Dynamic Aperture: Field quality requirements update including beam-beam effects

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USLARP – HiLumi Collaboration Meeting 11th May 2015, Fermilab

Outline

- **HL-LHC scenarios in the presence of Beam-beam Effects**
- **Effect of multipolar errors element by element**
- **Effect of the Inner Triplet Errors b10 and b14 on BB**
  - **General Observations**
  - **Average versus Minima Dynamic Aperture**
  - **Compensation effects**
- **Summary**

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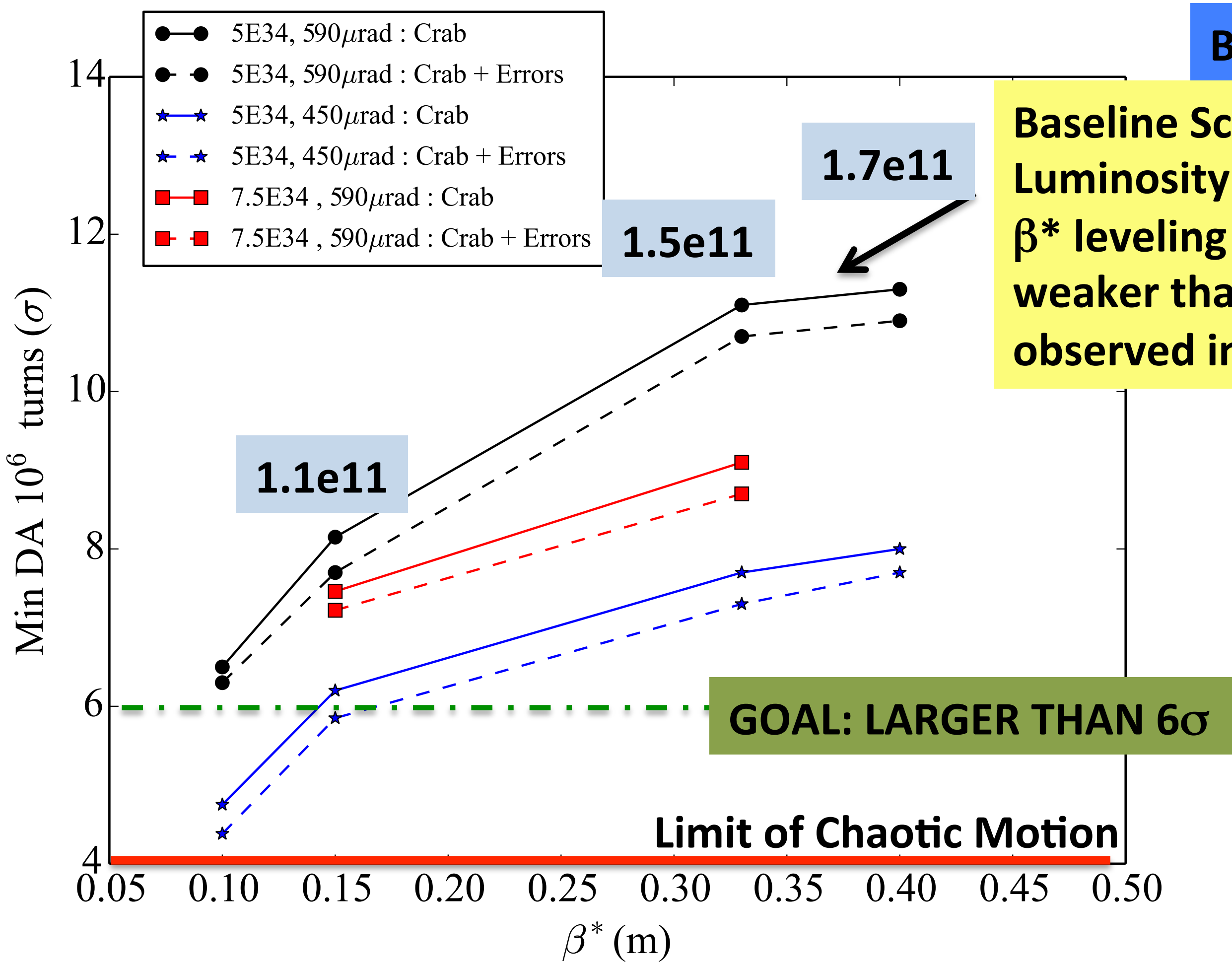
The beauty of β* leveling: Dynamic Aperture



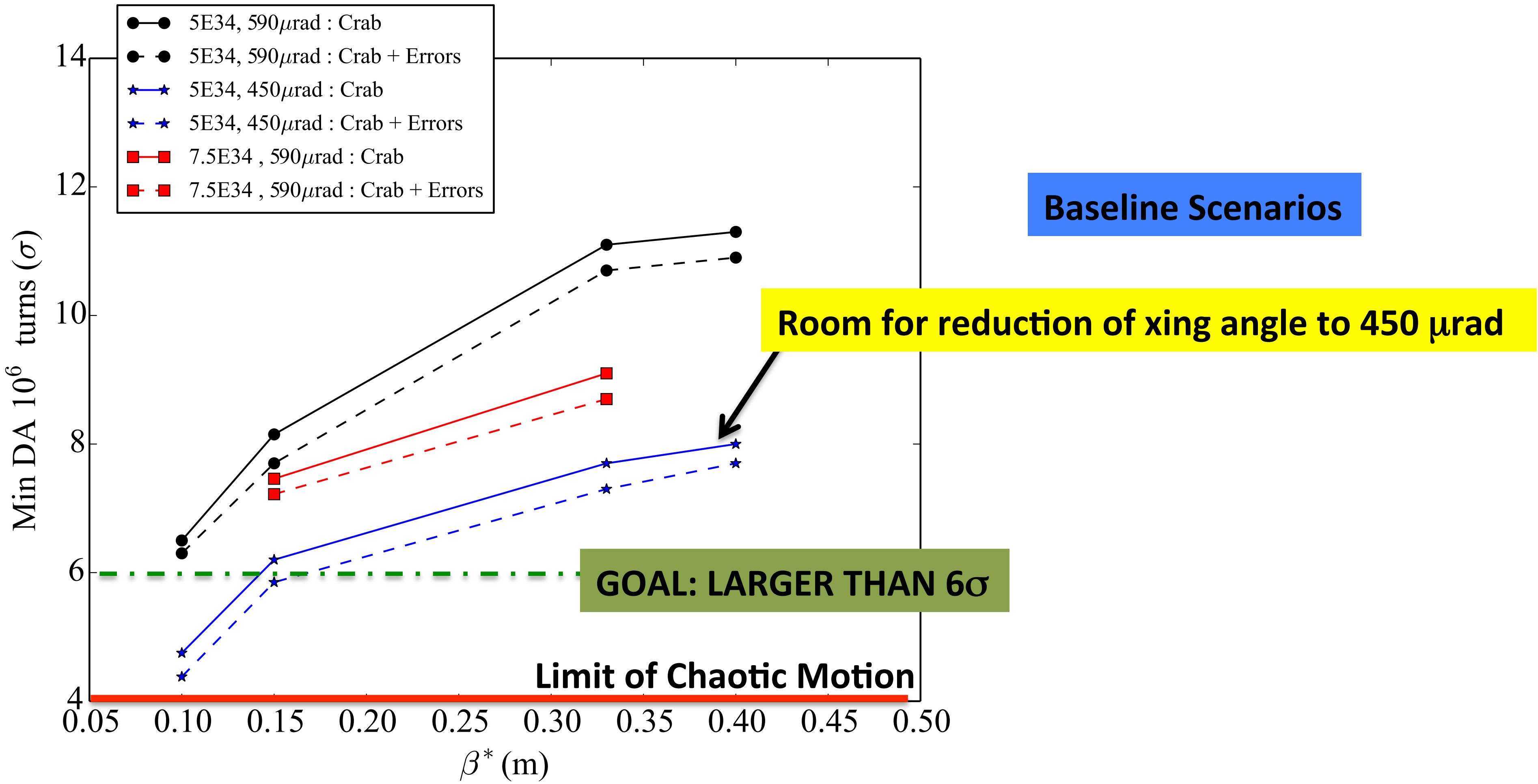
Baseline Scenarios

Baseline Scenario 5e34 leveled Luminosity 590 μrad xing angle
β* leveling → beam-beam long-range weaker than nominal LHC and what observed in 2012 RUNI

See E. Metral talk tomorrow

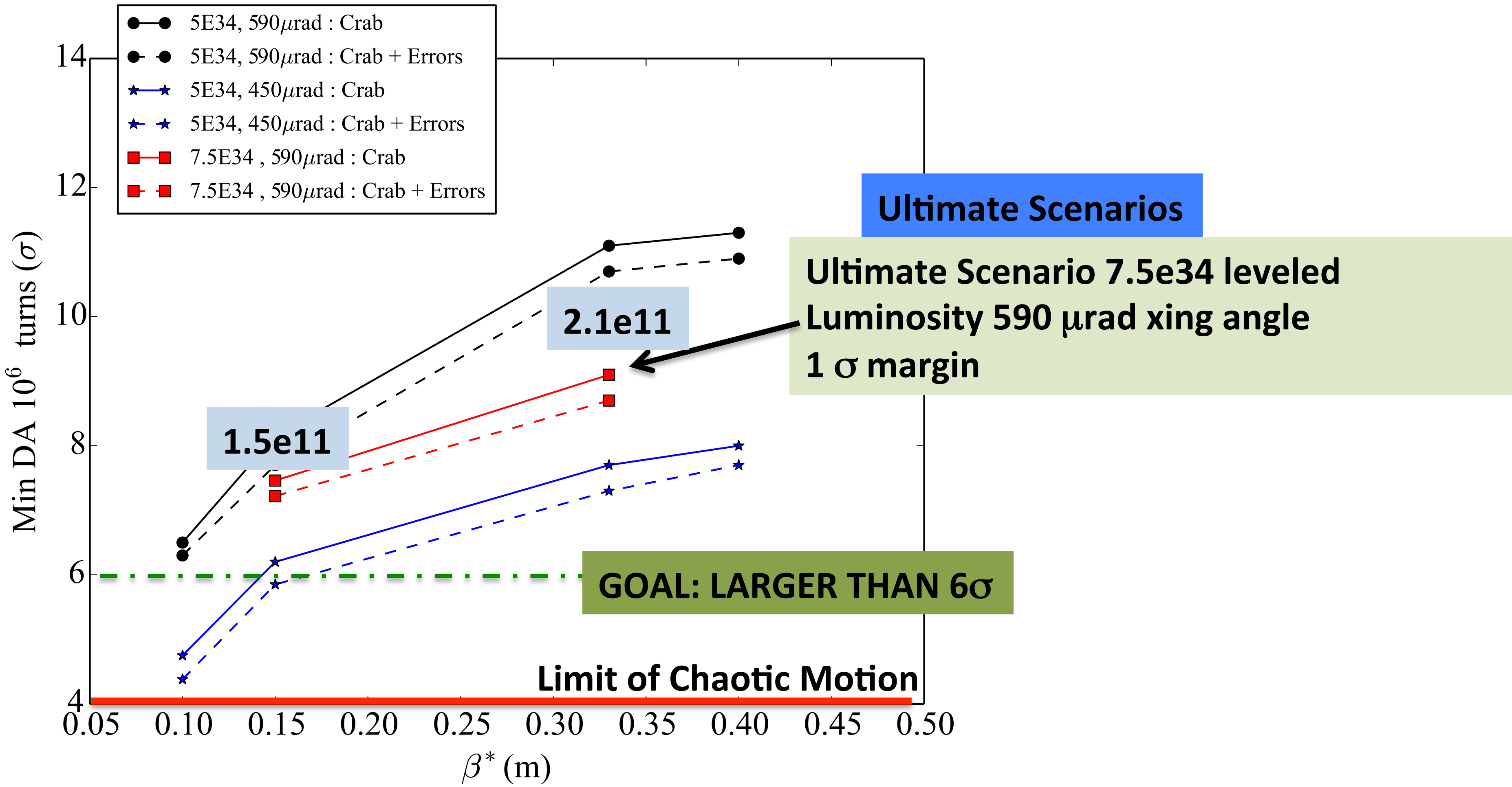
β* leveling is extremely "beautiful" for beam-beam dynamics
Baseline Scenario is robust → very large margins

The beauty of β* leveling: Dynamic Aperture



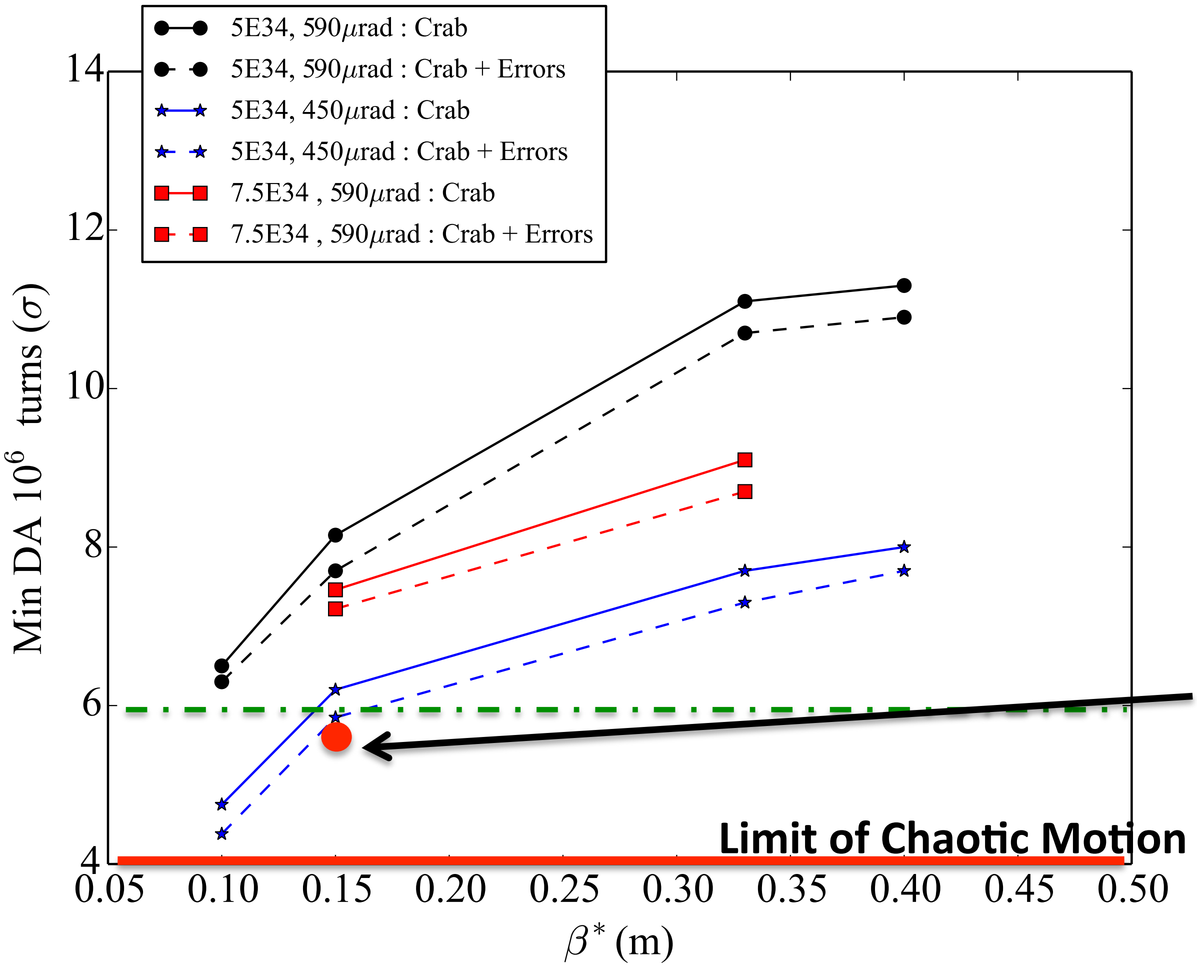
β* leveling is extremely "beautiful" for beam-beam dynamics
Baseline Scenario with reduced xing angle is robust → at limit only end of store

The beauty of β* leveling



β* leveling is extremely "beautiful" for beam-beam dynamics
Ultimate Scenario is robust → still margins

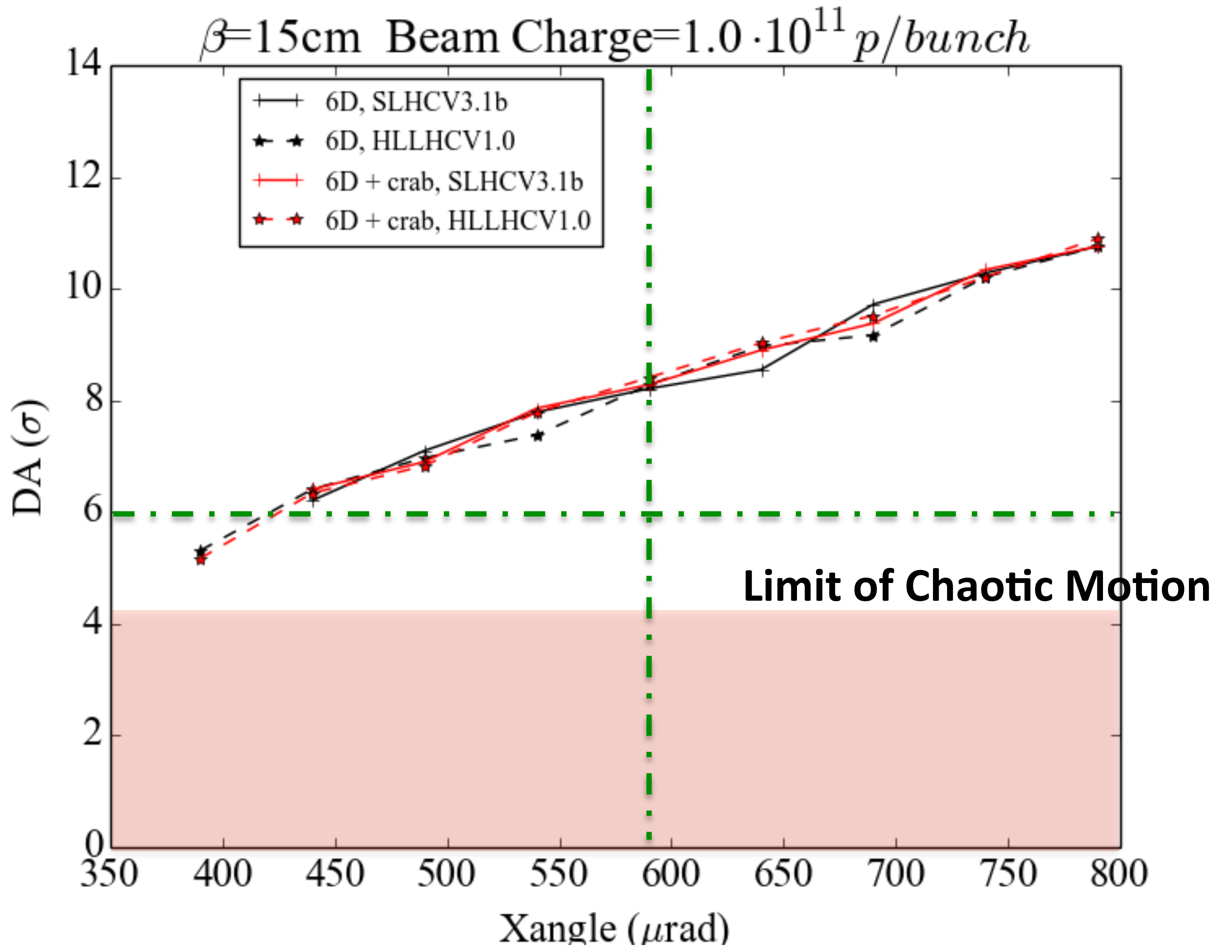
If no β* leveling is possible?



Extreme case
Need to be ensured

A larger angle will be needed, extreme case is NOT acceptable, yet!

Dynamic aperture HL-LHC IP1&5: summary

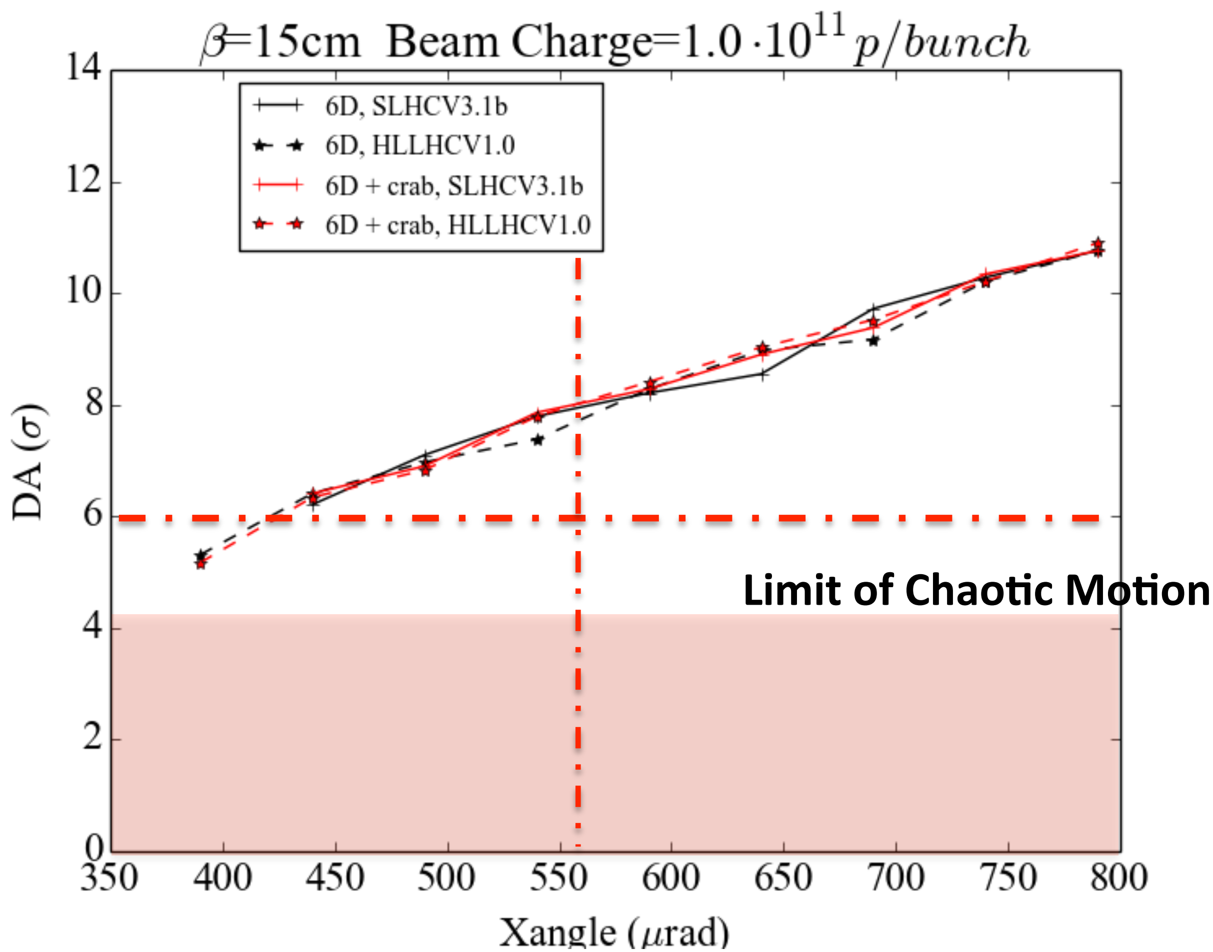


$$d_{sep} = \alpha \cdot \sqrt{\frac{\beta^*}{\epsilon/\gamma}}$$

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

In nominal condition 590 μrad DA=8.4 σ
Plenty of margin but…to be used for other knobs (Q', Landau Damping…)

Dynamic aperture HL-LHC IP1&5: Error Bars



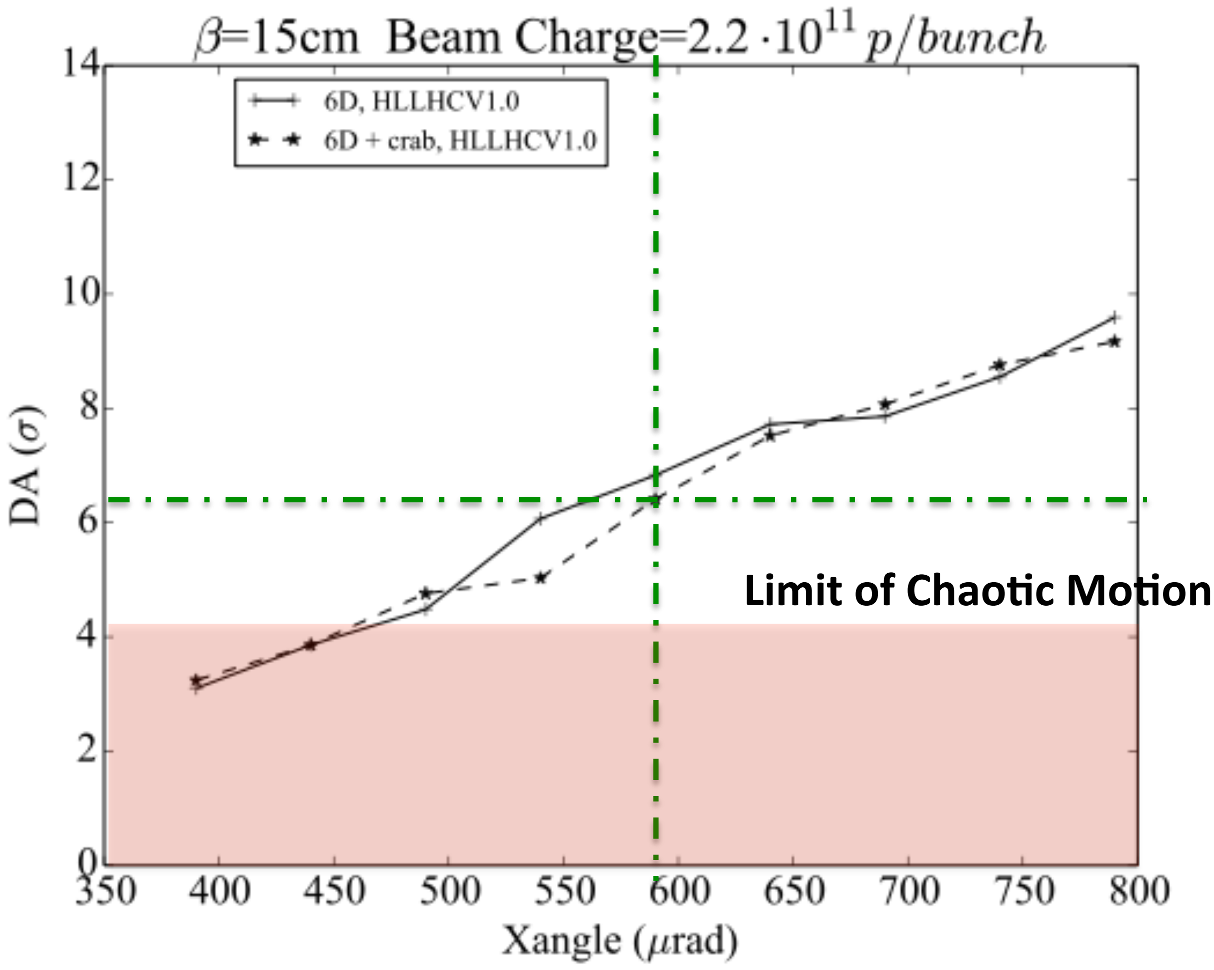
$$d_{sep} = \alpha \cdot \sqrt{\frac{\beta^*}{\epsilon/\gamma}}$$

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

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 8.4 σ → 7.5 σ

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

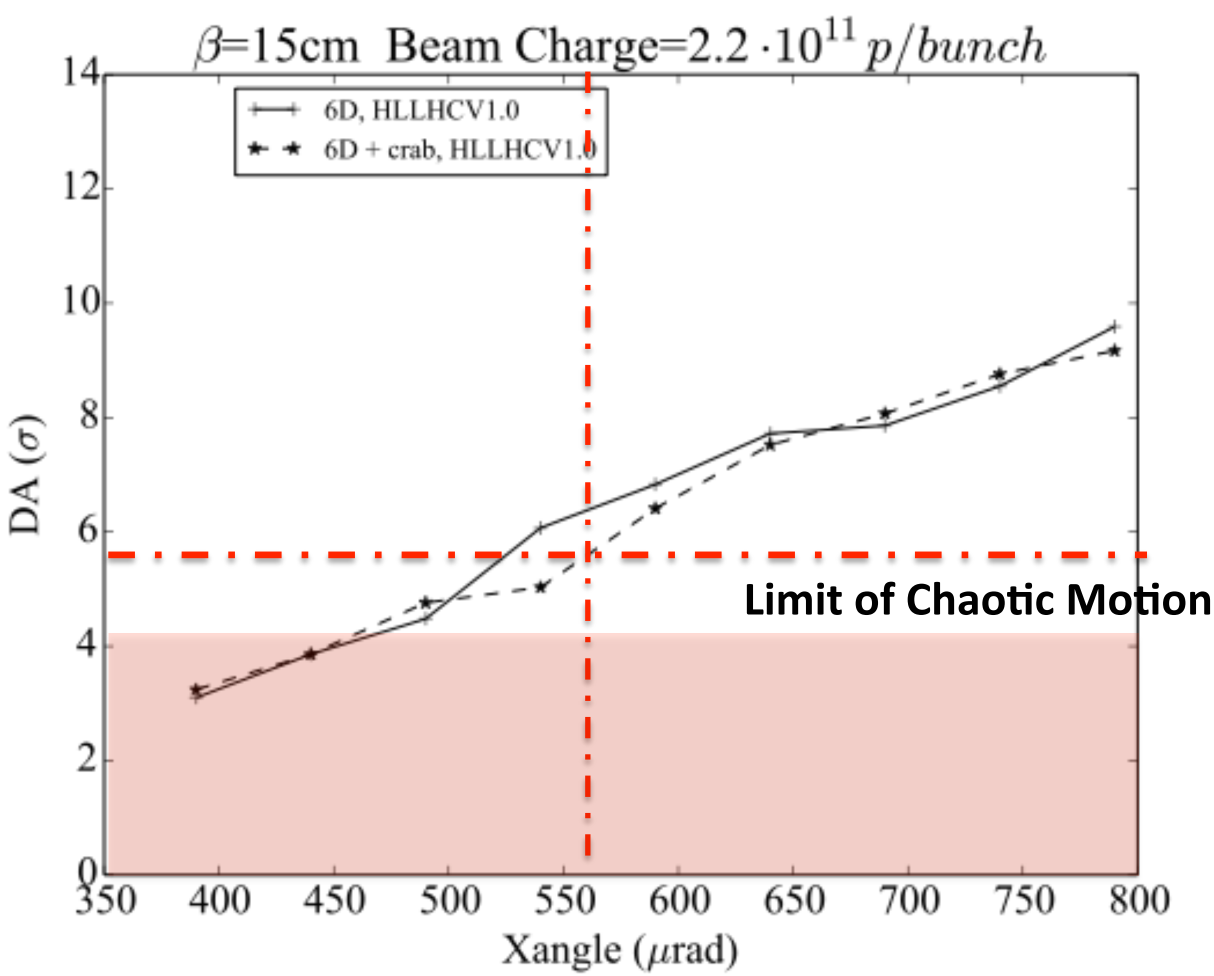


$$d_{sep} = \alpha \cdot \sqrt{\frac{\beta^*}{\epsilon/\gamma}}$$

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

In nominal condition 590 μrad DA=6.4 σ

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



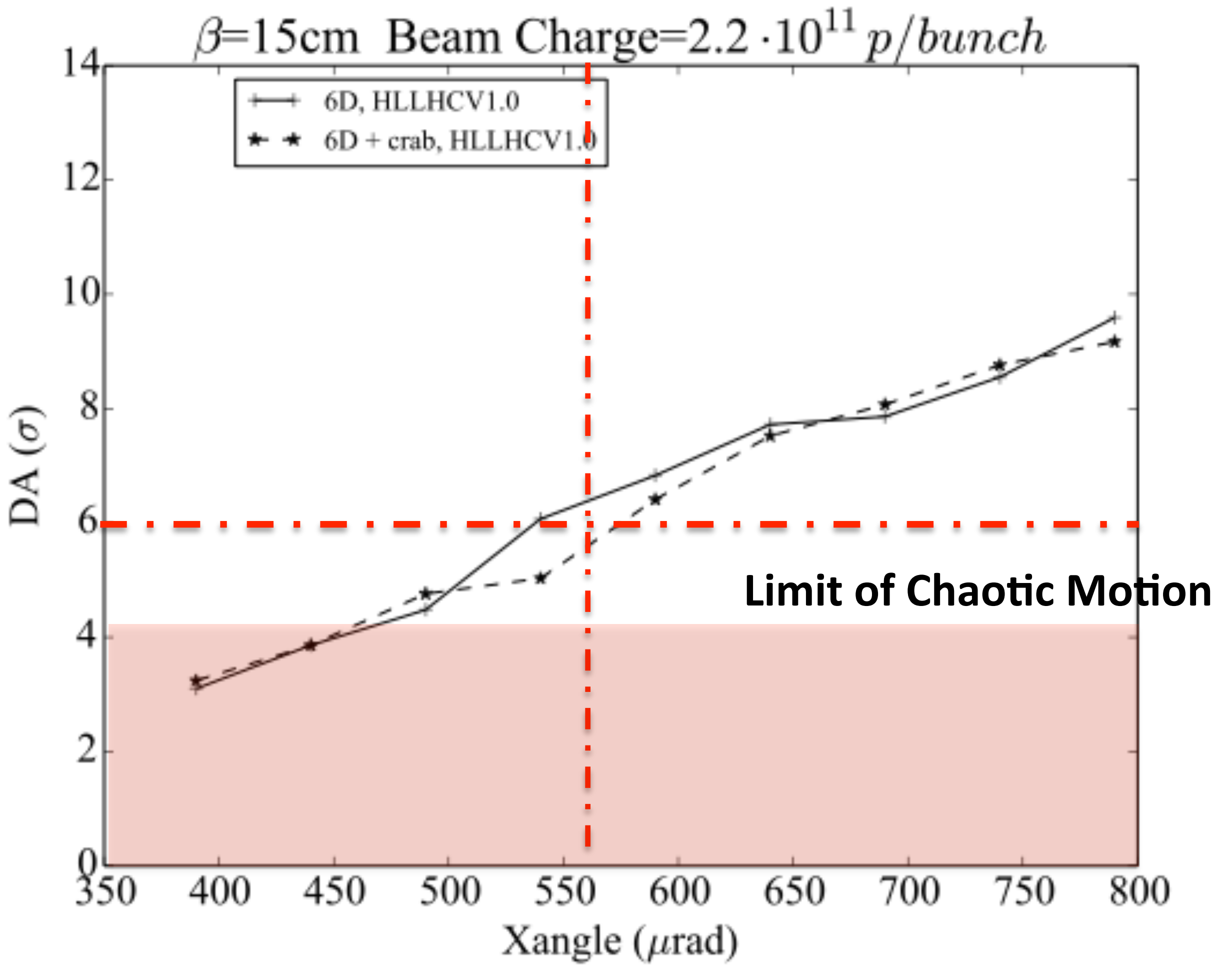
$$d_{sep} = \alpha \cdot \sqrt{\frac{\beta^*}{\epsilon/\gamma}}$$

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

1. **10% larger ε_n (2.5→2.75)**
2. **Equivalent to reduction of the angle 590μrad→560μrad**
3. **Equivalent to reduction of DA 0.9σ**

10% increase ε_n reduces DA 6.4 σ → 5.5 σ

Dynamic aperture HL-LHC: IP1&5



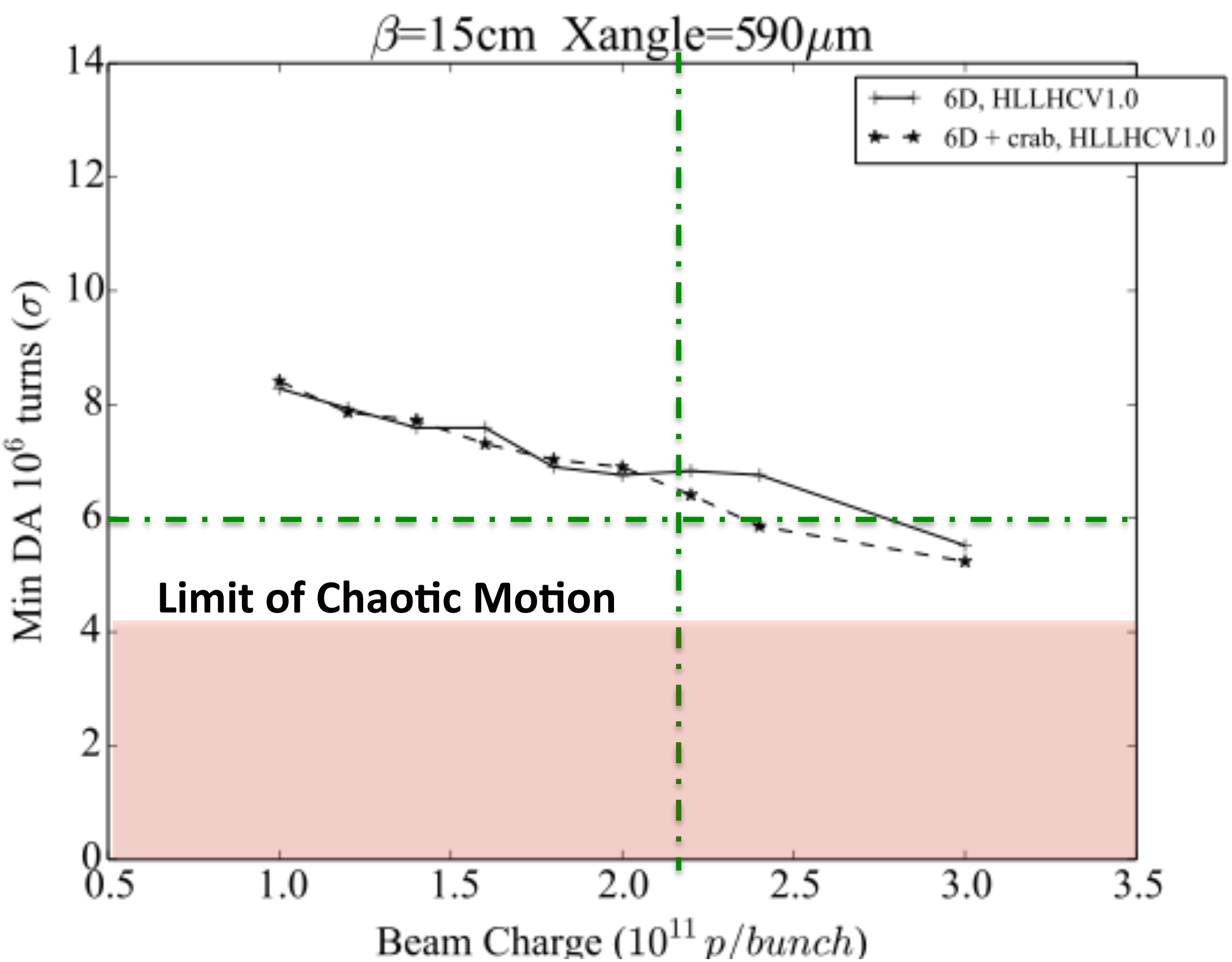
$$d_{sep} = \alpha \cdot \sqrt{\frac{\beta^*}{\epsilon/\gamma}}$$

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

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**

Margins can be lost very fast with Beam-beam if not attentive!
Beams will not explode but integrated Luminosity reduced!

Dynamic aperture HL-LHC IP1&5: Intensity

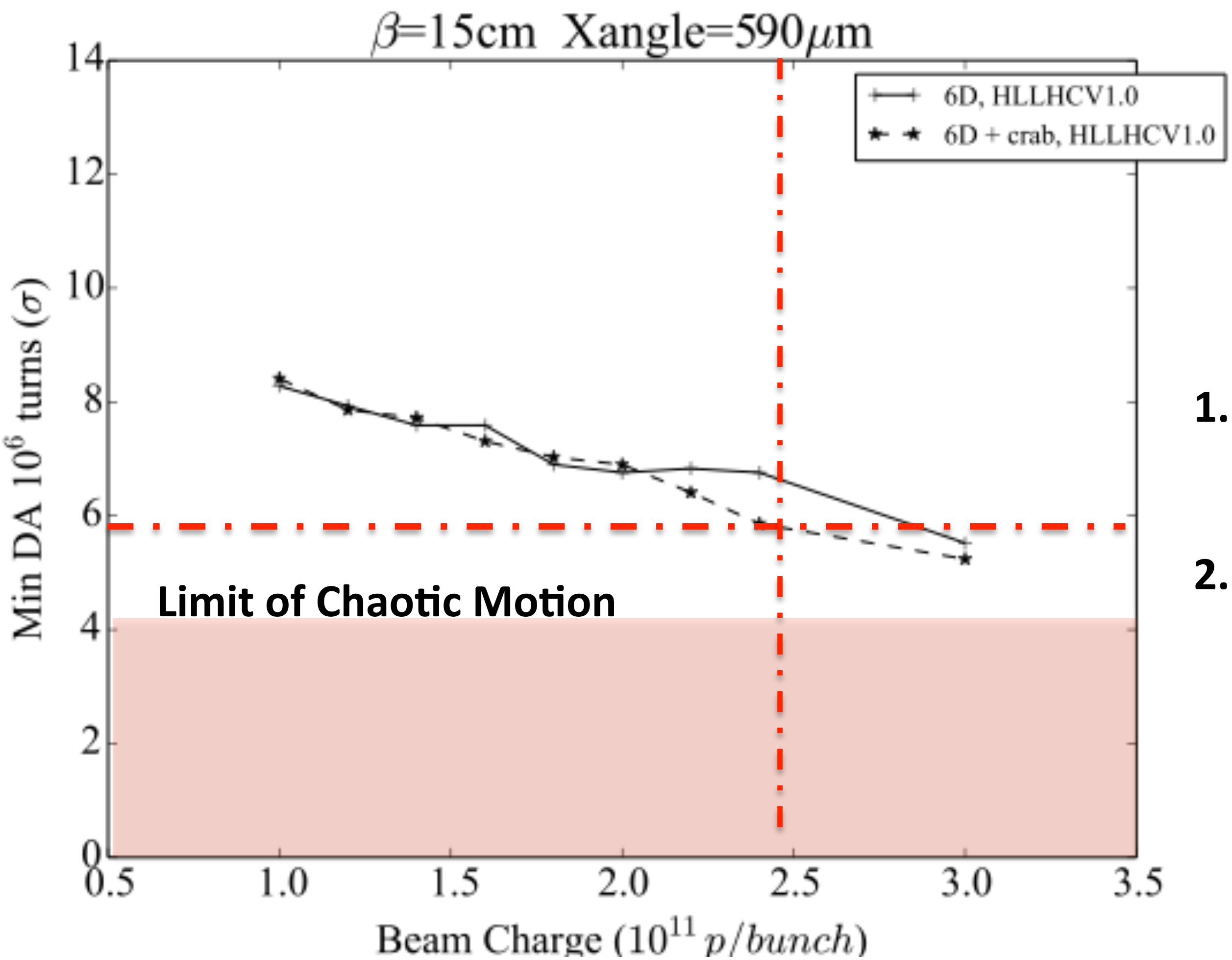


$F_{bb} \propto Intensity$

$DA \propto Intensity$

In nominal condition 2.2e11ppb DA=6.4 σ

Dynamic aperture HL-LHC IP1&5: Intensity



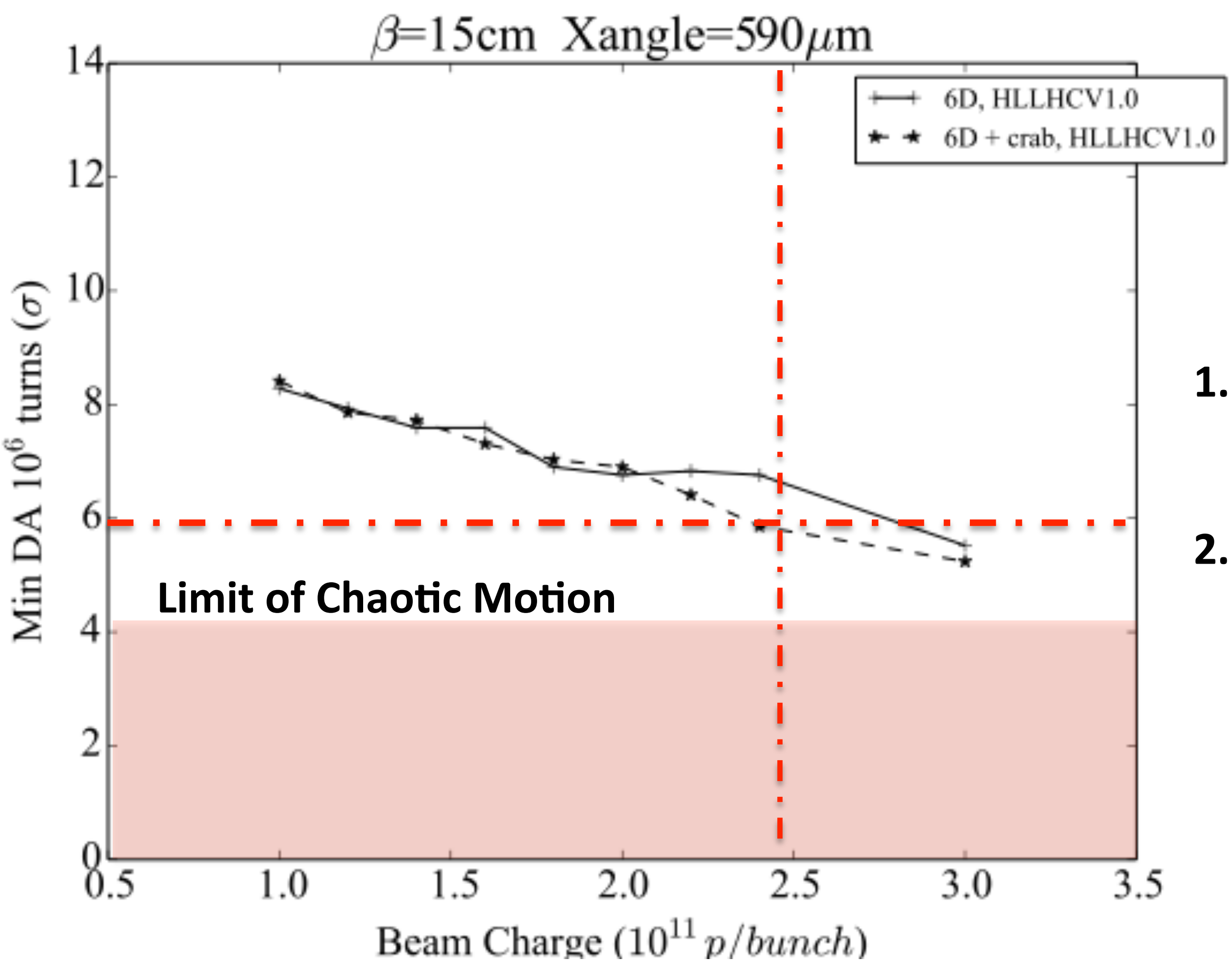
$$F_{bb} \propto Intensity$$

$$DA \propto Intensity$$

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

10% Intensity fluctuations reduces DA 6.4 → 5.9 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**

Margins can be lost very fast with BB if not attentive!
Anything larger equal to 0.5 s is not negligible!

Outline

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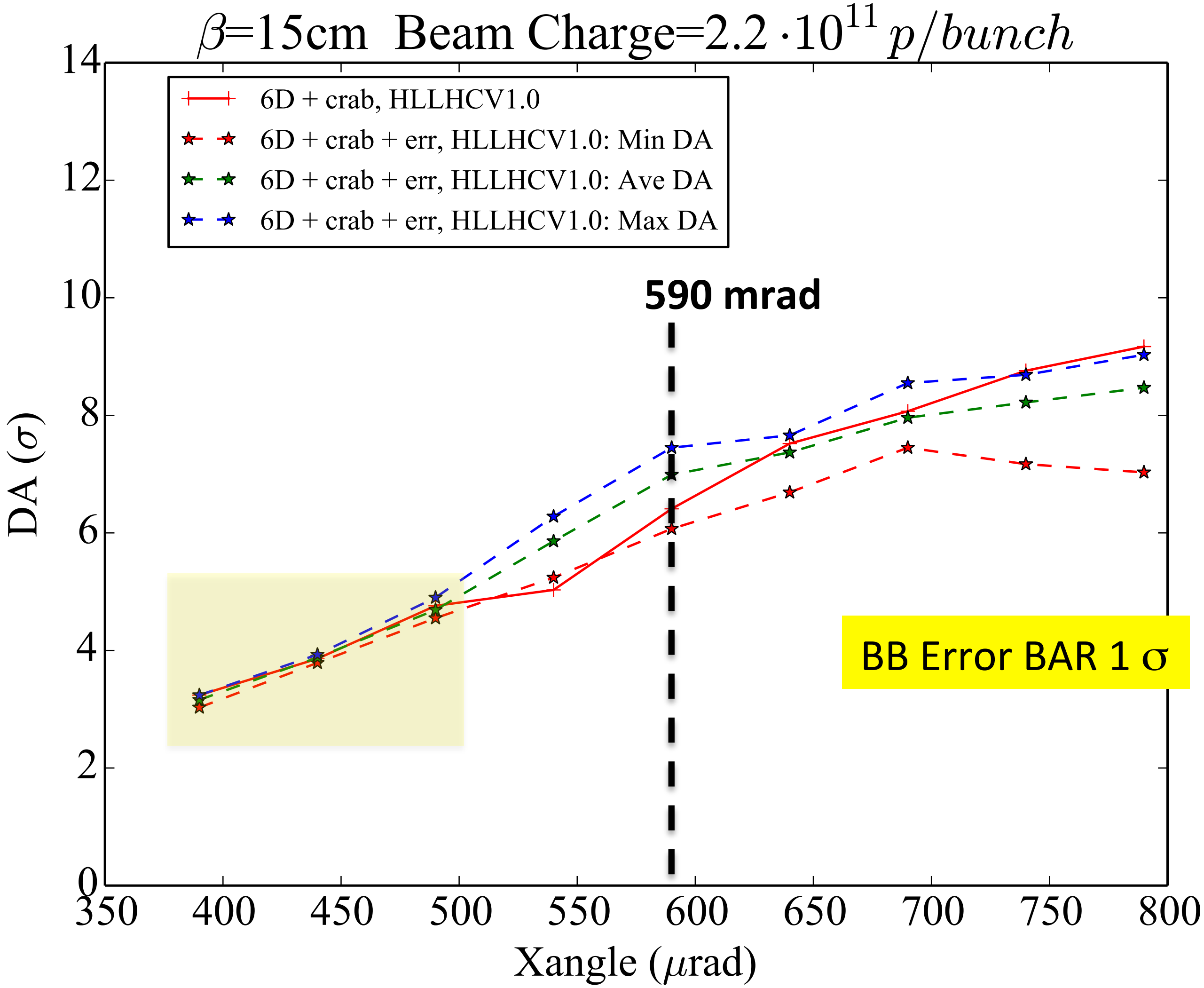
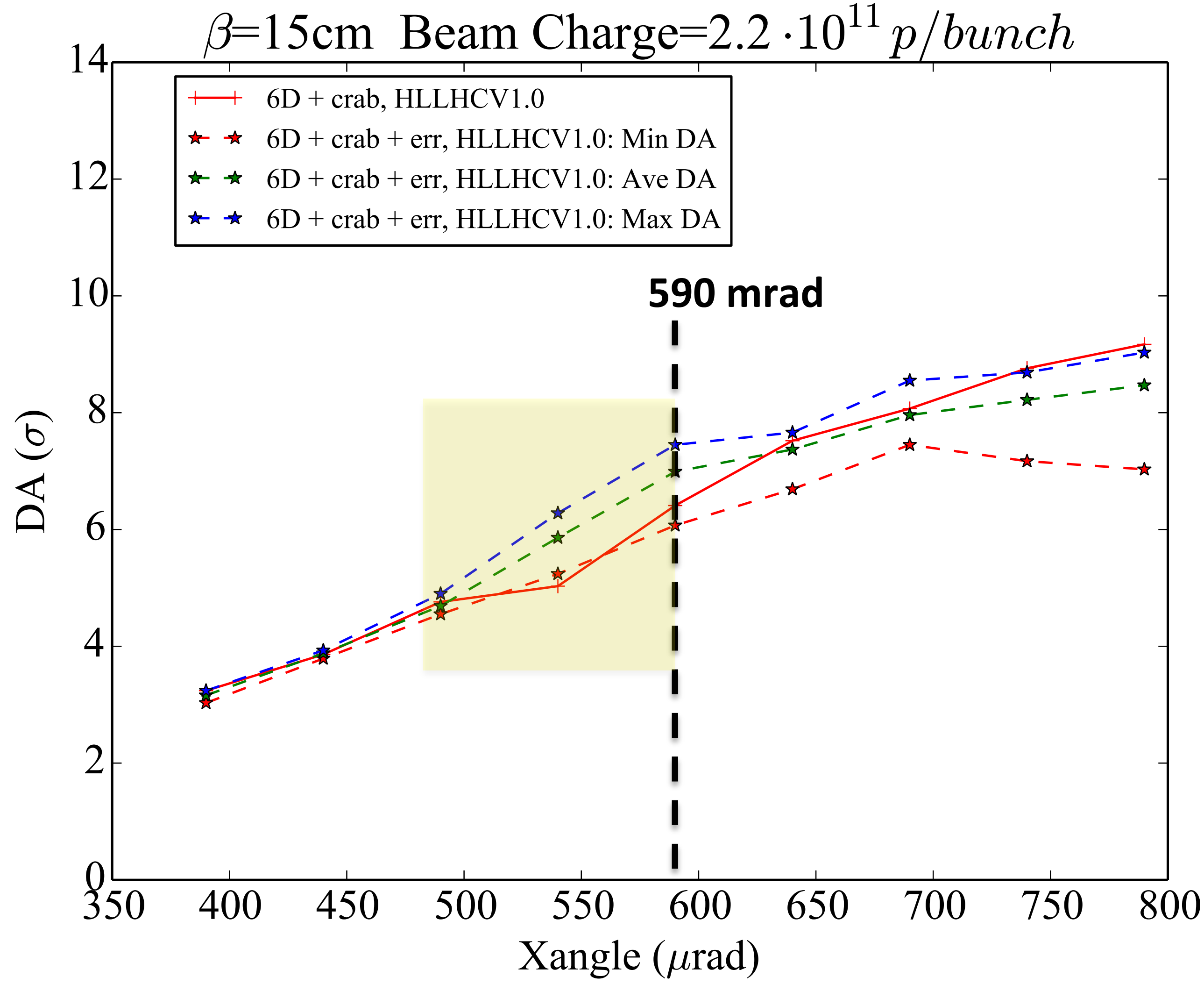
- **Effect of multipolar errors element by element**
- Effect of the Inner Triplet Errors b10 and b14 on BB
  - General Observations
  - Average versus Minima Dynamic Aperture
  - Compensation effects
- Summary

Multipolar Errors and crossing angle



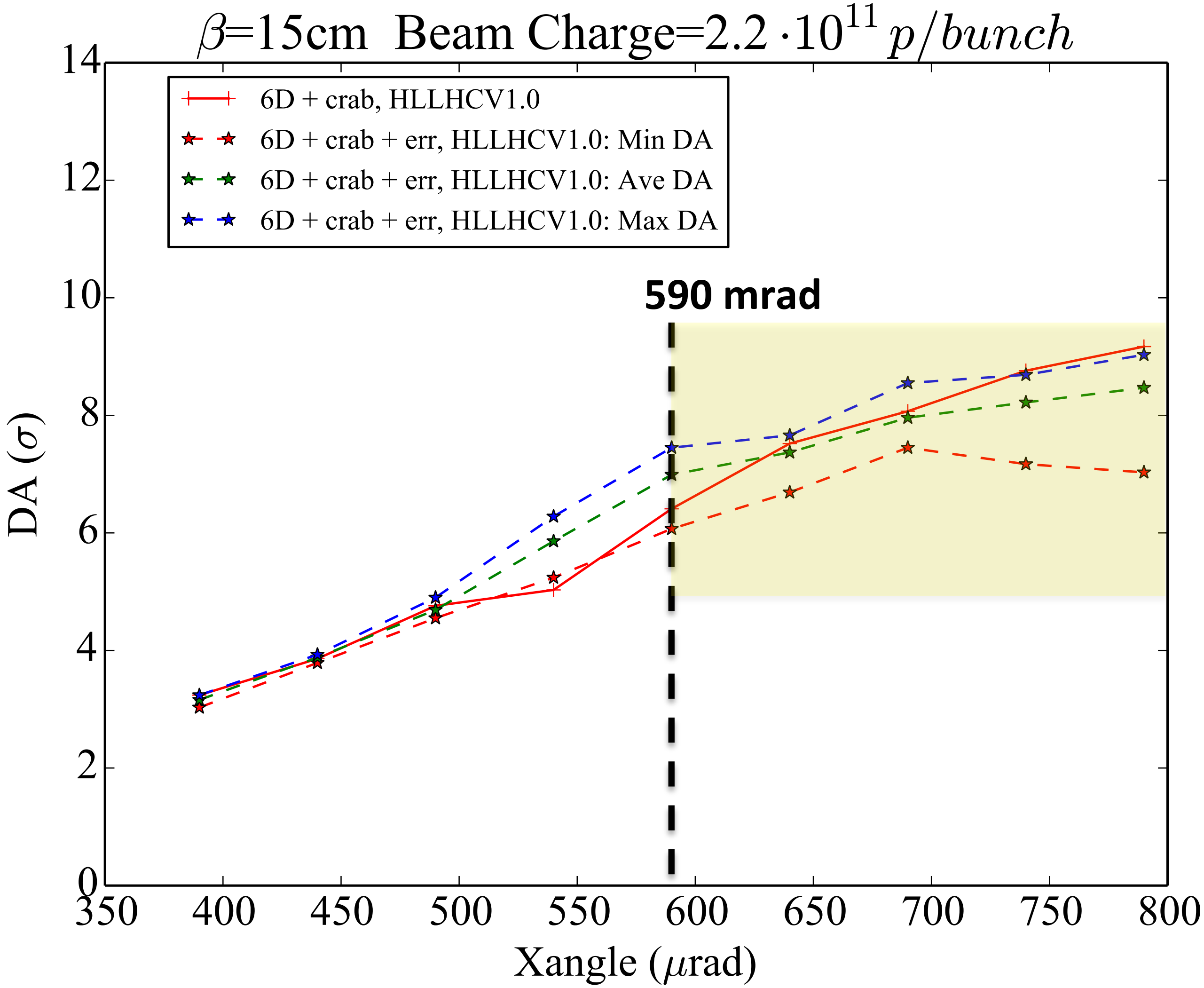
The impact is clearly negligible when beam-beam is strong < 500 μrad

Multipolar Errors and crossing angle



In all other cases Errors do have an important impact "positive or negative" on DA

Multipolar Errors and crossing angle



Negative effects more pronounced for larger angle where errors are stronger!

Outline

- HL-LHC scenarios in the presence of Beam-beam Effects
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- **Effect of the Inner Triplet Errors b10 and b14 & BB**
  - **General Observations: preliminary results**
  - **Average versus Minima Dynamic Aperture**
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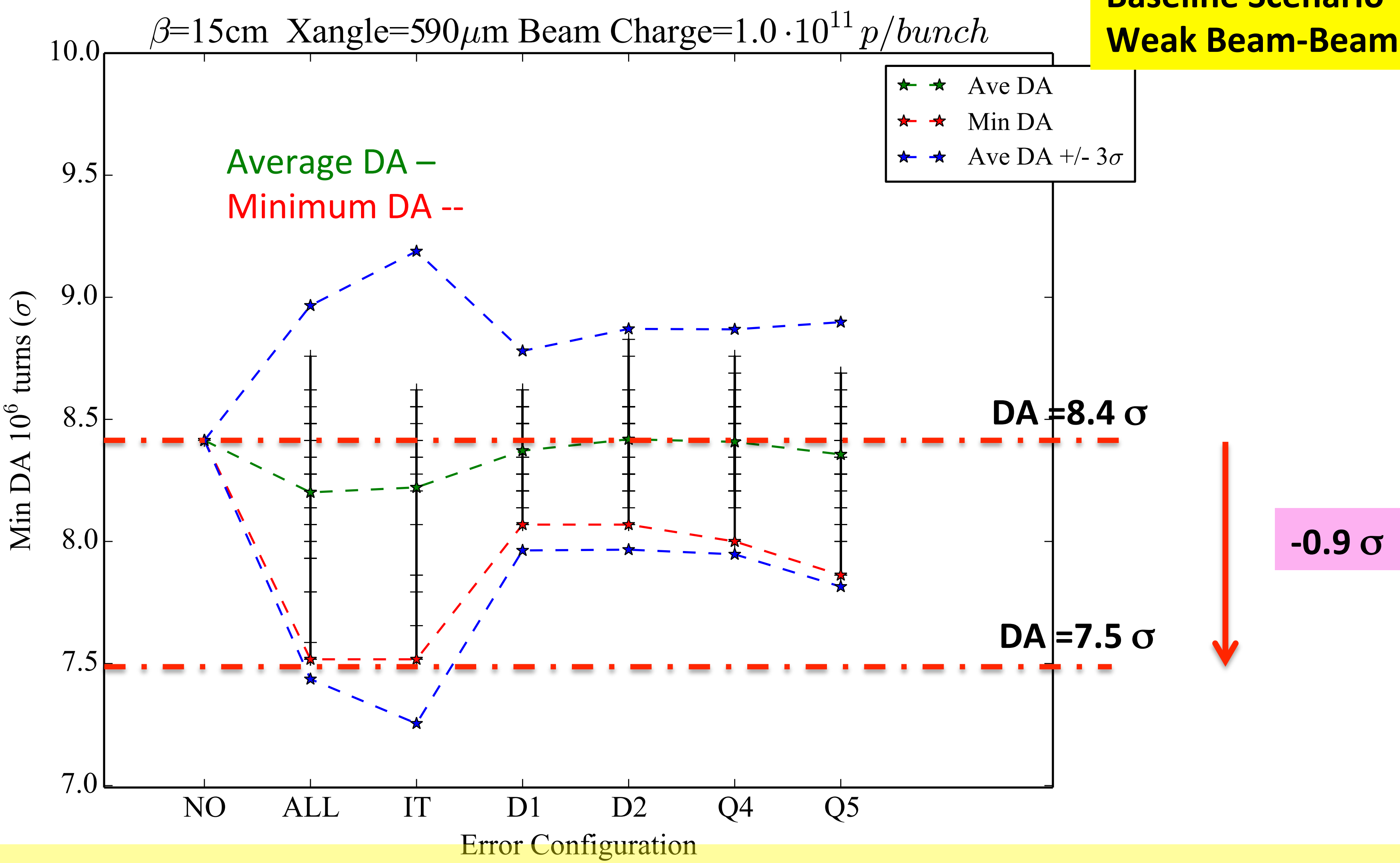
- Summary

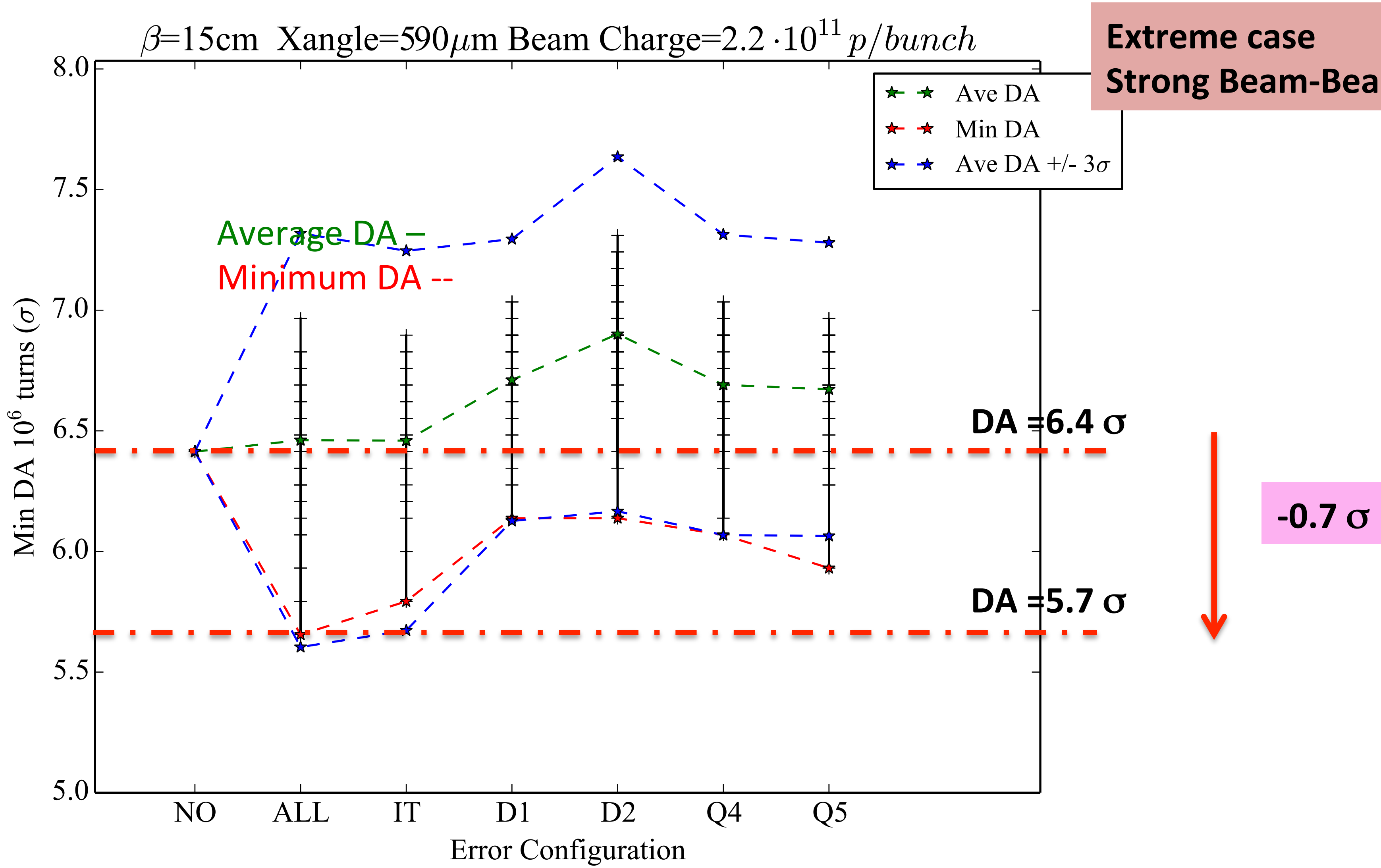
Multipolar errors elements impact: 1.0e11 ppb

Baseline Scenario
Weak Beam-Beam



Errors do have an impact: minimum and average DA is lower!
Driven by Inner Triplet element errors

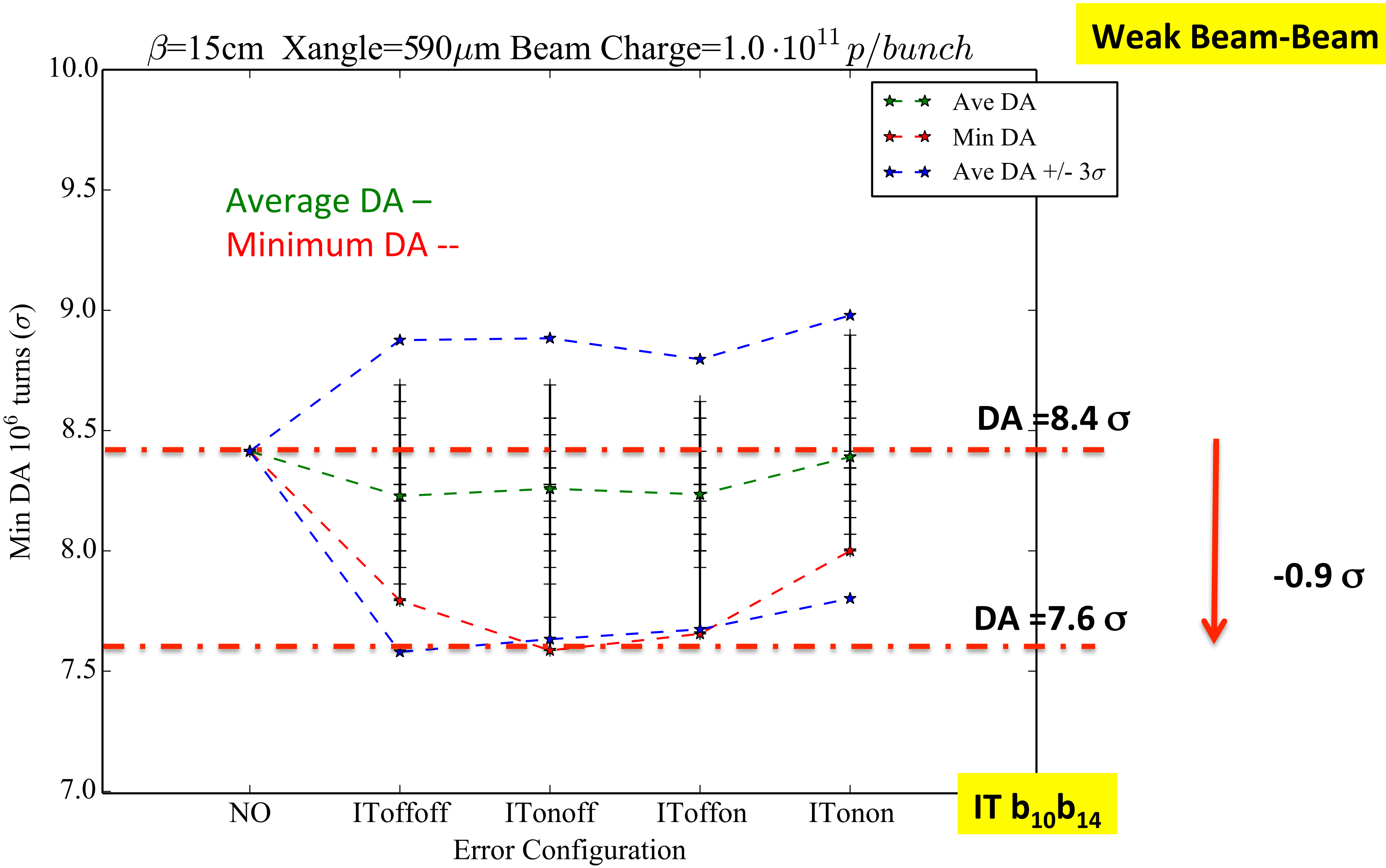
Multipolar errors elements impact: 2.2e11 ppb



Extreme case
Strong Beam-Beam

Beam-Beam stronger → Errors reduce DA 0.7 σ Smaller effect
Driven by Inner Triplet element errors
Minima is reduced but average increases DA

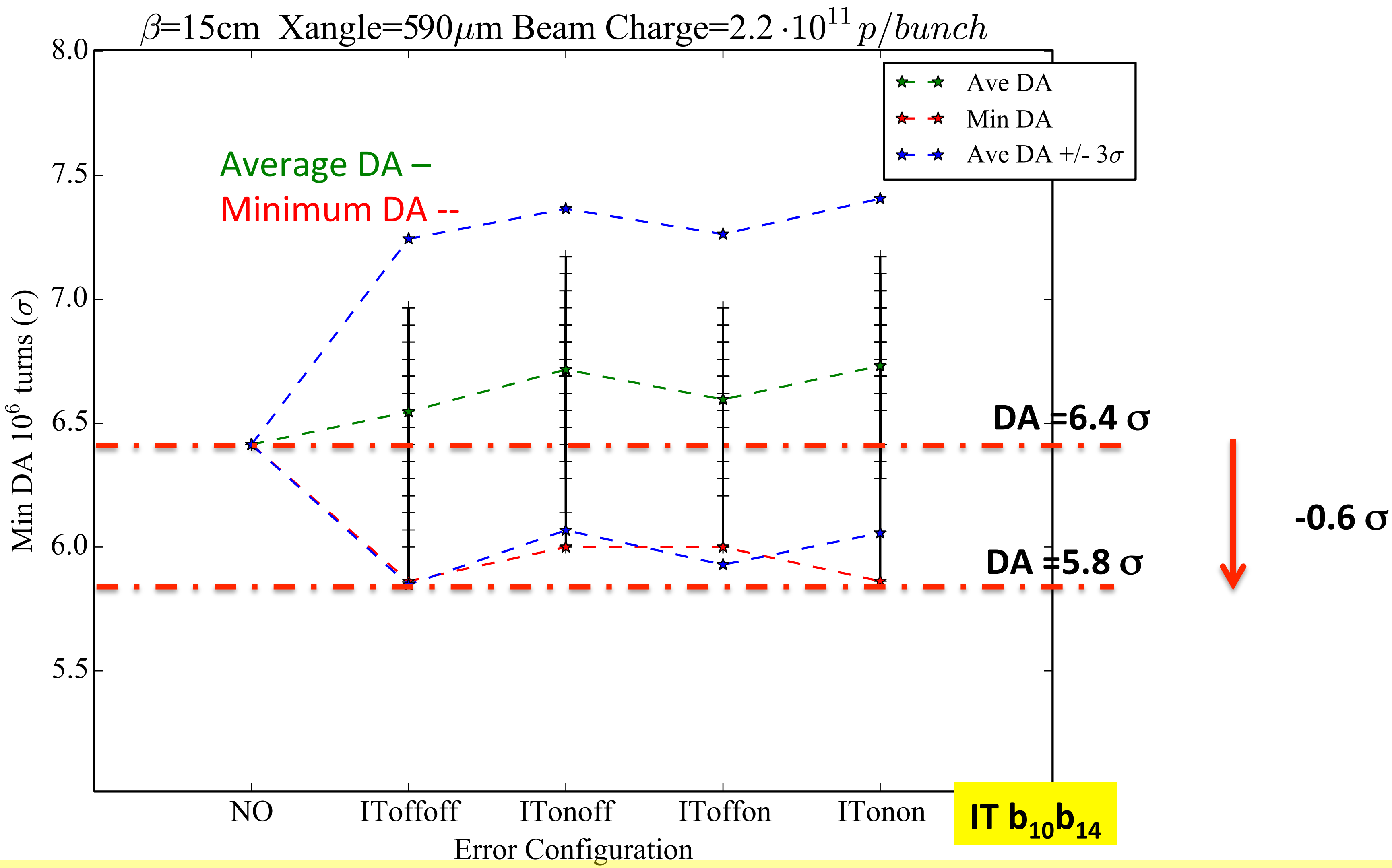
Multipoles b10 and b14 in the INNER TRIPLET



Minima and Average reduce DA.
DA depends on b10 & b14 but not in a simple way!

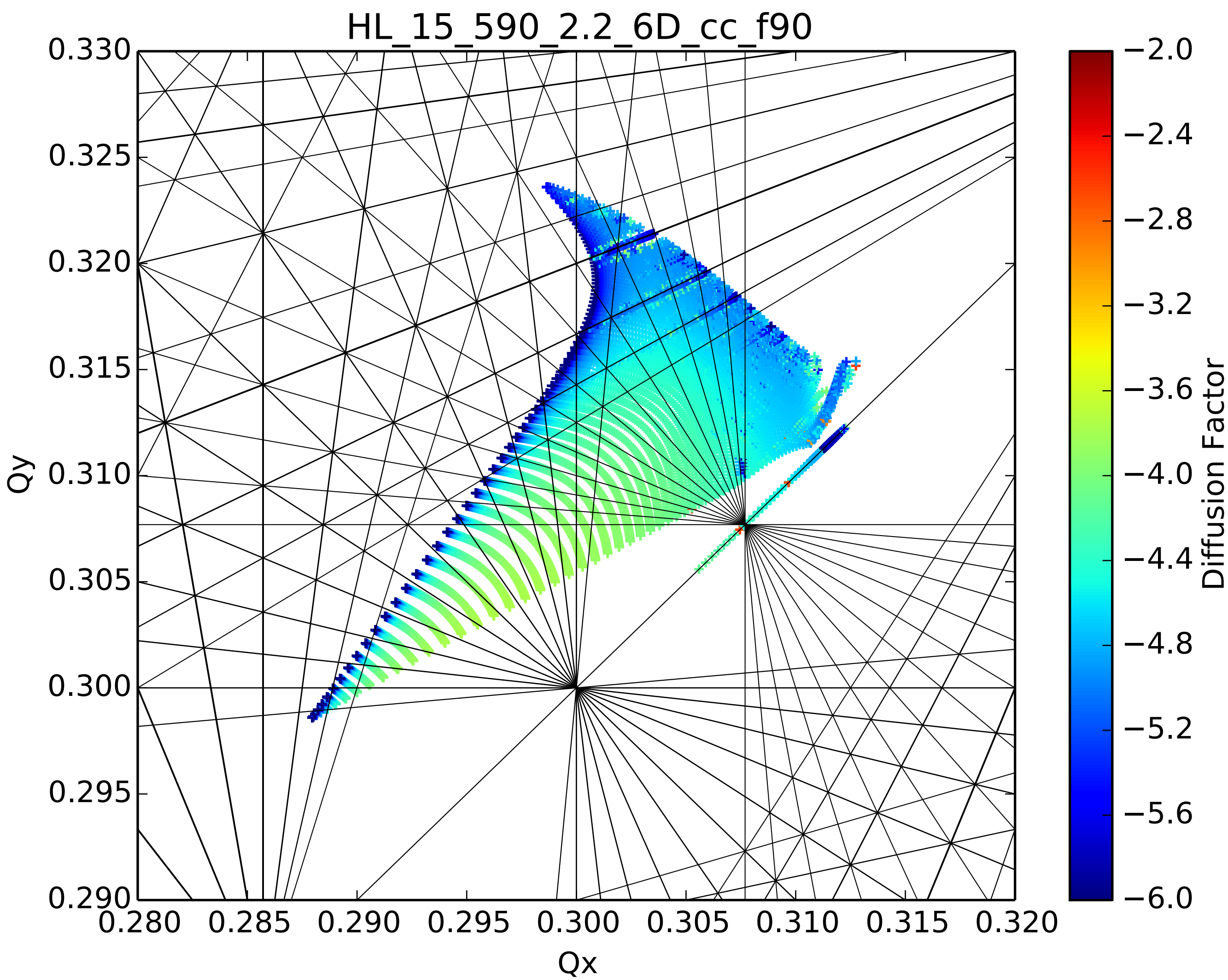
Multipoles b10 and b14 in the INNER TRIPLET

Strong Beam-Beam



BB dominates → Seems independent of b10 and b14

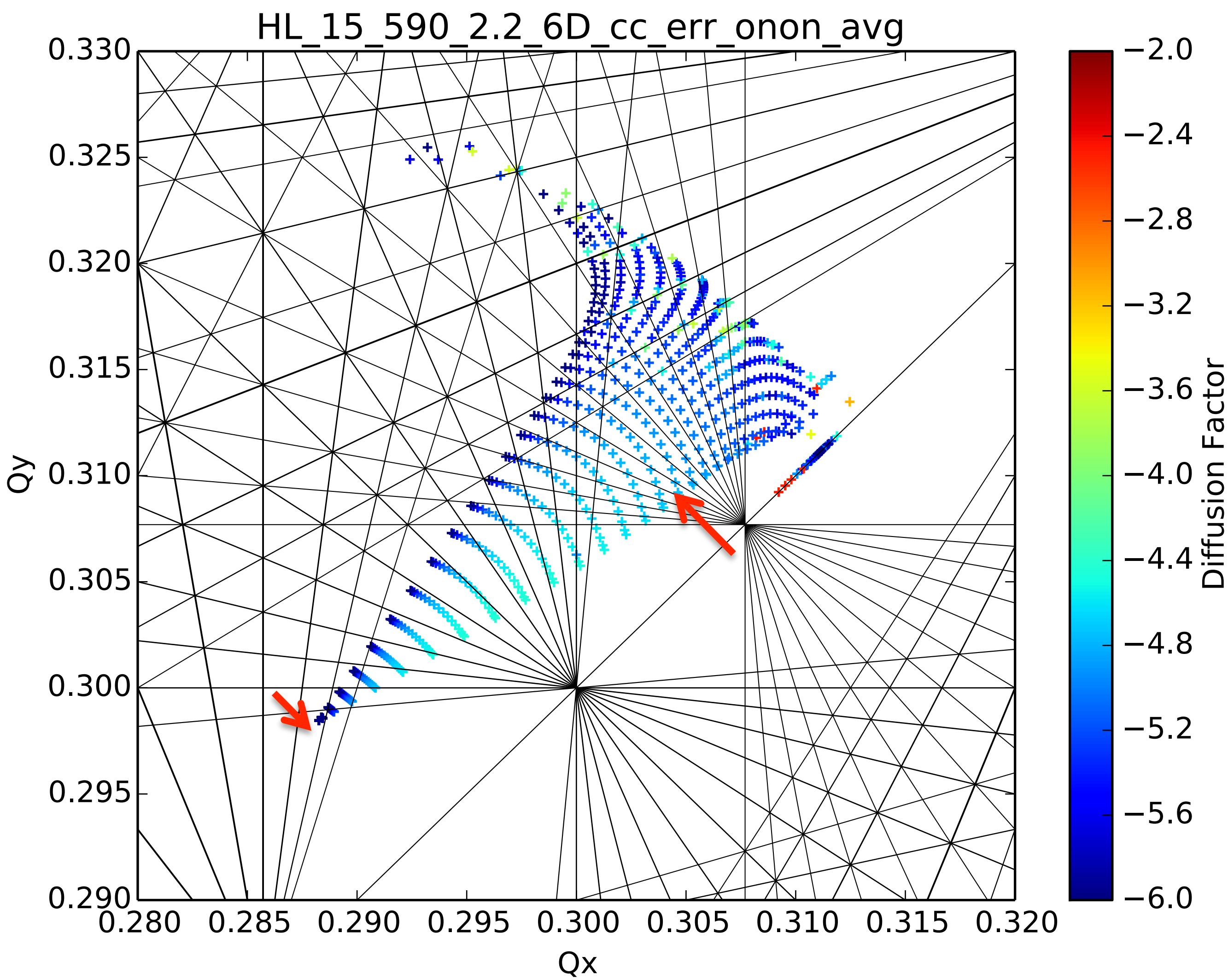
What is happening?



DA =6.4 σ

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

Multipolar errors: average seed



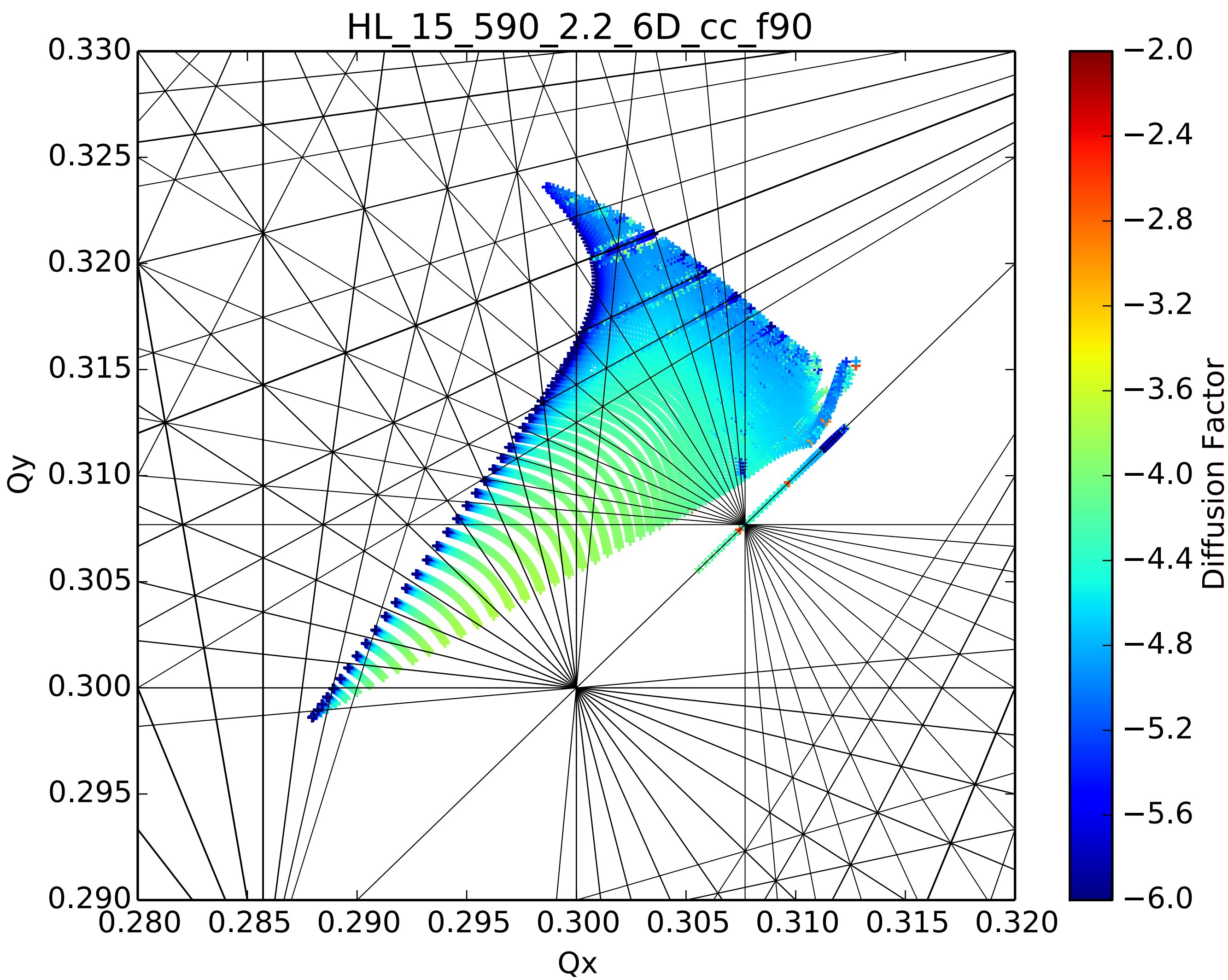
DA =6.4 σ

+ 0.3 σ

DA =6.7 σ

Larger Average DA due to "compensation" → reduction of spread visible

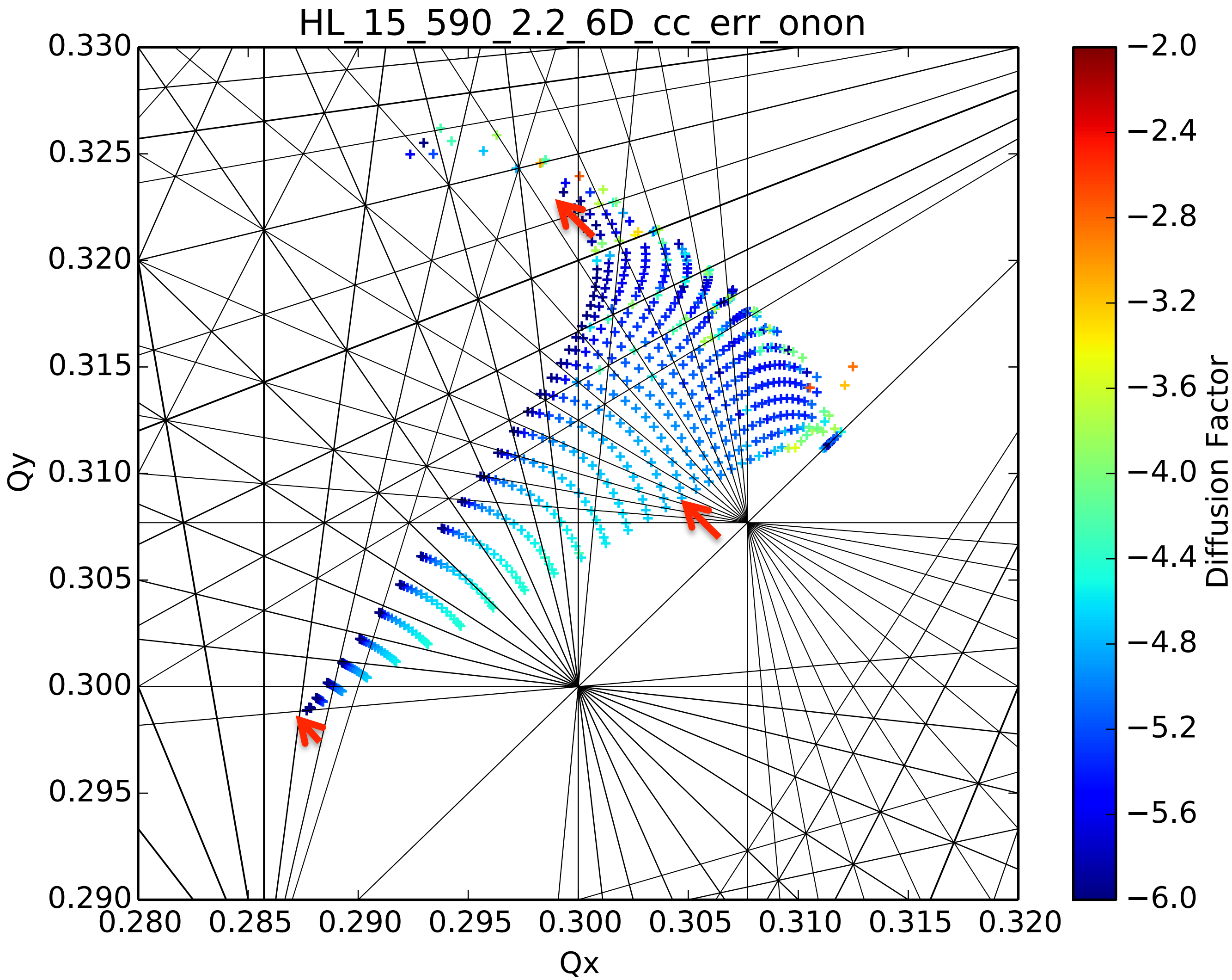
No Multipolar errors



DA =8.4 σ

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

Multipolar errors: minimum DA seed



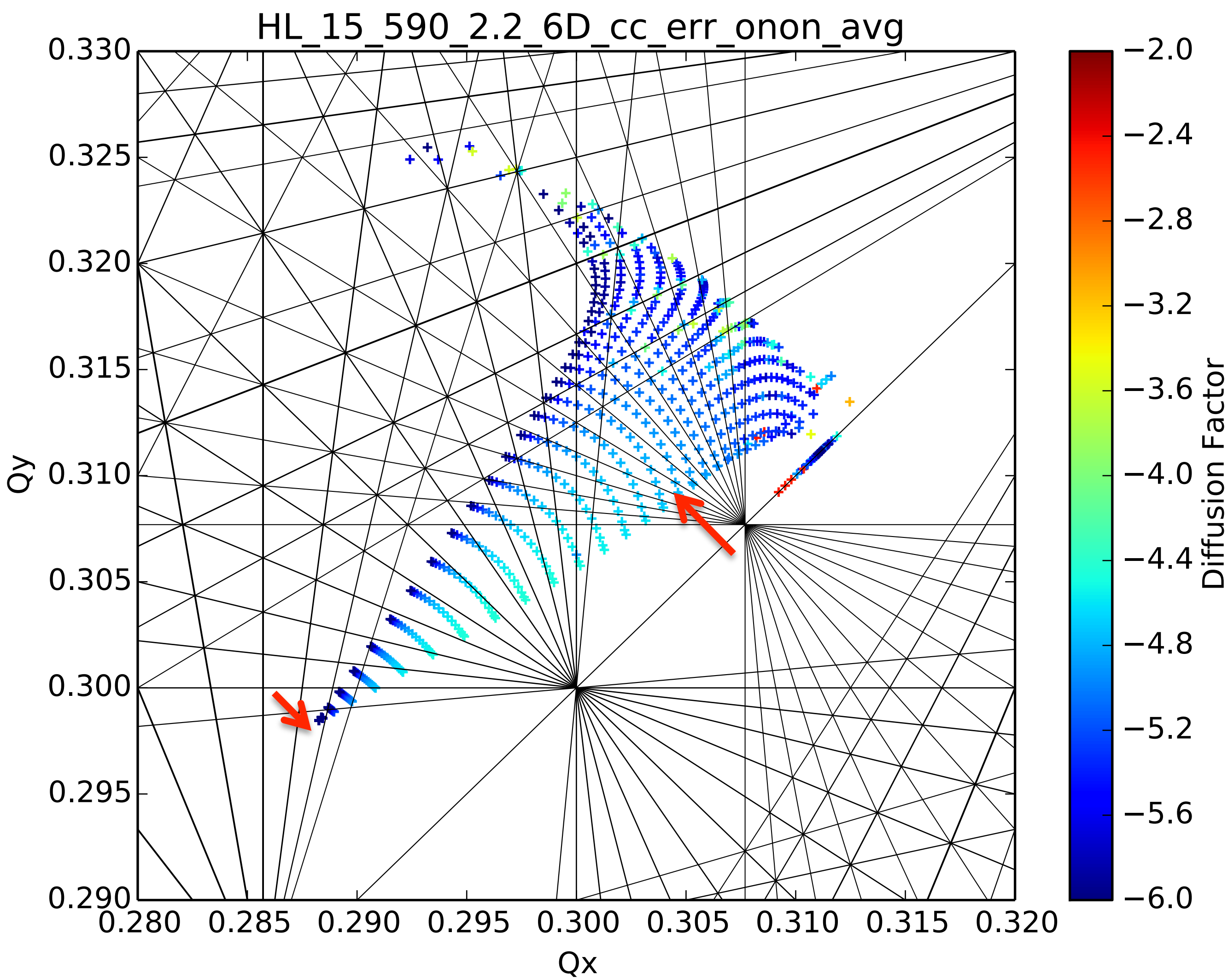
DA =8.4 σ

-0.8 σ

DA =7.6 σ

Minimum DA has larger spread and shift

Multipolar errors: average seed



DA =6.4 σ

+ 0.3 σ

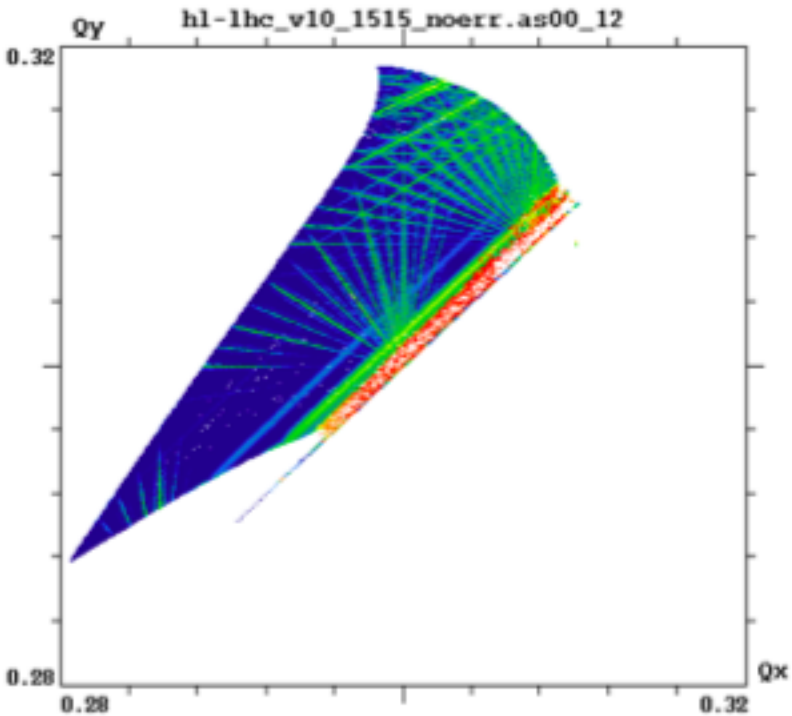
DA =6.7 σ

The effect is stronger for 1.0e11 ppb case!

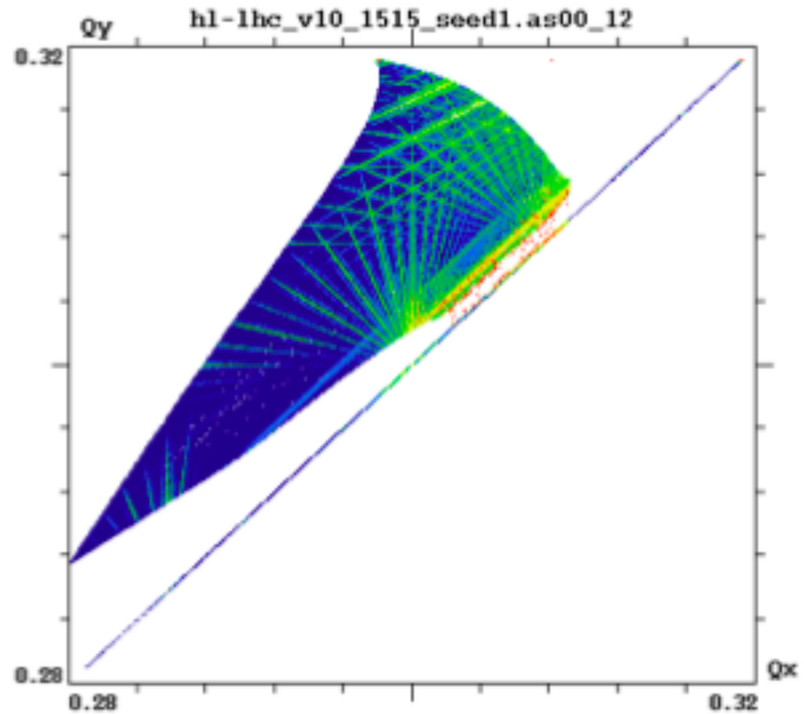
Similar results confirmed by Lifetrac

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

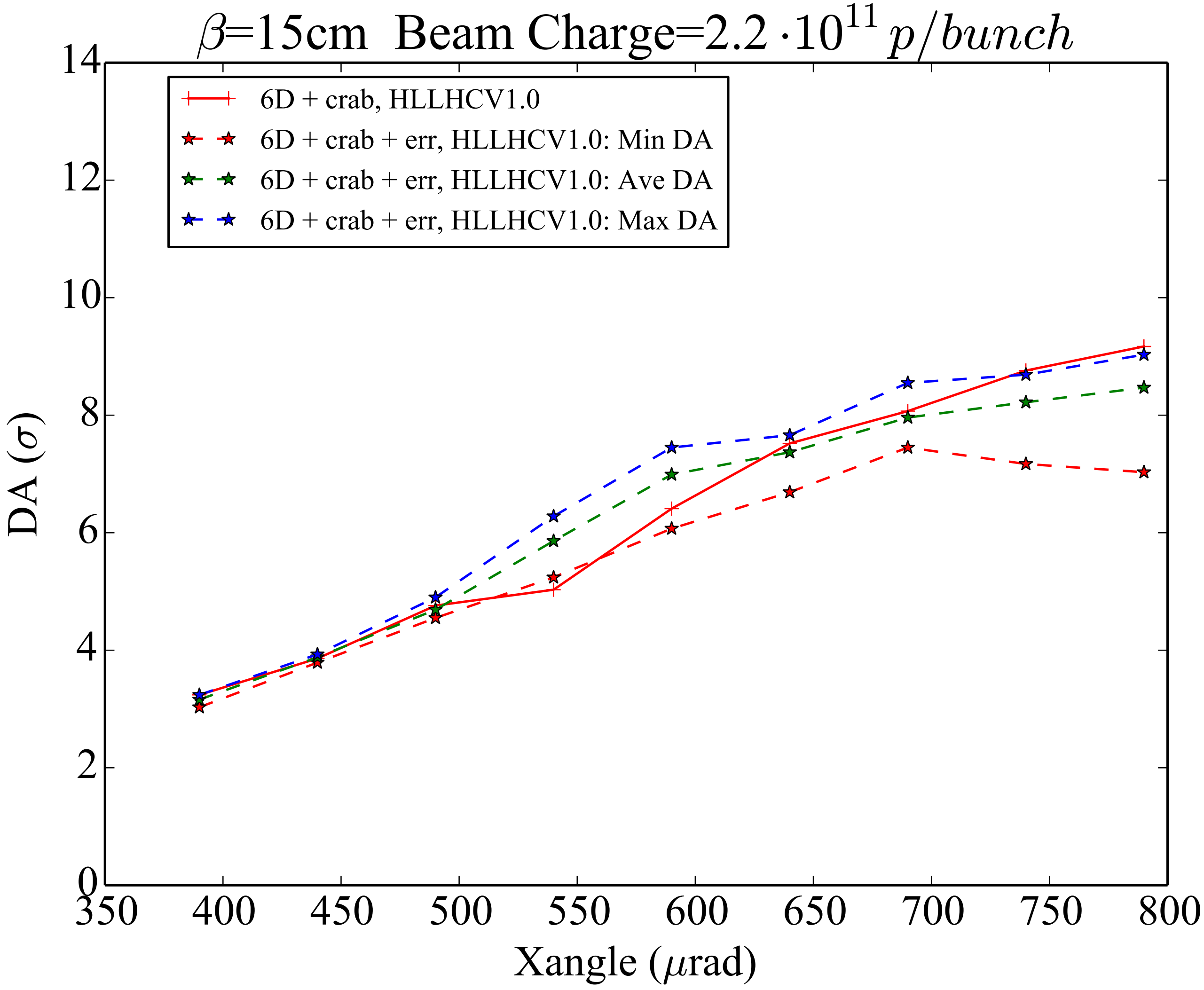
No errors



Seed #1

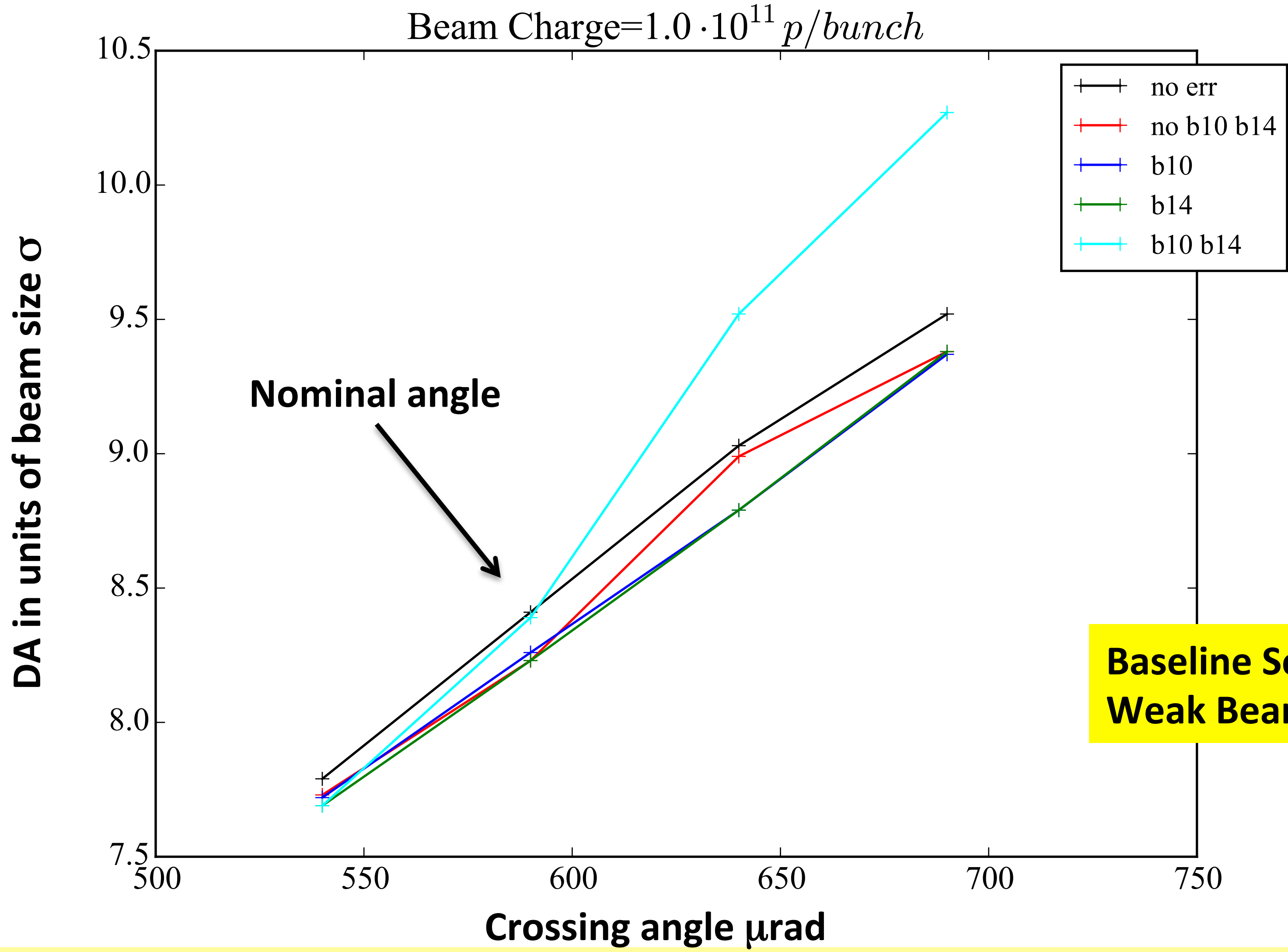


Multipolar Errors



The effects change significantly depending on crossing angle

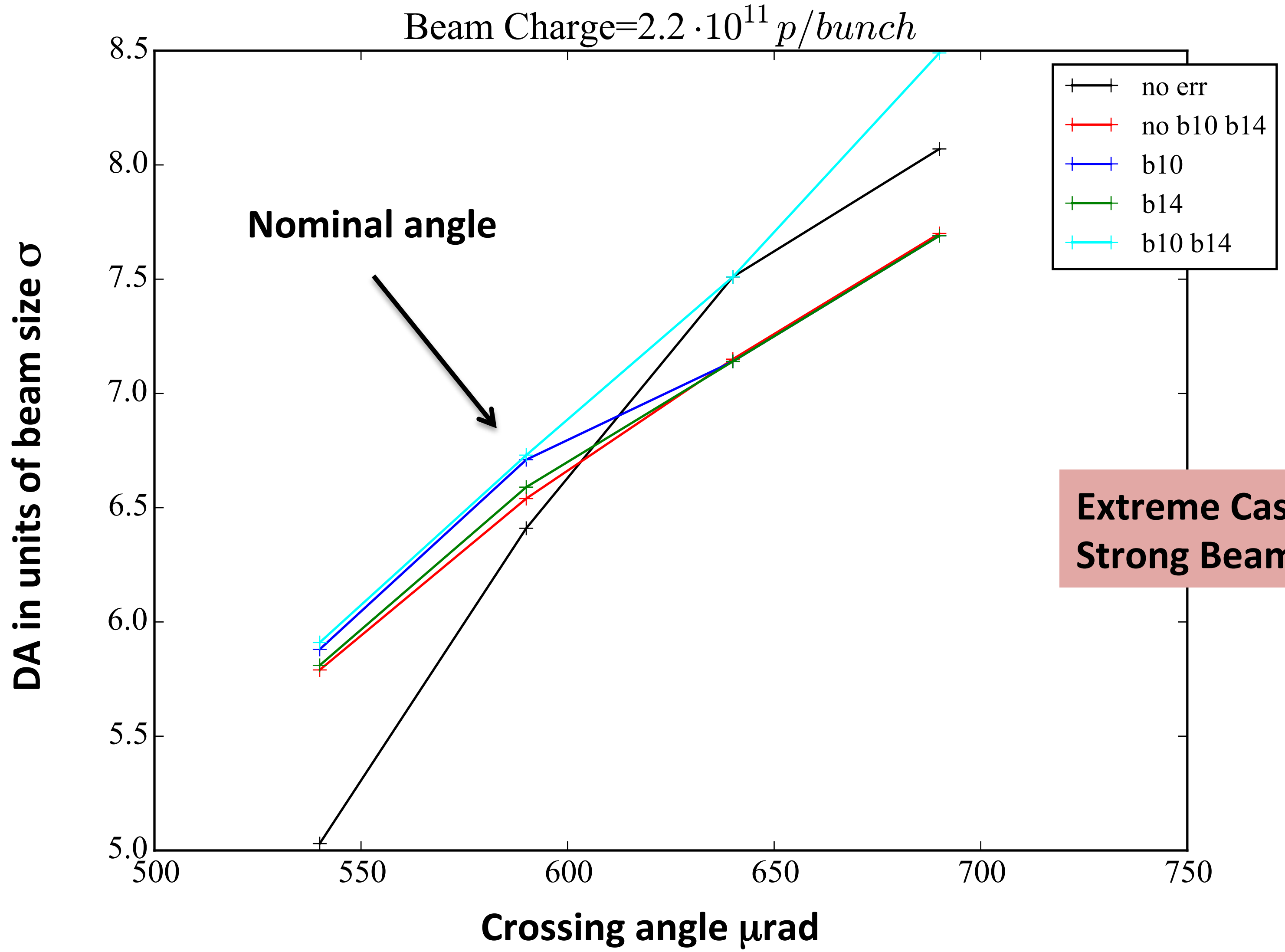
Multipolar Errors in Inner Triplet: b10 & b14



Baseline Scenario
Weak Beam-Beam

B10 and b14 do have an important impact they seem compensating some BB effects. Can we rely on this? NO! Is then the minima DA criteria (how this value deviates from BB only) the right way to quantify the impact?

Multipolar Errors in Inner Triplet: b10 & b14



Extreme Case
Strong Beam-Beam

b10 and b14 have an effect which changes the dynamics.
Is the minima DA criteria the one to use with Beam-Beam?

Summary

- **Baseline scenario for HL-LHC is robust, extreme case is not yet acceptable**

- Beam-Beam effects put an **error bar on simulations of 0.5-1** σ anything that affects DA by such quantity is NOT NEGLIGIBLE! And does affect the dynamics!

- **Multipolar errors are not negligible** INNER TRIPLET dominates
- The study of errors (i.e. b10 and b14 multipoles from Ezio) have shown:

  - **STRONG BB multipolar errors are marginal and negligible!**
    → Not our scenario!
  - **MEDIUM and WEAK BB: multipolar errrors do have important effects**
    - **Negative effect** → reductions of DA
    - **Positive effect** → increase of DA → Compensation effects
    - The impact on DA depends on the beams working point variations (10^{-3})
    - In the picture not yet in IP2-IP8 and other knobs Q', Octupoles…

Conclusions

- **The dynamics in the presence of BB is very complicated** with multipolar errors it becomes difficult to define tolerances: many effects (degradation/compensation)
  - Models have been tested versus BB dominated cases
  - Experimental studies are foreseen to study effects of controlled multipoles

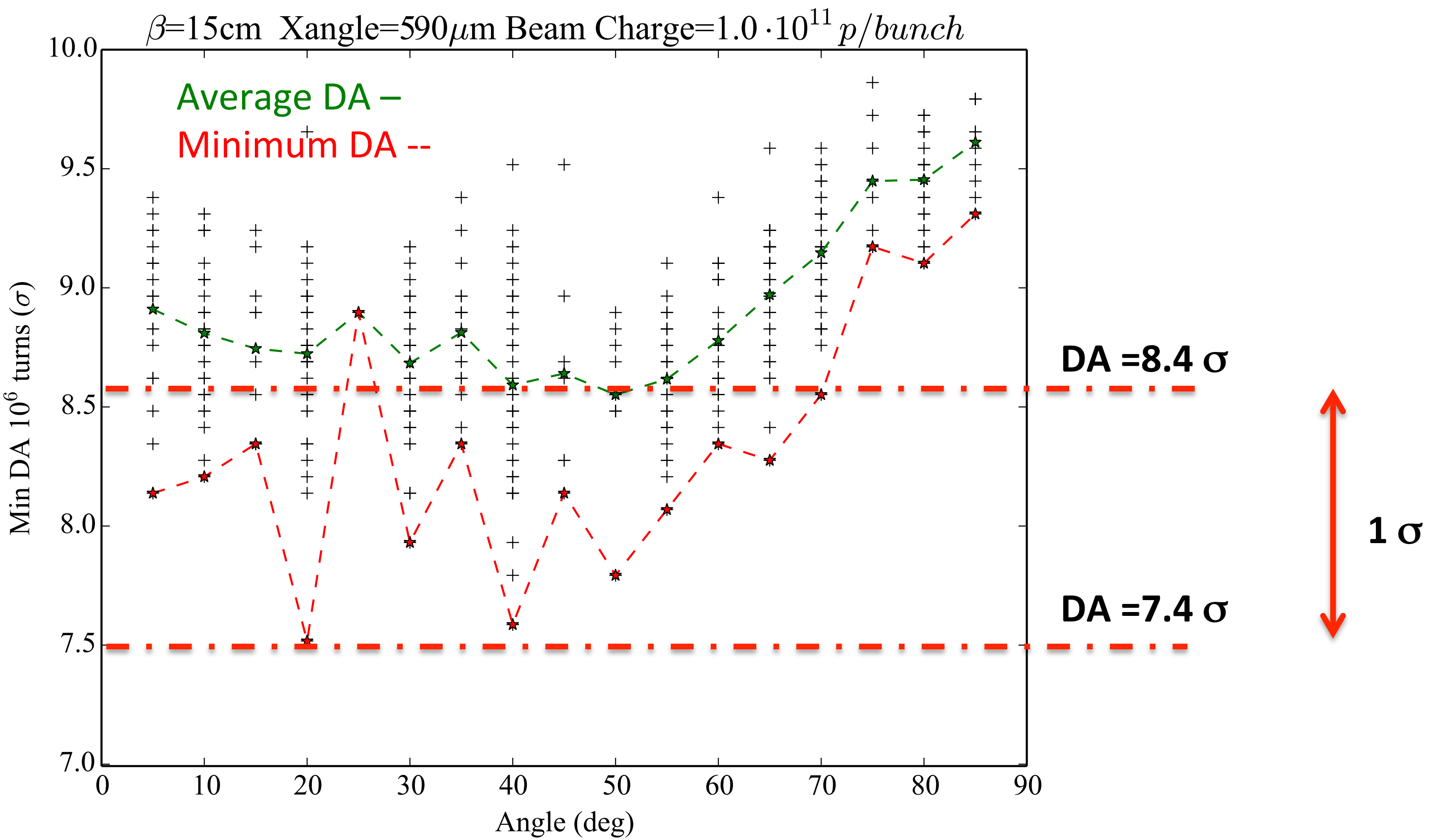
- **How to evaluate the tolerances on multipolar errors in the presence of BB?**
  → Different seeds give different effects

  - Take deviations from Beam-Beam driven DA due to errors: Maxima- Average-Minima should be evaluated versus Beam-Beam error bars (intensity and emittance fluctuations)

  - The single beam studies are simpler to estimate multipole impacts/ tolerances, maybe a bit over constraining but robust
    → Proved to be a successful point in the LHC

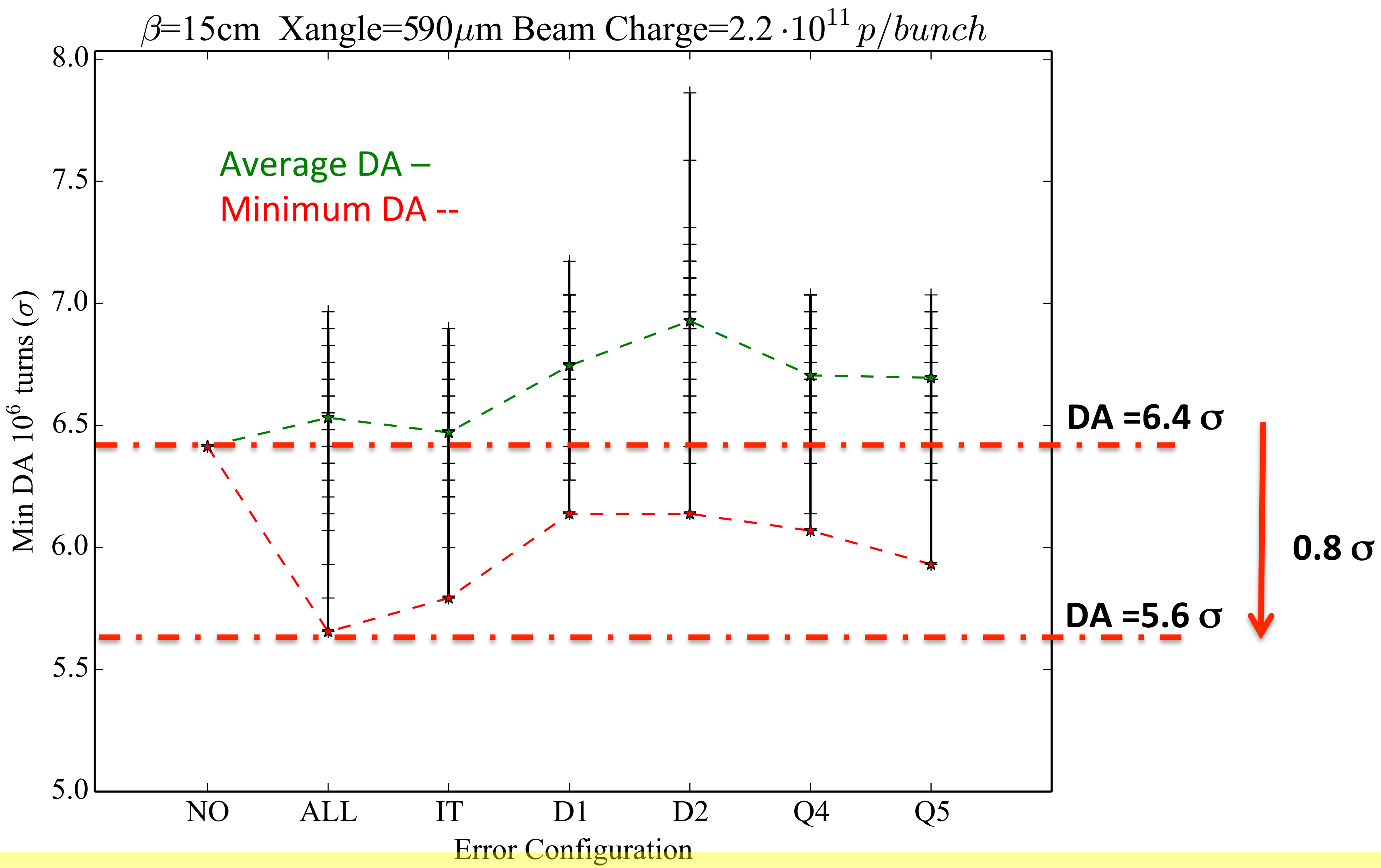
It is necessary to keep a "certain" margin between BB driven DA and single beam→ LHC design used factor 2 for HILUMI LHC we need further studies to evaluate

Multipolar errors impact IP1&5:
β* leveling



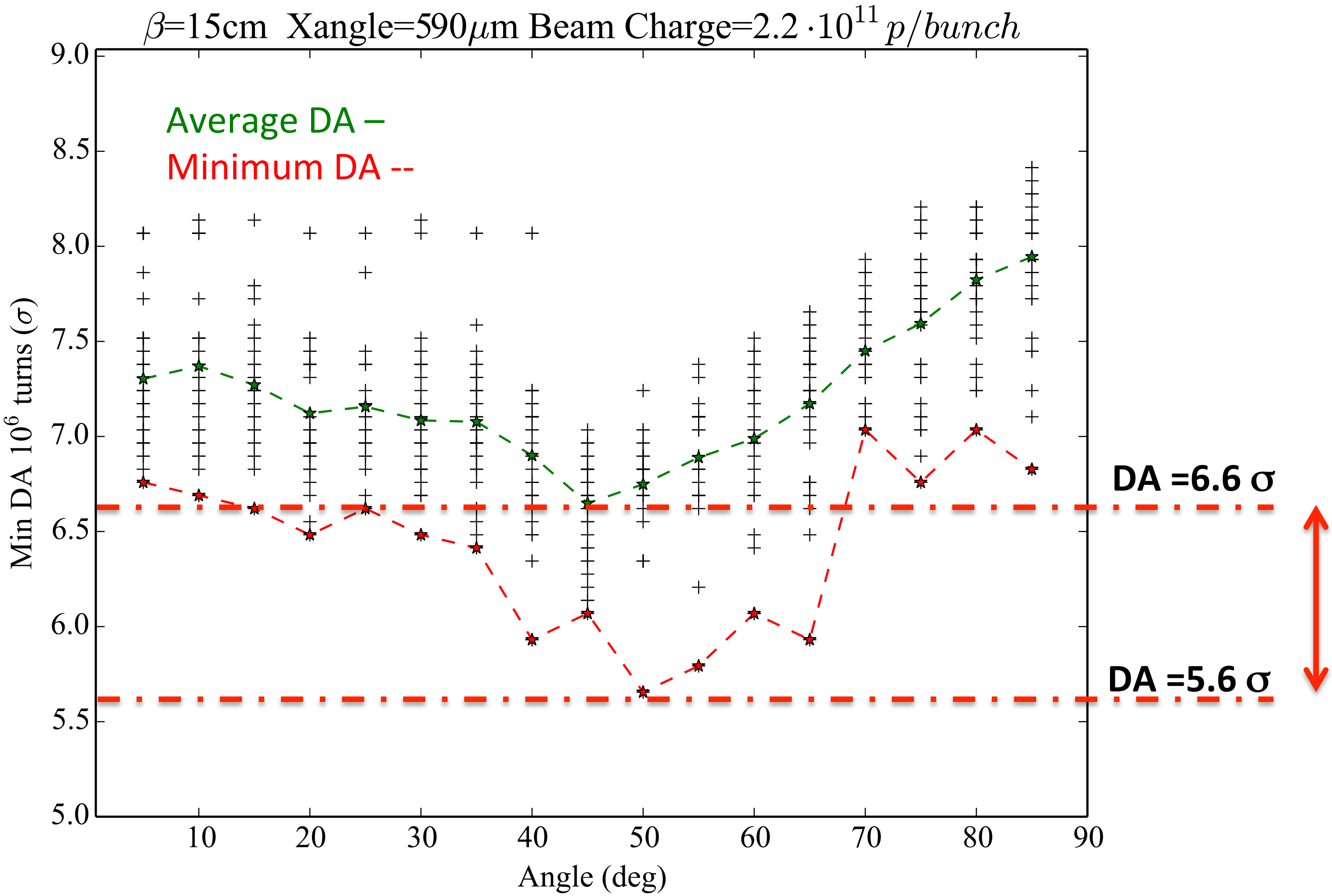
Minimum DA rigorous criteria for LHC design we all profited of in 2012.
Intensities up to 1.6e11 and emittances of 2-2.5μm

Multipolar errors impact IP1&5:
NO β* leveling



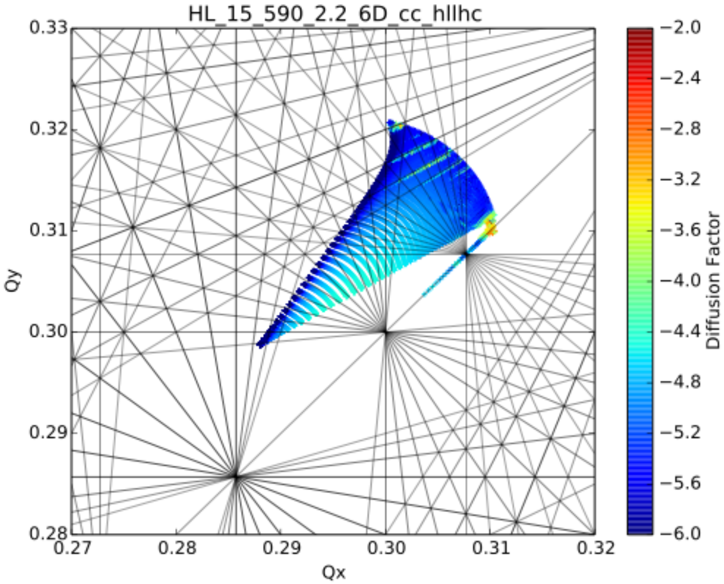
Errors do have an impact (0.8 σ reduction)
Dominated by Inner Triplet element and Q5…

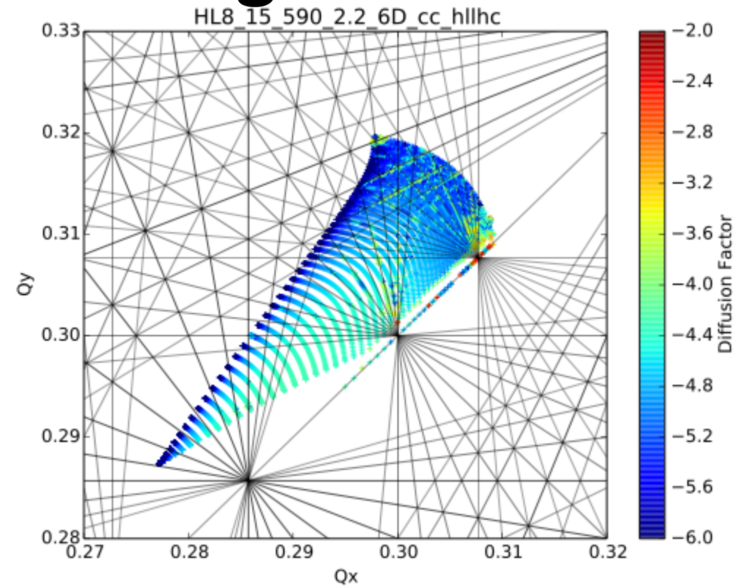
Multipolar errors impact IP1&5: NO β* leveling



Minimum DA criteria → LHC design criteria shown to be successful

What do we need these margins for?



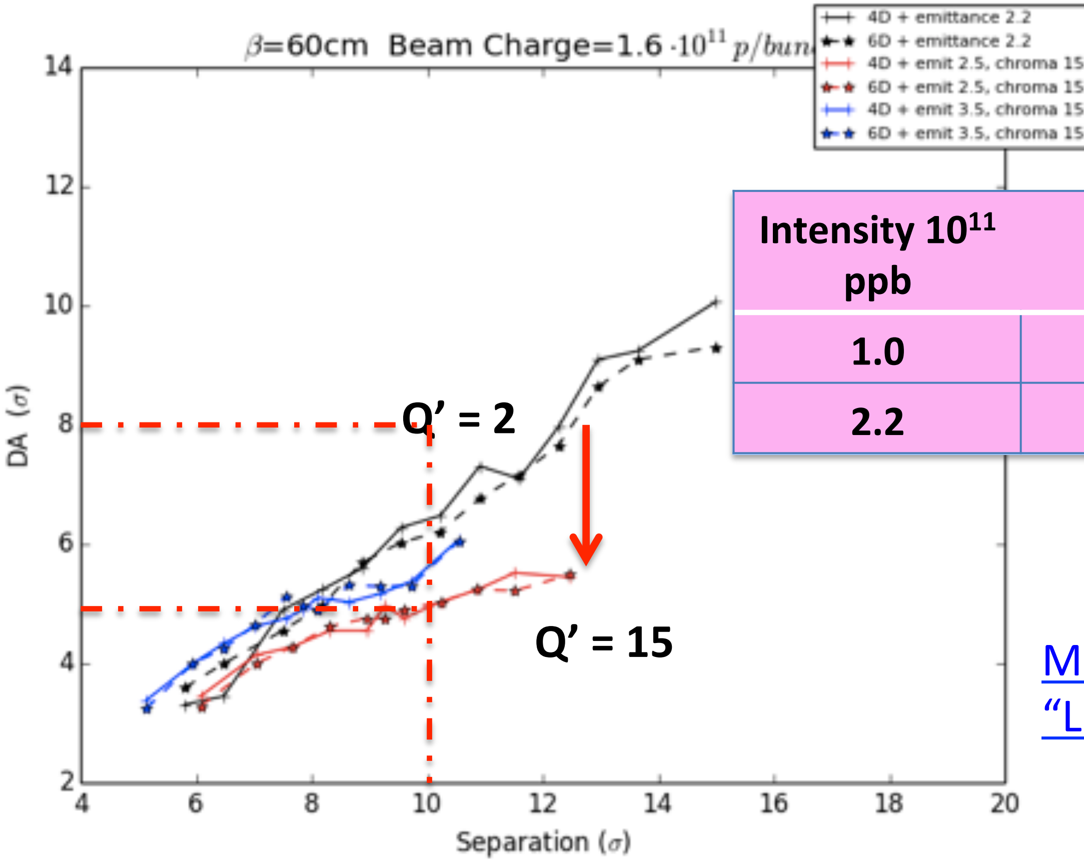


Intensity 10^{11} ppb	IP1&5	IP8 (-340mrad ext x-angle -270μrad septrometer)	IP8 (-560μrad ext x-angle + 270μrad spectrometer)	IP8 (-340μrad +270μrad spectrometer)
1.0	8.41	8.07	7.93	7.72
2.2	6.42	6.28	6.06	5.86

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

M. Lamont
"Lifetimes in Stable Beams Revisited"

CHROMATICITY HAS A VERY STRONG IMPACT!

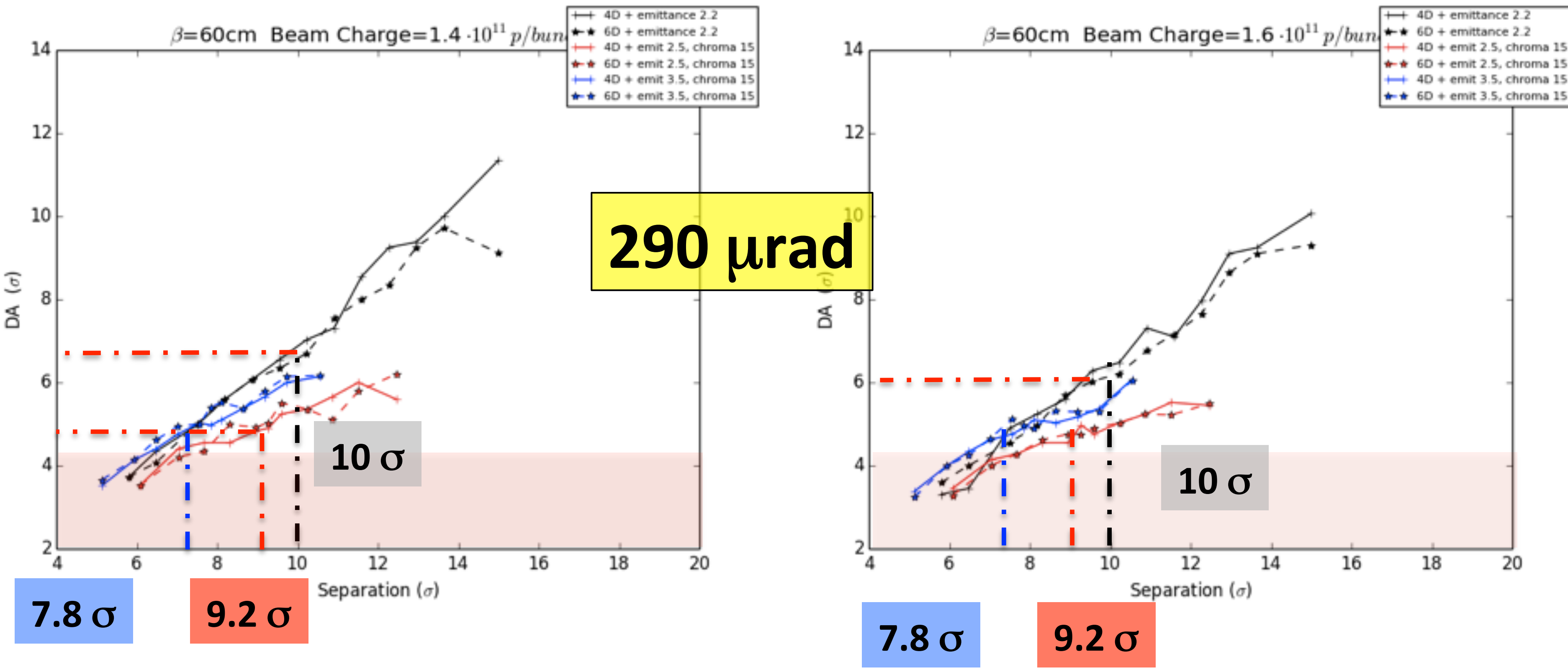
If for any reason we need to use it (i.e. stability in collision) then no margins!

Have we seen this in 2012? Yes!

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

Something else….

2) Second Part Year: Q' = 15 (No Octupoles)



Chromaticity has a BAD impact on DA!

During physics fills without octupoles we were on the limit any particle at 4-5 sigma was lost!

Chaotic motion starts before, 2 sigma particles.

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