New optics layout (V1.3) and possible simplifications (MS10)

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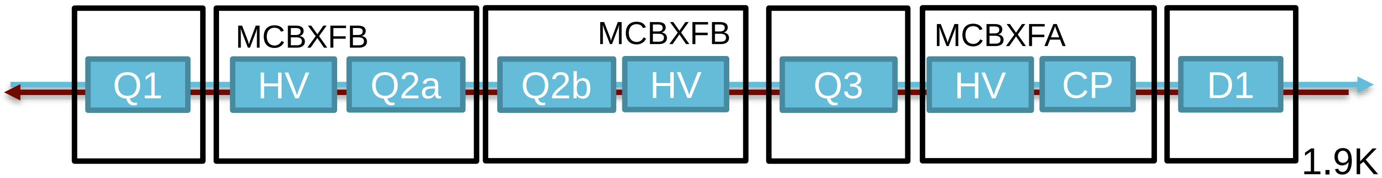
Thanks to S. Fartoukh

7th HL-LHC Annual Meeting, Madrid 15/11/2017

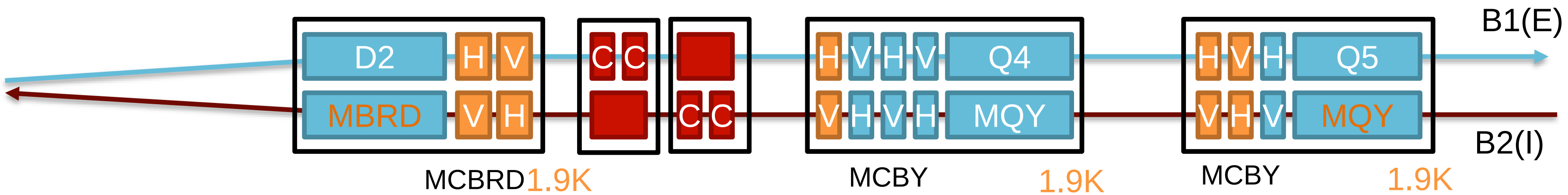
HL-LHC Layout for Optics V1.3

HLLHCV1.3 implements the latest optics model of the baseline layout after re-baseling

Triplet area Right IR 1 and 5



Triplet area Right IR 1 and 5 (in orange differences with the LHC)



In addition to the interaction region in Point 1/5:

- Additional MS in Q10 in IR1,5 (MCBC to be replaced with an MCB+MS)
- MQY at 1.9 K for Q5 in IR6 (instead of double MQY V1.2)

Studies are ongoing to save MCBY type correctors and re-use existing MQML-type for Q5 by further re-scoping crossing plane flexibility and taking full advantage of the operational remote alignment system.

Protected aperture

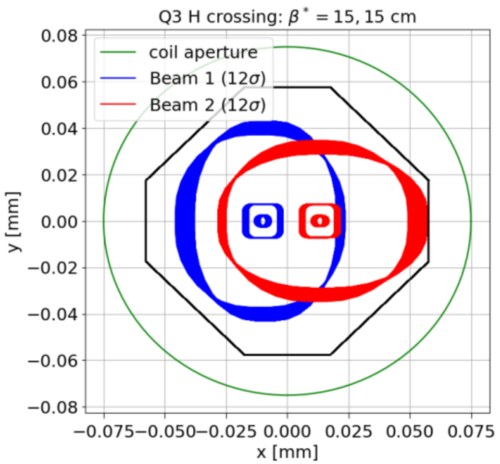
- Protected aperture is limited in the horizontal plane by TCT-MKD phase advance.
- This results in tight optics constraints in IR6 with the potential of limiting β* reach in Point 5.
- Optimization of the MKD to TCT1-5 horizontal phase advances: improvement β* reach for both choices of crossing planes.

Parameter	7 TeV	0.45 TeV
Radial CO [mm]	2	
Mom offset	$2\ 10^{-4}$	
Dispersion	0.1	
Beam size	1.1	1.025
IP transverse shift	±2 mm	n/a

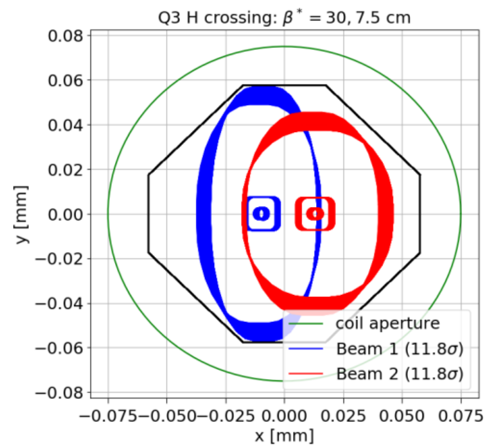
$\Delta\mu_x$ MKD-TCT [°]	Aperture [σ@2.5μm]
0-20	11.2
30	11.9
40	12.9
50	13.8
60	14.5
70-90	14.6
No TCT	19.4
Injection	12.6

R. Bruce et al. CERN-ACC-2017-0051

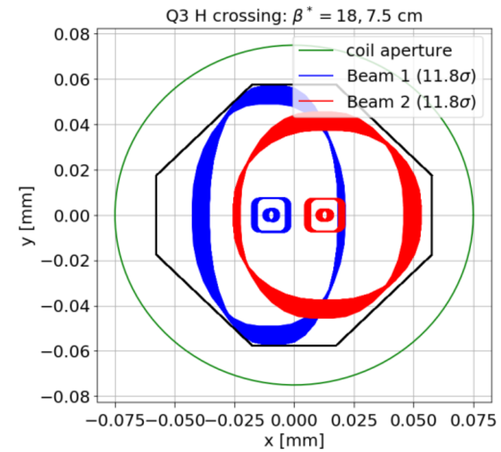
Performance optimization



Round optics with crab cavities: β*=15/15 cm, θ=±250 μrad



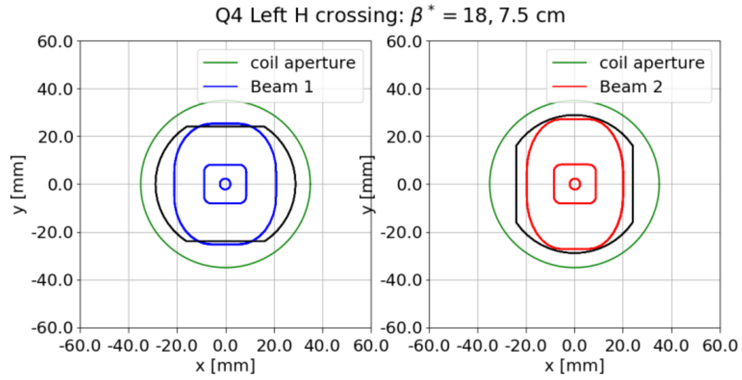
Flat optics without crab cavities: β*=30/7.5[1)] cm, θ=±250 μrad



Flat optics with crab cavities: β*=18/7.5[1)] cm, θ=±250 μrad

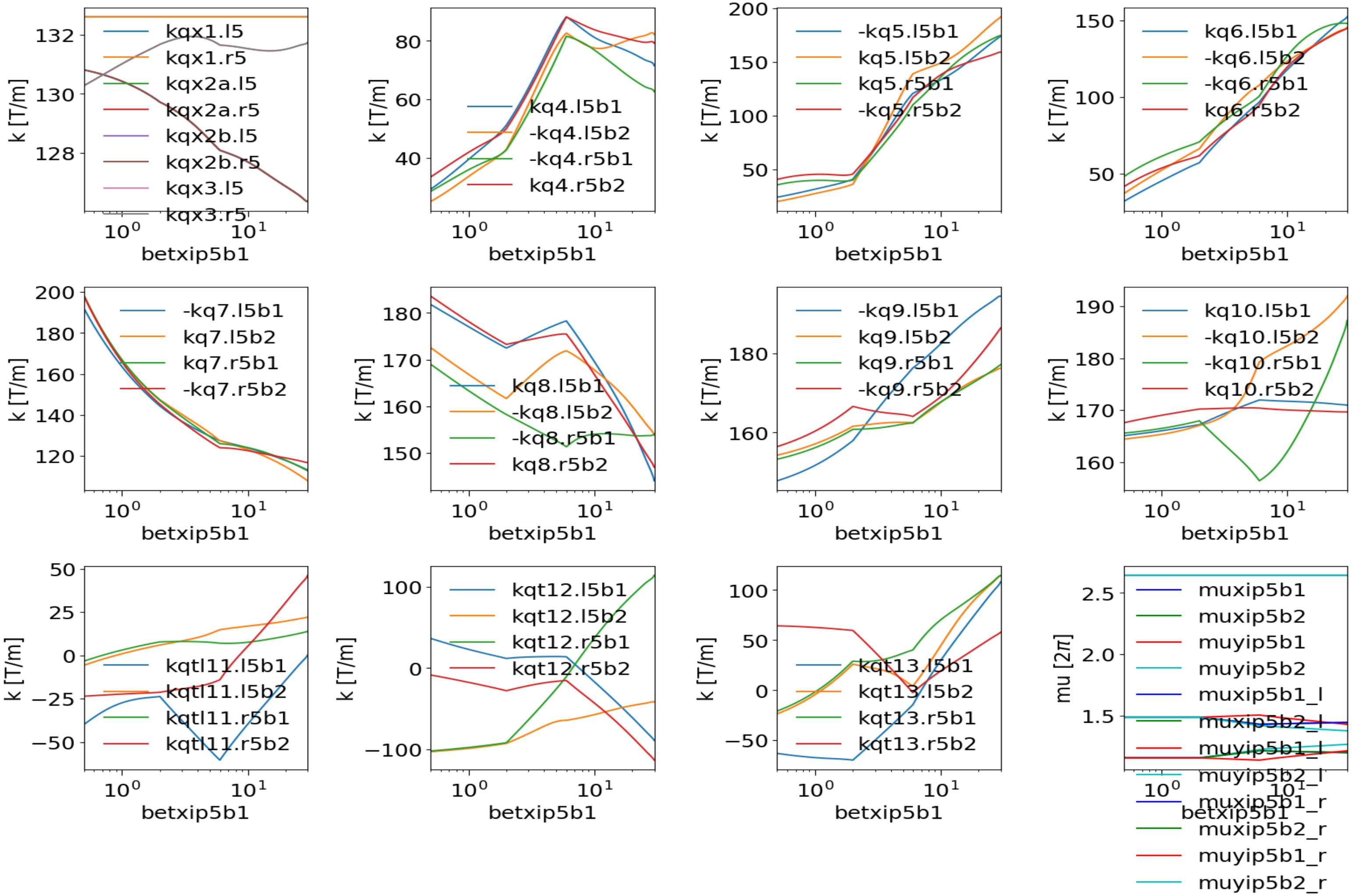
Optimization of the MKD to TCT1-5 horizontal phase advances: improvement β* reach for both choices of crossing planes otherwise limited to 14.6 σ.

Flat optics possible with operational remote alignment system or MQYY (was ~40/15 cm without good phase).
DA to be evaluated.



Operational scenarios for IR1/5 circuits

Optics transitions can be given in the form of step wise 5th order polynomials in β* or spline interpolated in values.

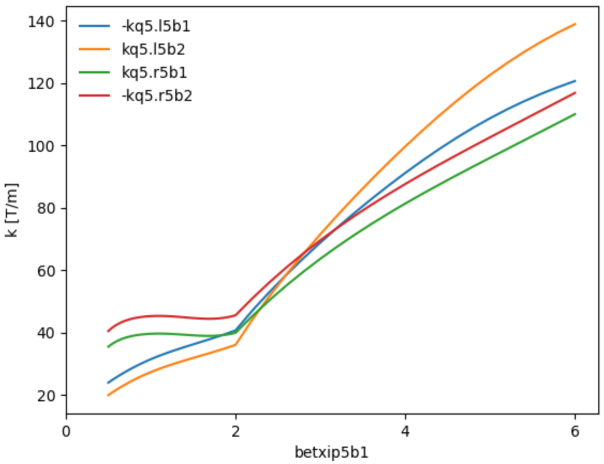


Smooth and fast optics transitions

Study to use smooth values of normalized gradient to:

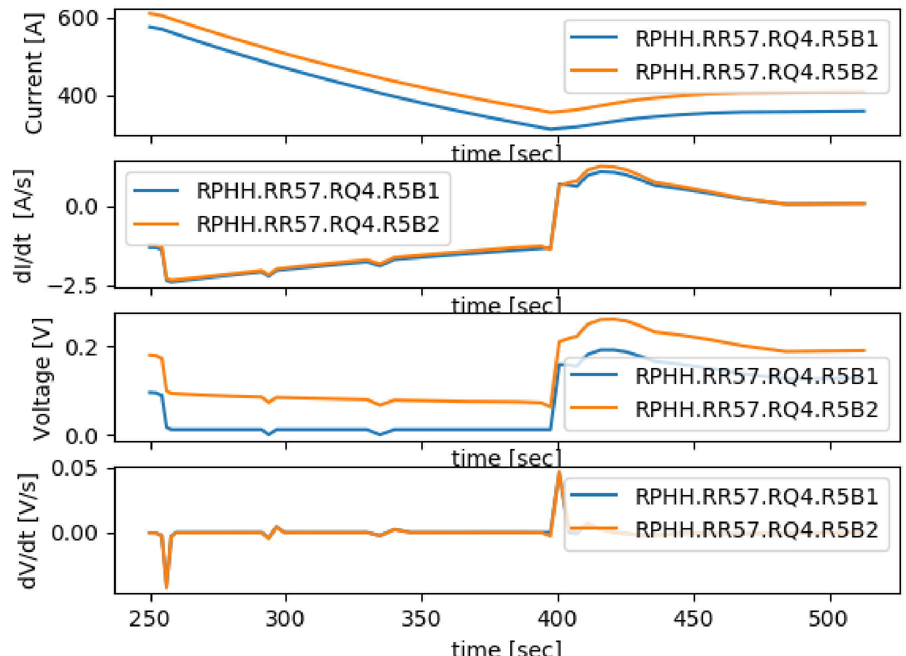
- define smooth current function that generate fast and beta-beating free optics transition during the energy ramp.
- Machine test (without beam) will be attempted end of this year.

Q5 IR1/5 gradient
at fixed energy



0.5 m ← β* ← 6 m

Q5R5 using Q4R5 LHC simulated circuit response during an energy ramp

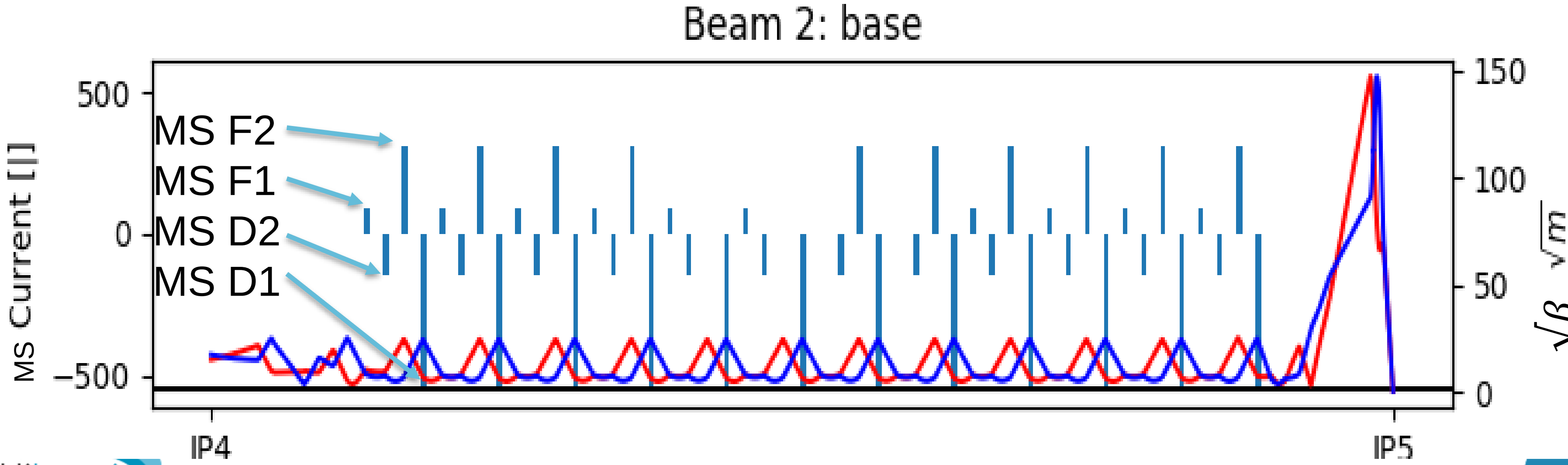


1.6 TeV → 3.7 TeV

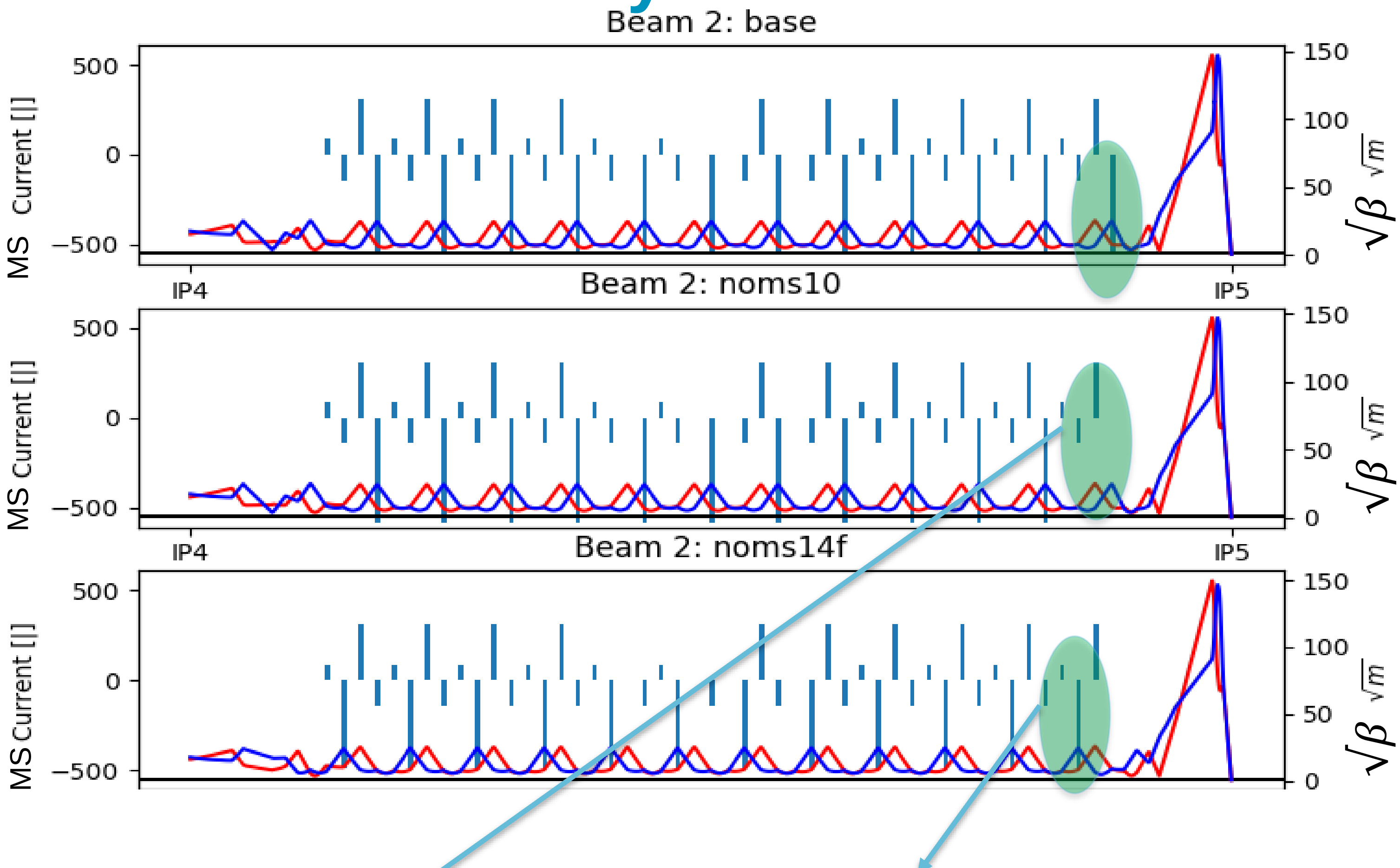
In collaboration with MCF, WP6, OP

MS Optimization in ATS arcs

- The effect of MS in Arc 81,12,45,56 around IP1/5 are enhanced for correcting chromatic aberrations, any uncompensated geometric aberration is enhanced too.
- Each arc has 1 out of 4 MS families with an odd number of sextupoles. The additional MS in Q10 restores symmetry and increases strength margins.
- New optics devised for symmetry restoration and strength reduction for defocusing MS. One MS14 (w.r.t the LHC) is removed from the remaining uncompensated focusing family.



Why MS10



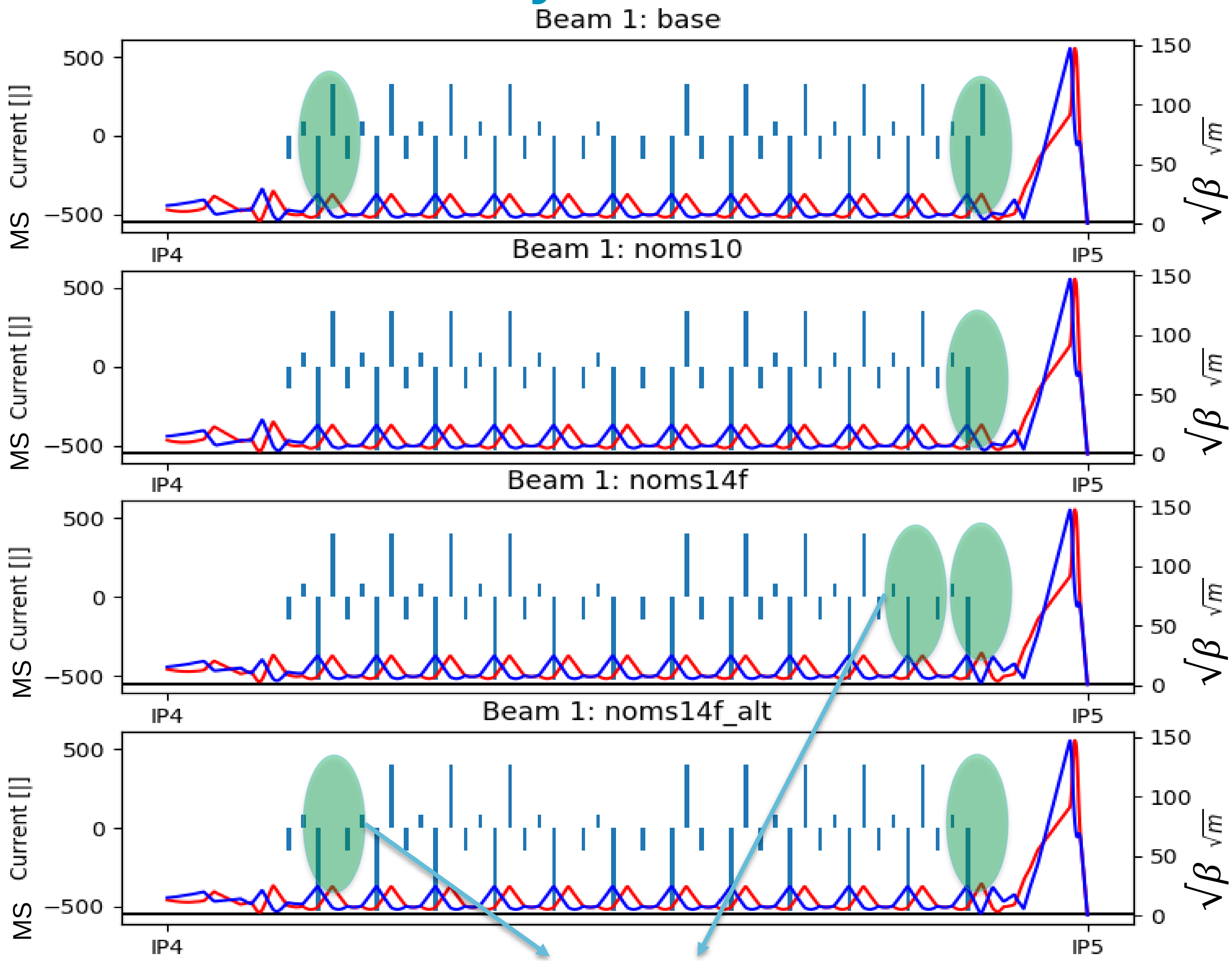
noMS10:

- Simple removal of the sextupole
- Increase current to 580 A (not compatible with ultimate energy)

noMS14f:

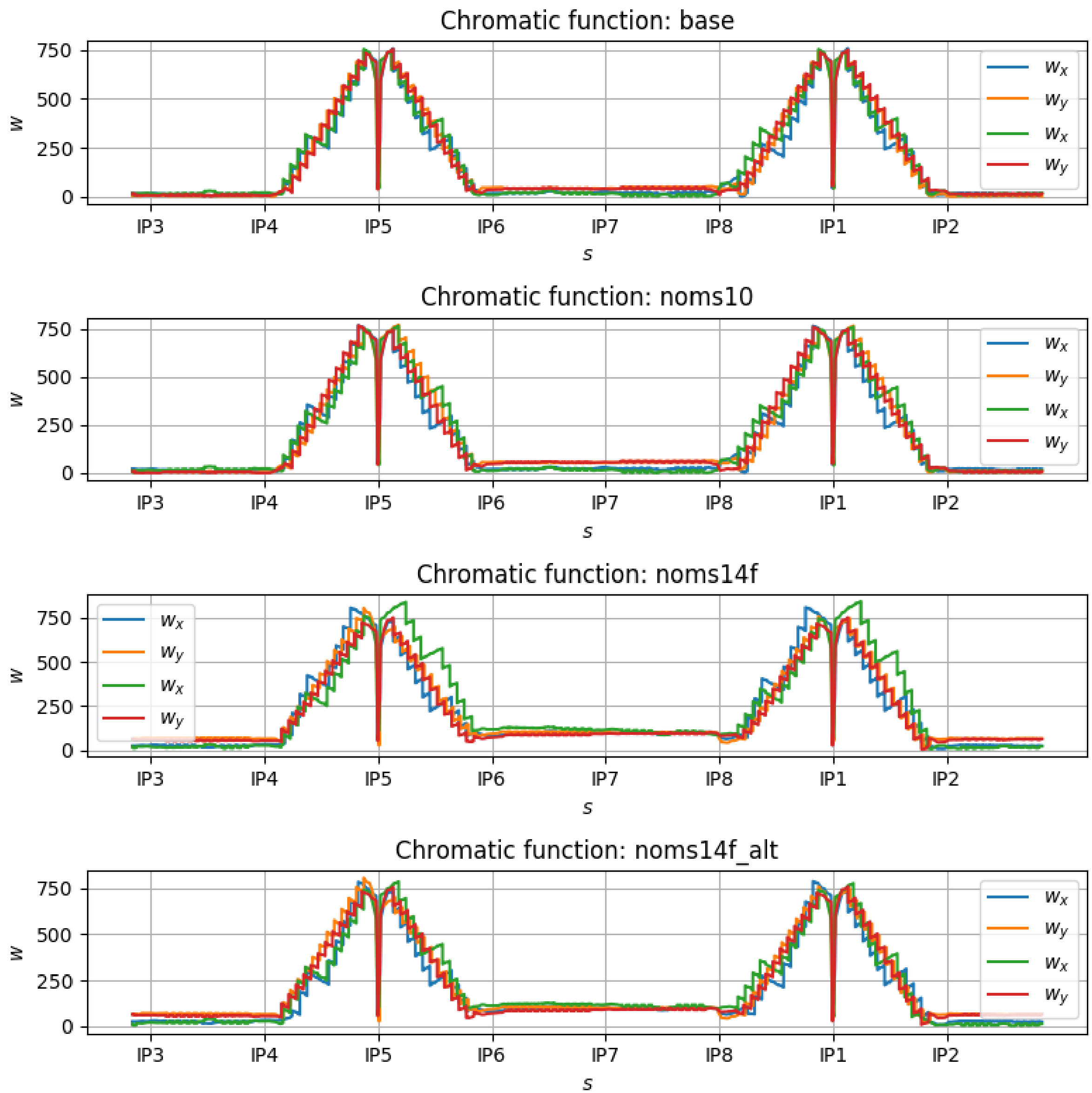
- Change of the vertical IR1/5 phase advance Right Beam 1 and Left Beam 2
- New ATS optics for Point 2,4,6,8.

Why MS10



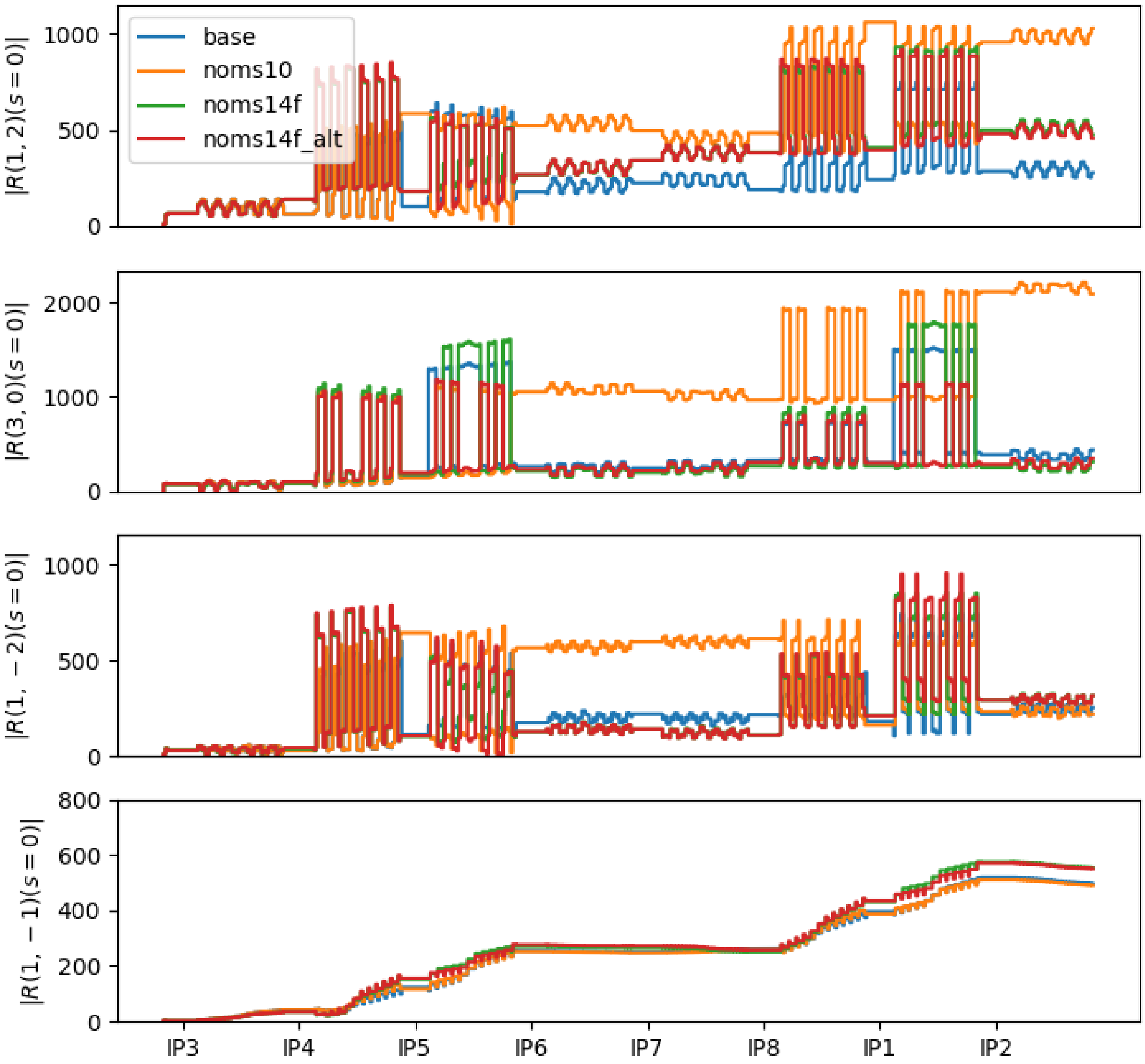
Removal of focusing sextupoles, since there is strength margin.

Why MS10



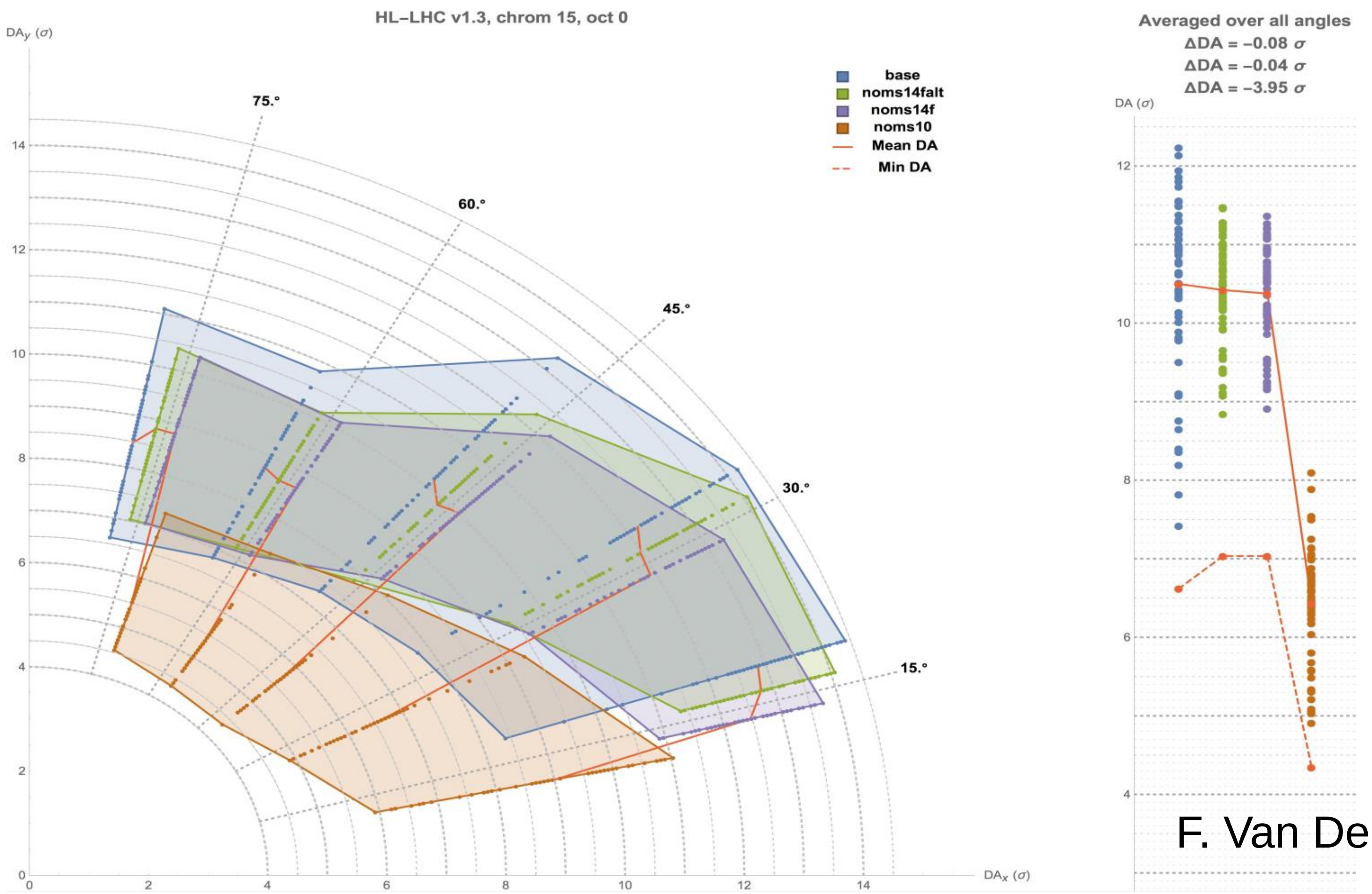
All options correct similarly well β’(δ)

Why MS10



Not all options correct geometric aberrations well enough.
Baseline is the best, followed by the noMS14f options.

DA with imperfection Q'=15



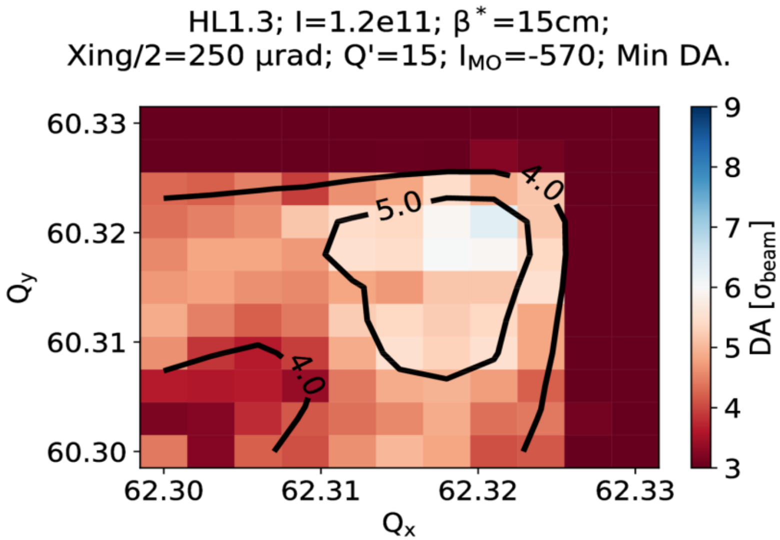
F. Van Der Veken

Xing=295 µrad, Q=62.31/60.32, No octupoles and beam-beam.

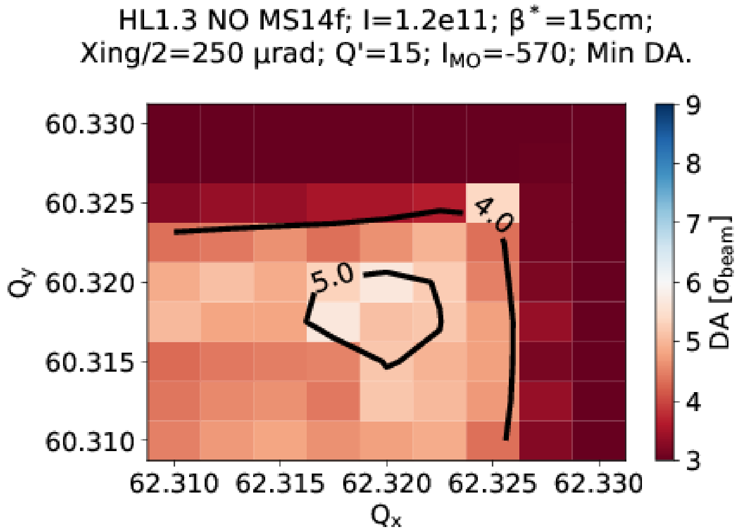
Best alternative (noMS14f) equivalent to baseline, but in a simplified scenario.

DA with BB

Baseline

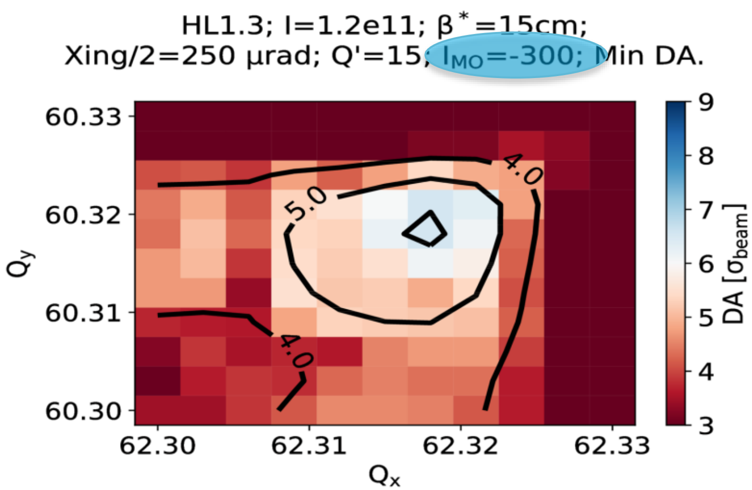


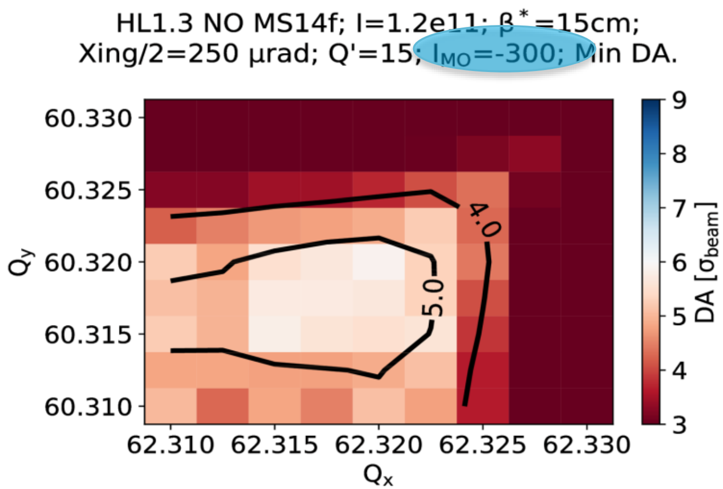
Alternative



Q'~15 $|D_{max}|$=2.9/0.6 m with dispersion correction.

D. Pellegrini

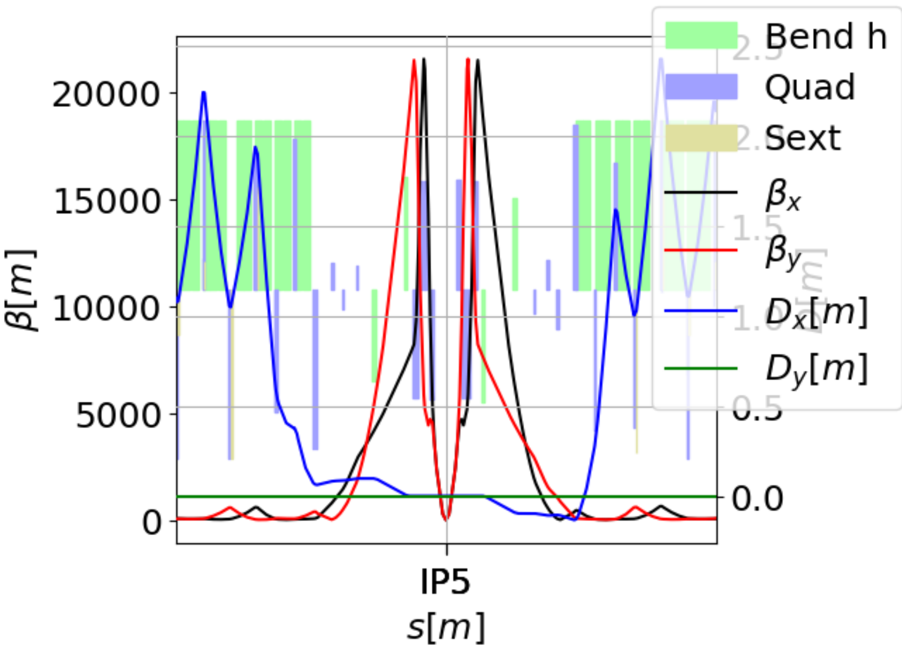


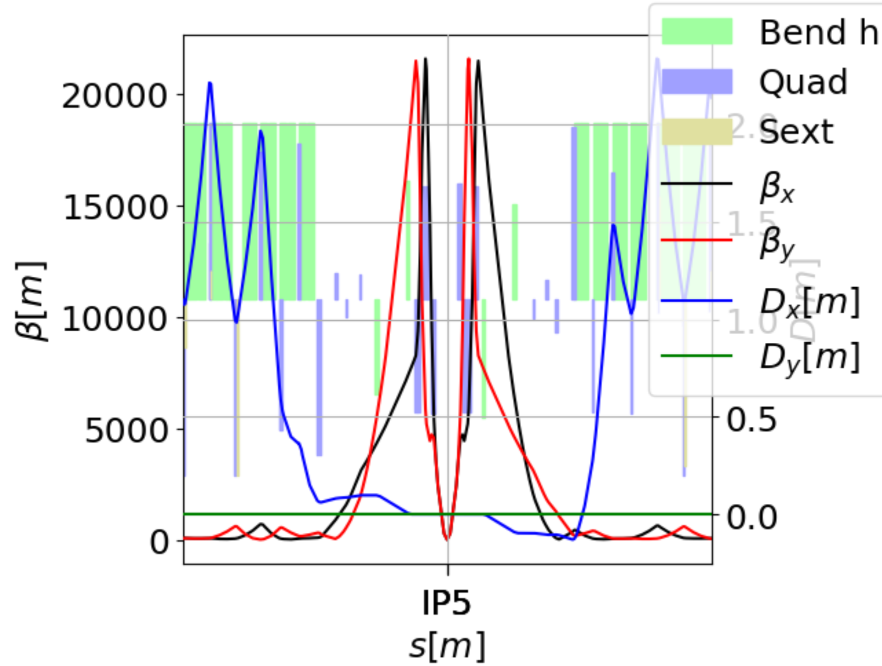


Best alternative (noMS14F) not equivalent to baseline also with lower MO

Linear optics comparisons

	Baseline	noMS14F
Crabbing angle [μrad]	±190	±195
Q7 strength margin	1%	1%





Baseline and noMS14F options are very similar, beside phase advances covering β* range from 0.5 to 30 m.

Option noMS14F is slightly more flexible and allow larger crabbing angle.

Figure of merit for IR 5-6

	Baseline			No MS10/14F		
	Round	FlatCC	Flat	Round	FlatCC	Flat
β* Xing/Sep [cm]	15/15	18/7.5	30/7.5	15/15	18/7.5	30/7.5
Xing angle [μrad]	±250	±240	±245	±250	±240	±245
TCDQ margin[1)] B1/B2 [mm]	2.0/1.0	1.7/1.1	1.7/1.5	1.2/1.0	1.3/1.2	0.9/1.3
Q5.L6 [T/m]	163	167	175	162	170	174
Q5.R6 [T/m]	159	166	165	164	170	168
MKD-TCT5 [°]	30	27	27	36	33	31
Protected H[2)] Ap. [σ]	11.9	11.7	11.7	12.5	12.2	12
Protected V[2)] Ap. [σ]	11.2	11.2	11.2	11.2	11.2	11.2
Crossing plane	V	H	H	V	H	H
Aperture[3)] Xing [σ]	13.2/12.0	14.2/10.4	15.6/10.4	13.2/11.9	14.2/10.2	15.6/10.2
Aperture[3)] Sep [σ]	16.5/14.5	12.7/10.3	12.9/10.4	16.5/14.4	12.7/10.2	12.9/10.2

1) 3 mm minimum gap assumed (C. Bracco +2 mm requested)
2) assuming different settings for TCTH and TCTV, which is under study (R. Bruce)
3) without/with operation remote alignment (or MQYY and no b.s. in no crabbing pipe in the cryomodule)

Alternative has slightly less flexibility in IR6, resulting in worse MKD-TCT phase advance. Not an issue if crossing plane is frozen.

Conclusion on MS in Q10

- Baseline with MS in Q10 gives better performance.
- Removing MS 10 results in strong DA degradation.
- Alternatives without MS10 and also removing MS14F have been studied:
  - similar performance in terms of linear optics,
  - however miss the target of DA of 6 σ with beam-beam and ocutpoles by about 0.5 σ,
  - specific mechanism of DA loss with octupoles and beam-beam not fully understood, investigations on-going.

Conclusion

Study for performance

- phase advance for β* reach: improved performance
- flat optics with/without CC: promising options, further motivates operational remote alignment system
- fast and smooth optics transitions: increase physics time

Study for simplifications:

- Impact of removing MS in Q10: : Best alternative does not reach the target DA=6σ, therefore since the baseline has no DA margins, the alternative is not advisable
- Further simplification reducing further the changes with respect to LHC layout under study.

Backup

HL-LHC Layout for Optics V1.3

HLLHCV1.3 implements the latest optics model of the baseline layout

The hardware changes with respect to HL1.2 are:

- MQY at 1.9 K type for Q4 in IR1-5 with 4x orbit correctors instead of MQYY- type
- Additional MS in Q10 in IR1-5 (MCBC to be replaced with an MCB+MS)
- MQY at 1.9 K for Q5 in IR6 instead of double MQY

The hardware changes with respect to the LHC are, besides the whole TAXS-D2 area:

- Q4 in IR1-5: MQY detached from D2 and displaced towards the arc, rotation of one beam screen, additional orbit corrector
- Q5 in IR1-4: MQY+3xMCBY corrector replacing MQML+1xMCBC orbit corrector, displaced towards the arc
- Additional MS in Q10 in IR1-5: MQML+MCB+MS replacing MQML+MCBC
- Q5 in IR6: MQY 1.9 K/200 T/m replacing MQY 4.5 K/160 T/m

Options

Baseline
- Adding MS+MCB to replace MCBC in Q10 IR1/5
- Same length but different interfaces
- MS at 550A

Arc	MS14	MS13	MS12	MS11
B1: 81,45	F1(10)	D1(12)	F2(10)	D2(12)
B2: 81,45	D1(12)	F1(10)	D2(12)	F2(10)
B1: 12,56	D2(12)	F2(10)	D1(12)	F1(10)
B2: 12,56	F2(10)	D2(12)	F1(10)	D1(12)

NoMS10:
- Same as in LHC.
- Smaller impact since either ATS squeeze is low or sextupoles are low
- MS up to 581A (11 vs 12 MSD, no ultimate energy)

Arc	MS14	MS13	MS12	MS11
B1: 81,45	F1(9)	D1(12)	F2(10)	D2(12)
B2: 81,45	D1(11)	F1(10)	D2(12)	F2(10)
B1: 12,56	D2(11)	F2(10)	D1(12)	F1(10)
B2: 12,56	F2(9)	D2(12)	F1(10)	D1(12)

NoMS14f:
- New phase for IR1/5: μ_y 2.642 –> 2.392.
- Remove MS14 in IR15LR or IR84R/26L
- Redo all optics in IR1/5/2/4/6/8
- MS up to 550A

Arc	MS14	MS13	MS12	MS11
B1: 81,45	F1(8)	D1(12)	F2(10)	D2(12)
B2: 81,45	D1(11)	F1(10)	D2(12)	F2(10)
B1: 12,56	D2(11)	F2(10)	D1(12)	F1(10)
B2: 12,56	F2(8)	D2(12)	F1(10)	D1(12)

<u>Strong sextupoles</u>, weak sextupoles; (F)ocusing, (D)efocusing; Familiy (1)(2)

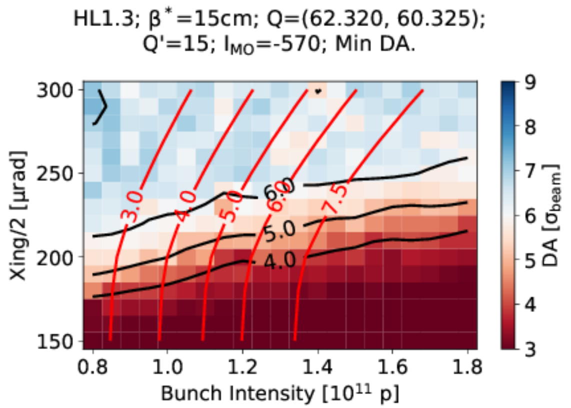
Studies for simplifications

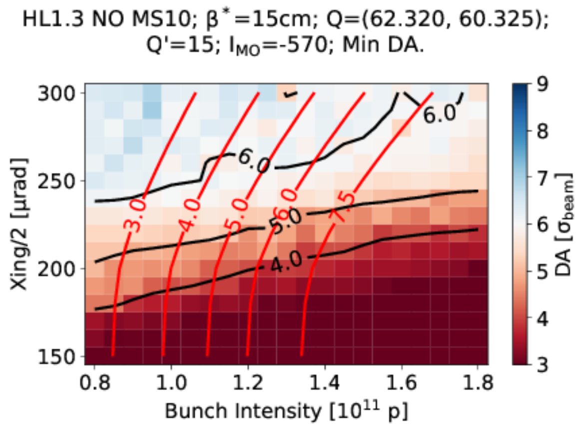
The following hardware options are being studied:

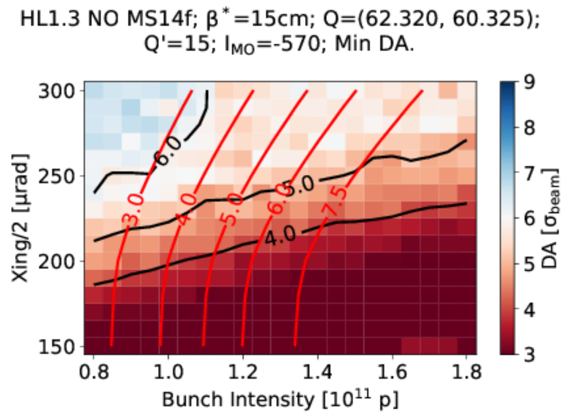
- Q4 in IR1-5:
  - MQY at 1.9K type with 4x correctors replaced by
  - 4.5K with 3x correctors + warm corrector + no crossing plane flexibility + operational online alignment system
- Q5 in IR1-5:
  - MQY at 1.9K type with 3x orbit correctors replaced by
  - MQML at 4.5K with 1x correctors + no crossing plane flexibility + operational online alignment system
- Q5 in IR6:
  - MQY at 1.9K for Q5 in IR6 replaced by
  - MQY at 4.5K up to 180 T/m (i.e. ultimate energy gradient) + reduced optics flexibility in IR6
- Additional MS in Q10 in IR1-5:
  - MCBC to be replaced with an MCB+MS replaced by
  - new optics with reduced DA + disconnection of 4 MS in Q14 in IR1-5

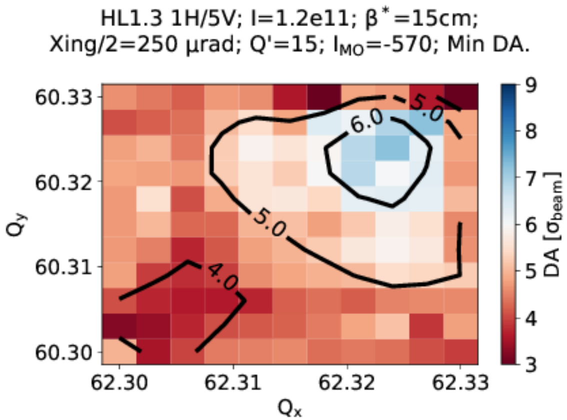
MS in Q10 is the main topic of the talk

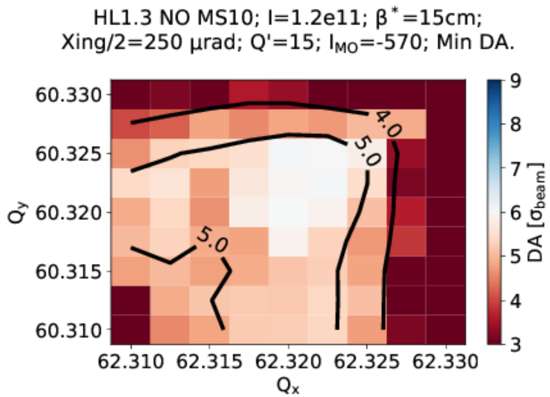
DA with BB

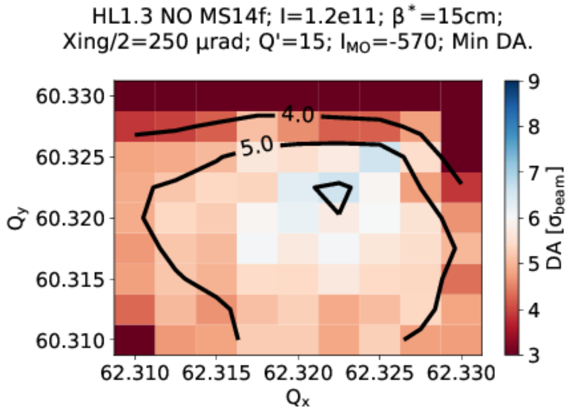












Q'=13.2/8.0
$|D_{max}|$=7.3/6.8 m

Q'=12.7/7.2
$|D_{max}|$=7.3/7.2 m

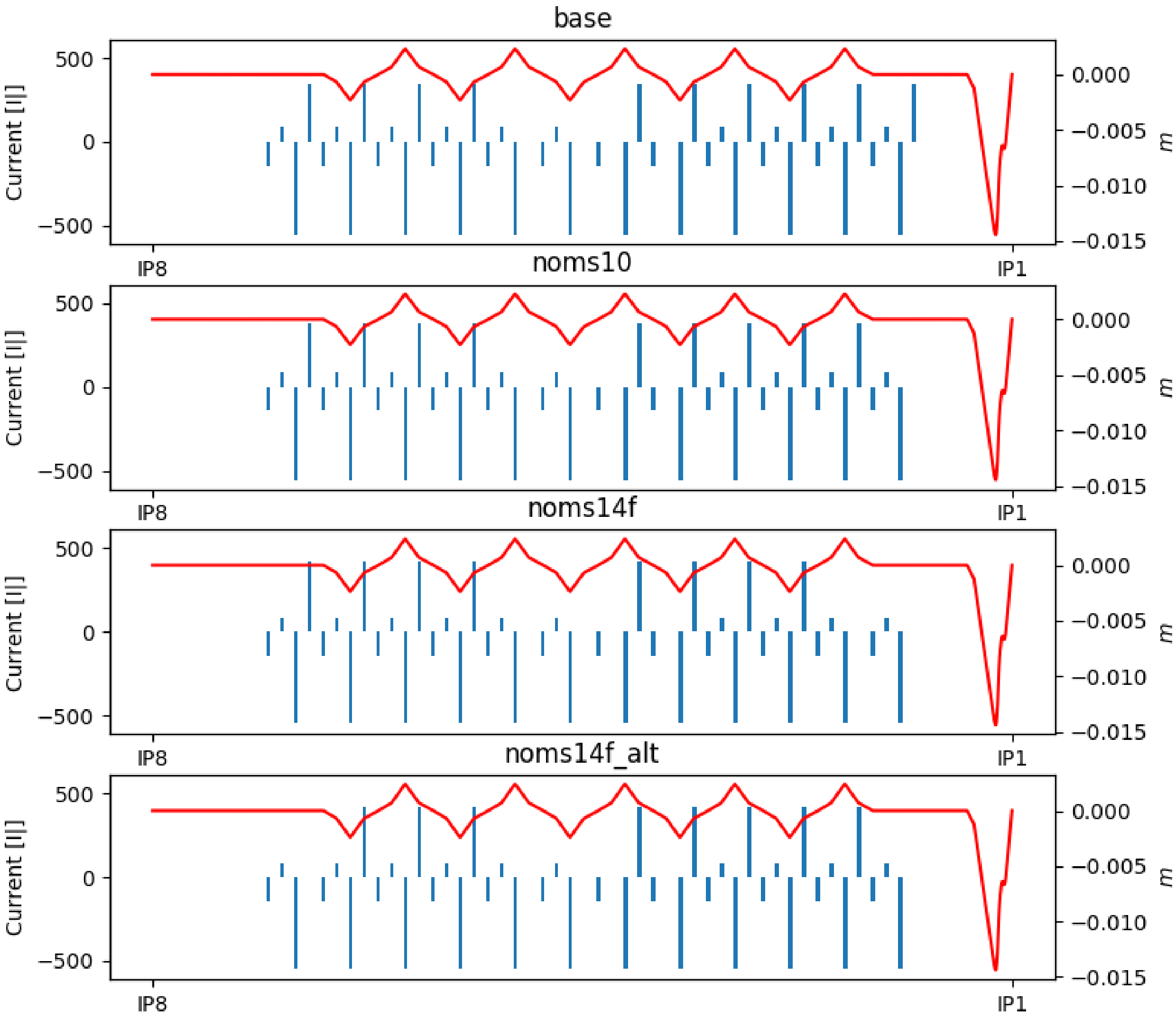
Q'=18.9/182
$|D_{max}|$=6.6/9.1 m

No dispersion correction, beam-beam and full optics.

D. Pellegrini

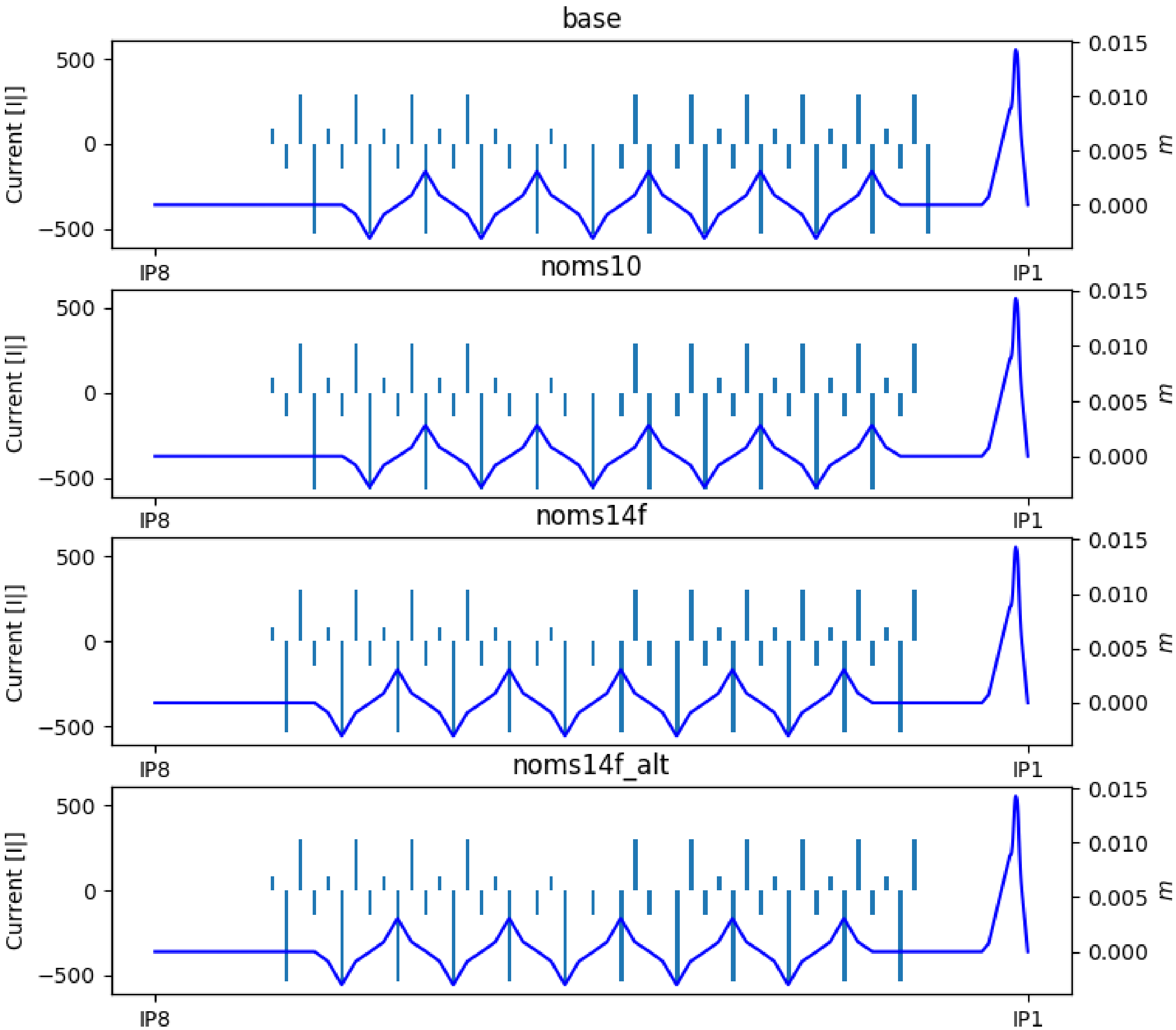
Best alternative (noMS14F) not equivalent to baseline!

Why MS10



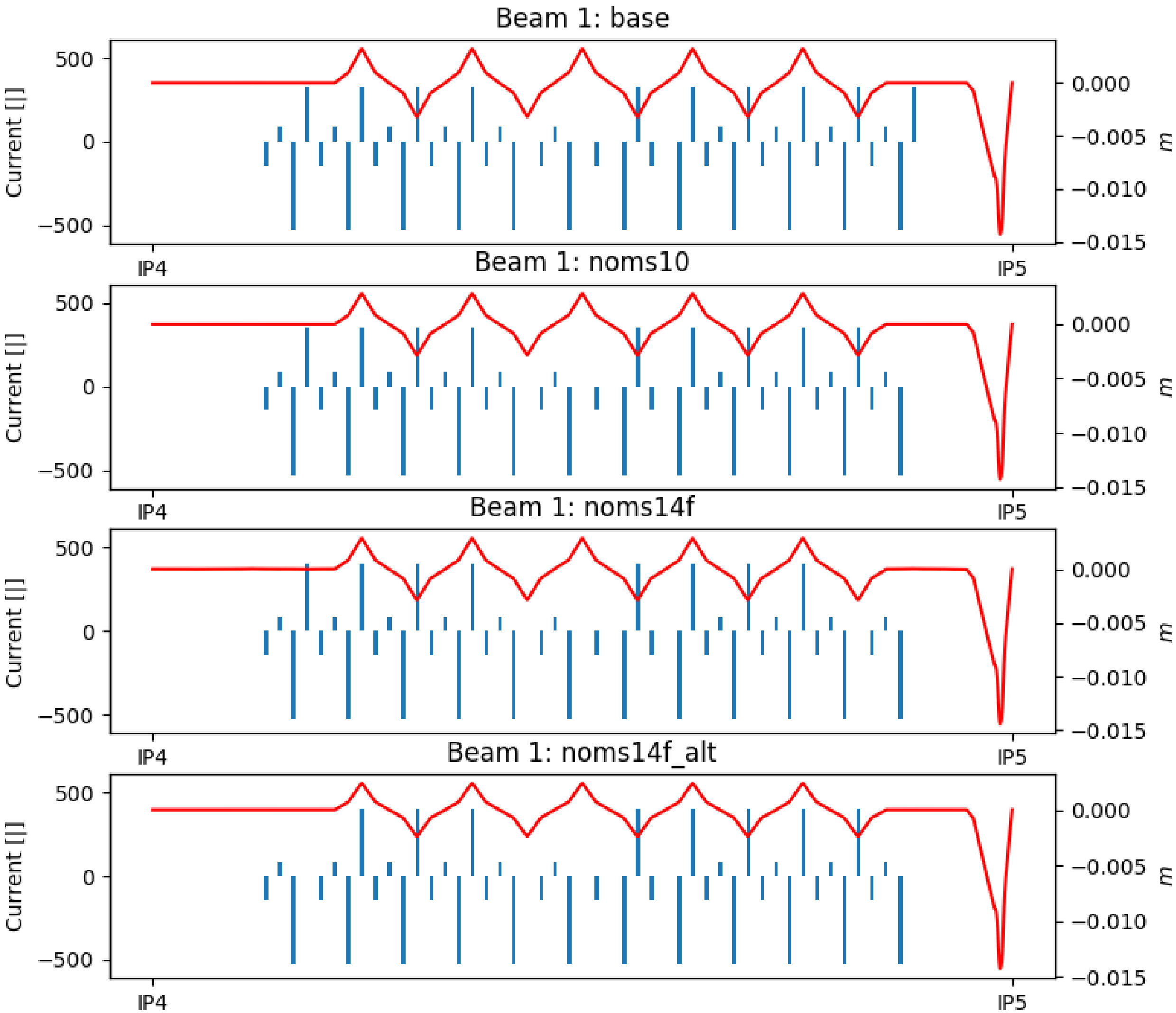
base
noms10
noms14f
noms14f_alt
Current [|I|]
500
0
−500
0.000
−0.005
−0.010
−0.015
m
IP8
IP1

Why MS10



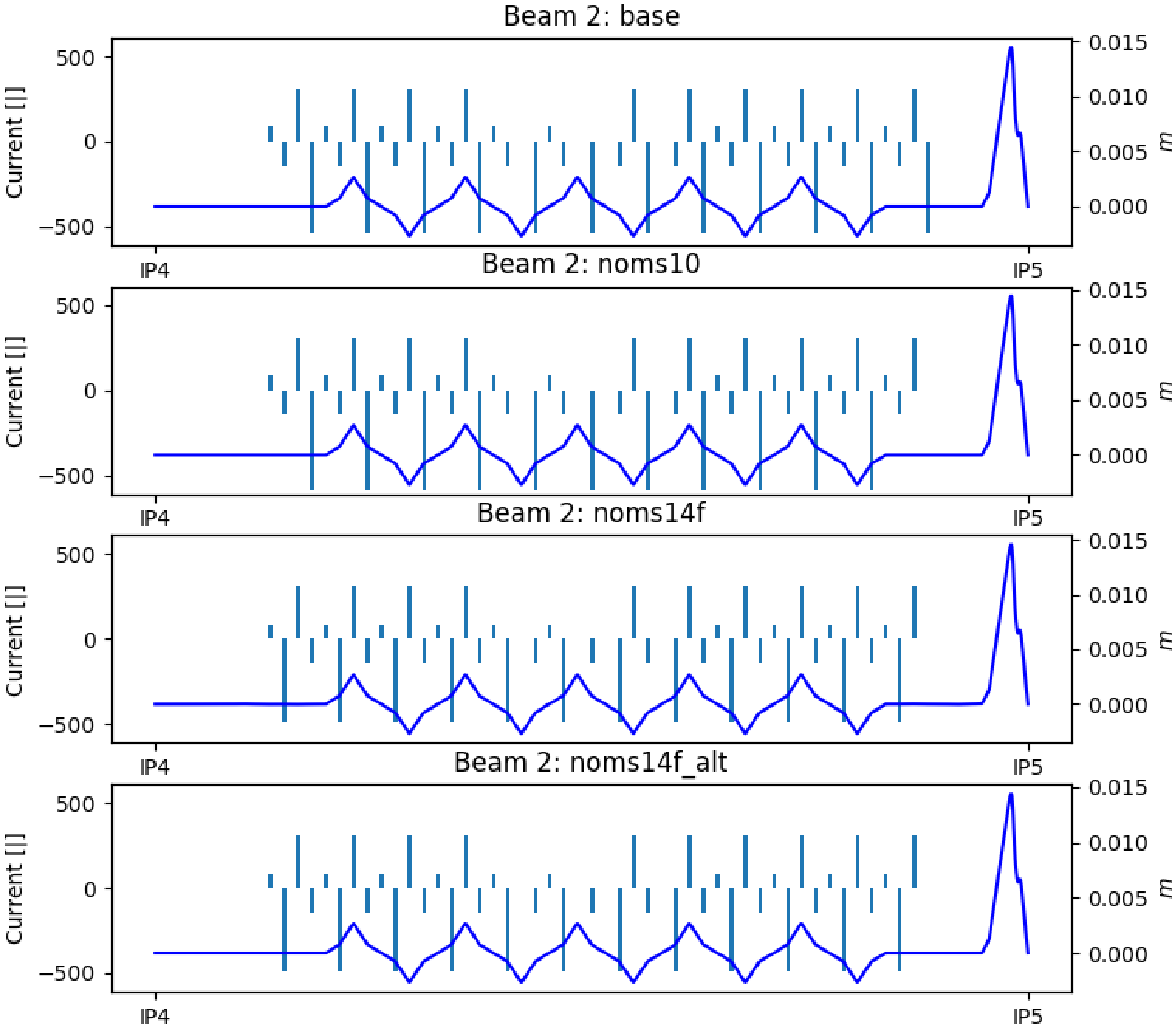
base
noms10
noms14f
noms14f_alt
Current [|I|]
500
0
−500
0.015
0.010
0.005
0.000
m
IP8
IP1

Why MS10



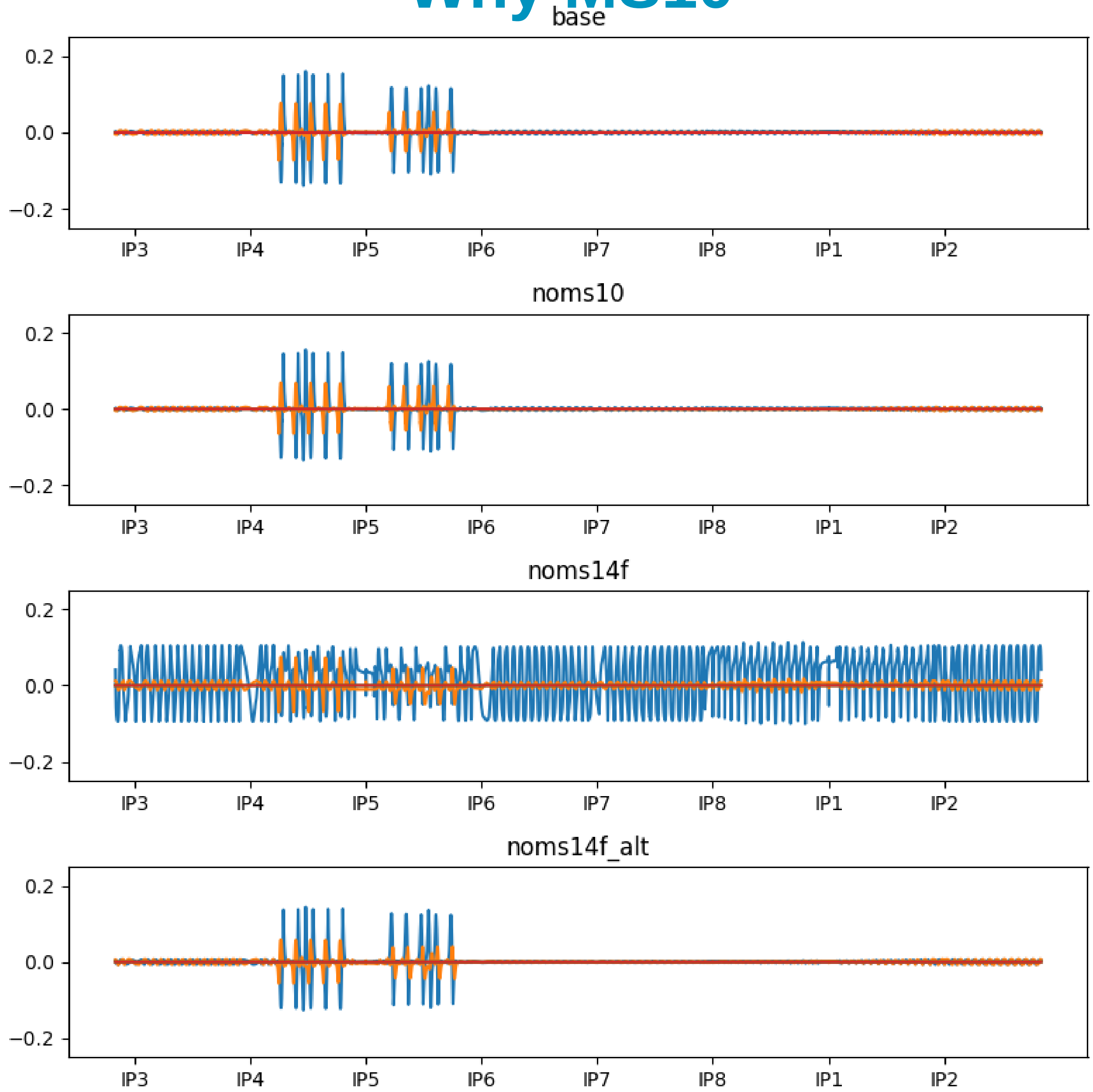
Beam 1: base
Current [I]
500
0
−500
0.000
−0.005
−0.010
−0.015
m
IP4
IP5
Beam 1: noms10
Current [I]
500
0
−500
0.000
−0.005
−0.010
−0.015
m
IP4
IP5
Beam 1: noms14f
Current [I]
500
0
−500
0.000
−0.005
−0.010
−0.015
m
IP4
IP5
Beam 1: noms14f_alt
Current [I]
500
0
−500
0.000
−0.005
−0.010
−0.015
m
IP4
IP5

Why MS10



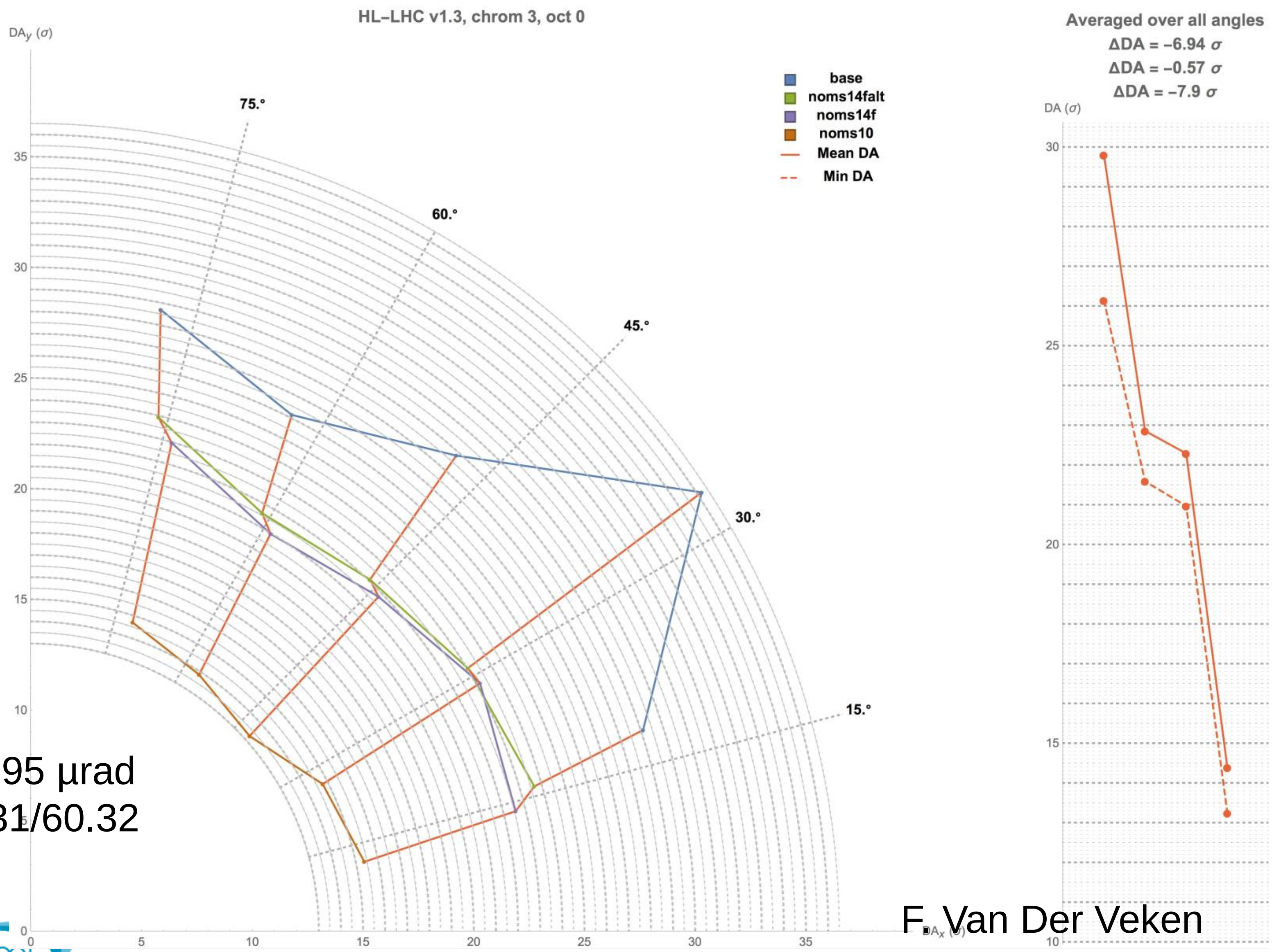
Beam 2: base
Beam 2: noms10
Beam 2: noms14f
Beam 2: noms14f_alt
Current [I]
500
0
−500
0.015
0.010
0.005
0.000
m
IP4
IP5

Why MS10



base
0.2
0.0
−0.2
IP3
IP4
IP5
IP6
IP7
IP8
IP1
IP2
noms10
noms14f
noms14f_alt

Da Sextupole only Q'=3



Xing=295 μrad
Q=62.31/60.32

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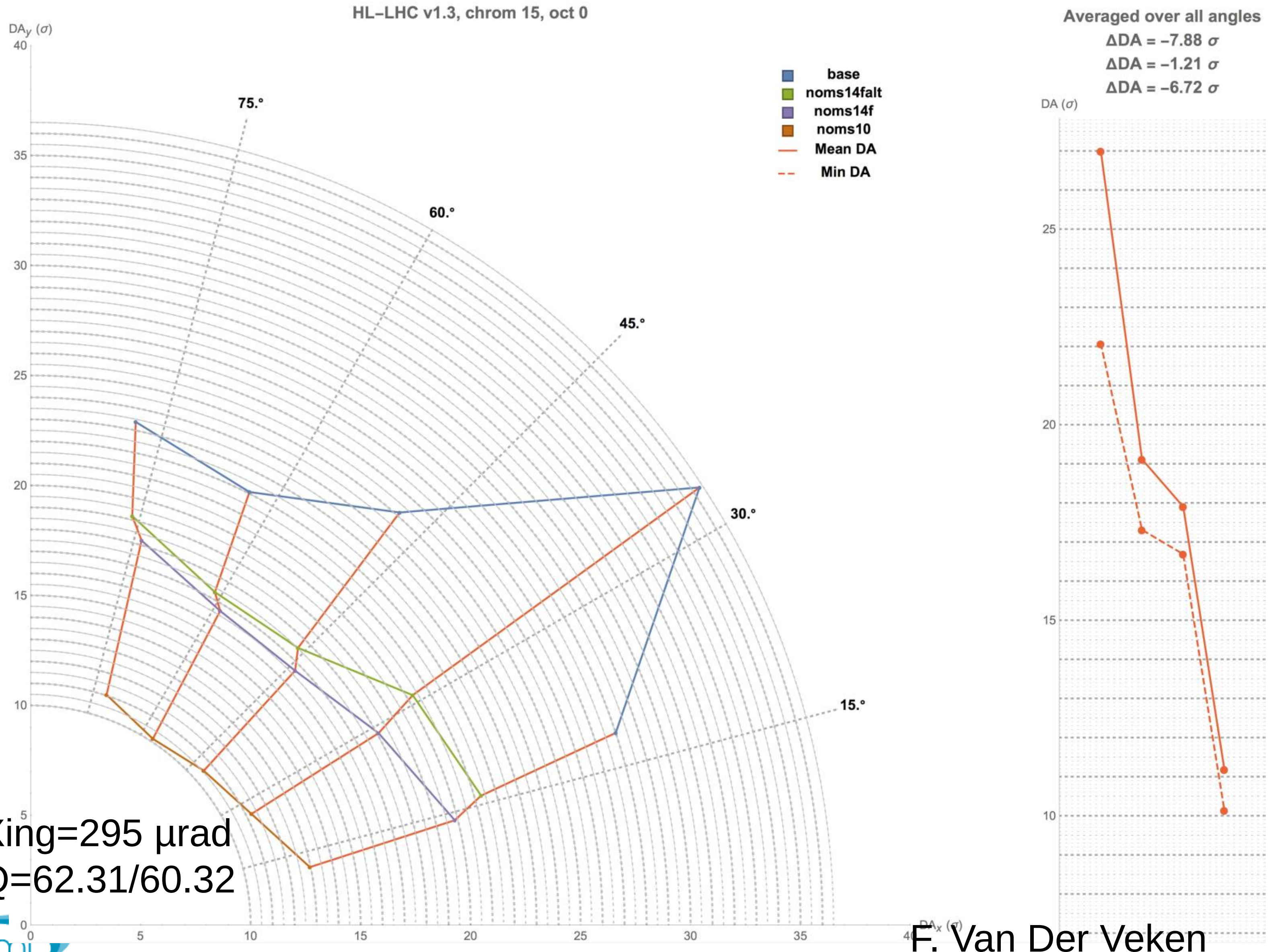
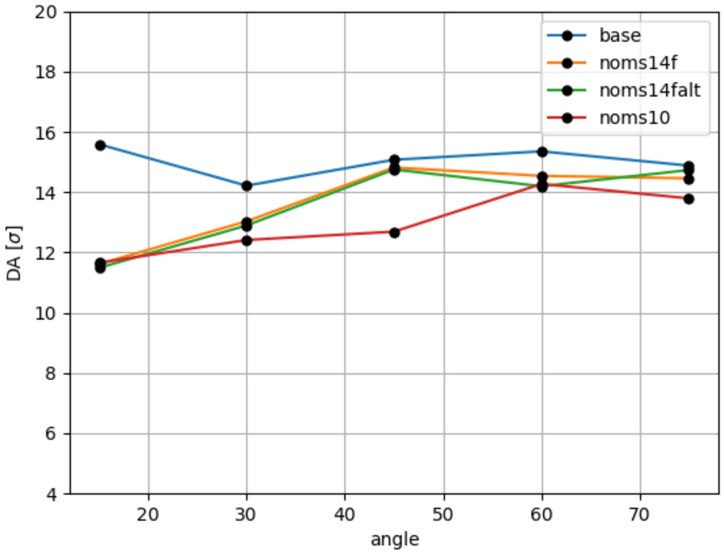
Da Sextupole only Q’=15



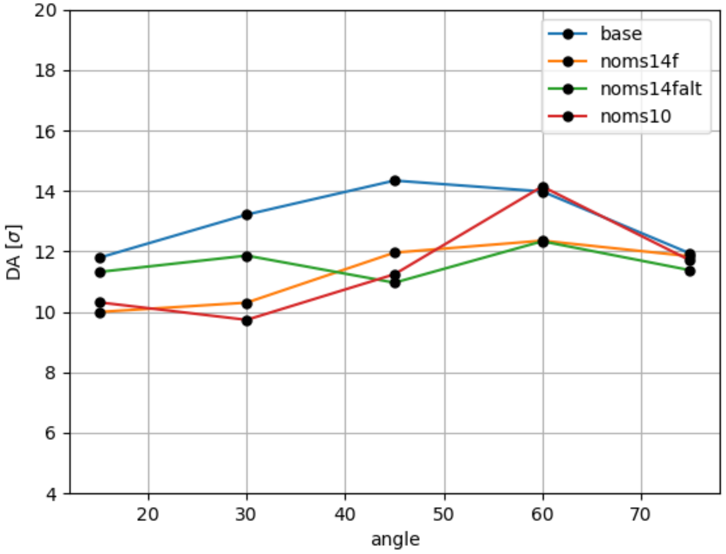
Xing=295 µrad
Q=62.31/60.32

F. Van Der Veken

DA sextupole and octupoles



NO dispersion correction



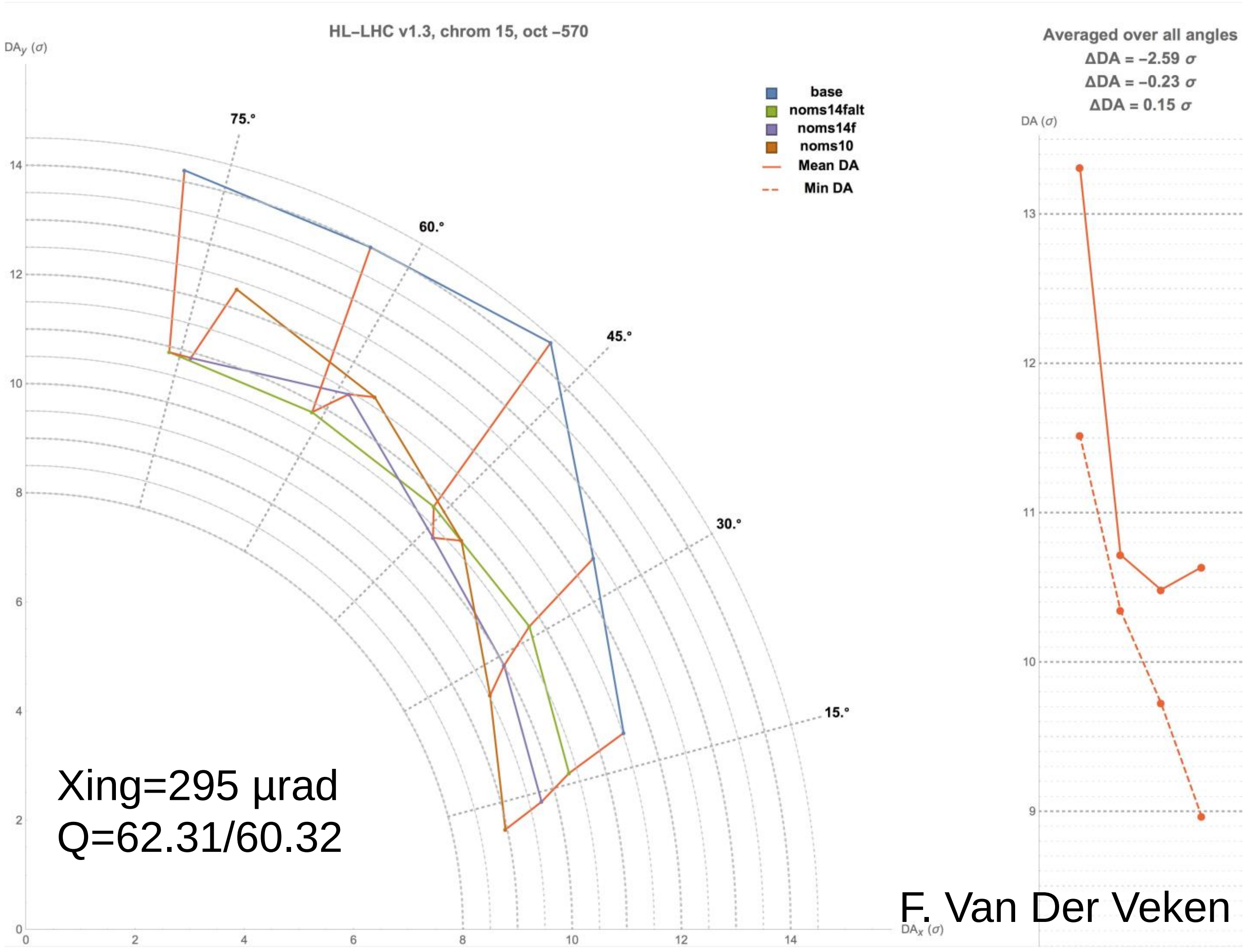
With dispersion correction

MO=-570, Xing=250, 62.31/60.32 tune, $\delta=2.7\ 10^{-4}$

Dispersion correction with strong MO reduce DA by about 2 σ.

MO feed-downs likely cause (a3, b3, a2).

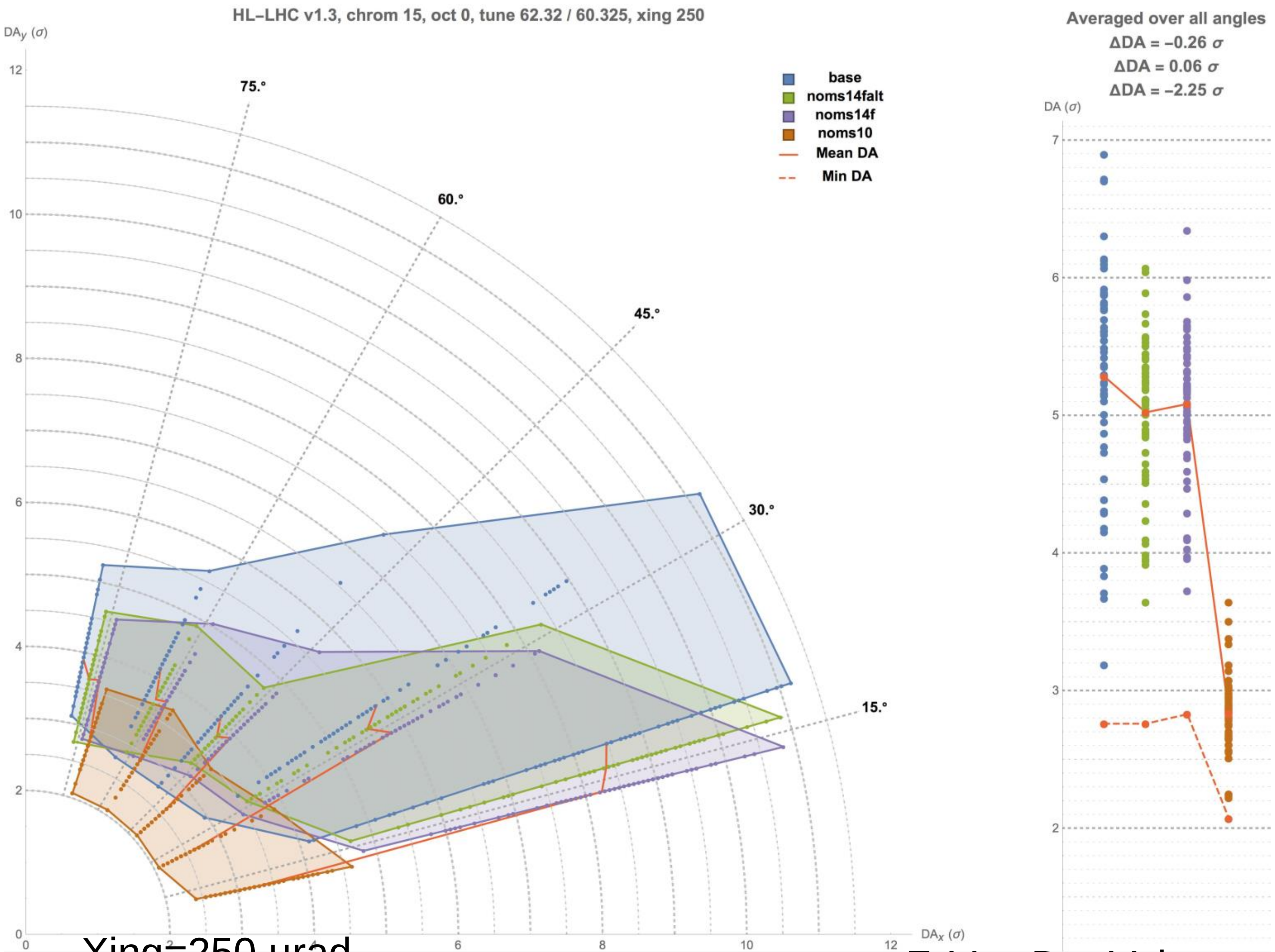
Da Sextupole only and MO



Xing=295 µrad
Q=62.31/60.32

F. Van Der Veken

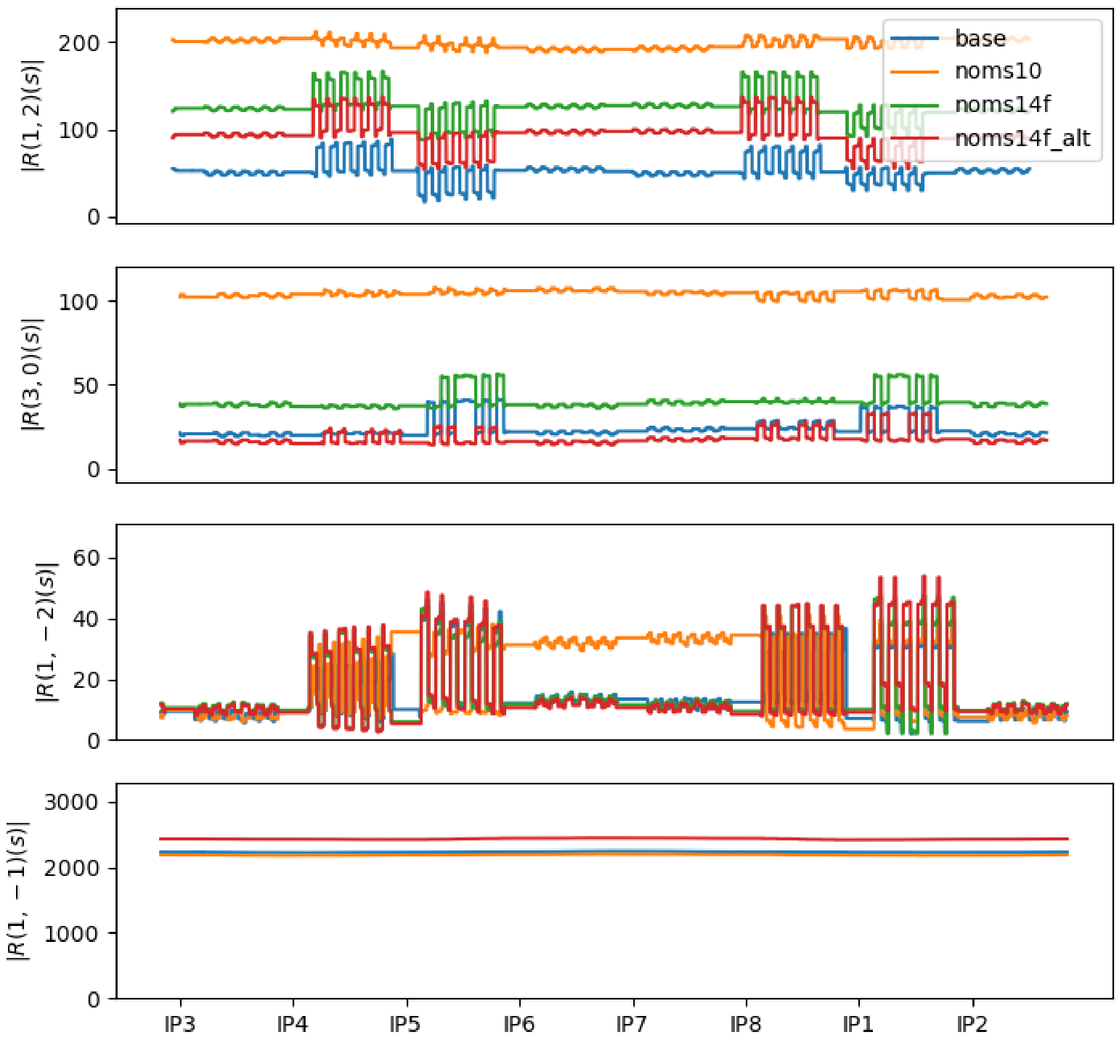
Da Sextupole only and MO



Xing=250 µrad
Q=62.320/60.325

F. Van Der Veken

Why MS10



base
noms10
noms14f
noms14f_alt
|R(1, 2)(s)|
|R(3, 0)(s)|
|R(1, −2)(s)|
|R(1, −1)(s)|
IP3
IP4
IP5
IP6
IP7
IP8
IP1
IP2

Operational scenarios for IR1/5 circuits

No MS14f option injection to VDM