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Report No. 24

Design and Beam Transport Simulations of a Multistage Collector , Part I

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Simulations of the beam transport system from the undulator exit through decelerator tube into the collector have been carried out using EGUN and GPT codes. The latter has also been employed to study trajectories of the primary and scattered particles within the collector at the presence of a deflecting magnetic field.

Beam Transport Undulator exit - Collector Entrance:

The layout of the studied beamline section is shown in Fig. A. Throughout the simulations in Part 1 it is assumed:

* electron gun voltage of 90 kV,
* 1 A beam current,
* 1.4 MeV beam energy at the entrance to the Undulator,
* uniform energy distribution (1.31-1.42 MeV),
* energy spread after the FEL interaction 110 keV,
* 17-20 π mm mrad beam emittance.

The simulations start at Screen 3 at the end of the undulator. The input for the beam transverse phase space is based on the results presented in an internal report [1]. According to the report the beam at Screen 3 is round and has a diameter of 7.5 mm. Considering also experimental results indicating some what larger beam size*, beam diameter is set to be 9 mm. After being transported by a focussing /defocussing set of Quadrupoles (Q5-Q8) the converging beam enters the decelerator tube (Figs. 1a, 1b). The Quad strengths [T/m] are:

Q5 : 0.07 , Q6 : -0.115 , Q7 : 0.115, Q8 : -0.064

Five solenoids are employed to keep the beam size small enough within the drift section (decelerator tube exit - collector entrance) so that it does not hit the beampipe. The specs for the solenoids are given at Table 1. At this stage the beam energy varies between ~ 60-170 keV. An approach of softly focused beam transport has been adopted to avoid overfocusing of electrons at the low enegy range. The solenoids focus the beam to a waist at the collector entrance that is as small as possible when the beam enters the collector.

Beam radius @ collector entr. : ~7.5 mm (EGUN)
Beam radius @ collector entr. : ~5.2 mm (GPT)

The difference in the simulation results may stem mainly from the different space charge models implemented in each of the codes. However, this effect will be further investigated.

Phase space distribution of electrons at the collector entrance is shown in Fig. 2 .

Asymmetrical Multistage Collector :

Beam optics simulations within the asymetrical collector were carried out by taking the output of EGUN/GPT runs and using them as input for the collector simulations.
The designed collector geometry causes the beam to enter off center. The electrode plates are shaped to generate electric field components that attracts the particles towards the collector- center (Fig. 3). As was indicated in other collector designs (CREL, FOM) secondary electron emission has little influence on the charge collection efficiency. Particularly in asymetrical collectors fields generated by the elecrodes are very efficient to push the low energy electrons back to the surface.

Using GPT, simulations are performed to study the collection efficiency taking into account 3D space charge and multi scattering process from copper electrode surface. Currently two different collectors geometries (Collecotor A type and Collectors B & C Type) with various plate potentials are investigated (Figs. 3-6). The test collector has the same geometry as B&C but utilizes only two power supplies(Figs. 5,6). It would be the first configuration to be used to study the collection efficiency. In addition to the electric fields, a magnetic field from the side of the collector is applied to deflect the electrones further towards the center, supressing effectively backstreaming.

The collection performance of each collector type is listed on Table 1. Further optimization of the plate voltages and the associated collection efficiency would be meanfull:

- utilizing the energy spectrum data obtained from the present 2 Tube collector experiments.
- checking the assumptions made for the initial beam parameters. If beam diagnostics such as the designed optical transition radiation monitor at the dec. tube entrance will not be available in short term, beam transmission experiments using solenoids and the collector tubes will provide important feed back to the simulations.

Mechanical Design (Figs. B,C, see cost estimation)

The collector comprises 5 copper electrodes supported by alumina insulator posts. Four ceramic feedthrouhgs will be used in providing the high voltage to the electrodes. The spike electrode reflects the high energy electrons back to the charge collecting electrodes. An Ion pump (~40 lt) should be mounted to the Vacuum chamber housing the collector assembly.

Remarks:
* on screen 3 measured beam profile (with FEL interaction) is a square shaped electron beam with ~15 mm side length. Please let me know if there are beam profile measurements indicating otherwise.

[1] Calculation and Simulation of optimal e-beam transport through quadrupoles, A. Abromovich et al.

Figure 1a:
EGUN Simulations along the decelerator tube and transport line up to the collector.

Figure 1b:
GPT Simulations starting from screen 3 transporting the beam through the decelerator tube up to the collector.

Figure 2:
Phase Space distribution of the electrons at the entrance of the collector.

Figure 3:
Asymmetrical collectors A, B, C with various electrode geometry and potentials. Collectors B&C have the same geometry but different plate potentials.

Figure 4:
Electron incidence points on the electrode plates defining charge collected at each plate. Side views (y-z plane)

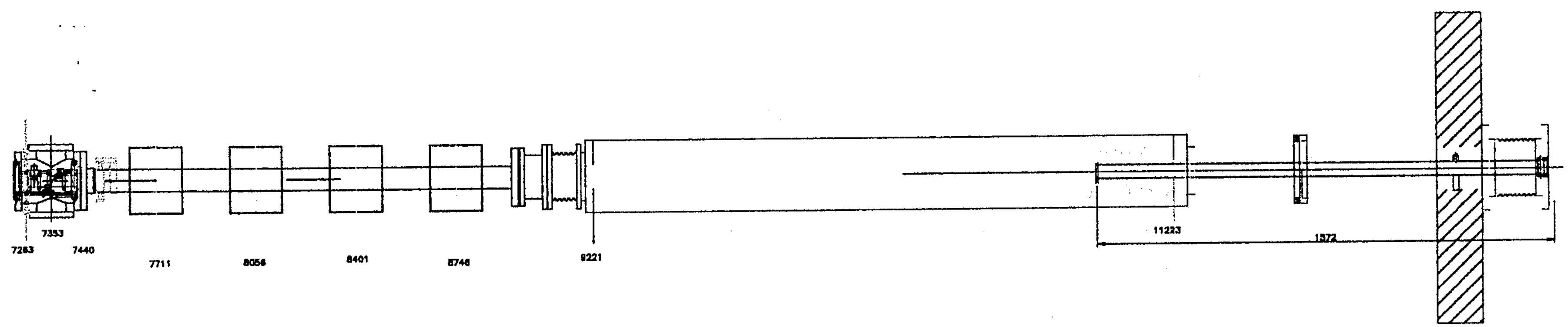
Figure 5:
Test Collector with a geometry similar to B&C. The design should allow to check the charge collection efficiency and backstraeming utilizing two power supplies.

Figure 6:
Electron incidence points within the test collector side (y-z plane) and top (x-z plane) views respectively.

Fig. A:
Layout of the studied Beamline

Fig. B:
Schematic of the asymetrical Collector. Simulations are carried out according distances shown on this drawing.

Fig.C:
Schematic of an alternative beam line up to the Collector.



Layout of the studied transport line

Fig.A

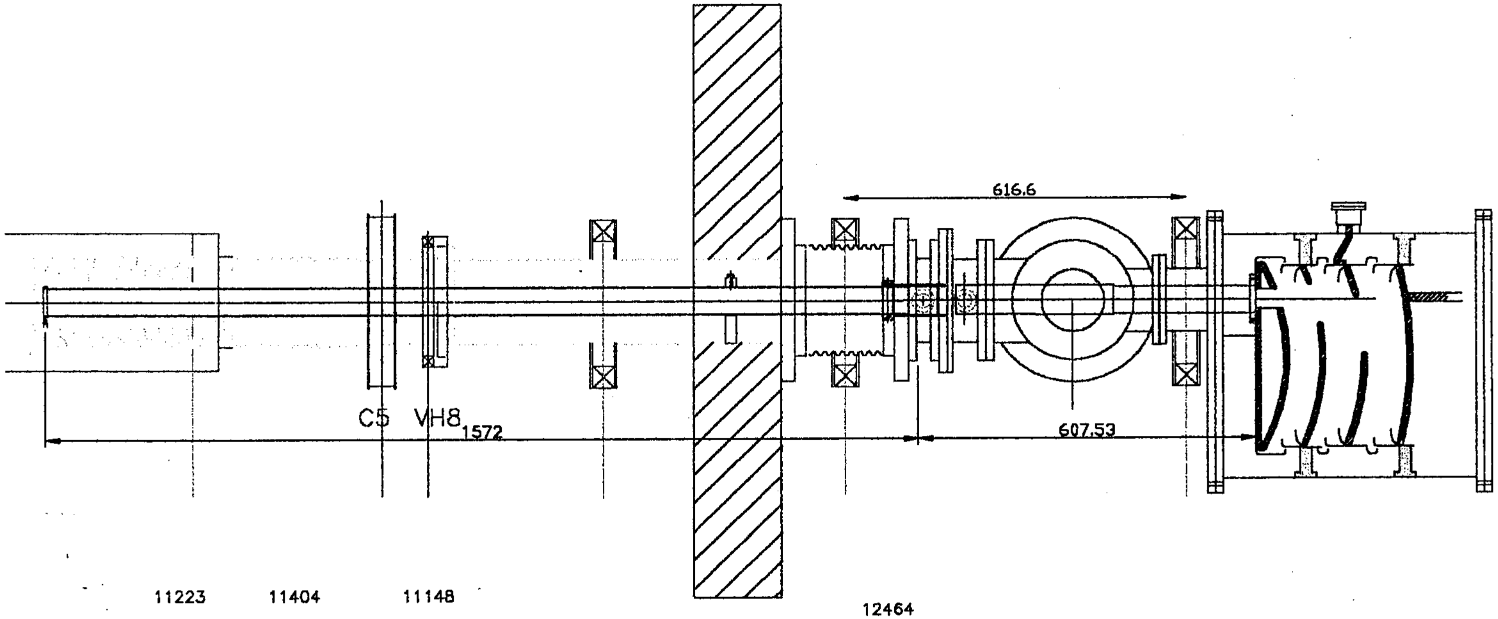


Fig. C

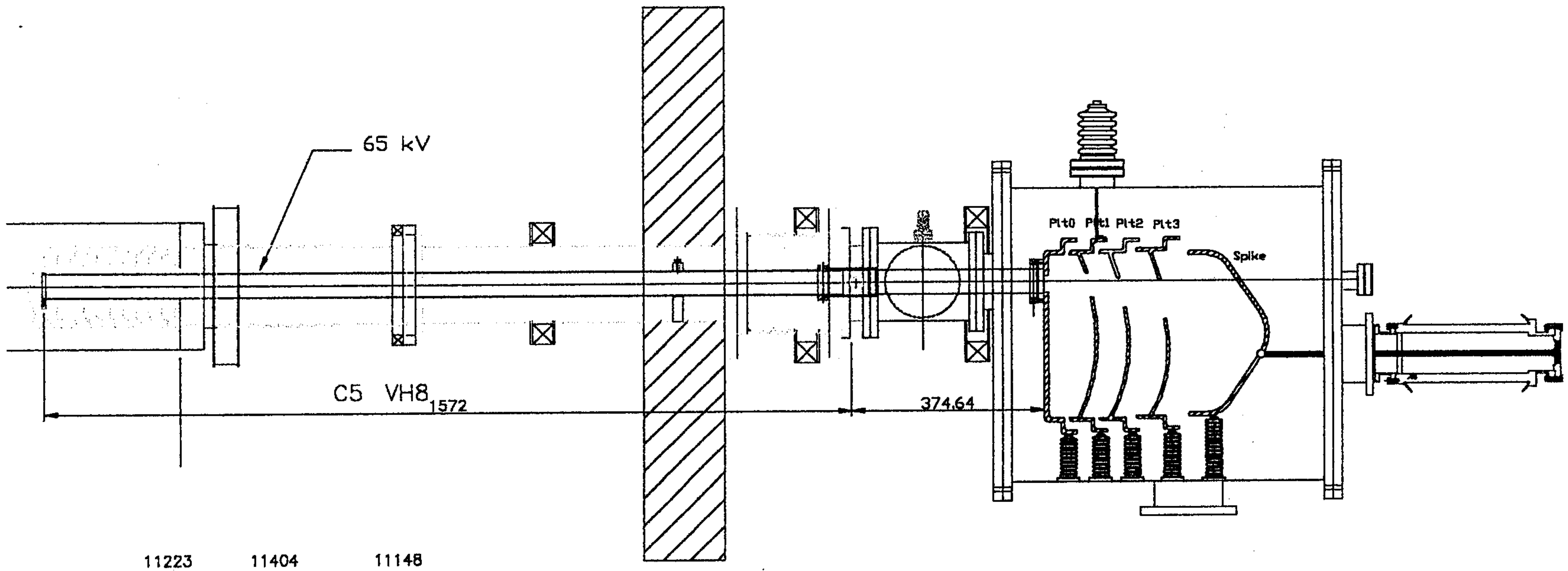


Fig. B

SC MATIC OF THE ASYMMETRICAL COLLECTOF

Table 1.

90 kV Egun

Collector A

Current[A]	Voltage [kV] (w.r.t. ground)
Plt 0 : -	Plt 0 : 65
Plt 1 : 0.246	Plt 1 : 30
Plt 2 : 0.485	Plt 2 : -20
Plt 3 : 0.235	Plt 3 : -70
	Spike : -120
Tot. : 0.966	

Collector B

Current[A]	Voltage [kV] (w.r.t. ground)
Plt 0 : 0.015	Plt 0 : 65
Plt 1 : 0.016	Plt 1 : 55
Plt 2 : 0.682	Plt 2 : 5
Plt 3 : 0.271	Plt 3 : -70
	Spike : -120
Tot. : 0.984	

* Collector C

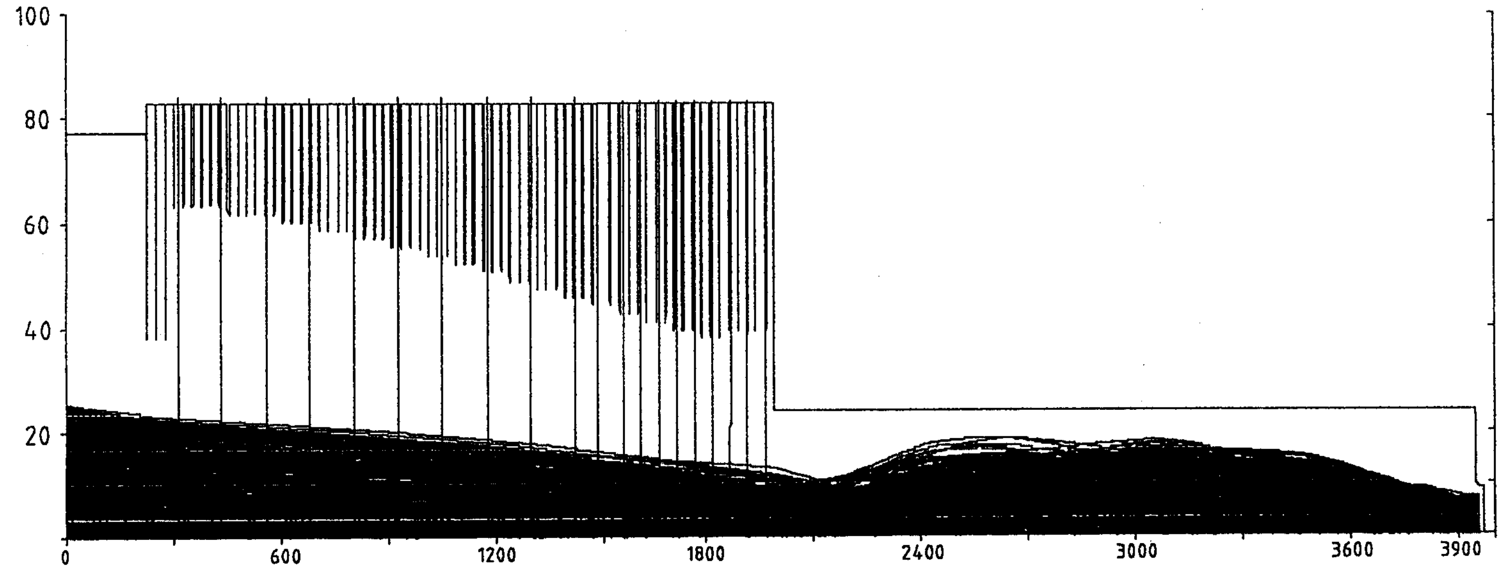
Current[A]	Voltage [kV] (w.r.t. ground)
Plt 0 : 0.016	Plt 0 : 65
Plt 1 : 0.063	Plt 1 : 55
Plt 2 : 0.595	Plt 2 : -5
Plt 3 : 0.314	Plt 3 : -70
	Spike : -120
Tot. : 0.988	

Test Collector

Current[A]	Voltage [kV] (w.r.t. ground)
Plt 0 : 0.0	Plt 0 : 65
Plt 1 : 0.023	Plt 1 : 65
Plt 2 : 0.077	Plt 2 : 65
Plt 3 : 0.894	Plt 3 : 35
	Spike : -120
Tot. : 0.994	

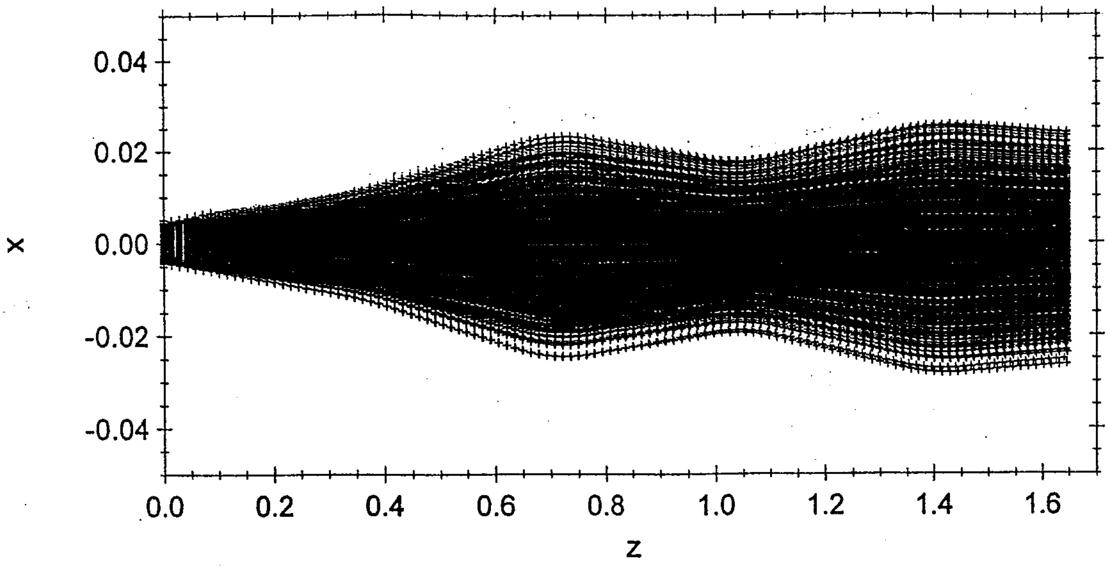
Solenoids:

1 Solenoid with 2000 Ampturns, 95 mm (from center of the coil to z axis)
1 Solenoid with 2000 Ampturns, 130 mm (from center of the coil to z axis)
1 Solenoid with 2500 Ampturns, 130 mm (from center of the coil to z axis)
1 Solenoid with 3000 Ampturns, 130 mm (from center of the coil to z axis)
1 Solenoid with 4000 Ampturns, 130 mm (from center of the coil to z axis)

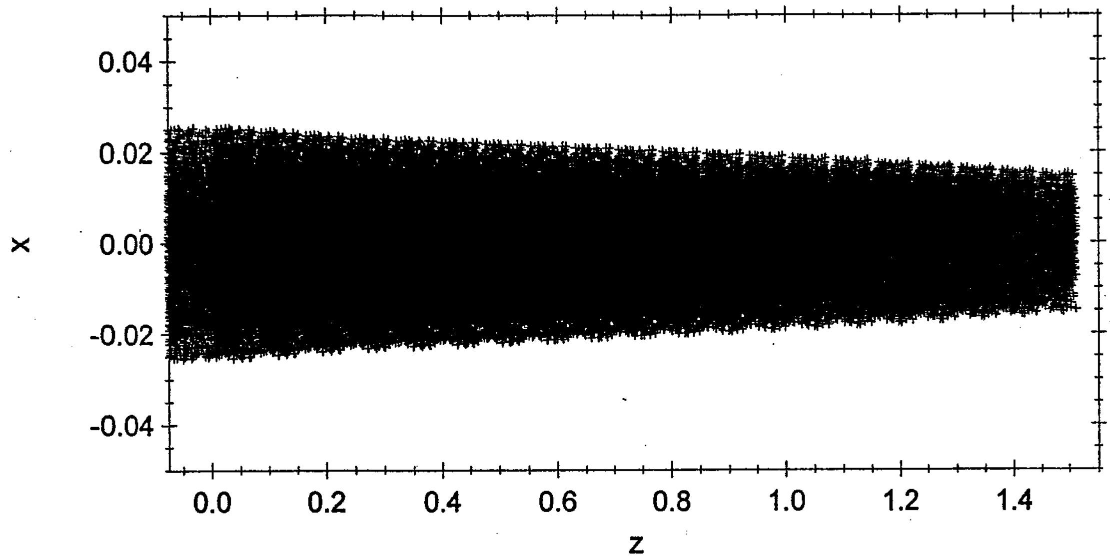


EGUN Simulation (Decelerator Tube - Collector Entr.)

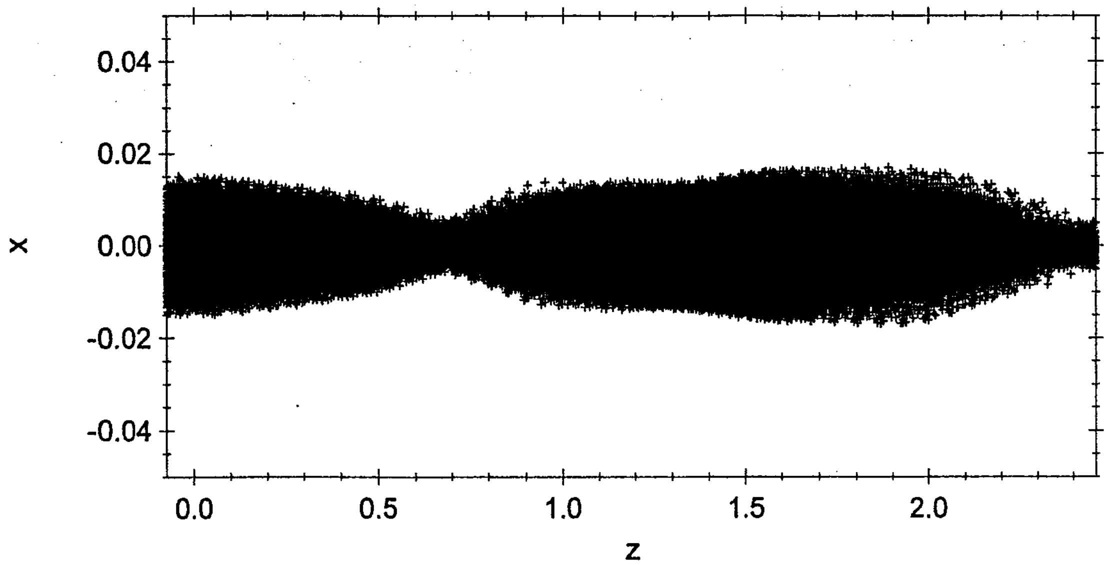
Fig.1a



Beam Transport Screen 3-Dec. Tube entrance



Beam Transport through Dec. Tube



Beam Transport Dec. Tube exit- Collector entrance

Fig. 1b

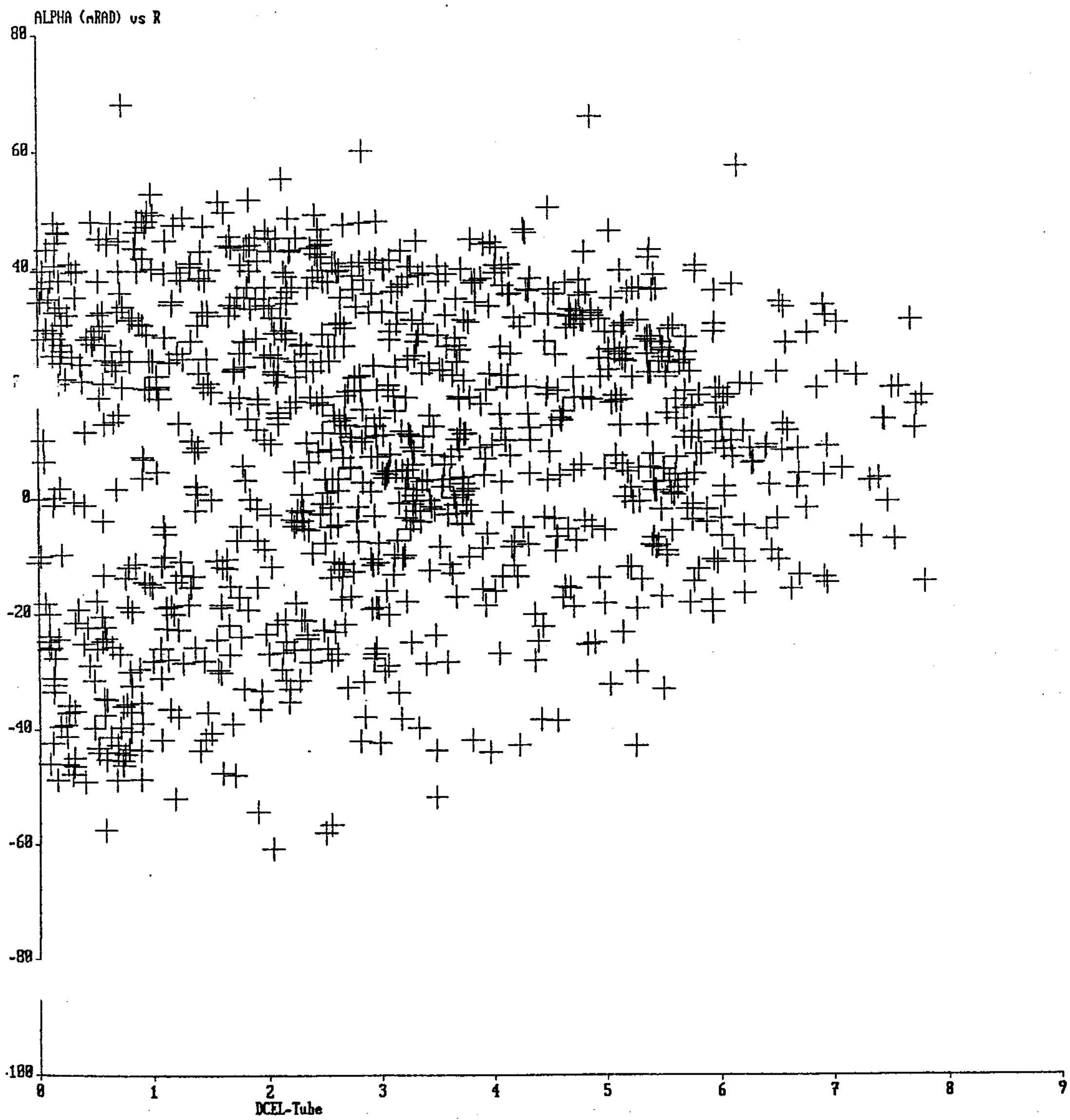
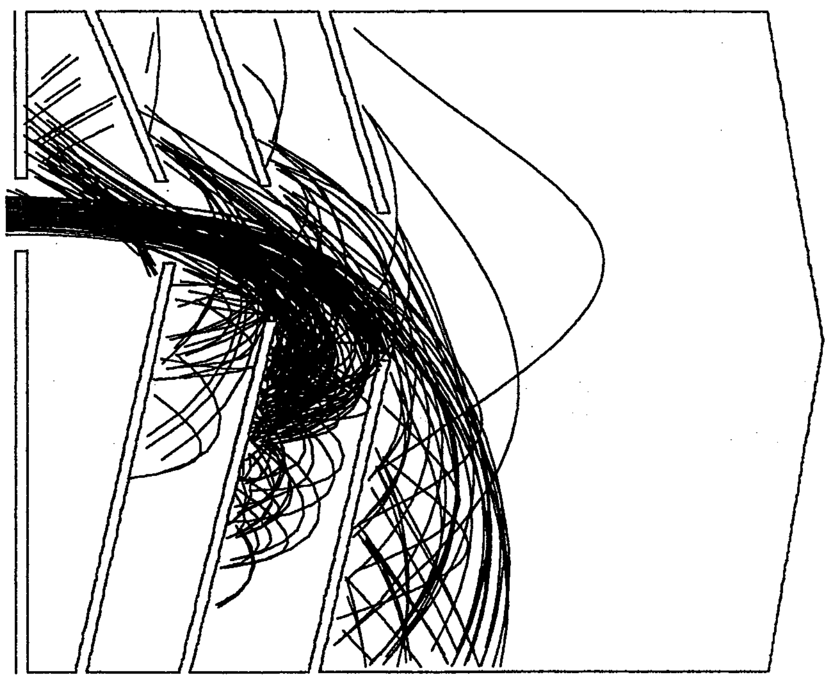


Figure 2.

A

B & C



Asymetrical Multistage Collector Designs

Figure 3.

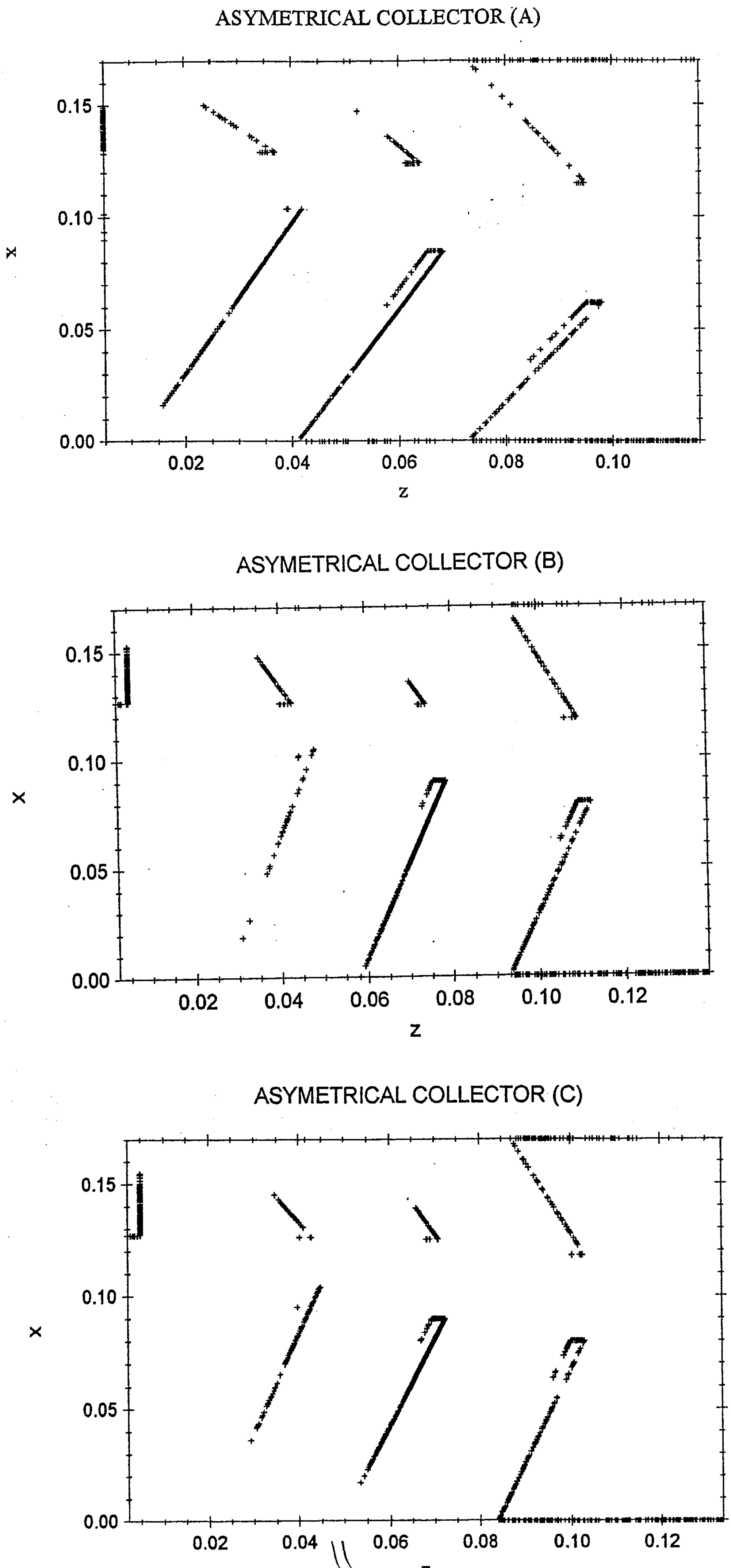
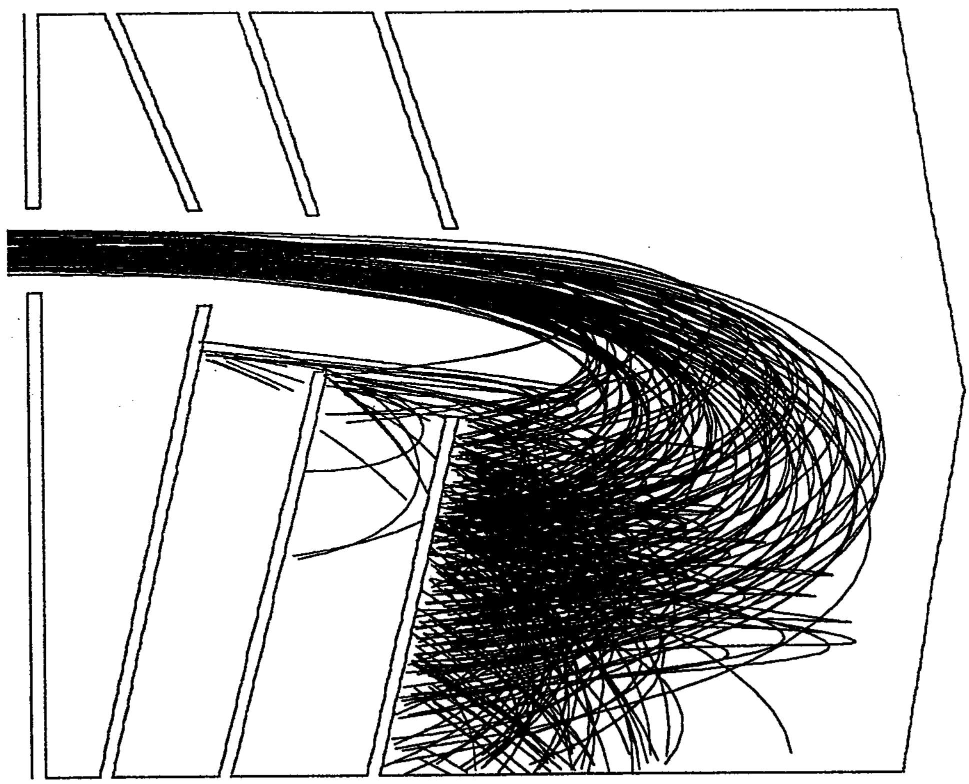

ASYMETRICAL COLLECTOR (A)
0.15
0.10
0.05
0.00
x
0.02
0.04
0.06
0.08
0.10
z
ASYMETRICAL COLLECTOR (B)
0.15
0.10
0.05
0.00
x
0.02
0.04
0.06
0.08
0.10
0.12
z
ASYMETRICAL COLLECTOR (C)
0.15
0.10
0.05
0.00
x
0.02
0.04
0.06
0.08
0.10
0.12

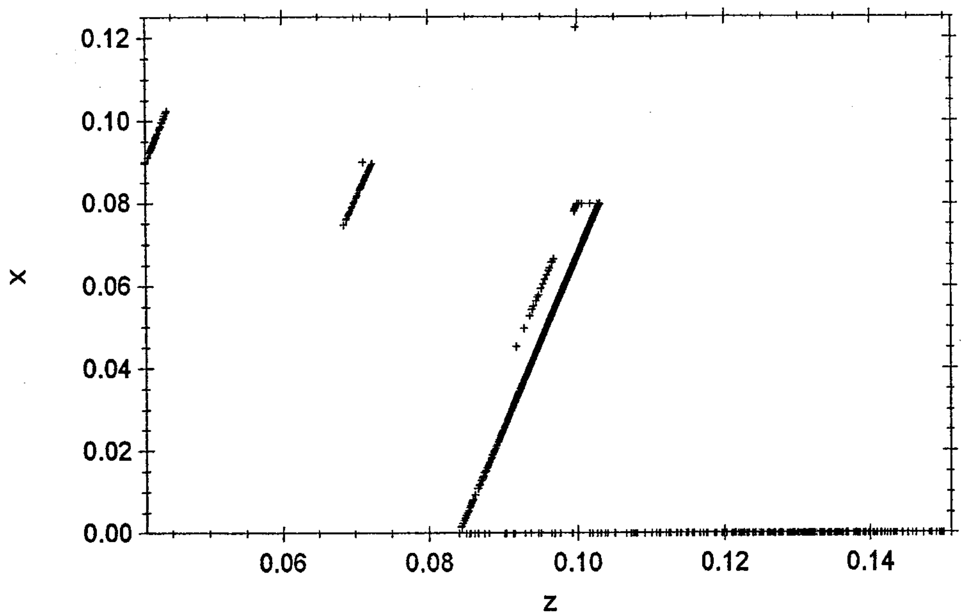
Figure 4.



TEST COLLECTOR

Figure 5.

TEST COLLECTOR



Top View

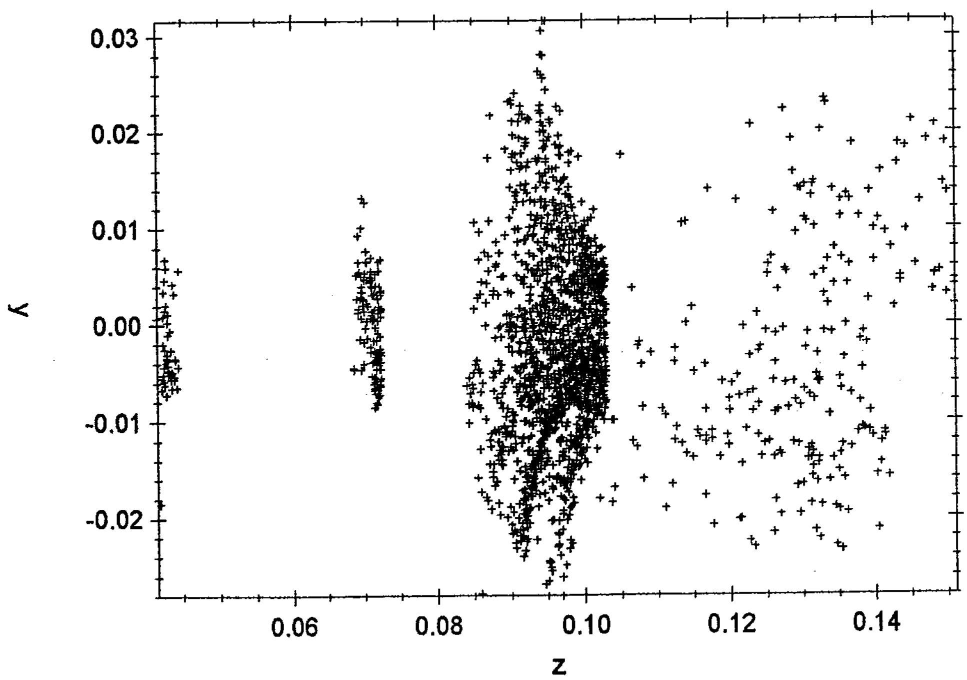


Figure 6.

Rough cost estimation for the collector components (31.05.00)

- 3 x Feedthroughs HV
  1x$2500. (100kV)+ 2x$970.(60kV)
  (Sub Total: ~$4500.)
- 1 x Viewport (1x$210.)
- 1x 20-40 lt Ion Pump+Controller (used one, to get free of charge)
- 5 x ceramic Insulator posts (RAFAEL)
- 7 x Flanges (2x$60.,3x$70.,1x$90.,1x$20.)
  (Sub. Total: ~$500)
- High Voltage Power Supplies for electrode plates
  Plt1 $8 000., Plt2 $10 000., Plt3 $25 000., Spk $ 6 000.
  (Sub. Total : ~$50 000.)
- 4 x 10A power supplies
  (Sub. Total : $2500.)
- 4 solenoids (no cost)
- ~30 m Insulator cable Collector-egun connection (~130 kV)
  $10./m ,
  (Sub Total: ~$300.)
- Insulator for the Spike electrode (~130 kV) (RAFAEL)
- Isolation Transformer
  ~$10 000.
- Mashine Shop costs (welding / mashining on the available Vacuum Chamber for Feedthgrouhs, Viewport, Flanges)

- 1 x T Flange (Optional)
  $600.

TOTAL: ~ $68 k

II. Beam Transport and Collector Simulations based on inhomogeneous energy distribution

In part II following assumptions on the beam parameters have been made:

* 90 kV electron gun voltage ,
* 1 A beam current,
* 1.4 MeV beam energy at the entrance to the Undulator,
* energy distribution according to the output of FEL3D simulation having 50% feedback in the resonator. (Emin-Emax:1.32-1.44 MeV),
* energy spread after the FEL interaction 120 keV,
* 17-20 π mm mrad beam emittance.

The transport of the beam from decelerator tube exit into the collector has been accomplished using 5 solenoids having the same specs as given in part I. Solenoid currents will be varied however to keep the beam for the above mentioned energy distribution confined within the vacuum pipe. The beam radius @ collector entrance is ~7.5 mm (Figs.1). The phase-space distribution at this position is shown in Fig. 1a. It is important to note that specs of the solenoids are checked to be valid for beam currents less or in close vicinity (~10%) of 1A. A safety margin in terms of Ampturns for 1A beam has been included.

Multistage collector simulations are performed employing the same geometry as was used in Collector C and test collector in part I. Plate potentials and the collected current at each plate is shown at Table 1. The trajectories of electrons in a small fraction of the beam are shown in Figs. 2. The size of the beam at collector plates (x-z and y-z planes) can be seen in Figs. 5. The performance of the collector regarding heat dissipation will be given additionally.

<u>Figure 1:</u>
EGUN Simulations along the decelerator tube and transport line up to the collector.

<u>Figure 1.a:</u>
Phase Space distribution of the electrons at the collector entrance.

<u>Figure 2:</u>
Asymmetrical collector type C with various electrode potentials . Plate Potentials for C(I) and C(II) are listed at Table I.

<u>Figure 3:</u>
Side views (y-z plane) of electron incidence points on the electrode plates for the cases C(I) and C(II).

<u>Figure 4:</u>
Test Collector utilizing two power supplies. Plate Potentials are listed at Table 1.

<u>Figure 5:</u>
Electron incidence points within the test collector shown from side (y-z plane) and top (x-z plane) respectively.

Table 1.

90 kV Egun
(Beam Energy spectrum resulting from 50% reflection)

Collector C (I)

Current[A]	**Voltage [kV]** (w.r.t. ground)
Plt 0 : 0.0175	Plt 0 : 65
Plt 1 : 0.0855	Plt 1 : 50
Plt 2 : 0.6550	Plt 2 : -10
Plt 3 : 0.2310	Plt 3 : -75
	Spike : -140
Tot. : 0.989	

Collector C (II)

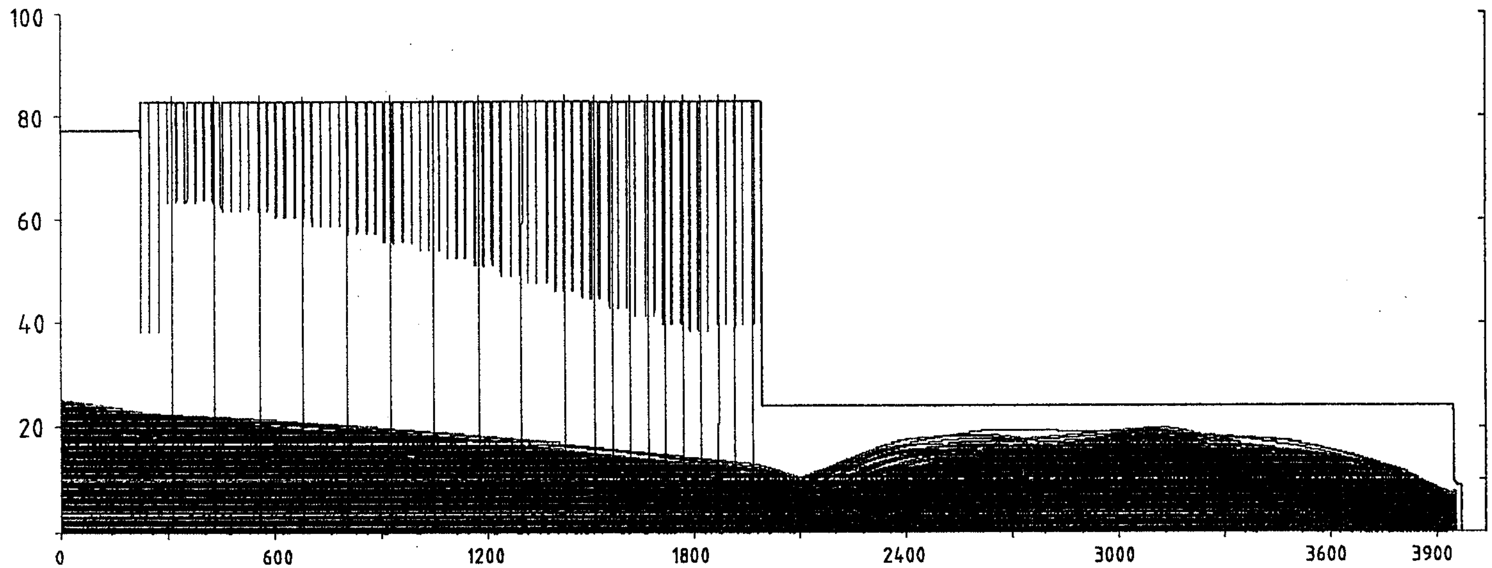
Current[A]	**Voltage [kV]** (w.r.t. ground)
Plt 0 : 0.017	Plt 0 : 65
Plt 1 : 0.042	Plt 1 : 55
Plt 2 : 0.664	Plt 2 : -5
Plt 3 : 0.270	Plt 3 : -70
	Spike : -120
Tot. : 0.993	

Test Collector

Current[A]	**Voltage [kV]** (w.r.t. ground)
Plt 0 : 0.0	Plt 0 : 65
Plt 1 : 0.008	Plt 1 : 65
Plt 2 : 0.117	Plt 2 : 65
Plt 3 : 0.870	Plt 3 : 25
	Spike : -135
Tot. : 0.995	

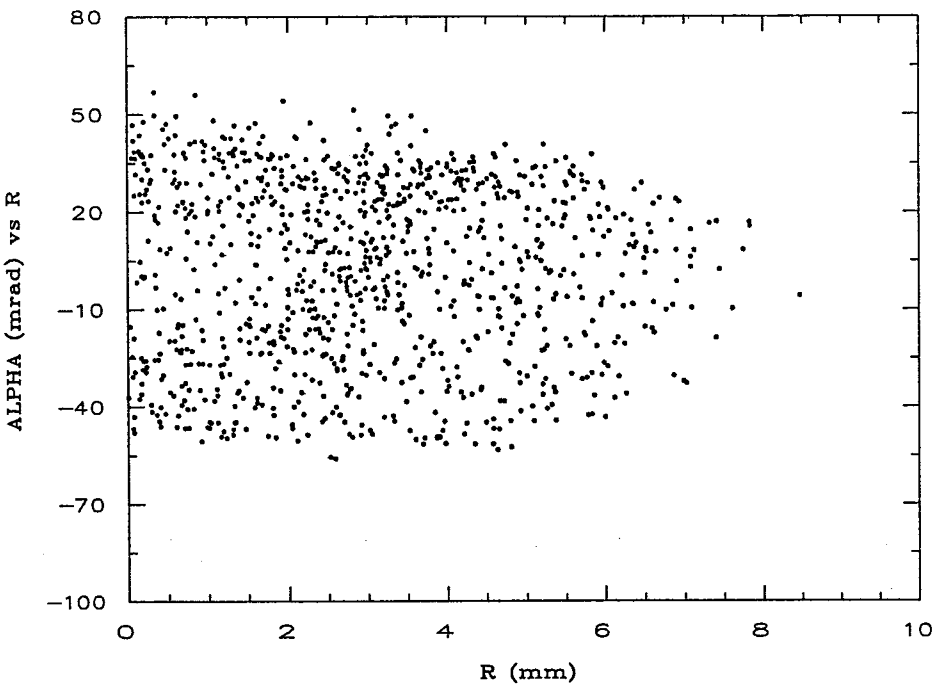
Solenoids:

1 Solenoid with 2000 Ampturns, 95 mm (from center of the coil to z axis)
1 Solenoid with 2000 Ampturns, 130 mm (from center of the coil to z axis)
1 Solenoid with 2500 Ampturns, 130 mm (from center of the coil to z axis)
1 Solenoid with 3000 Ampturns, 130 mm (from center of the coil to z axis)
1 Solenoid with 4000 Ampturns, 130 mm (from center of the coil to z axis)



EGUN Simulation II (Decelerator Tube - Collector Entr.)

Fig. 1



Phase Space Distribution @ collector entrance

Fig. 1a

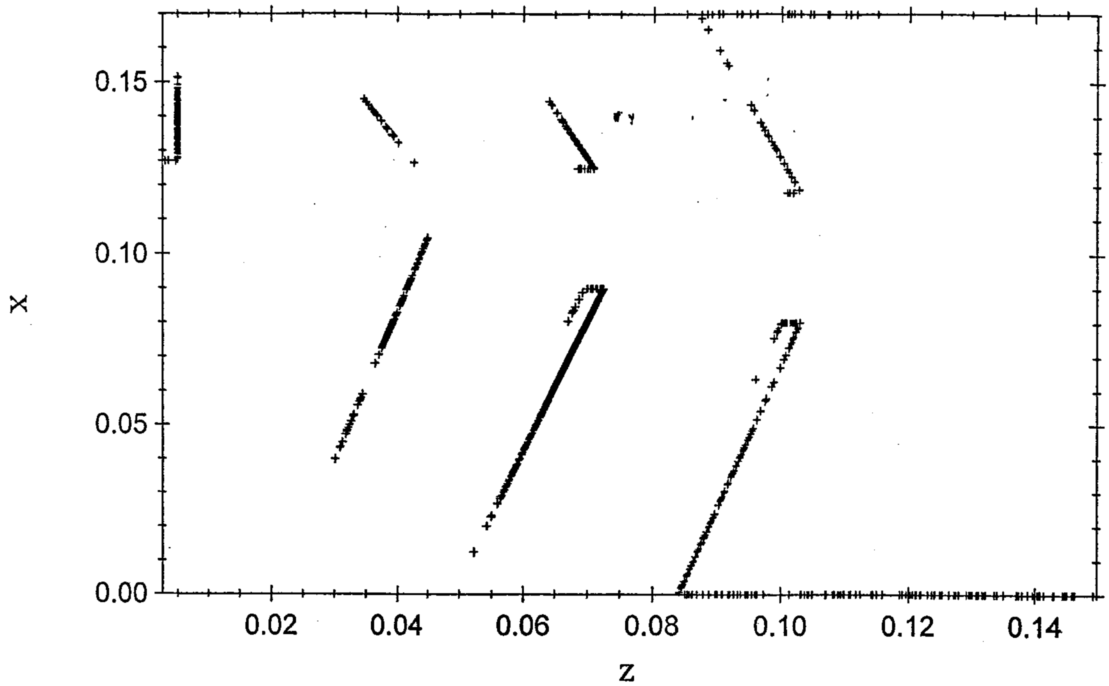
I.)

II.)

Collector Type C with different Plate Potentials

Fig. 2

COLLECTOR TYPE C (I)



COLLECTOR TYPE C (II)

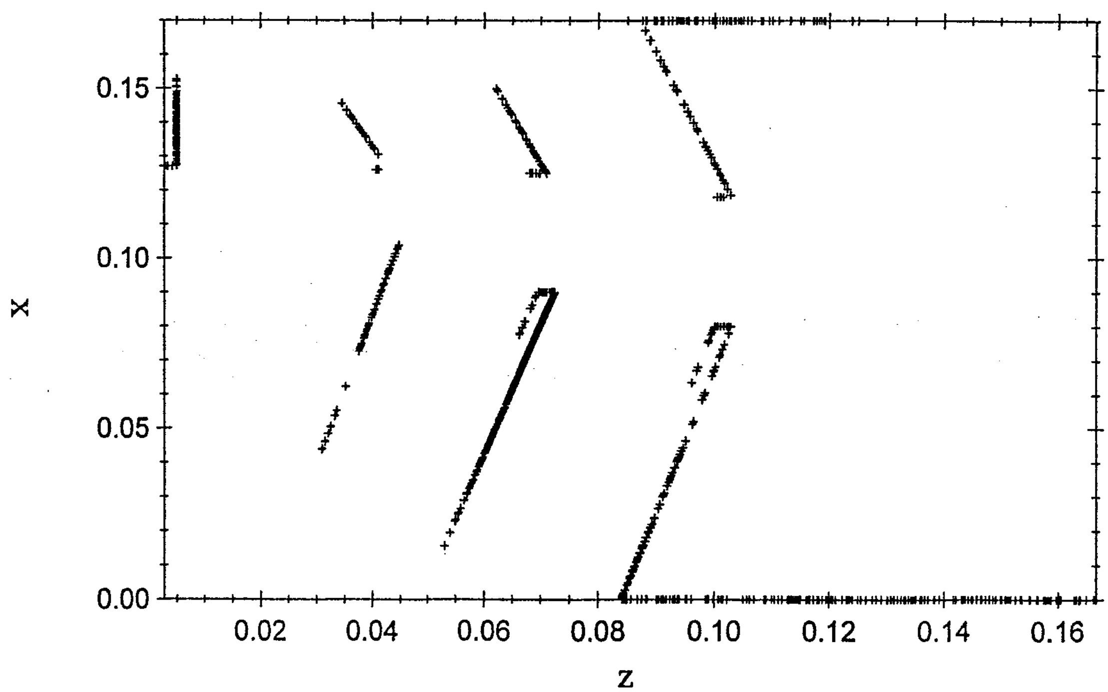
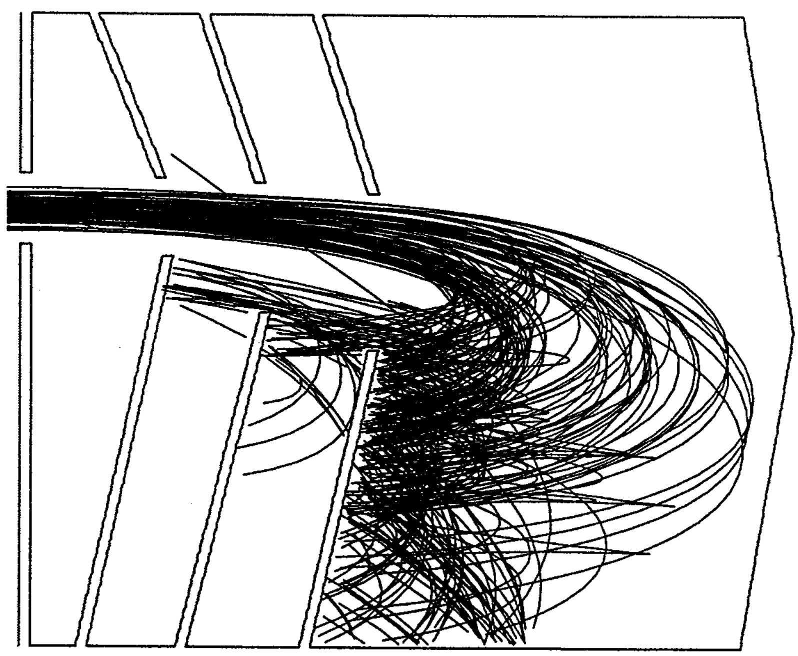


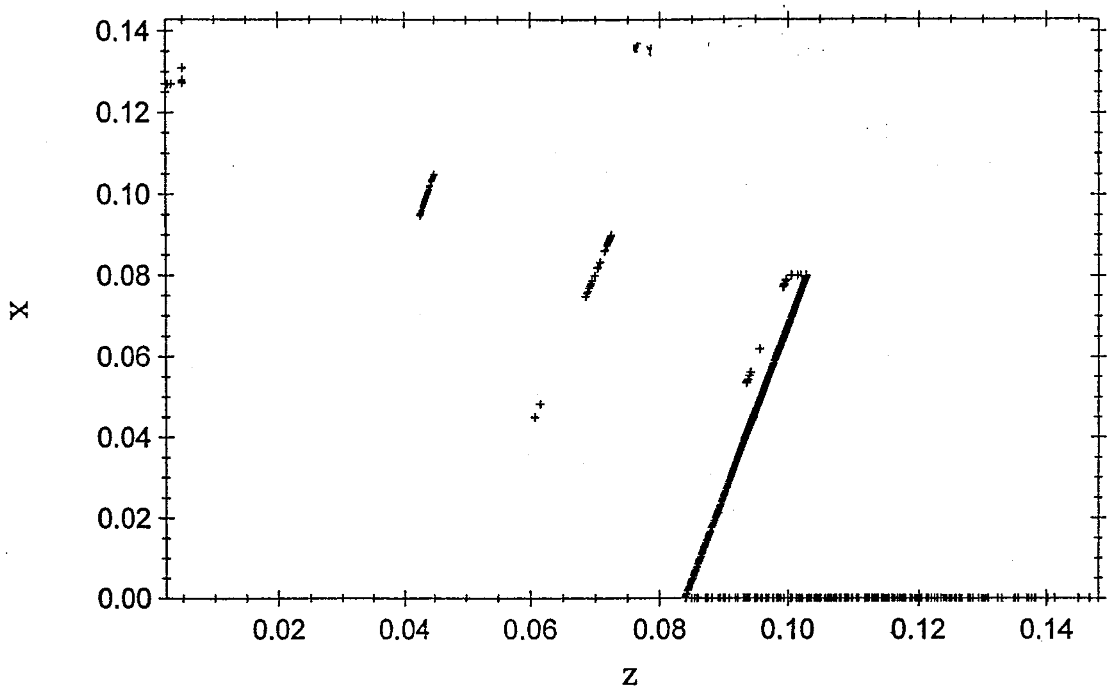
Fig. 3



Test Collector

Fig. 4

TEST COLLECTOR



TOP VIEW

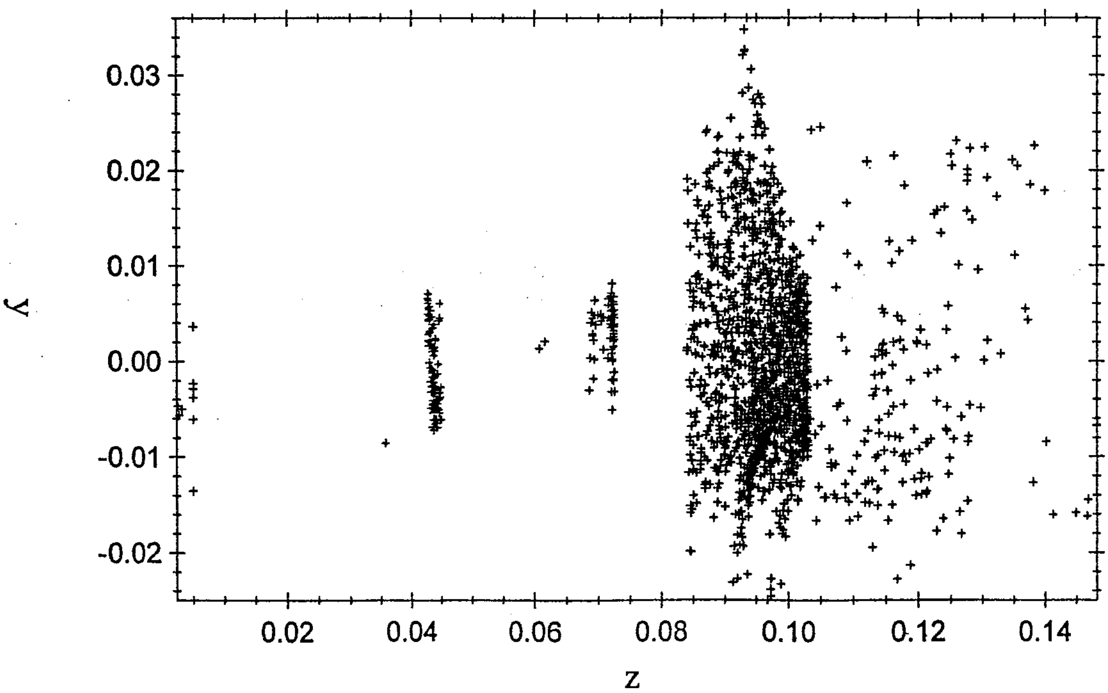


Fig.5