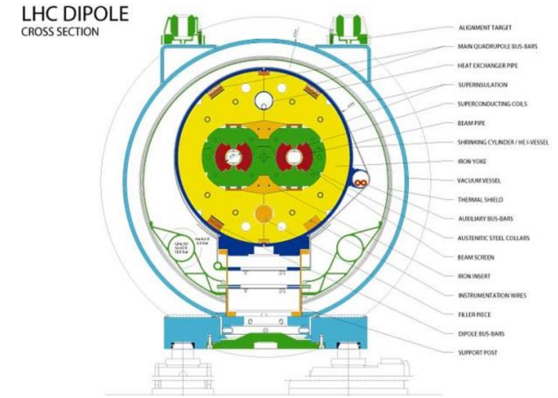
Future Circular Collider Study
Kickoff Meeting

14th February 2014

Material R&D towards superconductors for the 16 T horizon and 20 T horizon

A. Ballarino, CERN, Geneva

Large Scale Production



LHC ~ 1200 tons of Nb-Ti

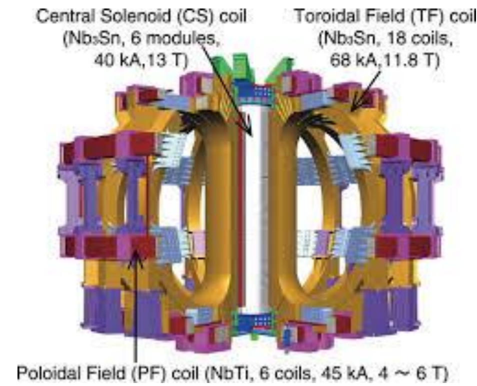
~ 200 kg of HTS (Bi-2223)

ITER PF and CC coils

~ 200 tons of Nb-Ti

TF and CS coils

~ 500 tons Nb_3Sn



Hi-Lumi LHC 11 T Dipoles, IR Quadrupoles

High Luminosity LHC

~ 25 T tons Nb_3Sn

+ ~ 5 tons for CERN development program

+ ~ 5 tons for LARP development program*

* Arup Ghosh, BNL

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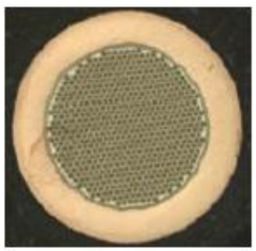
Nb_3Sn Electrical Performance

ITER - Nb_3Sn

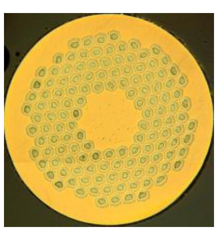
Non-Cu Jc ≥ 800 A/mm²
(12 T, 4.2 K)



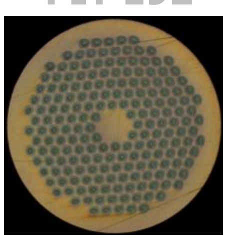

Hi-Lumi LHC - Nb_3Sn

Non-Cu Jc ≥ 1340 A/mm²
(15 T, 4.2 K)
Non-Cu Jc ≥ 2500 A/mm²
(12 T, 4.2 K)

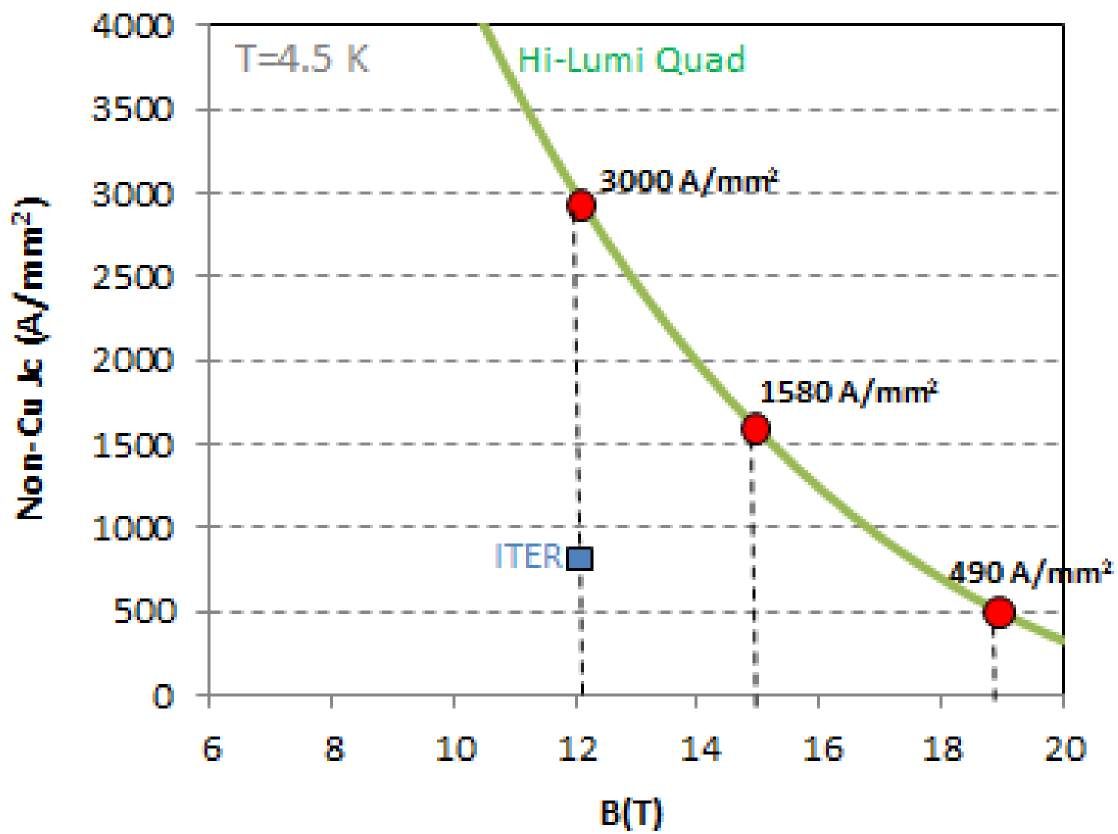
RRP 132/169



PIT 192



Critical current density versus field



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16 T for 100 TeV in 100 km

Cosine theta type magnet, **Nb-Ti** and **Nb_3Sn**. Bore Φ = 40 mm

16 T magnet in 100 km tunnel					
	Width (mm)	Average radius (mm)	Overall Jc (A/mm2)	Strand Jc (eng) (A/mm2)	Conductor mass (t)
Nb_3Sn layer 1	20	30	193	386	1690
Nb_3Sn layer 2	20	50	385	770	2710
20 mm collar					
Nb-Ti layer 1	15	87.5	337	523	4710
Nb-Ti layer 2	15	102.5	433	672	5520

4300 tons Nb_3Sn + 10200 tons of Nb-Ti

~9 times Nb_3Sn for ITER and Nb-Ti for LHC

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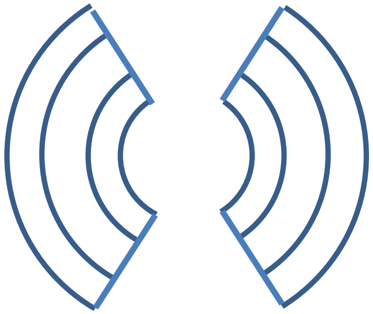
20 T for 100 TeV in 80 km

Cosine theta type magnet, **Nb-Ti** and **Nb_3Sn** and **HTS** insert. Bore Φ = 40 mm

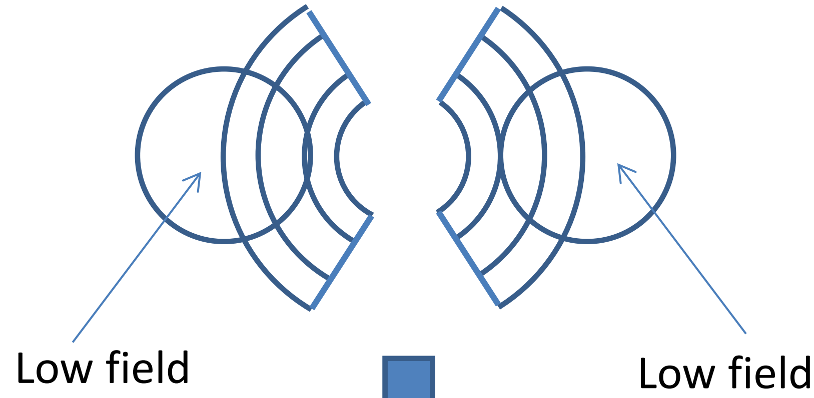
20 T magnet in 80 km tunnel					
	Width (mm)	Average radius (mm)	Overall Jc (A/mm2)	Strand Jc (eng) (A/mm2)	Conductor mass (t)
HTS layer	25	32.5	231	600	1409
10 mm collar					
Nb_3Sn layer 1	20	65	193	386	2930
Nb_3Sn layer 2	20	85	385	770	3685
20 mm collar					
Nb-Ti layer 1	15	122.5	337	523	5275
Nb-Ti layer 2	15	137.5	433	672	5925

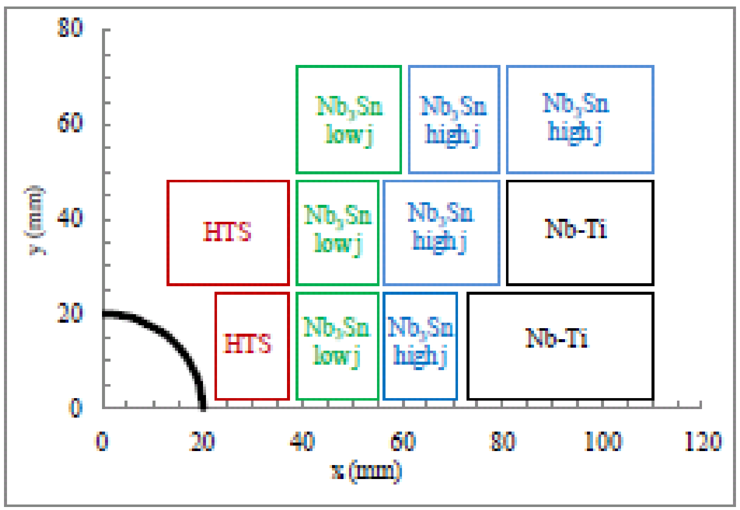
1400 tons of HTS + 6600 tons Nb_3Sn + 11300 tons of Nb-Ti

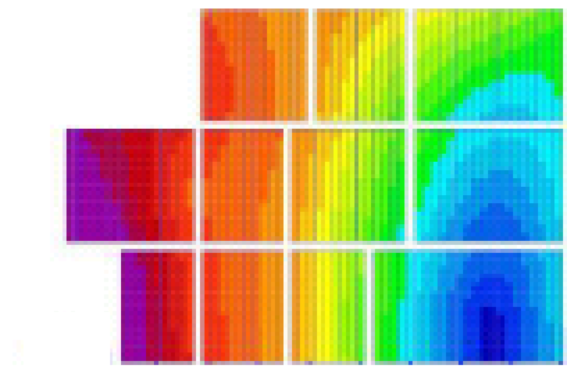
~13 times Nb_3Sn for ITER ~10 times Nb-Ti for LHC



Standard cos θ dipole coil







L. Rossi and E. Todesco

By adopting a graded block design it may be possible to **better optimize the use of the different conductors.** This will change the numbers in the tables, but **the order of magnitude will remain**. Also, **higher Jc will decrease conductor total quantity**. The final distribution will depend on further optimization.

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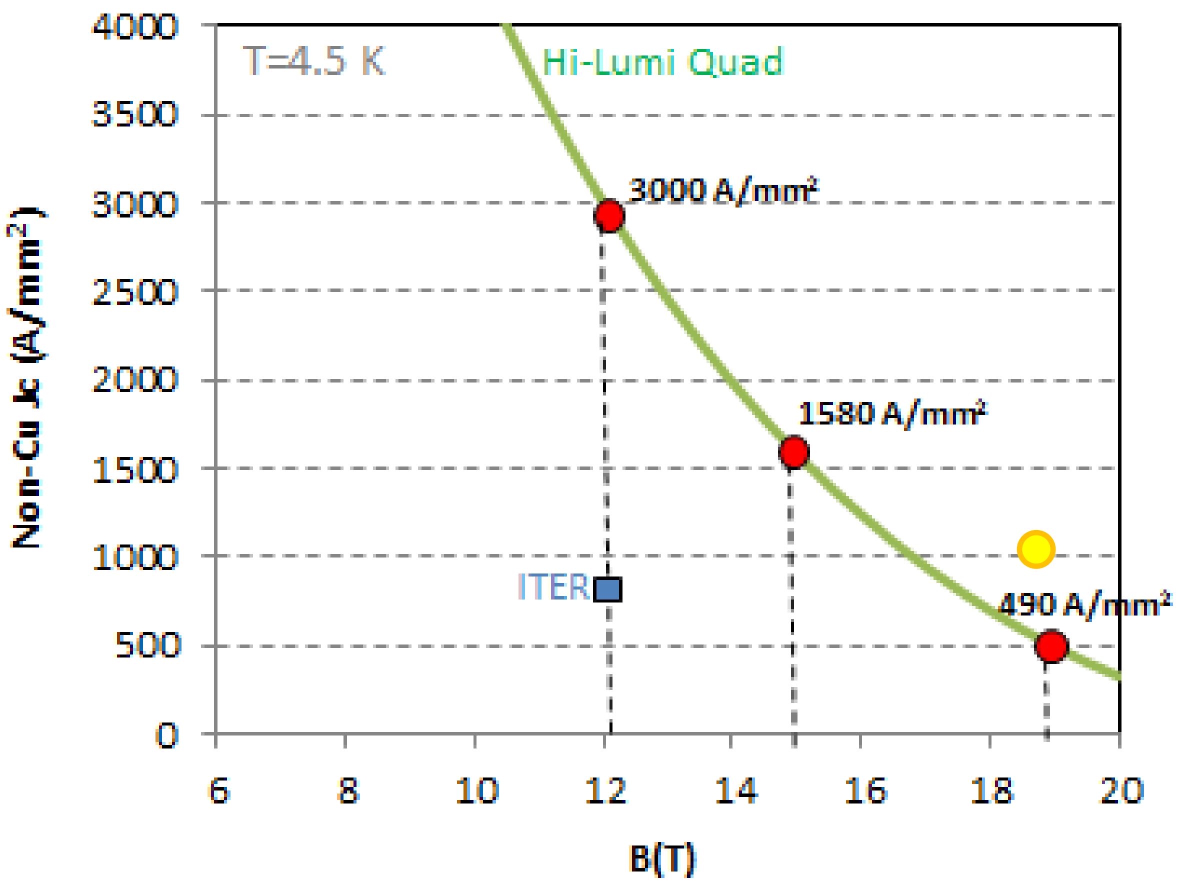
Nb_3Sn Electrical Performance

B_{op}=16-20 T + 20% margin => B_{des}=19-24 T at 4.5 K

Nb_3Sn for HE: Jeng ~ 386 A/mm^2

=> Jc ~ 900-1000 A/mm^2 at 19 T and 4.5 K

New generation of Nb_3Sn conductor



Factor 2 in Jc

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HTS Electrical Performance

B_{op}=16-20 T + 20% margin => B_{des}=19-24 T at 4.5 K

HTS $\Rightarrow$ Hirr (4.2 K) > 30 T

HTS for **HE**: Jeng ~ 600 A/mm^2 at 24 T and 4.5 K

REBCO tape:

Jeng today up to ~300-350 A/mm^2 at 20 T and 4.5 K (B//c)

Factor 2 in Jeng

BSCCO 2212 round wire:

Demonstrated **Jeng up to ~ 550 A/mm^2** at 20 T and 4.5 K

New generation of HTS conductors

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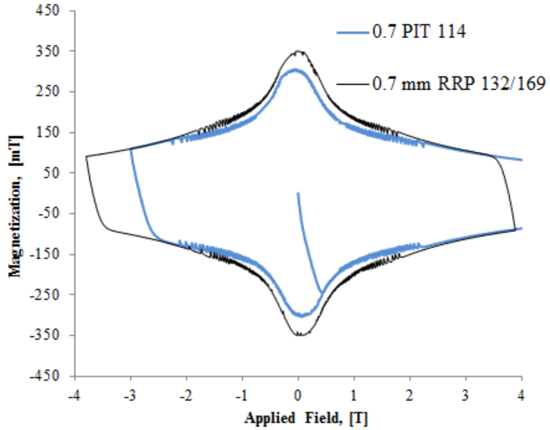
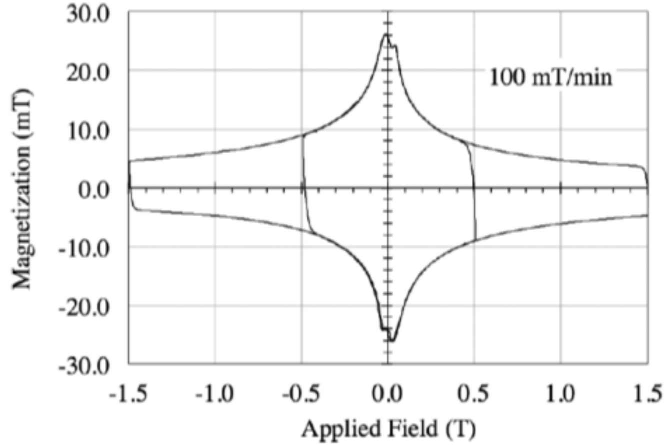
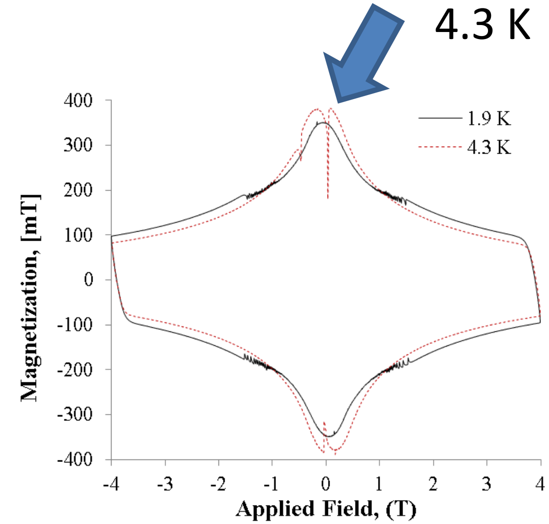
11 T Dipole Strand



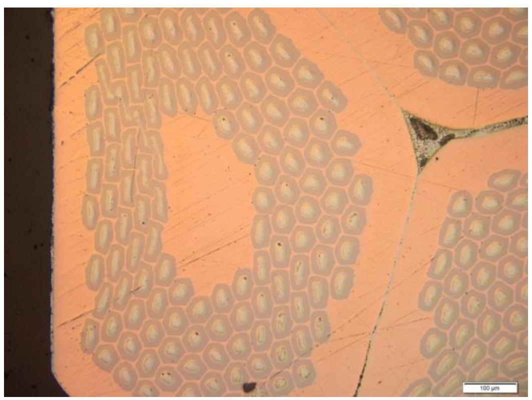
LHC Main Dipole Strand





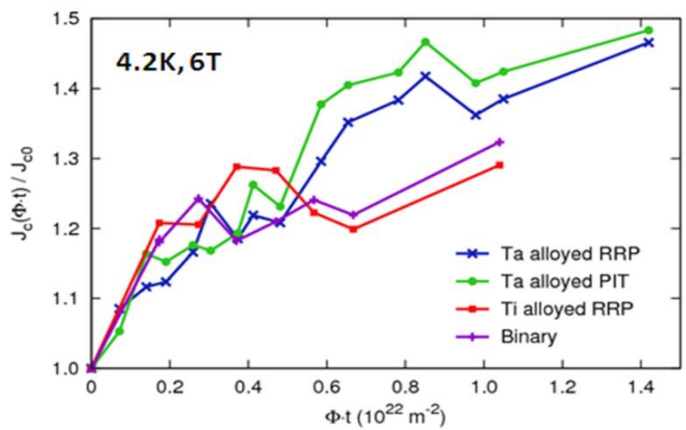
B. Bordini and D. Richter, CERN

There is more than Jc…



L. Oberli and A. Bonasia, CERN

Neutron Irradiation



R. Flukiger and T. Spina, CERN

A. Ballarino, CERN

To get there….

Nb_3Sn (16 T magnets)

- **Increase Jc** in high fields
- Develop **wire architectures** that meet the characteristics required for accelerator quality magnets (reduce **filaments size** for field quality, assure stability requirements **(RRR)**, guarantee **mechanical properties** as needed for cabling, winding and operation in a magnet assembly)

HTS (20 T magnets)

Eucard 2 Program

- **Increase Jc** at 4.5 K and in high fields
- **Reduce** (or cope with…) **conductor anisotropy** (REBCO tape)
- Develop and demonstrate high current **HTS cables**
- Understand and handle **quench performance and quench protection** (first on strands and cables and after on magnets)
- Study and demonstrate **field quality** - for tape and wire geometry. Improve conductor geometry as needed – striation for tape, smaller filament size for wire ….

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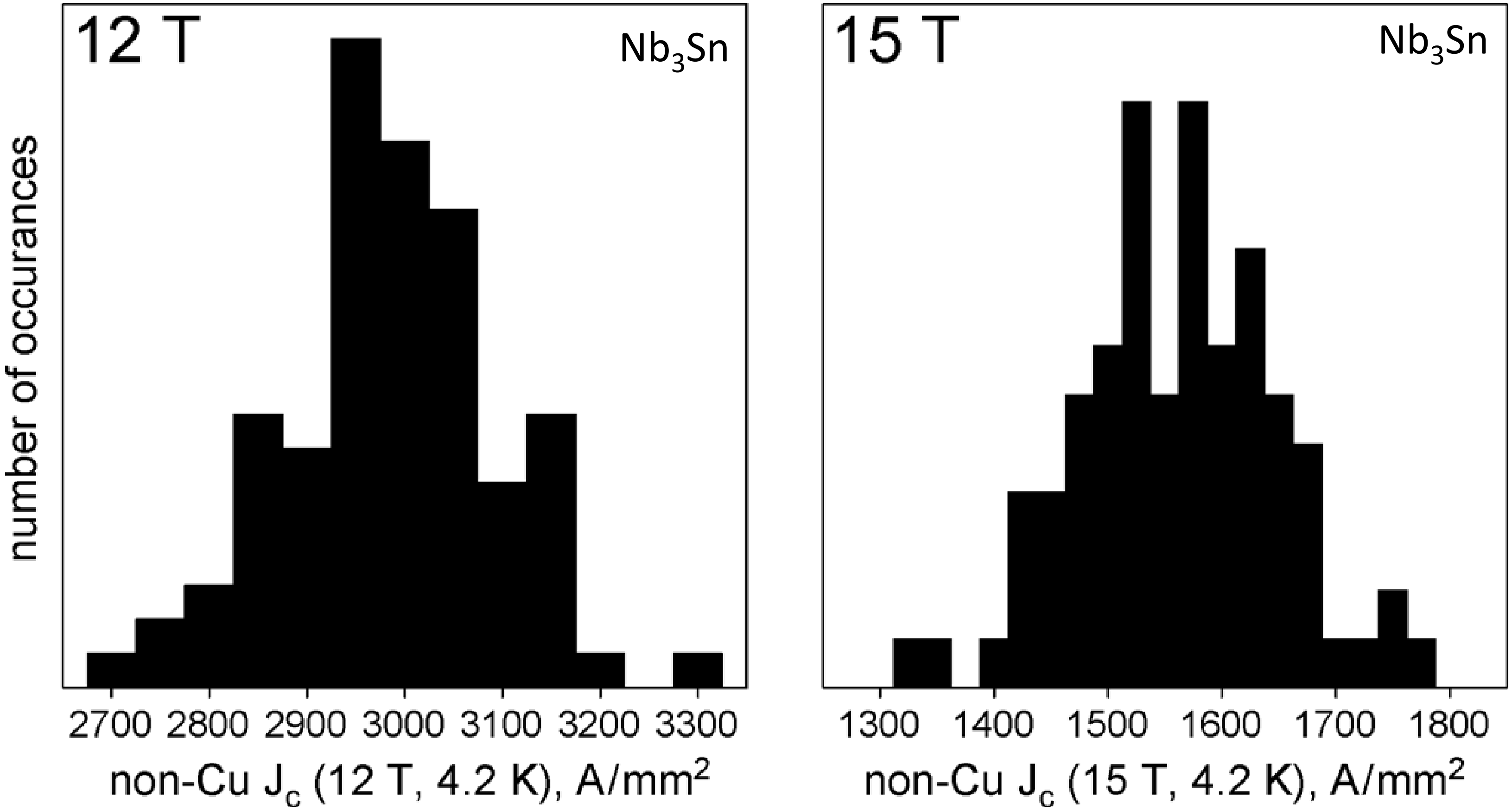
To get there....



Courtesy of Jeff Parrel, OST

Production of conductor of a sufficiently robust quality for large scale production ⇒ good yield (low cost Euro/(kA·m))

A. Ballarino, CERN

Conclusions (1/2)

- In order to make a 100 TeV superconducting machine possible, conductors need to undergo a sustained and intensive **program of R&D** including:

(i) **development of materials** that meet the desired characteristics for accelerator quality magnets;

(ii) **work with conductor manufacturers** to ensure that the developed strands are also of a sufficiently robust quality for large scale production (i.e. good yield)

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Conclusions (2/2)

- Whereas the annual production of **Nb_3Sn** was in the past about 15 t, for ITER the producers increased this to about 100 tons in order to achieve the total required delivery of about 500 tons. **Scaling of production rate** should be feasible – once we know what we want.
  N.B. the required performance of Nb_3Sn is beyond the ITER current levels

- The **quantity of HTS required** is many times the present production capacity. It is too early to discuss this (and *a fortiori* to hazard a guess of cost)

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