**1. Phase Space Representations of Particle Sources**

a) Consider a source at $s_0$ with radius $w$ emitting particles. Make a drawing of this setup in configuration space and in phase space. Which part of phase space can be occupied by the emitted particles?

b) Any real beam emerging from a source like the one above will be clipped by aperture limitations of the vacuum chamber. We can model this by assuming that a distance $d$ away from the source there is an iris with an opening with radius $R = w$. Make a drawing of this setup in configuration and phase space. Show which parts of phase space are occupied by the beam at a location after the iris.

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**2. Quadrupole Errors and Tune Shifts**

In the lecture a quadrupole focussing error was introduced into Hill’s equation by replacing the focussing function $K(s)$ with $K(s) + \Delta k(s)$. It was then proposed that the error in the focussing function could be represented as a gradient error $\Delta (kl)$ leading to a tune shift $\Delta Q = \frac{1}{\pi} \beta_0 \Delta (kl)$. Assume that the tune shift is small with respect to the tune and prove this statement.

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**3. Momentum Compaction and Transition Energy**

Dispersion leads to path length changes for off-momentum particles. This is characterized by the momentum compaction factor $\alpha_c$ defined in the lecture. Considering that timing is very important in an accelerator, can path length changes be related to a change of the revolution period? Or in mathematical terms, how does $\Delta T$ depend on $\Delta \frac{p}{\beta}$? Is it possible to build an accelerator where $\Delta T = 0$ regardless of $\Delta \frac{p}{\beta}$?