EXERCISES FOR THE COURSE ON COLLECTIVE EFFECTS (LUND 2013)

1) How would the transverse force of page 13 be modified in the case of a particle moving with the same velocity as the bunch but in opposite direction? What would be its value when the relativistic mass factor becomes infinite, compared to the case of the space charge interaction (i.e. for a particle moving in the same direction as the bunch)?

2) Compute numerically the value of the maximum incoherent space charge tune shift using the formula of page 17 for the case of a LHC-type bunch at the entrance of the SPS:

- Radius of the SPS machine: 1100 m.
- Number of protons in the bunch: 1.3 10^{11} p/b.
- Beam momentum: 26 GeV/c.
- Normalized transverse rms beam emittances in both planes: 3 μm.
- Full (4 σ) bunch length: 4 ns.

Knowing that in sychrotrons one usually try to run with a maximum incoherent space charge tune shift of ~ - 0.3 to avoid overlapping with too many resonances (inducing emittance blow-ups and/or beam losses), do you think that space charge is a limitation in the SPS? What would happen if the normalized transverse rms beam emittances in both planes were 2 μm, or even 1 μm (i.e. if the previous machine, the PS, would deliver a much brighter beam)?

3) Derive the equation of the transverse space charge tune shift of page 18 and check that it is indeed the same result as in page 17.

4) Derive the nonlinear space charge tune shift of page 29 starting from the general equations of page 19 for the electric fields (some useful mathematical formulae can be found in http://emetral.web.cern.ch/emetral/USPAS09course/Introduction.pdf in "Useful relations"). Check that the maximum transverse space charge tune shift is 80% of the one for a bi-Gaussian bunch.

5) What are the possibilities to try and improve the machine / complex performance when limited by space charge?

6) What can be done to mitigate the beam-beam effects?

7) What can we do to reduce the machine impedances (and therefore the related RF heating and beam instabilities)?

8) What can be done to mitigate the e-cloud effects?