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- **Conclusions and recommendations**

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- Linear coupling should also be studied in more detail during all the LHC cycle

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    - Next: measure the coherent tune shift along a batch (ADTObsBox)

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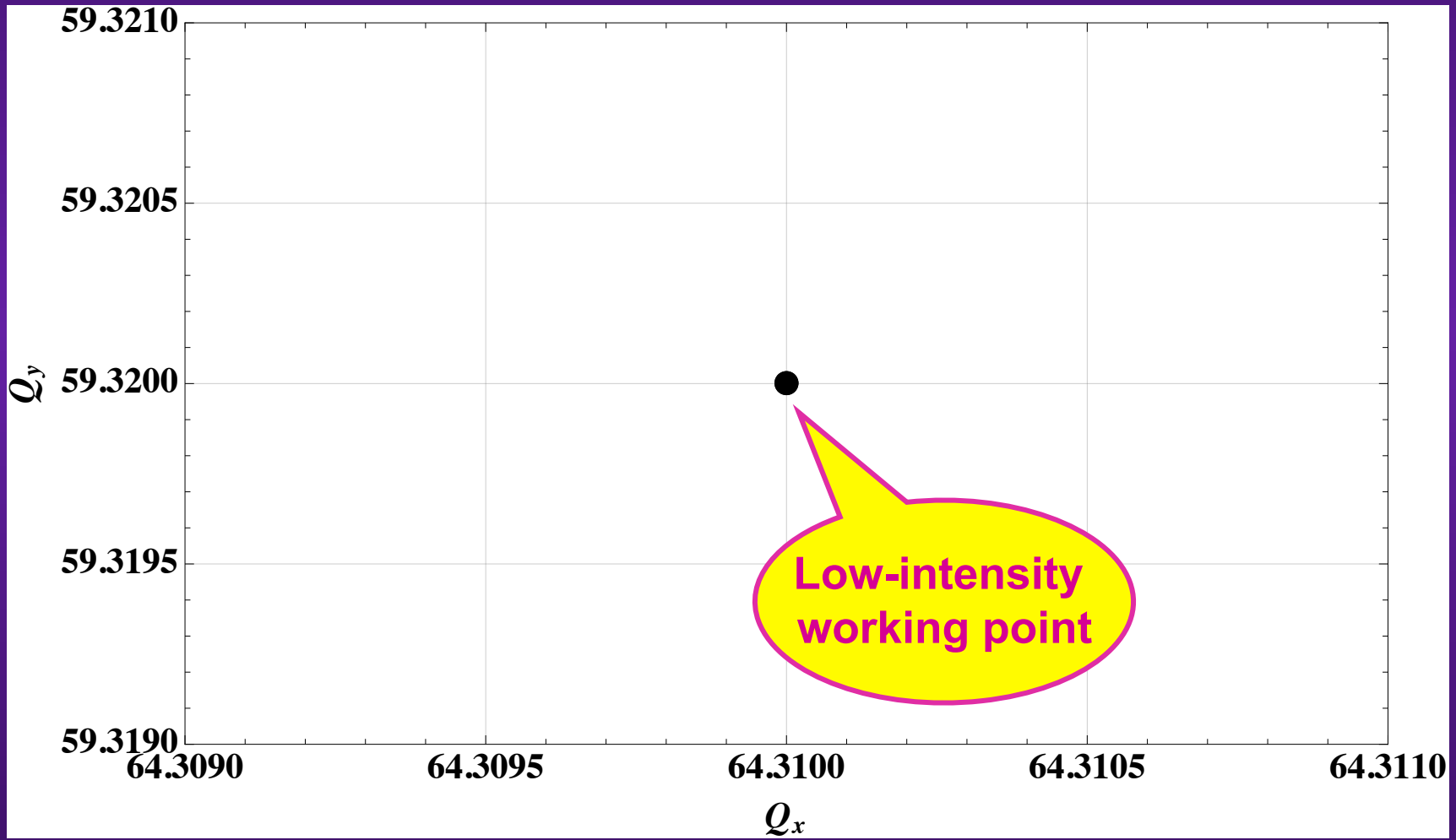
  => Because the coherent tunes are shifted by linear coupling differently compared to the incoherent tunes (providing the Landau damping) due to the nonlinear fields (from octupoles to create the tune spread). Therefore in some cases a too strong coupling can be detrimental, leading to instabilities due to a loss of transverse Landau damping

EFFECT OF LINEAR COUPLING ON BEAM STABILITY

- *Reminder on single-beam stability from Landau octupoles*



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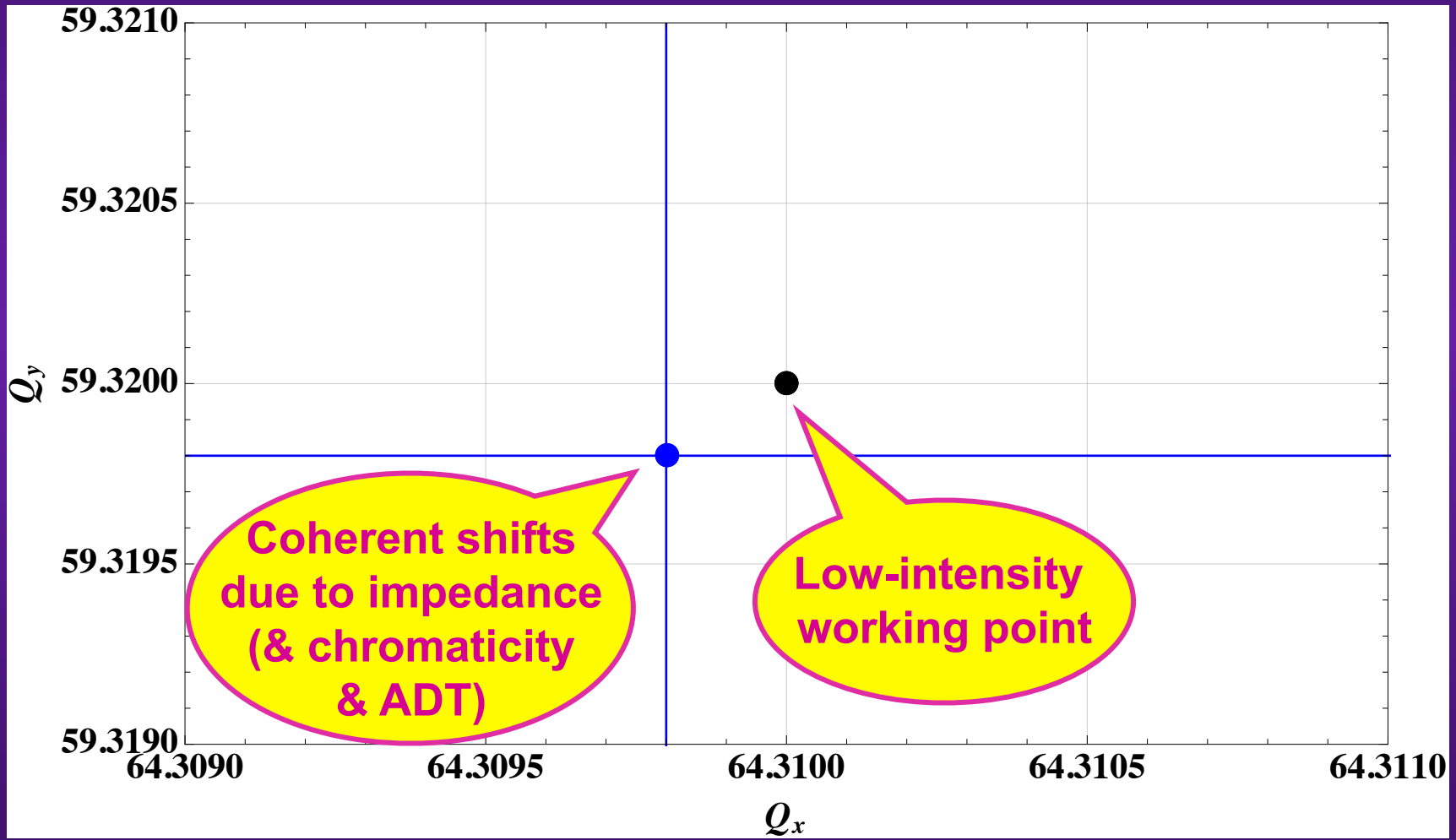

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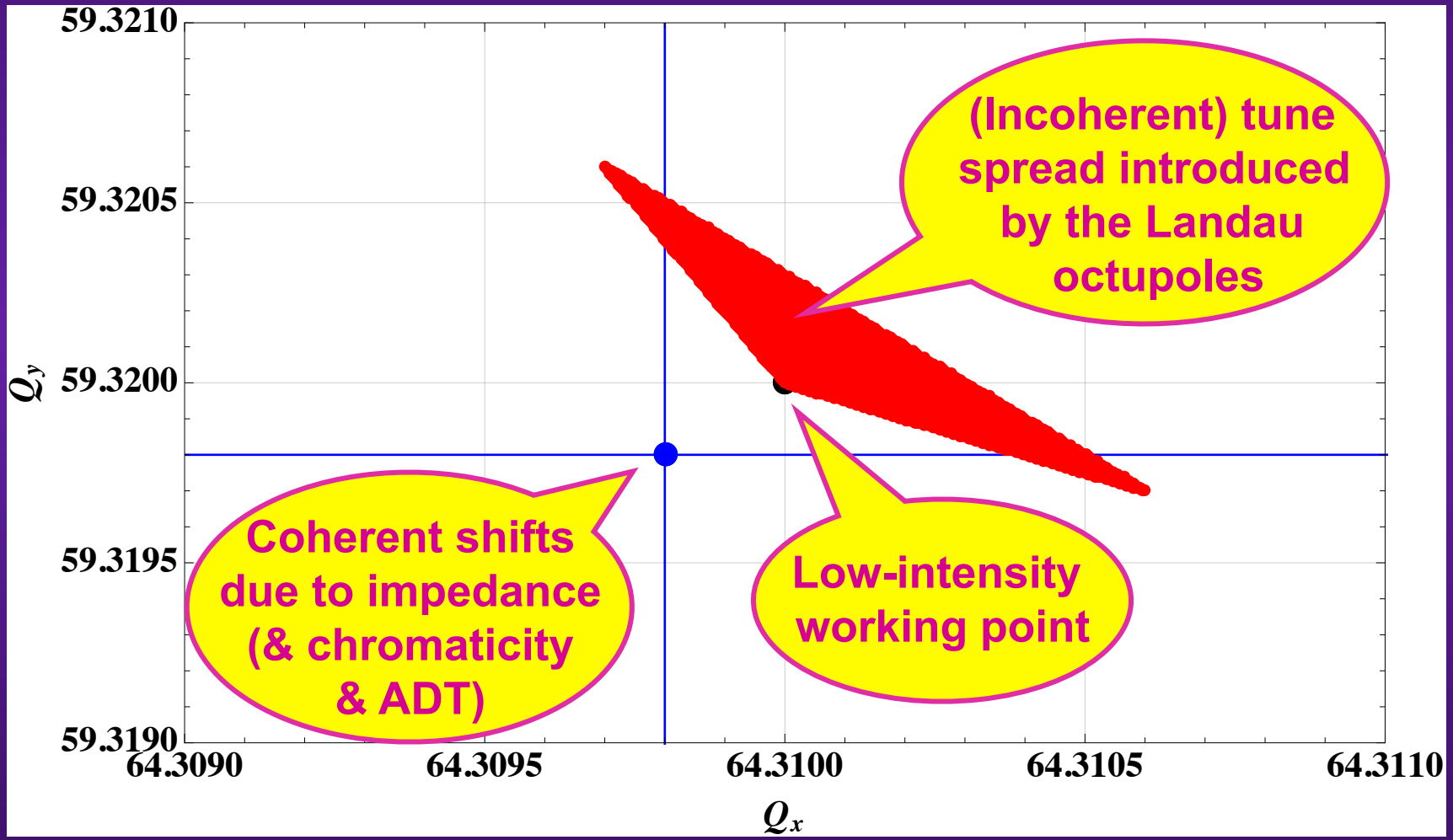

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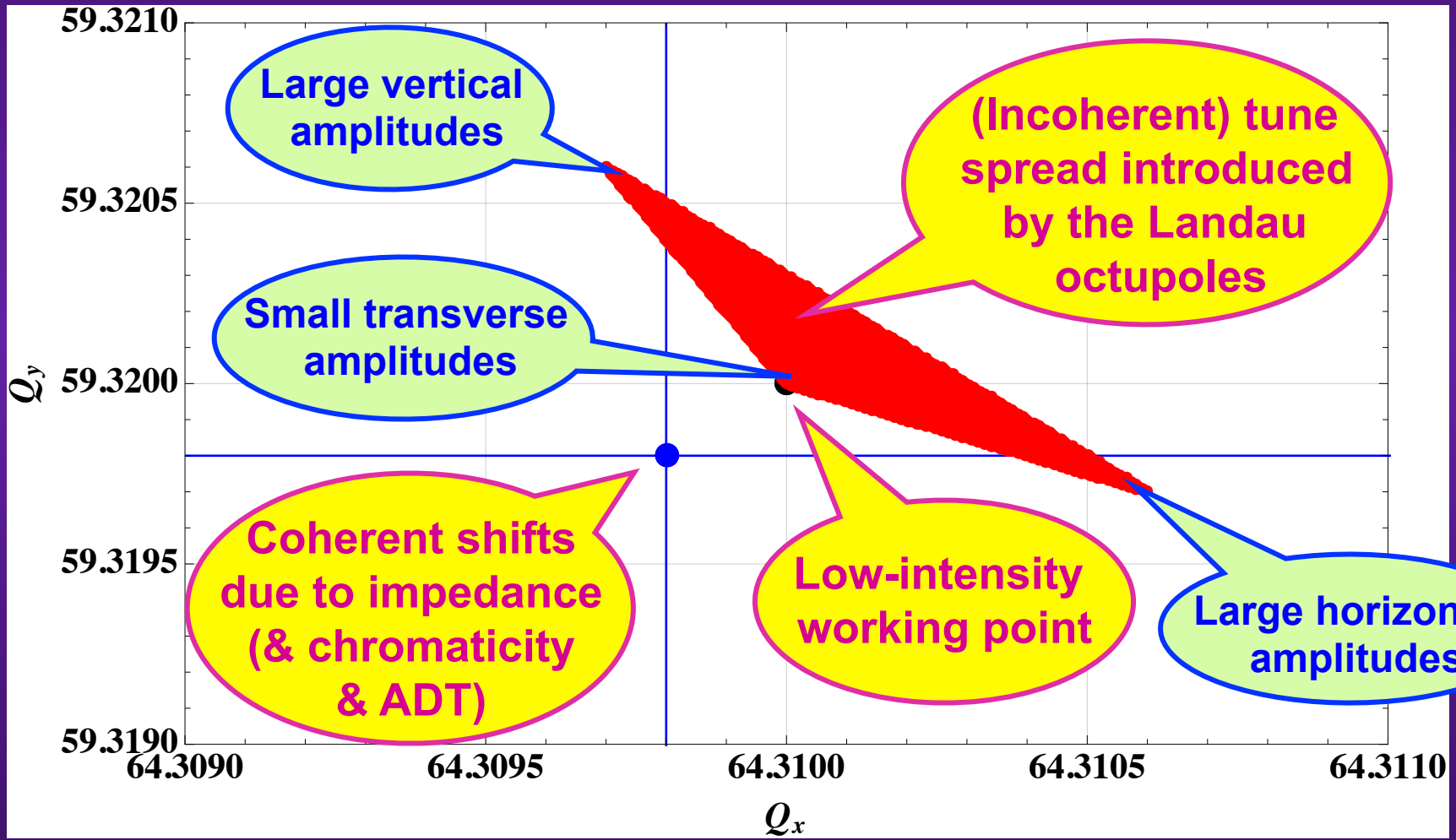
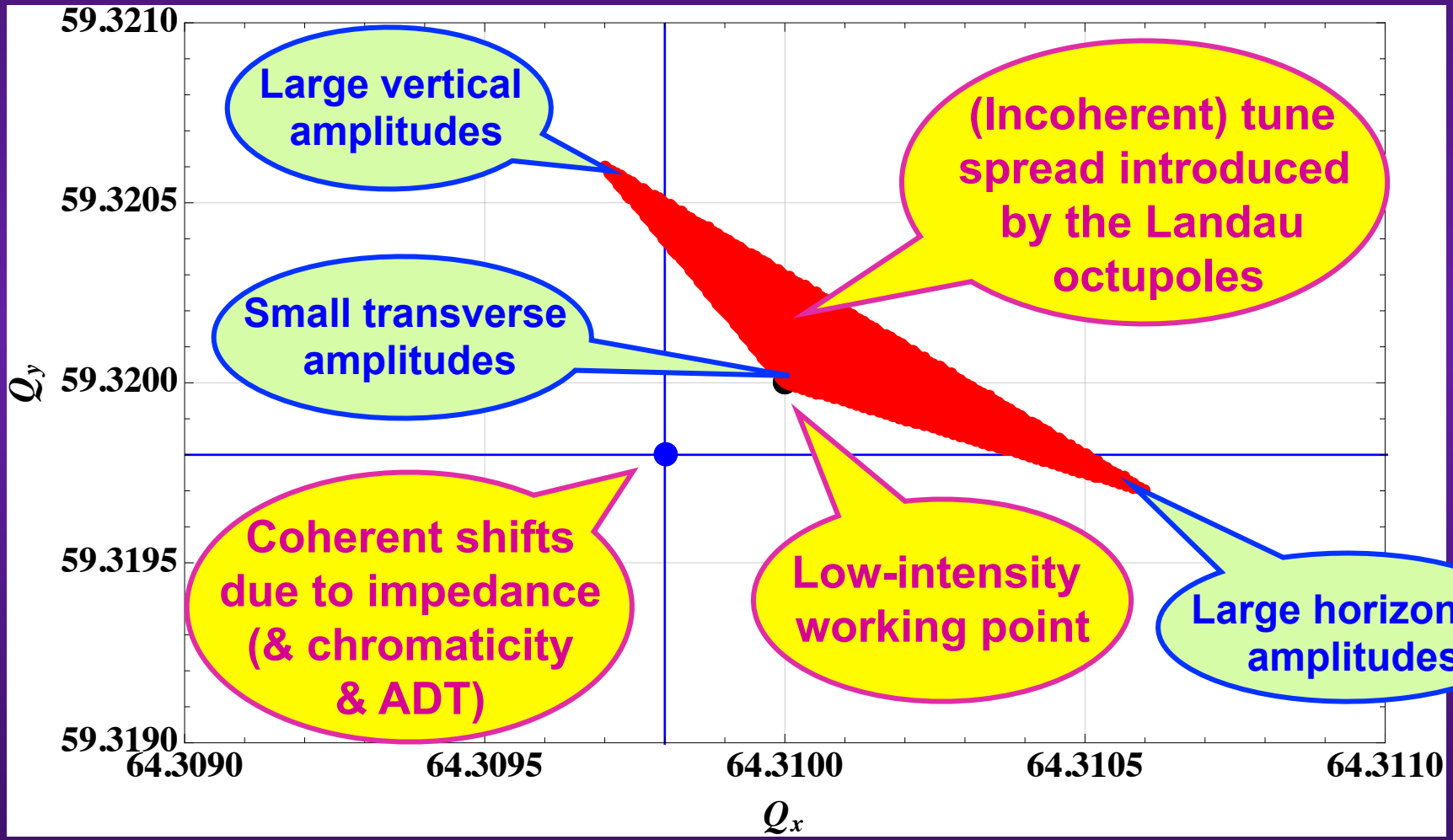


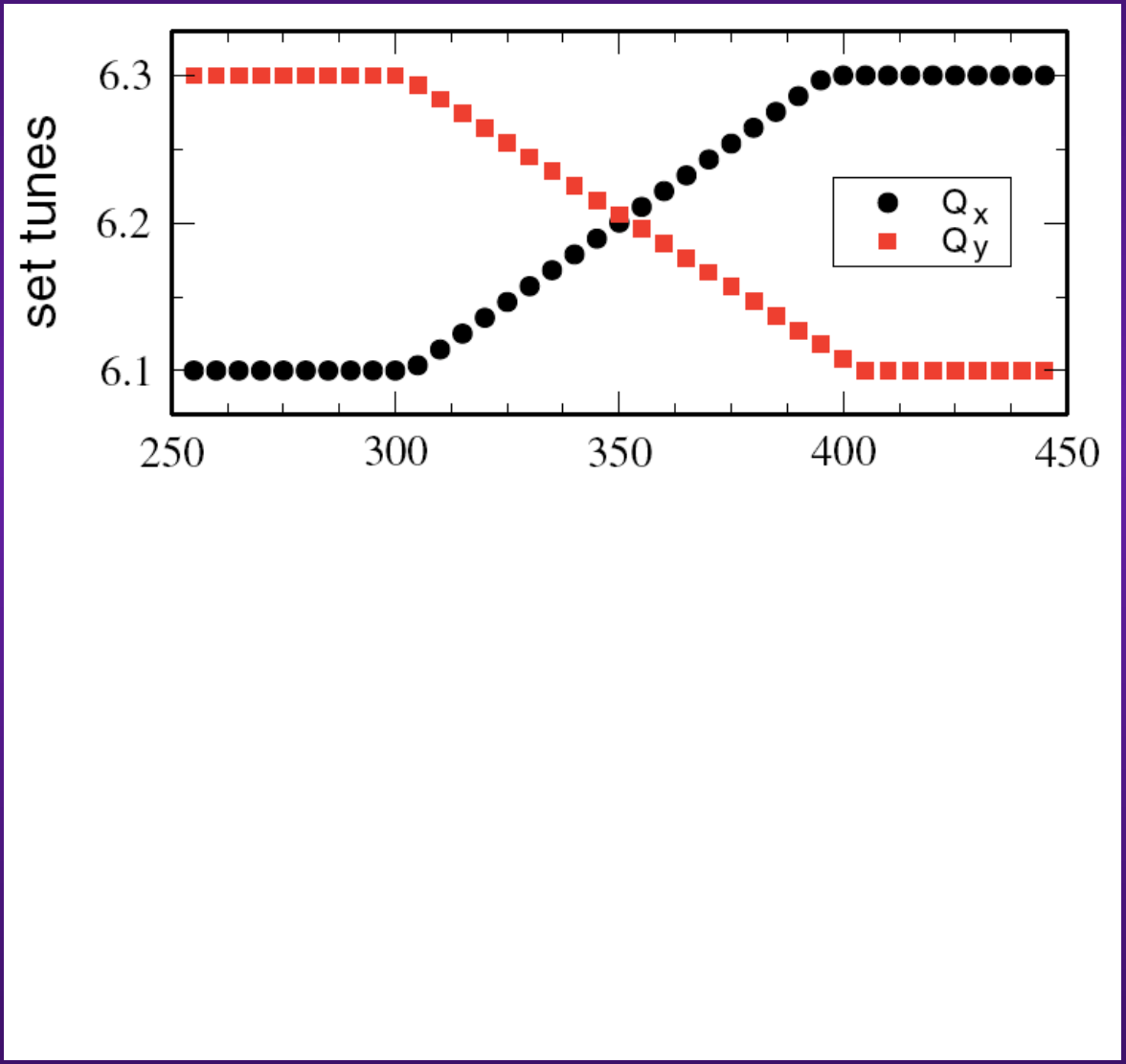
EFFECT OF LINEAR COUPLING ON BEAM STABILITY

=> Beam stability is reached when the coherent tunes are inside the tune spread (Landau damping)



EFFECT OF LINEAR COUPLING ON BEAM STABILITY

- *Reminder on linear coupling => Case of the PS machine (due to skew quadrupoles)*



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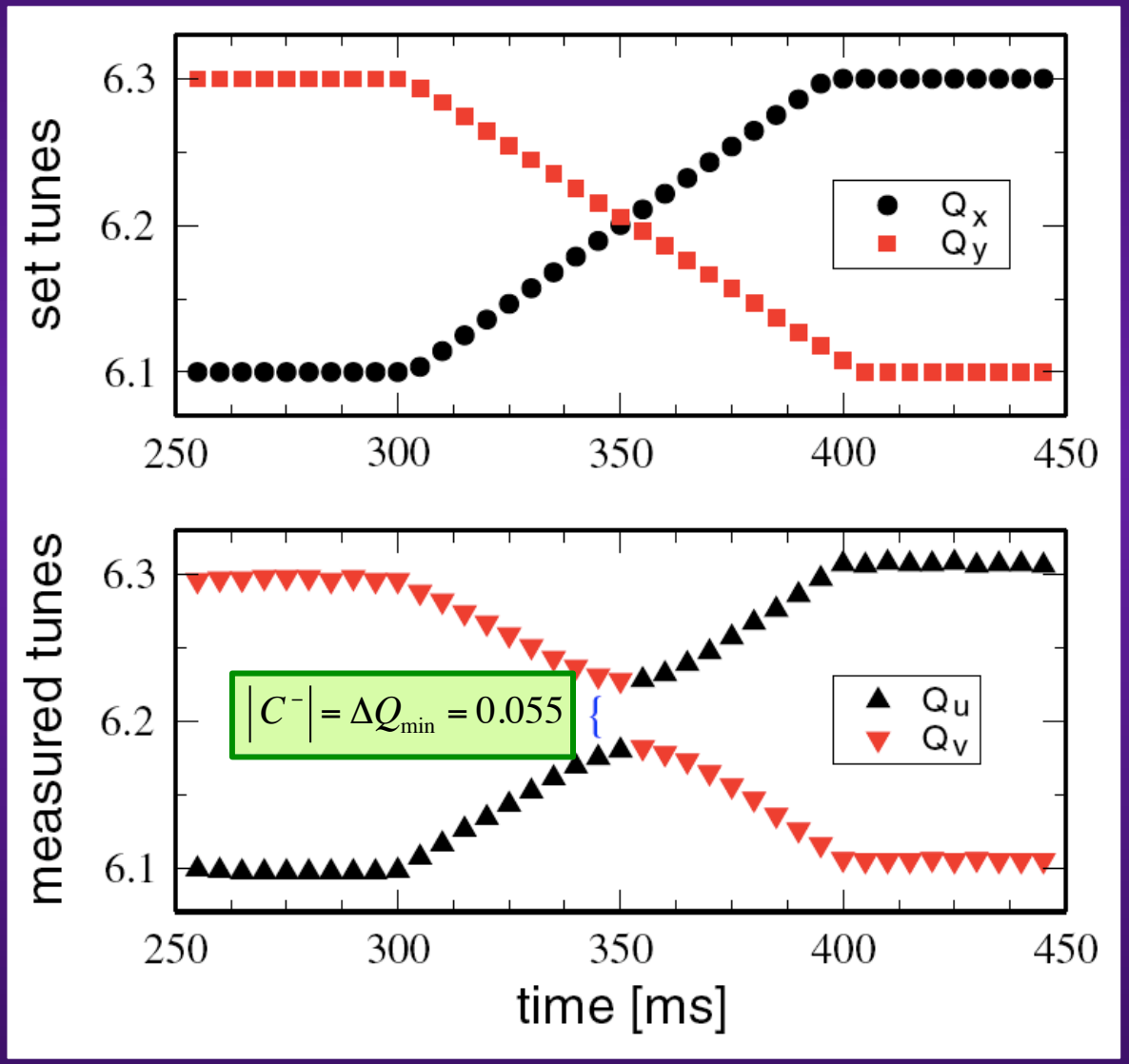

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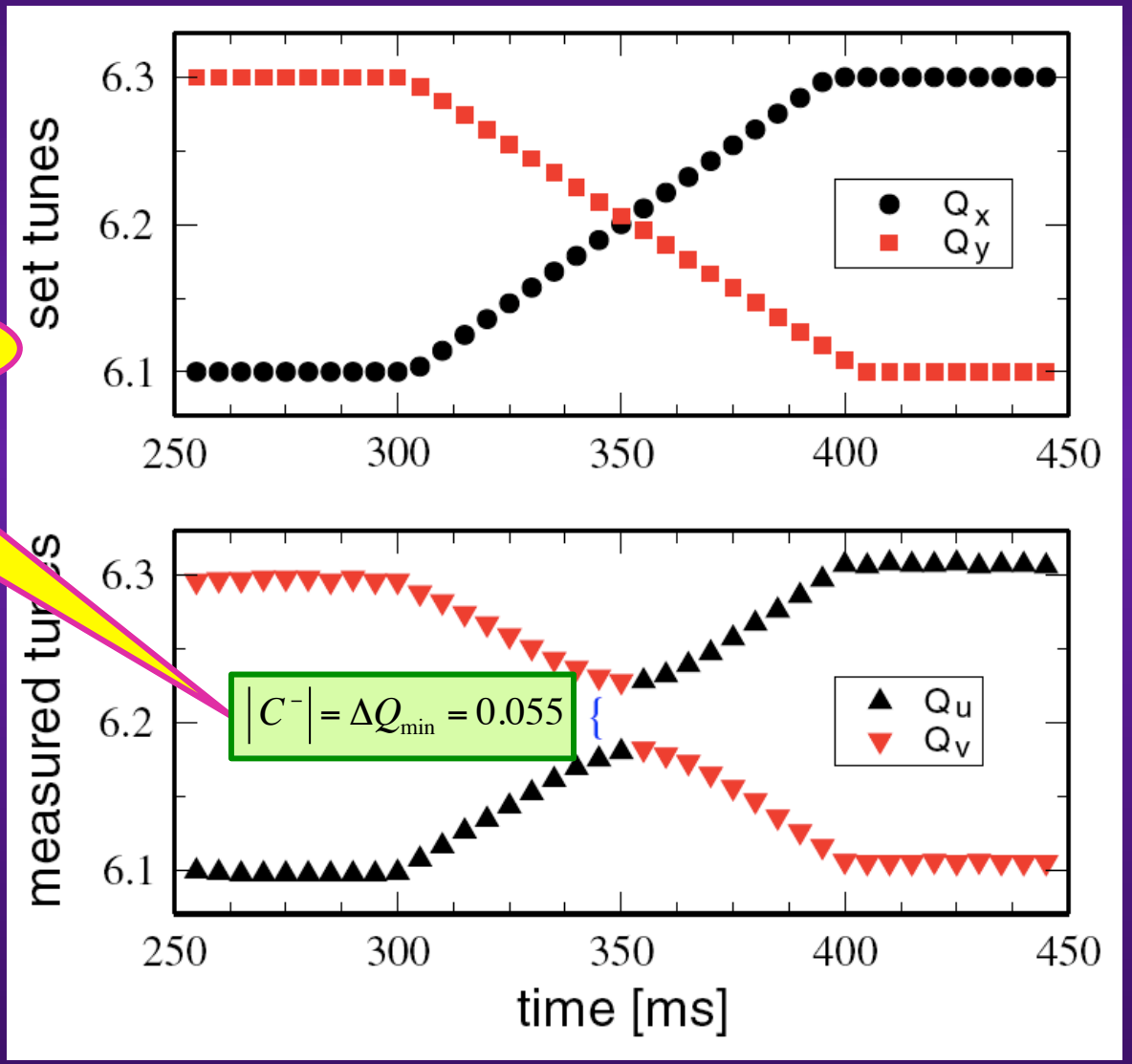
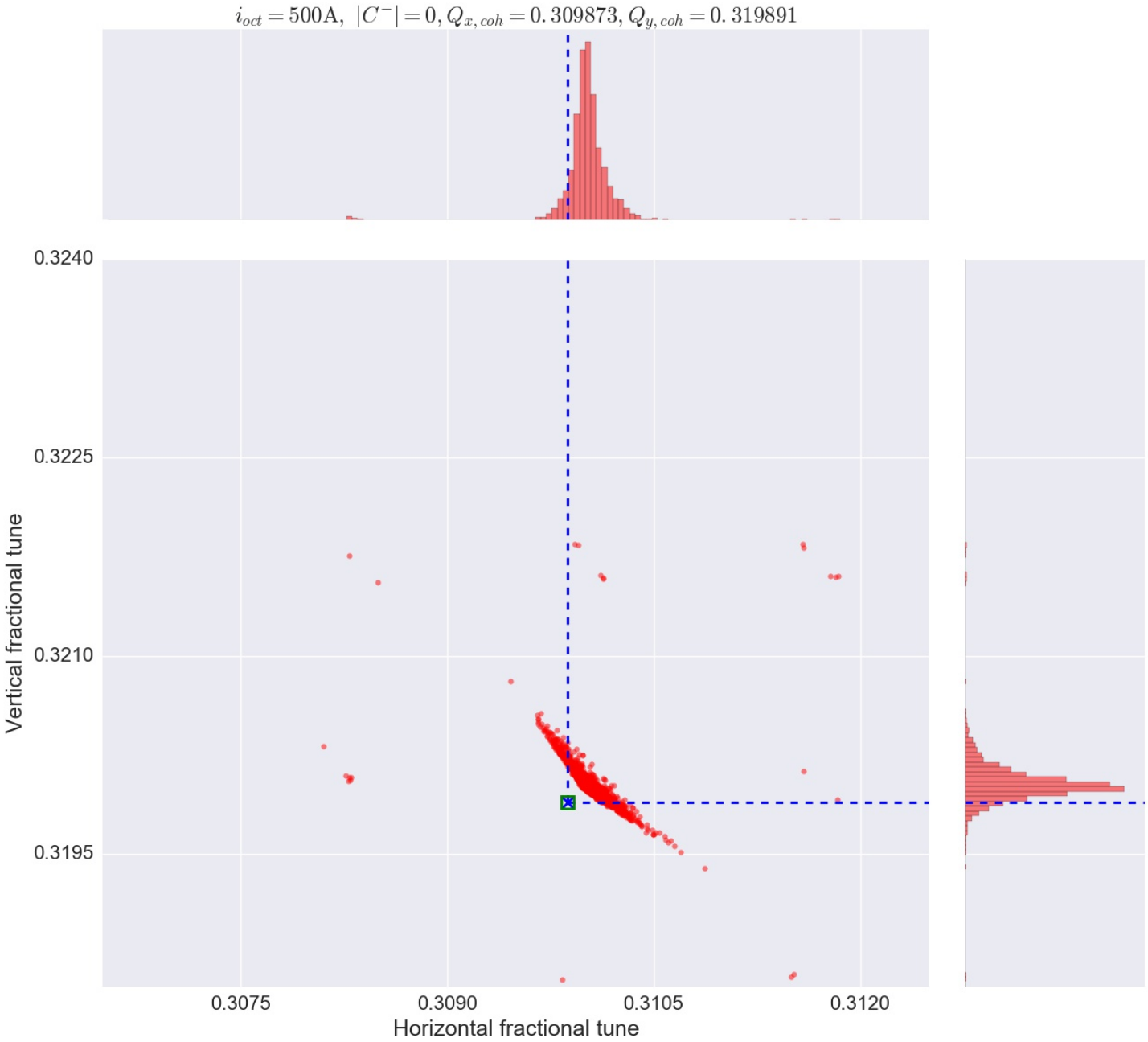


= Closest tune approach

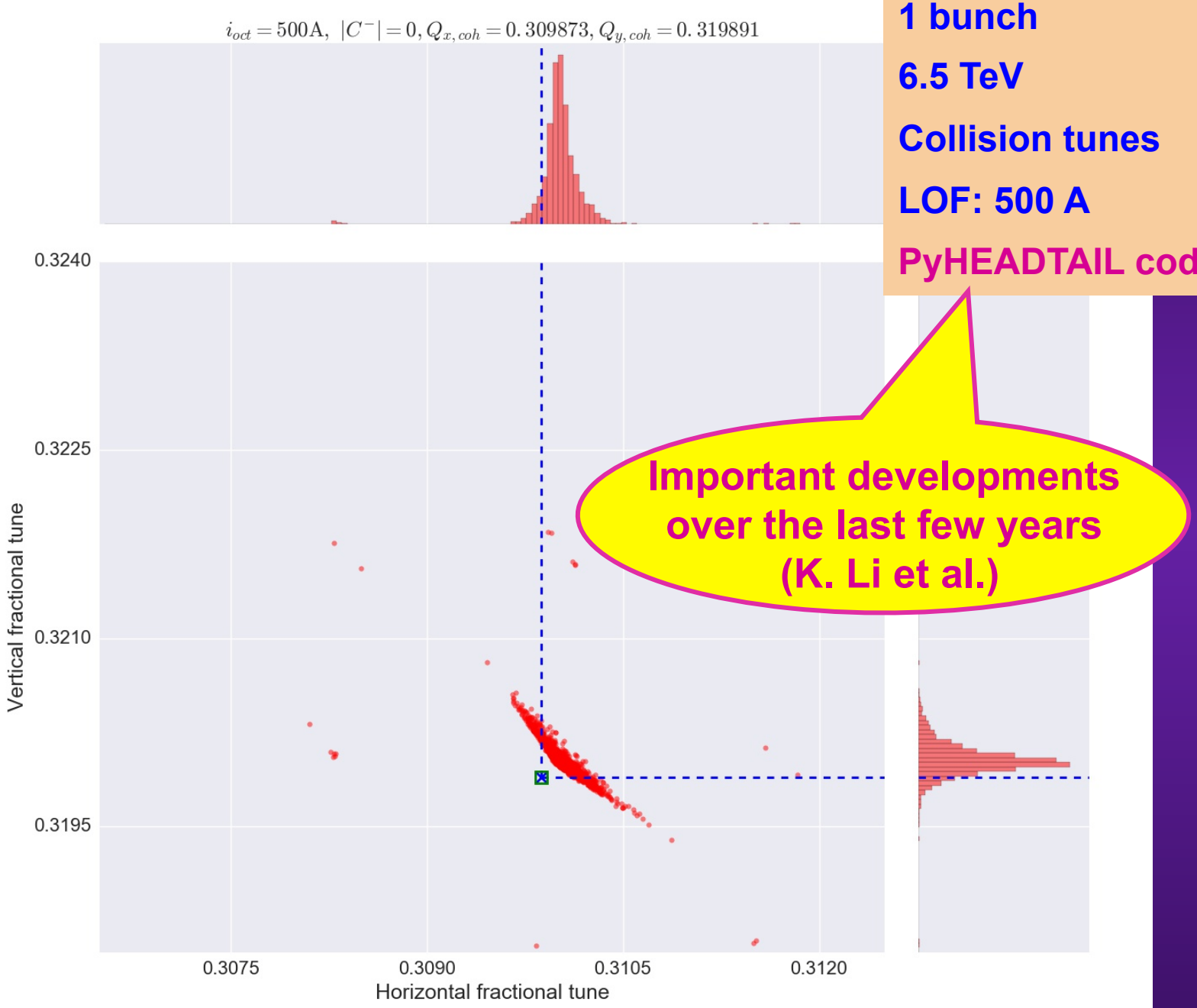
SIMULATIONS

$\left|C^{-}\right| = 0$



L.R. Carver

$|C^-| = 0$



1 bunch

6.5 TeV

Collision tunes

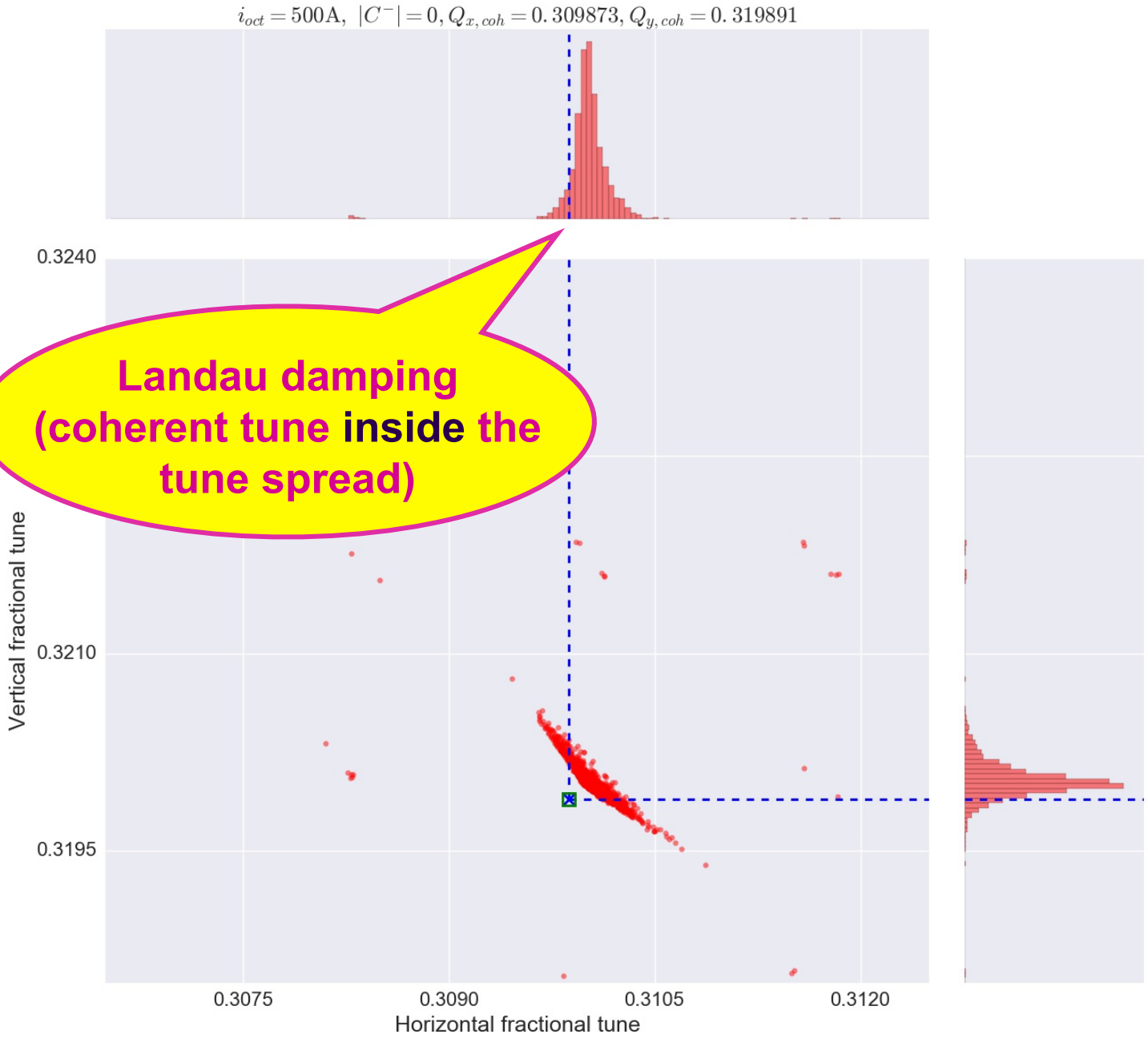
LOF: 500 A

PyHEADTAIL code

Important developments over the last few years (K. Li et al.)

L.R. Carver

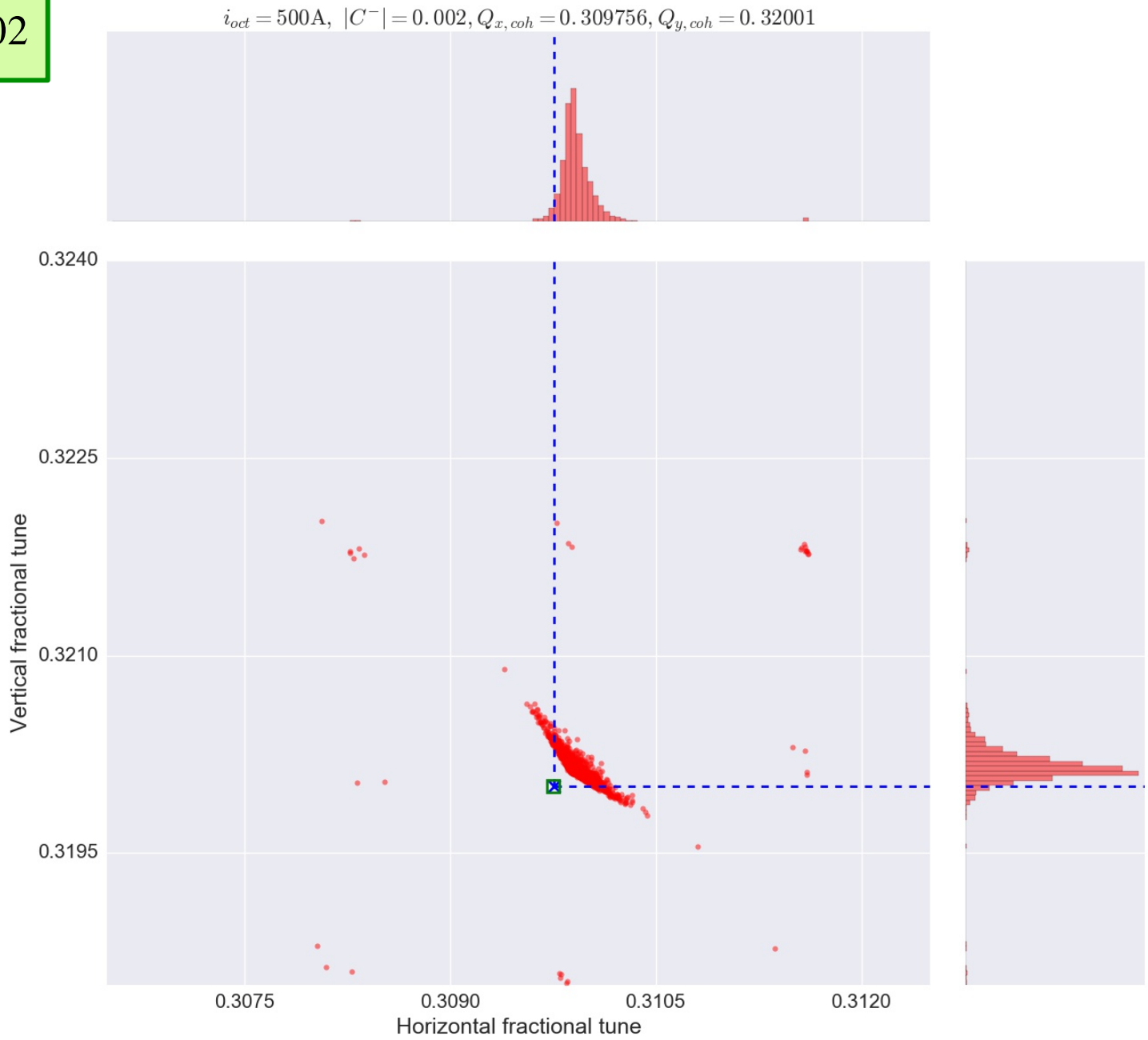
$|C^-| = 0$



Landau damping (coherent tune inside the tune spread)

L.R. Carver

$\left|C^{-}\right| = 0.002$



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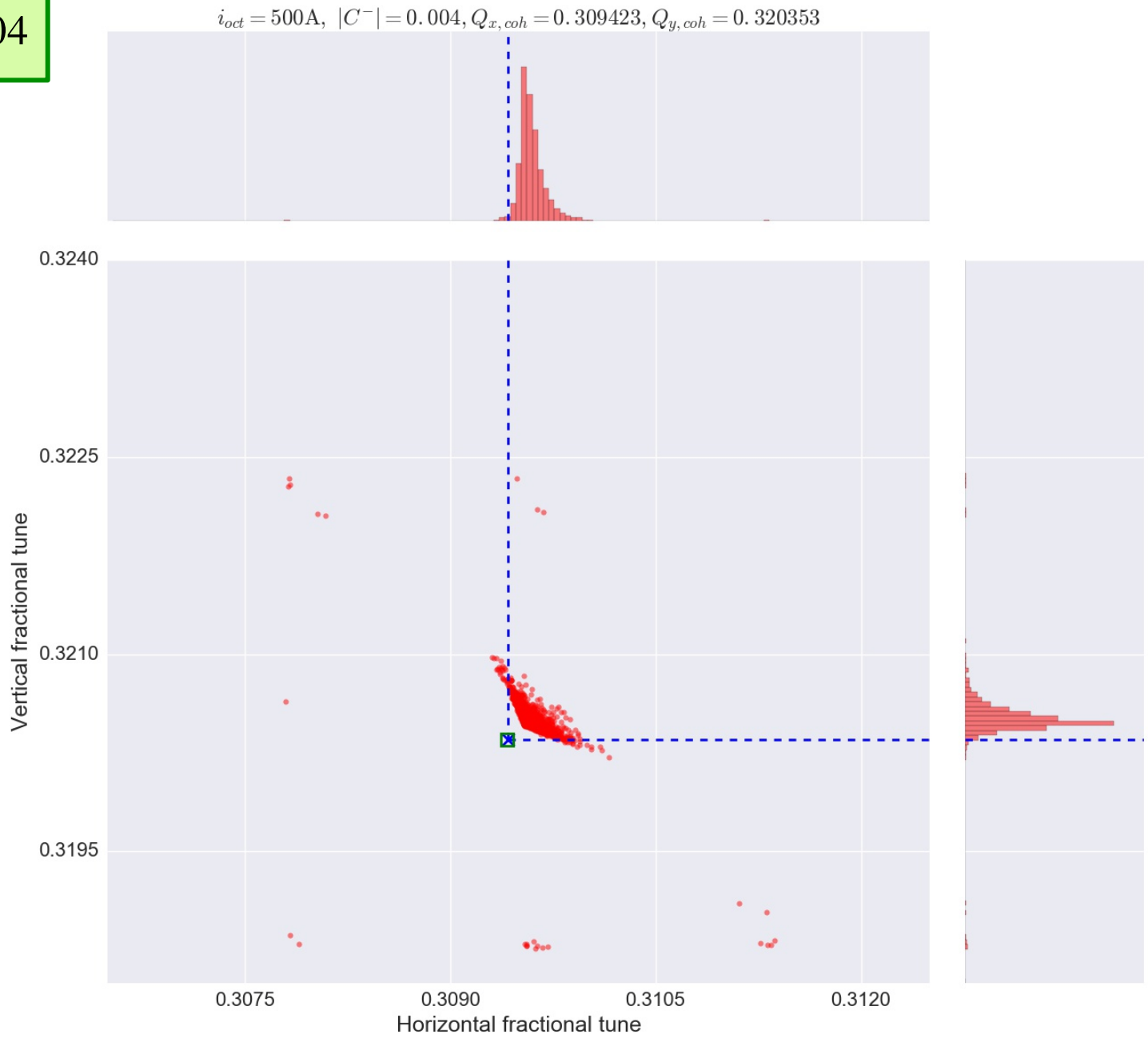
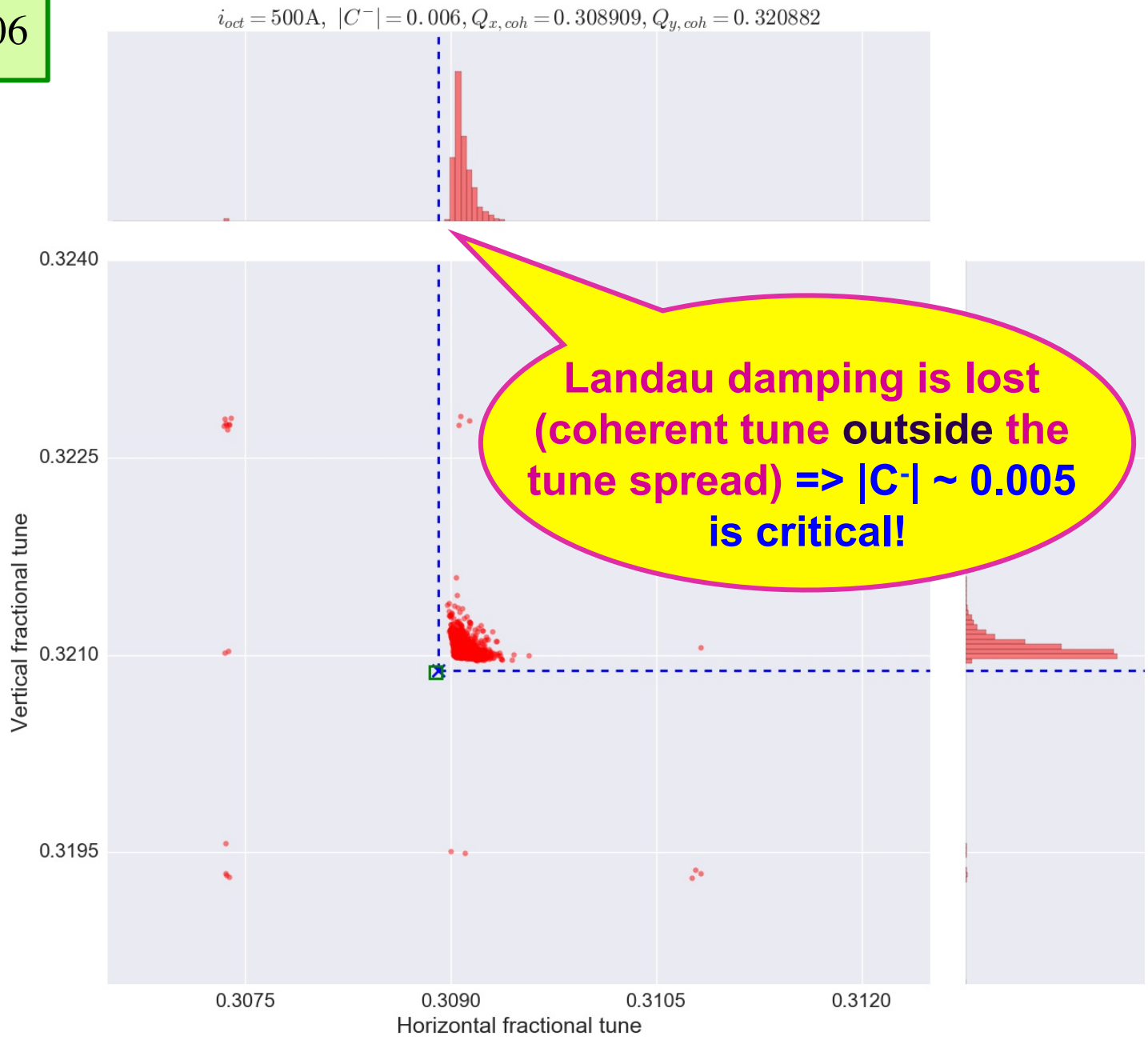
$\left|C^{-}\right| = 0.004$



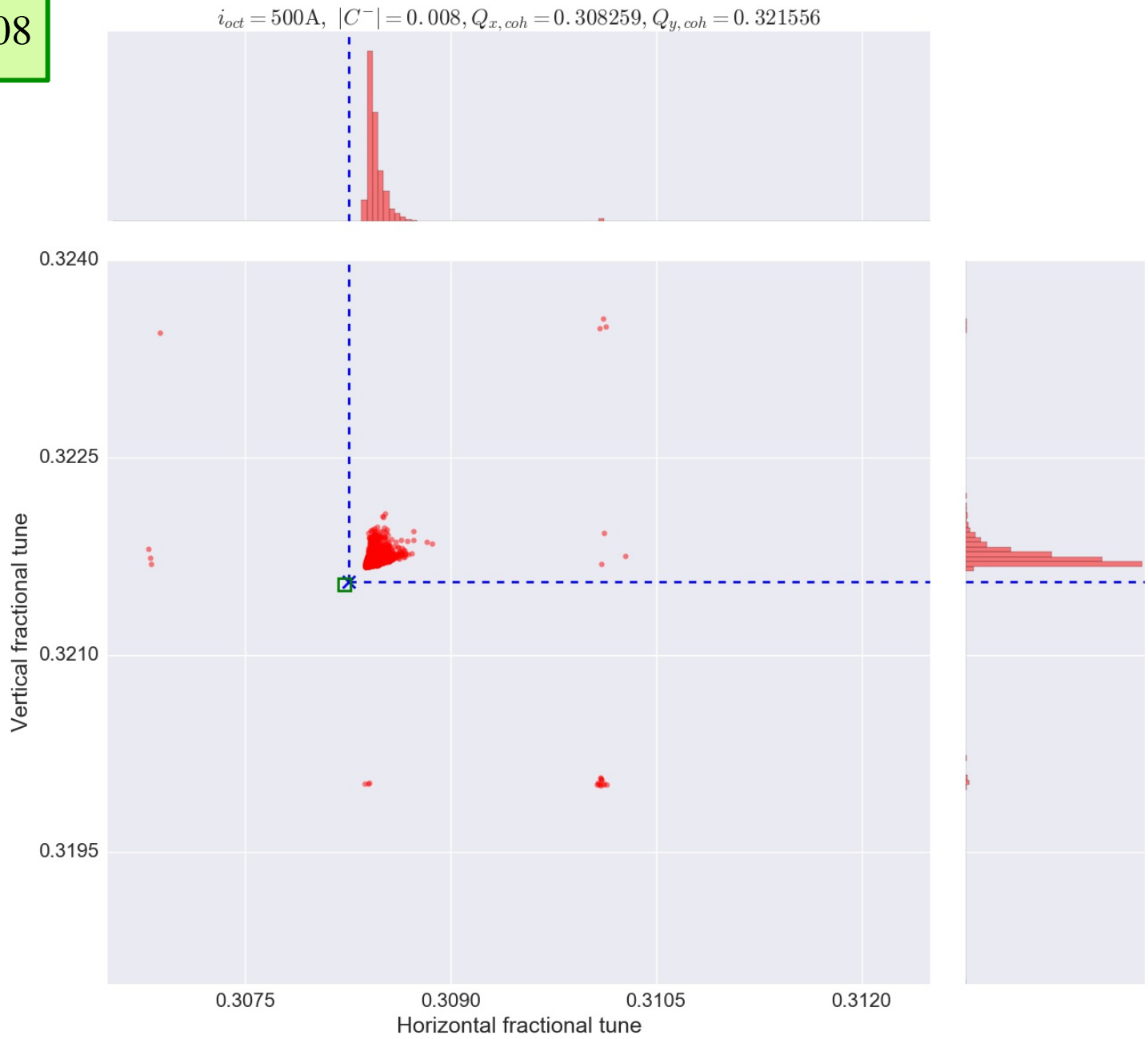
L.R. Carver

$\left|C^{-}\right| = 0.006$



L.R. Carver

$\left|C^{-}\right| = 0.008$



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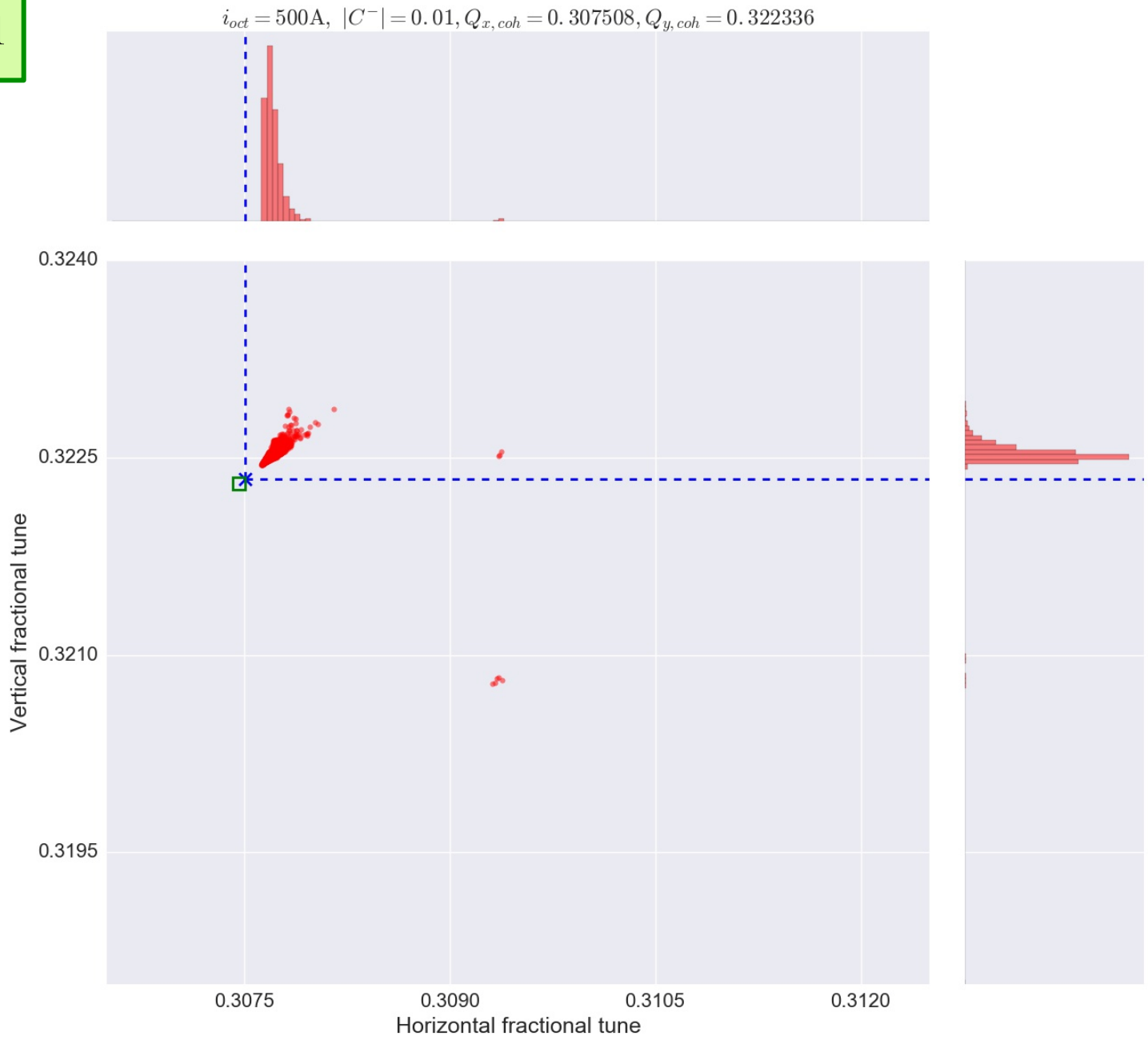
$\left|C^{-}\right| = 0.01$



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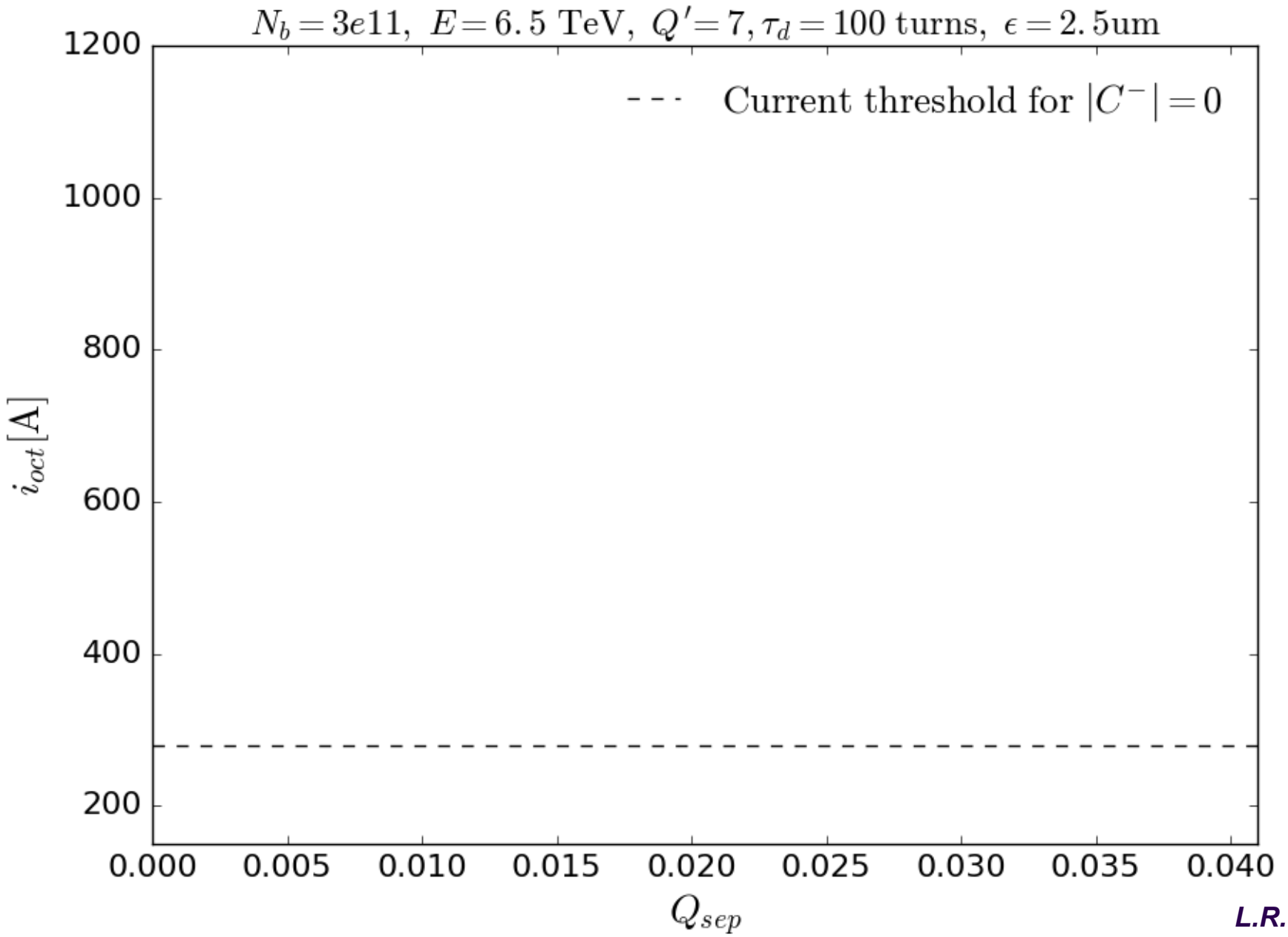
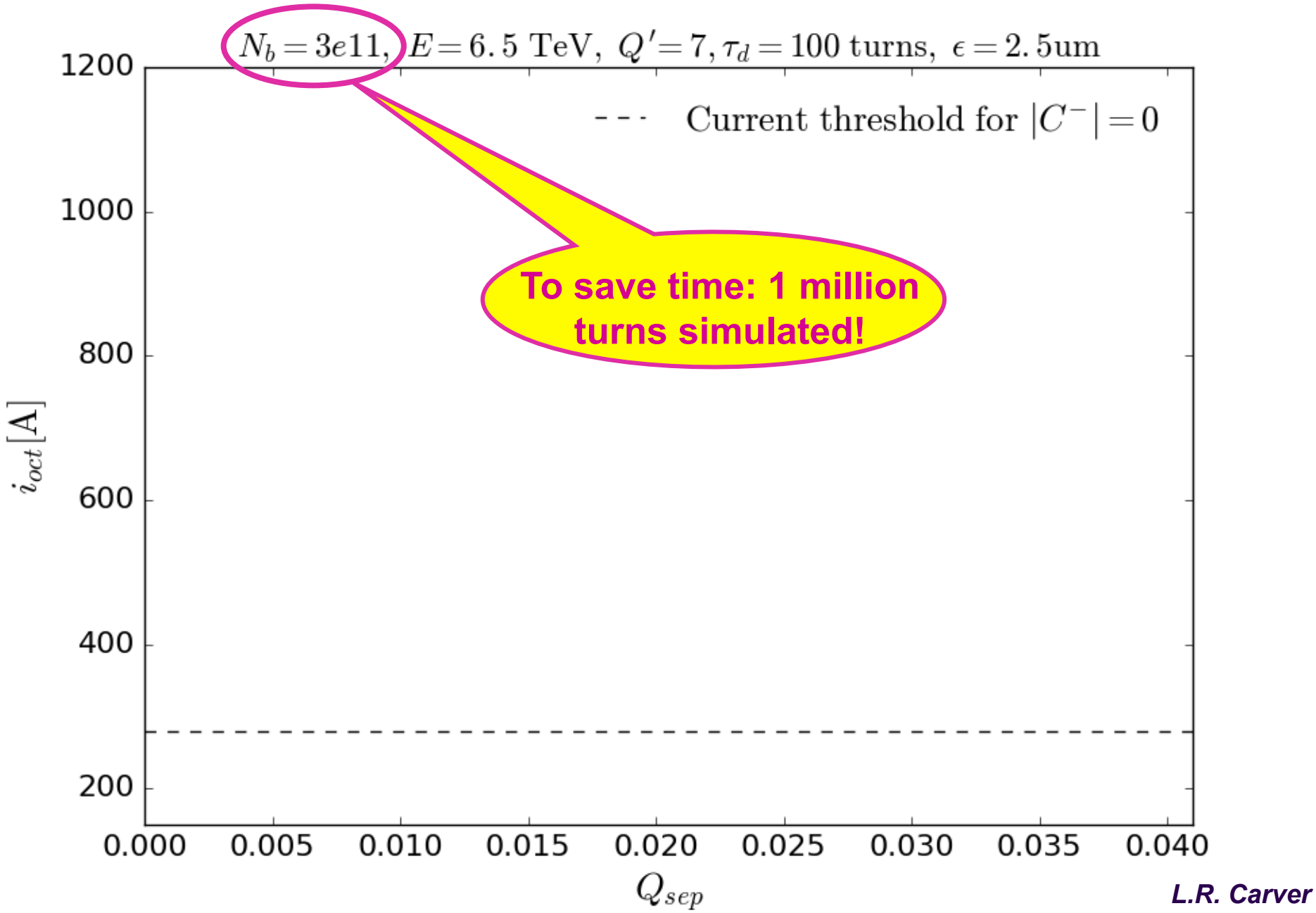

$N_b = 3e11,\ E = 6.5$ TeV, $Q' = 7, \tau_d = 100$ turns, $\epsilon = 2.5$um
Current threshold for $|C^-| = 0$
1200
1000
800
600
400
200
i_{oct} [A]
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
Q_{sep}

L.R. Carver


$N_b = 3e11,\ E = 6.5$ TeV, $Q' = 7, \tau_d = 100$ turns, $\epsilon = 2.5$um
Current threshold for $|C^-| = 0$
To save time: 1 million turns simulated!
1200
1000
800
600
400
200
i_{oct} [A]
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
Q_{sep}

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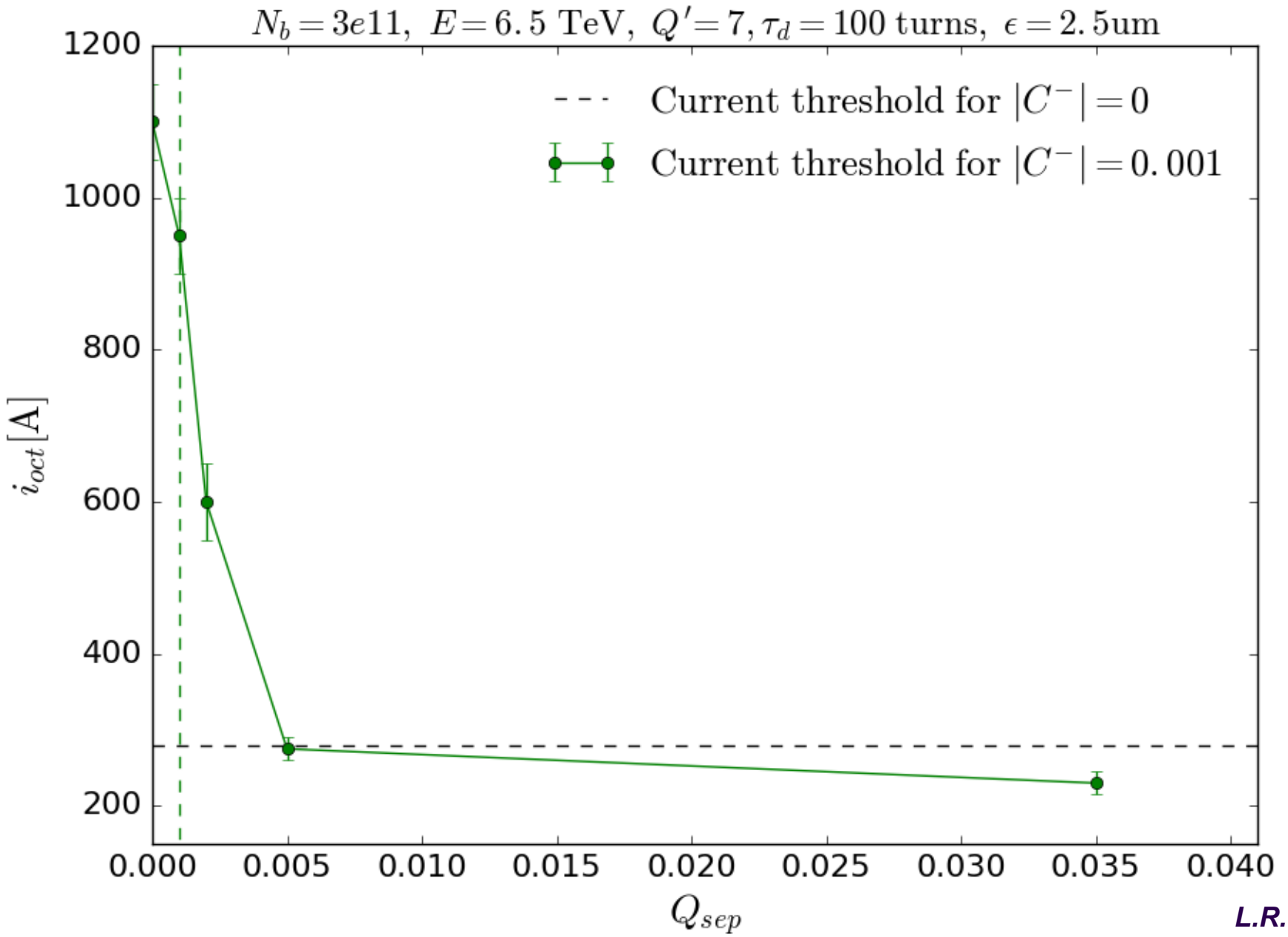
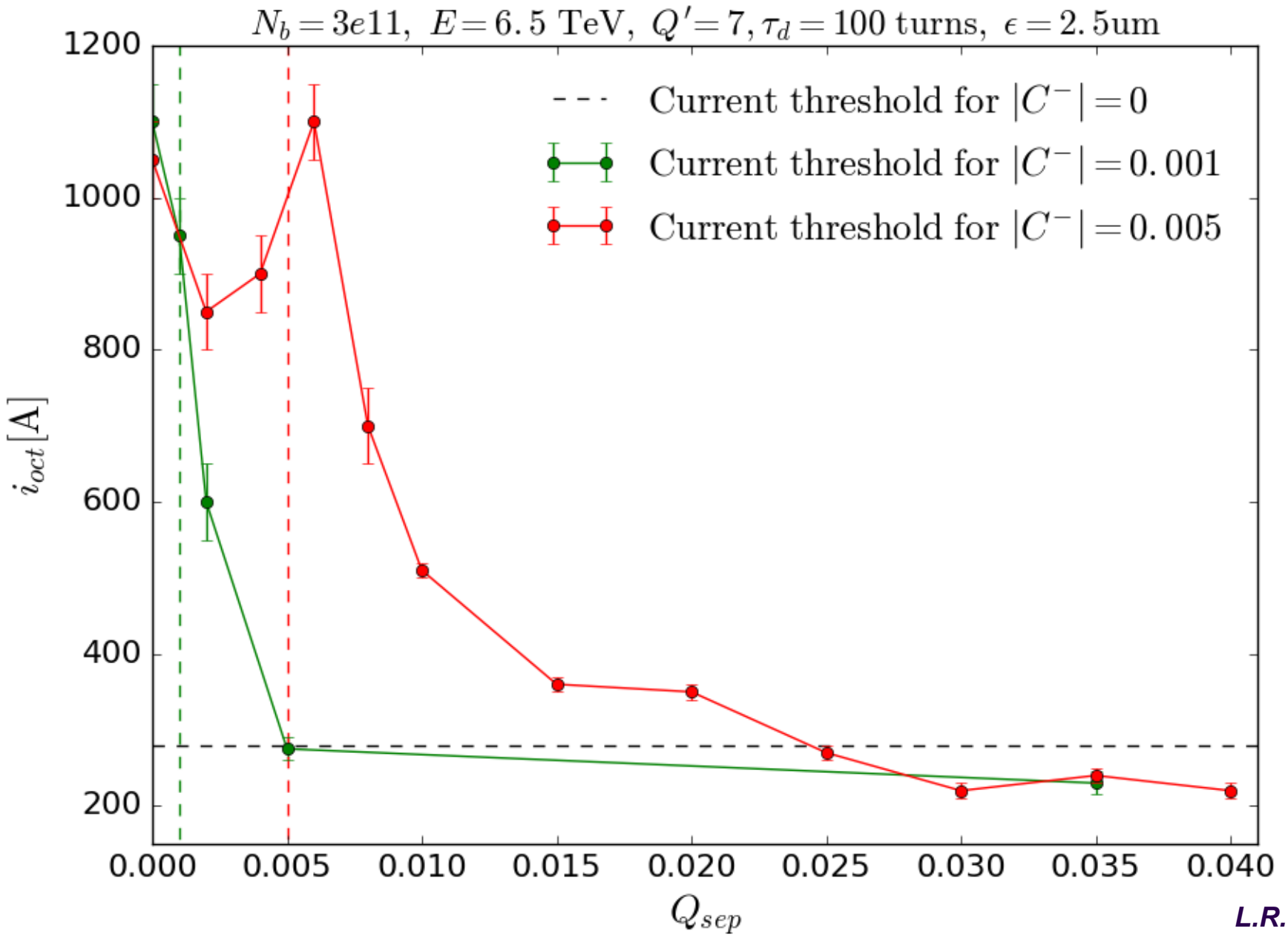

$N_b = 3e11,\ E = 6.5$ TeV, $Q' = 7, \tau_d = 100$ turns, $\epsilon = 2.5$um
Current threshold for $|C^-| = 0$
Current threshold for $|C^-| = 0.001$
i_{oct} [A]
Q_{sep}
1200
1000
800
600
400
200
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040

L.R. Carver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Current threshold for $|C^-| = 0$
Current threshold for $|C^-| = 0.001$
Current threshold for $|C^-| = 0.005$
i_{oct} [A]
Q_{sep}
1200
1000
800
600
400
200
0.000
0.005
0.010
0.015
0.020
0.025
0.030
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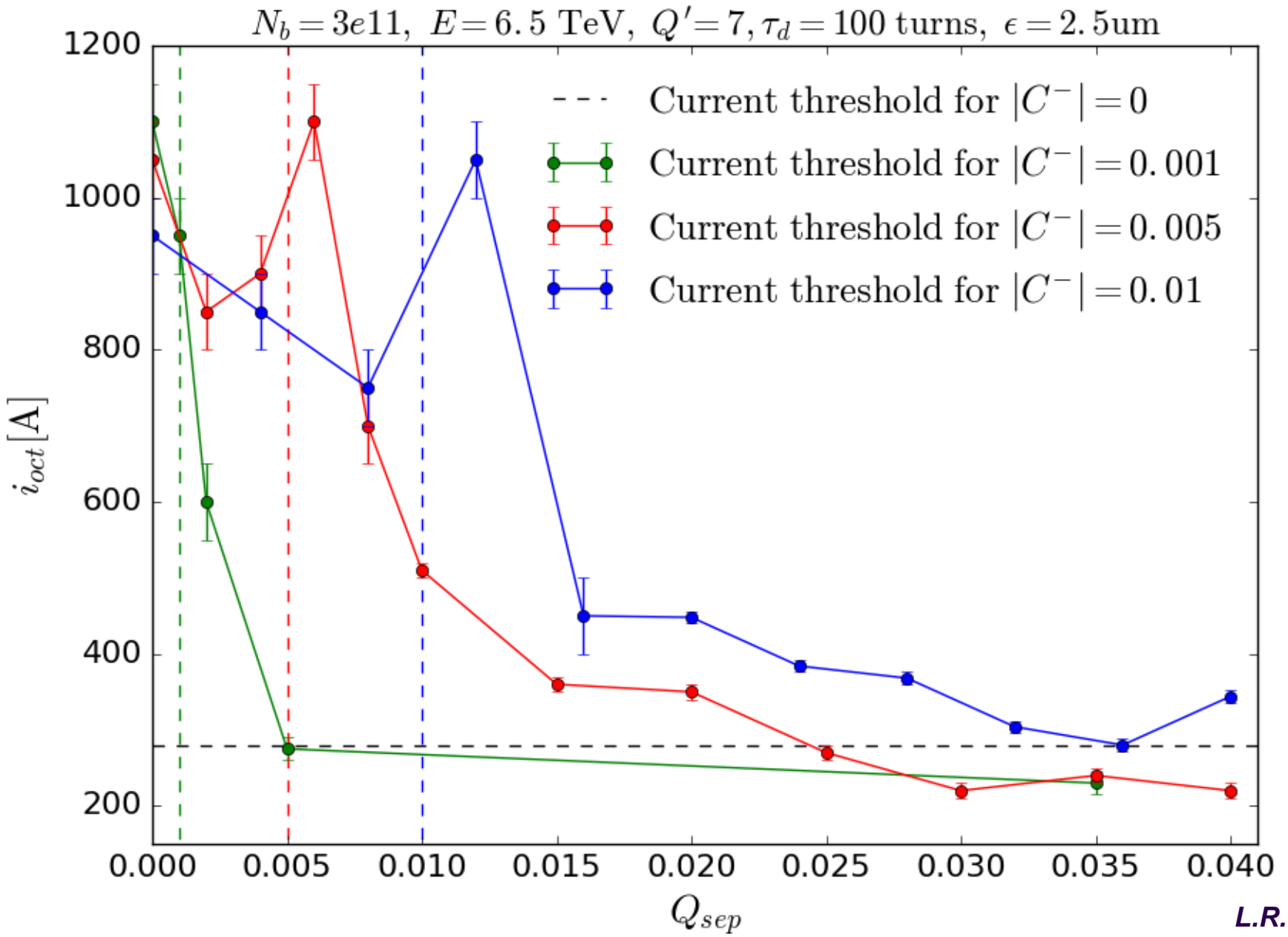
L.R. Carver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Current threshold for $|C^-| = 0$
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Current threshold for $|C^-| = 0.005$
Current threshold for $|C^-| = 0.01$
i_{oct} [A]
Q_{sep}
1200
1000
800
600
400
200
0.000
0.005
0.010
0.015
0.020
0.025
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0.035
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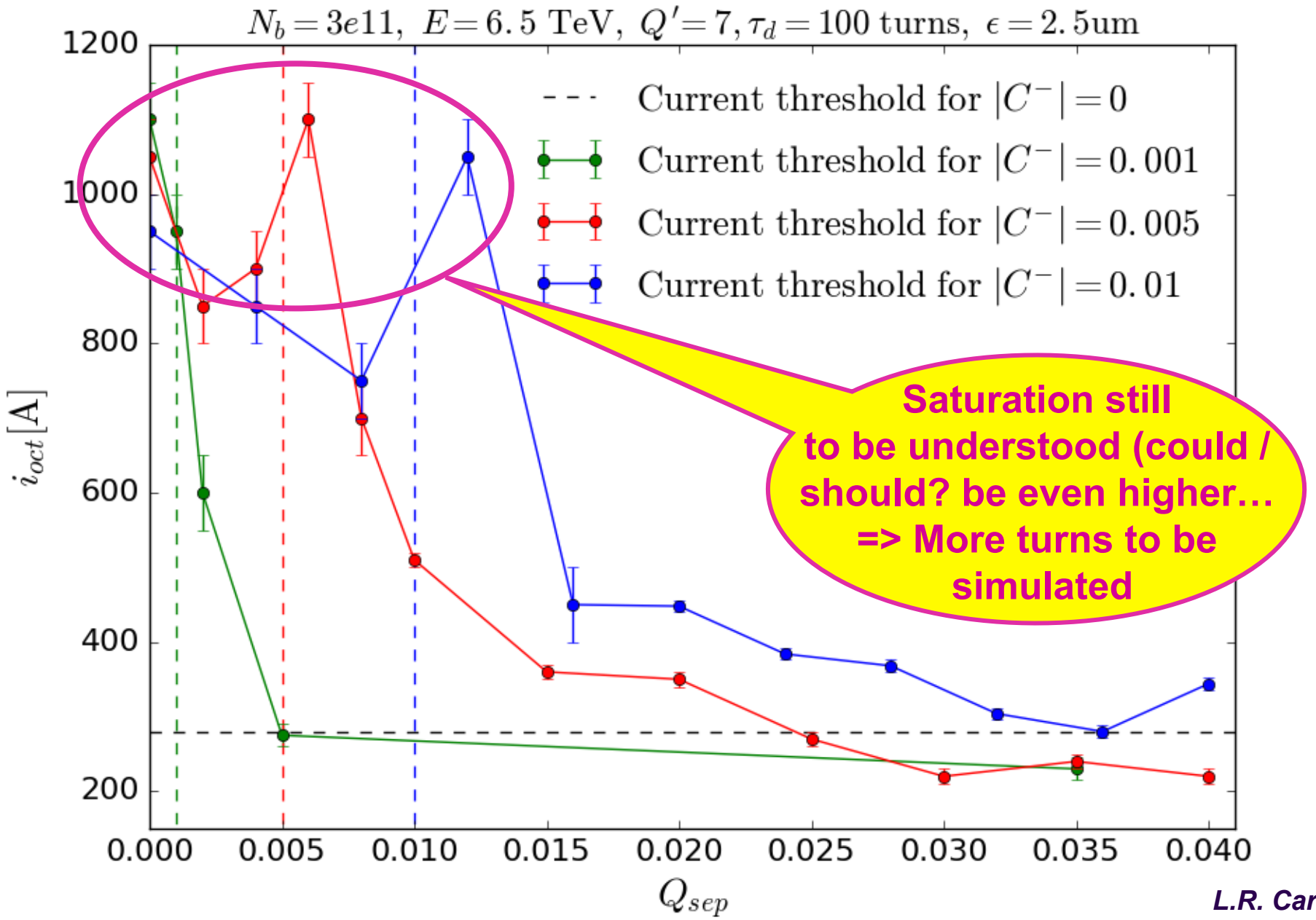
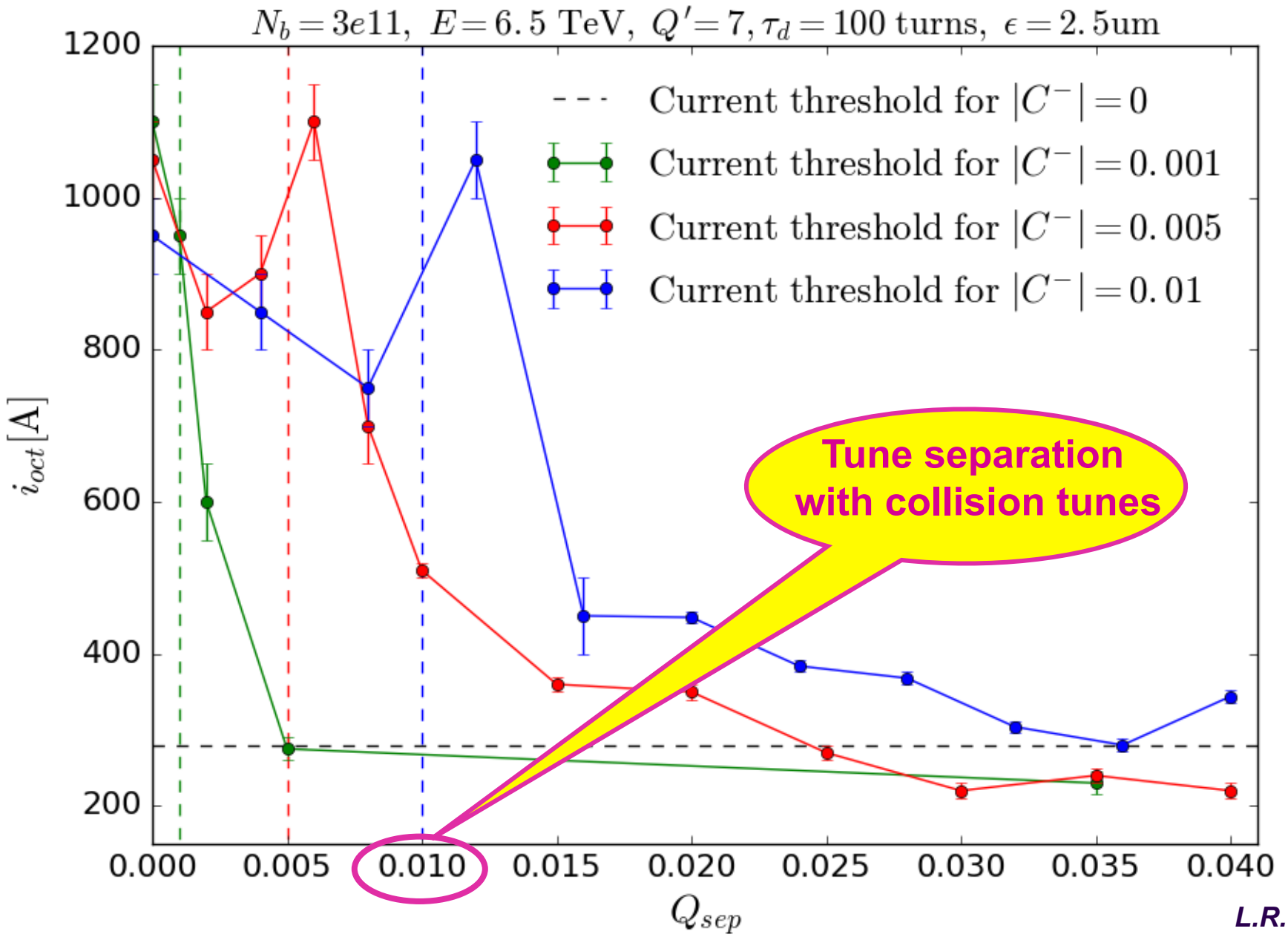

$N_b = 3e11,\ E = 6.5$ TeV, $Q' = 7, \tau_d = 100$ turns, $\epsilon = 2.5$um
Current threshold for $|C^-| = 0$
Current threshold for $|C^-| = 0.001$
Current threshold for $|C^-| = 0.005$
Current threshold for $|C^-| = 0.01$
Saturation still to be understood (could / should? be even higher… => More turns to be simulated
i_{oct} [A]
Q_{sep}
1200
1000
800
600
400
200
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040

L.R. Carver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Current threshold for $|C^-| = 0$
Current threshold for $|C^-| = 0.001$
Current threshold for $|C^-| = 0.005$
Current threshold for $|C^-| = 0.01$
Tune separation with collision tunes
i_{oct} [A]
Q_{sep}
1200
1000
800
600
400
200
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040

L.R. Carver

- **Conclusion from simulations:** A too strong coupling can lead to instability even in the presence of high Landau octupoles current

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- **Recommendation:** Keep $|C^-|$ at the ~ 0.001 level or increase the tune separation

MEASUREMENTS (in 2016)

- **Dedicated instability measurements in the LHC on 16/04/2016 with a single bunch**

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  - **1) During the betatron squeeze**

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  - **1) During the betatron squeeze**
  - **2) At top energy (before the betatron squeeze)**

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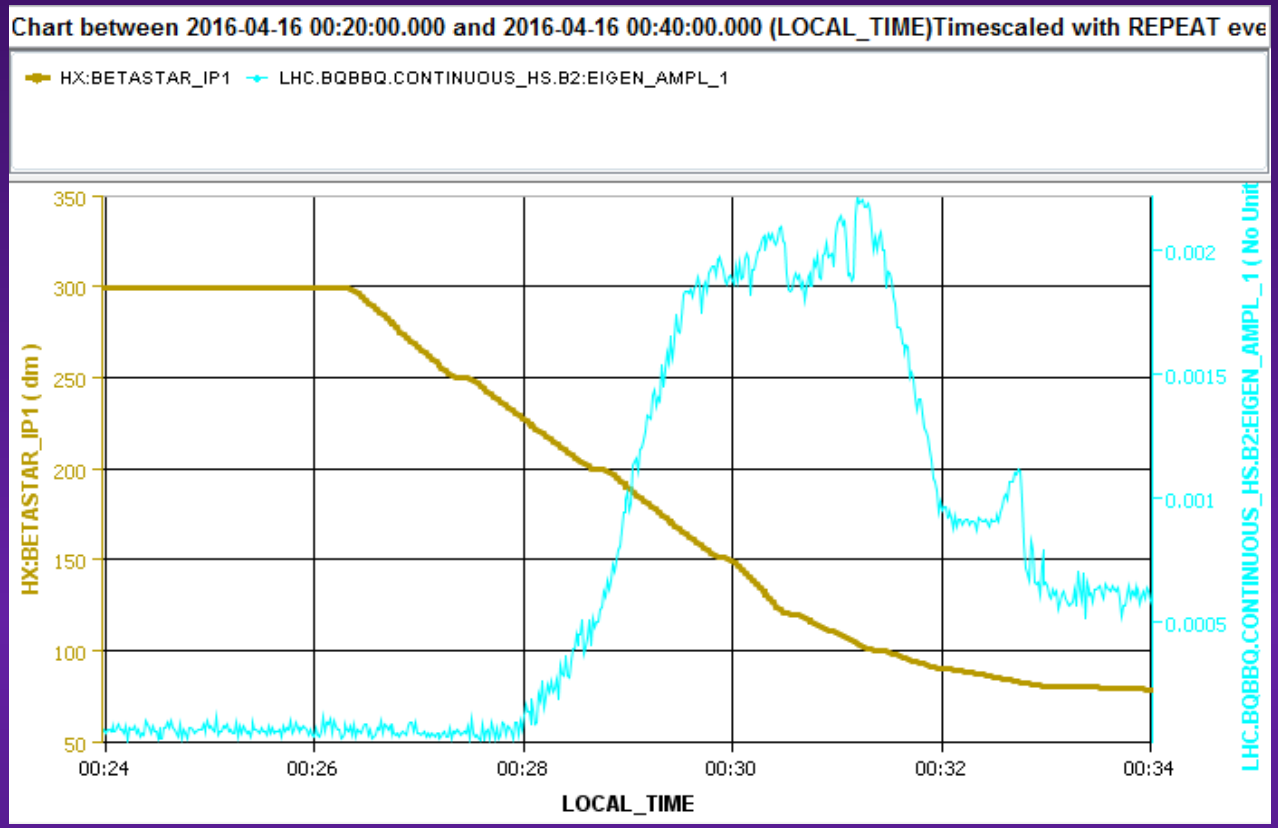

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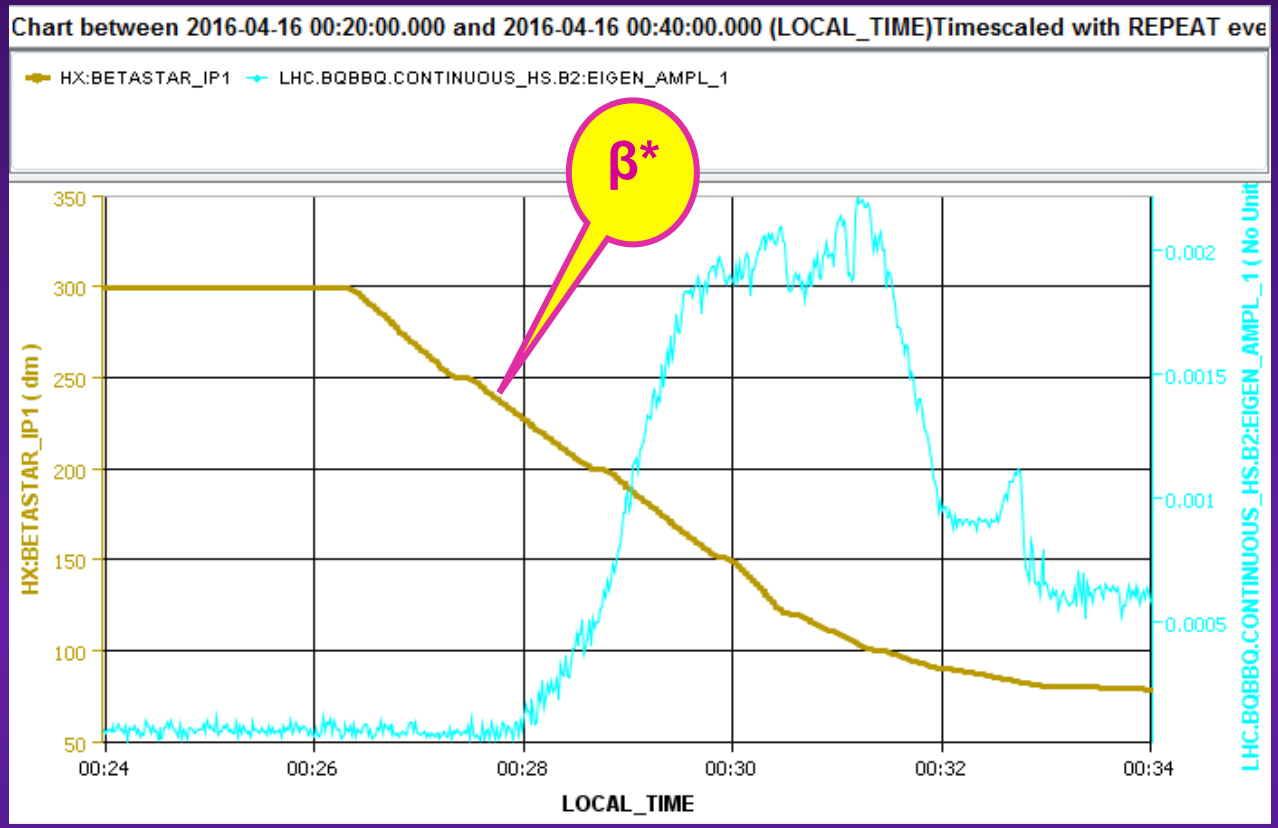

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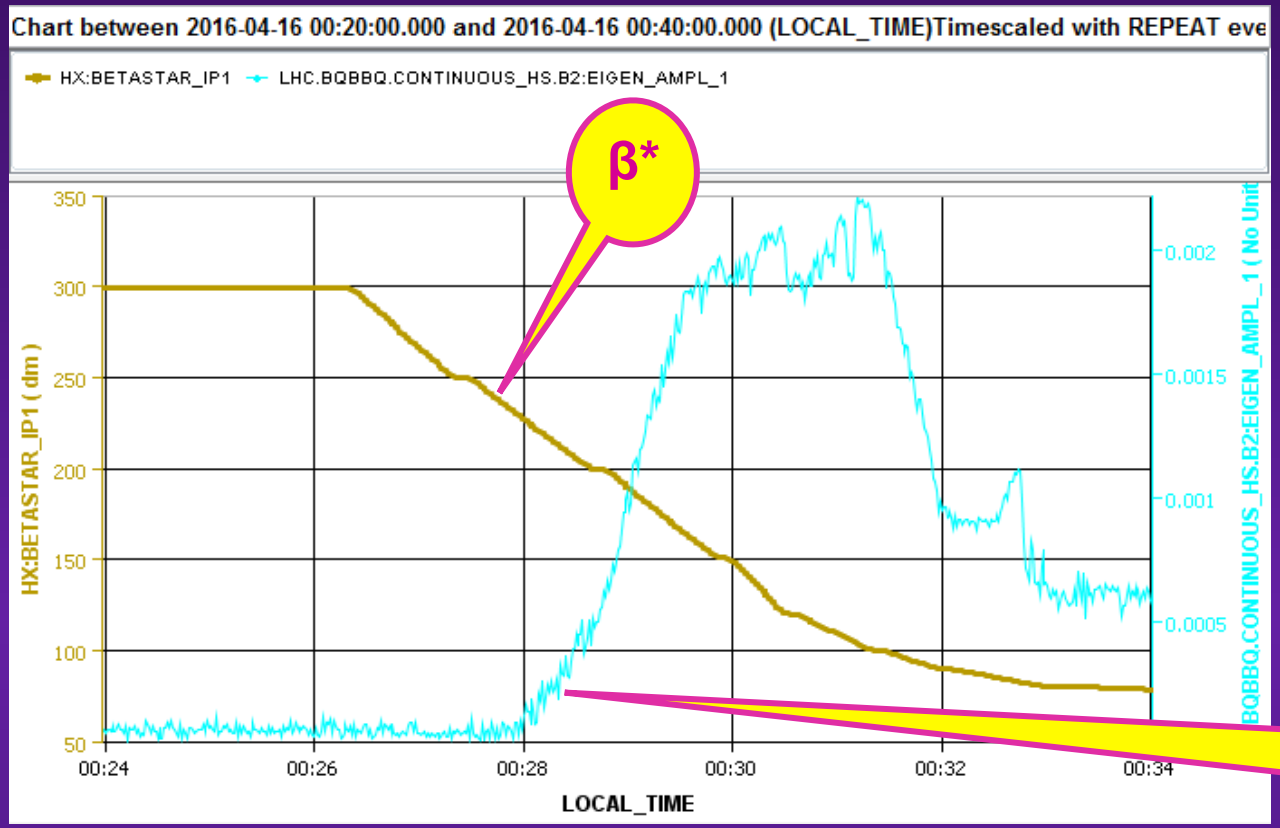

B2V BBQ activity

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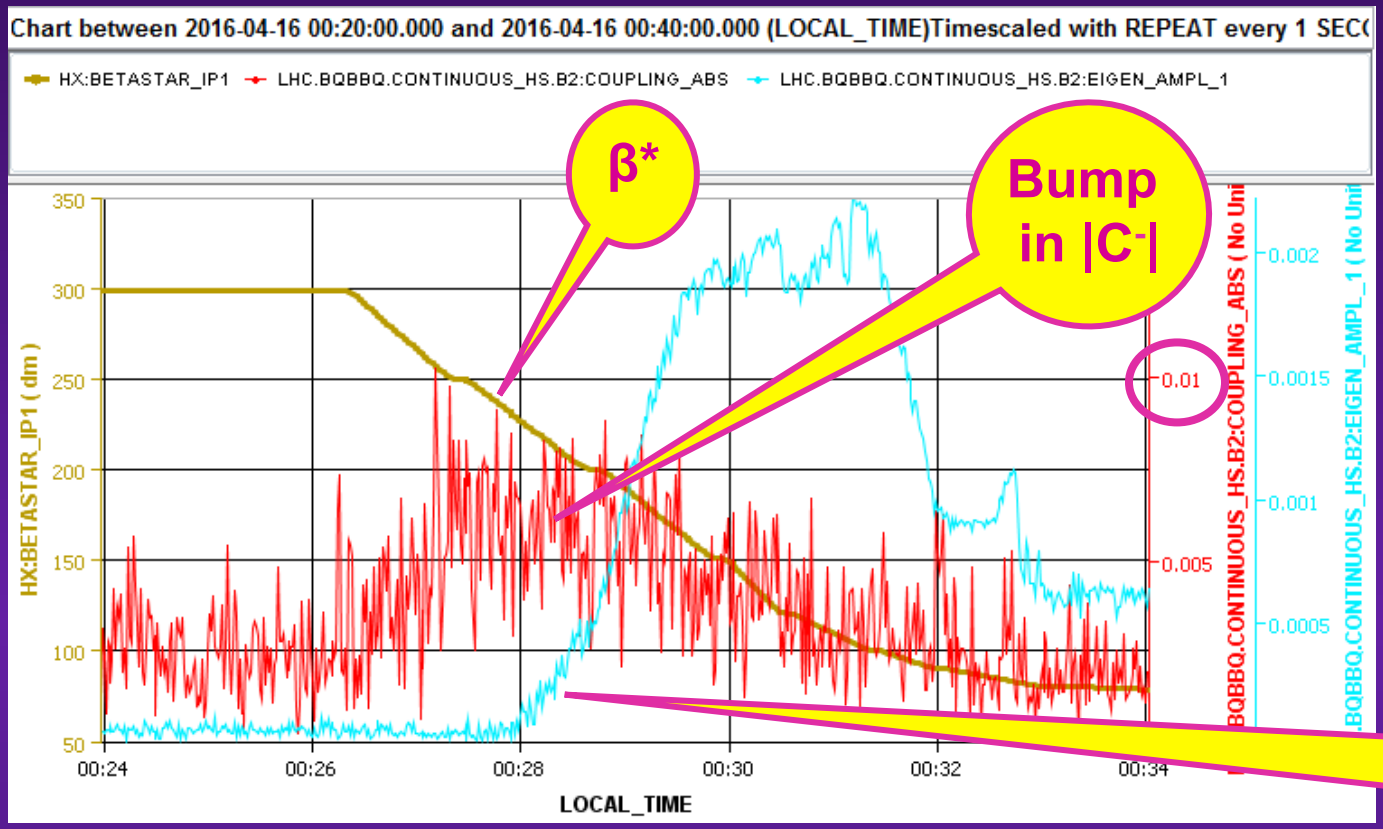

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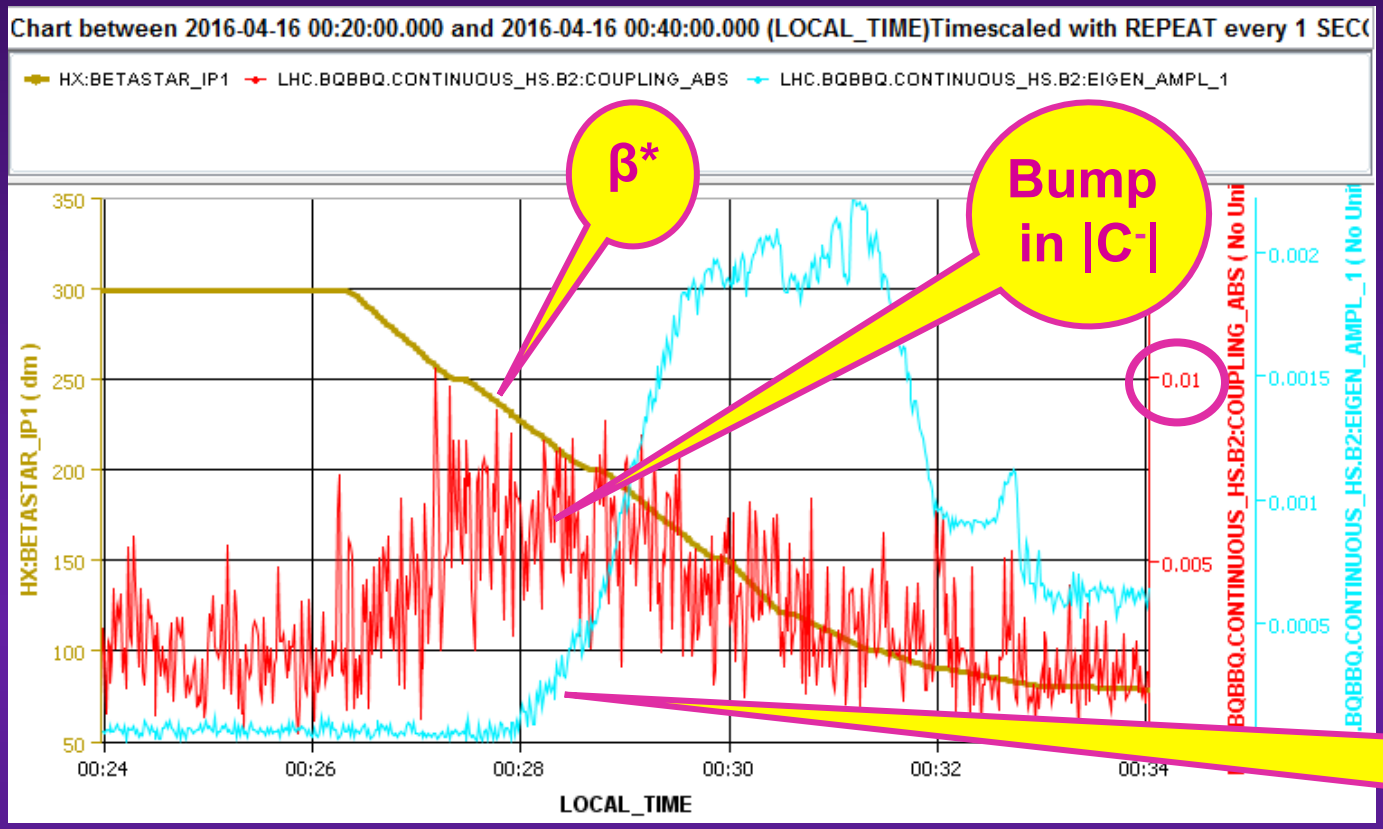

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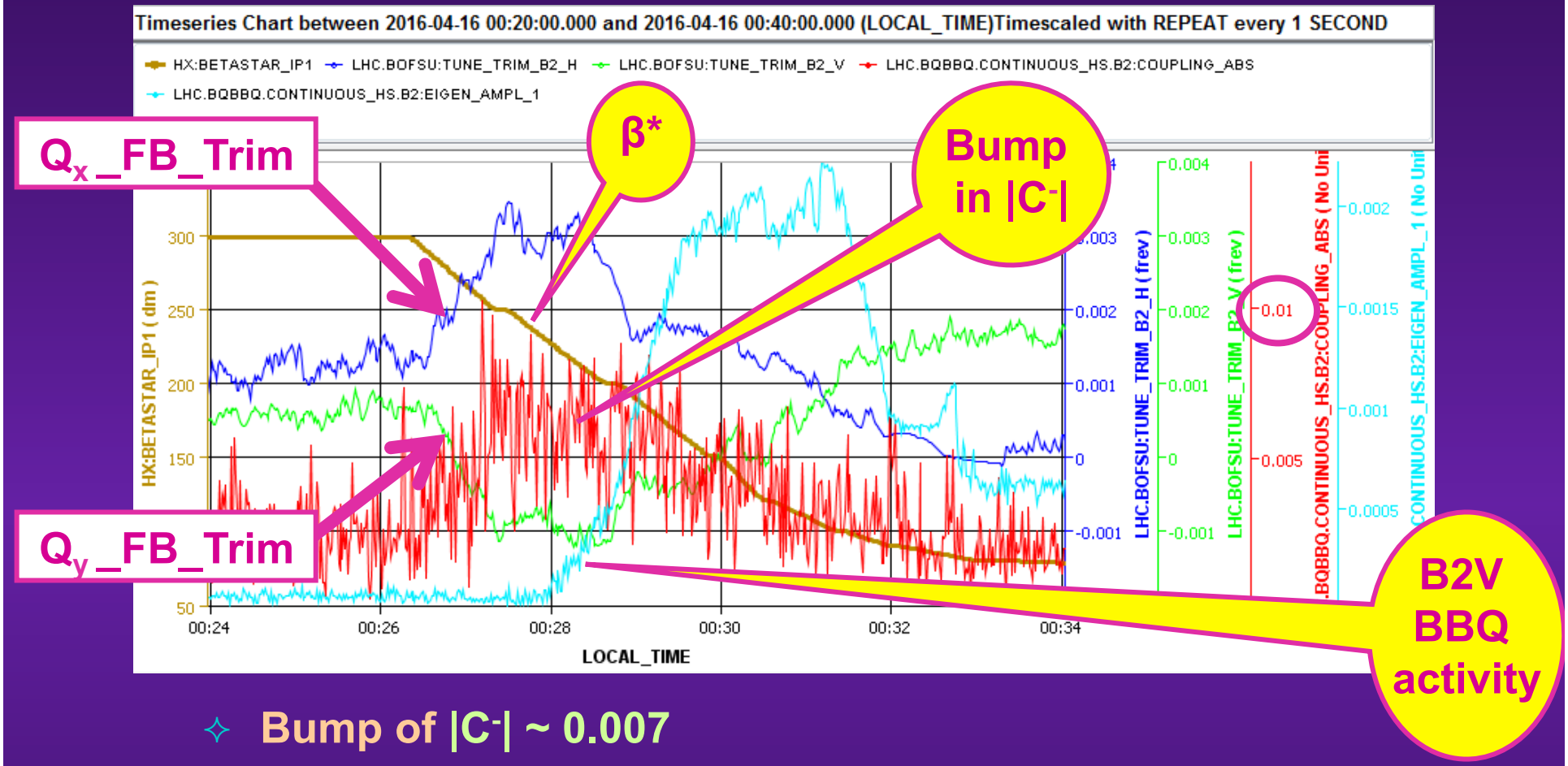

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- Q_u/Q_v kept at 0.31/0.32 (tune feedback) => Q_x ~ 0.312 and Q_y ~ 0.318 => $Q_y - Q_x$ ~ 0.006 (i.e. tune feedback is amplifying the coupling effect!)

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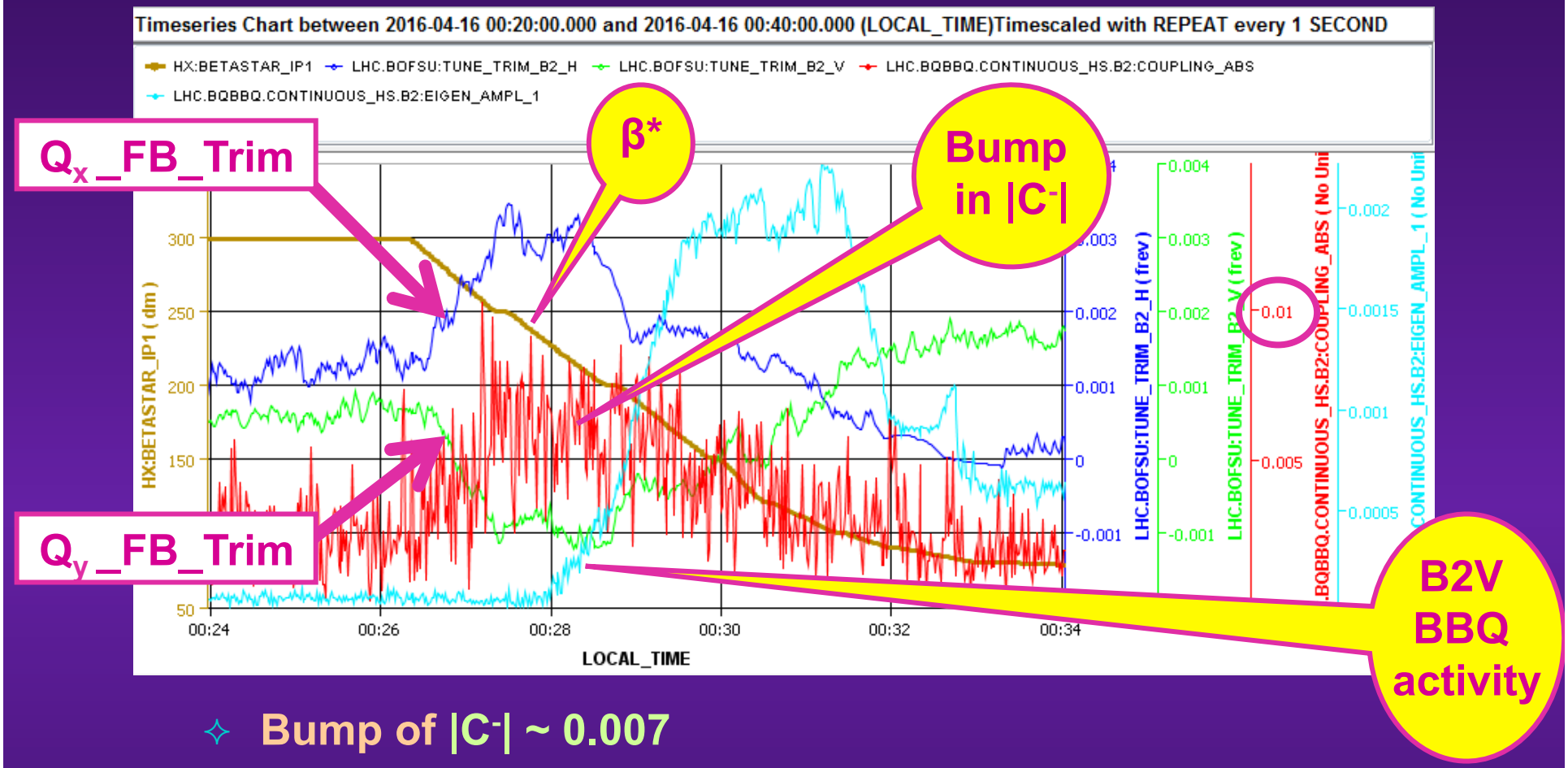

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- B2V instability observed with LOF = + 285 A, i.e. ~ 4 times higher octupole current than uncoupled threshold (~ 70 A)

- **2) At top energy (before the betatron squeeze)**

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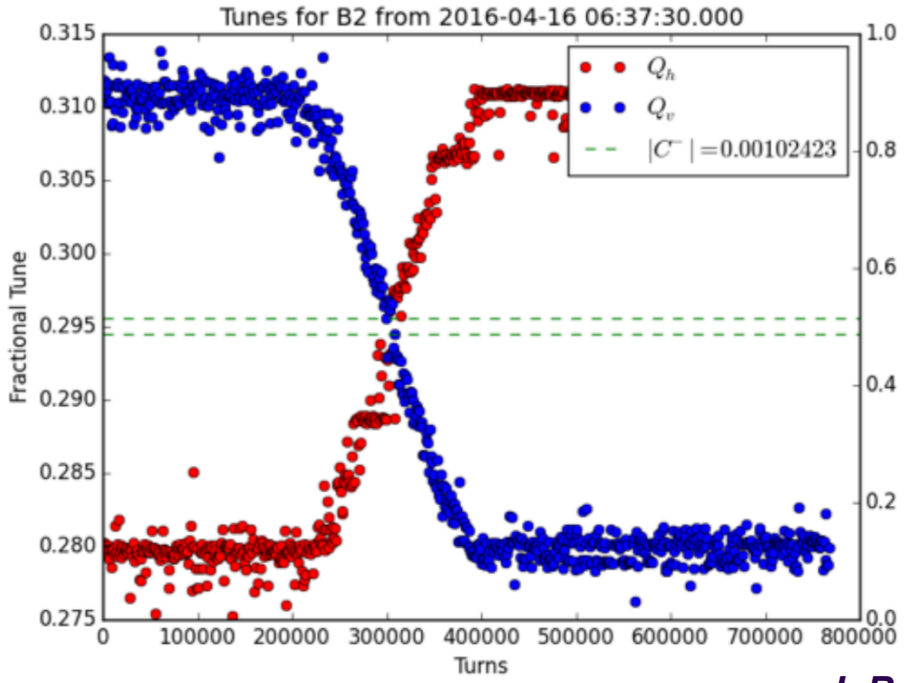
✧ $|C^-| \sim 0.001$ and $Q_{sep} = 0.03$:

=> Stability limit: LOF ~ 70 A



L.R. Carver

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✧ $|C^-| \sim 0.001$ and $Q_{sep} = 0.03$:
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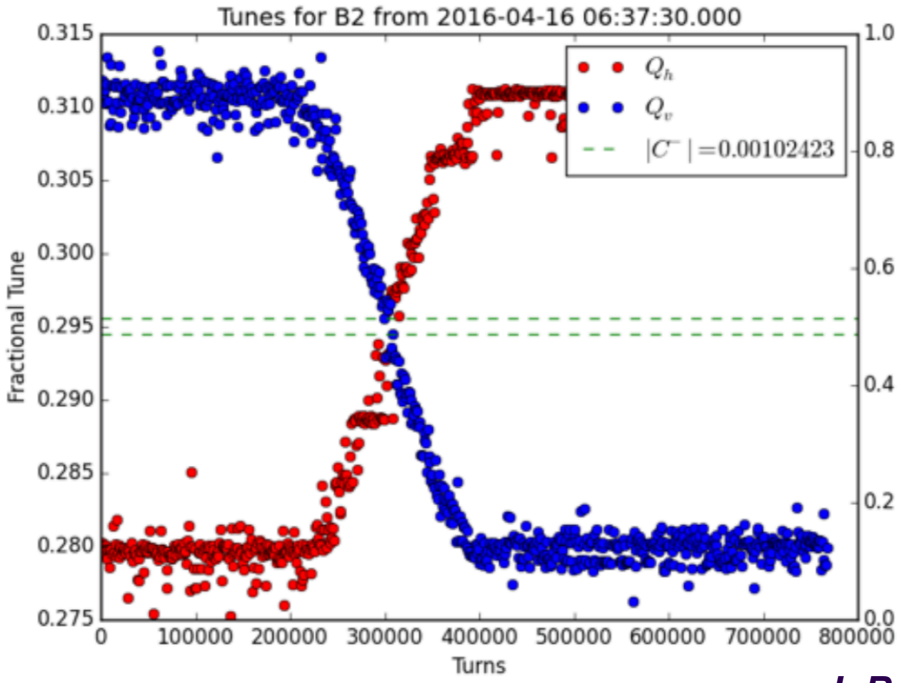
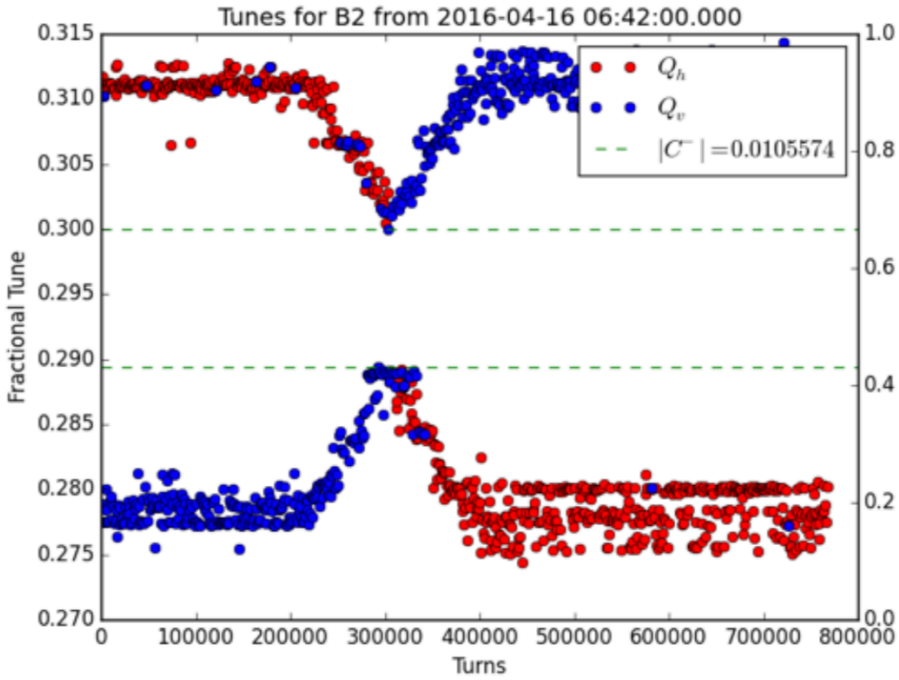
✧ $|C^-| \sim 0.01$ and $Q_{sep} \sim 0.018$
=> Stability limit: LOF ~ 310 A





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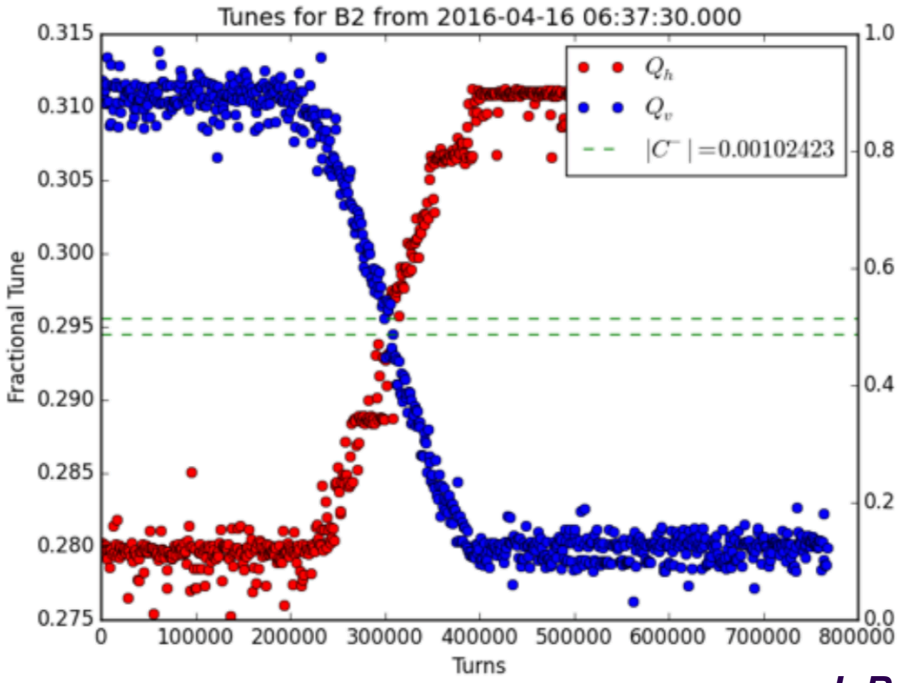
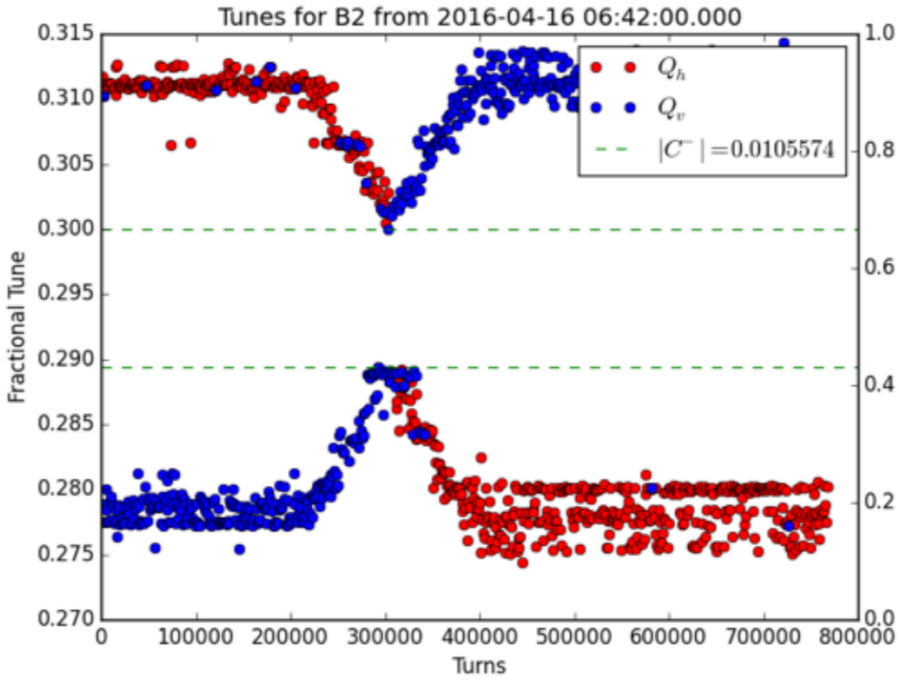
i.e. 4.4 × 70

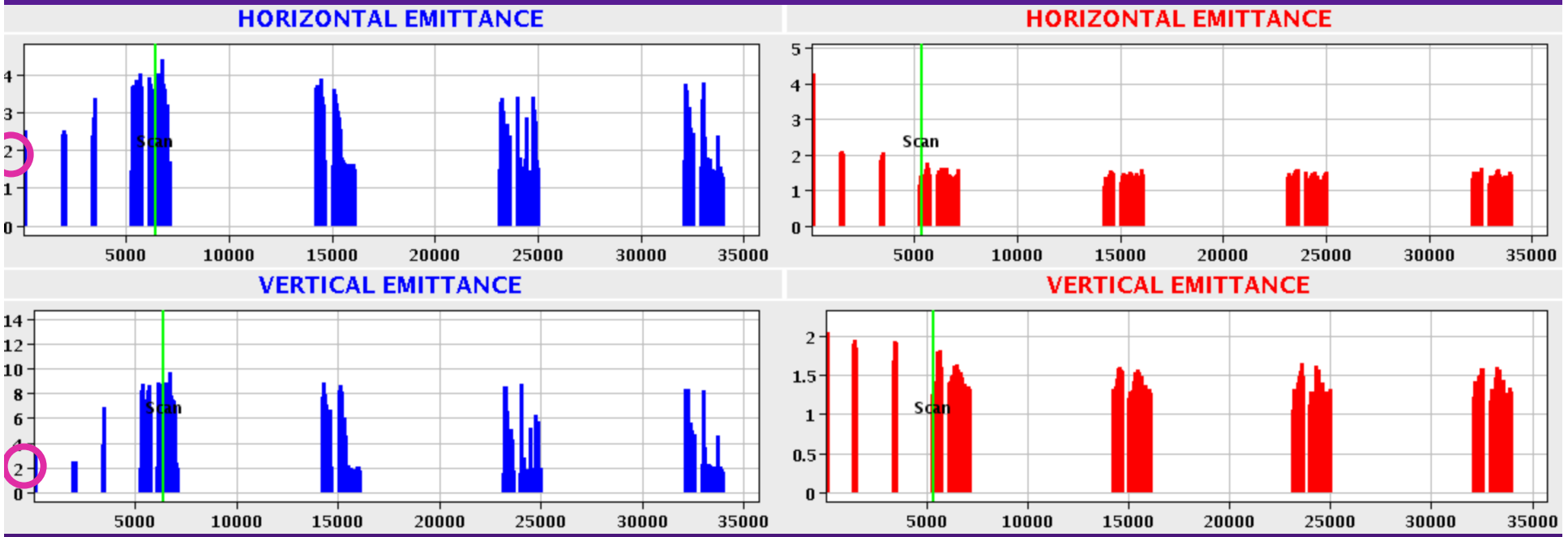




L.R. Carver

- **What about the B1 instabilities observed during the week-end 23-25/09/2016?**

Sunday 25/09/16, Fill #5332 (600 bunches)



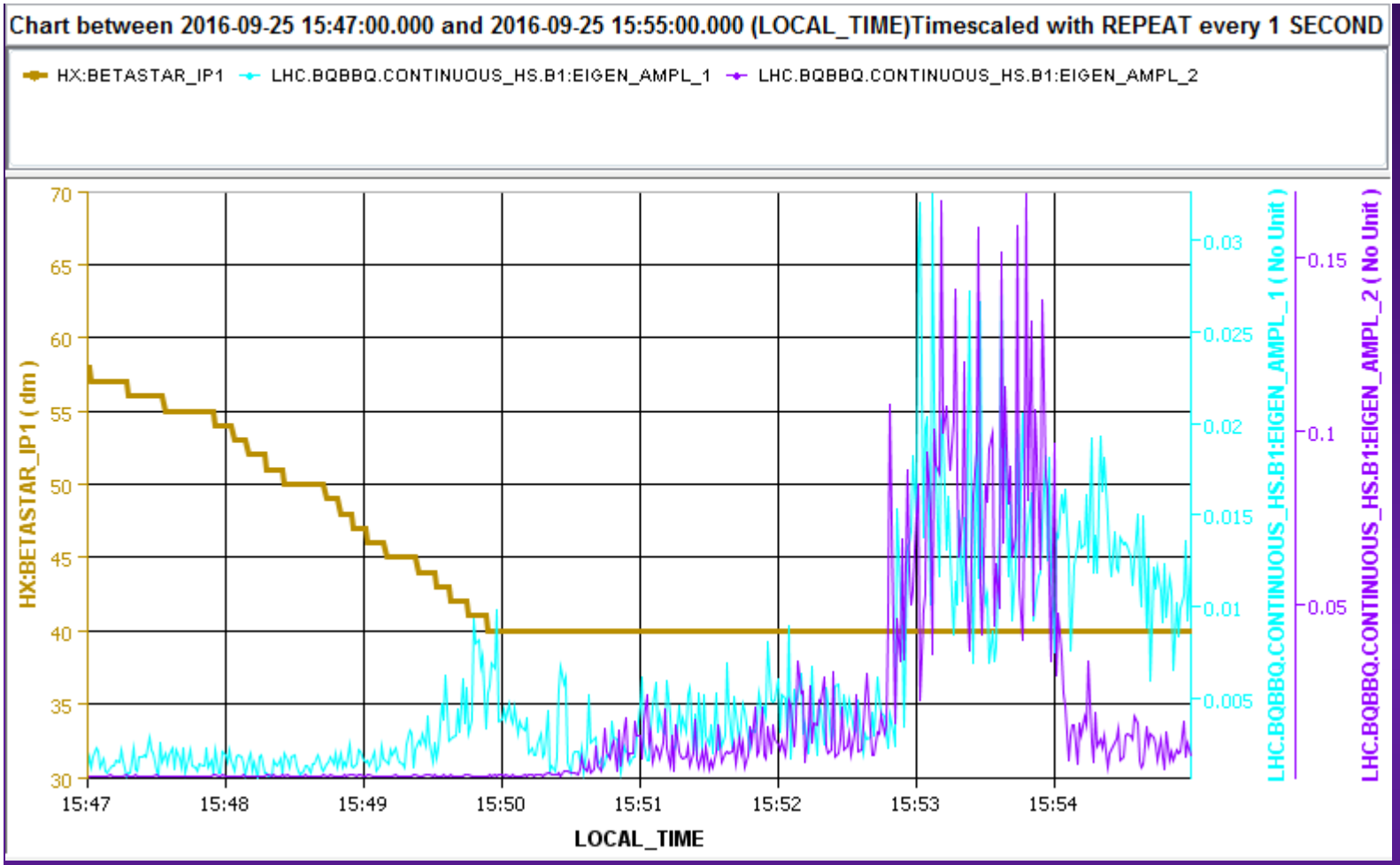
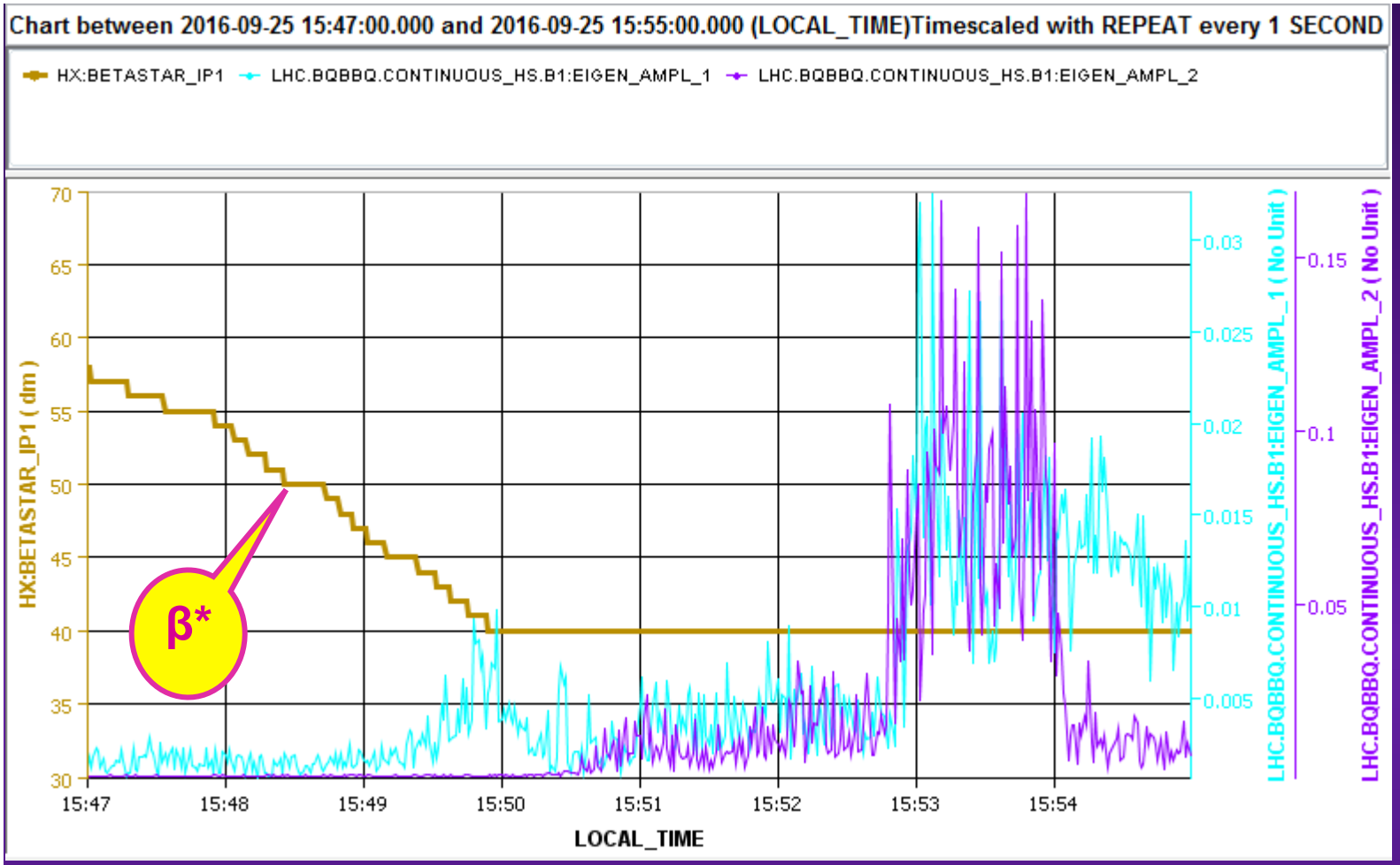


Chart between 2016-09-25 15:47:00.000 and 2016-09-25 15:55:00.000 (LOCAL_TIME)Timescaled with REPEAT every 1 SECOND
HX:BETASTAR_IP1
LHC.BQBBQ.CONTINUOUS_HS.B1:EIGEN_AMPL_1
LHC.BQBBQ.CONTINUOUS_HS.B1:EIGEN_AMPL_2
HX:BETASTAR_IP1 (dm)
LHC.BQBBQ.CONTINUOUS_HS.B1:EIGEN_AMPL_1 (No Unit)
LHC.BQBBQ.CONTINUOUS_HS.B1:EIGEN_AMPL_2 (No Unit)
LOCAL_TIME
70
65
60
55
50
45
40
35
30
0.03
0.025
0.02
0.015
0.01
0.005
0.15
0.1
0.05
15:47
15:48
15:49
15:50
15:51
15:52
15:53
15:54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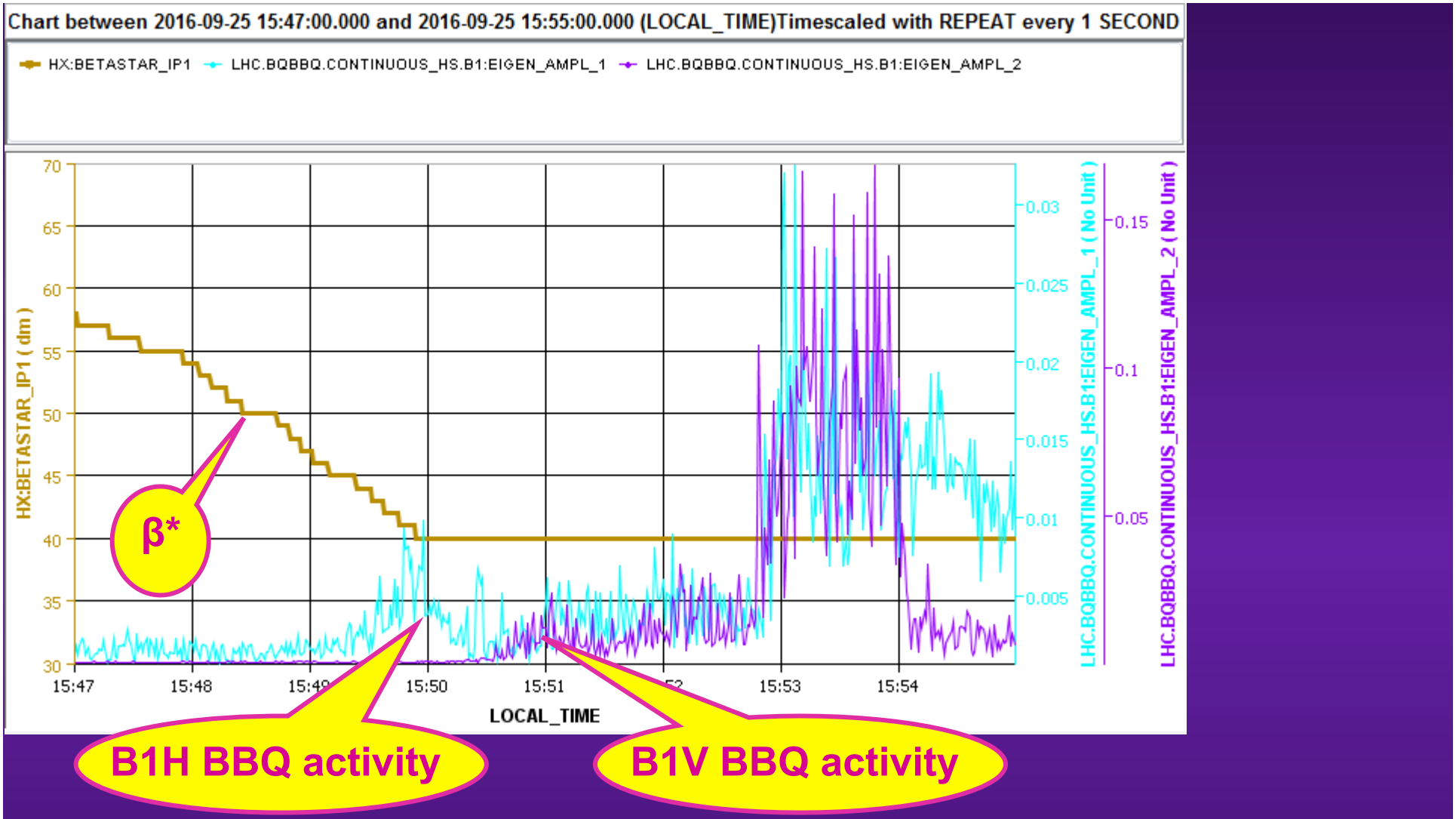
LHC.BQBBQ.CONTINUOUS_HS.B1:EIGEN_AMPL_2 (No Unit)
LOCAL_TIME
β*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HX:BETASTAR_IP1 (dm)
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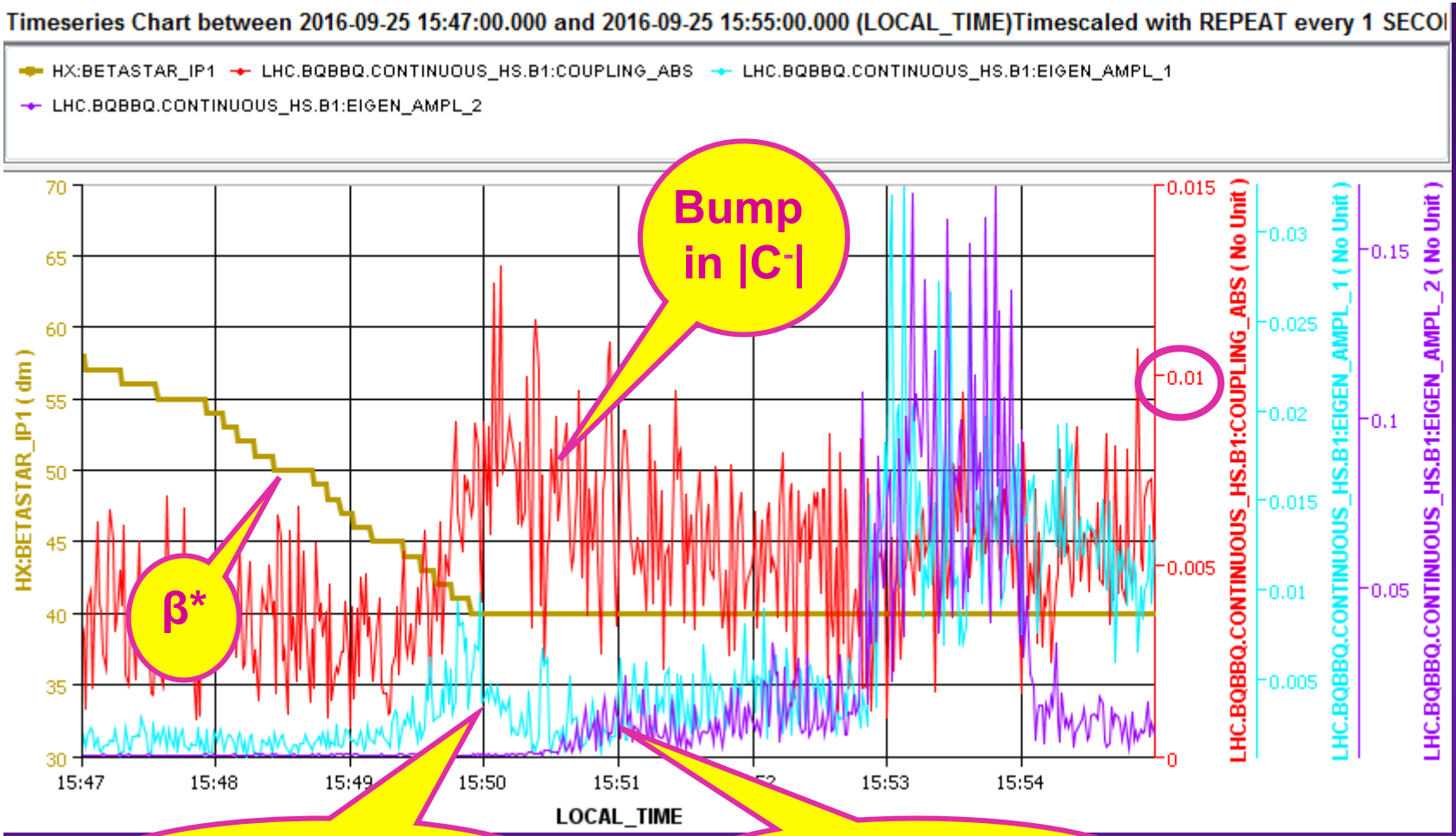
LHC.BQBBQ.CONTINUOUS_HS.B1:EIGEN_AMPL_2 (No Unit)
LOCAL_TIME
β*
B1H BBQ activity
B1V BBQ activity



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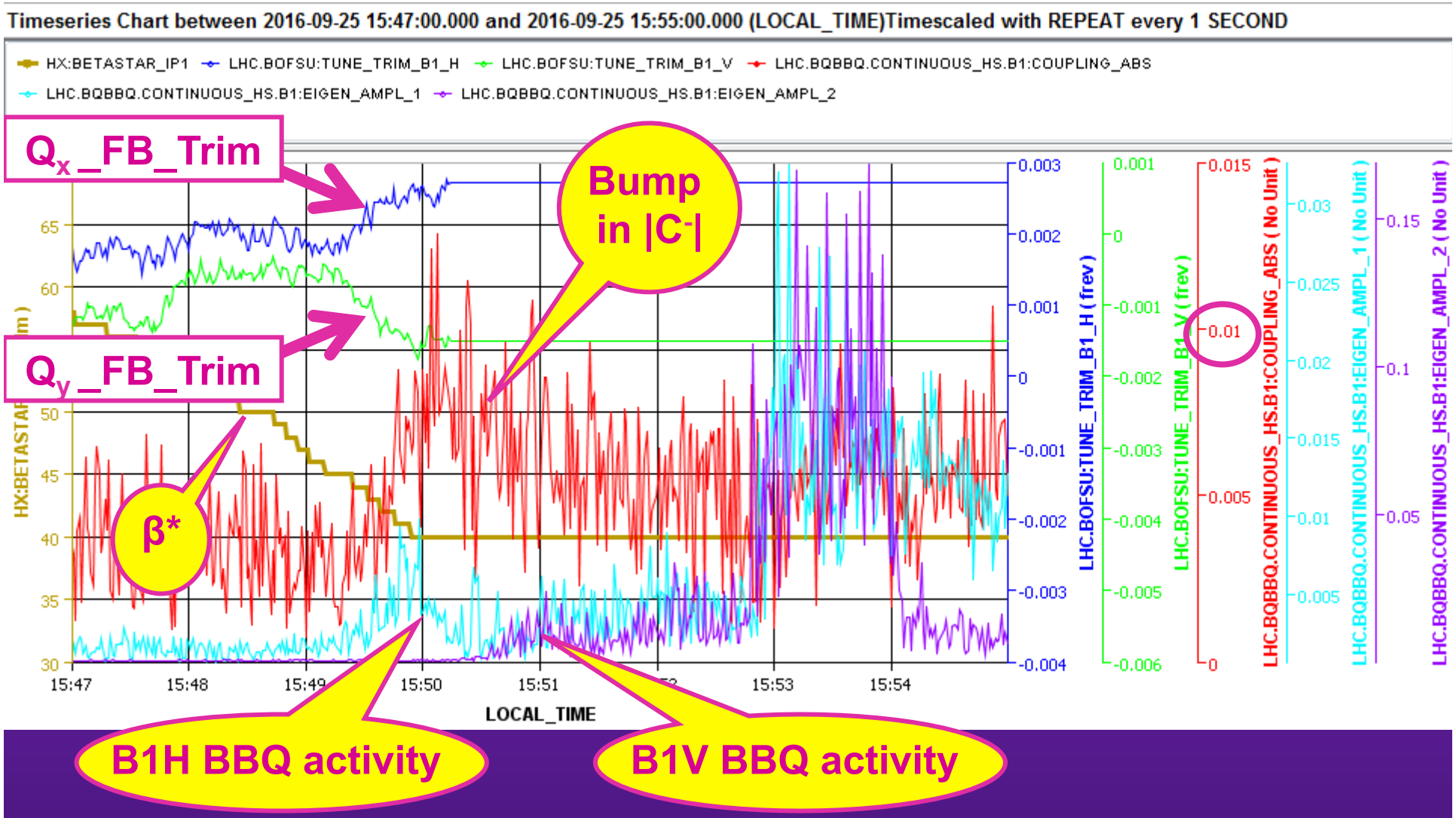

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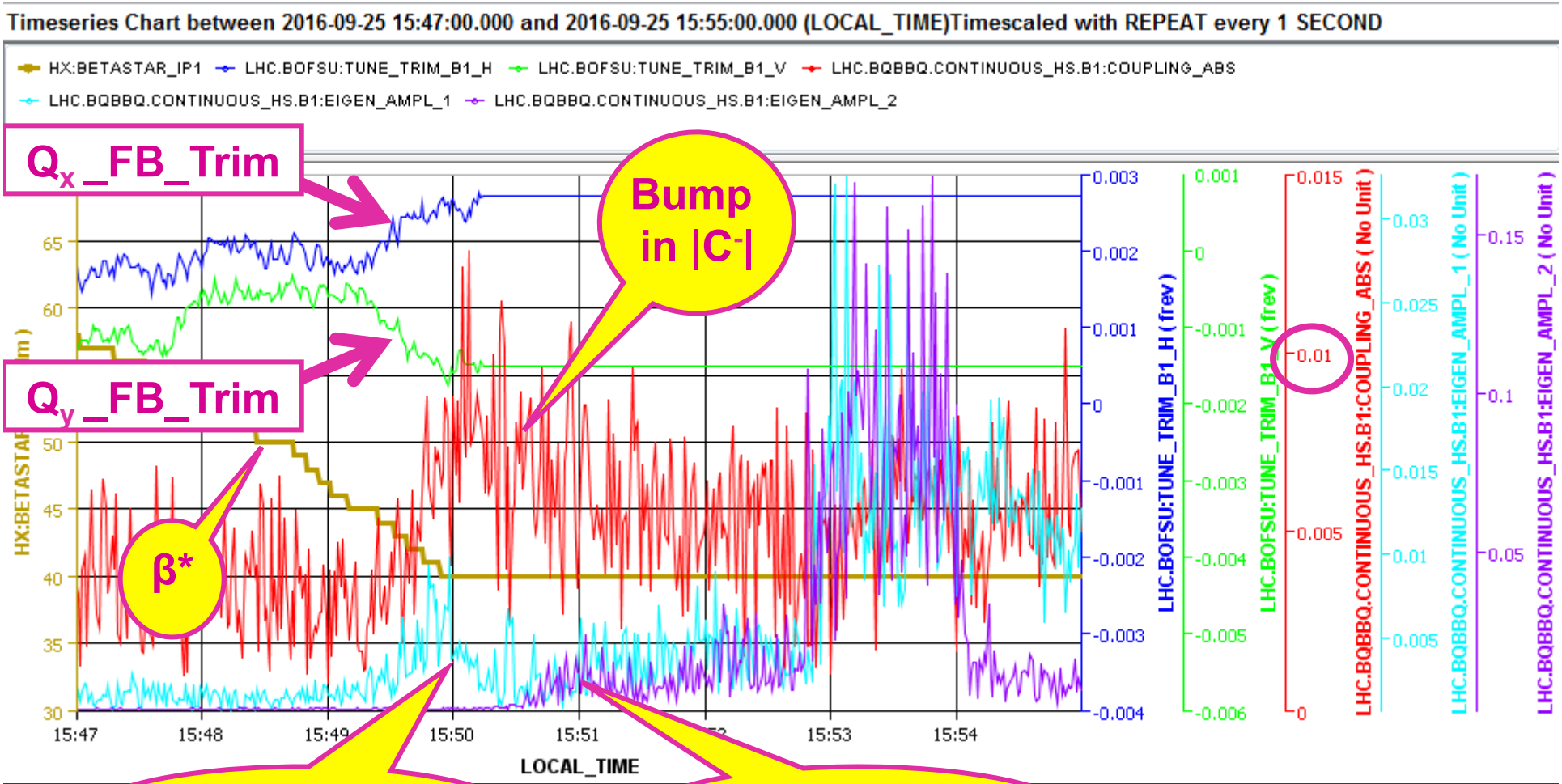

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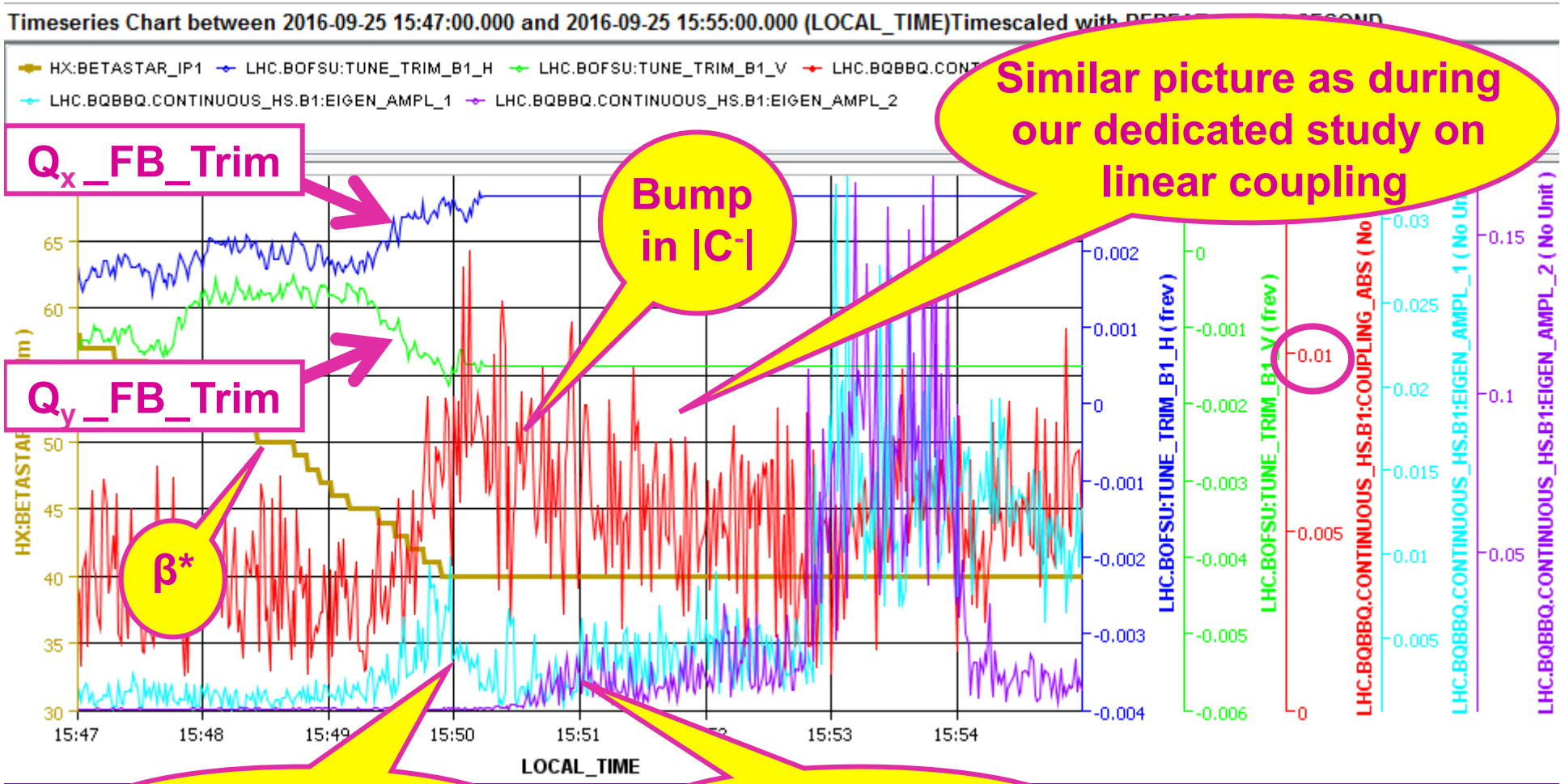

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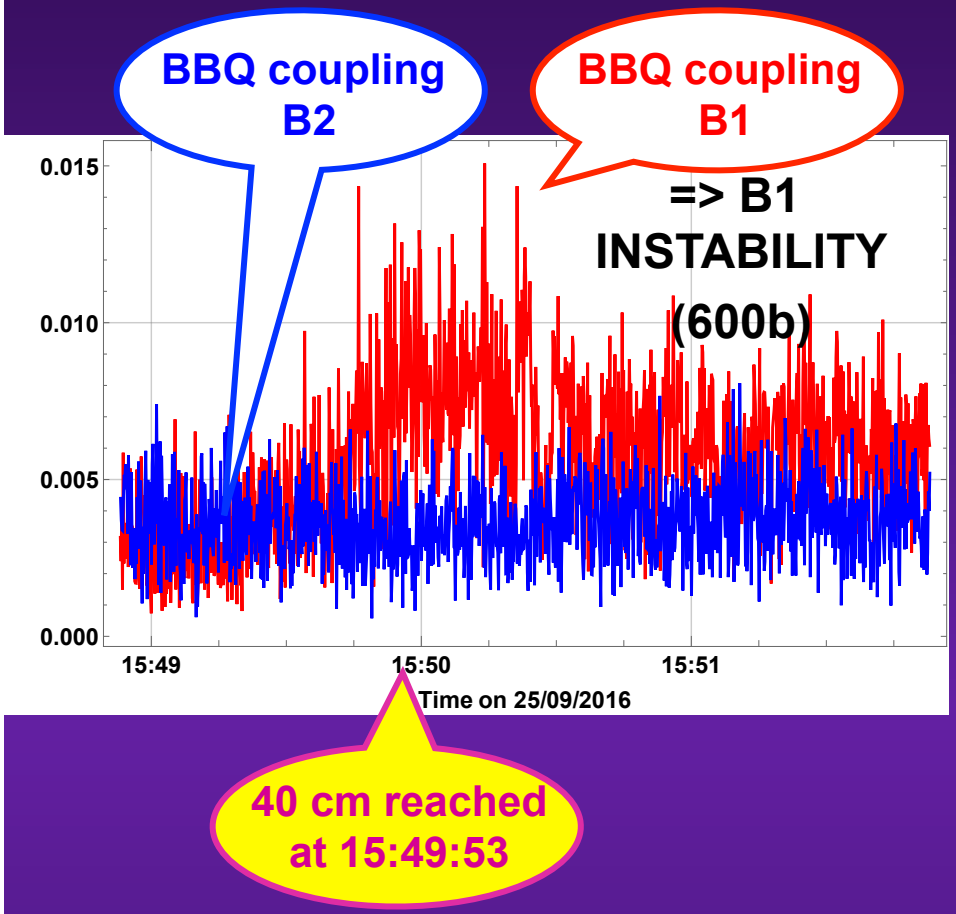
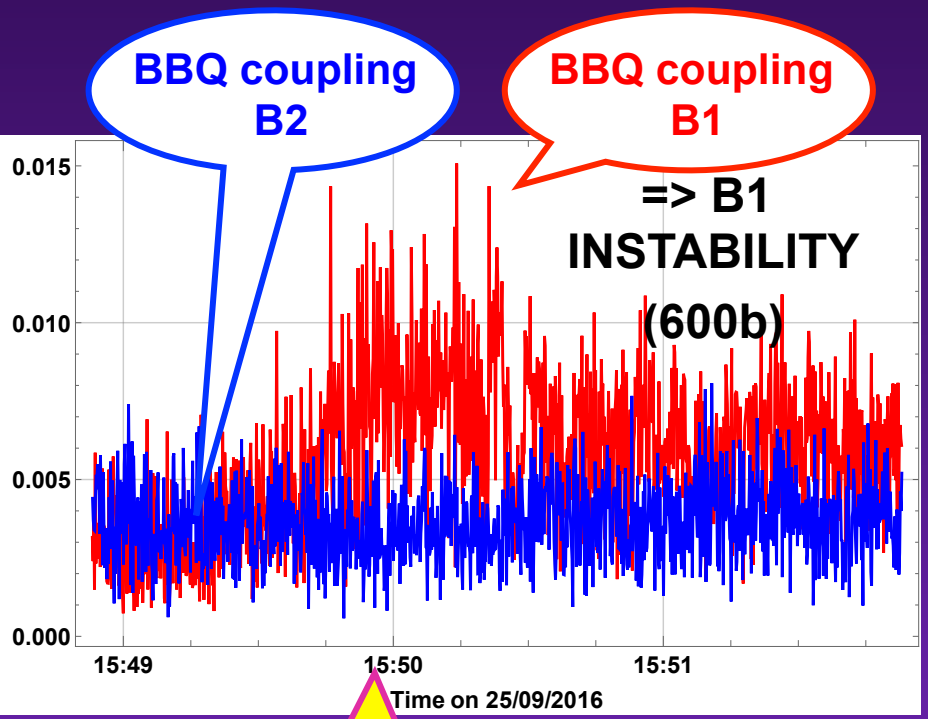
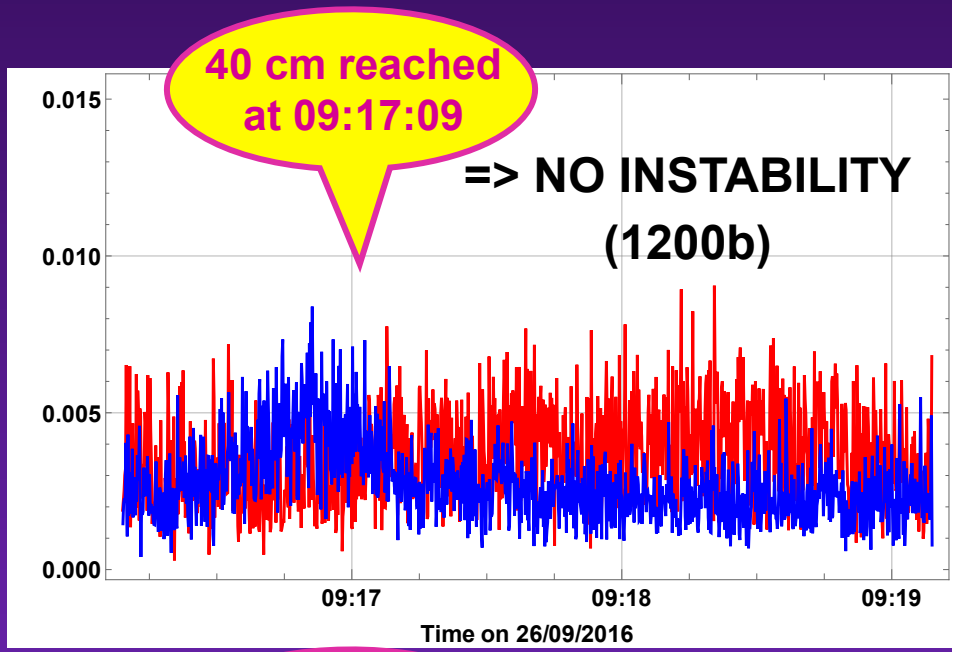
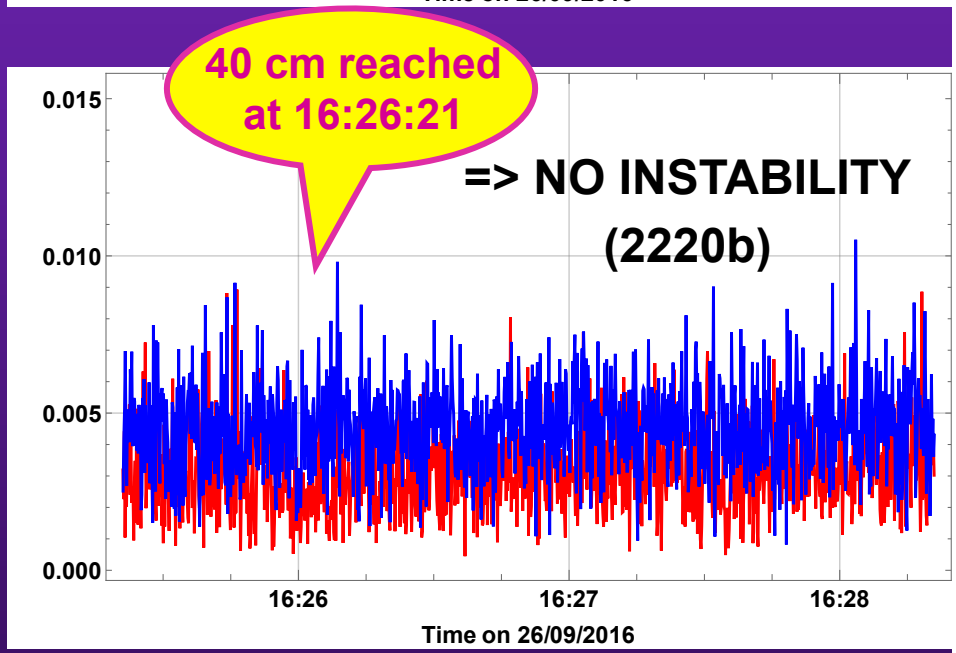

BBQ coupling B2
BBQ coupling B1
=> B1 INSTABILITY (600b)
0.015
0.010
0.005
0.000
15:49
15:50
15:51
Time on 25/09/2016
40 cm reached at 15:49:53

Linear coupling was then corrected







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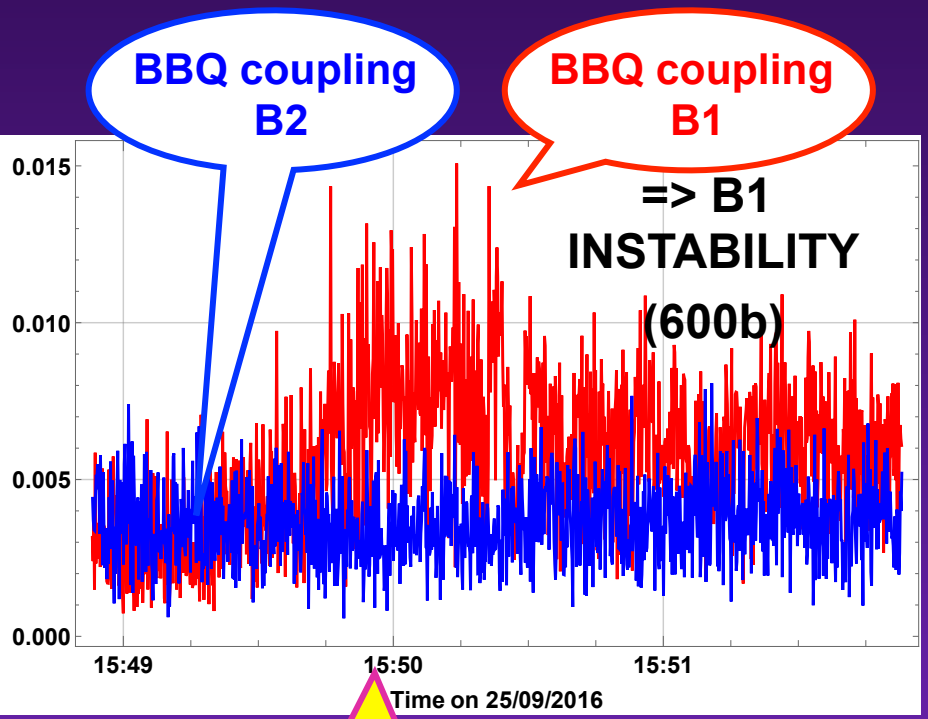

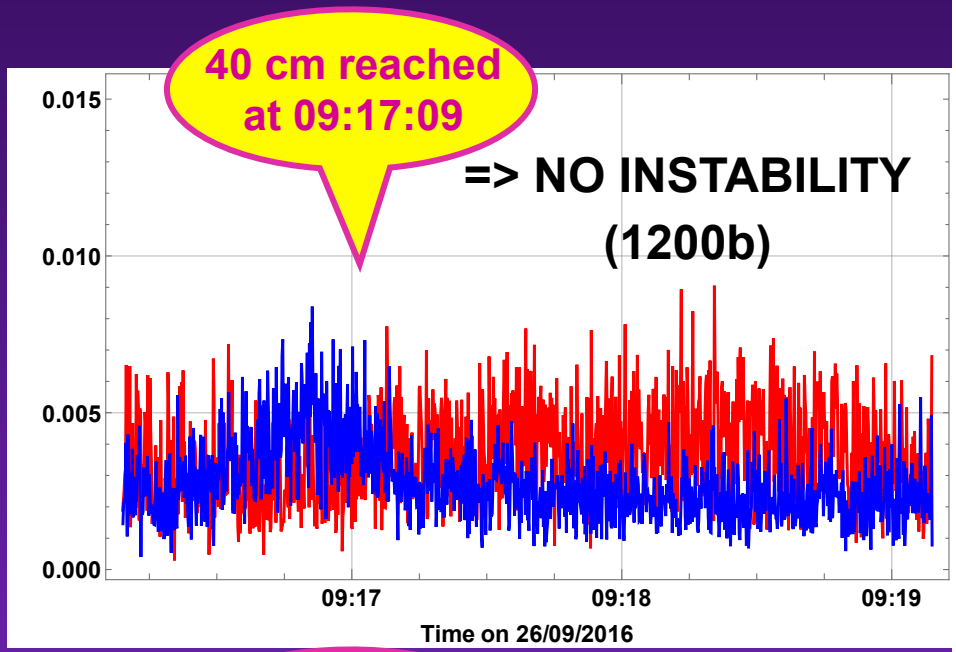

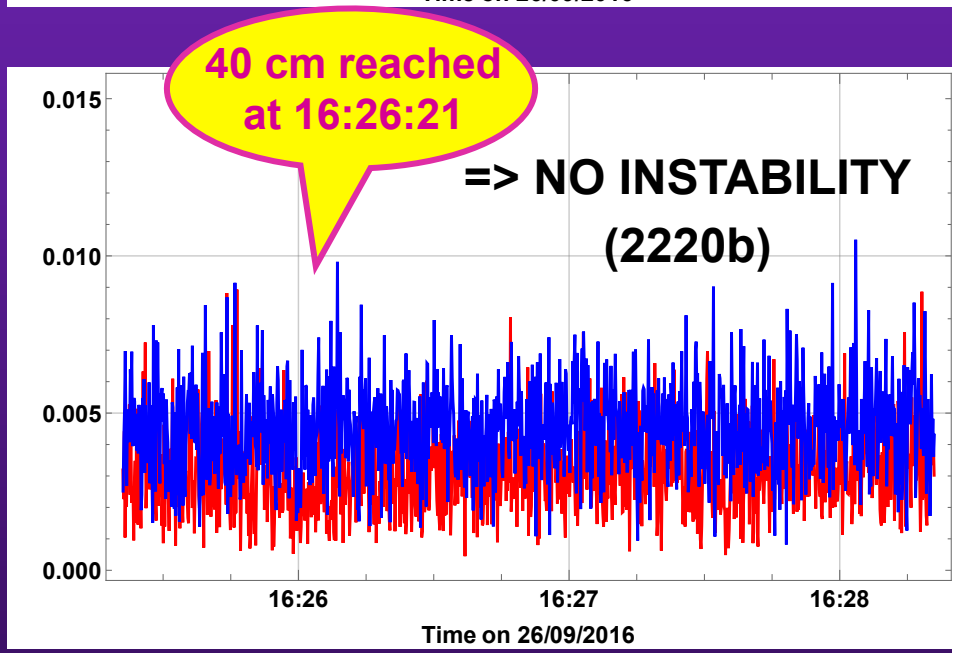

- Warning for BBQ coupling => Measurement from OMC team with AC dipole + pilot:
  - ~ 0.005 before correction
  - < 0.001 after correction

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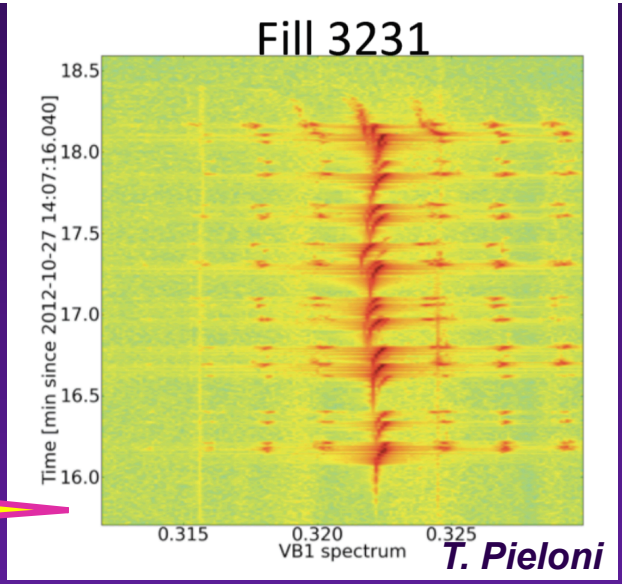

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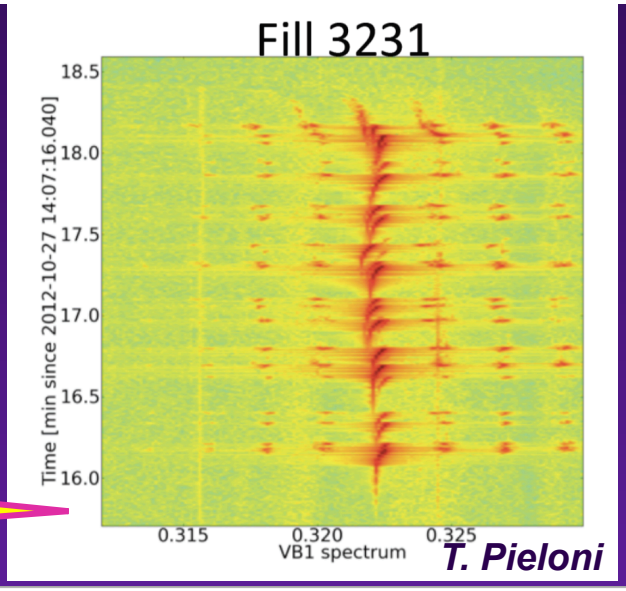
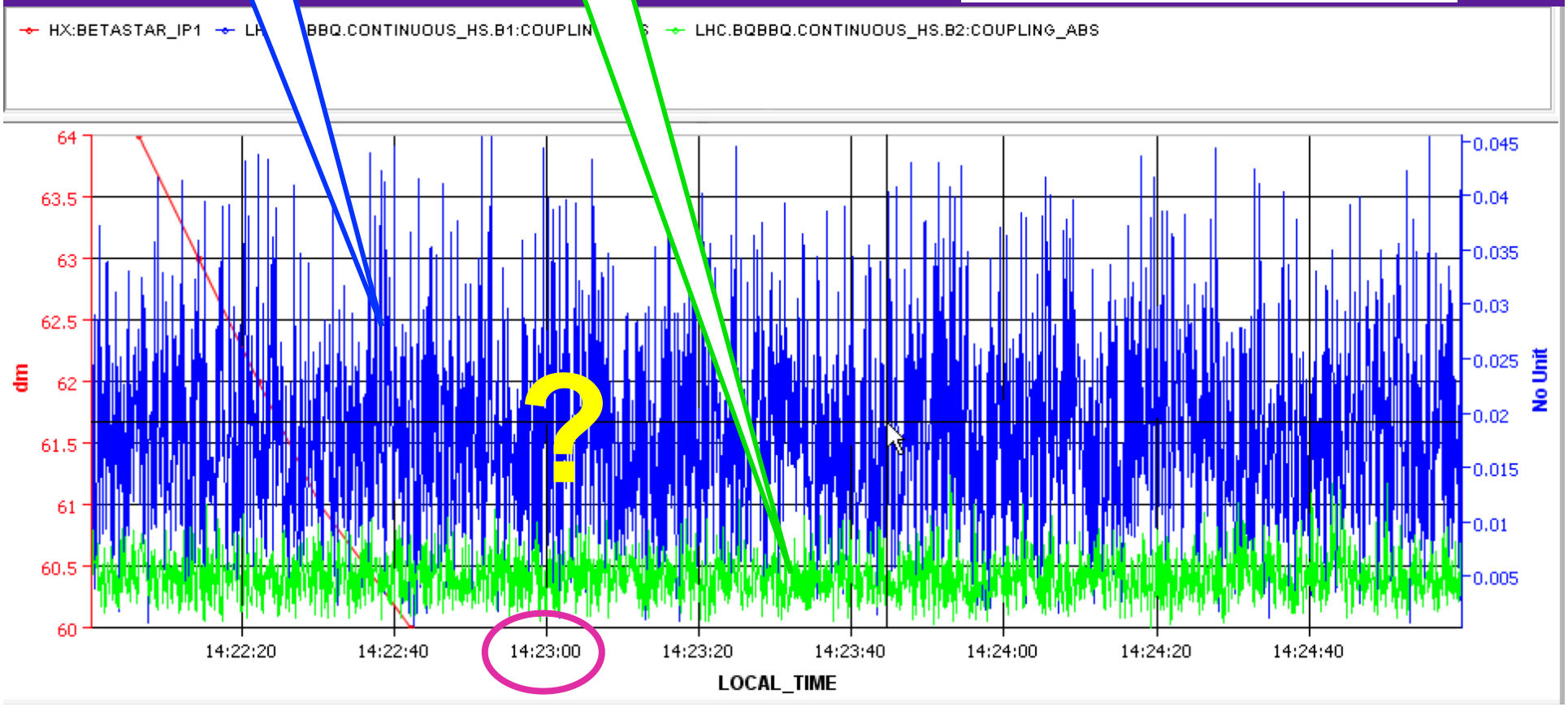


BBQ coupling B1

BBQ coupling B2

~ 14:23



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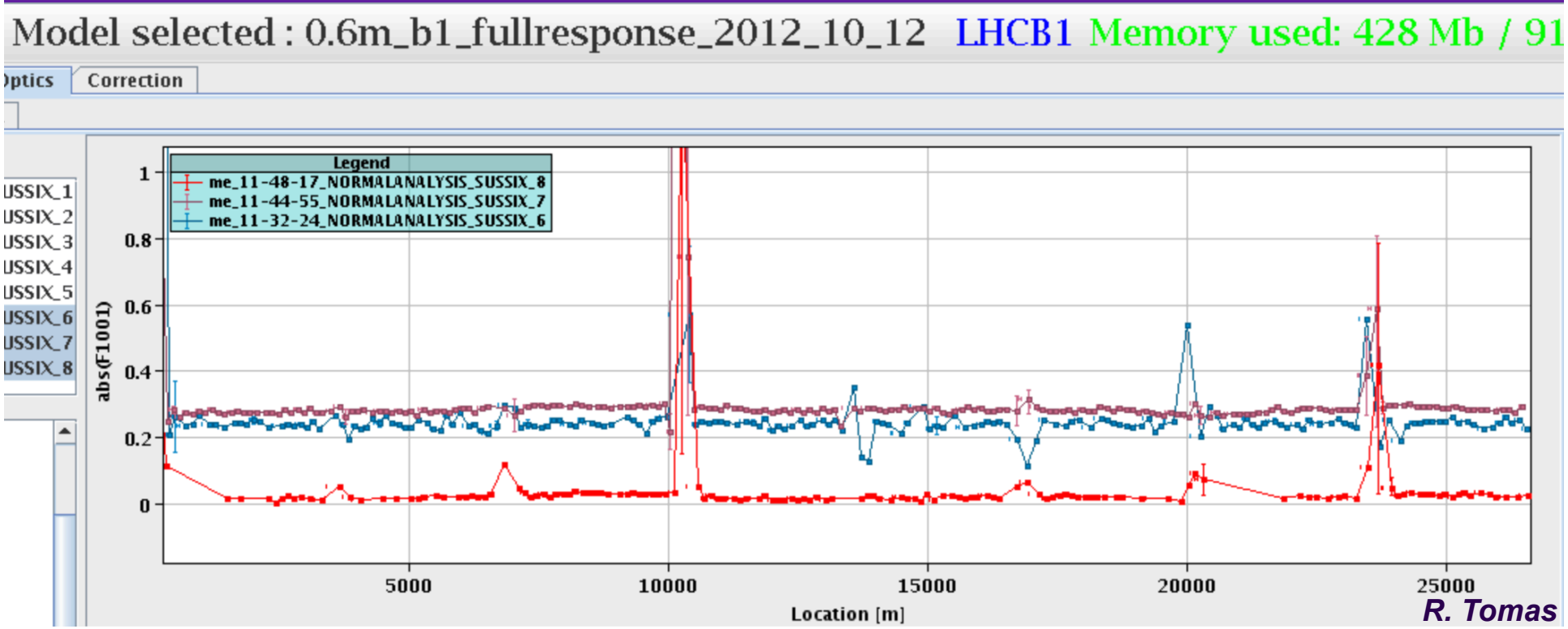

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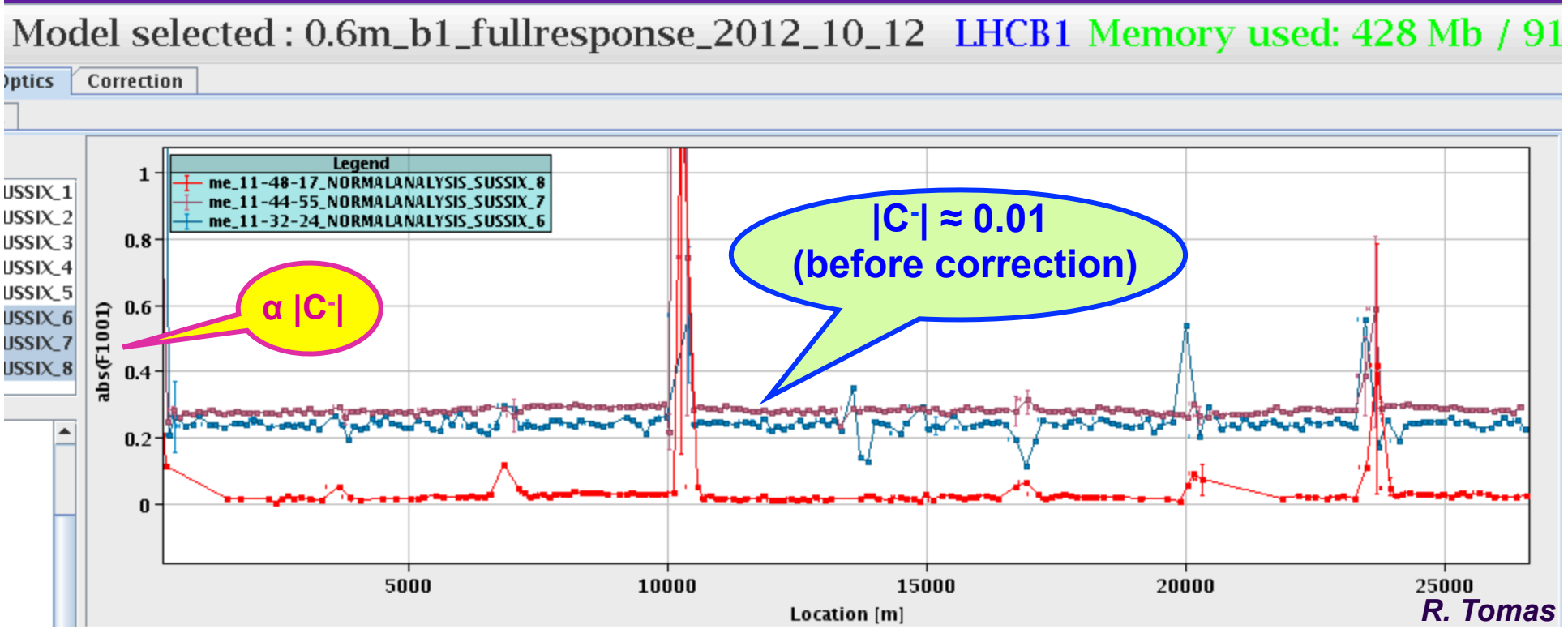

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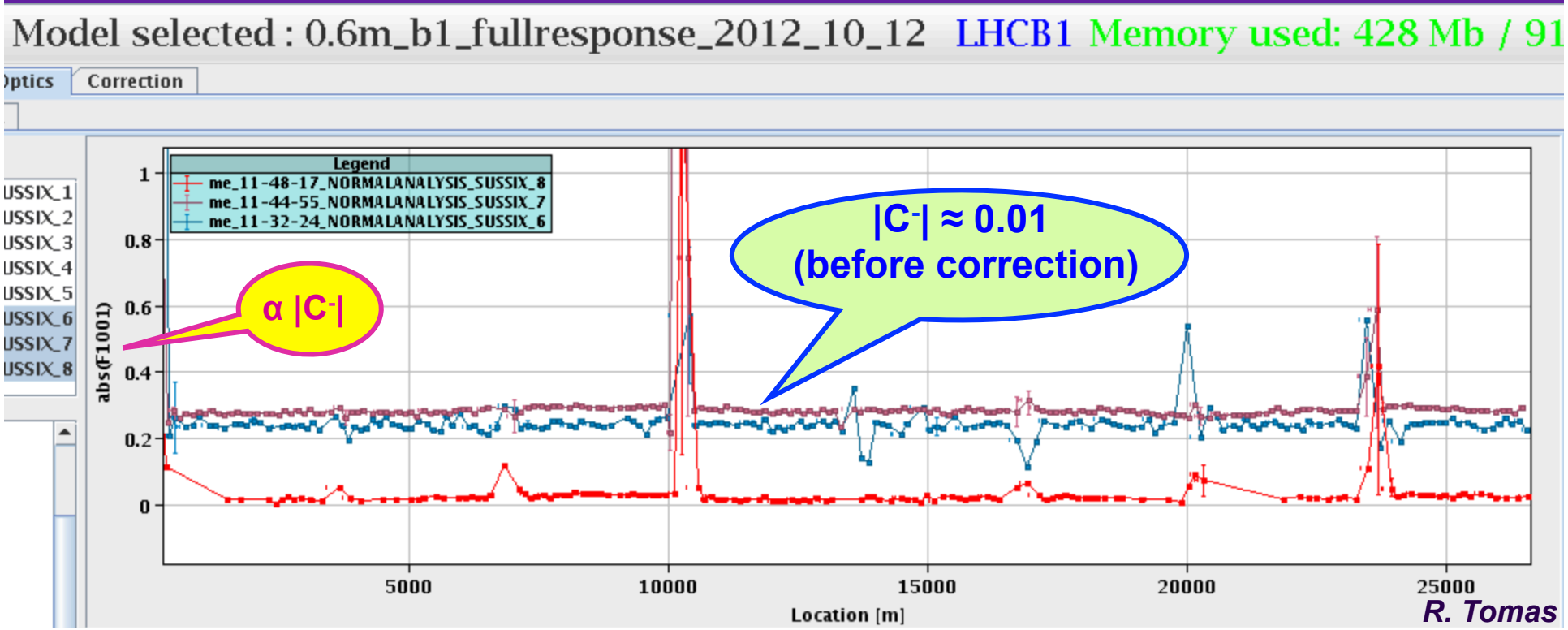

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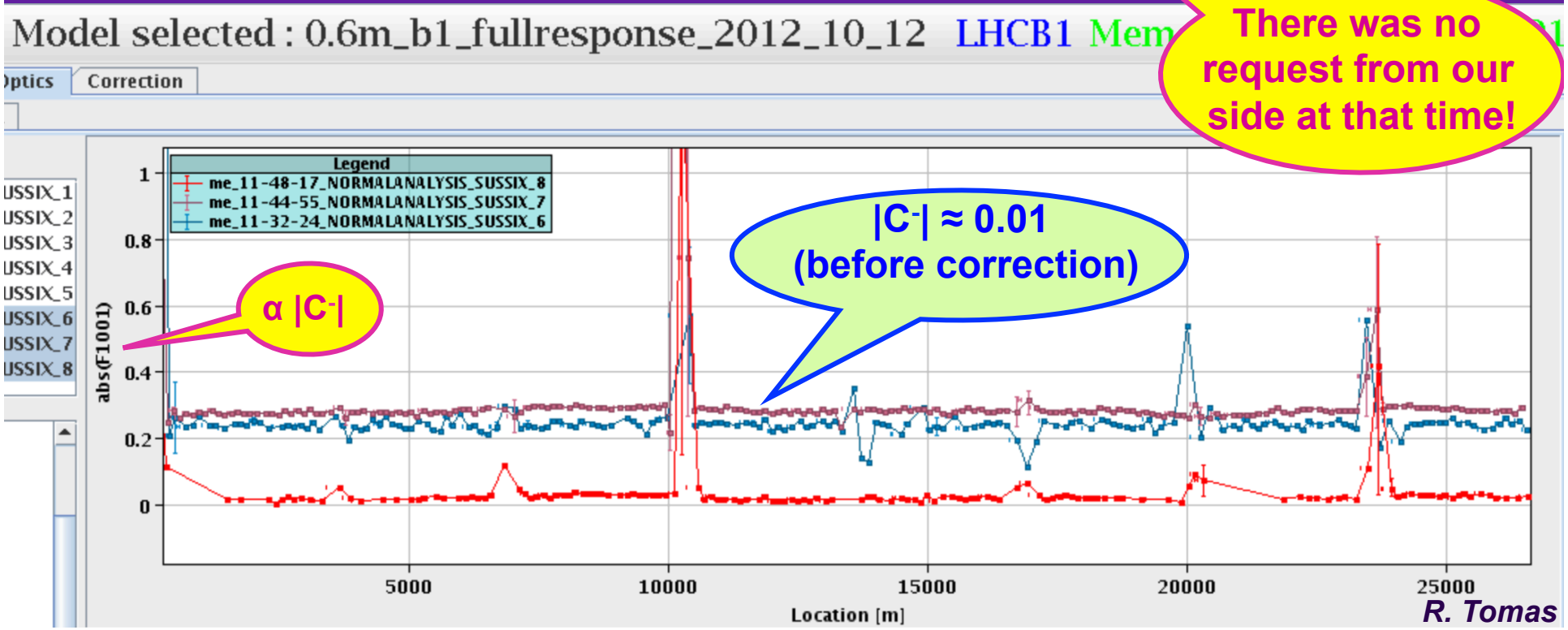

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- **Others? => Ongoing**

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Ongoing huge simulation work with very promising results => To be discussed in the future

RECOMMENDATIONS

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  - Same thing then to be done i) Injection, ii) Flat top and iii) Ramp