Updated studies on PITZ radiation biology beamline

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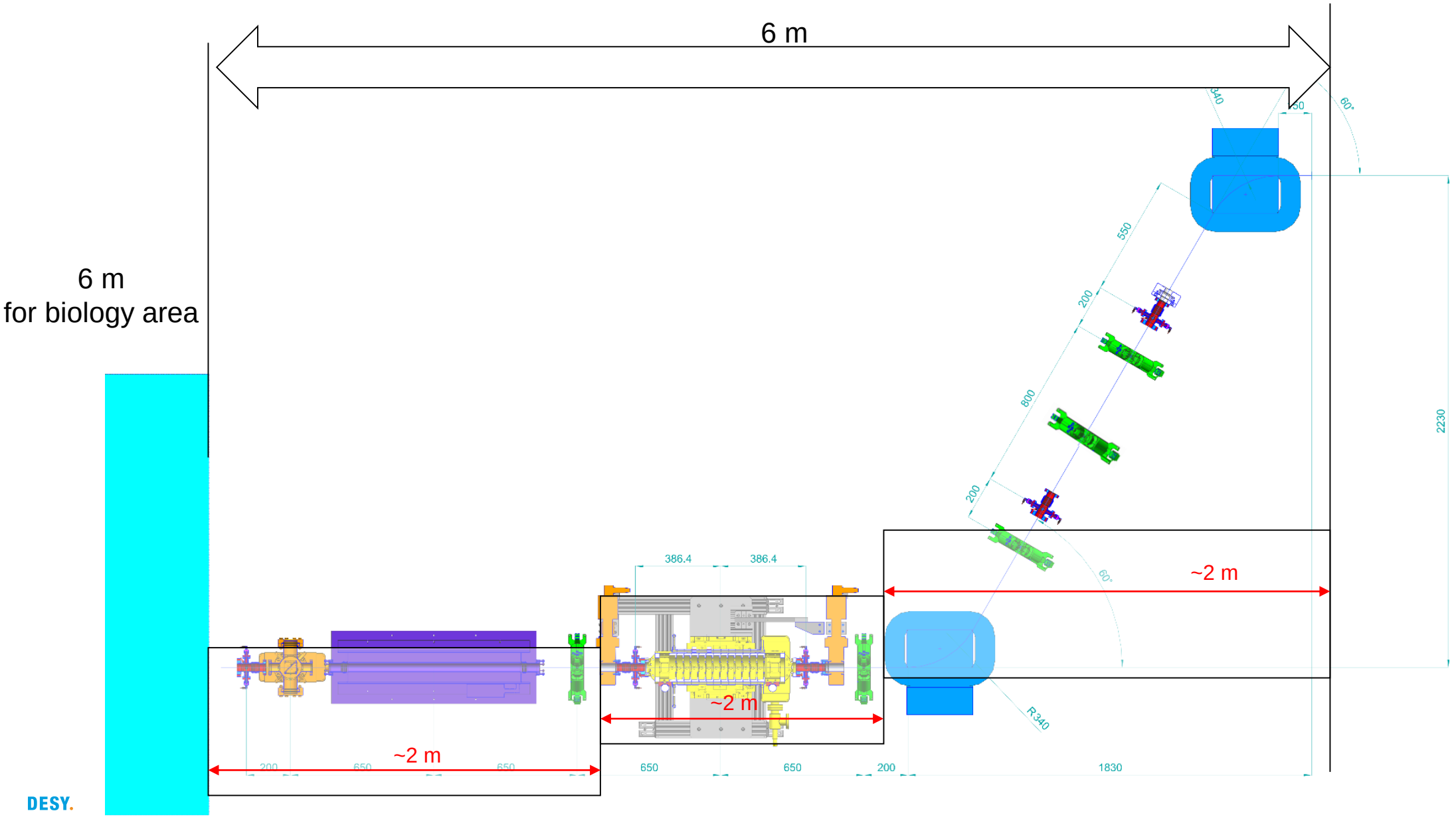
Outline

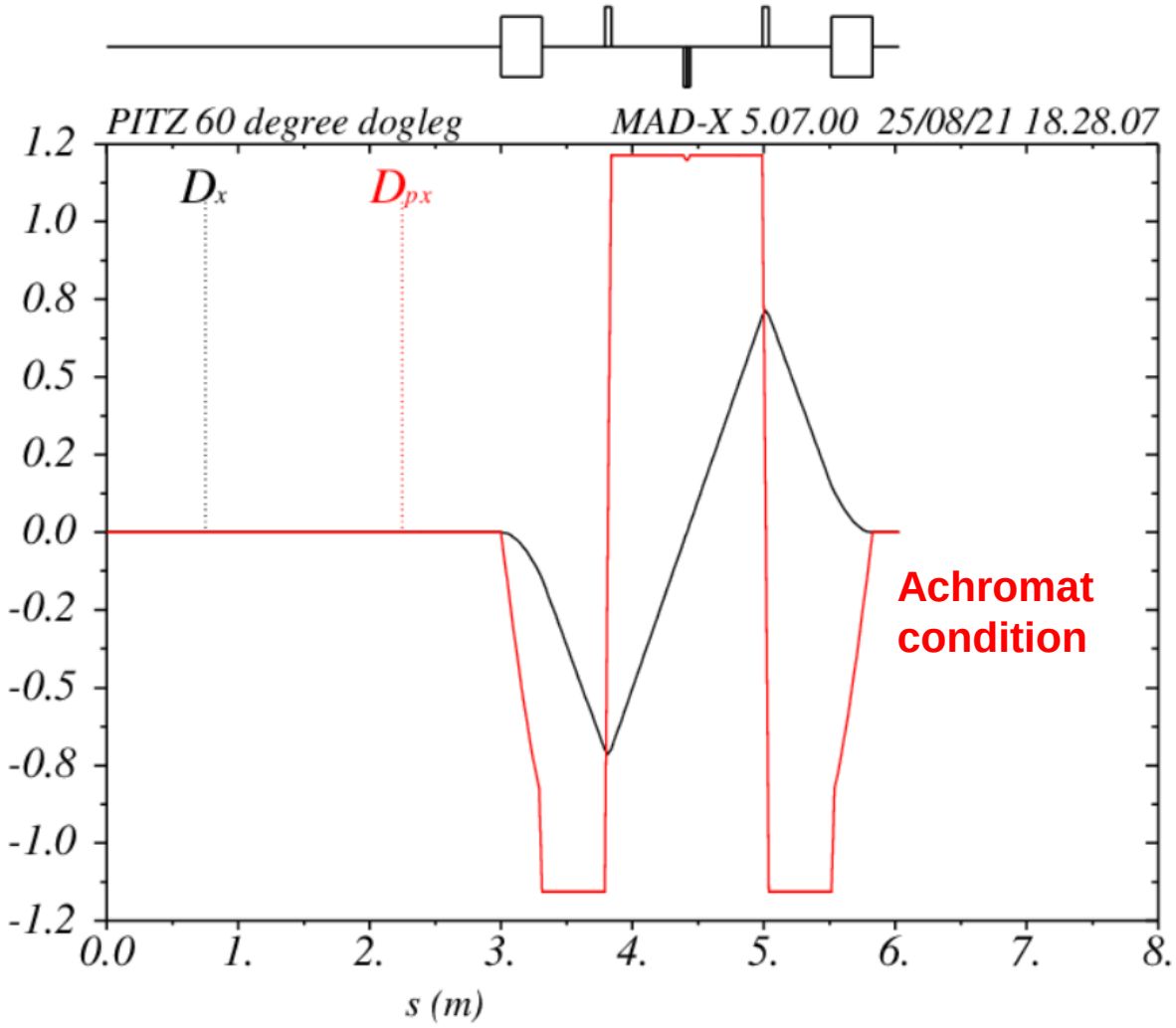
- Space charge effect in dogleg optics by SCO with a model beam
  - Vs bunch charge, vs emittance, vs peak current
- Beam optics simulation after dogleg for 1 nC case
- Some discussions for final focusing

Some boundary conditions

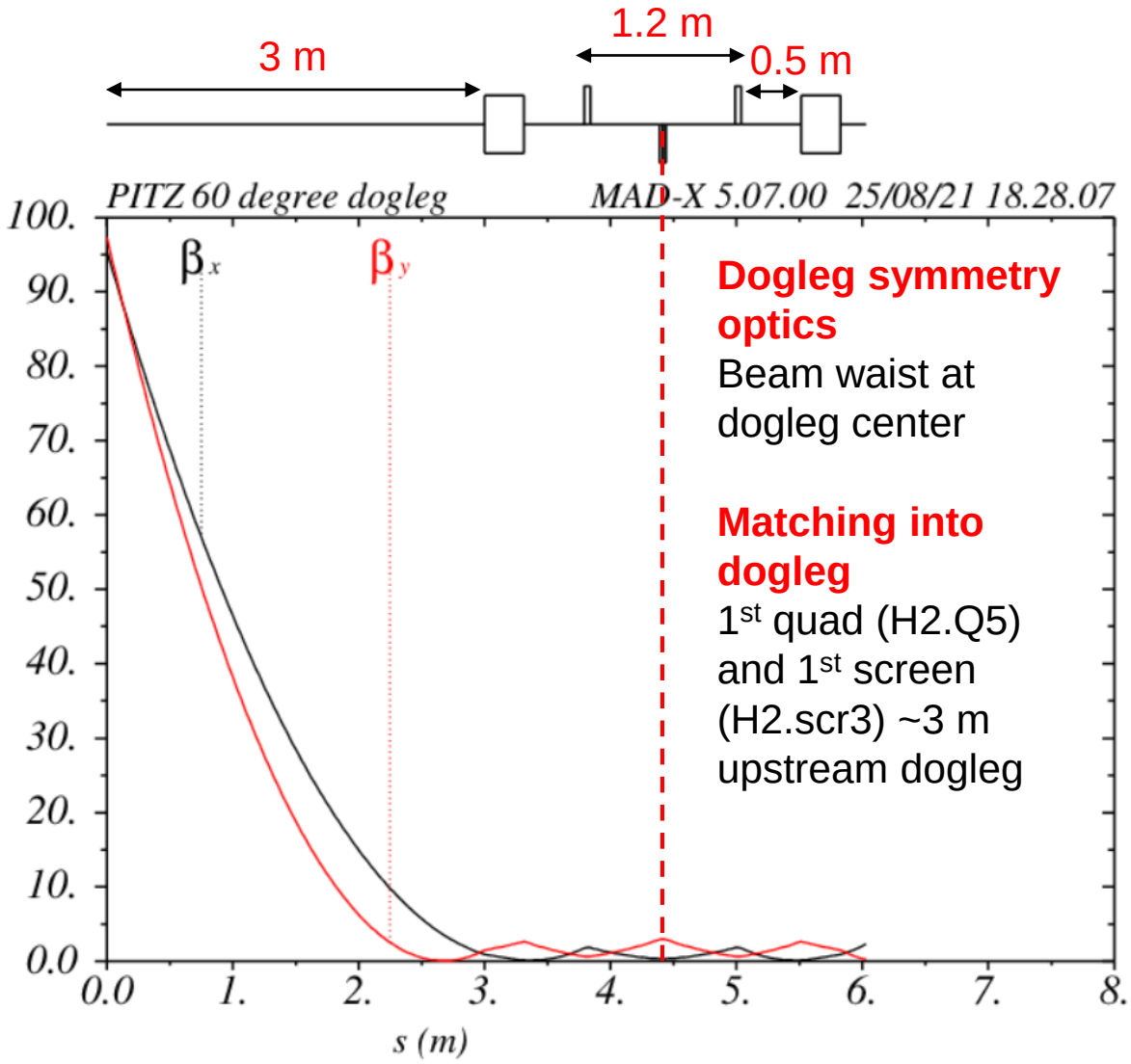


60 degree dogleg optics w/o space charge

By MadX



Achromat condition



Dogleg symmetry optics

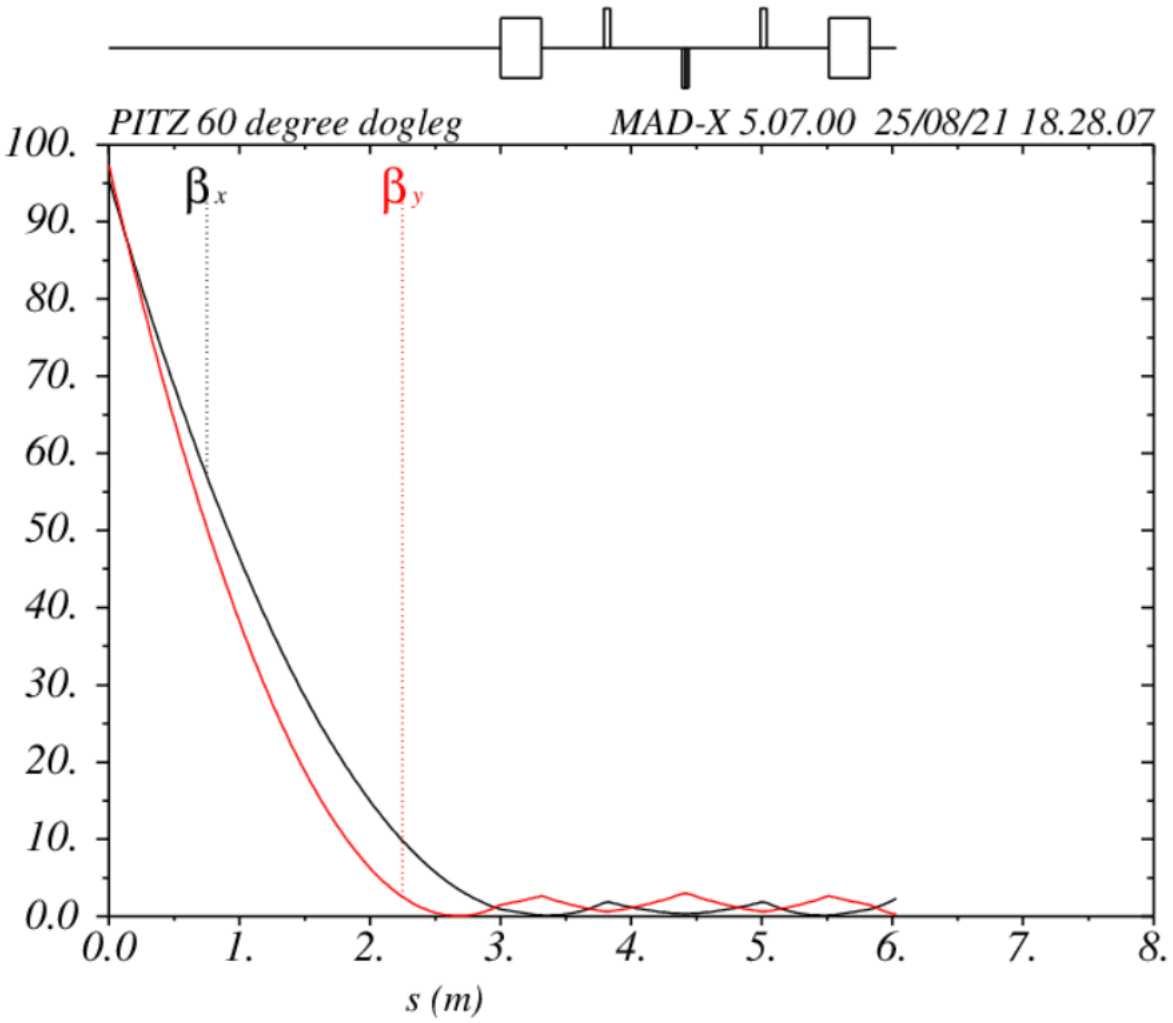
Beam waist at dogleg center

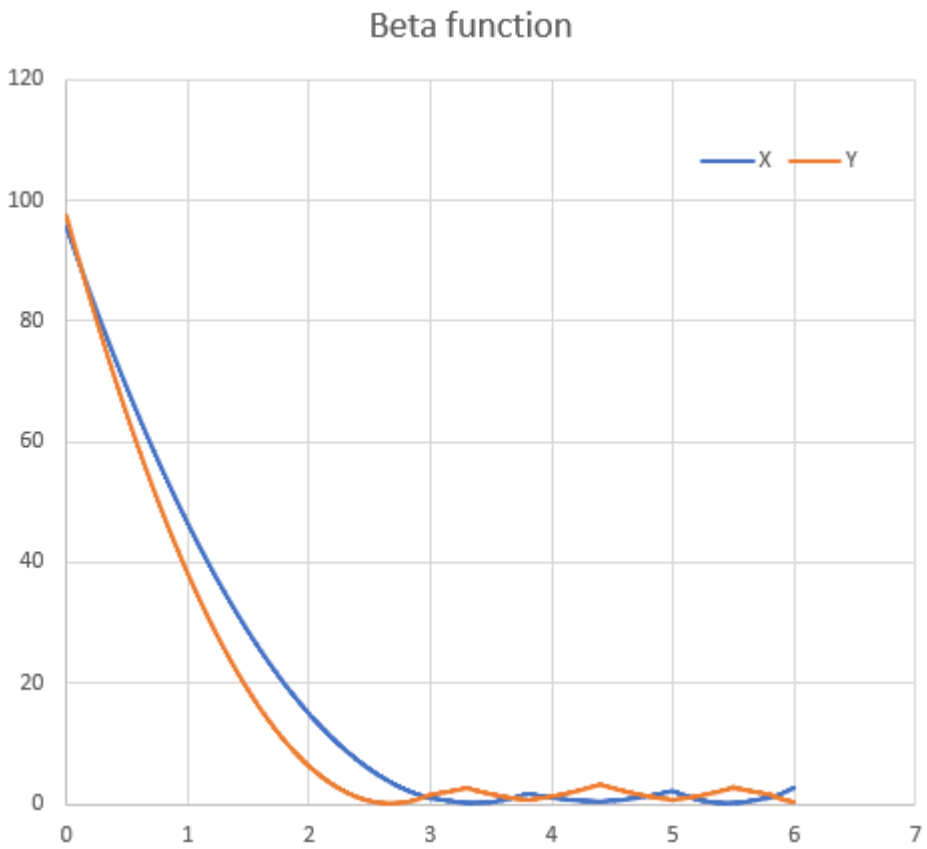
Matching into dogleg

1st quad (H2.Q5) and 1st screen (H2.scr3) ~3 m upstream dogleg

60 degree dogleg optics w/o space charge

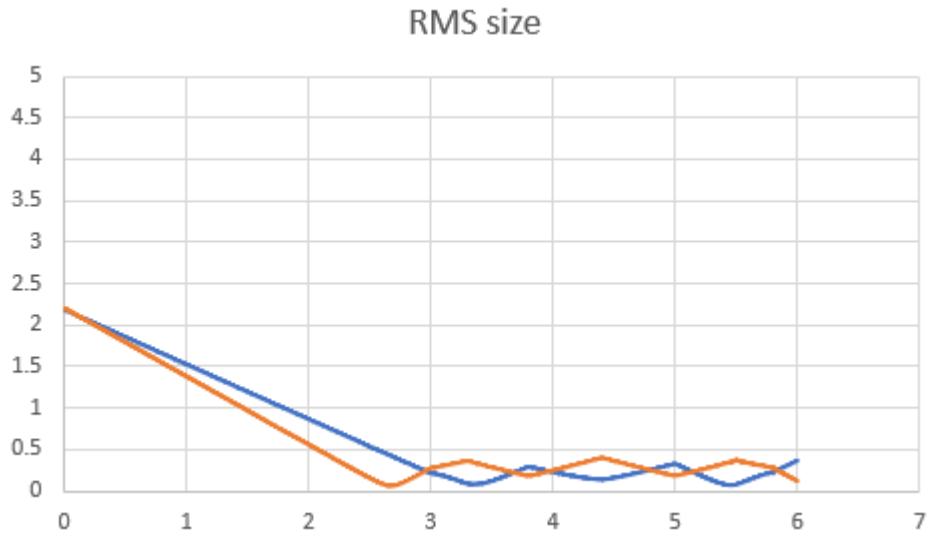
MadX vs SCO

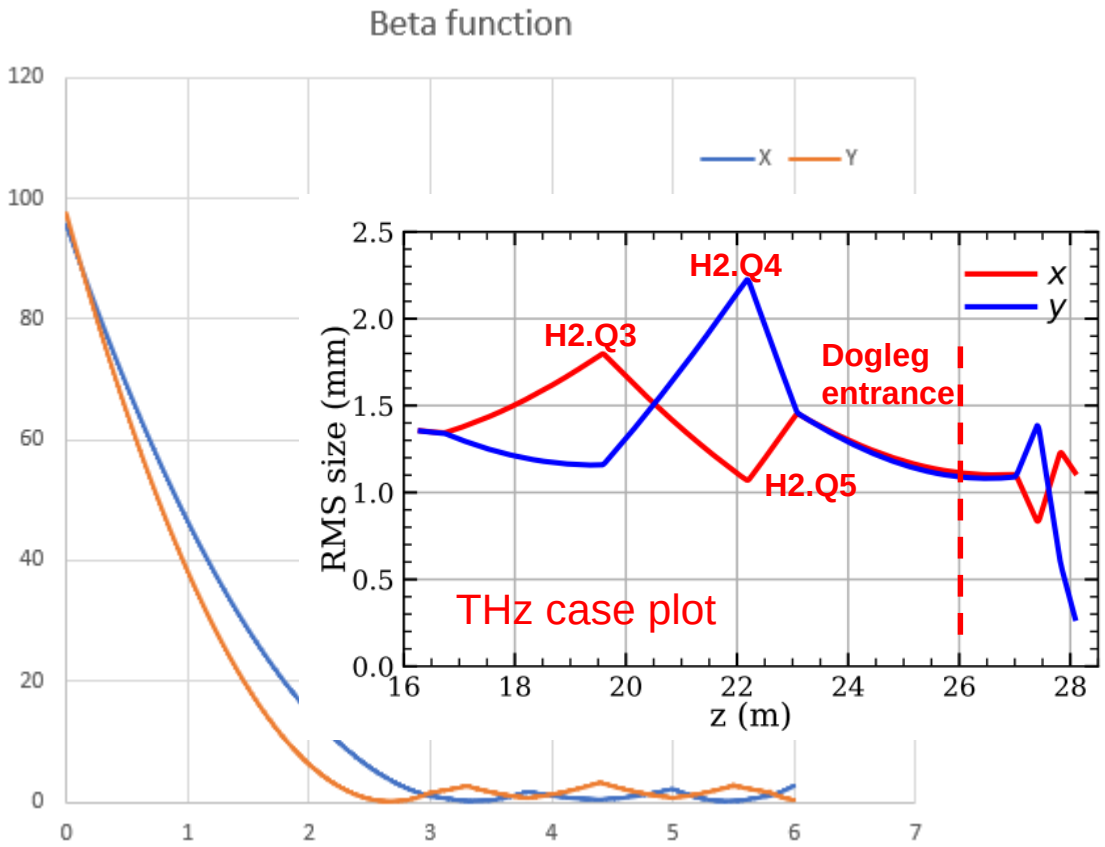




60 degree dogleg optics w/o space charge

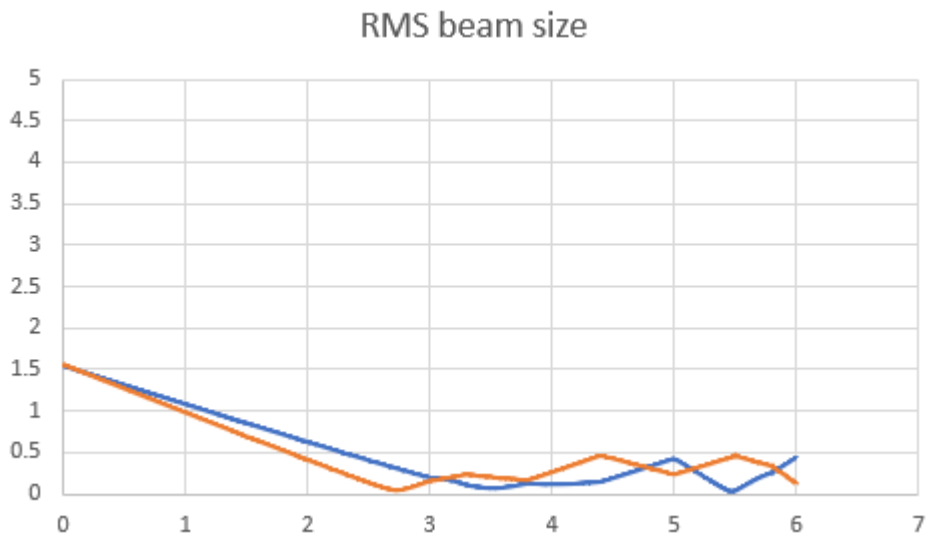
By SCO, 0 pC, 2 um.rad case

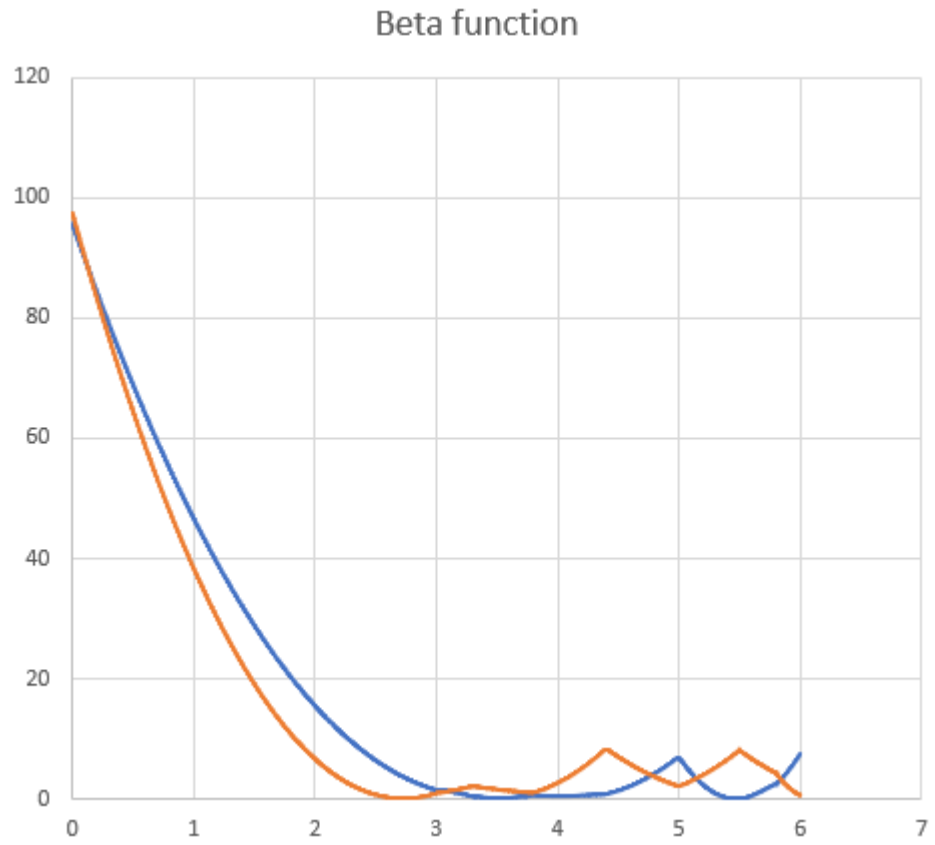




60 degree dogleg optics with space charge

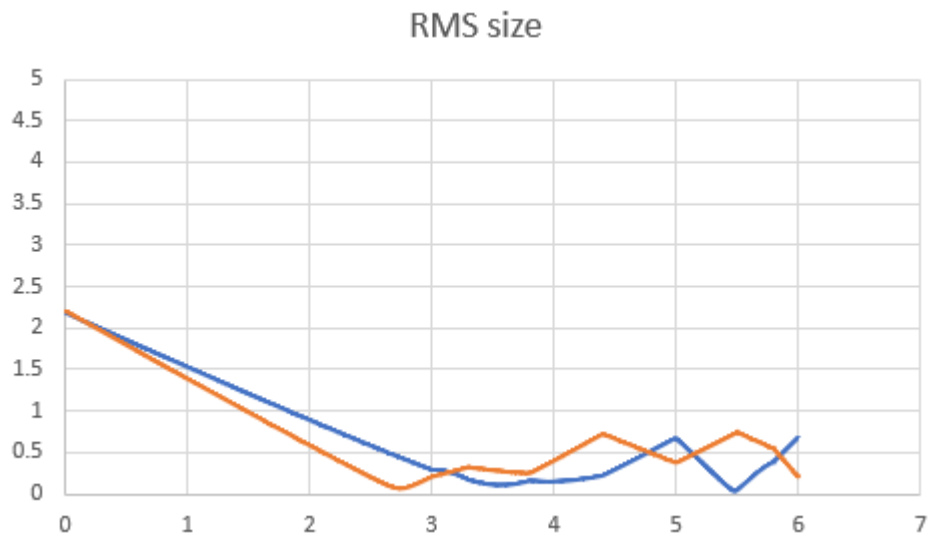
By SCO, 0.25 nC, 1 um.rad, 20 A

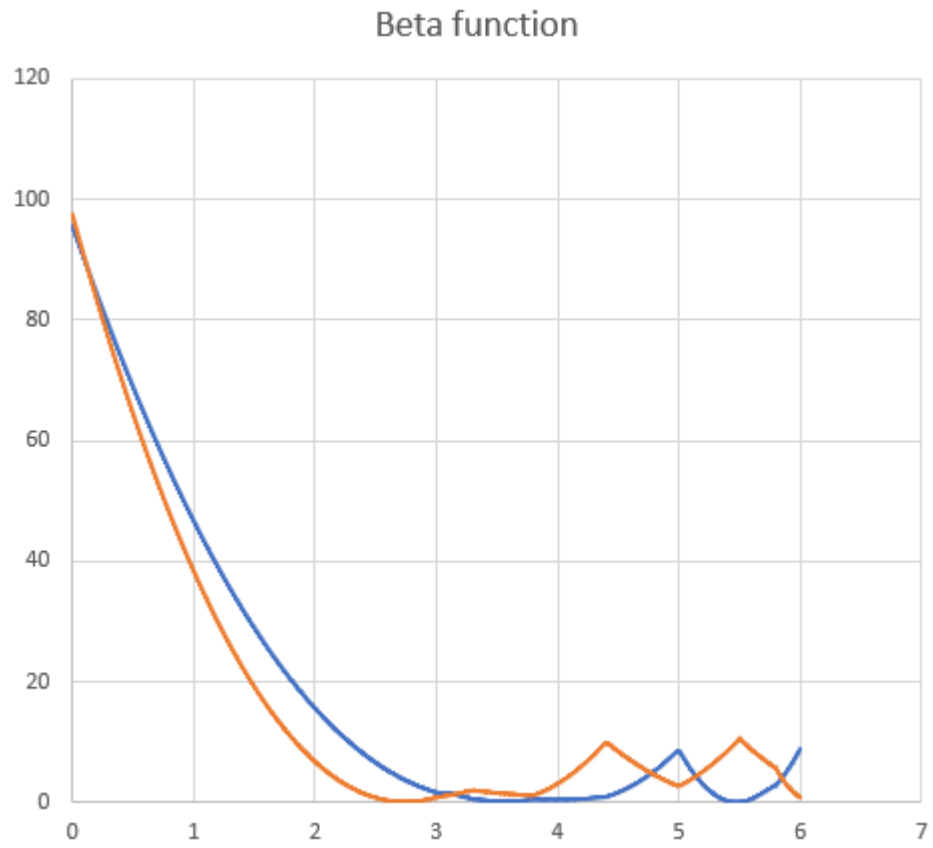




60 degree dogleg optics with space charge

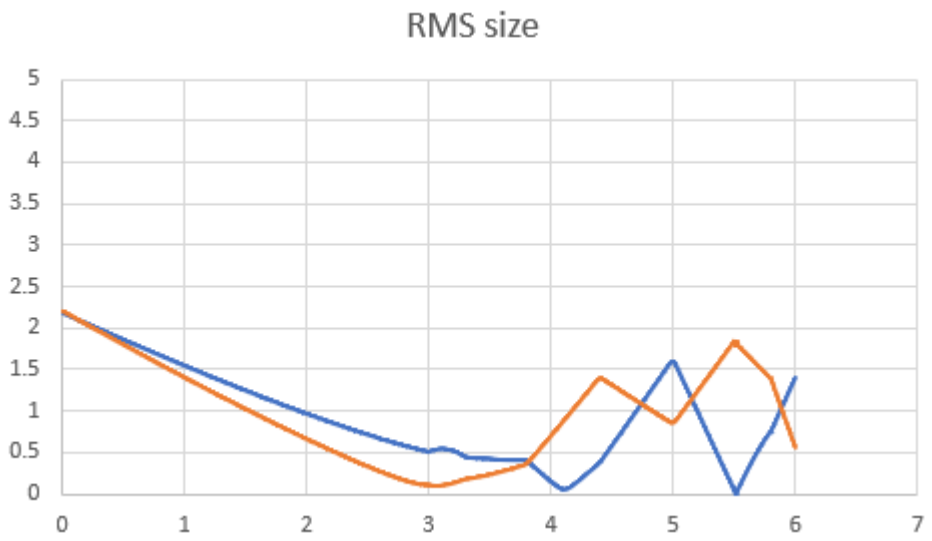
By SCO, 1 nC, 2 um.rad, 50 A

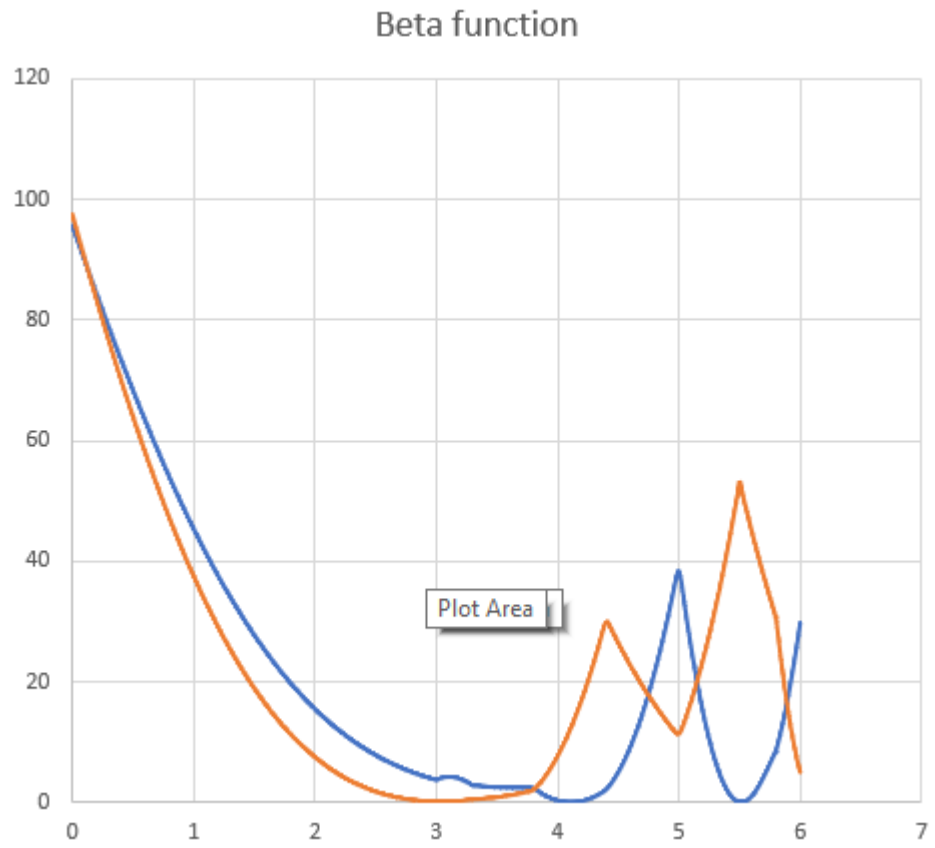




60 degree dogleg optics with space charge

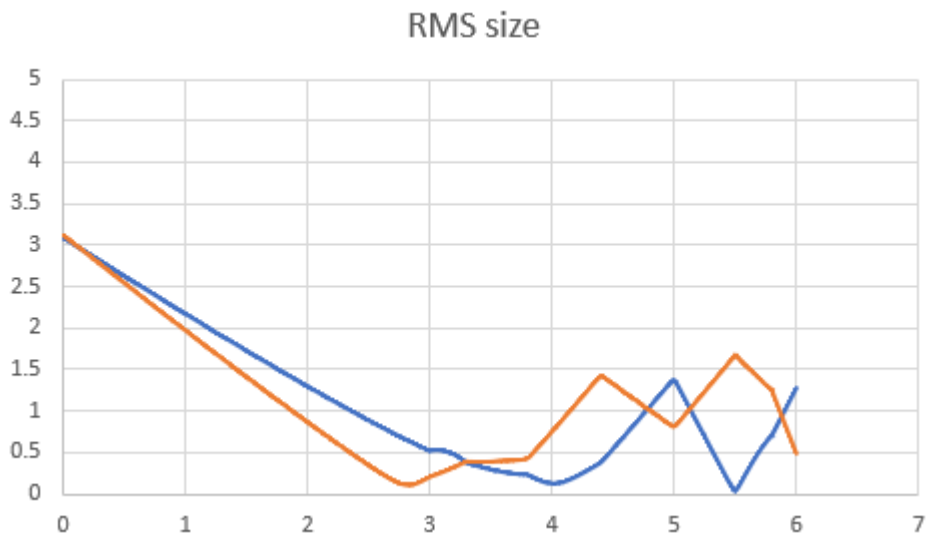
By SCO, 4 nC, 2 um.rad, 200 A

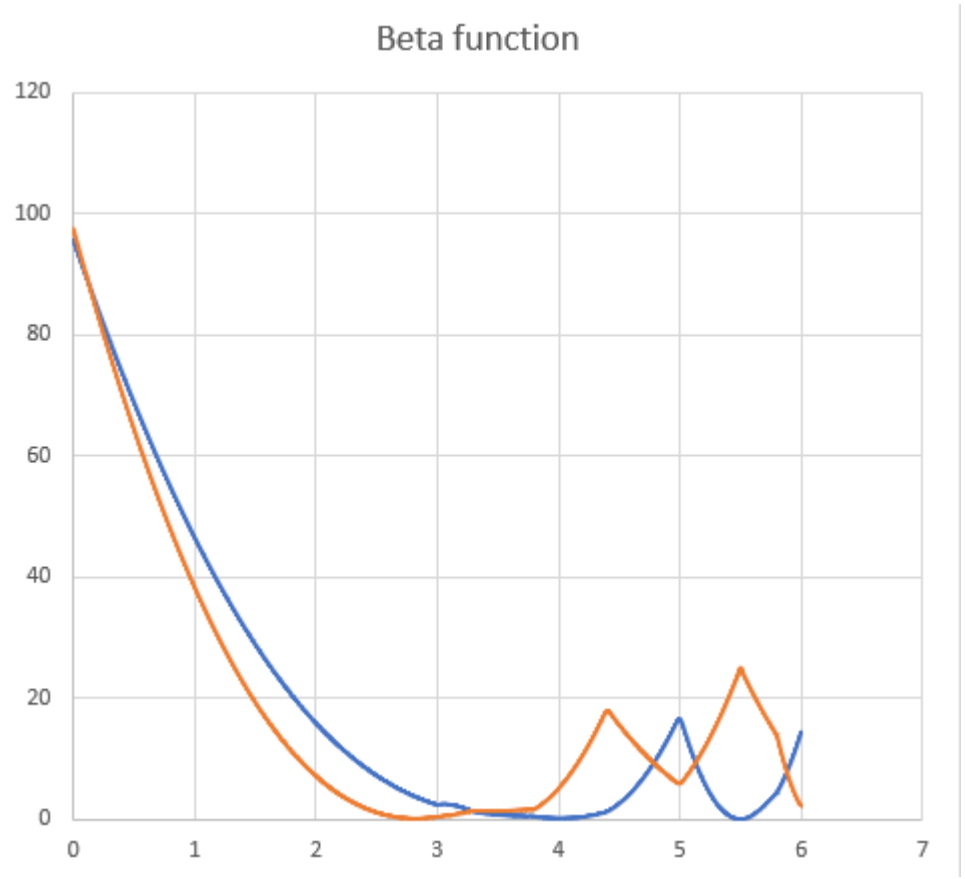




60 degree dogleg optics with space charge

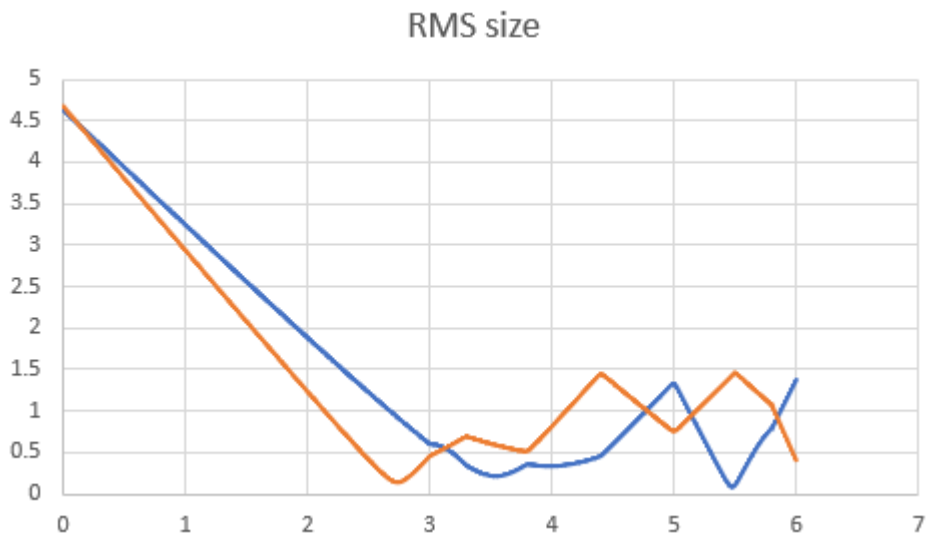
By SCO, 4 nC, 4 um.rad, 200 A

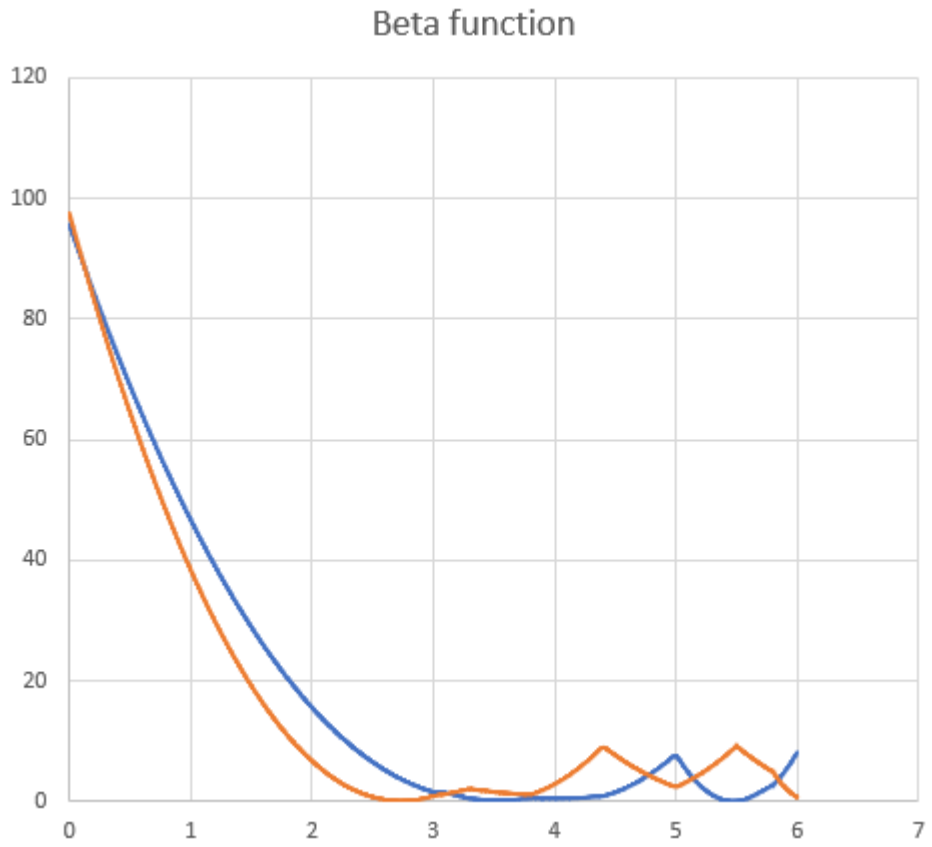




60 degree dogleg optics with space charge

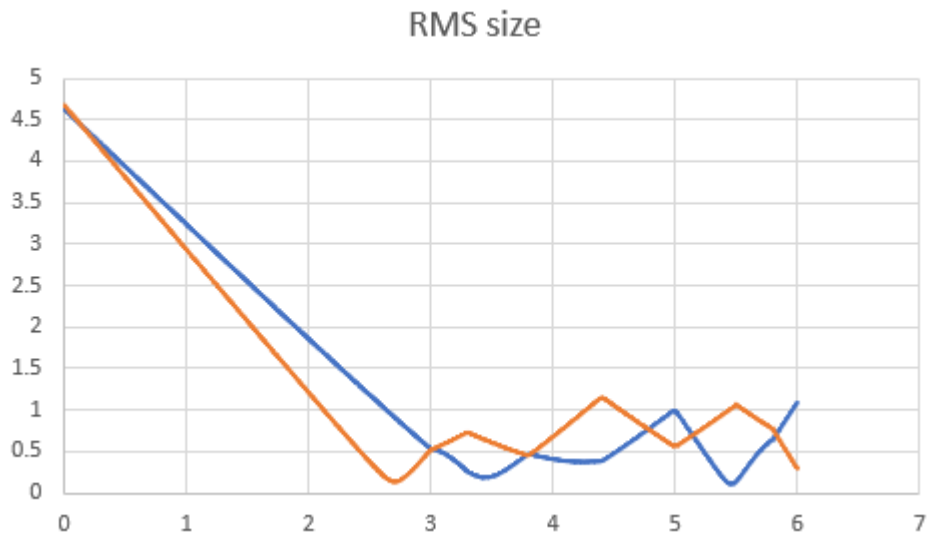
By SCO, 4 nC, 9 um.rad, 200 A

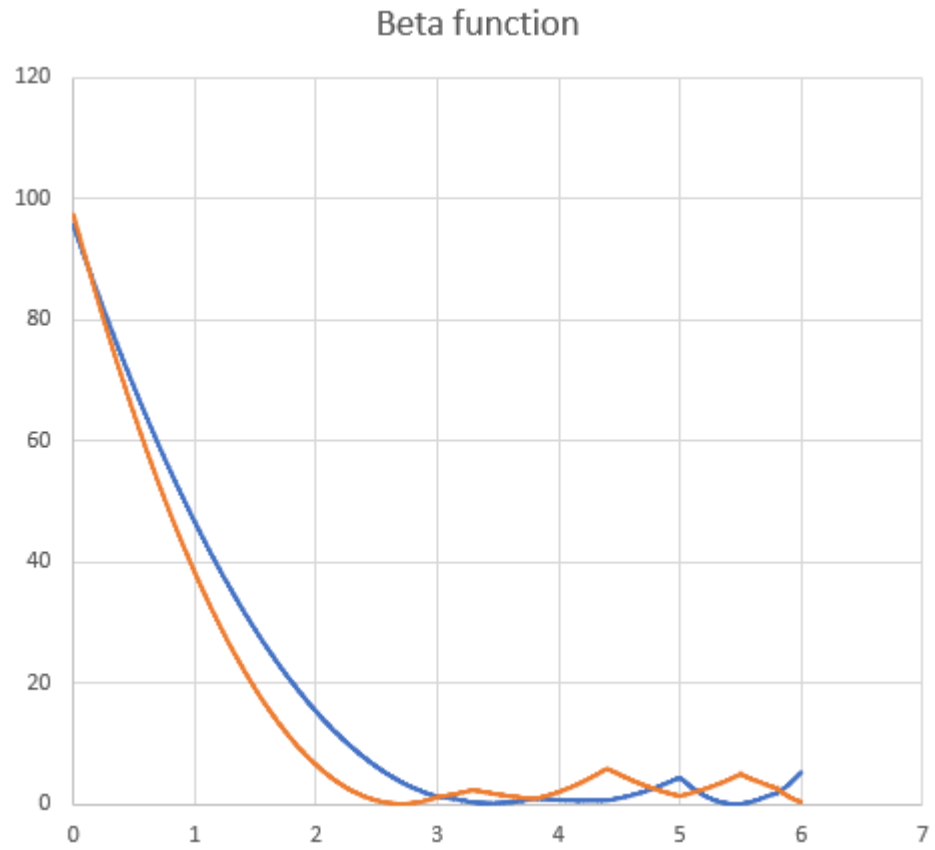




60 degree dogleg optics with space charge

By SCO, 4 nC, 9 um.rad, 100 A

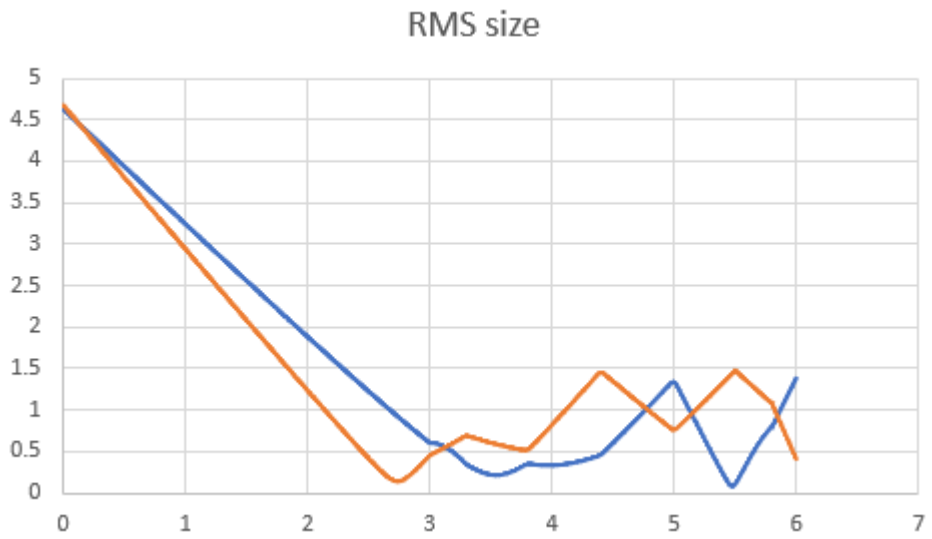


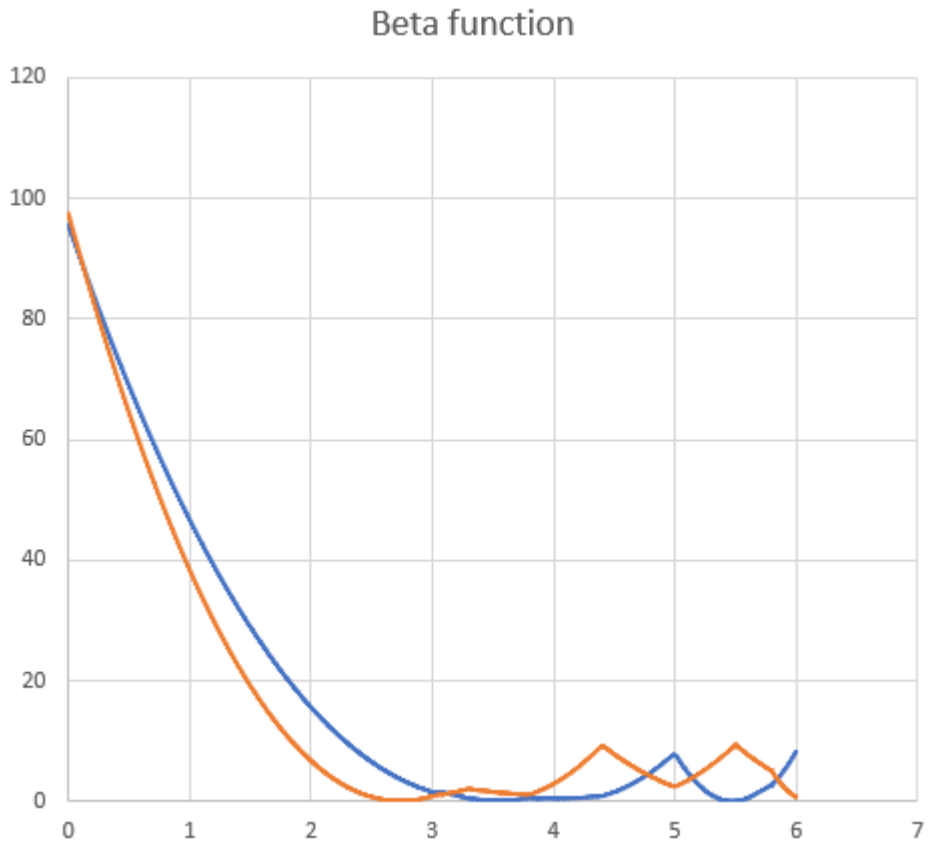


60 degree dogleg optics with space charge

By SCO, 5 nC, 9 um.rad, 200 A

Exactly same as 4 nC, 9 um.rad, 200 A

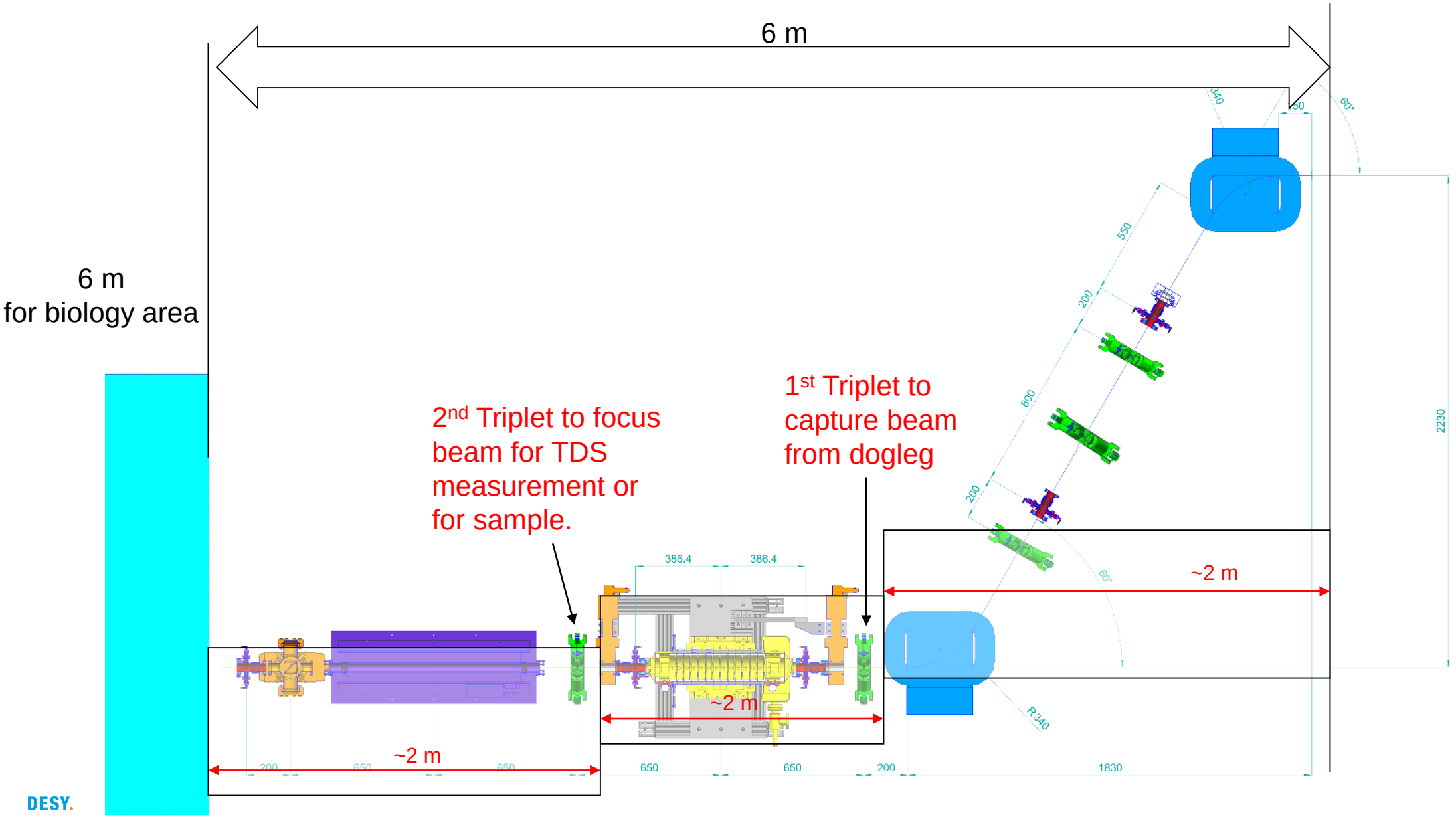




Once matched at 3 m upstream dogleg, MadX optics still works, no crazy beam size inside the dogleg.

Lower peak current, large emittance make beam more emittance dominated, optics closer to MadX optics.

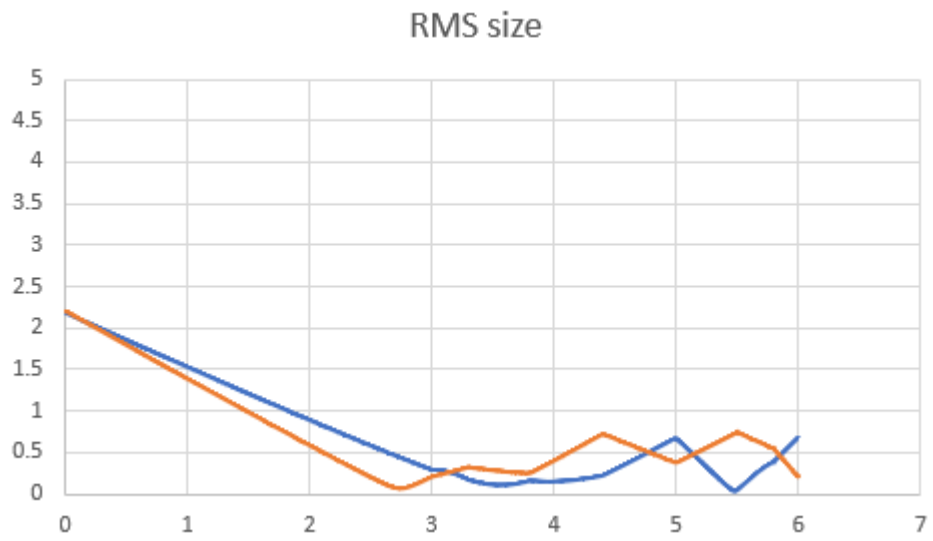
Some considerations

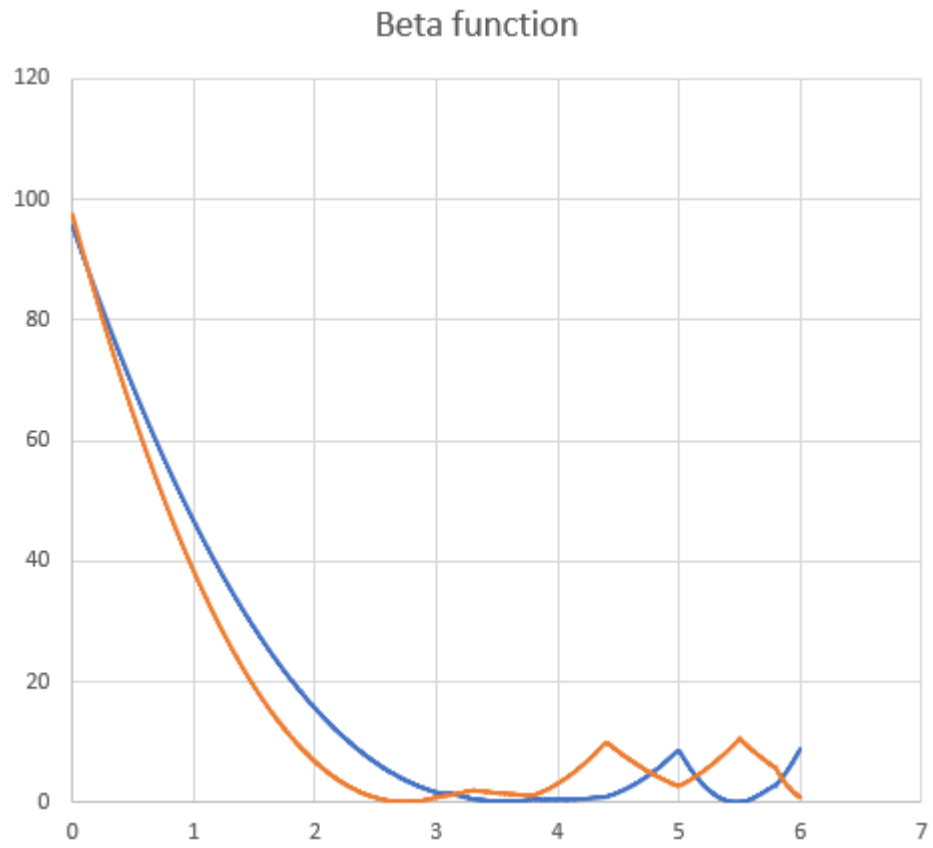


1 nC case by SCO

2 um.rad, 50 A (with beam optics from MadX)

Deviated from dogleg symmetry optics due to space charge effect



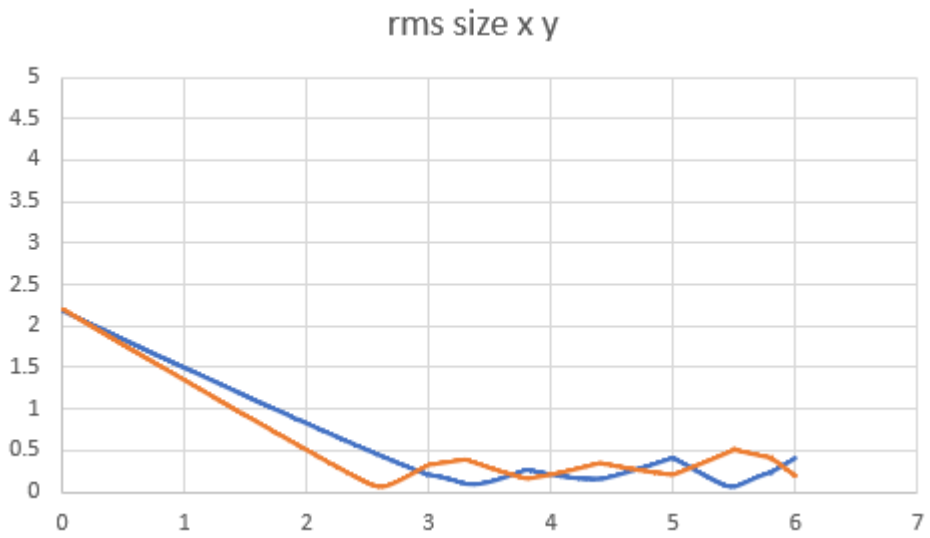


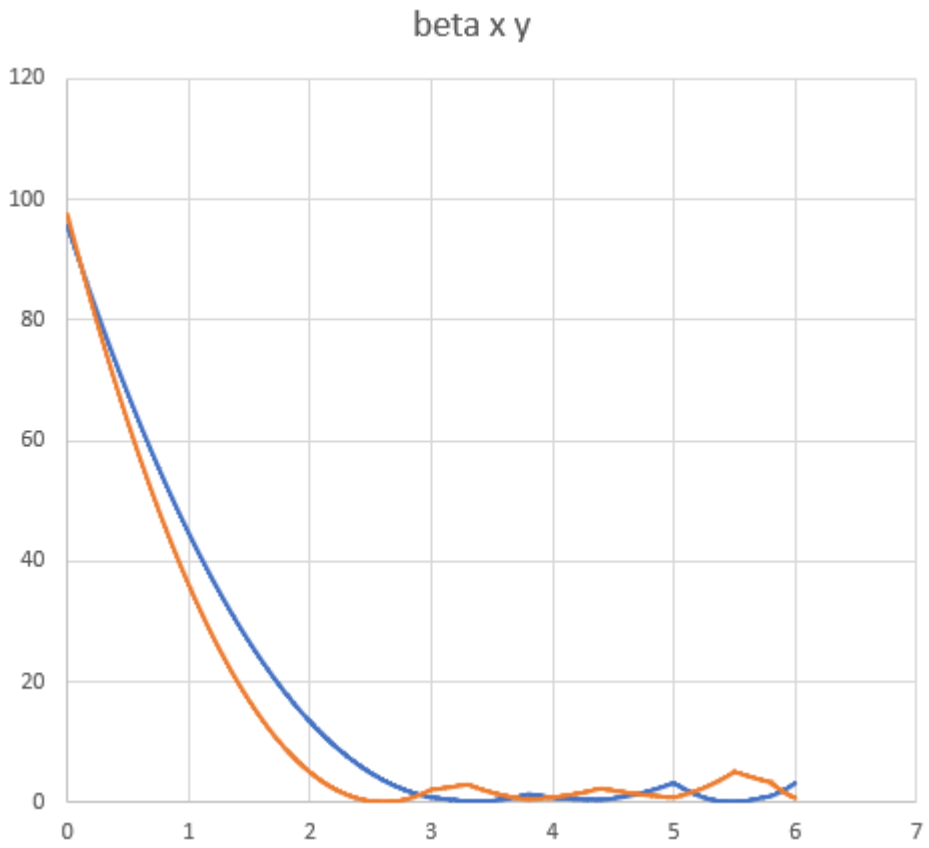
1 nC case by SCO

2 um.rad, 50 A (with modified beam optics)

Increased initial beam focusing by 5% to overcome space charge defocusing in the 1st 3 meter.

Closer to symmetry optics in dogleg.

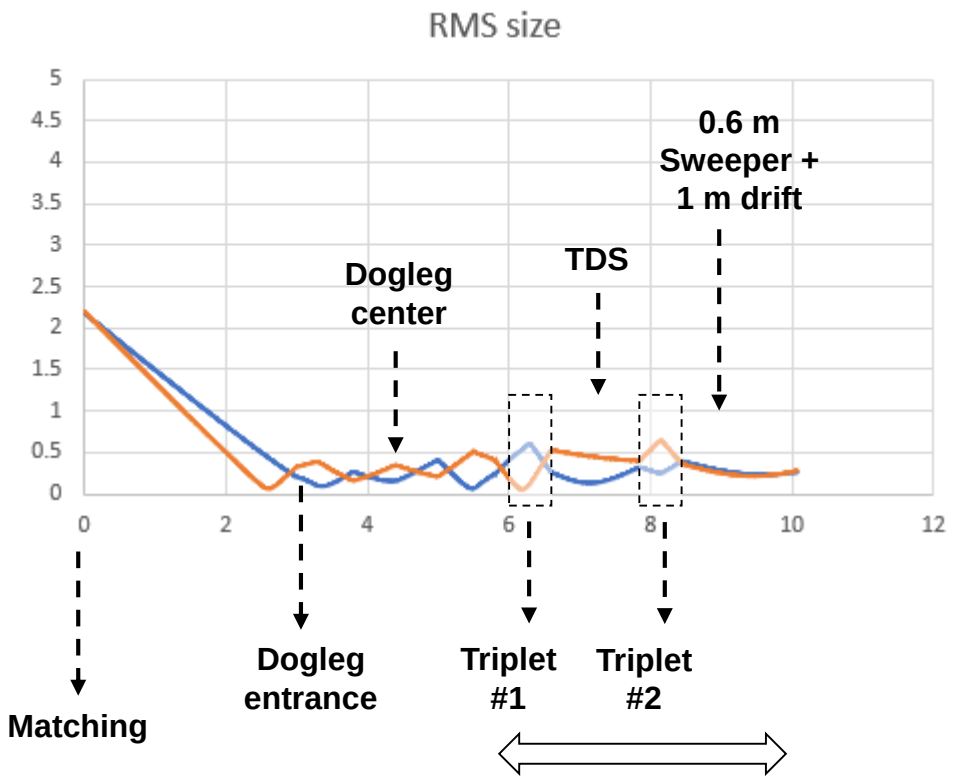


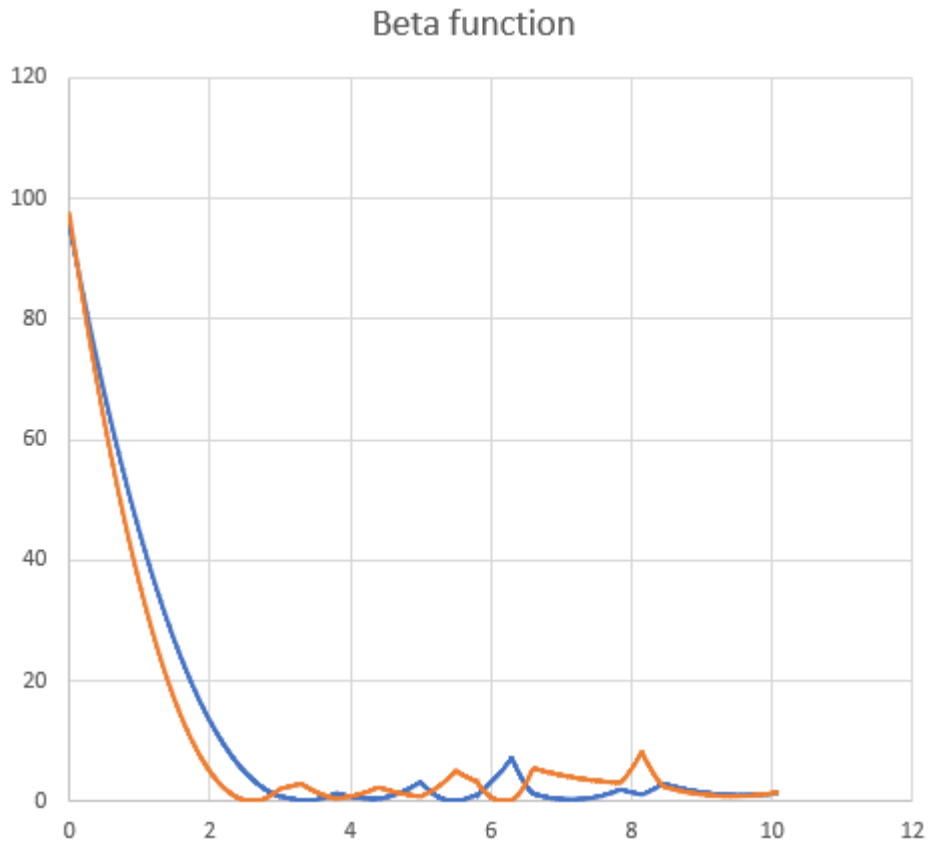


1 nC case by SCO

2 um.rad, 50 A (with modified beam optics)

~4 m transport line from Dogleg exit (~5.8 m) to sample (~10 m)





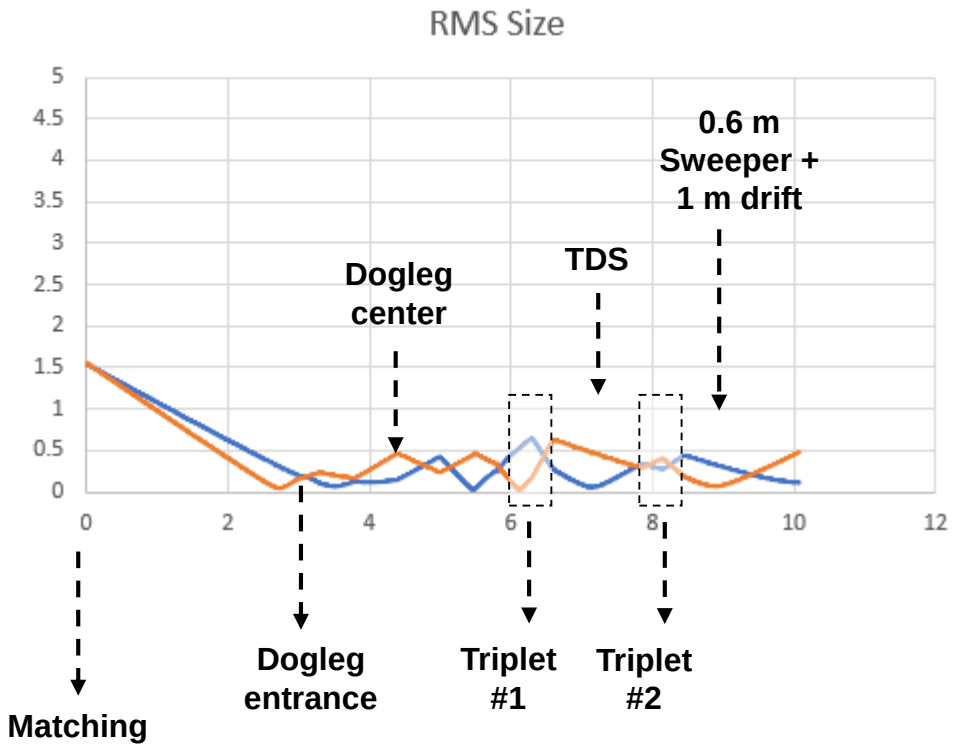
4 m from Dogleg exit (~5.8 m) to sample

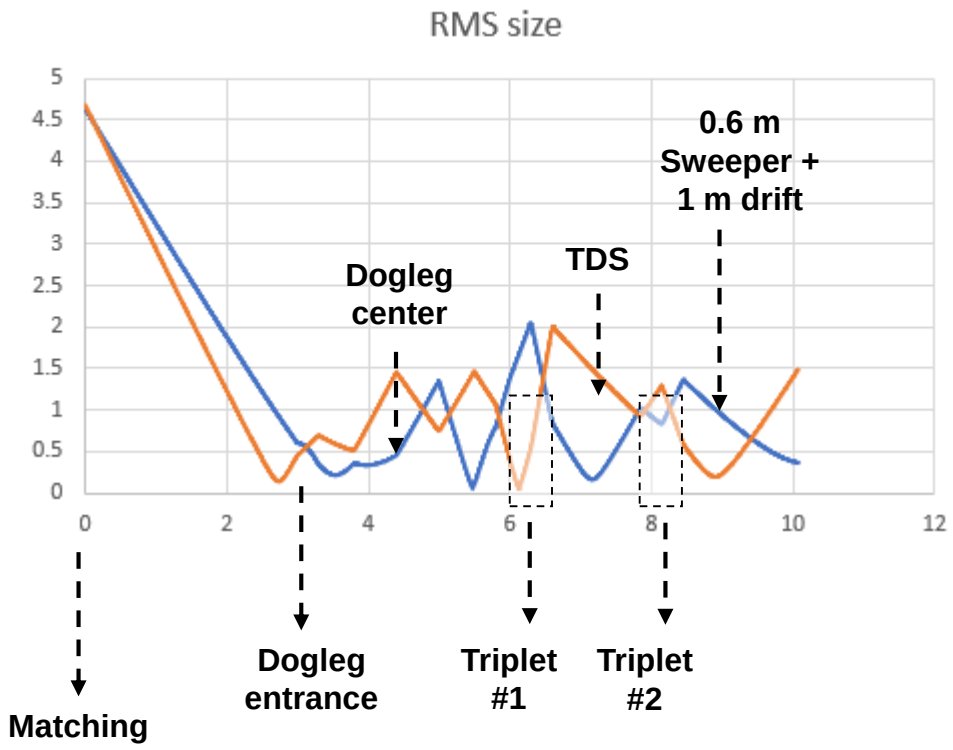
0.25 nC and 4 nC case plugged into 1 nC optics

No re-optimization of triplets, no modification of matching optics

0.25 nC, 1 um, 20 A, initial matching from MadX is used.
4 nC, 9 um, 200 A, initial matching from MadX is used.

Compared to 1 nC, 2 um, 50 A, beam optics looks reasonably close, additional triplet tuning is needed.





Beam focusing size at sample for tumor painting

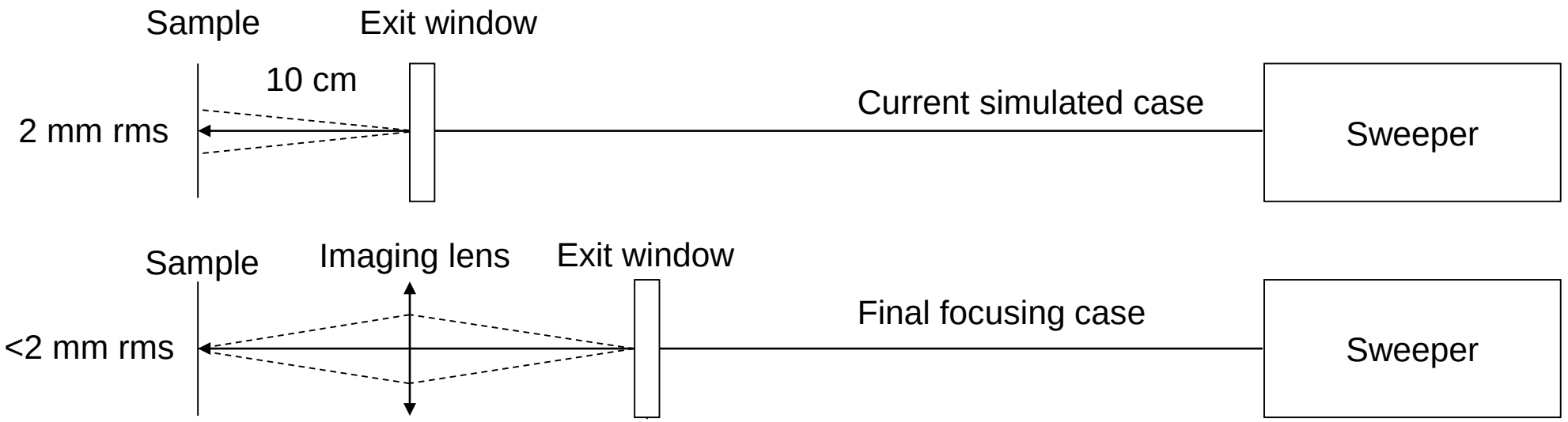
20 MeV case

- 1 nC/2um.rad/50A beam SCO simulation shows a **0.27 mm rms beam size on sample (no scattering)**
  - Exit window scattering is not considered, roughly 20 mrad rms scattering angle
  - 10 cm drift from window to sample → **2 mm rms size, FWHM ~4.7 mm**
- What's the beam size needed for tumor painting (25 x 25 mm^2)?
  - PITZ booster: 200 bunches (1 MHz) to 900 bunches (4.5 MHz, needs faster sweeper)
    - Then **14 x 14 or 30 x 30** micro beam painting, → beam separation **1.78 or 0.83 mm**
    - If beam separation is half the FWHM beam size, then beam **rms size at least 1.52 or 0.71 mm**
      - Without window scattering, beam rms size is too small for superficial tumor painting?
  - Longer bunch trains will allow smaller beam to paint the tumor, or paint a bigger area (needs stronger sweeper)
    - e.g 1 ms, 4500 bunches train to paint 25 x 25 mm^2, then beam **rms size >= 0.32 mm**
    - For 25 x 25 mm^2 superficial tumor painting, does smaller beam size (0.32 - 2 mm rms) help? NO? Same does.

Final focusing just before the sample for tumor painting

20 MeV case

- What if a certain case needs a smaller beam size <2 mm on the sample?
  - A focusing lens has to be placed after the exit window, but this will focus the sweeping range as well.



1) 1:1 imaging will not reduce sweeping range
2) Beam size on sample equal to beam focusing on exit window, window scattering does not matter anymore
3) Needs extra space for such a symmetric imaging lens
4) Beam focusing allowed by window damage threshold will limit beam size at sample
5) For sharp focusing to create peak does effect in depth, 25-50 mm rms size is needed at lens (10 cm away from sample), window scattering is too small (only 2 mm rms)

Summary

- SCO model beam simulations show the dogleg optics designed with MadX still work under space charge.
  - Lower peak current, larger emittance will help the optics.
  - Matching into the dogleg is not easy, upstream quads too far away, few diagnostics
- A preliminary 4 m beam transport line from dogleg exit to sample is optimized with a 1 nC model beam.
  - 0.25 nC and 4 nC beam transportations with the 1 nC optics also work, triplet focusing adjustments are needed.
- Some discussions:
  - Beam focusing at sample required for sweeping mode (for superficial tumors)
    - 30 x 30 bunch painting 25 x 25 mm^2, beam size at least >0.7 mm rms
    - Window scattering leads to 2 mm rms (if 10 cm from window to sample)
  - Final Imaging lens after exit window needed to achieve < 2 mm rms focusing in sweeping mode
    - To spare healthy superficial tissue in deep seated tumor radiation?
    - Is it necessary for painting superficial tumor case?
- Further beamline optics optimization or verification with S2E beam tracking is still needed.