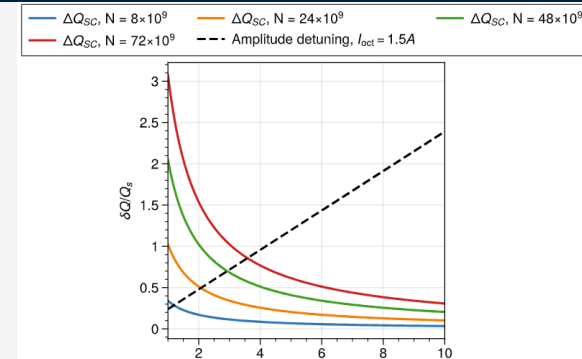


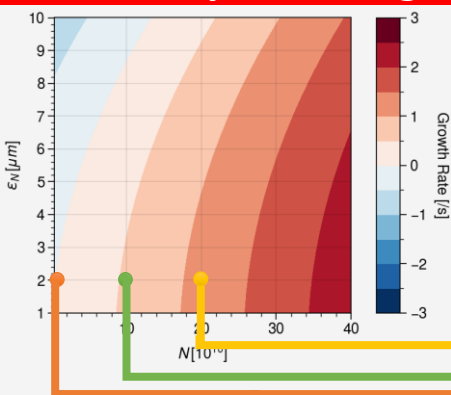
Landau Damping with Space Charge in the LHC

Idea:

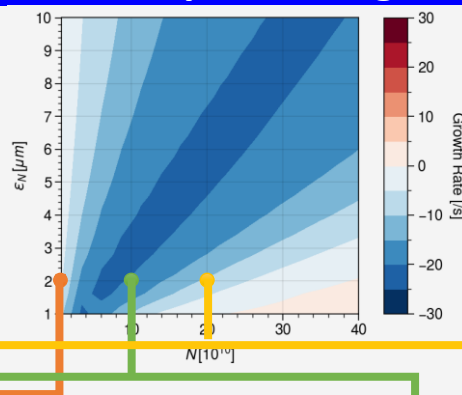
- During early LHC commissioning, LHC was operated without Landau octupoles: injection was stable, but an instability occurred during ramp. The reason for this was never fully ascertained.
 - Two possible explanations: **residual nonlinearities** or **space charge contribution**
- For intense beams at small transverse emittance, tune shift from SC can be larger than from external nonlinearities



Without space charge

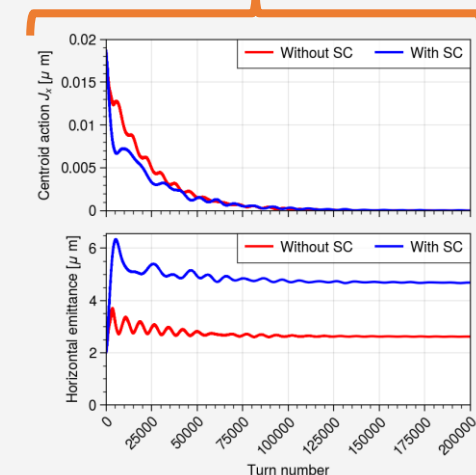


With space charge



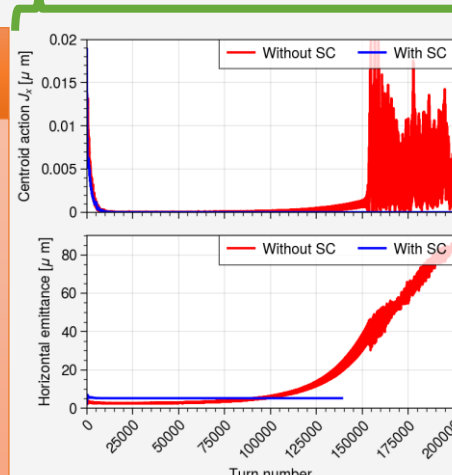
Tune shift measurements at injection were used to estimate residual detuning:

- Coefficients combined with formulae from Burov and growth rate simulations to estimate overall stability of LHC at injection without space charge as a function of **intensity** and **emittance**
- Effect of space charge was incorporated following formulae of Macridin et al



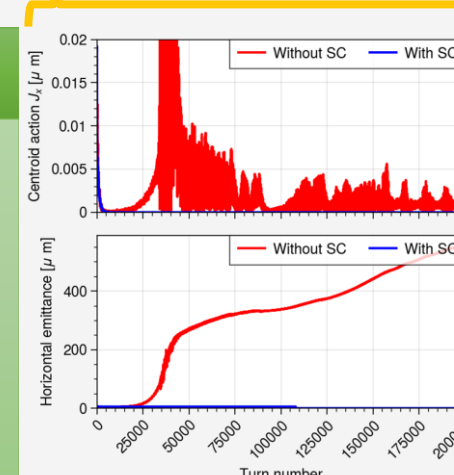
$$N_B = 8 \times 10^9$$

No instability:
Intensity too low to overcome Landau damping from residual nonlinearities



$$N_B = 1 \times 10^{11}$$

No SC: Slowly growing instability
SC applied: damped instability



$$N_B = 1 \times 10^{11}$$

No SC: rapid instability growth (order 20k turns)
SC applied: fully damped instability