W. Chou
5/25/00
WG5

Machine Experiments for Achieving High Peak Current

Proton driver = High intensity + short bunch length

→ High peak current
(hundreds of amperes)

- Expt. for high longitudinal brightness
  - Inductive inserts expt. at PSR/LANL (also at KEK-PS)
- Expt. for high intensity bunch compression
  - AGS
  - Fermilab booster
- Expt. for μ-wave instability when $\gamma < \gamma_t$
  - CERN SPS

4 Technical design issues

4.1 High longitudinal brightness

- High N_b/ϵ_L due to:
  - High beam power, a few bunches ⟶ large N_b
  - Short bunch length ⟶ small ϵ_L
- Minimize ϵ_L dilution:
  - Avoid transition (lattice design)
  - Avoid microwave instability
    - → Keep beam below transition
    - Keep resistive wall impedance small (uniform beam pipe)
  - Avoid coupled bunch instability (low Q cavity)
  - → Inductive insert for compensating space charge
  - Minimize filamentation during early acceleration (rf parameters optimization)
  - Longitudinal damper

→ 4.2 High intensity bunch compression

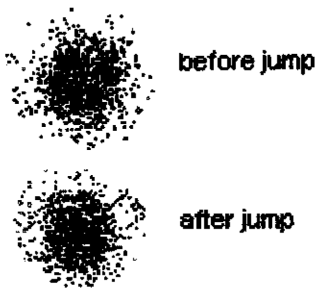
- Microwave instability during debunching;
- Beamloading during debunching;
- η-spread (or α-spread) effect:
  - due to higher order momentum compaction factor α_1
  - due to space charge tune spread ΔQ

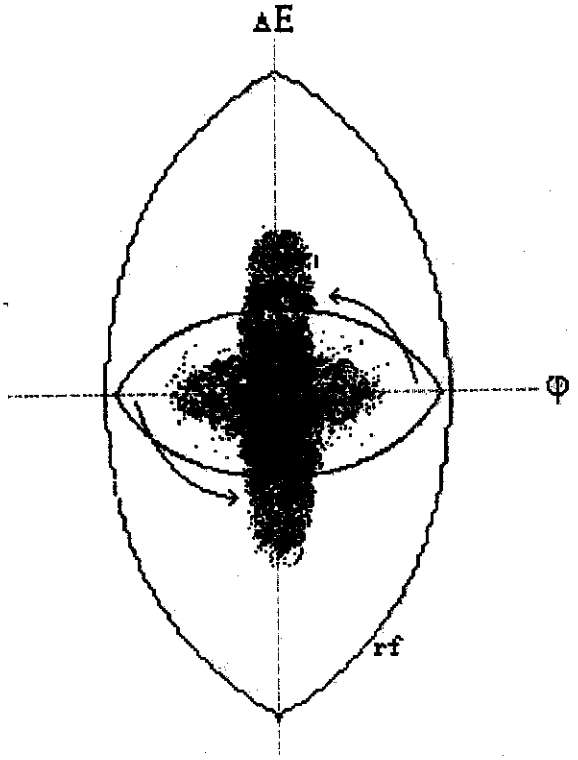
Table 5: Longitudinal Brightness of Proton Machines

Machine	$E_{\max}$ (GeV)	N_{tot} (10^{12})	N_b (10^{12})	ϵ_L (eV-s)	N_b/ϵ_L (10^{12}/eV-s)
Existing:					
CERN SPS	450	46	0.012	0.5	0.024
FNAL MR	150	20	0.03	0.2	0.15
FNAL Booster	8	4	0.05	0.1	0.5
PETRA II	40	5	0.08	0.12	0.7
KEK PS	12	3.6	0.4	0.4	1
DESY III	7.5	1.2	0.11	0.09	1.2
FNAL Main Inj	150	60	0.12	0.1	1.2
CERN PS	14	25	1.25	0.7	1.8
BNL AGS	24	63	8	4	2
LANL PSR	0.797	23	23	1.25	18
RAL ISIS	0.8	25	12.5	0.6	21
Planned:					
Proton Driver Phase I	16	30	7.5	2	3.8
Proton Driver Phase II	16	100	25	2	12.5
Japan JHF	50	200	12.5	5	2.5
AGS for RHIC	25	0.4	0.4	0.3	1.3
PS for LHC	26	14	0.9	1.0	0.9
SPS for LHC	450	24	0.1	0.5	0.2

Bunch Rotation

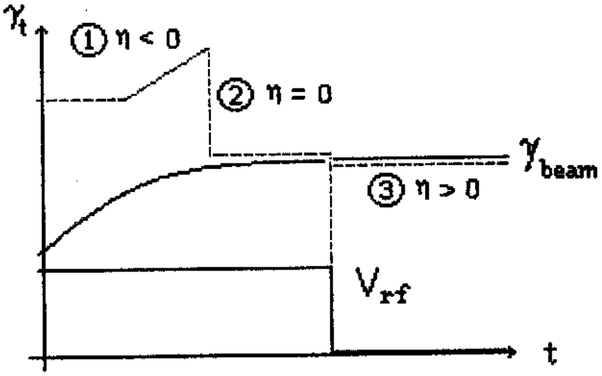
1. RF AmplitudeJump

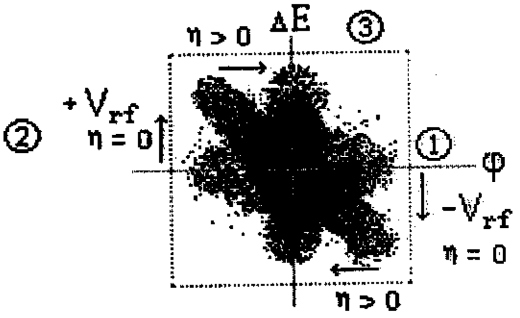




2. RF Phase Jump

3. γ_t Gymnastics





$$\eta = \alpha - \frac{1}{\gamma^2}$$

$$16\ \text{GeV} \rightarrow \gamma = 18 \rightarrow \frac{1}{\gamma^2} = 0.00$$

For $\frac{\Delta p}{p} = \pm 1.5\%$, $\Delta Q = 0.2$
the η variation is:

$$\eta \in [-0.003, -0.008]$$

$$\alpha = \frac{\Delta L / L}{\Delta P / P}$$

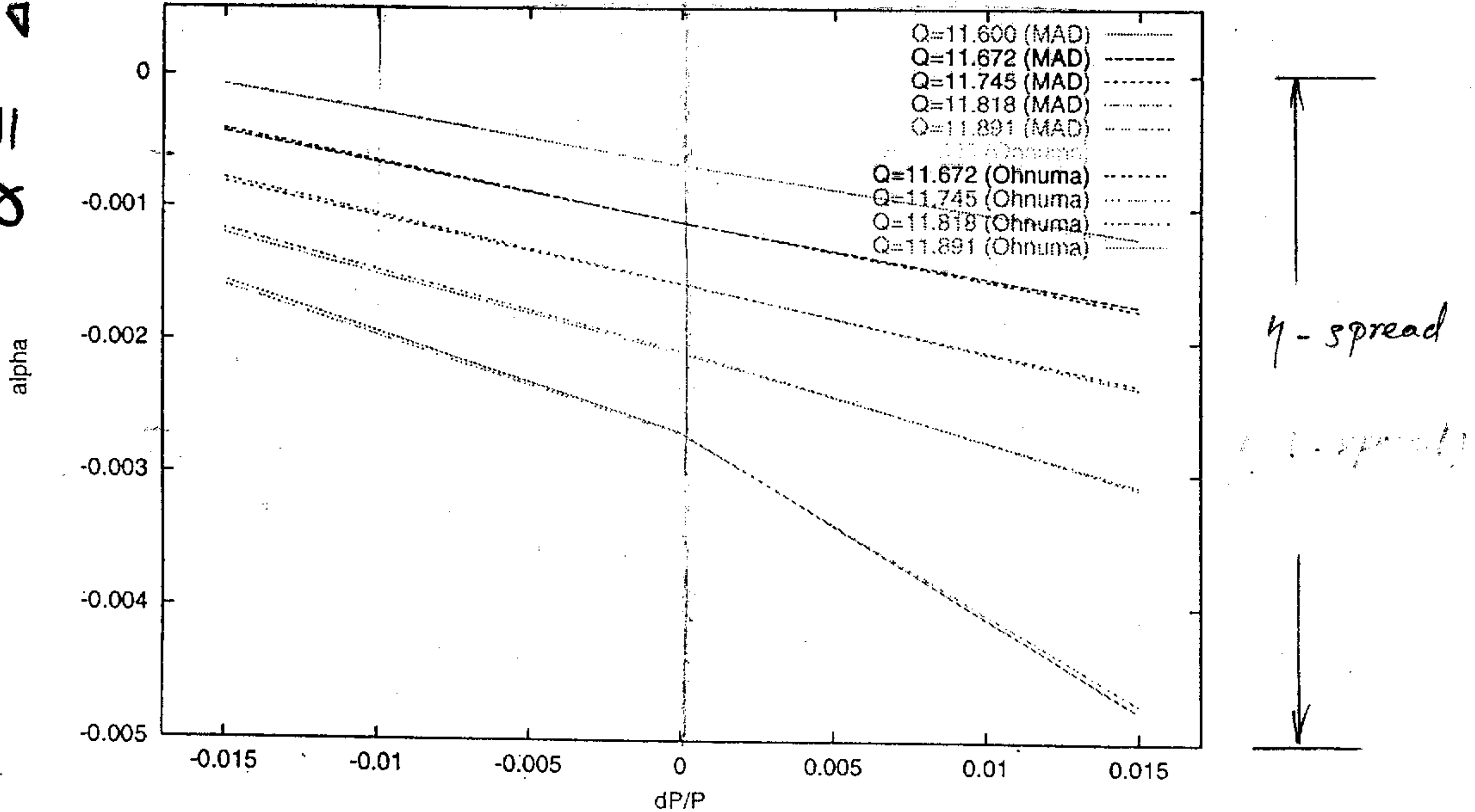


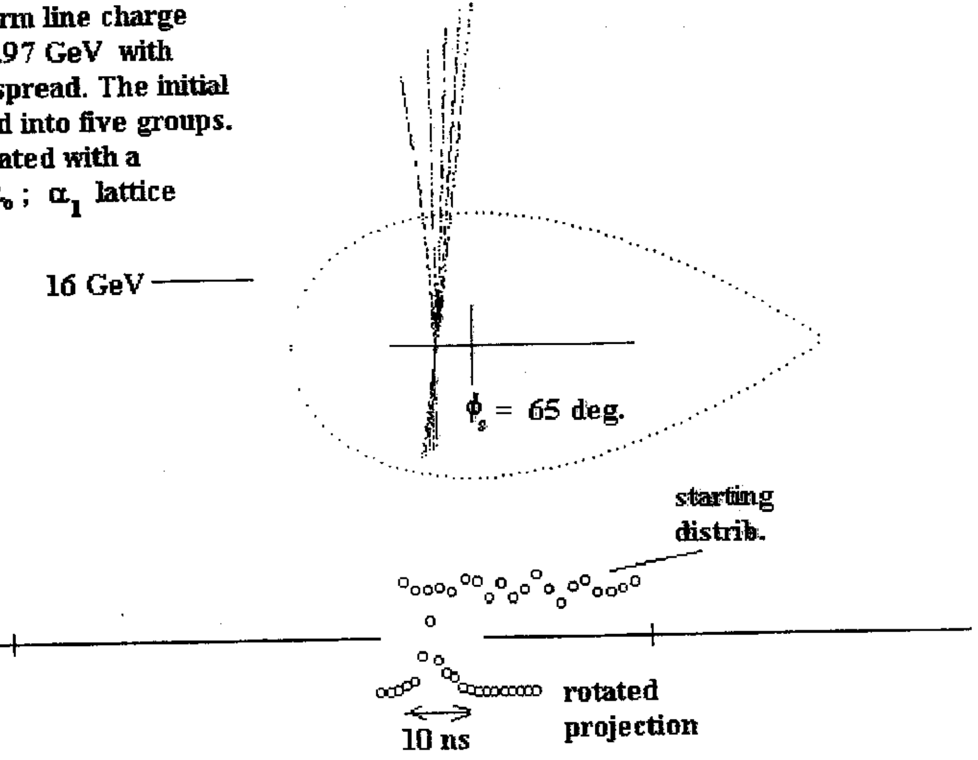
Figure 11: Ritson's (No negative bend, RBEND) 16 GeV Proton Driver lattice (No.2)

J.Griffin 3-1-00

Weiren:

Here are couple of 'final' comments regarding bunch rotation in a space charge dominated lattice. The 'fan' effect I showed earlier can be demonstrated in an interesting way by starting with a uniform line charge distribution with very small, or zero, momentum spread. If the distribution is divided randomly (in time) and each group rotated under the influence of a different set of lattice parameters, one gets a set of five clearly defined results. The result with a real distribution would, of course, fall within these boundaries.

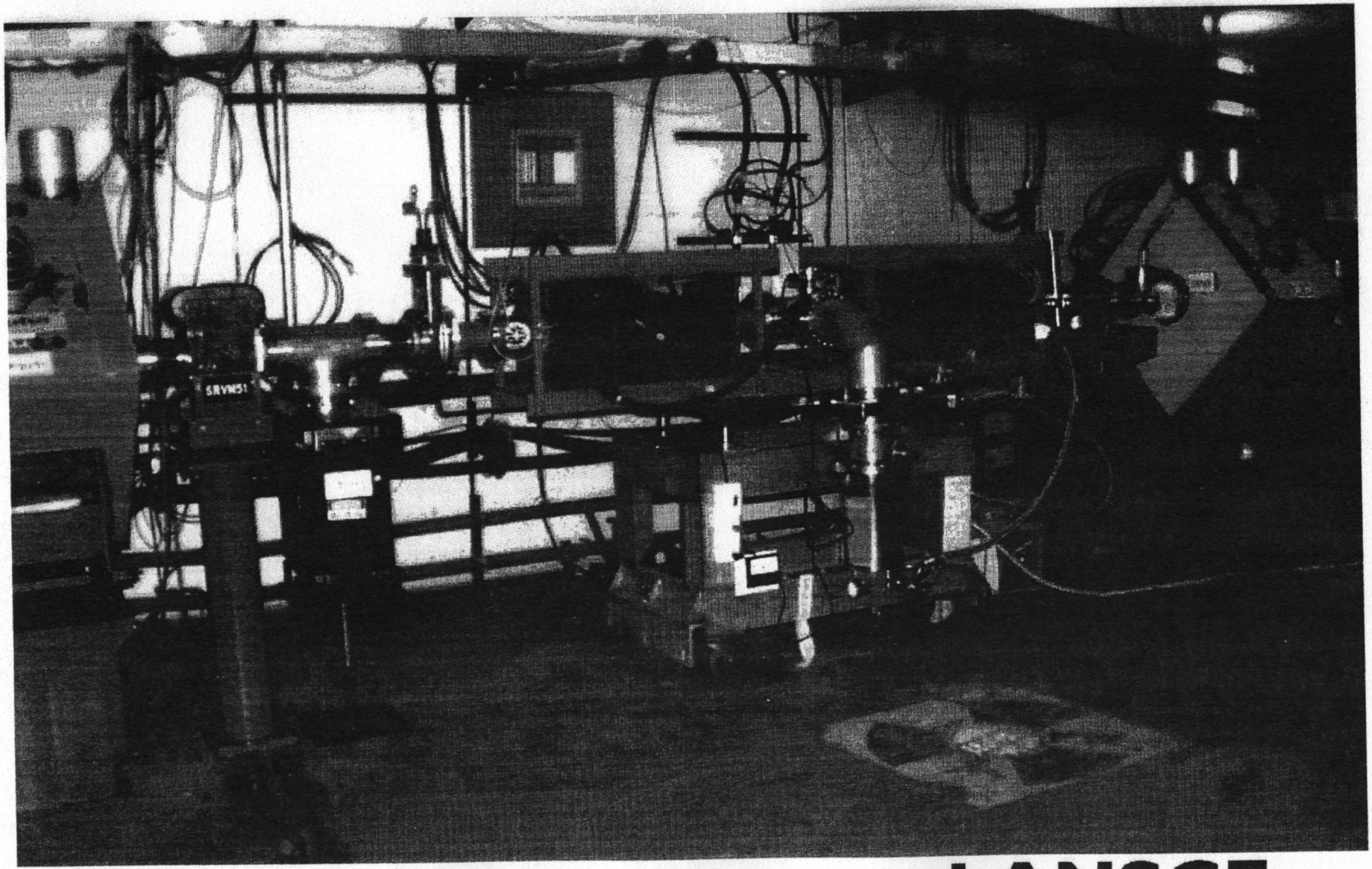
550 turn bunch rotation starting with a 60 ns uniform line charge distribution at 15.97 GeV with zero momentum spread. The initial charged is divided into five groups. Each group is rotated with a different set of α_0 ; α_1 lattice parameters.



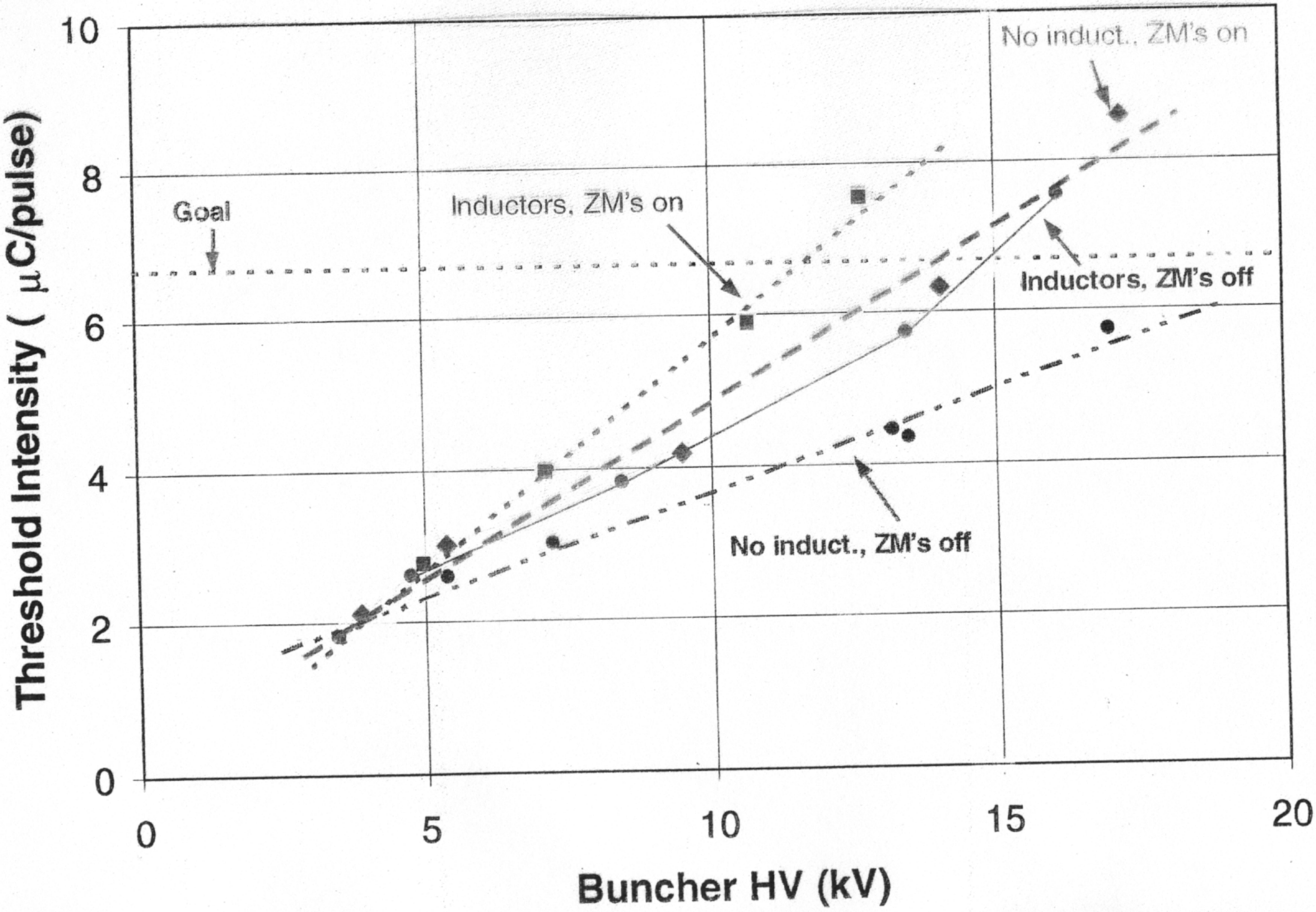
5.2 Machine experiments

1. Beam test of Finemet cavity (Fermilab/MI, BNL/AGS)
2. Inductive insert (LANL/PSR, ANL/IPNS)
3. Lab "contest" on intense short bunch production:
    - Six labs: BNL, KEK, Fermilab, CERN, Indiana U. and GSI.
    - Two experiments:
        - bunch compression;
        - μ-wave instability below γ_t.
    - Three competing items:
        - Max I_{peak}
        - Max N_b/eV-s
        - Max compression ratio

Inductor in Section 5



July 1999 Results from Inductor and Sextupole Tests

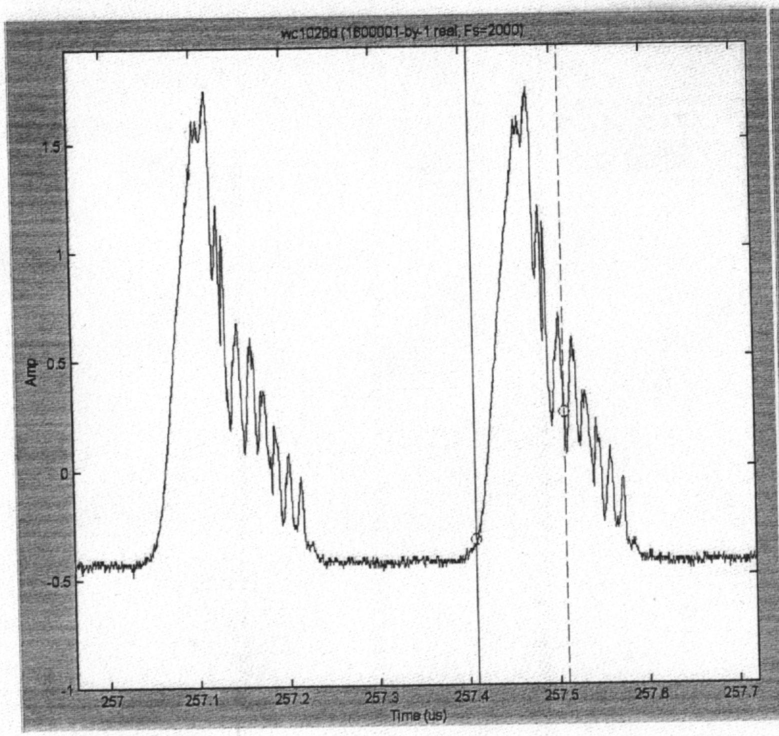


Effect of Heating the Inductor Ferrite

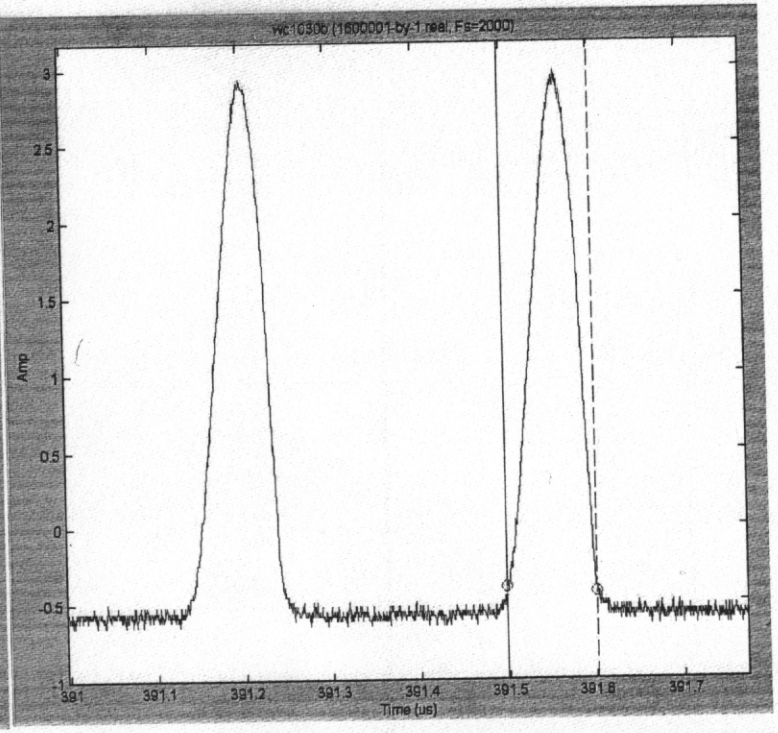
- Ferrite Inductor (2 modules) at room temperature
- 3.3 μC accumulated

- Ferrite at 130° C
- 3.3 μC accumulated
- Longitudinal signal at cavity resonance down 30db from room temperature case

Wall Current Monitor



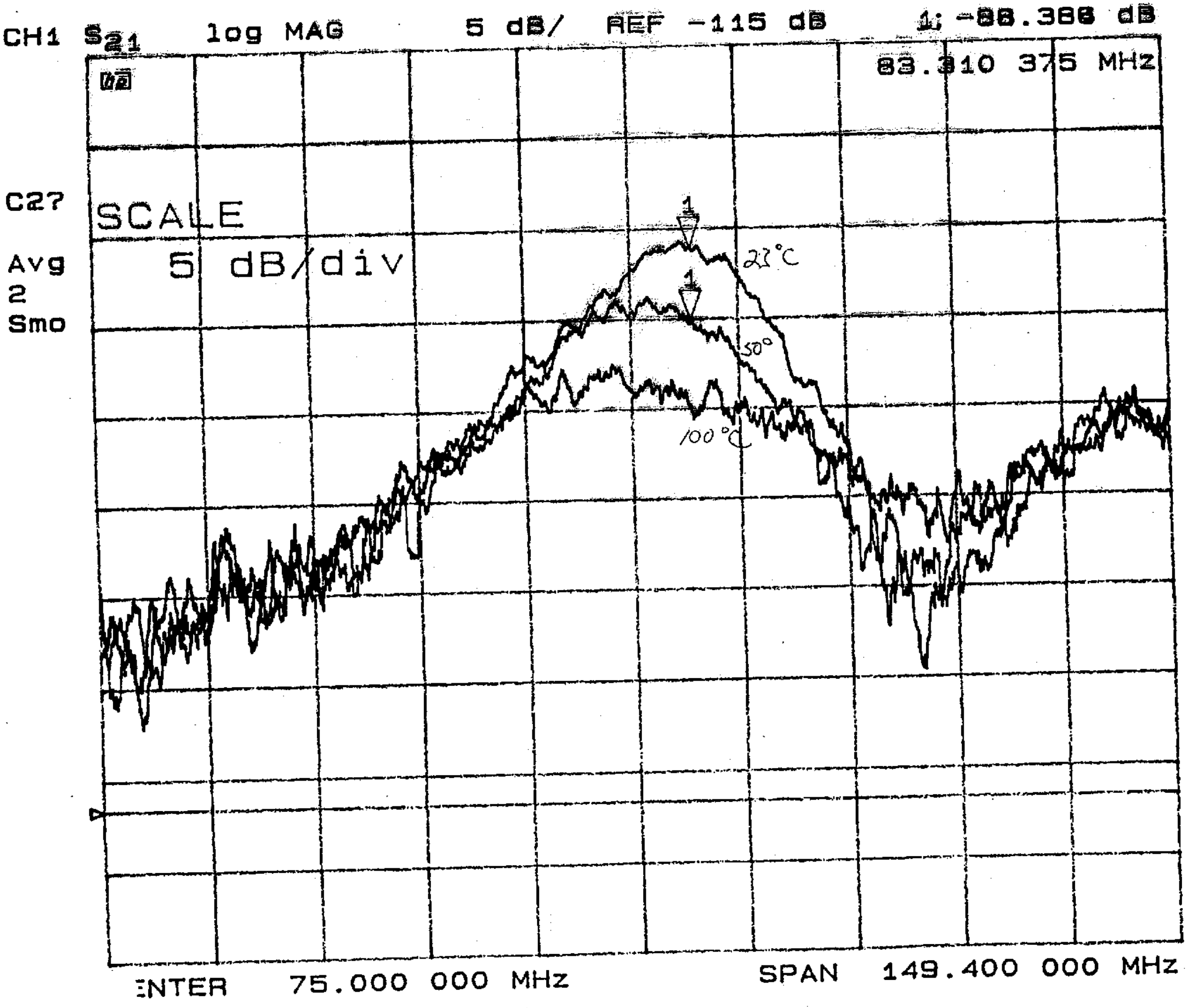
Bk91, p150



Bk92, p10

Changing Temperature of Cores

9/24/99 15:50



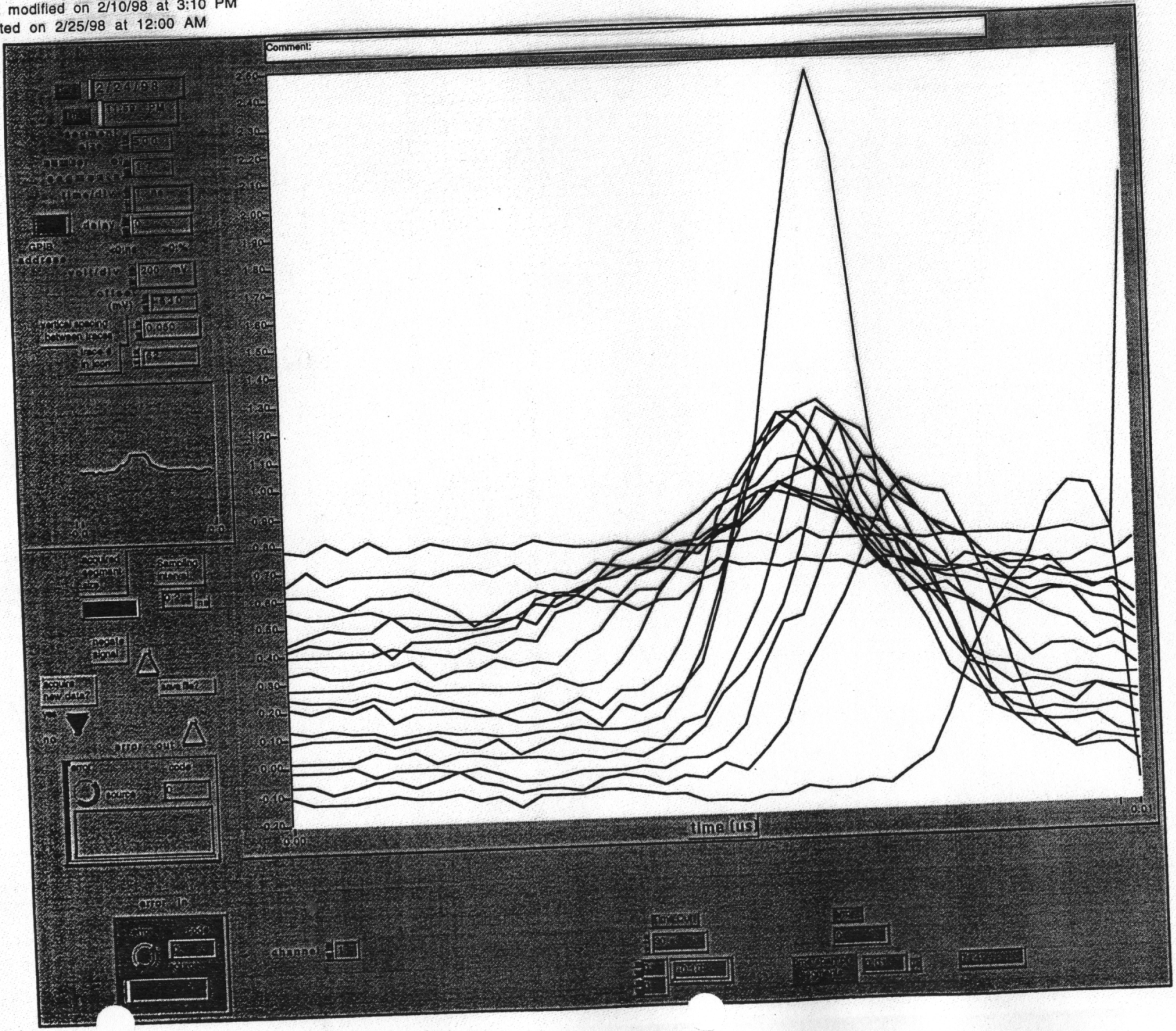
7 M4C21A cores

blue 23°C
Red 50°C
Green 100°C

Lec 93xx
READ
Seq WF

Fermilab Booster Expt.

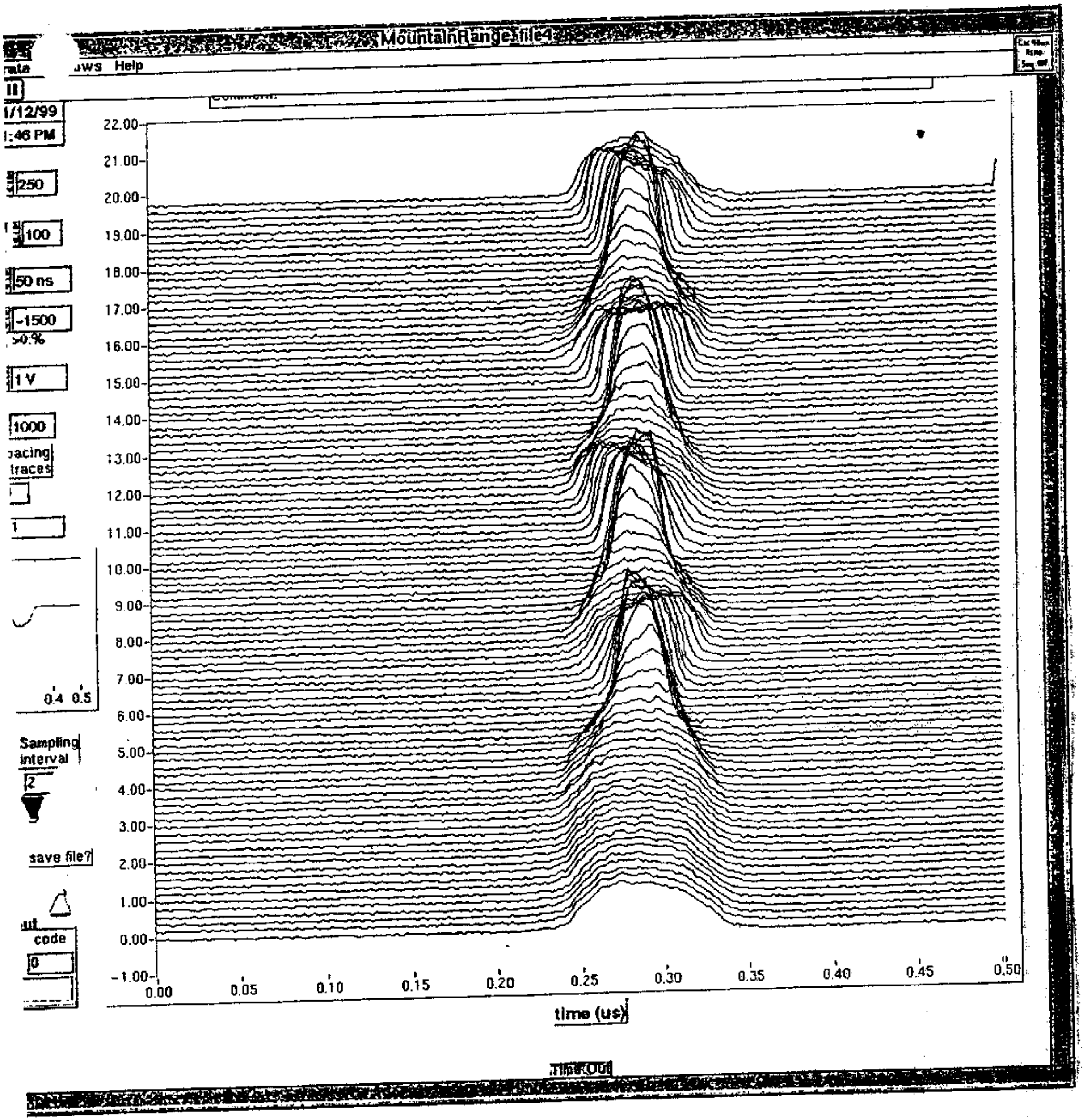
BoosterMountainRange
Last modified on 2/10/98 at 3:10 PM
Printed on 2/25/98 at 12:00 AM



2/24/98
11:59 PM
segment size 500
volt/div 200 mV
vertical spacing between traces 0.050

1.6×10^{12} total
80 bunches
= 2×10^{10}/bunch

AGS Expt.



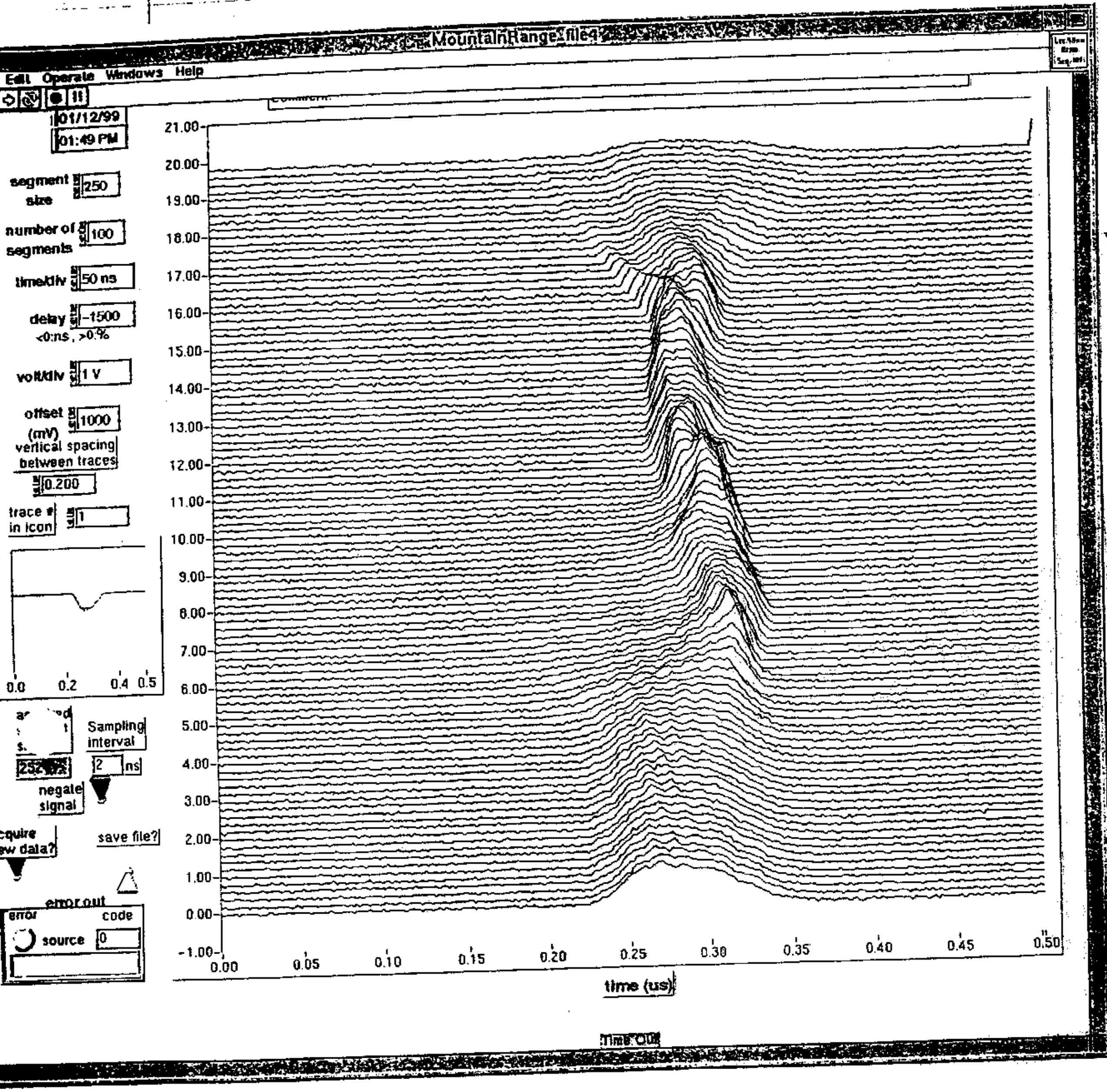
(5×10^{12})

STP

20KV/(

″

Vrf (min)



01/12/99
01:49 PM

segment size 250

number of segments 100

time/div 50 ns

delay -1500
<0:ns , >0:%

volt/div 1 V

offset (mV) 1000

vertical spacing between traces 0.200

trace # in icon 1

Sampling interval 2 ns

negate signal

cquire
ew data?

save file?

error out
error
source
code 0

5 Tp

10 KV/T

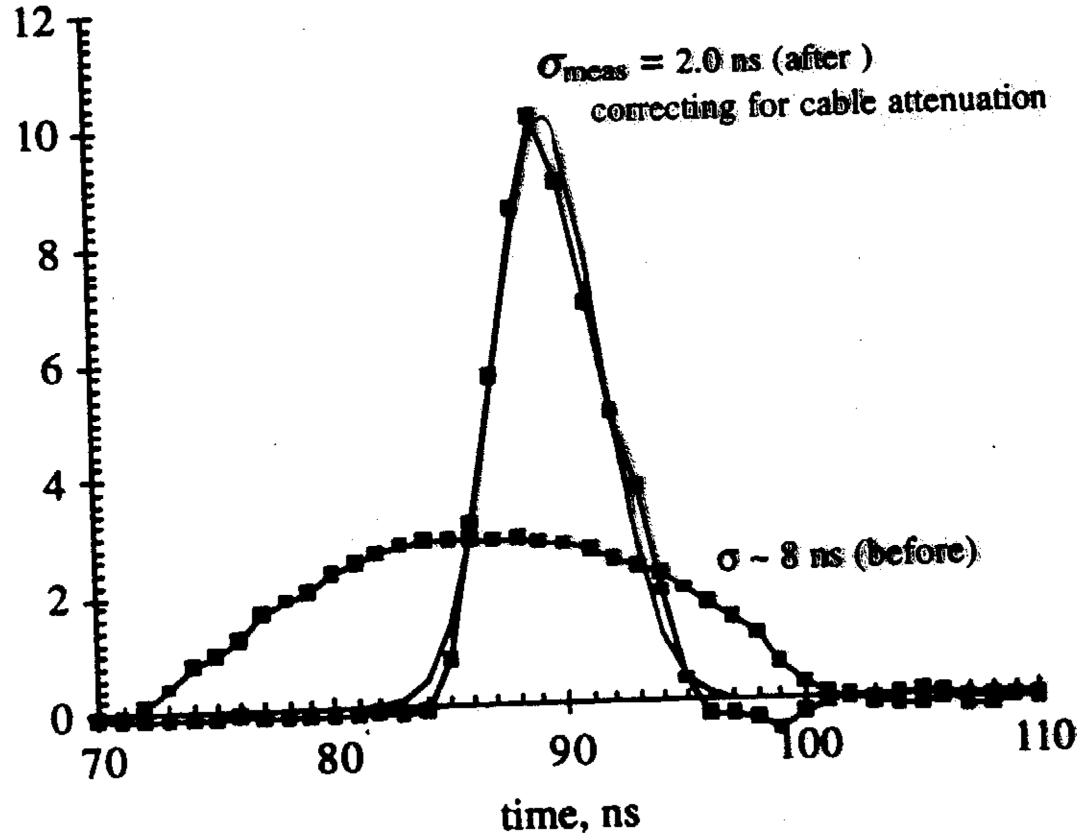
Vrf (minim

BNL E-932 (J. Norem et. al)

σ = 2 ns Bunching was Demonstrated at the AGS

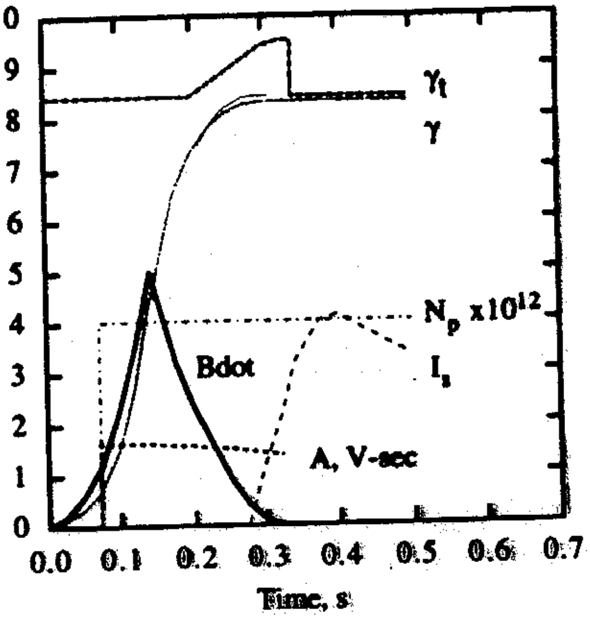
The bunch rotation was done by dropping γ_t to the beam γ.

- Fairly realistic parameters
  $\varepsilon_{L,\,AGS} \sim \varepsilon_{\mu\ \text{collider driver}}$,
  charge ~ 1/10 required for muons
- Some bunch spreading with rf before rotation improved σ
- Other options and better tuning are possible
- short bunches were stable
- Lower f_{rf} and V_{rf} than proton driver (bunching is harder)

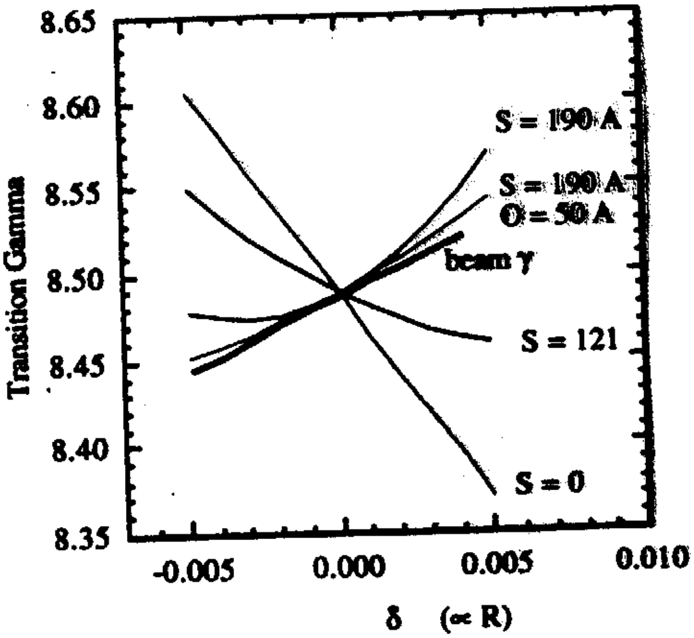


Bunching was done "below" (or at) transition.

- AGS was run in the following mode:

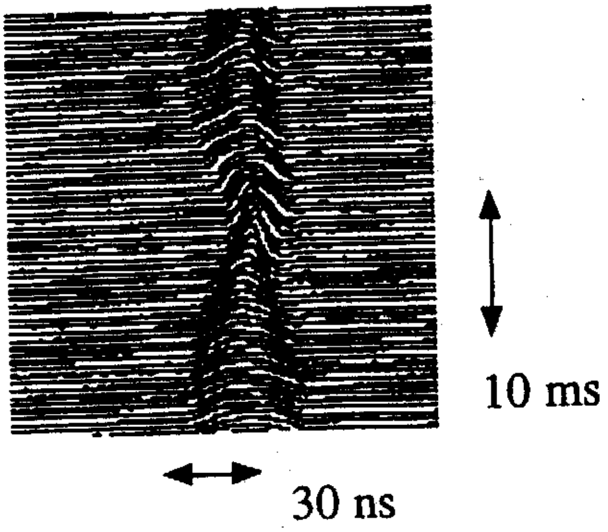


- An attempt was made to run with $\gamma_t(E) \sim \gamma_{beam}$, but the AGS power supplies would not run this high.



Results:

Time evolution of the bunch was stable.



"After all these years carefully avoiding transition
it looks like the beam is stable there. . ."

Measurement of γ_t	
Phase flip	$\gamma_t = 8.34 \pm 0.05$
synchrotron freq	$\gamma_t = 8.43 \pm 0.05$
previous data	$\gamma_t = 8.45$
Debunching	$\gamma_t = 8.45 \pm 0.04$
Measurement of α_1	
beam loss vs freq	$\alpha_1 = 3.5 \pm 1.5$ @ $I_s = 100\text{A}$
bunching simulations	$\alpha_1 = 0. \pm 1.$

Simple bunch rotation gave bunch lengths of $\sigma \sim 2.7$ ns, however after spreading the bunch by modulating the rf at the synchrotron frequency, the shortest bunch was achieved.

CERN SPS expt. (T. Bohl)

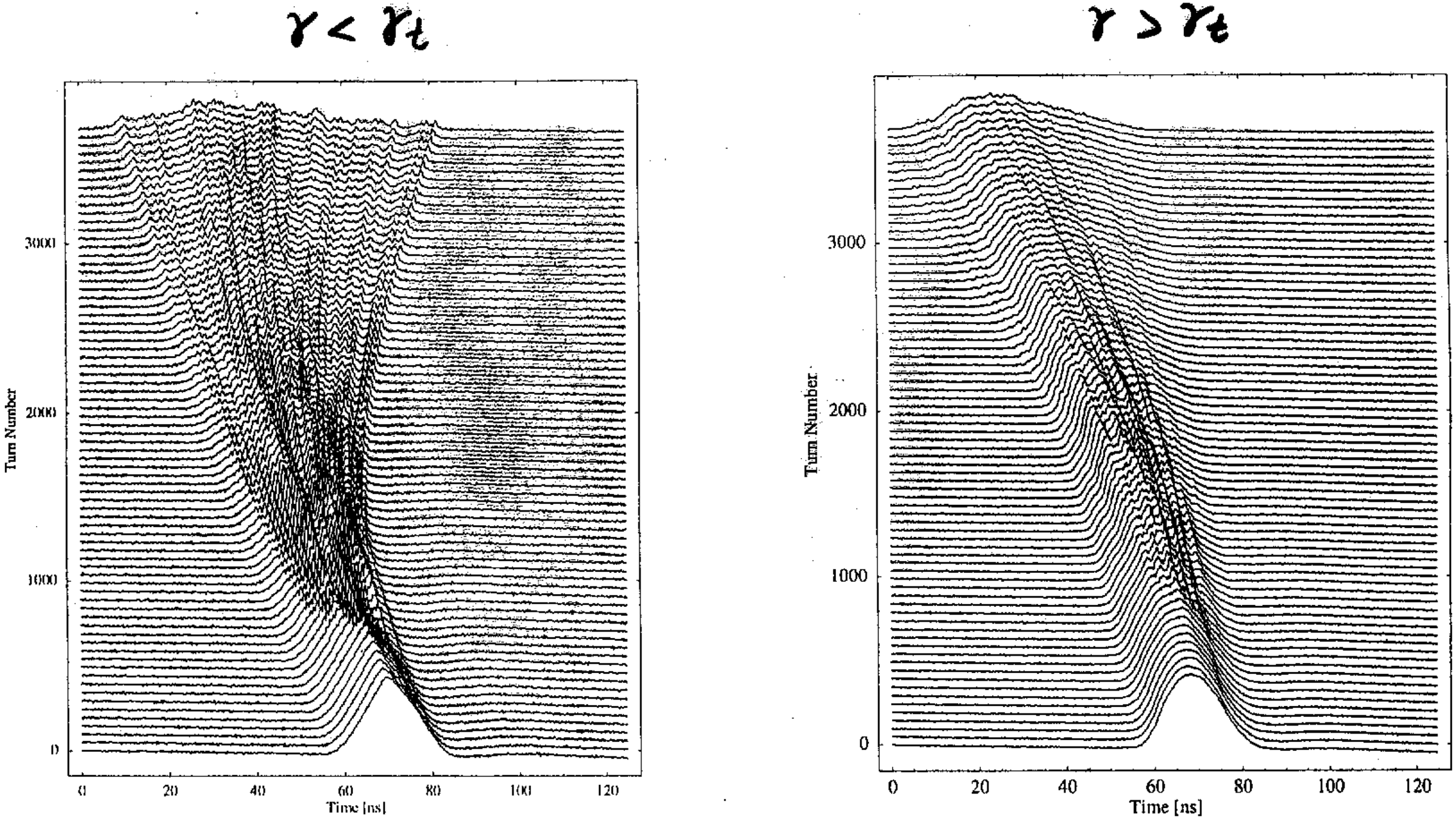


Figure 6: Mountain range in time domain. Left side: $\gamma = 21.3$, $\eta = 3.5 \times 10^{-3}$, (1999-11-08). Right side: $\gamma = 27.7$, $\eta = -5.5 \times 10^{-3}$, (1999-10-08). $\gamma_t = 23.2$.

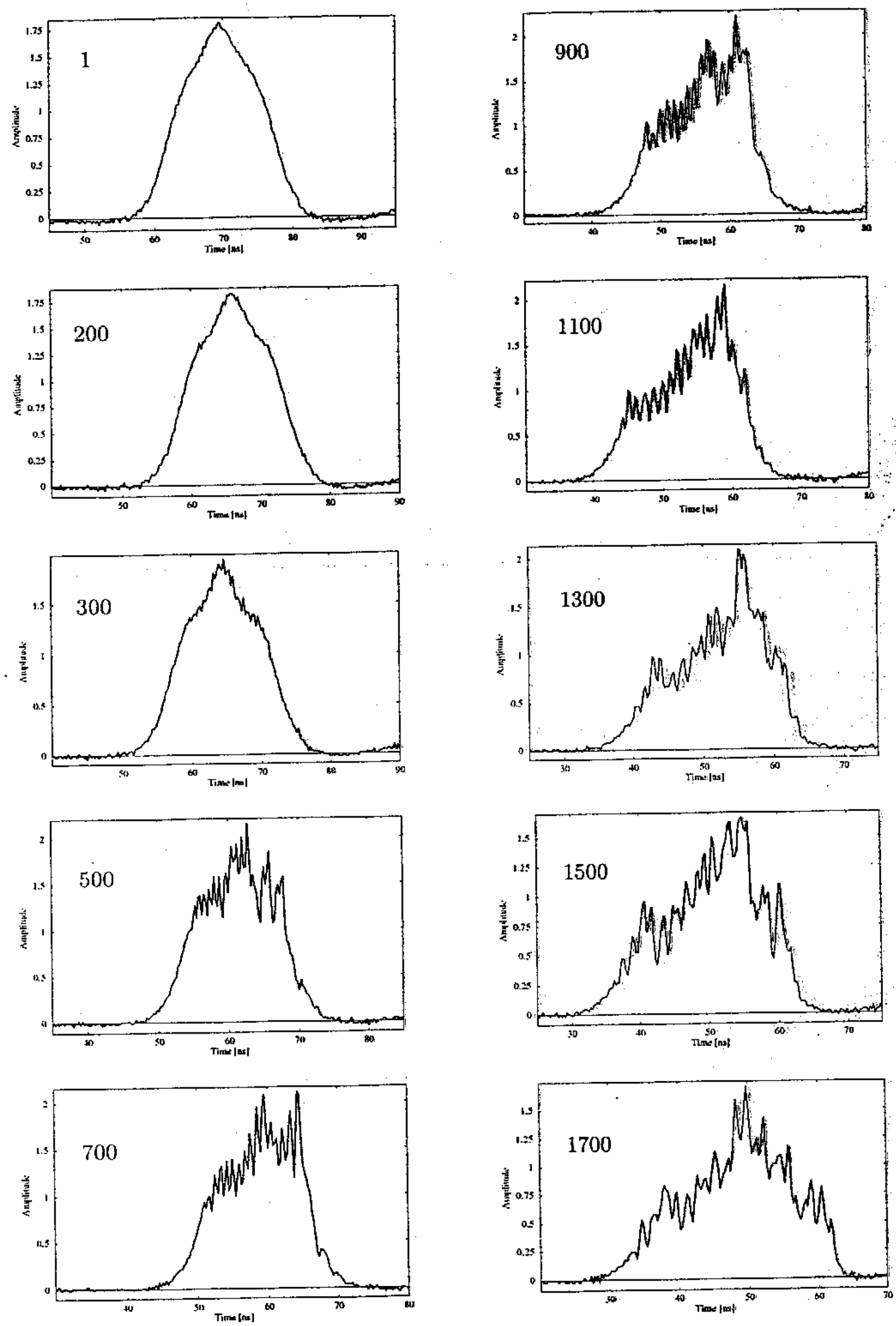


Figure 14: Longitudinal bunch profiles at different times (indicated by turn numbers 1 to 1700). $\gamma = 21.3$, $\eta = 3.5 \times 10^{-3}$, $\gamma_t = 23.2$, (1999-11-08).

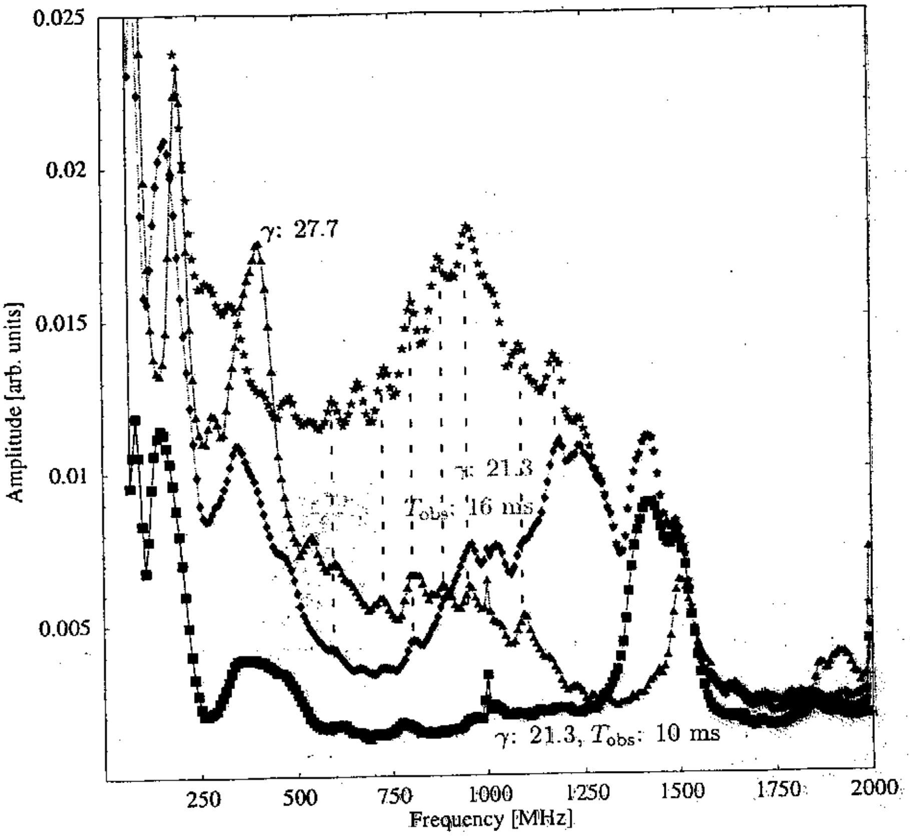


Figure 17: Mode amplitude spectra for $\gamma = 27.7$, $\gamma = 21.3$ and different T_{obs}. Apart from obvious cases, vertical dotted lines indicate peaks which align for $\gamma < \gamma_t$ and $\gamma > \gamma_t$. $\gamma_t = 23.2$.

Questions remain:

- When space charge is significant (which is the case for proton driver), is there any μ-wave instability when $\gamma < \gamma_t$?
- when the beam is bunched, is there any μ-wave instability if $\gamma < \gamma_t$?