IR non-linear correction with beam-beam

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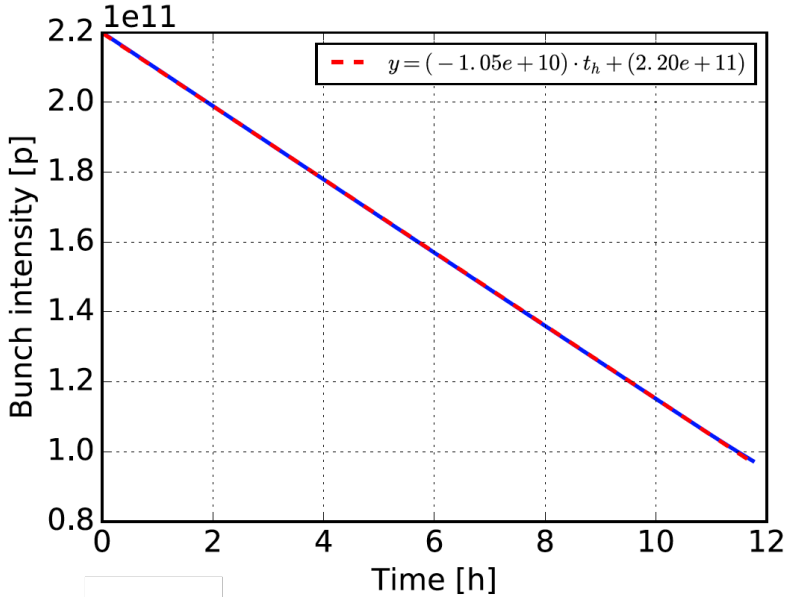
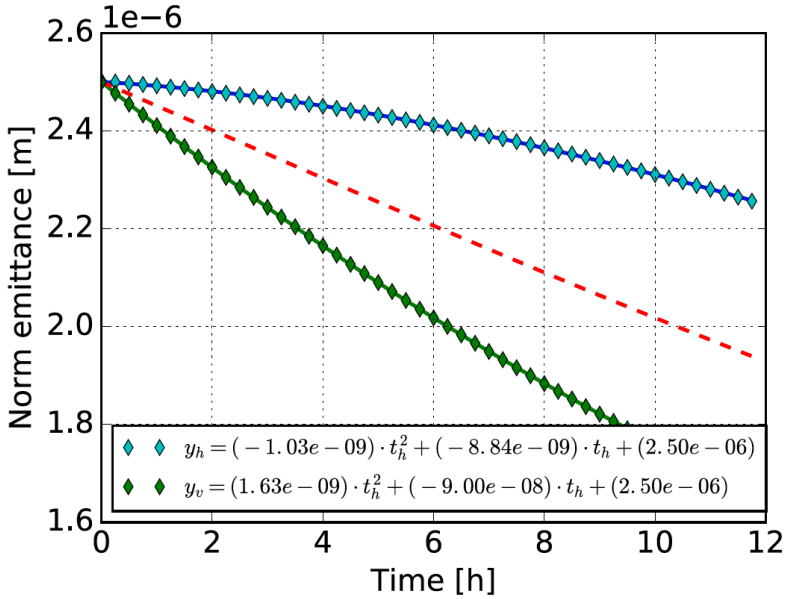
Introduction

- Multi-parametric simulations for Dynamic Aperture with beam-beam effects for β* and crossing angle levelling
  - Main updates:
    - Fold in the simulations the evolution of emittance during levelling following the luminosity model;
    - Since H and V emittances vary differently with time, explore the non-round beams scenario;
    - Include machine errors and perform statistical analysis to identify our margins.

Evolution of Emittance

- Modified the Luminosity model (already robust for LHC) to the HiLumi parameters to test the evolution of beam parameters during the fill.
- The information gained by the model was folded in our SixTrack simulations.





Evolution of Emittance

- Based on the model the steps we perform in bunch intensity are translated into time;
- The evolution of normalized emittance during the levelling process is modelled with a starting point of $\epsilon_{n,x} = \varepsilon_{n,y} = 2.50 \mu\mathrm{rad}$ (round).

Intensity [e11 ppb]	Time [h]	ε_{nx} [µm-rad]	ε_{ny} [µm-rad]
2.2	0	2.50	2.50
1.9	2.86	2.47	2.26
1.6	5.71	2.42	2.04
1.3	8.57	2.35	1.85
1.275	8.81	2.34	1.83
1.25	9.05	2.34	1.82
1.12	10.29	2.30	1.75

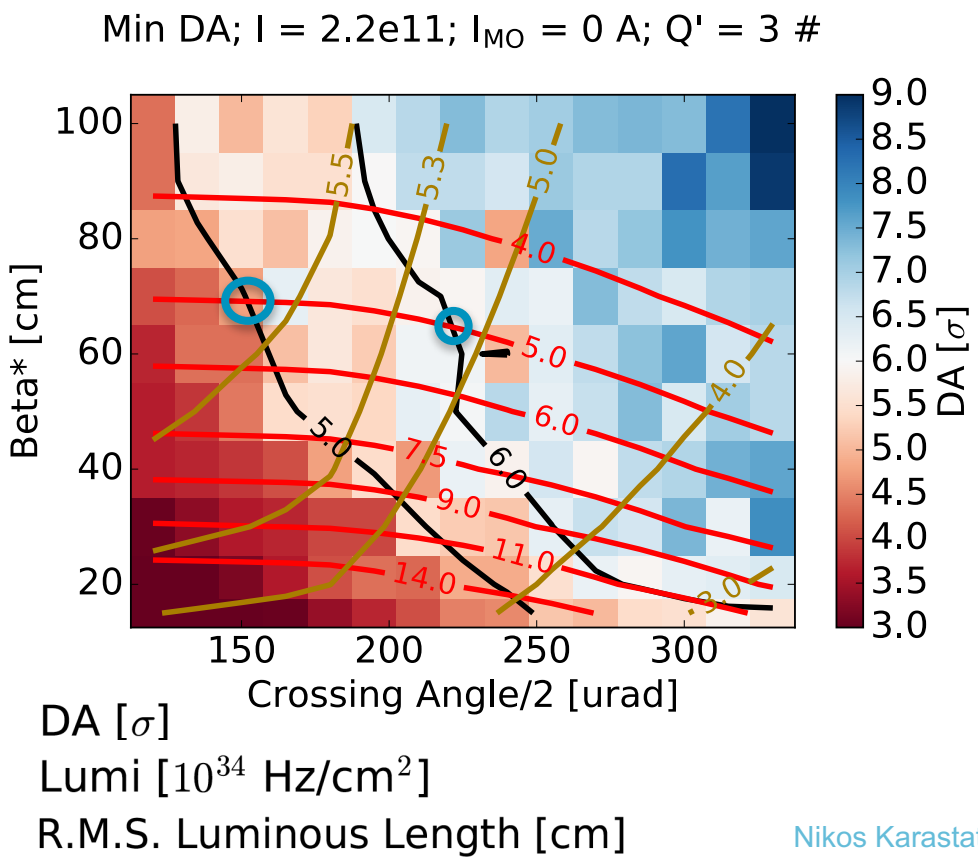
Global DA Scanning of Parameters

- Simulation Set-up:
  - HL-LHC v1.2 optics, half number of crab cavities (CC max angle 380μrad)
  - Octupoles are set to 0A and chromaticity to 3. The nominal tunes are used and (for now) no multi-pole errors are considered.
  - IP1, IP5 and IP8 head-on, IP2 separated (halo collisions)
  - Beams are assumed **round** at the beginning of the levelling process and **evolve** as described.

- Tracking with SixTrack for 10^6 turns and estimating the **minimum DA**.
- Scanning of the **crossing angle** vs **β*** for various intensity steps.
- Superimposing the **luminosity** and **luminous region** curves for various parameters.
- Reminder: Based on the LHC experience and simulations we formulate two scenarios :
  - **Aggressive** : DA of **5σ**
  - **Relaxed** : DA of **6σ**

Start of levelling – Nb = 2.2e+11 ppb

No difference between fixed and dynamic emittance (beams assumed round at beginning of SB)

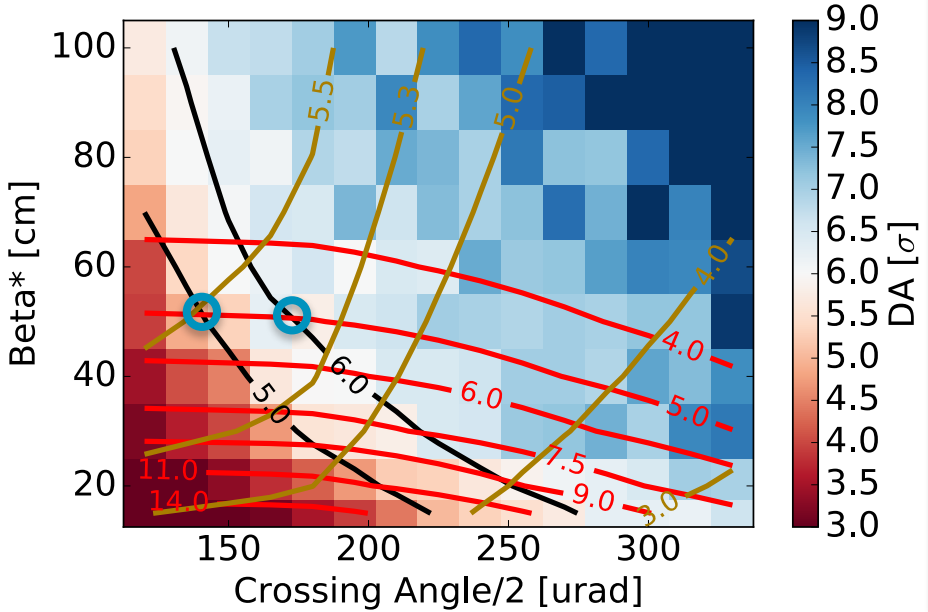


Nb = 1.9e+11 ppb

Small gain in DA due to smaller beam size, increase of luminosity, slight change of pileup.

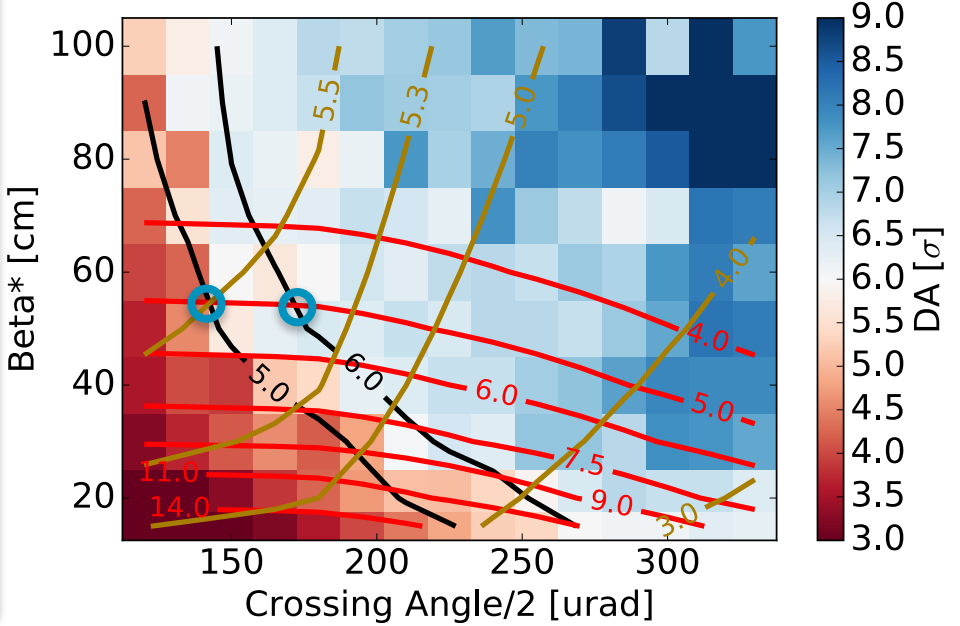
Round Beams

Min DA; I = 1.9e11; I_{MO} = 0 A; Q' = 3 #



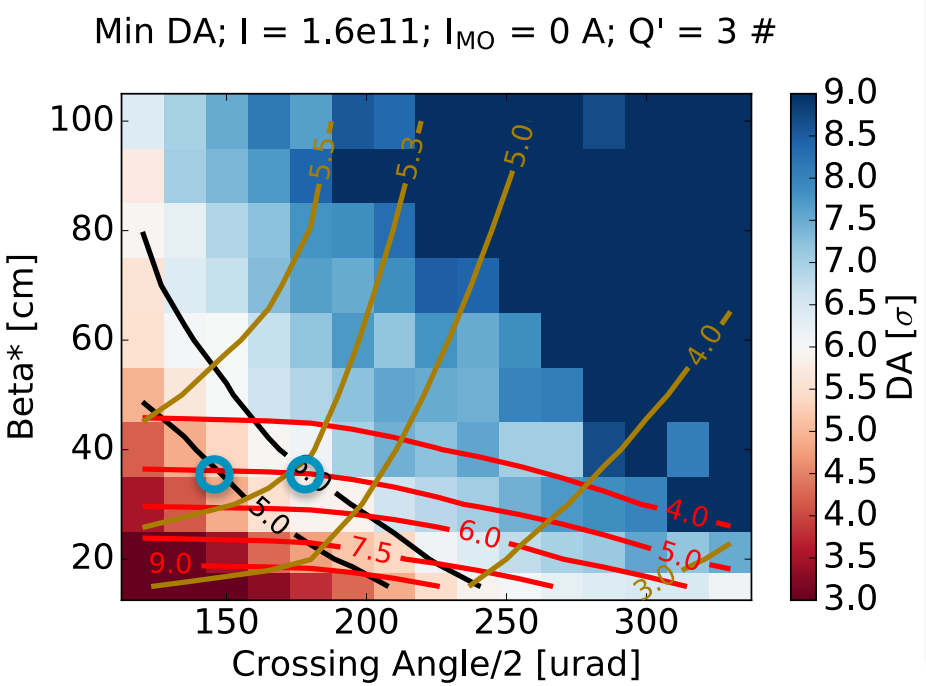
Non-round Beams

Min DA; I = 1.9e11; I_{MO} = 0 A; Q' = 3 #

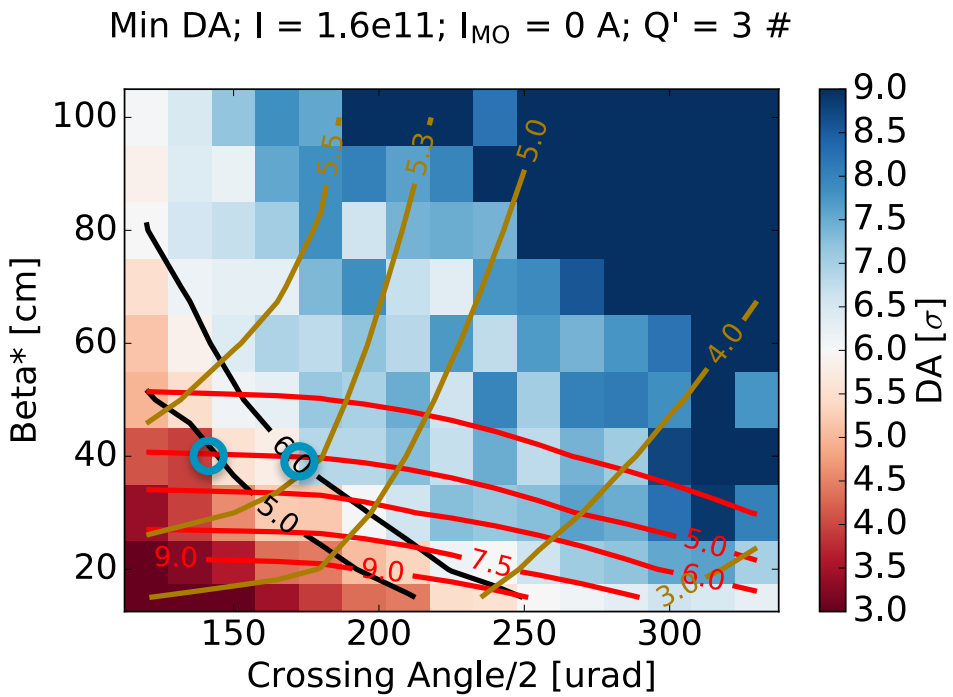


Nb = 1.6e+11 ppb

Round Beams

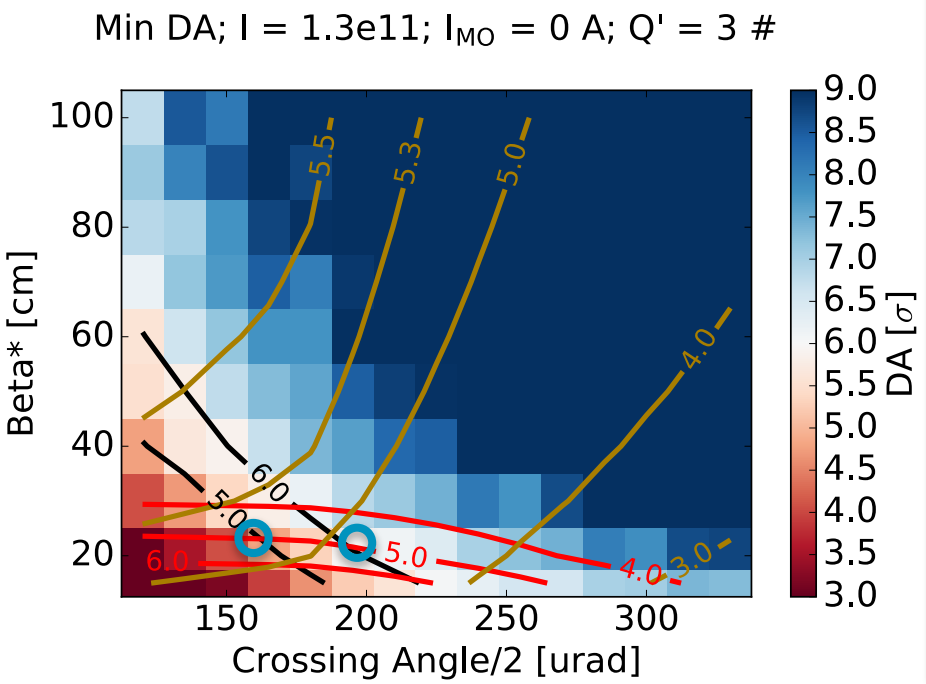


Non-round Beams

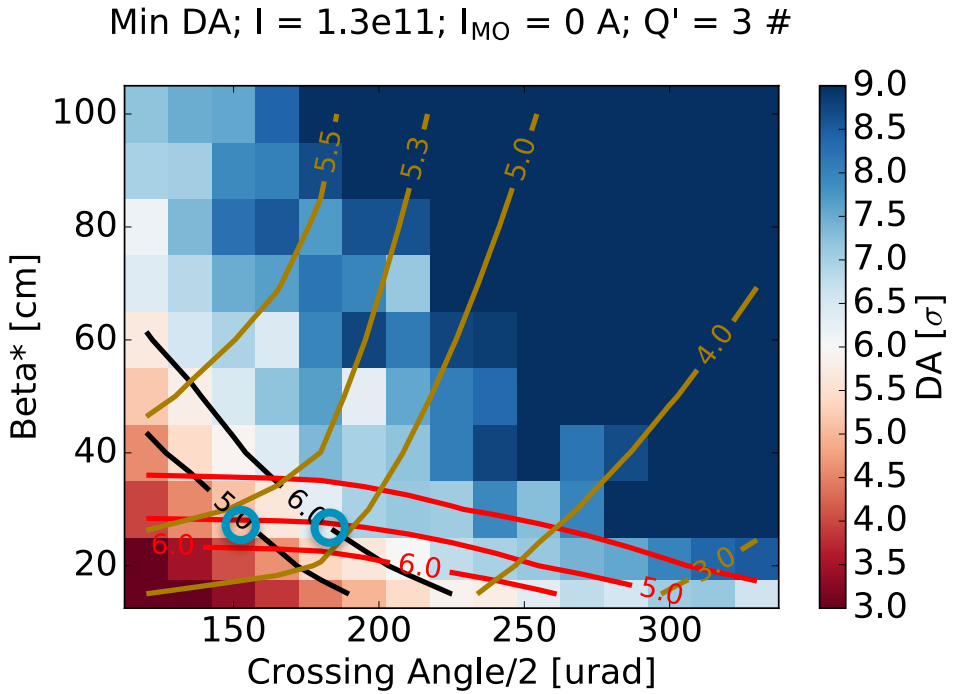


Nb = 1.3e+11 ppb

Round Beams

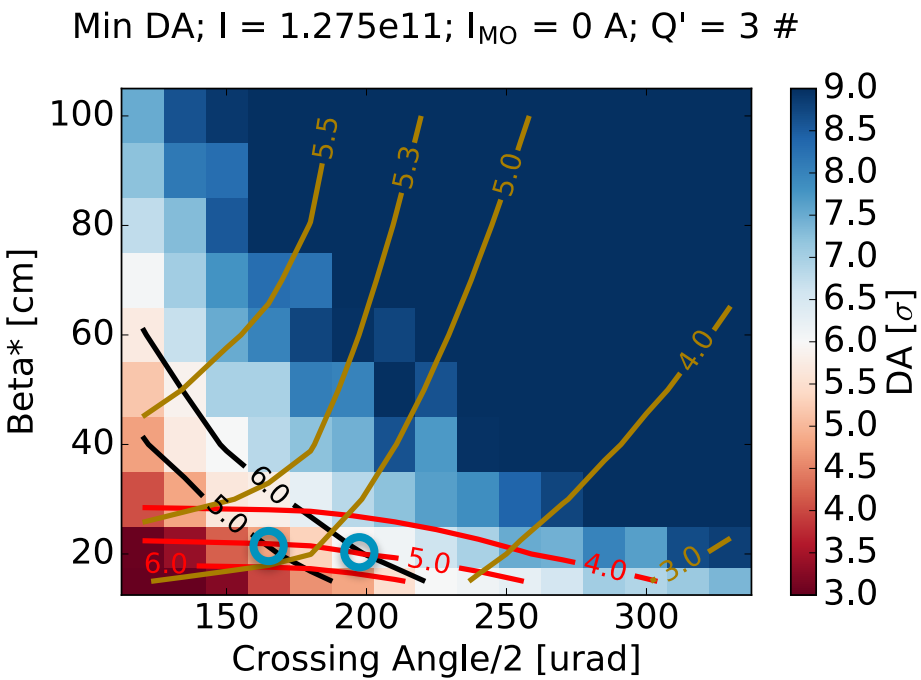


Non-round Beams

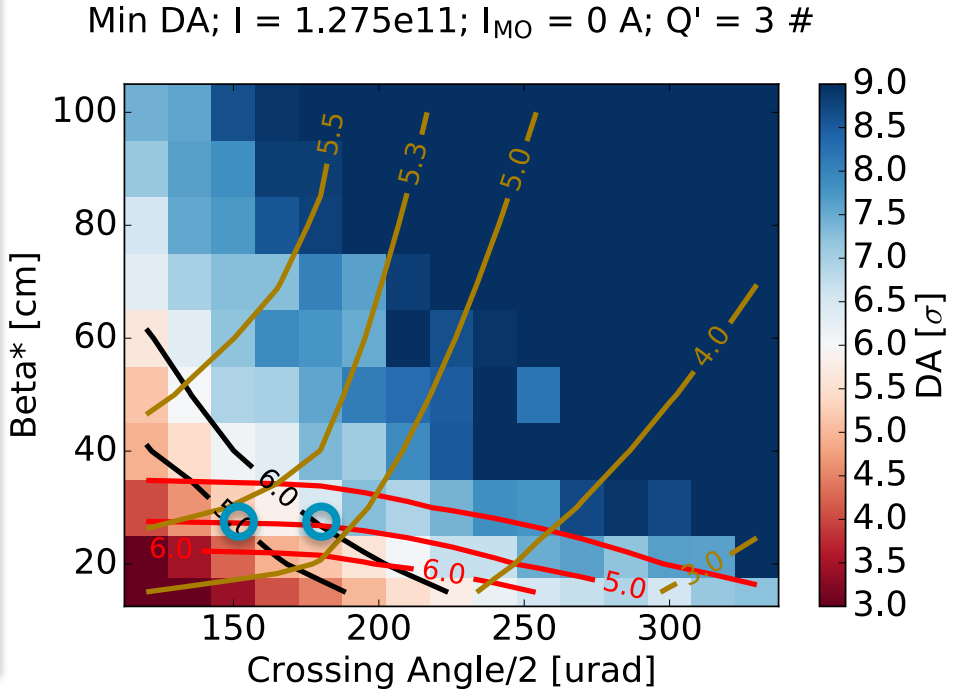


Nb = 1.275e+11 ppb

Round Beams

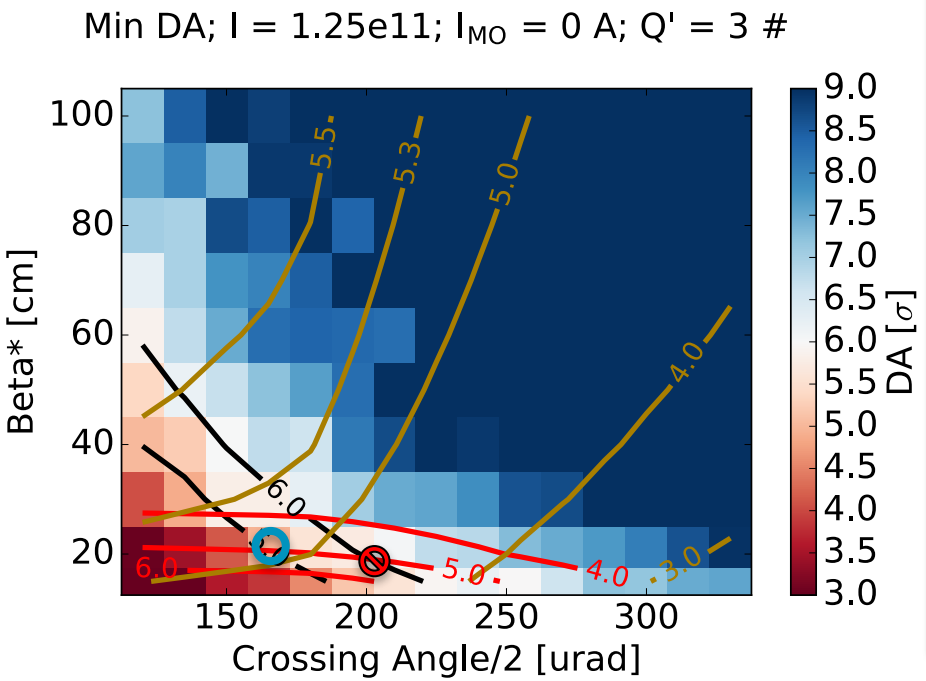


Non-round Beams

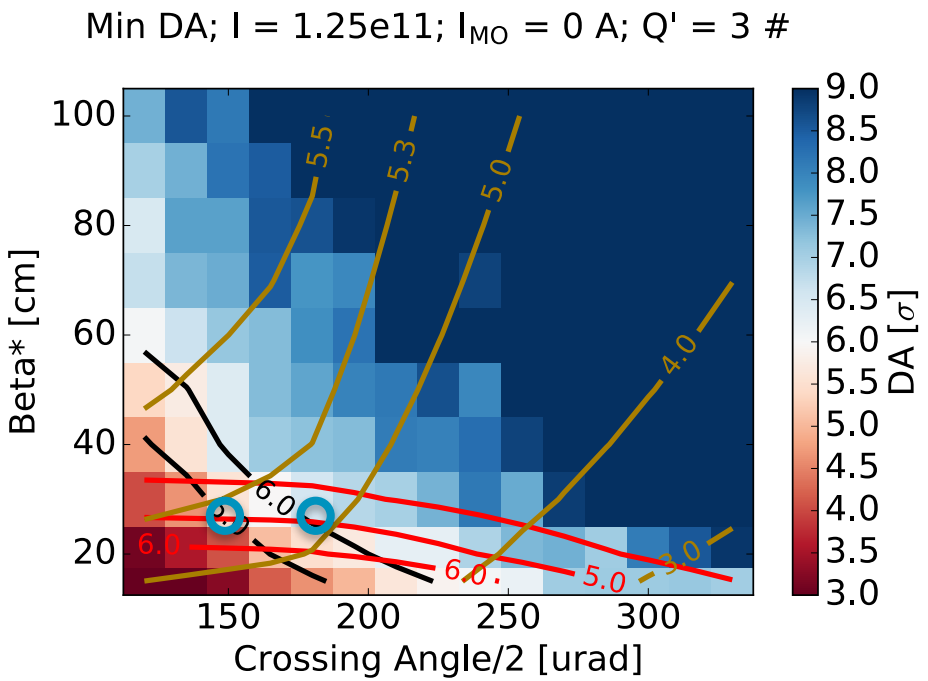


Nb = 1.25e+11 ppb

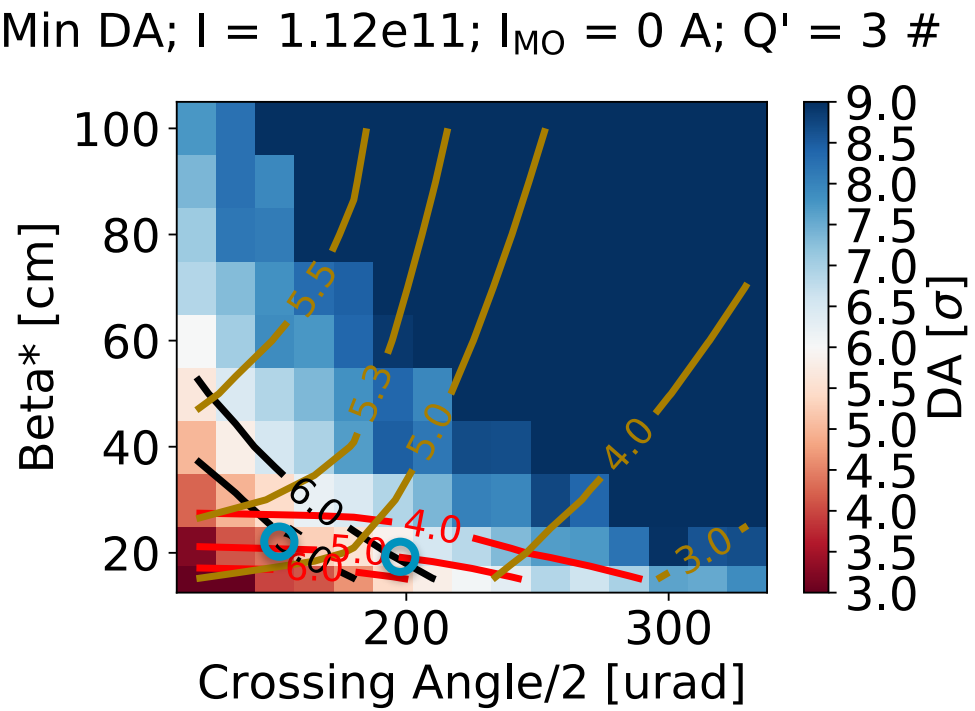
Round Beams



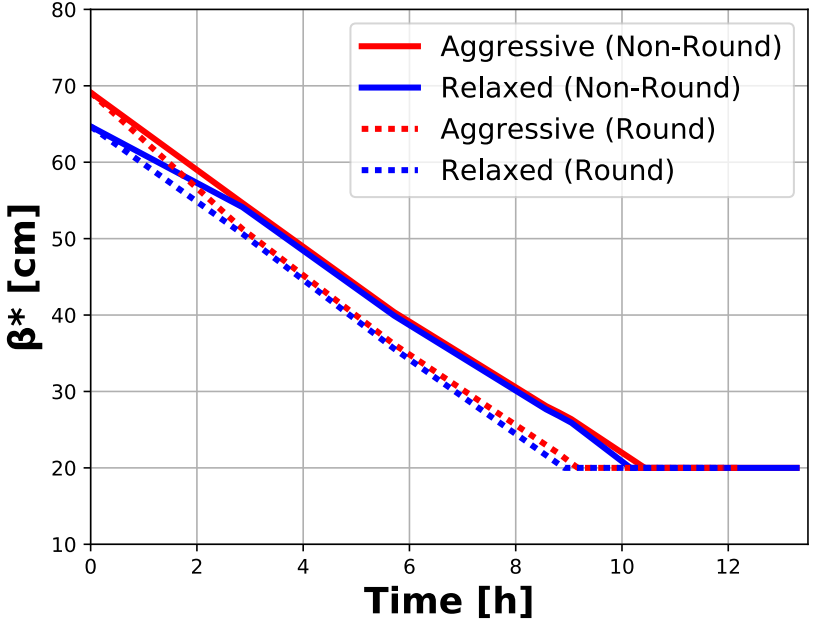
Non-round Beams

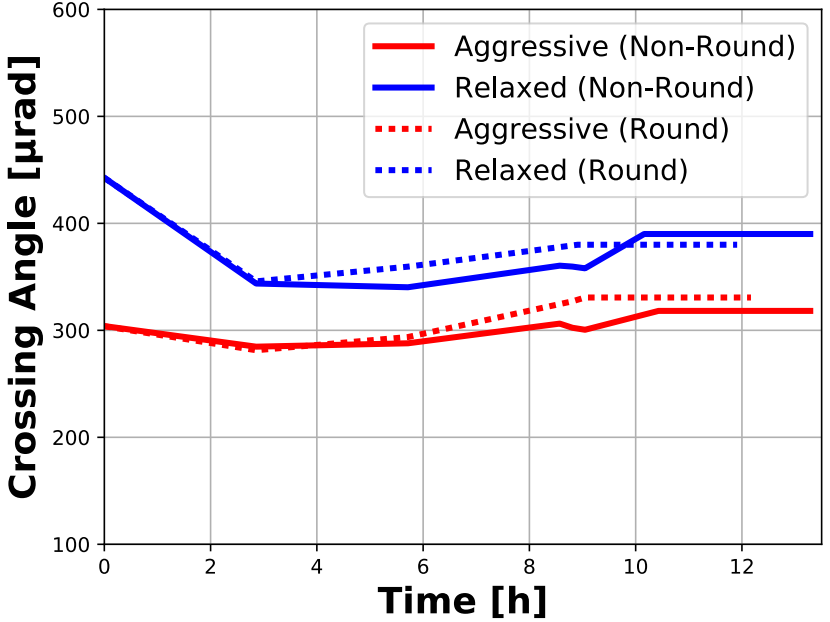


Nb = 1.12e+11 ppb

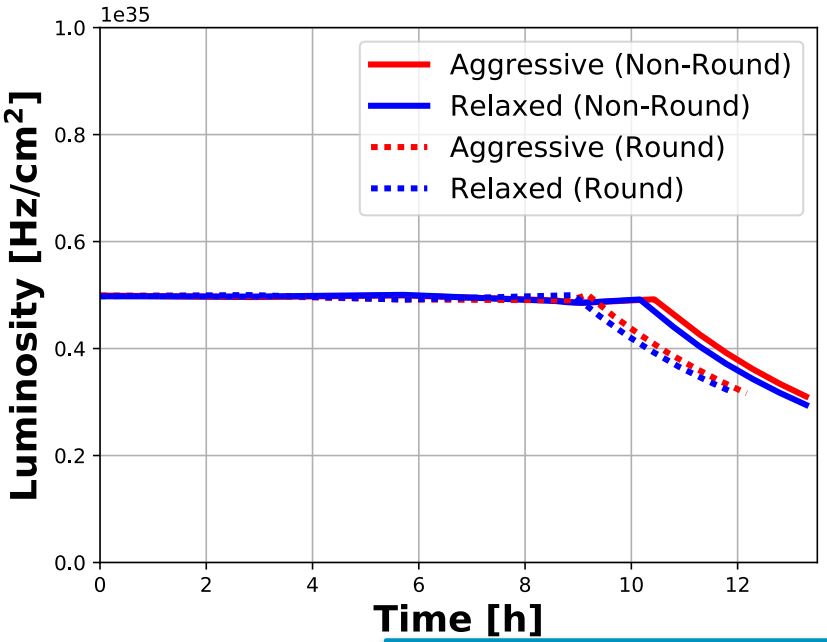


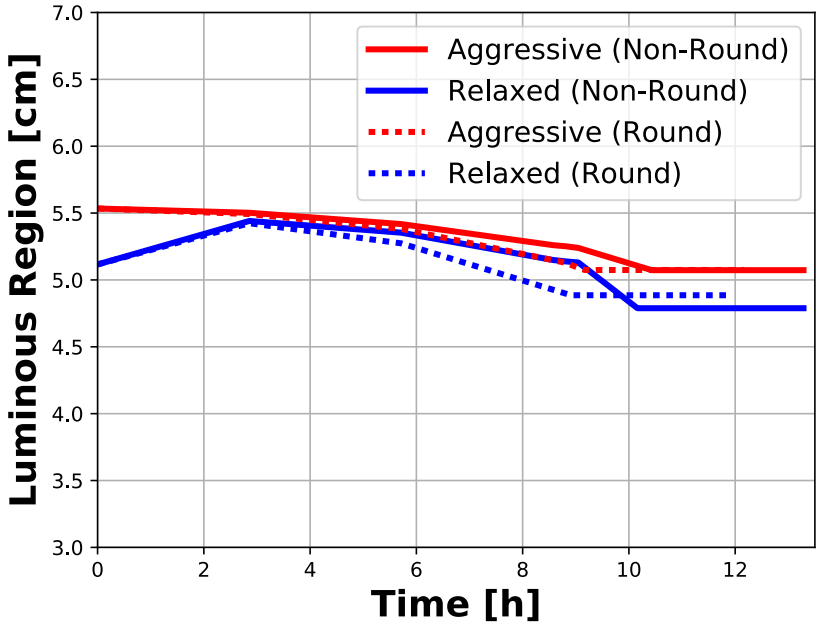
Parameter Evolution During Levelling





Parameter Evolution During Levelling





Round Relaxed : 1603.8/pb
Round Aggressive: 1605.1/pb
Non-round Relaxed: 1828.8/pb
Non-round Aggressive: 1877.4/pb

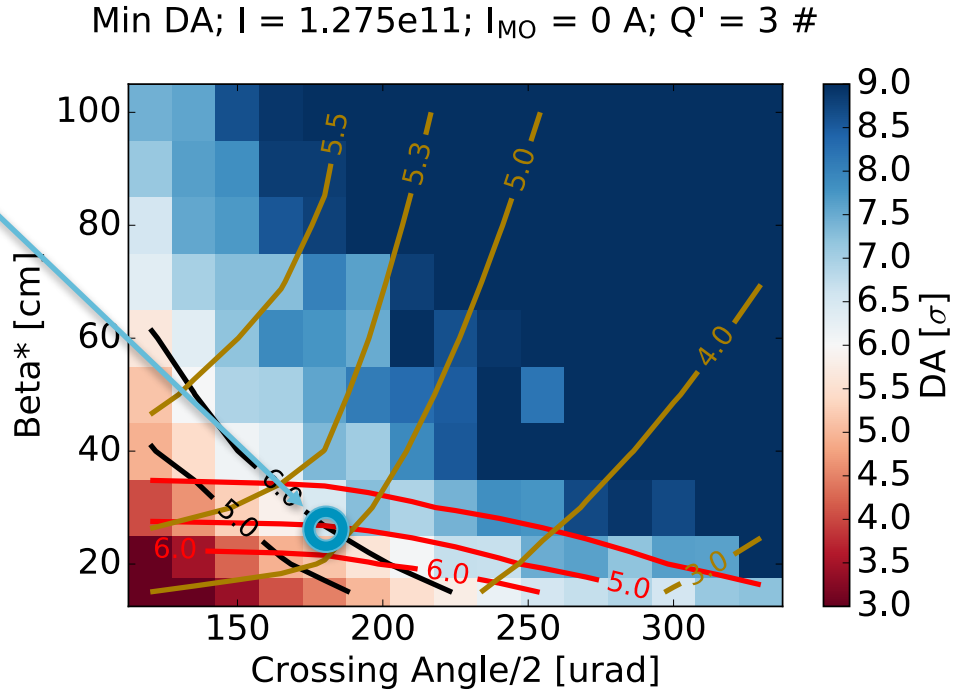
Inclusion of Machine Errors

- The next step is to include machine errors:

- Updated the HL-LHC v1.2 mask file to properly include all possible errors:
  - MB + orbit distortion correction
  - Field errors on separation dipoles, quadrupoles, the new IT/D1/D2/Q4/Q5
  - Correctors Errors at IR1 and IR5
    - b3, b4, b5, b6, a2, a3, a4, a5, a6
    - For IR2, IR8 the b3, b4, b6, a2, a3, a4 the correctors are not taken into account, since their impact is negligible.

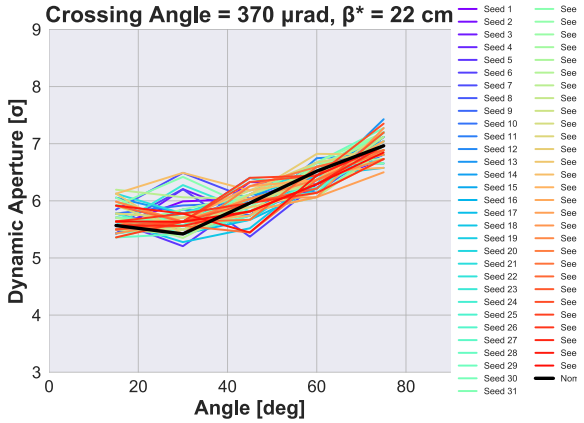
Inclusion of Machine Errors

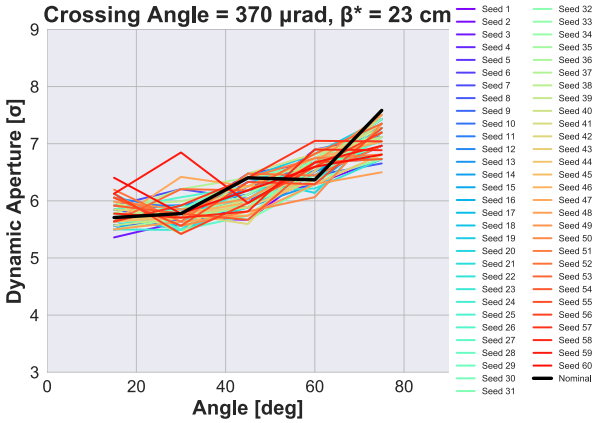
- Go at the **nominal end of levelling**;
- Identify the **point** of the ”relaxed” scenario:
  - *DA of 6σ and Luminosity of* $5 \times 10^{34} Hz/cm^2$ *)*
- Scan for a grid around this point with **60** realizations (‘seeds’) of the machine for the nominal 1M turns.
  - Crossing angles of **340 – 380μrad** and β* of (20..) **22-30cm** *(on-going to extend this to 20cm)*
- Perform a **statistical analysis** of the results to identify/verify the margins.
- *A very lengthy procedure with a few technical restrictions… i.e. apologies to whoever wanted to use the queues ☺*

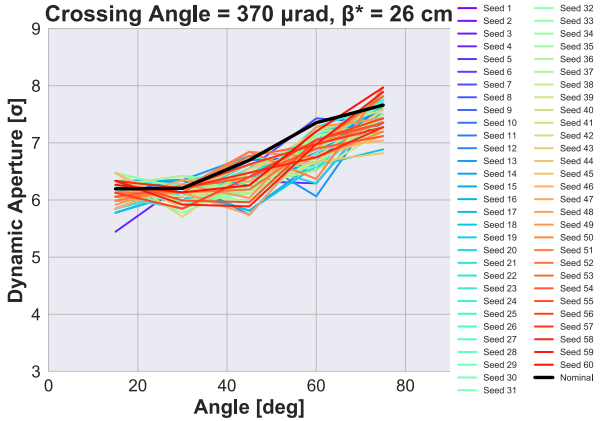


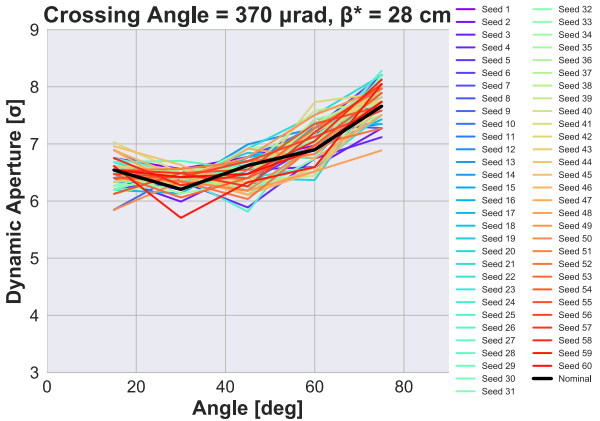
“Moving vertically for a fixed crossing angle”

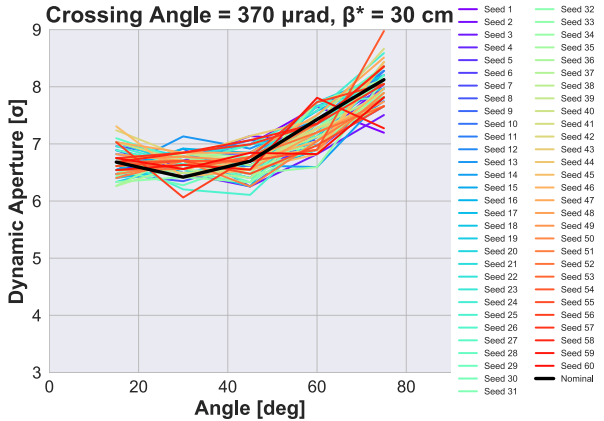
DA vs Angle – Crossing Angle 370μrad



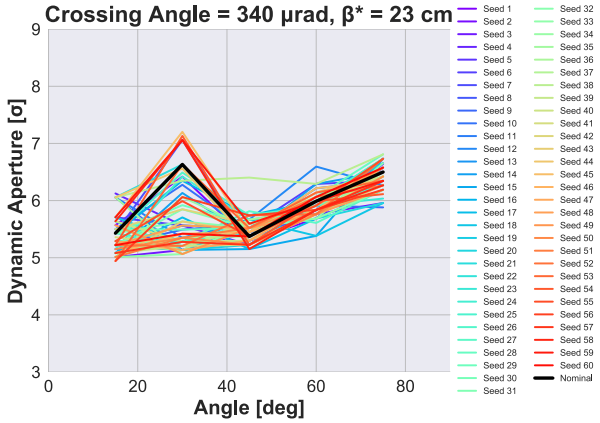


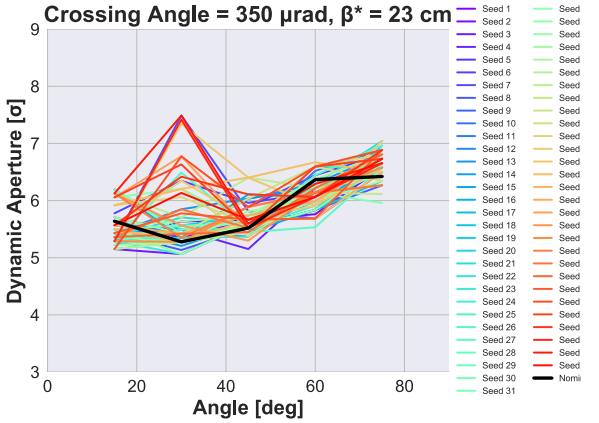


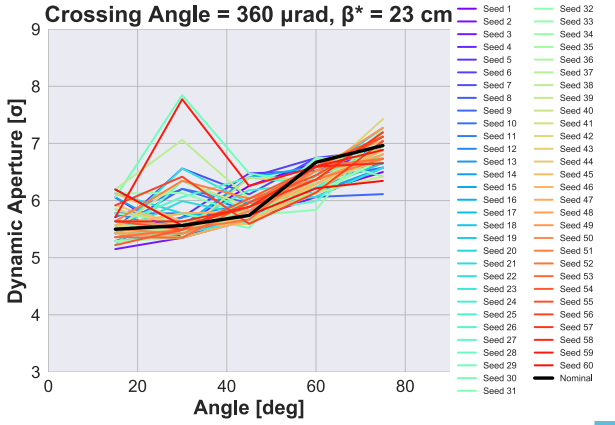


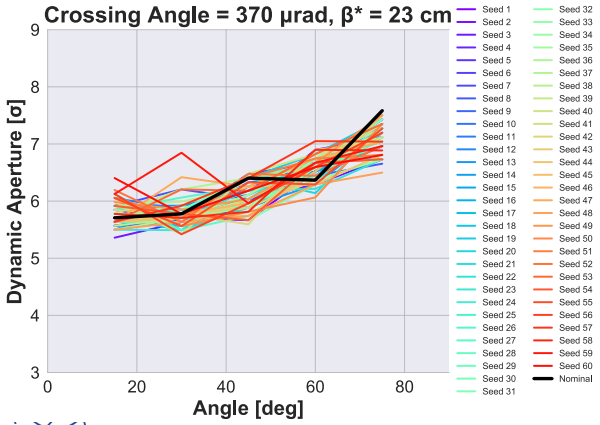


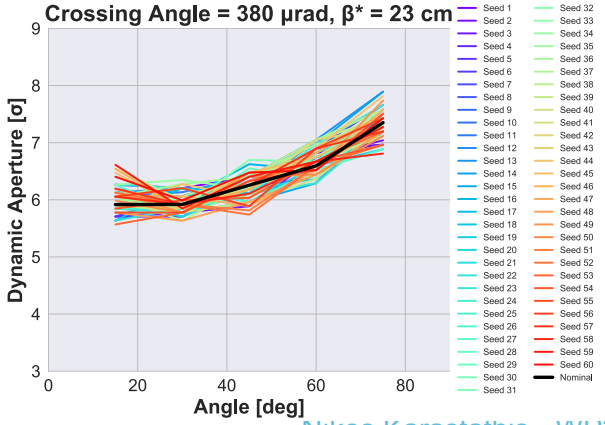
DA vs Angle – β* = 23cm



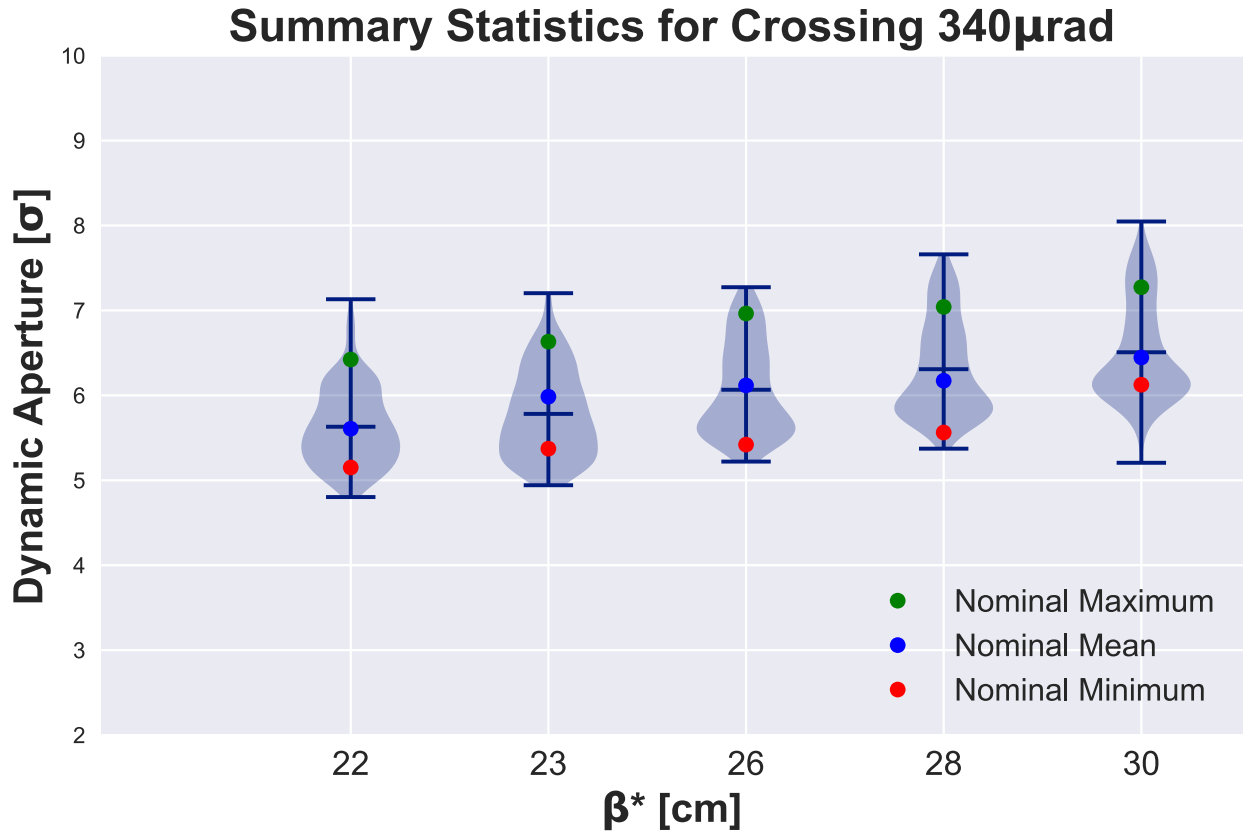




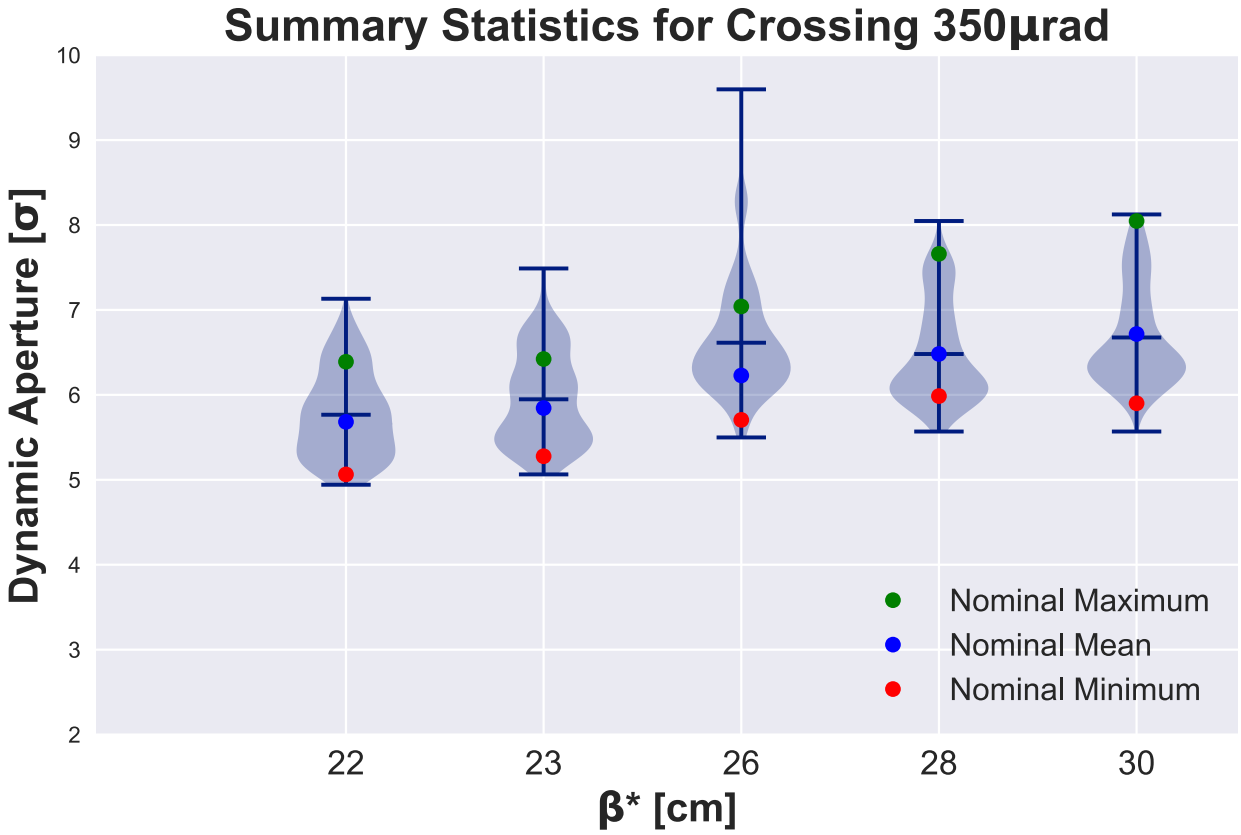




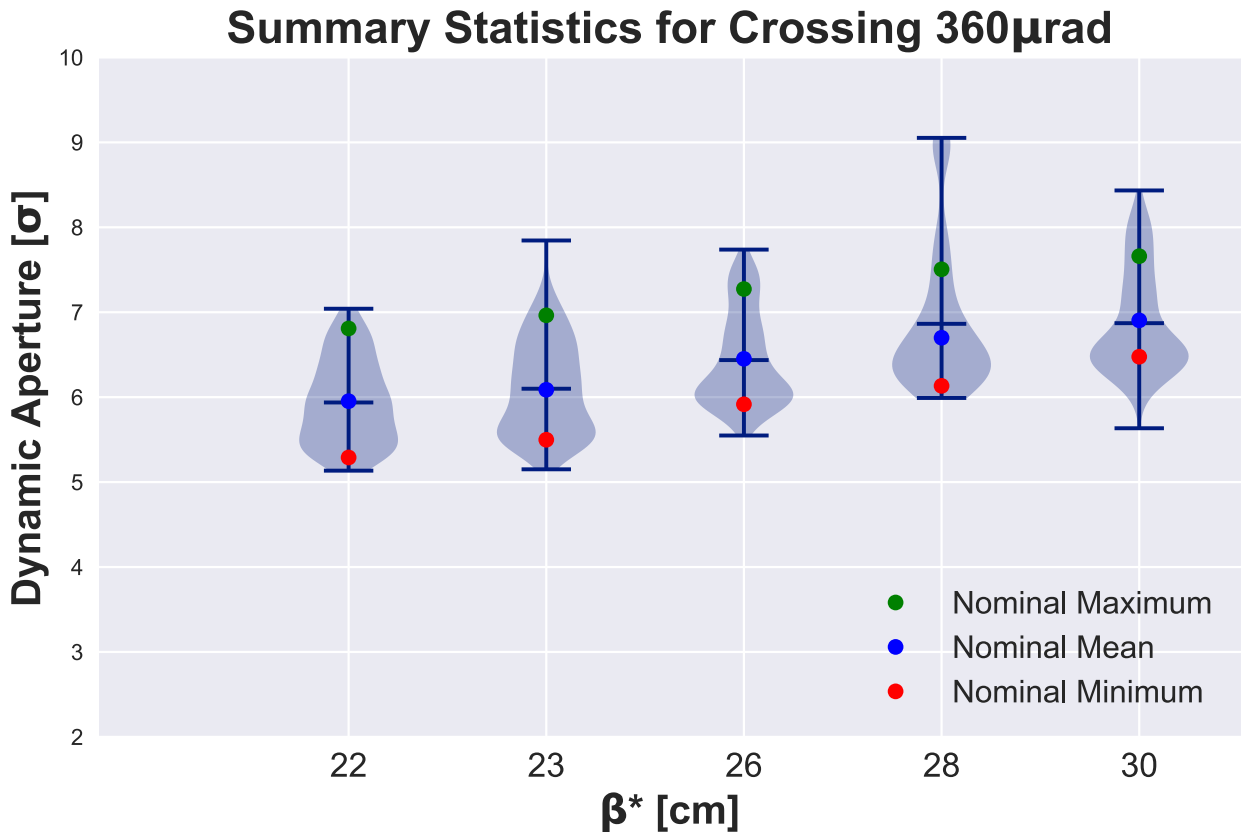
Summary Statistics - Crossing 340µrad



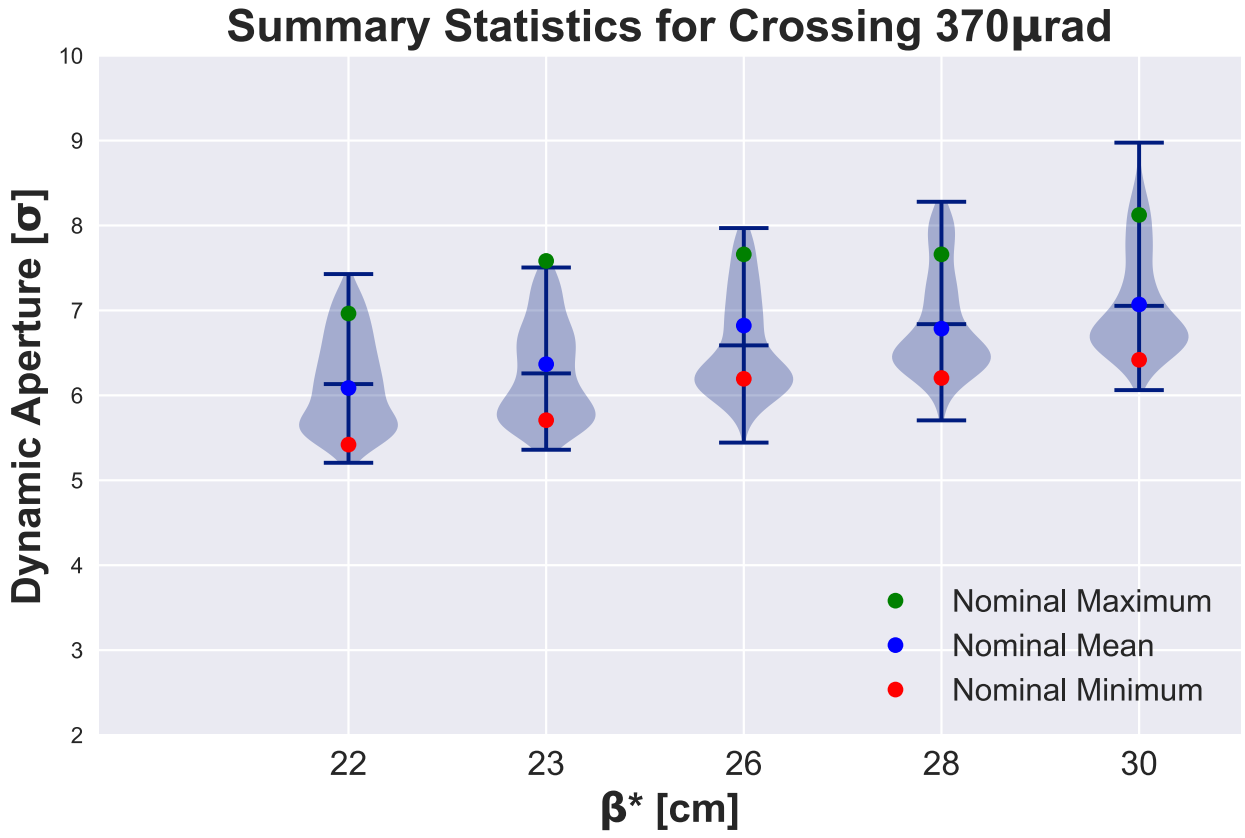
Summary Statistics - Crossing 350μrad



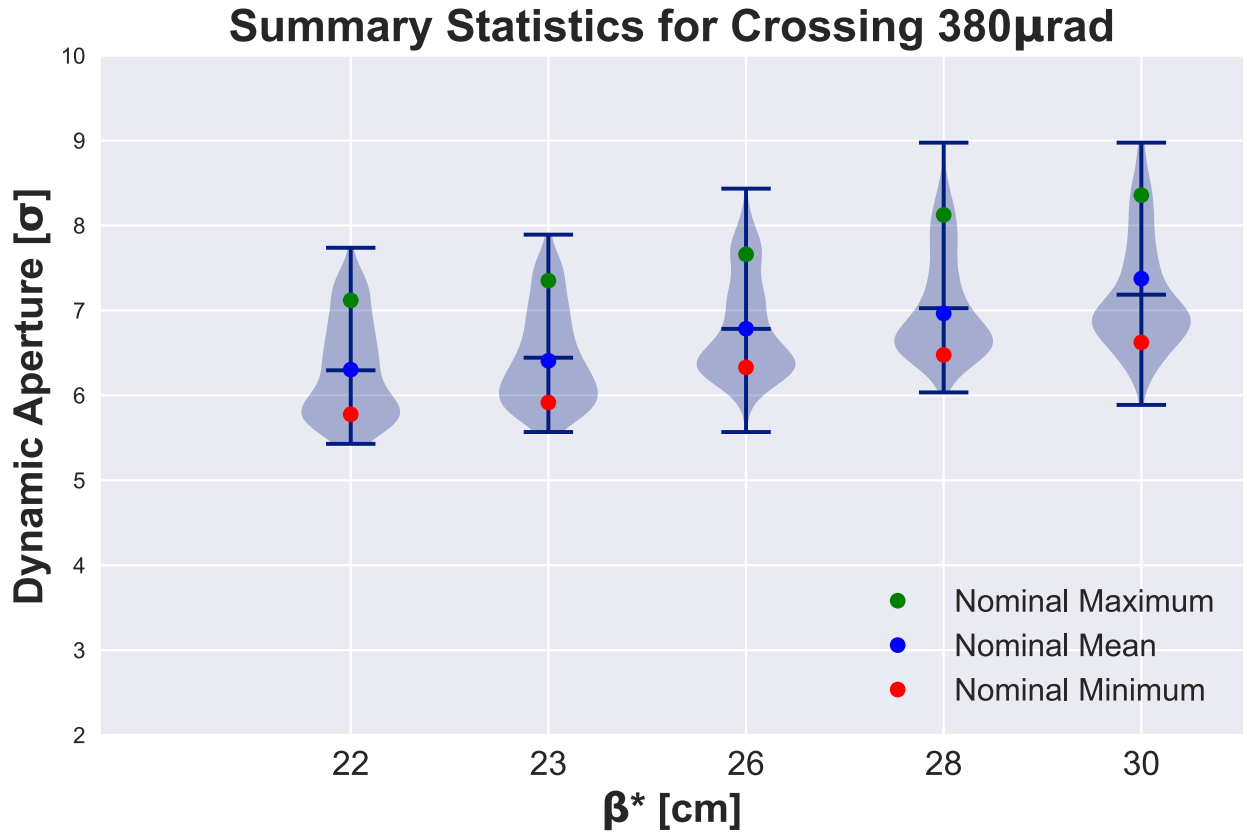
Summary Statistics - Crossing 360µrad



Summary Statistics - Crossing 370µrad

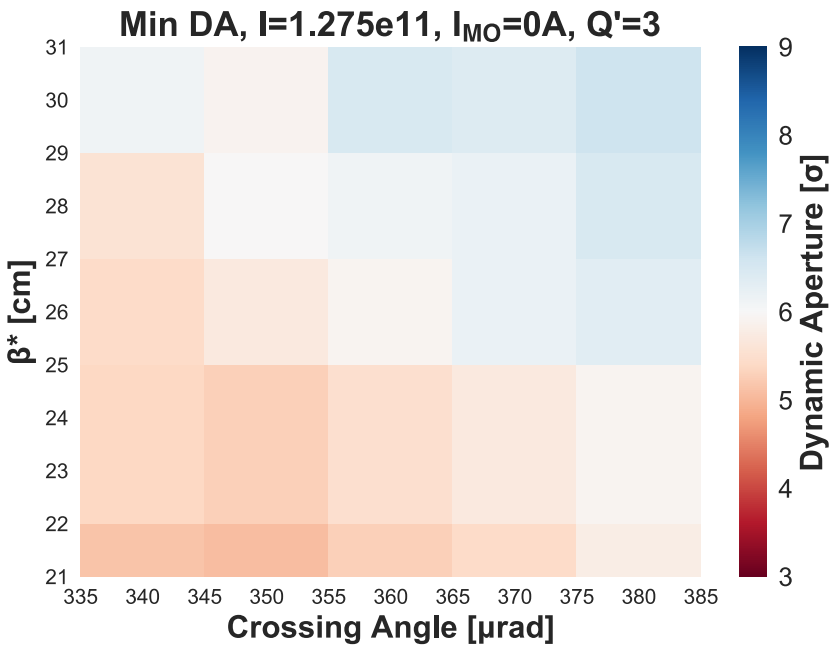


Summary Statistics - Crossing 380µrad

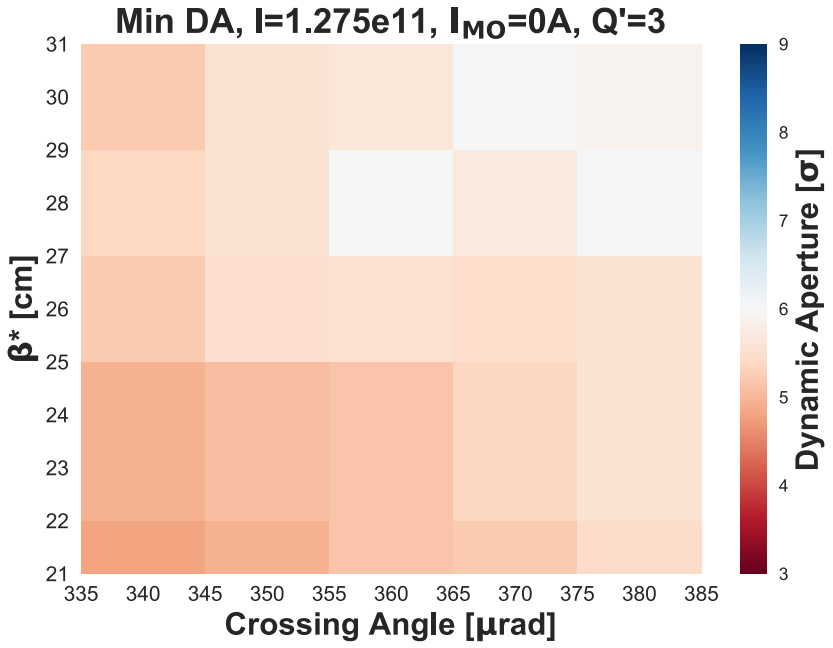


Minimum DA Grid

Nominal



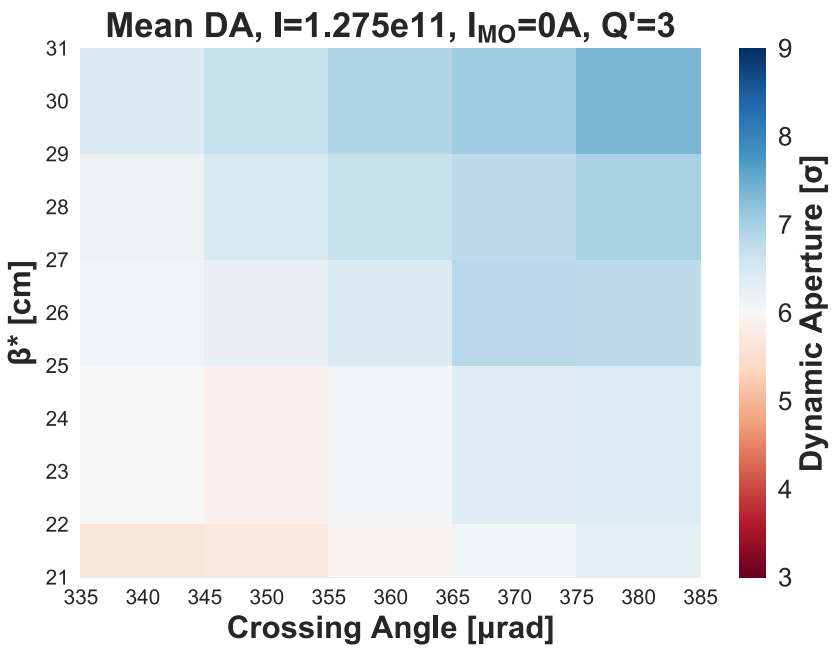
With Errors



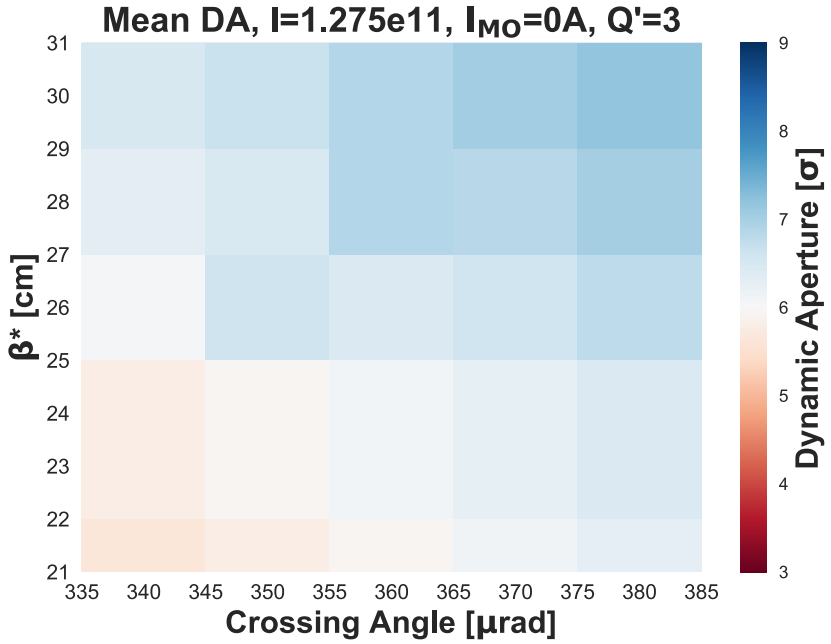
Maybe too pessimistic…

Average DA Grid

Nominal



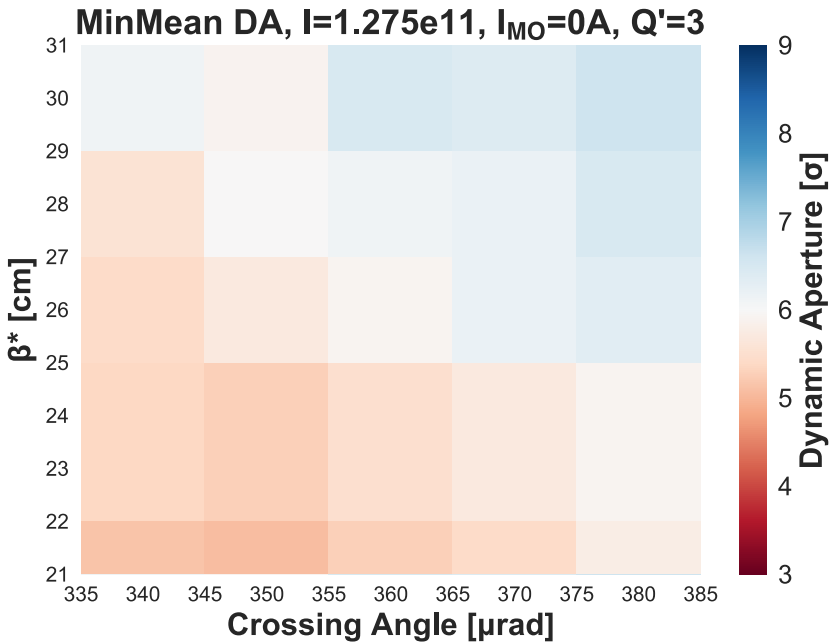
With Errors



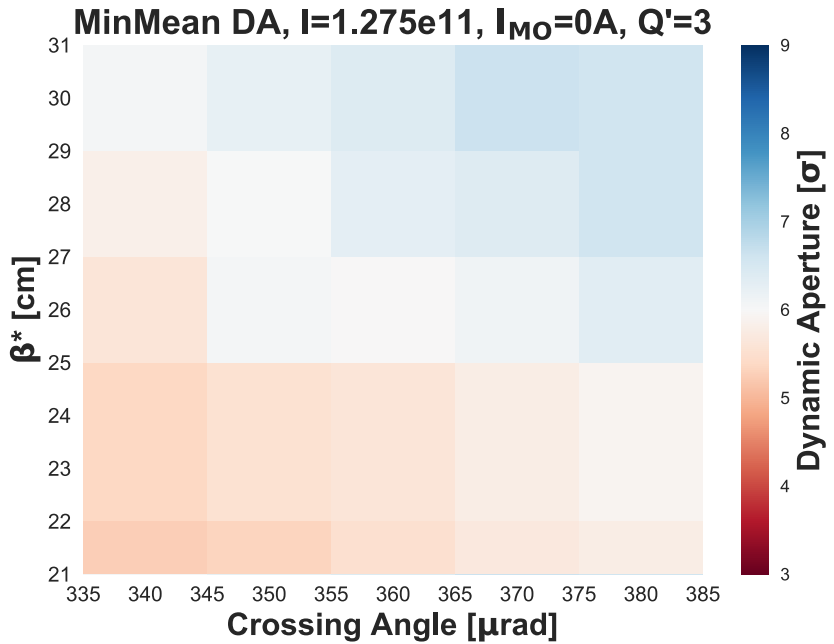
Maybe too optimistic…

Min of Mean of Angles DA Grid

Nominal



With Errors



Overview of Summary Statistics

- **Global average DA** at **6.4σ** with an **average standard deviation** of **0.56σ**.
  - *The standard deviation for the full population for all configurations is at the **0.7σ** level, while the one per angle in each configuration at the **0.3σ** level.*

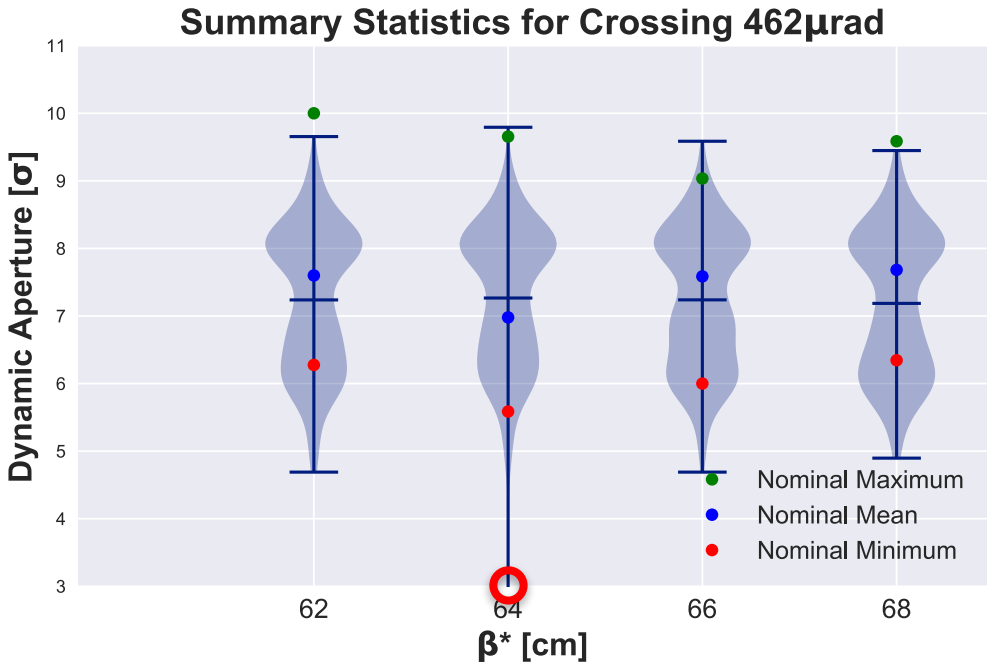
- **Global minimum** at **4.8σ**, at the furthest (from the point of interest) configuration considered, as expected.

- Minimum DA might be *too pessimistic* as an estimator, average maybe *too optimistic*.

- Both relaxed and aggressive scenarios are operationally and in terms of DA potentially viable.

Dependence on the Choice of Levelling Step

- Performing similar analysis for start of levelling (Nb=2.2e11ppb)
  - In total, we observe a larger spread in terms of DA (9.79-2.40σ)
- **Global average DA = 7.12σ**, **average standard deviation 1.02σ**
- The **Global minimum** of **2.40σ** is just one angle of one seed (462μrad, 64cm, Seed26, 15deg)! *The other angles for this seed are ok (8.0σ, 8.0σ, 6.8σ, 8.2σ).*
  - 2% of the population below the 5σ limi
  - 1 measurement (<0.01% of population) below 4σ limit
  - Next minimum at **4.3σ**

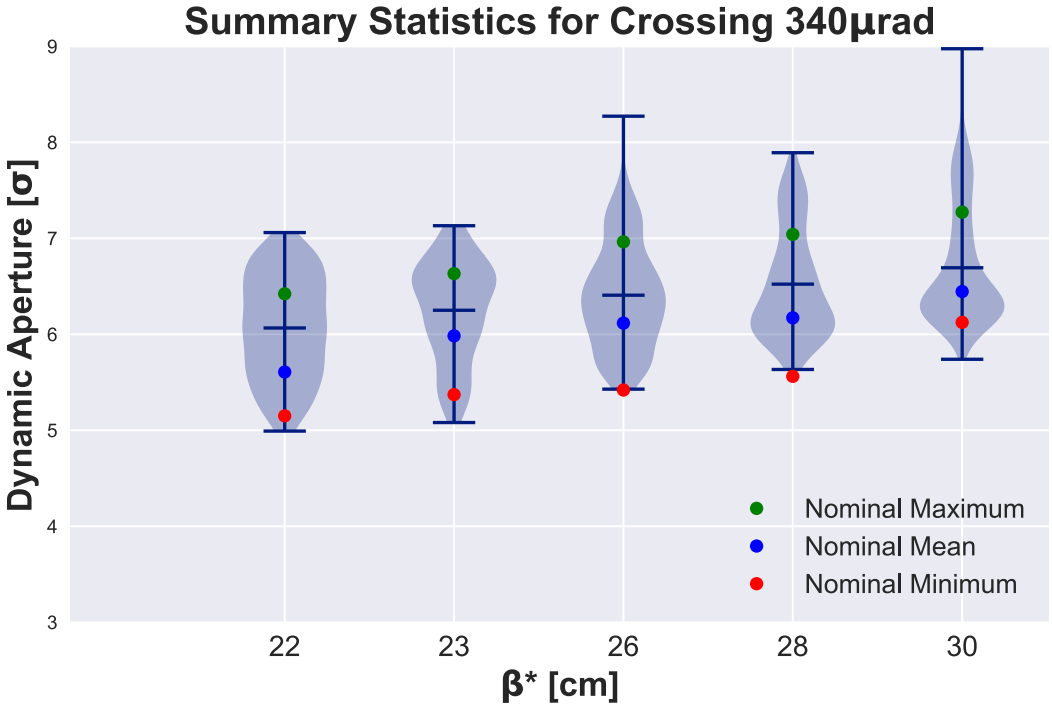


You have to take into account simulation uncertainties especially how well-defined the DA contours are for this Nb point. (Slide #6)

Preliminary

Inclusion of Fringe Fields

- A preliminary study was performed for N_b=1.275e11 with the inclusion of **fringe fields**.
- The **global average DA** was found at **6.7σ** with an **average standard deviation** of **0.6σ**.
- The **global minimum** was found to be **4.9σ**, at the furthest point from the POI, as expected.



This is something that needs to be followed-up.

Summary

- The simulations with **non-round beams** indicate an increase in DA and due to the self-consistent calculation of luminosity the parameter evolution shows the capability of lengthier levelling times.

- The inclusion of errors result in **global average** of DA **6.4σ** *(after correcting for the 'failed' cases)*, with an average standard deviation of **0.56σ.** The **global minimum** is at **4.8σ** and is found at the **furthest** configuration from the point of interest, as expected.

- Dependence of the results on the choice of levelling step was found to be within the uncertainties.

- These results indicate that the two scenarios formulated for the levelling process are well within margins, without regarding further optimization (tune, etc.)
  - Target DA without inclusion of errors is at **6.0σ**;
  - Target DA with the inclusion of machine errors is at **5.0σ.**

- Very preliminary results with the inclusion also of fringe fields seem that they do not have a significant impact on minimum DA.

HiLumi
HL-LHC PROJECT

Thank you!

CERN