CERN, TE seminar
9th October 2014

HL-LHC IR MAGNETS

E. Todesco
CERN, Geneva Switzerland

On behalf of WP3 team (HL-LHC IR magnets), including LARP, KEK, INFN, CIEMAT and CEA collaborations

CONTENTS

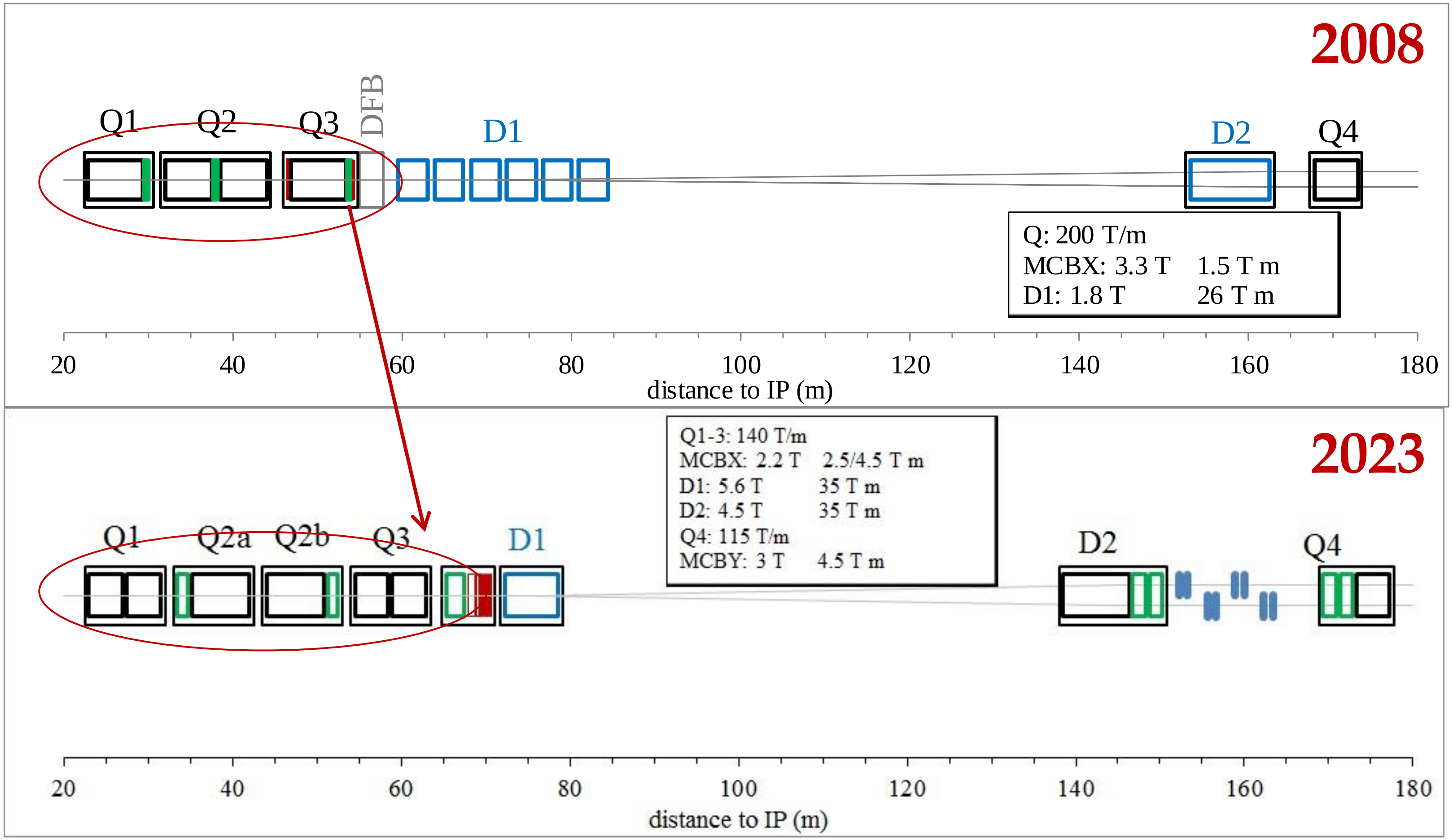
- Project targets and the new IR Layout
- Cooling and radiation
- The magnet zoo

PROJECT TARGETS

- HL-LHC project, to be installed in LS3
  - Target: begin able to get 3000 fb^{-1} of integrated luminosity (10 times more than LHC)
    - Peak luminosity of 5×10^{34} cm^{-2} s^{-1}
- At the time of defining LHC parameters, competition with SSC – luminosity was our asset
  - Energy: SSC 20 TeV LHC 7 TeV
  - Luminosity SSC 10^{33} cm^{-2} s^{-1} LHC 10^{34} cm^{-2} s^{-1}
  - So very ambitious target – increasing it by a factor 5 is challenging !
  - Activity since more than ten years **O. Bruning, et al., "LHC luminosity upgrade: a feasibility study" et al., LHC Project Report 626 (2002).**
  - Design study since 2013 led by L. Rossi, turning into project
- How get more collisions? More intense beams and more focusing in collision
  - Focusing → optics → magnets

LAY OUT: APERTURE INCREASE

- From 70 mm to 150 m aperture in the triplet
  - But only 10 m longer thanks to Nb_3Sn

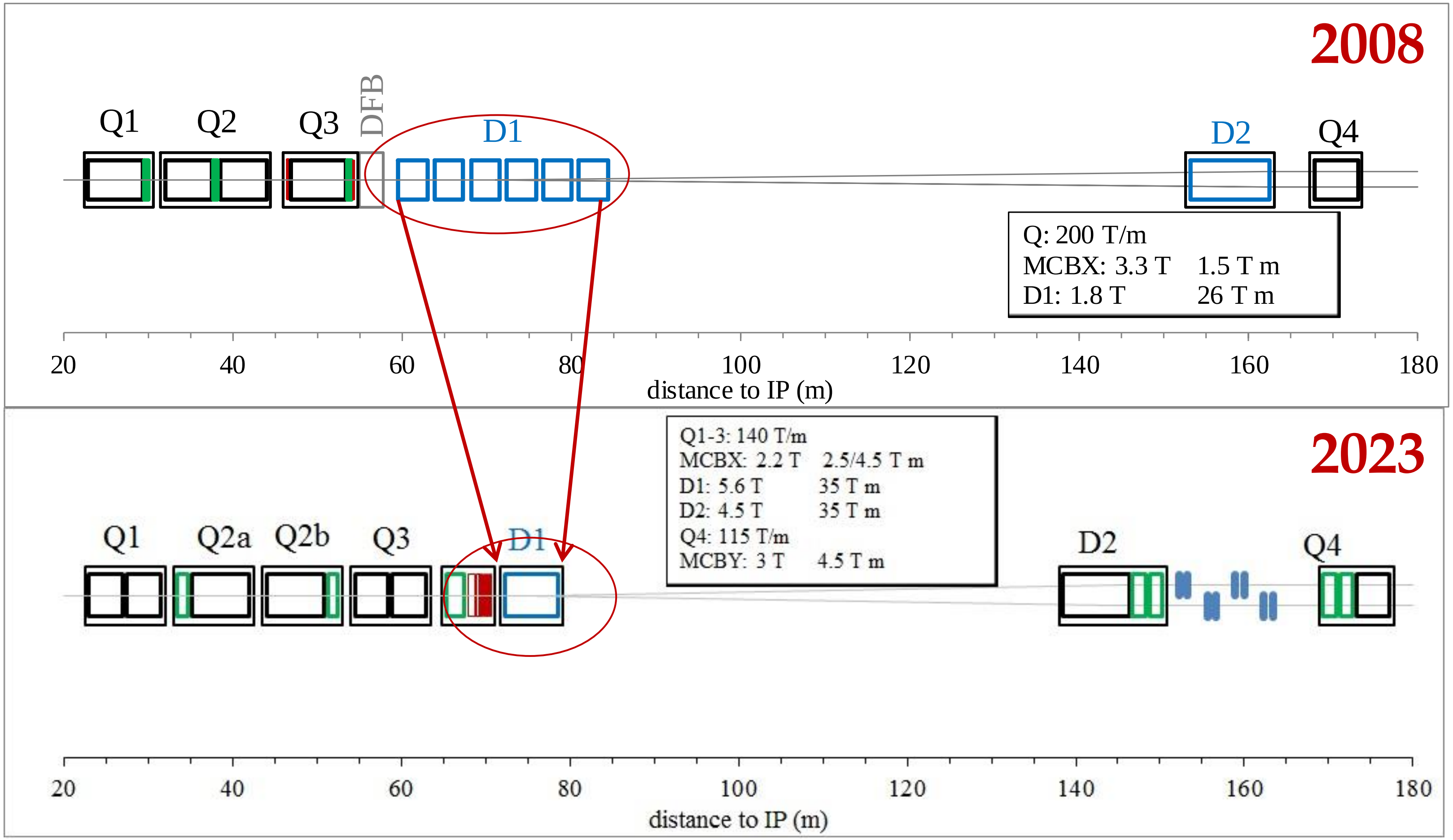


Q: 200 T/m
MCBX: 3.3 T 1.5 T m
D1: 1.8 T 26 T m

Q1-3: 140 T/m
MCBX: 2.2 T 2.5/4.5 T m
D1: 5.6 T 35 T m
D2: 4.5 T 35 T m
Q4: 115 T/m
MCBY: 3 T 4.5 T m

LAY OUT: SC SEPARATION DIPOLE

- Resistive D1 (20-m-long, 1.28 T) replaced by SC
  - 5.6 T operational field, 6.23-m-long: 15 m recovered



2008

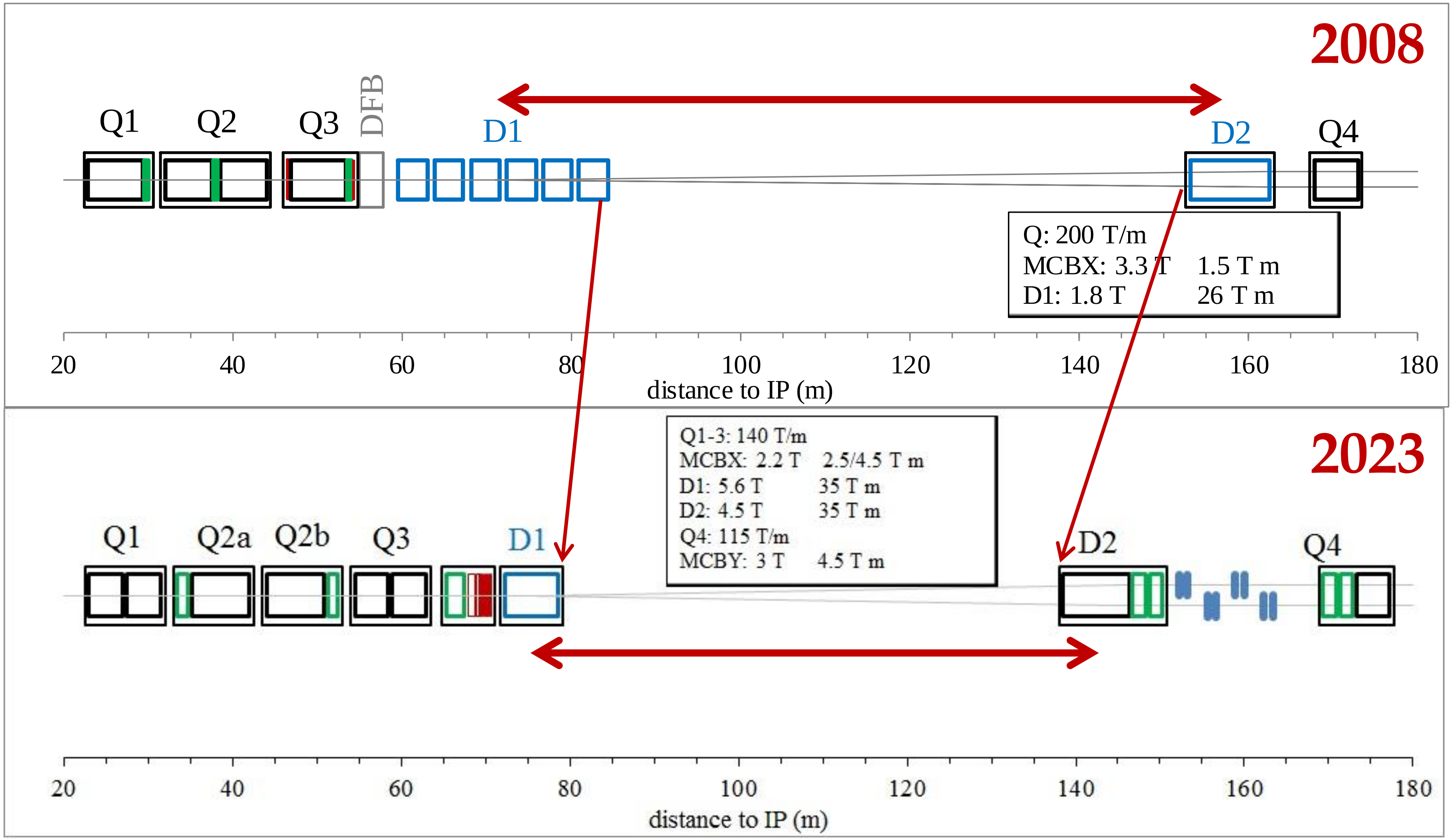
Q: 200 T/m
MCBX: 3.3 T 1.5 T m
D1: 1.8 T 26 T m

2023

Q1-3: 140 T/m
MCBX: 2.2 T 2.5/4.5 T m
D1: 5.6 T 35 T m
D2: 4.5 T 35 T m
Q4: 115 T/m
MCBY: 3 T 4.5 T m

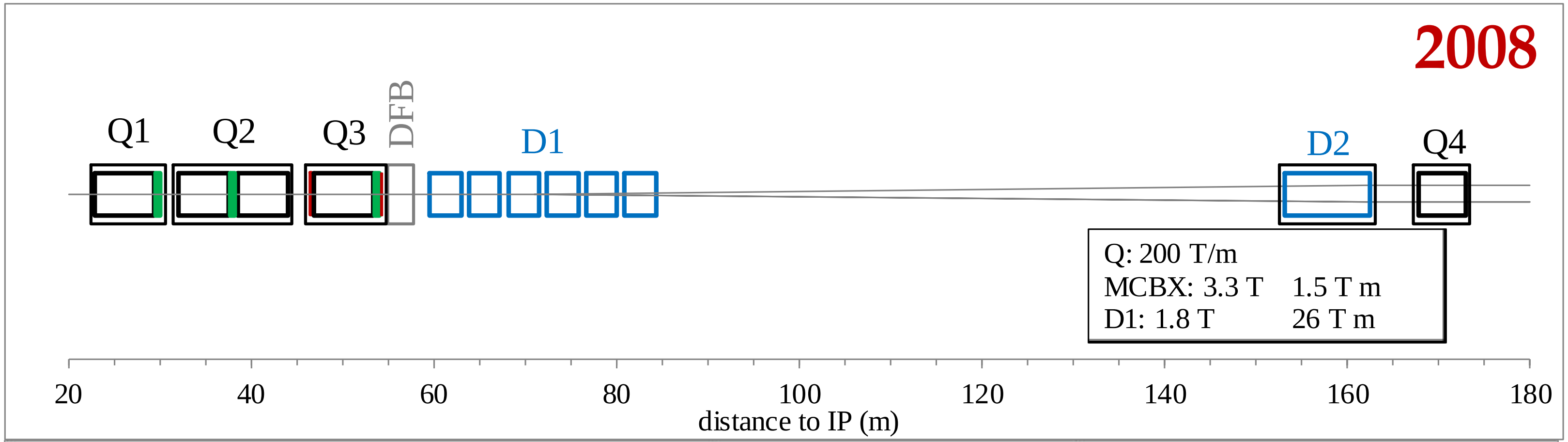
LAY OUT: FASTER SEPARATION

- Strength of D1/D2 increased from 26 T·m to 35 T·m
  - To bring beams at 194 mm only 70 m, it was 90 m in the LHC



LAY OUT: FASTER SEPARATION

- Strength of D1/D2 increased from 26 T·m to 35 T·m
  - This makes room for crab cavities (about 10 m)



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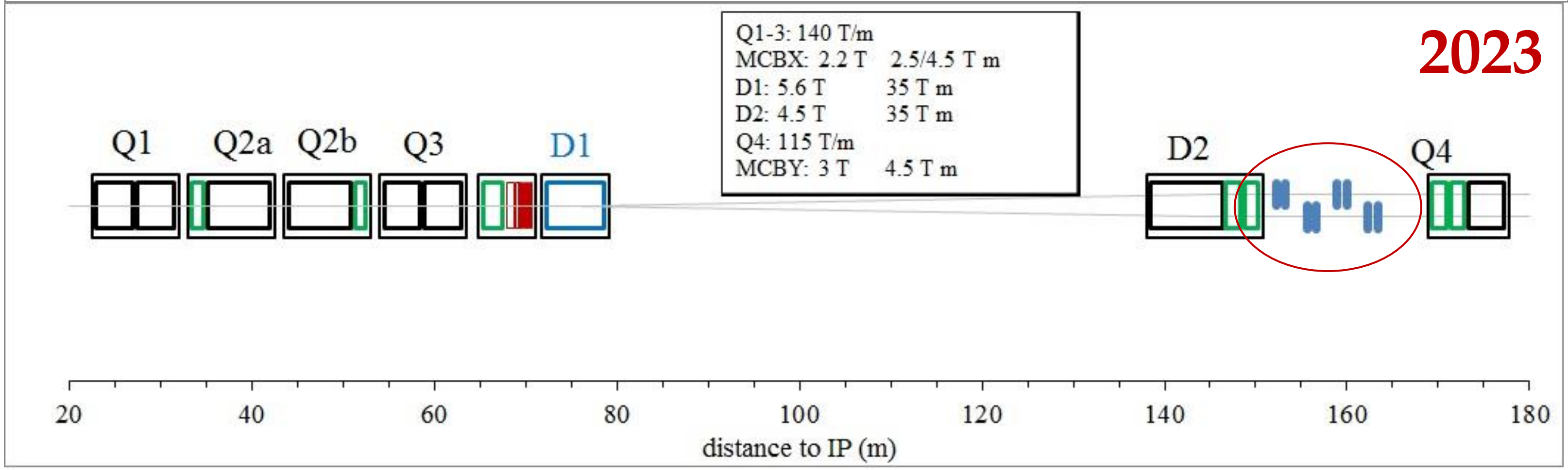

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MCBY: 3 T 4.5 T m

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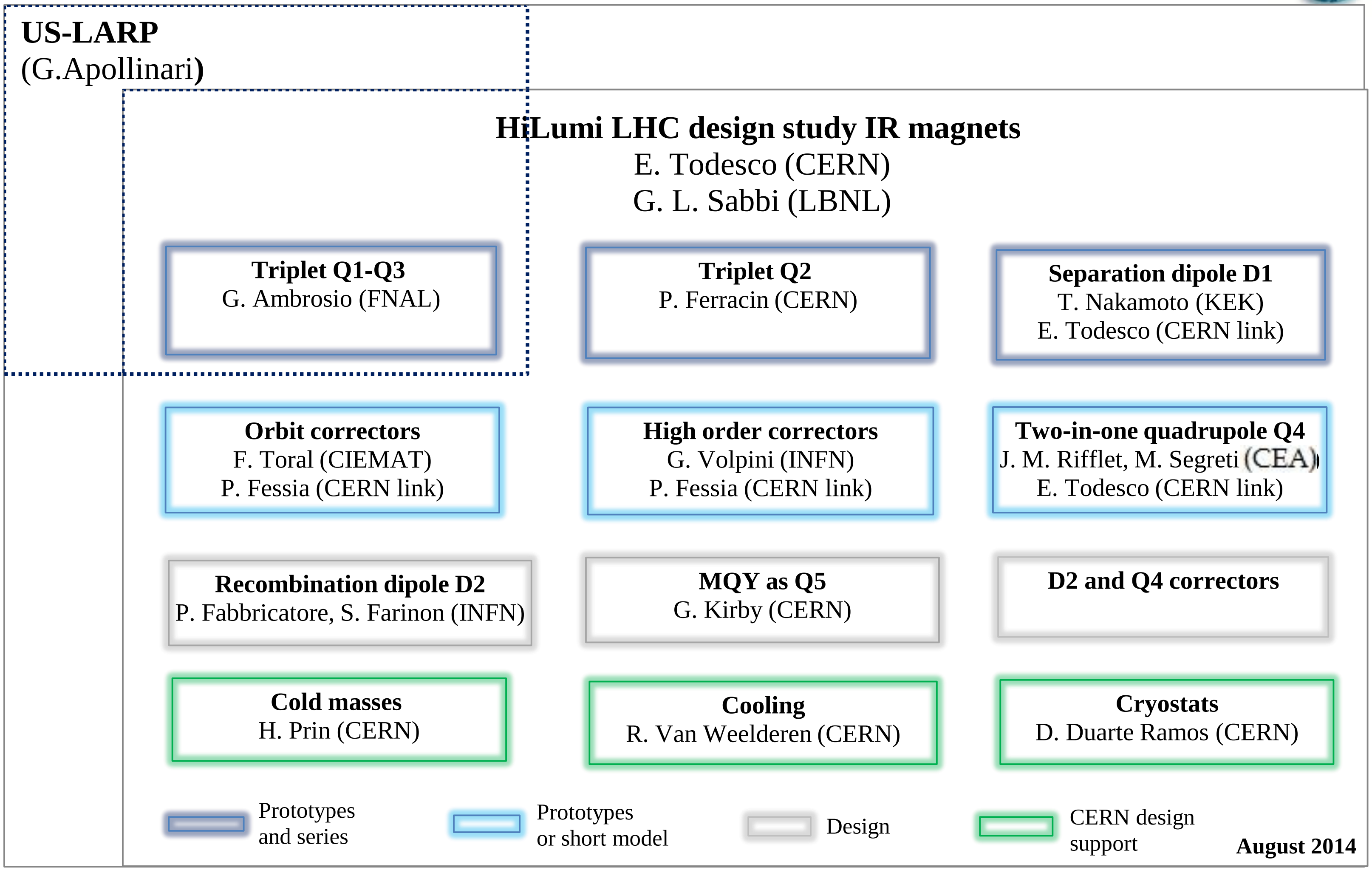
THE IR REGION MAGNET ZOO

- 92 magnets of 13 different types plus spares
  - 11 different cross-sections
  - Lengths between 0.1 m (correctors) to 7-8 m (D2, triplet)
  - Total of ~240 m of magnets (60 per IP side)
- Technologies
  - Nb_3Sn (triplet)
  - Nb-Ti (with nested option for orbit correctors)
  - Superferric (correctors)
- 5 collaborations
  - US Larp (half of the triplet)
  - KEK (separation dipole D1)
  - Ciemat (orbit correctors prototypes)
  - INFN (high order correctors prototypes and D2 design)
  - CEA (Q4 short model)

PRESENT STRUCTURE



US-LARP
(G.Apollinari**)**

HiLumi LHC design study IR magnets
E. Todesco (CERN)
G. L. Sabbi (LBNL)

Triplet Q1-Q3
G. Ambrosio (FNAL)

Triplet Q2
P. Ferracin (CERN)

Separation dipole D1
T. Nakamoto (KEK)
E. Todesco (CERN link)

Orbit correctors
F. Toral (CIEMAT)
P. Fessia (CERN link)

High order correctors
G. Volpini (INFN)
P. Fessia (CERN link)

Two-in-one quadrupole Q4
J. M. Rifflet, M. Segreti (CEA)
E. Todesco (CERN link)

Recombination dipole D2
P. Fabbricatore, S. Farinon (INFN)

MQY as Q5
G. Kirby (CERN)

D2 and Q4 correctors

Cold masses
H. Prin (CERN)

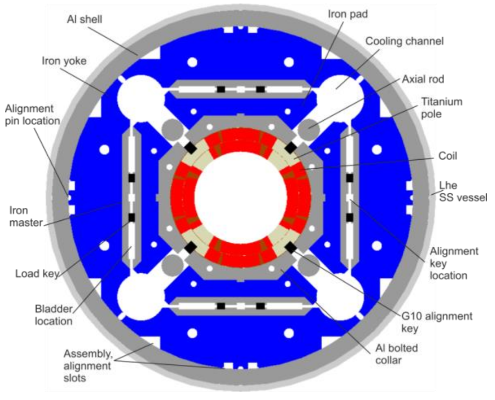
Cooling
R. Van Weelderen (CERN)

Cryostats
D. Duarte Ramos (CERN)

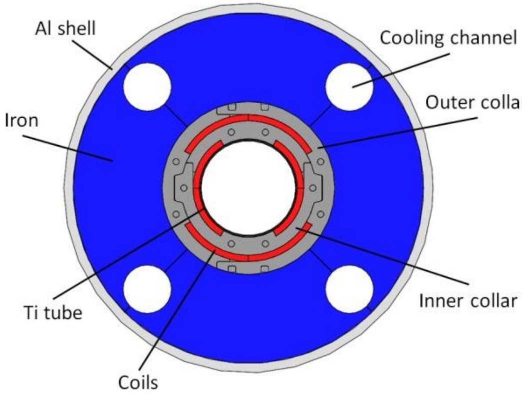
🟦 Prototypes and series
🟦 Prototypes or short model
⬜ Design
🟩 CERN design support

August 2014

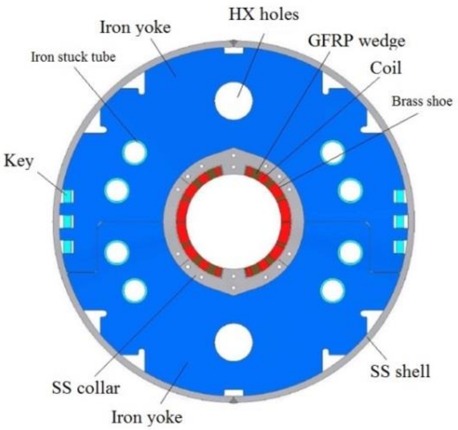
THE IR REGION MAGNET ZOO



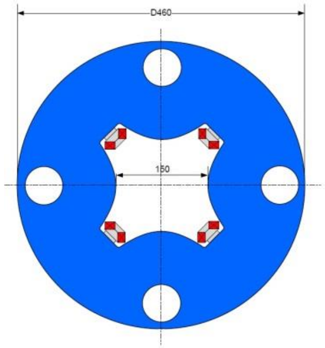
Triplet QXF (LARP and CERN)



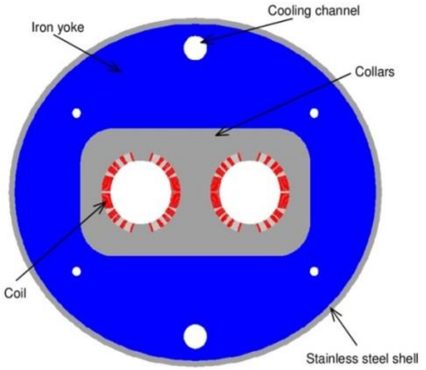
Orbit corrector (CIEMAT)



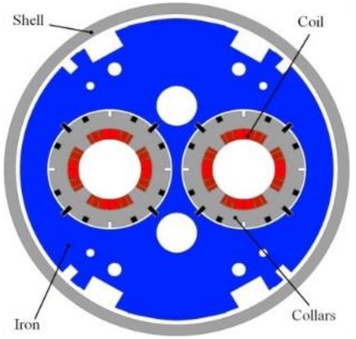
Separation dipole D1 (KEK)



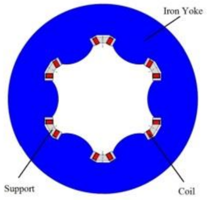
Skew corrector (INFN)



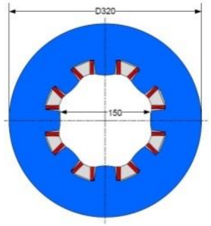
Recombination dipole D2
(INFN design)



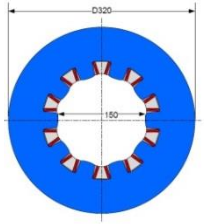
Q4 (CEA)



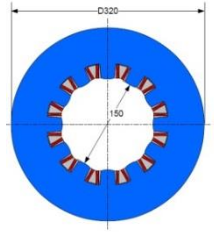
Corrector sextupole (INFN)



Corrector octupole (INFN)



Corrector decapole (INFN)



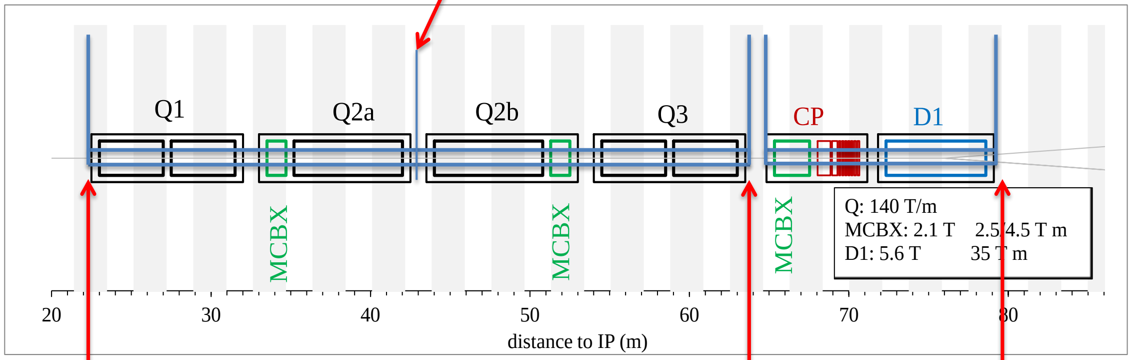
Corrector dodecapole (INFN)

Cross-sections in scale

COOLING AND RADIATION

- Large heat load from collision debris
  - On triplet-correctors-D1, we will have ~600 W on cold mass [L. Esposito, F. Cerutti, IPAC 2014]
  - Ability required to remove 50% more, so about 1 kW
    - Split system with 2 heat exchangers [R. V. Weelderen, G. Bozza, H. Allain]

Additional low pressure pumping



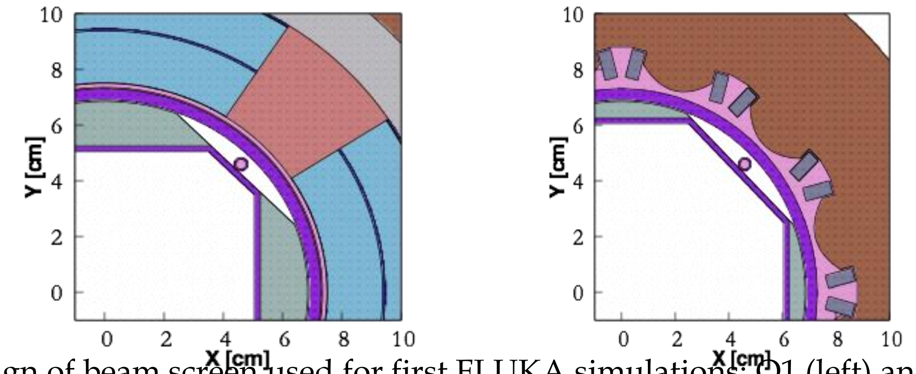
- Phase-separator &
- Piping entries/exits

- Phase-separator &
- Piping entries/exits
- QRL-jumper

- SM &
- QRL-jumper
- Phase-separator
- Piping entries/exits

COOLING AND RADIATION

- A good fraction of the heat load from collision debris intercepted by the beam screen (tungsten inserts)
  - They allow to keep radiation dose below 20-30 MGy
  - On triplet-correctors-D1, we will have ~500 W on the beam screen [L. Esposito, F. Cerutti, IPAC 2014]
  - Ability required to remove 50% more, plus electron could budget, so also in this case towards 1 kW
    - Removal at 40-60 K, four cooling tubes [R. V. Weelderen, G. Bozza, H. Allain]
    - Beam screen is a critical object (cooling, assembly, manufacturing), prototype needed for 2015 [C. Garion , V. Baglin, R. Kersevan]



Conceptual design of beam screen used for first FLUKA simulations: Q1 (left) and corrector (right)

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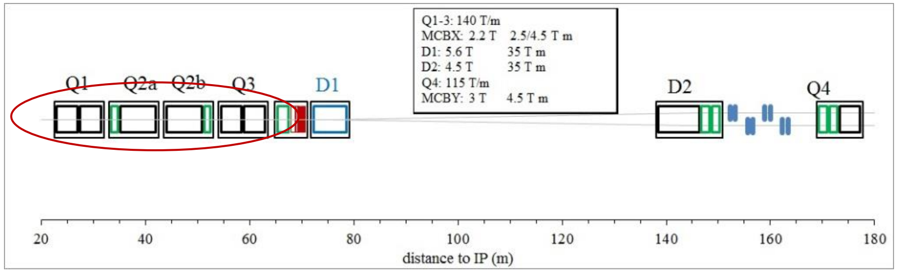
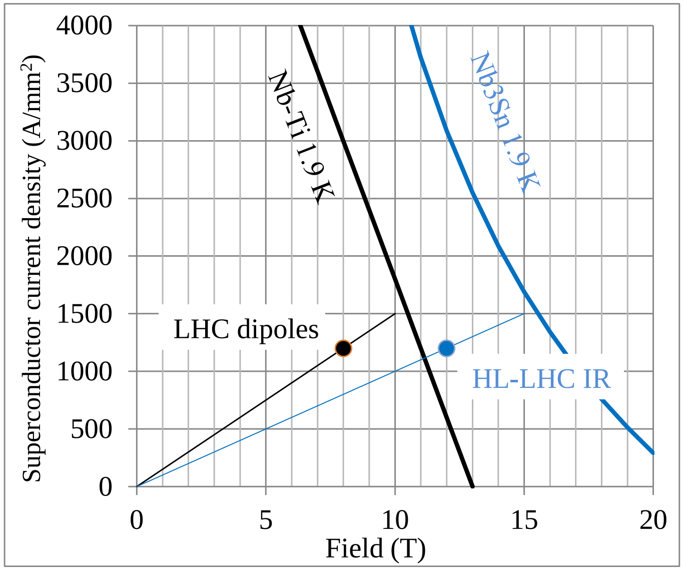
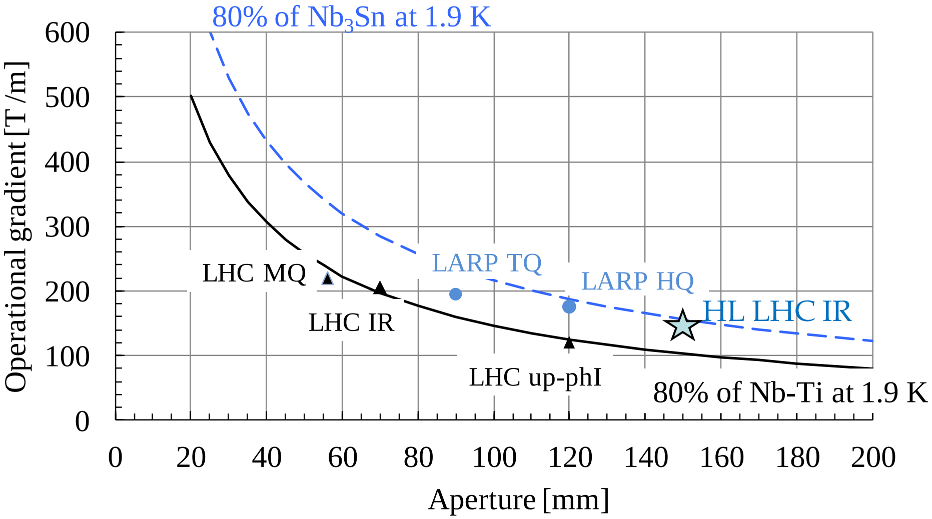
TRIPLET



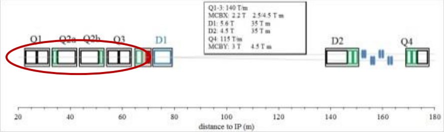
- Nb_3Sn, 150 mm aperture, 140 T/m, 6.8/8.0 m long
  - Nb_3Sn provides ~50% more gradient for the same aperture
  - Similar current density, 50% larger field



Loadline for LHC dipole and HL LHC triplet

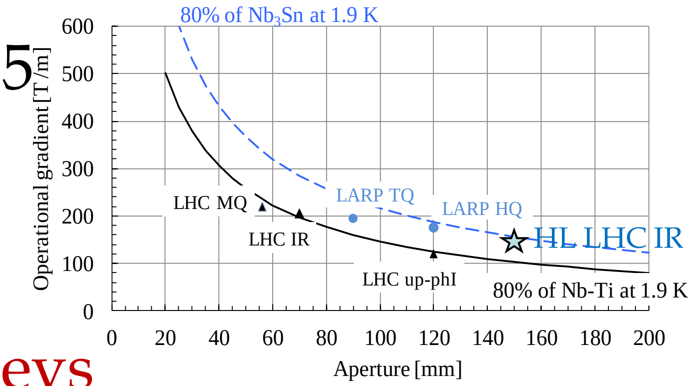


Gradient versus aperture for Nb-Ti and Nb_3Sn

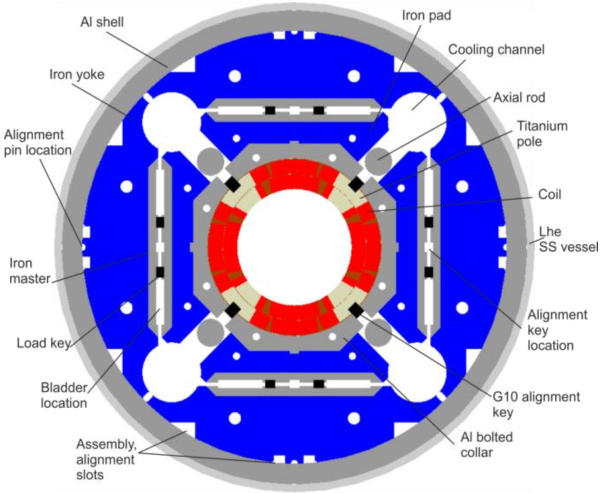


TRIPLET

- LARP works on inner triplet since 2005
    - TQ quadrupoles (90 mm aperture)
    - HQ quadrupoles (120 mm aperture)
    - First long coils (LQ, 3.4-m-long)

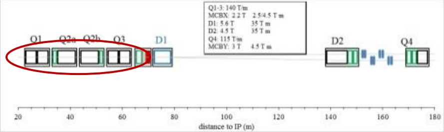


- Structure: Al shell and bladders and keys
    - Prima in accelerators for material and structure
        - ~70 MPa during assembly, ~150 MPa thanks to Al shrinkage
        - Very effective way to control stress
- Fine tuning of field quality
    - Magnetic shimming

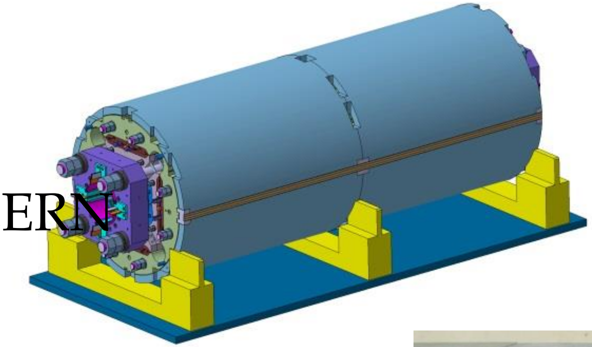


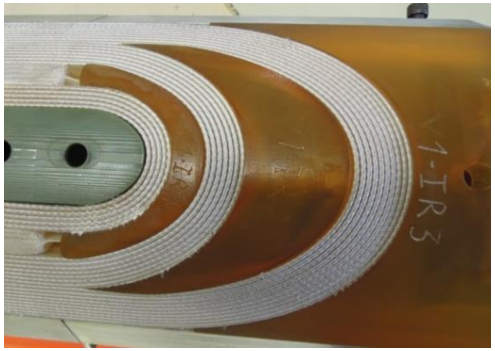
QXF cross-section [G. Ambrosio, P. Ferracin et al. ASC 2014]

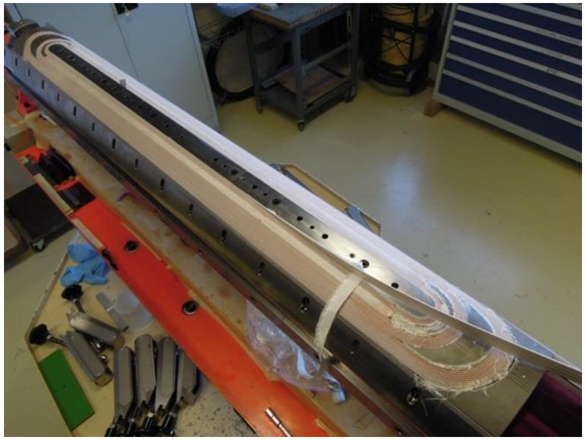
TRIPLET: STATUS



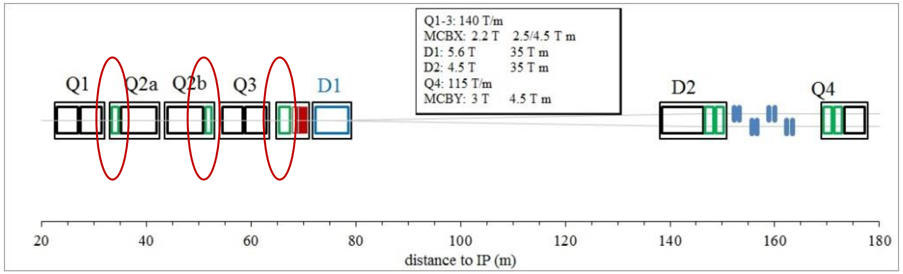
  - Winding tests, first coils
- Tentative milestones
  - March 2015: first short coil at CERN
  - 2015: test short quad in US (also with CERN coils)
  - 2016: first long tested (US)





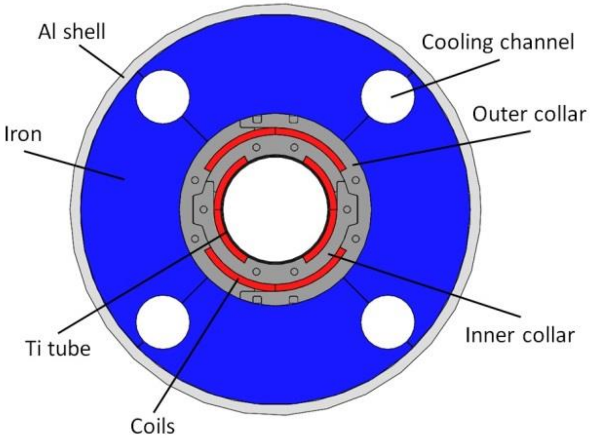


ORBIT CORRECTORS



- Space is performance, so we go for a nested solution with low field

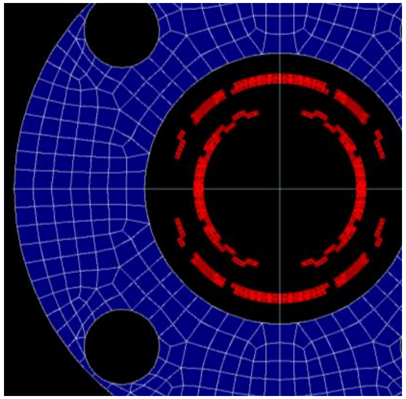
- Nb-Ti, nested 150 mm aperture, 2.1 T
  - MCBXB: 4.5 T · m, 2.1–m-long MCBXA: 2.5 T · m, 1.2–m-long
  - Going to 3 T would give 4 times larger forces to gain 1 m
- Design by CIEMAT collaboration
  - Also making a 1.2-m-long magnet
- Structure under study: nested collars plus internal support (a prima)
  - Since they are HV, forces push coil inward

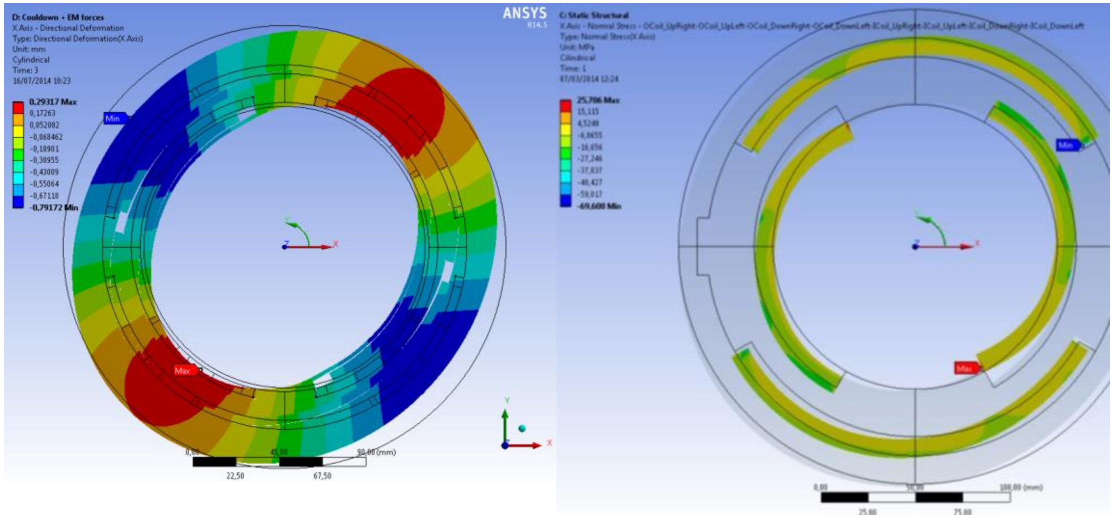


Tentative cross-section [J. Garcia, F. Toral, J. Munilla, P. Fessia]

ORBIT CORRECTORS: STATUS

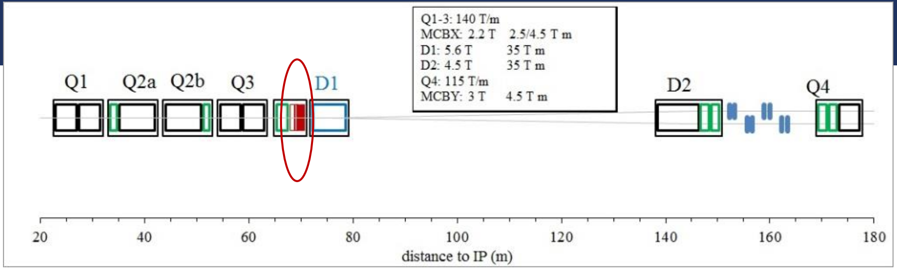
- 2014: first cross-section, mechanical model
- Tentative milestones
  - 2015: engineering design
  - Early 2016: first winding
  - End 2016: test of 1.2-m-long corrector
- Options
  - Type of internal support
  - Two layers
  - Alternative designs



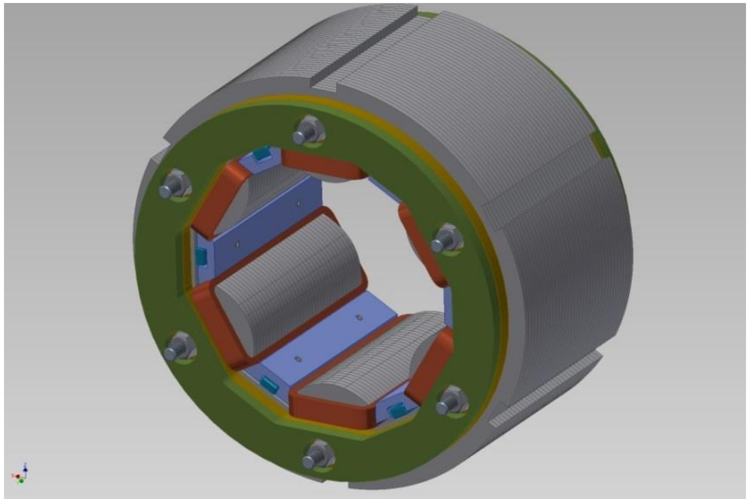


A mechanical model [J. Garcia, F. Toral, J. Munilla, P. Fessia]

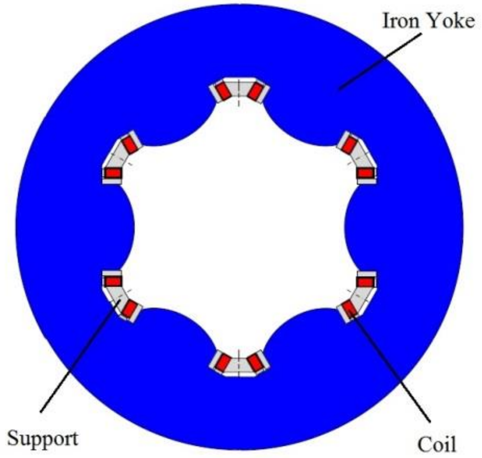
HIGH ORDER CORRECTORS



- Superferric, 150 mm aperture, pole field ~2.5 T
  - Design studied for S-LHC [F. Toral, et al, MT-22]
  - Short heads, non nested (easier operation), low current (200 A)
  - 5 types of magnets (quad sex oct dec dode)
- INFN-Milano providing 5 prototypes



3d view of the sextupole corrector [G. Volpini]



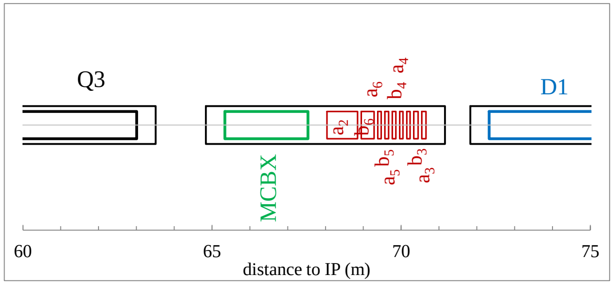
Sextupole corrector [G. Volpini]

NONLINEAR CORRECTORS

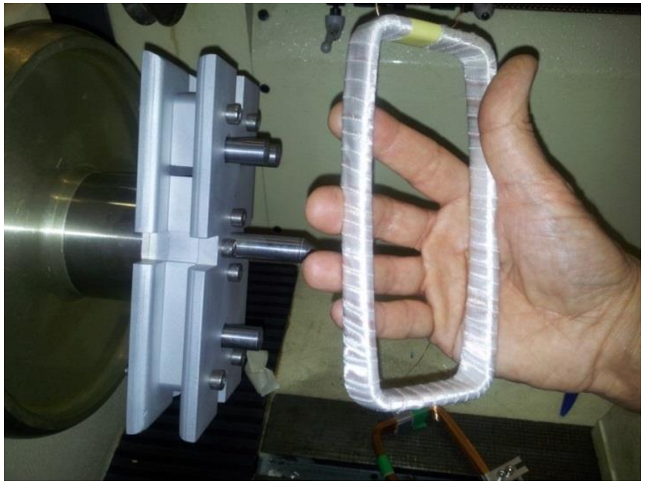
- 2014: cable ordered
- June 2014: dummy coil winding, insulation and impregnation tests
  - Some issues in insulation being addressed
  - Simulations to check cross-talk in progress

- Tentative milestones
  - 2015: sextupole test
  - 2016: octupole and decapole test
  - 2017: dodecapole and quad test

  [G. Volpini, et al., ASC conference 2014]

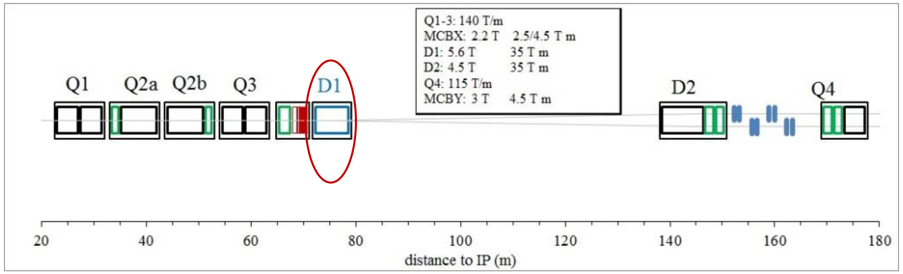


Detail of corrector lay-out

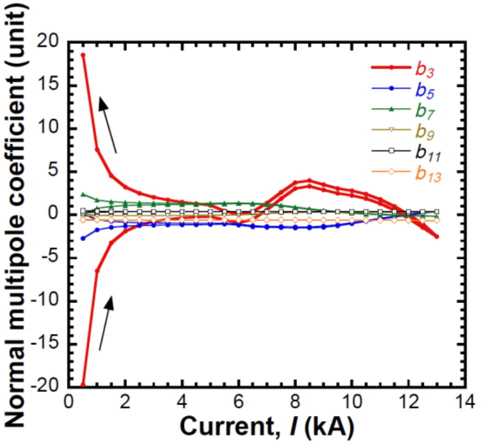


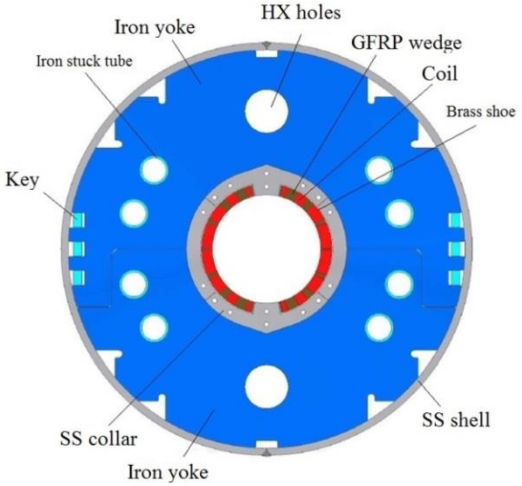
Coil wound in LASA [G. Volpini et al.]

SEPARATION DIPOLE



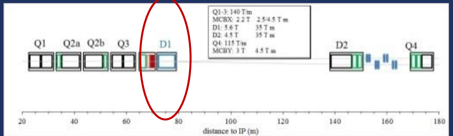
- Nb-Ti, 150 mm aperture, 5.6 T, 6.27-m-long
- KEK makes design and short model [T. Nakamoto, M. Sugano, Q. Xu, ASC conference 2014]
- Structure: iron and shell keeping forces (as MQXA)
  - Challenge: large aperture, field quality large saturation
  - Iron shaping



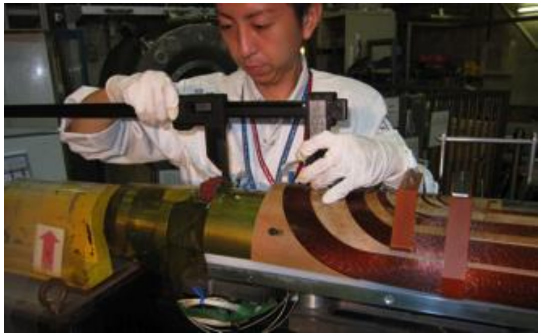


D1 cross-section [T. Nakamoto, Q.Xu, M. Sugano]

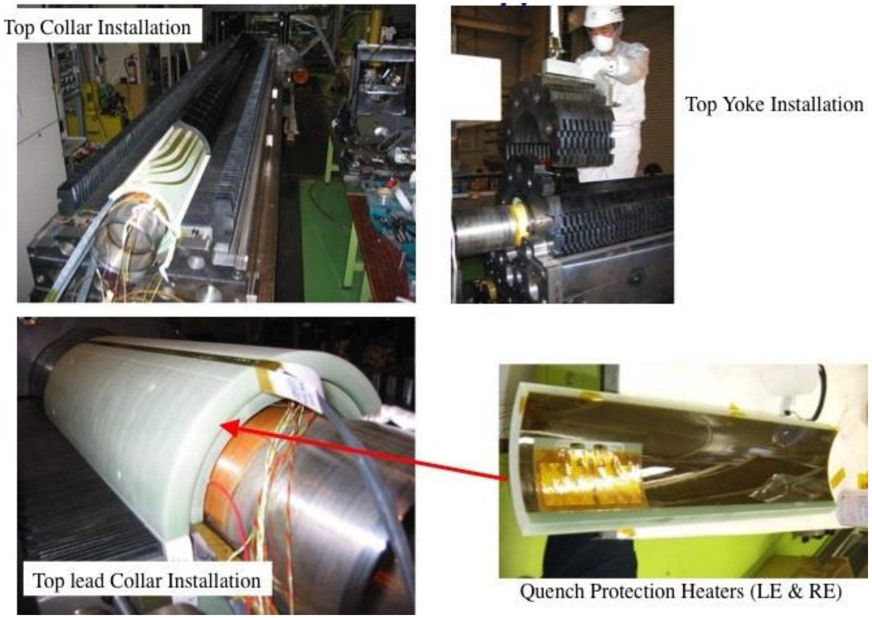
SEPARATION DIPOLE



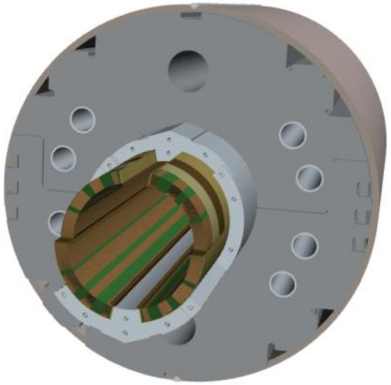
  - January 2013: engineering design
  - May 2014: first winding tests (iteration on heads)
  - October 2014: first coil cured
- Milestones
  - Early 2015: first short coil
  - Summer 2015: short model test



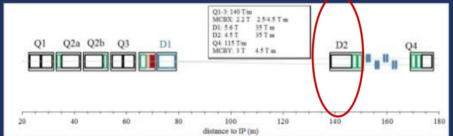
D1 winding at KEK



Yoking test

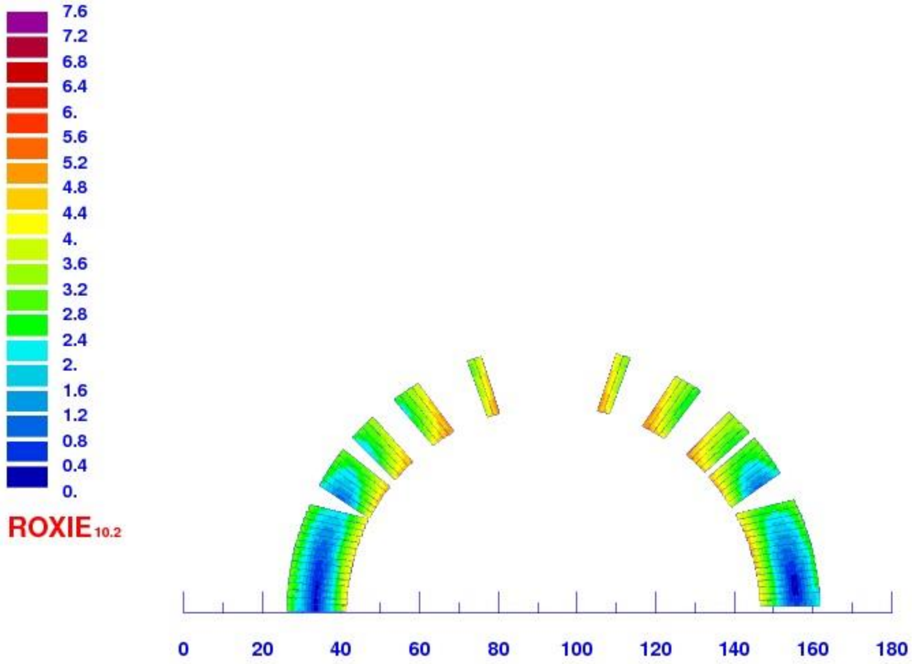


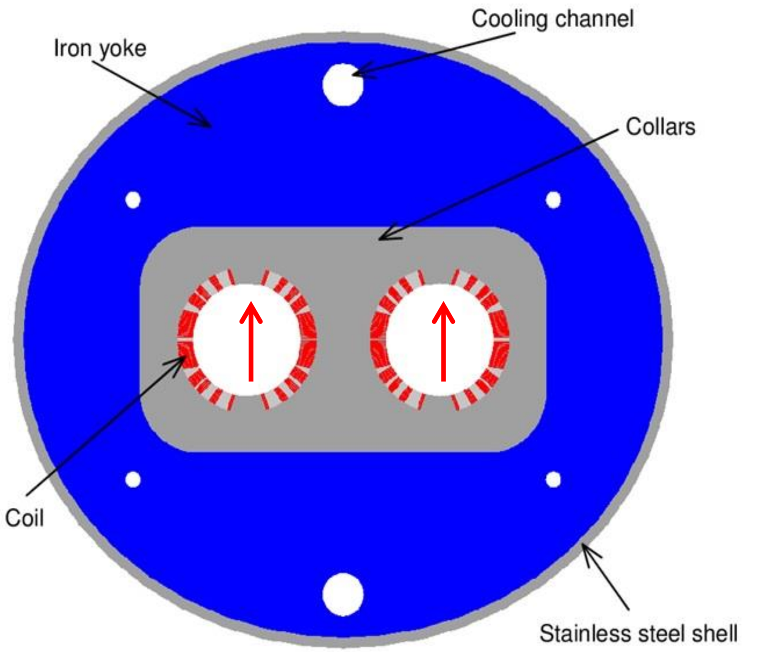
CAD model



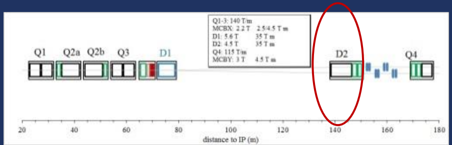
RECOMBINATION DIPOLE

- Nb-Ti, 105 mm aperture, 4.5 T, 7.8-m-long
- The structure under analysis is self standing collars
  - Challenge: field quality, large cross talk
  - Novel design with left/right asymmetric coil [G. L. Sabbi, X. Wang]
- INFN-Genova studying design



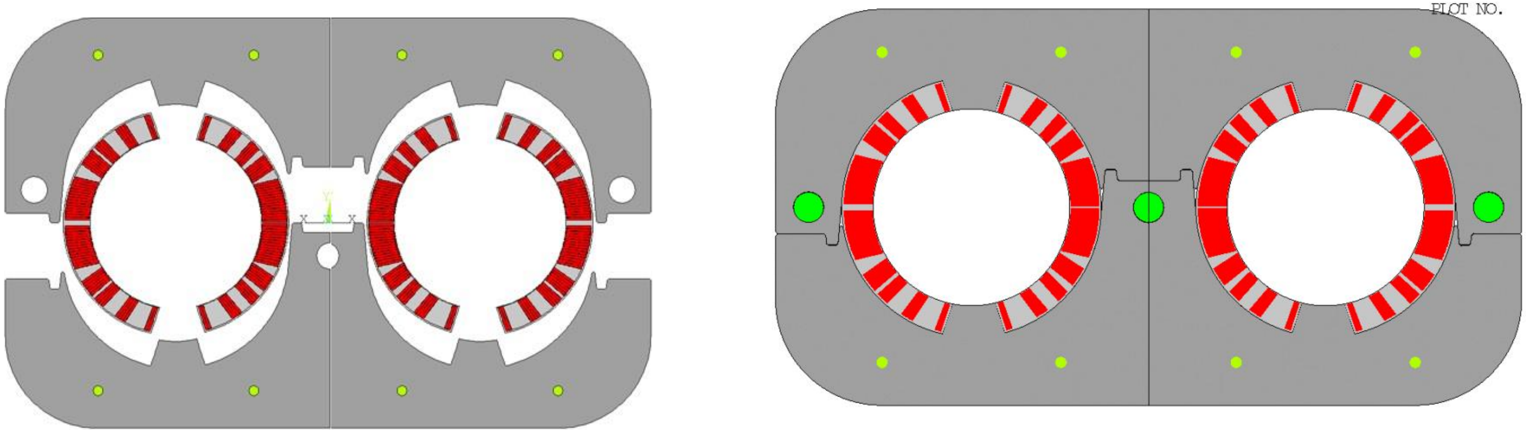


D2 cross-section [P. Fabbricatore, S. Farinon]



RECOMBINATION DIPOLE

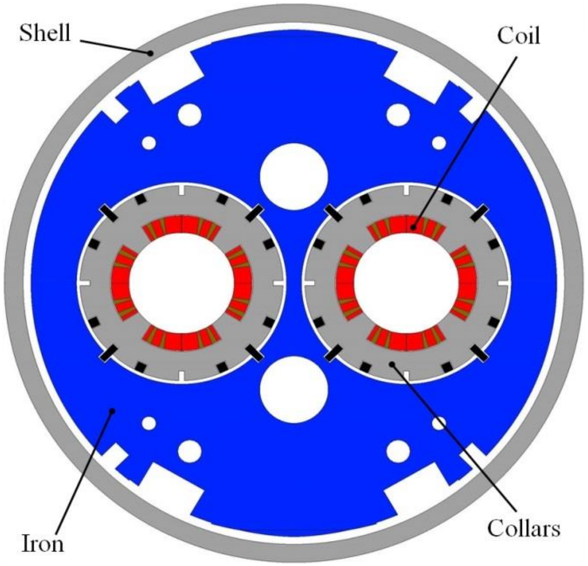
- Conceptual design started in 2013 [R. Gupta, G. L. Sabbi, X. Wang]
  - US collaboration exploring first options
- June 2014: 2D magnetic design completed [S. Farinon, P. Fabbricatore]



- Milestones (very tight)
  - End 2014: coil ends and mechanical design
  - Engineering in 2015
  - Aiming at having short model manufactured in 2016
    - Challenging magnet: long, two in one, asymmetric

LARGE APERTURE TWO-IN-ONE QUAD

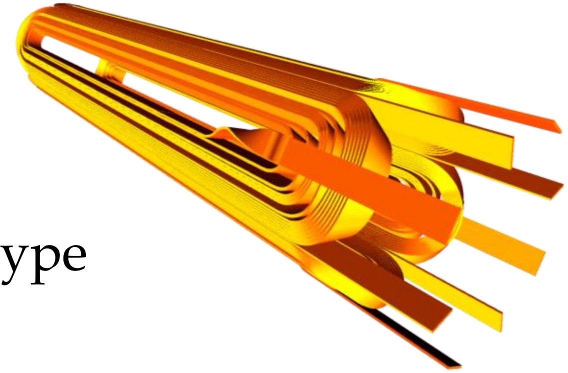
- Nb-Ti, 90 mm aperture, 115 T/m, 3.8-m-long
- CEA providing short model single aperture and engineering for long
- Structure: self standing collars keeping forces (as MQ)
  - Challenge: field quality, large cross talk
- LHC MB cable (outer layer)
  - No quench heaters required



Q4 cross-section [J.-M. Rifflet, M. Segreti, ASC 2014]

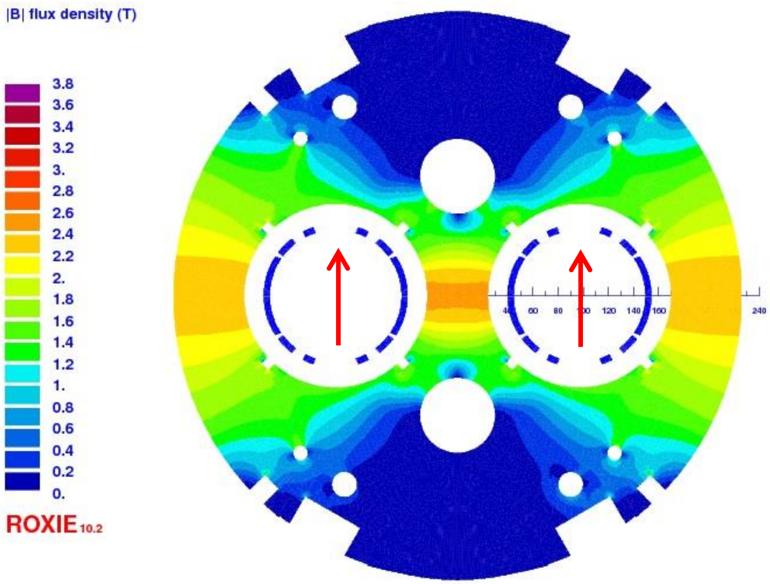
LARGE APERTURE TWO-IN-ONE QUAD

  - 2012: conceptual design started
  - June 2014: completion of conceptual design with ends and connections
- Milestones
  - Winter 2015-2016: test short model
  - End 2016: engineering design of the prototype

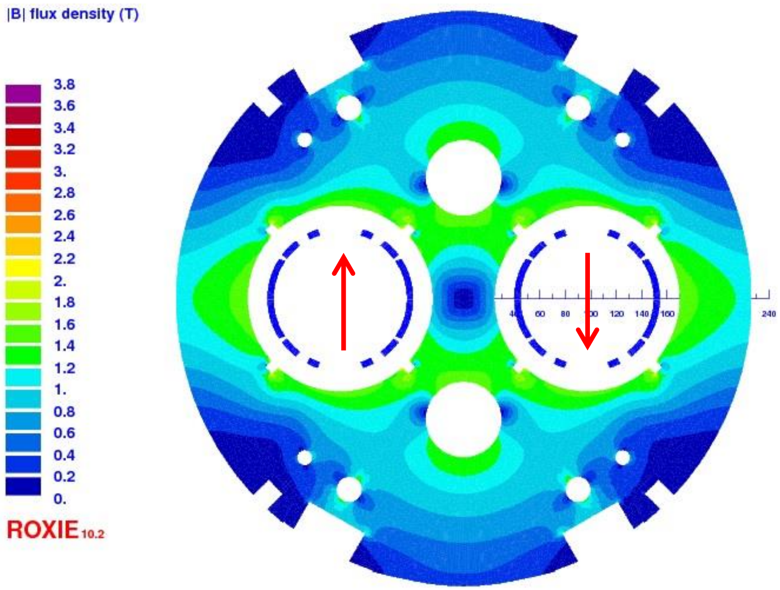


D2 AND Q4 CORRECTORS

- Nb-Ti, 100 mm aperture, 3 T
- Challenge: large cross talk, and operational mode
  - All combinations of left/right fields must be possible, and field quality must be very good
  - Conceptual design started [J. Rysti]



At 2230 A, 2.00 T per aperture



At 2230 A, 2.10 T per aperture

NEXT YEAR TARGETS

- Design study timeline
  - 2012 – aperture selection
  - 2013 – magnet design and technology selection
  - 2014 – engineering of the first magnets (triplet, D1, Q4)
- 2015: from study to project
  - First hardware tested
    - D1 short model
    - QXF short model
    - Corrector sextupole prototype
  - Completing magnet design
    - D2
    - orbit correctors
    - orbit correctors for D2/Q4
  - Completing engineering design for Q4

FUTURE TARGETS

- 2012 – aperture selection
- 2013 – magnet design and technology selection
- 2014 – engineering of the first magnets (triplet, D1, Q4), design of the others

- 2015-2016: short models
- 2017-2018: prototypes
- 2019-2021: production

- String test 2019 (ambitious target)
- Installation starting 2023

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