Application of Vlasov method to instabilities driven by e-cloud in the SPS dipoles

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e-cloud meeting
4 December 2020

Introduction

A linearized method for studying instabilities driven by e-cloud was recently developed, where the eigenmodes of the bunch motion are identified as a function of the strength of the e-cloud

- *G. Iadarola et al., [Phys. Rev. Accel. Beams 23, 081002, 2020]*

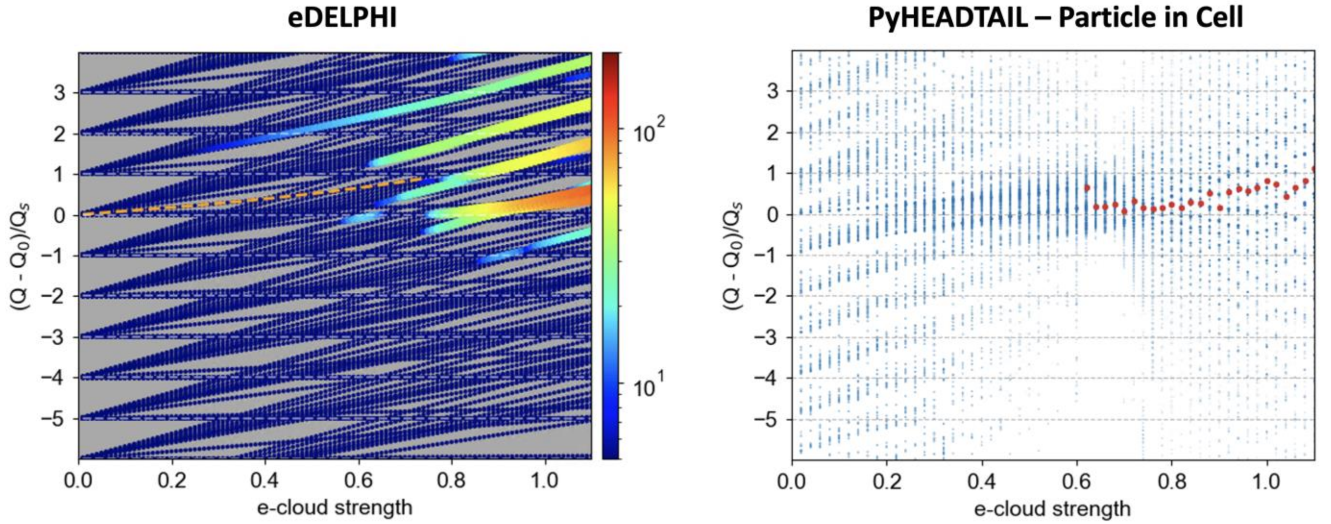
- The method has been applied to the case of instabilities driven by e-cloud in the LHC dipoles and quadrupoles at injection energy
  - *G. Iadarola et al., [e-cloud meeting, Oct 2020]*

Here we apply the method to study the transverse instabilities driven by e-cloud in the SPS dipoles at injection

- For the e-cloud we consider the following parameters
  - The e-cloud is characterized for a density of 2×10^{12} e^-/m^3 (before bunch arrival)
  - The e-cloud strength is scanned in the range 0.1-2 to study the effect on stability

Introduction

- For the studied LHC cases, results using the linearized model with the Vlasov method (eDELPHI) have been compared to macroparticle simulations
  - Good agreement was found both with macroparticle simulations using the linearized model as well as full particle-in-cell simulations



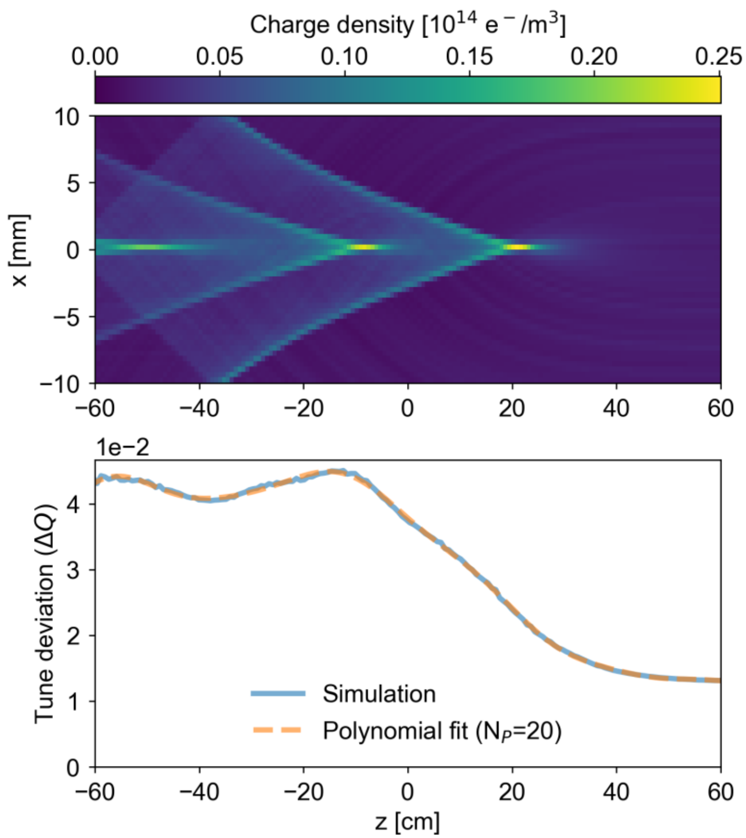
G. Iadarola et al

- Here we use the Vlasov method exclusively to study the transverse stability in the vertical plane in the SPS dipoles at injection, considering the effects of
  - The bunch intensity: 1 x 10^{11} vs. 2 x 10^{11} protons per bunch
  - The synchrotron tune: scanning Q_s between 0.002 and 0.02, in steps of 0.002

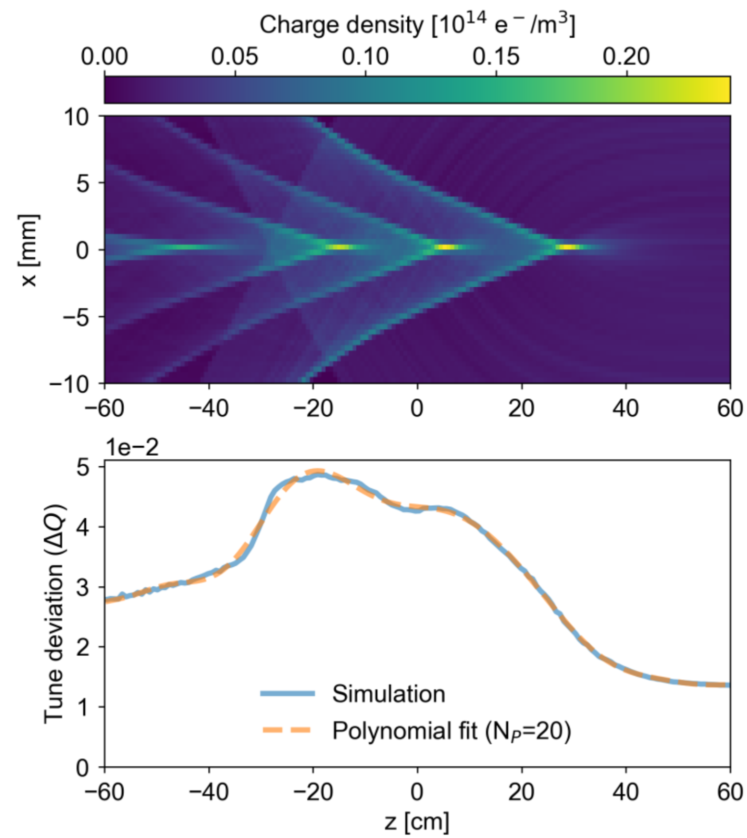
Detuning forces from the e-cloud

The dependence of the detuning forces on the z coordinate is described by a polynomial

$N_b = 1.0 \times 10^{11}$



$N_b = 2.0 \times 10^{11}$



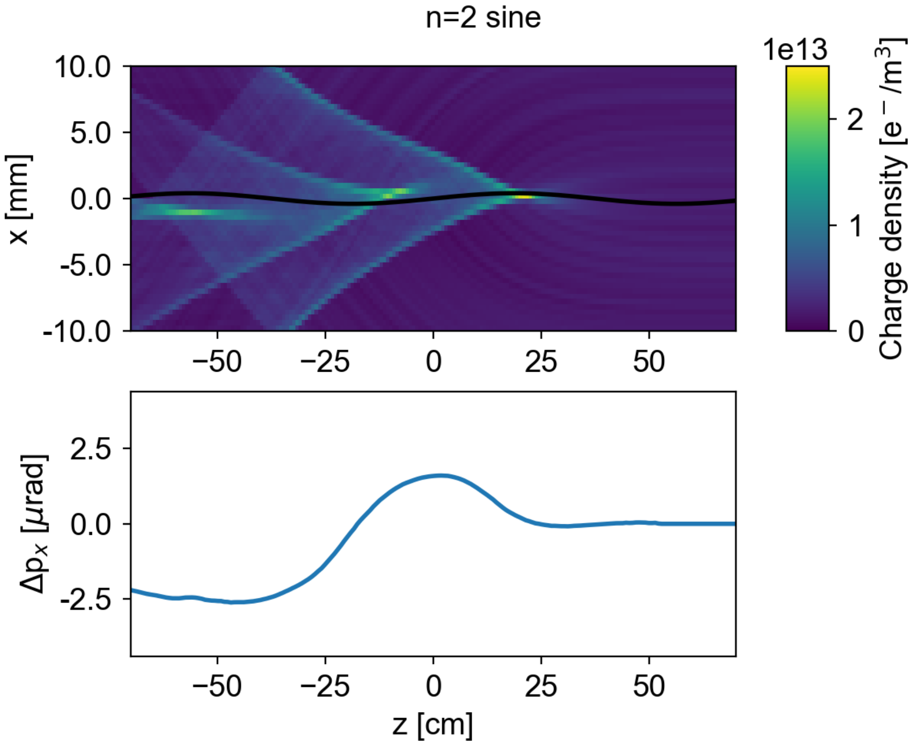
Characterization of the dipolar forces

The dipolar forces are characterized by means of single-pass PyECLOUD-PyHEADTAIL simulations with a set of pre-distorted bunches

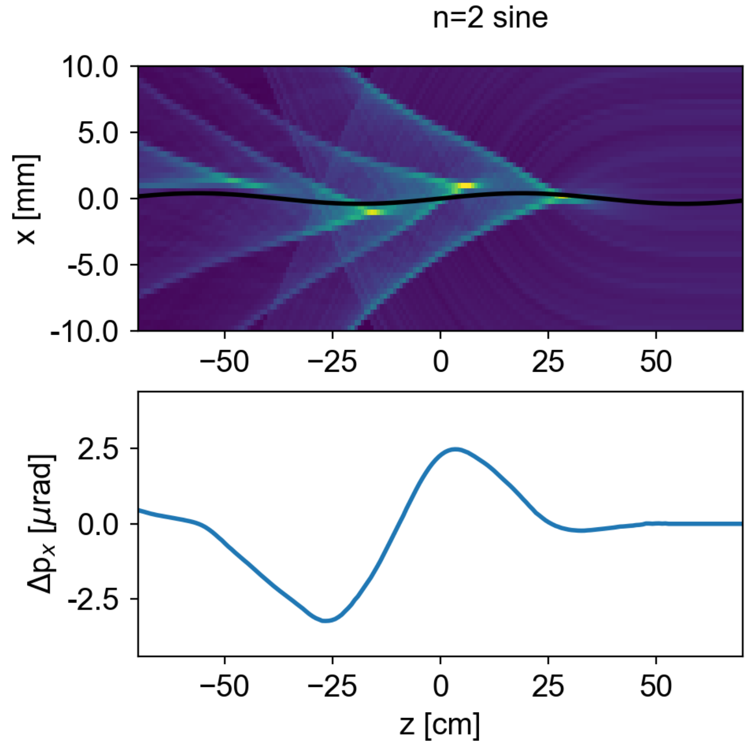
Test functions:

$$h_n(z) = \begin{cases} \mathcal{A}_n \cos\left(2\pi f_n^z z\right), & \text{if } n \text{ is even} \\ \mathcal{A}_n \sin\left(2\pi f_n^z z\right), & \text{if } n \text{ is odd} \end{cases} \qquad f_n^z = \begin{cases} \frac{n}{2}\frac{1}{L_{\text{bkt}}} & \text{if } n \text{ is even} \\ \frac{n+1}{2}\frac{1}{L_{\text{bkt}}} & \text{if } n \text{ is odd} \end{cases}$$

N_b = 1.0 x 10^{11}



N_b = 2.0 x 10^{11}

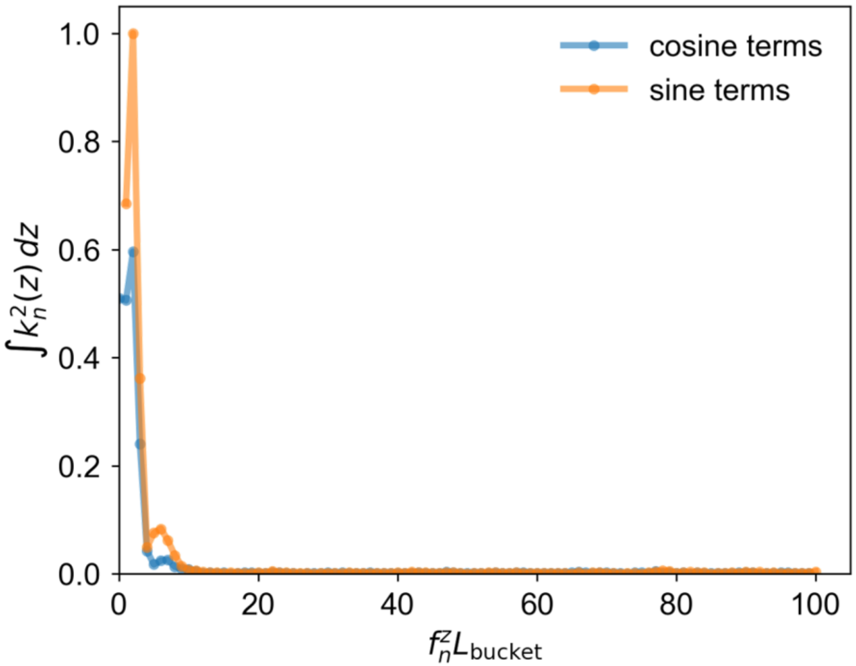


Characterization of the dipolar forces

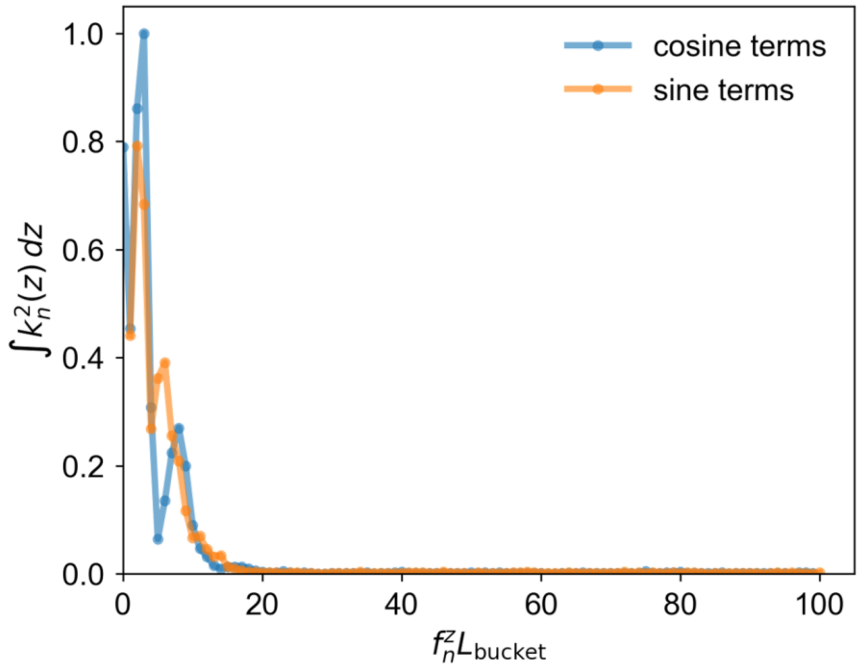
The dipolar forces are characterized by means of single-pass PyECLOUD-PyHEADTAIL simulations with a set of pre-distorted bunches

- For $N_b = 1 \times 10^{11}$, the response of the e-cloud is visible for frequencies up to $10 \times f_{RF}$
- For $N_b = 2 \times 10^{11}$, the response of the e-cloud is visible for frequencies up to $20 \times f_{RF}$

N_b = 1.0 x 10^{11}



N_b = 2.0 x 10^{11}



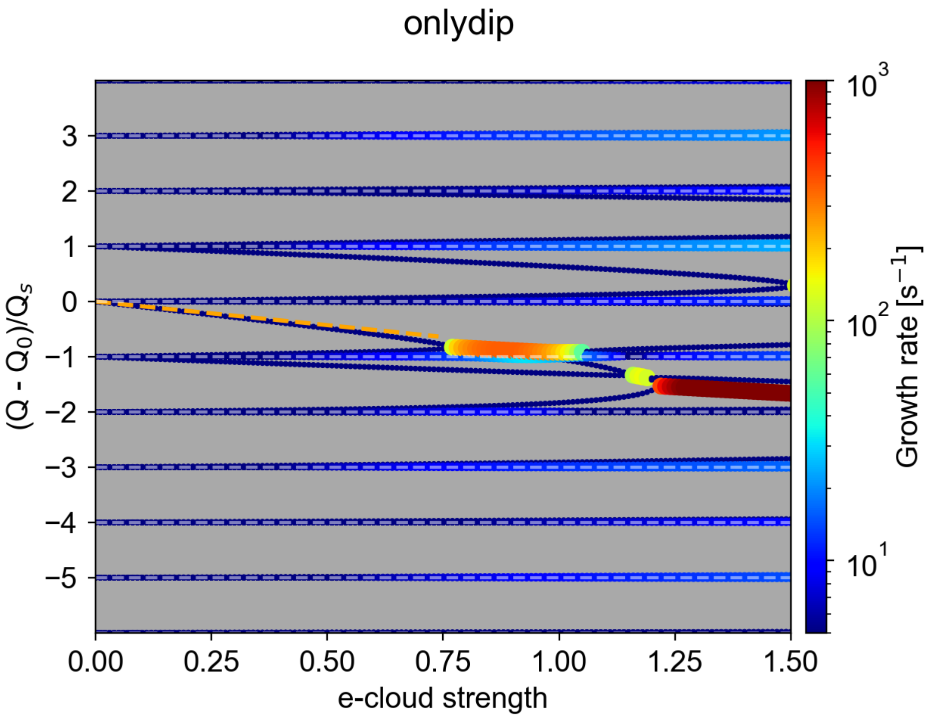
Each picture is normalized to its maximum

Instability growth rates

Eigenmodes and growth rates have been determined **with dipolar forces alone**

- The instabilities appear to be triggered by mode coupling (TMCI)
- The instability threshold is slightly lower for **lower** bunch intensity

N_b = 1.0 x 10^{11}



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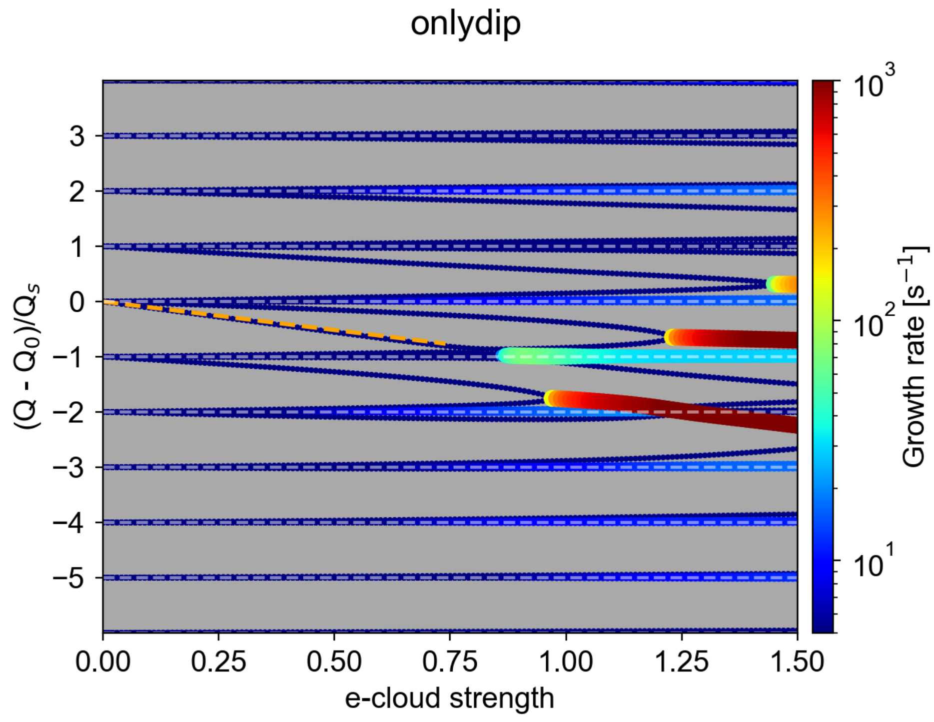
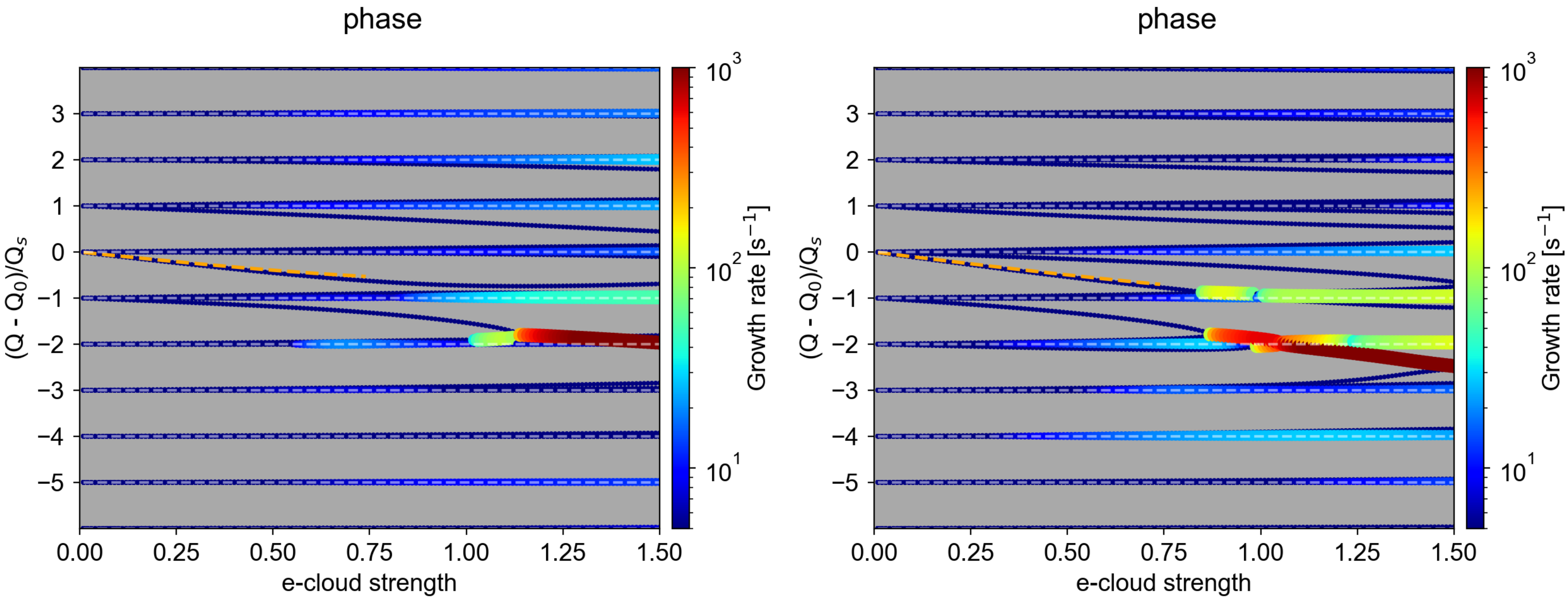


Instability growth rates

Eigenmodes and growth rates have been determined **with dipolar forces + the phase shift from quadrupolar forces**

- The instabilities appear to be triggered by mode coupling (TMCI)
- The instability threshold is slightly lower for **higher** bunch intensity

N_b = 1.0 x 10^{11} **N_b = 2.0 x 10^{11}**

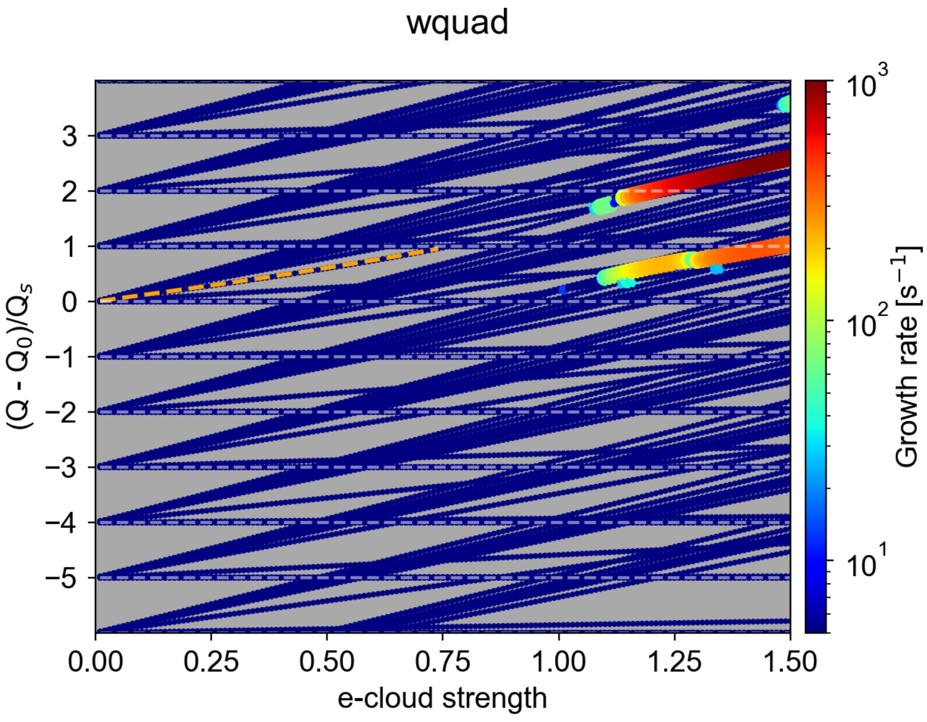


Instability growth rates

Eigenmodes and growth rates have been determined **with dipolar forces + the full effect of quadrupolar forces**

- The instabilities appear to be triggered by mode coupling (TMCI)
- The instability threshold is slightly lower for **higher** bunch intensity

N_b = 1.0 x 10^{11}



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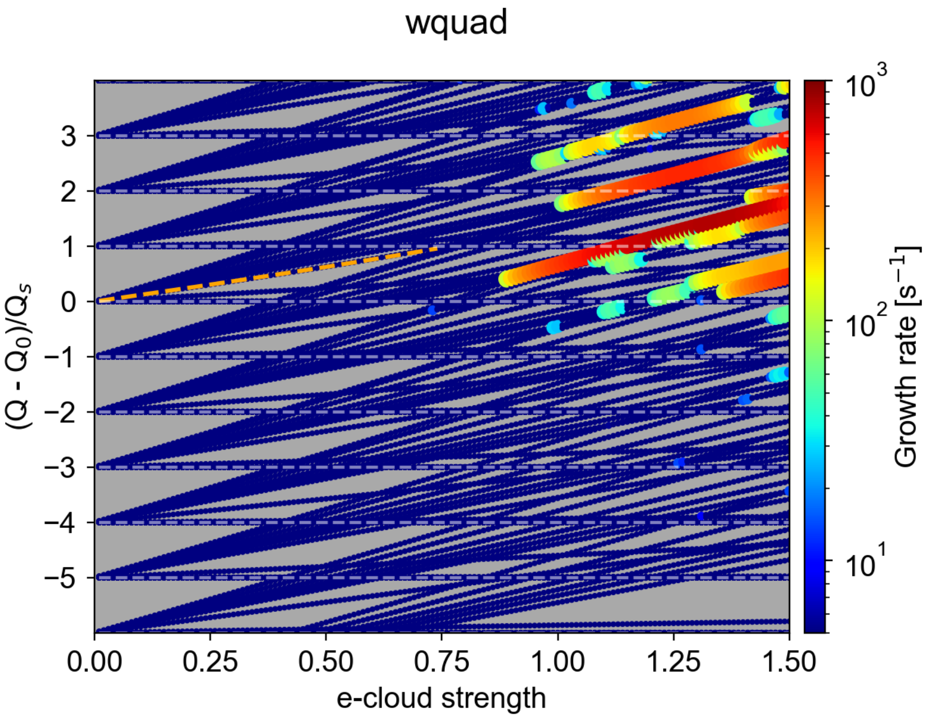
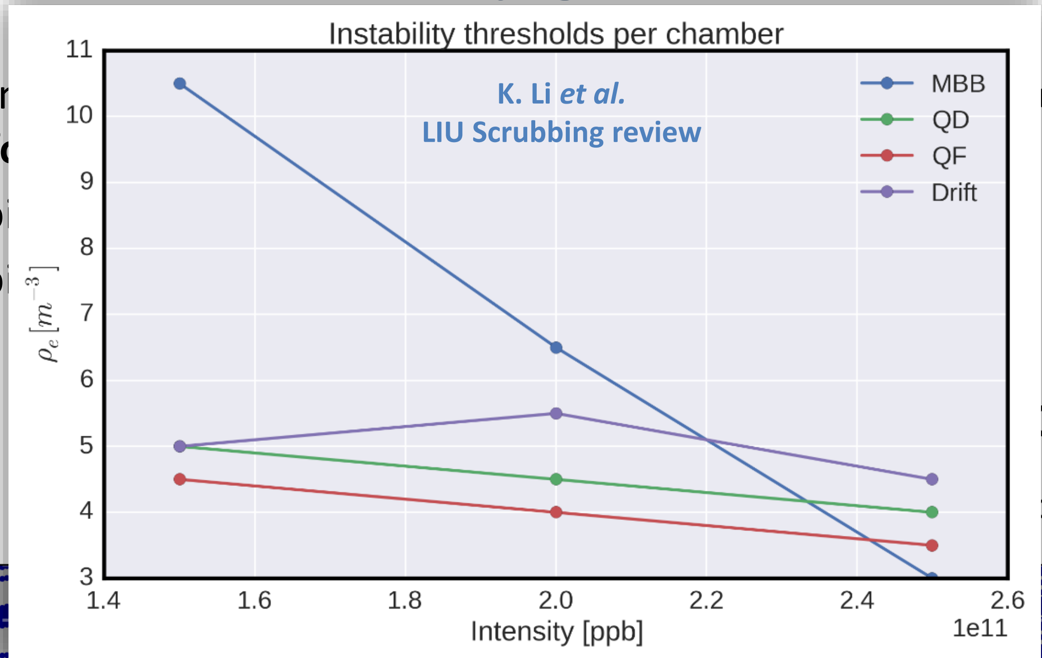


Instability growth rates

Eigenmodes ar… es + the full effect of **quadrupolar f…**

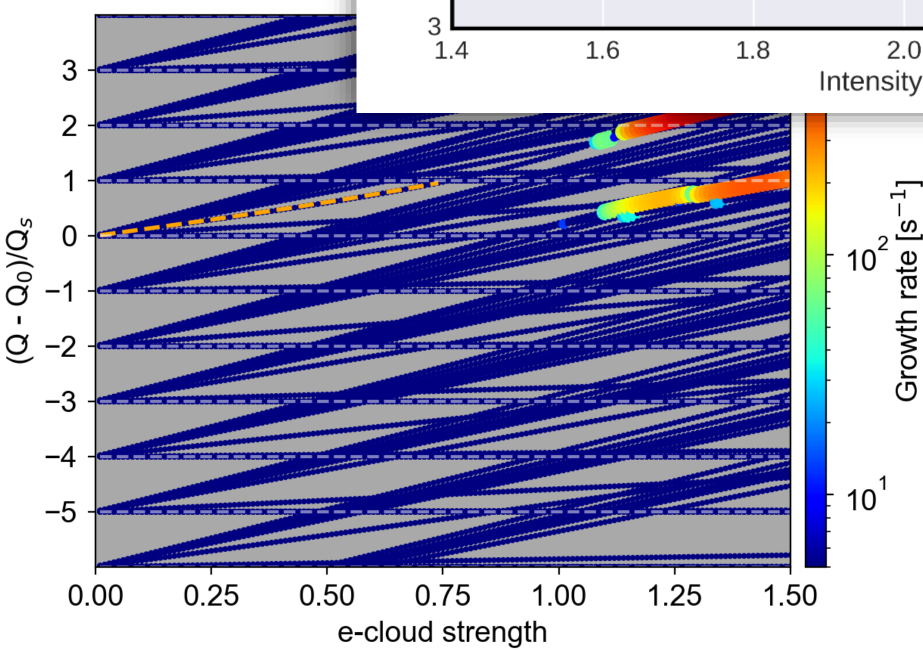
- The instabi…
- The instabi…

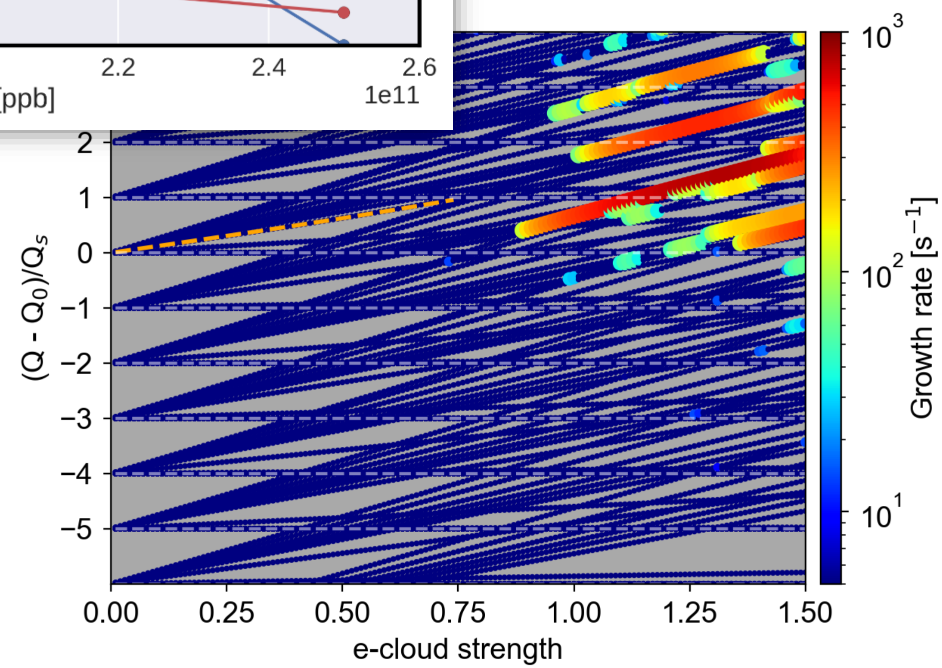


The scaling with intensity is qualitatively in agreement with results from past PyECLOUD-PyHEADTAIL studies using full PIC

N_b … **0 x 10**

… quad



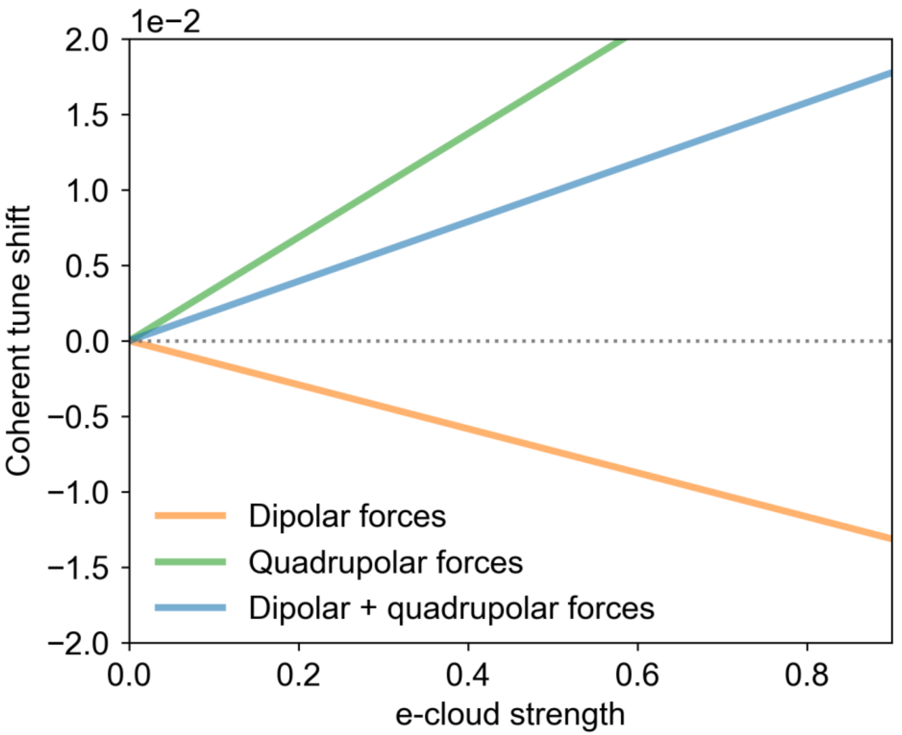


Coherent tune shift

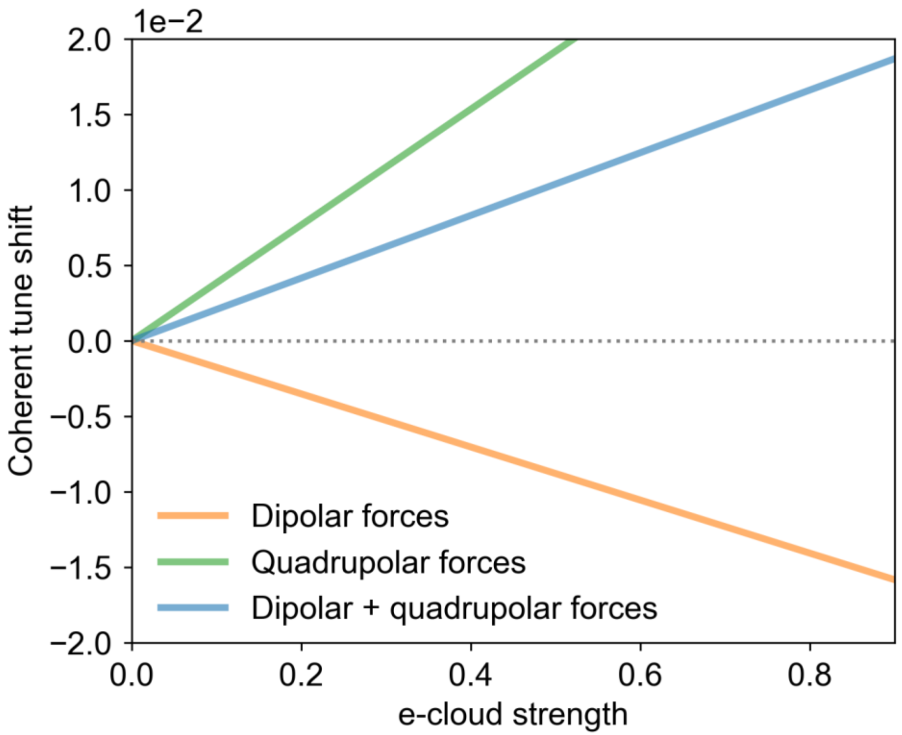
The coherent tune shift below the instability threshold can be estimated with the model

- A cancellation between the detuning from dipolar and quadrupolar forces occurs
- The tune shifts are very similar for the two bunch intensities

N_b = 1.0 x 10^{11}



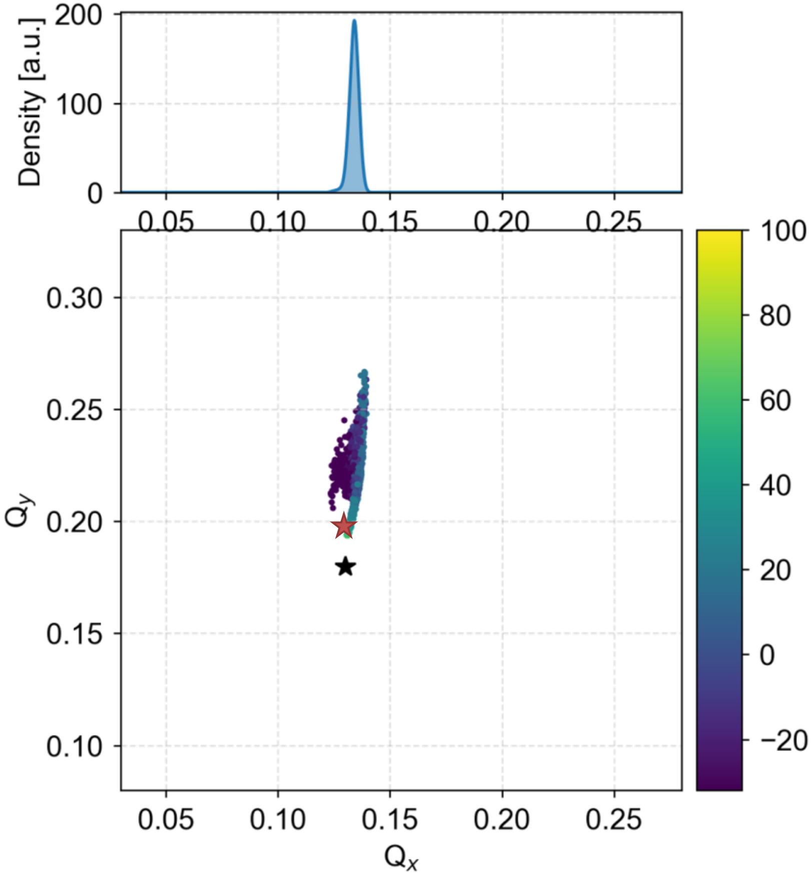
N_b = 2.0 x 10^{11}



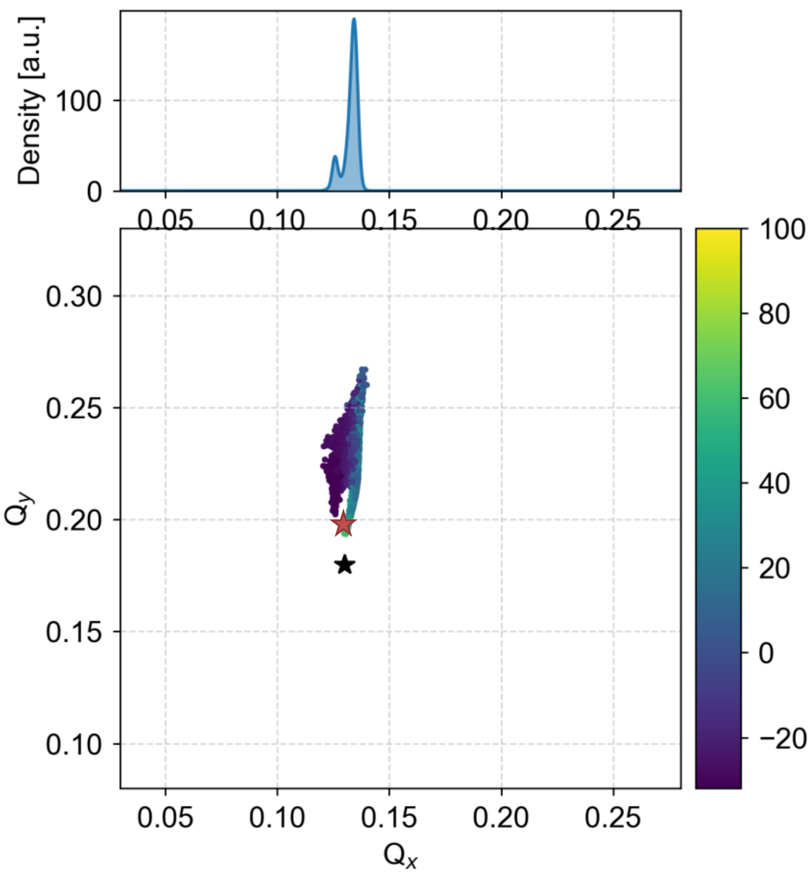
Tune shift vs tune spread

The coherent tune shift is much smaller than the incoherent tune spread

$N_b = 1.0 \times 10^{11}$



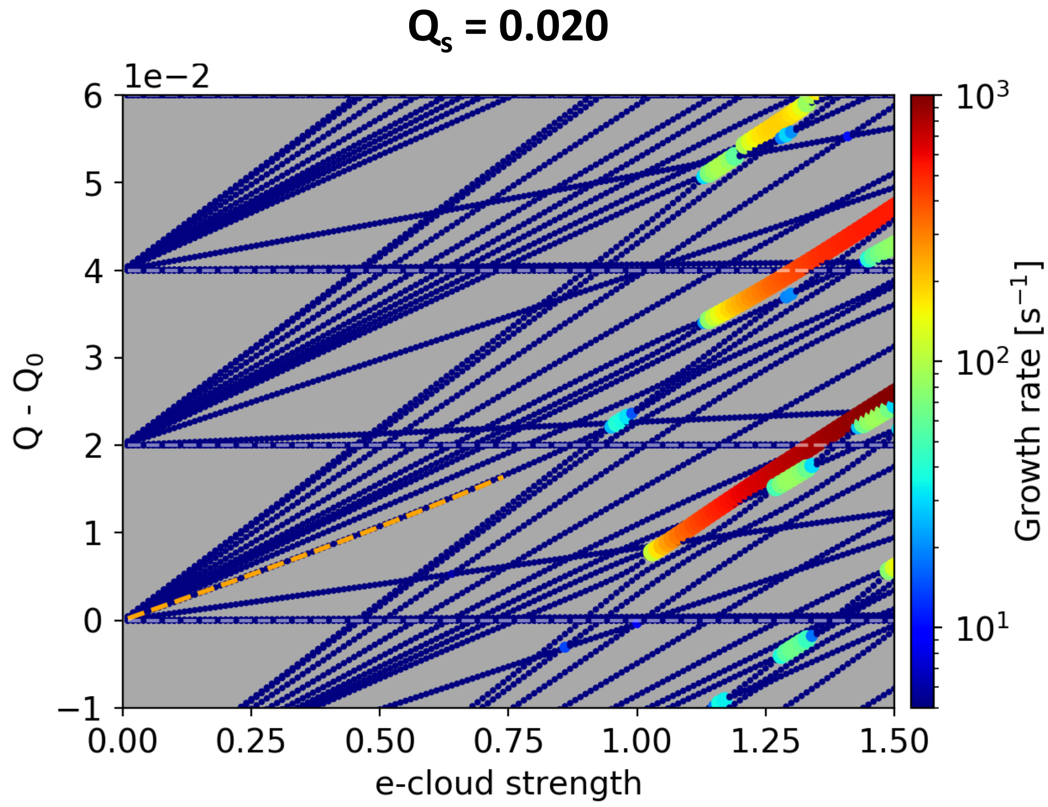
$N_b = 2.0 \times 10^{11}$



Effect of synchrotron tune

The effect of the synchrotron tune has been studied with bunch intensity $N_b = 2 \times 10^{11}$

Q20: Q_s = 0.017
Q26: Q_s = 0.0059



Effect of synchrotron tune

The effect of the synchrotron tune has been studied with bunch intensity $N_b = 2 \times 10^{11}$

- When Q_s decreases the synchrotron sidebands move closer together

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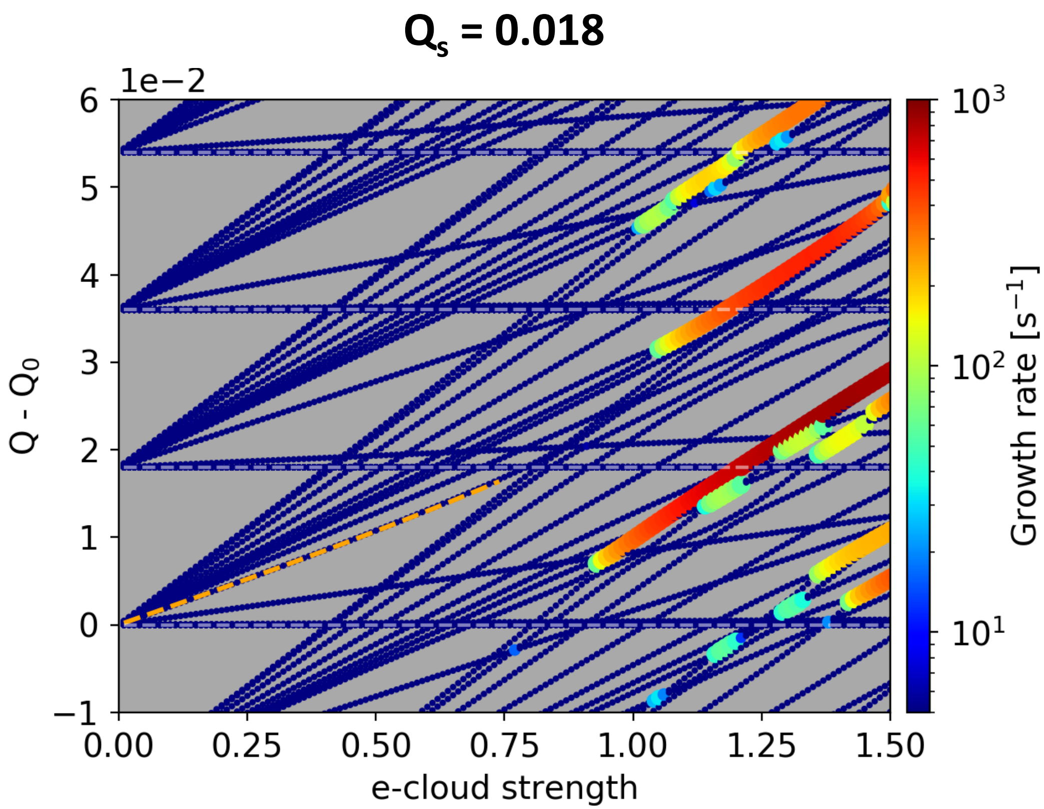
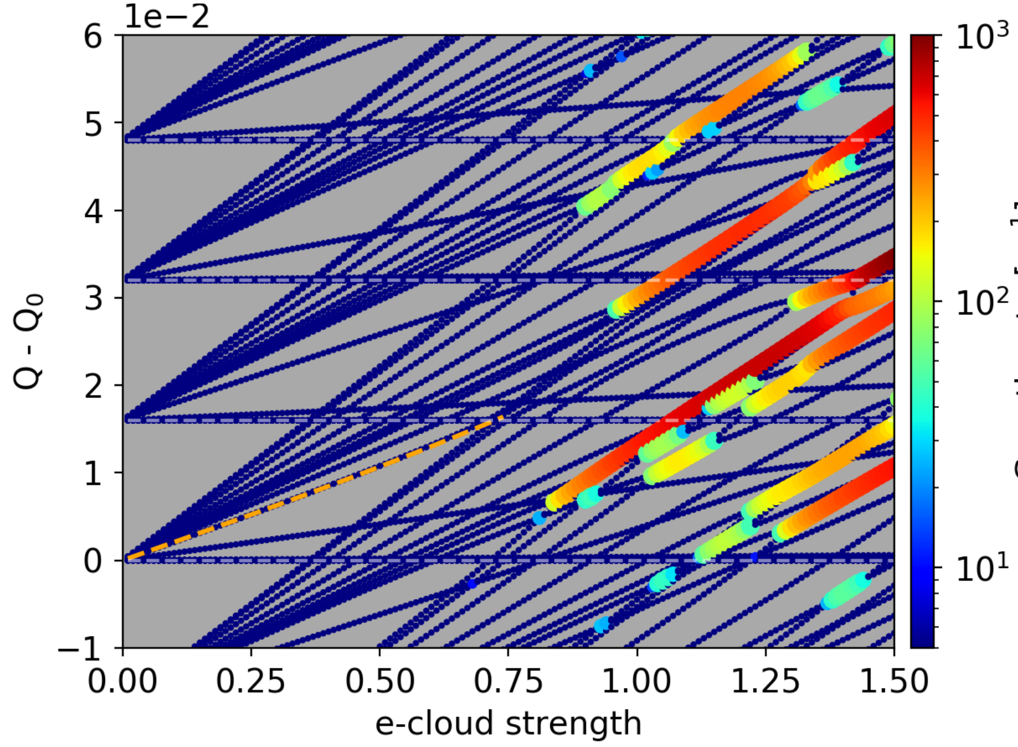


Effect of synchrotron tune

The effect of the synchrotron tune has been studied with bunch intensity $N_b = 2 \times 10^{11}$

- When Q_s decreases the synchrotron sidebands move closer together

Q_s = 0.016



Q20: Q_s = 0.017
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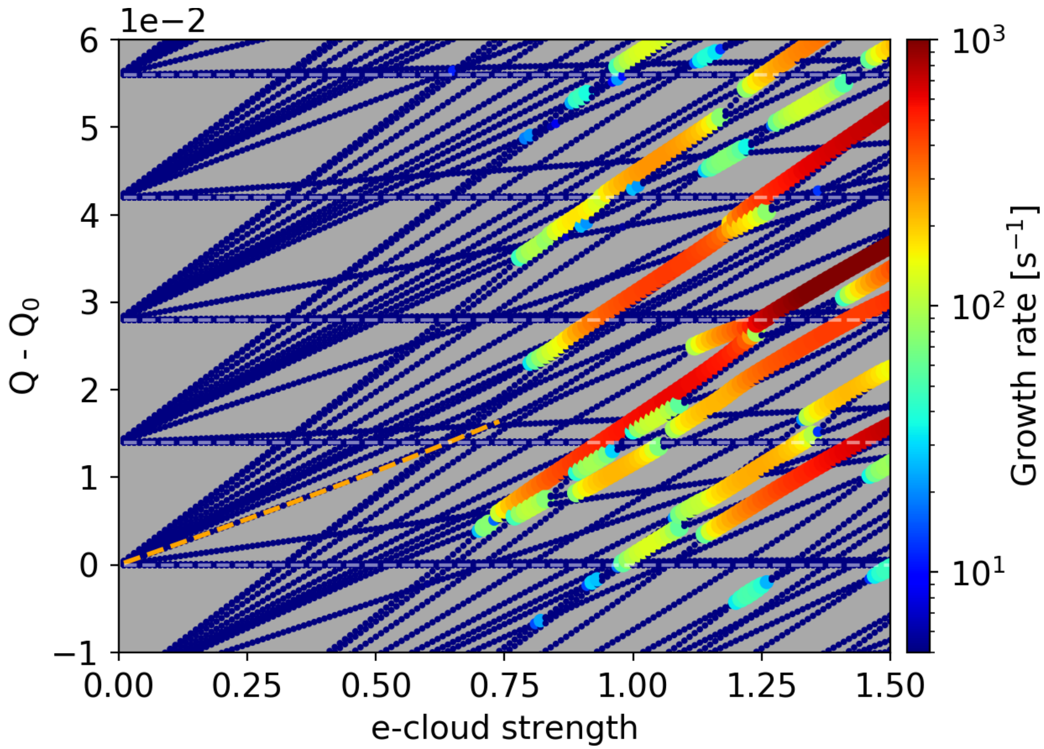
Effect of synchrotron tune

The effect of the synchrotron tune has been studied with bunch intensity $N_b = 2 \times 10^{11}$

- When Q_s decreases the synchrotron sidebands move closer together
  → A smaller e-cloud strength is sufficient to trigger instabilities

Q_s = 0.014



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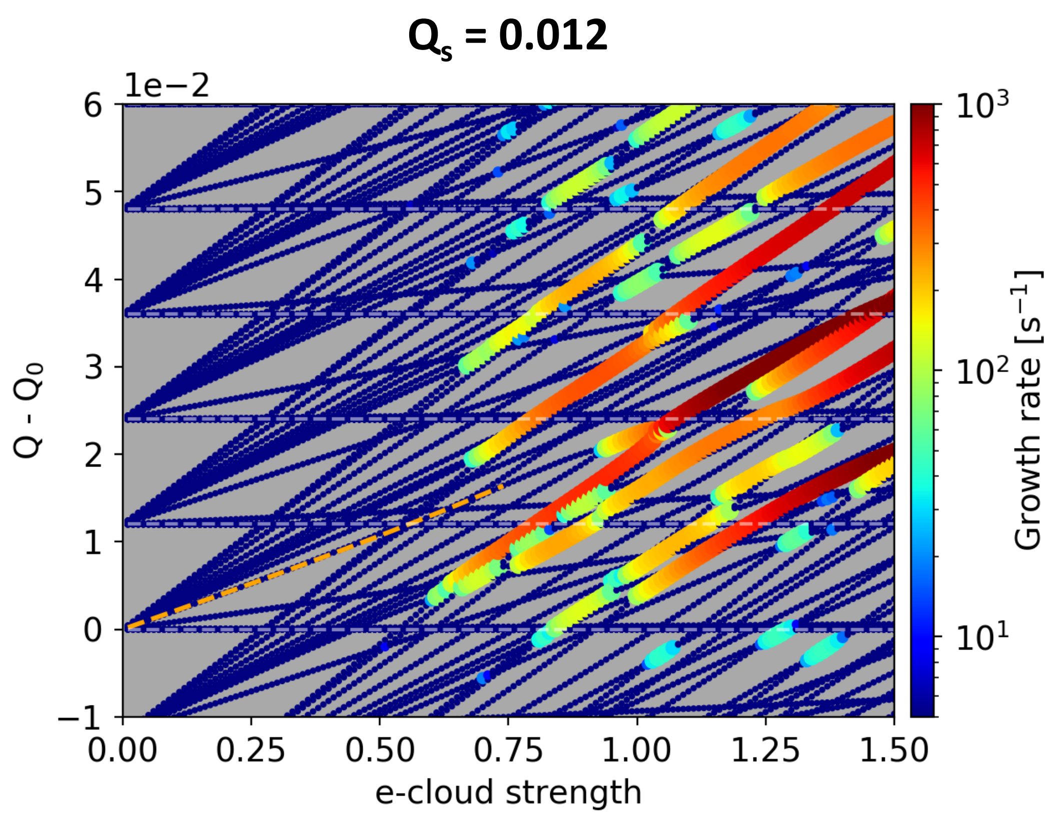

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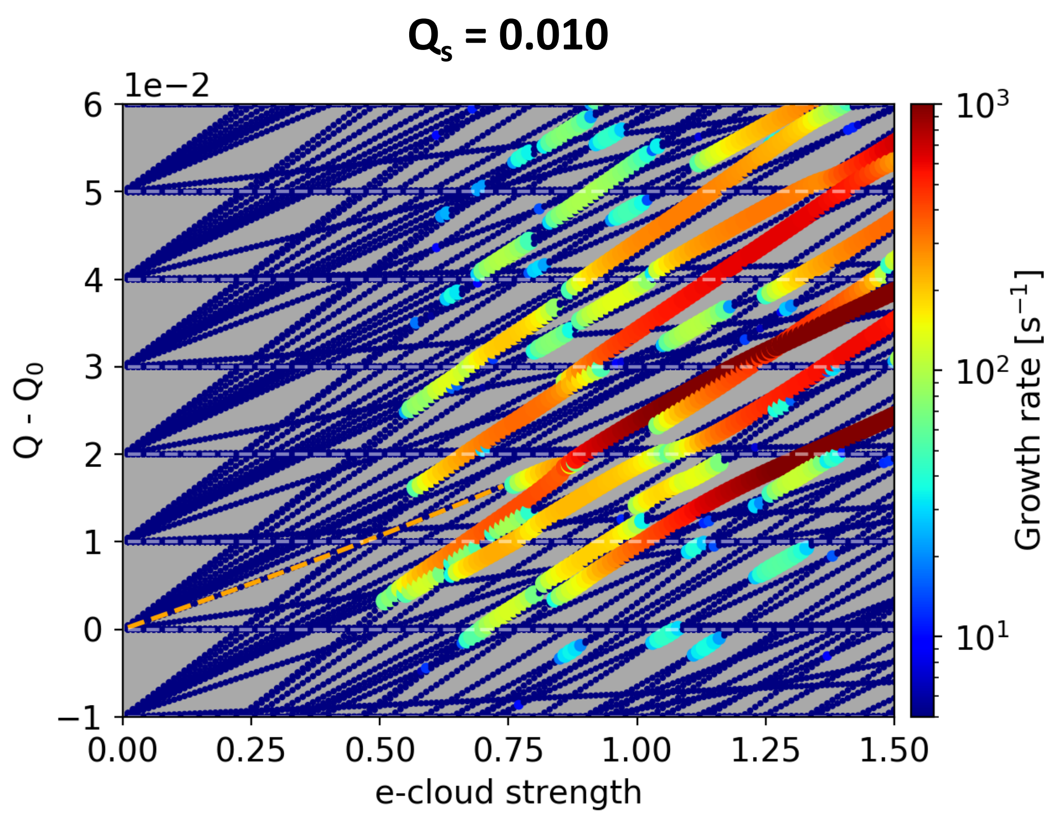

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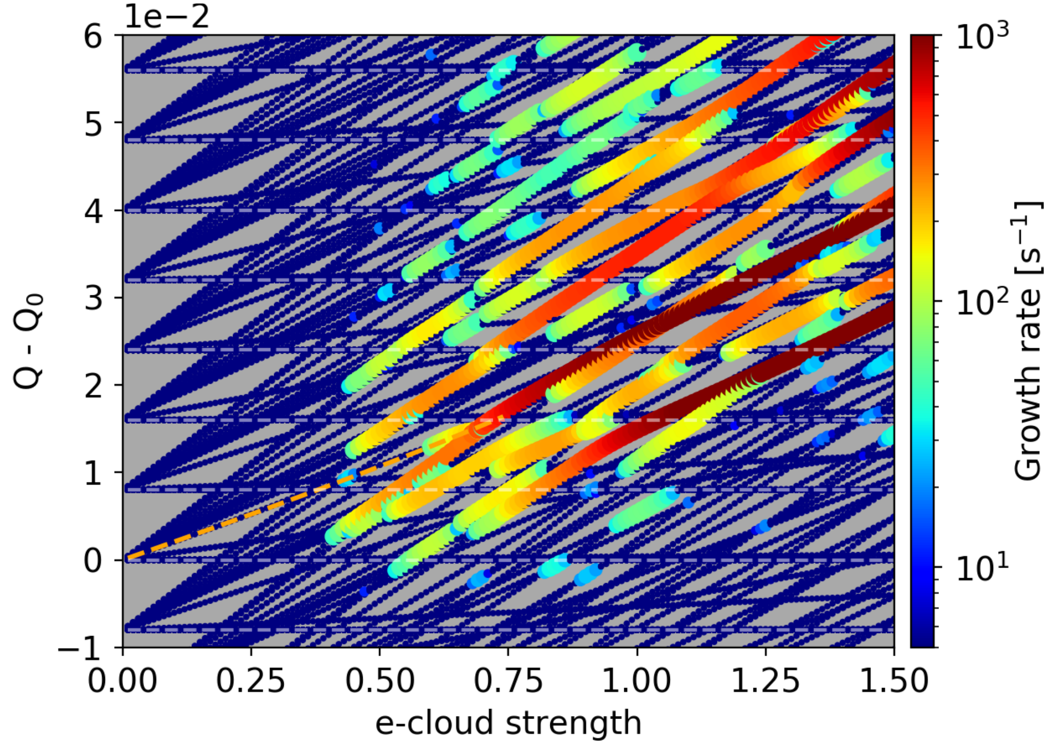
$Q_s = 0.008$



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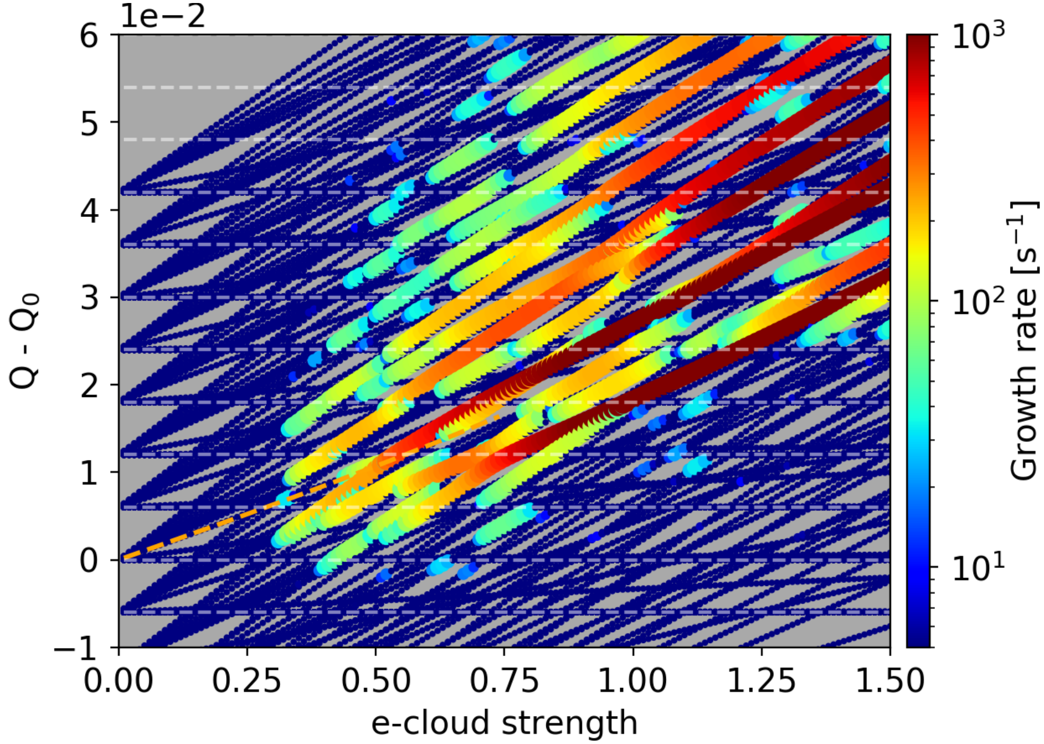
Q_s = 0.006



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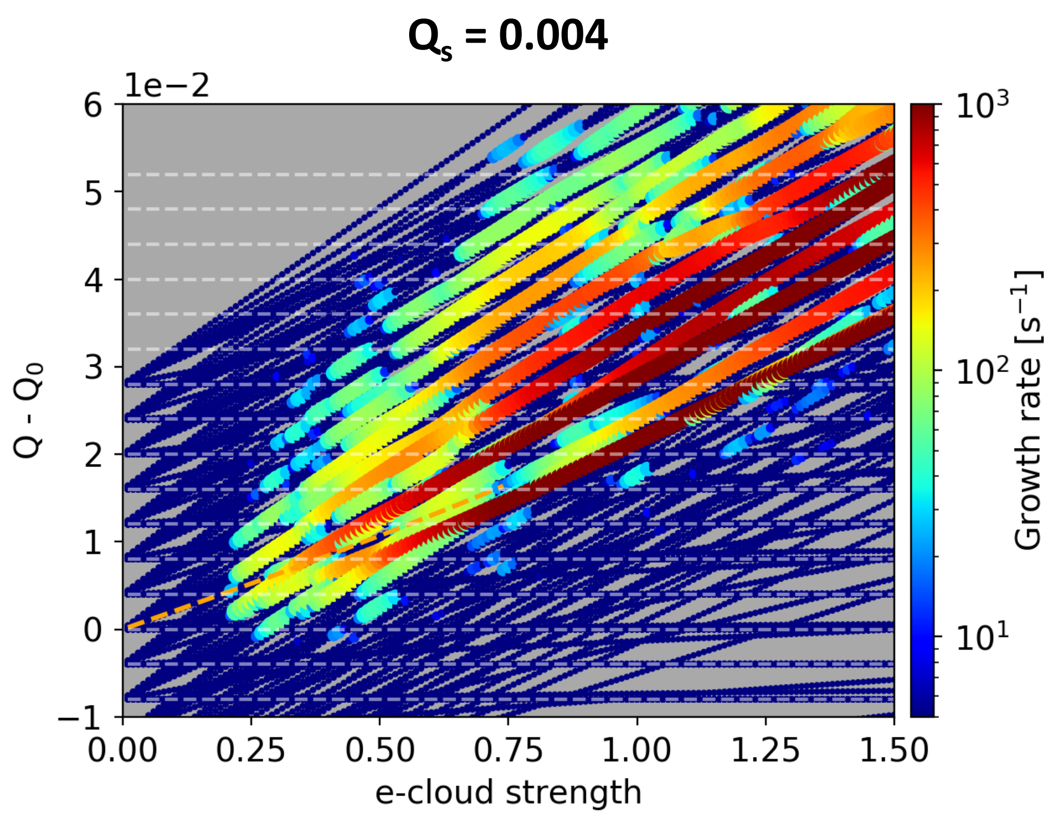

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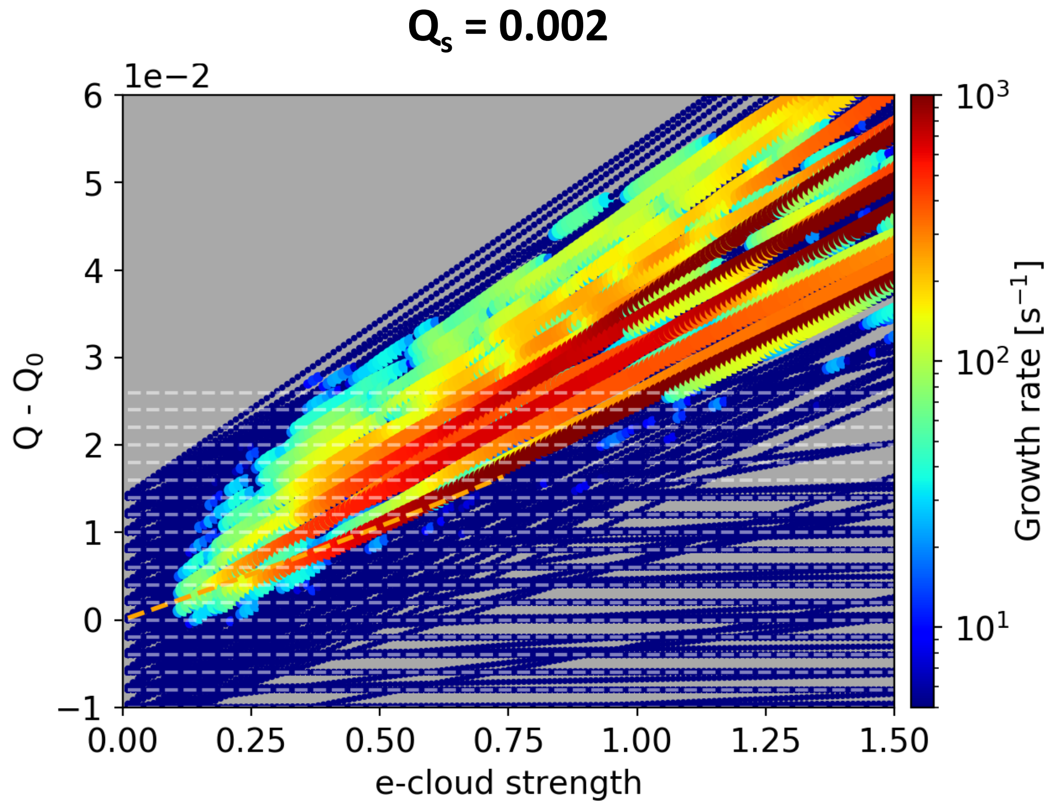

Effect of synchrotron tune

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- When Q_s decreases the synchrotron sidebands move closer together
  → A smaller e-cloud strength is sufficient to trigger instabilities
  → This is visible also on the imaginary part of the eigenvalues

Q20: $Q_s = 0.017$
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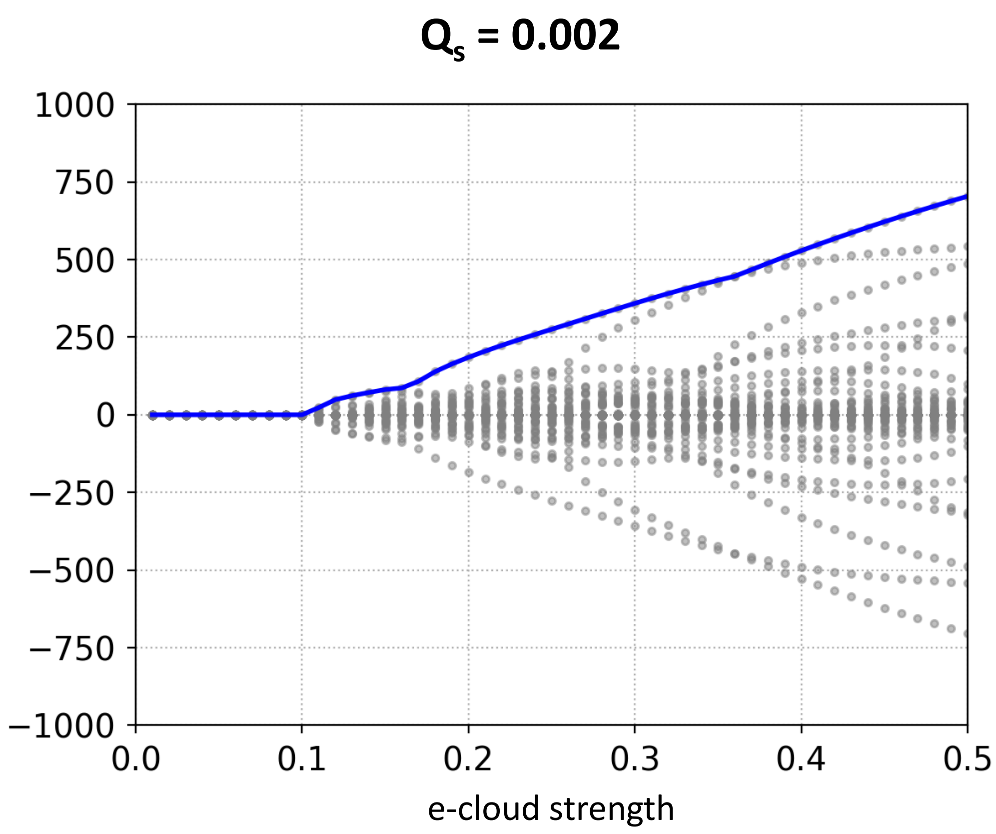

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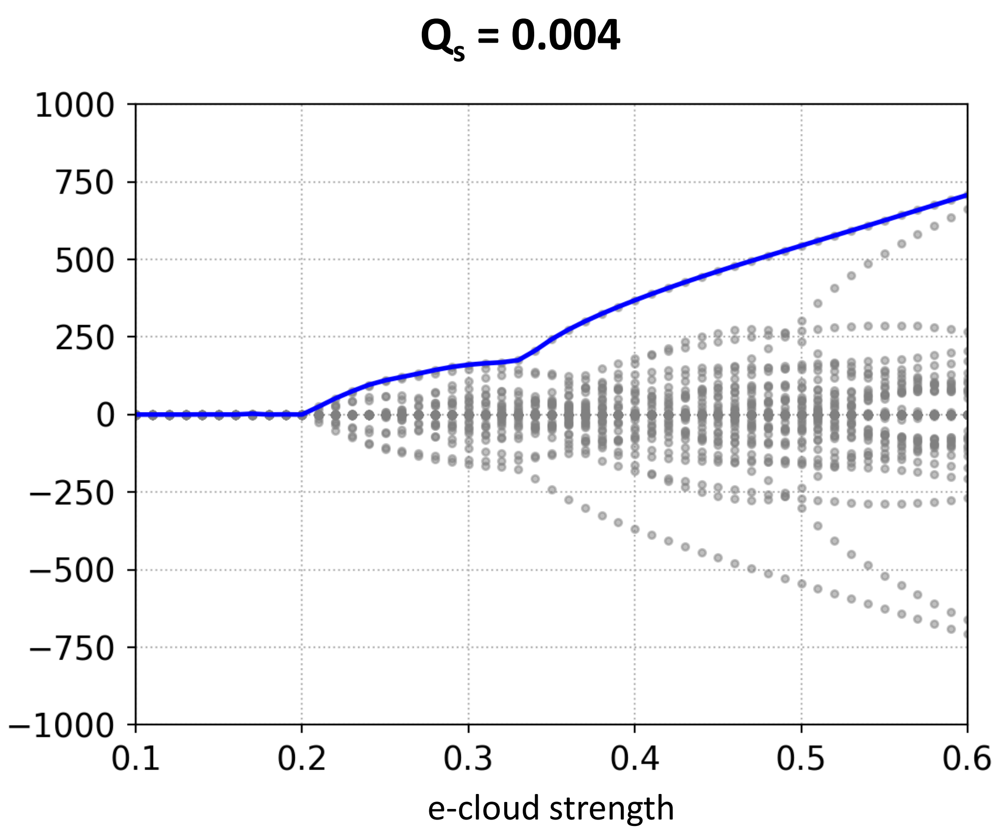

Note the sliding x-axis!

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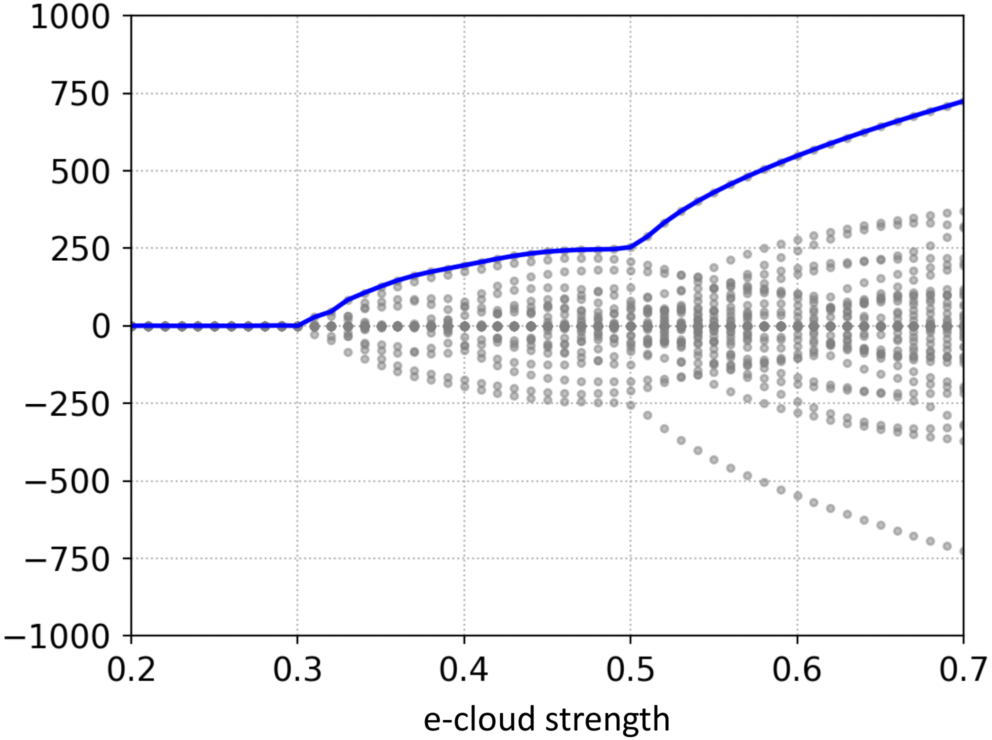

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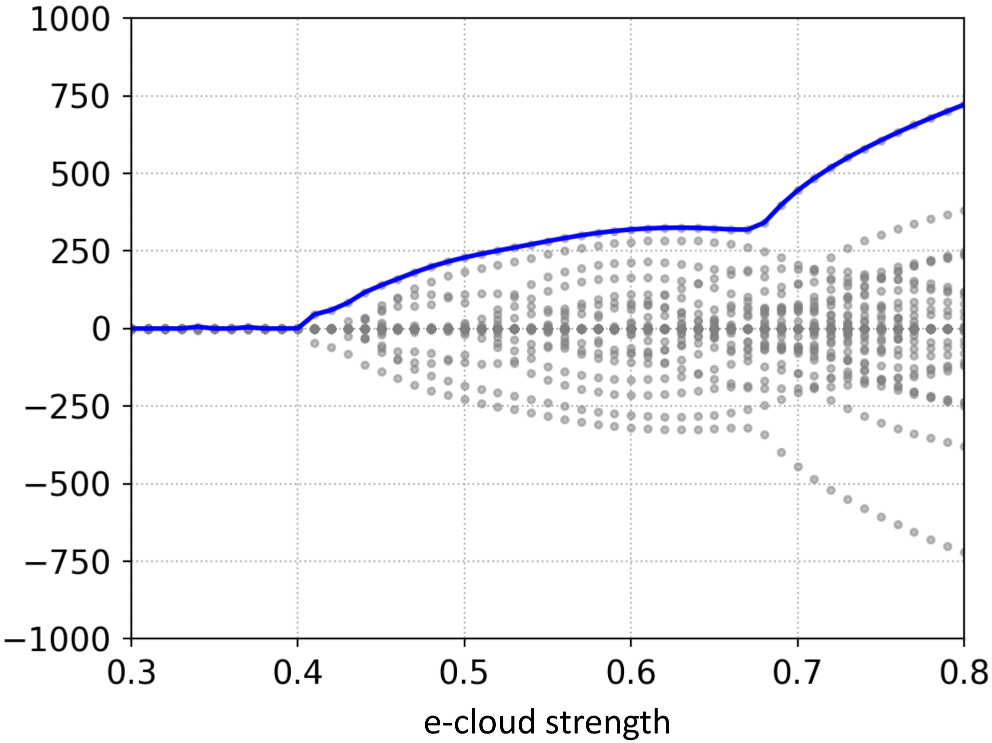
Q_s = 0.008



Q20: Q_s = 0.017
Q26: Q_s = 0.0059

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Effect of synchrotron tune

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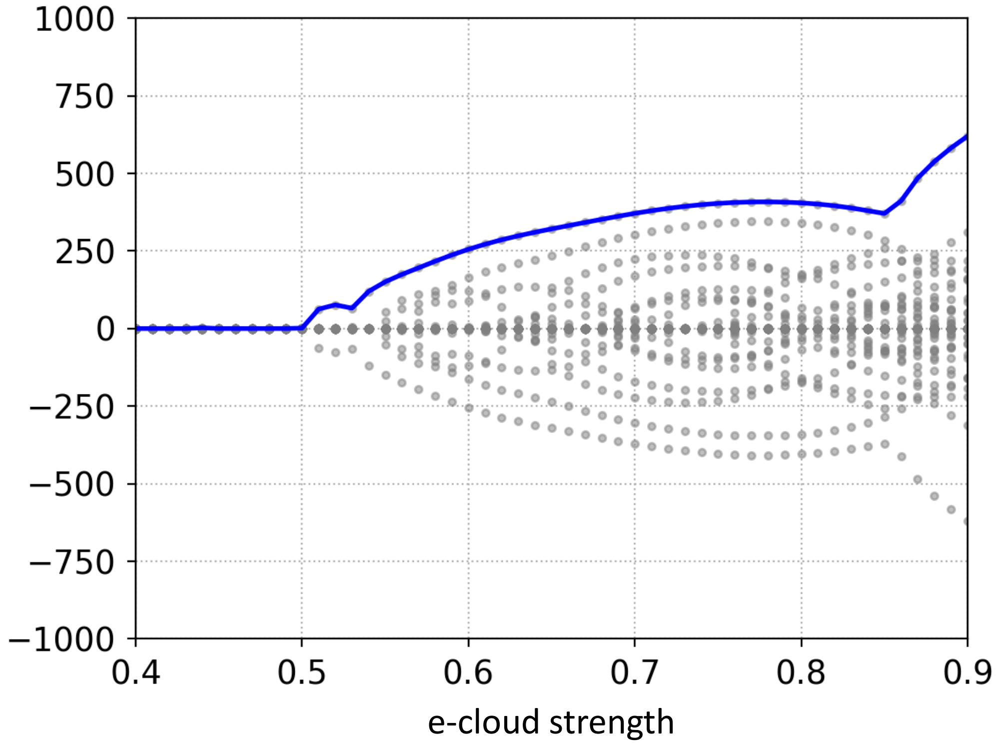
Q_s = 0.010



Q20: Q_s = 0.017
Q26: Q_s = 0.0059

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Effect of synchrotron tune

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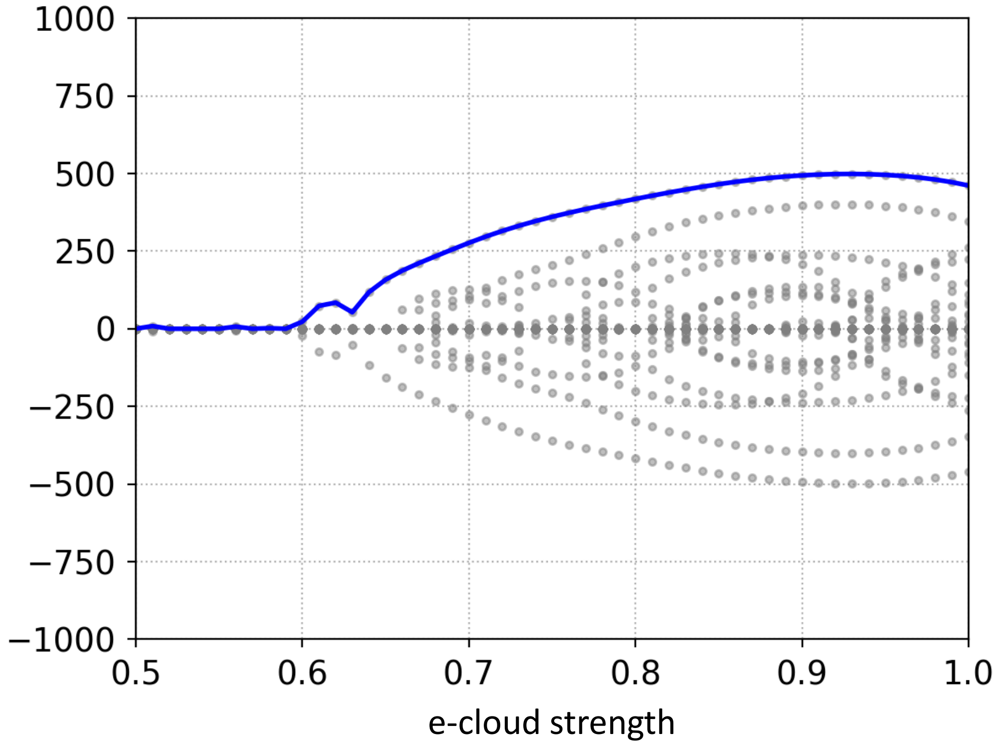
Q_s = 0.012



Q20: Q_s = 0.017
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Q20: Q_s = 0.017
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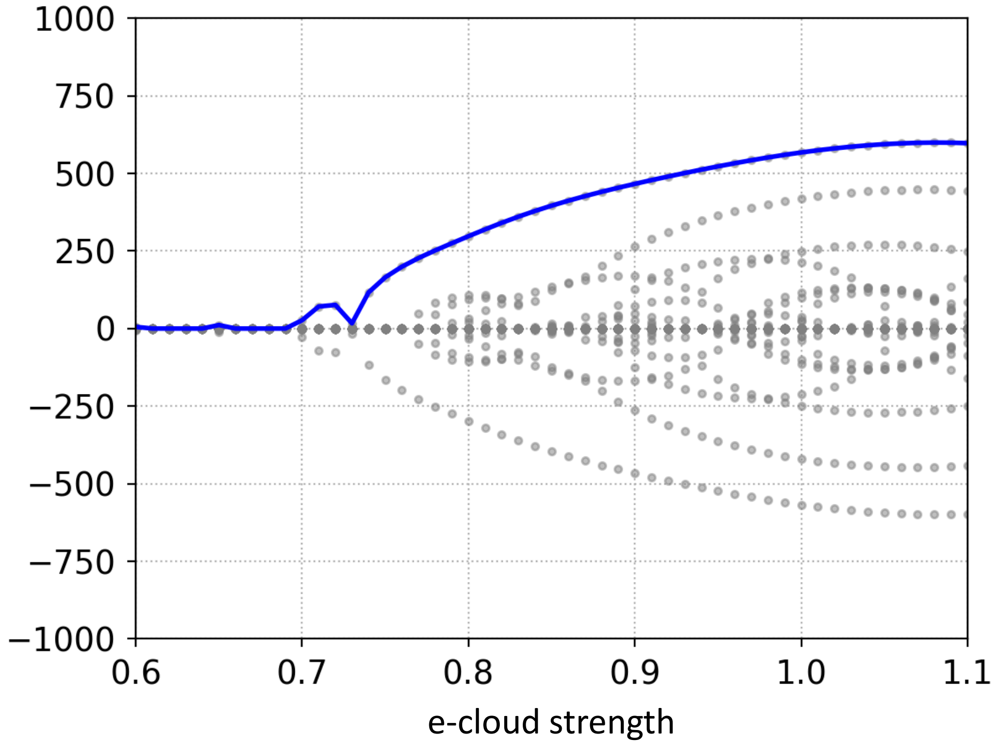
Q_s = 0.014



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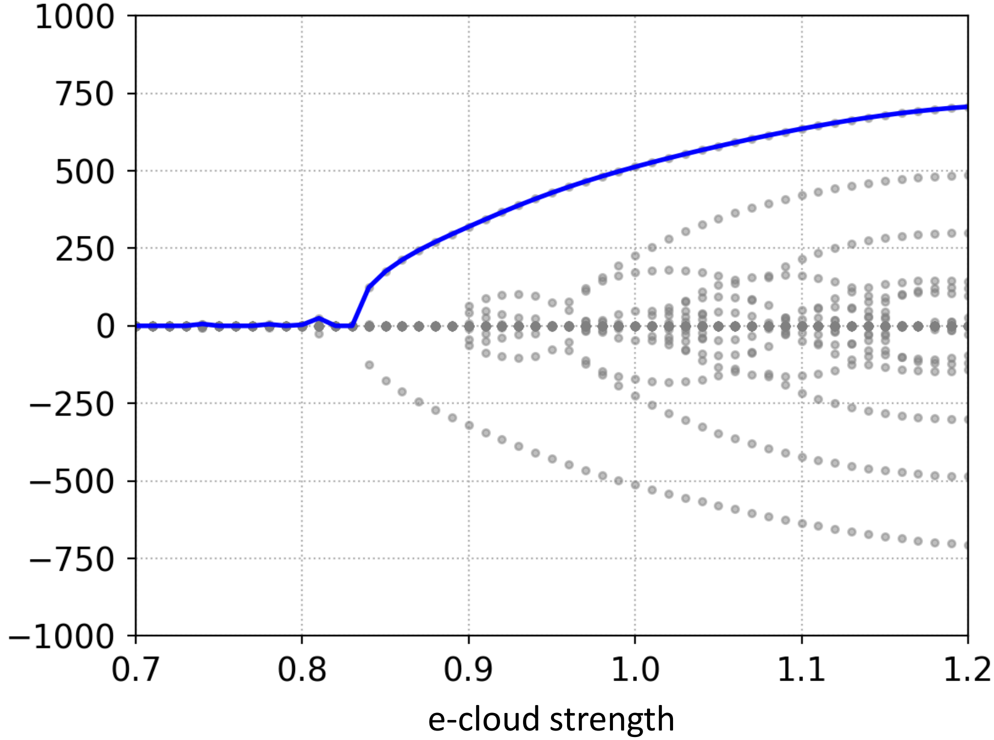
Q_s = 0.016



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Note the sliding x-axis!

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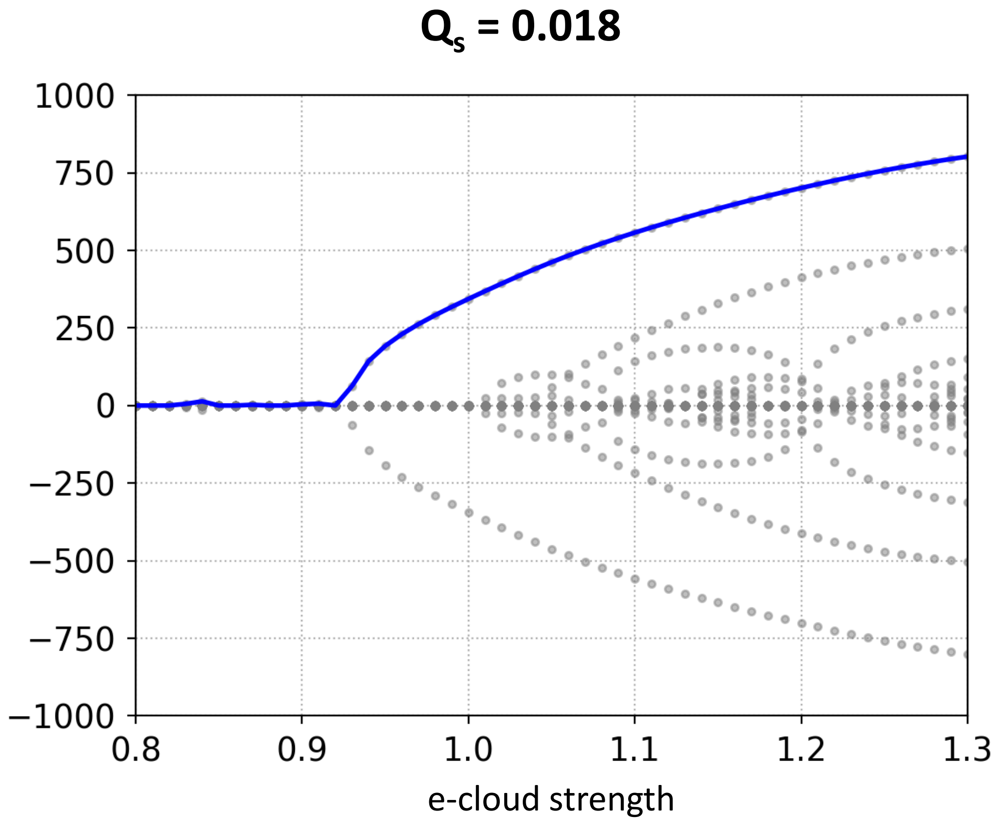

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- When Q_s decreases the synchrotron sidebands move closer together
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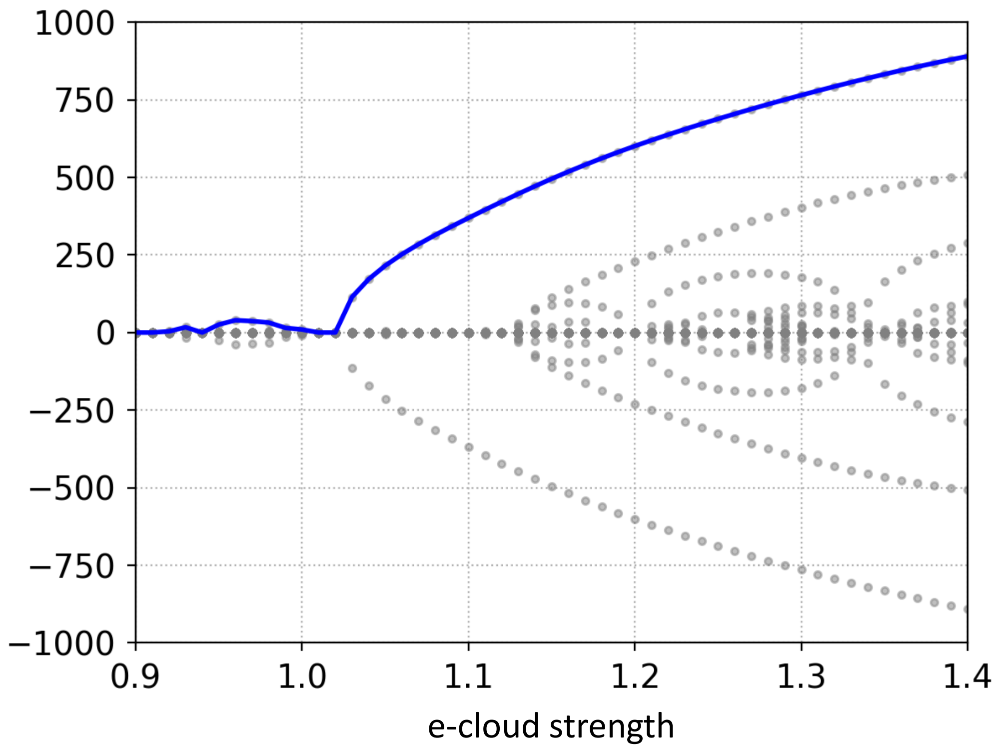
Q_s = 0.020



Q20: Q_s = 0.017
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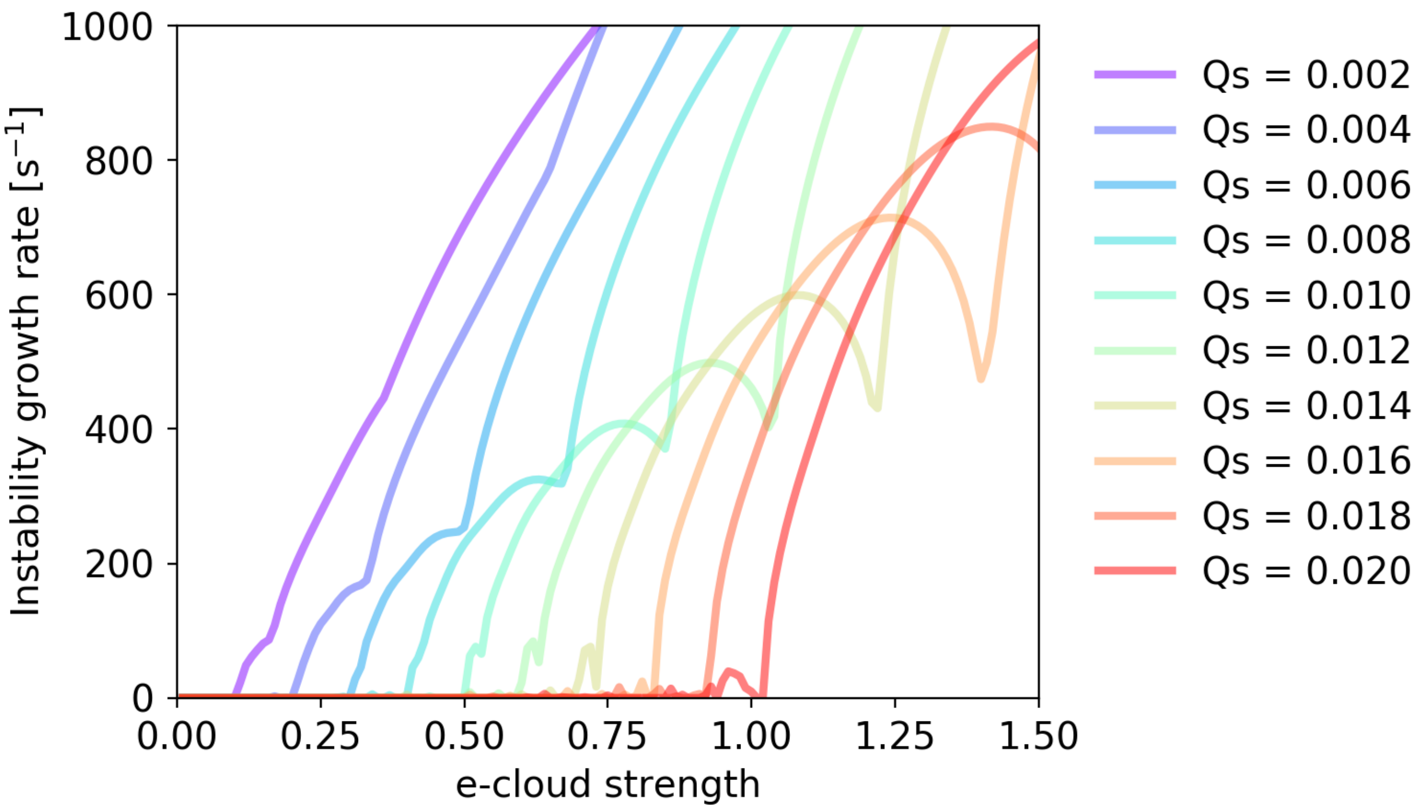
Note the sliding x-axis!

Instability growth rate vs Q_s

The instability growth rates as a function of the e-cloud strength for different Q_s with bunch intensity N_b = 2 x 10^{11}



Summary and conclusions

The linearized model using the Vlasov method was applied to instabilities driven by e-cloud in the SPS dipoles at injection

- Instabilities are found to be triggered by transverse mode coupling (TMCI)

- The effect of the bunch intensity was studied
  - Increasing the bunch intensity leads to lower instability thresholds
  - Results are qualitatively in agreement with past PIC studies

- The effect of the synchrotron tune was studied
  - Decreasing the synchrotron tune leads to lower instability thresholds
  - This is due to the synchrotron sidebands becoming closer, thus facilitating the coupling between modes