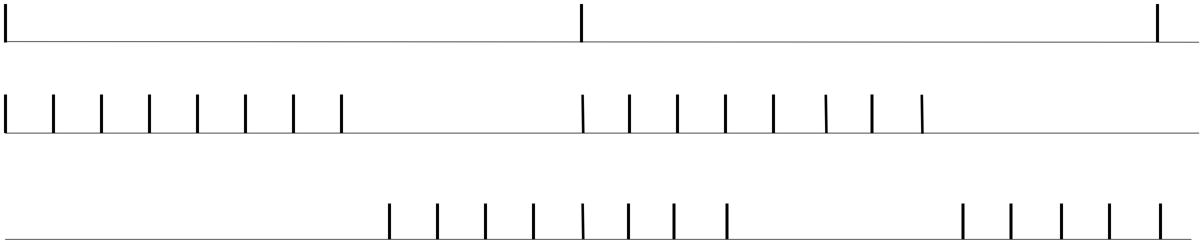
Laser beam paths for the CTF

PS-LP Note 96-10
CTF Note 96-13
S.C.Hutchins, PS-LP

Major changes to the optical system are required for CTFII: the addition of the Probe beam, optical adjustment of the RF-Laser phase for the Drive and Probe beams, energy and beam quality measurement at the vacuum chamber and independent variable attenuators for both beams. Although the development of a single-axis Pulse Train Generator (PTG) will be started in 1996 we must start operation of CTFII with the present 48-pulse PTG[1] which produces a tapering mesh of 12 beam paths, this dictates the approach to the imaging system, as relay imaging cannot be used and monitoring the optical path is difficult.

The situation for CTF(1995)

The 48 pulse train is generated from the two pulses which are amplified in the laser, which are separated by 4ns, these are divided into 4 pulses in PTGIII, where the delay in the long arm is 8ns. These 4 pulses are all on the same axis, the image of the aperture (A3) is projected (or relayed) to the cathode by the lens L3 with a magnification of 2. PTGI then splits this single axis train into a 4x2 matrix where each axis has a different delay in multiples of the 3 GHz RF period and each one can be independently steered to the cathode, in this way four bursts of 8 pulses are produced, with a gap of 2ns between each burst, 32 pulses in all. A continuous train would require that each of the four single axis pulses be split into 12 having an equal spacing of 333ps between them, to achieve this the 4x2 matrix is again split to produce a 4x4 array of beams, the extra delay is 2.66 ns which places the delayed 1st pulse of each burst at the correct time to become the 9th. The following figure illustrates this:-

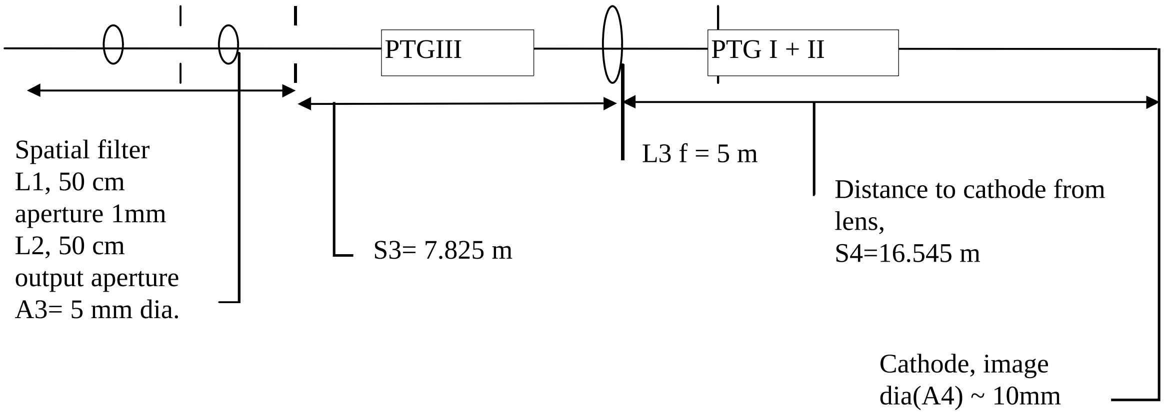


The first line represents 3 of the 4 pulses at the output of PTGIII, their spacing is 4ns. The second line represents the 8 pulse lines from PTGI, each of these is on a different axis. The third line is the output from PTGII, again these are on 8 new axes but the whole group has been delayed by 2.66ns. Only the first 4 of this last group are sent to the cathode, the useful pulses are in a 3x4 matrix, in which all the pulses are made to overlap at the cathode. This 3x4 matrix may be referred to as a 12-pulse generator.

Original calculations of lens choice and placement were by S.Schreiber in 1994 for the path of the sixth pulse in the train, before the addition of the polarising stage. Dimensions shown are with the polarising splitter stage (PTGIII) added, extra path length 800 mm for the first group of 24 pulses, plus 2.4m for the delay of the second group.

---

[1] The present system is developed from the proposal documented in "*Minutes of the meeting on the CTF Pulse Train Generator held on 23/6/93*" reported by J-P Delahaye, PS/LP Note 93-43.



using Gaussian lens formula, 1/S3+1/S4=1/f, where f=5 m
S4/S3 = Magnification = A3/A4

For the sixth pulse M= 16.545/7.825 = 2.114 = Mag. A3 = 5 mm dia. giving **10.6 mm dia.(maximum) at the cathode**, which was calculated as 12 mm before the polarising stage was added.

Pulses in the 12-pulse train see different values of S4, the sixth pulse is in the middle of the train, the first pulse path is 2 ns shorter and the last 2 ns longer, 2 ns = 0.6 m

Pulse 1 magnification = 2.04, giving 10.2 mm at the cathode
Pulse 12 mag. 2.19, giving 10.95 mm.

These small differences may be ignored, the pulse train then repeats for the second pulse generated in the laser 2-pulse mode, with the same dimensions, however, for the 3rd and 4th sets of 12 pulses in the 48 pulse train, the polarising splitter adds in an extra delay to S3 of 2.4 m, equal to 8 ns, giving the following dimensions:

S3=7.825+2.4=10.225 m.
S4=16.545 m as before.
Under these conditions the lens is unable to image the aperture onto the cathode, as the image distance with this lens is 9.8 m. The pulses in this part of the train are observed to be about **5.0 mm** dia. for maximum aperture.

If necessary this difference may be corrected by the addition of an optic in the long arm of the polarising splitter, the required focal length at L3 would be approximately 6.5 meters, but this must be composed of the 5 m lens L3, plus an optic with a negative focal length of 22 m. As this would have to be specially made, a cheaper solution would be to use a telescope, possibly two 50 cm lenses, which could be adjusted to give the required focal length.

Review of 1995

In practice, the CTF has usually run in 1995 with a spot size of 5 mm on the cathode, measurements of extraction efficiency on the cathode have shown that the best emission is strongly centred on the cathode and little is to be gained from a larger laser spot. In addition, for some measurements the smallest possible spot size has been required.
The accuracy of the energy measurement can also be improved, we presently monitor the energy at the beginning of the system and apply a calibration factor which must take account of all losses in the pulse train generators and the path, which may be affected by slight misalignments without being readily apparent. For CTFII the energy reference will be taken as close as possible to the photocathode, using Pyro-electric detectors with integrated

amplifiers, developed by J.Durand. These are sensitive to radiation and require lead shielding.
Daily adjustments have been required to the PTGs to keep the whole train centred on the same spot, this is due to the poor mechanical implementation, the choice of materials and method of assembly could be improved, but as previously mentioned, a new single axis PTG is proposed for which studies of the most appropriate mounting system will be made.

The Drive beam for CTFII

The Laser-RF phase adjustment (delay) and the variable attenuator will be added before the aperture A3 (which will be increased to 6mm diameter), so that adjustments will not affect imaging on the cathode. The variable attenuator will have the advantage that it does not change the optical delay to cathode as the present fixed attenuators do. The long arm of the polarising splitter stage (PTGIII) will be equipped with the compensating lens discussed above, the spot size on the cathode will therefore be nearly uniform throughout the 48 pulse train. The CTFII configuration with optical access 7 m from the cathode would make S4 (the lens-cathode distance) 12 meters longer, but it is foreseen to use the hole to the CTF presently serving the streak camera for TCM observation, so that S4 will now be approximately 22 m. The present magnification of x2 is a workable maximum, with higher magnification it is difficult to generate a small laser spot, useful for setting up.

For the available lenses the following results are obtained for object distance (S3) and magnification.

Plano-convex lens	focal length, m	object distance, m	magnification
R=2500	5.0	6.47	3.4
R=2765	5.53	7.38	2.9
R=3396	6.8	9.8	2.23
R=4100	8.2	13	1.7

The 6.8 m lens is the best choice as it avoids a long object distance on the optical table, which will be fully occupied with the probe beam optics, also it gives a low magnification factor. The 8.2 m lens may be used to provide a fine focused spot for measurements of cathode efficiency distribution.

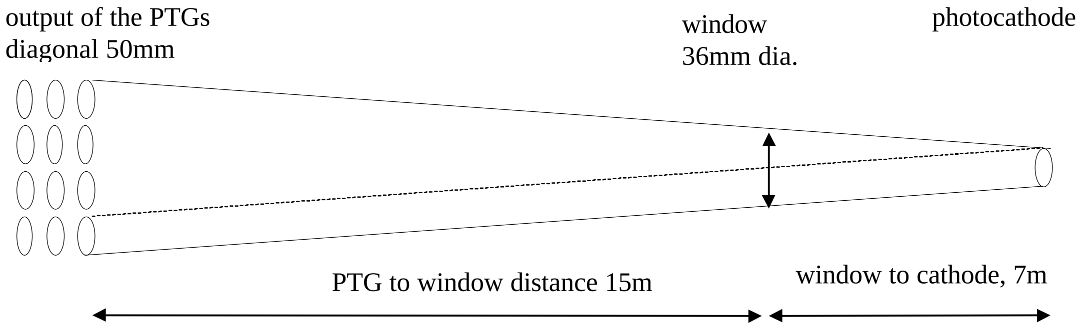
The beam path will descend directly down the ex-TCM hole to a small optical table in the CTF, this avoids the use of “hanging” mirrors for the Drive beam, although no stability problems have been observed due to these mirror supports, the accessibility of tables will facilitate alignment of the paths. From this table the path follows to a second table at 3.5 meters distance, opposite the central magnet of the bunch compressor, which is itself 7 m from the cathode. On the second table is mounted a sample plate to measure the beam energy and position, followed by the x-y scan, then a second sample plate for the “virtual cathode”, both of the samples will be sent on a reference path which will place the point of monitoring at the effective cathode distance. The sample plates are at near 0^o AOI to be polarisation insensitive and are anti reflection coated (AR) one side and for 2% reflectivity the other. The energy measured will therefore be 2% of that on the cathode, the exact splitting ratio will be measured. A third plate will be used to send 1/10000 to a CCD camera for beam position and energy distribution monitoring of the beam, this will provide a fixed reference point for alignment.

From the x-y positioner, which also raises the laser pulse train to the height of the drive beam axis, the train is sent to a window integrated into the vacuum chamber of the bunch compressor. This window is on the axis of the Drive Beam, avoiding the horizontal offset and aperture restrictions of the current CTF, this allows the maximum range of x-y position movement for centring the beam and for measurements of the photocathode efficiency distribution. The window will be of fused silica, 36mm dia. clear aperture, welded onto an anti-magnetic stainless steel “skirt” which will itself be welded as an integral part of the vacuum chamber.

It is possible to have an anti reflection coating on both faces of this window as this area is not UHV baked. This is the contrary to the current situation and that for the probe beam in CTFII, where it is only possible to have an anti reflection coating on the inside of the window despite the easy access to both faces, as these sections are “baked out” at 150°C and the coatings cannot withstand this temperature in air.

The window will have to be polished to high optical quality, as there is 7m between it and the cathode, the smallest fault in thickness will cause distortion of the beam.
The electron beam will be diverted off axis in the bunch compressor allowing the window to be on-axis and yet not obstruct the beam. To avoid radiation damage to the window, which would reduce its transparency, an interlock is required from the first magnet of the bunch compressor to the Klystron modulators ensuring that no RF can be applied to the cannon and accelerating sections when this magnet is off, as even dark current would reduce its transparency, it is not sufficient to interlock with the laser.

The maximum beam dimension is the diagonal which at the output of the PTGs is 50mm and at the cathode 10mm, at the window which is 15m from the PTG and 7m from the cathode this diagonal will be 23mm, leaving 6mm range either side of the centre position to align the laser. This is assuming a 10mm dia. spot, with a 5mm spot +/- 9mm movement will be possible. For photocathode scans a single pulse from the centre of the “mesh” will be able to scan over +/- 12mm.



The beam passes above the vacuum chamber of the Probe beam which is 50mm lower than the drive beam and has an external diameter of 44mm. This gives a vertical aperture restriction at -28mm, lower than that of the window and therefore presents no problem. The beam will be reflected onto the axis of the machine by a 50mm dia mirror mounted on a long arm supported on the magnet table. The will be sampled after the x-y-stage to provide a “virtual cathode” with CCD camera monitoring as at present.

The Probe Beam

The UV light for the Probe beam will be generated by a second 4th harmonic conversion on the remaining 2nd Harmonic green light [2]. This beam will also require spatial filtering, a motorised attenuator, fine phase adjustment and the generation of a second pulse with variable delay, by polarisation splitting and recombined to be on the same axis. As the laser will normally be working in its 2-pulse mode, two UV pulses would be produced for the probe beam, at a fixed separation of 4ns, making four probe pulses. The foreseen instrumentation for the probe beam would be perturbed by this second pulse, therefore one pulse will have to be removed by a Pockels cell. This would be most effectively done at the second harmonic

---

[2] Described in “The CTF Laser” PS-LP Note 96-11

where the cells have good transmission and the pulse selector would not affect the drive beam generation, a solution to this problem will be devised during the 1996 run.

To allow for the filling time of the CLIC Transfer Structure (CTS) the probe beam must arrive at its photocathode 12ns after the first pulse of the Drive beam arrives at its photocathode, this will then place the probe beam at the entrance to the CLIC Accelerating Structure when this is fully “charged”. The Probe beam path will therefore be 9.2m +22m +12ns =35m counted from the exit of their respective spatial filters. This delay will be achieved by passing the beam between the three tables in the CTF.

To achieve a good control of the beam quality, relay imaging must be used. A single lens of 9m focal length placed at the half-way point in the path would image with magnification=1, but it would be difficult to avoid spherical aberrations by keeping the beam diameter small over this distance. A better solution is to use two relay imaging “cells” of 18m length with lenses of 4m focal length in each. The lenses will be placed on the first table, the first at 8.5m from the spatial filter and the second 18m later, giving an image magnification of the aperture in the laser room of 1.

The same monitoring is foreseen for the Probe and Drive beams,namely a virtual cathode showing the x-y deplacement, a fixed image monitor and a local joulemeter.

BPM tests

During 1995 tests were made on a high precision beam Position monitor which had a resolution of better than 1 um in lab measurements.

For these tests a highly stable beam was required having a single pulse and small “footprint” on the cathode. Monitoring of the measured barycenter on the virtual cathode screen had shown a “normal” movement of 0.2 mm, to overcome this, a large 8mm dia. beam was sent to the table at the window to the CTF vacuum chamber, where a small aperture of 2-3 mm dia was used to select the central portion of the beam which was then focused onto the cathode to provide a spot of 1mm diameter.

In the machine however, only 5um resolution was observed on the BPM as the beam was unstable in angle through the measuring system.

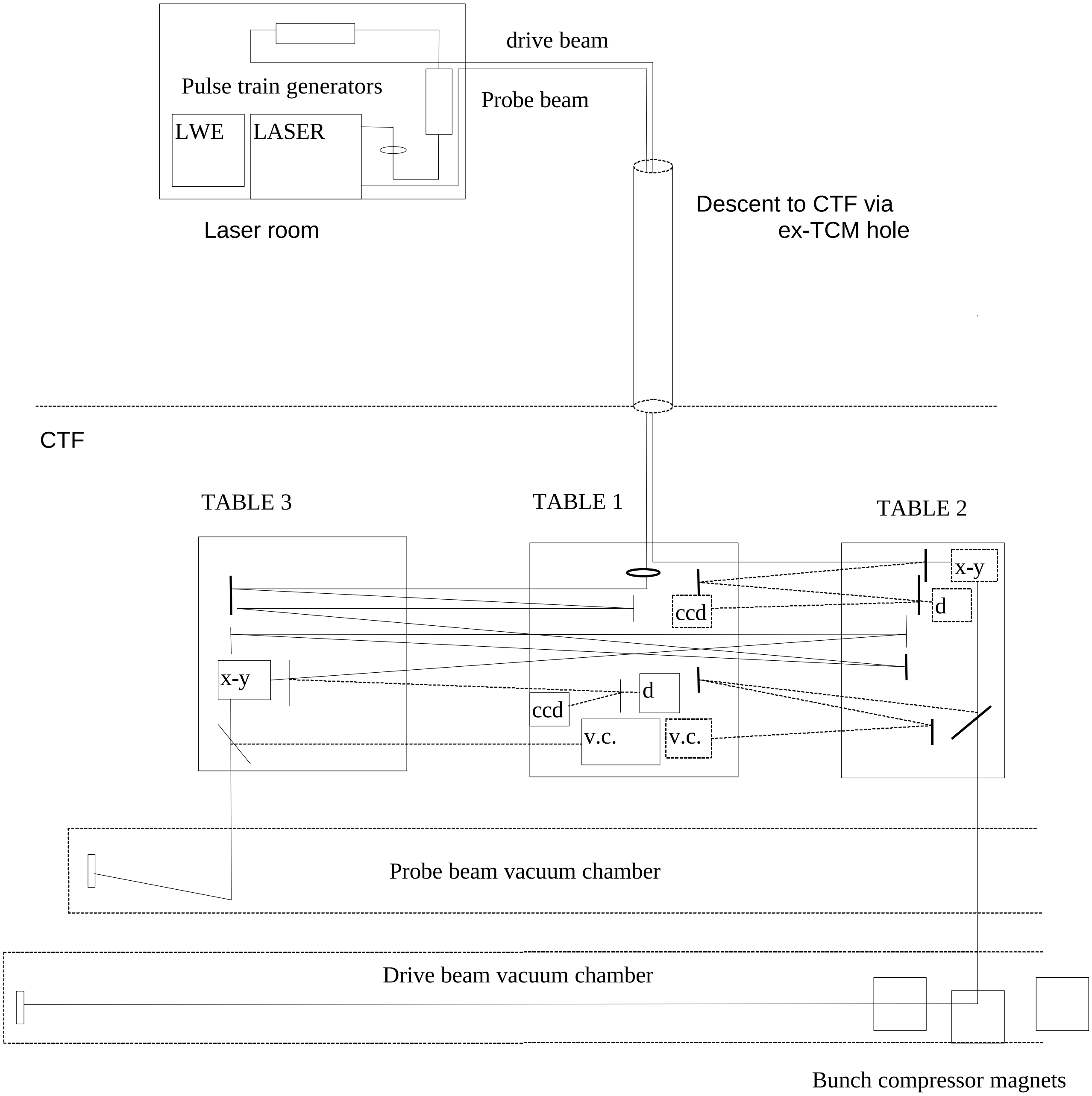
There are several potential sources of this instability, one of which is the position of the UV light on the cathode. It is important to remember that a given deplacement on the cathode does not result on the same deplacement of the electron beam due to the electron focusing in the gun and accelerating sections.

The resolution of the current virtual cathode barycenter measurement is 0.2mm on a screen of 60 mm horizontal dimension, this limit derives from the pixel size of the CCD camera, the transfer function of the optics used and the bandwidth of the analogue circuitry which transmits the pixel charges. It is planned to change to a VME digital system which will have higher resolution and enable the use of larger format CCD arrays, but this will not be available in 1996. It was hoped to have UV-sensitive, large format CCD detectors for beam diagnostics this year but the current cost of such cameras is in excess of CHF35000 per piece.

As the required light spot should be small, it is possible that a 4mm diameter beam could be used to directly illuminate the existing, small-area, UV sensitive CCD camera, this has an active surface of 6.4 x 4.8 mm with pixels of 9.2 x 8.4 um. This camera does not have the

necessary synchronisation signal, which is required to capture each 10Hz pulse, but successive measures could provide an indication of the pulse stability with a resolution of 2 pixels or 20um.
If this measurement can be implemented this year it would help identify and separate the sources of beam instability- optical and electrical.

Schematic diagram of the CTFII beam paths



The Optical layout, showing Drive and Probe beam paths, virtual cathodes (v.c.), energy detection (d), x-y positioning(x-y) and monitoring of the beam profile (ccd). The paths are arranged that the virtual cathodes are the same distances as the real photocathodes, the probe beam is delayed 12ns after the Drive beam to allow for the filling time in the CLIC Accelerating Structure, (CAS).