TESLA COLLABORATION

Transparencies from the Meeting on

Cold- and Beam Test of the First Nb Superstructure Prototypes

DESY, February 25 and 26, 2002

March 2002, TESLA 2002-04

The meeting on "Cold- and beam test of the first Nb Superstructure prototypes"
February 25 and 26 in Seminar Room 292, Building Id.

February 25,2002

Talks on the test cryomodule components (Convener: D. Proch)

9:15	A. Matheisen	"Status of the test cryomodule: short overview of components and preparation of final assembly"	1
9:30	R. Lange	"Schedule of the cryomodule assembly"	15
9:45	R. Lange	"Cold test of new tuner"	17
10:00	J. Sekutowicz	"Summary of RF measurements at room temperature"	26

10:30 Coffee break

Talks on the test program (Conveners: H. Schlarb/M. Huening)

10:50	J. Sekutowicz	"Preliminary program of the cold test, what do we like to measure ?"	45
11:10	M. Huening	"Short summary of the HOM experiments in TTF linac"	66
11:25	N. Baboi	"What can we improve in HOM measurements ?"	89
11:40	M. Ferrario	"Estimation of bunch-to-bunch energy variation in TTF linac with two superstructures and standard cryomodule"	96
11:55	H. Schlarb	"Limits in energy measurements at the injector region and at the end of linac"	102
12:10	S. Simrock	"Limits in the amplitude and phase control for 2x7-cell superstructure and for standard cryomodule at 2MV/m and 15 MV/m operation"	112

12:30 Lunch

Talks on the TTF linac preparation(Conveners: P. Castro/S. Schreiber)

13:30	P. Castro	"Proposed re-arrangement of TTF linac for the beam test of superstructures"	130
13:45	S. Schreiber	"Injector: stability of charge at operation at 1 MHz and at 54 MHz"	133
14:00	S. Choroba	"RF power distribution system for the test cryomodule and 1* cryomodule at ACC2 position"	140
14:15	M. Wendt	"BPMs, electronics and automatic data read-out for the HOM experiment and for the FM experiment"	145

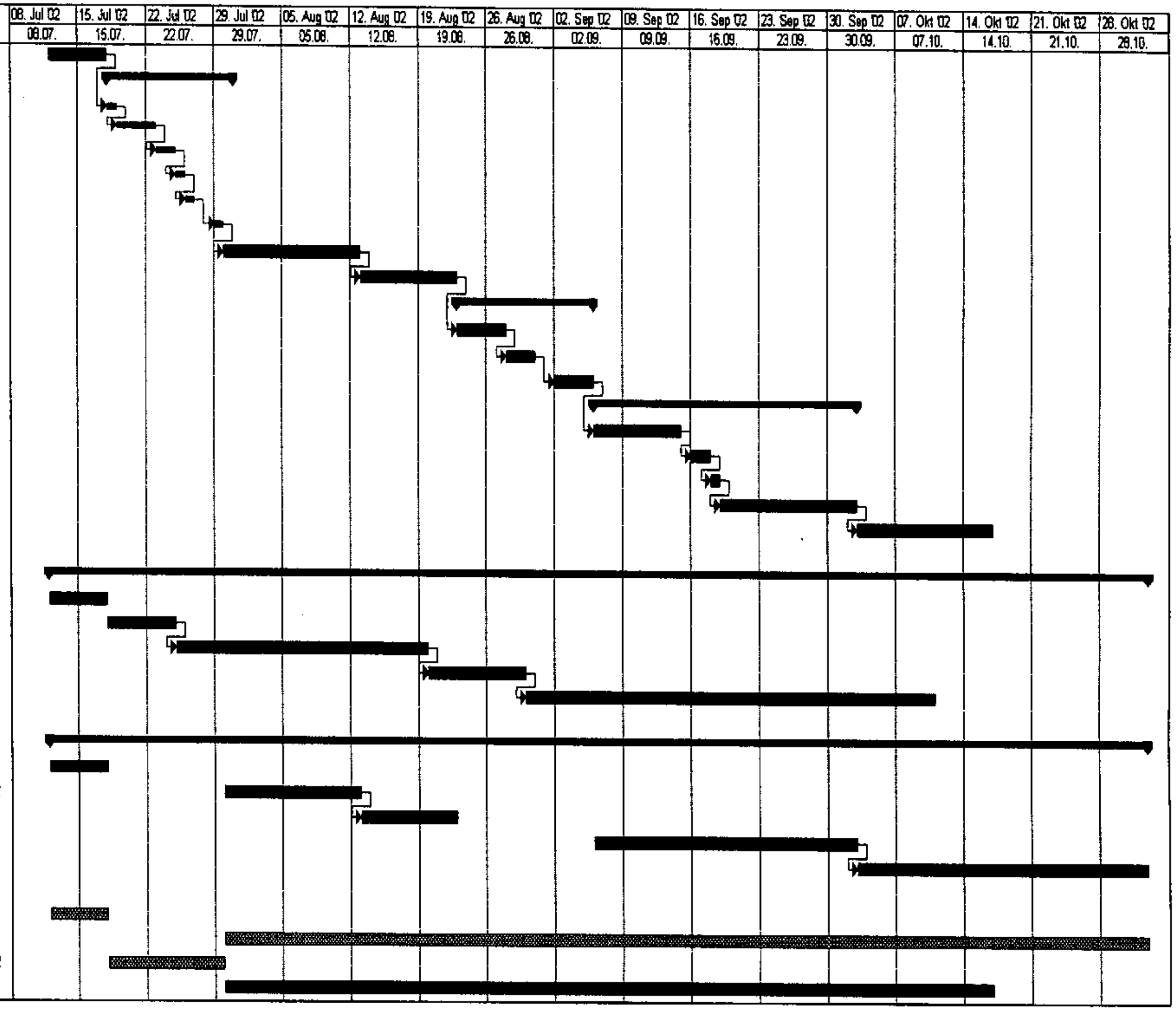
14:30 Coffee break

14:50	K. Rehlich	"Diagnostics: re-arrangement for the beam test of superstructure"	160
15:05	H. Schlarb	"Interlock re-arrangement for the test"	162
15:20-16:00		Discussion on: Other technical aspects of the test	

February 26,2002

9:00- 12:00 Discussion on : Other technical aspects of the test, schedule, manpower and AOB.

Nr.	Vorgangsname	Dauer	Anfang	Ende
1	**Cool-down**	5 Tage	Fr 12.07.02	Mi 17.07.02
2	RF-measurements without beam	9 Tage	Do 18.07.02	Di 30.07.02
3	Cable calibration:8 pickups/6HOMs	1 Tag	Do 18.07.02	Do 18.07.02
4	Field flatness adjustment SST#1 (2 Methods)	2 Tage	Fr 19.07.02	Mo 22.07.02
5	Field flatness adjustment SST#2 (2 Methods)	2 Tage	Di 23.07.02	Mi 24.07.02
6	FM -passb. SST#1 and SST#2/Field Flatt. vs. F	1 Tag	Do 25.07.02	Do 25.07.02
7	HOM measurements: Qs and F: SST#1	1 Tag	Fr 26.07.02	Fr 26.07.02
8	HOM measurements: Qs and F: SST#2	1 Tag	Mo 29.07.02	Mo 29.07.02
9	FM coupler conditioning SST#1 and SST#2 , 1*	10 Tage	Di 30.07.02	Mo 12.08.02
10	Linac commissioning	8 Tage?	Di 13.08.02	Do 22.08.02
11	Energy variation measurements with beam	10 Tage	Fr 23.08.02	Do 05.09.02
12	SST#1	3 Tage	Fr 23.08.02	Di 27.08.02
13	SST#2	3 Tage	Mi 28.08.02	Fr 30.08.02
14	SST#1+SST#2	4 Tage	Mo 02.09.02	Do 05.09.02
15	HOM measurements with beam	22 Tage	Fr 06.09.02	Mi 02.10.02
16	Active HOM Measurements/Calibration of BPMs	7 Tage	Fr 06.09.02	Sa 14.09.02
17	Re-arrangem. of laser from 1 MHz to 54 MHz	2 Tage?	Mo 16.09.02	Di 17.09.02
18	Re-calibration for 54 MHz	1 Tag?	Mi 18.09.02	Mi 18.09.02
19	HOMs search of SST#1 and SST#2	11 Tage?	Do 19.09.02	Mi 02.10.02
20	**Reserve**	10 Tage?	Do 03.10.02	Mi 16.10.02
21				
22	**Linac activities**	85 Tage?	Fr 12.07.02	Fr 01.11.02
23	RF-gun cavity conditioning	5 Tage?	Fr 12.07.02	Mi 17.07.02
24	Capture cavity conditioning	5 Tage?	Do 18.07.02	Mi 24.07.02
25	Injector commissioning for long pulses	18 Tage?	Do 25.07.02	Mo 19.08.02
26	Linac commissioning	8 Tage?	Di 20.08.02	Do 29.08.02
27	Linac operation for the FM and HOM experimer	33 Tage?	Fr 30.08.02	Do 10.10.02
28				
29	**ACC2 activities (1*)**	85 Tage?	Fr 12.07.02	Fr 01.11.02
30	Warm conditioning of couplers off resonance	5 Tage?	Fr 12.07.02	Mi 17.07.02
31	Cold conditioning of couplers	10 Tage?	Di 30.07.02	Mo 12.08.02
32	High gradient 1 Hz	8 Tage?	Di 13.08.02	Do 22.08.02
33	High gradient 1 Hz	22 Tage?	Fr 06.09.02	Mi 02.10.02
34	High gradient long pulse 5/10 Hz	22 Tage?	Do 03.10.02	Fr 01.11.02
35				
36	***Linac Interlock closed 24 h***	5 Tage?	Fr 12.07.02	Mi 17.07.02
37	***Linac Interlock closed 24 h***	72 Tage?	Di 30.07.02	Fr 01.11.02
38	***Linac Interlock closed for the night shift***	8 Tage?	Do 18.07.02	Mo 29.07.02
39	***Need for Klystron 1***	60 Tage?	Di 30.07.02	Mi 16.10.02



II

TESLA 2002-04

A. Matheisen

"Status of the test cryomodule: short overview of components and preparation of final assembly"

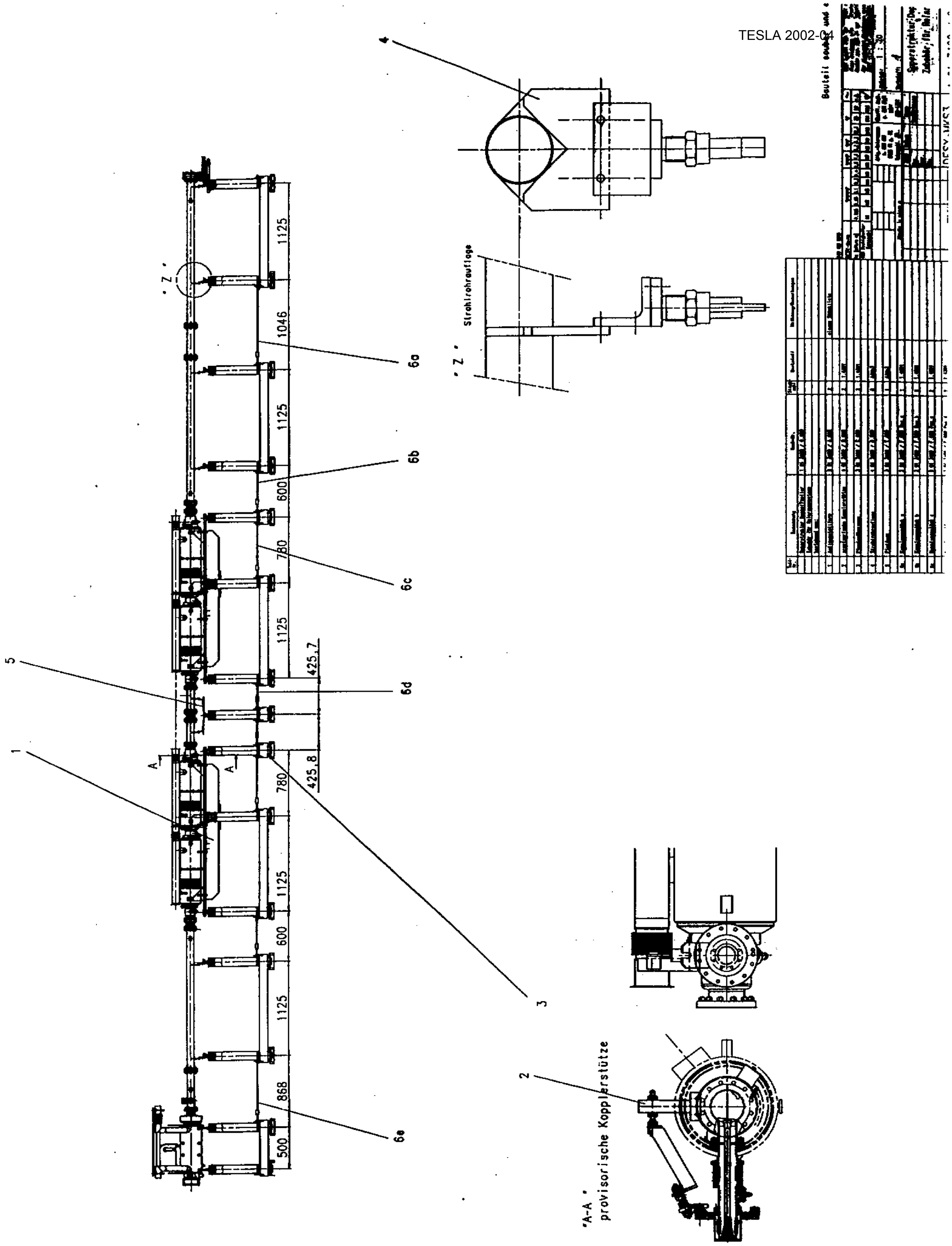
tooling

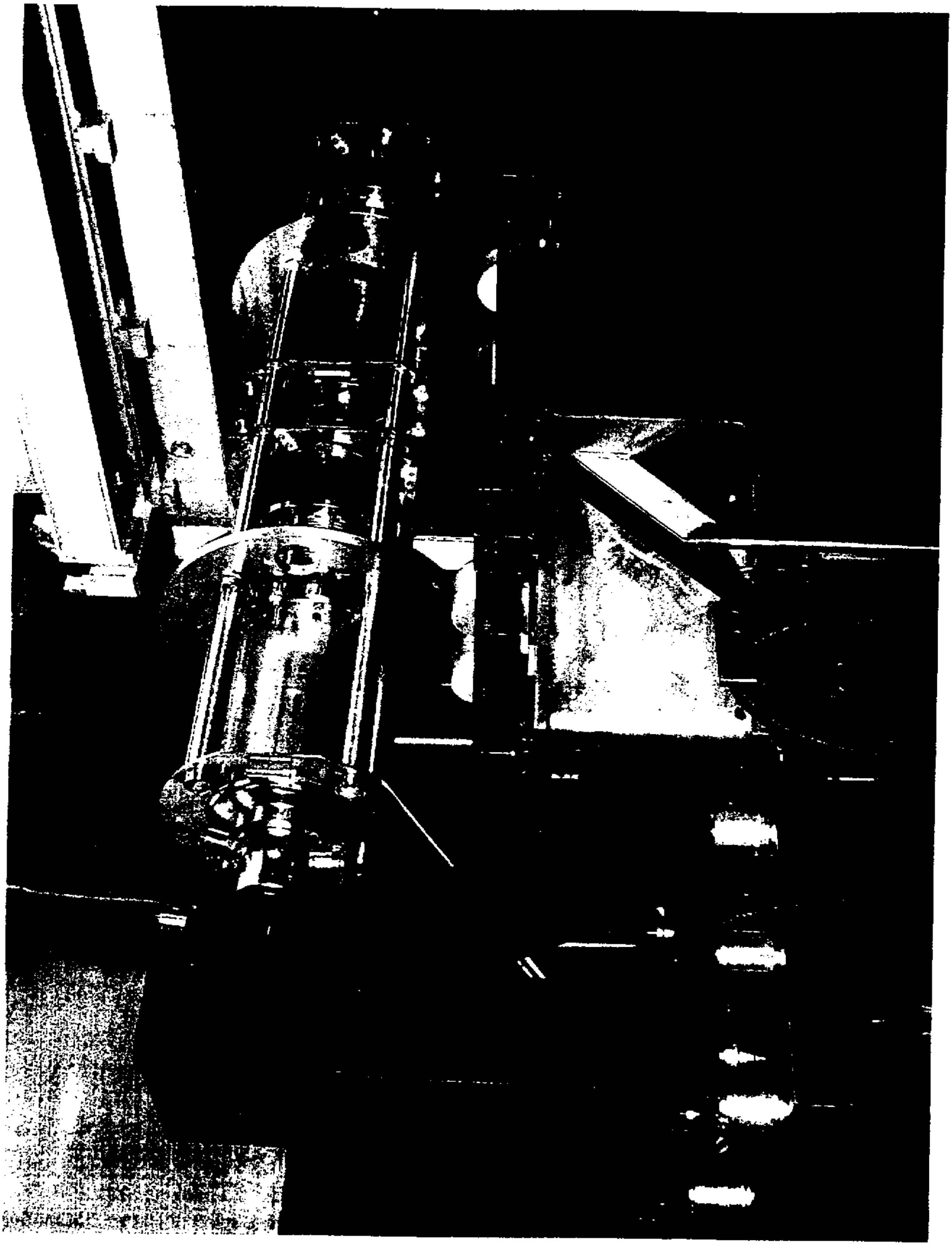
item	status	expected	Comment
frame	OK		only one available
Chemistry	OK		cleaning rinsing ongoing
High pressure rinsing	OK		overloaded equipped with additional fixed points
carts and carrier	OK		occupied by module 5
assembly line in clean room	95 % ready	KW 10.02 final adaptation	

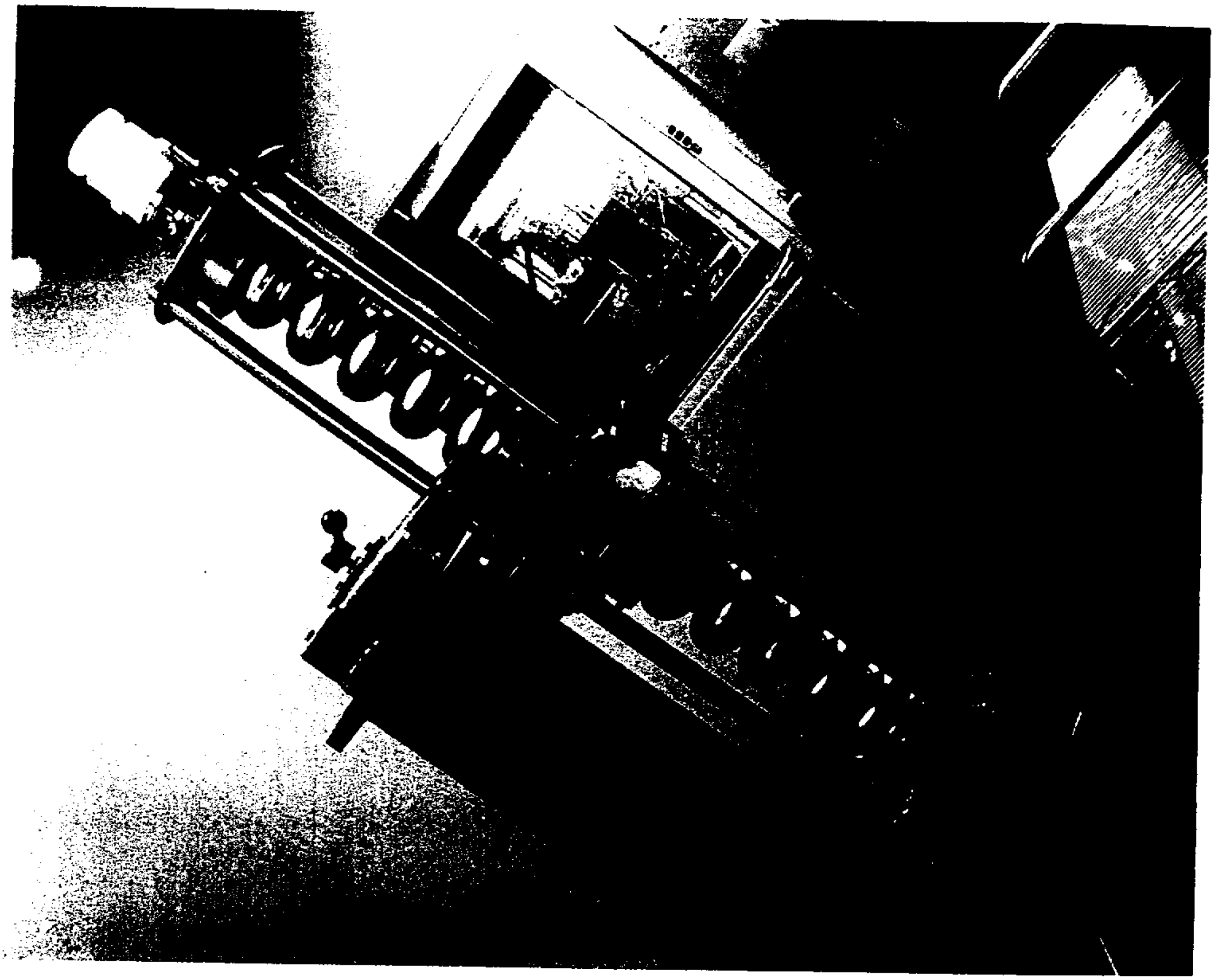
module

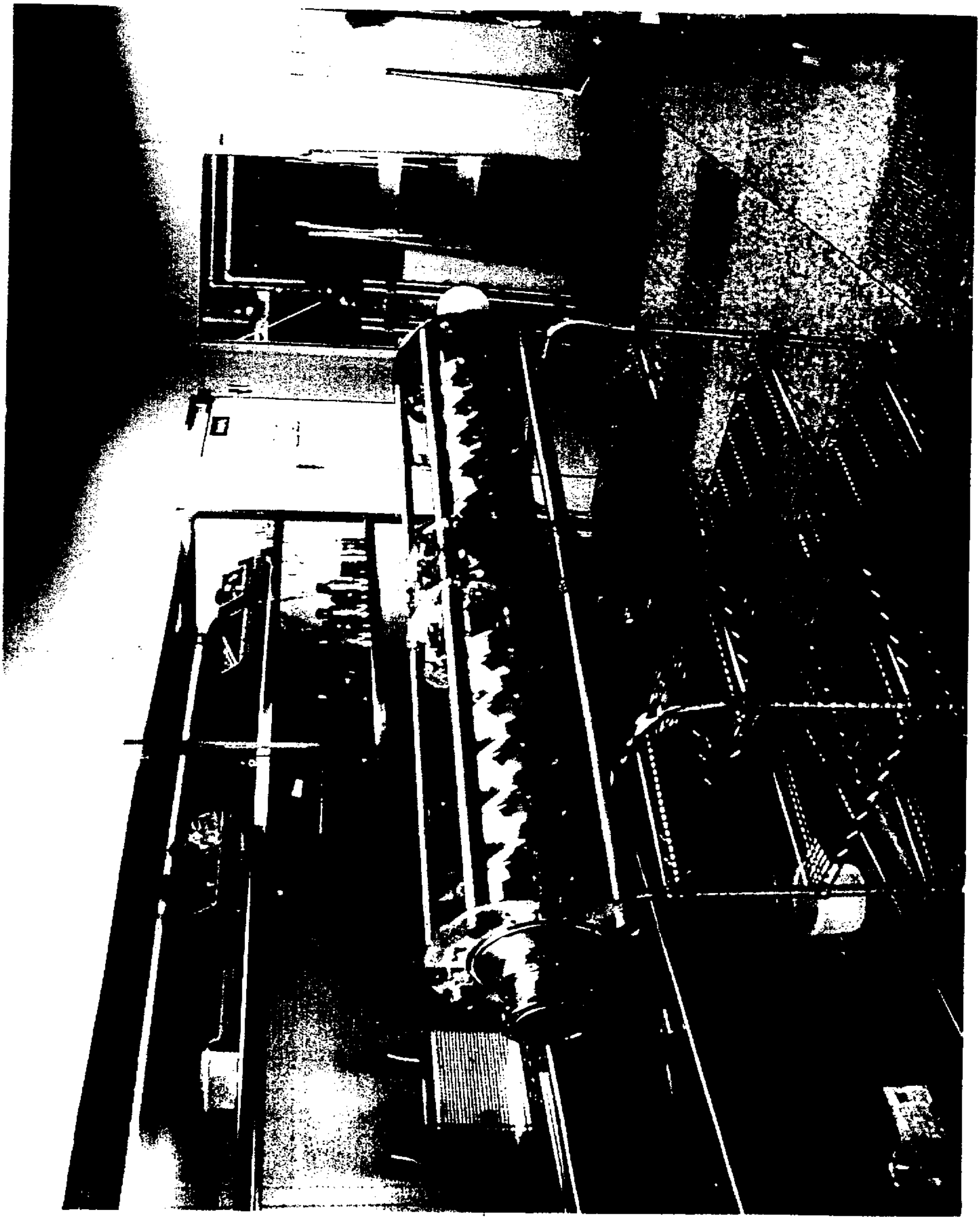
item	status	expected	Comment
beam line components	Ok	under cleaning KW9-10	
HOM test absorber	OK	under cleaning KW 9-10	
gate valves	1 Ok	No 2 under leak test/ KW 10-11	
magnetic schieding	90% done	KW 10.02	adaptation of middle part necessary
Quadrupole	under welding and leak check	KW 9-10.02	

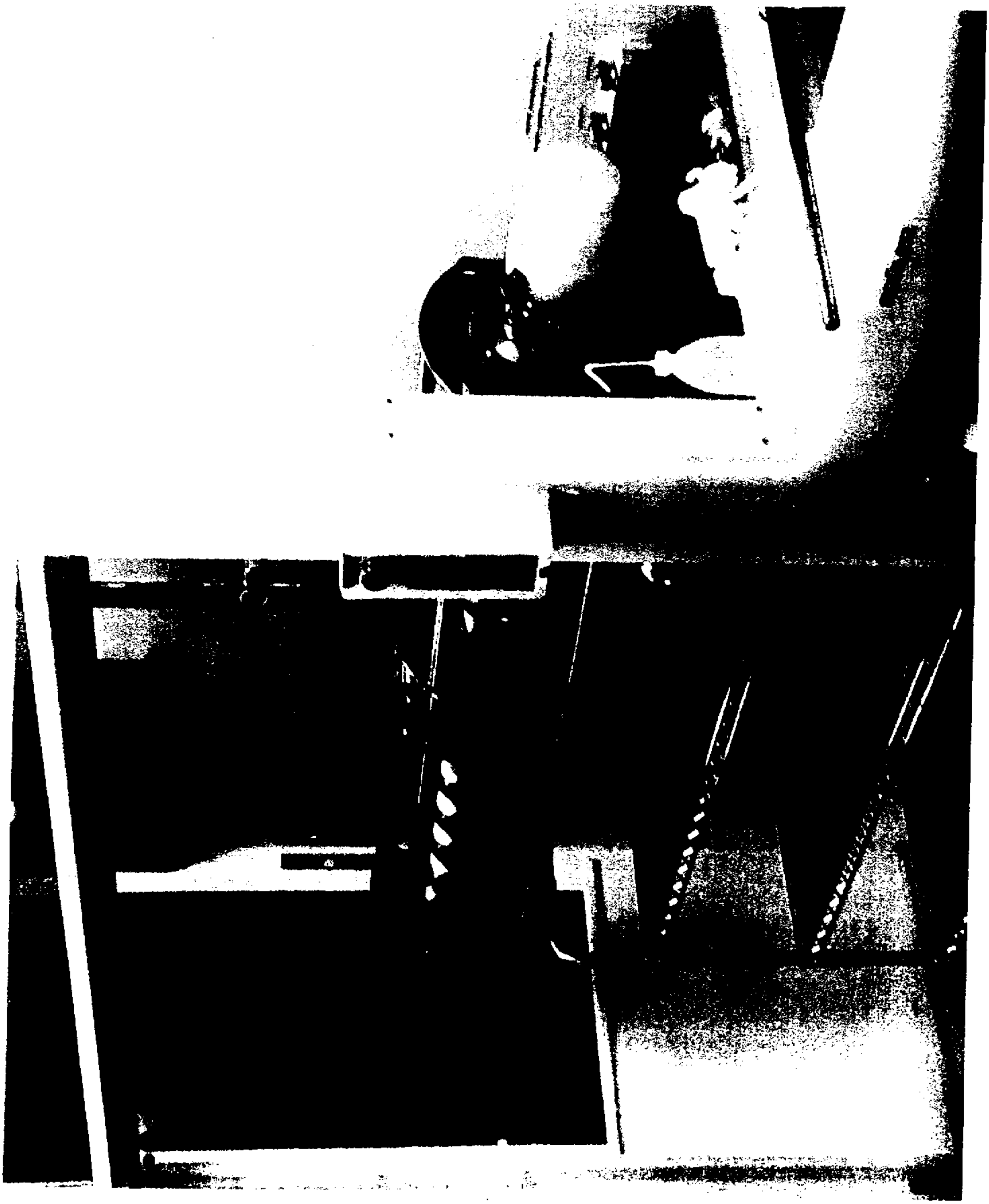
2

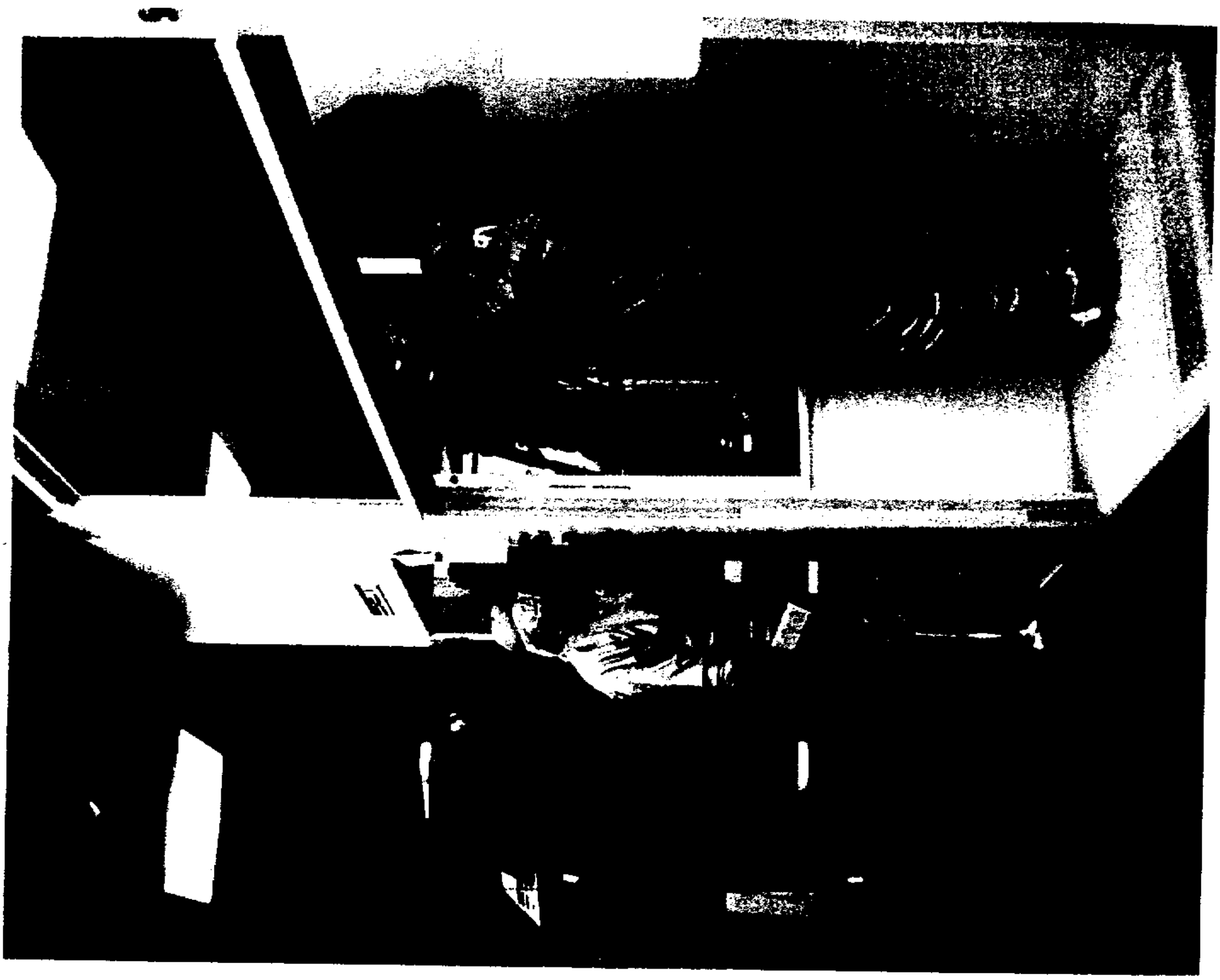

1
2
3
4
5
6a
6b
6c
6d
6e
1125
1046
1125
600
780
1125
425,7
425,8
780
1125
600
1125
868
500
"Z"
Strahlrohrauflage
"A-A"
provisorische Kopplerstütze

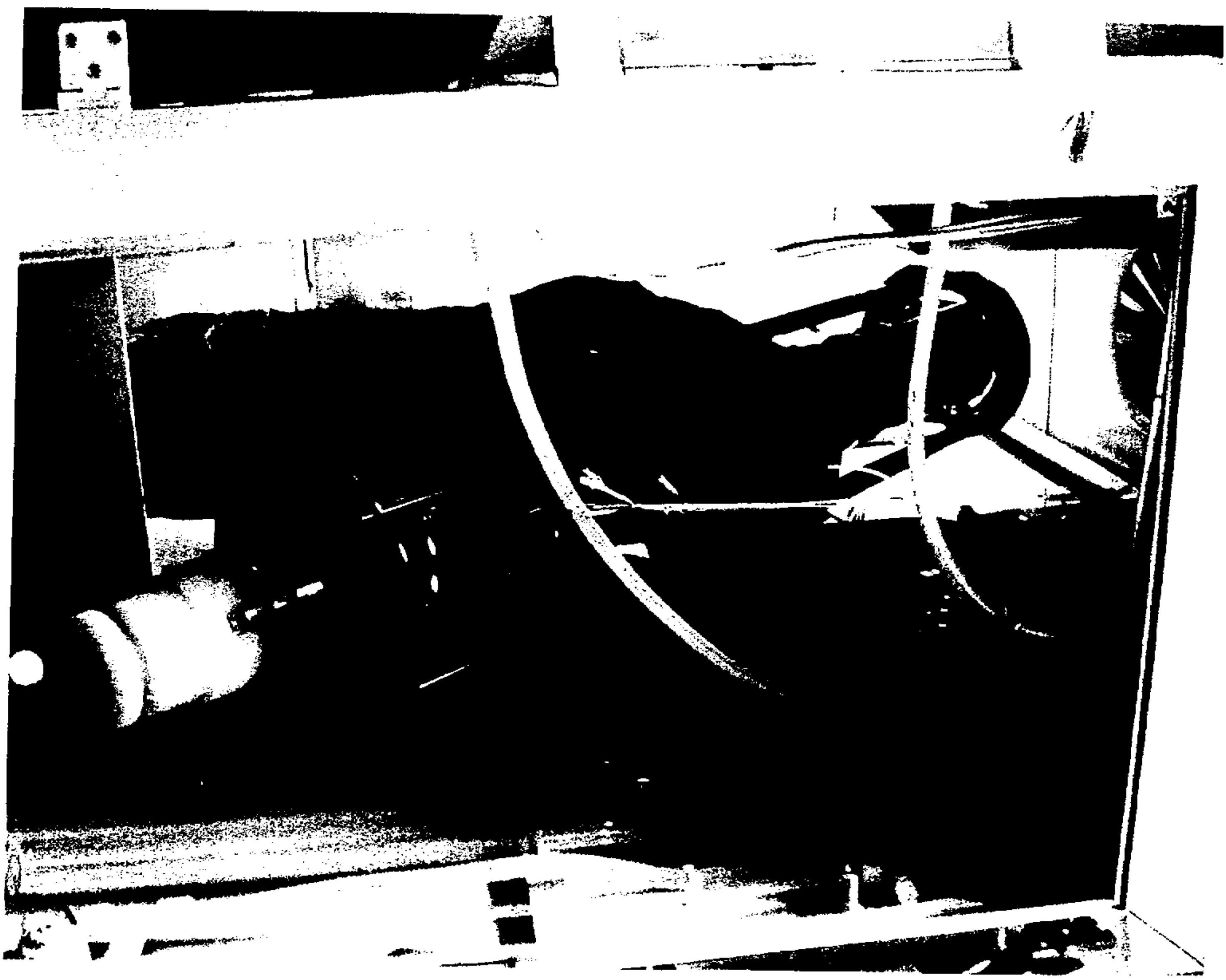


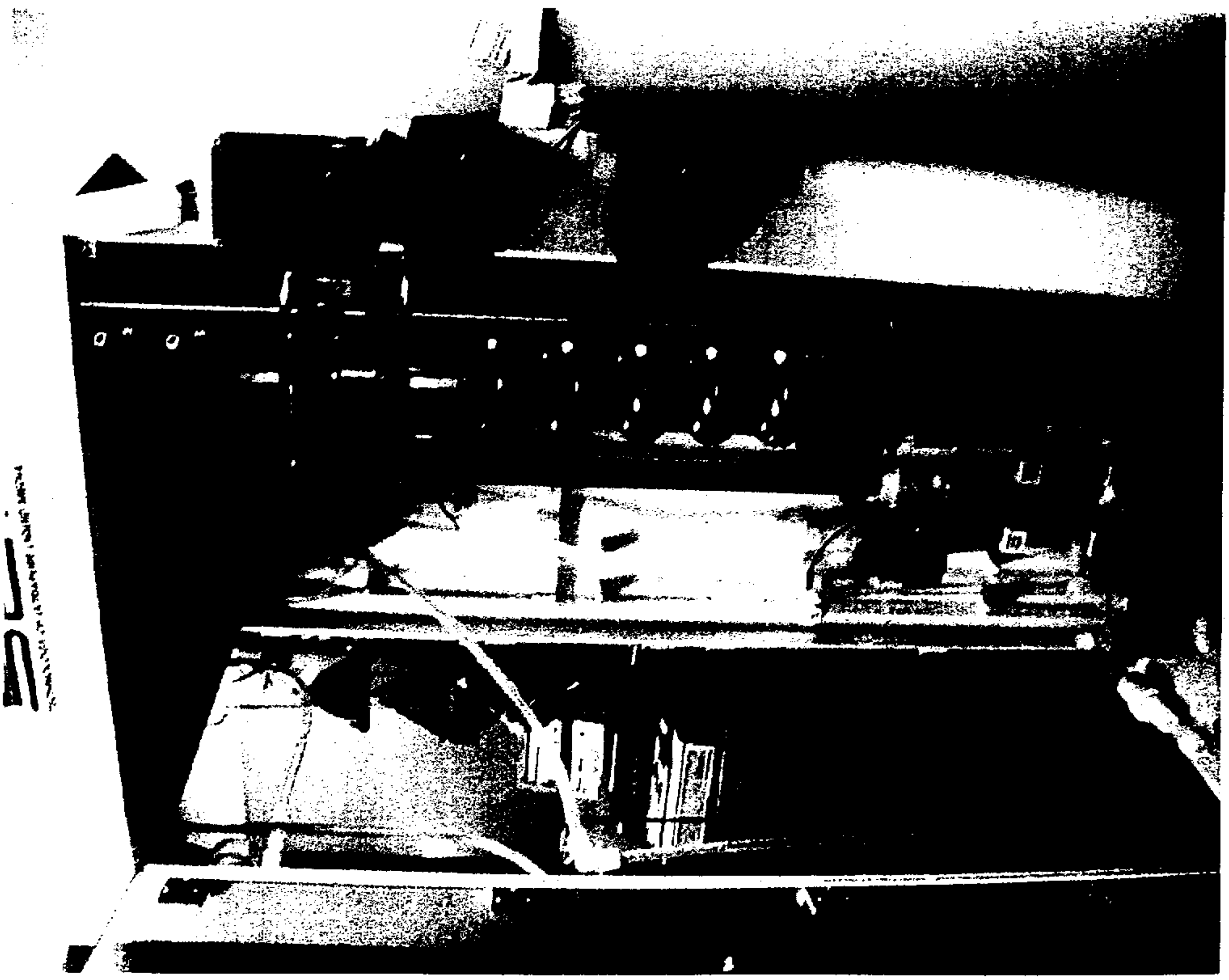


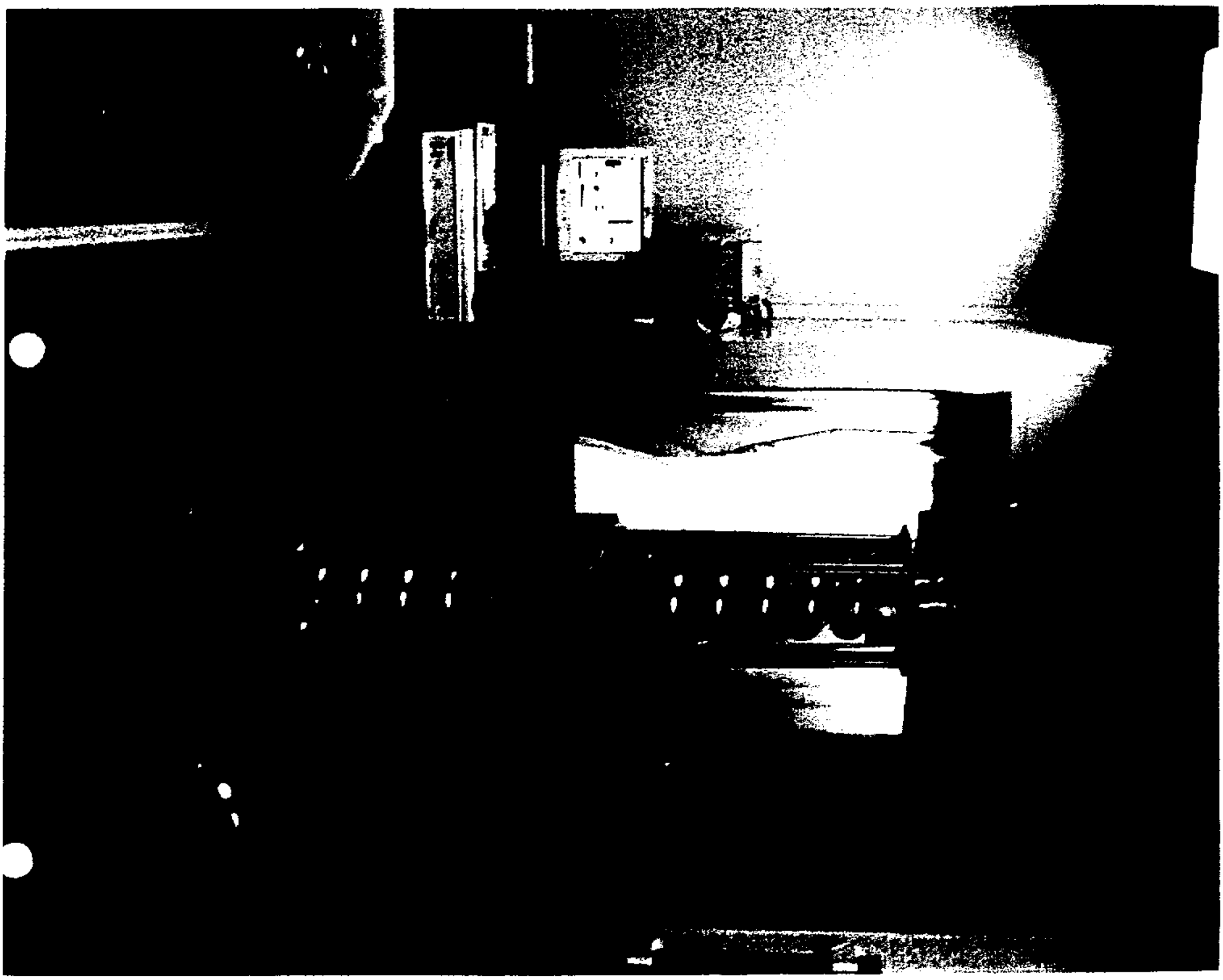


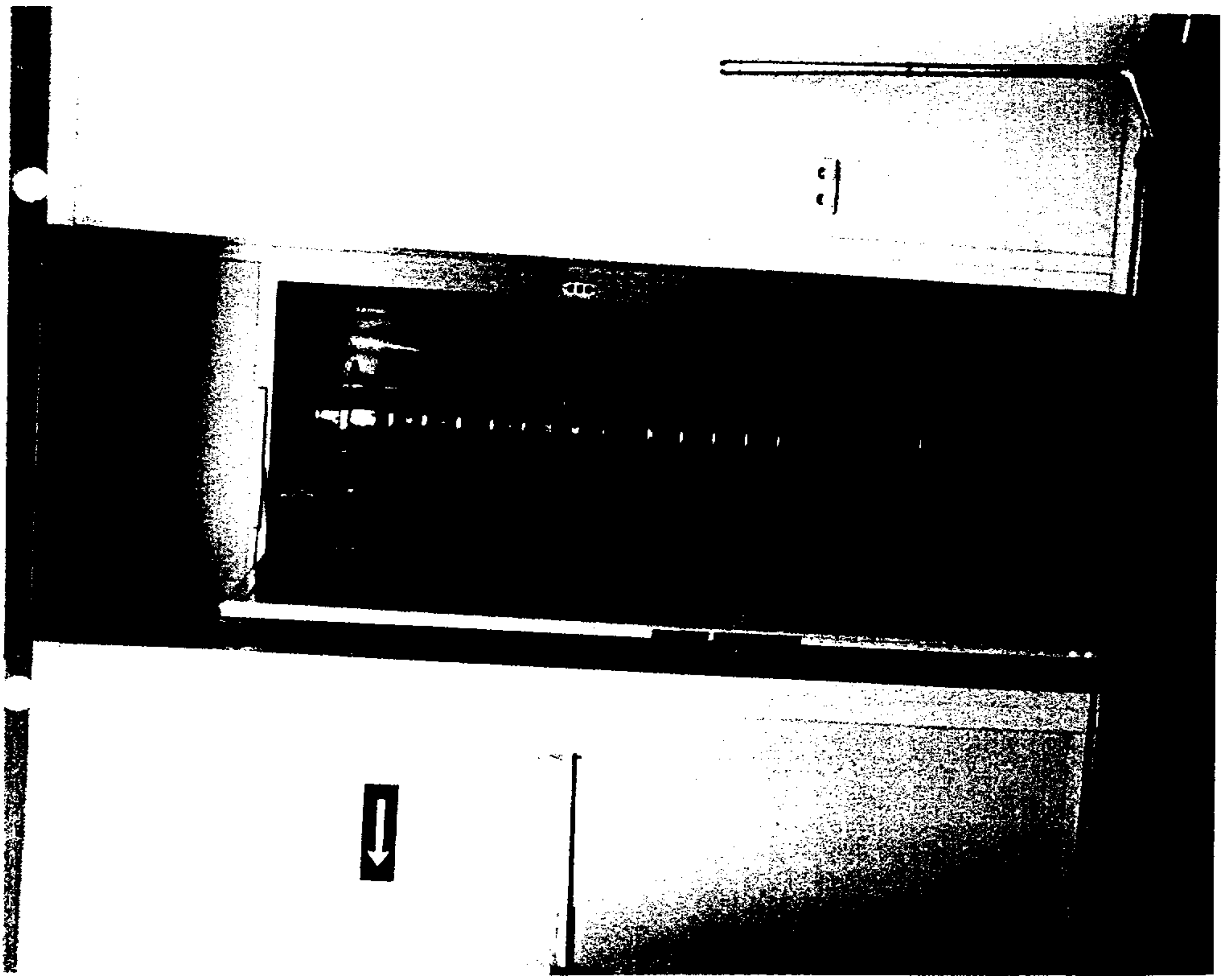












Status of equipment for Cavity Preparation

A.Matheisen 25.2.02

Cavities

	welding of structure	Rf measurements in lab done	Chemical treatment	assembly to module	testrun to qualify infrastructure
2*7 cell No 1					
Status	December 01	February 02	stand by		
Expected			KW 9 .02	KW11.02	
2*7 cell No 2					
Status	January 02	on going			
Expected		KW9.02	KW 9-10.02	KW 11.02	
2*7 cell test cavity					
Status	none		KW 8-9.02		on going
expexted				test KW9.02	KW 8-9

R. Lange

"Schedule of the cryomodule assembly"

Status :22–Feb–02 Jensch/Lange –MKS1–

Time–Schedule for Superstructure–Module Assembly, Installation in Linac, Warm Tests, Cool Down and Cold Tests together with Module 1*.

What has to be done , untill superstructure module assembly can be started?

–String superstructure ready	==> HP/Cleanroom work	on the way
–All parts ready	==>Vacuum vessel	o.K.
	Cold mass	o.K.
	Thermal shields	o.K.
	Superinsulation	o.K.
	Flanges, screws etc.	o.K.
	Tubing partly different	on the way
	Quad incl. Hom–Ads, BPMs	on the way
	Current lead	on the way
	Super–Tuners tests	on the way
	Cabling, Sensors...	on the way
	Magnetic Shielding? Decision	necessary!

–Preparation/check all components — Start 28–March–02

–Tooling set for module type 2 — Start 28–March–02
==>Preparation area incl. Surveyors
(Posts, reference points,cold mass, rail..)
==>Cantilever area
(Railway)

Module 5 and Superstruktur cryostats are of different types and need different tooling !
(Vacuum–vessel, distances supports/posts, cavity vessel, alignment...)

Module 4, 5 and...	are of module–type 3
Module 2, 3, 1* and ..	are of module–type 2
Module Superstructure	is of module–type 2 and contains some specials

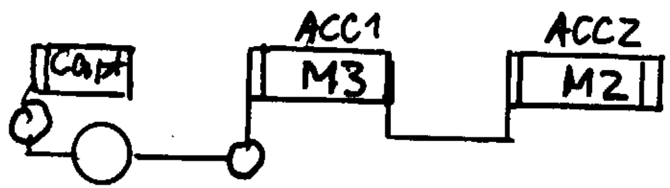
==>Superstructure tooling cannot be set up before Module 5 is ready!!!
After setting up the tooling, superstructure assembly can be started.
Up to now for module 5 assembly there is a delay of 9 days.

–Start Superstructure module assembly	==>04–April–02	
Superstructur e module ready	==>10–May–02	Must be ready!!!! Or delay!!!!
–Installation superstructure in linac	==>28–May–02	
–Final Test superstructure /M1*	==>25–June–02	
–Cool Down Linac (Capt/Super/M1*)	==>09–July–02	
–Start Cold Tests	==>12–July–02	

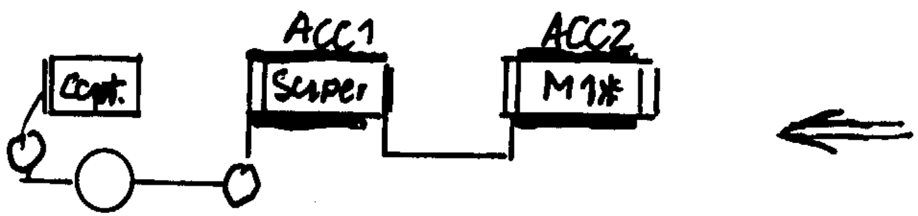
––––––––––This Schedule is very optimistic but possible–––––––––––––––

Steps untill TTF2

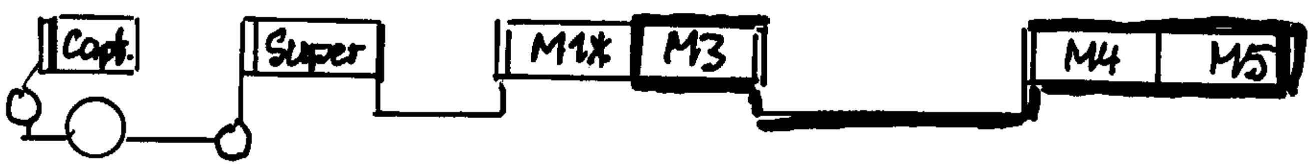
22-Feb-02 RLange MKS



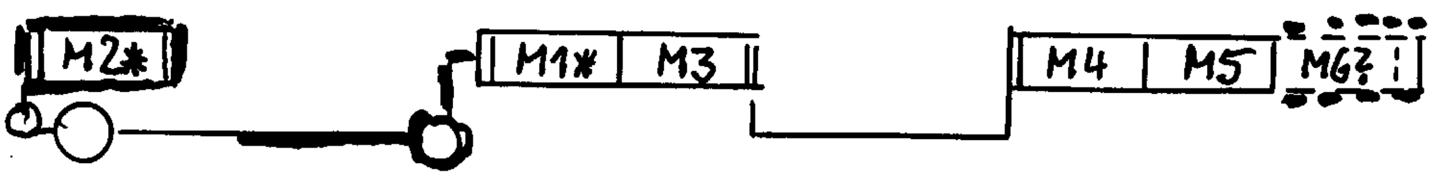
Current Status
TTF1
untill End April-02
(since June-99)



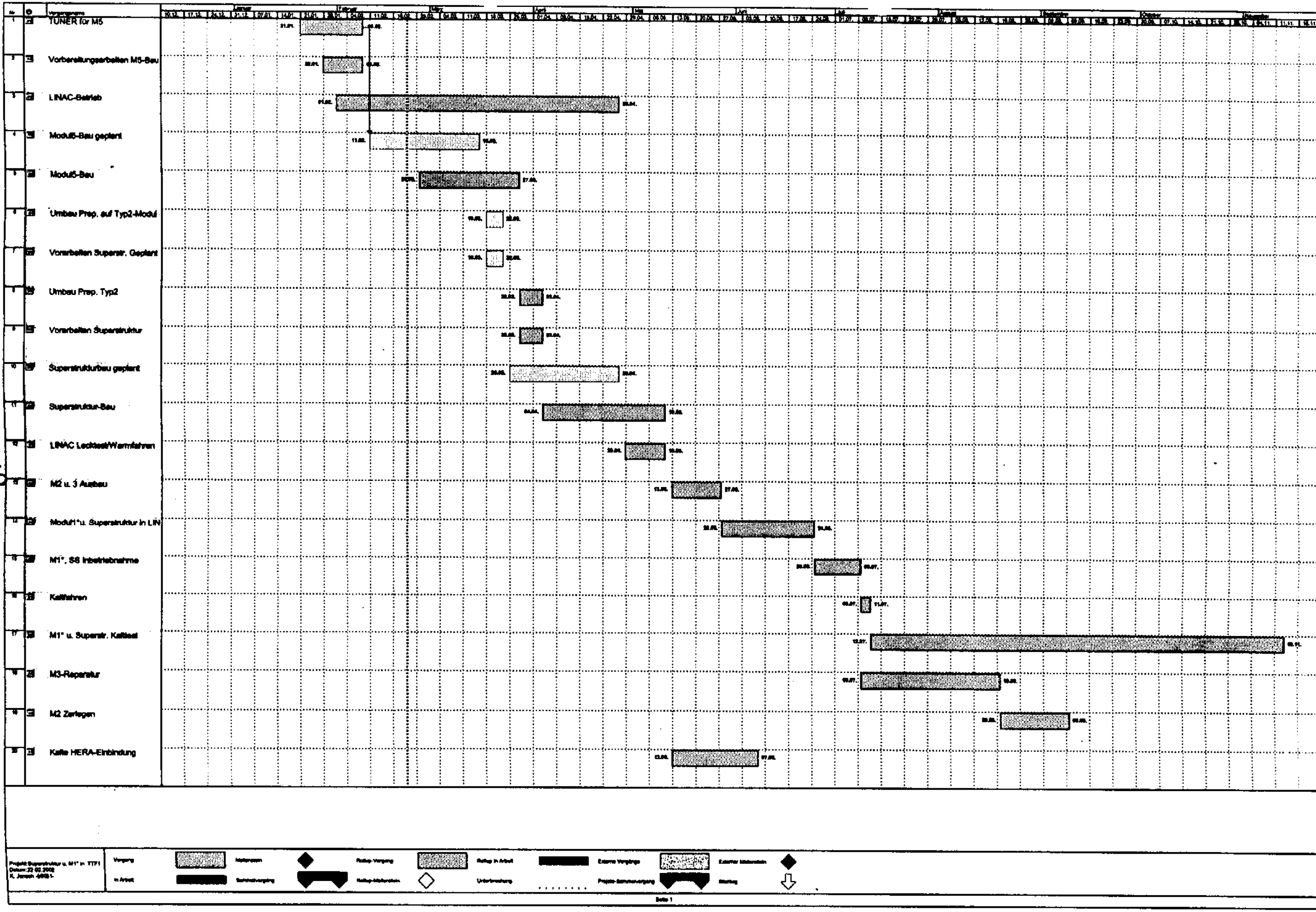
Test superstructure and M1*
with beam
untill End Oct-02



Test M3, M4, M5
without beam
untill End Jan-03

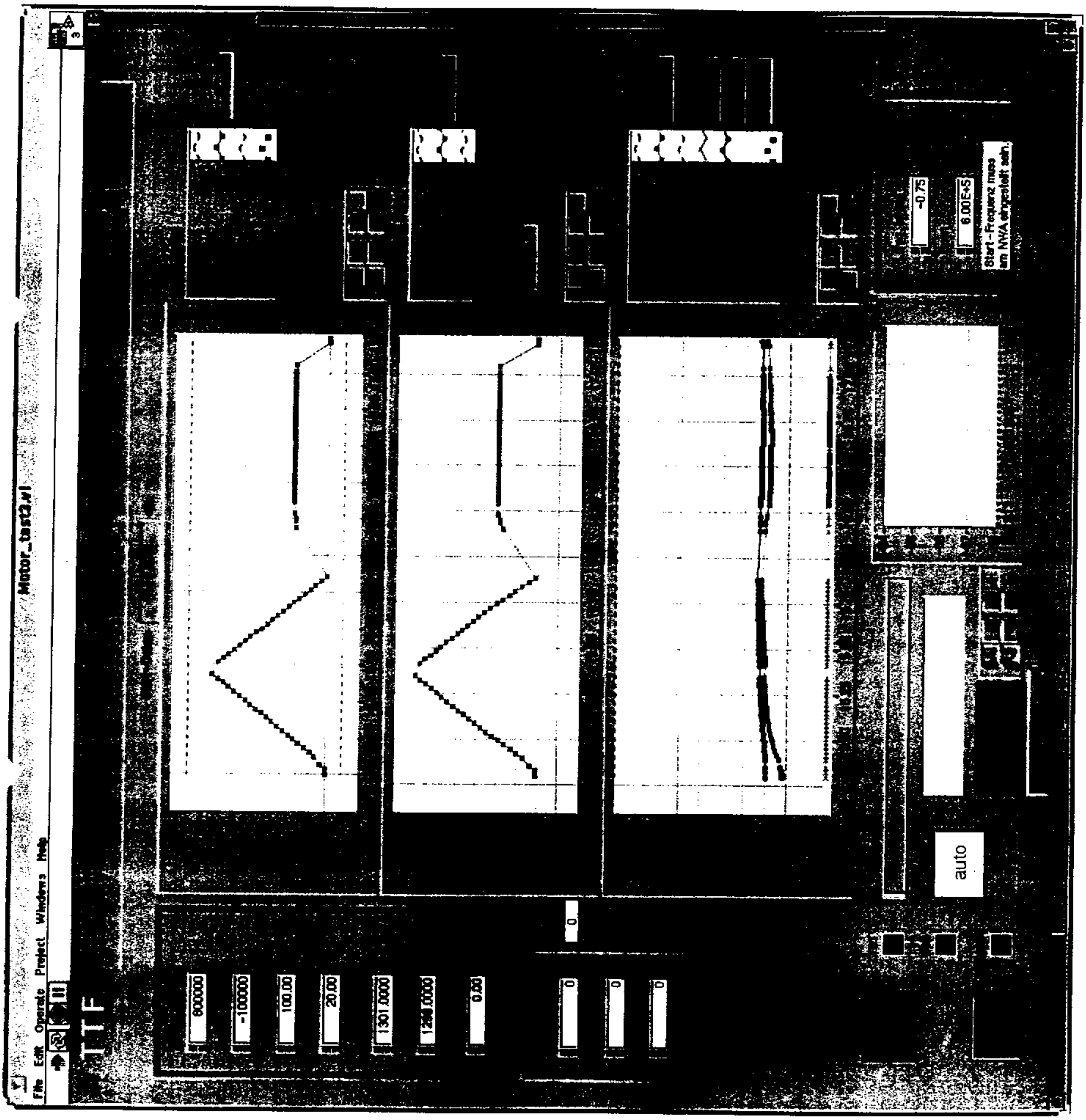


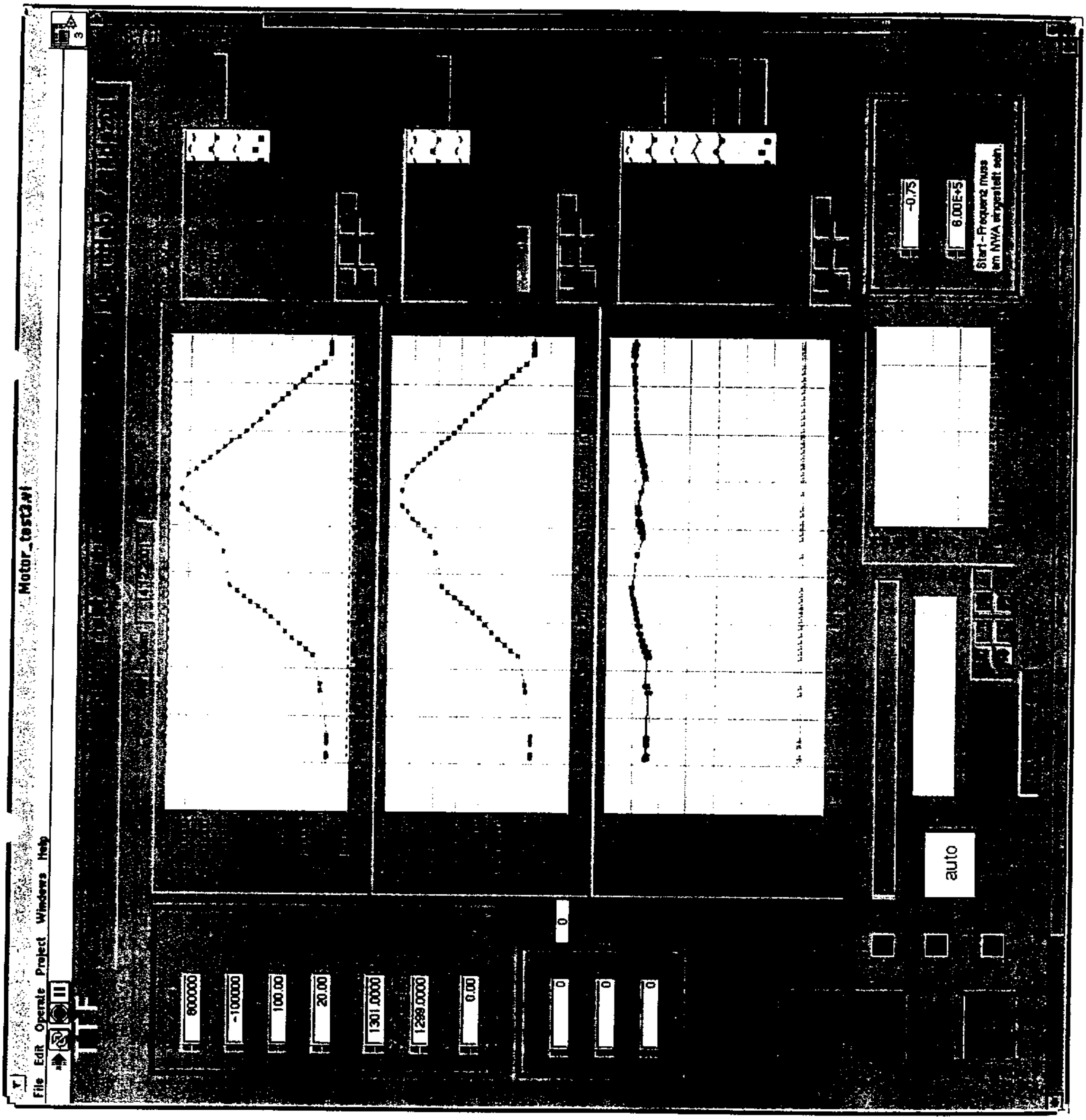
TTF 2
Begin July-03

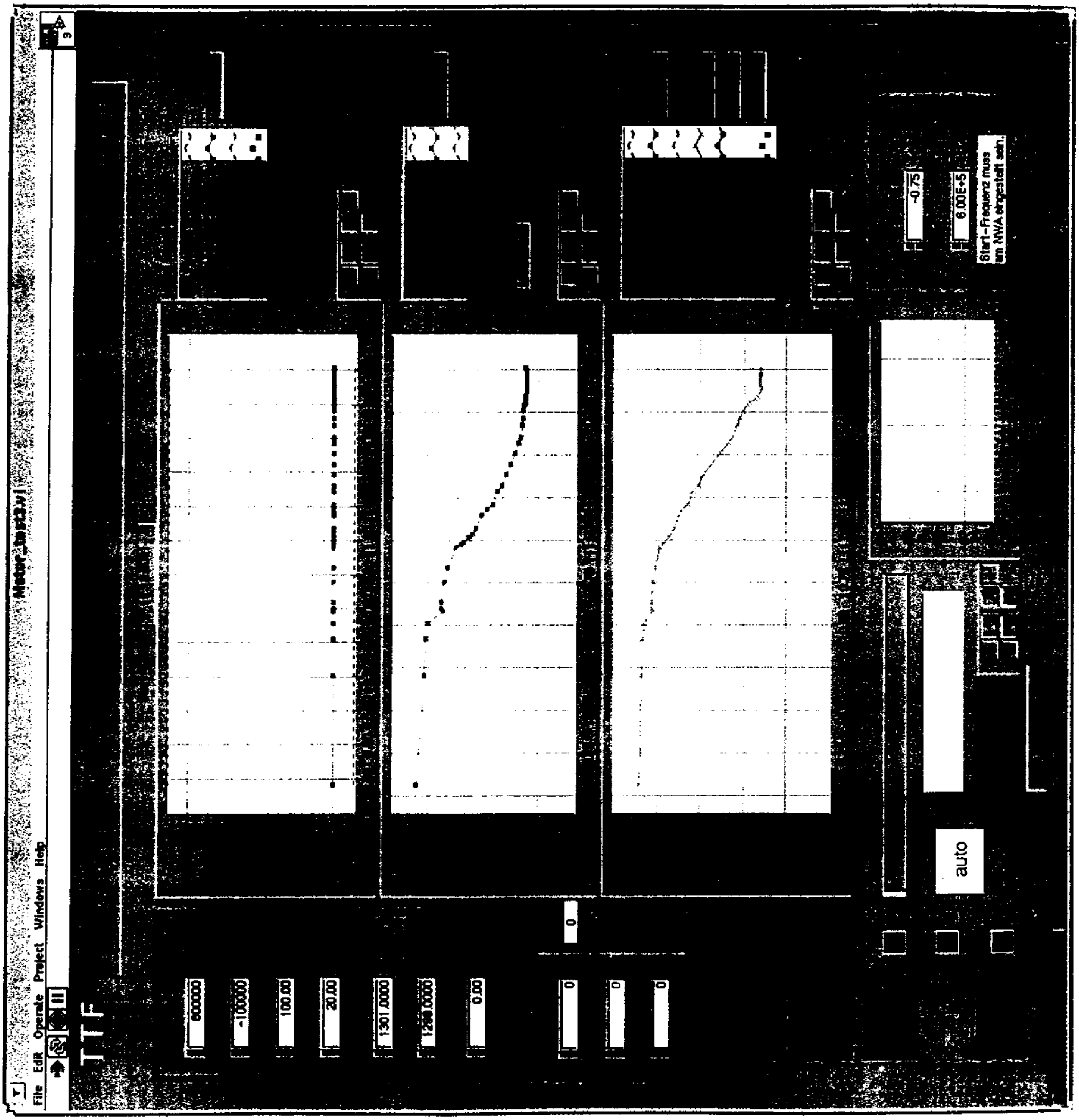

TUNER für M5
Vorbereitungsarbeiten M5-Bau
LINAC-Betrieb
Modul5-Bau geplant
Modul5-Bau
Umbau Prep. auf Typ2-Modul
Vorarbeiten Superstr. Geplant
Umbau Prep. Typ2
Vorarbeiten Superstruktur
Superstrukturbau geplant
Superstruktur-Bau
LINAC Lecktest/Warmfahren
M2 u. 3 Ausbau
Modul1*u. Superstruktur in LIN
M1*, SS Inbetriebnahme
Kaltfahren
M1* u. Superstr. Kalttest
M3-Reparatur
M2 Zerlegen
Kalte HERA-Einbindung

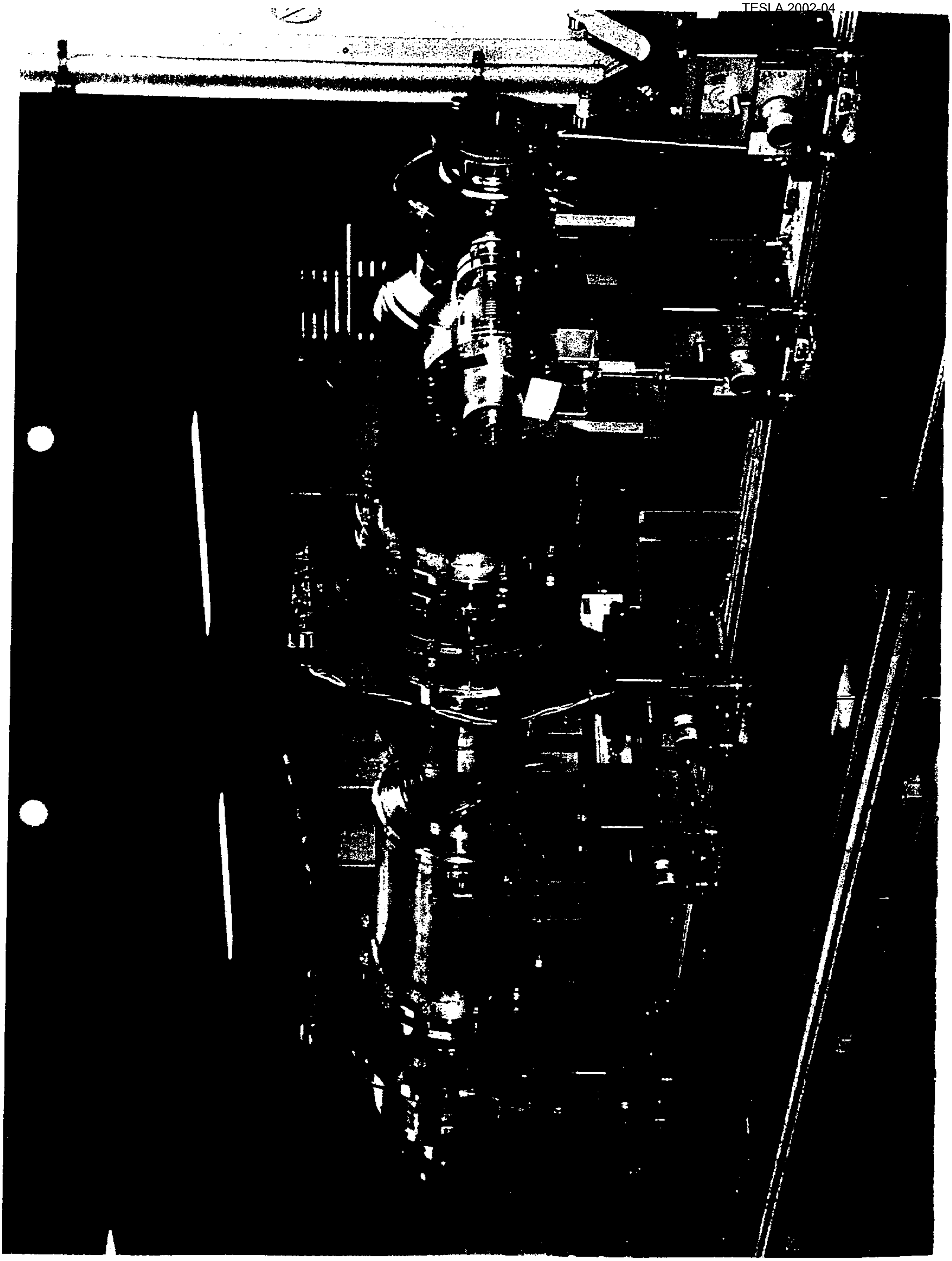
R. Lange

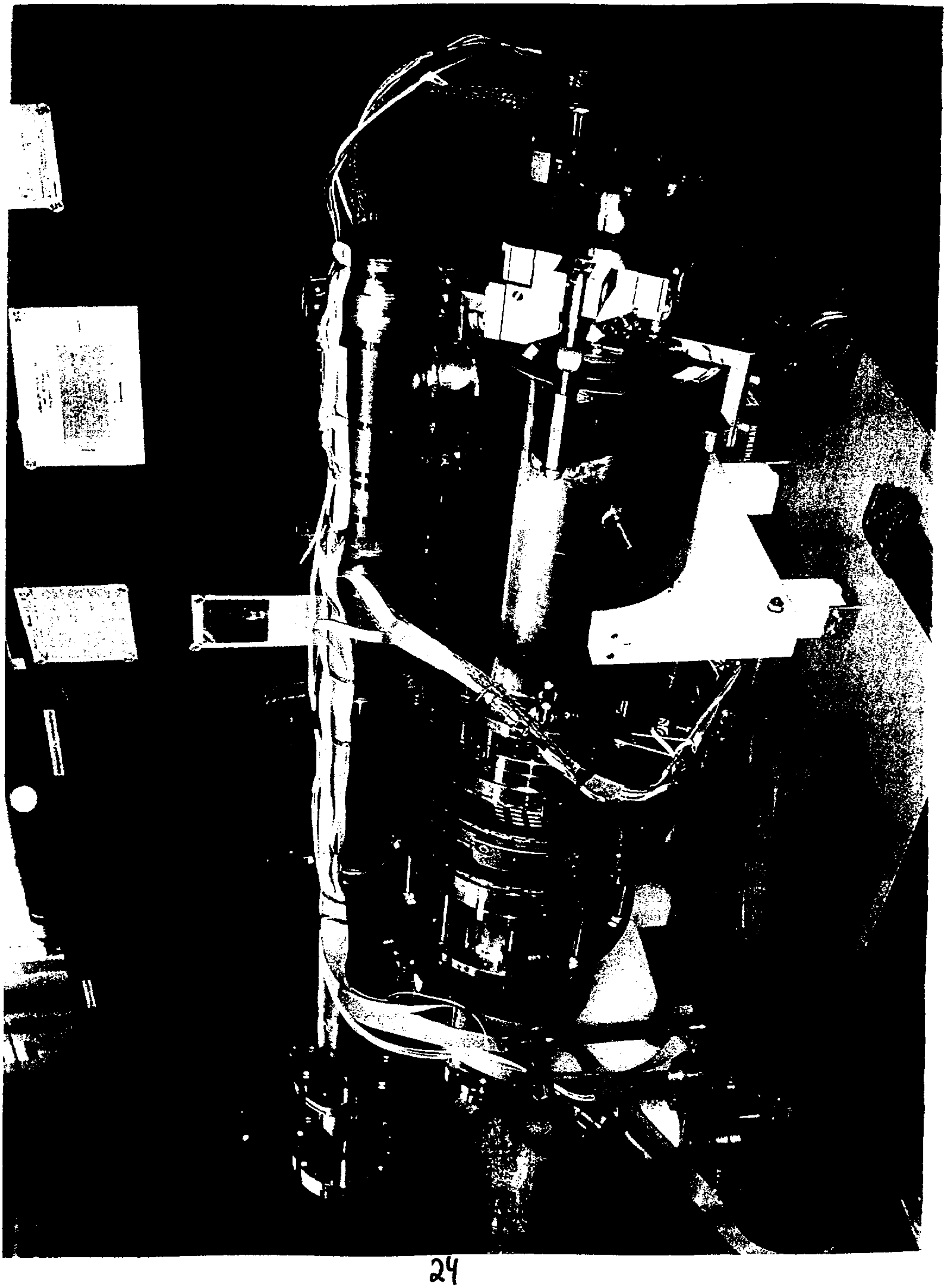
"Cold test of new tuner"


Motor_test3.vi
File Edit Operate Project Windows Help
TTF
800000
-100000
100.00
20.00
1301.0000
1298.0000
0.00
auto
-0.75
6.00E+5
Start-Frequenz muss am NWA eingestellt sein.


Motor_test3.vi
File Edit Operate Project Windows Help
auto
-0.75
6.00E+5
Start-Frequenz muss im NWA eingestellt sein.
800000
-100000
100.00
20.00
1301.0000
1299.0000
0.00


File Edit Operate Project Windows Help
TTF
auto
Start-Frequenz muss am NWA eingestellt sein.





Status:22–Feb–01 Albrecht/Lange –MKS1–

Tests of Cold Tuners for Supersructure Cavities.

Where/how do we test superstructure tuners?
–On old 9–cell cavity with He–vessel
Modifications for He–vessel necessary(bellow, flanges, bolts..)
To fix the cavity length installation of standard tuner necessary!(instead of clamps)
–At 300K in our workshop before and after CHECHIA tests.
(fr, alignment, survey , motor/gear..)
–In CHECHIA at 300K, 4K and 2K and again at 300K.

What do we test in CHECHIA? Using Video/NWA/Computer

–300K	fr= f(Cav–pressure, He–vessel–pressure..)
–Cool Down	fr= f(T, He–P)
–4K	fr= f(motor–steps)
–2K	fr= f(motor–steps)
–300K	fr= f(Cav–Pressure, He–Pressure)

How many superstructure tuners have been/will be tested?
–1 prototype in Feb–02 (expensive version)
–1 superstructure tuner (modified, final version)
==>All 4 superstructure tuner will have a cold test in CHECHIA.
Second superstructure tuner already prepared for CHECHIA test.

Some results and comparisions

	Super–Tuner	Standard–Tuner
Tuning range max . Length	1.1 mm	1.9 mm
Tuning range max. Frequency	430 kHz	820 kHz
Tuning motor–steps/Hz	0.38–0.42	0.74
Delta f(warm/cold)=fr(300K)–fr(2K)	2000kHz	2000kHz
Delta f(4.3K/2K=fr(4.3K)–fr(2K)	70kHz	30kHz
Adjust Cav. 300K to get fr equ. 2K	<1.3Ghz	>1.3Ghz
Tuning at 2K means	Length>	Length<
Tuning at 2K means	fr>	fr<

Comparision Superstructure–Tuner/Standard–Tuner stiffness difficult, for both are installed.

Conclusion:
Test results show, the superstructure –tuner is able to tune superstrukturs at 2K.
Important :Correct adjustment at 300K is necessary.

Summary of RF Warm Measurements

J. Sekutowicz

DESY, February 25, 2002

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Colleagues involved in the presented work:

R. Bandelmann, T. Büttner, J. Iversen, D. Kostin,
G. Kreps, W.-D. Möller, H.-B. Peters, S. Zheng

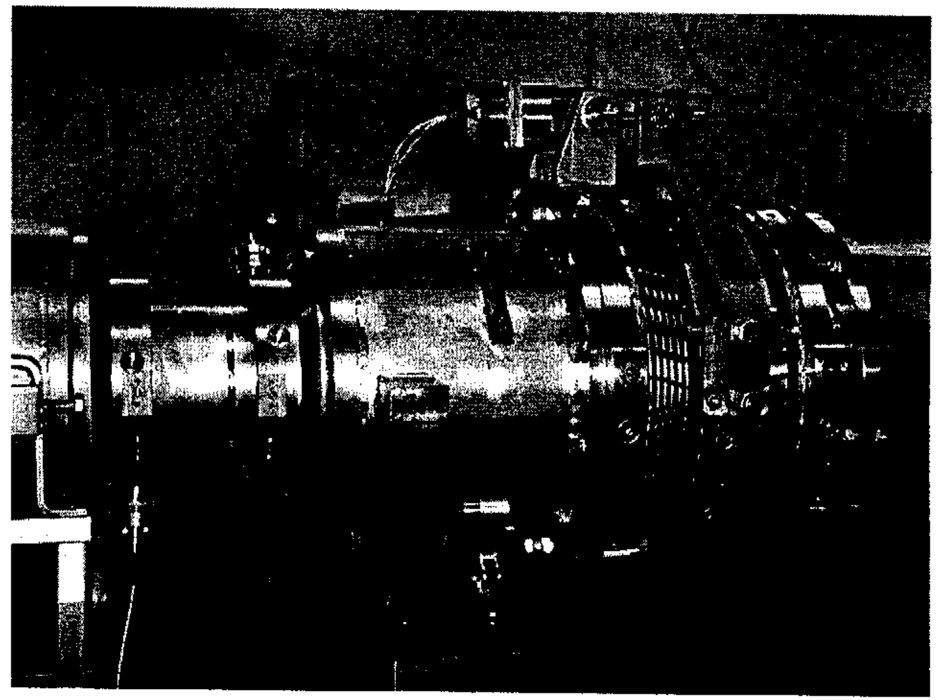
1. *FM passband and FM Couplers*
2. *Tuning of the FM rejection filter of HOM couplers*
3. *HOM measurements*

TESLA 2002-04

Two Nb prototypes of 2x7-cell superstructure have been built:

SST_I made of subunits **7Z1** and **7Z5**

SST_II made of subunits **7Z6** and **7Z3**



All **4 subunits had been tested** in the vertical cryostat before they were sent to ZANON for final welding.

All have reached **Eacc** of **18 MV/m**, limitation was still in the superconducting gaskets, placed 90 mm apart from the end-cell.

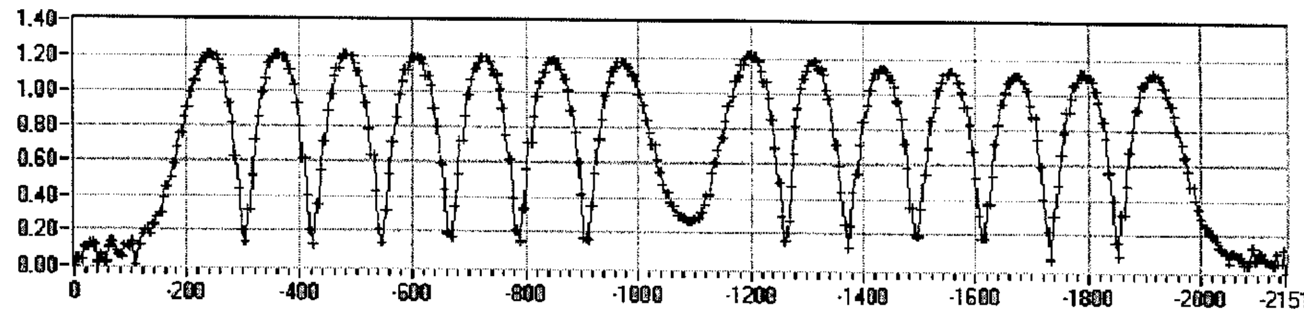
1 *FM passband and FM Couplers*

Field flatness of both superstructures, after the final welding, is still **better than 90 %**, in spite of milling, transportation and welding, performed on subunits equipped with LHe-vessels (no access to cells for tuning even if it is necessary):

28

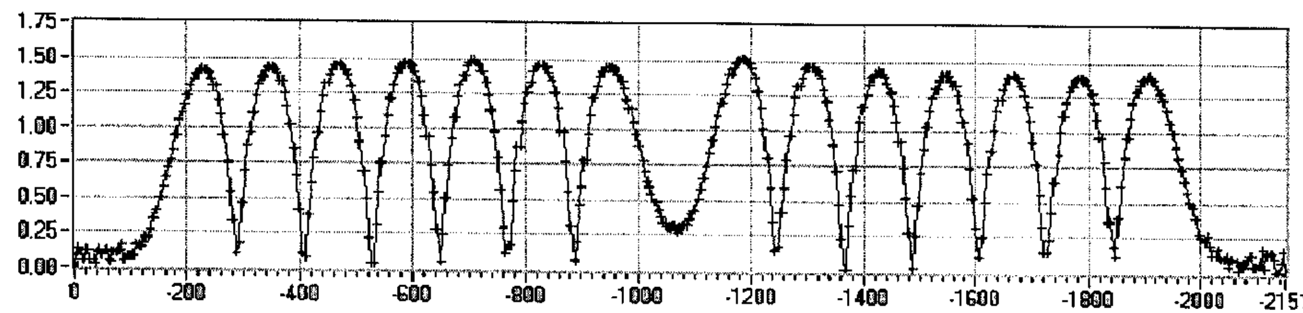
SST_I

Expected ff = 91 % when cold



SST_II

Expected ff = 93 % when cold



Conclusions here:

+ we can pre-tune cavities providing field flatness (ff) of 99 %

+ we can weld LHe vessel keeping ff better than 98 %

- final BCP must be less than 20-25 μm to keep ff better than 95 %, the removal rate of the chemical treatment seems to be difficult to control,

+ we can achieve much better field flatness when sequence of preparation steps will be similar to the sequence used for 9-cell structures.

FM couplers

Expected operation at gradients in the range of :

2 MV/m (HOM experiment) up to 18 MV/m (energy gain measurements)

and the beam current I_b=4 mA define the range of Qext:

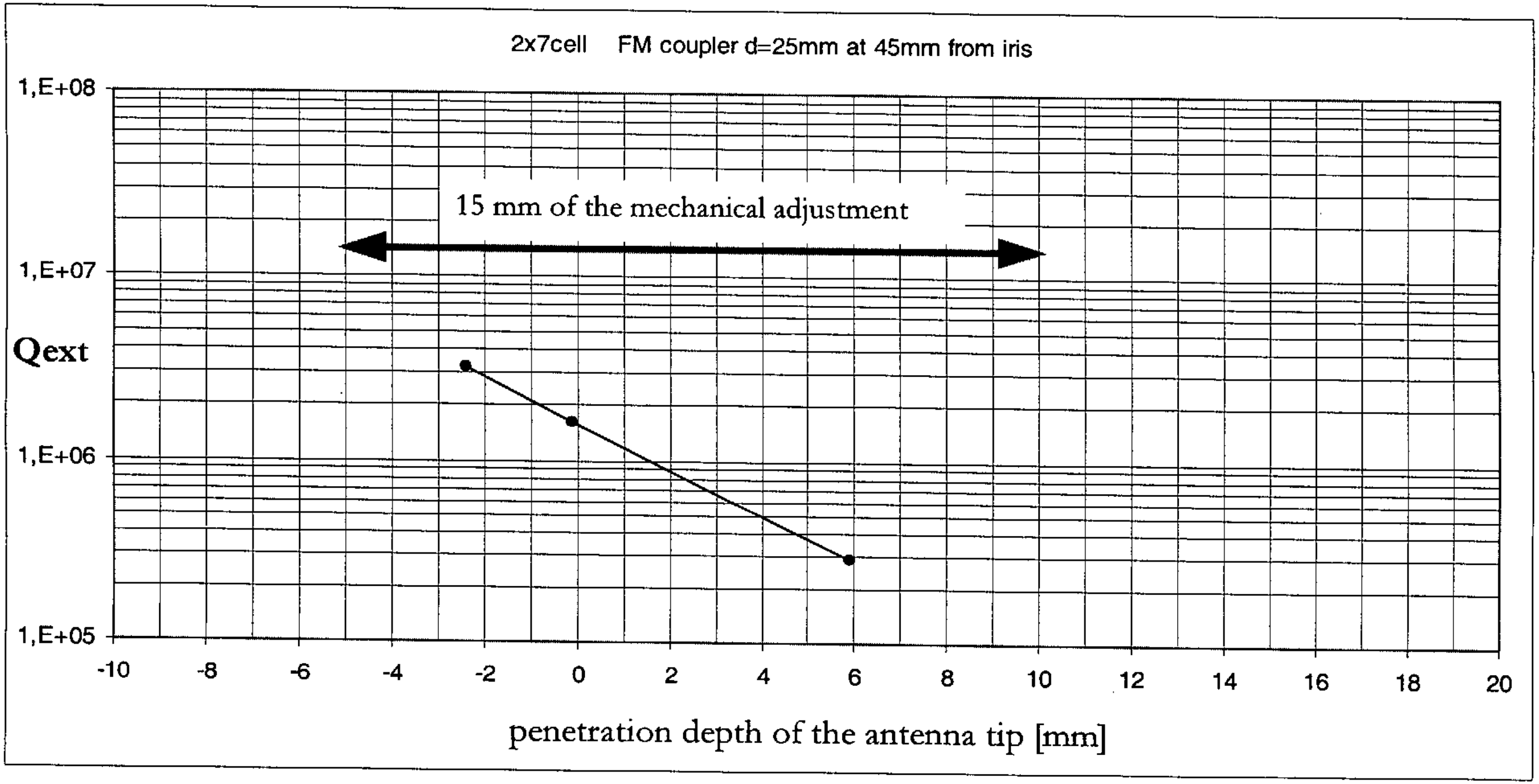
30

Table 1. Range of Qext for the superstructure experiment

No.	*Beam parameters : q , f_{rep}*	*2 MV/m*	*18 MV/m*
1	4 nC 1 MHz	**5.5 10^5**	**5 10^6**
2	74 pC 54 MHz	**5.5 10^5**	**5 10^6**

SST parameters : active length L=*1.614 m*, R/Q=*1457 Ω*

Qext of FM coupler vs. penetration depth measured on SST_I



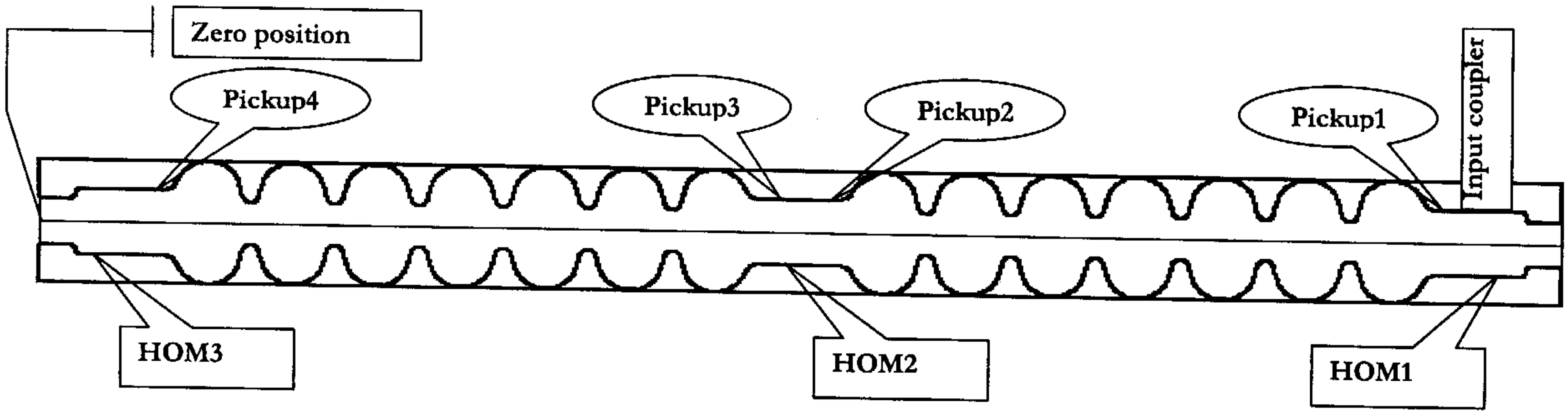
The whole required range of Qext is covered by the mechanical adjustment of the penetration depth and, in addition, we will have a 3-stub tuner at the front of input coupler.

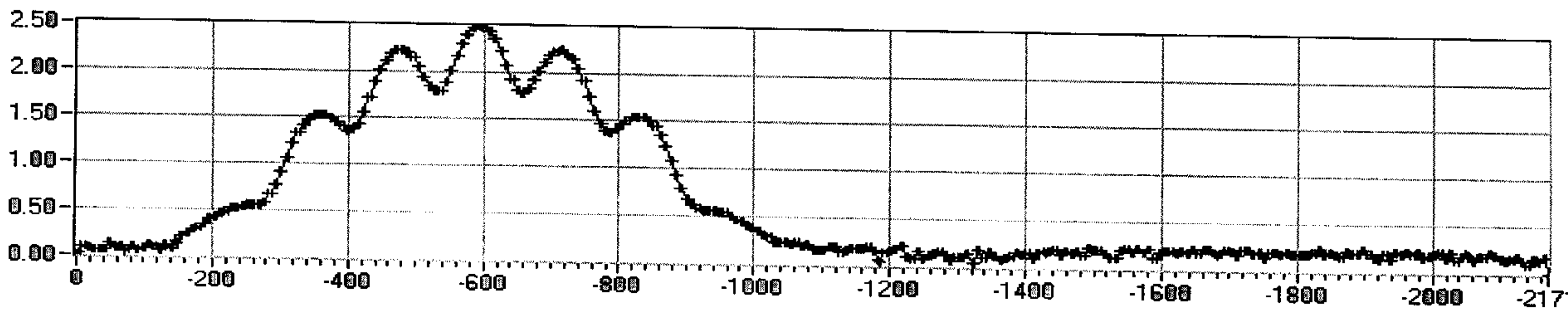
Other modes from FM passband; frequencies and Q's

Table 2. Qext of all modes from the FM passband

	SST_I		*SST_II*	
Mode No.	*f [MHz]*	*Qext coupler*	*f [MHz]*	*Qext*
1	1274.244	4.3E+06	1274.432	4.0E+06
2	1274.594	**9.6E+09**	1274.491	**4.5E+08**
3	1277.857	1.4E+06	1277.882	1.2E+06
4	1278.012	5.8E+07	1277.983	1.3E+07
5	1282.843	7.9E+05	1282.822	7.1E+05
6	1282.955	3.1E+06	1282.922	2.7E+06
7	1288.408	5.1E+05	1288.256	9.1E+05
8	1288.424	1.8E+06	1288.426	1.3E+06
9	1293.046	1.3E+06	1293.116	1.4E+06
10	1293.309	1.4E+06	1293.379	1.0E+06
11	1296.385	1.4E+06	1296.444	1.7E+06
12	1296.717	1.0E+06	1296.774	8.5E+05
13	**1297.595**	**2.8E+06**	**1297.649**	**2.6E+06**
14	1297.882	6.0E+06	1297.938	5.5E+06

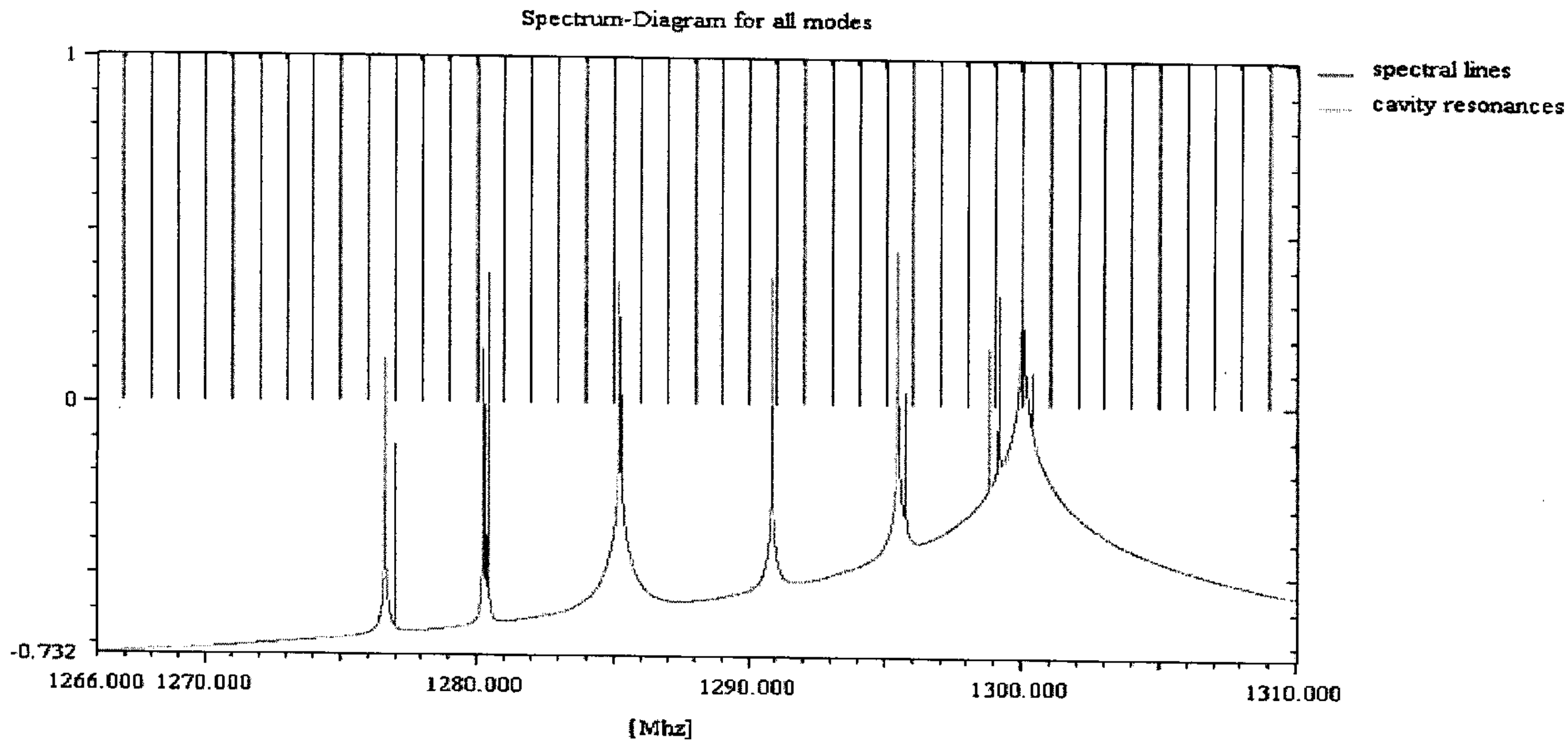
Mode No. 2 in both superstructures has big external Q of FM coupler because there is <u>no stored energy in the subunit next to the FM coupler</u>.





Mode 2 (R/Q)= 0.07 Ω

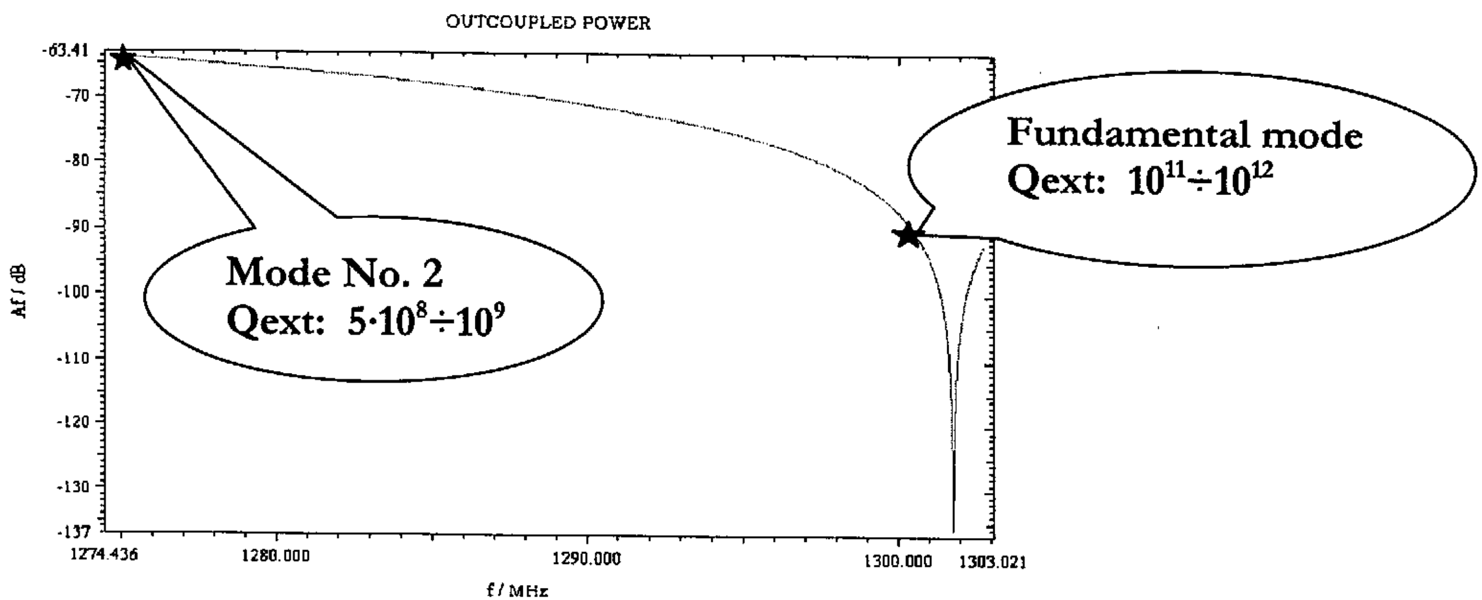
This situation was simulated with HOMDYN in 1998, and there was **<u>no influence on the beam</u>**, even half of the FM pass-band with **(R/Q)s near to zero and Qs about 10^9**, hits exactly spectral lines.



Mutual position of FM passband and spectral lines for the 1 MHz beam.

Is there any additional damping of these modes ?

The rejection filter of HOM coupler is adjusted to suppress 1300 MHz thus rejection of 1275 MHz is ~ 30 dB weaker !!!



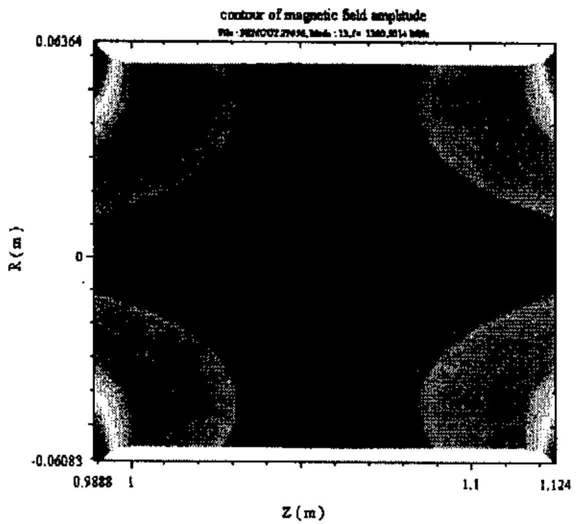
This will give some damping to Qext of the order of $5\cdot10^8 \div 10^9$.

We expect additional damping of this mode by the HOM couplers No 2 and No 3.

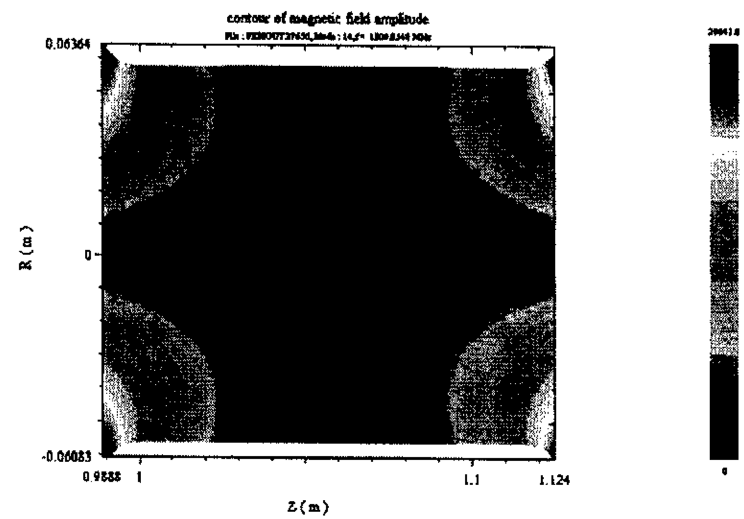
The expected Qext will be in the range of: few$\cdot10^8$

2. *Tuning of the FM rejection filter of HOM couplers*

- Adjustment of filters of the HOM coupler No. 1 and No. 3 which are attached to the end beam tubes is similar to the adjustment of filters for TTF cavities.
- Situation is different for the HOM coupler 2, which is attached to the interconnection. In the interconnecting tube, 0-modes (both subunits in phase) have different field pattern from π-modes (both subunits in contra phase)



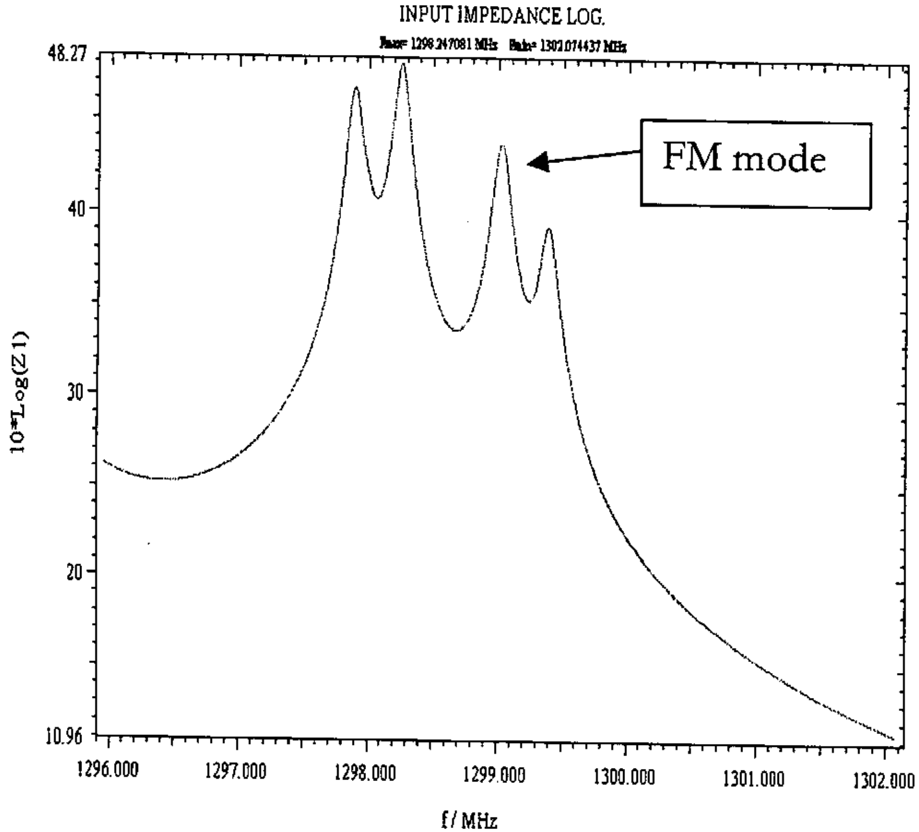
π-0 mode



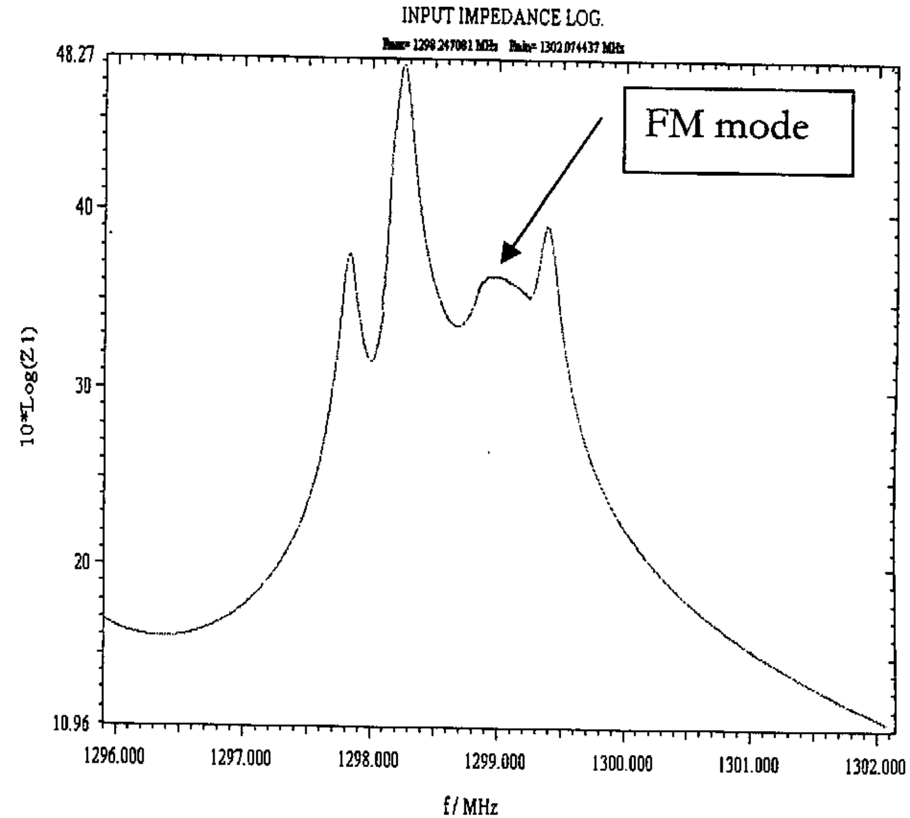
π-π mode

magnetic field in the interconnection

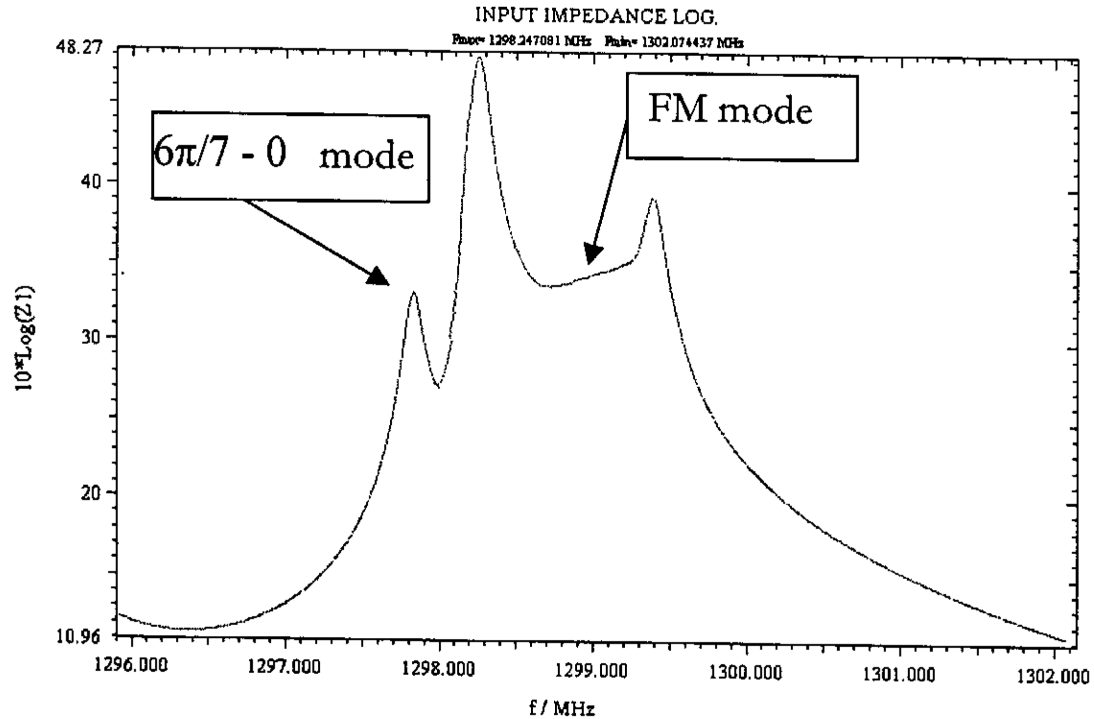
Strong overlapping of modes due to low quality factor of warm Nb makes difficult direct optimising of the rejection filter for the suppressing of accelerating mode. The tuning procedure is shown stepwise below.



Transmission signal from the HOM coupler before suppressing of FM mode (2nd from the right).



Transmission signal from the HOM coupler when filter is partially tuned.



Signal from the HOM coupler when filter is further tuned. The FM mode is shadowed and can hardly be seen between two resonances. The most left peak, the $6\pi/7$ - 0 mode is still visible.

The method of tuning has been proposed by G. Kreps. The filter will be adjusted first for the $6\pi/7$ - 0 mode and then slightly detuned towards higher frequency.

Conclusion:

The method was never tested before and could not be verified since cold test of 2x7 cell structures is, with the present infrastructure at DESY, impossible.

Adjustment of 4 pick-ups

The 4 pick-ups in each SST are mechanically adjusted to have the same penetration depth. We would like to keep Qext of all in the range of $2\ 10^{11}$.

Table 4. Pick-up transmission for FM pass-band: SST_I

Mode	Pickup 1 [dB]	Pickup 2 [dB]	Pickup 3 [dB]	Pickup 4 [dB]
π-7/7 π	-34,0	-30,6	-32,5	-40,0
0-7/7 π	-31,0	-31,2	-32,7	-32,2
π-6/7 π	-22,8	-24,2	-26,2	-24,8
0-6/7 π	-25,3	-25,3	-25,8	-25,7
π-5/7 π	-23,9	-24,3	-25,4	-24,7
0-5/7 π	-23,3	-23,2	-25,0	-24,6
π-4/7 π	-26,1	-26,4	-26,5	-26,1
0-4/7 π	-21,4	-21,4	-26,2	-26,0
π-3/7 π	-31,3	-31,6	-33,3	-32,7
0-3/7 π	-25,4	-25,2	-33,2	-32,9
π-2/7 π	overlapping	overlapping	-48,7	-48,6
0-2/7 π	-31,2	-31,1	-48,5	-48,7
π-1/7 π	-	-	-	-
0-1/7 π	-41,6	-42,0	<-80	<-80

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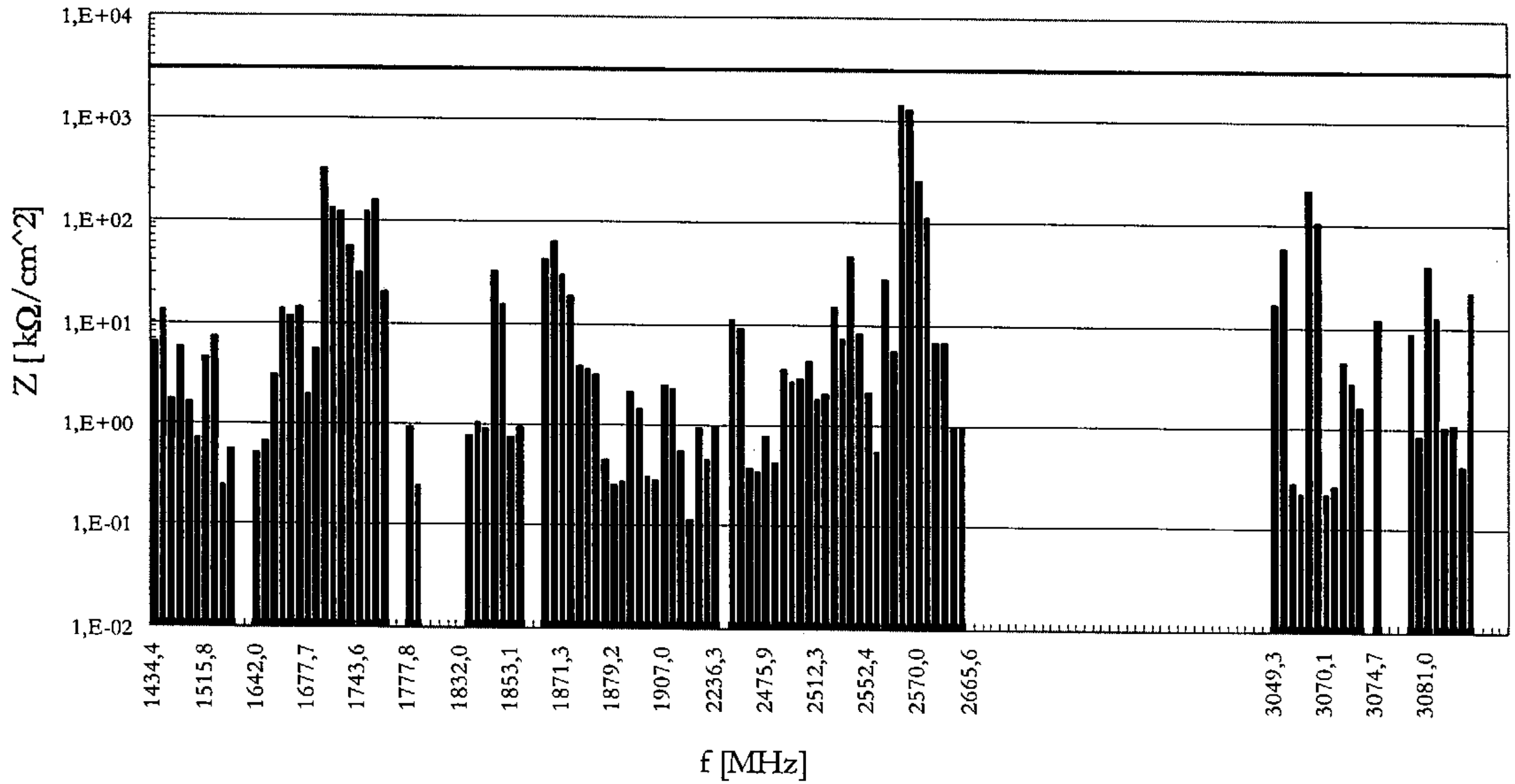
3. *HOM measurements*

122 dipole modes of the warm SST1 have been measured. All modes are damped sufficiently below the BBU limit (solid line). The most dangerous modes are listed in Table 3.

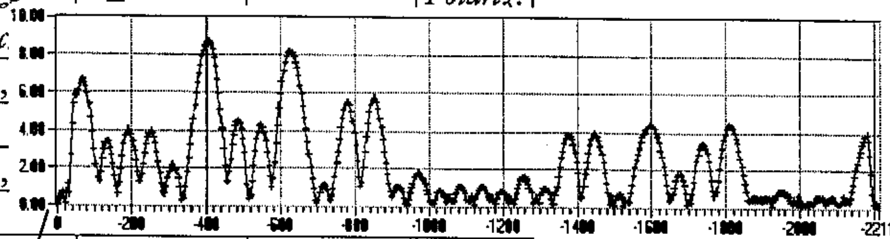


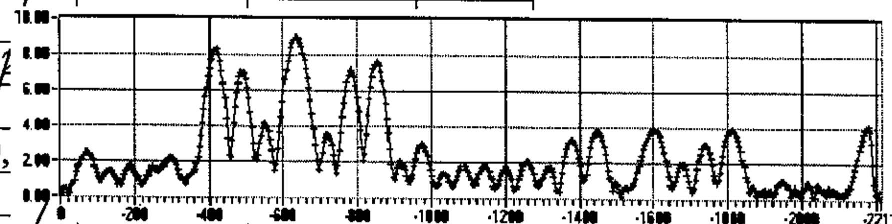
Longitudinal impedance of dipole modes. The red line shows BBU limit: $Z_{max}=(R/Q)_{max}10^5$ (computation done by Nicoleta).

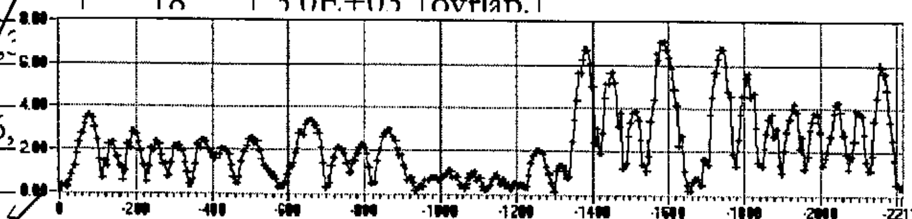
40

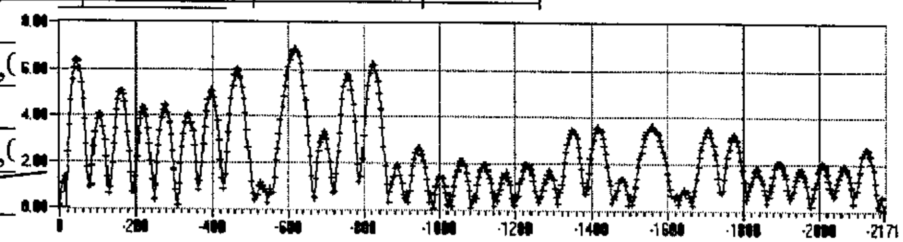
Table. 4 Most dangerous dipole modes of SST1

F *[MHz]*	*R/Q* *[Ω/c*	*Z*		*Polariz.*
1708,113	17,			
1709,778				
1712,771	13,			
1714,451				
1748,715	12,1	156	1,3E+04	60
1750,547				
1848,868	5,[illegible]			
1849,470				
1865,490	10,			
1866,220				
1871,330	6,1	29	4,8E+03	ovrlap.
1872,534		18	3,0E+03	ovrlap.
1906,968	2,[illegible]			
1921,455				
2568,736	26,			
2569,000				
2643,646	4,[illegible]			
2646,035		[illegible]	[illegible]	[illegible]
3079,063	1,[illegible]			
3079,[illegible]96				
3081,[illegible]47	2,[illegible]			
3082,[illegible]03				









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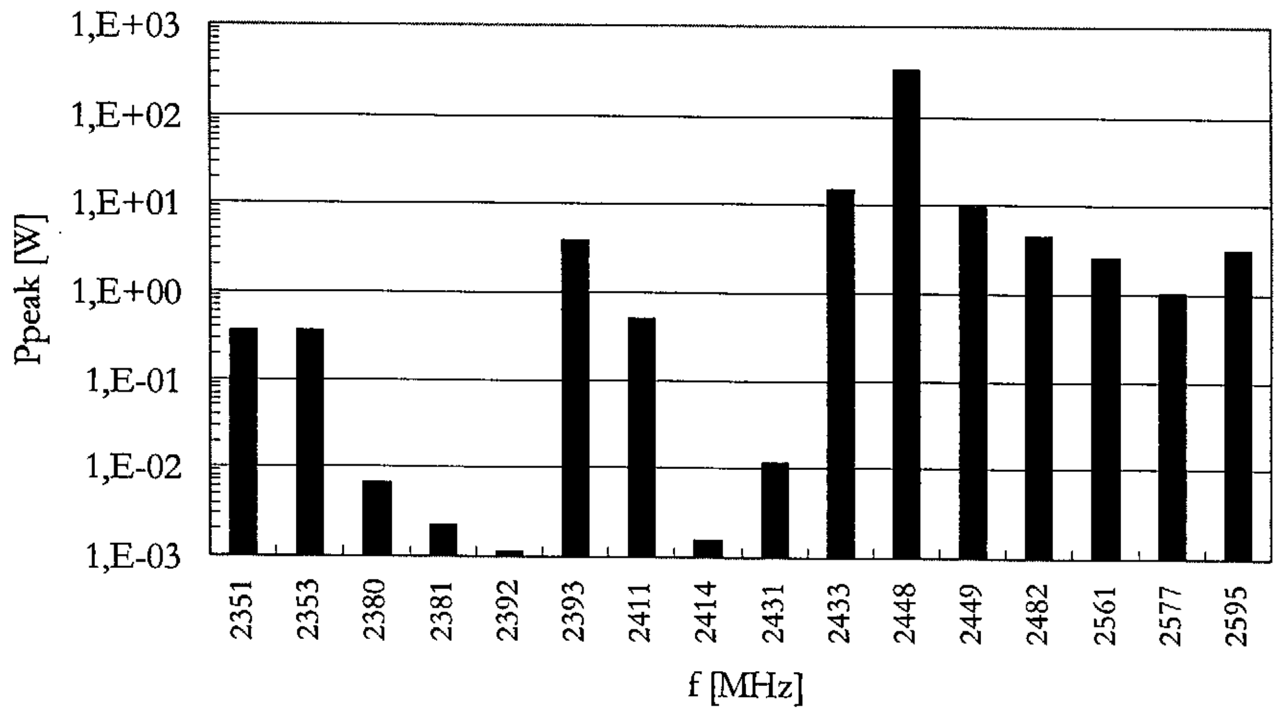
We must note here that accurate measurements of dipole modes are very difficult since many of modes overlap for warm Nb cavities. The measurements become more and more difficult when frequency increases. The overlapping also makes measurements of polarisation very difficult.

18 monopole modes



Power of monopole modes at resonant excitation.

The damping is sufficient and total power stays below power capability of the output line of HOM couplers.

Final Remarks

Test of the final tuner position

SST_I

We have tuned SST1 to 1297.72 MHz, the frequency which after:

final 6 μm BCP	(Δf =-0.060 MHz)
evacuation	(Δf = 0.390 MHz)
cool-down	(Δf = 1.950 MHz)

should lead to the operation frequency of 1300.000 MHz.

+ At this position sub-unit 7Z5 was pulled by the tuner by about 0.5 mm, exactly as required.

- sub-unit 7Z1 was at force-free position and the tuner was at position with maximum hysteresis
  To avoid backlash we will make more final BCP, about 15 μm instead of 5 μm, to lower the frequency of the 7Z1.

SST_II

The same situation is expected for the SST_II because the sub-unit 7Z6 had less BCP treatment than 7Z3. Also here additional 10-15 m BCP will help us to avoid backlash of the tuner.

Summary

- Both superstructures have reasonable field flatness, better than 91 %
- Qext FM coupler can be reached in the whole required range
- Damping of HOMs in SST_I is good (140 modes have been measured)
- HOM measurements in SST_II in progress, should be ready next week
- Polarization measurements are difficult due to overlapping of modes
- Tuning of the rejection filter of the HOM coupler attached to the interconnection must be done very carefully. Unfortunately the result of tuning procedure will be known first after cool down in the TTF linac.
- Slightly more final BCP treatment is needed for the subunits 7Z1 and 7Z6, to avoid backlash of tuners

J. Sekutowicz

"Preliminary program of the cold test, what do we like to measure ?"

Preliminary program of the cold test, what do we like to measure ?

J. Sekutowicz

DESY, February 25, 2002

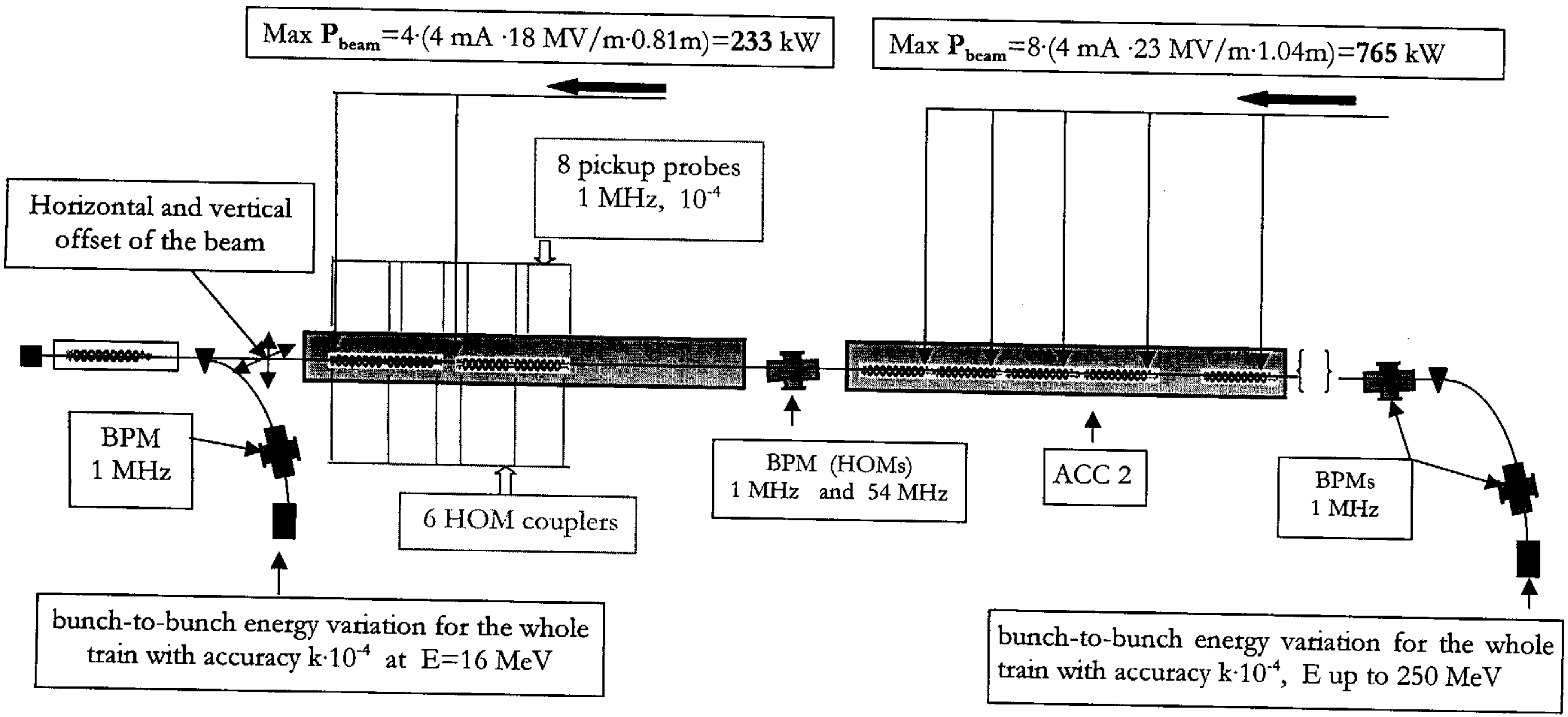
Colleagues involved in the presented topics:

P. Castro, M. Ferrario, A. Gössel, M. Huening, M. Liepe, H. Schlarb, S. Simrock, S. Schreiber, K. Rehlich, M. Wendt.

We will have 3 types of measurements. For all measurements SST must be cooled down

- • RF-measurements
- •• FM measurements with beam
- ••• Interaction between beam and HOMs

The test cryomodule will be placed at ACC1 position. Cryomodule 1 will be installed at ACC2 for the high gradient test.*



Whole re-arrangement of the TTF linac will be coordinated by:
P. Castro/S. Schreiber

- <u>RF-measurements without beam (*group a*)</u>

  - spectrum of the fundamental mode passband
  - spectrum of HOMs and damping
  - test of two methods proposed to balance field
  - sensitivity of the field profile vs. frequency of each sub-unit
  - maximum E_{acc} : is the limitation in cavities or in HOM couplers ?

Table 1. Group *a*: List of data to be measured for each superstructure

No.	Measurement	List of data to be measured	apparatus	accuracy
1	spectrum of the fundamental mode passband	Frequencies, Qext of 14 modes 4 Pick ups signals	NA	
2	spectrum of HOMs and Qext	Frequencies and Qs 120 dipole modes: 1^{st}, 2^{nd}, 3^{rd} and 5^{th} passband TM011 monopole passband Signals from HOM couplers	NA	
3	test of two methods proposed to balance field	Signals of 4 pick-ups for FM, Number of steps of stepping motors, Signals of 4 pick-ups for other 13 modes	NA, PM ? NA, PM	
4	sensitivity of the field profile vs. frequency of each sub-unit	Number of steps of stepping motors Signals of 4 pick-ups for FM		
5	Maximum E_{accc}:	Signals of 4 pick-ups for FM Incident power in FM coupler Signals from HOM couplers for FM Signals of Temperature sensors (V and I)	PM V-meter	

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This group of measurements is a replacement for the cold test in Chechia or in Cryomodule Test Stand.

It will be the first check at 2 K:

- of fully equipped 4 subunits with tuners after the final cleaning and the final assembly
  we will have all components tested individually before the assembly(cavities, tuners, FM couplers…), but there will not be a Chechia-like test !!!!!
- of the rejection filter adjustment of the both HOM couplers placed at interconnections
  the proposed adjustment method has never been verified
- if there are cold leaks in subunits, couplers and beam line….

The modification of the infrastructure built for the 9-cell cavities was minor. This made the project less expensive and less time consuming but there is a risk.

The RF-group of measurements will be coordinated by:
S. Simrock/M. Liepe/G. Kreps/JS

- **FM measurements with beam = re-filling process of stored energy in cells (*group b*)**
  - End-cells signals vs. time
  - Energy variation within one train (expected variation $< 5 \cdot 10^{-5}$)

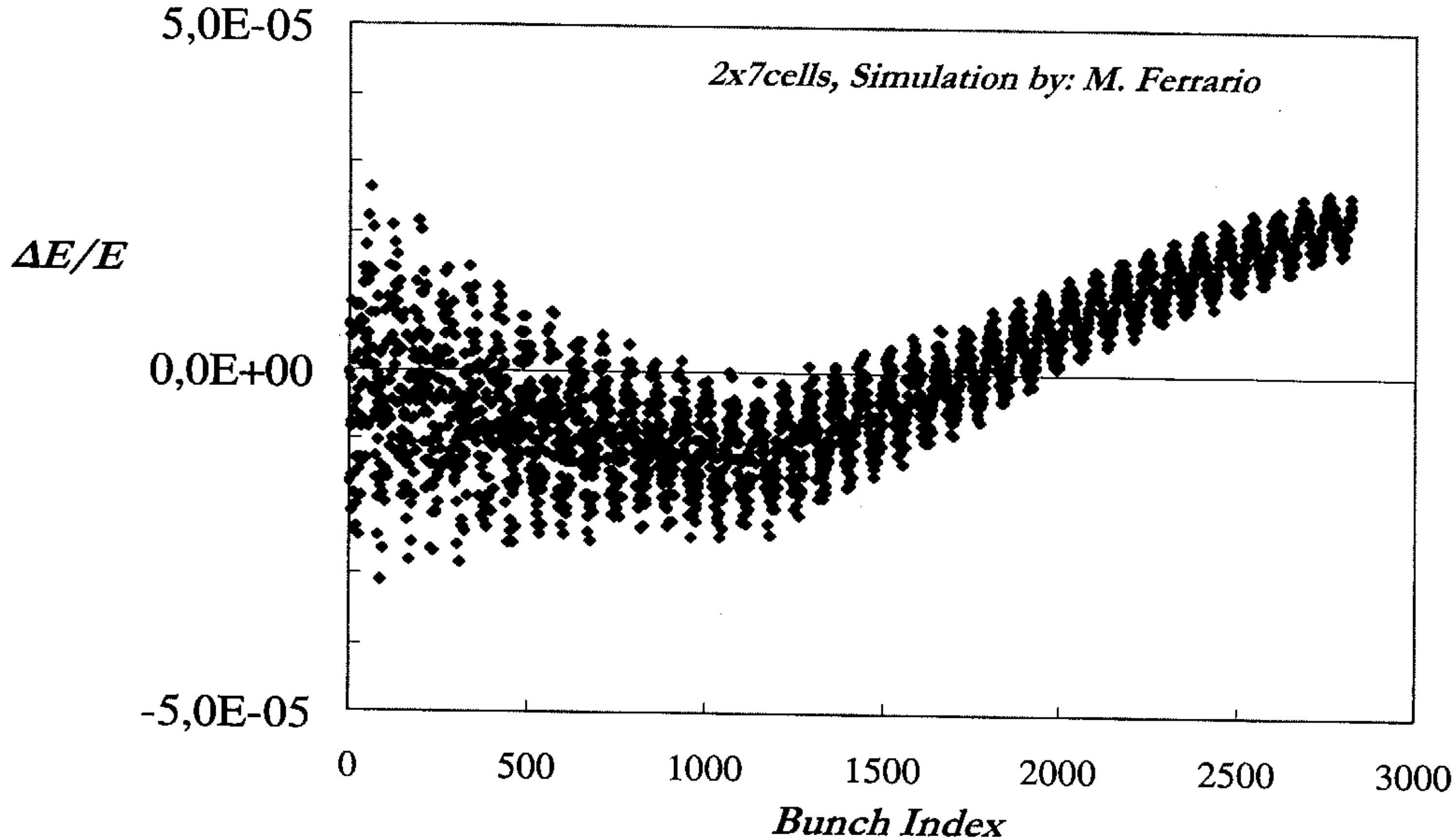

Figure shows whole the "new" TESLA train. It is similar for the "old" TESLA train of 800 bunches

Indirect measurements of the re-filling process (all signals normalized):

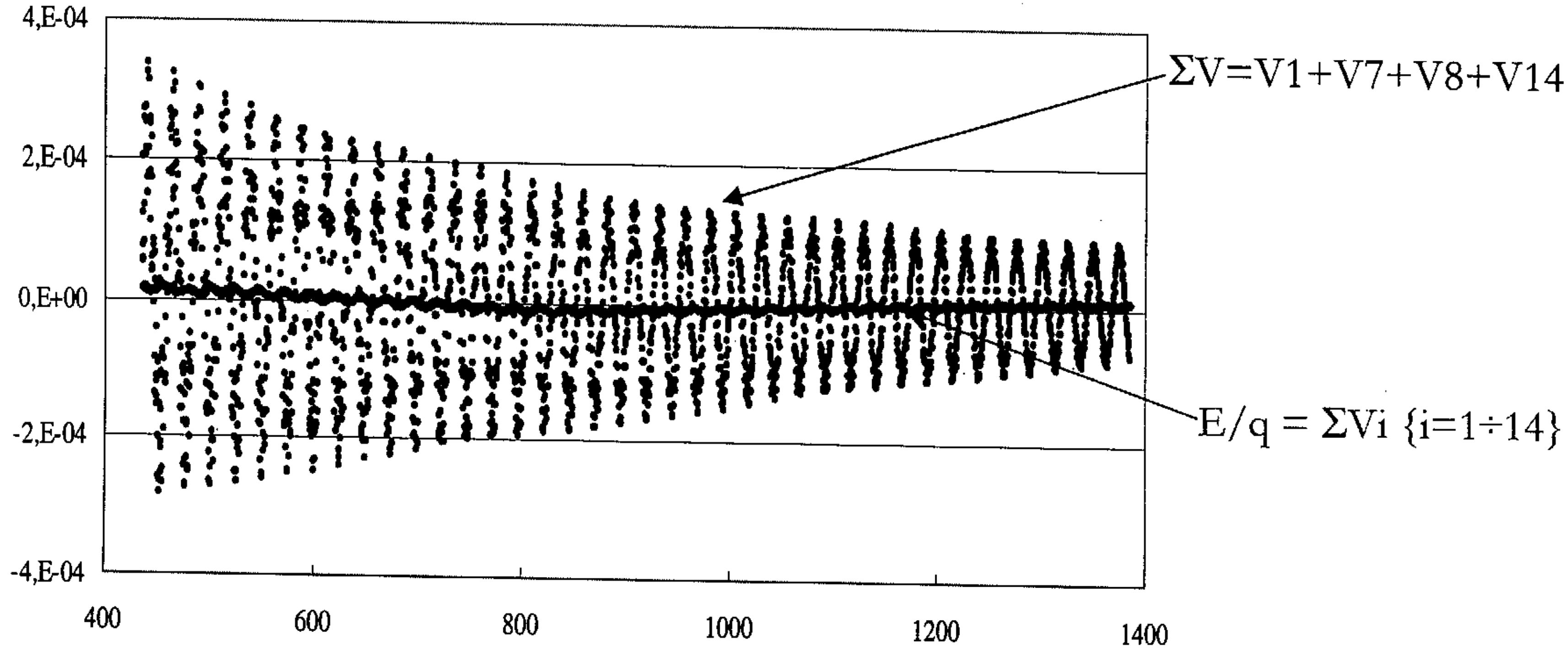

Figure displays end-cells signals (pickups) vs. time
in 2x7-cell SST with an ideal beam loading compensation

This method was never tested before. The big advantage is that presence of other accelerating structures in the linac is of "no meaning"

Energy variation within one train: direct measurements *(more information from Holger, Massimo and Sigi)*

For this test we would like to operate linac with 800 μs long pulses and with following beam parameters:

- 1 MHz bunch frequency
- nominal charge of 4 nC/bunch
- bunch length about 1mm

Presence of the second cryomodule at ACC2 makes this measurements more difficult (*study in progress, some modification of HOMDYN code needed, Massimo*)

Roughly (qualitatively):

- Energy variation for a 9-cell cavity is lower than in SST, when the beam loading compensation is ideal.
- The main reason for the energy variation is the mode beating in accelerating cavity

$8\pi/9$ modes in standard cavities will have different frequencies

and

$6\pi/7$ groups will have different frequencies for both superstructures

one may expect that energy variation for whole linac will be uncorrelated (?) $\rightarrow 1/\sqrt{n}$

(n number of cavities)

- To estimate energy variation we will perform two measurements:

    1. ACC2 will be operated at Eacc of ~ 2 MV/m and ACC1 at ~2 MV/m

and

    2. ACC2 will be operated at Eacc of ~ 2 MV/m and ACC1 at ~18 MV/m

(it will be easier to vary gradient of ACC1 because both 3-stub tuners will be for this cryomodule remote controlled)

Change in the measured energy variation at the end of TTF linac should give estimation for each cryomodule.

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But:

<u>we need to know how good is the control of amplitude and phase for different gradients ? *(Stefan's talk)*</u>

Both measurements: direct and indirect will be done in parallel

Table 2. Group *b* of measurements: List of data to be measured for each superstructure

No.	Measurement	List of data to be measured/additional information	apparatus	accuracy
1	***Indirect*** End-cells signals vs. time for the whole train of bunches	**Signals of 4 pick-ups, 1 MHz,** status of 3-stub phase shifters, status of tuners (position, steps …) Eacc, P_{inc}, Qext, HOMs signals (TM011) mode.	ADCs	~10-4
2	***Direct*** Energy variation within one train	**Energy measurements at the injector region:** Signals from BPMs for the whole train of 800 bunches **Energy measurements at the end of TTF linac:** Signals from BPMs for the whole train of 800 bunches **Both SSTs: HOMs signals of TM011 modes** **Status of ACC2:** Eacc ,Qext, Pin of 8 cavities, signals of 8 pickups, HOMs signals (TM011) mode **Beam quality:** q/per bunch and its stability within whole train bunch length ….	BPMs BPMs	~10-4 ~10-4

Coordinators:

The FM measurements with beam will be coordinated by:
H. Schlarb/ M. Ferrario/S. Simrock

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••• Interaction between the beam and HOMs (*group c*)

1. energy deposition in monopole modes
2. active excitation of HOMs up to 3.1 GHz with amplifier (50 W)
3. search for deflecting trapped modes (as proposed by S. Fartoukh and S. Simrock)

58 ad. 1. Energy deposition in monopole modes without modulation of charge will be done simultaneously with previous group *b*.

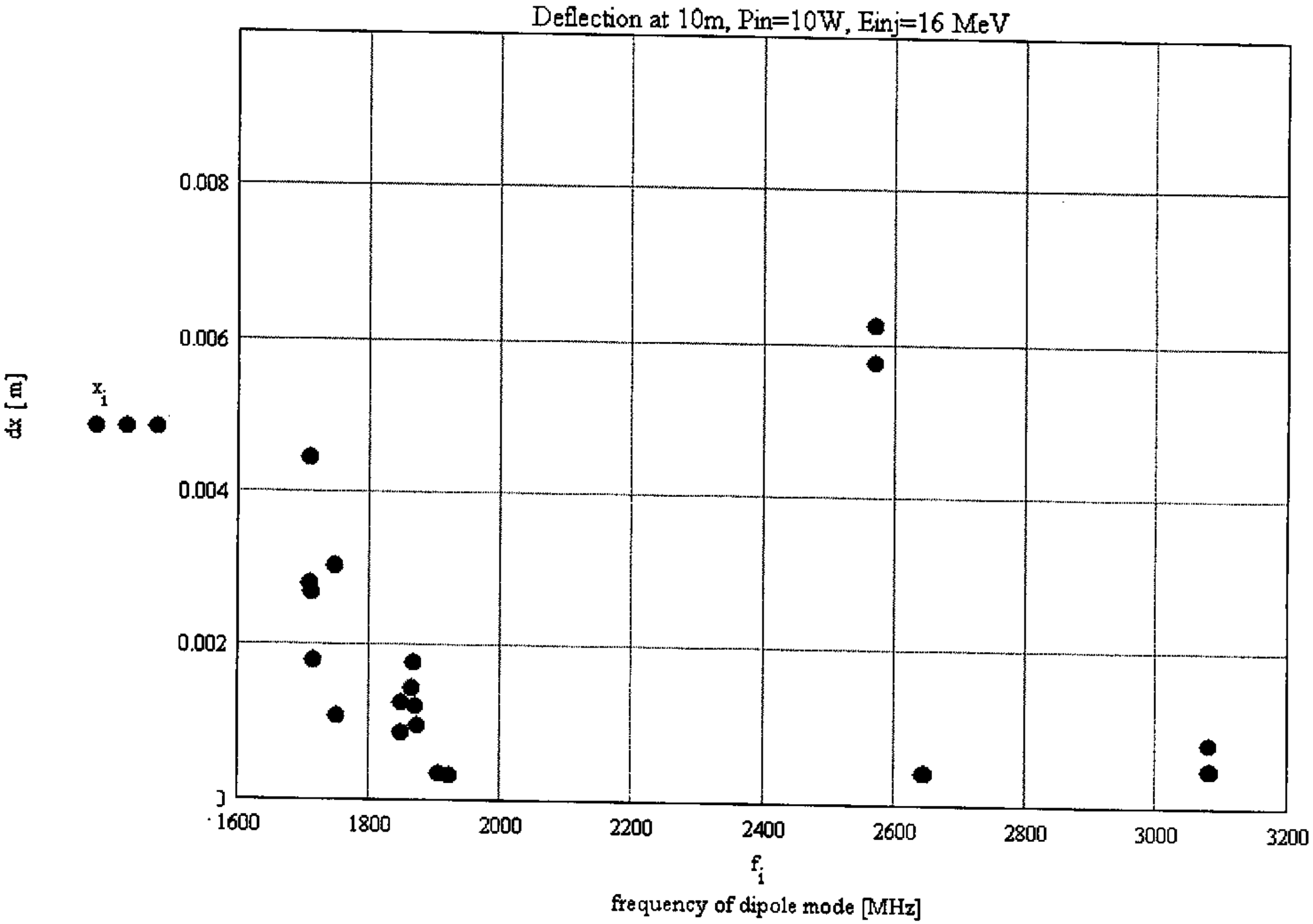
ad. 2. Active excitation of HOMs : What is the idea behind this measurements ?

With this measurements we can calibrate setup (BPMs) for the search of deflecting trapped modes.

The accelerated beam (1 MHz or 54 MHz) will be injected on axis.

HOMs will be excited via one of HOM couplers (phase lock possible when we use one of two others couplers)

An example: Pin= 10 W, Gradient in Superstructure 2 MV/m , Injection energy 16 MeV



Maximum radial position of the deflected beam ad. 3. Search for deflecting trapped modes *(group c)*

Beam parameters:	54 MHz bunch frequency + modulation of charge
Beam position:	10÷20 mm off axis (this time in both planes)
Gradient:	2 MV/m

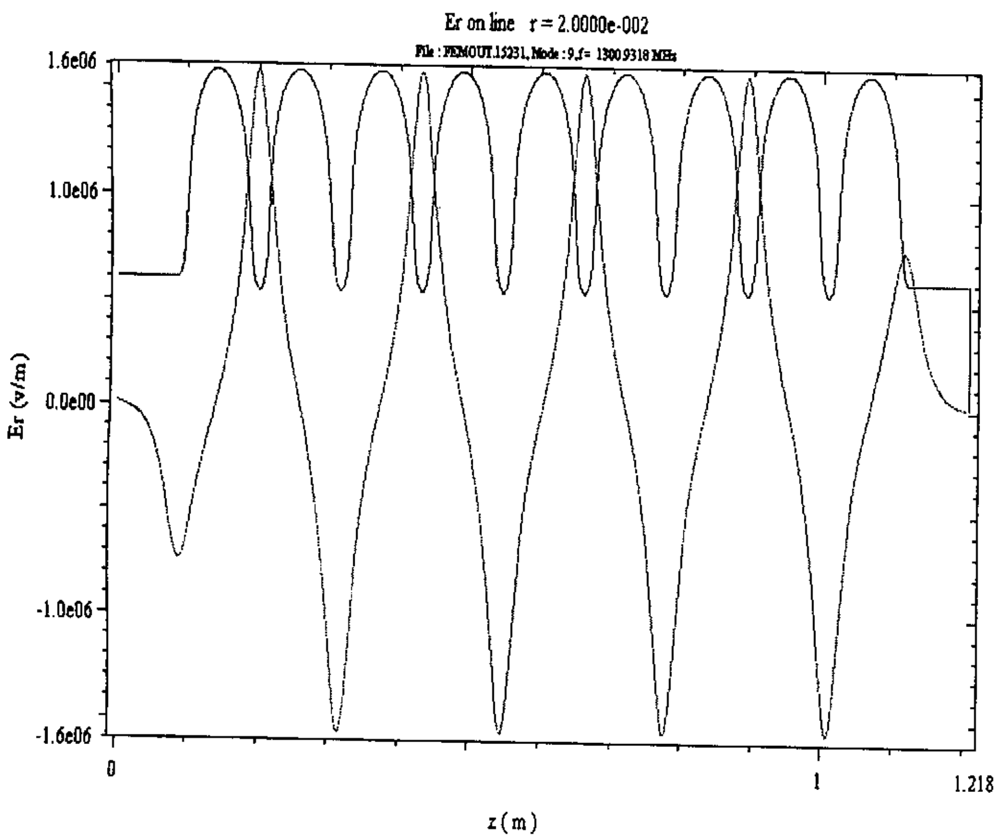
This test has been done already twice for standard TTF cavities.

In both runs some modes have been found with the same frequency (~2.58 GHz) in the whole tested cryomodule. No clear explanation up to now.

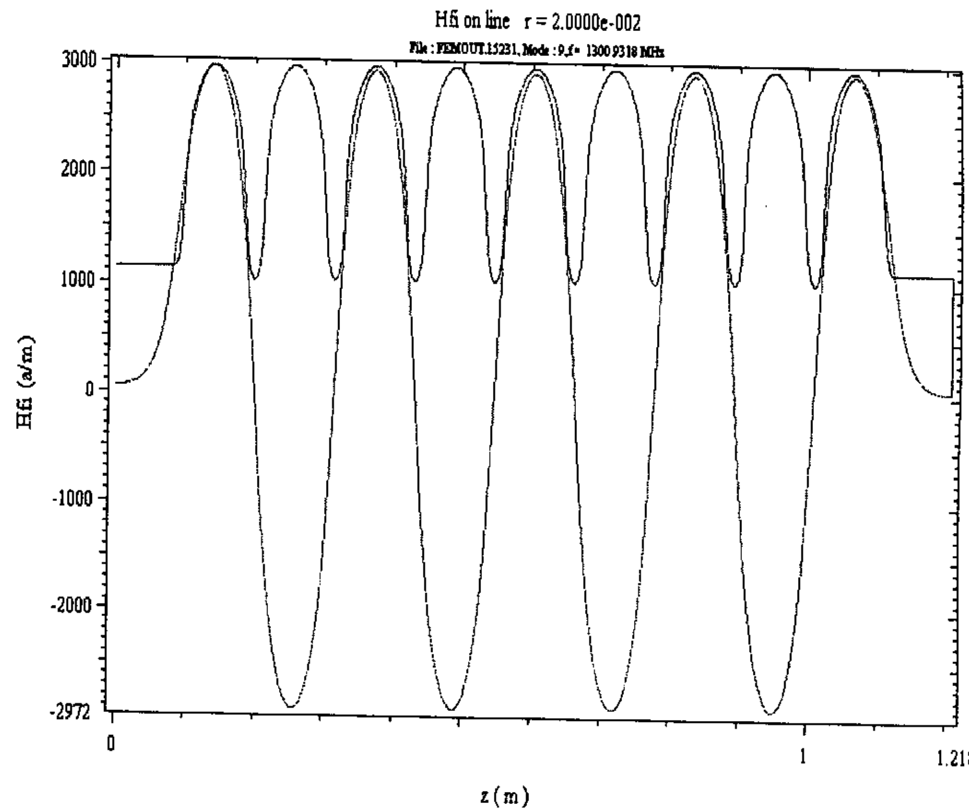
Is the following phenomenon a possible explanation ?

Bunches injected at 20 mm off axis in 9-cell structure are exposed to deflecting force which results from strong radial electric and angular magnetic field of the fundamental mode.

Example: Er(r=20mm) and Hφ (r=20mm) when 9-cell cavity is operated at 2.2 MV/m

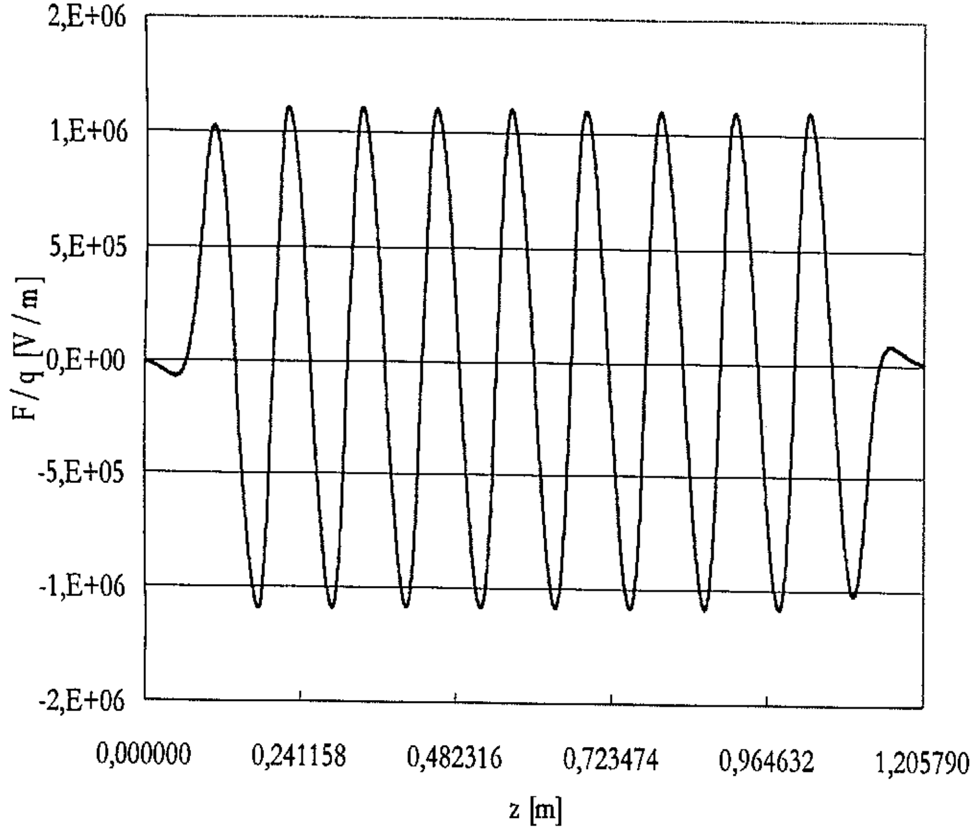


Er(r=20mm)

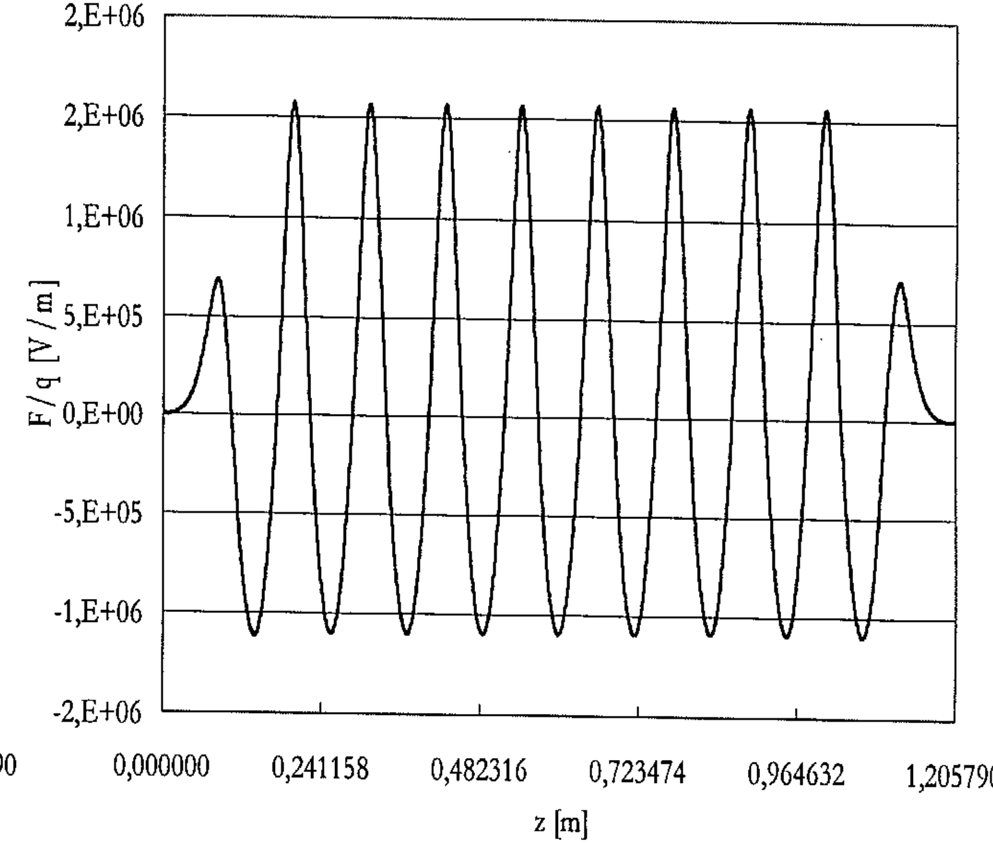


Hφ (r=20mm)

The deflecting force depends on the injection phase, but both components from the electric and the magnetic field add up.



Maximum energy gain (2.2 MeV)



Almost no energy gain (-0.1 MeV)

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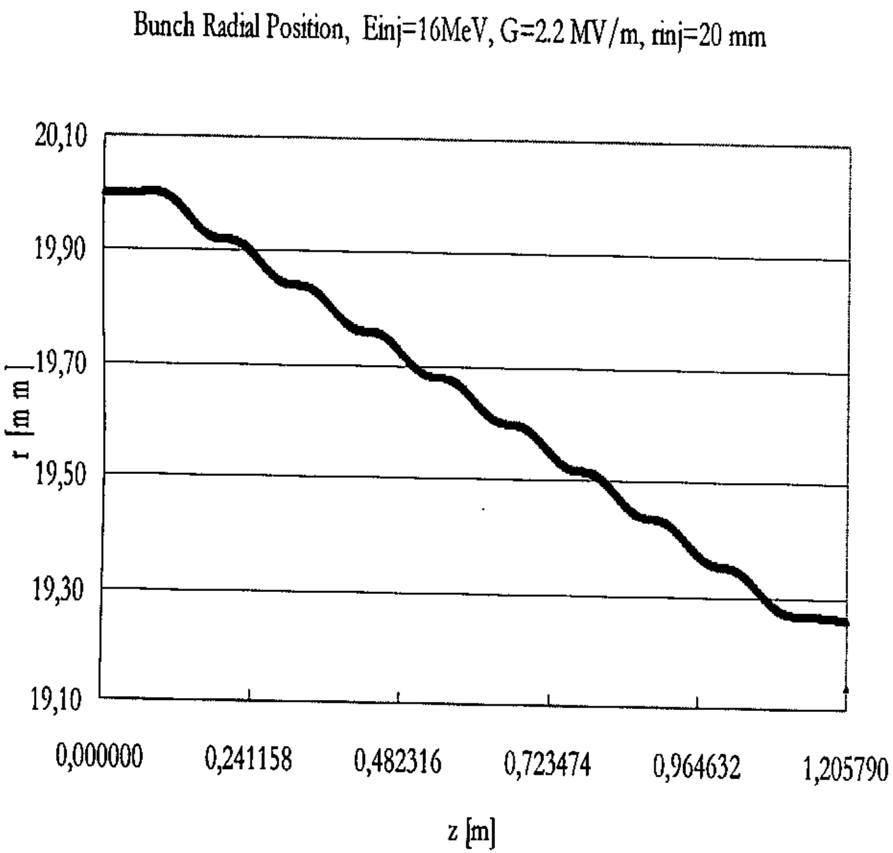
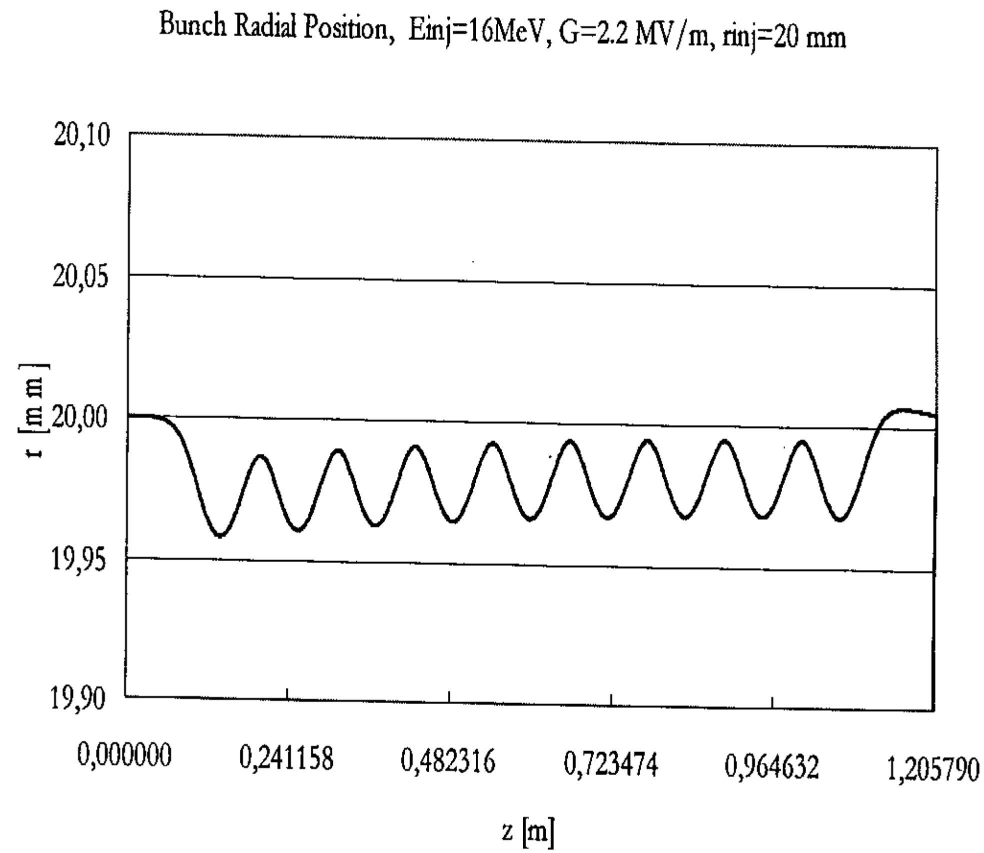
The radial position of bunches is as follows:



Energy gain: oscillation (60μm) +focusing



No energy gain : oscillation (30μm)

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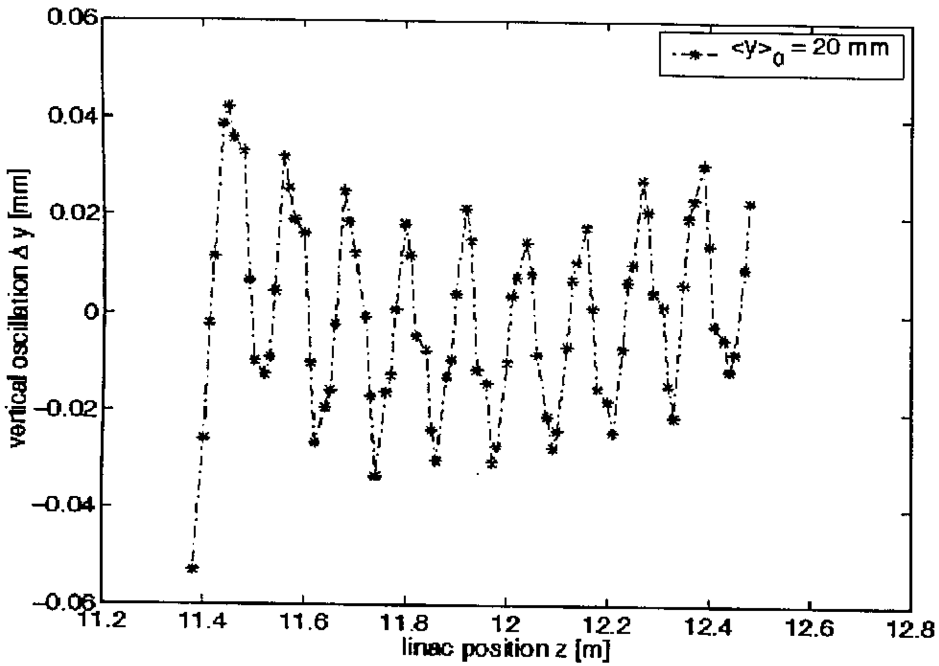
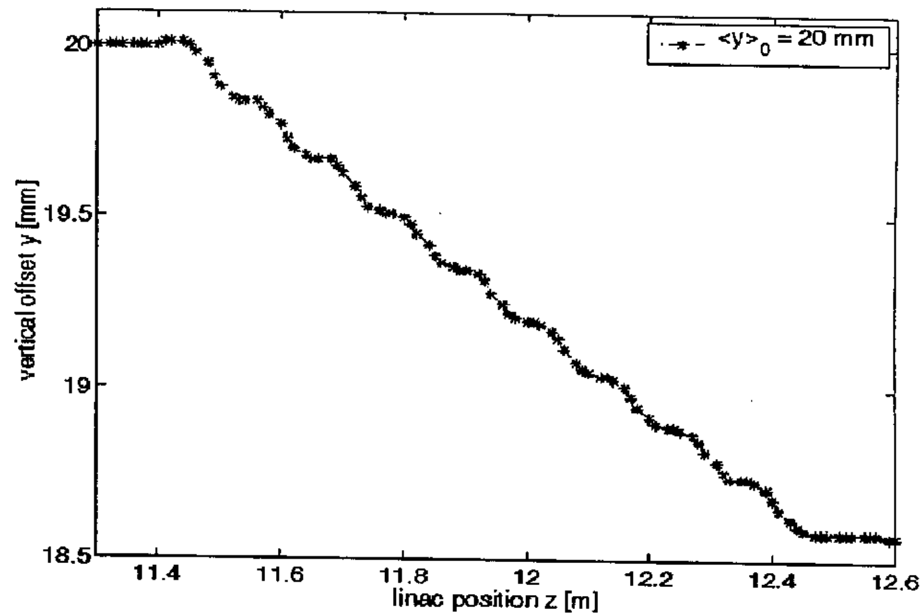
Similar result was computed by Holger[1] (code Astra).





Mean wave length of this oscillation corresponds to <u>f = 2586 MHz</u> !…?…!

Is this a reason why some modes almost at this frequency are present in all cavities ?
Is this a reason why some modes decay much faster than expected ?

If this is true: can we build special 3.9 GHz cavity (λ=35 mm) operate it at 25 MV/m to have an undulator ??

[1] **Thanks for the correction of my first wrong result**

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Conclusion: we should look closer to this phenomenon in the next HOMs measurements

Table 3. Group of measurements *c*: List of data to be measured for each superstructure

No.	Measurement	List of data to be measured	apparatus	accuracy
1	Energy deposition in monopole modes Without modulation (simultaneously with *b*)	Signals from 3 HOM couplers	PM SA	
2	Active excitation of HOMs up to 3.1 GHz with amplifier (50 W).	Signals of BPMs Power of amplifier Beam parameters Gradient	BPM electronics PM	
3	Search for deflecting trapped modes	Signals of BPMs Signals from 3 HOM couplers Modulation frequency Beam parameters		

Interaction between the beam and HOMs will be coordinated by:
N. Baboi/M. Huening/ M. Wendt/O. Napoli/J. S.

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M. Huening

"Short summary of the HOM experiments in TTF linac"

HOM Experiment

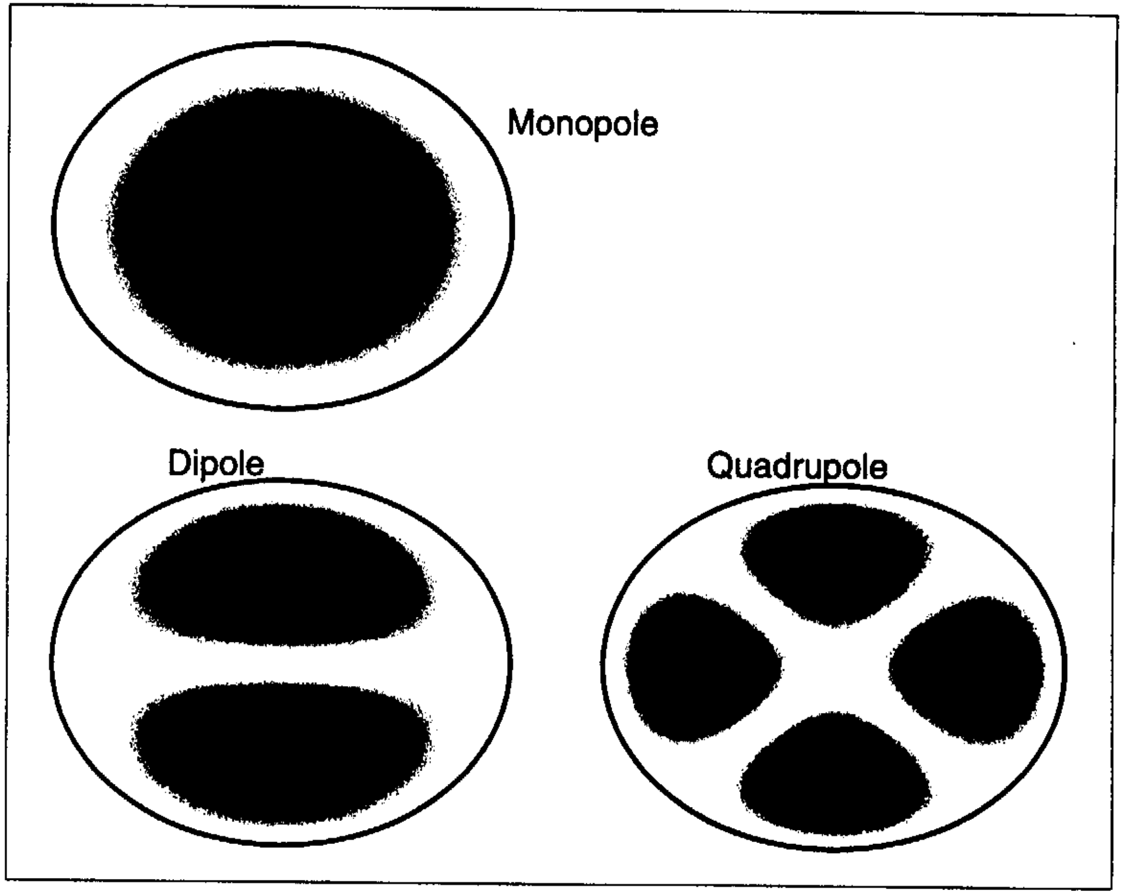
Markus Hüning

10. Januar 2002

– Typeset by FoilTeX –

Higher Order Modes

The longitudinal field



[redacted] [redacted] [redacted]

Dipole Mode

$$
\begin{aligned}
E_z &= J_1\left(k_r r\right)\cos\phi e^{-ik_z z} \qquad (1)\\
E_r &= -i\frac{k_z}{2k_r}\left[J_0\left(k_r r\right) - J_2(k_r r)\right]\cos\phi e^{-ik_z z}
\end{aligned}
$$

Close to the center this can be approximated by

$$
\begin{aligned}
E_z &\approx \frac{k_r}{2} r\cos\phi e^{-ik_z z} \qquad (2)\\
E_r &\approx -i\frac{k_z}{4}\cos\phi e^{-ik_z z}
\end{aligned}
$$

Dipole Mode

A loss factor can be defined

$$k_d = \left(\frac{\omega}{c}\right)^2 \frac{\omega}{4} \left(\frac{R}{Q}\right) \qquad (3)$$

With the energy lost by a bunch

$$U_q = k_d q^2 \rho^2 \qquad \rho = \text{offset} \qquad (4)$$

and the transverse kick

$$V_\perp = \frac{\omega^2}{2c} \left(\frac{R}{Q}\right) \rho q. \qquad (5)$$

⇒ Study modes simultaneously with HOM-coupler and BPM.

[redacted] [redacted] [redacted]

Dipole Mode

Definition of Q_L from Energy

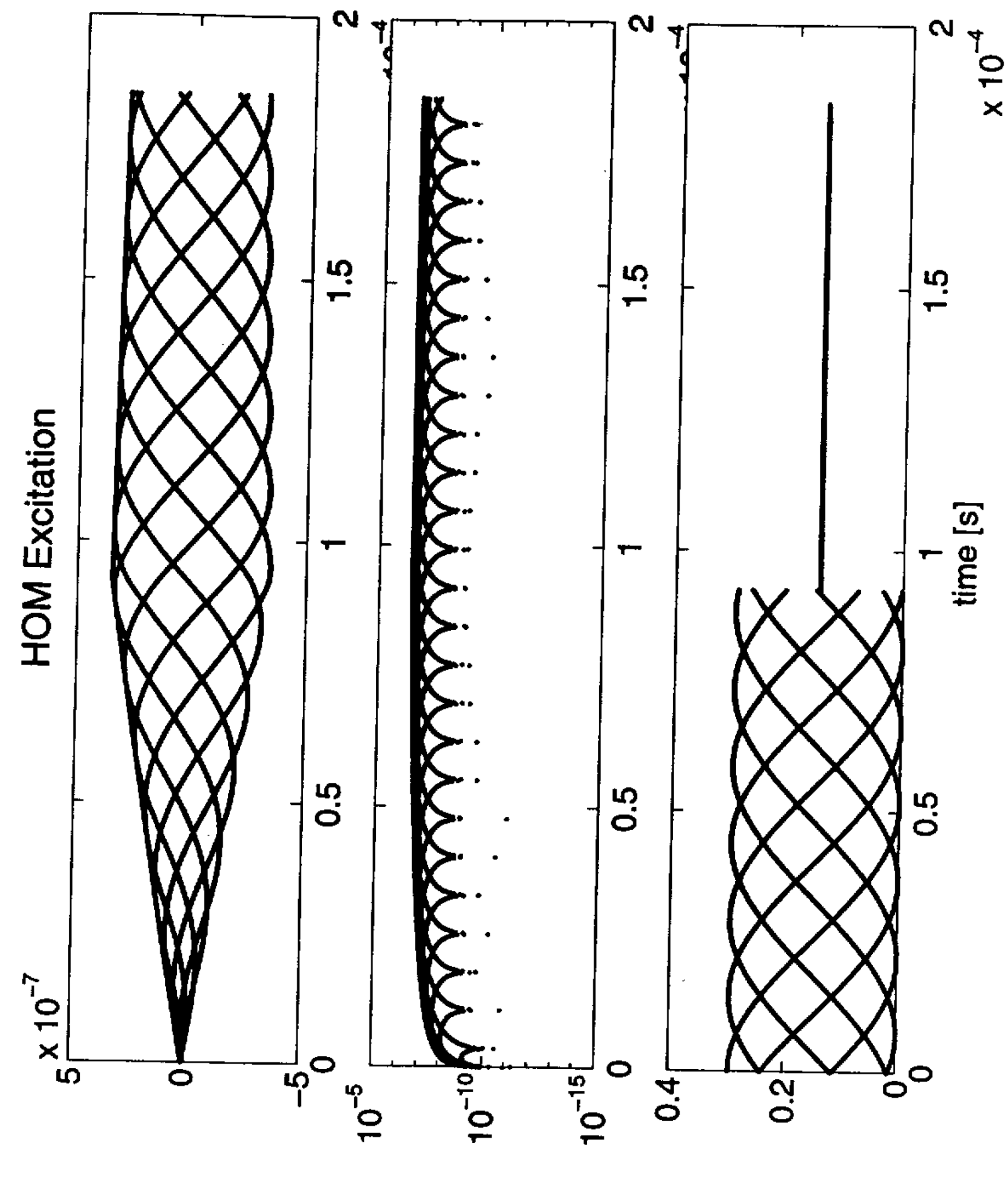
$$Q_L = \frac{\omega U}{P_d} \tag{6}$$

(Energy) time constant

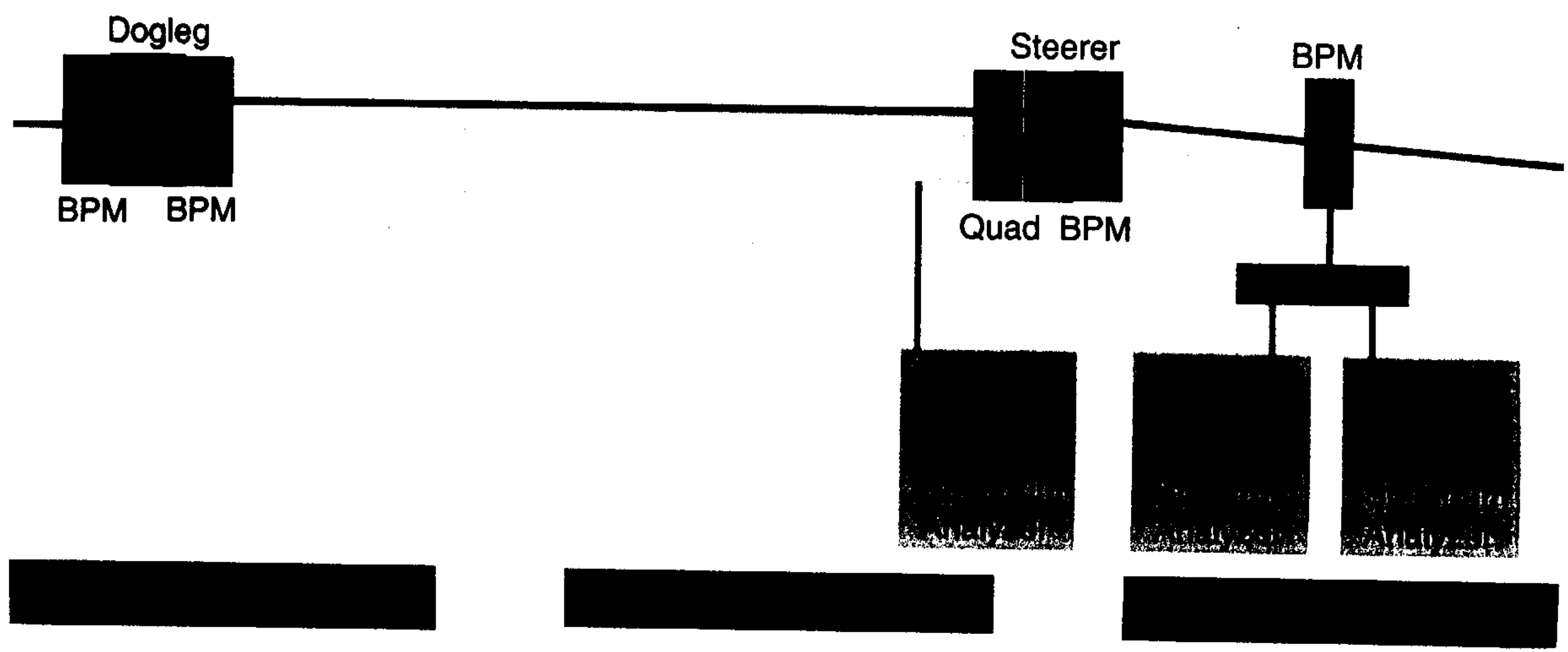
$$\tau_E = \frac{\omega}{Q_L} \tag{7}$$

Then the power coupled out of the cavity is

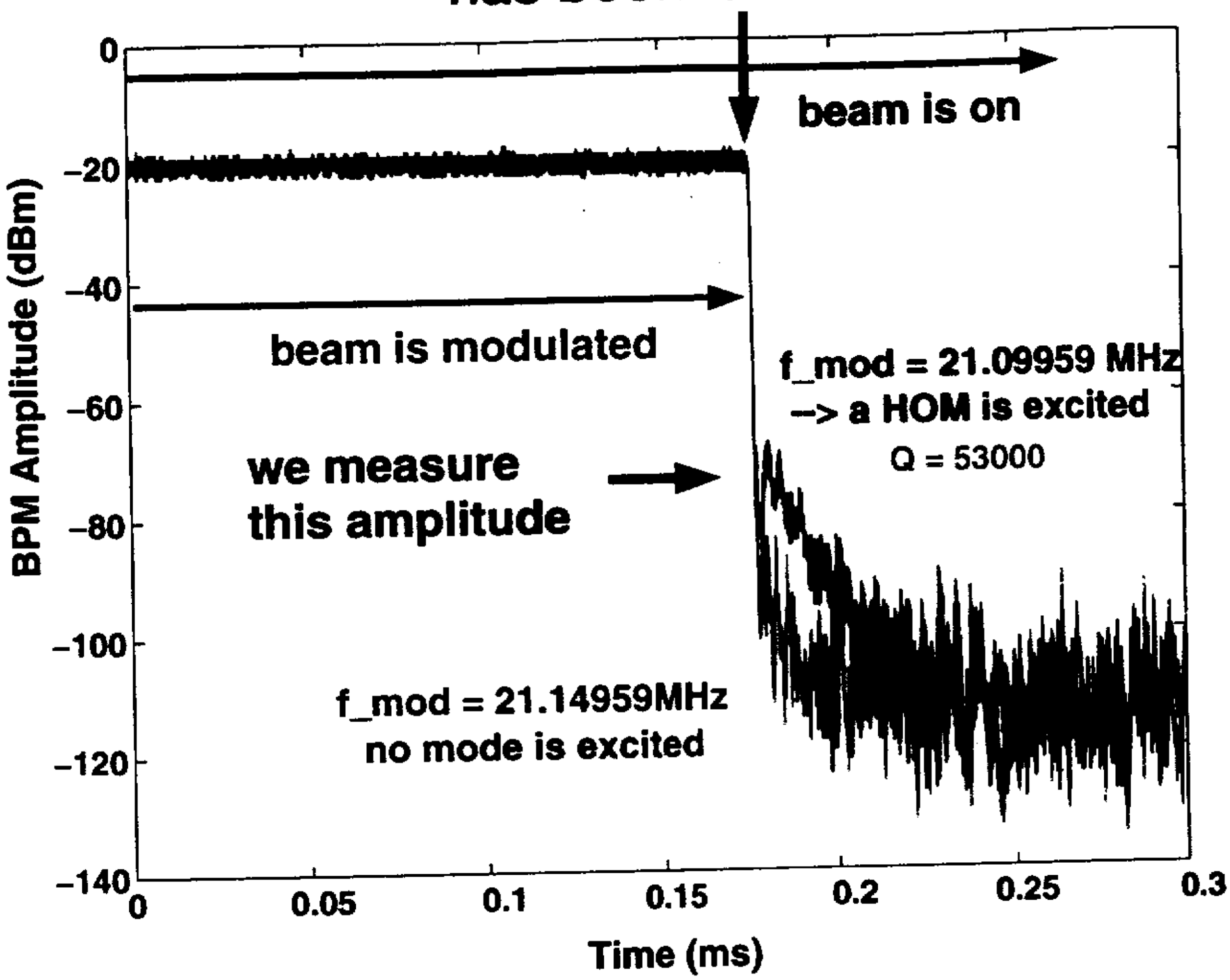
$$P_d = \frac{U}{\tau_E} \qquad = k_d q^2 \rho^2 f_b \tag{8}$$

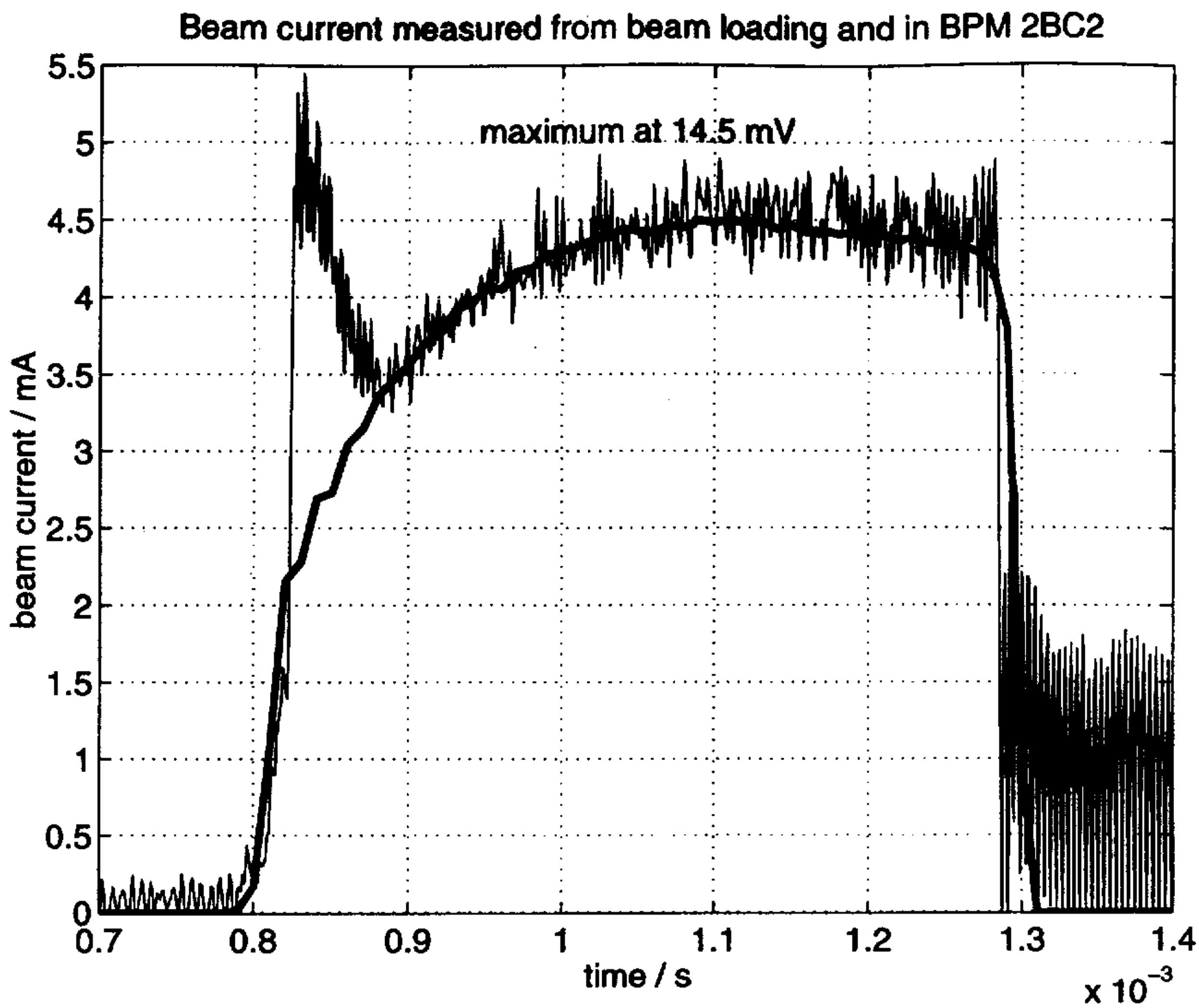

HOM Excitation
x 10^-7
time [s]
x 10^-4

Setup



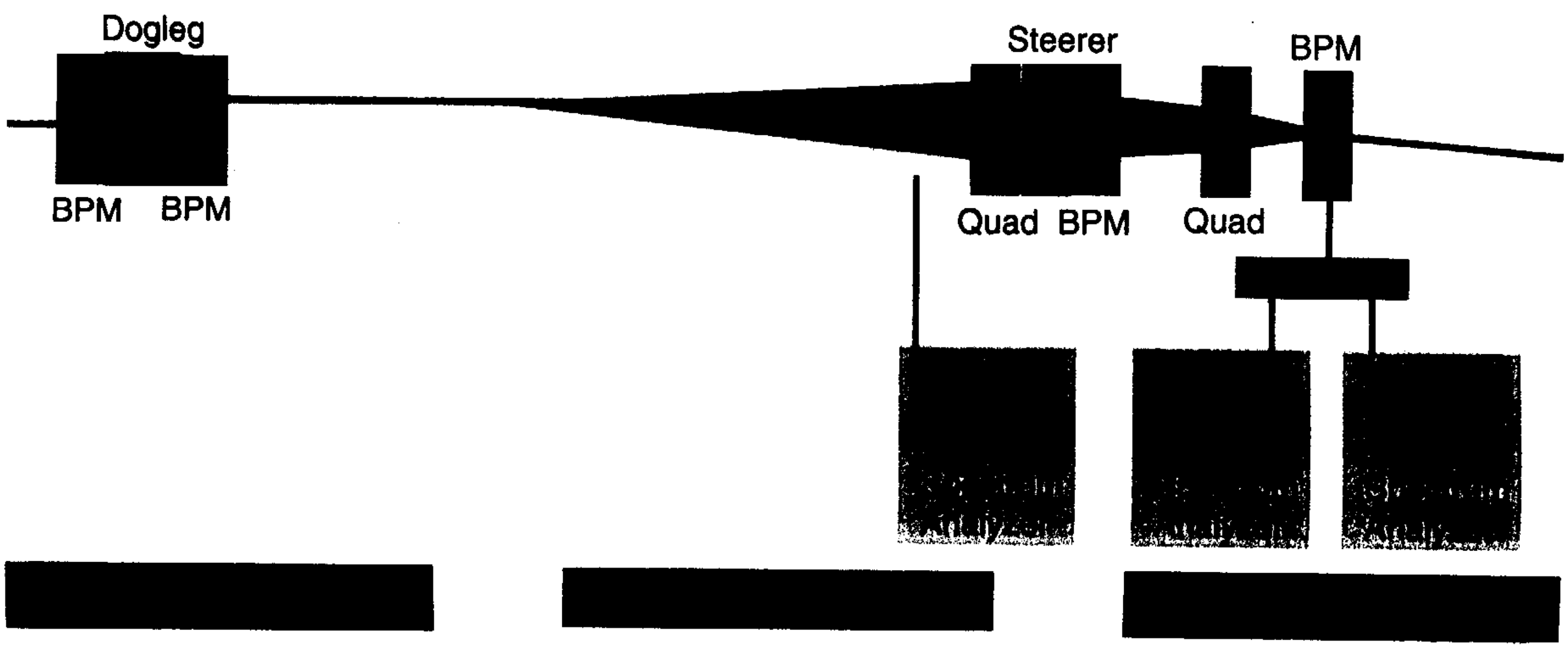
Observe beam deflection after modulation has been turned off





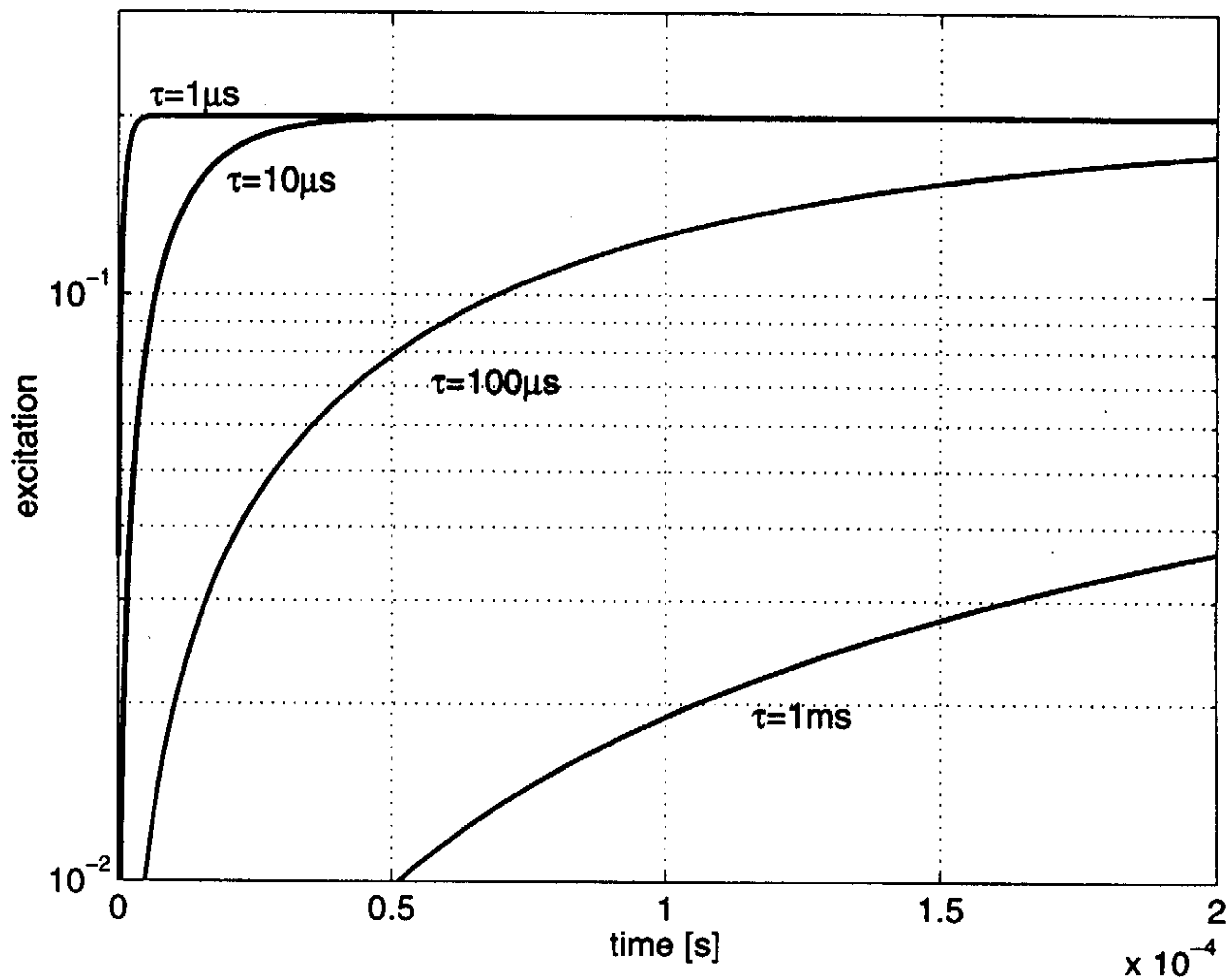
Beam current measured from beam loading and in BPM 2BC2
maximum at 14.5 mV
beam current / mA
time / s
x 10^-3
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4

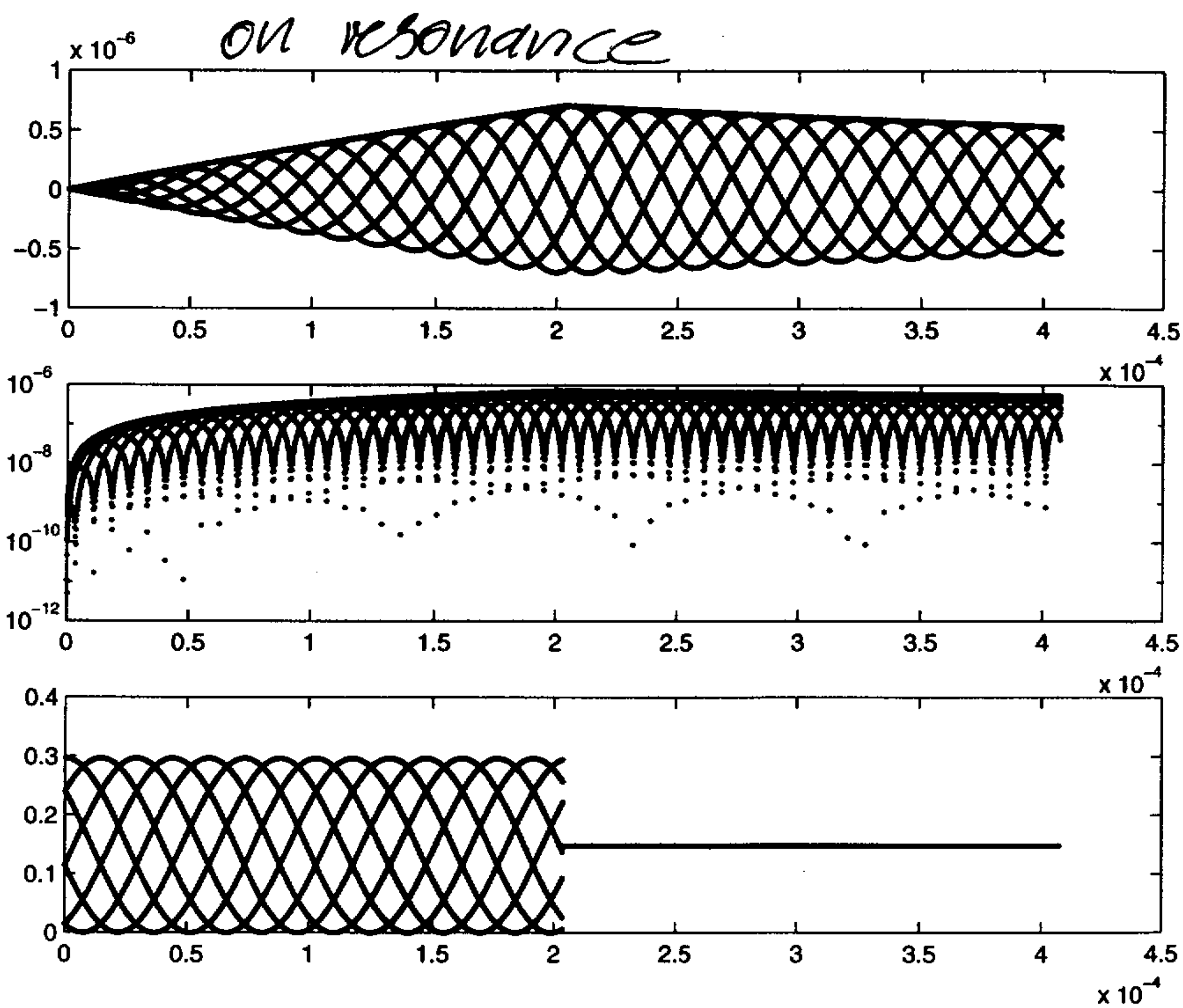
Locate the HOM

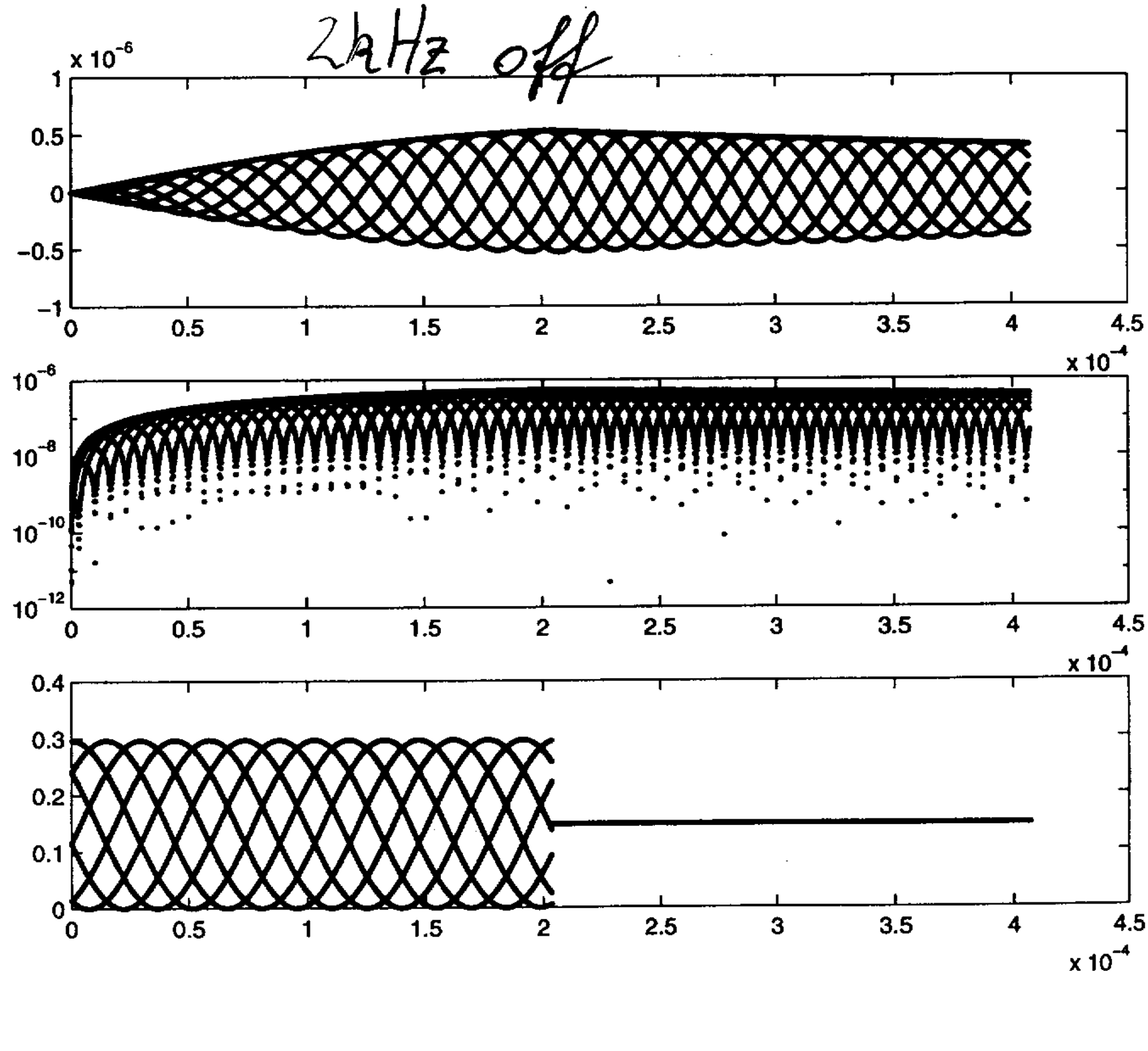


Trigger

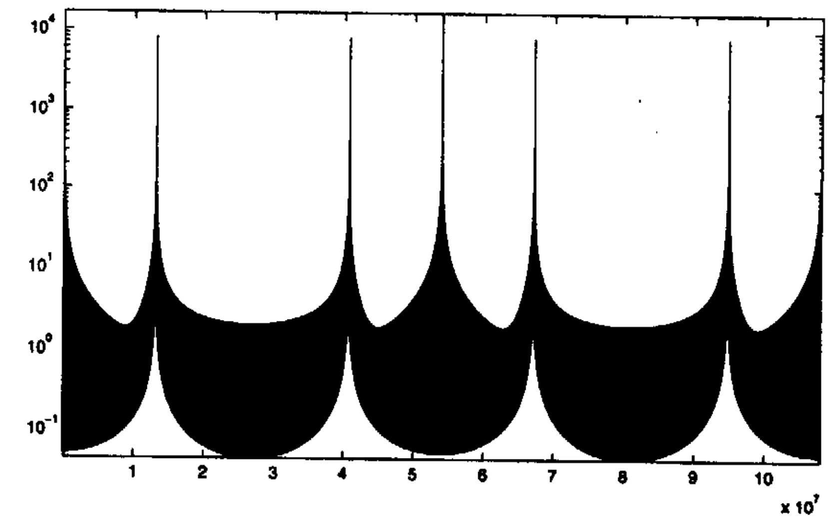
A second trigger for τ is required

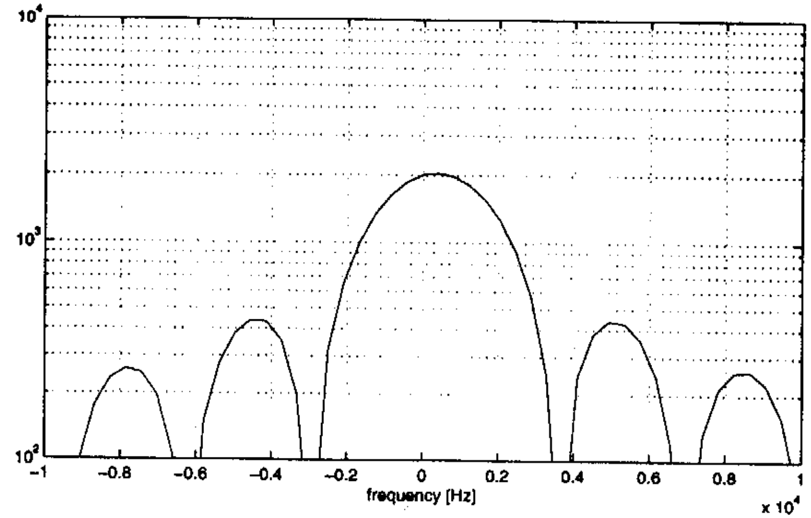



on resonance
x 10^-6
1
0.5
0
-0.5
-1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
x 10^-4
10^-6
10^-8
10^-10
10^-12
0.4
0.3
0.2
0.1

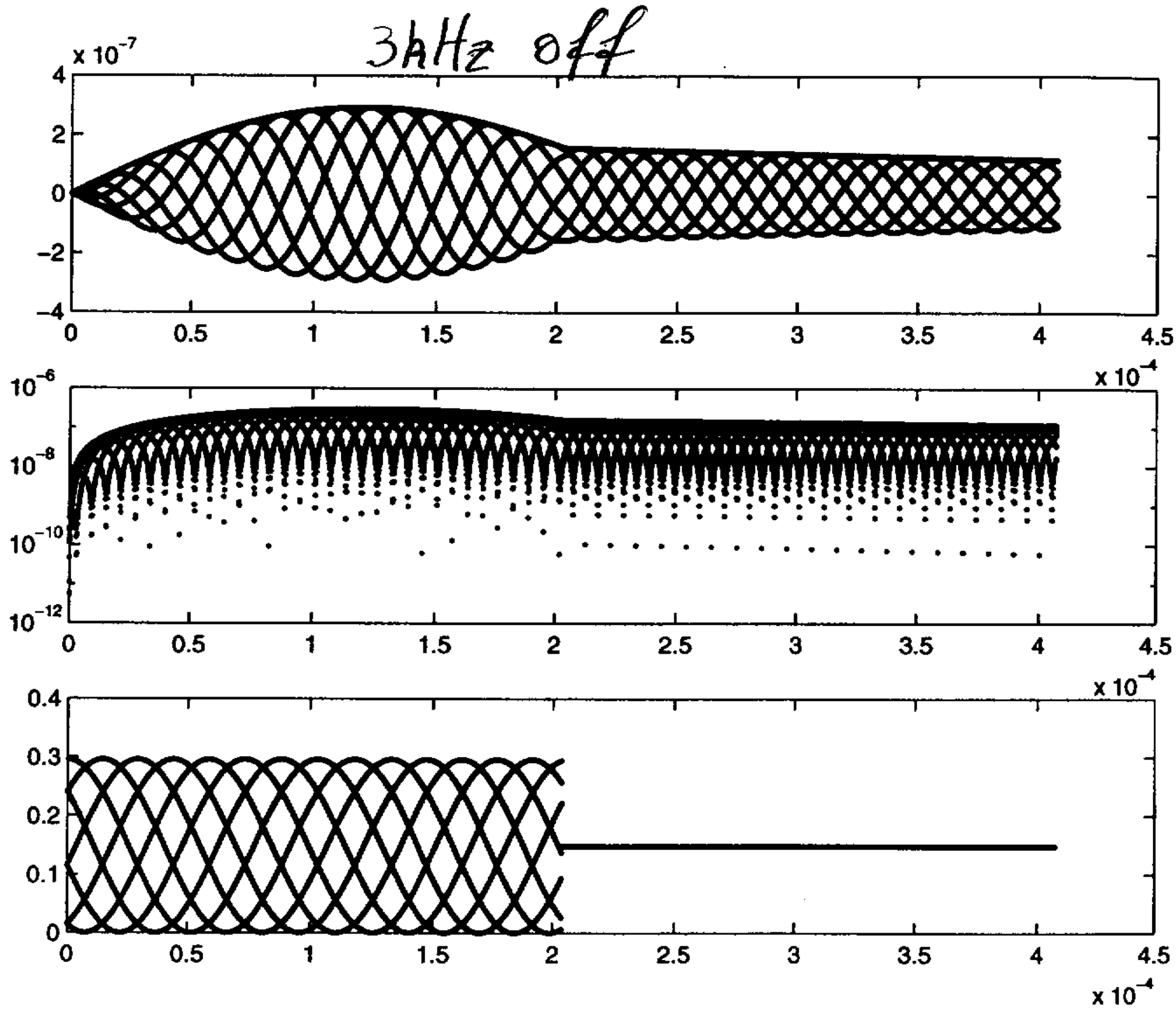

2kHz off
x 10^-6
1
0.5
0
-0.5
-1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
x 10^-4
10^-6
10^-8
10^-10
10^-12
0.4
0.3
0.2
0.1
0

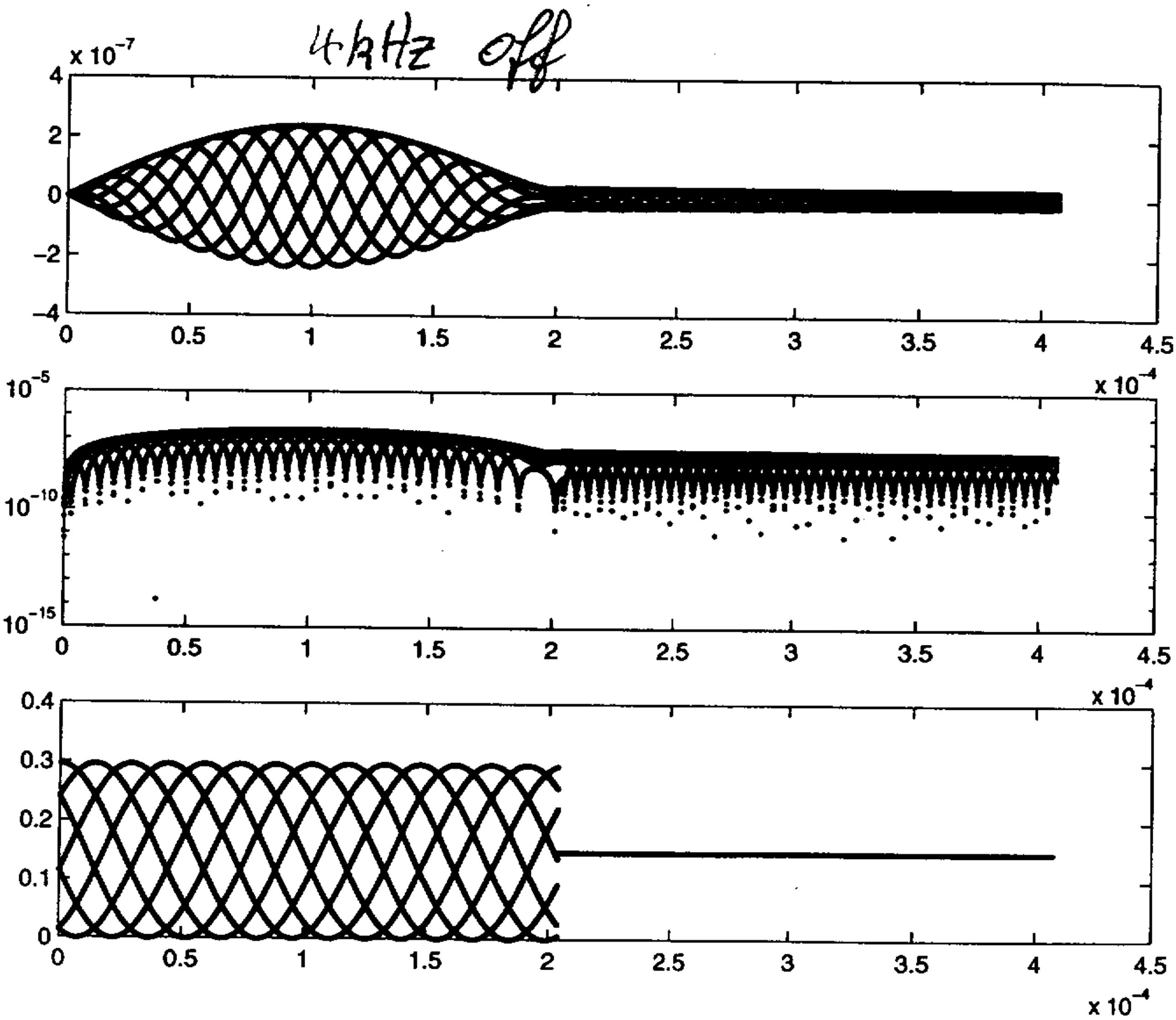
Steps of Scan

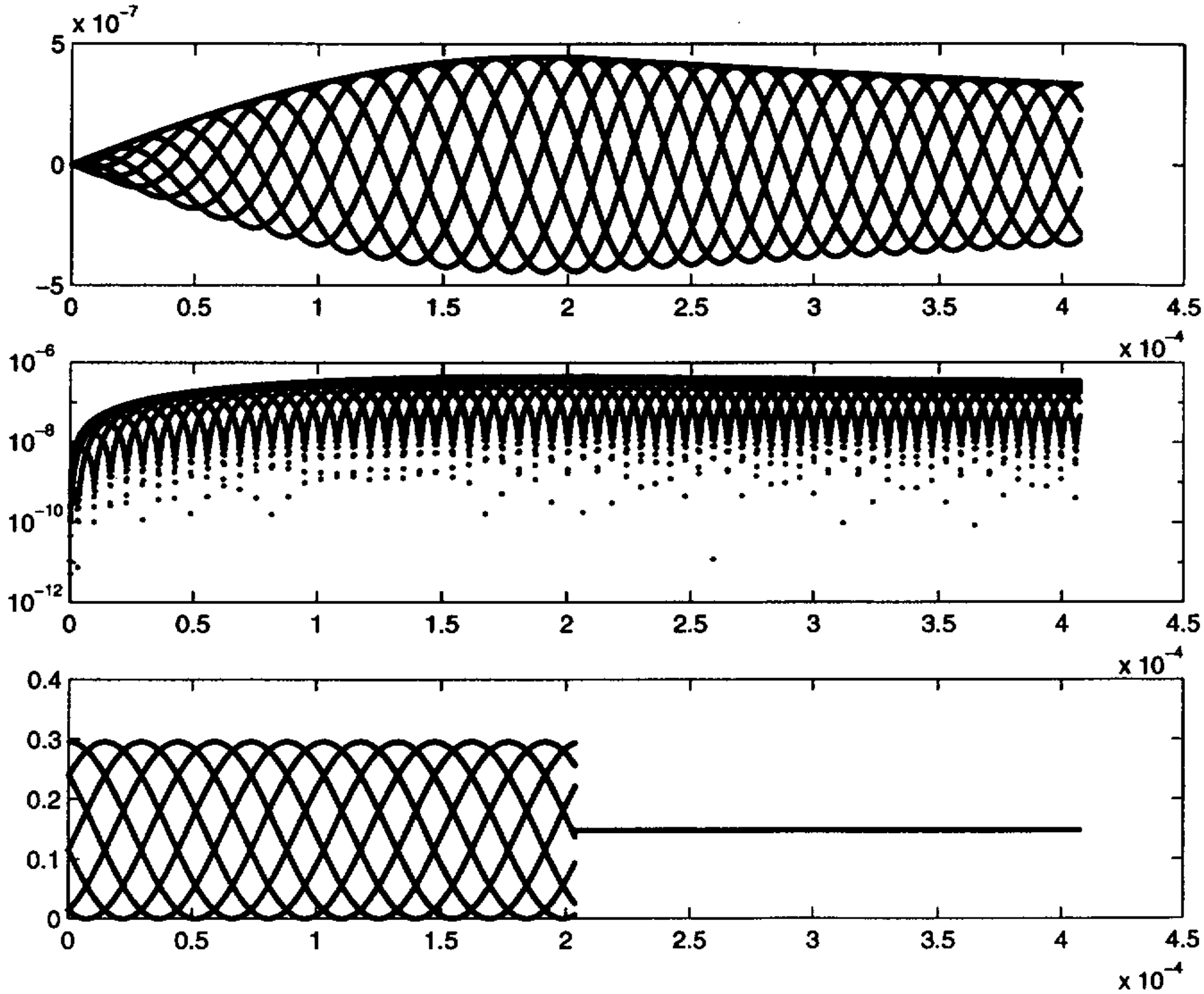


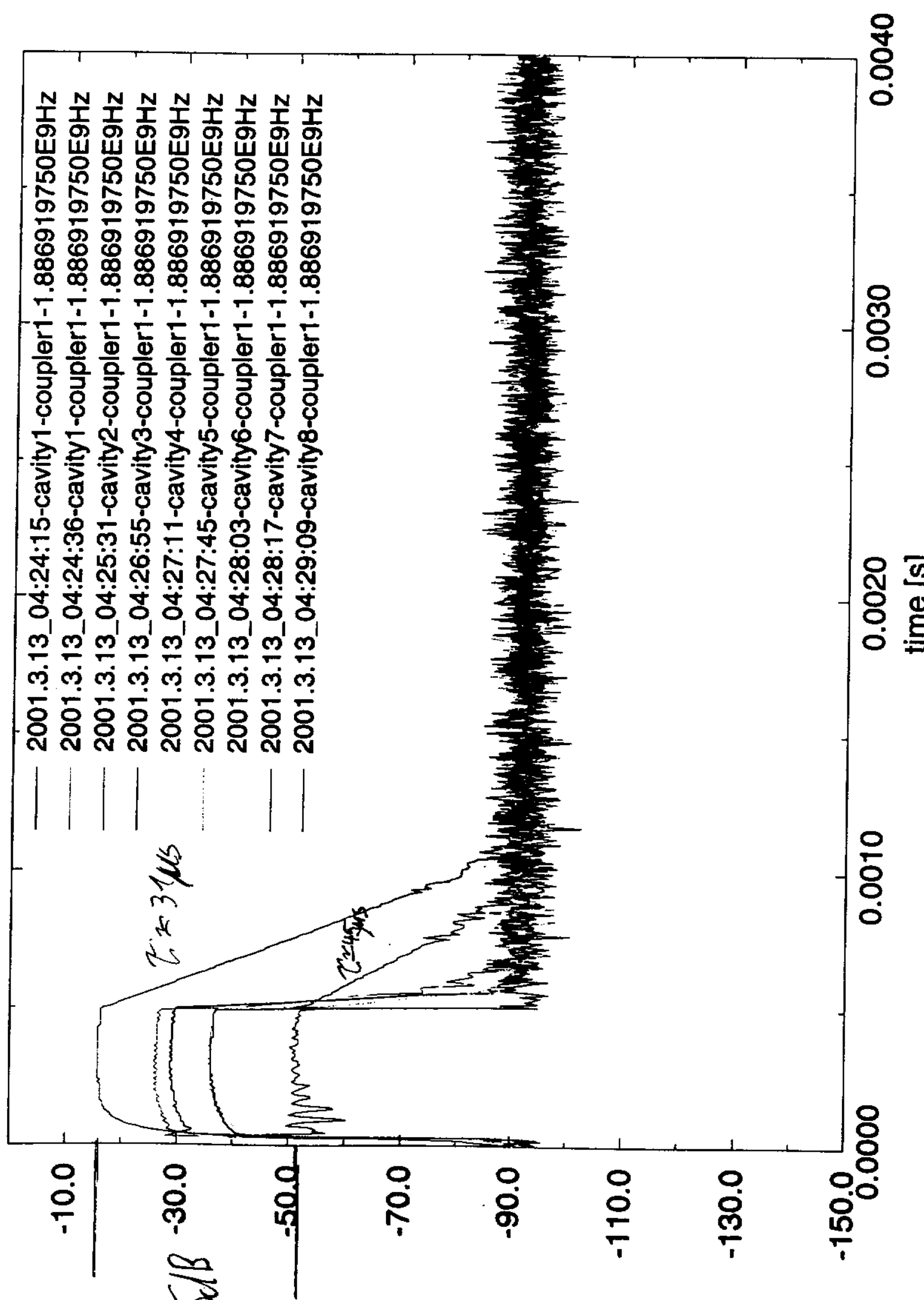


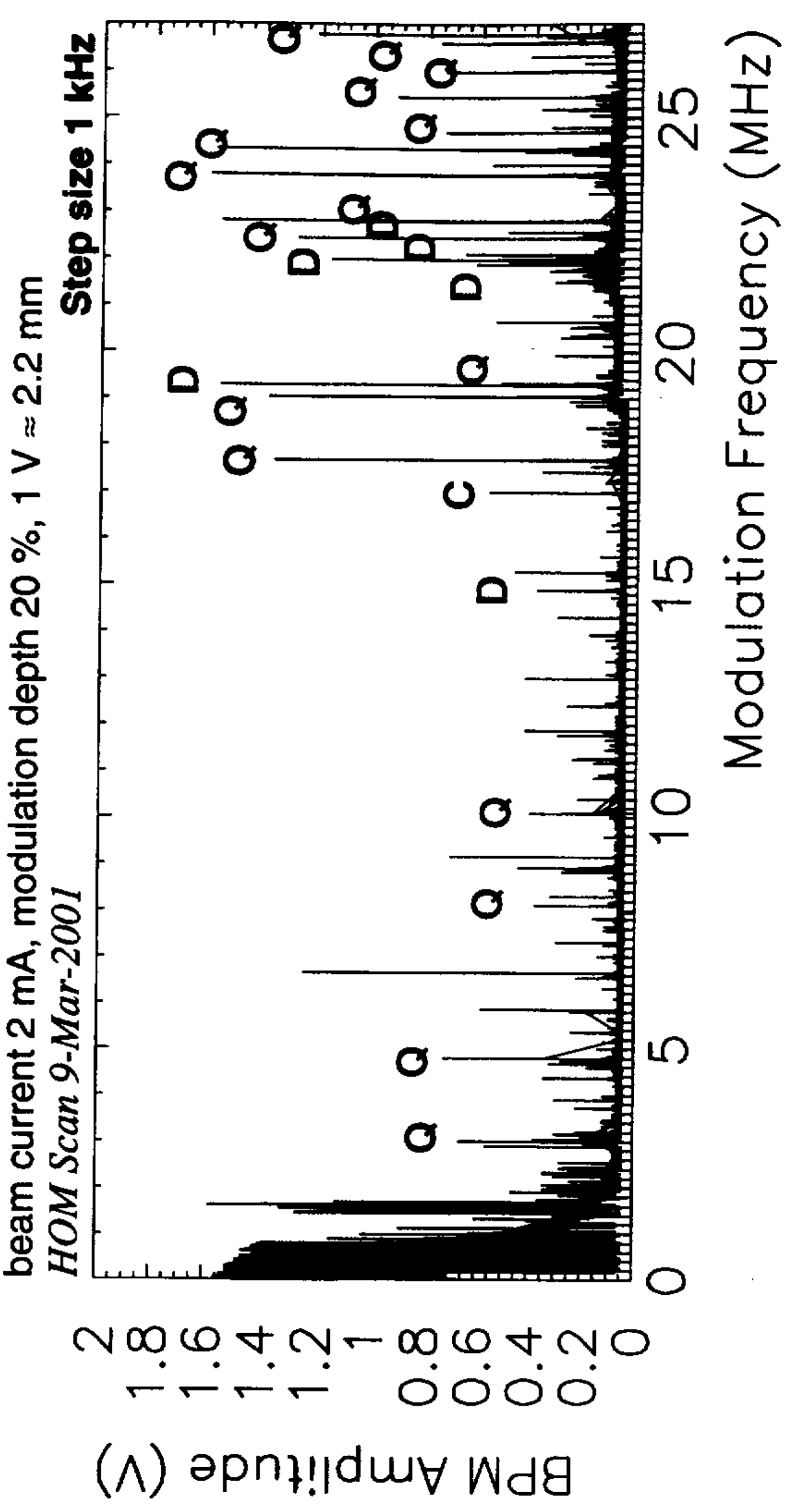
[redacted] [redacted] [redacted]


3kHz off
x 10^-7
4
2
0
-2
-4
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
x 10^-4
10^-6
10^-8
10^-10
10^-12
0.4
0.3
0.2
0.1
0

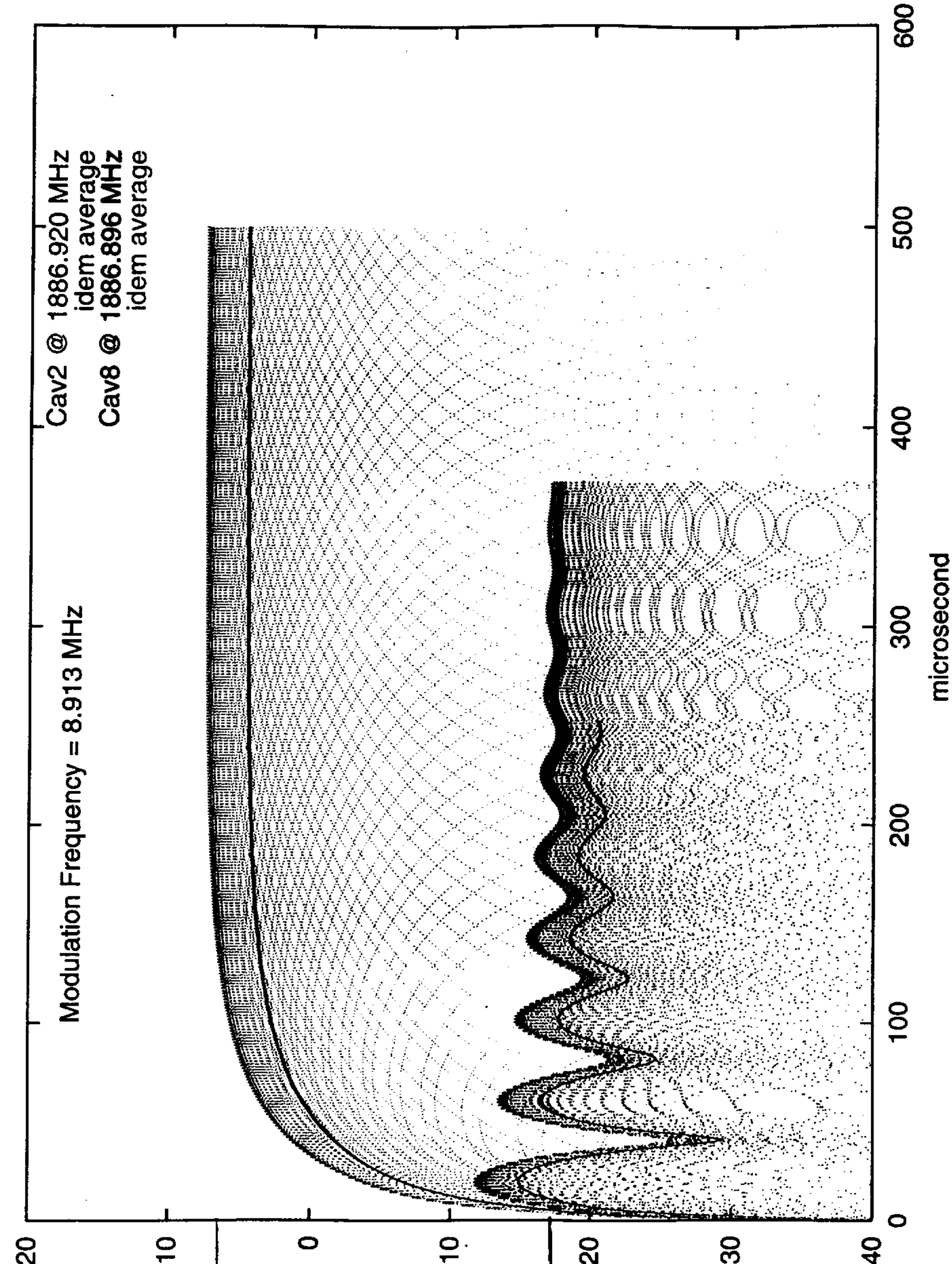

4kHz off
x 10^-7
4
2
0
-2
-4
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
x 10^-4
10^-5
10^-10
10^-15
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
x 10^-4
0.4
0.3
0.2
0.1
0
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
x 10^-4


x 10^-7
5
0
-5
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
x 10^-4
10^-6
10^-8
10^-10
10^-12
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
x 10^-4
0.4
0.3
0.2
0.1
0
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
x 10^-4

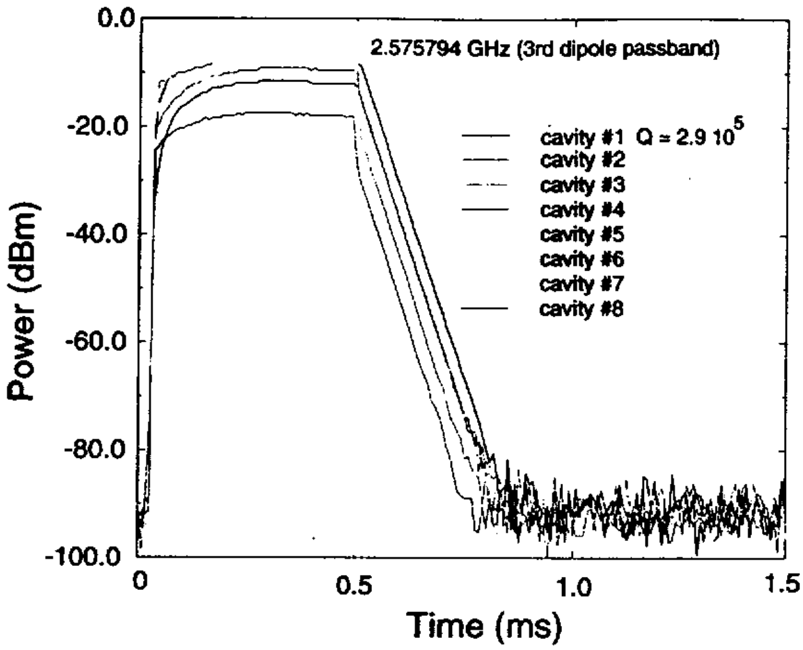

2001.3.13_04:24:15-cavity1-coupler1-1.886919750E9Hz
2001.3.13_04:24:36-cavity1-coupler1-1.886919750E9Hz
2001.3.13_04:25:31-cavity2-coupler1-1.886919750E9Hz
2001.3.13_04:26:55-cavity3-coupler1-1.886919750E9Hz
2001.3.13_04:27:11-cavity4-coupler1-1.886919750E9Hz
2001.3.13_04:27:45-cavity5-coupler1-1.886919750E9Hz
2001.3.13_04:28:03-cavity6-coupler1-1.886919750E9Hz
2001.3.13_04:28:17-cavity7-coupler1-1.886919750E9Hz
2001.3.13_04:29:09-cavity8-coupler1-1.886919750E9Hz
HOM power [dBm]
-10.0
-30.0
-50.0
-70.0
-90.0
-110.0
-130.0
-150.0
time [s]
0.0000
0.0010
0.0020
0.0030
0.0040



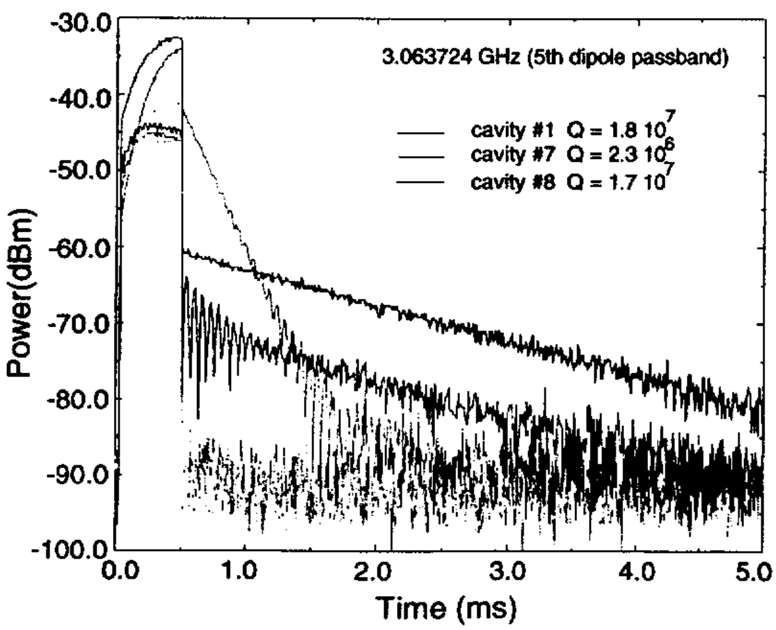
about 20 HOM candidates with strong deflection
(dipole D mode and quadrupole mode Q asignment - preliminary)
about 60 other excited modes with weak deflection


Modulation Frequency = 8.913 MHz
Cav2 @ 1886.920 MHz
idem average
Cav8 @ 1886.896 MHz
idem average
P_HOM [dBm]
microsecond
20
10
0
-10
-20
-30
-40
0
100
200
300
400
500
600

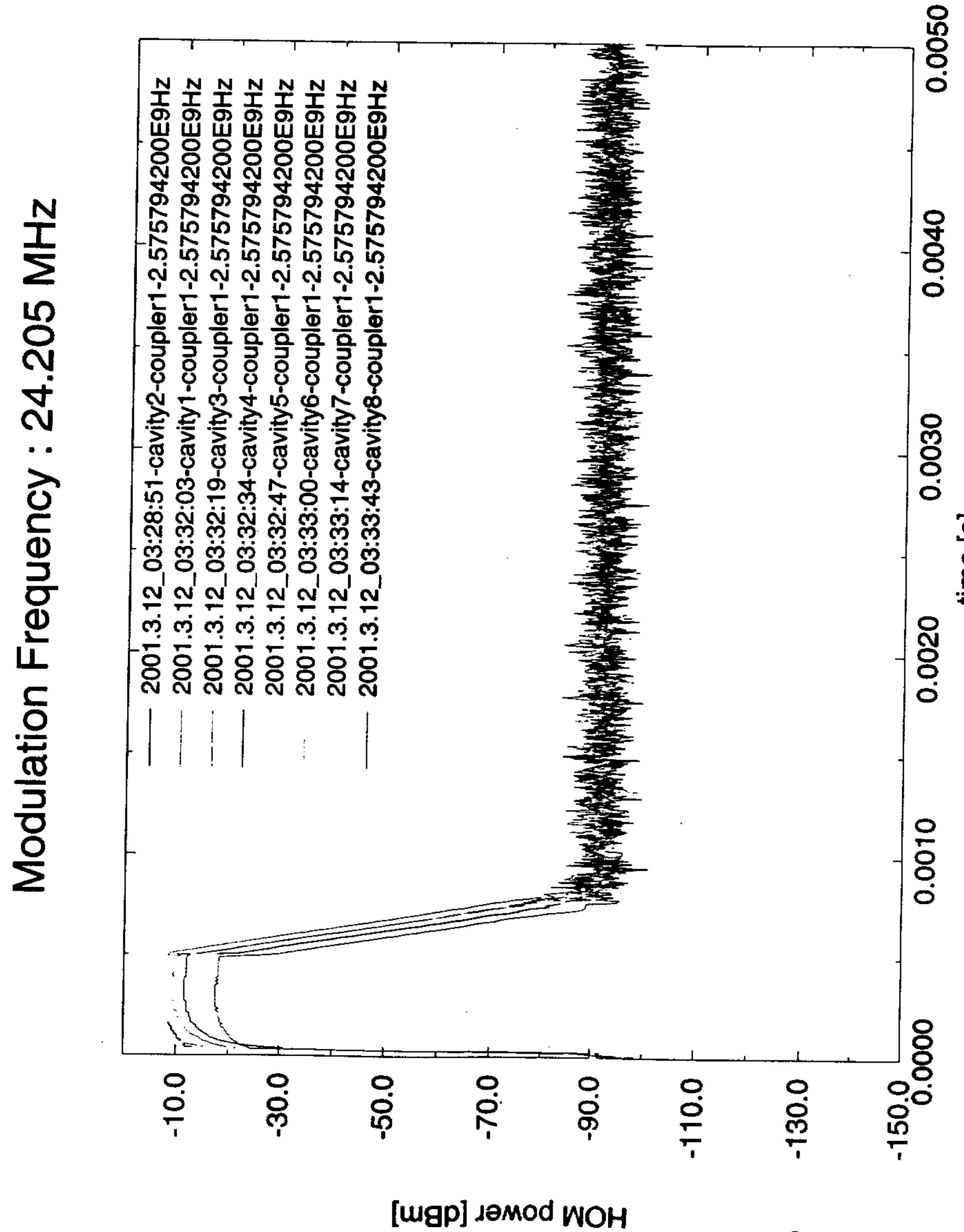
☺ Examples of time domain spectra:



the excited mode is present in all cavities



several modes in different cavities are excited


Modulation Frequency : 24.205 MHz
2001.3.12_03:28:51-cavity2-coupler1-2.575794200E9Hz
2001.3.12_03:32:03-cavity1-coupler1-2.575794200E9Hz
2001.3.12_03:32:19-cavity3-coupler1-2.575794200E9Hz
2001.3.12_03:32:34-cavity4-coupler1-2.575794200E9Hz
2001.3.12_03:32:47-cavity5-coupler1-2.575794200E9Hz
2001.3.12_03:33:00-cavity6-coupler1-2.575794200E9Hz
2001.3.12_03:33:14-cavity7-coupler1-2.575794200E9Hz
2001.3.12_03:33:43-cavity8-coupler1-2.575794200E9Hz
HOM power [dBm]
-10.0
-30.0
-50.0
-70.0
-90.0
-110.0
-130.0
-150.0
time [s]
0.0000
0.0010
0.0020
0.0030
0.0040
0.0050

N. Baboi

"What can we improve in HOM measurements ?"

WHAT CAN WE IMPROVE in HOM MEASUREMENTS with MODULATED BEAM ?

Nicoleta Baboi

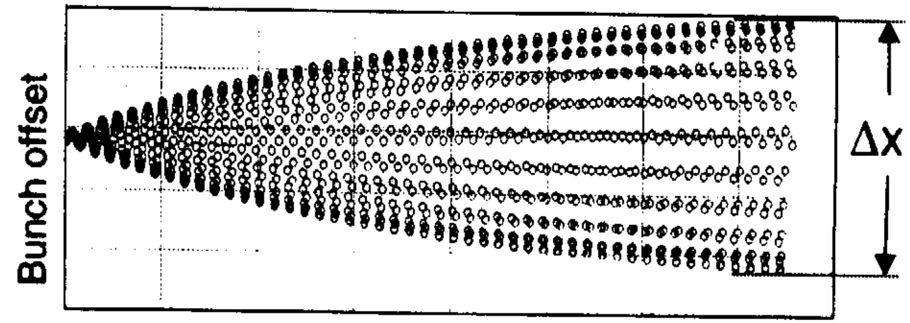
Reminder of principle
Past problems
What could we do ?

DESY, February 25, 2001

Basic principle

Excite mode when: $\omega_{\text{mod}} = |\omega_l - m \cdot \omega_b| \leq \omega_b/2$:

$$\Delta x'_{res\,\max} = c\frac{e}{E}\delta x_0 \left(q_0 \frac{\omega_b}{2\pi}\right)\lambda \frac{1}{\omega_l}\left(\left(\frac{R}{Q}\right)Q\right)_l$$



- Assumptions:
  - steady state: bunch train length » $\tau = 2Q/\omega$
  - exactly on resonance
  - horizontal polarization
- Requirements:
  - low energy
  - large beam offset
  - high average current
  - high modulation amplitude
  - long bunch train ⇒ reach steady state
  - high bunch frequency ⇒ avoid resonance overlap
  - low frequency step ⇒ not to miss high-Q modes

Problems in the last measurements

- many quadrupole modes excited much stronger than dipole ones
- instabilities of the beam (position, charge, etc.)
- calibration
- instrumentation limitation

- time and men power
- too much automatization?

What can we improve?

- We need more information!
  - polarization ✓
  - vertical plane
  - check mode character
  - increase BPM resolution
- Possible changes:
  - reduce beam deflection ⇒ avoid quadrupole modes
    - but we loose sensitivity; which can be regained by:
  - increase current
  - increase bunch frequency
  - more sensitive BPMs
- Make complementary measurements (e.g. use two BPMs)
- It needs lots of time! But we have fewer cavities and HOM couplers and a bit more experience

What can we improve? (2)

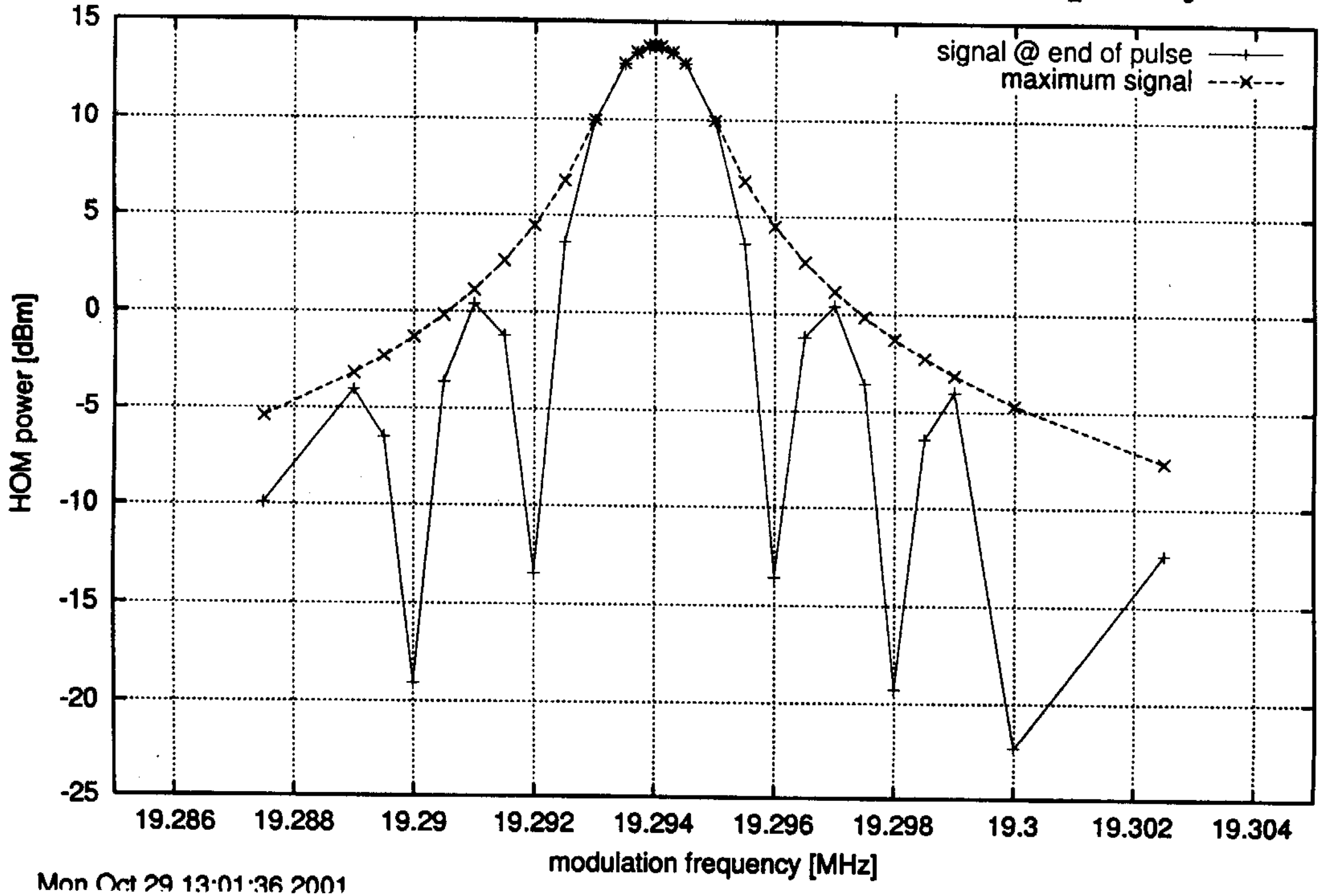
- Measure R/Q with → BPM
  → HOM couplers
  - ➢ no superimposed resonances, as seen at BPM
  - ➢ need calibration of cables at higher frequencies

- Will be better prepared
  - ➢ know more problems
  - ➢ use RF measurements of HOMs → dipoles +
    → quadrupoles ?
    (+ monopoles)

Olivier Napoly

5^{th} Dipole Passband Trapped Mode

Prediction for : f =3068 MHz , R/Q = 1.1 Ω/cm^2 , $Q = 3.4\ 10^7$ in cavity C7, as a function of the modulation frequency



M. Ferrario

"Estimation of bunch-to-bunch energy variation in TTF linac with two superstructures and standard cryomodule"

THE HOMDYN MODEL

M. FERRARIO
INFN-LNF

LONG TERM MULTI-BUNCH BEAM CAVITY INTERACTION FOR RELATIVISTIC AND NON RELATIVISTIC BEAMS:

TRANSIENTS, BEAM LOADING & SPACE CHARGE EFFECTS

* NORMAL MODES EXPANSION OF CAVITY FIELDS

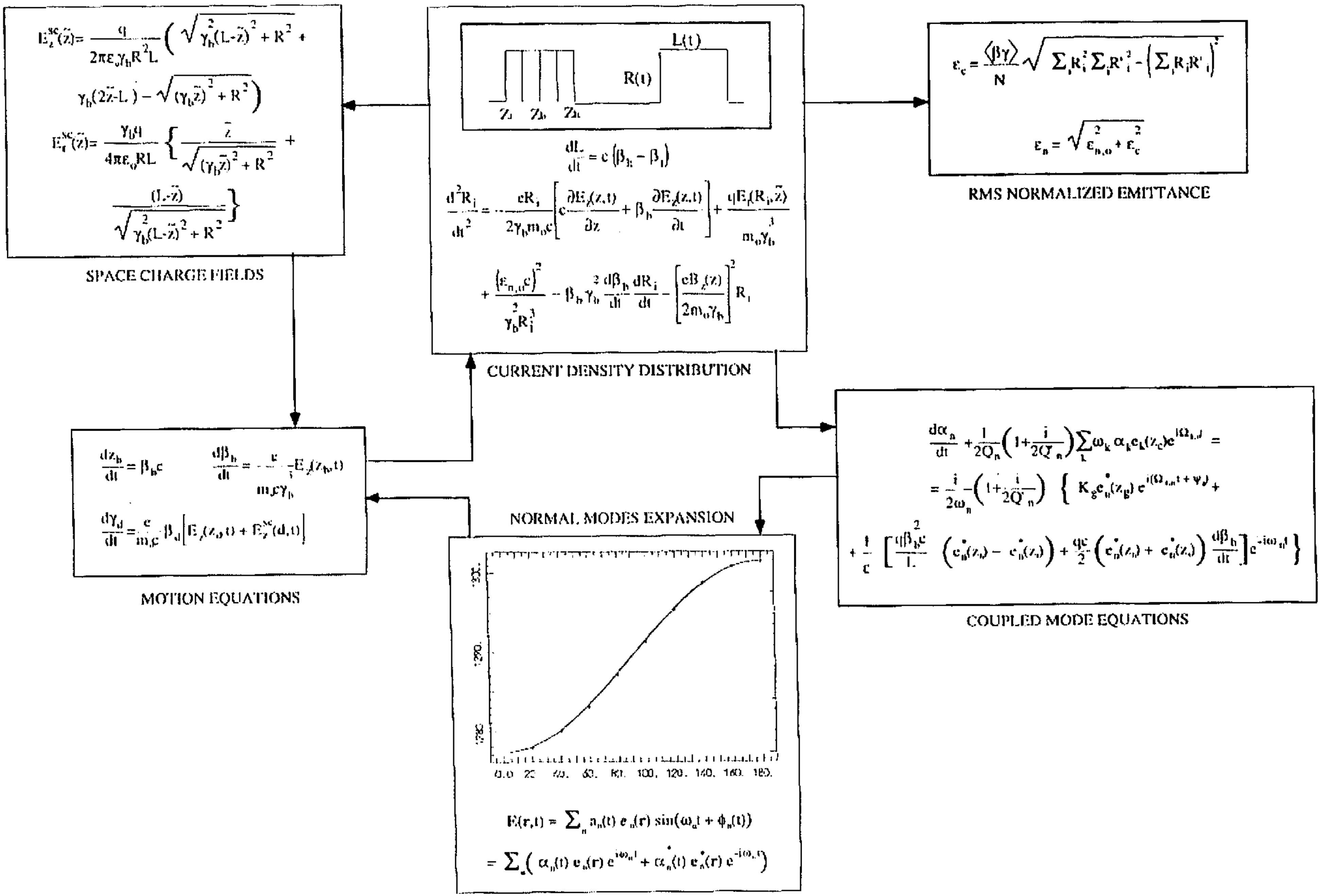
we describe the field amplitude evolution under the slowly varying envelope approximation for each resonant mode

analytical propagation of field from bunch to bunch, including external generator

* CURRENT DENSITY DESCRIPTION OF BUNCHES BY UNIFORM MULTI-SLICE CYLINDER

we describe the transverse dynamics by the bunch envelope equation for each bunch slice

analytical computation of slice space charge fields


SPACE CHARGE FIELDS
CURRENT DENSITY DISTRIBUTION
R(t)
L(t)
RMS NORMALIZED EMITTANCE
MOTION EQUATIONS
NORMAL MODES EXPANSION
COUPLED MODE EQUATIONS

RELATIVISTIC BEAM

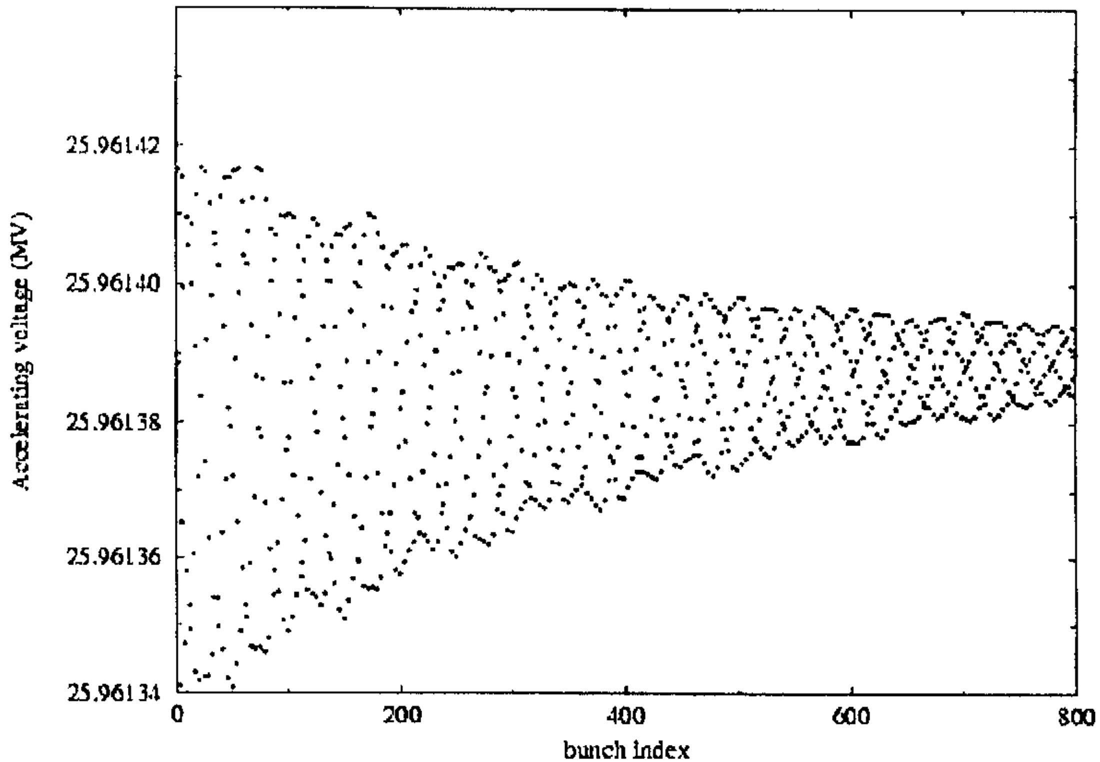
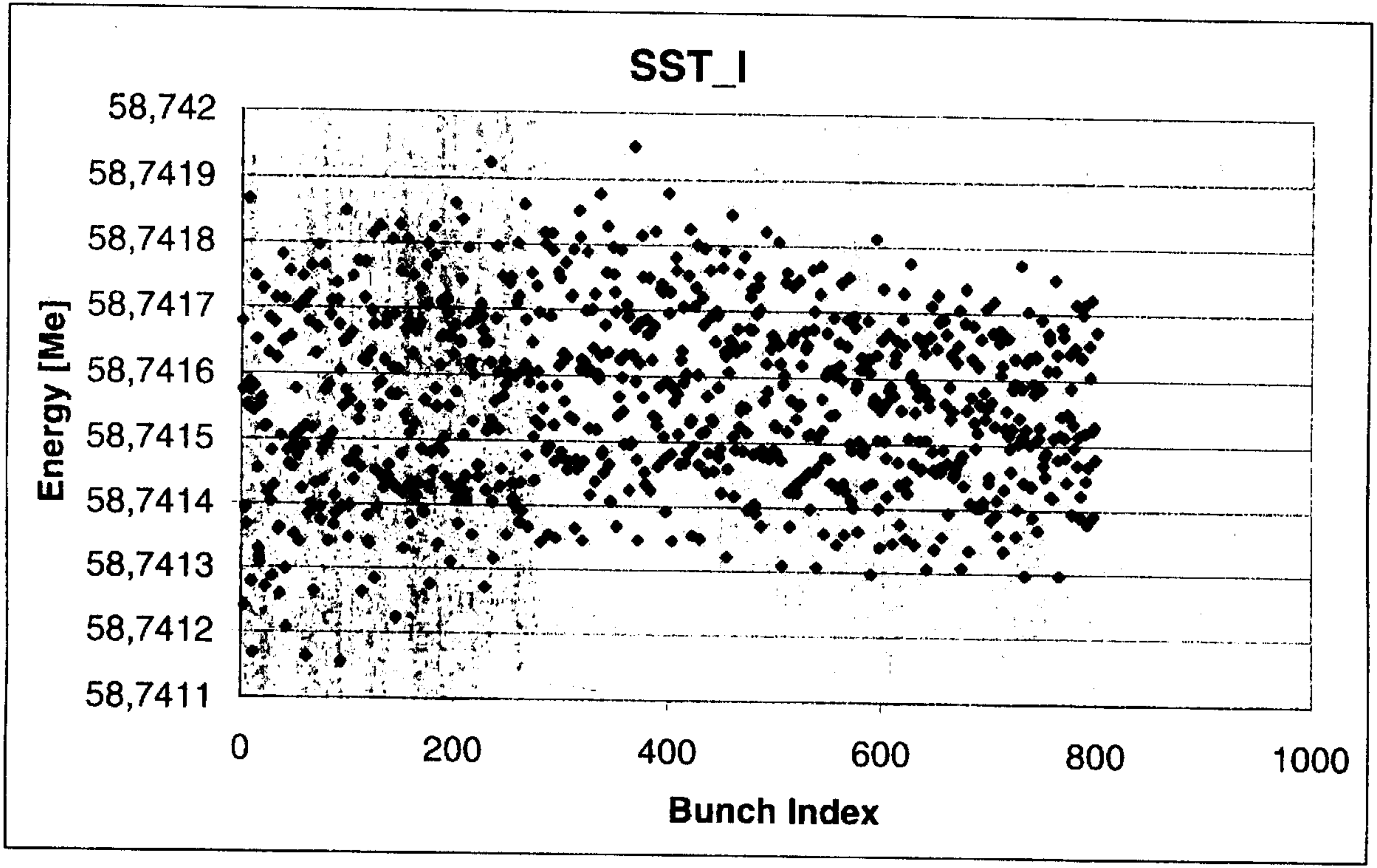


Figure 2: Total accelerating voltage during the entire TESLA beam pulse. The residual oscillations, are mainly caused by the nearest mode of the pass-band, decaying according to the time constants of the modes. The induced bunch-to-bunch energy spread is very small, from 3 10^{-6} at the beginning to 0.5 10^{-6} at the end.

(13)

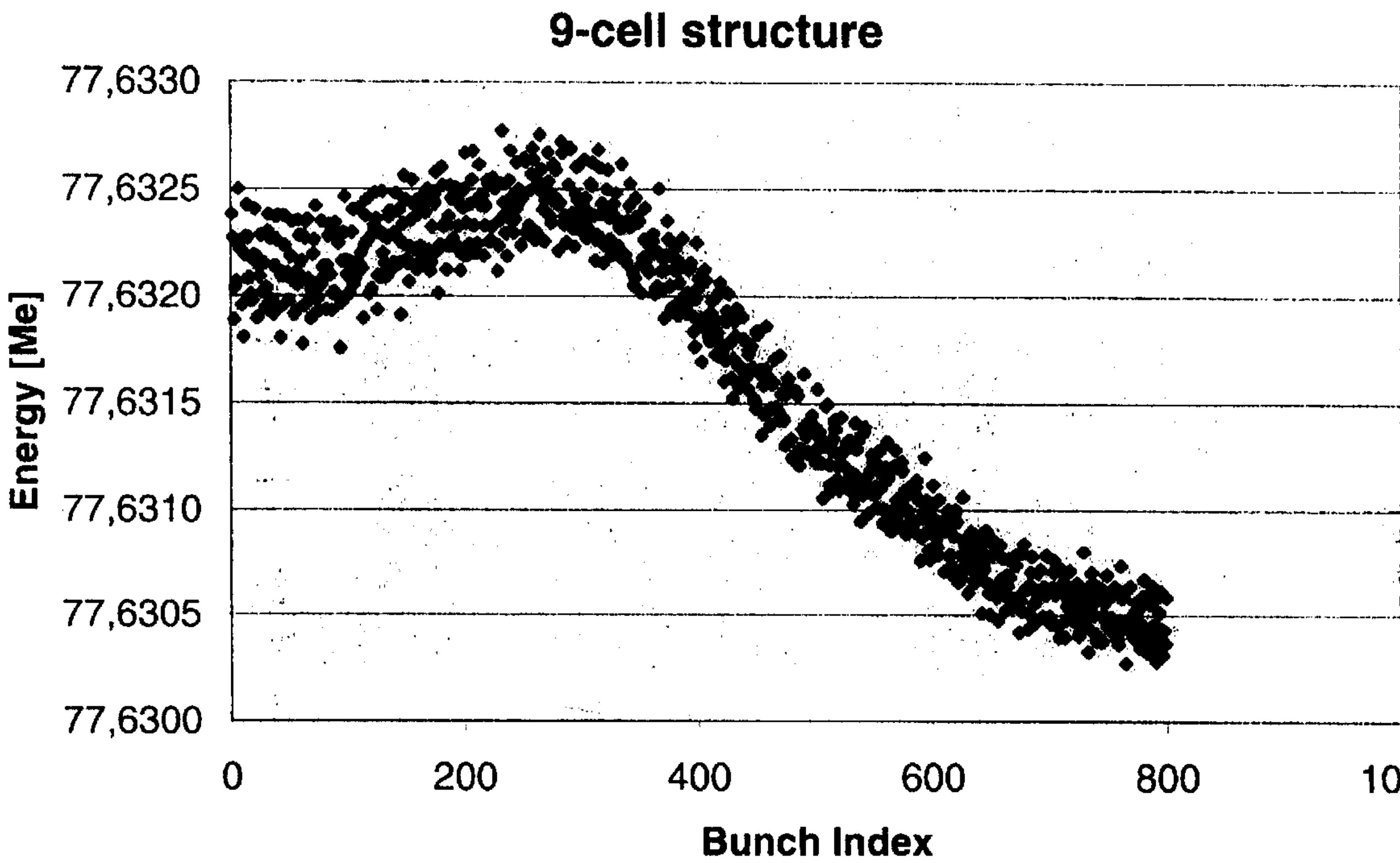
99

$E_0 \simeq 16$ MeV $E_{acc} = 25$ MV/m



$\frac{\Delta E}{E} \sim 2 \cdot 10^{-5}$

$E_0 = 58.7$ MeV $E_{acc} = 20$ MV/m

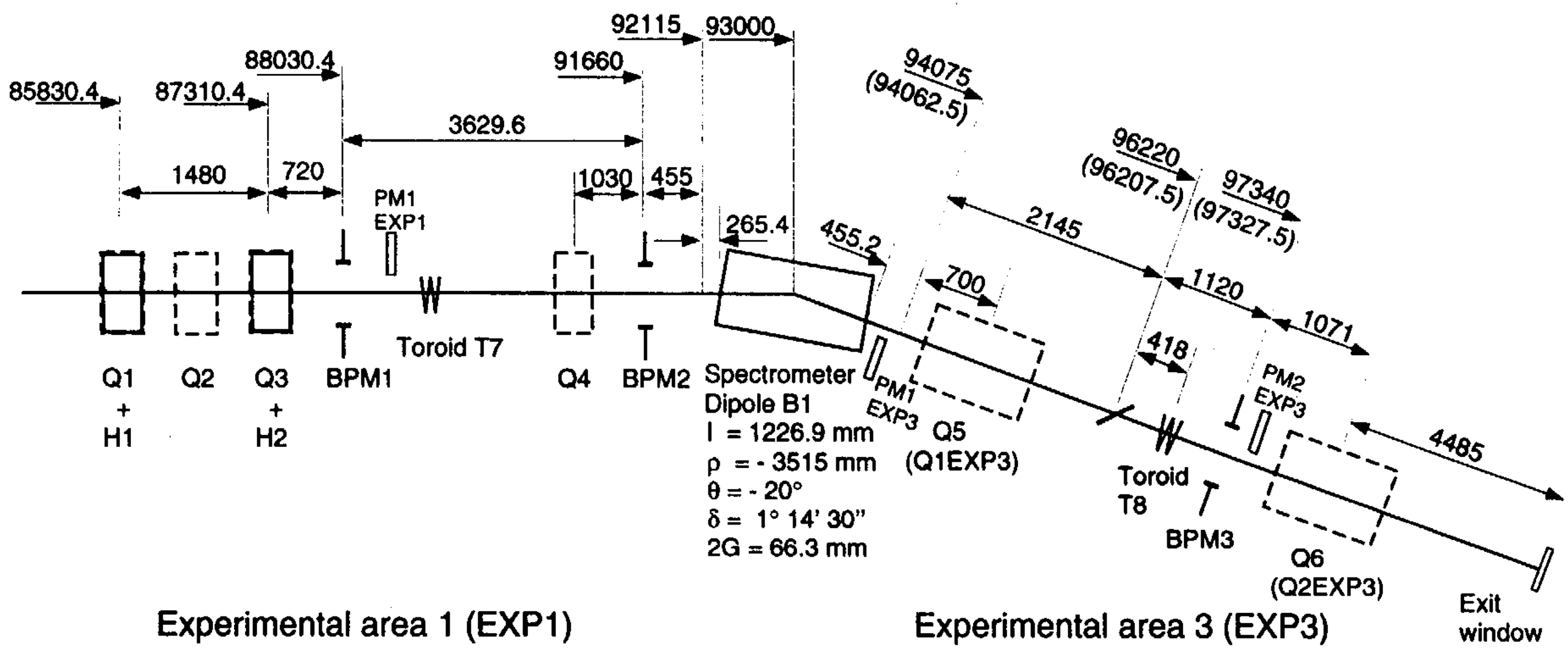


$\frac{\delta E}{E} \sim 2 \cdot 10^{-5}$ $\frac{\Delta E}{E} \sim 10^{-4}$

H. Schlarb

"Limits in energy measurements at the injector region and at the end of linac"

Beamline EXP1 & EXP3



Orbit Independent Measurement

Momentum of bunch can be written in first order approximation

$$p = p_0 + \Delta p \approx p_0 \cdot \left(1 + \frac{\Delta x_3}{D_x(s_3)}\right)$$

Collective betatron motion occurs as small perturbation of the measured beam position:

$$x_3 = \Delta x_3 + \delta x_\beta$$

To remove the betatron motion, two bpms in front of the spectrometer dipole can be used. One finds:

$$\frac{\Delta p}{p_0} = a_1 x_1 + a_2 x_2 + a_3 x_3 \quad \text{with}$$

Transfer Matrix

$$a_1 = \frac{1}{D_x l_{12}} \cdot (M_{11} l_{2d} + M_{12}) = -0.958\, m^{-1}$$

$$a_2 = -\frac{1}{D_x l_{12}} \cdot (M_{11}(l_{12} + l_{2d}) + M_{12}) = 1.380\, m^{-1}$$

$$a_3 = \frac{1}{D_x} = -0.672\, m^{-1}\,.$$

Dispersion

If the bpm's are calibrated and the resolution known, then the rms energy resolution yields:

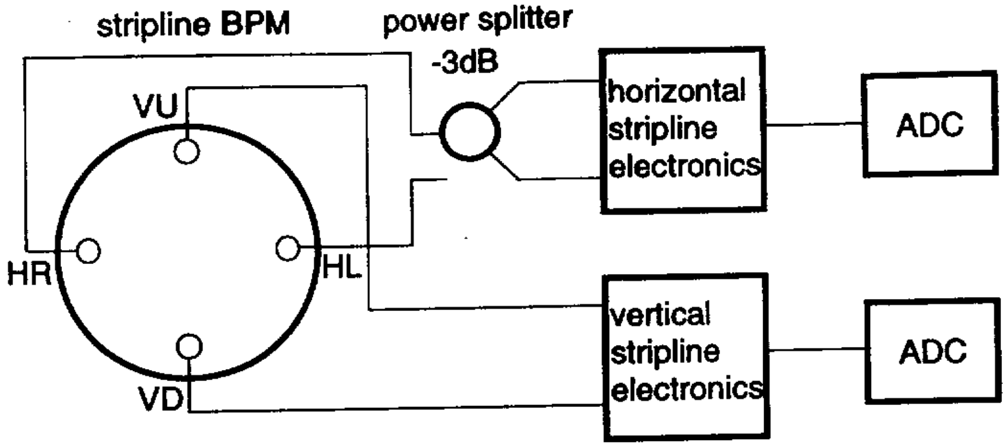
rms resolution of bpm's

$$\frac{\delta p_{res}}{p_0} = \sqrt{\sum_i (a_i \delta x_{i,res})^2} = \underline{1.2\ 10^{-4}}$$

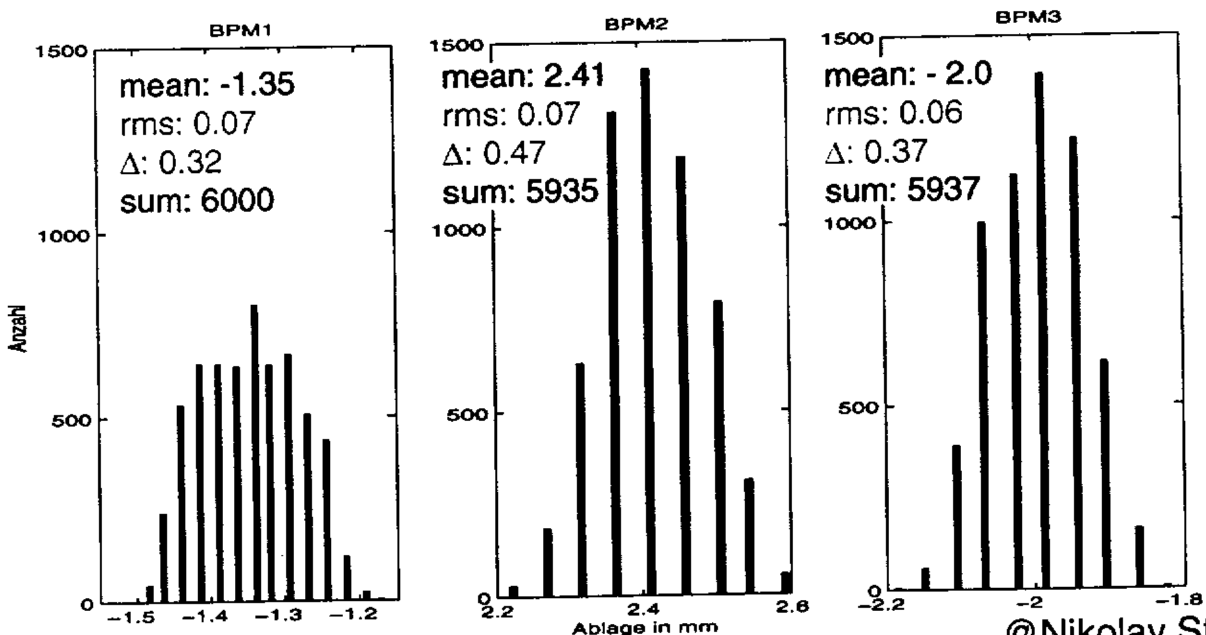
(assumption: bpm noise is statistically independent)

Resolution of BPM's in the experimental area

Experimental setup:



- Measurement (10/01) resolution bunch to bunch at 1 Hz:

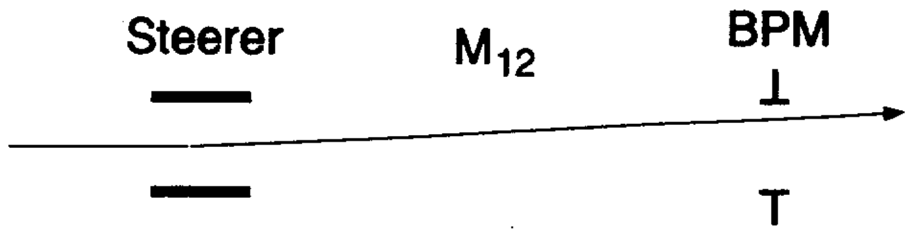


@Nikolay Sturm

- Jitter from electronic noise within a bunch train is expected to be smaller
- Mesurements are planed this week (requires long pulse operation)

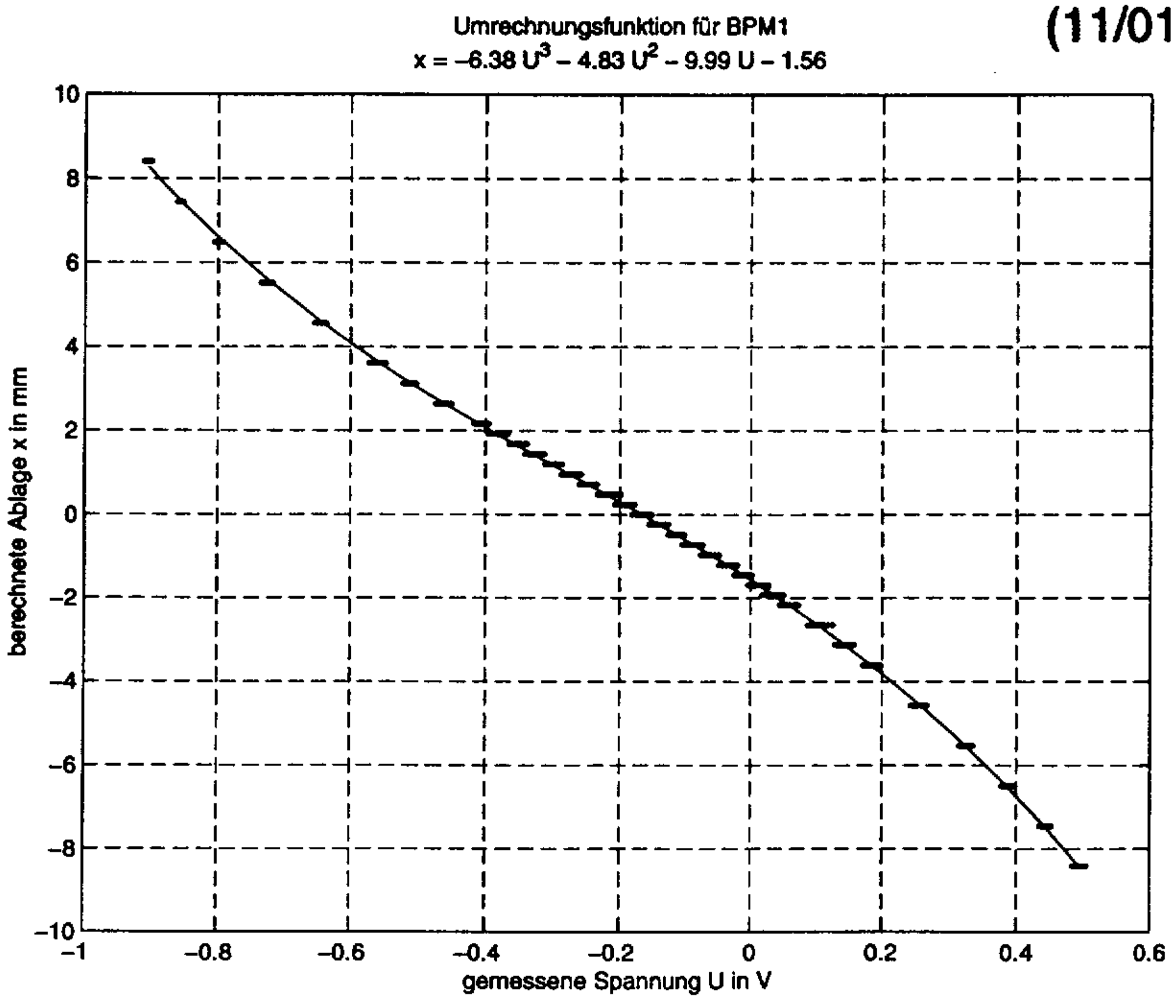
Calibration of BPM's

Using well known steerers to induce kicks to the beam



Example BPM1EXP1:

(11/01)

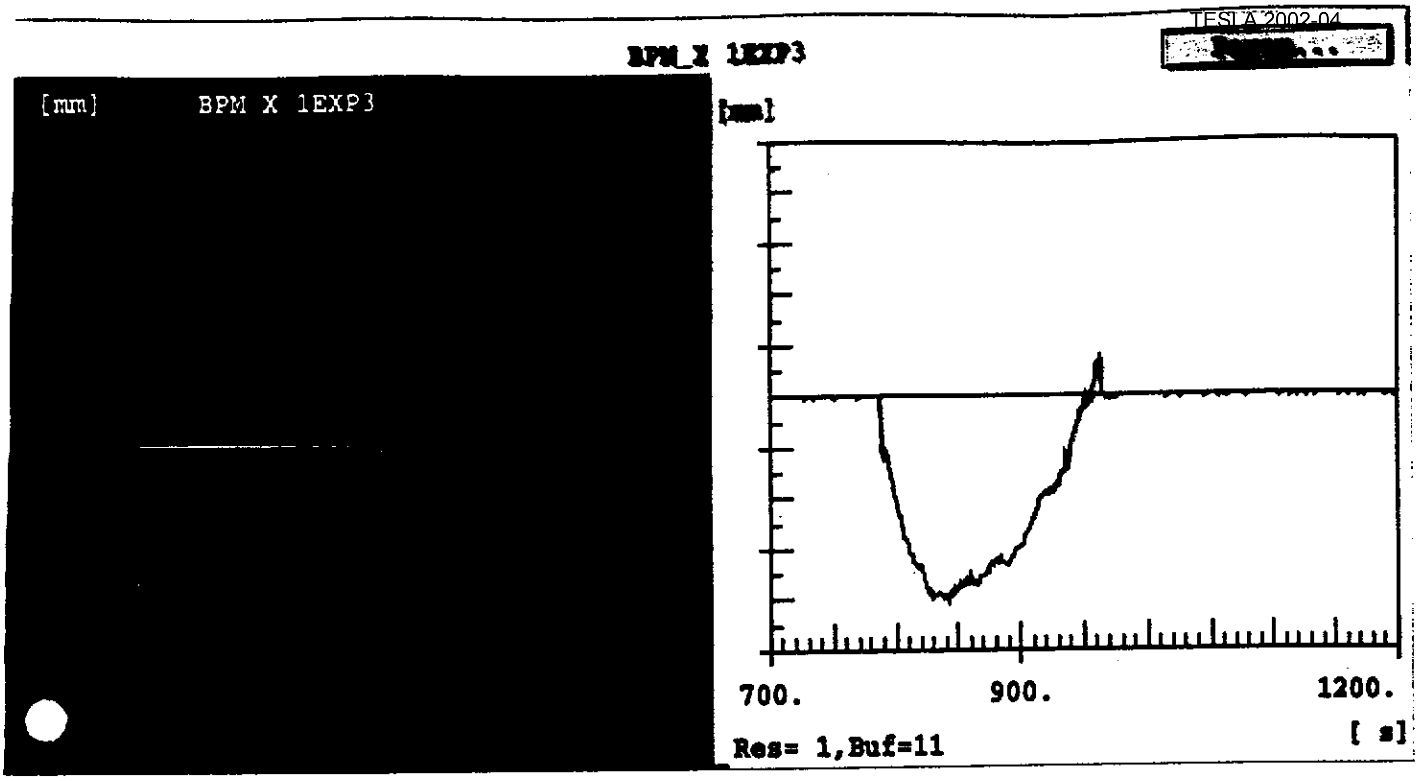


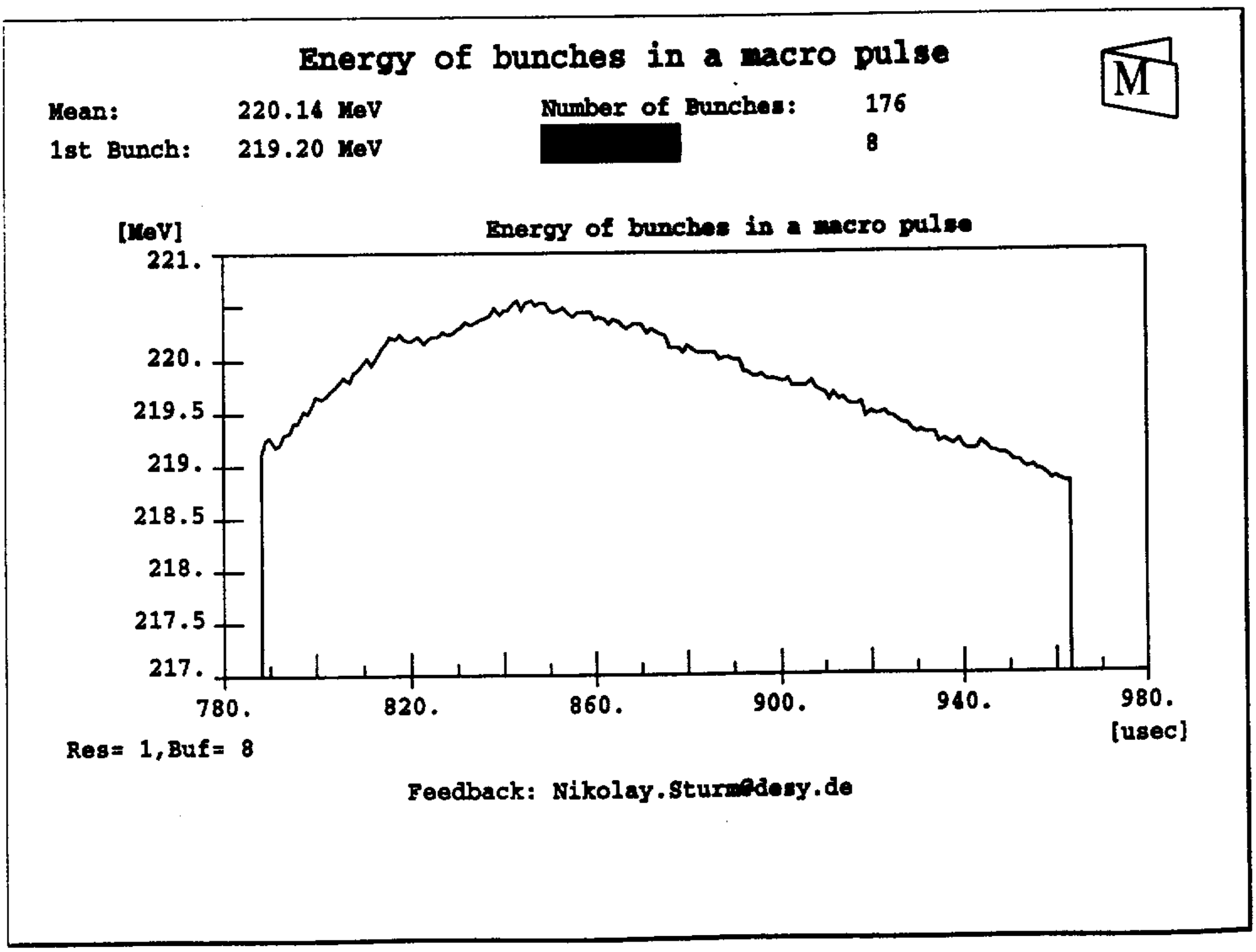
Results for the bpm electronic response functions:

$$x_{\text{BPM1}} = -6,38 \cdot U^3 - 4,83 \cdot U^2 - 9,99 \cdot U - 1,56$$

$$x_{\text{BPM2}} = -17,93 \cdot U^3 - 6,37 \cdot U^2 - 17,30 \cdot U - 0,02$$

$$x_{\text{BPM3}} = -12,74 \cdot U^3 - 7,32 \cdot U^2 - 10,31 \cdot U - 0,13$$





16.Feb.02 20:12.52

Test of Energy Server

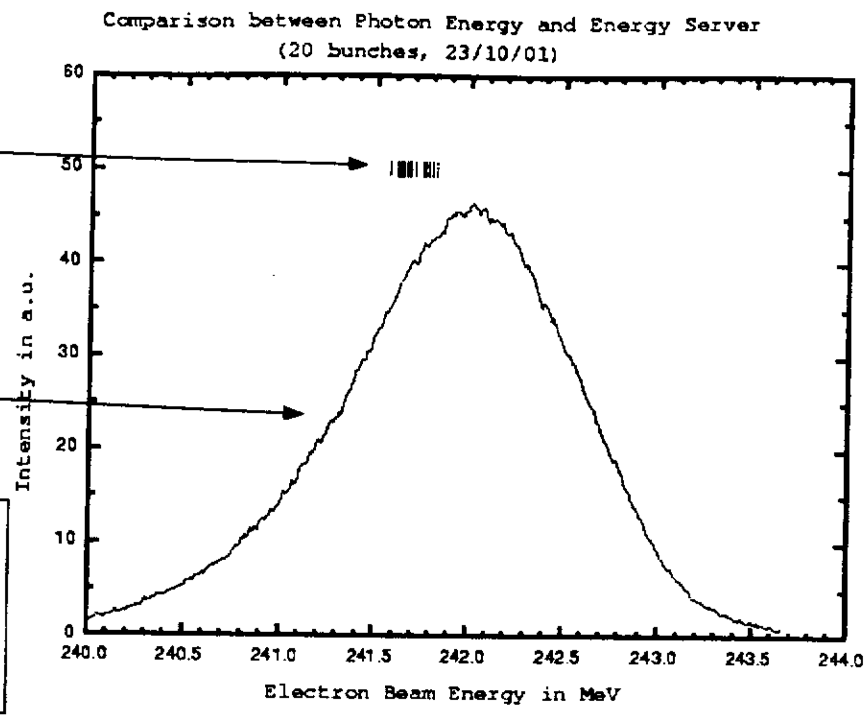
Dipole calibration:

wavelength calculated from bunch energy

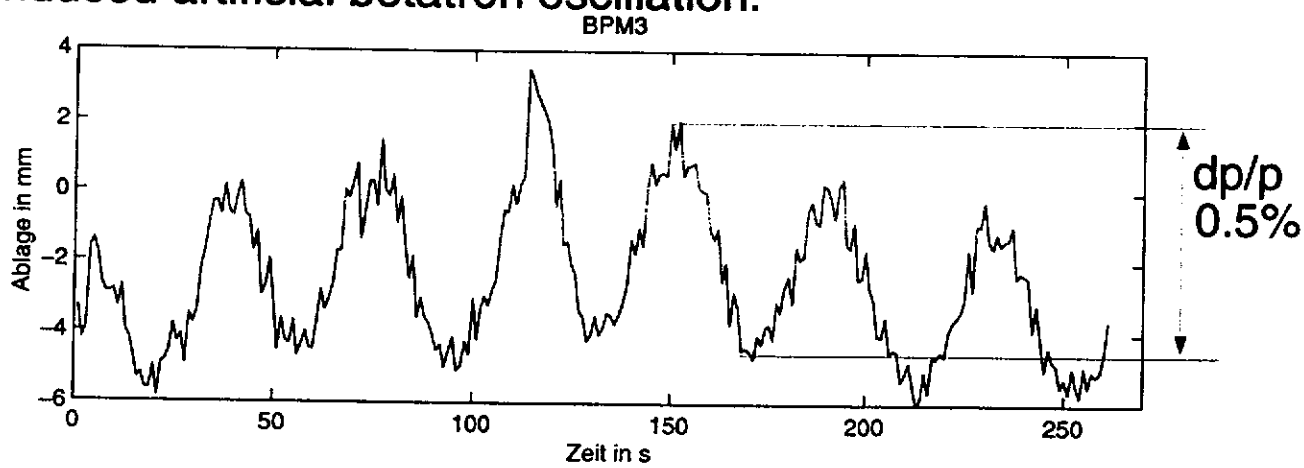
Sase spectrum averaged over several bunches

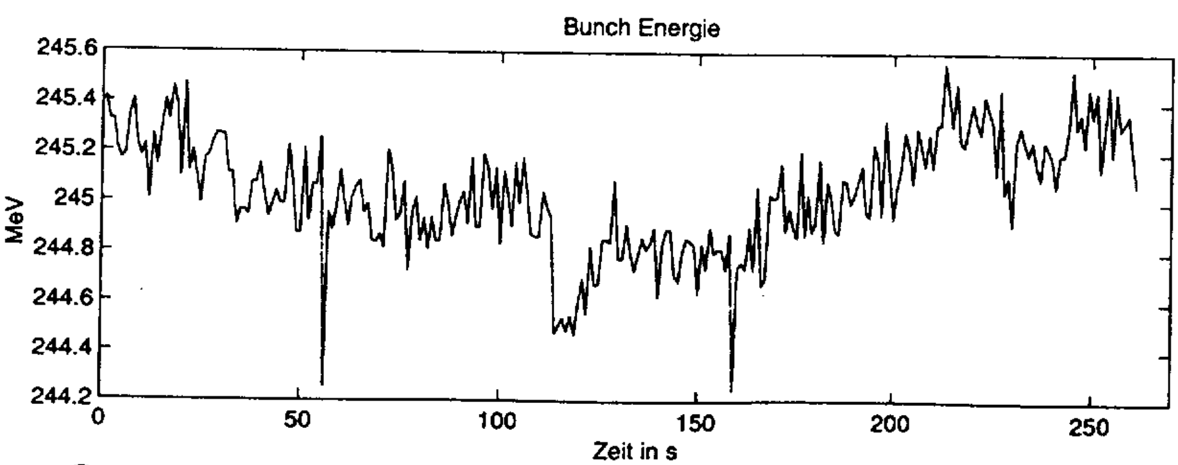
$$E_0 = \frac{2438,5 \pm 1}{\sqrt{\lambda_{\mathrm{Photon}}}}$$

$$E_0 = (8,09 \pm 0,1) \cdot I_{B1}$$



Induced artificial betatron oscillation:

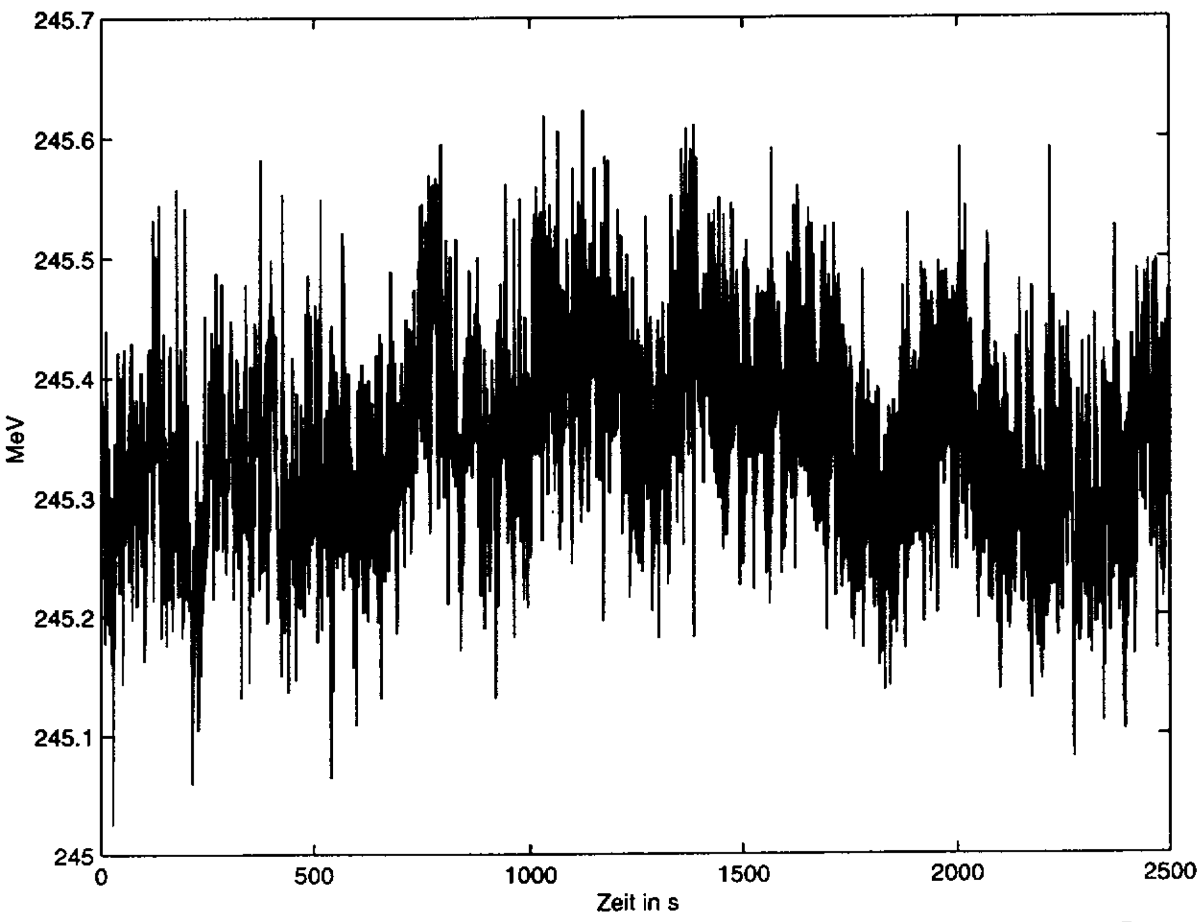




Correction reduces the influence of betratron motion by more than a factor of 10 (in limited meas. range).

Measured Energy Stability

- Varies from time to time and depends on the machine parameters
- Intra-bunch energy spread during the measurements about 1 %
- Energy jitter bunch to bunch at 1 Hz operation.



@Nikolay Sturm

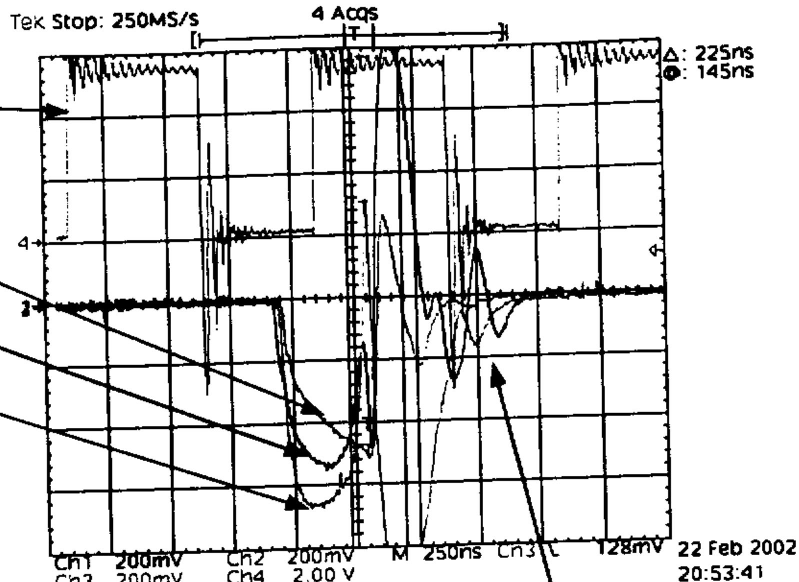
mean E = 245.35 MeV
rms E = 0.09 MeV
rms dE/E = $4 \cdot 10^{-4}$ time = 40 min.

⇒ Energy stability is more than an order in magnetude smaller than the intra-bunch energy spread

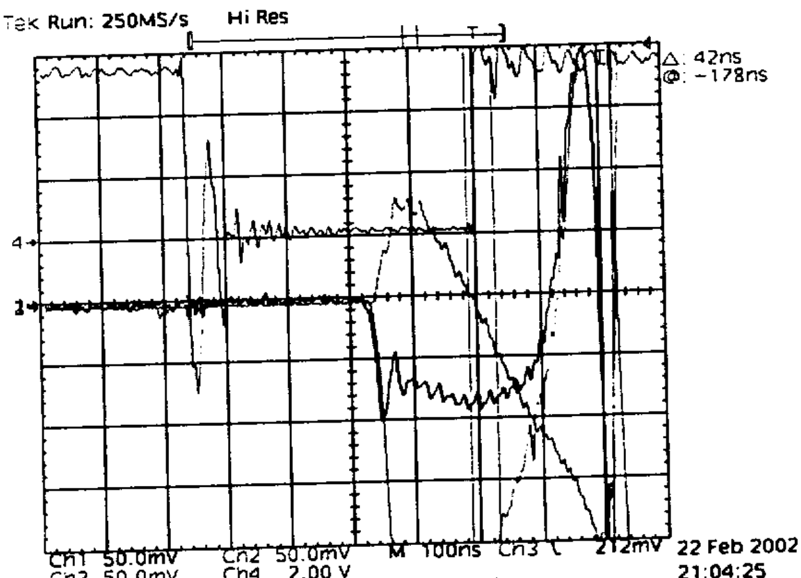
Cross-Talk to trailing Bunch

ADC-Clock

BPM1
BPM2
BPM3

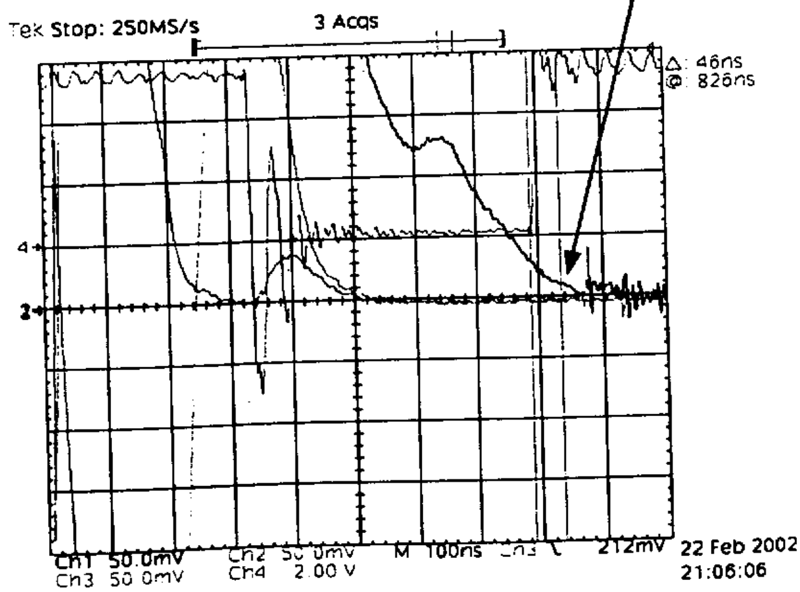


Large oscillations over a long time periode (few 100 ns)



Cross-talk to next bunch

Samlping time of ADCs



2.25 MHz operation with present electronics not possible

Required Steps for High Precision Energy Measurement

- Adjustment of ADC timing
- Recalibration of BPMs with beam (inj & exp ⇒ 4 hours stable beam conditions)
- Measurement of the intra-macro pulse resolution (2 hours beam time/ parasitically possible)
- Implementation to the server (is a server also for the injector desired ?)
- Test of servers (2 hours stable beam conditions)

⇒ major hardware changes are not expected

S. Simrock

"Limits in the amplitude and phase control for 2x7-cell superstructure and for standard cryomodule at 2MV/m and 15 MV/m operation"

LLRF for Superstructure Test

Stefan Simrock

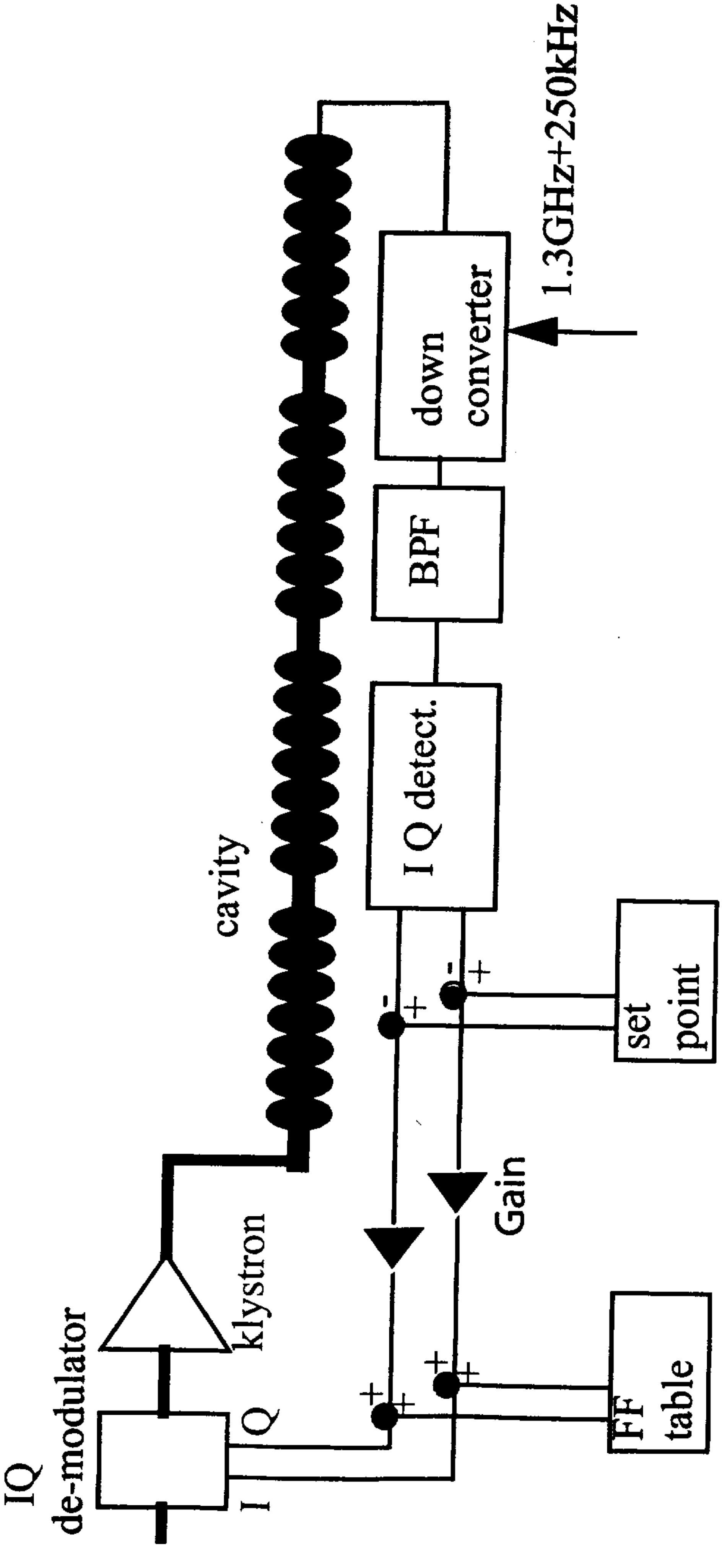
DESY

LLRF Parameters

- Operational
  - Medium (15 MV/m) and low gradient (2.5 MV/m)
    ... for ACC1(SS) and ACC2
  - Long beam pulses (up to 8 mA, 800 μs)
    ... 1 MHz and 54 MHz with current modulation

- Expected field stability with adaptive feedforward
  - $\Delta E_{acc} < 0.02$ MV/m
  - $\Delta\phi < 0.05$ deg. (15 MV/m), 0.3 deg. (2.5 MV/m)

  Note : assumes $\Delta I_b/I_b < 5\%$ within bunch train at 8 mA
  $\Delta I_b/I_b < 0.5\%$ pulse to pulse at 8 mA



1.3GHz+250kHz
down converter
BPF
I Q detect.
cavity
set point
Gain
klystron
IQ de-modulator
Q
I
FF table

LLRF for Superstructure (SS) Test

- RF Control
  - Separate klystron for SS- and 8 cav. cryomodule
  - Split 24 cav. LINAC system (24 cav.) in 2 x 8 cav. systems
    ... 8 probes for 2 x 2x7-cell cavity superstructure
  - control vector sum of 2 SS cavities
  - implement bandpass filter at downconverter output
  - modify LO tables for continuous phase shift
  - remote controlled waveguide tuners
- RF diagnostic
  - precise detuning measurements
    ... for cavity field flatness, microphonics, Lorentz force
  - high resolution and wide band gradient detection
    ... measure excitation of passband modes
  - measurement of IQ or A&P transfer function with lock-in

LLRF Tests with Superstructure

Contact Person: V. Ayvazyan (x4912), Stefan Simrock (x4556), H. Weddig (x4910)

Objectives:

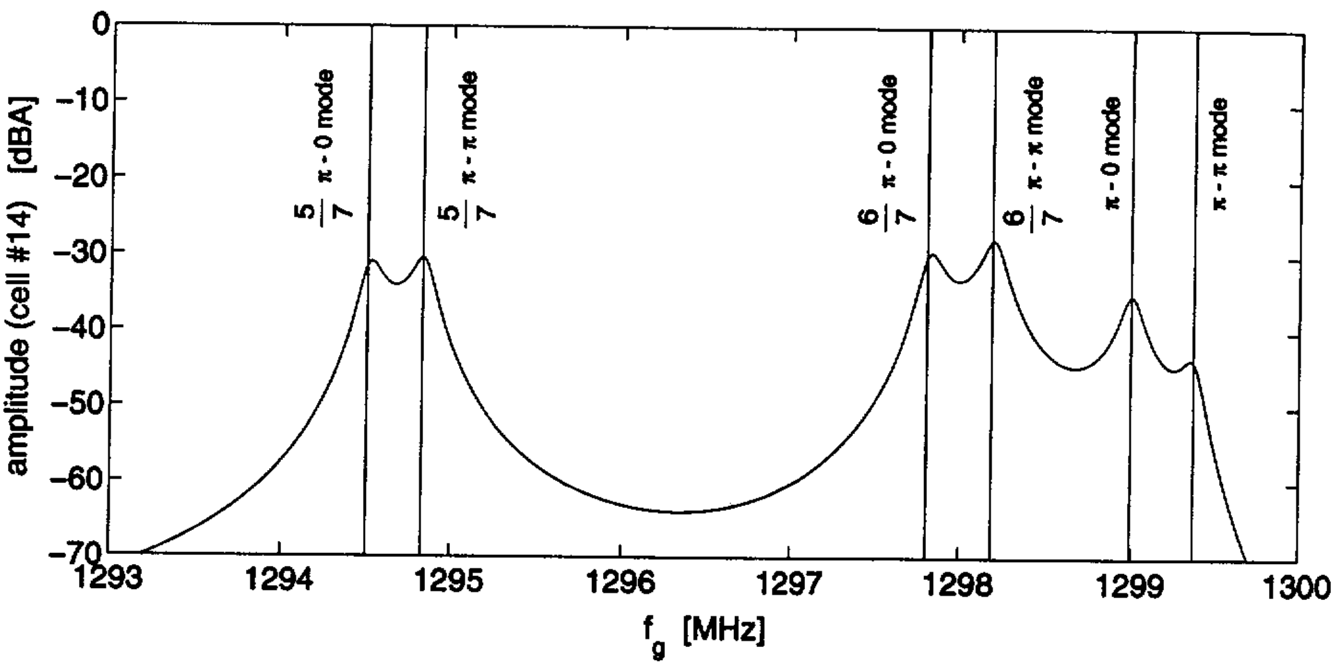
1. Determine LLRF performance limitations in presence of beam loading at low (2 MV/m) and medium (10-15 MV/m) gradients with/without passband filter.
   - Note : expected stability is 0.25 MV/m (rms) at all gradients
2. Measure excitation of other passband modes by beam and generator

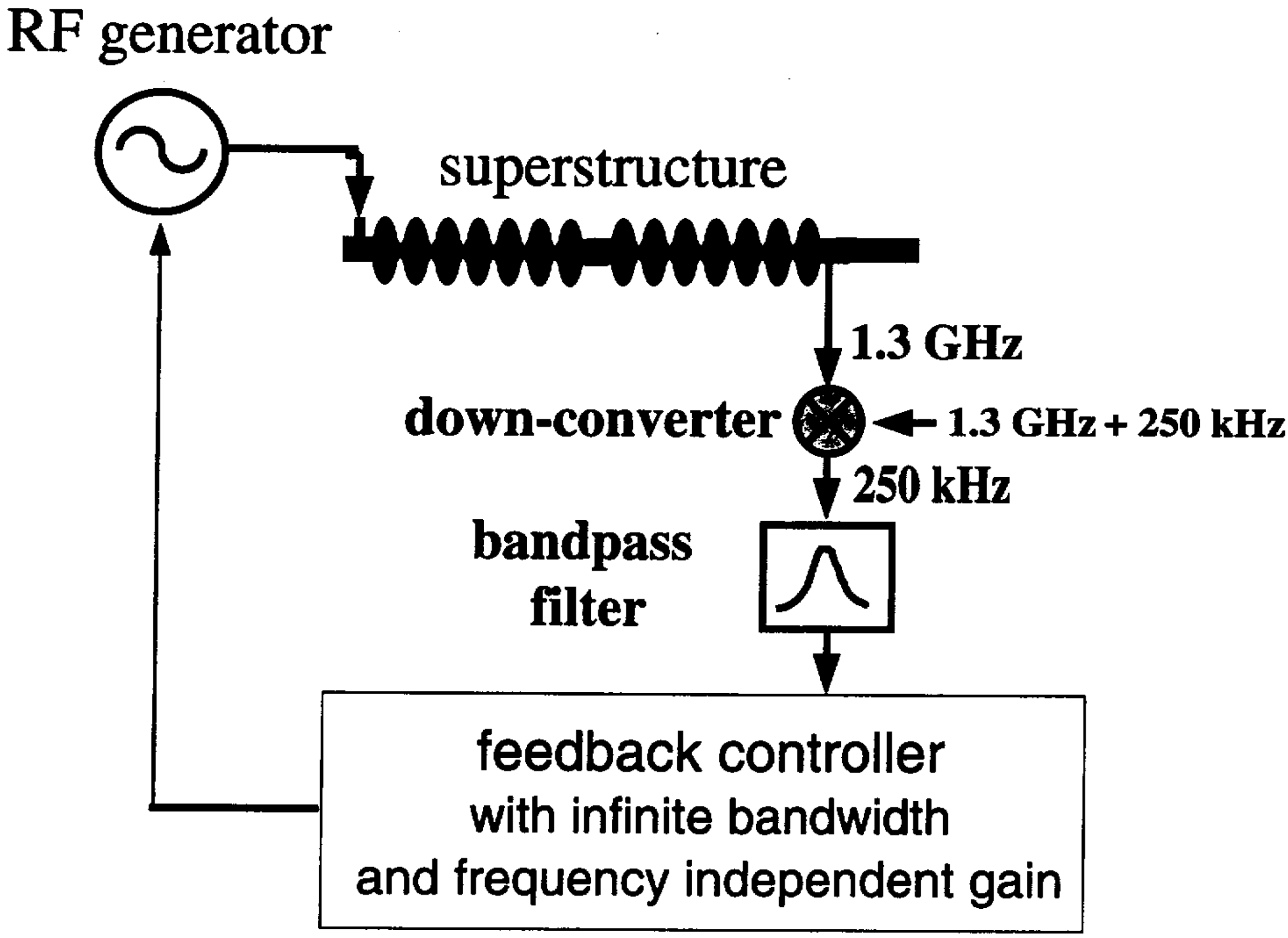
Prerequisites:

- Modified LLRF control with/without bandpass filters for 2 probe signals.
  - filter from 50-150 kHz around 250 kHz
  - Modify LO for sinusoidal operation (9*4 = 36 points on circle at 9 MHz)
- Remote control for waveguide tuners
  - Adjust phase of incident wave and loaded Q
- Monitoring of all 8 probe signals (2 per cavity)
- Detector for excitation of other passband modes (8 cavity probe signals).
  - Diode bandwidth few MHz
  - Downconverter bandwidth 30 MHz with 0.5 deg. rms phase noise (= 1 %)
  - Need digital lock-in to measure with high resolution of measurement.
- Precise detuning measurement for superstructures (accuracy 1 Hz averaged).
- Beam energy measurement (to resolve 1e-4 fluctuations of cavity field for individual bunches).
- List of passband modes with coupling to beam and generator.
- Precise measurement of bunch charge (1%) and bunch to bunch fluctuations.

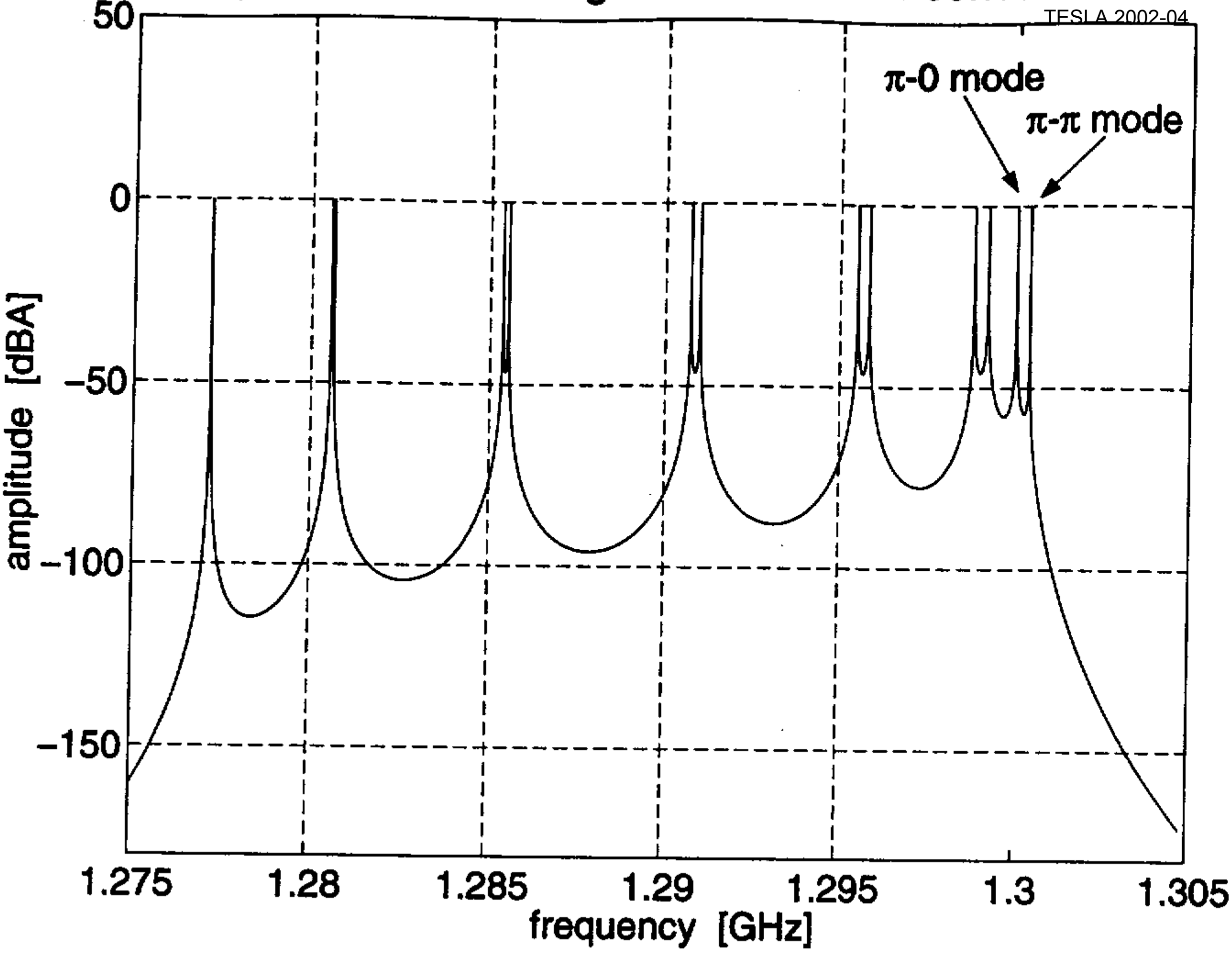
Detailed Procedure:

1. Gradient and phase stability
   - Feedforward only
   - Feedback, determine maximum gain with/without bandpass filter
   - Gradient and phase calibration with beam
2. Waveguide tuner
   - adjust for on-crest operation in both superstructures
   - adjust loaded Q equally
3. Excitation of passband modes
   - generator and/or beam, with/without filter, differenent beam currents, feedback gain, and gradients.
   - time domain and spectrum, identify which modes are excited
   - determine coupling of beam and generator to passband modes.
4. Cavity tuning
   - Adjust for best field flatness. Requires to know Hz/step each tuner and to determine ratio of stored energies (proportional to frequency change of SS versus detuning of individual cavities).

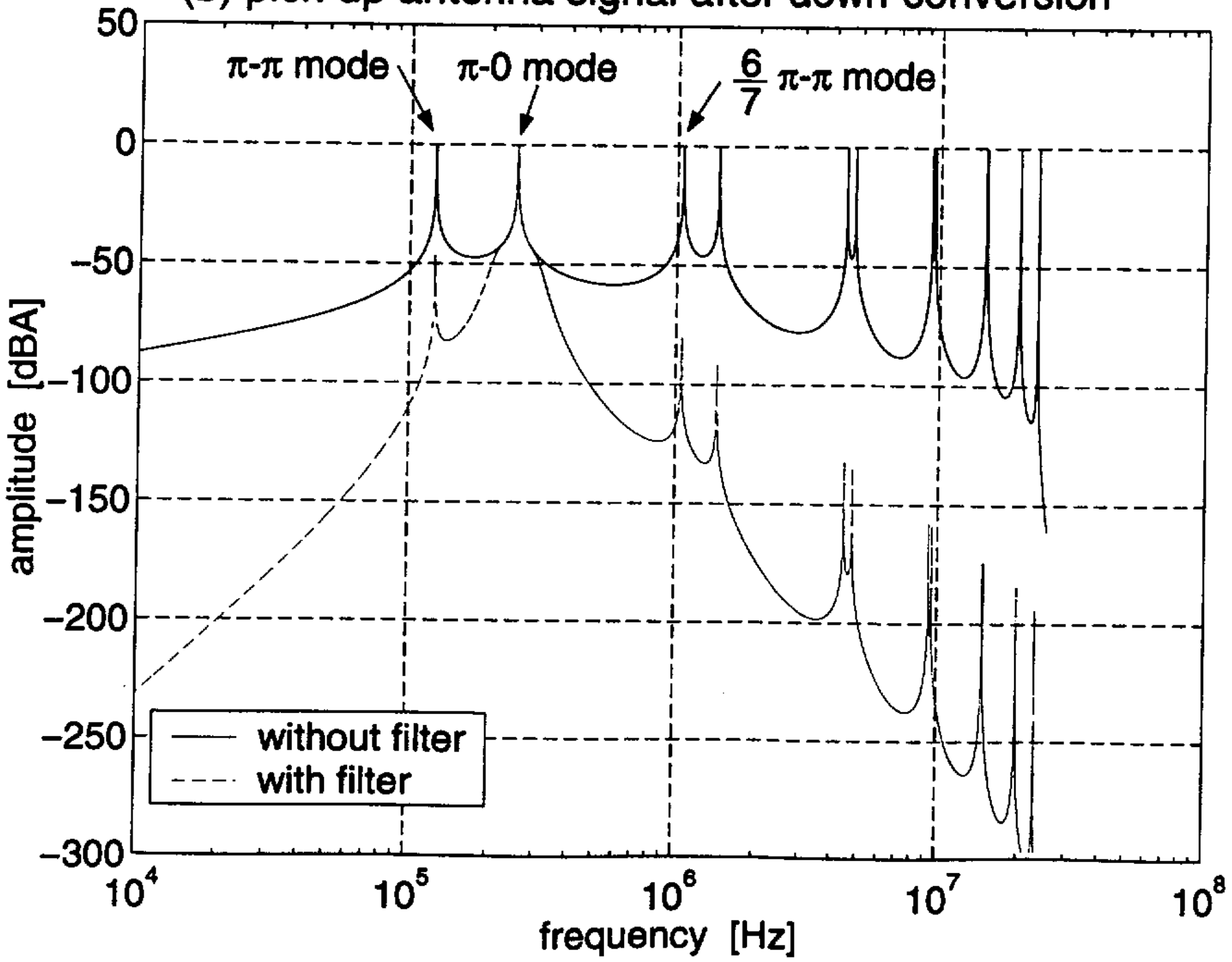

amplitude (cell #14) [dBA]
0
−10
−20
−30
−40
−50
−60
−70
1293
1294
1295
1296
1297
1298
1299
1300
f_g [MHz]
5/7 π - 0 mode
5/7 π - π mode
6/7 π - 0 mode
6/7 π - π mode
π - 0 mode
π - π mode

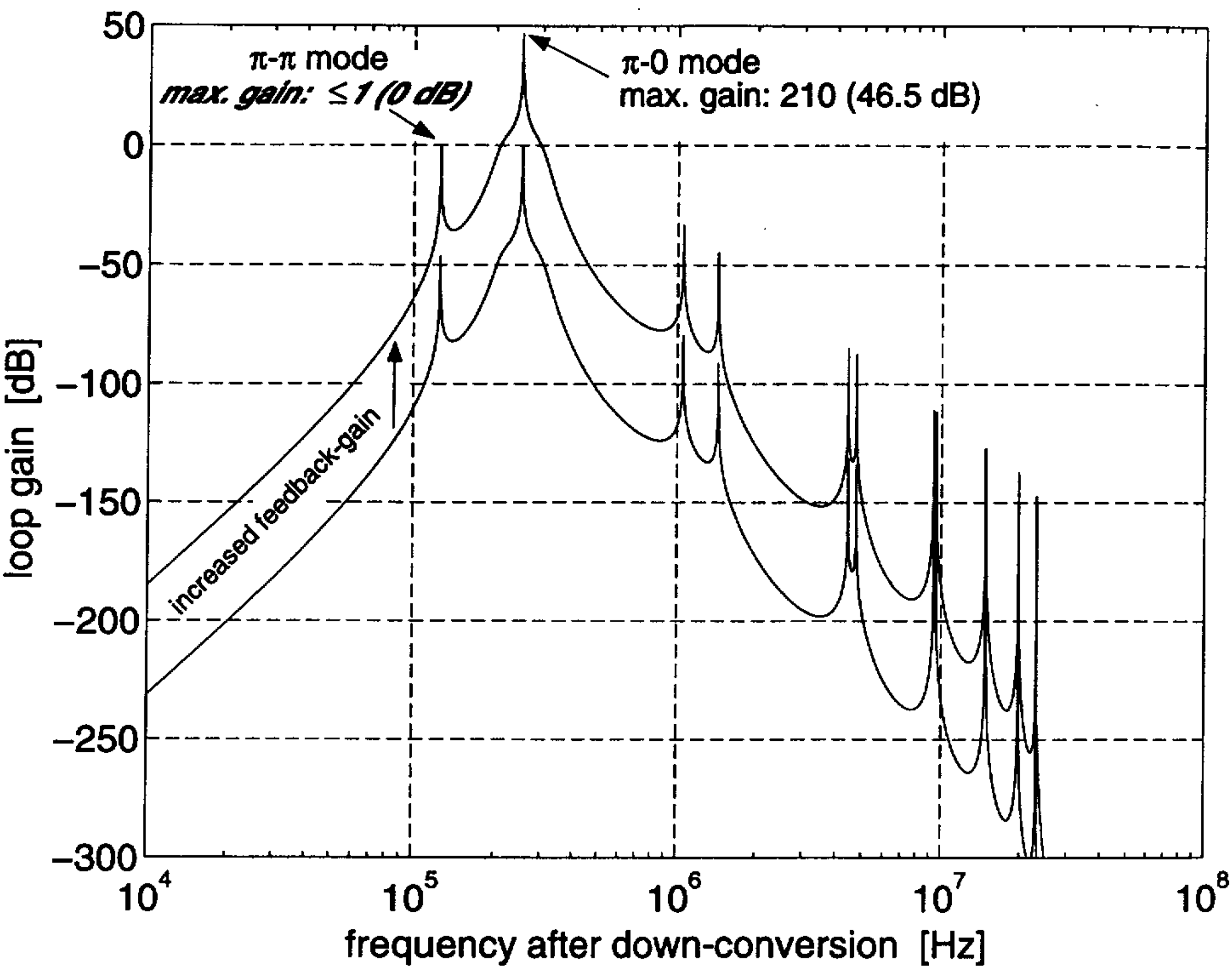

RF generator
superstructure
1.3 GHz
down-converter
1.3 GHz + 250 kHz
250 kHz
bandpass filter
feedback controller
with infinite bandwidth
and frequency independent gain

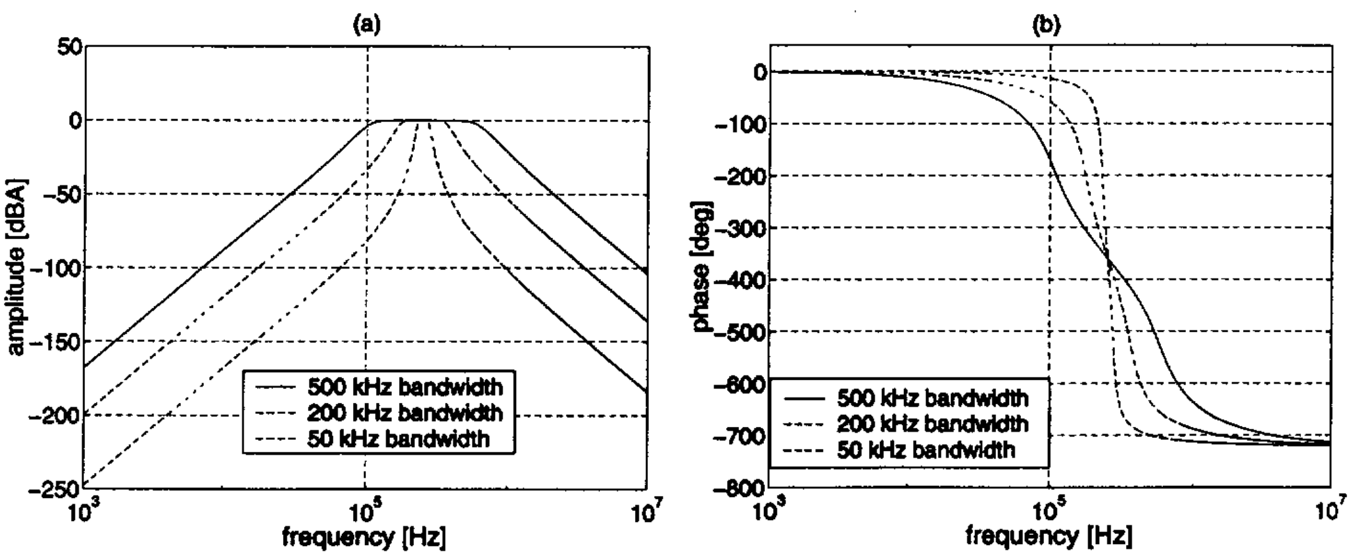
(a) pick-up antenna signal before down-conversion



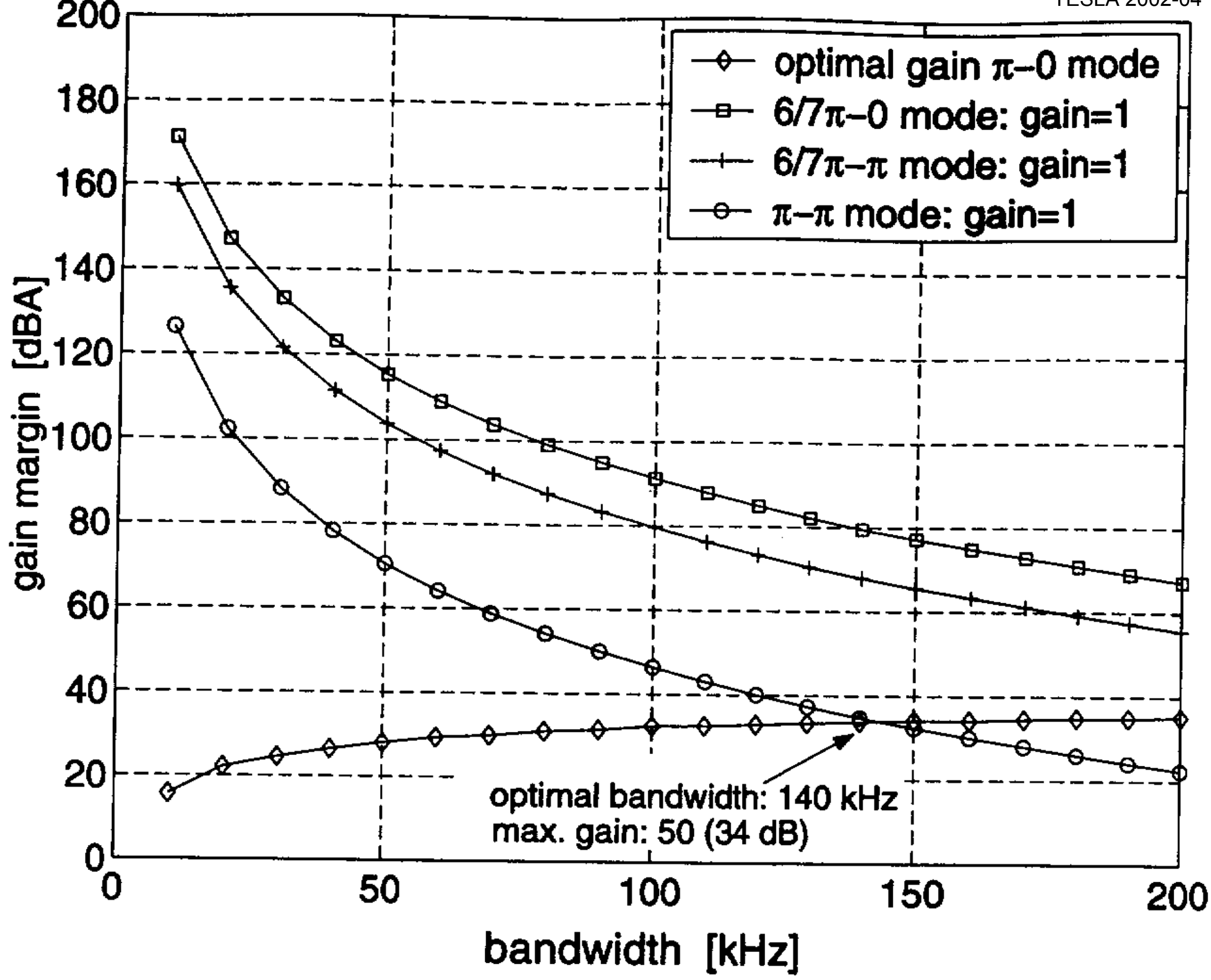
(b) pick-up antenna signal after down-conversion



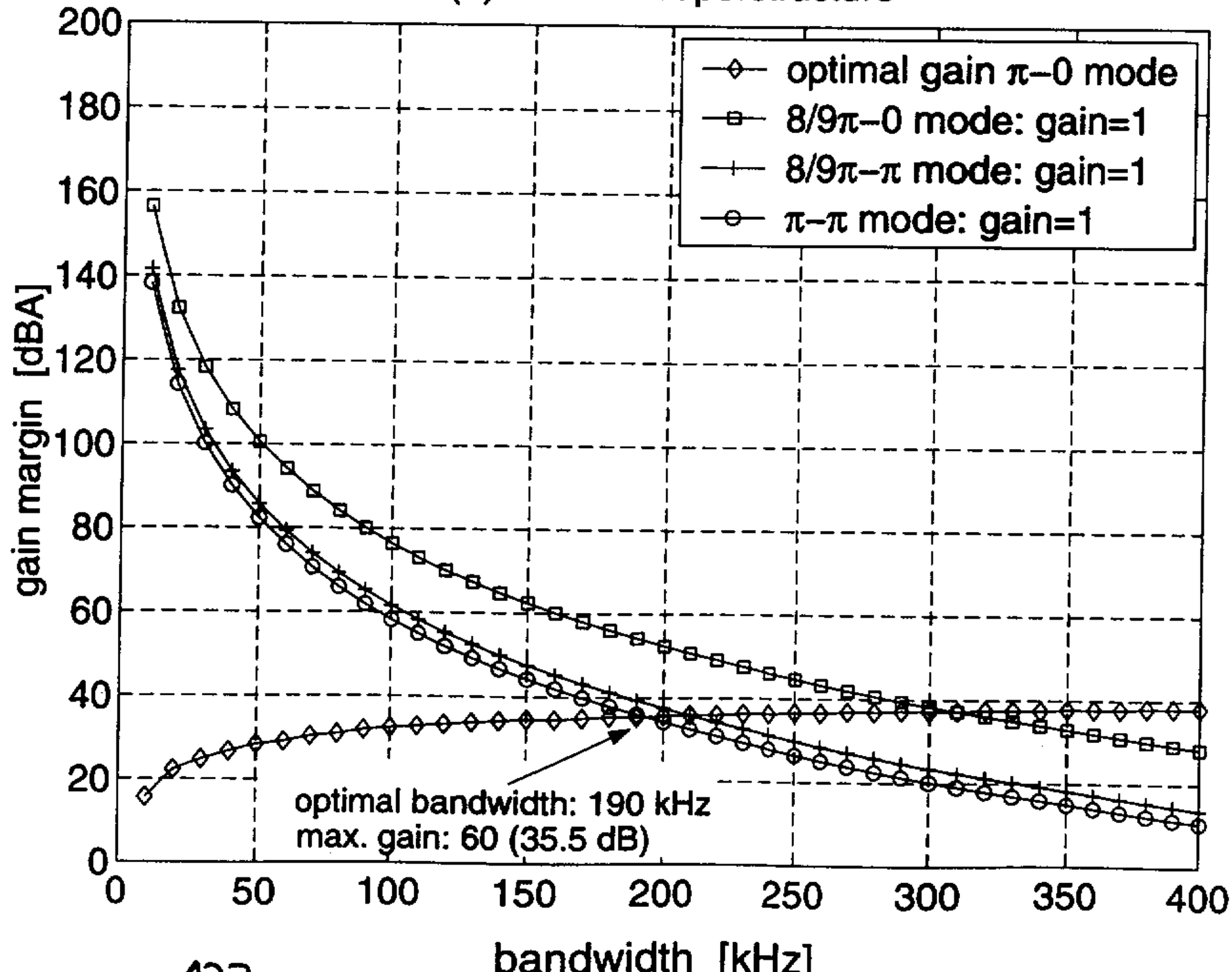

π-π mode
max. gain: ≤ 1 (0 dB)
π-0 mode
max. gain: 210 (46.5 dB)
increased feedback-gain
loop gain [dB]
frequency after down-conversion [Hz]
50
0
−50
−100
−150
−200
−250
−300
10^4
10^5
10^6
10^7
10^8


(a)
amplitude [dBA]
50
0
-50
-100
-150
-200
-250
10^3
10^5
10^7
frequency [Hz]
500 kHz bandwidth
200 kHz bandwidth
50 kHz bandwidth
(b)
phase [deg]
0
-100
-200
-300
-400
-500
-600
-700
-800
10^3
10^5
10^7
frequency [Hz]
500 kHz bandwidth
200 kHz bandwidth
50 kHz bandwidth

(a) 2x7-cell superstructure



(b) 2x9-cell superstructure



LLRF Measurements

- RF Control Performance
  - gradient and phase stability
    - ... rf and beam energy measurements
    - ... noise sources (beam, microphonics, Lorentz force)
    - ... Adaptive feedforward
  - Loop stability with/without bandpass filter
- Cavity Tuning
  - field flatness
  - resonance frequency
- Other RF measurements
  - excitation of passband modes by rf and beam
  - gradient and phase calibration (beam based)

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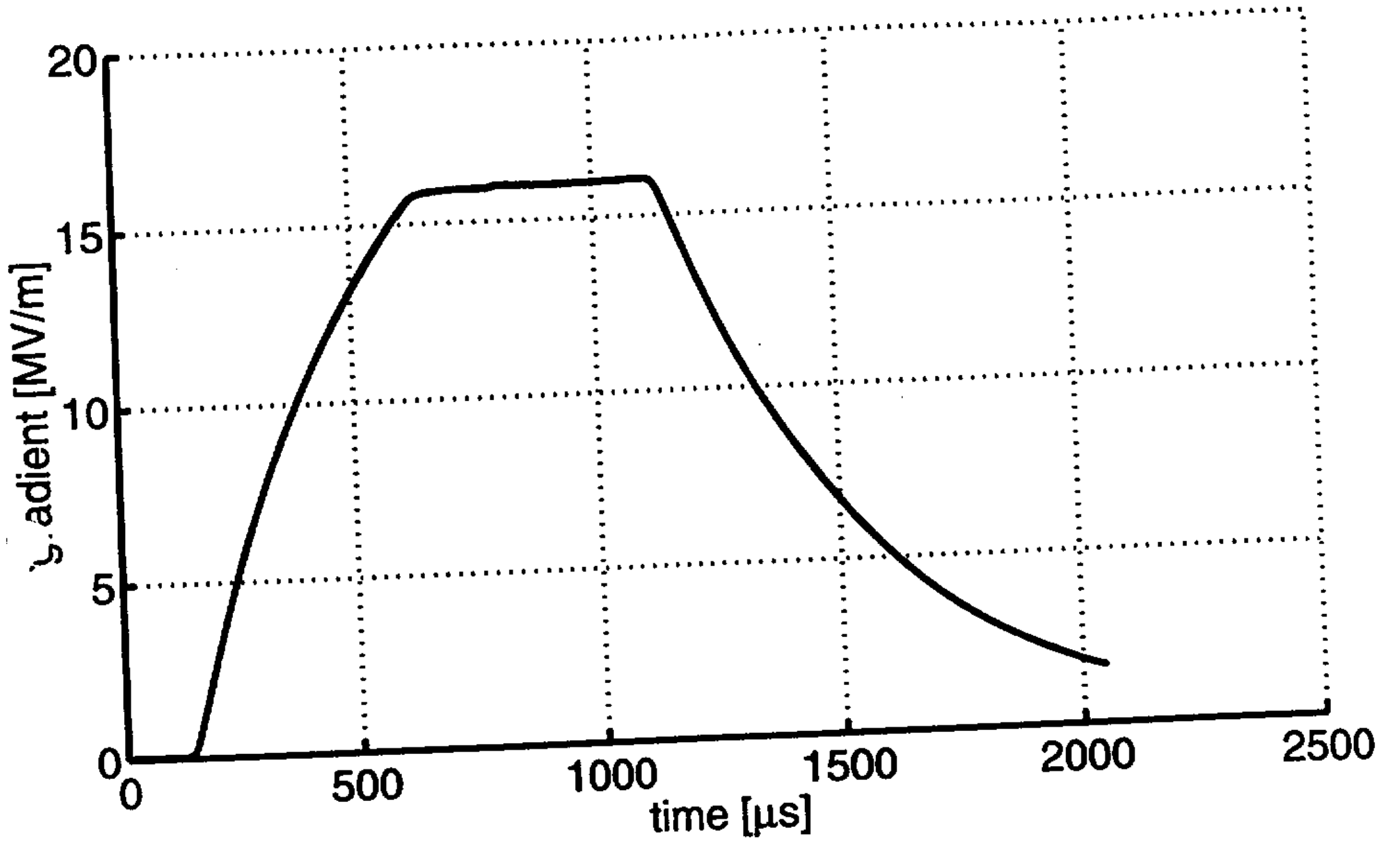
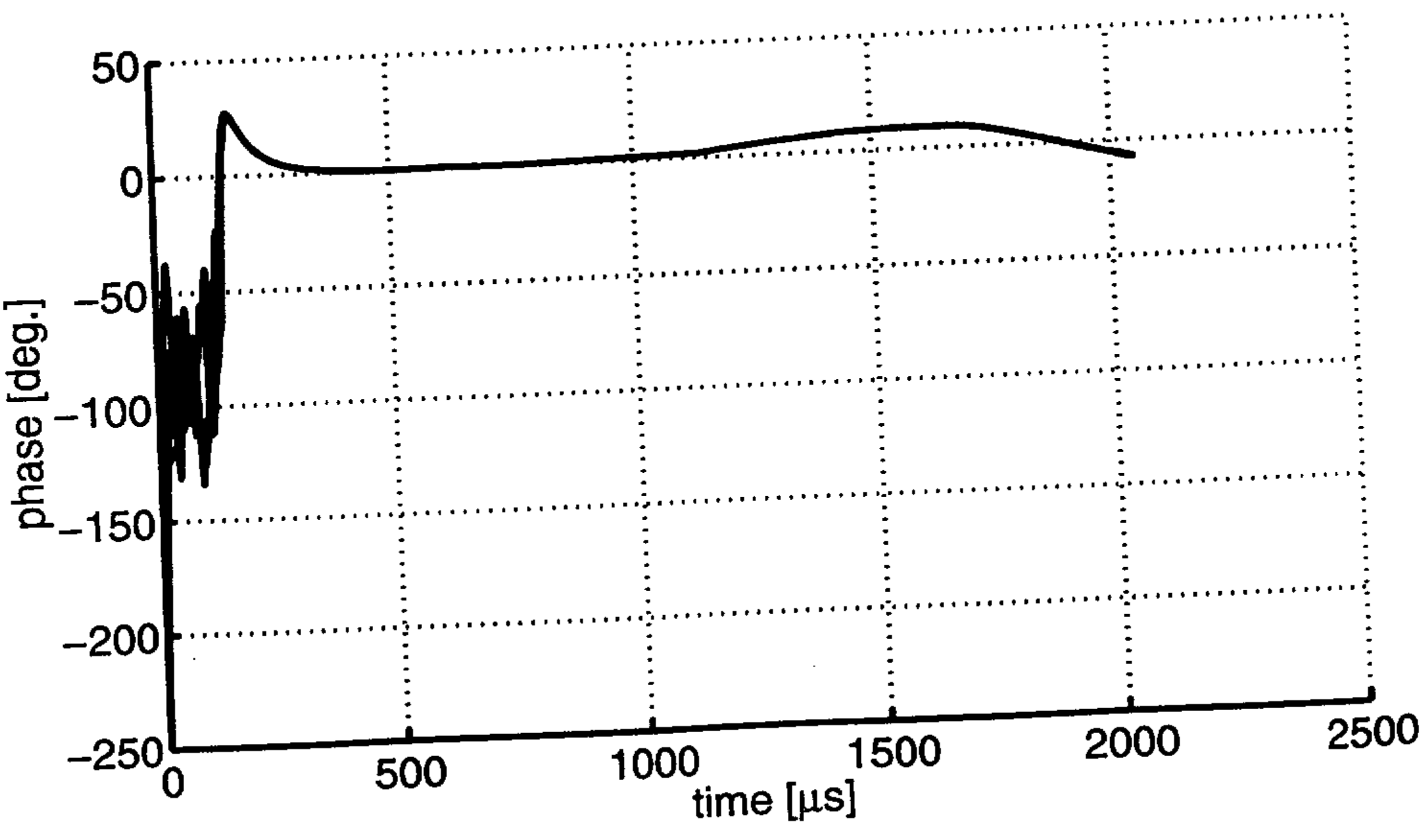
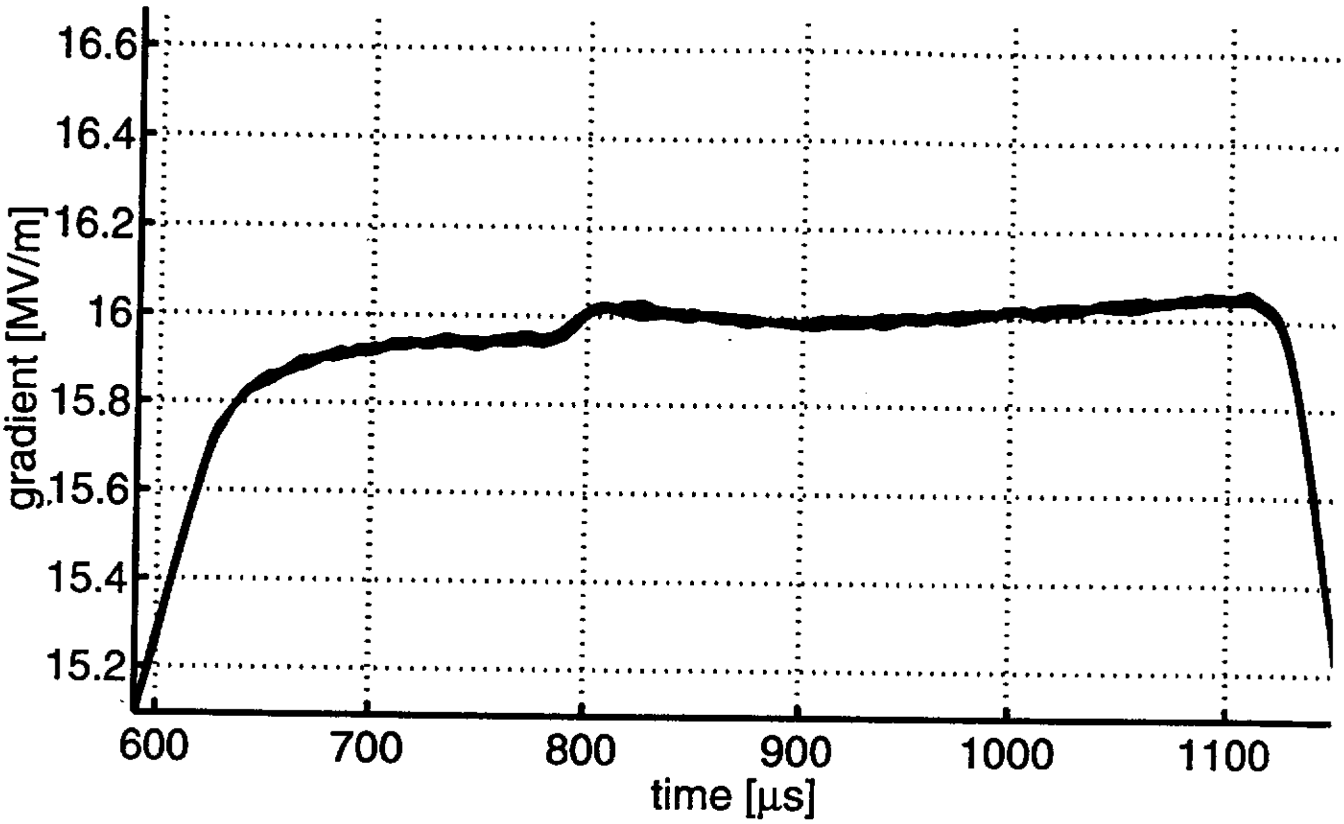
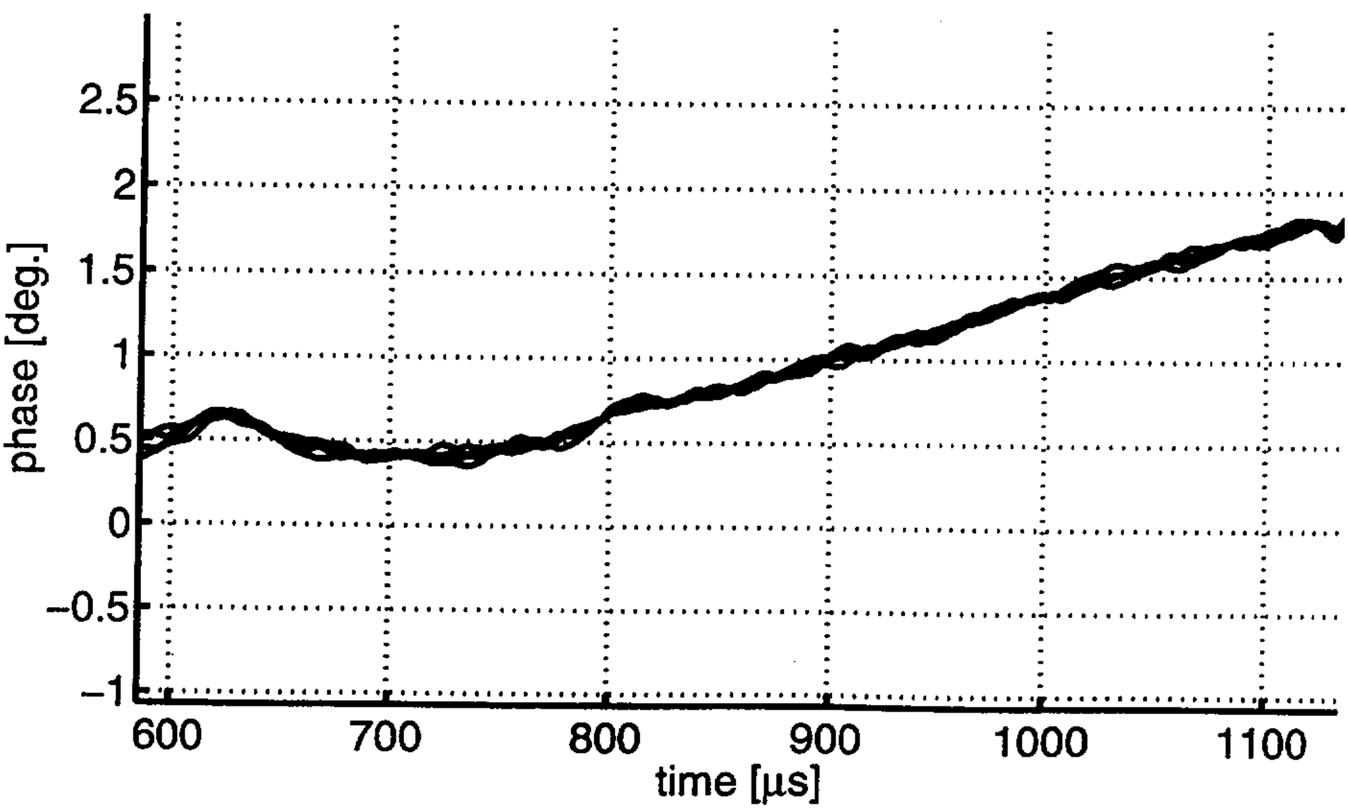


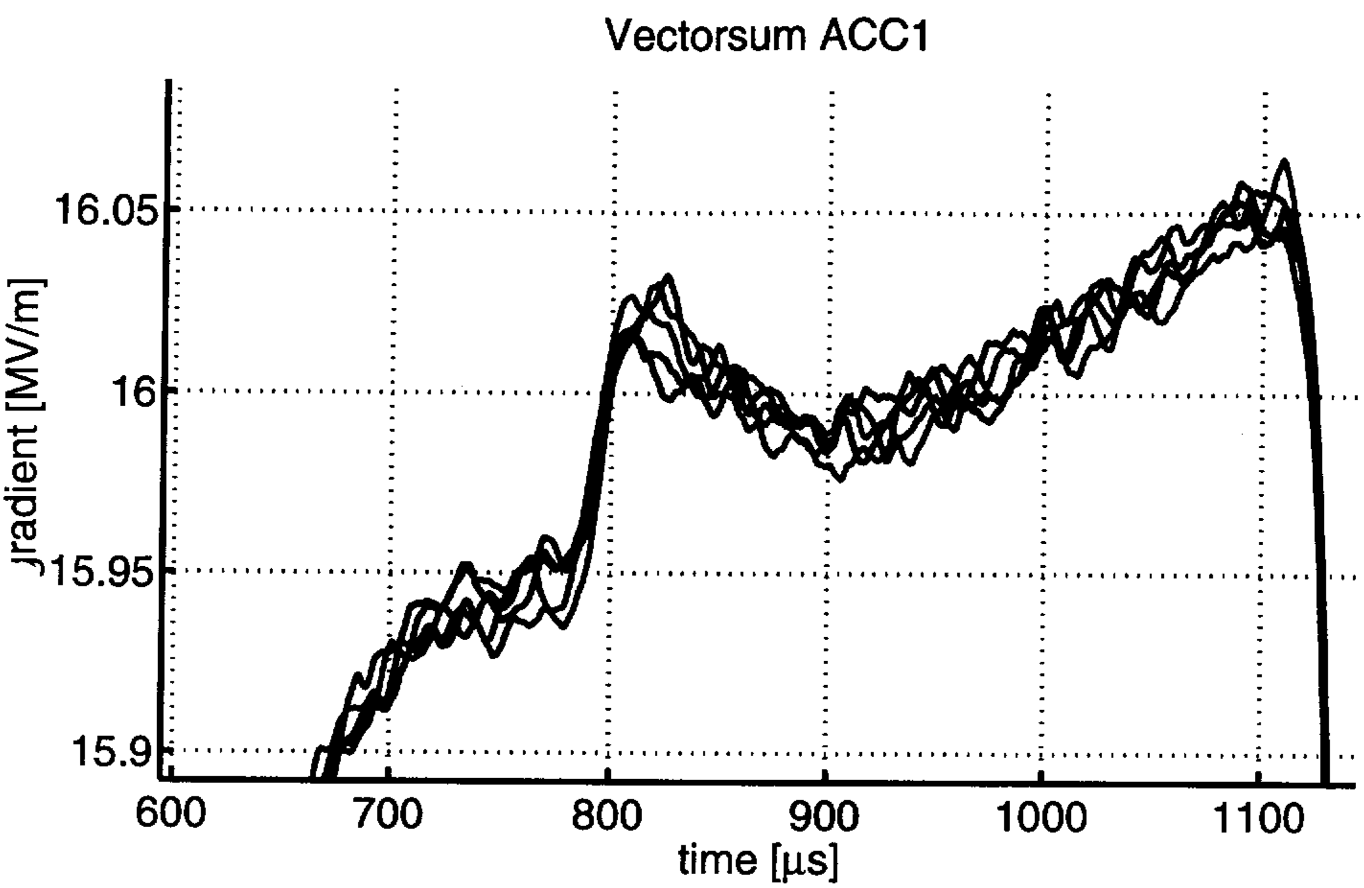
20
15
10
5
0
gradient [MV/m]
0
500
1000
1500
2000
2500
time [µs]

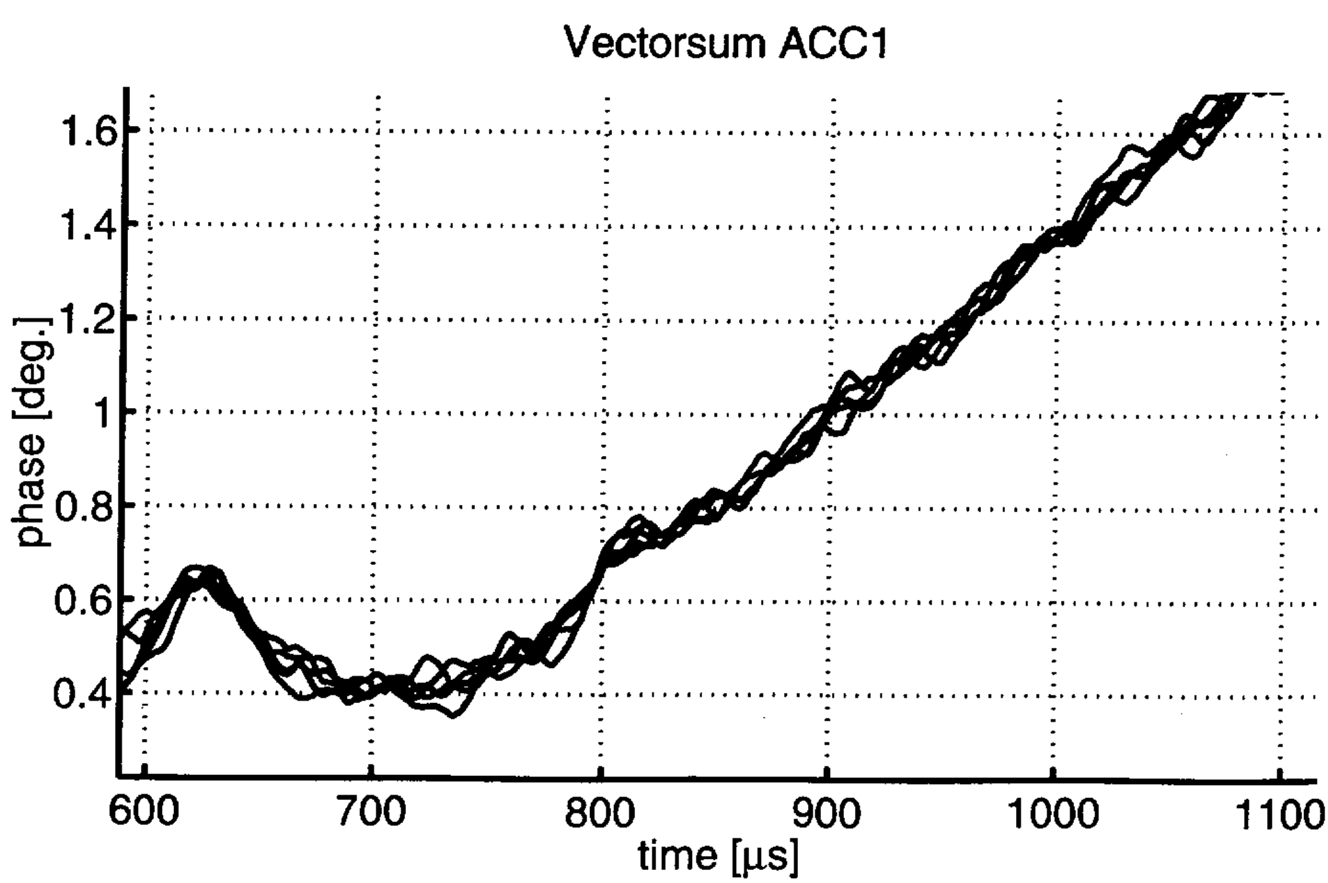


50
0
−50
−100
−150
−200
−250
phase [deg.]
0
500
1000
1500
2000
2500
time [µs]

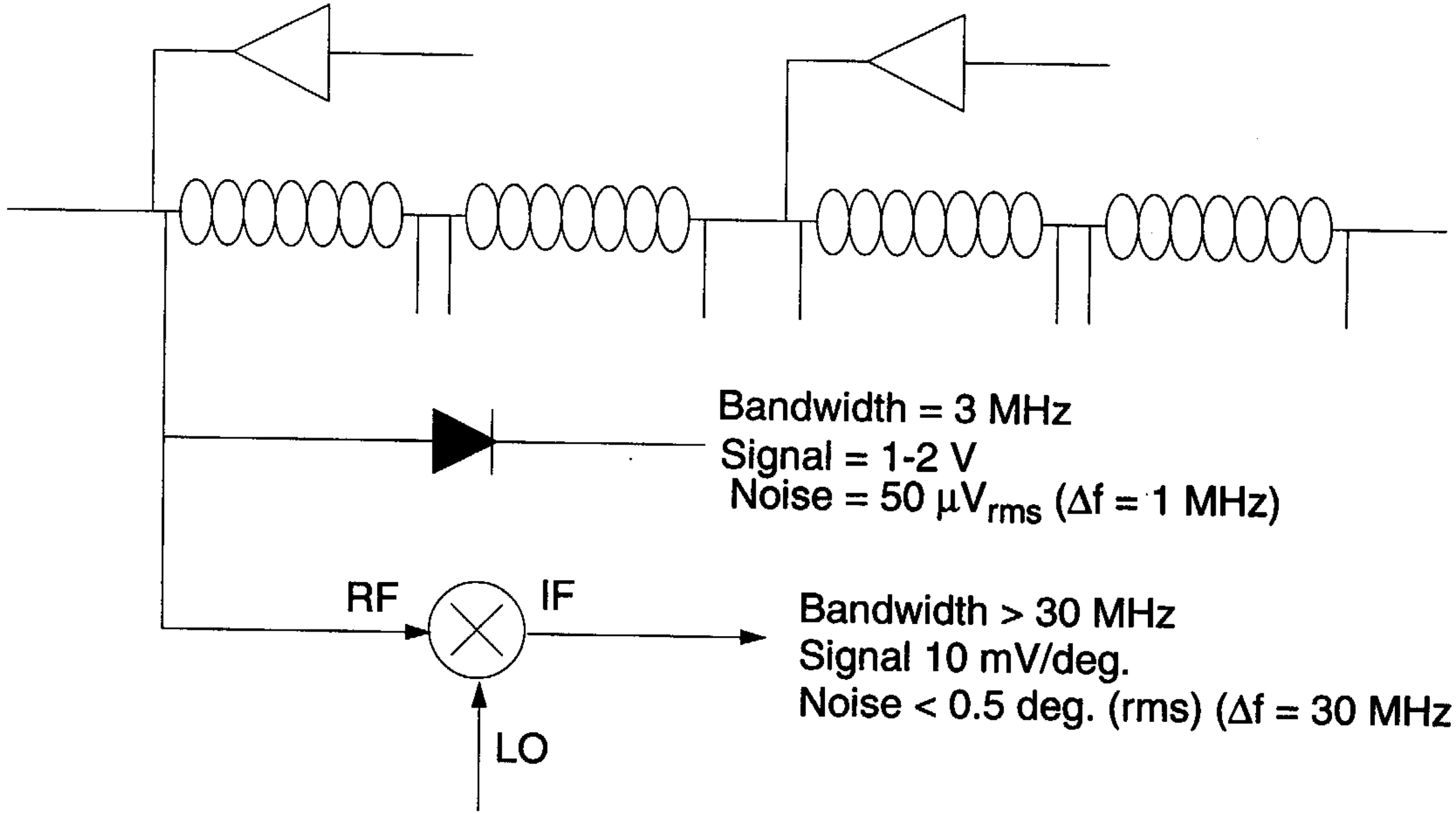

16.6
16.4
16.2
16
15.8
15.6
15.4
15.2
gradient [MV/m]
600
700
800
900
1000
1100
time [µs]

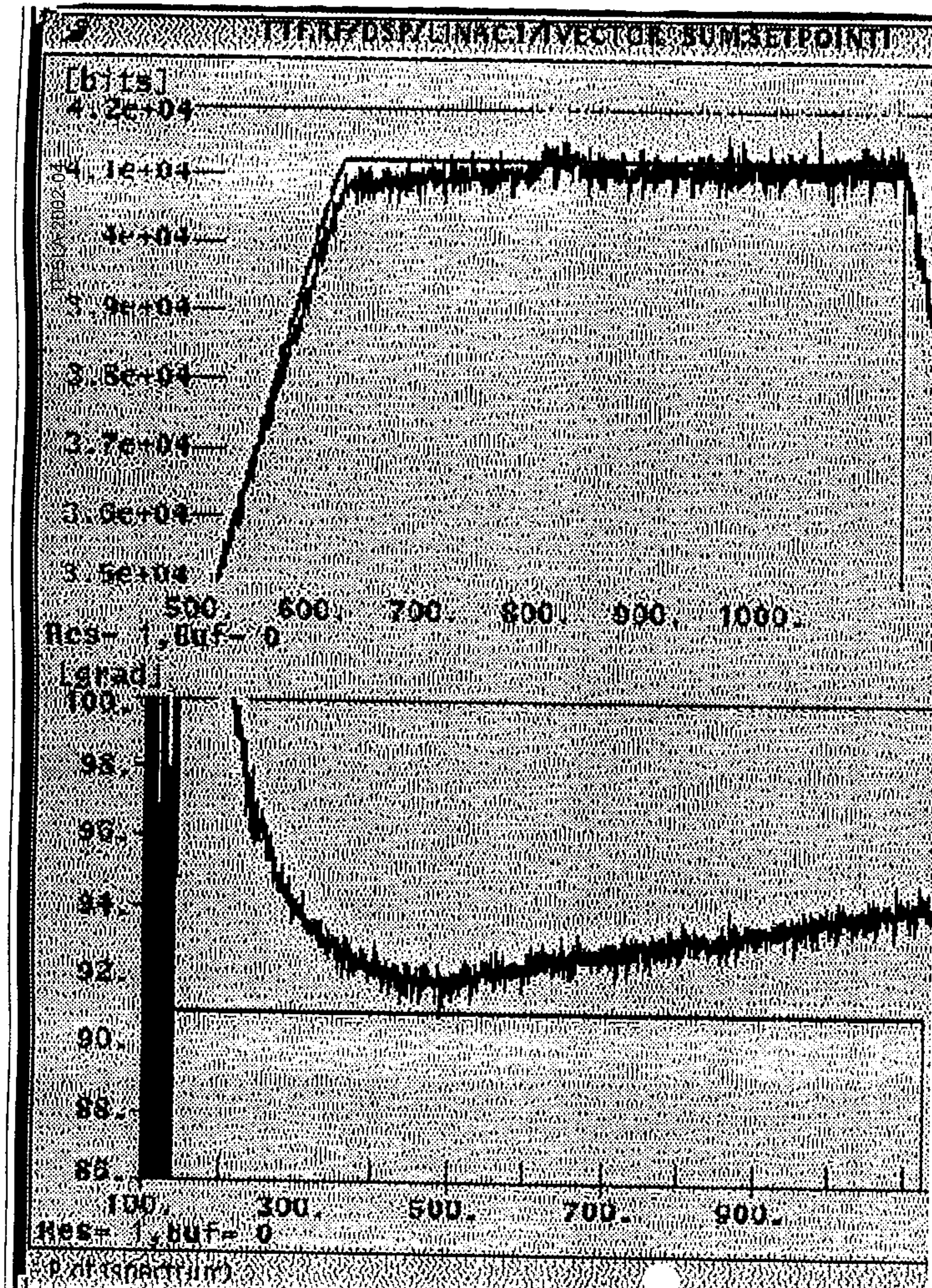

2.5
2
1.5
1
0.5
0
−0.5
−1
phase [deg.]
600
700
800
900
1000
1100
time [µs]

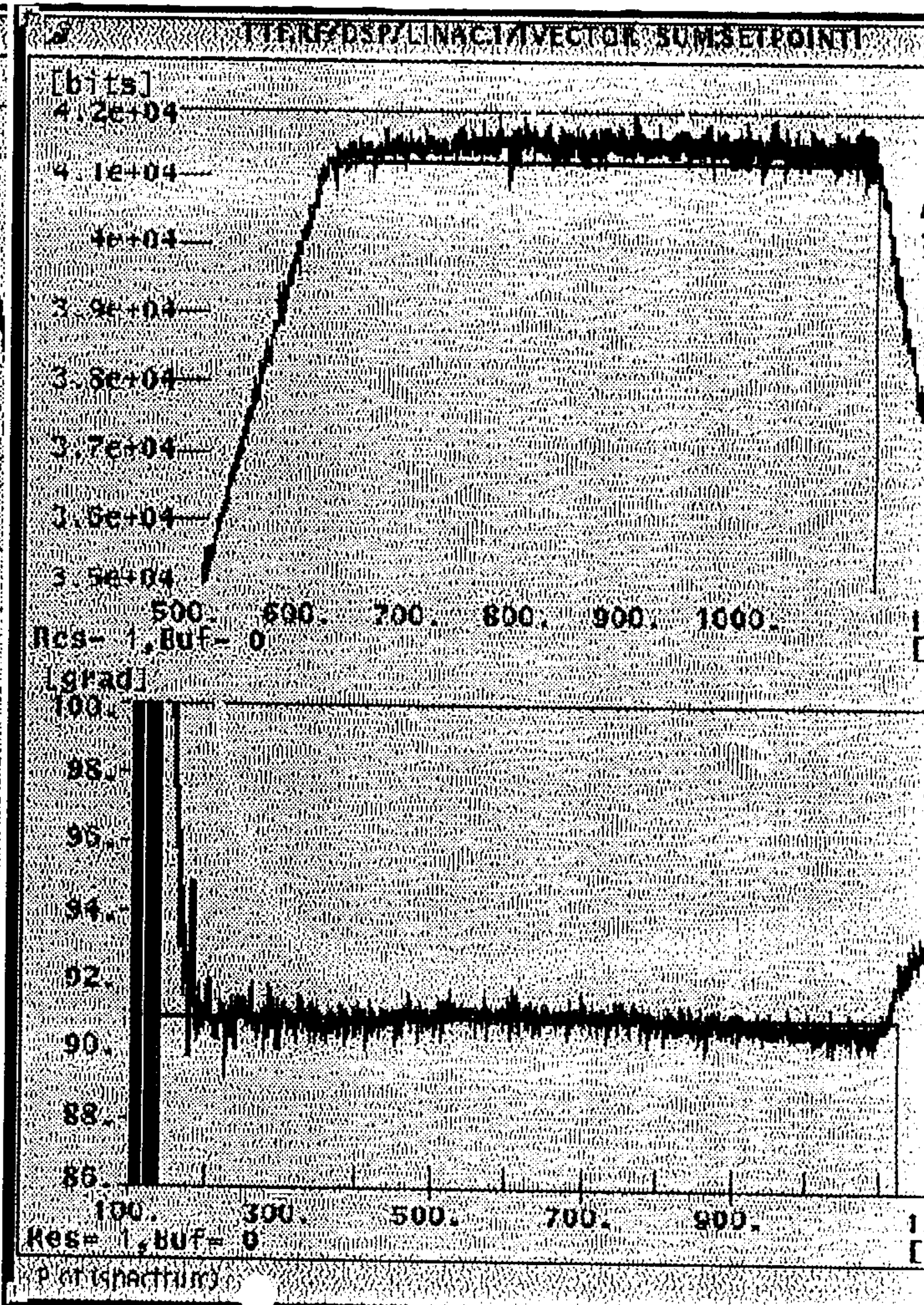

Vectorsum ACC1
16.05
16
15.95
15.9
gradient [MV/m]
600
700
800
900
1000
1100
time [µs]


Vectorsum ACC1
1.6
1.4
1.2
1
0.8
0.6
0.4
phase [deg.]
600
700
800
900
1000
1100
time [µs]

Excitation of Passband Modes




TTF/RF/DSP/LINAC1/VECTOR SUMSETPOINT1
[bits]
4.2e+04
4.1e+04
4e+04
3.9e+04
3.8e+04
3.7e+04
3.6e+04
3.5e+04
500. 600. 700. 800. 900. 1000.
Res= 1,Buf= 0
[grad]
100.
98.
96.
94.
92.
90.
88.
86.
100. 300. 500. 700. 900.
Res= 1,Buf= 0


TTF/RF/DSP/LINAC1/VECTOR SUMSETPOINT1
[bits]
4.2e+04
4.1e+04
4e+04
3.9e+04
3.8e+04
3.7e+04
3.6e+04
3.5e+04
500. 600. 700. 800. 900. 1000.
Res= 1,Buf= 0
[grad]
100.
98.
96.
94.
92.
90.
88.
86.
100. 300. 500. 700. 900.
Res= 1,Buf= 0

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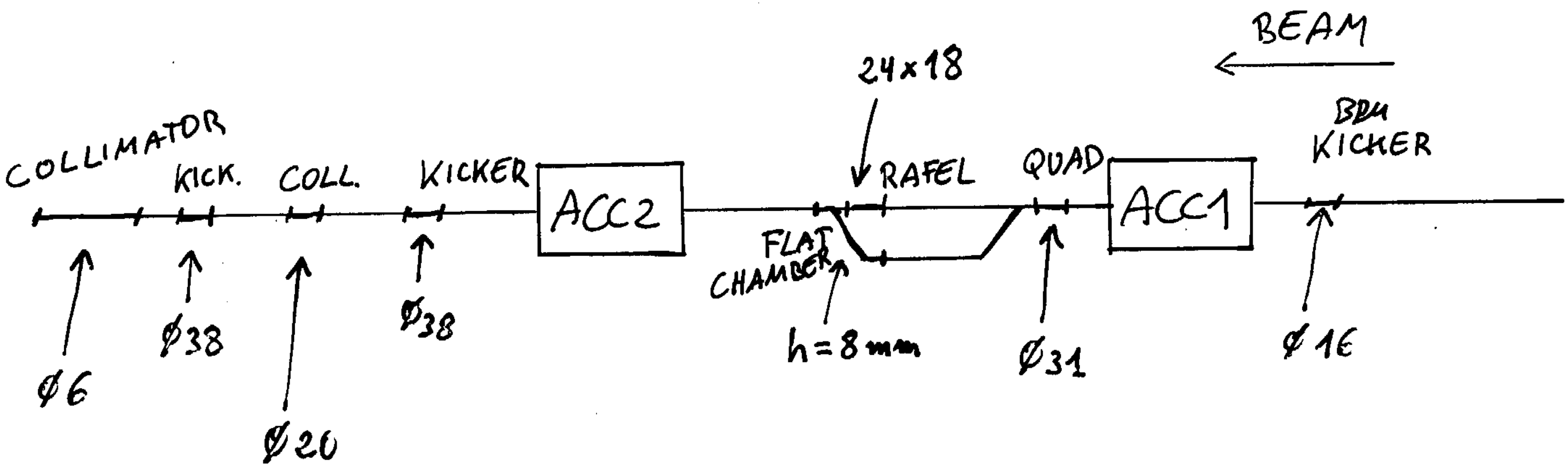
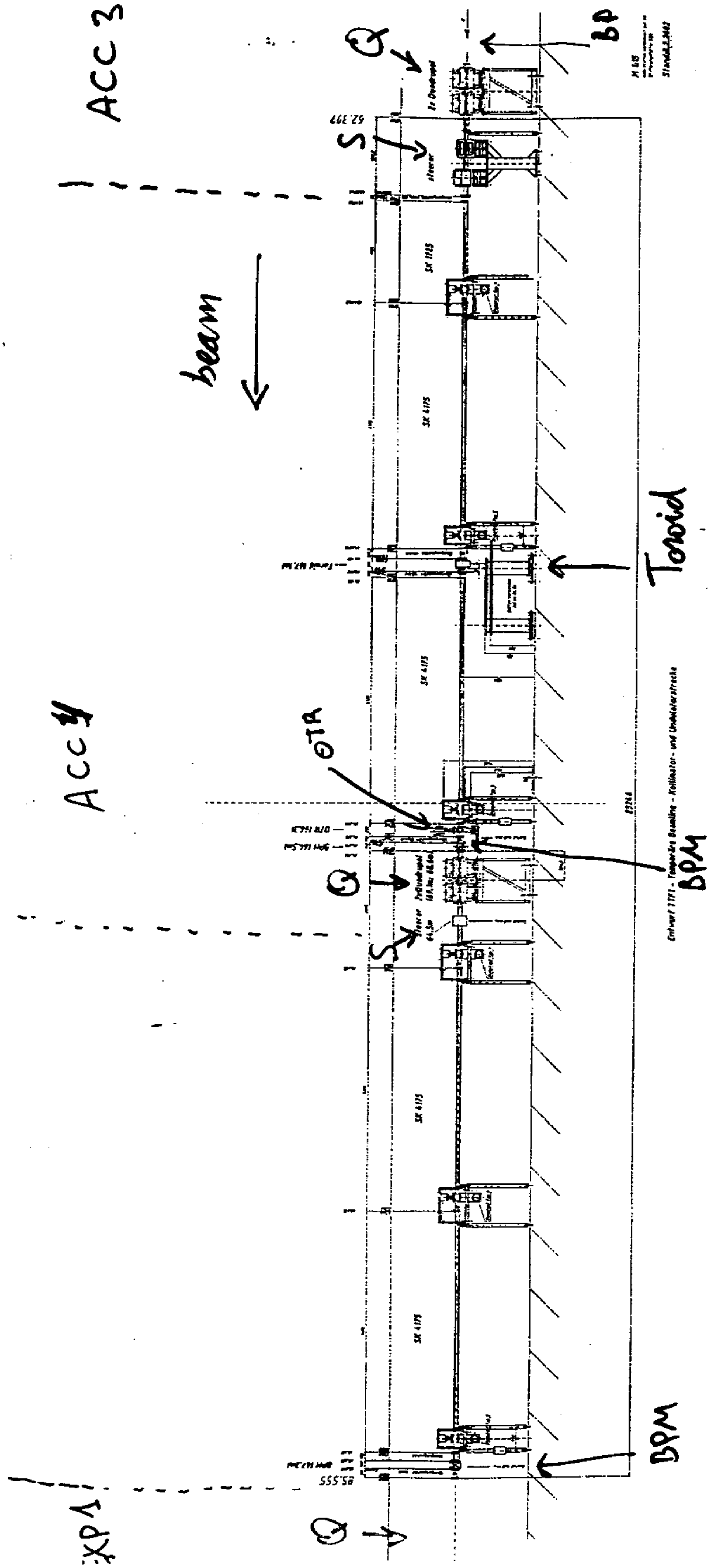
P. Castro

"Proposed re-arrangement of TTF linac for the beam test of superstructures"

Aperture limitations: Present status



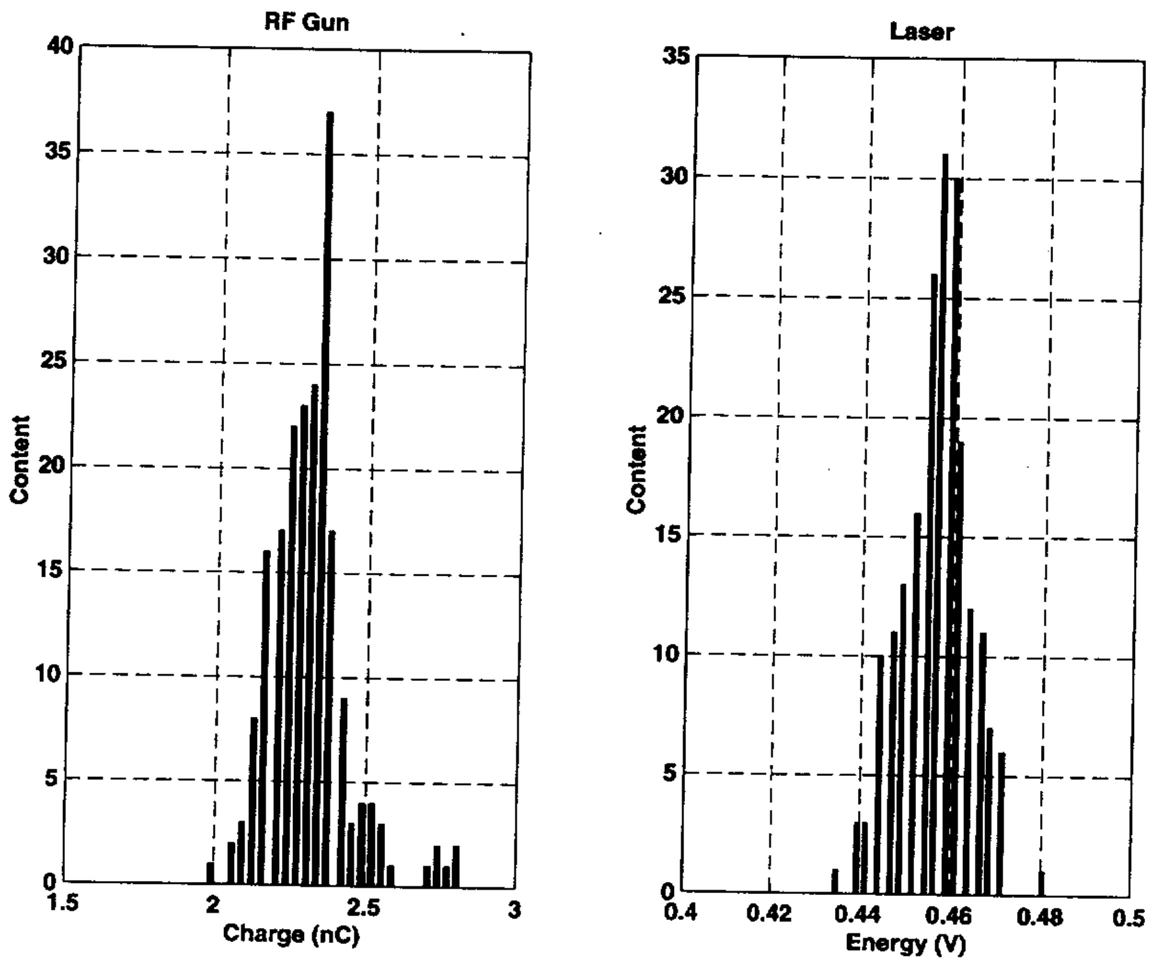

ACC 3
BP
Q
S
beam
Toroid
ACC 4
OTR
BPM
Q
S
BPM
Q

S. Schreiber

"Injector: stability of charge at operation at 1 MHz and at 54 MHz"

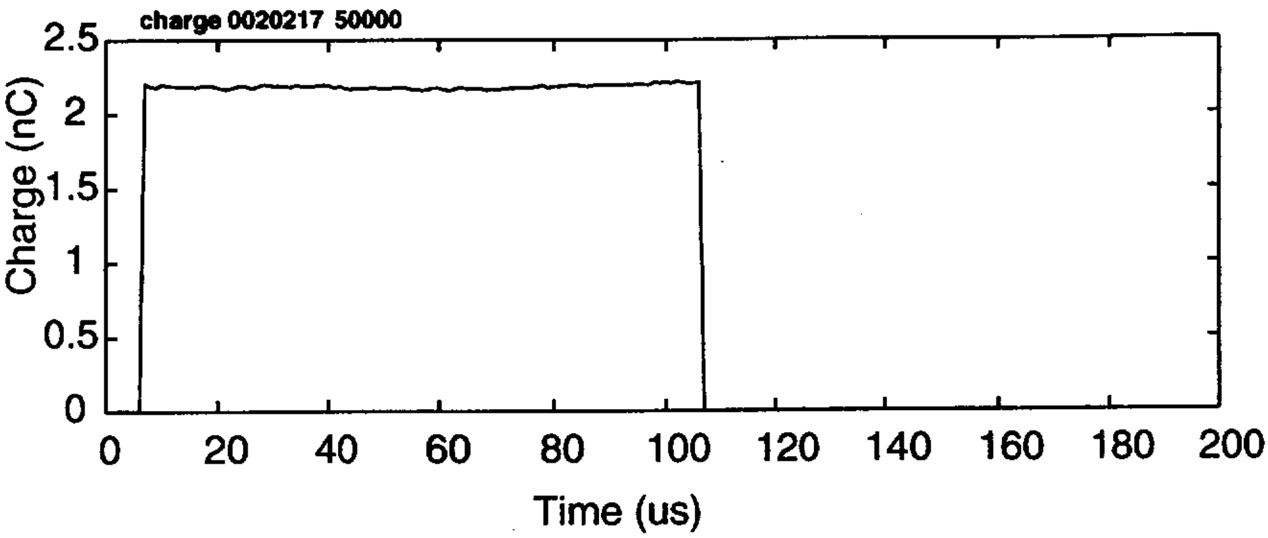
Typical Measurement of the Charge Stability

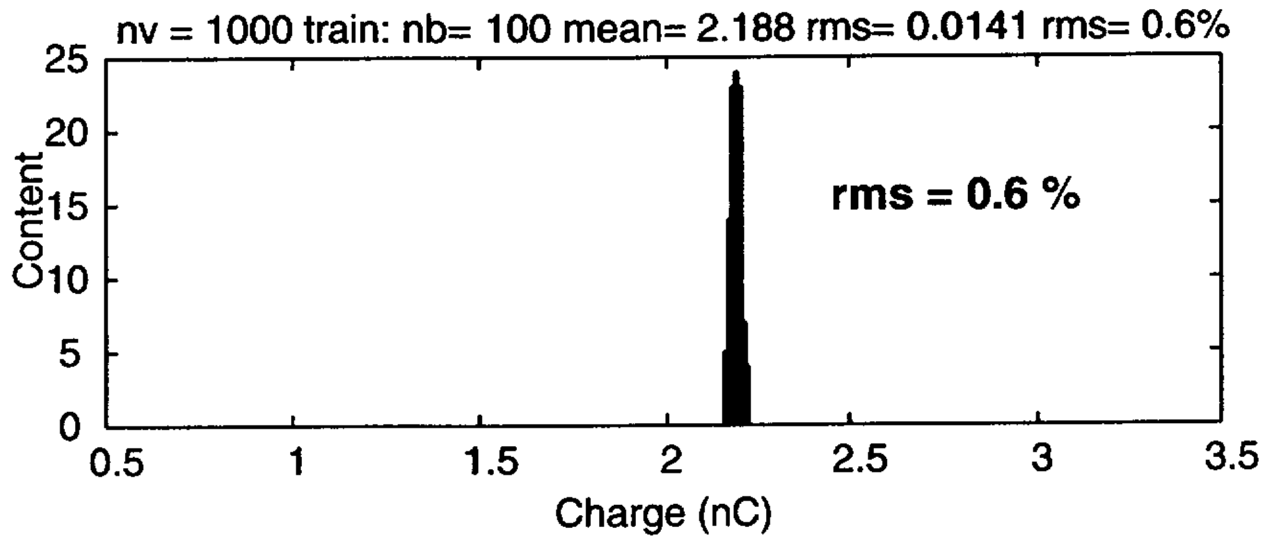
- Charge measured at ICT B1 rf gun exit
  Laser energy from photodiode (green)



- In this case:
  charge av = 2.3 nC, 5.7 % rms
  (smallest 3 %, seen also > 10%)
  laser = 1.7 % rms
  (have to check linearity of the diode)

Example of charge fluctuation in a flat pulse train

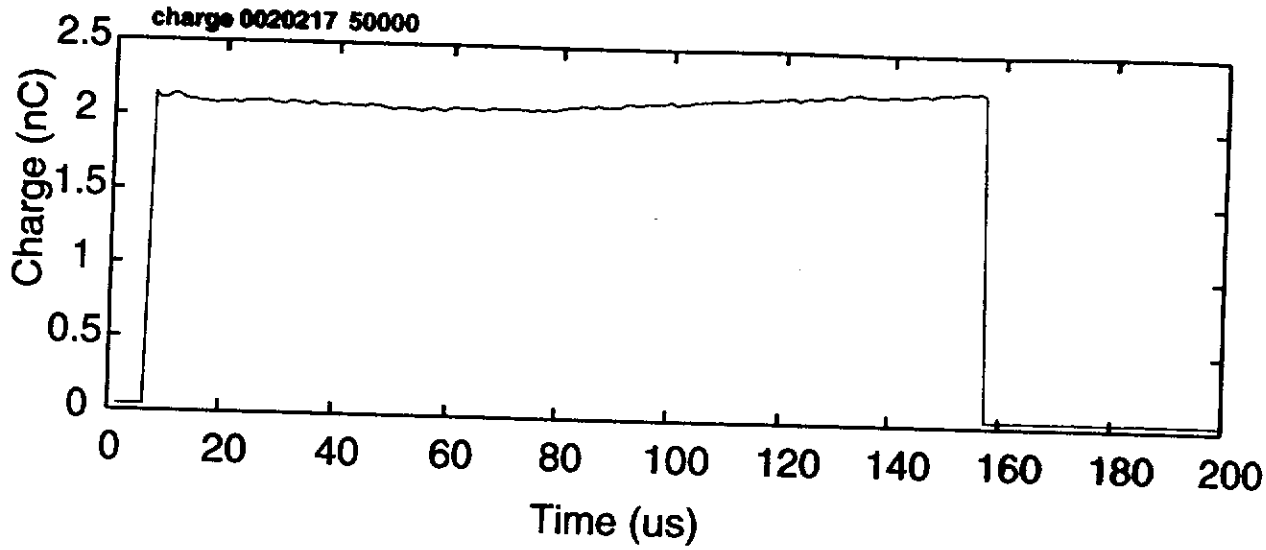


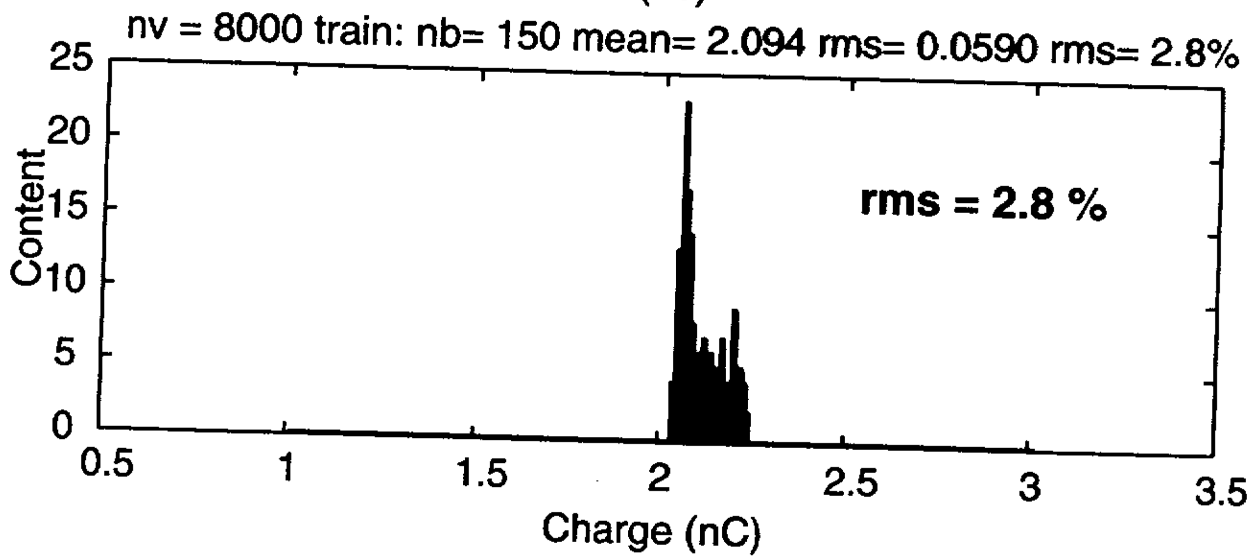


In this example:

- **pulse train length 100 us (1 MHz)**
- **average charge over the train 2.2 nC**
- **rms fluctuation along the train 0.014 nC = 0.6 %**

Example of charge fluctuation in a less flat pulse train



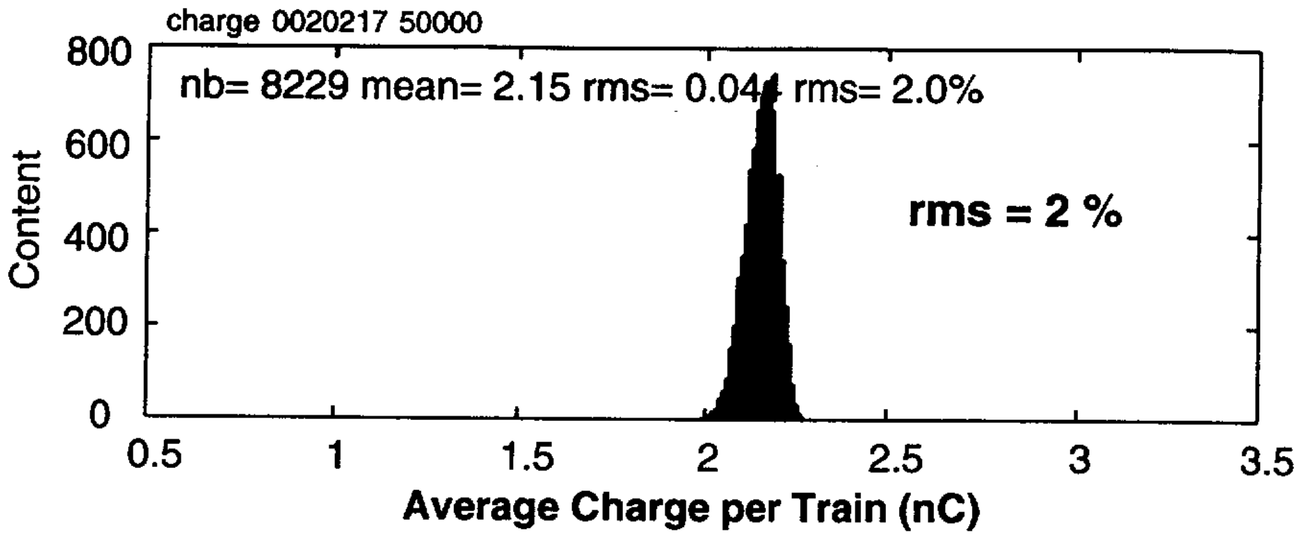


In this example, the train is less flat:

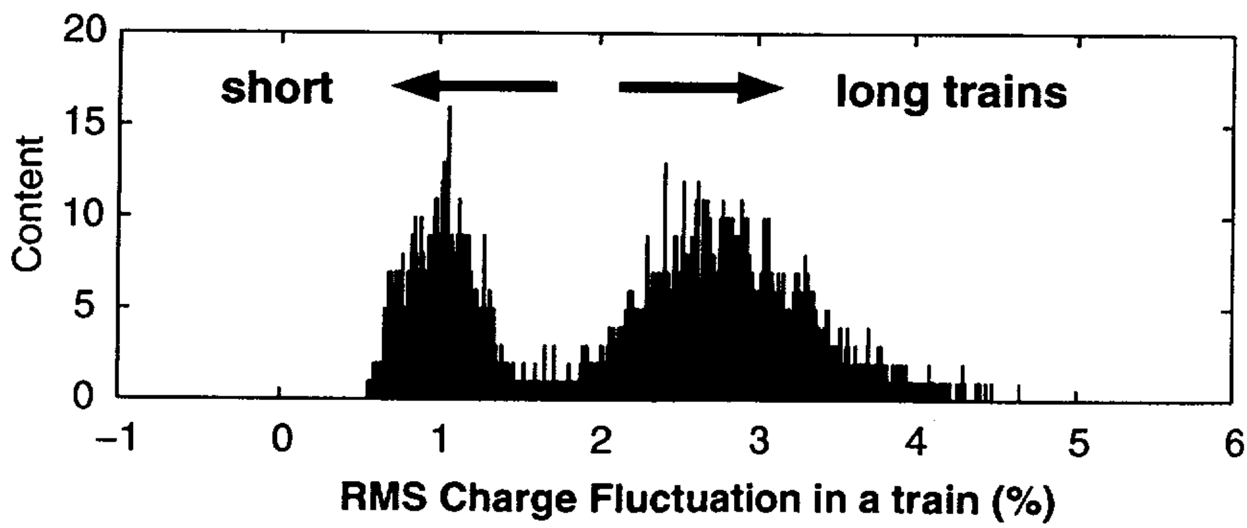
- **pulse train length 150 us (1 MHz)**
- **average charge over the train 2.1 nC**
- **rms fluctuation along the train 0.06 nC = 2.8 %**

To Expected Charge Fluctuations

- Data from the long pulse run 17-Feb-2002
  Collected over 8 hours (8229 trains of > 50 us)



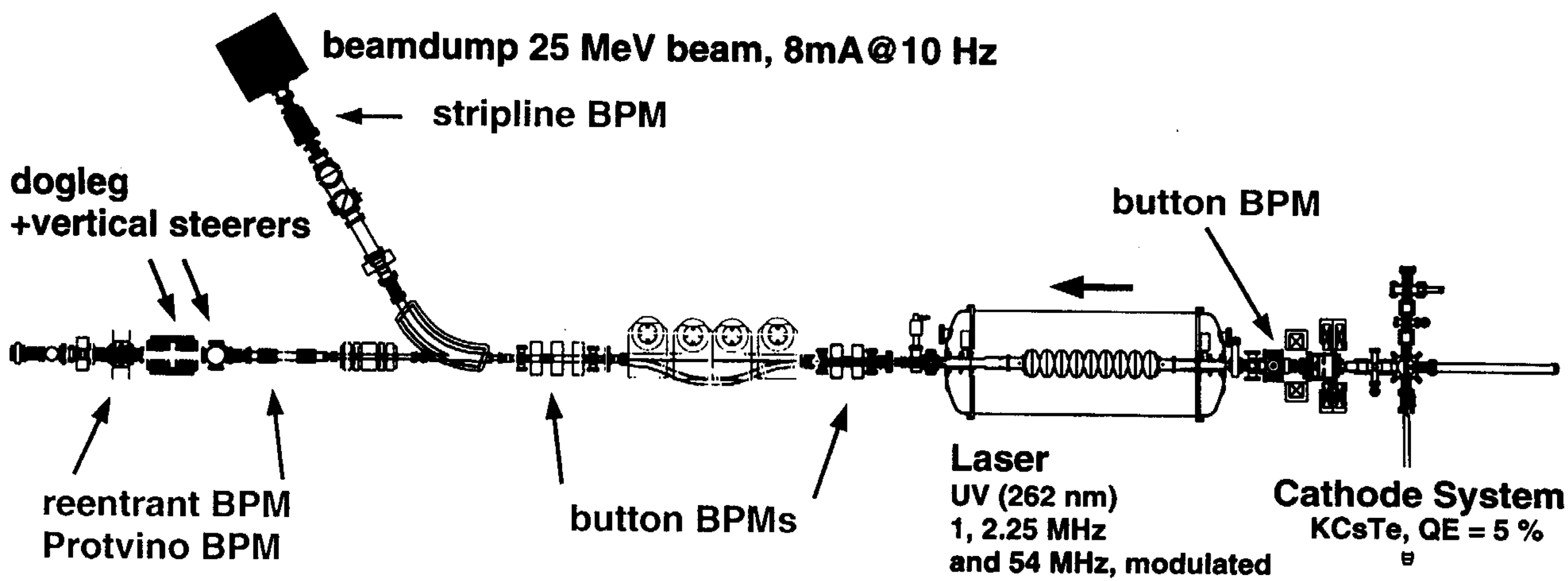
- the relative fluctuation for short trains is 1 % rms
  for longer trains 3 % rms



Injector layout for HOM SStructure experiments

Modifications:

- laser beam spot diameter 10 mm
- KCsTe if possible
- button BPMs equipped with electronics from the undulator
- additional stripline BPM in the spectometer arm to measure energy along the train
- additional vertical steerers around dogleg
- reestablish BIS long pulse operation mode in analysis mode



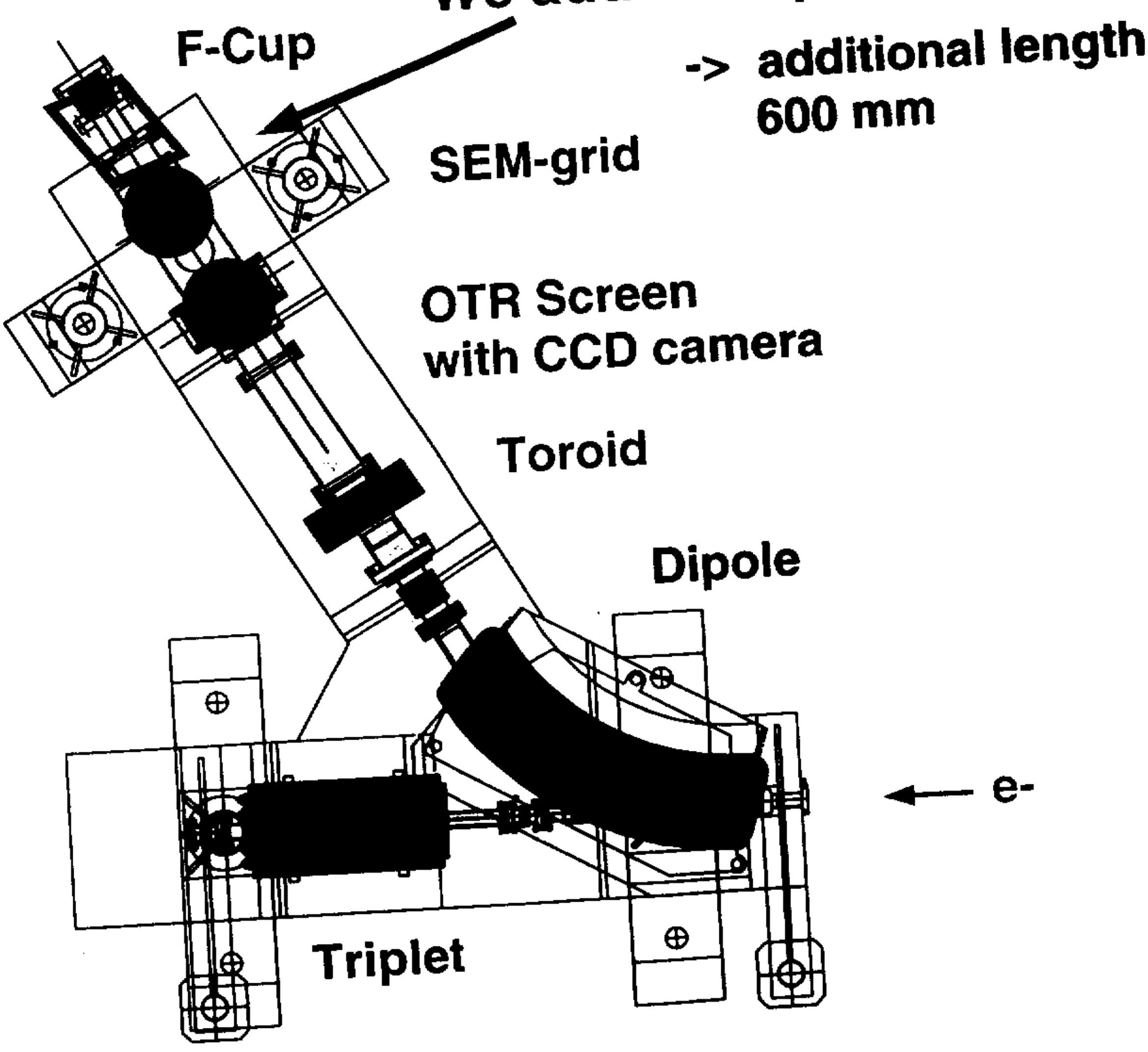
TESLA 2002-04

S. Schreiber
22-Feb-2002

esolution of the Injector Spectrometer

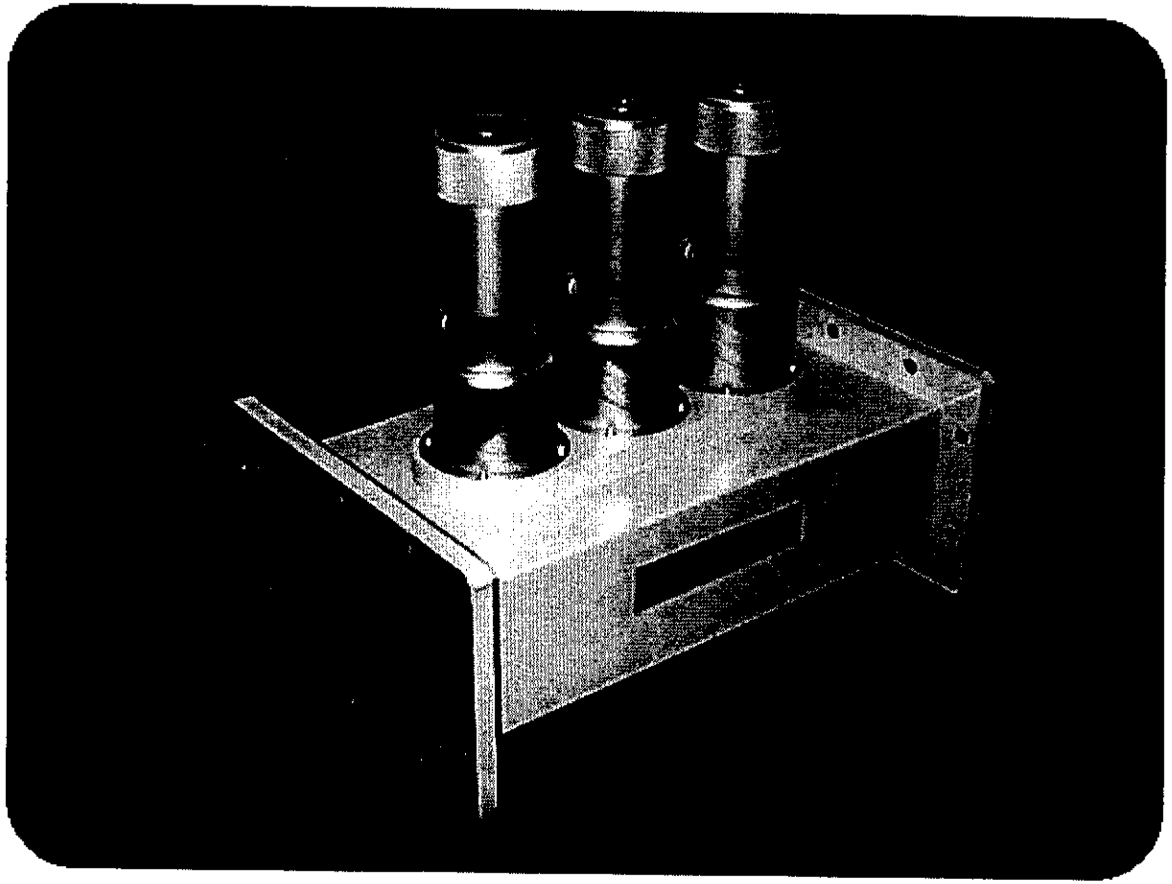
- Dispersion: 13.66 mm = 1 % dE/E at OTR screen (at SEM grid 16 mm)
  -> with a 500 um resolution BPM we achieve
  an energy resolution of dE/E = 0.04 %

- The resolution of the present OTR screen with the present camera magnification is
  1 pixel = 0.48 mm / 13.66
  = 0.035 +- 0.004 % dE/E

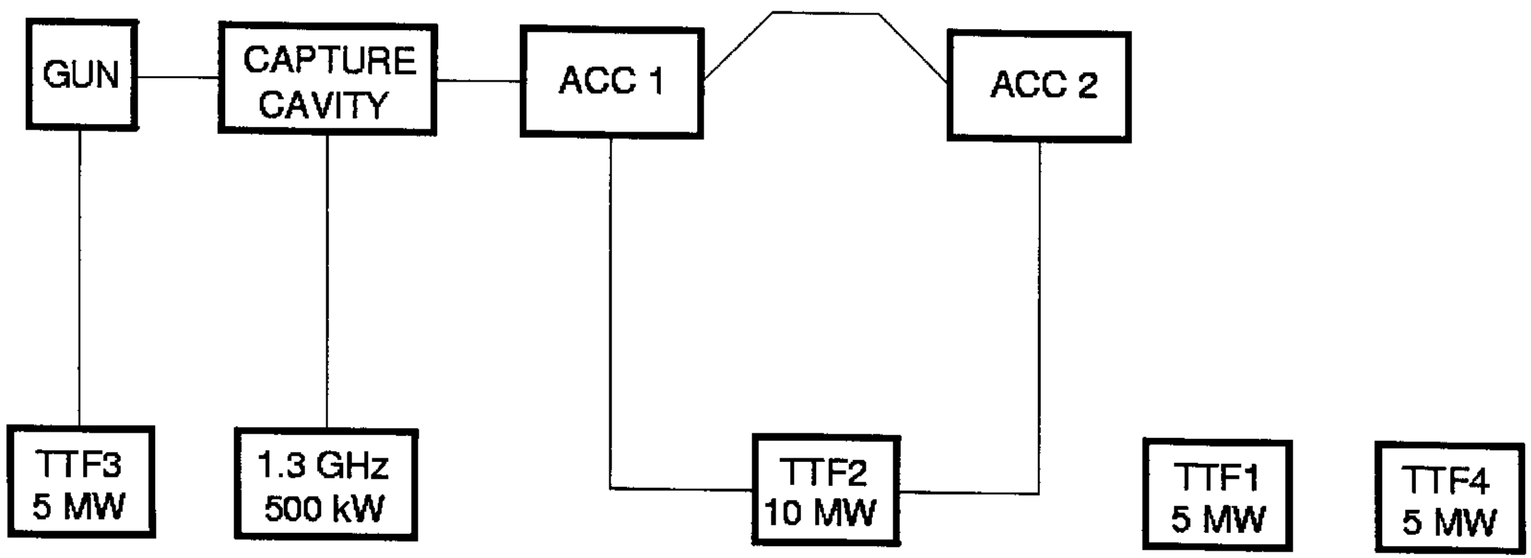


S. Choroba

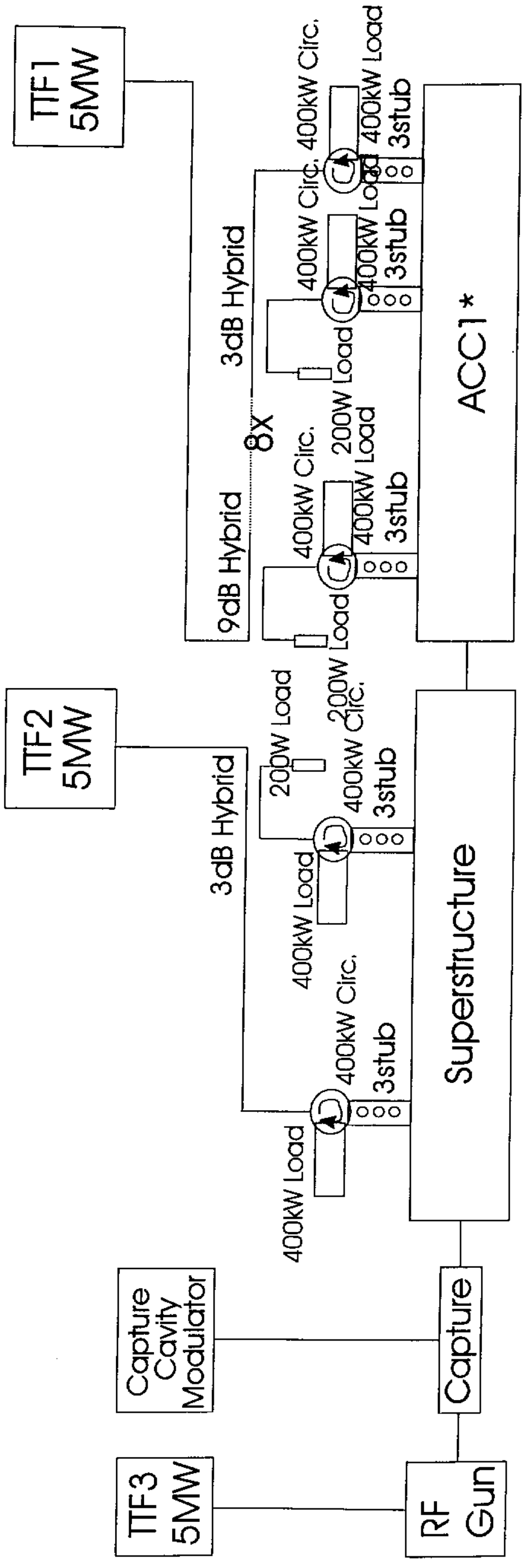
"RF power distribution system for the test cryomodule and 1* cryomodule at ACC2 position"

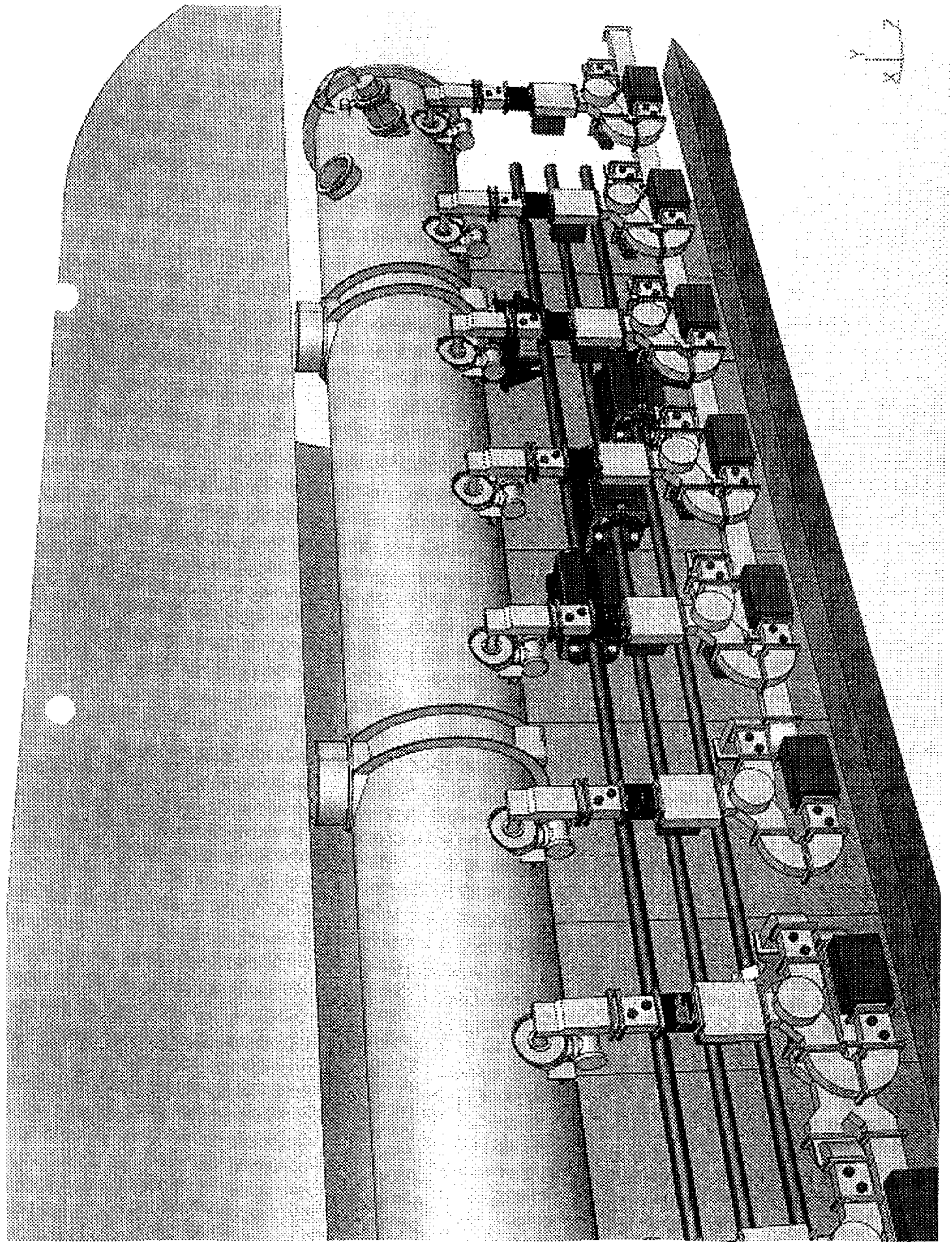


3 Stub Tuner (IHEP, Bejing)



RF System TTF Phase 1


TTF1 5MW
9dB Hybrid
8X
3dB Hybrid
400kW Circ.
400kW Load
3stub
200W Load
ACC1*
TTF2 5MW
3dB Hybrid
200W Load
200W Circ.
400kW Circ.
400kW Load
3stub
Superstructure
Capture Cavity Modulator
Capture
TTF3 5MW
RF Gun



TESLA 2002-04

M. Wendt

"BPMs, electronics and automatic data read-out for the HOM experiment and for the FM experiment"

Instrumentation Requirements for the Superstructure HOM Measurents

Manfred Wendt

February, 2002

TESLA 2002-04

Contents

- Measurement of the HOM-coupler signals
- Measurement of the BPM signals
- Measurement of beam orbit and energy

Measurement of the HOM-coupler signals

Semi-automatic search for:

$$f_{\text{HOM}} = n\, f_{\text{bunch}} \pm f_{\text{mod}}$$

Realisation:

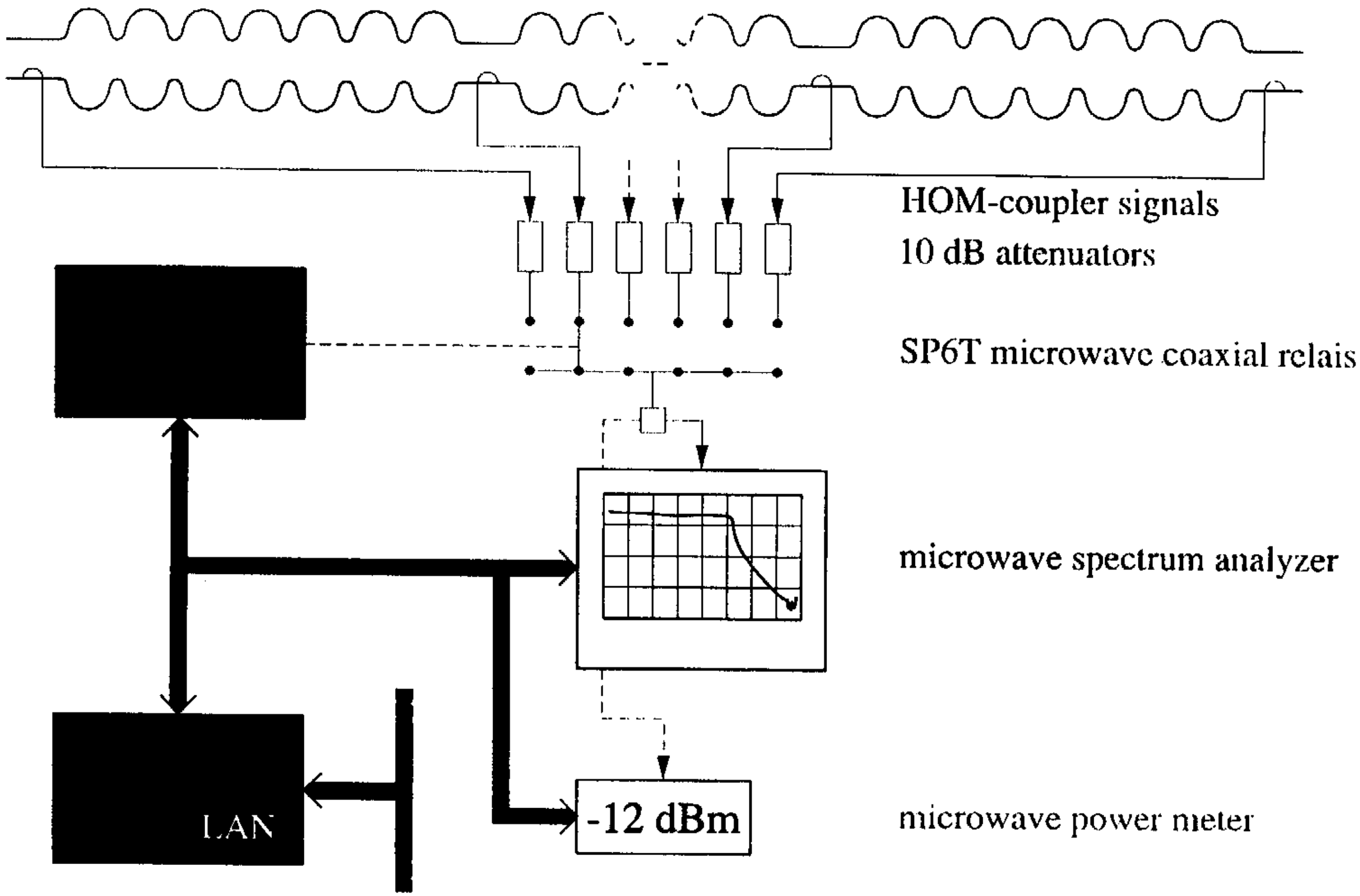
- Measurement of the HOM-coupler signals in the **time-domain** with a spectrum-analyser set to zero-span.
- Analysis the signal decay after the bunch passage to determine the Q-value of the mode.

Mea‹ urement of the HOM-cou‹ er signals

4

HOM Measurement Setup

accelerating structures:
2 superstructures (2 * 7-cell 1.3 GHz cavities) with 6 HOM-couplers



Beam Test of the Superstructure

Instrumentation details:

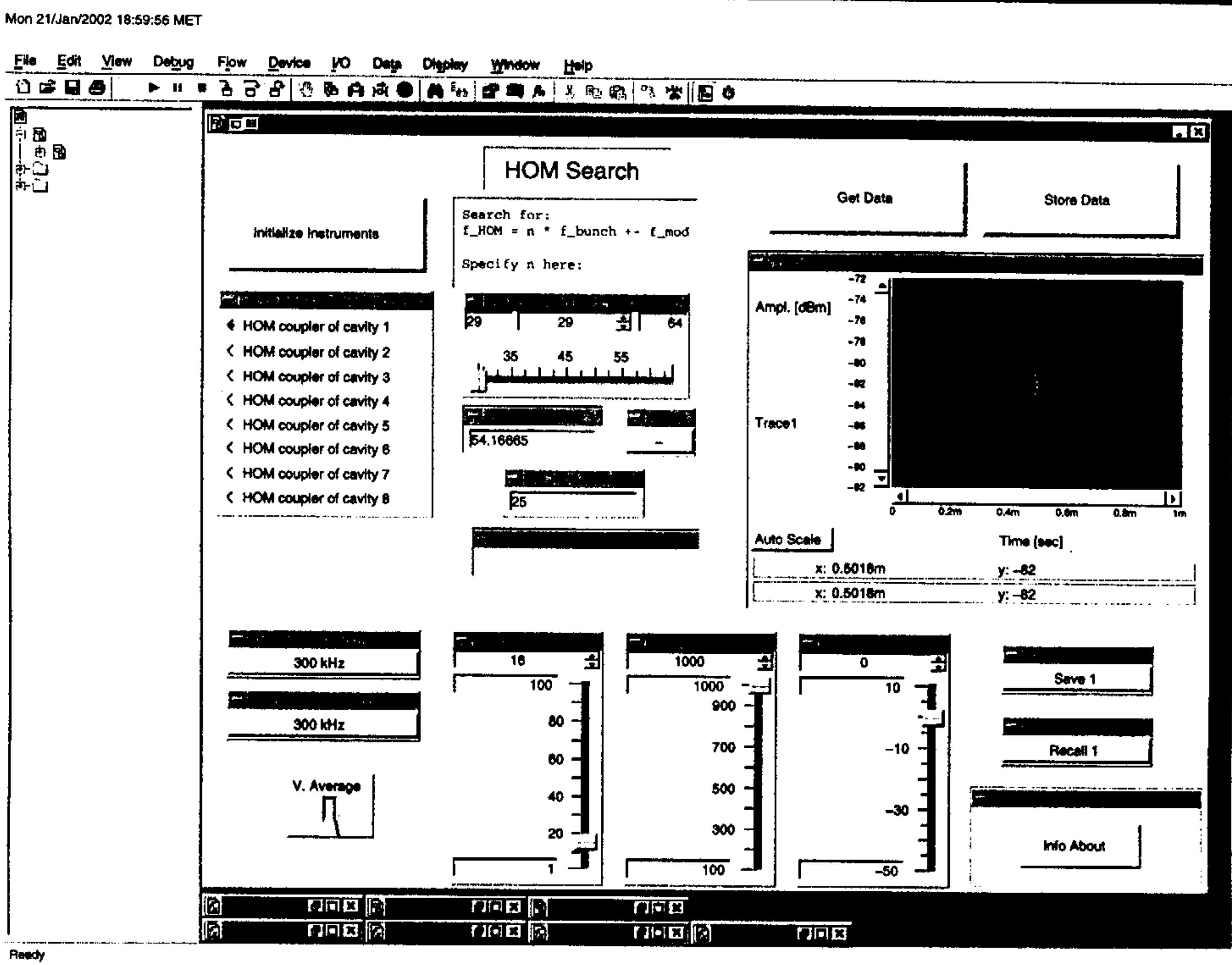
- 10 dB attenuators in the HOM-coupler signal path to reduce reflections and prevent overload of the spectrum-analyser.
- Measurement (network-analyser) of the insertion loss:
  HOM-coupler output – to – spectrum-analyser input
  of each HOM branch.
- GPIB-controlled SP6T microwave relais
  (*Keithley S46* microwave switch system).
- The spectrum-analyser (*HP E8563E*) has to be external triggered (plus evt. appropriate gating of the video signal), resolution and video bandwidth has to be set to moderate values (typ. $\geq$ 100 kHz).

Measurement of the HOM-coupler signals

GPIB instrument control and software:

- Spectrum analyser (plus evt. added power meter) and microwave swiches are computer controlled through a LAN/GPIB gateway.
- A semi-automatic measurement procedure *"HOM Search"* (witten in *Agilent VEE Pro*), running on a HP workstation, controls the instruments and stores the data.
- The driver sections for the new *Keithley* switch unit have to be rewritten, new drivers for the power meter have to be included!
- Other features could be further included into the procedure, like online Q-value determination...

Measurement of the HOM-coupler signals



Semi-automatic HOM measurement procedure *“HOM Search”*.

Beam Test of the Superstructure

Measurement of the BPM signals

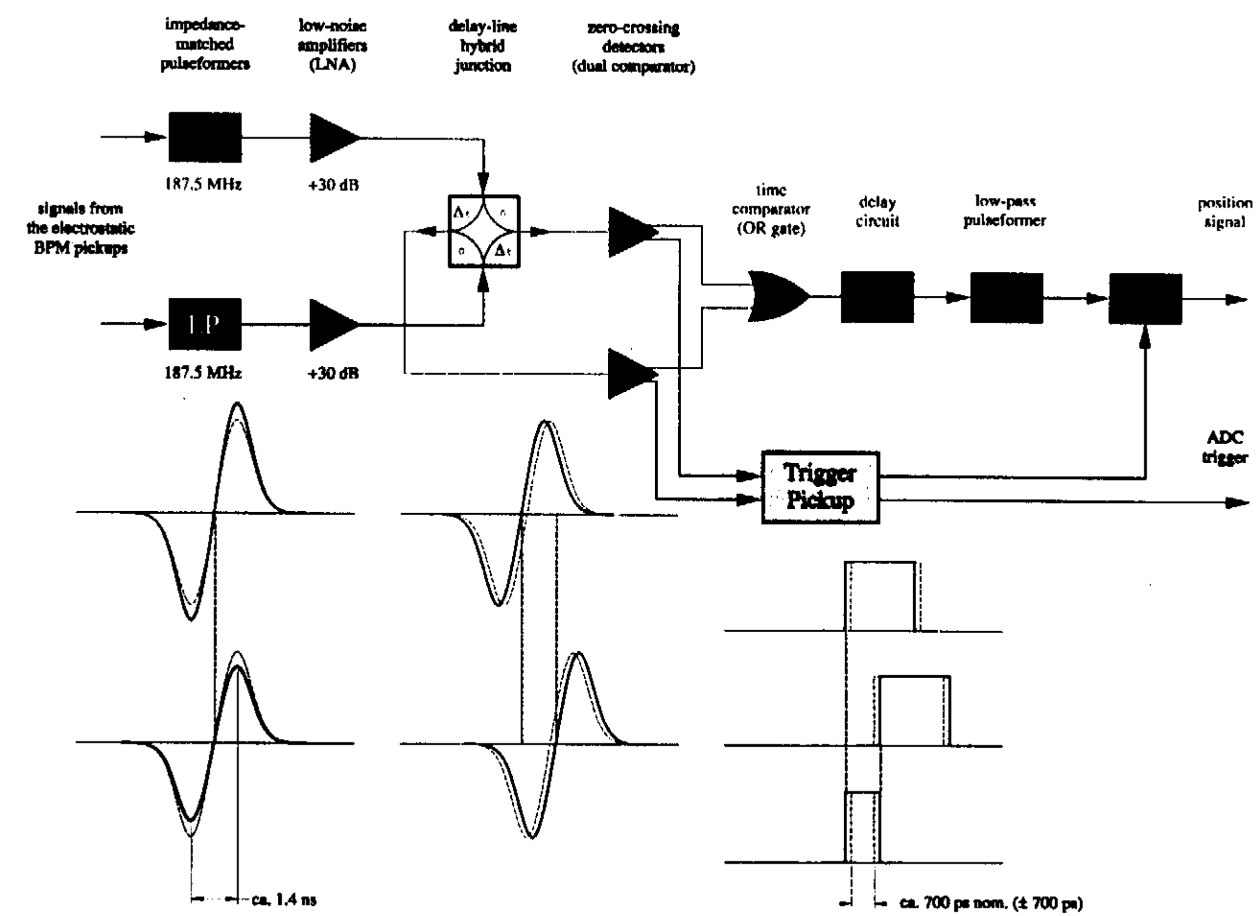
Beside (?!) the re-entrant cavity BPM (C. Magne), a **stripline BPM** (DESY-Zeuthen) will be used for the dipol mode search and analysis:

- The stripline BPM delivers high-level (100 mV range) broadband pulse signals, keeping the bunch structure.
- The read-out electronics of the undulator BPM's (with very little modifications) will be used for the signal processing.
- Both planes (horizontal and vertical) can be analysed simultaniously.

Measurement of the BPM signals

- Single bunch position resolution is expected to be 50...100 μm @ **10 ns (!) measurement time.**
- Limitations of the present electronics:
  Intensity dynamics may be limited to only 3...4.
  Beam position range is limited to 30...50 % of the aperture.
- For the data acquistions a oscilloscope (*Tektronix 7404*) is foreseen, it can be computer controlled directly over the LAN.
- The setup of all this new hard- and software requires approx. 3 weeks of preparation!

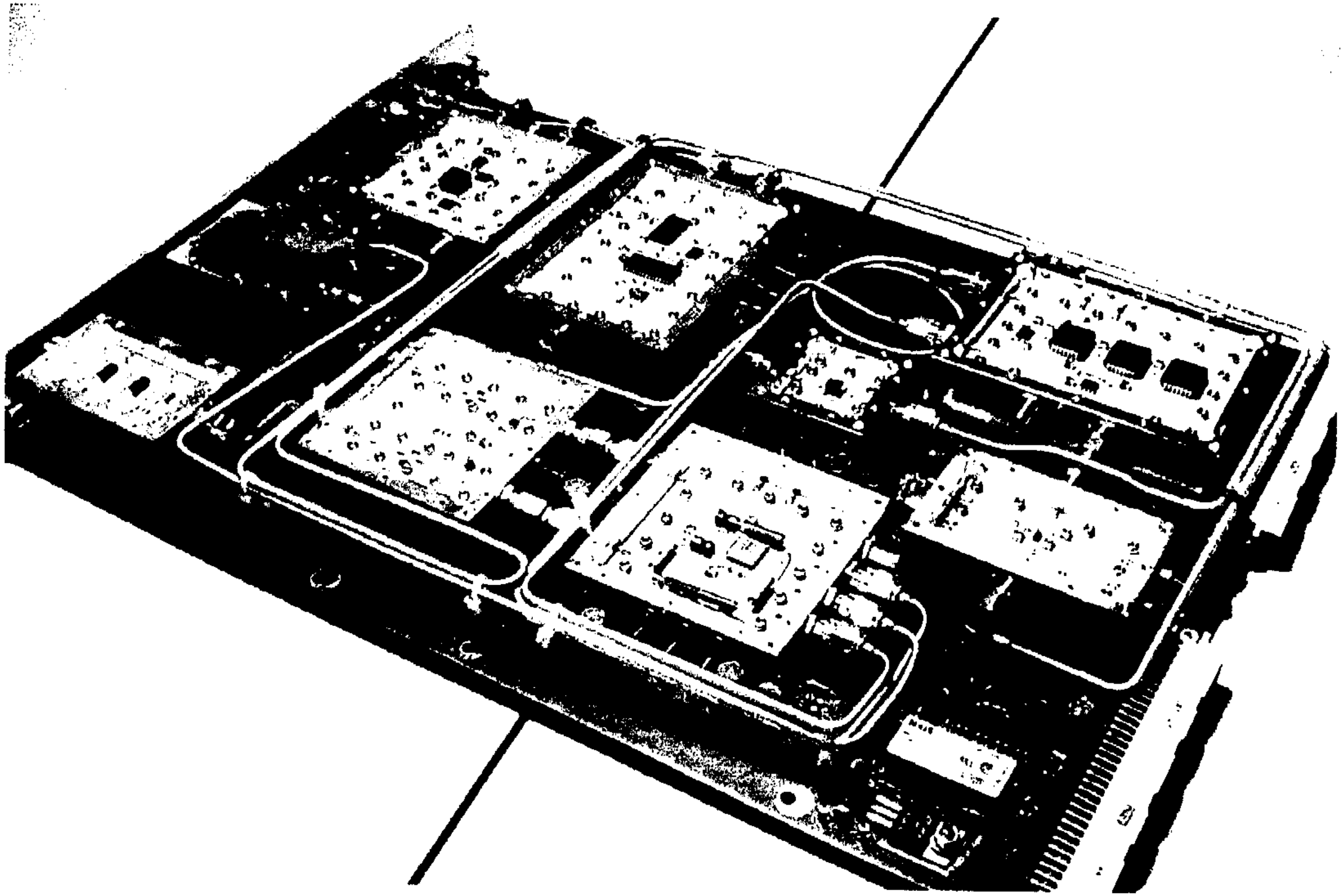
Measurement of the BPM signals



Schema of the "monopulse" AM/PM BPM read-out electronics:

Major modifications TBD: Bypass of the LNA's and the T&H amp.

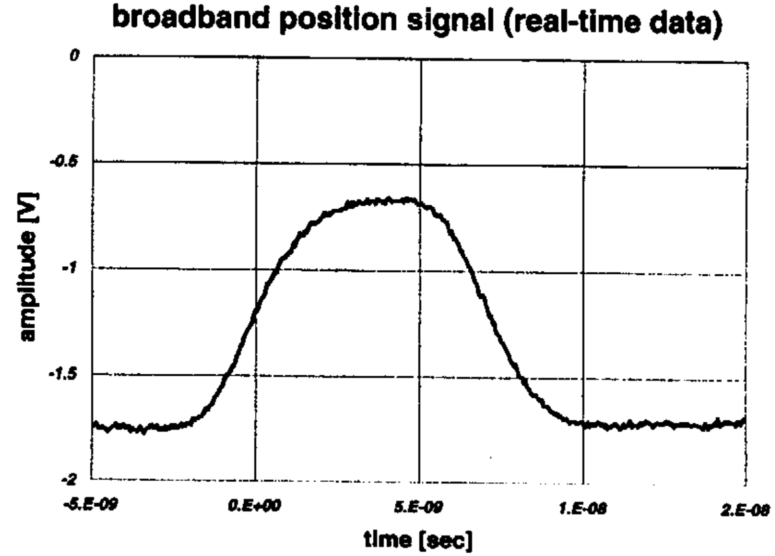
Measurement of the BPM signals



The BPM electronics is implemented as modular hardware

Measurement of the BPM signals

The single bunch analogue position signal of the BPM electronics (between LP and T&H amp) resolves the beam displacement within 10 ns!



For the data acquisition of the individual beam positions of all bunches in the train a commercial oscilloscope (*Tektronix 7404*) will be used.

Measurement of beam orbit and energy

Ar least 6 Beam position monitors (BPM) are located along the linac. Button BPM's at the injector, stripline BPM's (Zeuthen type) at the accelerating structures and in the spectrometer.

- The read-out electronic system of the undulator BPM's will be re-arranged and used for beam orbit / energy measurements.

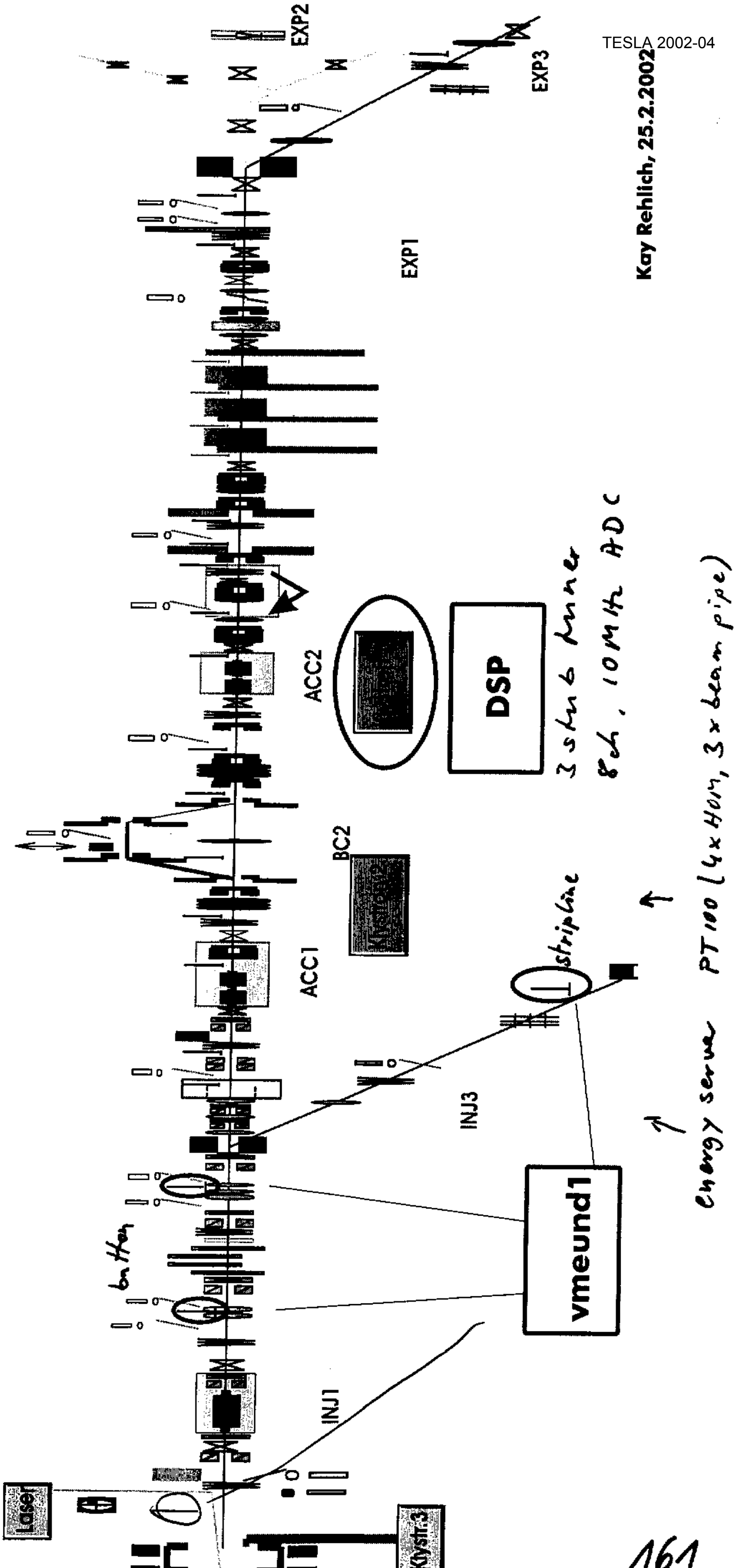
- Data-acquisition time is limited to the usual 1 μs ($\equiv$ 1 MHz), the resolution is expected to be $\approx$ 100 μm.

Mea‿urement of beam orbit ar‿d energy

- All hardware components are available; analogue read-out electronics, VME ADC- and trigger-boards, VXI- and VME-crates...
- Cableing will be an issue, only a few cables may be re-used. Good BPM performance requires well matched (electrical length) cables of high quality.
- The setup of the new infrastructure **needs time and manpower!**

K. Rehlich

"Diagnostics: re-arrangement for the beam test of superstructure"


EXP2
EXP3
Kay Rehlich, 25.2.2002
EXP1
ACC2
DSP
3 stub tuner
8 ch, 10 MHz ADC
BC2
ACC1
stripline
PT100 (4x HOM, 3x beam pipe)
INJ3
energy servo
vmeund1
button
INJ1
Laser
Klystr.3

H. Schlarb

"Interlock re-arrangement for the test"

Requirements on the interlock system for Super Structure Tests

- Instantaneous temperature rise not critical for moderate β-function:

  Example: $\beta \approx 20$ m, $\varepsilon \approx$ 1e-5m, E = 250 MeV, Q = 4nC

  $\Rightarrow \sigma = 450\ \mu m$

  $\Rightarrow$ # bunches $\approx$ 400 until steel cracks

Hence with weak quadrupoles the risk to damage the beam pipes is relatively small.

$\Rightarrow$ sufficient time to switch of the linac

- To limit the neutron production at energies above the geant resonance threshold:
  Beam Losses < 10-20 W (point-like source)
  For 5Hz, 8mA, 800μs beam parameters:

  $\Rightarrow$ BC2 @ 80MeV: losses < 0.4% $\cdot$ I
  $\Rightarrow$ ACC3 @ 250MeV: losses < 0.1% $\cdot$ I

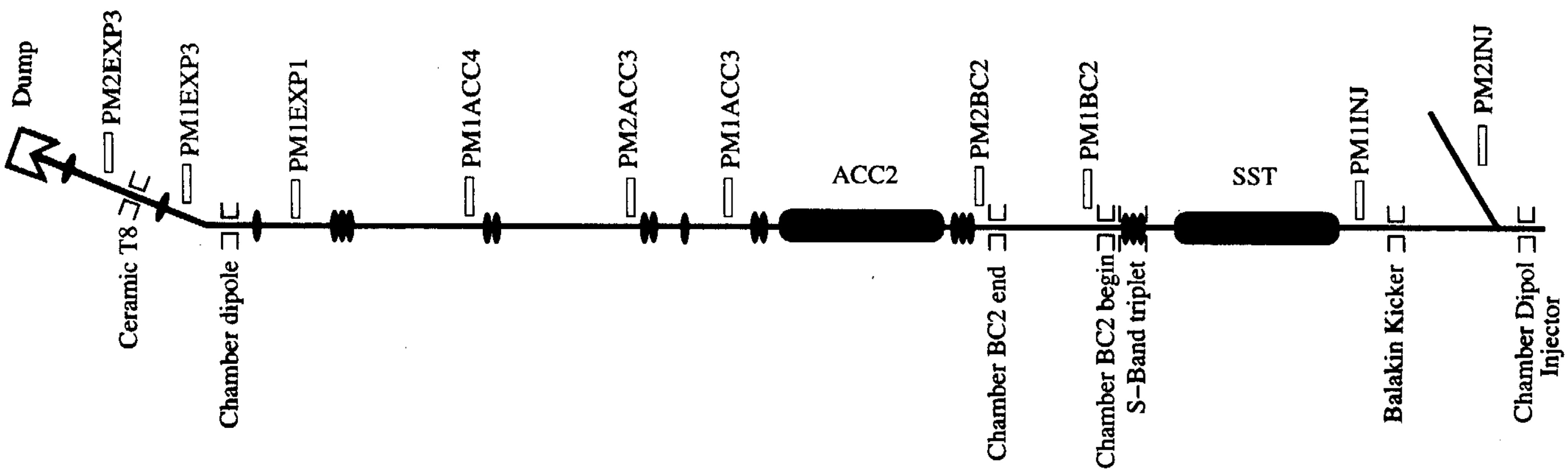
$\Rightarrow$ Can only be achieved by photomultiplier based interlock (BLM)

- To guarantee the functionality of the Beam Loss Monitor System (BLM) based on photomultiplier toroids are required for supporting.

- Safety of exit window (to be discussed)

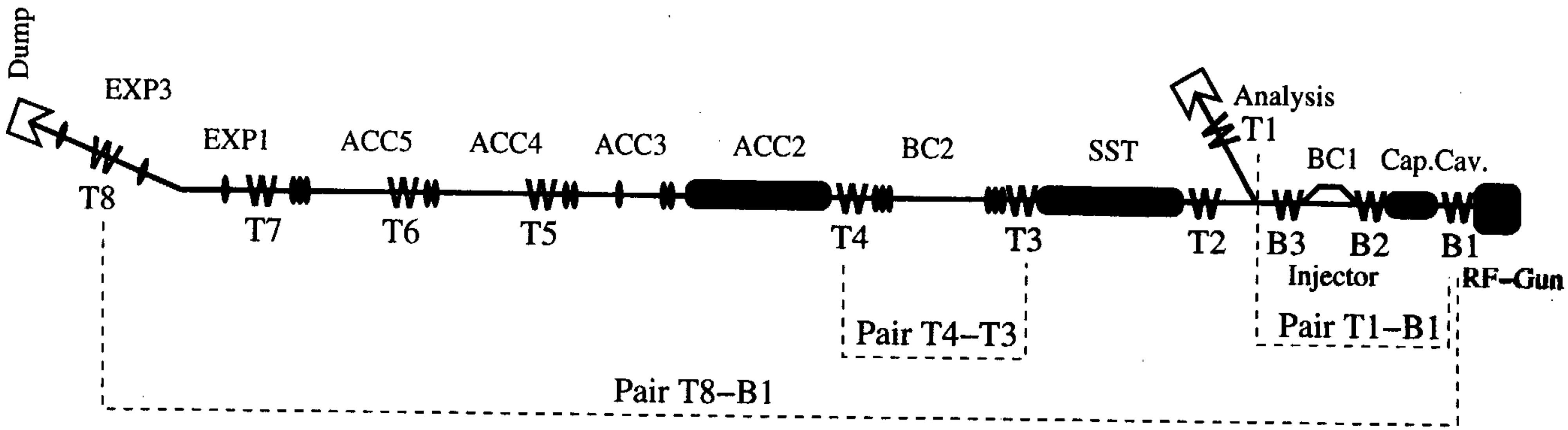
H.Schlarb 24.02.2002
D.Pugachov

Photomultiplier Interlock System for Super Structure Test



- 10 photomultipliers are required
- cables exist as well as required PM types

Fast Protection System based on Toroids for Super Structure Test



– For linac operation same combination of toroids can be used as before
– Macro–pulse operation in analysis mode => B1–T3 have to be commissioned
– Only for diagnostic purpose: B2, B3, T2, and T5,T6 which have to be reinstalled to the beamline
– 30–50 us active protection by FPS is sufficient
– for high gradient tests in ACC2 the protections is more seriously

H.Schlarb 24.02.2002