Magnet Design for Beamstrahlung Photons Extraction Line

Carl Järmyr Eriksson, TE-MSC-NCM

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Agenda

- Problem background and initial magnet design procedure
- Magnet-photon beam conflicts
- Magnet design requirements and cross-sections
- Space claim summary and conclusions

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Problem background and initial approach

<u>Problem:</u>

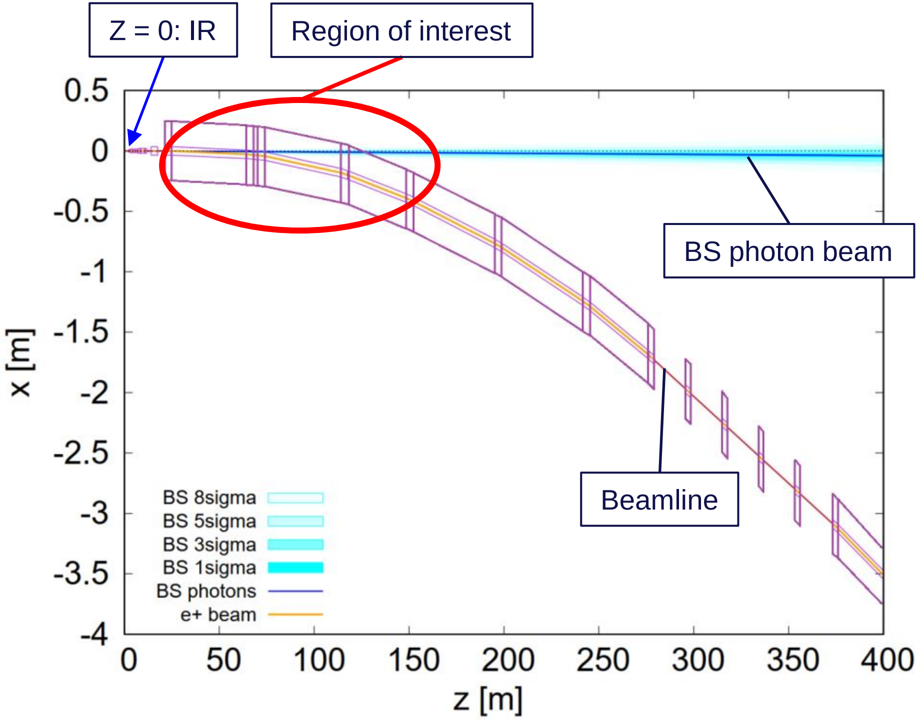
- What conflicts to expect between Beamstrahlung (BS) and magnets?
- Investigate magnet designs that avoid conflicts.

<u>Approach:</u>

- Magnet strength (K-factor) and positions, and BS envelope given by Z and tt-bar optics data.
- Generate magnet dimensions given the strength requirements.
- Plot BS envelope relative to magnet cross-section at both entrance and exit of the magnet to identify conflicts.

<u>Note:</u>

- 8-sigma BS envelopes assumed.
- All sextupoles within the region of interest were superconducting → not investigated.



Overview of BS position relative to beamline. Image courtesy of A. Ciarna.

Method for preliminary magnet designs

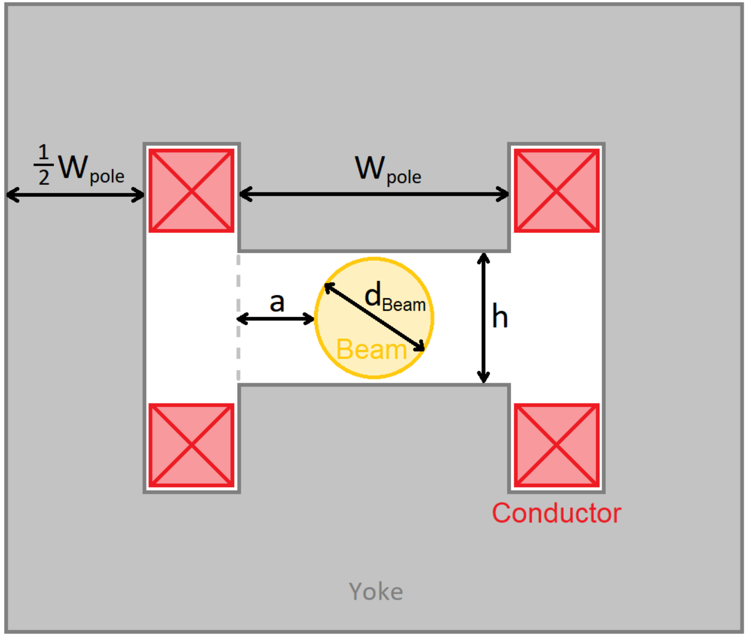
Dipoles

Assumptions made:

- H-shaped cross-section.
- Conductor shape and current density assumed.
- Spacing around beam aperture and conductors assumed.

Dimensions then given by magnet strength and beam aperture:

- Max field per magnet given by: $B_{max} = 3.3356 K_0 (B\rho)_{max}$
- Current per pole approximated by: $NI \approx \frac{B_{max} h}{2\mu_0}$
- Pole tip overhang given by: $2\frac{a}{h} = -0.14 \ln\frac{\Delta B}{B} - 0.25$
- Pole width given by: $W_{pole} = d_{Beam} + 2a$



Method for preliminary magnet designs

<u>Quadrupoles</u>

Assumptions made:

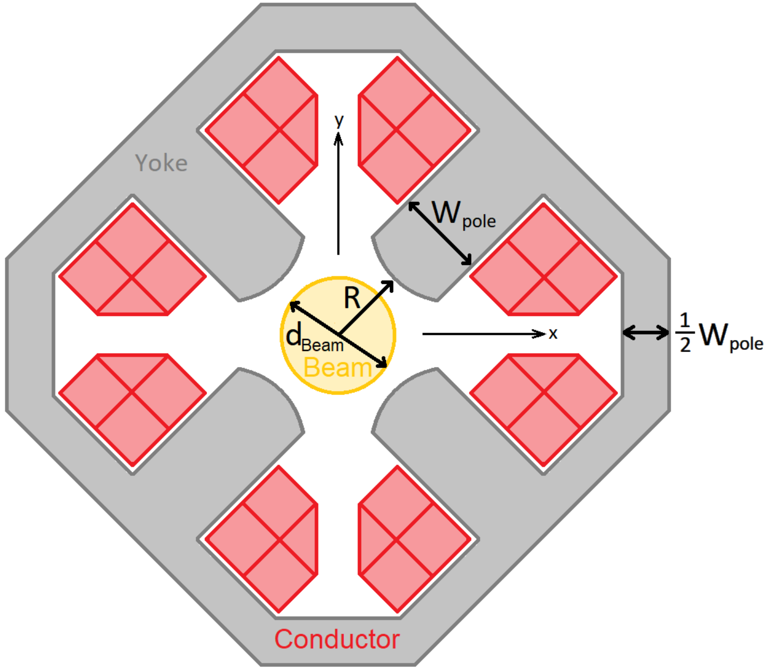
- Standard quadrupole cross-section.
- Straight poles assumed for simplicity.
- Conductor shape and current density assumed.
- Spacing around beam aperture and conductors assumed.

Dimensions then given by magnet strength and beam aperture:

- Max gradient per magnet given by:

$$G_{max} = 3.3356 K_1 (B\rho)_{max}$$

- Current per pole approximated by: $NI \approx \frac{G_{max} r^2}{2\mu_0}$
- Hyperbolic pole tips assumed: $2xy = R^2$
- Pole tip cut-off points given by conformal mapping of an optimal dipole tip; the cut-off points determine the pole width.



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Magnet-BS conflicts along lattice

- BS envelope within beam aperture
- BS envelope intersects beam aperture edge
- BS envelope intersects magnet poles
- BS envelope intersects magnet back-leg
- BS envelope fully separated from magnet cross-section

Name	L [m]	S [m]	BS status	Comment
QC4.1	3.50	24.55		BS envelope within beam aperture for all magnets before and up to this point.
BC1.1	39.39	64.25		BS envelope intersects beam aperture edge, enlarged vacuum chamber (VC) needed.
QC5.1	3.50	68.05		Magnet aperture radius needs to be enlarged significantly.
BC2.1	1.70	70.05		BS envelope intersects beam aperture edge, enlarged VC needed.
QC6.1	3.50	73.85		Magnet aperture radius needs to be enlarged significantly.
BC3.1	39.66	113.81		C-shape cross-section required.
QC7.1	3.50	117.61		Figure-of-eight cross-section required.
SY1R.1	0.15	118.06	-	Superconducting; not investigated.
SY1R.2	0.15	118.21	-	Superconducting; not investigated.
BC4.1	29.92	148.43		C-shape cross-section required.
QY2.1	3.50	152.23		BS envelope outside of magnet cross-section.
BC5.1	42.45	194.98		BS envelope outside of magnet cross-section, no conflicts foreseen beyond this point.

Magnet-BS conflicts along lattice

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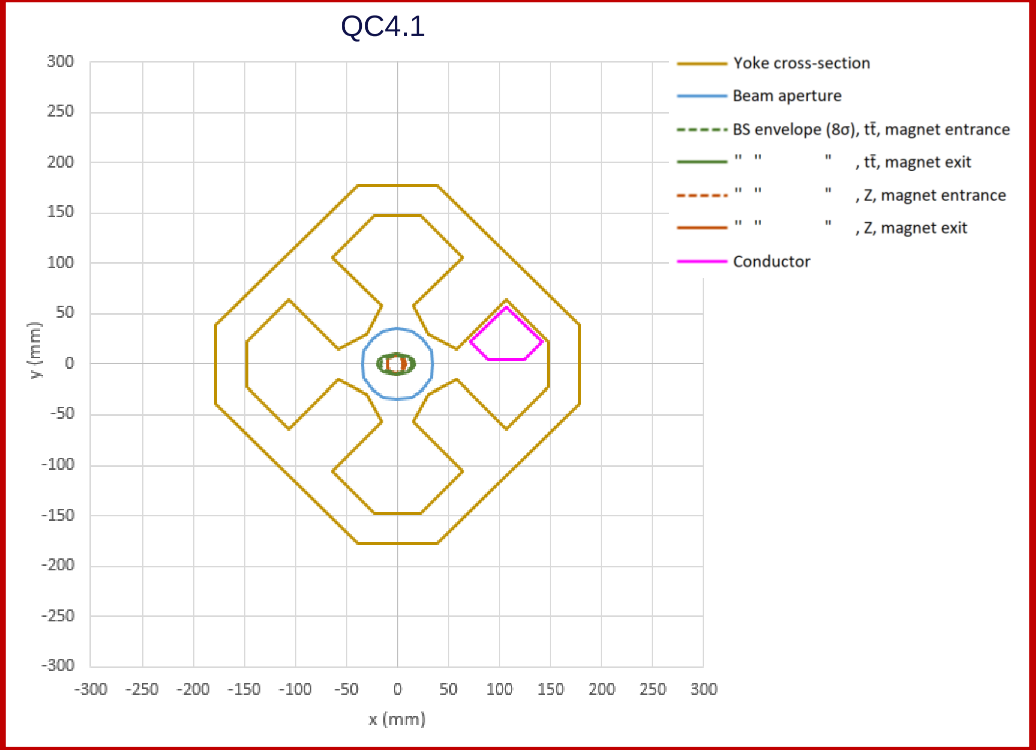

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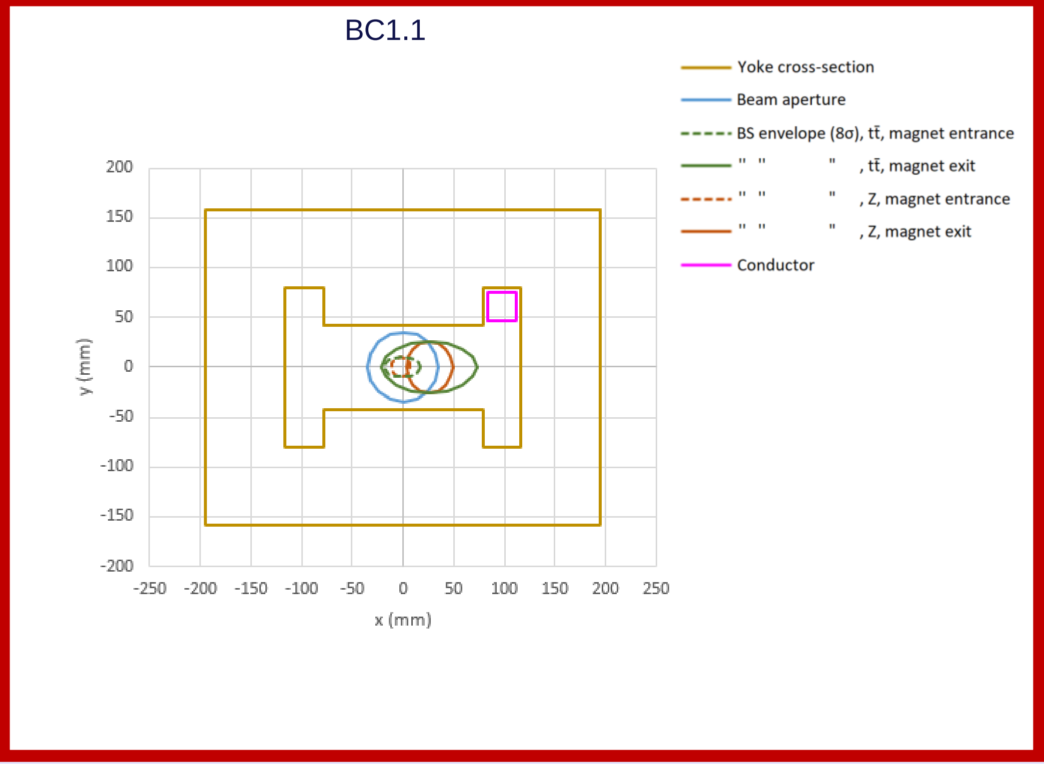

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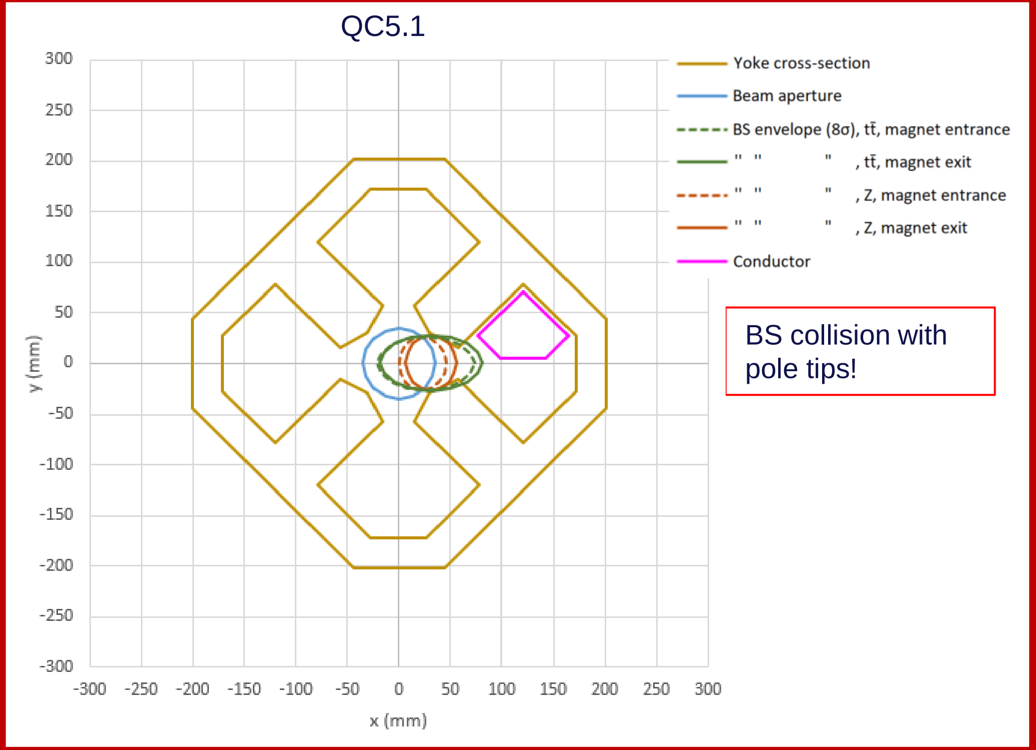

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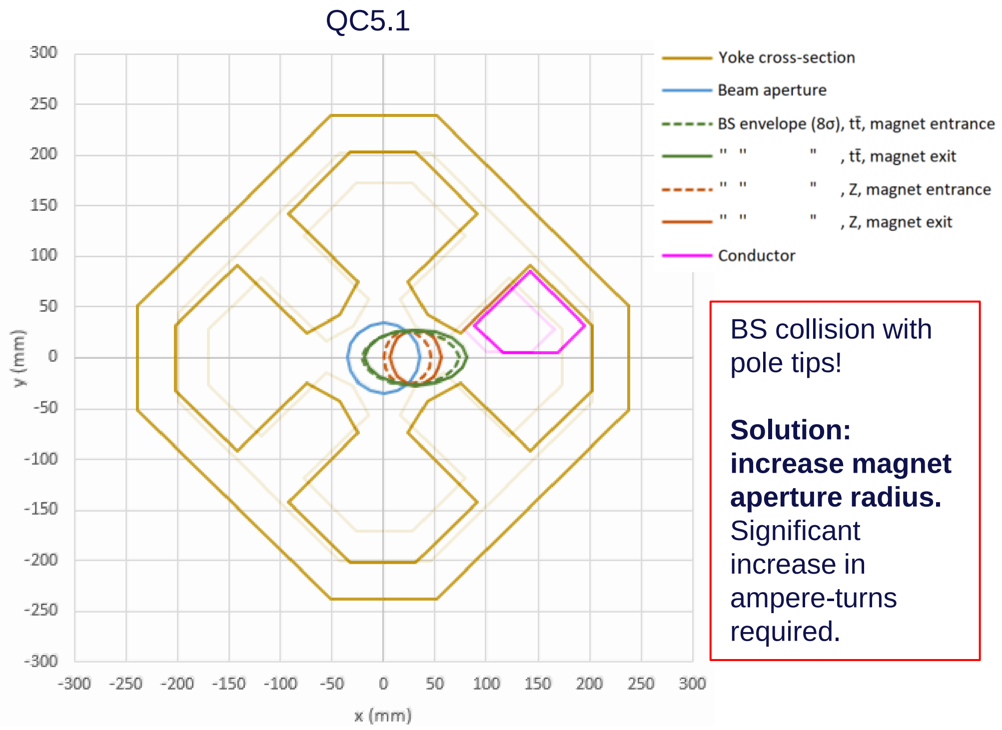

BS collision with pole tips!

Solution: increase magnet aperture radius. Significant increase in ampere-turns required.

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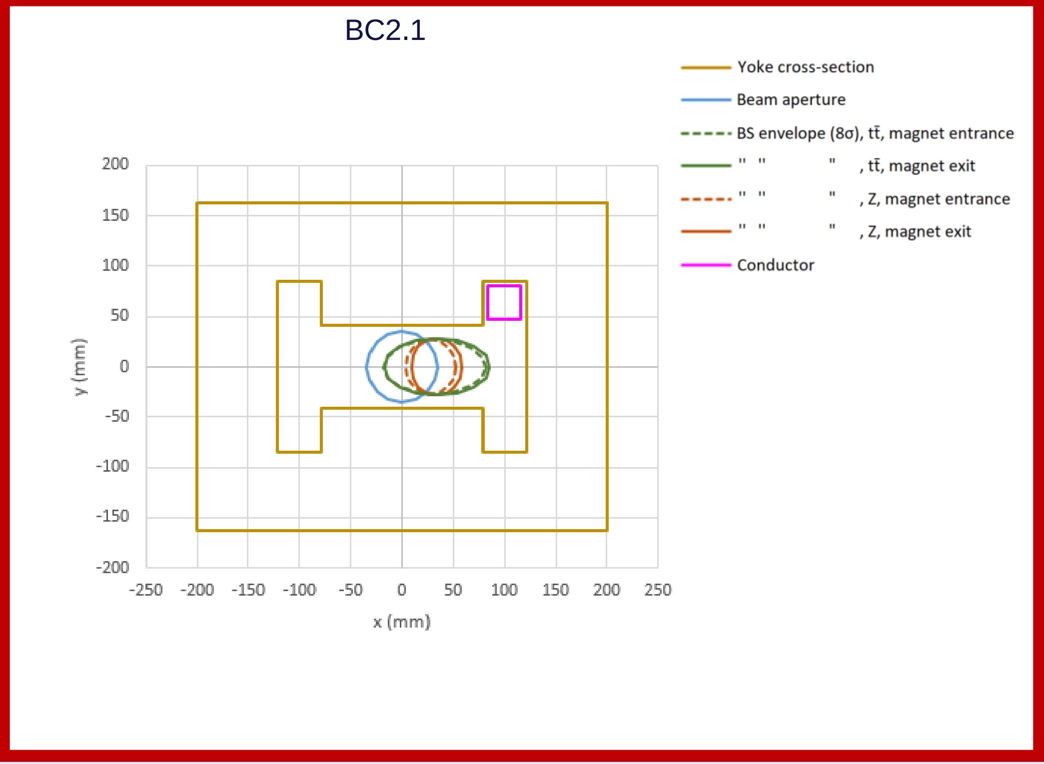

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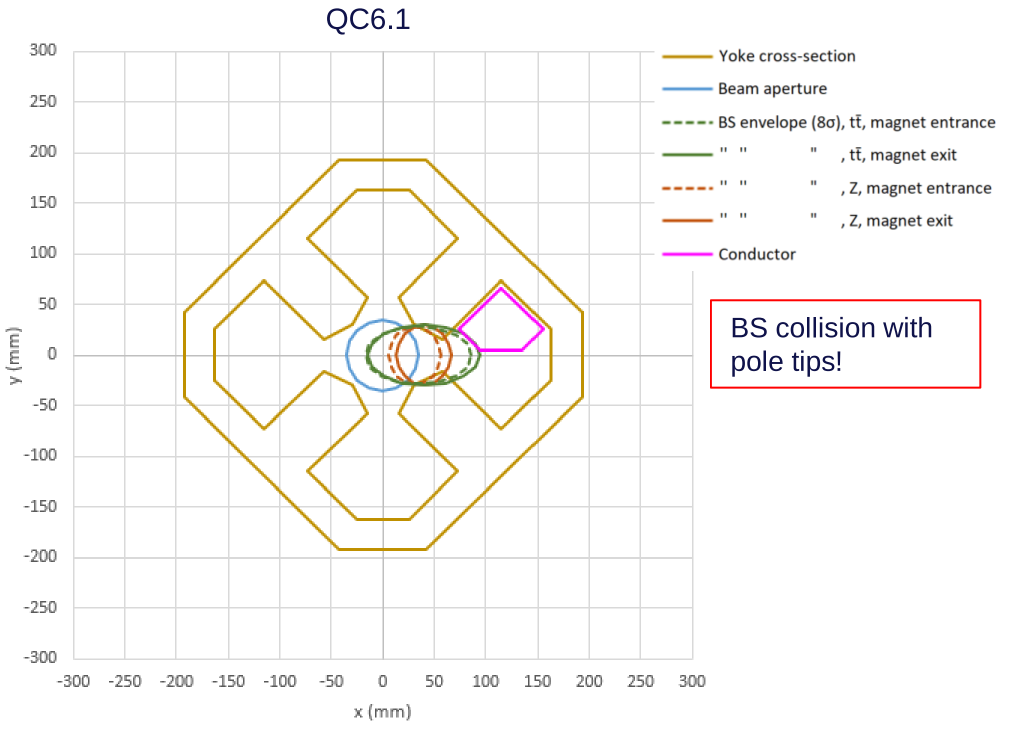

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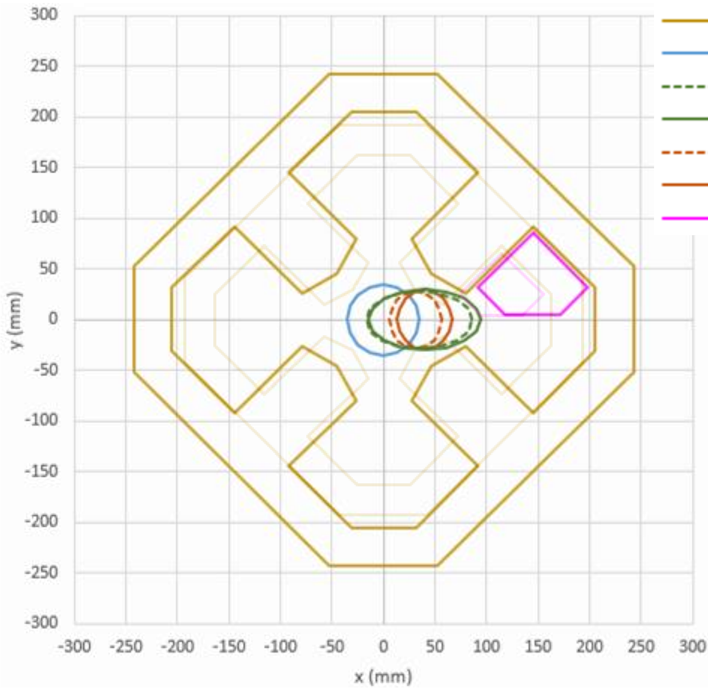
QC6.1



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Solution: increase magnet aperture radius. Significant increase in ampere-turns required.

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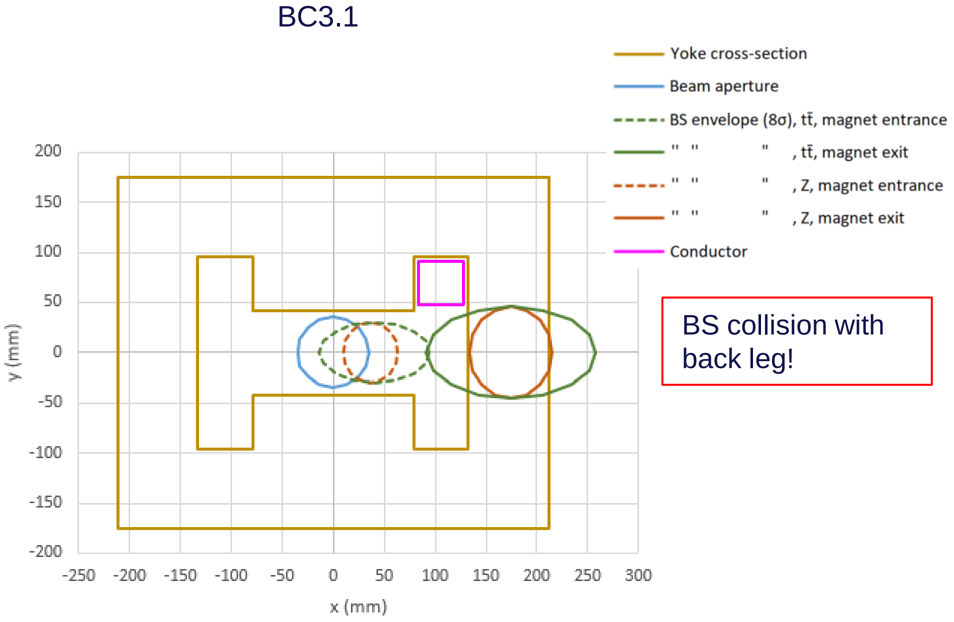

BS collision with back leg!

Magnet-BS conflicts along lattice

- BS envelope within beam aperture (blue)
- BS envelope intersects beam aperture edge (yellow)
- BS envelope intersects magnet poles (red)
- BS envelope intersects magnet back-leg (orange)
- BS envelope fully separated from magnet cross-section (green)

Name	L [m]	S [m]	BS status	Comm
QC4.1	3.50	24.55	(blue)	BS env
BC1.1	39.39	64.25	(yellow)	BS env
QC5.1	3.50	68.05	(red)	Magne
BC2.1	1.70	70.05	(yellow)	BS env
QC6.1	3.50	73.85	(red)	Magne
BC3.1	39.60	113.81	(orange)	C-shap
QC7.1	3.50	117.61	(orange)	Figure-
SY1R.1	0.15	118.06	-	Superc
SY1R.2	0.15	118.21	-	Superc
BC4.1	29.92	148.43	(orange)	C-shap
QY2.1	3.50	152.23	(green)	BS env
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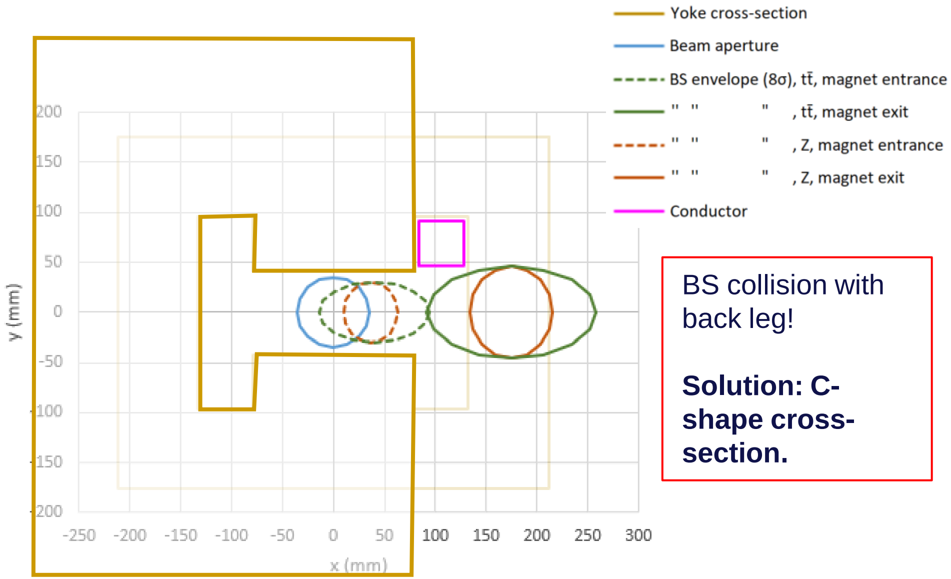
BC3.1



BS collision with back leg!

Solution: C-shape cross-section.

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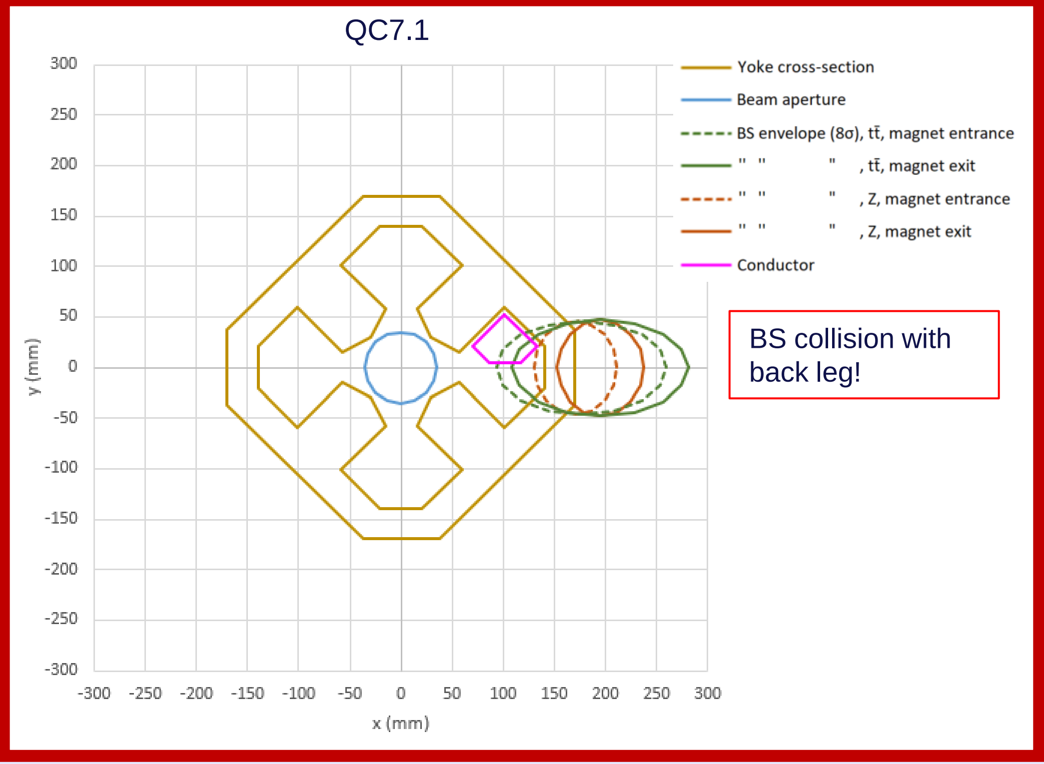

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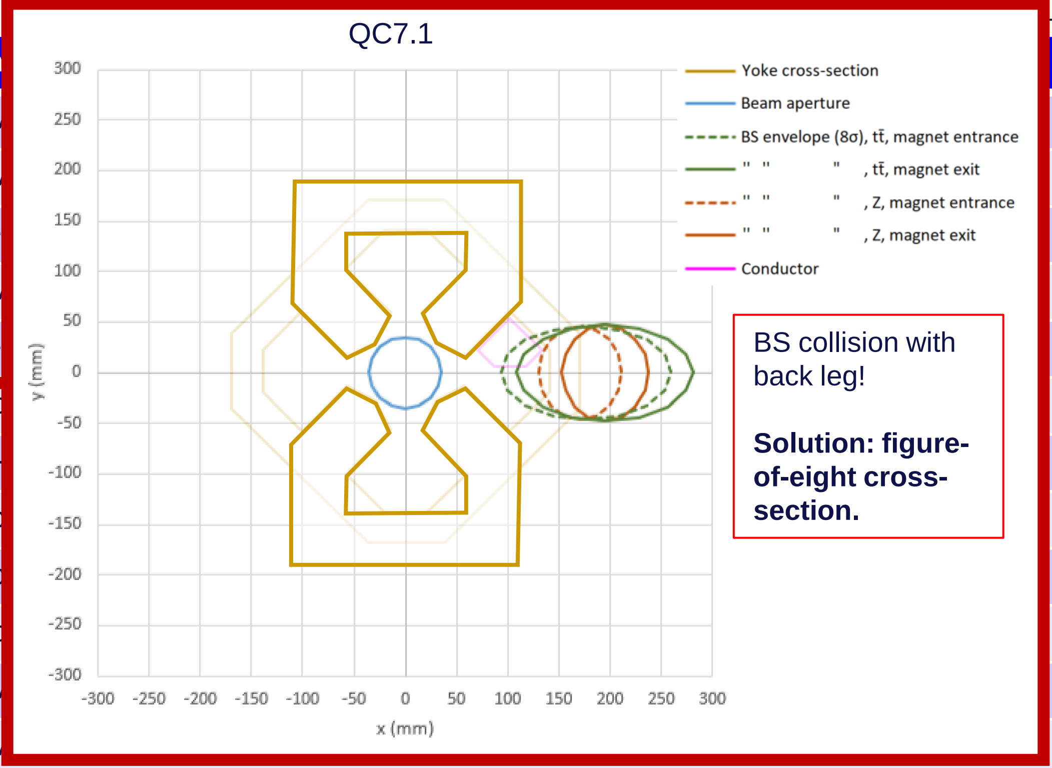

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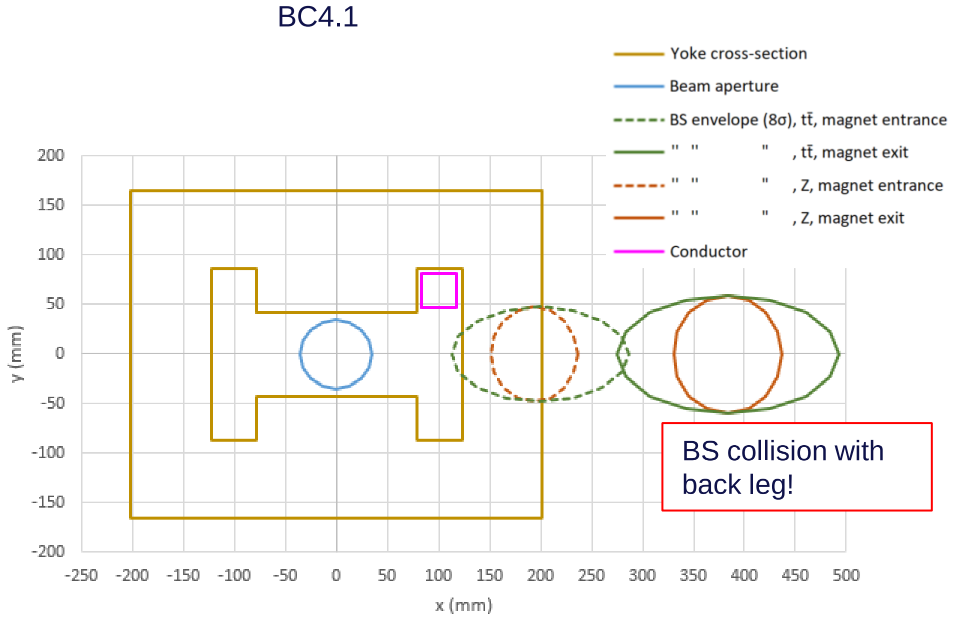

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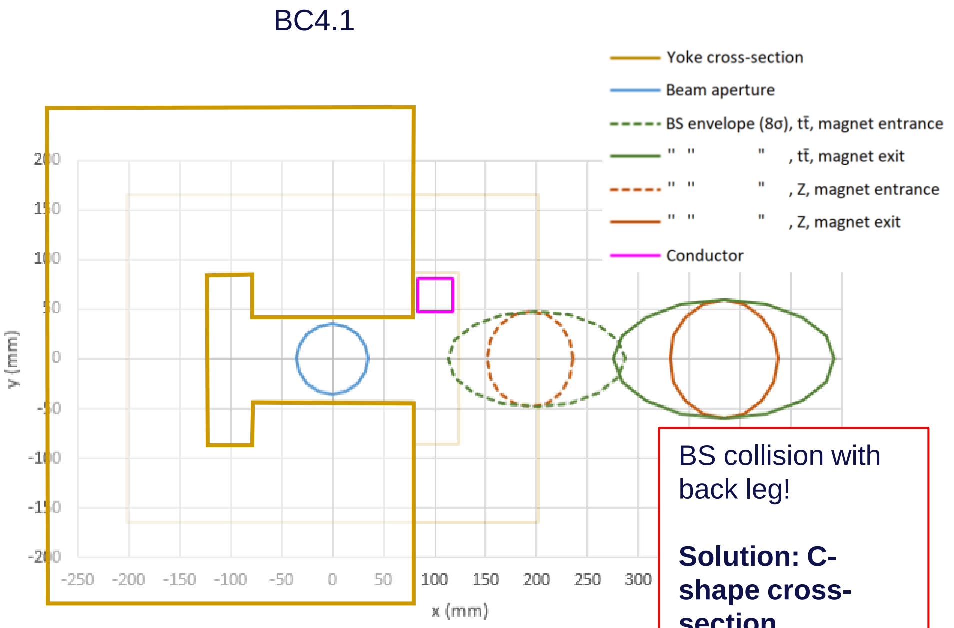

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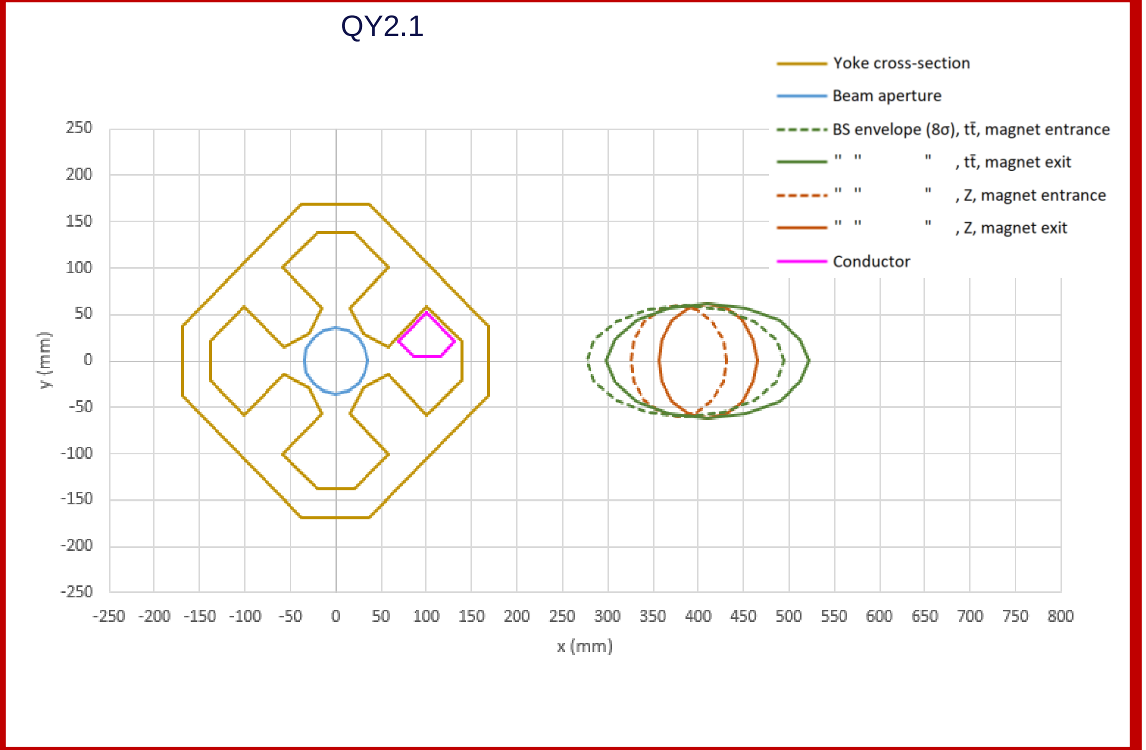

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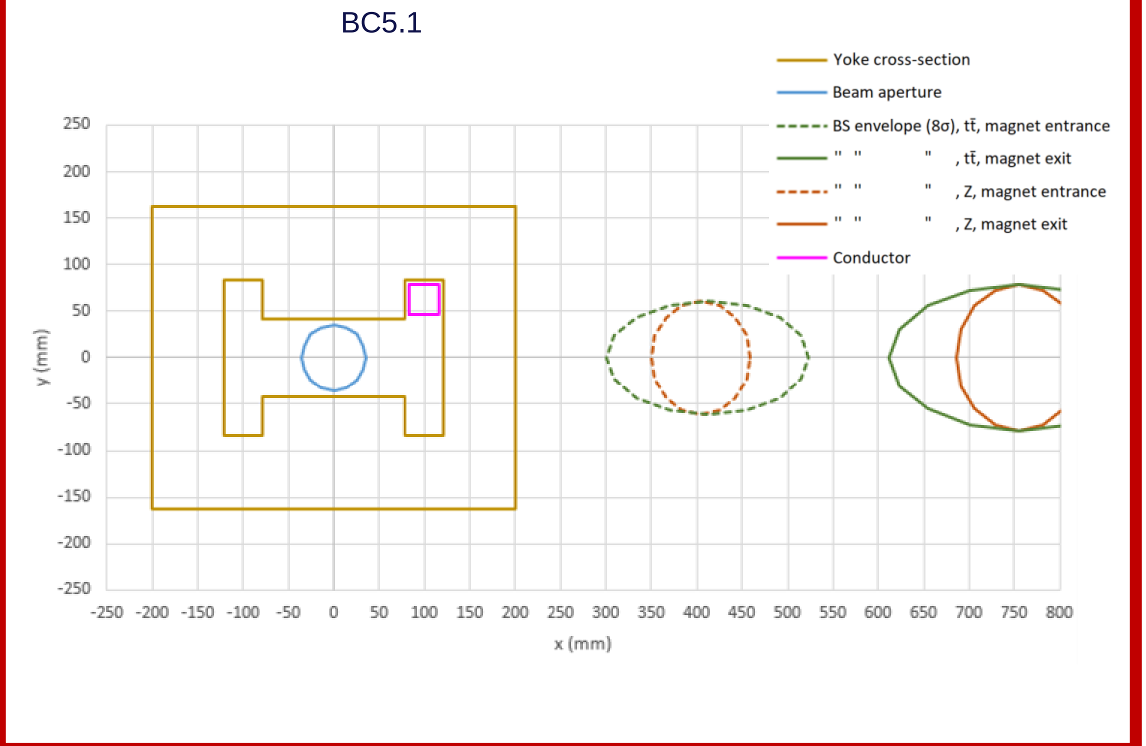

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Dipoles – design requirements

Region of BS-magnet conflicts

Name	Length [m]	B_{max} [T]	NI_{max} [A]	Comments
BC1.1	39.39	0.023	752	
BC2.1	1.70	0.032	1085	Short length
BC3.1	39.66	0.058	1943	C-shape
BC4.1	29.92	0.035	1164	C-shape
BC5.1	42.45	0.031	1035	
BC6.1	42.45	0.034	1136	
BC7.1	29.92	0.057	1918	
BS1.1	33.64	0.059	1958	
BS2.1	4.66	0.019	636	Short length
BS3.1	4.73	0.006	207	Short length
BG1.1, BG1.2, ...	20.72	0.067	2247	Large series

Dipole design requirements, for the first ~900 m downstream of the IR.

Only two cross-sections are needed for all dipole sections:

- For C-shape dipoles (BC3.1 and BC4.1), the cross-section adapted to the highest field (BC3.1) can be used for both.
- For the rest, the cross-section of BG1.1 can be used.

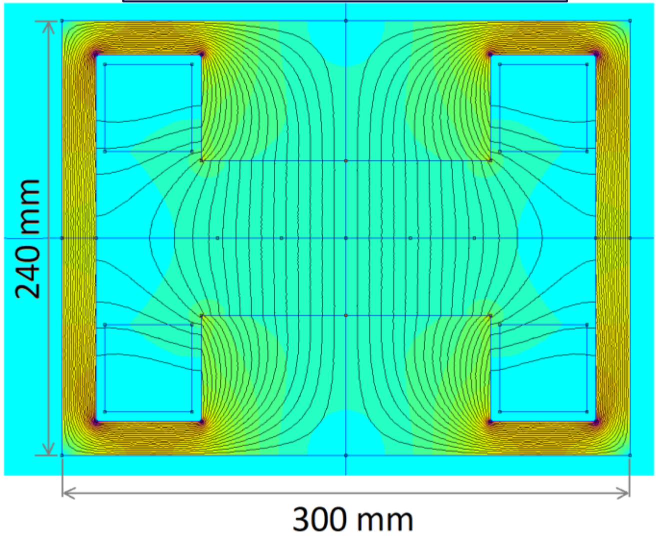
Some points to note:

- Varying ampere-turn requirements complicates series coupling between different dipole sections.
- Different lengths of the sections complicate standardization.
  - Longer sections must be divided into several magnets. Common magnet lengths could be found for several of these sections.

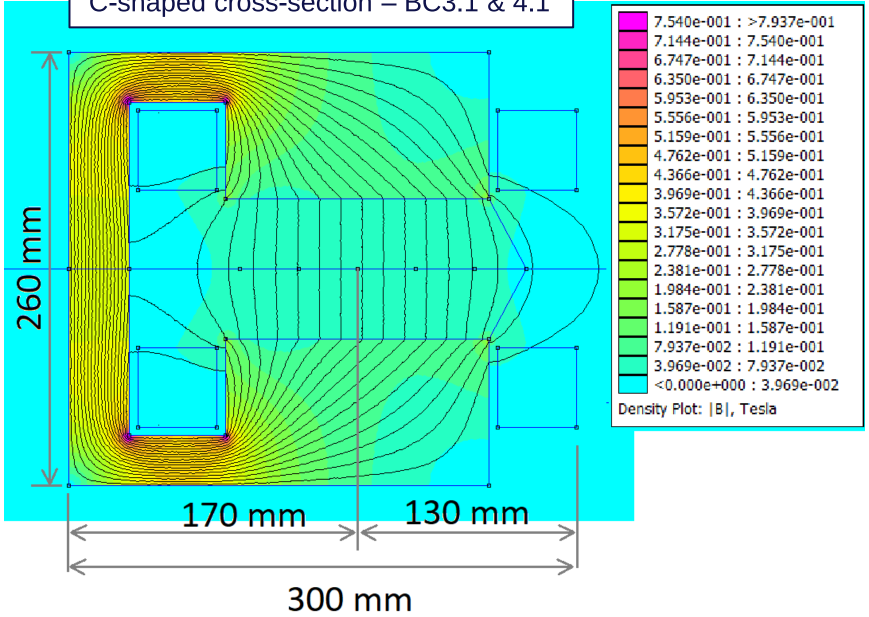
Dipoles – cross-sections

- Possible to reduce the number of dipole cross-sections to 2
- Low induction levels allow for significantly narrowed back legs.

Common H-shaped cross-section



C-shaped cross-section – BC3.1 & 4.1



Magnetic simulation sofware used: FEMM

Quadrupoles – design requirements (1/2)

Name	Length [m]	B_{max} (tip) [T]	NI_{max} [A]	Comments
QC1L1.1	0.7	2.156	18872	Superconducting
QC1R2.1	1.3	2.198	19237	Superconducting
QC1R3.1	1.3	1.949	17059	Superconducting
QC2R1.1	1.3	1.073	11531	Superconducting
QC2R2.1	1.3	2.604	27979	Superconducting
QT1.1	1.0	0.186	3100	
QC3.1	3.5	0.550	9189	
QC4.1	3.5	0.380	6346	
QC5.1	3.5	0.946	24471	Enlarged aperture to accomodate BS
QC6.1	3.5	0.806	20856	Enlarged aperture to accomodate BS
QC7.1	3.5	0.312	5212	Figure-of-eight cross-section
QY2.1	3.5	0.302	5053	
QY1.1	3.5	0.248	4137	
QY2.2	3.5	0.302	5053	
QA1.1	2.9	0.387	6460	
QA2.1	2.9	0.334	5584	
QA3.1	2.9	0.110	1840	

Region of BS-magnet conflicts

- Large range of field and current requirements makes optimizing the cross-section for every magnet costly.
- As for the dipoles, a common cross-section could be used for all quads (except QC5.1 - 7.1) to simplify manufacturing.
- Small number of different lengths means a high potential for standardization.

Quadrupoles – design requirements (2/2)

Name	Length [m]	B_{max} (tip) [T]	NI_{max} [A]	Comments
QA4.1	2.9	0.380	6355	
QA5.1	2.9	0.375	6274	
QA6.1	2.9	0.327	5468	
QS1.1	1.8	0.416	6944	
QS2.1	1.8	0.439	7339	
QS3.1	1.8	0.302	5040	
QFG2.1	2.9	0.479	8004	
QDG1.1	1.8	0.767	12811	
QFG2.2	2.9	0.479	8004	
QDG1.2	1.8	0.767	12811	

Quadrupole design requirements, for the first ~900 m downstream of the IR.

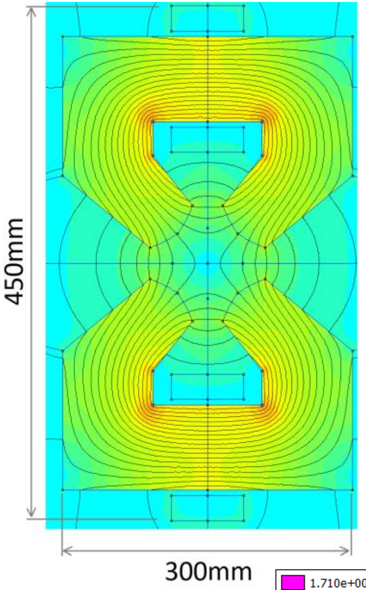
- Large range of field and current requirements makes optimizing the cross-section for every magnet costly.
- As for the dipoles, a common cross-section could be used for all quads (except QC5.1 - 7.1) to simplify manufacturing.
- Small number of different lengths means a high potential for standardization.

Quadrupoles – cross-sections

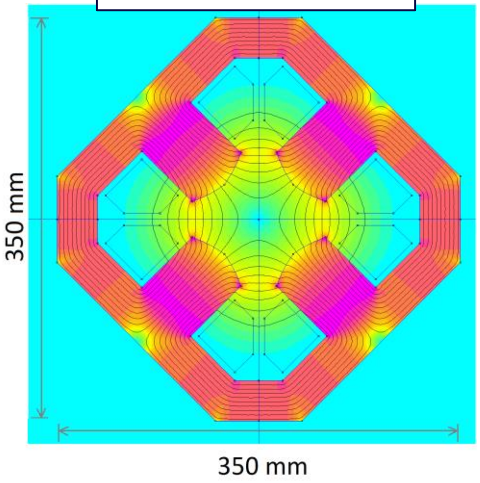
- Number of quad cross-sections can be reduced to 3

(All figures not necessarily the same scale in terms of size)

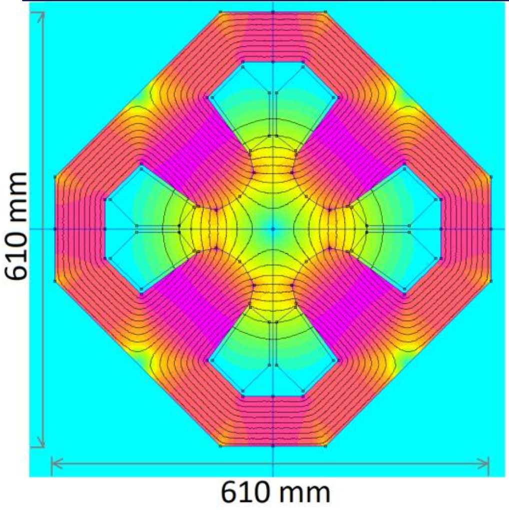
QC7.1 – Figure-of-eight

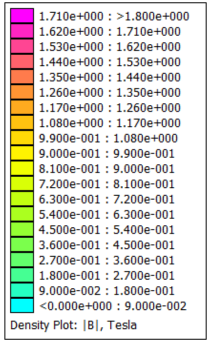


Common cross-section



QC5.1 & 6.1 – Enlarged aperture





Magnetic simulation sofware used: FEMM

Agenda

- Problem background and initial magnet design procedure
- Magnet-photon beam conflicts
- Magnet design requirements and cross-sections
- Space claim summary and conclusions

Space claim summary

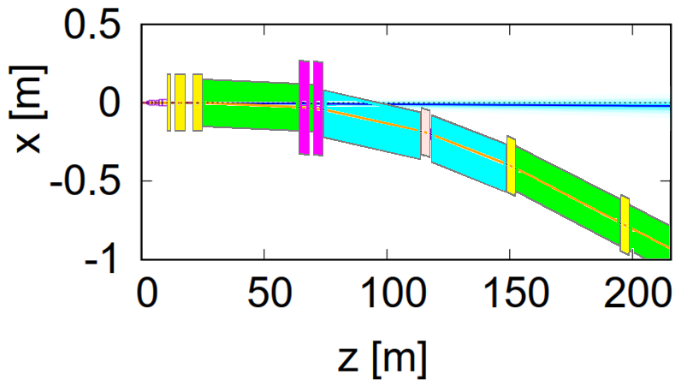
Name	S [m]	Length [m]	Height [mm]	Width [mm]	Cross-section
QC2R2.1	8.44	1.25	-	-	Superconducting; not investigated
QT1.1	11.73	1.00	350	350	Common quad cross-section
QC3.1	17.51	3.50	350	350	Common quad cross-section
QC4.1	24.55	3.50	350	350	Common quad cross-section
BC1.1	64.25	39.39	240	300	Common H-shape
QC5.1	68.05	3.50	610	610	Enlarged aperture
BC2.1	70.05	1.70	240	300	Common H-shape
QC6.1	73.85	3.50	610	610	Enlarged aperture
BC3.1	113.81	39.66	260	300	C-shape
QC7.1	117.61	3.50	450	300	Figure-of-eight cross-section
SY1R.1	118.06	0.15	-	-	Superconducting; not investigated
SY1R.2	118.21	0.15	-	-	Superconducting; not investigated
BC4.1	148.43	29.92	260	300	C-shape
QY2.1	152.23	3.50	350	350	Common quad cross-section
BC5.1	194.98	42.45	240	300	Common H-shape

Region of BS-magnet conflicts

All superconducting before this point → not investigated.

Same respective cross-sections for quads and dipoles beyond this point.

5 different cross-sections in total:
- Dipoles:
  - Common H-shape
  - C-shape
- Quads:
  - Common cross-section
  - Enlarged aperture
  - Figure-of-eight



Conclusions

- Accommodation of BS extraction line feasible, conflicts with magnets can be resolved.
- This first study gives rough estimates for the space needed for dipoles and quadrupoles downstream of the IR.
- Still a work in progress:
  - The issue of magnet lengths needs to be resolved, future iterations of the layout should take standardization into account, if possible.
  - Only preliminary designs at this stage.

FCC

Thank you for your attention.