TESLA-Report 1993-04

A Low Charge per Bunch Injection Line for the TESLA Test Facility

B. Aune, M. Jablonka, J.M. Joly, E. Klein

DSM/DAPNIA/SEA
Centre d'Etudes de Saclay
FRANCE

- January 1992 -

A LOW CHARGE PER BUNCH INJECTION LINE

FOR THE TESLA TEST FACILITY

B. Aune, M. Jablonka, J.M. Joly, E. Klein
SEA/DAPNIA (CE Saclay) France

Introduction

This report deals with the injector referred to as "injector 1" in the TESLA test facility proposal [1].

It is proposed to build an injector delivering the same current pulses as those required for the TESLA project (8 mA peak current, 800 µs duration, 10 Hz repetition rate) but with a bunch frequency of 1300 MHz instead of 1 MHz. This choice results in a reduction by a factor of 1300 of the charge per bunch (i.e. $3.85\ 10^7$ electrons per bunch instead of $5\ 10^{10}$), and in a much simpler scheme of injector.

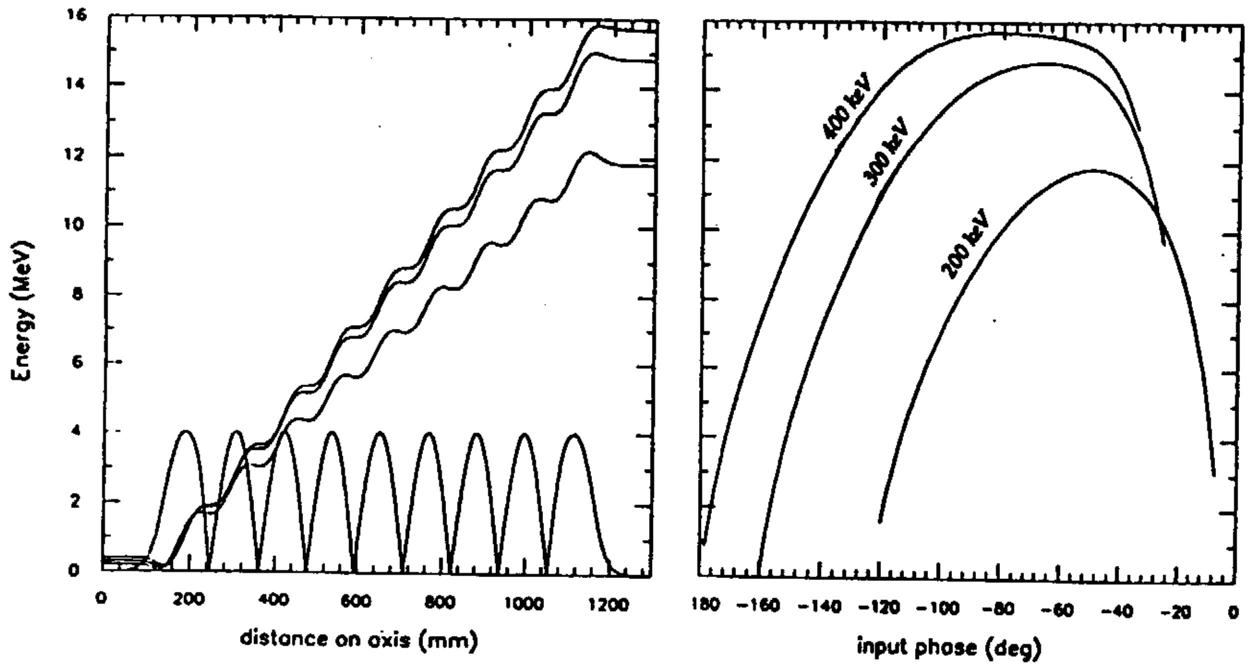
The proposed scheme consists in injecting electrons directly into a standard 9-cell S.C cavity housed in a separate cryostat and powered by a separate klystron. "Directly" means that there is no other preacceleration than the one provided by the gun high voltage. The beam delivered by the gun is only chopped and prebunched by velocity modulation before entering the cavity.

Results of preliminary beam dynamics study and some technical choices for the injection beam line components are given.

Choice of an electron gun

The first parameter that must be determined to permit direct capture in the SC cavity is the initial energy of the electrons, i.e the gun high voltage. For a β=1 traveling wave structure, with a 15 MV/m accelerating gradient, theory shows that a value of only few kV would be sufficient. However, both because of the reflected wave in a standing wave structure and of the far extending fringing field existing at a SC cavity entrance, a much higher value is required. Computer simulations (fig. 1) show that if 200 kV is suitable, 300 kV will insure a better average energy gain and better output energy spectrum.

Of course, a 200 or 300 kV gun is more expensive and less convenient than a 100 kV gun as used on many linacs, but building and installing a preaccelerating system would be, in our case, still more complicated. A group of Stanford has recently tested and optimized a 300 kV gun for a high brightness injector experiment [2]. As it is commercially available in 6 month [3], this gun could be recommended for our purpose. Its emittance has been measured and found equal to 3 π mm.mrad. We therefore use it as a base for our calculations and for the cost and time estimations.



(a) (b)

Fig. 1 :Electron dynamics in the 9-cell cavity for a 15 MV/m accelerating field and for initial energies of 200, 300 and 400 keV:

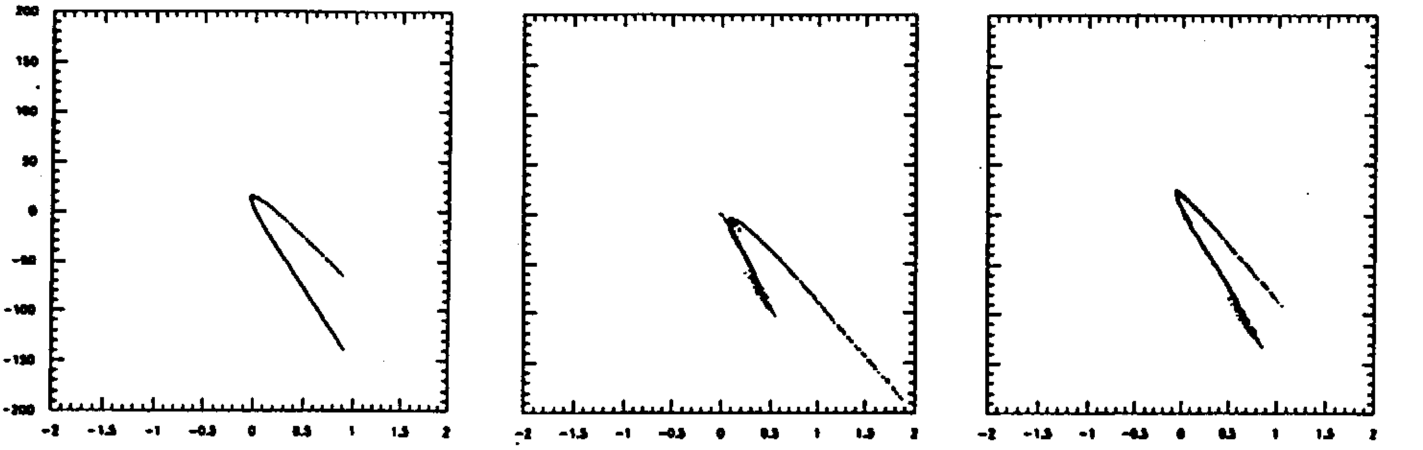
- (a) energy vs distance along axis for the optimum input phase.
- (b) output energy vs input phase.

Maximum axial electric field in the cavity (in arbitrary units) is plotted on graph (a). Though distance between extreme iris of the cavity is 1.04 m the variation is taken into account over 1.3 m.

Beam dynamics study

In order to carry out more complete simulations of the system, some other parameters have to be chosen at reasonnable, though not definitive, values. We have supposed an initial phase extension of 60°. A 1 m long drift space has been taken for prebunching by velocity modulation . Focusing along this drift has been supposed insured by one single solenoidal lens. Initial beam emittance has been made equal to 15 π mm.mrad in order to take an increase by the chopping system into account and to represent a higher proportion of the electrons. The PARMELA code, that has been used, has been modified to include a representation of the Ez law on the axis of the 9cell cavity (fig.1a). Out of the axis, fields are obtained by first order derivation.

For a 250 keV initial energy, 18 keV maximum energy modulation, 15 MV/m average accelerating field and 10 mA peak current, one obtains output parameters as 14 MeV, 1° of total phase extension, 160 keV of total energy dispersion (figs.2,3 and 4). Transverse emittance is increased by only 20%. Space charge is shown to cause only a slight lengthening of the bunch that can be compensated by increasing the energy modulation to 19.2 keV (fig.2). Radial effects are negligible.



Output energy (keV) vs output phase (deg)

Fig. 2 : Longitudinal space charge effect : for a 10 mA intensity, the effect is low and can be corrected by adjustment of $V_{buncher}$. From left to right :

- i peak= 0 mA $V_{buncher}$ = 18 kV
- i peak= 10 mA $V_{buncher}$ = 18 kV
- i peak= 10 mA $V_{buncher}$ = 19.2 kV

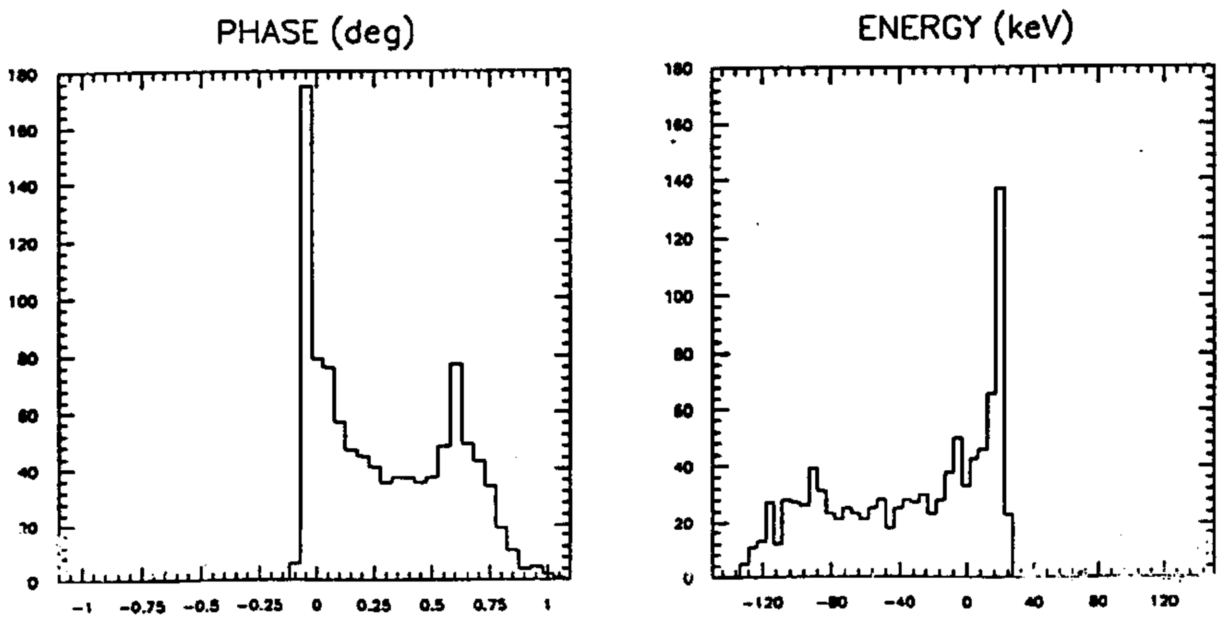


Fig. 3 : Phase and energy histograms at the output of the 9cell cavity generated by Parmela with 1000 particles. Initial energy is 250 keV, peak current is 10 mA, final energy is 14 MeV.

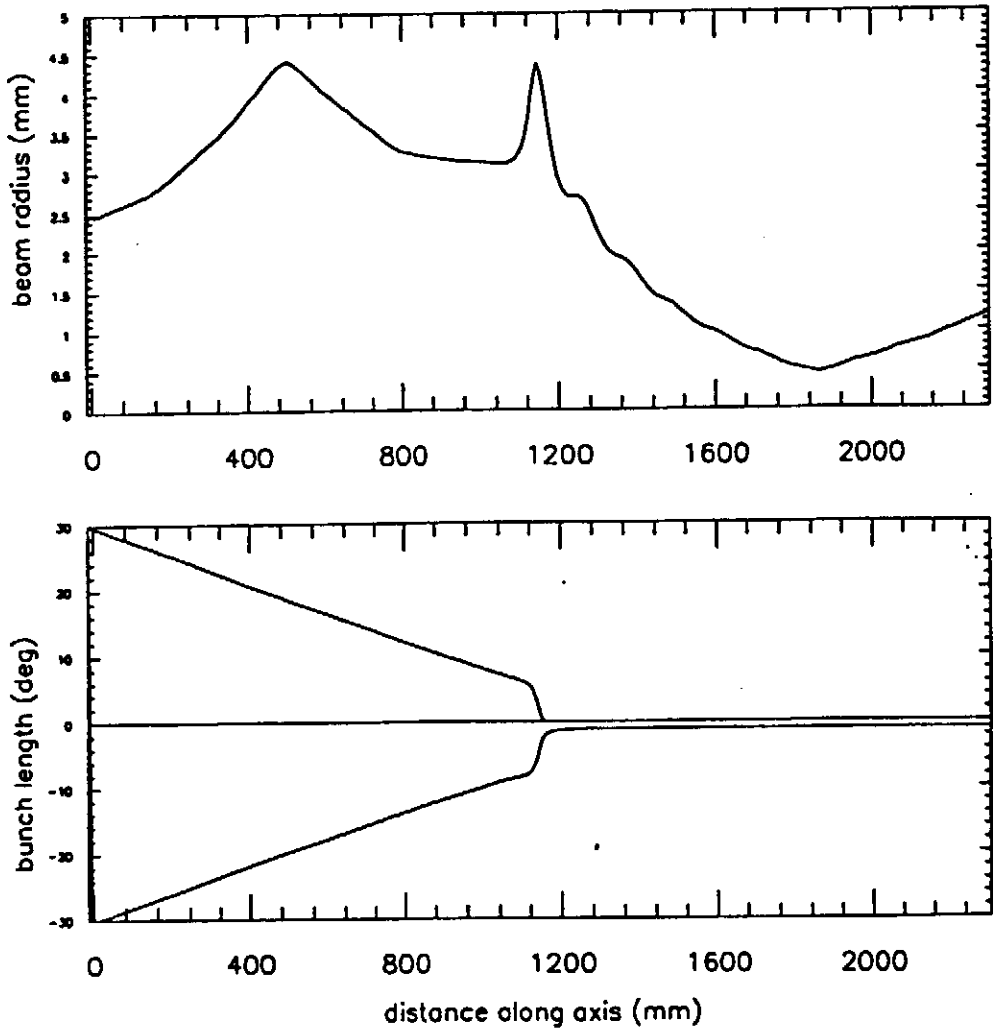


Fig. 4 : Beam radius and bunch length variation vs distance in the prebuncher drift space and in the 9-cell cavity. Origin is at the buncher location.

Chopping system

We propose not to follow the scheme that has been used on our MACSE injector [4] and that requires 2 deflecting RF cavities and 4 RF amplifiers with amplitude and phase stabilizations : if such a system insures a good emittance conservation, it is expensive and complicated. Instead, we propose using only one cavity (fig.5), deflecting the beam in only one direction (in a vertical plan for instance) : the beam is permanently set off axis by a steering coil and deflected back on axis, at the RF frequency, by the cavity. At an appropriate distance, the beam is focused at a small diameter and an horizontal slit (or collimator), placed on the axis, limits the transmission of the beam at 30° of phase, both sides of the maximum deviation.

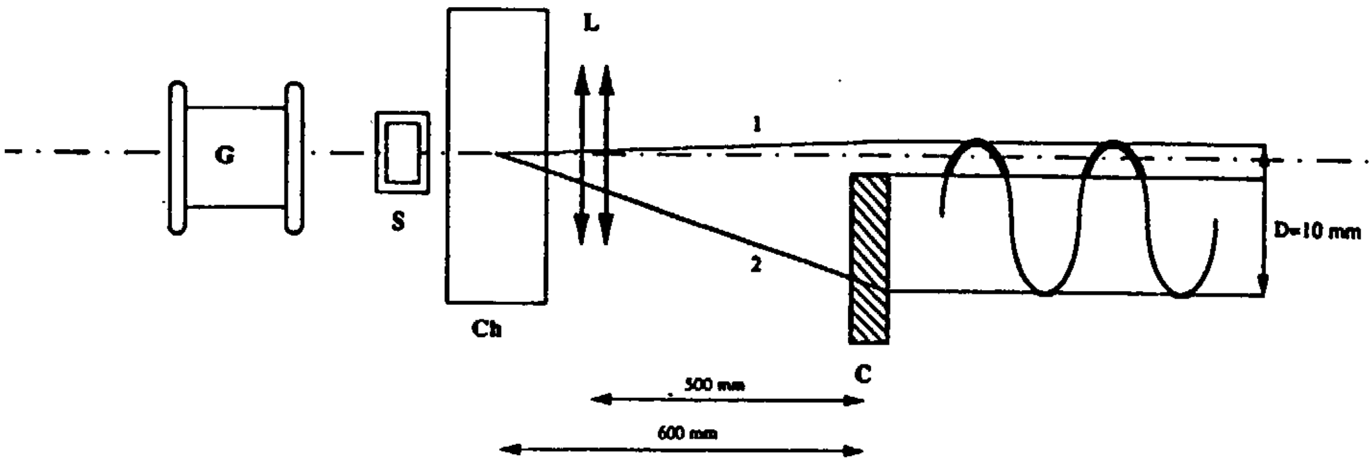


Fig. 5 : Schematic of the chopping system.
G-: gun S-: steerer Ch-: chopper cavity L-: pair of lenses
C-: collimator 1-2 : beam extreme positions

In using a big aperture solenoidal lens, a 50 mA beam of emittance 5 π mm.mrad can be focused down to a 1 mm spot at a distance of 500 mm. The cavity center is placed 600 mm before the collimator plan. As the RF power required in a deflecting cavity scales like γ^2 (γ is the Lorentz factor), it can be deduced from the MACSE experience that a 10 mm deviation can, here, be obtained with 30 W of peak power.

As this displacement, D=10 mm in the collimator plan, represents 180° of phase, the 30° transmitted either side of the maximum deviation correspond to a transverse movement of the beam given by :

$$d = D[1 - \cos(30°)] = 1.34 \text{ mm}$$

In the direction of the deflection, the beam cross section after chopping, will therefore appear with a width of 2.34 mm instead of 1 mm. The tranverse emittance is therefore roughly doubled. On another hand, the translation of the 1 mm beam spot over the collimator edge will result in a "risetime" and a "falltime" of the bunch current of 18°.

Of course, the transmission angle of the chopper can be set smaller than 60° : both transverse and longitudinal emittances will then become smaller but the transition time of the bunch current will become relatively more important. More current from the gun will also then be required and this may cause a transverse emittance growth. The best compromise between chopping angle and gun emission will be found when the gun performances are better known or will be searched manually when the whole system is operated.

The pair of solenoidal lenses represented on the schematic is necessary to avoid the rotation of the deflection plan that a single lens would produce (the 2 lenses are connected in opposite ways). Instead of solenoidal lenses, a pair of small quadrupoles (using printed circuit techniques) could be advantageous : it would permit to less focus the beam in the direction perpendicular to the deflection, in order to avoid an excessive power concentration on the collimator.

Preliminary design of the beam line

Based on all the previous considerations and on several other technical choices, we have set up a preliminary design of the 300 kV injection line (fig.6).

Some MACSE components are used, unchanged or scaled :

Two standard 200 mm long vacuum chambers, able to house several items, are used : one will hold the water cooled retractable chopper collimator associated with a viewscreen and the other will receive a Faraday cup, a wire scanner for beam profiling and a second viewscreen. Both chambers have a pumping port.

Intensity monitoring is made by toroids. Two models have to be used : One for 3 μs pulses (for beam adjustment) and one for the normal 800 μs pulses. They will be put on the same 260 mm long vacuum tube interrupted by a ceramic gap, internally screened to avoid charges deposition. Two of these monitors are to be used : one before the chopping and one after.

The rectangular TM110 copper cavity for the chopper and the cylindrical TM010 copper cavity for the buncher can both be derived from the 1.5 GHz ones used on MACSE. An optimization of these cavities will be necessary to take into account the change of the RF frequency and of the electrons velocity.

References

[1] "A proposal to construct and test a prototype of SC RF structure for a linear collider", Oct 1991, DESY.

[2] Todd I. Smith, "Production of intense low emittance beams for F.E.L using linear accelerators", Nuclear Instr. and Methods, A250(1986) 64-70.

[3] Hermosa Electronics- California 94025

[4] B. Aune, M. Jablonka, E. Klein, "The MACSE injector", Proceedings of the 2nd EPAC, Nice, (1990).

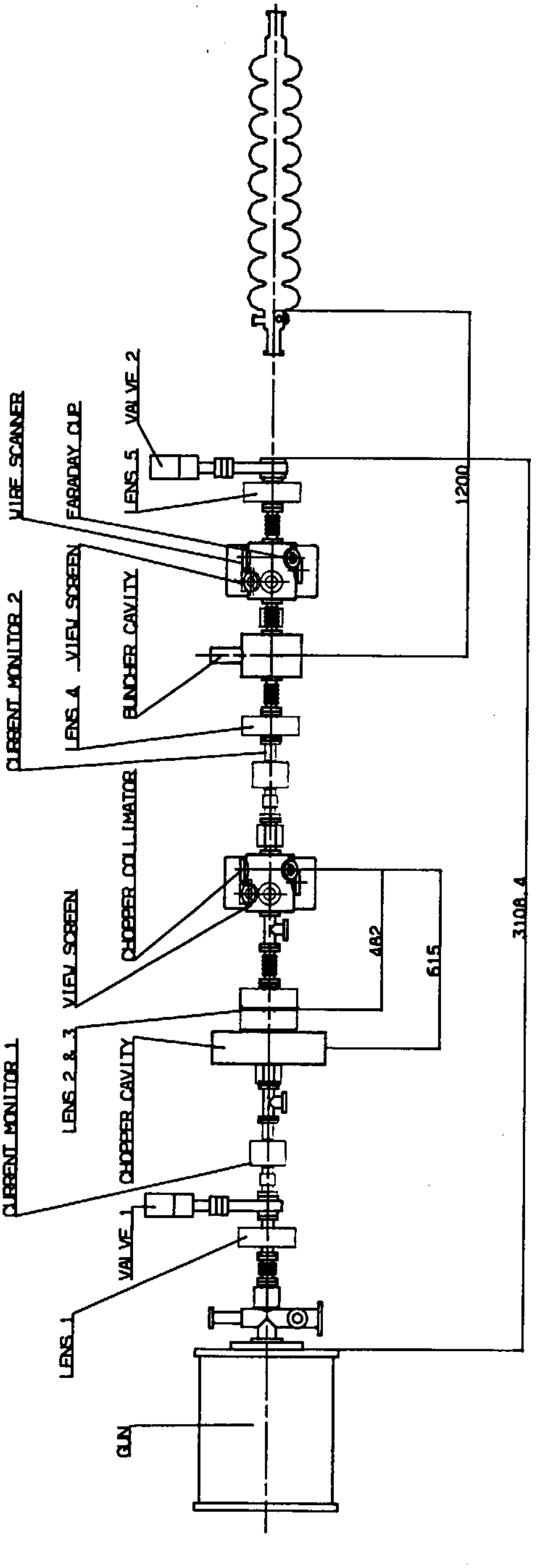


Fig 6 300 kV Injection line for Injector 1