Knob to change phase advance at injection

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Motivation

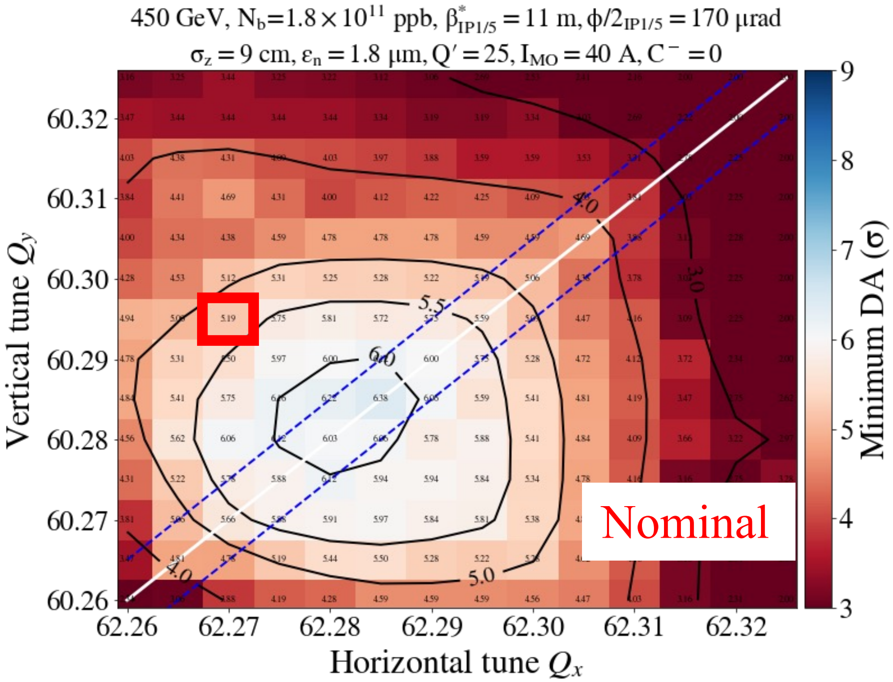
Electron cloud effects lead us to operate with exceptionally high chromaticity (Q' = 25) and octupoles (I_MO = 40 A), in order to mitigate coherent beam instabilities.

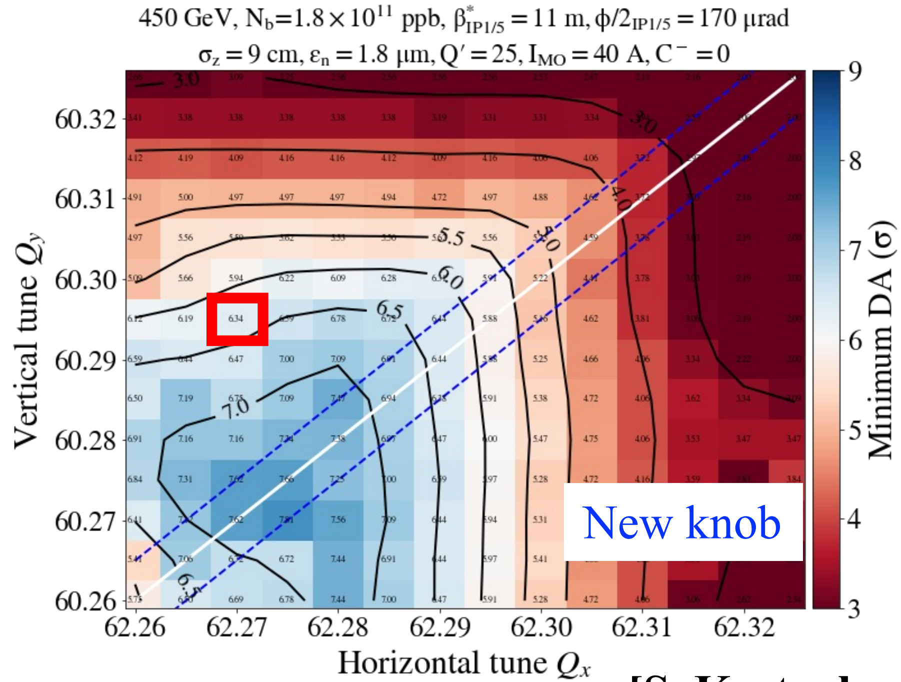
- Octupole magnets placement in the LHC lattice is far from optimal.
- Non-linearities driven by octupoles are strong, in particular resonances associated to them: 4Qx, 2Qx – 2Qy, 4Qy.

- Fortunately, there is some freedom for improvement.
- Phase advance can be changed on an arc-by-arc basis to minimize Resonance Driving Terms (RDT) of 4Qx, 2Qx – 2Qy, 4Qy while **keeping amplitude detuning unchanged**.

- Phase advance change is achieved with a relative change in the strengths of the MQT quadrupoles.

Dynamic aperture (Beam 1)





[S. Kostoglou]

- Dynamic aperture is barely enough due to high chromaticity and octupoles, small margin.
- Introducing the phase change and reducing RDTs leads to a significant increase of DA (>1σ)!

- Previous simulations suggest a 0.5-1σ drop in DA can be expected from e-clouds in the arcs (see [K. Paraschou, BE Seminar]).

The knobs

- Very simple addition to the MAD-X model.
- Can be trimmed off easily.

```
phase_change.b1 := 1.;
ADD2EXPR, var=kqtf.a12b1, expr=-0.0022477200000*phase_change.b1;
ADD2EXPR, var=kqtf.a23b1, expr=-0.0006109026670*phase_change.b1;
ADD2EXPR, var=kqtf.a34b1, expr=-0.0006740726670*phase_change.b1;
ADD2EXPR, var=kqtf.a45b1, expr=+0.0015222900000*phase_change.b1;
ADD2EXPR, var=kqtf.a56b1, expr=+0.0011189300000*phase_change.b1;
ADD2EXPR, var=kqtf.a67b1, expr=+0.0020387763940*phase_change.b1;
ADD2EXPR, var=kqtf.a78b1, expr=-0.0011010306070*phase_change.b1;
ADD2EXPR, var=kqtf.a81b1, expr=-0.0001300250000*phase_change.b1;
ADD2EXPR, var=kqtd.a12b1, expr=-0.0001437190000*phase_change.b1;
ADD2EXPR, var=kqtd.a23b1, expr=+0.0010619748420*phase_change.b1;
ADD2EXPR, var=kqtd.a34b1, expr=+0.0001529048423*phase_change.b1;
ADD2EXPR, var=kqtd.a45b1, expr=-0.0004891330000*phase_change.b1;
ADD2EXPR, var=kqtd.a56b1, expr=+0.0008419600000*phase_change.b1;
ADD2EXPR, var=kqtd.a67b1, expr=+0.0016072722540*phase_change.b1;
ADD2EXPR, var=kqtd.a78b1, expr=-0.0013696167460*phase_change.b1;
ADD2EXPR, var=kqtd.a81b1, expr=-0.0016425400000*phase_change.b1;
```

```
phase_change.b2 := 1.;
ADD2EXPR, var=kqtf.a12b2, expr=-0.0015000300000*phase_change.b2;
ADD2EXPR, var=kqtf.a23b2, expr=-0.0026080999780*phase_change.b2;
ADD2EXPR, var=kqtf.a34b2, expr=+0.0002292920220*phase_change.b2;
ADD2EXPR, var=kqtf.a45b2, expr=+0.0018962000000*phase_change.b2;
ADD2EXPR, var=kqtf.a56b2, expr=+0.0027266500000*phase_change.b2;
ADD2EXPR, var=kqtf.a67b2, expr=-0.0005254090387*phase_change.b2;
ADD2EXPR, var=kqtf.a78b2, expr=-0.0006960890387*phase_change.b2;
ADD2EXPR, var=kqtf.a81b2, expr= 0.0004939700000*phase_change.b2;
ADD2EXPR, var=kqtd.a12b2, expr=-0.0006047010000*phase_change.b2;
ADD2EXPR, var=kqtd.a23b2, expr=+0.0007281687569*phase_change.b2;
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ADD2EXPR, var=kqtd.a45b2, expr=-0.0003441180000*phase_change.b2;
ADD2EXPR, var=kqtd.a56b2, expr=+0.0002527790000*phase_change.b2;
ADD2EXPR, var=kqtd.a67b2, expr=-0.0024345517550*phase_change.b2;
ADD2EXPR, var=kqtd.a78b2, expr=-0.0006010707552*phase_change.b2;
ADD2EXPR, var=kqtd.a81b2, expr=+0.0014239700000*phase_change.b2;
```
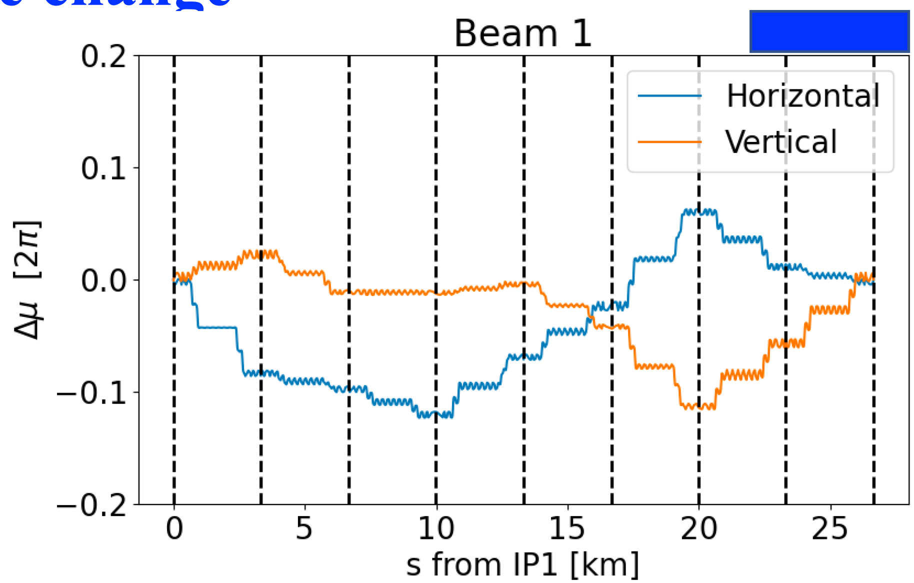
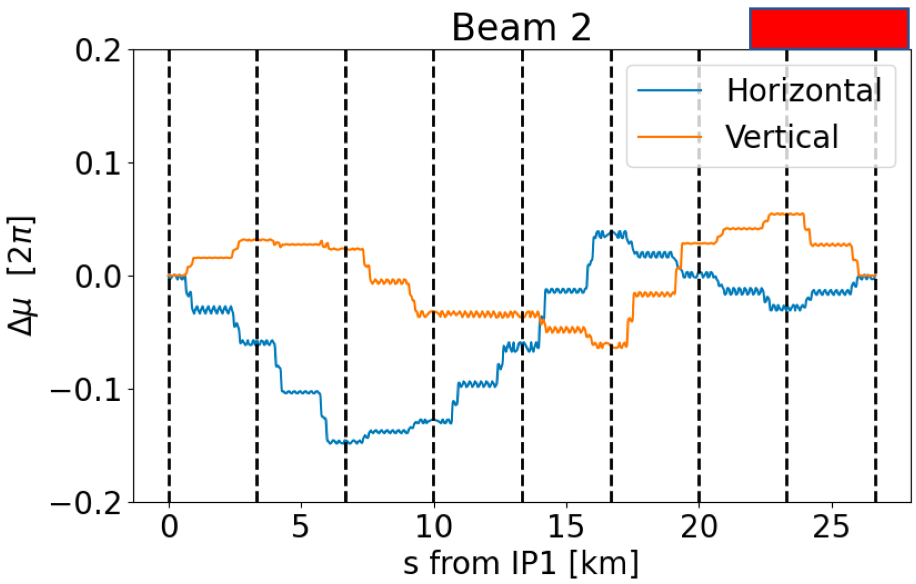
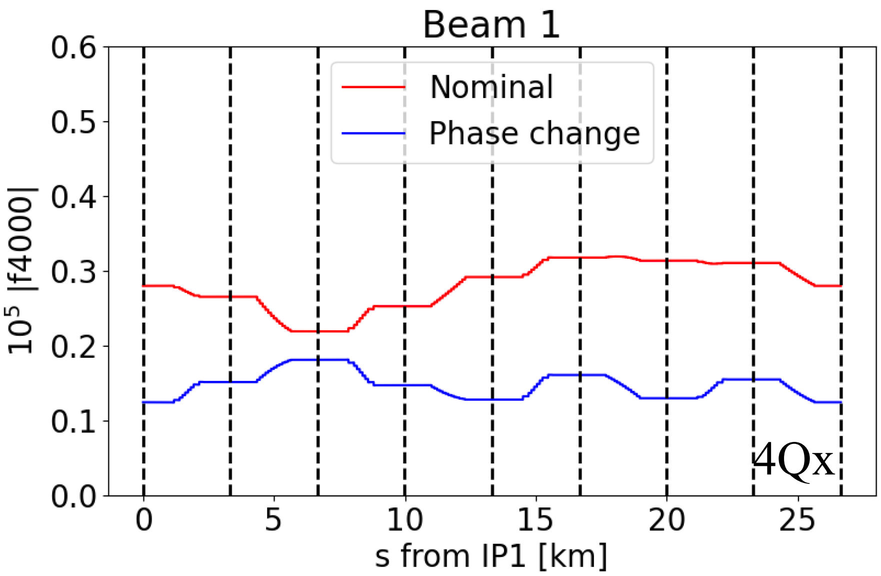

Phase change

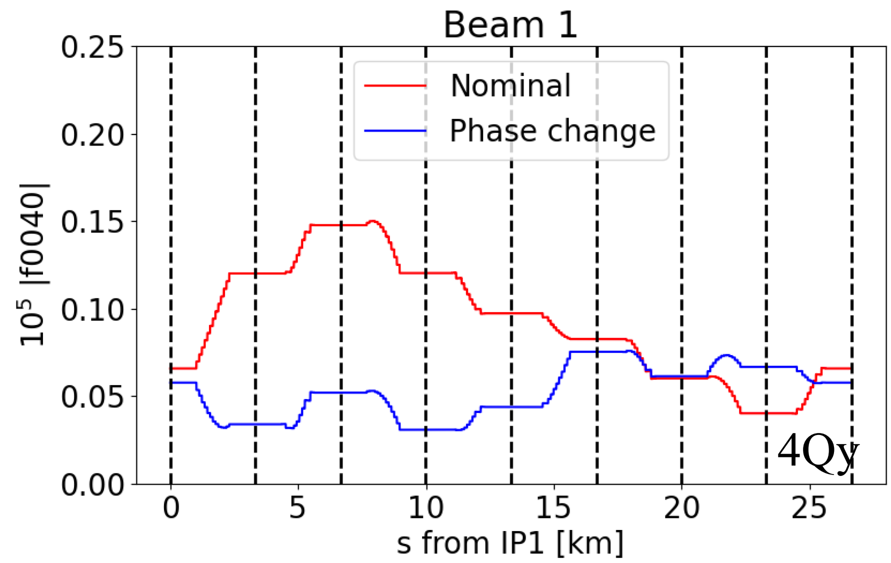
- Phase advance between sectors changes.
- Phase advance inside Insertion Regions stays same.
- Tune (total phase advance) remains the same ($\Delta Q < 10^{-3}$).

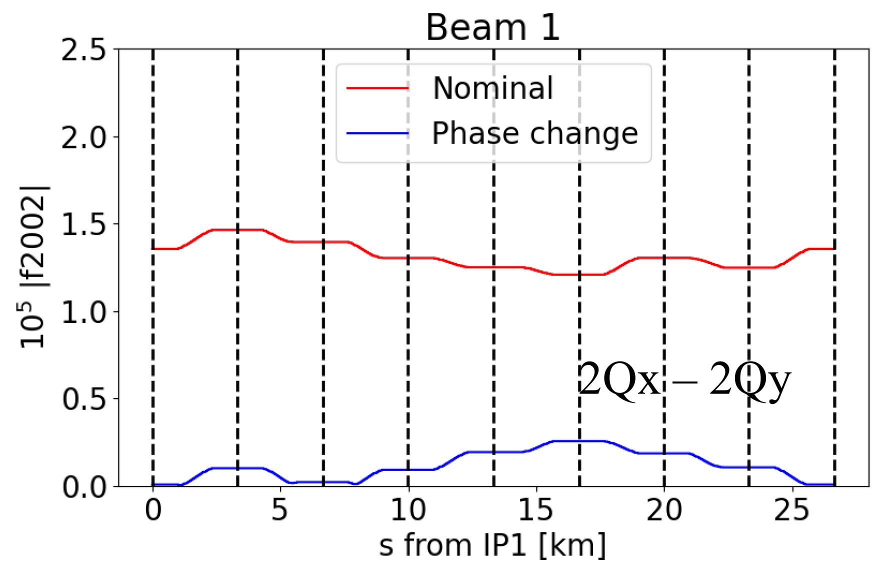




Resonance Driving Terms (Beam 1)

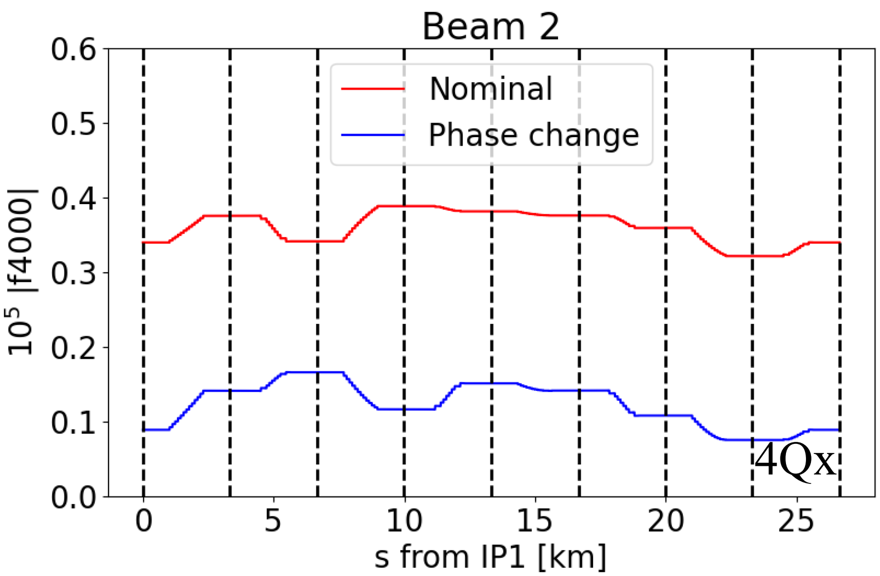


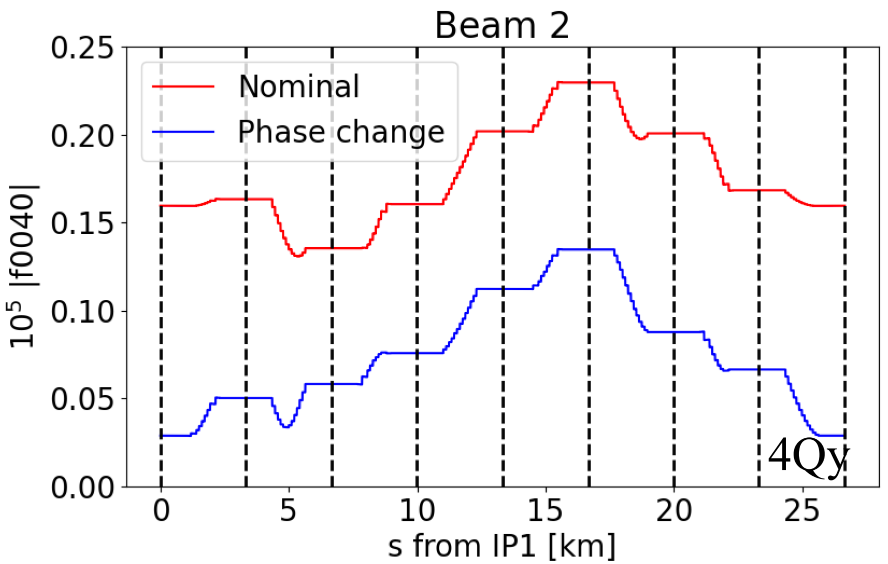




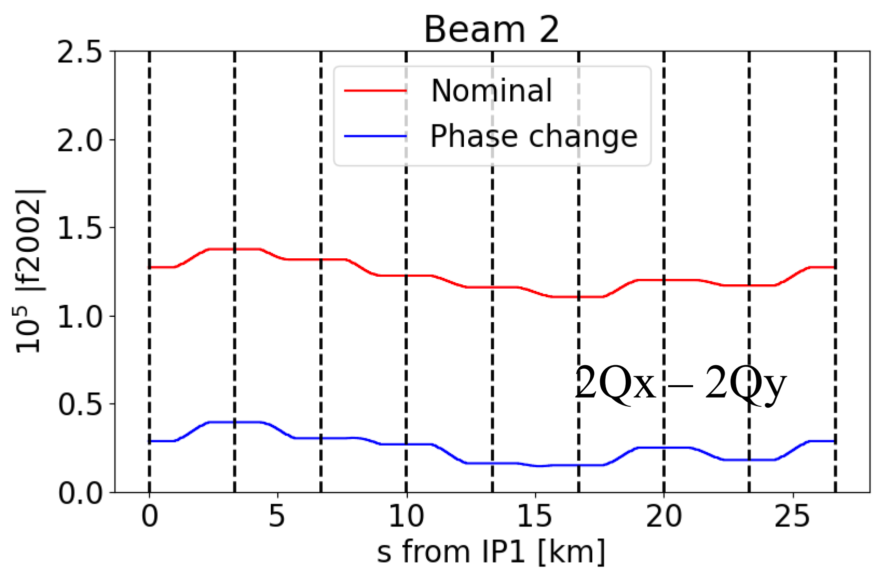
- Factor 2 reduction in 4Qx, 4Qy strengths.
- Factor 5 reduction in 2Qx-2Qy strength.
- **Less non-linearities.**

Resonance Driving Terms (Beam 2)

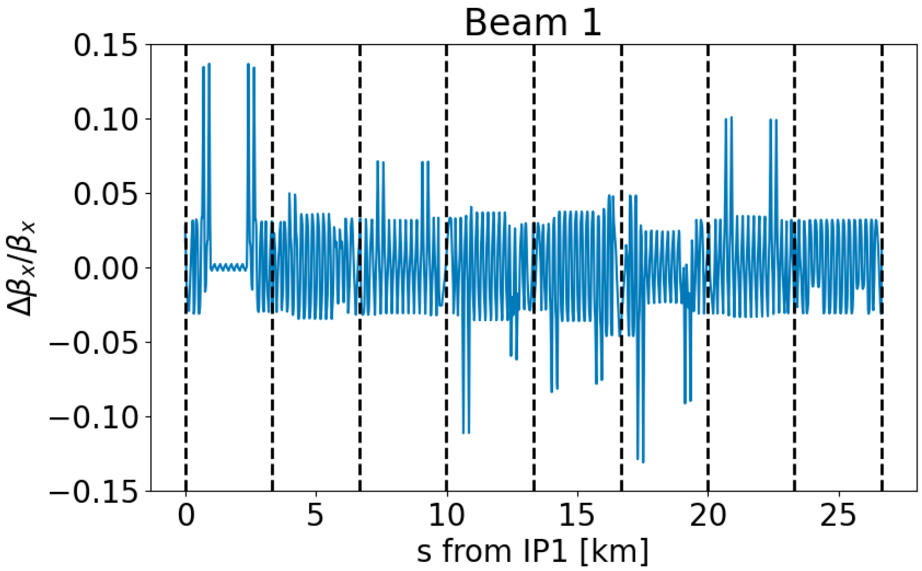


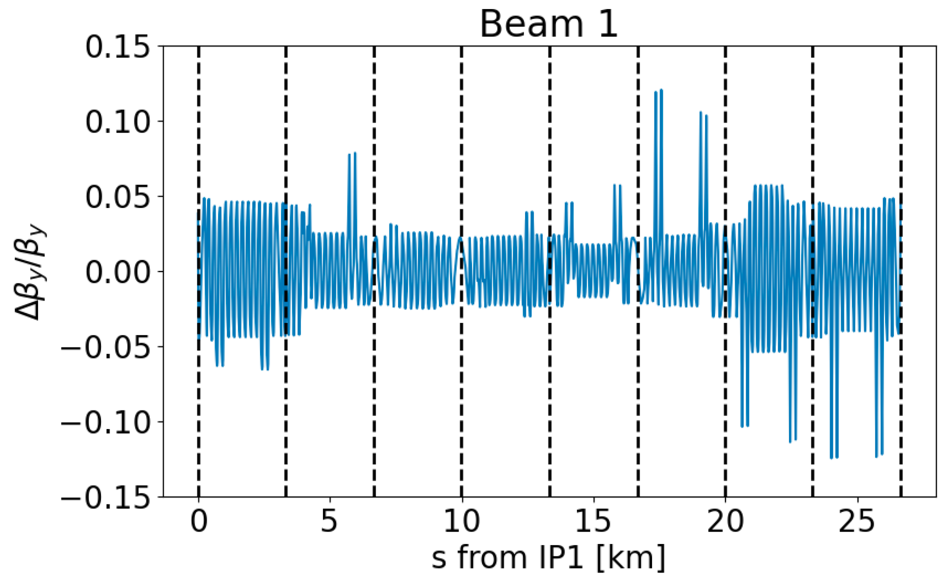


- Factor 2 reduction in 4Qx, 4Qy strengths.
- Factor 4 reduction in 2Qx-2Qy strength.
- **Less non-linearities.**



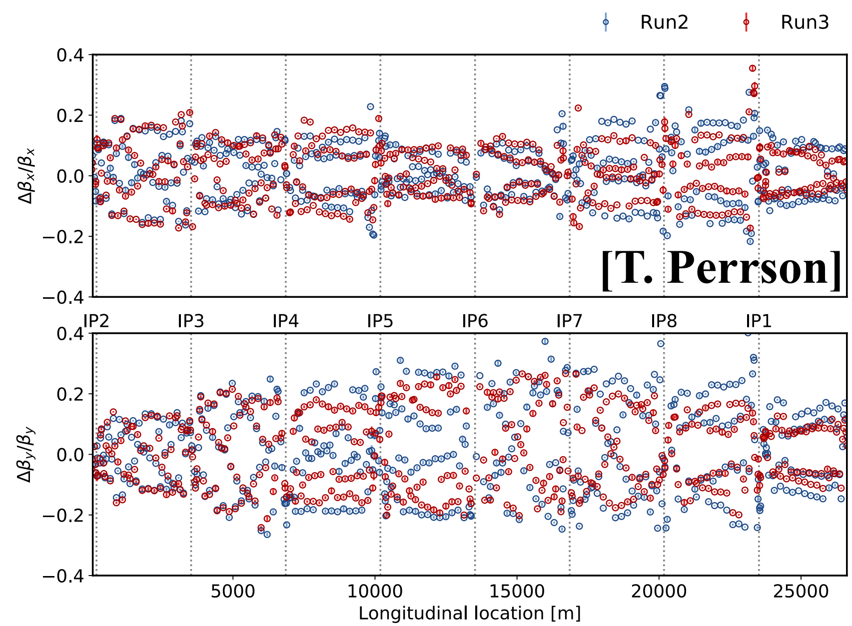
Beta-beating (Beam 1)



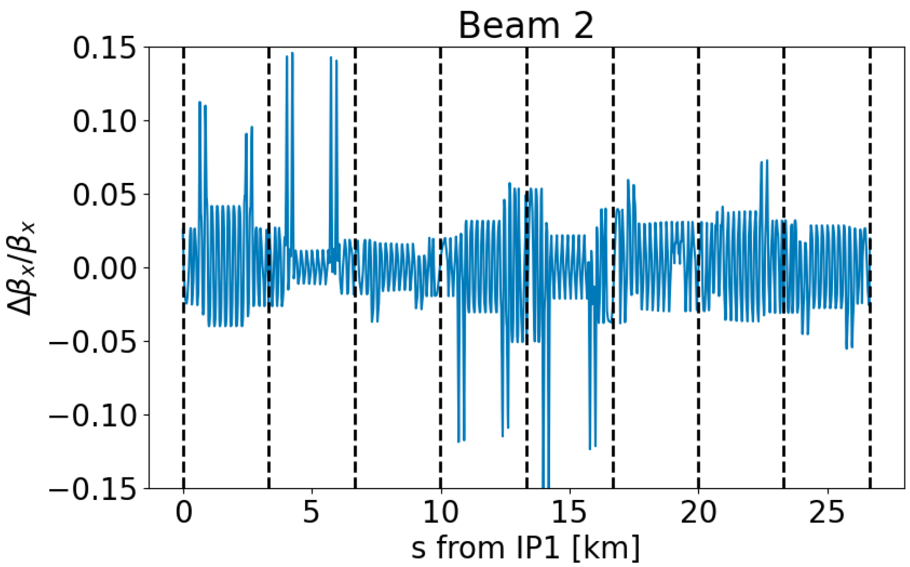


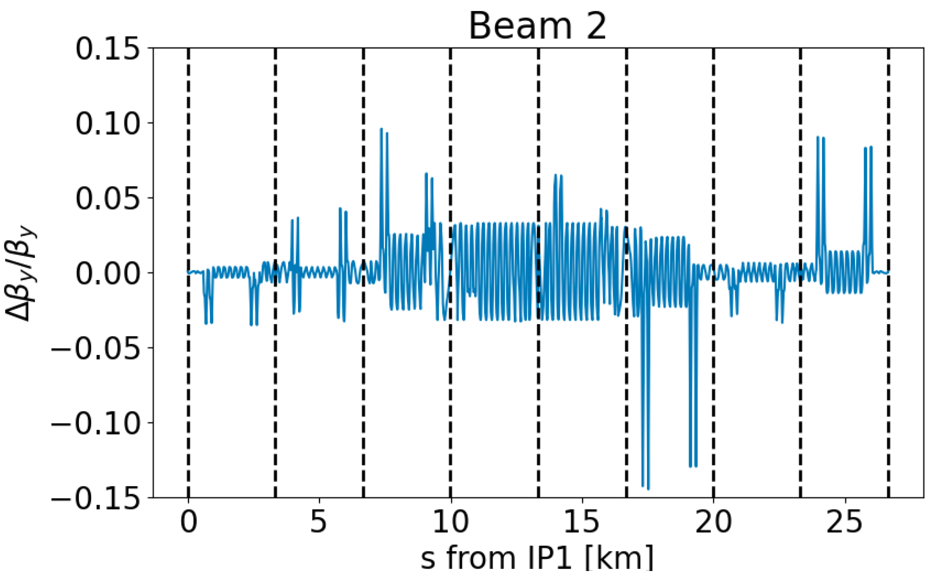
β-beating of around 5% is observed when comparing to nominal optics.

Very small compared to what is observed with the “virgin” machine.



Beta-beating (Beam 2)





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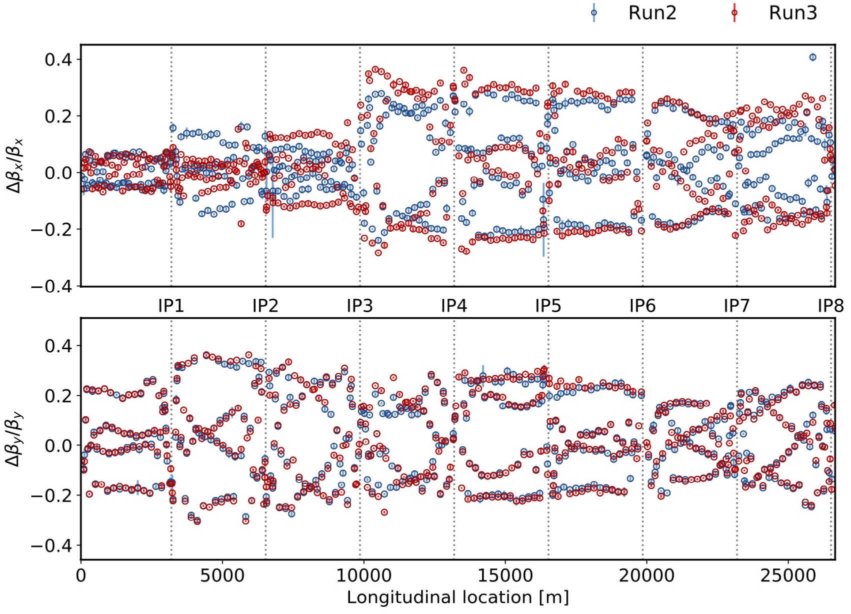
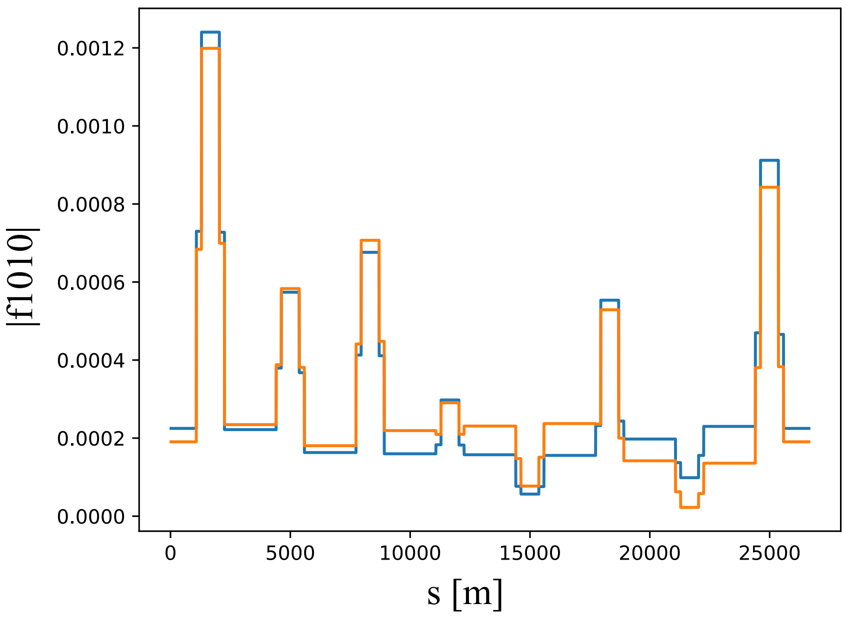
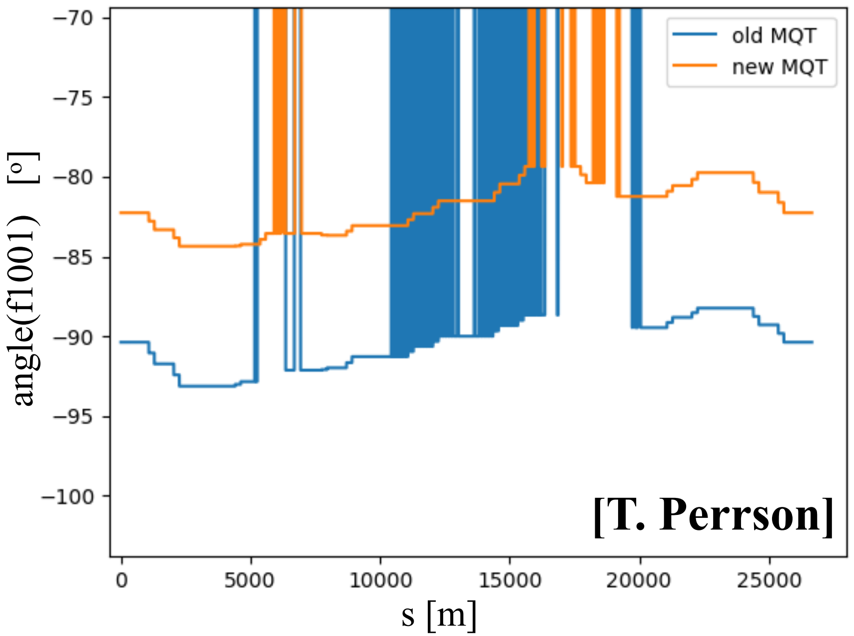


Response of linear coupling knob (Beam 1)

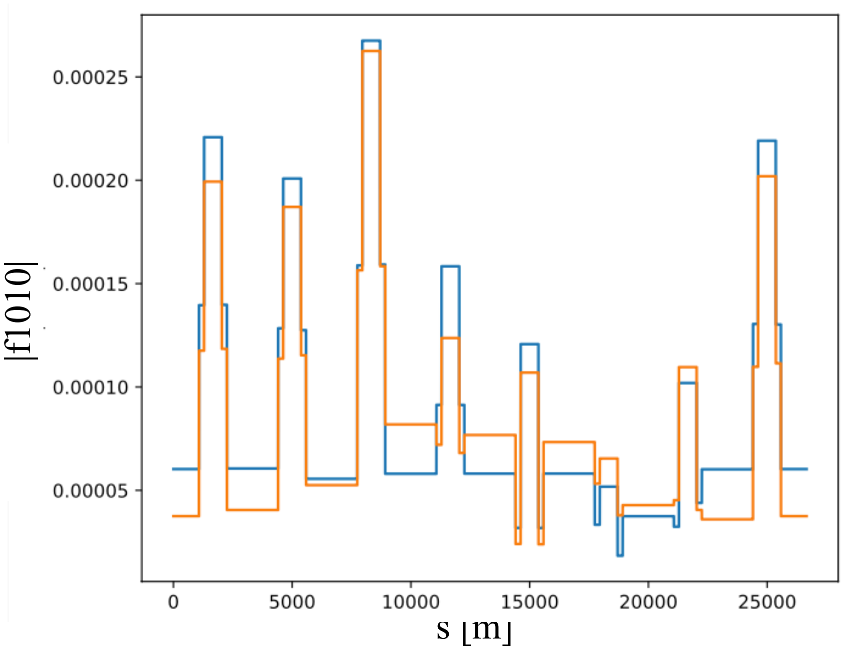


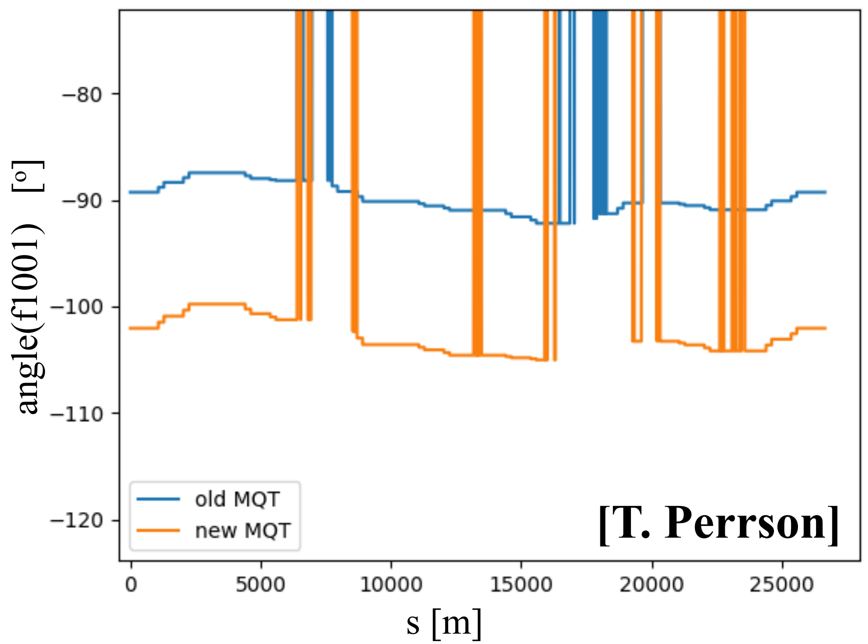


Small changes in linear coupling correction (f1010, f1001).

Angle between real and imaginary part of f1001 knob goes from 90 degrees to around 80-85 degrees.
Linear coupling knob remains almost orthogonal with the introduced phase change.

Response of linear coupling knob (Beam 2)





Small changes in linear coupling correction (f1010, f1001).

Angle between real and imaginary part of f1001 (linear coupling) knob goes from 90 degrees to around 100 degrees. Linear coupling knob remains almost orthogonal with the introduced phase change also for Beam 2.

Conclusion

- Knob to change phase advance per arc at injection can provide a significant margin in dynamic aperture and reduced non-linearities. Improvement in lifetime should be simple to confirm with pilots.

- Phase change is small and minimal perturbations to the optics, no obvious obstacle.

- Beam 1 and Beam 2 knobs are ready to be tested if no other concern.

Thank you for your attention!
Konstantinos Paraschou

Backup

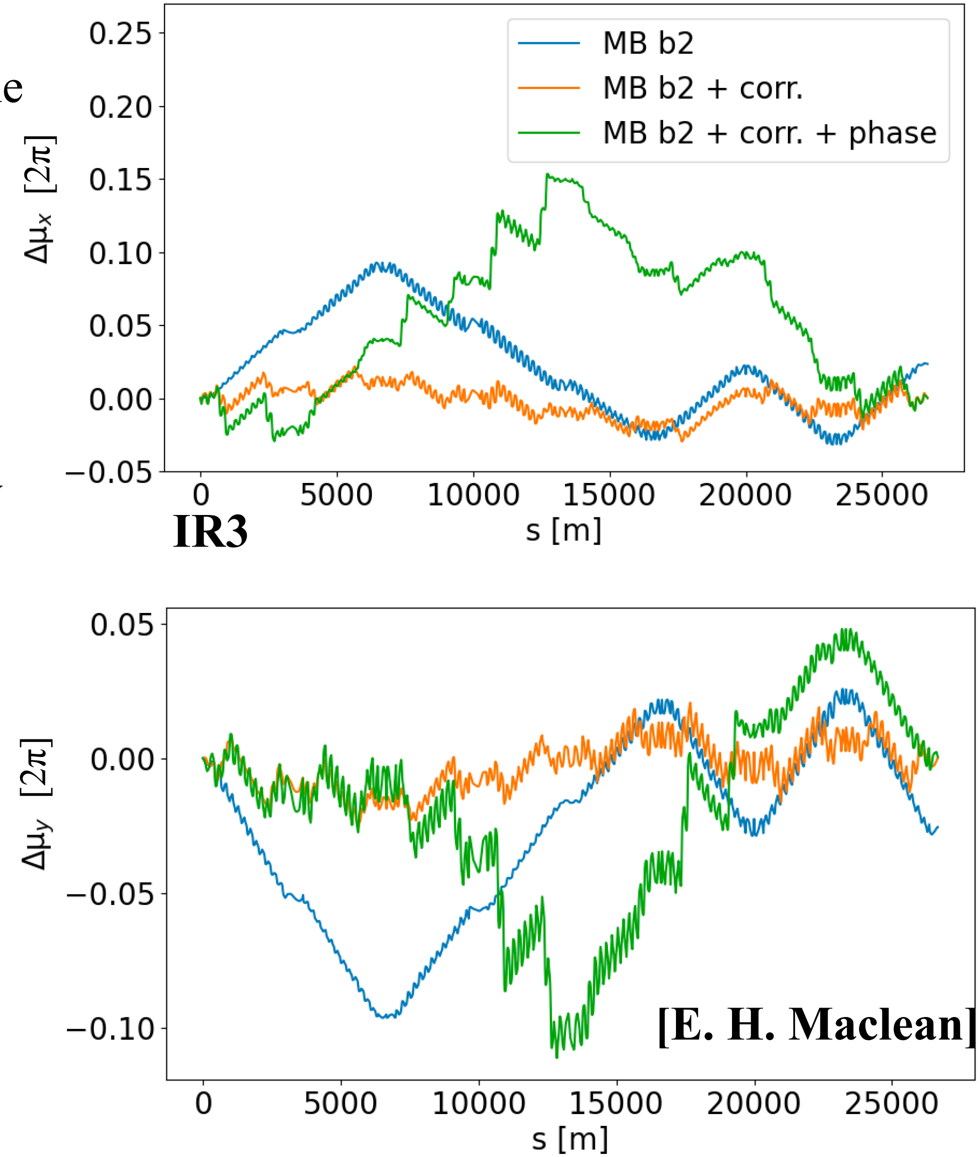
MB b2 field errors (Beam 1)

MQTs are also used to correct the phase difference induced by the b2 imperfections in the MB magnets.

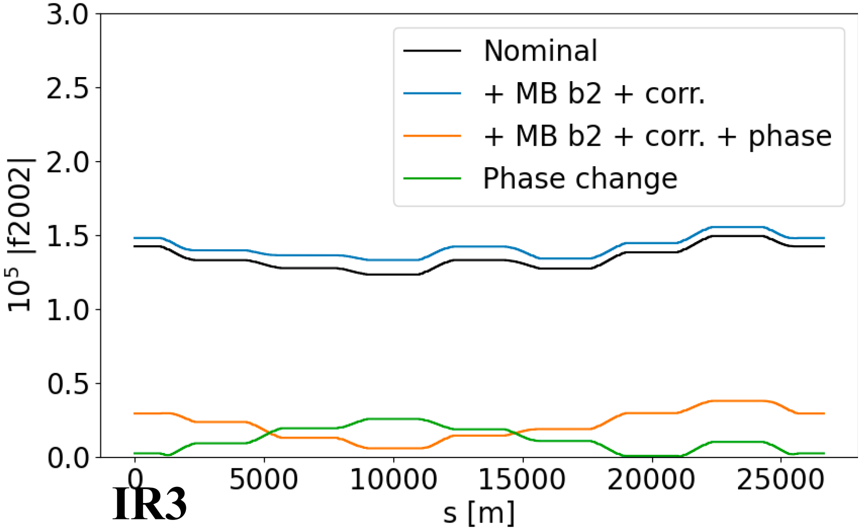
By adding corrections made in the “nominal” optics:

- Resonance driving terms stay reduced.
- β-beating from correction is similar to the one from the phase change.

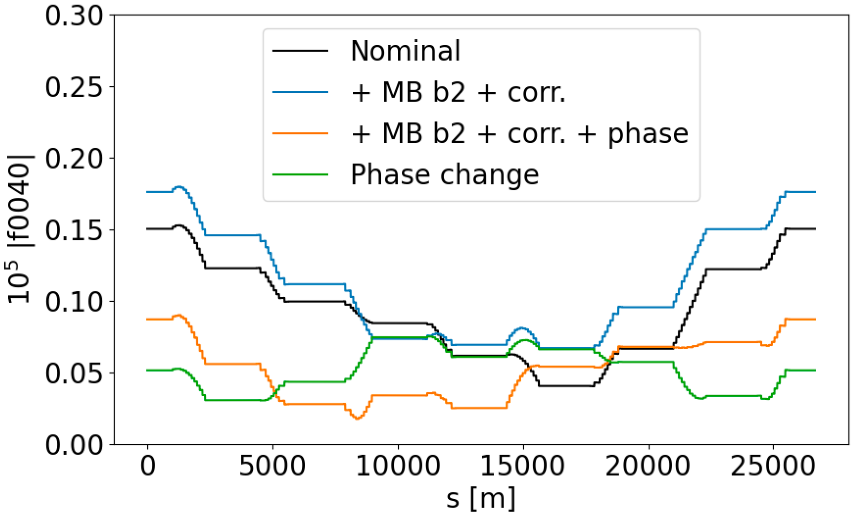
(Plots of β-beating and RDTs in appendix.)

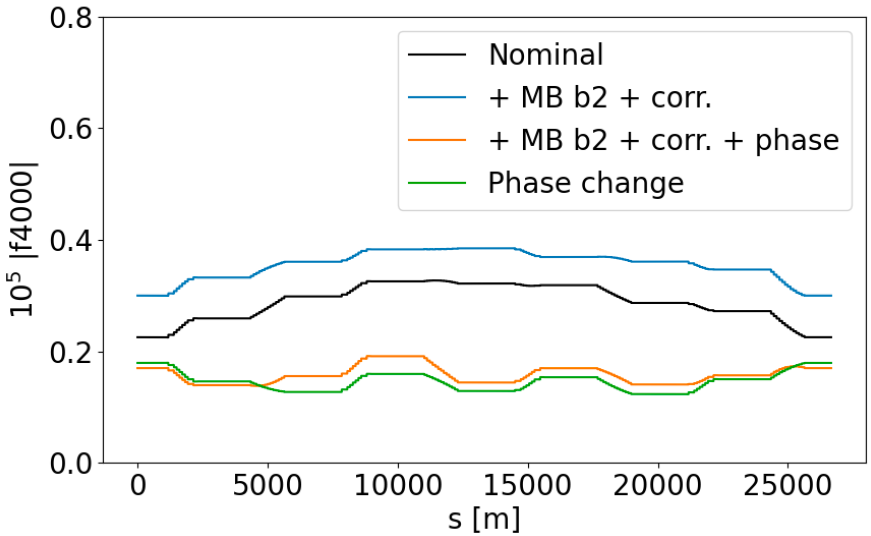


MB b2 errors – RDTs (Beam 1)



IR3





MB b2 errors – β-beating (Beam 1)