Development of Superconducting Magnets for LHC Luminosity Upgrade

-R&D for Nb_3Al Superconducting Magnet-

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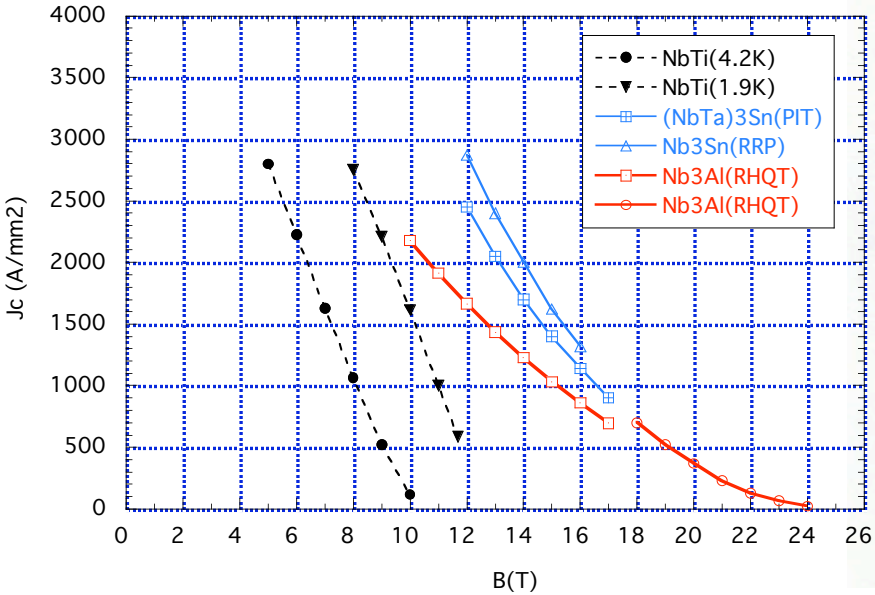
CERN - KEK Committee, 2nd meeting, 07 December 2007, B60-6-002 at CERN

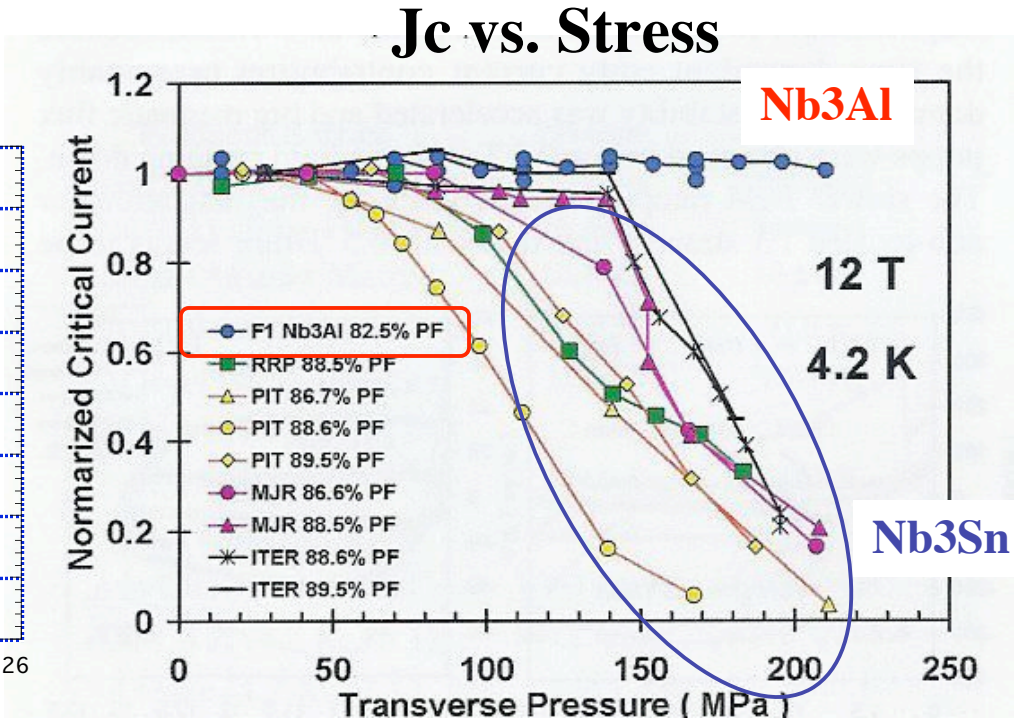
Contents

- Objective
- Development of Nb3Al Strand and Cable
- Design Study of 15 T Model magnet
- Summary and Plan

Advantage of Nb_3Al over Nb_3Sn

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





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

Better mechanical performance of Nb3Al >> No degradation of Jc below 220 MPa.
For Nb3Sn (RRP), Jc is decreased to be around half at 150 MPa.
@B=12T Jc~3000 A/mm^2 --> 1350 A/mm^2

Objective

For the LHC luminosity upgrade, we are developing

- High field superconductor and cable made with Nb_3Al,

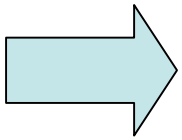
Complementary to Nb_3Sn superconductor and magnet development at CERN and US-LARP.

- Model coils with Nb_3Al cable to demonstrate its feasibility at a field range of 15 T.

Magnetic design in progress.

Hard strands, difficulty of cabling.

Higher temperature (> 800 °C) for the heat treatment.



This is a real R&D……

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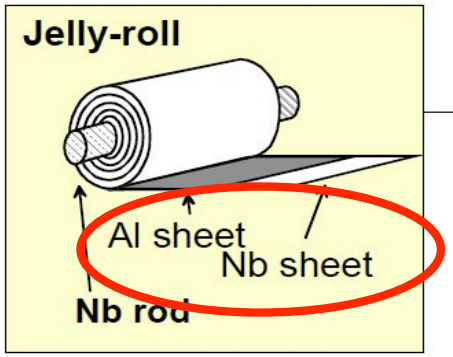
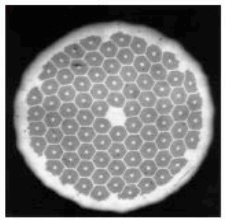
Rapid Heating, Quenching and Transformation process



Ta

Precursor : Nb/JR Nb/Al

Extrusion + Drawing



Joule Heating
+
Quenching

$Nb/Nb(Al)_{ss}$

bcc supersaturated solid solution

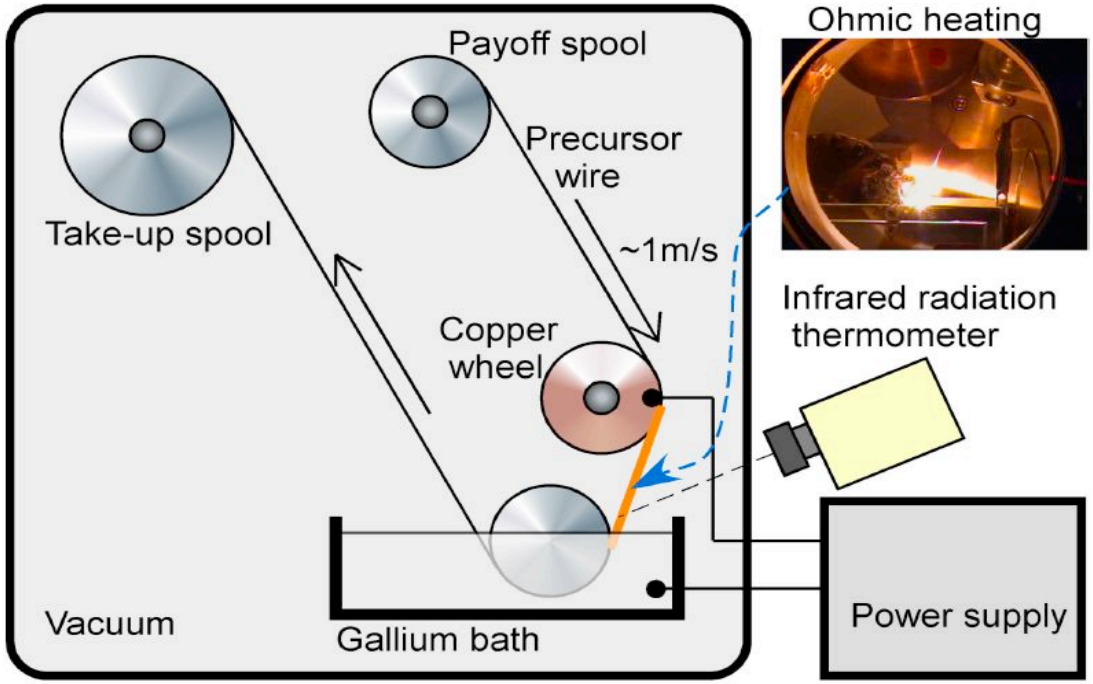
Cu cladding

$Cu/Nb/Nb(Al)_{ss}$

Winding
+
Transformation

$Cu/Nb/Nb_3Al$

stoichiometry
fine grain

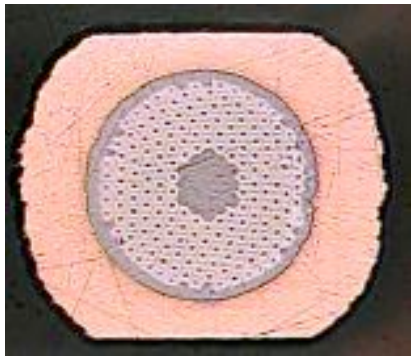


Ohmic heating

Infrared radiation thermometer

T. Takeuchi et al. IEEE Trans. Appl. Superc. 12, 1 (2002) 1088.

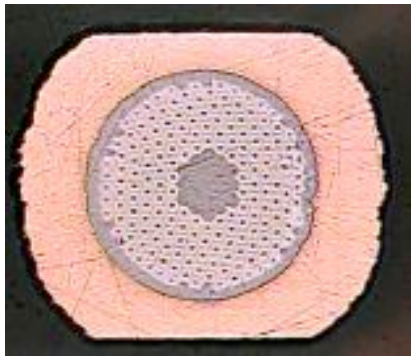
Development Items



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

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

Development Items



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2007

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

2006, 2007

Strands Developed by KEK/Hitachi-Cable

	M21-3 (2003)	ME396 (2004)	ME451 (2005)	ME458 (2006)	ME476 (2006)
Matrix material	Nb	Nb	Nb	Nb	Ta
Matrix ratio	0.8	0.6	0.69	0.79	0.8
Num of fila.	144	294	294	546	222
Sheath material	Nb	Nb	Nb	Nb	Ta
Wire dia. (mm)	0.8	0.8	1.37	1.35	1.35
Filament dia. (mm)	51	38	62.7	44.2	69
Twist pitch (mm)	32	32	55	non	54

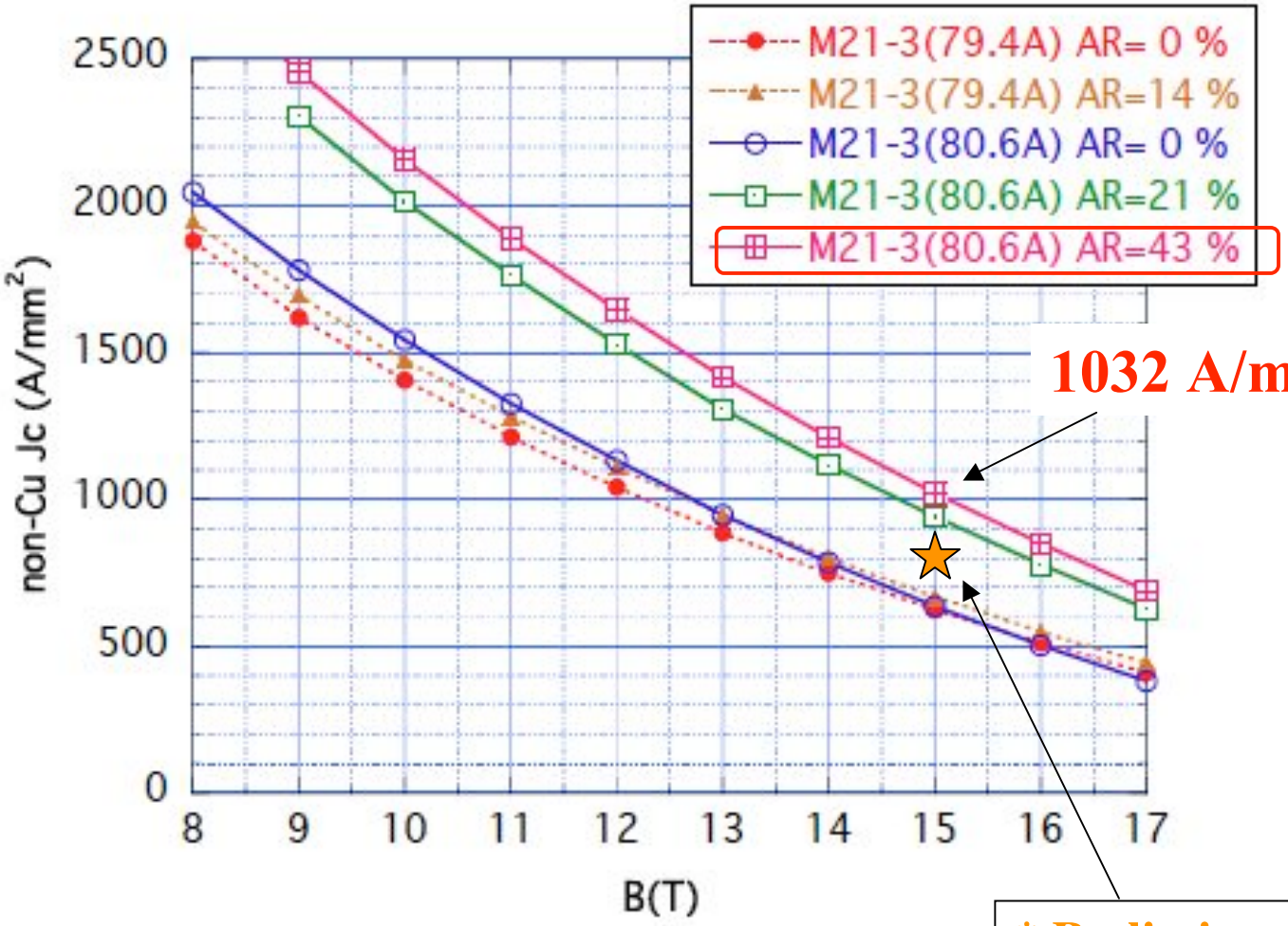
The wire diameter shown in this table for RHQ treatment.

Highest Jc

Present

2 lots of strands with Ta-matrix are being fabricated in 2007.

Highest non-Cu Jc of Nb3Al

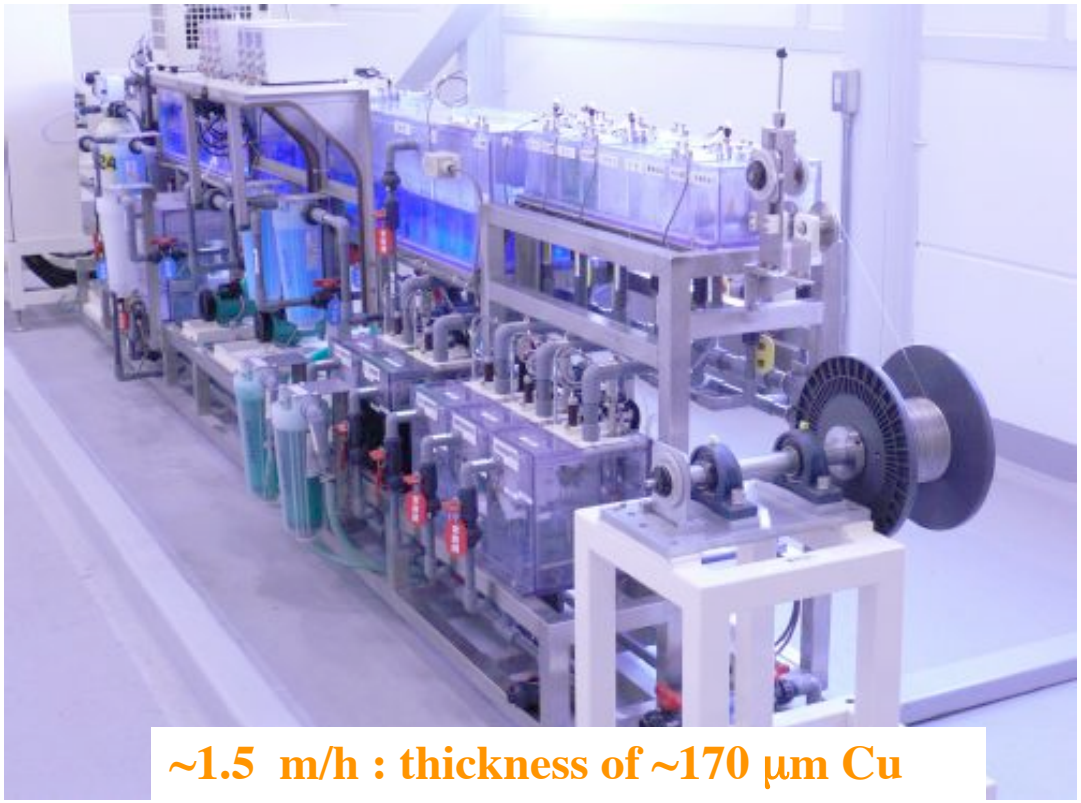


1032 A/mm² @ 15T

*** Preliminary**
ME476 (Ta matrix, ϕ1.0)
~800 A/mm² @ 15T

Continuous Electroplating for Ta-matrix Wire

1st: Ni layer
2nd: Cu layer



~1.5 m/h : thickness of ~170 μm Cu

*Work only within weekday

ME476 (ϕ0.76, 160 μm-Cu)

50 m long ⇨ Measurement of Cu thickness
Twist test

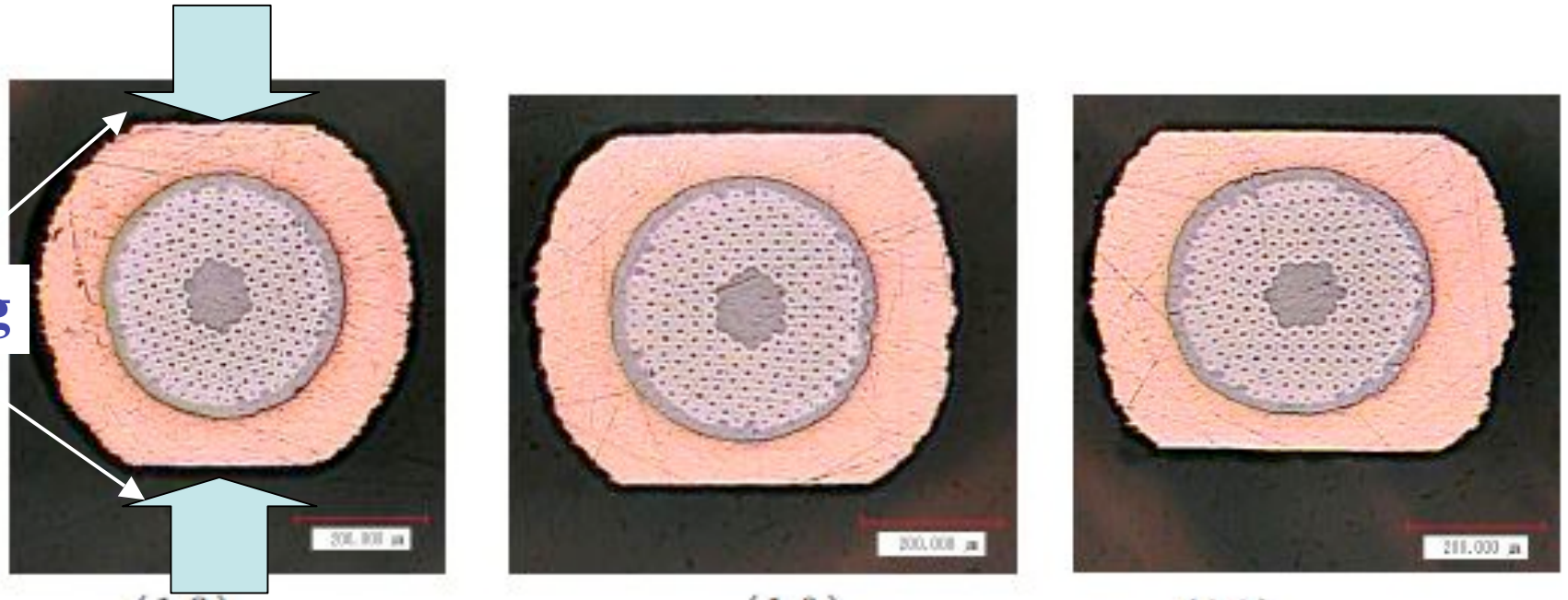
150 m long ⇨ In progress

Mechanical Bonding Strength

-Electroplating on the Ta-matrix wire.
-Visual inspection of cross section after the rolling.

Copper peel-off found in some cases.
But OK in most cases.

Rolling



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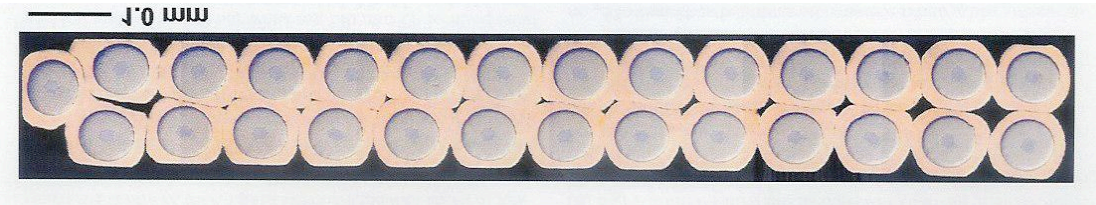
Trial Fabrication of Nb_3Al Rutherford Cable



Packing factor 87%

Feasibility demonstrated by NIMS & Fermilab in 2006, 2007.
(Of course, further improvements are necessary…)

Present KEK's strands 2007 will be cabled in 2008 for the model coil.

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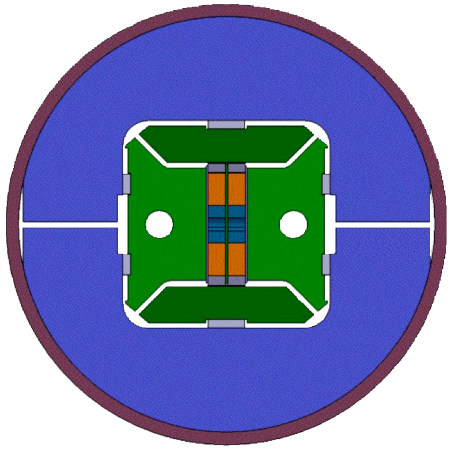
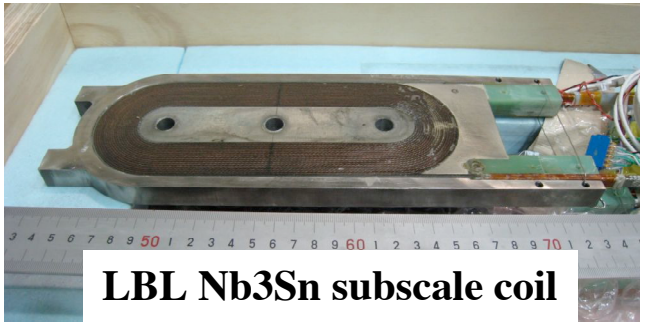
Basic Design

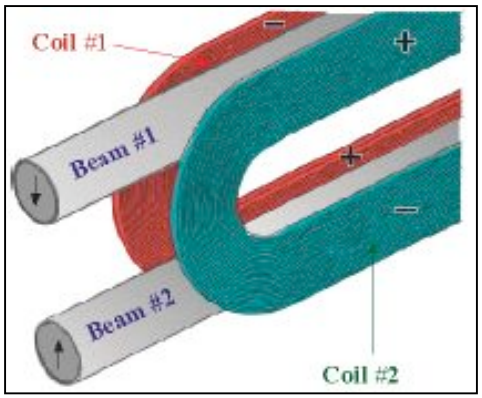
Goal: 15 T magnet with Nb3Al cable to demonstrate its feasibility.

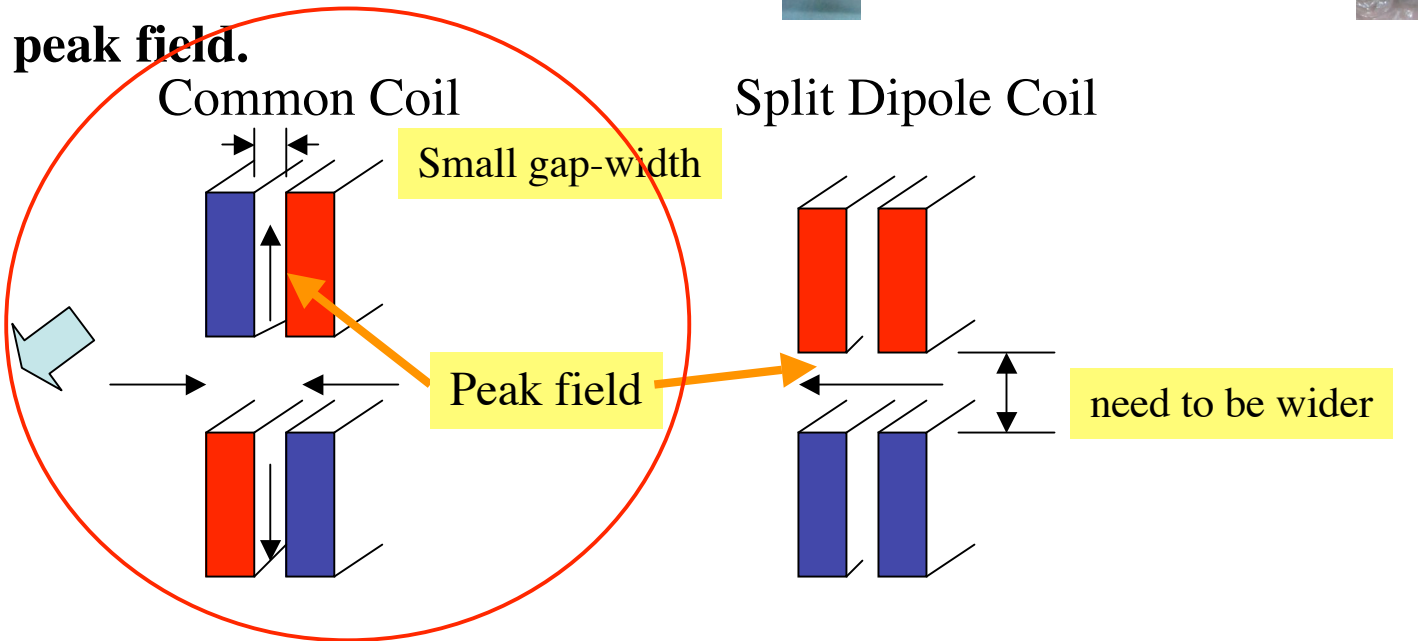


- **Shell structure**
  - **Easy assembly and disassembly**
- **Common-racetrack coil**
  - **Simple support structure**
- **Use 2 subscale Nb3Sn coils made by LBL**
  - **Saving cable length of Nb3Al.**
  - **Boost up the peak field.**



LBL Nb3Sn subscale coil



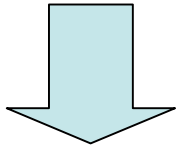


Strand Parameters For Field Design

- Strand Dia. : 1 mm
- Copper/NC Ratio : 1 -> 0.75 for higher Ic
- No. of Filament : 222
- Expected non-Cu Jc :

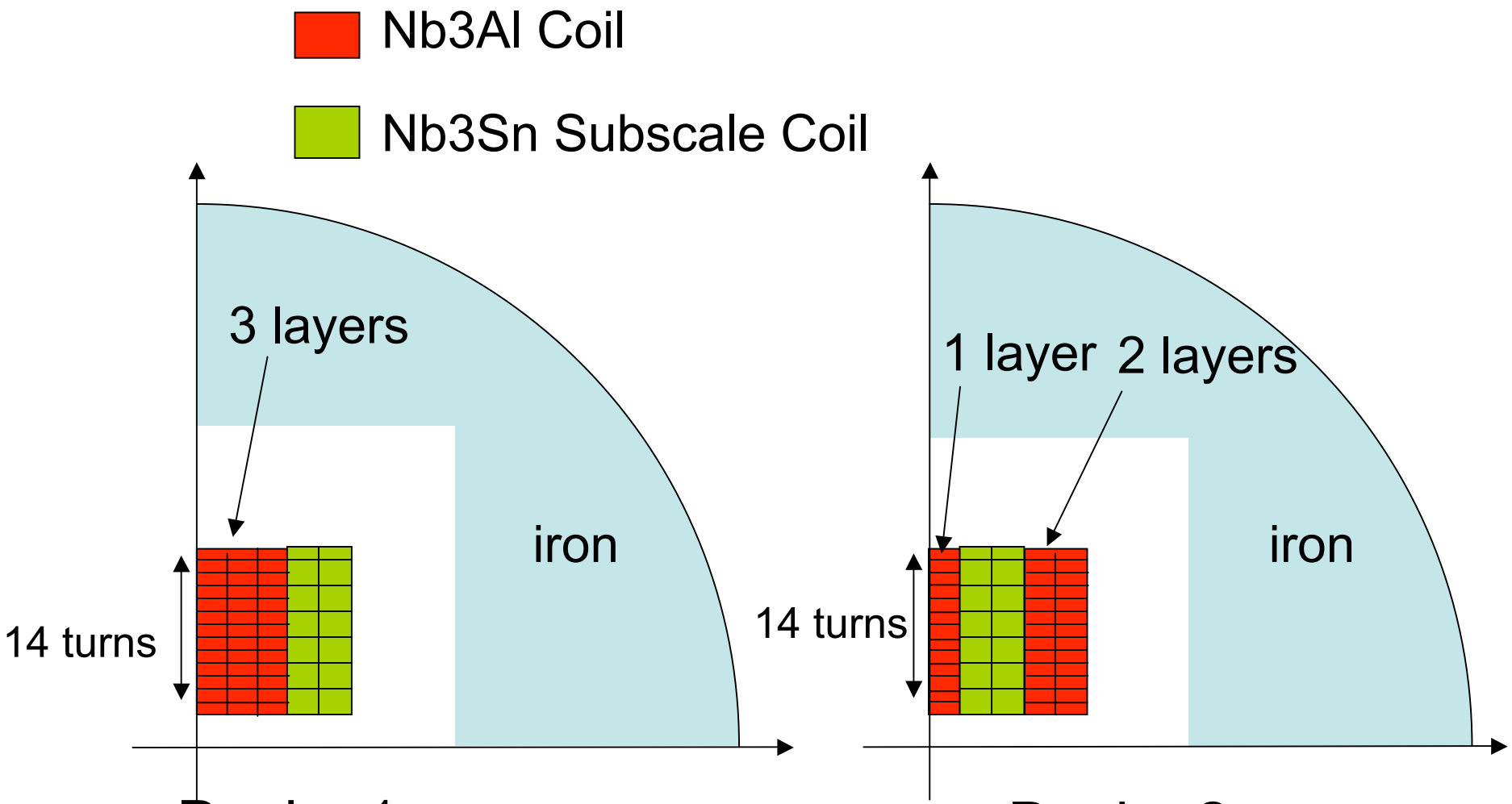
800 A/mm^2 @ 4.2 K, 15 T

*Based on the latest result with Ta-matrix.



Expected Strand Ic : 400 A @ 4.2 K, 15 T

Design - Common Coil -

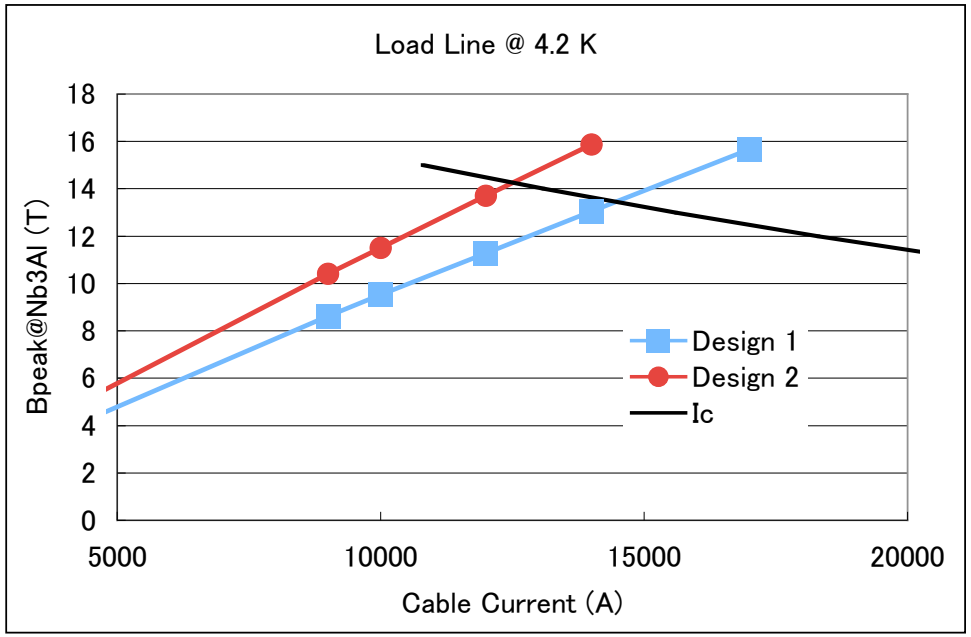


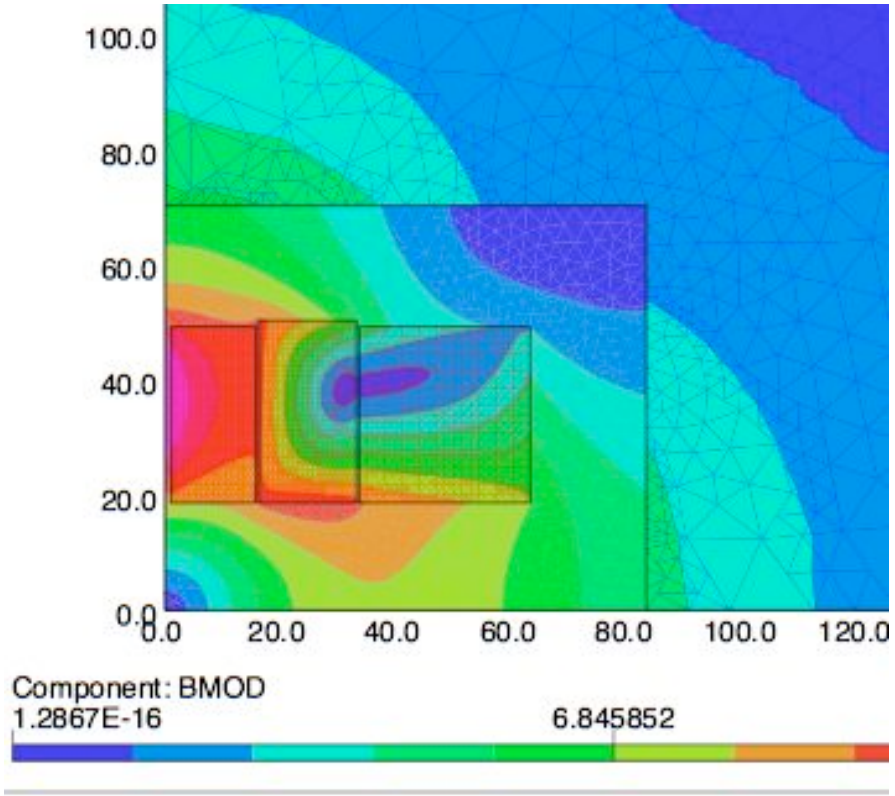
- Design1
- Design2

R_Yoke: 300 mm
W_island: 38 mm

Design 1 vs Design 2

To obtain higher peak field……

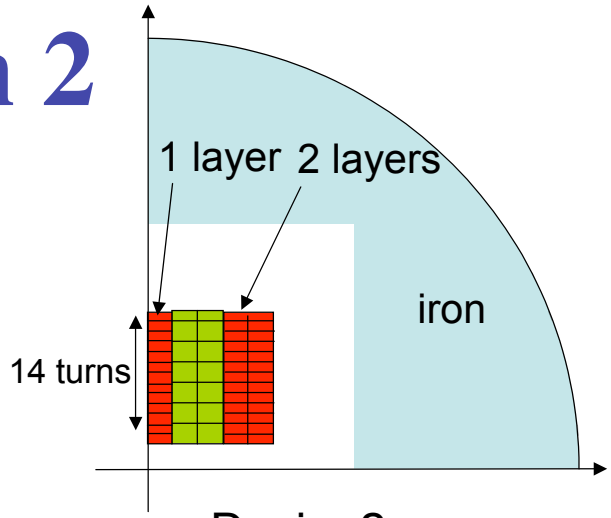




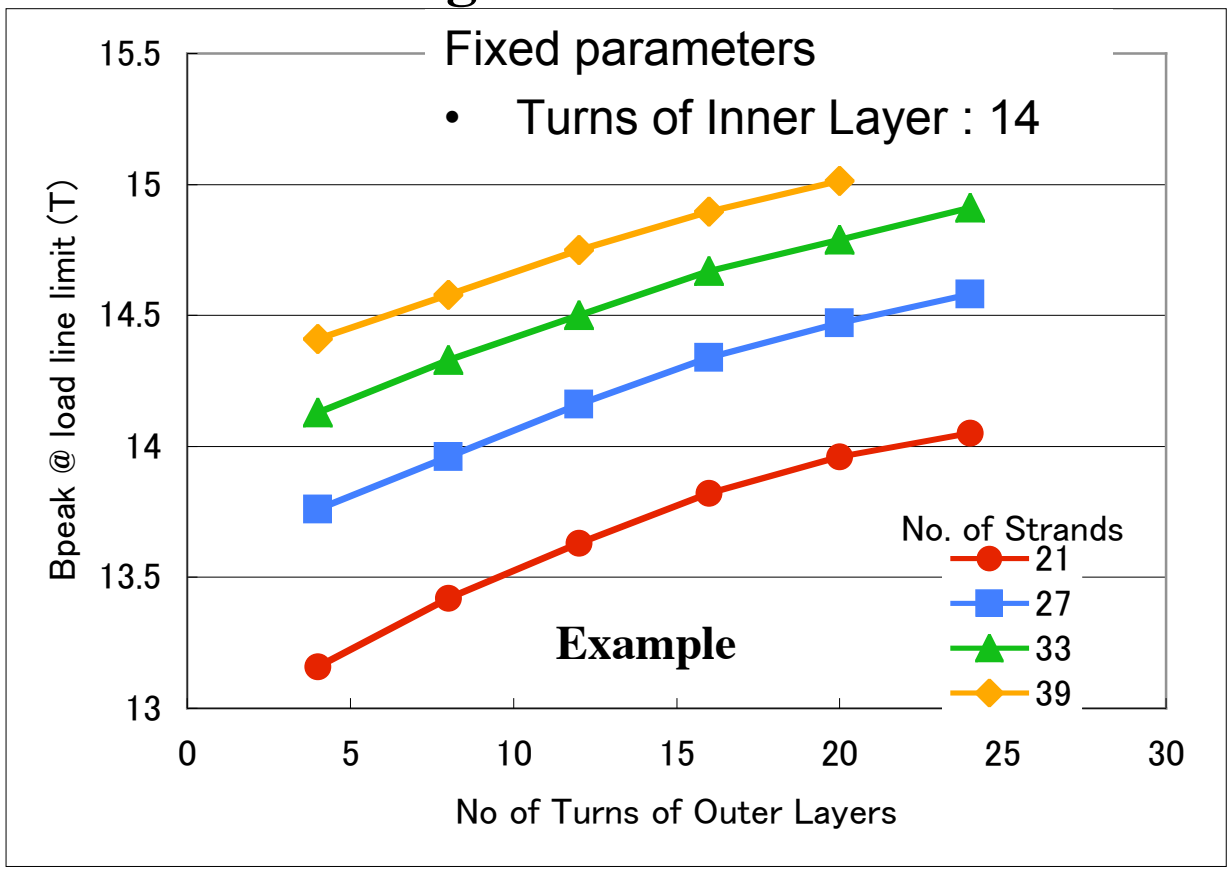
Design 2 is better because the higher current density in Nb3Sn coils is very effective.

Parametric Study for Design 2

- **Parameters**
  - **No. of cable strands**
  - **No. of turns**
  - **No. of layers**
- **Assuming fixed strand Ic characteristics**



• Design2



- **Difficult to reach 15 T with 27 strands.**

NIMS&Fermilab

- **Study is underway.**

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What we have done in 2007

- Evaluation of strand with Ta-matrix made in 2006.

- Fabrication of new strands with Ta-matrix.
  - Nb sheath (NIMS): 1000 m
  - Ta sheath (KEK/NIMS): 1000 m

* Both will be characterized and cabled for the model coil in 2008.

- Design study for the model coil.

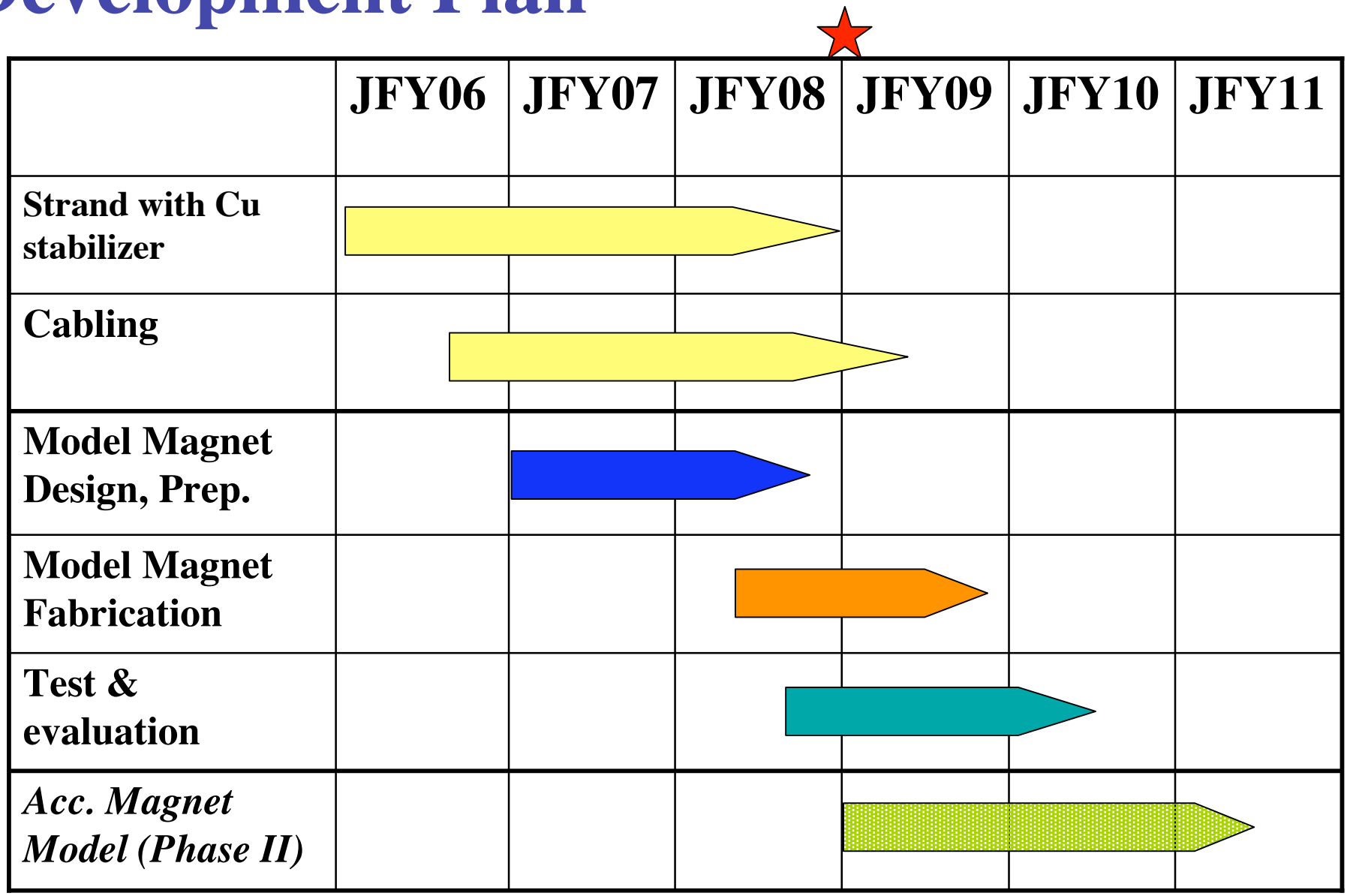
- Preparation of the fabrication.
  - Development of bladder for the magnet assembly at KEK
  - Order of parts (iron yoke, aluminum shell, etc…)
  - Visit to US-labs (Fermilab, LBL, BNL) for the technological discussion and the collection of the information.

Development Plan

- 2008
  - Nb3Al cable with strands made in 2007. (LARP-KEK)
  - Procurement of dummy cable for the practical winding.
  - New Nb3Al strands fabrication. (min. 1000 m)
    - Same as 2007 to check reproducibility.
    - New specification for higher Jc.
  - Finalization of magnet design and engineering.
  - Practice assembly and disassembly using 2 subscale coils developed by LBL.
- 2008-2009
  - Practice coil fabrication using dummy cable.
    - Winding, Heat treatment (> 800 °C), Epoxy impregnation
- 2009
  - 15 T Model magnet fabrication.

We may need to exchange the people between CERN and KEK for the technological R&D for the LHC luminosity upgrade as well as the present LHC hardware commissioning.

Development Plan



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

Budget Proposal

(Unit: kJYen)

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

* **Progress as of Dec. 2007 can be found in Appendix.**

** **To be transferred from CERN to KEK according to the exchange rate at April 2008.**

Summary

- **Progress in 2007**
  - **Nb3Al superconductor development in progress, with**
    Ta-matrix to reduce magnetization,
    Cu-stabilizer by using electro-plating,
    2 x 1000 m conductor in fabrication.

  - **Race-track coil development in preparation**
    magnetic design made,
    fabrication tool in design and progress.

- **Plan in 2008 and beyond**
  - **Nb3Al cable for race-track coil**
  - **Race track coil fabrication (- 2009)**
  - **A technical review is necessary for the progress and for the further R&D work beyond 2009 (to be extended as a part of CERN-KEK cooperation program).**