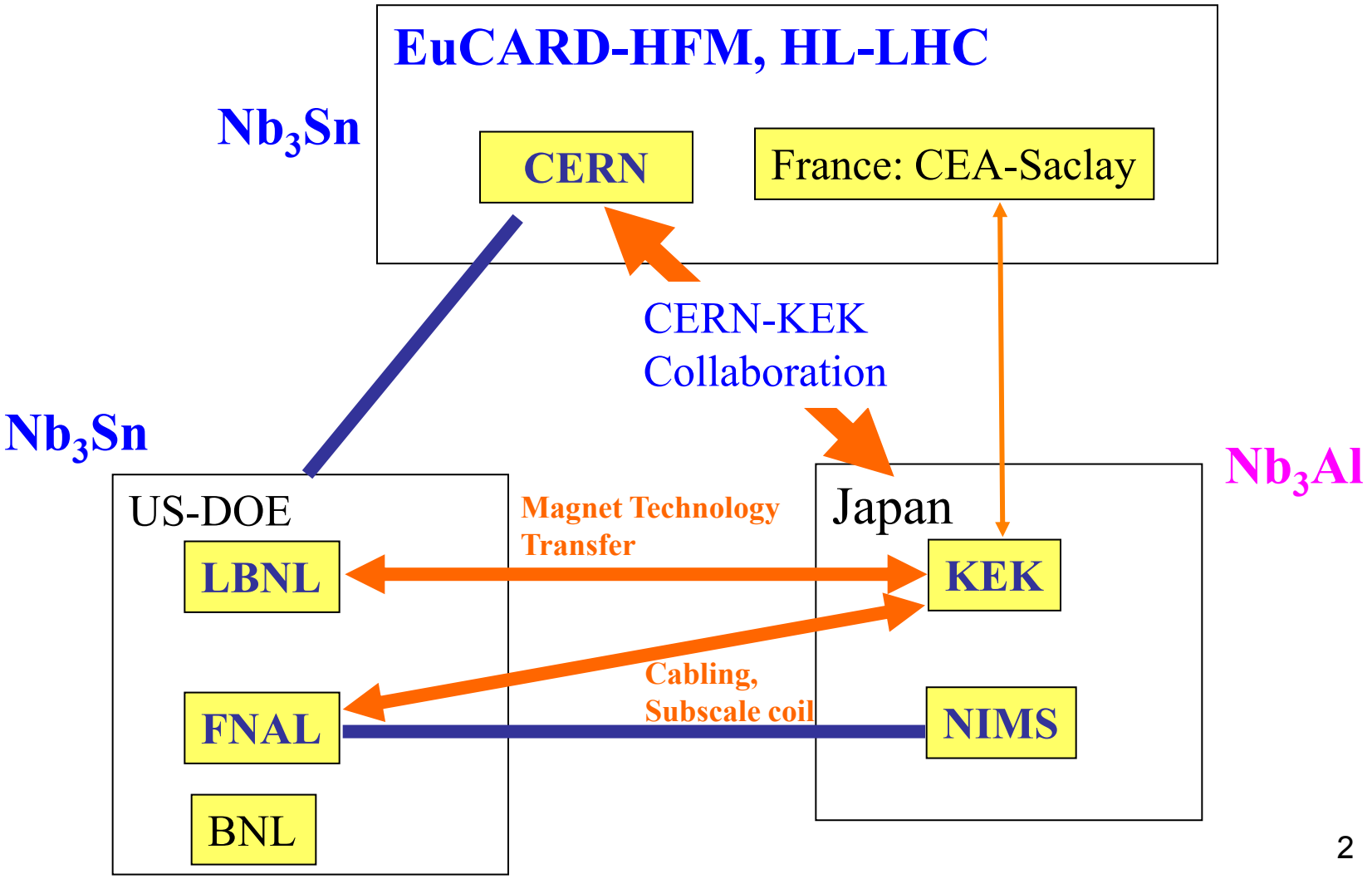
Progress and Summary of Nb_3Al Superconductor and Magnet Development Program

Tatsushi NAKAMOTO
KEK

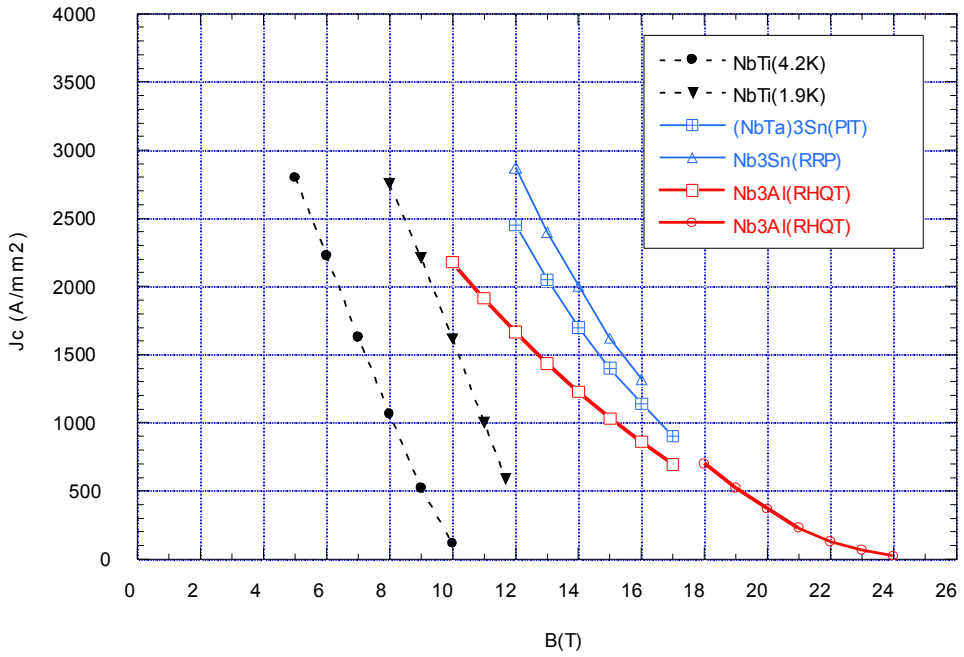
High Field Accelerator Magnet Development

A Global Cooperation Network

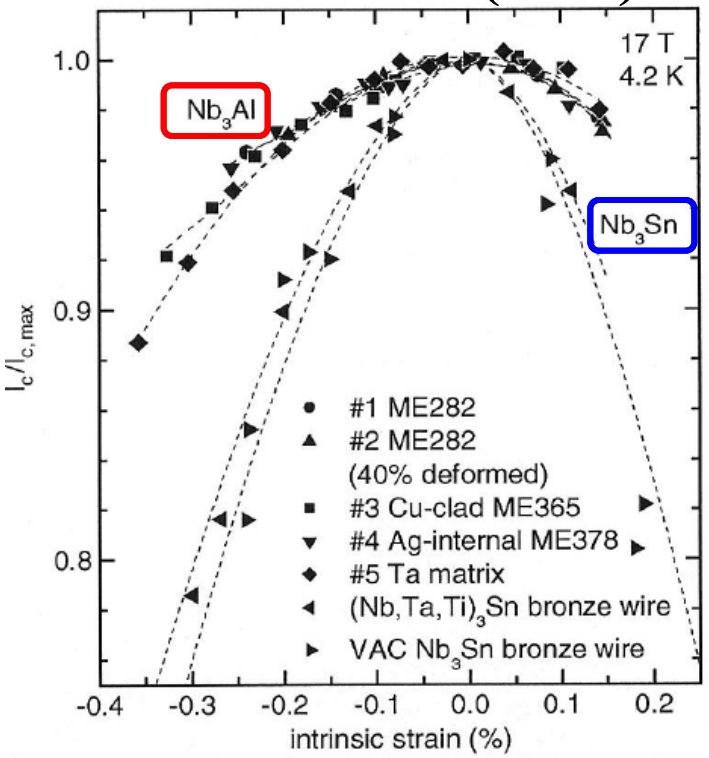


Potential of Nb_3Al

Jc vs. B



Jc vs. Strain (wire)



Supercond. Sci. Technol. 18 (2005) p. 284.
by N. Banno et al.

Nb3Al has,

-Lower critical current density (Jc) than Nb_3Sn.

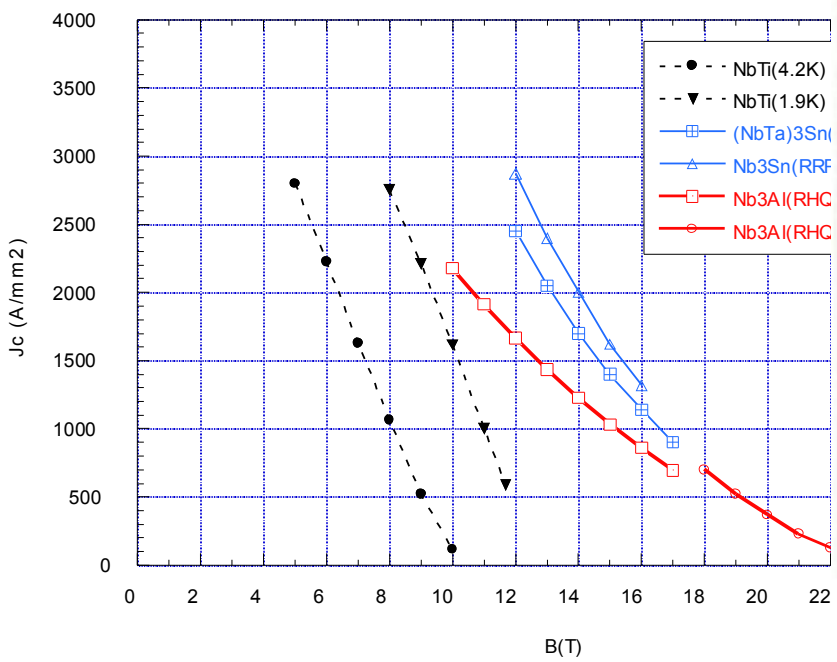
-But, less-sensitivity to strain, stress.

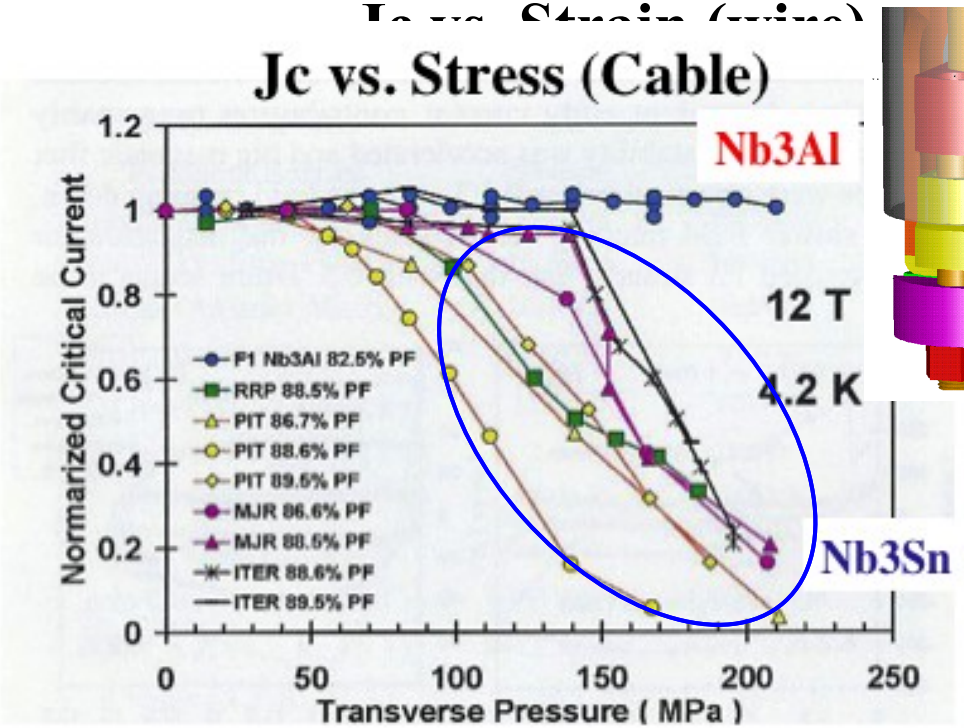
>> Candidate for HFM w/ large aperture, like D1.

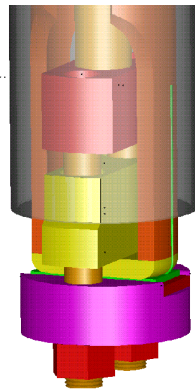
>> Possibility of "React-Wind" technology

- **Similar to current, matured "NbTi" coils.**
- **No heat reaction or impregnation after coil winding.**

Potential of Nb_3Al







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

Supercond. Sci. Technol. 18 (2005) p. 284.
by N. Banno et al.

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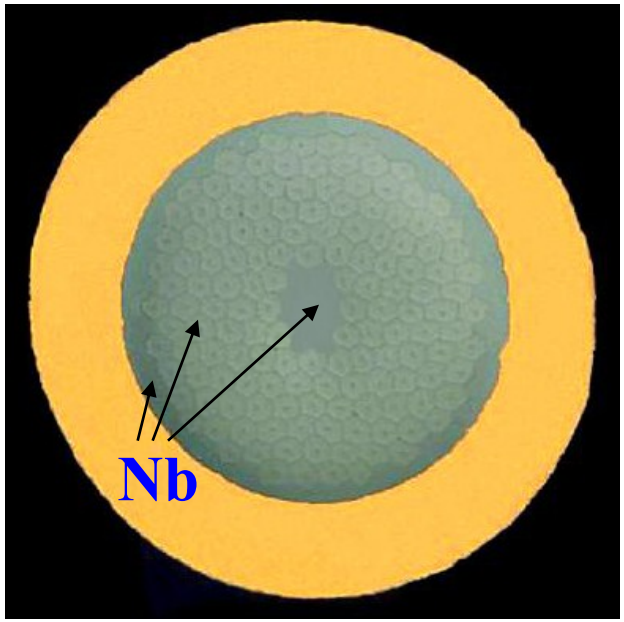
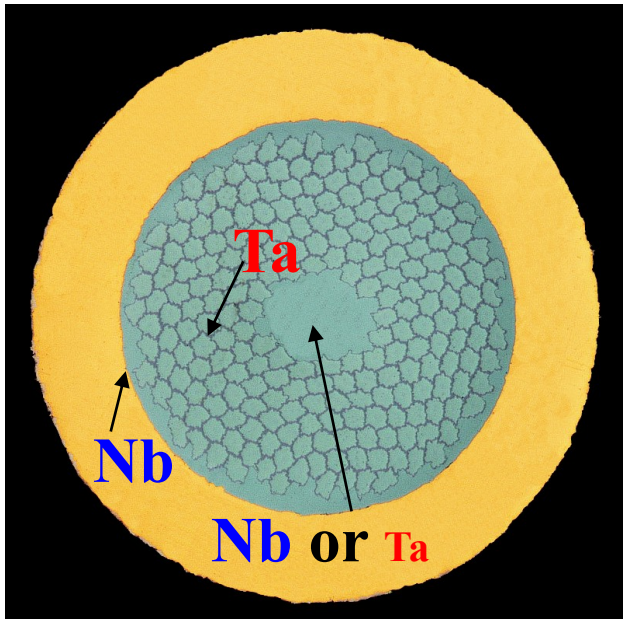
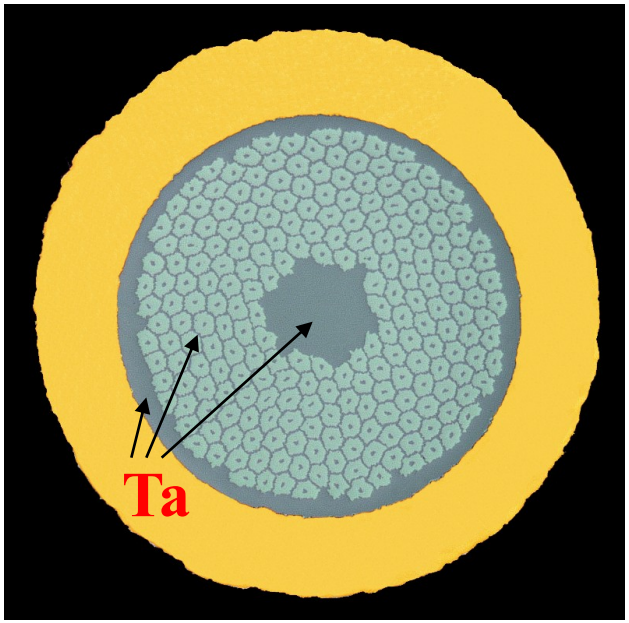
Copper Stabilized Nb_3Al Strands with Different Matrix

(a) F1 strand	(b) K1, K3, K4 strands	(c) K2 strand
(all Nb matrix)	(partial Ta matrix)	(all Ta matrix)



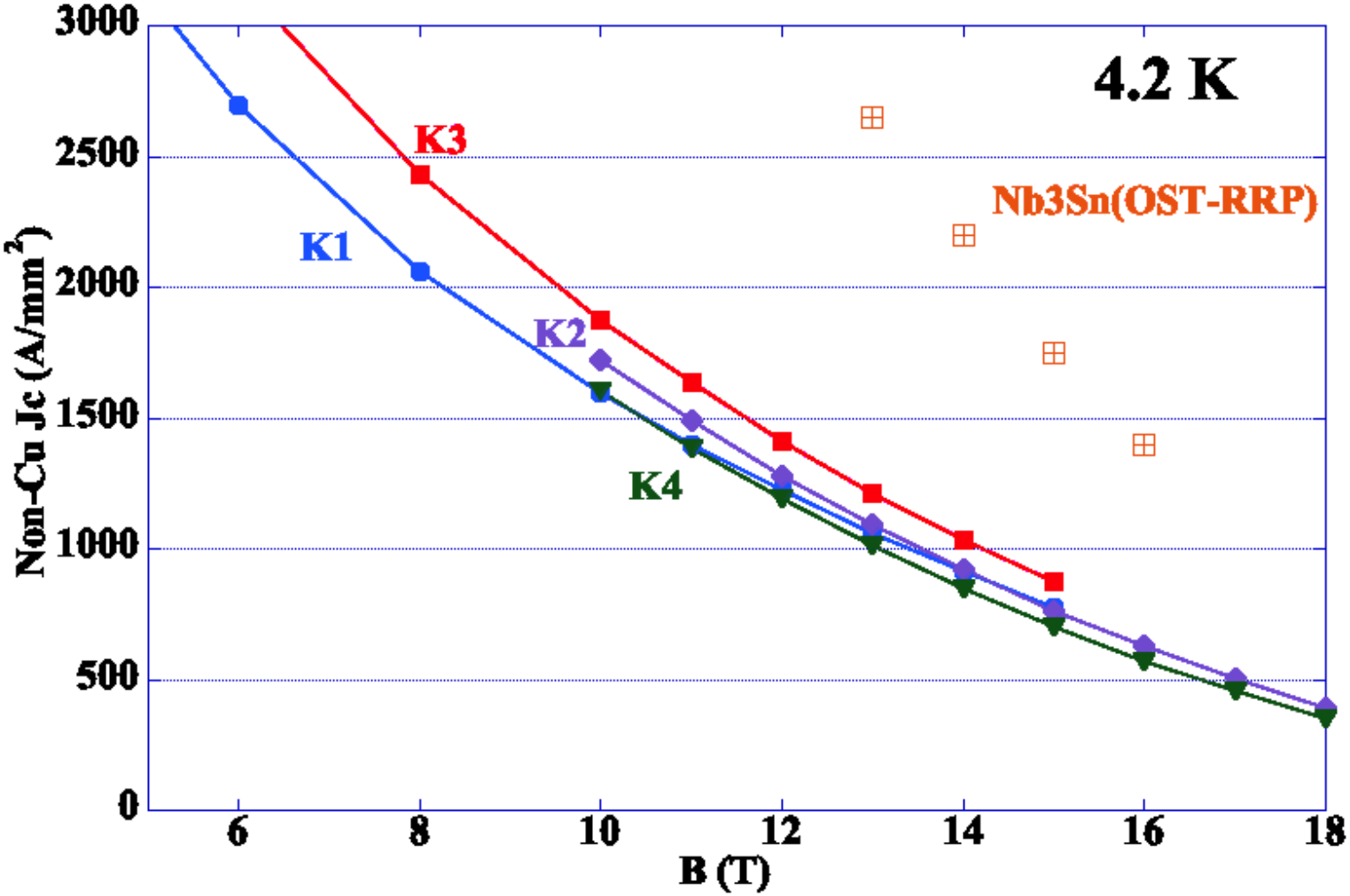




Dia. w/ Cu:	1.0 mm
Dia. w/o Cu:	0.7-0.73 mm
Area Reduction:	~70 %
Filament Dia.:	35 μm
Barrier Thickness:	4-6 μm
Twist Pitch:	45 mm
Piece Length:	< 1 km (400-ton extruder)

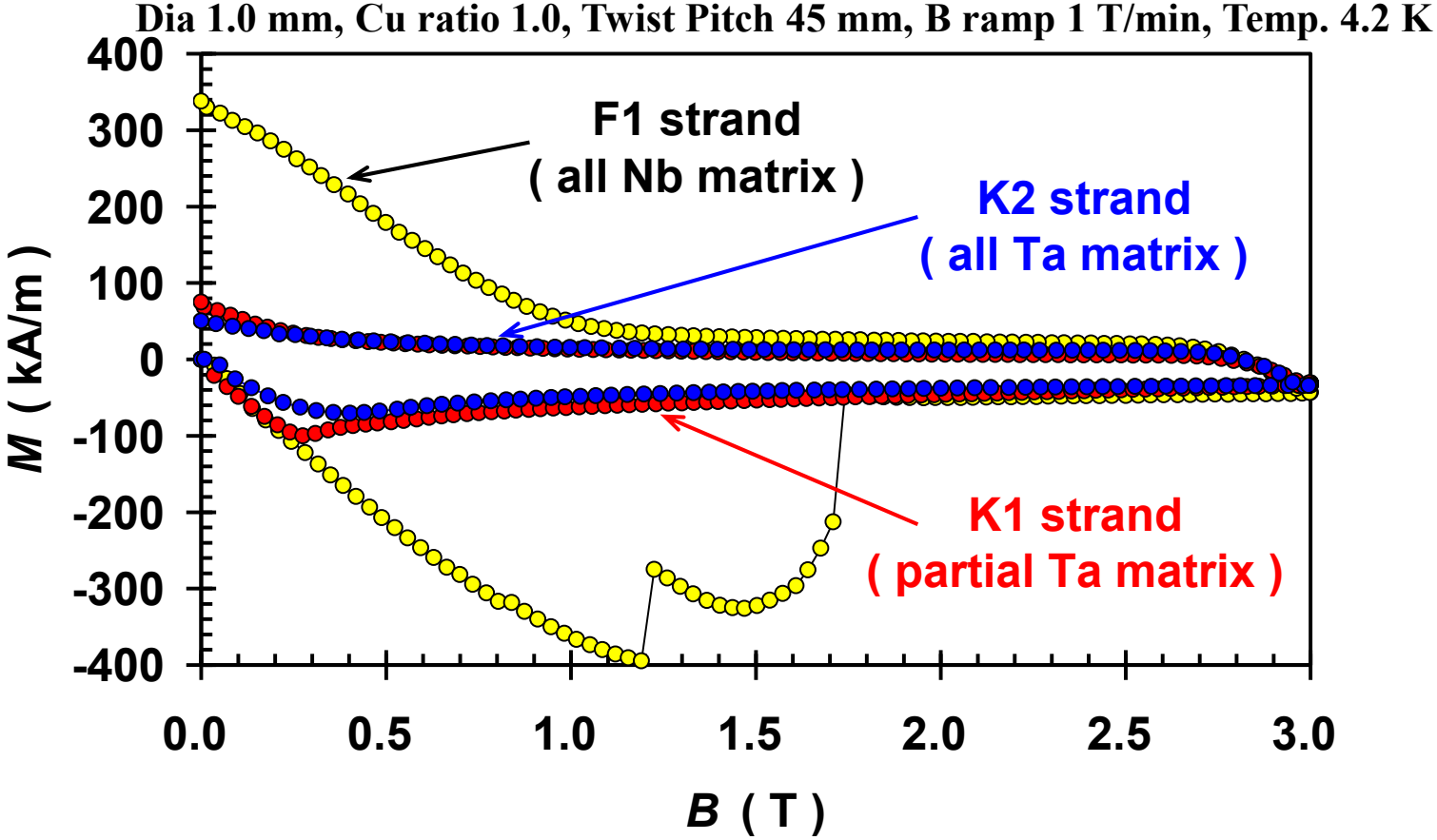
* ~2 lots production per year…
* Wire breakings

Non-Cu Jc of Nb_3Al w/ Ta Barrier



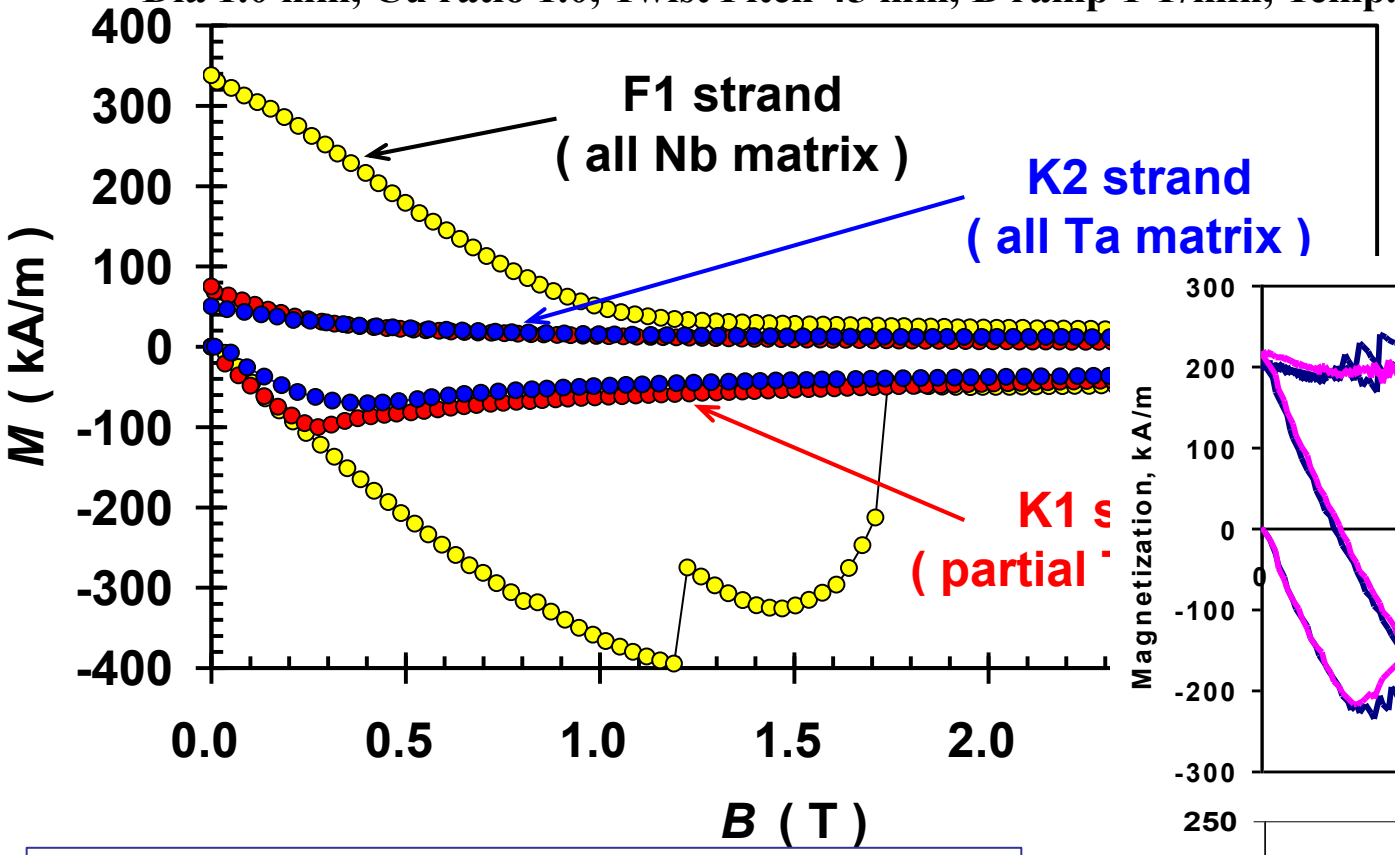
Non-copper current density of Nb3Al is still about half of Nb3Sn.

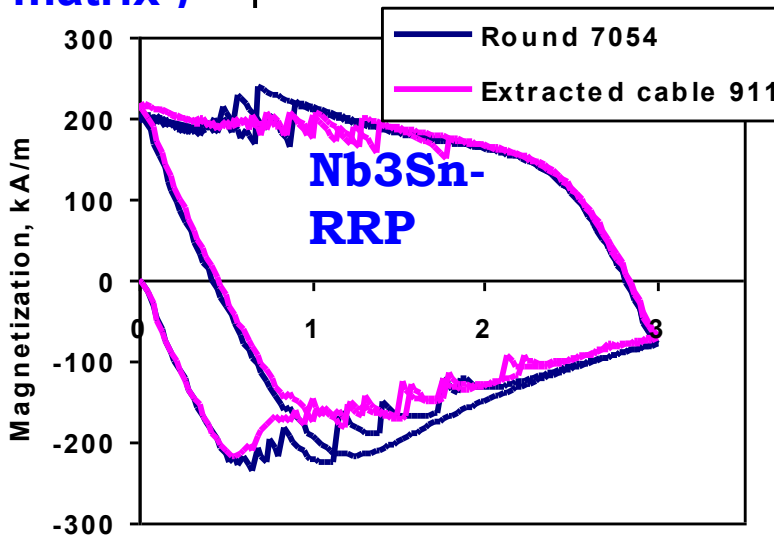
Magnetization Curves at 4.2 K

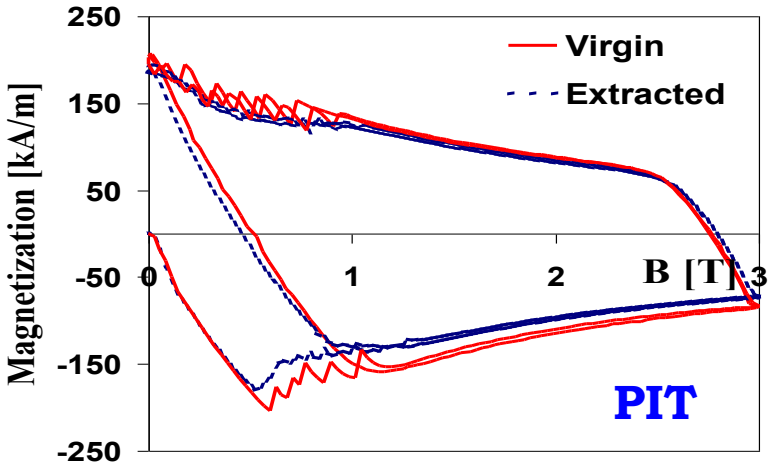


Magnetization Curves at 4.2 K

Dia 1.0 mm, Cu ratio 1.0, Twist Pitch 45 mm, B ramp 1 T/min, Temp. 4.2 K







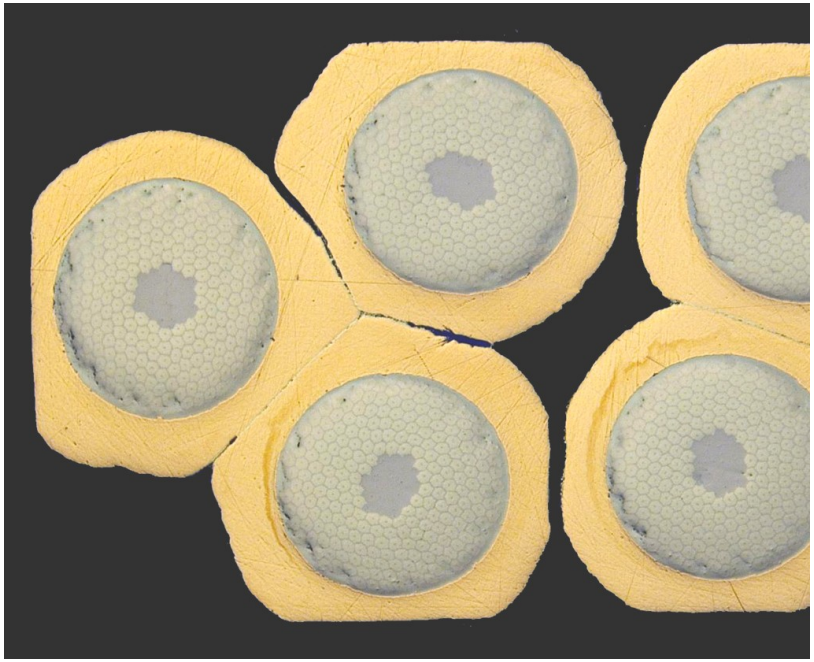
- Magnetization needs to be small enough for accelerator application.
- D_eff:

Nb3Al	~40μm
Nb3Sn-RRP	>70μm
Nb3Sn-PIT	~30μm

- No flux jump.

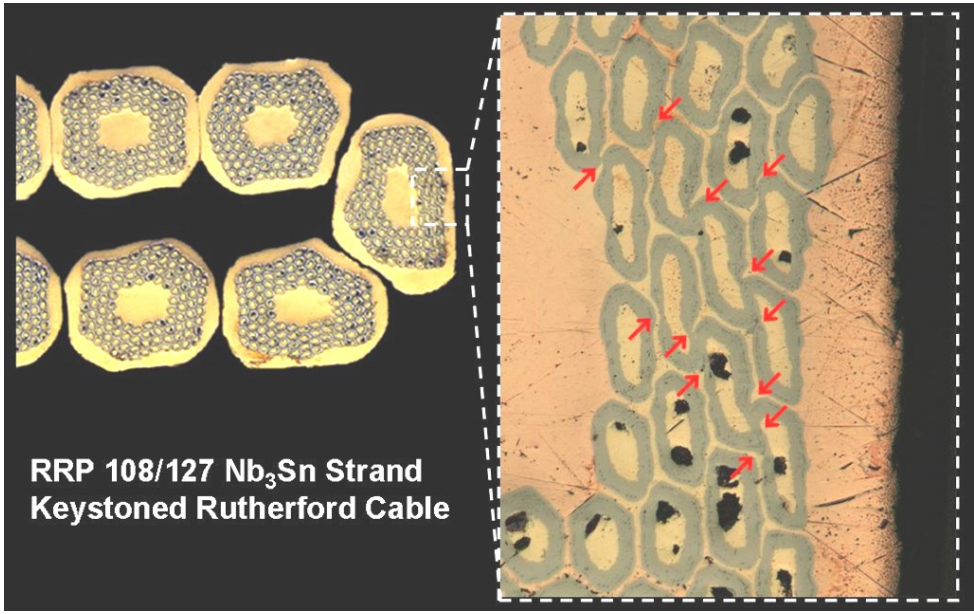
Deformation at Cabling

Nb3Al F3



- Copper stabilizer is much deformed and partially debonded.
- But precursor is NOT deformed.
- Robust??

Nb3Sn RRP

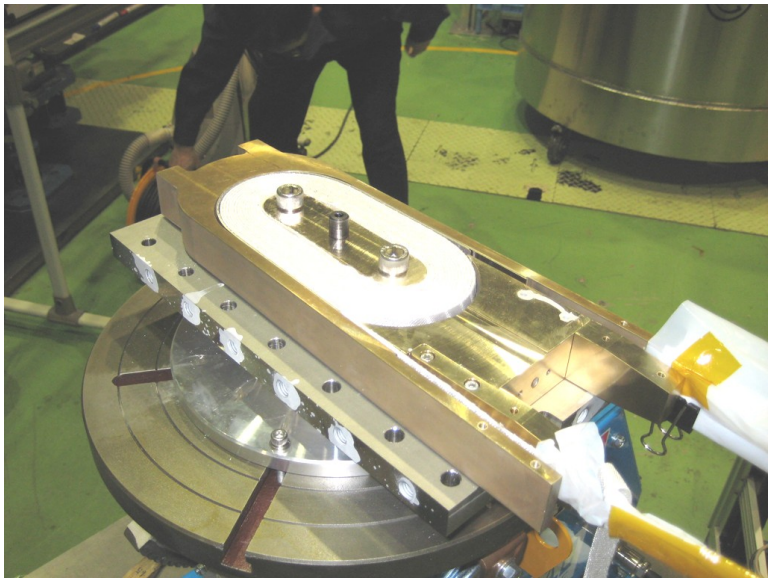


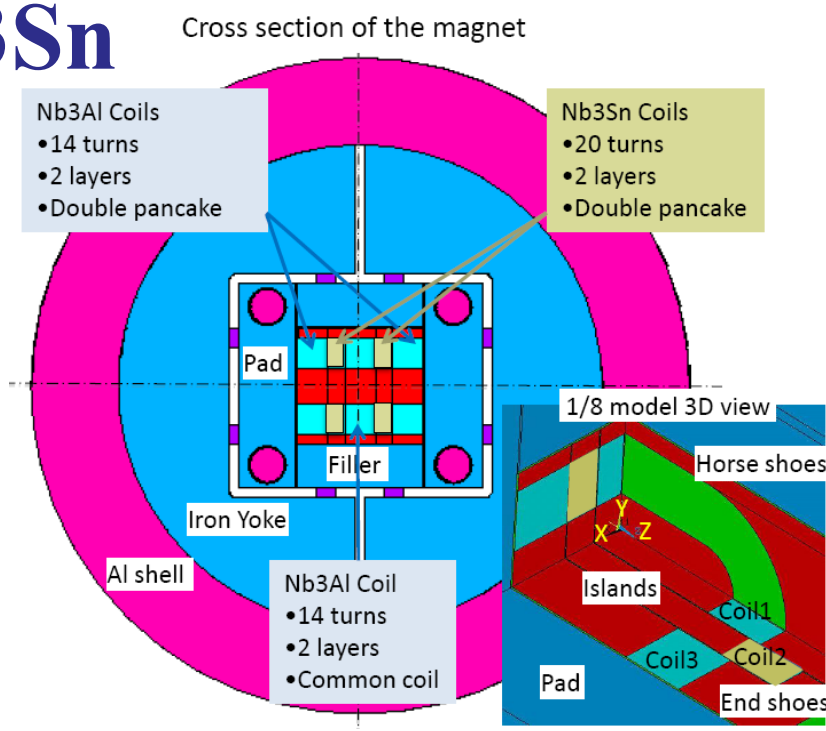
- Subelements:
  Elongated, merged, broken.
- Possible tin leakage

>> Degradation…

13 T Sub-scale Nb3Al/Nb3Sn Hybrid Magnet

- To demonstrate feasibility of Nb_3Al cable.
- Key design points
  - The common coil concept, and the shell structure,
  - Three Nb_3Al coils & two LBL-Nb_3Sn coils for Higher Peak Field.
- 2 practice coil windings and heat treatment with alumina-ceramic tape completed.
- The 1st Nb_3Al coil winding in progress. Issue of strand pop-up under low tension.





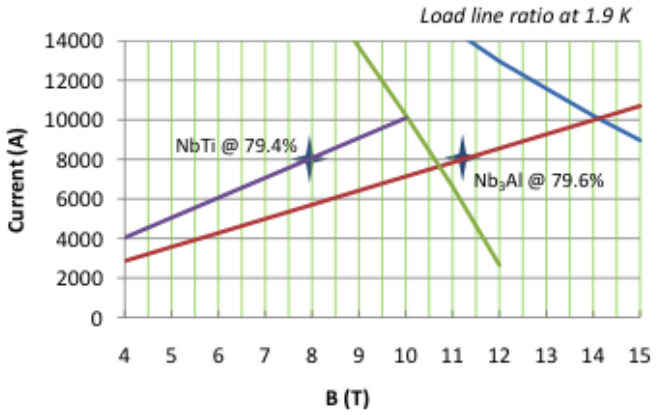
Item	Value
Operation current	12.1 kA
Peak field	13.1 T
Stored energy	71.8 kJ
Magnet Length	740 mm
Shell Dia.	680 mm
Nb3Al Strand Dia.	1 mm
Cu/Non-Cu ratio	0.96
No. of Stands	28
Cable dimension	13.93*1.84 mm2
Cable Insulation	0.25 mm
Nb3Al Coils No.	3
Turns No. per layer	14
Layers No. per coil	2
Nb3Sn Coils No.	2
Turns No. per layer	20
Layers No. per coil	2

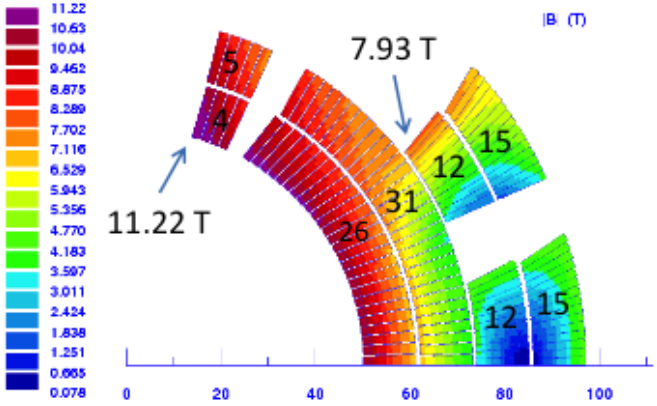
Preliminary Conceptual Design of Cosθ Model Coil

1&2 layers Nb_3Al + 3&4 layers NbTi @ 1.9 K
(NbTi: MQXA cable for inner layers)

Item	Value	
Main field (dipole)	10.77 T	
Operation current	8 kA	
Field homogeneity	<0.04% (R_r=25 mm) <1% (R_r=45 mm)	
Peak field in the coil	Nb_3Al - 11.22 T	NbTi - 7.93 T
Load line ratio *	Nb_3Al – 79.6%	NbTi - 79.4%
Strand diameter	Nb_3Al - 1 mm	NbTi - 0.82 mm
Cu/Non-Cu ratio	Nb_3Al - 1.0	NbTi - 1.2
Cable dimension	Nb_3Al - 11*1.84 mm^2 , NbTi - 11*1.47 mm^2	
No. of strands	Nb_3Al - 22	NbTi – 27
Keystone angle	Nb_3Al - 1.98 °	NbTi – 2.36°
No. of layers	4	
Bore diameter	100 mm	
End to end length	1500 mm	
Total strand length for 1.5 m coils	8.7 km (1&2 layer, Nb_3Al) + 8.7 km (3&4 layer, NbTi)	

* Calculated with J_c of K1 strand at 1.9 K



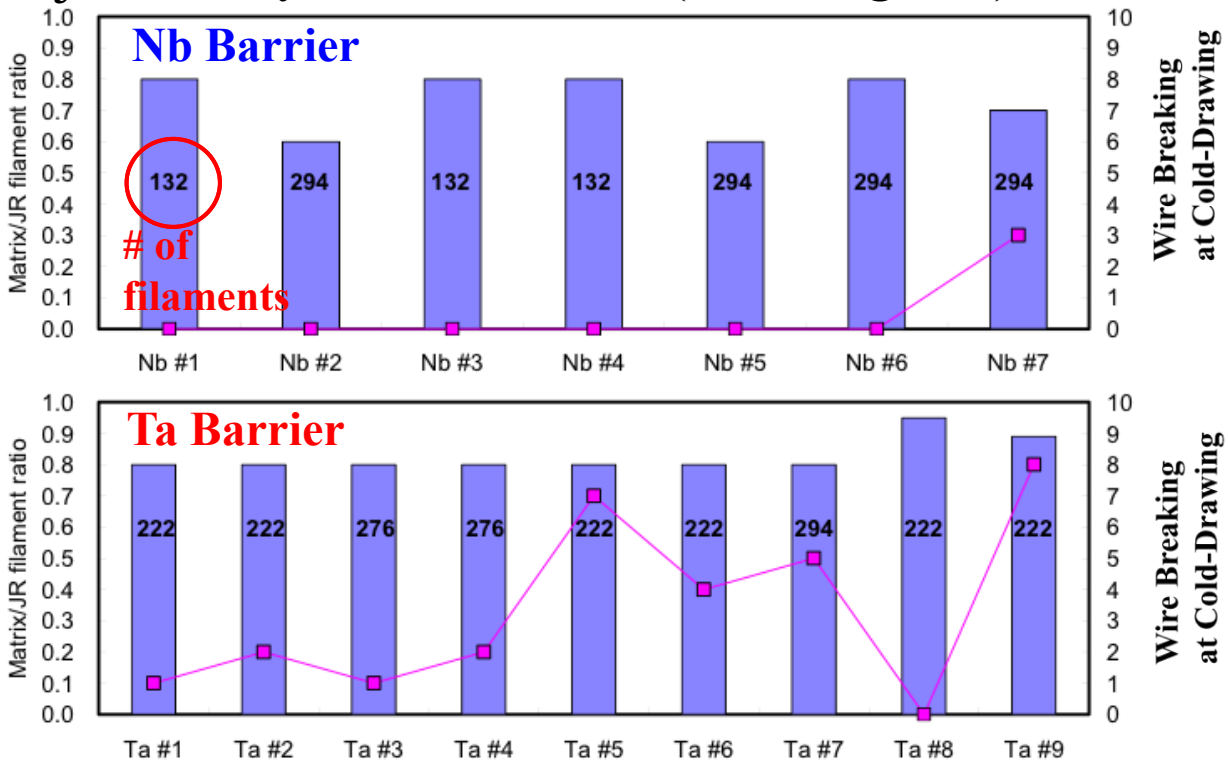


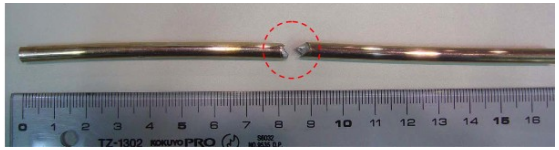
- **XU will station at CERN from 2011:**
  - **>> Design work for the HL-LHC**
  - **>> Present design study.**

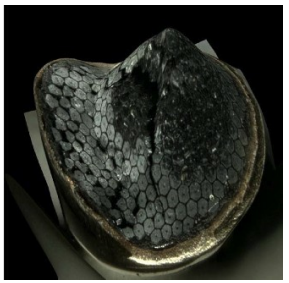
Budget Proposal for JFY2011

Breaking at Wiredrawing

Nb_3Al wires by 400-ton extruder (1-km long wire) since 2004

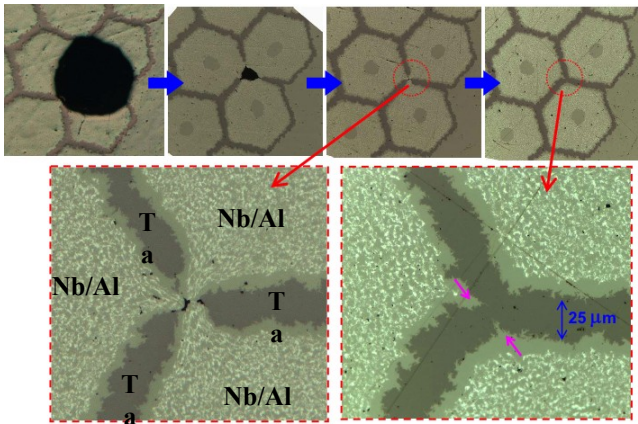






- **Many wire breakings with Ta matrix.**
- **Breaking initiated at Ta matrix.**
- **Need to reduce breaking rate for long wire production to develop model magnet in the NEXT R&D Program.**

>> Drawing trials with 5 different tantalum ingredients have been carried out.



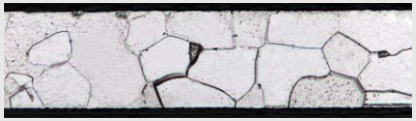
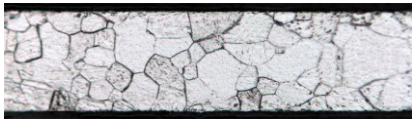
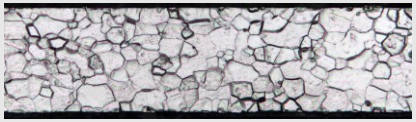
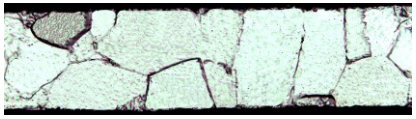
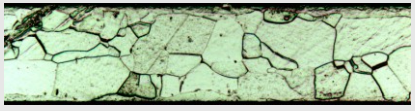
Wiredrawing Trials in 2010

- Own effort by Hitachi-Cable Co.
- Focus on property of tantalum sheet.
- KEK & NIMS have supported and provided new 4 tantalum sheets with different properties.

- Unsuccessful.
- No drawing trials reached the target diameter.

Preferable/Good
Inappropriate/NG

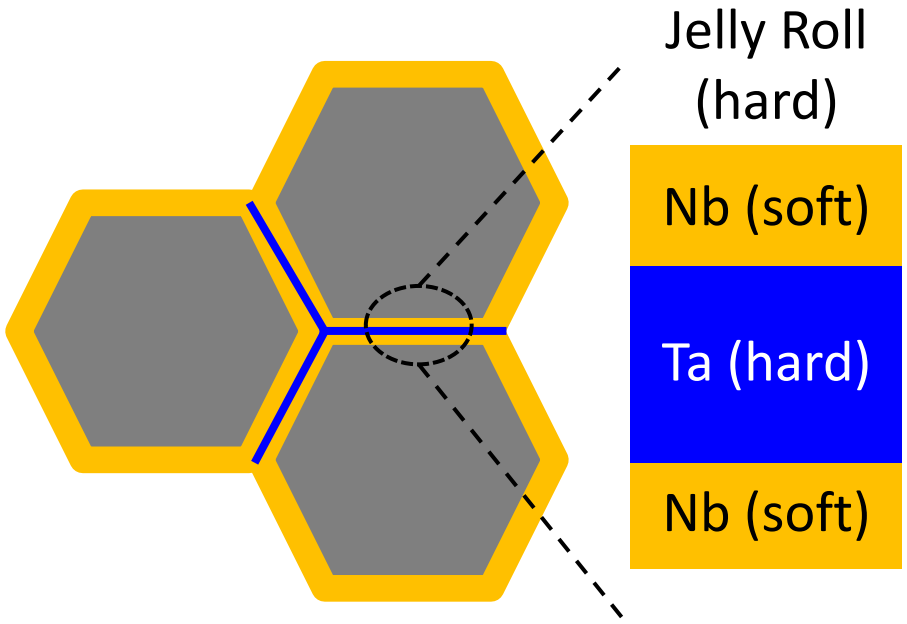
Target: ϕ1.5mm

Tantalum Sheet	Purity	Oxygen Content	Grain SIze	HV(0.1kg)	Elongation	Diameter of Wire Breaking
	99.99 %	< 20 ppm	30-100 μm	77.1	25.5	3 mm
	99.98 %	< 20 ppm	10-30 μm	132.6	29.5	10.26 mm
	99.98 %	< 20 ppm	5-10 μm	122.6	27.3	8.82 mm
	99.99 %	< 1 ppm	50-100 μm	79.4	11.3	3 mm
	99.99 %	< 1 ppm	10-70 μm	92.3	9	4.41 mm

To Reduce Irregular Deformation

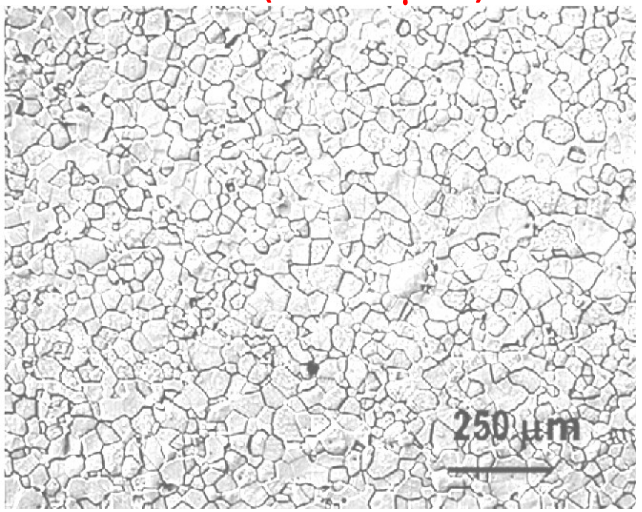
(A) Reduction of Stress Concentration
(New design concerning)
>> Niobium buffer layer implemented in K4 strand.

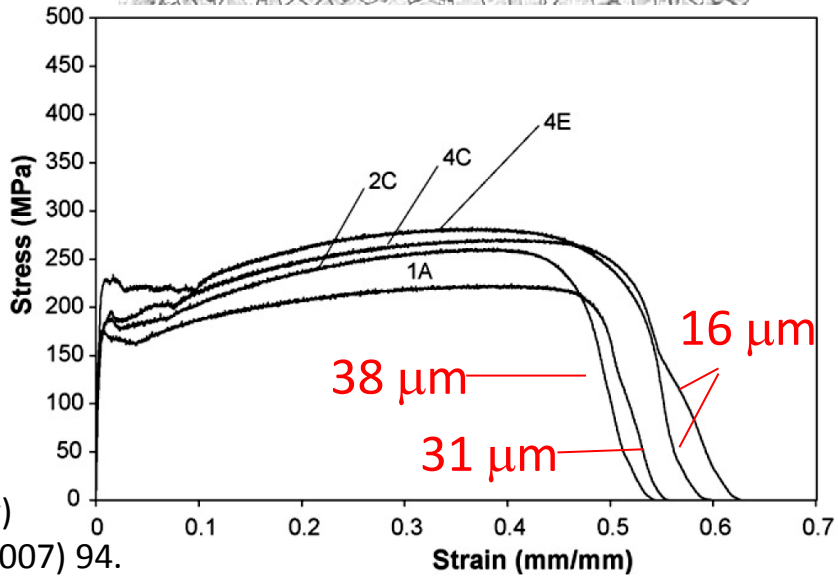
Nb/Ta/Nb sandwich design



(B) Improving of Cold-workability
(Microstructure control)

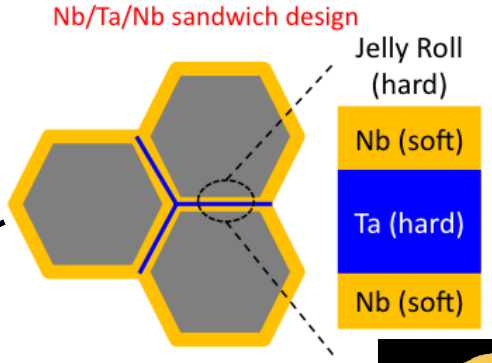
Fine Grain (10-20μm)



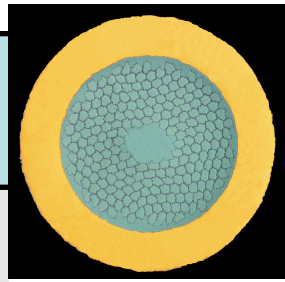


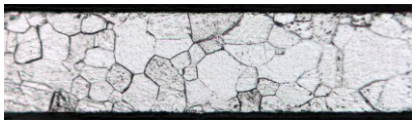
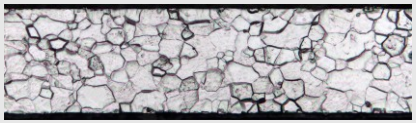
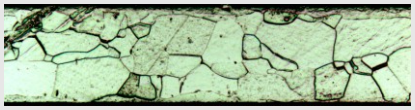
S. Mathaudhu et.al., (Texas A&M University)
Materials Science and Engineering A 463 (2007) 94.

New Wiredrawing Trials



- **Postpone the fabrication of K6 precursor. Carry-over of budget into JFY2011: 7 MJYen**
- **At least 4 trials, immediately in JFY2010!!**
  - **>> Need revision of budget profile.**
- **Fine grain + Elongation + Low HV + Nb buffer layer**



Tantalum Sheet	Purity	Oxygen Content	Grain Size	HV(0.1kg)	Elongation
	99.99 %	< 20 ppm	30-100 μm	**77.1**	**25.5**
	99.98 %	< 20 ppm	**10-30 μm**	**132.6**	**29.5**
	99.98 %	< 20 ppm	**5-10 μm**	~~**122.6**~~ **<80**	**27.3**
	99.99 %	**< 1 ppm**	50-100 μm	79.4	**11.3**
	99.99 %	**< 1 ppm**	10-70 μm	92.3	**9**

Improved by additional process

Budget Proposal for JFY2011

(Unit: MJYen)

	JFY 2009	JFY 2010	JFY 2011	JFY 2012	JFY 2013	JFY 2014
KEK or Grant (Own Effort)	9	3	4 + ?			
Present R&D Program	**54**	~~**30**~~	~~**21**~~			
New Program (Prospect)						
Money Transfer From CERN	54	30				

- **Carry-over of 7MJYen to JFY2011.**
- **Original budget of 21MJYen in JFY2011 is extended until JFY2013.**

>> Budget request of 9MJYen in JFY2011 to be reviewed.

>> Rest of 12MJYen and nonapproved 59MJYen to remain for the New Program.

>> Corresponding R&D covered by KEK's own effort: 7M(2012), 5M(2013).

Budget Proposal for JFY2011

(Unit: MJYen)

	JFY 2009	JFY 2010	JFY 2011	JFY 2012	JFY 2013	JFY 2014
KEK or Grant (Own Effort)	9	3	4 + ?	7 + ?	5 + ?	
Present R&D Program	**54**	~~30~~ **23** → Carry-over	~~21~~ **7 + 9**			
New Program (Prospect)						
Money Transfer From CERN	54	30	9			

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Present R&D Program	**54**	~~**30**~~ **23**	~~**21**~~ **7 + 9** (Carry-over)		**Prospect. To be reviewed at 2011**	
New Program (Prospect)				**28** (10km Nb3Al precursor)	**13** (RHQ, plating, cabling)	**30** (Model dipole development)
Money Transfer From CERN	54	30	9	28	13	30

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2011-2014 Total: 80MJYen (prospect)

Balance (as of Nov. 2010): 936 kCHF

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	JFY 2009	JFY 2010	JFY 2011	JFY 2012	JFY 2013	JFY 2014
KEK or Grant (Own Effort)	9	3	4 + ?	7 + ?	5 + ?	
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New Program (Prospect)			?	28 (10km Nb3Al precursor)	13 (RHQ, plating, cabling)	30 (Model dipole development)
Money Transfer From CERN	54	30	9 + ?	28 - ?	13	30

Due to the intermediate technical review 2011, a part of the budget for the NEW R&D Program could be attributed in JFY2011.

2011-2014 Total: 80MJYen (prospect)

Balance (as of Nov. 2010): 936 kCHF

Budget Detail in JFY2011

(Unit: kJYen)

		JFY 2010 Budget	JFY 2010 Predicted Closing	JFY 2011 Budget
Magnet R&D	Jigs, Yoke, Shell	1000	1563	1500
	Coil	3000	1300	2500
	PS, DAQ, Cryostat	2000	0	0
Wires and cable for the magnet	Further processes for the previous year's precursor	0	2090	4000
	Precursor (1 km)	10000	0	Carry-over 7000
	Cabling	Fermilab Collab.	Fermilab Collab.	Fermilab Collab.
	consumable	800	0	0
	Long wire production R&D	0	10000	0
Fundamental Study	15T Solenoid, Jc Stress Depend.	2000	200	Own Effort
	Thermal conductivity meas.	3000	380	Own Effort
	Cyanate ester resin, Gamma ray irradiation	1500	0	Own Effort
	Neutron diffraction, Strain Study	3000	1836	Own Effort
	Short strand R&D	1700	1448	Own Effort
Travel Expenses		2000	4183	1000

Total: 9MJYen

Appendix

Budget Plan at Dec. 2009

(Unit: kJYen)

	JFY2009	JFY2010	JFY2011
Nb3Al wires, Subscale Magnet R&D	21,000	16,800	14,300
Fundamental Study	31,000	11,200	4,700
Travel, etc,	2,000	2,000	2,000
Total	54,000	30,000	21,000

3 years total: 105,000 kJYen approved at Committee 2008.

Budget request for JFY2011 (planned in 2009) was 21 MJYen.

>> should be revised.

Accounting

(Unit: JYen)

		JFY 2009 Final	JFY 2010 As of Today	JFY 2010 Prediction
Magnet R&D	Jigs, Yoke, Shell	Covered by another grant	1,362,772	1,562,772
	Coil	3,816,210	Own Effort	Own Effort +1,300,000
	PS, DAQ, Cryostat	2,414,430	0	0
Wires and cable for the magnet	Further processes for the previous year's precursor	6,226,080	2,089,500	2,089,500
	Precursor (1 km)	6,636,000	(6,247,500)	0
	Cabling	Fermilab Collab.	Fermilab Collab.	Fermilab Collab.
	consumable	1,273,125	0	0
	Long wire production R&D	0	4,073,146	10,000,000
Fundamental Study	15T Solenoid, Jc Stress Depend.	13,488,300	0	200,000
	Thermal conductivity meas.	3,777,900	380,534	380,534
	Cyanate ester resin, Gamma ray irradiation	1,102,668	0	0
	Neutron diffraction, Strain Study	10,124,887	629,758	1,836,458
	Short strand R&D	4,326,272	1,447,793	1,447,793
Travel Expenses		814,128	4,182,943	4,182,943

54MJYen Original 30M >> 23MJYen

Carry Over 7MJYen