26.06.2000

THE TWO-STAGE COLLECTOR OF THE ISRAELI FEL

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INTERNAL REPORT N26

These results were presented as posters on the Third Israeli Conference on Plasma Physics and its Applications in Beer-Sheva (February, 2000) – Case of uniform beam density distributions with energy spread (reflectivity=0.9);

and on the Israel Physical Society 46th Annual Meeting (May, 2000) - Case of beam density distributions for reflectivity 0.5 (non-uniform distribution).

Abstract

The Israeli Free Electron Laser (FEL) employs a Van de Graaff type electrostatic accelerator operating with a 1A...1.5A electron beam current at a 1.4MeV beam energy. The electron beam exiting from the interaction region is characterized by a large (up to 9%) energy spread. The beam current density distribution versus energy depends on the mirror reflectivity. For the Israeli FEL it was shown by simulations that, for a reflection factor R=0.5 of the out-coupling mirror, a highly peaked current density versus beam energy distribution is obtained. A two-stage collector is being designed and constructed, optimized for collecting the beam with energy spread.

The collector consists of two tubes. The first tube contacts one of the lowest potential electrodes of the deceleration structure having a potential of 75kV (if 43kV electron gun is employed). The potential of the second collector tube was varied in the simulations in order to optimize collection efficiency and to a minimize back-streaming of electrons. The spacing between the two tubes should be as short as possible in order to minimize a local potential depression due to the grounded enclosure (at the position of the gate valve).

Multiple electron scattering at the collector electrodes were taken into account. Results of simulations show a substantial increase of the back-streaming current due to multiple scattering.

In order to decrease the back-streaming current (without affecting the collector acceptance) a beam scraper positioned inside the first stage (tube) was designed.

In a future development stage, the beam will be guided without electron interception by a series of solenoid lenses from the decelerator tube exit into an asymmetrical multistage collector. The latter will incorporate four copper electrode plates, each with an optimized shape, position and potential to prevent back-streaming while realizing high charge recovery (>99%) and overall system efficiency of 50÷60%.

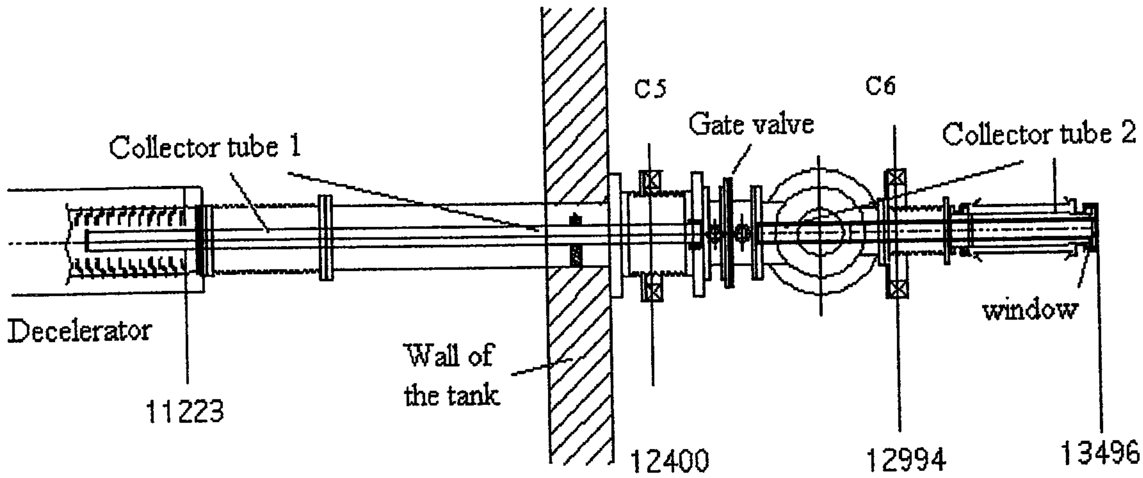
1. Introduction

- A final part of the electrostatic beam accelerator [1] retrieval system is a collector. It is employed for electron collection after beam deceleration. A collector may be used as a beam energy analizer also.
- Electron beam energy spread in the region of interaction is determined by radiation conditions. Simulation results gave a 7% energy spread on the interaction region [2]. This results in a large kinetic energy distribution in the beam at the collector entrance (in the range of 38keV…138keV). To collect efficiently such a beam is a serious problem.

2. Method

•The EGUN-2 computer code by Herrmannsfeld was used [3].
•Secondary scattered electrons were included as rays with average characteristics in correspondence with reference [4].

3. The two-stage collector structure



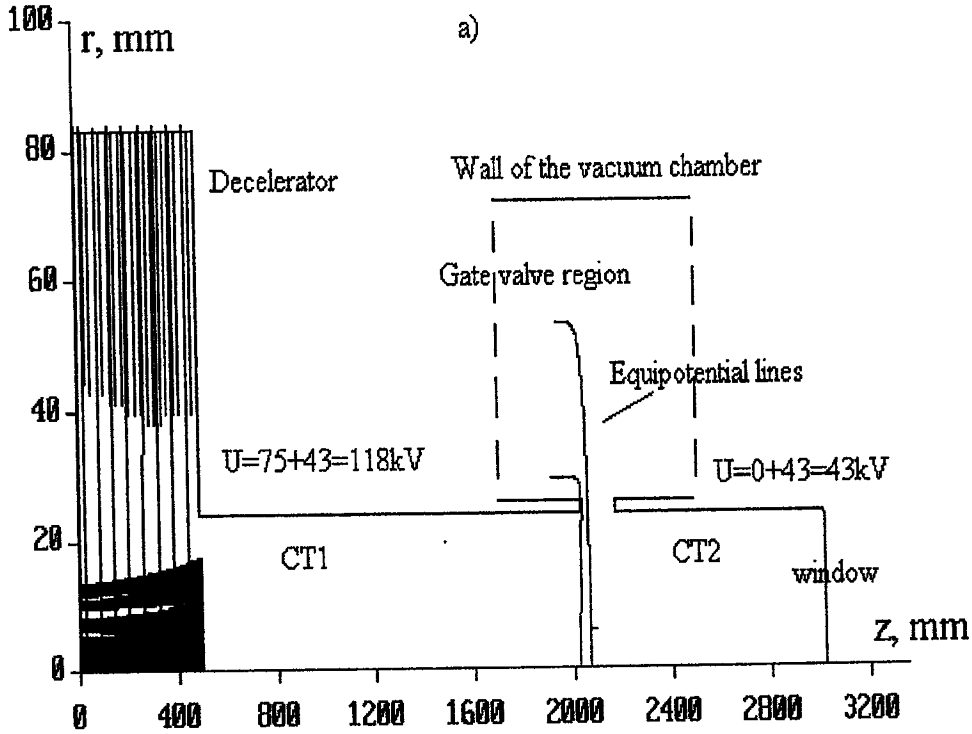
4. Initial beam parameters

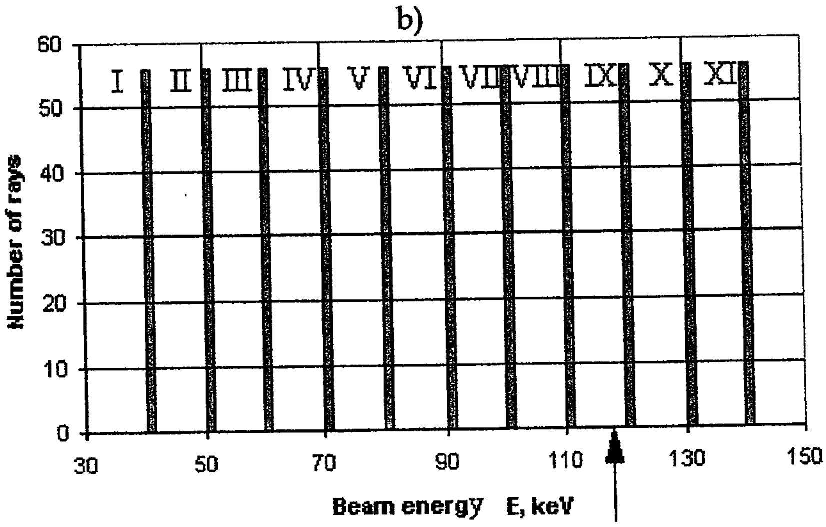
At the decelerator entrance:

- Beam energy 1.32-1.42MeV;
- Beam current - 1A;
- Emittance - 22 π *mm*mrad;
- Uniform current density distribution.

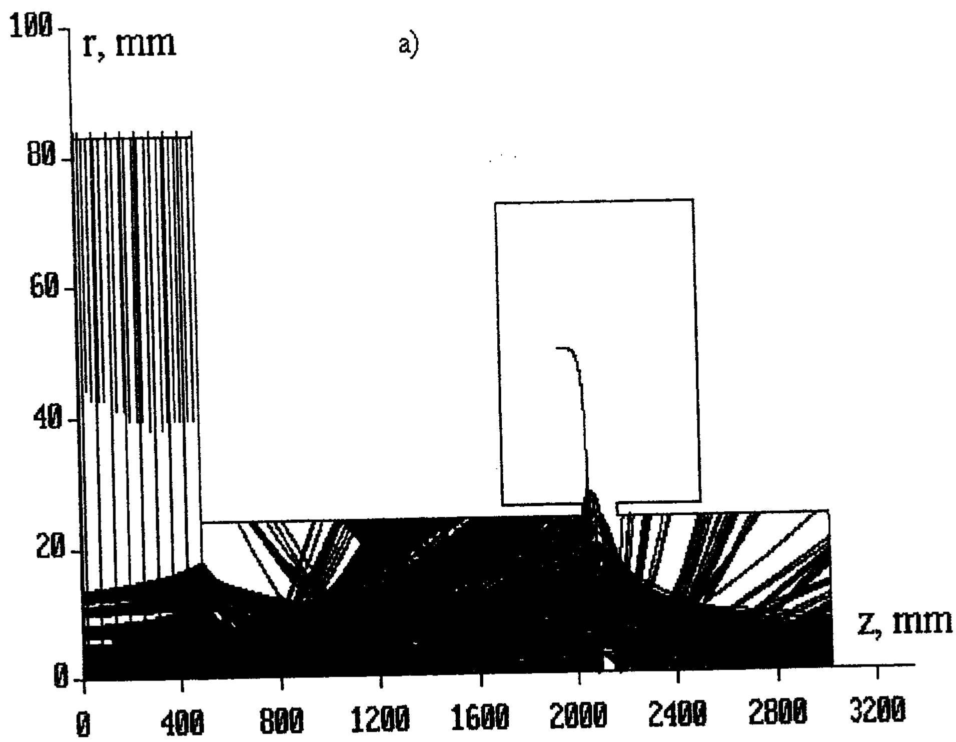
5. Results of simulations

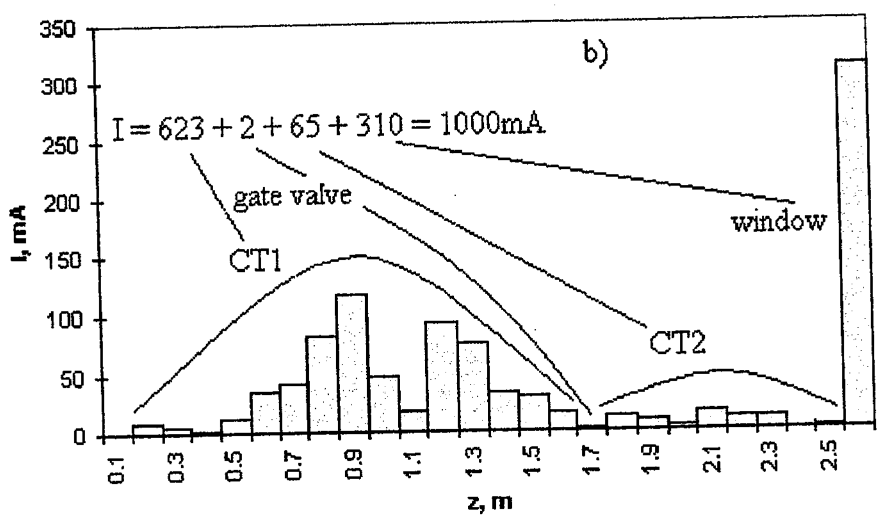
5.1. Beam tracing.





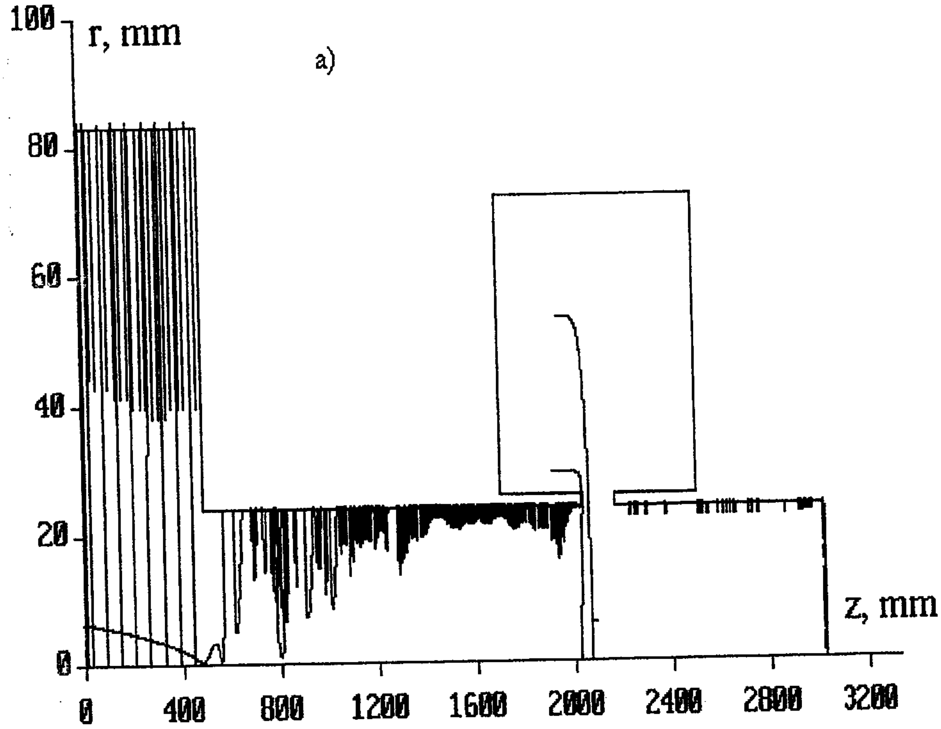
Beam at the CT1 entrance (a) and its energy composition (b)

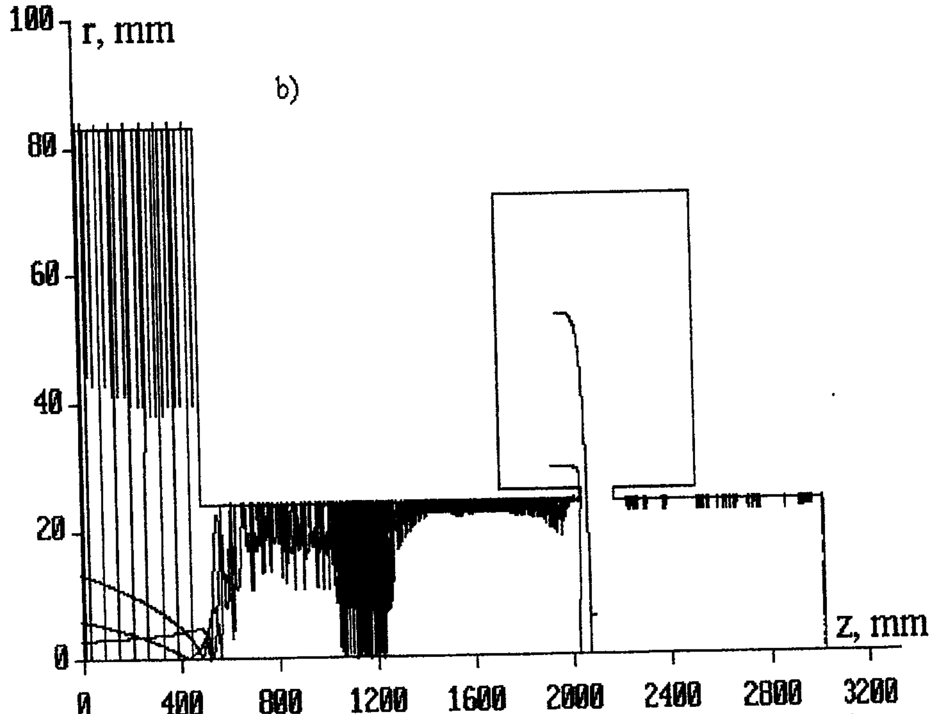




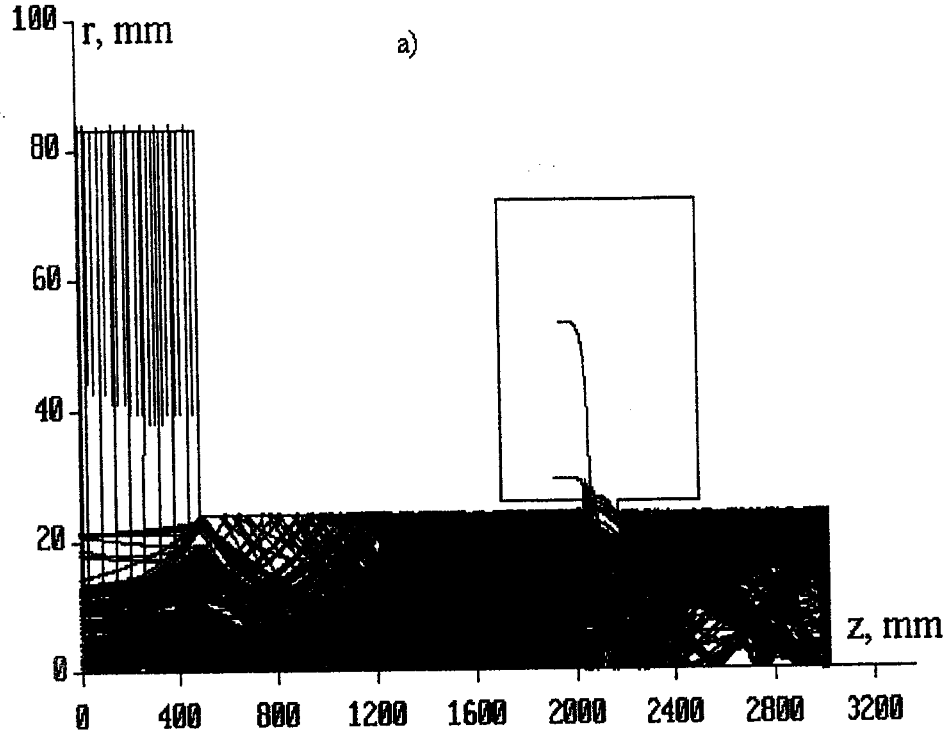
a) Trajectories of the prime beam rays in the collector region,

b) Histogram of beam longitudinal distribution for U(CT1)=75kV, U(CT2)=0.

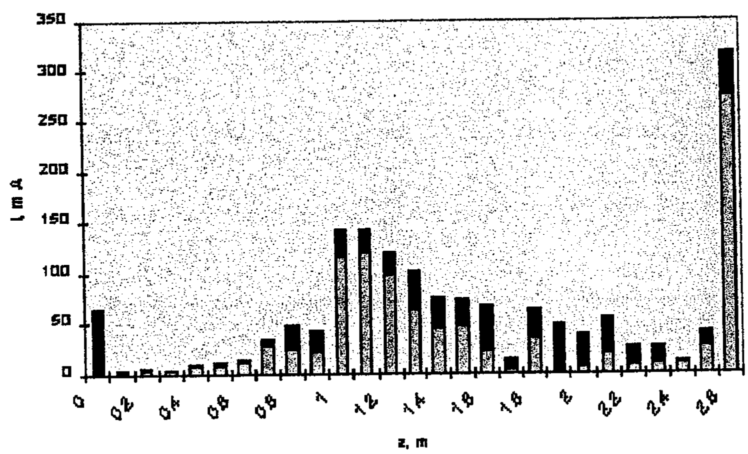




Low-energy secondary electron rays in the collector region.
a) Initial velocities are perpendicular to the wall surfaces.
b) Initial velocities have angles 0 and $\pm\pi/4$.



b)



a) Beam ray trajectories,

b) Histogram of the collected beam longitudinal distribution for prime beam (lower part of the each column) and elastically scattered beam (upper part) for U(CT1)=75kV , U(CT2)=0 in respect to ground. The left column (position z=0) is the beam current which returns into the decelerator in the reverse direction.

5.2. Multiple secondary effect (conclusions).

The results was presented at the FEL -99 Conference in Hamburg [5]:

•Beam tracings and histograms of the longitudinal beam distributions of the collected beam were shown. Simulations were carried out for the prime and for the secondary beams up to **6-th order** multiple elastic scattering.

•It was shown that the secondary low energy electrons do not travel in the longitudinal direction, but their **space charge** influences the dynamics of collected electrons and their longitudinal distribution.

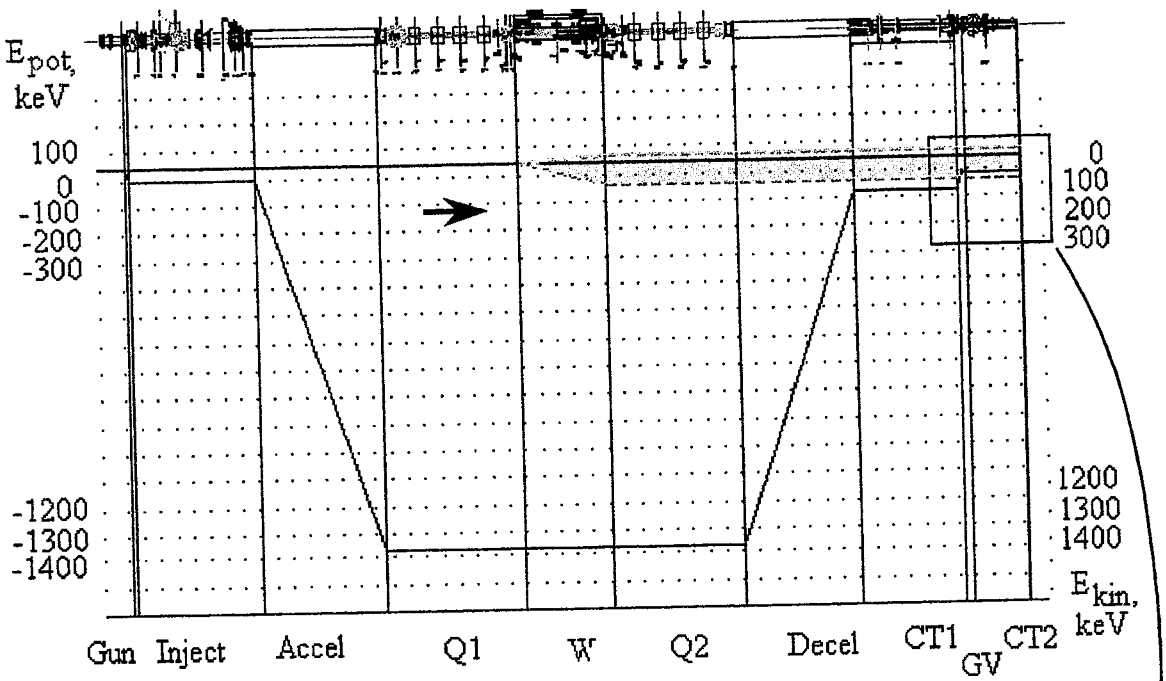
•The simulated **efficiency** varied from **66%** to **83%** for variation of U(CT2) from -60kV up to 0Volt respectively. Positive potential on the second collector stage was not used because the distance between the two collector stages was very large (135mm) and the gate valve was at ground potential. Negative potentials on the second collector stage was varied up to a potential leading to zero current to the second collector. For high collection efficiency positive potential on the CT2 electrode must be used.

5.3. Two stage collector modernization.

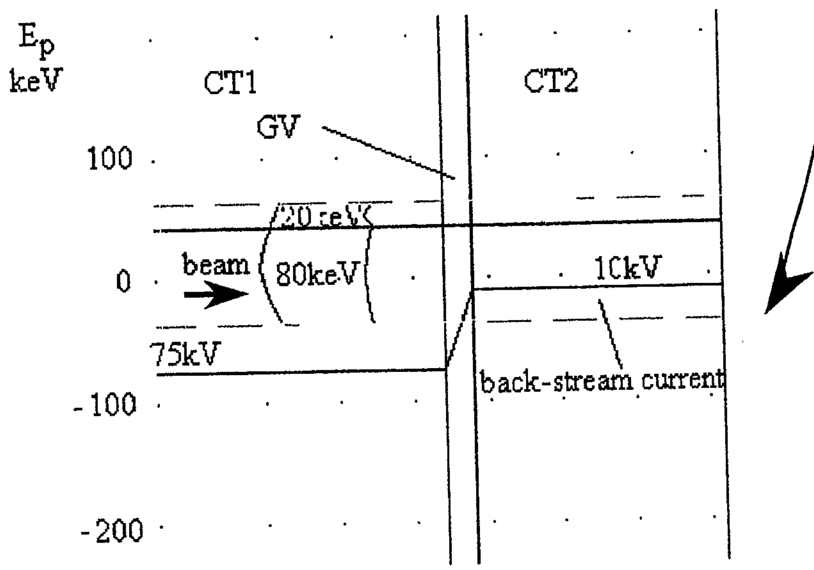
For collection efficiency improvement **two innovation** were made:

- The distance between the two collector stages was decreased (to 45mm);

- A scraper was introduced to reduce the back-streaming current.



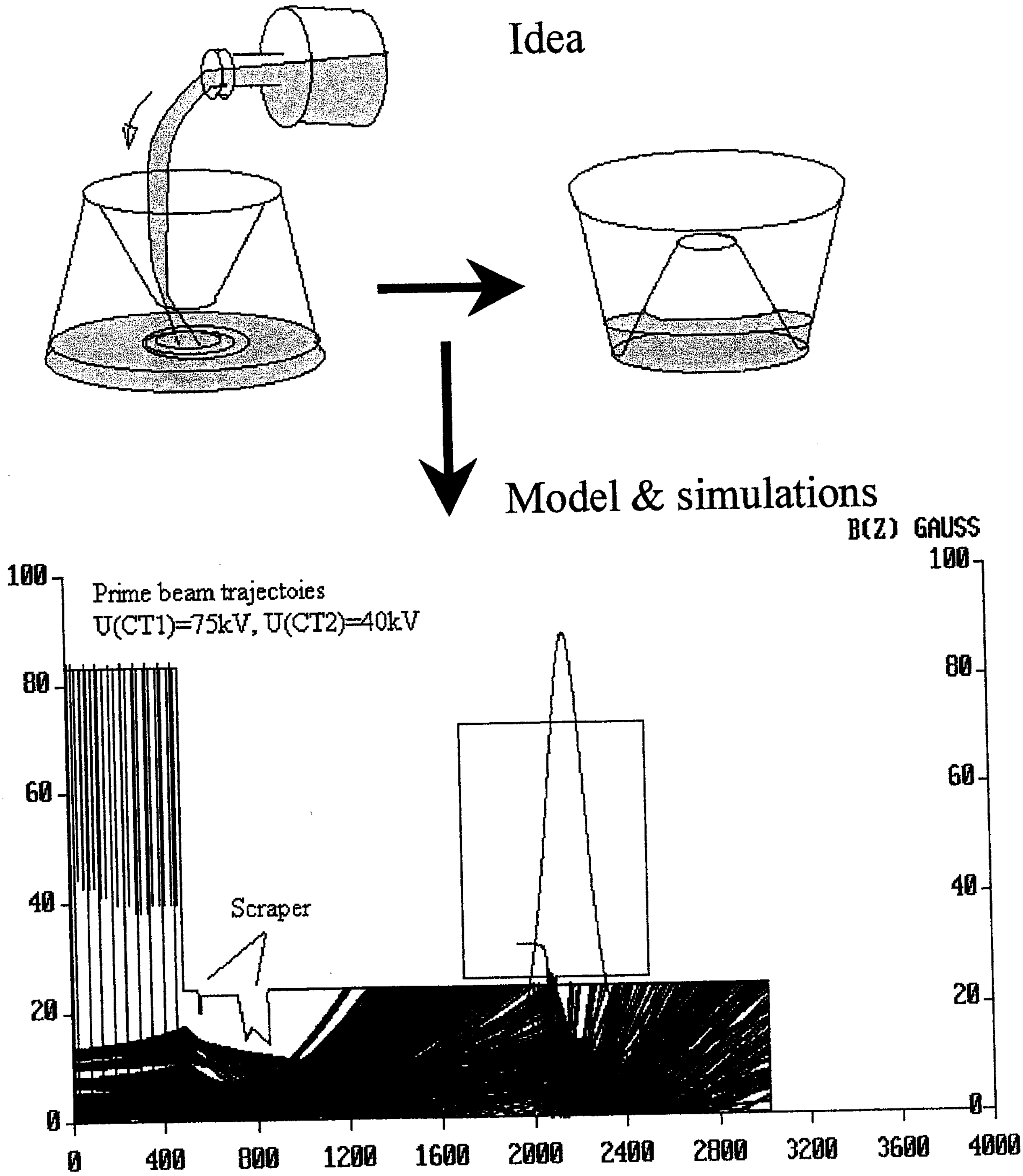
NB! If the distance between CT1 and CT2 (see GV in enlargement) is large, the potential on the beam axis is nearly to zero for any potential on the collector stage CT2.

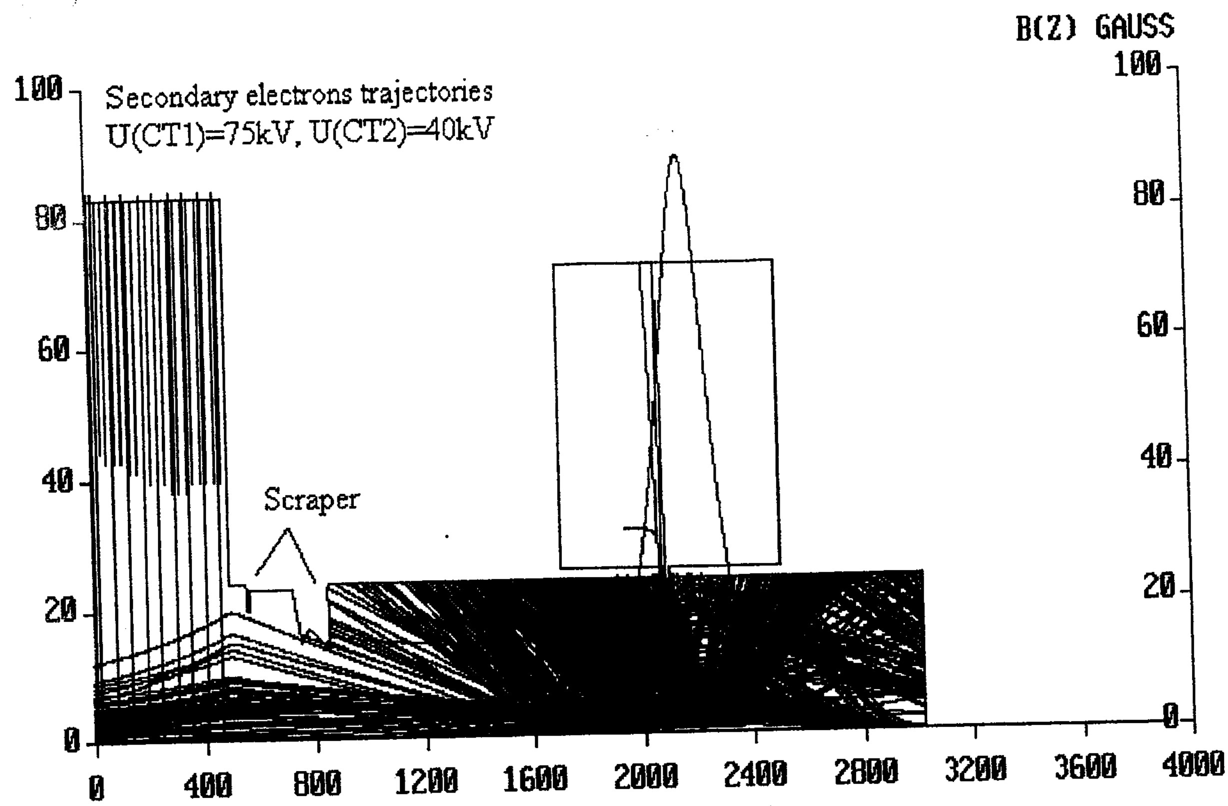


EA FEL energy diagram for the case of a short distance between the two collector stages

Beam scraper preventing back streaming.

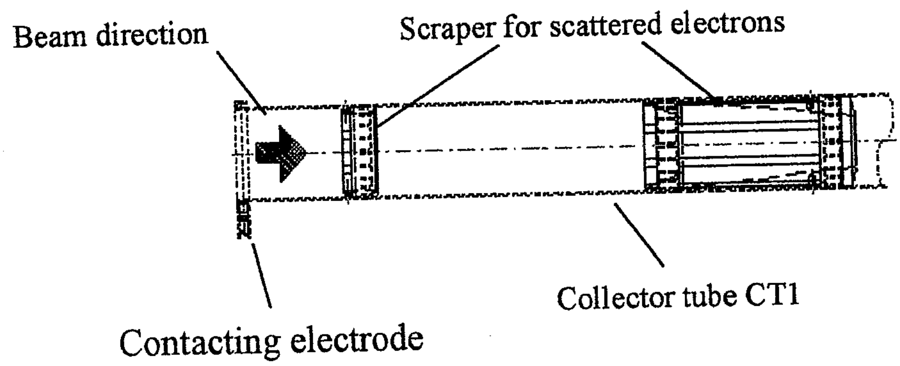
Designed to prevent **back-streaming..**



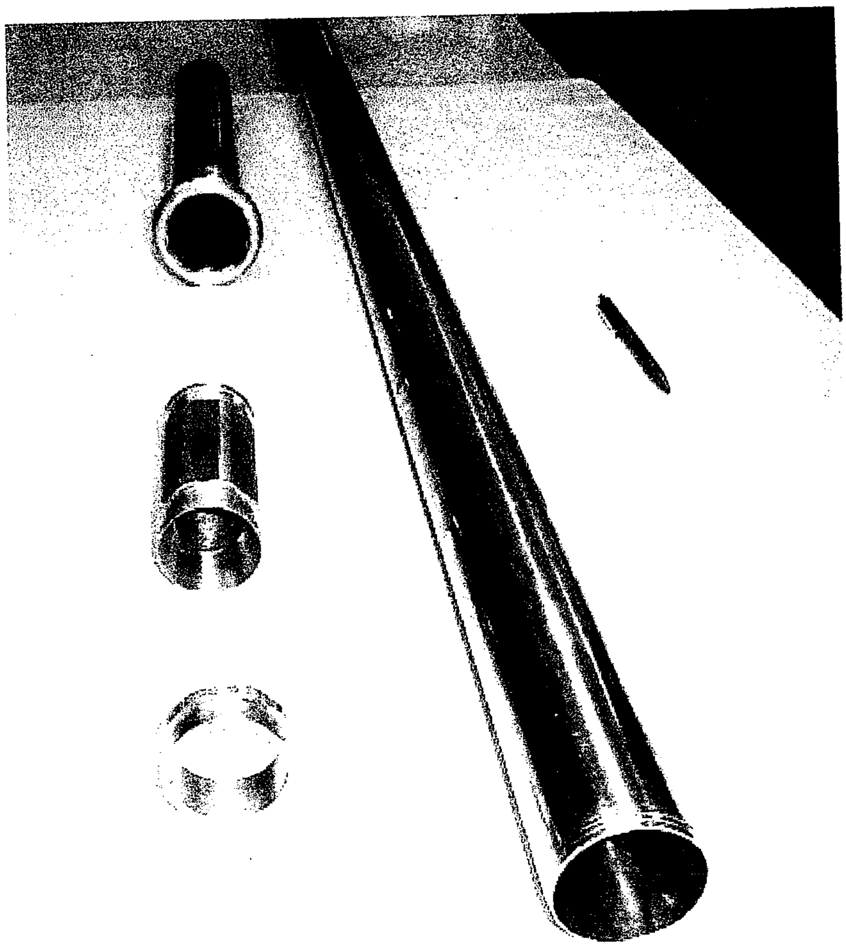


NB! The scraper does not decrease collector acceptance for the prime beam

Scraper design



Two-stage collector components



1. Beam current, mA

	C1	(Scraper)	C2	Window	C2+Win	Back	ε, %
U2=0	411	110	217	282	499	90 (9%)	91.
U2=20kV	294	54	205	437	642	55	94.5
U2=40kV	**209**	**18**	**210**	**559**	**769**	**20**	**98**
U2=75kV	138	7	159	680	839	23	97.7

2. Peak beam power (kWt), collector efficiency η and retrieval system efficiency η^*.

	C1	(Scraper)	C2	Window	C2+Win	Total	η, %	η^*, %
U2=0	32	5	7	8	15	47	38	87.5
U2=20kV	23	2	8	18	26	49	39	90.9
U2=40kV	**19**	**1**	**11**	**29**	**40**	**59**	**27**	**93.7**
U2=75kV	16	1	13	57	70	86	0	91.4

Average kinetic beam energy E_{av} at the collector entrance is (38keV+138keV)/2 = 88keV.
The difference between the kinetic beam energy (without radiation) 1.4MeV and the average beam energy (1.32+1.42)/2=1.37MeV is 30keV. This beam energy reduction is caused by radiation. For 1kWt radiation power and assuming a 100% beam power to radiation conversion efficiency we obtain a duty factor is 1/30.
In the above table the collector efficiency η and back-stream current coefficient ε are:

$$\eta = \frac{P_{beam} - P_{diss} - P_{backstream}}{P_{beam}} \qquad \varepsilon = \frac{I_{beam} - I_{backstream}}{I_{beam}}$$

Requirement power supply parameters:

For τ=1ms, dU=1kV: U1=75kV, I1=15mA, C1=0.8μF;
U2=0-40kV, I2=30mA, C2=0.8μF.

If dU=10kV, C1=C2=0.08μF.

NB! All presented results were obtained for a 43kV electron gun voltage, where the snode has a ground potential. As a results the beam kinetic energy at the collector entrance for Ui=75kV is 75+43=118keV. In this case an optimal potential of the second stage is U2=40kV. For the 60kV e-gun the reported results occur for Ui=60kV (Ekin =60+60=120kV) and U2=20kV. For the 80kV e-gun U1=40kV (Ekin=80+40=120kV) and U2=0. In this case the second stage of the collector is at ground potential. This case is advantaged for us and a 80...100kV e-gun is now under construction.

6. Conclusions

•The two-stage collector for the Israeli FEL is **designed** on the basis of beam dynamics simulations including multiple electron scattering effects which were taken into account. Elements of the two stage collector are being made.

•For the two-stage collector with minimum distance between its two stages **(45mm)**, and with **beam scraper** insertion the simulated back-streaming current is 20mA or **2%**, of the prime beam.

•The simulated Israeli FEL energy retrieval system efficiency for the two-stage collector is **93.7%.** The simulated efficiency of the two-stage collector itself is 27%.

•The collector may also be used as an energy analizer. In an electrostatic accelerator electrons move in the potential field: each electron arriving at the collector "**remember**" its energy before deceleration. Thus, beam energies of 1.32…1.42MeV before the decelerator transform to 38keV…138keV at the stage CT1. By changing the collector potential U(CT2) it is possible to determine the **high-energy limit** of the electron beam at the wigglwr exit. For these measurements (with a high negative potential) the distance between the two collector stages must be increased, due to possibility of sparking. Measurements can be carried out in a very low duty regime only, due to very low collection efficiency for negative potential on the second collector stage CT2.

•In a future development stage, the beam will be guided without electron interception by a series of solenoid lenses from the decelerator tube exit into an asymmetrical multistage collector. The latter will incorporate four copper electrode plates, each with an optimized shape, position and potential to prevent back-streaming, while realizing high charge recovery (>99%) and high overall system efficiency of 50...60.

7. References

[1] A.Abramovich, et.al., "Lasing and radiation-mode dynamics in a Van de Graaff accelerator-free electron laser with an internal cavity", Appl.Phys.Lett. 71(26), 1997.

[2] A.Abramovich, et.al., "High spectral coherence in long-pulse and continuous free-electron laser: measurements and theoretical limitations", Phys. Rev. Lett., 82(26), 1999.

[3] W.B.Herrmannsfeld, "EGUN - an electron optics and gun design program", SLAC-Report-331, 1988 & comments for Windows-95 PC version, 1997.

[4] J.T.Goldstein et. al., "Scanning electron microscopy and x-ray microanalysis", Plenum Press, 1994.

[5] S.Efimov et.al., "Energy Retrieval System of the Israeli EA-FEL", 21-th International Conference FEL-99, DESY, Hamburg, Mop-21, 1999.

NEW !

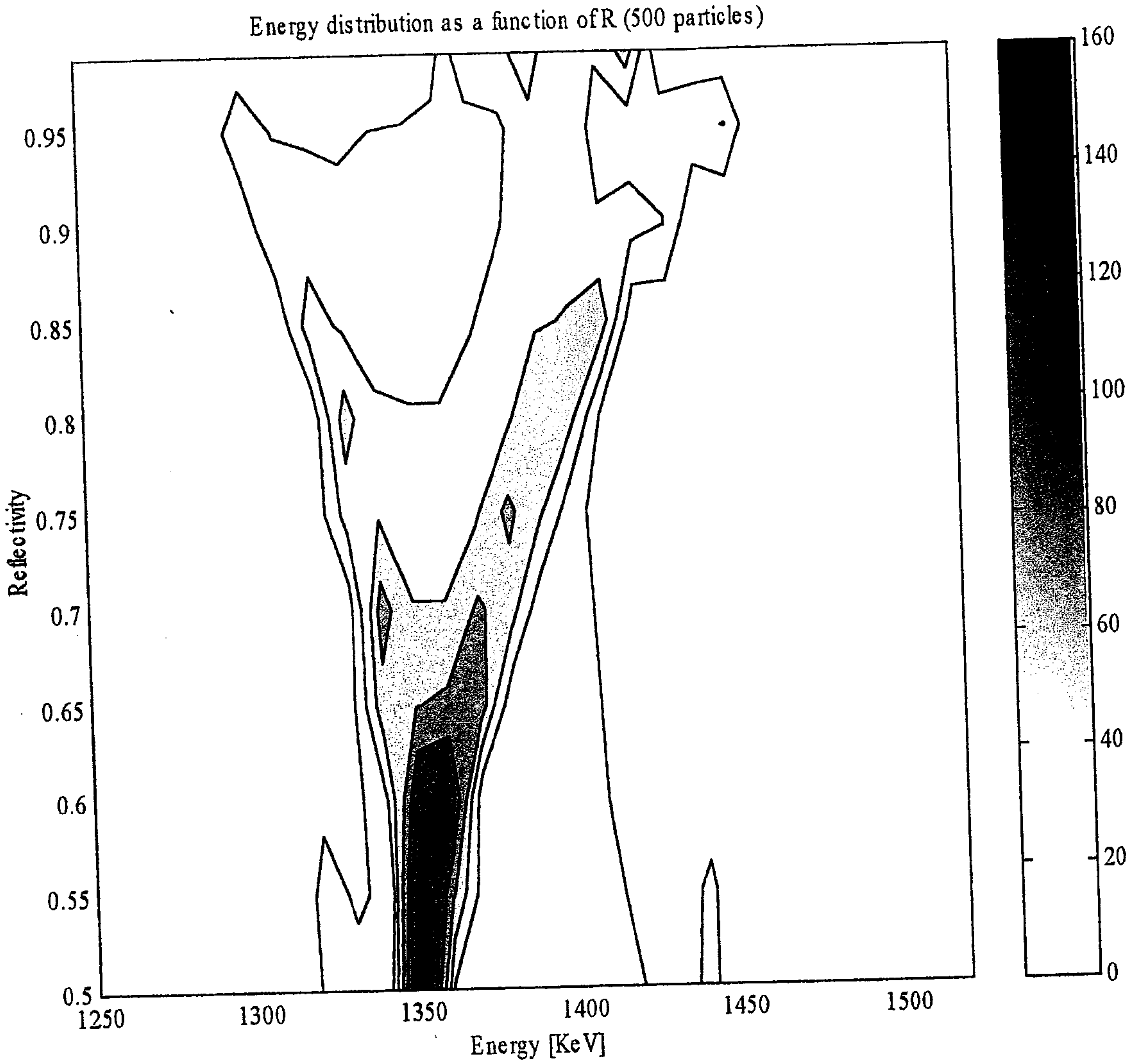


Fig.1a. Beam density distribution on the beam energy as a function of the beam reflectivity on the wiggler exit. The color bar shows the number of particles with a specific energy.

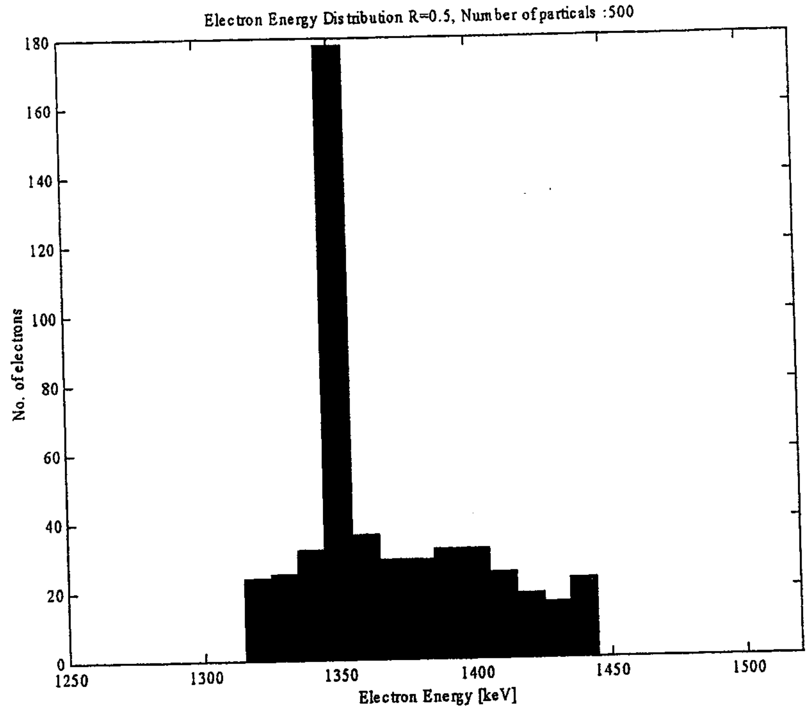


Fig. 2a. A histogram of the beam density distribution on beam energy for a reflectivity of 0.5 (a cross section of the Fig. 1a). I_{beam}=1.5A.

1. Beam current (mA) for U1=75kV, U2=40kV

	C1	(Scraper)	C2	Window	C2+Win	Back	ε, %
Uniform	**209**	**18**	**210**	**559**	**769**	**20**	**98**
R=0.5	**193**	**21**	**183**	**563**	**785**	**22**	**97.8**

2. Peak beam power (kWt) and collector efficiency η for U1=75kV, U2=40kV

	C1	(Scraper)	C2	Window	C2+Win	Total	η, %
Uniform	**19**	**1**	**11**	**29**	**40**	**59**	**27**
R=0.5	**21**	**1**	**19**	**28**	**47**	**68**	**23**

A short solenoid in the scraper region is used for additional beam focusing .