Quadrupole Designs for the beta-beam project

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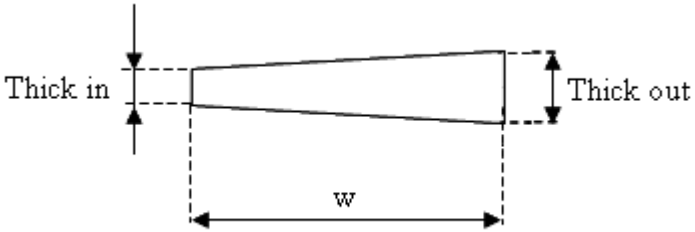
Framework

- Features of the quadrupole for the beta-beam project:
  - Nominal integrated gradient of 84 T/m
  - 124 mm minimum aperture diameter

- Here we propose three different options in the coil design:
  - A 124 mm aperture quadrupole
  - A 250 mm aperture quadrupole
  - A 130 mm aperture quadrupole with an open mid-plane

- Cross-sections are based on the LHC main dipole inner layer cable:
  - w = 15.42 mm
  - Thick in = 2.00 mm
  - Thick out = 2.33 mm

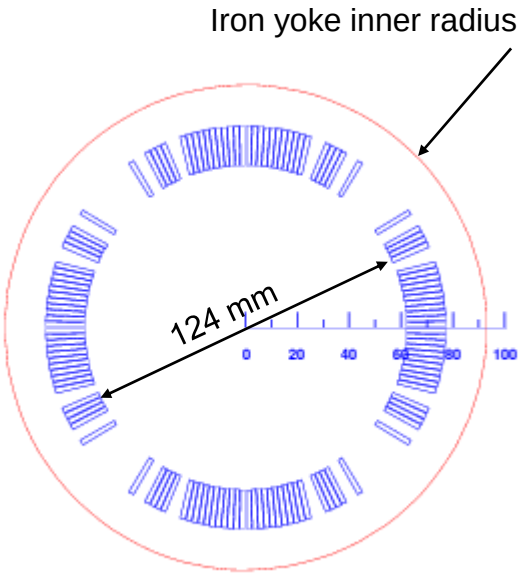


- We assume an operational temperature of 1.9 K.
- To make a fair comparison between designs we assume a 2-m-long magnet (corresponding nominal gradient of 84/2=42 T/m).

124 mm aperture quadrupole

124 mm Aperture Quadrupole

- The aperture diameter is set at 124 mm.
- Field harmonics (b_6, b_{10} and b_{14}) are below 10^{-4} times the main field (1 unit) with an reference radius taken as 1/3 of the aperture diameter.
- An iron yoke is set at 15 mm from the coil.

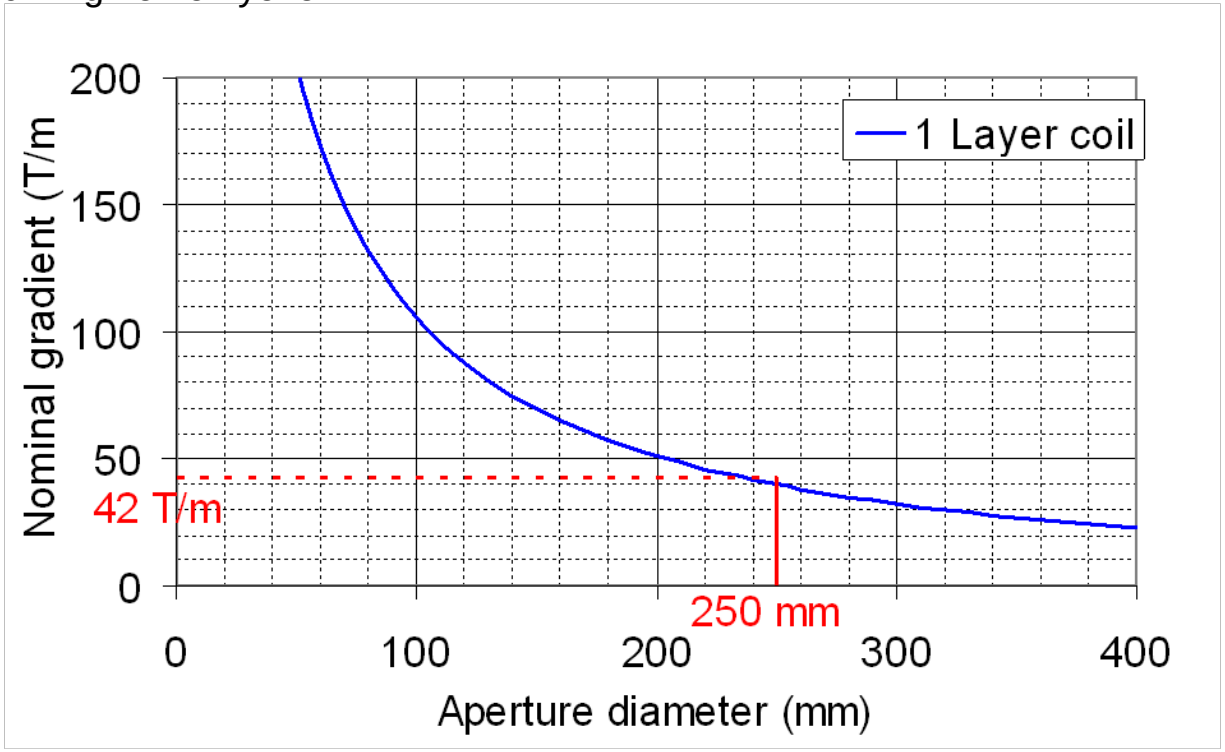


- Magnet features:
  - Quench gradient : 124 T/m (12% provided by the yoke)
  - Quench current : 22.1 kA
  - Quench field in the coil : 8.43 T
- Nominal parameter and current margin for a 2-m-long magnet:
  - Operational gradient : 42 T/m
  - Operational current : 7.5 kA
  - Current margin : 65 %
    - to be compared to the 20% usually meet in accelerator magnets.
    - This huge margin can be used to prevent quench due to heat deposition on the magnet.
    - This margin can also be used to enlarge the aperture (see next slides).

250 mm aperture quadrupole

250 mm Aperture Quadrupole

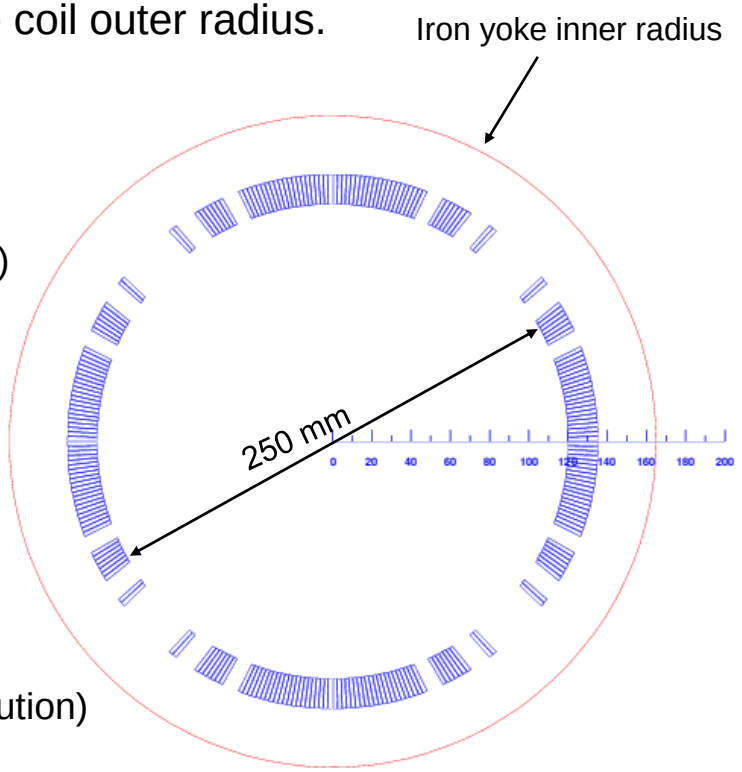
- What is the aperture of a quadrupole which provides a nominal gradient of 42 T/m with a current margin of 20%?
- We use a scaling law giving the nominal gradient VS the coil aperture [1]:
  - Assuming a 1 layer coil made of the LHC inner layer cable.
  - Assuming no iron yoke



[1] L. Rossi and E. Todesco, "Electromagnetic design of superconducting quadrupoles", Phys. Rev. ST Accel. Beams 9 (2006)

250 mm Aperture Quadrupole

- Field harmonics (b_6, b_{10} and b_{14}) are below 1 unit at Ref=1/3 Ap. Diameter.
- An unsaturated iron yoke is set at 30 mm from the coil outer radius.

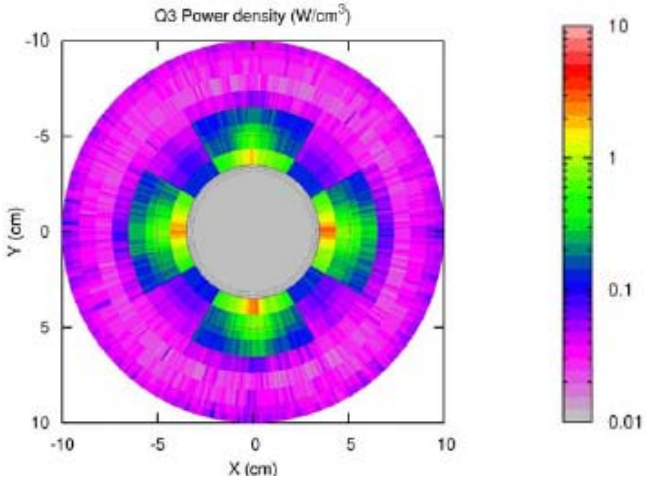


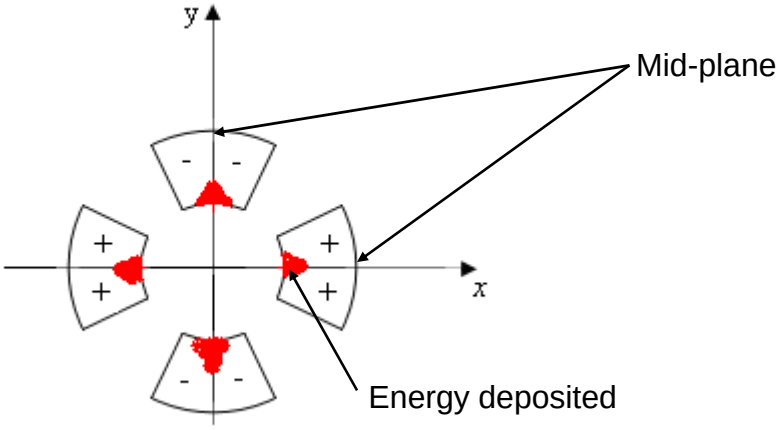
- Magnet features:
  - Quench gradient : 62 T/m (14% provided by the yoke)
  - Quench current : 20 kA
  - Quench field in the coil : 8.83 T
- Nominal parameter and current margin for a 2-m-long magnet:
  - Operational gradient : 42 T/m
  - Operational current : 13 kA
  - Current margin : 32 % (>20% due to the yoke contribution)
- There is still some margin to enlarge the aperture. However, the cable keystone angle would not fit with larger aperture.

Open mid-plane Quadrupole

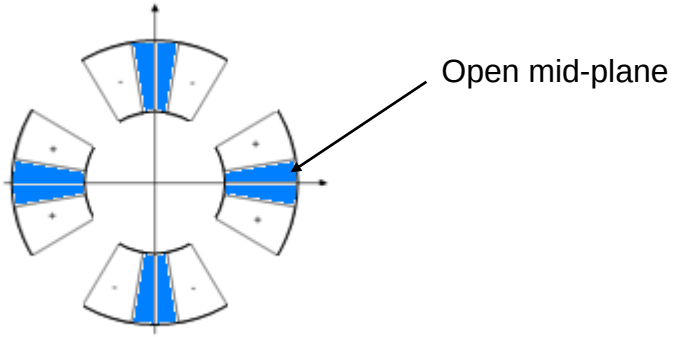
Open mid-plane Quadrupole

- In a quadrupole beam losses are mainly located in the mid-plane:
  - Damage the superconducting cable
  - Might lead to a quench



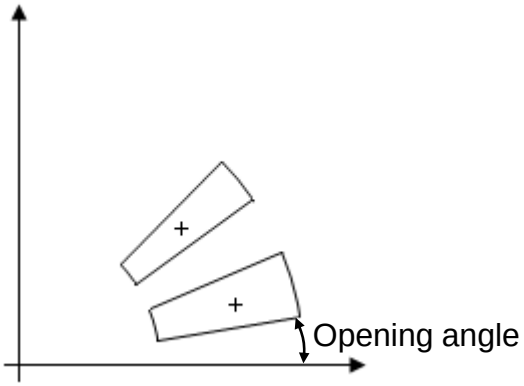


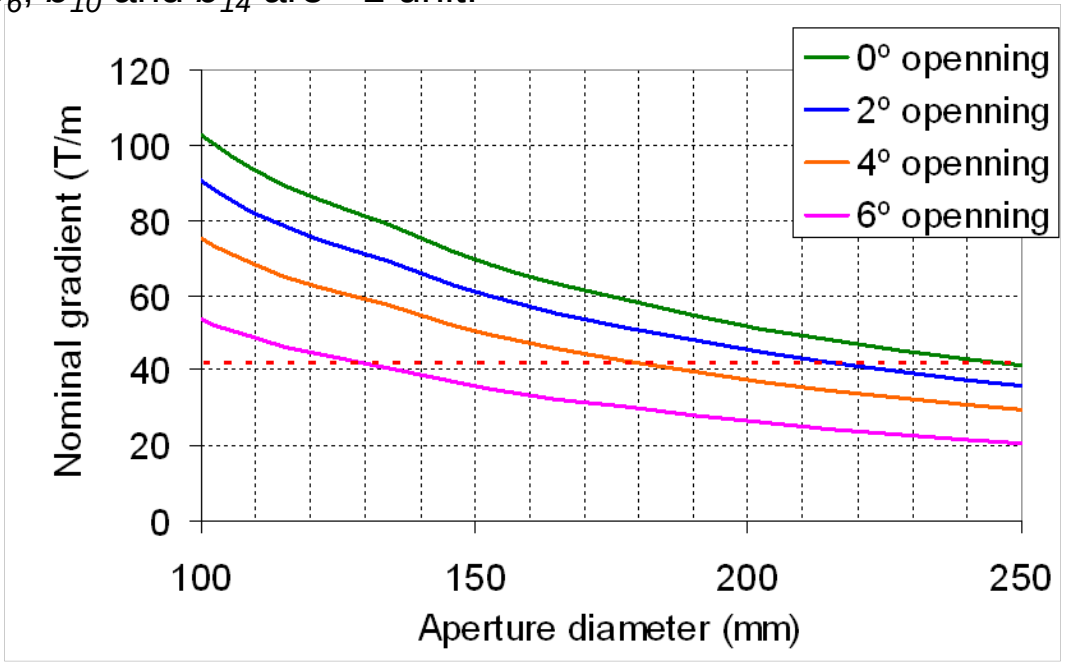
- To avoid the peak of the heat deposition an open mid-plane can be inserted
  - How is the field strength (gradient) affected by insertion of an open mid-plane?



Open mid-plane Quadrupole

- We consider a quadrupole made of 2 pure sector blocks of the LHC main dipole cable.
- Ironless coil is assumed and b_6, b_{10} and b_{14} are <1 unit.

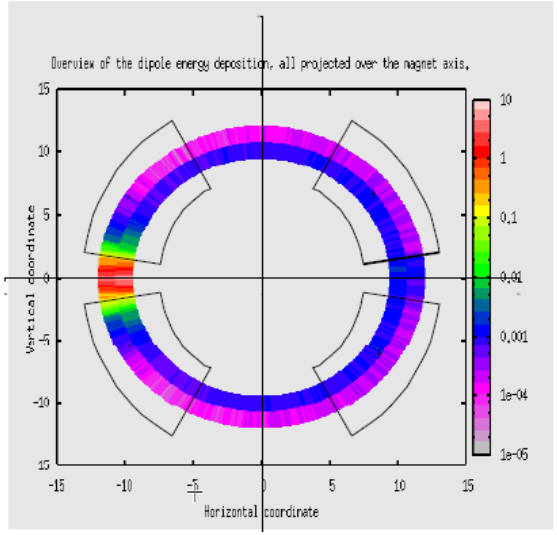


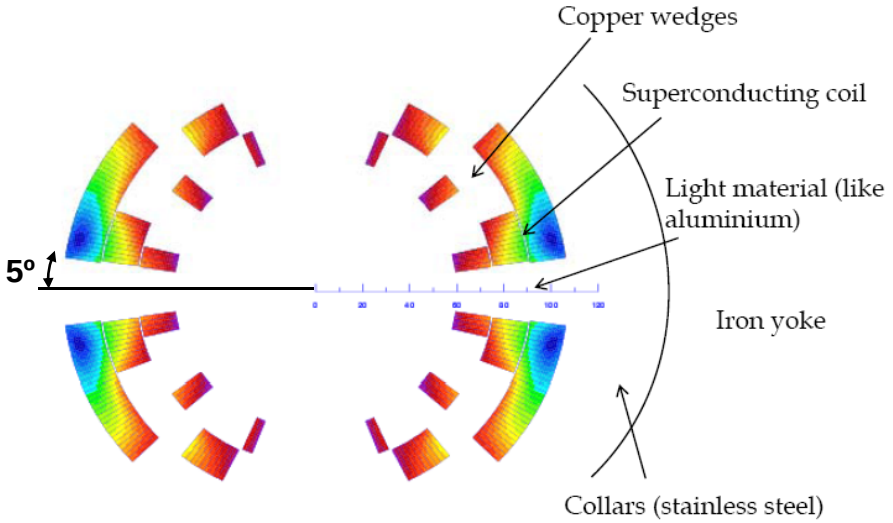


- Aperture diameter corresponding to a nominal gradient of 42 T/m with 20 % margin from the quench:
  - 2º opening : 220 mm
  - 4º opening : 180 mm
  - 6º opening : 130 mm

Benchmark

- An open mid-plan **dipole** for the beta-beam project has already been designed and presented in [2]





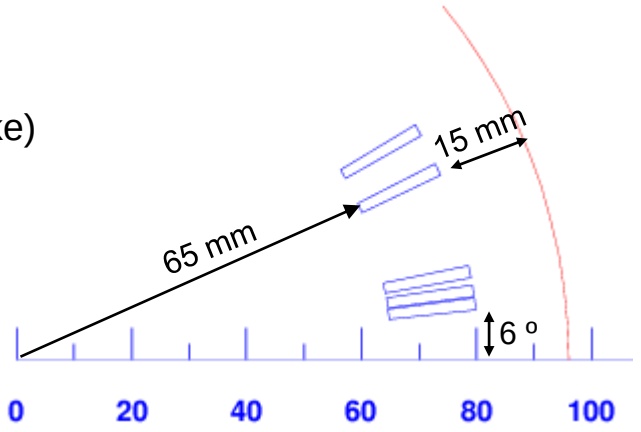
- The dipole design was based on 5º opening. It allows to decrease the heat deposition on the superconducting coil by a factor 10.

[2] J. Bruer, http://beta-beam.web.cern.ch/beta-beam/task/meetings/22ndOct08/beta%20beam%20presentation2.pdf

Open mid-plane Quadrupole

- Quadrupole with an open mid-plane of 6º has been chosen (5º for the dipole).
- The aperture diameter is of 130 mm.
- Multipoles b_6, b_{10} and b_{14} are below 1 unit (reference radius taken at 1/3 of the aperture radius).
- An iron yoke is set at 15 mm from the coil.

- Magnet features:
  - Quench gradient : 60 T/m (23% provided by the yoke)
  - Quench current : 37 kA
  - Quench field in the coil : 5.2 T



- Nominal parameter and current margin for a 2-m-long magnet:
  - Operational gradient : 42 T/m
  - Operational current : 26 kA
  - Current margin : 30 %

Summary

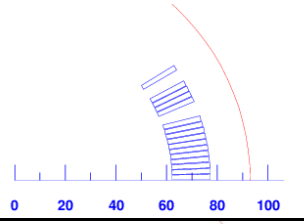
- We have presented 3 different quadrupole designs for the beta-beam project.
- All are based on the inner layer cable of the LHC main dipole. A temperature of 1.9 K has been considered.
- The study has been done assuming 2-m-long magnets.

	units	design 1	design 2	design 3
Aperture	mm	124	250	130
Quench gradient	T/m	124	62	60
Quench field	T	8.43	8.83	5.2
current margin	(%)	65	32	30
Op. Gradient	T/m	42	42	42
Op. current	kA	7.5	13	26
Cable length/magnet	m	256	496	80

- Design 1:

  + Small operational current (7.5 kA)

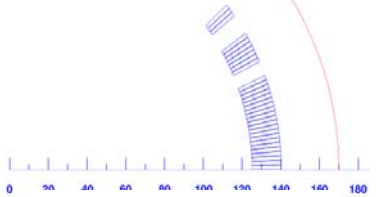
  = Amount of cable needed (256 m) in between what we have for design 2 and 3



- Design 2:

  = Operational current (13 kA) in between what we have for design 1 and 3

  - Large amount of cable (496 m)



- Design 3:

  + Small amount of cable (~80m)

  - Large operational current (26 kA)