3Sn SCU: achievable fields?



Increase the conductor packing factor in the coil pack $J_c(Nb_3Sn)$
→reduce the insulation thickness

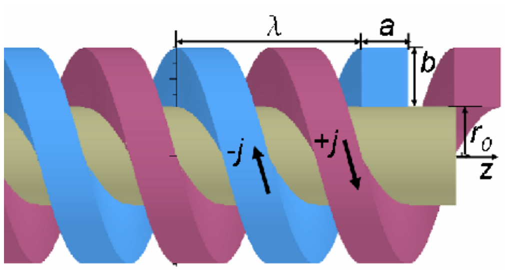
Ceramic insulation development
→nGimat Co. under a DOE SBIR

Insulation thickness:

Formvar: ~15 μm

S-glass: 50 ~ 65 μm

nGimat: 10 ~ 25 μm



$$K_h = \sqrt{2}K$$

λ [mm]	r_0 [mm]	J_c [kA/mm²]	B_0[T] @J_c	B_0[T] @0.8J_c	K @0.8J_c
12	3.15	1.73	1.28	1.08	1.21
10	3.15	1.84	0.86	0.73	0.68
11	3.0	1.8	1.15	0.98	1.0
10	3.0	1.81	0.92	0.79	0.74

Not plotted in the figure

APS Groups:
Engineering Group
Magnetic Devices Group (Group Leader: Liz Moog)

Kurt Boerste	**John Grimmer**
Tom Buffington	**Quentin Hasse**
Jeff Collins	**Suk Hong Kim**
Roger Dejus	**Robert Kustom**
Frank Depaola	**Mike Merritt**
Chuck Doose	**Shigemi Sasaki**
Joel Fuerst	**Isaac Vasserman**

Summary: Helical Nb_3Sn SCU

- **The goal of the program at ANL is to develop a field mapping system:**
  - **For the mapping system, ~10-mm-period models of Nb_3Sn helical undulators are to be developed to meet the ILC design parameters**
  - **A short 14-mm-period model Nb_3Sn undulator has been designed, fabricated, and tested in LHe. The average current density in the coil pack reached 1.28 kA/mm² (~90% of J_c).**
  - **Analytical and numerical analyses and a scaling law are continued**
- **Essential R&D and engineering tasks:**
  - **Achieve the highest field for the shortest period using SC wire with S-glass insulation for short models**
  - **Develop and test a 2- to 3-m-long undulator to demonstrate the field quality and mechanical integrity including cryostat**
  - **Achieve the highest field for the shortest period using SC with ceramic insulation when available**
  - **Test the stability or stability margin of the undulator under LHe pool-boiling and/or using cryocoolers**
- **LDRD support: $36.6K in FY06, $40K in FY07, $40K in FY08??**