A multitude of Magnets for HL-LHC, and beyond

or: *“Be fruitful and multiply, and fill the Tunnel, and subdue the Bosons”*
(Genesis, 1:28)

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Superconducting Technologies for Next Generation of Accelerators

CERN - GLOBE of Science and Innovation

4-5 December 2012

SUPERCONDUCTING TECHNOLOGIES
FOR THE NEXT GENERATION OF ACCELERATORS
WORKSHOP

Outline

- Magnet overview for HL-LHC
- Ideas for an implementation
- Other needs for LHC
- Beyond LHC

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- Magnet overview for HL-LHC
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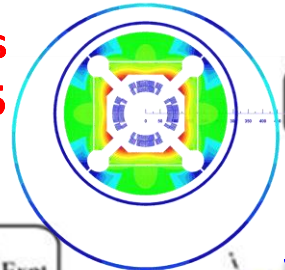
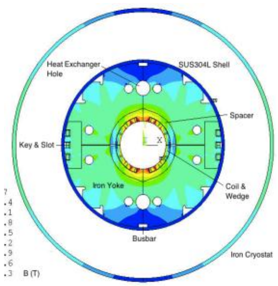
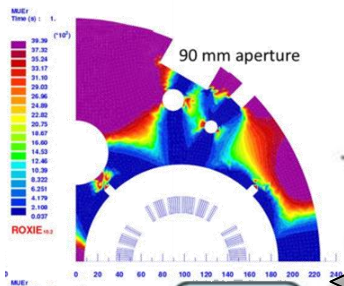
Magnet geography for HL-LHC

IR quadrupoles in IP1 and IP5

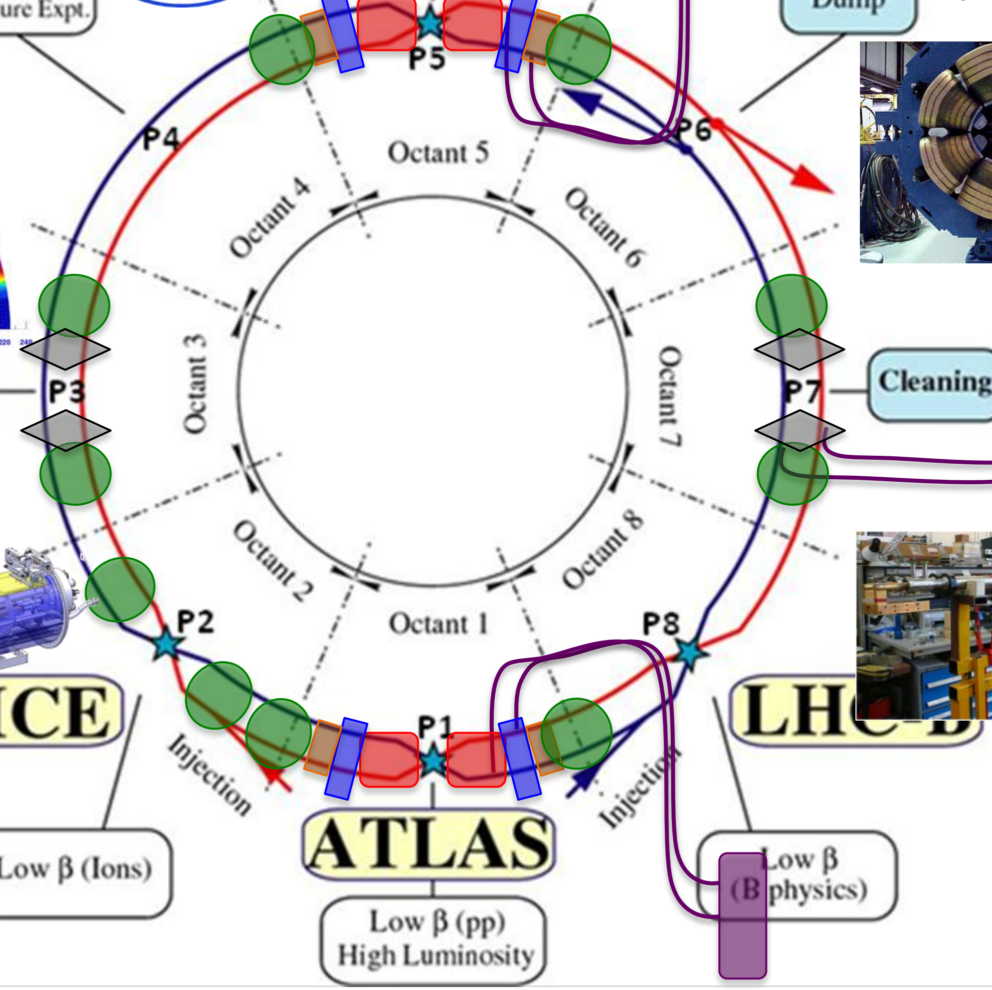


Dipoles D1 & D2 in IP1 and IP5

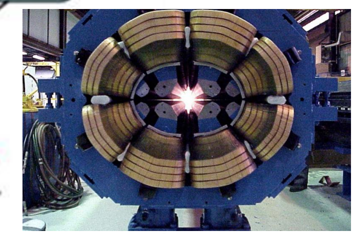




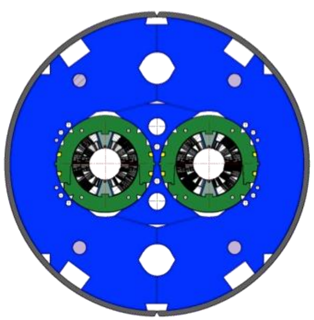
Matching section Q4 in IP1 and IP5

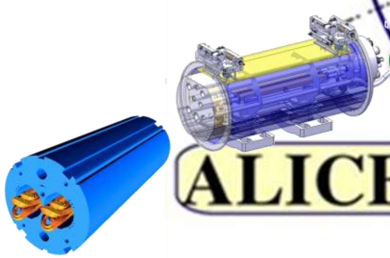


MQW shielding and spares



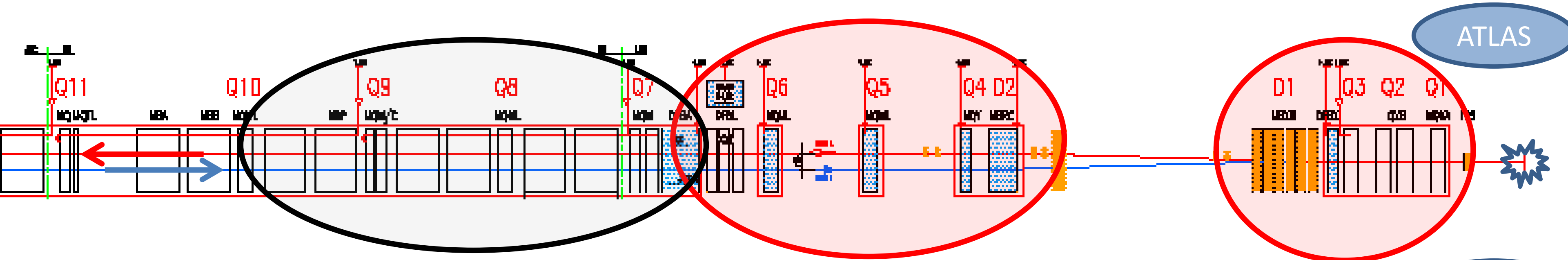
SC links





Collimation units (11 T MB)
in IP2, possibly IP3/IP7, IP1/IP5

The LHC most affected zone (MAZ)



3. Special collimation locations where we need space by using a new 11 T dipole

2. New entrance to the matching section: Q4 magnets (other magnets ? collimators and SC RF Crab Cavities)

CMS

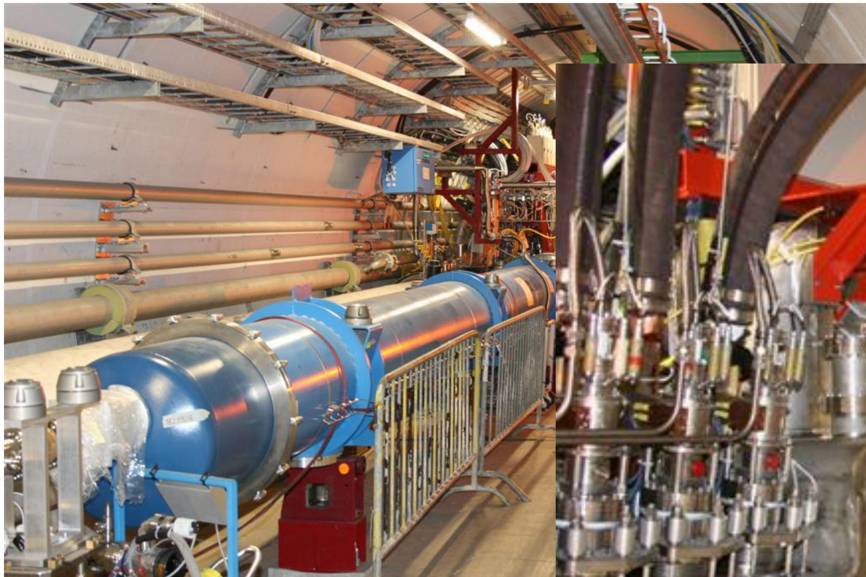
1. New Q1…Q3/D1 magnets in the IRs and interface to detectors; relocation of Power Supplies via the SC links

300 m x 4 +… : about 1.5 km long accelerator, pushed performance in a high radiation environment: 10…100 MGy

By courtesy of L. Rossi

The MAZ in real life

D1, towards DFBX



DFBX and Q3, towards Q1

Q1

The region is packed with equipment, cables, very limited access. In addition, radiation dose will be (hopefully) significant by LS3

A catalog of magnet units

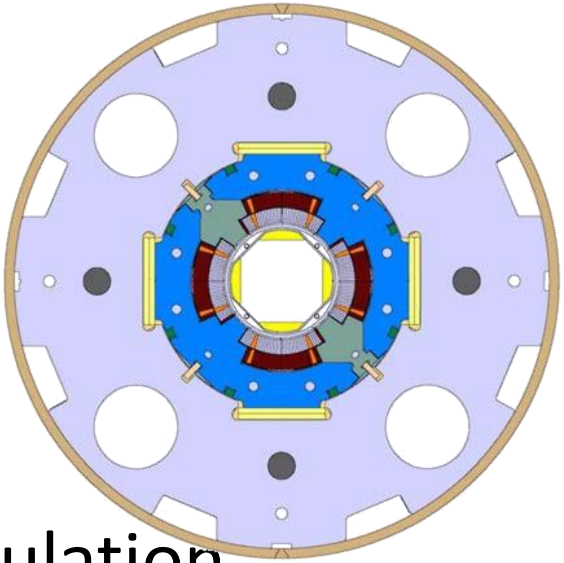
Magnet type	Name	Quantity	Peak Field (T)	Coil bore (mm)	Length (m)	Energy (MJ)	Deadline (year)
Twin Dipole	DS-MB	10…20	11	60	11 (2×5.5)	11	2017/2020
Quadrupole	Low-β Q1/Q2/Q3	16	12…13	150	8-10	12	2020
Dipole	D1	4	5	160	8	6	2020
Twin Dipole	D2	4	3…5	100 (?)	5-10	?	2019
Twin Quadrupole	Q4	4	8	85…90	4.5	1.2	2019
Twin Quadrupole	Q5	4	8 ?	70	4.5	0.6	2019

NOTE

Most of the above units must be intended as cryostated cold masses, containing multiple single magnets (e.g. Q2), suitable (TBD) corrector packages (orbit, trims, field errors) and the transitions/interconnections to the next magnet/feedbox

IR-quadrupoles: MQXC

Material		NbTi
Aperture	(mm)	120
Gradient	(T/m)	118
Current	(A)	12850
Temperature	(K)	1.9
Peak field	(T)	8.1

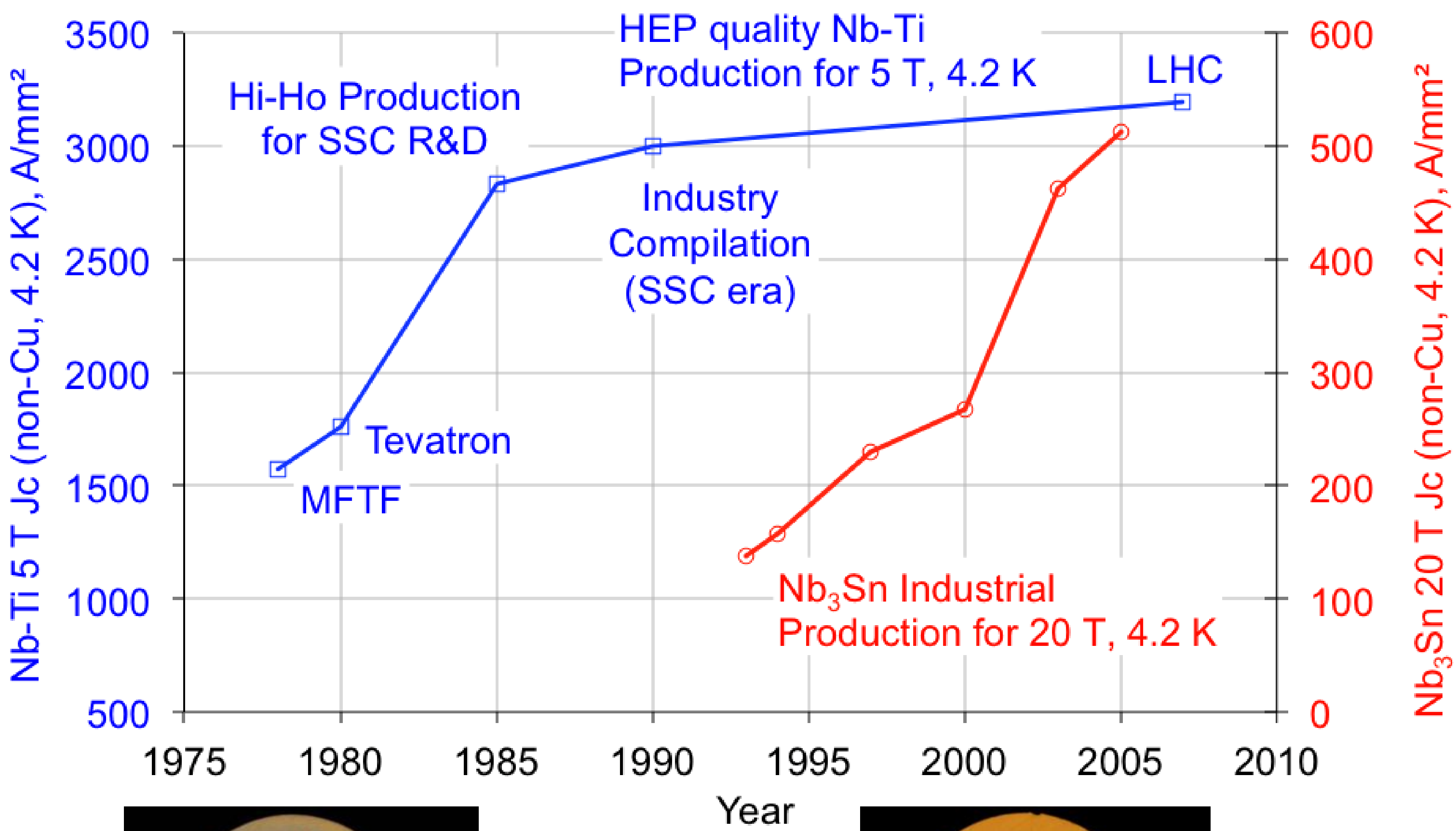


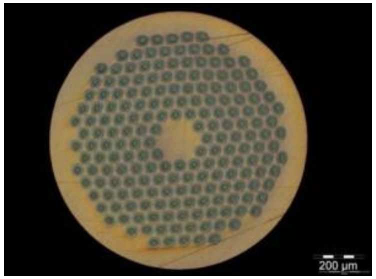
- Self-locking collars, porous insulation
- Result of EU-financed SLHC-PP development, R&D approaching completion
- Lengths and quantities:
  - Q1/Q3: 9.5 m magnets (8 magnets + 2 spares)
  - Q2: 2 x 8 m magnets (8 magnets + 2 spares)
  - A total of some 20 magnets to be produced

See the talk of G. Kirby

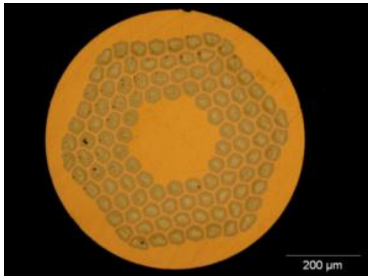
Why do we go for Nb_3Sn ?

Data by courtesy of J. Parrell (OST)





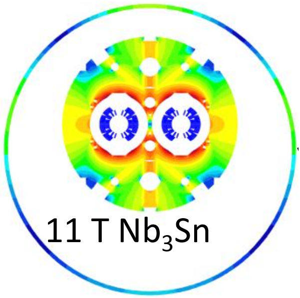
1 mm, 192 tubes PIT
from **Bruker EAS**

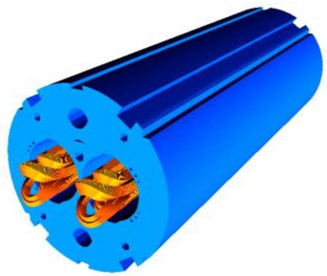


0.7 mm, 108/127 stack
RRP from **Oxford OST**

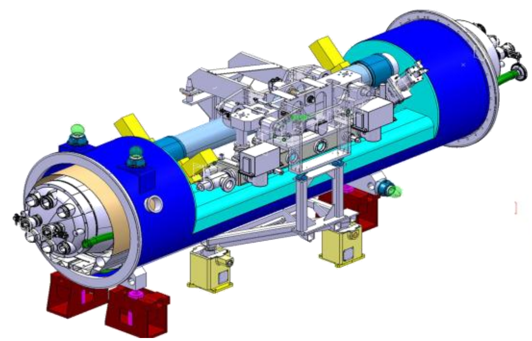
DS: collimators & 11 T dipoles

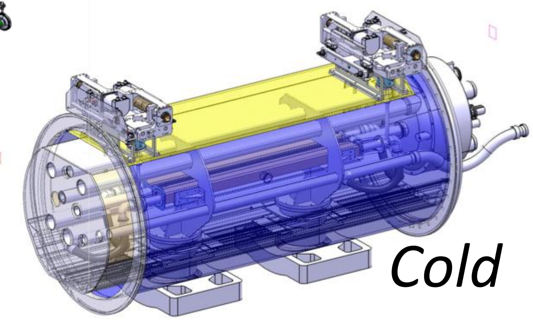
11 T dipole twin aperture magnet



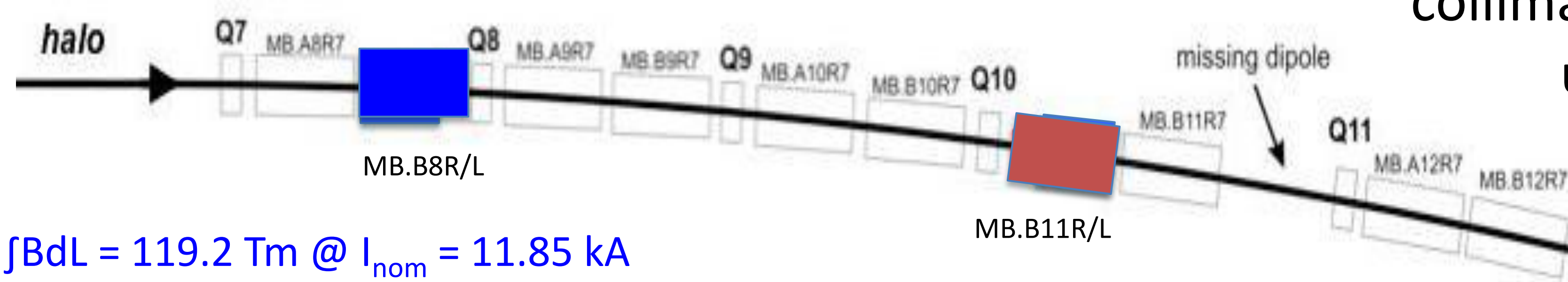


Warm collimator unit

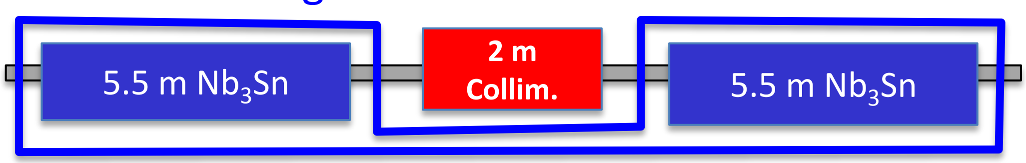




Cold collimator unit



$\int BdL = 119.2$ Tm @ $I_{nom} = 11.85$ kA
in series with MB with 20 % margin

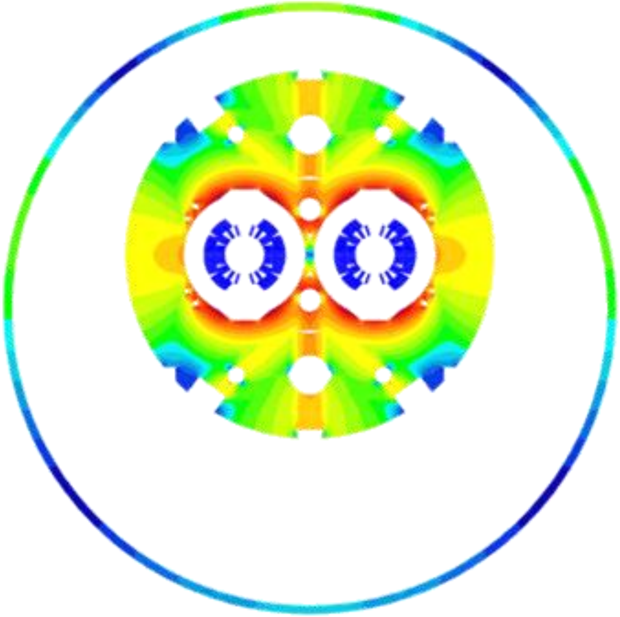


LS2 2017-18: IR-2 (demonstration)

LS3 2020: IR7/8, IR1/5 as part of HL-LHC (TBC)

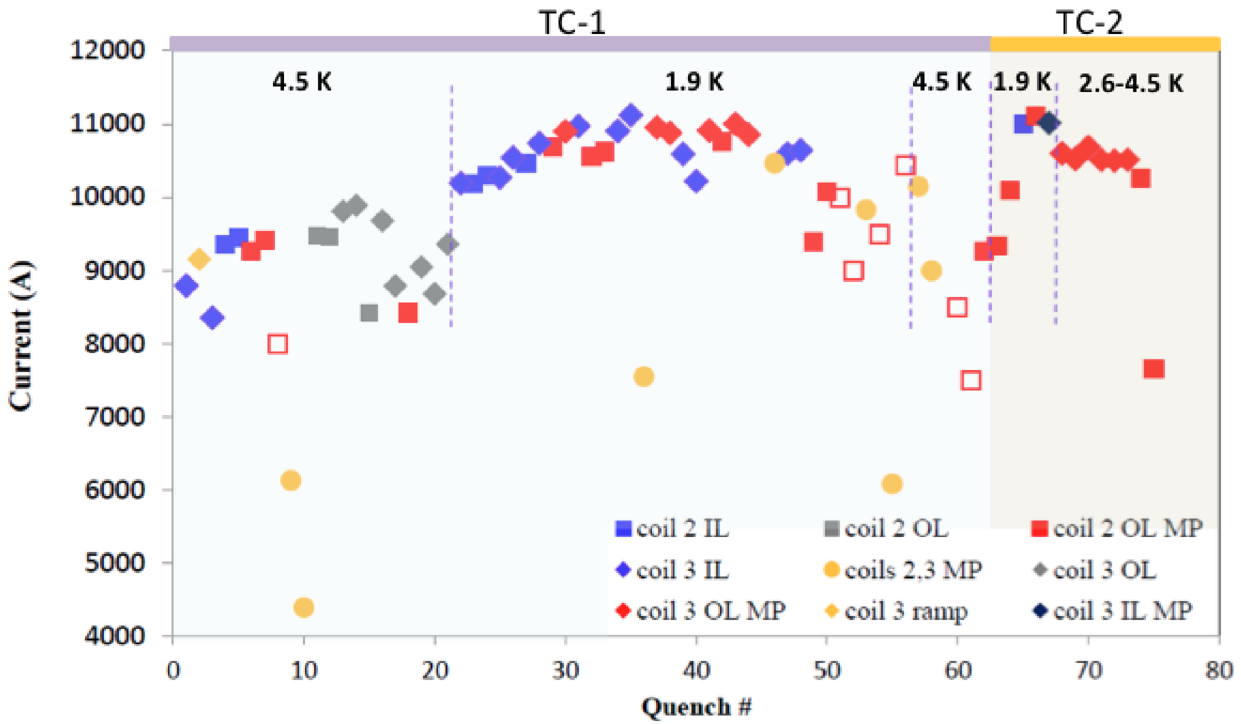
DS-MB

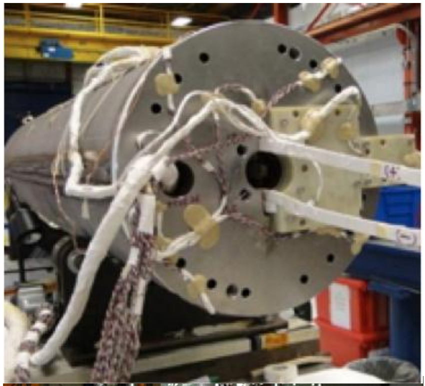
Material		Nb_3Sn
Aperture	(mm)	60
Field	(T)	10.8
Current	(A)	11850
Temperature	(K)	1.9
Peak field	(T)	11.3

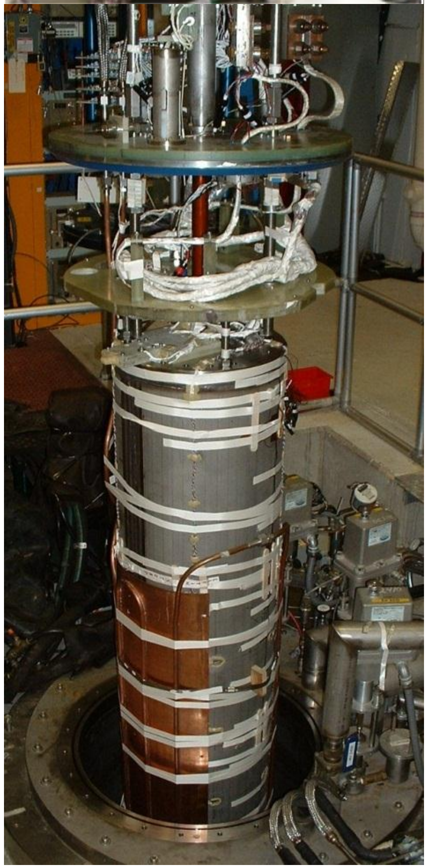


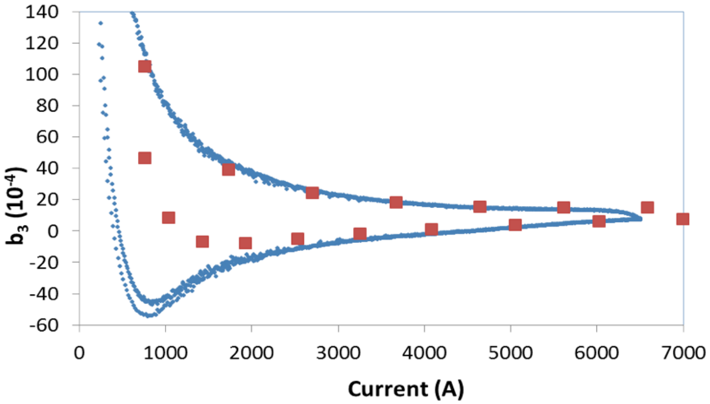
- Twin aperture, collared coils
- R&D in collaboration with Fermi National Laboratory (Chicago, IL)
- Lengths and quantities:
  – LS2: 4 x 2 x 5.5 m magnets (8 magnets + 2 spares)
  – LS3: 16 x 2 x 5.5 m magnets (32 magnets + 3 spares)
  – A total of some 45 magnets to be produced

11 T (MBHSP01) test results at FNAL









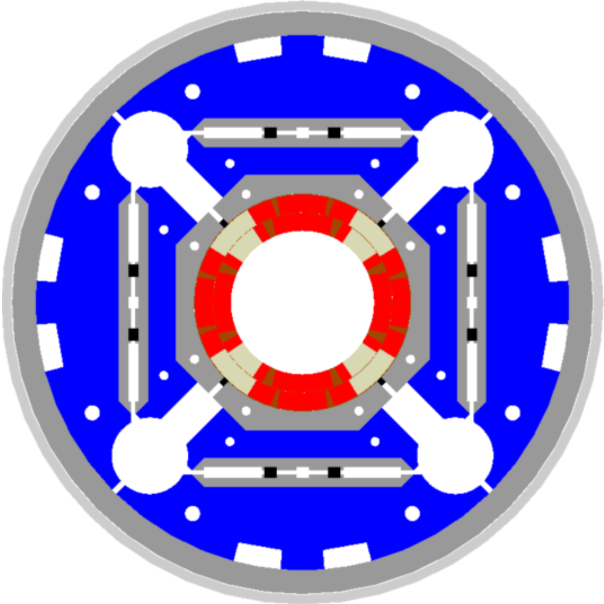
Quench performance short of the 11 T objective.
Some deviations observed between expected and measured field quality

There is work to do

See the talk of M. Karppinen

IR-quadrupoles: MQXF

Material		Nb_3Sn
Aperture	(mm)	150
Gradient	(T/m)	140
Current	(A)	17300
Temperature	(K)	1.9
Peak field	(T)	12.2

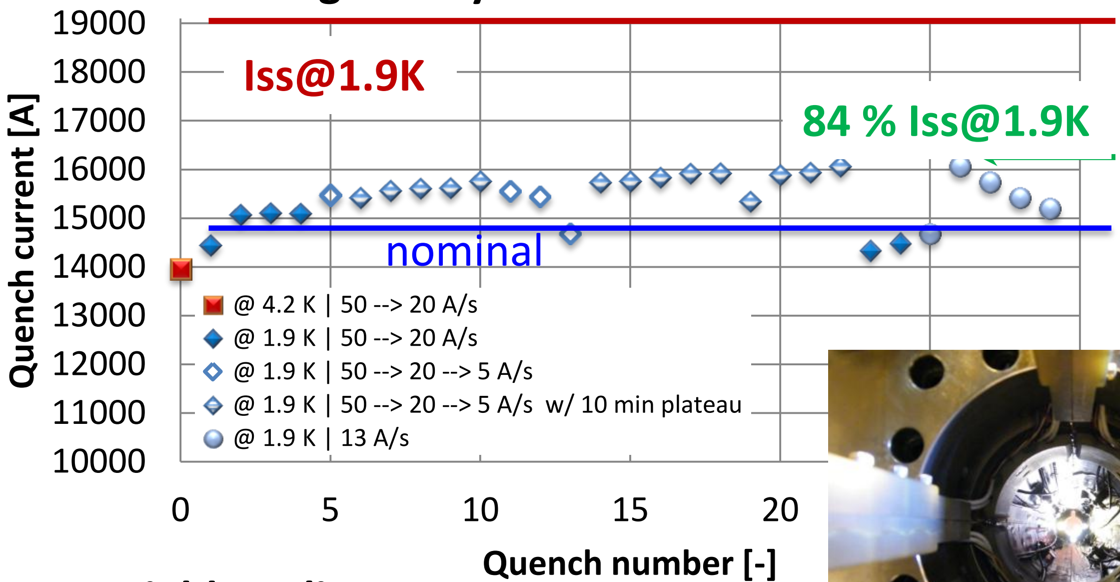


- Bladder-and-key structure
- Common R&D with US to develop model (2014) and prototype (2015)
- Lengths and quantities:
  - Q1/Q3: 2 x 4 m magnets (16 magnets + 2 spares)
  - Q2: 2 x 6.8 m magnets (8 magnets + 2 spares)
  - A total of some 30 magnets to be produced

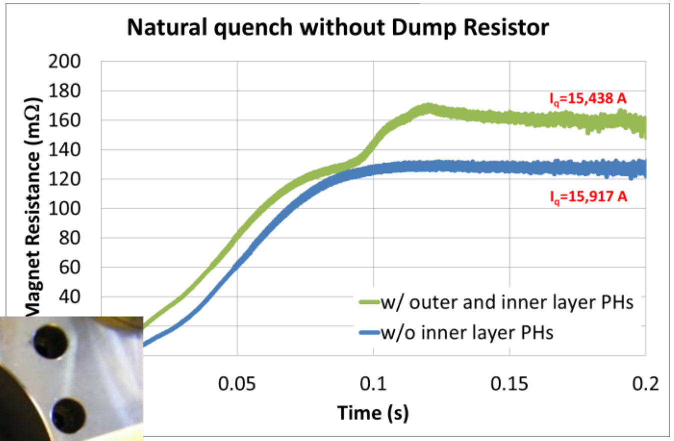
See the talk of G. Kirby

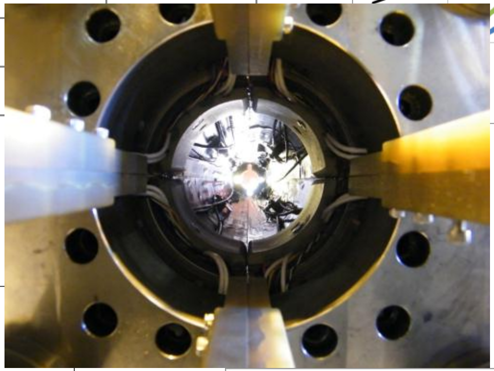
HQ cold test in SM18

Training history



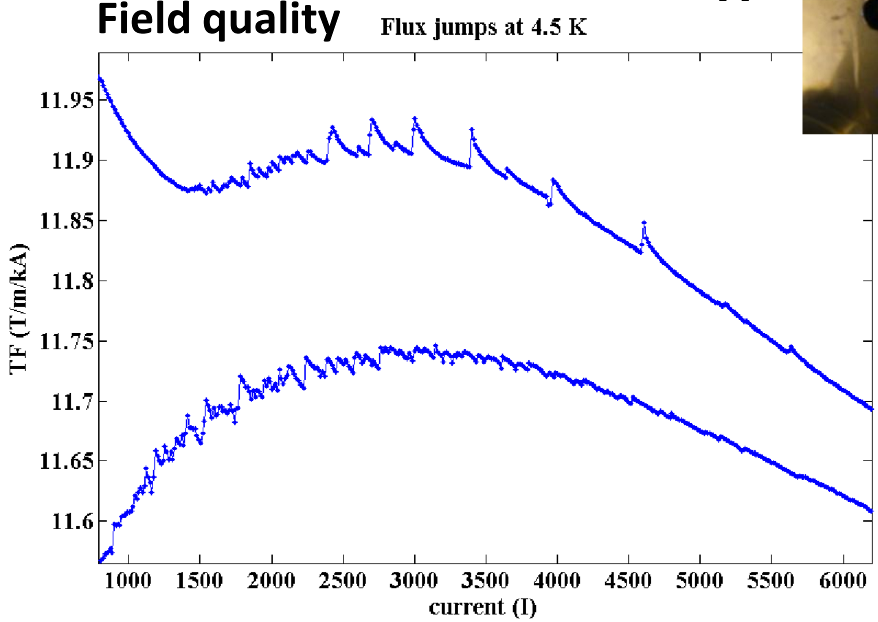
Protection



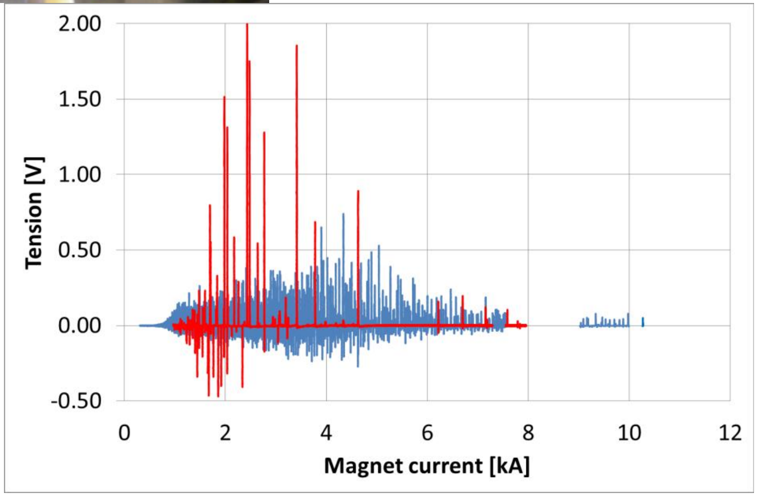


120 mm aperture HQ quadrupole from US-LARP

Field quality

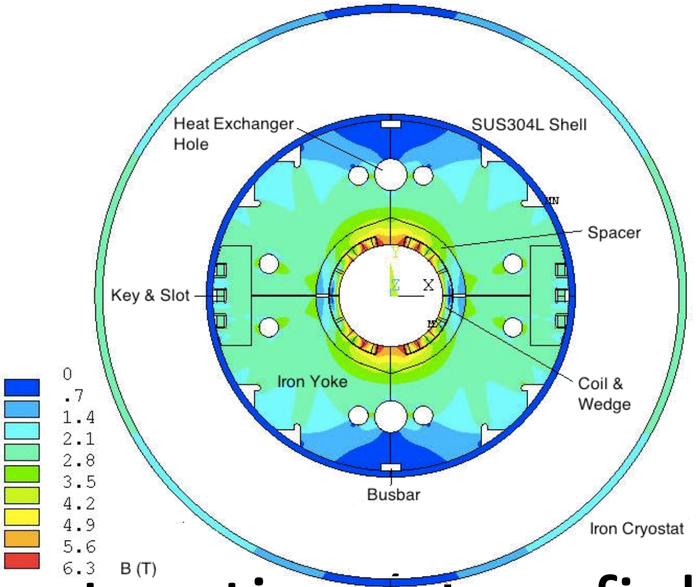


Flux jumps



D1 separation dipole

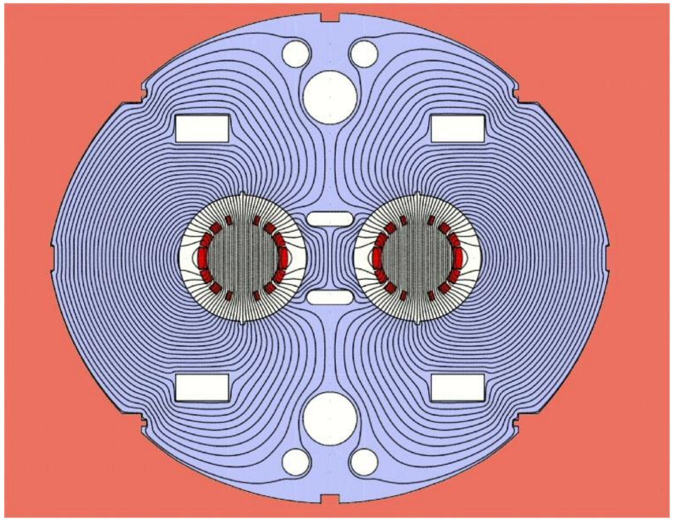
Material		NbTi
Aperture	(mm)	160
Field	(T)	5.2
Current	(A)	11000
Temperature	(K)	1.9
Peak field	(T)	6.1



- Single layer coil, large iron saturation (stray field), large forces on the coil/structure
- R&D in collaboration with Japan (KEK)
- Lengths and quantities:
  - D1: 7.7 m magnets (4 magnets + 2 spares)
  - A total of 6 magnets to be produced

D2 recombination dipole

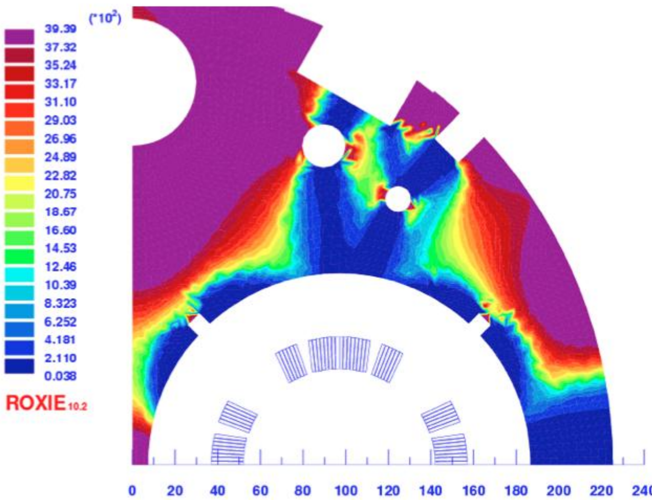
Material		NbTi
Aperture	(mm)	90...100
Field	(T)	o(4)
Current	(A)	
Temperature	(K)	1.9
Peak field	(T)	



- Single layer coil, large iron saturation (stray field), large forces on the coil/structure
- R&D in collaboration with BNL (US)
- Lengths and quantities:
  - D2: o(10) m magnets (4 magnets + 2 spares)
  - A total of 6 magnets to be produced

MS-quadrupoles: Q4

Material		NbTi
Aperture	(mm)	90
Gradient	(T/m)	120
Current	(A)	16188
Temperature	(K)	1.9
Peak field	(T)	5.9



- Single layer coil using LHC-type2 cable (spare)
- R&D in collaboration with CEA-Saclay
- Lengths and quantities:
  - Q4: 4.5 m magnets (4 magnets + spares)
  - A total of 6 magnets to be produced

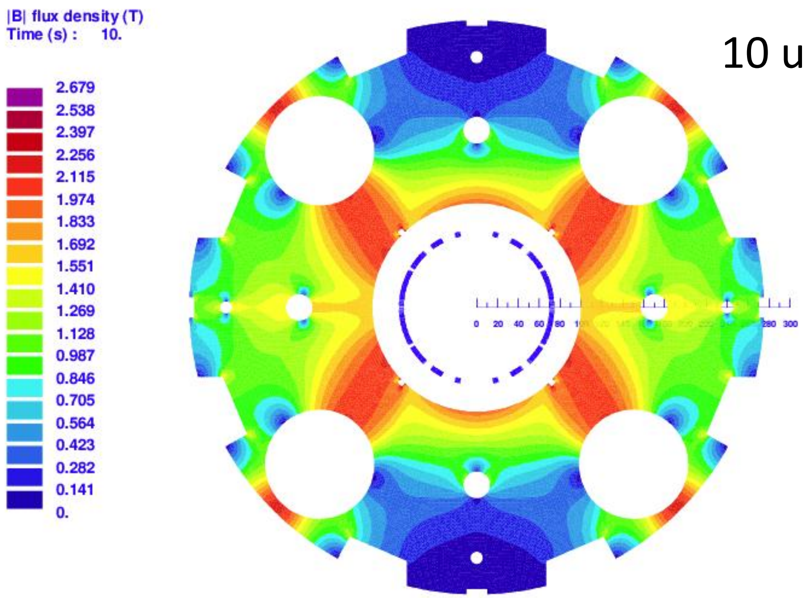
Correctors

- At present, the corrector layout for HL-LHC is not finalized, however …
- … we have a fairly good idea from the existing LHC, and the Phase-I (SHLC-PP) study:

	Current	Integrated strength (field)	Coil Aperture
MCXB (B_1/A_1)	**+/- 2.4 kA**	**1.5 Tm**	**140 mm**
MQXS (A_2)	**+/- 2.4 kA**	**0.55 Tm@40 mm**	**140 mm**
MCXT (B_6)	**+/- 120A**	***0.075 Tm @ 40 mm***	***140 mm***
MCXO (B_4)	**+/- 120A**	***0.035 Tm @ 40 mm***	***140 mm***
MCXSO (A_4)	**+/- 120A**	***0.035 Tm @ 40 mm***	***140 mm***
MCXSS (A_3)	**+/- 120A**	***0.055 Tm @ 40 mm***	***140 mm***
MCXS (B_3)	**+/- 120A**	***0.055 Tm @ 40 mm***	***140 mm***

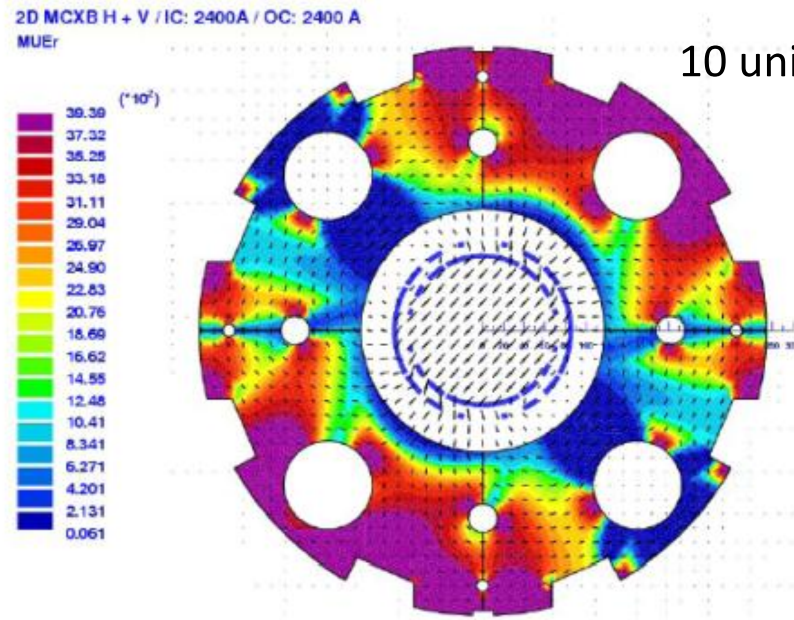
Courtesy of M. Karppinen

A zoo of correctors



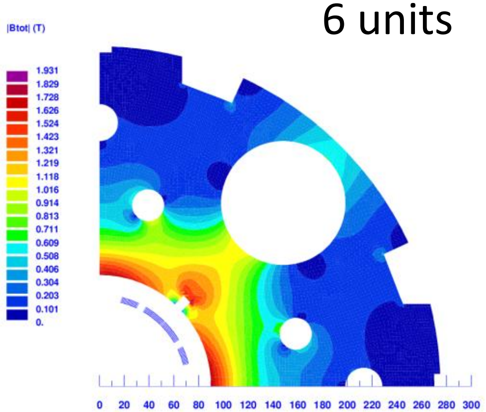
10 units

MCXB (single layer): design and winding trials



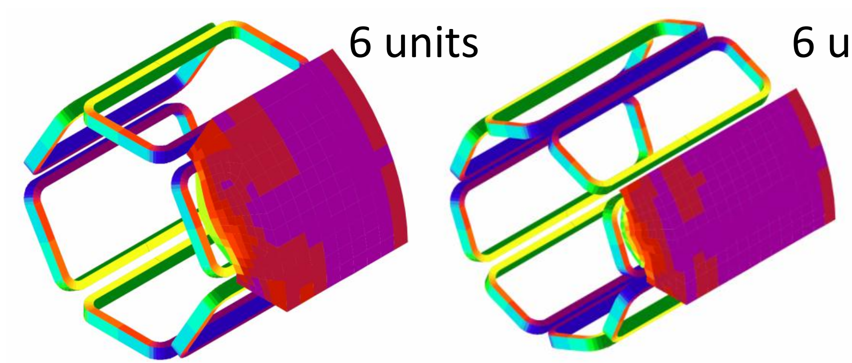
10 units

MCXBH+V (nested): concept



6 units

MQSX (single layer): concept

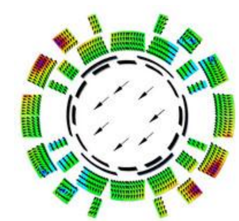


6 units

6 units

MCXS, MCXSS MCXO, MCXSO: prototype (CIEMAT)

6 units



MCBX with nested high-order correctors

MCXT

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An industrial action for HL-LHC

- CERN must have all technologies in hand to insure the long-term exploitation of the LHC (includes tooling)…
- However, CERN does not need to build all components that enter in the LHC !
- At present, US is proposing the largest contribution to the HL-LHC construction (o(250 MCHF))…
- However, a large share is not covered !
- CERN is launching an industrial action to attract EU-industries on-site, to develop Nb_3Sn magnet technology for HL-LHC, and prepare for the magnet construction in the period 2016-2020
- We are convinced that this R&D can have far-reaching consequences on SC magnet technology

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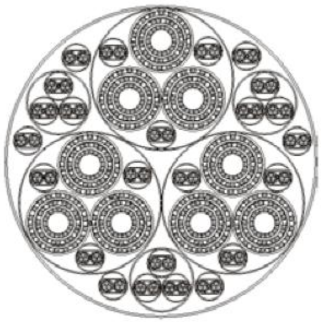
SC links

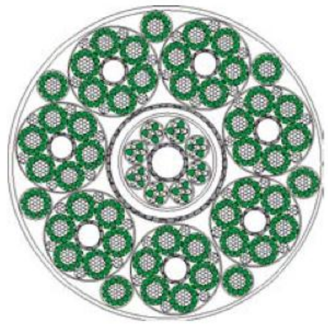
By courtesy of A.Ballarino, CERN

HTS tapes

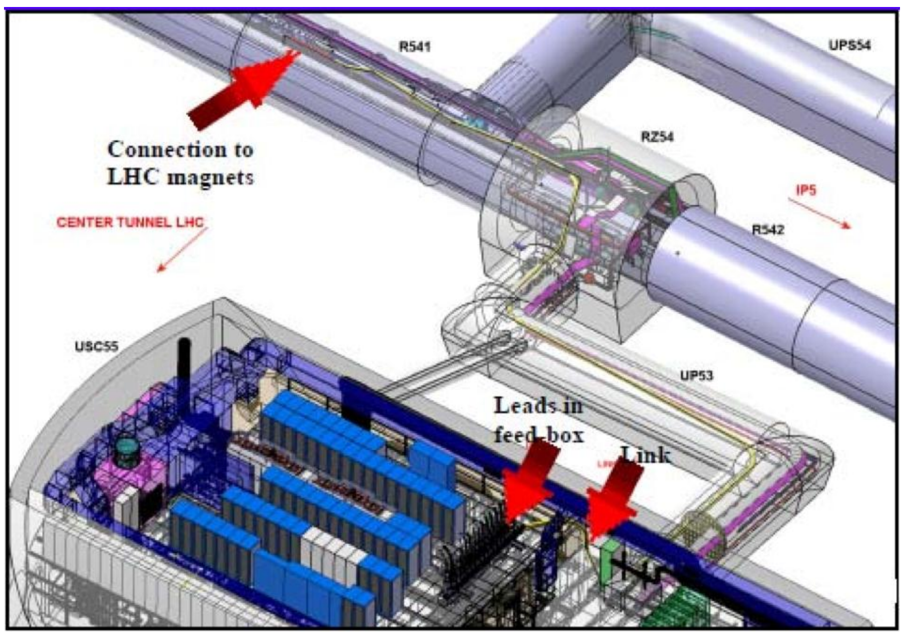


Φ= 75 mm
Itot =190 kA @ 25 K (2 × 95 kA)

Round wires



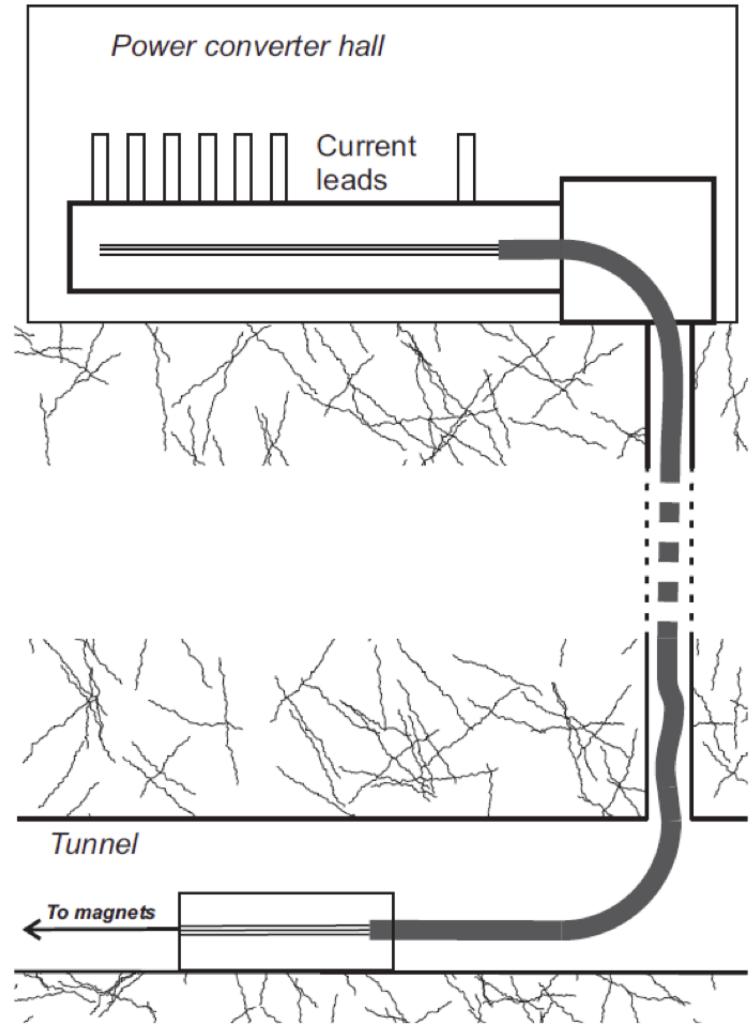
Φ= 60 mm
Itot =100 kA @ 25 K (2 × 50 kA)



Repositioning the converters in the cavern

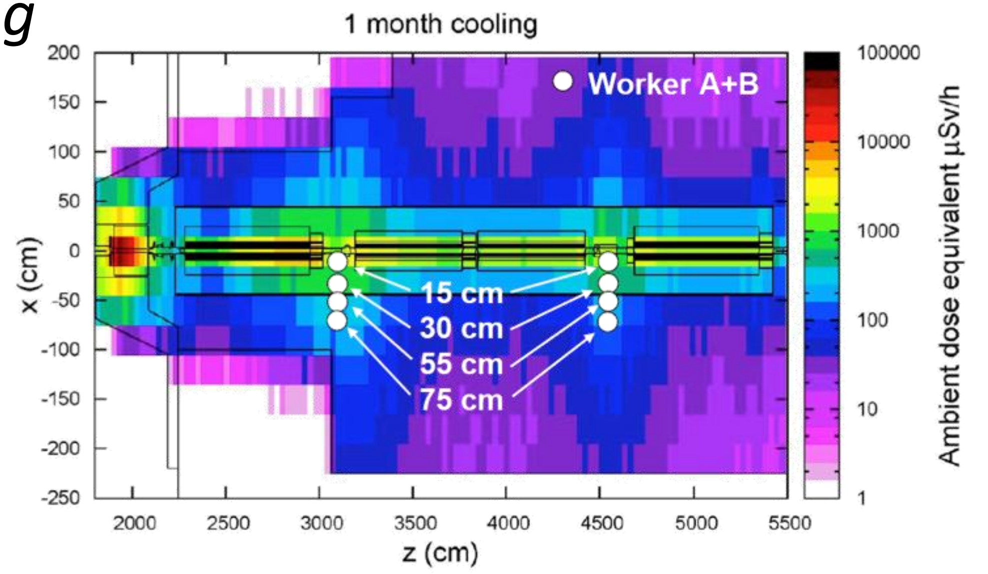
See also the talk of A. Ballarino

Removal of the converters from the cavern



Removal/installation

- The LHC-IR region is crowded, limited access, and will be activated by LS3
- Removal of magnets would result in relatively high dose, unless performed using (closely controlled) remote handling tools
- New magnets will have to survive (10 times) harsher conditions and *remote handling* **should be planned from the start**
  - **Design and manufacturing features**
  - **Associated RH tools and machines**



See also the talk of V. Parma

Other magnet needs

- 15 dipoles and 4 quadrupoles will be exchanged during LS1
- Some 25 magnets to be re-built, a few (10 ?) to be prepared for installation during LS2
- Irradiation dose of magnets next to collimators (MBW, MQW) is of concern – shielding !
- Spare coils, new spare magnets (4+4) to be built for installation during LS2

LHC is a living machine

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Is there a physics beyond the LHC ?

Will the LHC serve the Decepticons to revive Megatron …

Or zap the conscience of Jed de Landa back to Maya time …

Or reveal that the Universe is a sentient being …

Or cause everybody to black-out and see a vision of the future ?

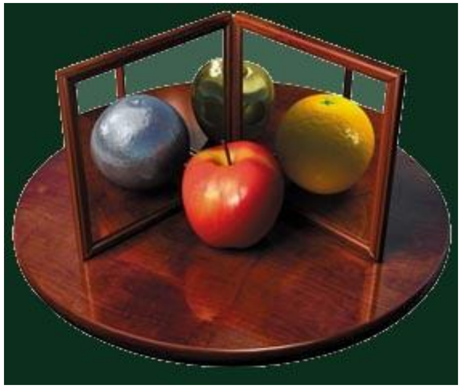
Amazing how much rubbish you can find on the web !!!

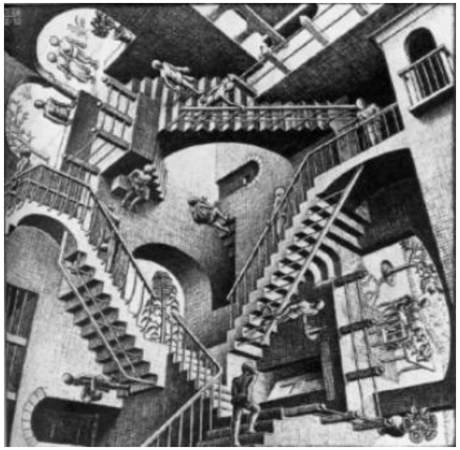
Also on the www: HE-LHC Scope

http://indico.cern.ch/conferenceDisplay.py?confId=97971

- *"[…] a 33 TeV centre-of-mass energy proton–proton accelerator in the LHC tunnel […] and the need for new injectors, possibly with 1 TeV energy".* (The High-Energy Large Hadron Collider, CERN–2011–003, also EuCARD–Conf–2011–001)
- Technicolor, Supersymmetry, Extra dimensions: *"[…] the need to explore the high energy frontier will remain. We will always be able to make that case, today and tomorrow".* (Elements of a Physics Case for a High-Energy LHC, J.D. Wells, pp. 1-5, CERN–2011–003, 2011)
- *"A project on the scale and innovation level of the HE-LHC has a long preparation lead time".* (CERN Accelerator Strategy, S. Myers, pp. 6, CERN–2011–003, 2011)

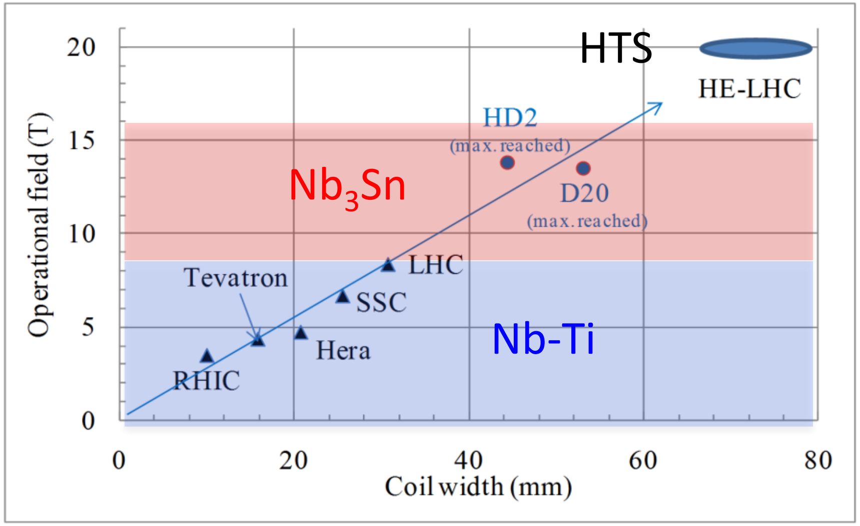
technicolor

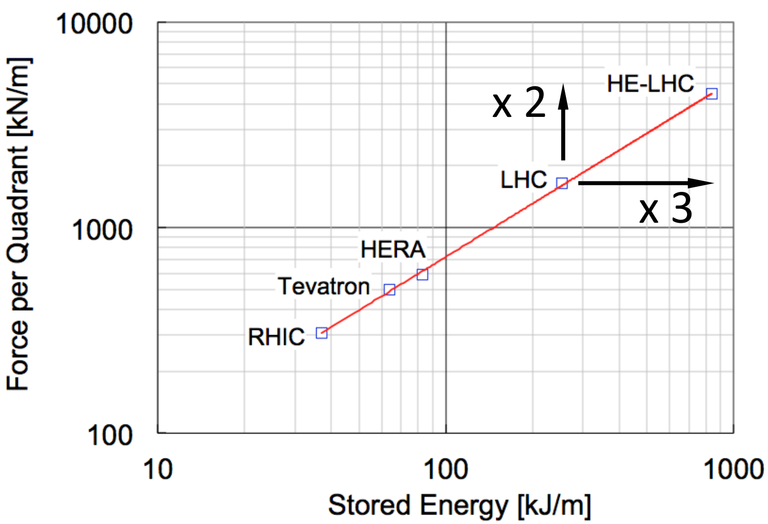


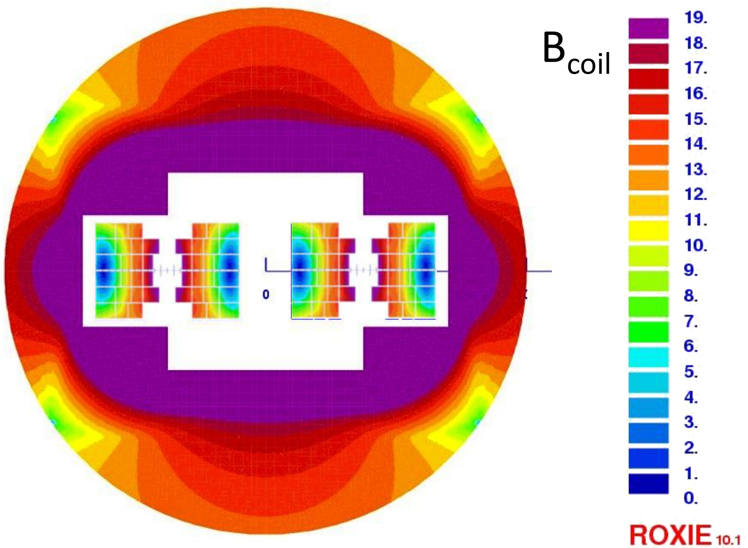


A *really high field* dipole

- Engineering extrapolation is difficult, but does not seem impossible
- May require a *genetic mutation* in the art of SC magnet design an construction



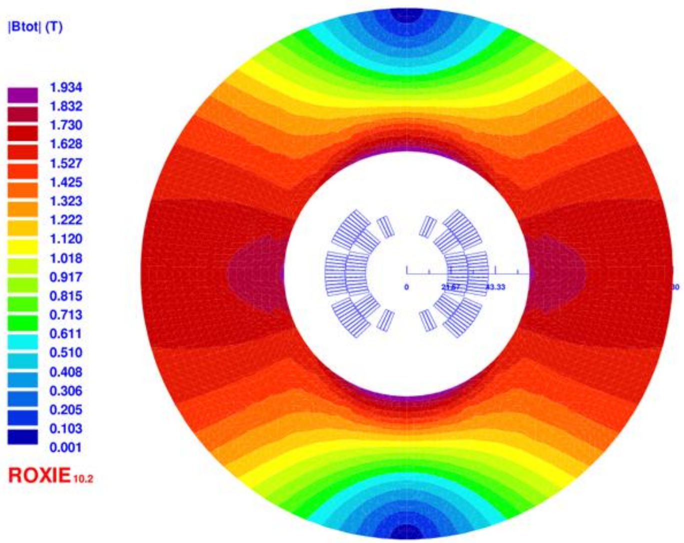


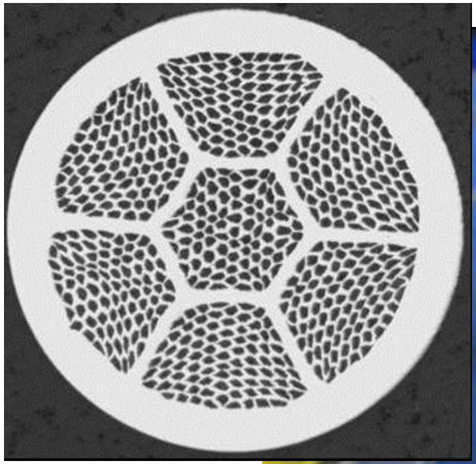


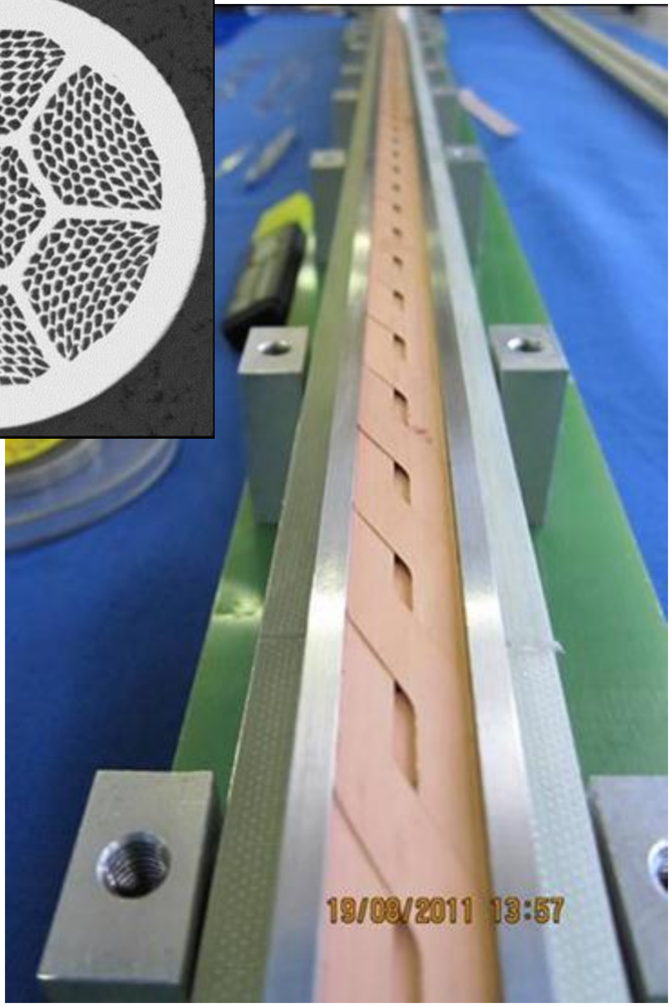
By courtesy of E. Todesco

Program FP7: EuCARD2 - May 2013

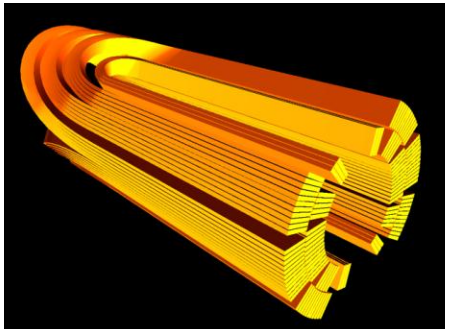
Develop 10 kA class HTS accelerator cable using Bi-2212 and YBCO. Test stability, magnetization, and strain tolerance





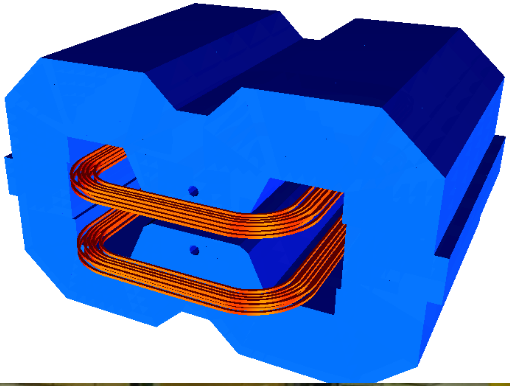


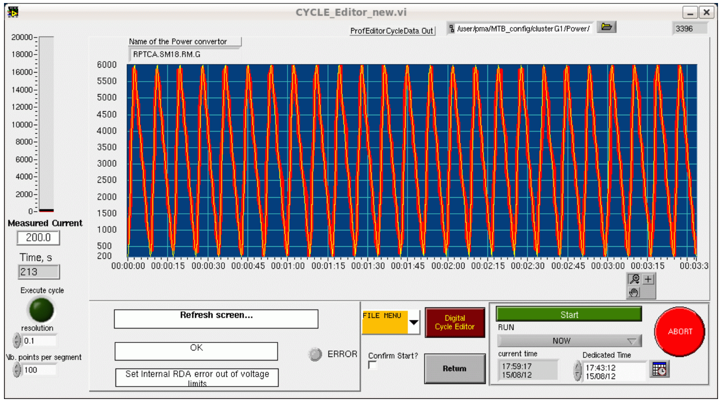
Build a 5 T, 40 mm bore HTS **accelerator quality** dipole as a technology demonstration



Low-field magnets – a new frontier ?

Injection field	(T)	0.14
Injection current	(A)	500
Flat-top field	**(T)**	**1.8**
Flat-top current	(A)	5800
Ramp time	(s)	1.1
Field ramp-rate	**(T/s)**	**1.5**
Good field region	(mm^2)	42 x 30
AC loss	**(W/m)**	**< 2**





New concepts for **improved energy-efficiency** have been tested, with typical parameters range of interest for the CERN injector complex

Summary

- The physics case for an HL-LHC **is strong**: it would be utterly unreasonable to scrap the upgrade of a machine that is producing physics at the frontier of our knowledge
- The magnet challenges are many, they are tough, they are motivating, **and they open a new window onto large scale applications of superconductivity**
- And there is more, beyond magnets for HL-LHC
- This is why we want to make sure **you are on board** in this new adventure !

CERN