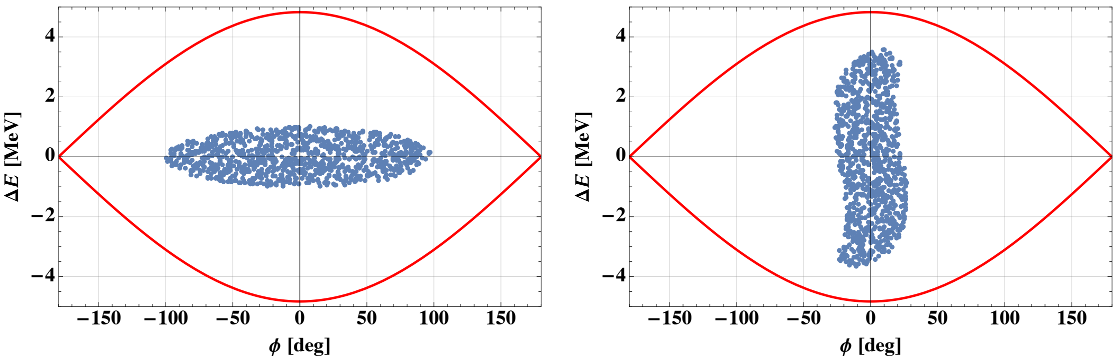
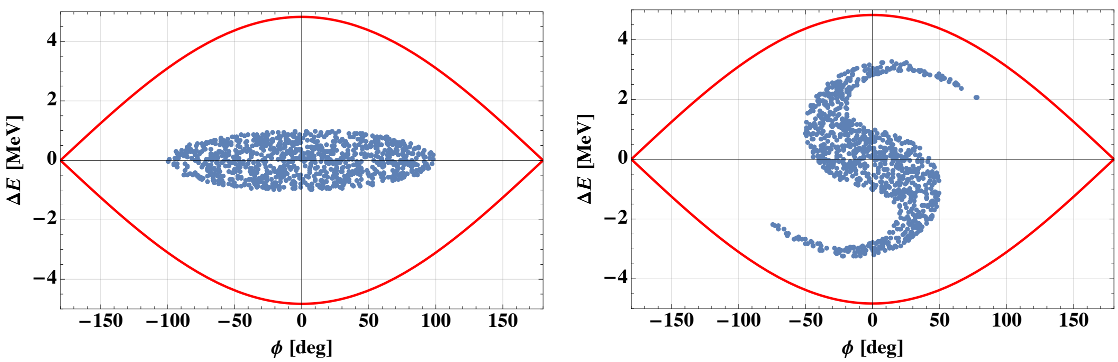
LONGITUDINAL BEAM DYNAMICS EXAMINATION

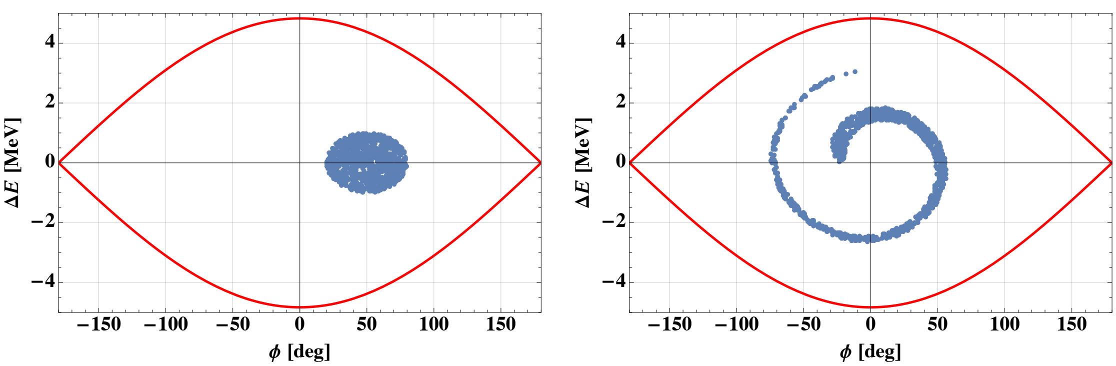
1) In the six cases below, a bunch of particles is injected into an RF bucket (left pictures). The right pictures are taken after some time. Could you explain what we see in these pictures (Are we below or above transition? Are the particles oscillating clockwise or anti-clockwise? Why? Etc.) and why the bunch of particles got these shapes after some time? Conclude on what needs to be done when a bunch of particles is injected into a synchrotron.



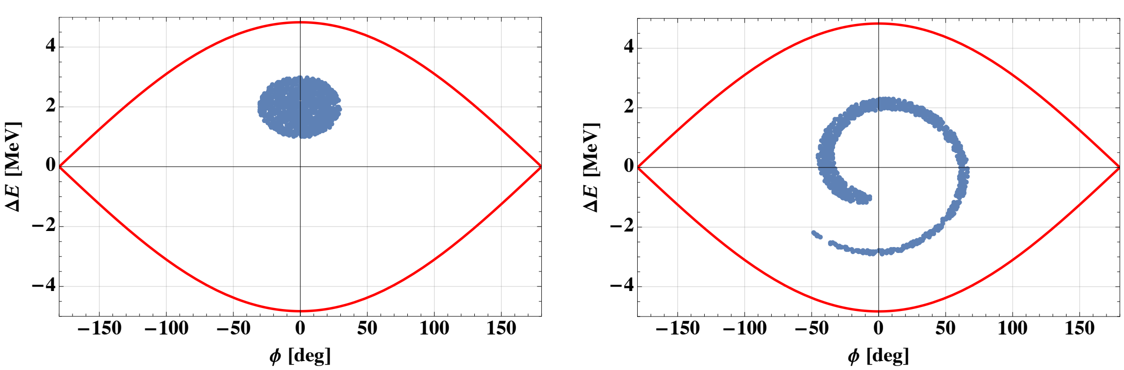
a)



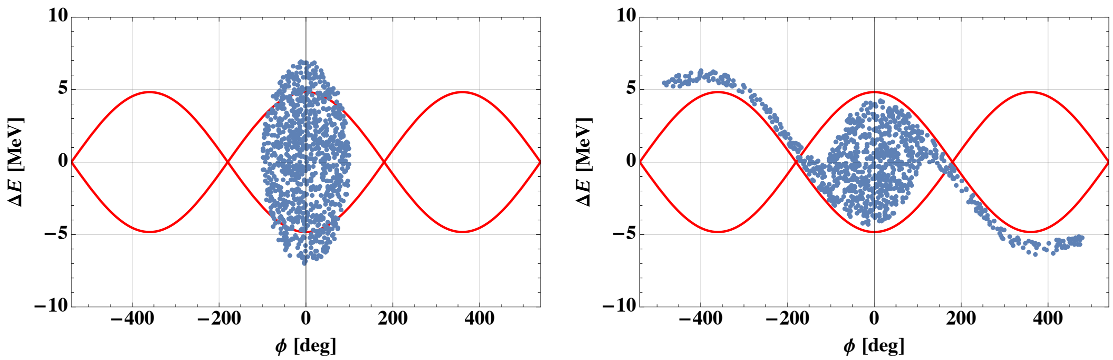
b)



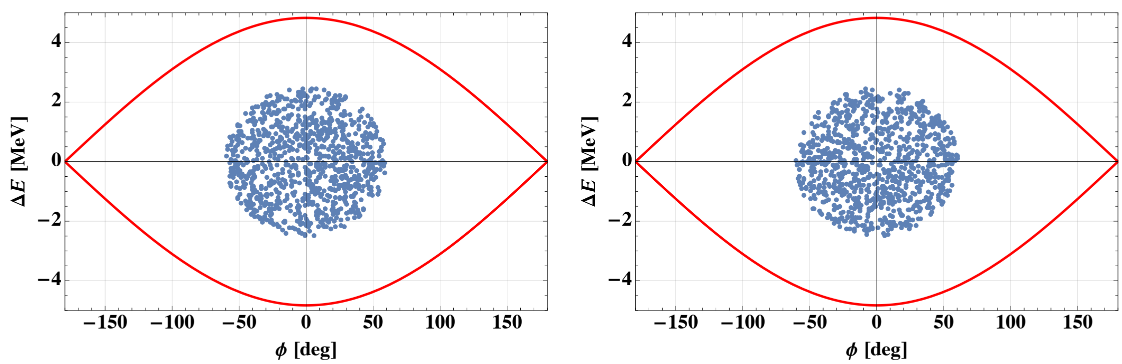
c)



d)



e)



f)

2) Consider the CERN SPS synchrotron, whose parameters are given in the table below

Circumference	$C = 6911$ m
Momentum compaction factor	$\alpha_p = 1.92 \times 10^{-3}$
Number of dipoles	$N_d = 744$
RF harmonic number	$h = 4620$
Total RF voltage	$V_{RF} = 3$ MV
Energy gain per second during acceleration	$dE / dt = 78$ GeV/s
Maximum magnetic field	$B_{max} = 2.03$ T

a) A bunch of particles is injected with a beam momentum of 26 GeV/c. What are: i) the revolution frequency; ii) the RF frequency; iii) the slip factor; iv) the synchrotron tune; v) the number of machine revolutions per synchrotron oscillation (in phase space); vi) the maximum length (in ns) of the injected bunch (in order not to lose particles); and the maximum energy spread (in MeV) of the injected bunch (in order not to lose particles)? Draw the motion of the particles in phase space.

b) The particles are usually accelerated up to a beam momentum of 450 GeV/c. How long does the acceleration last? What is the energy gain per turn and the corresponding accelerating synchronous phase (in degrees)? At 450 GeV/c the magnetic field reaches its maximum value B_{max}: deduce the length of one dipole and the variation of the magnetic field dB/dt during acceleration? What was the magnetic field at injection energy? Draw the motion of the particles in phase space during acceleration.

c) During some studies, instead of being accelerated, the particles are decelerated from 26 GeV/c down to 20 GeV/c. Compute the slip factor at 20 GeV/c. Will the particles cross the transition energy (explain what it is)? What should be the value(s) of the synchronous phase during the deceleration? Draw the motion of the particles in phase space during deceleration.

N.B.: The proton rest energy is $E_0 = 0.938$ GeV, the elementary charge is $e = 1.6 \times 10^{-19}$ C and the velocity of light is $c = 2.997925 \times 10^{8}$ m/s.