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SUMMARY OF THE MD's ON ECOOL - DECEMBER 1993

Reported by J. Bosser (15.1.1994)

Geneva, Switzerland
7 February, 1994

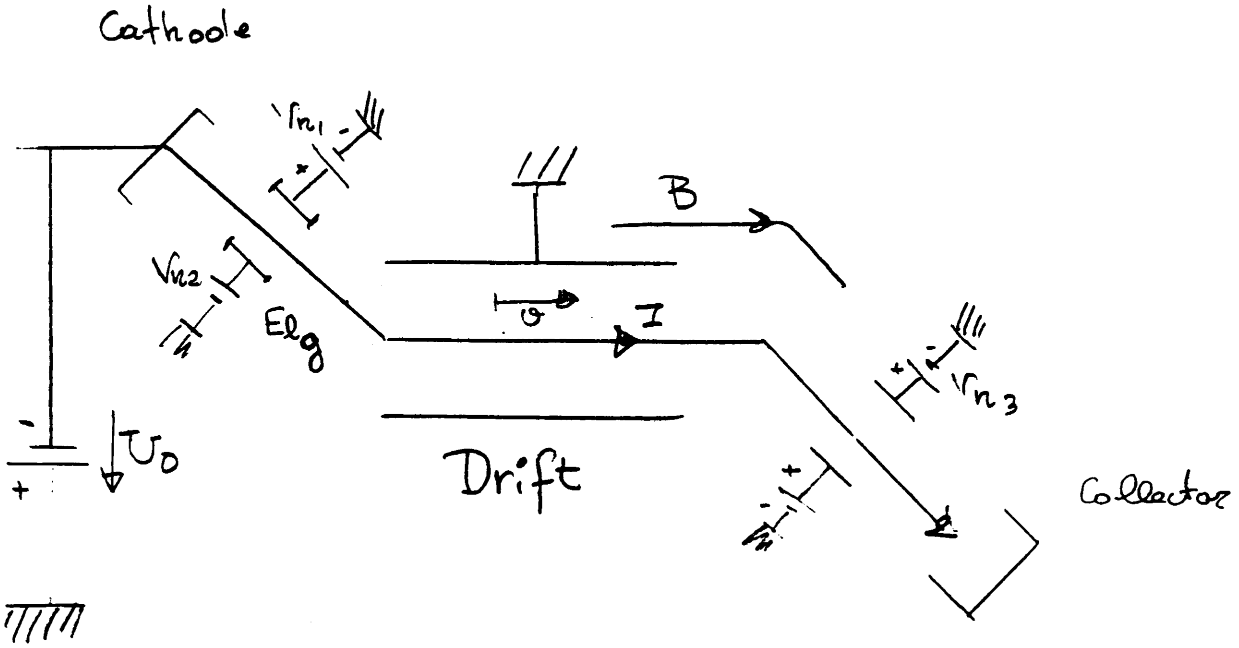
SUMMARY OF THE DECEMBER 1993 MD'S ON ECOOL

(Reported by J. Bosser 15/1/94)

<u>Participants</u>: R. Ley, G. Tranquille, F. Varenne, R. Brown, F. Caspers, G. Molinari, R. Maccaferri

The sessions were organized as follows:
- Neutralisation,
- Servo system,
- Machine physics,
- Various results,
- Hϕ transverse profiles.

1) <u>RECALL</u>, <u>SYMBOLS</u>



Elg = Gun neutralisation electrode
Elc = Collector neutralisation electrode

Electron kinetic energy

$$E_c = -e\left[-U_0 + U_{sp}\right]$$

U_{sp} space charge potential: $U_{sp}(\eta) = \frac{91.71\, I}{\beta}(1-\eta)$

η : Neutralisation factor $= \frac{\text{Positive ion density}}{\text{Electron beam density}}$

$$(\gamma-1) m_e c^2 = e\left[U_0 - U_{sp}\right] \quad , \quad (\gamma-1) \simeq \frac{\beta^2}{2} = \left(\frac{v}{c}\right)^2 \cdot \frac{1}{2}$$

$$v^2 \simeq \frac{2e}{m}\left[U_0 - U_{sp}\right] \qquad k = \frac{2e}{m}$$

$$\boxed{v \simeq \left\{k\left[U_0 - \frac{91.71\, I}{\beta}(1-\eta)\right]\right\}^{1/2}} \quad (1)$$

We set $U = U_0 - U_{sp}$ such as $v^2 = kU$

$$2v\, dv = k\, dU$$

$$\frac{dv}{v} = \frac{1}{2}\frac{dU}{U} = -\frac{1}{2}\frac{dU_{sp}}{U} = \frac{1}{2U}\left[\frac{-\frac{91.71}{\beta}(1-\eta)\Delta I + \frac{91.71\, I\, d\eta}{\beta}}{U}\right]$$

Since $\frac{91.1 \cdot I}{\beta} = U_{sp}(0)$ we approximate

$$\boxed{\frac{\Delta f_r}{f_r} \cong \frac{\Delta v}{v} \cong \frac{1}{2U_0}\left[-\frac{91.71}{\beta}(1-\eta)\Delta I + U_{sp}(0)\, \Delta\eta\right]} \quad (2)$$

f_r revolution frequency.

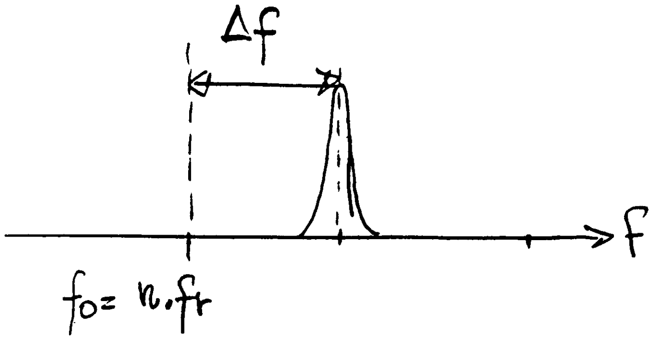
<u>Magnetic field</u> $B = 1{,}57\left[p\left[\text{MeV}/c\right]\right]$ Gauss

2) Measurement of the neutralisation coefficient η

Two methods : Absolute, Phase shift.

2.1 Absolute : We use a longitudinal Schottky PU connected to a spectrum analyser which central frequency is set at a harmonic "n" of f_r

$$f_0 = n f_r$$



- First : $\eta = 0$ and therefor $\Delta\eta = \eta - 0 = \eta$

- Second : $\eta = 0$, $\Delta\eta = 0$,

we check that equation (2)

$$\Delta f = -(n f_r) \frac{91.71}{\beta} \Delta I$$

is confirmed by varying I. Therefore the coefficient $\frac{91.71}{\beta}$ is experimentally verified.

- Third : I is constant ($\Delta I = 0$) then (2)

$$\Delta f = (n f_r) \frac{1}{2} \frac{U_{sp}(0)}{U} \Delta\eta \quad , \quad U_{sp}(0) = \frac{91.1}{\beta} I$$

$$\Delta\eta \equiv \eta \; , \; U \simeq U_0 \; , \; \underbrace{(n f_r) \frac{U_{sp}(0)}{2 U_0} = \Delta f_{max}}$$

$$\boxed{\eta(\Delta f) = \frac{\Delta f}{\Delta f_{max}}} \qquad (3)$$

2.1.1) Measurements with the absolute method

A) $p = 310$ MeV/c

$U_0 = 27.9$ kV, $\beta = 0.314$, $f_r = 1.197732$ MHz
$n = 34$, $nf_r = 40.723$ MHz
$I = 2.5$ A, $U_{sp}(0) = 730$ V $\Delta f_{max} = 532$ kHz
$I = 1.5$ A, $U_{sp}(0) = 435$ V $\Delta f_{max} = 318$ kHz

I (A)	V_{n1} kV	V_{n2} kV	V_{n3} kV	V_{n4} kV	Δf kHz	$\Delta\phi$ °	$\eta(\Delta f)$	$\eta(\Delta\varphi)$ see 2.2
2.5	1	0	1	0	70	5	0.13	0,086
	2	0	2	0	105	9	0.19	0.154
	3	0	3	0	158	15	0.29	0.257
	4	0	4	0	183.5	17	0.34	0.291
	5	0	5	0	209	22	0.39	0.376
	6	0	6	0	293	30	0.55	0.513
1.5	4	0	4	0	140	15	0.44	0.427
	5	0	5	0	146	17	0.46	0.487
	6	1	6	0	157.5	19	0.49	0.541
	6	0	0	6	138	16	0.43	0.456
	6.3	0	6.3	0	160	19	0.5	0.541
	0	6.3	0	6.3	280	31	0.88	0.884 ← see remark

(see 2.

<u>Remark</u>: When looking to the phase measurement we notice that with this configuration (0, 6.3, 0, 6.3)

(5)

from the moment the e-beam is neutralised and therefore the p-beam off cooling the phase is oscillating and $\langle\eta\rangle = 0{,}83$. Once the p-beam velocity $\simeq$ e-beam velocity, and therefore the p-beam is cooled, the phase oscillation disappears and η jumps from 0.83 to 0.88!

Conclusion: At 310 MeV/c $\eta \simeq 0{,}5$ except for the only measurement at $I = 1.5A$ when we "invert" the voltages on the neutralisation electrodes

B). $p \simeq$ 200 MeV/c

$V_0 = 11.7$ kV, $\beta = 0{,}208$, $f_r = 0.7816$ MHz

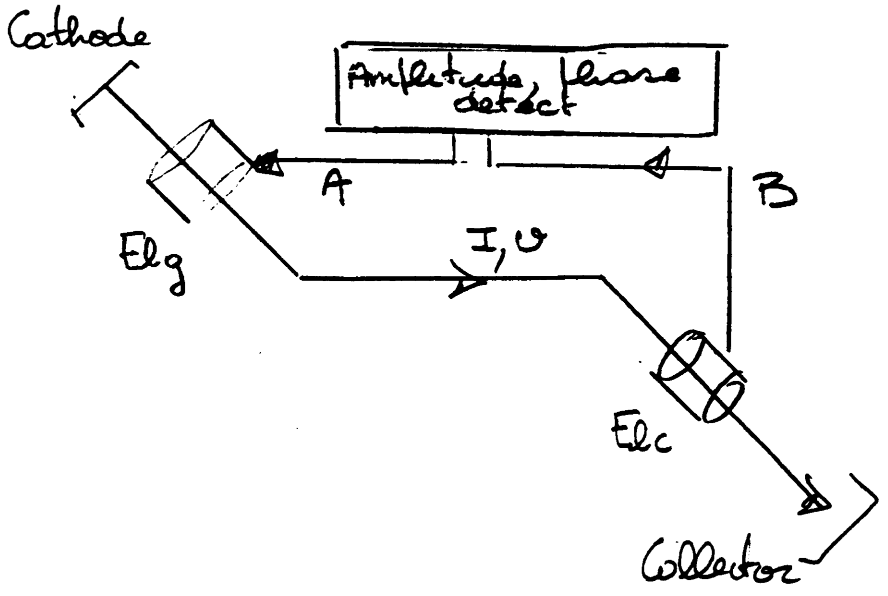
$n = 52$, $nf_r = 41.1633$, $I_p = 4.10^9$

$I = 0{,}4$ A, $U_{sp}(0) = 175$ V, $\Delta f_{max} = 308$ kHz

I A	V_{n1} kV	V_{n2} kV	V_{n3} kV	V_{n4} kV	Δf kHz	$\eta(\Delta f)$	
0,4	5,5	0	5,5	0	287,2		Unstable, period 2,2
	5,5	1	5,5	1	289,6	0.94	Stable
	6.3	0	6.3	0	286,4	0.94	Unstable $\Delta\phi = 25°$
	6.3	1	6.3	1	293.6	0.95	
	6,3	2	6,3	2	295.2	0,96	
	6.3	2,5	6.3	2,5	296	0.96	
	6,3	3	6,3	6.3	3		Unstable

Conclusion: For this nominal low intensity e^- beam: no difficulties to come to $\eta = 0.96$

2.2) Time of flight



The principle consists in measuring the phase difference "ϕ" between a signal A exciting the beam by mean of Elg, and the detected signal B on Elg

$$\phi = \frac{\omega L}{v} \qquad d\phi = -\frac{\omega L}{v^2}\, dv$$

$$\boxed{\Delta\phi = -\frac{\omega L}{v^2}\,\Delta v}$$

ω: excitation frequency : $\omega = 2\pi\,(380.10^6)\,\text{rad s}^{-1}$,
L : distance between electrodes,
v : electron velocity.

The system is easily calibrated with the method described in 2.1).

The main interest consists in the fact that it gives a description in the time domain rather than in the frequency domain.

Once calibrated we find that at 310 MeV/c

$I = 1.5\,A$: $\eta(\Delta\phi) = 0.0285 \times \Delta\phi$ (degree)

$I = 2.5\,A$: $\eta(\Delta\phi) = 0.017 \times \Delta\phi$ (degree)

2.2.1) Figure caption

All the plots are performed when $p = 200$ MeV/c. $I = 0.4$ A where not specified. Ordinate: 1 unit $= 10°$

Abscissa: 1 unit $= 1.99$ s. Vacuum $\simeq 10^{-11}$ torr.

Fig 2.2.1 $V_{n1} = V_{n3} = 6300$ V, $V_{n2} = V_{n4} = 0$.
Non periodic oscillations around 70°

Fig 2.2.2 : $V_{n1} = V_{n3} = 6300$ V, $V_{n2} = V_{n4} = 0$
$I = 0.5$ A. Periodic oscillations with period $\simeq 2$ s. Phase discontinuity $80 - 65 = 15°$

Fig 2.2.3 : $V_{n1} = V_{n3} = 6000$ V, $V_{n2} = 3000$ V, $V_{n4} = 2000$ V
Stable phase shift of $\simeq 82°$. The phase (and therefore the neutralisatio was unstable for $V_{n1} = V_{n3} = 6000$ V, $V_{n2} = V_{n4} = 300$

Figure 2.2.4a: Phase evolution $U_{n1} = U_{n3} = 3000$ V
$U_{n2} = U_{n4} = 0$ V.
2.2.4.b : Phase evolution $U_{n1} = U_{n3} = 3000$ V, $U_{n2} = U_{n4} = 1$

Figure 2.2.5 : Illustration of the remark in 2.1.1 A). Figure 2.2.5 a) differs from 2.2.5 b) by a time scaling only. 1) The ion beam is cooled. 2) Neutralisation is set on and neutralisation proceeds in less than 2 s, the ion beam is off cooling. 3) During the $\simeq 24$ s, where the ion beam energy is moved toward it new (since neutralisation is ON) energy, the phase is oscillating. 4) The ion beam velocity = neutralized

e-beam velocity: There is a jump of 10° in Φ and ϕ becomes stable. 8)

Figure 2.2.6 : Module $\left|\frac{B}{A}\right|$ and phase $\angle\frac{B}{A}$ of the transfer function between 300 MHz and 500 MHz. No neutralisation. No particularities within this bandwidth

Figure 2.2.7 : Same as 2.2.6 but with neutralisation. $V_{n1} = 6000V$, $V_{n2} = 3000V$ $V_{n3} = 6000V$, $V_{n4} = 2000V$

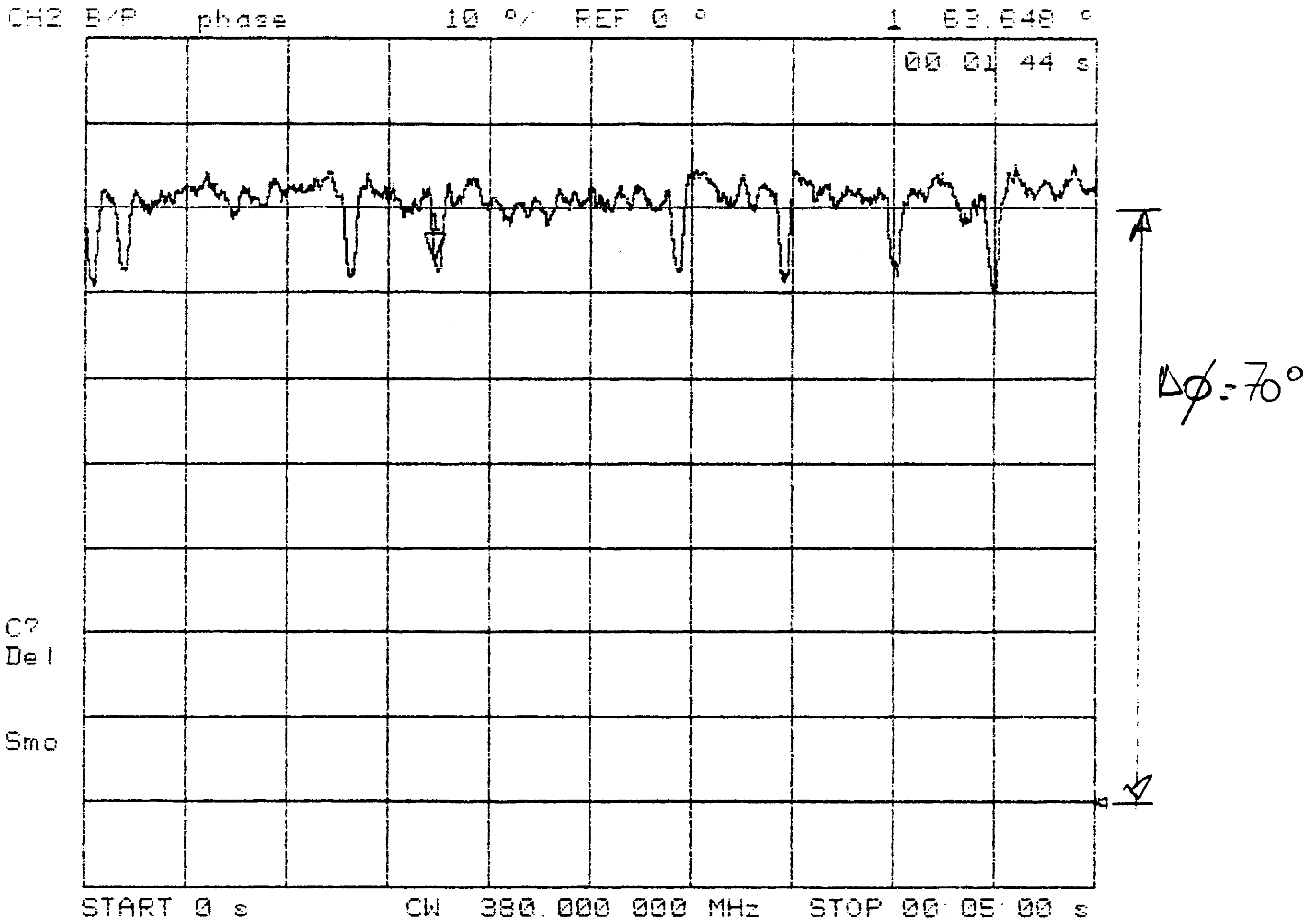

CH2 B/P phase 10 °/ REF 0 ° 1 63.648 °
00:01:44 s
C?
Del
Smo
START 0 s CW 380.000 000 MHz STOP 00:05:00 s
Δφ=70°

Fig 2.2.1

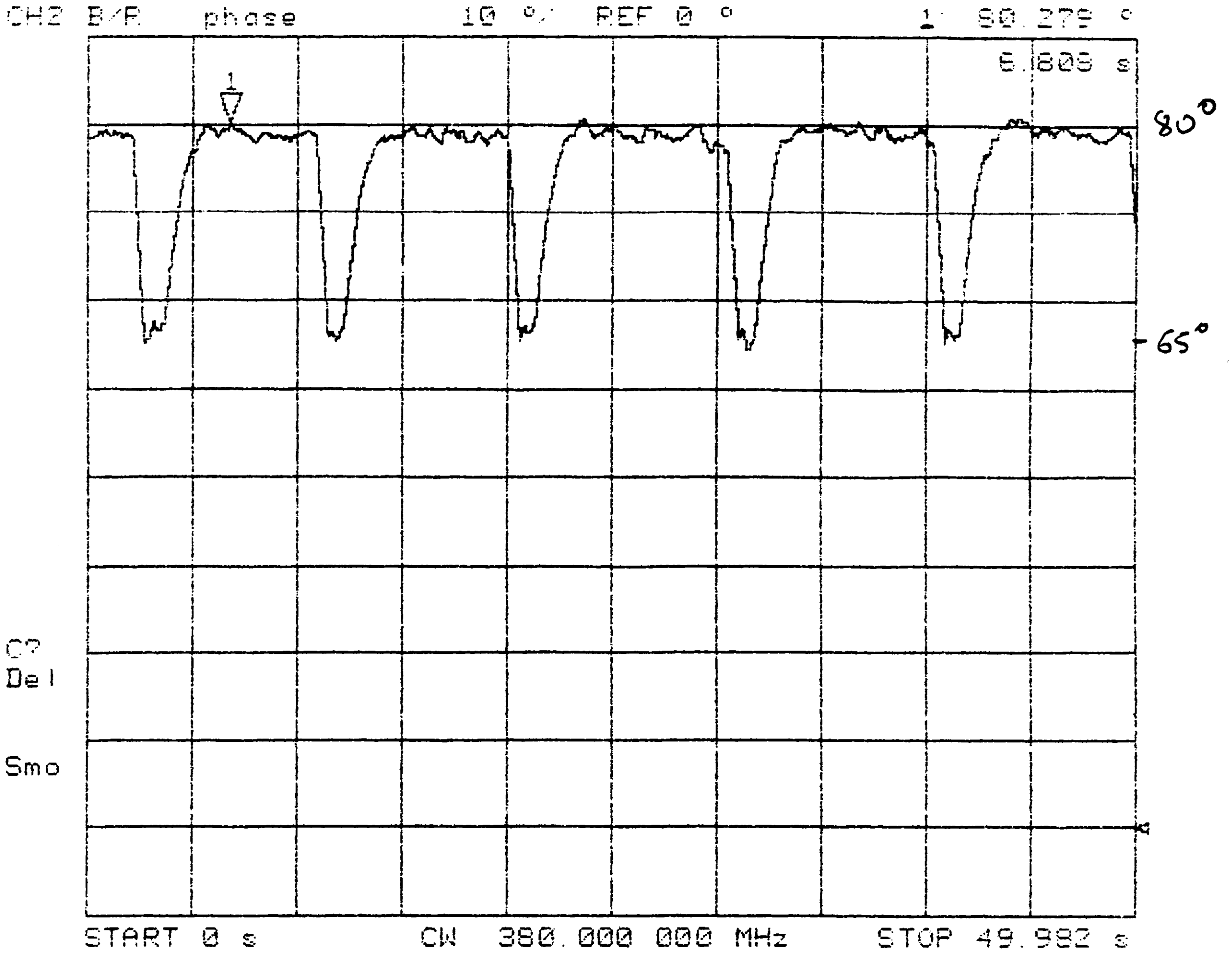
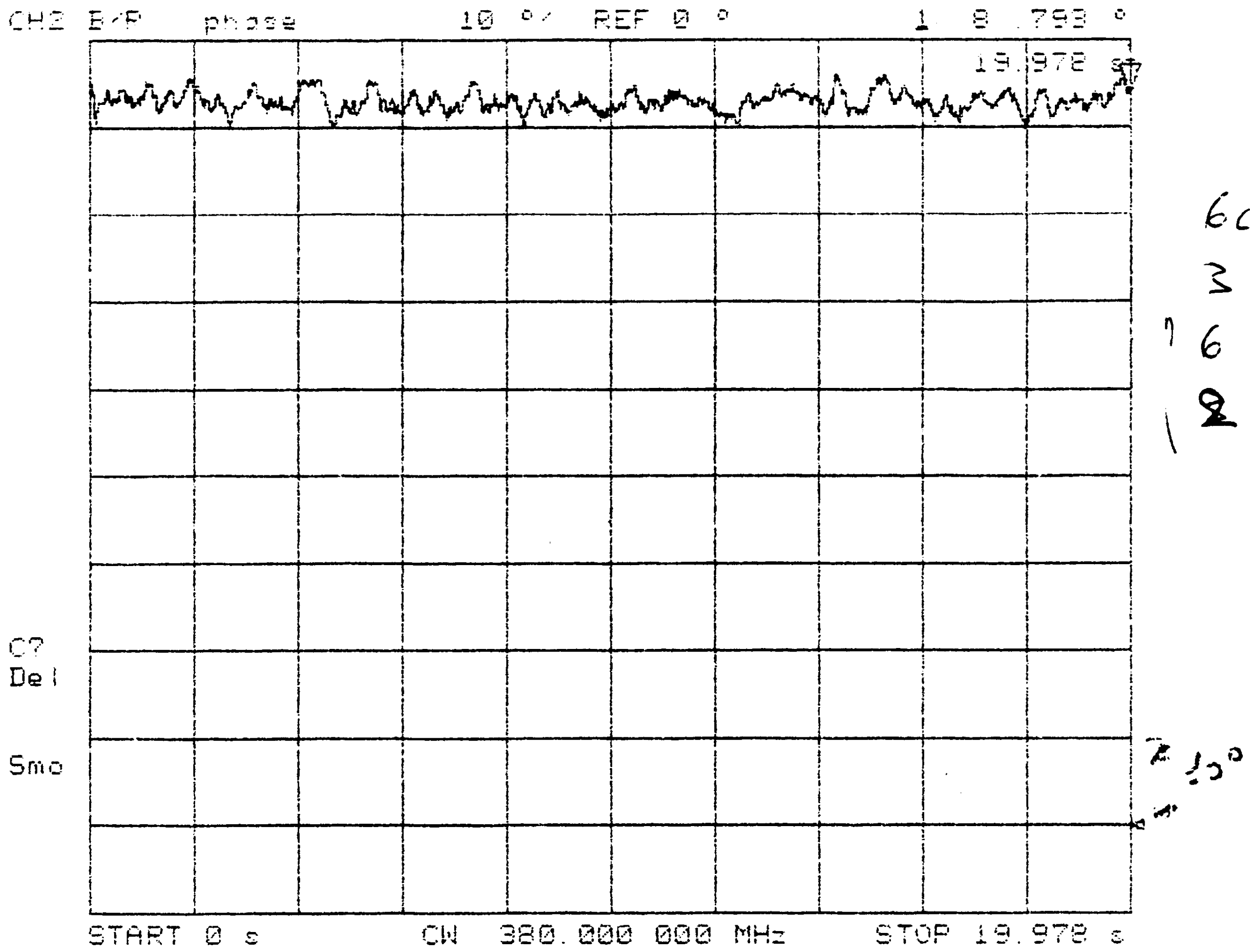

CH2 B/R phase 10 °/ REF 0 ° 1: 80.279 °
6.808 s
80°
65°
C2
Del
Smo
START 0 s CW 380.000 000 MHz STOP 49.982 s

Figure 2.2.2

200 Skl
0.4 A

(11)

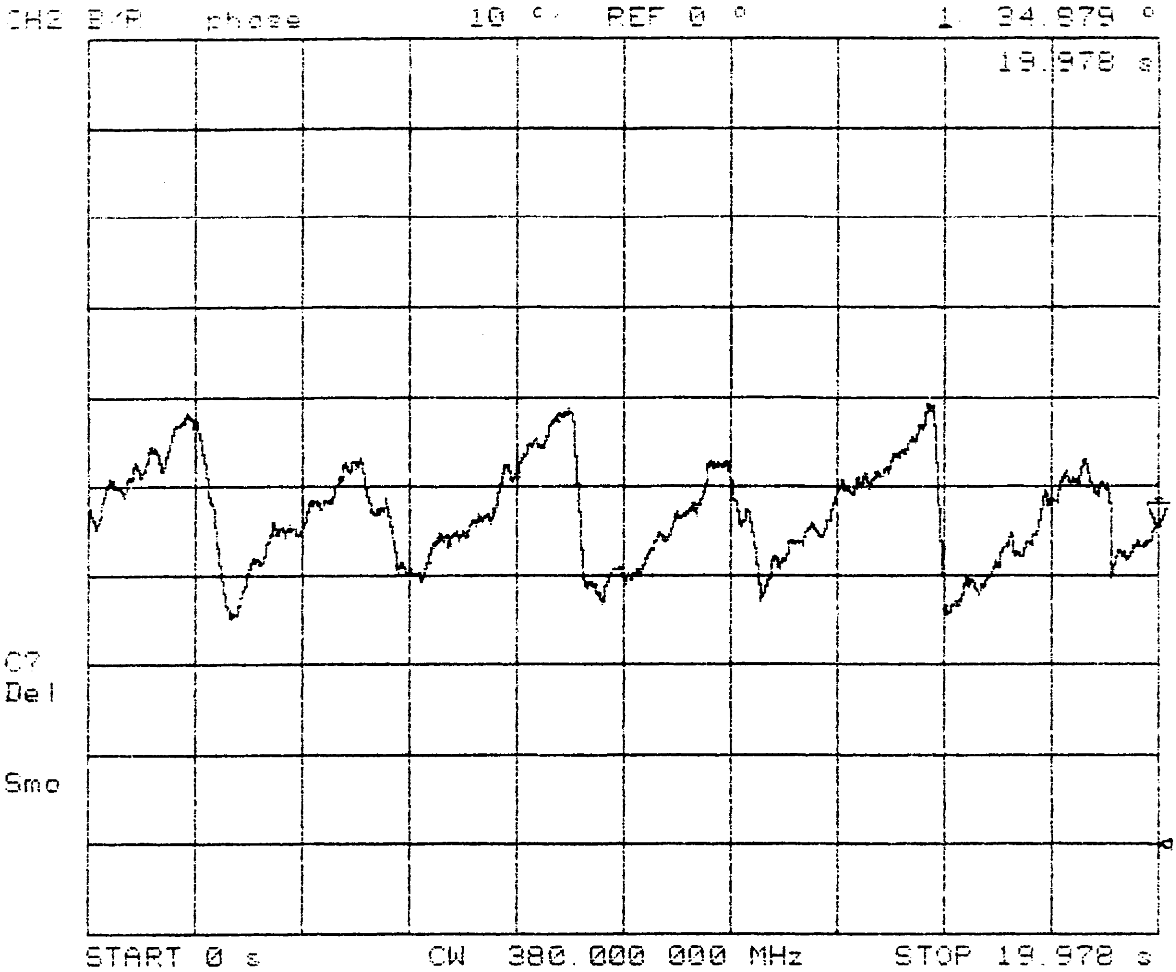


16,3,6,3 instable η = 0.0 %

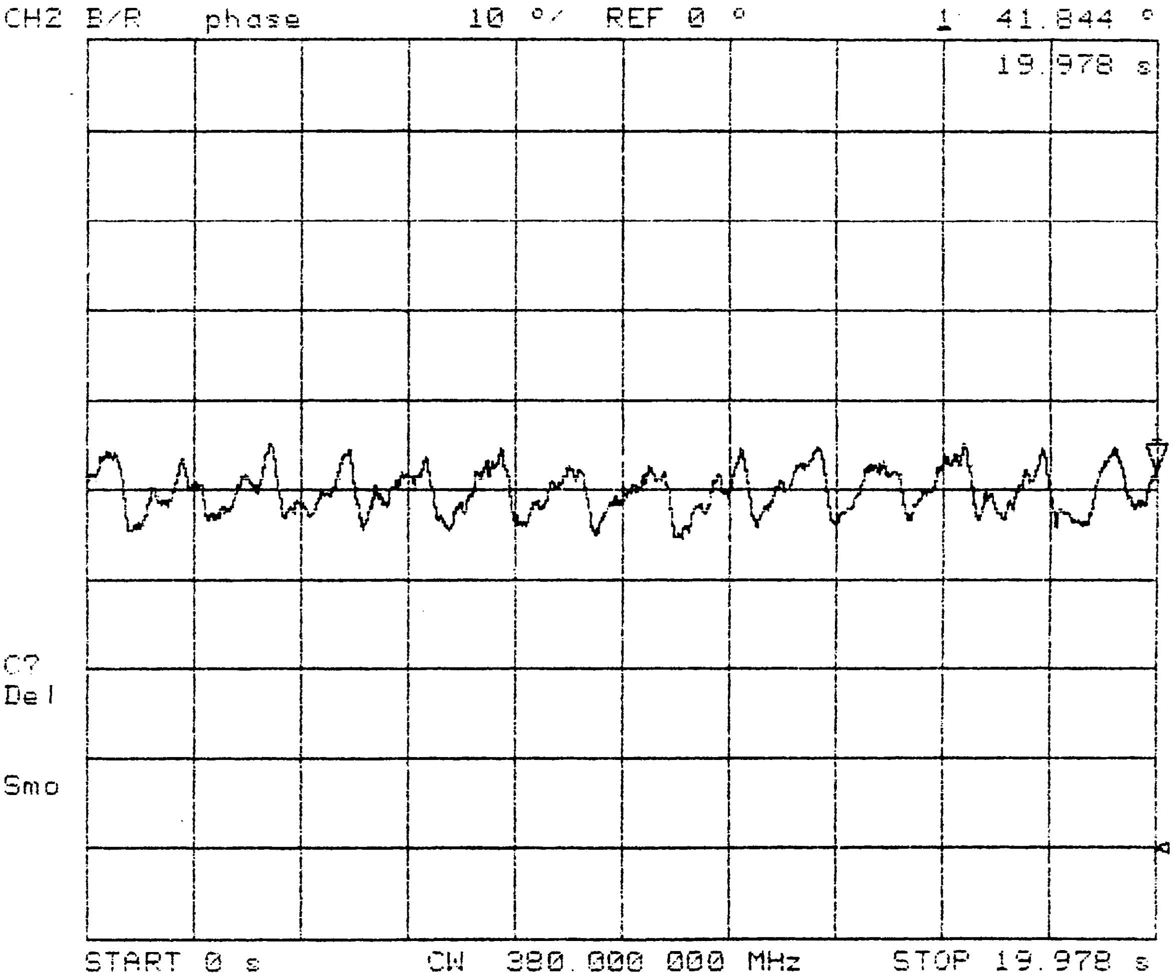
Δf = 302.5 kHz.

Figure 2.2.3

200 MeV
0,4 A.

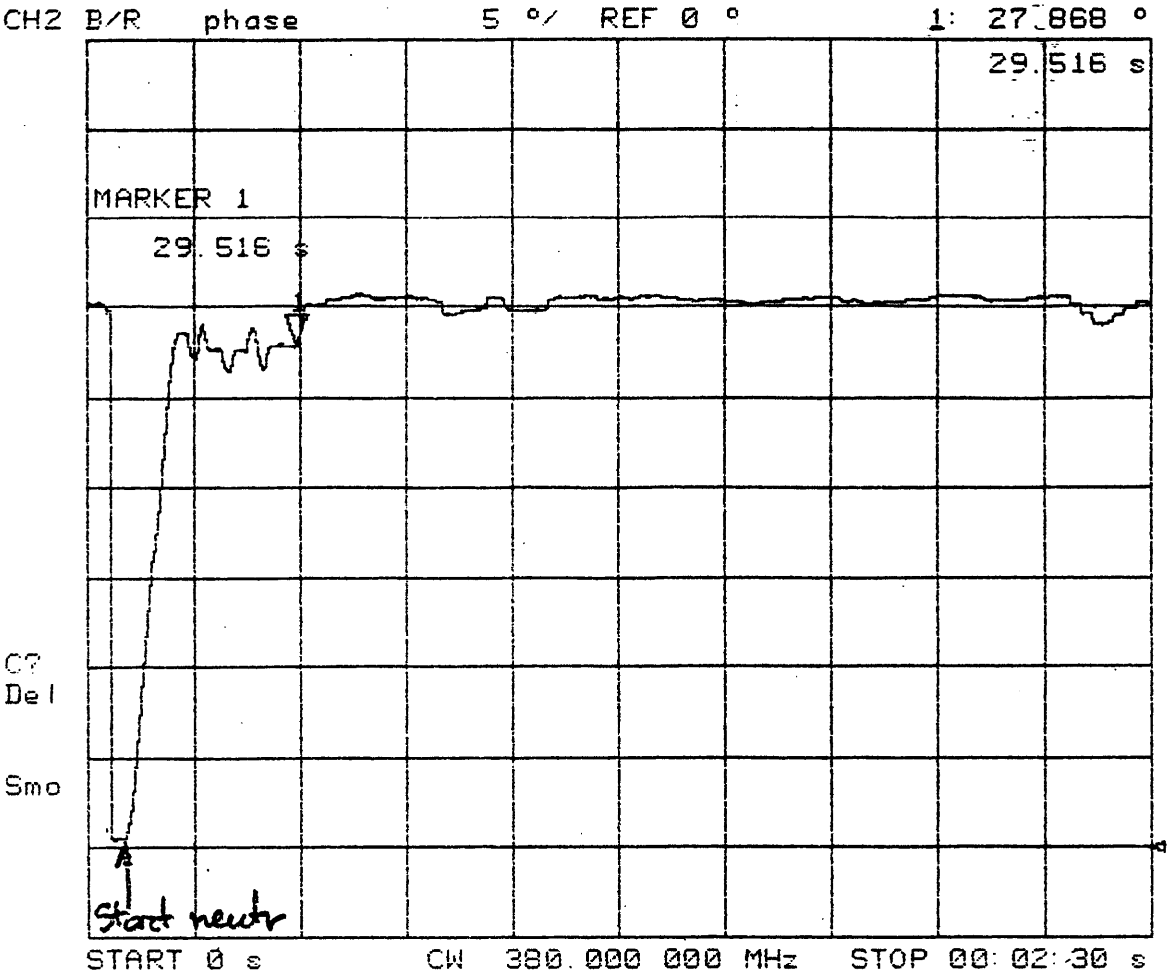


3000
0
2.2.4 a)



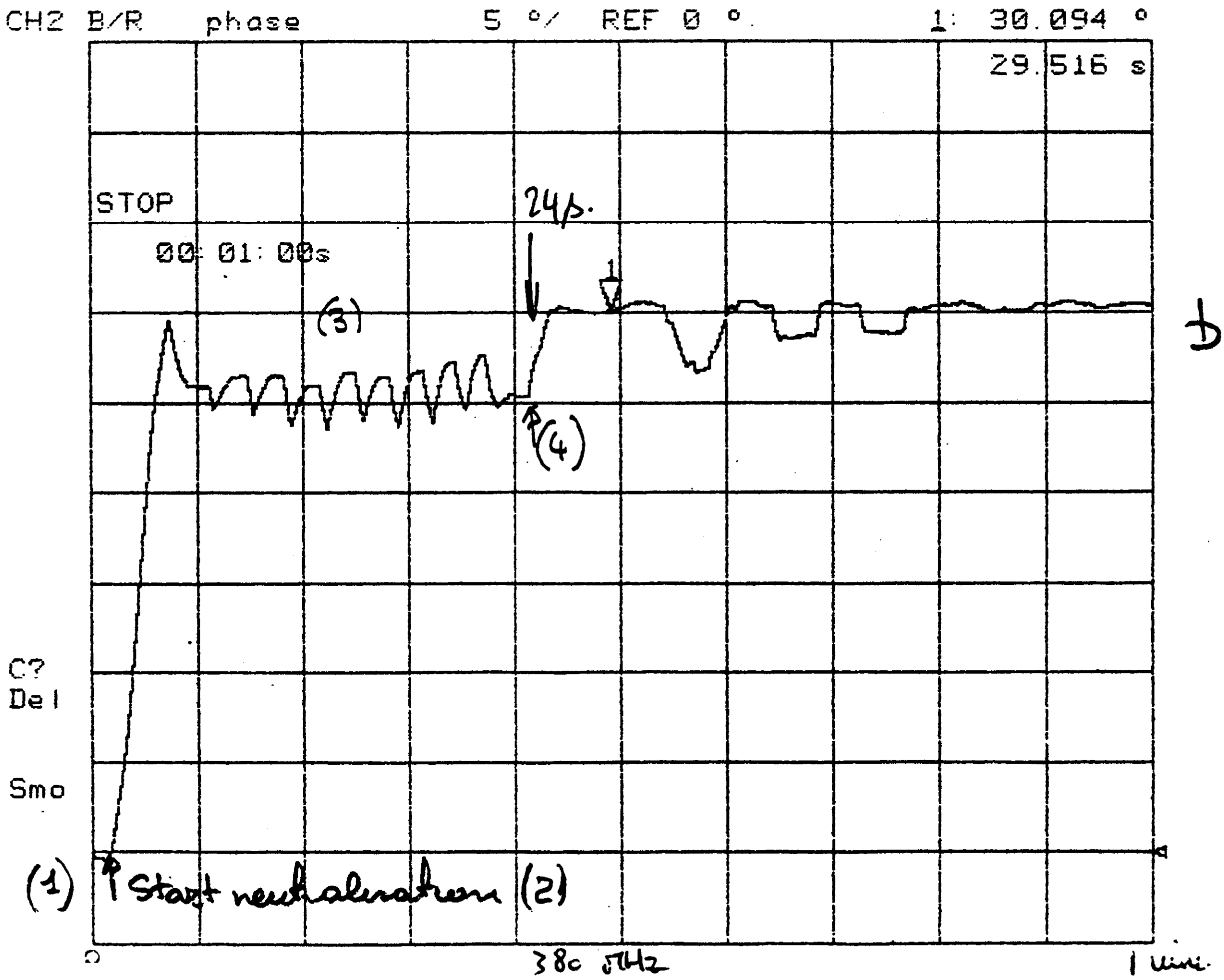
3000
6000
2.2.4 b)

0 6,3 0 6,3



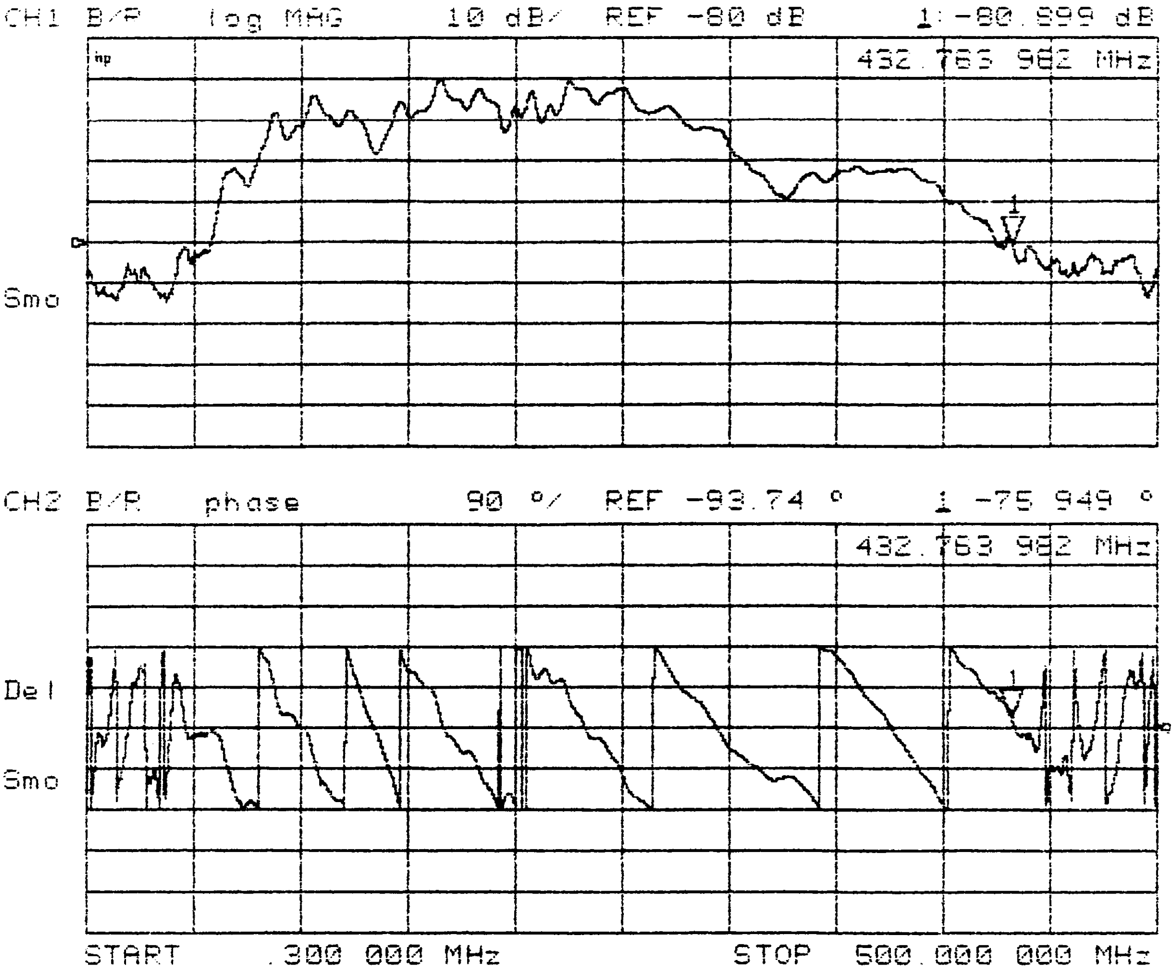
a)

Fig 2.25



b

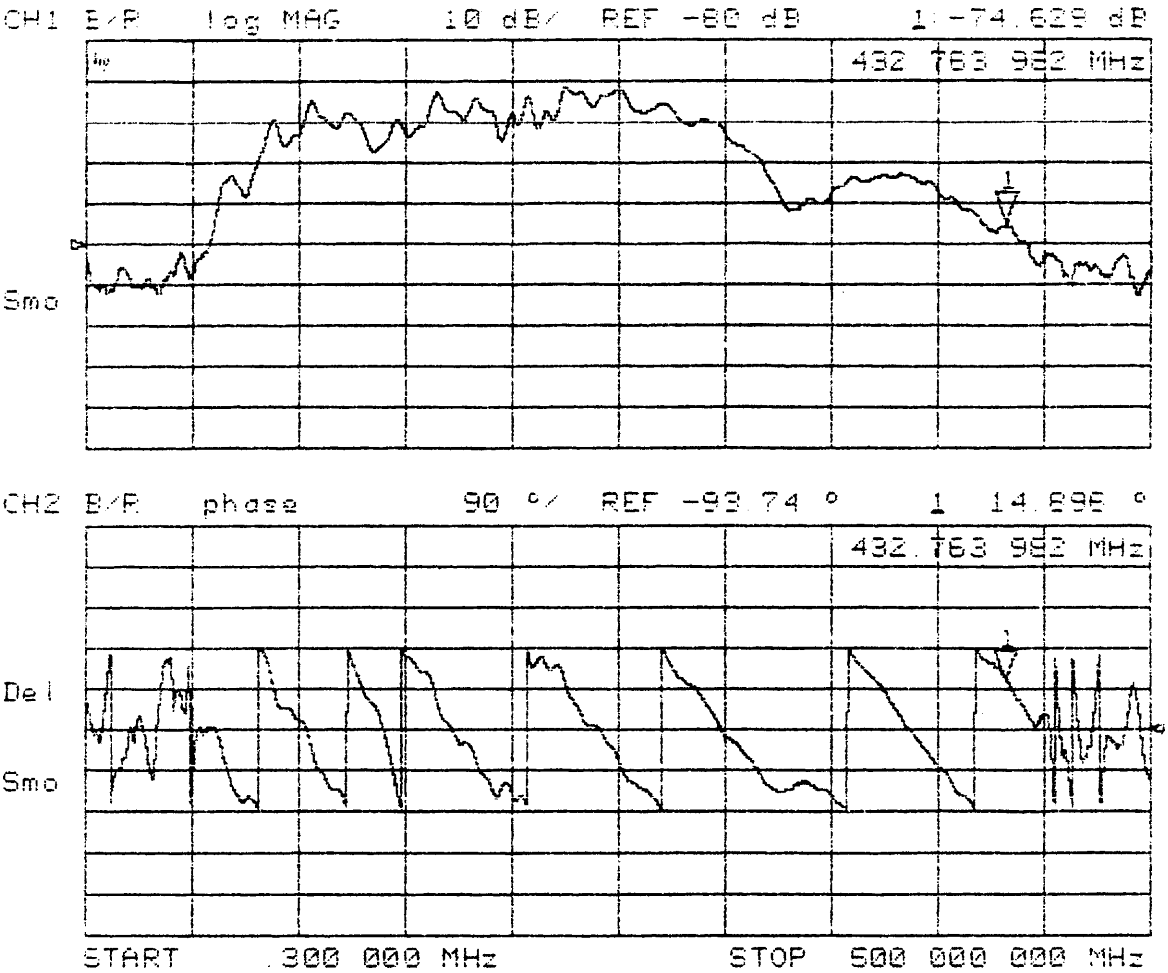
200 Mev
0,4 A



Neutralis. OFF.

Figure 2.2.6

200 Ωel
0,4 A



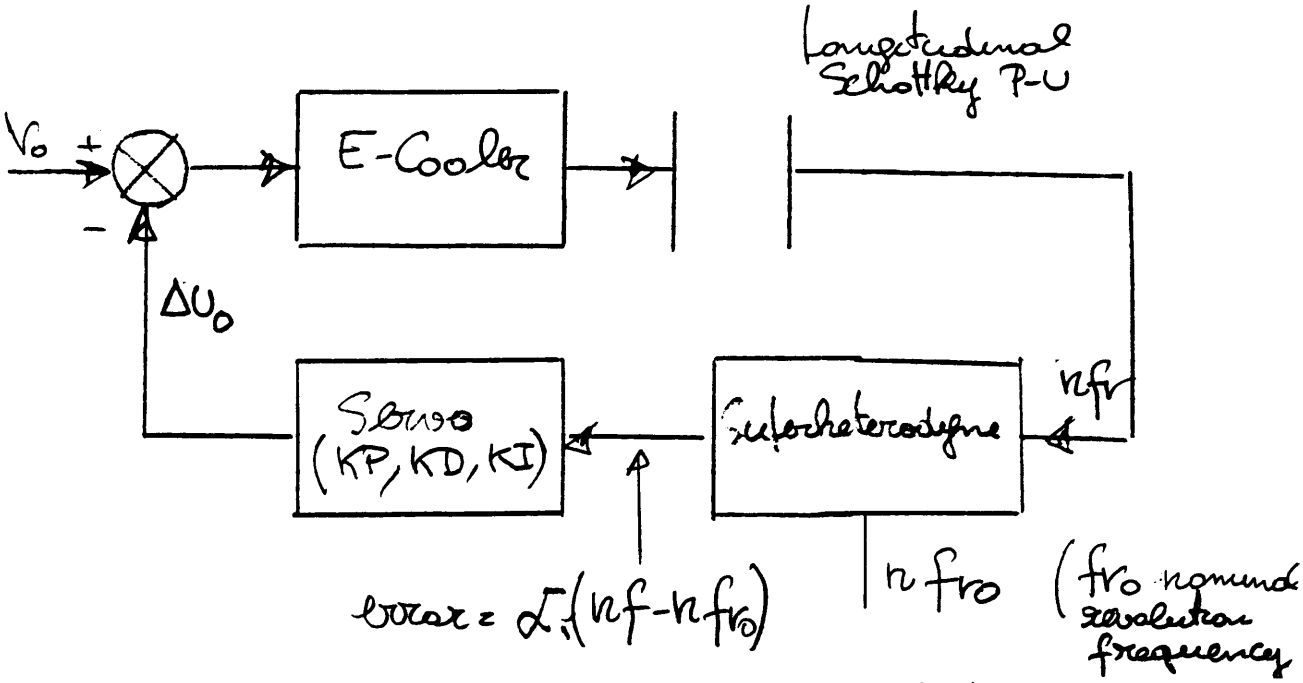
Neutral on (6, 3, 6, 2)
100%

Figure 2.27

3) Calibration and optimisation of the servo-system:

3.1) **Aim** : In order to keep v (or β) constant whenever I or η are modified (equation 1) a servo-system has been implemented.

It consist in the measurement of the actual signal at the output of a longitudinal P-U at a given harmonic "n" of the revolution frequency fr



This signal is applied to a superheterodyne which output signal is proportional to $n(f_r - f_{r0})$. A filter with response:

$$\Delta U_0 = \left(KP + KD\frac{d}{dt} + KI\int dt\right) \text{error}$$

provides an error signal ΔU_0 algebraically added to U_0 in order to reduce $(f_r - f_{r0})$ to a minimal value (0 if possible)

The aim was to calibrate the system and to optimise the coefficients KI, KD, KP.

3.2) Measurement at 300 MeV/c

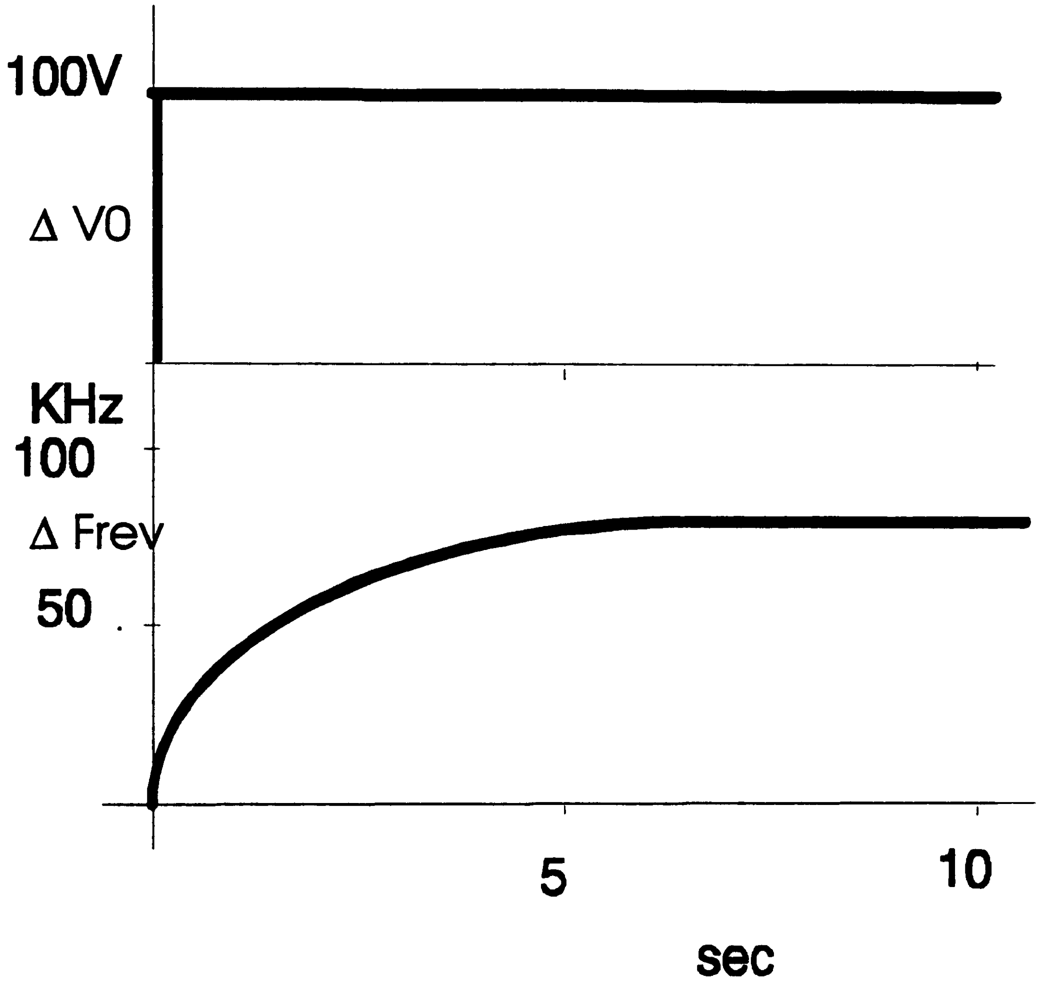
3.2.1) Measurement of the open loop system

Calibration: Application of a step on V0

Frev=1197732 Hz
Harmonic= 34
Fmeas=40'722888 Hz

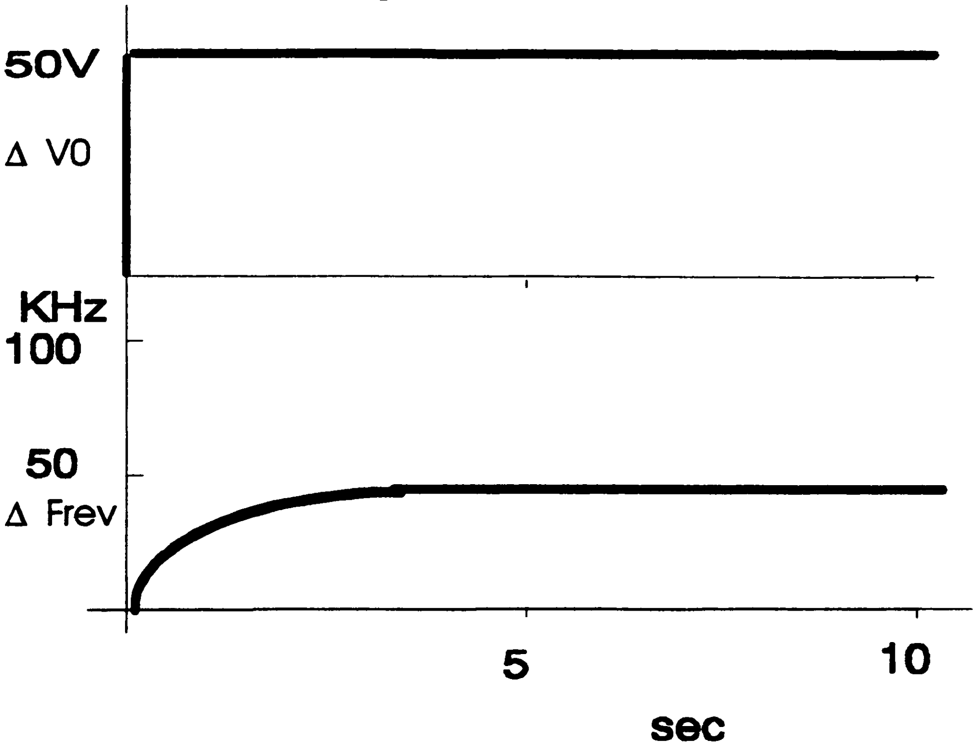
Step	Spectrum	Superetherodyne
+100v	+73 KHz	+66KHz
-100V.	-71 KHz	-73 KHz

Response with a step of 100V, servo loop OFF

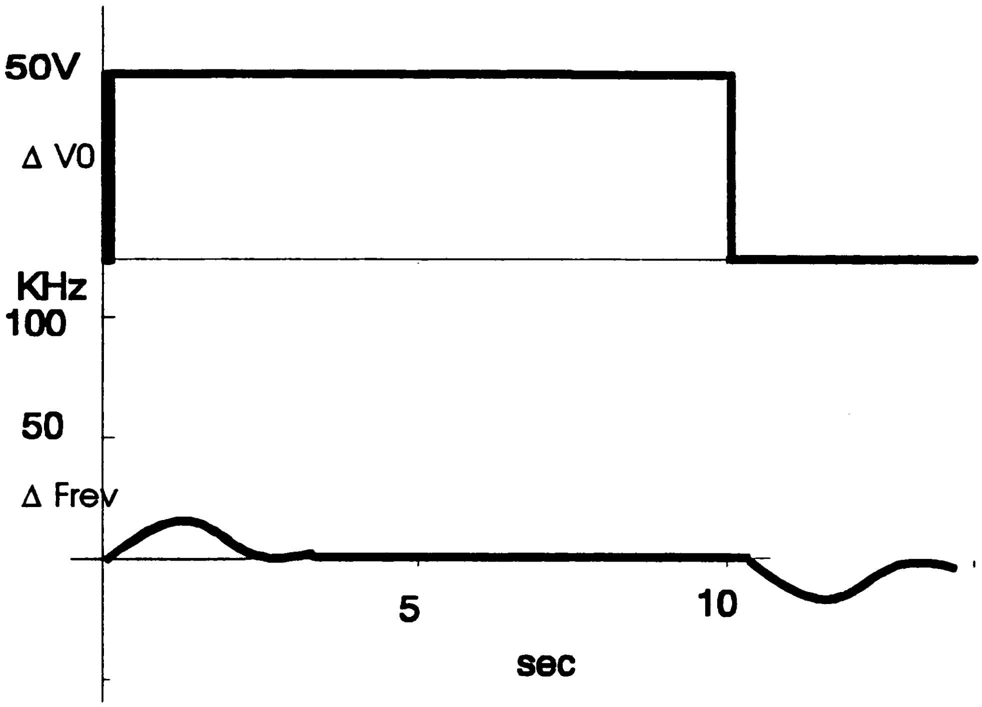


V0 =27.744 V. (+100 V) Vs=20 KV.

Same measurement with a step of 50V



3.2.2) Servo system ON

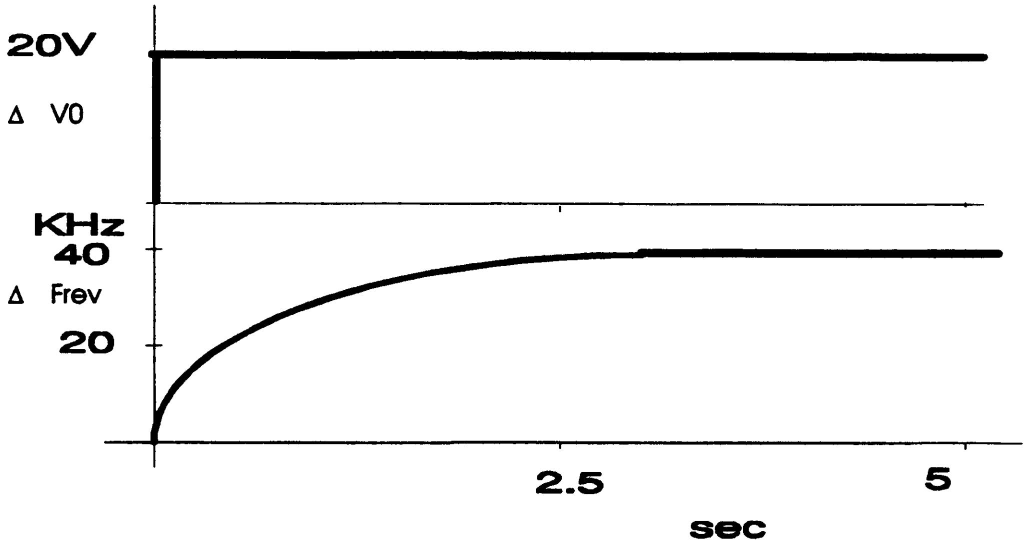


V0=27744 (+50V) ; Vs= 20 KV.; KP= 2500; KI= 35; KD=8000; KDV0=511

3.3) Measurement at 200 Mev/c

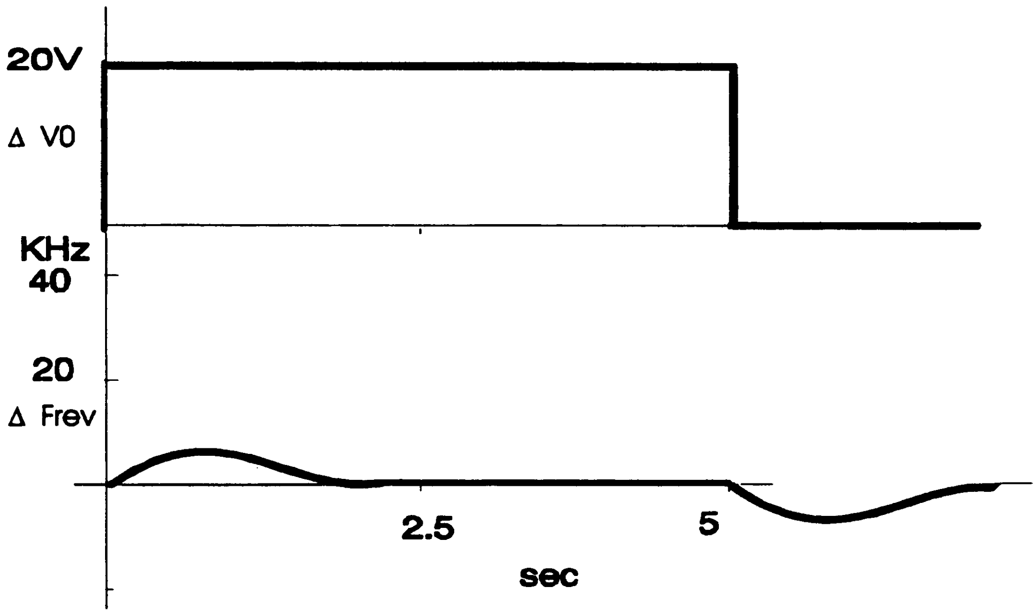
Frev=795778 Hz
Harmonic 51
Fmeas=40'584678 Hz

3.31) Open loop response with a step of 20V



V0=11.841V.(+20) Vs= 8 KV.

3.3.2) Response with closed loop

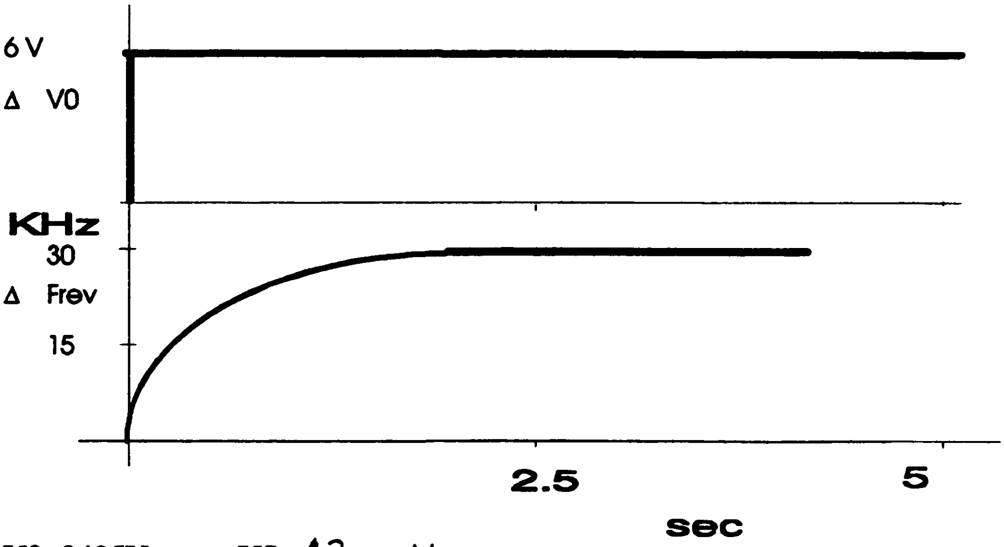


Kp=2500 ; Ki=35 ; Kd=8000; KDV0=128

3.3) Measurement at 105 MeV/c

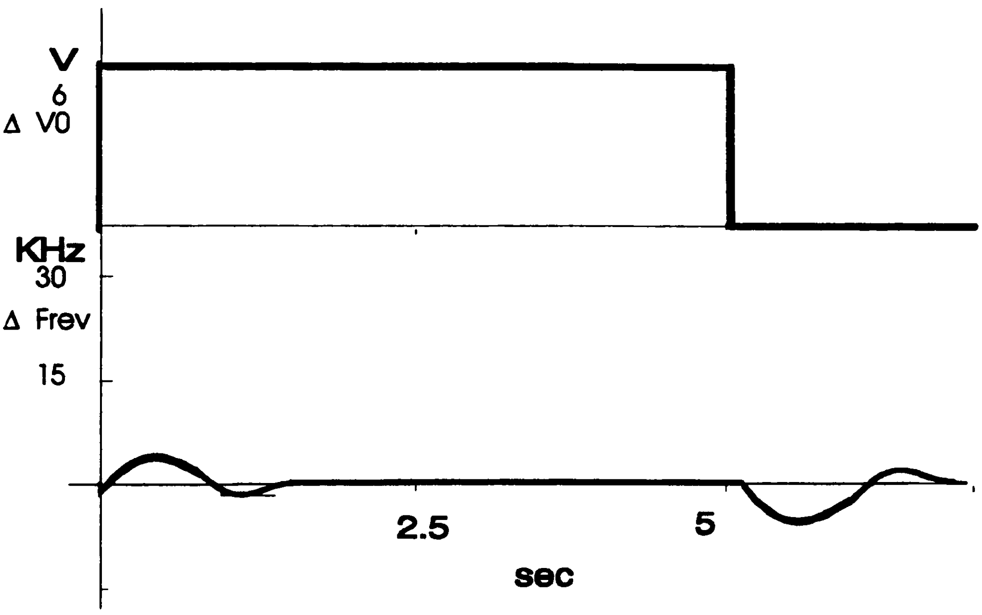
Frev=424520
Harmonic 95
Fmeas 40329400

3.3.1) Open loop response with a step de 6 V



V0=3425V VS=3000V

3.3.2) Response with closed loop



Kp=2500(400) ; ki=35(3);kd=8000(1000); kdv0=64(511)

3.3) Measurements at 100 MeV/c.

We obtain a system with an average error equal to zero but no absolutely stable. This has to be improved.

4) Machine Physics

We get good results: at the second 300 MeV/c flat-top

: when decelerating from 310 MeV/c to 200 MeV/c

The deceleration from 200 to 100 MeV/c was accompanied by a large proton beam loss (from 10^{9} p to $2 \cdot 10^{8}$ p). We note a large coherent Q-shift.

This Q-shift, leading to losses, may be attributed to compensation solenoids although the magnetic field is almost the same as the one we usually use.

5) Various results

5.1) Change in perveance

At 310 MeV/c we notice a sudden jump of the electron current from $I_e = 2.5A$ (nominal perveance) to 2.3A. This was followed instabilities of the proton beam.

This current discontinuity and instabilities is suppressed when applying a positive voltage on V_{n3} (or V_{n4}) all the other neutralisation electrodes being at 0 V. 2+
The current flowing through the electrode was about 1 µA (continuously). This looks like (the occurence of) a secondary electron trapping in the collector region

5.2) Change in energy

When we changed to cathode heating we changed the cooling energy while the electron current remains constant.

Increasing the cathode heating power induces an reduction of the cooled ion energy (or of the electron velocity). This can be explained by the existence of an electron cloud (due to gas ionisation) inducing a supplementary space charge potentential (from the cathode to at least to Elc.)

When putting a positive voltage of about 1k to one of the Elf electrodes (all the other neutralisation electrodes being at 0V) this phenomena was suppressed

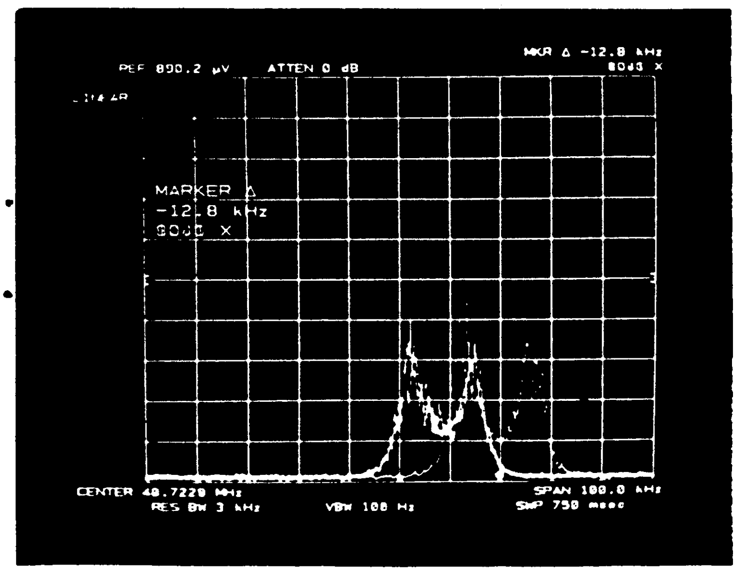
Examples with $I = 1.5A$ ($V_{steering} = 20\,kV$)

Heating: from 25A to 30A introduces a reduction $\Delta f \simeq -60\,kHz$ (at $f_0 \simeq 40\,MHz$)

: from 25A to 27.5A introduces a reduction $\Delta f \simeq -35\,kHz$ (at $f_0 = 40\,MHz$)

This reduction in revolution frequency is slow, since related to the cathode thermal inertia but also the cancelation of this effect by applying 1 kV to V_{n1} takes more than 1 minute

The next photo ($N_p = 15.3 \cdot 10^9$, $p = 310\,MeV/c$) shows how a shift of $-12.8\,kHz$ due to an increase of the cathode intensity (increase of about 1A) is compensated by putting $V_{n1} = 1\,kV$ (all the other $V_n = 0\,V$)



longitudinal distribution

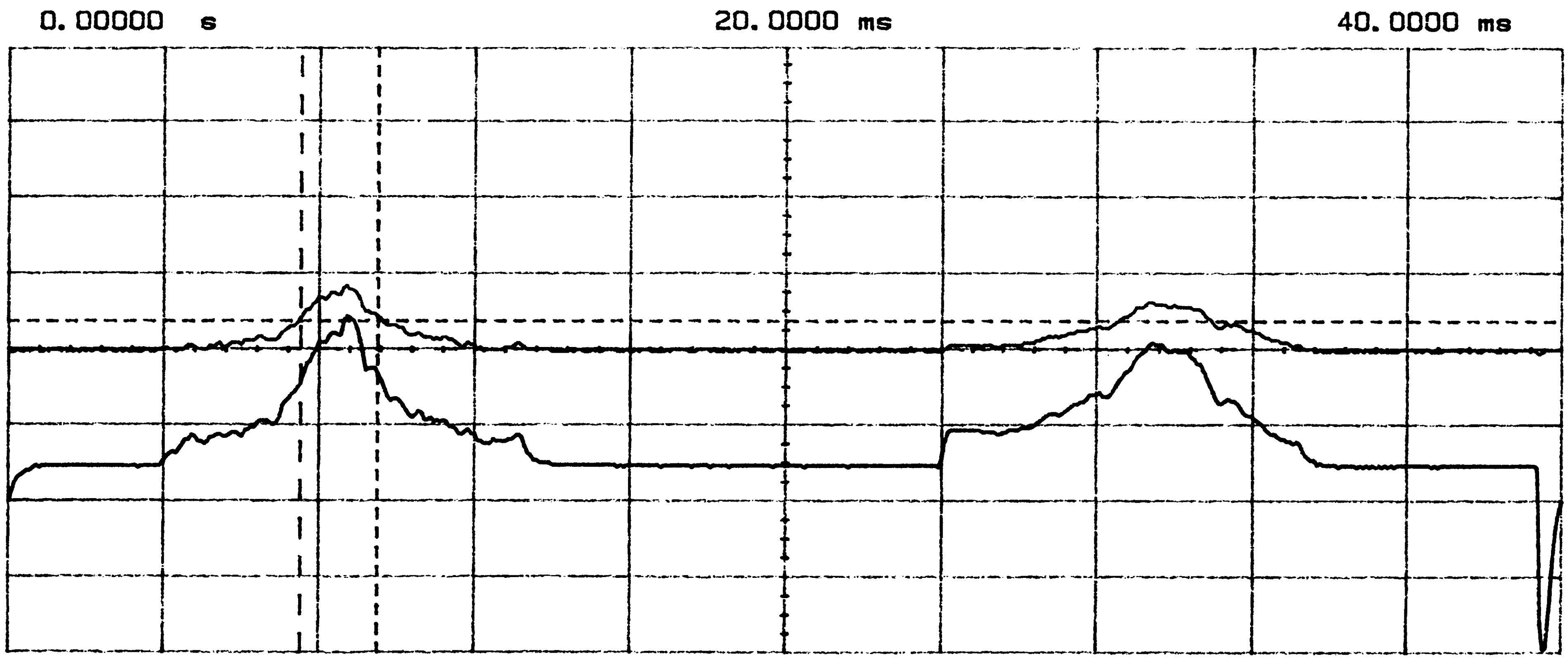
6°) HΦ transverse profiles

Used at $p = 310$ MeV/c.

The digitalisation of the HΦ transverse distribution on a scintillator gave reliable measurements

Fig 6.1 is a typical measurement

Fig 6.2 is a measurement without and with a shift in revolution of about 10 kHz ($f_0 = 40.7$ MHz) introduced by the experiment mentionned in 5.2. There are no significant changes in emittance



Channel 1 = 50.00 mVolts/div
Function1 = 100.0 mVolts/div
Timebase = 4.00 ms/div
Start = 7.52000 ms
Vmarker1 = 0.000 Volts

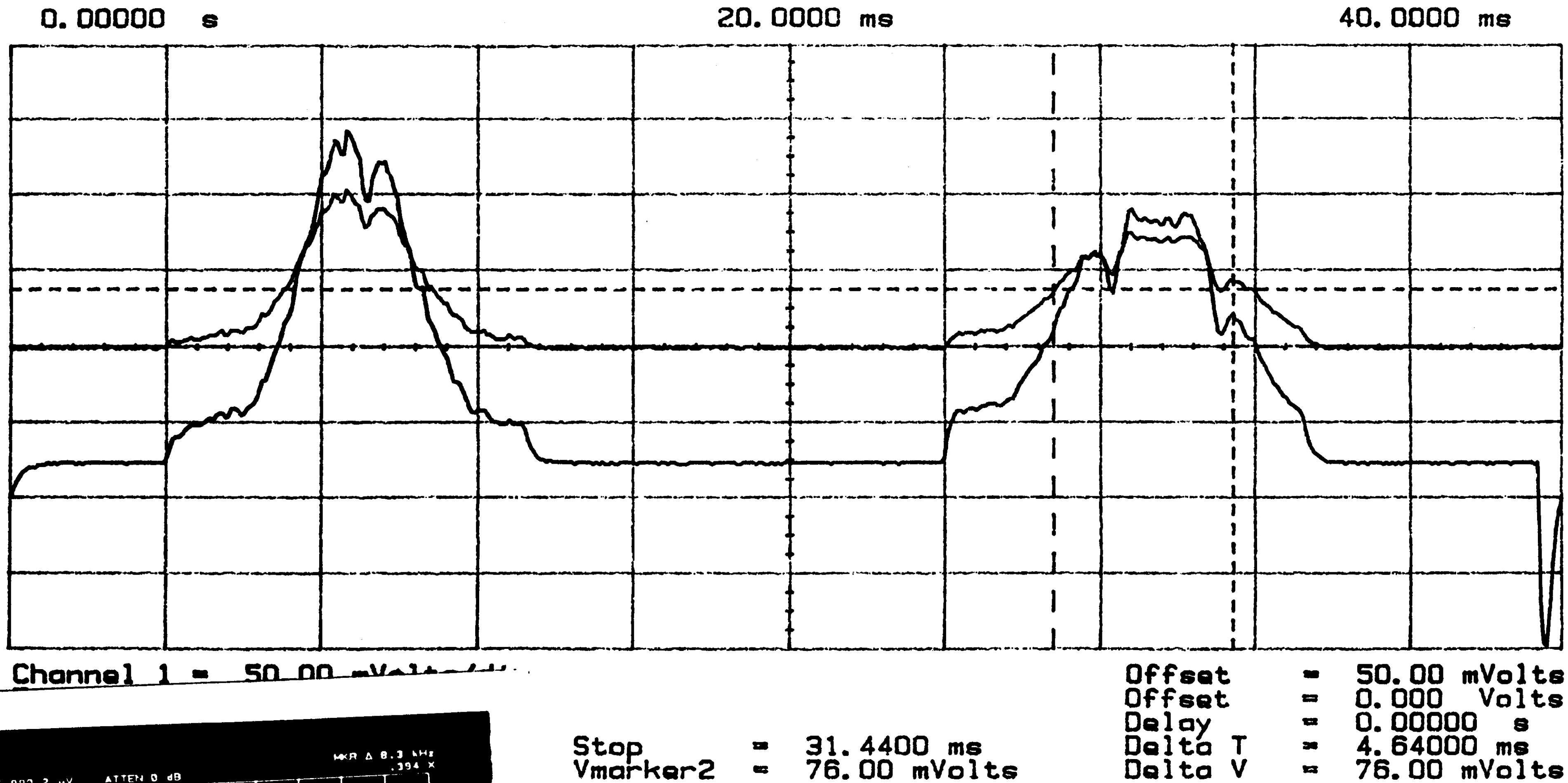
Stop = 9.52000 ms
Vmarker2 = 36.00 mVolts

Offset = 50.00 mVolts
Offset = 0.000 Volts
Delay = 0.00000 s
Delta T = 2.00000 ms
Delta V = 36.00 mVolts

Fig 6.1

$\varepsilon_h \simeq 3\pi$

$\varepsilon_v \simeq 2.0\pi$


0.00000 s
20.0000 ms
40.0000 ms
Channel 1 = 50.00 mVolts/div
Stop = 31.4400 ms
Vmarker2 = 76.00 mVolts
Offset = 50.00 mVolts
Offset = 0.000 Volts
Delay = 0.00000 s
Delta T = 4.64000 ms
Delta V = 76.00 mVolts

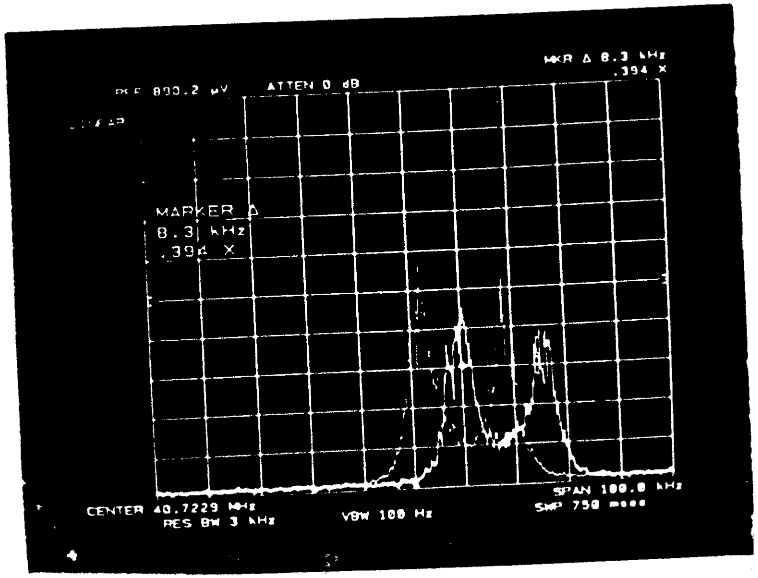

ATTEN 0 dB
MKR Δ 8.3 kHz
.394 X
MARKER Δ
8.3 kHz
.394 X
CENTER 40.7229 MHz
RES BW 3 kHz
VBW 100 Hz
SPAN 100.0 kHz
SWP 750 msec

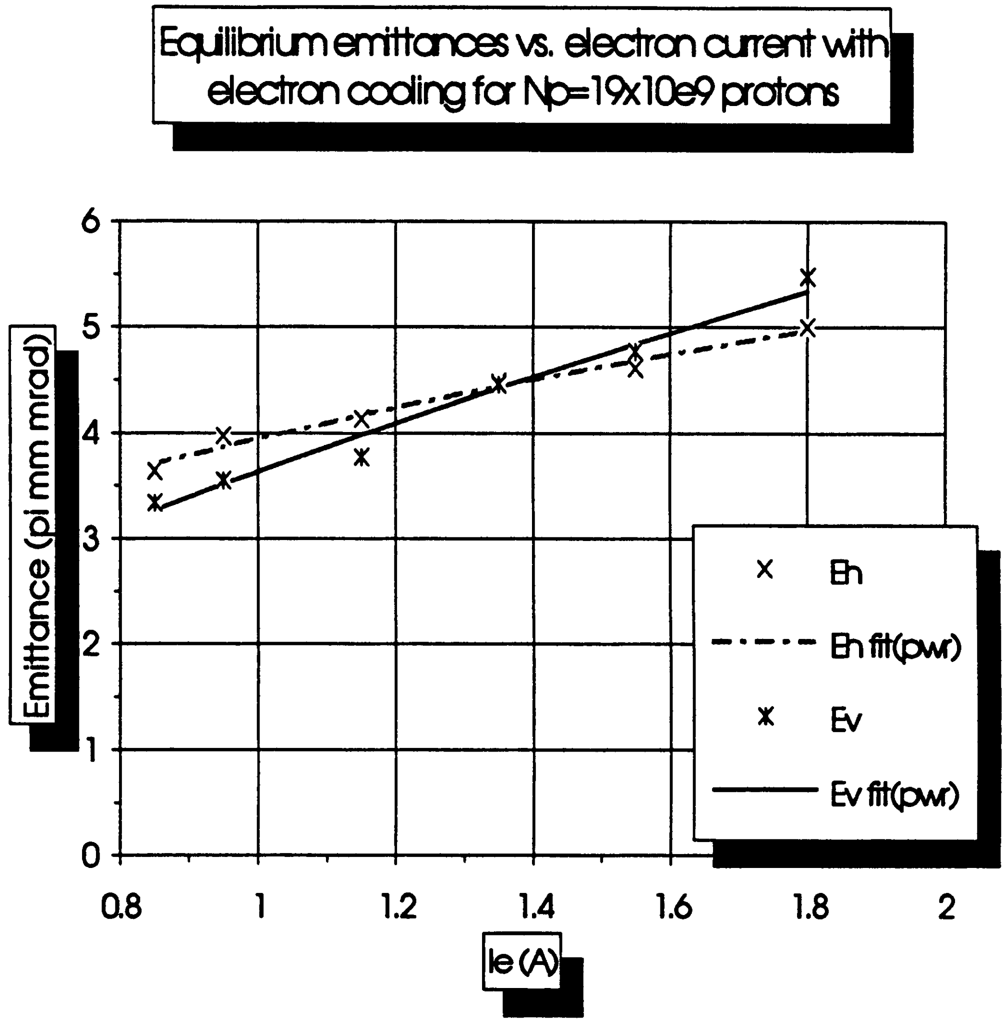
Figure 6.5

A series of measurements were made to determine the influence of particle number and electron beam intensity on the transverse equilibrium emittances at 310.1 MeV/c.

(i) E_h, E_v vs. I_e

The electron beam intensity was varied by modifying the grid potential Vg and then centering the proton beam energy to the nominal value via the cathode potential Vo. The transverse equilibrium emittances were measured from the H0 profiles. This measurement was made for a circulating beam intensity of 1.9x10E10 protons.

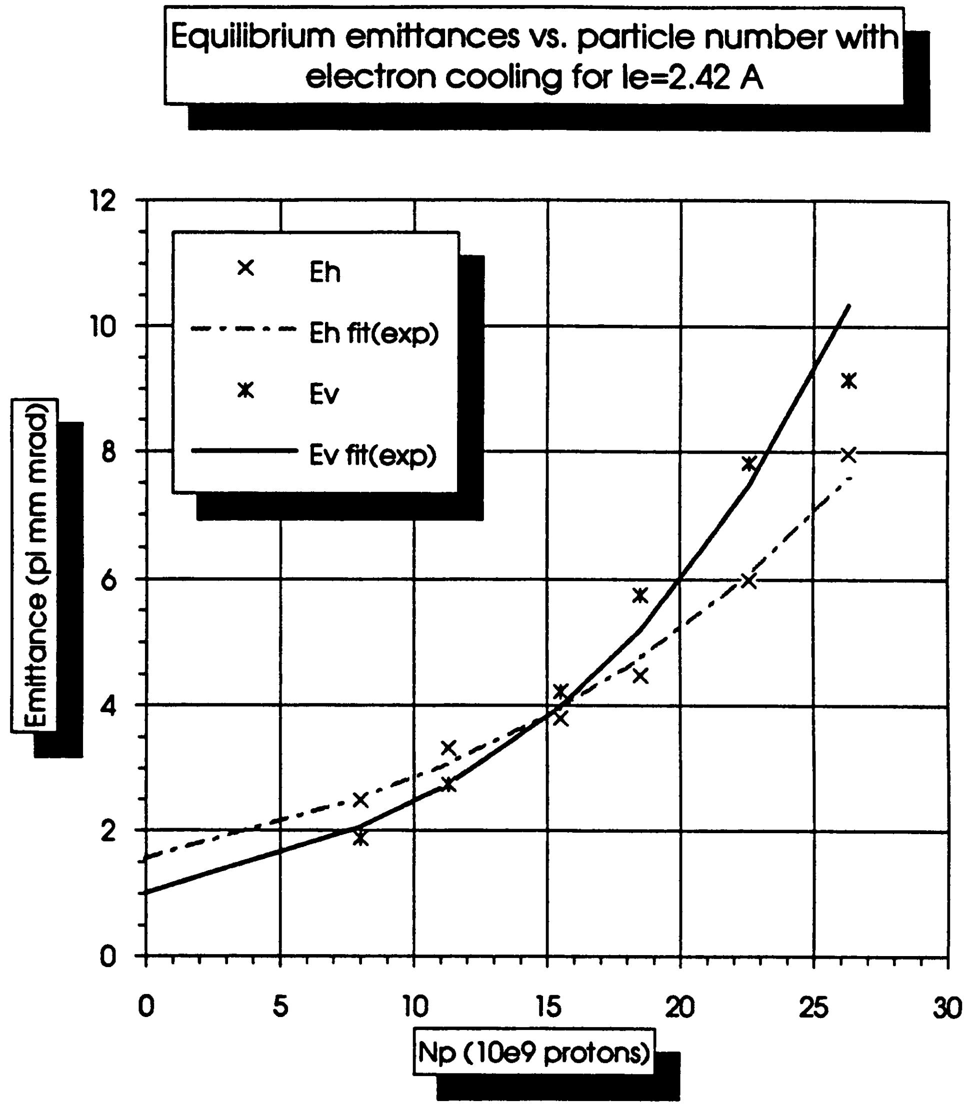
Ie (A)	h FWHM (mm)	Eh (pi mm mrad)	v FWHM (mm)	Ev (pi mm mrad)	
0.85	1.3	3.6	0.85	3.3	lower limit
0.95	1.37	4.0	0.88	3.6	
1.15	1.4	4.1	0.91	3.8	
1.35	1.46	4.5	0.99	4.5	
1.55	1.48	4.6	1.02	4.8	
1.8	1.54	5.0	1.09	5.5	



(ii) E_h, E_v vs. N_p

The injected proton beam intensity was varied by changing the head-tail clipper length (dump-swith). After the injected beam had been cooled down to equilibrium, the transverse emittances were measured from the H0 profiles. This measurement was made for an electron current of 2.42 A.

Np (x10E9)	h FWHM (mm)	Eh (pi mm mrad)	v FWHM (mm)	Ev (pi mm mrad)
8	1.09	2.5	0.64	1.9
11.3	1.26	3.3	0.77	2.7
15.5	1.34	3.8	0.96	4.2
18.5	1.46	4.5	1.12	5.8
22.6	1.69	6.0	1.31	7.8
26.3	1.94	7.9	1.41	9.2



7) CONCLUSIONS

7.1) Neutralisation:

- The oscillations can be awarded to the fact that the positive potential, provided by the Elg, Elc electrodes, is not large enough in order to maintain the positive ions trapped.
- Neutralisation must be studied with high intensity e-beams and as a function of the magnetic field and if possible of the vacuum pressure.
- The oscillation time constant, amplitude, should find an theoretical explanation.
- The phenomena mentionned in 2.1.1, remark should be analysed
- Time of flight should be extended to a real BTF i.e experiments given in fig 2.2.5 and 2.2.6 have to be analysed over a larger bandwidth and therefore observe the plasma frequency and some instabilities

7.2) Servo system

- To be improved at: 100 MeV/c = p
- To be put operationnal for all the momenta taking into account some safety rules
- It seems that this facility has left the

experimental domain and is more a technical problem.

7.3) Machine physics

So many to do! The effects of the main solenoid and of the compensation solenoids should be mastered. At each MD we lose 1 to 2 day in order to fix the LEAR for cooling

7.4) Various results

Change in perveance, Change in energy; Need for more measurements. The problems of of interest and could be part of the Russian collaboration

7.5) H∅ profiles

Unfortunately do not work under 200 MeV/c
Should be operational.
Anyway we have to find a mean to measure transverse profiles in a short time (every 10ms)