FCC-ee warm magnets

Thoughts about the main bending magnets

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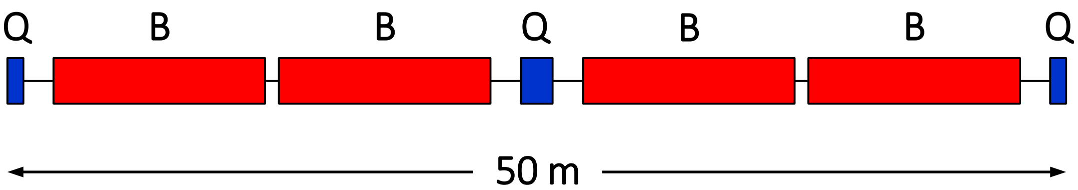
The two tentative lattices for FCC-ee have similar integrated fields though different integrated gradients

strengths @ 175 GeV per ring

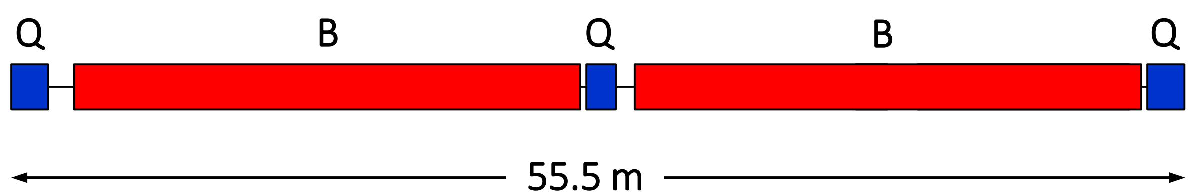


B: $6528 \times 60\ \mathrm{mT} \times 10\ \mathrm{m} = 3917\ \mathrm{Tm}$

QF: $2000 \times 21.4\ \mathrm{T/m} \times 1.5\ \mathrm{m} = 64200\ \mathrm{T}$

QD: $2002 \times 17.5\ \mathrm{T/m} \times 1.5\ \mathrm{m} = 52552\ \mathrm{T}$

Bastian Härer



Katsunobu Oide

B: $2928 \times 52\ \mathrm{mT} \times 23.93\ \mathrm{m} = 3643\ \mathrm{Tm}$

QF: $1460 \times 8.8\ \mathrm{T/m} \times 3.5\ \mathrm{m} = 44968\ \mathrm{T}$

QD: $1460 \times 21.8\ \mathrm{T/m} \times 1.4\ \mathrm{m} = 44560\ \mathrm{T}$

The conceptual design is based on a tentative aperture

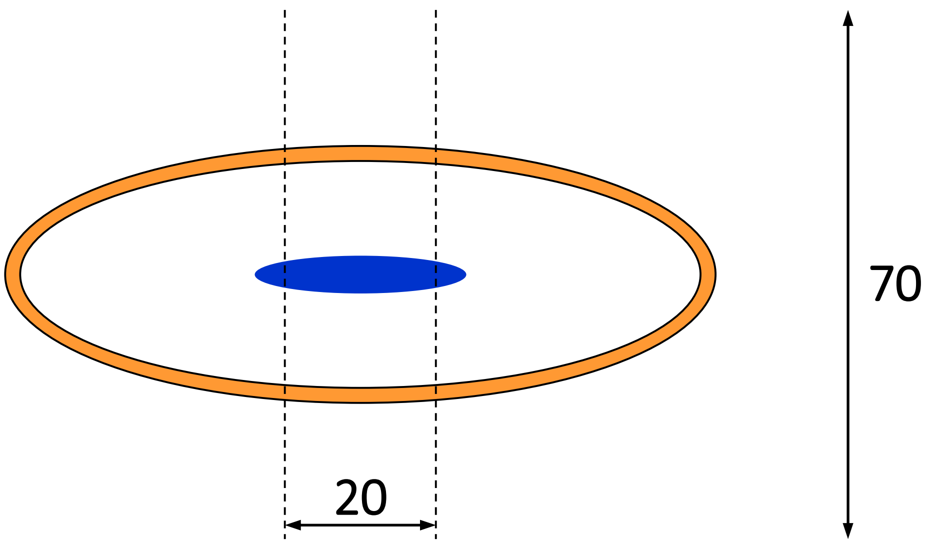
Katsunobu Oide

10^{-4} field homogeneity in ±10 mm horiz. (not counting quad term)

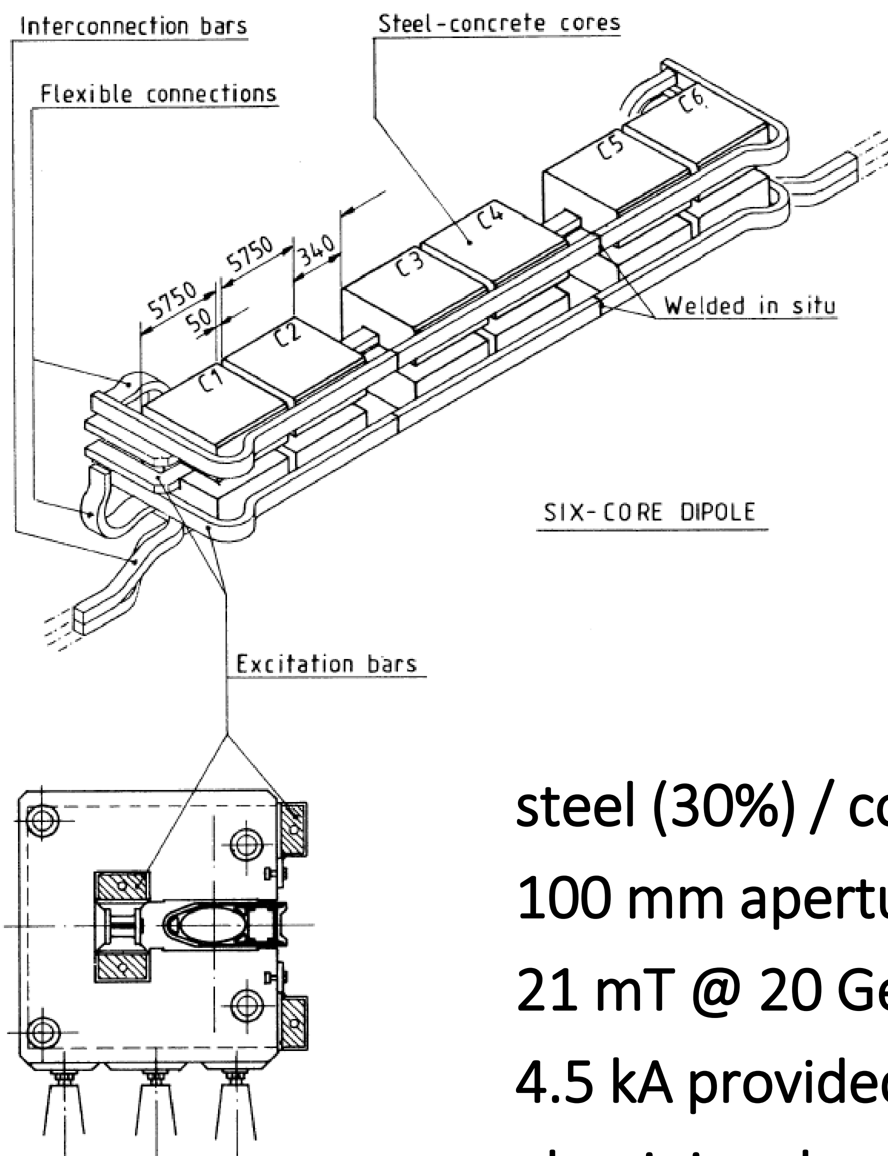
$\varepsilon_x/\varepsilon_y \approx 2000$

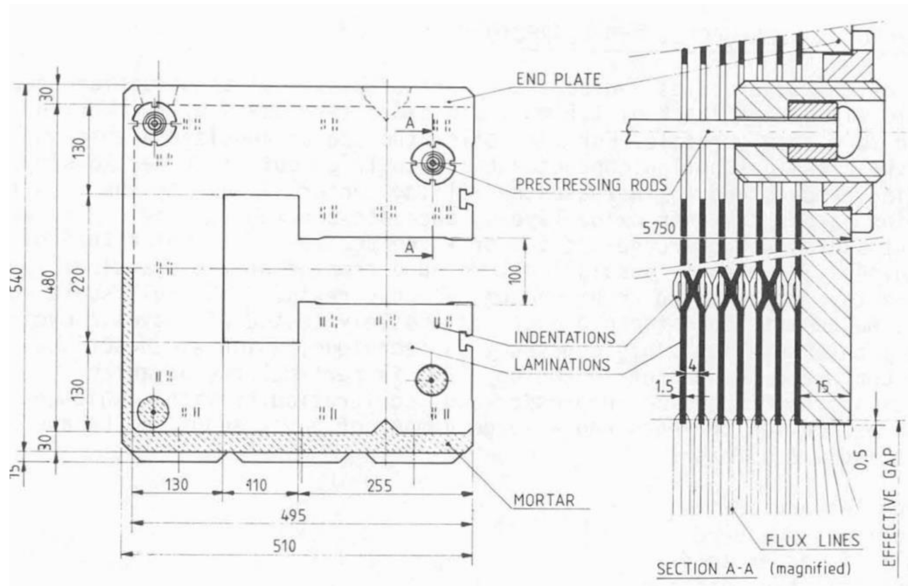
Roberto Kersevan

ellipse 90 × 30 mm + 2 mm wall + extra (bake-out, welding beads for short absorbers)



The closest case in history of many, low field dipoles is LEP





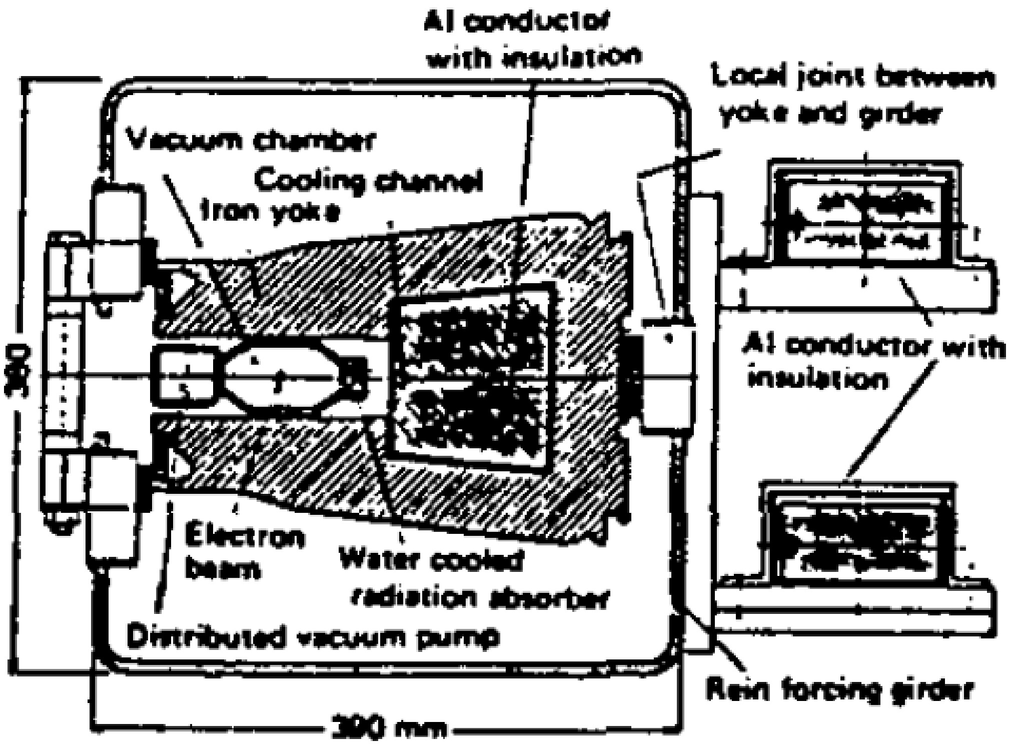
steel (30%) / concrete cores, 5.75 m long each

100 mm aperture

21 mT @ 20 GeV, 110 mT 100 GeV

4.5 kA provided by 4 water cooled 90 × 44 mm^2 aluminium bars

Another case in history with many (though less) low field dipoles is HERA



TECHNICAL DATA at 30 GeV

Field strength	0.1638 T
Bending radius	610.4 m
Gapheight	51.5 mm
Good field cross section	40x80 mm^2
Conductor (aluminum)	100 cm^2
Number of turns in coil	1
Current	6767 A
Power	2.57 kW
Mass (including girder for quadrupole and sextupole	4200 kg

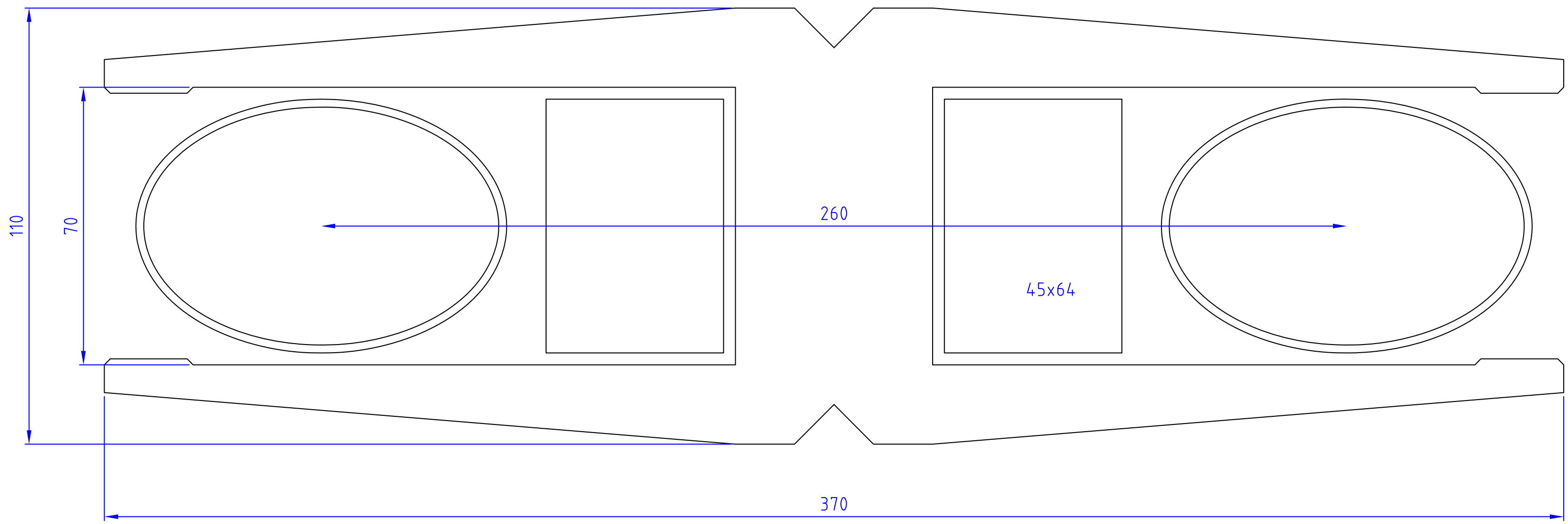
5 mm laminations

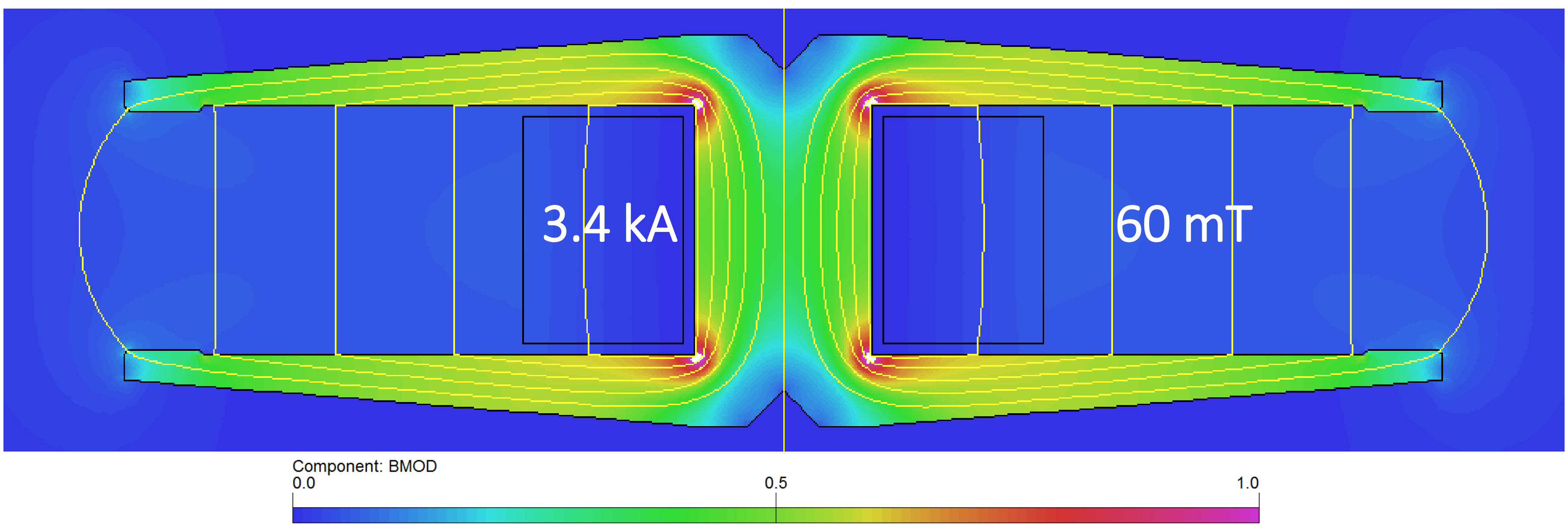
9 m length

In HERA the aperture of the C dipoles was towards the inside of the ring? (like in Diamond too)

circumference 6336 m

The conceptual design is an X dipole, with a twin aperture compact yoke (not diluted) and low consumption coils





This concept has several advantages

<u>two-in-one</u>

cuts in half the power consumption, as the Ampere-turns are recycled

less units to manufacture, transport, install, align, remove

<u>*reasonable* power consumption</u>

14 MW for 65.3 km of dipoles of a double synchrotron (@ 175 GeV)

(cooling hole in busbar not shown, but most likely convenient)

<u>compact yoke</u>

111 kg/m * 6528 * 10 = 7246 t (LHC ≈50000 t)

thick laminations (5 mm?) punched in one go

no dilution (à la LEP) should make easier the recycling of the raw material at the end of operation

<u>one-turn conductor</u>

no cost for coil manufacturing

no inter-turn insulation, less sensitive to radiation damage

easier recycling of raw material at the end of operation

Al is likely a better choice than Cu in this case: lighter, cheaper, less activated

Cu, two 30 × 64 mm^2 bars

202 W/m (@ 175 GeV)

34 kg/m

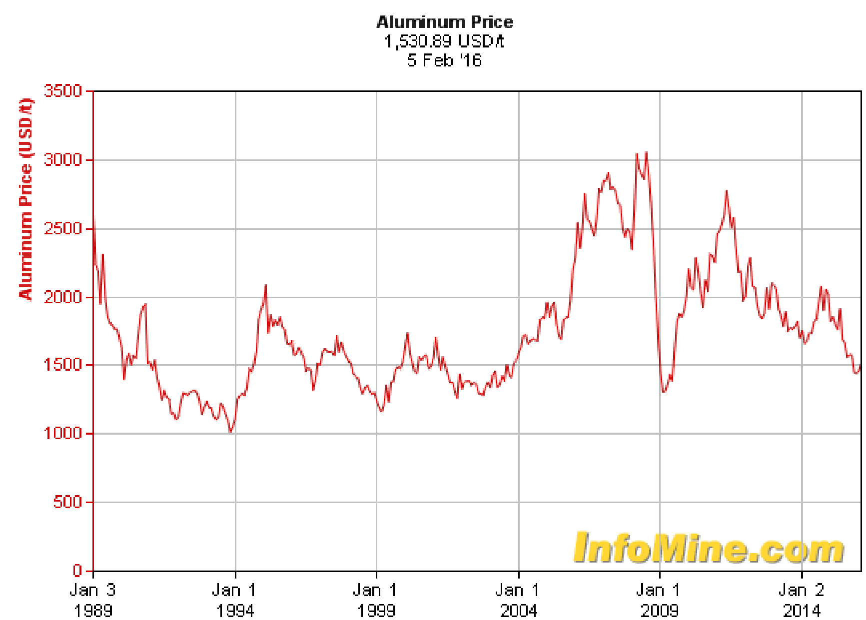
2220 t * 4669 USD/t = 10.4 MUSD

Al, two 45 × 64 mm^2 bars

208 W/m (@ 175 GeV)

16 kg/m

1044 t * 1531 USD/t = 1.6 MUSD



The low power comes from the low resistance, which brings also low resistive voltage

Al, two 45 × 64 mm^2 bars

3360 A (@ 175 GeV)

$$V = RI = 4.1 \text{ kV}$$

for 65.3 km of dipoles (in between cables not included)

The pole is compact though the width seems realistic in terms of field homogeneity

2d harmonics @ 10 mm radius

b_2 = -3.8 quadrupole component not critical

b_3 = 0.0

b_4 = -0.8

b_5 = -0.3

b_6 = -0.1

a change in iron permeability impacts only b_2

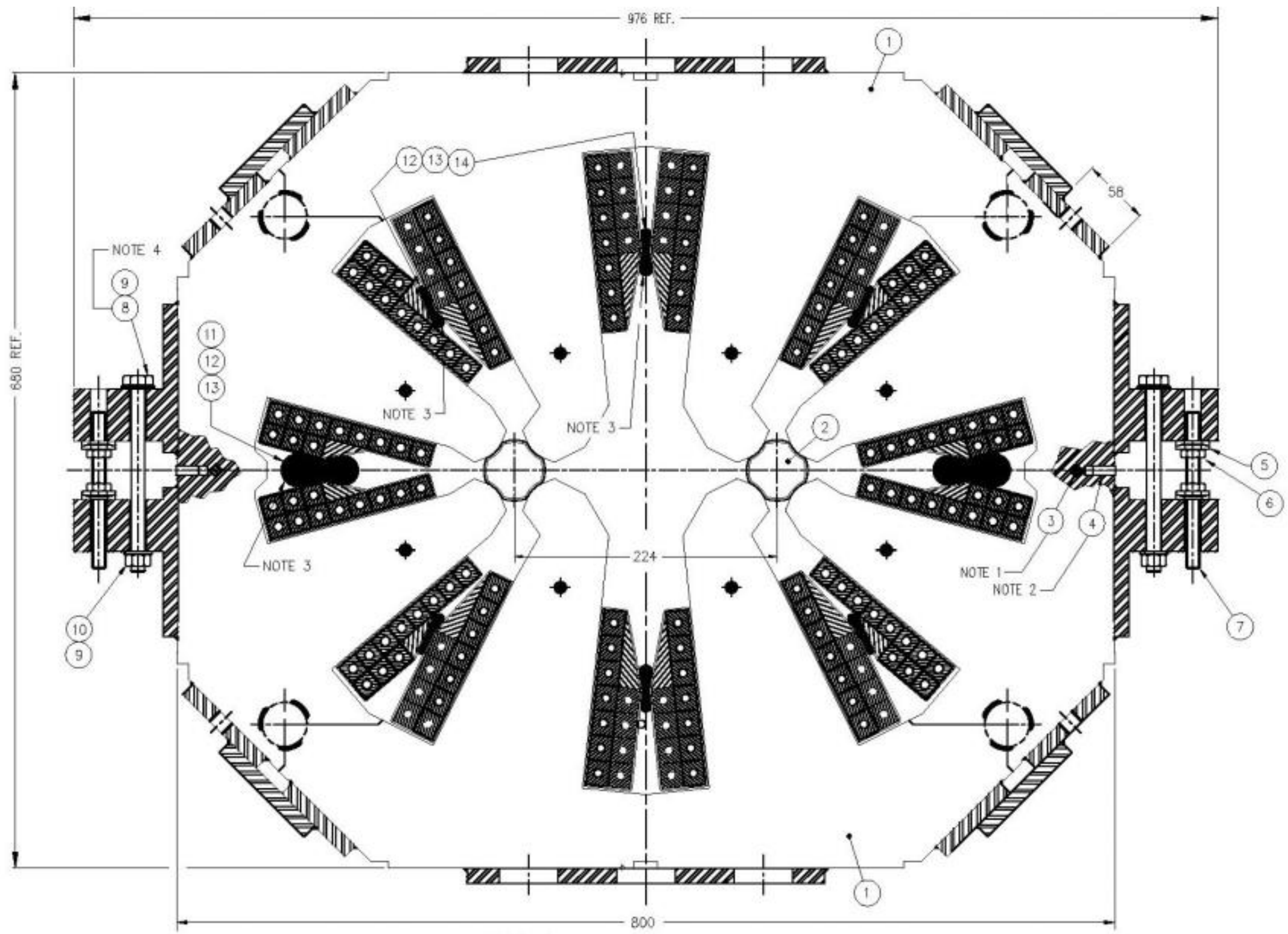
the position of the busbar has a (weaker) impact on b_2

end effects will likely play a role

effects at lower (than 60 mT) fields to be examined

conceptually, there is no problem in actually making it more <u>combined function</u>

The design of the quadrupoles is pending – it depends too much on the interbeam distance, the aperture and the gradients



à la MQW? [35 T/m in 46 mm dia. aperture, 224 mm interbeam dist.]

Conclusions

- the requirements need an iteration: aperture, good field region, min and max strengths
  - beam physics (lattice design, impedance effects, closed orbit distortion, injection, …)
  - vacuum chamber, including absorbers
  - radiation dose

- shall the twin concept be retained as a baseline?

- FCC-ee is a large, short lived machine: the magnets need to be
  - reliable
  - cheap to build
  - cheap to operate (low energy consumption)
  - recyclable

thank you