Preliminary considerations of HL-LHC dynamic aperture: beam-beam effects and multipolar errors

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Acknowledgements: C. Tambasco, R. deMaria, M. Giovannozzi, G. Arduini, A. Valishev

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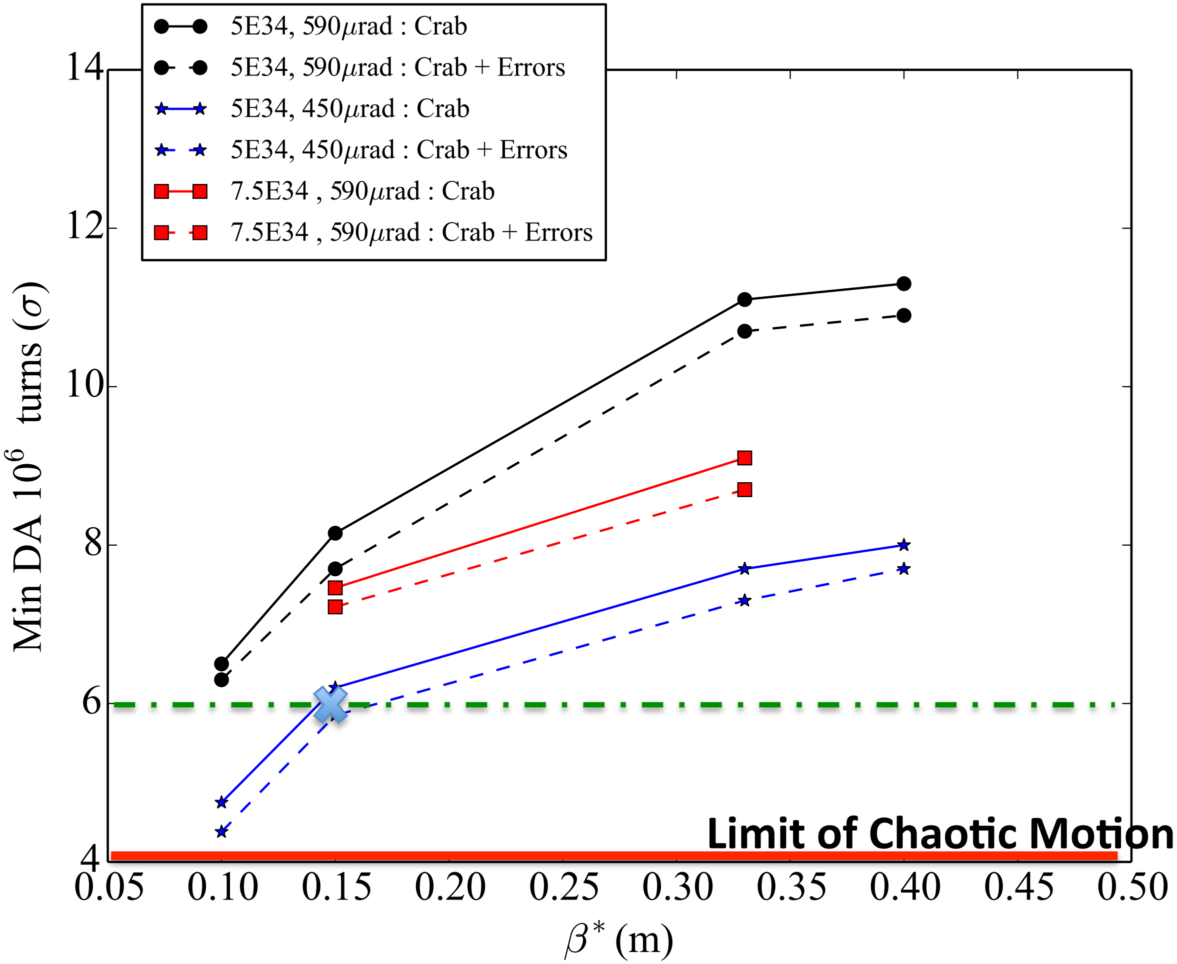
TL Meeting 23rd January 2015, CERN

Contents

- Beam-beam error bars on DA: what is in the shadow of beam-beam?
- Errors effects on DA: identify the element
- Identifying the multipoles effects b10 and b14
  - Strong BB nominal conditions
  - Weak BB nominal conditions
  - Lifetrac simulations
  - Larger crossing angles (still preliminary)
- Summary

Da for the HL-LHC baseline scenario



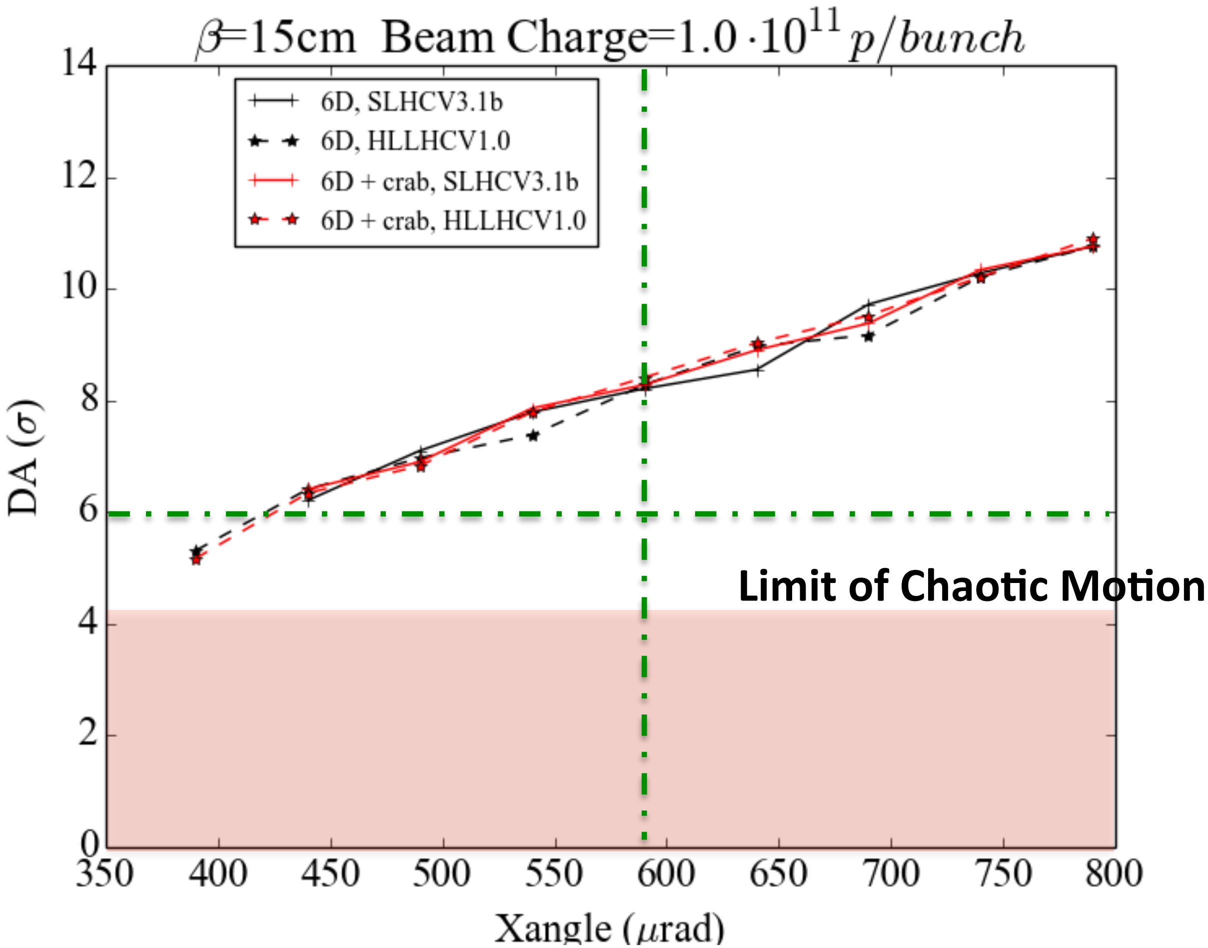
Baseline 1
5e34 leveled Luminosity
β* leveling

Ultimate
7.5e34 leveled Luminosity
β* leveling

Extreme case:
NO β* leveling

β* leveling is extremely "beautiful" for beam-beam dynamics
Gives higher potentials for the HL-LHC

Dynamic aperture HL-LHC IP1&5: crossing angle scan

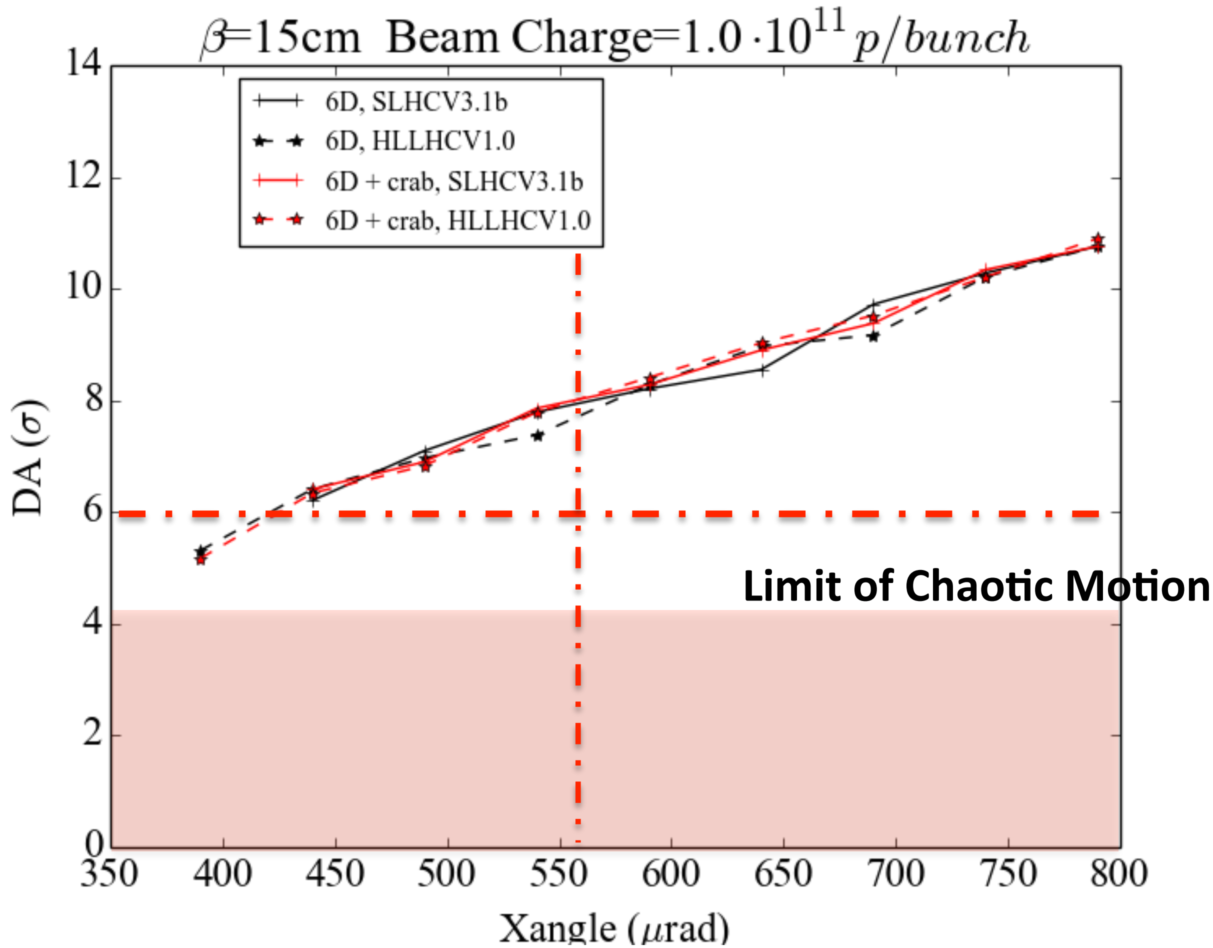


$$d_{sep} = \alpha \cdot \sqrt{\frac{\beta^*}{\epsilon/\gamma}}$$

$$DA \propto d_{sep} \propto \alpha$$

In nominal condition 590 mrad DA=8.4 Sixtrack
Plenty of margin but…

Dynamic aperture HL-LHC IP1&5: the beauty of β*leveling



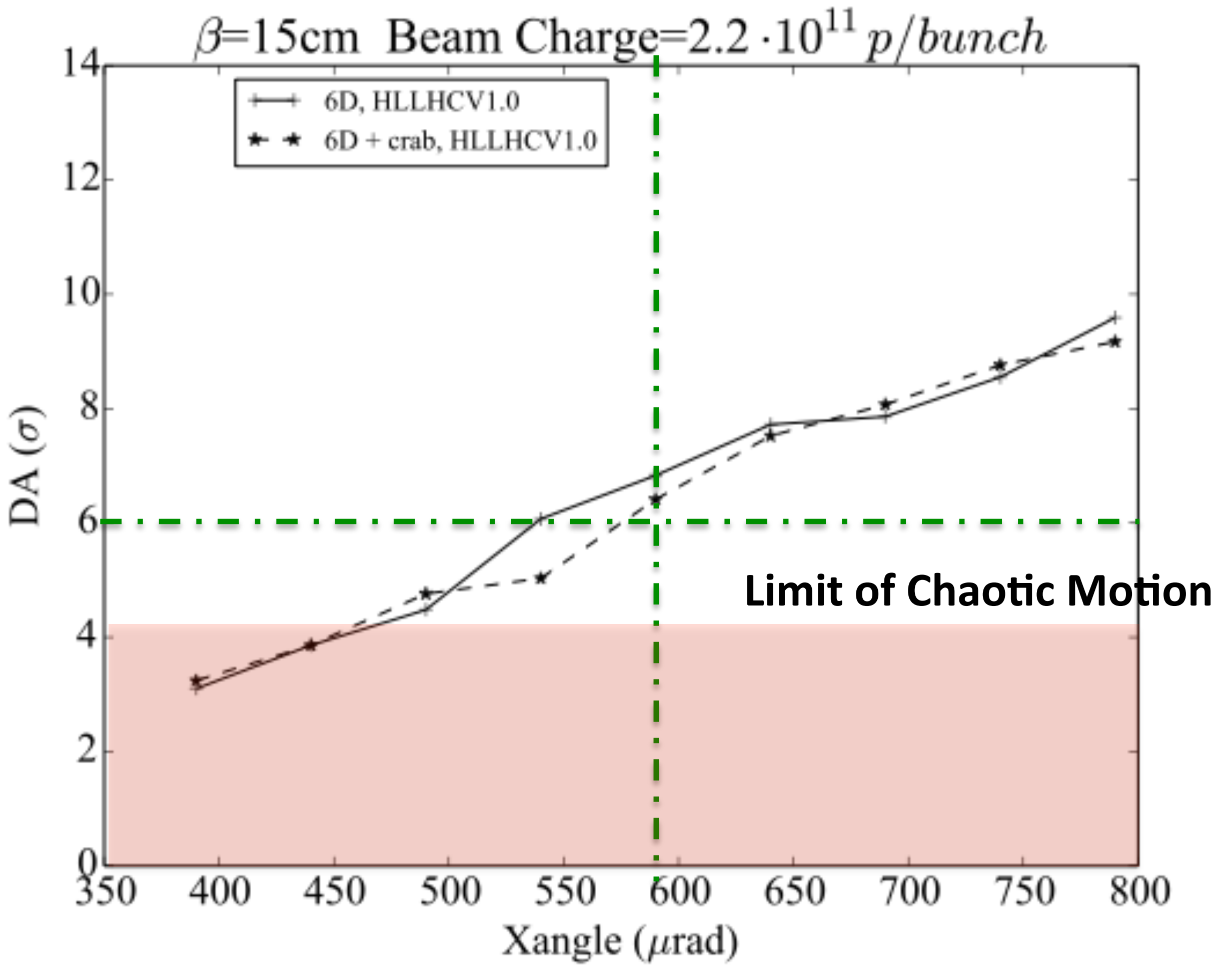
$$d_{sep} = \alpha \cdot \sqrt{\frac{\beta^*}{\epsilon/\gamma}}$$

$$DA \propto d_{sep} \propto \alpha$$

1. **10% larger ε_n (2.5→2.75)**
2. **Equivalent to reduction of the angle 590μrad→560μrad**
3. **Equivalent to reduction of DA 1σ**

10% increase ε_n (bbb fluctuations injectors, growth) → reduces DA 8.5 → 7.5 σ

Dynamic aperture HL-LHC IP1&5:
NO β* leveling

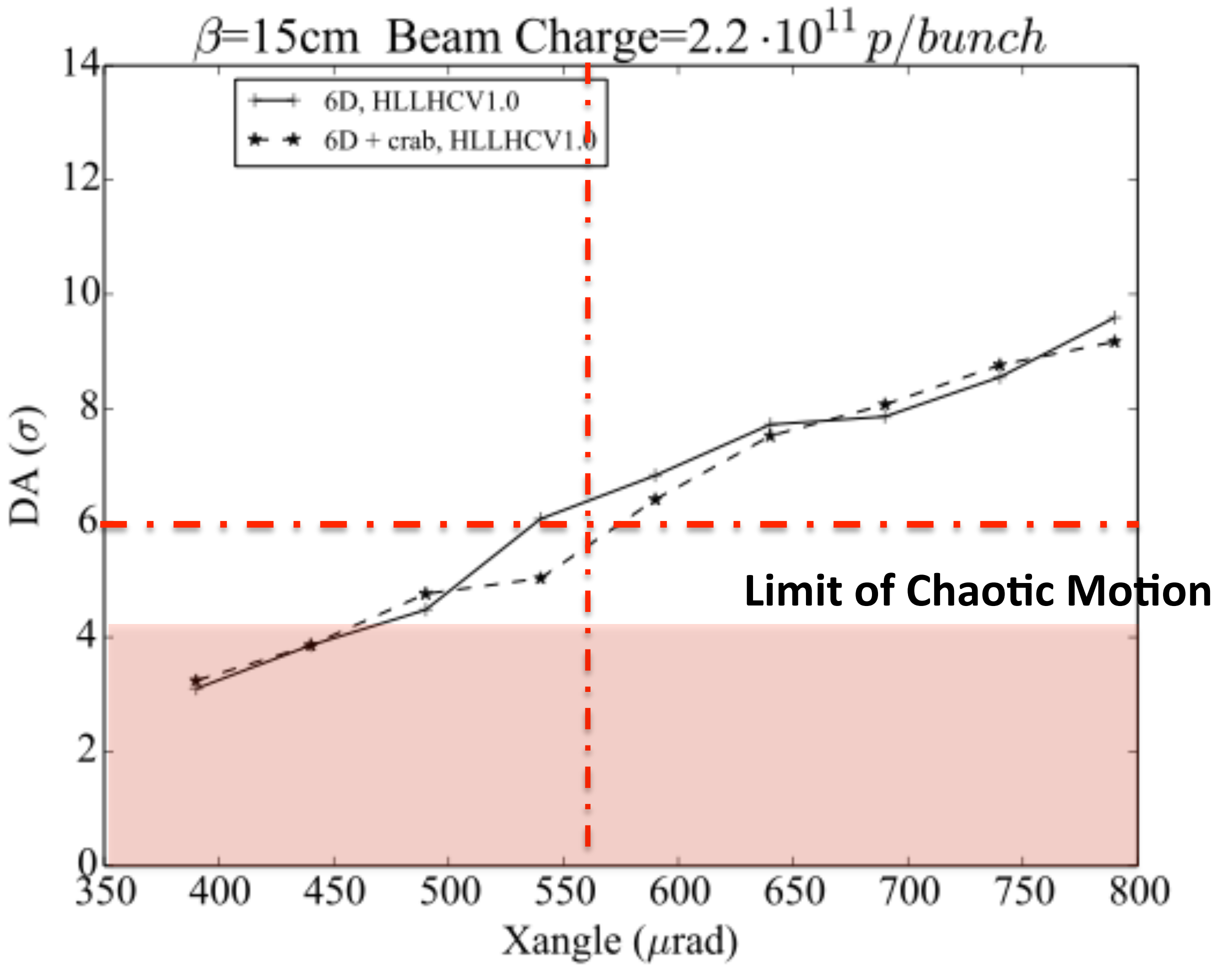


$$d_{sep} = \alpha \cdot \sqrt{\frac{\beta^*}{\epsilon/\gamma}}$$

$$DA \propto d_{sep} \propto \alpha$$

In nominal condition 590 μrad DA=6.4

Dynamic aperture HL-LHC: IP1&5



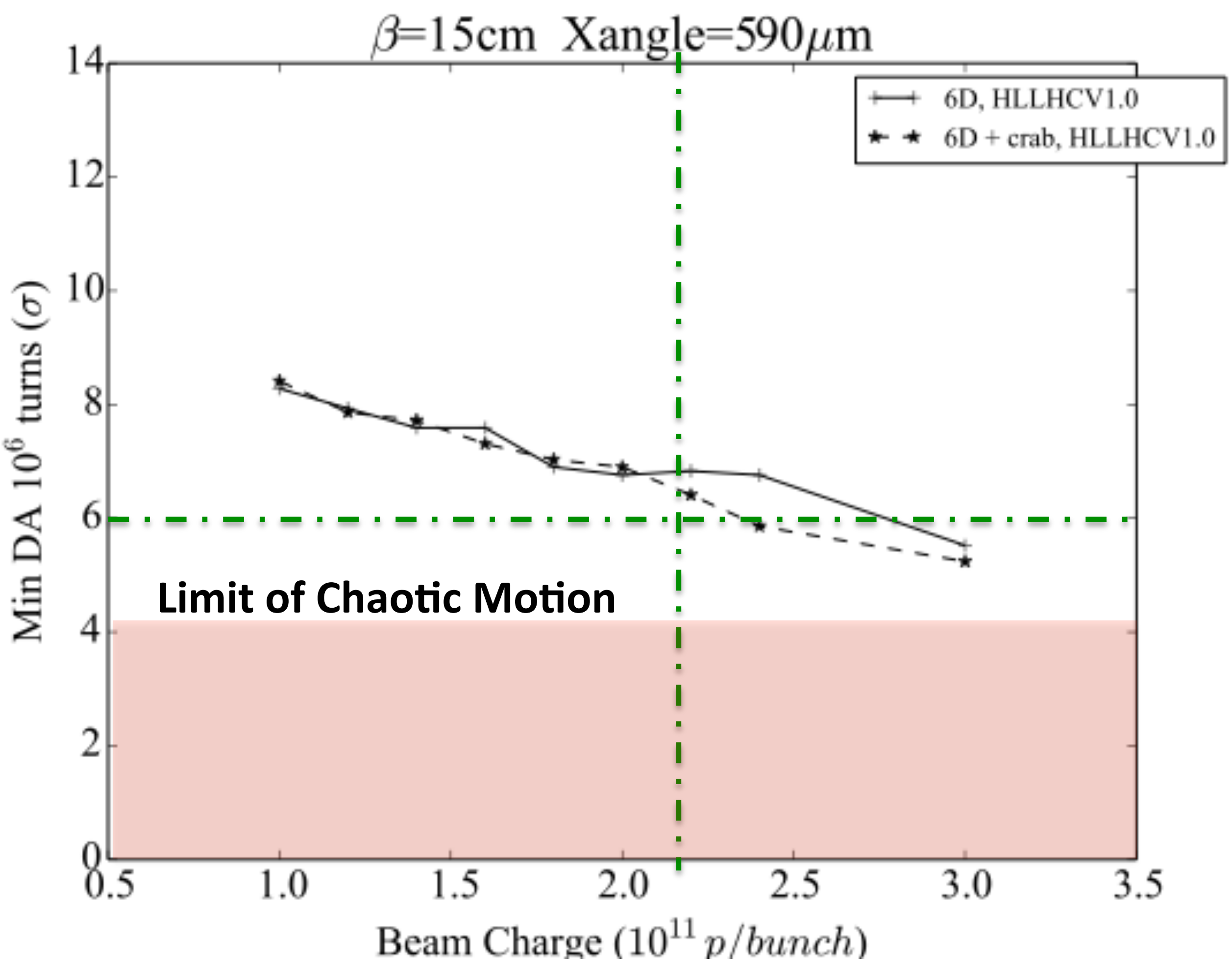
$$d_{sep} = \alpha \cdot \sqrt{\frac{\beta^*}{\epsilon/\gamma}}$$

$$DA \propto d_{sep} \propto \alpha$$

1. 10% larger ε_n (2.5→2.75)
2. Equivalent to reduction of the angle 590μrad→560μrad
3. Equivalent to reduction of DA 1σ

10% increase ε_n reduces DA 6.4 → 5.5 σ

Dynamic aperture HL-LHC IP1&5: Intensity

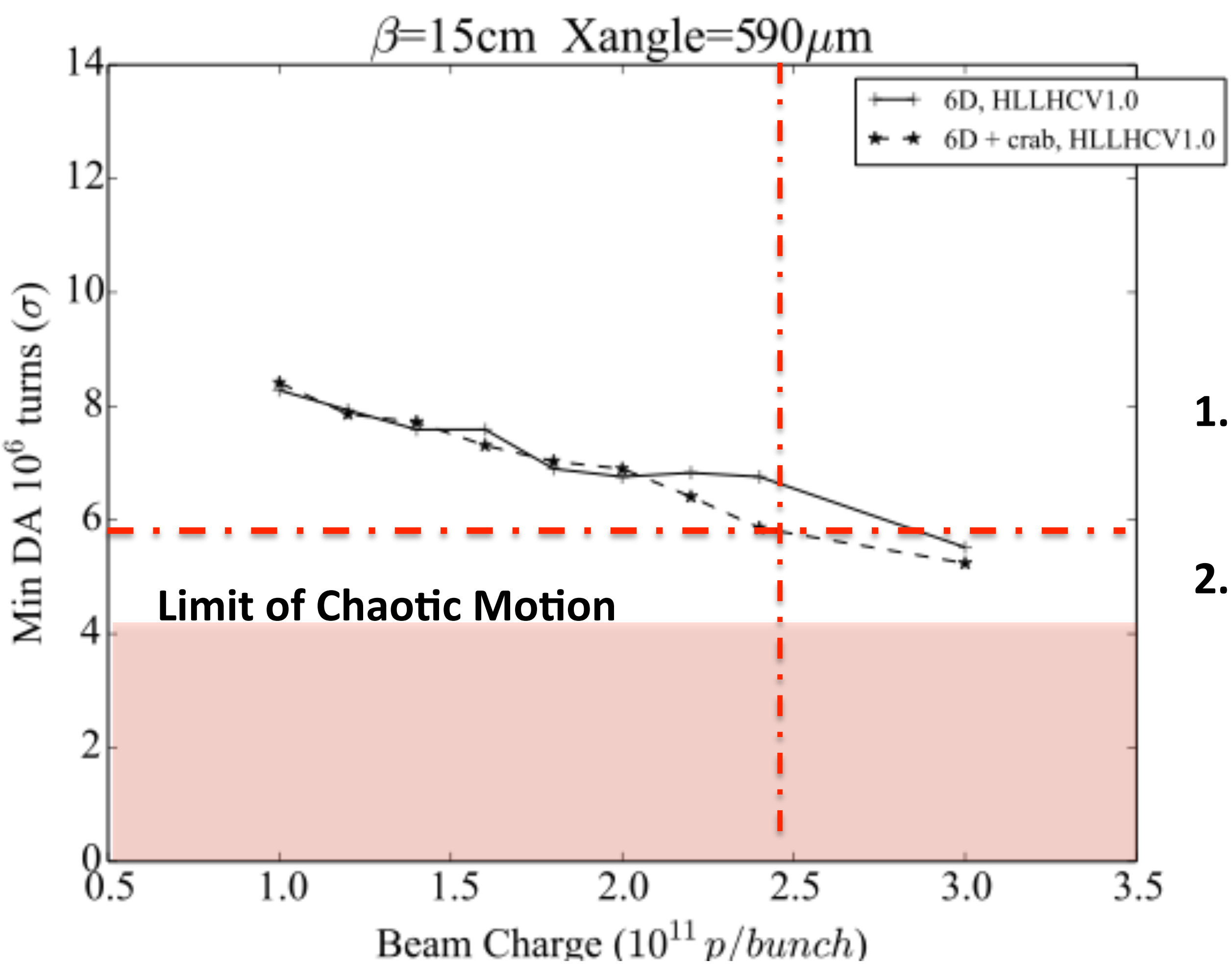


$F_{bb} \propto Intensity$

$DA \propto Intensity$

In nominal condition 2.2e11ppb DA=6.4 σ

Dynamic aperture HL-LHC IP1&5: Intensity



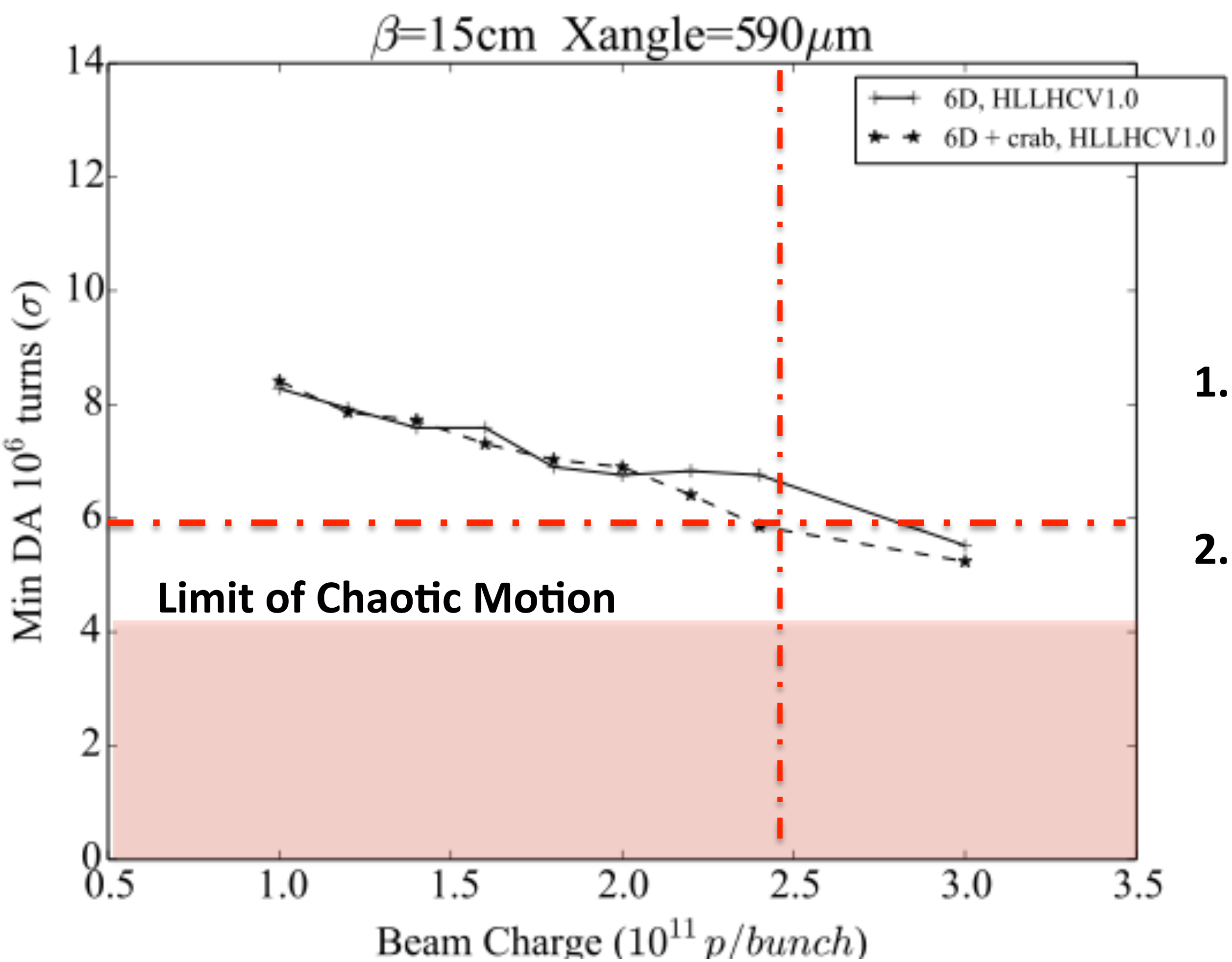
$$F_{bb} \propto Intensity$$

$$DA \propto Intensity$$

1. **10% Intensity increase (2.2→2.4)**
2. **Equivalent to reduction of DA 0.6 σ**

10% Intensity fluctuations reduces DA 6.4 → 5.8 σ

Dynamic aperture HL-LHC IP1&5: Intensity



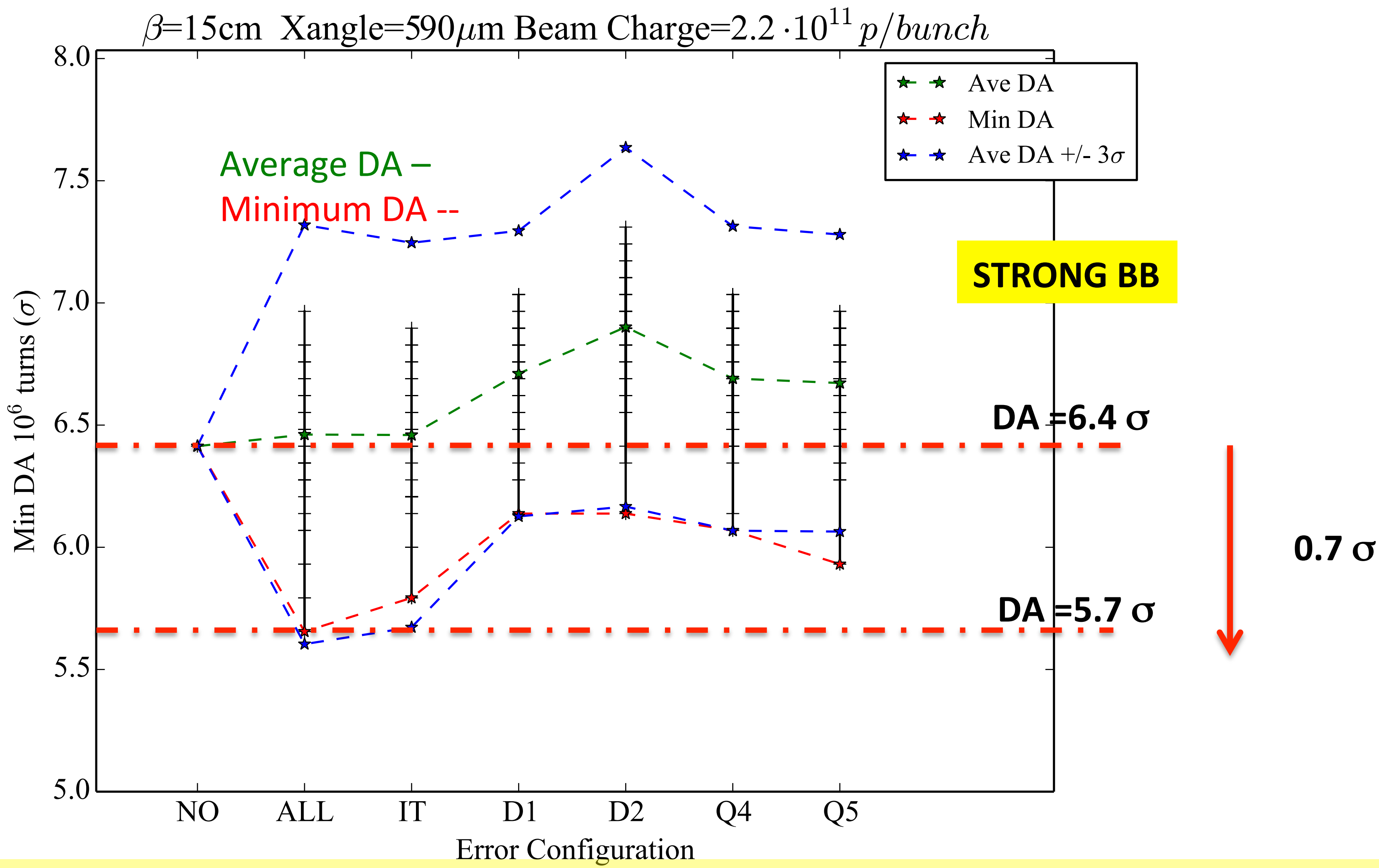
$F_{bb} \propto Intensity$

$DA \propto Intensity$

1. **10% Intensity increase (2.2→2.4)**
2. **Equivalent to reduction of DA 0.6 σ**

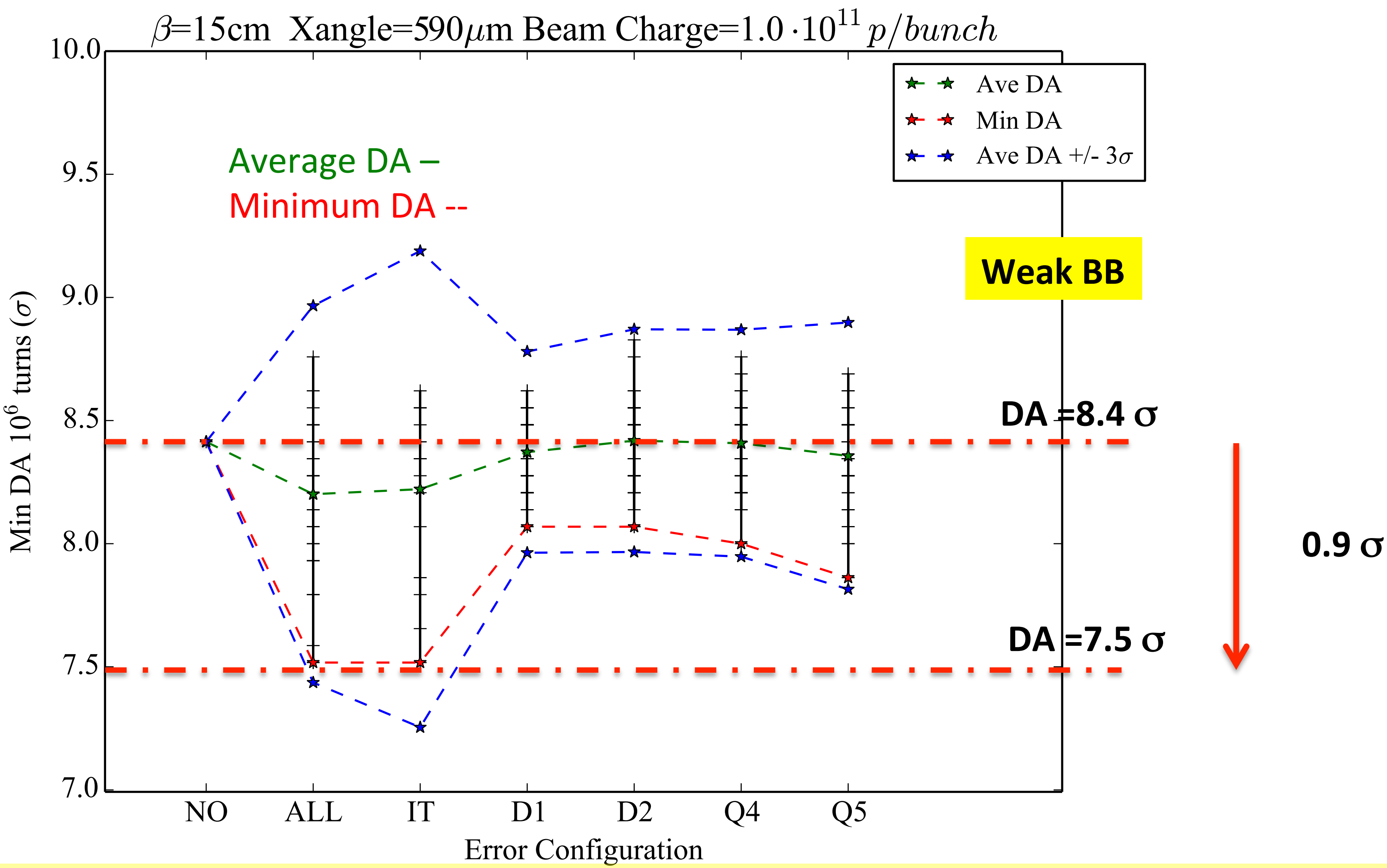
With BB error bars on DA values are between 0.5 and 1 sigma.
Any fluctuation of emittance and intensity can modify the DA

Multipolar errors single element impact: IP1&5 extreme case MIN DA criteria



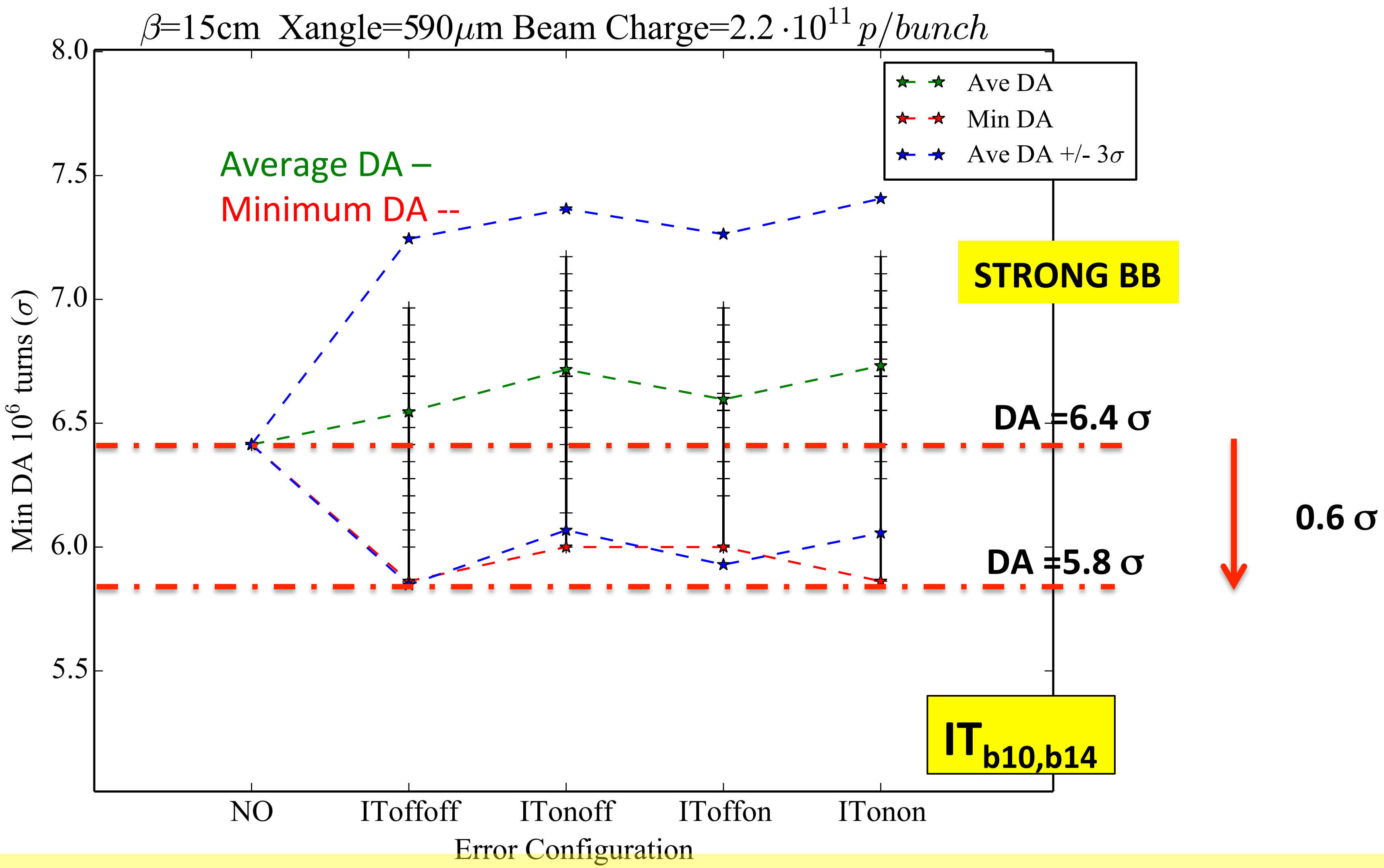
Errors do have an impact (0.7 σ reduction)
Driven by Inner Triplet element errors

Multipolar errors single element impact: IP1&5 and β* leveling



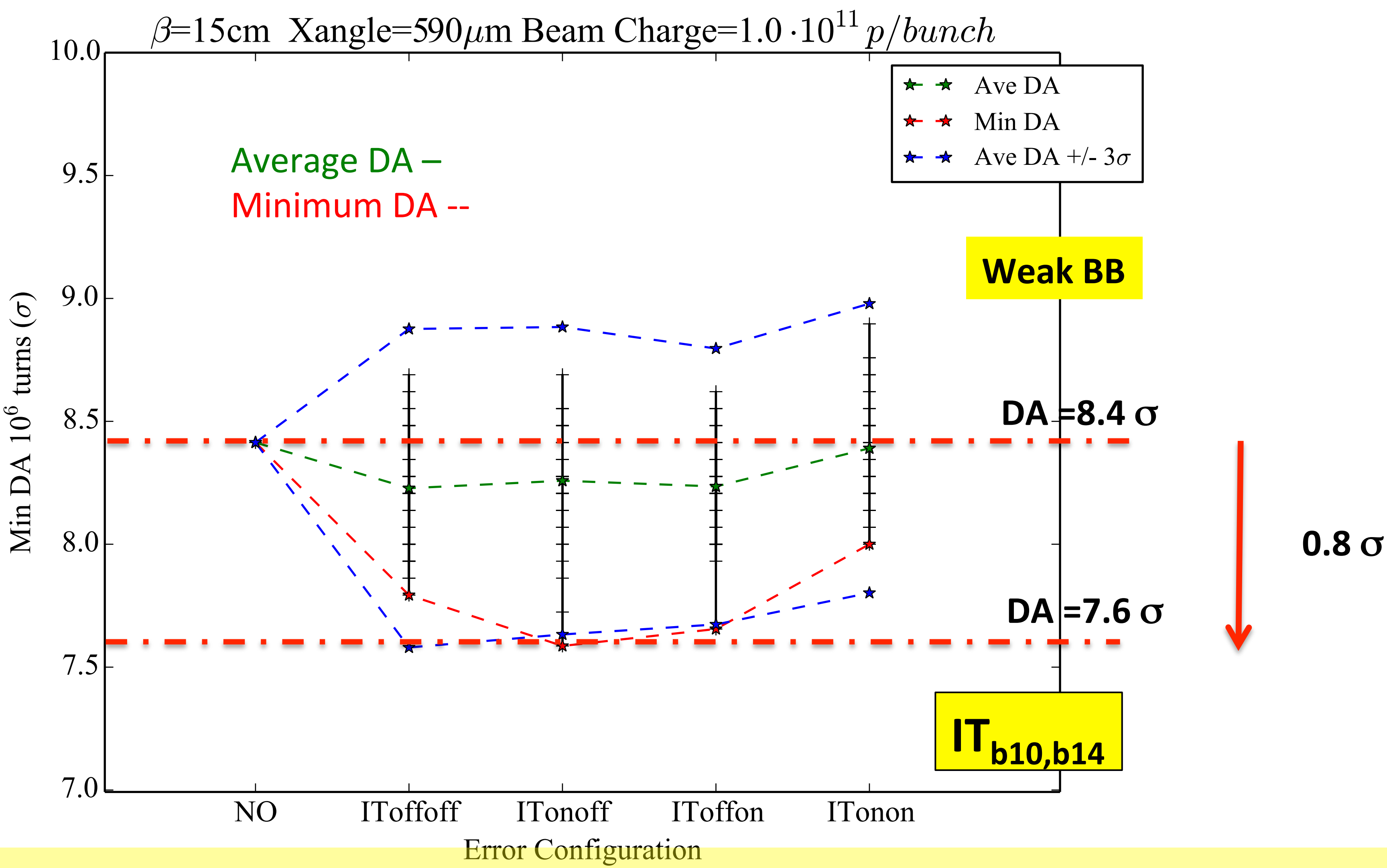
Errors do have an impact (0.9 σ reduction)
Driven by Inner Triplet element errors and seems stronger when BB weak

Multipolar errors: b10 and b14 in the IT: strong BB



Average DA improves with b_{10} b_{14}
Minimum DA criteria gives reduction 0.6 s in all cases!

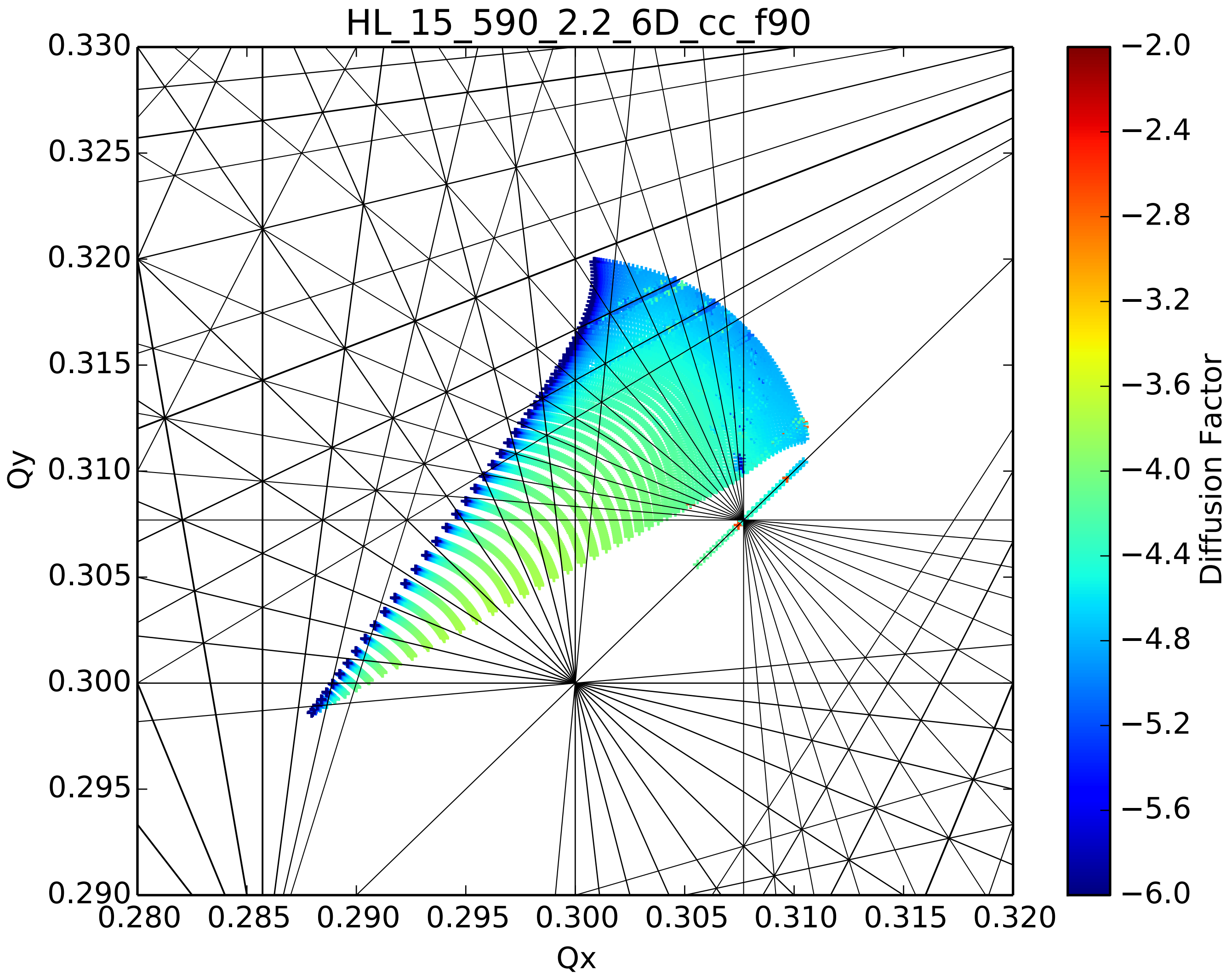
Multipolar errors: b10 and b14 in the IT: weak BB



Average reduced slightly

Minima DA improves with b_{10} and b_{14}

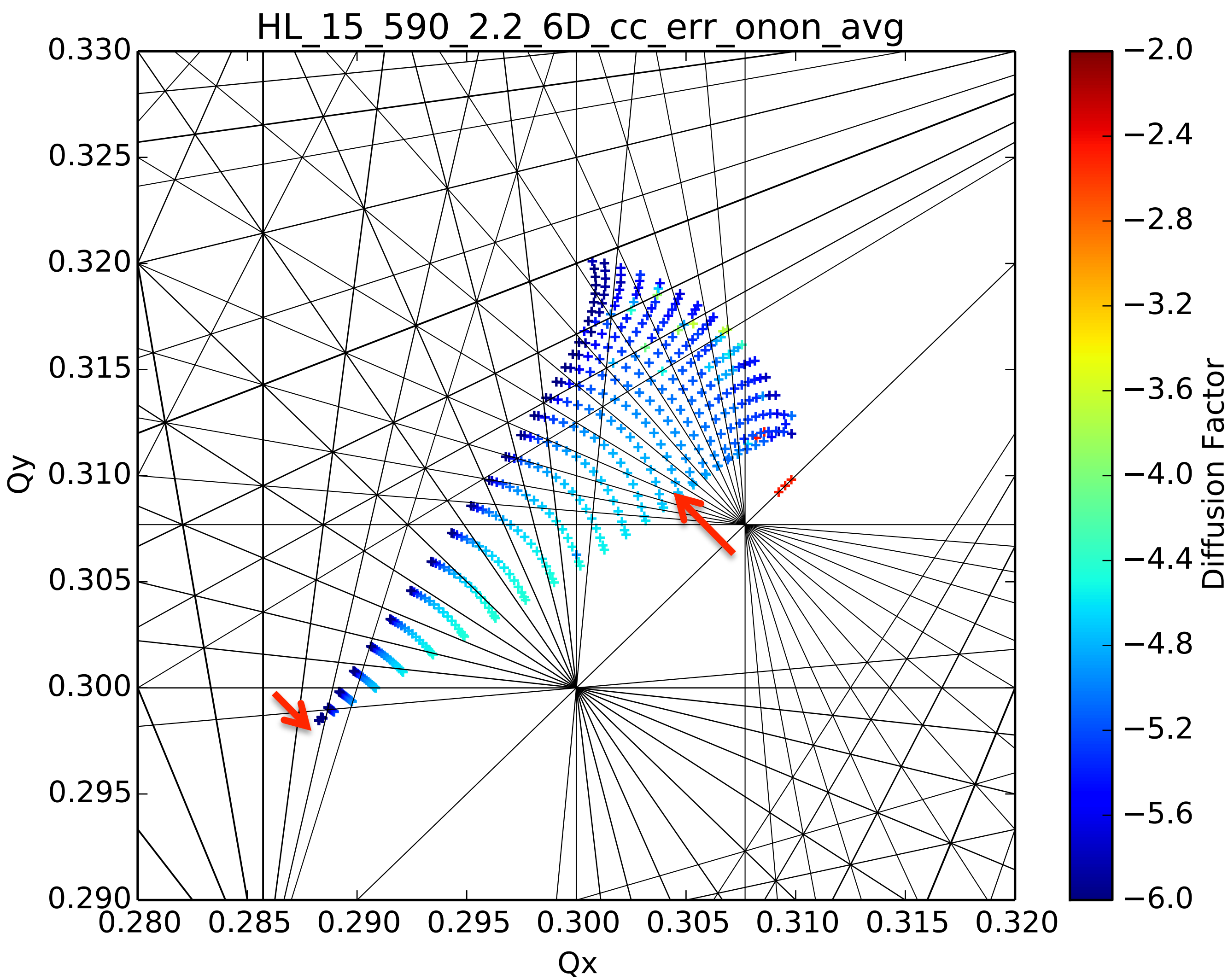
No Multipolar errors: 6 sigma particles



STRONG BB

DA = 6.4 σ

Multipolar errors: average seed



DA =6.4 σ

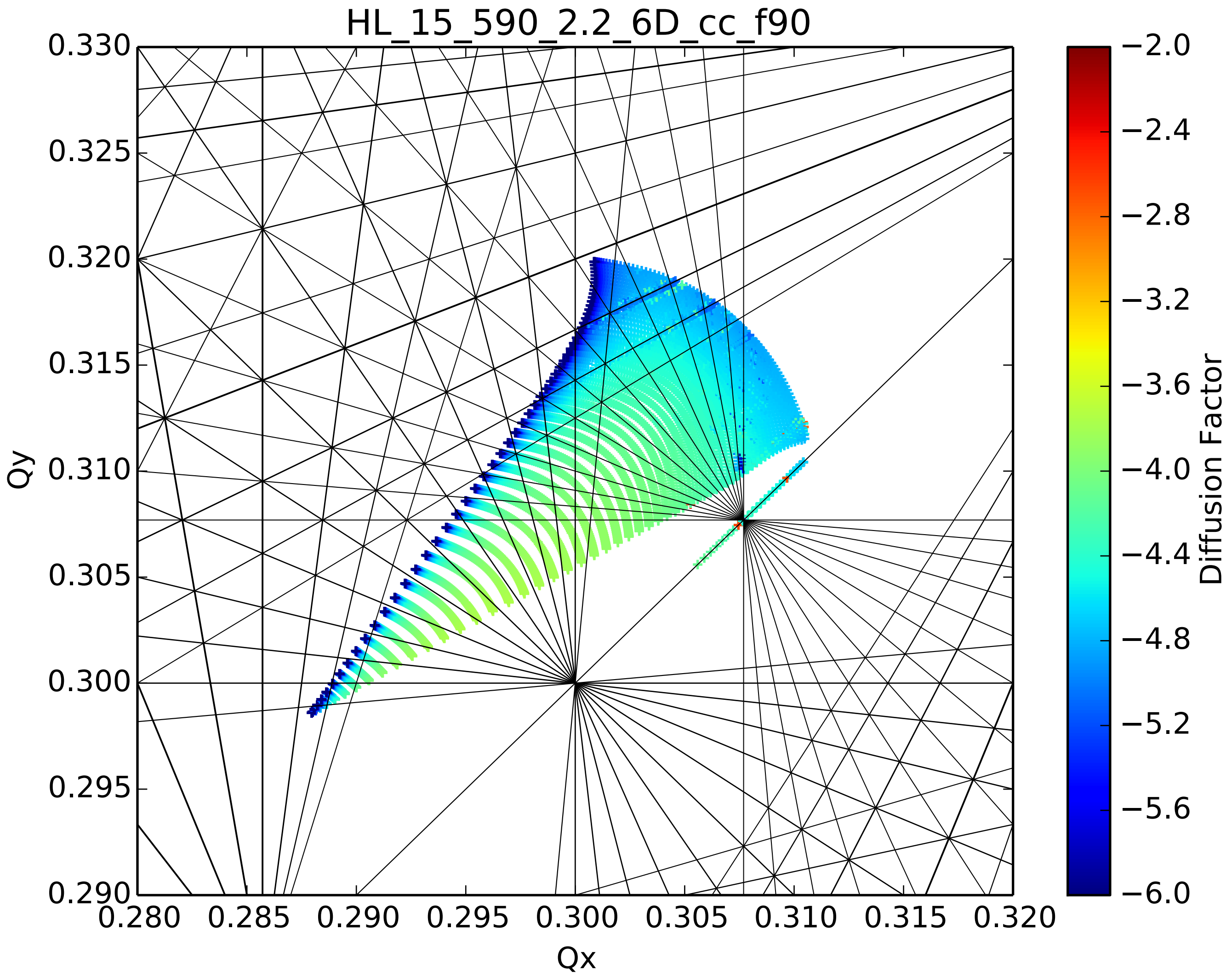
+ 0.3 σ

DA =6.7 σ

Average seeds improve DA

Reduced spread and small shift in tune diagram →get's away from resonance

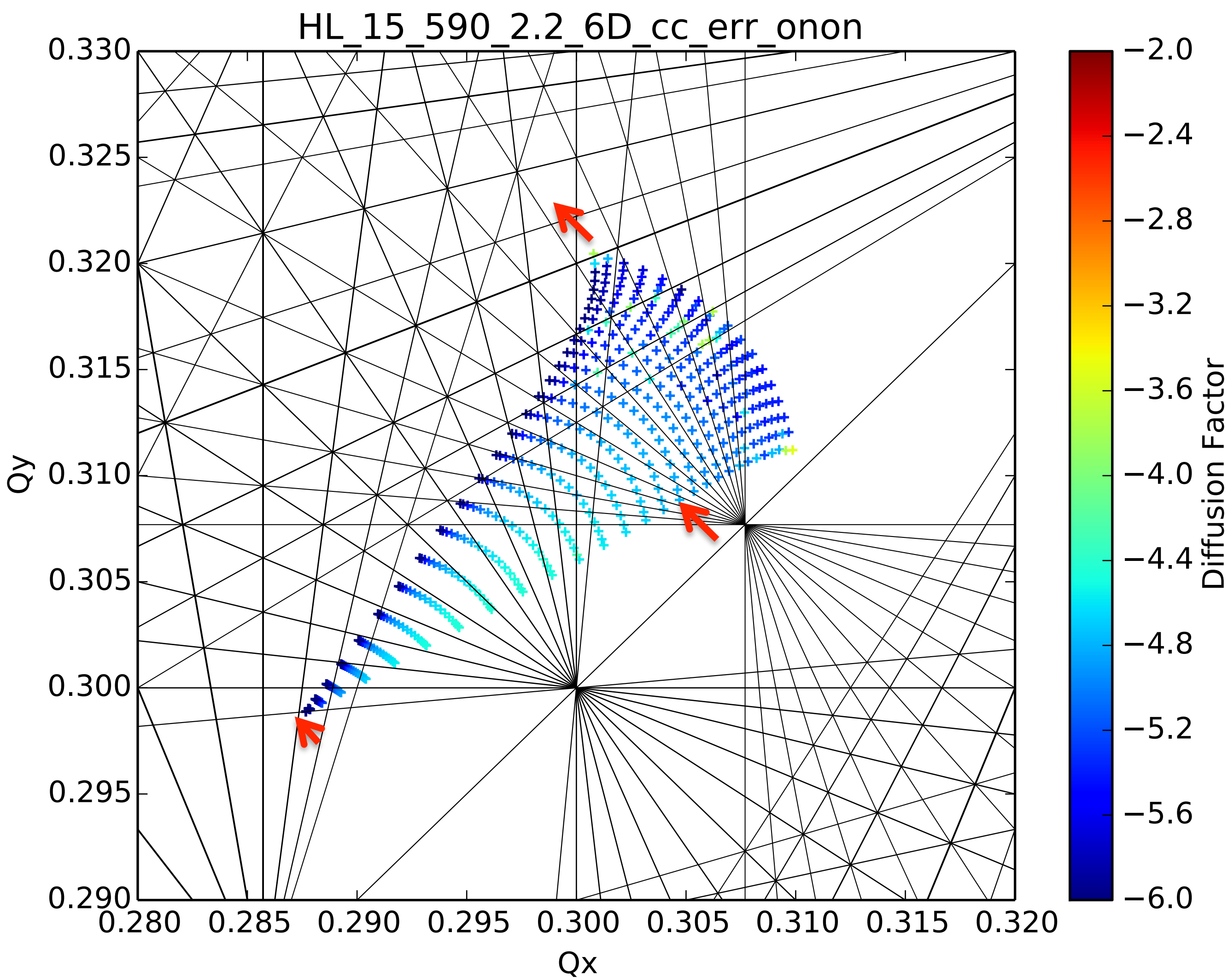
No Multipolar errors: 6 sigma particles



STRONG BB

DA = 6.4 σ

Multipolar errors: minimum DA seed



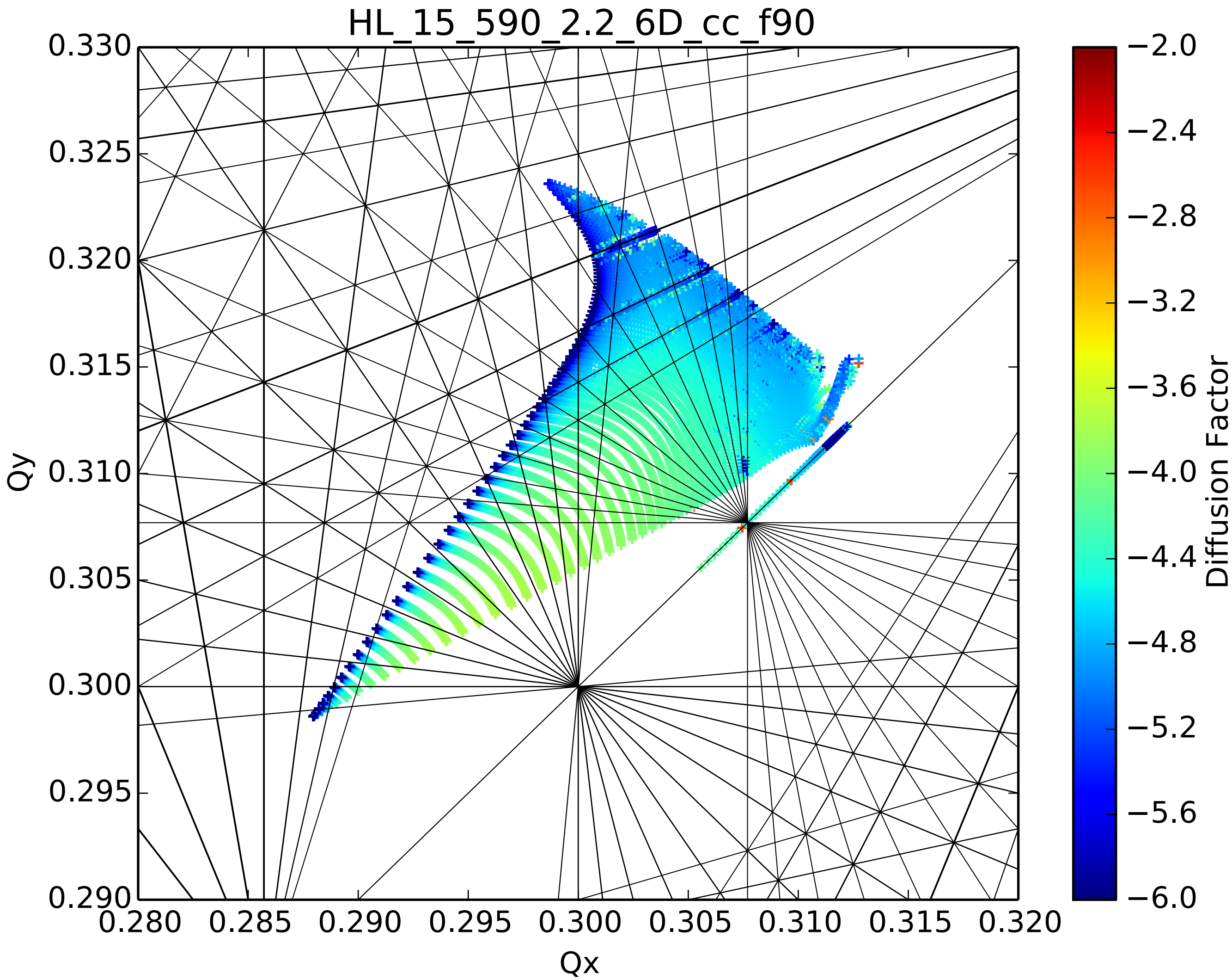
DA =6.4 σ

-0.6 σ

DA =5.8 σ

Minima DA seeds reduces DA
Reduced spread and small shift away from the diagonal

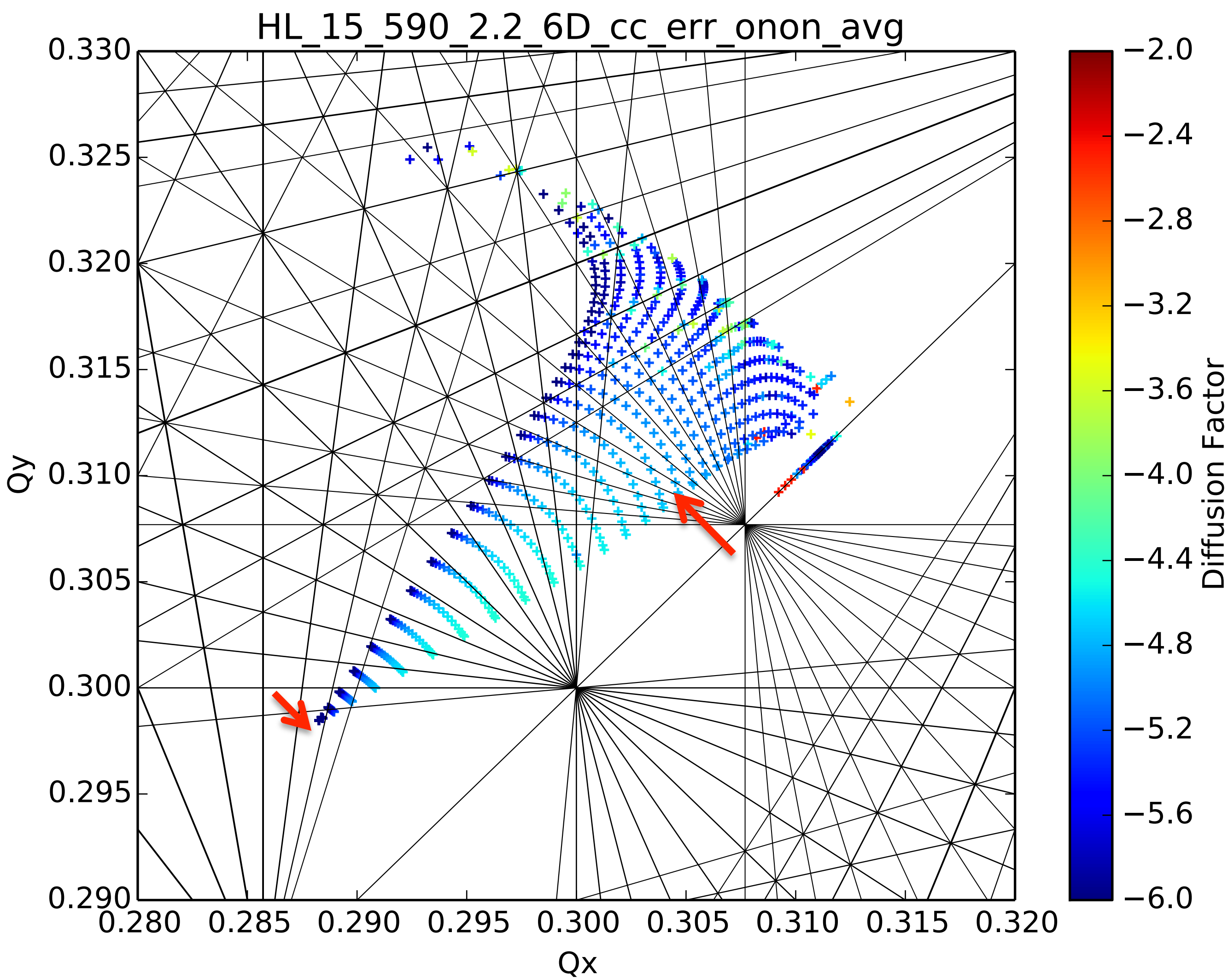
No Multipolar errors: 8sigma particles



STRONG BB

DA =6.4 σ

Multipolar errors: average seed 8 sigma particles



DA =6.4 σ

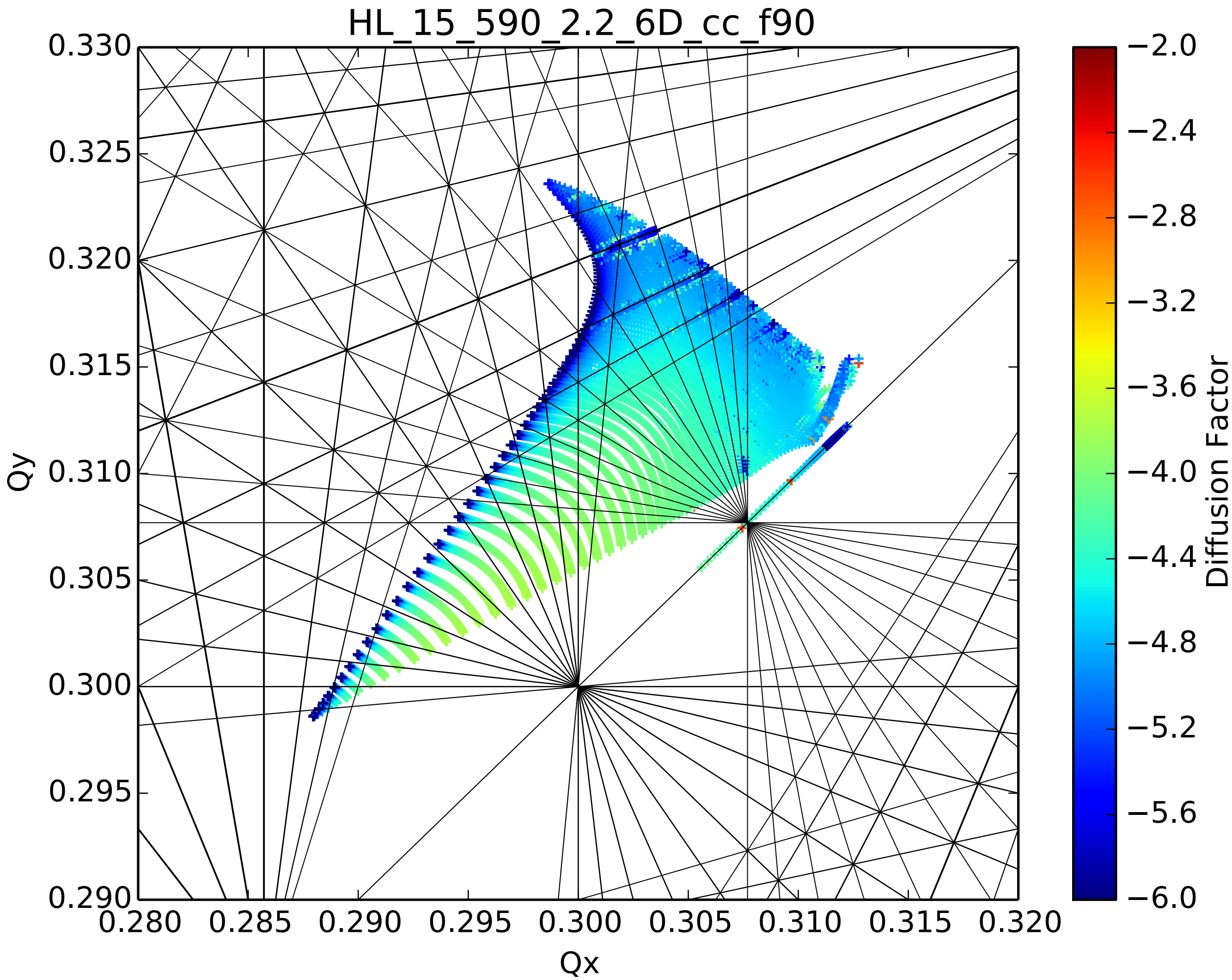
+0.3 σ

DA =6.7 σ

Average seeds improve DA

Reduced spread and small shift to the diagonal

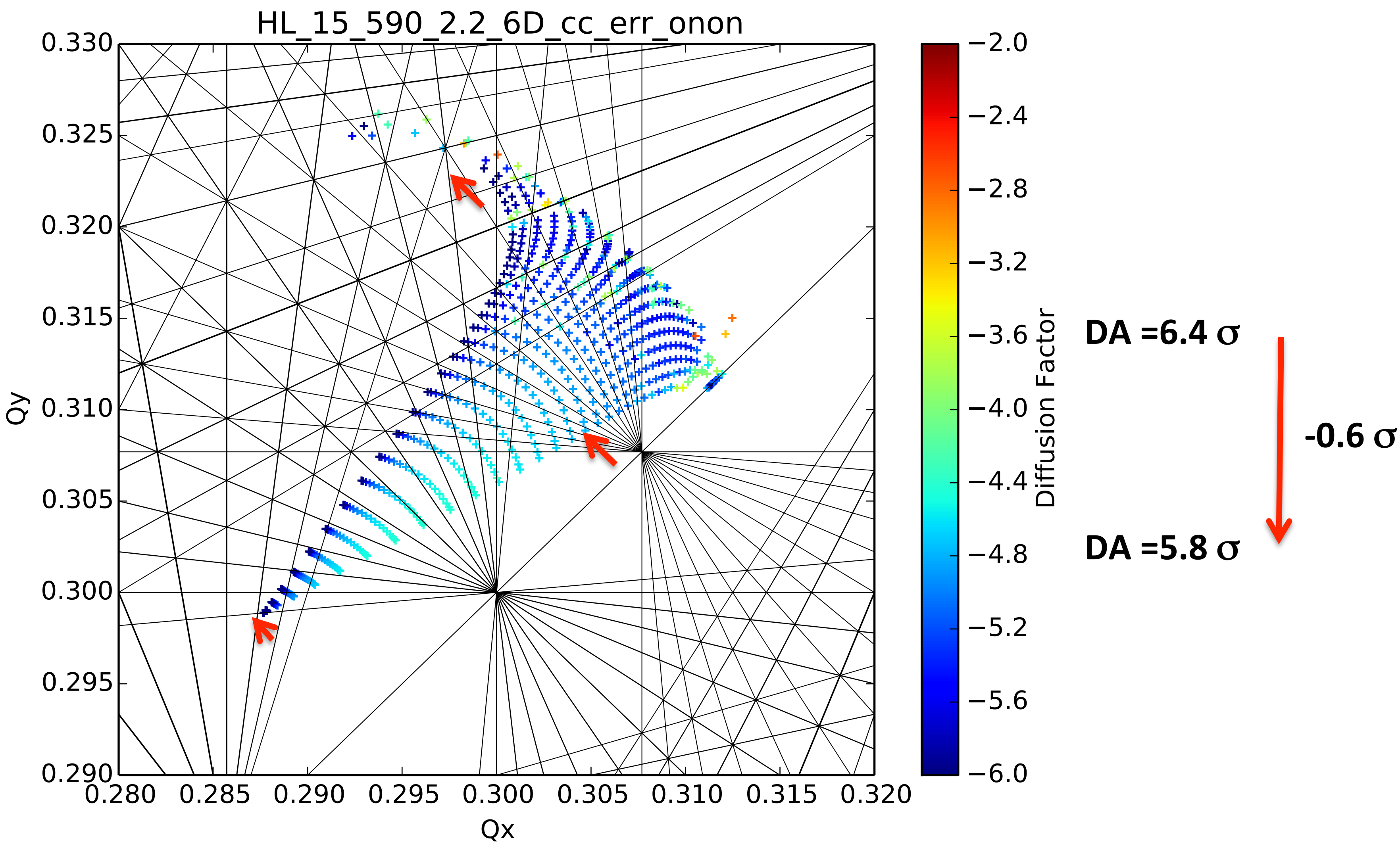
No Multipolar errors: 8sigma particles



DA =6.4 σ

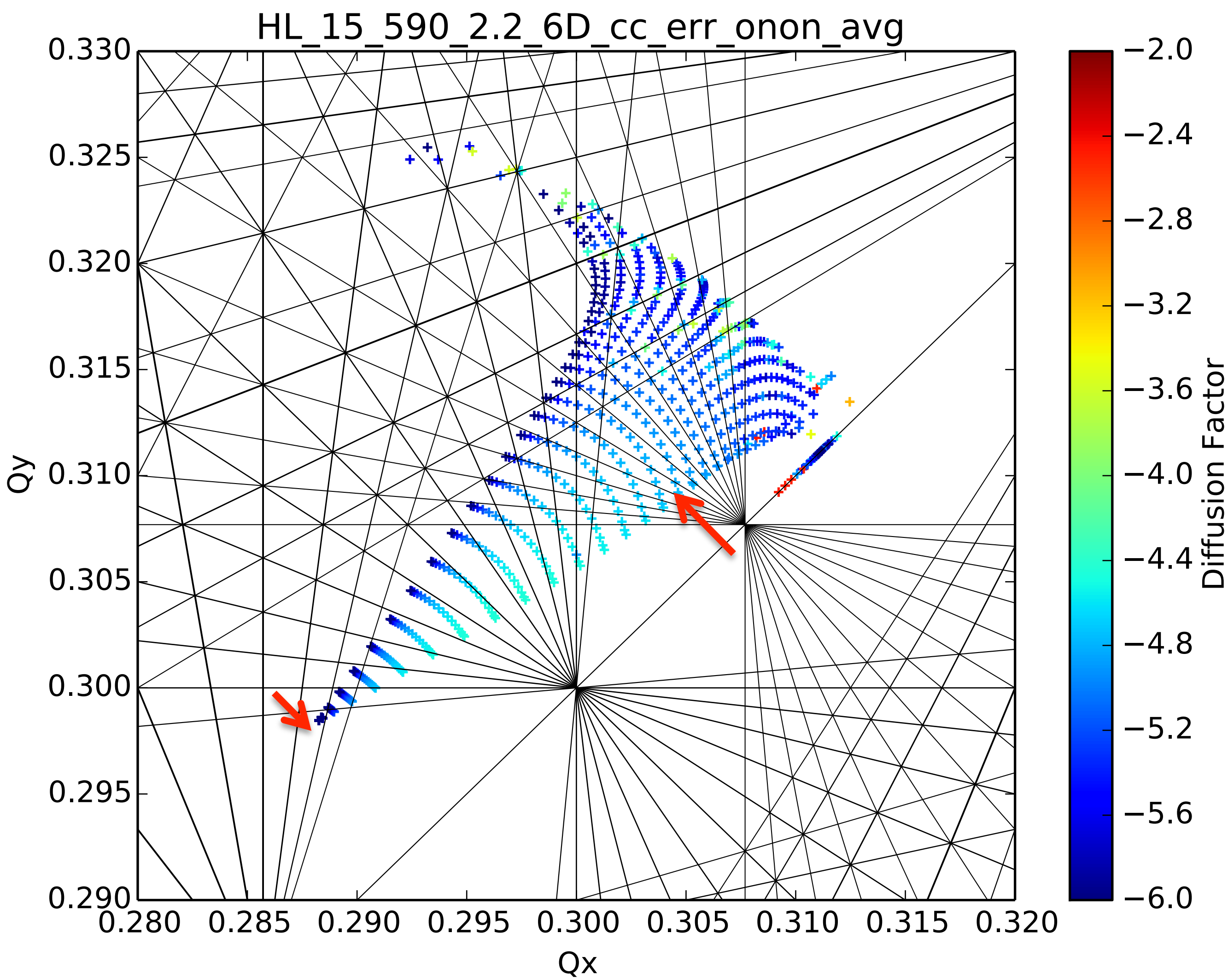
Errors do have an impact (1 σ reduction)
Driven by Inner Triplet element errors

Multipolar errors: minimum seed 8 sigma particles



Minima DA seeds reduces DA
Reduced spread and small shift away from the diagonal

Multipolar errors: average seed 8 sigma particles



DA =6.4 σ

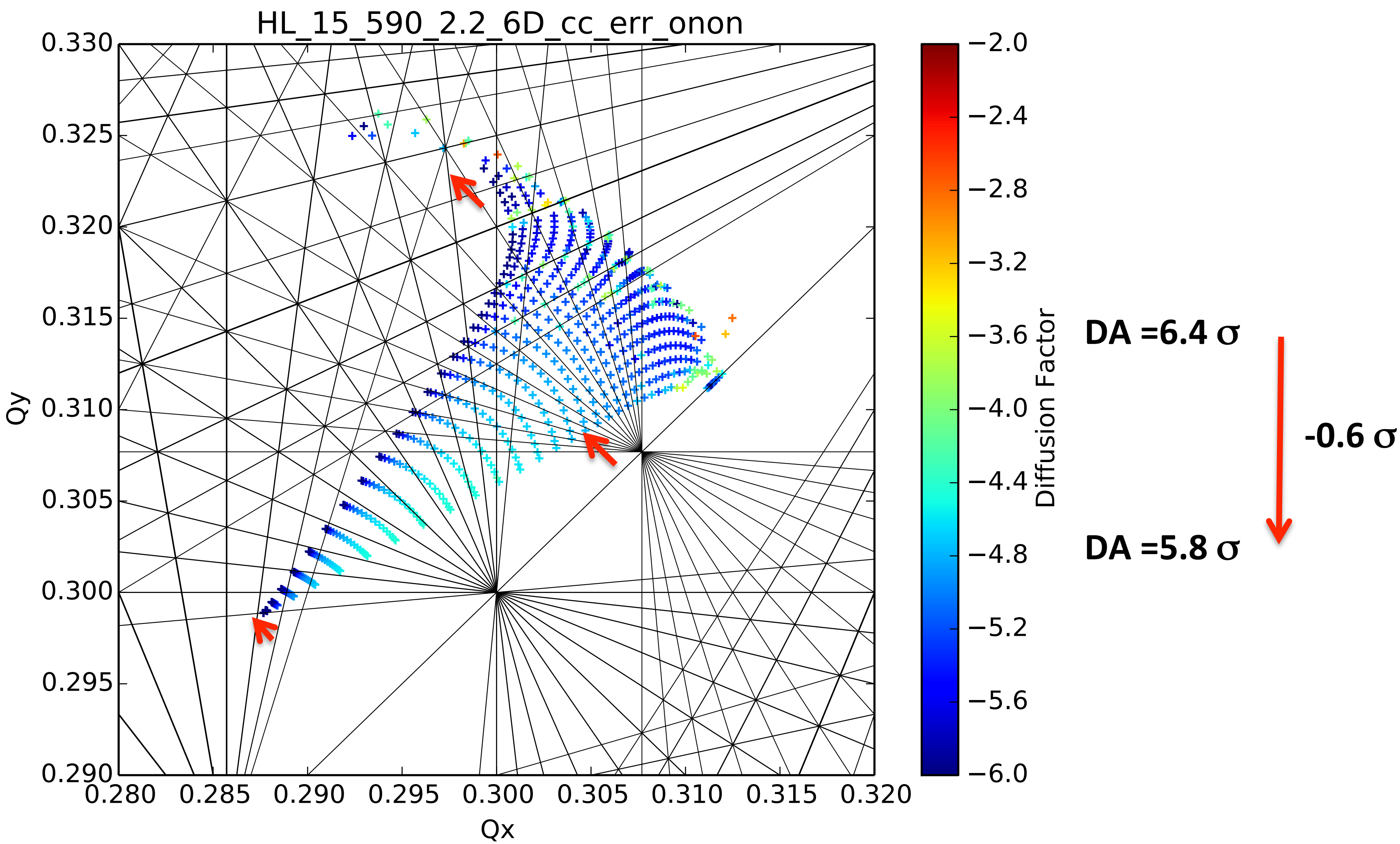
+0.3 σ

DA =6.7 σ

Average seeds improve DA

Reduced spread and small shift to the diagonal

Multipolar errors: minimum seed 8 sigma particles

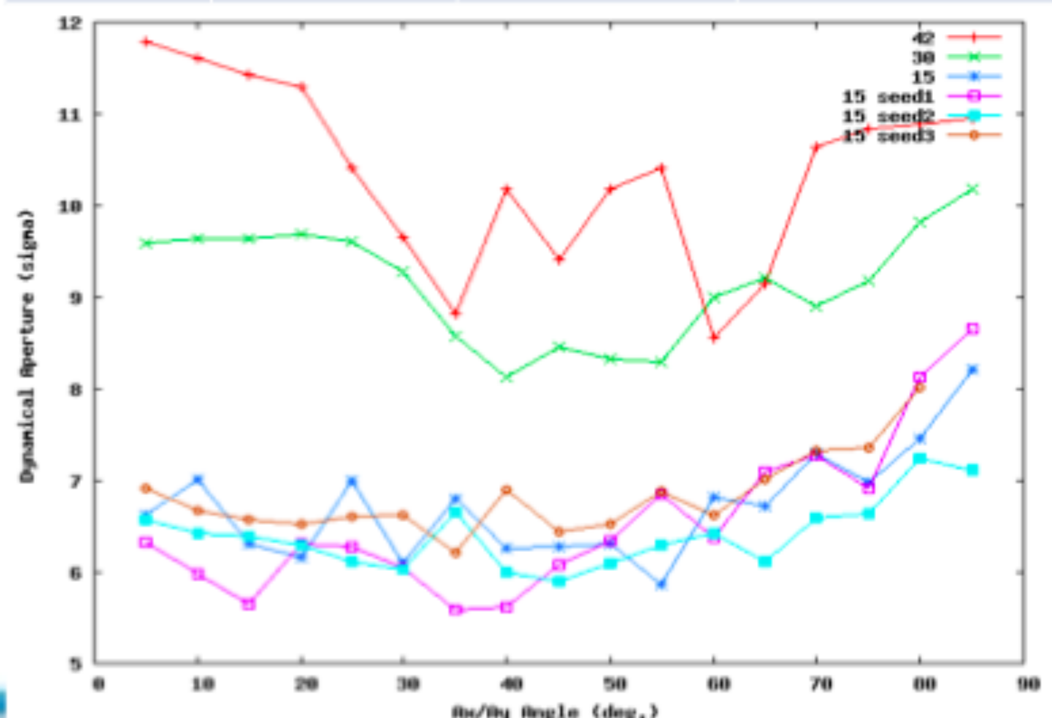


Minima DA seeds reduces DA
Larger spread and small shift away from the diagonal

A. Valishev results BB meeting 2014

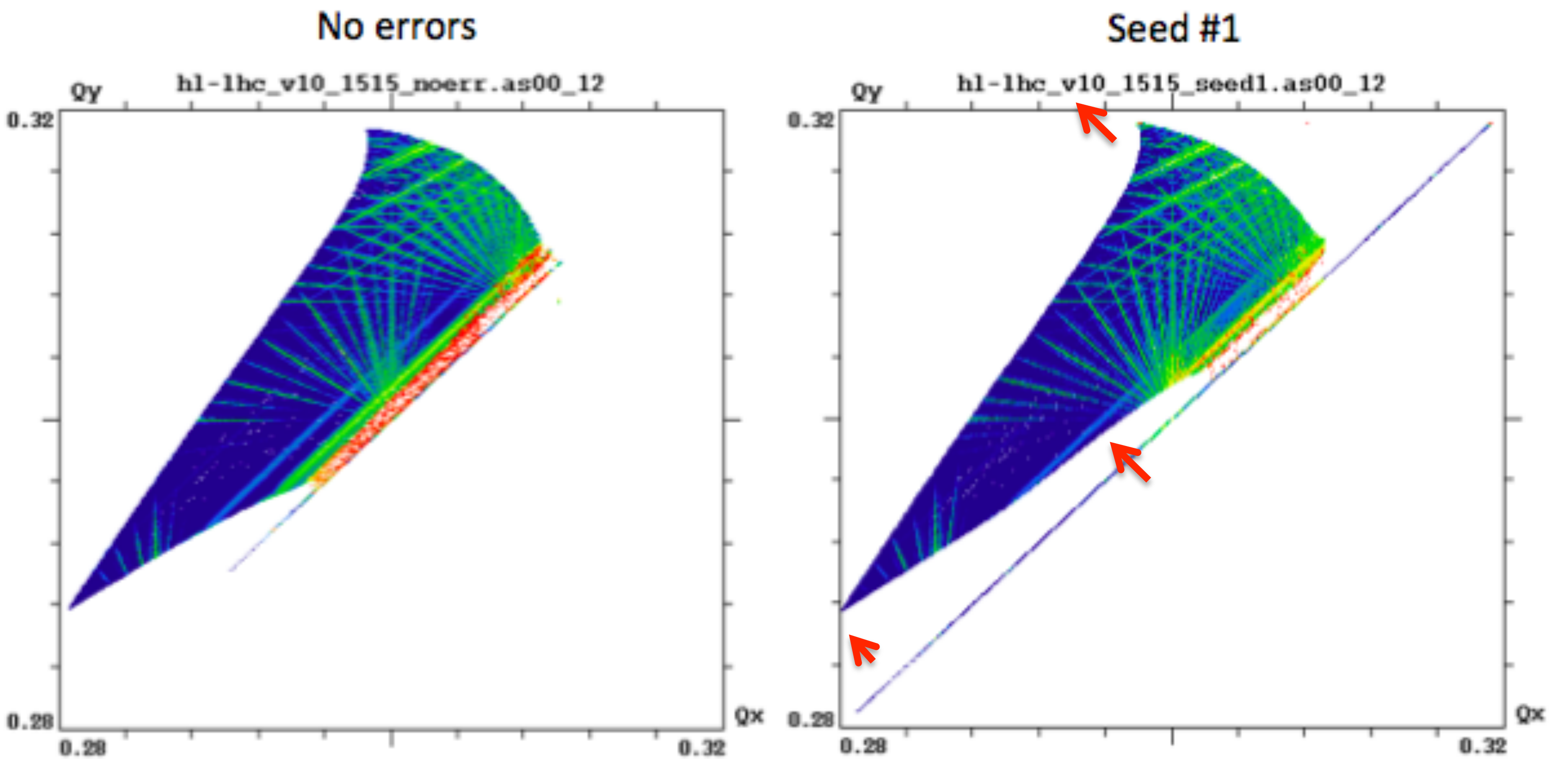
Ultimate intensity (extreme) case $N_p=2.2\times10^{11}$

X-angle=590 μrad (Vcc=12.5 MV)			
β^* (cm)	L (10^{34})	bb sep. (σ)	Min DA (σ)
70	5.1	23.6	–
42	8.5	20.7	8.5
30	11.8	17.6	8.1
15	22	12.5	5.8 (5.6 w/err)



A. Valishev results BB meeting 2014

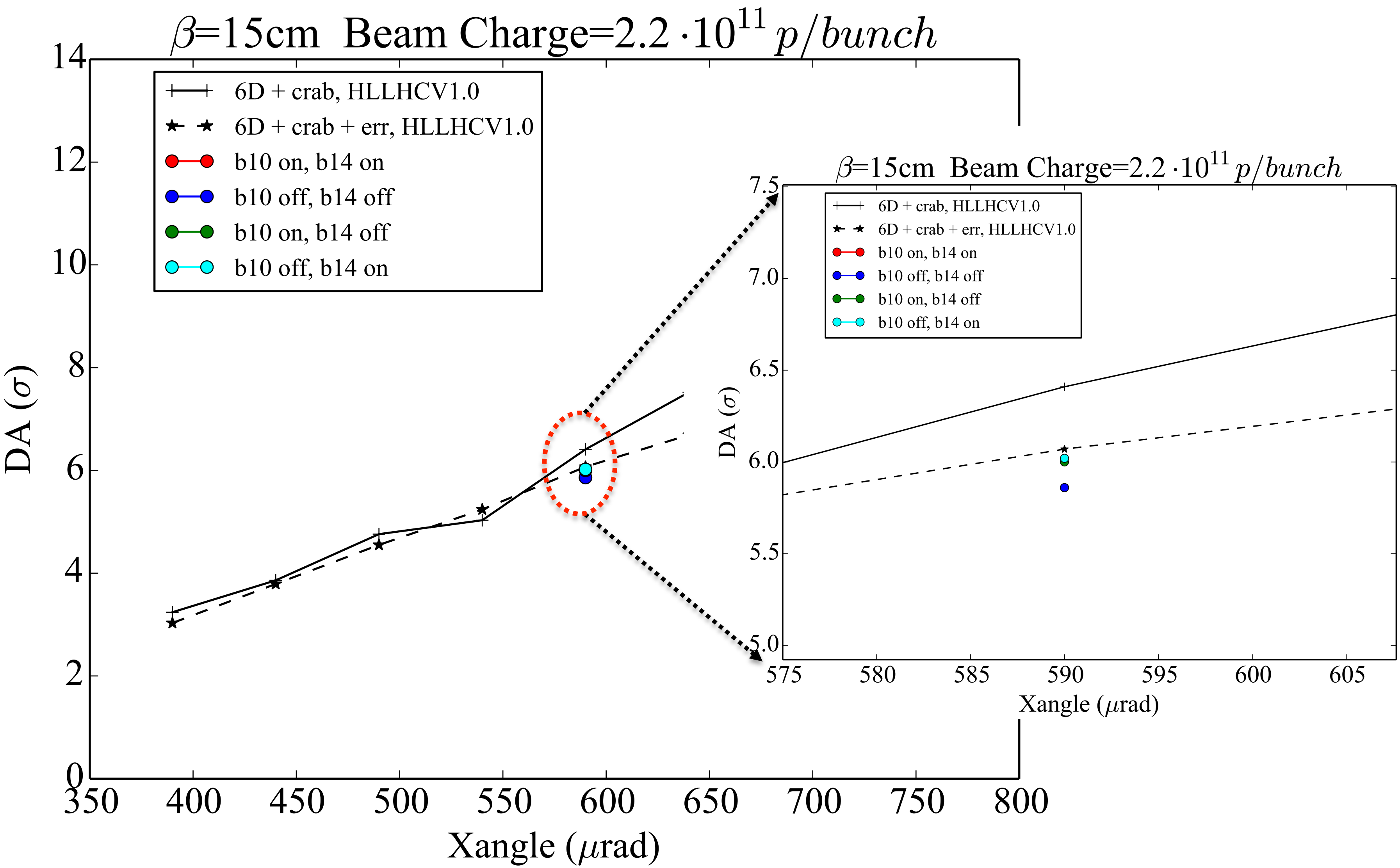
Ultimate intensity (extreme) case N_p=2.2×10^{11}



Similar effect from Lifetrac

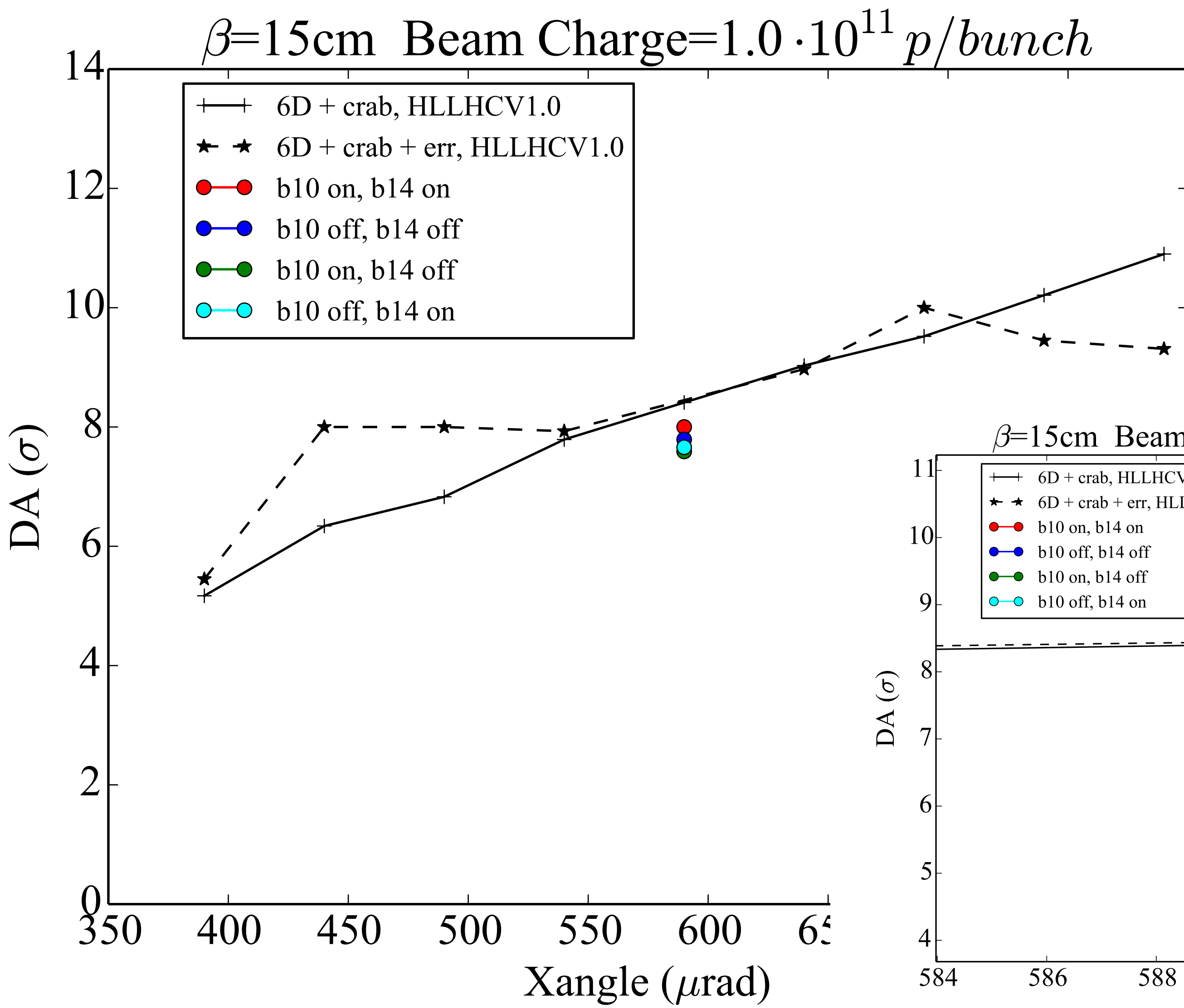
Differences respect to Sixtrack due to the IP8 LR and HO shift due to IP8

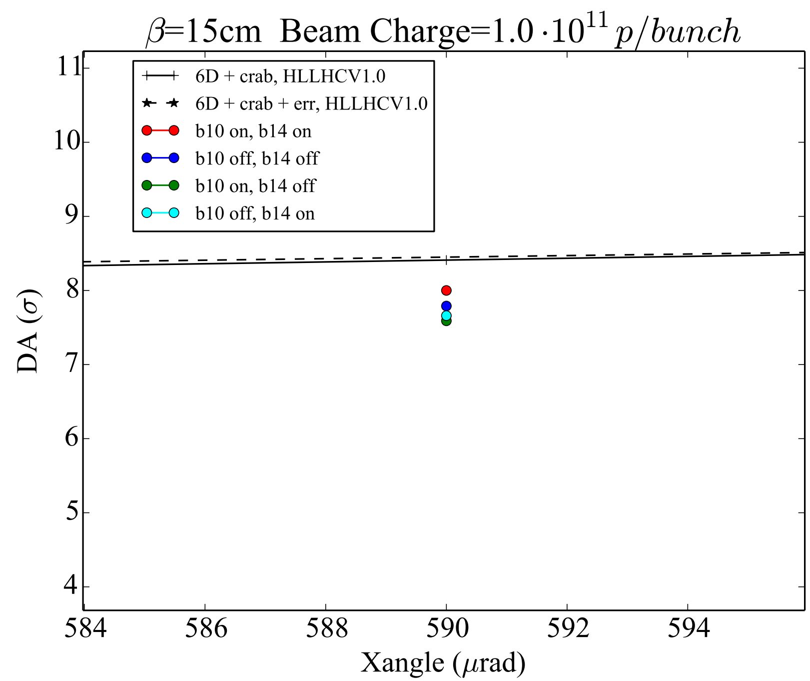
Multipolar errors single element impact:



B10 and b14 when off lower DA, in general small effect 0.2 σ !

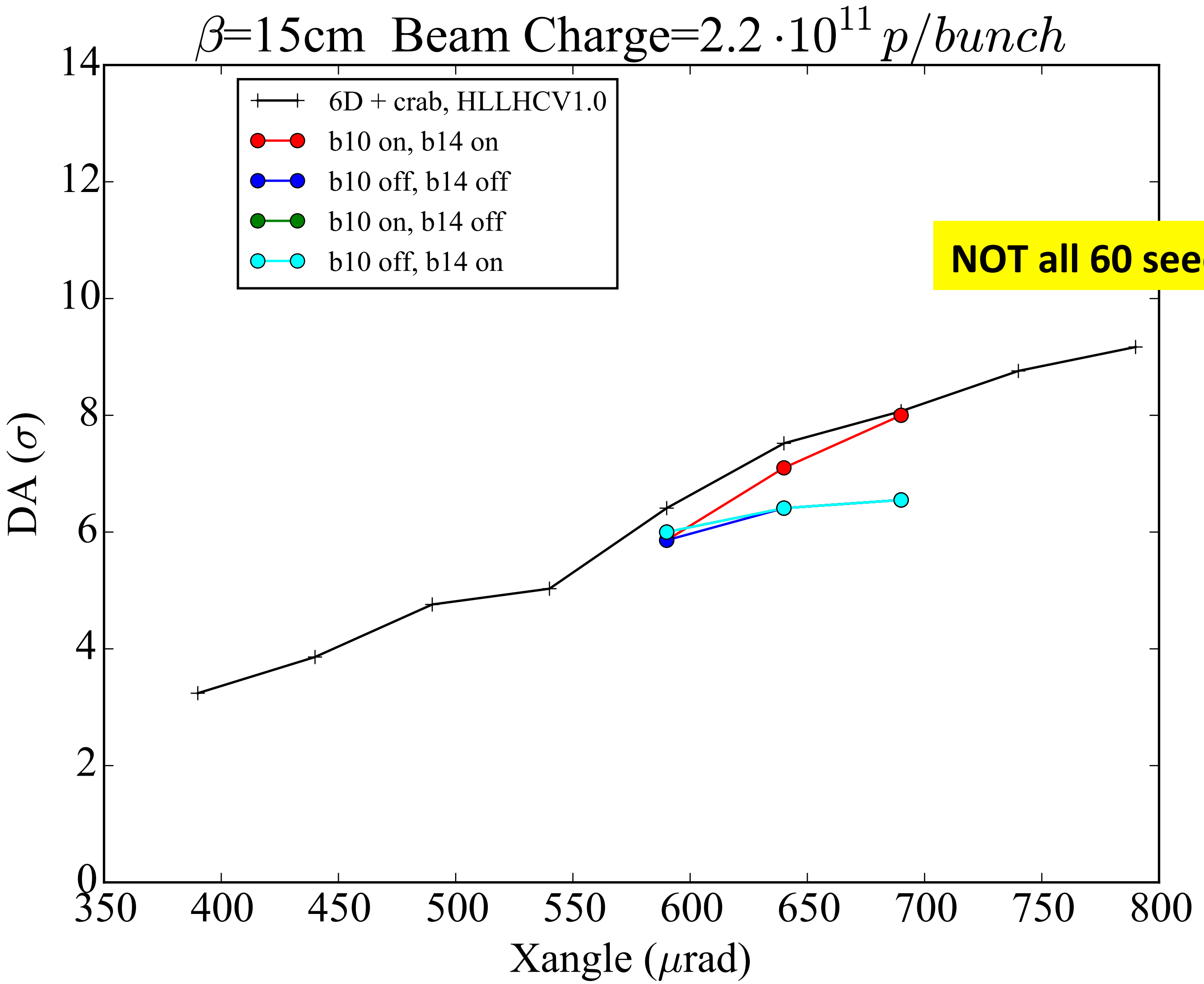
1e11 ppb x-ing angle scan





B10 and b14 when off lower DA, in general small effect 0.4 σ !

Multipolar errors larger angles

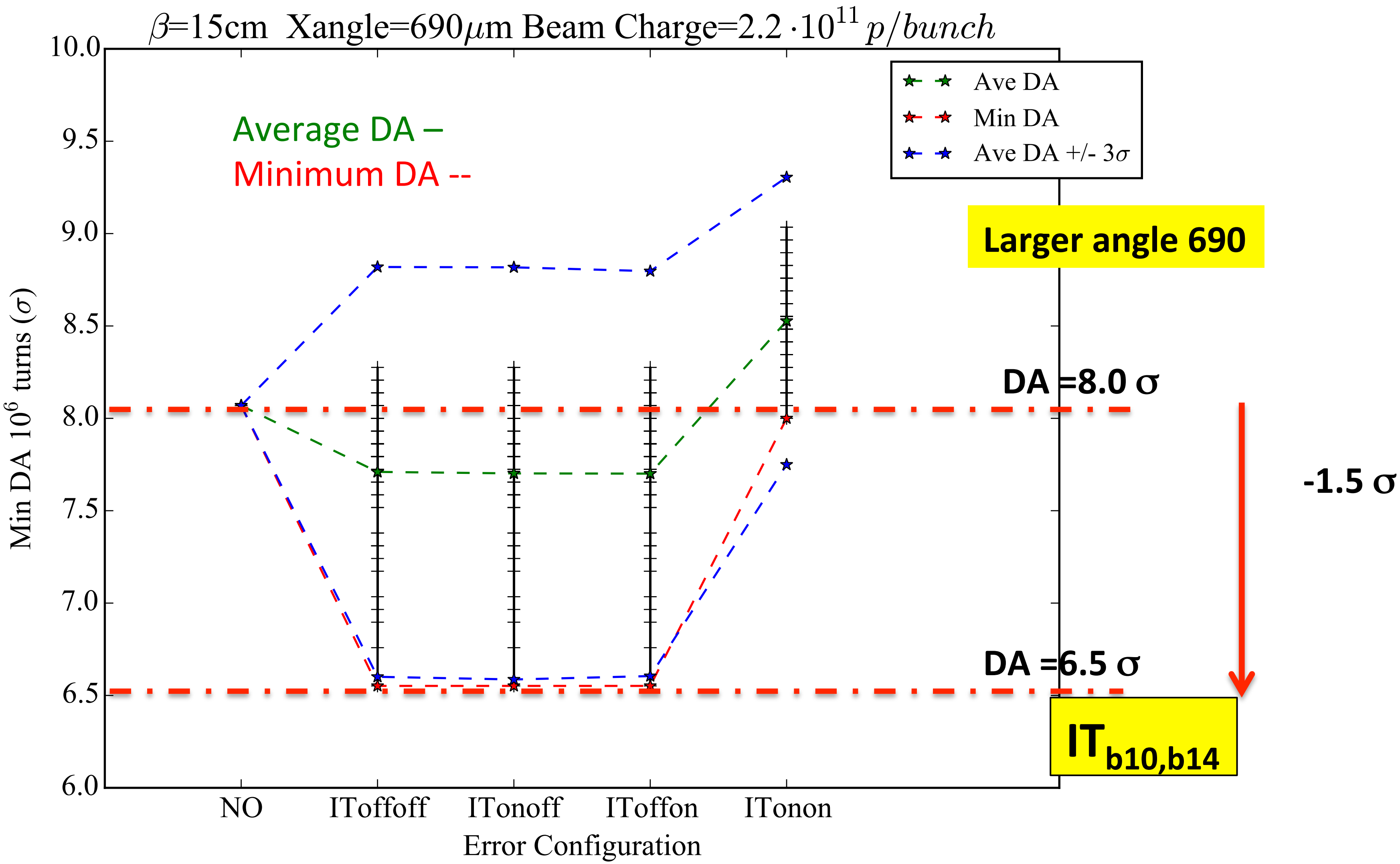


NOT all 60 seeds

B10 and b14 when off lower DA, in general small effect 0.2 σ !

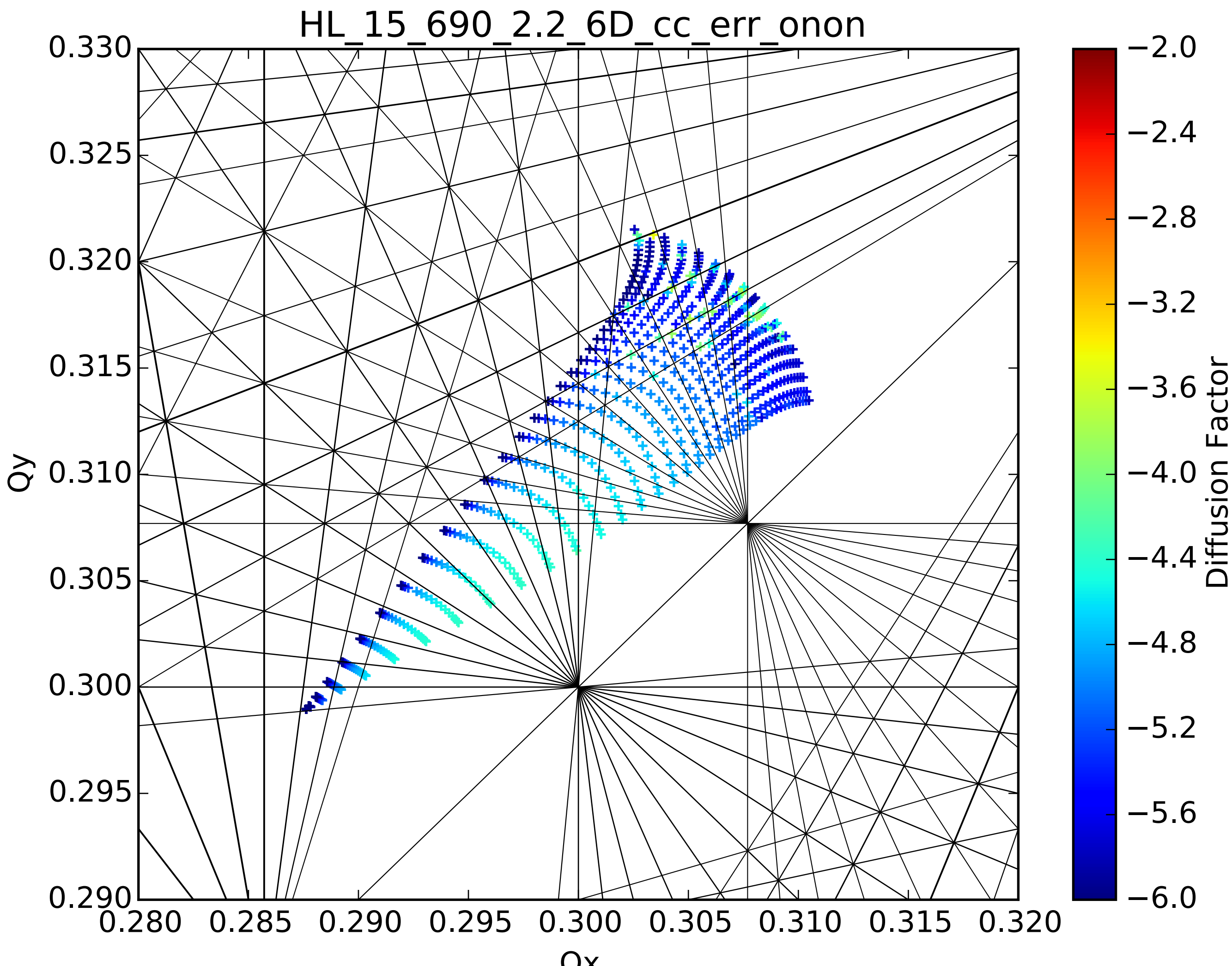
Multipolar errors: b10 and b14 in the IT: strong BB

NOT all seeds!



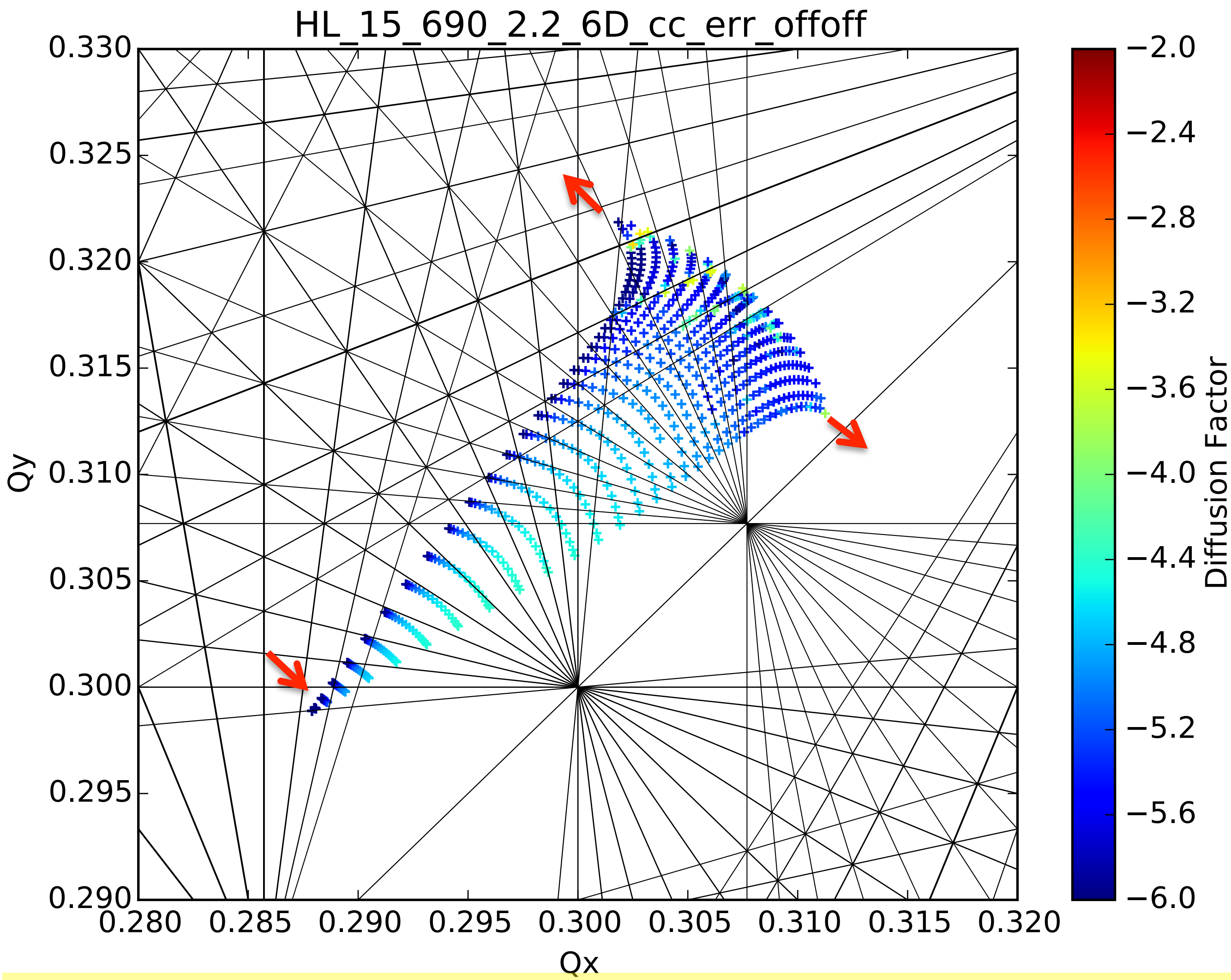
Similar behaviour!

Multipolar errors: b10 and b14 reduces the spread



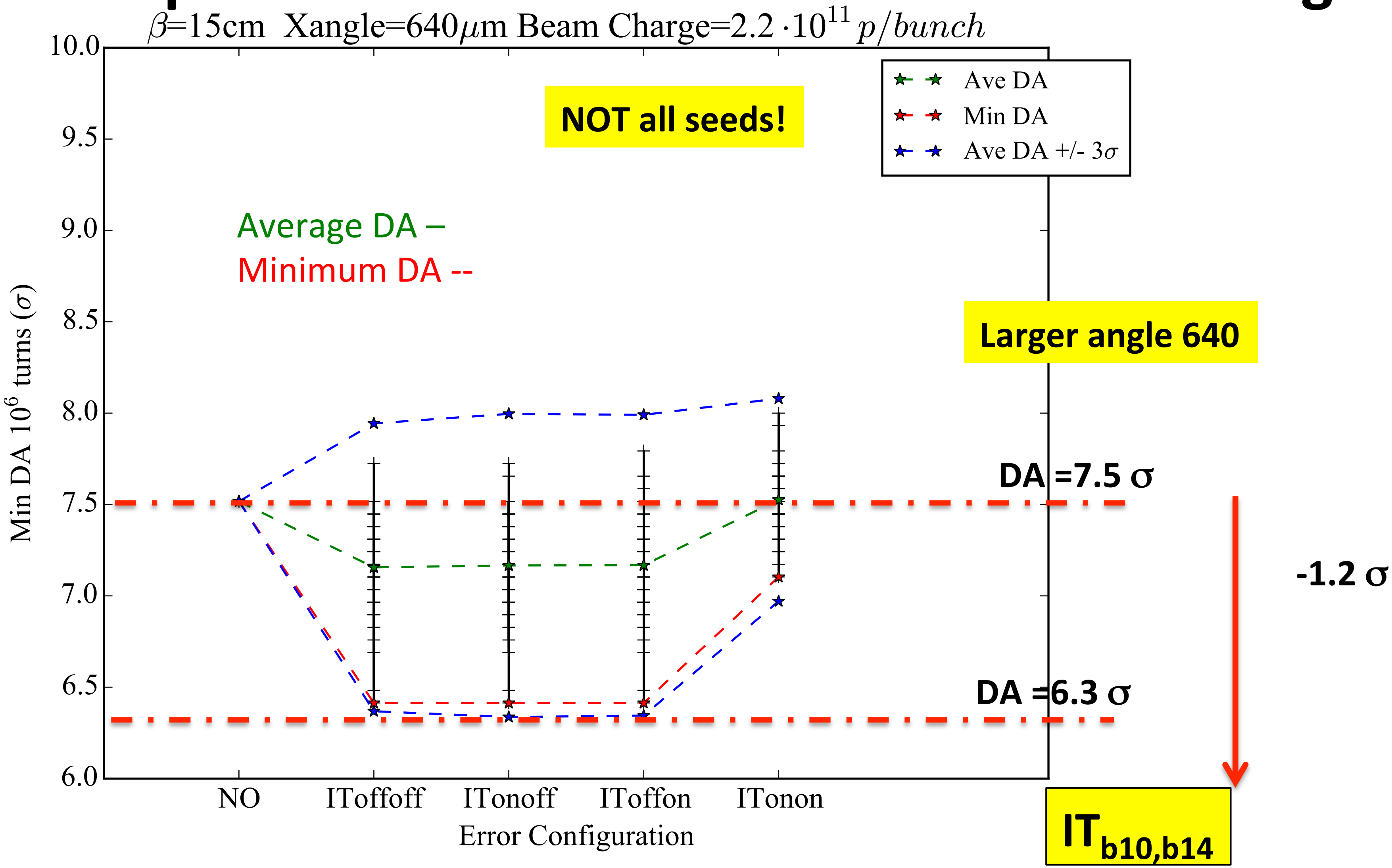
B10 and b14 might be compensating LR driven resonances!
Still need to wait for all seeds but similar behavior as for nominal parameters!

Multipolar errors: b10 and b14 offoff larger spread



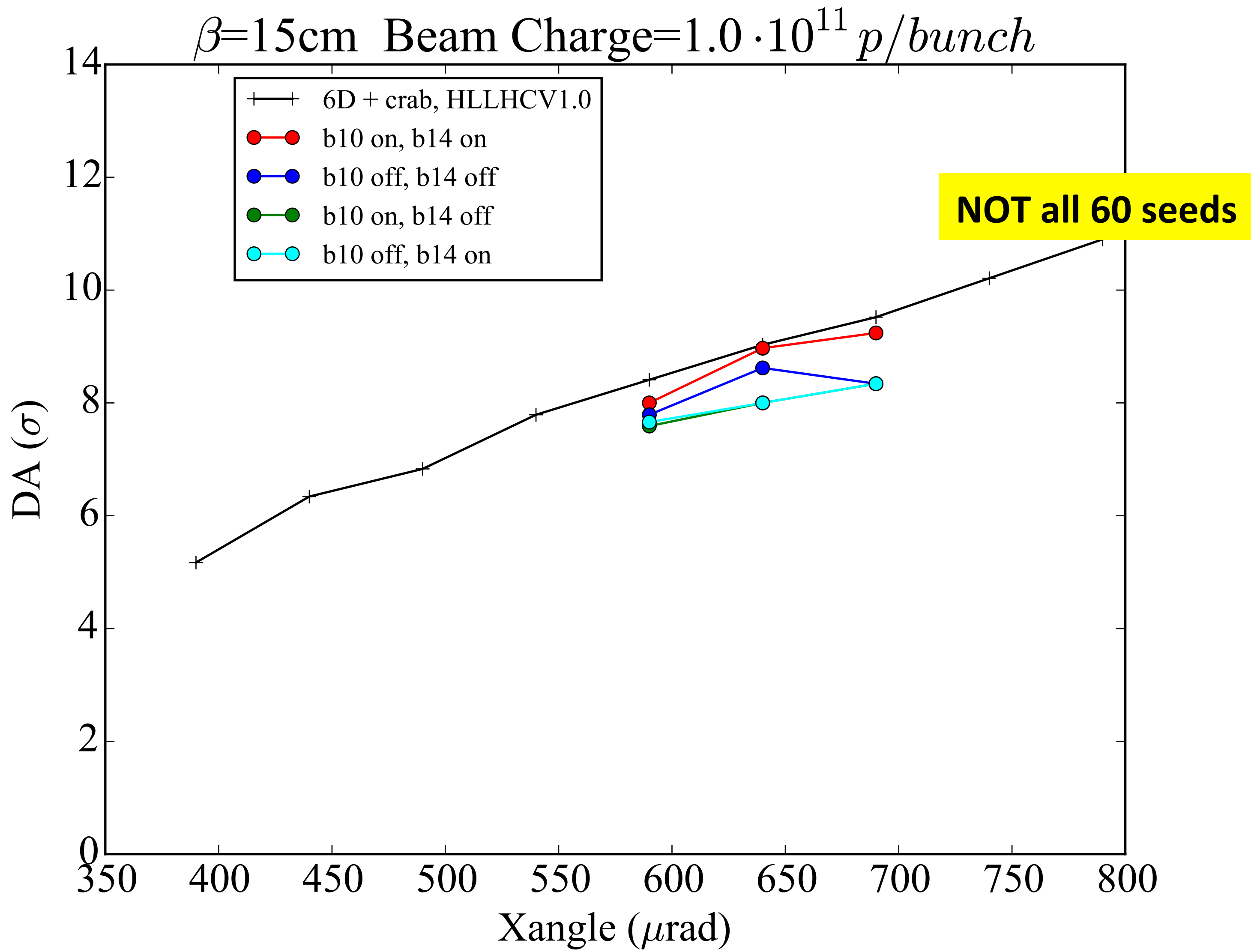
B10 and b14 might be compensating LR driven resonances!
Still need to wait for all seeds but similar behavior as for nominal parameters!

Multipolar errors: b10 and b14 in the IT: strong BB



Average DA improves with b_{10} b_{14}
Minimum DA criteria should reduce it….

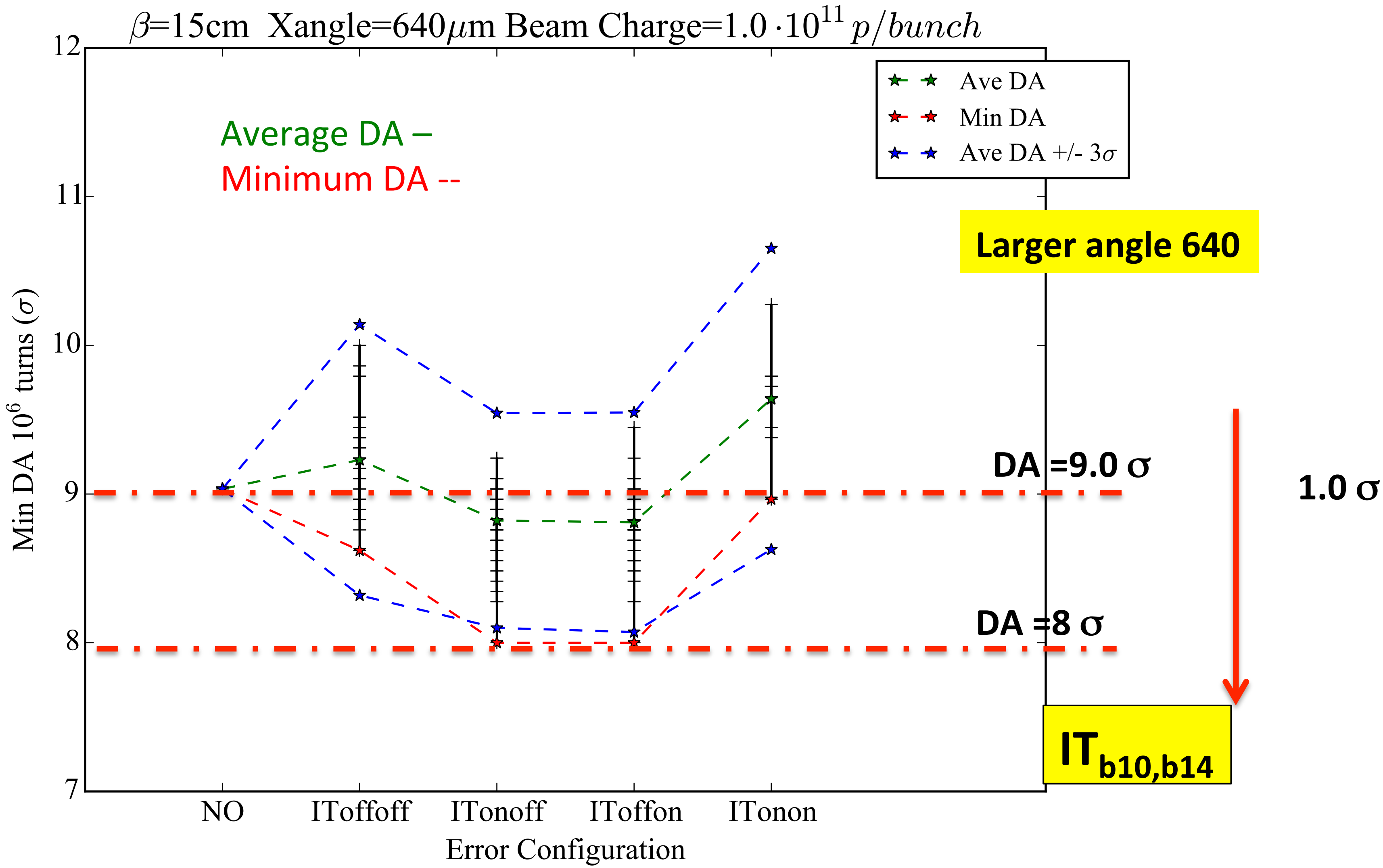
Multipolar errors larger angles



Similar trend!

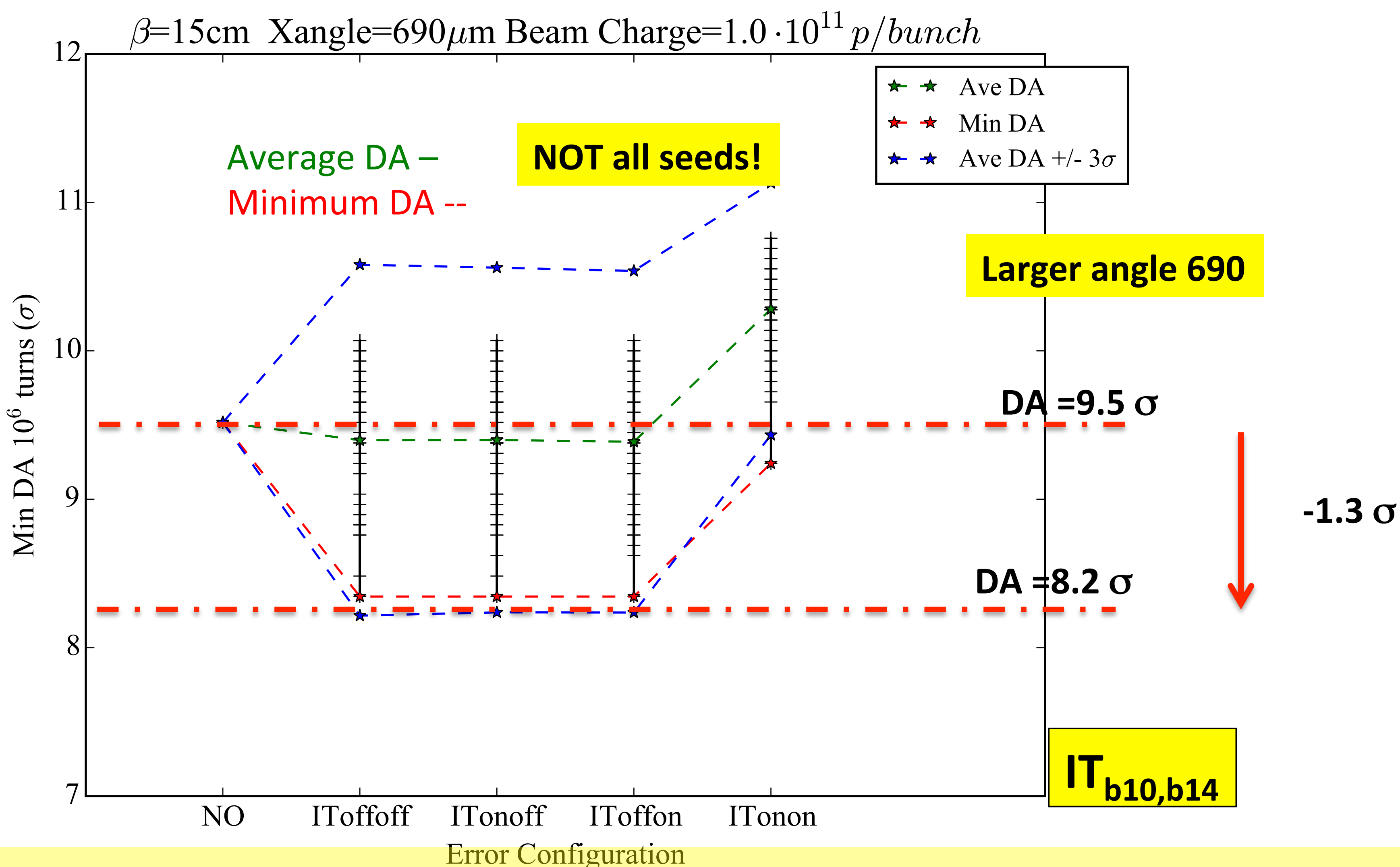
Multipolar errors: b10 and b14 in the IT: strong BB

NOT all seeds!



Average DA improves with b_{10} b_{14}

Multipolar errors: b10 and b14 in the IT: strong BB



Average DA improves with b_{10} b_{14}

Summary

- **At nominal crossing angle any BB fluctuations (intensity or emittances) 0.5/1 σ.**
  - Anything in 0.5 s range DA is in the shadow of BB (our error bar)

- **Errors** do have an impact and it is **dominated by Inner Triplet!**
  - **0.6-0.8 σ reduction in DA when BB weaker → can make us loose margins!**

- **For STRONG BB** →2.2e11 ppb
  - **ON/OFF Effects** on DA of maximum 0.2 σ → in **shadow of BB fluctuations**
  - **DA IMPROVES (+0.2σ) when these multipoles are ON:** this is due to a reduction of the tune spread and small shift in tune diagram → compensation of some LR driven resonances…
  - Minima DA criteria avoids relying on non controlled compensations
  - **Need to analyze the other multipoles dependency** to identify which multipole or combination of them can change in a relevant way the DA with BB changes above 0.5 σ

- **For WEAK BB**→1.0e11 similar behaviour
  - The improve of minima DA **(0.1 σ)** when these multipoles are on is due to a reduction of the tune spread and small shift in tune diagram.

Summary

- **Lifetrac with errors**→for different condition (IP8 + all errors on)
  - **Reduction of spread: more pronounced due to the larger spread (IP8 on) and shift (IP8 LR on)**
  - **No reduction of DA but might be due to seed**

- **At larger angles** → 2.2e11 and 1e11 ppb similar bahavior!
  - **Still collecting all seeds**
  - But similar Behavior observed
  - Reduction of spread when b10 and b14 ON

- **IMPORTANT:** next steps…
  - identify which multipole is dominating …b6?
  - Random components of other multipoles?

Round optics - Simulation Details

optics files:

SLHC optics:

/afs/cern.ch/eng/lhc/optics/SLHCV3.1b/opt_0400_0400thin.madx beta*=40cm in IR1/5, beta*=10 m in IR2/8
/afs/cern.ch/eng/lhc/optics/SLHCV3.1b/opt_0330_0330thin.madx beta*=33cm in IR1/5, beta*=10 m in IR2/8
/afs/cern.ch/eng/lhc/optics/SLHCV3.1b/opt_0150_0150thin.madx beta*=15cm in IR1/5, beta*=10 m in IR2/8
/afs/cern.ch/eng/lhc/optics/SLHCV3.1b/opt_0100_0100thin.madx beta*=10cm in IR1/5, beta*=10 m in IR2/8

HLLHC optics:

/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/opt_round_thin.madx

error tables:

error study:

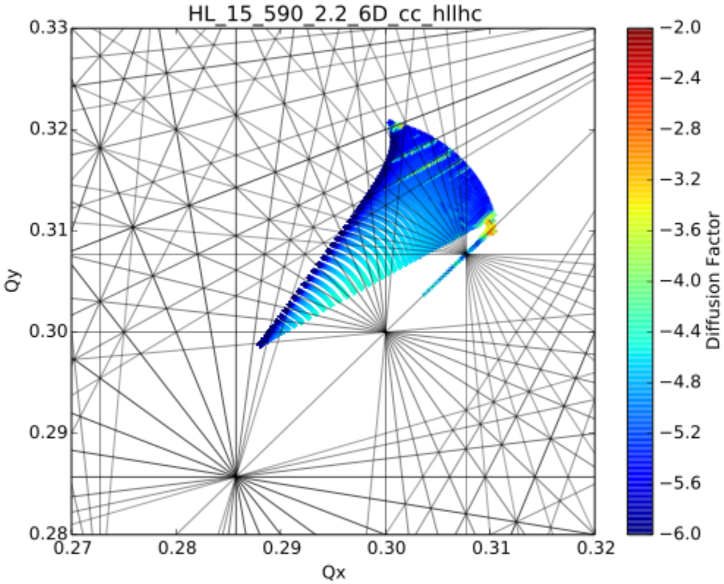
/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/errors/IT_errortable_v3_spec";! target error table for the new IT
/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/errors/D1_errortable_v1_spec";! target error table for the new D1
/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/errors/D2_errortable_v5_spec ";! target error table for the new D2
/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/errors/Q4_errortable_v1_spec";! target error table for the new Q4 in IR1 and IR5
/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/errors/Q5_errortable_v0_spec";! target error table for the new Q5 in IR1 &IR5 & IR6

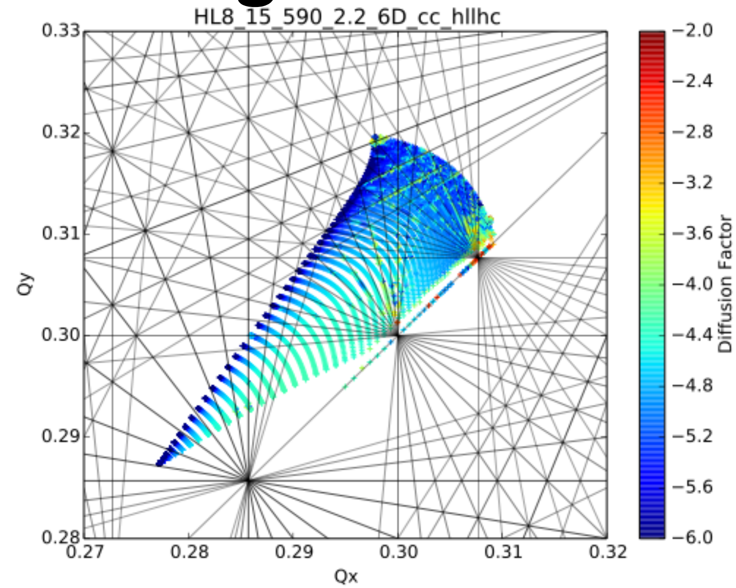
b_{10} b_{14} studies

call,file="/slhc/IT_errortable_v66_4";! target error table for the new IT
call,file="slhc/errors/D1_errortable_v1_spec";! target error table for the new D1
call,file="slhc/errors/D2_errortable_v5_spec";! target error table for the new D2
call,file="slhc/errors/Q4_errortable_v1_spec";! target error table for the new Q4 in IR1 and IR5
call,file="slhc/errors/Q5_errortable_v0_spec";!

Back up slides

What do we need these margins for?



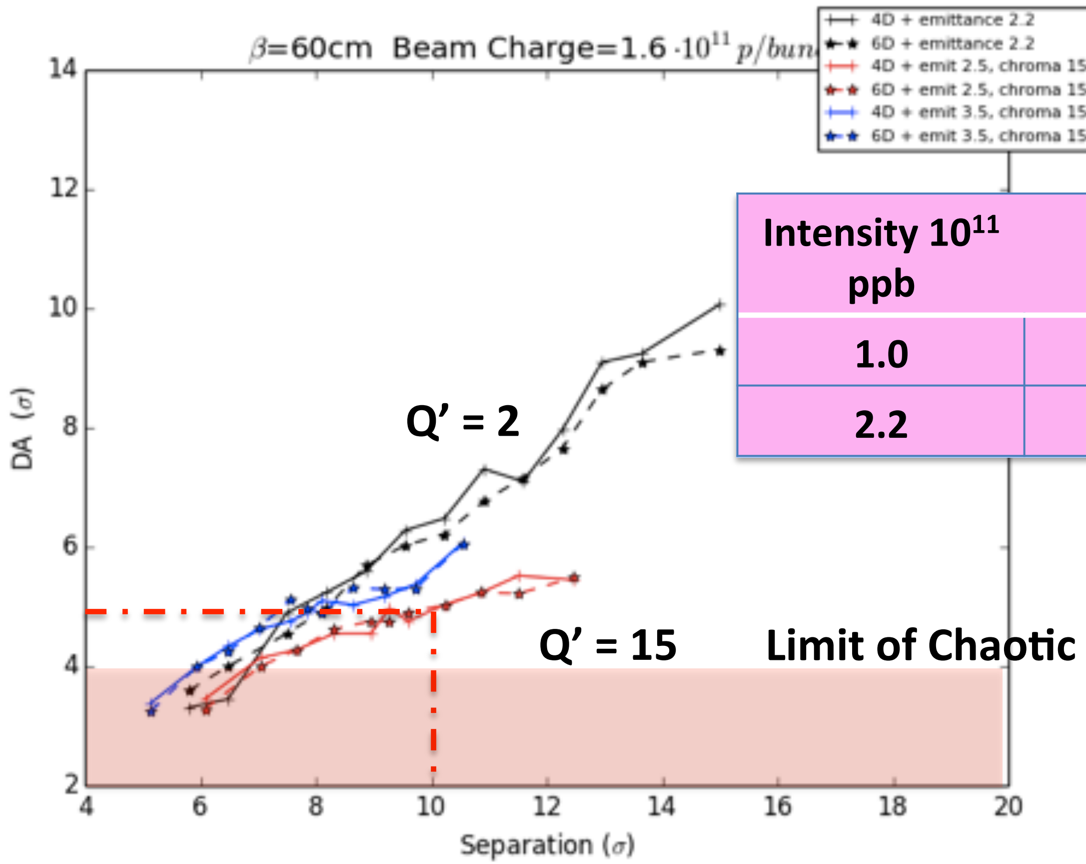


Intensity 10^{11} ppb	IP1&5	IP8 (-340mrad ext x-angle -270μrad septrometer)	IP8 (-560μrad ext x-angle + 270μrad spectrometer)	IP8 (-340μrad +270μrad spectrometer)
1.0	8.41	8.07	7.93	7.72
2.2	6.42	6.28	6.06	5.86

→ **ΔDA = -0.5 σ**

We optimize the scenarios to put IP8 (LHCb) in the shadow of the two main IP1&5 (ATLAS and CMS) but they do take part of the margins!
Then IP2 (ALICE)…. Something else?...

What do we need these margins for?



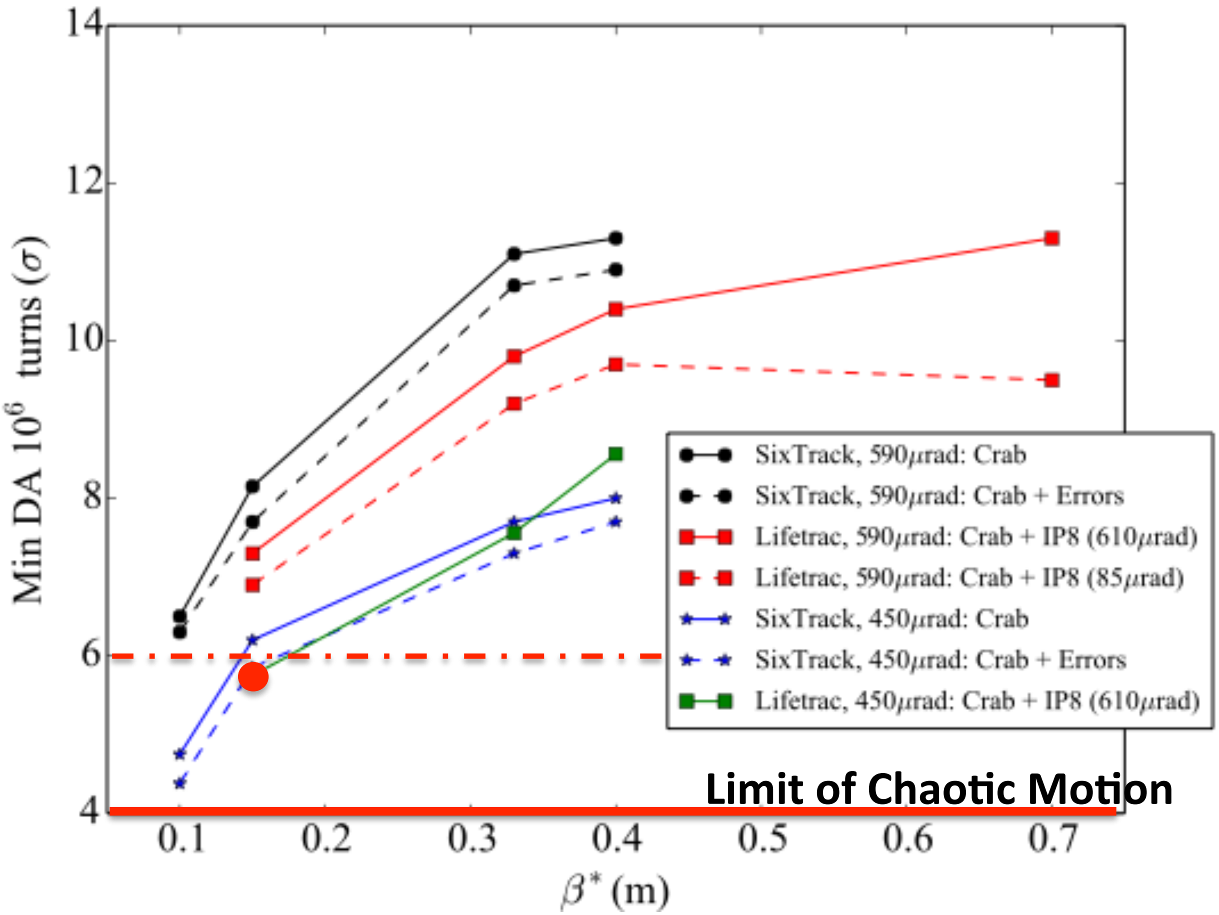
Intensity 10^{11} ppb	IP1&5&8 Q'=2	IP1&5&8(-) Q'=15	IP1&5&8(+) Q'=15
1.0	7.72	6.48	4.83
2.2	5.86	4.83	4.76

CHROMATICITY HAS A VERY STRONG IMPACT!

If for any reason we need to use high chroma (i.e. stability in collision) then no margins! Have we seen this in 2012? Yes!

With high chroma integrated lumi per fill much smaller despite higher brightness

No β* leveling



Extreme case

IP1&5	6
Mult Errors	-0.5
IP8	-0.6
Chroma	-2
IP2	-0.2
Octupoles	?
=================	
Total DA	3…

Extreme case NO β* leveling needs to be guaranteed! DA is below 6 σ → Fundamental to keep all contributions at MINIMUM (Multipolar Errors, other IPs)

Round optics - Simulation Details

optics files:

SLHC optics:

/afs/cern.ch/eng/lhc/optics/SLHCV3.1b/opt_0400_0400thin.madx beta*=40cm in IR1/5, beta*=10 m in IR2/8
/afs/cern.ch/eng/lhc/optics/SLHCV3.1b/opt_0330_0330thin.madx beta*=33cm in IR1/5, beta*=10 m in IR2/8
/afs/cern.ch/eng/lhc/optics/SLHCV3.1b/opt_0150_0150thin.madx beta*=15cm in IR1/5, beta*=10 m in IR2/8
/afs/cern.ch/eng/lhc/optics/SLHCV3.1b/opt_0100_0100thin.madx beta*=10cm in IR1/5, beta*=10 m in IR2/8

HLLHC optics:

/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/opt_round_thin.madx

error tables:

for old simulations:

/afs/cern.ch/eng/lhc/optics/SLHCV3.1b/errors/IT_errortable_v3 target error table for the new IT
/afs/cern.ch/eng/lhc/optics/SLHCV3.1b/errors/D1_errortable_v1 target error table for the new D1
/afs/cern.ch/eng/lhc/optics/SLHCV3.1b/errors/D2_errortable_v1 target error table for the new D2
/afs/cern.ch/eng/lhc/optics/SLHCV3.1b/errors/Q4_errortable_v1 target error table for the new Q4 in IR1 and IR5
/afs/cern.ch/eng/lhc/optics/SLHCV3.1b/errors/Q5_errortable_v0 target error table for the new Q5 in IR1 and IR5 and IR6

new error study:

/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/errors/IT_errortable_v3_spec";! target error table for the new IT
/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/errors/D1_errortable_v1_spec";! target error table for the new D1
/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/errors/D2_errortable_v5_spec ";! target error table for the new D2
/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/errors/Q4_errortable_v1_spec";! target error table for the new Q4 in IR1 and IR5
/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/errors/Q5_errortable_v0_spec";! target error table for the new Q5 in IR1 &IR5 & IR6