Development of Nb3Al Superconducting Magnets for LHC Luminosity Upgrade

- Technical Progress and Further Plan -

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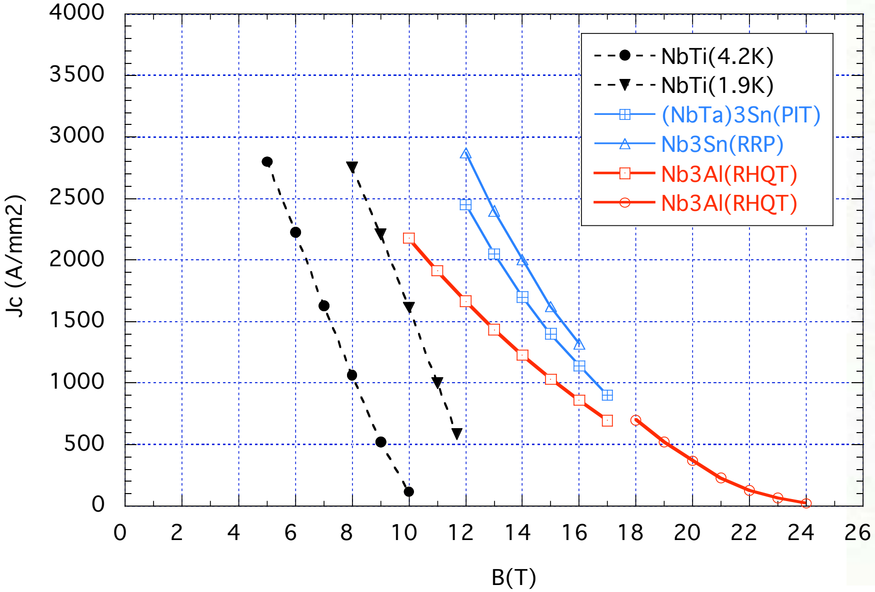
KEK

CERN-KEK Committee, 3rd meeting, 12 December, 2008

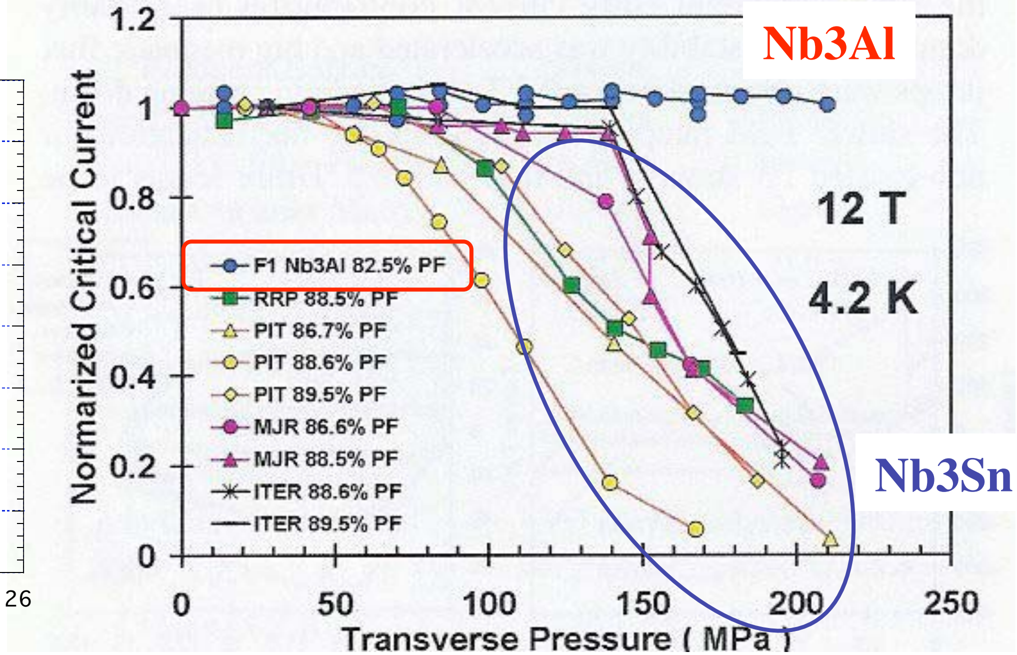
Advantage of Nb_3Al over Nb_3Sn

As of now, critical current density (Jc) of Nb3Sn is higher than Nb3Al. But, ….

Jc vs. B



Jc vs. Stress



Presented at MT-20
By A. Kikuchi et al.

Better mechanical performance of Nb3Al >> No degradation of Jc below 210 MPa.

For Nb3Sn (RRP), Jc is decreased to be around half at 150 MPa.

@B=12T Jc~3000 A/mm² --> 1350 A/mm²

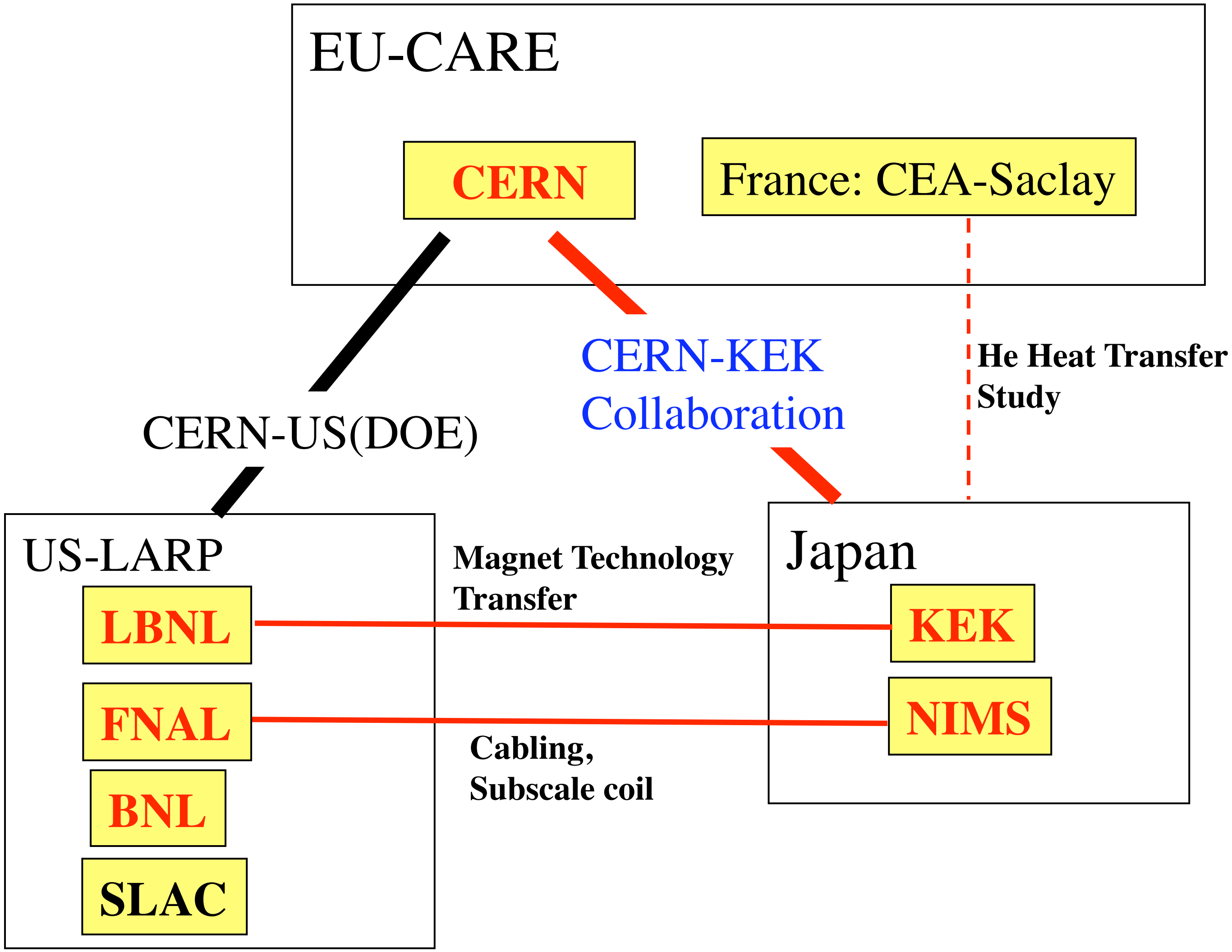
Objective

For the LHC luminosity upgrade, we have been developing

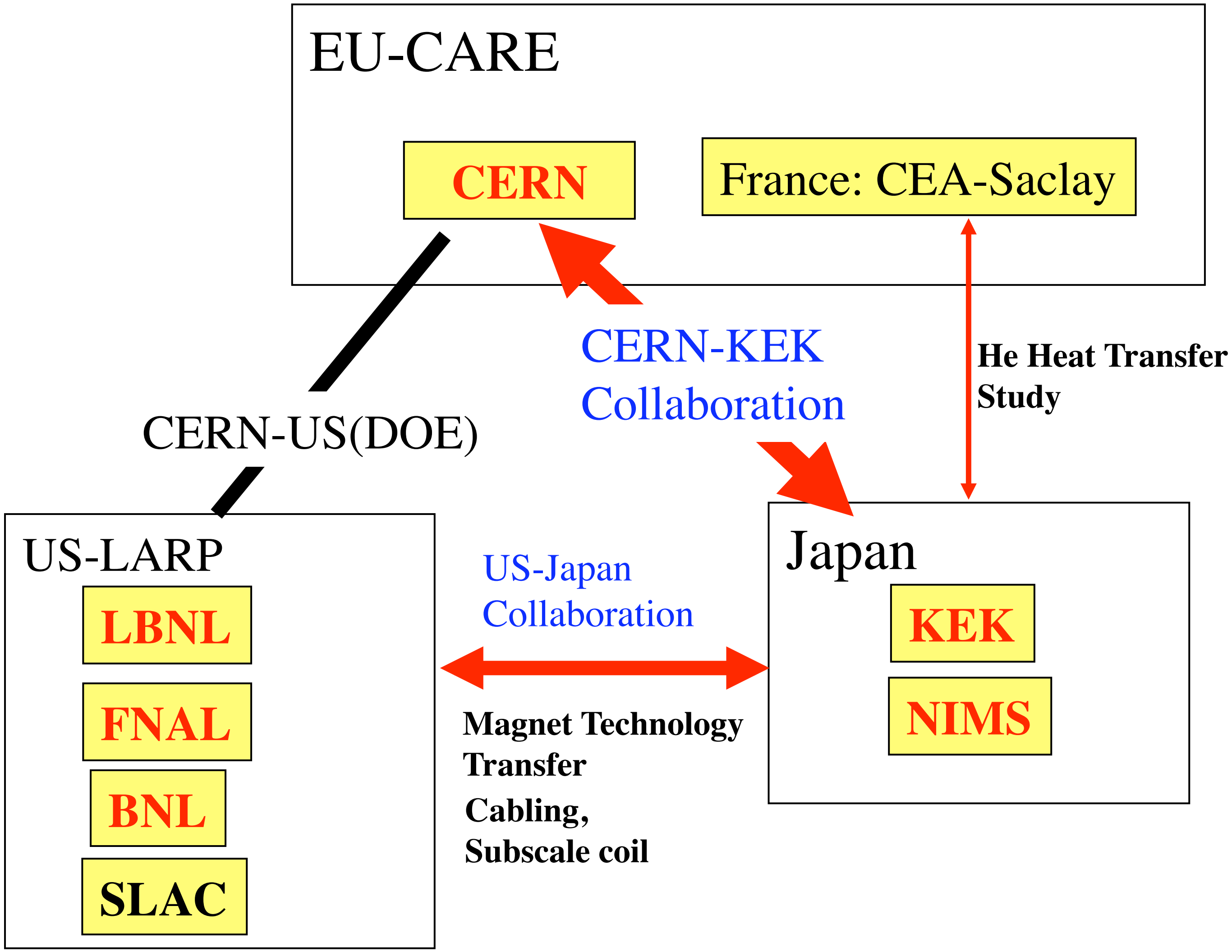
-High field superconductor and cable made with Nb_3Al,

Complementary to Nb_3Sn superconductor and magnet development at CERN and US-LARP.

High Field Accelerator Magnet Development
A Global Cooperation Network: Present



High Field Accelerator Magnet Development
A Global Cooperation Network: Proposal



Participants / Collaborators

KEK: N. Kimura, T. Nakamoto, T. Ogitsu, K. Sasaki,
A. Terashima, K. Tsuchiya, Q. Xu, and A. Yamamoto,
NIMS: N. Banno, A. Kikuchi, and T. Takeuchi,

In cooperation of:
CERN: L. Rossi/G. de Rijk et al., (TBA)
Fermilab: M. Lamm et al., (TBA)
LBNL: G. Sabbi/S. Caspi et al., (TBA)
BNL/LARP: P. Wanderer et. al., (TBA)
CEA/Saclay: B. Bourdy et al (TBA)

Technical Progress in 1st stage
JFY2006-2008

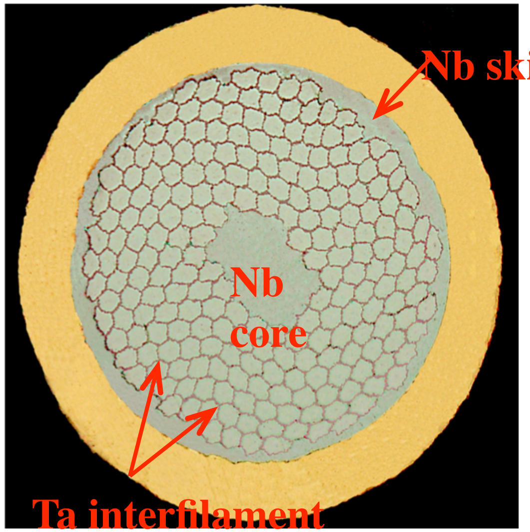
Development Items

- Strand development (KEK and NIMS)
  - Higher non-Cu Jc: Target 1500 A/mm2 at 15 T
  - Reduction of low-field-magnetization
    - Ta-matrix (Non-superconductor at 4.2K)
      - Ta sheath wire by KEK
      - Nb sheath wire by NIMS

Break at extrusion & drawing
Effects to Jc?

  - Cu stabilization technique
    - Mechanical strength
    - Electroplating on Ta-matrix wire
    - Long piece-length

ME493



- Cable development (NIMS and Fermilab)
  - trial fabrication
    - packing factor
    - twist pitch
  - race track coil

Nb3Al: Rapid Heating Quench Method

Mono-filament

↓ Jerry-Roll: Nb+Al sheets, Nb or Ta core

Multi-filament

↓

Precursor (Nb/Al)

↓ ⇐ Rapid Heating Quenching (RHQ)

(Nb/Al)ss — Strand w/o Cu

↓

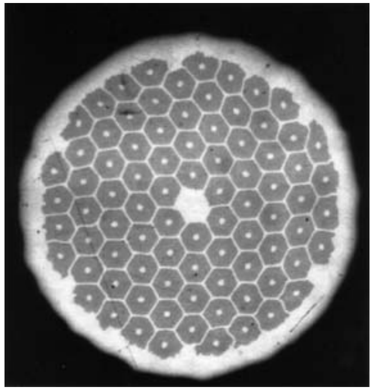
Cu stabilization

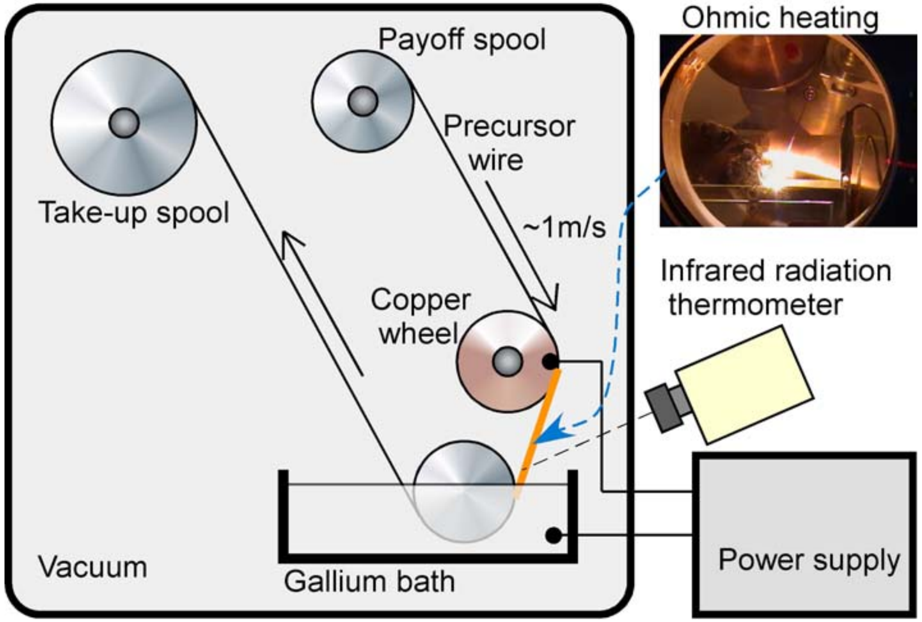
↓

Area reduction

↓ ⇐ 2^{nd} heating (800°C×10h)

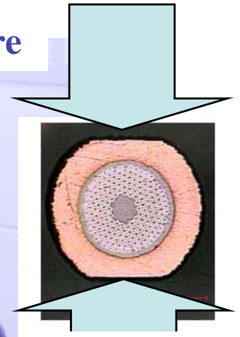
Nb_3Al — A15 strand w/ Cu





Continuous Electroplating for Ta-matrix Wire

~1.5 m/h : thickness of ~170 μm Cu

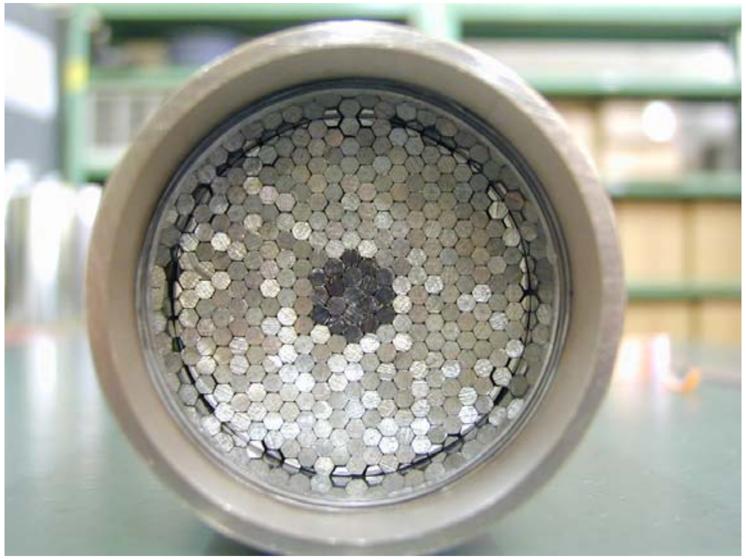


Rolling

Nb-Al billet fabrication experience (Hitach Cable)

Extruder	Billet size	1.35ϕ wire length	# of fabrication ~2005	~2008
100 ton	28 mmϕ ,< 150 mmL	~35 m	many	
400 ton	61 mmϕ ,< 300 mmL	~330 m	~30	+ 9
4000 ton	141 mmϕ ,< 600 mmL	~4000 m	3	

4000 ton billet



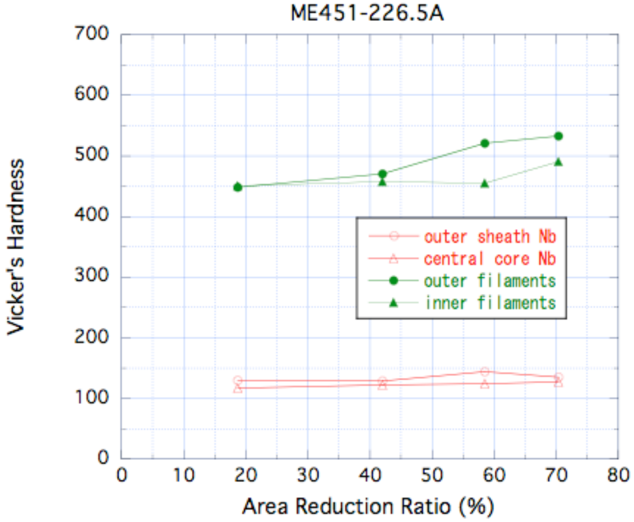
Fabricated or fabricating strands

	2003		2005			2006	2006		2007		2007		2008	2008
線材 No.	M21-3		ME451			ME458	ME476		ME492		ME493		ME1	ME2
Matrix material	Nb		Nb			Nb	Ta		Ta		Ta		Ta	Ta
Core material	Nb, Nb		Nb, Nb			Nb, Nb	Ta, Ta		Ta, Ta		Nb, Nb		Nb, Ta	Nb, Nb
Matrix ratio Skin	0.8		0.69			0.79	0.8	Nb	0.8	Ta	0.8	Nb	0.8 Ta	0.8 Nb
Num of filam	144		294			546	222		222		222		222	222
Billet dia (mm)			55.5 ϕ			58 ϕ	57.5 ϕ		57.5 ϕ		57.5 ϕ			
Frequency of wire breaking			3			3 and crack	2		7		4			
RHQ														
Wire dia (mm)	0.8		1.35			1.35	1.35		1.35		1.35		1.35	1.35
Filam dia (μm)	51		62.7			44.2	69		69.8		69.8		69	69
Barrier thick(μm)	4.6		6.4			4.4	8		8		8		10	8
Al thickness (nm)	170		150			150	208		211		211		210	210
Twist pitch (mm)	32		55			0	54		0		0		54	54
RHQ I (A)	80.6	80.6	228	228		222	226	226		202				
AR ratio (%)		32						45		72		66.2		
wire dia (w/o Cu)		0.66		0.94	0.72			1.00		0.715		0.785		
wire dia (with Cu)								1.40		1.00		1.00		
filament dia (μm)		34.7		44	33			38		37		40.6		
barrier thick (μm)		3.1		4.5	3.4			4.4		4.2		4.7		
twist pitch (mm)								98		45		45		
non-Cu Jc (A/mm2)														
@ 10T w/o AR	1602													
@ 12T	1172													
@ 15T	661					430	623							
@ 10T AR		2176			1720					1776		1669		
@ 12T AR		1663			1302					1320		1230		
@ 15T AR		1032	630	949	817			807		785		718		

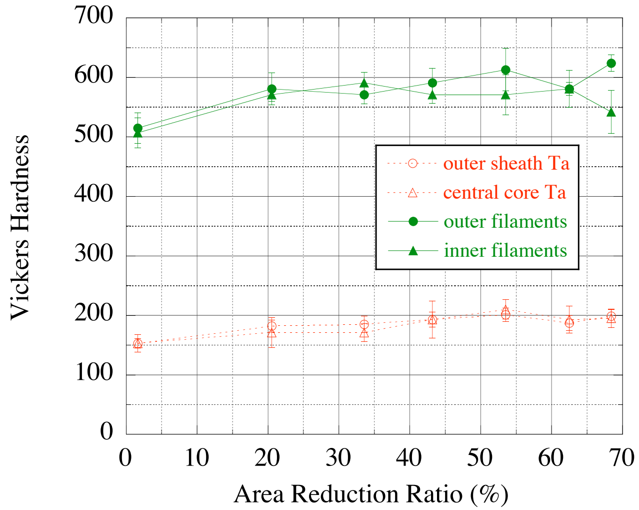
Mechanical Property of Nb3Al Wire (No Copper)

Vicker's hardness

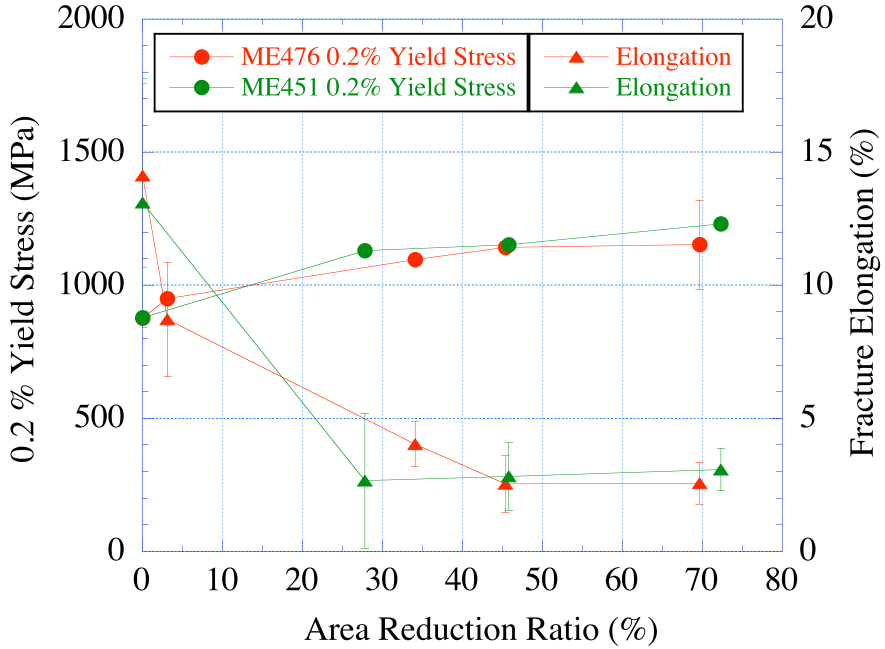
Nb-matrix (ME451)



Ta-matrix (ME476)



0.2% Yield Stress & Fracture Elongation



Difference b/w Nb and Ta is not so significant.

Continuous Electroplating for Ta-matrix Wire

KEK

1) Strike plating of thin Ni on the surface
2) Electroplating of thick copper
3) Heat treatment for stabilize the bonding

electroplating speed: ~1.5 m/h

(Cu thickness of ~0.17 mm)

NIMS

1) Ion-plating of thin Cu
2) High speed electroplating of thick copper
3) Heat treatment for stabilizing the bonding

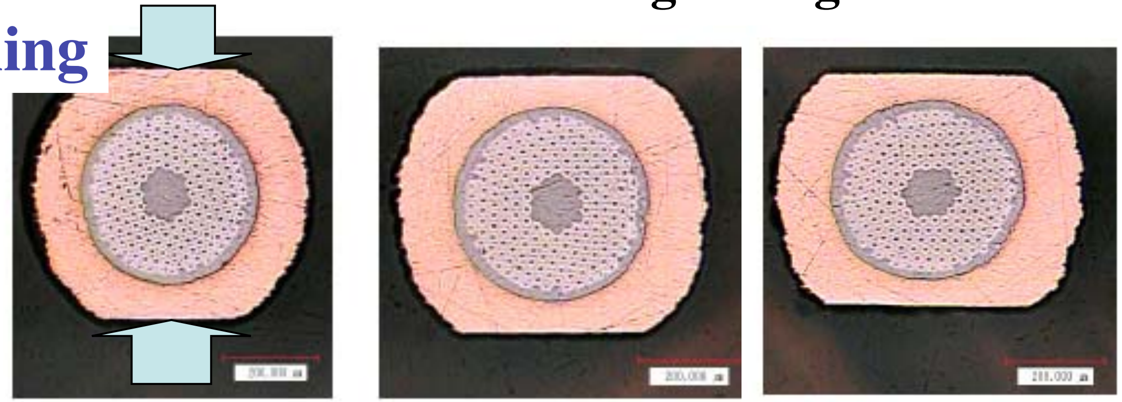
ion-plating speed: 120 m/h

electroplating speed: ~6 m/h

Copper Stabilizer

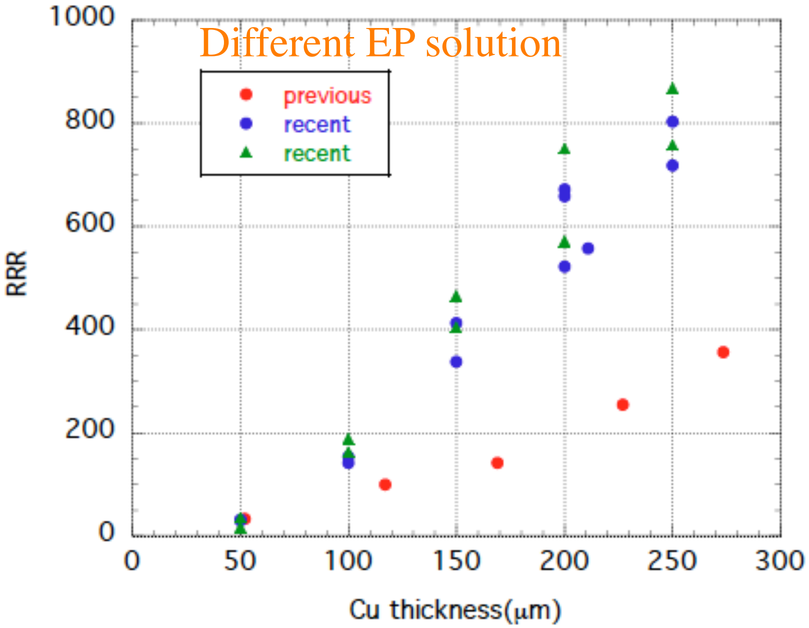
Mechanical Bonding Strength

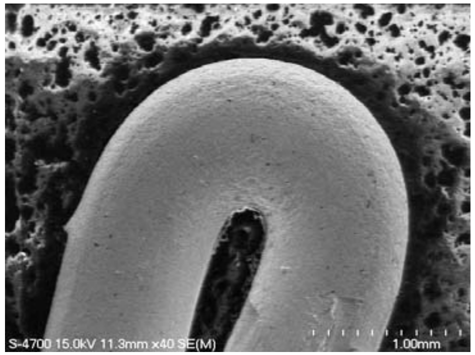
Rolling



(18) (19) (20)

RRR of electroplated copper



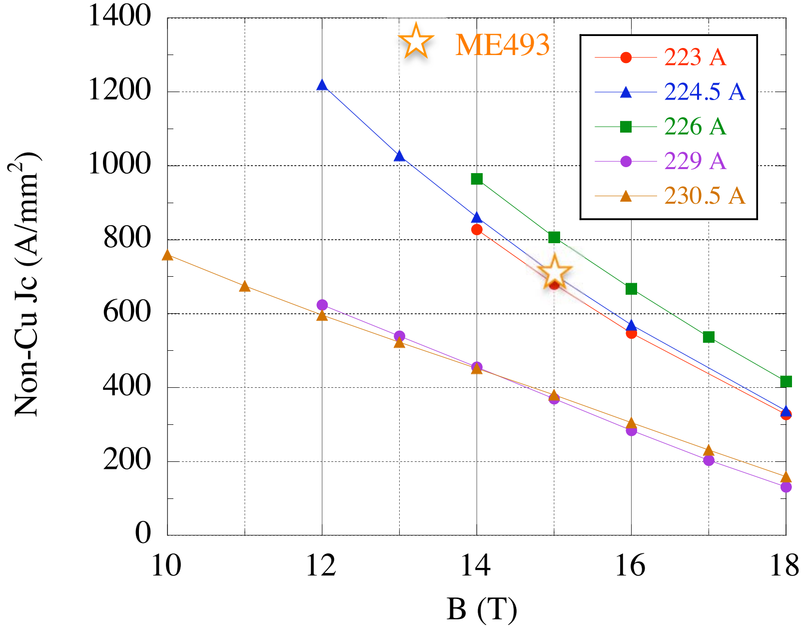


Bent wire to see the folds and projections of Cu stabilizer

Jc of Nb3Al Wire with Ta Matrix

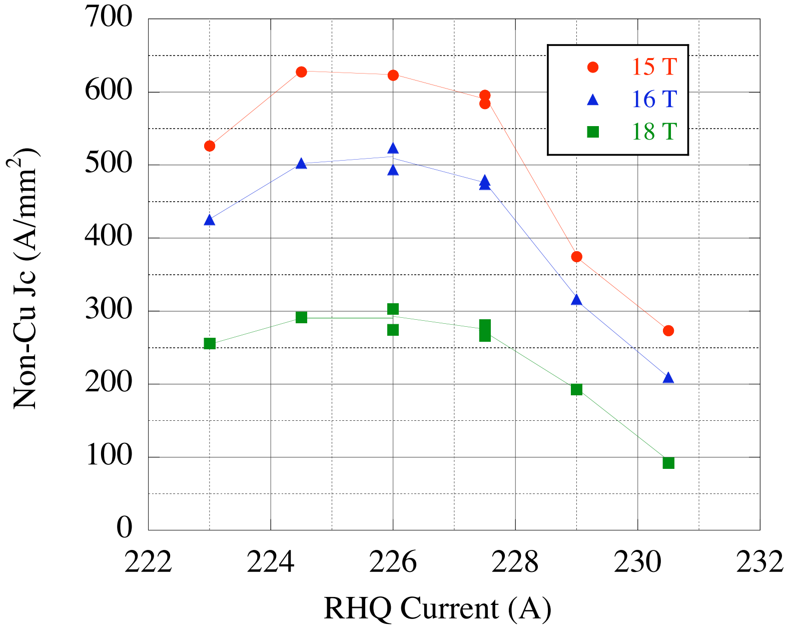
Non-Cu Jc of ME476 (with Ta matrix)

wire dia = 1.0 mm
ME476 w/ Ta 807 A/mm2 @15T
ME493 w/ Ta 718 A/mm2 @15T
(ME451 w/ Nb 946 A/mm2 @15T)



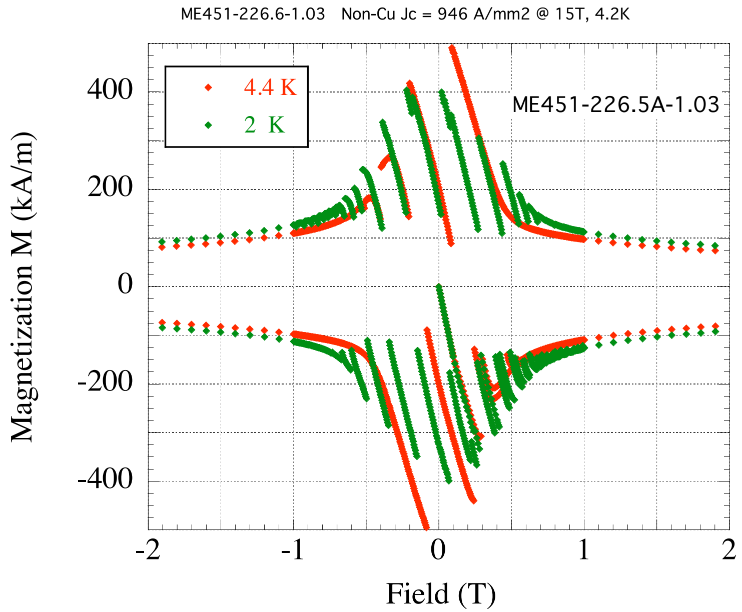
Note: Non-Cu Jc of the samples treated at different RHQ current

Effect of the RHQ current on non-Cu Jc
(wire dia = 1.35 mm)

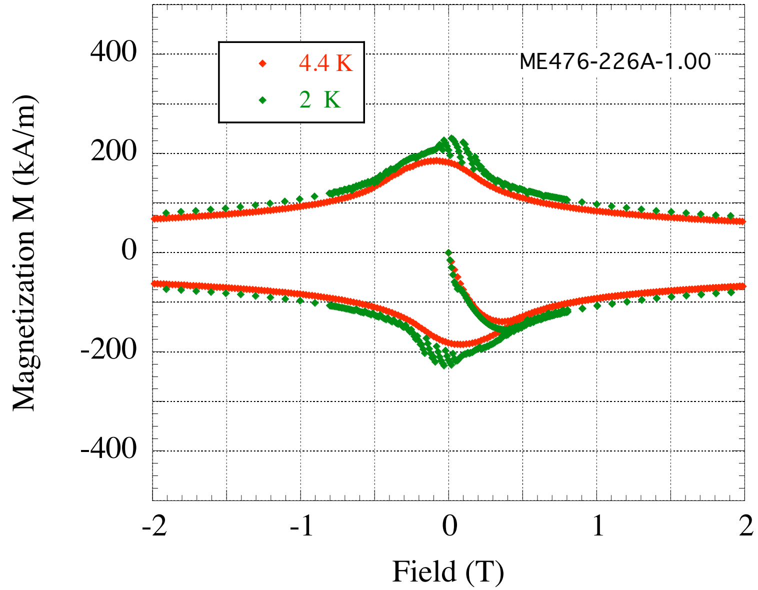


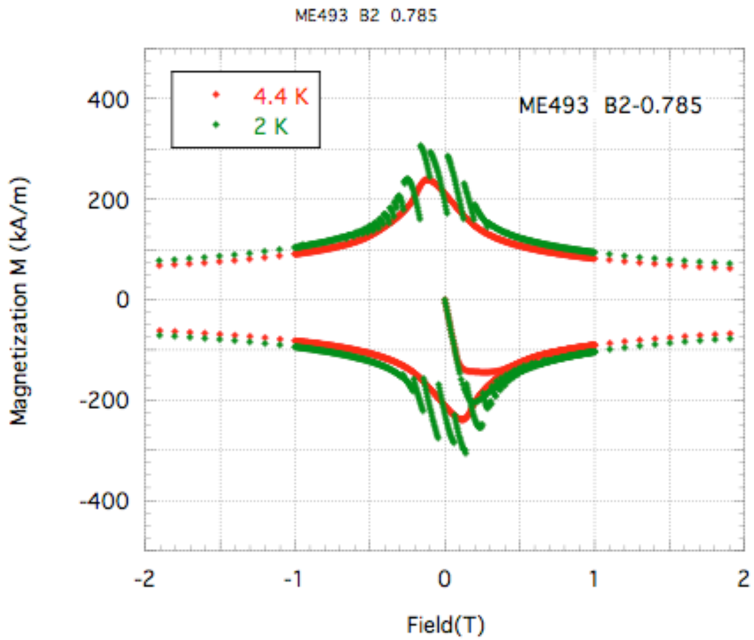
Low Field Magnetization

Nb-matrix (ME451)



Ta-matrix (ME476, 493)



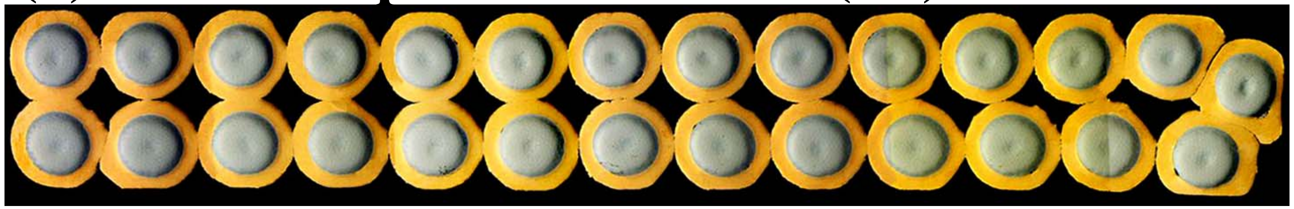


No flux jumps observed at 4.4 K

Progress at NIMS/Fermilab -Cabling-

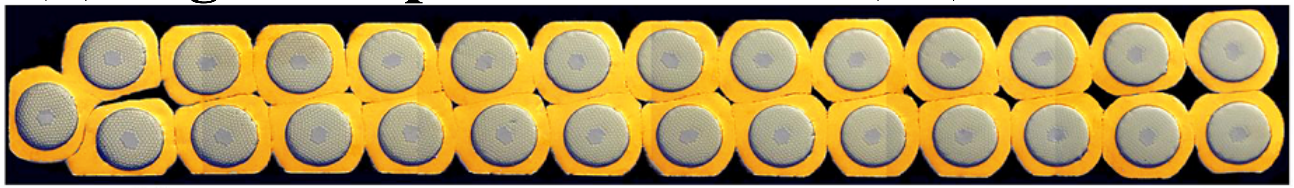
Nb_3Al cable R&D (FY2006-2007)

(a) Low Compacted 27 strand(F1) Cable



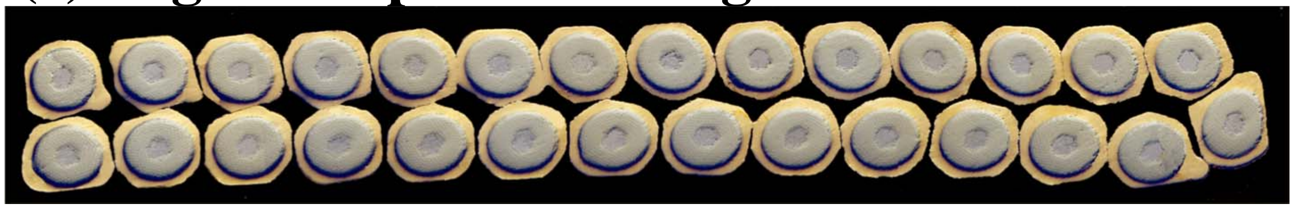
Width: 14.17 mm, Thickness: 1.99 mm, Rectangular, PF: 82.5 %

(b) High Compacted 27 strand(F3) Cable



Width: 14.18 mm, Thickness: 1.78 mm, Keystoned, PF: 87.0 %

(c) High Compacted & High Current 28 strand(F4)



Width: 13.95 mm, Thickness: 1.85 mm, Rectangular, PF: 86.5 %

Increasing of

Cable Packing Factor

(82% → 87%)

Increasing of

Cable Critical Current

(27strand → 28 strand)

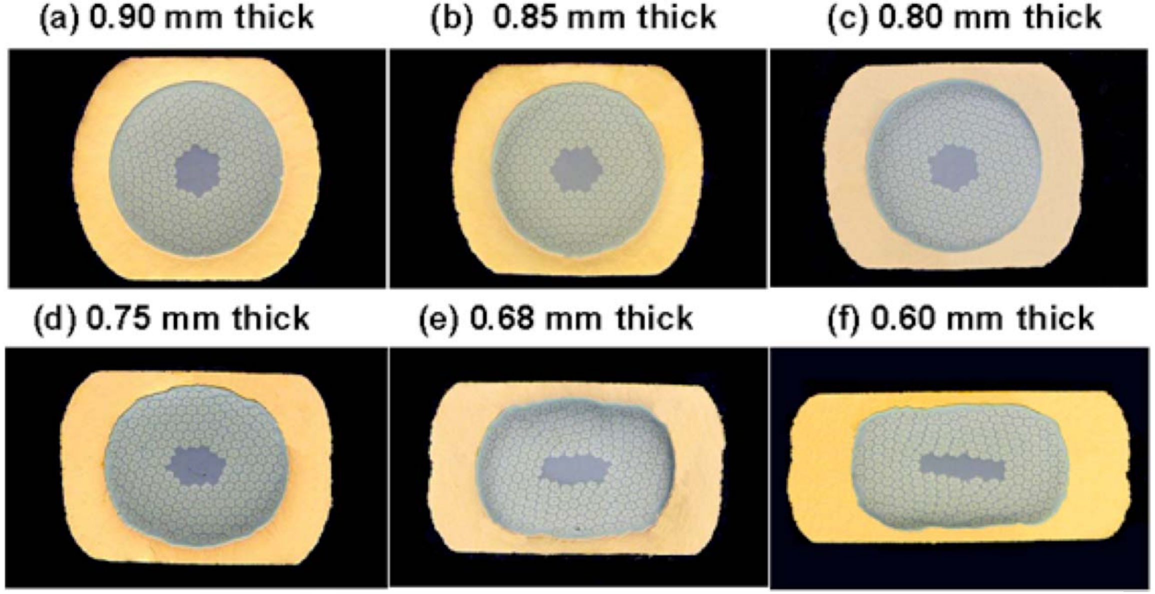
(Cu ratio: 1.0 → 0.6)

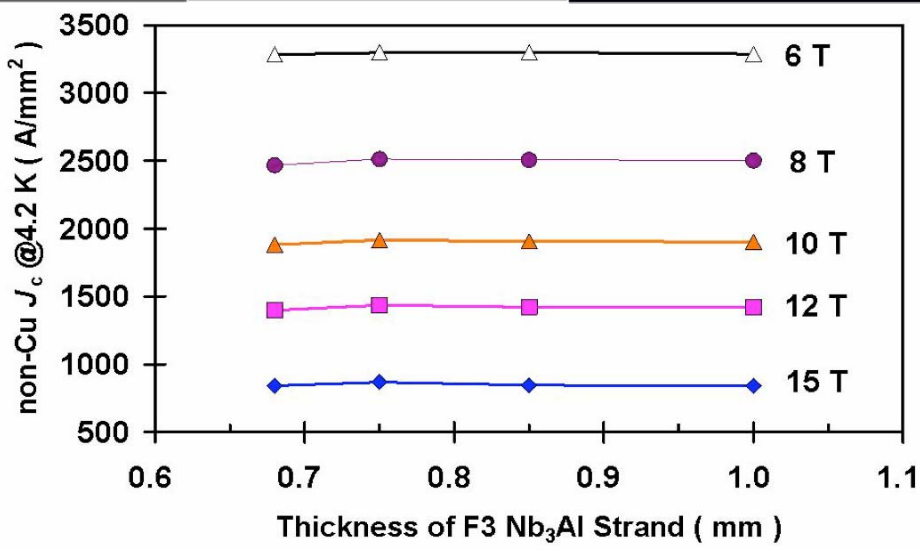
Feasibility of Nb3Al Rutherford cable has been demonstrated.

National Institute for Materials Science (A. Kikuchi)

Progress at NIMS

Jc is not affected by mechanical deformation





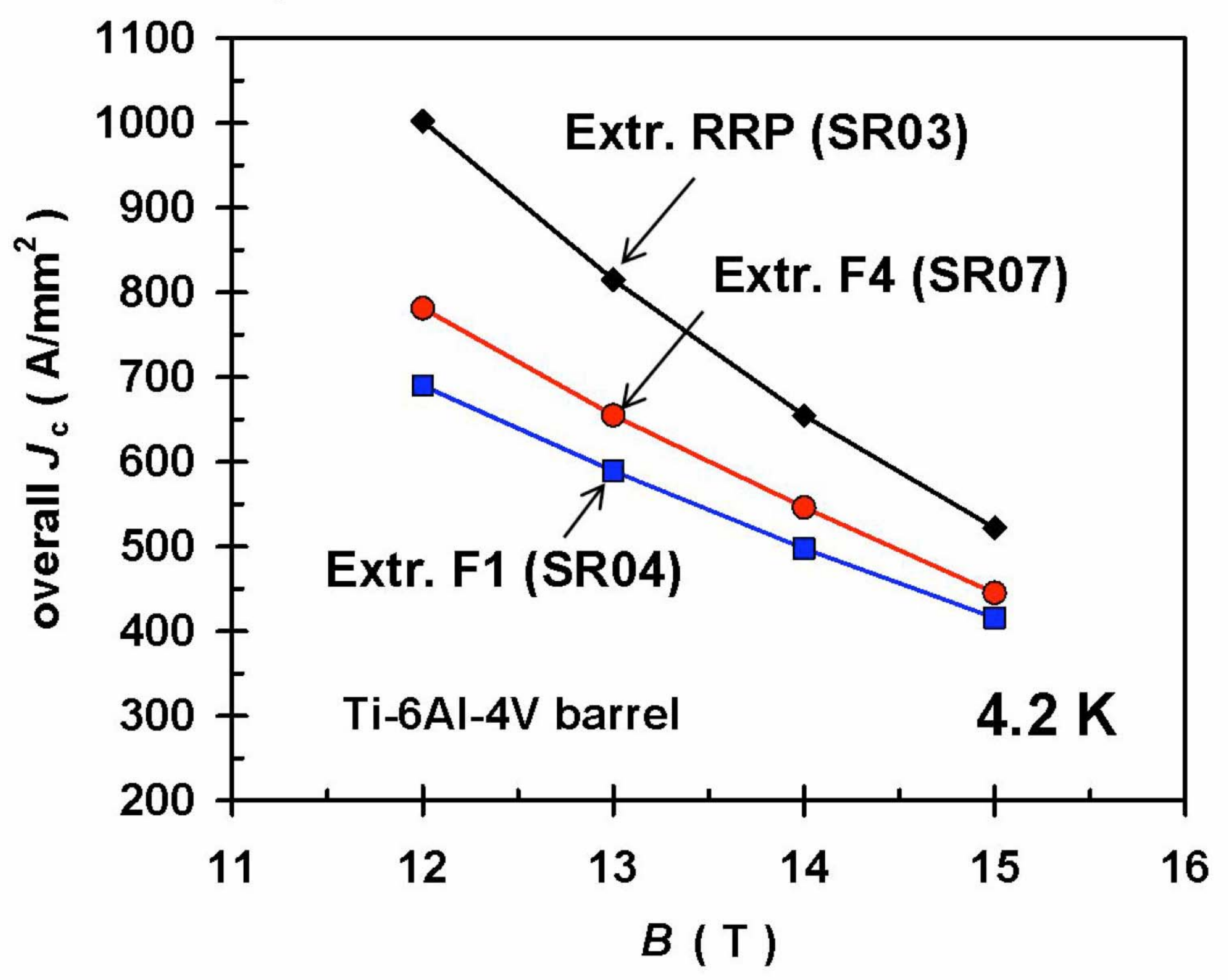
F3 w/ Ta Matrix Strand Rolling Test

No Cu separation

No Jc degradation by rolling

Progress at NIMS/Fermilab

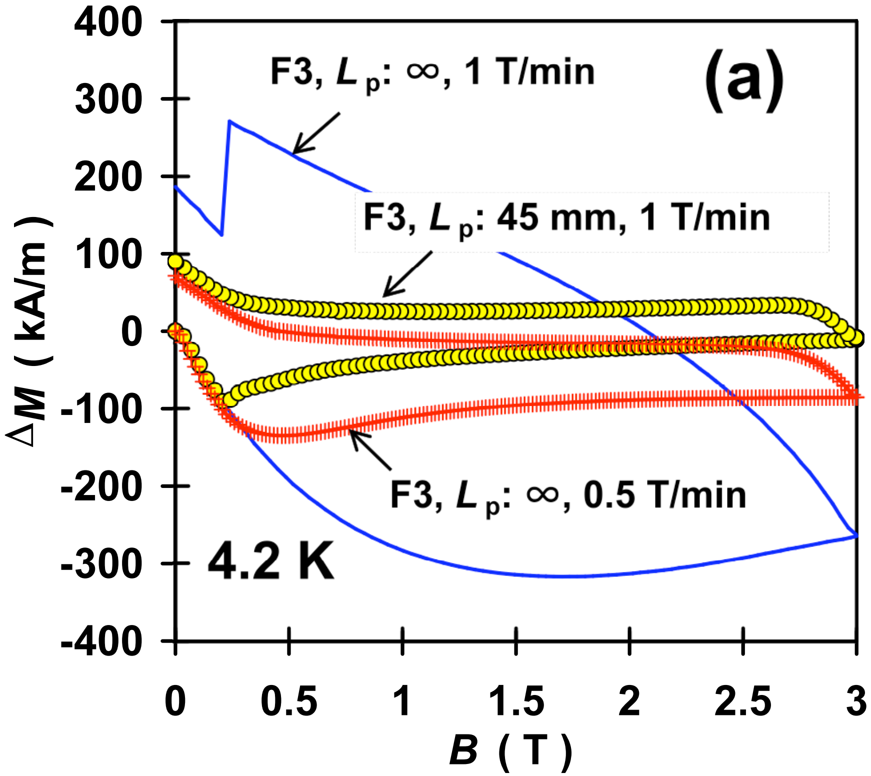
Nb_3Al cable R&D (FY2006-2007)

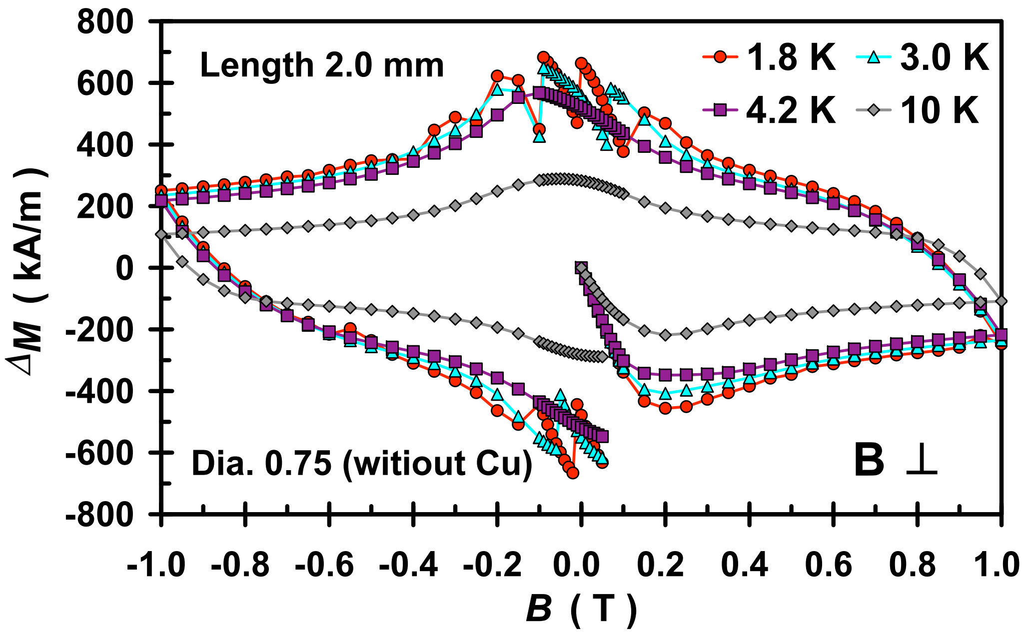


SR: Short Race-track coil

Progress at NIMS

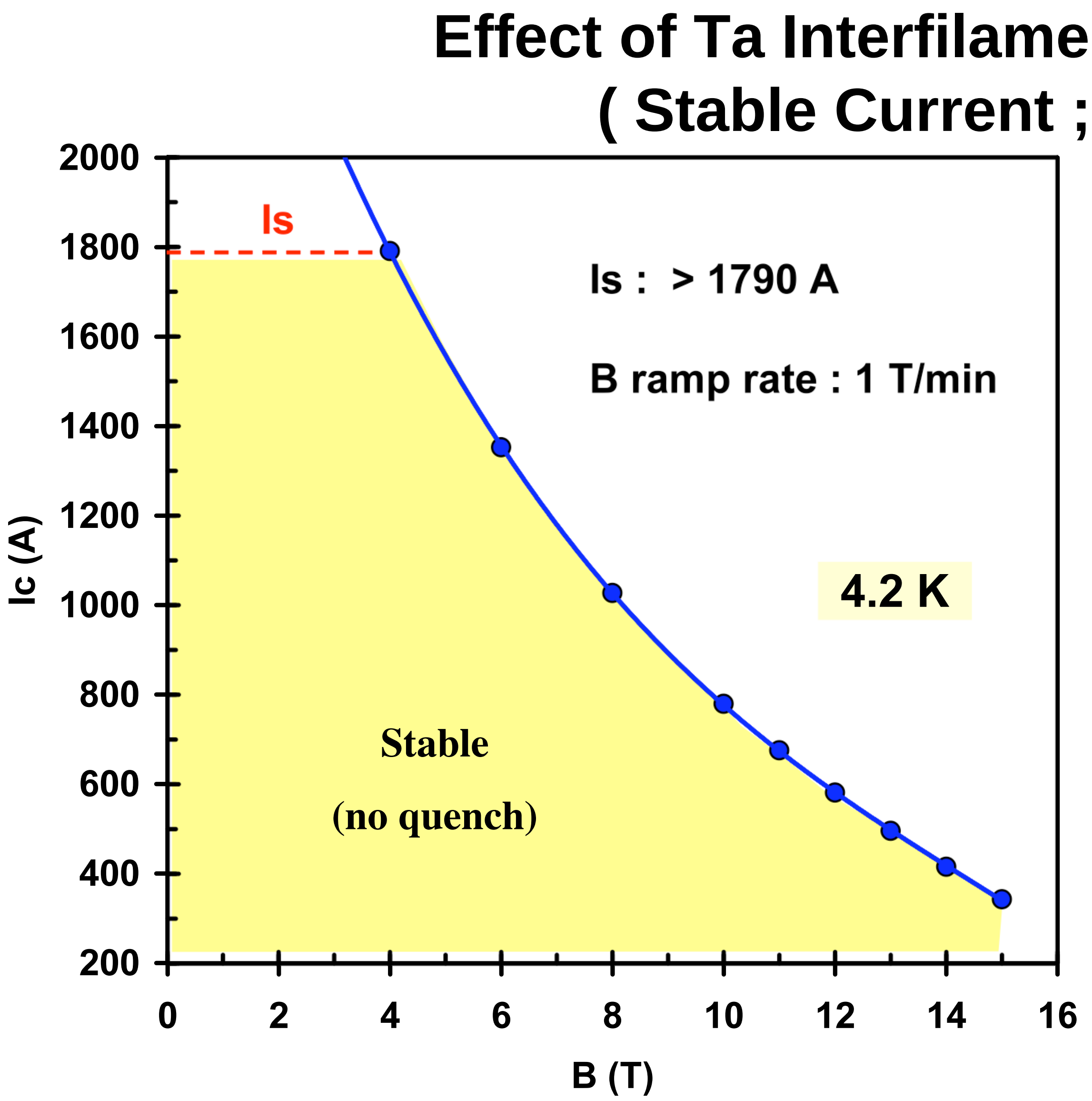
Effect of Ta Interfilament Matrix
(Low Field Magnetic Stability)





No flux jumps at 4.2 K

Progress at NIMS

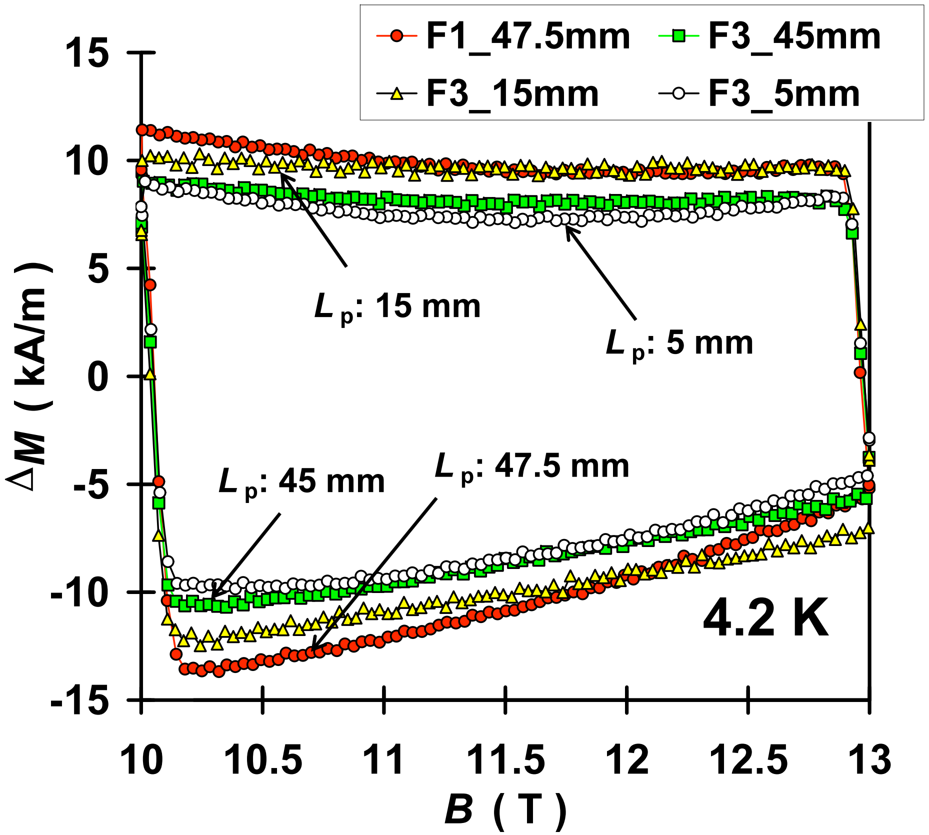


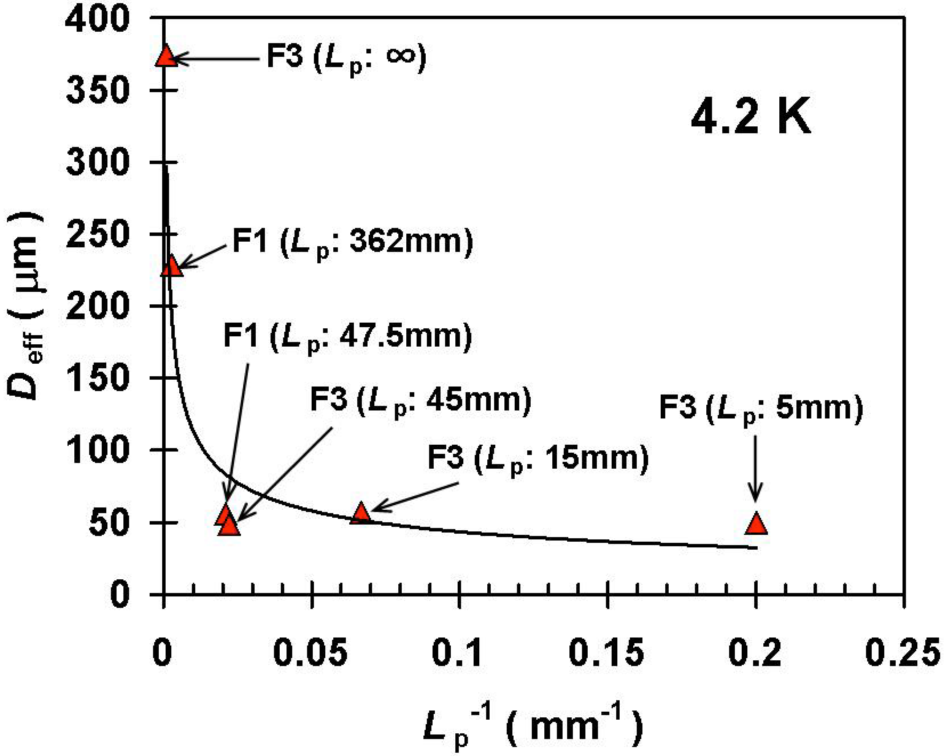
Sweeping Field Test

(F3)

Progress at NIMS

Strand Twist Pitch ; L_p and Effective Filament Diameter ; D_{eff}

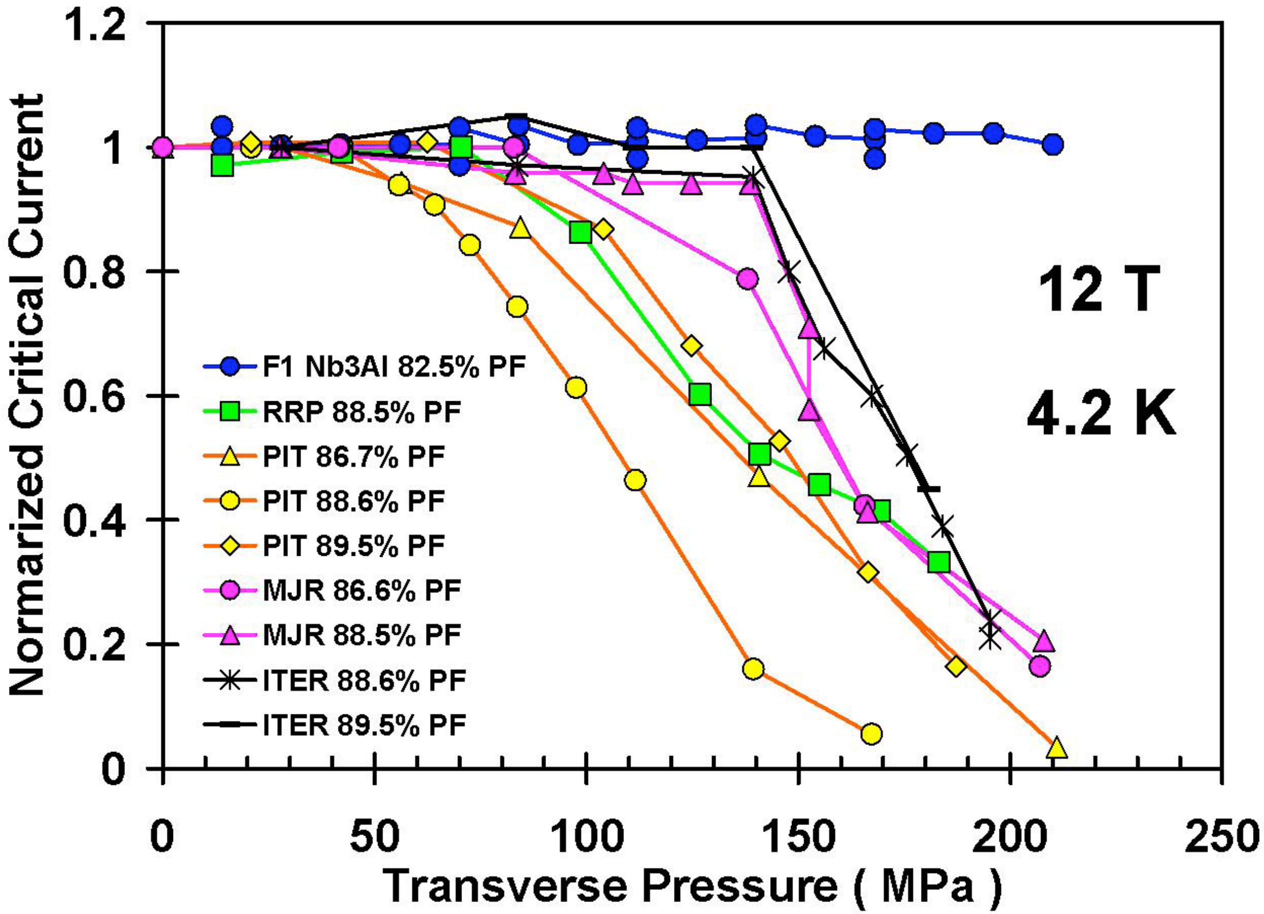


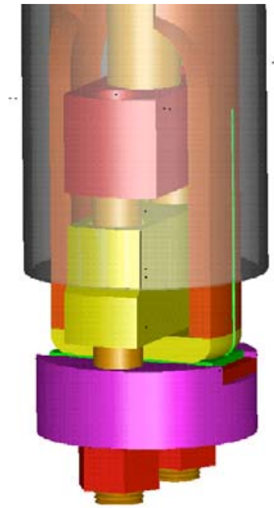


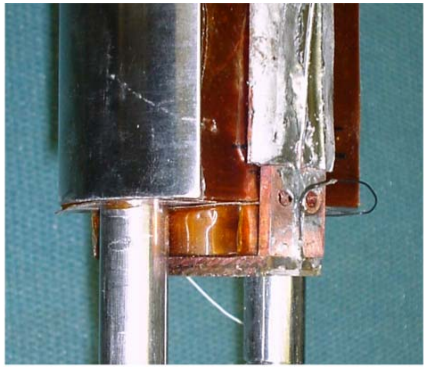
~ 50 µm

Progress at NIMS/Fermilab

Transverse Pressure Test (F1 strand)



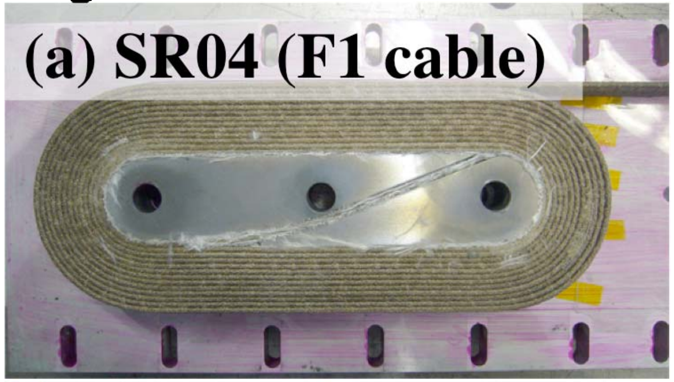




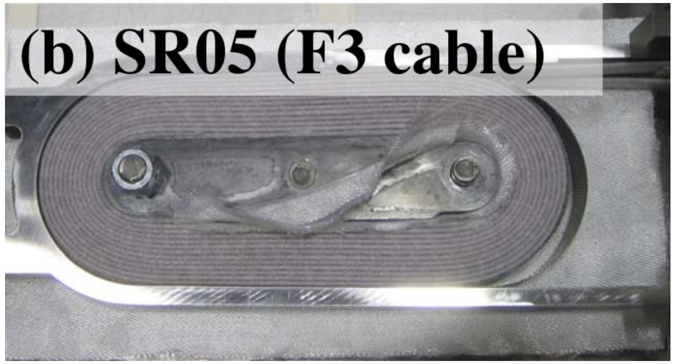
No Ic degradation up to 210 MPa

Progress at NIMS/Fermilab

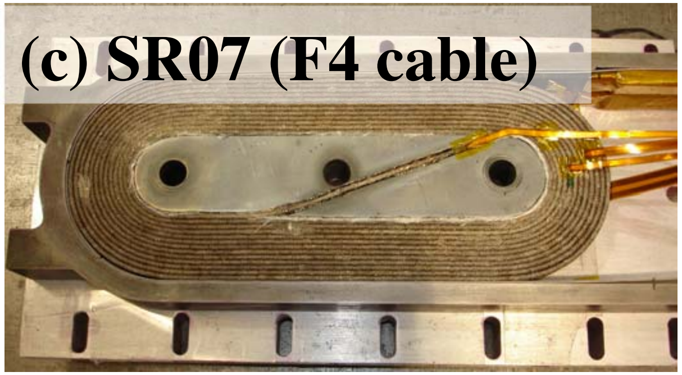
Nb_3Al small racetrack magnet R&D (FY2006-2007)



- 25cm cable SC transformer test (Fermilab)
- 2m cable test (FRESCA)
- Magnet test (Fermilab)



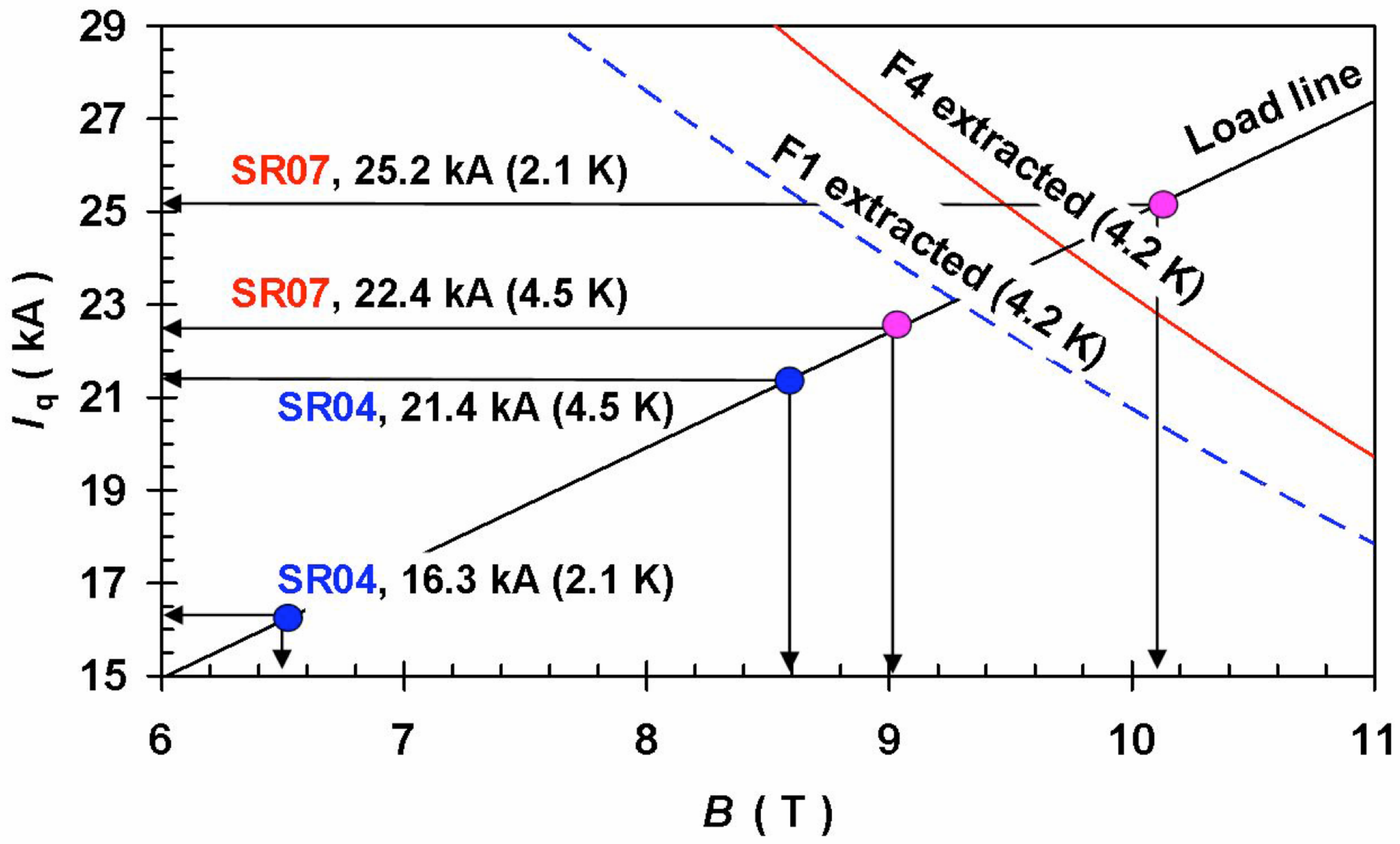
- 25cm cable SC transformer test (Fermilab)
- No magnet test



- 25cm cable SC transformer test (Fermilab)
- Magnet test (Fermilab)

Progress at NIMS/Fermilab

Nb_3Al small racetrack magnet R&D (FY2006-2007)



Summary of Nb3Al R&D in 1st stage: JFY2006-2008

- **Low field magnetic instability at 4.2 K was successfully improved by Ta-matrix.**

- **Robustness and very good RRR of Cu stabilizer by electroplating was confirmed. The next target would be speed-up of the process for mass-production.**

- **A Rutherford cable made of 27 Nb3Al strands with Ta-matrix with PF of 87 % was successfully fabricated: feasibility of Nb3Al cable was demonstrated.**

- **On the other hand, the initial target Jc of 1500 A/mm2 at 15 T has not been achieved yet.**

- **As of now, 700 m and 200 m length strands with Cu were fabricated and will be cabled next February. Another 2 sets of precursor wires with more ductile Nb and Ta will be made by March 2009. All of them, even not enough, will be used for the High Field Subscale Magnet R&D.**

Further R&D Plan in 2nd stage JFY2009-2011

R&D Items for the Next 3 Years

1a. High Field Subscale Magnet
- To demonstrate performance of Nb3Al cable
- Design, fabrication and testing

1b. Fabrication of Nb3Al Strands
- with Ta matrix
- cabling for "the subscale magnet"

Stress & Radiation Issues

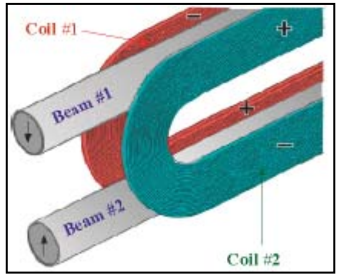
2. Fundamental study
- Mechanical property of Nb3Al SC (strand, cable, coil).
- Radiation resistant resin for vacuum impregnation.
- Thermal and mechanical properties of insulations and alloys for the coil composites.
- Further R&D of Nb3Al wires with new ideas.

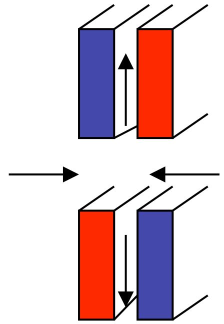
High Field Nb3Al Subscale Magnet R&D

First goal of this program

–*to fabricate ~~10~~ 13 T small magnet* for demonstrating the feasibility of high field magnet with Nb_3Al.

Basic design concept

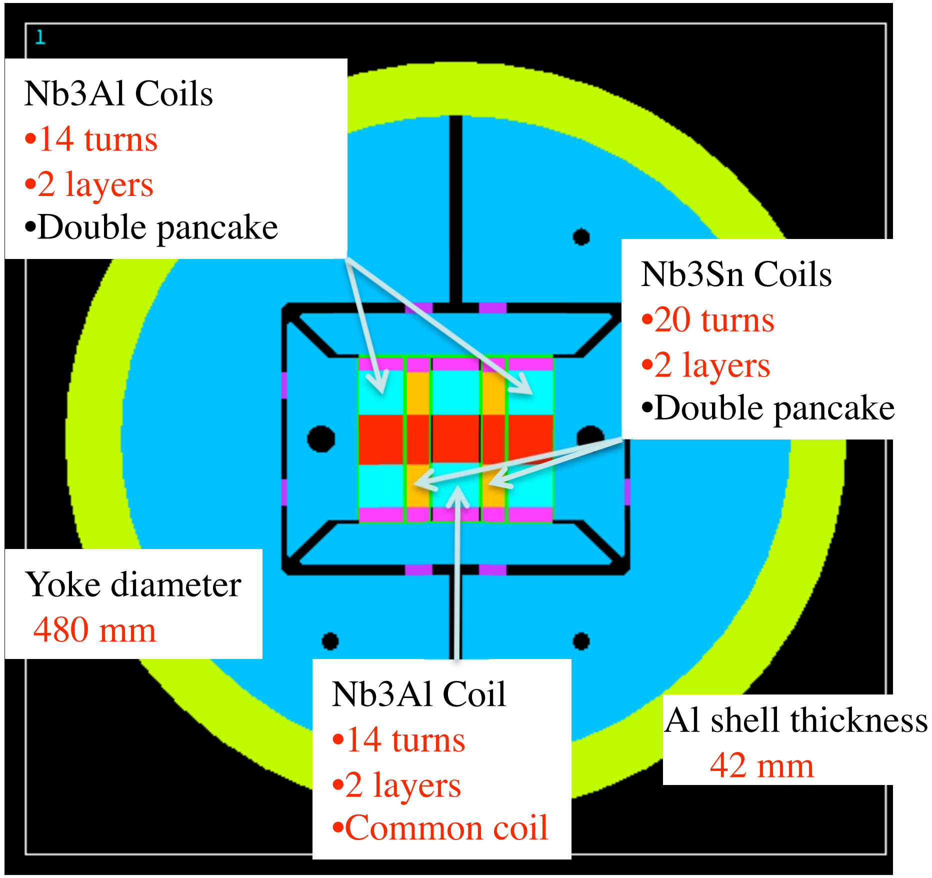




- Common coil **configuration**
  - Simple structure compared with Block dipole
- Shell structure
  - Easy assembly and disassembly
- Use Nb_3Sn subscale coils as backup coils
  - Save the Nb3Al cables
    - (borrowed 2 subscale coils from LBL)

High Field Nb3Al Subscale Magnet R&D

2D Magnet Design



LBNL type structure

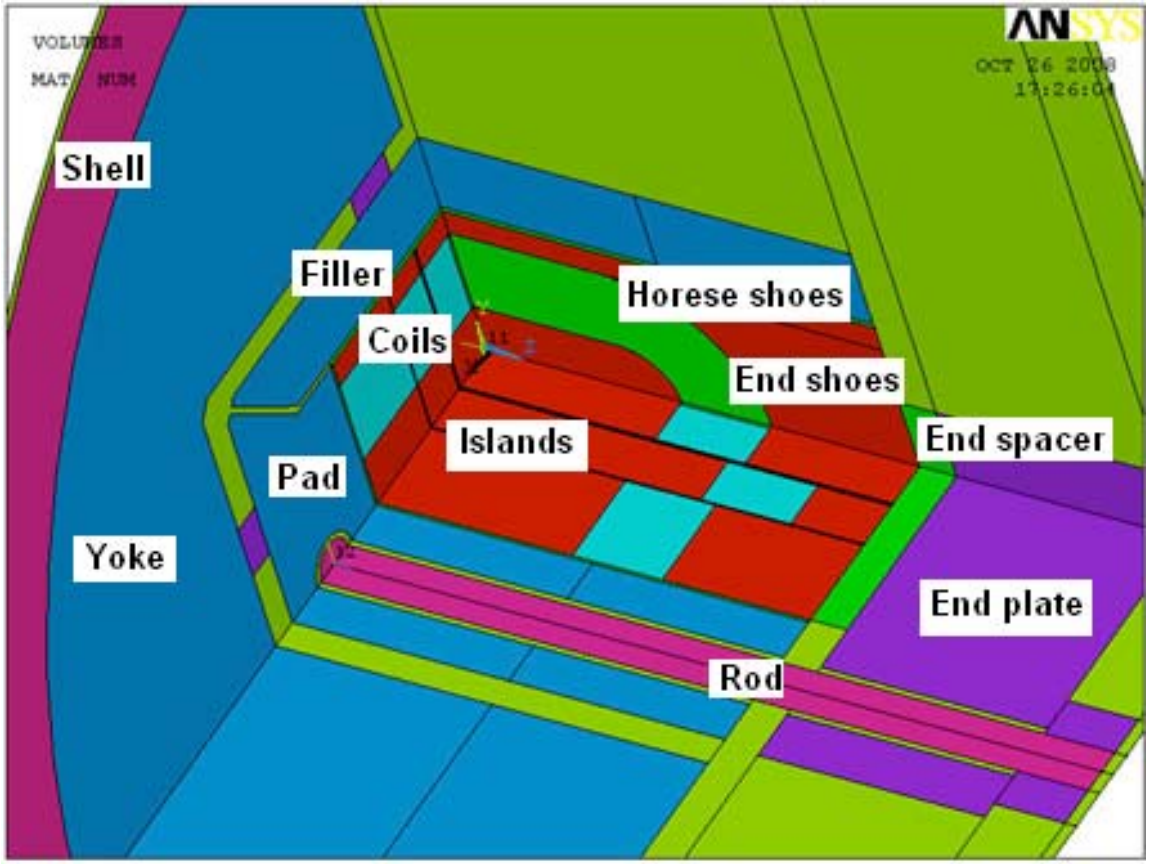
Key parameters

Nb3Al Strand Dia.	1mm
Cu ratio	0.75
Non-Cu Jc	873.8A/mm2 @ 15 T
No. of Stands	27
Cable dimension	14.05*1.83mm^2
Cable Insulation	0.25mm
Coils No.	3
Turns No. per layer	14
Layers No. per coil	2 (2 Double pancakes + 1 Common coil)

Nb3Sn Coils No.	2
Turns No. per layer	20
Layers No. per coil	2 (Double pancake)

High Field Nb3Al Subscale Magnet R&D

3D Magnet Design



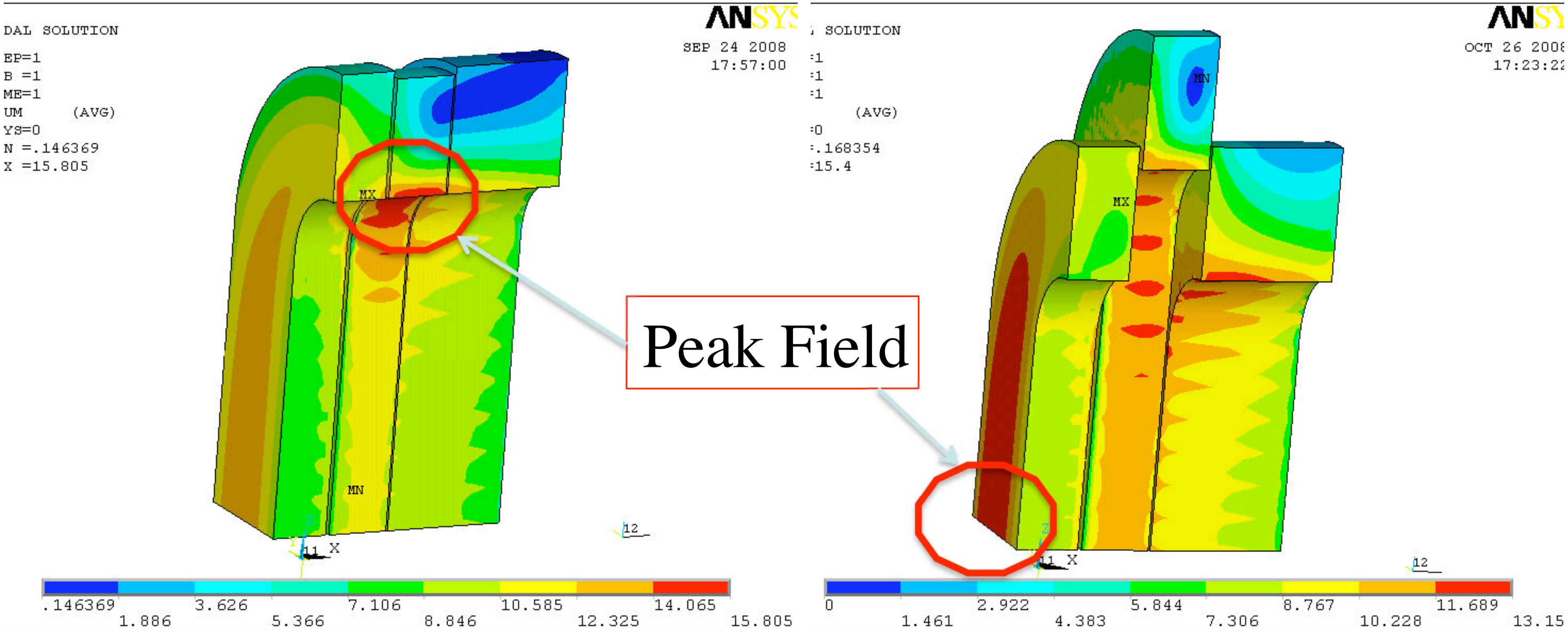
Coil Straight Length

Nb3Al : 200 mm.

Nb3Sn: 304.4 mm.

High Field Nb3Al Subscale Magnet R&D

Peak Field



Peak field :
Nb3Sn coil end

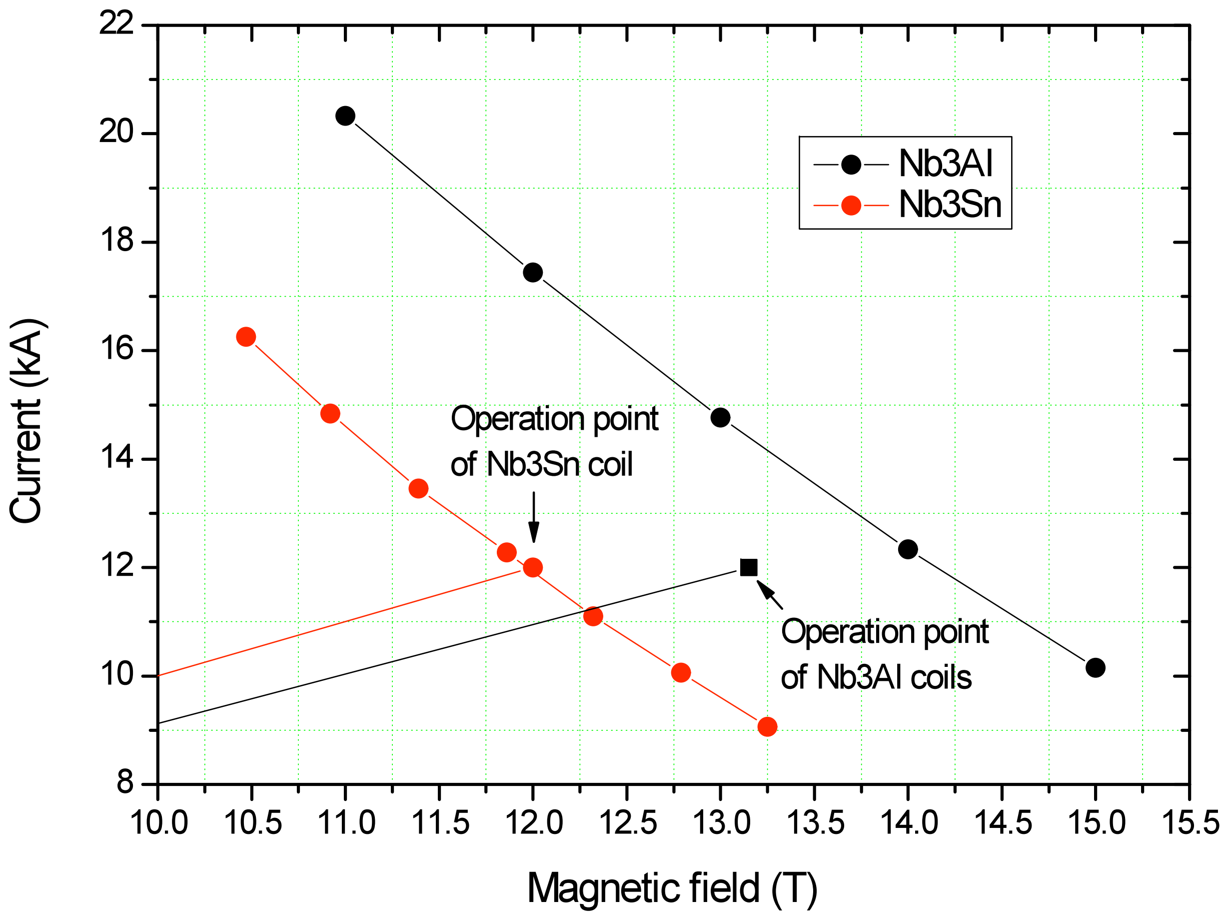
Peak field :
Center of Nb3Al coil

13.2 T in Nb3Al (Coil1).
12.0 T in Nb3Sn (Coil2).

@12.2 kA

High Field Nb3Al Subscale Magnet R&D

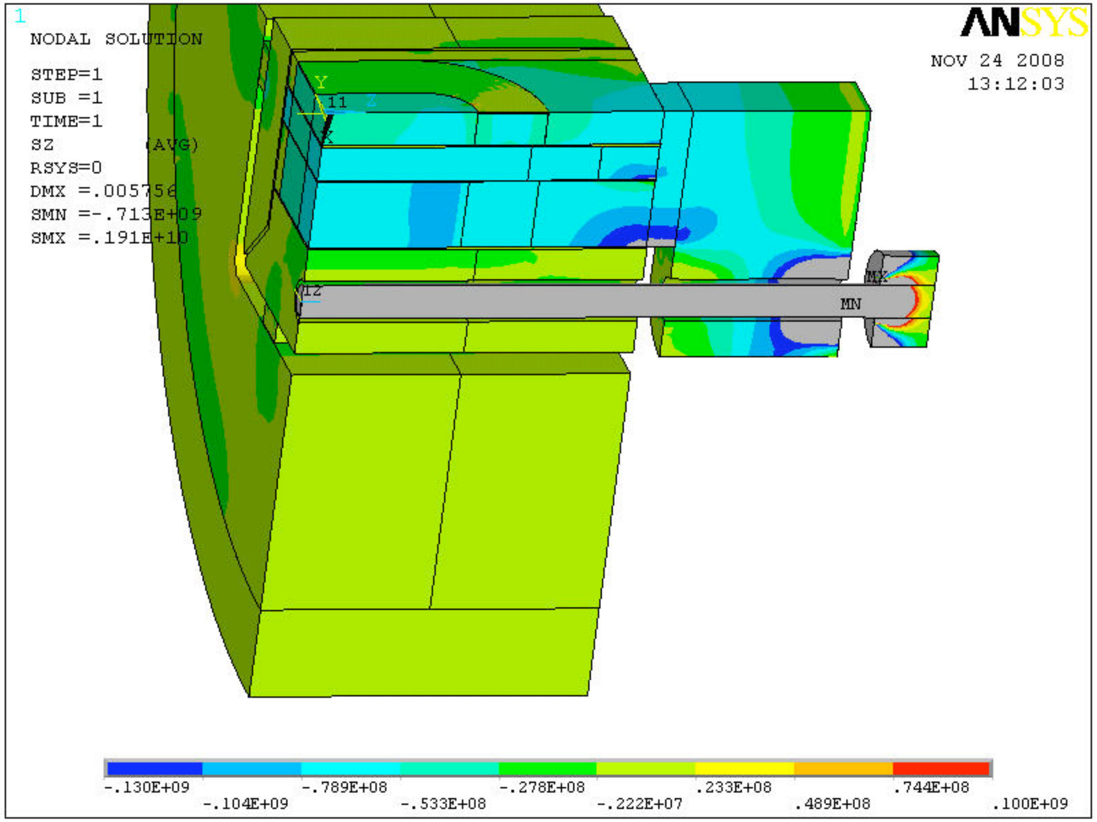
Load line of current magnet design



The maximum operation current is limited by Nb3Sn coil.

High Field Nb3Al Subscale Magnet R&D

pre-stress in three directions



Lorentz Force (1/8 model)

X direction – 240 kN

Y direction – 240 kN

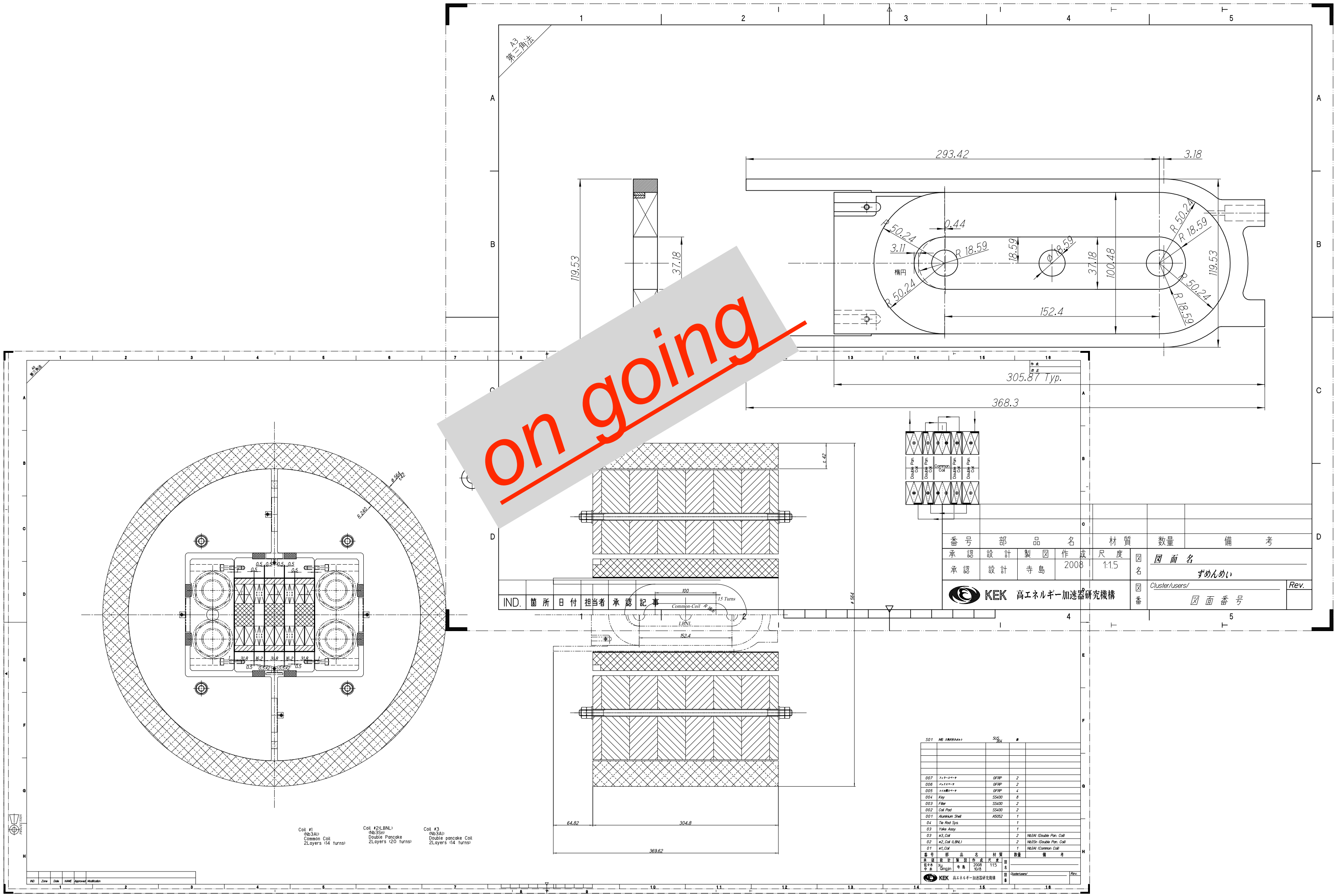
Z direction – 100 kN

2 Al rods are not enough.

developing New Magnet Design with 4 Al rods!

High Field Nb3Al Subscale Magnet R&D

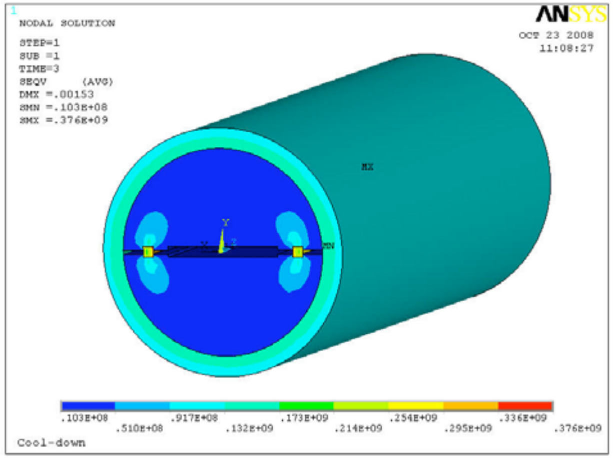
Detail Drawings

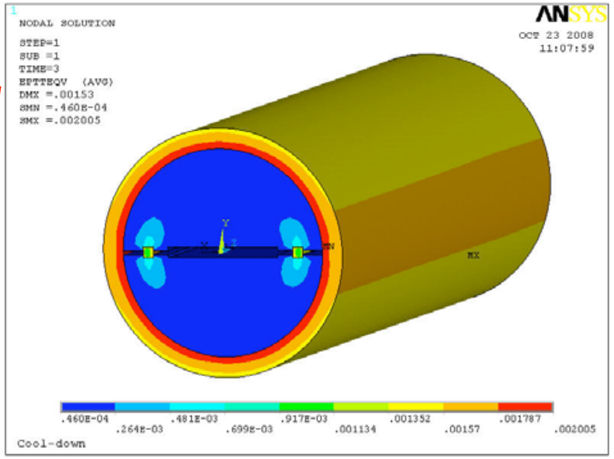


High Field Nb3Al Subscale Magnet R&D

Preparation of bladder test experiment

Picture of the bladder test system



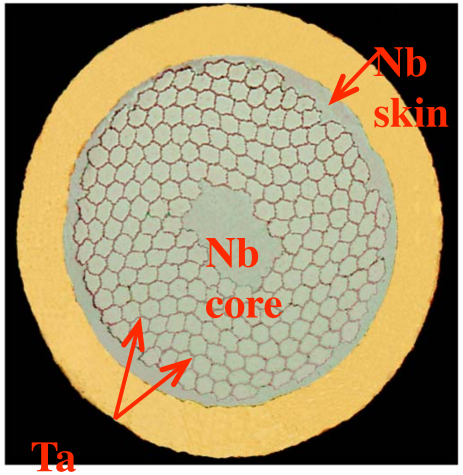


3D simulation of the test components

High Field Nb3Al Subscale Magnet R&D

- Design study is on going.
  - Peak Field : 13.2 T
  - Shorter coil than Nb3Sn
  - 4 Al rods
- Detail Drawings
- Preparation of fabrication
  - Bladder will be tested in KEK soon for the assembly practice.

Nb3Al Strands and Cable for the Magnet



- Nb3Al wires with similar specification have been fabricated for the subscale magnet.

- Ceramic insulation will be delivered soon.

- Wire 2007-2008: ME492, 493. Several breaks. Electroplating completed. Final length 200 m +700 m. Cabling in next February at Fermilab. For Practice coil winding and Coil A.

- Wire 2008-2009: ME1, 2. 1000 m + 1000 m. precursor with RHQ process anticipated in next February. Electroplating and cabling in 2009. For Practice coil winding and Coil B.

- *Wire 2009: 1000 m. For Coil C.*

- *Wire 2010: 1000 m. For Coil D.*

Schedule of Magnet R&D

JFY 2008

- **Design of Nb3Al/Nb3Sn subscale common magnet.**
- **Procurement of jigs and support structure.**
- **Cabling with the length for the practice and Coil A (@Fermilab).**
- **Precursor of Nb3Al wires for Coil B.**

JFY 2009

- **Practice coil winding 1: winding, heat treatment, impregnation, bus work, instrumentation.**
- **Fabrication of the Nb3Al Coil A.**
- **Electroplating and cabling of Nb3Al wires for the Coil B.**
- **Production of Nb3Al wires for the Coil C.**

JFY 2010

- **Production of Nb3Al wires for the Coil D.**
- **Cabling of Nb3Al wires for the Coils C & D.**
- **Fabrication of the Nb3Al Coils B & C.**
- **Magnet assembly.**

JFY 2011

- **Fabrication of the Nb3Al Coil D (backup).**
- ***Magnet test.***

R&D Items for the Next 3 Years

1a. High Field Subscale Magnet
- To demonstrate performance of Nb3Al cable
- Design, fabrication and testing

1b. Fabrication of Nb3Al Strands
- with Ta matrix
- cabling for "the subscale magnet"

2. Fundamental study

Stress & Radiation Issues

- Mechanical property of Nb3Al SC (strand, cable, coil).
- Radiation resistant resin for vacuum impregnation.
- Further R&D of Nb3Al wires with new ideas.
- Thermal and mechanical properties of insulations and alloys for the coil composites.

Mechanical Behaviors of Nb3Al SC Coil

High field accelerator magnets like aiming the LHC luminosity upgrade cannot neglect "stress issues"….

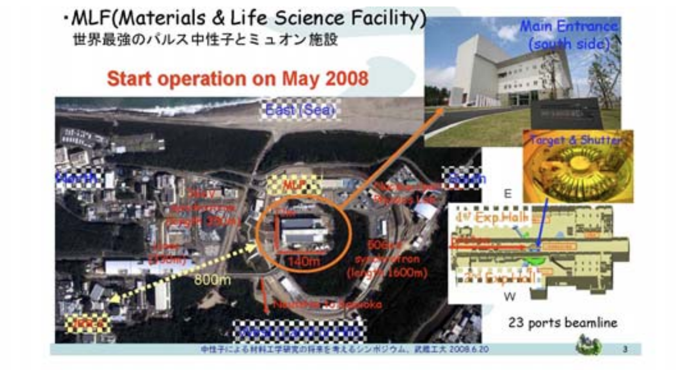
Mechanical behaviors under compressive stress ~200 MPa (and bending stress) need to be fully investigated.

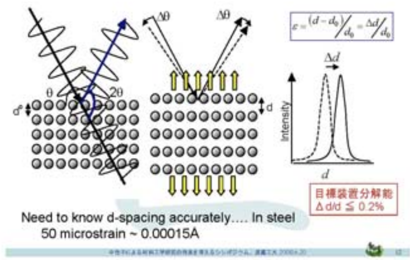
- **Nb3Al (strand, cable, coil)**
- **Impregnation resin**
- **Insulator**

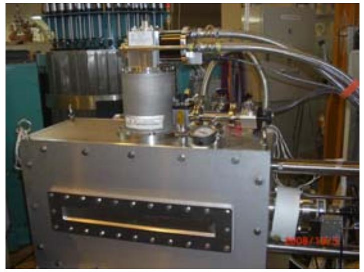
Strain Meas. by Neutron Diffraction at J-PARC

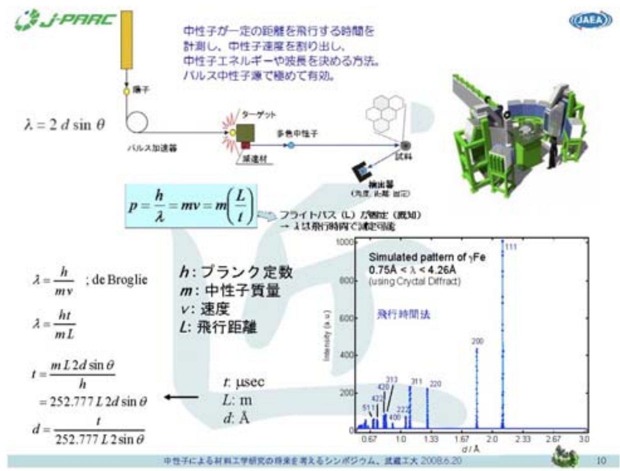
The "lattice distance" of Nb3Al can be determined by the neutron diffraction with very good accuracy: Intrinsic strain of Nb3Al wires, Strain under the compressive stress (strand, cable, coil) at 4 K to RT.

Measurement could reveal the nature of robustness of Nb3Al….









Diffraction peaks of Nb3Sn using the previous pulsed neutron source KENS

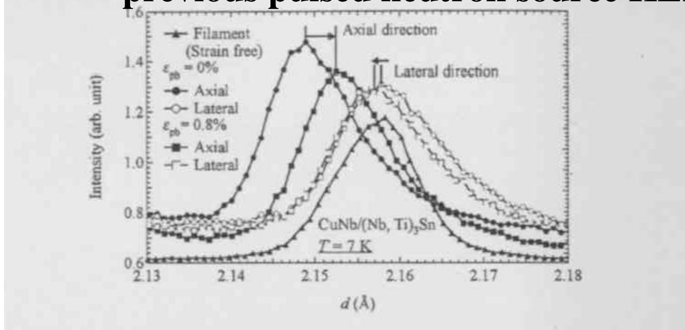
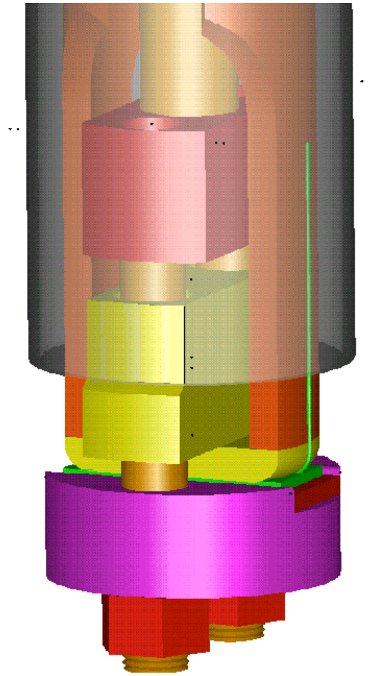


FIG. 6. The 211 diffraction peaks of Nb_3Sn for $CuNb/Nb_3Sn$ wires with and without the prebending treatment and for Nb_3Sn filament measured at 7 K by a cryocooler.

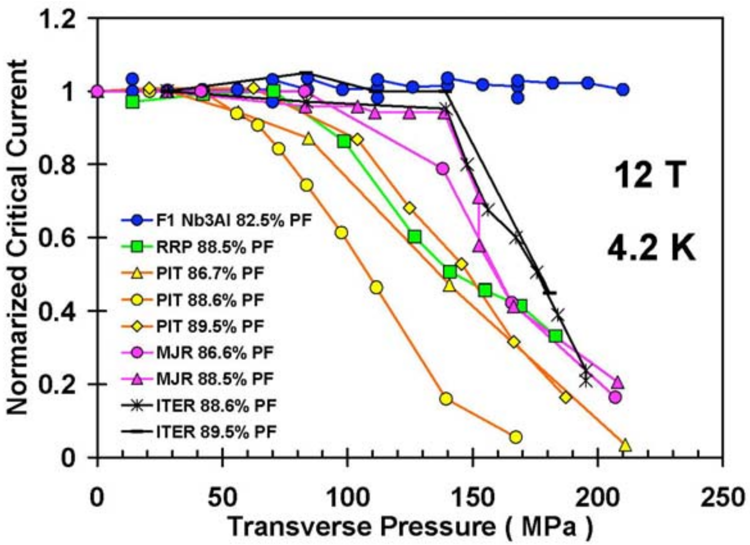
Oguro et. Al., Journal of Applied Physics, **101**, 103913 (2007)

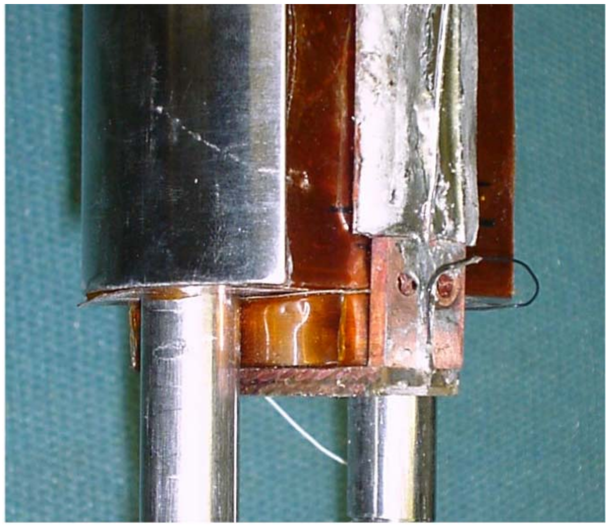
Jc of Nb3Al Wires Under Various Stresses

Stress dependence of Nb3Al strand in the cable.
- **compressive**
- **bending**



Correlation with the strain determined by the neutron diffraction measurement.





Courtesy of Fermilab

R&D Items for the Next 3 Years

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- with Ta matrix
- cabling for "the subscale magnet"

2. Fundamental study

Stress & Radiation Issues

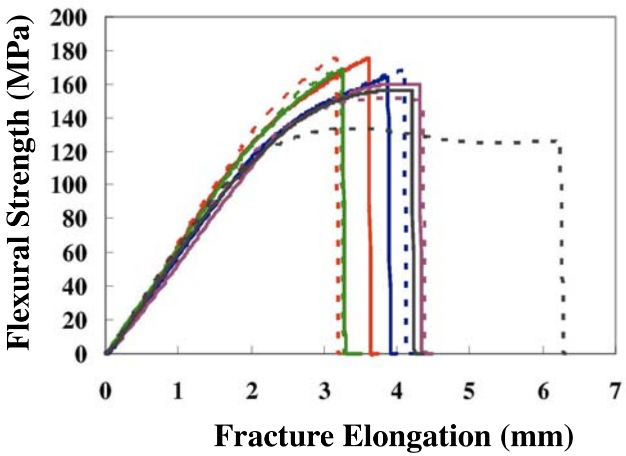
- Mechanical property of Nb3Al SC (strand, cable, coil).
- Radiation resistant resin for vacuum impregnation.
- Thermal and mechanical properties of insulations and alloys for the coil composites.
- Further R&D of Nb3Al wires with new ideas.

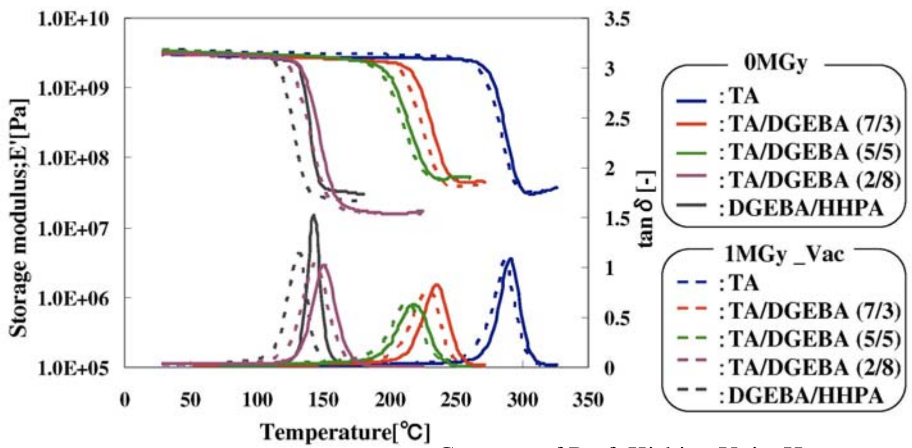
Cyanate Ester Based Resin for Nb3Al Coil Impregnation

- **Radiation resistant resin with Cyanate Ester will be adopted for the Nb3Al coil impregnation.**
  - low viscosity
  - control of solidification
  - mechanical strength
- **4 Japanese institutes and company have formed the collaboration to develop the Cyanate Ester based resin for the present Nb3Al subscale coil and future accelerator magnets.**

  Mitsubishi Gas Chemical: provider of Cyanate Ester resin
  Univ. of Hyogo: evaluation (bonding strength, mechanical properties)
  JAEA: gamma-ray irradiation, evaluation (evolved gas)
  KEK: specification, specimens
- **Preliminary irradiation study of Cyanate Ester / Epoxy resin was carried out.**

(*Not for accel. Magnet application)





Courtesy of Prof. Kishi at Univ. Hyogo

R&D Items for the Next 3 Years

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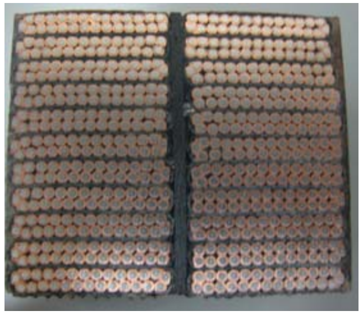
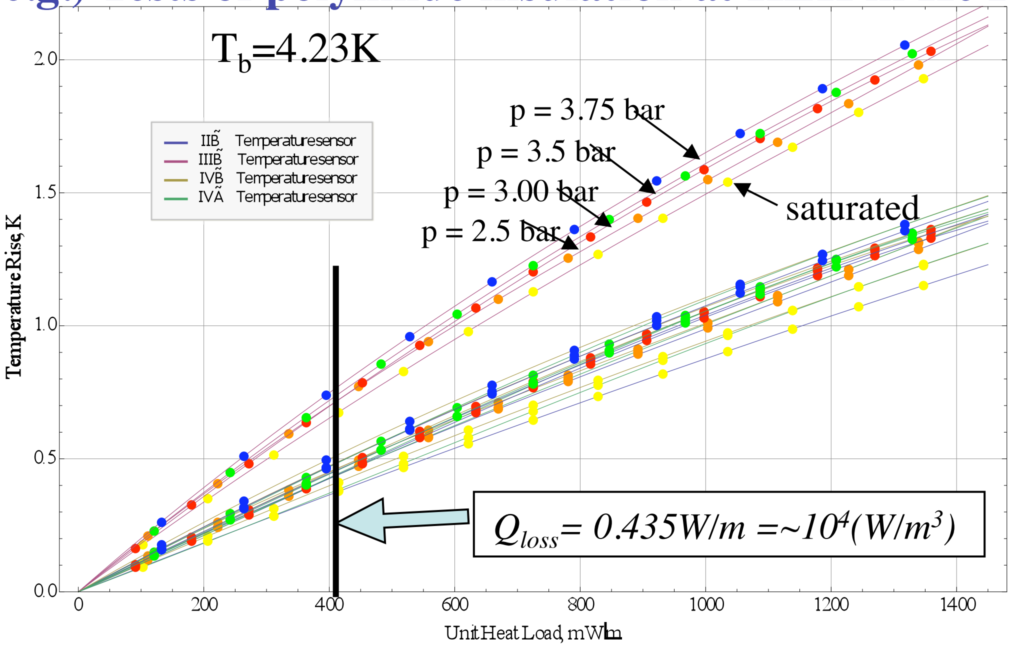
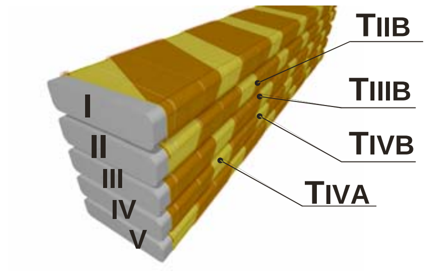
Thermal & Mechanical Properties of Coil Composites

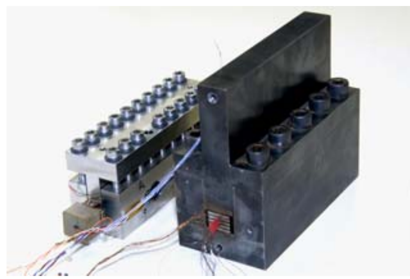


- **Magnet Design**
  - Thermal contraction
  - S-S curve
- **Thermal stability**
- **Temperature distribution with energy deposition by debris**
  - He heat transfer study in He I, HeII, HeS
  - Thermal conductivity of elements and composite

e.g.) Tests of polyimide insulation at KEK in He I and HeS







R&D Items for the Next 3 Years

1a. High Field Subscale Magnet
- **To demonstrate performance of Nb3Al cable**
- **Design, fabrication and testing**

1b. Fabrication of Nb3Al Strands
- **with Ta matrix**
- **cabling for "the subscale magnet"**

2. Fundamental study
- **Mechanical property of Nb3Al SC (strand, cable, coil).**
- **Radiation resistant resin for vacuum impregnation.**
- **Thermal and mechanical properties of insulations and alloys for the coil composites.**
- **Further R&D of Nb3Al wires with new ideas.**

Further R&D of Nb3Al SC Wires with New Ideas

Candidates of R&D items are as follows;

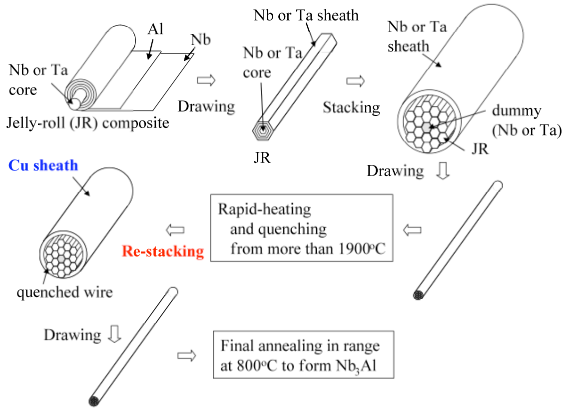
- **Fabrication of 10 km length wire by 4000 ton extruder: demonstration of mass production at the same level as Nb3Sn wires.**

- **Re-stacked filament covered with copper tube stabilizer: very low magnetization wire for the accelerator application.**

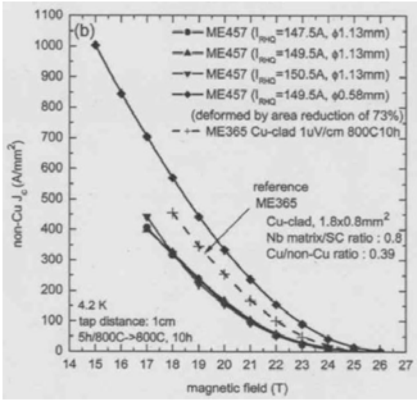
- **High Jc wire with low strain sensitivity.**

Further R&D of Nb3Al SC Wires : e.g. Restacked Wire

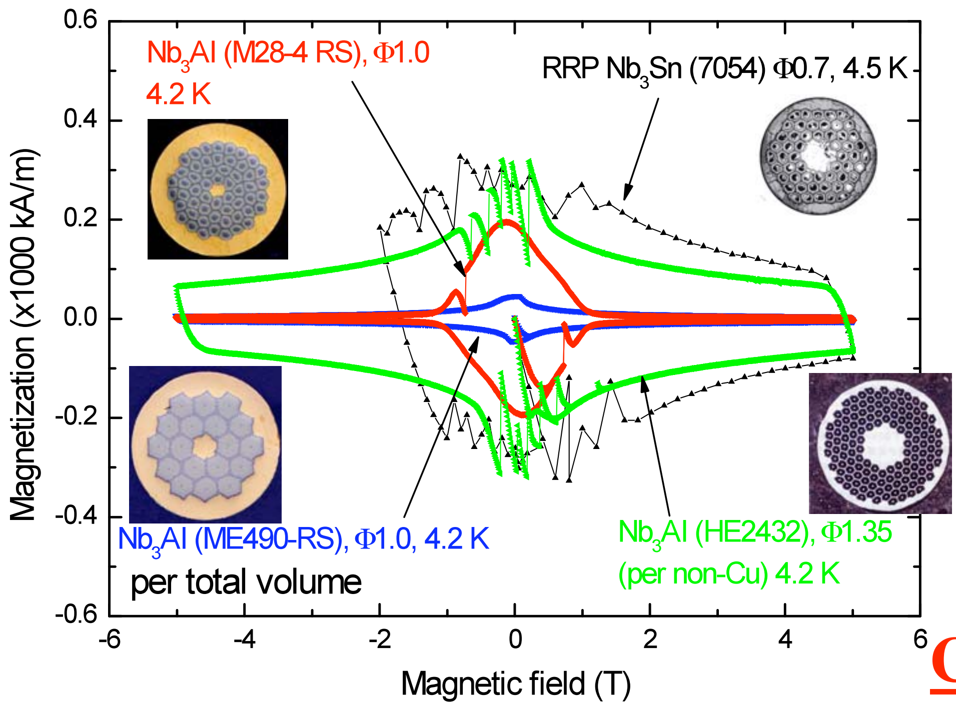
- **Schematic of Re-stack method**



N. Banno et al., SUST **21** (2008) 115020 (7pp)

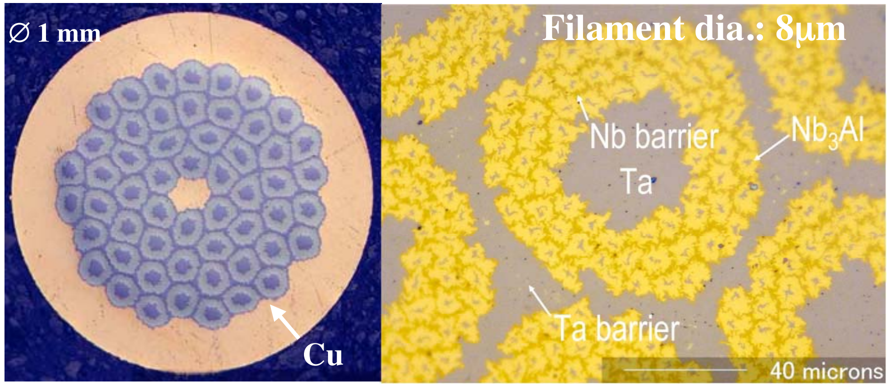


Jc ~ 1,000 A/mm2 obtained

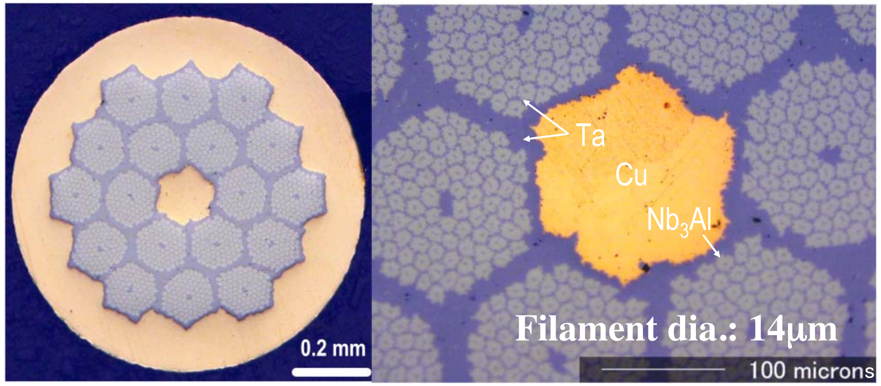


- **Actual achievement**

(1) Nb-barrier wire



(2) Ta-barrier wire



(1) Nb-barrier wire: Success of 20 m length, d_f=8μm.
Filament coupling at low field.

(2) Ta-barrier wire: 10 m, d_f=14μm.
Suppression of filament coupling.

Challenge for long wire fabrication

銅チューブ5~10m → 素線最終長さ500~1000m

Renovation of Test Facility

- **15 kA Power Supply for Magnet Test**
- **Modification of Cryostat for Magnet Test**
- **DAQ**
- **Temperature-controllable Cryostat**

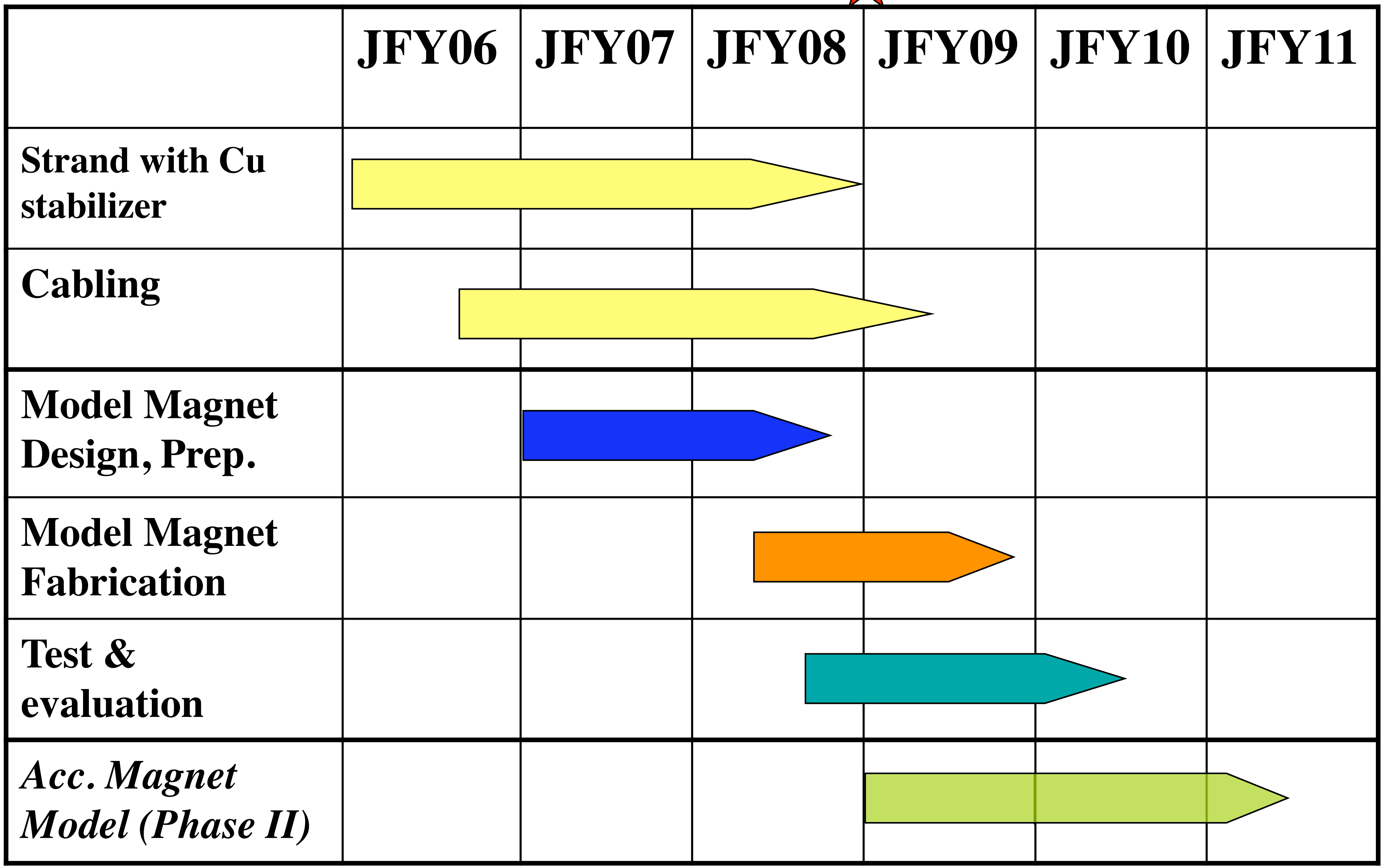
Adoption of New Experimental Apparatus

- **Tensile Tester with Cryo-cooler for Neutron Diffraction Meas.**
- **>15 T SC Solenoid for Mechanical Study and Jc Meas. Under Compressive Stress**

Covered by KEK internal budget and CERN-KEK budget

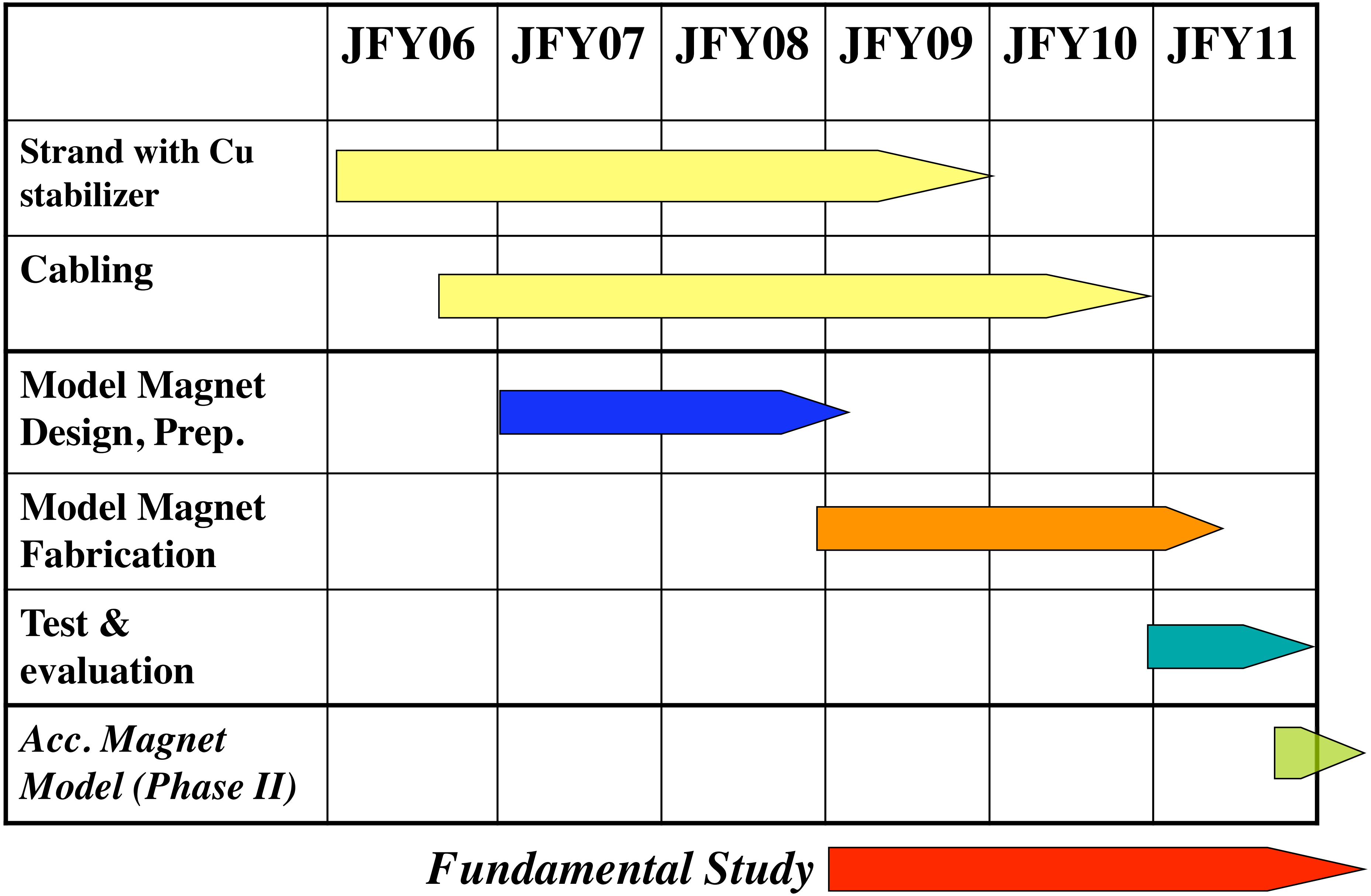
Schedule and Budget Proposal

Development Plan (presented 2007)



★ **The plan to be reviewed and to be updated for further extension by the end of FY-08.**

Development Plan –Past and New-



Budget so far

(Unit: kJYen)

	JFY-06	JFY-07	JFY-08	JFY-09
Strand	15,800	23,000	14,000	New Proposal
Cable	(US-JP)	(US-JP)	2,000	New Proposal
Model Coil	1,000	5,000	12,000	New Proposal
Test	2,000	3,500	5,500	New Proposal
Work Assist. Travel, etc,	1,200	1,500	1,500	2,000
Total	20,000	33,000	~~35,000~~ 22,000	~~2,000~~ 15,000 kJYen remained….

Budget Proposal for the Next 3 Years

1 CHF= 90 JYen

(Unit: kJYen)

	JFY-09	JFY-10	JFY-11
Subscale Magnet R&D	21,000	13,800	4,300
	Another Grant: 6,700 kJYen		
Fundamental Study	31,000	14,200	14,700
Travel, etc,	2,000	2,000	2,000
Total	54,000	30,000	21,000

3 years total:
105,000 kJYen

Construction and commissioning of J-PARC by summer of 2009

More HR will be available on this R&D later.

Note: budget transfer to NIMS may be needed.

Budget Detail

		JFY 2009	JFY 2010	JFY 2011
Magnet R&D	Jigs, Yoke, Shell	Covered by another grant	0	0
	Coil	3000	3000	1500
	PS, DAQ, Cryostat	2000	2000	2000
Wires and cable for the magnet	Completion of electroplating for wires07-08	6000	0	0
	Wires(1 km)	8000	8000	0
	Cabling	Fermilab Collab.	Fermilab Collab.	Fermilab Collab.
	consumable	2000	800	800
Fundamental Study	SC Solenoid & Tensile Tester	17000	2000	1000
	Thermal conductivity meas.	0	5000	2000
	Cyanate ester	1000	2000	700
	Tensile tester w/ cryo-cooler	9000	4000	2000
	Strand R&D: short	4000	1200	1000
	Strand R&D: long	0	0	8000*

*Production of a 10 km long wire by 4000 ton extruder will cost ~20000 kJYen.

>> Necessary Additional Financial Support (8,000 + 12,000)

Summary of Further R&D Plan in 2nd stage: JFY2009-2011

- **Design, fabrication and testing of the High Field Subscale Magnet will be carried out to demonstrate performance of Nb3Al cable.**

- **Nb3Al wires with Ta-matrix will be fabricated to make the High Field Subscale Magnet: 3 double pan-cake coils and 1 back-up.**

- **Fundamental studies in terms of stress and radiation issues will be carried out:**
  - **Direct strain measurement by neutron diffraction,**
  - **Jc under compressive stress,**
  - **Development of Cyanate Ester based resin for vacuum impregnation,**
  - **Thermal and mechanical properties of coil composite.**

- **Further R&D of Nb3Al wire (with small amount) will proceed.**