Beam-beam effects for round and flat optics: DA simulations

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Acknowledgement: R.DeMaria,M.Giovannozzi, lhc@home team

Possible Scenarios :

Baseline1 : Luminosity of 5e34

- Round optics: 70cm → to 10cm β*
- Full crab crossing in IP1 and IP5
- Leveling luminosity with β* in IP1, IP5.
- Adding contribution of IP8 and IP2
- Minimum crossing angle/Maximum Intensity

Flat Optics

- From round to flat optics (40/40 down to 30/7.5 cm)
- No crab crossing
- Leveling luminosity with β* in IP1, IP5.

Baseline2 : Luminosity of 7.5e34

- Round optics: 33cm → to 10cm β*
- Full crab crossing in IP1 and IP5
- Leveling luminosity with β* in IP1 & IP5
- Adding contribution of IP8 and IP2

Extreme Case: no β* leveling

- 15cm β* Round optics
- No β* leveling
- Nominal crossing angle 590 μrad IP1&5

BB expected Effects for Possible Scenarios

Baseline1 : Luminosity of 5e34

Head-on strong ΔQ = max 0.033 to → 0.01
Long Range:
IP1&5 From 26σ → 12.5σ (Int 2.2e11 → 1.1e11)
IP8 2 LR at 5s (others > 20σ)
IP2 all > 30σ

Flat Optics

Moderate HO
From round → flat (40/40 →30/7.5 cm β*)
Leveling luminosity with β* in IP1, IP5.
→ R. Tomas talk "Alternative scenarios"

Baseline2 : Luminosity of 7.5e34

Head-on strong ΔQ = max 0.033 to → 0.01
Long Range:
IP1&5 From 18σ → 12.5σ (Int 2.2e11 → 1.5e11)
IP8 2 LR at 5s (others > 20σ)
IP2 all > 30σ

Extreme Case: no β* leveling

Head-on strong ΔQ = max 0.033 to → 0.01
Long Range: strongest
→ IP1&5 at 12.5 σ at Int 2.2e11

GOALS:

Ensure that a 6 σ DA and define constrains:

- Minimum crossing angle acceptable
- Intensity limits
- IPs contribution
- Multipolar errors effect
- Other parameters that could reduce performances

Simulation Summary

Explore the parameter range:

- round optics (10,15,33,40 cm)
- flat optics (30cm/7.5cm, 40/10,40/20,40/30,40/40)
- 4D/6D BB lens
- X-angle scan from 190 —>790urad
- Normalized Emittance = 2.5 μm
- Initial amplitude from 0—>12σ
- Beam intensity from 0.9E11—>3.0E11 ppb
- 17 angle in xy plane (every 5 deg)
- w & w/o multipolar errors
- w & w/o Crab Crossing
- 2 Ips
- IP8 contribution
- single multipolar error family contribution
- HLLHCV1.0 and SLHCV3.1b optics

To be done:

- IP2 not in the picture yet but marginal effects (d_{sep} > 30σ)

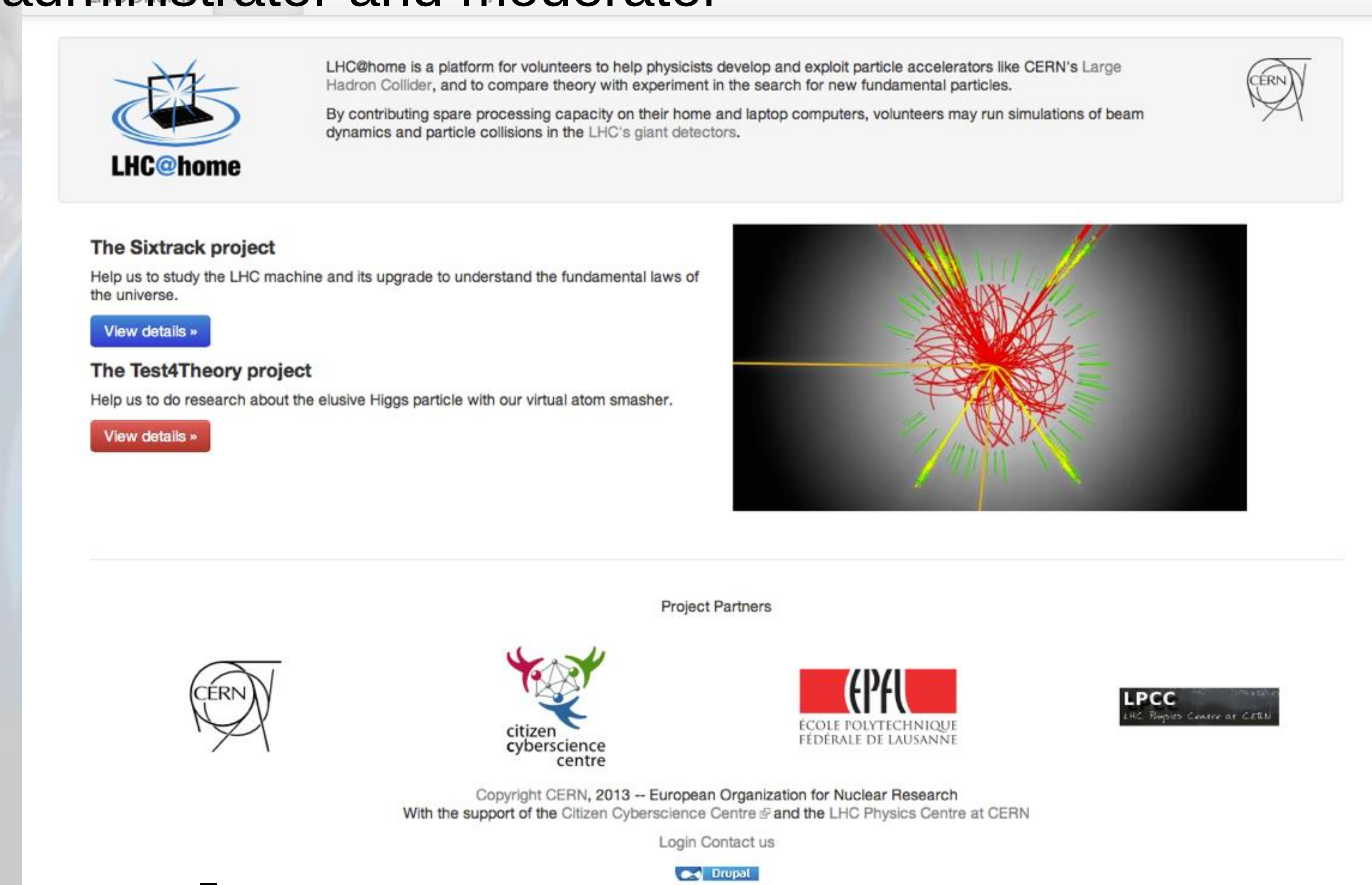
LHC@Home

Close to 10Mjobs to cover all possible cases!
It’s impossible to run such number of jobs on CERN lsf:
BOINC is the only way to go! **EPFL** is proud sponsor of the LHC@Home project on BOINC platform!

We are at present :

- Testing existing and developing new features
- Extensive use (more than 30M jobs up to now…)

- Forum administrator and moderator



http://lhcathomeclassic.cern.ch/sixtrack/
http://lhcathome.web.cern.ch

Thanks to LHC@Home Team for the support (E.McIntosh, R.Demaria, I.Zacharov, N. Hømyr et al.)
and to CERN-IT team.

Outline

Round optics IP1(ATLAS) and IP5 (CMS) main drivers:

- Crossing angle scans
- Intensity scans
- Effect of crab crossing
- Impact of multipolar errors
- Impact of IP8 (LHCb)
- Summary of 5e34 and 7.5e34 Lumi scenarios

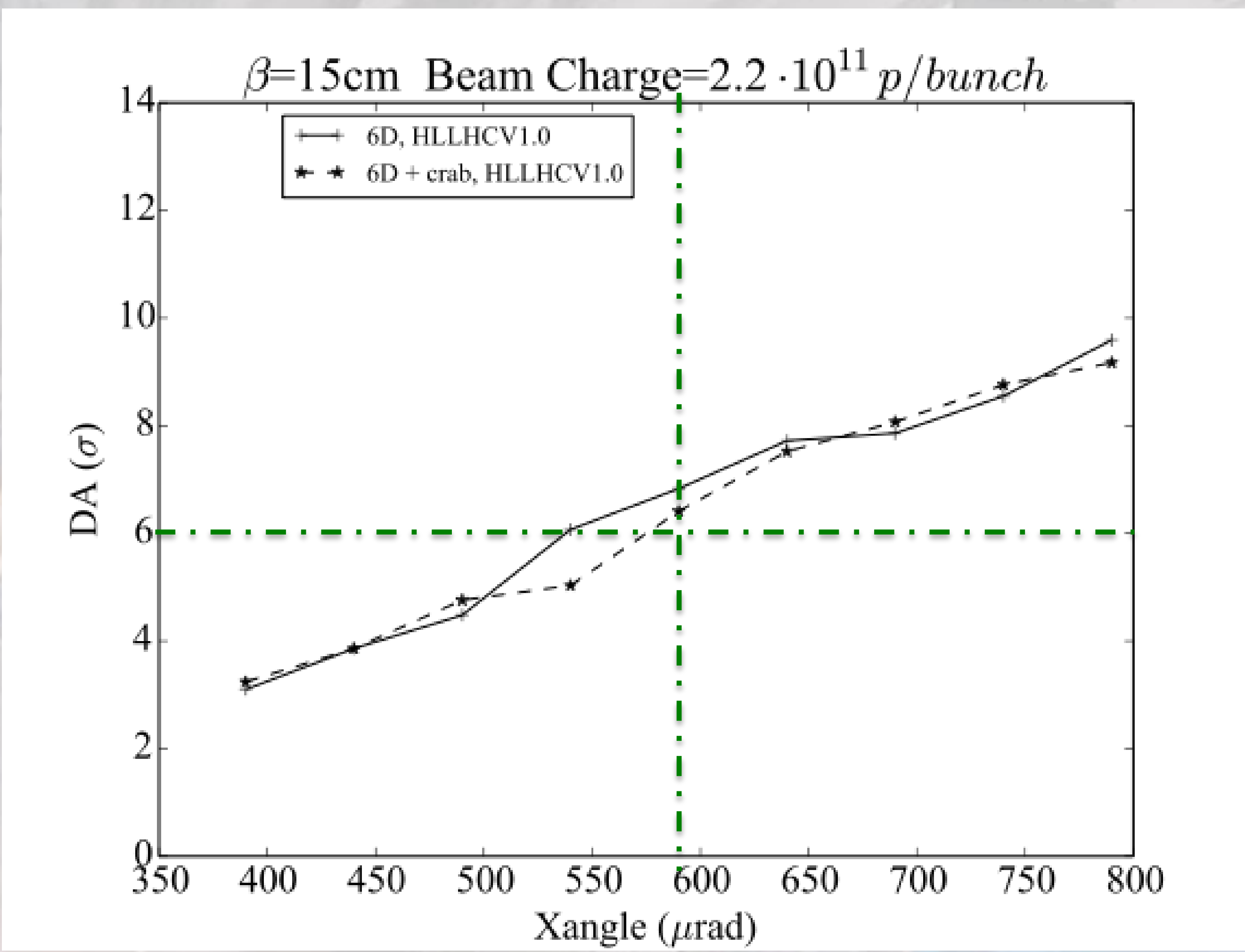
Flat optics:

- Crossing angle scans
- Intensity scans
- Multipolar Errors
- Possible use → R. Tomas talk

Summary and Future work

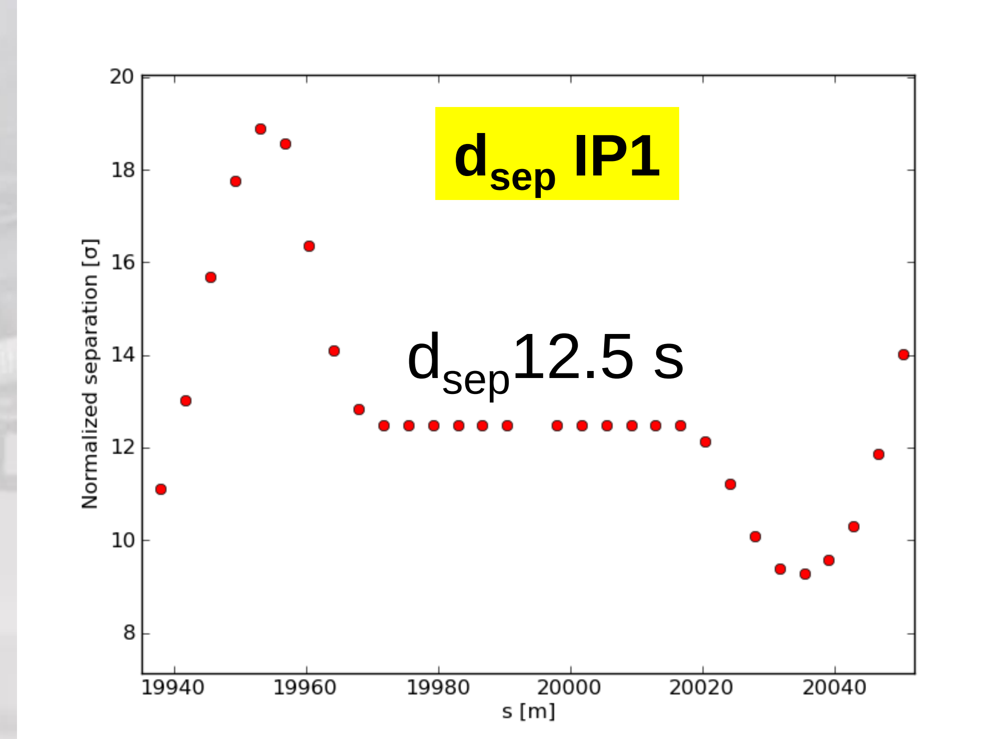
Round optics15 cm, 2.2E11: crossing angle scan

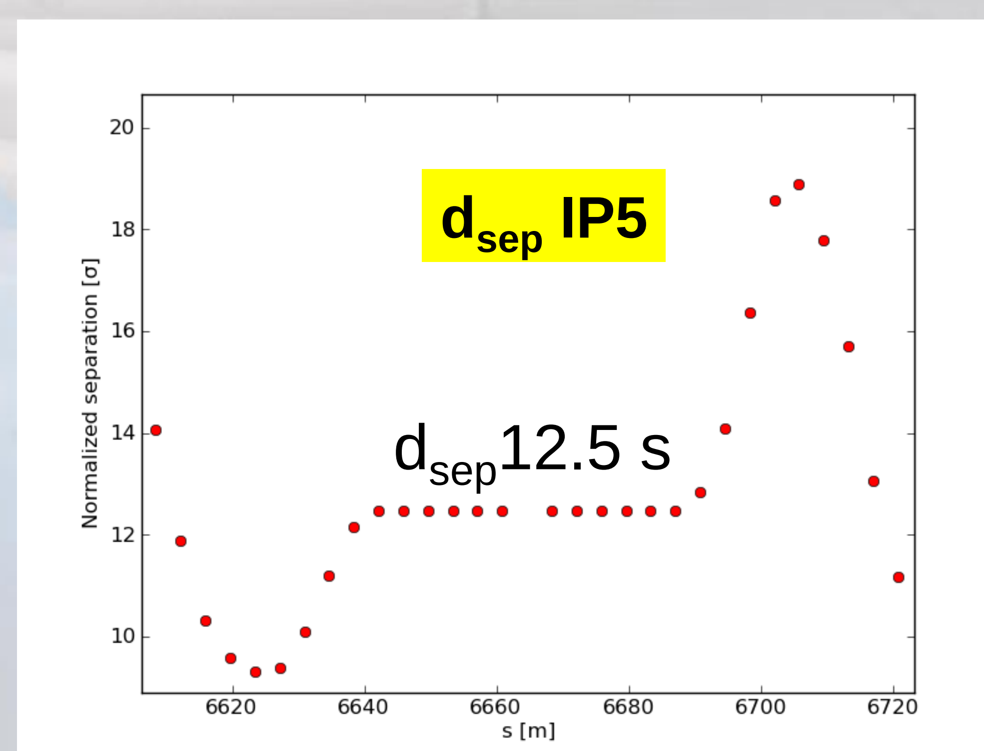
IP1 & IP5 only HLLHCV1.0 optic



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

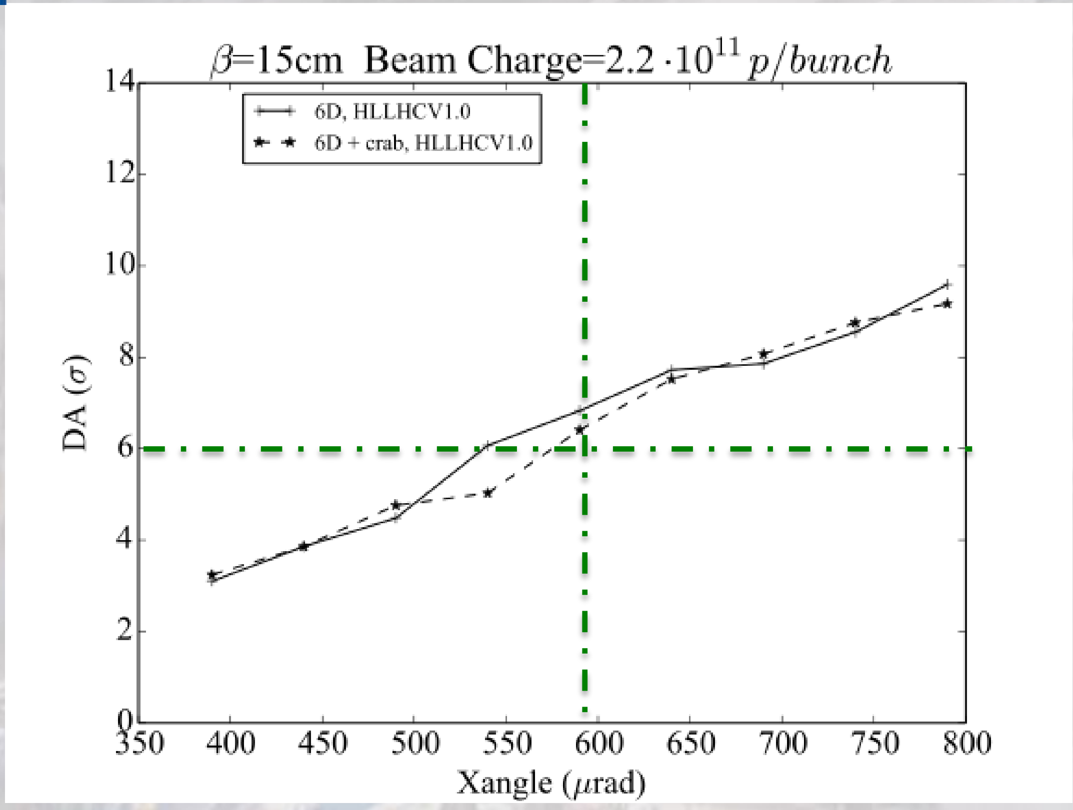
$$DA \propto d_{sep} \propto \alpha$$





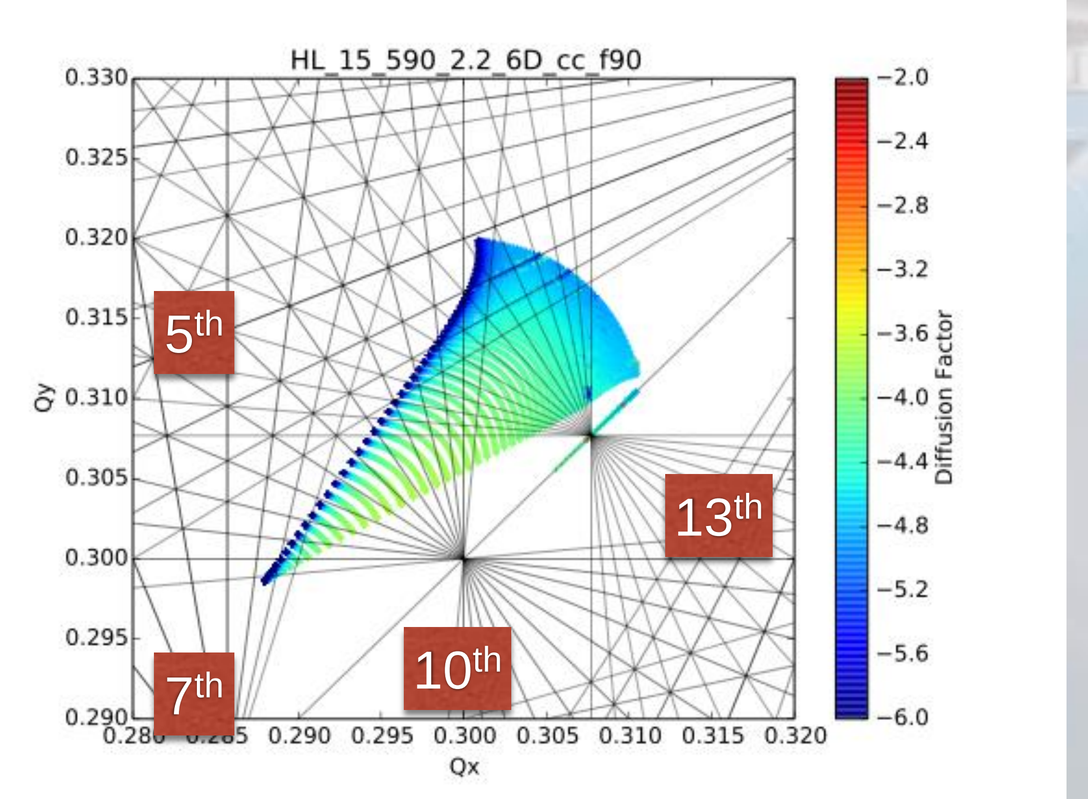
Beam beam LR separation is proportional to crossing angle. Reducing angle → reduce separation → increase beam beam LR effects and decreases DA linearly

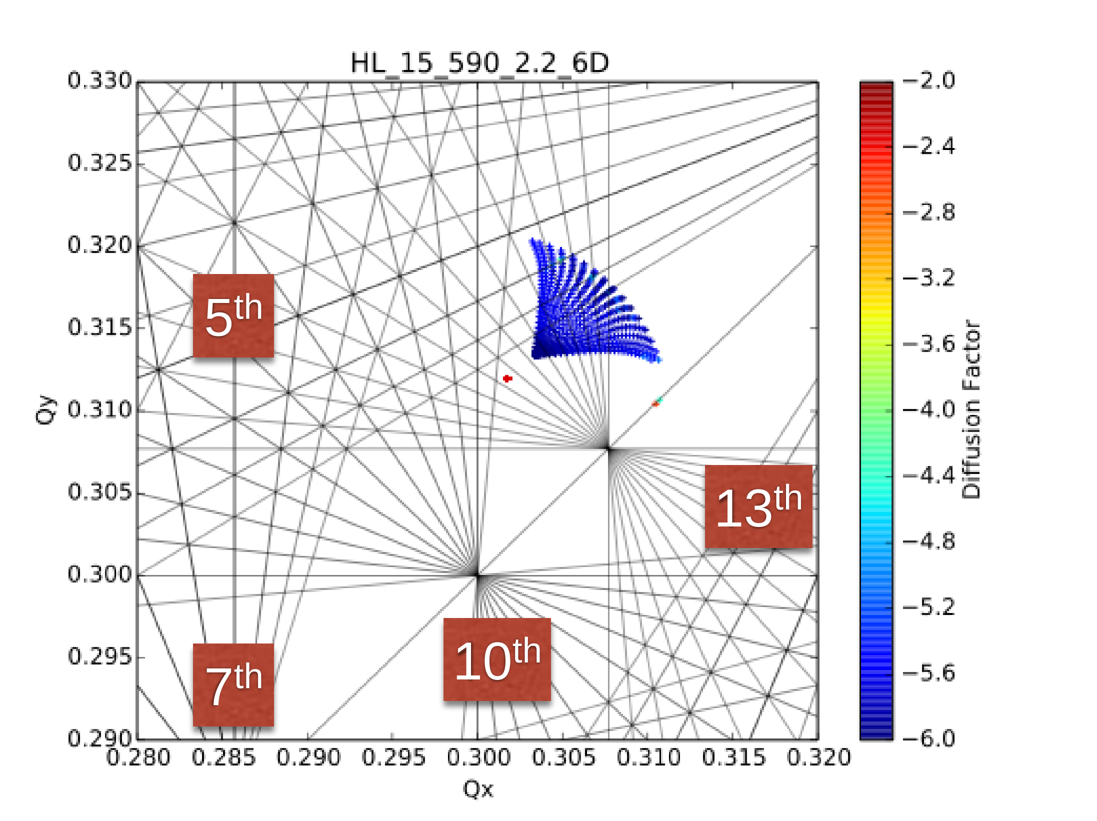
Nominal scenario: Full Crabing



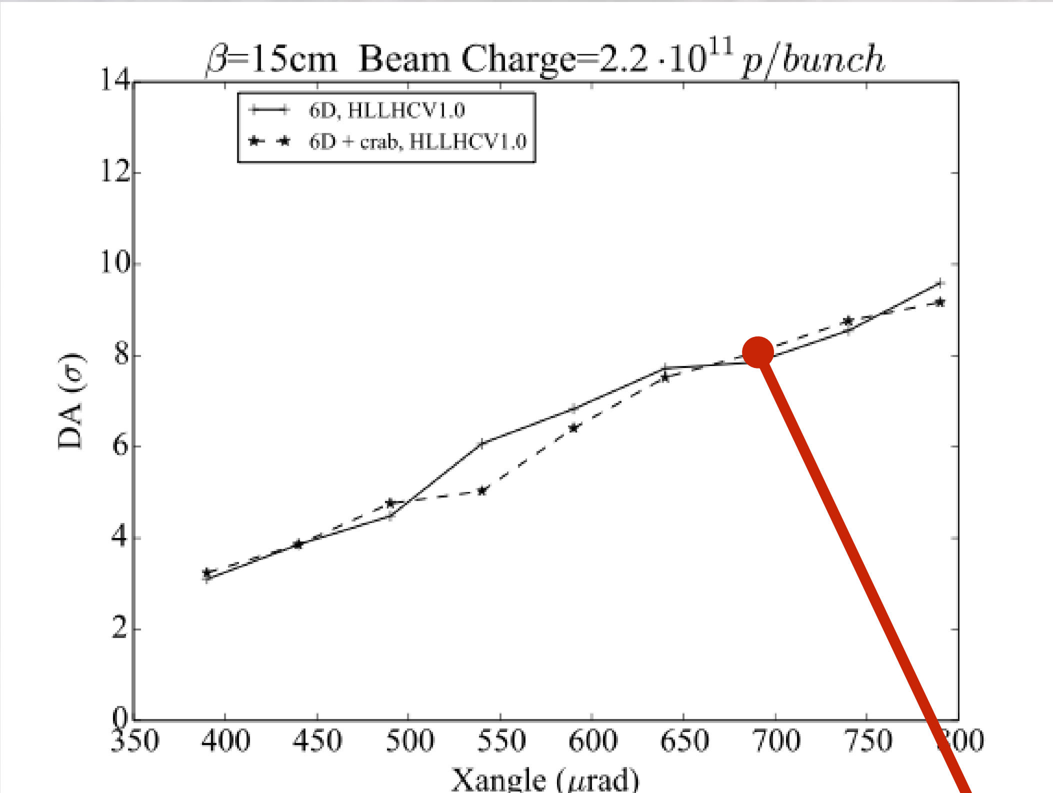
IP1 & IP5 only HLLHCV1.0 optic

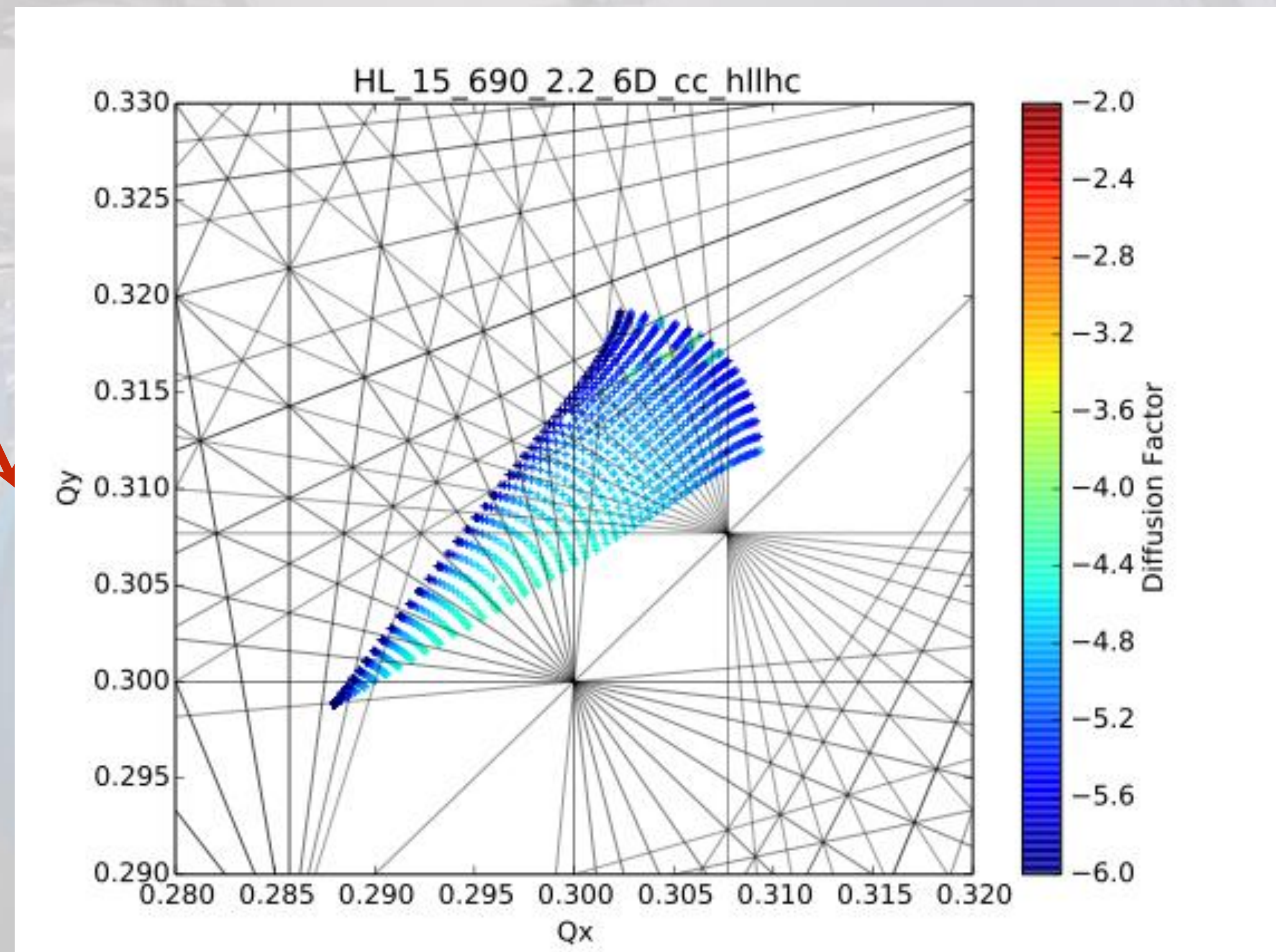
Crab Crossing introduces large HO tune shift
Different resonances are crossed
We should choose working points very carefully to avoid reduction of performances.
Our limits seems coming from 13th-5th and diagonal resonances



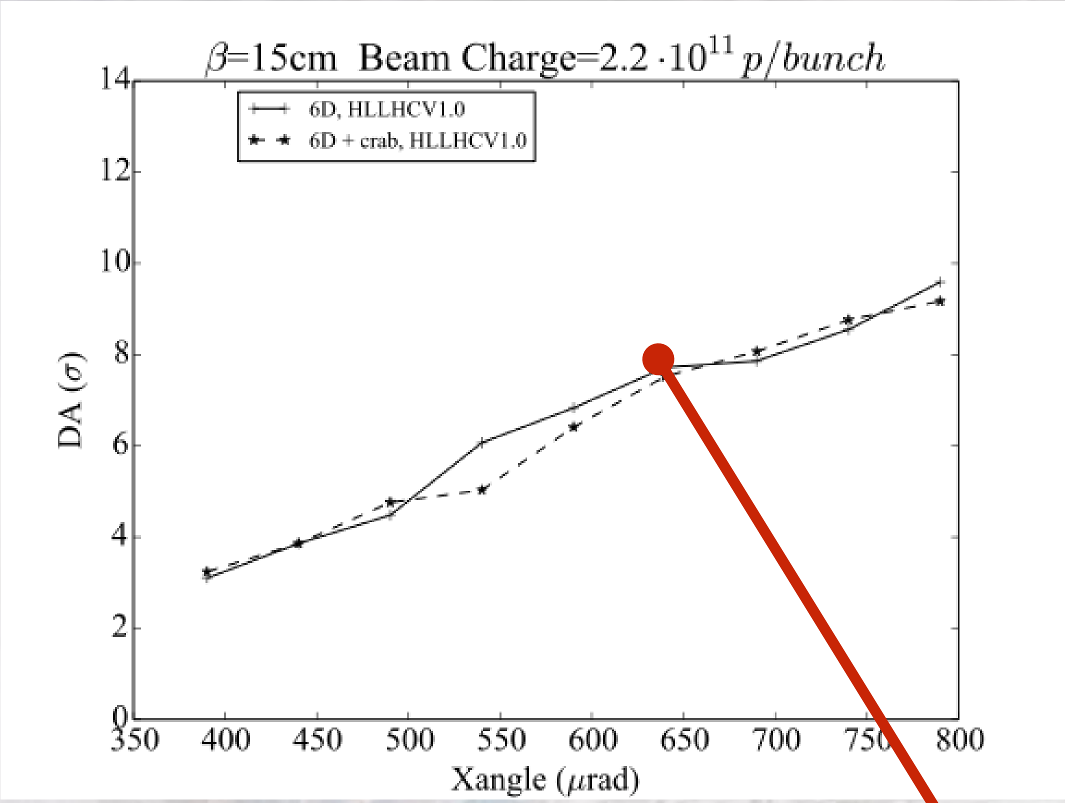


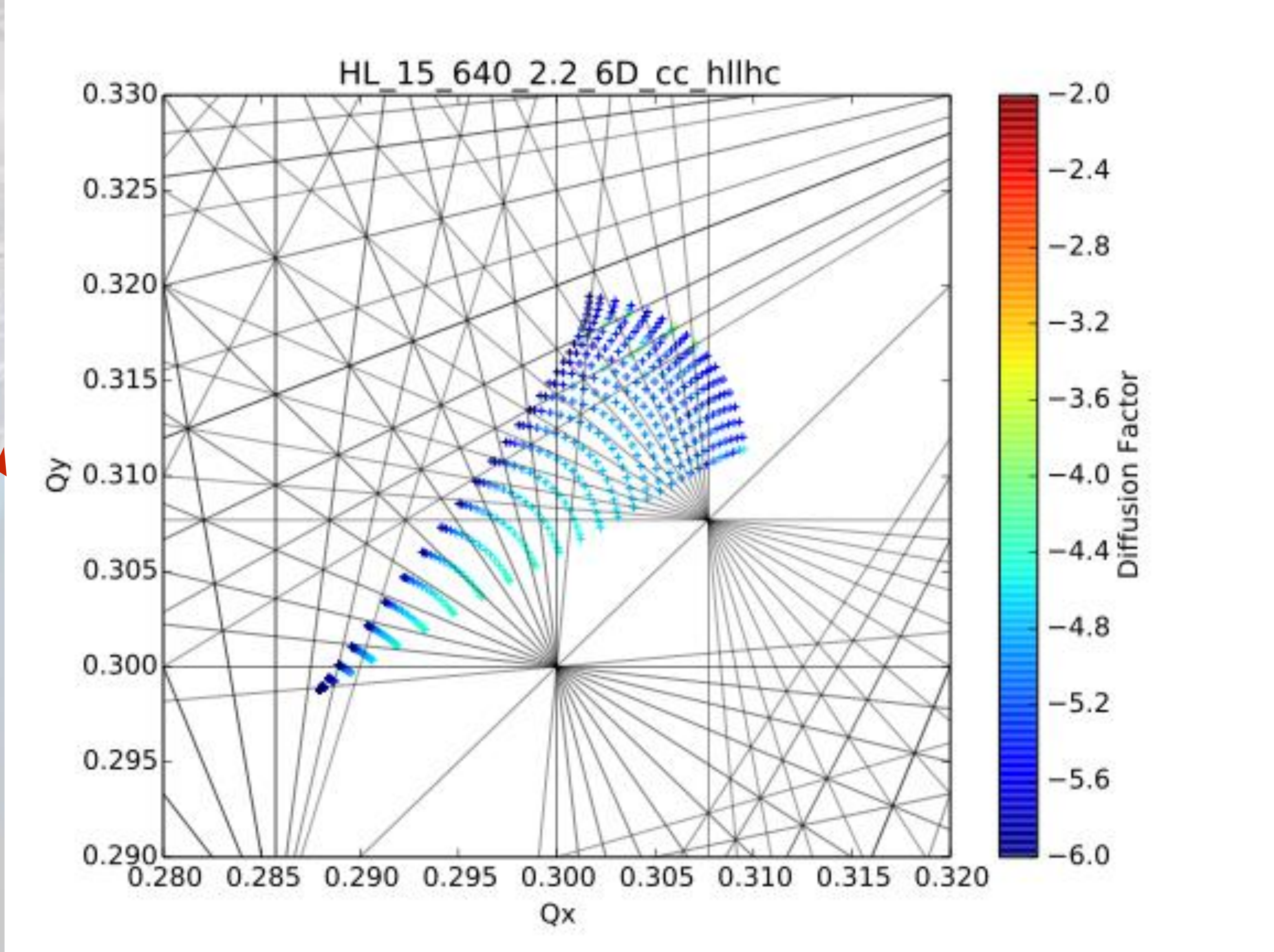
Round 15cm, 2.2E11, 690μrad



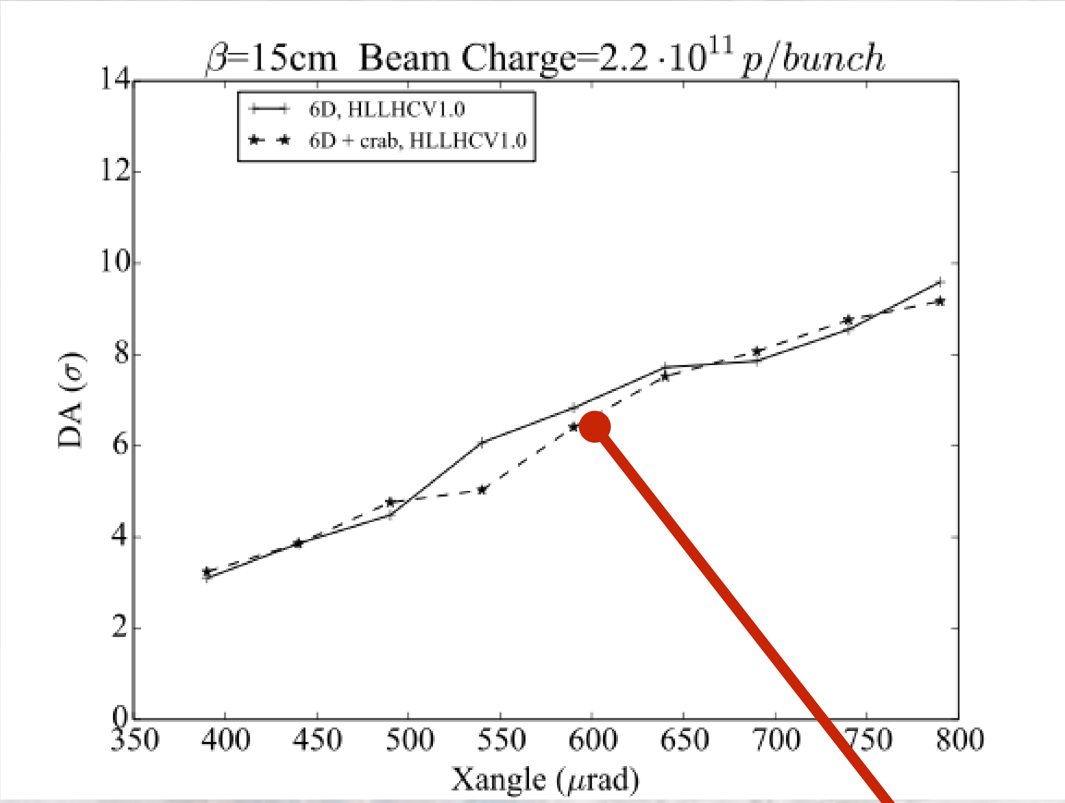


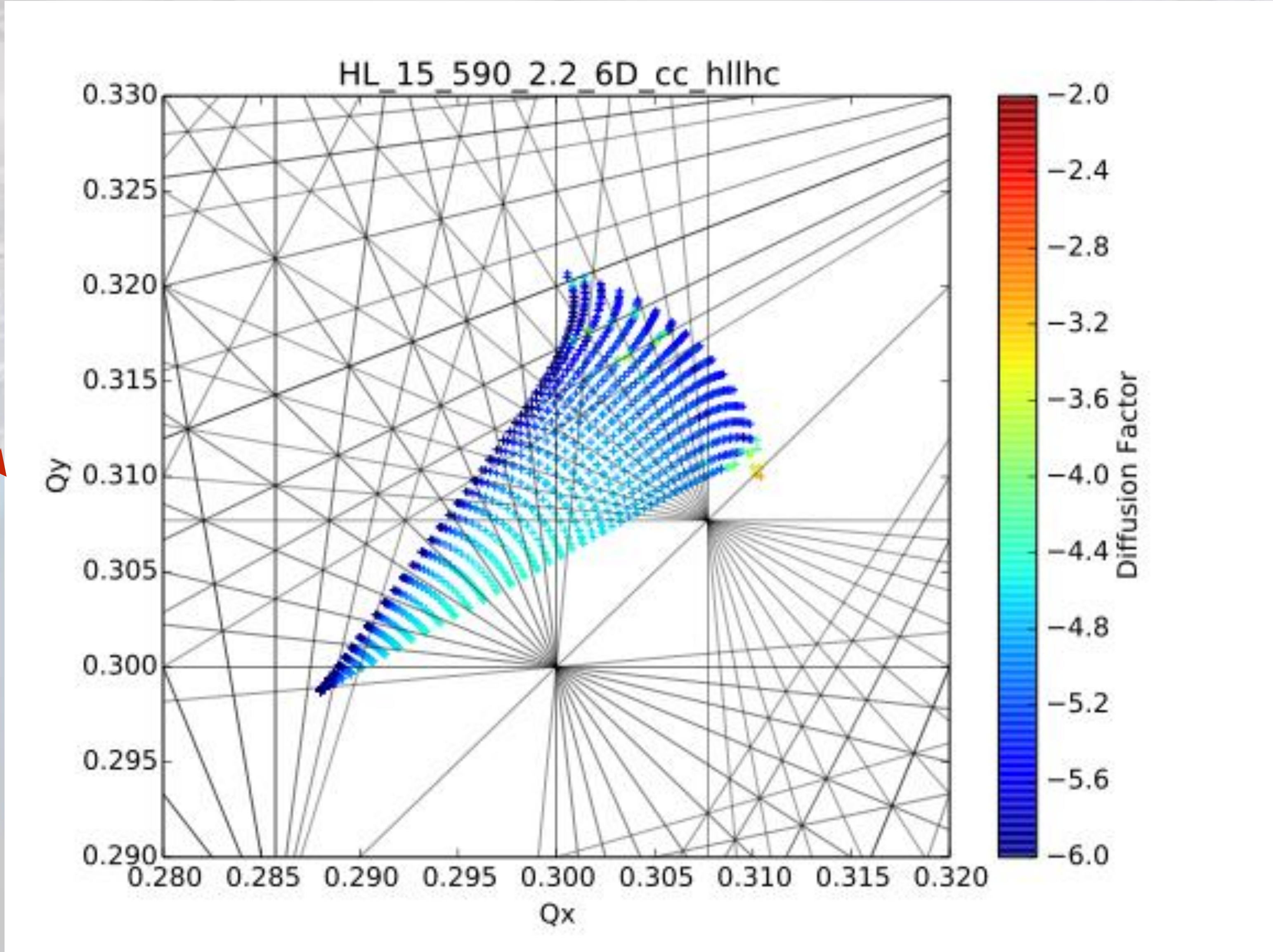
Round 15cm, 2.2E11, 650μrad



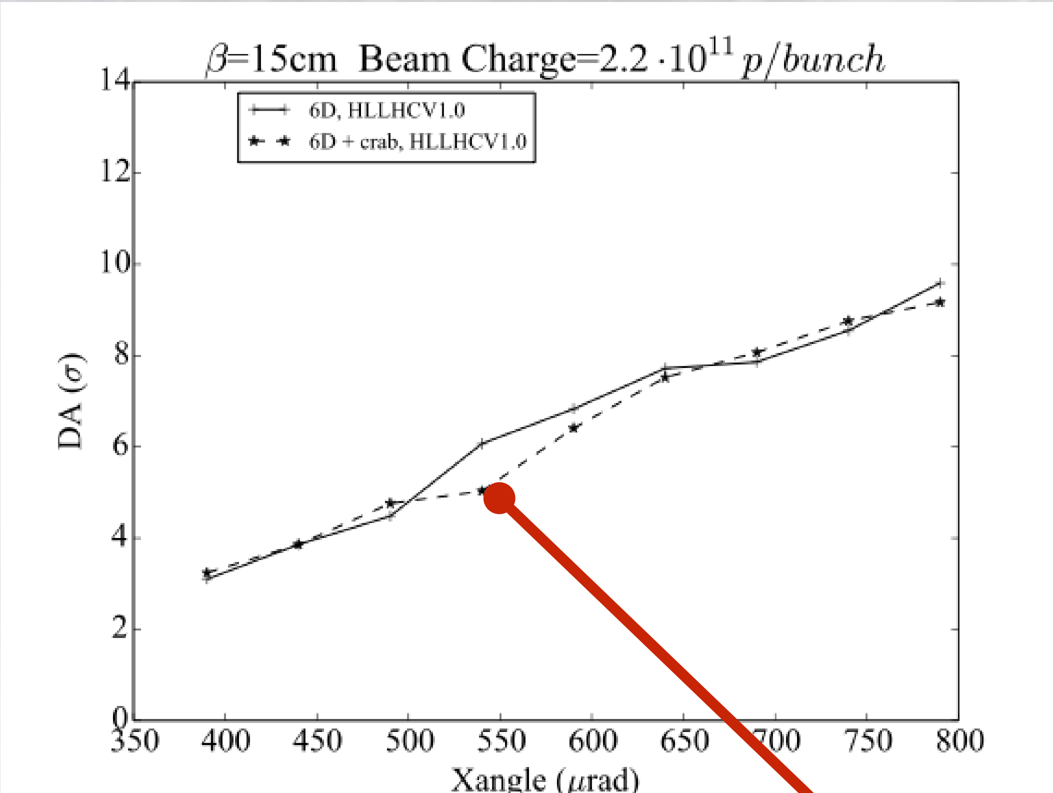


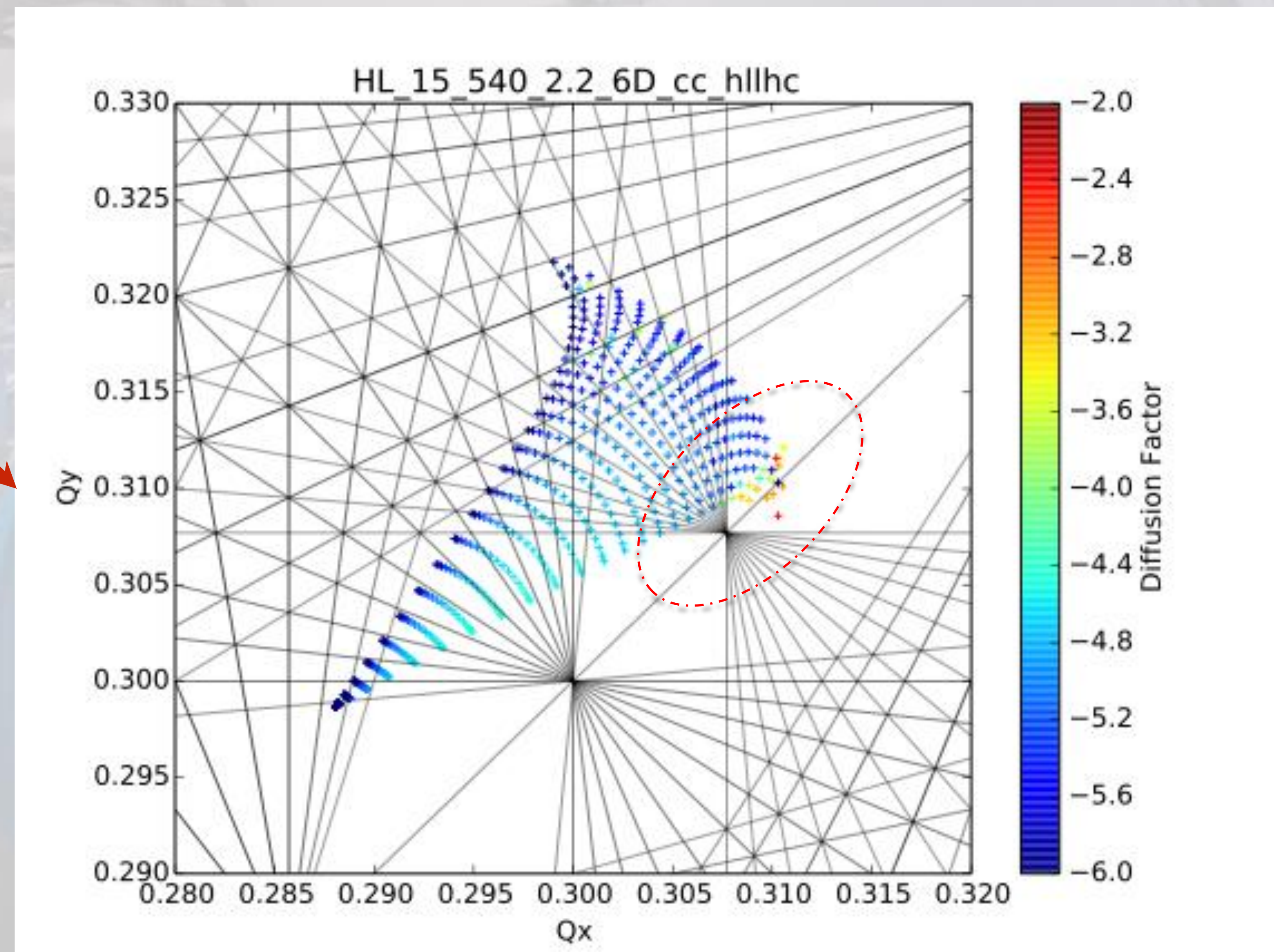
Round 15cm, 2.2E11, 590μrad



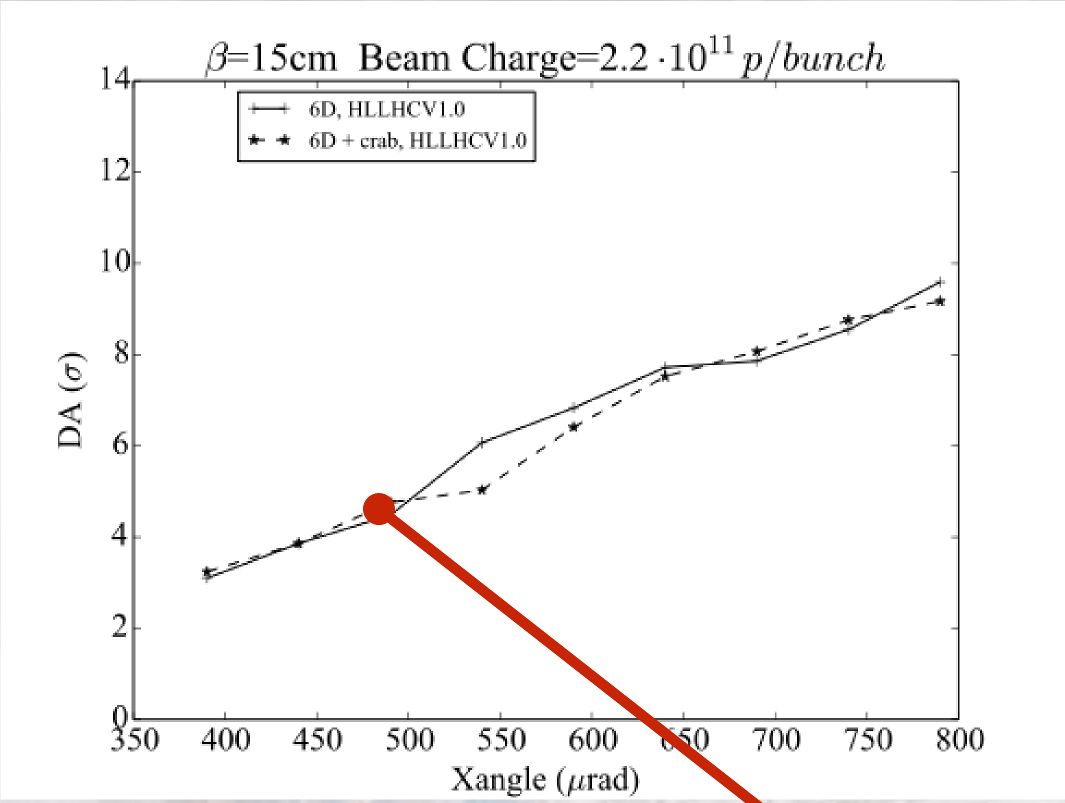


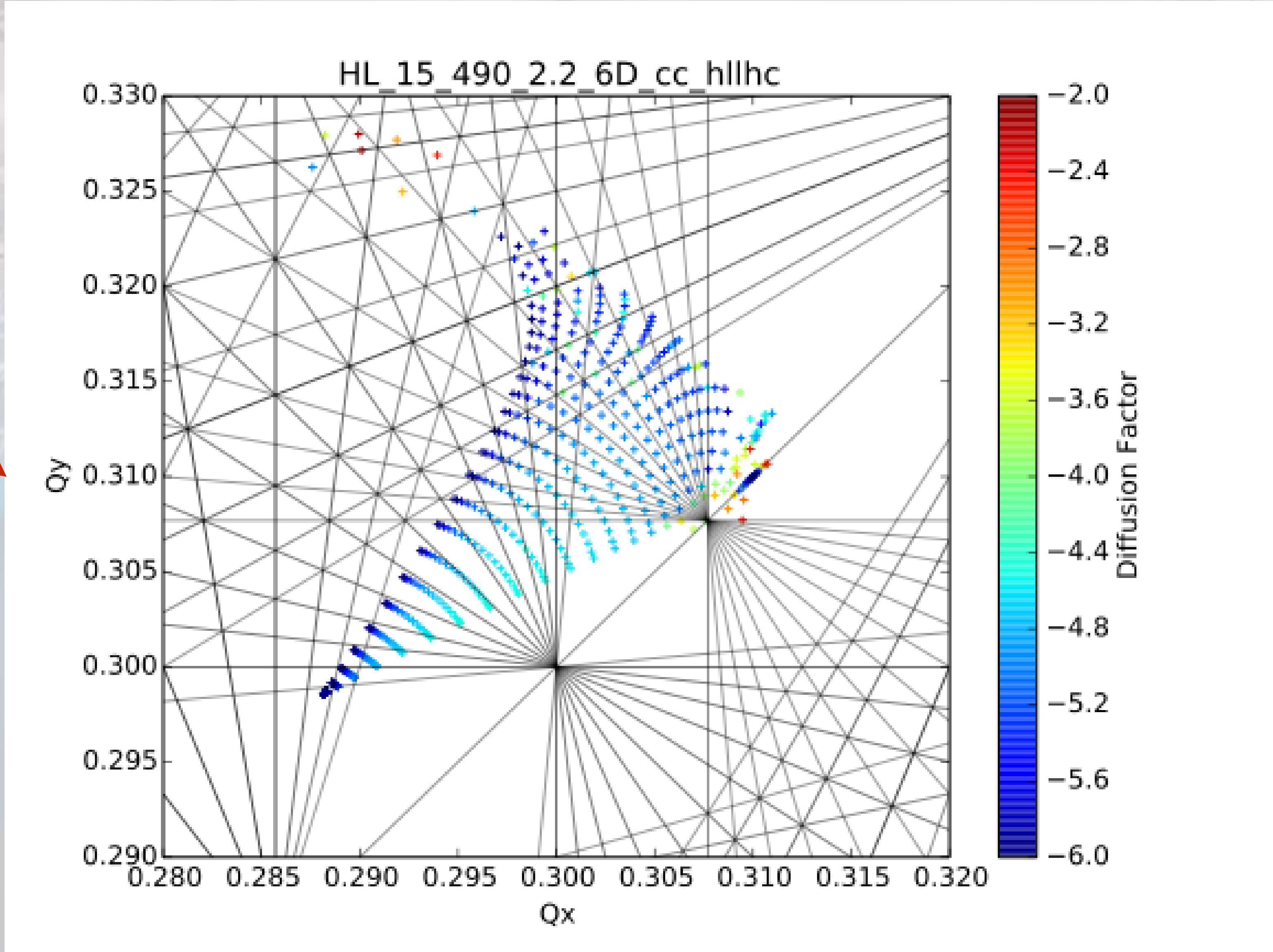
Round 15cm, 2.2E11, 540μrad



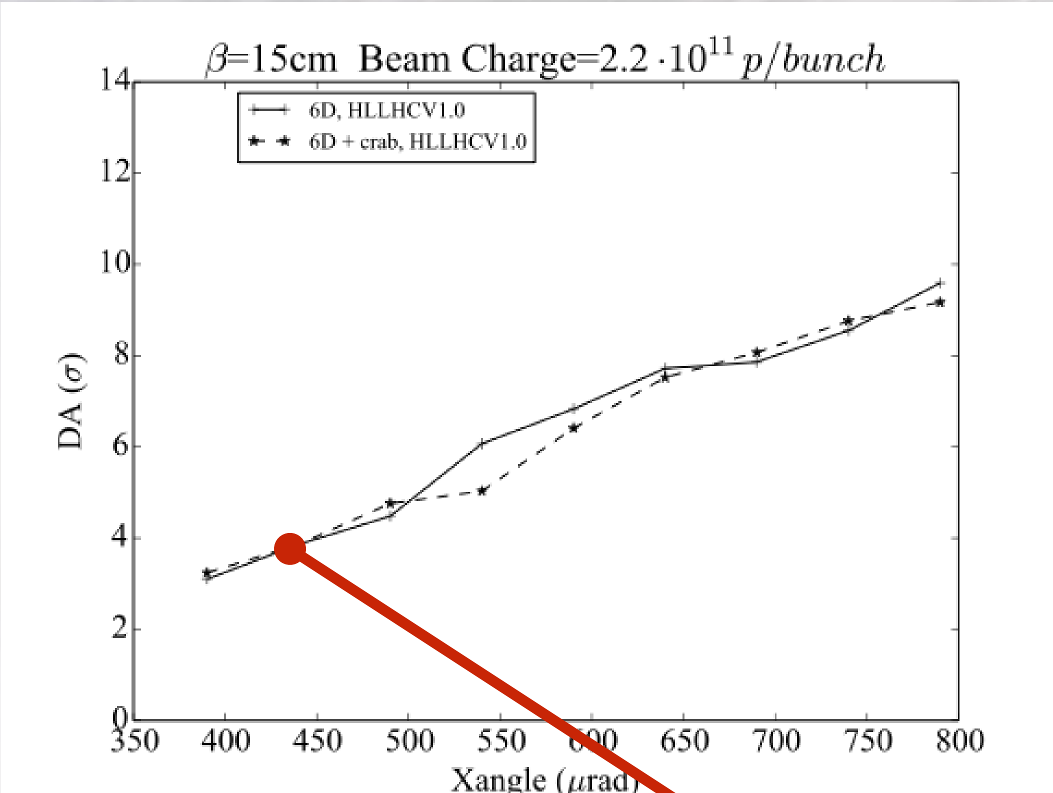


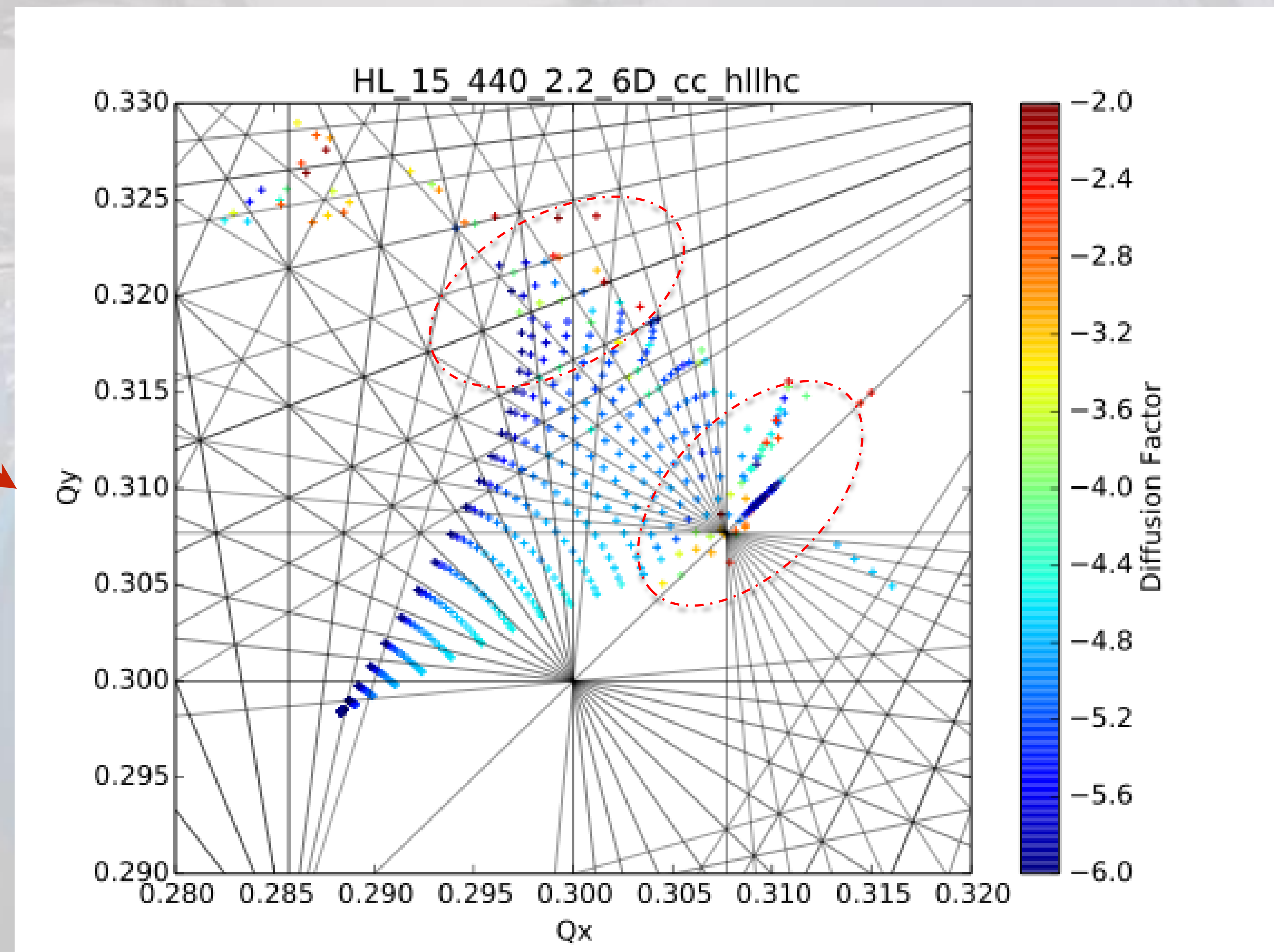
Round 15cm, 2.2E11, 490μrad



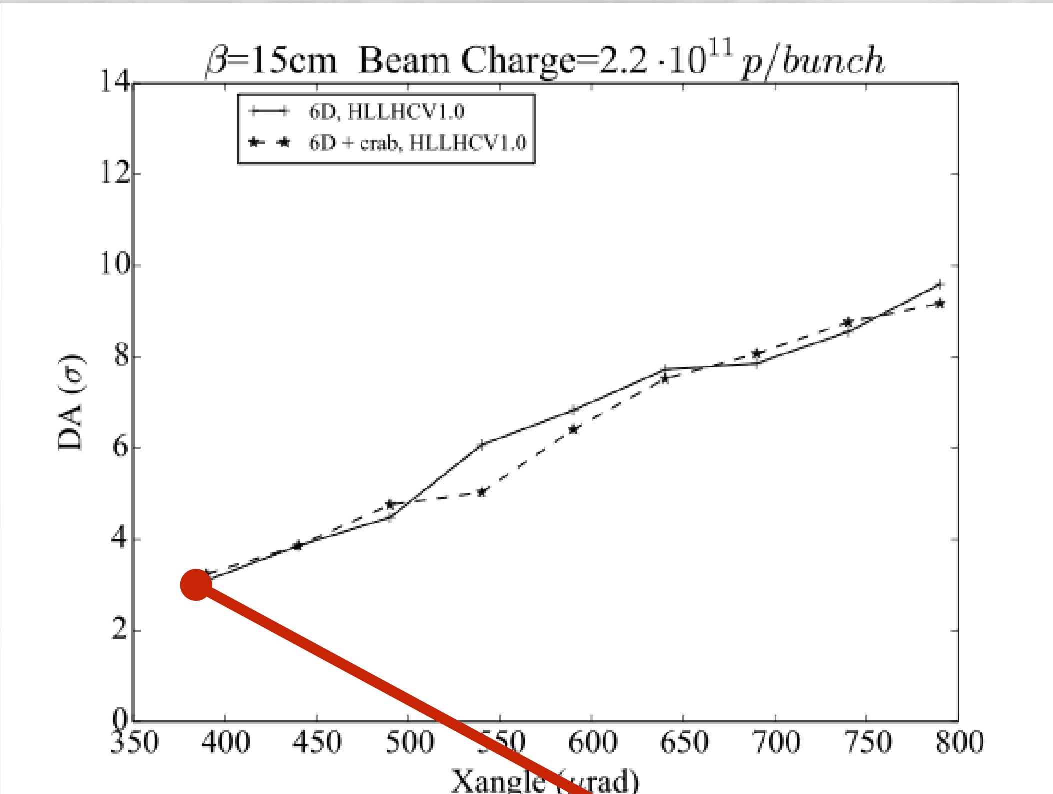


Round 15cm, 2.2E11, 440μrad

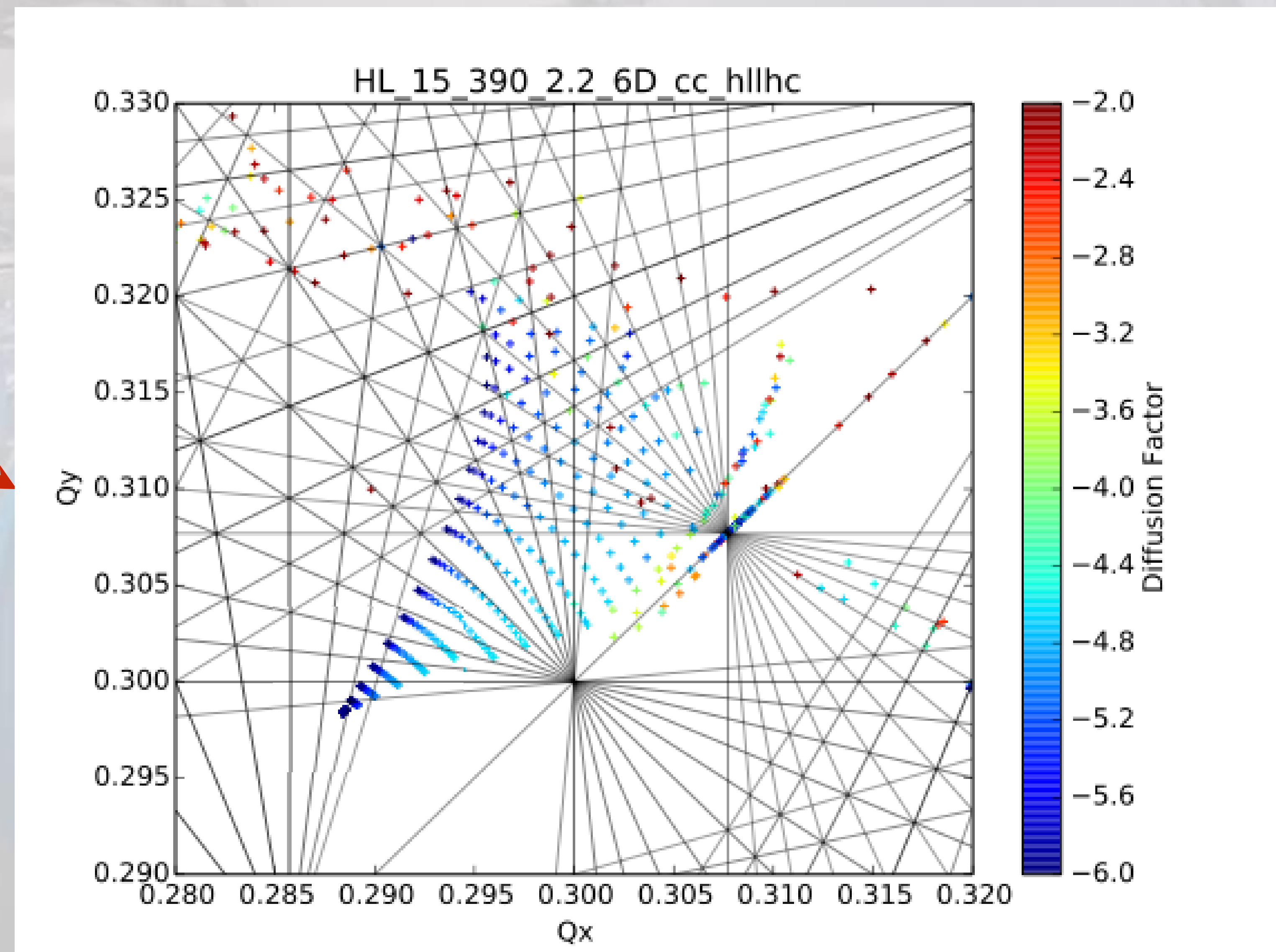




Round 15cm, 2.2E11, 390µrad



Crossing angle changes the separation (strength) of BB-LR that strongly affect the tails.
Core particles are almost not affected.
DA mainly dominated by long range effects

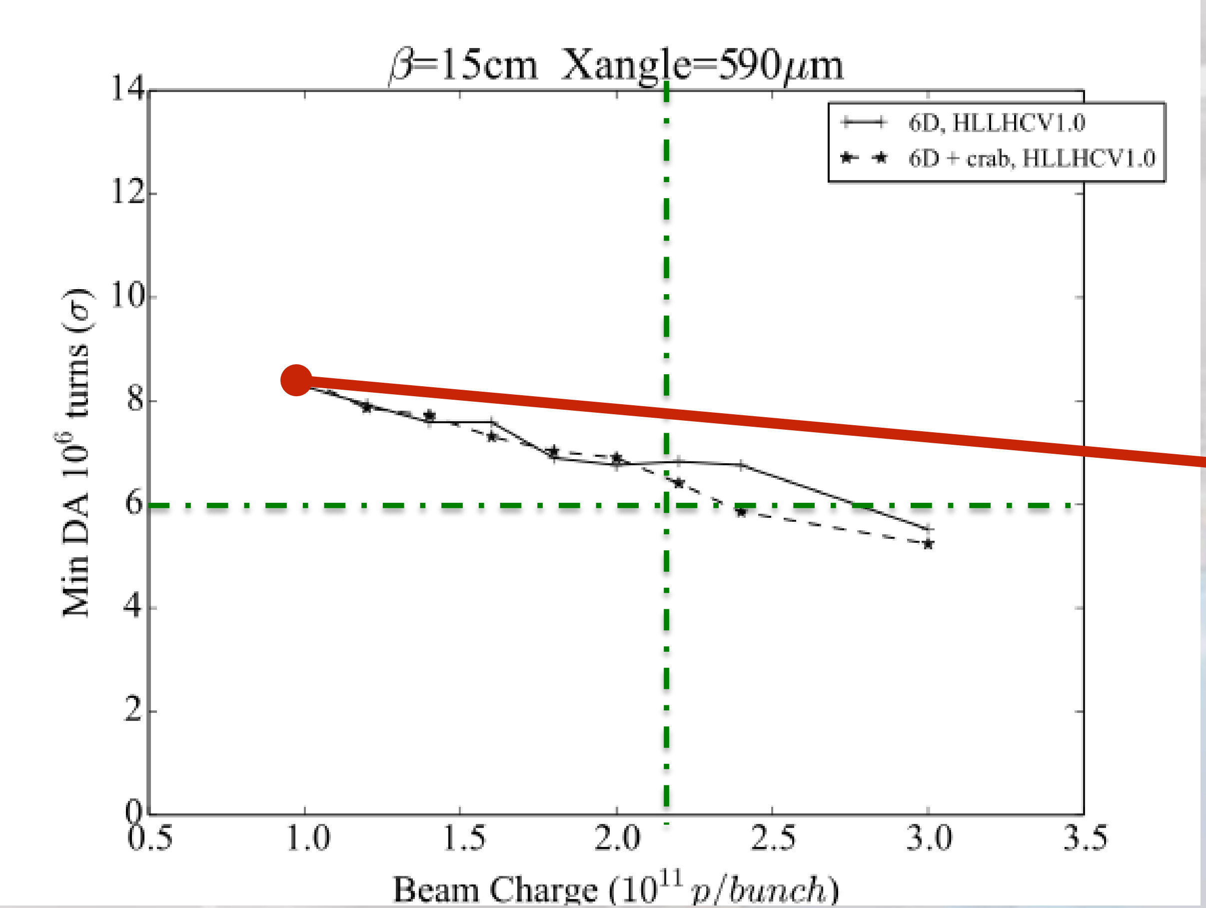


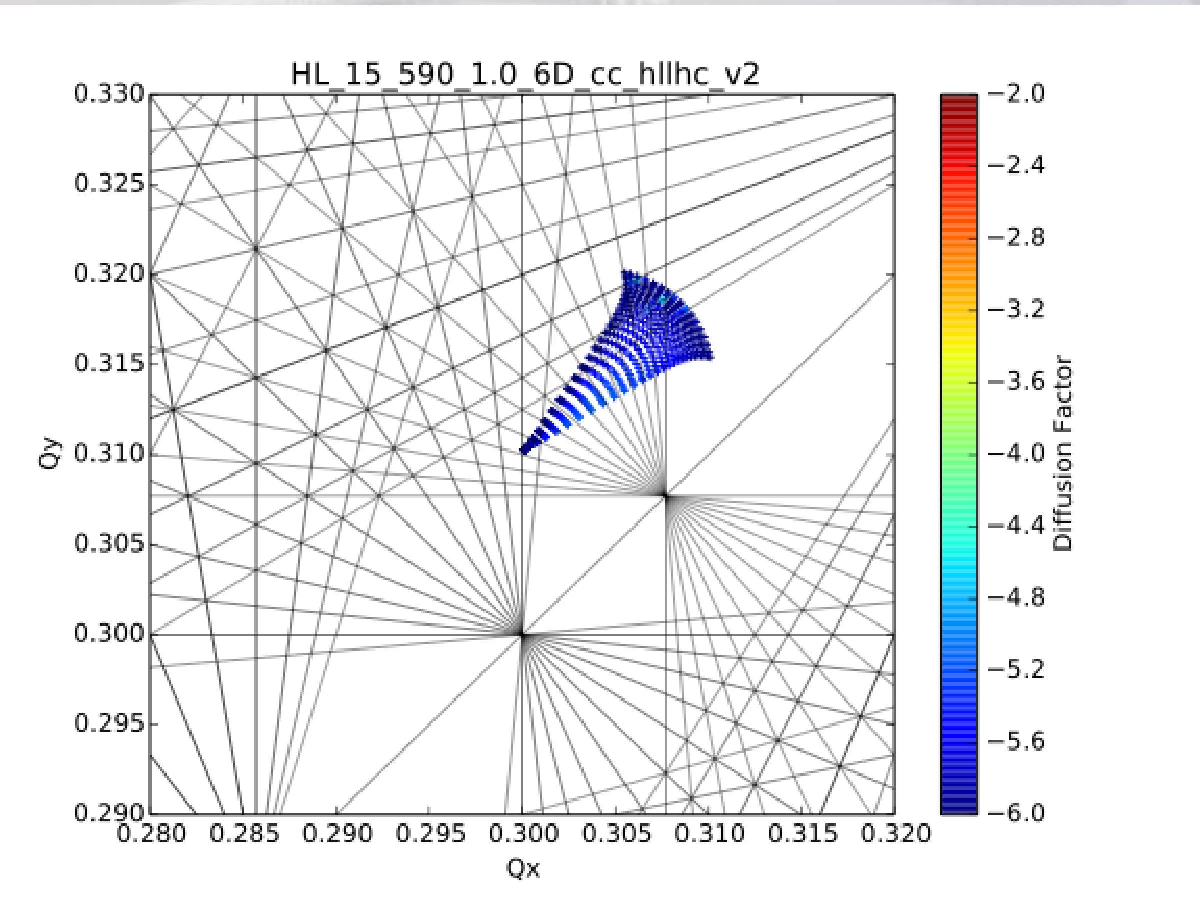
Larger angle weaker long range effects → better DA

We are confined between 13th and 5th order resonances

Round optics15 cm, 590µrad: intensity scan

IP1 & IP5 only HLLHCV1.0 optic





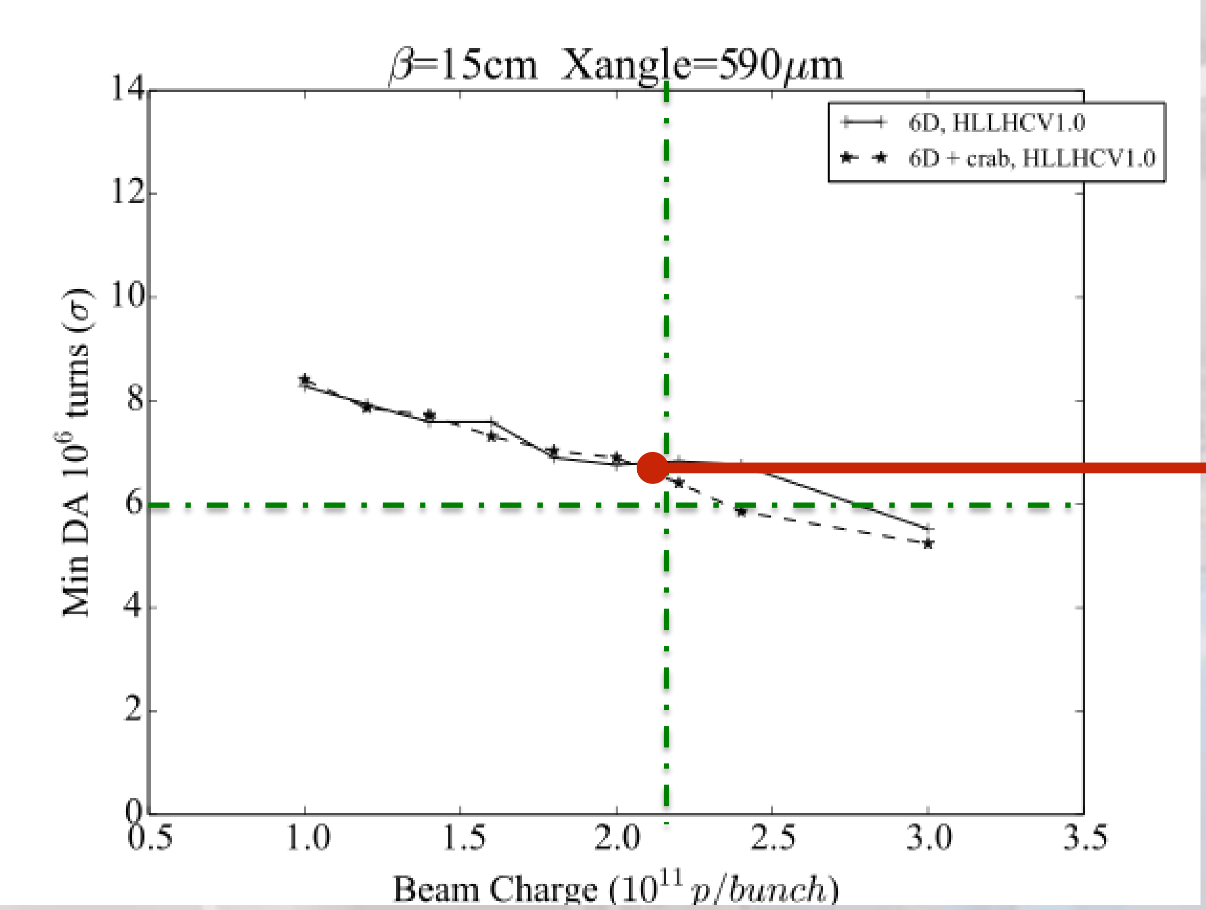
$$F_{bb} \propto Intensity$$

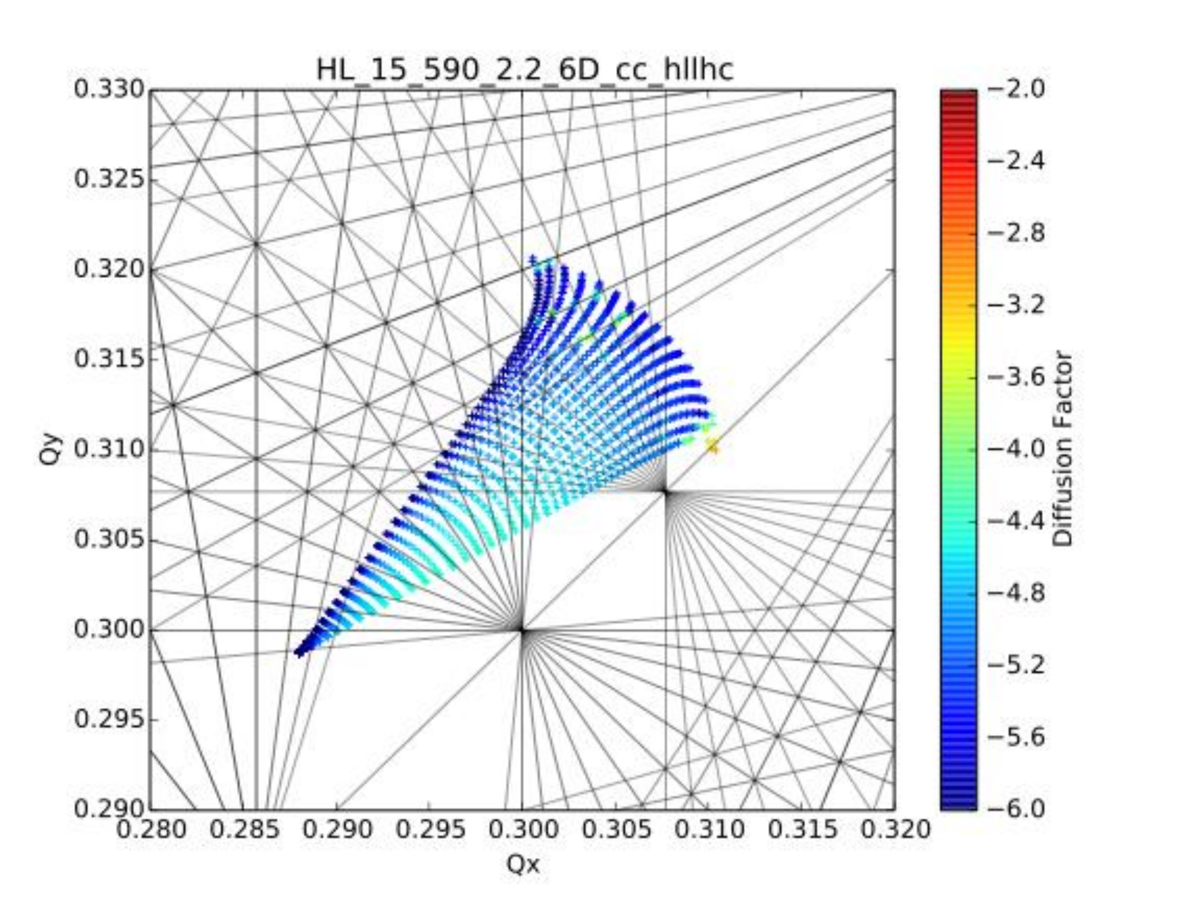
$$DA \propto Intensity$$

Changing Intensity we change Head-on BB and Long Range BB
Beam-beam Forces proportional to Intensity → DA depends linearly with Intensity

Round optics15 cm, 590µrad: intensity scan

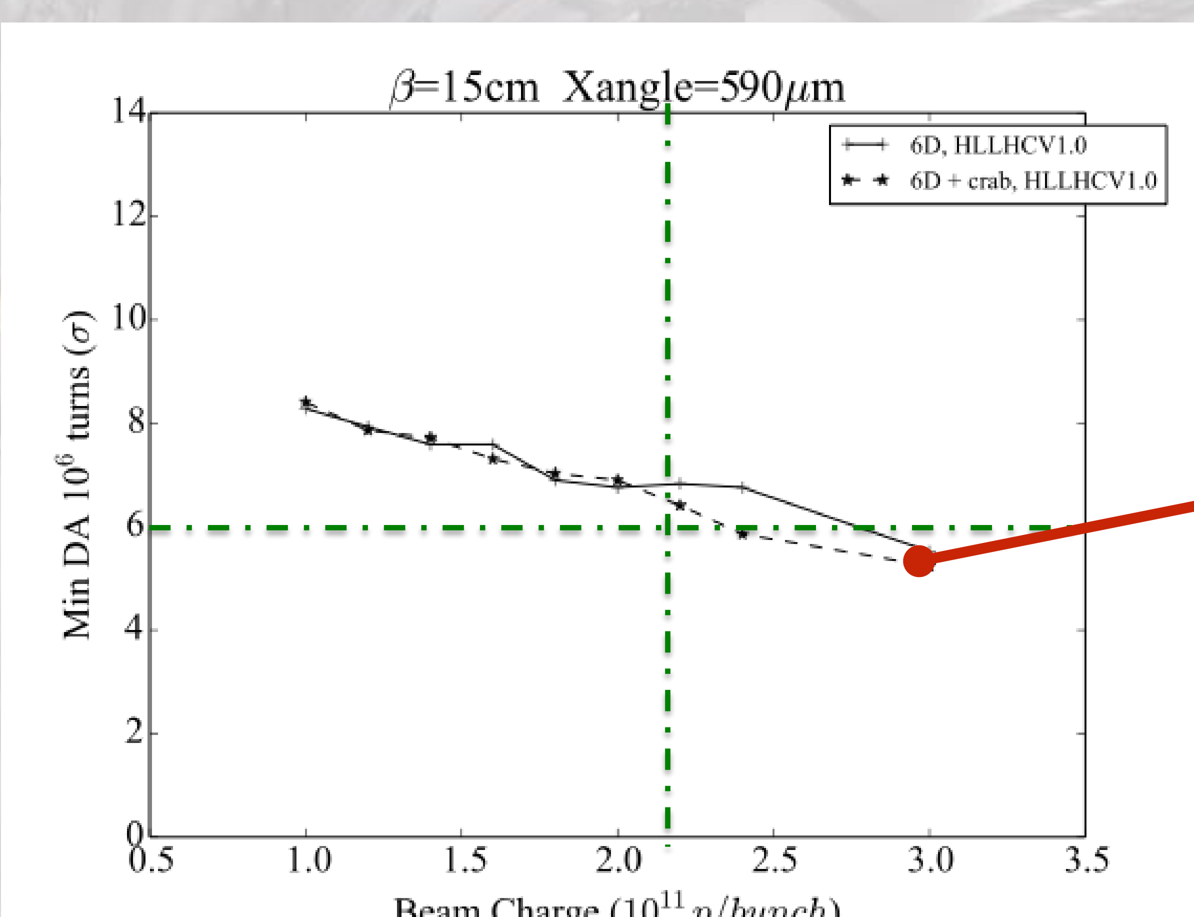
IP1 & IP5 only HLLHCV1.0 optic

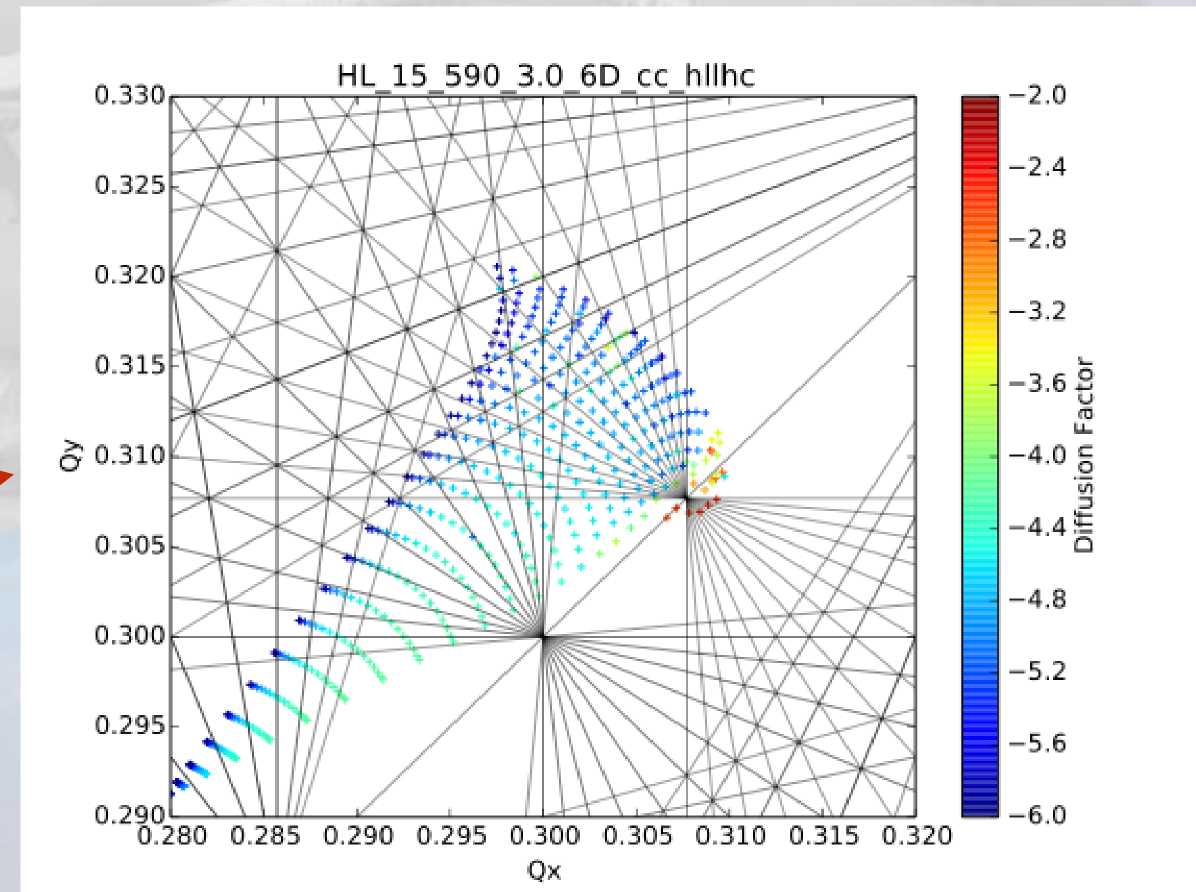




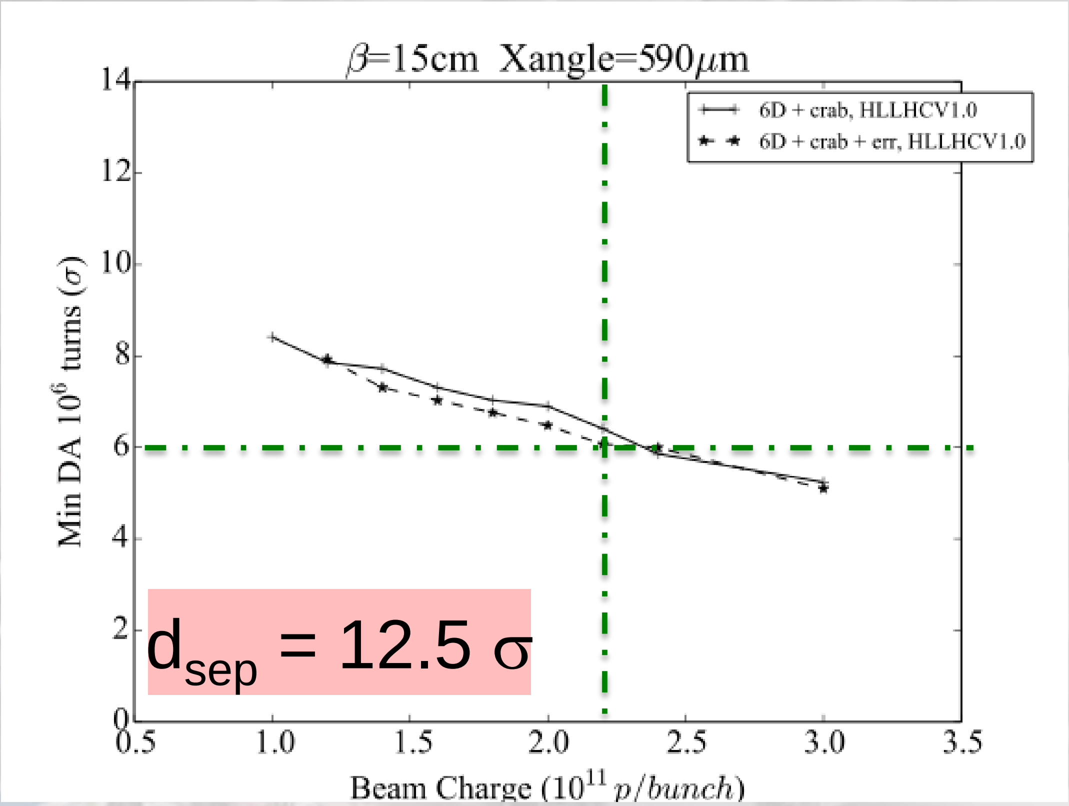
Round optics15 cm, 590µrad: intensity scan

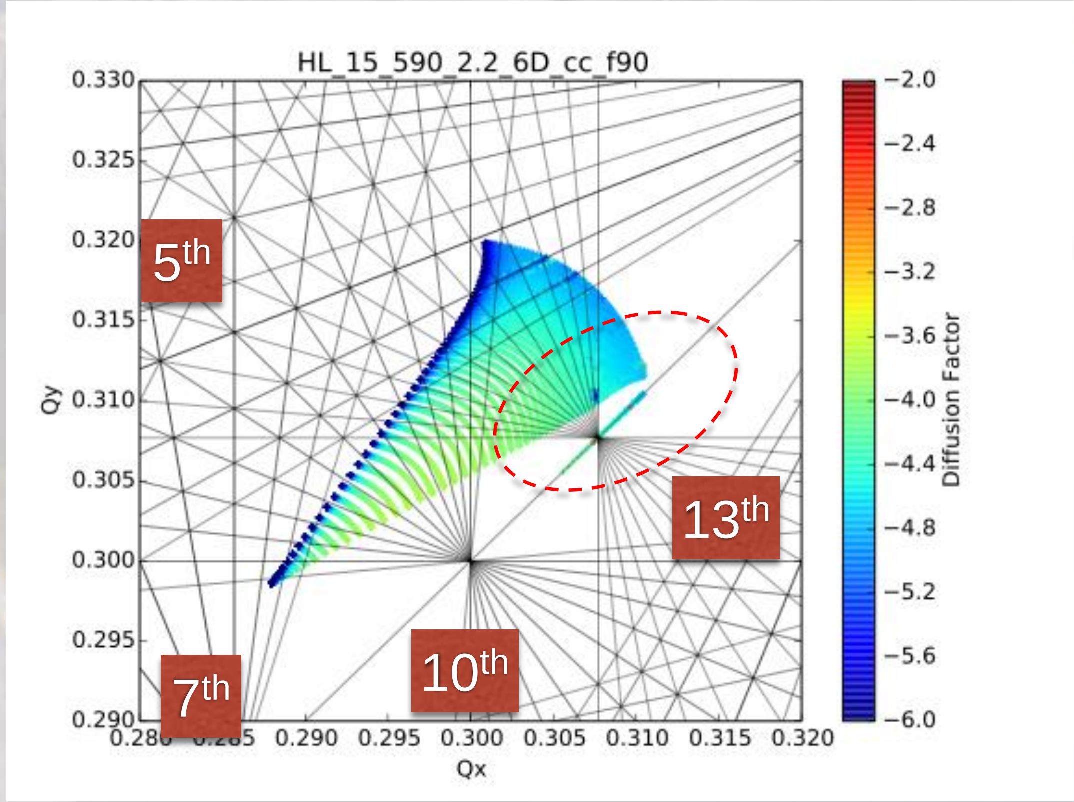
IP1 & IP5 only HLLHCV1.0 optic





Round Optics: Multipolar Errors

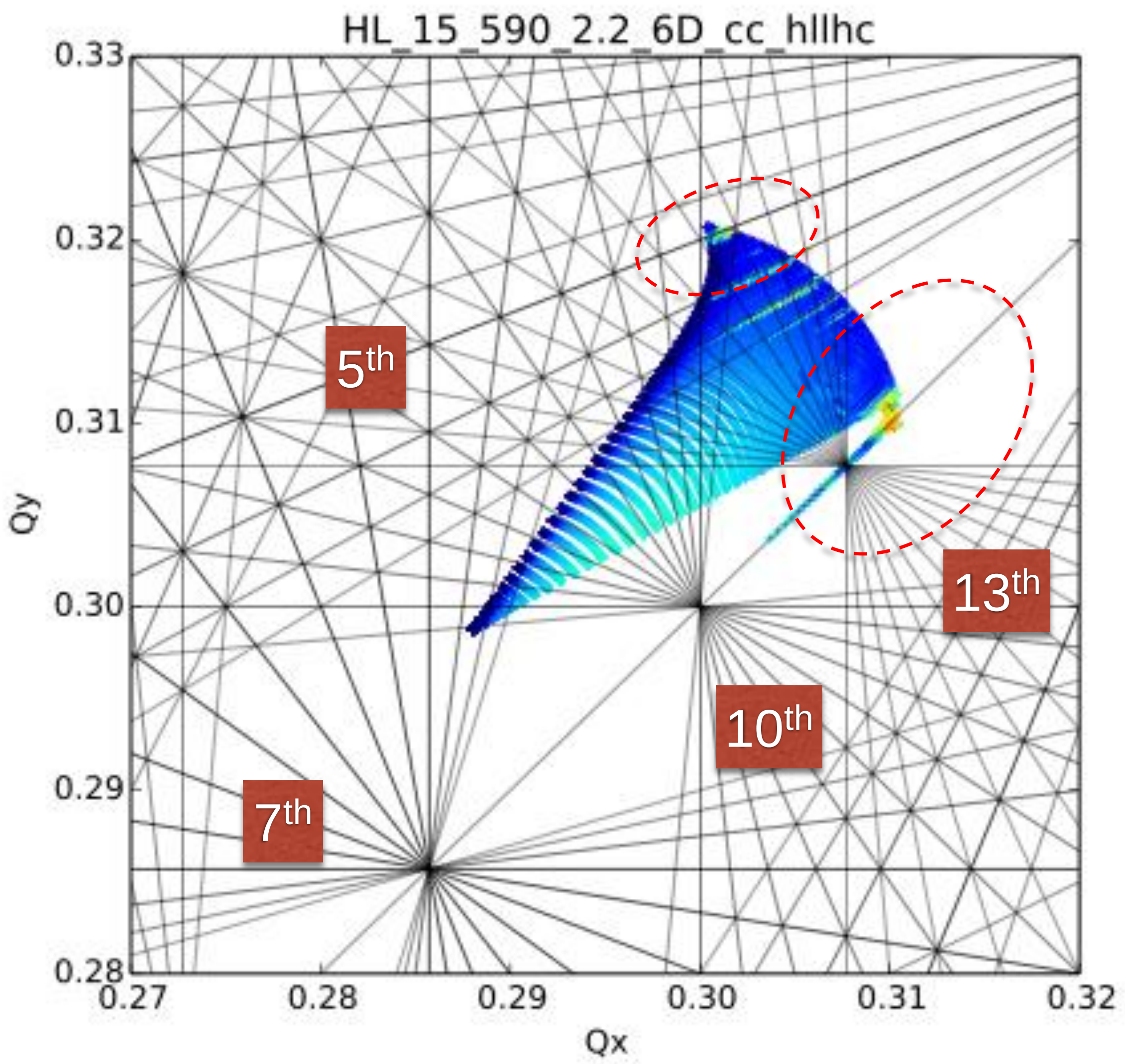


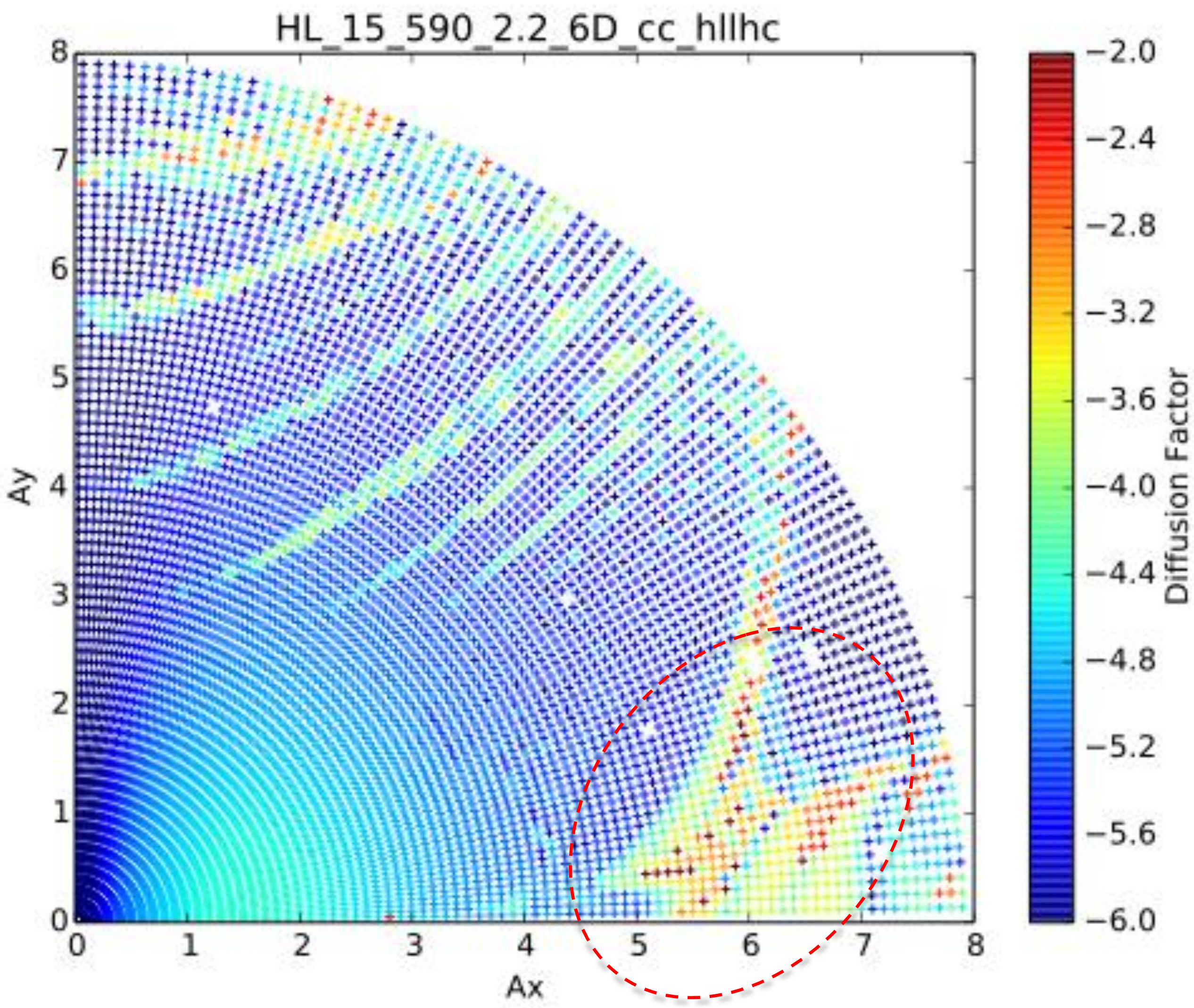


Multipolar errors give a reduction of 0.5 σ in DA

Round Optics: details for15cm

IP1 & IP5 only HLLHCV1.0 optic

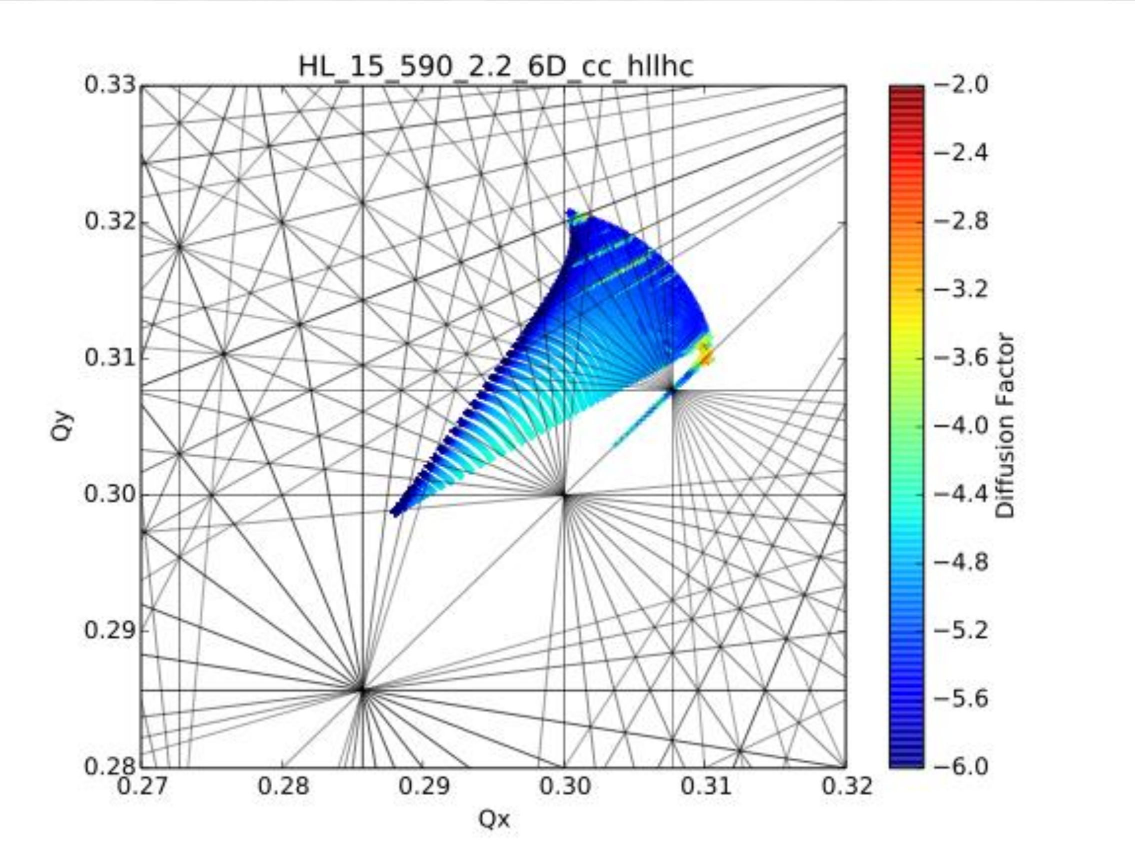




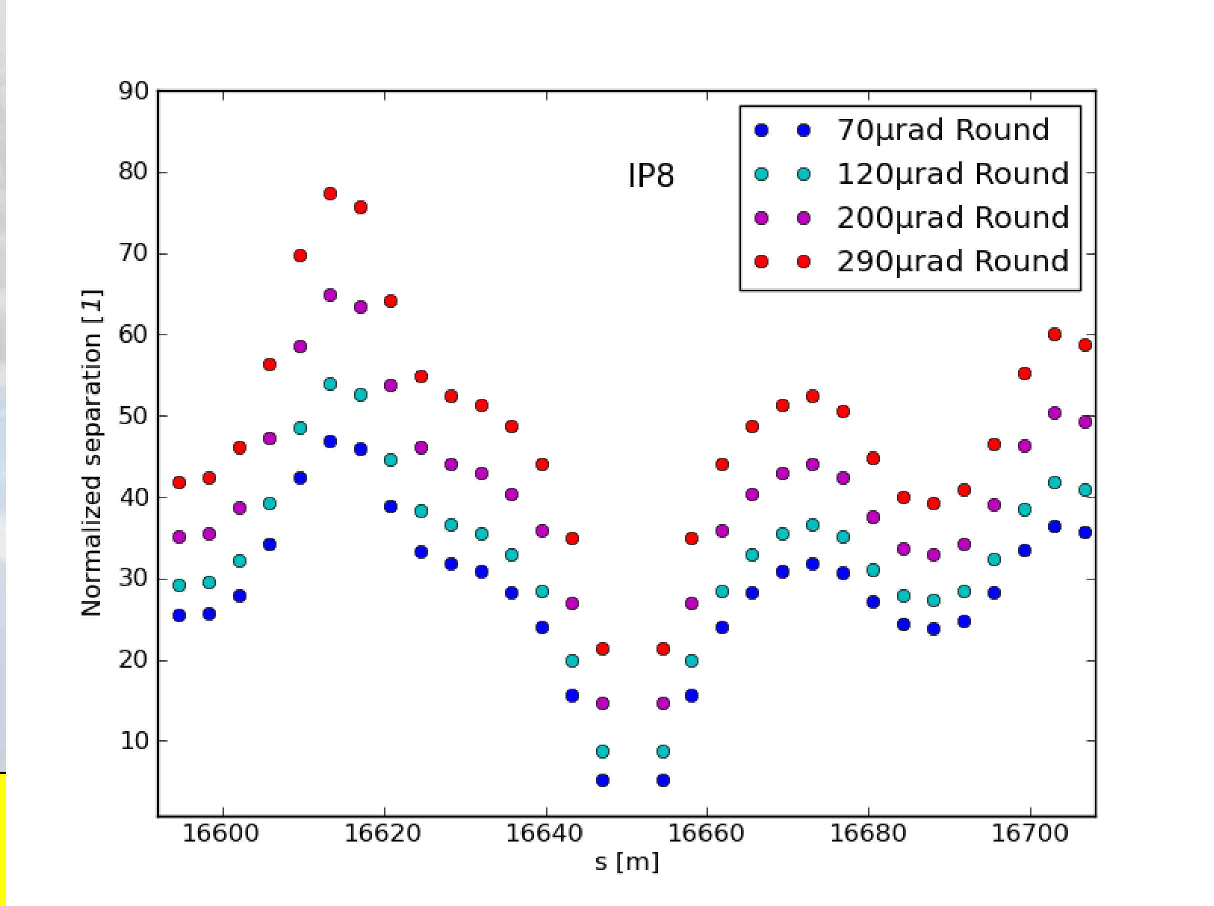
DA is 6σ but particles at 4-5 σ are affected by the BBLR show higher diffusion rates
Effect driven by 5th and 13th order resonance

HLLHCV1.0: effect of IP8

IP1 & IP5 only HLLHCV1.0 optic



Int ppb 10^{11}	DA No IP8
1.0	8.41
2.2	6.42



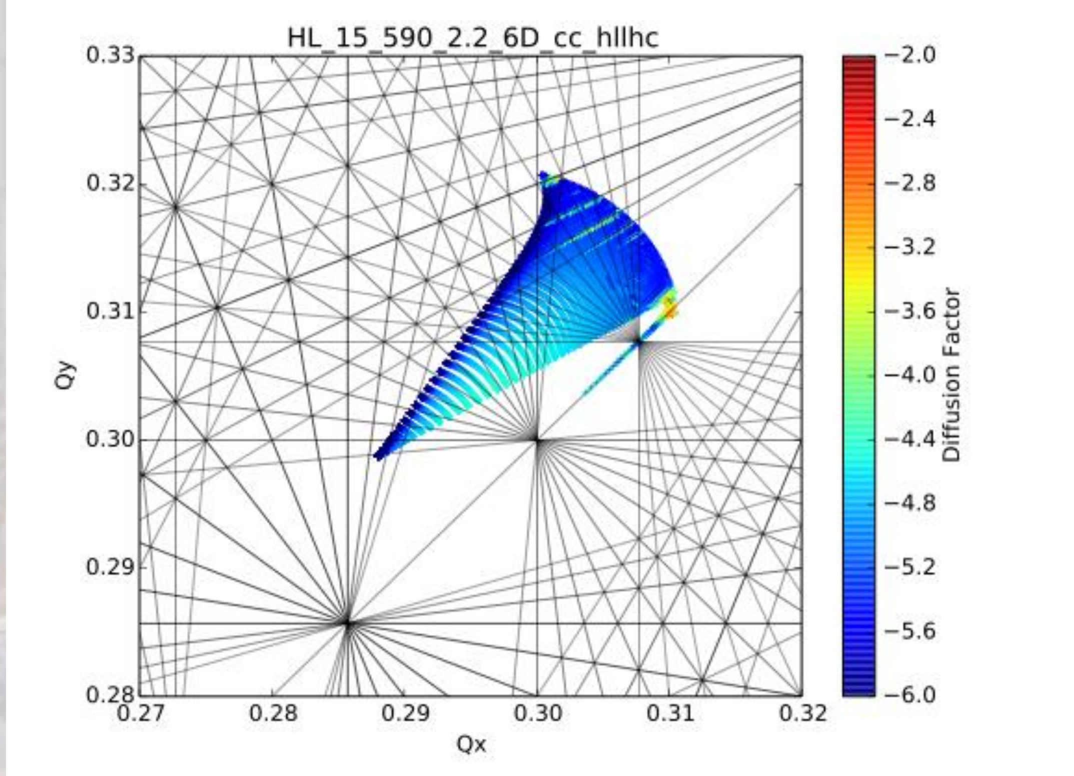
Full head-on from IP8 DQ = - 0.01

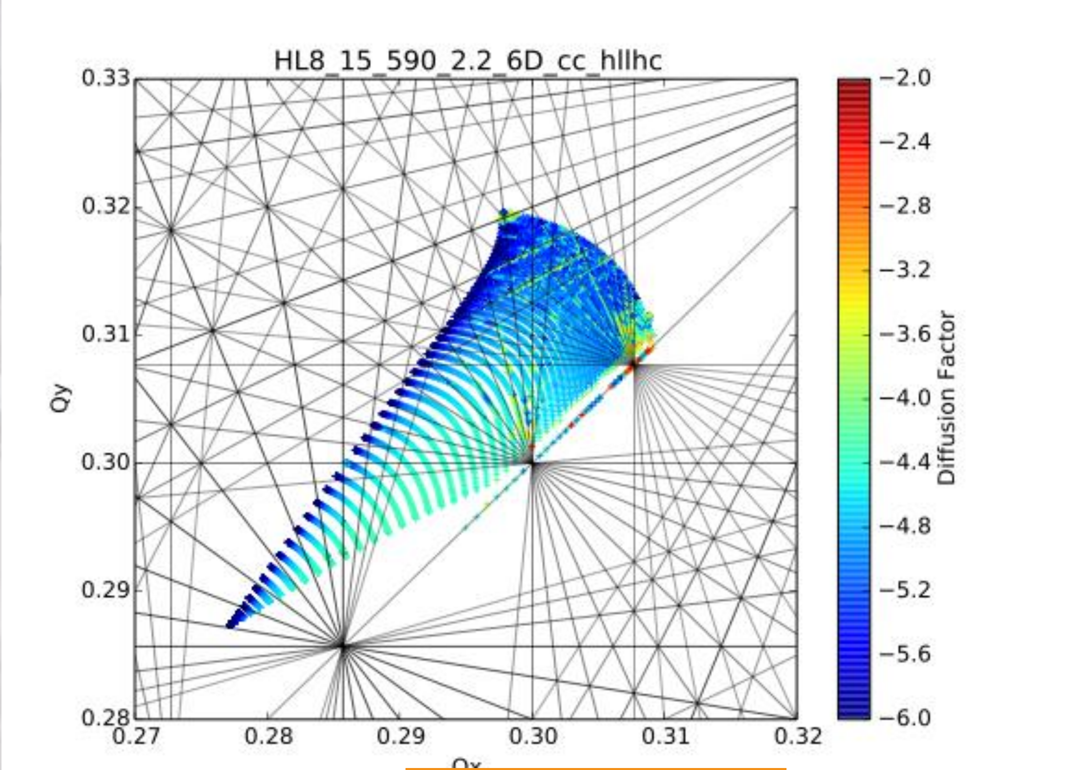
Three cases for IP8 LRs at 3m β*:

- **α_{IP8} = 610 μrad → all LR d_{sep} > 43 σ**
- **α_{IP8} = 290 μrad → 2 LR with d_{sep} 20σ all others LR d_{sep} > 38 σ**
- **α_{IP8} = 70μrad → 2 LR with d_{sep} 5σ all others LR d_{sep} > 15 σ**

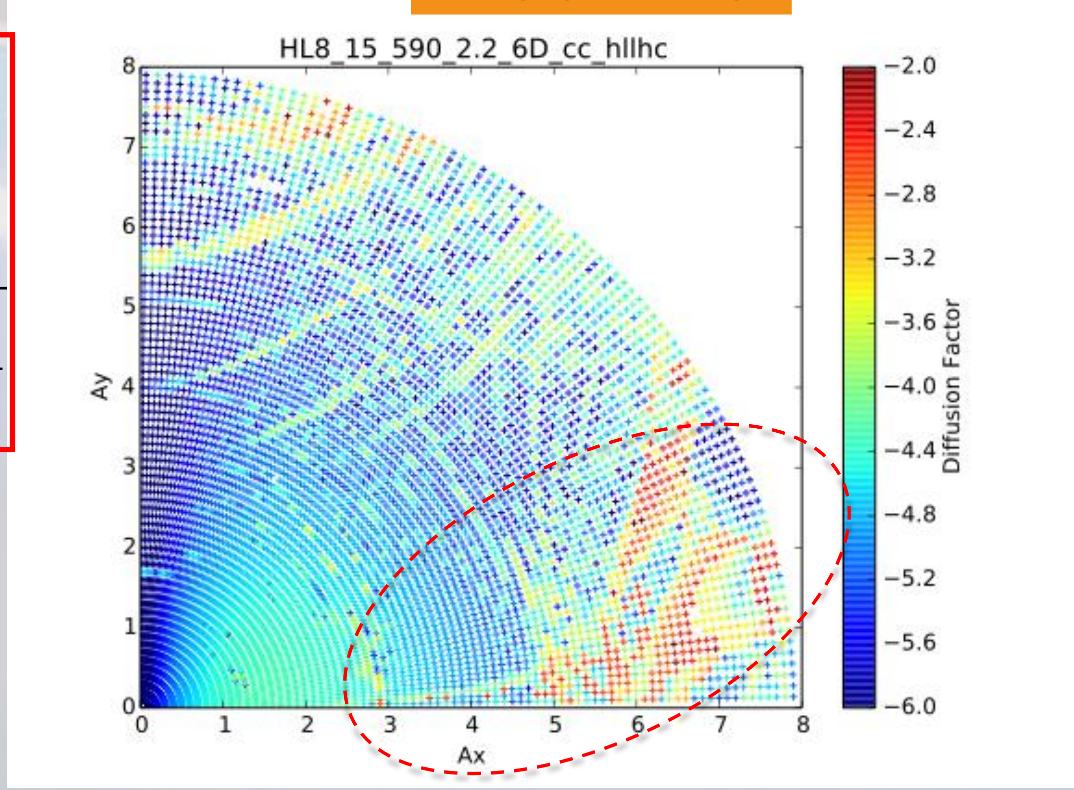
HLLHCV1.0: effect of IP8

IP1 & IP5 only HLLHCV1.0 optic





IP1&5 + IP8

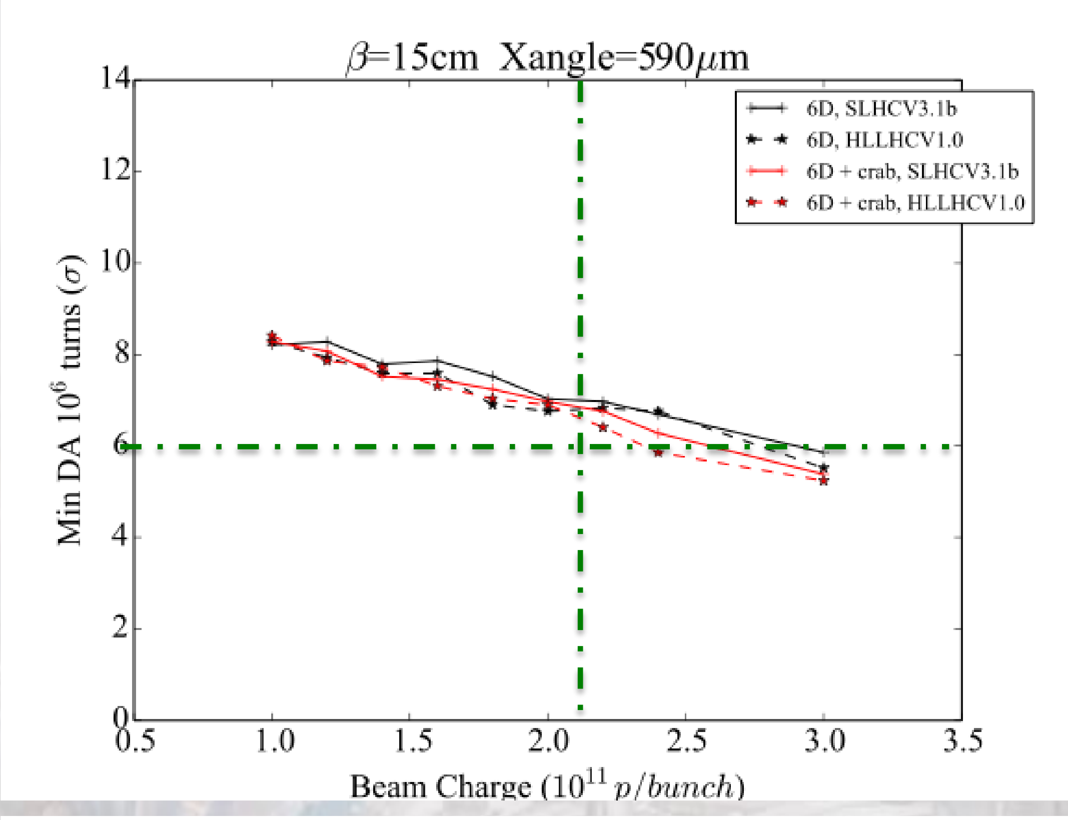


	No IP8	IP8 (-340mrad ext x-angle -270μrad septrometer)	IP8 (-560μrad ext x-angle + 270μrad spectrometer)	IP8 (-340μrad+270μrad spectrometer)
1.0	8.41	8.07	7.93	7.72
2.2	6.42	6.28	6.06	5.86

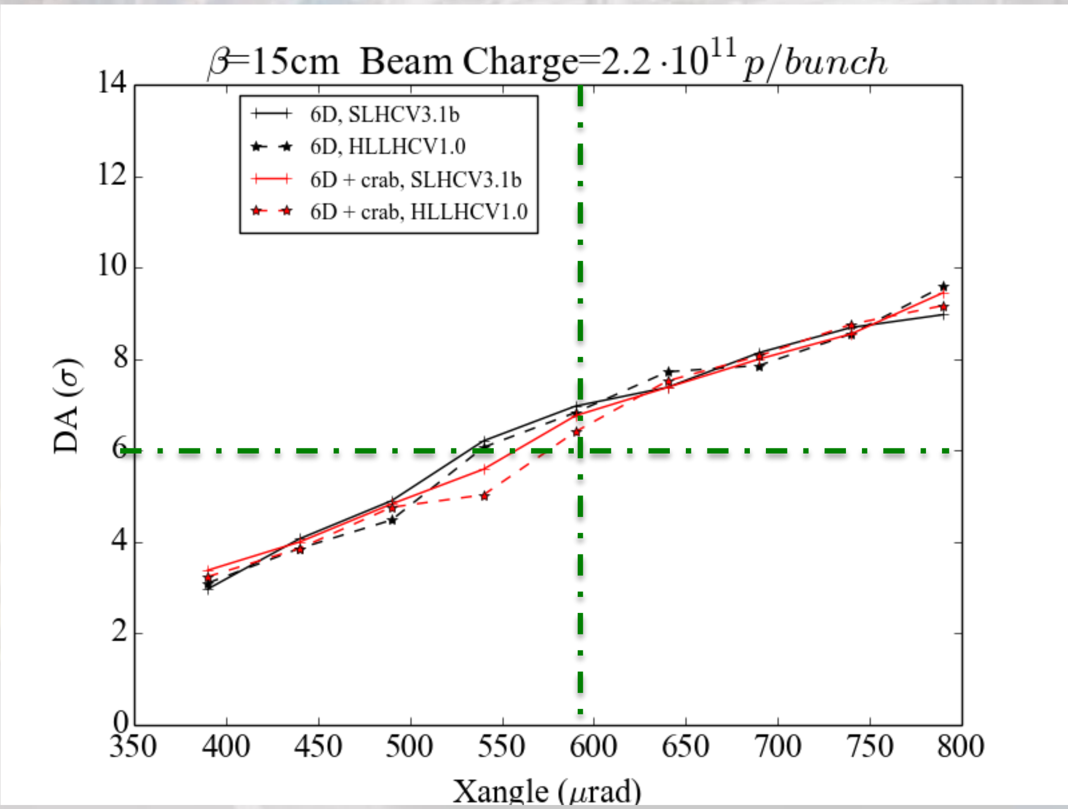
Full head-on from IP8 DQ = - 0.01
Three cases for IP8 LRs at 3m β*:

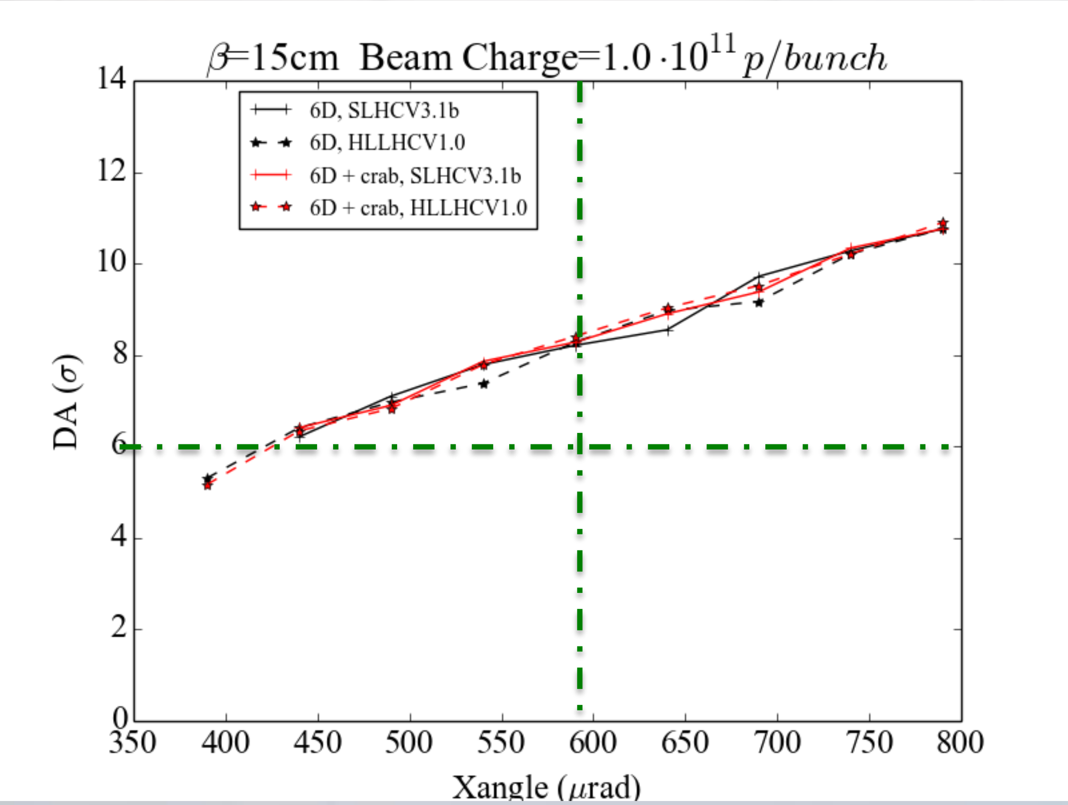
- **α_{IP8} = 610 μrad → ΔDA = -0.35@2.2e11 (0.14@1.1e11) σ**
- **α_{IP8} = 290 μrad → ΔDA = -0.5@2.2e11 (0.36@1.1e11) σ**
- **α_{IP8} = 70μrad → ΔDA = -0.7@2.2e11 (0.56@1.1e11) σ**

Older SLHCV3.1b vs new HLLHCV1.0

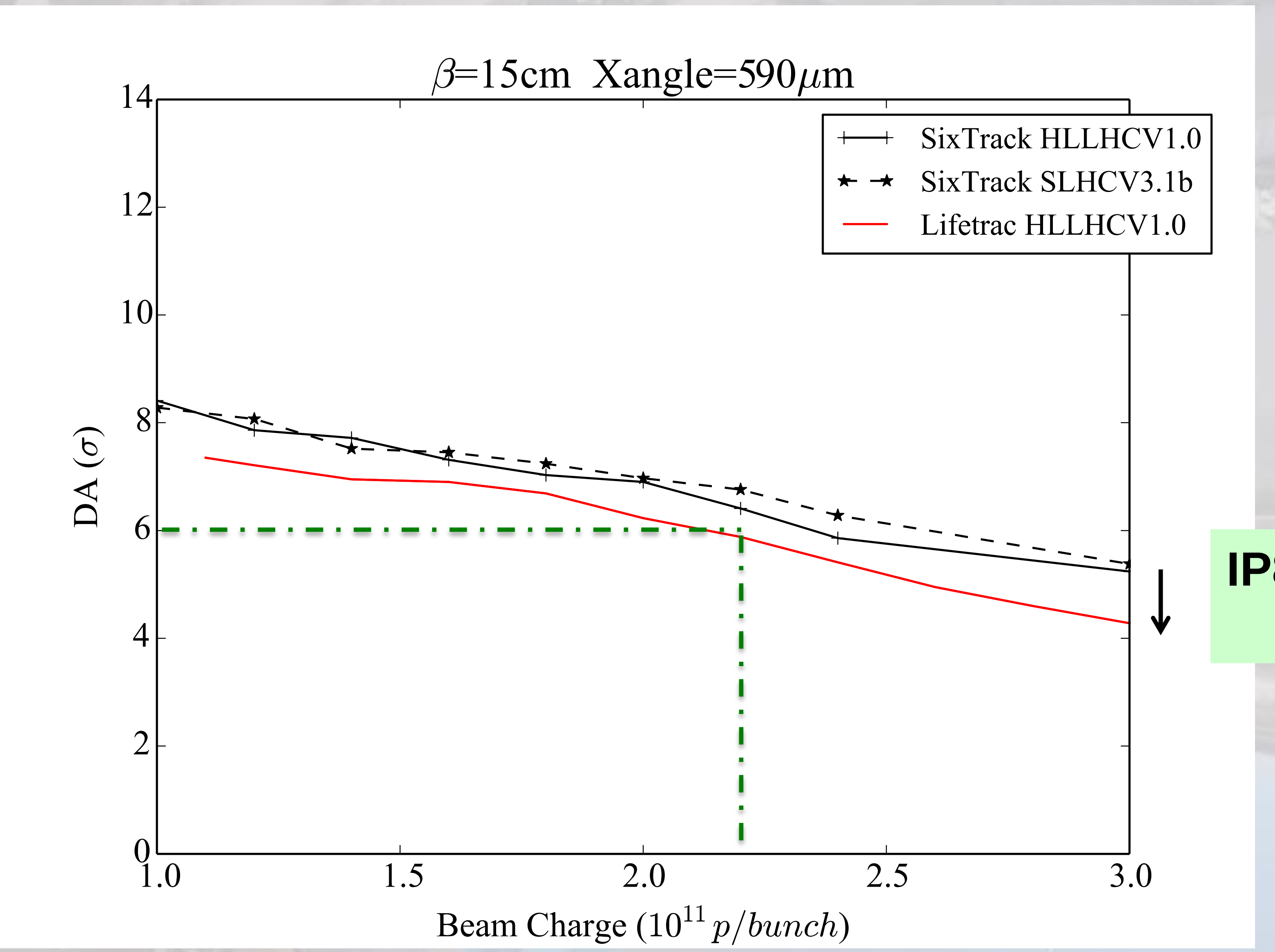


New HLLHCV1.0 round 15 cm optic has been tested and give DA results compatible with older SLHCV3.1b





HLLHCV1.0 vs SLHCV3.1b

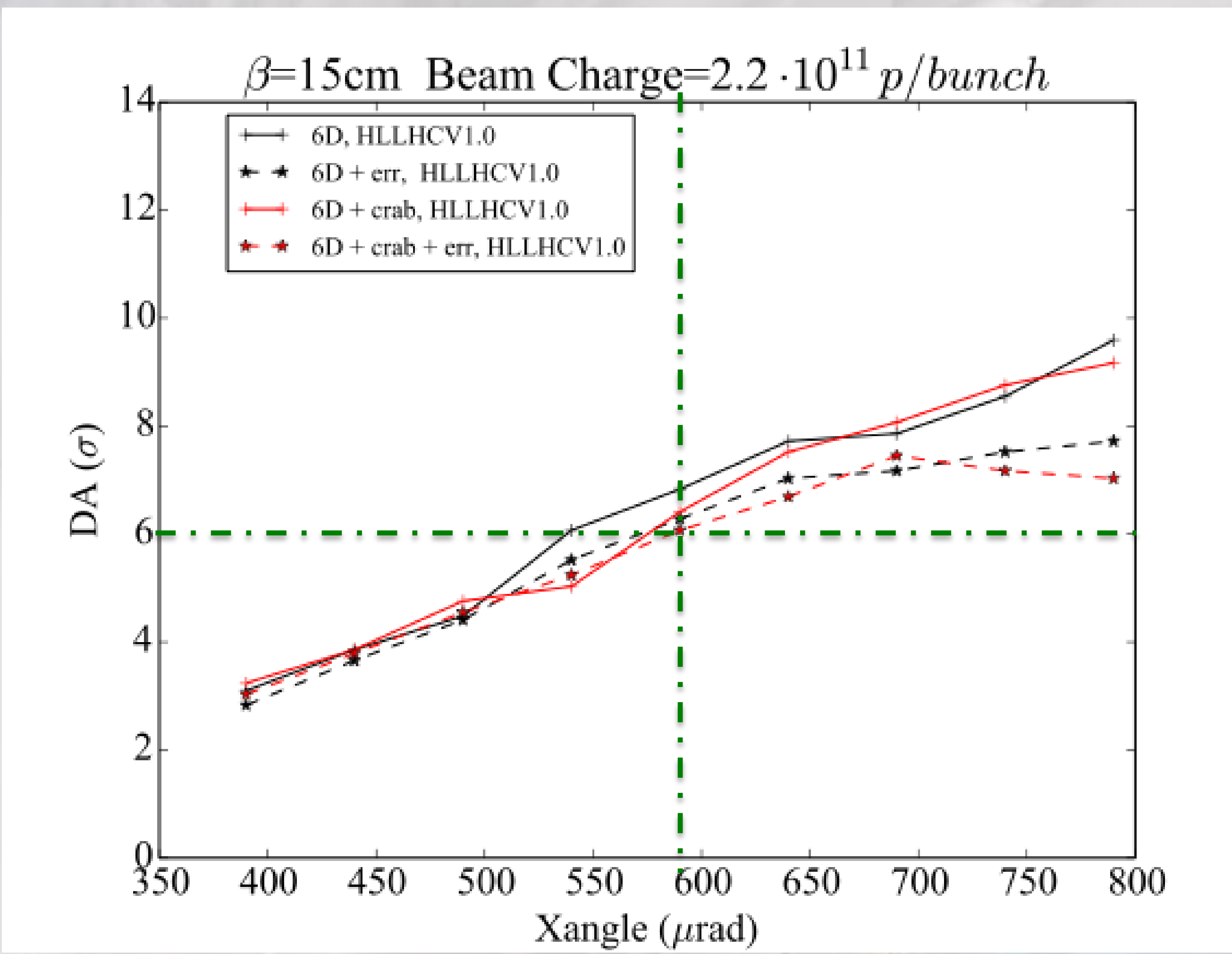


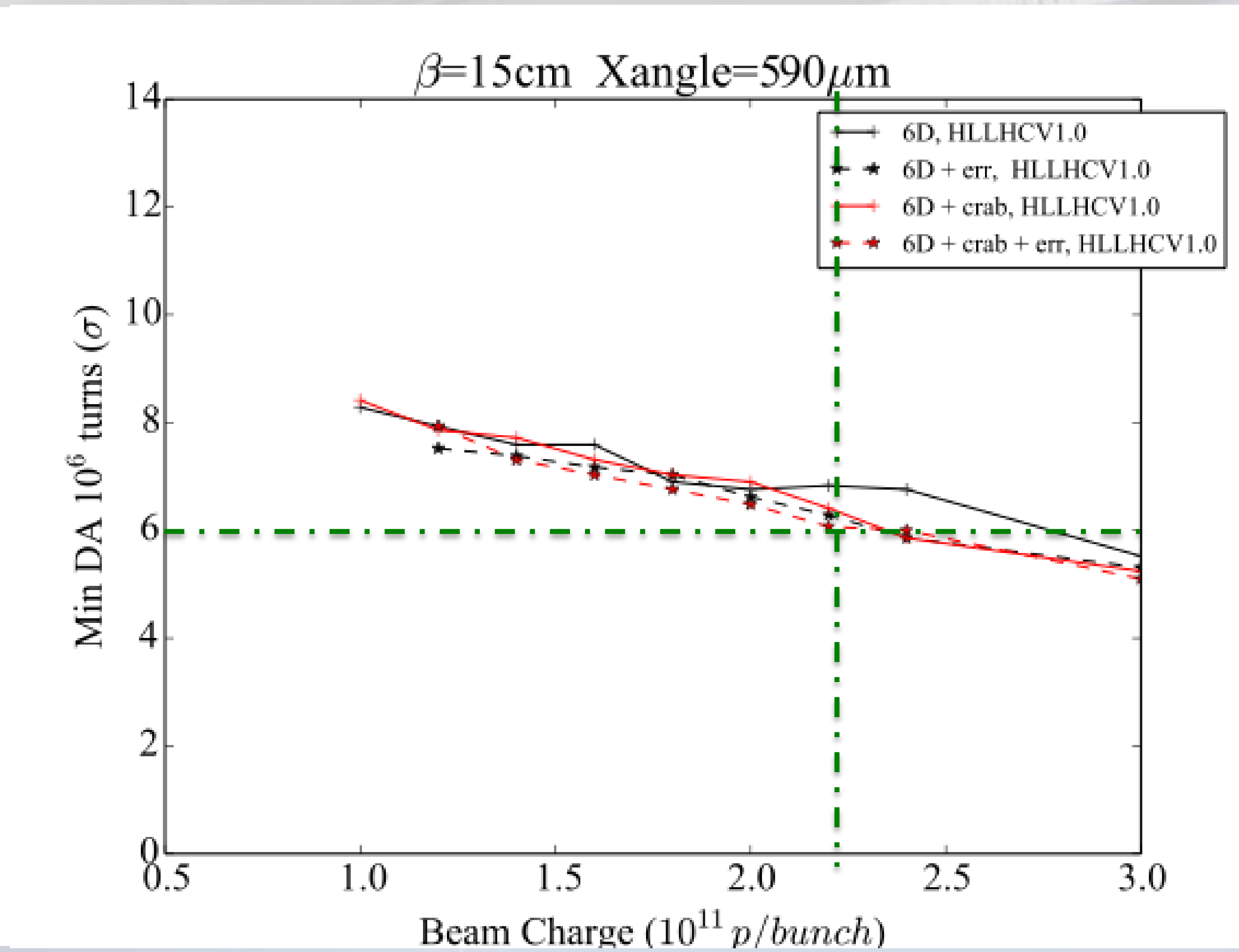
IP8 contribution with 6 10 μrad x-angle

All studies have been performed also with Lifetrac
The two codes show good agreement (10-20% variations)
0.5 σ reduction for this case comes from the IP8 contribution on in Lifetrac simulations.

Nominal scenario: error effect

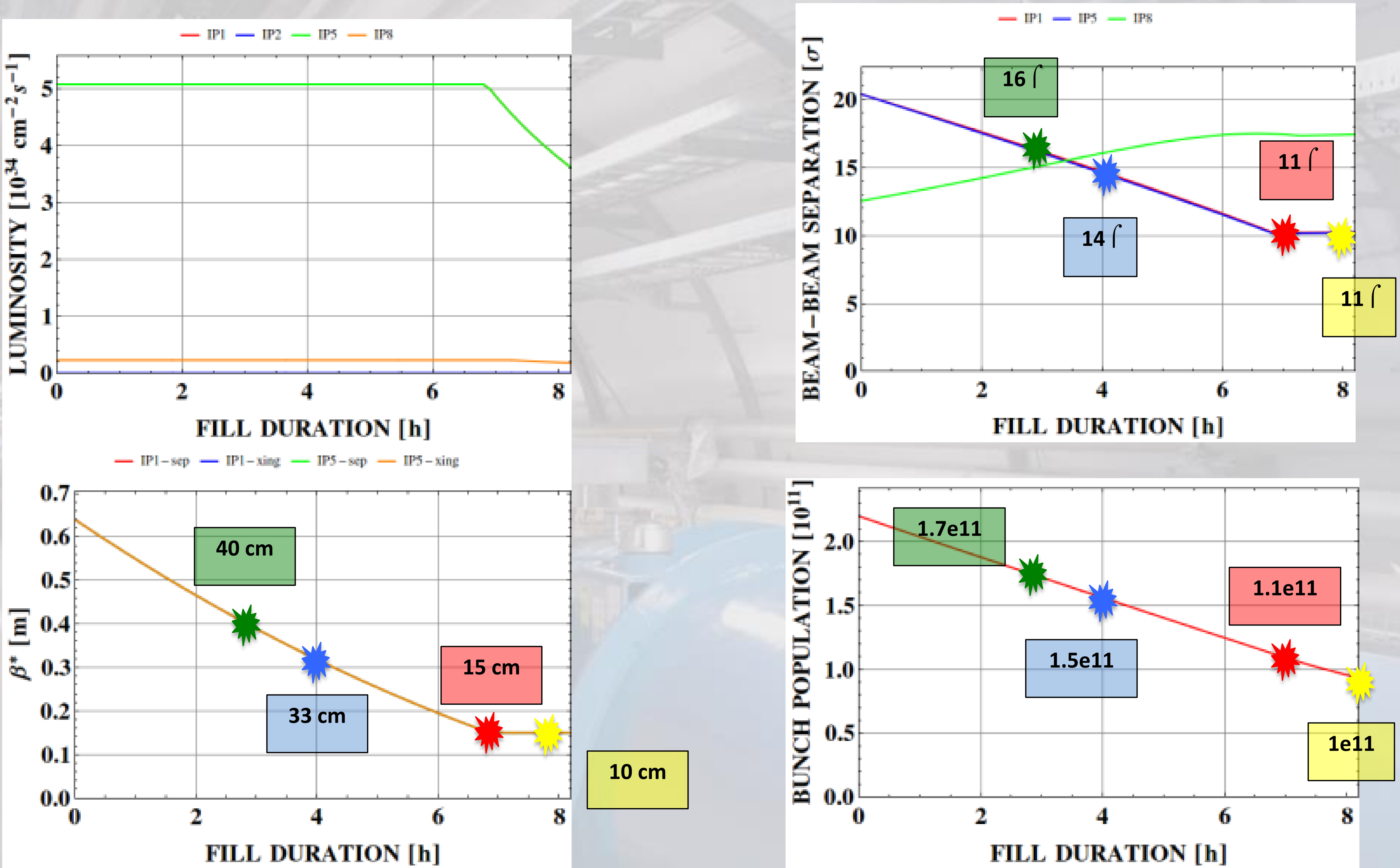
IP1 & IP5 only HLLHCV1.0 optic





Multipolar Errors do have an impact of 0.5-1.0 σ at nominal intensity for 15 cm optics.
Above 600 μrad x-angle multipolar errors not anymore in shadow of Beam-Beam
Nominal scenario is at limit of 6 σ DA for nominal amplitude.

β* leveling scenario at 5E34



Courtesy R. De Maria

β* leveling with round optics and full crabbing in IP1 and IP5
We modelled 4 optics during betatron squeeze
Beam parameters follow the luminosity leveling at 5E34 (7.5E34)

β* leveling scenario at 5E34

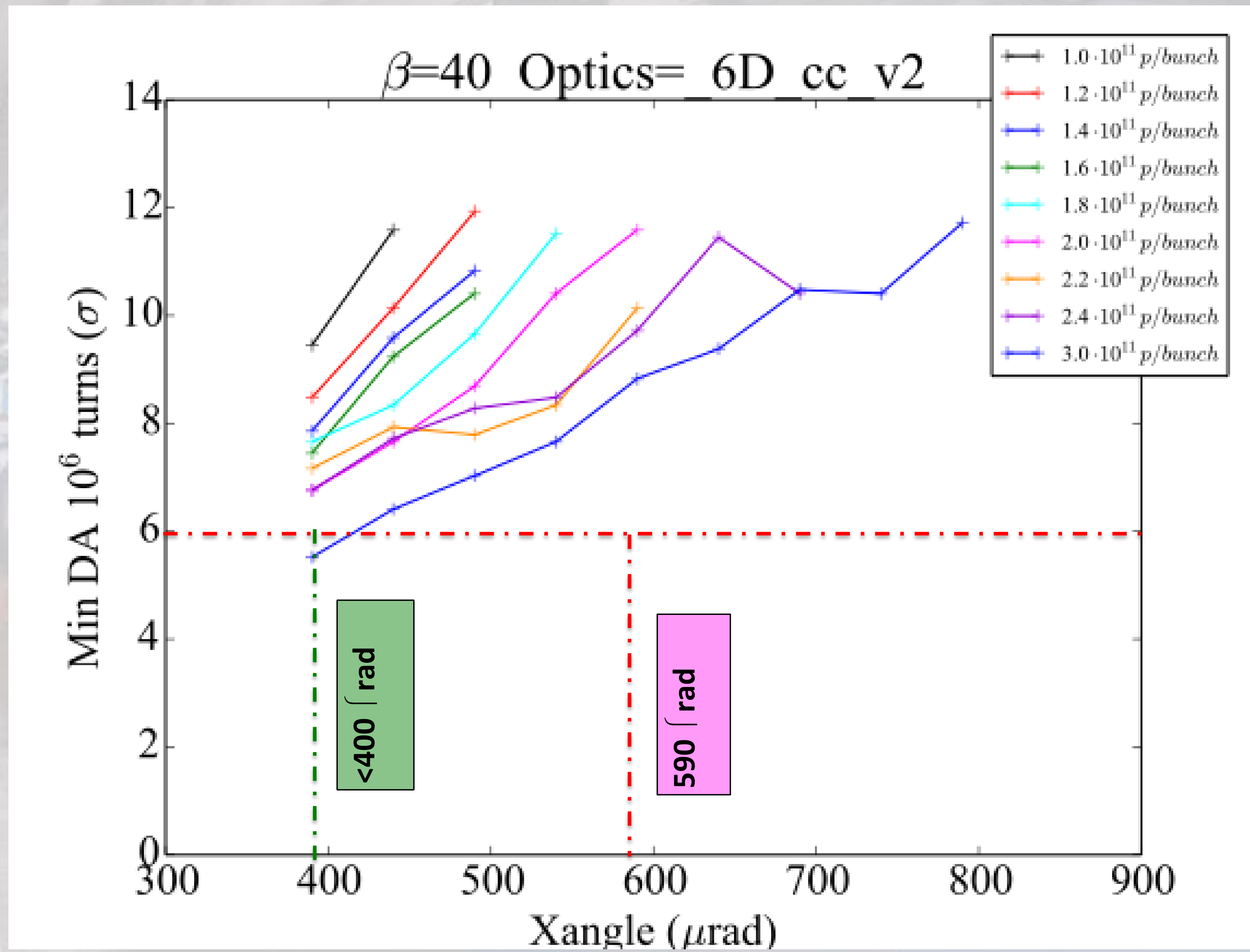
Two cases 5e34 and 7.5e34

Leveled Luminosity	Intensity ppb at β* = 40cm	Intensity ppb at β* = 33cm	Intensity ppb at β* =15cm	Intensity ppb at β* =10cm
5E+34	1.7E+11	1.5E+11	1.1E+11	1E+11
7.5E+34	x	2.1E+11	1.5E+11	x

We Define:

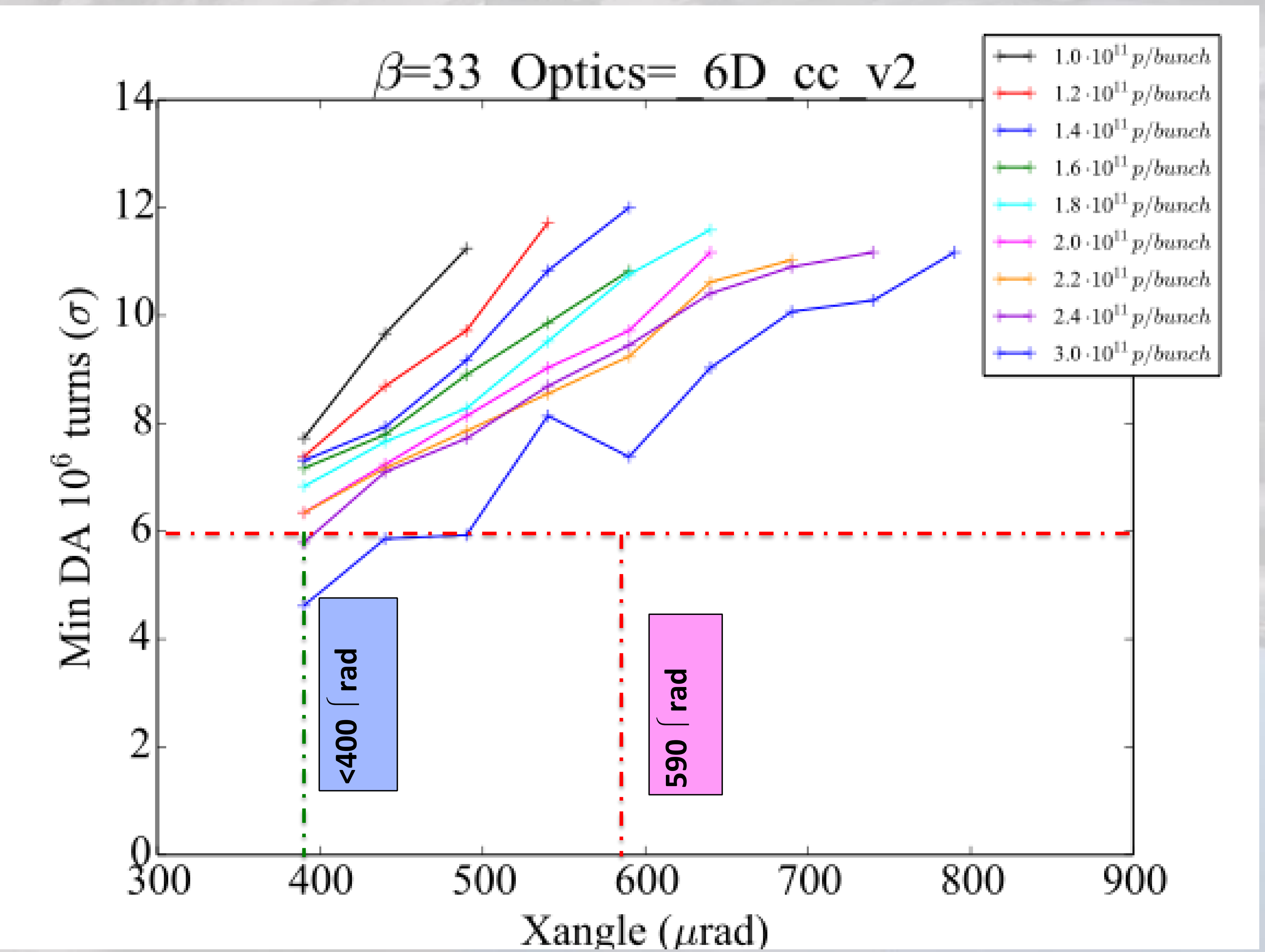
- **Minimum crossing angle** acceptable to ensure 6σ DA
- **Maximum Intensity** acceptable per β* step during leveling

β* leveling at 5E34: 40 cm



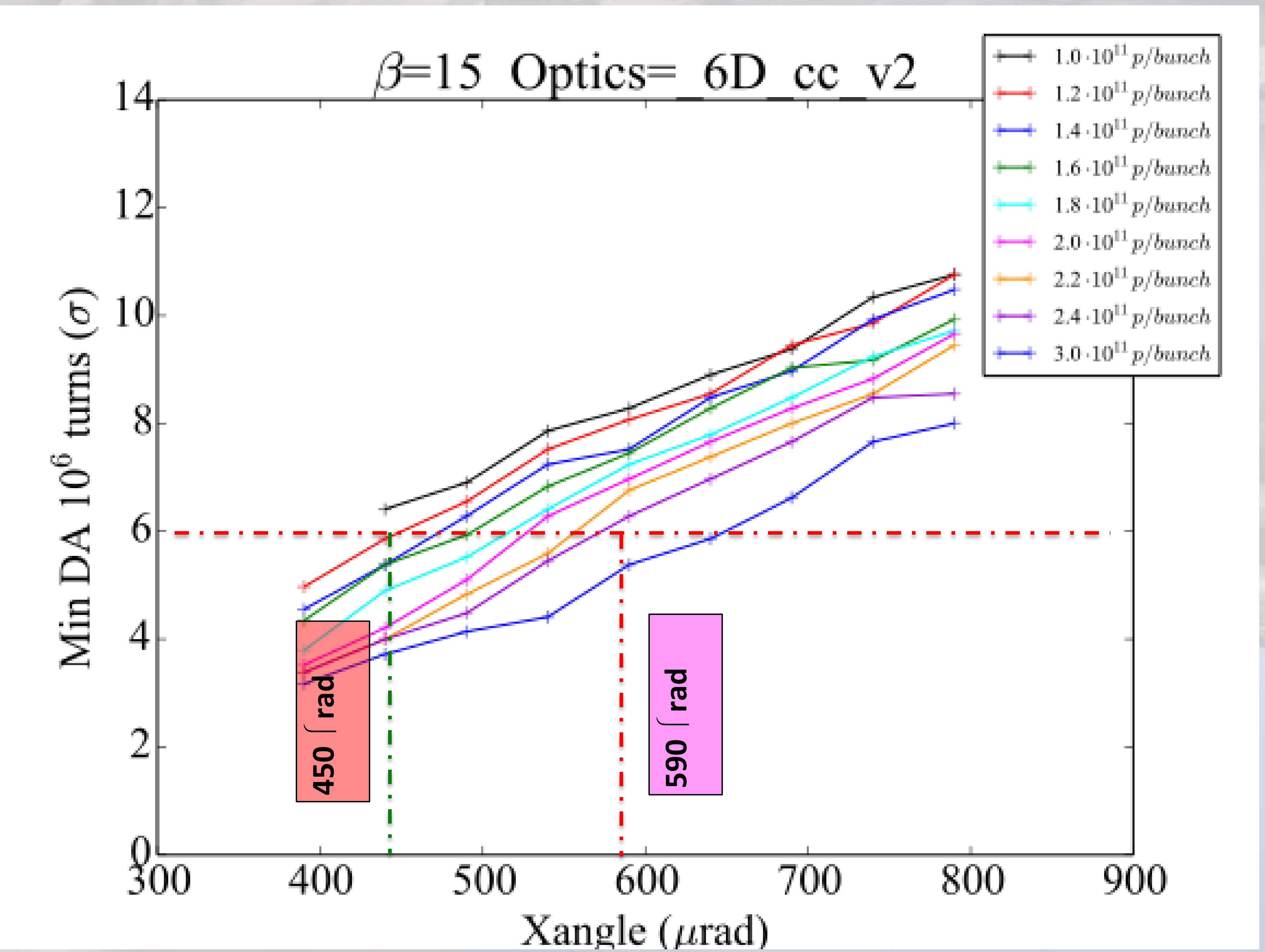
Minimum crossing angle <400 µrad at 1.7E11
At nominal angle all Intensities are acceptable

β* leveling at 5E34: 33 cm



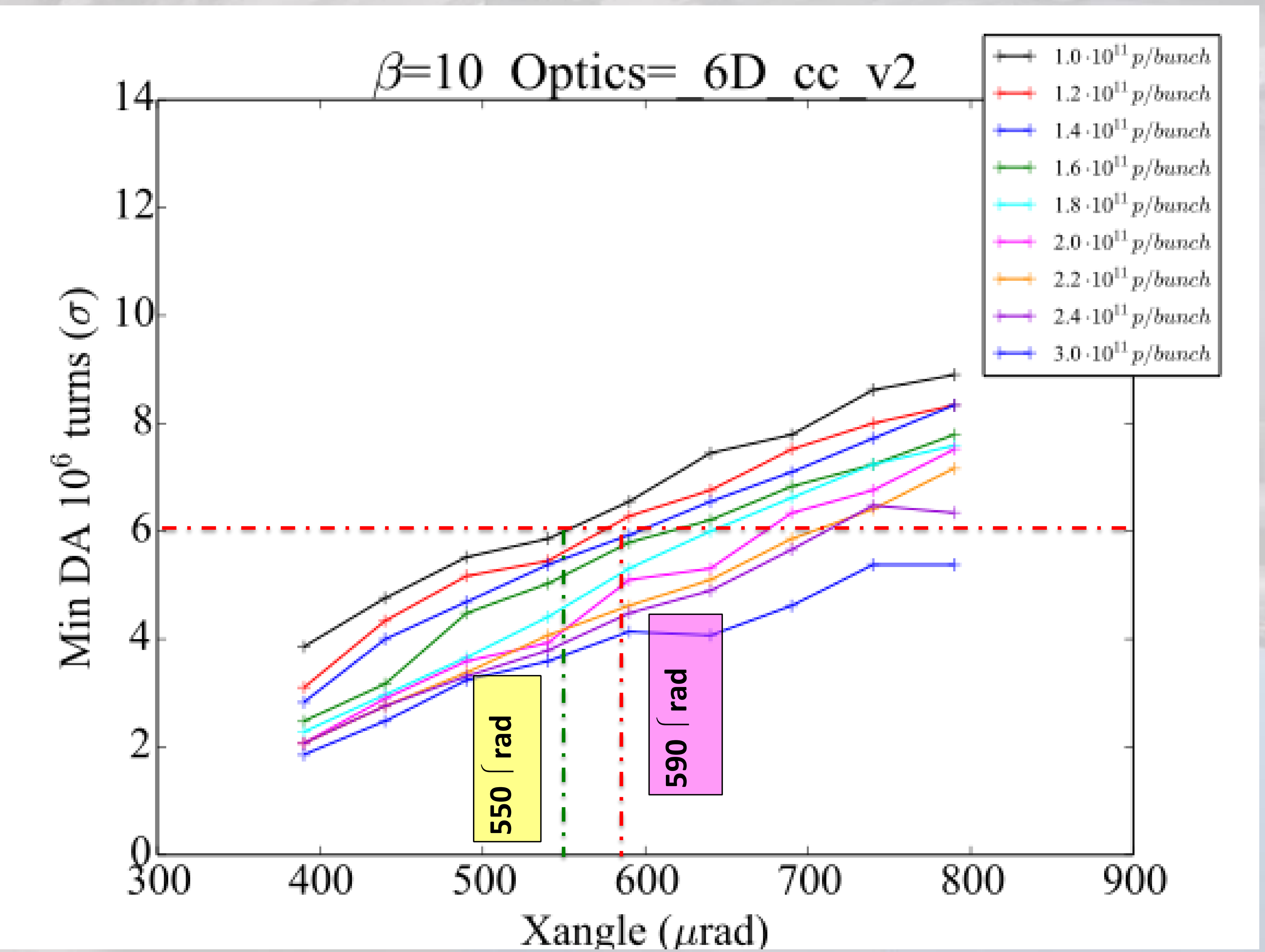
Minimum crossing angle <400 µrad at 1.5E11

β* leveling at 5E34: 15 cm



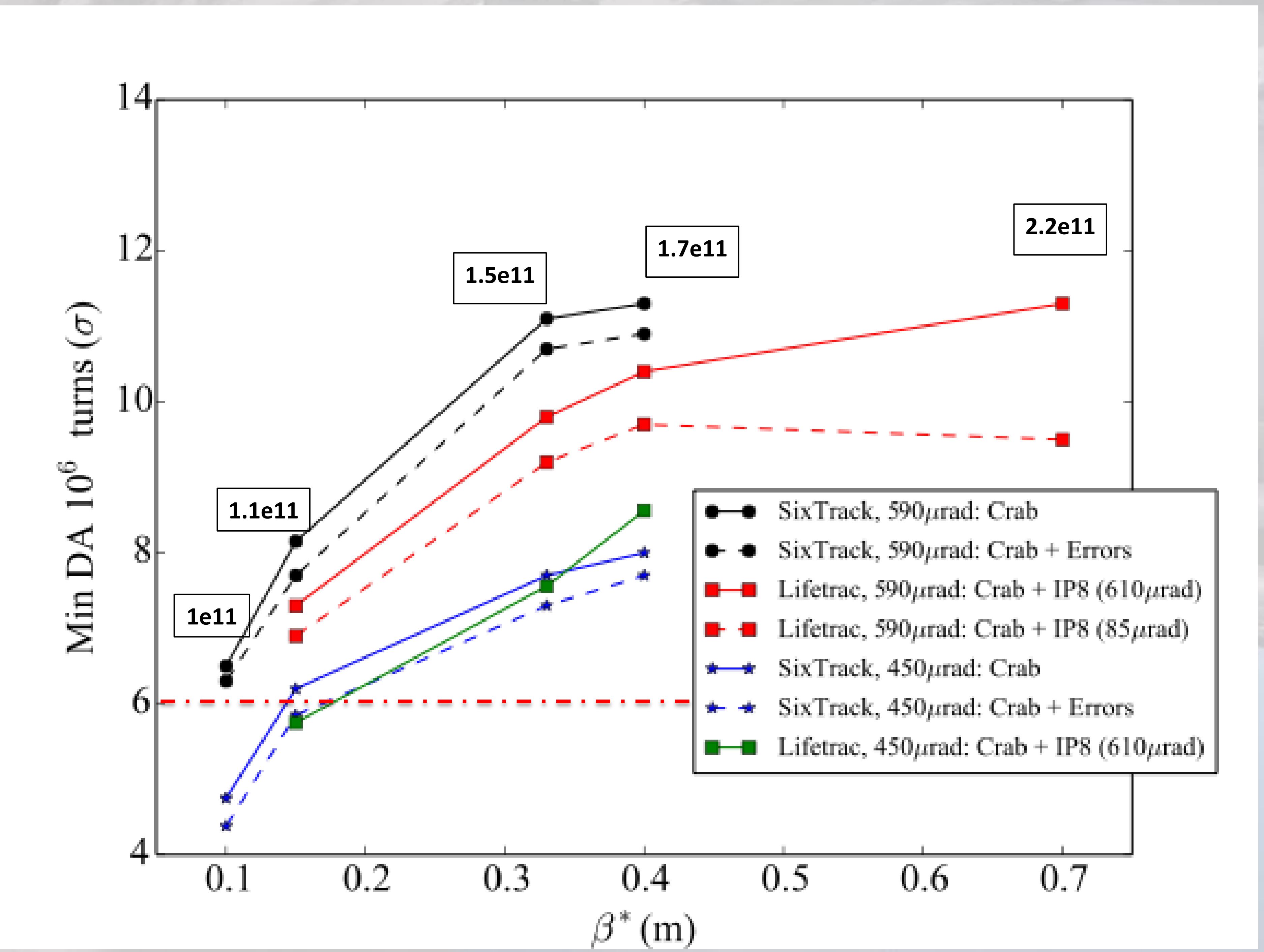
Minimum crossing angle 450 ⌠rad for β* levelling (int 1.1E11)
At nominal x-angle 590µrad limited to int 2.4E11 (optimistic case)

β* leveling at 5E34: 10 cm



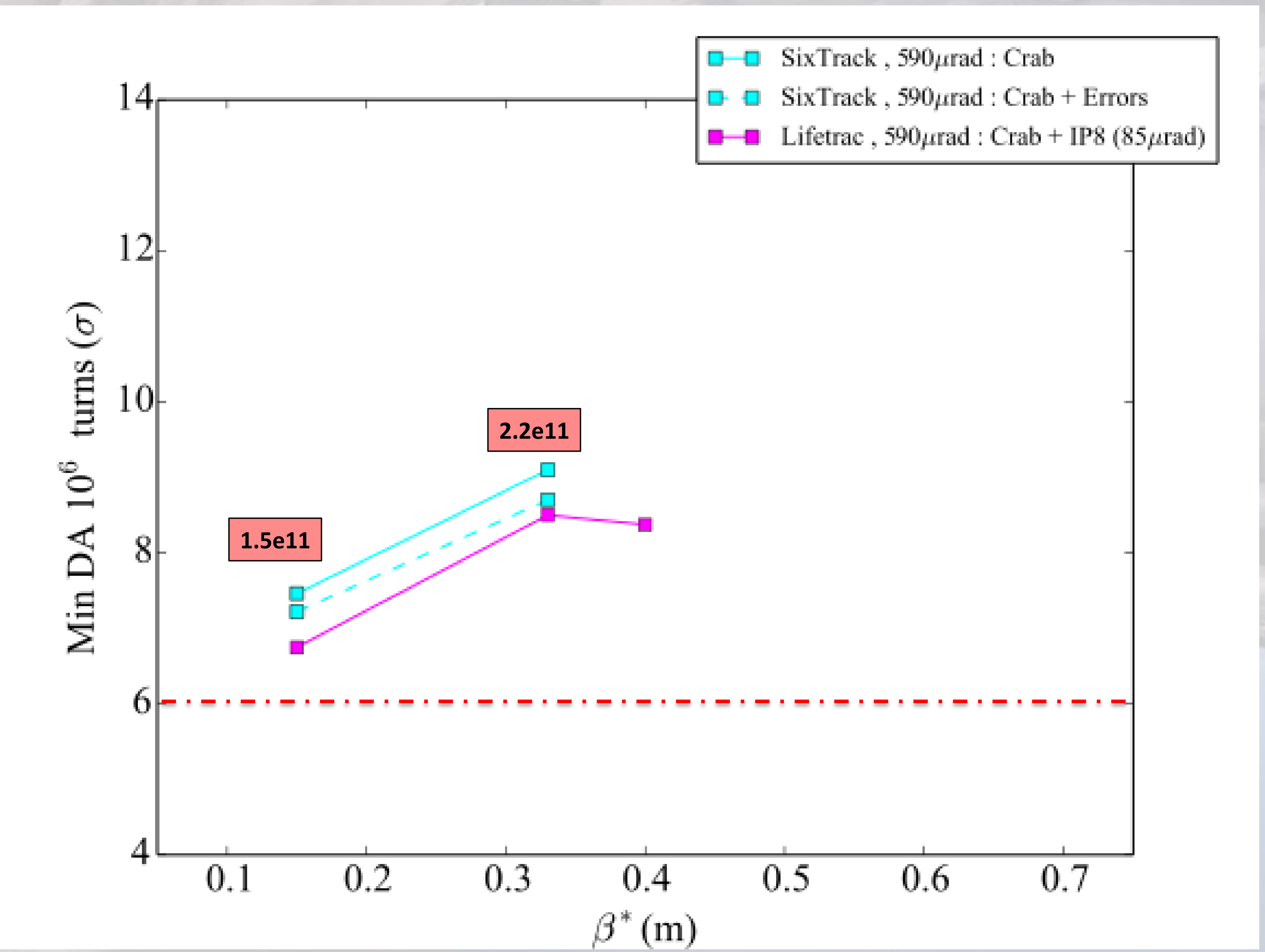
Minimum crossing angle 550 ⌠rad for β* levelling (int 1E11)
At nominal x-angle 590µrad limited to int 1.4E11

β* leveling summary for 5e34 Lumi Leveled: Nominal and reduced x-angle



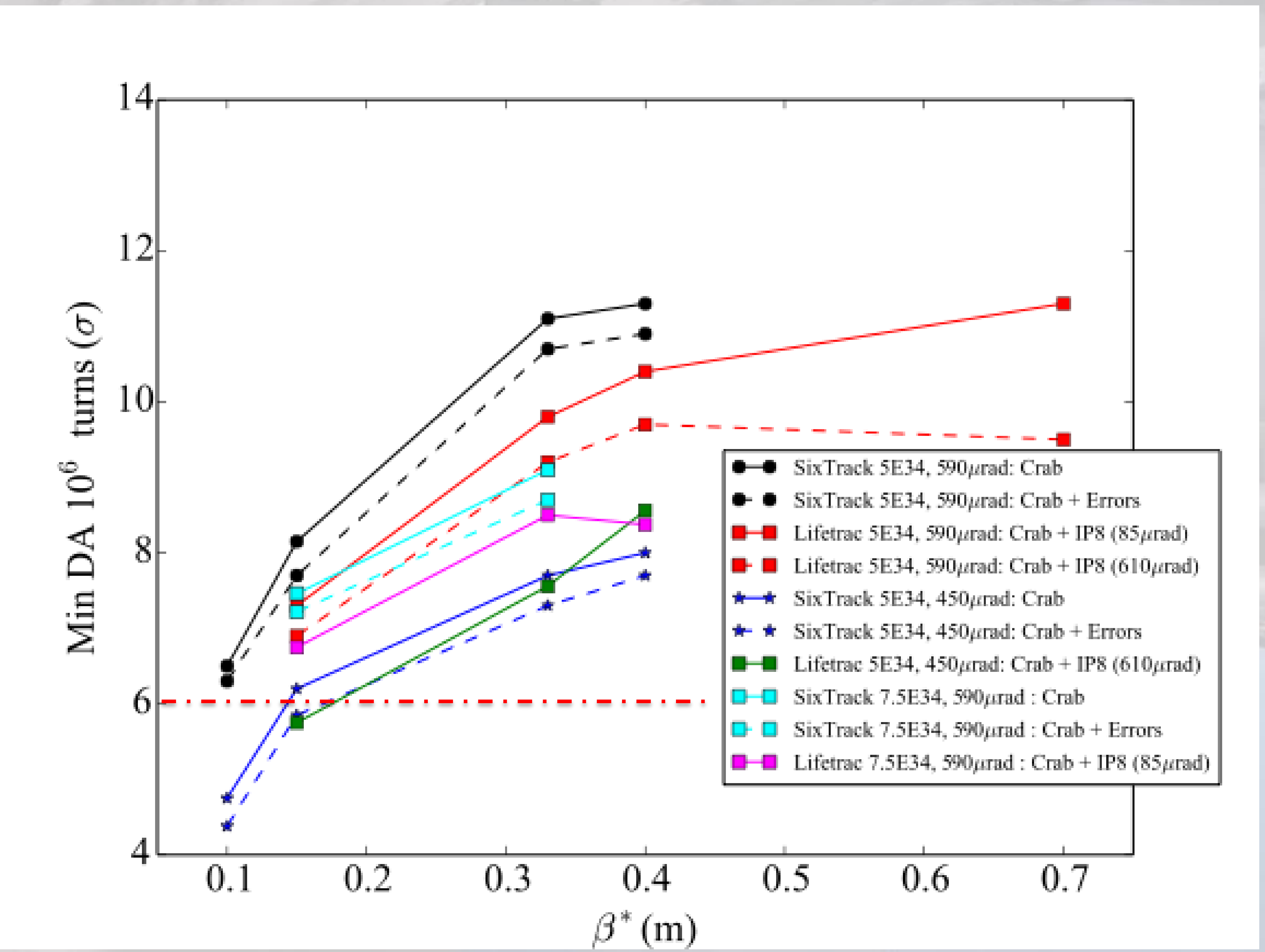
Nominal scenario with leveled lumi at 5e34 at 590μrad is robust thanks to b* leveling
DA always above 7σ

β* leveling summary 7.5e34 Lumi leveled



Nominal scenario with leveled lumi at 7.5e34 at 590μrad is robust thanks to β* leveling DA always above 7σ

Round optics β* leveling summary



Outlook

Round optics IP1(ATLAS) and IP5 (CMS) main drivers:

- Crossing angle scans
- Intensity scans
- Effect of crab crossing
- Impact of multipolar errors
- Impact of IP8 (LHCb)
- Summary of 5e34 and 7.5e34 Lumi scenarios

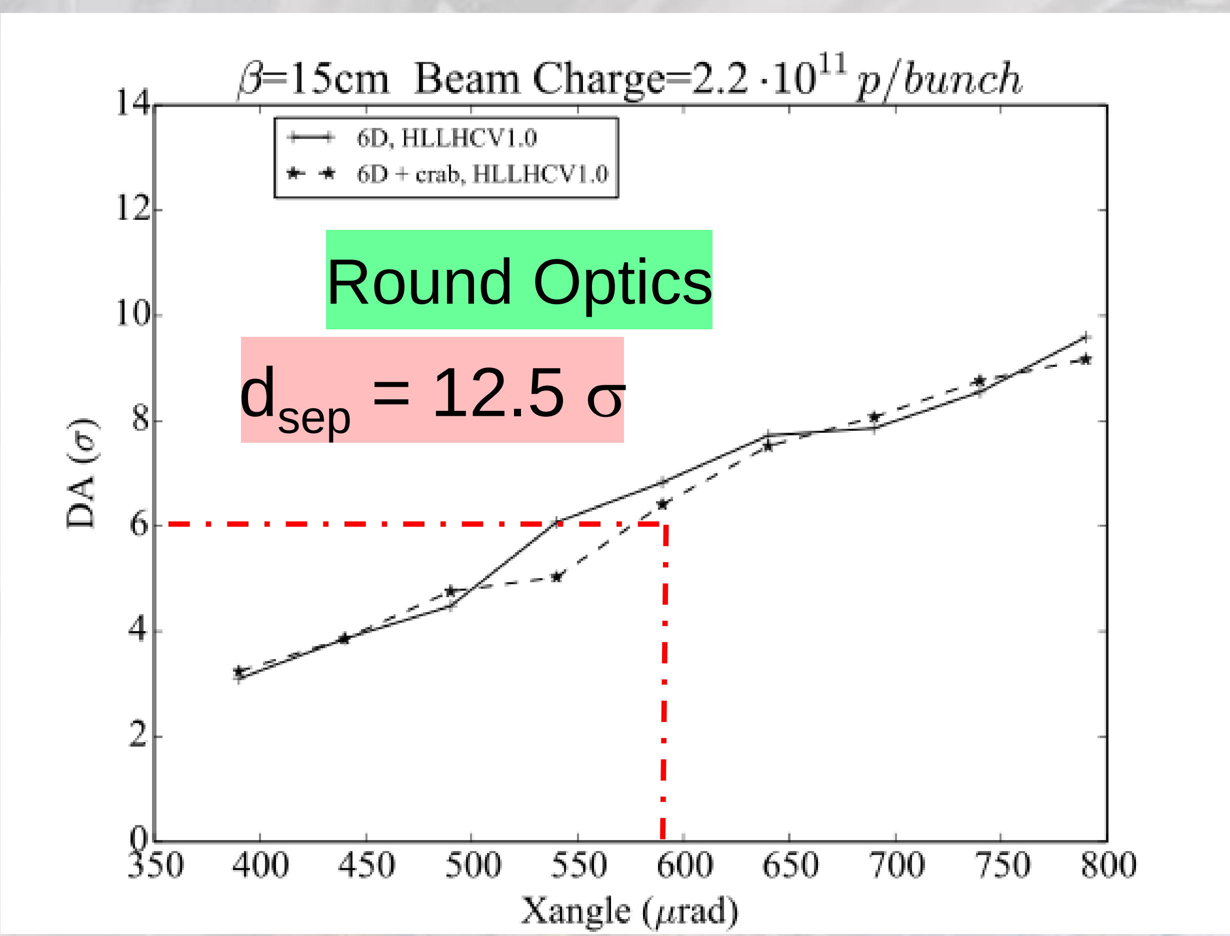
Flat optics:

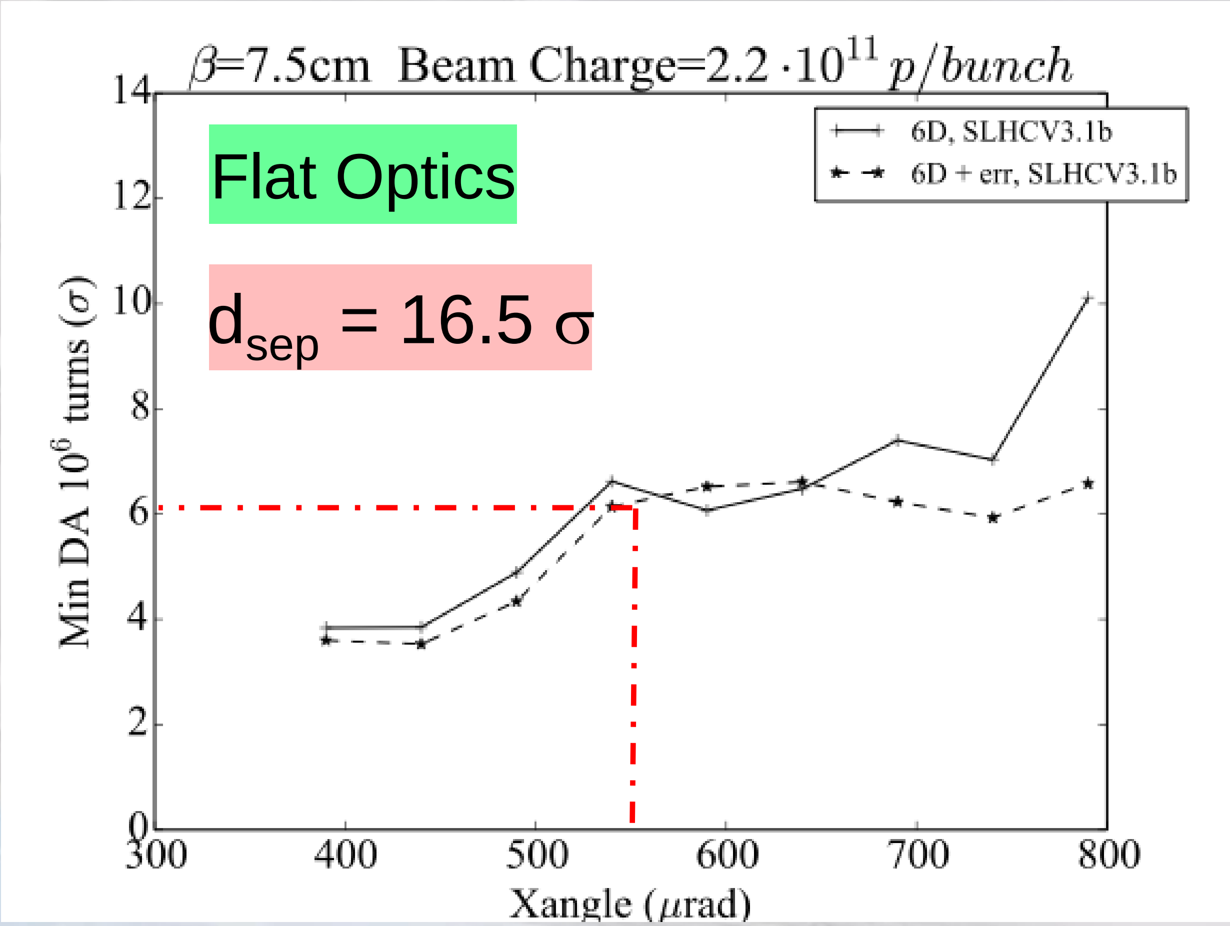
- Crossing angle scans
- Intensity scans
- Multipolar Errors

Summary and Future studies

SLHCV3.1b Flat Optic: x-angle scan

IP1 &IP5 only No Crab Crossing





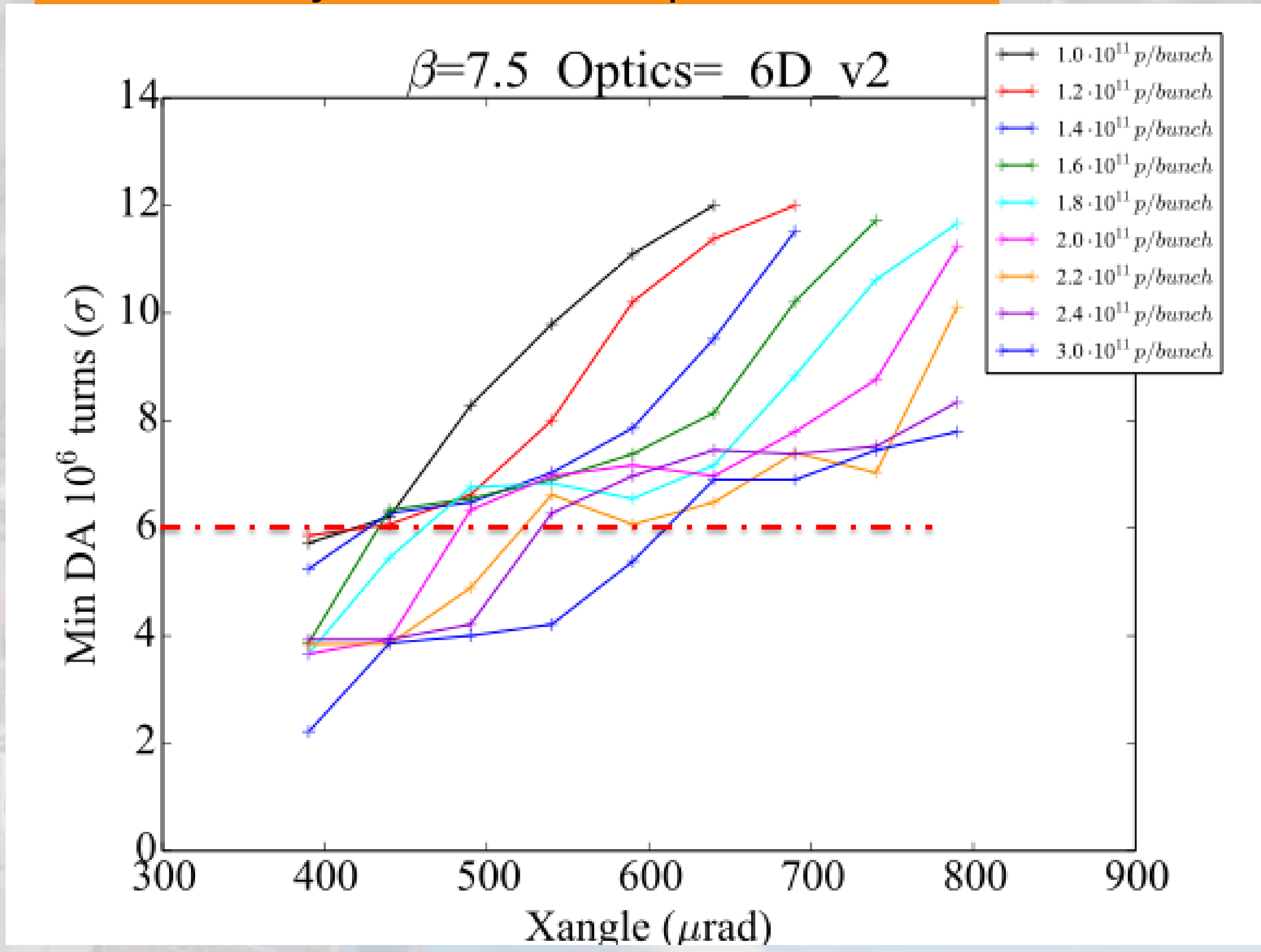
$$DA \propto \alpha$$

$$DA \not\propto \alpha$$

Different behaviour due to tune shift due to the not perfect HV passive compensation between IP1 and IP5.
Flat optics need in general LARGER d_{sep} to obtain same DA
Linear dependency typical for round is not valid for flat (S-shape DA vs angle)!

SLHCV3.1b Flat Optics: Intensity scans

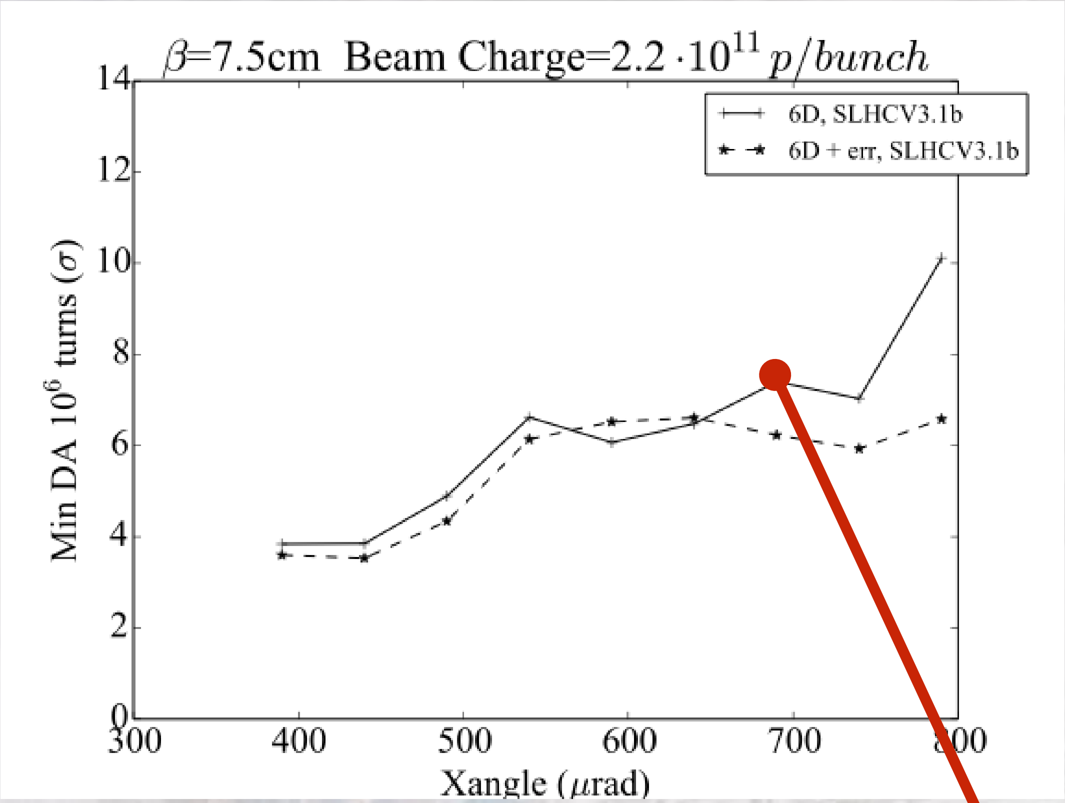
IP1 &IP5 only, SHLCV3.1b optics No Crab

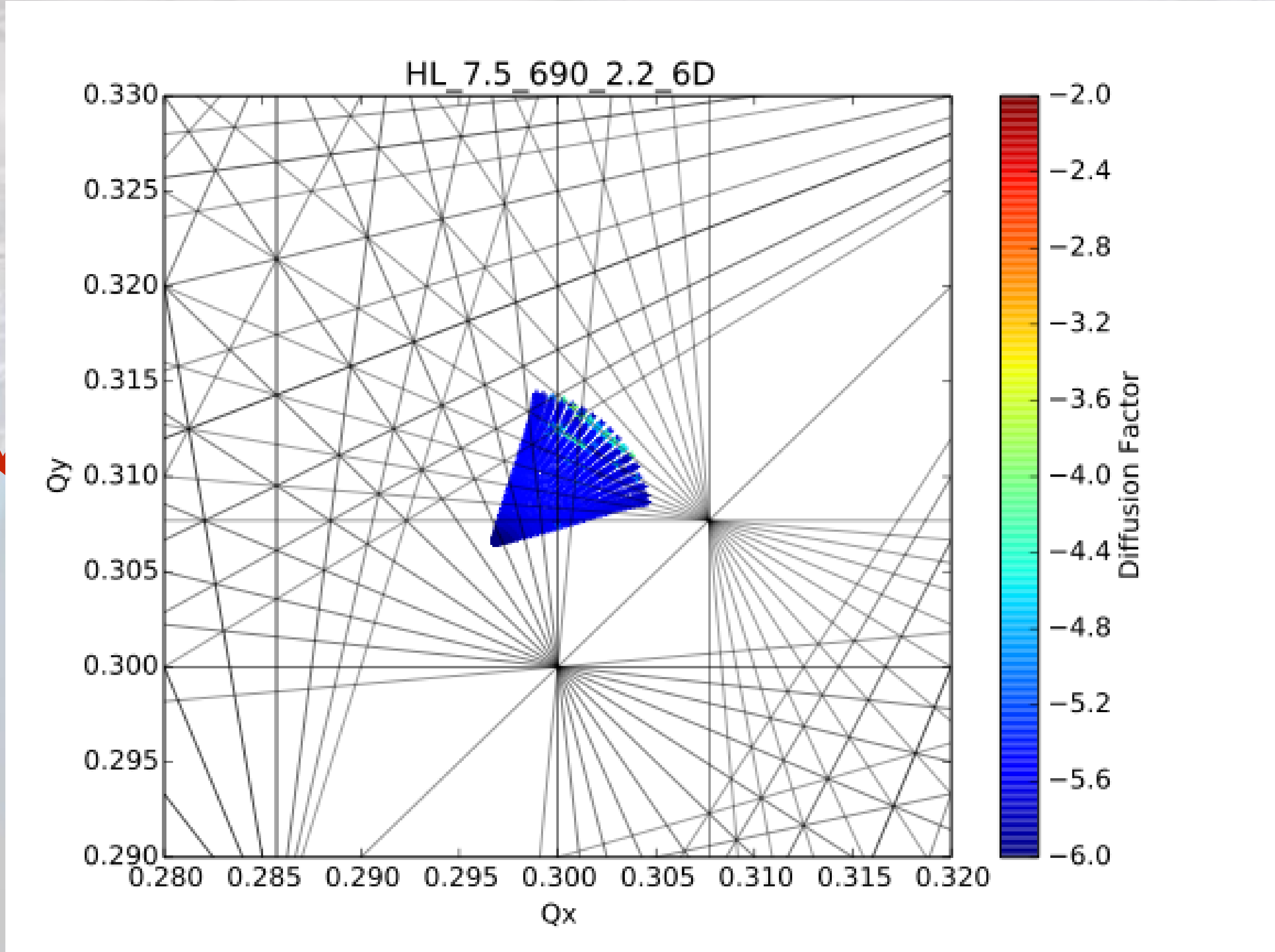


$DA \not\propto Intensity$

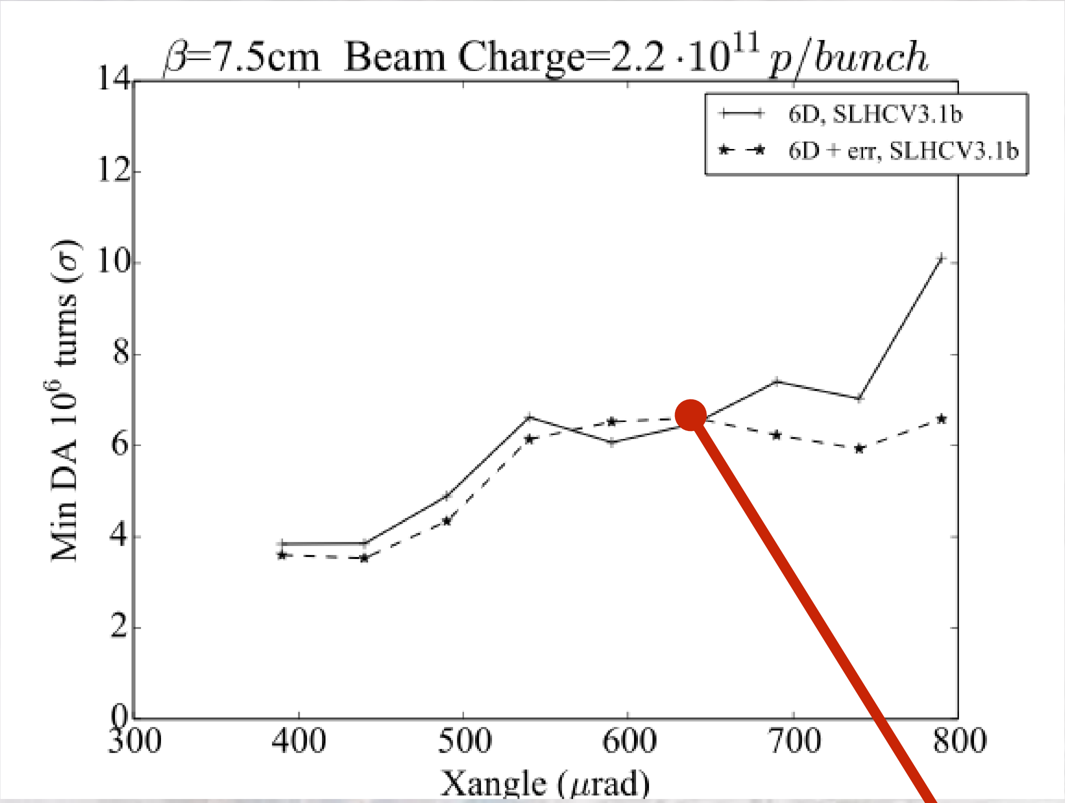
Different behaviour due to tune shift along the diagonal:
not perfect HV passive compensation between IP1 and IP5.
Linear dependency typical for round is not for flat with strong LRs!
Linear dependency for weaker LR, reduced tune shift!

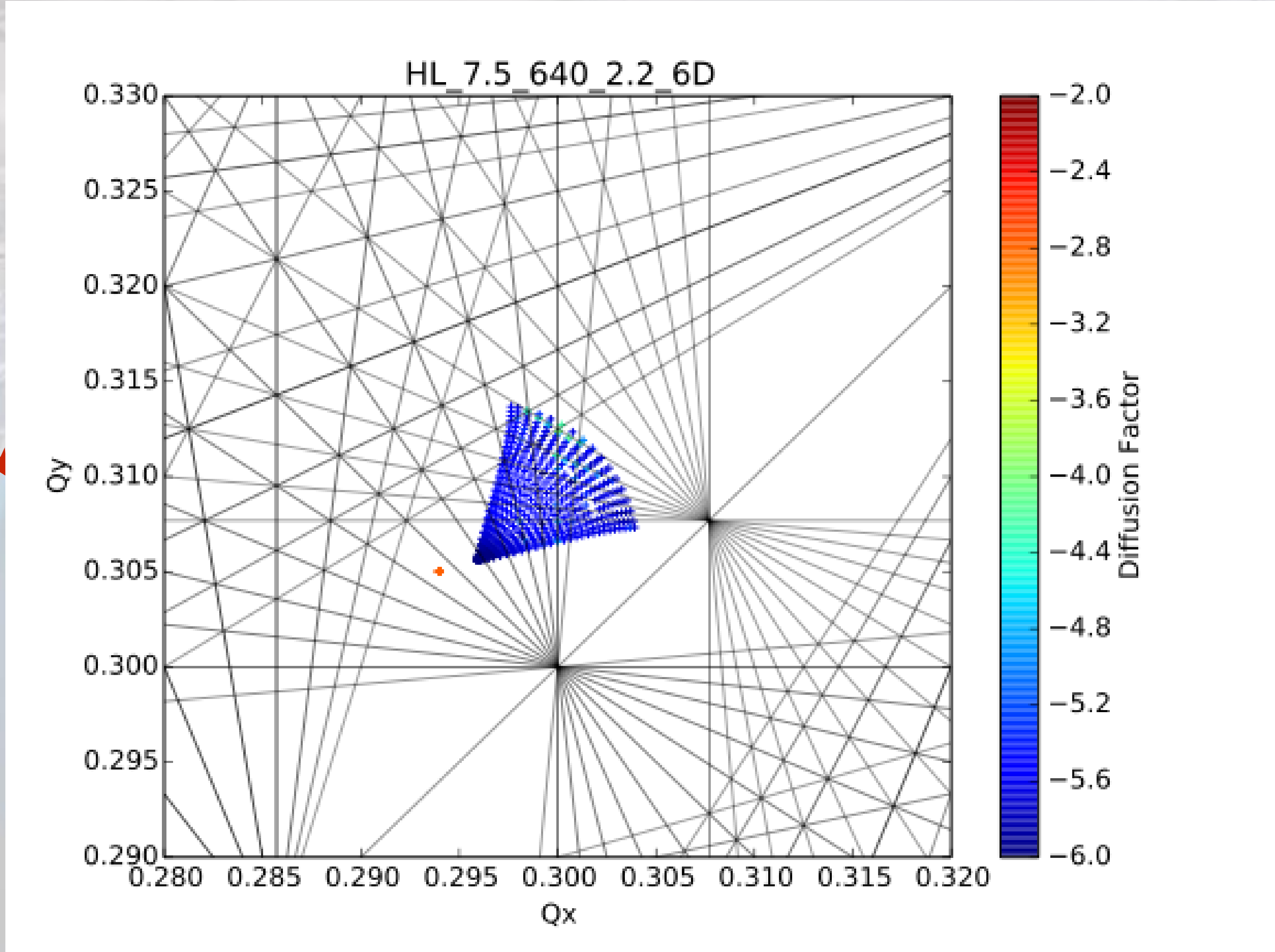
Flat 7.5cm/30cm, 2.2E11, 690μrad



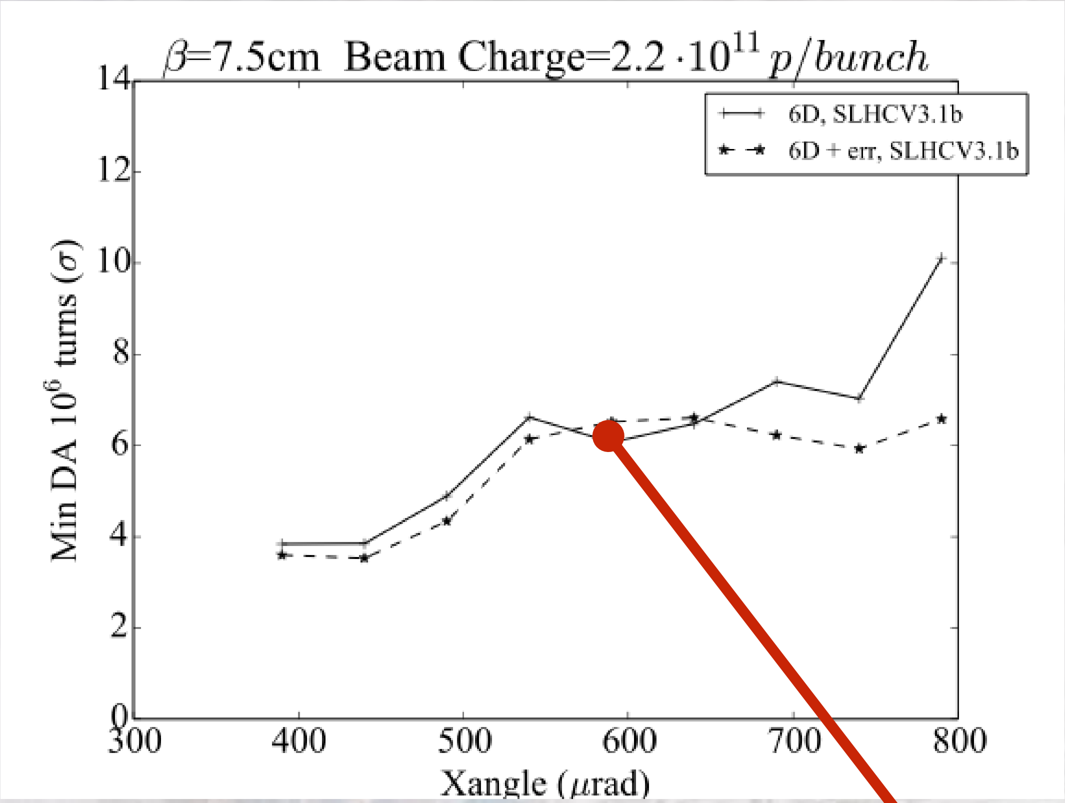


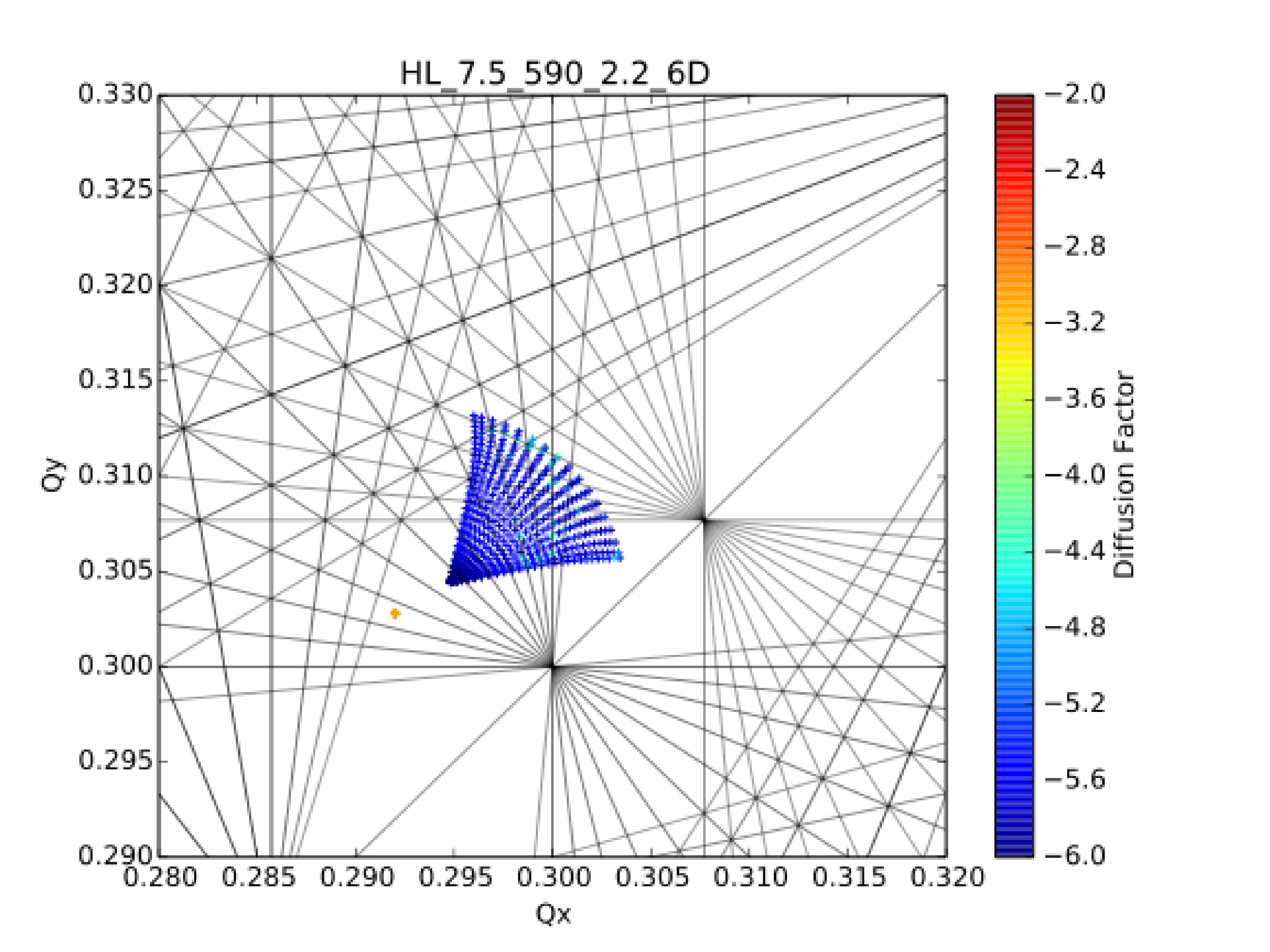
Flat 7.5cm/30cm, 2.2E11, 640μrad



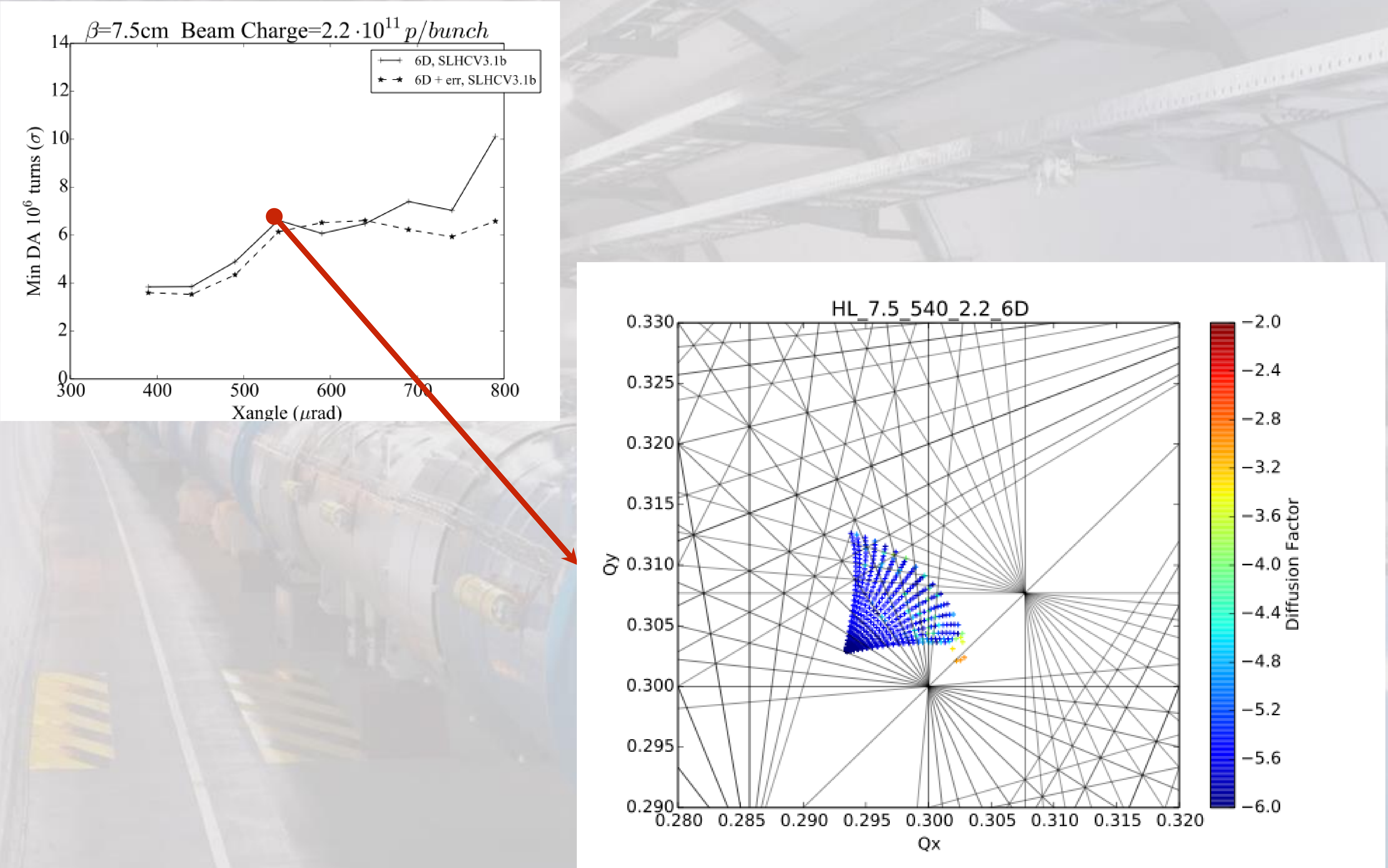


Flat 7.5cm/30cm, 2.2E11, 590μrad

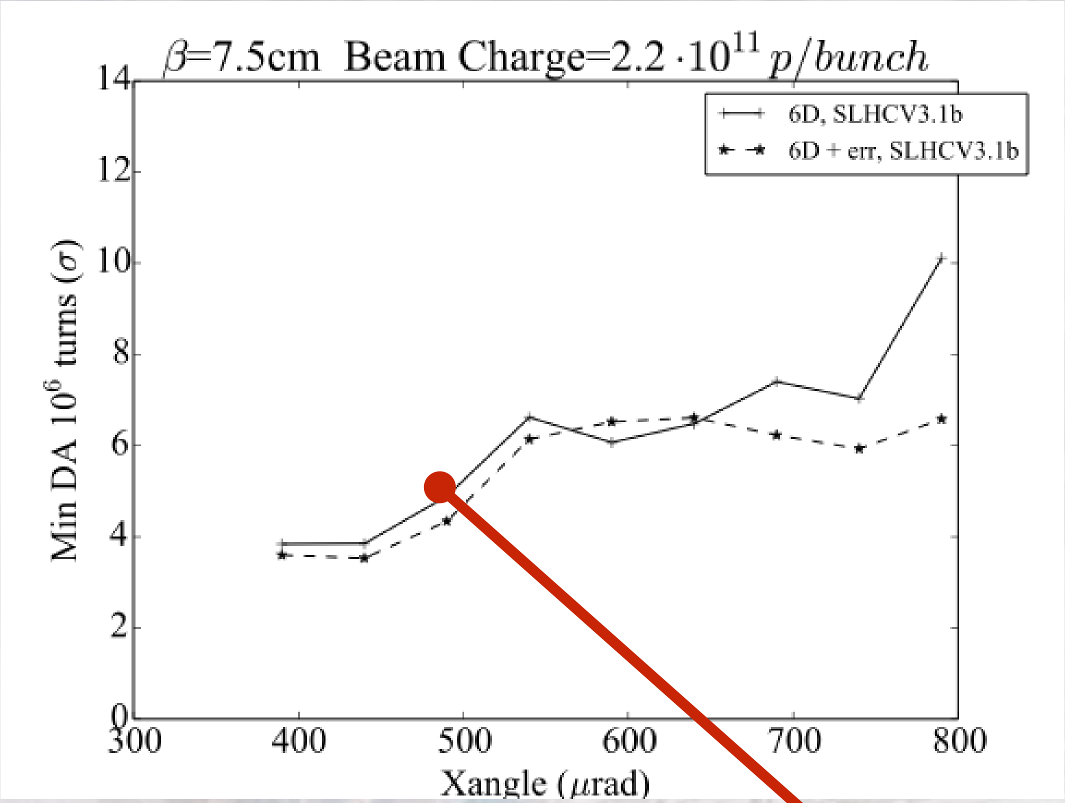


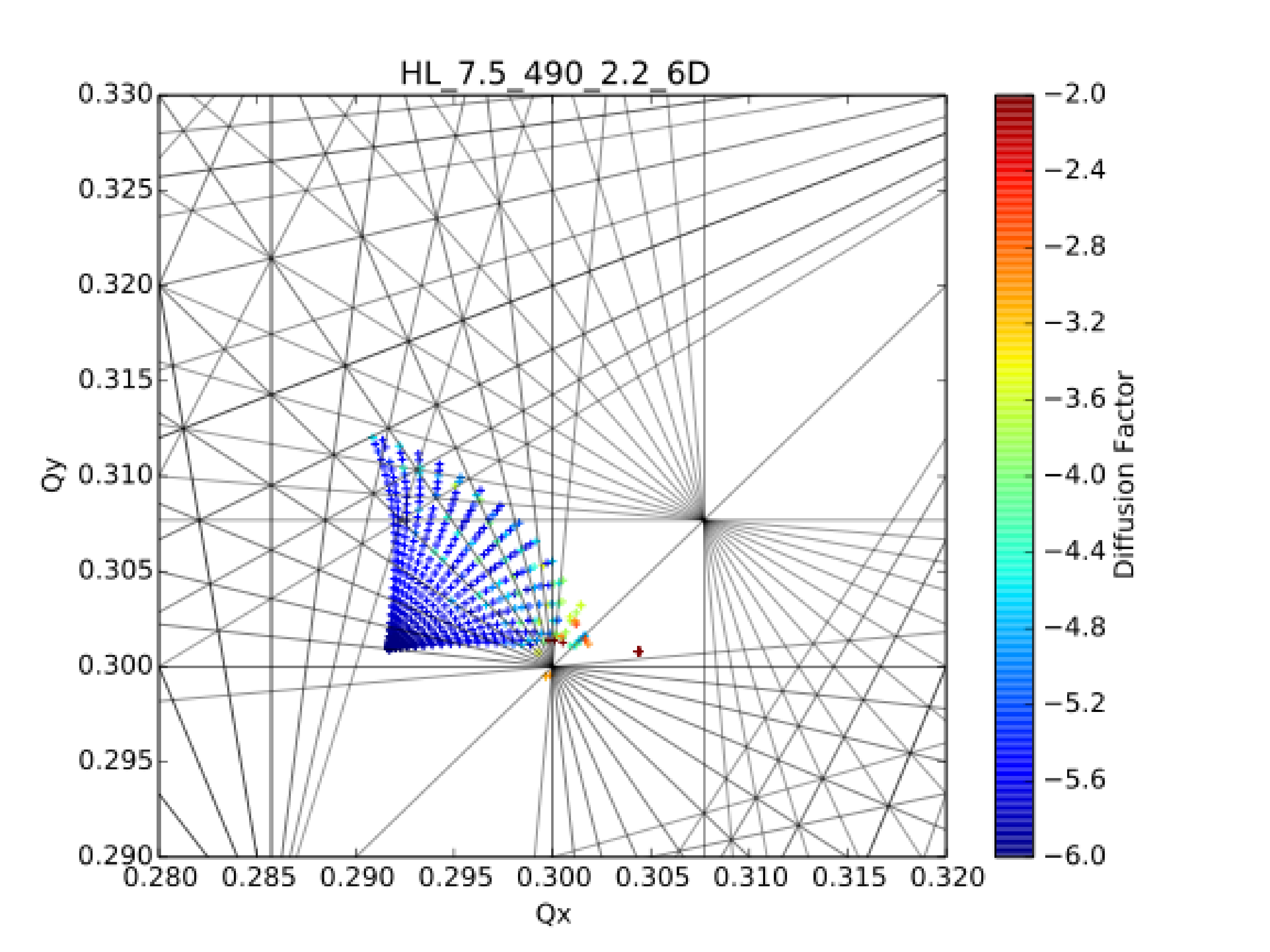


Flat 7.5cm/30cm, 2.2E11, 540µrad

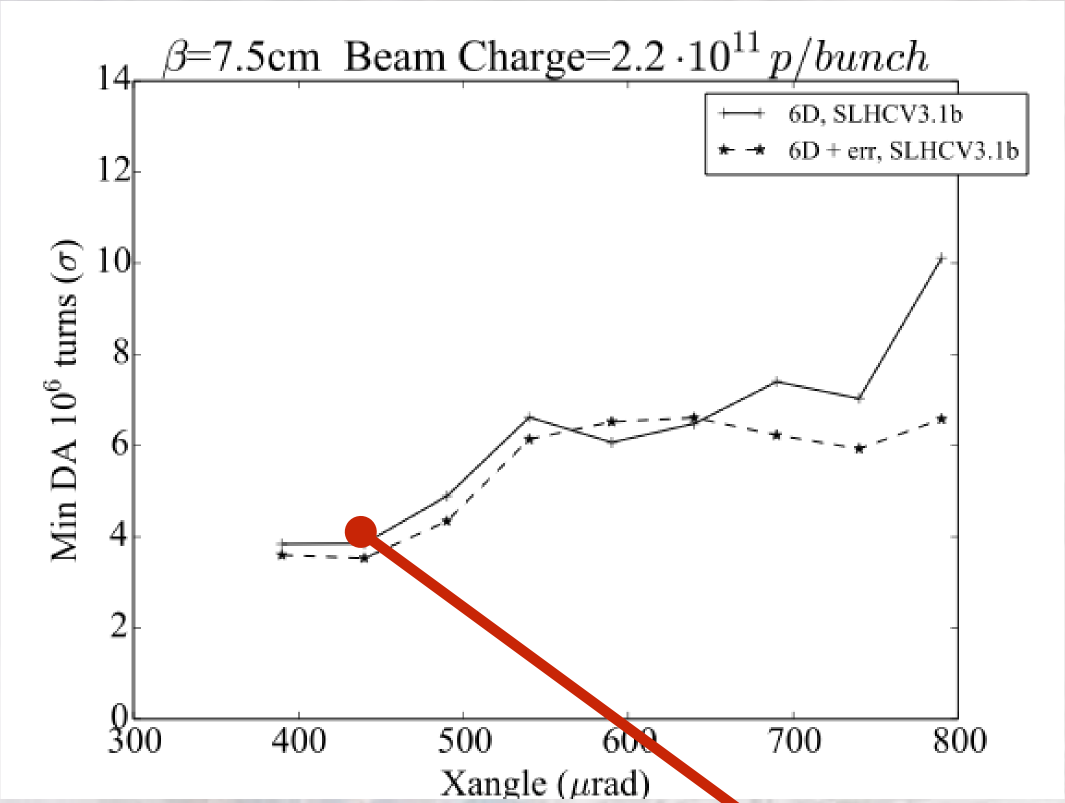


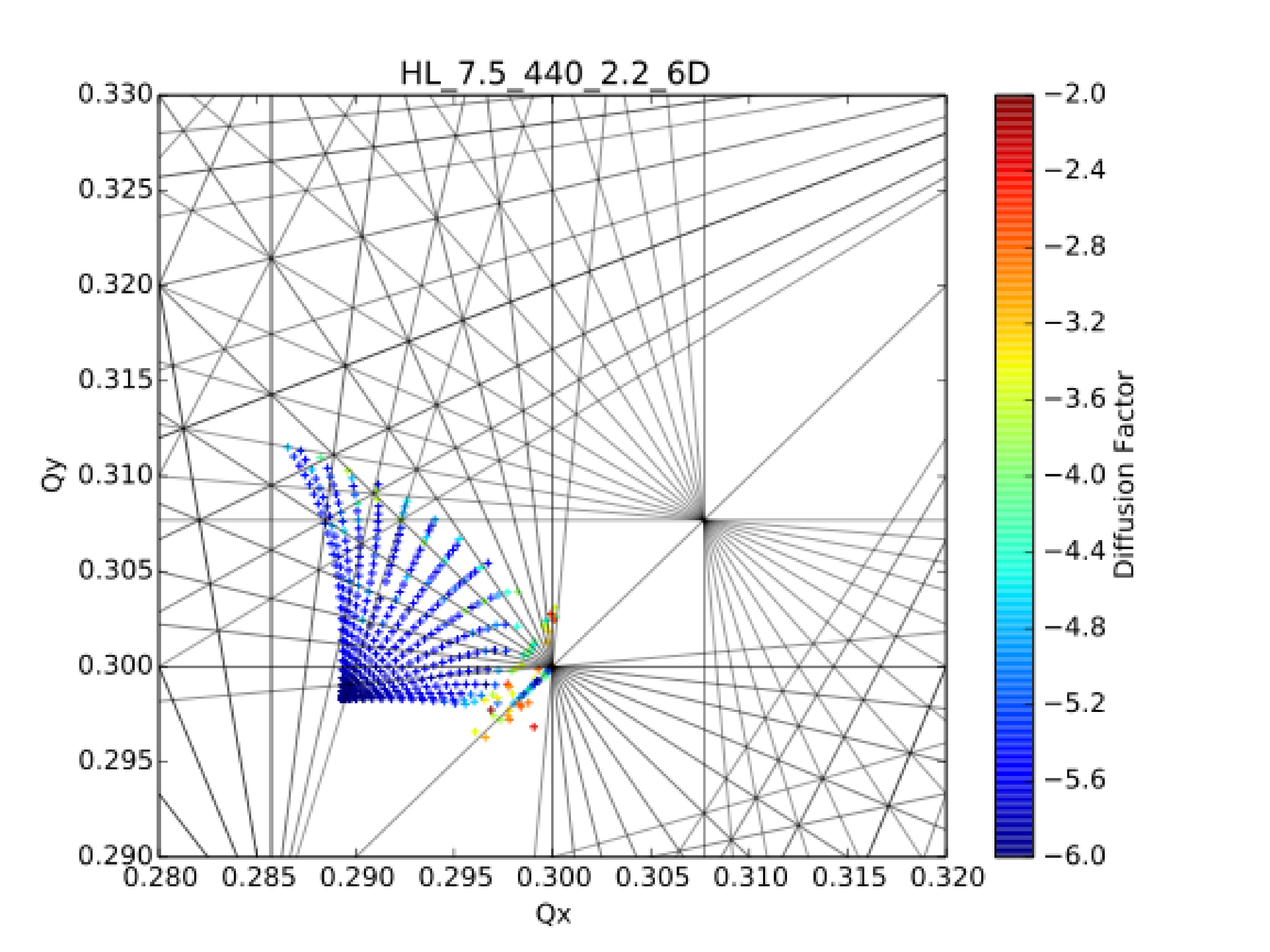
Flat 7.5cm/30cm, 2.2E11, 490μrad



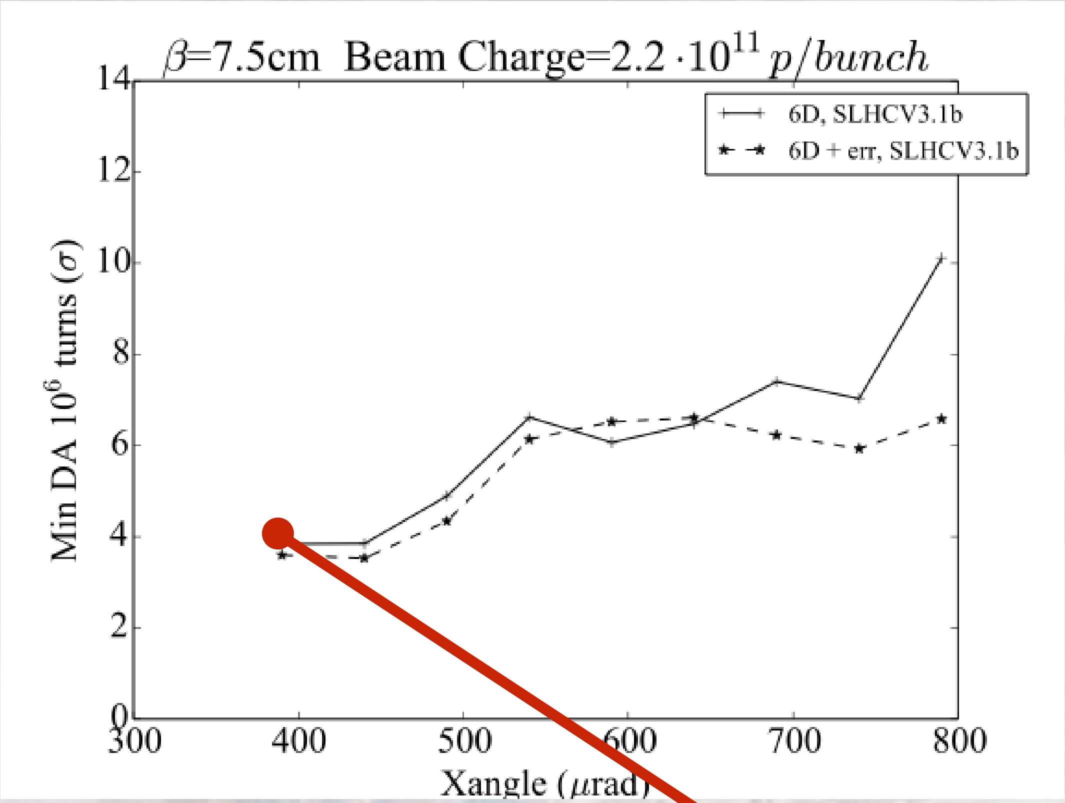


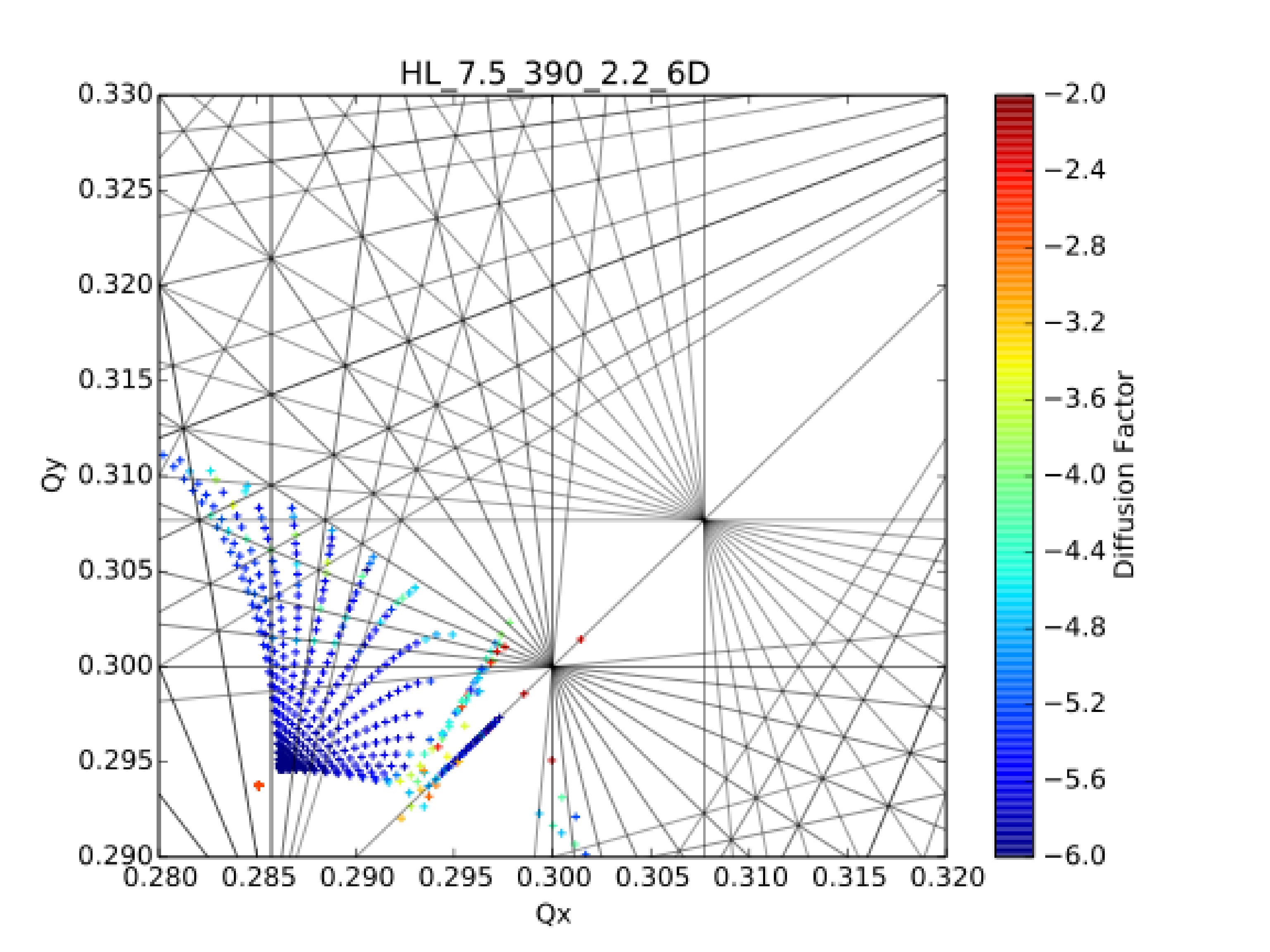
Flat 7.5cm/30cm, 2.2E11, 440μrad



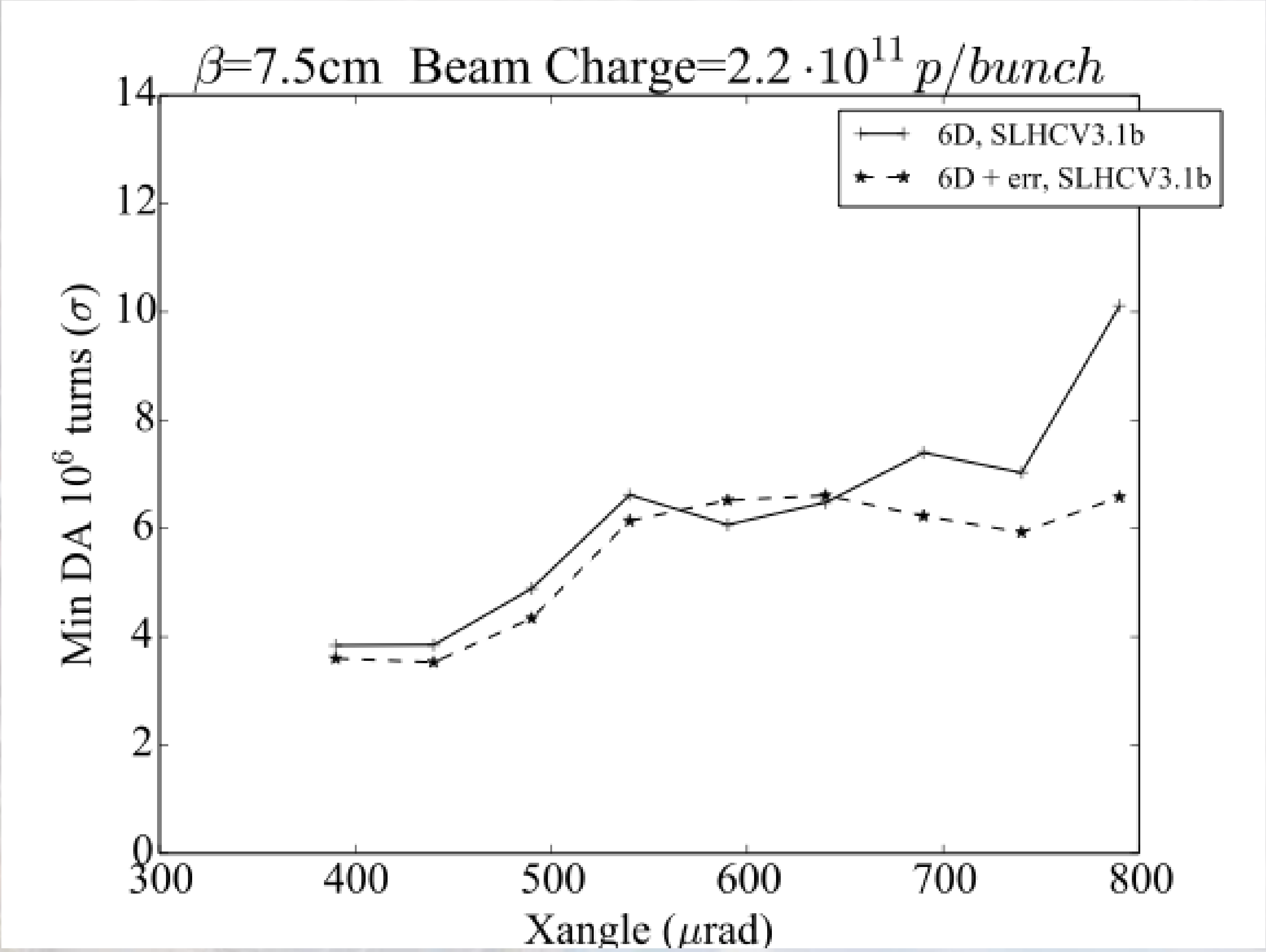


Flat 7.5cm/30cm, 2.2E11, 390μrad





Flat 7.5cm/30cm, 2.2E11



AT each β* step: HO changes and loss of partial HV passive compensation of LR changes
→ Tune shift → Footprint moves in the tune space

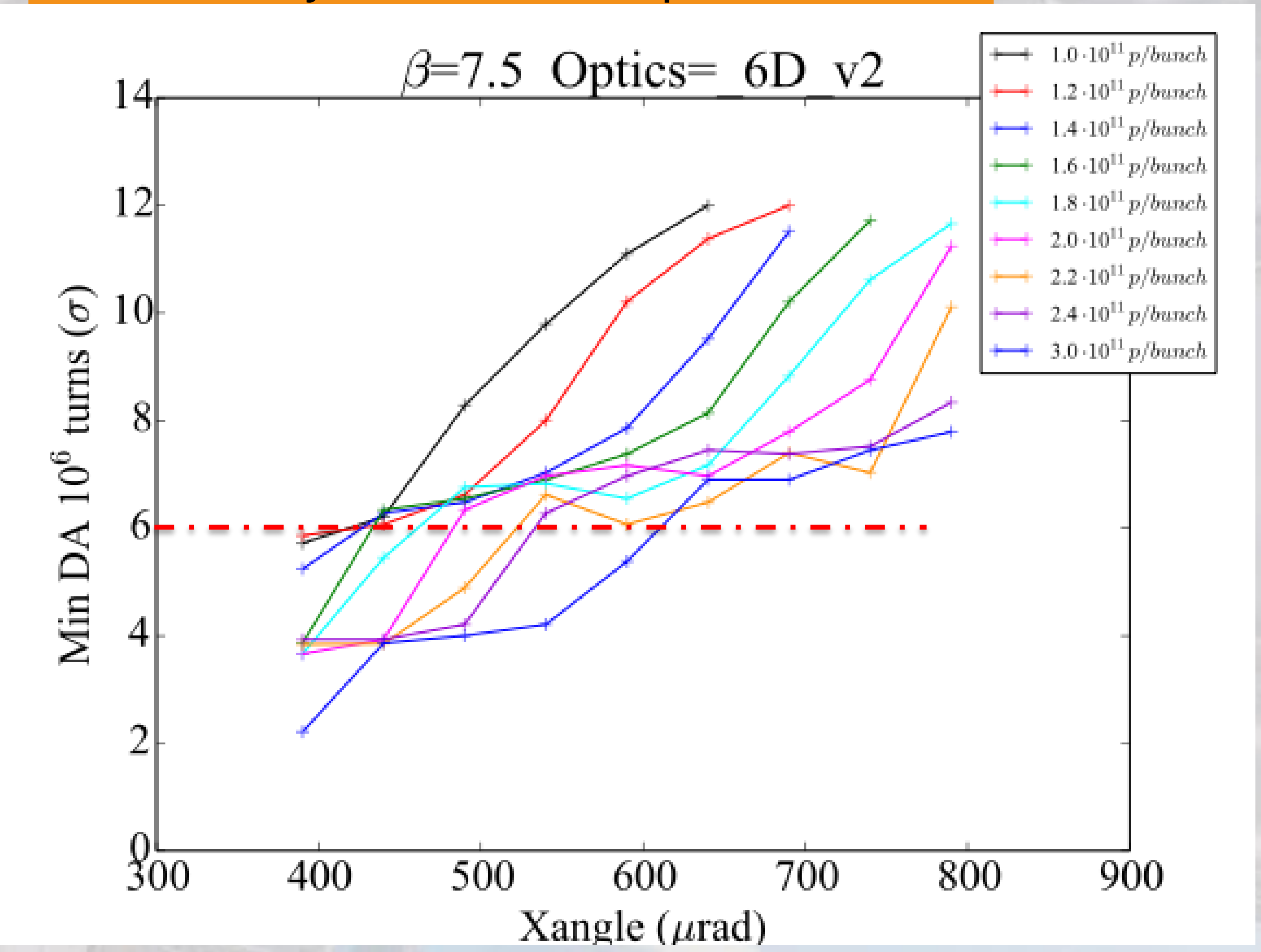
- **We Cross different resonances (10th, 7th…)**
- **DA depends on driving resonances (might explain S-shape of DA)**

For flat optics case we will need to shift tunes back to best WP at each β* step (need to define optimal working points per step with simulations)

SLHCV3.1b Flat Optics 7.5cm/30cm

IP1 &IP5 only, SHLCV3.1b optic No Crab

$DA \not\propto Intensity$



Linear dependency typical for round is not for flat with strong LRs!
Linear dependency for weaker LR, reduced tune shift we go back to linear bahaviour!
Studies need to be repeated with tune scans !
Changing optics (beta ratio) changes the x-angle dependence

For flat optics case we will need to shift tunes back to best WP at each β* step (need to define optimal working points per step)

Summary

- **Without β* levelling:** at nominal crossing angle of 590μrad (IP1&5 only) the nominal intensity of 2.2E11 is at the limit below 6σ DA (details in T. Pieloni talk Thursday)
- **Lifetrac and Sixtrack** are consistent and give equivalent results (within 10-20%)

Round Optics

- For both codes with **β* luminosity levelling at 5E34** the baseline scenario for round optic is robust: DA always above 7σ
  - → room for an important reduction of crossing angle if needed (down to 450μrad) or allow for higher intensities
- For both codes with **β* luminosity levelling at 7.5E34** the scenario for round optic is also robust: DA always above 6σ
- **Multipolar errors reduce DA by 0.5-1σ**
  - →(see details in T. Pieloni talk Thursday "DA criteria")
- **IP8 contribution to DA:** deterioration of maximum 0.5 σ expected in the worst case scenario

Flat Optics

Flat optics behaves differently from round due to partial LR compensation broken (H/V)

→Important tune shift at each β* step → working point optimization fundamental to improve DA

→With β* leveling we might not need extra separation.

→ Possible scenarios without crab-crossing and β* leveling (R. Tomas talk Thursday)

What is still needed: future Studies

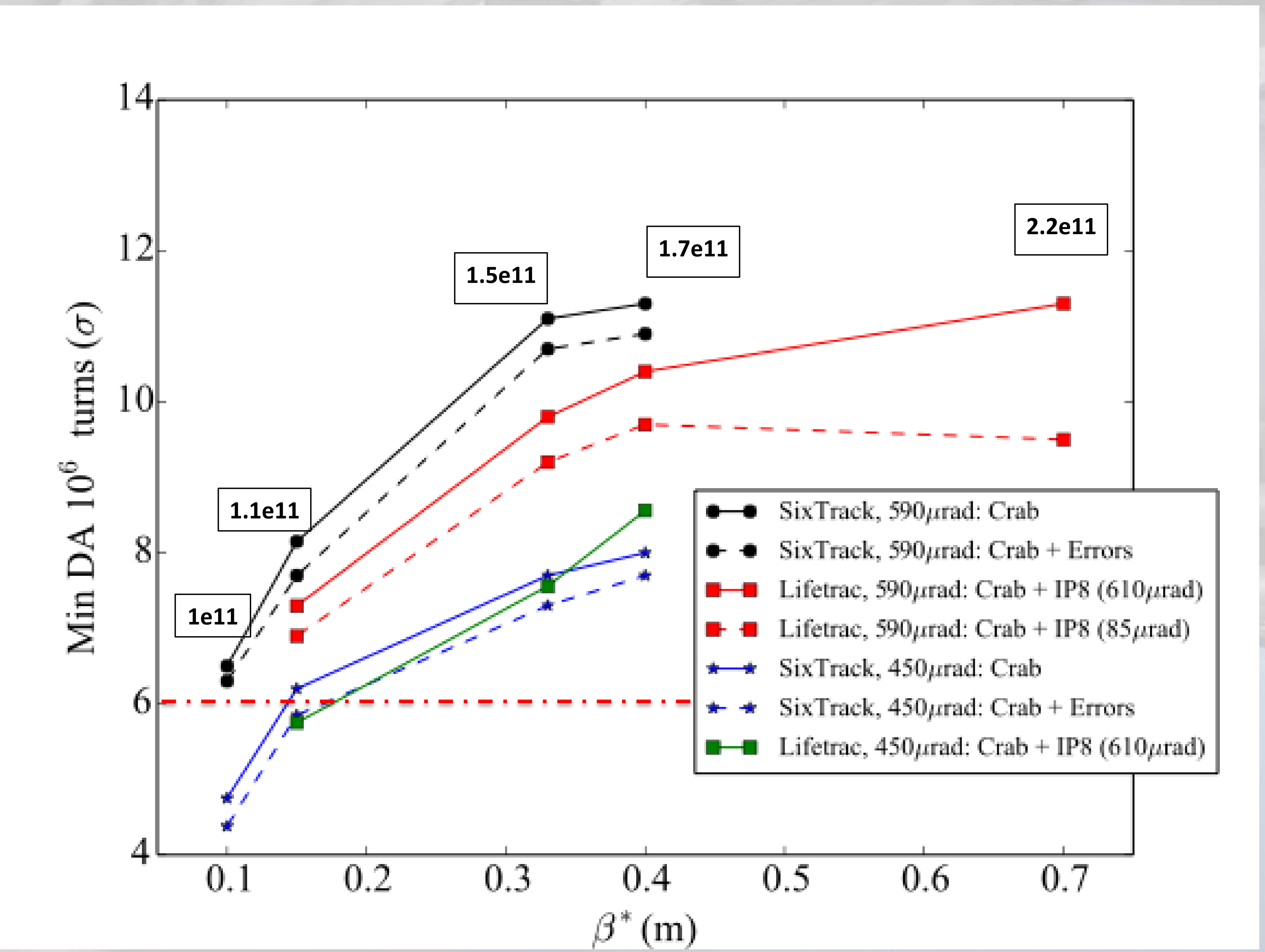
Round Optics: ostill some studies needs to be done

- Impact of Higher Chromaticity
- Impact of Landau Octupoles (positive/negative effects)
- Imperfect machine (orbit errors, beta beating, coupling…)
- Sensitivity to working point
- Complete study of sensitivity to IP2and IP8 to evaluate/propose x-angles

Flat Optics: needs still many studies

- Similar Exercise as for the round optics

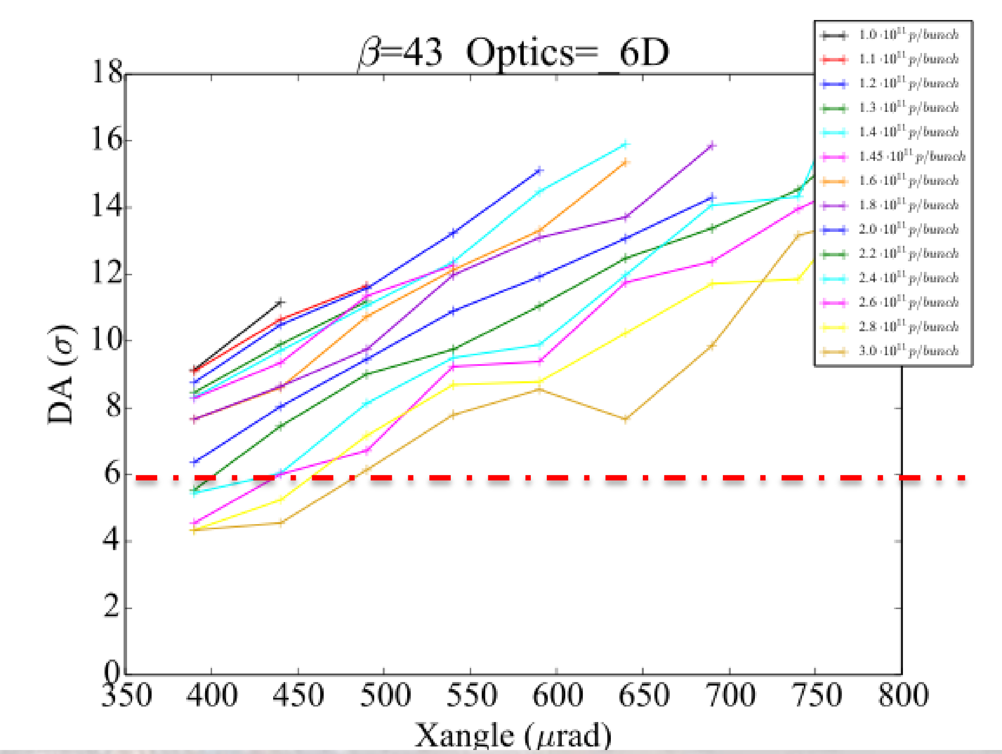
β* leveling summary: Sixtrack & Lifetrac

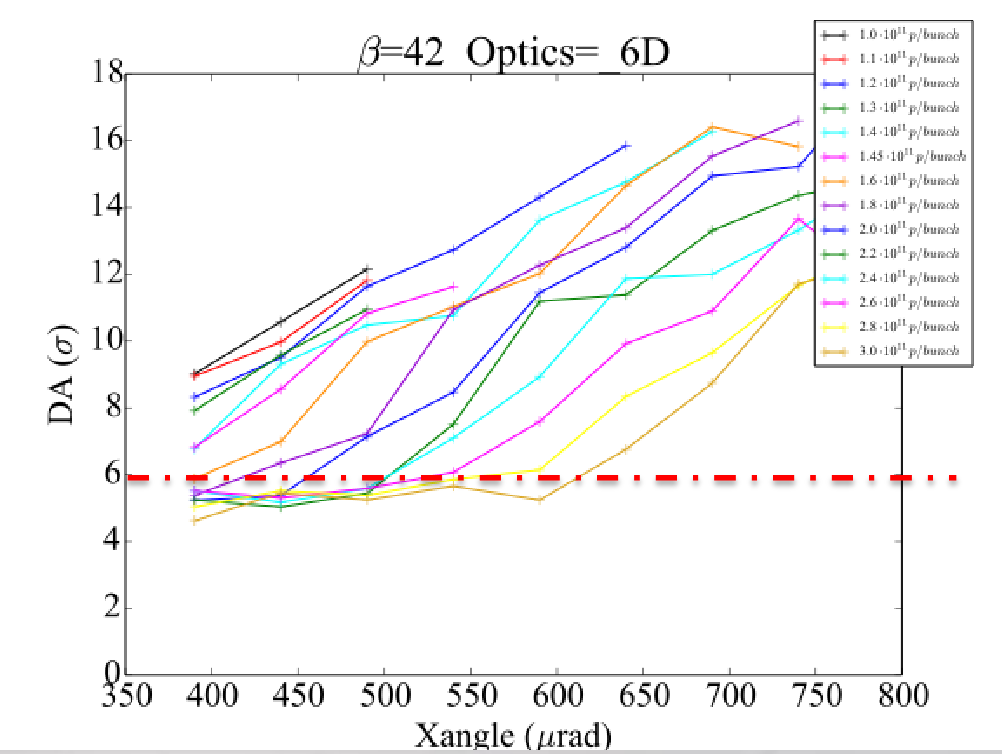


BackUp Slides

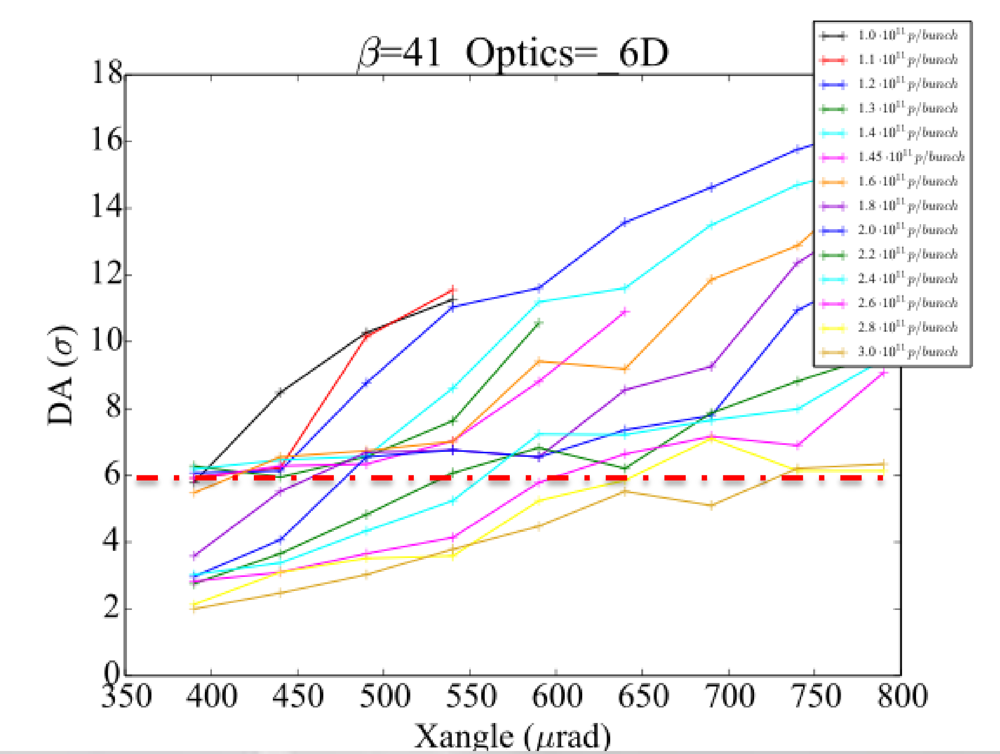
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

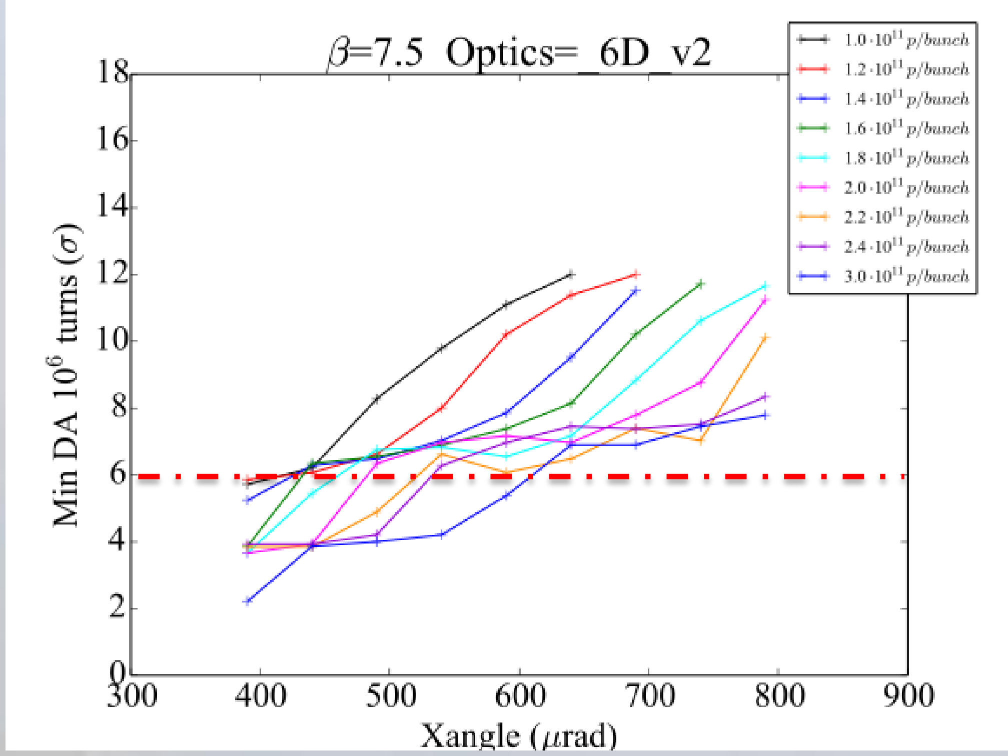
Same exercise as for round over several optics:



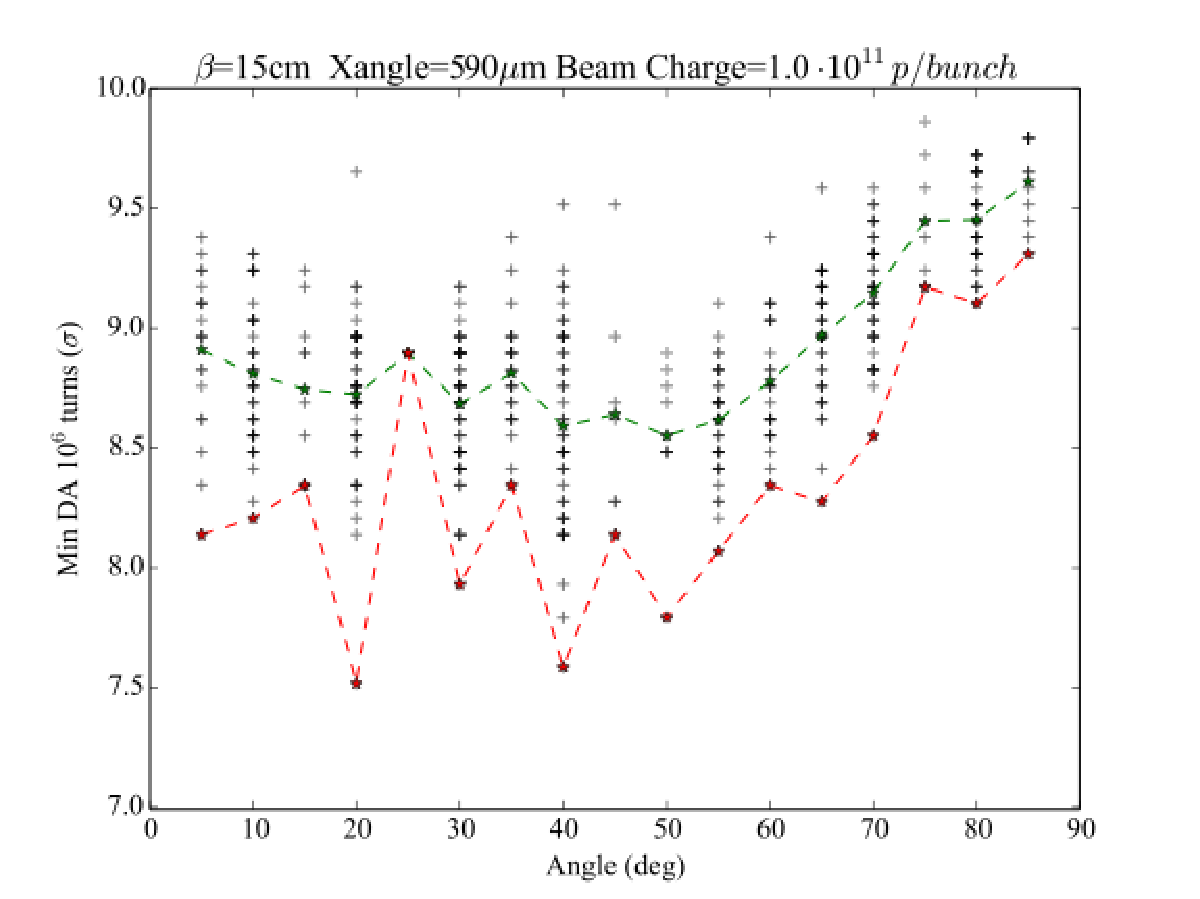


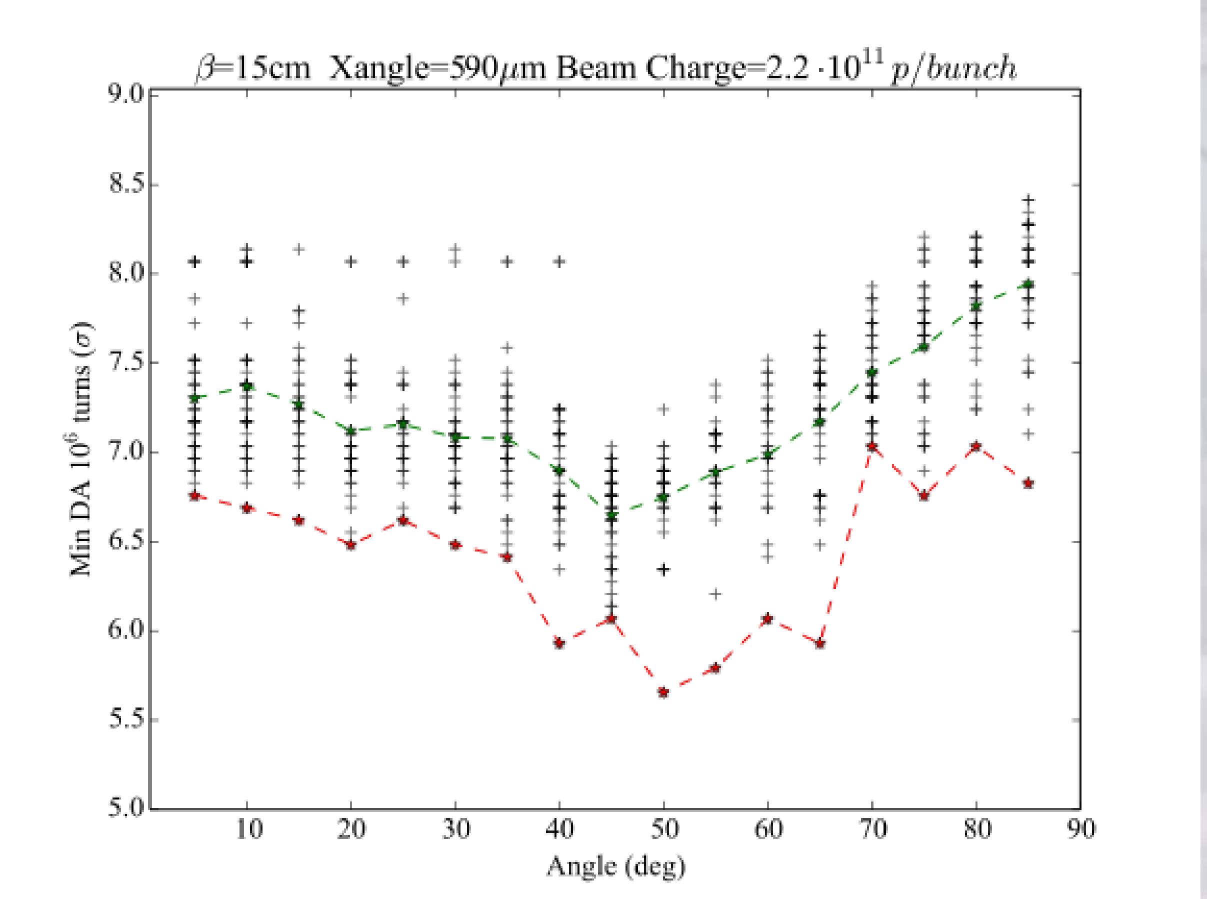
Several Optics Explored to identify Intensity limits and minimum crossing angles!
Possible scenarios with β* leveling without crab crossing and reduced x-angle proposed
(see R. Tomas talk Thursday "Alternative Scenarios")
BBLR compensation studies on-going (see A. Valishev "BBLR Compensation", Y. Papaphilippou "BBLR ..")





HLLHCV1.0: All error, 60 seeds

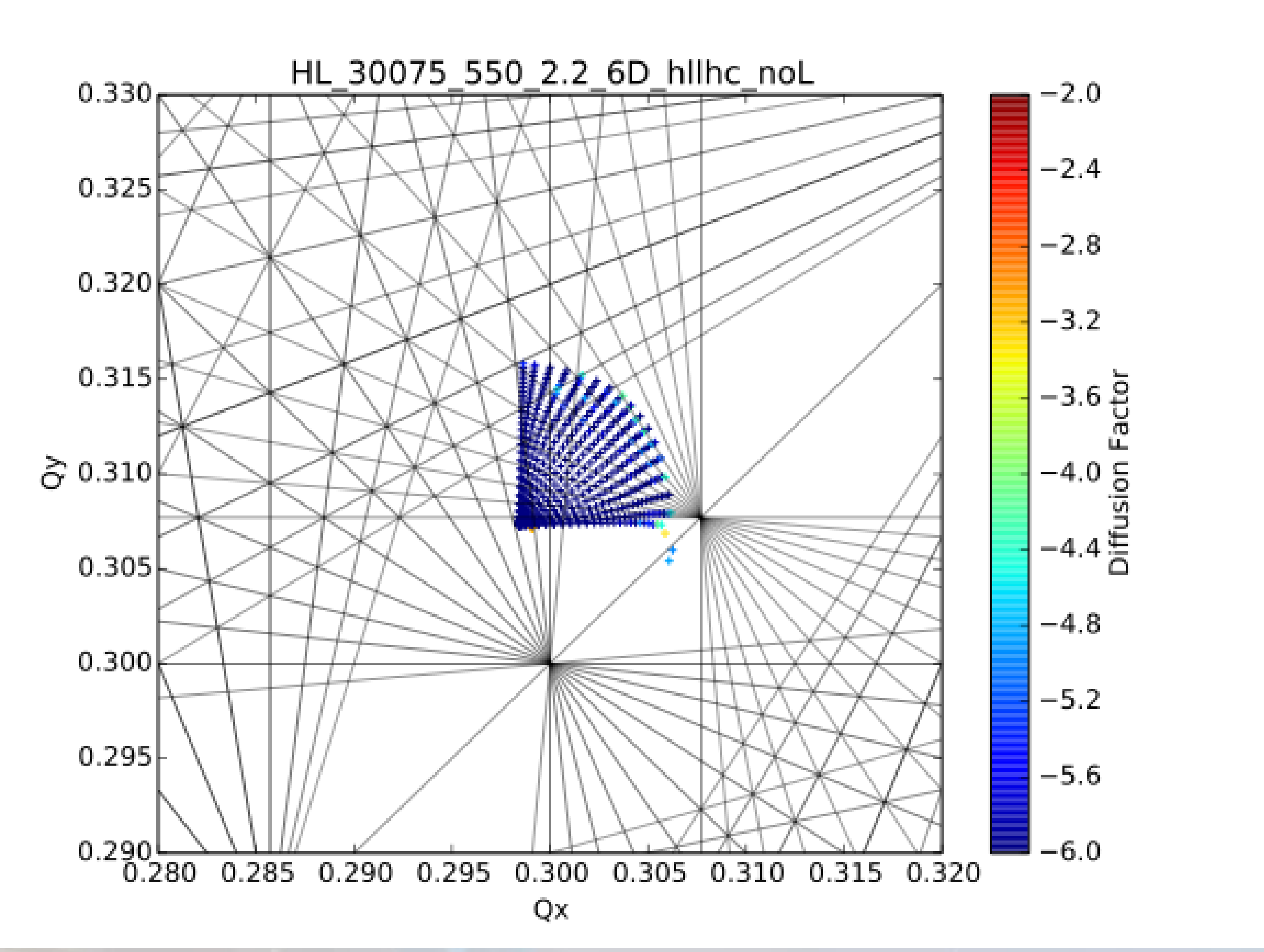




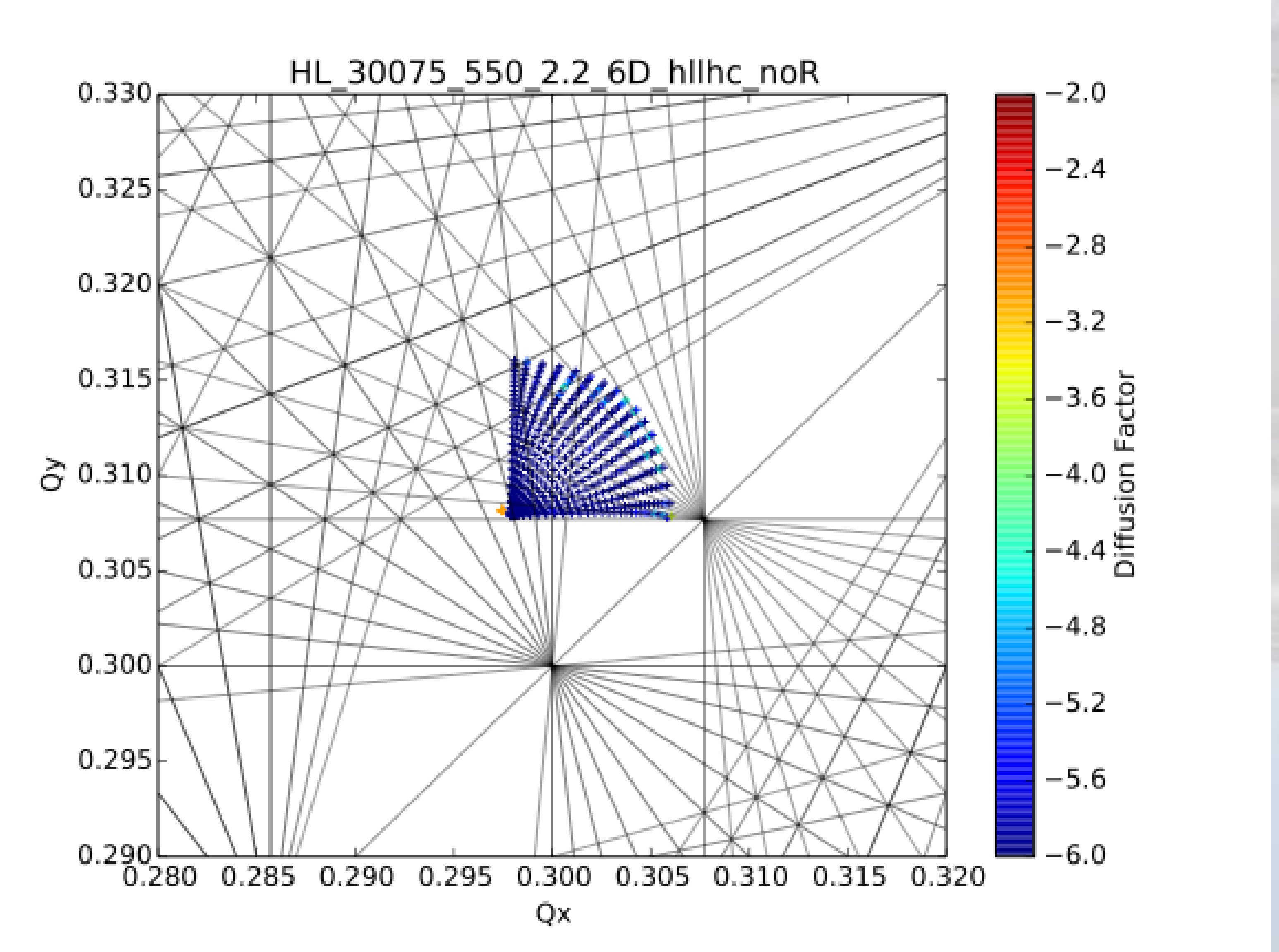
DA computed for 60 error seeds on HLLHCV1.0 optics.
Spread of 2σ, quoting the minimum DA may be a little pessimistic.

IP1 &IP5 only
60 seed error
HLLHCV1.0 optic

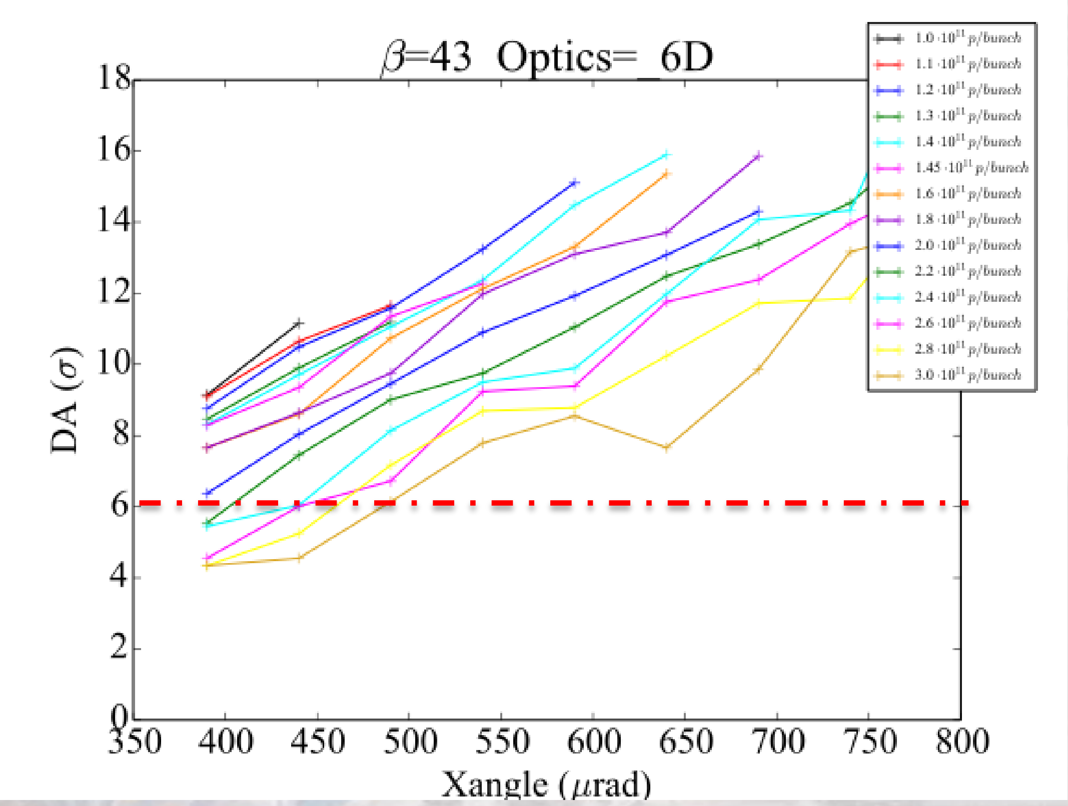
Flat 7.5: FMA fixed Intensity

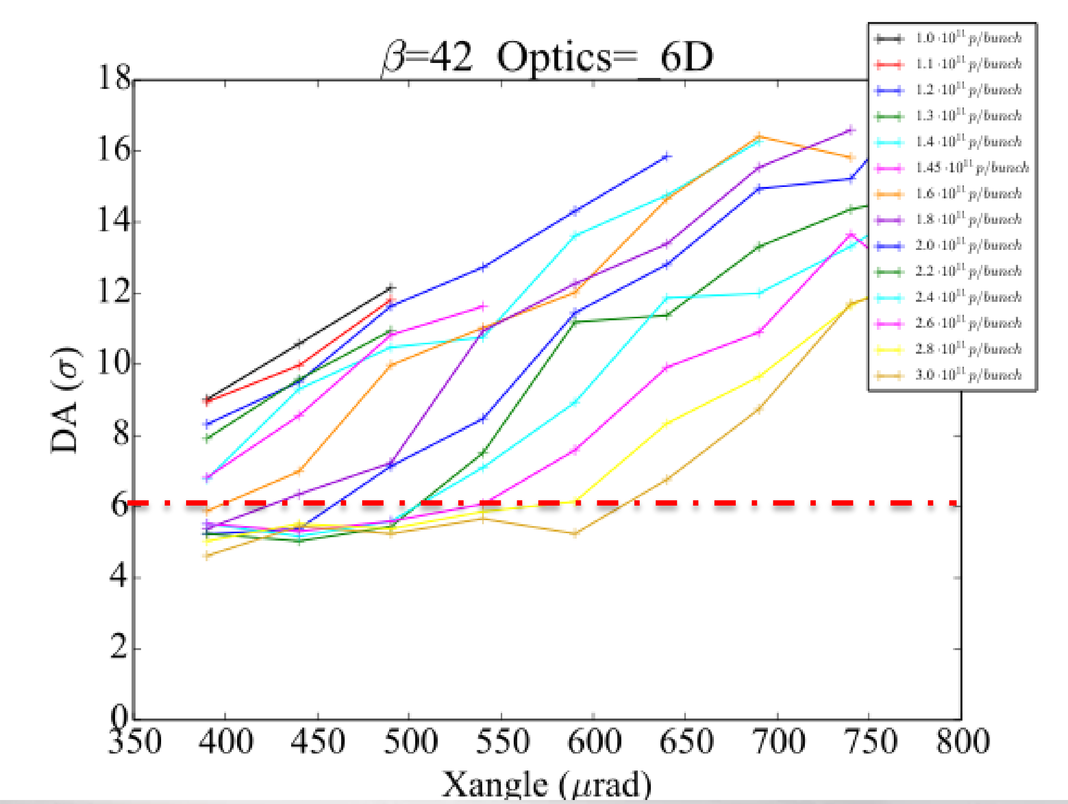


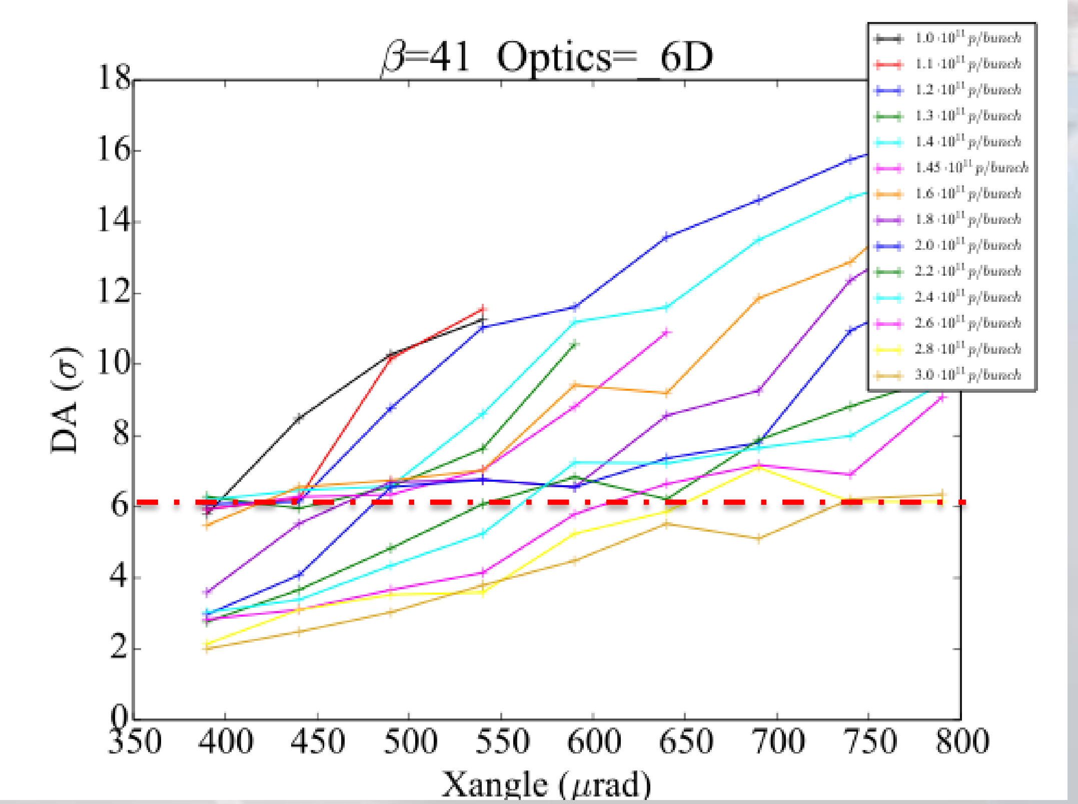
Flat 7.5: FMA fixed Intensity

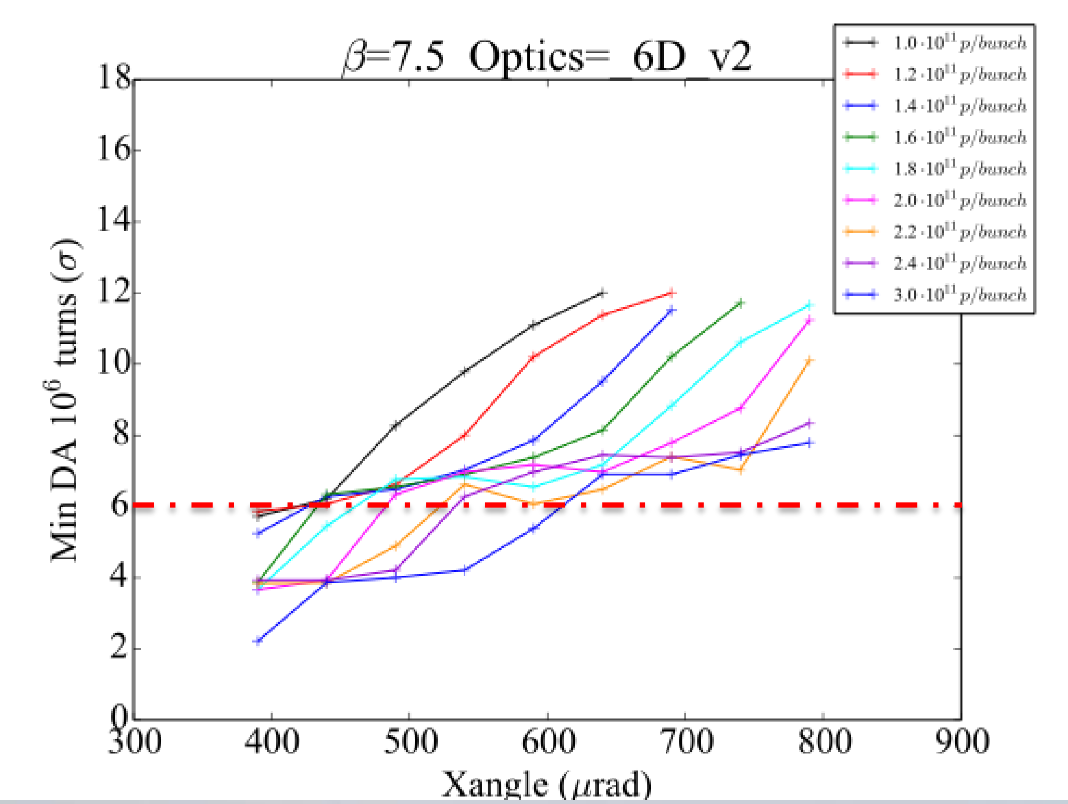


7.5 optics

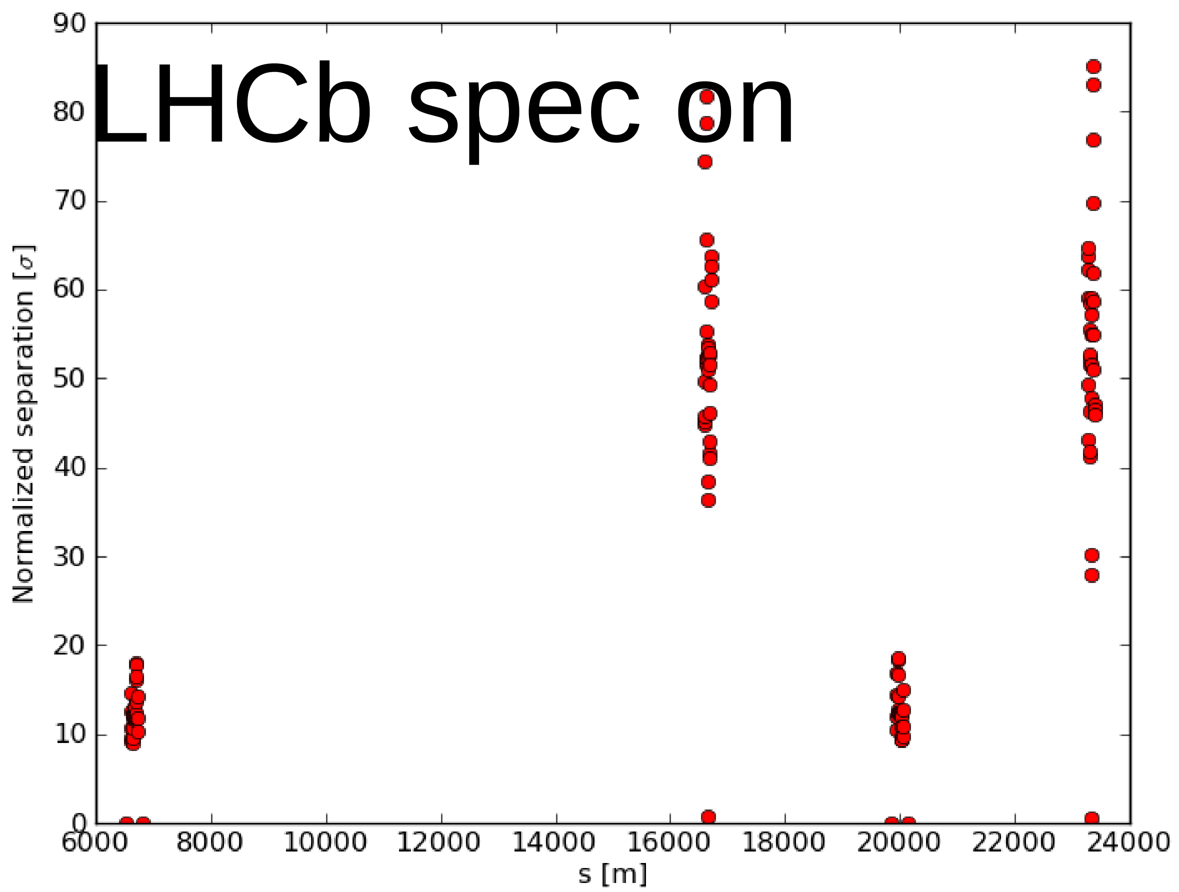

β=43 Optics=_6D
DA (σ)
Xangle (μrad)
1.0·10^11 p/bunch
1.1·10^11 p/bunch
1.2·10^11 p/bunch
1.3·10^11 p/bunch
1.4·10^11 p/bunch
1.45·10^11 p/bunch
1.6·10^11 p/bunch
1.8·10^11 p/bunch
2.0·10^11 p/bunch
2.2·10^11 p/bunch
2.4·10^11 p/bunch
2.6·10^11 p/bunch
2.8·10^11 p/bunch
3.0·10^11 p/bunch

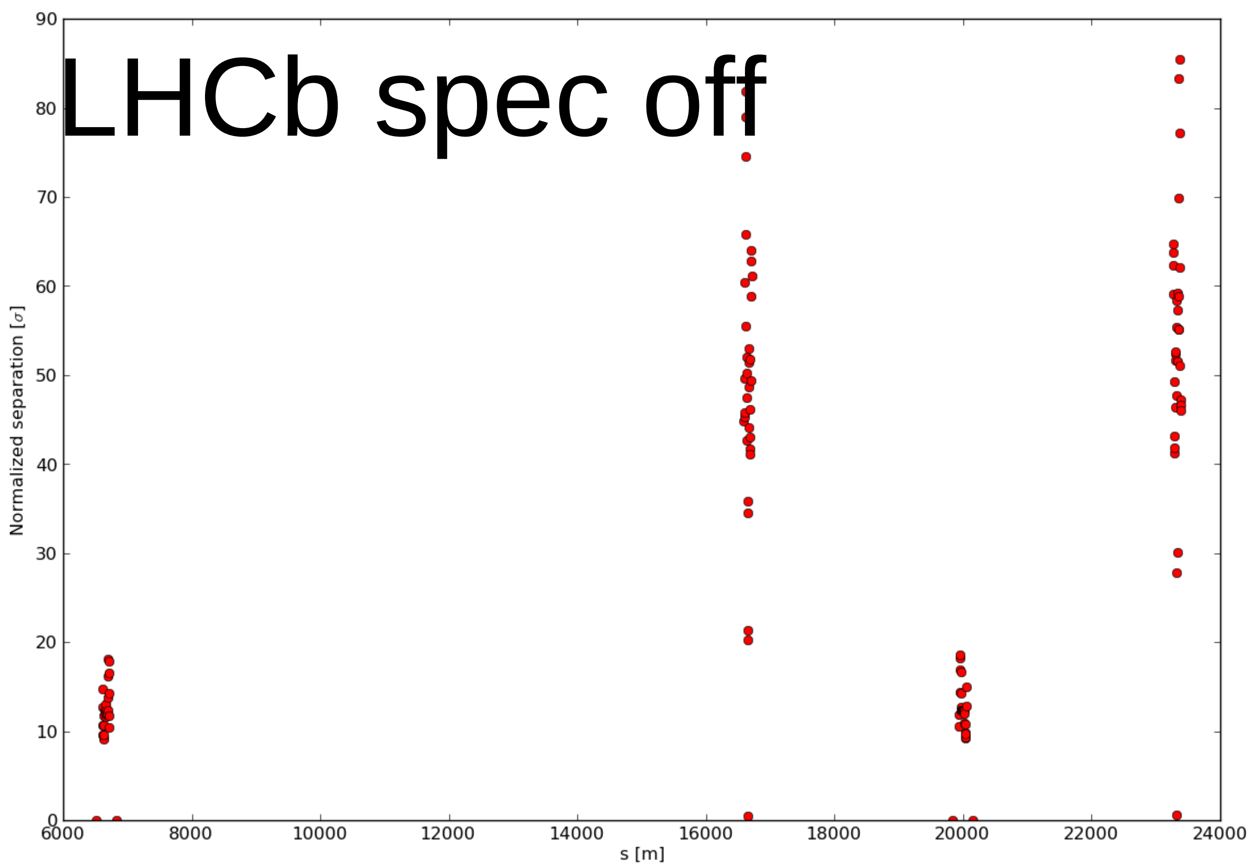

β=42 Optics=_6D
DA (σ)
Xangle (μrad)
1.0·10^11 p/bunch
1.1·10^11 p/bunch
1.2·10^11 p/bunch
1.3·10^11 p/bunch
1.4·10^11 p/bunch
1.45·10^11 p/bunch
1.6·10^11 p/bunch
1.8·10^11 p/bunch
2.0·10^11 p/bunch
2.2·10^11 p/bunch
2.4·10^11 p/bunch
2.6·10^11 p/bunch
2.8·10^11 p/bunch
3.0·10^11 p/bunch


β=41 Optics=_6D
DA (σ)
Xangle (μrad)
1.0·10^11 p/bunch
1.1·10^11 p/bunch
1.2·10^11 p/bunch
1.3·10^11 p/bunch
1.4·10^11 p/bunch
1.45·10^11 p/bunch
1.6·10^11 p/bunch
1.8·10^11 p/bunch
2.0·10^11 p/bunch
2.2·10^11 p/bunch
2.4·10^11 p/bunch
2.6·10^11 p/bunch
2.8·10^11 p/bunch
3.0·10^11 p/bunch


β=7.5 Optics=_6D_v2
Min DA 10^6 turns (σ)
Xangle (μrad)
1.0·10^11 p/bunch
1.2·10^11 p/bunch
1.4·10^11 p/bunch
1.6·10^11 p/bunch
1.8·10^11 p/bunch
2.0·10^11 p/bunch
2.2·10^11 p/bunch
2.4·10^11 p/bunch
3.0·10^11 p/bunch

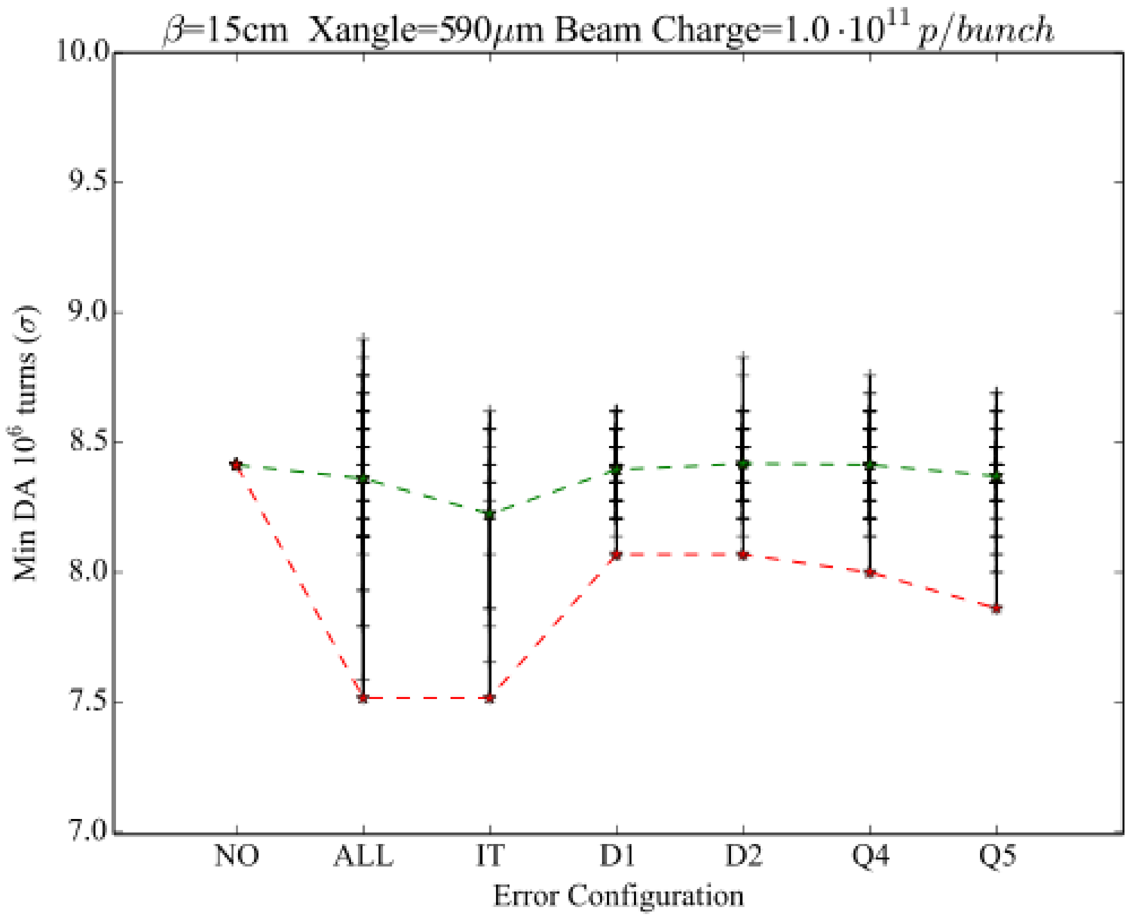
Separations

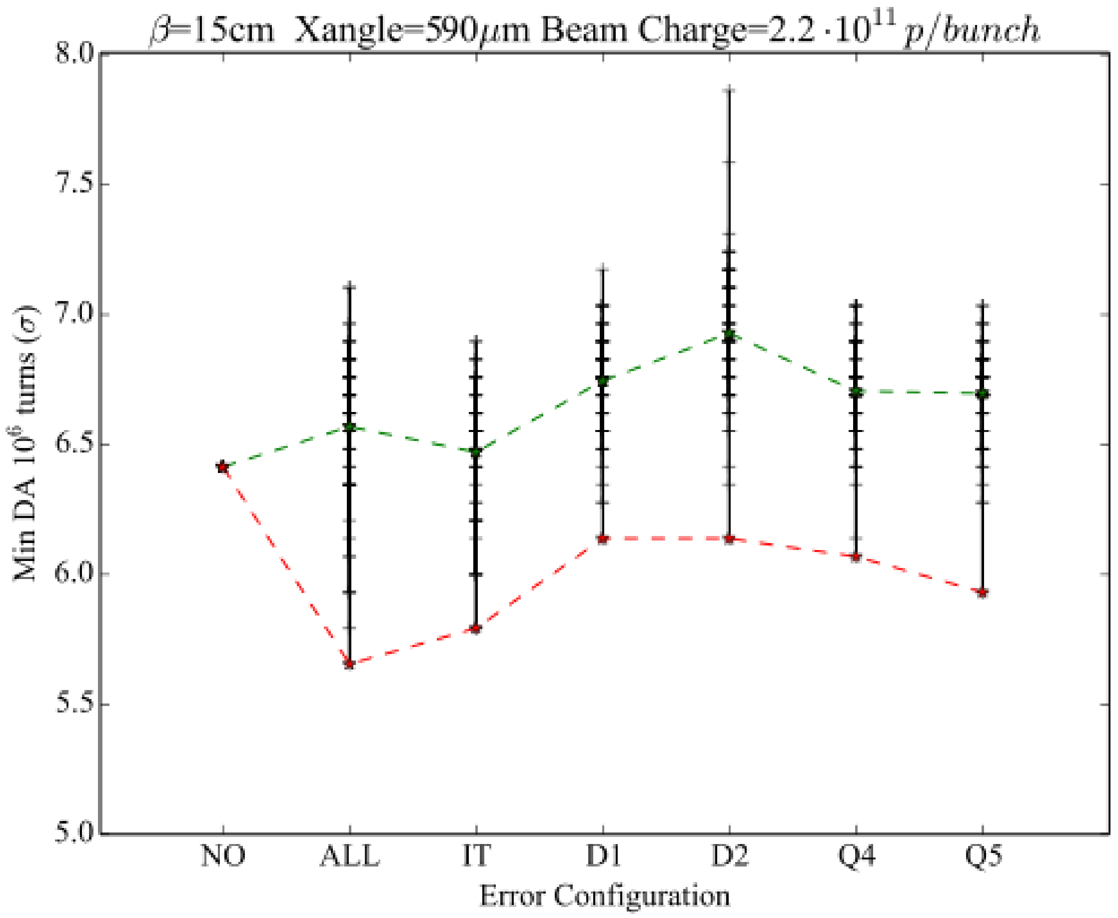




IP5 IP8 IP1 IP2 IP5 IP8 IP1 IP2

HLLHCV1.0: single error effect





Error family tested singularly on HLLHCV1.0 and minimum DA for all the 60 seeds is computed.
No single family of error strongly dominate the DA

IP1 &IP5 only
60 seed error
HLLHCV1.0 optic

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

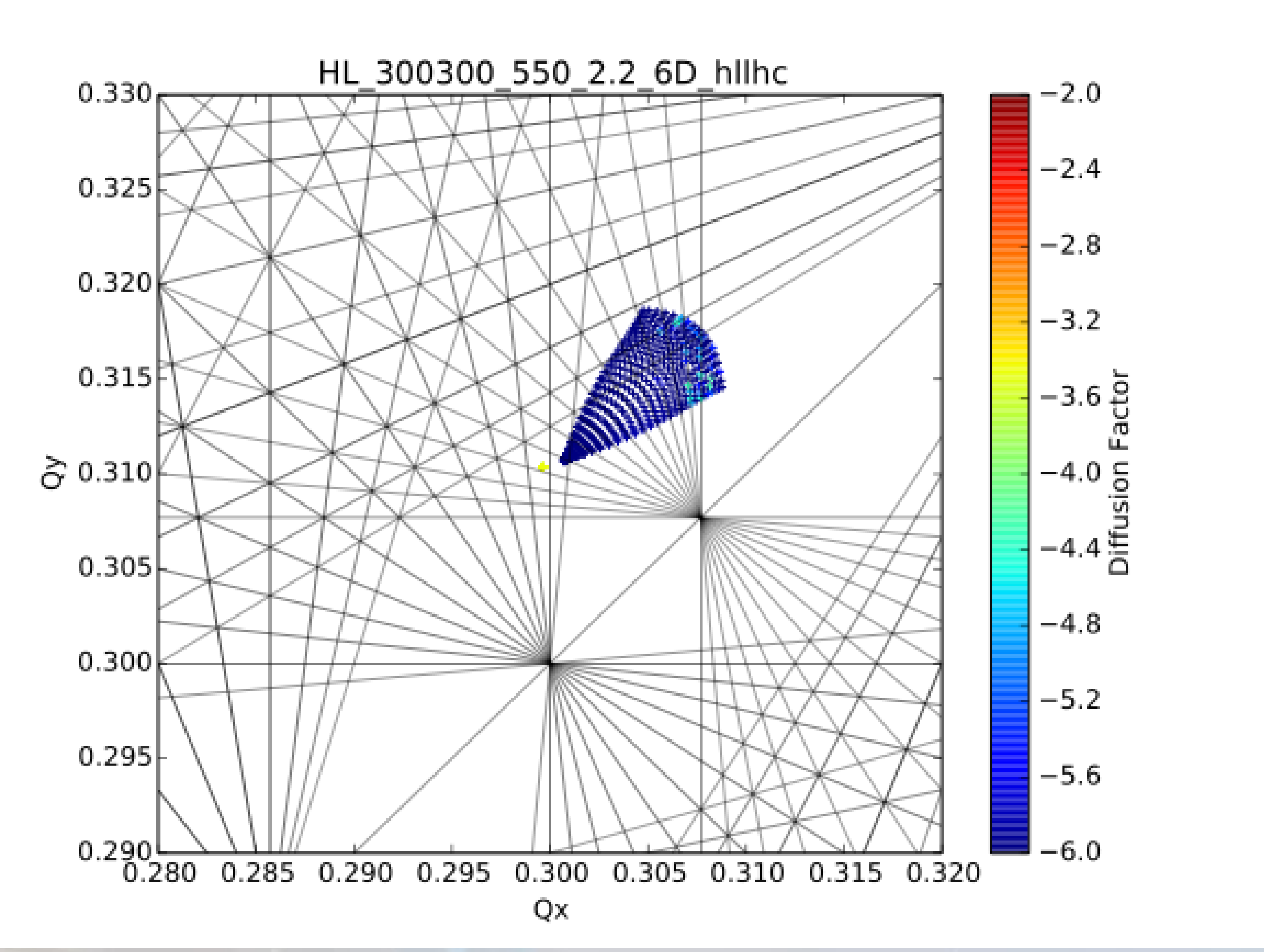
new error study:

/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 and IR5 and IR6

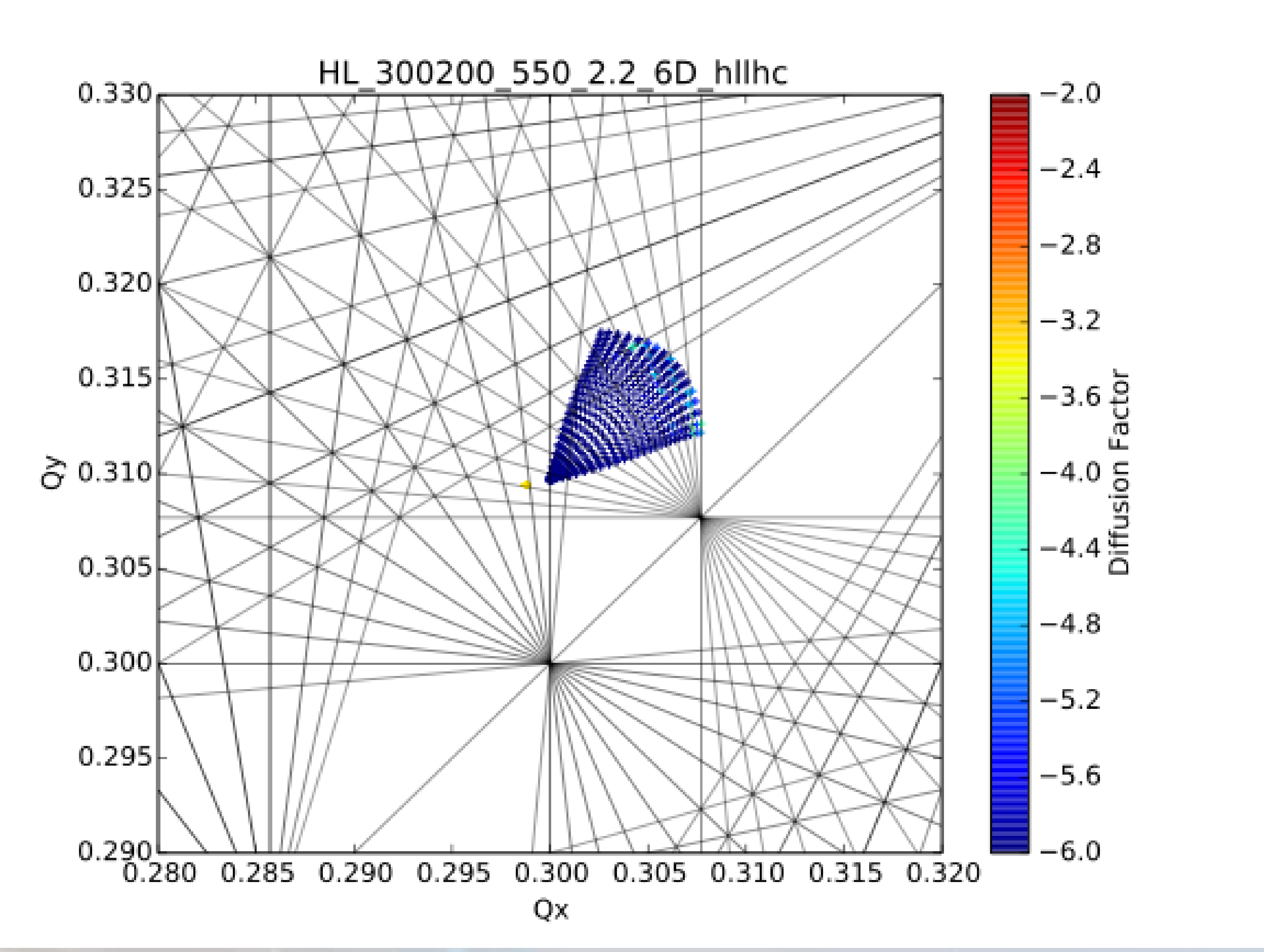
IP8 conf:

nominal crossing angle
sep = 0, solenoid on at nominal field
21 slices

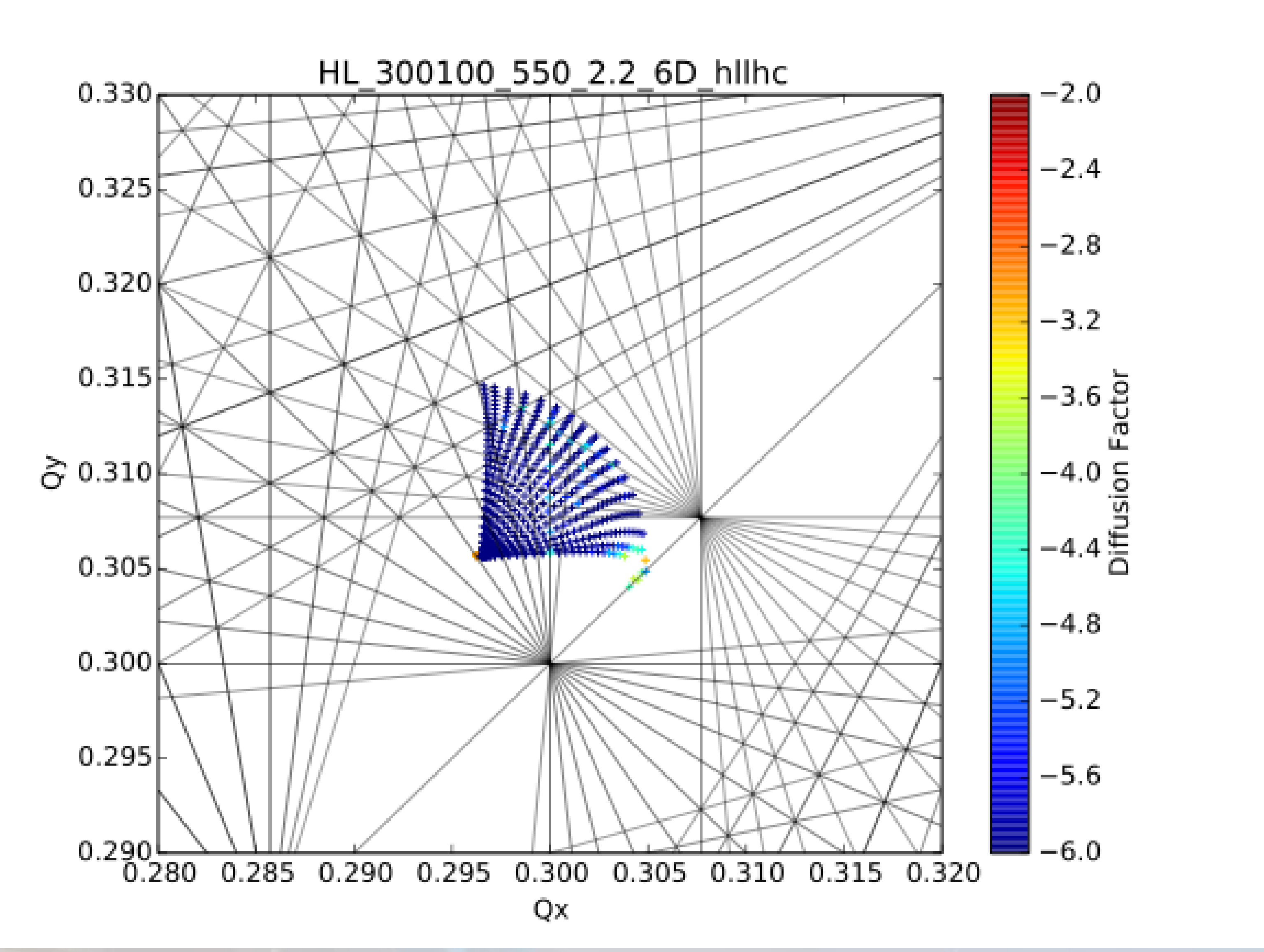
Flat 7.5: FMA fixed Intensity



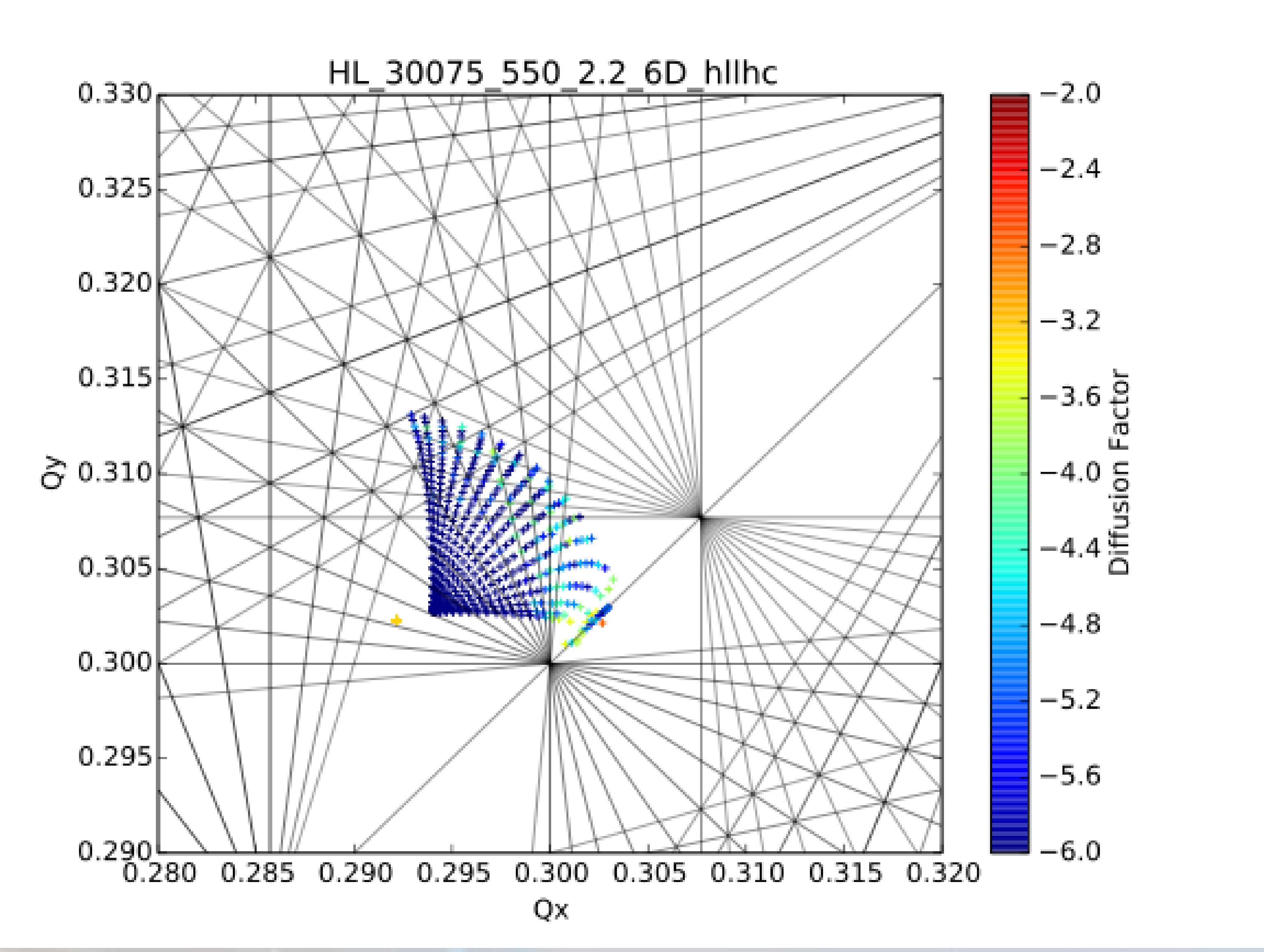
Flat 7.5: FMA fixed Intensity



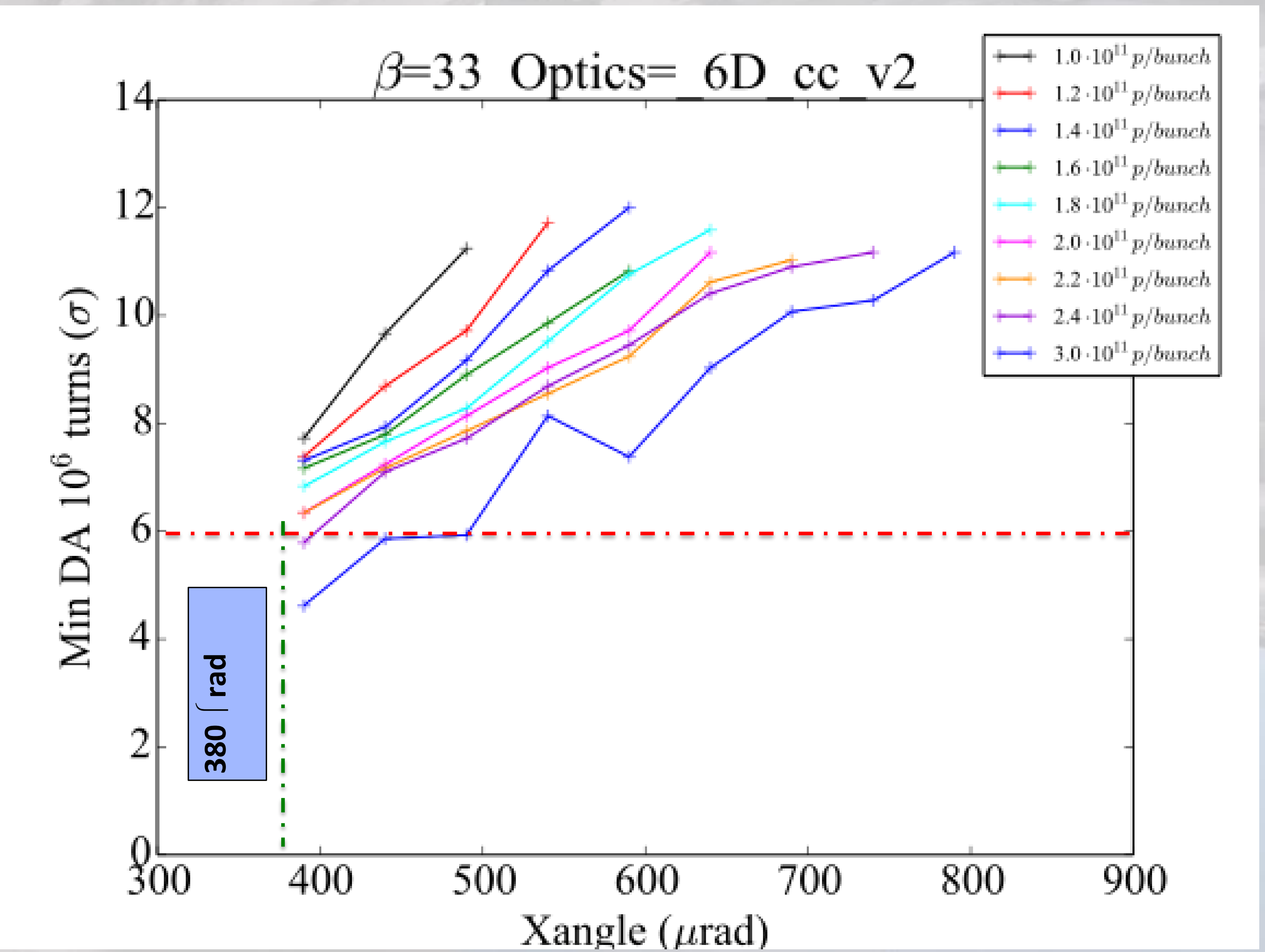
Flat 7.5: FMA fixed Intensity



Flat 7.5: FMA fixed Intensity



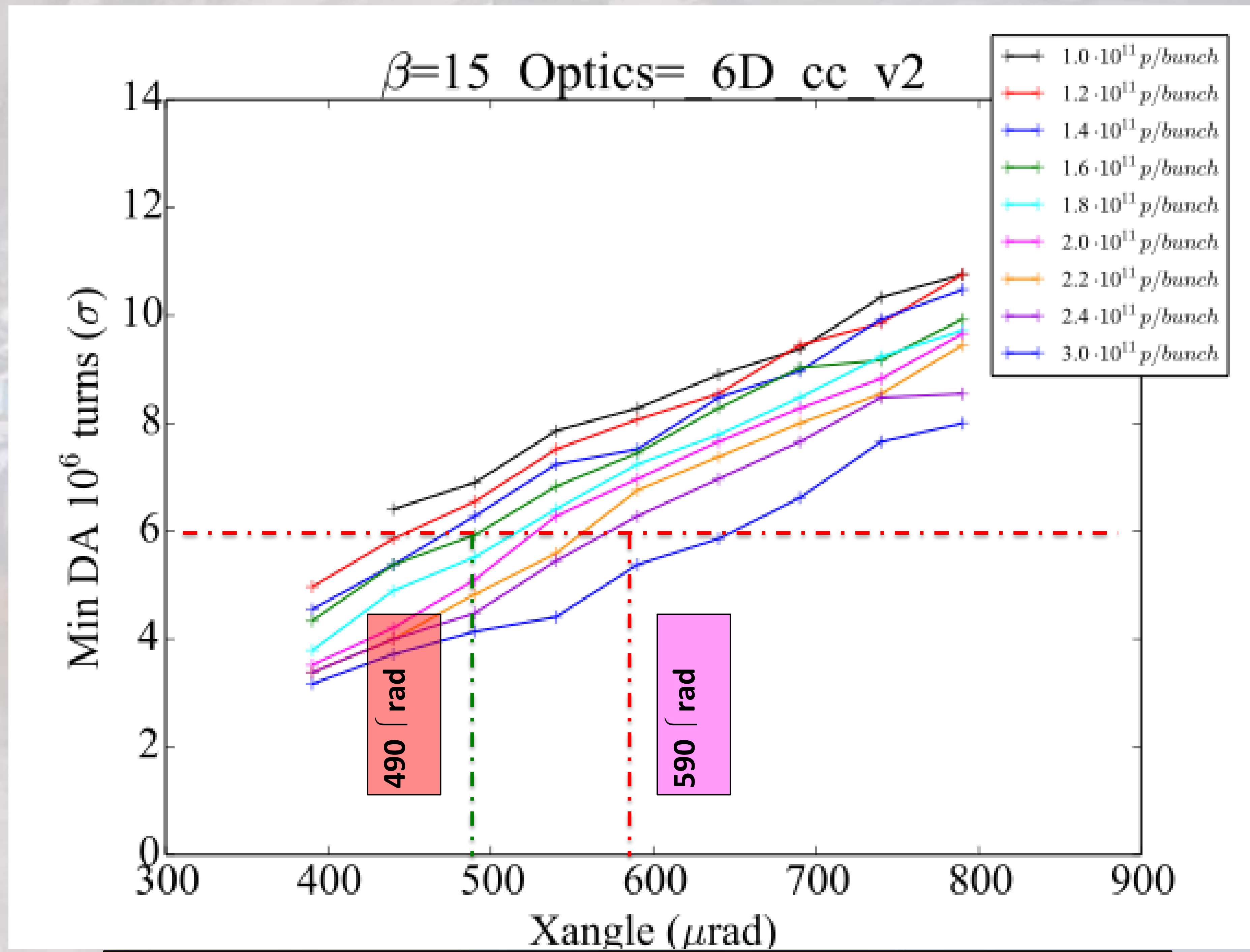
β* leveling at 7.5E34: 33 cm



Minimum crossing angle 380 μrad at 2.2E11

IP1 &IP5 only
SHLCV3.1b optic
Fully Crabbed
No error

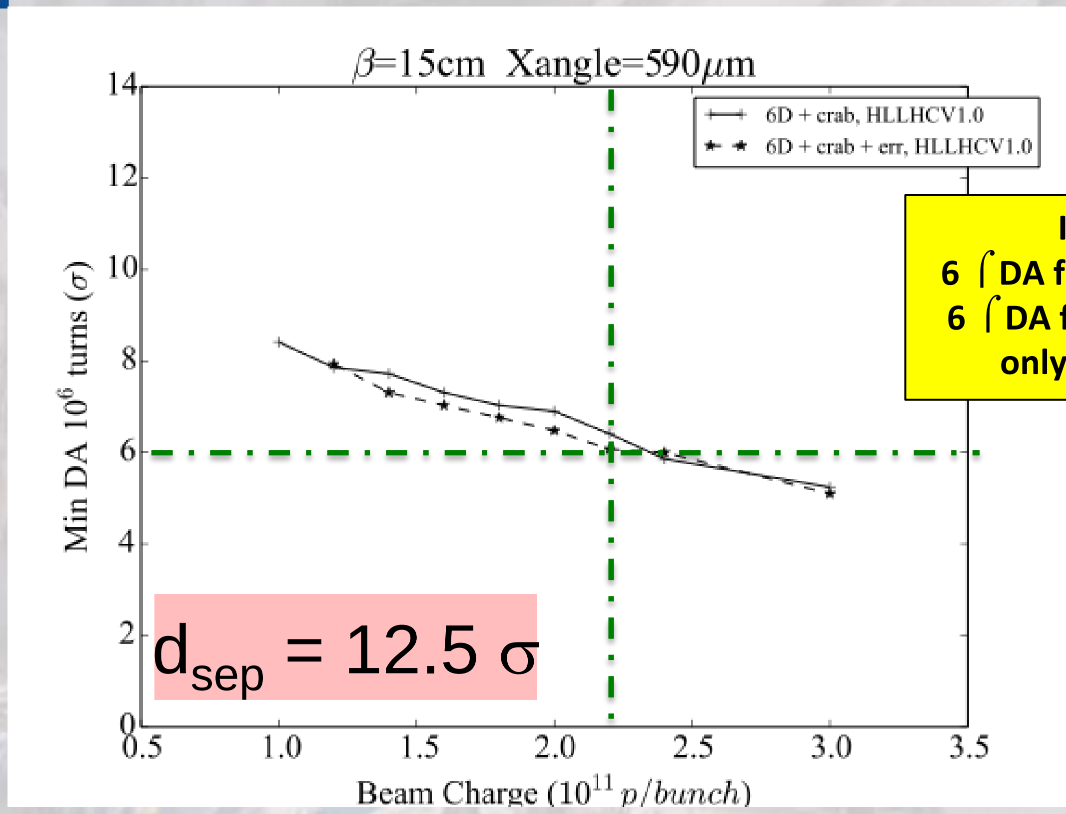
β* leveling at 7.5E34: 15 cm

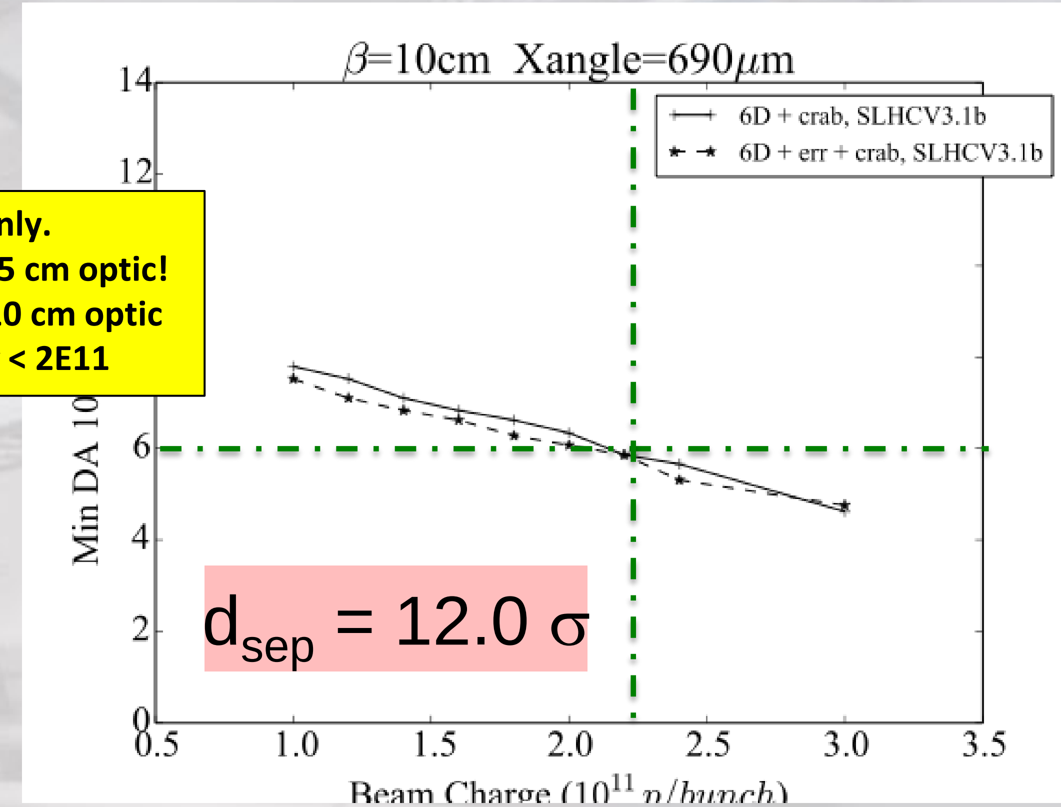


Minimum crossing angle 490 ⌠rad for β* levelling (int 1.5E11)
At nominal x-angle 590µrad limited to int 2.4E11

IP1 &IP5 only
SHLCV3.1b optic
Fully Crabbed
No error

Round Optics: Multipolar Errors





IP1 and IP5 only.
6 ∫ DA for nominal 15 cm optic!
6 ∫ DA for nominal 10 cm optic
only for intensity < 2E11