1st EuroCirCol Review
Geneva, May 11-13, 2016

EU/CERN program on 16T dipoles for the FCC

Davide Tommasini

Salient common assumptions

Imposed

1.	Number of magnets (FCC/HE-LHC)	4578/1232
2.	Magnet length	14.3 m
3.	Free physical aperture	50 mm
4.	Field amplitude	16 T

Under review

5.	Margin on the load-line @ 1.9K	18 %
6.	Total quench delay	40 ms
7.	Critical current density @ 4.2 (1.9) K, 16T	1500 (2200) A/mm^2
8.	Minimum Cu/nonCu	1
9.	Maximum strand diameter	1.1 mm
10.	Maximum stress on conductor	200 Mpa
11.	Maximum hot spot temperature (@ 105% I_{nom})	350 K
12.	Maximum number of strands in a cable	40
13.	Maximum allowed TOTAL voltage to ground	2-2.5 kV

Question addressed by the CERN/EU program

Initially, focused to provide a credible feasibility statement by end 2018

Are 16T accelerator magnets feasible?

- field amplitude & margin
- field quality
- conductor availability & performance
- protection
- structural aspects (conductor & magnet)
- manufacture

If yes, at which cost?

- conductor cost
- field amplitude & margin
- magnet cost model

16T R&D

EuroCirCol WP5

FCC 16 T Technology Program

US Program ?

EuroCirCol WP5

Deliverables of WP5 described in H2020-INFRADEV-1-2014-1
1) Explore design options for an accelerator dipole magnet producing 16 T
2) Identify the preferred dipole design options and perform a cost estimate
3) Develop a cost model (optimistic, likely and conservative)
4) Produce the engineering design of the selected baseline configuration

Task 5.1: Coordination (CERN)

Task 5.2: Design options (**CIEMAT**, CEA, CERN, INFN)

Task 5.3: Cost model (**CERN**, CEA, CIEMAT)

Task 5.4: Conceptual design (**INFN**, CEA, CIEMAT)

Task 5.5: Conductor studies (**CERN**, UNIGE, UT)

Task 5.6: Quench protection (**TUT**, CERN, INFN)

Task 5.7: Engineering design & manufacturing folder (**CEA**, CERN)

10 video meetings since June 2015, in addition to special events

FCC 16T Technology Program: conductor

Initially focussed to Jc increase : target Non-Cu Jc (16T, 4.2K) > 1500 A/mm2

Cost target 5 Euro/kAm, though, **first**, performance has to be achieved

A number of R&D and industrial initiatives are being explored:

- Purchase of wires in Europe
- Industrial R&D in Europe
- Purchase of wires in US
- Collaboration agreement with KEK
- Collaboration agreement with Russia
- Program with Korean Industry being discussed
- Collaborations with several European Universities and Research Centres

It is highly desirable that a strong industrial R&D program is established in the US

FCC 16T Technology Program: magnet models

3 stages

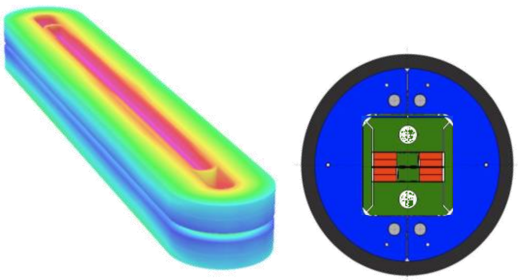
1. ERMC (different versions, non-graded and graded)
2. RMM (different versions, non-graded and graded)
3. Demonstrator

ERMC

Enhanced Racetrack Model Coil

16 T midplane field

- Demonstrate field on the conductor
- Mechanics
- Coil technology development including “grading” splice

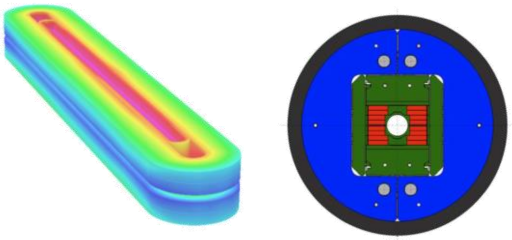


RMM

Racetrack Model Magnet

16 T in a 50 mm cavity

- Demonstrate field in the aperture
- Mechanics
- Training-friendly transitions



FCC 16T Technology Program: additional topics

Conductor

1. Establish conductor cost model
2. Explore electro-mechanical behaviour of mixed cables (Sc strands + Cu strands)
3. Explore splice techniques, possibly including splicing before or during the heat treatment
4. Characterize the stress & dimensional evolution of a conductor during the heat treatment
5. Explore conditions and limits of windability

Insulation

1. Explore & characterize ceramic binders, ceramic impregnation, other binders
2. Characterize the mechanical performance (resin + tapes), define a benchmark.
3. Characterize the electrical performance, explore new concepts/alternatives
4. Characterize the thermal performance, explore new concepts/alternatives

Structure

1. Characterize compression and traction of the structural components, at T_{amb} and T_{cold}
2. Characterize the stress-strain properties and thermal contraction of coils/cable stacks.

Instrumentation

1. "Invent" "slim" pressure gauges (ex capacitive gauges with sputtered dielectric, other?)
2. Measure the field amplitude in ERMC
3. Identify the longitudinal quench location in the ERMC and the RMM
4. Measure field quality in the RMM (at least sextupole component, dynamically)

Next Steps for EuroCirCol

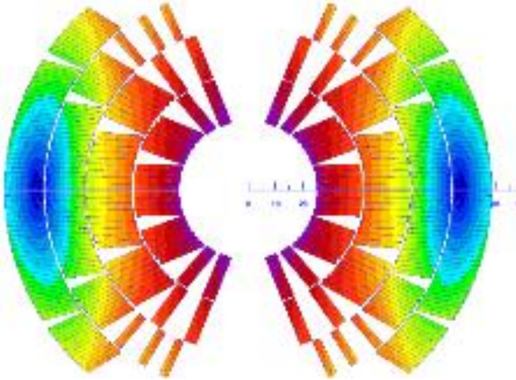
1) refine the parameter space (considering recommendations from this review)
2) select design(s) to be explored in the new parameter space (considering recommendations from this review)
3) present a EuroCirCol baseline 2D conceptual design at the annual meeting
4) select (Nov-Dec 2016) ONE design to complete until the end of the study

Perform a 2^{nd} Technical Review in June 2017

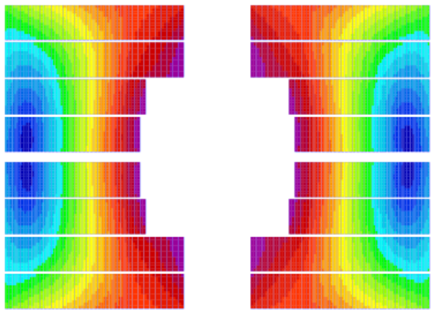
Summary of options

Design		Cos-θ	Block	Common-C
Operating current	(kA)	10.275	8.47	9.0
Field in the aperture	(T)	16.0	16.0	16.0
Margin at 4.2 K	%	10.0	9.3	10.0
Intrabeam spacing	(mm)	250	250	280
Stored magnetic energy per unit length/ap	(MJ/m)	1.5	1.7	2.4
Inductance/aperture	(mH/m)	25	44	58
LI/aperture	(H.A/m)	257	374	522
Diameter IL	(mm)	1.1	1.1	1.1
Strands/cable IL	-	28	24	24
Cu/Non-Cu IL	-	1.0	1.0	1.0
Diameter OL	(mm)	0.7	0.7	1.1
Strands/cable OL	-	38	37	12
Cu/Non-Cu OL	-	2.0	1.0	2..4
Total area of Cu/aperture	(mm^2)	5004	4751	5502
Total area of Non-Cu/aperture	(mm^2)	3403	4751	3368
Total mass of Non-Cu for FCC-hh	(t)	3876	5412	3740
Total mass of conductor for FCC-hh	(t)	9576	10824	10110
J_{eng} IL	(A/mm^2)	386	371	394
J_{eng} OL	(A/mm^2)	703	595	789
J_{overal} IL	(A/mm^2)	270	260	265
J_{overal} OL	(A/mm^2)	459	386	480
Hot spot temperature	(K)	328	308	350
Voltage to ground	(V)	1400	1200	TBA
Voltage turn-to-turn	(V)	103	82	TBA
V layer-to-layer	(V)	1800	1100	TBA

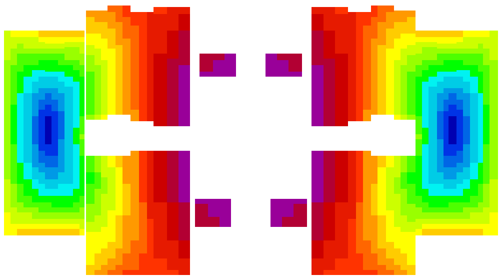
Cos-θ



Block



Common-Coil



Concluding Remarks

The EU/CERN 16T dipoles program established until 2019 is very ambitious, considering that during the same time most of efforts have to be devoted to HILUMI.

The FCC 16T Technology Program has been established such to provide important results even with presently available conductors, and remains flexible enough to accompany conductor development. The program is focused to develop and understand the technologies and operational parameters for a 16T dipole.

The EuroCirCol WP5 is focused to provide a constructional design of a 16T model magnet, single aperture, incorporating all features to be extendable to a long 16T accelerator double aperture magnet.

The conductor development remains an absolute necessity: it will be important to motivate an effective industrial R&D (in addition to production).

Thank you for your attention