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Derivation of the CTF Beam Characteristics from Measured Transverse Profiles

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The profiles were measured by H. Braun, A. Riche, L. Rinolfi and J.C. Thomi on September 7, 1993

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CTF Parameters

The measurements were performed on the beam at high energy, by varying the force of quadrupole Q420 and recording the corresponding transverse profiles of the bunches.

The energy measured after LAS was 61.8 MeV (measured). The solenoid around LAS was active.

Quadrupoles strengths (A)

	for H profile	for V profile
Q410	0	0
Q415	6.5	- 6.5
Q420	varying > 0	varying < 0

Intensities single bunch

UMA 385:	120 10^8 e^-	
UMA 406:	100 10^8 e^-	Q = 1.6 nC

Measurements of the Beam Profiles

The Cerenkov light emitted when intercepting the bunch in beam monitor TCM 435 is transported to a streak camera where it is analyzed by conversion into an electronic beam, amplification (micro channel) and deflection to convert the time distribution into space distribution. This space distribution is recorded by a CCD camera after conversion into a photon beam.

In the 'transverse mode', there is no deflection (1).

The FWHH of the transverse profile are measured on the plots obtained from the computer controlling and analyzing the output from the streak camera associated with the Cerenkov detector. The current is varied in quadrupole Q420, the second quadrupole of a series of 3 which focus the bunch into the power transfer structure (TRS) ringing at 30 GHz. The currents of the other 2 quadrupoles are set such that in the interval of variation for the current IQ420, the minimum of the beam size can be observed for IQ420 at the centre of the interval. It is also necessary to verify that the transmission is independent of the force of Q420.

Shape of the Profiles

The fact that the profiles are quasi triangular for values of I Q420 not too far from the one giving the minimum profile size is of considerable help for the accuracy of the measurements (fig. 1). If xm is the half width of the basis of the profile, all particles are contained between -xm and +xm, and the rms size of the distribution is $\sigma = \frac{xm}{2}$. The profiles obtained for values of I Q420 far from the minimum of the size are discarded, because they are parabolic, which makes more difficult the evaluation of σ.

The variation of the sizes xm and ym for the H and V profiles are shown on Fig. 2.

Calculation of the Emittance and the Beam Parameters

The characteristics of the beam are calculated at position P of the output coupler of the accelerating cavity LAS. It is made by least square fit: in each plane, there are 3 unknowns which are the parameters of the ellipse of emittance: the second moments of the distributions in x and in $\frac{dx}{ds}$:

$$<x^2>, <x*\frac{dx}{ds}>, <(\frac{dx}{ds})^2>$$

The method is well known:
By the measurements, we have only access to the size of the beam profile, i.e. to $<x^2>$, at position N, but the second moments at N and at the upstream point P are linked by a linear relation:

$$<x^2>N = Rx,x^2 <x^{*2}>P + 2\,Rx,x\,Rx,xp <x^*xp>P + Rxp,xp^2 <xp^2>P$$

xp stands for $\frac{dx}{ds}$.

On the left, $<x^2>$ is evaluated at position N.

On the right, $<x^2>$, $<xp^2>$, $<x\ xp>$ are evaluated at position P.

$R_{i,j}$ are the elements of the transport matrix between P and N.

The elements of R depend on the force of the quadrupole which is varied, and may be easily calculated for each of these values. Then, with 3 measurements of the profiles at N, each of them with a different value for I Q420, we can find out the 3 second moments at P which are unknown, but do not vary in the experience. Fitting on more measurement than unknown quantities helps for the accuracy of the result. The values of the emittance (square root of the determinant of the matrix of the second moments) and of the other parameters alpha and beta of the ellipse follow.

The dispersion in energy modifies the profile one would get if this dispersion were null. The measured emittance is greater than the one which would be obtained from a monochromatic beam. The contribution from the energy dispersion could be unfold by using dipoles, but generally it is not done so. At the opposite, in our measurement, the stigmatism of the quadrupole certainly exaggerates the value of the emittance by enlarging the size of the profiles recorded measurements.

The program which is used to calculate beam characteristics from downstream measurements has been tested on a fictive beam for which these characteristics are known and the size of the profiles are obtained by simulation. The set of data for the FORTRAN program is given in the Appendix. The essential data are the table (I Q420, xm), and the description of the beam line between P and N for calculating the elements of the transport matrix. Here, xm represents twice the value of the corresponding sigma, then we will divide the resulting parameters by 2, to interpret them in terms of rms values, and the emittances by a factor 4, for the same evident reason.

Results: Parameters for the Ellipse of Emittance

Results concerning the beam characteristics are relative to the position at the LAS output coupler, 0.56 m in front of Q410, first quadrupole of the triplet.

rms values

		Horizontal plane	Vertical plane
xmax	(mm)	3.45	7.0
xint	(mm)	3.42	1.3
$\frac{dx}{dz}max$	(mrad)	0.74	1.25
$\frac{dx}{ds}int$	(mrad)	0.37	0.25
normalized emittance	(mm mrad)	153	204
β	(mm/mrad)	9.3	28
α		-1.75	-5.2

Comparison with Previous Measurements:

The emittances found from measurements end 92 and shown in (2) were (mm mrad)

H: 55. V: 150.

The bunch charge was higher (3.4 nC at gun exit, 2.6 nC at LAS output). The solenoid around LAS was not excited.

Comparison with Results of Pure Beam sSmulation with PARMELA

L. Rinolfi applied recently program PARMELA to the simulation of the CTF beam line with parameters which were those of the experimental beam line. The charge is 1.6 nC per bunch, the laser spot and duration are similar to those used during the experiment, the power on the gun and the accelerating sections are also set to the experimental values. Results of the simulation give, at the level of Q410, emittances which are 3 to 4 times less than the values obtained from the measurements: the simulation giving:

28 ± 2 mm mrad at gun exit,

52 ± 3 mm mrad at QN410 entry

The discrepancy is up to now unexplained.

(1) Measurement of the short bunch length in the CLIC TEST FACILITY (CTF) S. Battisti, CERN/PS 93-40 (BD), CLIC Note 211

(2) Characteristics of CTF beam from beam profile measured as a function of quadrupole strength, A. Riche, 10-02-93

(3) Emittances at CTF: Results of simulations, L. Rinolfi, 11-11-93

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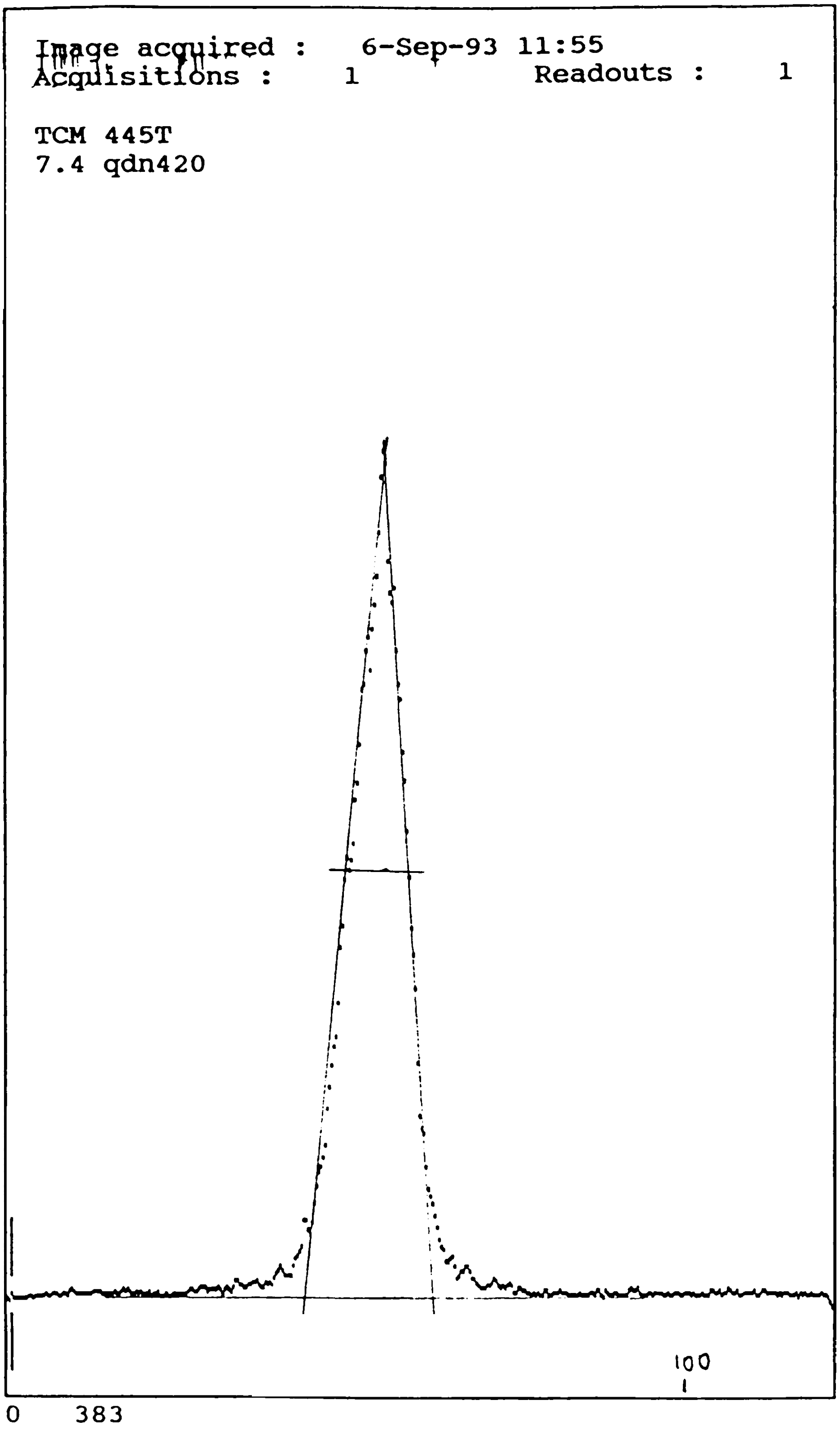

Fig.1: Beam profile on horizontal projection obtained at TCM 453 with 7.4 A in Q420

horizontal scaling : 4.7
xm measured : 0.9 cm
xm beam : 0.9/4.7 = 1.91 cm

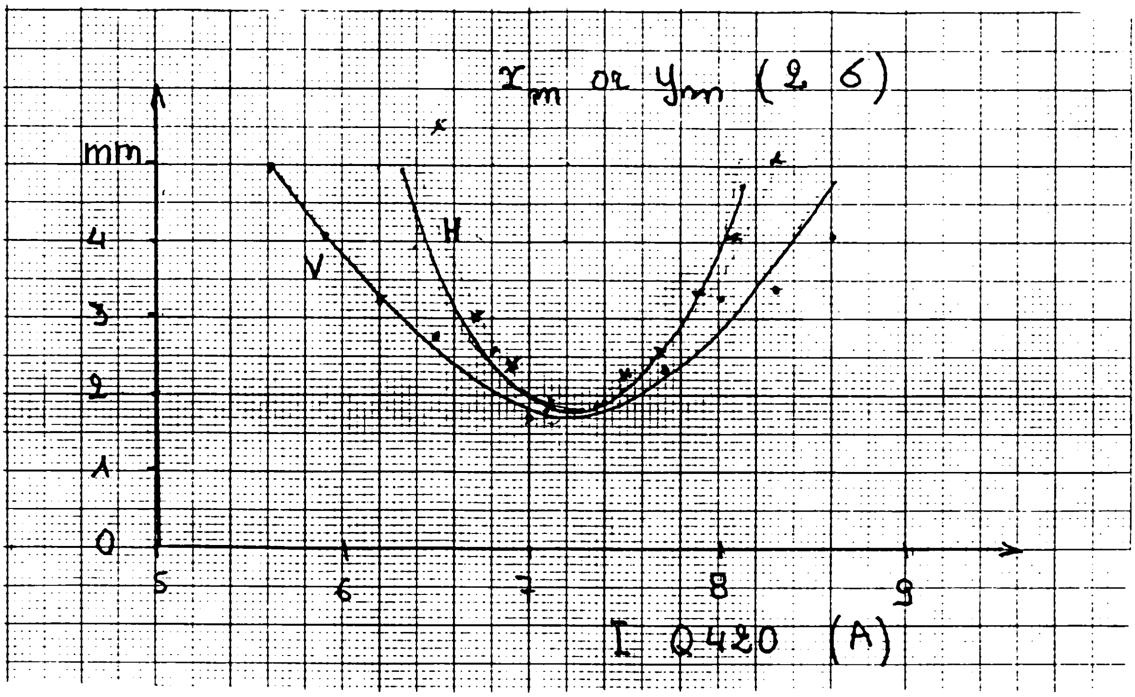

Fig.2 Horizontal and Vertical profiles:
size at point N varying with I Q420

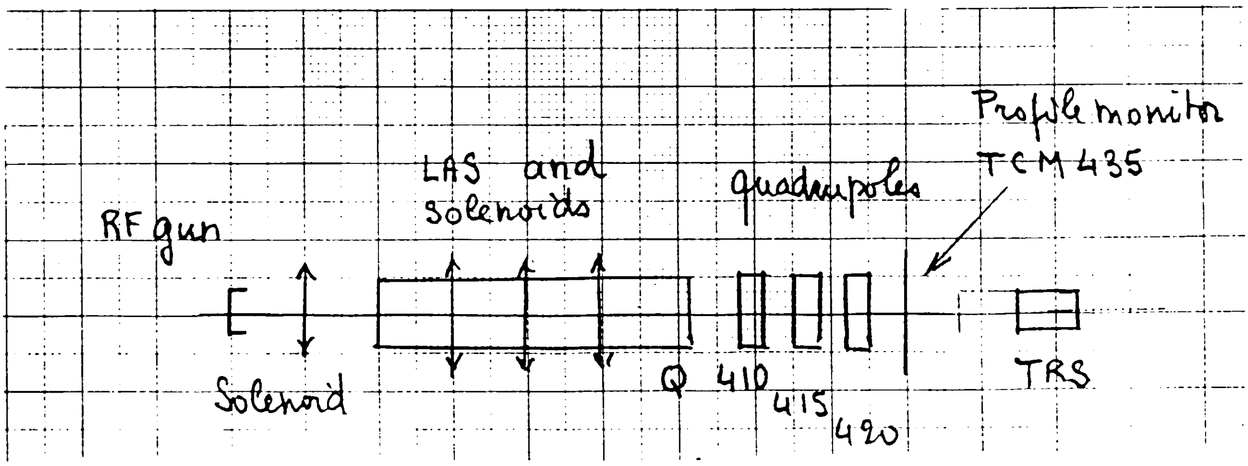

Fig.3 Sketch of CTF beam line

```
' NB OF DATA SET FOR EMITTANCE CALCULATION '   HORIZONTAL
  1
'Part.sign +-1, Nb exp.points, 1or2 :HorV, Nb of sigmas for 1/2 proj.
-1 11  1  1. 1
'Emitt. calculated for above nb of sigmas & also for population: '
.80
'Ampere , H 1/2 Project.(M) , V 1/2 Prj. , Weight '
 5.6  4.89E-03            .1
 5.9  4.04E-03            .1
 6.2  3.19E-03            .5
 6.5  2.77E-03            .2
 6.8  2.55E-03            .5      4
 7.1  1.81E-03            .5
 7.4  1.91E-03            .5
 7.7  2.34E-03            .1
 8.0  3.24E-03            .5
 8.3  3.35E-03            .2
 8.6  4.04E-03            .5
'Title (Format A8,EX:  One element with variable current)'
 qd 420  in ctf beam line, 060993, measurement x
'Nb of elements in the line,including drifts'
7
'-1:Lens, 0:Thin L., 1:Thick+Accel., 3:Drift acc or no +-2:Matrix:2Lines'
3
'Meters, DE(MeV), E(GeV), Gradient(T M-1 A-1) , Amp  ,0 or 1:Fix OR Var.'
0.5566 0.   0.      0.      0.      0
-1
0.200 0.  .062   -.2745  0.00001  0
3
0.0953 0.   0.      0.      0.      0
-1
0.200 0.  .062   +.2745    6.50    0
3
0.0980 0.   0.      0.      0.      0
-1
0.200 0.  .062   -.2745    6.50    1
3
1.7557 0.   0.      0.      0.      0
```

```
' NB OF DATA SET FOR EMITTANCE CALCULATION '    VERTICAL
  1
'Part.sign +-1, Nb exp.points, 1or2 :HorV, Nb of sigmas for 1/2 proj. '
-1 12  1  1. 1
'Emitt. calculated for above nb of sigmas & also for population: '
.80
'Ampere , H 1/2 Project.(M) , V 1/2 Prj. , Weight '
-6.5  5.53E-03          .1
-6.7  2.98E-03          .1
-6.9  2.34E-03          .5
-7.0  1.70E-03          .2
-7.1  1.70E-03          .5
-7.2  1.70E-03          .5
-7.3  1.70E-03          .5     V
-7.5  2.23E-03          .1
-7.7  2.55E-03          .5
-7.9  3.30E-03          .2
-8.1  4.04E-03          .5
-8.3  5.11E-03          .5
'Title (Format A8,EX:  One element with variable current)'
 qd 420  in ctf beam line,measurement y 070993
'Nb of elements in the line,including drifts'
7
'-1:Lens, 0:Thin L., 1:Thick+Accel., 3:Drift acc or no +-2:Matrix:2Lines'
3
'Meters, DE(MeV), E(GeV), Gradient(T M-1 A-1) , Amp  ,0 or 1:Fix OR Var.'
0.5566 0.   0.      0.       0.      0
-1
0.200 0.  .062   +.2745  0.00001  0
3
0.0953 0.   0.      0.       0.      0
-1
0.200 0.  .062   -.2745   -6.50    0
3
0.0980 0.   0.      0.       0.      0
-1
0.200 0.  .062   +.2745   -6.50   1
3
1.7557 0    0               0.      0
```

1 **AUTIN B./PS**
2 **BOSSART R./PS**
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4 **CHAUTARD F.**
5 **CORSINI R.**
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