



# Exercises on Beam Diagnostics

Accelerator Beam Diagnostics

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ASP-2016 Kigali Rwanda

# Bunch Shape Monitor

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The RF frequency of the RFQ is 352 MHz and the designers of the Bunch Shape Monitor promise a phase resolution of 1 degree. What time resolution does this correspond to?

**Solution:**

352 MHz corresponds to a wave length of  $\frac{1}{352 * 10^6} s = 2.8ns$

The time resolution is  $\frac{2.8ns}{360} = 7ps$

# BLVD

Some years ago a BLVD (Bunch Length and Velocity Detector) was in operation at CERN. The device worked like the BSM (Bunch Shape Monitor) described in the lectures. However it was movable along the axis of beam movement. If the detector is moved along this axis, then the movement corresponds to a phase shift. If you move the detector far enough (360 degrees of phase advance) then the bunch shape measured will coincide with the one measured in the first position. Like this the beam velocity (and energy) can be measured. By how much do you have to move the detector (same RF and phase resolution as above).

## Solution:

The relationship between kinetic particle energy and the relativistic  $\beta$  is  $T = \left( \frac{1}{\sqrt{1-\beta^2}} - 1 \right) * E_0$

$E_0$  is the rest mass of the proton ( $\sim 1 \text{ GeV}/c$ )

Solving the equation for  $\beta$  gives us:

$$\beta = \sqrt{1 - \left( \frac{1}{\frac{T}{E_0} + 1} \right)^2}$$

# BLVD(2)

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Inserting 3 MeV/c for  $T$  and 938 MeV/c for  $E_0$  results in  $\beta=0.08$

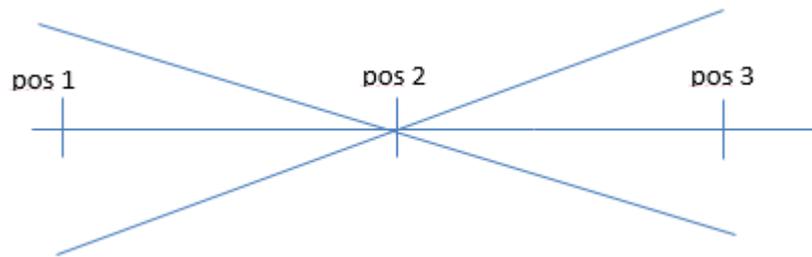
We therefore have to calculate how far the particle moves in 2.8 ns. With  $c=300.000$  km/s we get  $s=6.8$  cm.

For 160 MeV  $\beta$  is already 0.52 and the distance becomes 44 cm, almost too long for vacuum bellows.

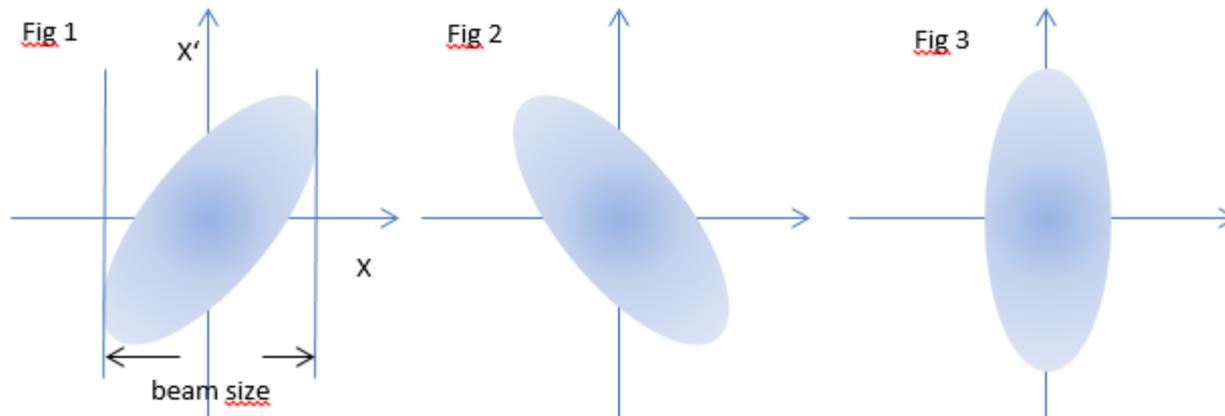
# 3 profile Emittance measurements

## 3 profile measurement

During the lecture on the phase space scan has been presented. There are however other ways to measure emittance as well. One method is to measure 3 beam profiles around a waist:



The following figure shows 3 phase space ellipses as calculated for the 3 positions above. Which ellipse corresponds to which position?



# 3 profile Emittance

## Solution:

Fig. 3 corresponds to the measurement in position 2. This can easily be seen because here the beam size is minimal.

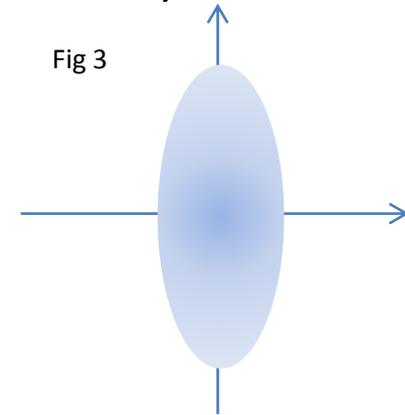
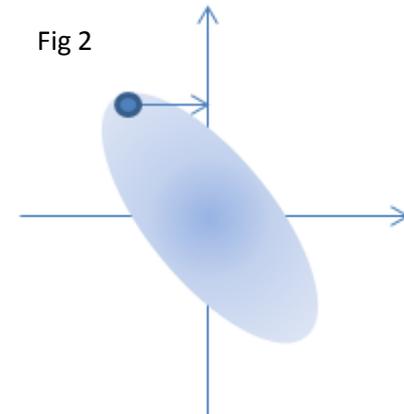


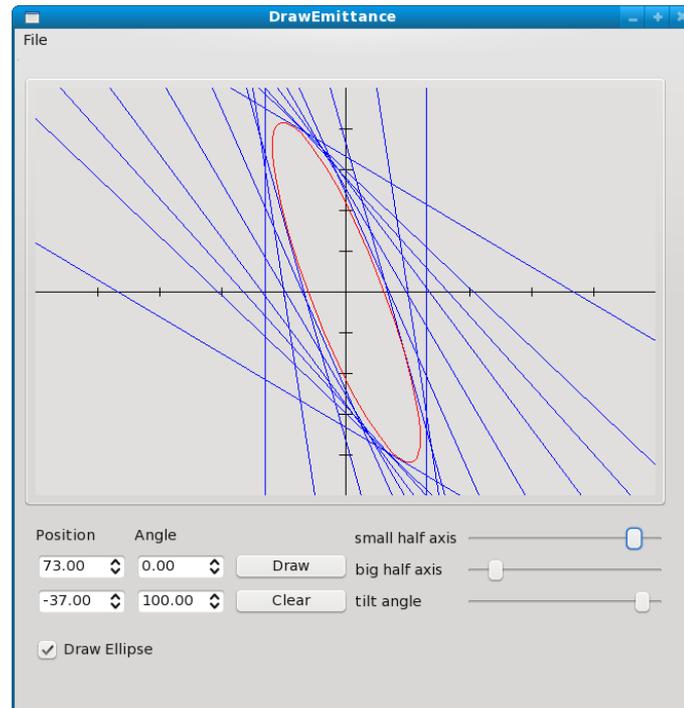
Fig. 2 corresponds to the measurement in pos 1.

Consider the particle indicated in the figure. Its angle will not change as it is moving through the drift space, while the positions must become smaller (the beam is converging).



# 3 profile Emittance (2)

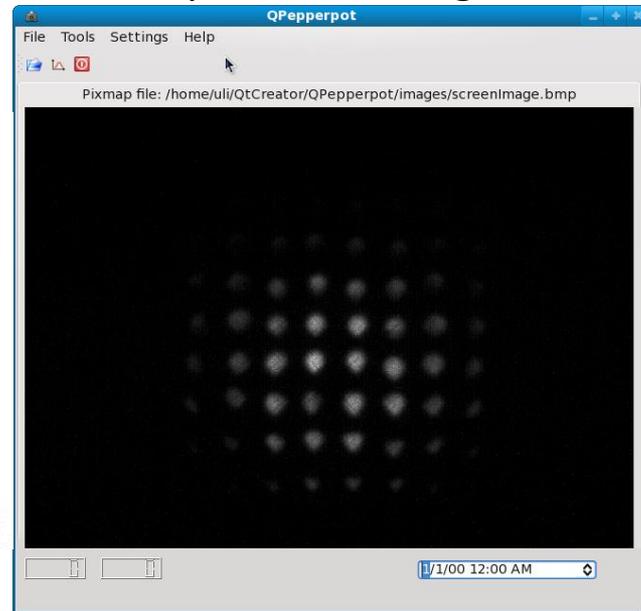
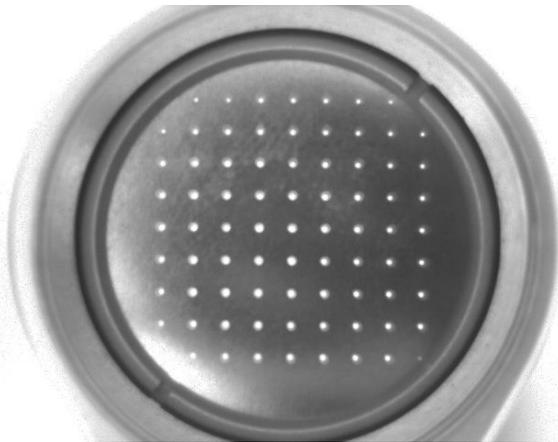
In this measurement the beam size is determined at each of the positions. This corresponds to vertical lines in phase space. Using simple optics calculations these lines are transformed to one of the measurement positions, where they form tangents to the emittance ellipse. Measurement errors can be minimized when measuring at more than 3 positions, when the supplementary measurements are redundant.



# Pepperpot Emittance

## Pepperpot measurement

In order to measure beam emittance in a single beam pulse a plate with a matrix of holes is placed into the beam and, after a drift space, the image of the holes is observed with a TV camera.



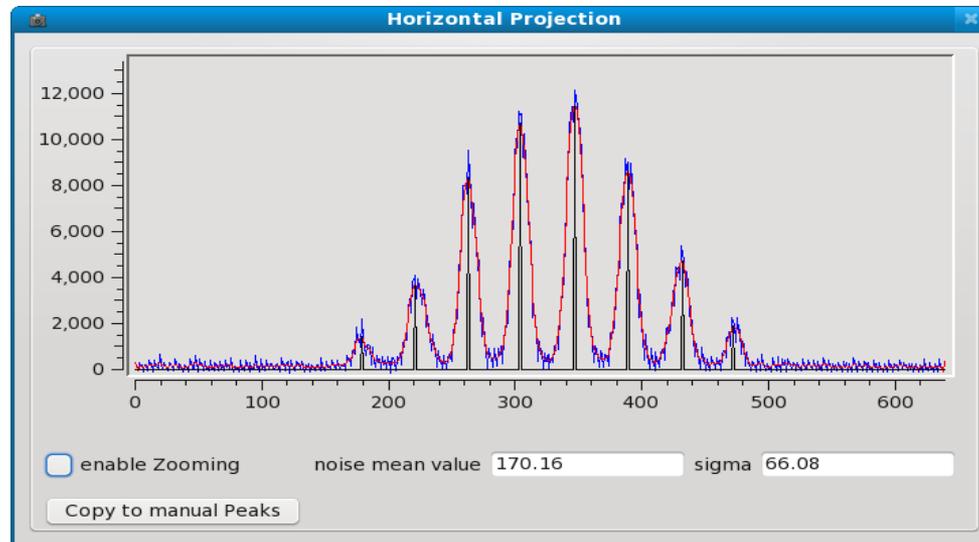
What are the steps you need to transform a pepperpot image into a phase space plot?

# Pepperpot(2)

## Solution:

The position of the pepperpot and the screen must be known precisely. The calibration no of pixels / mm must be known. A parallel beam corresponds to an image where the hole image is a the same distance as the holes in the pepperpot plate. For a convergent beam the distance of the hole images is smaller.

A projection of the image to the horizontal axis is calculated (hor. Emittance. The algorithm for the vertical emittance works correspondingly with a projection onto the vertical axis).



# Pepperpot(3)

Each series of vertical holes corresponds to a vertical position slice in phase. A peak find algorithm determines the peaks in the pepperpot image. The distribution around a peak corresponds to the angular distribution (vertical slice in phase space) for this vertical series of holes. The center of the distribution within the slice is determined by the image peak distance as compared to the distance of the holes in the pepperpot.

The angular distribution for each vertical series of holes is plotted in the phase space diagram.

