MAGNETS SPECIFICATIONS AND TARGETS

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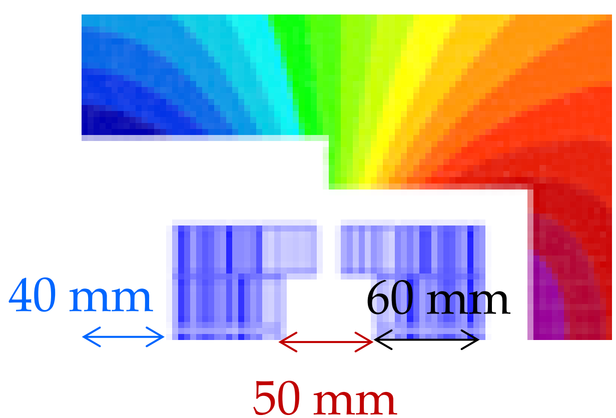
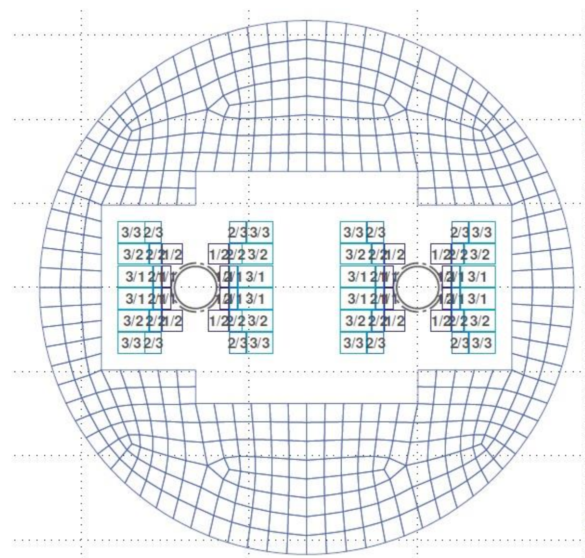
CONTENTS

- Beam separation
- The arcs
- Insertion regions

BEAM SEPARATION

- 192 mm in the LHC
  - No major aperture from LHC to FCC (from 56 mm to 50 mm)
  - Coil width increases by factor ~2 (from 30 to 60 mm)
  - So in principle, 60 mm more $\rightarrow$ 250 mm
- First proposals [E. Todesco et al, CERN 2011-003] for the 20 T were 300 mm
  - Coil width of ~80 mm
- Baseline for the 16 T is 250 mm





Proposal for layout of 16 T dipole [J. van Nugteren]

- Constraints on 2-in-1 magnets close to IR (D2) to be checked

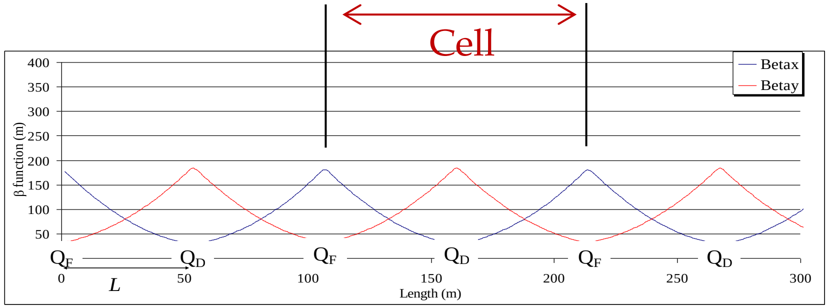
The arc magnets aperture

- Cell length doubling w.r.t. the LHC: 2L from 100 to 215 m
  [see D. Schulte and B. Dalena talks]
  - L is the quadrupole spacing, so cell length is $2L$
  - This is the only free parameter we can play with
  - $\beta \propto L$, so impact on the aperture (we lose √2)
    but we have less quads, more packing factor
  - We gain a factor √ 7 in the energy

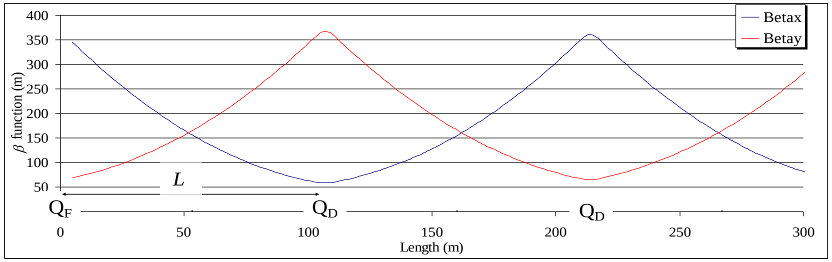
$$\beta_f = (2+\sqrt{2})L \sim 3.4L$$

$$\beta_d = (2-\sqrt{2})L \sim 0.6L$$

$$|x(s)| = \sqrt{\frac{\varepsilon\beta(s)}{\gamma_r}}$$



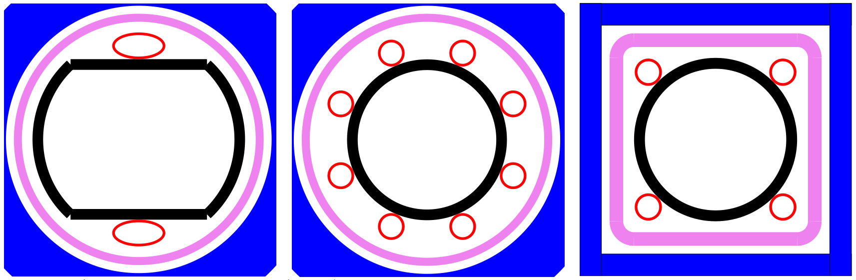
  - Beam size reduced by √ 2/7~ 50% w.r.t. LHC, but shielding needed (plus offset due to tolerances)→ 50 mm



Sketch of beta functions in LHC and FCC

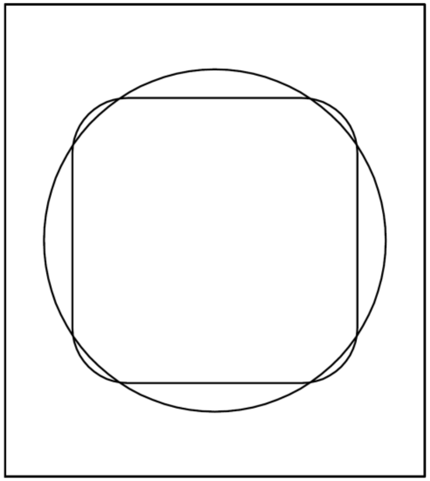
Aperture shape and cooling

- Large cooling channels are required to remove synchrotron radiation load [C. Garion talk]
  - D. Schulte was proposing a square beam screen to save space in case of a block design



  - Mechanical simulations to explore this possibility
    - In case of square, more material is needed on the midplane to have the same rigidity of the roman arc - negligible gain

The LHC type beam screen seems the best way to exploit the aperture



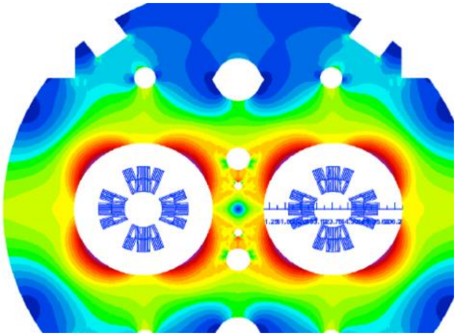
Square and round aperture having the same deflection in the midplane [M. Juchno]

THE ARC QUADRUPOLES

- LHC: 220 T/m, 3.15 m integrated gradient ~690 T

$$G\ell_q = \frac{B\rho}{f} = \frac{\sqrt{2}B\rho}{L}$$

- From 7 to 50 TeV: * 7.14
- From L=100 to L=215 m (cell length) : /2.15
- Needed gradient: ~2250 T
  - So, with 420 T/m we will have 5.4-m-long quad
  - Over a 50 mm aperture the peak field is
    420*25/1000 =10.5 T + 15% = 12 T peak field



Conservative design at 380 T/m
[M. Karpinnen]

  - 1 m shorter quadrupole means 1% more (precious) margin in the dipole
- Over a cell of 200 m, 11 m for quadrupoles
  - filling factor similar to the LHC, where we have 100 m and 6.3 m for quadrupoles

FIELD QUALITY

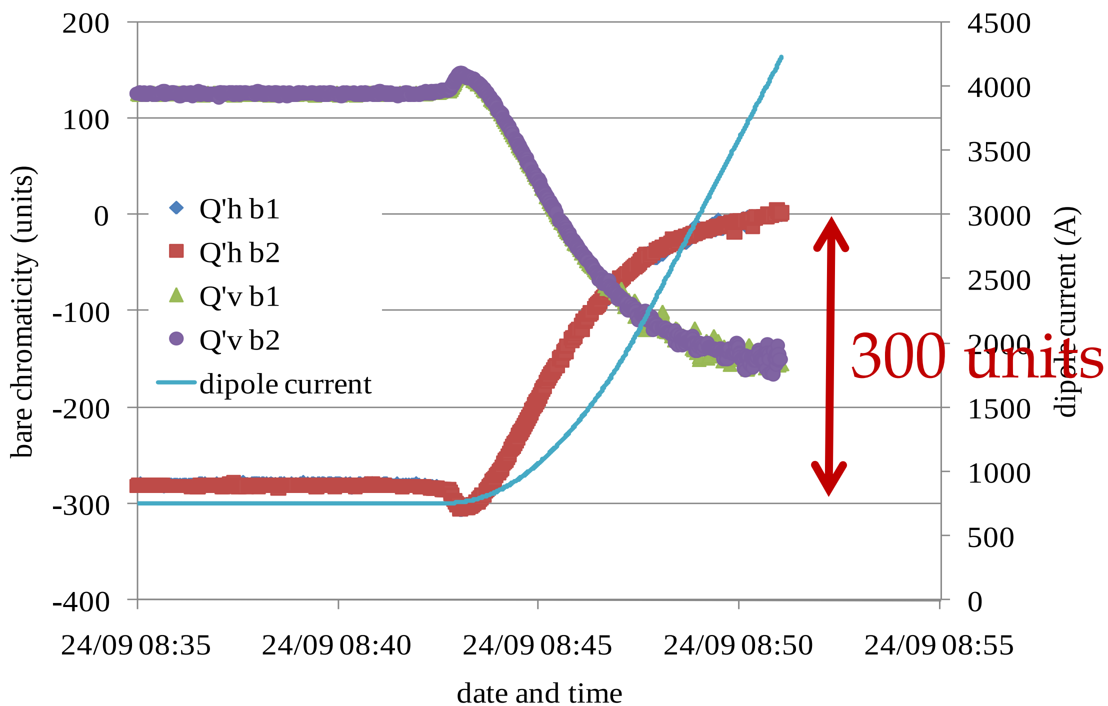
- Question: are there some requirements that scale with length?

- Tune:
  - Machine size increases by factor four, but doubling the cell length the tune due to the arc will only double
  - Tune control and precision of quadrupoles: we are in the same range

- Chromaticity
  - In the LHC, 1 unit of b_3 in the dipoles gives 45 units chromaticity
  - In FCC, this sensitivity doubles $\rightarrow$ 1 b_3 unit gives 90 units of chroma [R. Tomas, private commun.]

FIELD QUALITY

- Persistent currents induce a change of b_3 during the ramp
  - It is ~7 units in the LHC, giving a chromaticity change of 7*45~300 units – corrected through spool pieces with ~1% precision
  - In the FCC, a good target would be 5 units, not to exceed a 5*90~450 units change

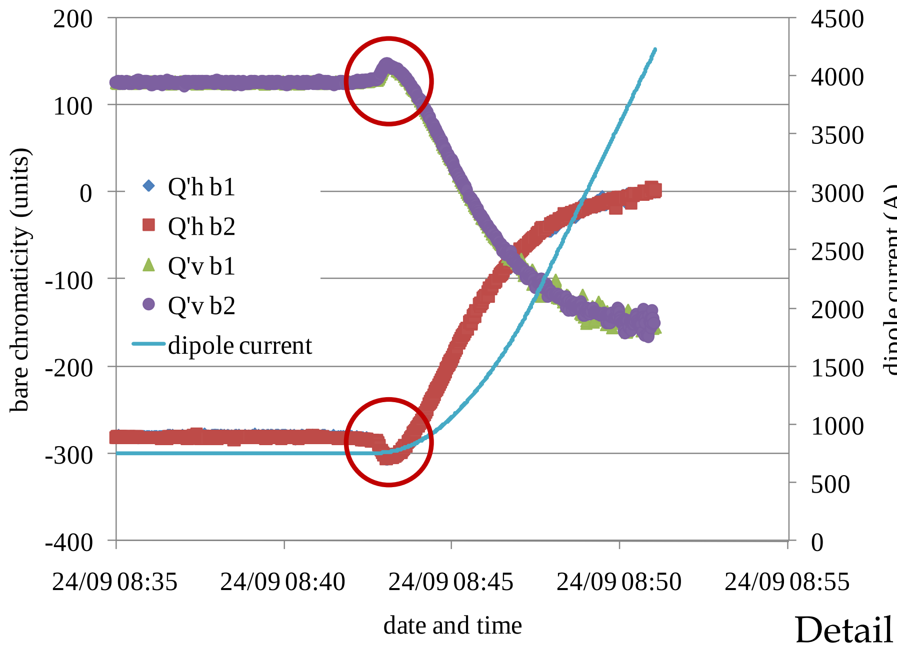


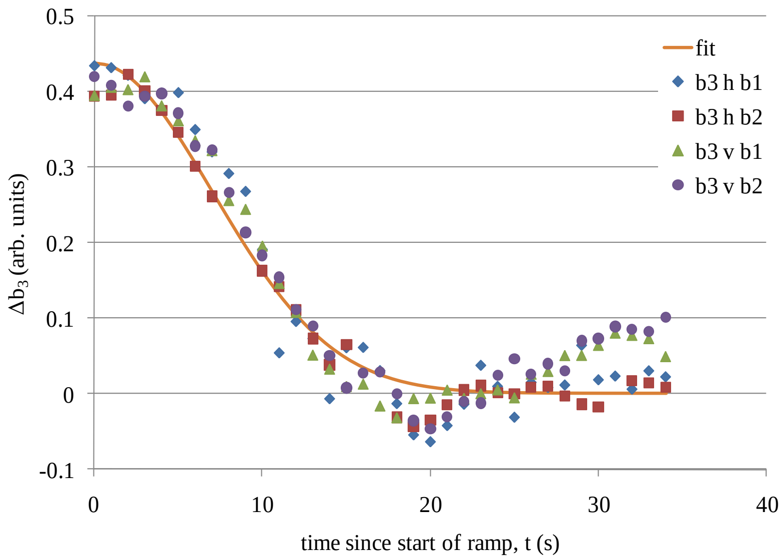
Bare chromaticity due to b3 in the dipoles during injection and ramp

[N. Aquilina, et al. presented at ASC, submitted to PRSTAB]

FIELD QUALITY

- Decay and snapback induce a change of b_3 at the beginning of the ramp
  - It is ~1 unit in the LHC, giving a chromaticity change of ~45 units
    - It has been ~0.5 units in the 4 TeV run
  - In the FCC, a good target would be 0.5 units, not to exceed a ~50 units change

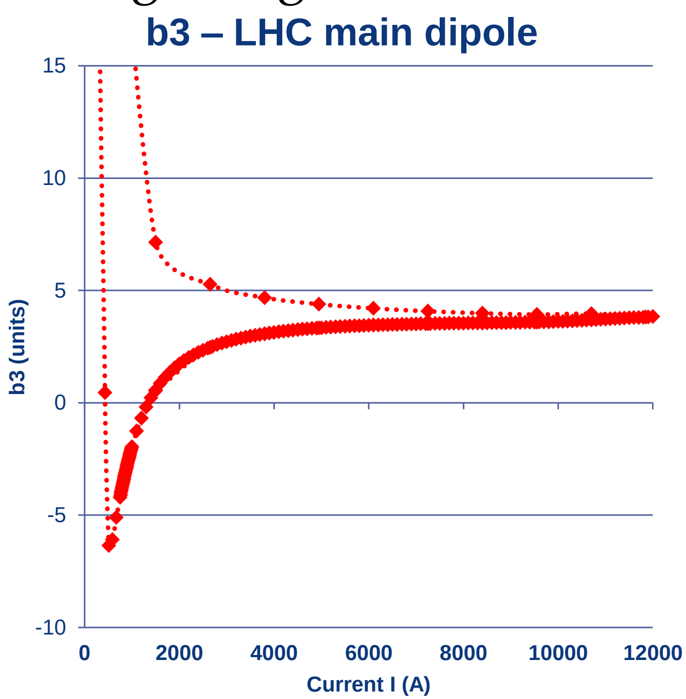


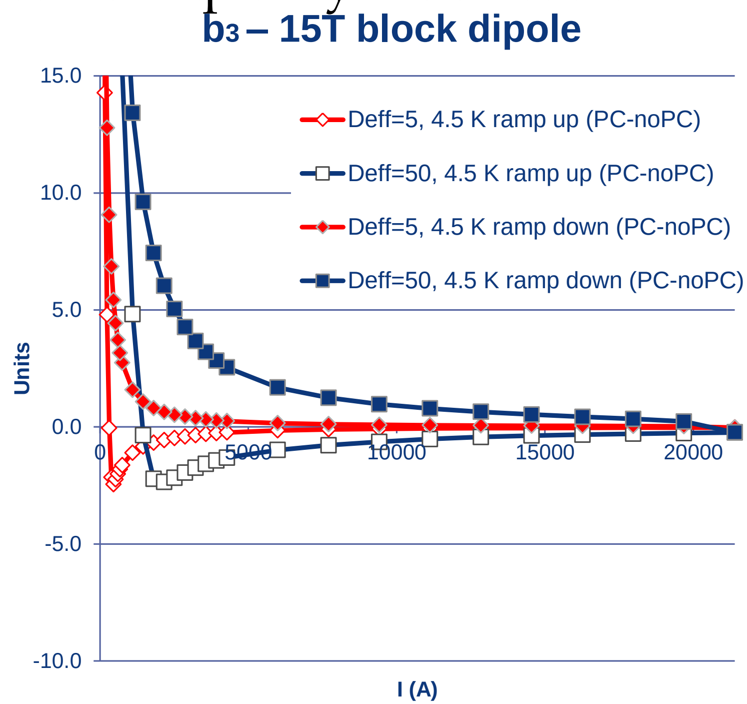


Detail of snapback [N. Aquilina, et al. presented at ASC]

FIELD QUALITY

- Good news: first simulations on persistent current effect [S. Izquierdo Bermudez]
  - Less than 3 units change on the ramp, even with 50 mm filaments (not critical)
  - Having a large coil width makes field quality much easier





b3 versus current in LHC and FCC dipoles [S. Izquierdo Bermudez]

FIELD QUALITY

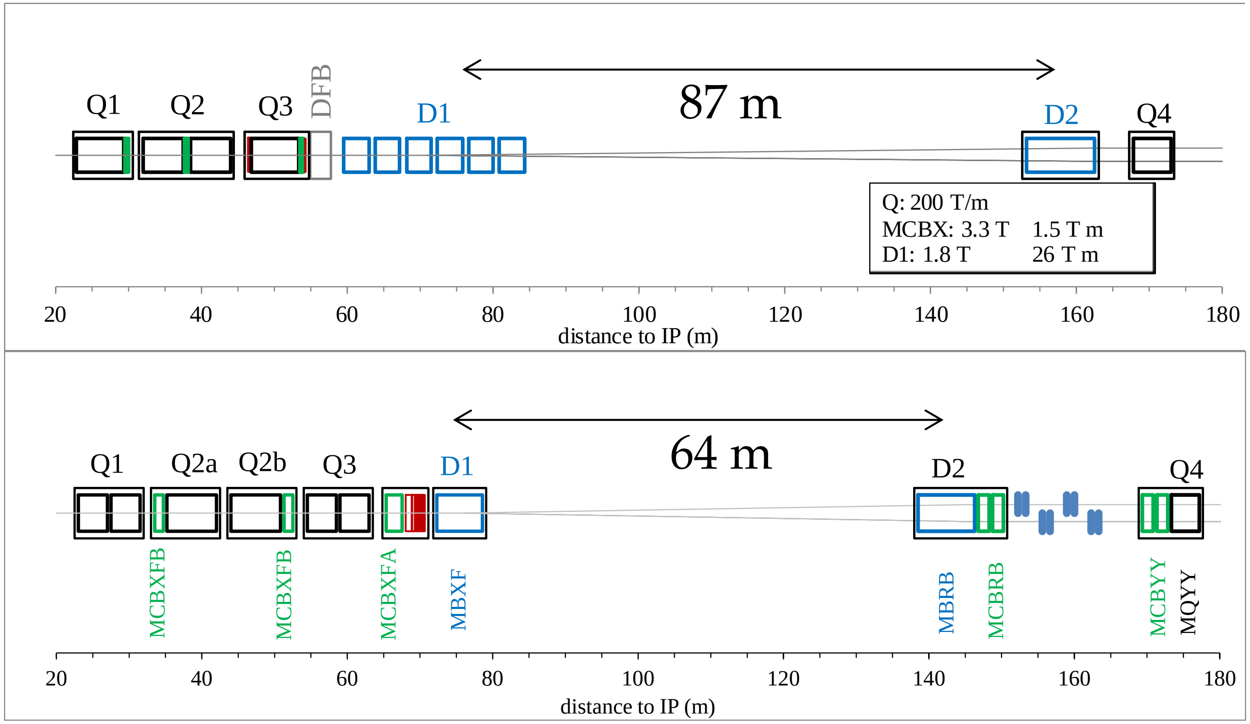
- Nonlinear effects and dynamic aperture
  - My guess: keep the same level of the LHC, ~1 unit
  - A first tracking to check dynamic aperture with reasonable field errors is the next step [see B. Dalena talk]

- Alignment and feed down effects
  - Guess of ~0.1 mm precision, effects still to be checked

CONTENTS

SEPARATION DIPOLE

- LHC: D1 give a bending of 26 T m = 1.1 mrad
  - Beam separation is 192 mm, so distance D1-D2 is 96/1.1= 87 m



- For HL LHC we aim going to 35 T m, 1.5 mrad
  - distance D1-D2 reduced to 96/1.5= 64 m

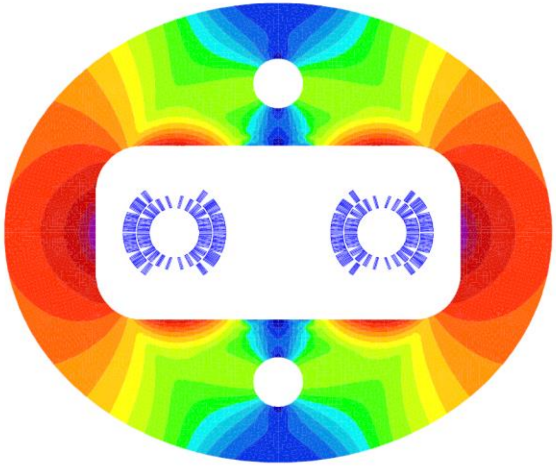
Separation dipole

- For FCC
  - Energy from 7 to 50 TeV : *7.14
  - Beam separation from 192 to 250 mm: *1.30
  - We take D1-D2 distance ~ as in HL LHC (10% longer): 70 m
  - Needed kick is 35*7.14*1.30/1.1~300 T m [R. Tomas Garcia proposal]
- So two 12.5-m-long 12 T dipole would make the job

- Aperture: depends on β^*
  - First guess at 60 mm aperture - no bottlenecks to increase it if needed

Recombination dipole

- Needed kick is 300 T m
- This is a two-in-one dipole
  - 60 mm aperture first guess
  - 10 T seems a reasonable guess, two modules 15 m long [see P. Fabbricatore talk]
  - Cross-talk between apertures to be controlled, solution for HL LHC provides good layout
    - The electromagnetic cross-talk is the constraint that limits the field



D2 conceptual design [P. Fabbricatore]

Triplet: length and gradient

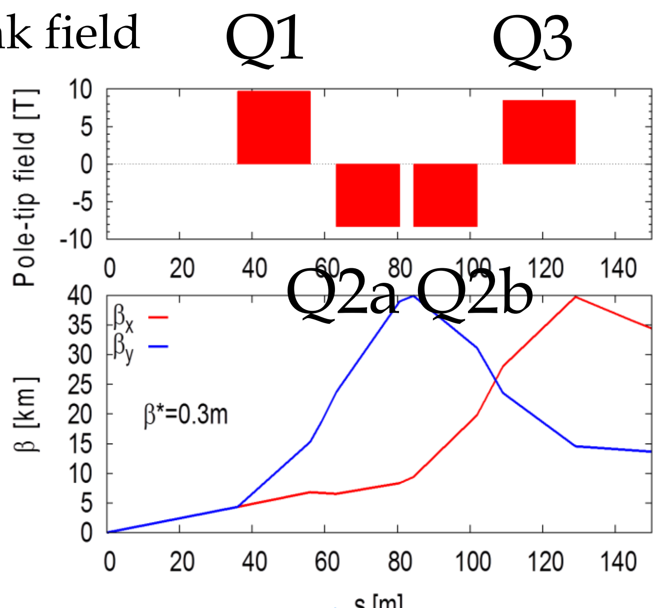
- Scaling of the energy is hard
  - Take the 150 mm aperture HL LHC triplet, G=140 T/m over l_t=30 m length, 4200 T total
  - Energy scaling: keeping same gradient one has a 200 m triplet …
- Relevant parameter is distance of first magnet to interaction point (l^* = 23 m in LHC)
  - Depends on experiment size l, where $l^2 B \propto E$
  - To gain a factor 7, increase l* from 23 to 36 m (50%), so factor (1.5)^2=2.2 from the size, and the rest (3) from the field B
    - Is this reasonable ? Or should we go to 40-45 m and just double B?

$$G l_t \propto \frac{E}{l^* + \frac{l_t}{2}}$$

- Integrated gradient ~ inverse focal length of triplet
  - Assuming a 75 m long triplet, we go from 23+30/2 m in the HL-LHC to 36+75/2 in FCC, so we gain a factor 1.9

Triplet: Length and Gradient

- So from 4200 T in the LHC to 4200*7.13/1.9=16000 T in FCC for a 75 m triplet → 215 T/m gradient
  - 100 mm aperture magnets would give maximum gradient of 225 T/m and a peak field of 225*50 +15% = 13 T peak field
  - This is a reasonable target, magnets lengths are
    - Q1/Q3 is 20 m (two modules of 10 m)
    - Q2a/Q2b is 17.5 m (two modules of 9 m)
    - Twice the length in HL LHC, 10% more peak field
    - 40 km beta function
      - 4 km in LHC, 20 km in HL LHC
  - One could think about pushing up the gradient with HTS to have more compact triplet and/or more aperture (see next slide)

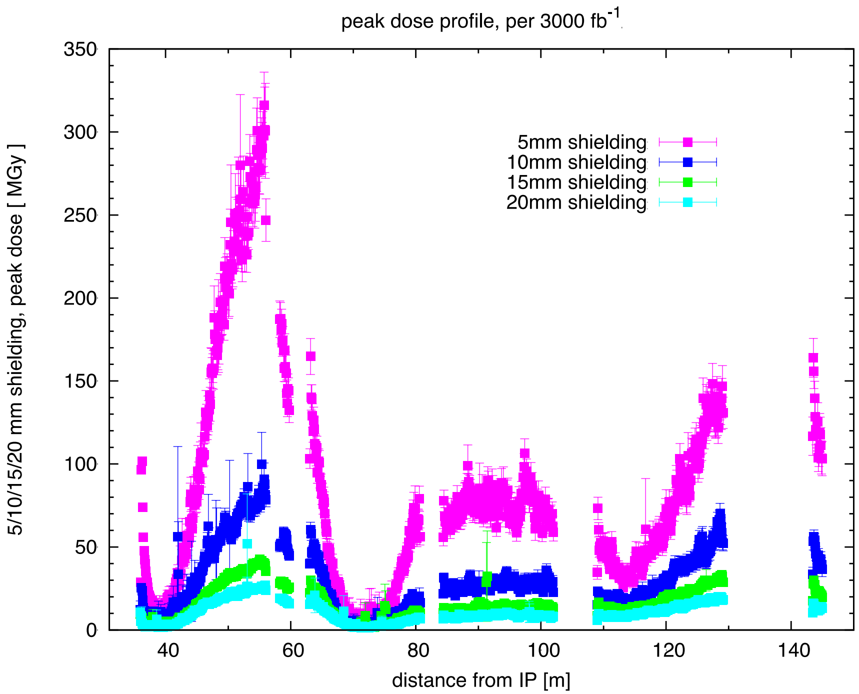


Triplet: dose

- This can be a hard bottleneck ! With 20 mm shielding, with 3000 fb^{-1} we are at 30 MGy
  - This means 150 MGy at 15 ab^{-1} – I think this is not recoverable with optics (larger magnets, etc)
  - In HL LHC we have magnets resisting 30 MGy (no specific actions)

for FCC we will need to be able to withstand ~150 MGy

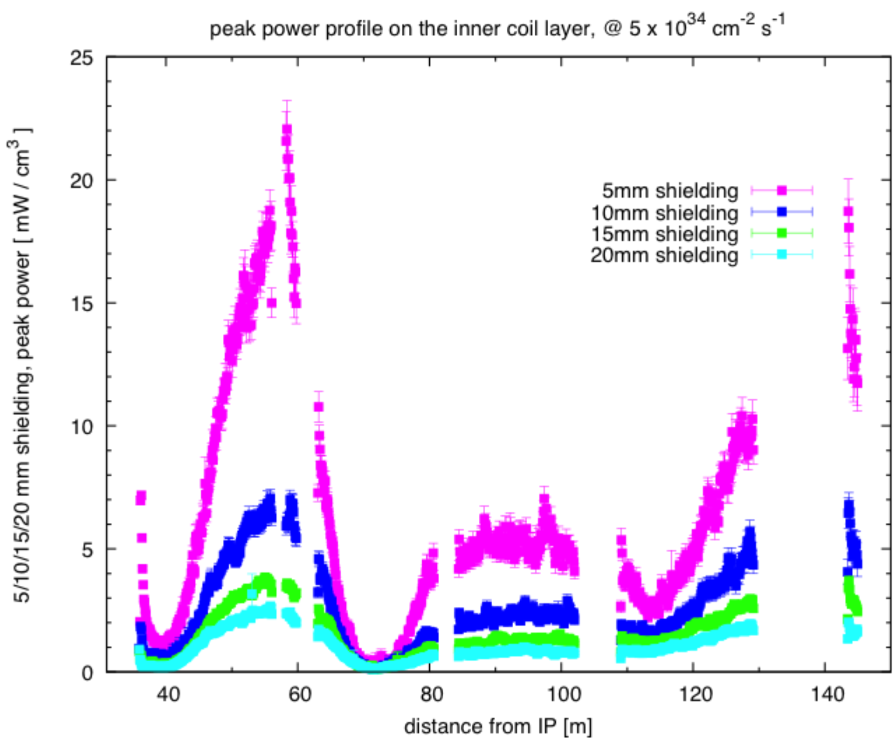
-Impregnation with cynate
-Check all «plastic» parts
-SC should be able to resist
-More shielding ?



Dose in the triplet after 3000 fb^{-1} [M. I. BesanaF. Cerutti]

TRIPLET: HEAT LOAD

- On the other hand, the heat load is not a problem with shielding even at 25×10^{34} cm^{-2} s^{-1} (would be ~10 mW/cm^3)



Peak power density at 5×10^{34} cm^{-2} s^{-1} [M. I. Besana, F. Cerutti]

SUMMARY

- First guess of magnet main parameters
  - Fine tuning needed after first conceptual design
  - Note: MQ at 380-450 T/m in Bottura and Schoerling talks, here we give our best suggestion

		Aperture (mm)	Field (T)	Gradient (T/m)	Peak field (T)	length (m)	Units (adim)
main dipole	MB	50	16		16.5	14.3	~5000
main quadrupole	MQ	50		420	12.0	5.4	~800
Separation dipole	MBX	60	12		12.5	12	4 per IP
Recombination dipole	MBRB	60	10		10.5	15	4 per IP
Triplet	MQX	100		225	13.0	10	16 per IP
MS quadrupole	MQY	70		300	12.0	TBD	TBD

  - Arcs rather finalized, iterations on interaction regions
  - Concern for radiation dose on the triplet
- Field quality should not pose additional challenges to what we see in the LHC – but tracking is needed