The CERN FCC Conductor Development Program

A. Ballarino, CERN

FCC Week 2017
MAY 29 - JUNE 2
BERLIN, GERMANY

The CERN FCC Conductor Development Program

- Present **baseline** of the **100 TeV**, **100 km** FCC machine: **16 T** dipoles relying on **Nb_3Sn technology**
- **Scope** of the conductor development program:
  - Provide feedback on possibility of achieving beyond state-of-the-art **HL-LHC Nb_3Sn** high-field performance (**Jc @ 16 T**) to enable design of compact and cost effective 16 T magnets;
  - Foster **Nb_3Sn conductor development in industry** and support the industrial development with academic **activities** (material studies and characterization) **in laboratories and institutes world-wide**;
  - **Procure** (and cable) **Nb_3Sn conductor** to feed the on-going magnet model-coils activity;
  - Investigate potentials of **other superconductors** (performance in high fields and cost)

Nb_3Sn: Requirements and challenges

- **Performance increase**

  Jc at 16 T required to be up to **~ 50 % higher** than what achieved on the HL-LHC Nb_3Sn series production

- **Cost reduction** is required to make 16 T magnets commercially affordable. Present cost of high-performance (HL-LHC) Nb_3Sn is > 20 Euro/kA m (4.2 K, 16 T). **FCC target is 5 Euro/kA m (4.2 K, 16 T)**. Required: increase of Jc, production of large billets, optimization of raw materials – with no performance penalty, optimization of processing cost, savings in labor cost. Cost studies are part of the on-going conductor development program.

- Feasibility of **large** (**~ 7000-9000 tons** for FCC h-h, ~ 2500 tons for HE-LHC) **Nb_3Sn series production**
  - ITER: ~ 500 tons total, 100 tons/year, 8 companies
  - HE-LHC: ~ 20 tons total (initially 2 companies, now 1 company)
  - FCC h-h: 7000-9000 tons total (~ 1000 tons/year (7 years production) with 7-8 companies)

Development targets – Nb_3Sn (starting with a 4 years program)

Wire diameter	mm	**~ 1**
Non-Cu Jc (16 T, 4.2 K)*	A/mm^2	**≥ 1500**
~~**μoΔM(1 T, 4.2 K)**~~	~~mT~~	~~**≤ 150**~~
~~**Deff**~~	~~μm~~	~~**≤ 20**~~ **≤ 50**
RRR	-	**≥ 150**
~~**Unit length**~~	~~km~~	~~**≥ 5**~~ **≥ 0.1**
Cost	Euro/kA m**	**≤ 5**

Focus is on Jc

*Je ~ 600 A/mm^2

*Cu:non Cu ~ 1

** 16 T, 4.2 K

Process shall enable scalability and have potentially low cost for large production

Development targets – Nb_3Sn (starting with a 4 years program)

Wire diameter	mm	**~ 1**
Non-Cu Jc (16 T, 4.2 K)*	A/mm^2	**≥ 1500**

Effort is – at this stage – on **conductor (wire) development** and characterization. Rutherford cable optimization (and preparation/implementation of cabling facilities) will be the next step.

Cost	Euro/kA m**	**≤ 5**

*Je ~ 600 A/mm^2

*Cu:non Cu ~ 1

** 16 T, 4.2 K

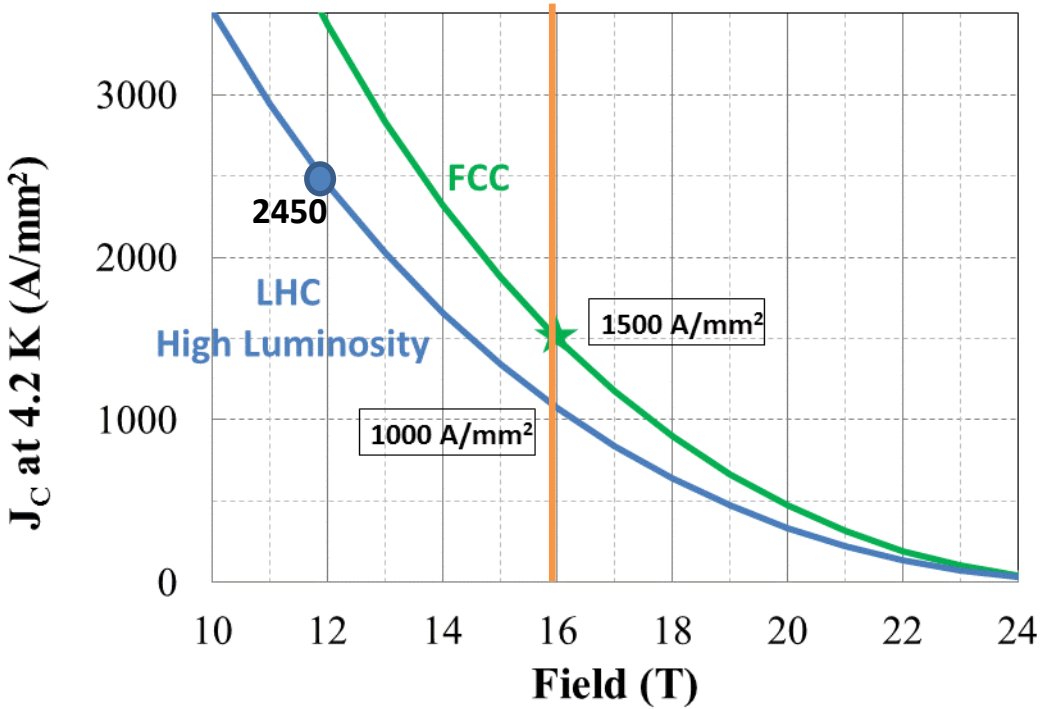
Process shall enable scalability and have potential low cost for large production

HL-LHC Nb_3Sn wire performance

	Layout	Sub-Element size	J_c (12 T), *RMS* [A/mm²]	J_c (15 T), *RMS* [A/mm²]	B_{c2}(4.3 K), *RMS* [T]	J_c (16 T), *RMS* [A/mm²]	J_c (18 T), *RMS* [A/mm²]	Degradation J_c (15% rolling) [%]	Minimum RRR (15% rolling) -
0.7 mm RRP	108/127	46 µm	**2676**, *68*	**1410**, *58*	**24.5**, *0.39*	**1098**, *55*	**610**, *47*	0	>100
0.85 mm RRP	108/127	55 µm	**2835**, *44*	**1601**, *33*	**25.9**, *0.19*	**1289**, *30*	**785**, *25*	0	>100
0.85 mm Bundle Barrier PIT	192	39 µm	**2323**, *83*	**1342**, *49*	**26.7**, *0.1*	**1093**, *40*	**688**, *26*	5.5 %	>150

See this morning presentation of B. Bordini

Nb_3Sn – HL-LHC vs FCC



On-going FCC conductor activity – Nb_3Sn

- Collaboration agreement with **KEK- Japan.** Development of Nb_3Sn wire started at **Jastec** and **Furukawa** Presentation of T. Ogitsu
- Collaboration agreement with **KAT – Korea**. Development of Nb_3Sn wire started Presentation of J. Kim
- Collaboration agreement with **Bochvar Inst.– Russia**. Development of Nb_3Sn wire on-going at **TVEL** Presentation of V. Pantsyrny Poster of I. Abdyukhanov
- Collaboration agreement with **Univ. of Geneva** Presentation of C. Senatore
- Collaboration agreement with **Univ. of Vienna** Poster of S. Pfeiffer
- Collaboration agreement with **ASC at Florida State University** Presentation of P. Lee

On-going FCC conductor activity – Nb_3Sn

- In parallel with the development of the conductor, **procurement of Nb_3Sn wire for FCC** is being launched – about 290 km of wire (**~ 1.5 tons**), to cover the needs of the magnet program from 2018 to 2019. For this procurement:

  Target Jc(4.2 K, 16 T) = 1200 A/mm^2

  Minimum Jc (4.2 K, 16 T) = 1000 A/mm^2
- The magnet program will require additional **~ 6 tons** of conductor from 2020 to 2023
- The specified high-field conductor has diameters of 1 mm and 1.1 mm, and a Cu to non-Cu volume ratio of 0.8-1.

On-going FCC conductor activity

- Collaboration agreement with **SPIN, Genova** Presentation of M. Putti

  Development and characterization of MgB_2, Bi-2212 and iron based superconductors
- Collaboration agreement with **Columbus Superconductors**. Production of MgB_2 wire optimized for high fields

MgB_2 and IBS: materials not mature today for magnets development, but showing potentials and worth investigating for future applications

Conclusions

- **Nb_3Sn development and achievement of goals** (performance and cost) are challenging of key importance for the **FCC magnet** development program
- Development **activity** has been launched in industry and in laboratories **world-wide**. Development/implementation of **new technologies** enabling achievement of performance, e.g. AP methods, both in laboratories and in industry are encouraged - and have started. It is the time, now, to demonstrate potentials of Nb_3Sn – and feasibility of 16 T Nb_3Sn magnets
- Work on Nb_3Sn specific to FCC has started in mid-2016. Development will take more than 4 years. However, for the **FCC CDR** report (mid-**2018**) the established plan , the on-going activities and first development results will be reported


Thanks for your attention