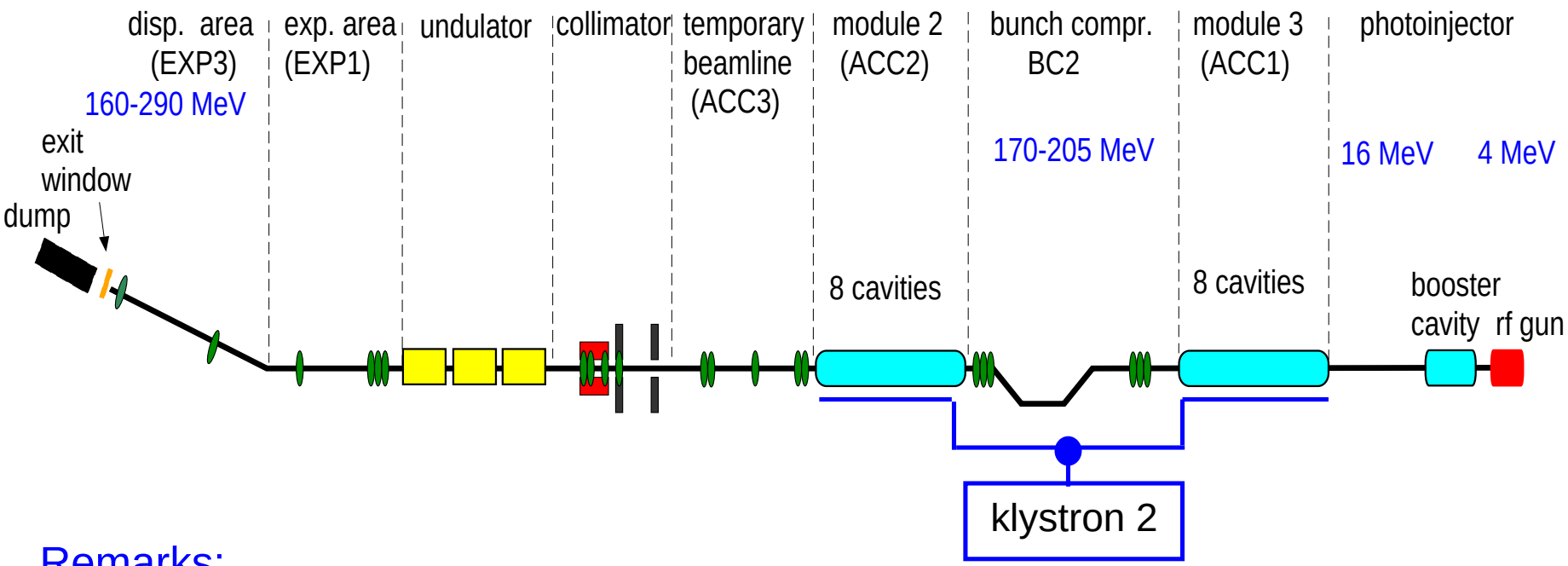
TTF Linac Operation Results & Status

H. Schlarb
DESY
TTF Meeting
Sep. 23, 2002, Daresbury

- Results of the Full Performance Test with Module 3 (March-May 2002)
- Status and first Results of the Superstructure-Test

TTF Linac beamline during Full Performance Test 03/2002



Remarks:

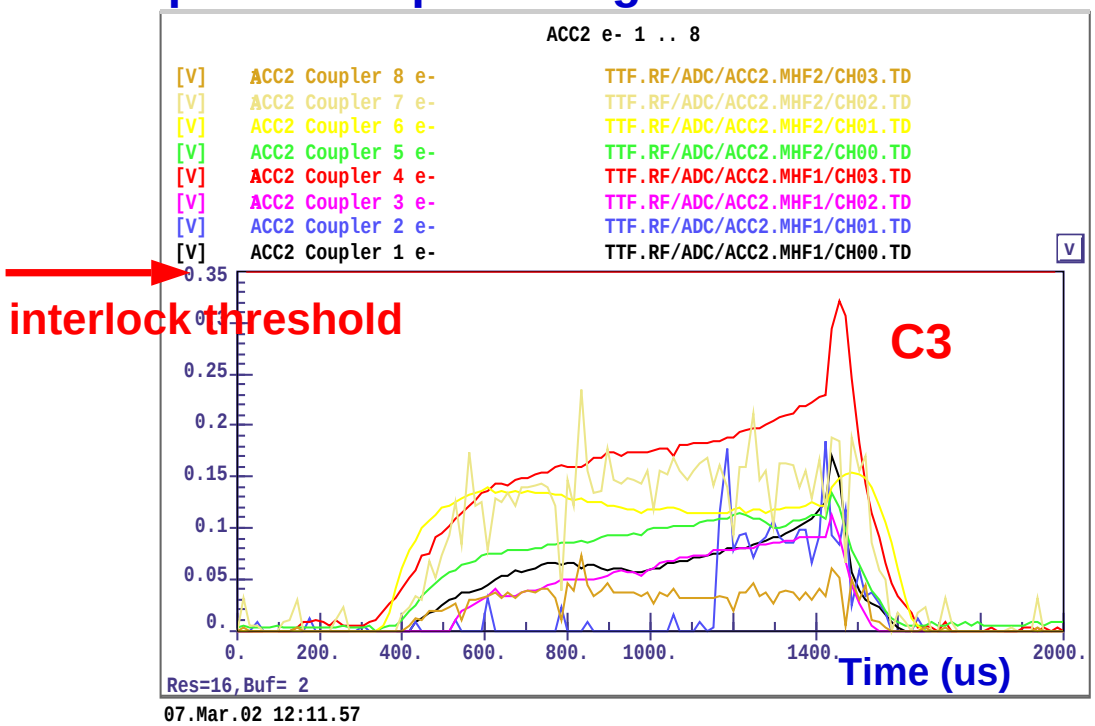
- beamline as for the FEL run, bunch compressor was switched on
- requires sophisticated beam loss interlock to protect the permanent magnets
- ACC1 is equipped with module 3: rf test predicts 22.5 MV/m average gradient
- ACC2 is equipped with module 2: achieved gradient with beam = 19.2 MV/m
  (but troubles with input couplers at high gradient operation)
- only one klystron was available to feed the power to two acceleration modules
  ⇒ start operation with unbalanced gradients ACC1:ACC2 = 18:12 MV/m
  but could not achieve required energy stability for macropulse operation
  ⇒ changed power splitter in waveguide distribution to switch off ACC2

Why did we switch off Module 2 for this test?

- Module 2 is limitted by the input coupler performance
  There is no time now to process them

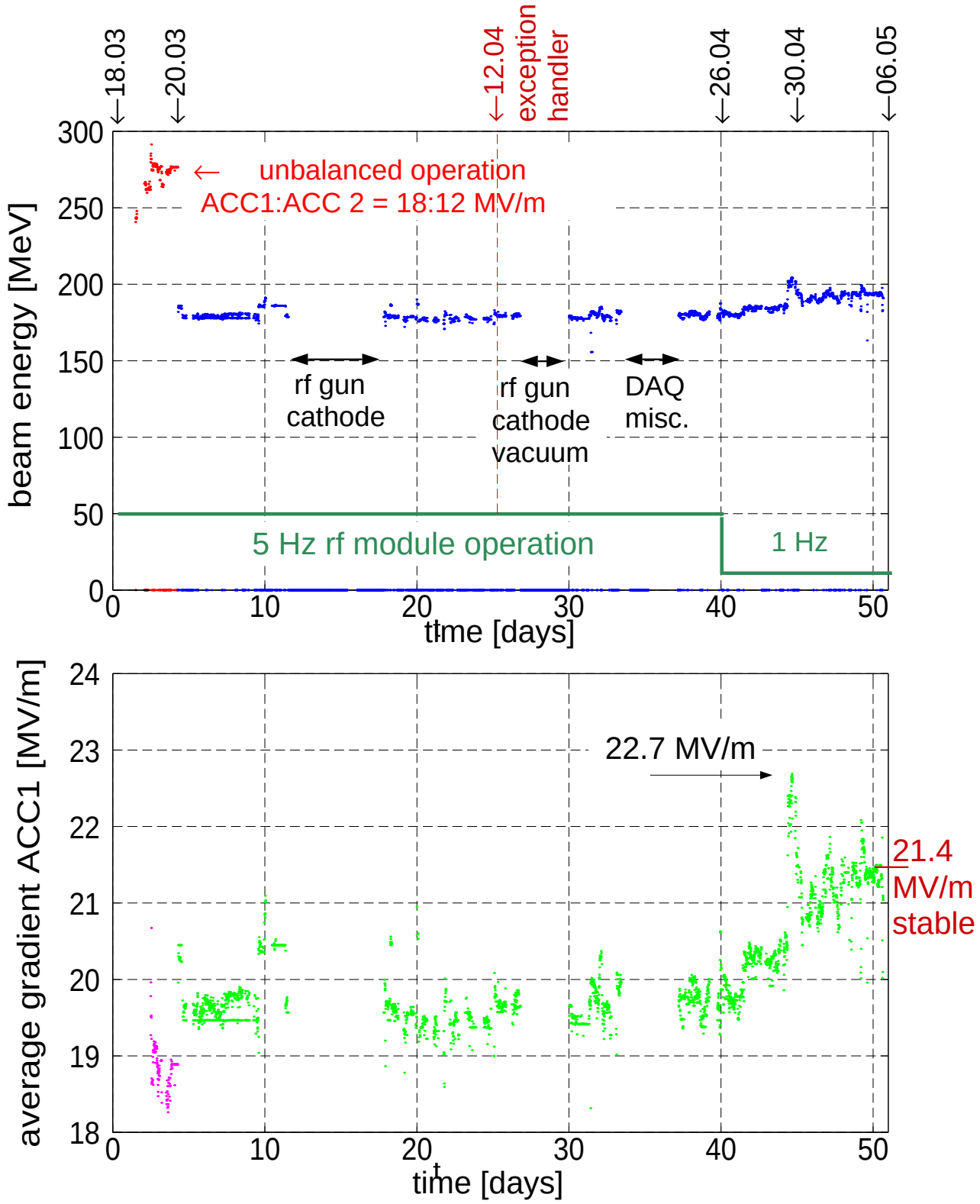
- Running module 2 with lower gradient then module 1 leads to llrf regulation difficulties when fully loaded with beam,
  since we use one klystron for both modules

power coupler e- signals



Beam energy and average gradient ACC 1

Development of the beam energy and the operation gradient



Module 3 Test Nov. 1999/ Apr 2002

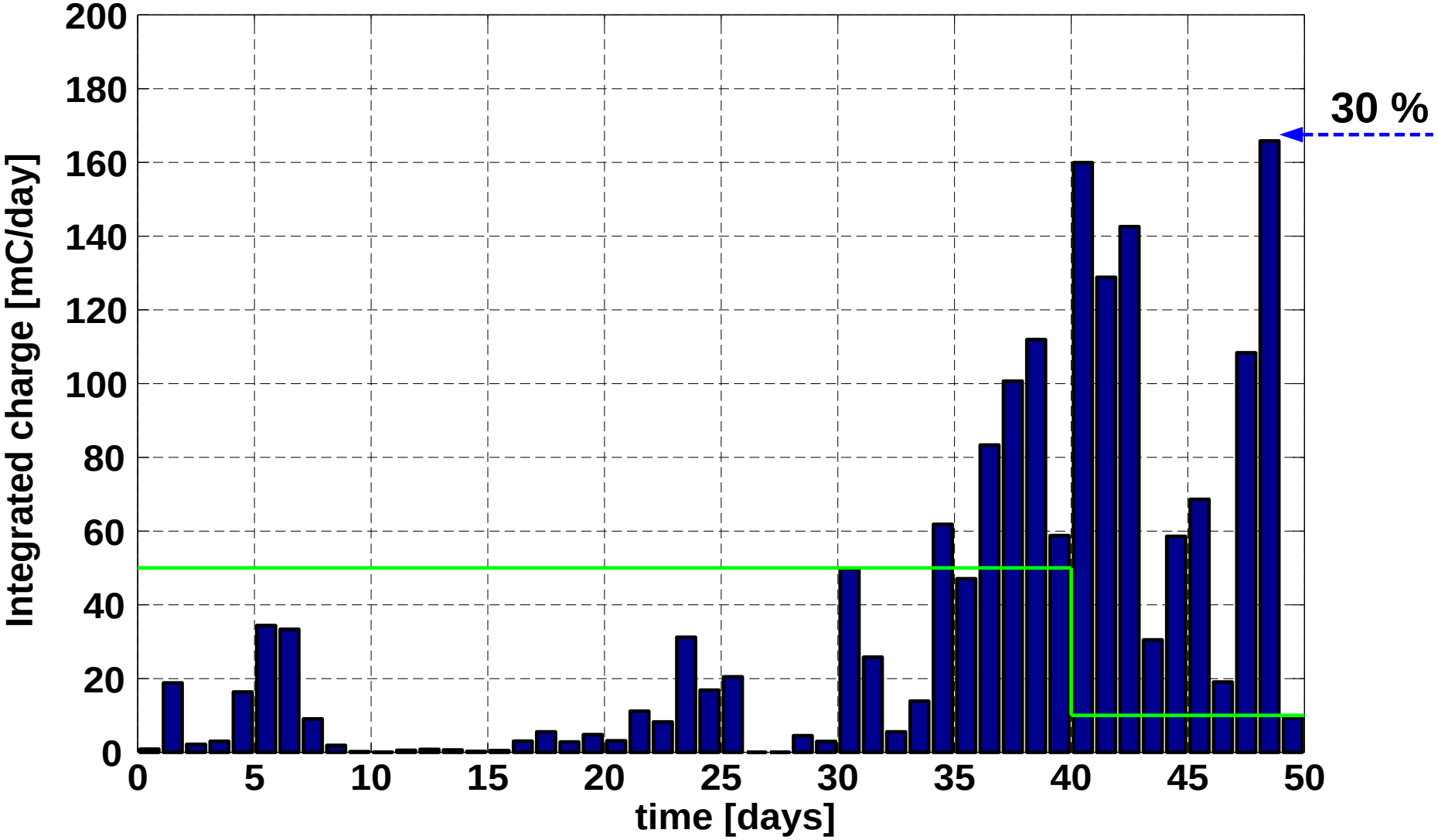
Couplers have been conditioned from 7.Oct to 25. Oct: 342 h test time, 72 % rf on
Single cavity tests 25-Oct. to 9. Nov. 1999
module test 9-Oct to 14-Nov 1999 C1 with 1,1dB, C8 with 3.0 dB att.

#	Cav ID	Cplr ID	vert Emax MV/m	hor Emax MV/m	Emax ~1 W		Xray max MGy/min	stabl e 3 h MV/m	stabl e 11 h MV/m	linac 1 Hz Emax MV/m	linac 1 Hz Estable MV/m
1	D41	DE1	23.3	-	22.7	21.6	0.3	23.0	21.8	21.3	19.9
2	S32	DE2	28.1	-	27.0	25.6	0.07	26.0	24.8	23.8	22.3
3	S29	DE3	26.7	25.1	25.0	24.0	0.6	25.0	23.4	24.8	23.2
4	S30	DE4	28.4	25.3	25.0	23.0	0.0	24.6	23.5	23.8	22.3
5	D39	AC1	25.2	29.9	26.3	24.2	0.6	23.2	22.2	24.8	23.1
6	D40	AC2	23.0	28.3	30.3	28.0	0.05	25.2	25.2	25.3	23.7
7	S28	DE5	25.3	-	28.5	25.0	0.1	25.1	23.9	24.3	22.7
8	D42	AC5	24.4	-	18.4	17.5	0.0	17.8	17.0	15.1	14.1
					single test			rf module test		with beam	

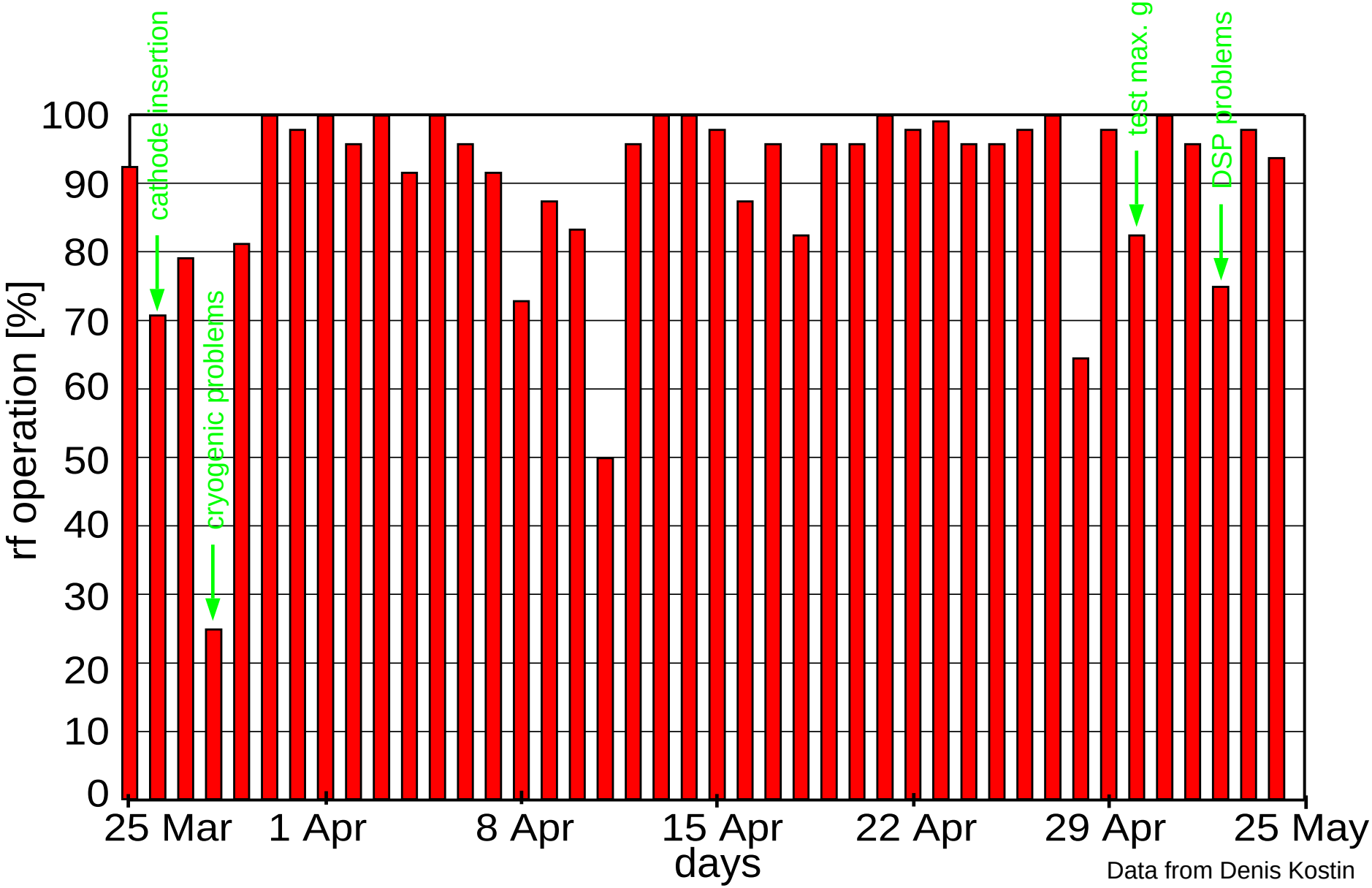
RF average (99): 23.7 MV/m (stable 3 h) & 22.7 MV/m (stable 11 h), 10Hz
Cryo losses: 5.9 W total, 0.74 W/cavity (3.8 W total, 0.5 W/cavity at 21 MV/m)
Beam operation (2002): 22.7 MV/m maximum (but intolerable high cryo-losses)
21.4 MV/m achieved with stable 800us beam (cryo losses < 2 W all cav.)

Charge transported through the TTF Linac

- **goal: 1Hz operation and 8 mA beam current**
  ⇒ integrated charge = 550 mC/day

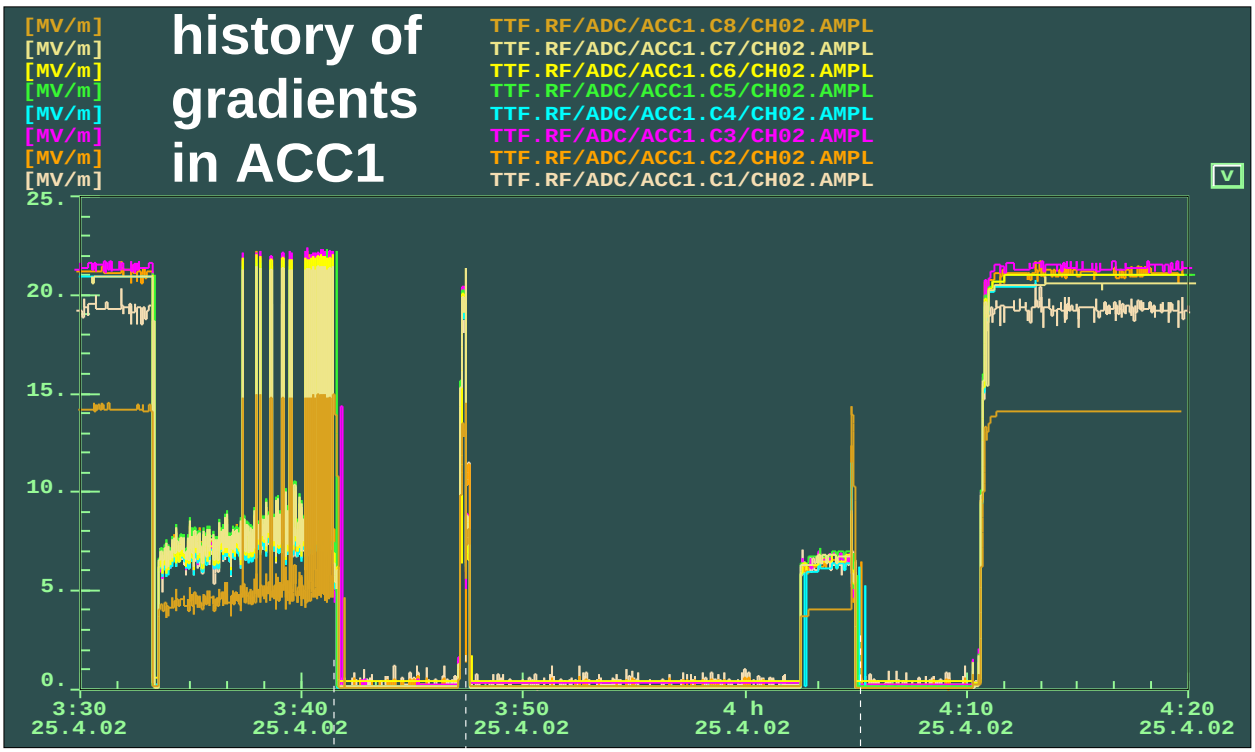


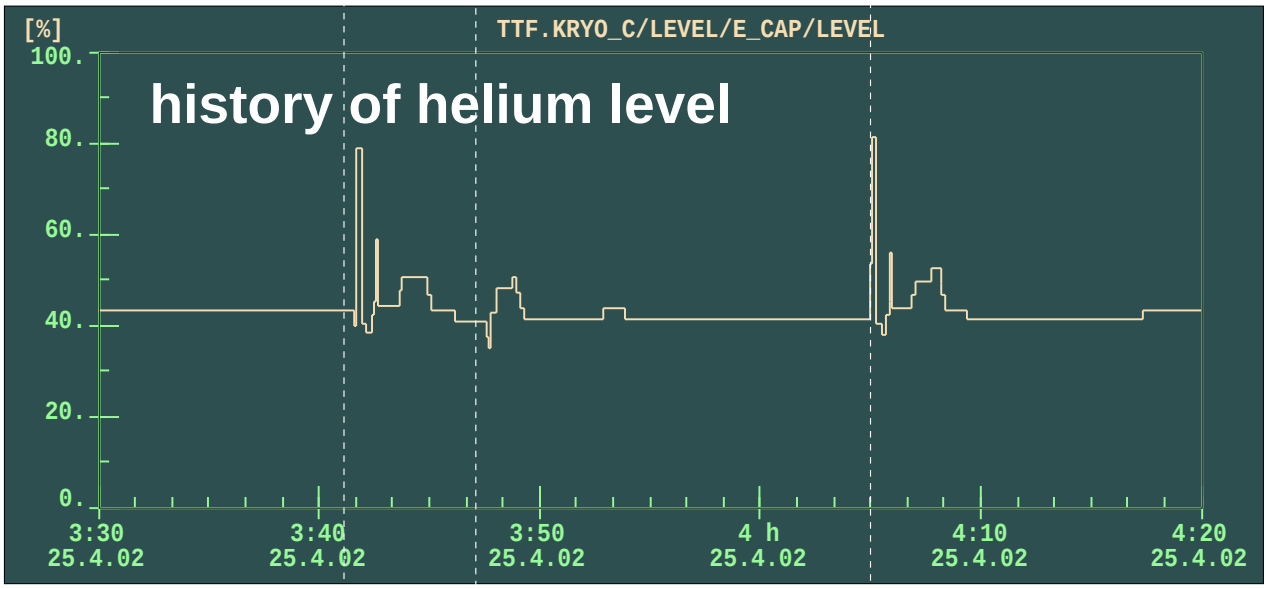
RF Operation of Module 3

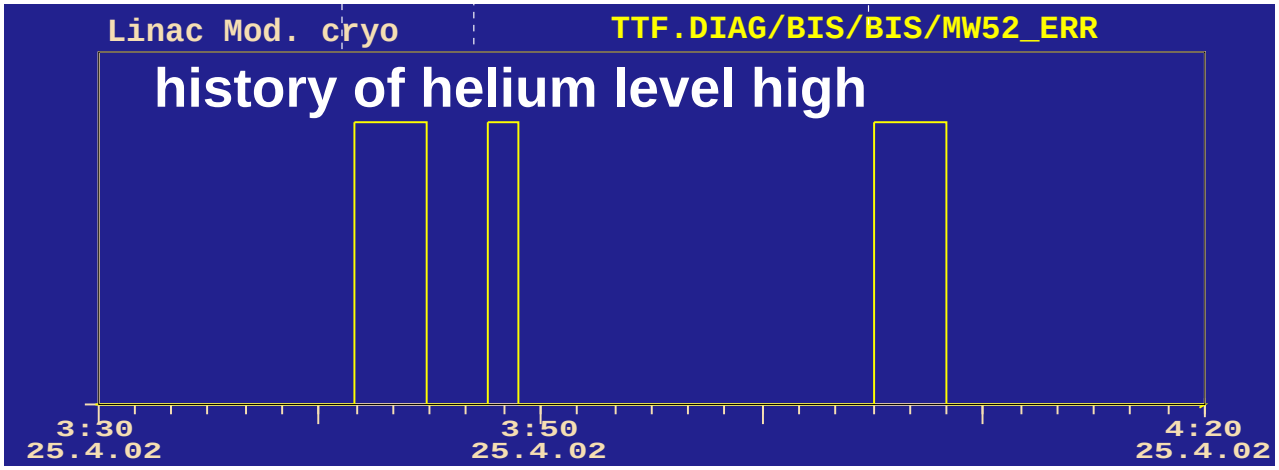


Data from Denis Kostin

Interlock helium level high

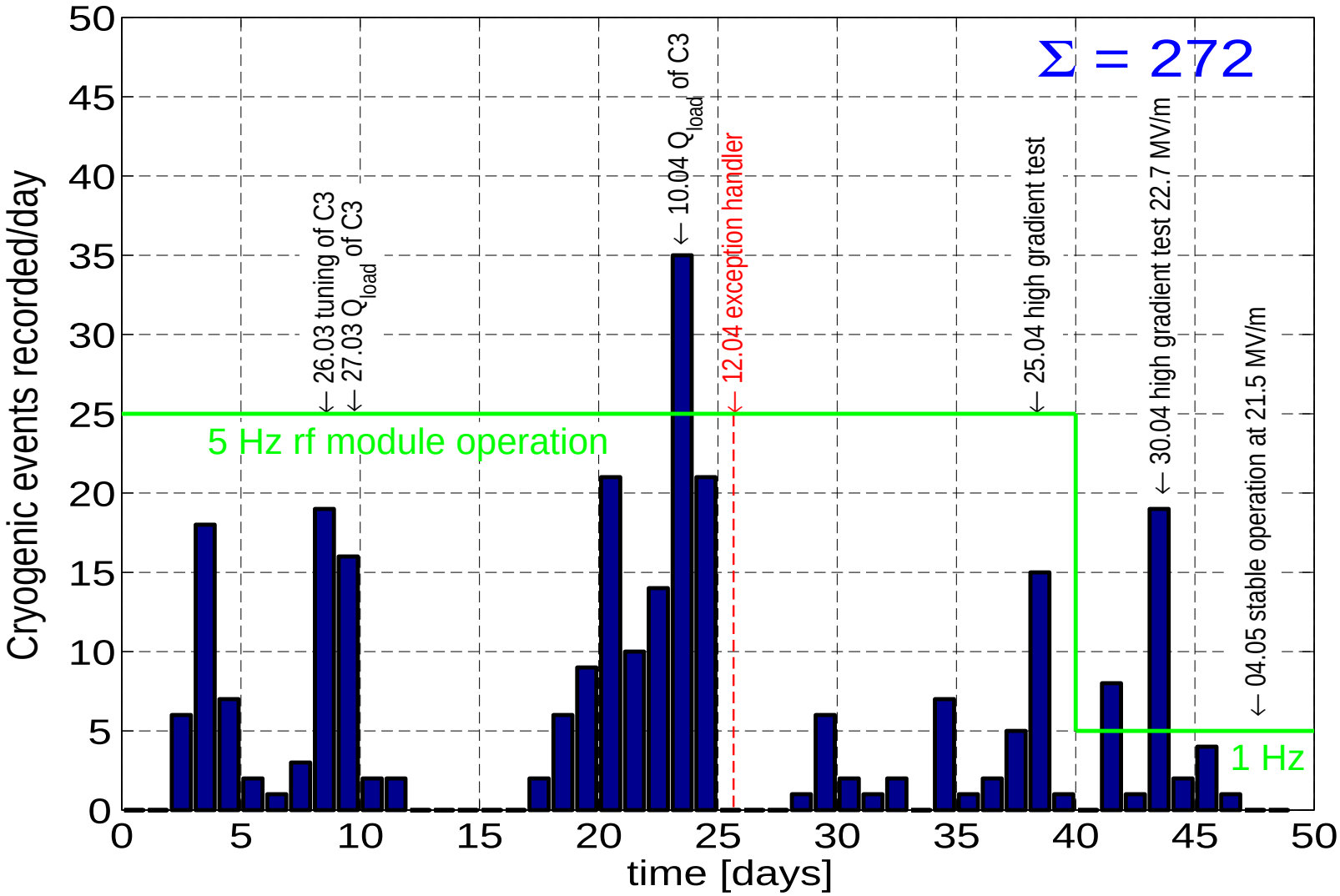






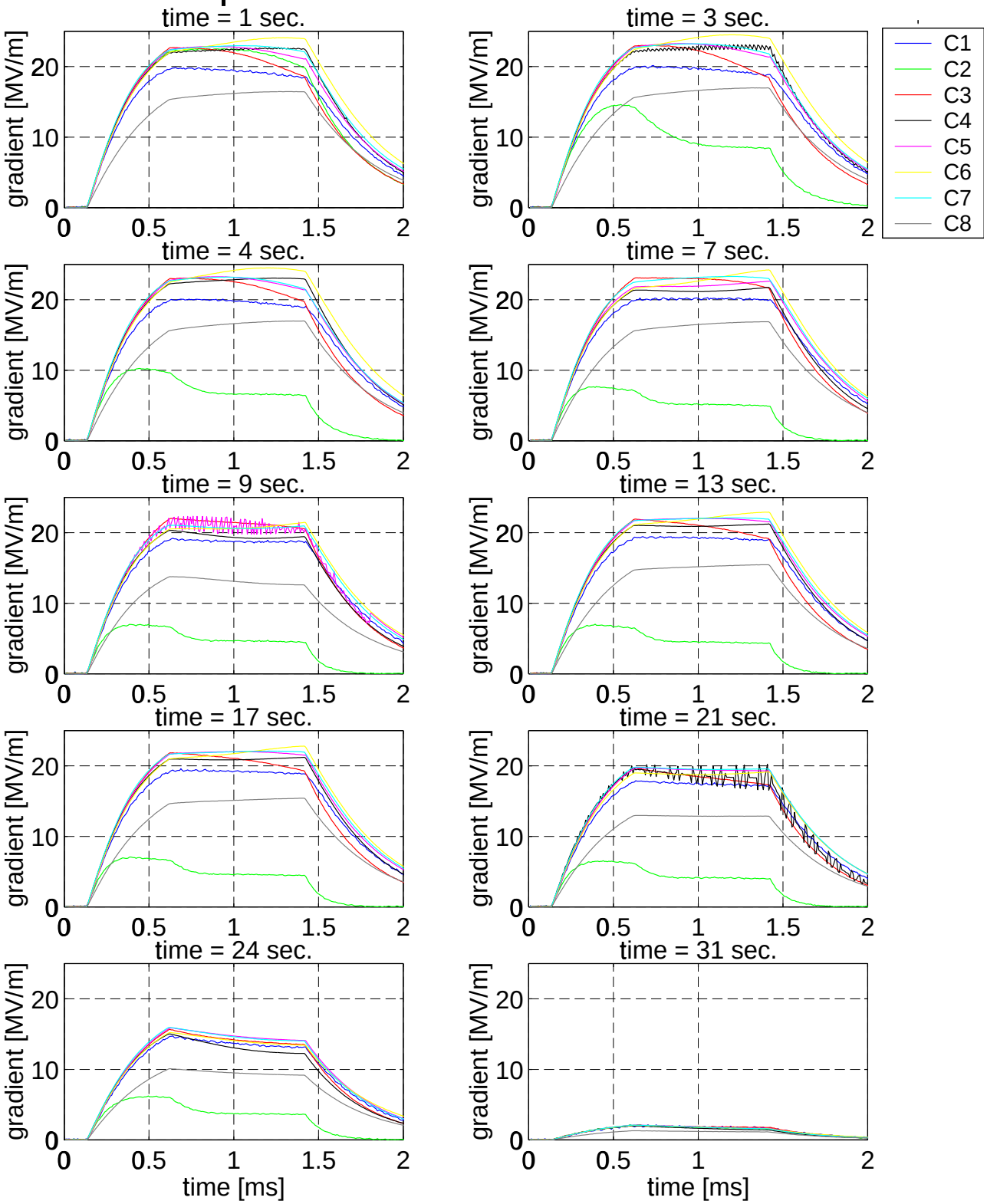
How many quenches have been produced?

- statistics analysed from cryogenic interlock: "level high" (level > 48 %, nom. 40-42 %)
- Q-drop of cavities cannot cause "level high" interlock event
- ≈ 1% of the events account to cryogenic operation (not corrected)

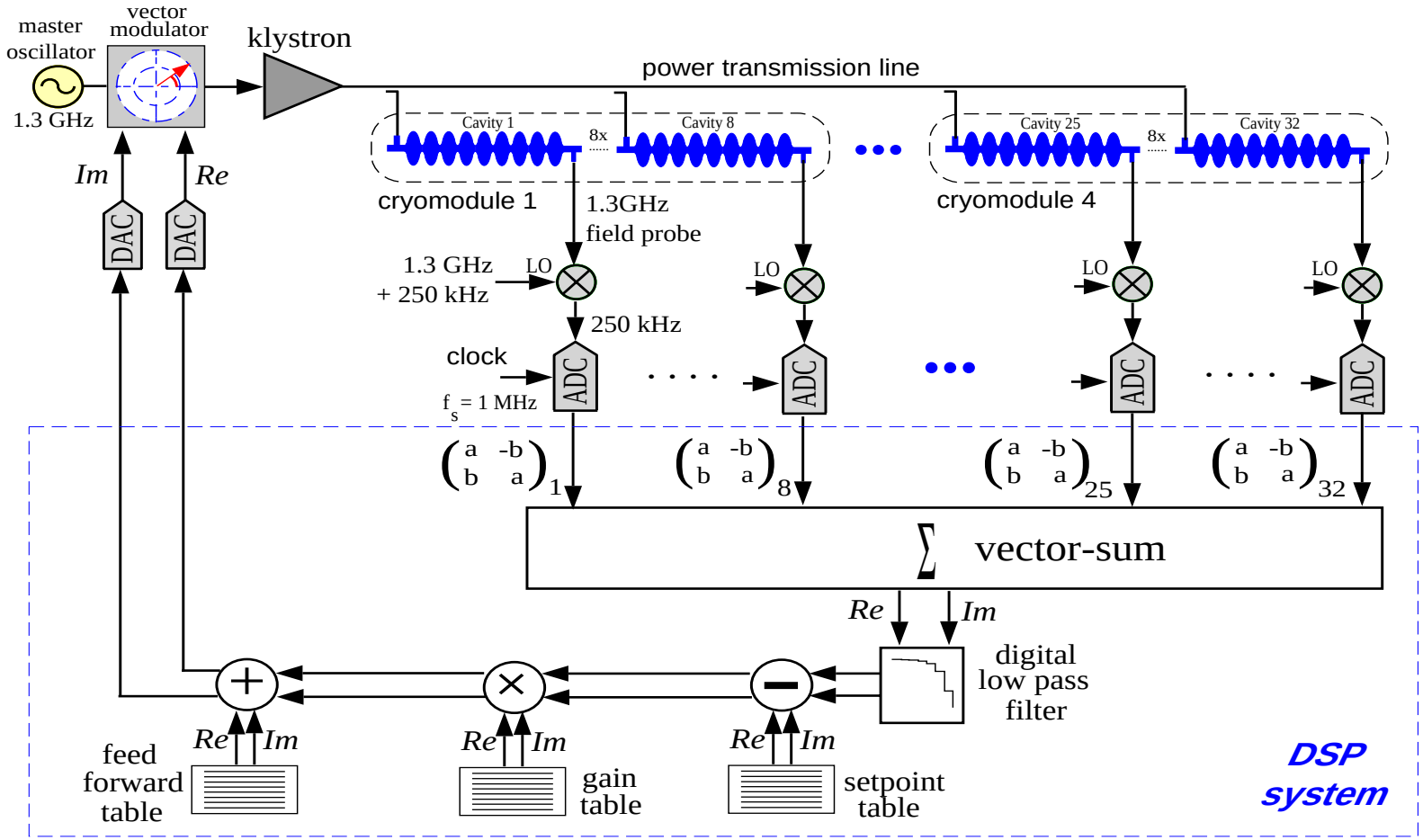


Example of a quench in Cavity 2

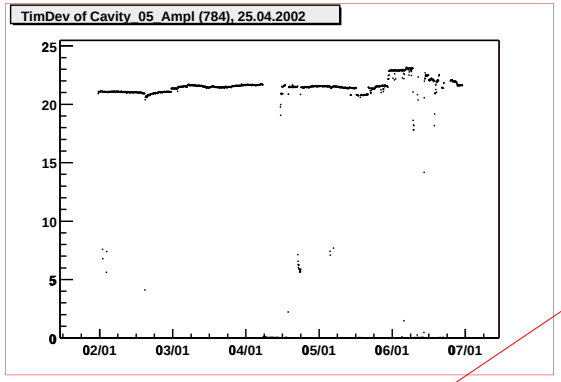
- date: 27 March 2002
- exception handler has not yet been installed
- module operation did continue for > 20 sec.



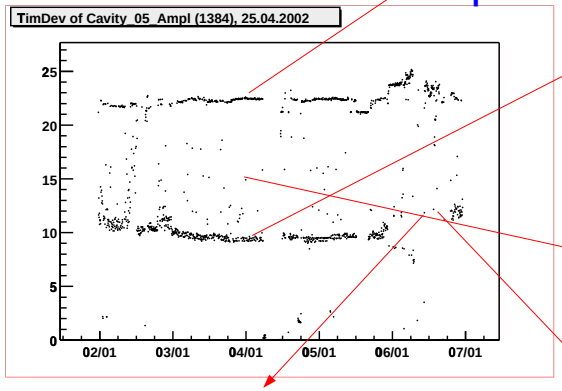
Digital Control at the TTF



Gradient C5 begin flat top

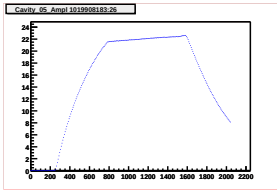


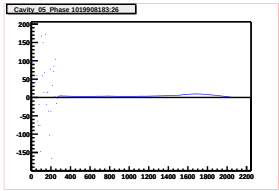
Gradient C5 end flat top



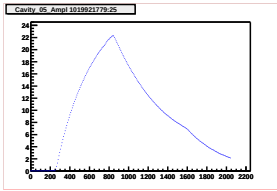
Gradient Phase

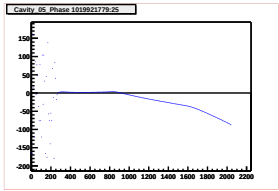
nominal operation



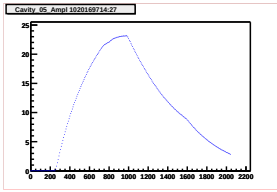


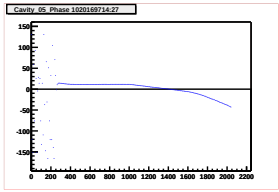
exception handler (early cut)



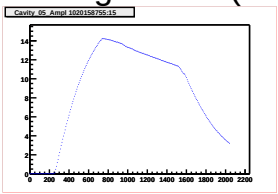


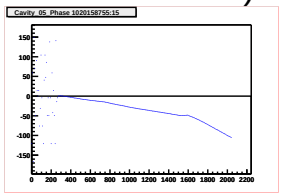
exception handler (cut > 200µs)



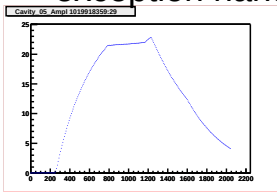


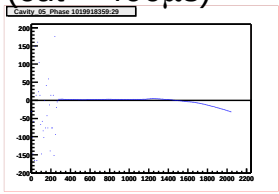
low gradient (break down or FB off)





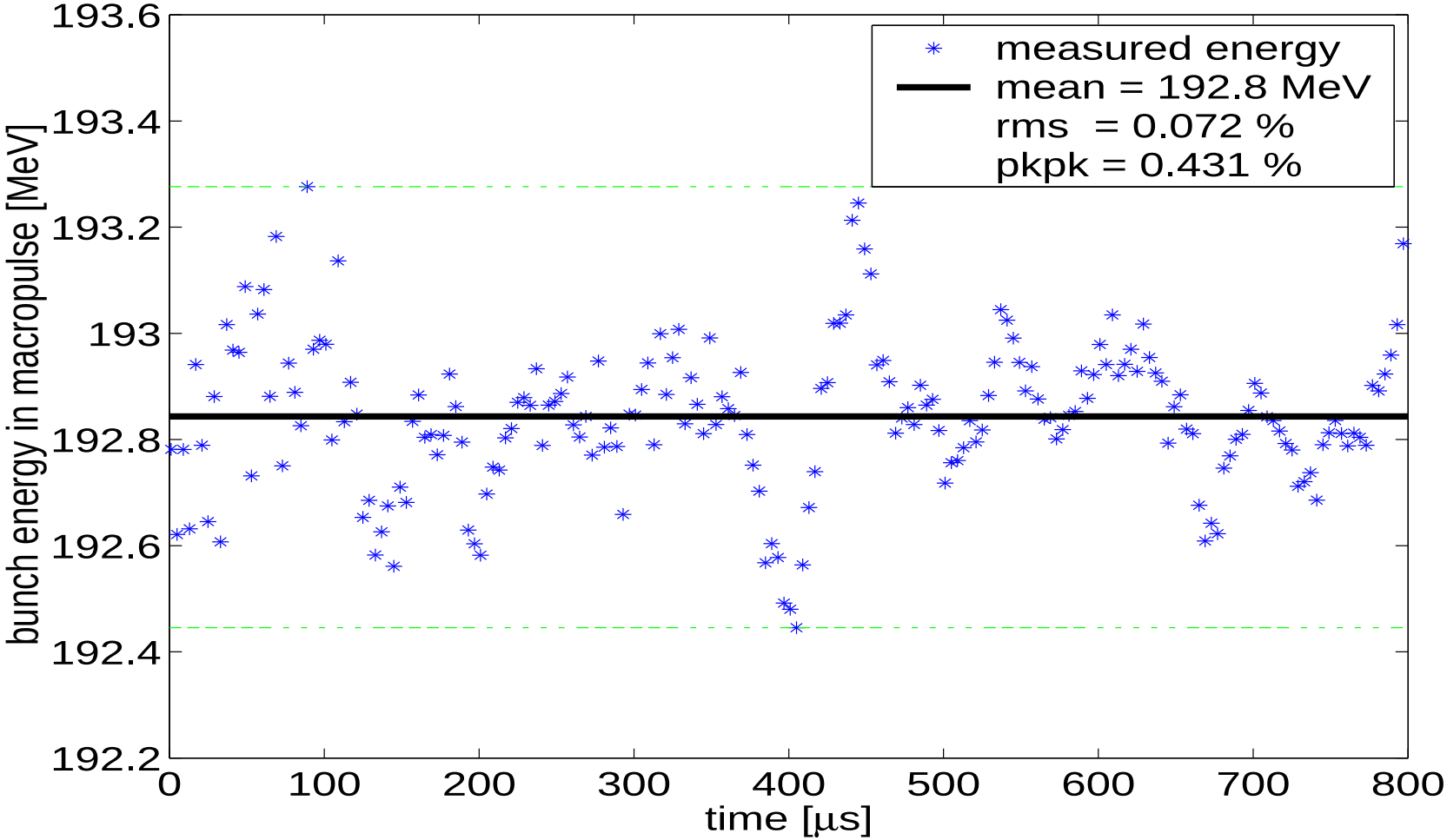
exception handler (cut > 400µs)





Achieved energy spread in macropulse

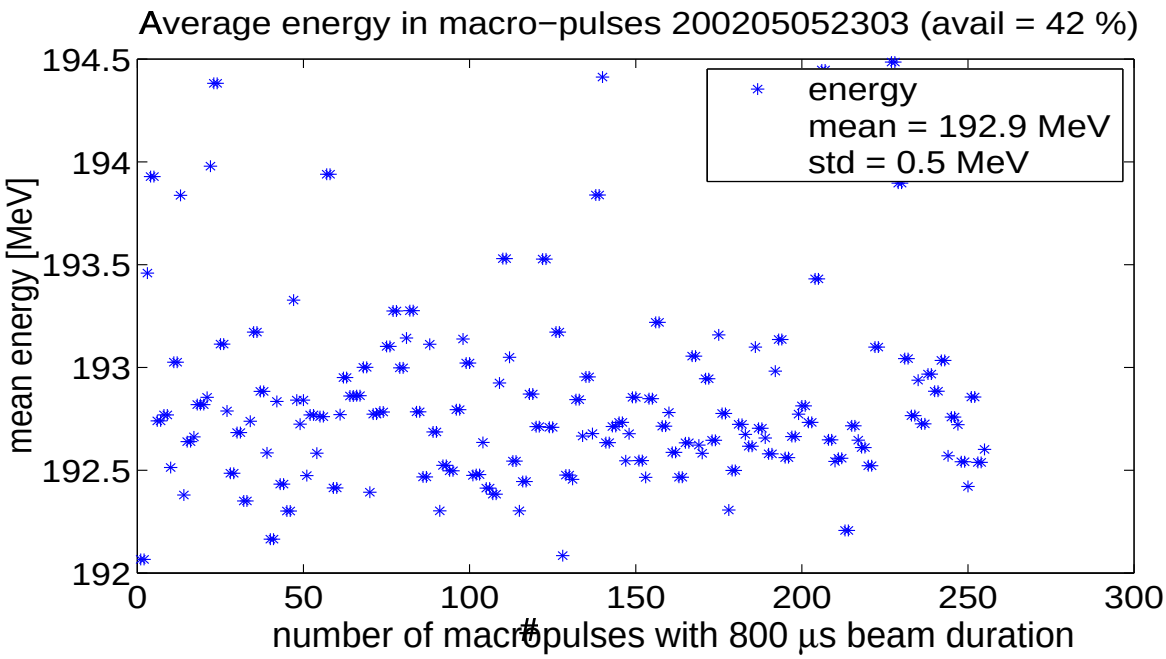
Date: 05. May 2002
Beam current = 5.9 mA

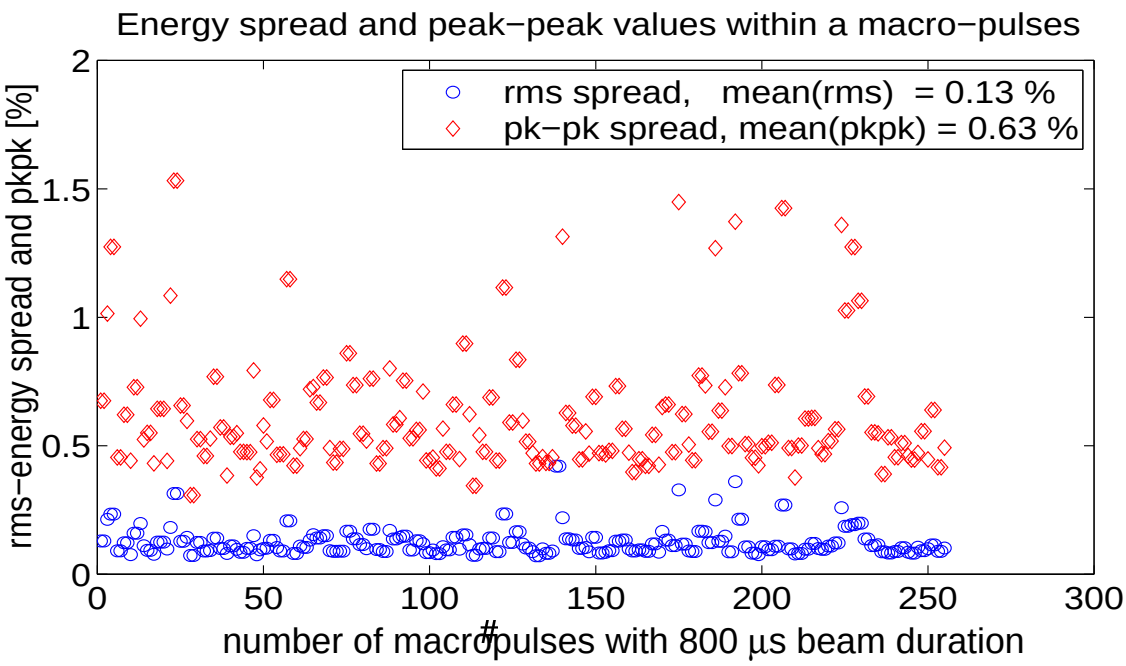


Energy Stability achieved at high gradient

average gradient = 21.3 MV/m at 1 Hz rep. rate.
dynamic cryogenic losses within resolution < 1W

Record of 1 hour operation

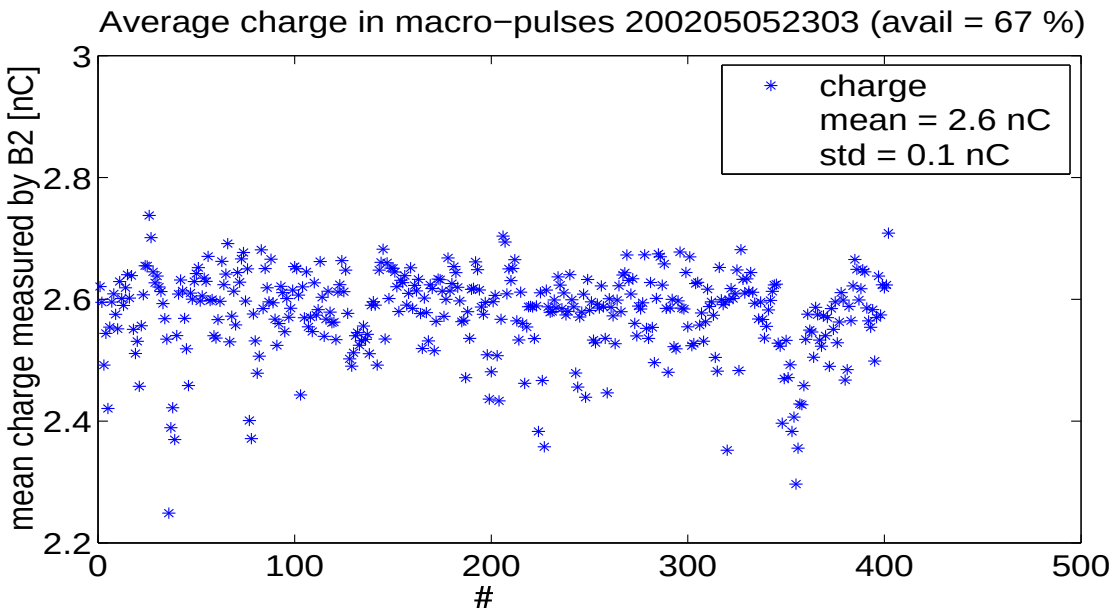


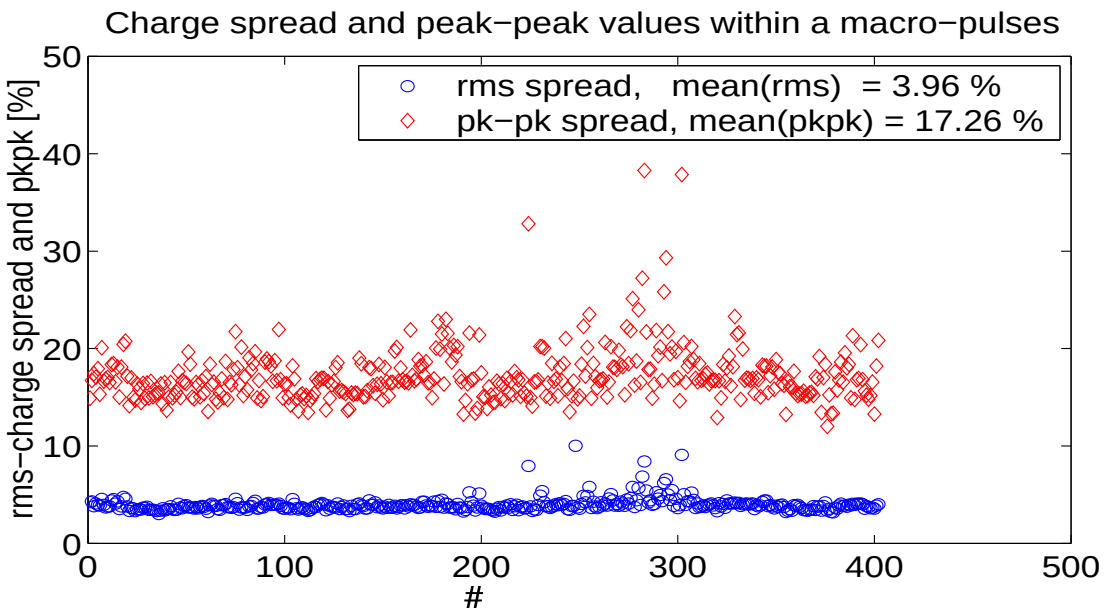


Charge stability during macropulse operation

average gradient = 21.3 MV/m at 1 Hz rep. rate.
dynamic cryogenic losses within resolution < 1W

Record of 1 hour operation





Summary of Full Performance Test for Module 1*

- rf-module operation 5Hz @ 19.5 MV/m = 39 days
  1Hz @ 20.3 MV/m = 4 days
  1Hz @ 21.5 MV/m = 6 days

- highest gradient (1Hz) = 22.7 MV/m

- stable beam operation at 21.4±0.2 MV/m with
  - 5-6 mA beam current
  - 0.15% macropulse energy spread
  - dynamic cryogenic losses < 2 W
    (within measurement accuracy)

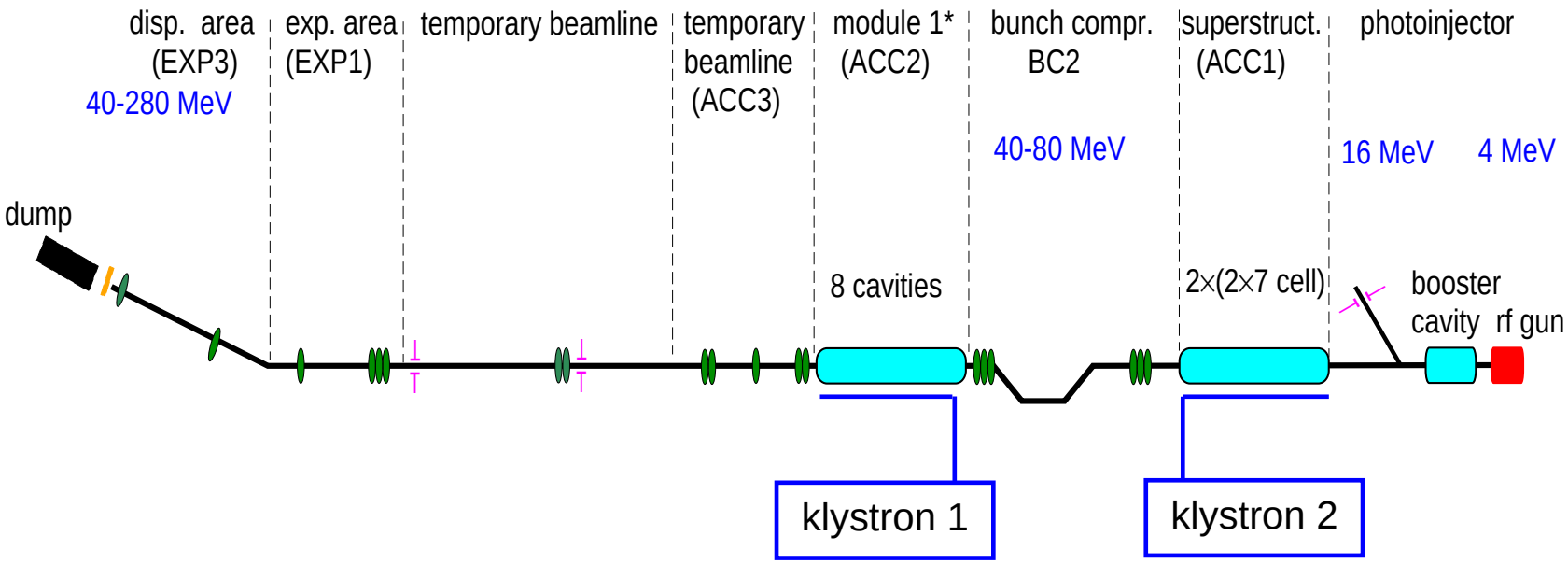
- successfull rf operation with exception handler

- highest charge transported/day ≈ 170 mC (30%)

- gained valuable experience for operation

- many reflected power events of rf gun (up to 50%) reduced the performance of linac operation and increased the required machine tuning time.

TTF Linac beamline for Superstructure Test (SST)



Shutdown activities: 07. May - 31. July

- rf gun G3 exchanged with G4 (FNAL)
- analysis beamline extended to incorporate a BPM in the dispersive section
- ACC1: module 3 exchanged with superstructure (expected gradient ≈ 17-18 MV/m)
- BC2: previous dipole vacuum chamber with 24mm vertical gap is installed
- ACC2: module 2 is exchanged by module 1* (expected gradient > 25 MV/m)
- collimator and undulator have been removed, re-entrant BPM and quadrupoles are reused
- photon-diagnostics is removed from tunnel
- klystron 2 feeds superstructure & klystron 1 delivers rf to module 1*

Chronological order TTF Linac run for superstructure

July:

- 05.07. pump down of rf gun
- 08.07. personal interlock test
  start warm conditioning of couplers
- 09.07. start conditioning of rf gun G4
- 20.07. start HOM measurement with network analyzer
- 25.07. cool down of linac finished + interlock checks
- 26.07. start injector beam commissioning

August:

- 09.08. long macropulse operation at injector
- 15.08. coupler conditioning of SST terminated
- 17.08. could not pass beam through superstructure
  ⇒ warm up linac, found closed manual valve
  ⇒ opened end cap and repaired valve

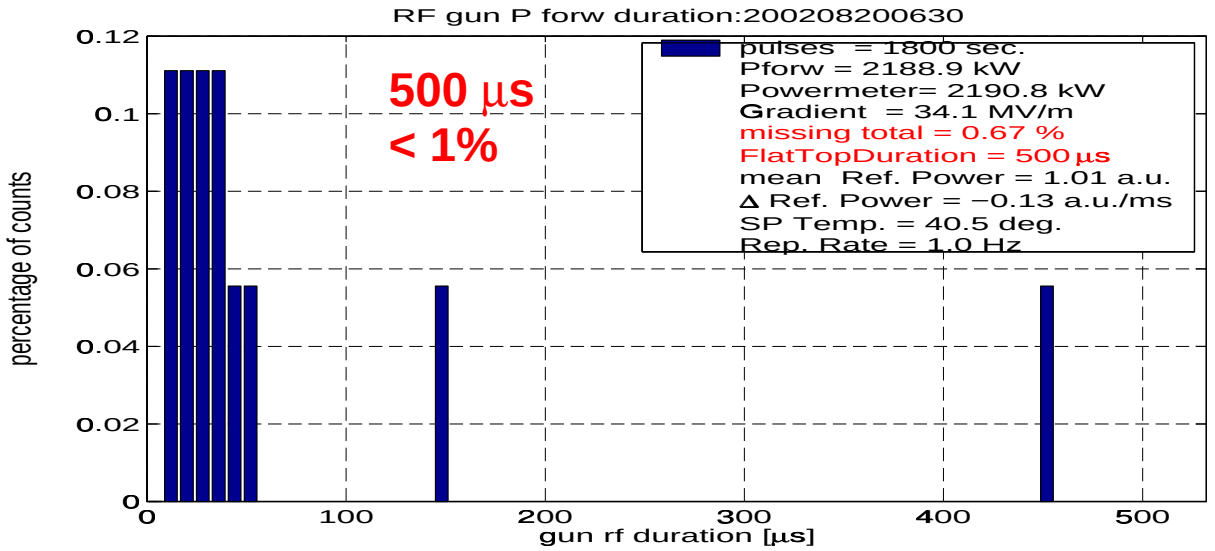
September:

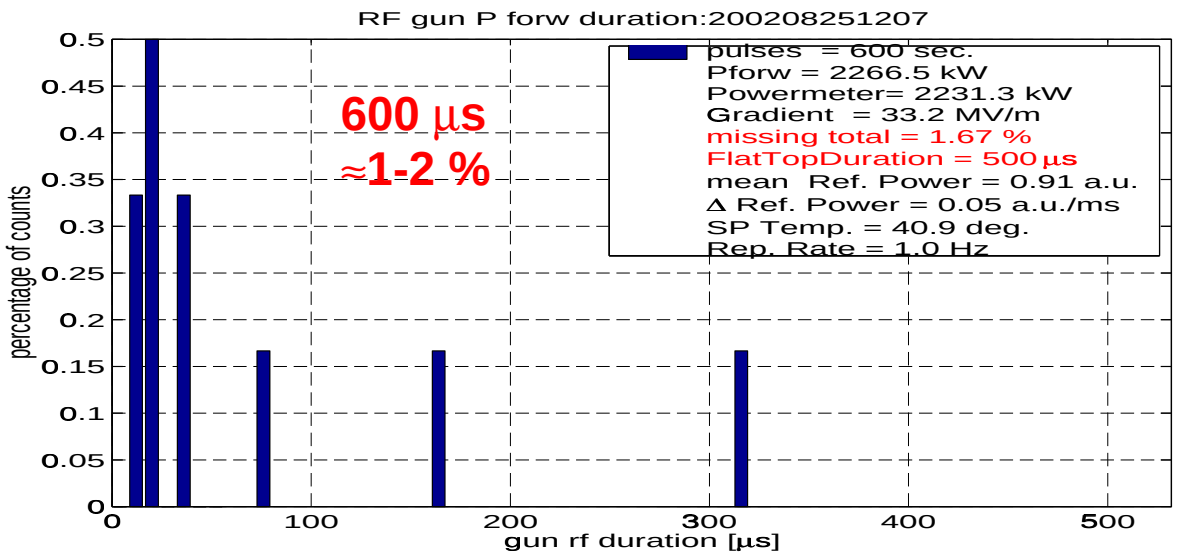
- 02.09. cool down + interlock of superstructure
- 04.09. start commissioning of linac
- 10.09. LLRF feedback for SS operable
- 13.09. long macropulse operation (500μs)
- 17.09. finished macropulse energy stability studies
- 18.09. start active HOM excitation

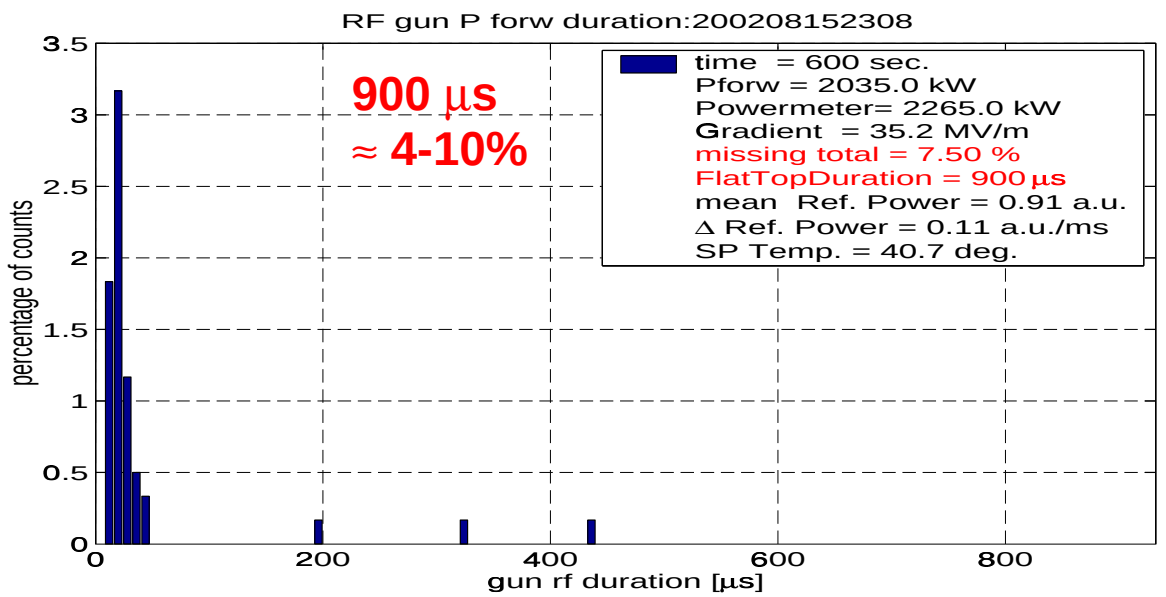
- 25.09. is planned to implement 54MHz operation
  in laser system

Reflected Power Events of rf gun G4

Amount of reflected power events depends strongly on rf pulse length:

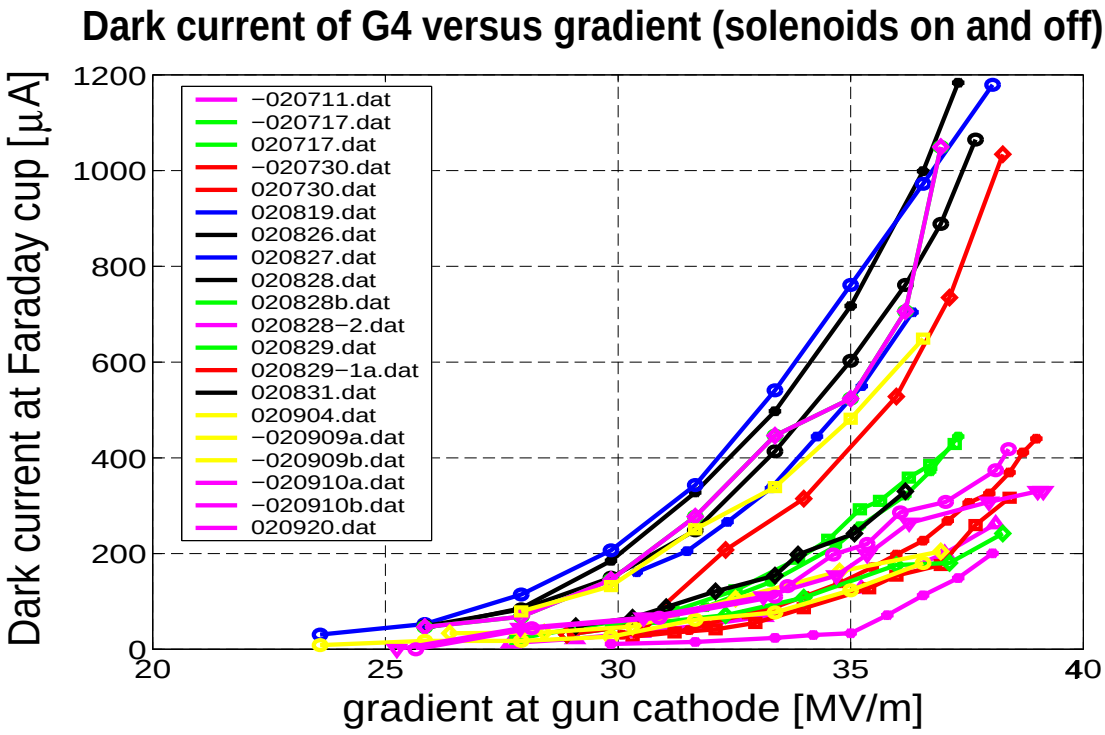


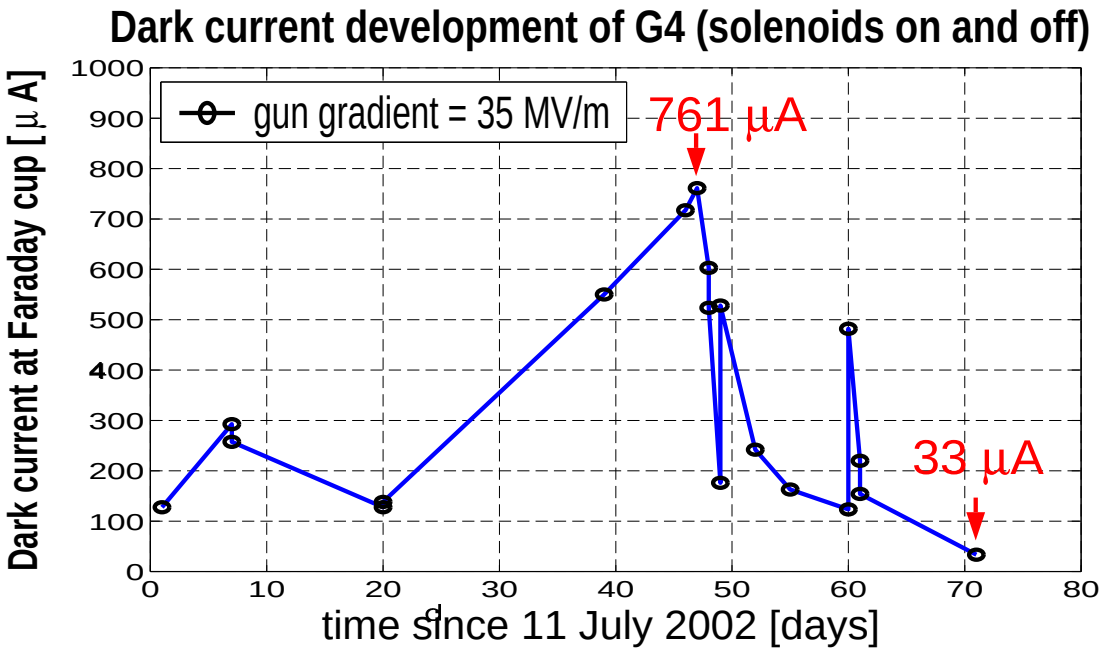




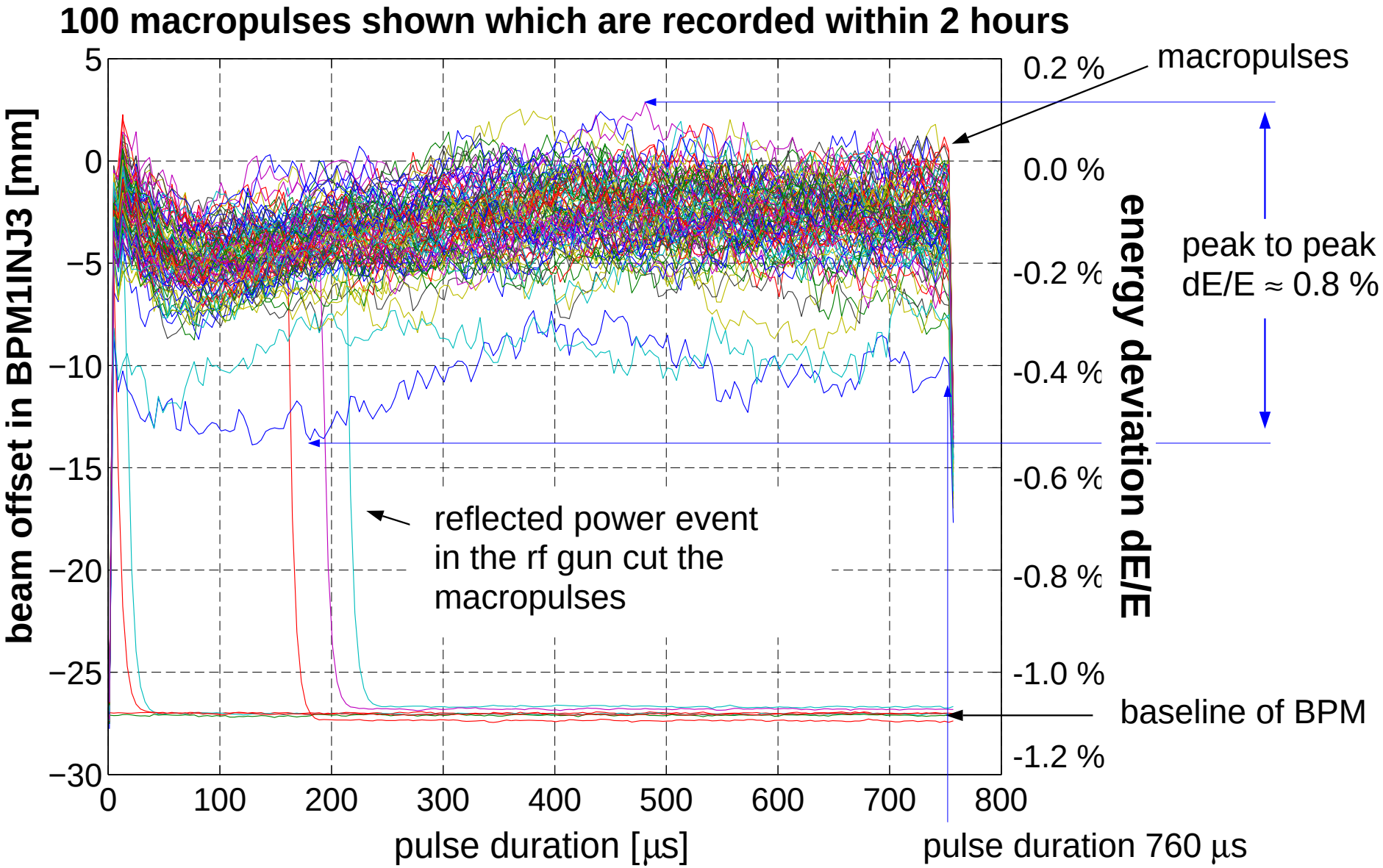
Dark current emitted from G4 rf gun

- high dark current causes difficulties for beam size measurements
- dark current drop continuesly since 27. August 2002
- cathode C11 (from last run) is used





Beam energy stability in the Injector

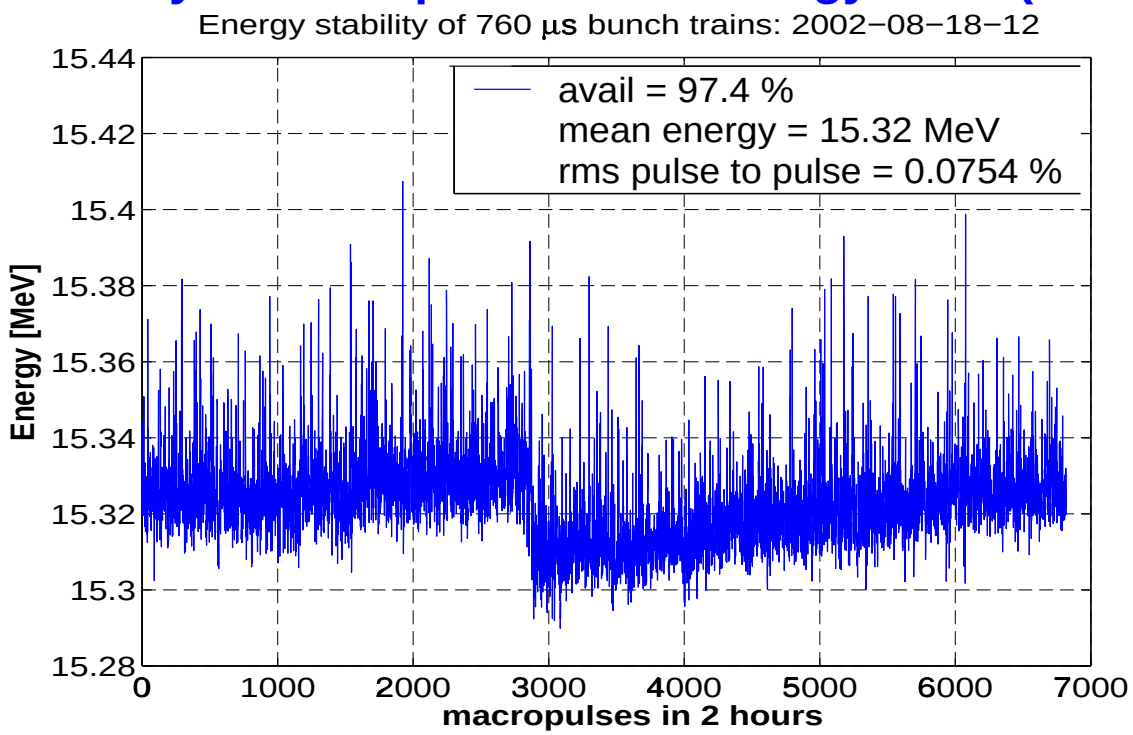


Beam energy stability in the Injector

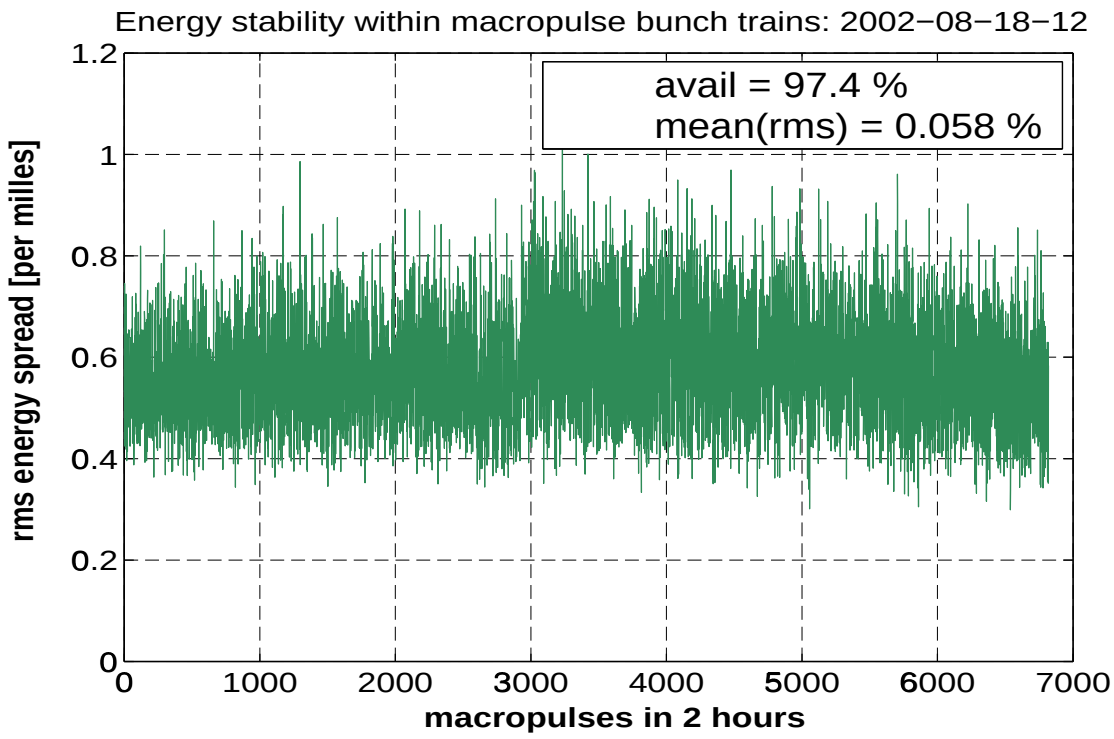
The achieved energy stability from pulse to pulse (<0.3%) and the energy spread within the pulse trains (<0.1%) meets the requirements for the superstructure energy test.

But: Energy flatness has been achieved only with charge drop along the macropulse

History of Macropulse Beam Energy Jitter (2 hours)



History of Macropulse Energy Spread (2 hours)

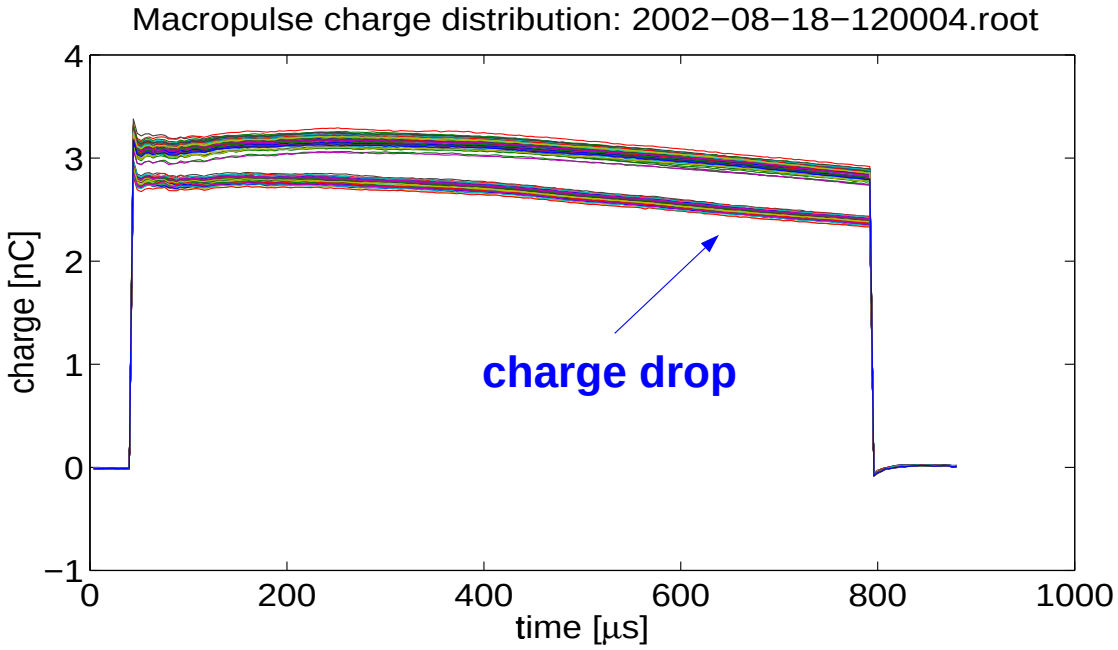


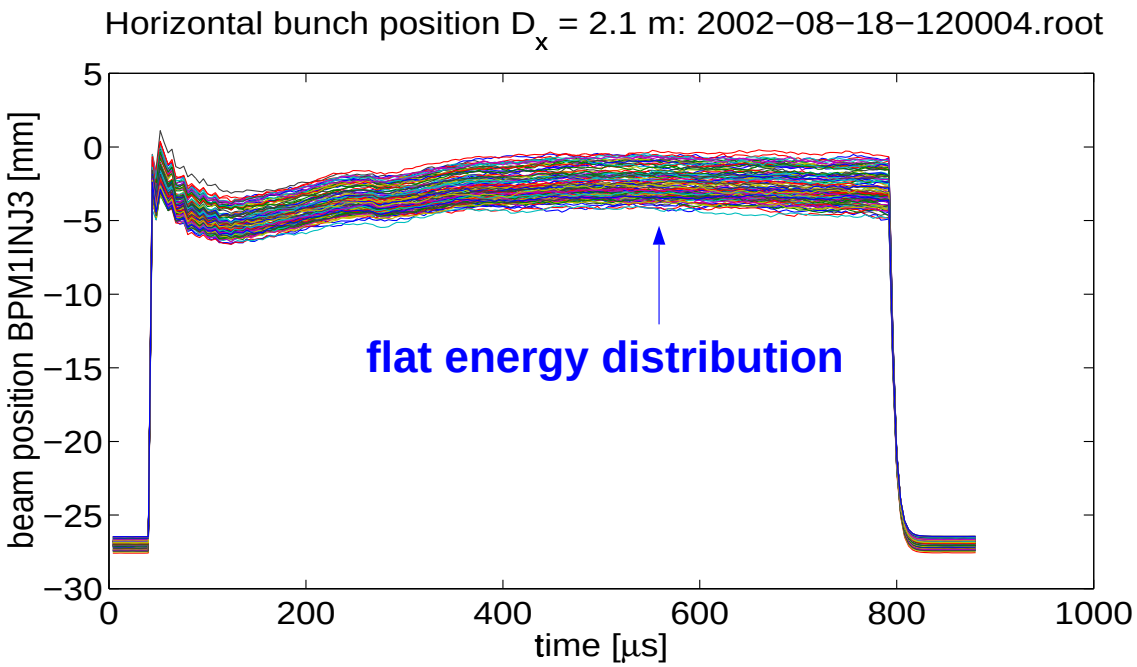
Improper Compensation of Beam Loading

If charge is high the feedback of the capture cavity cannot compensate the gradient drop due to beam load

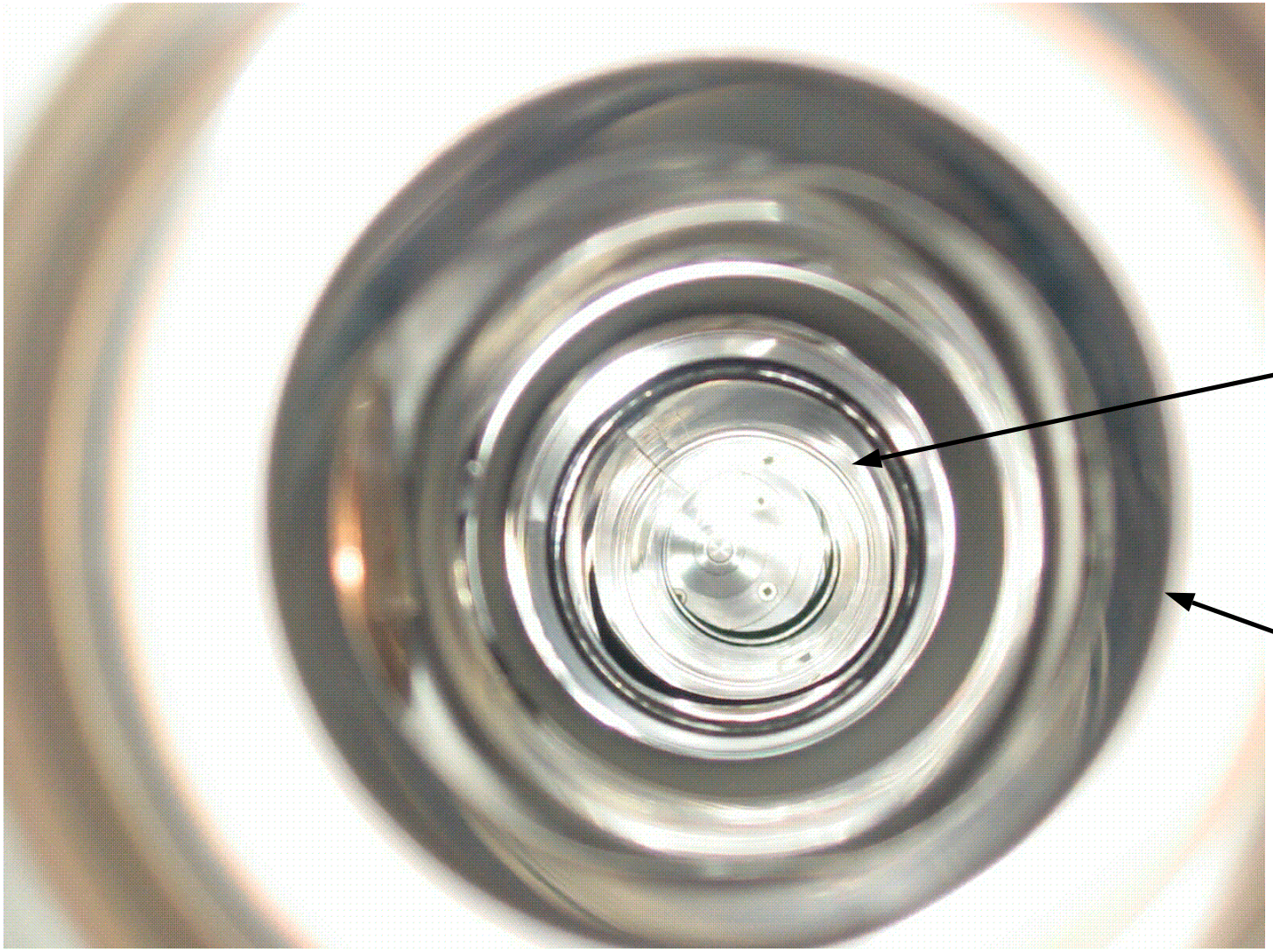
⇒ decrease charge toward the macropulse end

⇒ in the LLRF the feed foreward table have to be adapted .





View inside the superstructure



ACC1 / Superstructure module

Couplers processing

1	2
D3C1	D3C2
DESY III	DESY III

Time: 8 July - 15 August 2002 39 days

Total time	940hr	100%
P_{for} > 2kW (RF on)	300hr	32%
P_{for} > 100kW	150hr	16%
P_{for} > 200kW	120hr	13%

Results:

1. OFF resonance	500kW @ 1.3ms	1.08.02
2. ON resonance	100kW @ 690µs+610µs (FT) E_{acc}=15MV/m	15.08.02

Denis Kostin, MHF/SL, DESY

ACC2 / module 1* Couplers processing

1	2	3	4	5	6	7	8
F6	AC3	DE7	F4	F7	F10	DE6	F9
FNAL	DESY II	DESY II	FNAL	FNAL	FNAL	DESY II	FNAL

Time: 15 July - 20 Sept. 2002 66 days

Total time	1580hr	100%
P_{for} > 2kW (RF on)	712hr	45%
P_{for} > 100kW	456hr	29%
P_{for} > 200kW	254hr	16%
Klystron 1 OFF	300hr	19%

Status:

1. OFF resonance	330kW @ 1.3ms	15.09.02
	Total time: 63 days -> 1500hr RF on time: 660hr (44%)	
2. ON resonance	80kW @ 500µs+800µs (FT) E_{acc}=15MV/m	18.08.02
	330kW @ 100µs	
	200kW @ 200µs Limited by e- pickup signals in warm parts of DESY II couplers	19.08.02

Comments:

1. Couplers in the modules were not heated up to 150°C.
2. RF surfaces in vacuum for FNAL/DESY II couplers are 2.5 times bigger compared with DESY III coupler, while pumping speeds FNAL/DESY II/DESY III are respectively 1.8/17/14 l/s (DESY III is effectively pumped out faster).
3. Photomultiplier on DESY II is set far away from cold window.
4. DESY II coupler have a capton foil isolation – outgassing.
5. We need more sensitivity of the photomultipliers for FNAL and DESY II couplers (pp.2,3)

Denis Kostin, MHF/SL, DESY

Experimental Program and Status of Superstructure Test

1) Measurement Q_{ext} with network analyzer (at 2 K)

   20.-31. July (≈10 shifts) ⇒ completed

2) Measurement of gradient stability:
   4 mA beam current with 500μs beam duration

   12.-17. August (≈20 shifts) ⇒ completed

3) Excitation of HOMs by an external rf generator

   13.-25. August ⇒ successfully started, but still ongoing

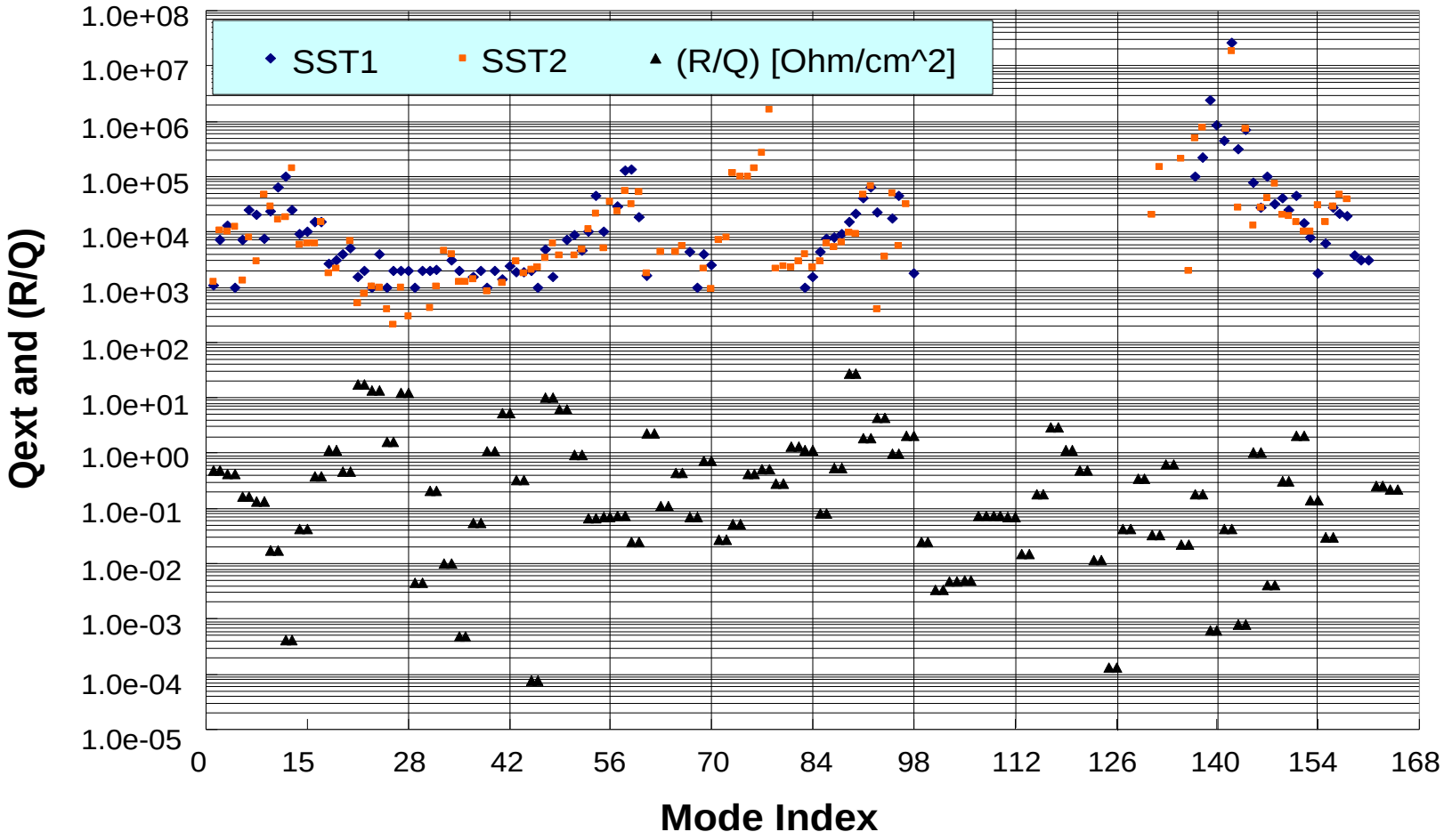
4) Excitation of HOMs by density modulated beam with 54 MHz bunch spacing

   25. August ⇒ switch laser to 54MHz operation

Higher Order Mode damping in SST1 & SST2

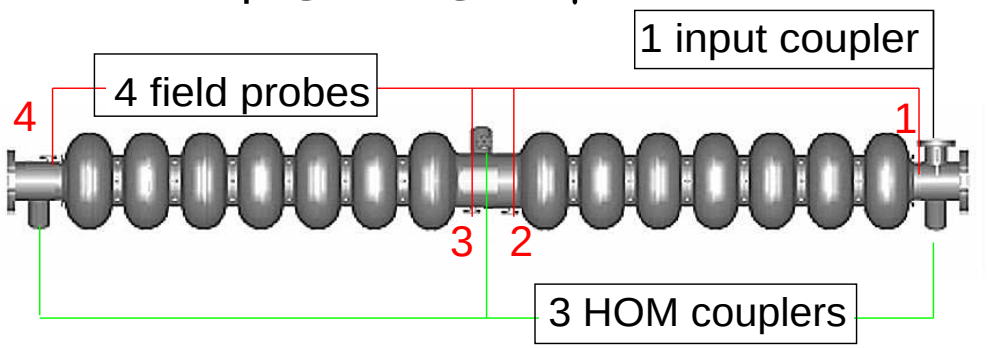
- measurement of Q external with network analyzer at the HOM-couplers
- R is obtained by numerical simulations

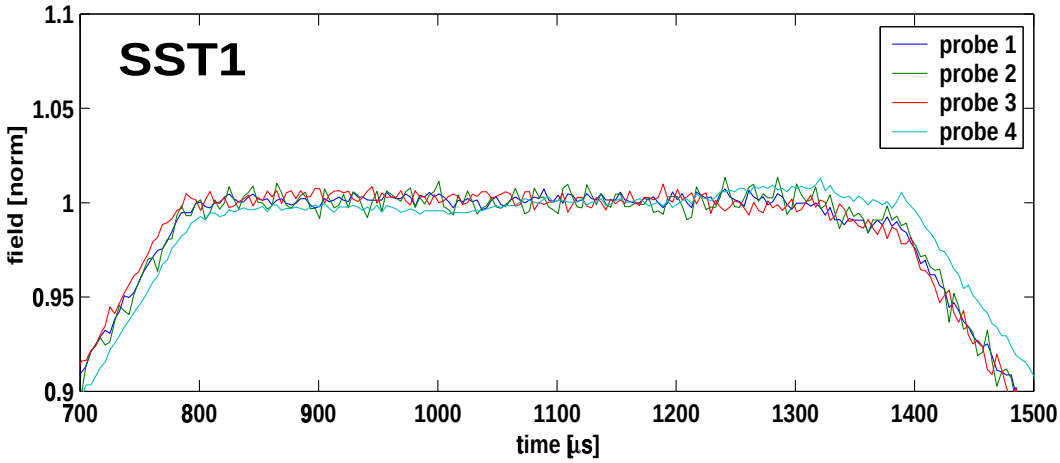
⇒ damping of relevant (R/Q) is excellent and much better than assumed for TESLA beam dynamics simulations

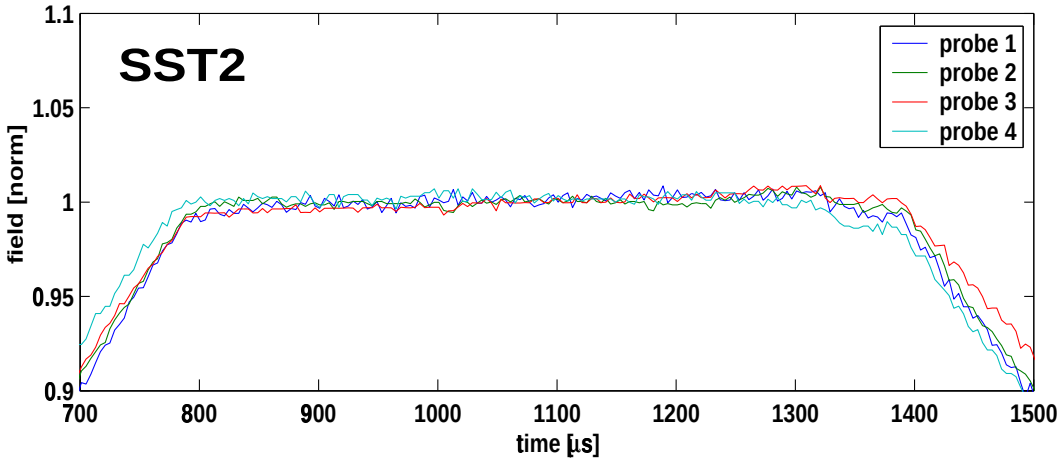


Refilling process of stored cavity energy

If refilling fails then the gradient measured at 4th probe should drop along the rf pulse if beam is applied:
maximum: 5% drop @4mA@500µs ⇒ not observable

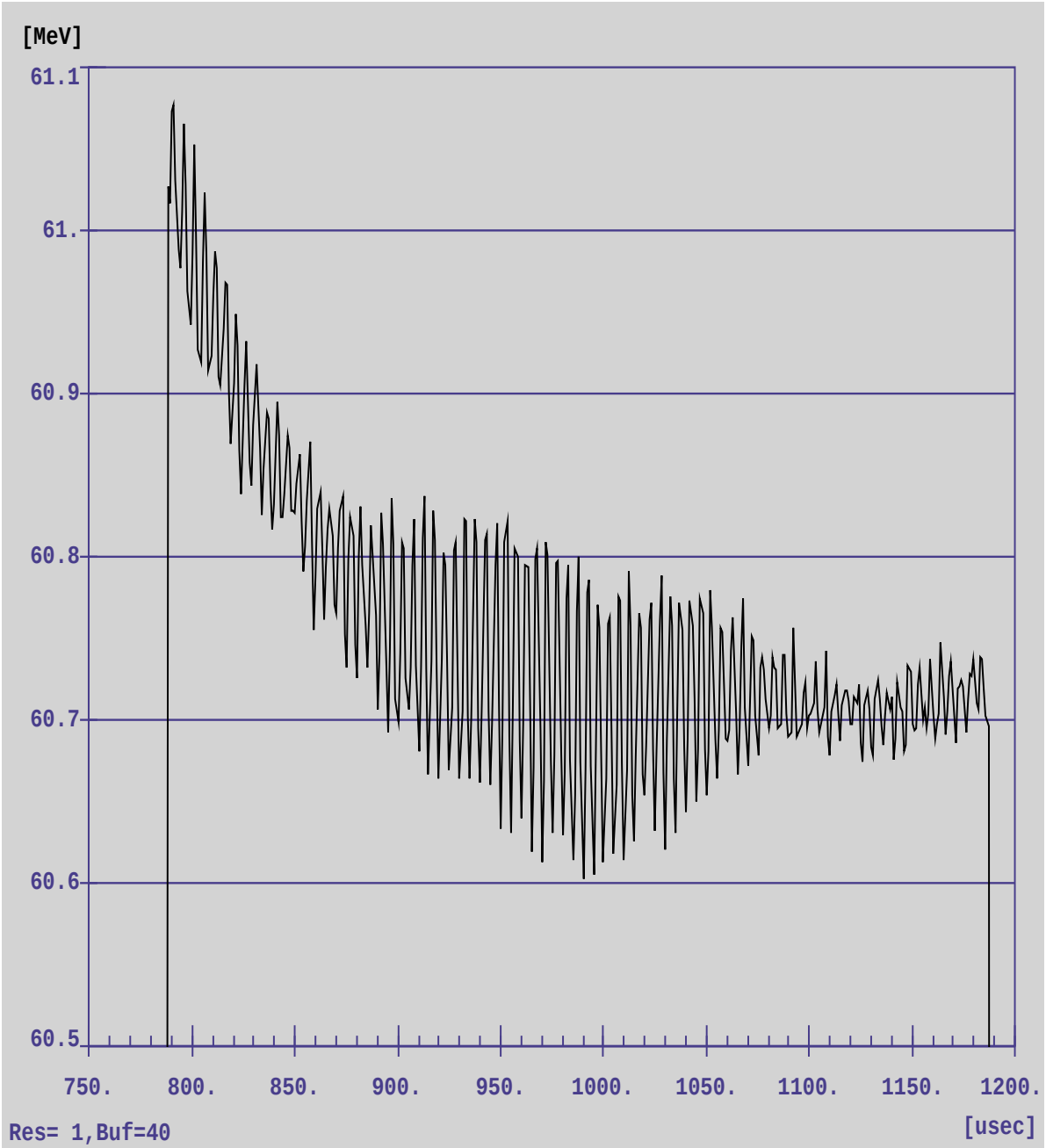






Energy of bunches in a macro pulse

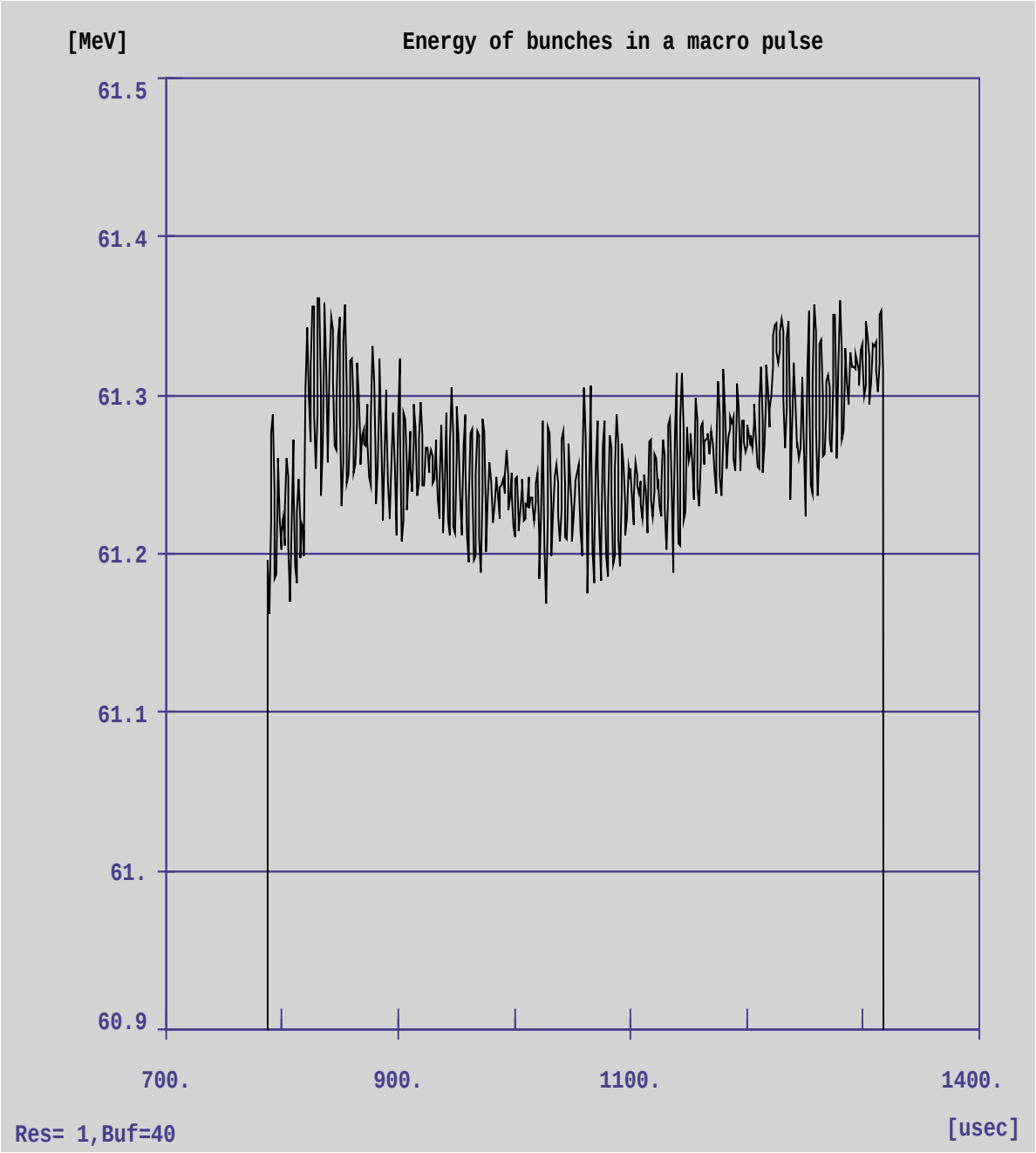
Mean:	61.26 MeV	Number of Bunches:	400
1st Bunch:	60.99 MeV	Status:	34



14.Sep.02 15:05.33

Energy of bunches in a macro pulse

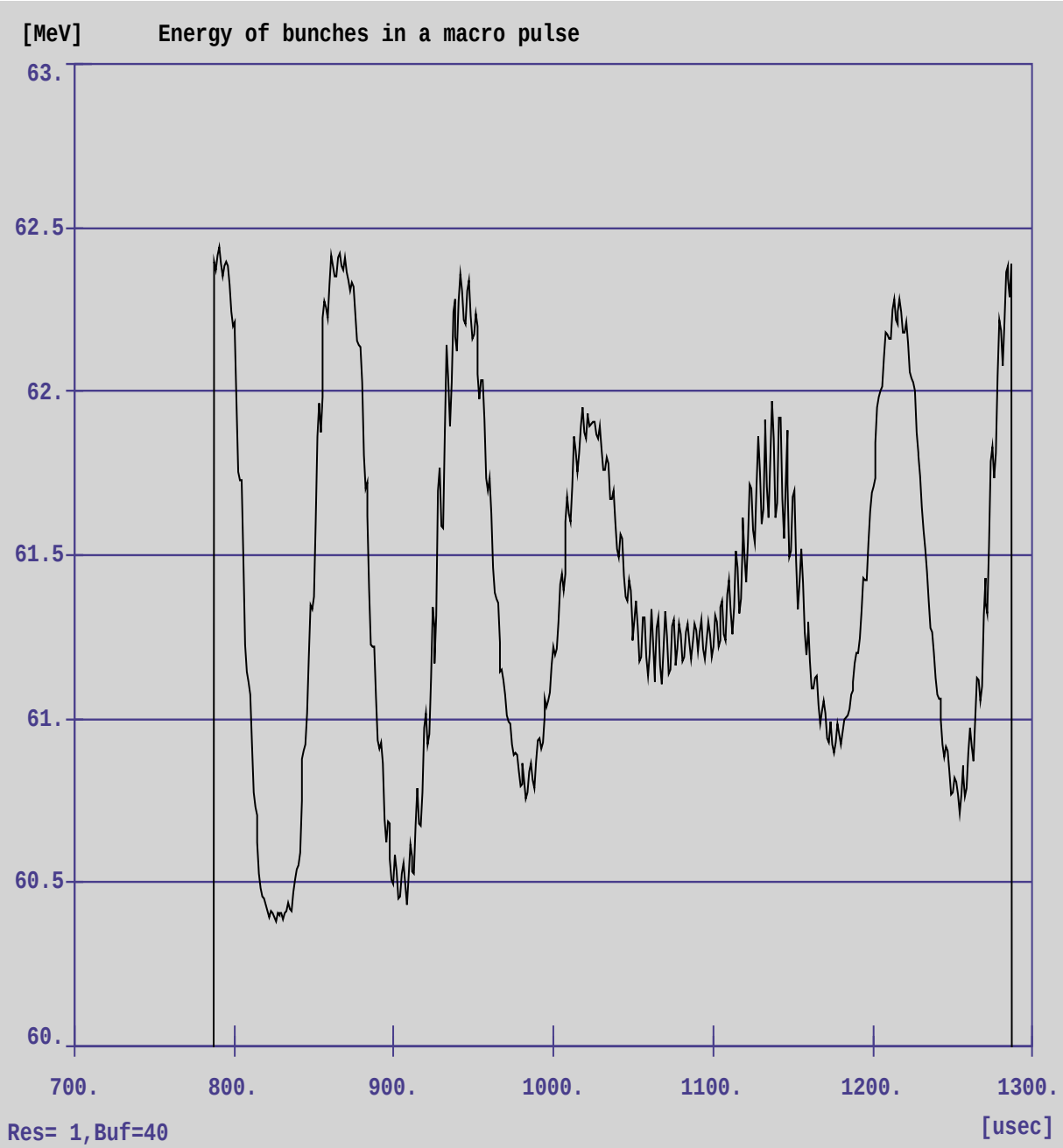
Mean:	61.18 MeV	Number of Bunches:	530
1st Bunch:	61.21 MeV	Status:	40



15.Sep.02 08:23.13

Energy of bunches in a macro pulse

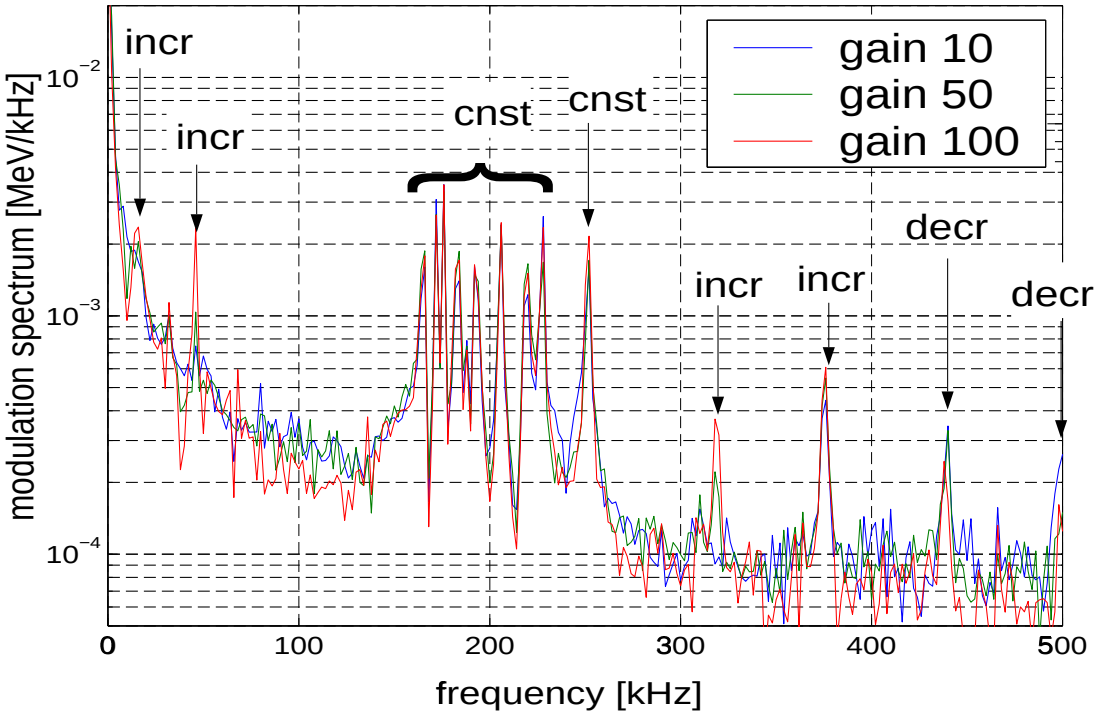
Mean:	61.30 MeV	Number of Bunches:	500
1st Bunch:	62.41 MeV	Status:	42



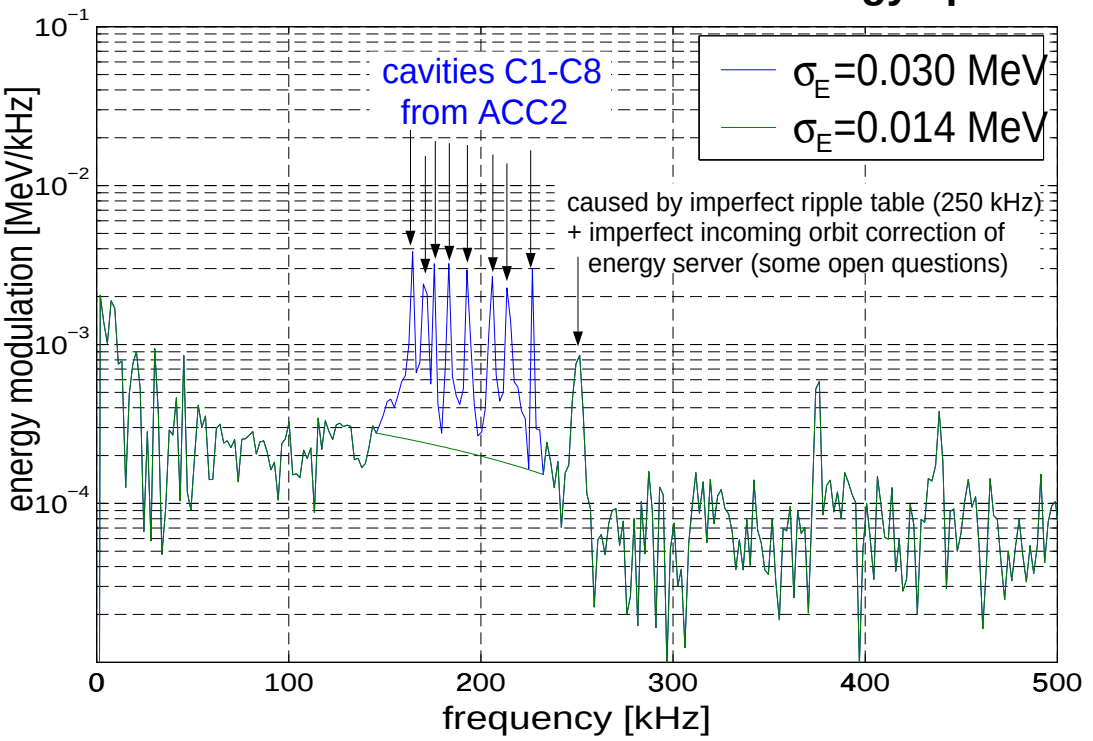
14.Sep.02 11:00.27

Investigations on the beam energy oscillations

Dependence of the energy sprectum on the feedback gain:



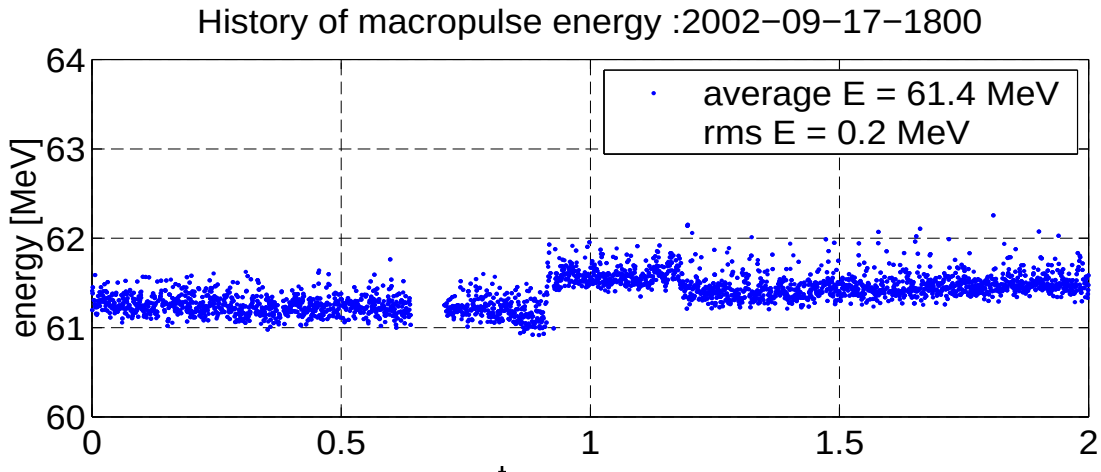
Contribution of ACC2 cavities to the energy spectrum

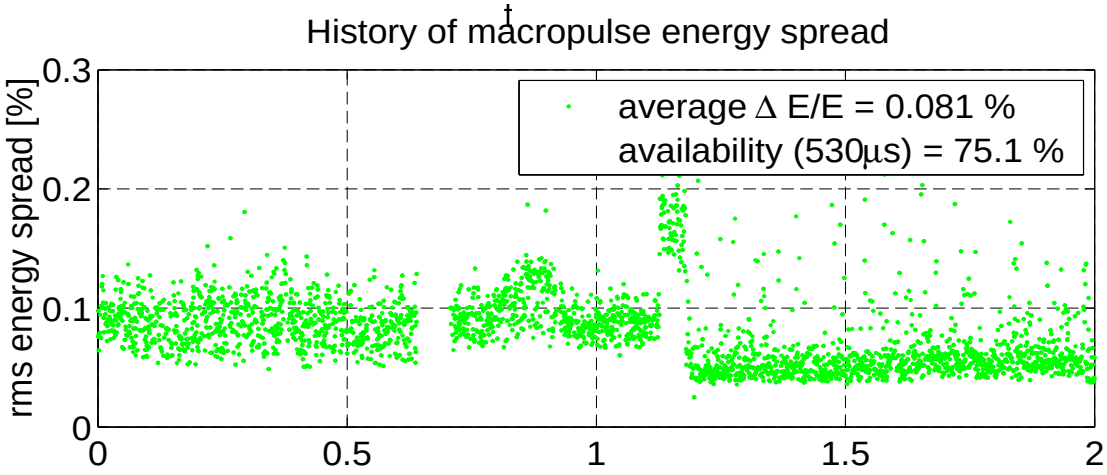


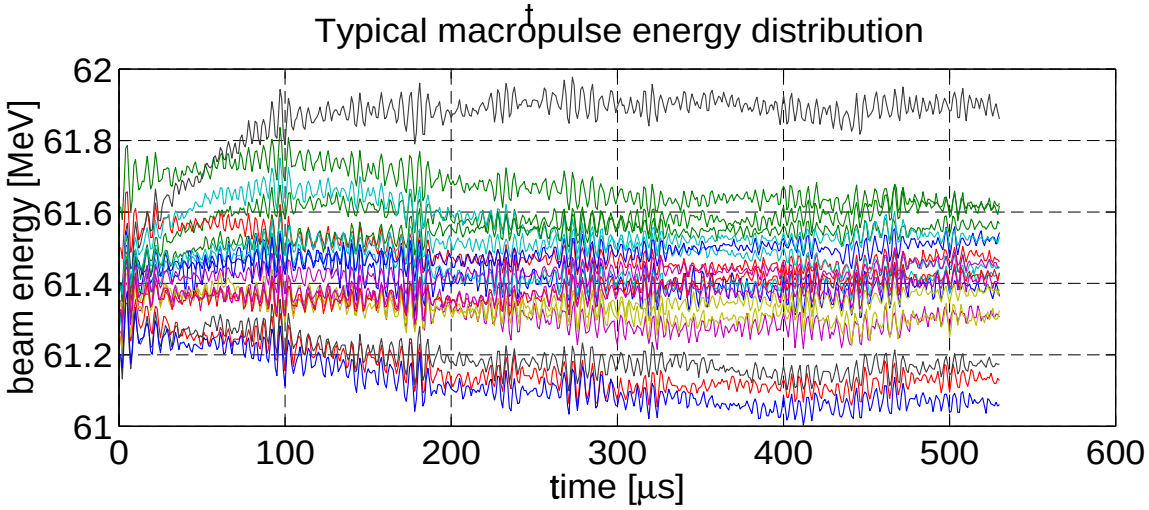
Achieved energy stability with Superstructure

module 1* (cavities detuned in proper way) &
LLRF parameter properly adjusted, 3.8 mA current
:

⇒ average (2 hours):rms dE/E = 8e-4
⇒ smallest (2 hours) rms dE/E < 3.5e-4

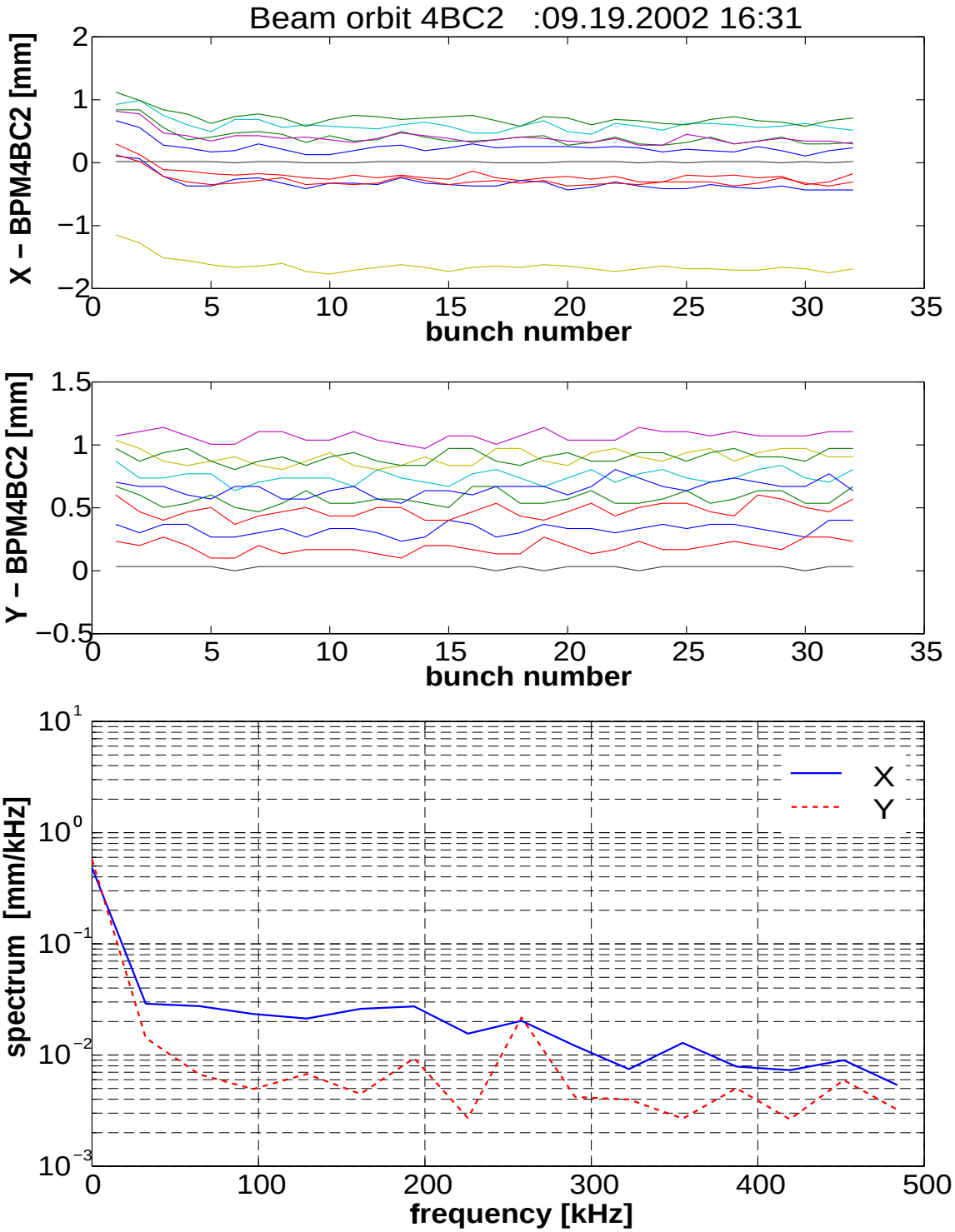






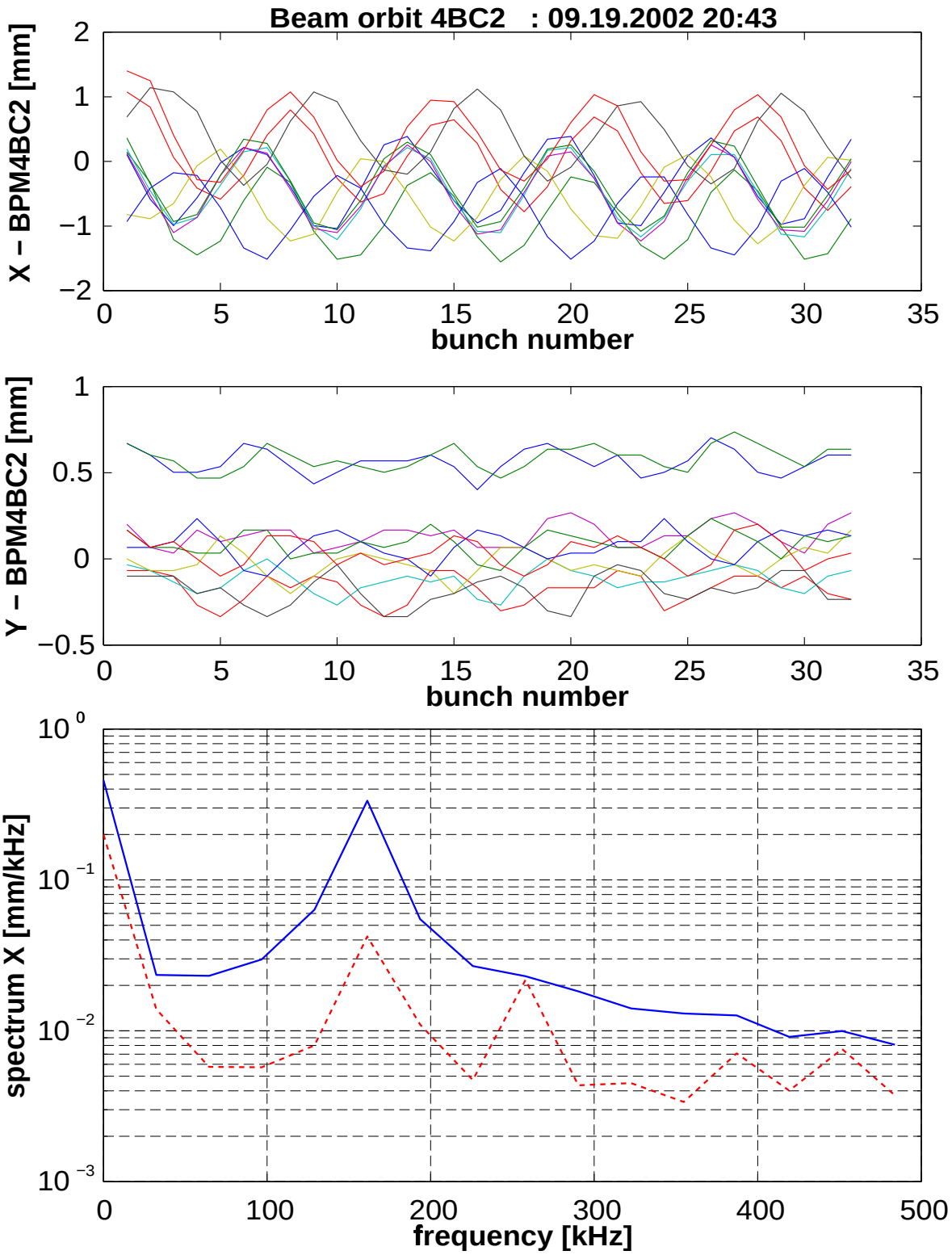
Beam orbit jitter without HOM excitation

Rather large macropulse to macropulse jitter in X
About 250 kHz intrapulse oscillation in Y ⇒ injector
If ribble table is imperfect ⇒ large 250 kHz oscillation X & Y



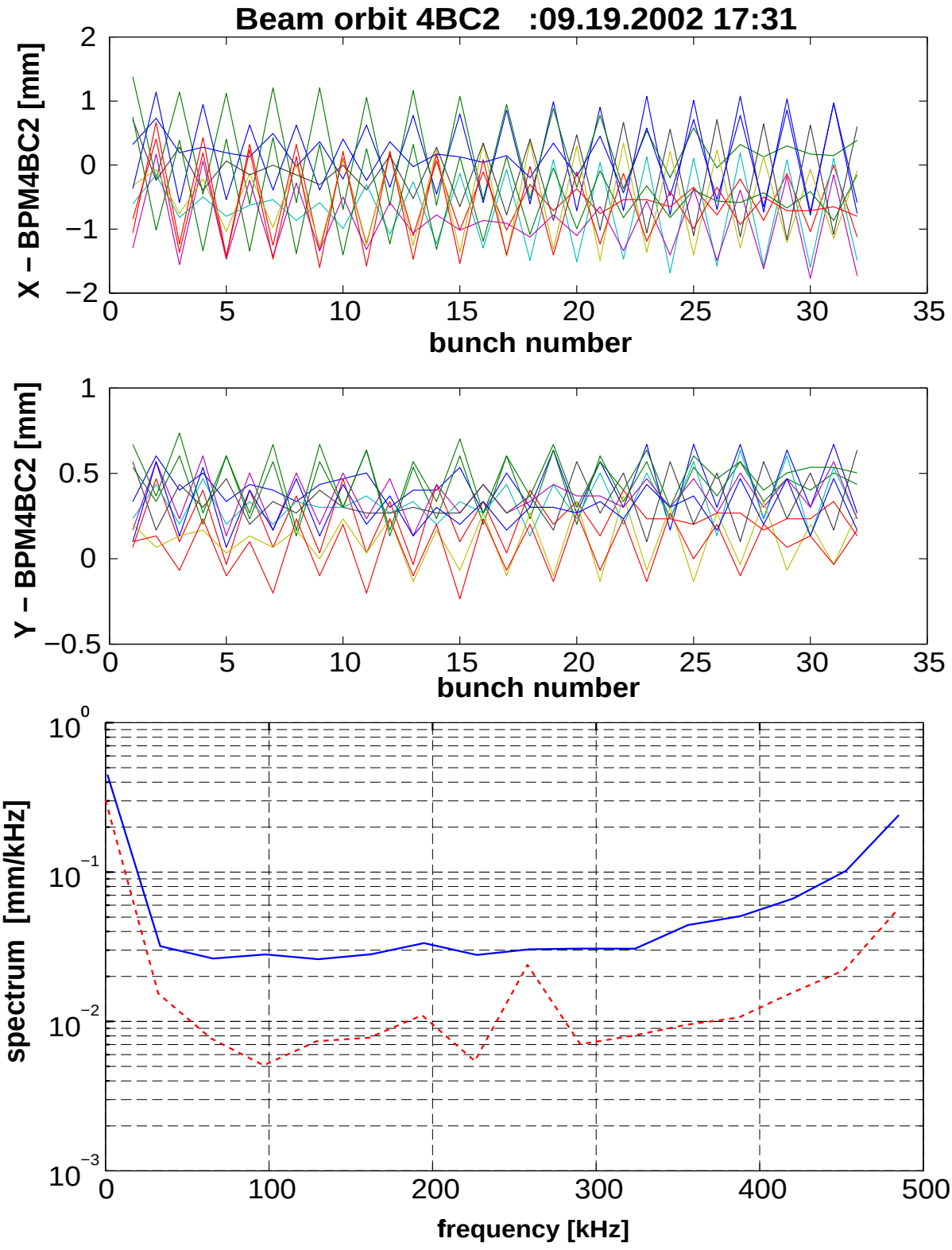
Orbit Response of HOM excitation

Frequency of mode = 1.709106 GHz
Foreward power = 20.3 W, reflected power = 66.3 mW (HOM1)
Transmit power (HOM 3) = 8.6 W



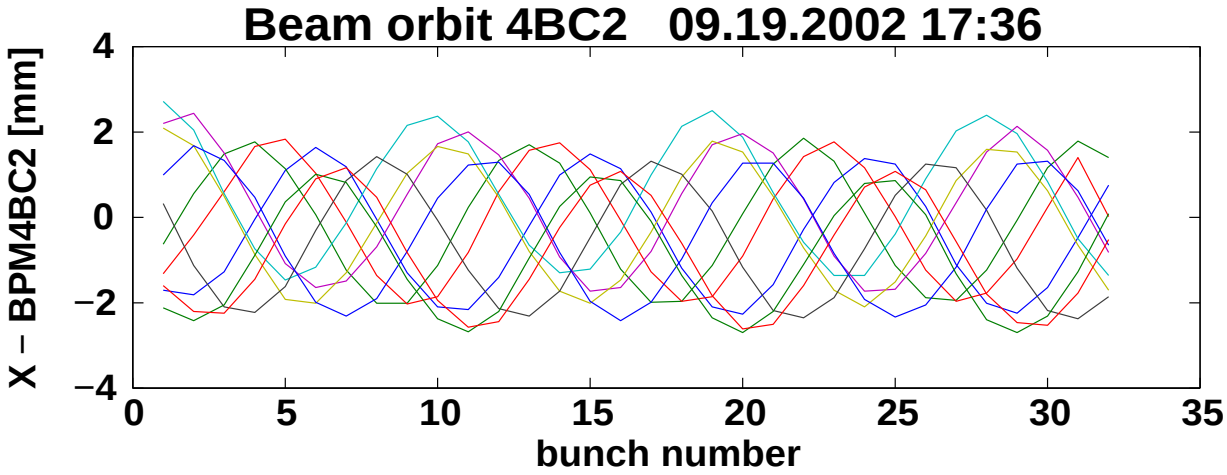
Orbit Response of HOM excitation

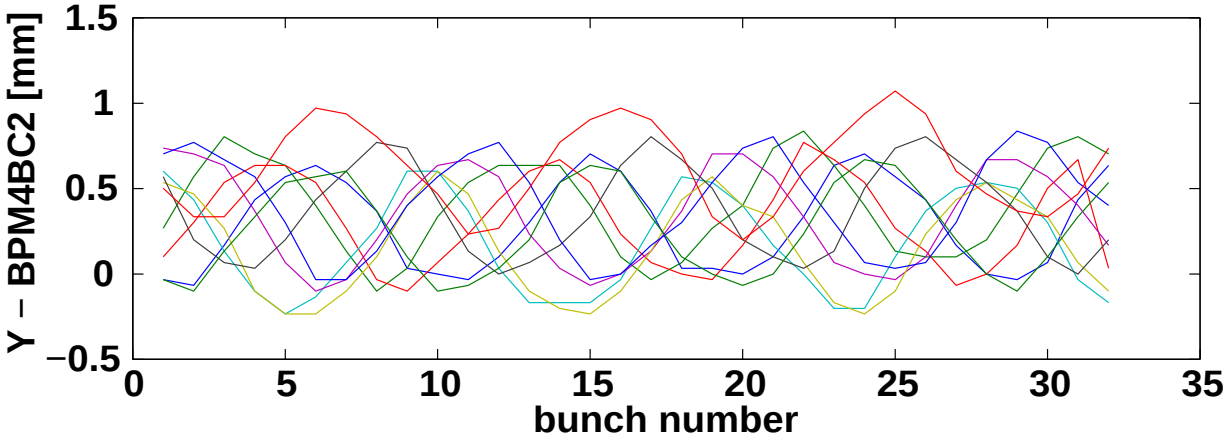
Frequency of mode = 2.573400 GHz
Foreward power = 19.9 W, reflected power = 19.7 W (HOM1)
Transmit power (HOM 3) = 0.162 W

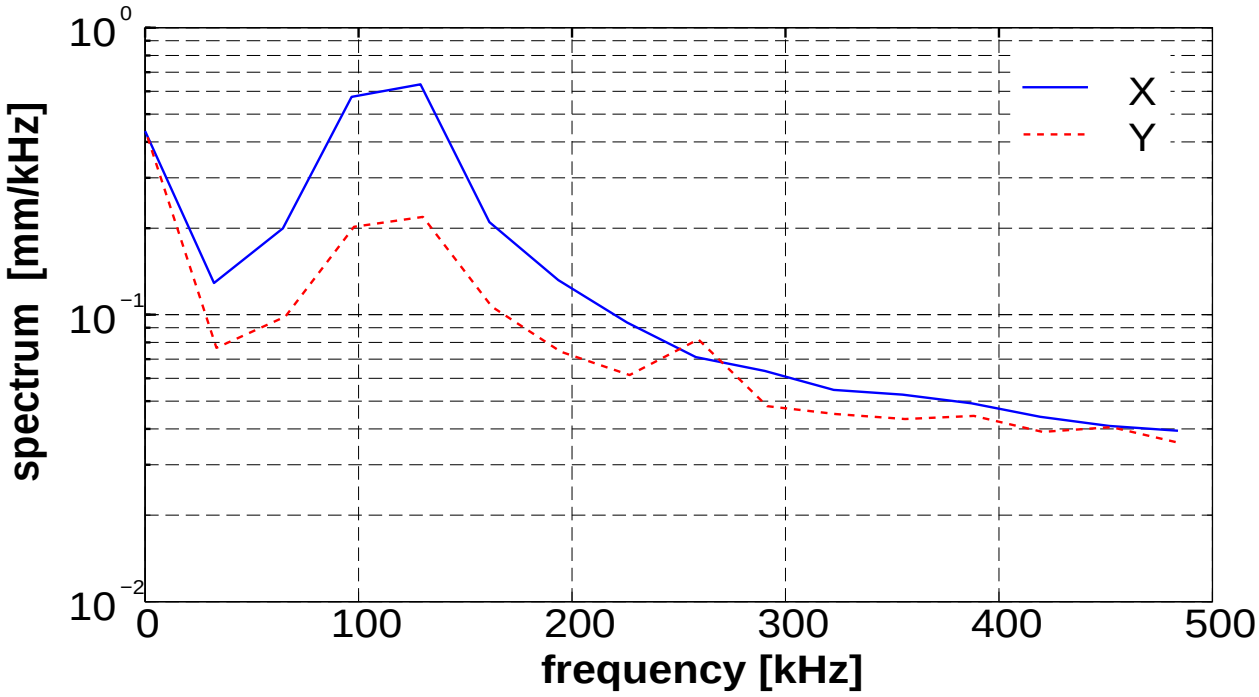


Orbit Response of HOM excitation

Frequency of mode = 2.5740300 GHz
Foreward power = 8.42 W, reflected power = 3.6 W (HOM1)
Transmit power (HOM 3) = 3.6 W







Summary of Superstructure Test completed sofar

- good performance of new cavity tuners
  (0.4 Hz/step, small hysteresis effects)

- field balance methode between cavities work

- good cavity production
  - meet resonance frequency within 30 kHz
  - field flatness 92%

- poor tuning of fundamental mode filters of the pick-ups
  which are installed between the cavities
  ⇒ SST1 couples out 20 W @ 15 MV/m and
  ⇒ SST 2couples out 150 W @ 15 MV/m
  (critical at higher gradients)

- very good higher order mode damping

- high energy flatness of gradient
  - rms dE/E down to 3.5e-4 (close to resolution)
  - a factor of two better than achieved in previous runs

- no transient effects due to rf energy flow

- quick coupler processing and good coupler performance

- no trapped mode observed (3 GHz, 5th dipole passband)
  - network analyzer + active HOM excitation show no evidence for strong beam dynamic effects

Summary of Vacuum Leaks in Modules

TTF-Meeting
23. Sep. 2002
Holger Schlarb

linac section	module 1 ACC1	module 2 ACC2	module 3 ACC1	module 1* ACC2	super structure ACC1
number of leaks	1	6	7	1	
insulation to beam pipe	x cavity flange	x 4: bpm feedthrough 1: C6 e-pickup (at input coupler)	x 1: bpm feedthrough 2: C2/C8 e-pickup (at input coupler) 1: C7 coupler flange	x	
insulation to helium			x 2: C5 welding at helium tank C8 welding at bellow		
insulation to input coupler		x	x		
input coupler to beam pipe		x 1: C1 ceramic window	x 1: C8 ceramic window		
He to beam pipe	-	-	-	-	-
cool-down warm-up	3	2	1	2	2