Tune-scans for HL-LHC and LHC

D. Kaltchev

CERN-TRIUMF HL-LHC Collab.

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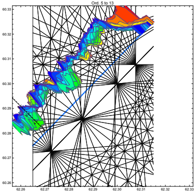
Optics configurations used

What's in black is kept constant including $\beta^\star$ (leveling scenarios not considered)

- **HL-LHC** V1.2 **baseline:**
  - bunch charge Nb=2.2 or 1.1$\times 10^{11}$;
  - IR1,5 Xing half-ang = 295 μrad, $\beta^\star$= 15 cm
  - IR8 $\beta^\star = $ 3m, Xing half-ang =-135-250=-385 μrad (LHCb spect. pol.=-1)
  - IR2 $\beta^\star = $ 10m, hor. sep. = 2 mm, Xing = 170 μrad
  - emit$_n$= 2.5 μm, bunch len. = 7.5 cm, $\frac{\Delta p}{p}$=2.7$\times 10^{-4}$
  - 25 ns, chrom = 3
- **LHC** V6.503 at peak Lumi 1×10^{34}
- conditions for tracking
  - Hirata BB ON, crab cavities OFF or ON with fully crabbing of strong beam enforced (the default)
  - standard MadX-SixTrack-SixDesk env.

Tune-scan (TS) conditions

- tune-scan A HL-LHC,
  Nb=1.1×10^{11}, crabs OFF, along line $\|$ diag. –>

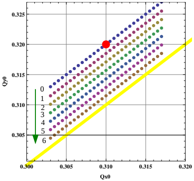


1D

- tune-scan B LHC (to compare with TS A)

- tune-scan C HL-LHC,
  Nb=**2.2**$\times 10^{11}$, crabs ON. It is 2D: looking for a better w.p. closer to diagonal in yellow –>

  (Yannis)



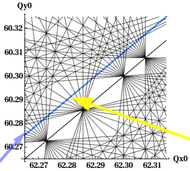
2D

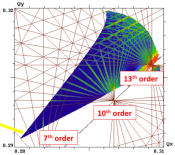
- QxBB=Qx0+ΔQx QyBB=Qy0+ΔQy

  Qx(y)BB is as reported by MadX or SixTrack with CC on

Tune-scan A

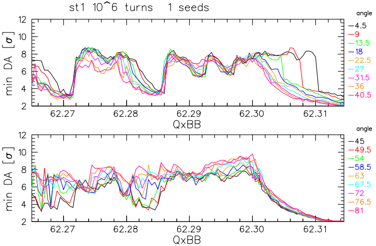
HL-LHC with Nb = 1.1×10^{11}, IP1,5,2,8 and crab OFF





Nominal HL-LHC footprint at 2.2 E11

Tune-scan line



old style plot

< 2010

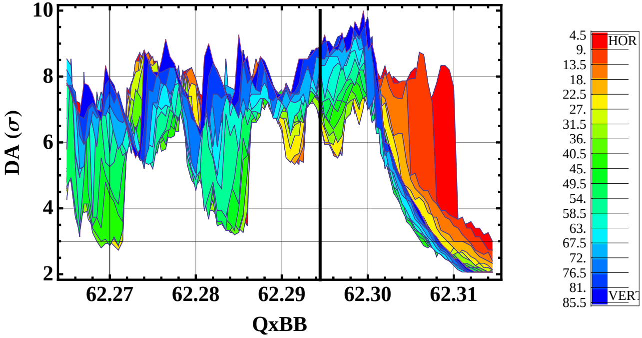
18 azimuthal angles

split into two plots

$$QxBB = Qx0 - \Delta Q$$

Figure 1 OLD STYLE PLOT: DA-by-angle dep. on perturbed tune

New-style plots: Let's color intervals between the constant-angle contours.
Color Hue is proportional to angle value. Some overlapping unfortunately takes place ..



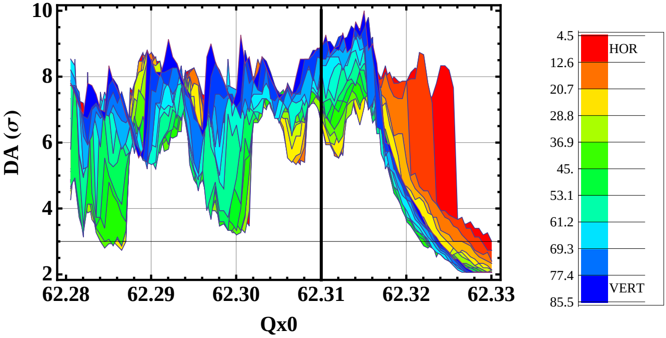
Here color Hue is proportional to upper bound of the angle interval (4.5 deg)

Tune-scan A

Keeping all angles, just shortening the Legend (scaling the Hue).

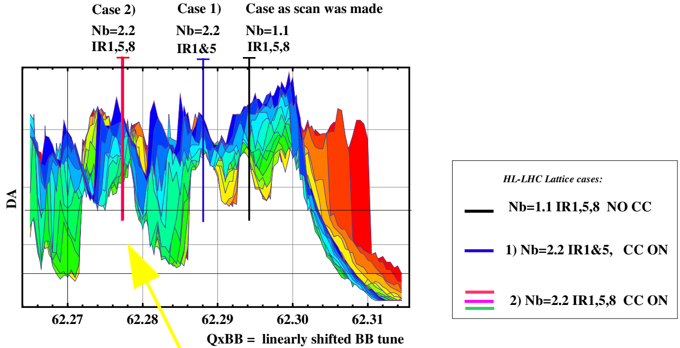
And shifting by the approximately constant BB tune shift $\Delta Q_x = 0.0155$.

Qx0 is the unperturbed tune.

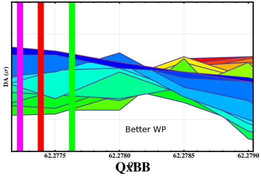


Tune-scan A: when in terms of QxBB explains other cases:

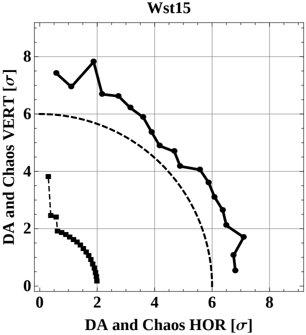
Take CC ON, Nb=2.2$\times 10^{11}$ for two cases: 1) “no IP8” and 2) “with IP8”.



Case 2) needs a litle shift to the right.
The result is “best w.p. from TS A”.



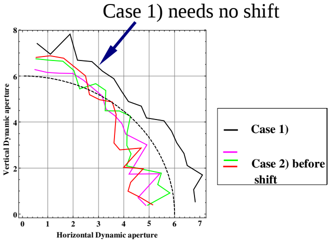
DA for case 1): no BB in IR2 and 8

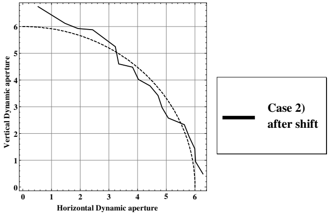


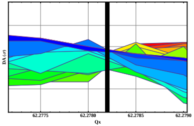
the only case when the chaotic border was > 2 at some angles

DA for cases 1) and 2). The shift for 2) works – improves DA.

tune-scan A is quite universal







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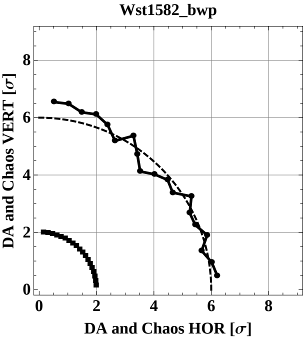
DA for case 2) with IR2 added (still at best w.p. from TS A)

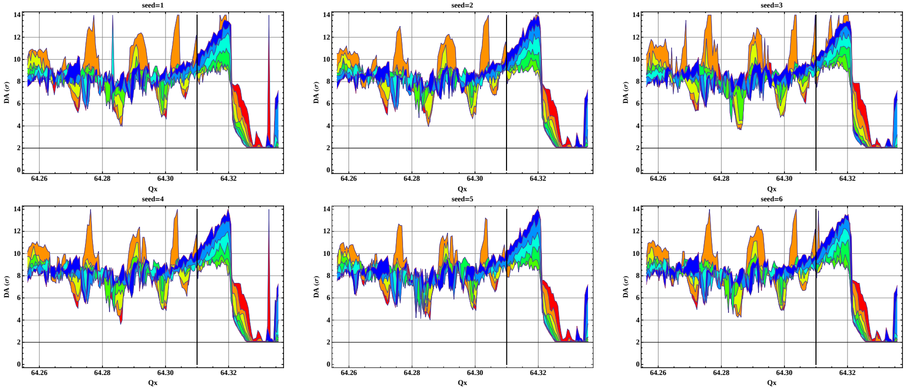
some tiny increase in ΔQ from 0.0318 to $\sim$ 0.033 due to IR2



It will further improve for w.p. closer to diagonal —> pages 14+

Tune-scan B (LHC as-built with corrected tripl. errors)

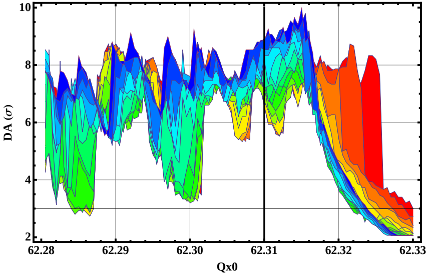
Tune-scans for seeds 1–6. Color code is same as above, but only 9 angles.
The three resonance dips near 64.31 are known from previous studies.

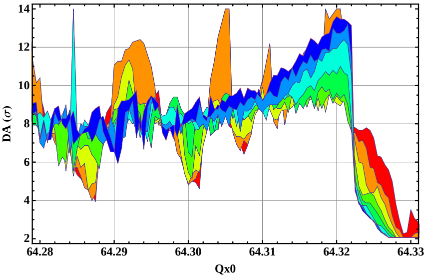


First 6 seeds for LHC with corrected triplet. Here **Qx represents Qx0 (sorry)**.

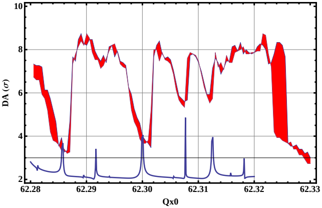
Tune-scans A and B compared

Top: **HL-LHC**, Nb=1.1×10^{11} BB and Sext. Bottom: **LHC**, BB+sext and corr. tripl. for seed 1

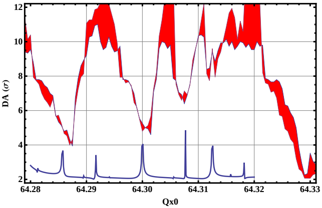




red only, i.e. DA near HOR plane

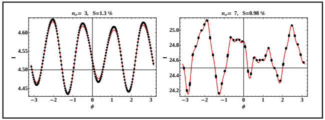


(a) HL-LHC



(b) LHC

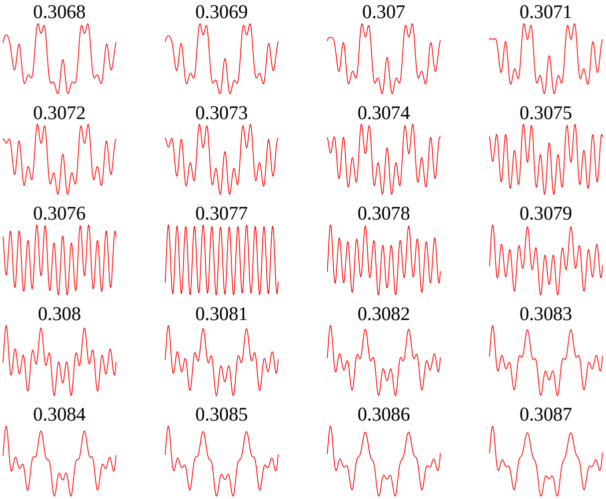
The simple Two-Head-On-IPs BB model HOR plane only for the perturbed CS invariant (Poincaré surface of section) seems to explain dip locations. This invariant, when confirmed with tracking (black dots), looks like:



Near resonance it begins to oscillate fast. The blue curves on the right show module of some high-order Fourier coefficient (C10 used here).

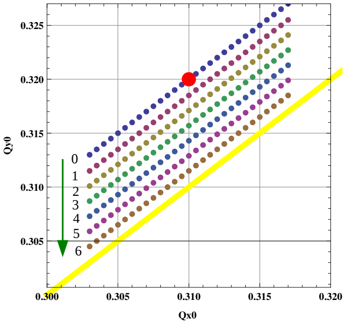
detour 1/2: fast osc. of invariant

sample lattice



Tune-scan C (2D)   11 angles

$\Delta Q^{\mathrm{BB}} \simeq 0.033$



TS lines

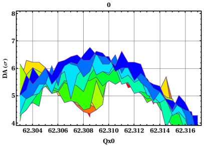
Tune-scan lines parallel to diagonal and approaching it from above:

$0, 1, 2 \ldots, 6$ (TS A line is 0 here)

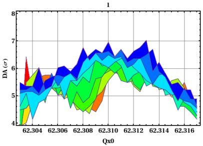
step in tune $\Delta Qx = 10^{-3}$

step in distance to diagonal (yellow) = $\sqrt{2}\Delta\ Qx \simeq 14 \times 10^{-4}$

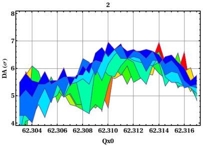
Tune-scan C (by TS line)



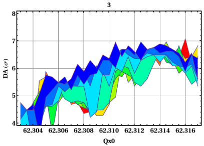
(a) 1 Dist=10^{-2}. Min DA is 5.5 at the best w.p. from TS A. Seen to be near 45-deg plane (green).



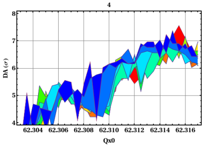
(b) 2



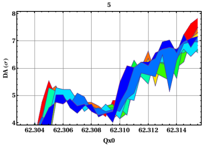
(c) 3



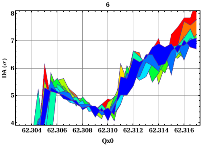
(d) 4



(e) 5



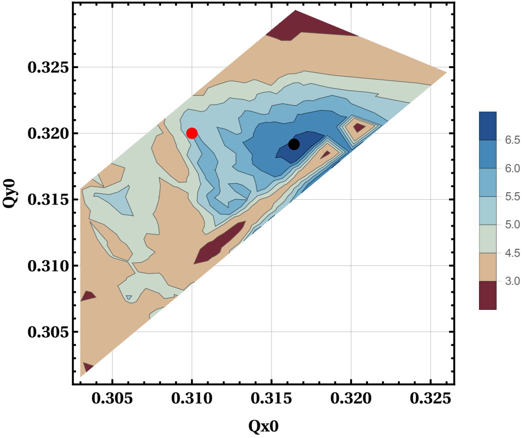
(f) 6



(g) 7 Dist=1.4×10^{-5}. Min DA grows to 6.5. Seen to be near VERT plane (blue).

Tune-scan C

extending the domain up and to the right (to capture best-DA region)



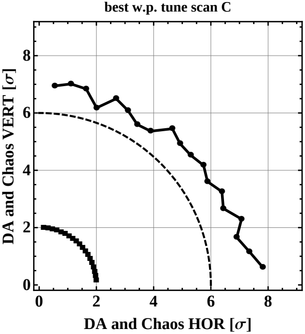
Min DA over 11 angles. The black dot is “best w.p. from TS C”: (Qx0,Qy0)=(0.316,0.319).

Black dot tested next $\longrightarrow$

DA at the best w.p. of TS C

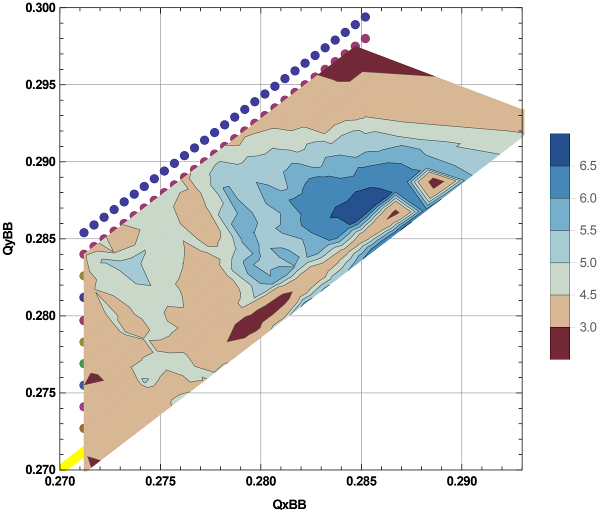
A sigma gained (compare with page 10)

Wname	QxBB/ QyBB	dQx/ dQy	CHx/ CHy
Wst1582_BP	62.284 / 60.2868	0.0324 / 0.0327	3.26843 / 2.10872



w.p. set to (0.3164,0.3195) with MadX only

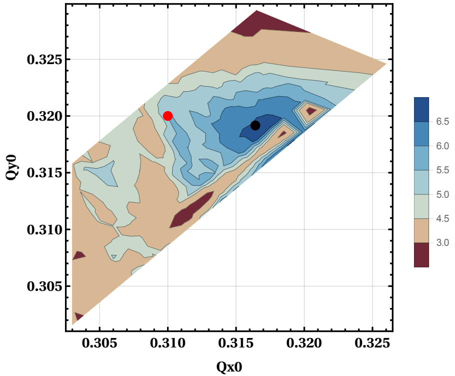
Tune-scan C (2D) in terms of QxyBB

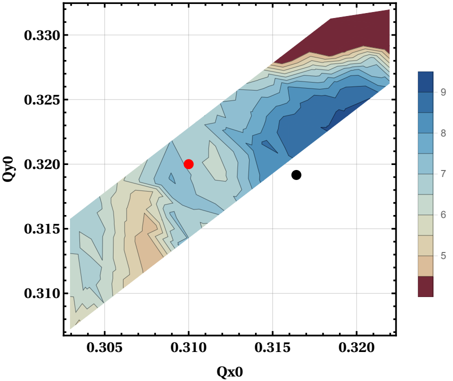


continued Jan 2017

Tune-scan D (2D), Nb=1.1×10^{11}

So that D is same as A, but crab ON and IR2 ON, or same as C, but Nb=1.1×10^{11}.

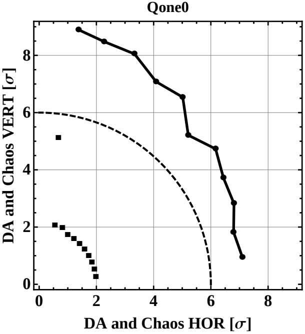




Min DA over 11 angles.
Left: TS C repeated and Right: TS D

(DA at the nominal tune (red point) will be studied without and with IT field errors ⇒)

DA at nominal tune (no errors)

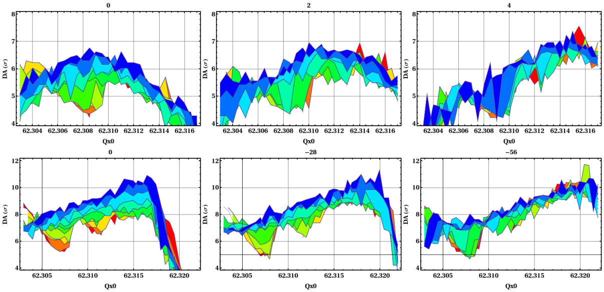


Tune-scan C and D shown by TS line

To see the effect of halving Nb.

Top: Nb=2.2×10^{11} Bottom: Nb=1.1×10^{11}

from left to right – approaching the diagonal starting from Dist=0.01.



A table from HiLumi LHC WP3 page shows max Integrated strengths [1]

and these are the corrector data

		MCQSX	MCSX/MCSSX	MCOX/MCOSX	MCDX/MCDSX	MCTX	MCTSX
Order		2	3	4	5	6	6
Aperture	(mm)	150	150	150	150	150	150
Integrated strength[1]	(T m)	1.000	0.063	0.046	0.025	0.086	0.017
Coil length[2]	(mm)	841	123	99	107	449	102
Gradient	(T/m^{n-1})	25	11	3690	50600	640000	613000
Number of apertures		1	1	1	1	1	1
Number of circuits		1	2	2	2	1	1
Units needed		4	8	8	8	4	4
Spares		2	4	4	4	2	2

[1] Integrated strength is the field at the 50 mm ref radius times the magnetic length

Results taken from ref. paper [2] are: corr. strengths (Fig 2) and integrated mult. field at 5 cm (Table 3).

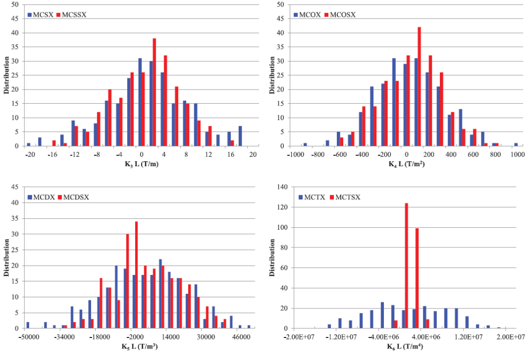


Figure 2: Distribution of the strength of the non-linear correctors: a_3, b_3 (upper left); a_4, b_4 (upper right); a_5, b_5 (lower left); a_6, b_6 (lower right).

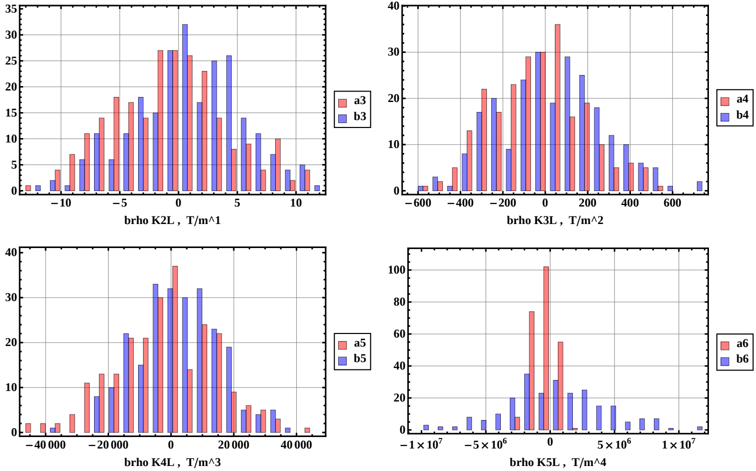
Table 3: Strength of the Triplet Correctors.

		Computed mT m at 50 mm	Specification mT m at 50 mm
normal	3	31.2	63
	4	22.9	46
	5	16.9	25
	6	57.3	86
skew	2	500.0	1000
	3	26.3	63
	4	18.8	46
	5	11.7	25
	6	11.2	17

mT×meter (confirm with prev page)

[2] M. Giovannozzi, S. Fartoukh, R. De Maria: SPECIFICATION OF A SYSTEM OF CORRECTORS FOR THE TRIPLETS AND SEPARATION DIPOLES OF THE LHC UPGRADE, Proceedings of IPAC2013

Same errors and same correctors used as in ref. paper above



my result for integrated strengths

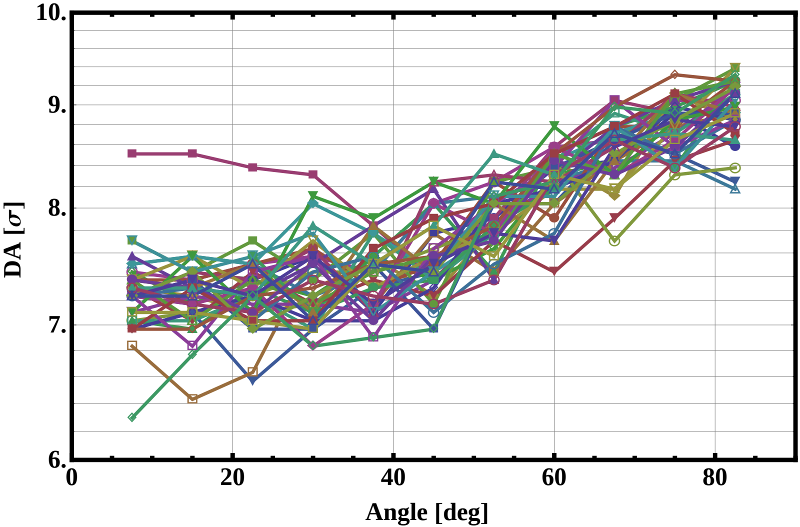
(comp. with Table 3 of ref. paper) **need to explain the difference**

		correctors, mT.m	
		Computed	Specified
norm	3	16	63
	4	15.3	46
	5	9.6	25
	6	30.8	86
skew	2	186	1000
	3	15.1	63
	4	11.4	46
	5	12.3	25
	6	5.5	17

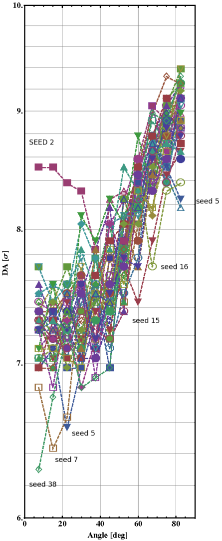
DA at nominal tune with IT field errors, no A2, no D1,D2

i.e., at the red point for TS D on page 21

FIRST 40 seeds



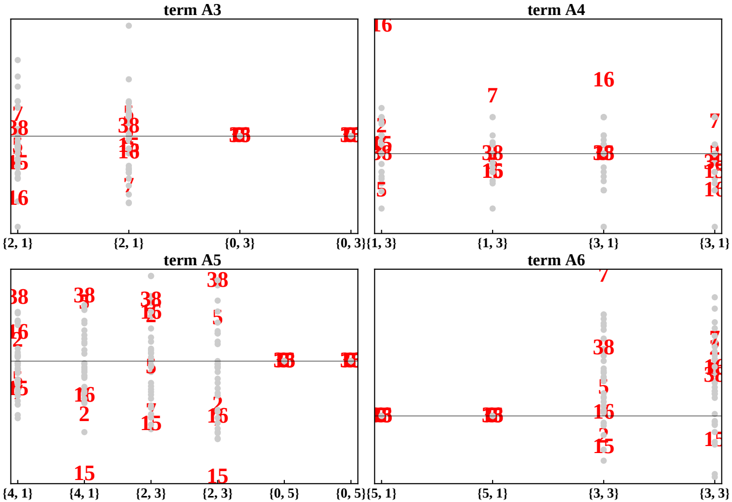
Identify worst seeds



- “worst” seeds 38, 7, 5 , 15 and 16
- good seed: 2
- may be correlated with dr. terms next $\Rightarrow$

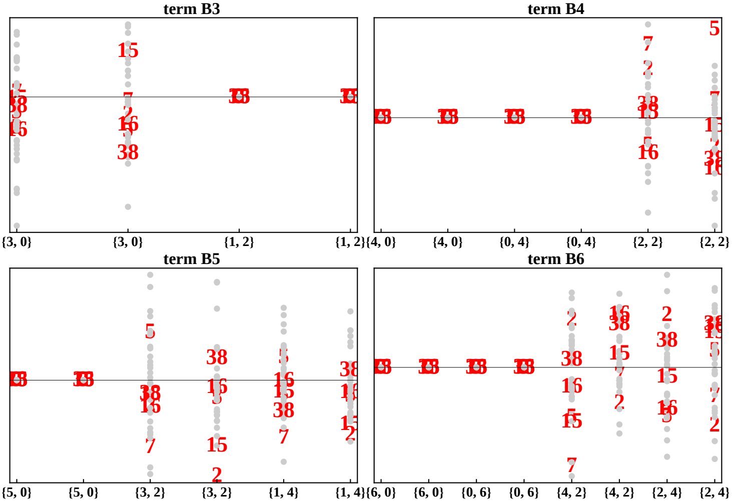
skew driving terms, Beam1

Relative units. First of pair: IR5. Second of pair: IR1. Where terms is 0, means corrected. Bad seeds (red) are seen to corresp. to near maxima for A4 (1,3), A5 all not-corrected – main cause for DA loss and A6 (3,3)



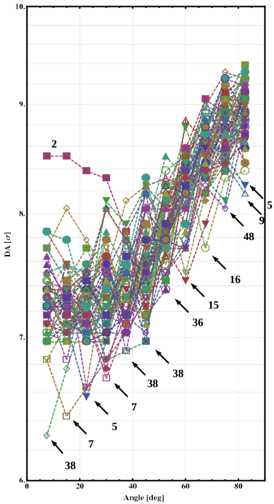
normal driving terms, Beam1

Bad seeds (red) are seen to corresp. to near maxima for B4 (2,2), B6(4,2)

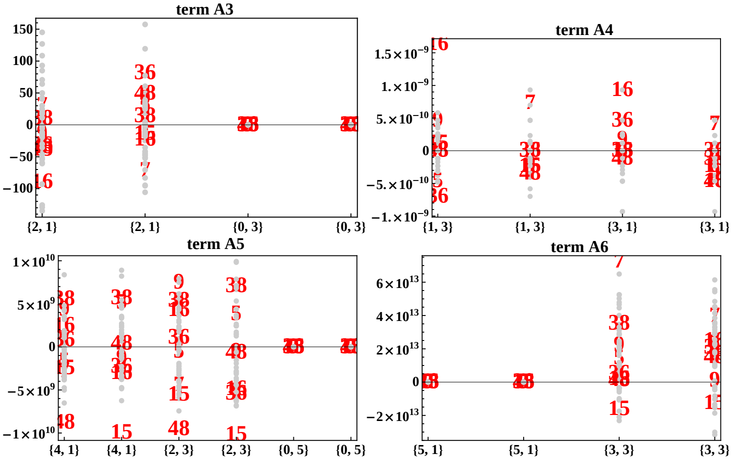


Use all 60 seeds. Identify worst for each angle

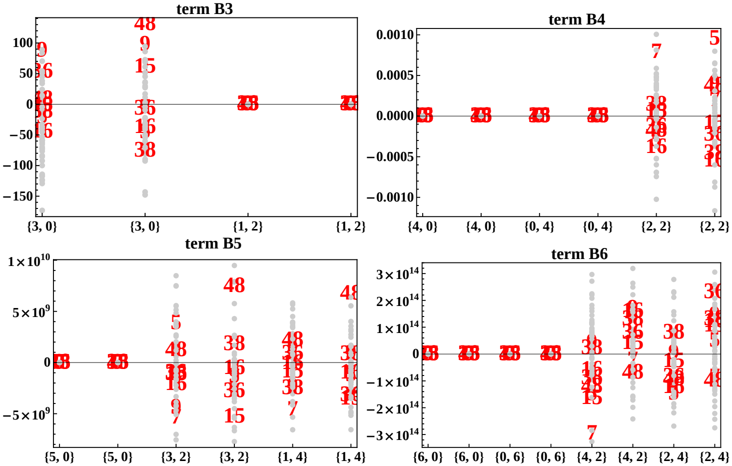
3 new “worst” seeds: 36, 48 and 9



	highest |dr. term| found on the next plots	
ang [deg]	seed	dr. term
7.5	38	A5 (2,3)
15	7	A6 (3,3) and B6 (4,2)
22.5	5	B4 (2,2)
30	7	3,3 and 4,2
37.5	38	A5 (2,3)
45	38	A5 (2,3)
52.5	36	B6 (2,4) ?
60	15	A5 2,3
67.5	16	A4 (1,3) ? check
75	48	B3 (3,0) and B5 (3,2)
82.5	9	A5 (2,3)


term A3
term A4
term A5
term A6

normal



term B3
100
50
0
−50
−100
−150
{3, 0}
{3, 0}
{1, 2}
{1, 2}
term B4
0.0010
0.0005
0.0000
−0.0005
−0.0010
{4, 0}
{4, 0}
{0, 4}
{0, 4}
{2, 2}
{2, 2}
term B5
1×10^10
5×10^9
0
−5×10^9
{5, 0}
{5, 0}
{3, 2}
{3, 2}
{1, 4}
{1, 4}
term B6
3×10^14
2×10^14
1×10^14
0
−1×10^14
−2×10^14
−3×10^14
{6, 0}
{6, 0}
{0, 6}
{0, 6}
{4, 2}
{4, 2}
{2, 4}
{2, 4}