RRP-Nb_3Sn Conductor for the QXF Magnets

A. K. Ghosh, D.R. Dietderich, and A. Godeke

Joint LARP CM20/HiLumi Meeting

NAPA, CA, Apr 08-10, 2013

Work supported by the US LHC Accelerator Research Program (LARP) through US Department of Energy

Outline

- Introduction
- RRP® 108/127 Strand
  - OST strand production
- RRR Control
- RRP® strands with smaller filaments
  - 169 and 217 re-stack
- Procurement Strategy
- Summary

Introduction

- The 150 mm aperture QXF magnet program in LARP is presently based on the RRP 108/127 Ti-Ternary strand.
- Strand specification

• Strand Diameter, mm	0.85
• J_c(12 T) at 4.2 K, A/mm^2	> 2650
• I_c, A	> 684
• J_c(15 T) at 4.2 K, A/mm^2	> 1400
• I_c, A	> 381
• d_s, µm (nominal)	< 60
• Cu-fraction, %	> 53
• Cu/non-Cu	> 1.13
• RRR	> 150
• Piece length	> 550 m

RRP® Ti-Ternary vs. Ta-Ternary

Advantages of Ti-Ternary

- Does not require Nb-7.5wt% Ta alloy rods
  - Ti introduced by Nb – 47 wt.% Ti rods
- Ti content can be tweaked easily to maximize H_{c2}
- Ti accelerates Nb_3Sn reaction
- At 650 ^{o}C/48h , Ti-Ternary has higher J_c(15T) than Ta-Ternary
- Higher strain tolerance
  - i.e. higher irreversible strain limit

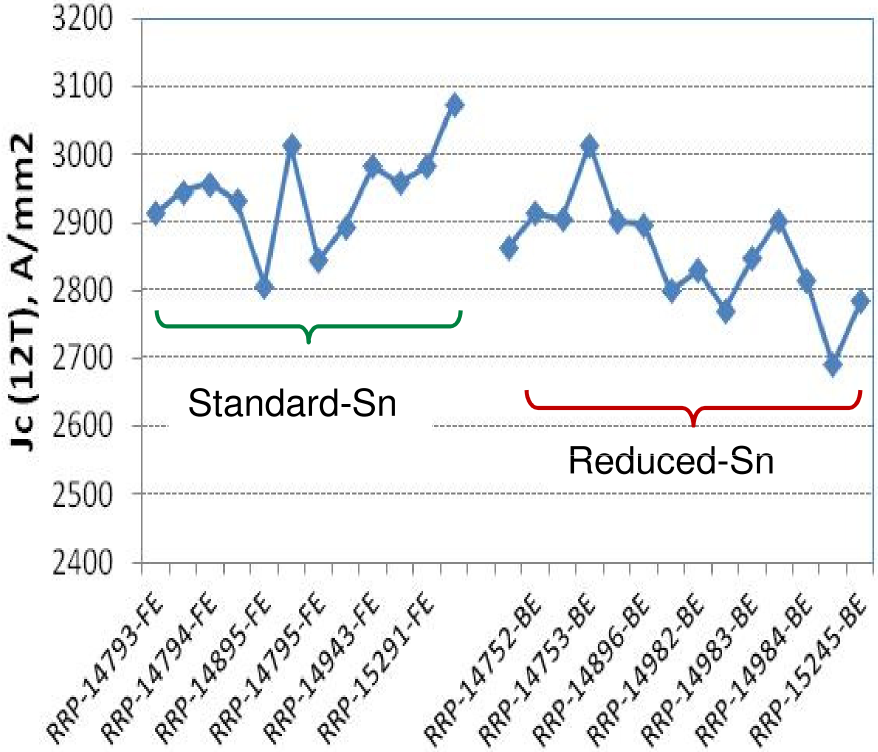
Ti-Ternary RRP® 108/127 Wire

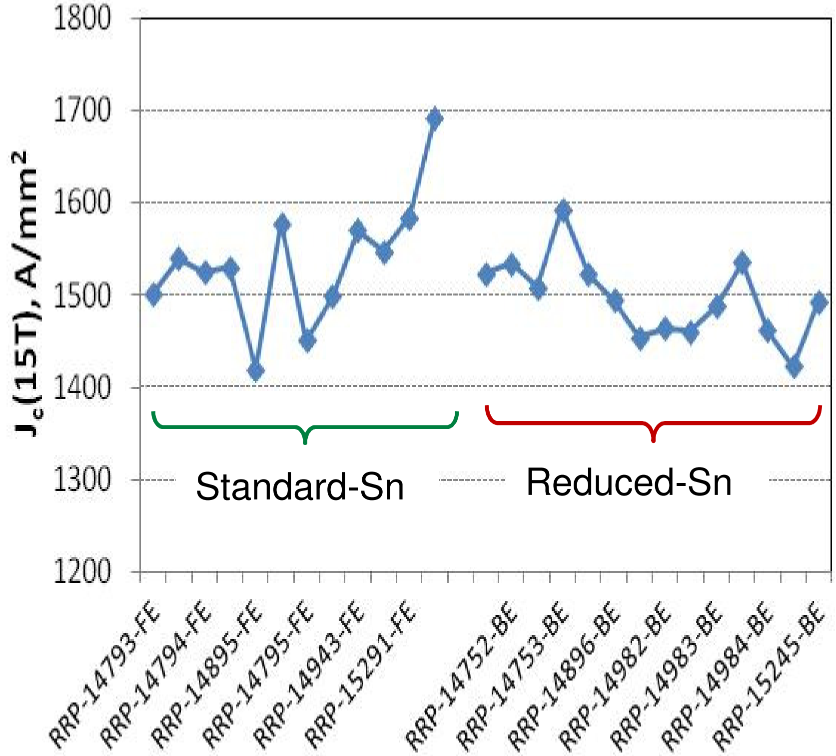
- Oxford Superconducting Technology has recently delivered 400 kg of wire ~ 13 billets
  - Data provided at 0.778 mm
  - Wire initially held at 1.04 mm
  - Wire being delivered at 0.85 mm
  - Two types of billets
    - Standard Sn content
    - 5% lower Sn content

Wire Reaction schedule

210 ^{o}C/72h + 400 ^{o}C/48h + 650 ^{o}C/50h

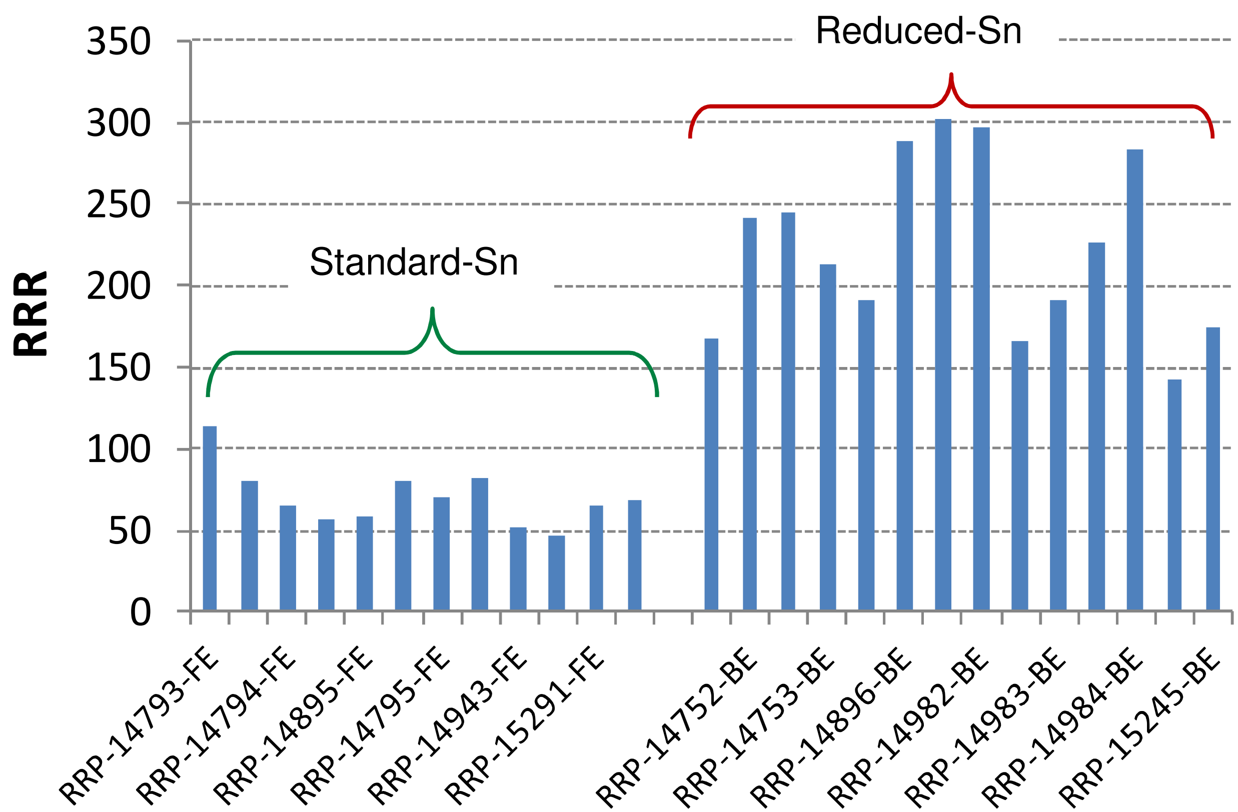
J_c of 108/127 wire - 13 billets





J_c of "reduced-Sn" billets are somewhat lower than the standard-Sn billets

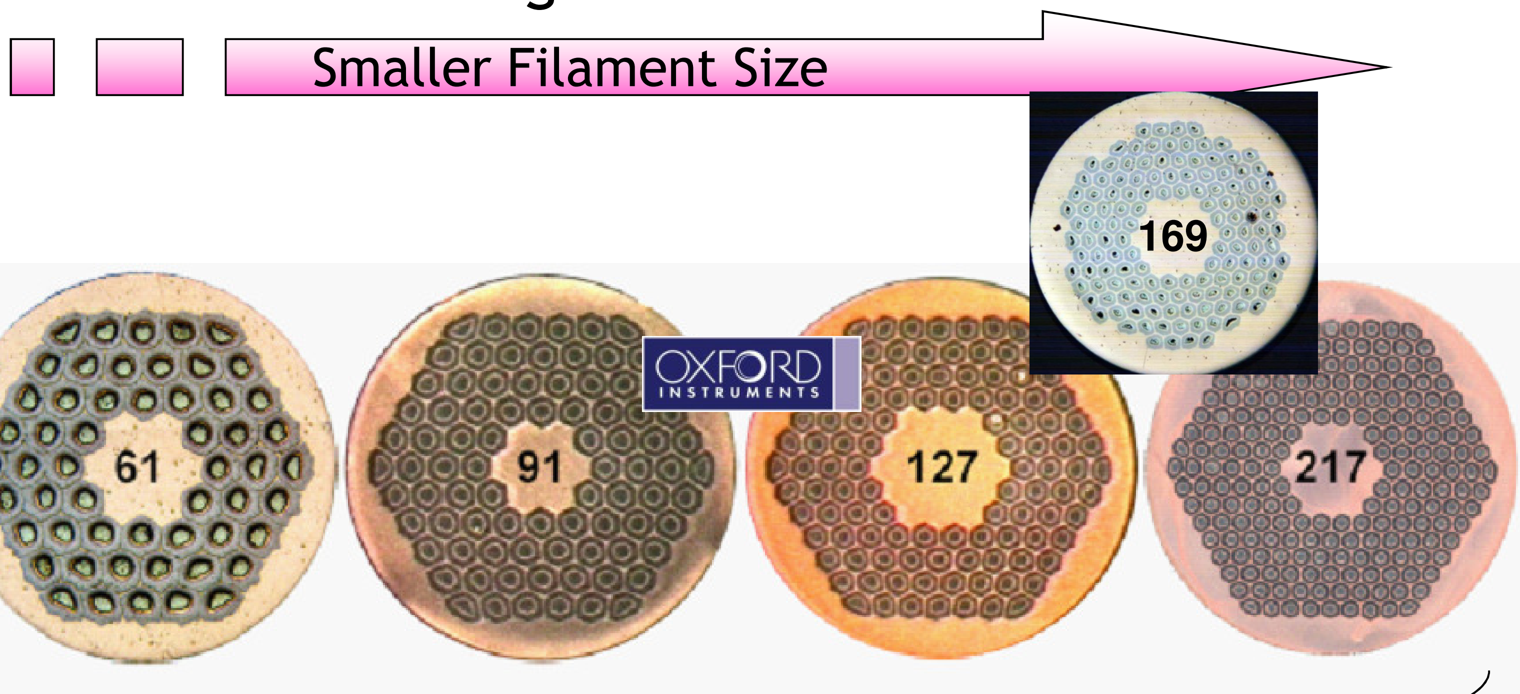
RRR of 108/127 wire



- Reduced-Sn billets show marked increase in RRR

RRP® strands with smaller filaments

- Smaller sub-elements can minimize flux jumps and improve stability.
- Filament Magnetization decreases



Courtesy of Jeff Parrell (OST)

Sub-element (Filament) diameter, μm

$$d_s = \frac{D_w}{\sqrt{N(1+R)}}$$

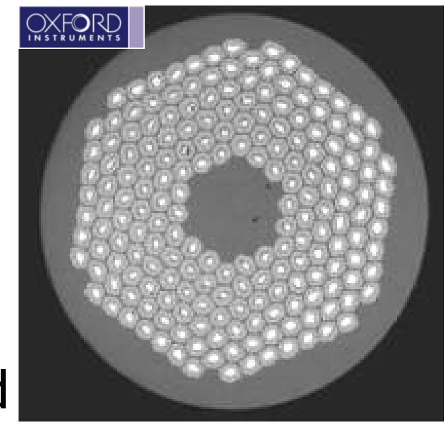
R=Cu/Non-Cu=1.15 , 46.5% SC, 53.5 % Cu

D_w	Subelement Size d_s					
Wire Diameter, mm	54/61 Stack	84/91 Stack	108/127 Stack	144/169 Stack	192/217 Stack	252/271 Stack
# of Sub-elements, *N*	**54**	**84**	**108**	**144**	**192**	**252**
1	93	74	66	57	49	43
0.85	79	63	56	48	42	37
0.8	74	60	52	45	39	34
0.778	72	58	51	44	38	33
0.7	65	52	46	40	34	30

Presently, sub-element rod sizes are very small for assembly of 217. Larger diameter re-stack billets will make it easier to control production of 217, and enable re-stacks with higher number of sub-elements.

192/217 Re-stack Development

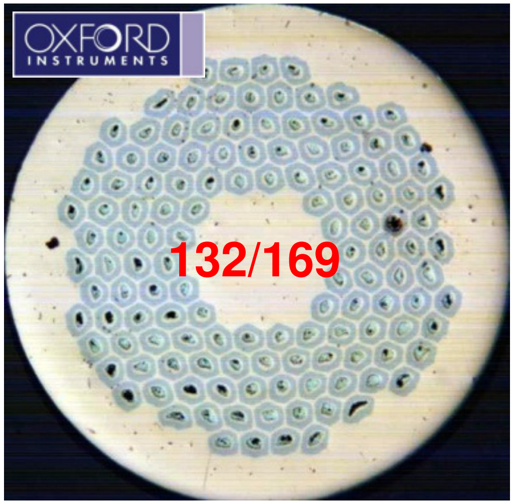
- 217 Re-stack billets with standard sub-elements have very low RRR for wire size of ~ 0.8 mm.
- To increase RRR ⟶ new sub-element design
  - ➢ Increase starting *Nb* filament diameter
  - ➢ Control roundness of *Nb* mono-rods
  - ➢ Increase spacing between *Nb* filaments
  - ➢ Increase barrier thickness
  - New 2700 A/mm^2 class conductor being fabricated



- First results from OST for wire fabricated with 30% thicker barrier -- **0.778 mm diameter**
- 650C/ 50 h
  - J_c (12T) = 2590 A/mm^2
  - J_c (15T) = 1350 A/mm^2
  - **RRR 118-129**

169 re-stack option for QXF

- OST has gained manufacturing experience of the 169 re-stack with
  - FNAL driven conductor development for their high field and the 11T magnet program, and
  - CERN's procurement for FRESAC2 (1.0 mm) and recent 0.85 mm conductor for QXF.
  - CDP has initiated a 90 kg lot order of wire at 0.85 mm for delivery in 12 months.
  - At present there is ~ 15% premium in cost compared to 108/127. This will reduce with manufacturing experience.



Procurement Planning

- Driven by the schedule of coil winding
- For SQXF, there is sufficient conductor “in-house”
- Typical time for strand delivery from OST assumed to be 15 months although as OST exits ITER strand production, delivery time may shrink to 12-13 months.
- Cable mapping, cabling, cable qualification, and insulation is assumed to take 4 months.

Coil winding Schedule

Magnet Coil	Winding Start	Cabling Start	Strand PO Placement	Strand Reg Kg	Strand Reg Km	UL, m
SQXF-PC01	3/4/2014	11/4/2013		44	8.8	190
SQXF-PC02	CERN					
SQXF-PC03	5/28/2014	1/28/2014		44	8.8	190
SQXF-04	6/18/2014	2/18/2014		44	8.8	190
SQXF-05	8/20/2014	4/22/2014		44	8.8	190
SQXF-06	9/10/2014	5/13/2014		44	8.8	190
SQXF-07	CERN					
SQXF-08	10/1/2014	6/3/2014		44	8.8	190
LQXF-PC01	1/19/2015	9/21/2014		125	25	541
LQXF-02	2/9/2015	10/12/2014		125	25	541
LQXF-03	3/16/2015	11/16/2014		125	25	541
LQXF-04	4/6/2015	12/7/2014	**9/13/2013**	125	25	541
LQXF-05	4/27/2015	12/28/2014	**10/4/2013**	125	25	541
LQXF-06	7/9/2015	3/11/2015	**12/16/2013**	125	25	541
LQXF-07	7/29/2015	3/31/2015	**1/5/2014**	125	25	541
LQXF-08	8/20/2015	4/22/2015	**1/27/2014**	125	25	541
LQXF-09	9/9/2015	5/12/2015	**2/16/2014**	125	25	541
LQXF-10	9/30/2015	6/2/2015	**3/9/2014**	125	25	541
LQXF-11	4/4/2016	12/6/2015	**9/12/2014**	125	25	541
LQXF-12	6/1/2016	2/2/2016	**11/9/2014**	125	25	541
LQXF-13	6/22/2016	2/23/2016	**11/30/2014**	125	25	541
LQXF-14	6/1/2016	2/2/2016	**11/9/2014**	125	25	541
LQXF-15	6/22/2015	2/22/2015	**11/29/2013**	125	25	541
LQXF-16	12/5/2016	8/7/2016	**5/15/2015**	125	25	541

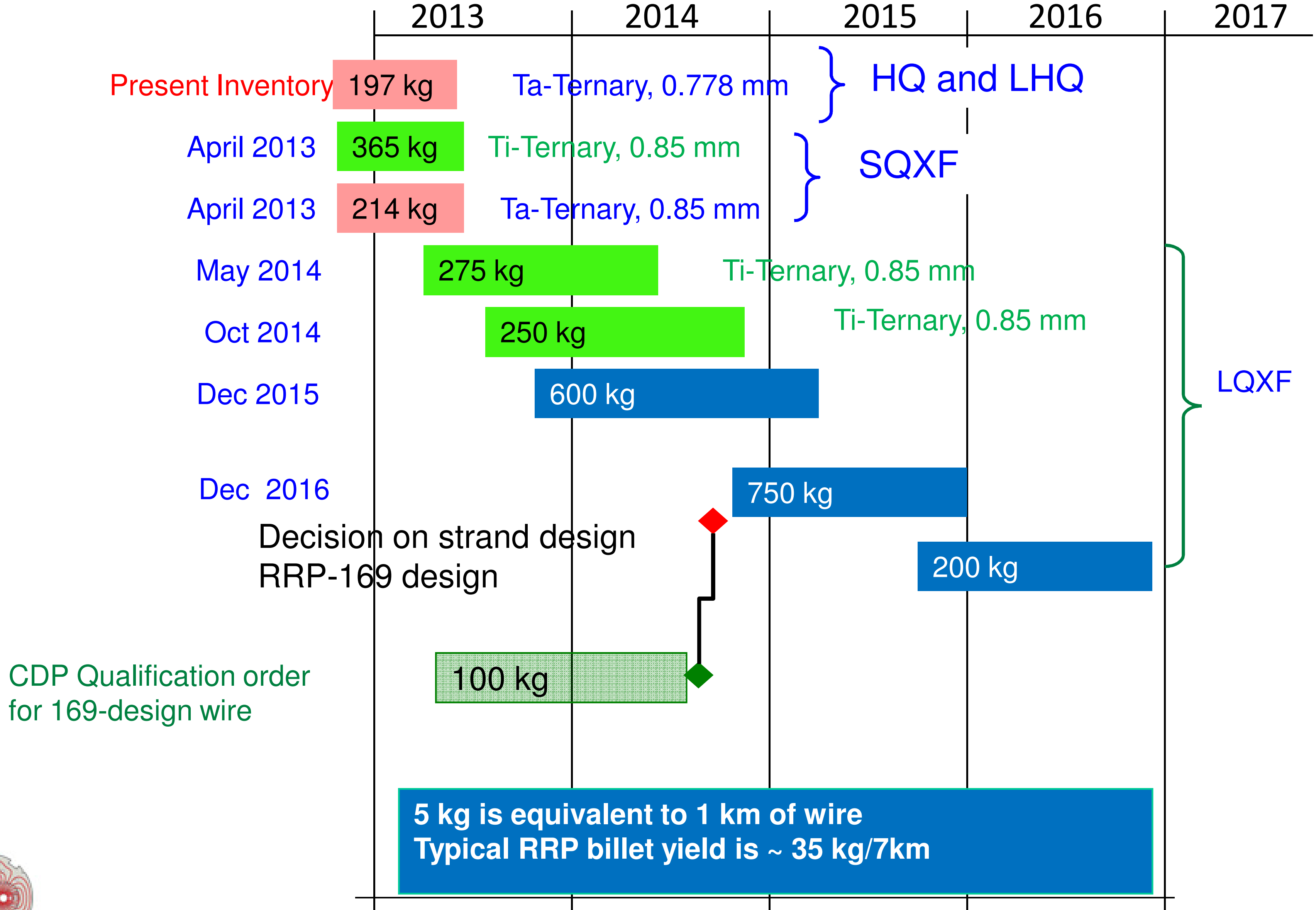
SQXF1
SQXF1b

LQXF1

LQXF2

LQXF3

Procurement strategy (April 2013)



Summary

- Present Status of RRP wire for QXF
  - 108/127 design has good J_c properties
    - 5% reduction in Sn-content enables high RRR without loss of J_c
  - Ti- ternary allows lower reaction temperature for equivalent J_c at 12 T and higher J_c at 15 T than the Ta-ternary
    - Good piece length (billets in 2 to three pieces)
  - As OST develops manufacturing experience with 169 Re-stack wire (CERN,FNAL, CDP) LARP can transition to this wire within the next 18 months
  - Strand procurement has been developed to meet the coil winding schedule for the LQXF magnets

Questions

- For QXF what filament magnetization is acceptable ?
  - 108 to 144 filaments reduces sub-element diameter d_s from 56 to 48 μm, a 15% reduction
  - For the HQ magnet, conductor at 0.778 mm with 108 sub-elements has d_s of 51 μm
- What is the minimum copper fraction required for quench protection ?
- What should be the minimum RRR requirement for the strand ?
  - For the extracted strand ?
- What should be the width of the SS core ?
- What is the thickness of the insulation required for turn-to-turn integrity ?

End of Presentation