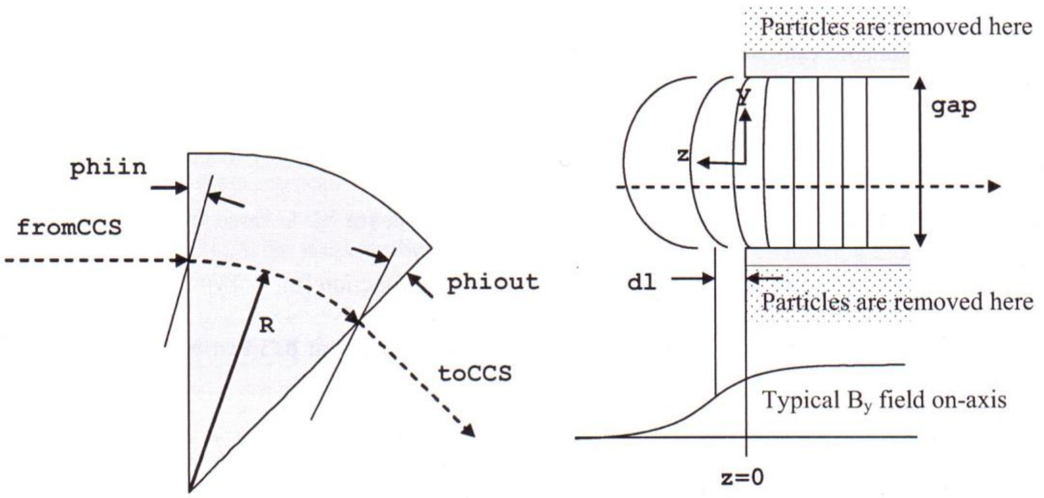
Investigation of fringe field effects on particle tracking in the Laser diagnostics chamber

Following the discussions at the last FETS meeting further particle tracking to evaluate the effect of the fringe fields of the dipole magnet on the particle motion have been performed. For clarity of the results, the way GPT defines a sector magnet, mainly the phase angle and the fringe fields are presented first (please see also GPT reference ~ page 153). This is followed by the parameters used for the simulation, a plot of the field distribution in Z and the particle tracking results.



For the fringe fields the following relations between the fringe field parameters dl, b1 and b2 and the corresponding field distributions used for the particle tracking:

$$B_y(z, y=0) = \frac{1}{1+\exp\left(\mathbf{b_1}\,(z-\mathbf{dl})+\mathbf{b_2}\,(z-\mathbf{dl})^2\right)}$$

$$B_y = \frac{B\left(1+e^f\cos(h)\right)}{1+2e^f\cos(h)+e^{2f}}$$

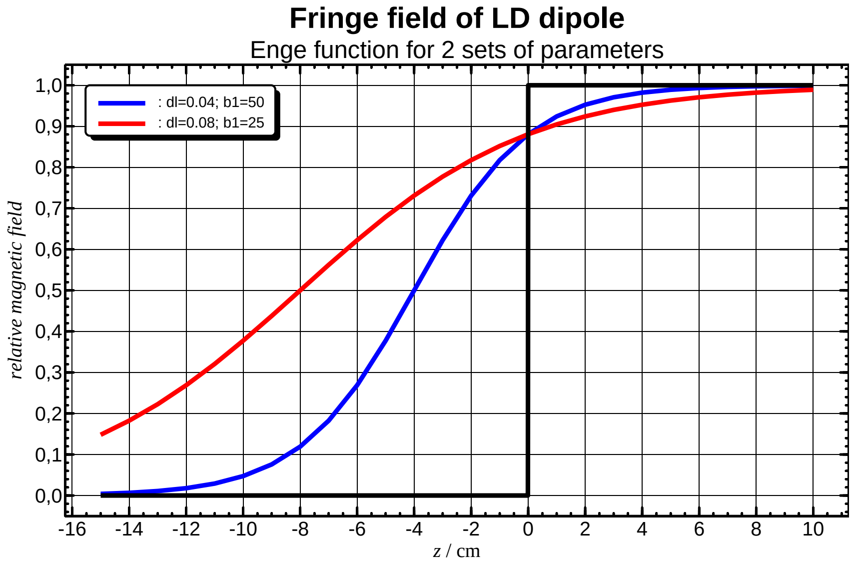
$$B_z = -\frac{B\left(e^f\sin(h)\right)}{1+2e^f\cos(h)+e^{2f}}$$

with $f=\mathbf{b_1}\,z+\mathbf{b_2}(z^2-y^2)$ and $h=y(\mathbf{b_1}+2\mathbf{b_2}\,z)$.

In the simulations the following parameters have been used to produce the results presented:

sectormagnet("wcs","Dipoleout", Rbend,Bbend*Bfactor,0.35,0.35,0.04,50,0);

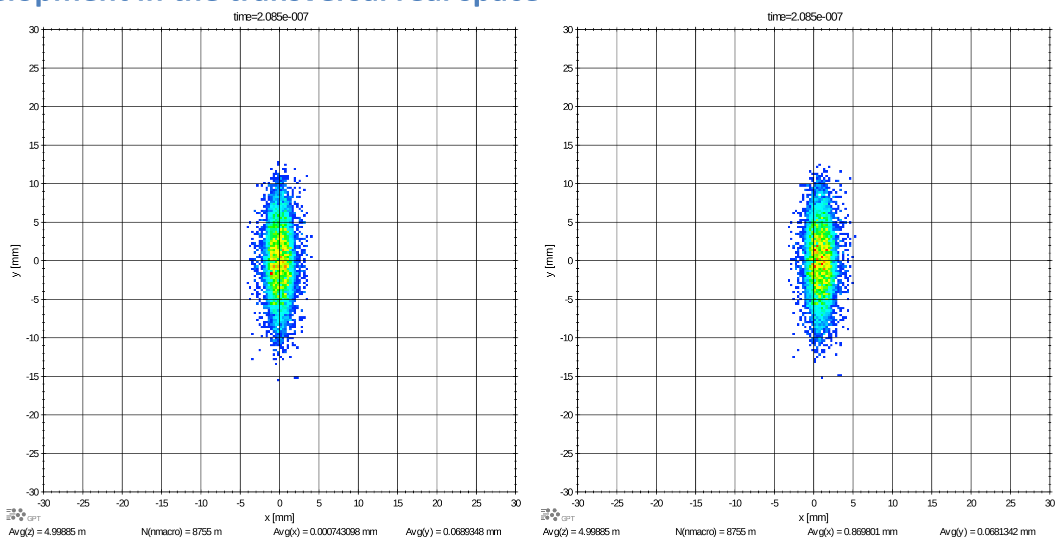
The value of 0.35 for the phase angle is equivalent to 20 degree, the "drop of length" dl is half the gap distance with the fist coefficient of the Enge function b1=50 and the second b2=0. The actual settings of these parameters is crucial for the precise shape of the field and various suggestions how to determine those values are made (one would lead to dl = 0.08 and b1=25) but in the end GPT suggest to adjust the parameters to a field map or use the field map instead, which I think is reasonable. Two distributions of the fringe field are shown in the next plot of which the one how will show the smallest effect was chosen, so the results are rather underestimates of what our dipole will produce than the worst case. The expected real function might be between the two cases but to investigate this in the required depth a (3D) field map is necessary.



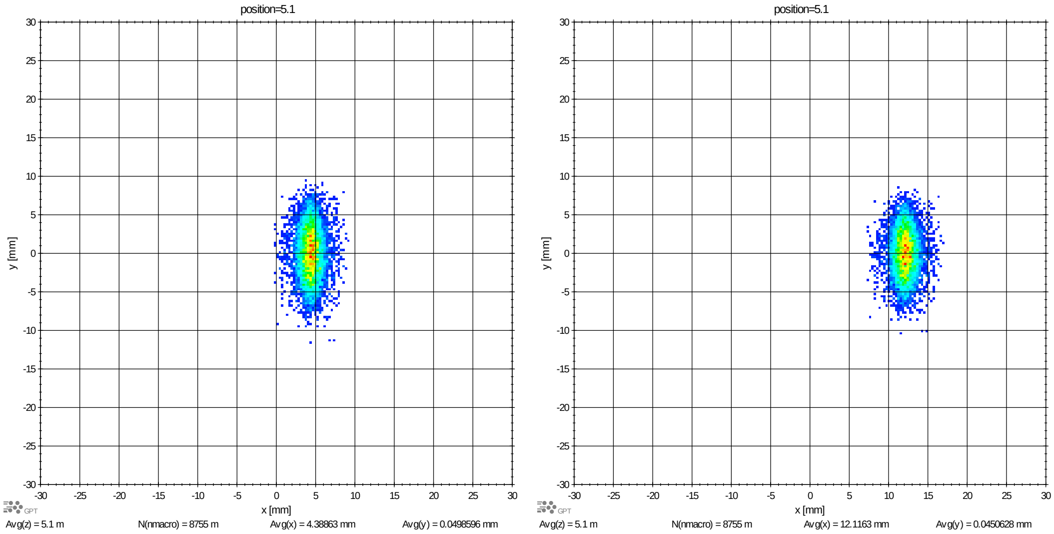
Variation of relative magnetic field in z direction (z=0 is dipole entrance) for two different sets of fringe field parameters. The blue curve was chosen for the following simulations.

From earlier investigations the "Bfactor" was chosen such that the beam exits the vacuum chamber at the same position as without fringe field (Bfactor =0.874). The first set of graphs shows the transversal density profile for the case with only edge focusing (left hand side graphs and the results with the additional fringe field.

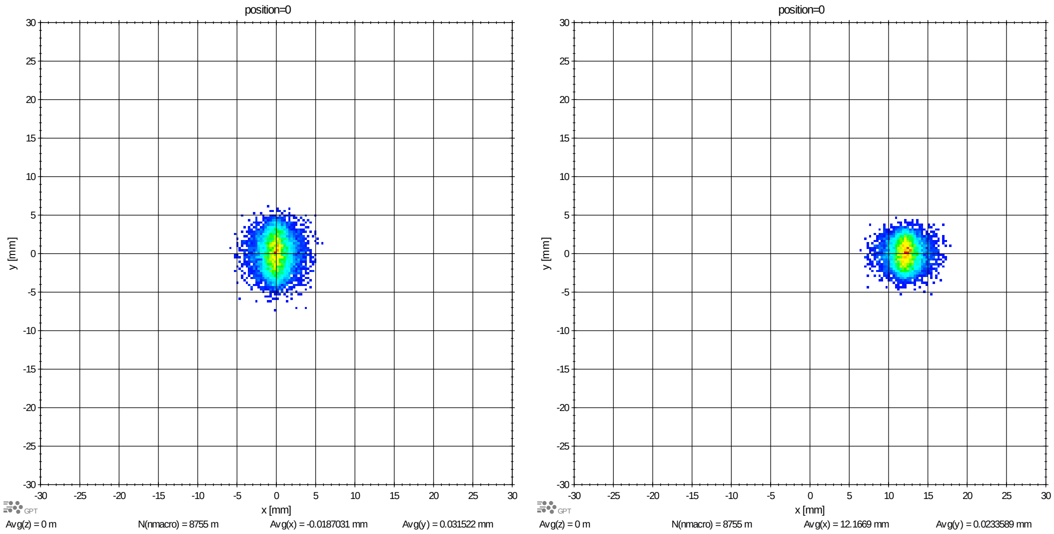
Development in the transversal real space



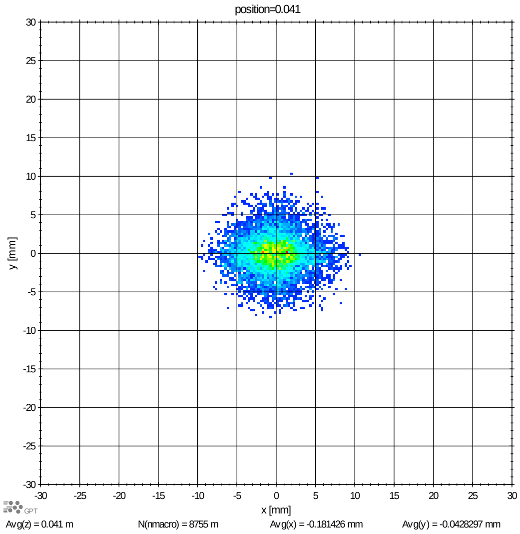
In the case without fringe fields the beam enters the dipole on axis (in x and y) in the case of fringe fields the beam is already slightly (<1 mm) off axis (in x) at the entrance to the dipole vessel, as the deviation is with below 1mm relatively small compared to the size of the aperture this is of no (small) significance for the experimental setup.

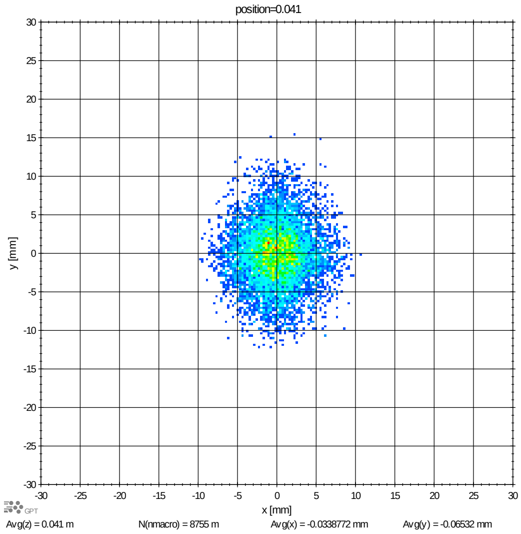


Already half way to the point of interaction with the laser beam (at ~5.19 the MEBT coordinate system, wcs) the deviation between the case without and with fringe field is nearly 8 mm.

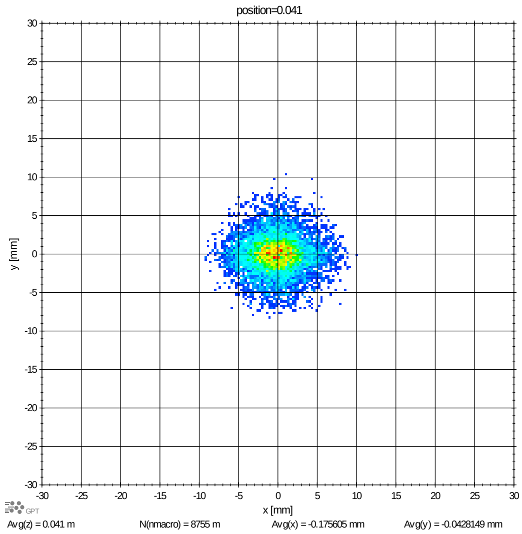


At the point of interaction with the laser (coordinate system =laserinteraction) the beam is already 12 mm off the position (in x) compared with the case without fringe field. This is significant in terms of the mechanical layout of the experimental setup. It should also be mentioned that a significant focusing in the y-direction can be observed in the case of fringe fields. We will look at this later on again.

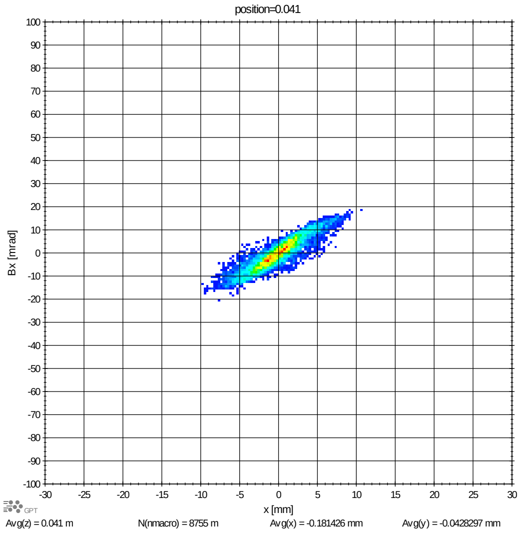


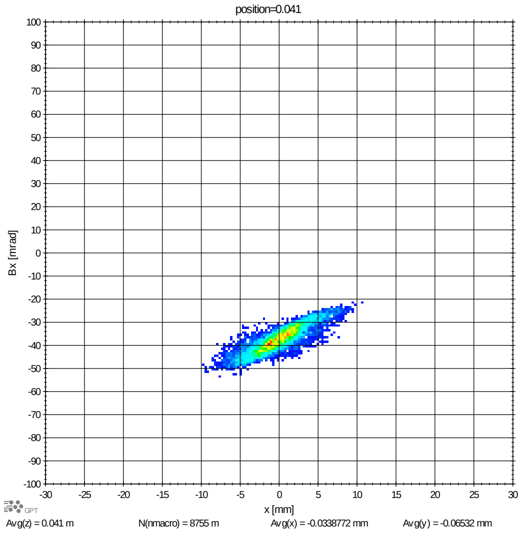


At the end of the sector magnet (coordinate system =dipoleout) both beams are centered in respect to the new coordinate system in real space. While the size of the distribution in the x direction is quite similar in both cases, the distributions in the y direction are quite different. For comparison the transversal beam distribution with "ideal" sector magnet without edge focusing and fringe fields is shown below.

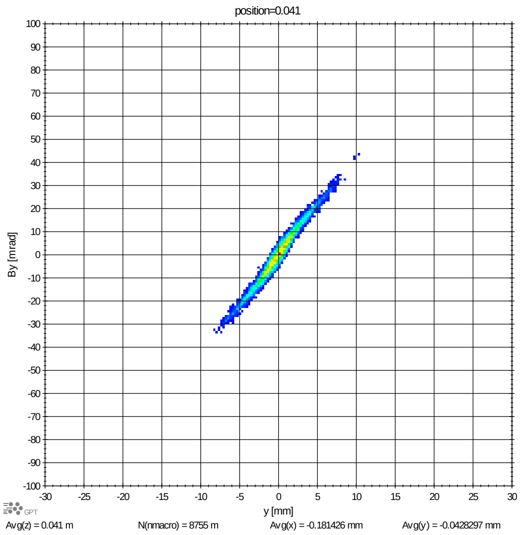


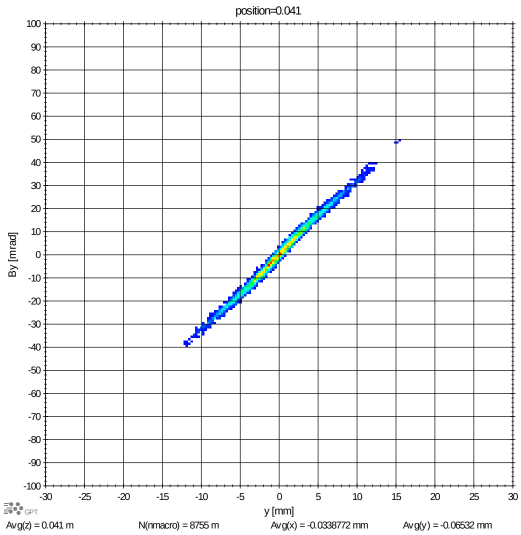
Output in direction of the "beam dump 2" transversal phase space





Exactly at the output phase of the dipole vessel (coordinate system =dipoleout) the beam shows an average displacement in angle (x direction) of -40 mrad (= not enough bend), this could lead to a significant displacement towards the beam dump 2, otherwise the distributions are quite similar. The angular displacement will be discussed later in this document.

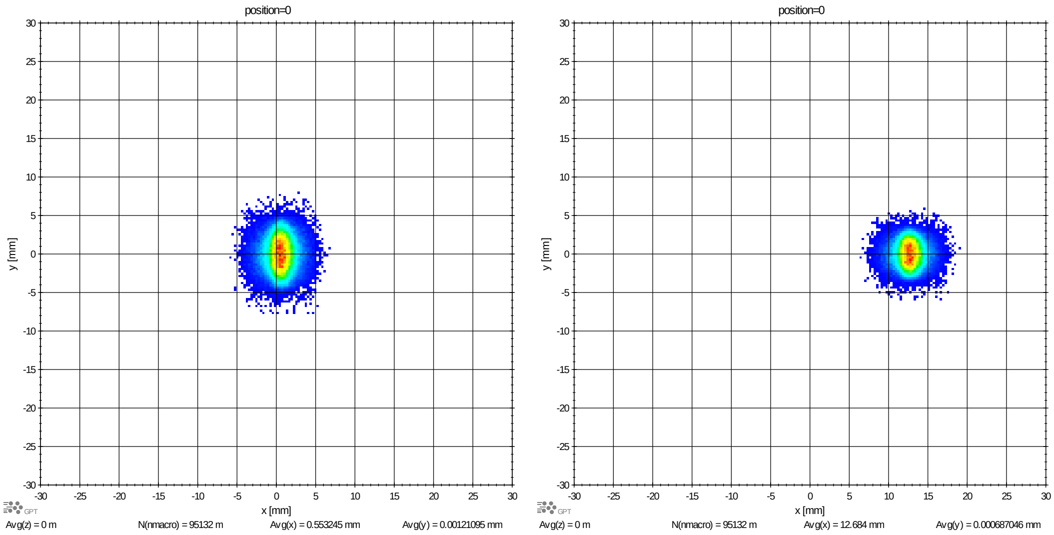




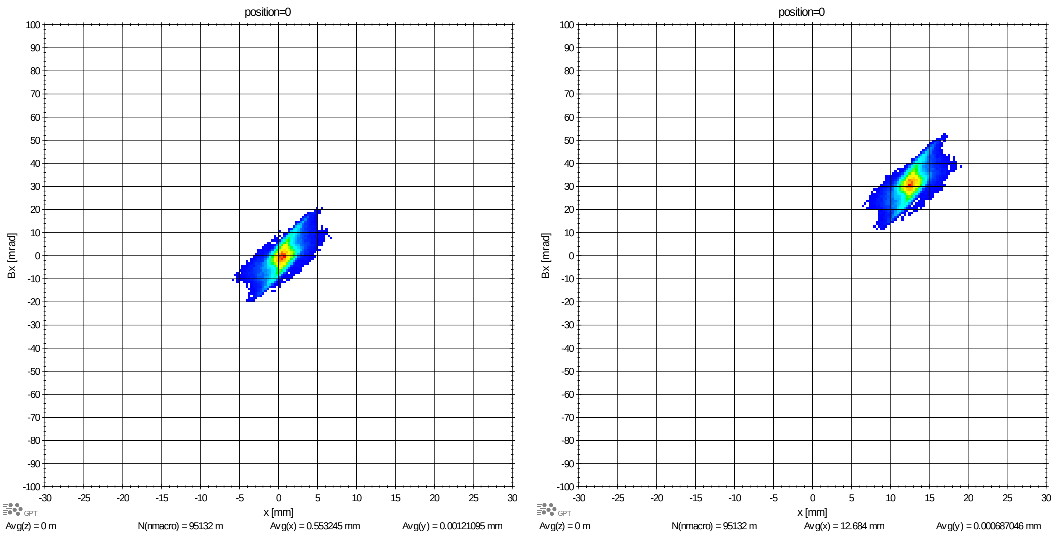
The distributions in the y phase space show differences due to the additional focusing in the y plane due to the fringe fields. These differences should not influence the beam transport strongly but the further MQP settings might need some adjustment to optimize the power distribution in the "beam dump 2".

Beam at laser interaction plane in transversal (phase) space

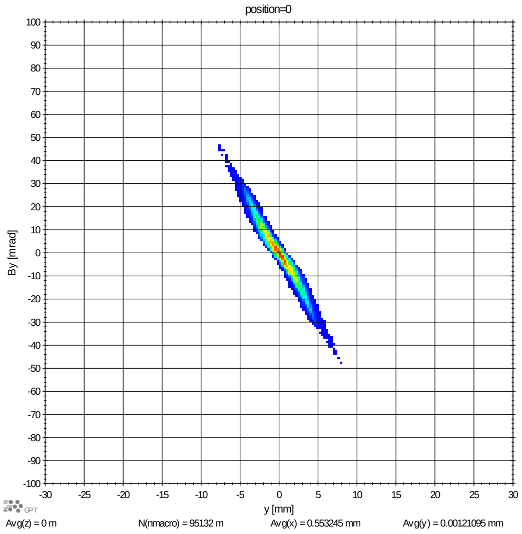
The following results are produced using ~100 k macro particles and shown in the coordinate system for the laser neutralized atoms (coordinate system =laserinteraction).

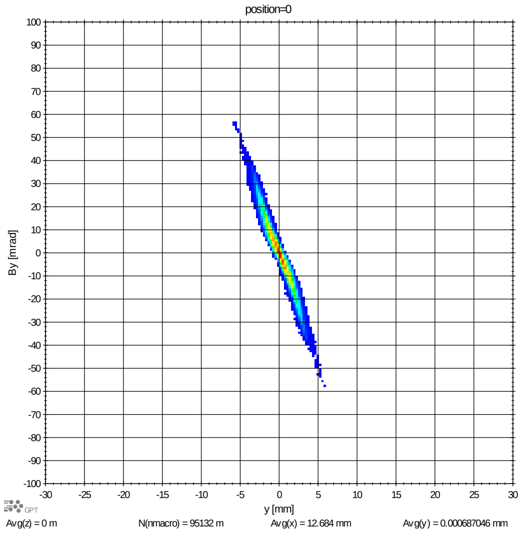


As mentioned before the particle beam at the interaction point with the laser will be displaced by ~ 12 mm compared with the case neglecting the fringe fields (interestingly the "no fringe field beam is also very slightly displaced….). As the displacement is in the direction of the laser propagation the problem is not so much that the laser will not hit the particle beam, but rather that the starting point of the particles that are neutralized will be different and therefore the algorithm to reconstruct of the emittance has to consider this.



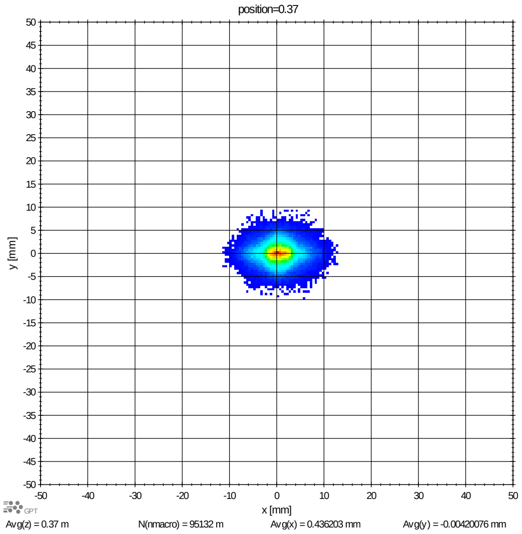
Beside the displacement in position the beam with fringe fields is also severely displaced in the angle in the x direction (+30 mrad = to much bend). This will cause the (positive) position deviation to increase with increasing drift length from interaction point to detector. These two, together with the fact that they add up will require detailed investigations with the need of a full 3D fieldmap. This has to be done on short notice as it influences directly the "orientation" of the output flange in the middle with consequences for the spaces for the MQP following the dipole and the space requirements in the back side part of the bunker.

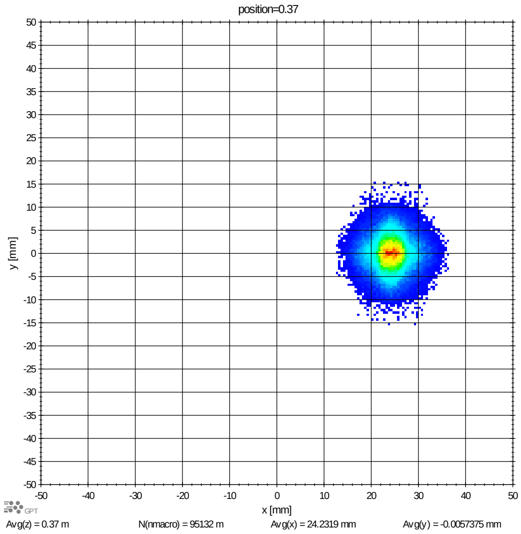




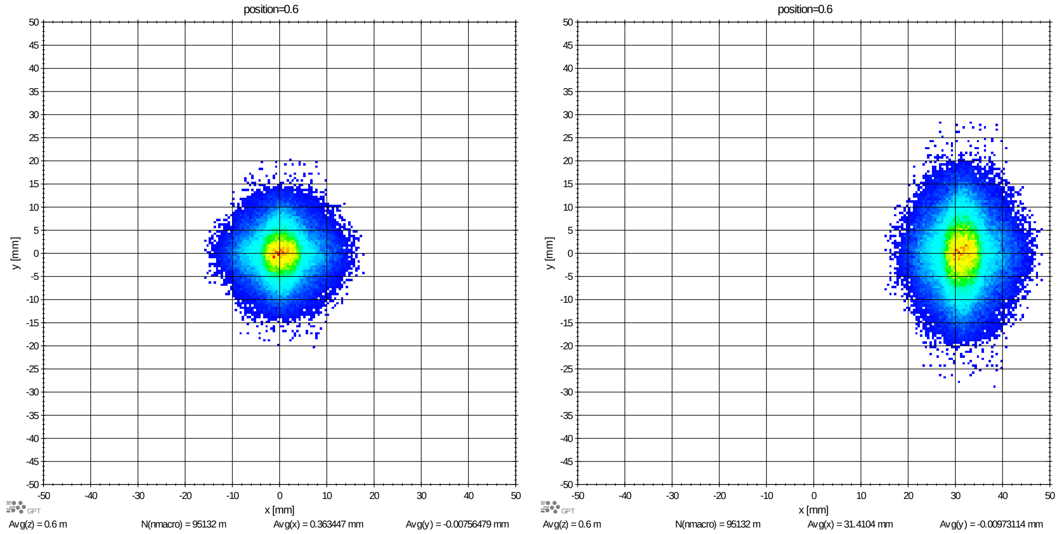
As expected both beams are well on axis in the y direction, with the minor differences due to the additional y focusing. This should not cause any significant changes.

Beam behind laser interaction plane

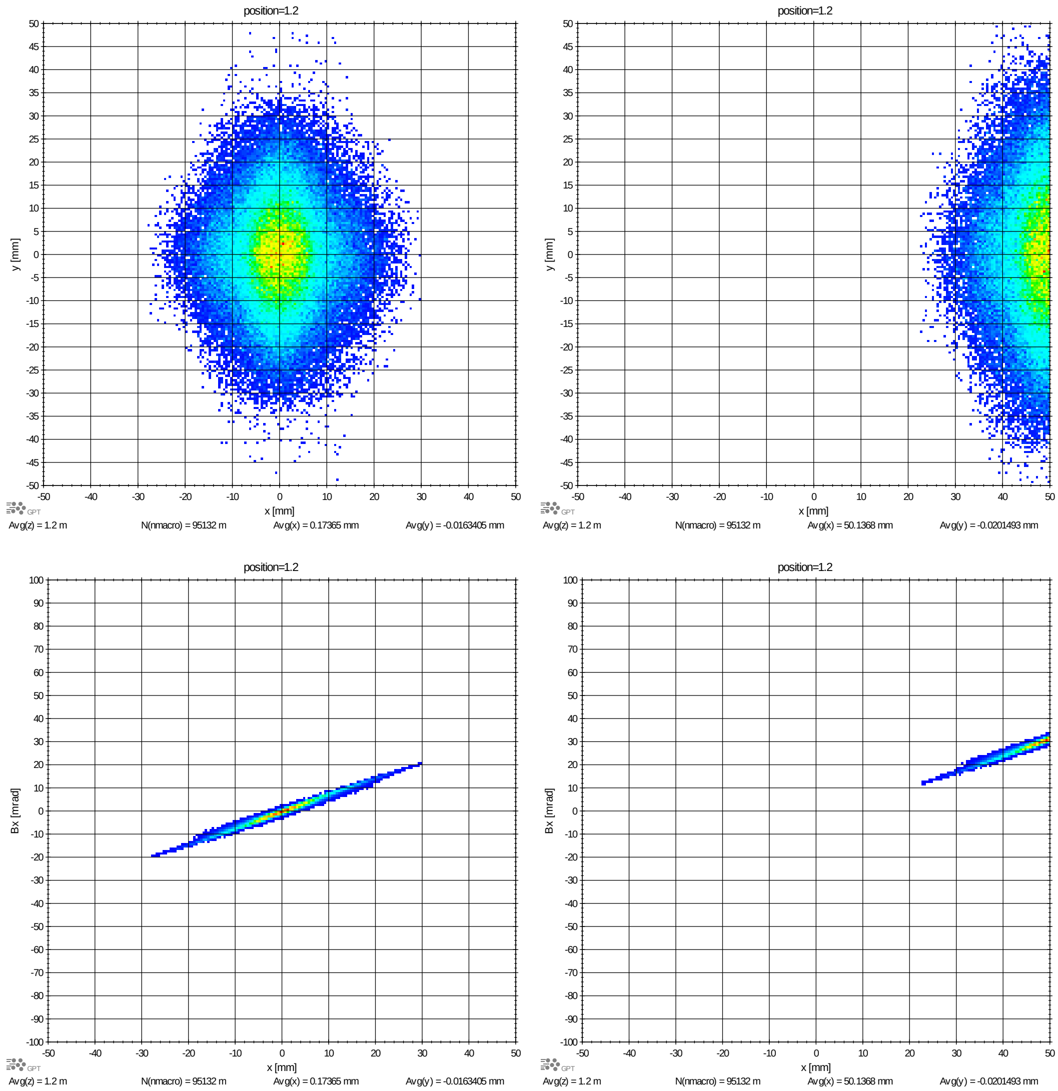




As indicated in the previous section the deviation from the nominal axis (coordinate system =laserinteraction) of the neutralized beam in position increases with drift length. In the given case the difference increases from ~12 mm to ~24 mm in the drift of 37 cm from the interaction. This point (0.37 m) is just at the inside of the LD vessel. This helps to see look if particle losses will occur at the following aperture (+- 50 mm in x, +- 25 mm in y - elliptical, so rather not in this case but any further significant increase (for instance red curve in graph on page 2) of the fringe field would).

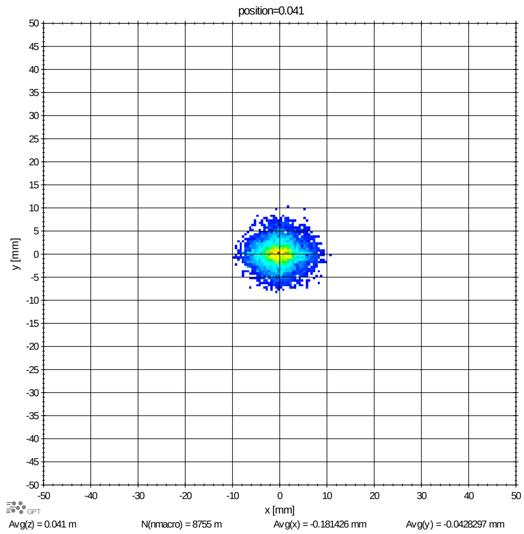


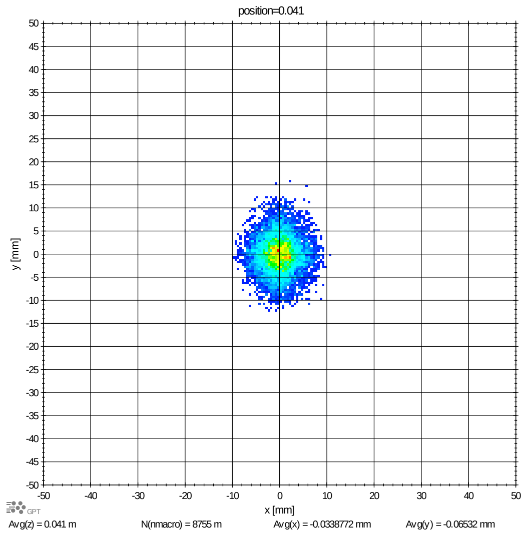
At a distance of 0.6 m from the interaction point (which is a reasonable distance to the detector as shown previously), the beam center (fringe field case) moves to ~31 mm and the first particles might be collimated on the drift tube (diameter 50 mm) or not be captured by the detector (<50 mm diameter), while at 1.2 m most of the beam would be lost.

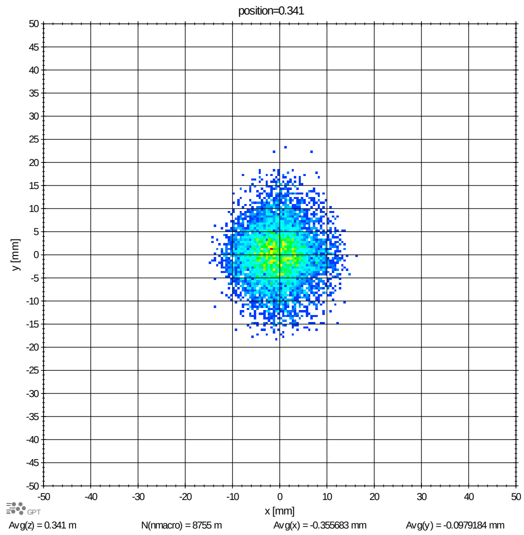


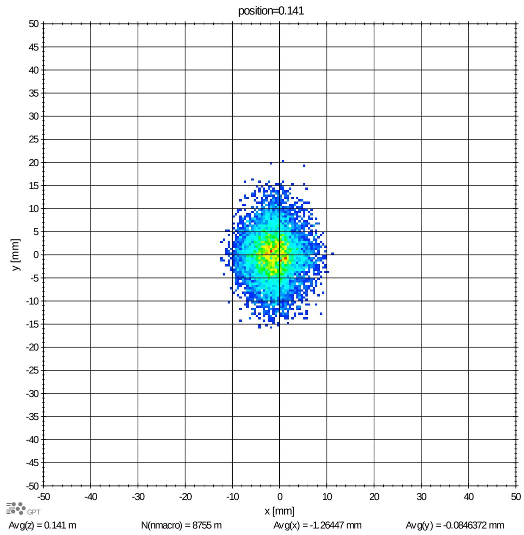
Beam in direction of beam dump 2

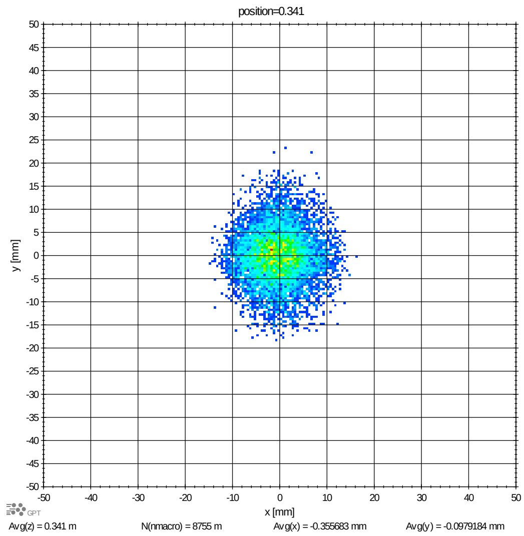
As mentioned earlier the beam leaves the diagnostic vessel at the origin of the new coordinate system for the chosen settings as shown below. But still has an angle in x at this position. Interestingly this angular offset seems to generate very little deviation in the x position when moving towards the beam dump as shown in the next plots.

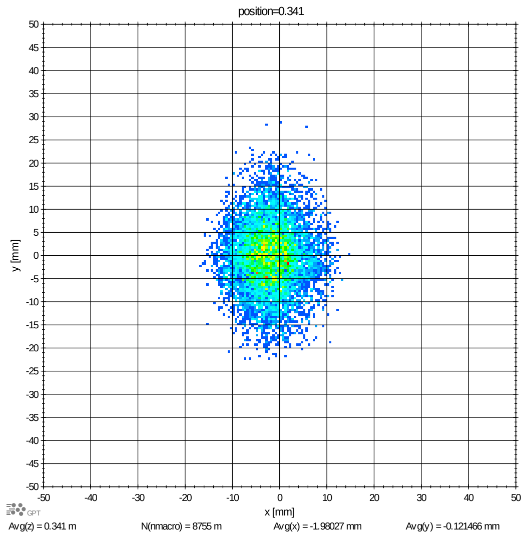


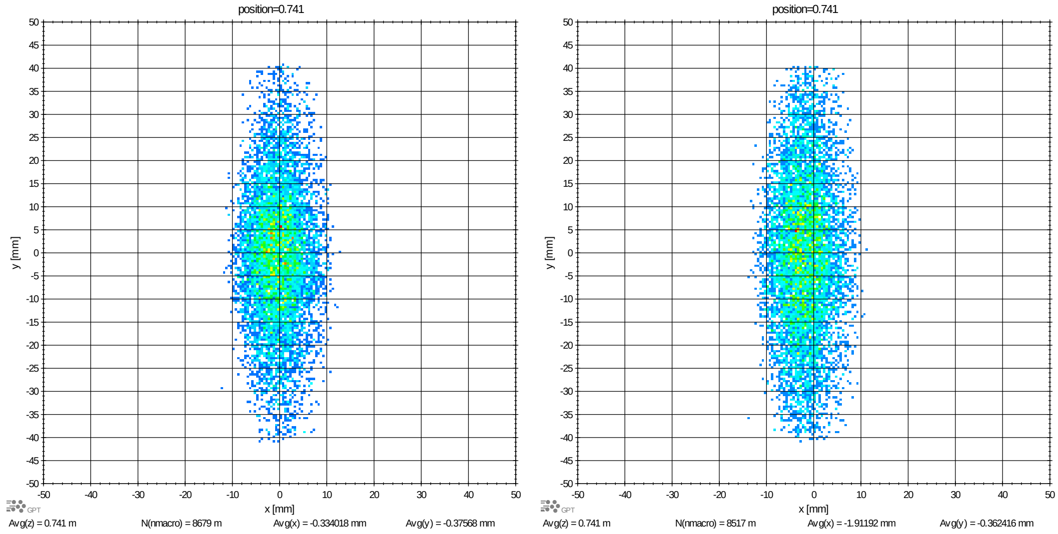




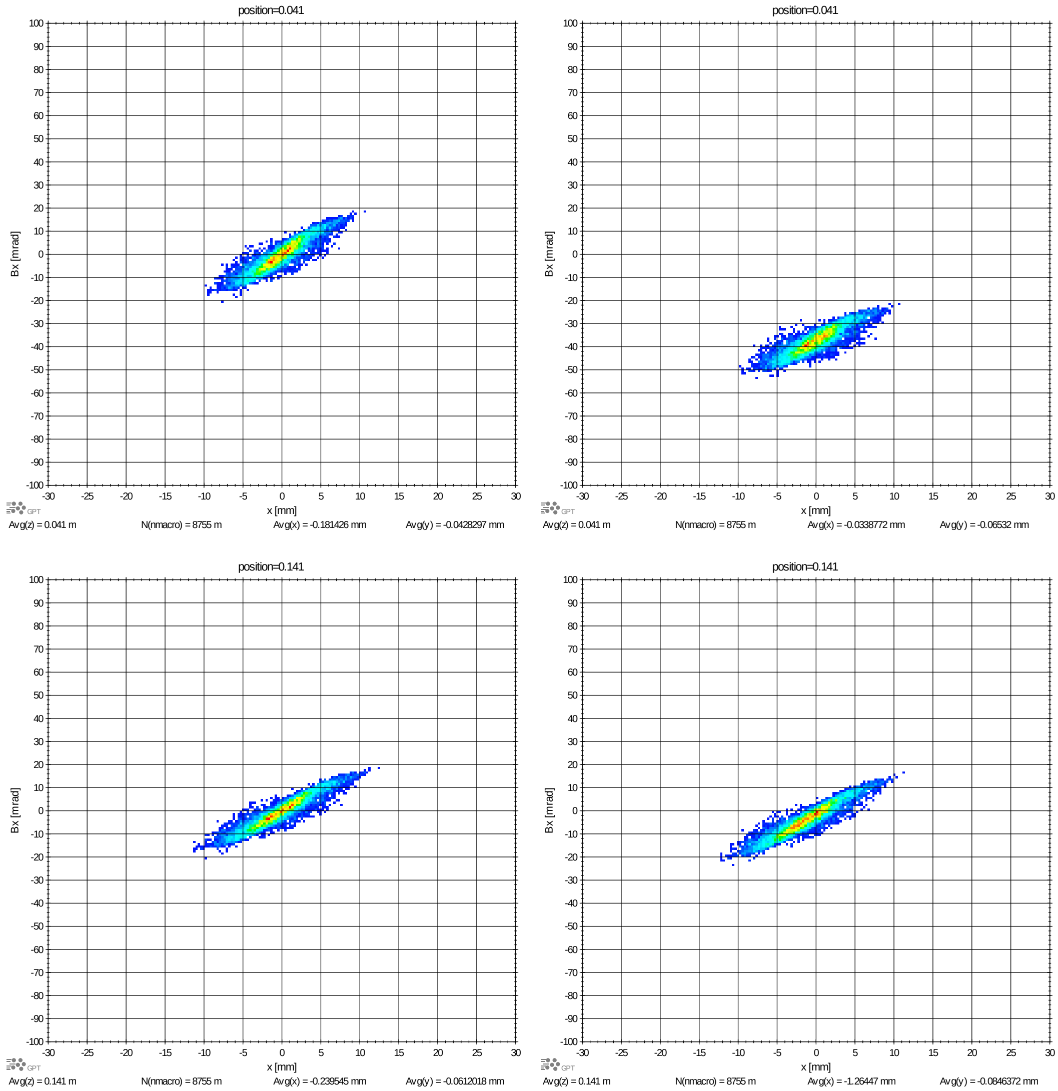


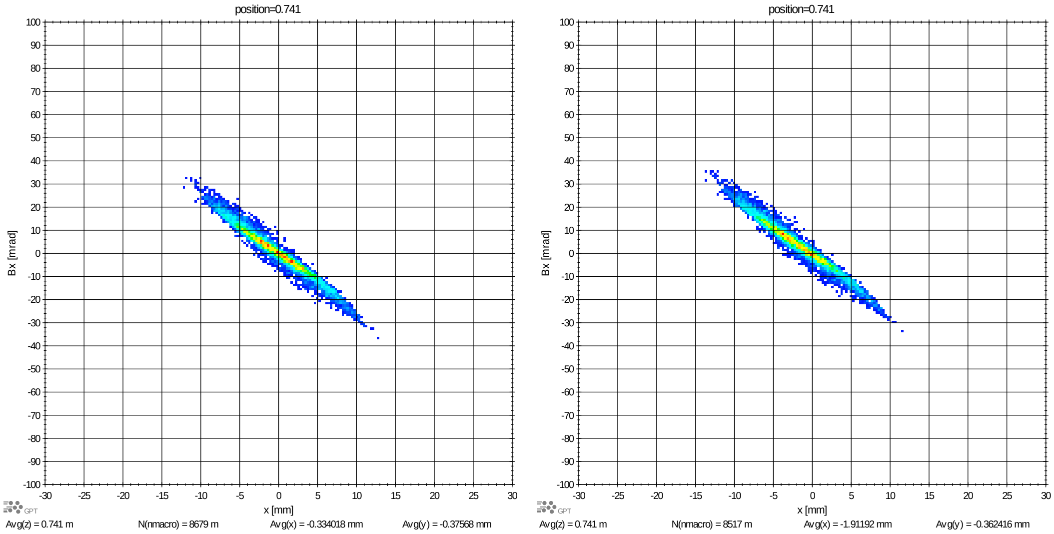






This is very good indeed as it seems to remove one potential problem, but what is the cause of this behavior. One reason is shown in the next four plots. While the beam shows the angular offset at the output phase of the dipole, the fringe field at the output corrects this practically to zero, with a remaining offset of ~ 1mm and ~ 5 mrad which would be fine for the purpose of hitting the beam dump.





Additionally the situation improves due to the MQP installed in the beamline. They effectively refocus the beam towards the“ideal” axis of the beam (in respect to the hardware). Therefore no further measures seem to be required.

Summary

Following the discussion at the FETS meeting (3.7.2013 see also presentation on webpage) a few additional GPT simulations have been performed with the goal to confirm the effects shown earlier, to demonstrate on a realistic example severe the problem is and how it will influence the further progress. The examples shown demonstrate the need of a full 3D fieldmap of an realistic dipole model. The size of the effect is large enough to require a redesign of the dipole vessel with consequences for the following beam line and the layout in the bunker. Taking the "knock on" effect into account it is clear that a trustable solution is required in a short period of time to allow for the enevitable changes to be incorporated in the overall design of the LD experiment and the final layout in the bunker.