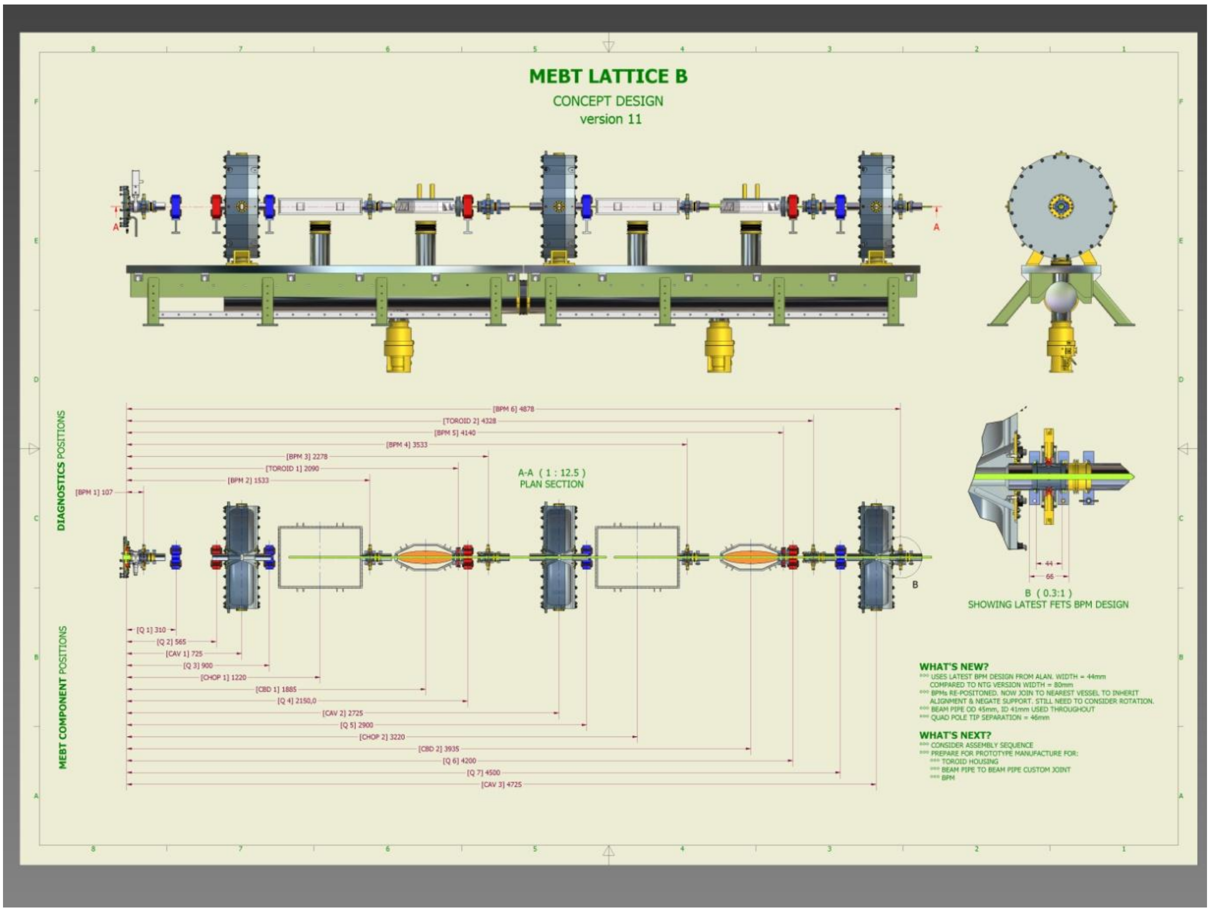
Aim

To freeze of the lattice design and to start the engineering process in earnest after the FETS meeting on 17.4.2013 it was felt that significant progress is required in very short time. Alan contribute with an field map for the cavities and the required parameters to evaluate the RF power requirements while I started a series of GPT simulations to optimize beam transport. In the following the results are summarize with the to date files available at the FETS WIKI.

Lattices under investigation:

The lattices that have been subject to the investigations are mainly based on the MEBT lattice B as shown below.



Lattice V3

The lattice V3 should be identical with MEBT lattice **B.** The aim of the work on this lattice on Thursday night was to show that this lattice can achieve a beam transmission larger 90% with the field map - significantly more than what was presented on Wednesday.

Lattice V4

The lattice V4 is based on the lattice V3 but with some modifications in the position of the beam elements. The aim of the work performed on Sunday was to increase the transmission above 95% , to address the larger MQP size that was mentioned on Wednesday as well, to further reduce the required RF power and to clean up the GPT input file. Please refer to the input files for further details.

Also an reduced beam pipe inner diameter of 19 mm (=> outer diameter of beam pipe =40 mm, distance between QP - poles = 41 mm) to reduce the difficulties (and price) of the MQP.

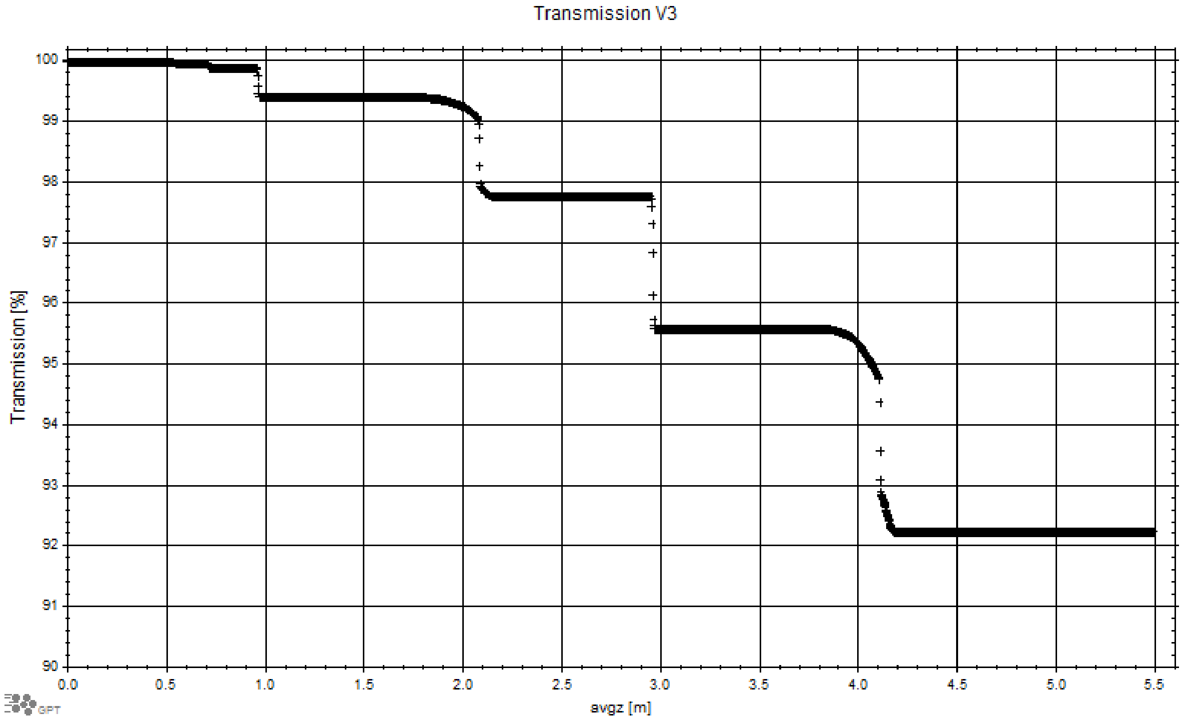
Additionally an 8th MQP was inserted between the first chopper dump and the second chopper. This MQP will reduce the losses in the second part of the MEBT by ~ 1-2 %.

It should be mentioned that the assumed radius of the cavities is 15 mm - this could ether give the opportunity to improve the cavity performance or could be seen as a further safety margin to ensure that no beam is lost in the cavity (copper) under normal circumstances (no particle loss recorded in the simulations for 15 mm so the actual cavity with >15 mm radius should be rather safe).

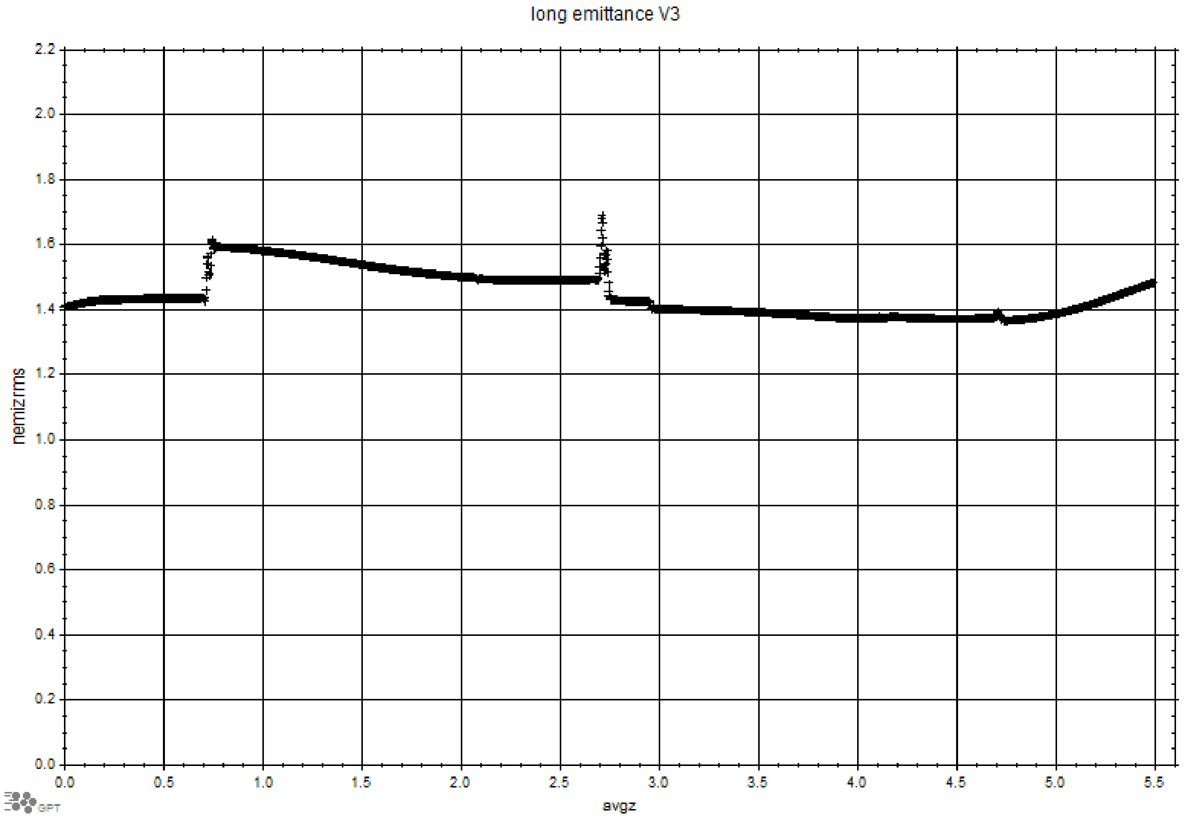
Summary of results for particle tracking using lattice V3

As the analysis has been manly performed on the V4 case this is mainly for completeness. Tracking a total of 97651 particle from the GPT output file of the RFQ simulation:

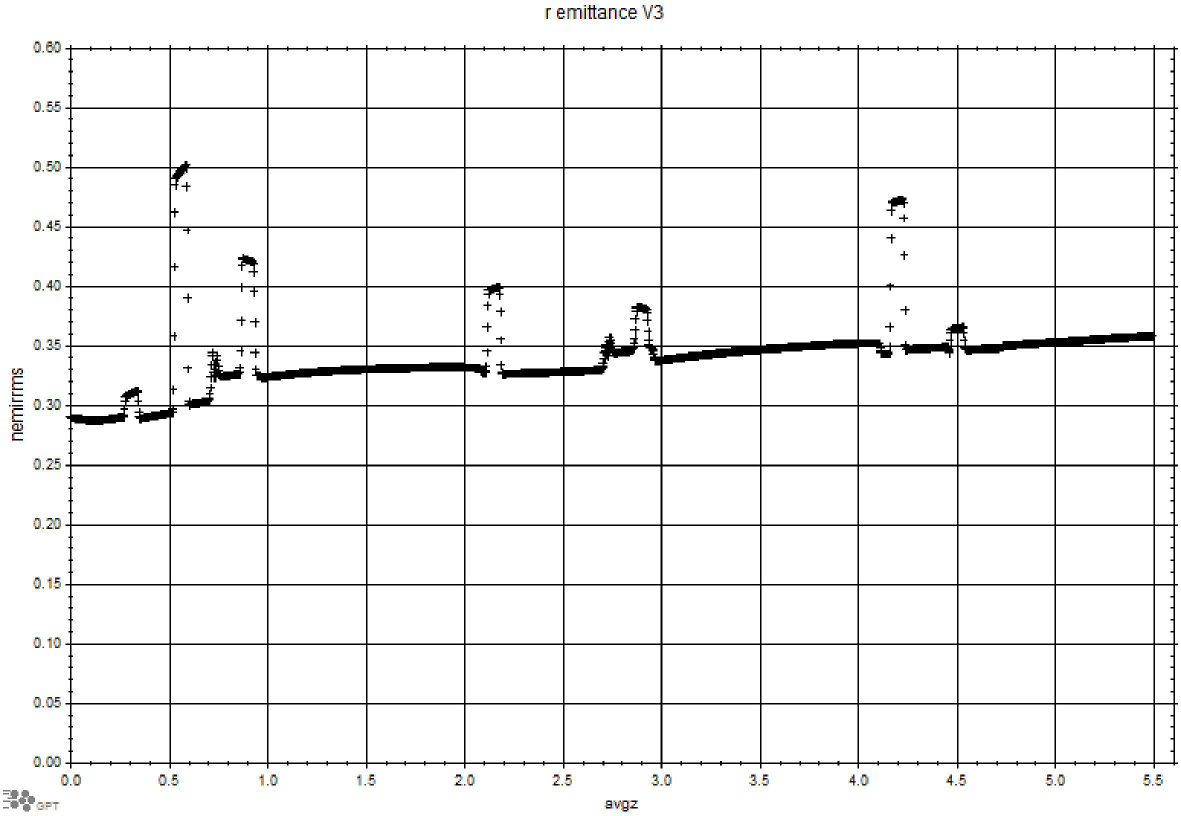
Transmission

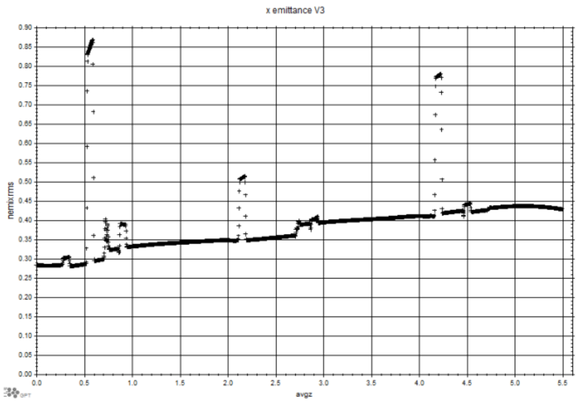


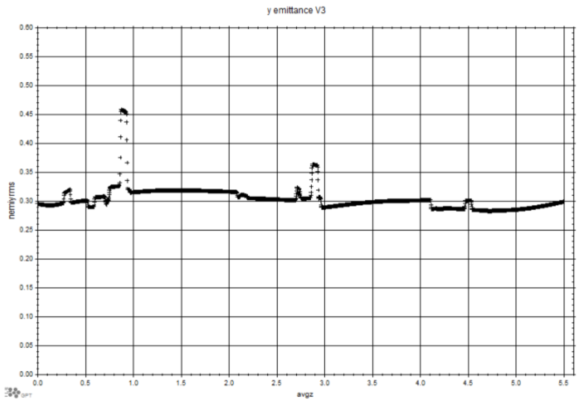
Long emittance seems not to suffer from a phase error as V4. Overall increase below 10%.



Transversal emittances



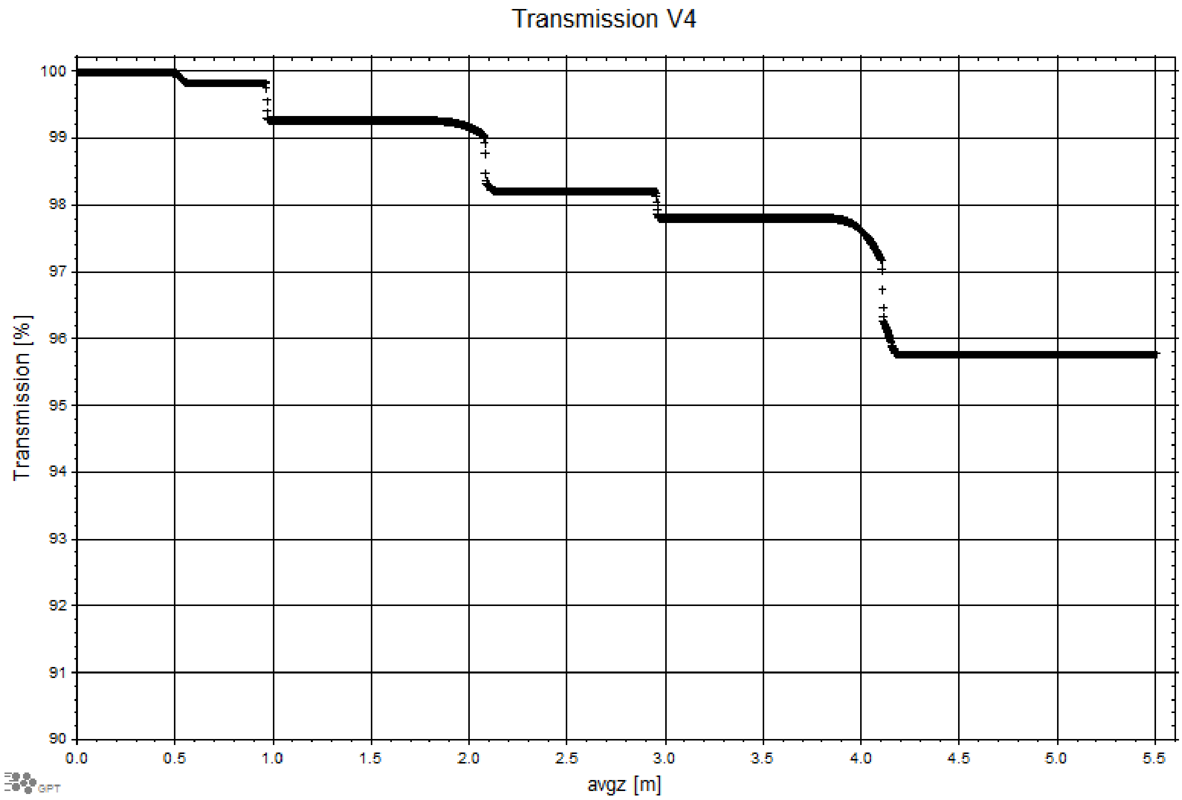




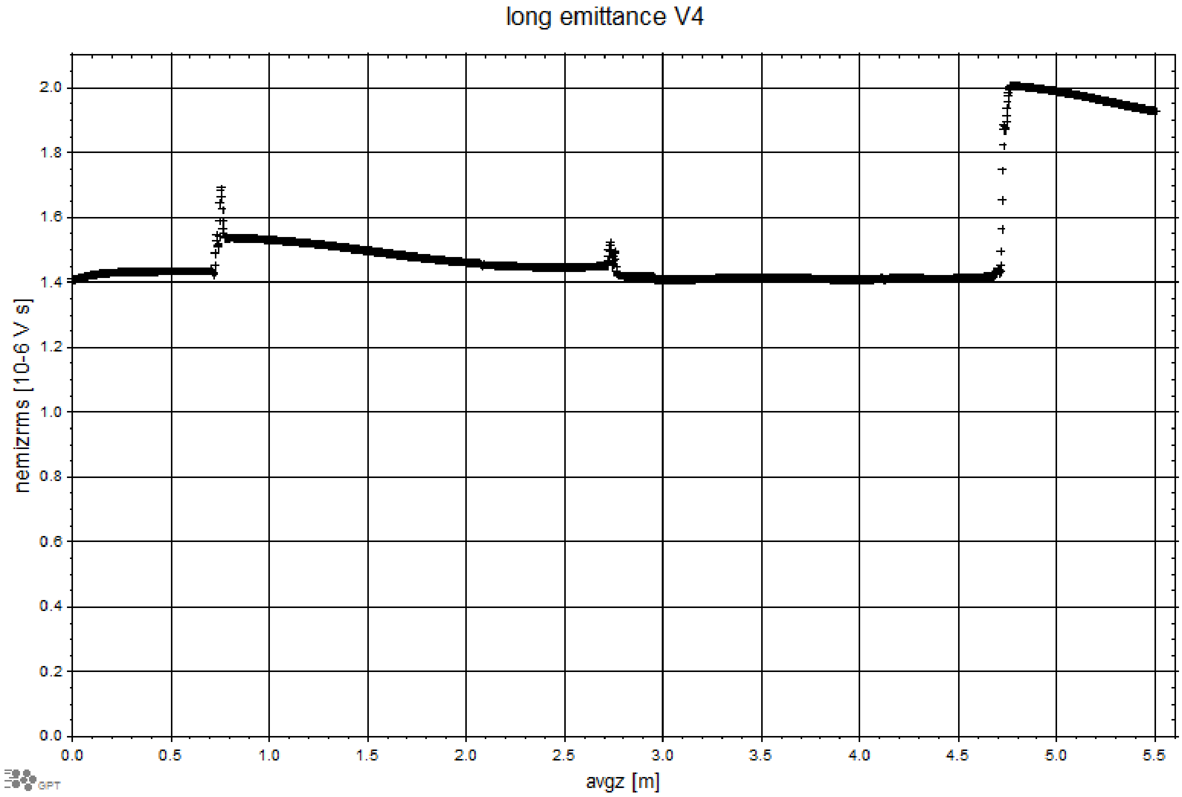
show a very similar behavior as in the case V4 with the r increase similar and the x increase even more pronounced while the y increase is virtually zero.

Summary of results for particle tracking using lattice V4

Tracking a total of 97651 particle from the GPT output file of the RFQ simulation produces the following results :

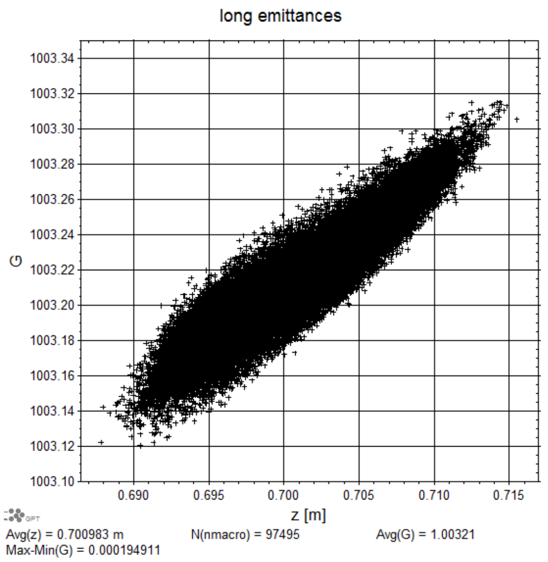


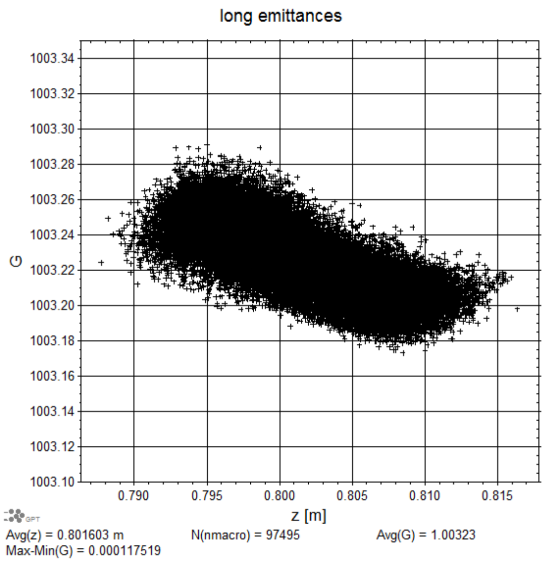
The beam transmission for this case is in the range of 95.8 %. Most of the losses occur at 4 distinct positions. The first major loss of ~0.7 % is at the entrance of the chopper (z=0.97) where a aperture collimates the beam in the y dimension to +- 10 mm (distance of the electrodes). The next major loss of again ~ 0.7 % is at the end aperture of the beam dump (z=2.09) with again a collimation in the y dimension to +- 4.5 mm. ~0.5 % is lost at the entrance of the chopper 2 (z=2.97) and the exit of the beam dump (z=4.1) with ~0.8 %. These losses in the y direction account for ~2.7 % of the total of 4.2 %. The other 1.5 % are losses on the beam pipe in the x direction (positions ~0.5 m = second quad, ~2 m = beam dump 1 to QP4 and beam dump 2 to QP7. Further optimization should allow for a reduction of those losses in x direction at positions 2 m and 4 m.



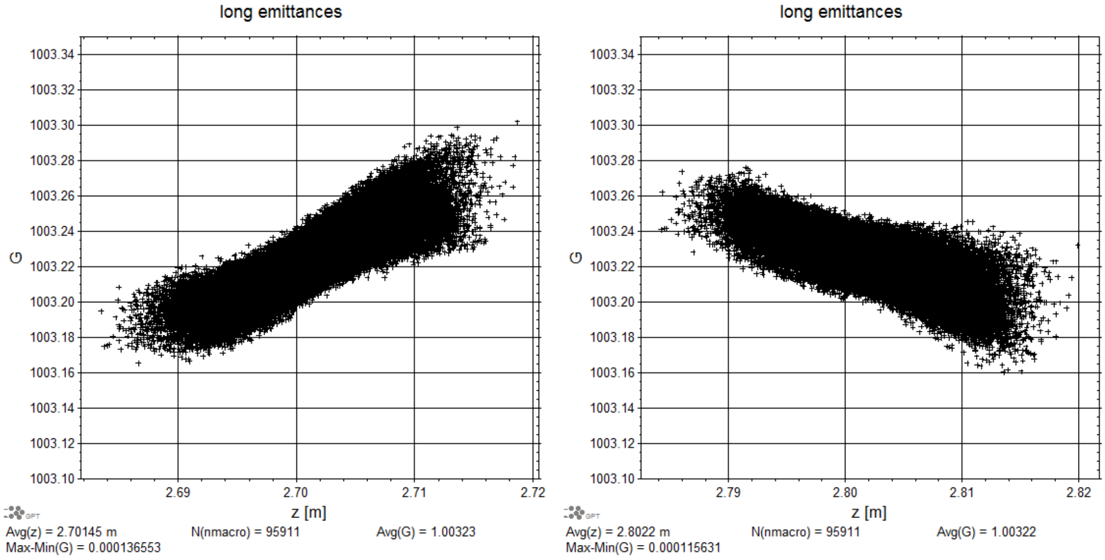
While on first sight the longitudinal emittance seems to show a strong increase of ~36% (at the end), this might be mainly a feature of the RMS algorithm. A second look confirms that a similar increase (21 %) seems to happen in the first cavity but following the emittance decreases again and reaches the original value after the second cavity. This reversible emittance growth, which is not concerning, also seems to happen in the third cavity as the development of the emittance after the cavity indicates. Interestingly this does not happen at the V3 as using identical values for the phase amplitude and position. But a more close look at the data reveals the following:

Detailed phase space plot, before / after first cavity

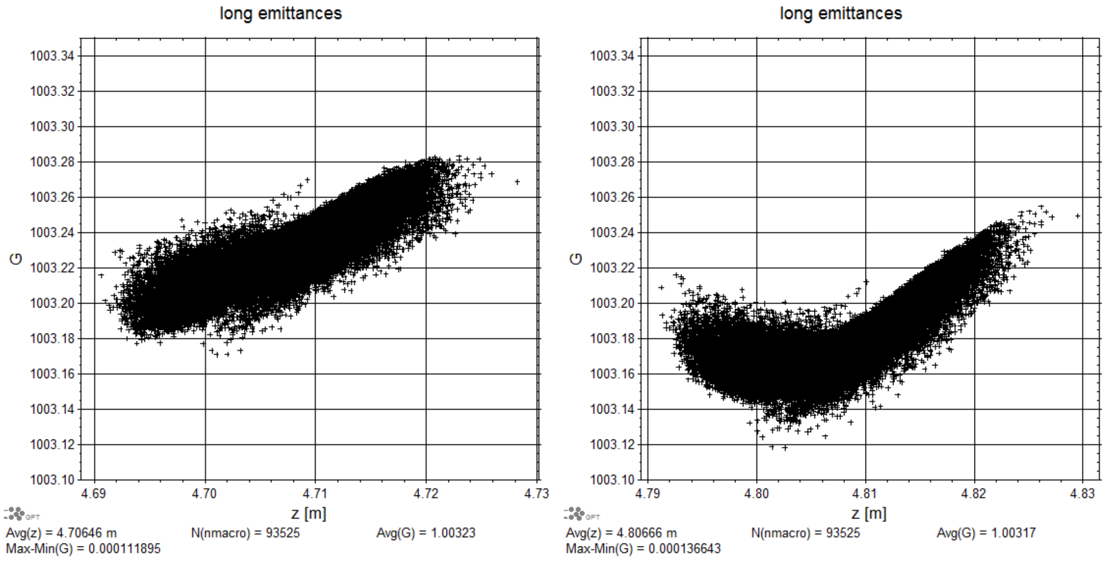




Detailed phase space plot before / after second cavity

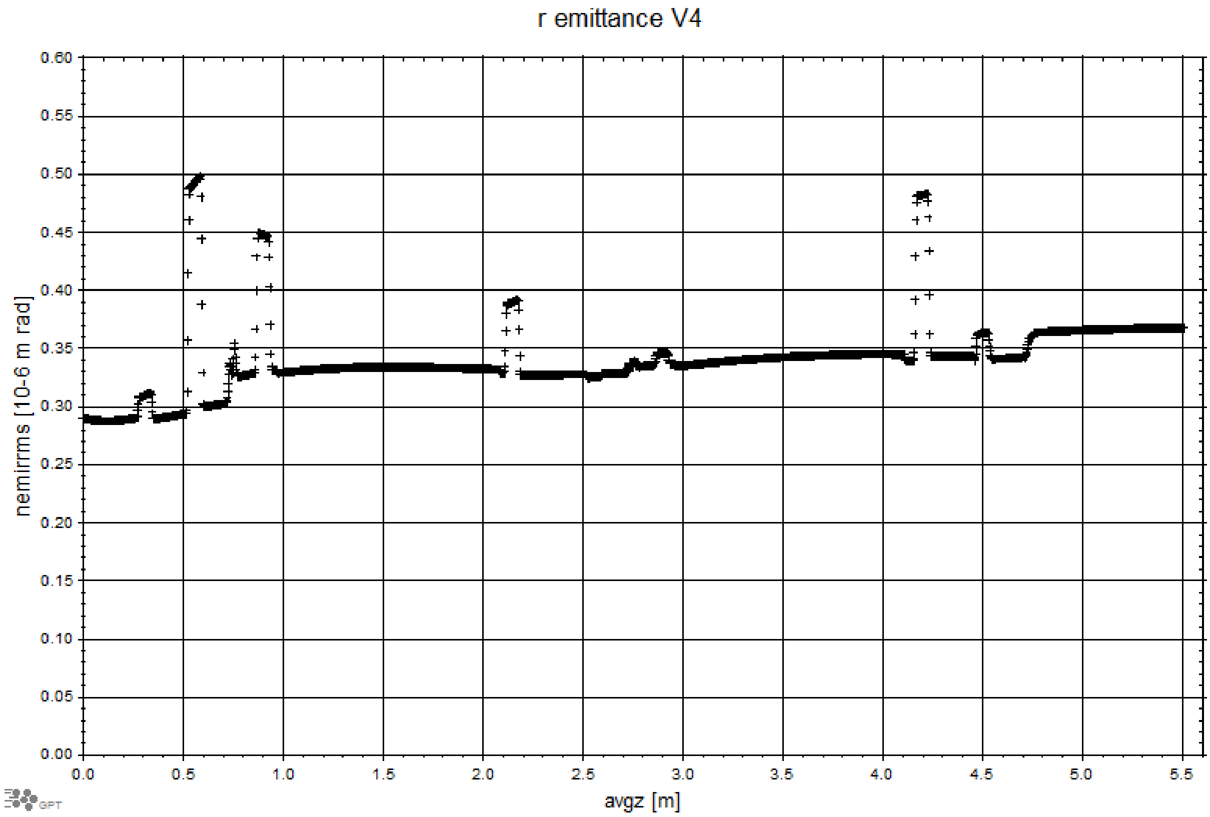


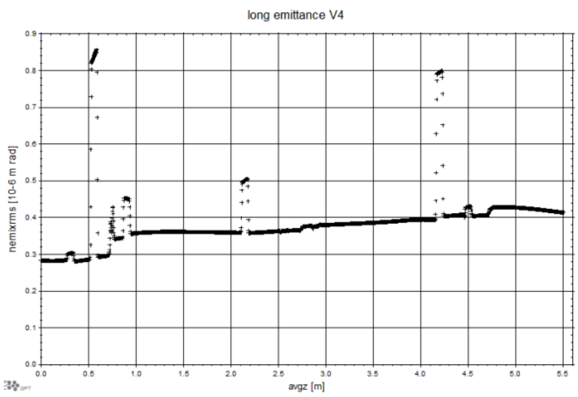
Detailed phase space plot before / after third cavity

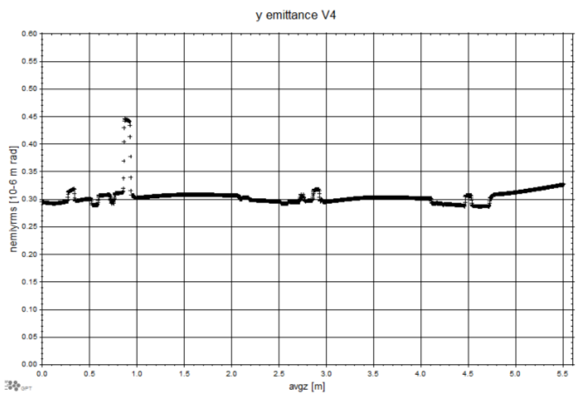


obviously the phase of the third cavity is not matched, the beam gets not rebunched but decelerated. As this has no effect on the further beam transport (and lies at the end of the MEBT, I haven't touched this value so far. A proper adjustment of the phase3 (it should be increasing the value by about pi half) should get this right, reduce the emittance growth shown and will only require 2-3 runs with GPT (~1 hour time with 10 k particles including data analyses.). I might have a go later today and will inform you on the results.

The combined transversal emittance (r - emittance) is shown below followed by the x and y emittances.



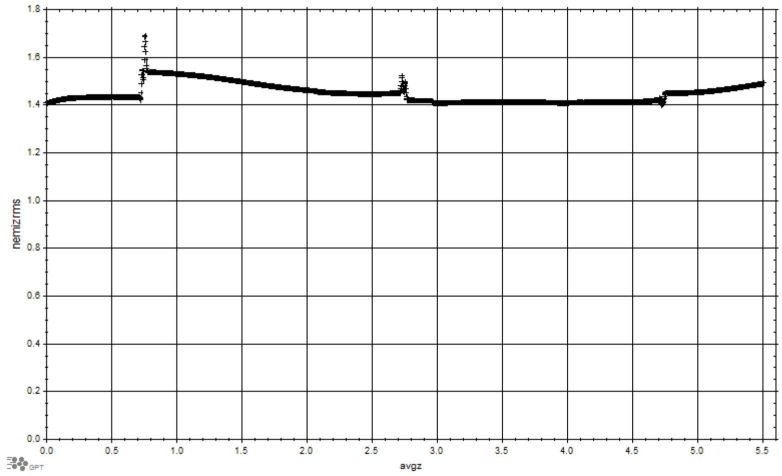


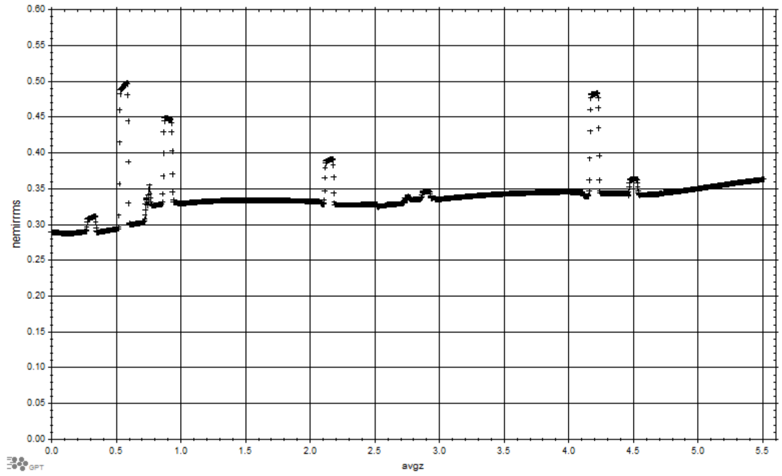


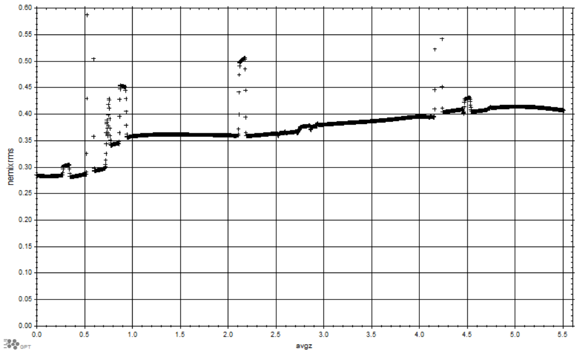
While the overall emittance growth in the transversal plane (r- emittance) is moderate in the range of 20 %, this growth is clearly dominated by the growth in the x plane (~50%) while the growth in the y plane is ~ 10 %. As long as the beam is not injected into a following accelerator the observed emittance growth is of no concern. It might be worth to look into the section between 0.5 and 1 m and understand the x emittance growth at this position.

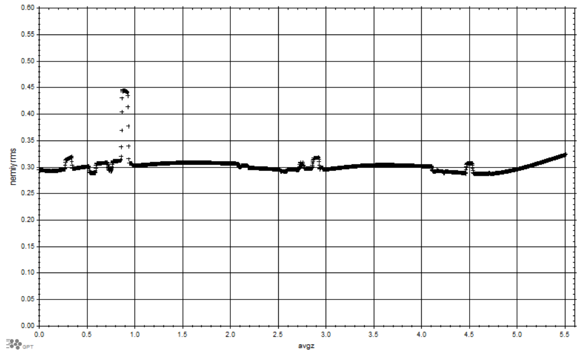
Update for particle tracking using lattice V4 concerning phase of last cavity

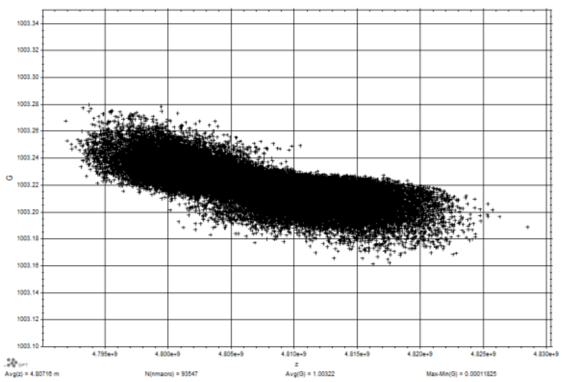
As discussed before the phase of the cavity 3 was ~ pi/2 to small. After changing the value from 1.05 to 2.4 the following results can be achieved:











Considerations for the required RF power

Using the data provided by Alan:

"I've modeled the MEBT cavity in Superfish based on dimensions taken from Pete's data. This may not be the latest version as some changes were made to accommodate pumps etc but I don't think that made much difference. The results I get are:

f = 324.04 MHz

E0 = 1.837 MV/m

T = 0.613

L = 0.15 m

E0TL = 169 kV which is the number Morteza always quotes

Epeak = 27.6 MV

P = 6286 W

U = 0.0859 J

Q = 27820

The power and stored energy given by Superfish are only for the half cell that it models so for the full cavity P = 12.57 kW. If the required voltage is actually 0.75 * 169 kV = 126.75 kV then P = 0.75^2 * 12.57 kW = 7.07 kW."

and the relation

Q= w U / P with U the stored energy and P the required RF power (or the power loss) using the scaling factors of the GPT runs and assuming that we add 25% margin accounting for the fact that the real Q is often around 80% of the SF estimate and 5% additional safety margin.

For V3 the scaling and calculated RF power are :

SCALE1=0.61	12.57 kW $*0.61^2 *$ 1.25 = 5.83 kW
SCALE2=0.45	12.57 kW $*0.45^2 *$ 1.25 = 3.17 kW
SCALE3=0.3	12.57 kW $*0.30^2 *$ 1.25 = 1.41 kW

For V4 the scaling and calculated RF power are :

SCALE1=0.59	12.57 kW $*0.59^2 *$ 1.25 = 5.45 kW
SCALE2=0.37	12.57 kW $*0.37^2 *$ 1.25 = 2.15 kW
SCALE3=0.3	12.57 kW $*0.30^2 *$ 1.25 = 1.41 kW

We should check that the fieldmap from Alan, Morteza and Ciprian are identical or sufficiently similar. I am pretty sure that we could reduce the RF level in the first cavity to 0.56-0.57 reducing the power to ~5 kW allowing for one unit and also reducing the RF defocusing which might save some particles.

Suggested further investigations (not in order of sheduling)

1) Comparison of field maps (Alan, Morteza, Ciprian) and verification of RF power

2) investigate transmission for overall beam pipe diameter of 42 (previous values, 45 pole tip distance) for V4 lattice

3) Inclusion of quadruple field maps into simulation.

4) Optimization of beam transport in V4 lattice -increase transmission by ~ 1.2 %

  - optimize cavity 1 & 3 in terms of amplitude (lower), phase and emittance growth (can be done first)

  - mainly focus on reduction of losses in the x plane - second part of lattice, MQP strength

5) decouple the last MEBT section after beam dump 2, from rest produce an input file for the last MEBT section for laser diagnostic particle tracking. (happy to do this JP as I would include further features)

6) Evaluate the power distribution in both beam dumps (can be done immediately and should be redone for the final design)

7) ....further actions could be discussed after a MEBT meeting which should happen soon....

Lattice V3 - details (just for completeness please check values if you want...)

Lattice Set-up

screen("wcs","I",0);# Usual screen at z=0

rmax ("wcs","I", 0.021);

Bfac=15.4 ; #/10.017; # Q1 correction 0.1 down

quadrupole("wcs", "z", 0.310, 0.070, Bfac);

#map3D_B("wcs", "z", 0.200,"quad_B_field_map1.gdf","x","y","z","Bx","By","Bz",Bfac); # Alan Field-map Q1

Bfac=-16.6; # Q2 correction 0.1 up

quadrupole("wcs", "z", 0.560, 0.070, Bfac);

#map3D_B("wcs", "z", 0.500,"quad_B_field_map2.gdf","x","y","z","Bx","By","Bz",Bfac); # Alan Field-map Q2

SCALE1=0.61;

PHASE1=1.75;

frequency=324e6;

k=0.0;

map25D_TM("wcs","z",0.730,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE1,k,PHASE1, 2*pi*frequency);

rmax ("wcs","z",0.725, 0.015,0.02);

Bfac=10.55; #/10.017; # Q3 # Q3 correction 0.1 up

quadrupole("wcs", "z", 0.900, 0.070, Bfac);

#map3D_B("wcs", "z", 0.800,"quad_B_field_map1.gdf","x","y","z","Bx","By","Bz",Bfac); # Alan Field-map Q3

beam chopper at 95-140 cm

#erect("wcs",0, 0, 1.200, 1,0,0, 0,0,1, 0.450, 0.450, 0.450, 1.0*0.85*0.146e6); #   First Chopper: CH1 +/- 1.15 kV @ 20 mm gap (1.26 KV for 0.75 % coverage)

#NOTE that E1=(1.15kV+1.15kV)/20mm is equal to E2=0.85*.146e6

#Juergen 12th October

#erect("wcs",0, 0, 1.220, 1,0,0, 0,0,1, 0.450, 0.470, 0.450, 0.82*0.14e6);

#erect("wcs",0, 0, 1.263, 1,0,0, 0,0,1, 0.450, 0.560, 0.450, 0.82*0.14e6);#good

#erect("wcs",0, 0, 1.243, 1,0,0, 0,0,1, 0.450, 0.520, 0.450, 0.85*0.146e6);#very good

#erect("wcs",0, 0, 1.220, 1,0,0, 0,0,1, 0.450, 0.470, 0.450, 0.14e6);   #%100 coverage factor!!

#Juergen 15th October

#erect("wcs",0, 0, 1.220, 1,0,0, 0,0,1, 0.450, 0.450, 0.480, 1.0*0.82*0.14e6);

#erect("wcs",0, 0, 1.220, 1,0,0, 0,0,1, 0.450, 0.450, 0.485, 1.0*0.82*0.14e6);

#XYmax("wcs","z",1.200,0.042, 0.020, 0.45);

#Juergen 12th October

#XYmax("wcs","z",1.220,0.042, 0.020, 0.470);

#Juergen 15th October

#XYmax("wcs","z",1.263,0.042, 0.020, 0.56);#good

XYmax("wcs","z",1.243,0.042, 0.020, 0.56);#very good

```
screen("wcs","I",1.200);# Usual screen at chopper1

#Rectangualr aperture as chopper is rectangular.

#X extension is twice the 21 mm radius of the pipe.

#For y extension we consider the chopper gap

#(20 mm between two parallel plates) lenght of chopper

#in z is 45 cm according to Mike.

# beam dump at 170-210 cm

#------Two New XY according to Juergen email and one ccs in the name of dump1 and one screen accordingly------------

#original XYmax

#XYmax("wcs","z",1.885,0.042, 0.015, 0.38);

# Now according to Juergen email:

XYmax("wcs","z",1.91,0.042, 0.015, 0.38);#kf40 flange size

#original XYmax

#XYmax("wcs","z",2.085,0.042, 0.008, 0.01);

# Now according to Juergen email:

#XYmax("wcs","z",2.09,0.042, 0.008, 0.01);

# 15th October, Juergen changes: We increased length(force on particles)

#of the chopper and the particles are chopped and hit higher positions at

#y directions and therefore there is no fear to increase the aperture size from 8 mm to

#9 mm as per below:

#XYmax("wcs","z",2.09,0.042, 0.009, 0.01);

XYmax("wcs","z",2.09,0.042, 0.009, 0.01);

#XYmax("wcs","z",2.085,0.042, 0.010, 0.01);

#XYmax("wcs","z",2.09,0.042, 0.011, 0.01);

#Most important aperture:collimator or scraper to seperate chopped from unchopped beam

screen("wcs","I",2.09);# Usual screen at dump1

#------------------------------------------------------------------------------------------------------------

# Now Juergen calculated the angle for the dump:

#(1.91-0.38/2)=172 m  and (2.09-0.01/2)=2.085 m

#0.0015/2=7.5 mm and 0.008/2=4 mm

#therefore:

#tan(theta)=(7.5-4)mm/(2.085-1.72)m  =0.0096 rad thus theta=atan(0.0096))=0.0096

#beause theta is very small.

#We need a rotation of x-z plane around x axis about the above mentioned angle to get to the dump plane,

#now we need our new z axis to be perpendicular to this plane, therefore:
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```
#define a new coordinate system with the name of 'dump1'

#ccs("wcs",0,0.004,2.085, 1,0,0, 0,cos(0.0096+pi/2),cos(0.0096),"dump1"); therefore:

#ccs("wcs" ,0,0.004,2.085, 1,0,0, 0, -0.9999,0.9999,"dump1");

#define your new screen  for this new dump 1 frame:

#screen("wcs","I", 1.91,"dump1");

#------------------------------------------------------------------------------------------------------------

#ccs("wcs",0,0,2.502, 1,0,0,0,cos(0.0096+pi/2),cos(0.0096),"dump1"); therefore:

#ccs("wcs",0,0,2.502, 1,0,0, 0,-0.9999,0.9999,"dump1");

#screen("wcs","I", 2.502,"dump1");

#------------------------------------------------------------------------------------------------------------

#Bfac=-5.0 ; #/10.017 & 4.6;

Bfac=-5.15; # correction 0.05 down

#Bfac=-5.25;

quadrupole("wcs", "z", 2.15, 0.070, Bfac);

#quadrupole("wcs", "z", 2.15, 0.070, Bfac);

#map3D_B("wcs", "z", 0.200,"quad_B_field_map1.gdf","x","y","z","Bx","By","Bz",Bfac);        # Q4     Alan Field-map  Q1

PHASE2=1.70;

SCALE2=0.45;

frequency=324e6;

k=0.0;

map25D_TM("wcs","z",2.725,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE2,k,PHASE2, 2*pi*frequency); #C2 #right for the new combined field map

rmax ("wcs","z",2.725, 0.015,0.02);

#screen("wcs","I",2.725);# Usual screen at trwcell rmax

#screen("wcs","I",2.740);# Usual screen after trwcell rmax

Bfac=7.2;  # correction 0.9 down

#Bfac=8.1; #/10.017 & 8.0;

quadrupole("wcs", "z", 2.900, 0.070, Bfac);

#map3D_B("wcs", "z", 0.800,"quad_B_field_map1.gdf","x","y","z","Bx","By","Bz",Bfac);  # Q5

#erect("wcs",0, 0, 3.243, 1,0,0, 0,0,1, 0.450, 0.520, 0.450, 0.85*0.146e6);#like chopper one for the second chopper

# beam chopper at 295-340 cm

#erect("wcs",0, 0, 3.200, 1,0,0, 0,0,1, 0.450, 0.450, 0.450, 1.0*0.82*0.14e6);                    # CH1 +/- 1.15 kV @ 20 mm gap (1.26 KV for 0.75 % coverage)

#Juergen 12th October

#erect("wcs",0, 0, 3.220, 1,0,0, 0,0,1, 0.450, 0.470, 0.450, 1.0*0.82*0.14e6);

#XYmax("wcs","z",3.200,0.044, 0.020, 0.45);
```

```
#Juergen 12th October

#XYmax("wcs","z",3.220,0.044, 0.020, 0.47);

XYmax("wcs","z",3.243,0.042, 0.020, 0.56);#like aperture for dump one for the second chopper

screen("wcs","I",3.200);# Usual screen at chopper 2

# beam dump at 370-410 cm

XYmax("wcs","z",3.935,0.042, 0.015, 0.38);

XYmax("wcs","z",4.115,0.042, 0.009, 0.01); #aperture for the second beam dump

screen("wcs","I",4.115);# Usual screen at dump2

#-------------------------------------------------------------------------------------------------------------------

#ccs("wcs",0,0,4.4876, 1,0,0, 0,cos(0.0101+pi/2),cos(0.0101),"dump2");

#ccs("wcs",0,0,4.4876, 1,0,0, 0,-0.9999,0.9999,"dump2");

#screen("wcs","I", 4.4876,"dump2");

#-------------------------------------------------------------------------------------------------------------------

Bfac=-8; #/10.017;

quadrupole("wcs", "z", 4.200, 0.070, Bfac);

#map3D_B("wcs", "z", 4.200,"quad_B_field_map1.gdf","x","y","z","Bx","By","Bz",Bfac);  # Q6  Alan Field-map  Q1


Bfac=7; #/10.017;

quadrupole("wcs", "z", 4.500, 0.070, Bfac);

#map3D_B("wcs", "z", 4.500,"quad_B_field_map2.gdf","x","y","z","Bx","By","Bz",Bfac);  #   Q7     Alan Field-map Q2


PHASE3=1.05;

SCALE3=0.3;

frequency=324e6;

k=0.0;

map25D_TM("wcs","z",4.725,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE3,k,PHASE3,  2*pi*frequency);  #C3    right  for  the  new
combined field map

rmax ("wcs","z",4.725, 0.015,0.02);

screen("wcs","I",5);# Usual screen at z=5

#screen("wcs","I",0,5,0.25);

#Bending magnet for later usage

#ccs("wcs", - 0.25, 0, 5, 0,0,1 ,0,1,0, "to");      #We define a custom coordinate system: ccs(ECS,CCSname)

                                         #ECS : the coordinate system transform

                                         #and CCSname:the name of the custom coordinate system

#Rbend = 0.25 ;

#Bbend = -m*c*G*beta/(Rbend*q) ;

#pp("Bbend=",Bbend) ;
```

```
#sectormagnet("wcs","to", Rbend,Bbend);

#tout(0, 2.3e-7, 1e-10,"wcs");                    # output at fixed time steps

#tout(0, 2.3e-7, 1e-10,"to");                     # output at fixed time steps

#screen("wcs","I",1.30);

#screen("to","I",0);            # at the end of the sector magnet

#Juergen screen Dump   for chopper 1 -------------------------------------------

ccs("wcs", 0, 0, 2.502, 1,0,0 ,0,0.0095998,-0.99995392, "Dump1"); # 1 degree

screen("wcs", 0, 0, 2.502, 1,0,0 ,0,0.0095998,-0.99995392, 0.000001, "Dump1");

#--------------------------------------------------------------------------------

#Juergen screen Dump for chopper 2 --------------------------------------------

ccs("wcs", 0, 0, 4.4876, 1,0,0 ,0,0.01009982,-0.99994899, "Dump2"); # 1 degree

screen("wcs", 0, 0, 4.4876, 1,0,0 ,0,0.01009982,-0.99994899, 0.000002, "Dump2");

#--------------------------------------------------------------------------------

#Simulation output control

tout(0, 2.3e-7, 1e-10);          # Generate output files between t=0 to t=t in steps of delta t)

dtmax = 5E-11;

#tmax=1.8e-7;
```

Lattice V4 - details - red amplitues, green positions to be checked.

rmax ("wcs","I", 0.019); - general aperture of infinite length and radius 19 mm

Bfac1=**15.22** ;

quadrupole("wcs", "z", **0.310**, 0.070, Bfac1);

Bfac2=**-16.65**;

quadrupole("wcs", "z", **0.560**, 0.070, Bfac2);

SCALE1=**0.59**;

PHASE1=0.7;

frequency1=324e6;

k1=0.0;

map25D_TM("wcs","z",**0.745**,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE1,k1,PHASE1, 2*pi*frequency1);

rmax ("wcs","z",0.745, 0.015,0.02); - aperture for cavity with radius 15 mm

Bfac3=**10.73**;

quadrupole("wcs", "z", **0.900**, 0.070, Bfac3);

#erect("wcs",0, 0, 1.220, 1,0,0, 0,0,1, 0.450, 0.450, 0.480, 1.0*0.82*0.146e6);   First Chopper

XYmax("wcs","z",**1.220**,0.038, 0.020, 0.50); - aperture of first chopper

XYmax("wcs","z",**2.09**,0.038, 0.009, 0.01); beam dump aperture at 2.09

Bfac4=**-6.1**;

quadrupole("wcs", "z", **2.15**, 0.070, Bfac4);

Bfac5=**2.9**; **- new additional MQP**

quadrupole("wcs", "z", **2.560**, 0.070, Bfac5);

SCALE2=**0.37**;

PHASE2=0.7;

frequency2=324e6;

k2=0.0;

map25D_TM("wcs","z",**2.745**,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE2,k2,PHASE2, 2*pi*frequency2);

rmax ("wcs","z",**2.745**, 0.015,0.02);

Bfac6=**6.4**;

quadrupole("wcs", "z", **2.900**, 0.070, Bfac6);

#erect("wcs",0, 0, **3.220**, 1,0,0, 0,0,1, 0.450, 0.450, 0.480, 1.0*0.82*0.146e6);

XYmax("wcs","z",**3.220**,0.038, 0.020, 0.50);

XYmax("wcs","z",**4.115**,0.038, 0.009, 0.01); #aperture for the second beam dump

Bfac7=**-8**;

quadrupole("wcs", "z", **4.200**, 0.070, Bfac7);

Bfac8=**7**;

quadrupole("wcs", "z", **4.500**, 0.070, Bfac8);

SCALE3=**0.3**;

PHASE3=1.05;

frequency3=324e6;

k3=0.0;

map25D_TM("wcs","z",**4.725**,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE3,k3,PHASE3, 2*pi*frequency3); #C3 right for the new combined field map

rmax ("wcs","z",**4.725**, 0.015,0.02);

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Updated values for cavity 3

SCALE3=0.3;

PHASE3=2.4;

frequency3=324e6;

k3=0.0;

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