The CERN High Field Magnet Programs

Presented by P. Fessia,
Prepared by L. Bottura and P. Fessia
on behalf of the HL-LHC, FCC, EuCARD, EuCARD2 programs

4 August 2016

An alignment of interests along time…..

*Europe's top priority should be the **exploitation of the full potential of the LHC**, including the high-luminosity upgrade of the machine and detectors with a view to collecting **ten times more data than in the initial design, by around 2030**. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*

EU Strategy Group on Particle Physics recommended to

*"to propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy update **(NOTE: to take place in 2018)***

…

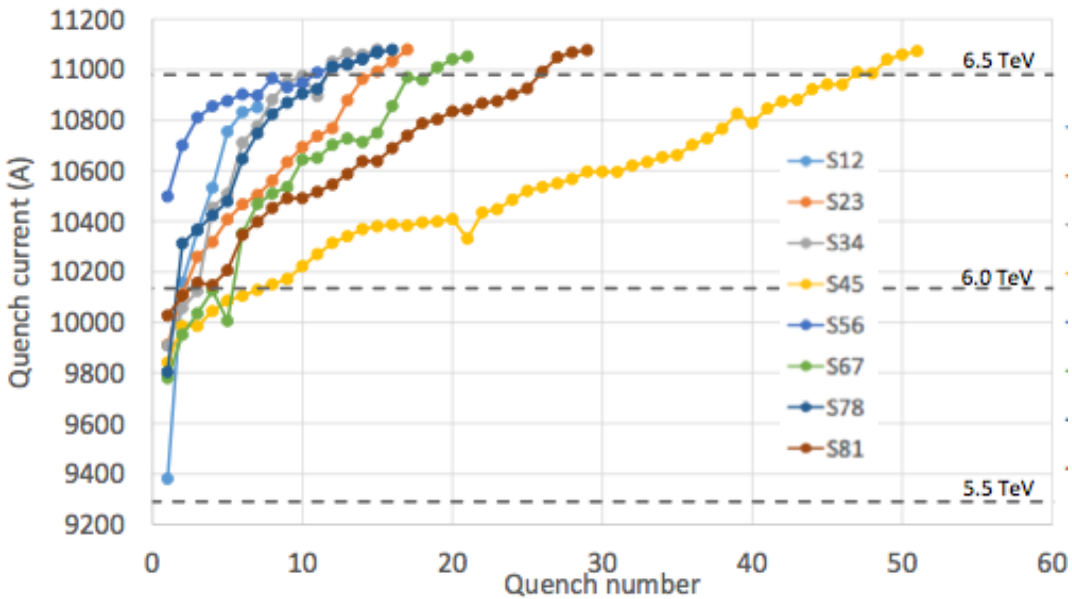
d) CERN should undertake design studies for accelerator projects in a global context,

…

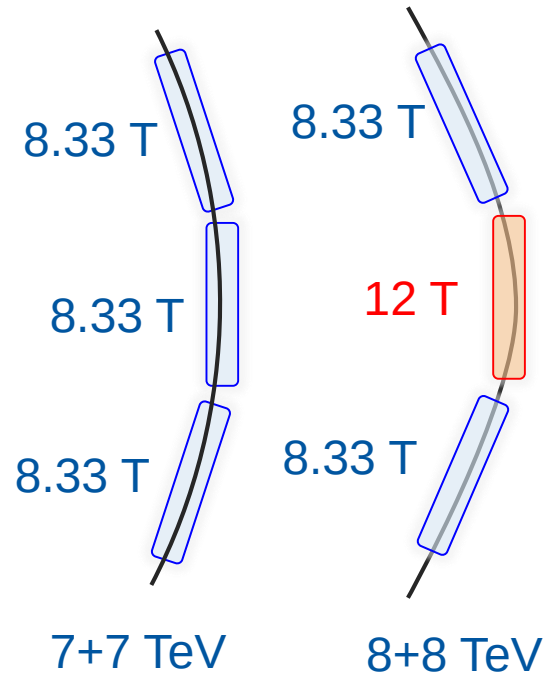
LHC to its present limit…..

- Training the machine up to 14 TeV c.o.m.
- (and somewhat beyond, up to 15 TeV c.o.m. at most ?)

Partial energy upgrade, a portion of the magnets may be could be upgraded to increase the energy (building on HL-LHC 11T development program), up to 16 TeV c.o.m. Feasibility and cost effectiveness to be studied



By courtesy of CERN-MP3

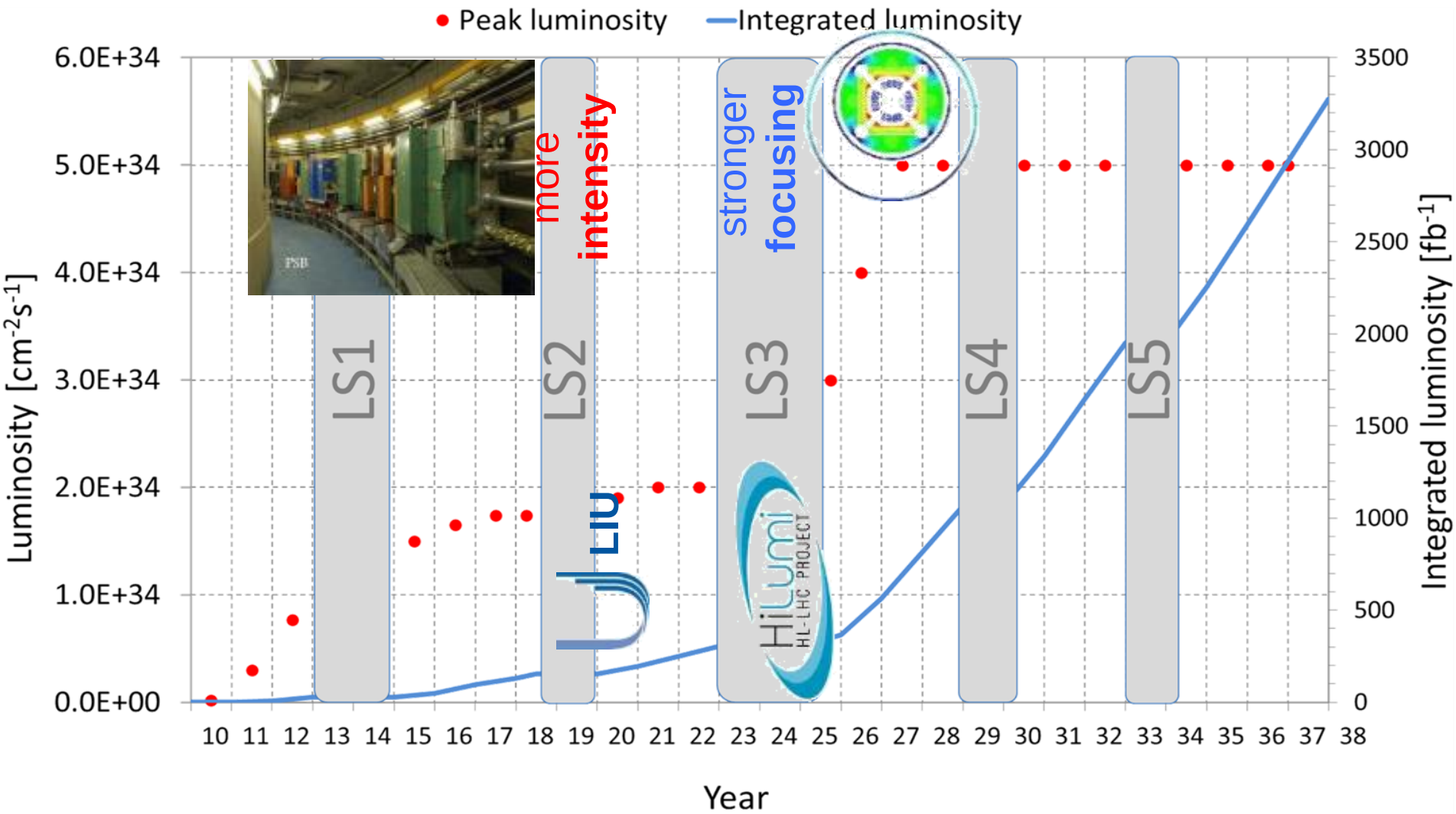


Scenarios under study by team led by O. Bruning

HL-LHC: new light with Nb_3Sn

More data

$$\text{Luminosity} = f * N^2 / 4\pi\,\sigma^2$$



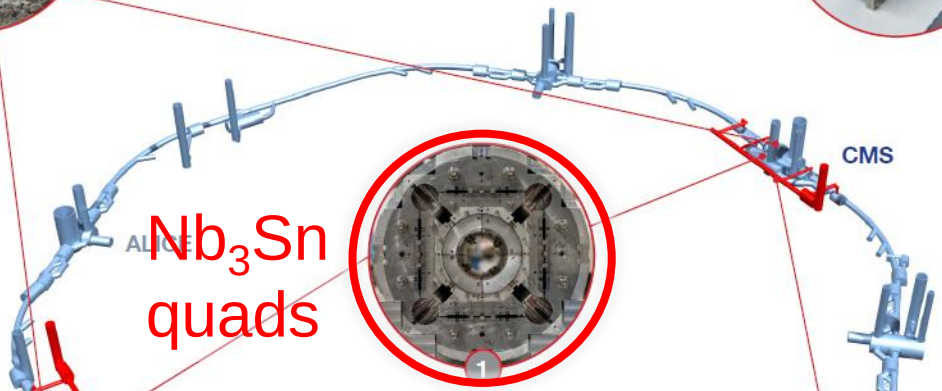
LHC HiLumi project

GÉNIE CIVIL
2 nouvelles galeries de 300 mètres et 2 puits près d'ATLAS et de CMS.

CAVITÉS « CRABE »
32 cavités supraconductrices « crabes » pour chacune des expériences ATLAS et CMS pour orienter les faisceaux avant les collisions.

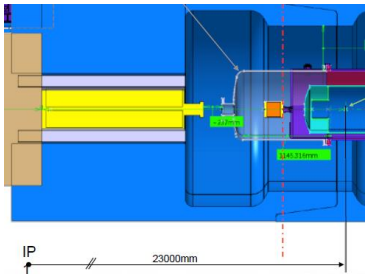
Cryo@P1-P5

Cryo@P4

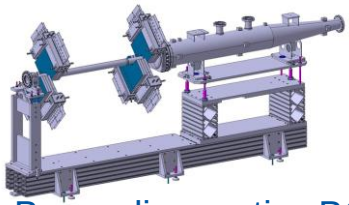


Nb_3Sn quads

AIMANTS DE FOCALISATION
12 aimants quadripôles plus puissants pour chacune des expériences ATLAS et CMS pour concentrer plus fortement les faisceaux avant les collisions.

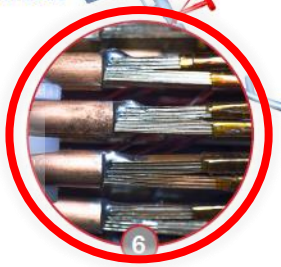


New TAS and VCX



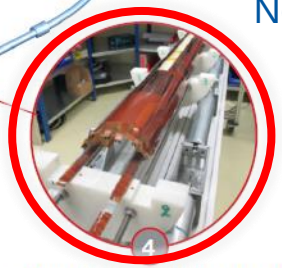
Beam diagnostics BGV

MgB_2 links



LIGNES SUPRACONDUCTRICES
Des lignes de transmission électrique à base d'un supraconducteur haute température pour transporter le courant vers les aimants depuis les nouvelles galeries près d'ATLAS et CMS.

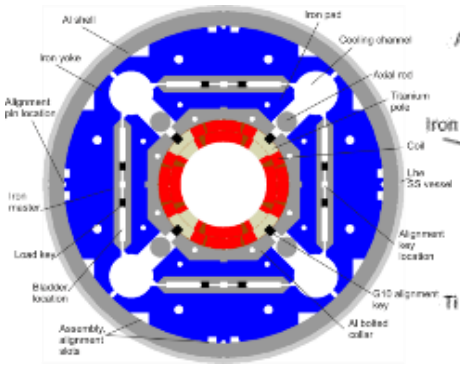
COLLIMATEURS
15 à 20 nouveaux collimateurs et 60 collimateurs remplacés pour renforcer la protection de la machine.



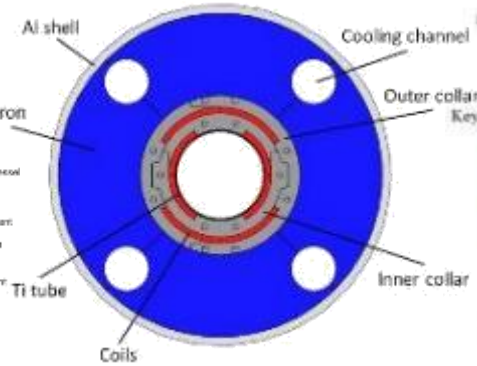
Nb_3Sn dipoles

AIMANTS DE COURBURE
4 paires d'aimants de courbure dipôles plus courts et plus puissants pour libérer de la place pour les nouveaux collimateurs.

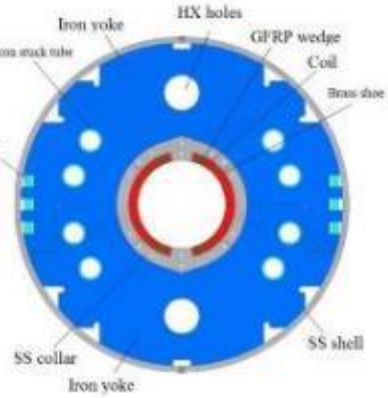
HL-LHC the required magnets



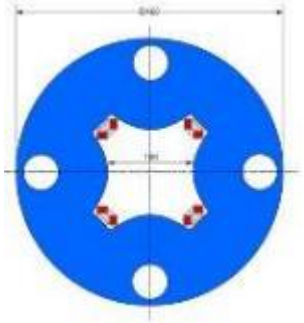
Triplet QXF (LARP and CERN)



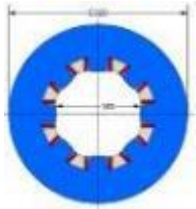
Orbit corrector (CIEMAT)



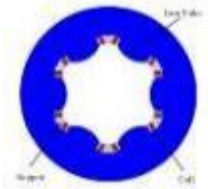
Separation dipole D1 (KEK)



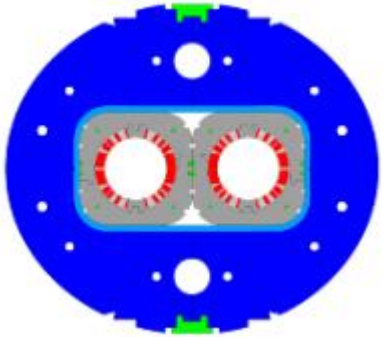
Skew quadrupole corrector (INFN)



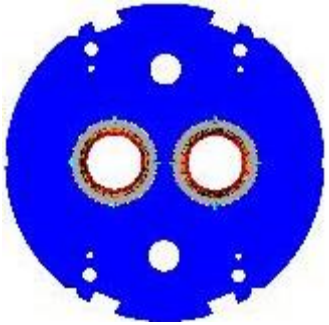
Corrector octupole (INFN)



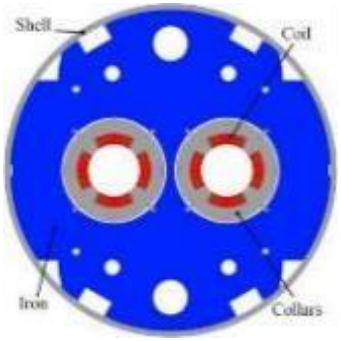
Corrector sextupole (INFN)



Recombination dipole D2 (INFN design)

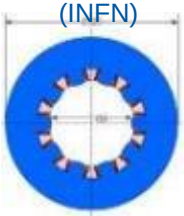


D2-Q4 orbit correctors (CERN)

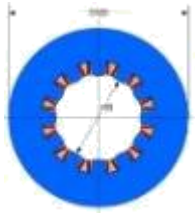


Q4 (CEA)

11 T (CERN)



Corrector decapole (INFN)



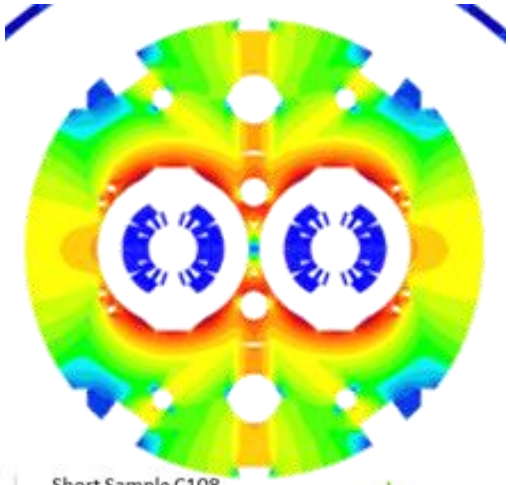
Corrector dodecapole (INFN)

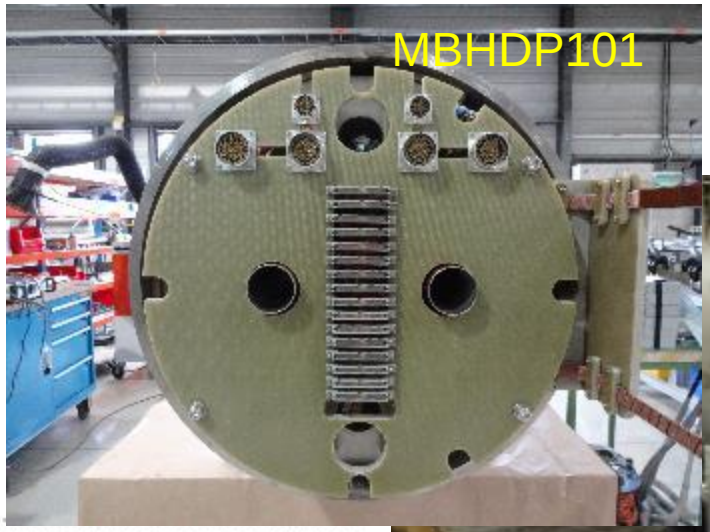
Cross-sections to scale

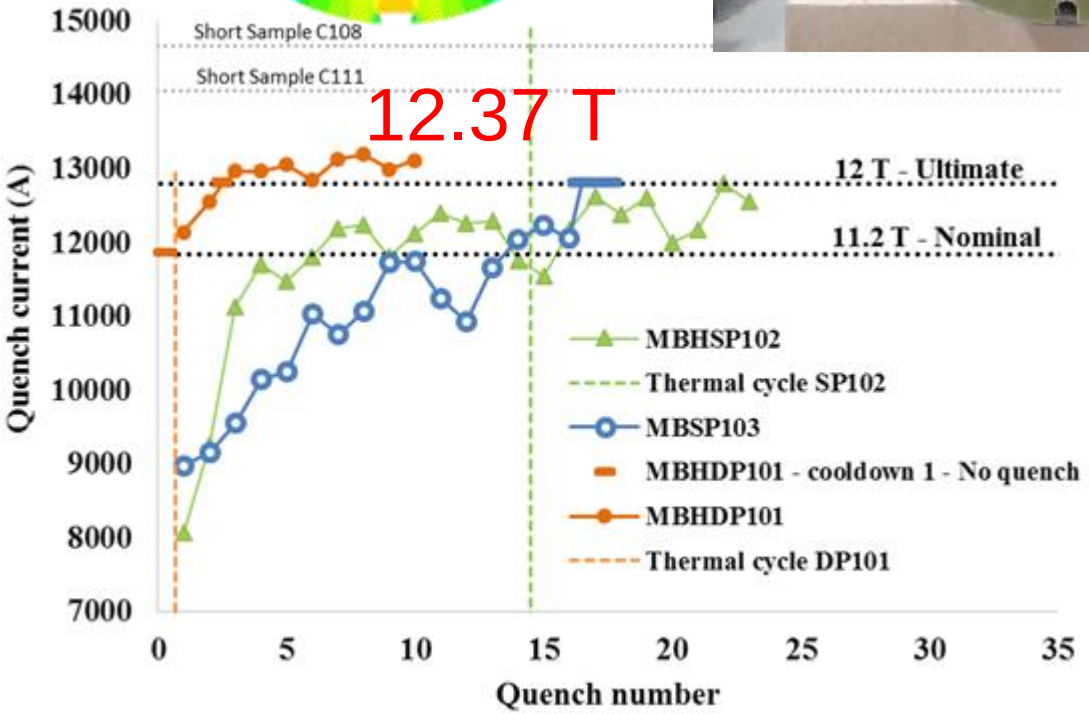
By courtesy of E. Todesco and F. Savary (CERN)

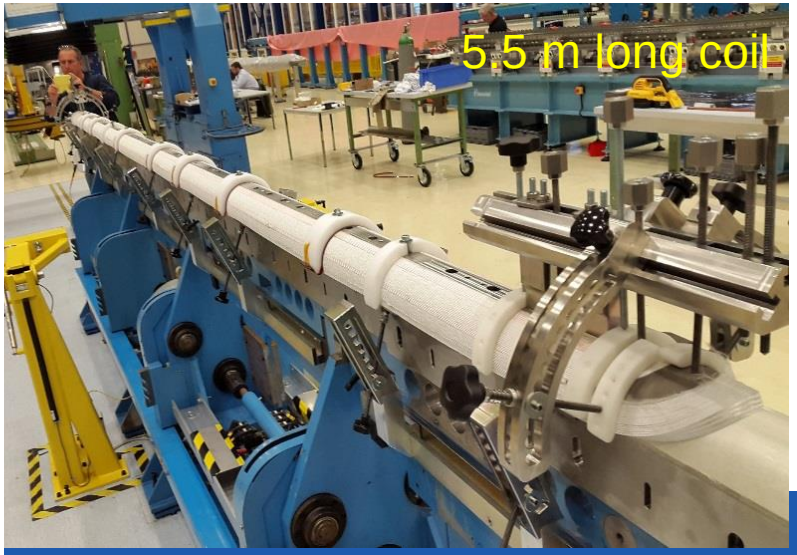
Test of CERN 11T models

Cos-θ



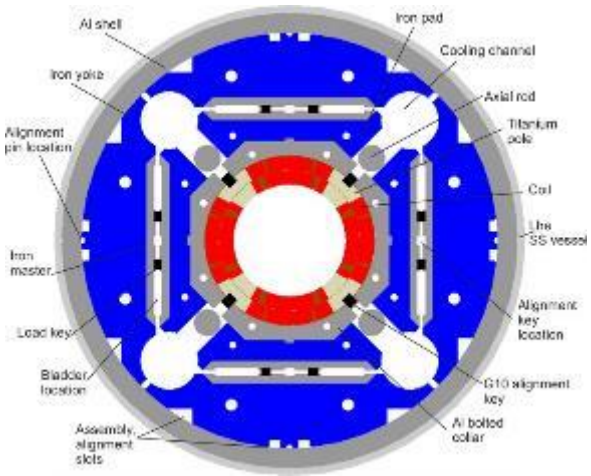


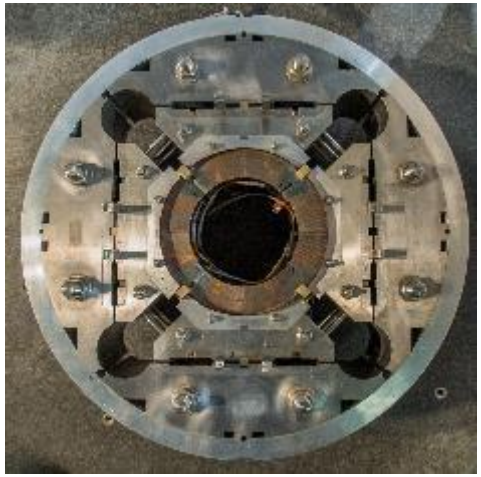




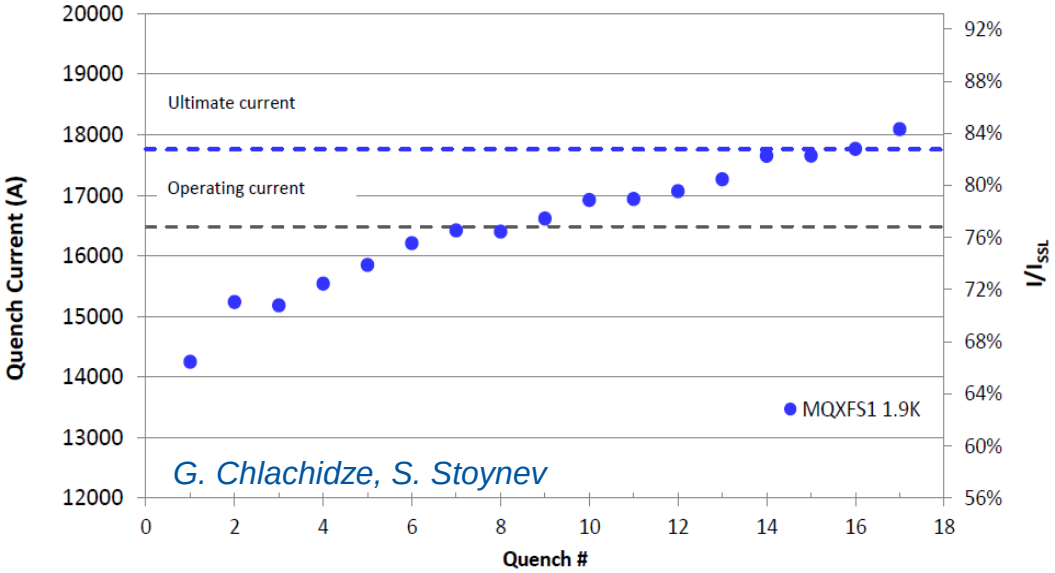
By courtesy of F. Savary (CERN)

Test of MQXFS1 (first model)



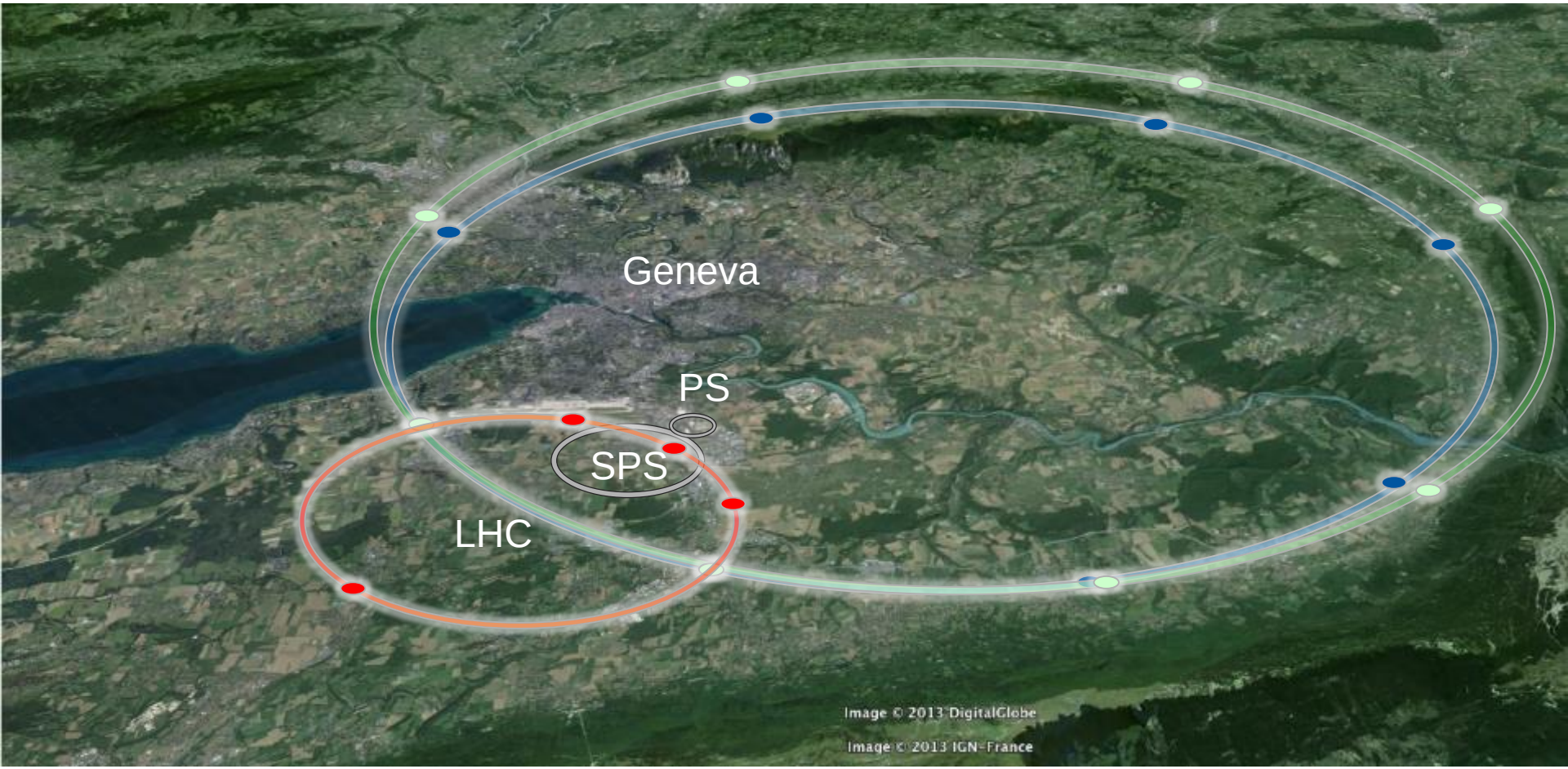


By courtesy of G. Ambrosio (FNAL), P. Ferracin (CERN et al)



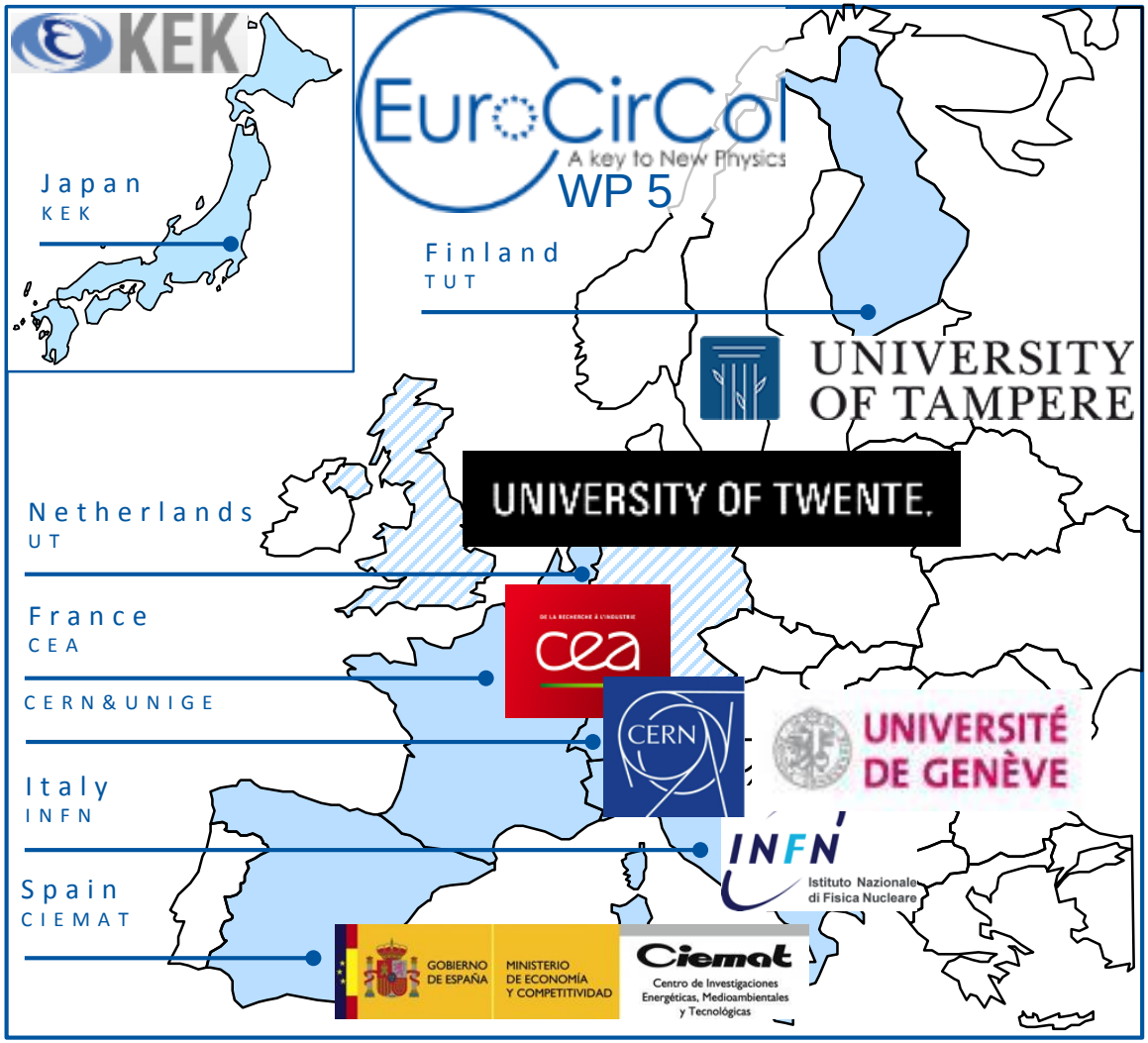
Enlarging the horizon

Ideas beyond the LHC: the FCC's



LHC	HE-LHC	FCC-hh	FCC-hh
27 km, 8.33 T	27 km, **20 T**	80 km, **20 T**	100 km, **16 T**
14 TeV (c.o.m.)	33 TeV (c.o.m.)	100 TeV (c.o.m.)	100 TeV (c.o.m.)
1300 tons NbTi	3000 tons LTS	9000 tons LTS	6000 tons Nb_3Sn
0.3 tons HTS	700 tons HTS	2000 tons HTS	3000 tons Nb-Ti

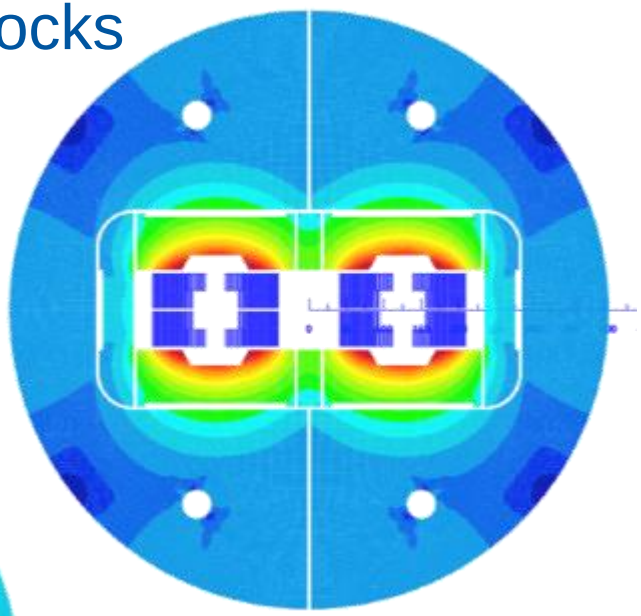
CERN/EU program for 16 T dipole



Design a 16 T accelerator-quality model dipole magnet by 2018

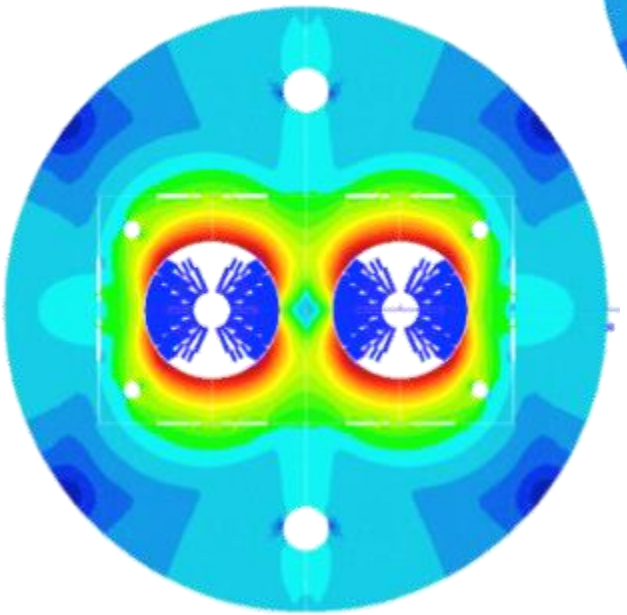
FCC: 16T dipole options

Blocks



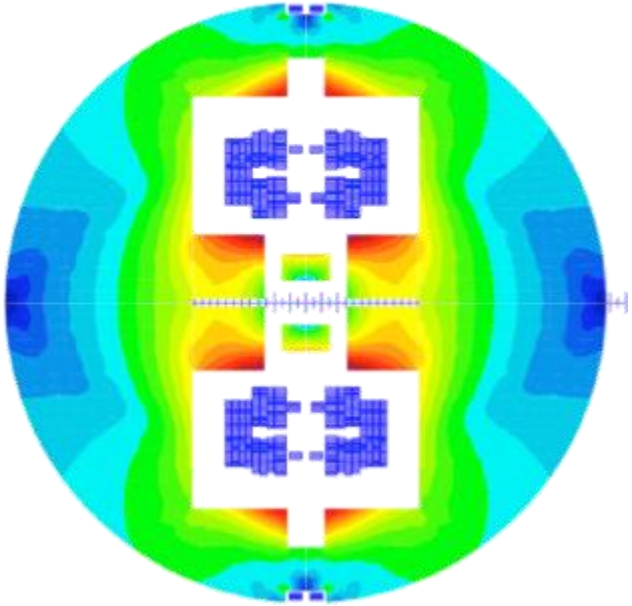
C. Lorin, M. Durante (CEA)

Cos-theta



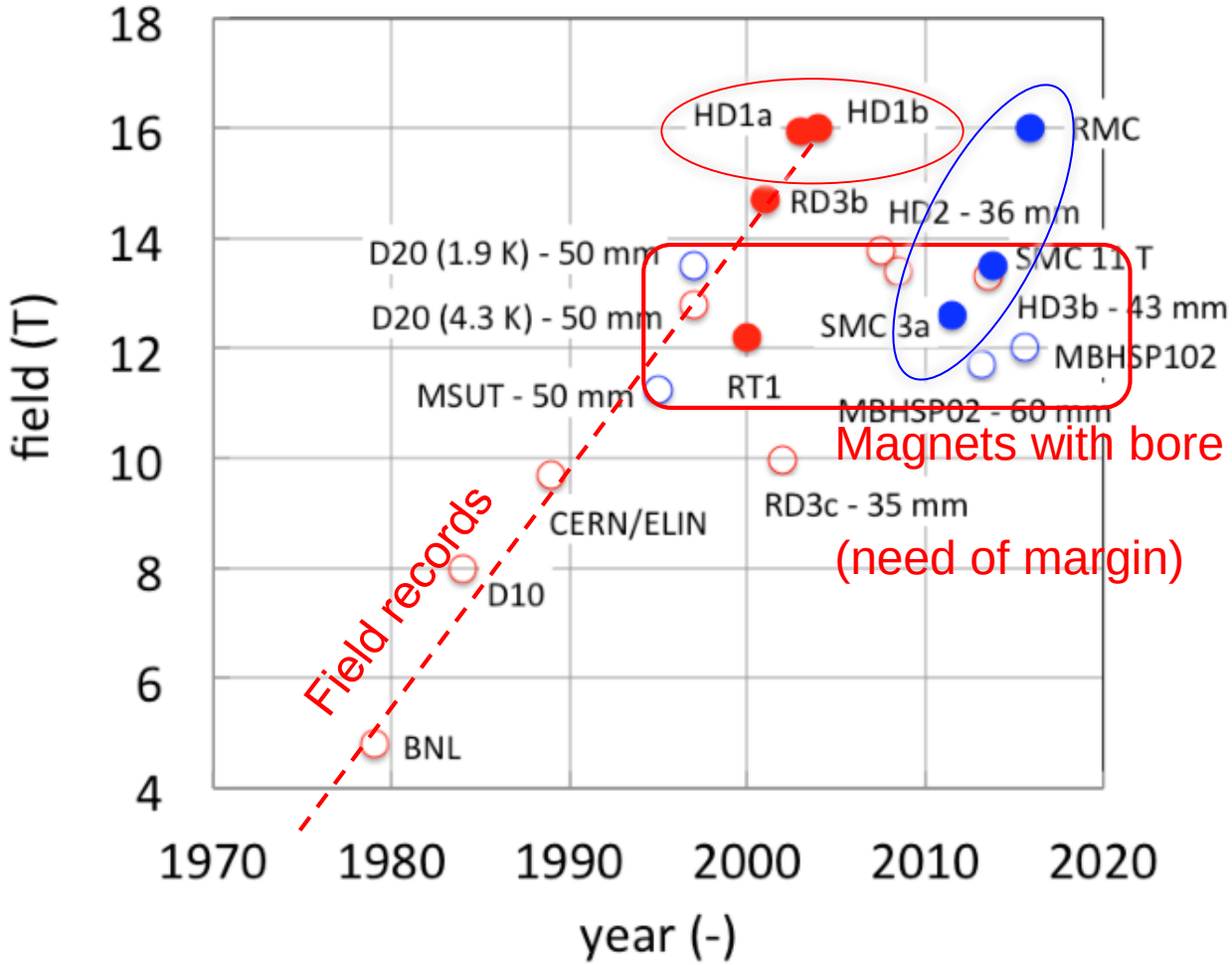
S. Farinon, P. Fabbricatore (INFN)

Common coils



F. Toral (CIEMAT)

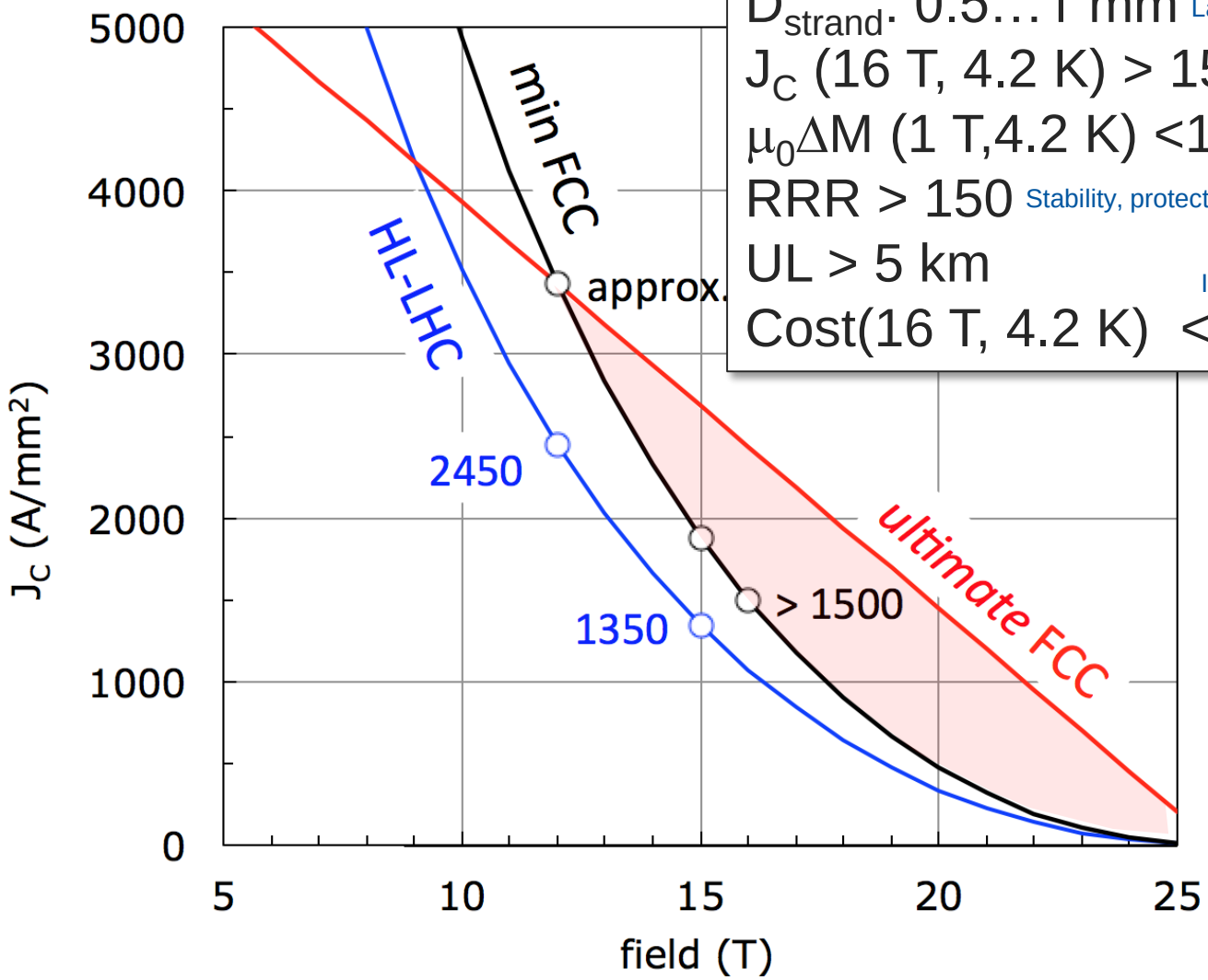
What has been reached: highest “dipole” fields



LBNL HD1

CERN RMC

FCC Nb_3Sn performance targets



D_{strand}: 0.5…1 mm Large cables, **cabling !**

J_C (16 T, 4.2 K) > 1500 A/mm²

Field quality

$\mu_0 \Delta M$ (1 T,4.2 K) <150 mT (D_{fil} < 20 μm)

RRR > 150 Stability, protection

UL > 5 km

ITER material cost per kg

Cost(16 T, 4.2 K) < 5 USD/kA m

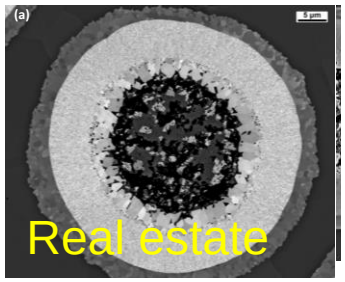
All single parameters are in reach, their combination is the challenge !

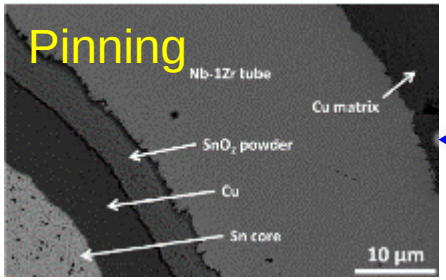
Ultimate Nb_3Sn ? Pursue the idea of improved high field pinning (q=1)

(D. Dietrich and R. Scanlan, A. Godeke)

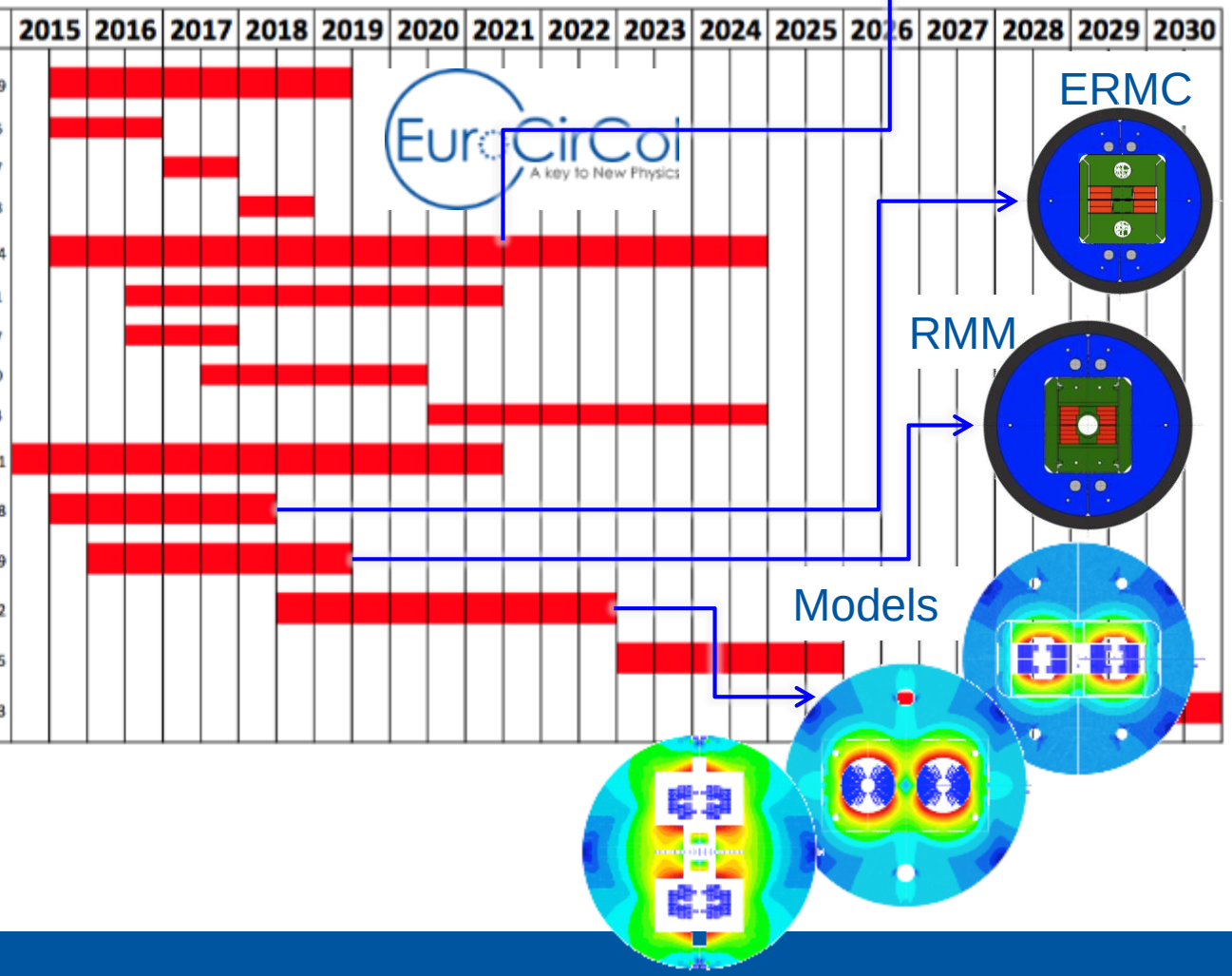
FCC plan

Proposed update





Activity	Begin	End
FCC EuroCirCol	01.05.2015	30.04.2019
EuroCirCol concepts	01.05.2015	31.12.2016
EuroCirCol design	31.12.2016	31.12.2017
EuroCirCol engineering	31.12.2017	31.12.2018
FCC Conductor Program	01.05.2015	31.12.2024
wire and material R&D	30.06.2016	30.06.2021
state-of-the-art wire for demonstrators	30.06.2016	31.12.2017
high Jc wire for 16 T models	30.06.2017	30.06.2020
high performance wire for 16 T models and prototypes	30.06.2020	31.12.2024
Core magnet technology R&D	01.01.2015	30.06.2021
Design, manufacture and test of ERMC	30.06.2015	30.06.2018
Design, manufacture and test of RMM	01.01.2016	30.06.2019
FCC 16 T Models	30.06.2018	31.12.2022
FCC 16 T Prototypes	01.01.2023	31.12.2025
FCC Production	01.01.2026	31.12.2033



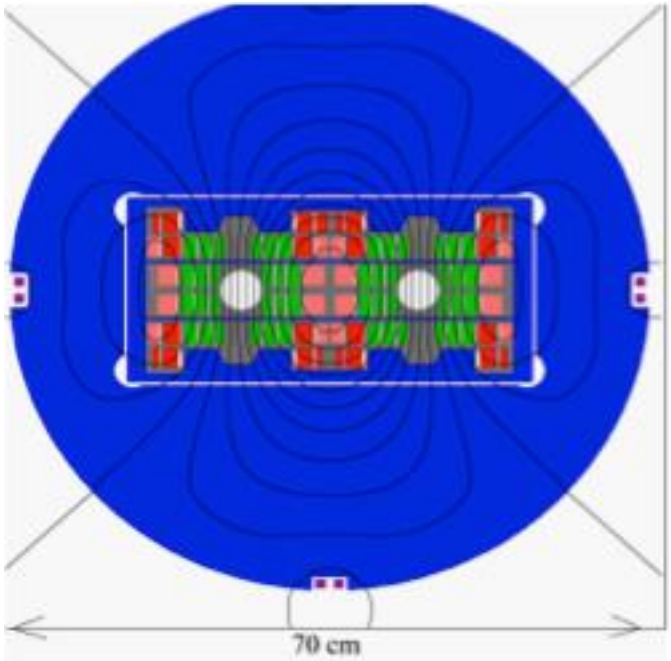
There is ample space (and desire) for contributions from collaborators

Going higher: ideas for 20 T

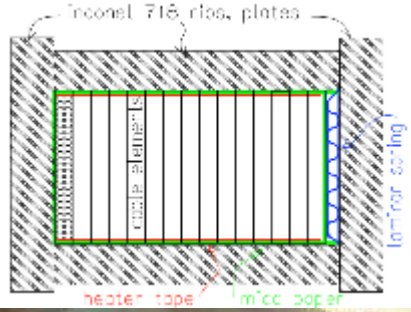
A 20 T HE-LHC dipole
E. Todesco, L. Rossi (CERN)

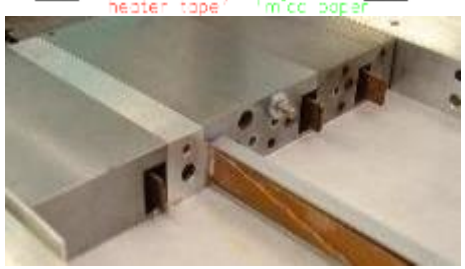
A 24 T LHC *Tripler*

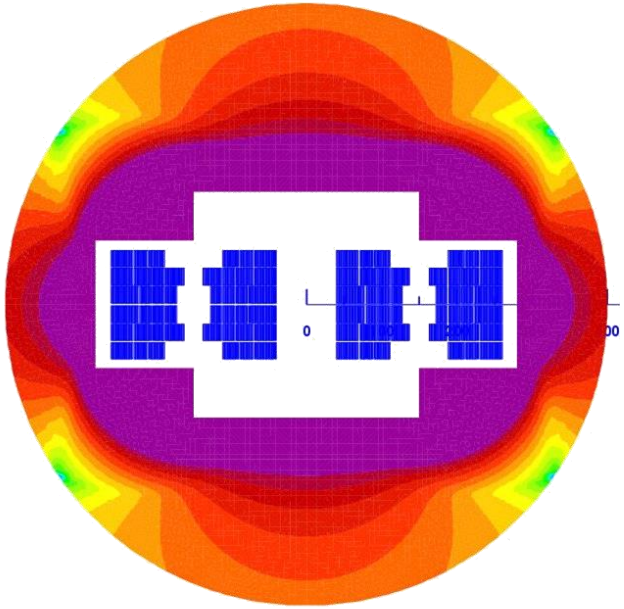
P. McIntyre (TAMU)



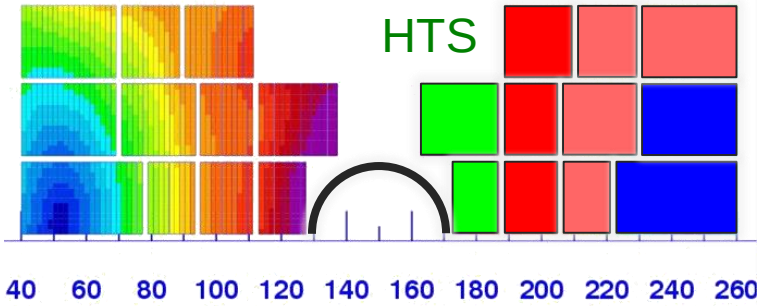
Stress managed winding







Nb_3Sn



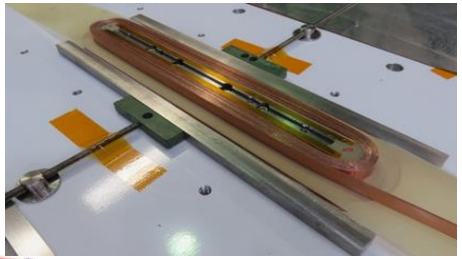
Cost optimized, graded winding

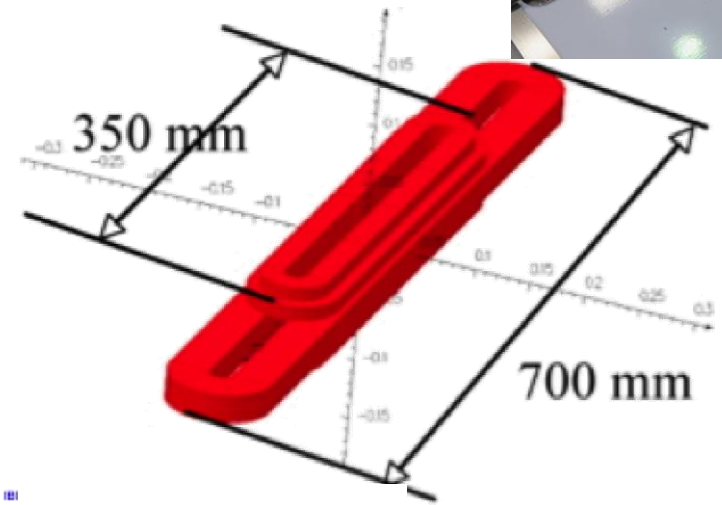
All options are based on an LTS winding (outsert), and an HTS field booster (insert)

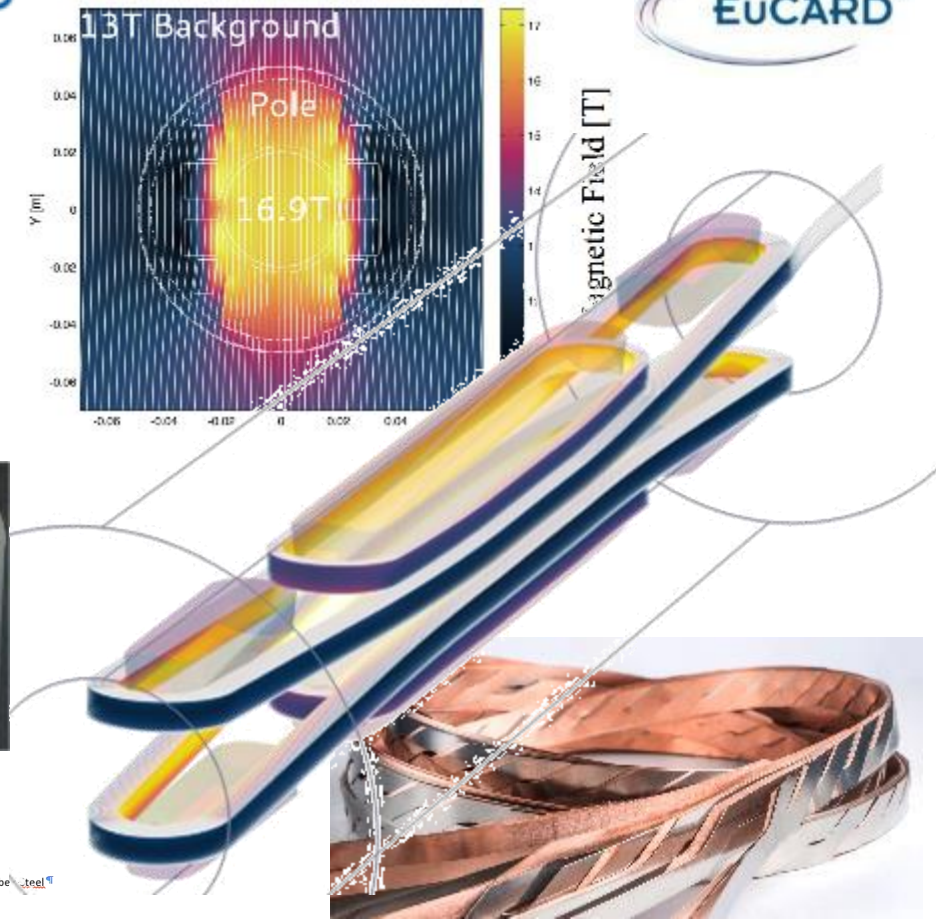
HTS for 20 T

6 T HTS (YBCO) insert for test in FReSCa2 (no bore)

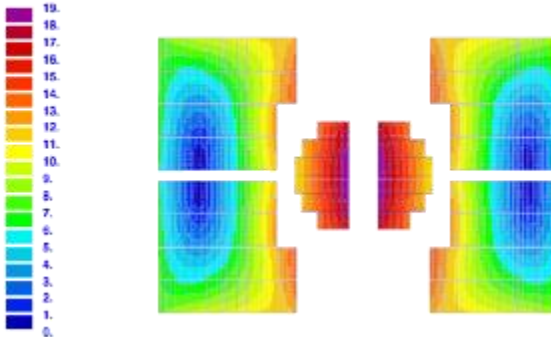
J. Van Nugteren, G. Kirby, G. de Rijk, CERN

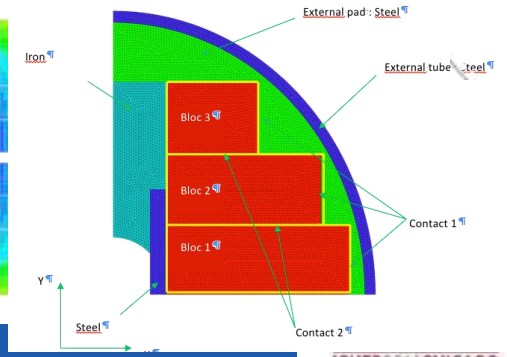






19 T

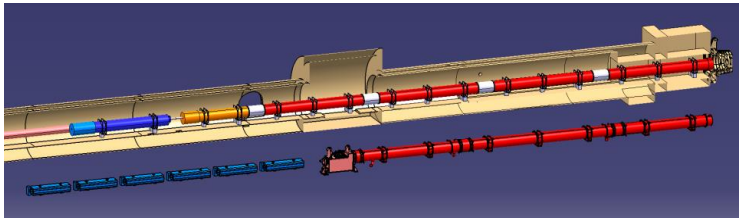


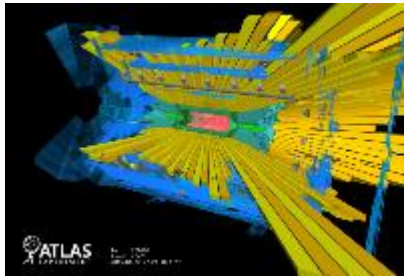


5 T HTS (YBCO) stand-alone dipole for test in FReSCa2 (40 mm bore)

J.M. Rey, CEA-Saclay

LHC Run-II provides results to define future HEP roadmap (European Strategy 2018)



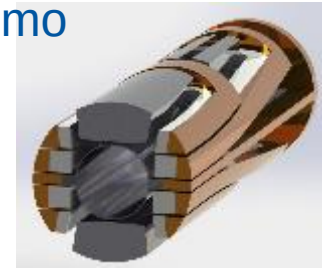


EuCARD²

Accelerator-grade HTS **5 T** demo

HL-LHC demonstrates large-scale use of Nb_3Sn

End of LHC useful life

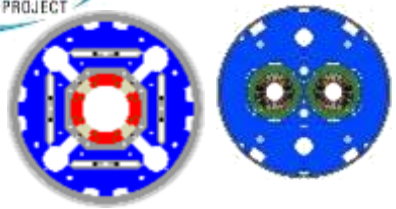


High Luminosity LHC

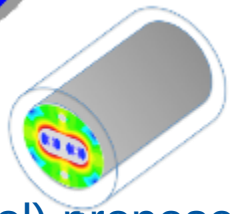
2015 2016 2017 2018 2019 2020 2025 2030 2035 2040

12 T accelerator technology

HiLumi HL-LHC PROJECT

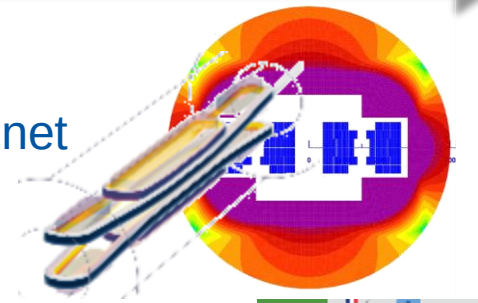


16 T magnet model(s)



16 T accelerator technology

20 T magnet model(s)



FCC

FCC CDR (EuroCirCol) propose a new energy frontier accelerator

FCC construction decision