John Adams Institute for Accelerator Science

Imperial College London | Royal Holloway University of London | University of Oxford

Dynamic Aperture studies of FCC-hh at collision

Emilia Cruz

Special thanks to: J. Abelleira, J. Barranco, A. Chance, B. Dalena, E. Maclean, R. Martin, R. Tomas, T. Persson, A. Seryi and L. van Riesen-Haupt.

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EuroCirCol

DA studies at Collision

- 60 seeds/10^5 turns/5 angles no beam-beam (C. Tabasco/Beam-Beam studies)
- Errors in triplet, separation/recombination dipoles/arcs
- Corrections

(Based on scripts of A. Chance, R. Martin and experience LHC: R. Tomas, E. Maclean and T. Persson)

- Chrom+tune correction
- Spurious dispersion (SSC and HL-LHC like)
- Crossing IPA and IPG
- Coupling correction
- Arc dipoles correction (*B. Dalena/ DA at injection*)

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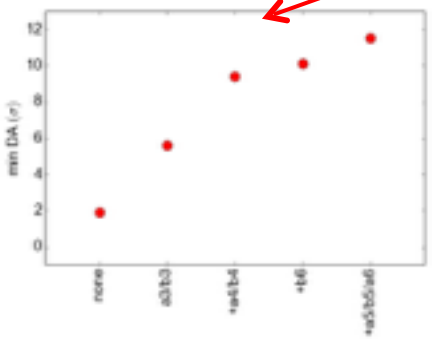
- **Non-linear correctors**
- **Phase Advance between main IPs**



Steady increase vs number of correctors used.
Final correctors: a3/b3/b4/a4/b6

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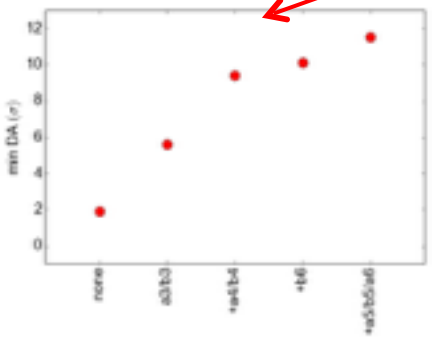

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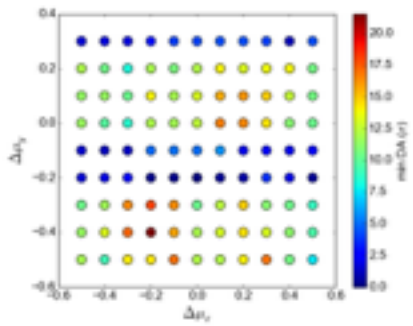

High Dependency on phase between main IPs
Vertical change shows higher change (+/- 0.1 makes a big difference)
Horizontal helps optimizing it

Results FCC week 2018 (and short after)

- All errors were included in studies: arc, triplet and separation/ recombination dipole errors.
- Explore different options of lattice
  - Different ß* options (ß*=0.15, 0.2, 0.3 and 1.1 m)
  - Normal and Alternative Design
  - Round and Flat beams
  - FCC-eh

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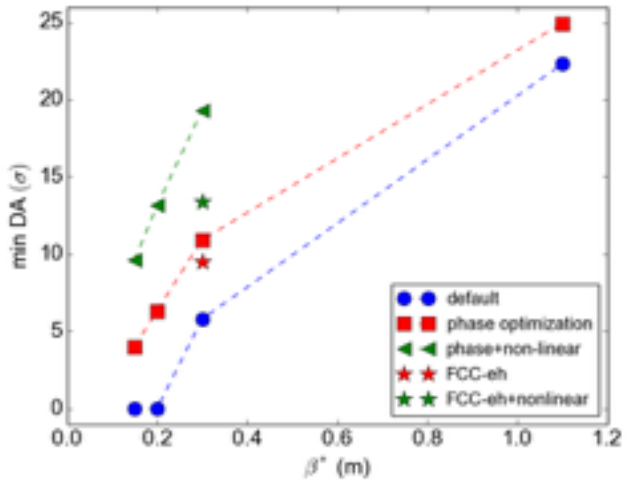


- Phase optimization results in acceptable DA for most cases > 10 σ.
- Non-linear correctors give a safety margin.
- Use of non-linear correctors become more crucial for ß*=0.15 and 0.2 m.

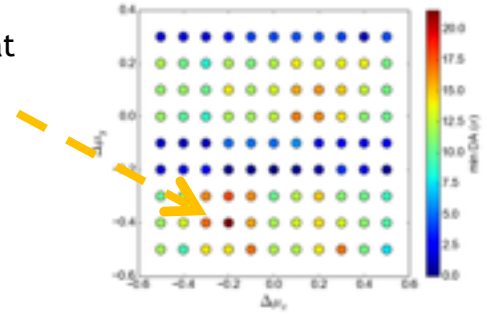
TO DO

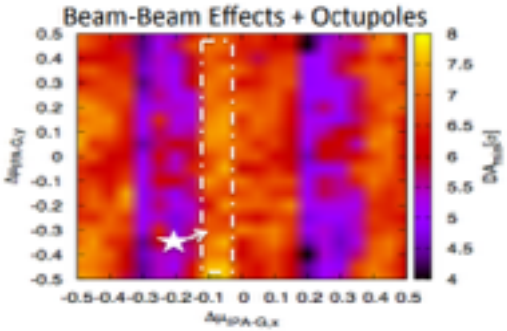
- Check compatibility with beam-beam
- Check FCC-eh, simulate errors on new IR
- Simulate errors on non-linear corrections
- Update in lattice and error tables.

Compatibility with beam-beam

- Phase dependency seen also in beam-beam. Not necessarily the same. Find a phase that works for both? If not, find a compromise.

Optimal phase at collision in this area





T. Pieloni, FCC week 18

- Check DA for collision at a zone that works also for the octupoles

DA @ collision. Errors in arcs/triplet/dipoles
No beam-beam

	DA	DA
Previous phase [-0.2, -0.4]	10.6σ	19.3σ
New phase [-0.1, -0.4]	10.1σ	19.6σ

- In general find zone in vertical phase that works for collision and then move horizontal to a zone that works for beam-beam+octupoles.

Updates

Updates in lattice and errors in magnets

- Lattice changes (summer 2018) *A. Chance/New Lattice Design*
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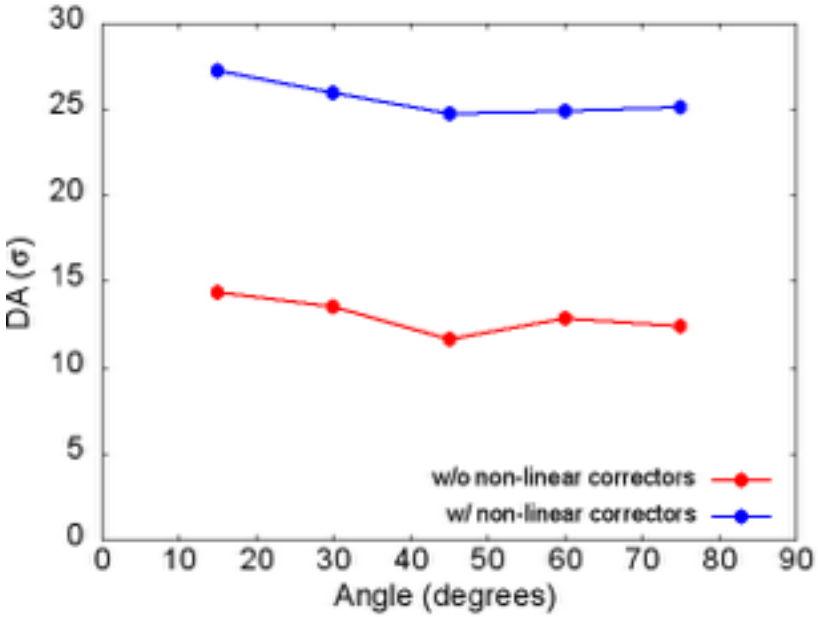

- Increase of 2-4 σ, from previous errortable
- Dependency in phase is less than before (to be checked)
- Main result is still:
  - DA > 10σ w/o non-linear corr
  - DA > 20 σ w/ non-linear corr
- Steady increase of non-linear corr
- Non-linear corr case is “ideal”. Check what happens when corrector strengths are off.

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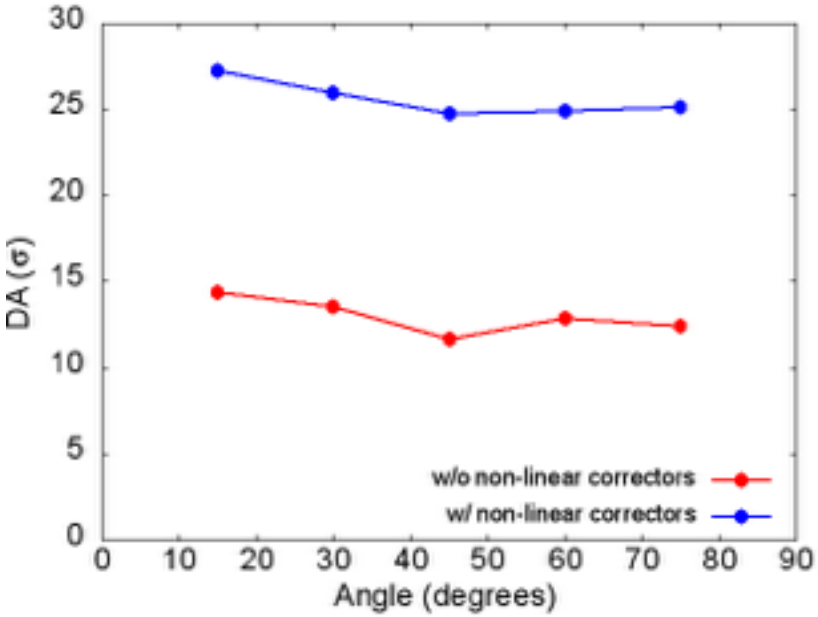

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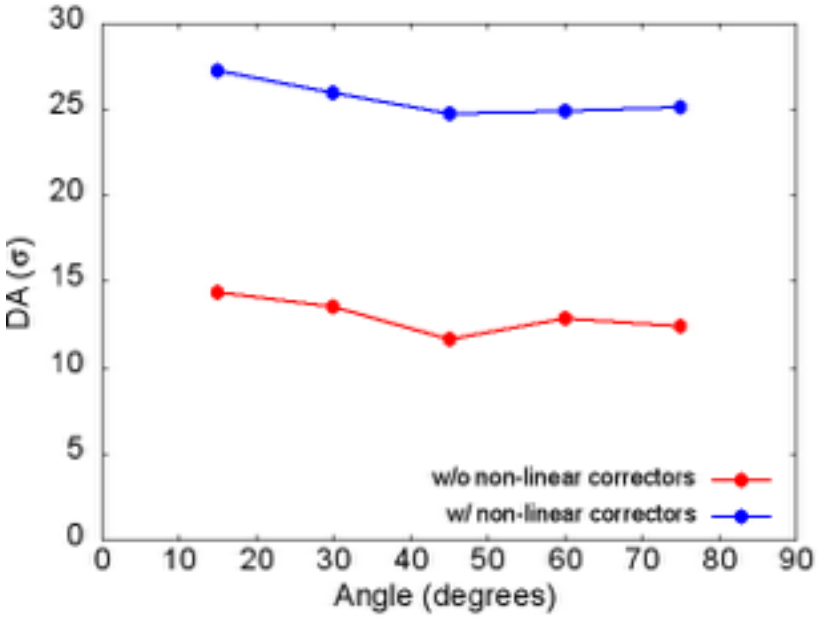

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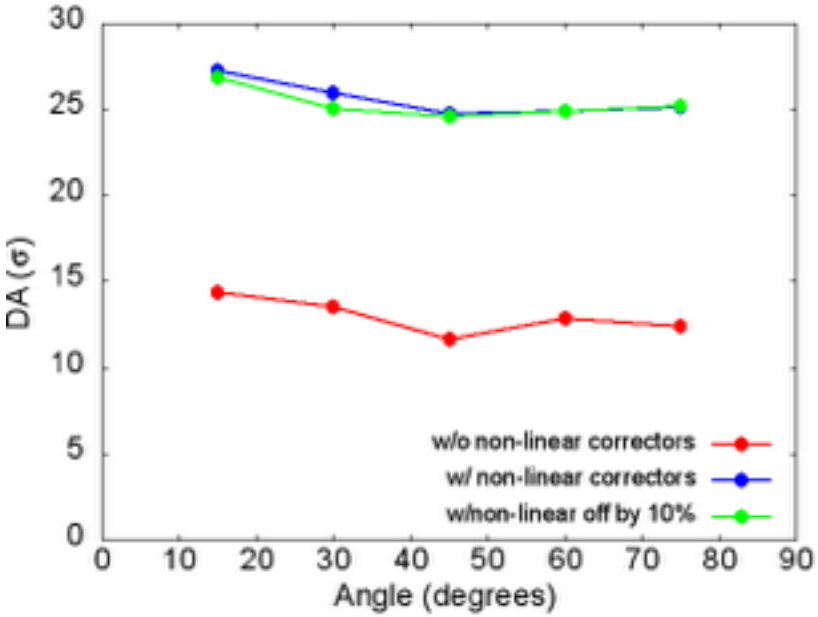

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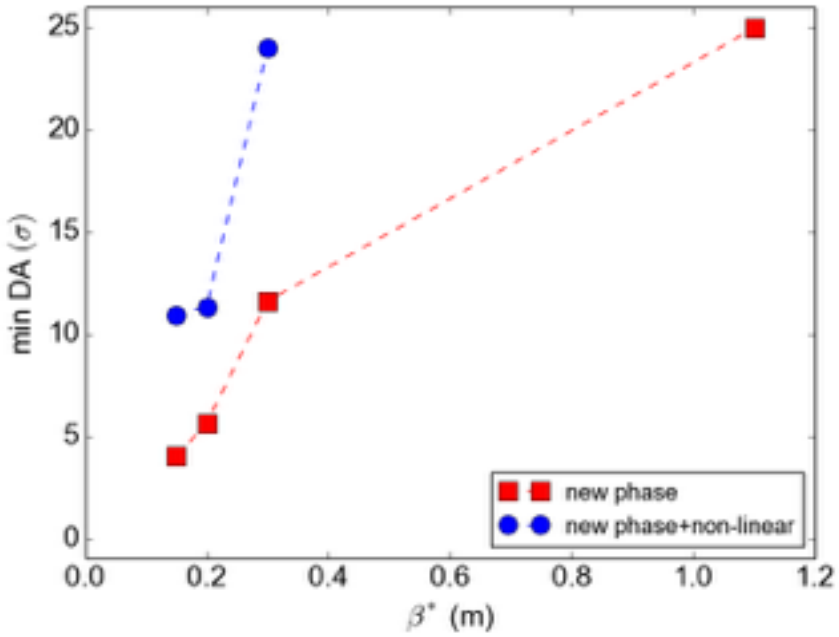
- Non-linear corr case is “ideal”. Check what happens when corrector strengths are off.
- Correctors strengths were purposely off by 10%. Look for effect on DA.
- Even when correctors were off DA stays very similar.

Different β*

- Explore different options of β* for the baseline design (β*=0.15, 0.2, 0.3, 1.1 m)

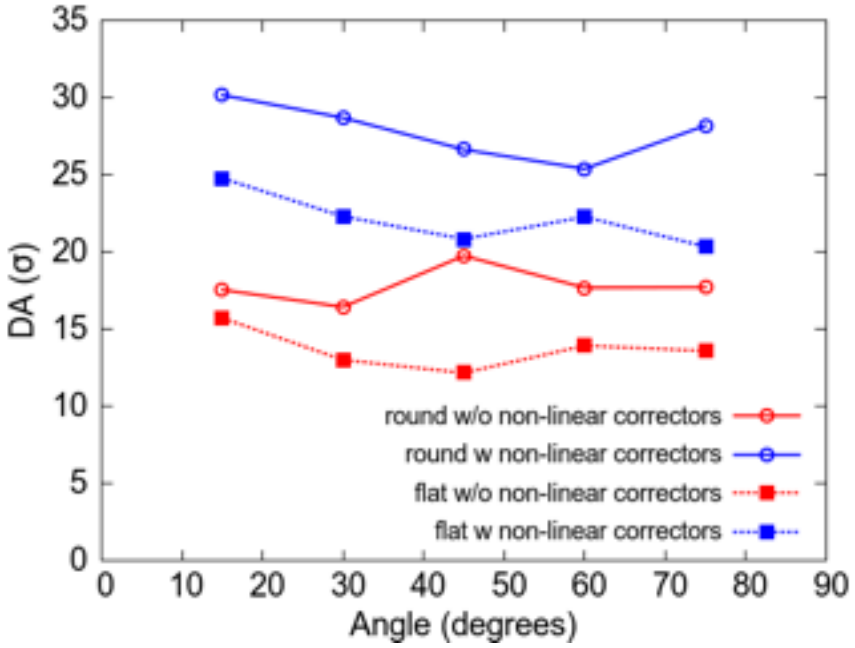
R. Martin/Overview of the IR



- β*=1.1 m ok even w/o non-linear corr
- Increase of 5-10σ for other cases when using non-linear correctors.
- Non-linear correctors crucial for acceptable DA for cases β*=0.15 and 0.2 m.
- Final results w/non-linear correctors:
  - DA > 20σ for β*=0.3 and 1.1 m
  - DA > 10σ for β*=0.15 and 0.2m

Alternative Design

Results for the alternative design for round (β*=0.3m) and flat beams (β*=0.15 and 1.2 m) *L. Van Riesen/Alternative IR for FCC-hh*

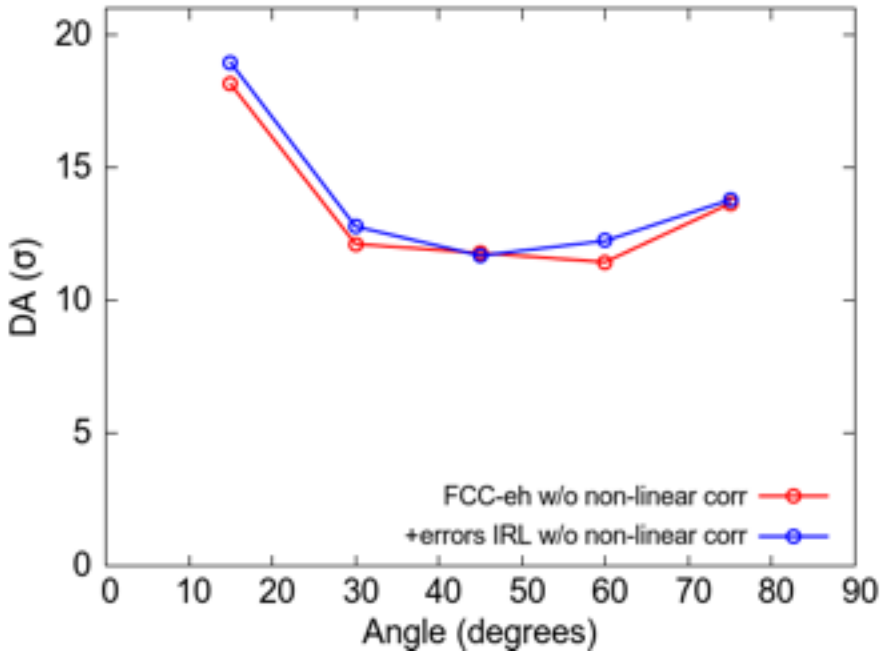


- Round case (β*=0.3m) really stable
  - DA=16.4σ w/o non-linear
  - DA=25.4σ w/ non-linear
- Flat case lower DA but sill stable:
  - DA=12.2σ w/o non-linear
  - DA=20.4σ w/ non-linear

- No tests done for other β*. But likely to follow same principle than normal design: stable for β*=1.1 m (even w/o non-linear), non-linear correctors for acceptable DA for β*=0.15 and 0.2m.

FCC-eh

Repeat studies for case including FCC-eh (β*=0.3m in IPA, IPG and IPL)



- Min DA is similar to case for FCC-hh
  - DA= 11.4σ
- Similar errors were added to the new triplet (IRL) to check impact and DA stay the same
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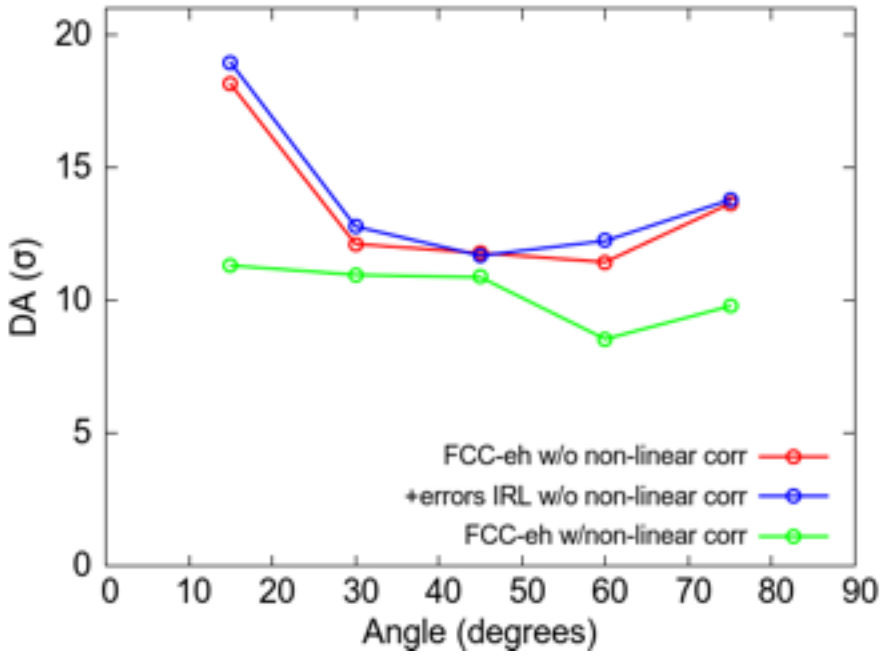

- Min DA is similar to case for FCC-hh
  - DA= 11.4σ
- Similar errors were added to the new triplet (IRL) to check impact and DA stay the same
  - DA= 11.6σ
- Surprisingly when non-linear errors were added DA went down (only case when this happens)
  - DA= 8.55σ

FCC-eh is the case where phase impacts the most, so more tests will be made with non-linear correctors

Summary

- The DAs at collision including errors (but no beam-beam): ß*≥30 cm round beams (for both normal and alternative design) and flat beams results in:
  - DA > 10σ w/o non-linear corr
  - DA > 20 σ w/ non-linear corr

- The case for FCC-eh has also >10 sigma w/o non-linear correctors (even when mock errors are implemented in the new IR), but the case with non-linear correctors needs to be checked.

- The most challenging cases of ß*=15 and 20 cm results in a DA of >10 sigma but only when non-linear errors are included.

- Use of non-linear correctors recommended. Just about necessary for ultimate case but they do offer steady increase (even when not correcting 100%) and also they become necessary if ones wishes to push the beta* below 0.3 m.

- In the case of compatibility with beam-beam+oct, a phase between main IPs was found that worked for both. This errortable seems to have a less dependency on the phase so its likely that a new phase can be found that works for both if the current one doesn't work.

Lessons on DA

Project (and contract!) is ending so a few lessons for the future in case lattice/ errortables changes results in DA

- The two corrections that have the most impact on DA at collision are: optimizing the phase between main IPs and adding non-linear correctors.
- Non-linear correctors offer a steady increase but optimal phase changes depending on error table and optics.
- Previous cases offer a big change on vertical phase. So method required to look for good zone in vertical phase and then optimize horizontally (get higher DA – changes of 2 sigma- or optimizing with beam-beam)
- Current error table doesn't have such an impact though, why? Under investigation.
- In the mid time if DA goes to zero (or lower than expected) is worth doing a small scan before anything else to check if it's the phase!