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MAFIA Applied to the Beam Dynamics Study in the Lead Linac Buncher

Yu.V. Bylinsky

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Introduction.

It is known that a linac is one of the most effective machines for heavy ion acceleration up to the intermediate range of energies. Usually it consists of several parts: source, charge state filter, accelerating cavities, stripper and so on. For the CERN Lead Ion Linac the following accelerating scheme has been chosen [1]: the RFQ should provide an initial energy gain from 2.5 to 250 keV/amu with further acceleration in the interdigital-H (IH) modules up to 4.2 MeV/amu. The RFQ and the 1st IH tank both work at the same frequency but they have different transverse focusing structures. The first is a FODO; the second is a triplet-drift-triplet structure. Moreover the bunches have to enter the IH longitudinally convergent. Therefore a precise beam parameters matching in transverse and longitudinal phase spaces is needed between the RFQ and the IH. A Medium Energy Beam Transport (MEBT) has been designed for this purpose. For transverse matching it is planed to use four quadrupoles. Longitudinal matching should be done by the four-gap (interdigital) buncher. The buncher is a quarter wave resonator, similar to the GSI design for the "High charge state injector" [2].

From previous experience there was some anxiety regarding longitudinal emittance blow-up in the buncher. Normally this effect is caused by non-uniformity of the electric field in the gap.

To analyze the beam behaviour and to estimate possible emittance growth it has been decided to provide a set of calculations, including an electromagnetic field generation and a particle motion simulation. It is obvious that the structure is not cylinder symmetric so a 2-dimensional model fails. Thus the MAFIA 3-D approach has been chosen to investigate the problem.

This note should be understood as a first attempt at a qualitative analysis of the particle motion in a 3-dimensional model of the RF structure using MAFIA.

Structure description.

All the shapes and dimensions of the buncher have been provided by the LEGNARO laboratory - the collaborator responsible for the MEBT in the Lead Linac Project. The main structure dimensions are collected in Table 1. From this table one can observe that a quarter wave coaxial line occupies the main portion of the cavity volume. The drift tubes, the most complex elements of the structure, present only a small part of it. Therefore an irregular mesh was used for the structure generation: a more detailed mesh near the beam axis and a rough mesh along the coaxial line. Mesh accuracy always is a compromise between the structure shapes and the field description precision on the one hand and a total number of mesh points allowed by the code and acceptable CPU time on the other.

Table 1. Main dimensions of the buncher components.

Cavity length	800 mm
Cavity diameter	150 mm
Drift tube length	20 mm
Drift tube diameter	40 mm
Aperture diameter	28 mm
Gap length	14.35 mm
Main stem length	600 mm
Main stem diameter (tapered)	50-10 mm
Short stem length	120 mm
Short stem diameter (tapered)	20-10 mm

In the model of the buncher, the axes were oriented in the following order: x axis - parallel to the beam axis, z axis - along the coaxial line, and y axis- normal to the stems plane. Due to the symmetry relatively to the plane y=0, only half of the structure was generated. As all of the buncher elements were shaped according to the mesh, some of the mesh lines were arranged at the contours of these elements. The MAFIA generated buncher structure is presented in fig.1a,b. The corresponding command file, used by the MAFIA M module, can be found in appendix A. The total number of mesh points was approximately 85000.

Unfortunately the MAFIA TS3 module used for the beam dynamics study requires a regular mesh. To get acceptable precision one should apply an enormous number of meshpoints. To reduce this number it has been decided to generate a short RF coaxial line having similar to the original structure the field properties around the beam axis. In order to keep the proper frequency, a magnetic tuner has been introduced at the beginning of the coaxial line. For the particle emission into the buncher volume an effective cathode was generated according to the MAFIA specification. A simplified model of the structure, having about 147000 meshpoints (2.5 mm meshstep), is presented in fig.2a,b and the command file can be found in appendix B.

Field generation.

To create an electromagnetic field in the structure, the MAFIA modules R and E were used. Interesting resonant modes should present a tangential electric field at the plane y=0 because a longitudinal accelerating component is desired on the beam axis. This plane was considered as a "magnetic" wall. All other planes: z=zmin, z=zmax, x=xmin, x=xmax, y=ymax were taken as "electric" walls with tangential magnetic field components on them. The working frequency of 101.28 MHz was tuned by varying the coaxial line length in the "full" model and the magnetic permeability of the tuner in the "simplified" model. Each step of the frequency tuning occupies about 2 hours CPU time on the PARCB cluster of the CERN IBM computer.

The longitudinal and transverse electric field components were compared in the models. One can observe these component distributions along the beam axis (see fig.3.2 a-c) and in the middle of the second gap along the stem direction (see fig.3.1 a-c) (the components are normalized to the highest value of the electric field). From these pictures one can see that the dipolar field component in the gap centre (one of the problems of the IH structure) is 10 times less than in the IH tank [3]. Moreover it is practically symmetric relative to the gap center due to smaller ratio of gap to drift tube diameter (0.8-1.2 in the IH tank and 0.36 in the buncher). Therefore the dipolar component influence on the beam can be neglected. However there is the normal transit time factor dependence on the transverse coordinate. It has a Bessel function form. A typical curve obtained for the buncher electrostatic model [4] is presented in fig.4. Fig.3 shows that there is a difference in the field distributions for the "full" and "simplified" models. But it is not large and we assume that a particle motion in the "simplified" model is similar to the original one. In fact this difference is of the same order as the discrepancy of the field distribution in the "full" model due to finite mesh size and consequently non-smooth contours of the buncher elements.

All of the following beam dynamics study uses the "simplified" model.

Initial bunch parameters.

In order to save CPU time it has been decided to study the beam dynamics for the buncher without the exact desired frequency. After several steps of the frequency tuning, the frequency becomes 89.81 MHz. To keep correct phase relations for the particle motion their velocity has been recalculated. The bunch parameters based on the MEBT design are collected in Table 2.

Table 2. Main bunch parameters

Energy	0.199 MeV/amu
Energy spread	±1.3 % (±2.8%)
Bunch length (89.81 MHz)	74 degree (180 - long bunch)
Bunch diameter	10 mm (25 mm - thick bunch)
Transverse divergence	±20 mrad (±11.5 mrad)

From the available MAFIA options, all phase densities were distributed as Gaussian. Unfortunately it is not possible in MAFIA release 3.1 to fill the phase ellipses in the input of the structure in the same manner as in the TRACE-3D calculations used for MEBT design. Thus for this study a three dimensional cylinder was created as a bunch. Initial phase portraits are presented in fig.5a-c. Particle momentum there is measured in $\beta\cdot\gamma$, where β is a relative velocity and γ is an energy (Lorentz factor) of the particle. Due to the bug in the code it has appeared that initial energy spread become ~2 times more and initial transverse divergence ~2 times less (see values in brackets in Table 2 and Nominal Input Set in Table 3). The corresponding command file, used by the MAFIA TS3 module, can be found in appendix C.

Field parameters definition.

In addition to the most important field parameters, namely the mode and the frequency, two other main parameters should be described. They are the amplitude and the phase of the field. A first approximation for the amplitude was defined in the following way. The effective gap voltage 25 kV is known from the MEBT design. From the longitudinal field distribution (see fig.3) it was found that the accelerating field amplitude at the beam axis is 0.37 of the maximum electric field. Eventually, taking into account the transit time factor, the field amplitude of 6.8 MV/m was used. Later it appears that such field provides slightly more longitudinal phase portrait rotation than in the MEBT design. It means that all further estimations for the emittance growth are slightly pessimistic.

The initial phase was calculated and then corrected to satisfy the main property of the buncher: the bunch centre should pass through the gap centre at zero field. In this way one should take into account the bunch length, the distance from the effective cathode to the first gap centre, and the initial field distribution (in zero phase there is a maximum of the decelerated field in the first gap). Finally, the field phase of -75 degrees was used for nominal bunch length.

For the "long" bunch the following field setup has been used: amplitude: 6.3 MV/m; initial phase: -130 degrees.

Beam dynamics study.

To examine the beam behaviour, particle dynamics was calculated for three different cases: for nominal setup, for "long" bunch (phase duration 180 degrees), and for "thick" bunch (25 mm in diameter). Particle parameters were saved in a file for the bunch positions inside the first and the last drift tubes, see fig.6a,b. In the MAFIA TS3 module, particle dynamics is calculated by finding a selfconsistent solution at each step of the integration loop. The size of the time integration step was about 0.05 nanoseconds. Typically 300 particles were used in the simulations. Getting beam through the buncher took approximately 2 hours CPU time for the above - mentioned setup (147000 meshpoints, 300 particles, 7000 integration steps).

The resulting phase projections of the bunch are shown in fig.7.1,2,3. One can observe a dispersion in the longitudinal motion for the particles having large phase displacement from the bunch centre. This dispersion increases for the "thick" bunch. It confirms that the particles displaced from the axis feel other fields than the particles without transverse displacement (i.e. there is a transit time factor dependence upon the radius). Particles near the "synchronous" particle do not get any energy gain (independently from their transverse position), therefore they have no dispersion in the longitudinal motion.

A similar picture can be found in the transverse motion. Particles with a large displacement from the beam axis are influenced by stronger transverse field components (see fig.3). Of course for different phases of the field the influence is different. Transverse dispersion becomes significant beginning with a beam radius of 5 mm. In addition it should be noted a transverse defocusing of the bunch. One can observe it at fig.7.1,2,3 b. From the phase projections the bunch dimensions have been obtained in the input and output of the buncher. The values (full width) of these parameters are collected in Table 3.

Concerning the longitudinal emittance blow-up, it should be mentioned that for reasonable bunch lengths (up to 90 degrees) even for thick beam (up to 25 mm in diameter) one can expect small emittance growth. Rough estimation, using the simplest technique, gives this value at about 5%. For high precision of the emittance blow-up evaluation it needs to provide a good treatment of the phase projections. The transverse emittance blow-up seems to be the same order as the longitudinal one.

Table 3. Input and output bunch parameters

	Nominal set		Long bunch		Thick bunch	
	input	output	input	output	input	output
Energy spread, %	5.6	10.2	5.7	17.5	5.7	10.4
Phase duration, deg.	70	60	169	134	70	54
Beam diameter, mm	10	12	10	12	24	24
Transverse divergence, mrad	23	31	23	32	23	52

Conclusion.

1. MAFIA release 3.1 could be used for qualitative beam dynamics

research in the Lead Linac buncher or in similarly complex RF structures. For a more detailed study the code should be developed further in the following areas:

- TS3 module should accept the irregular mesh;
- initial particle distribution generation by filling the input phase ellipses should be available;
- the phase portrait treatment should also provide the Twiss parameters of the effective phase ellipses.

2. For the designed structure geometry there is no need to compensate the dipolar field component by complicating the drift tube shapes.
3. Expected longitudinal emittance growth is less than 5% for these three cases.
4. Expected transverse emittance growth is less than 5% for these three cases.

Acknowledgments.

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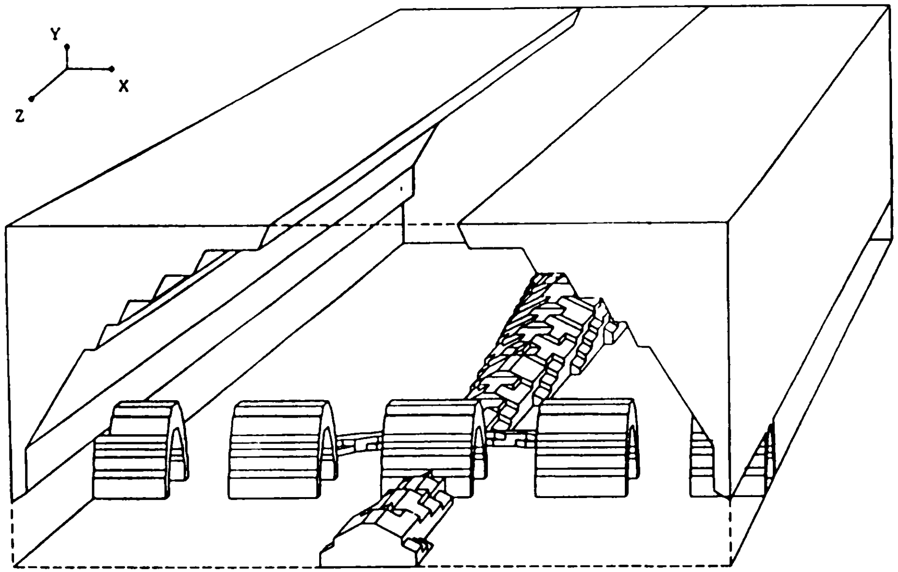
References.

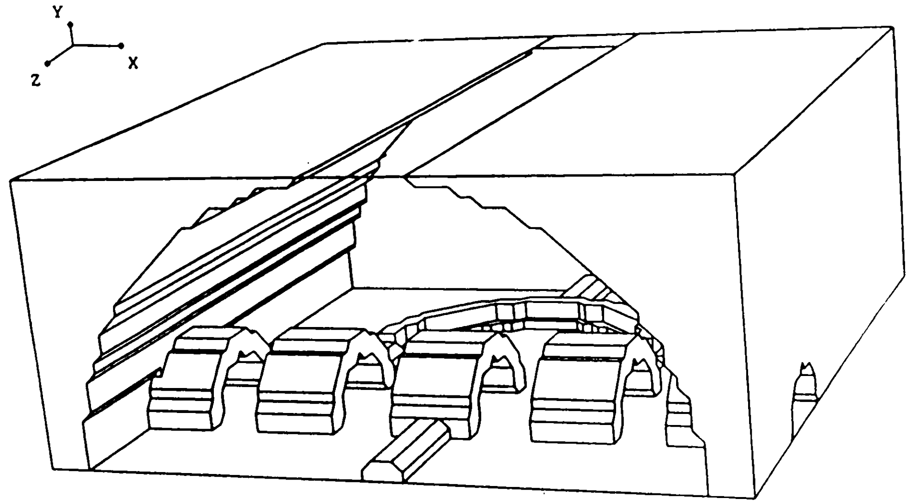
1. CERN Heavy Ion Collaboration (G.Amendola et. al., 33 authors), "A Heavy Ion Linac for the CERN Accelerator Complex", EPAC-3 Conf., Berlin, 1992.
2. W.Gutowski, U.Ratzinger, GSI Scientific Report. 1990, p.385.
3. J.-C.Nanan, "Applying MAFIA to the Study of the IH Lead Ion Linac", PS/HI Technical Note 92-03.
4. A.Parisi and A.Pisent, "Longitudinal Emittance Increase in MEBT Buncher", Report for the 12th Lead Ion Accelerating Facility Co-ordination and Specification Meeting, CERN, November, 1992.

Fig.1 Full model of the buncher

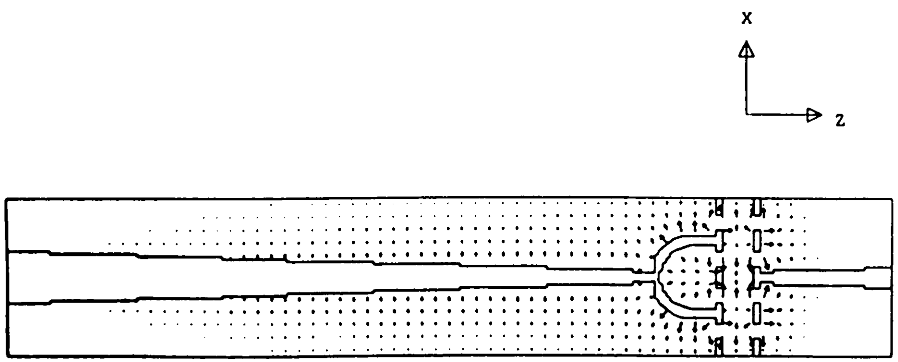
Fig.2 Simplified model of the buncher

a) 3D plot of the material distribution





b) electric field patterns at the cut plane of the structure



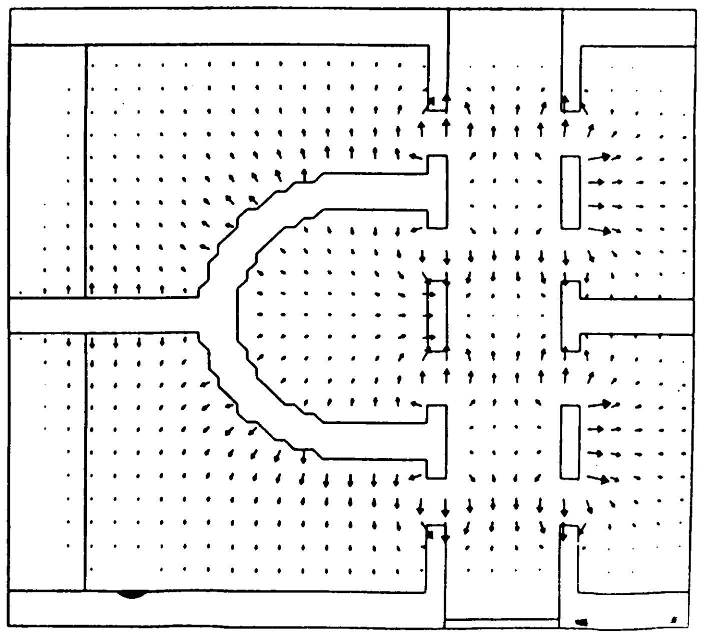


Fig.3.1 Electric field component distribution n the middle of the 2-nd gap

Full model

Simplified model

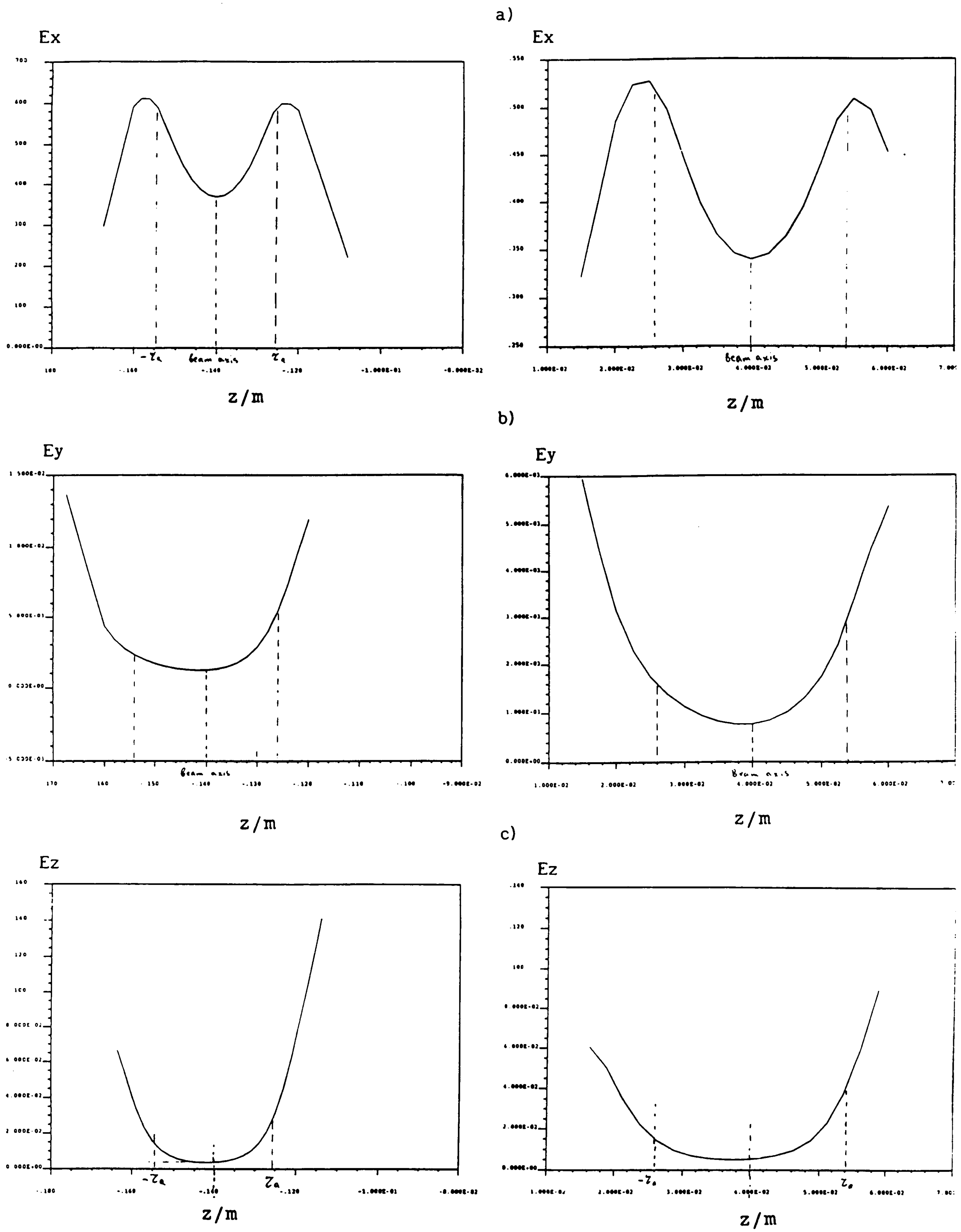
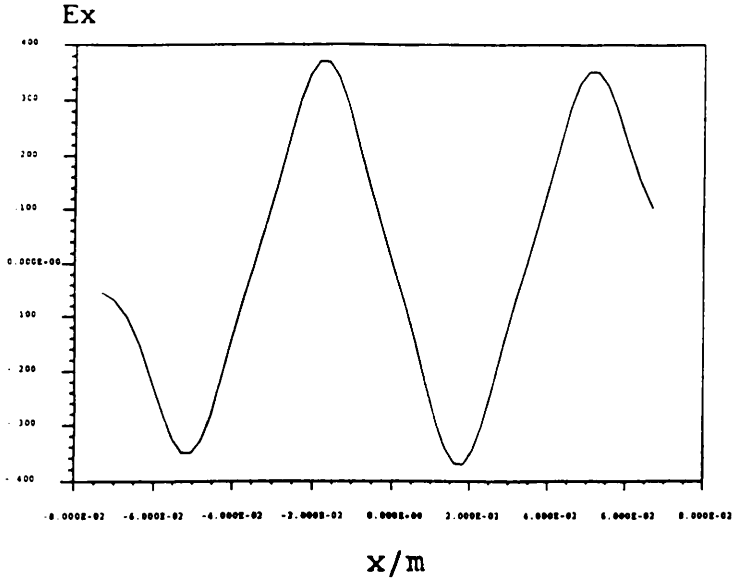
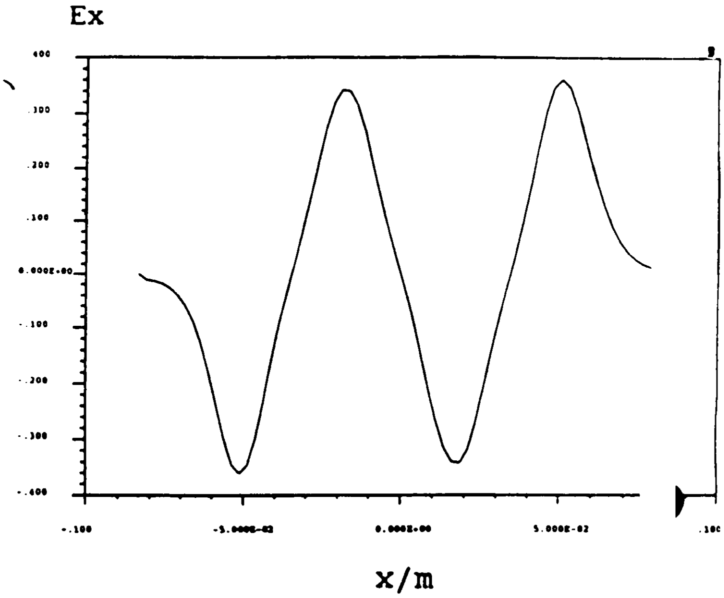


Fig.3.2 Electric field component distribution along the beam axis

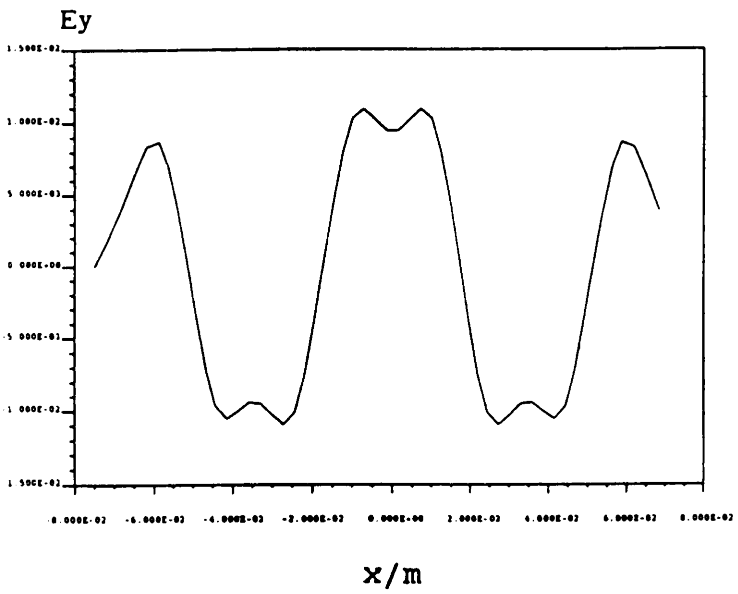
Full model | Simplified model

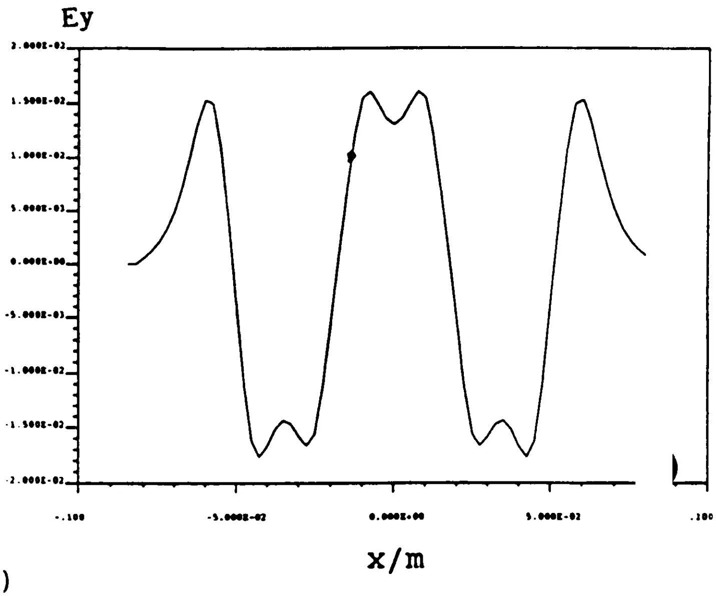
a)



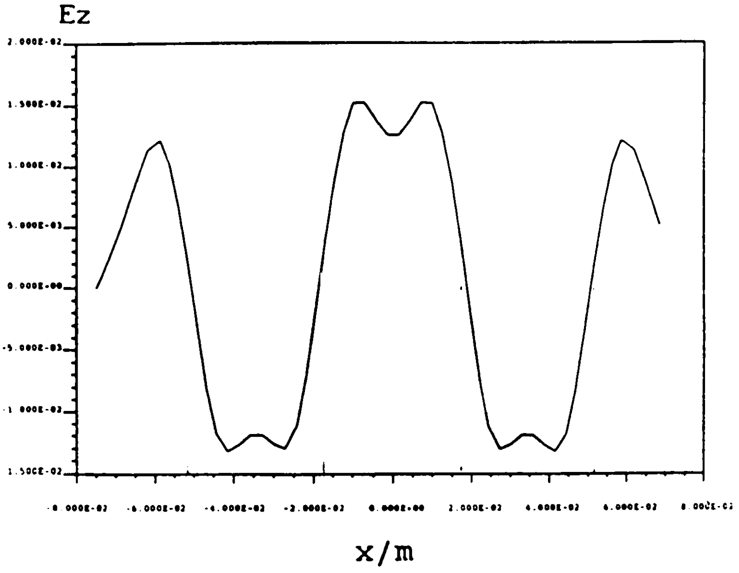


b)





c)



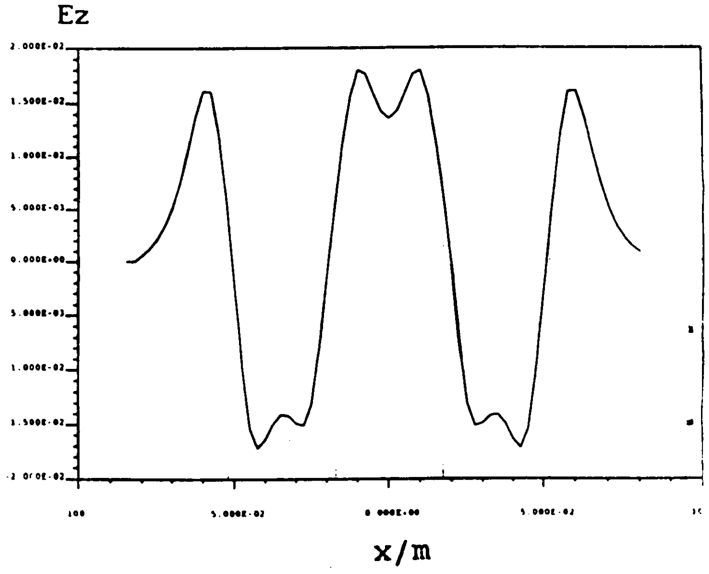


Fig.4 Transit time factor dependence on the radius
for the buncher electrostatic model

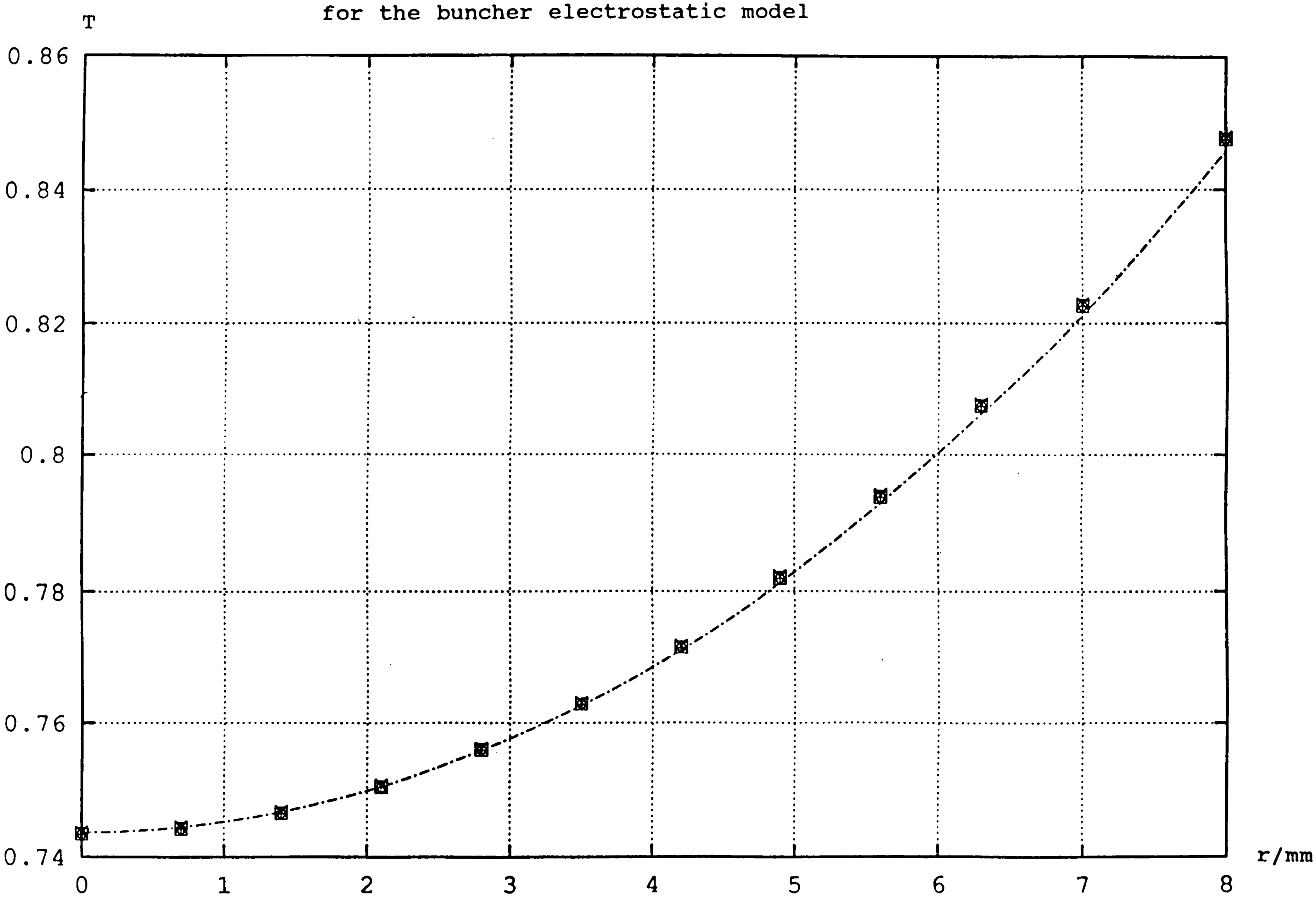
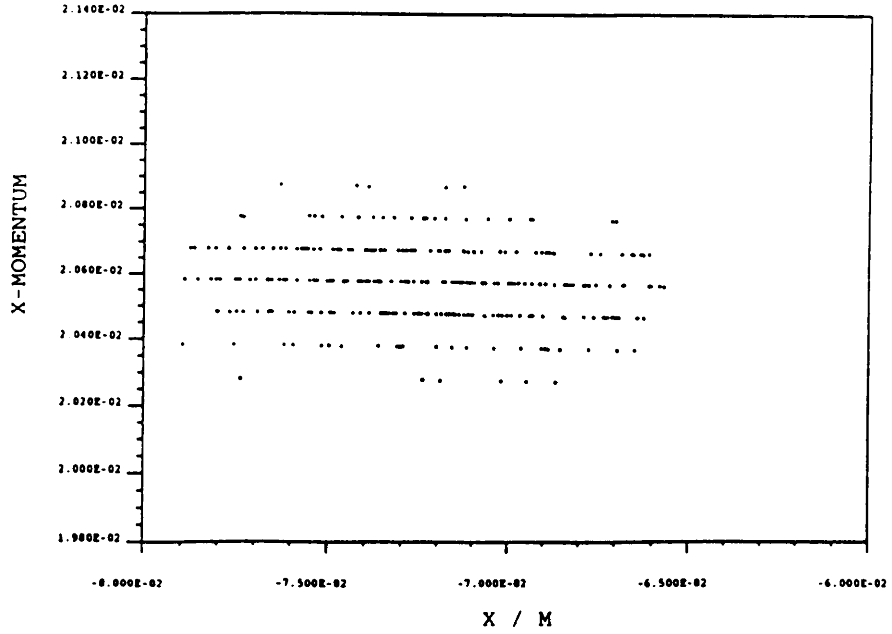
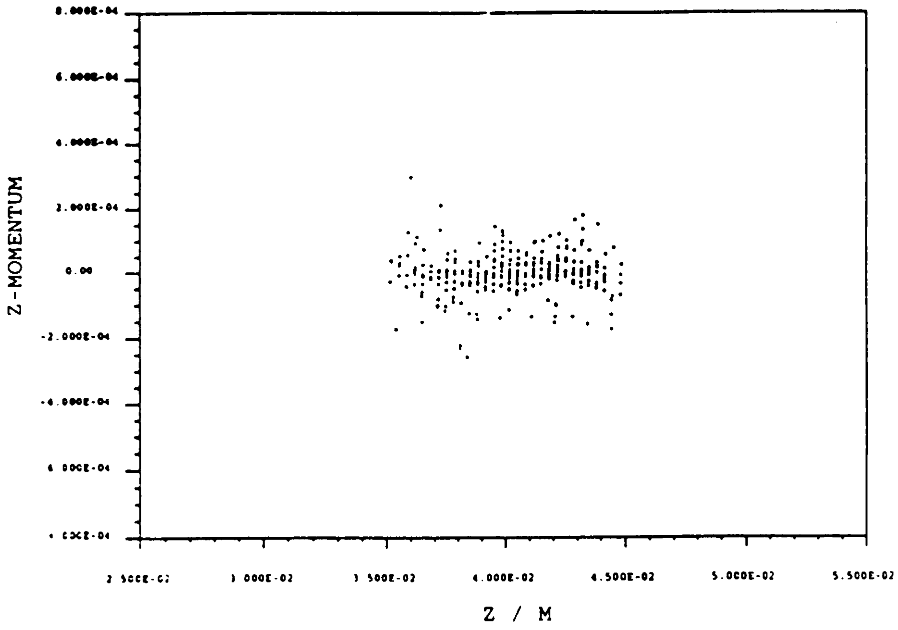


Fig.5 Initial phase projections of the "nominal" bunch

a) longitudinal phase space



b) transverse phase space



c) real transverse plane

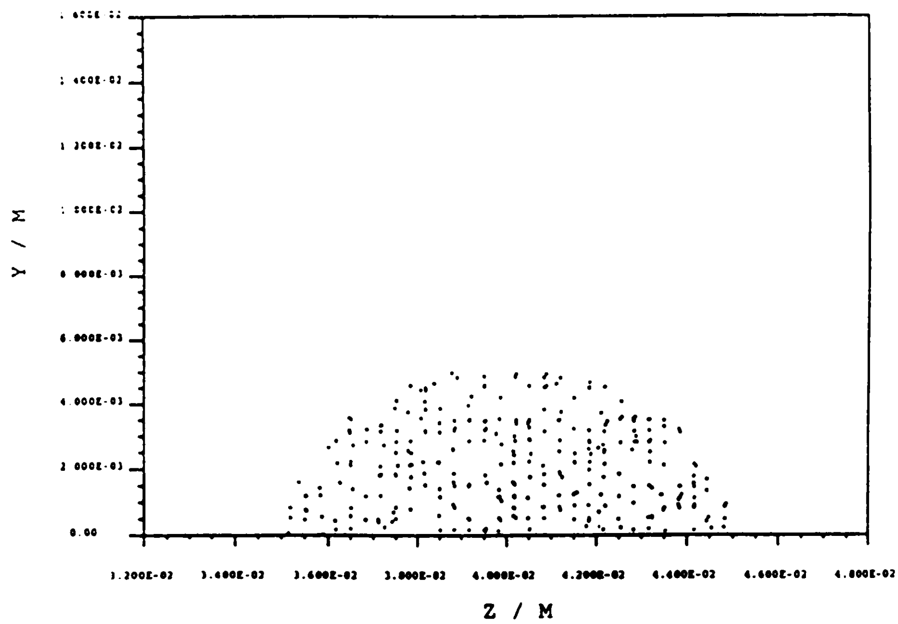
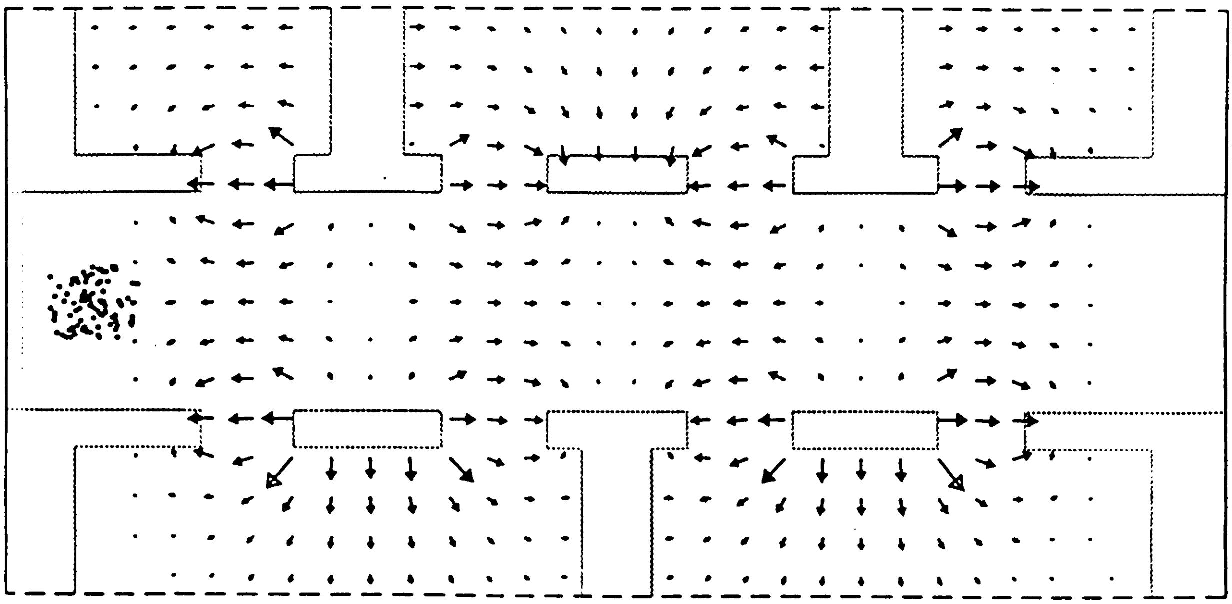


Fig.6 input (a) and output (b) bunch positions in the structure

a)



b)

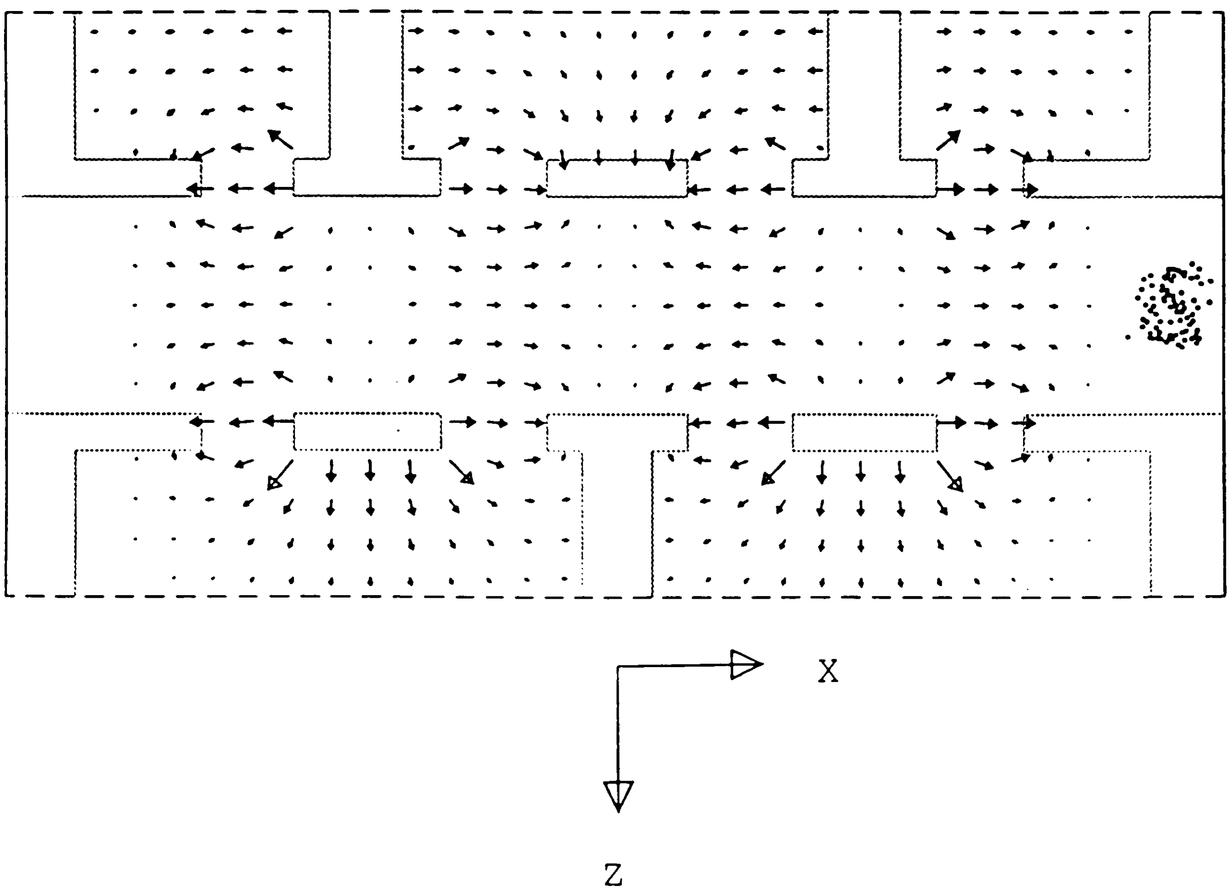
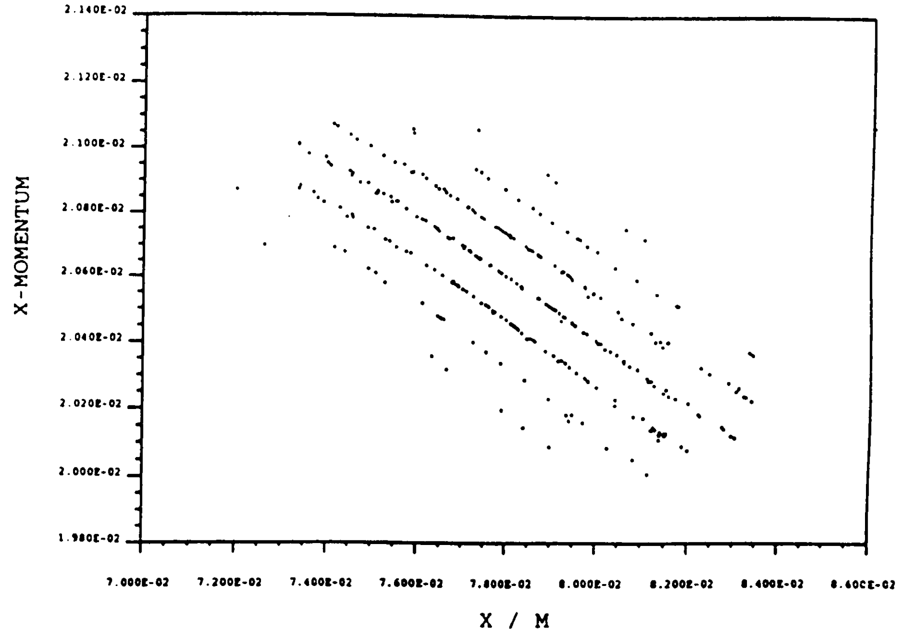
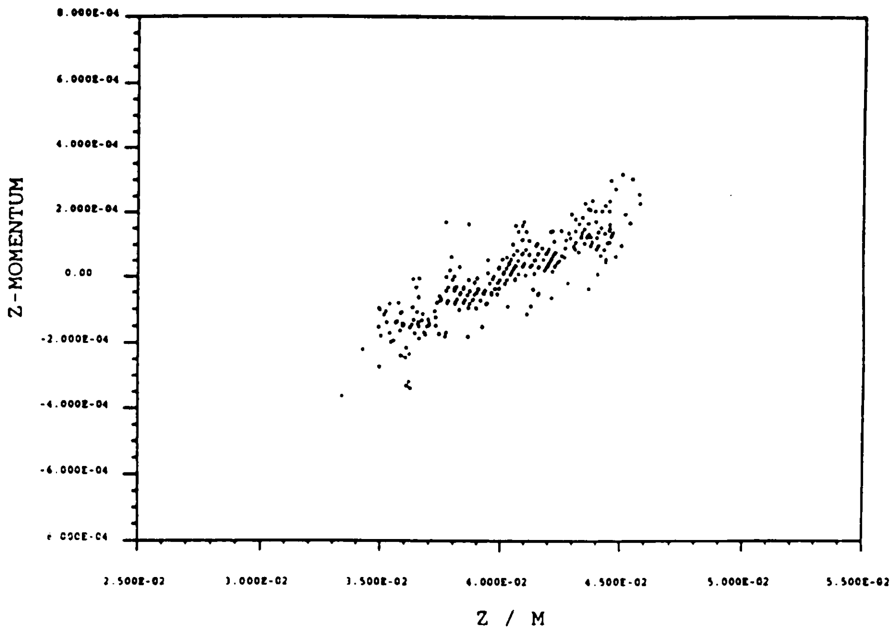


Fig.7.1 Resulting phase projections of the "nominal" bunch

a) longitudinal phase space



b) transverse phase space



c) real transverse plane

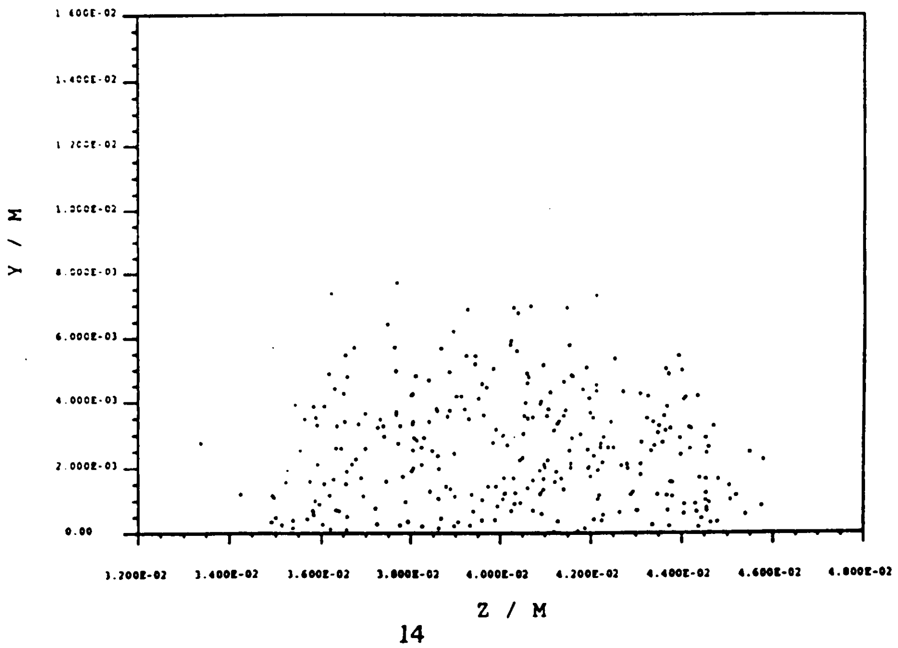
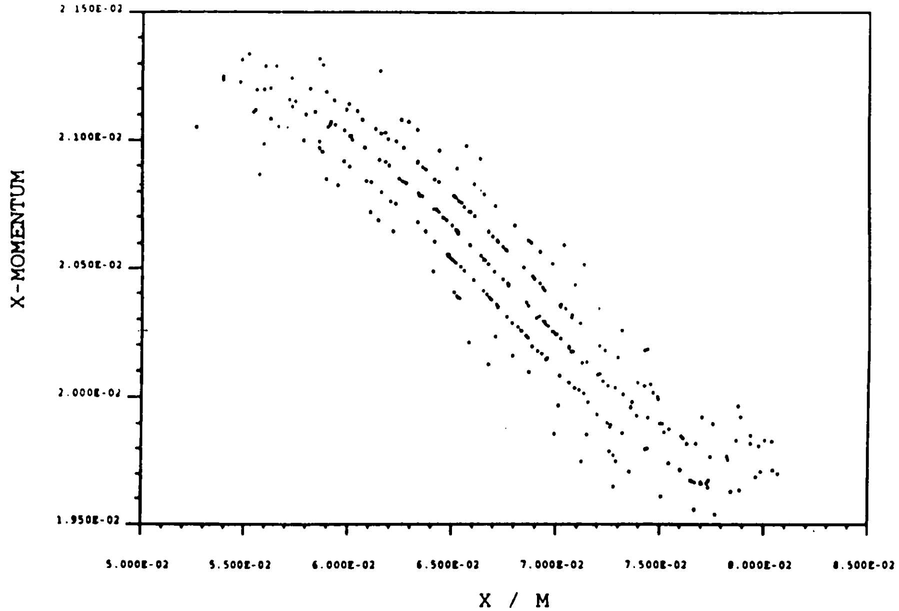
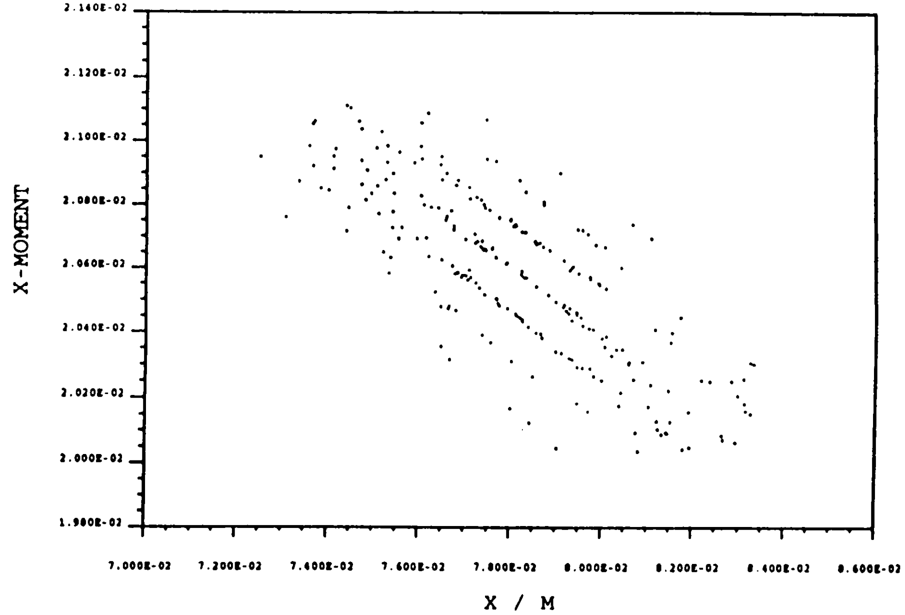


Fig.7.2 Resulting phase projections of the "long" bunch

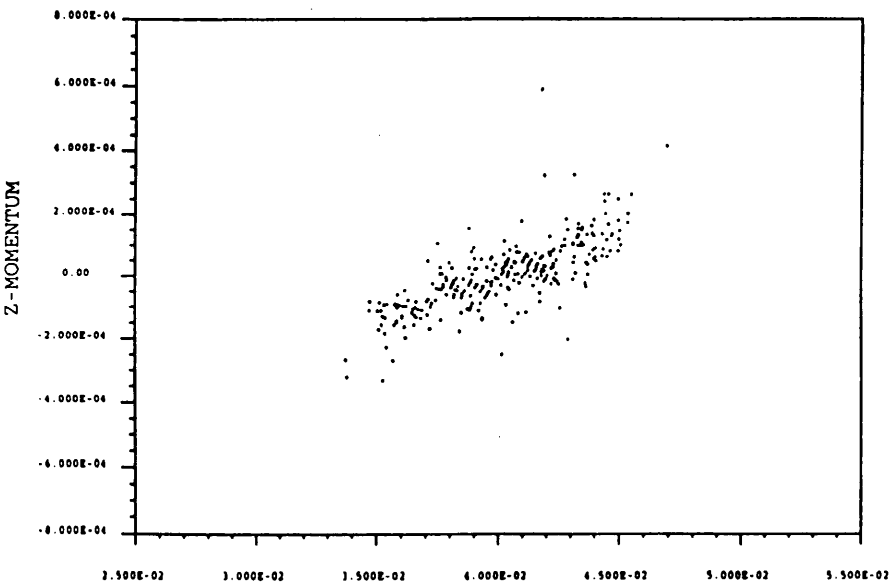
Fig.7.3 Resulting phase projections of the "thick" bunch

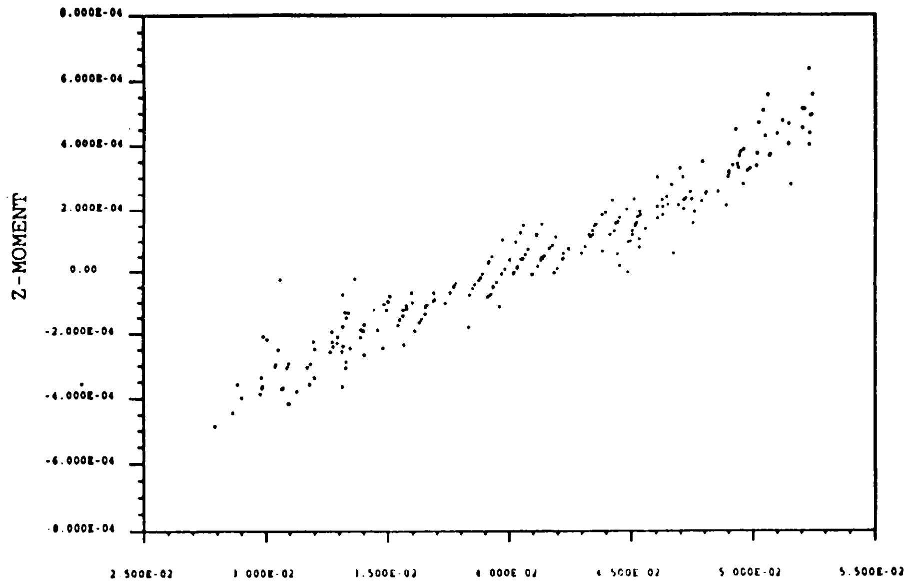
a) longitudinal phase space





b) transverse phase space





Appendix A: MAFIA command file to generate a full buncher structur

```
********** /home/pz/bylinsky/b3.com **********

$
#file name='bun' type=log action=open status=unk ex
#file name='bun' type=maf action=open status=unk ex
#file name='bun' type=pri action=open status=unk ex
$
#general          text(1)='Lead linac buncher (MEBT)'
                  text(2)='first approximation '

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$ All dimensions in mm
set scale 0.001

        def cavdiam=150.
        def cavleng=800.
        def aper=28.
        def tubediam=40.
        def beta=0.02321
        def freq=101.28e+6
        def c=2.998e+8
        def period="beta*c/freq/2.*1000."
$ Beam axis position from bottom
        def axis=140.
$ Drift tubes lengths
        def t2=20.0
                                   def gap="period-t2"
        def t3=t2
        def t4=t2
        def t1="(cavdiam-t2-t3-t4-4*gap)/2"
        def t5=t1
$ Stems dimensions
        def s11diam=50.
        def s12diam=10.
        def s21diam=20.
        def s22diam=10.
        def s3cur=period
        def s3diam=10.
        def hs3=26.
        def hs2="axis-aper/2"
        def hs1="cavleng-axis-aper/2-hs3-s3cur"

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
#mesh ratiol=50.00

          xm "-cavdiam/2" s 5  "-cavdiam/2+t1"
                          s 6  "-t3/2-t2-gap"
                          s 7  "-t3/2-gap"
                          s 6  "-t3/2"
                          s 7  "t3/2"
                          s 6  "t3/2+gap"
                          s 7  "t3/2+t4+gap"
                          s 6  "cavdiam/2-t5"
                          s 5  "cavdiam/2"

          ym          0.0 s 9  "aper/2"
```

```
                              s 3   "tubediam/2"
                              s 10   "cavdiam/2"

          zm "-cavleng"       s 30 "-cavleng+hs1"
                              s 5   "-cavleng+hs1+s3cur/2"
                              s 5   "-axis-tubediam/2"
                              s 3   "-axis-aper/2"
                              s 14 "-axis+aper/2"
                              s 3   "-axis+tubediam/2"
                              s 10  0.0
execute
SSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS
S Tank volume
#brick mat=1 vol "-cavdiam/2" "cavdiam/2" 0.0 "cavdiam/2" "-cavleng" 0
execute
S
#ccylinder orientation=z
          range= "-cavleng" 0.0
          center=0.0, 0.0
          radius="cavdiam/2"
          part=half
          whichpart='+y'
          material=0
execute
S  Big stem
#ccone     orientation=z
          range="-cavleng" "-cavleng+hs1"
          center=0.0, 0.0
          radii="s11diam/2" "s12diam/2"
          part=half
          whichpart='+y'
          material=1
execute
S  Short stem
#ccone     orientation=z
          range="-hs2" 0.0
          center=0.0, 0.0
          radii="s22diam/2" "s21diam/2"
          part=half
          whichpart='+y'
          material=1
execute
S  Support stems
#ccylinder orientation=z
          range= "-axis-aper/2-hs3"  "-axis-aper/2"
          center="t3/2+t2/2+gap", 0.0
          radius="s3diam/2"
          part=half
          whichpart='+y'
          material=1
execute
          center="-t3/2-t2/2-gap", 0.0
          material=1
execute
#torus     orientation=y
          minor="s3diam/2"
          major=s3cur
          center=0.0, 0.0, "-cavleng+hs1+s3cur"
          part=half
S           part=quarter
```

```
           whichpart='-z'
           material=
?
execute
S
S  Drift tubes
#washer   orientation=x
          range="-t3/2", "t3/2"
          center= 0,     "-axis"
          outerradius=  "tubediam/2"
          innerradius=  "aper/2"
          part=half
          whichpart='+y'
          material=1
execute
          range="-t2-t3/2-gap" "-t3/2-gap"
          material=1
execute
          range= "t3/2+gap" "t2+t3/2+gap"
          material=1
execute
          range= "-cavdiam"  "-t2-t3/2-2*gap"
          material=1
execute
          range="t2+t3/2+2*gap" "cavdiam"
          material=1
execute
S
open graypost

#3dplot material=all
        opaque=all
        box=yes
        rotation=-5,-5,0
        cells=no
execute
S
#2dplot material=all
        iycut=2
execute
end
```

Appendix B: MAFIA command file to generate a simplified model (shortening of coaxial line) of the buncher structure

```
********** /home/pz/bylinsky/b6.m.com **********

file name='buncher' type=maf action=open status=unk ex
file name='buncher' type=pri action=open status=unk ex
$
#general        text(1)='Lead linac buncher (MEBT)'
                text(2)='first approximation '
$ All dimensions in mm
set scale 0.001
        def cavdiam=150.
        def cavleng=180.
        def aper=28.
        def tubediam=40.
        def axis=40
        def bottom=50.
        def hmag=20.
        def beta=0.02321
        def freq=101.28e+6
        def c=2.998e+8
        def period="beta*c/freq/2.*1000."
        def steps=2.5
$ Drift tubes lengths
        def t2=20.4
        def gap="period-t2"
        def t3=t2
        def t4=t2
        def t1="(cavdiam-t2-t3-t4-4*gap)/2"
        def t5=t1
$ Stems dimensions
        def s11diam=50.
        def s12diam=12.
        def s21diam=30.
        def s22diam=10.
        def s3cur=period
        def s3diam=10.
        def s4diam=16.
        def tube=10.
        def begint="-cavdiam/2-tube"
        def endt="cavdiam/2+tube"
        def hs3="axis-aper/2"
        def hs2="bottom-aper/2"
        def hs1="cavleng-bottom-axis-s3cur"
$ Cathode dimensions
        def tcathode=steps
        def dcathode=aper

#mesh ratiol=10.00

          xm  begint       s "(cavdiam+2*tube)/steps"  endt

          ym  0.0          s "cavdiam/2/steps"         "cavdiam/2"

          zm "-s3cur-hs1"  s "cavleng/steps"           "bottom+axis"
execute
```

```
$ Tank volume
#brick
  mat=1 vol begint endt     0.0 "cavdiam/2"   "-s3cur-hs1" "bottom+axis
execute
$
#ccylinder orientation=z
           range= "-s3cur-hs1"  "bottom+axis"
           center=0.0, 0.0
           radius="cavdiam/2"
           part=half
           whichpart='+y'
           material=0
execute
$ Magnit
#ccylinder orientation=z
           range="-s3cur-hs1"  "-s3cur-hs1+hmag"
           center= 0.0,   0.0
           radius="cavdiam/2"
           part=half
           whichpart='+y'
           material=3
execute
$  Big stem
#ccylinder orientation=z
           range="-s3cur-hs1"  "-s3cur"
           center=0.0, 0.0
           radius="s12diam/2"
           part=half
           whichpart='+y'
           material=1
execute
$  Short stem
#ccylinder orientation=z
           range="axis+aper/2" "axis+bottom"
           center=0.0, 0.0
           radius="s22diam/2"
           part=half
           whichpart='+y'
           material=1
execute
$  Support stems
#ccylinder orientation=z
           range= 0.0  hs3
           center="t3/2+t2/2+gap", 0.0
           radius="s3diam/2"
           part=half
           whichpart='+y'
           material=1
execute
           center="-t3/2-t2/2-gap", 0.0
           material=1
execute
#rotations
               orientation=y
               normal=x
               anglerange=90 270
               point 0 "s3cur-s4diam/2"
               circle
               size=small
               radius="s4diam/2"
```

```
               type=concave
               point "s4diam/2" "s3cur"
               circle
               point 0 "s3cur+s4diam/2"
               point 0 "s3cur-s4diam/2"
               material=1
execute
$        Pipe
#ccylinder orientation=x
           radius=  "aper/2"
           center= 0,     axis
           range= "-cavdiam/2-tube"  "cavdiam/2+tube"
           part=half
           whichpart='+y'
           material=0
execute
$        Cathode
           range= "-cavdiam/2-tube"  "-cavdiam/2-tube+tcathode"
           material=5
execute
$      Drift tubes
#washer   orientation=x
          range="-t3/2", "t3/2"
          center= 0,     axis
          outerradius=  "tubediam/2"
          innerradius=  "aper/2"
          part=half
          whichpart='+y'
          material=1
execute
          range="-t2-t3/2-gap" "-t3/2-gap"
          material=1
execute
          range= "t3/2+gap" "t2+t3/2+gap"
          material=1
execute
          range= "-cavdiam"  "-t2-t3/2-2*gap"
          material=1
execute
          range="t2+t3/2+2*gap" "cavdiam"
          material=1
execute
open graypost
#3dplot material=all
        opaque=all
        box=yes
        rotation=-15,-20,0
        cells=no
execute
#2dplot material=all
        iycut=1
execute
noprintscreen
end
```

Appendix C: MAFIA command for the particle in sell dynamics

```
********** /home/pz/bylinsky/b6.ts3.com **********

#file
      name='bu.ts3' ty=pri ac=op ex
      name='buncher' type=maf action=open status=old ex
printscreen
message
define ezfield= 6.8e6
define phase0=-75
define bcharge=8e-14
define rbeam=5e-3
define angl=1.2
define pulslen=2.28e-10
define alorentz=1.000211815
define spread=2.797e-6
define npartic=300
$define maxtime=200
define timstep=4.e-13
define nstep=6801
define monlo=700
define monst=6100
define monhi=6800
define pulswid="pulslen"
#control
         delcalc
$#memory
$      sym=xparticl/300   action=delete  where=file  execute
$      sym=yparticl/300   action=delete  where=file  execute
$      sym=zparticl/300   action=delete  where=file  execute
$      sym=xmoment/300    action=delete  where=file  execute
$      sym=ymoment/300    action=delete  where=file  execute
$      sym=zmoment/300    action=delete  where=file  execute
$      sym=efield1/300    action=delete  where=file  execute
#general
          weight=1
          smooth=no
#boundary
          xbound elec elec
          ybound magn elec
          zbound elec elec
#material
          mat=1  type=elec
          mat=3  type=norm  mu=30.
          mat=5  type=elec  sourcetype=source
#time
          nend=nstep
          tstep=timstep
#load
 infile='buncher' source=file destination=core
 insym=e/1 outsym=ee/1 ex
 insym=b/1 outsym=bb/1 ex
$?
#initialfield
          name=field1
               type=dynamic
               esym=ee/1
```

```
                bsym=bb/1
                factor="ezfield"
                phase=phase0
          execute
$?
$show
#bunch
          bunch=1
          particles=userdefined
          number=npartic
          mass=7.806e9
          charge=bcharge
          show
#function
     name=trpos
          dimension=2
          type=circle
          aminimum=0.0
          amaximum=rbeam
          bminimum=0.00001
          bmaximum=179.99999
          kind=random
$          show
     name=trang
          dimension=2
          type=gaussian
          aminimum="-angl"
          amaximum=angl
          bminimum=0.00001
          bmaximum=179.99999
          kind=random
     name=long
          dimension=1
          type=gaussian
          amean=alorentz
          afwhm="2*spread"
          kind=random
     name=duration
          dimension=1
$          type=gaussian
          type=parabolic
          aminimum=1.e-12
          amaximum="@real03+pulslen"
          kind=random
      show
#cathode
          center=-0.0825  0.0  0.04
          normal=1 0 0
          xvector=0 0 -1
          gamma=long
          ejectiontime=duration
          angle=trang
          cathodearea=trpos
      show
     execute
#monitor
     symbol=efield1/300 field=eall
            itl=monlo its=monst ith=monhi
            yhigh .05 zlow 0. zhigh .08
     execute
```

```
#pathmonitor
$   delete
$   delete
$   delete
$   delete
$   delete
$   delete
      symbol=xparticl/300 field=rx       itl=monlo its=monst ith=monhi
                            first=1 last=npartic skip=1 ex
      symbol=yparticl/300 field=ry       itl=monlo its=monst ith=monhi
                            first=1 last=npartic skip=1 ex
      symbol=zparticl/300 field=rz       itl=monlo its=monst ith=monhi
                            first=1 last=npartic skip=1 ex
      symbol=xmoment/300  field=px       itl=monlo its=monst ith=monhi
                            first=1 last=npartic skip=1 ex
      symbol=ymoment/300  field=py       itl=monlo its=monst ith=monhi
                            first=1 last=npartic skip=1 ex
      symbol=zmoment/300  field=pz       itl=monlo its=monst ith=monhi
                            first=1 last=npartic skip=1 ex
 show
#control
           dumpsave=yes
 execute
#list
    symbol=xparticl/300      first=1      items=300
      execute
    symbol=ejectime/1
      execute
    symbol=xi/1
      execute
    symbol=eta/1
      execute
    symbol=gamma/1
      execute
    symbol=theta/1
      execute
    symbol=phi/1
      execute
    symbol=particle
      execute
    symbol=path/last/all
      execute
#memory
      sym=e/stat/vol       action=delete  where=core  execute
      sym=b/stat/vol       action=delete  where=core  execute
      sym=ee/1             action=delete  where=file  execute
      sym=bb/1             action=delete  where=file  execute
      sym=edl/last/vol     action=delete  where=file  execute
      sym=bdaqdt/last/vol  action=delete  where=file  execute
end
```